

executed

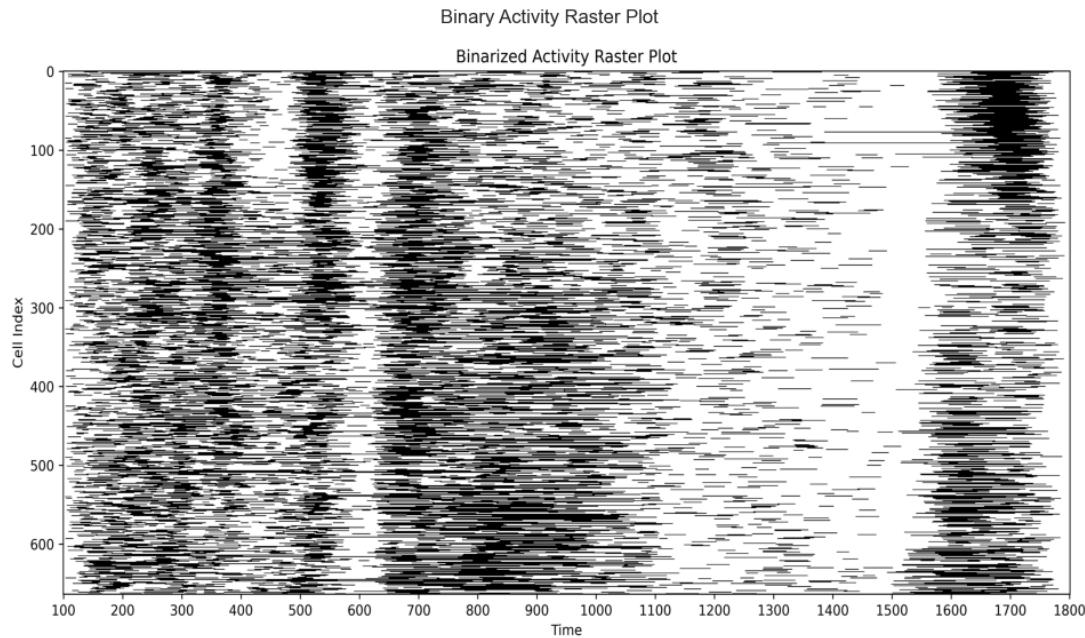
August 27, 2025

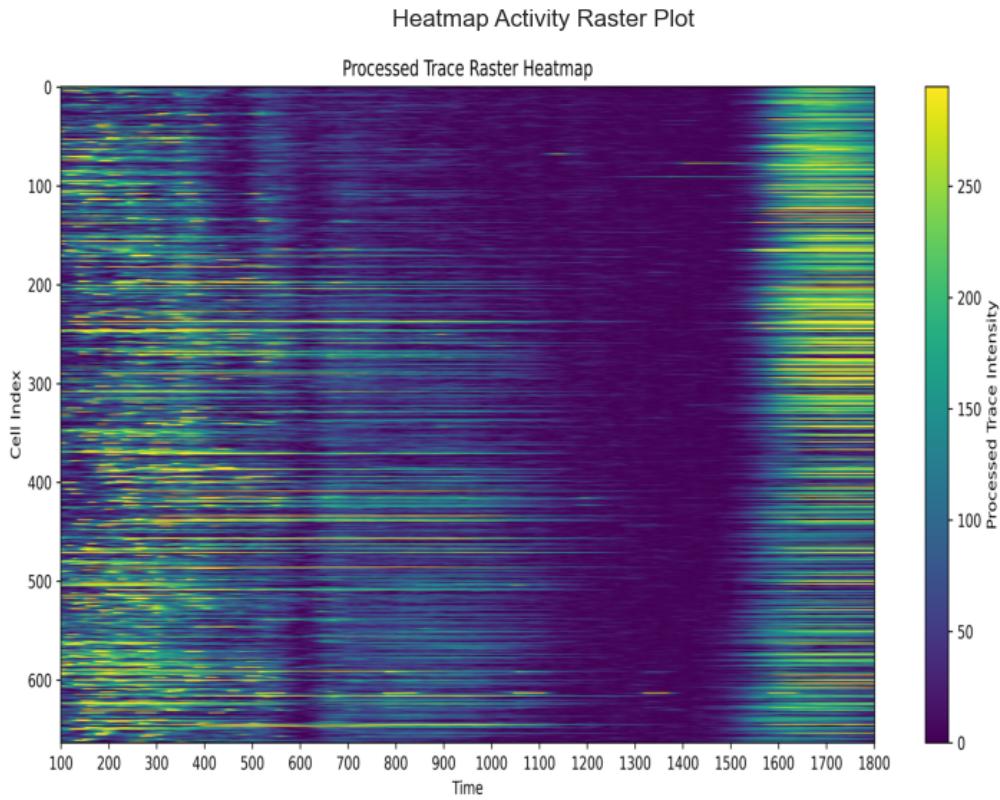
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





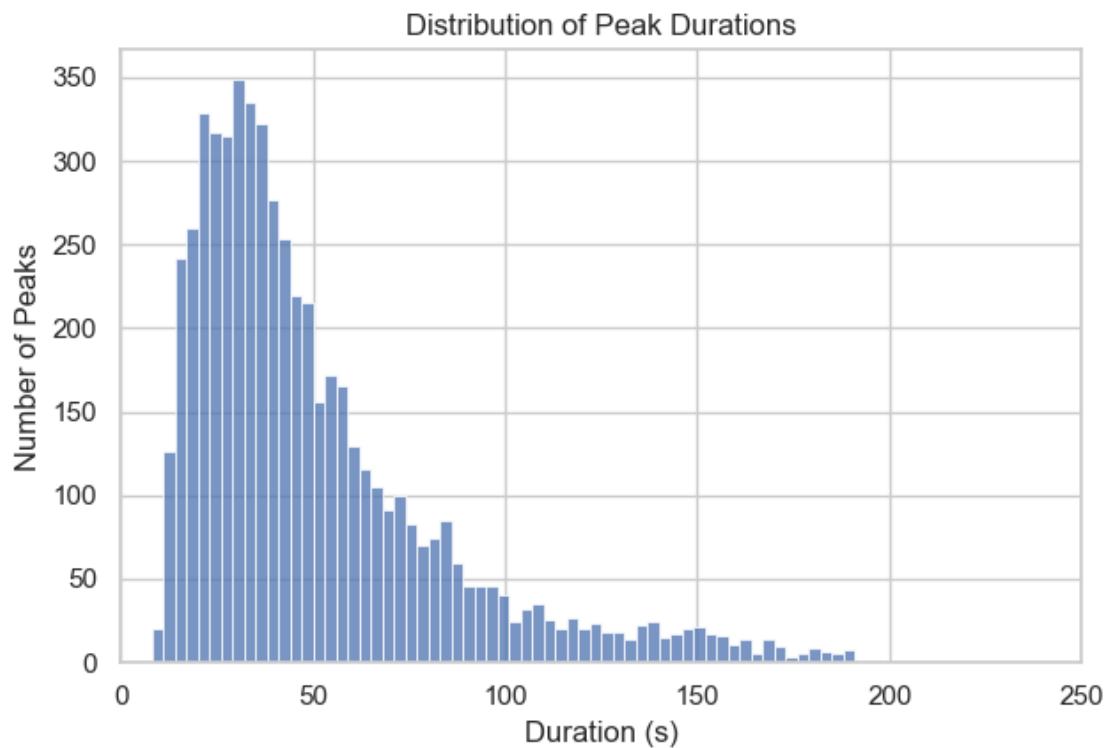
1.1.2 Peaks population

Total number of peaks: 5921

Total number of cells: 664

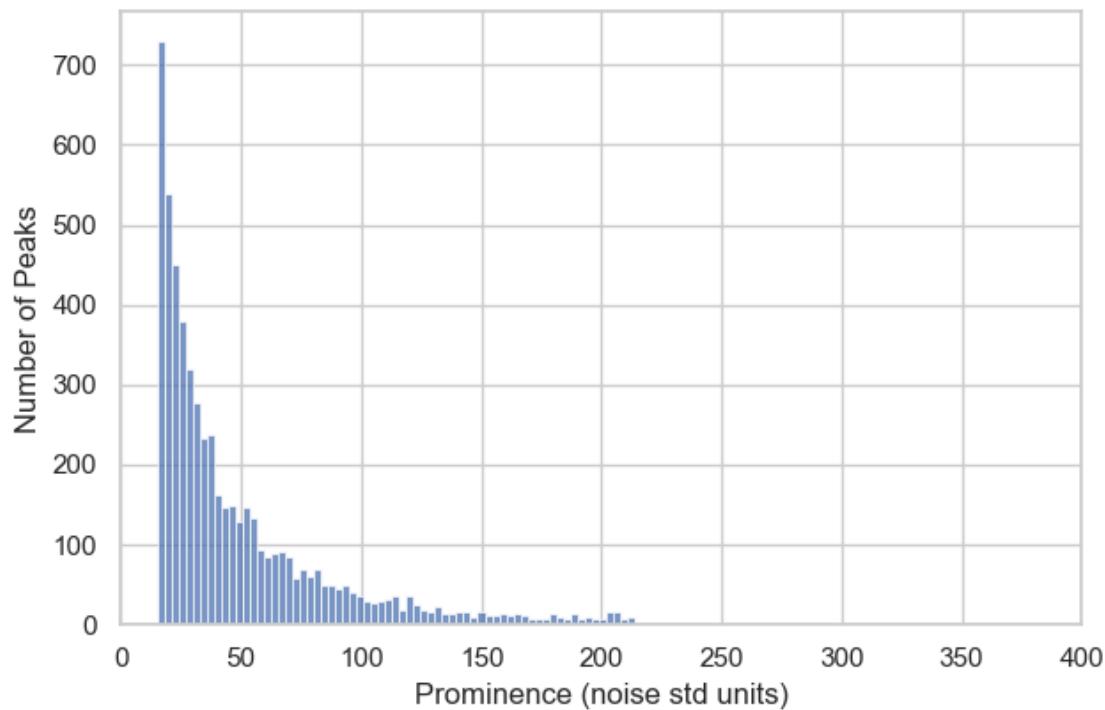
1.1.3 Peaks statistics

```
[2025-08-27 14:49:06] [INFO] calcium: plot_histogram: removed 253 outliers out  
of 5921 on 'Duration (s)' (lower=-96, upper=191)
```

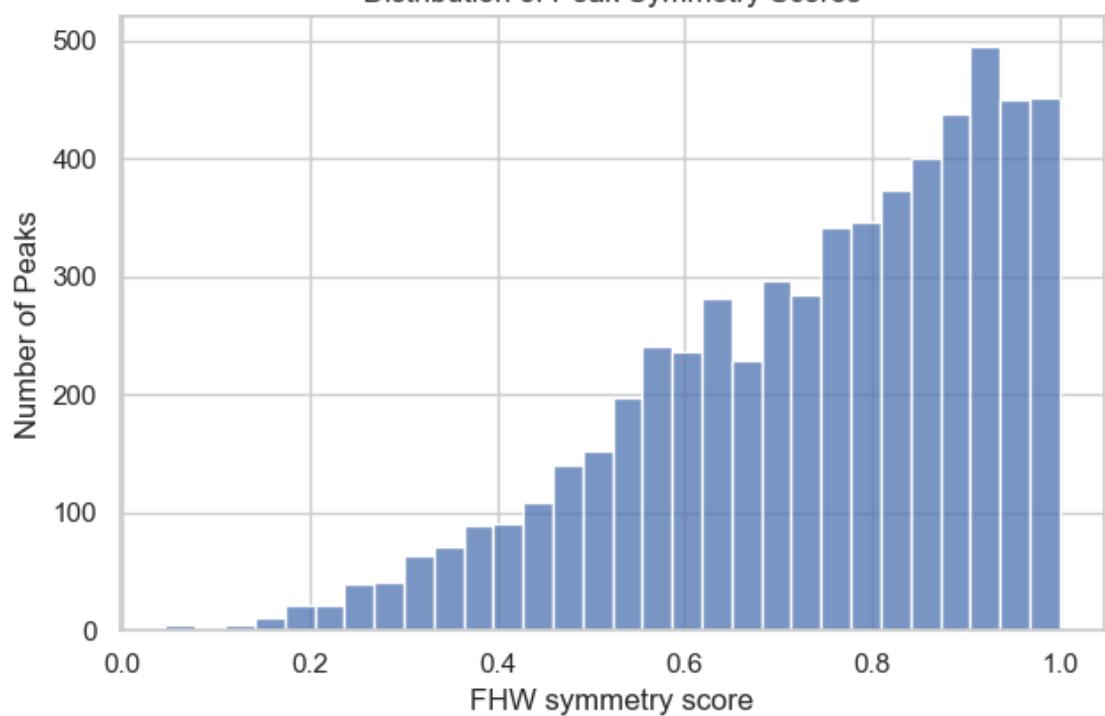


```
[2025-08-27 14:49:06] [INFO] calcium: plot_histogram: removed 324 outliers out  
of 5921 on 'Prominence (noise std units)' (lower=-121.4, upper=213.9)
```

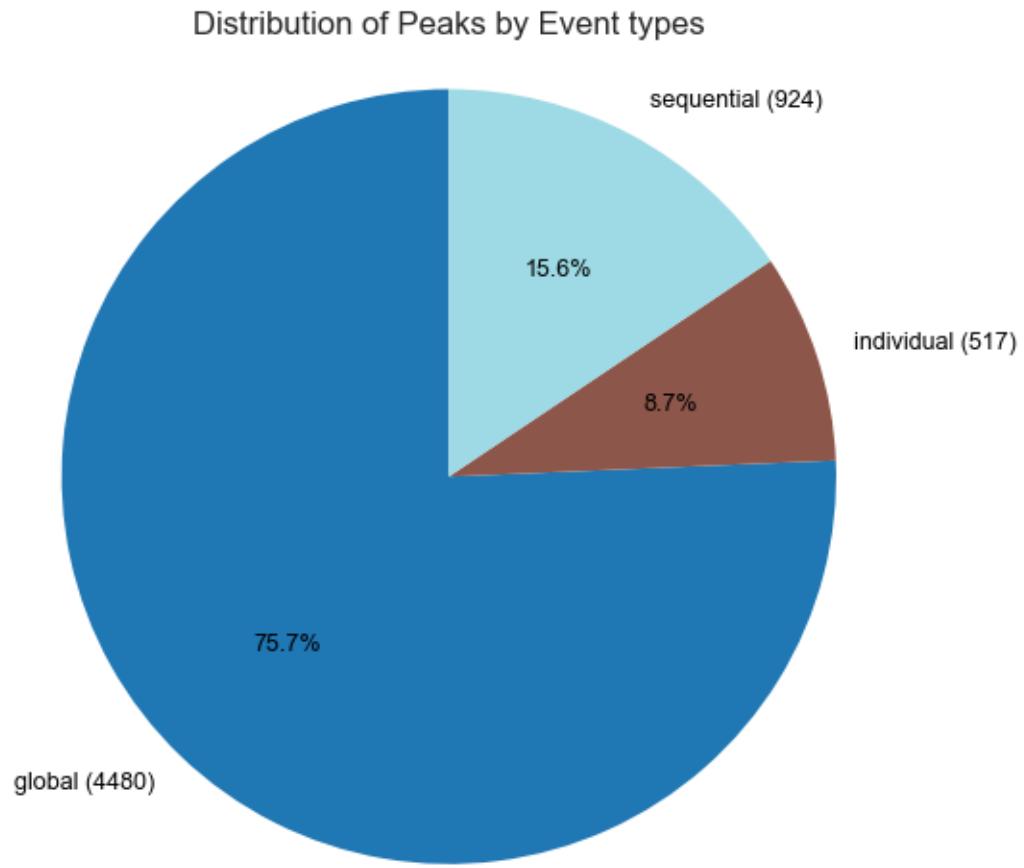
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

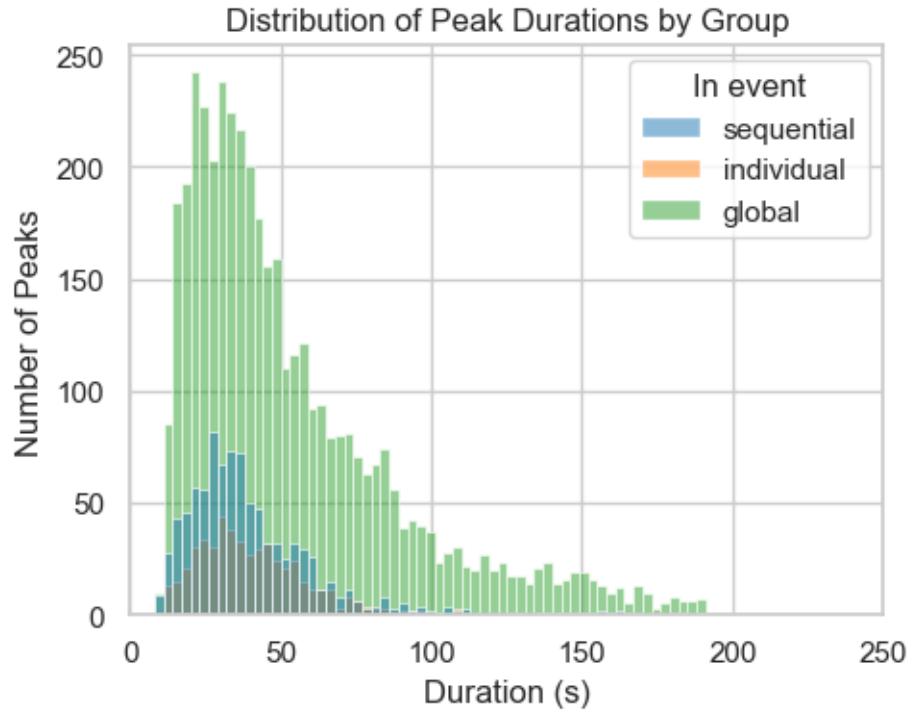


1.1.4 Distribution of peaks per event types

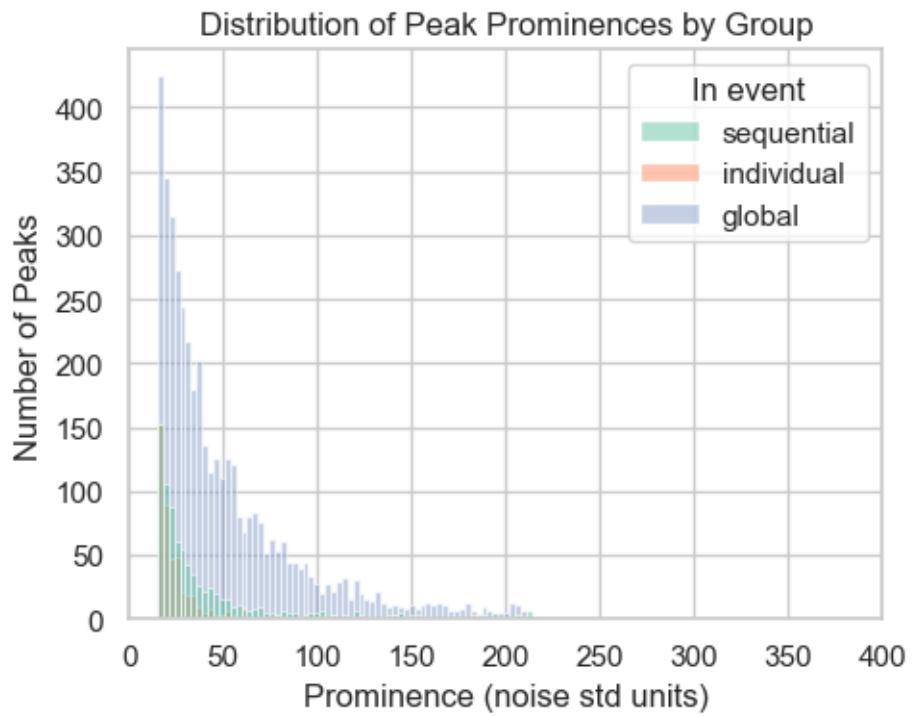


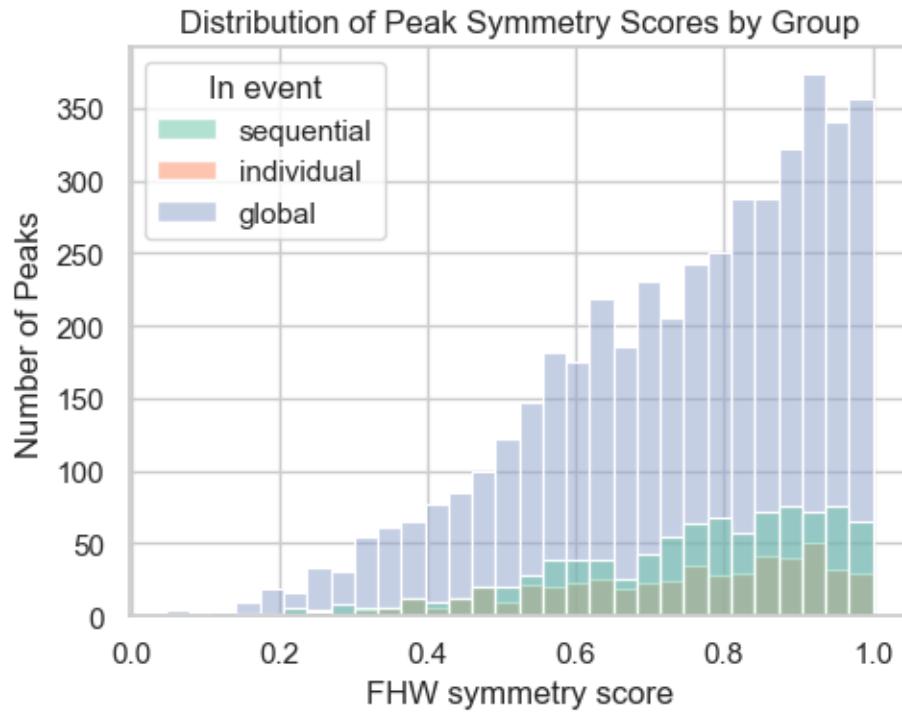
1.1.5 Peaks statistics per event types

```
[2025-08-27 14:49:06] [INFO] calcium: plot_histogram_by_group: removed 253 outliers out of 5921 on 'Duration (s)' (lower=-96, upper=191)
```



```
[2025-08-27 14:49:07] [INFO] calcium: plot_histogram_by_group: removed 324 outliers out of 5921 on 'Prominence (noise std units)' (lower=-121.4, upper=213.9)
```

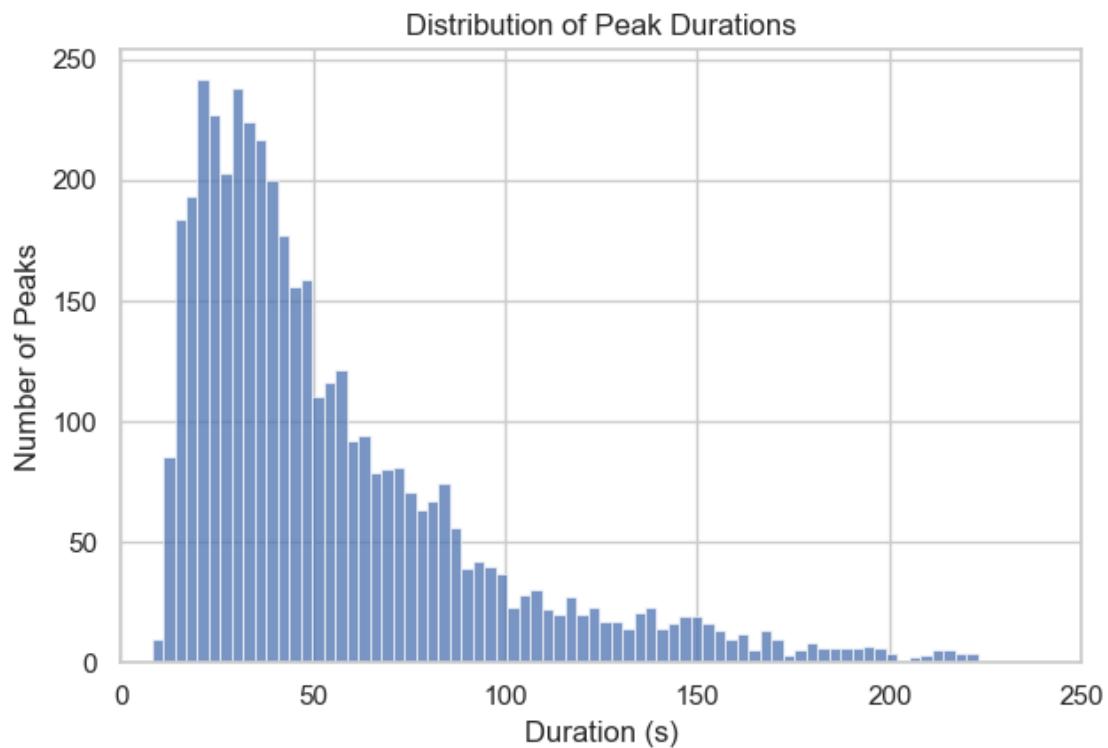




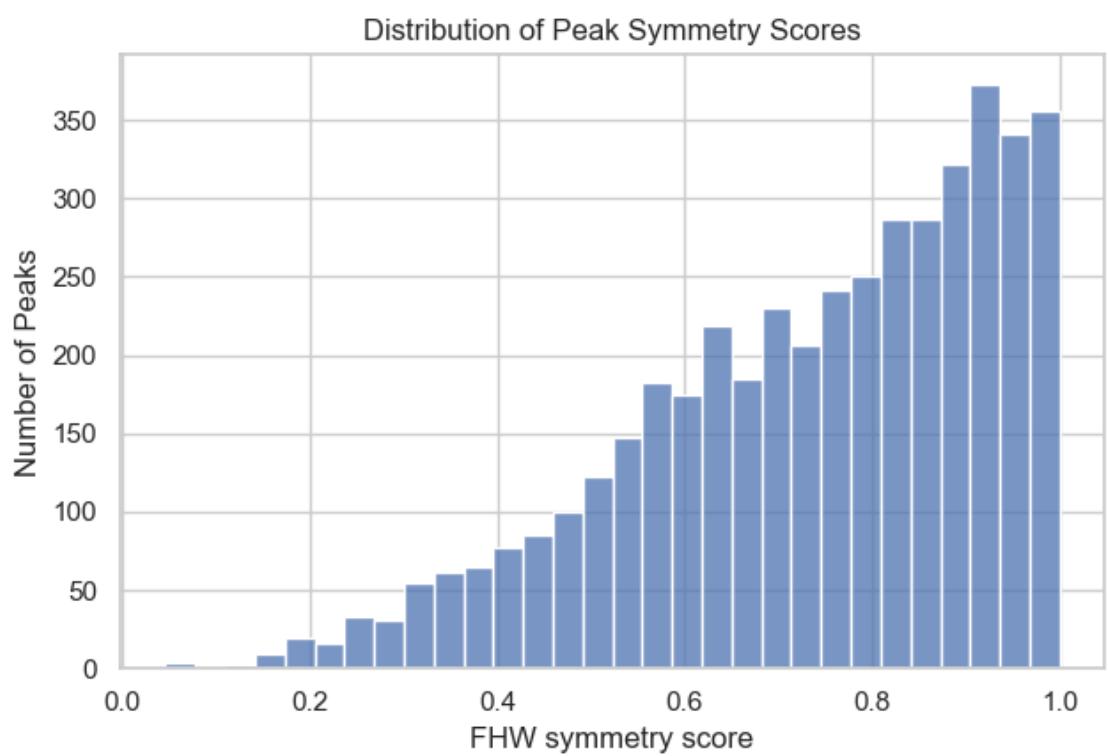
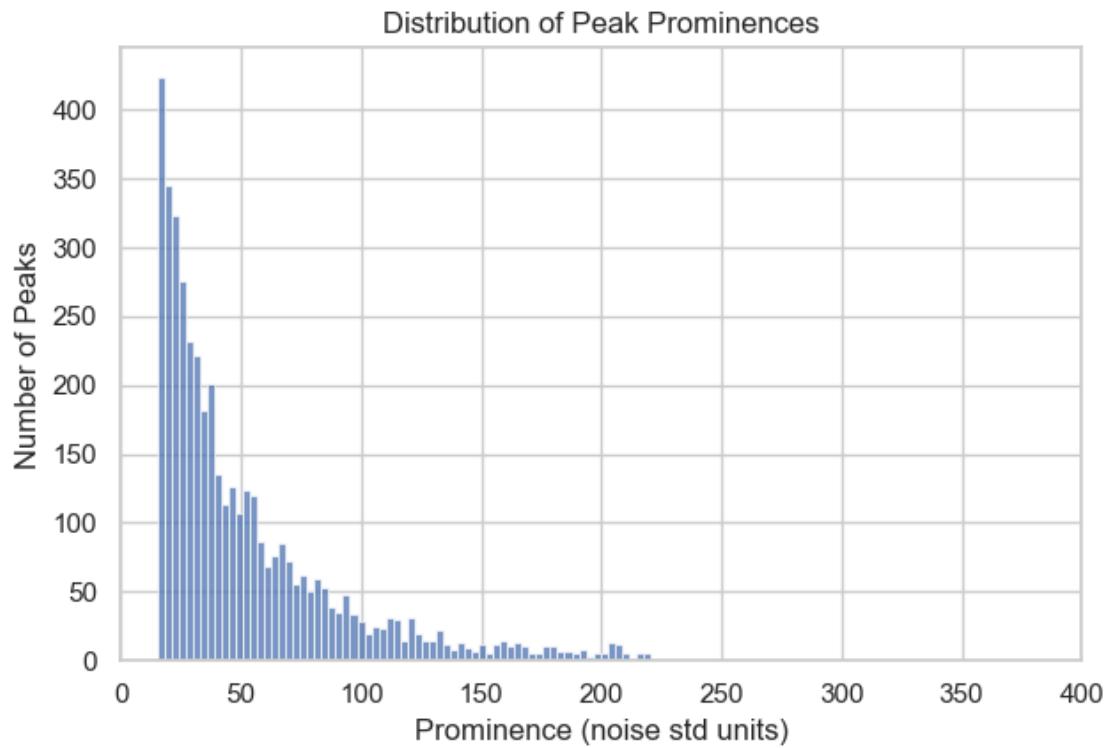
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 14:49:07] [INFO] calcium: plot_histogram: removed 190 outliers out  
of 4480 on 'Duration (s)' (lower=-119, upper=224)
```

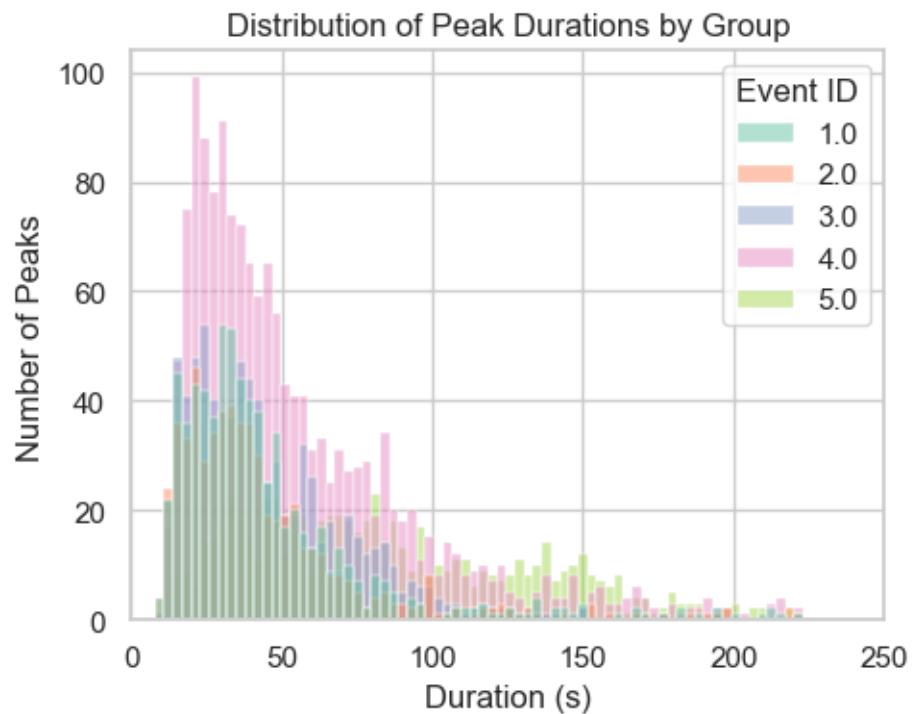


```
[2025-08-27 14:49:08] [INFO] calcium: plot_histogram: removed 215 outliers out  
of 4480 on 'Prominence (noise std units)' (lower=-124.28, upper=222.4)
```

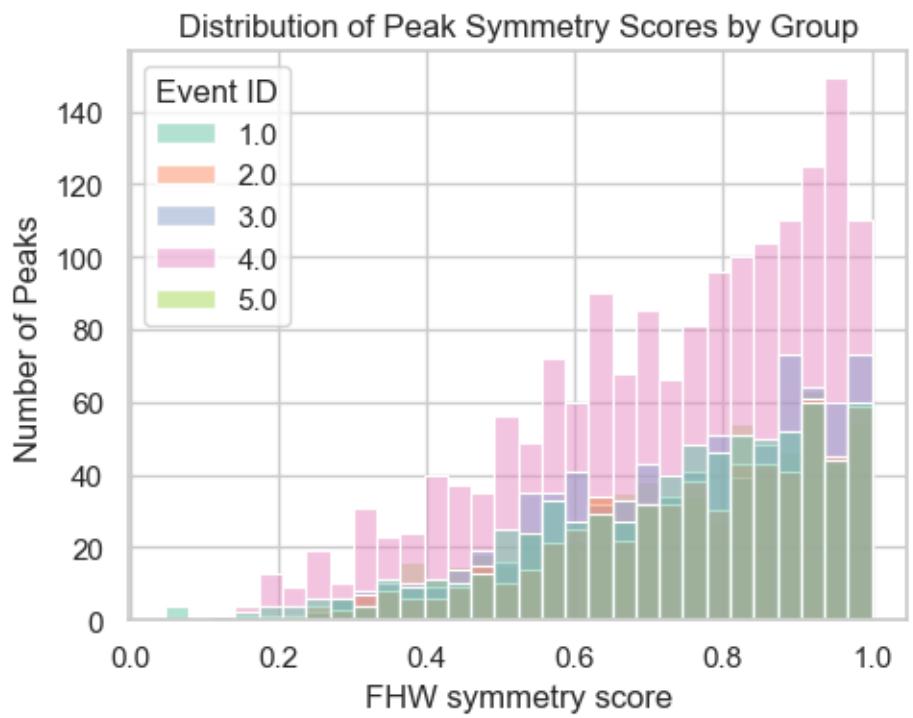
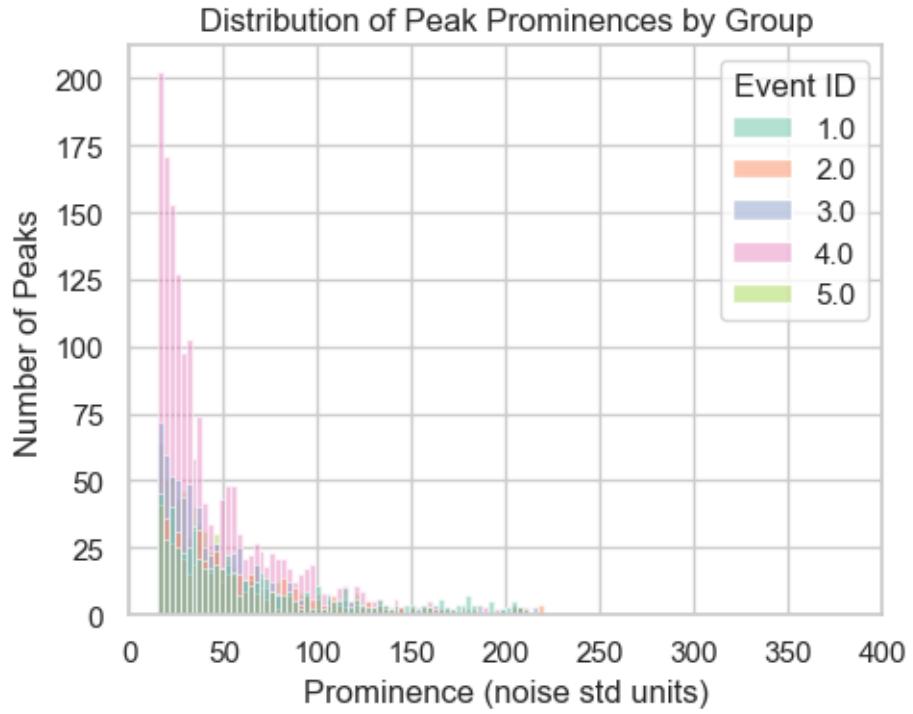


1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:49:08] [INFO] calcium: plot_histogram_by_group: removed 190 outliers out of 4480 on 'Duration (s)' (lower=-119, upper=224)

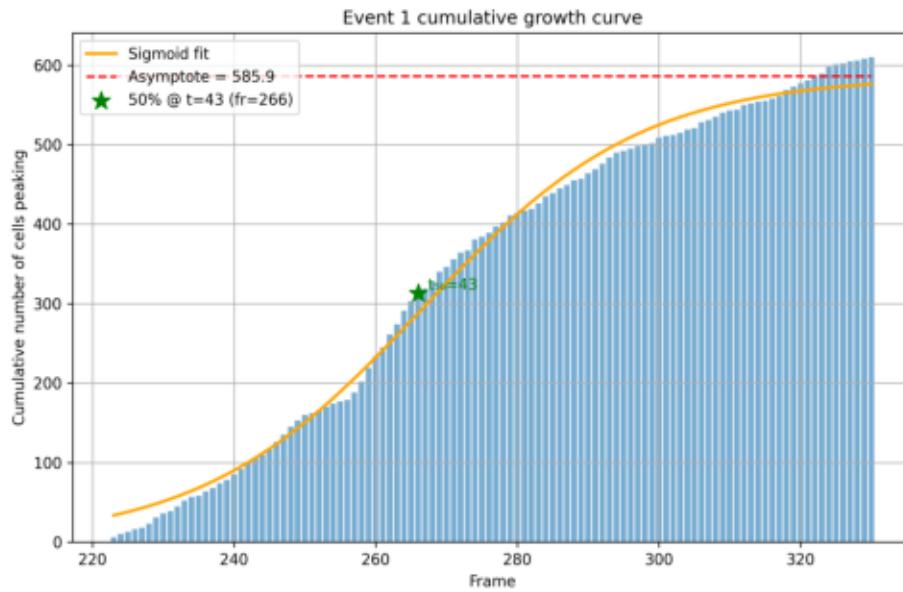


[2025-08-27 14:49:08] [INFO] calcium: plot_histogram_by_group: removed 215 outliers out of 4480 on 'Prominence (noise std units)' (lower=-124.28, upper=222.4)

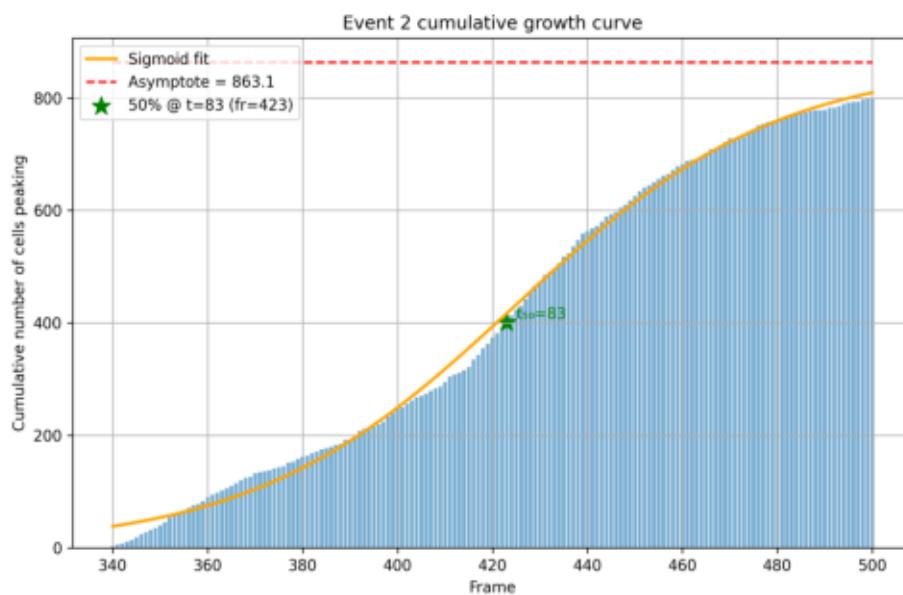


1.2.3 Kinetics of global events

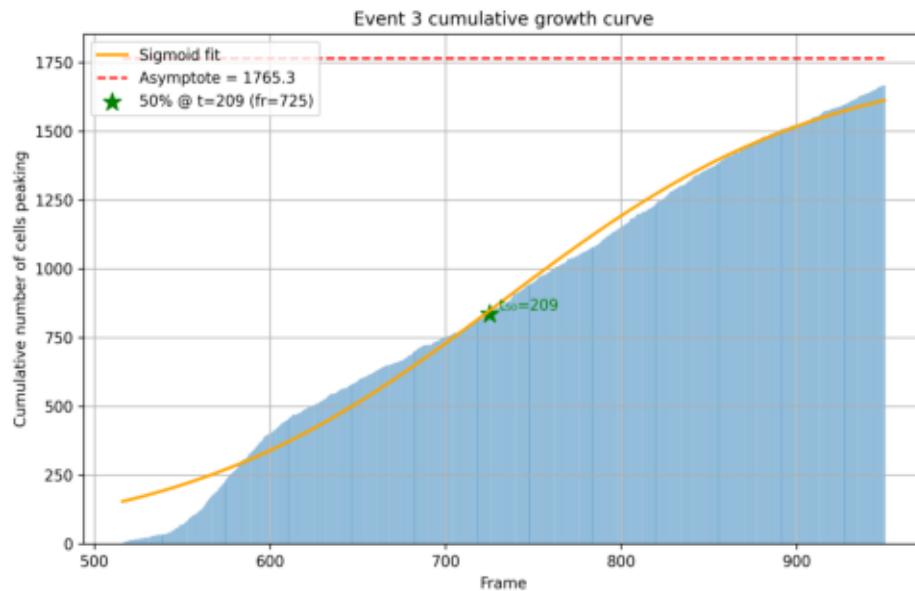
Event Activity Overlay (Event ID: 1)



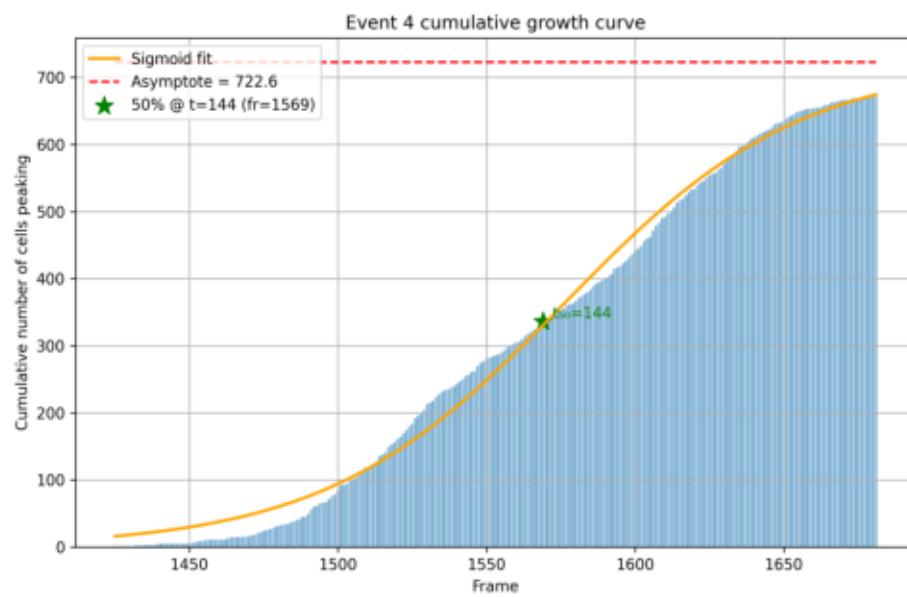
Event Activity Overlay (Event ID: 2)



Event Activity Overlay (Event ID: 3)



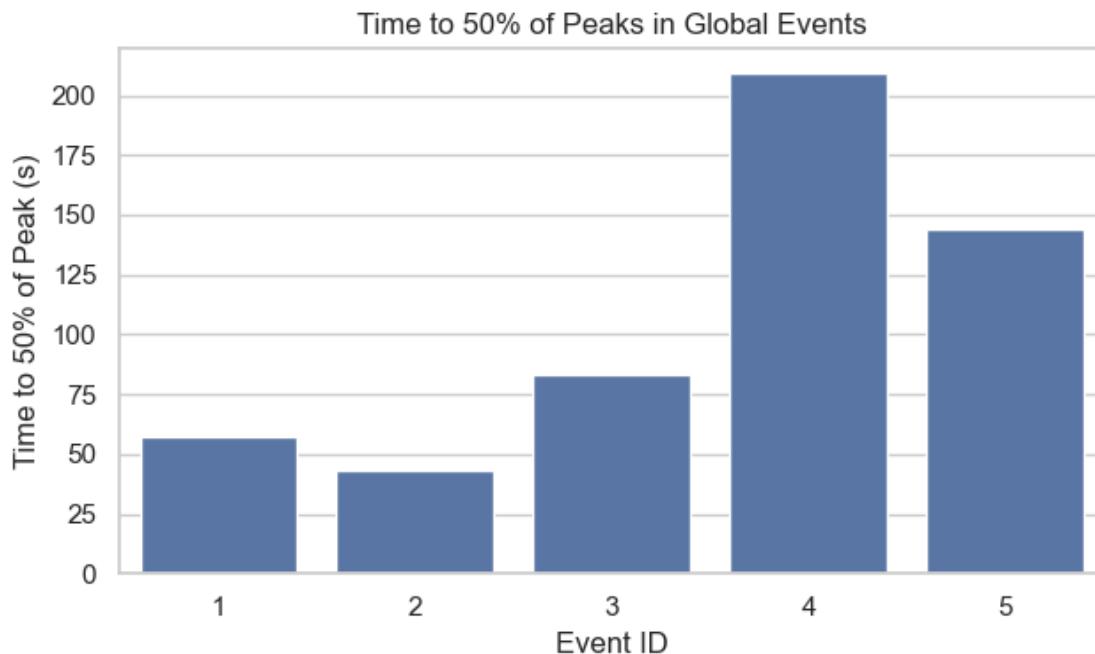
Event Activity Overlay (Event ID: 4)



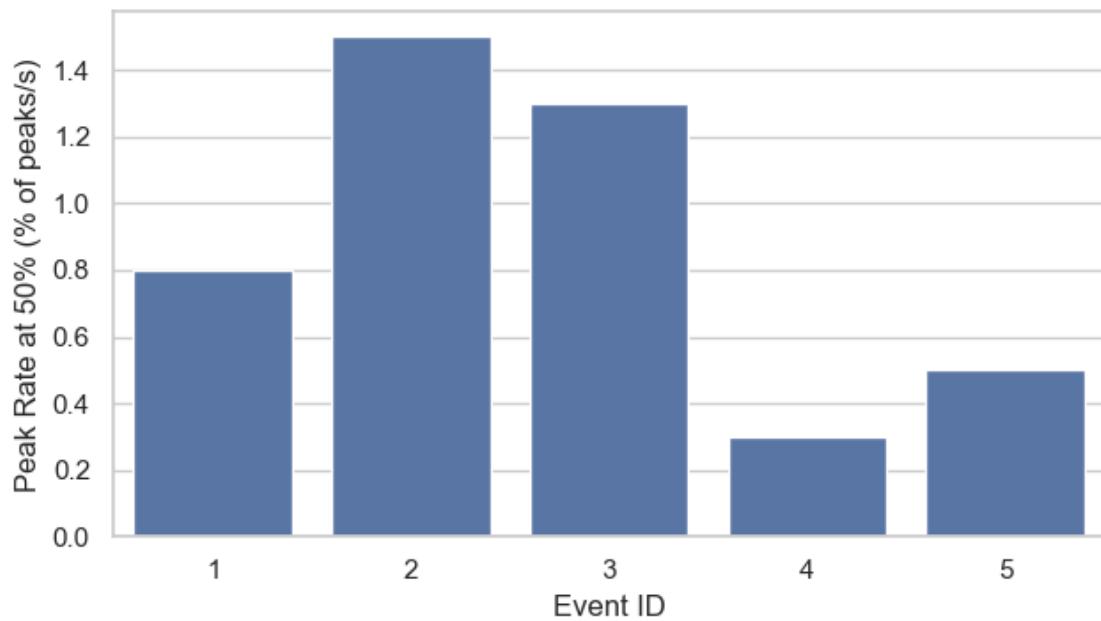
```

[2025-08-27 14:49:11] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\events\event-growth-curve-5.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250501\\Output\\IS03\\events\\event-
growth-curve-5.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250501\\Output\\IS03\\events\\event-growth-curve-5.png'

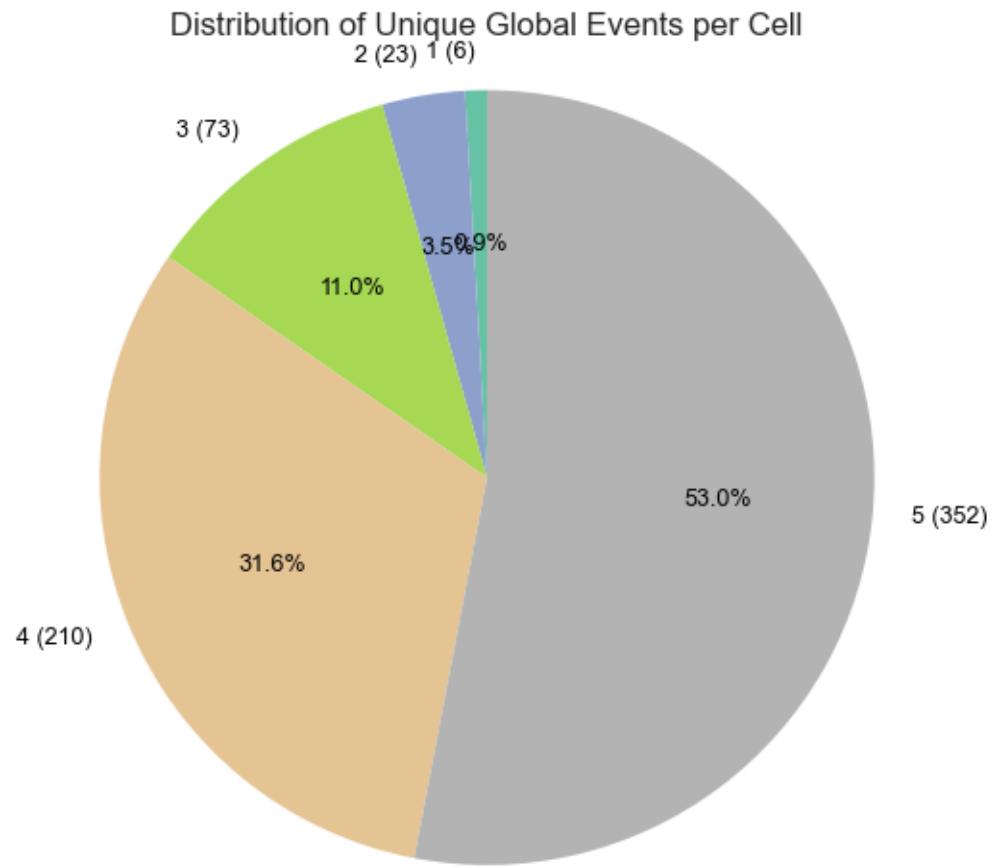
```



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

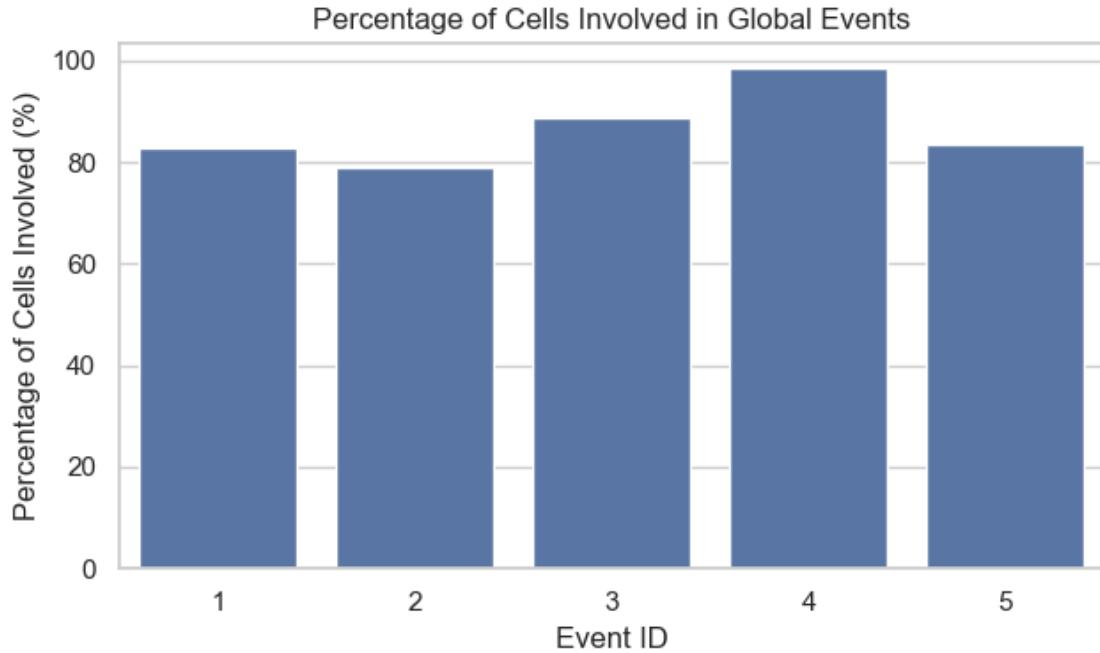


```
[2025-08-27 14:49:12] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250501\\\\Output\\\\IS03\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250501\Output\IS03\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [105.0, 170.0, 163.0, 1008.0]

Estimated periodicity: 0.491

1.2.6 Early peakers in the events

```

[2025-08-27 14:49:12] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest

```

```

er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 14:49:12] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 14:49:12] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-

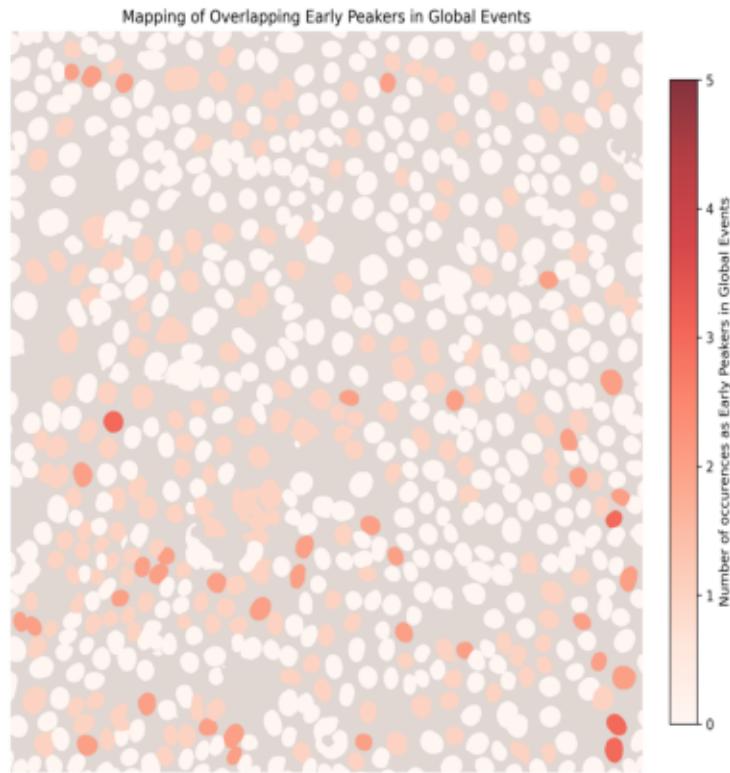
```

```
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 14:49:12] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

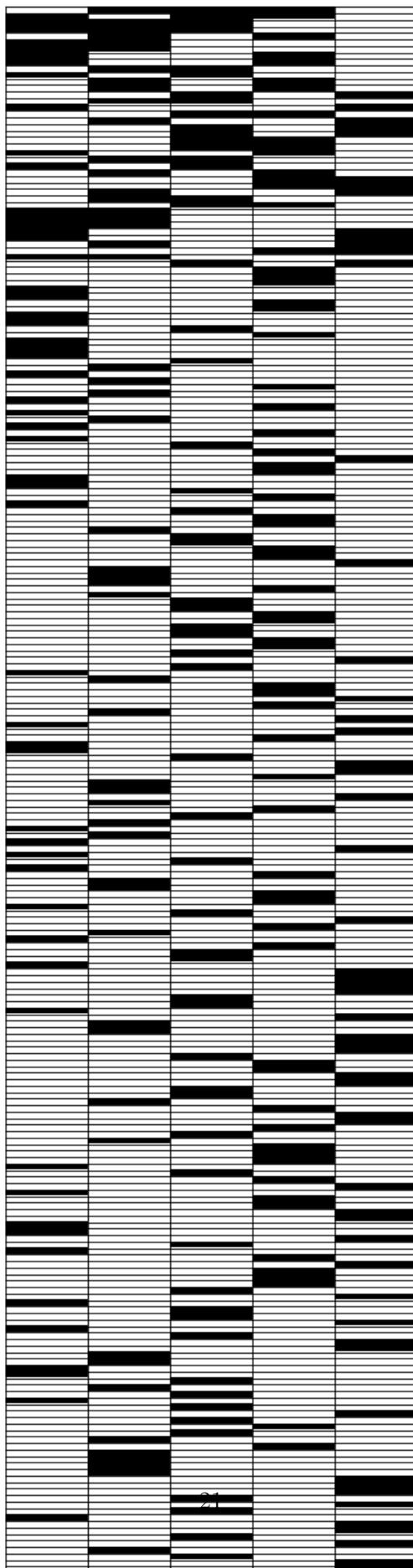
[2025-08-27 14:49:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



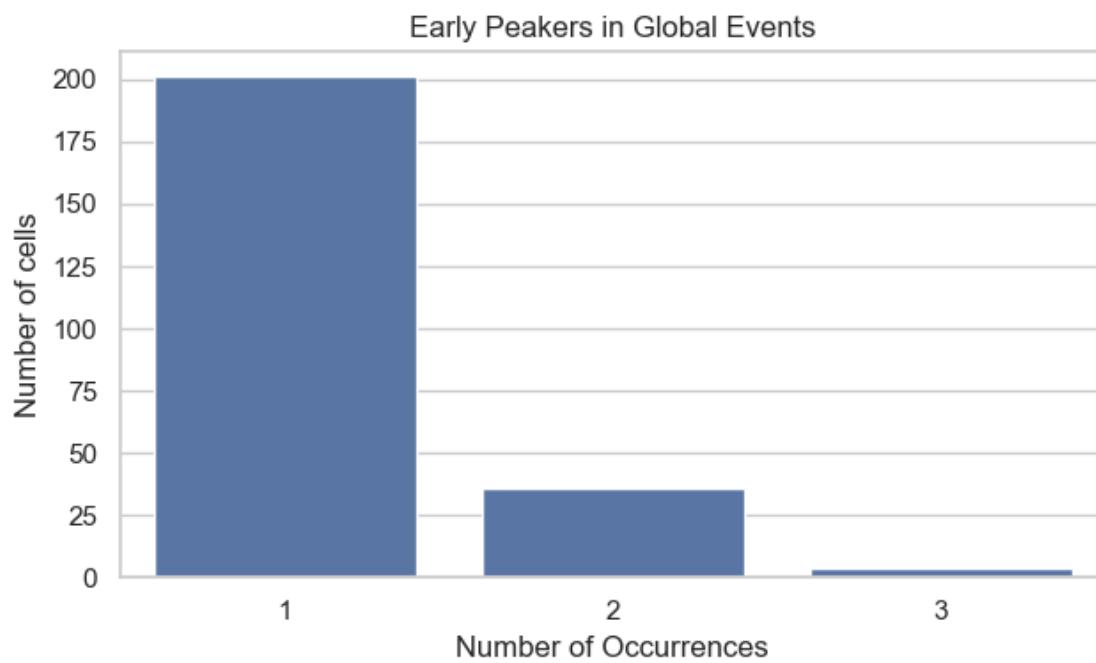
```
[2025-08-27 14:49:14] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 5 unique event IDs.
```

```
[2025-08-27 14:49:14] [INFO] calcium: Early peakers event-matrix: 241 cells x 5 events; black squares: 285
```

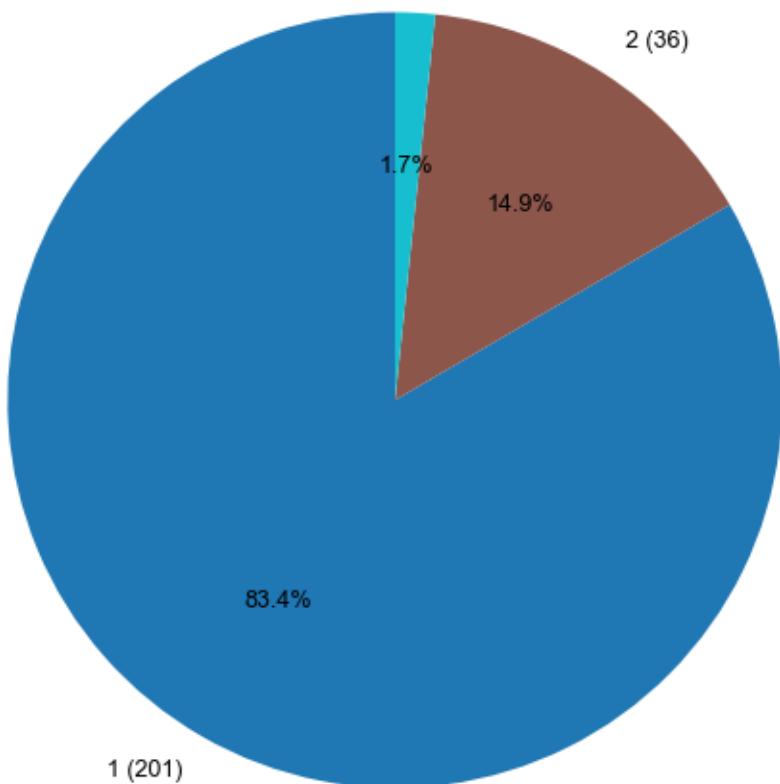


```
[2025-08-27 14:49:14] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[0, 1, 1, 1, 0],  
           [1, 0, 1, 1, 0],  
           [1, 1, 1, 0, 0],  
           ...,  
           [0, 0, 1, 0, 0],  
           [0, 0, 0, 0, 1],  
           [0, 0, 0, 0, 1]])
```



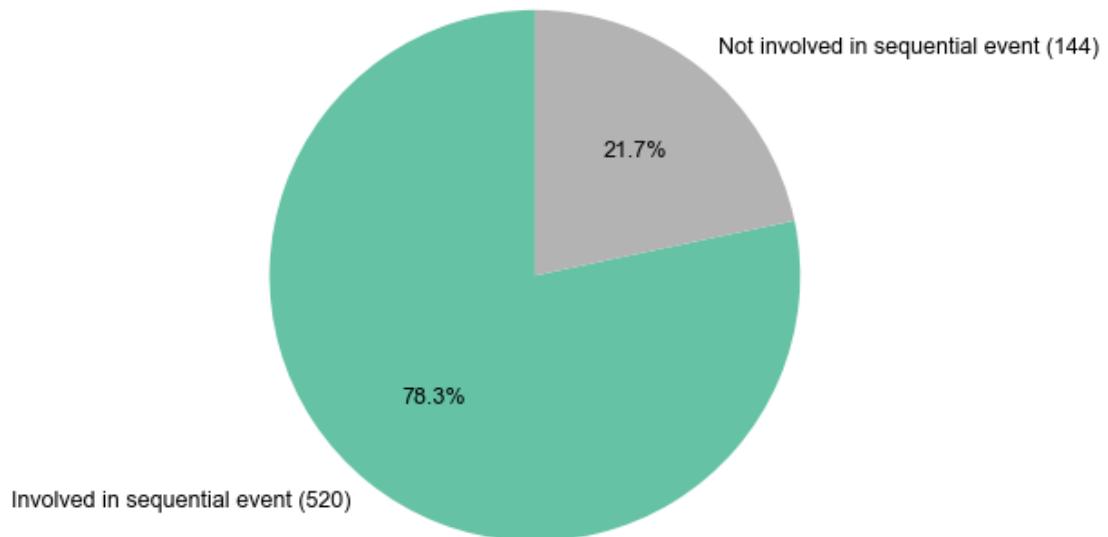
Distribution of Early Peakers in Global Events
3 (4)



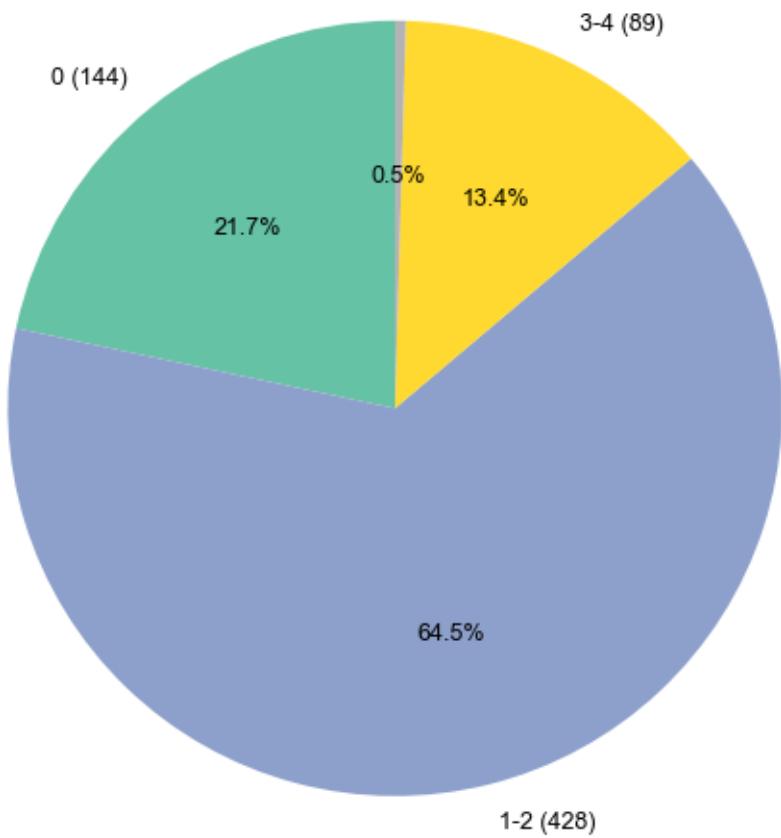
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

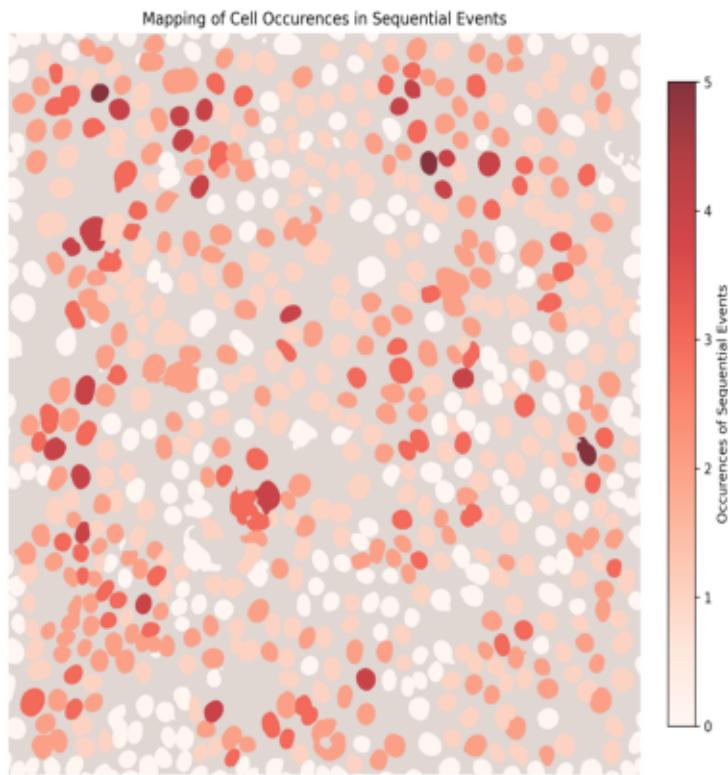
Distribution of Cells Involved in Sequential Events



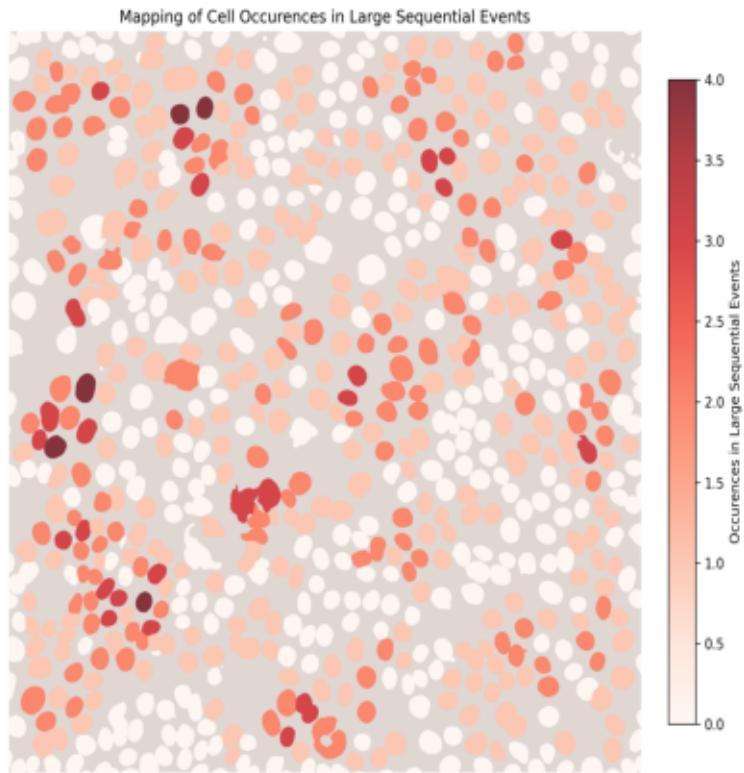
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (3)



Cell Mapping with Occurrences in Sequential Events Overlay

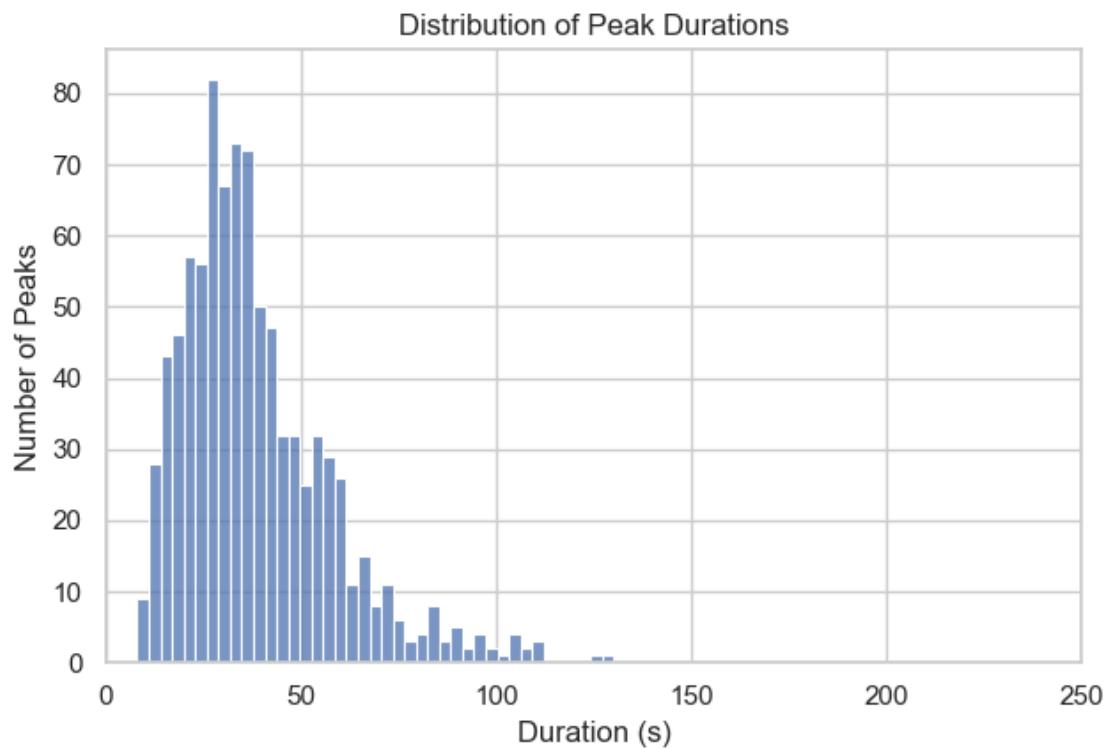


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

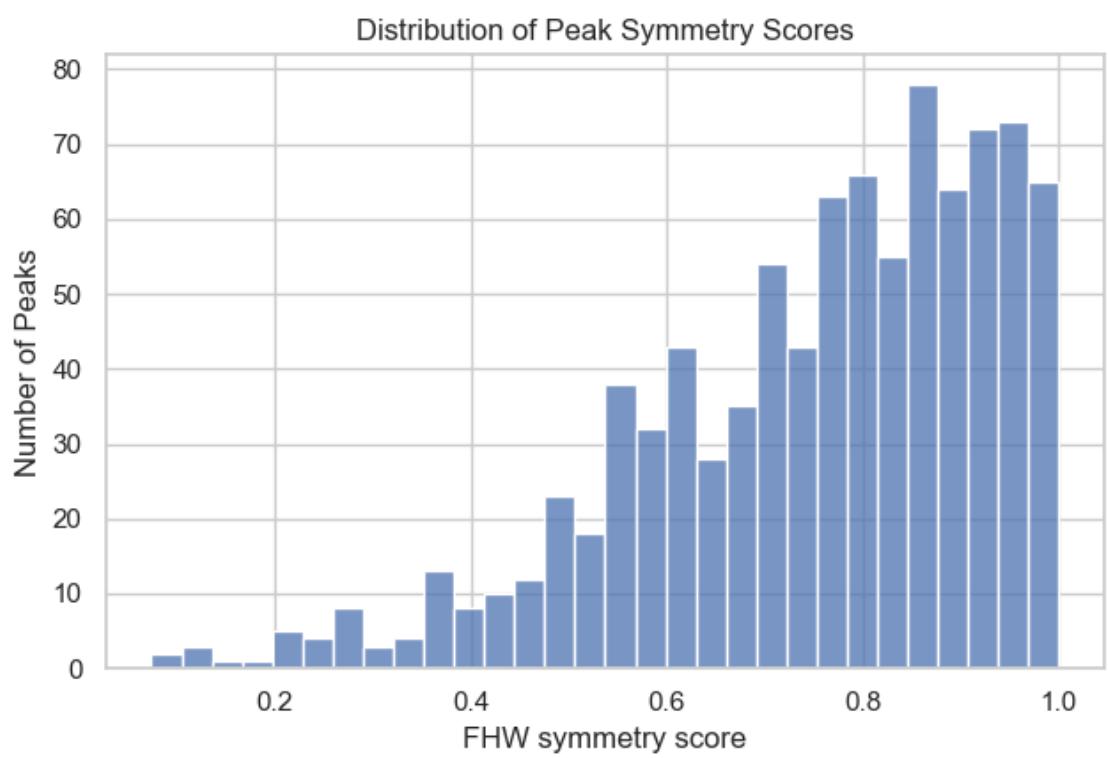
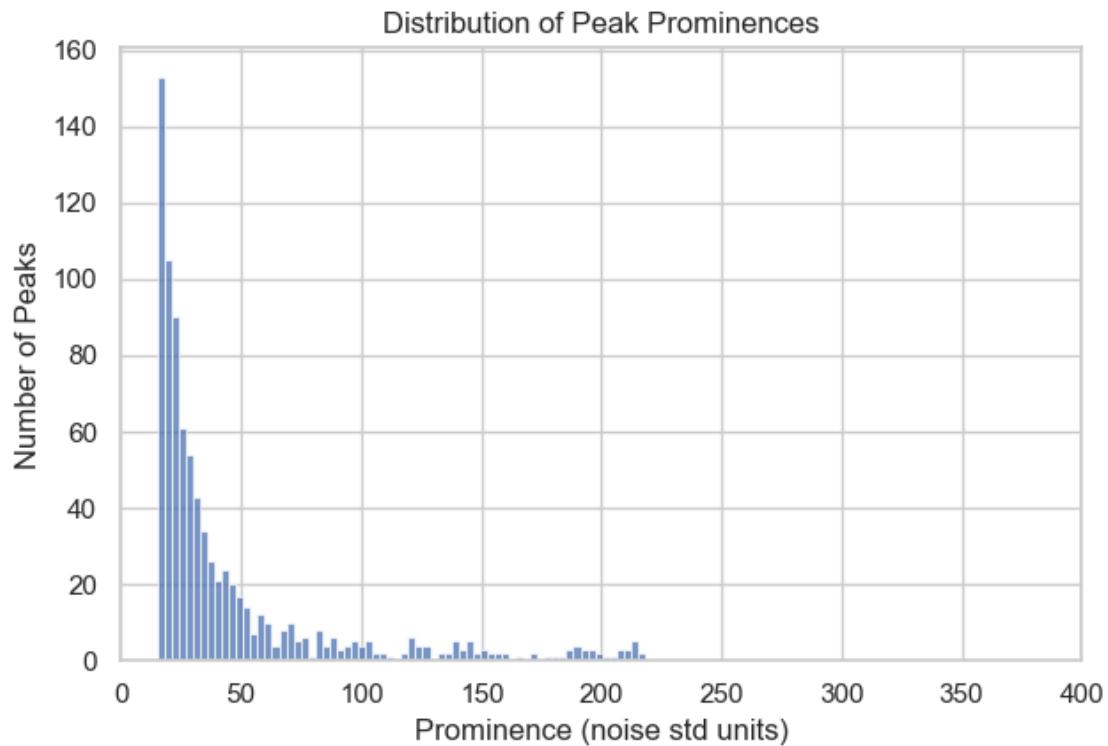


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:49:17] [INFO] calcium: plot_histogram: removed 24 outliers out of 924 on 'Duration (s)' (lower=-11, upper=133)
```

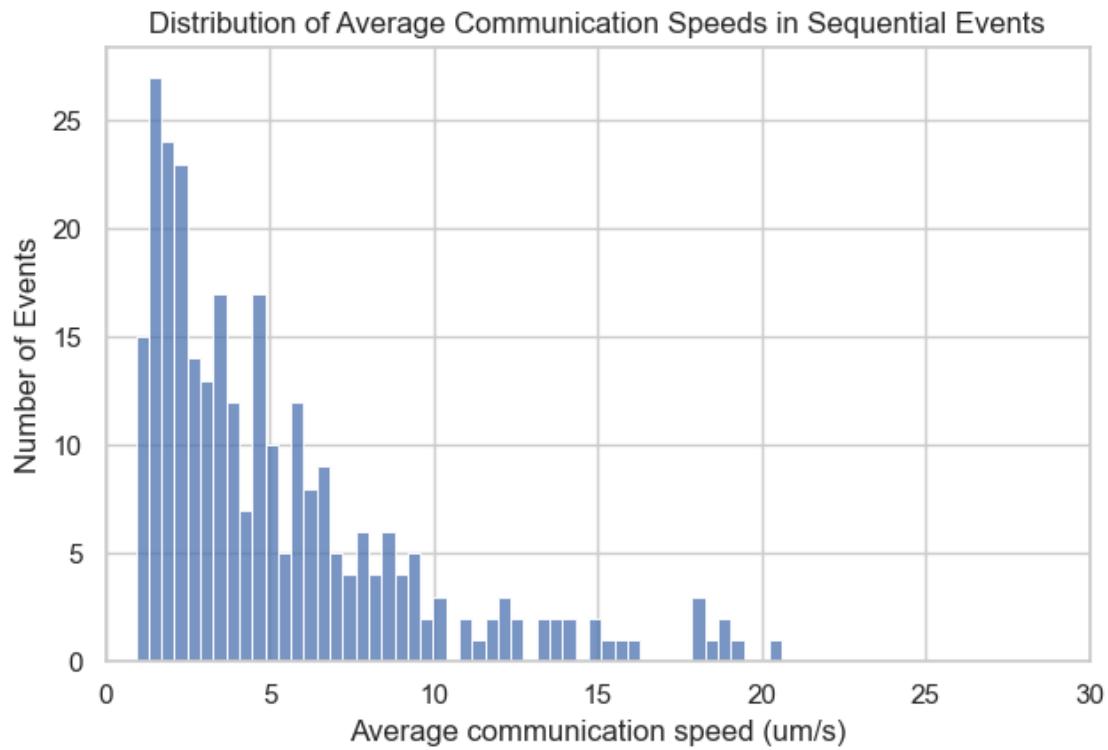


```
[2025-08-27 14:49:17] [INFO] calcium: plot_histogram: removed 75 outliers out of 924 on 'Prominence (noise std units)' (lower=-46.737, upper=219.81)
```



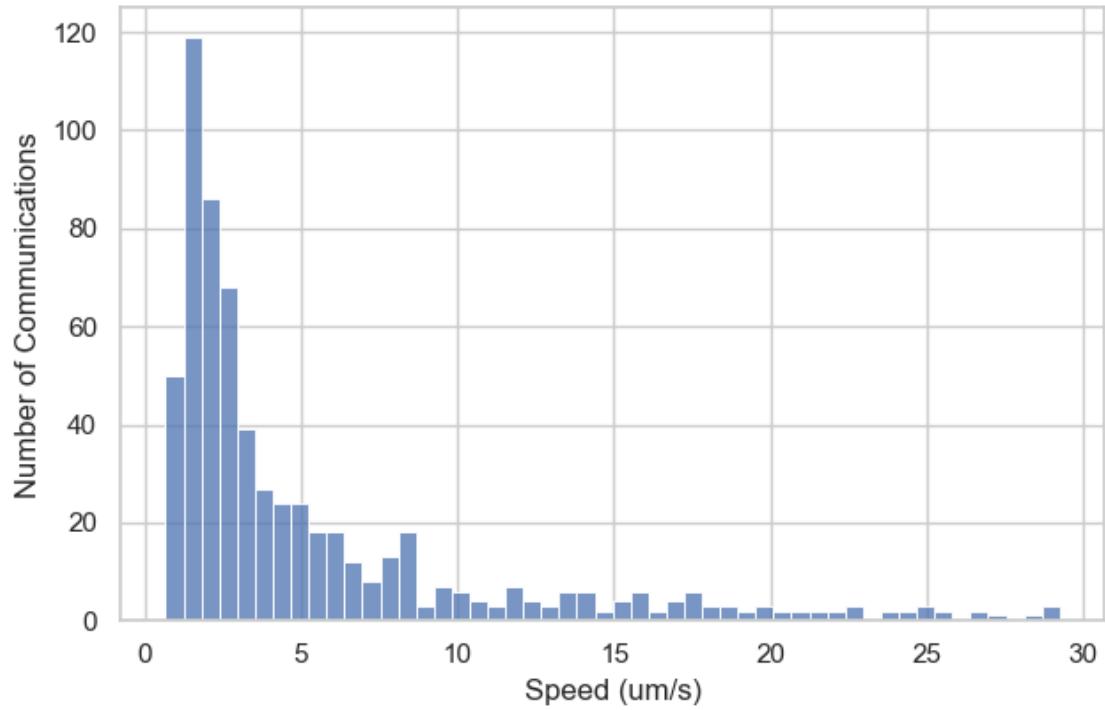
1.3.3 Cell-cell communication speed

[2025-08-27 14:49:17] [INFO] calcium: plot_histogram: removed 6 outliers out of 287 on 'Average communication speed (um/s)' (lower=-12.235, upper=21.505)

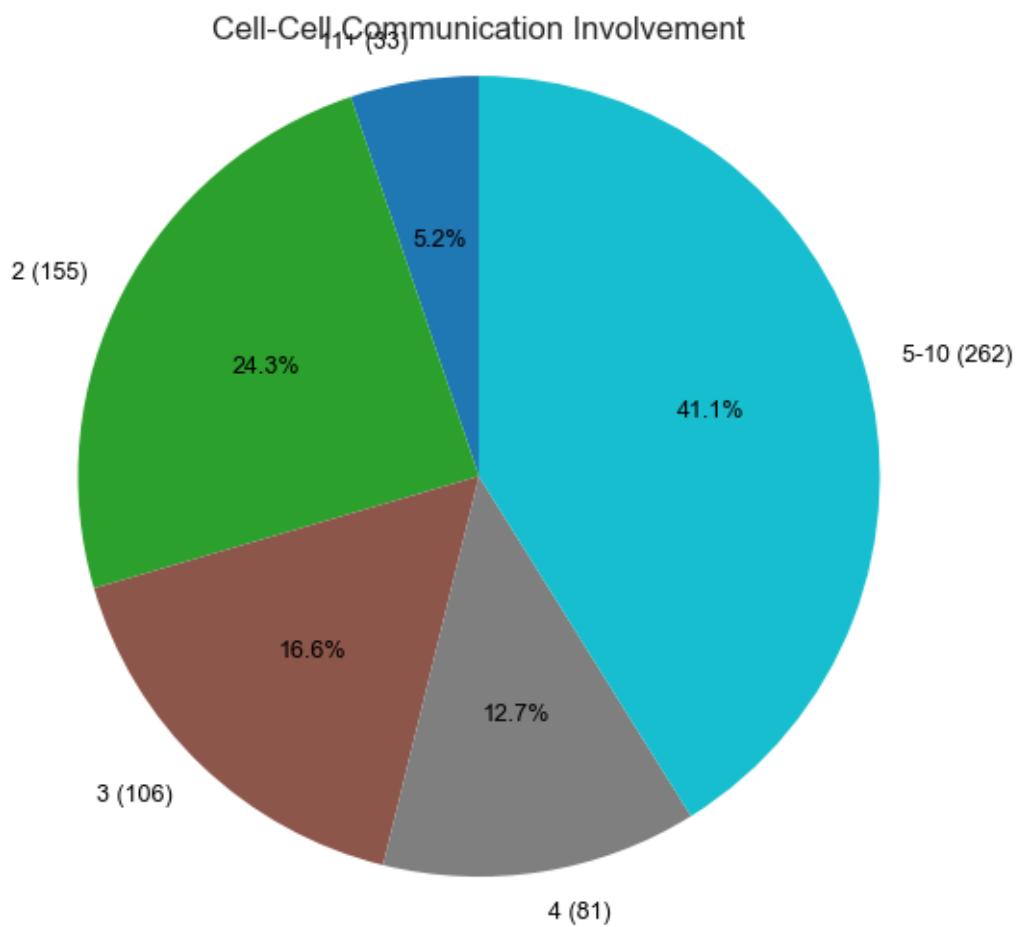


[2025-08-27 14:49:17] [INFO] calcium: plot_histogram: removed 2 outliers out of 637 on 'Speed (um/s)' (lower=-12.96, upper=31.14)

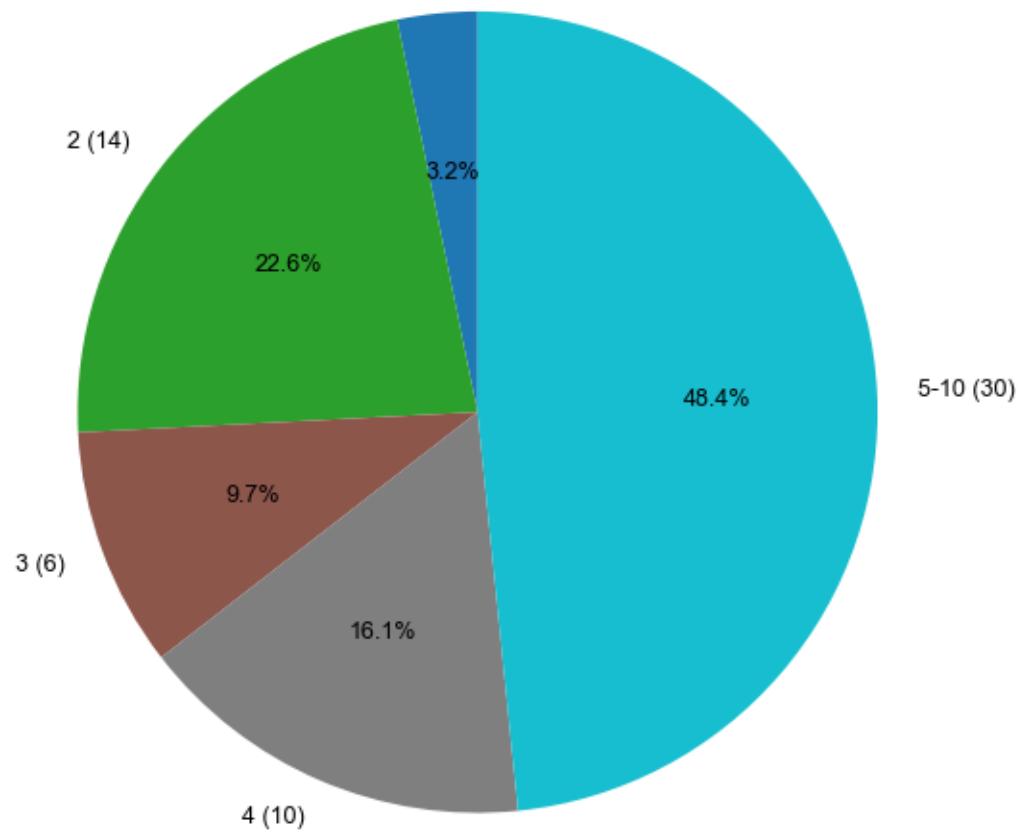
Distribution of Cell-Cell Communication Speeds



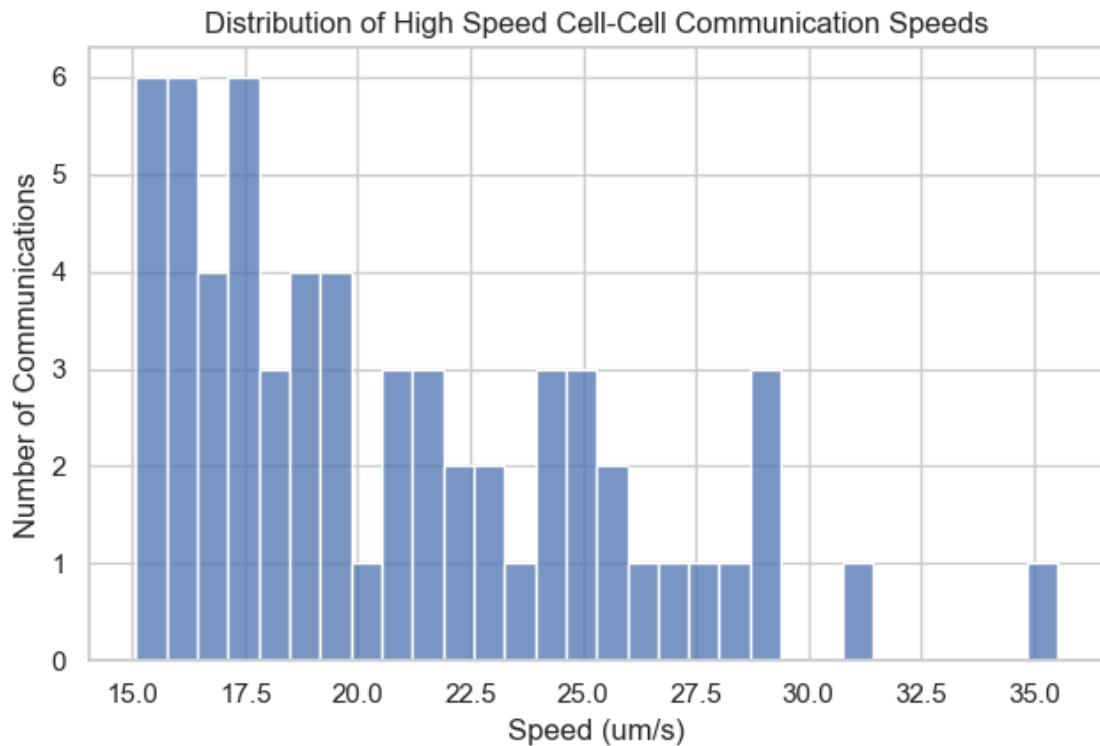
1.3.4 Double distribution in cell-cell communication speeds



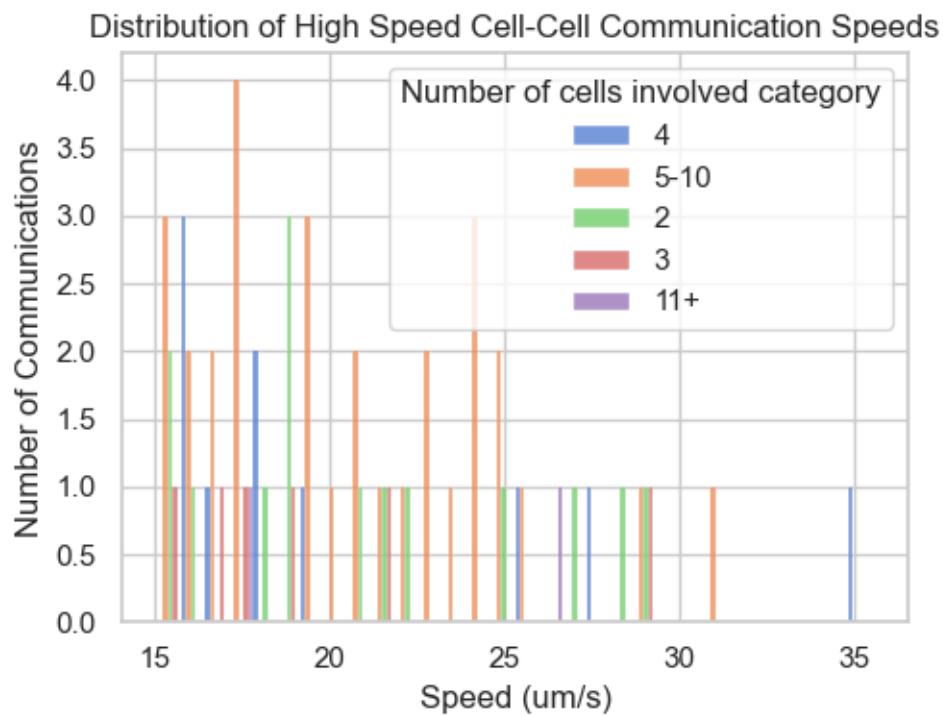
High Speed Cell-Cell Communication Involvement



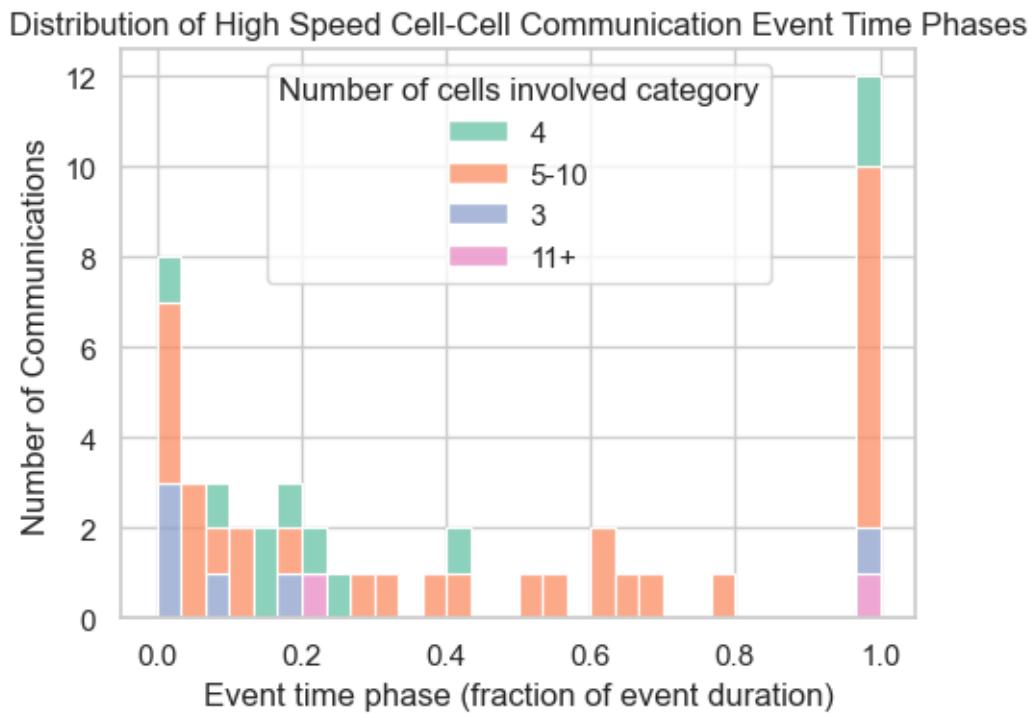
[2025-08-27 14:49:18] [INFO] calcium: plot_histogram: removed 0 outliers out of 62 on 'Speed (um/s)' (lower=-4.3675, upper=45.7)



```
[2025-08-27 14:49:18] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 62 on 'Speed (um/s)' (lower=-4.3675, upper=45.7)
```

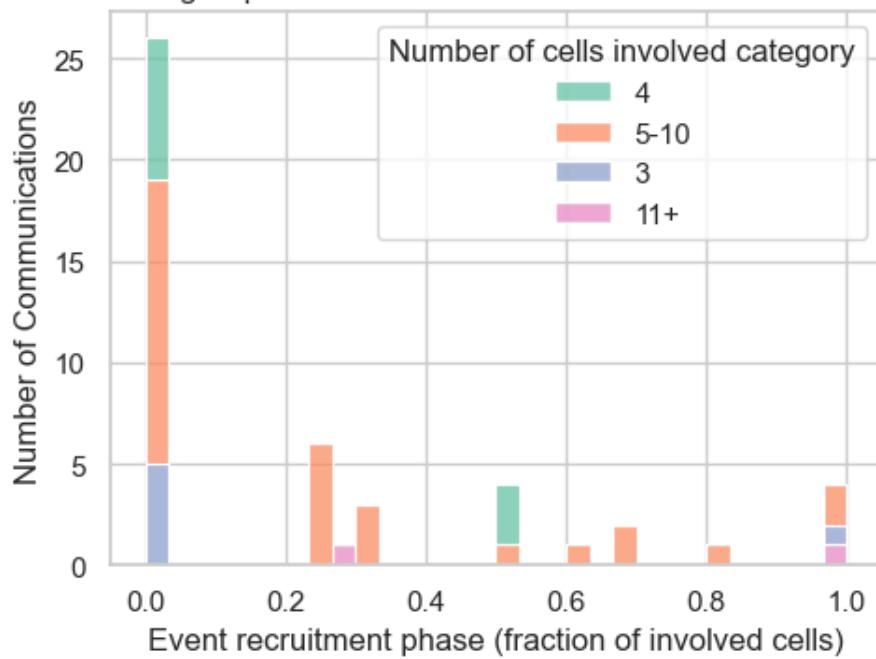


[2025-08-27 14:49:18] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 48 on 'Event time phase (fraction of event duration)' (lower=-2.1725, upper=3.0775)

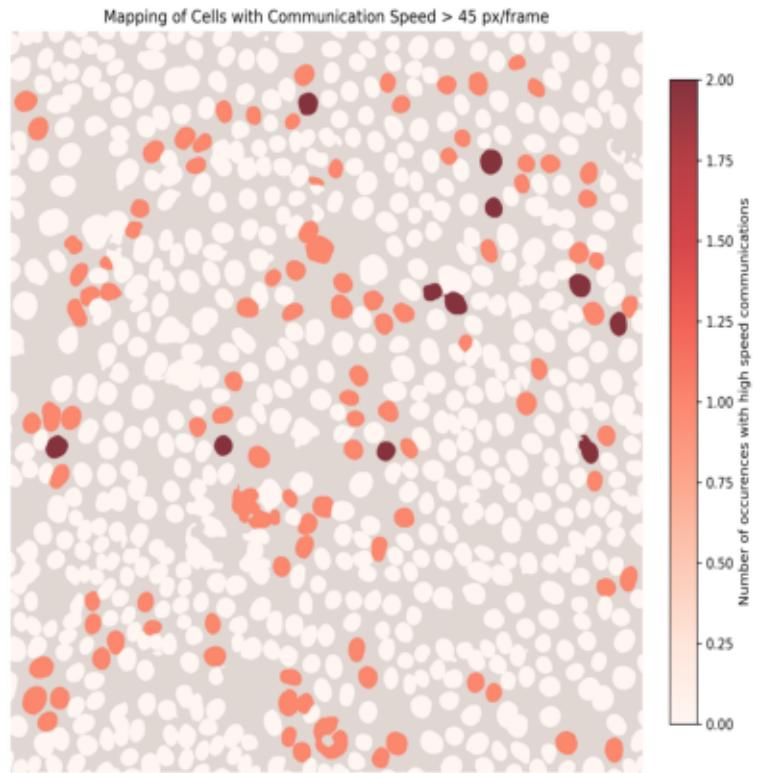


[2025-08-27 14:49:18] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 48 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.1175, upper=1.49)

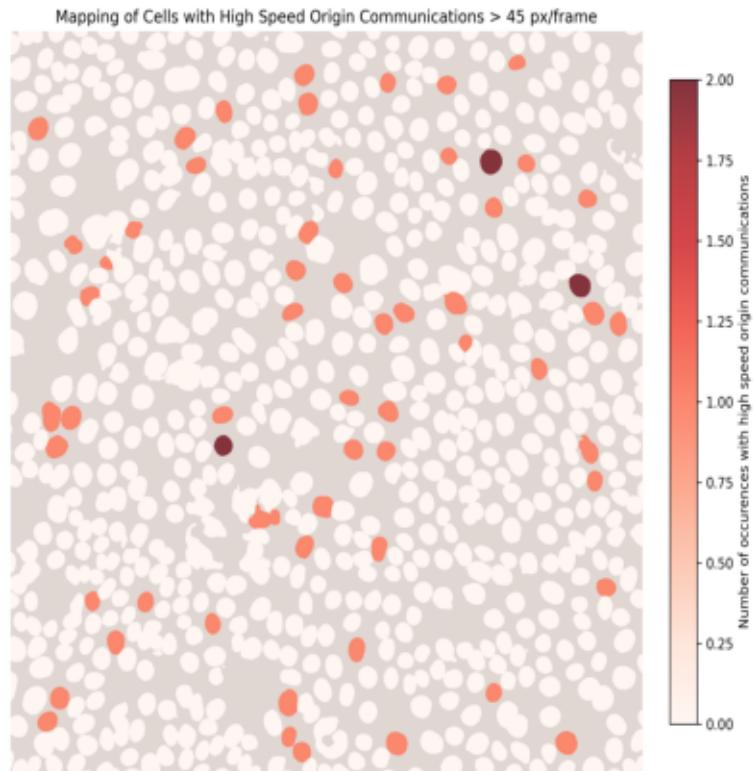
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
1	3015545705552	6	523	0	
2	3015489585360	6	487	0	
5	3015545709392	7	526	0	
7	3015545707376	8	970	6	
8	3015545709152	9	734	1	
..	
517	3015502163744	230	818	7	
524	3015502161536	233	901	13	
596	3015502166768	265	934	1	
603	3015502165856	270	1031	0	
627	3015502158992	283	1089	5	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
1	519	0	41.0	41.0	
2	518	0	26.0	27.0	
5	540	0	71.0	72.0	
7	1012	10	1106.0	1106.0	
8	699	2	218.0	218.0	
..	\
517	853	9	1194.0	1195.0	
524	939	8	1137.0	1138.0	
596	982	2	221.0	222.0	
603	1020	0	45.0	46.0	
627	1096	8	1195.0	1197.0	
	Duration (s)	Distance (um)	Speed (um/s)		\
1	0.0	35.52	35.52		
2	1.0	15.98	15.98		
5	1.0	21.07	21.07		
7	0.0	20.64	20.64		
8	0.0	21.36	21.36		
..		\
517	1.0	22.56	22.56		
524	1.0	18.09	18.09		
596	1.0	21.86	21.86		
603	1.0	15.70	15.70		
627	2.0	37.97	18.99		
	Event time phase (fraction of event duration)				\
1		1.00			
2		0.07			
5		0.17			
7		NaN			
8		0.00			
..		...			\
517		NaN			
524		1.00			
596		NaN			
603		0.03			
627		0.18			
	Event recruitment phase (fraction of involved cells)		dataset		\
1		0.5	20250501_IS03		
2		0.0	20250501_IS03		
5		0.0	20250501_IS03		
7		NaN	20250501_IS03		
8		0.0	20250501_IS03		
..			\
517		NaN	20250501_IS03		
524		0.5	20250501_IS03		

596		NaN	20250501_IS03
603		0.0	20250501_IS03
627		0.0	20250501_IS03

	Number of cells involved	category	Speed category
1		4	High speed
2		4	High speed
5		5-10	High speed
7		2	High speed
8		3	High speed
..	
517		2	High speed
524		4	High speed
596		2	High speed
603		5-10	High speed
627		3	High speed

[62 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
187		0	1
192		0	1
197		0	1
198		0	3
200		0	1
..	
1097		0	1
1099		1	0
1101		0	2
1105		0	1
1107		0	2

[343 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	187	114.73	6.83
2	192	301.60	7.80
3	197	61.75	9.10
4	198	321.75	10.40
5	200	342.23	11.38
..
653	1097	151.45	483.93
655	1099	229.78	484.90
657	1101	425.10	485.88
659	1105	176.47	487.50
661	1107	292.18	489.12

Number of peaks Is active Occurrences in global events \

0	11	True	5
2	7	True	4
3	8	True	5
4	9	True	5
5	12	True	5
..
653	6	True	4
655	10	True	5
657	10	True	4
659	15	True	5
661	8	True	4

Occurrences in global events as early peaker			Early peaker event IDs \
0	0	0	[]
2	0	0	[]
3	0	0	[]
4	0	0	[]
5	0	0	[]
..
653	0	0	[]
655	1	1	[5]
657	1	1	[3]
659	2	2	[3, 5]
661	0	0	[]

Occurrences in sequential events \		
0	2	
2	1	
3	2	
4	2	
5	1	
..
653	1	
655	1	
657	2	
659	3	
661	2	

Occurrences in sequential events as origin \		
0	1	
2	1	
3	1	
4	2	
5	0	
..
653	1	
655	0	
657	2	

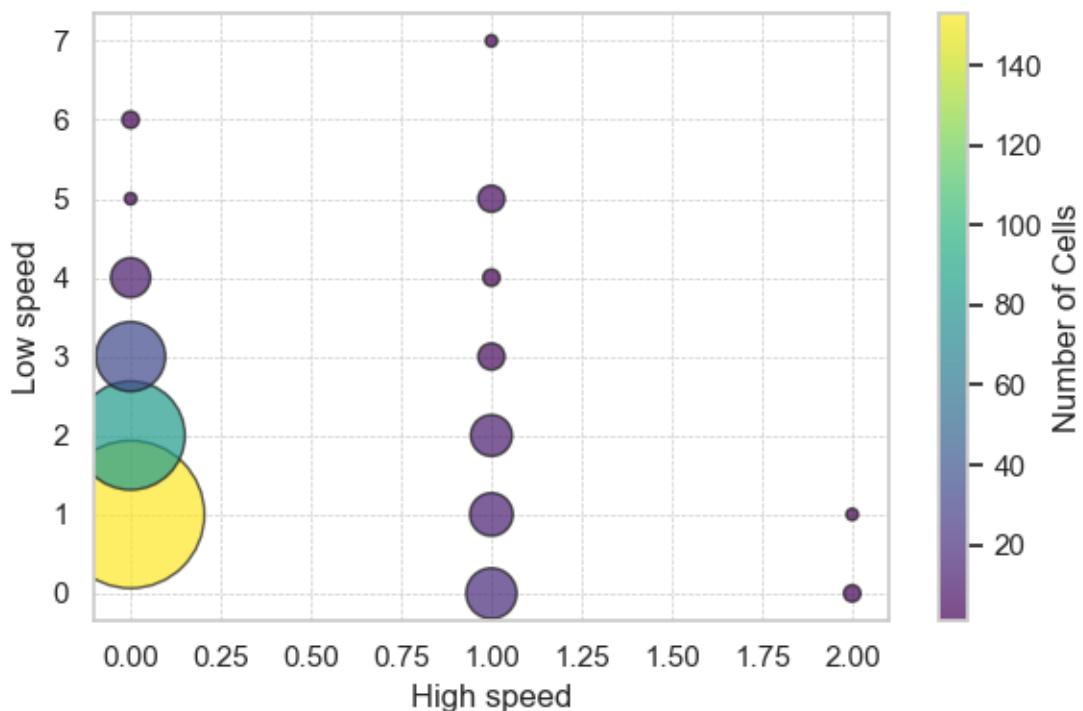
659		1	
661		1	
Occurrences in individual events Peak frequency (Hz) Periodicity score \			
0	2	0.0065	0.50
2	1	0.0041	0.62
3	0	0.0047	0.57
4	0	0.0053	0.46
5	2	0.0071	0.63
..
653	1	0.0035	0.66
655	2	0.0059	0.53
657	1	0.0059	0.82
659	2	0.0088	0.67
661	0	0.0047	0.63
Neighbor count Neighbors (labels) dataset \			
0	1 [216]	20250501_IS03	
2	3 [198, 204, 220]	20250501_IS03	
3	4 [201, 209, 231, 235]	20250501_IS03	
4	5 [192, 200, 220, 228, 234]	20250501_IS03	
5	4 [198, 208, 234, 248]	20250501_IS03	
..
653	4 [1070, 1079, 1095, 1108]	20250501_IS03	
655	3 [1053, 1071, 1080]	20250501_IS03	
657	4 [1056, 1068, 1089, 1100]	20250501_IS03	
659	3 [1076, 1086, 1095]	20250501_IS03	
661	3 [1087, 1090, 1111]	20250501_IS03	
Involved in sequential event Occurrences in sequential events category \			
0	Involved in sequential event		1-2
2	Involved in sequential event		1-2
3	Involved in sequential event		1-2
4	Involved in sequential event		1-2
5	Involved in sequential event		1-2
..
653	Involved in sequential event		1-2
655	Involved in sequential event		1-2
657	Involved in sequential event		1-2
659	Involved in sequential event		3-4
661	Involved in sequential event		1-2
High speed Low speed			
0	0.0	1.0	
2	0.0	1.0	
3	0.0	1.0	
4	0.0	3.0	
5	0.0	1.0	

```

...
653      0.0      1.0
655      1.0      0.0
657      0.0      2.0
659      0.0      1.0
661      0.0      2.0

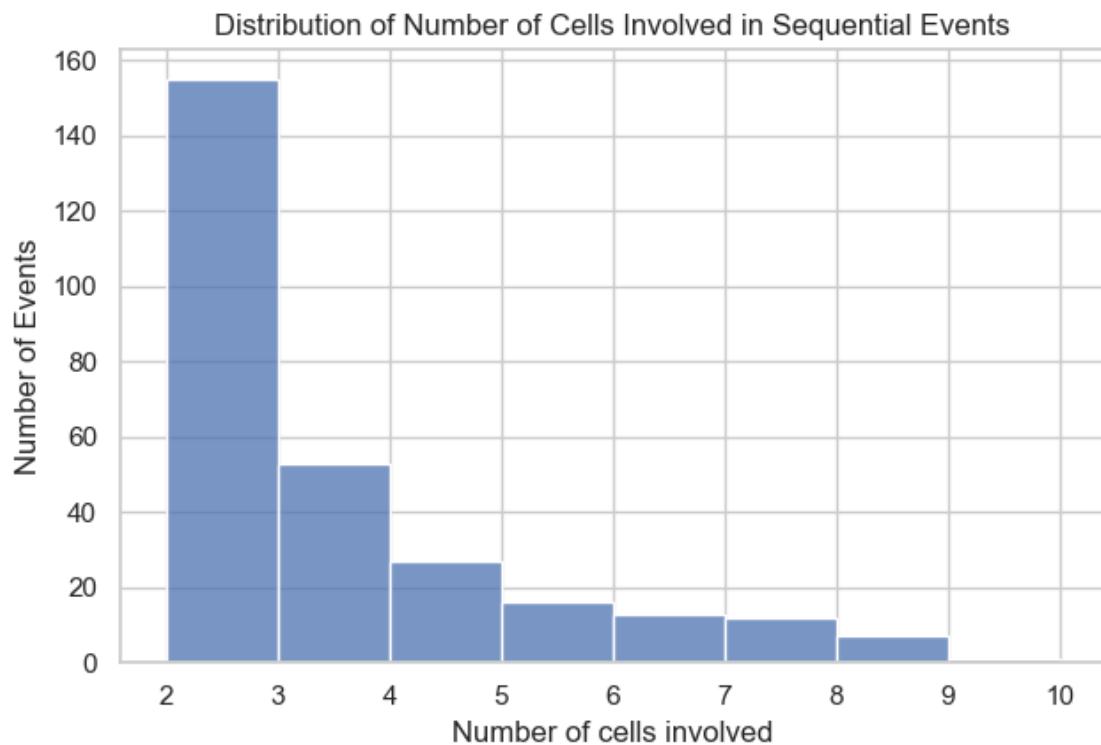
```

[343 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

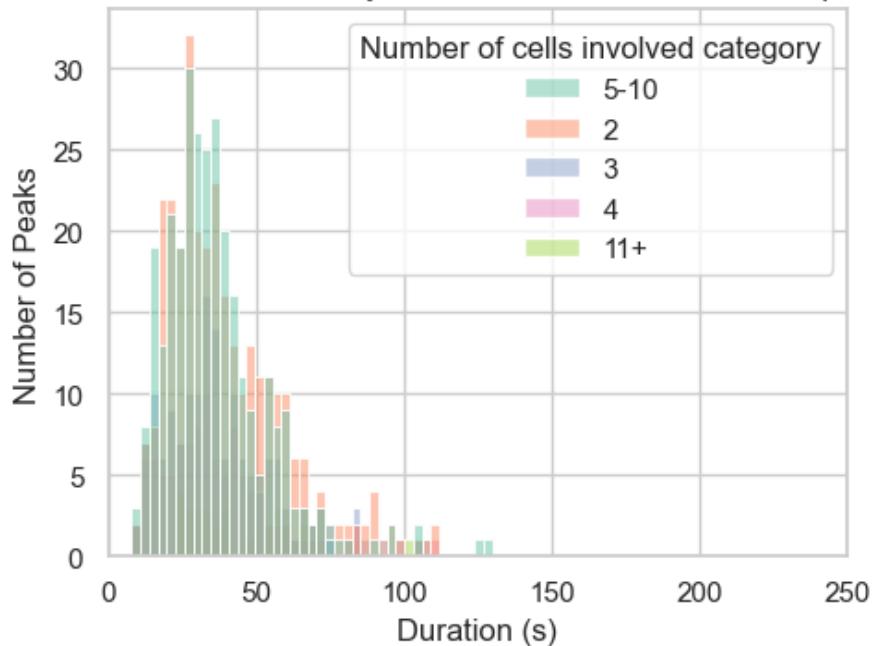
[2025-08-27 14:49:21] [INFO] calcium: plot_histogram: removed 3 outliers out of 287 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

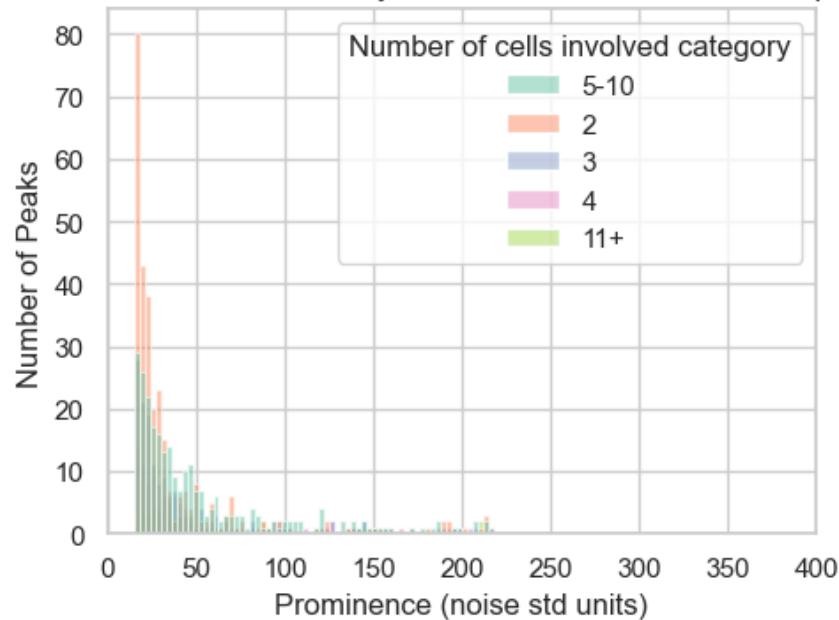
```
[2025-08-27 14:49:21] [INFO] calcium: plot_histogram_by_group: removed 24 outliers out of 924 on 'Duration (s)' (lower=-11, upper=133)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

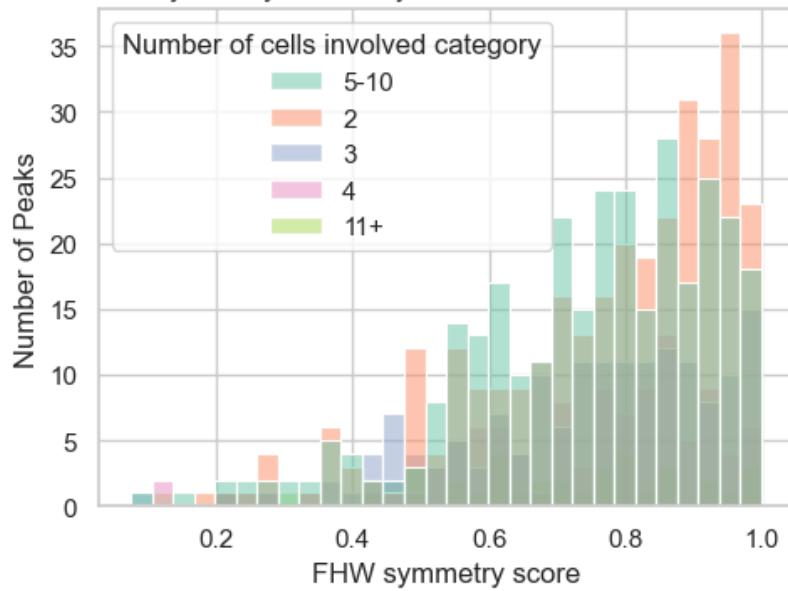


```
[2025-08-27 14:49:22] [INFO] calcium: plot_histogram_by_group: removed 75
outliers out of 924 on 'Prominence (noise std units)' (lower=-46.737,
upper=219.81)
```

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

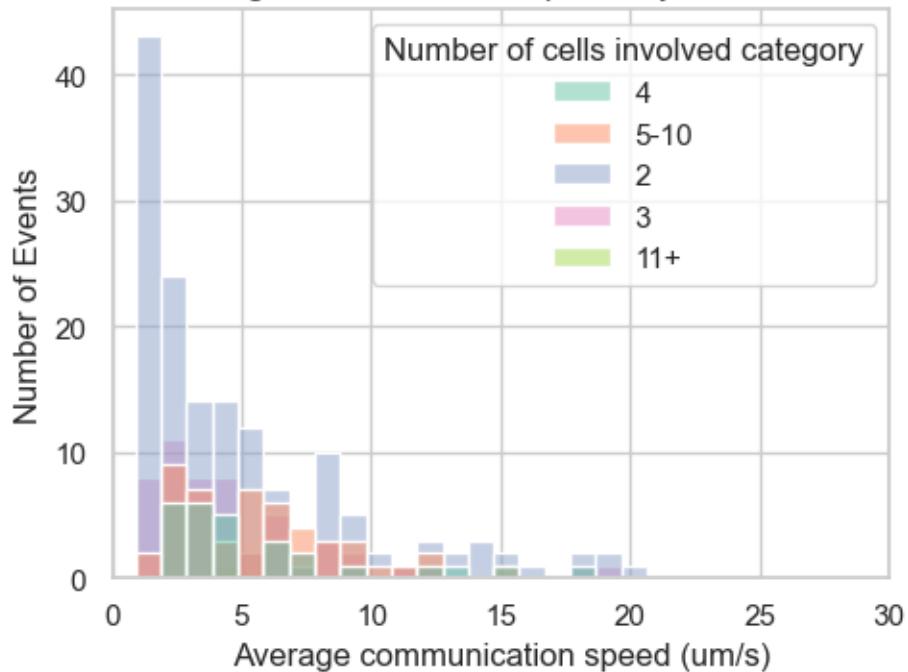


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



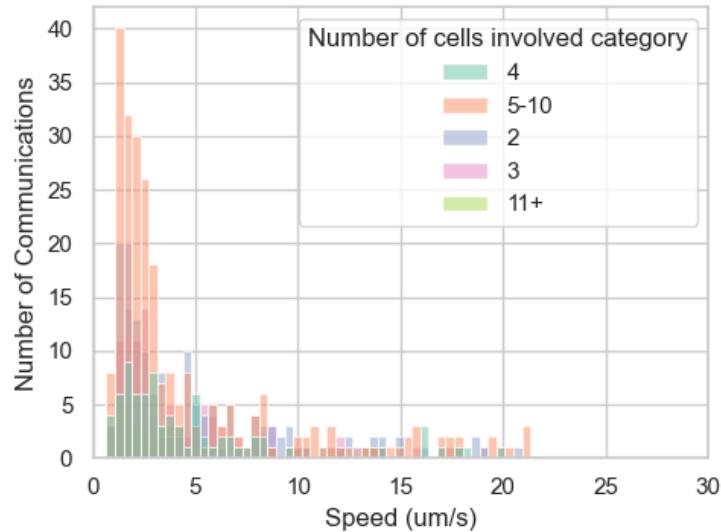
```
[2025-08-27 14:49:22] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 287 on 'Average communication speed (um/s)' (lower=-12.235, upper=21.505)
```

Distribution of Average Communication Speeds by Number of Cells Involved



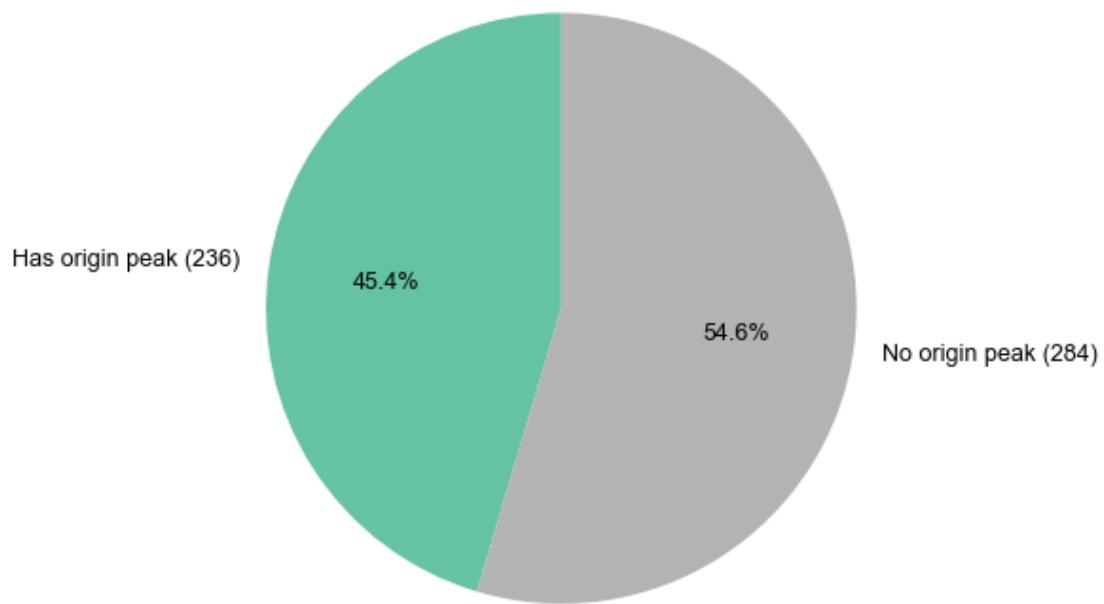
[2025-08-27 14:49:22] [INFO] calcium: plot_histogram_by_group: removed 24 outliers out of 637 on 'Speed (um/s)' (lower=-12.96, upper=21.34)

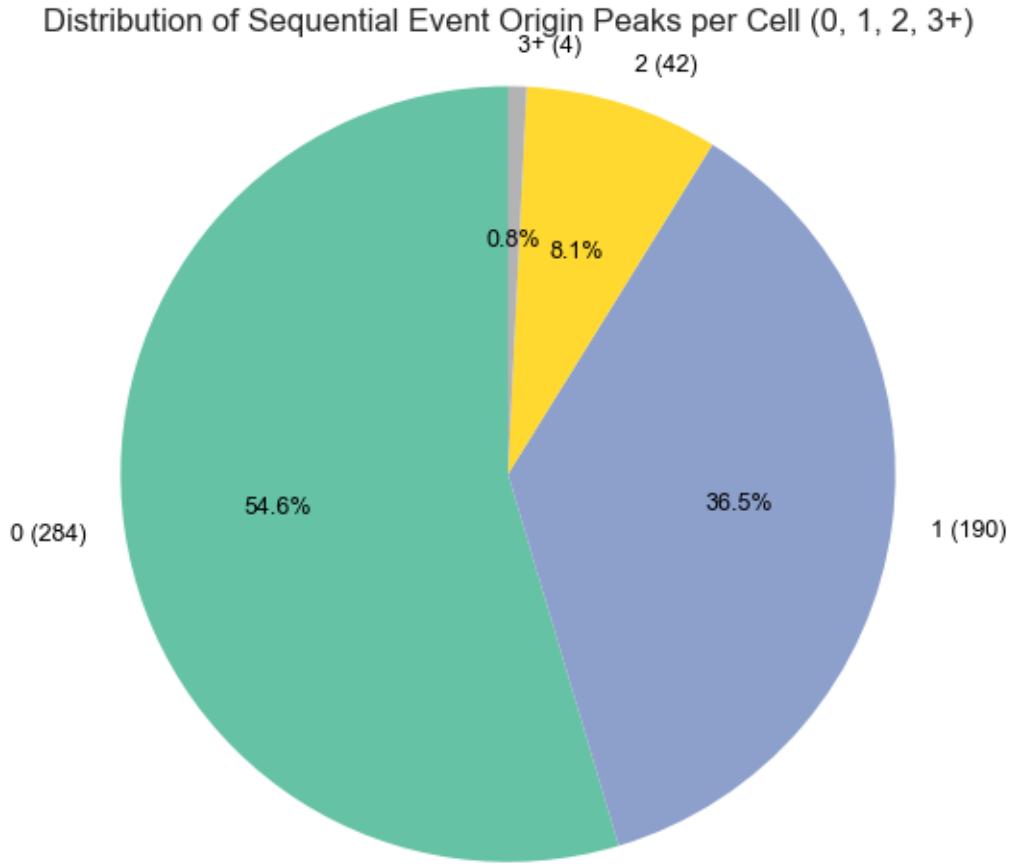
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

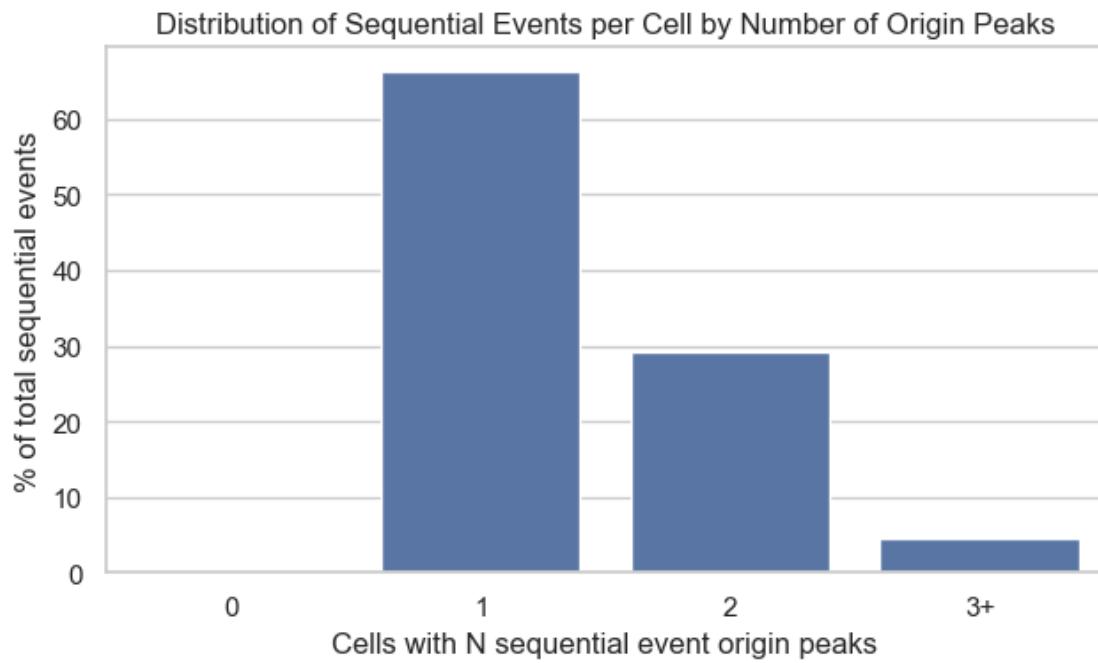
Distribution of Number of Sequential Event Origin Peaks per Cell



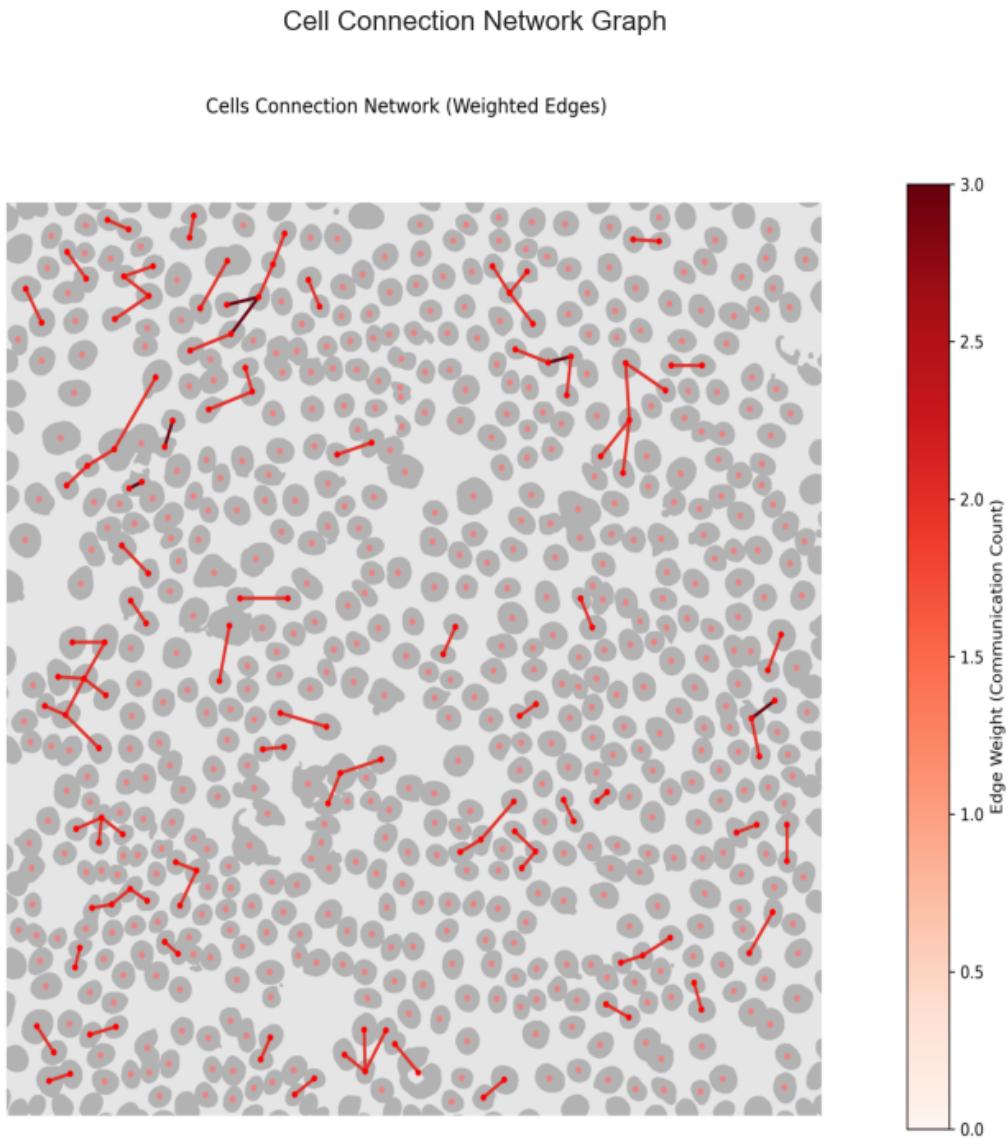


```
[2025-08-27 14:49:23] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250501\\Output\\IS03\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250501\\Output\\IS03\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'

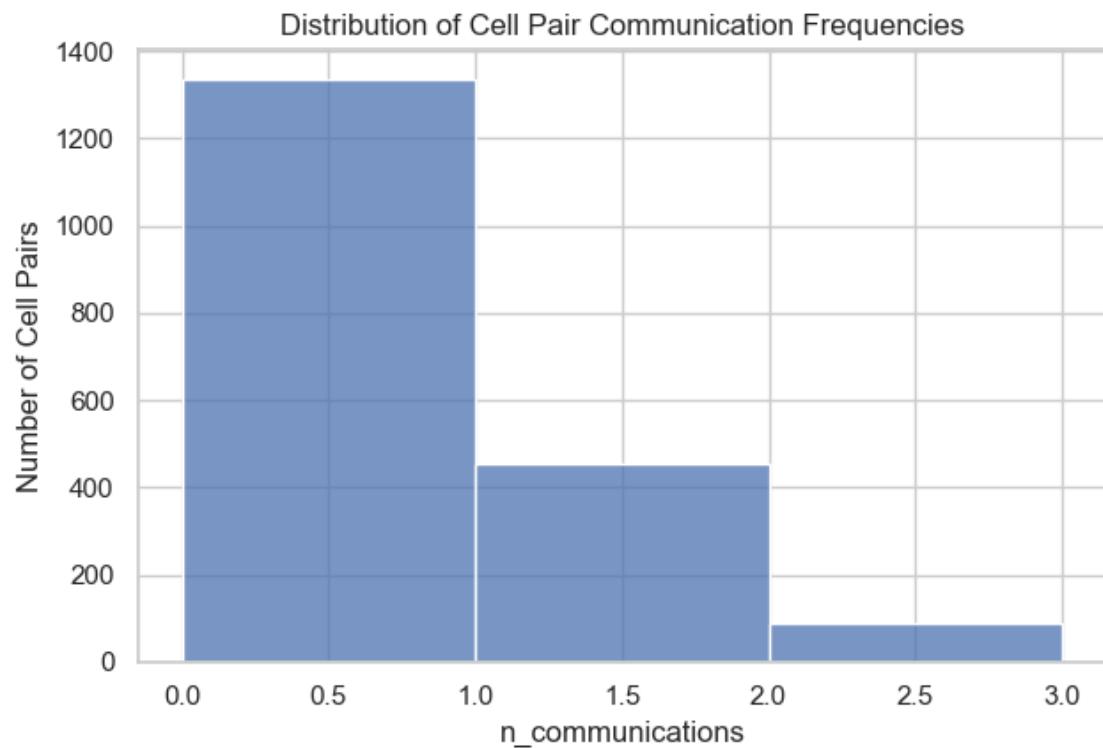


1.3.8 Connection network between cells



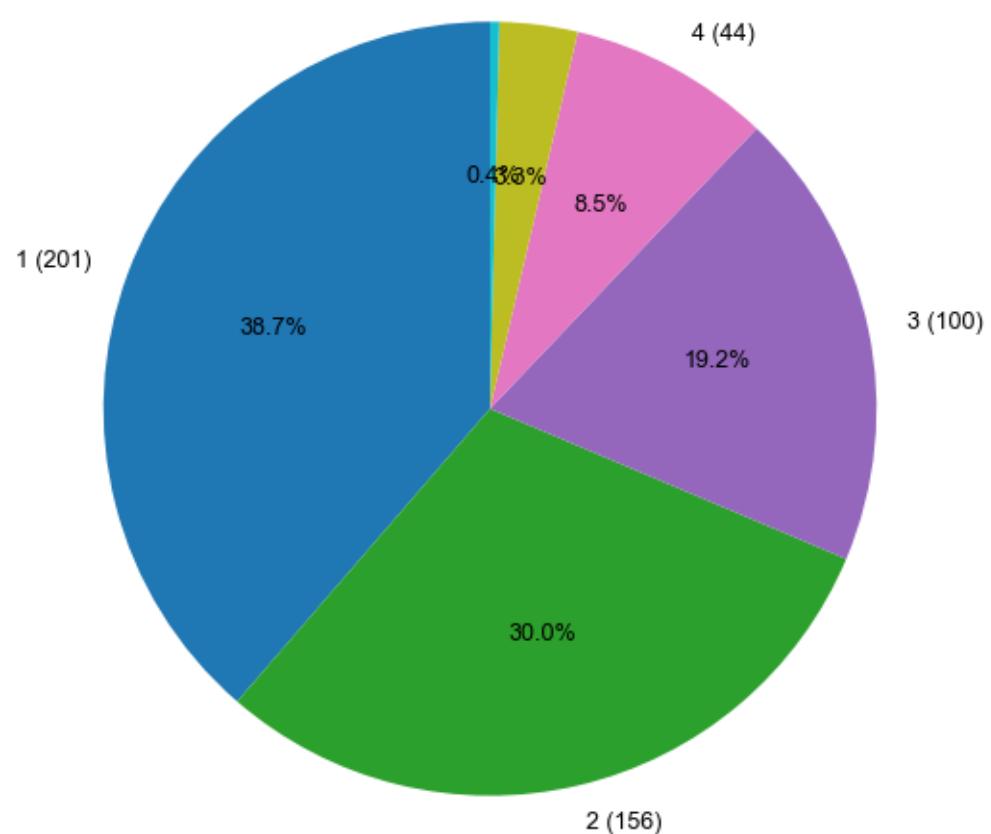
1.3.9 Pair/Trios with high communication networks

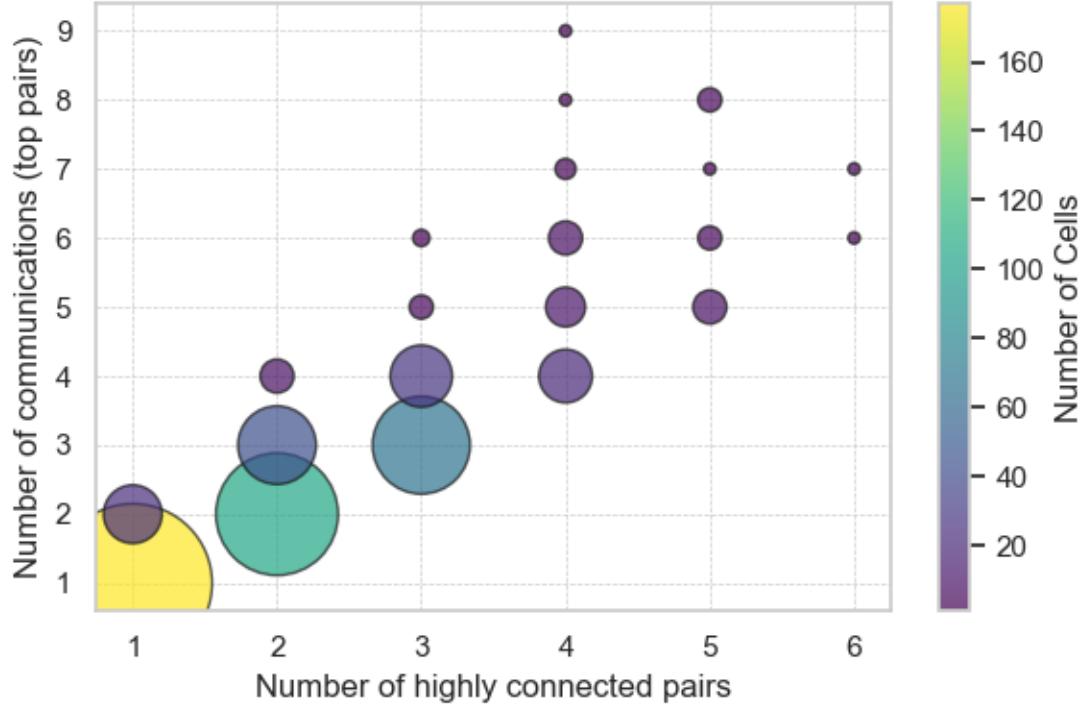
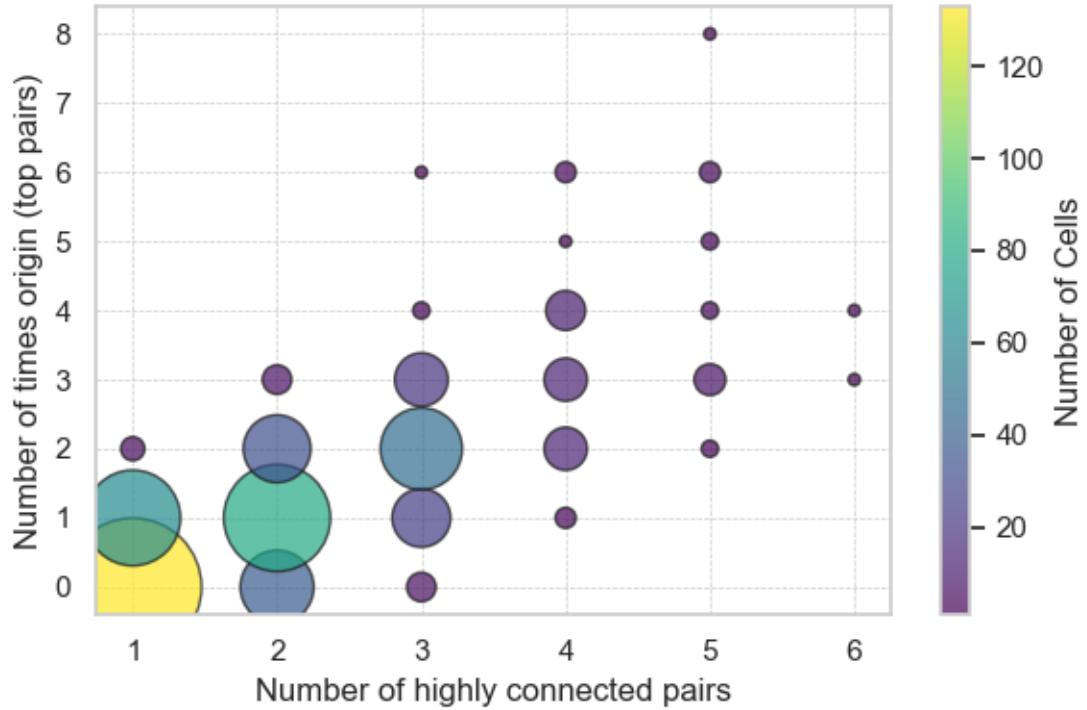
```
[2025-08-27 14:49:25] [INFO] calcium: build_neighbor_pair_stats: built 1879  
pairs across 1 datasets (mean distance=20.79 um)
```

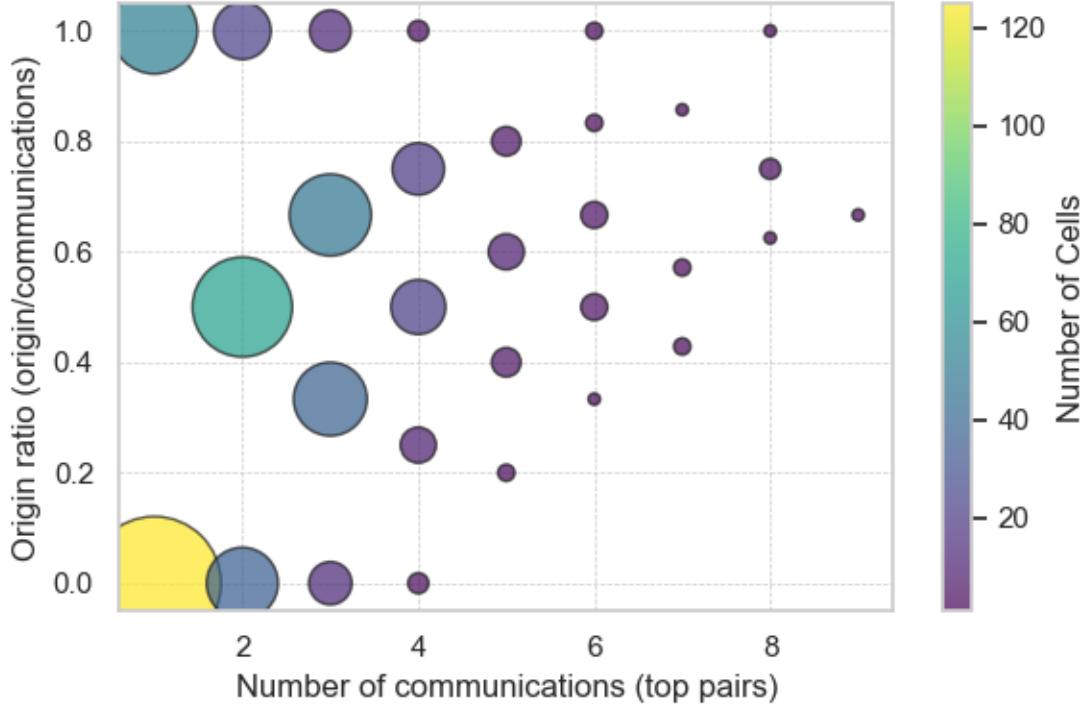
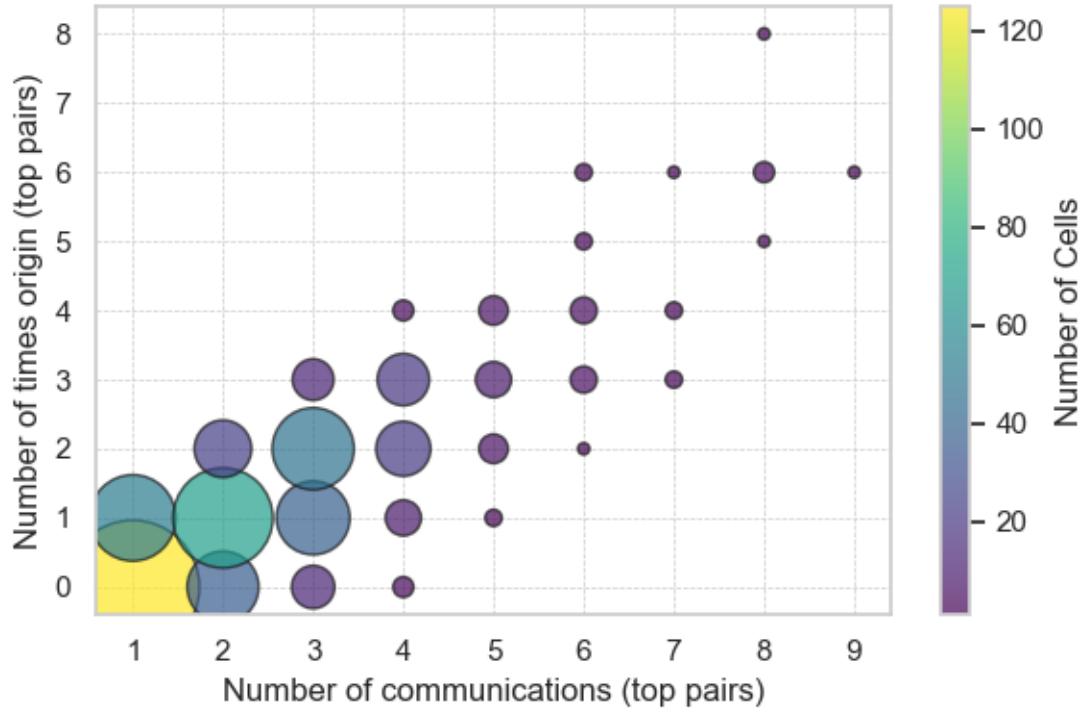


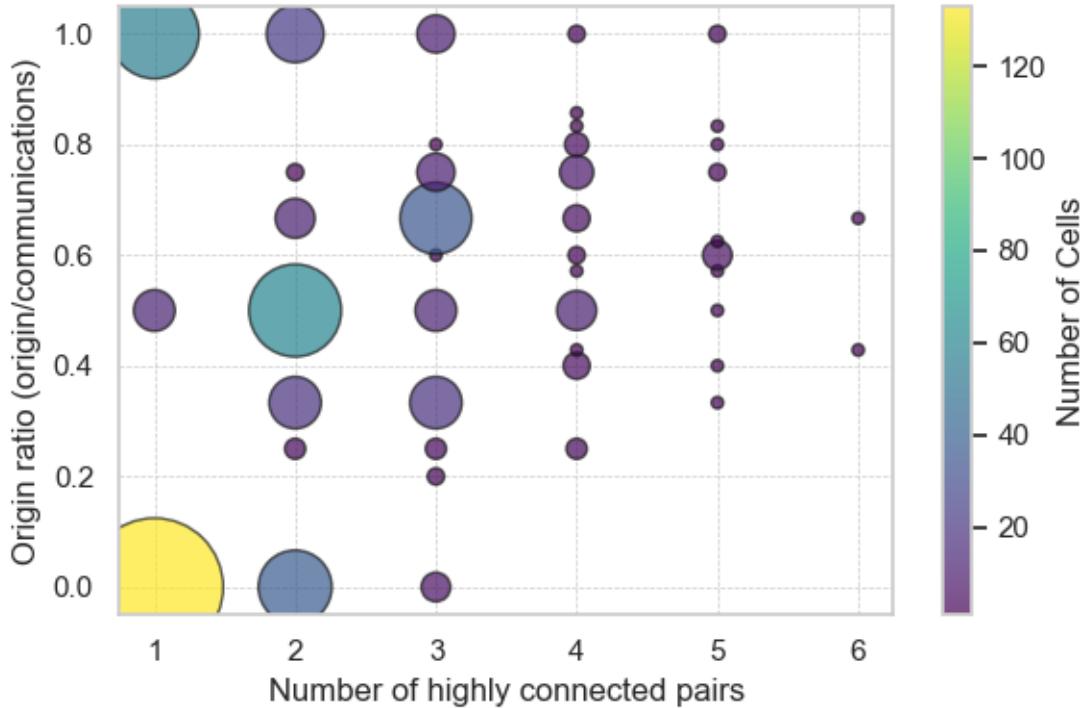
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=201 for Number of highly connected pairs=1

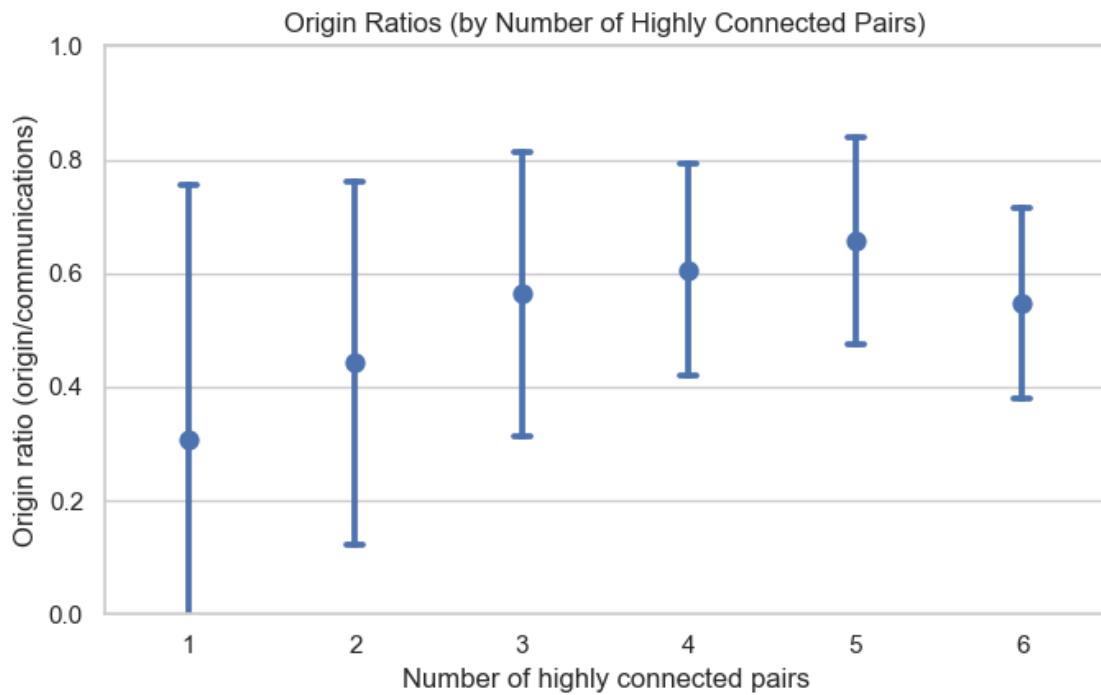
[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=156 for Number of highly connected pairs=2

[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=100 for Number of highly connected pairs=3

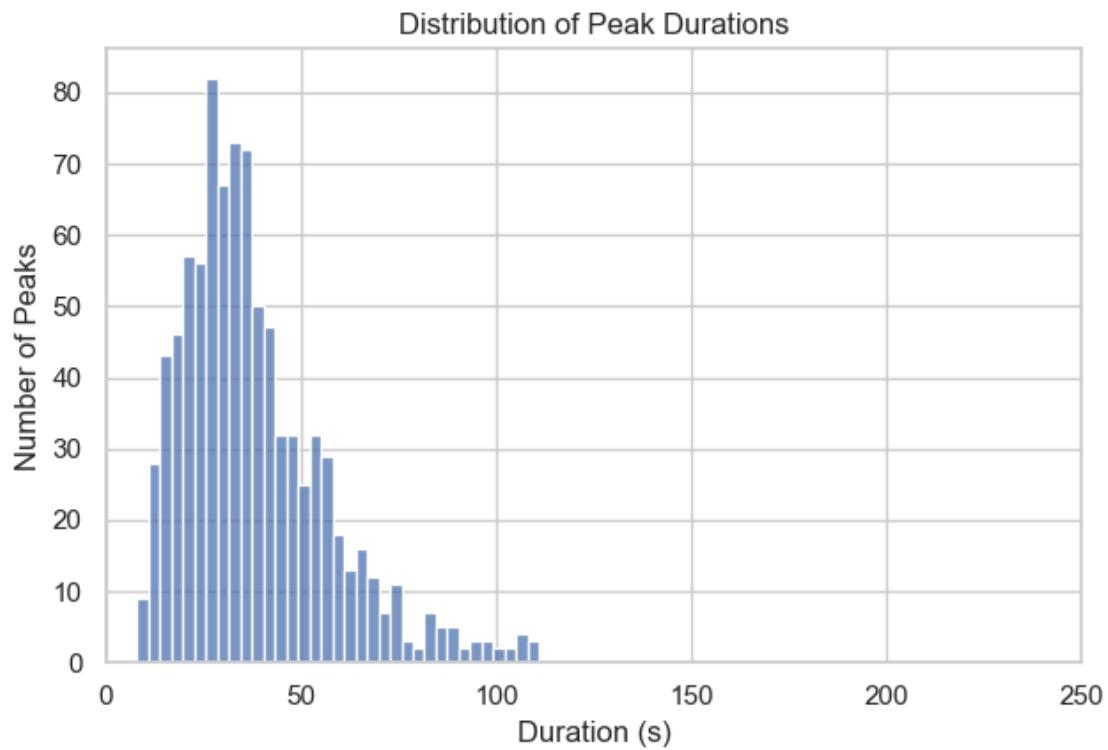
[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=44 for Number of highly connected pairs=4

[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=17 for Number of highly connected pairs=5

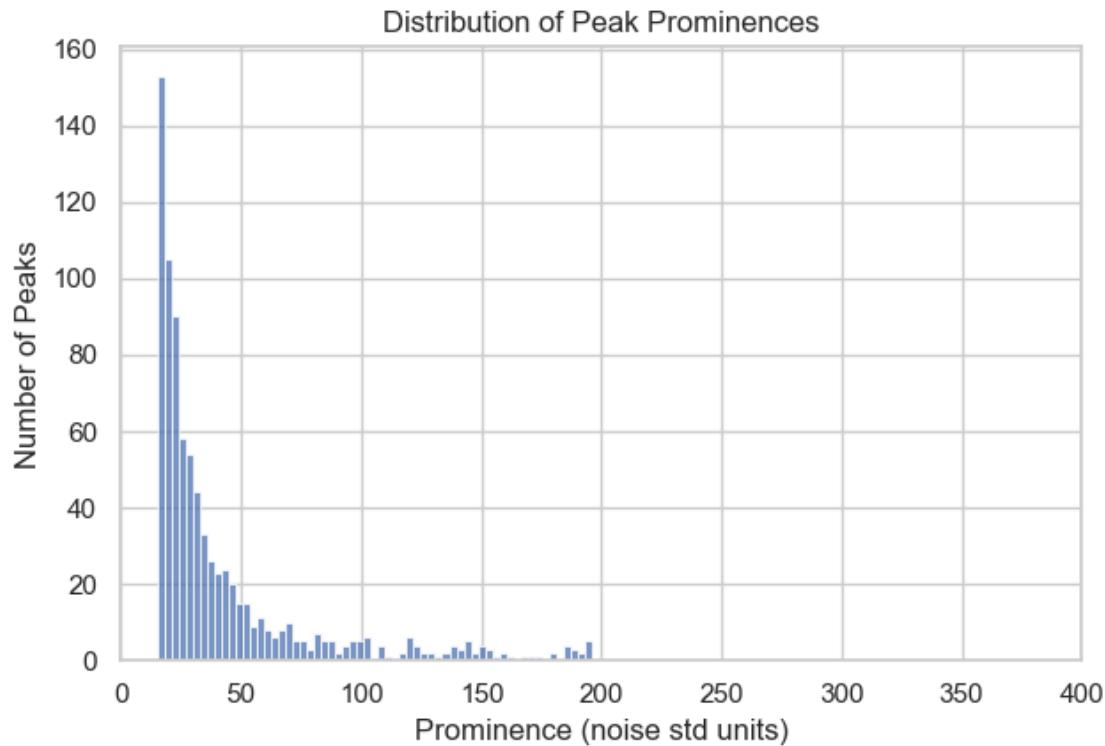
[2025-08-27 14:49:26] [INFO] calcium: plot_points_mean_std: N=2 for Number of highly connected pairs=6

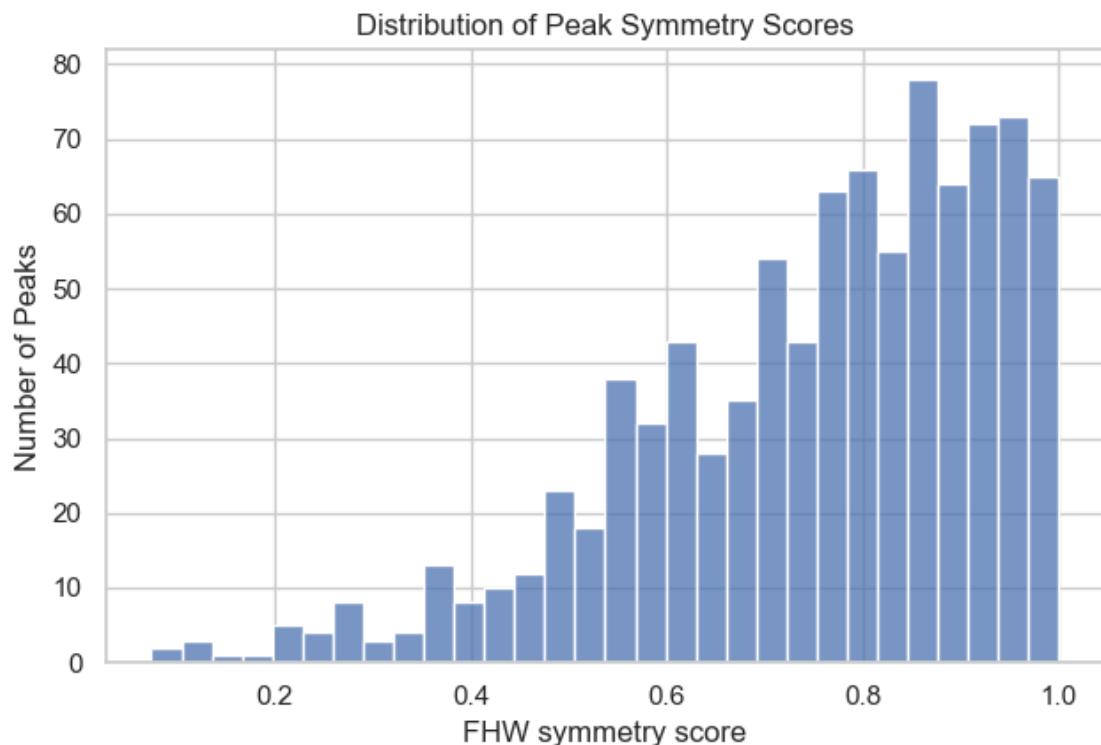


```
[2025-08-27 14:49:26] [INFO] calcium: plot_histogram: removed 26 outliers out of 924 on 'Duration (s)' (lower=-47, upper=121)
```

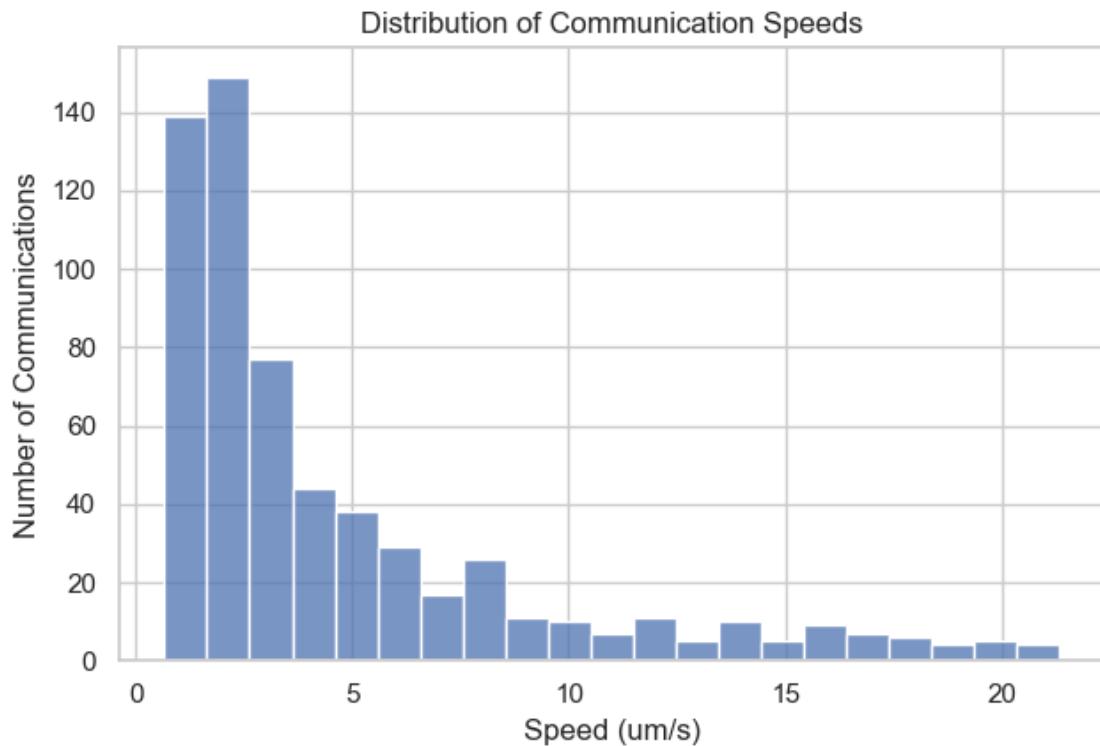


[2025-08-27 14:49:26] [INFO] calcium: plot_histogram: removed 92 outliers out of 924 on 'Prominence (noise std units)' (lower=-113.37, upper=197.6)

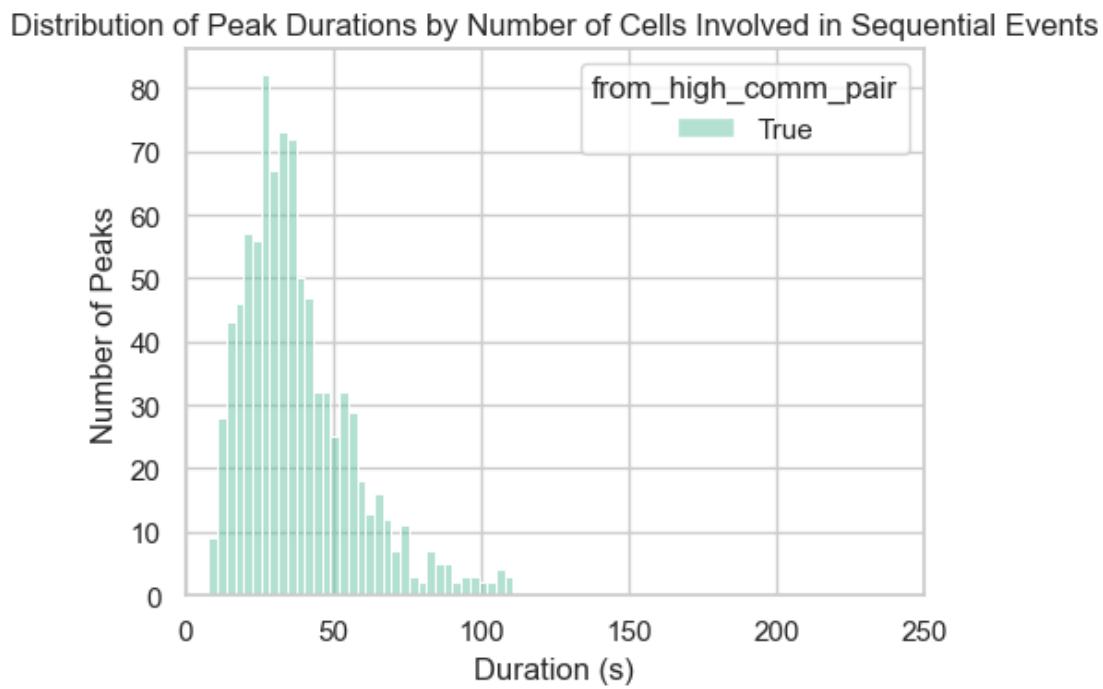




```
[2025-08-27 14:49:26] [INFO] calcium: plot_histogram: removed 24 outliers out of 637 on 'Speed (um/s)' (lower=-12.96, upper=21.34)
```

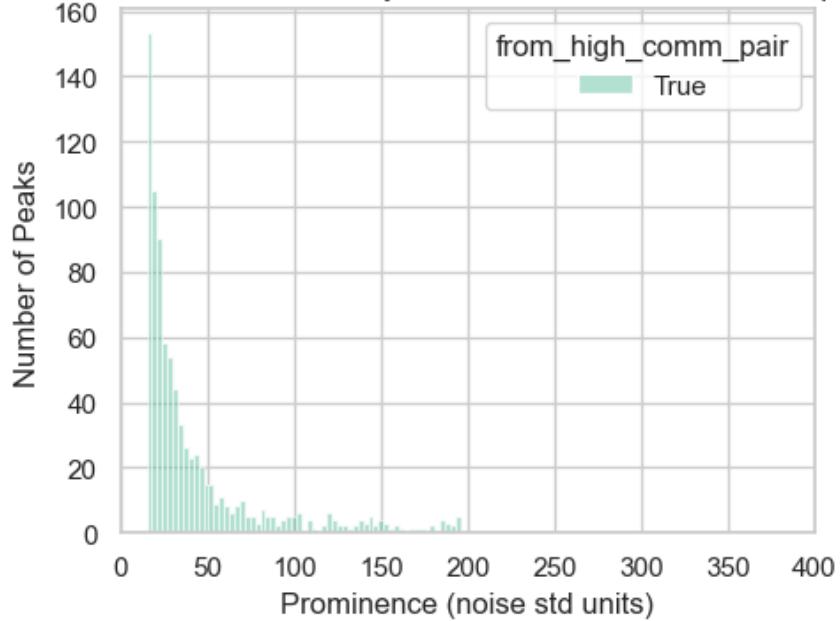


```
[2025-08-27 14:49:26] [INFO] calcium: plot_histogram_by_group: removed 26 outliers out of 924 on 'Duration (s)' (lower=-47, upper=121)
```

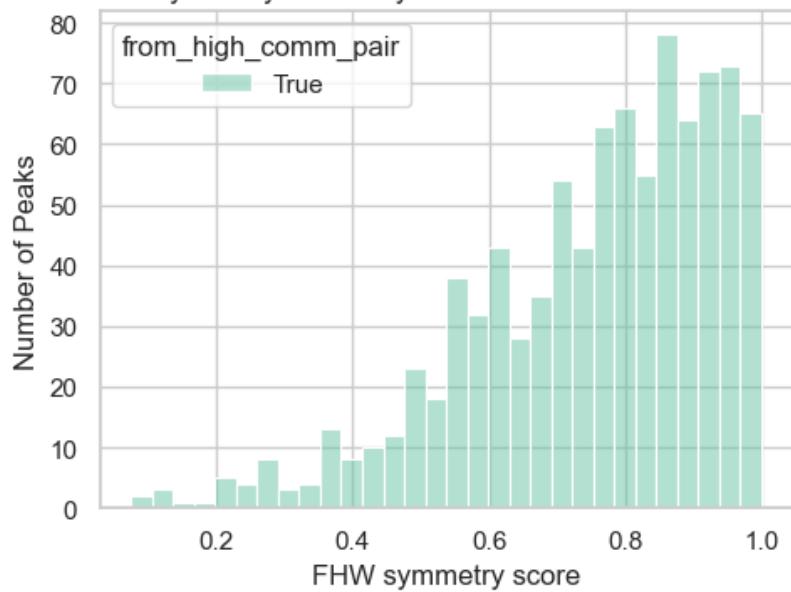


[2025-08-27 14:49:27] [INFO] calcium: plot_histogram_by_group: removed 92 outliers out of 924 on 'Prominence (noise std units)' (lower=-113.37, upper=197.6)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

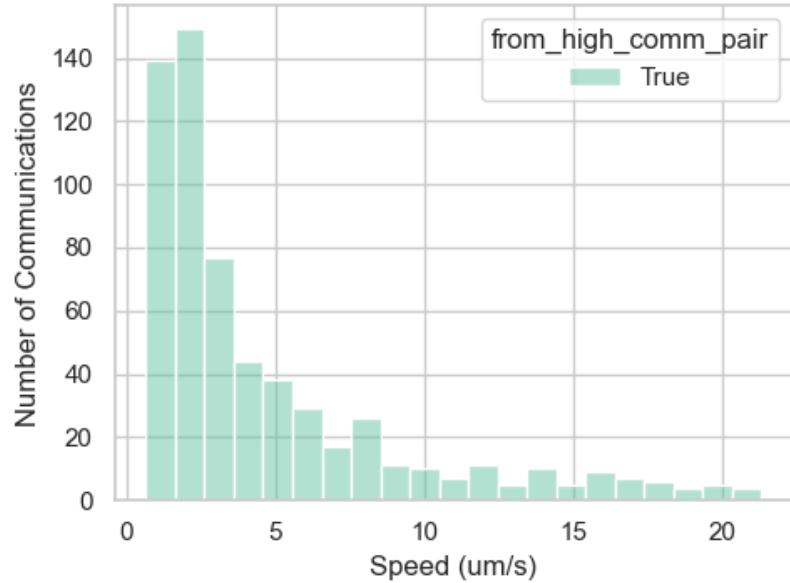


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 14:49:27] [INFO] calcium: plot_histogram_by_group: removed 24 outliers out of 637 on 'Speed (um/s)' (lower=-12.96, upper=21.34)

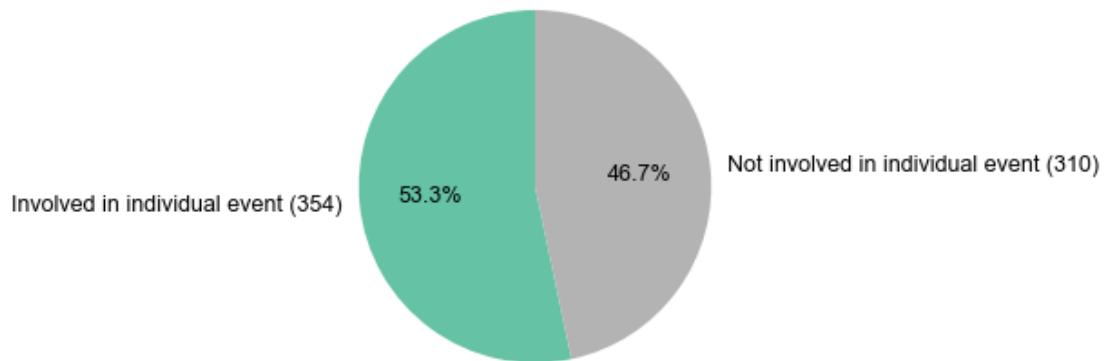
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



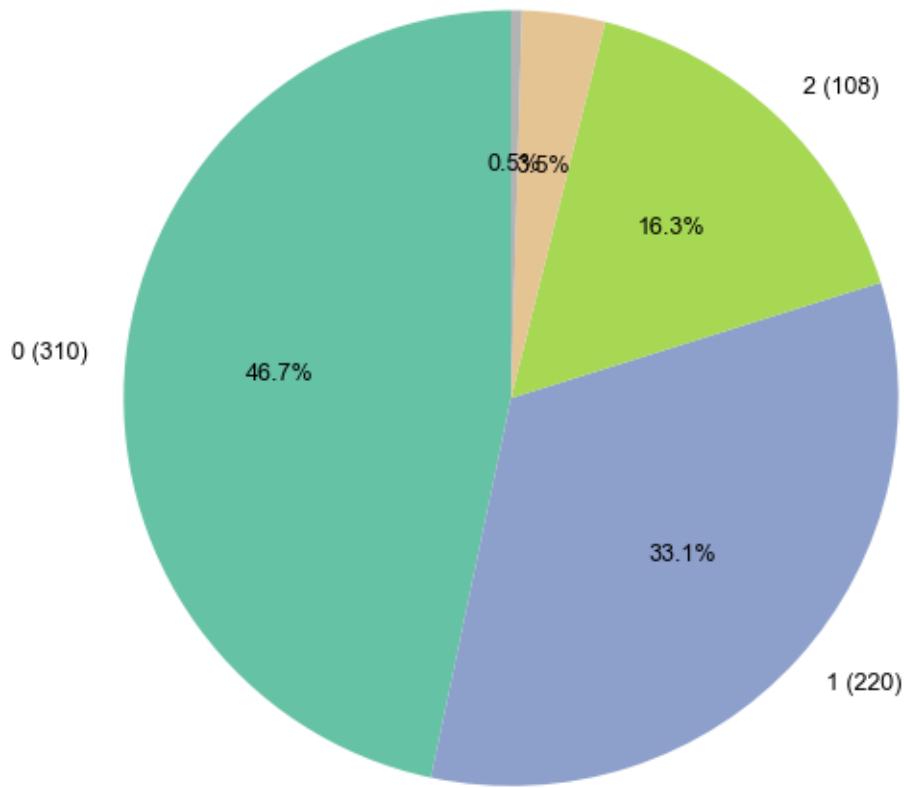
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

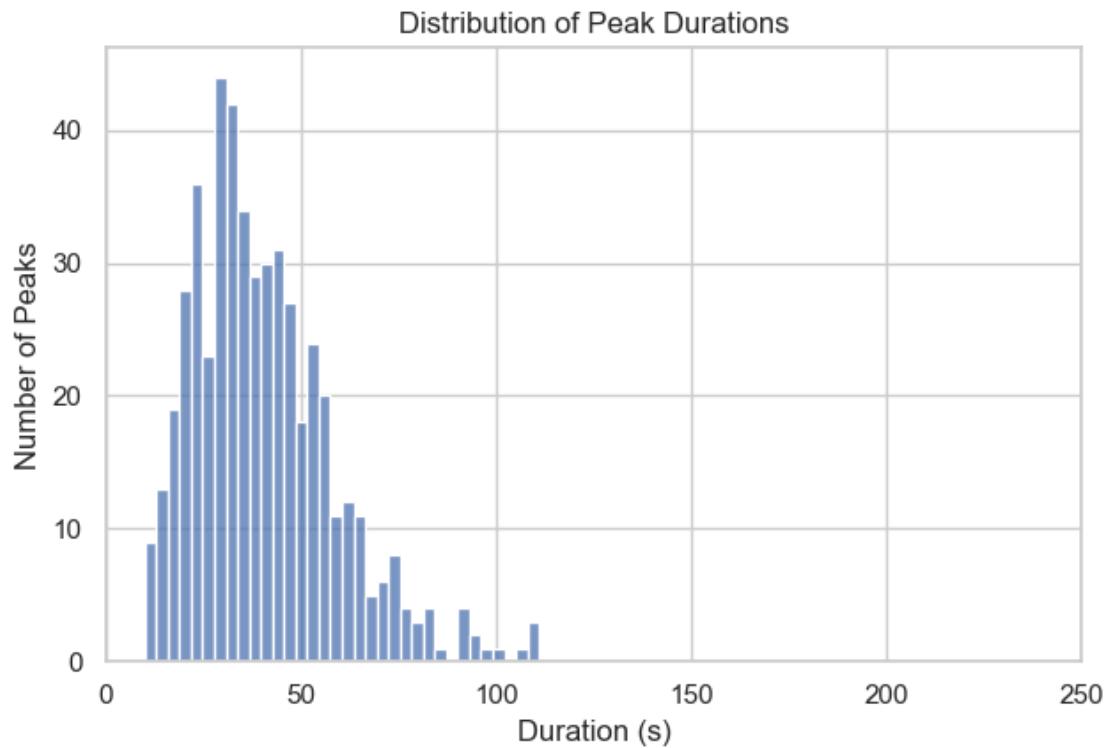


```
[2025-08-27 14:49:27] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS03\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250501\\Output\\IS03\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

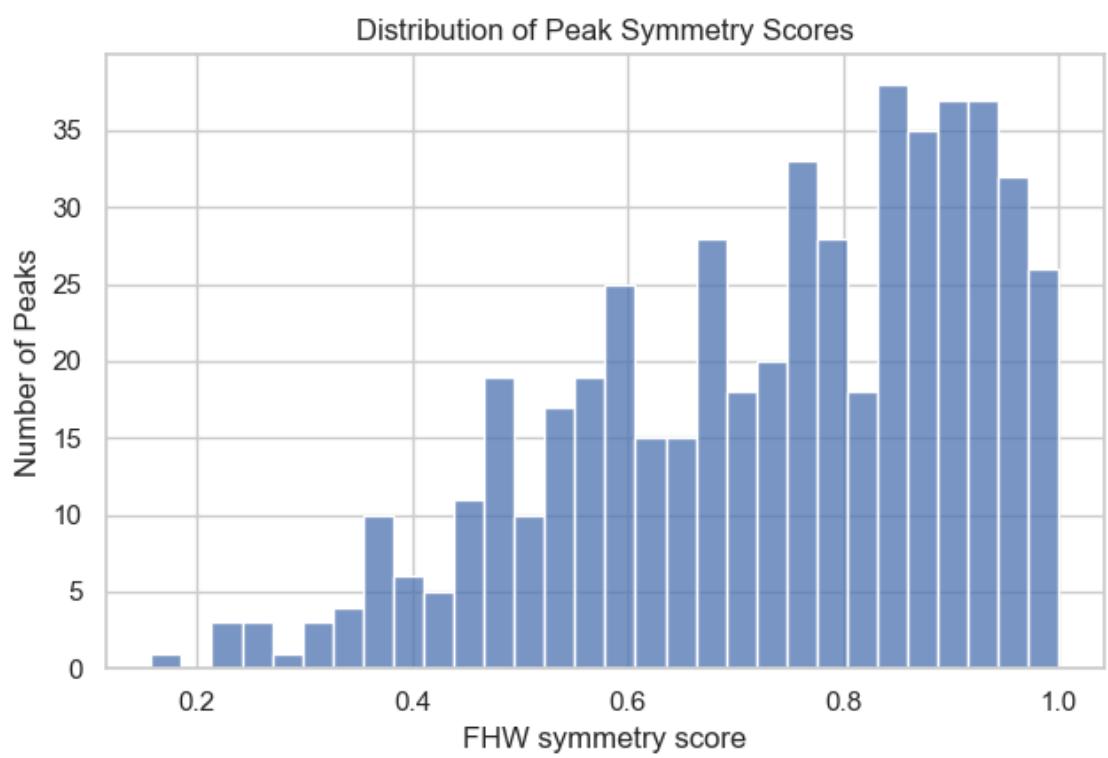
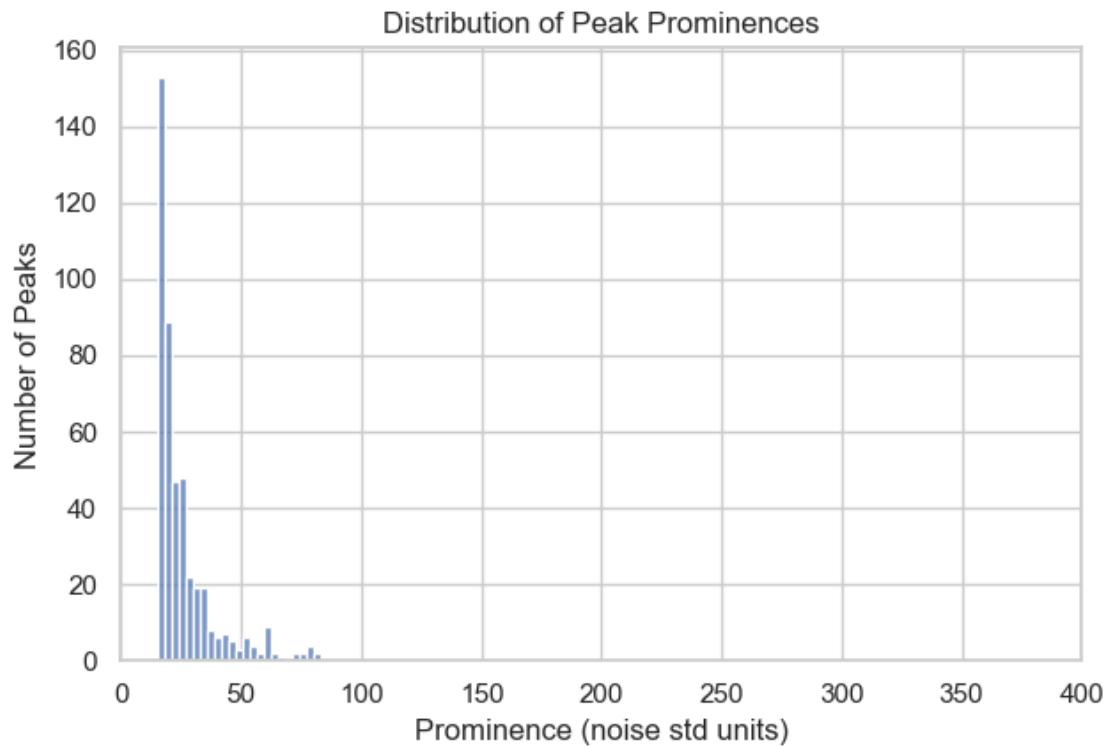
'D:\\Mateo\\20250501\\Output\\IS03\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

1.4.2 Peaks statistics in individual events

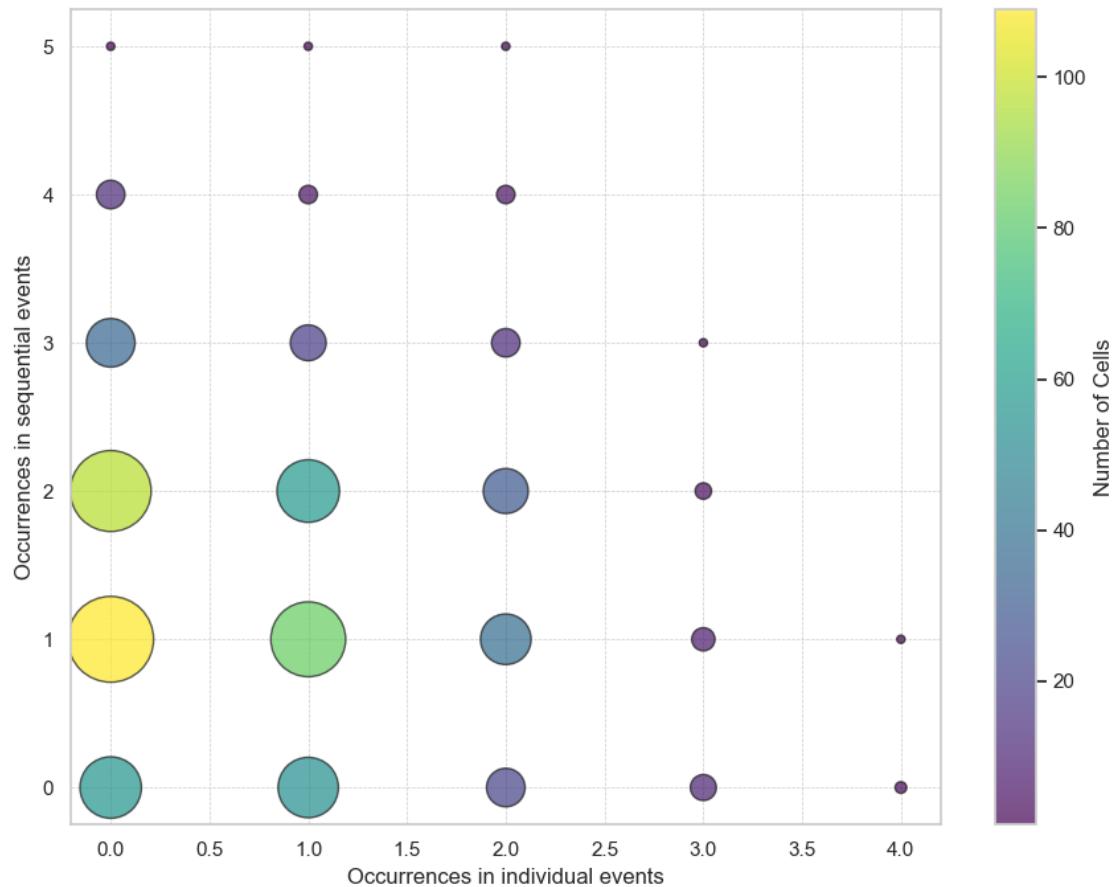
[2025-08-27 14:49:28] [INFO] calcium: plot_histogram: removed 13 outliers out of 517 on 'Duration (s)' (lower=-44, upper=124)



[2025-08-27 14:49:28] [INFO] calcium: plot_histogram: removed 57 outliers out of 517 on 'Prominence (noise std units)' (lower=-32, upper=83.5)

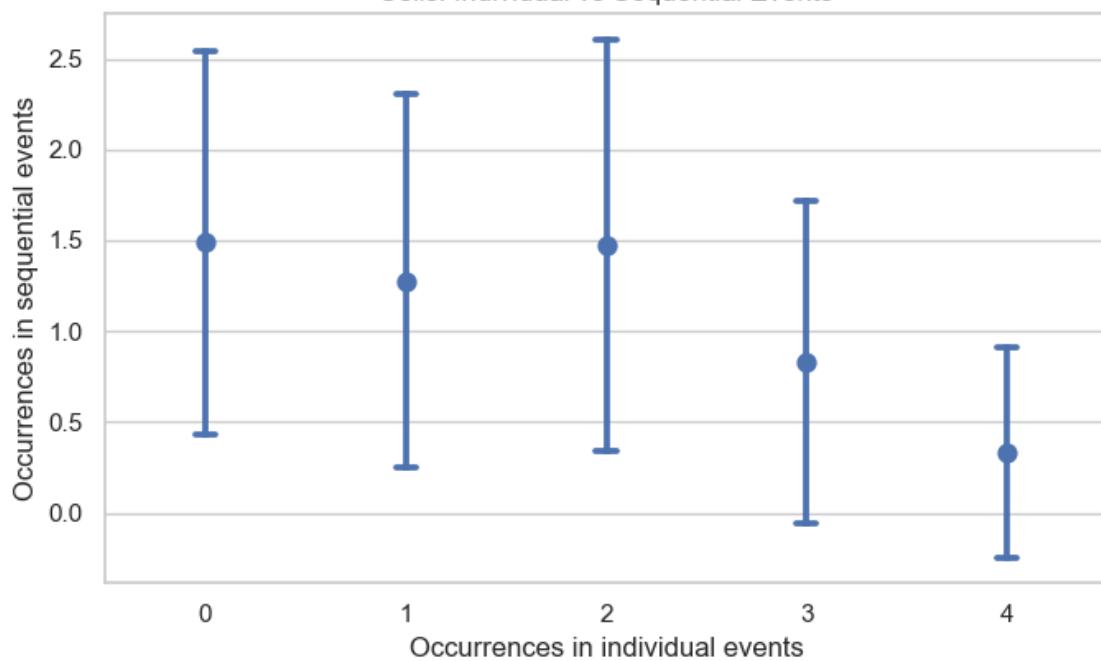


1.4.3 Correlation between event activity level & individual activity level

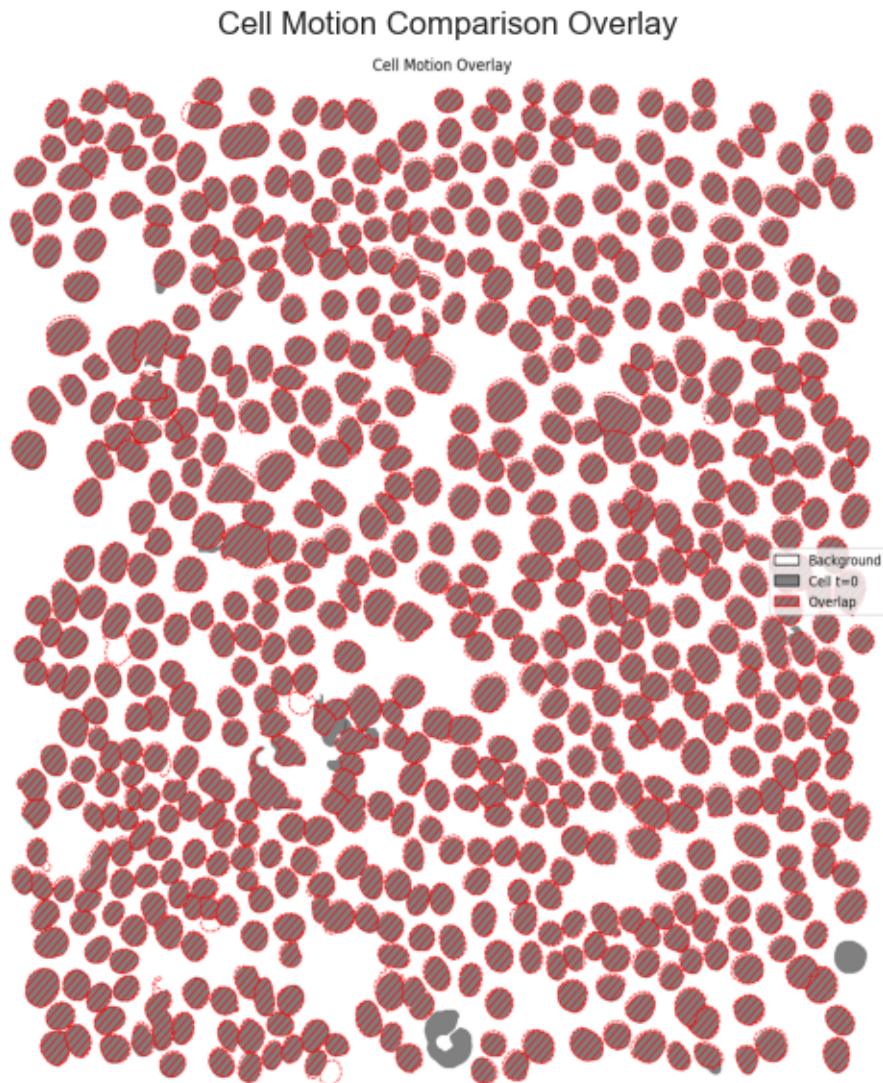


```
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: removed 0/664 outliers on 'Occurrences in sequential events' (lower=-2, upper=5)
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: N=310 for Occurrences in individual events=0
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: N=220 for Occurrences in individual events=1
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: N=108 for Occurrences in individual events=2
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: N=23 for Occurrences in individual events=3
[2025-08-27 14:49:28] [INFO] calcium: plot_points_mean_std: N=3 for Occurrences in individual events=4
```

Cells: Individual vs Sequential Events



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 664
- Hoechst image taken at t=1801: 656
- Number of cells difference: absolute 8, relative 1.21%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1028474
- Pixels segmented as cell at t=1801: 1092387
- Overlapping pixels between t=0 and t=1801: 987917 (93.16% of total)
- Pixels exclusive to t=0: 40557 (3.94% of total)
- Pixels exclusive to t=1801: 104470 (9.56% of total)

executed

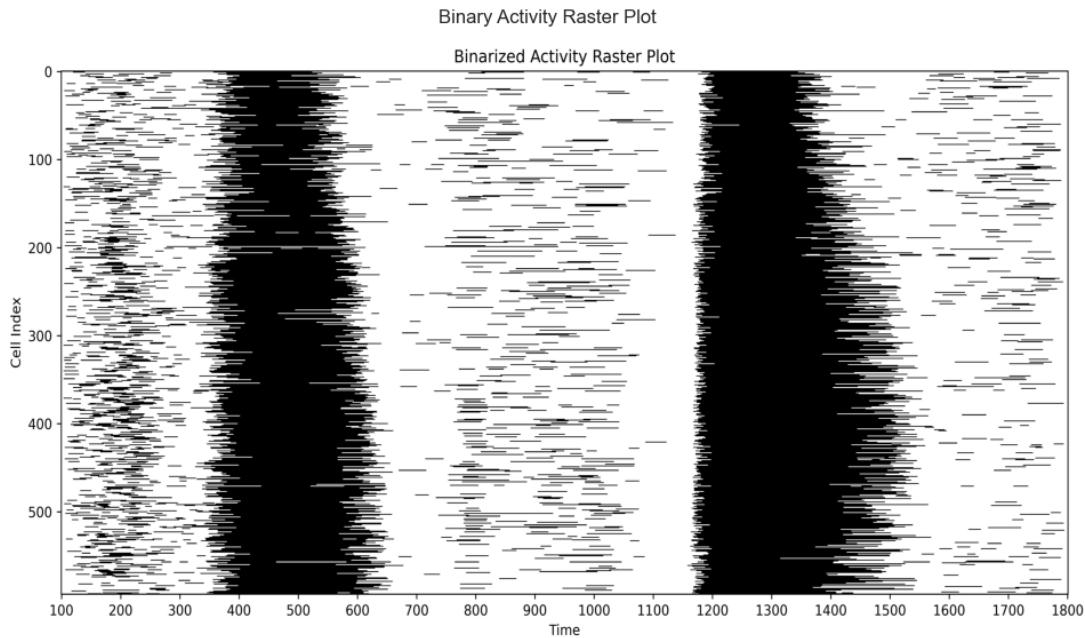
August 27, 2025

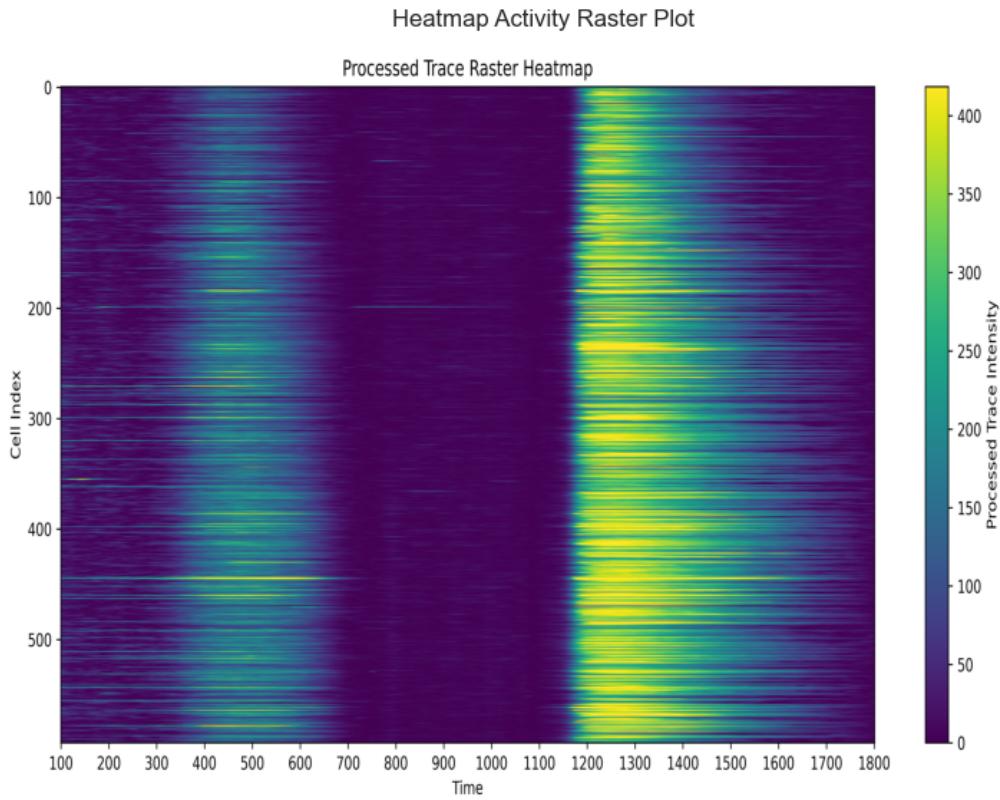
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





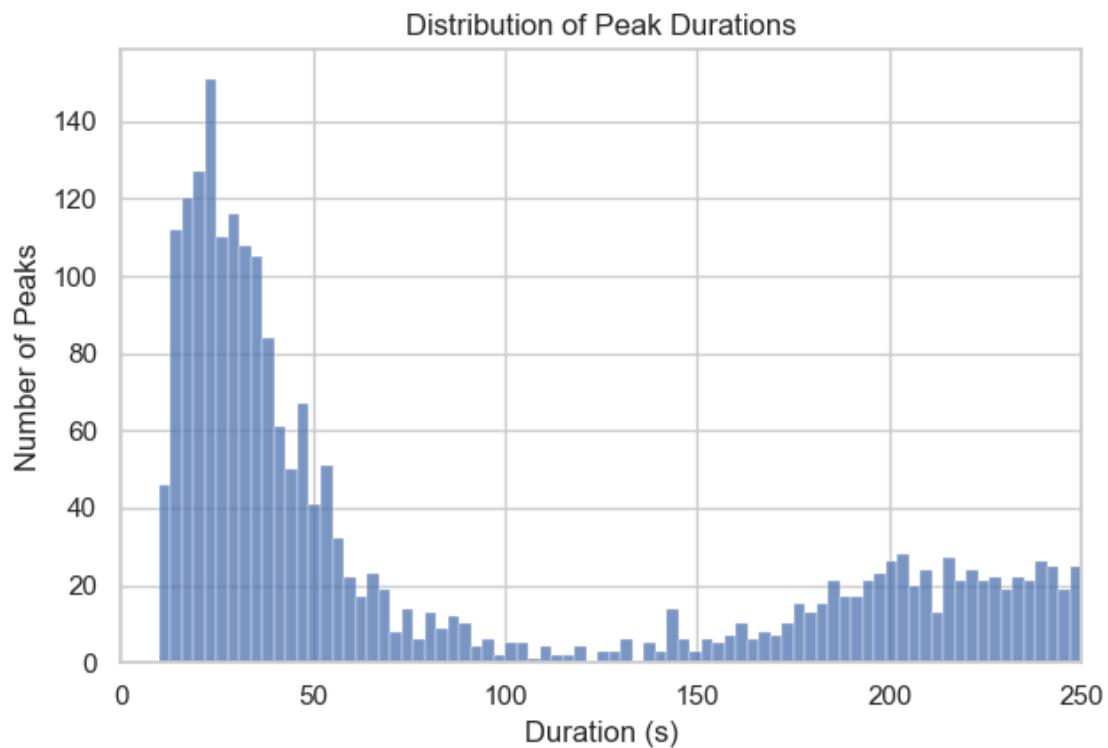
1.1.2 Peaks population

Total number of peaks: 2737

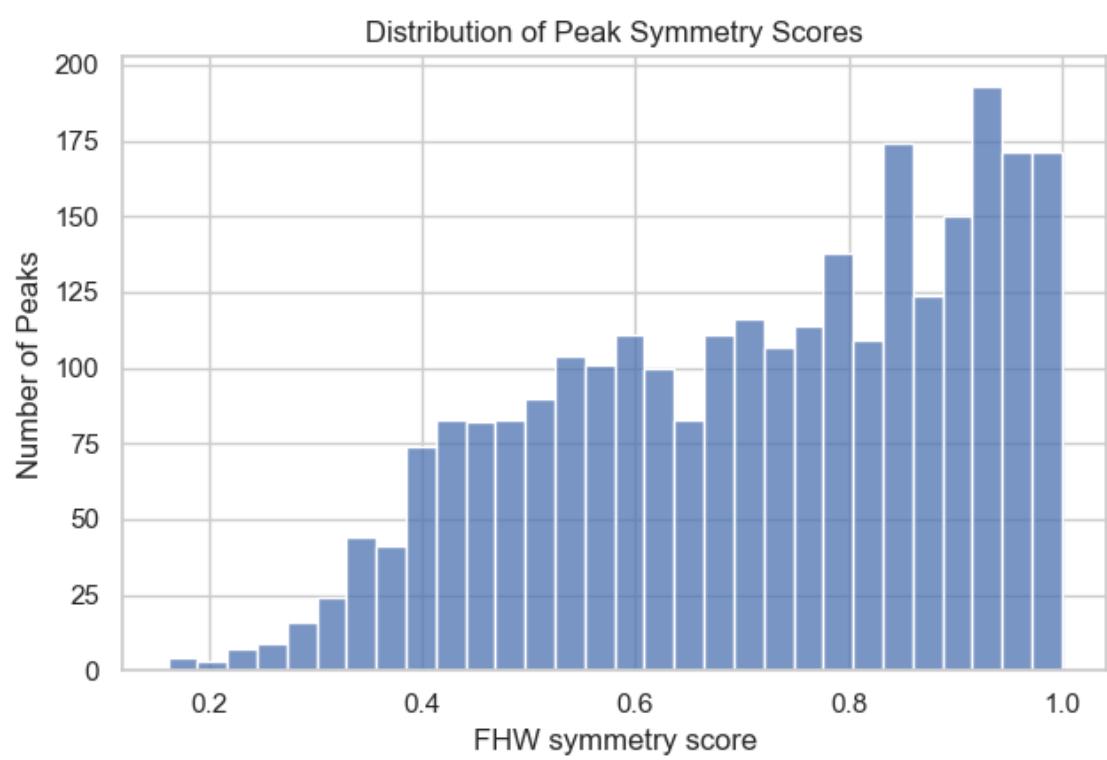
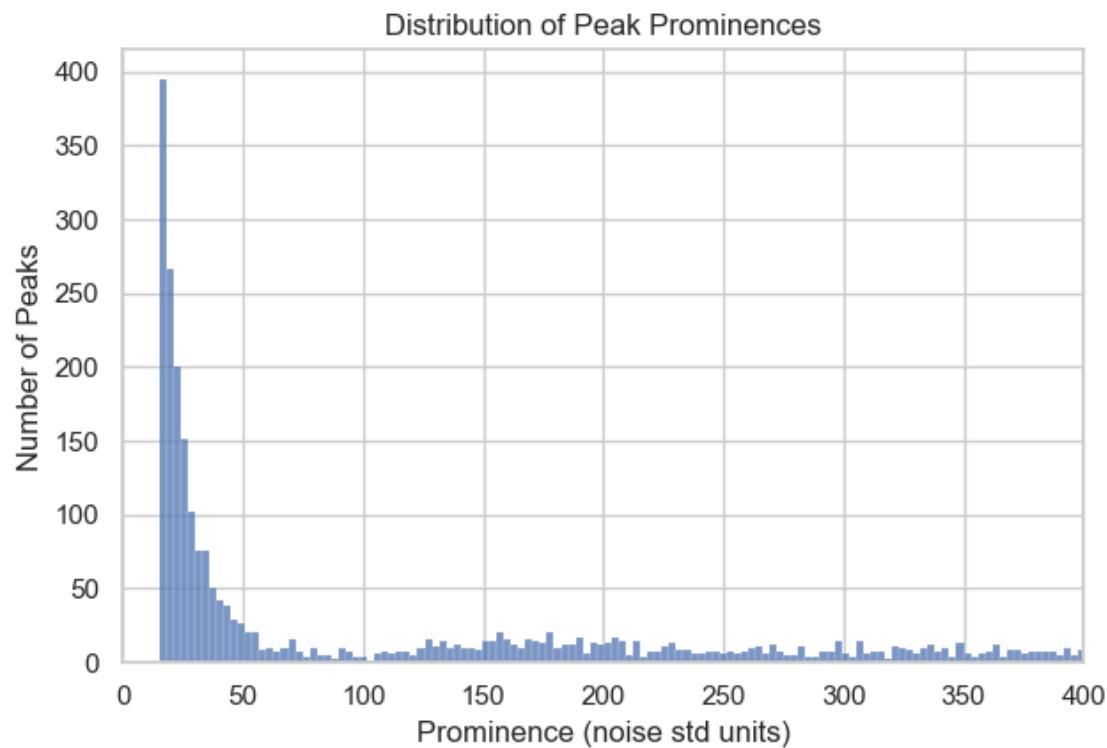
Total number of cells: 594

1.1.3 Peaks statistics

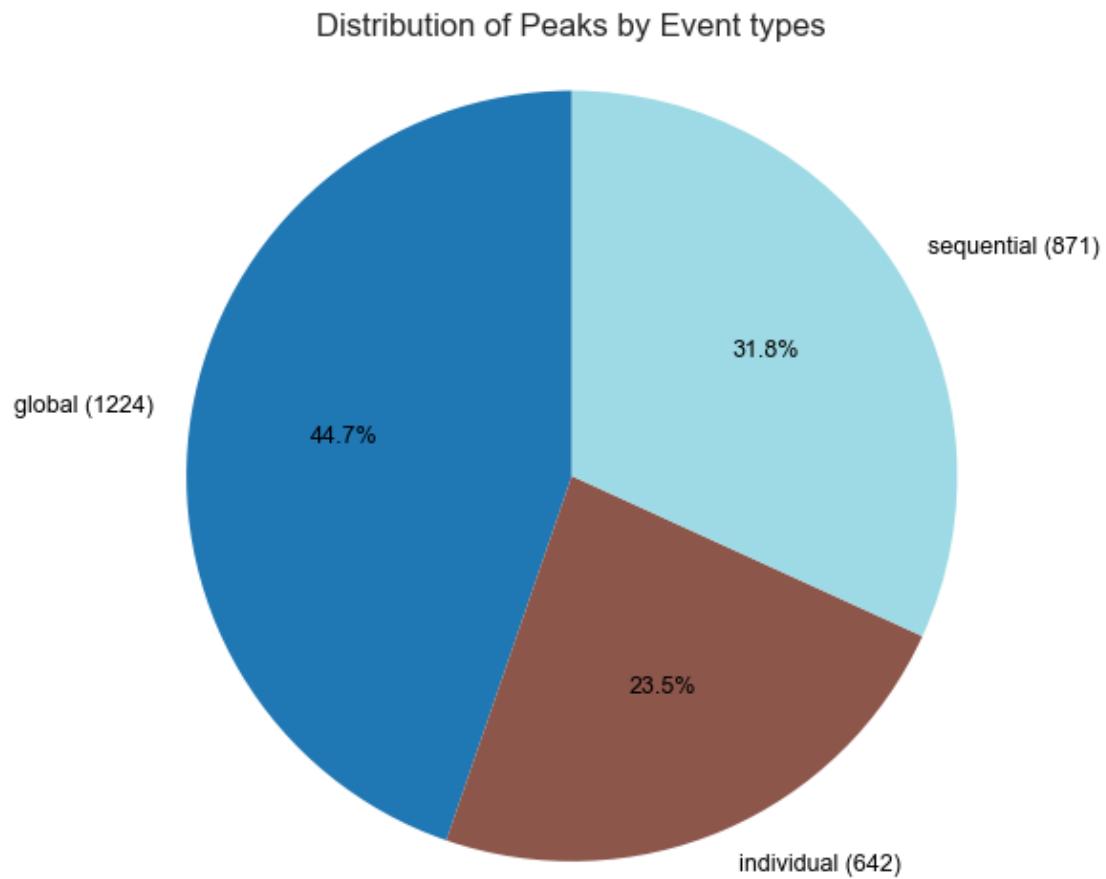
```
[2025-08-27 14:50:30] [INFO] calcium: plot_histogram: removed 0 outliers out of  
2737 on 'Duration (s)' (lower=-581, upper=840)
```



```
[2025-08-27 14:50:30] [INFO] calcium: plot_histogram: removed 1 outliers out of  
2737 on 'Prominence (noise std units)' (lower=-570, upper=809.7)
```

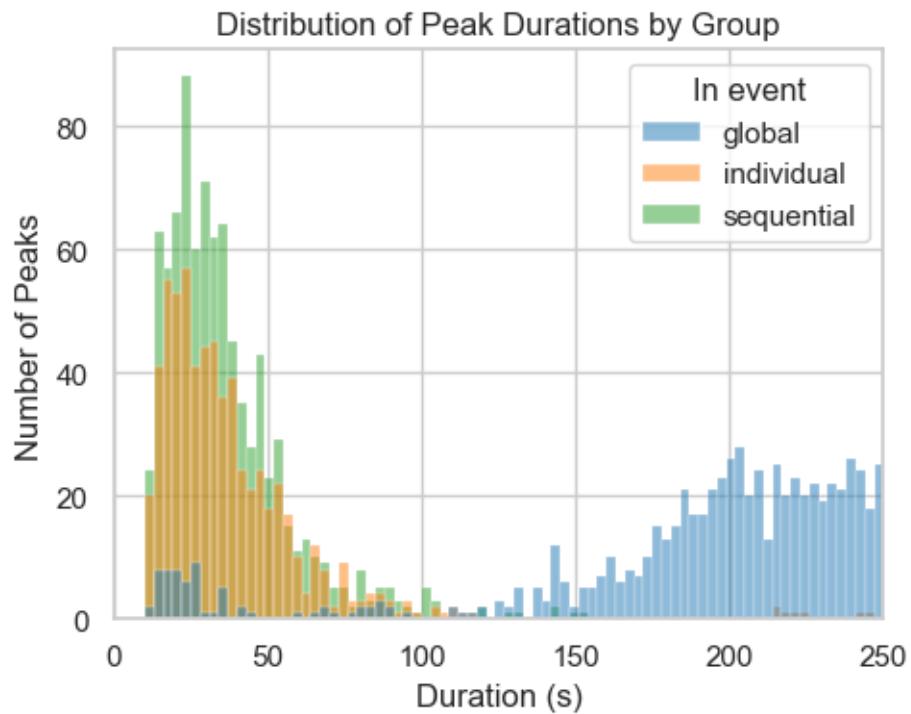


1.1.4 Distribution of peaks per event types

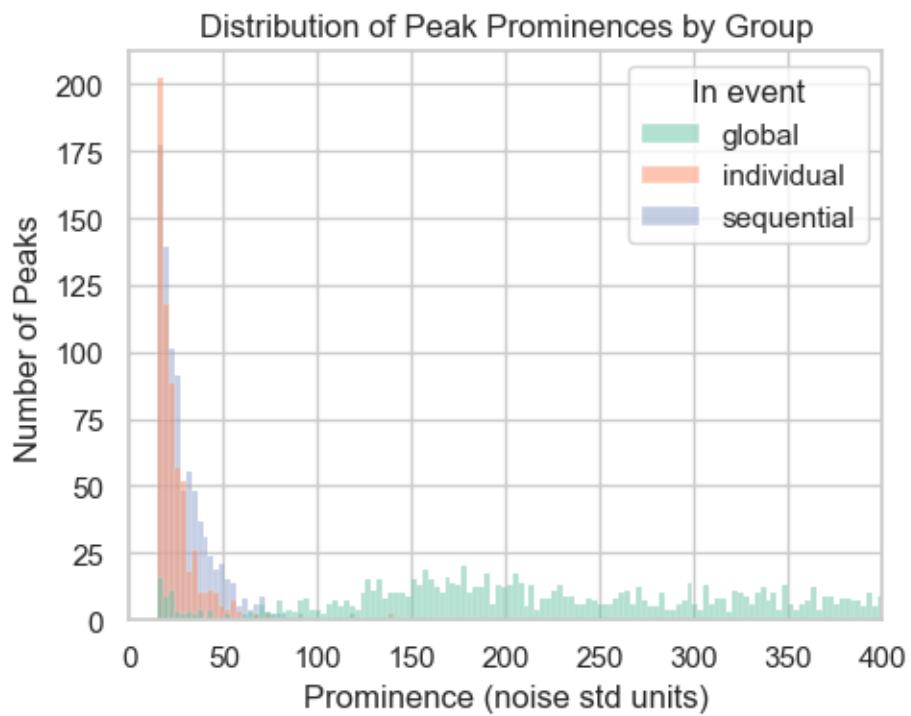


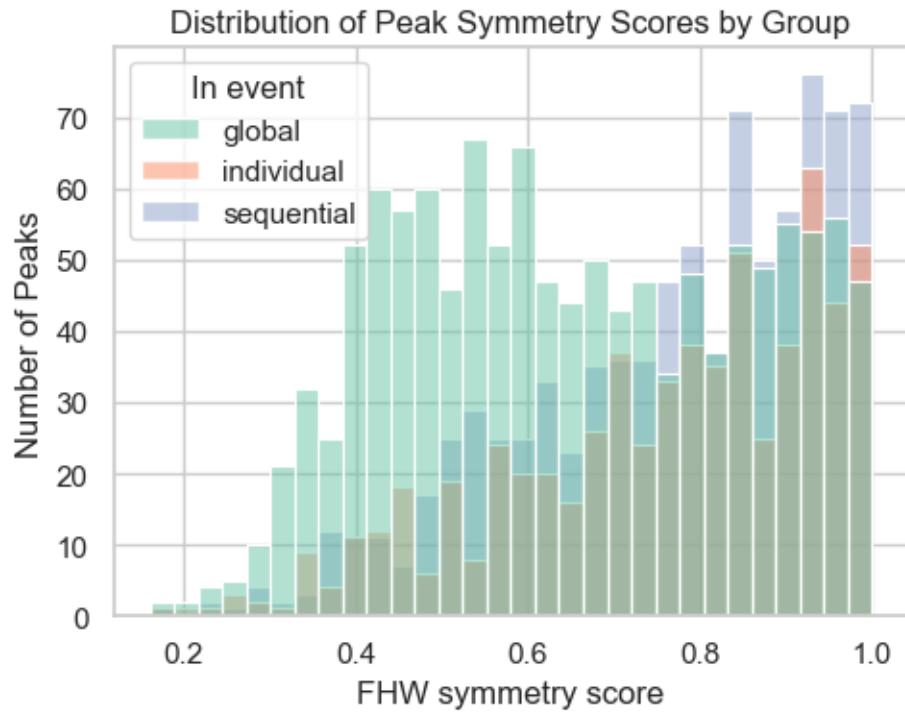
1.1.5 Peaks statistics per event types

```
[2025-08-27 14:50:32] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 2737 on 'Duration (s)' (lower=-581, upper=840)
```



```
[2025-08-27 14:50:33] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 2737 on 'Prominence (noise std units)' (lower=-570, upper=809.7)
```

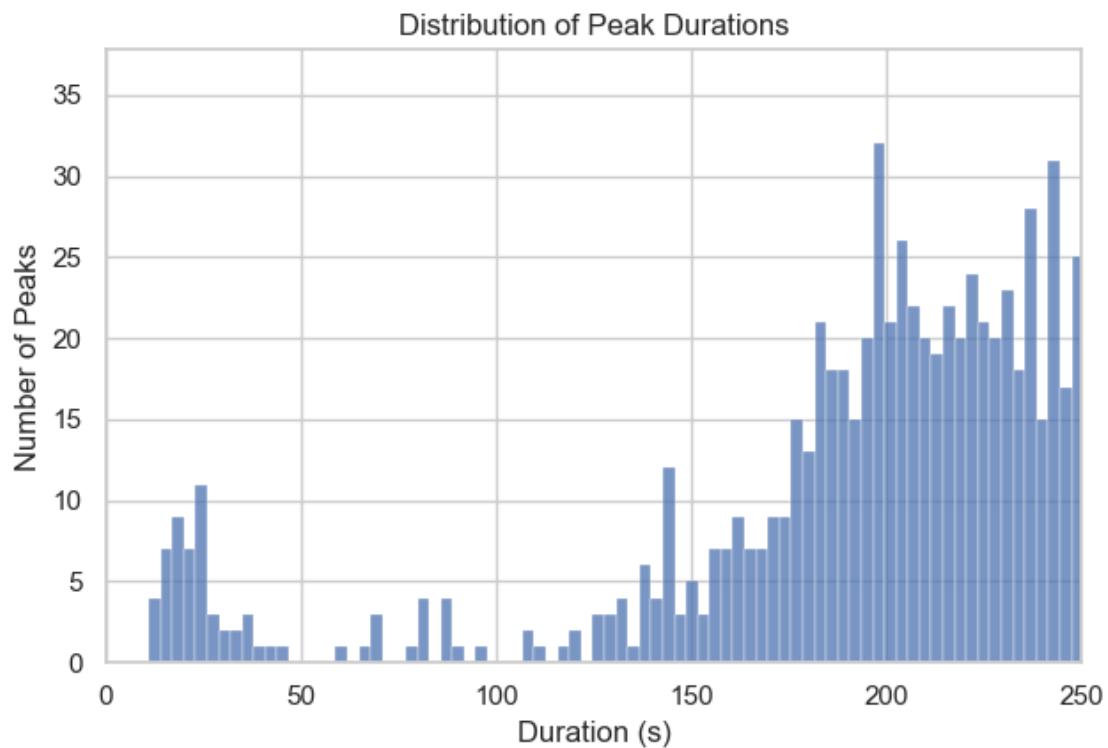




1.2 GLOBAL EVENTS

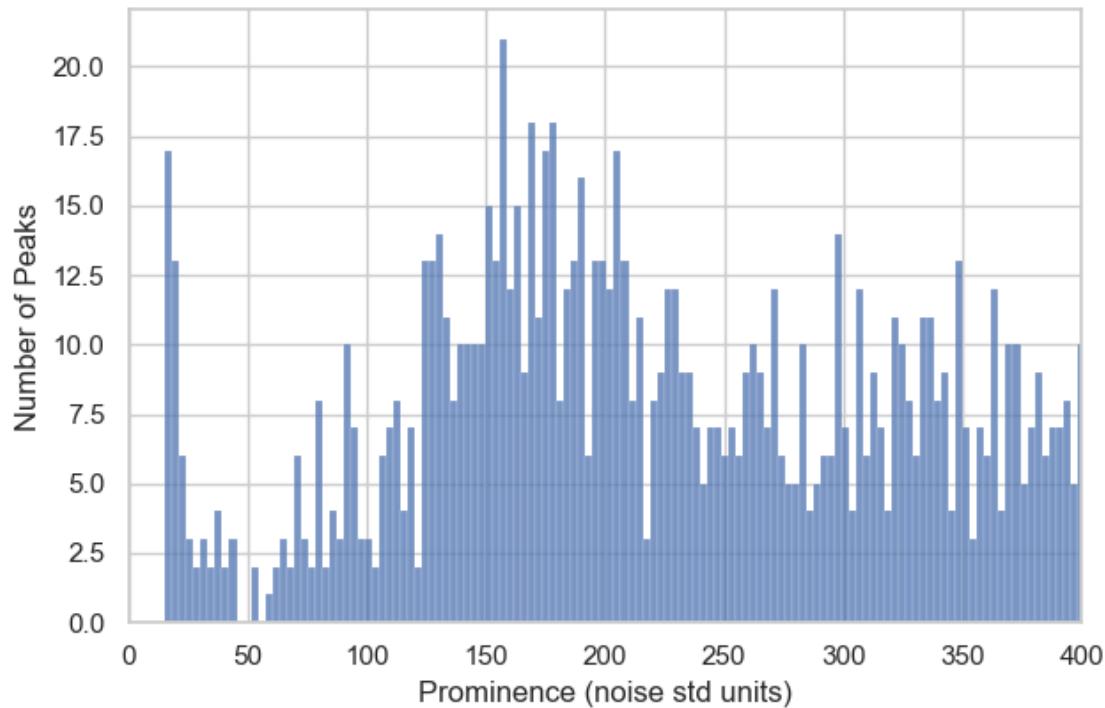
1.2.1 Peak statistics in global events

```
[2025-08-27 14:50:36] [INFO] calcium: plot_histogram: removed 0 outliers out of 1224 on 'Duration (s)' (lower=-60, upper=542)
```

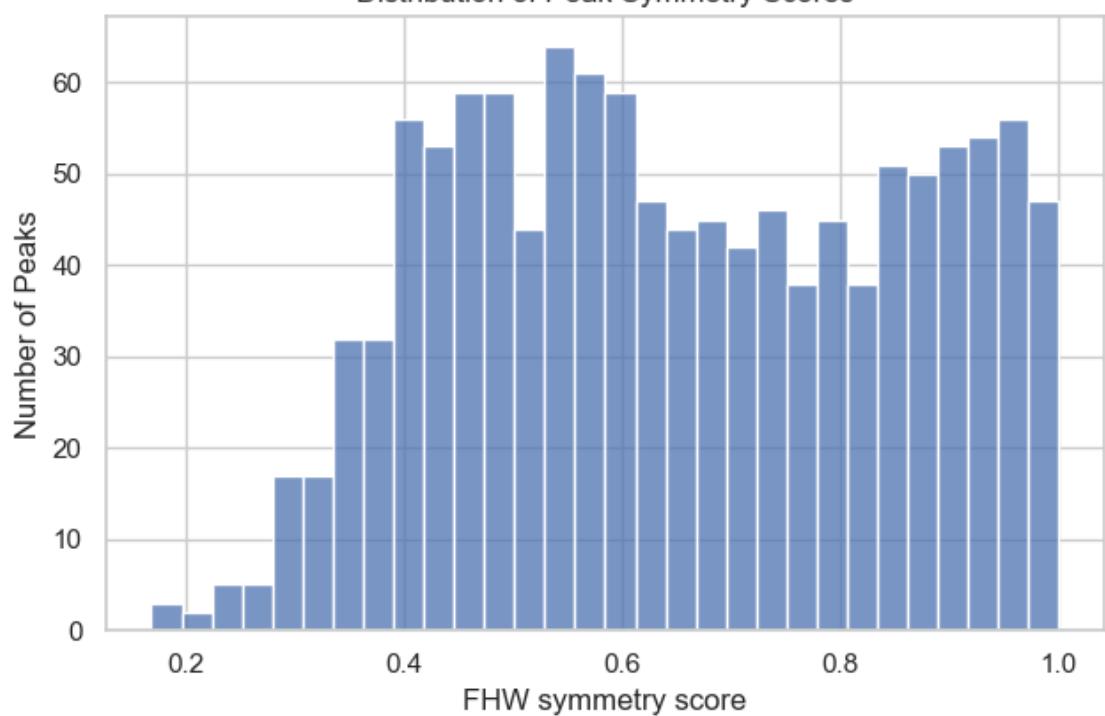


```
[2025-08-27 14:50:36] [INFO] calcium: plot_histogram: removed 1 outliers out of  
1224 on 'Prominence (noise std units)' (lower=-442.3, upper=964.35)
```

Distribution of Peak Prominences

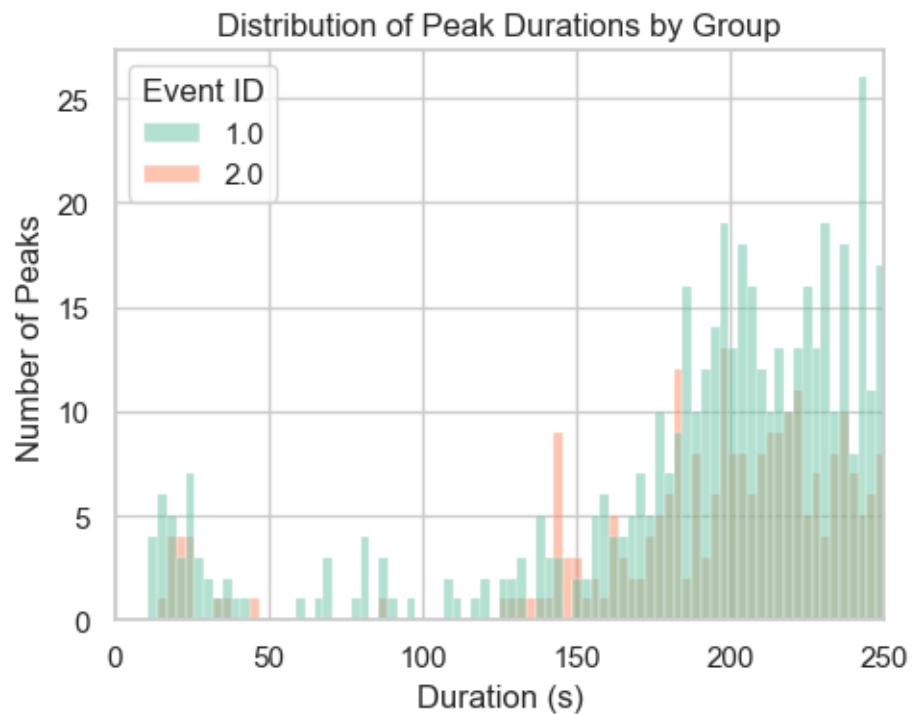


Distribution of Peak Symmetry Scores

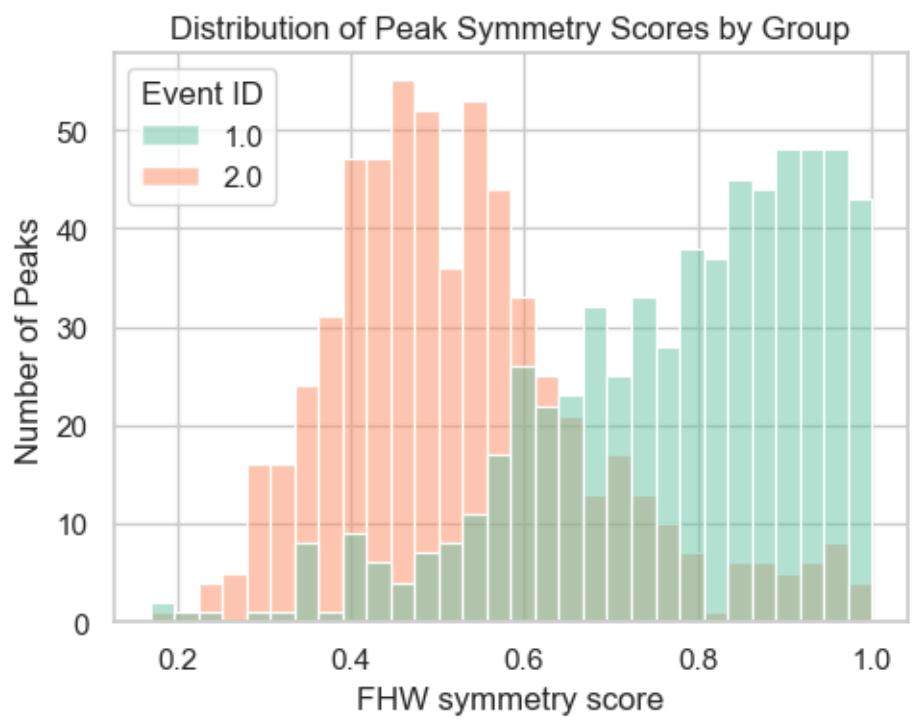
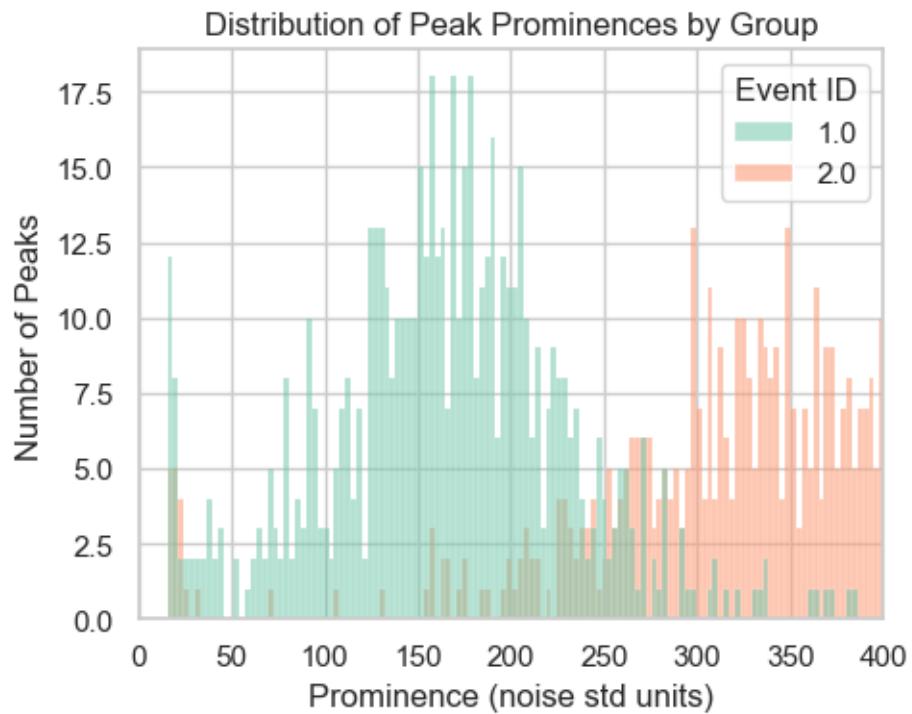


1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:50:38] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1224 on 'Duration (s)' (lower=-60, upper=542)

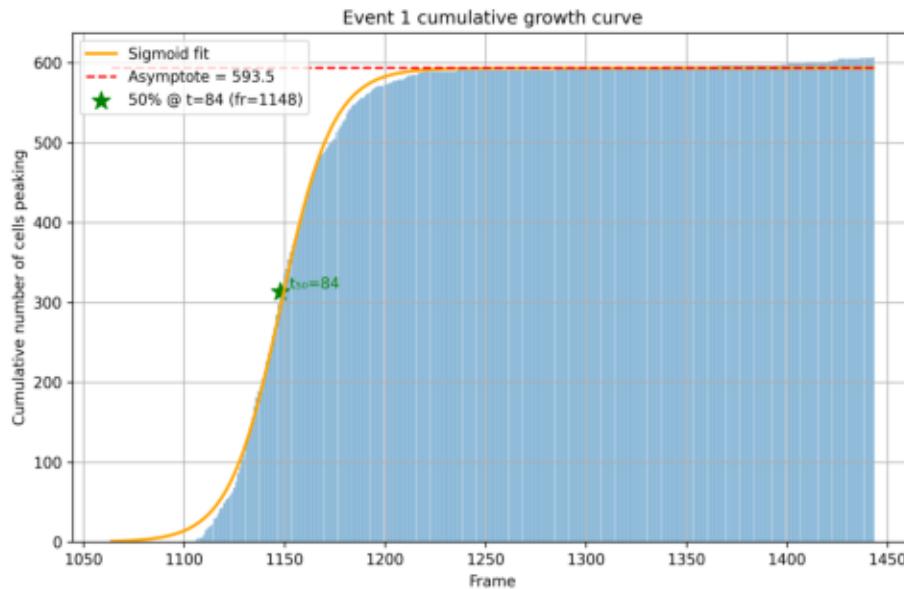


[2025-08-27 14:50:39] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 1224 on 'Prominence (noise std units)' (lower=-442.3, upper=964.35)



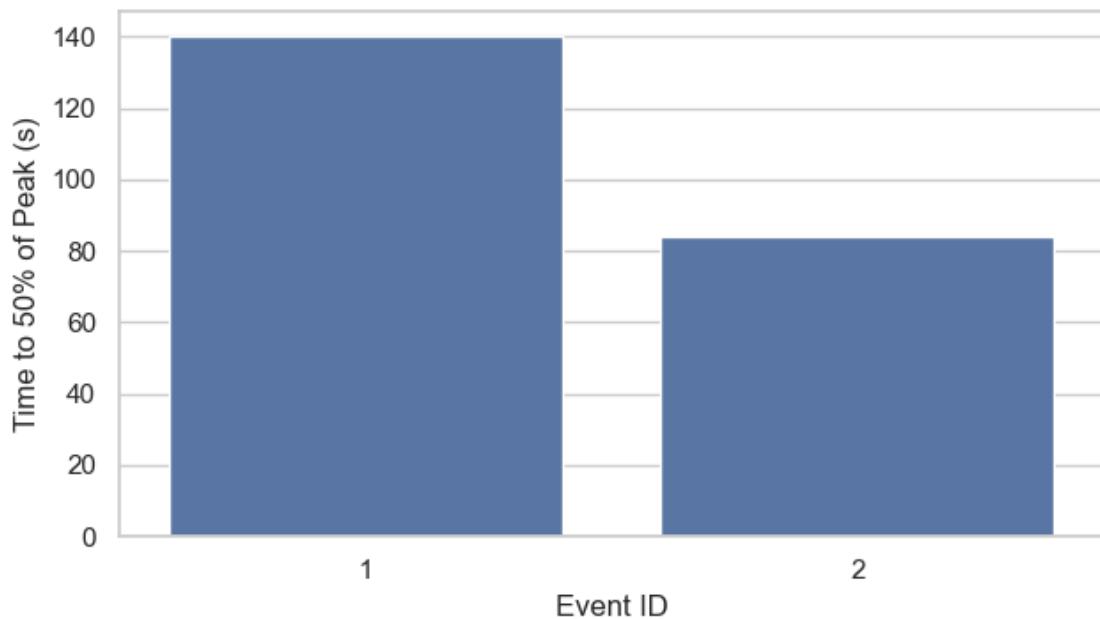
1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)

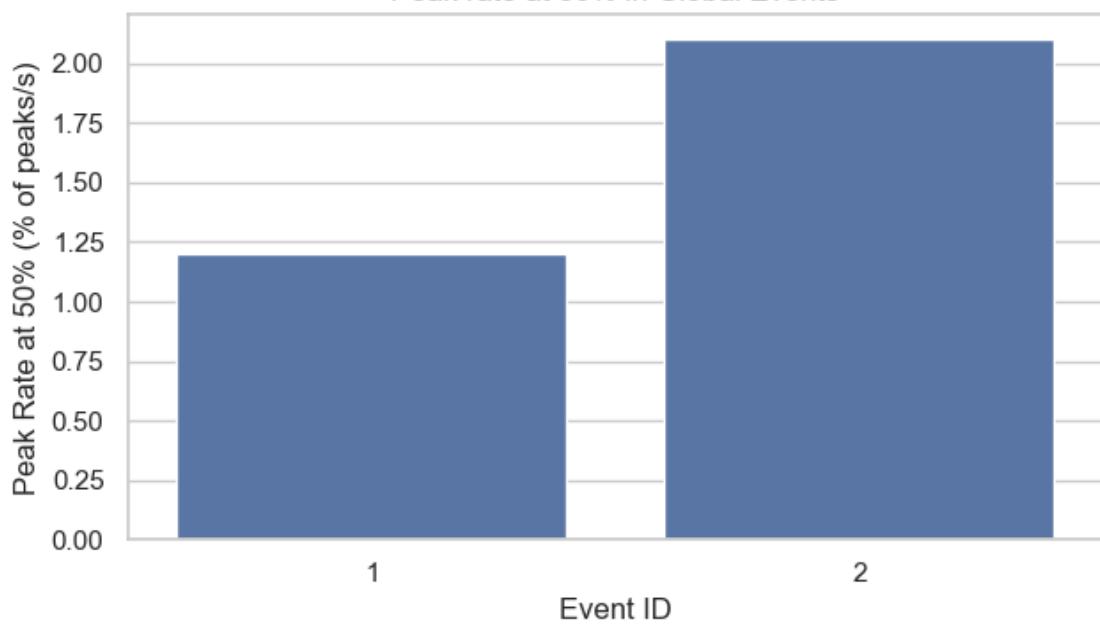


```
[2025-08-27 14:50:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\events\event-growth-curve-2.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250501\Output\IS06\events\event-
growth-curve-2.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250501\Output\IS06\events\event-growth-curve-2.png'
```

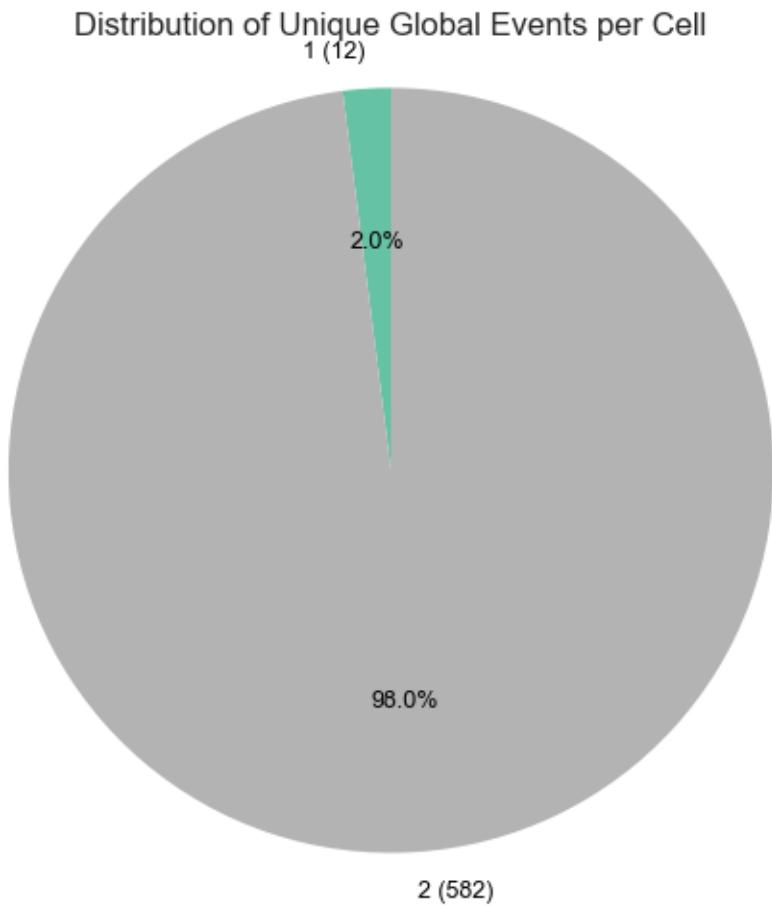
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

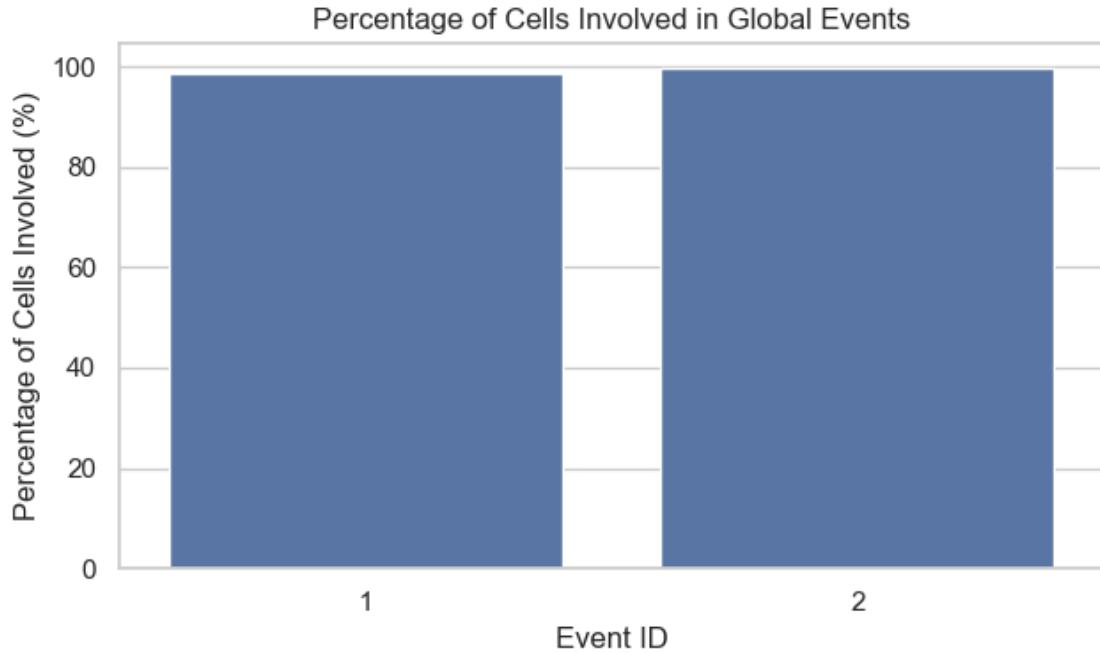


```
[2025-08-27 14:50:47] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250501\\\\Output\\\\IS06\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250501\Output\IS06\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [825.0]

1.2.6 Early peakers in the events

```

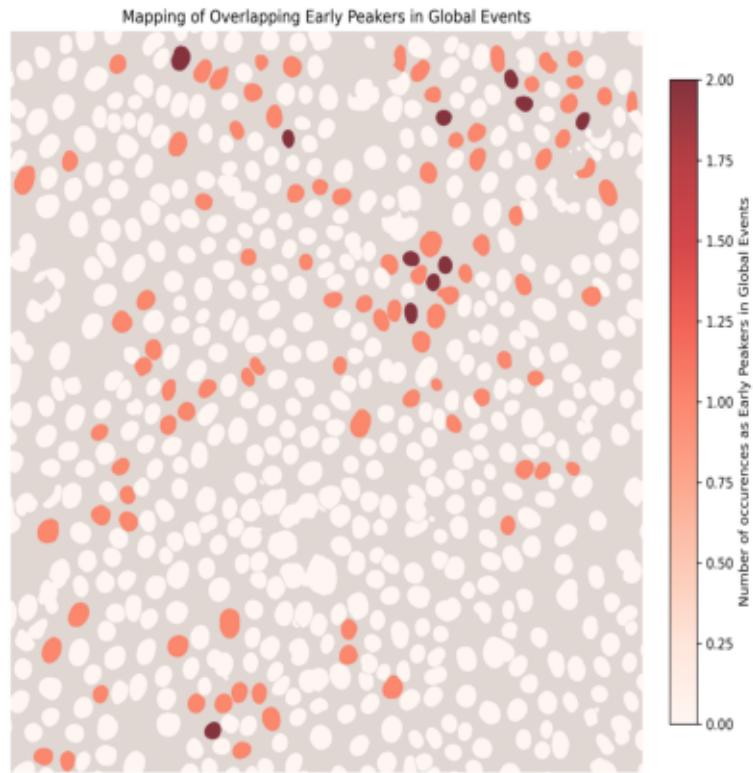
[2025-08-27 14:50:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__

```

```
    self._open()
File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

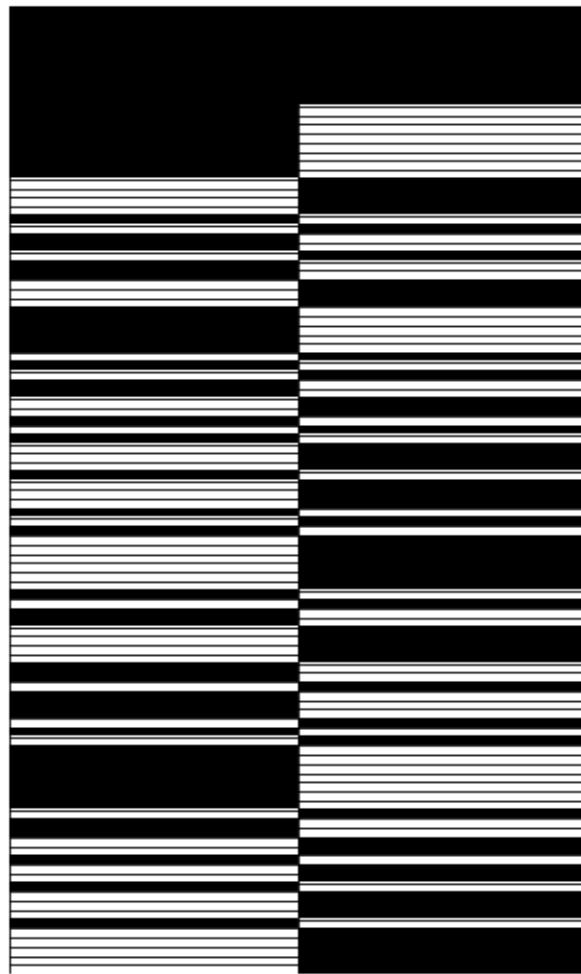
[2025-08-27 14:50:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



```
[2025-08-27 14:50:51] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 2 unique event IDs.
```

```
[2025-08-27 14:50:51] [INFO] calcium: Early peakers event-matrix: 106 cells x 2 events; black squares: 117
```

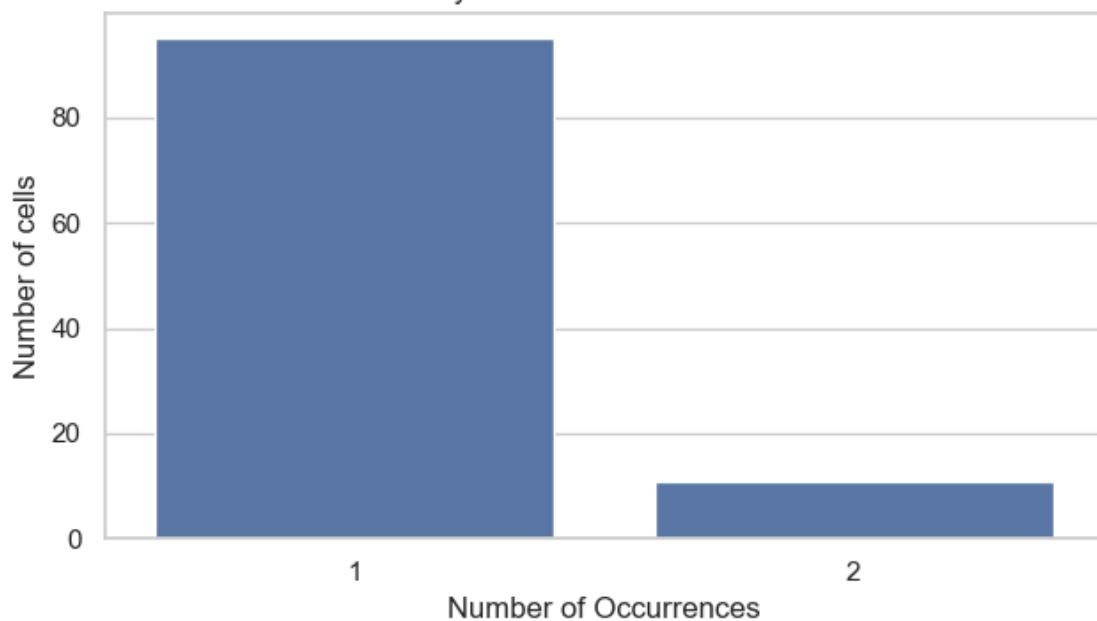


[2025-08-27 14:50:52] [INFO] calcium: Saved early peakers heatmap SVG to:
early_peakers_heatmap.svg

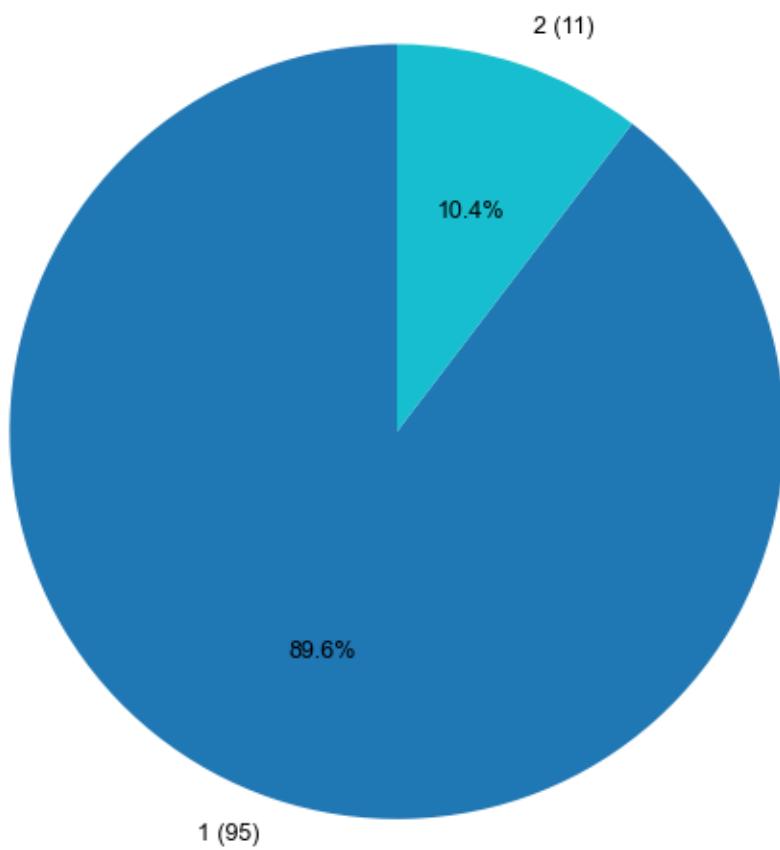
```
[19]: array([[1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 1],  
           [1, 0],  
           [1, 0],
```

```
[1, 0],  
[1, 0],  
[1, 0],  
[1, 0],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[1, 0],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1]
```


Early Peakers in Global Events



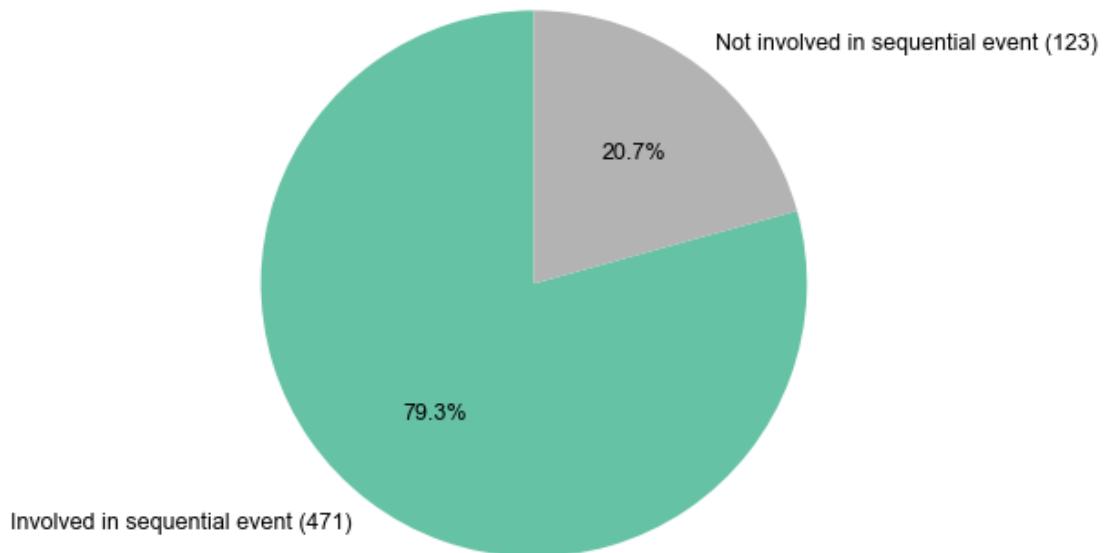
Distribution of Early Peakers in Global Events



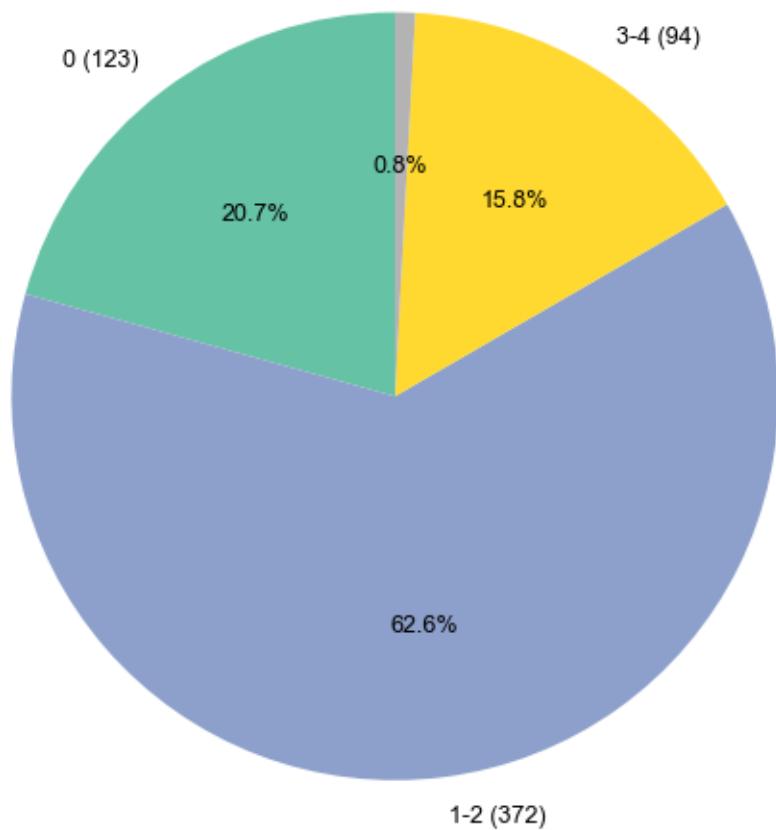
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

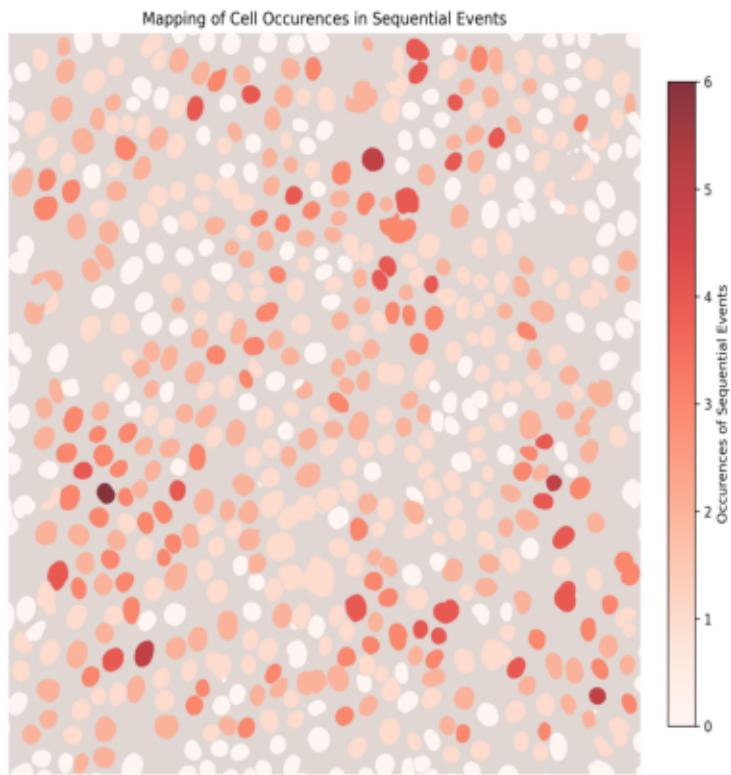
Distribution of Cells Involved in Sequential Events



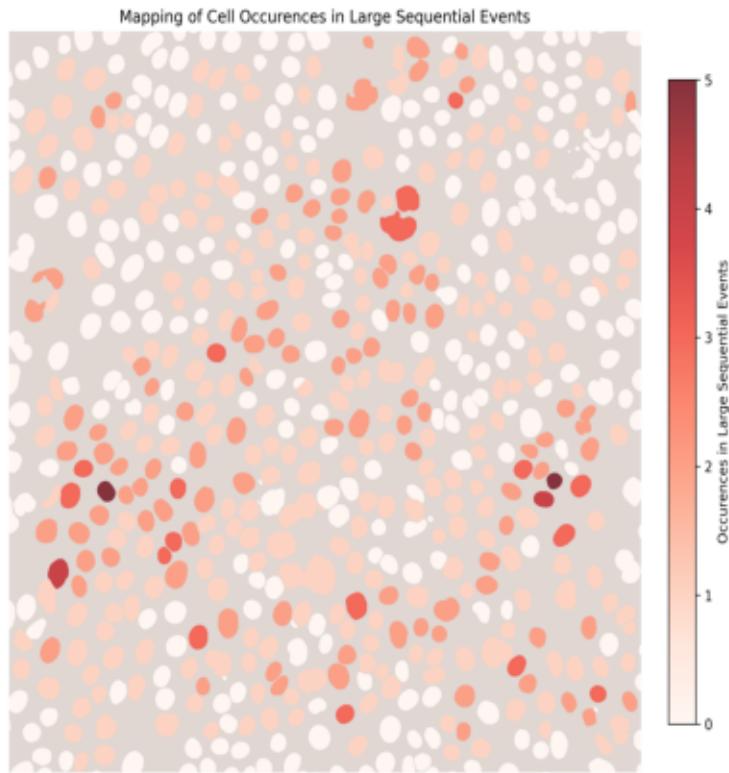
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (5)



Cell Mapping with Occurrences in Sequential Events Overlay

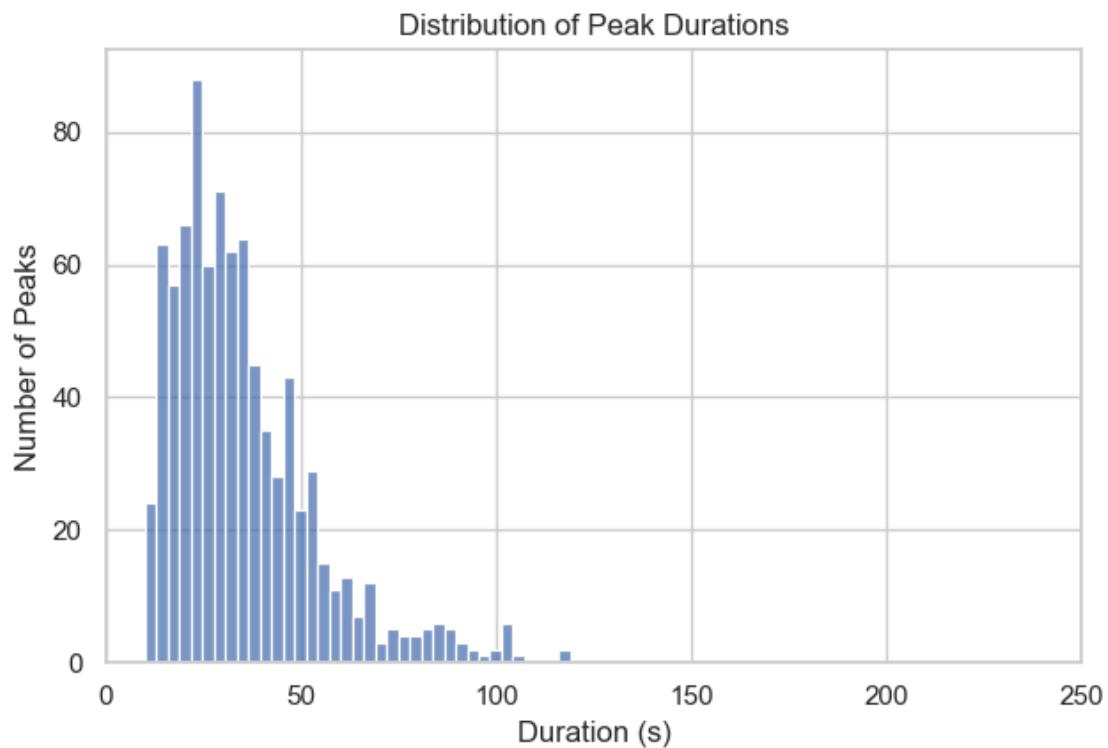


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



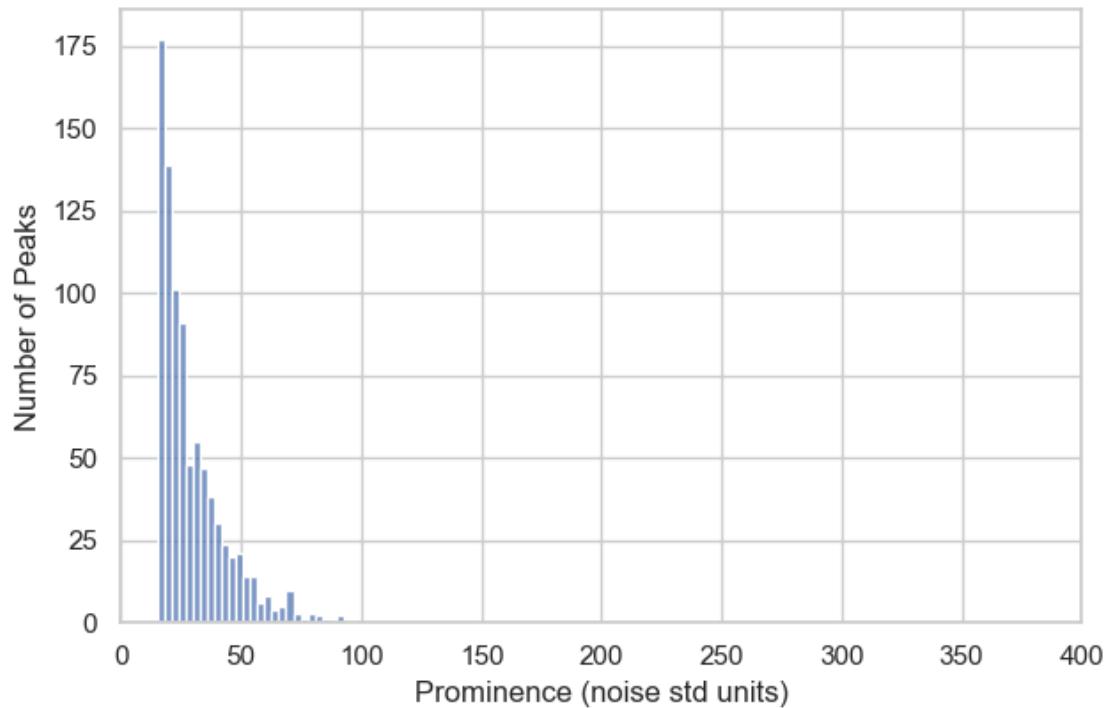
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:50:58] [INFO] calcium: plot_histogram: removed 6 outliers out of  
871 on 'Duration (s)' (lower=-11, upper=121)
```

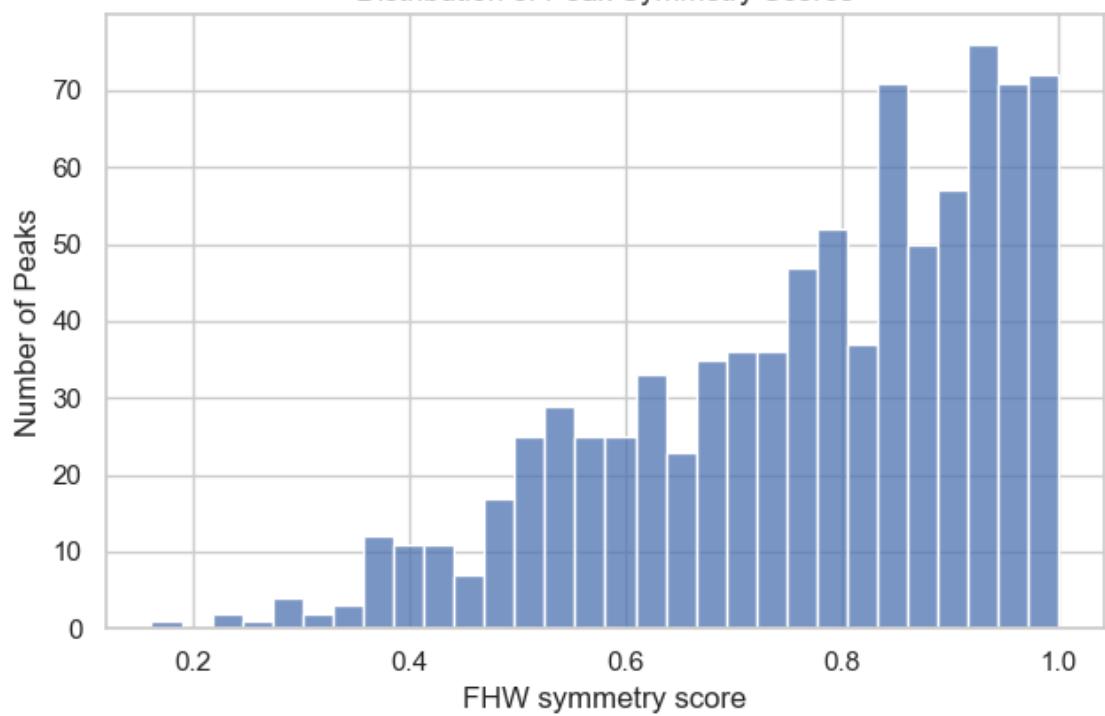


```
[2025-08-27 14:50:58] [INFO] calcium: plot_histogram: removed 7 outliers out of  
871 on 'Prominence (noise std units)' (lower=-6.6, upper=94.8)
```

Distribution of Peak Prominences

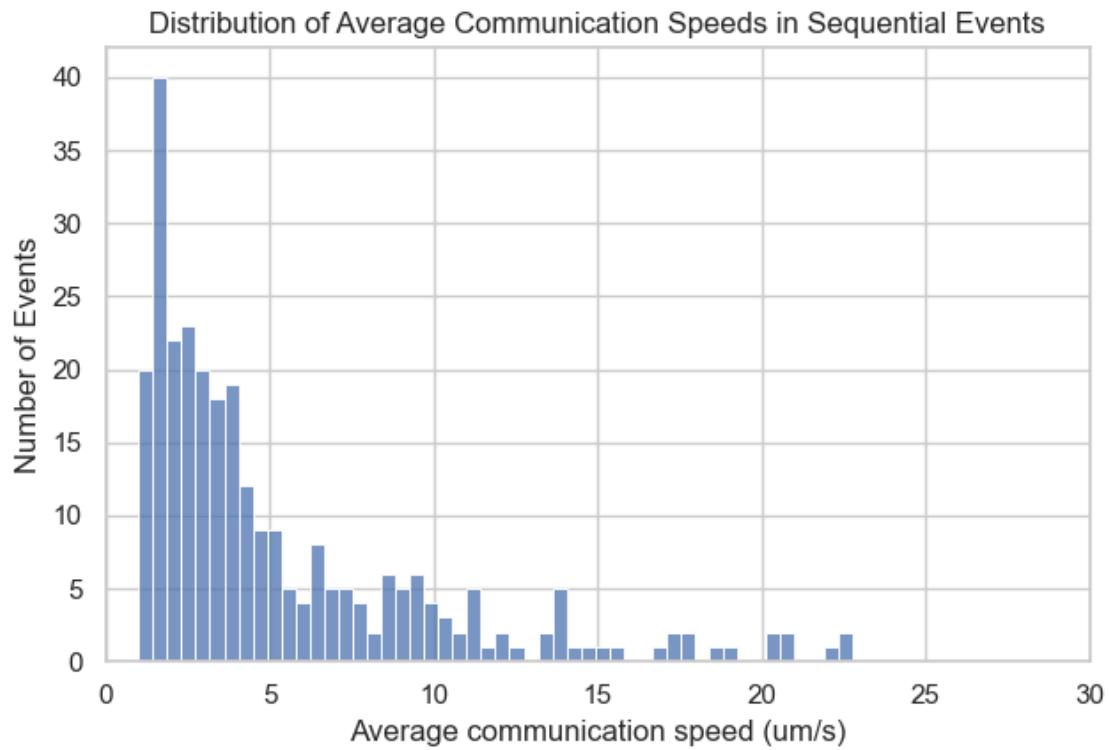


Distribution of Peak Symmetry Scores

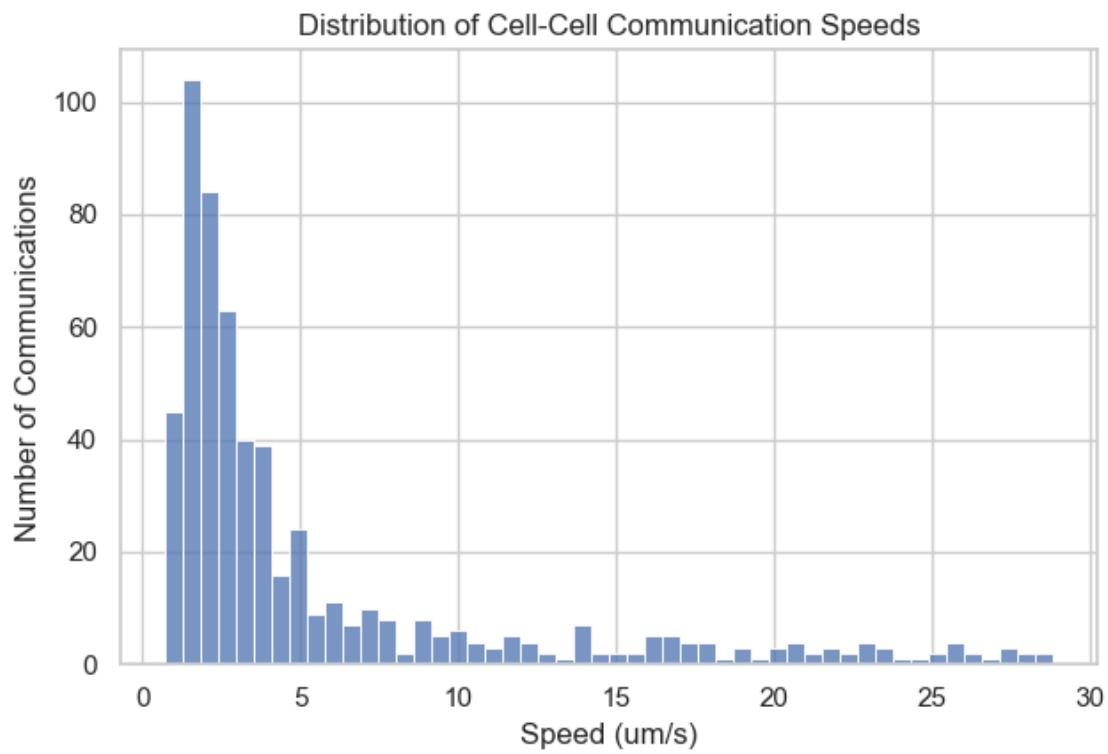


1.3.3 Cell-cell communication speed

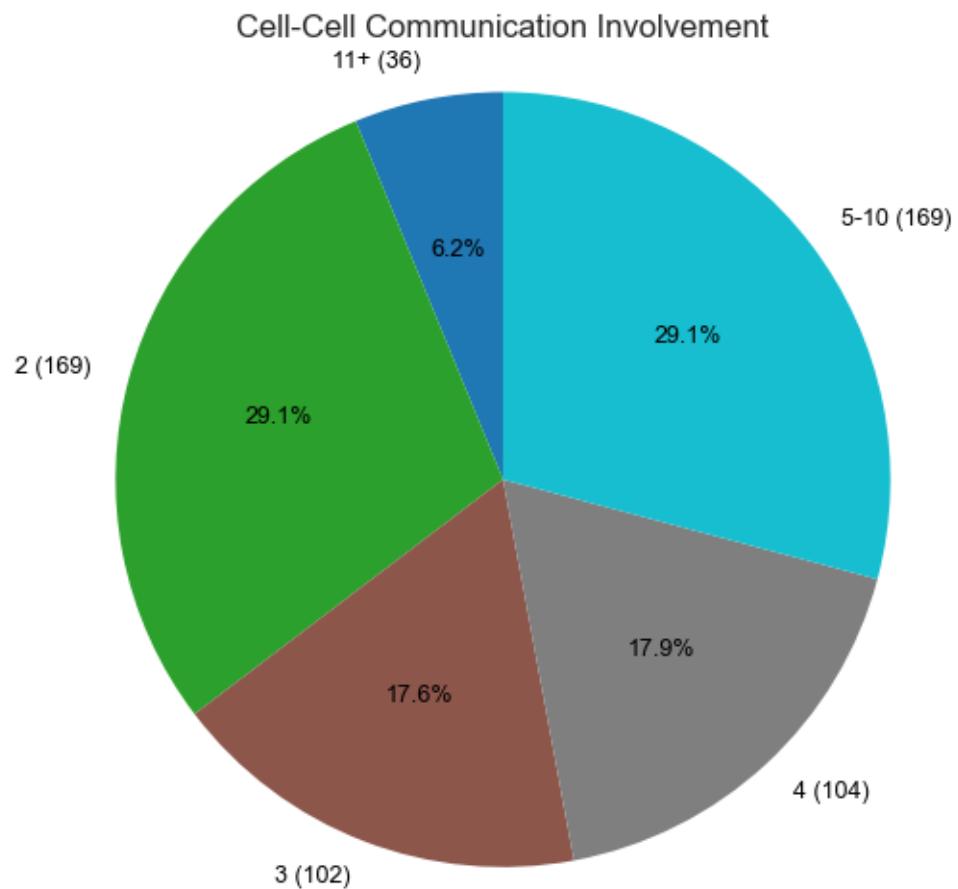
[2025-08-27 14:51:00] [INFO] calcium: plot_histogram: removed 6 outliers out of 291 on 'Average communication speed (um/s)' (lower=-13.485, upper=23.055)



[2025-08-27 14:51:00] [INFO] calcium: plot_histogram: removed 5 outliers out of 580 on 'Speed (um/s)' (lower=-11.635, upper=28.82)

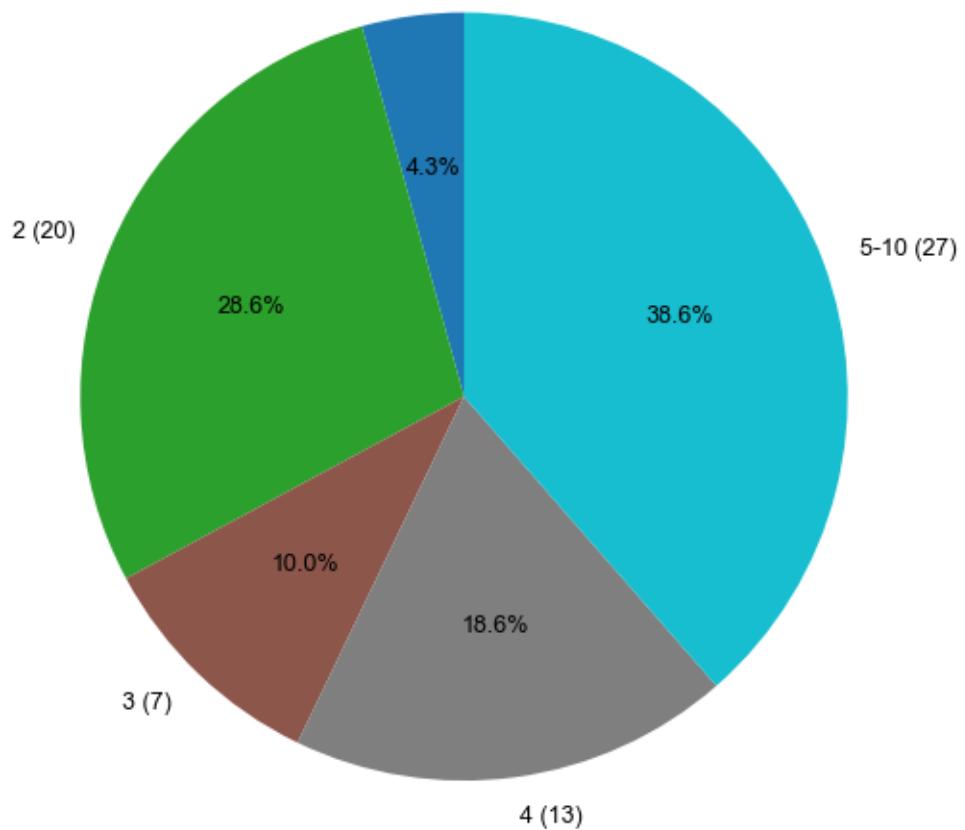


1.3.4 Double distribution in cell-cell communication speeds



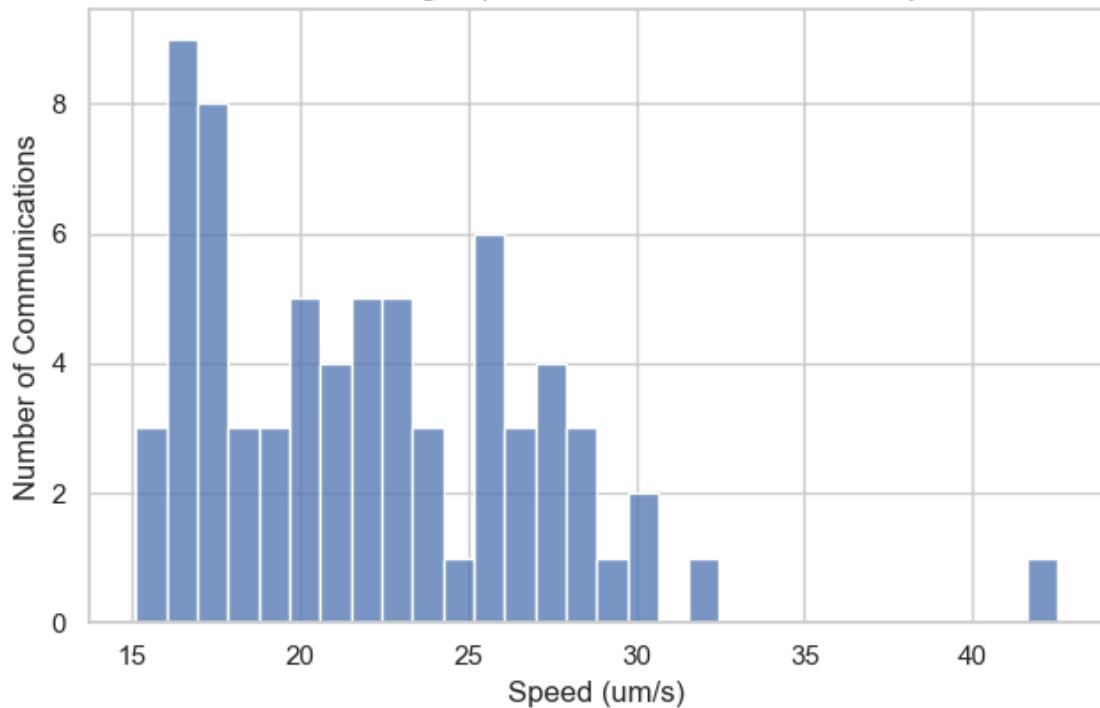
High Speed Cell-Cell Communication Involvement

11+ (3)



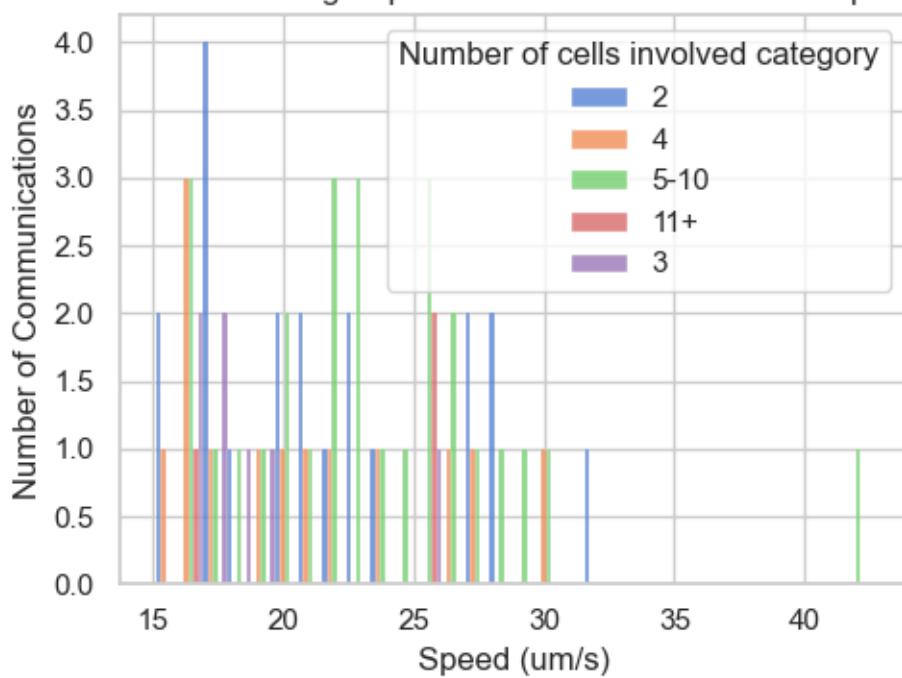
[2025-08-27 14:51:01] [INFO] calcium: plot_histogram: removed 0 outliers out of 70 on 'Speed (um/s)' (lower=-6.785, upper=50.143)

Distribution of High Speed Cell-Cell Communication Speeds

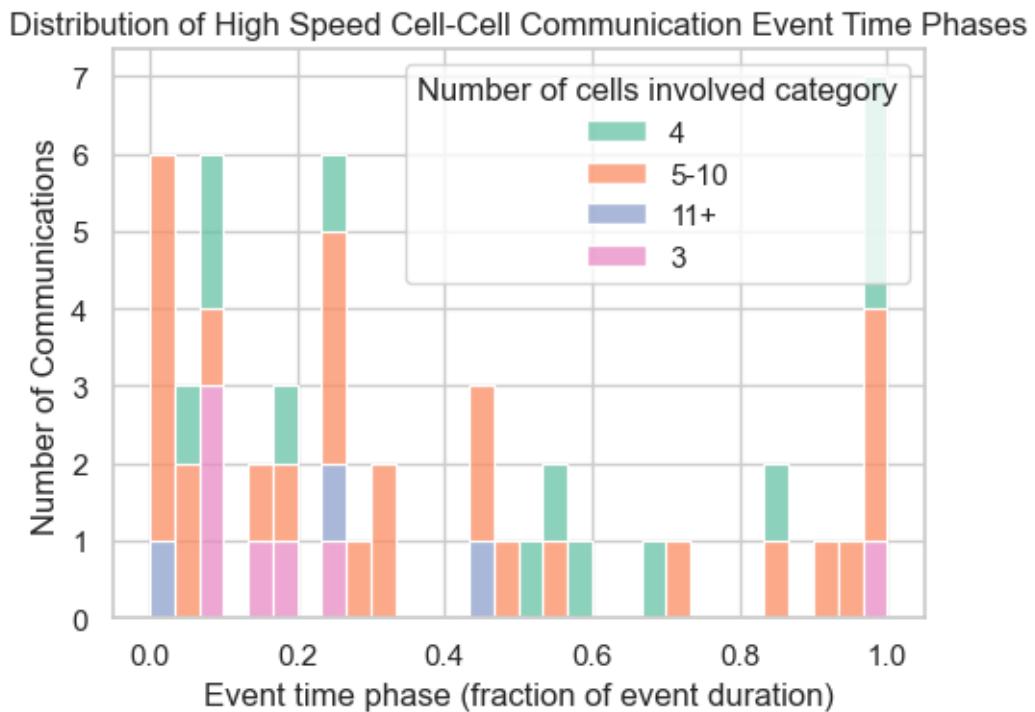


```
[2025-08-27 14:51:02] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 70 on 'Speed (um/s)' (lower=-6.785, upper=50.143)
```

Distribution of High Speed Cell-Cell Communication Speeds

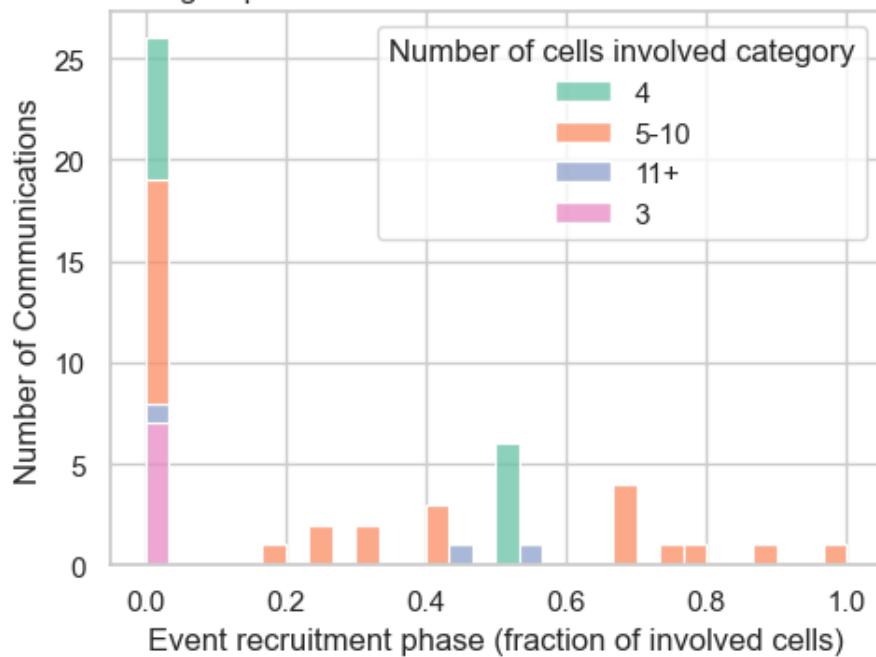


[2025-08-27 14:51:03] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 50 on 'Event time phase (fraction of event duration)' (lower=-1.63, upper=2.36)

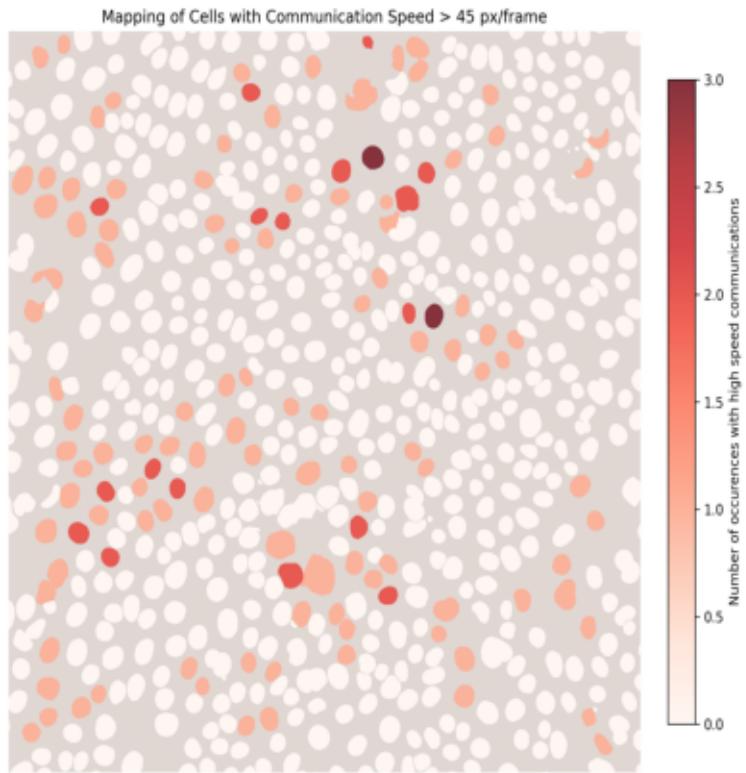


[2025-08-27 14:51:03] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 50 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)

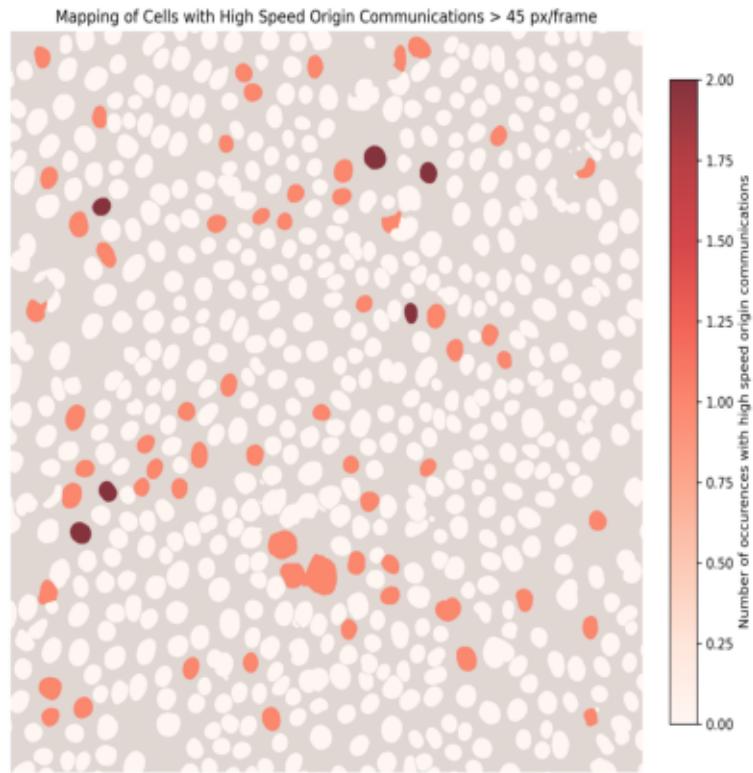
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
0	3015667934656	3	75		2
2	3015667929808	4	78		0
5	3015641177520	5	457		0
8	3015641181648	6	542		1
10	3015641181264	6	544		0
..	
518	3015507489792	247	665		2
521	3015507490704	249	726		0
555	3015507483984	275	790		4
568	3015507477648	283	791		0
576	3015507478896	290	788		3

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
0	67	2	746.0	746.0	
2	69	1	107.0	107.0	
5	426	0	97.0	97.0	
8	499	1	118.0	118.0	
10	587	1	113.0	114.0	
..	
518	691	5	670.0	671.0	
521	749	3	210.0	211.0	
555	819	5	1634.0	1635.0	
568	797	0	28.0	29.0	
576	805	3	1499.0	1500.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
0	0.0	20.50	20.50		
2	0.0	26.33	26.33		
5	0.0	23.54	23.54		
8	0.0	25.75	25.75		
10	1.0	30.36	30.36		
..		
518	1.0	17.58	17.58		
521	1.0	16.11	16.11		
555	1.0	21.57	21.57		
568	1.0	18.76	18.76		
576	1.0	17.16	17.16		
	Event time phase (fraction of event duration)	\			
0		NaN			
2		1.00			
5		0.59			
8		0.19			
10		0.04			
..		...			
518		NaN			
521		0.14			
555		0.06			
568		0.09			
576		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
0		NaN	20250501_IS06		
2		0.5	20250501_IS06		
5		0.0	20250501_IS06		
8		0.4	20250501_IS06		
10		0.0	20250501_IS06		
..			
518		NaN	20250501_IS06		
521		0.0	20250501_IS06		

555	0.0	20250501_IS06
568	0.0	20250501_IS06
576	NaN	20250501_IS06

	Number of cells involved	category	Speed category
0	2	High speed	
2	4	High speed	
5	4	High speed	
8	5-10	High speed	
10	5-10	High speed	
..
518	2	High speed	
521	3	High speed	
555	4	High speed	
568	3	High speed	
576	2	High speed	

[70 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
67		0	1
68		0	1
72		1	3
73		0	1
74		0	1
..
803		0	2
806		0	2
822		0	1
825		0	1
831		0	1

[331 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
1	67	43.23	8.45	
2	68	112.12	7.48	
5	72	322.40	10.72	
6	73	357.18	13.33	
7	74	371.48	16.90	
..	\
571	803	358.48	471.25	
573	806	50.38	472.23	
584	822	372.45	482.62	
587	825	419.57	483.93	
589	831	75.08	487.18	

Number of peaks Is active Occurrences in global events \

1	7	True	2
2	5	True	2
5	6	True	2
6	4	True	2
7	6	True	2
..
571	6	True	2
573	3	True	2
584	5	True	2
587	6	True	2
589	6	True	2

Occurrences in global events as early peaker			Early peaker event IDs \
1	0	0	[]
2	0	0	[]
5	0	0	[]
6	0	0	[]
7	0	0	[]
..
571	0	0	[]
573	0	0	[]
584	0	0	[]
587	0	0	[]
589	0	0	[]

Occurrences in sequential events \		
1	2	
2	1	
5	4	
6	2	
7	3	
..
571	3	
573	1	
584	1	
587	1	
589	2	

Occurrences in sequential events as origin \		
1	1	
2	1	
5	3	
6	0	
7	1	
..
571	1	
573	1	
584	1	

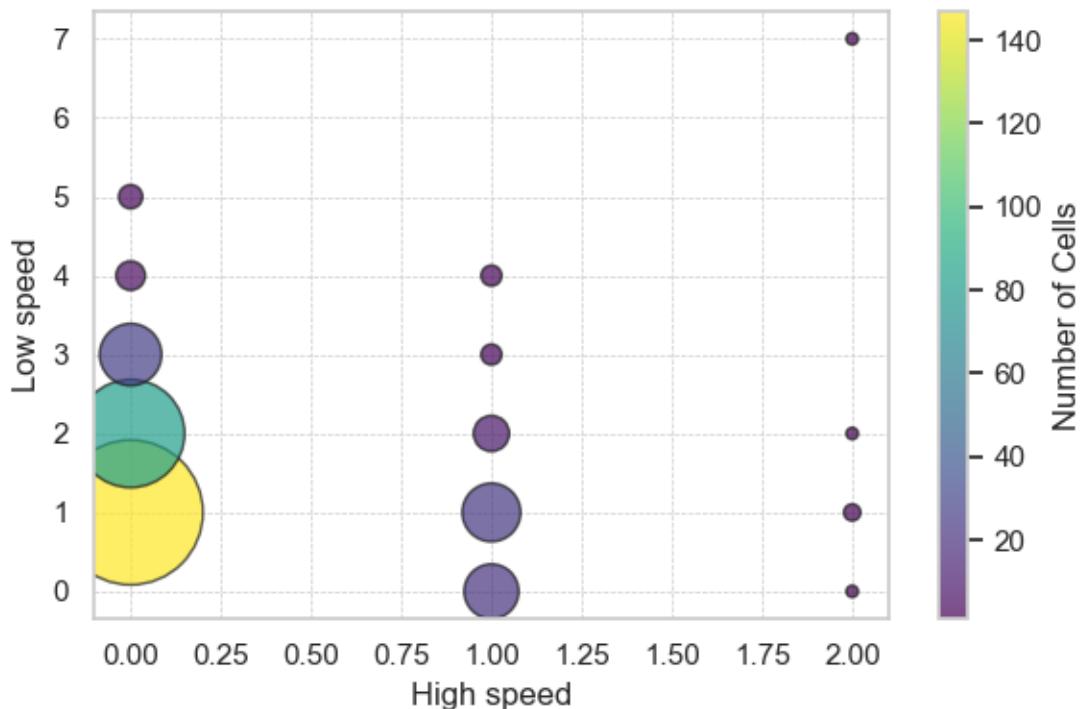
587		1		
589		1		
	Occurrences in individual events	Peak frequency (Hz)	Periodicity score	\
1	3	0.0041	0.62	
2	2	0.0029	0.70	
5	0	0.0035	0.51	
6	0	0.0024	0.70	
7	1	0.0035	0.52	
..
571	1	0.0035	0.57	
573	0	0.0018	0.61	
584	2	0.0029	0.56	
587	3	0.0035	0.66	
589	2	0.0035	0.58	
	Neighbor count	Neighbors (labels)	dataset	\
1	2	[75, 91]	20250501_IS06	
2	3	[76, 84, 107]	20250501_IS06	
5	4	[70, 78, 89, 94]	20250501_IS06	
6	4	[70, 74, 89, 106]	20250501_IS06	
7	4	[73, 79, 106, 114]	20250501_IS06	
..
571	5	[764, 784, 794, 822, 828]	20250501_IS06	
573	7	[779, 788, 799, 831, 832, 834, 835]	20250501_IS06	
584	4	[784, 803, 814, 828]	20250501_IS06	
587	3	[801, 814, 818]	20250501_IS06	
589	3	[799, 806, 835]	20250501_IS06	
	Involved in sequential event	Occurrences in sequential events category	\	
1	Involved in sequential event		1-2	
2	Involved in sequential event		1-2	
5	Involved in sequential event		3-4	
6	Involved in sequential event		1-2	
7	Involved in sequential event		3-4	
..
571	Involved in sequential event		3-4	
573	Involved in sequential event		1-2	
584	Involved in sequential event		1-2	
587	Involved in sequential event		1-2	
589	Involved in sequential event		1-2	
	High speed	Low speed		
1	0.0	1.0		
2	0.0	1.0		
5	1.0	3.0		
6	0.0	1.0		
7	0.0	1.0		

```

...
571      0.0      2.0
573      0.0      2.0
584      0.0      1.0
587      0.0      1.0
589      0.0      1.0

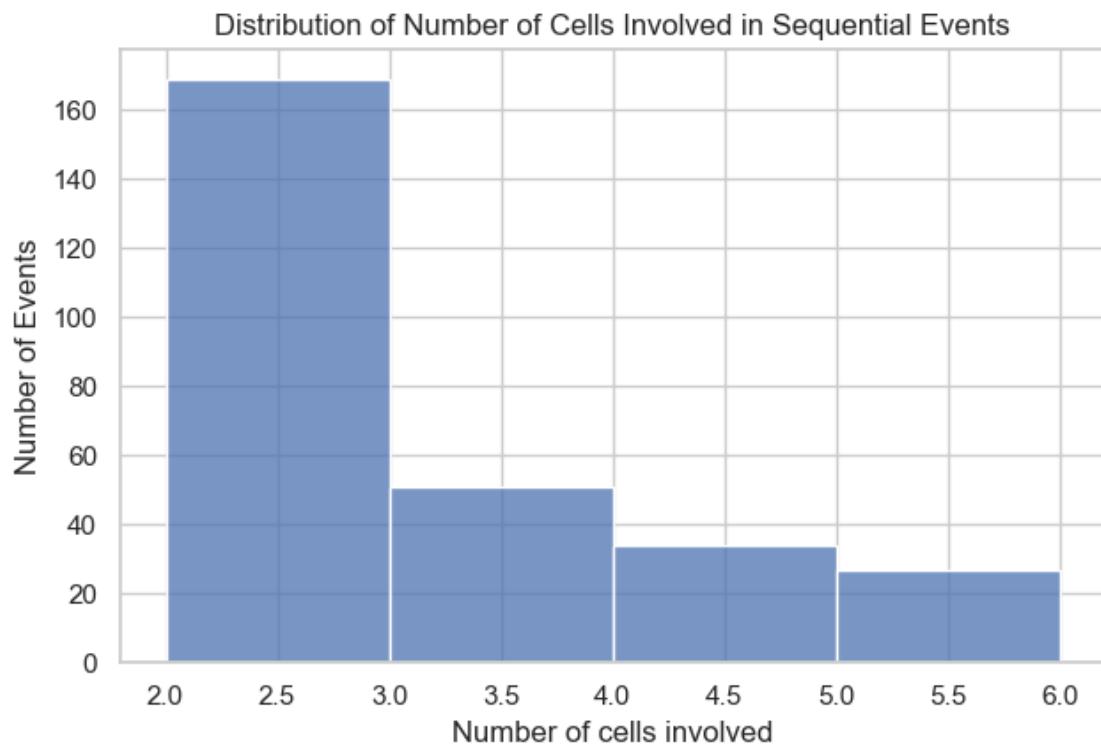
```

[331 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

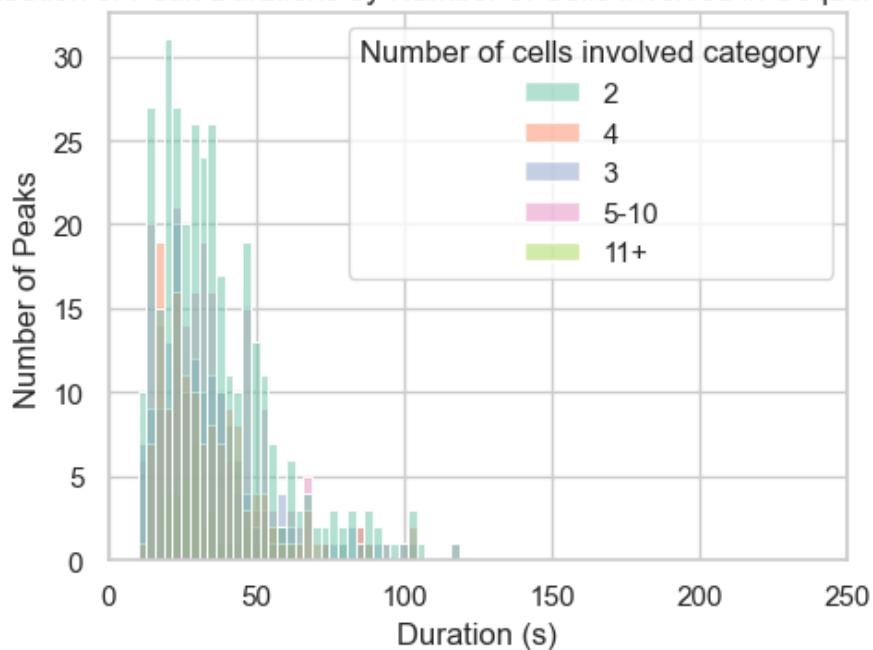
[2025-08-27 14:51:10] [INFO] calcium: plot_histogram: removed 10 outliers out of 291 on 'Number of cells involved' (lower=-1, upper=6)



1.3.6 Influence of cell count per event on statistics

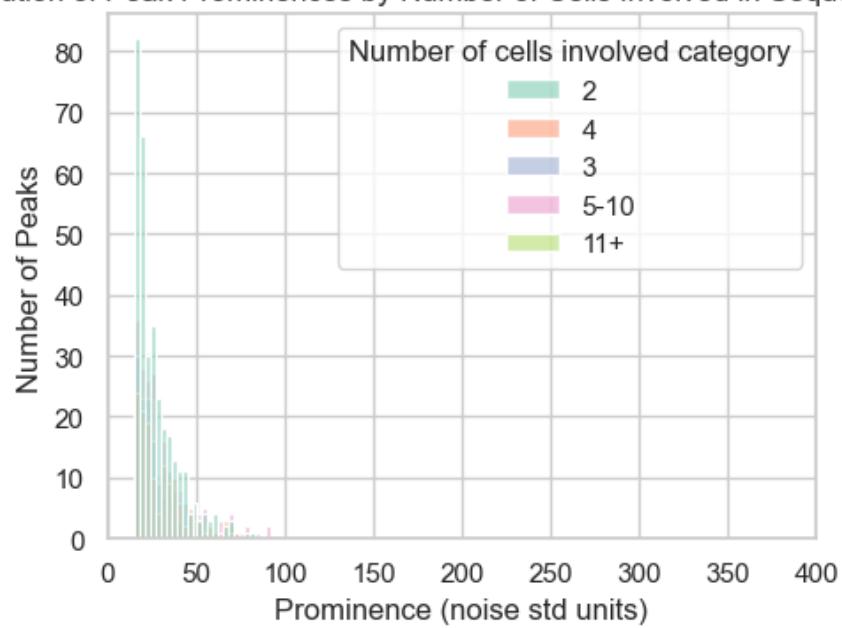
```
[2025-08-27 14:51:11] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 871 on 'Duration (s)' (lower=-11, upper=121)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

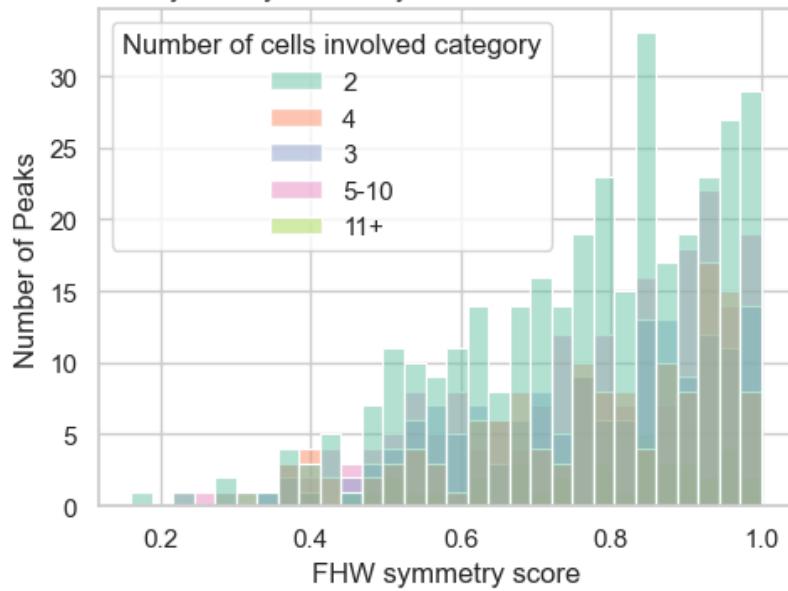


[2025-08-27 14:51:11] [INFO] calcium: plot_histogram_by_group: removed 7 outliers out of 871 on 'Prominence (noise std units)' (lower=-6.6, upper=94.8)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

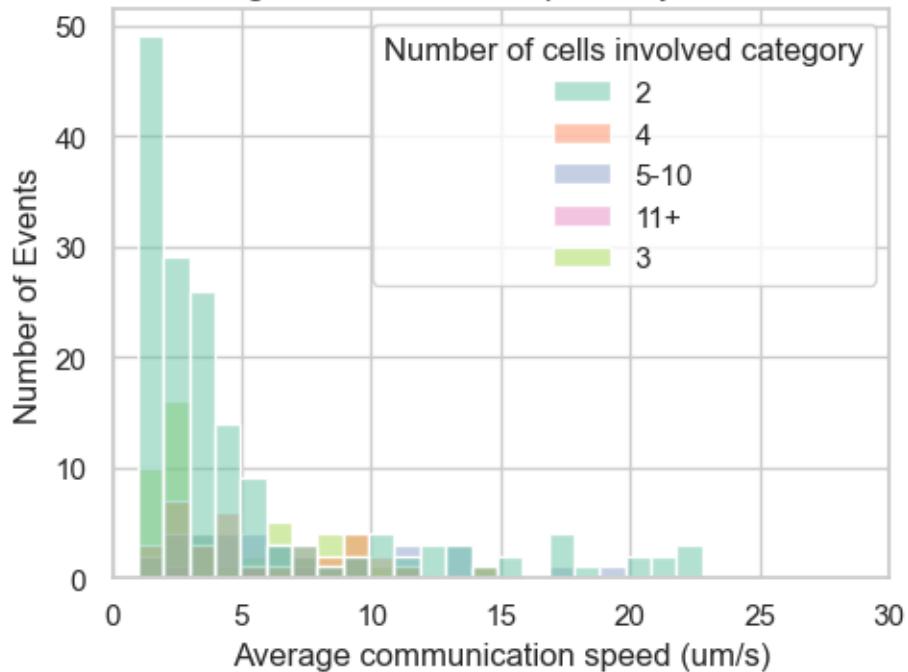


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



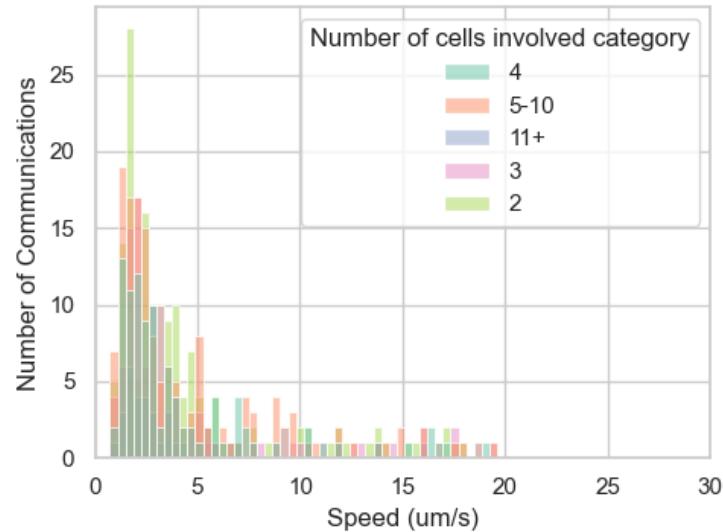
```
[2025-08-27 14:51:13] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 291 on 'Average communication speed (um/s)' (lower=-13.485, upper=23.055)
```

Distribution of Average Communication Speeds by Number of Cells Involved



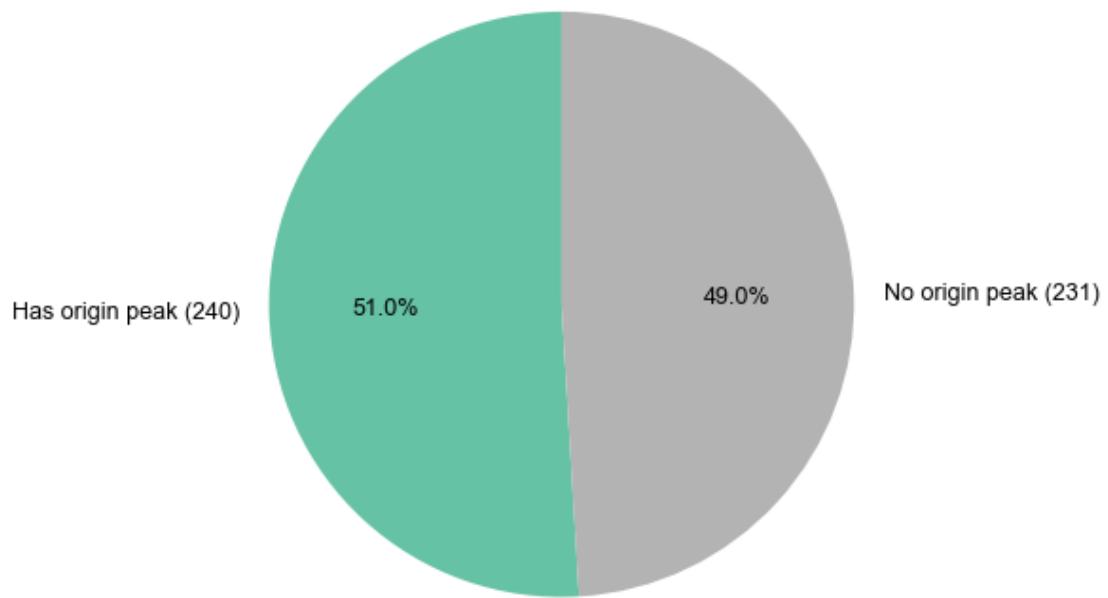
[2025-08-27 14:51:14] [INFO] calcium: plot_histogram_by_group: removed 44 outliers out of 580 on 'Speed (um/s)' (lower=-11.635, upper=19.83)

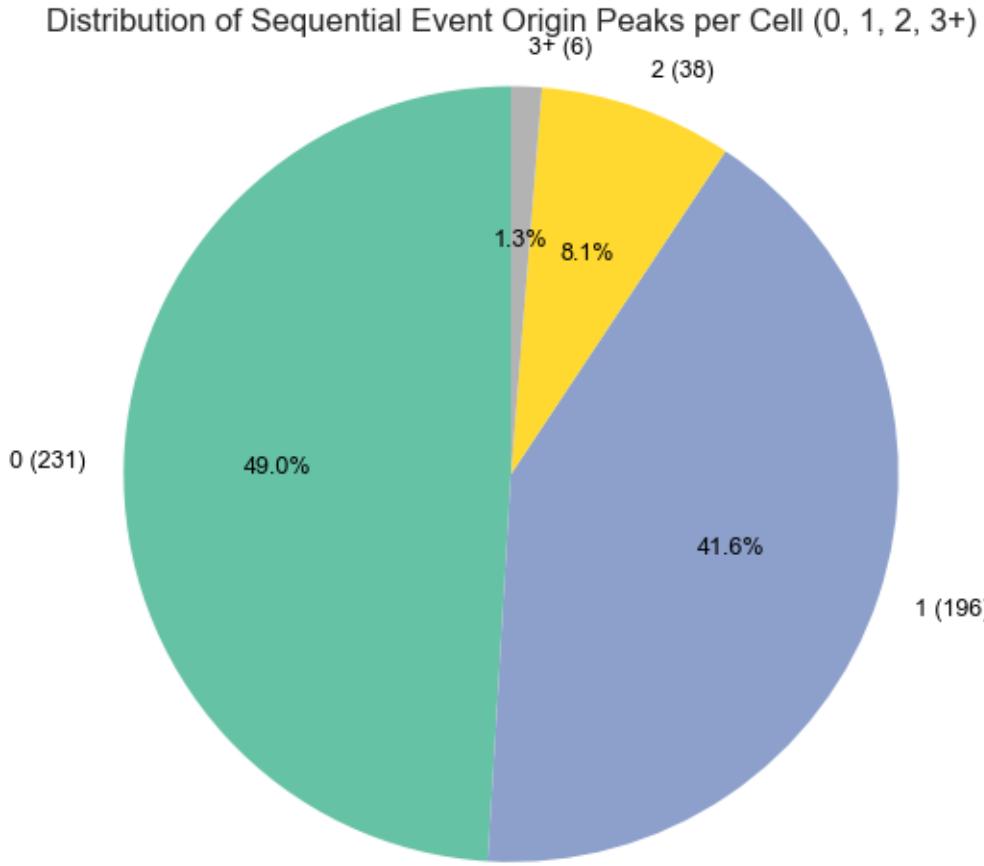
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

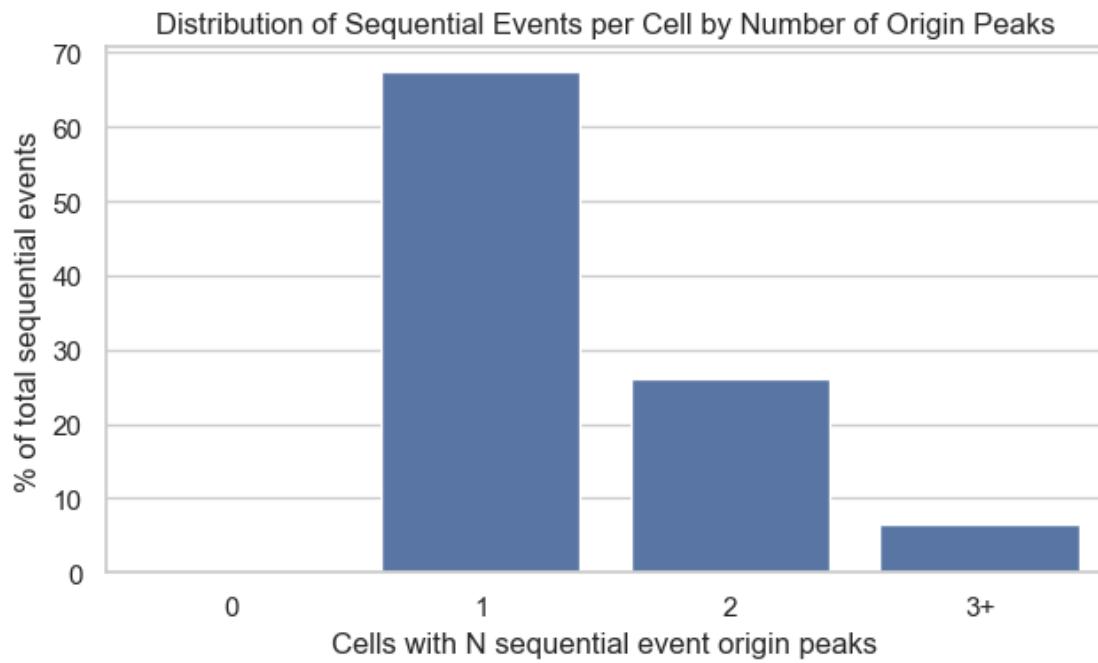
Distribution of Number of Sequential Event Origin Peaks per Cell





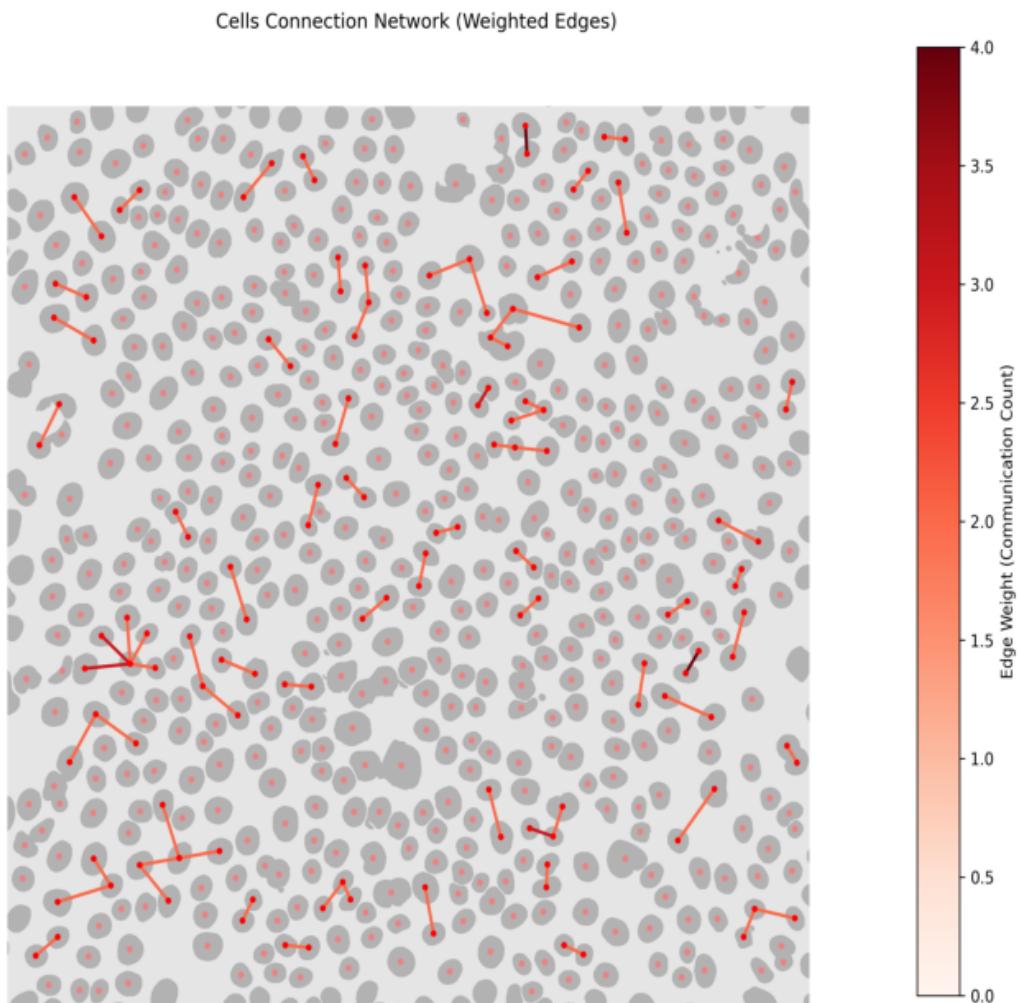
```
[2025-08-27 14:51:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\\\20250501\\\\Output\\\\IS06\\\\cell-
mapping\\\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250501\\Output\\IS06\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'



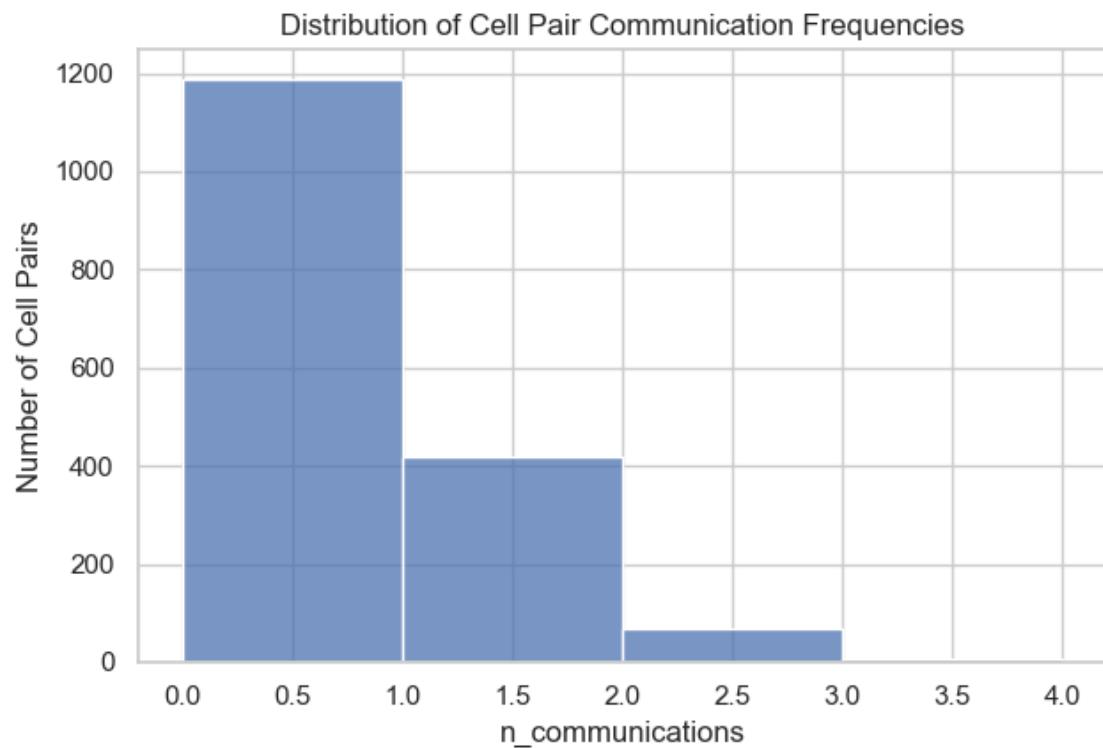
1.3.8 Connection network between cells

Cell Connection Network Graph



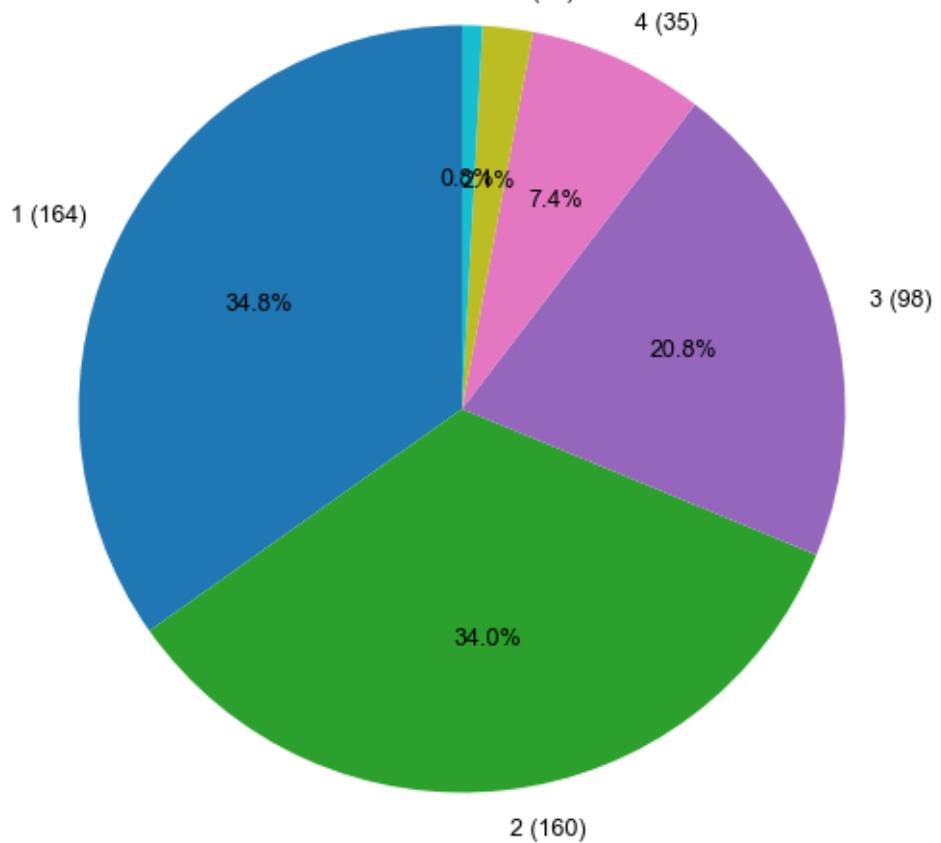
1.3.9 Pair/Trios with high communication networks

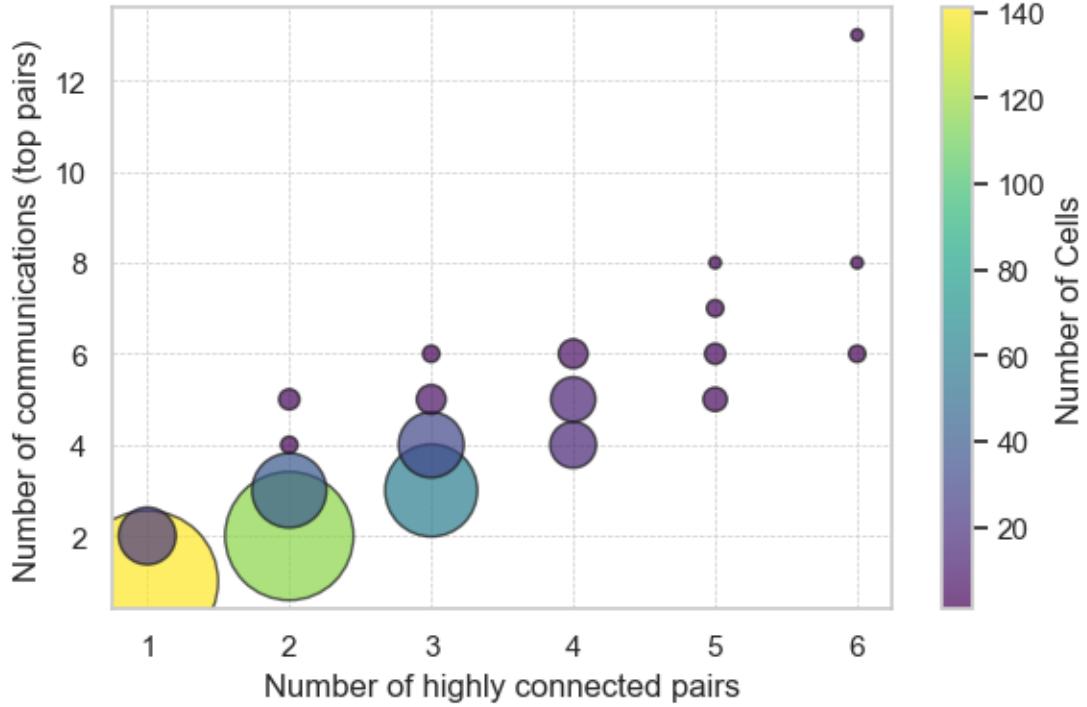
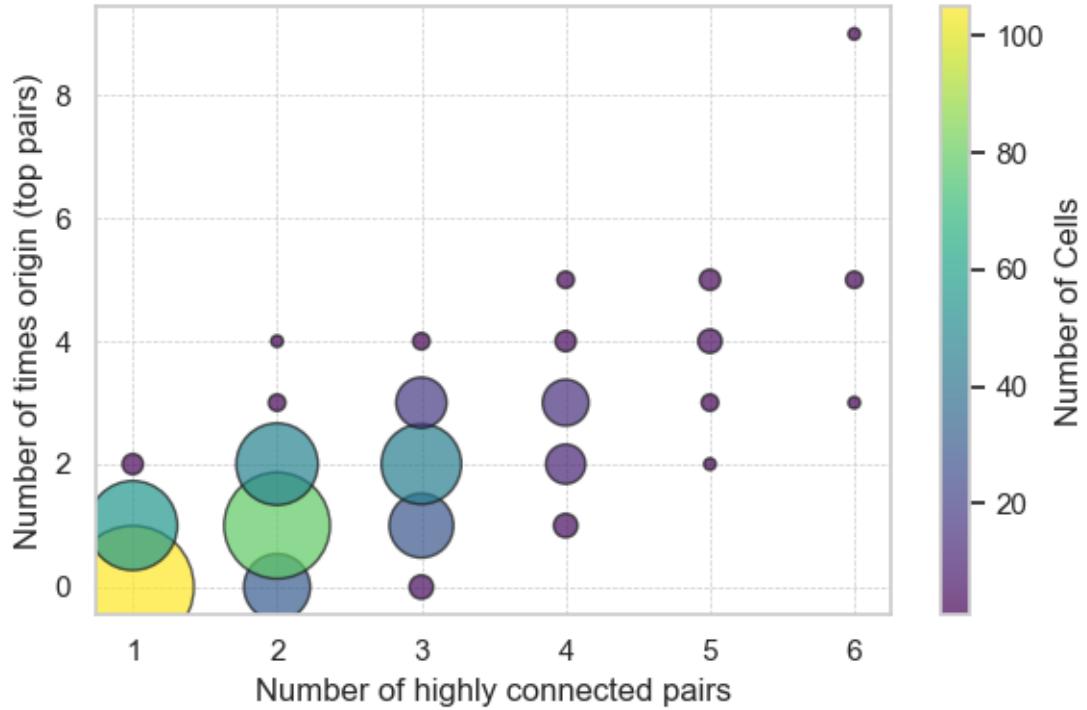
```
[2025-08-27 14:51:19] [INFO] calcium: build_neighbor_pair_stats: built 1684 pairs across 1 datasets (mean distance=22.00 um)
```

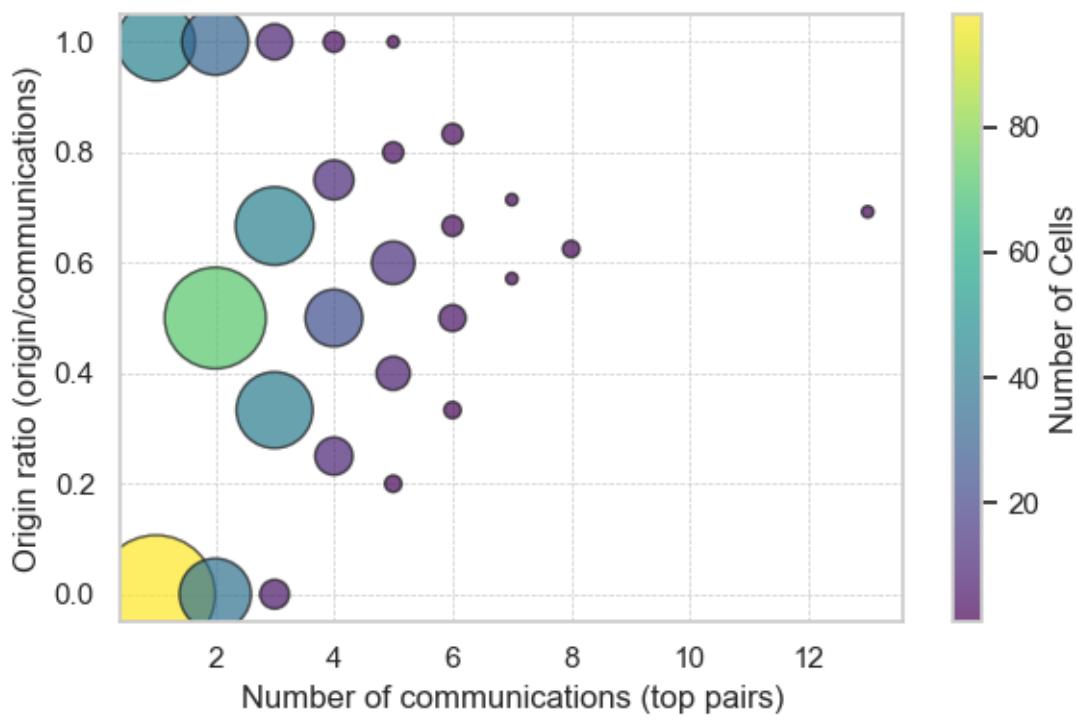
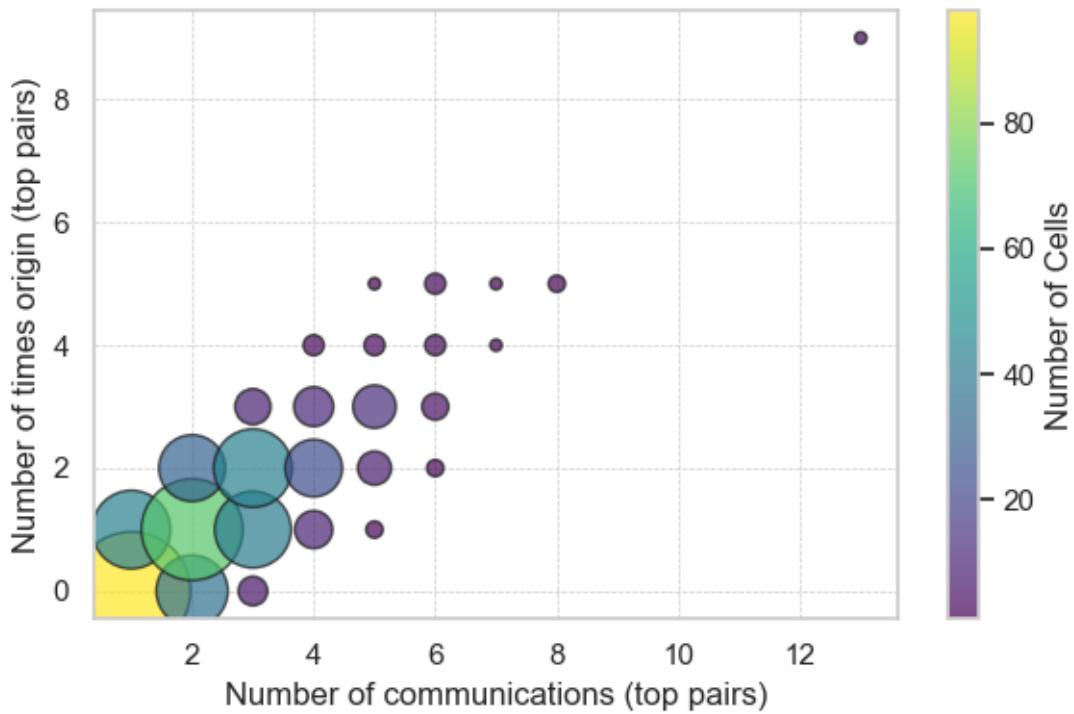


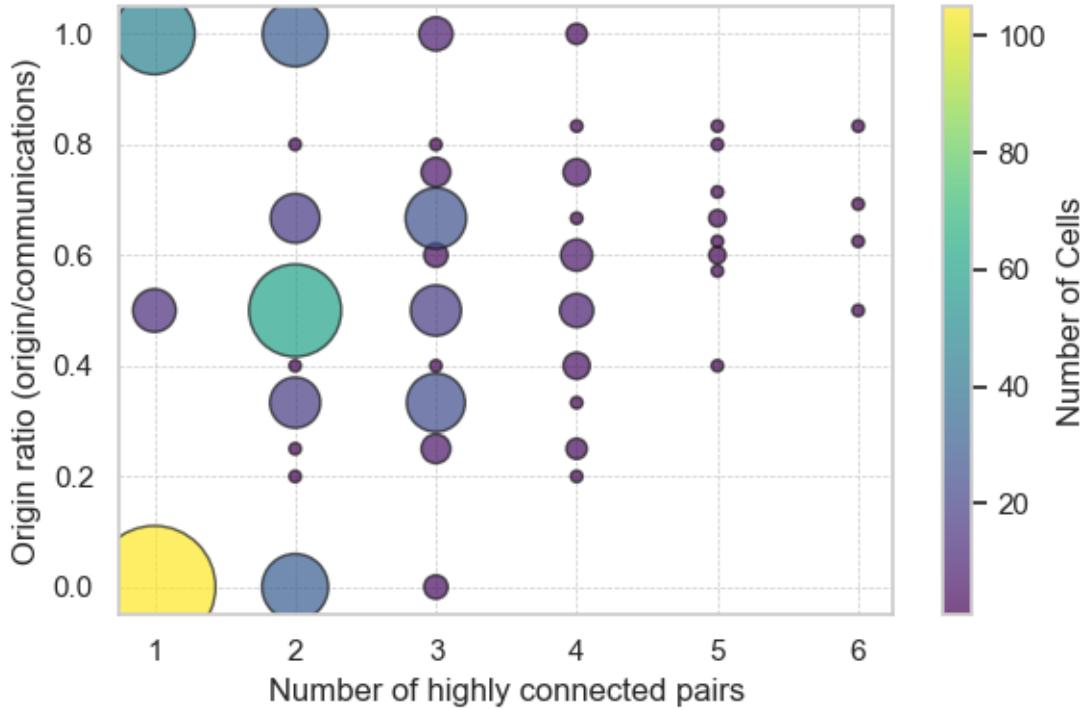
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=164 for Number of highly connected pairs=1

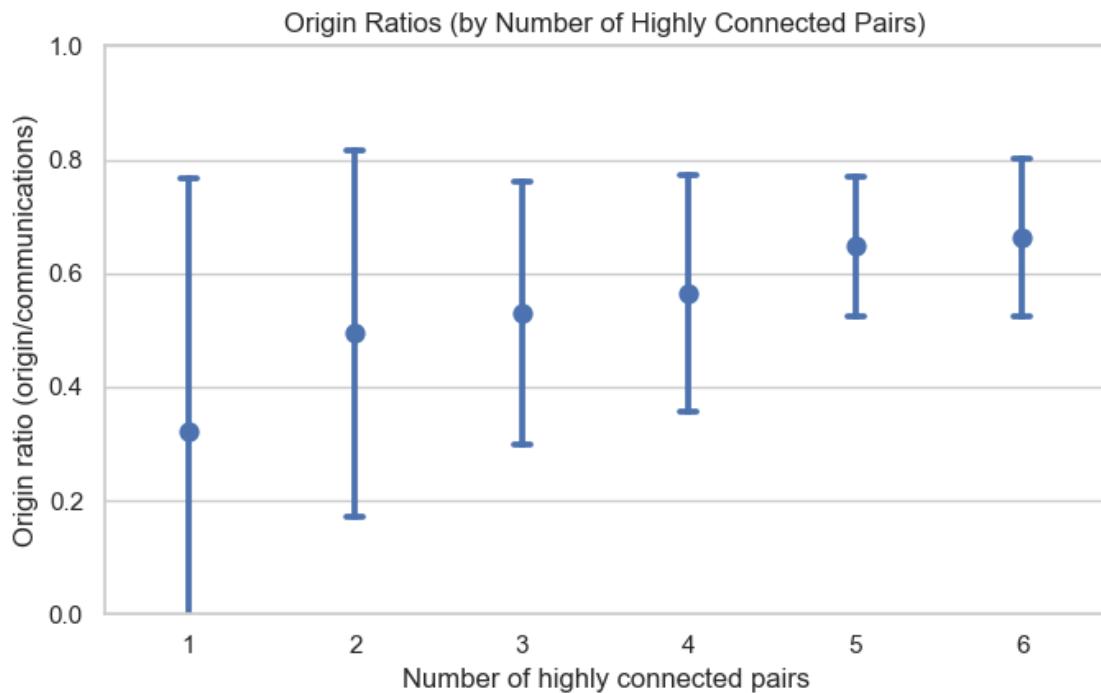
[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=160 for Number of highly connected pairs=2

[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=98 for Number of highly connected pairs=3

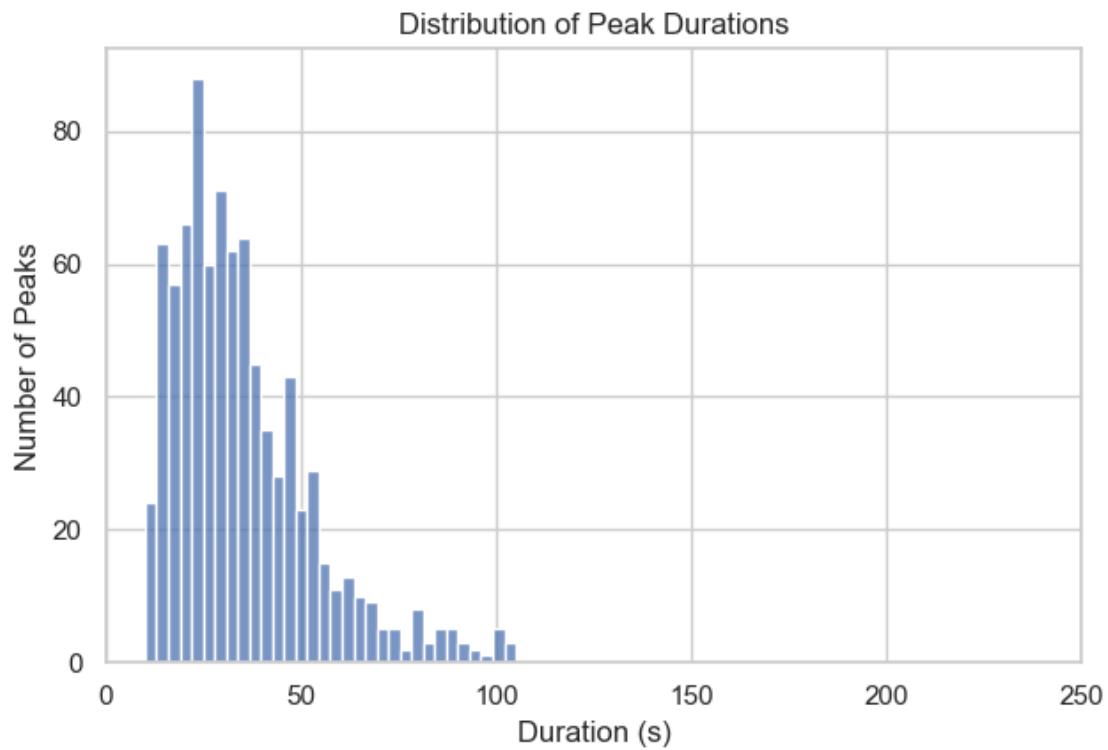
[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=35 for Number of highly connected pairs=4

[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=10 for Number of highly connected pairs=5

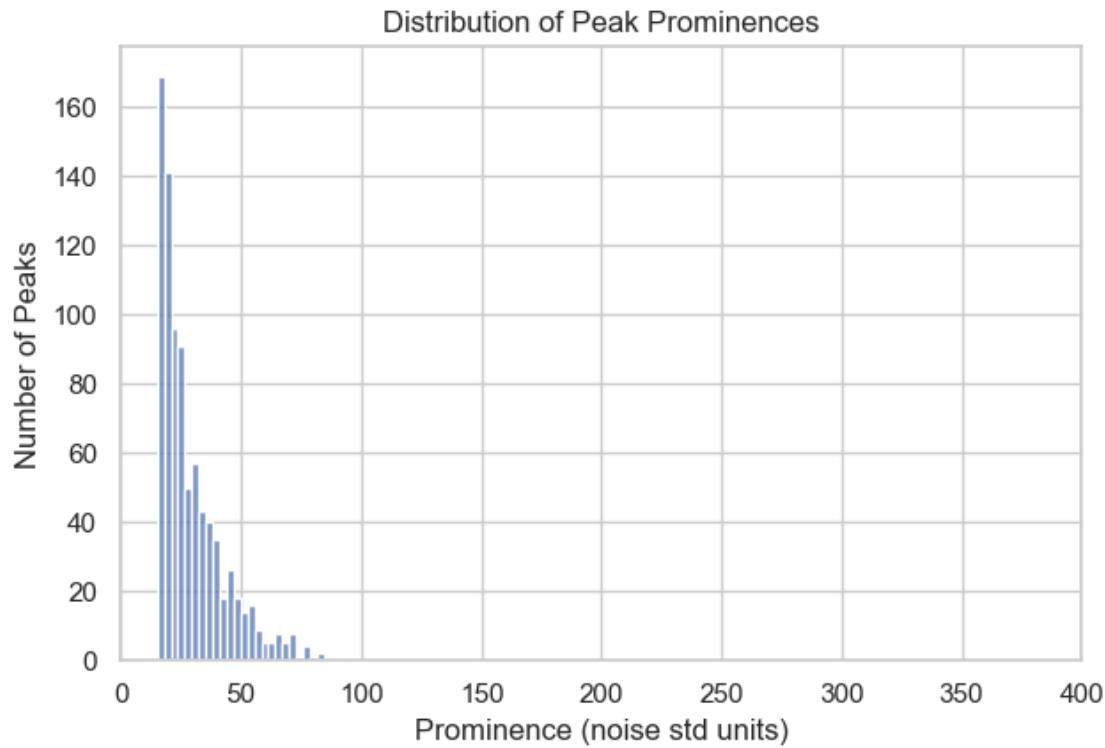
[2025-08-27 14:51:22] [INFO] calcium: plot_points_mean_std: N=4 for Number of highly connected pairs=6

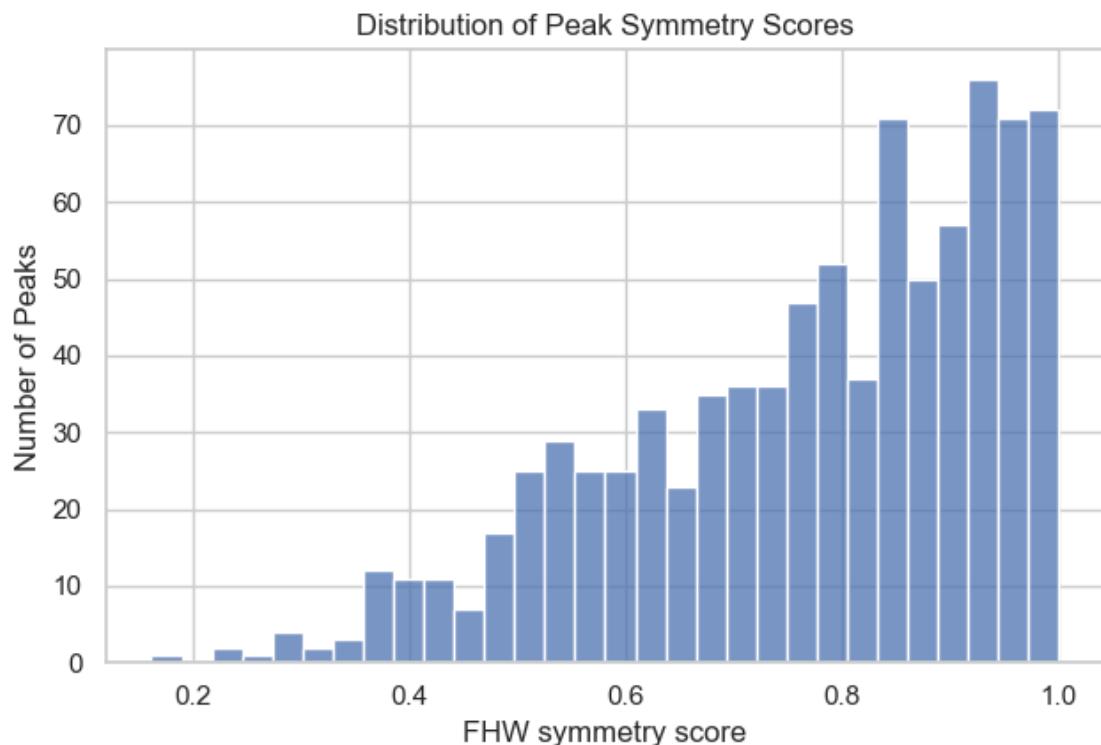


```
[2025-08-27 14:51:22] [INFO] calcium: plot_histogram: removed 8 outliers out of 871 on 'Duration (s)' (lower=-44, upper=110)
```

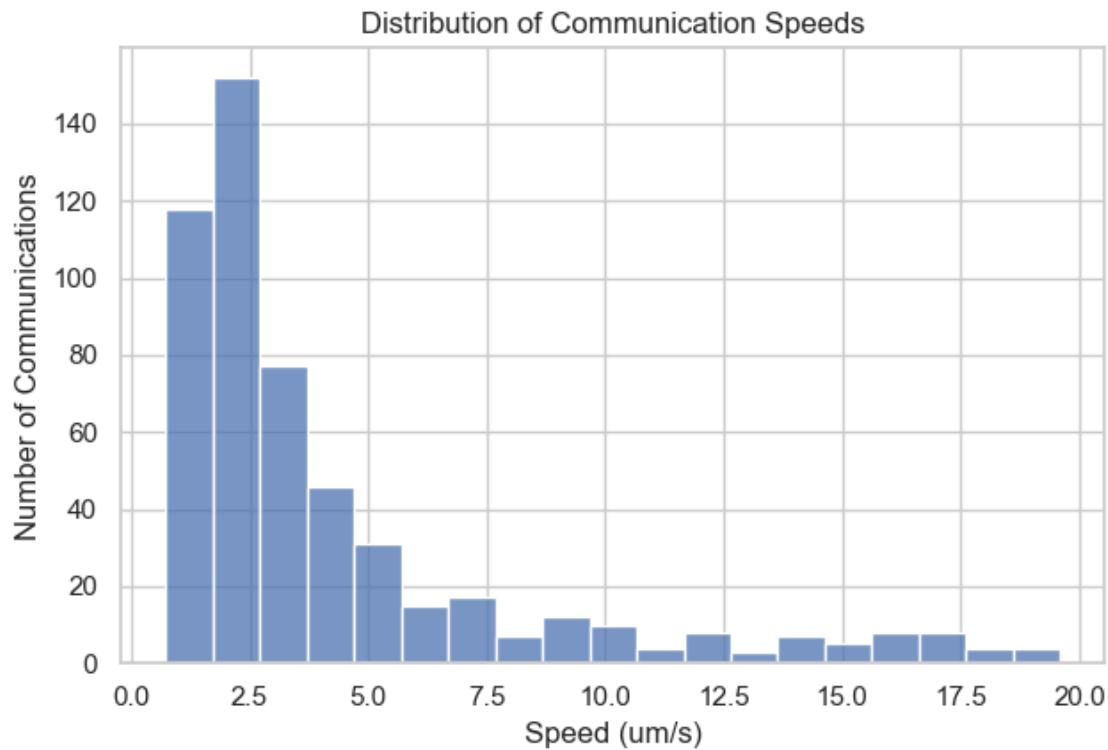


[2025-08-27 14:51:23] [INFO] calcium: plot_histogram: removed 9 outliers out of 871 on 'Prominence (noise std units)' (lower=-31.95, upper=86.35)

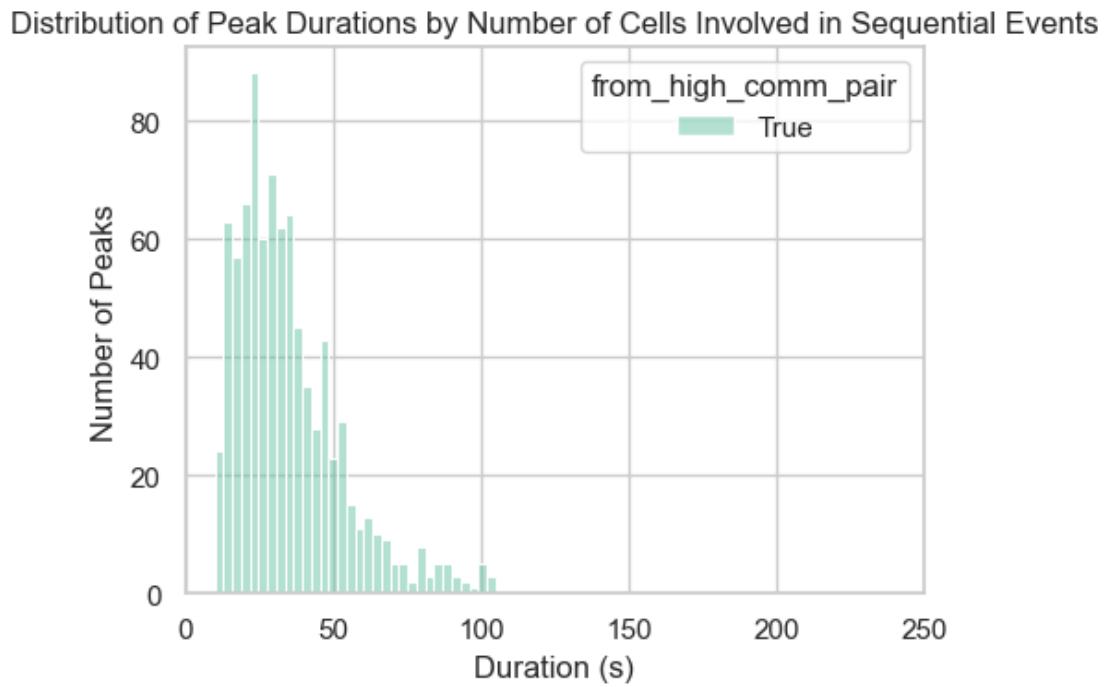




```
[2025-08-27 14:51:24] [INFO] calcium: plot_histogram: removed 44 outliers out of 580 on 'Speed (um/s)' (lower=-11.635, upper=19.83)
```

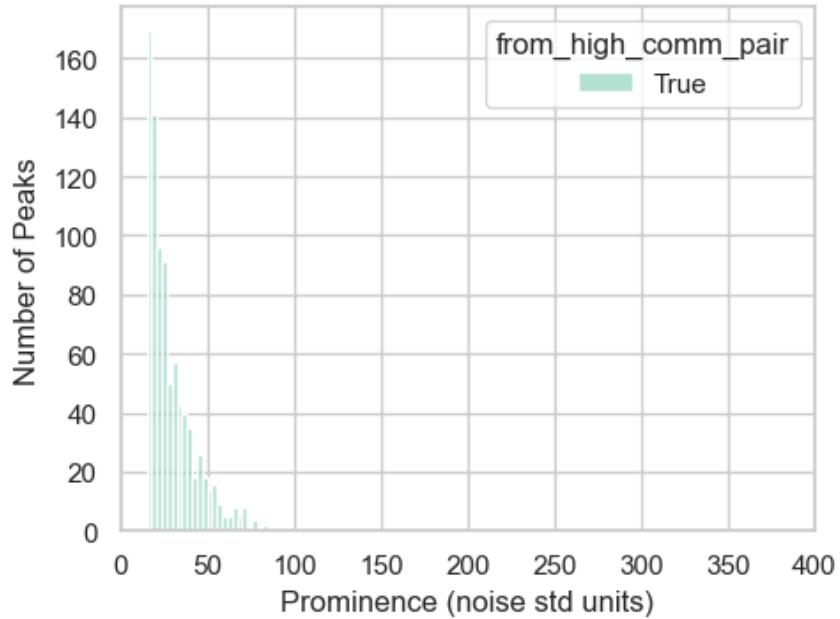


```
[2025-08-27 14:51:24] [INFO] calcium: plot_histogram_by_group: removed 8 outliers out of 871 on 'Duration (s)' (lower=-44, upper=110)
```

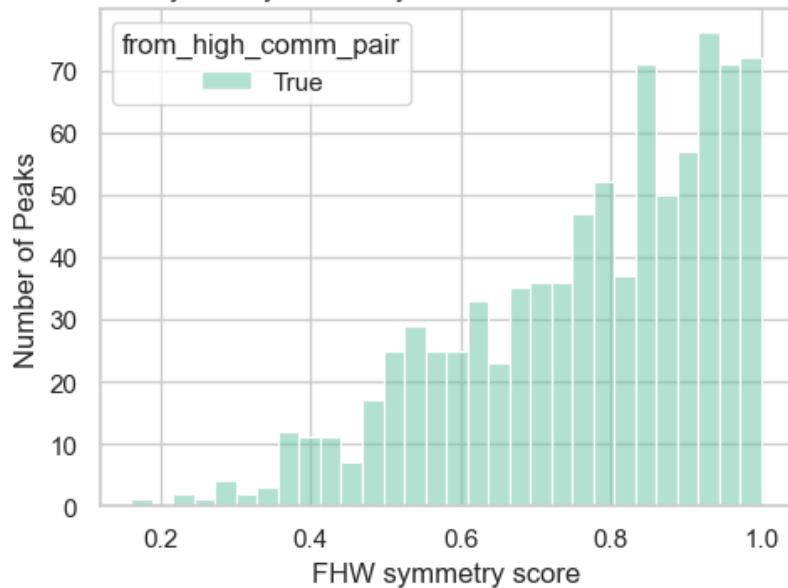


[2025-08-27 14:51:25] [INFO] calcium: plot_histogram_by_group: removed 9 outliers out of 871 on 'Prominence (noise std units)' (lower=-31.95, upper=86.35)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

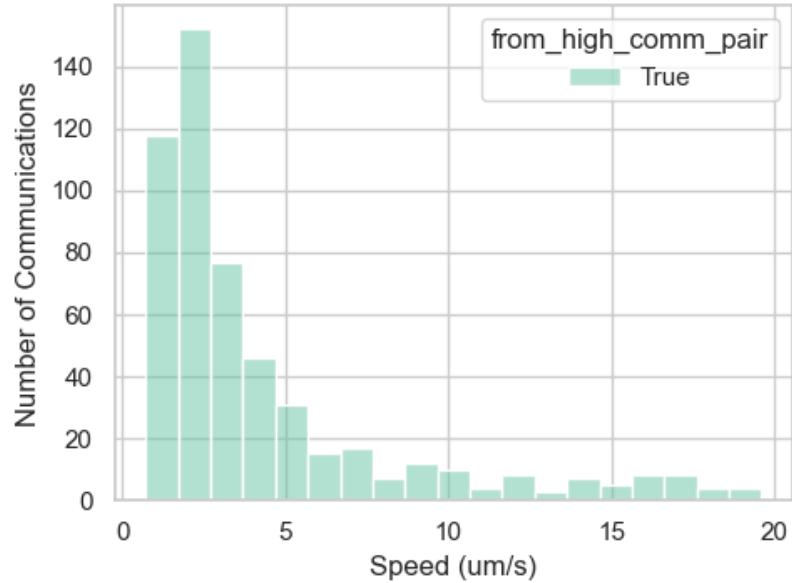


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 14:51:26] [INFO] calcium: plot_histogram_by_group: removed 44 outliers out of 580 on 'Speed (um/s)' (lower=-11.635, upper=19.83)

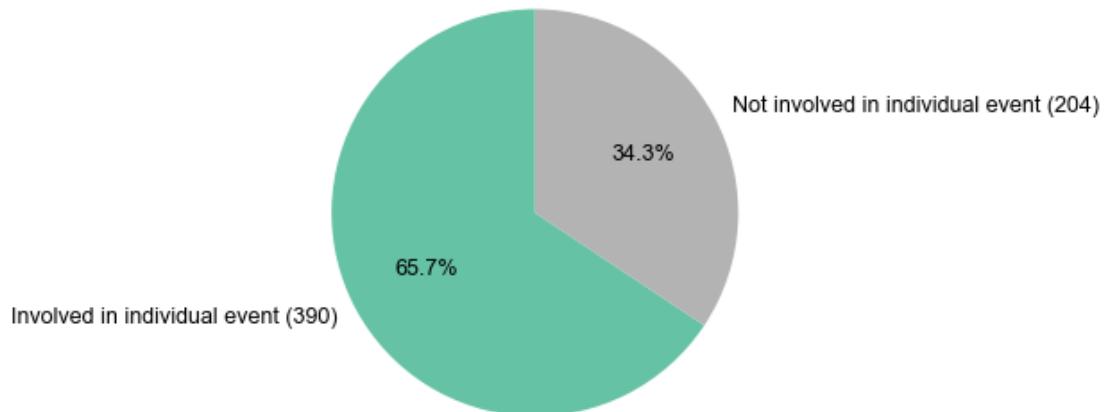
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

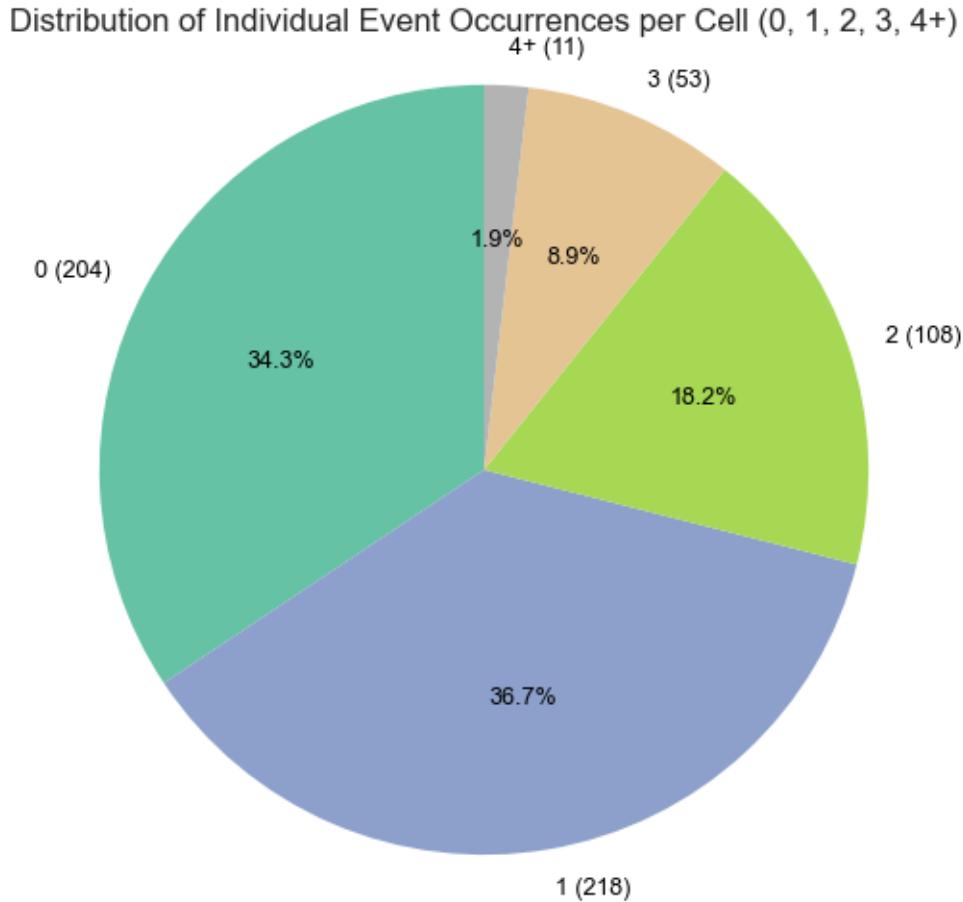


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



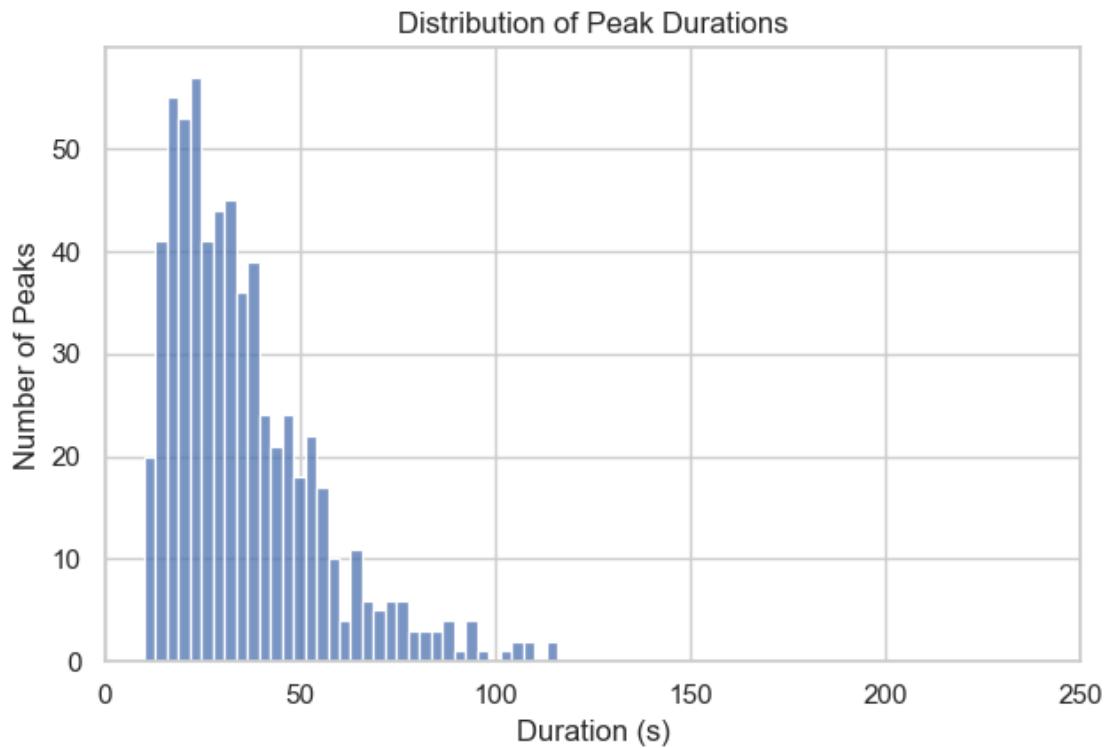


```
[2025-08-27 14:51:27] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS06\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250501\\Output\\IS06\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250501\\Output\\IS06\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

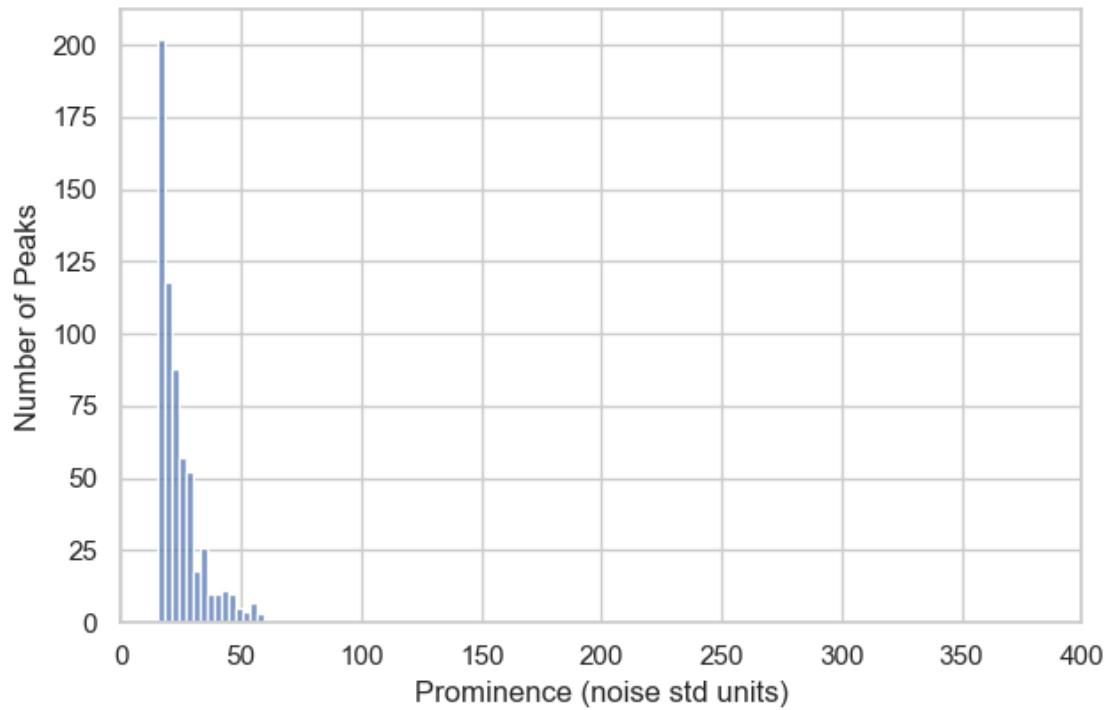
1.4.2 Peaks statistics in individual events

[2025-08-27 14:51:28] [INFO] calcium: plot_histogram: removed 11 outliers out of 642 on 'Duration (s)' (lower=-54, upper=121)

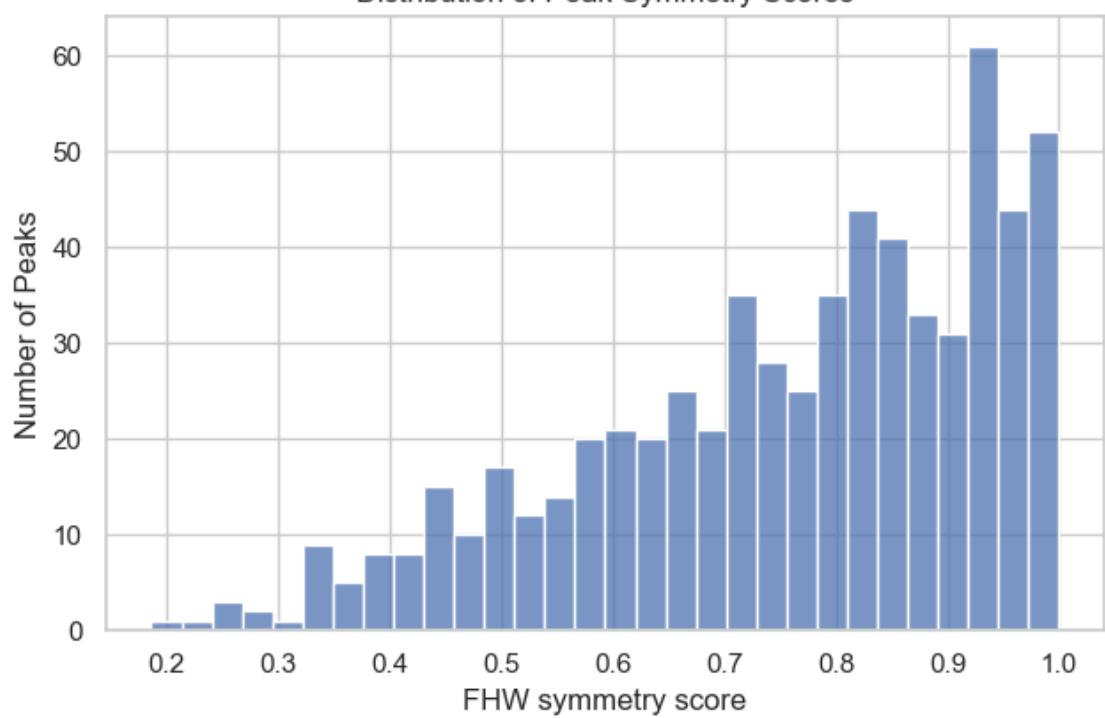


[2025-08-27 14:51:28] [INFO] calcium: plot_histogram: removed 21 outliers out of 642 on 'Prominence (noise std units)' (lower=-14.825, upper=59.9)

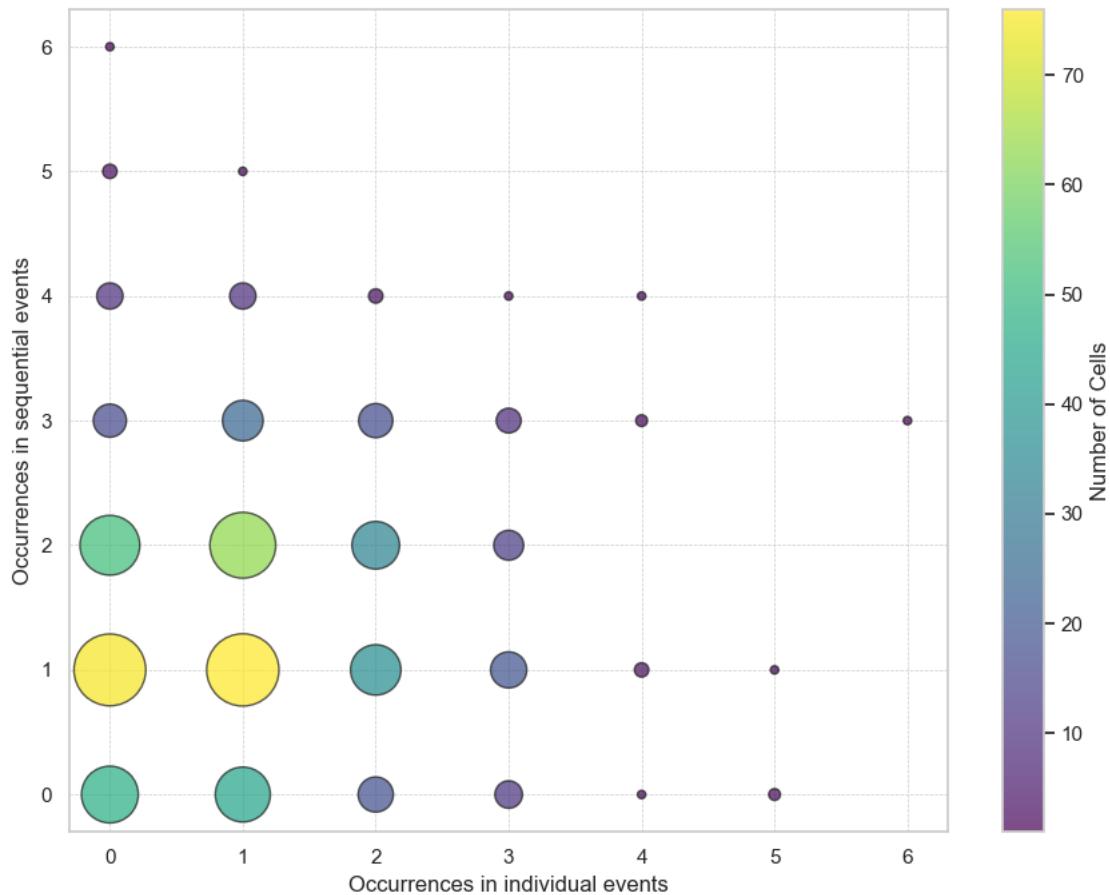
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



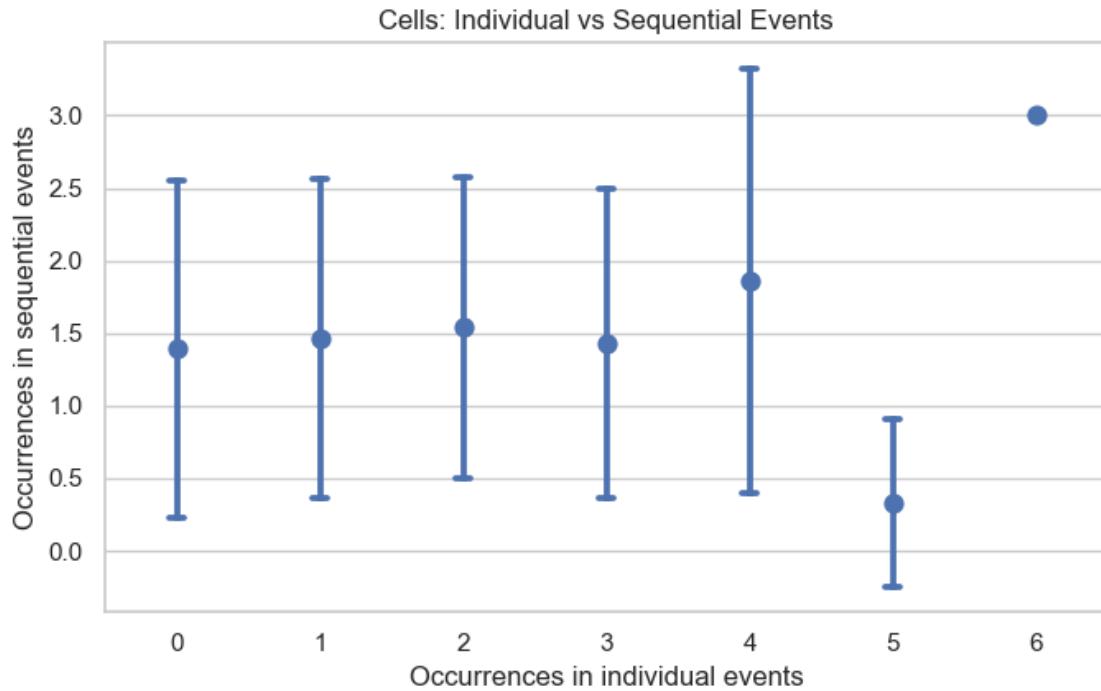
1.4.3 Correlation between event activity level & individual activity level



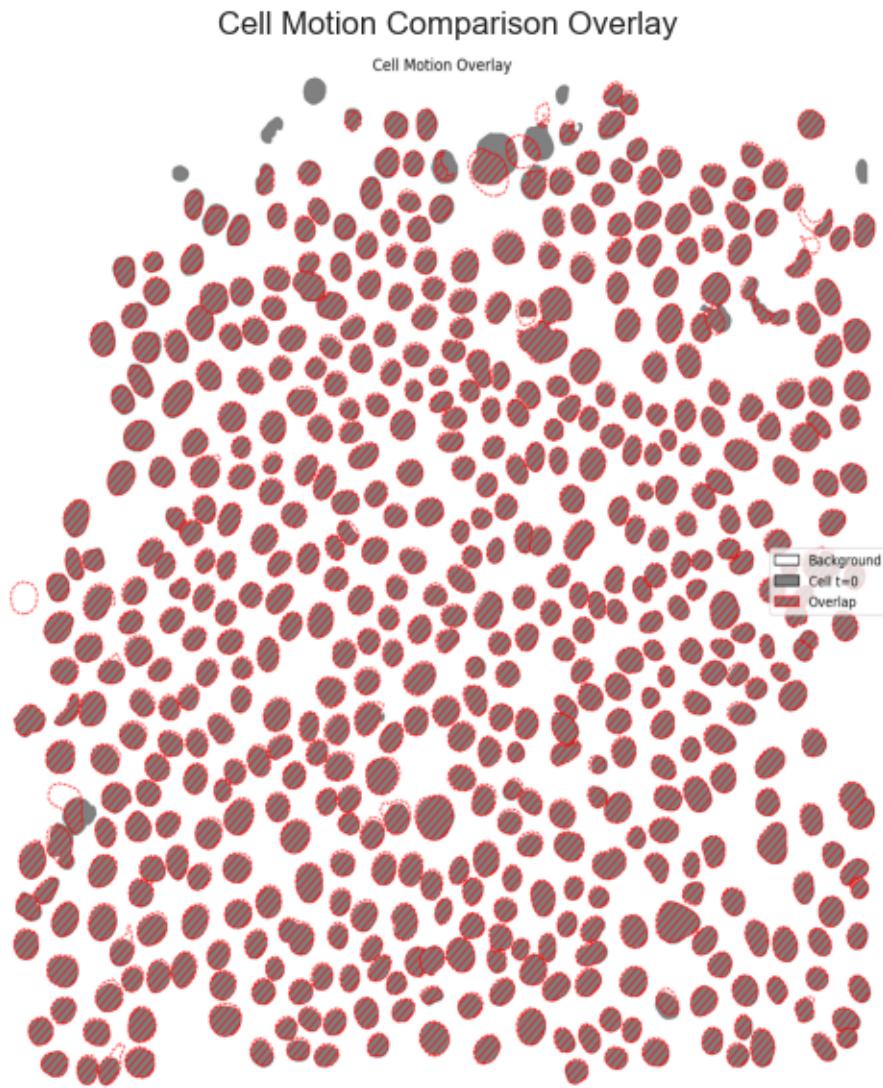
```
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: removed 1/594 outliers on 'Occurrences in sequential events' (lower=-2, upper=5)
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=203 for Occurrences in individual events=0
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=218 for Occurrences in individual events=1
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=108 for Occurrences in individual events=2
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=53 for Occurrences in individual events=3
[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=7 for Occurrences in individual events=4
```

[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=3 for Occurrences in individual events=5

[2025-08-27 14:51:30] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 545
- Hoechst image taken at t=1801: 544
- Number of cells difference: absolute 1, relative 0.18%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 715421
- Pixels segmented as cell at t=1801: 732022
- Overlapping pixels between t=0 and t=1801: 669249 (92.47% of total)
- Pixels exclusive to t=0: 46172 (6.45% of total)
- Pixels exclusive to t=1801: 62773 (8.58% of total)

executed

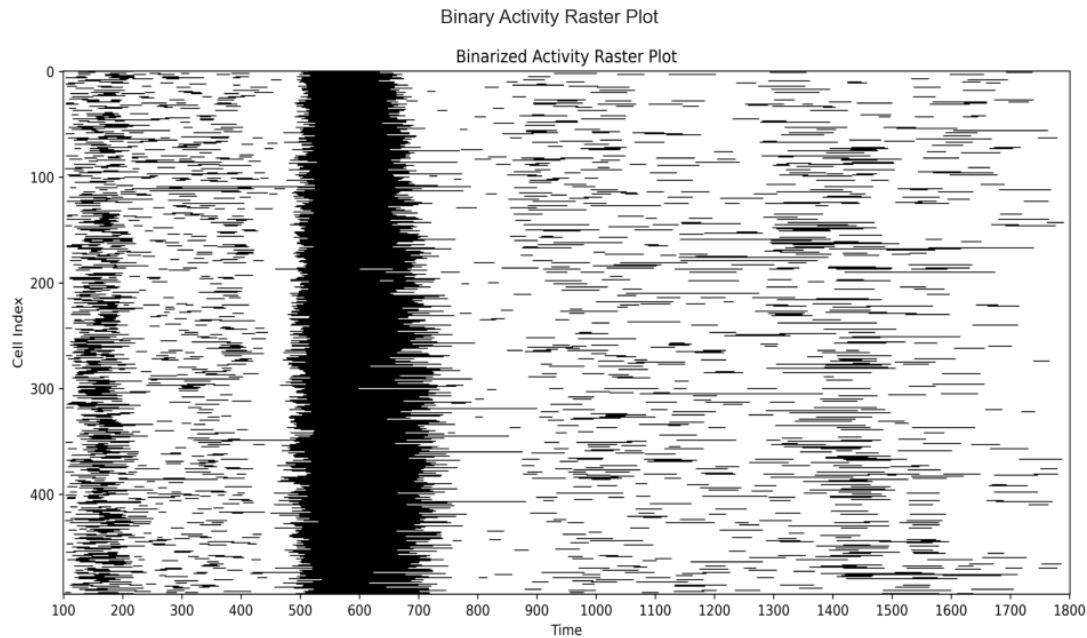
August 27, 2025

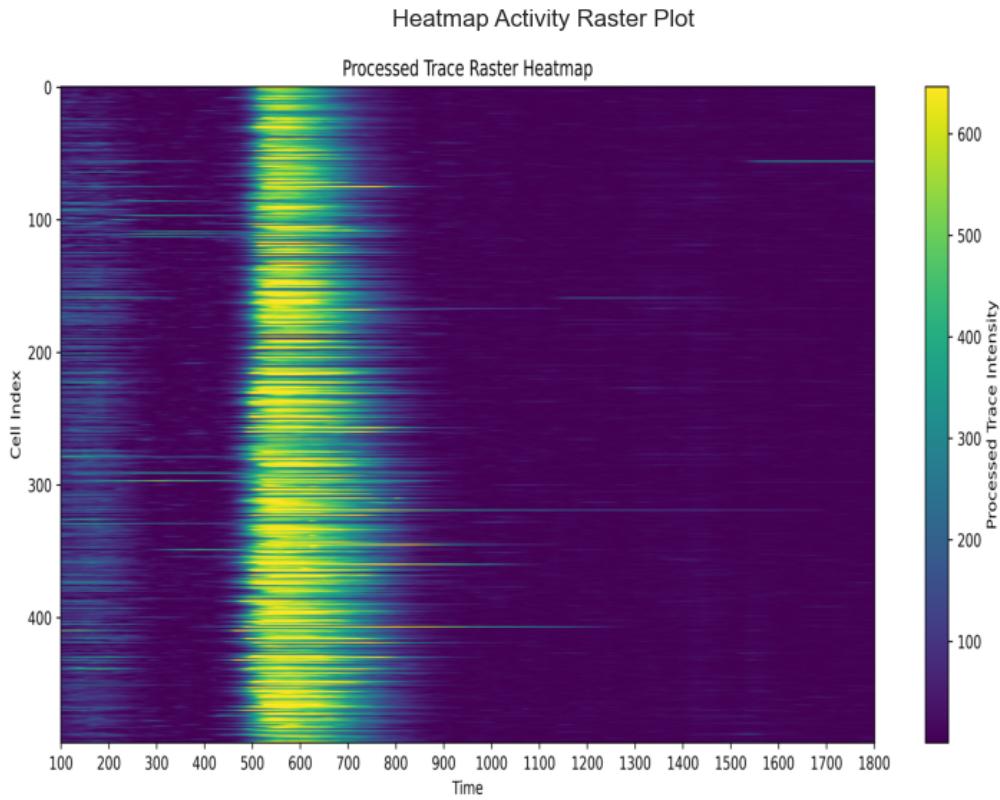
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





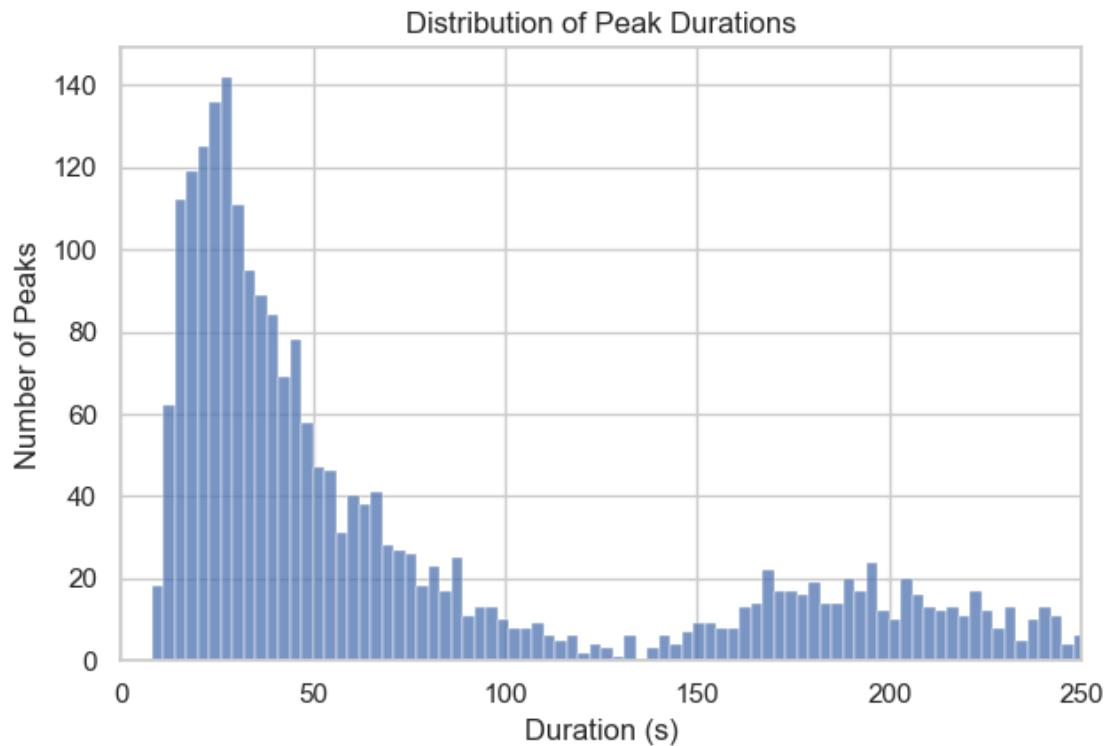
1.1.2 Peaks population

Total number of peaks: 2339

Total number of cells: 495

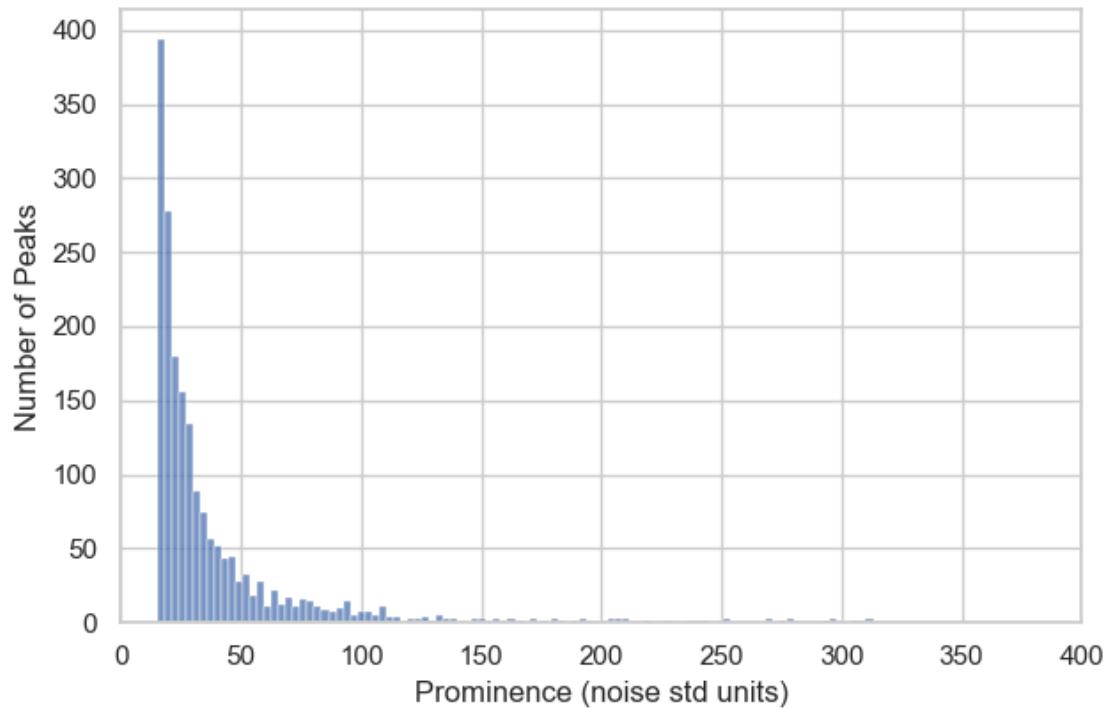
1.1.3 Peaks statistics

```
[2025-08-27 14:53:01] [INFO] calcium: plot_histogram: removed 6 outliers out of  
2339 on 'Duration (s)' (lower=-199, upper=326)
```

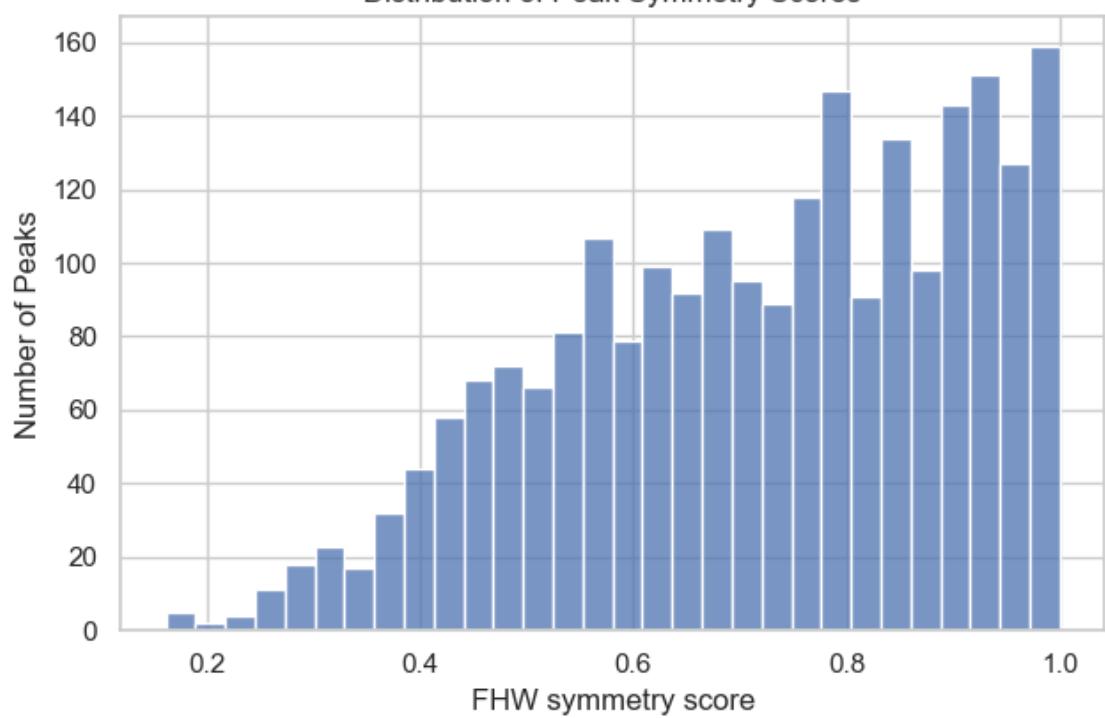


```
[2025-08-27 14:53:01] [INFO] calcium: plot_histogram: removed 466 outliers out  
of 2339 on 'Prominence (noise std units)' (lower=-200, upper=313.45)
```

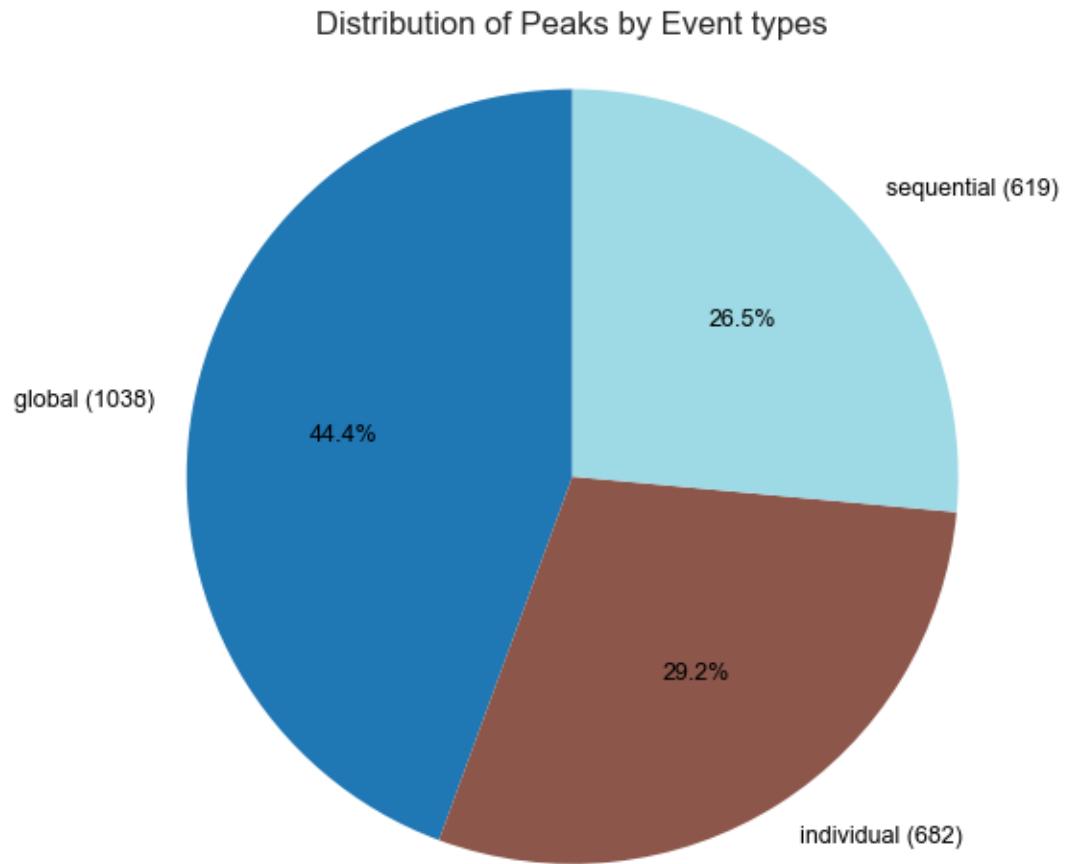
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

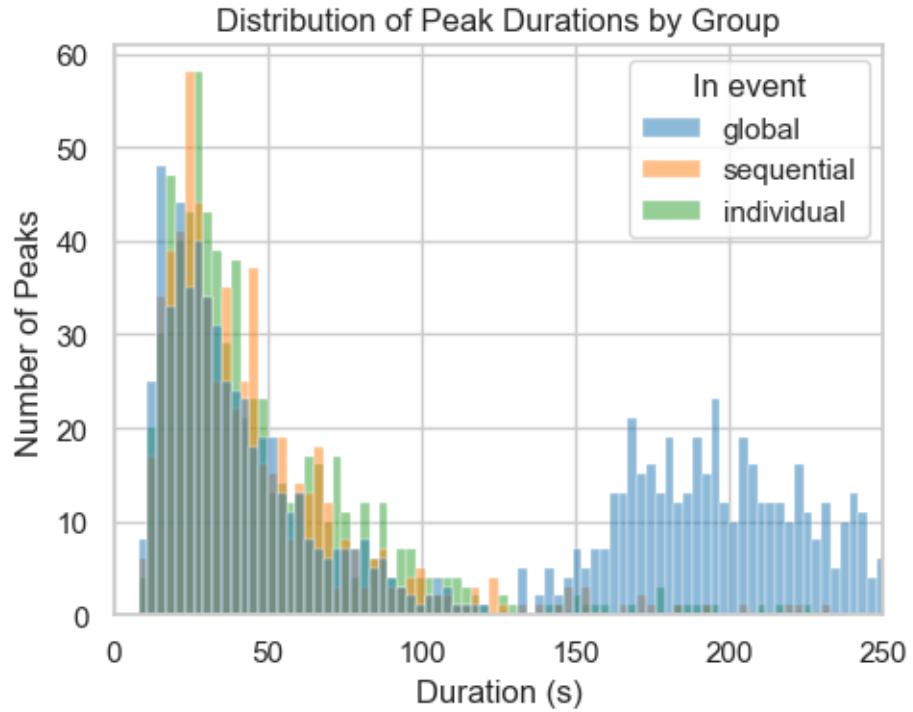


1.1.4 Distribution of peaks per event types

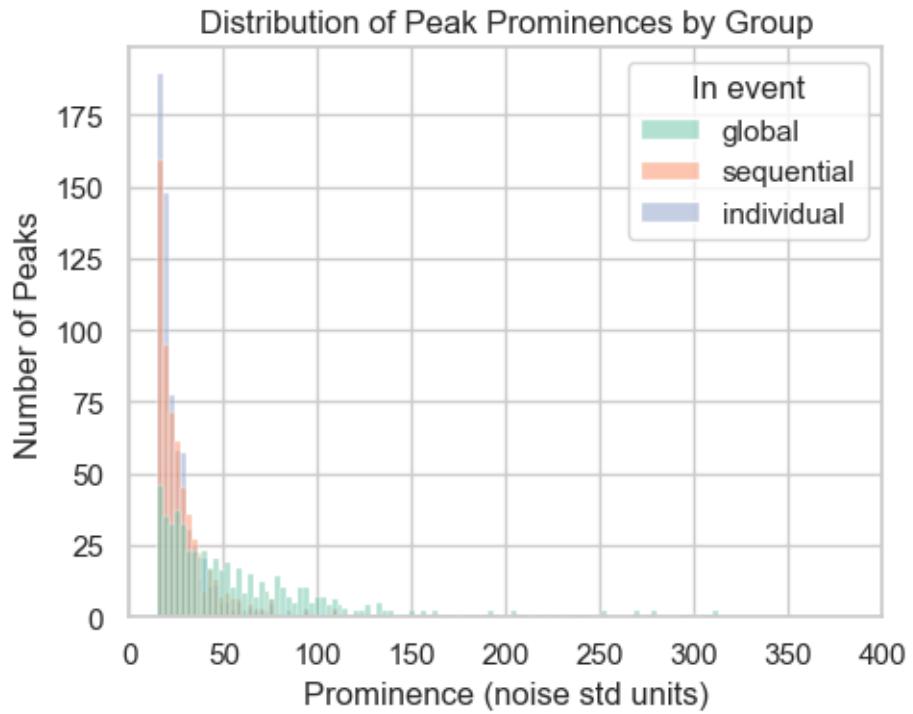


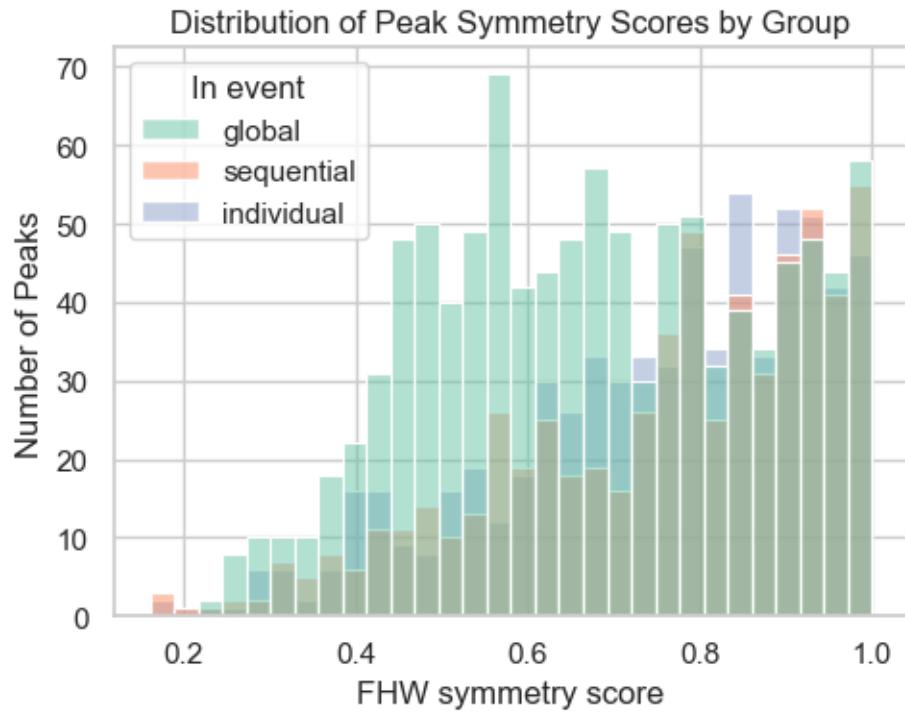
1.1.5 Peaks statistics per event types

```
[2025-08-27 14:53:03] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 2339 on 'Duration (s)' (lower=-199, upper=326)
```



```
[2025-08-27 14:53:04] [INFO] calcium: plot_histogram_by_group: removed 466 outliers out of 2339 on 'Prominence (noise std units)' (lower=-200, upper=313.45)
```

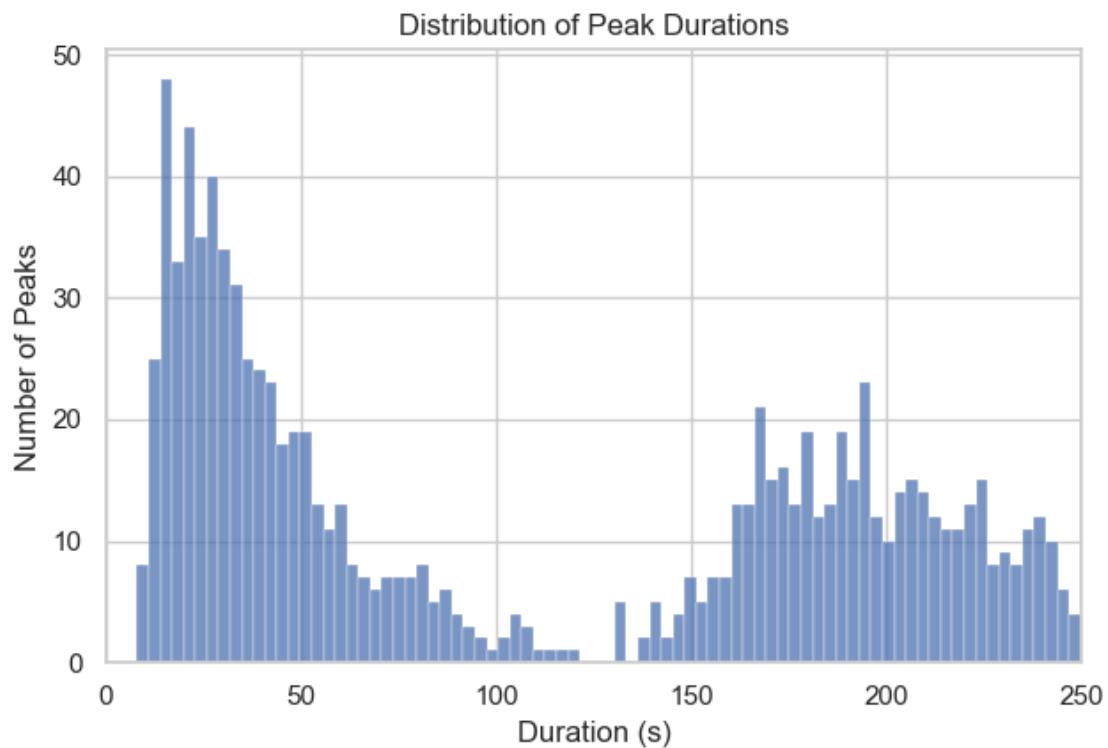




1.2 GLOBAL EVENTS

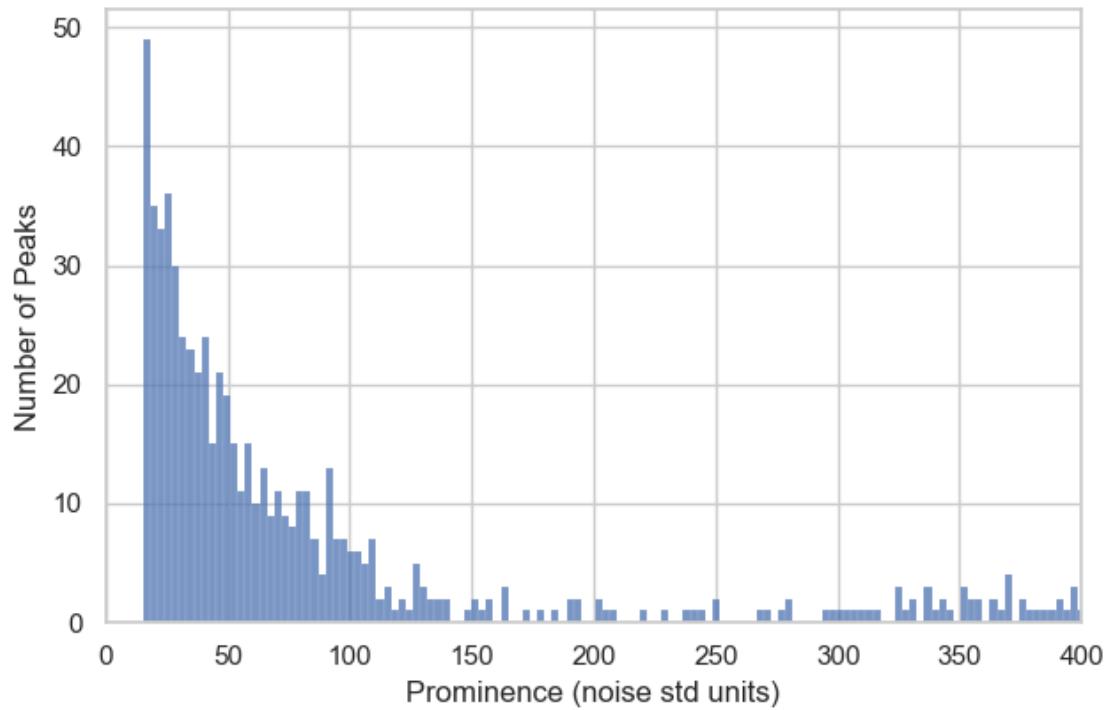
1.2.1 Peak statistics in global events

```
[2025-08-27 14:53:06] [INFO] calcium: plot_histogram: removed 0 outliers out of 1038 on 'Duration (s)' (lower=-464, upper=691)
```

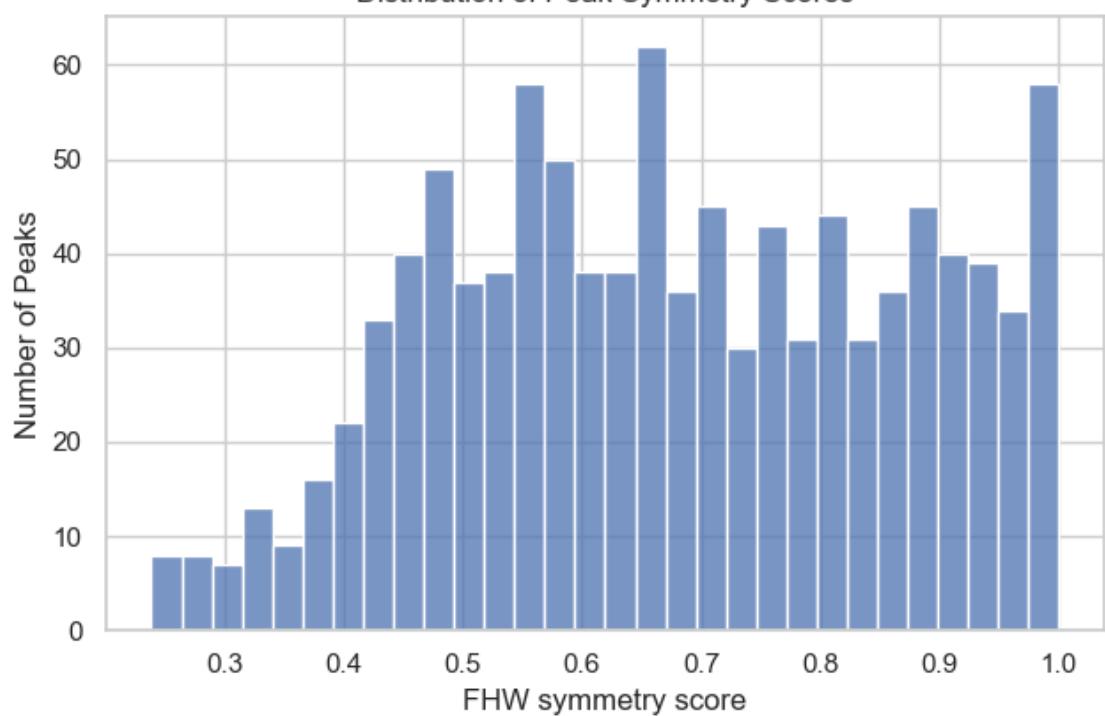


```
[2025-08-27 14:53:07] [INFO] calcium: plot_histogram: removed 0 outliers out of 1038 on 'Prominence (noise std units)' (lower=-1541.6, upper=2149.9)
```

Distribution of Peak Prominences

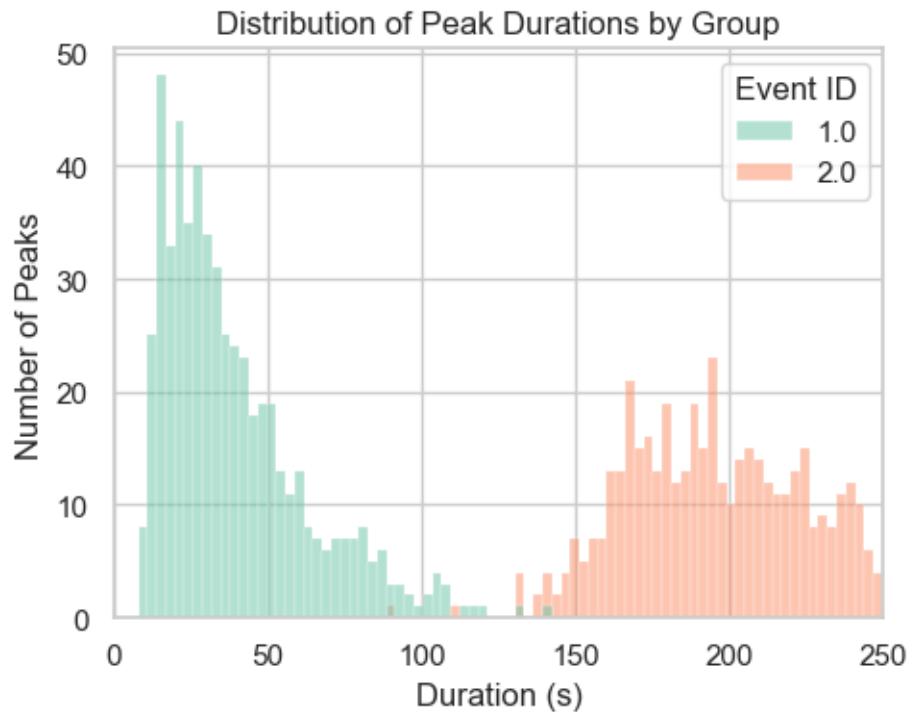


Distribution of Peak Symmetry Scores

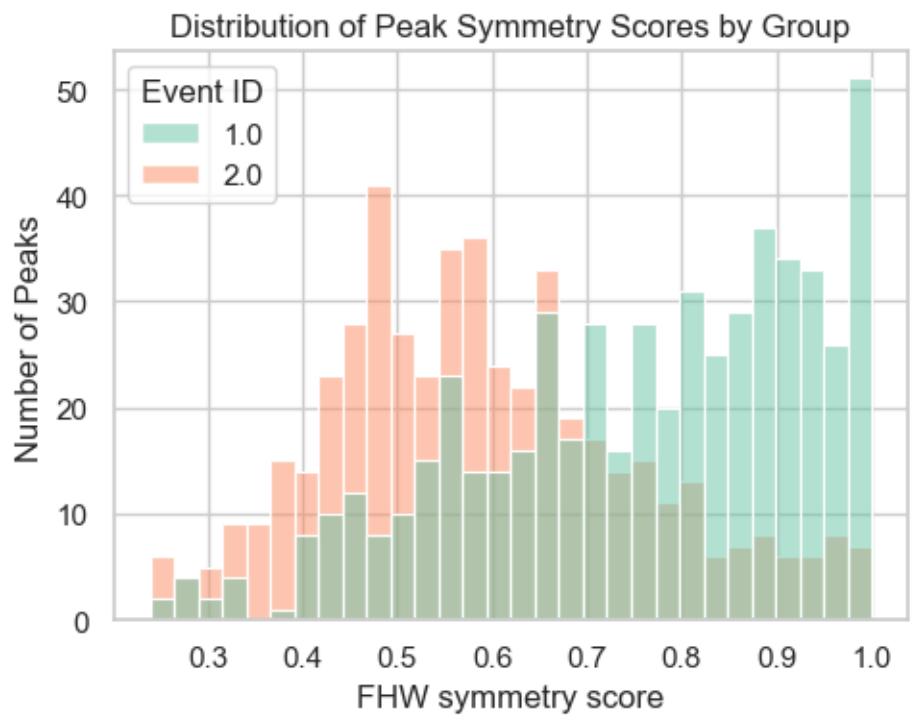
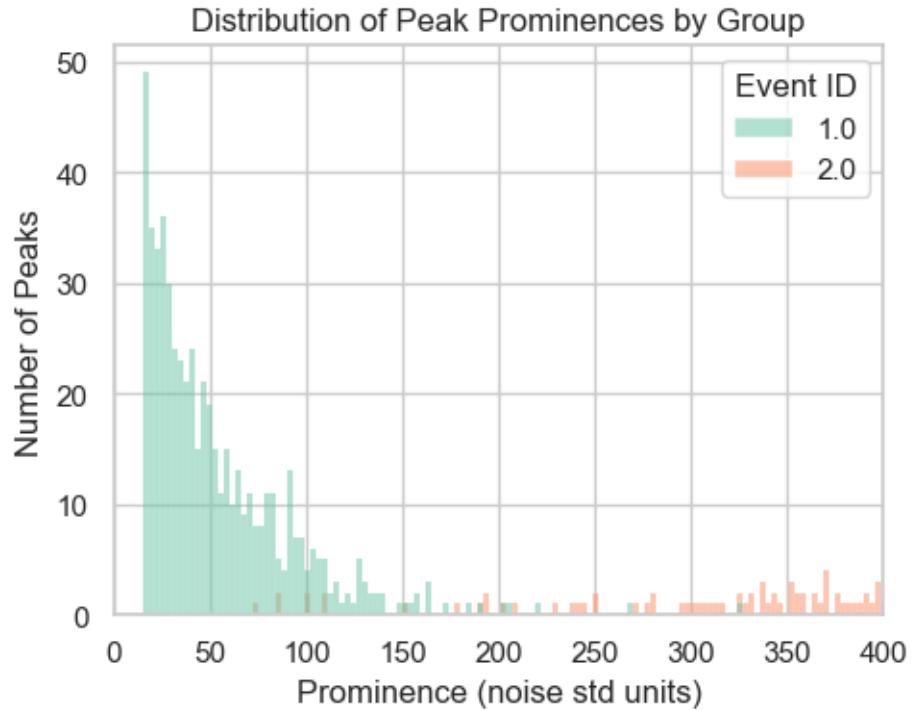


1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 14:53:08] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1038 on 'Duration (s)' (lower=-464, upper=691)
```

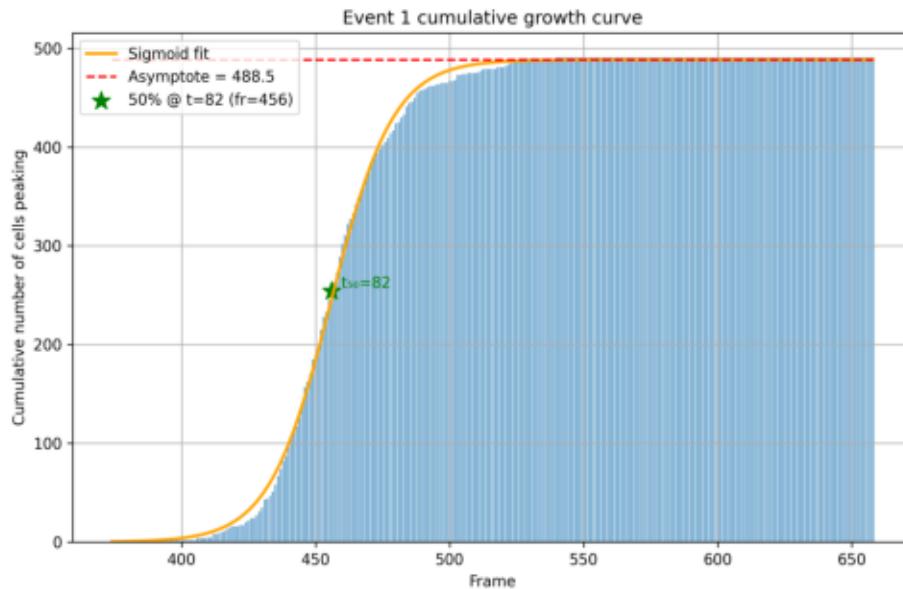


```
[2025-08-27 14:53:10] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1038 on 'Prominence (noise std units)' (lower=-1541.6, upper=2149.9)
```



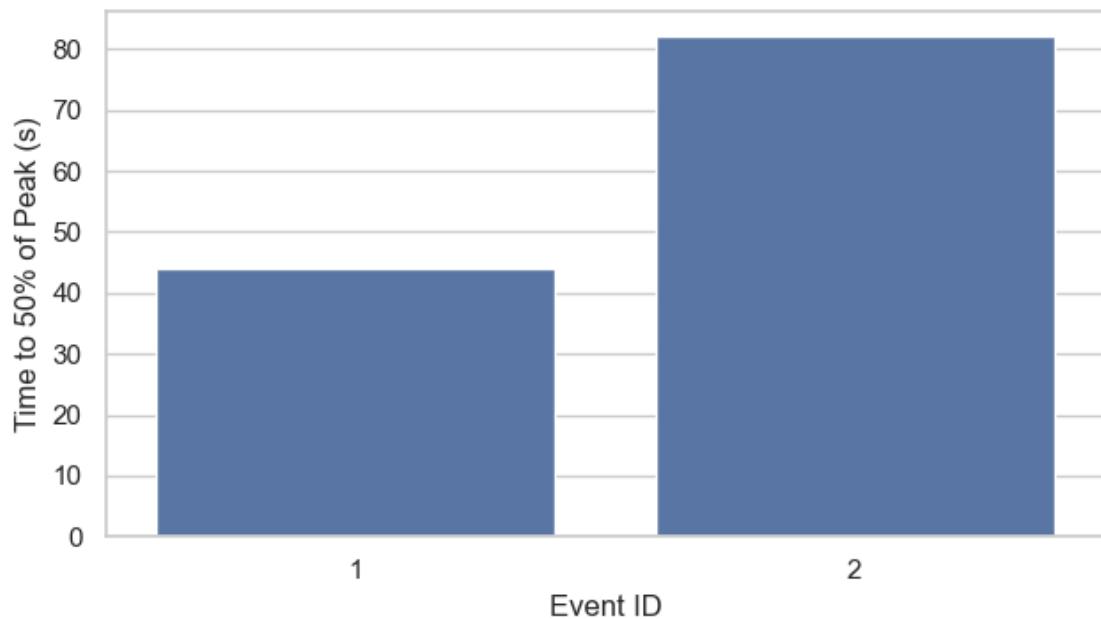
1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)

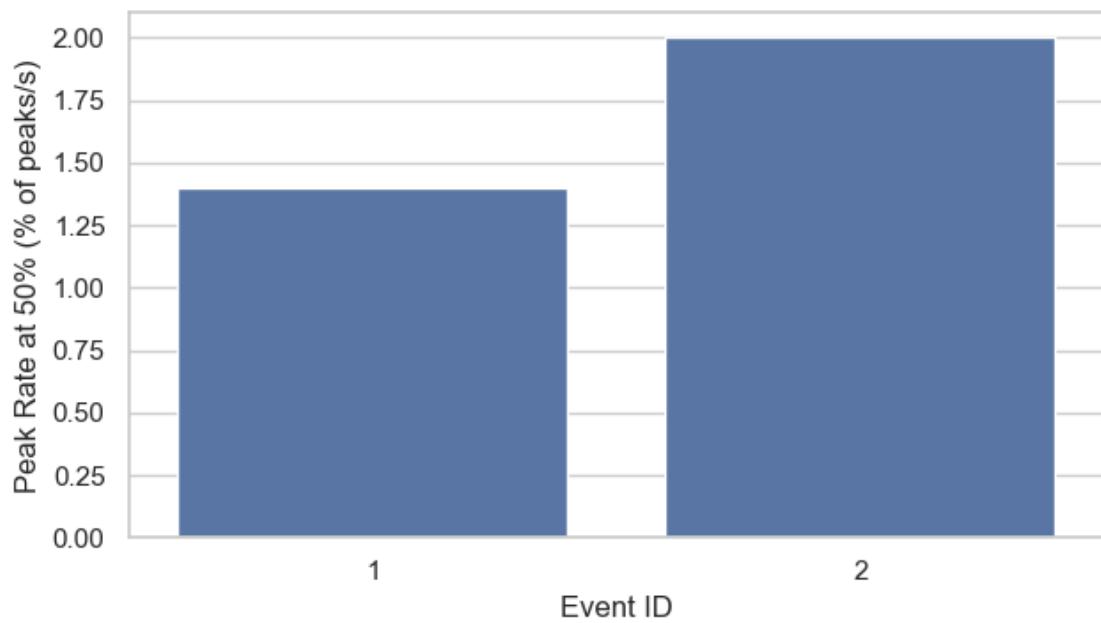


```
[2025-08-27 14:53:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\events\event-growth-curve-2.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250501\\Output\\IS08\\events\\event-
growth-curve-2.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\\Mateo\\20250501\\Output\\IS08\\events\\event-growth-curve-2.png'
```

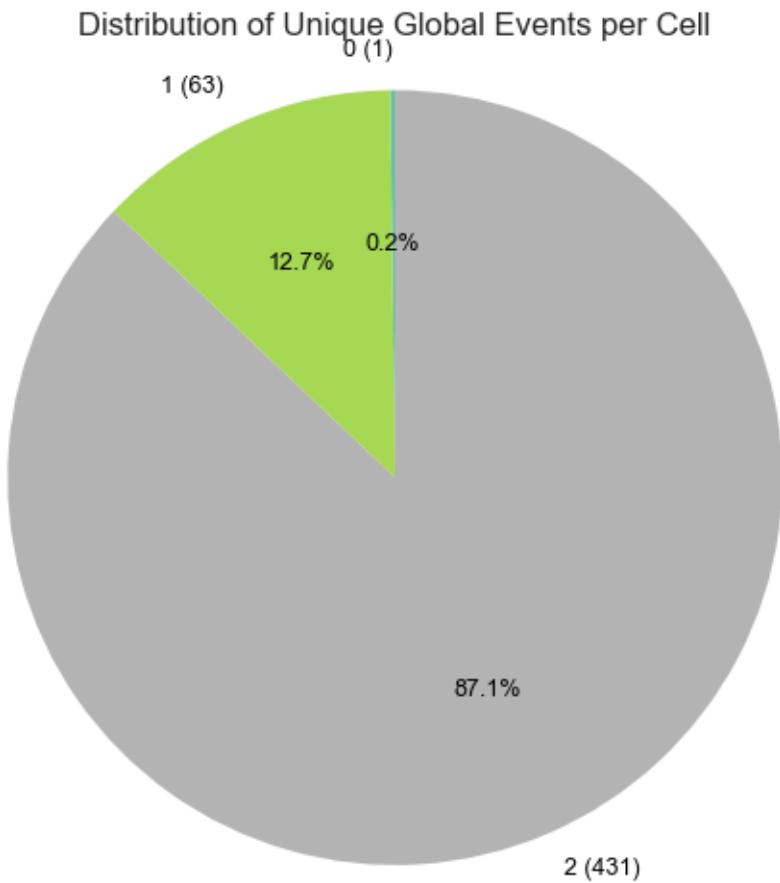
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

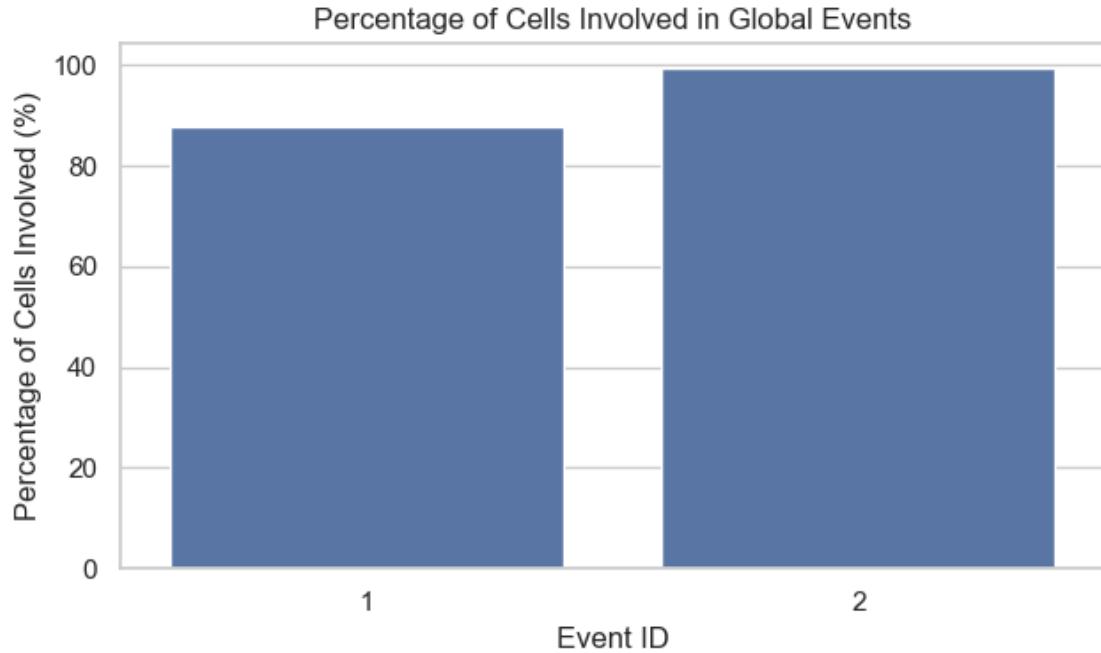


```
[2025-08-27 14:53:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250501\\\\Output\\\\IS08\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250501\Output\IS08\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [400.0]

1.2.6 Early peakers in the events

```

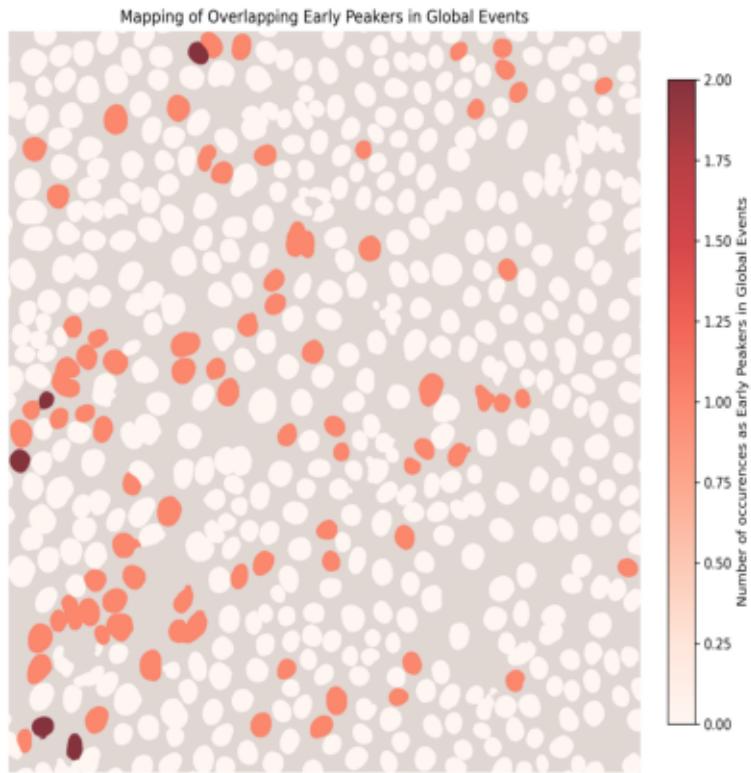
[2025-08-27 14:53:17] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__

```

```
    self._open()
File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

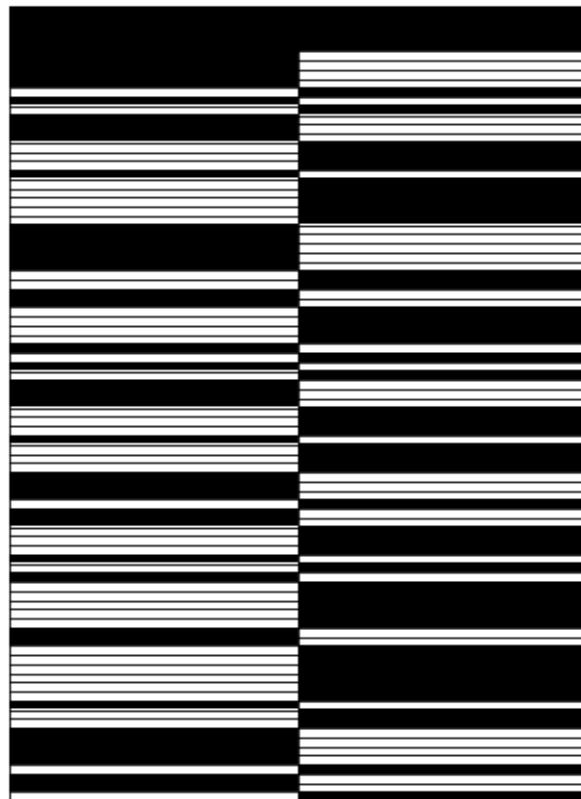
[2025-08-27 14:53:17] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



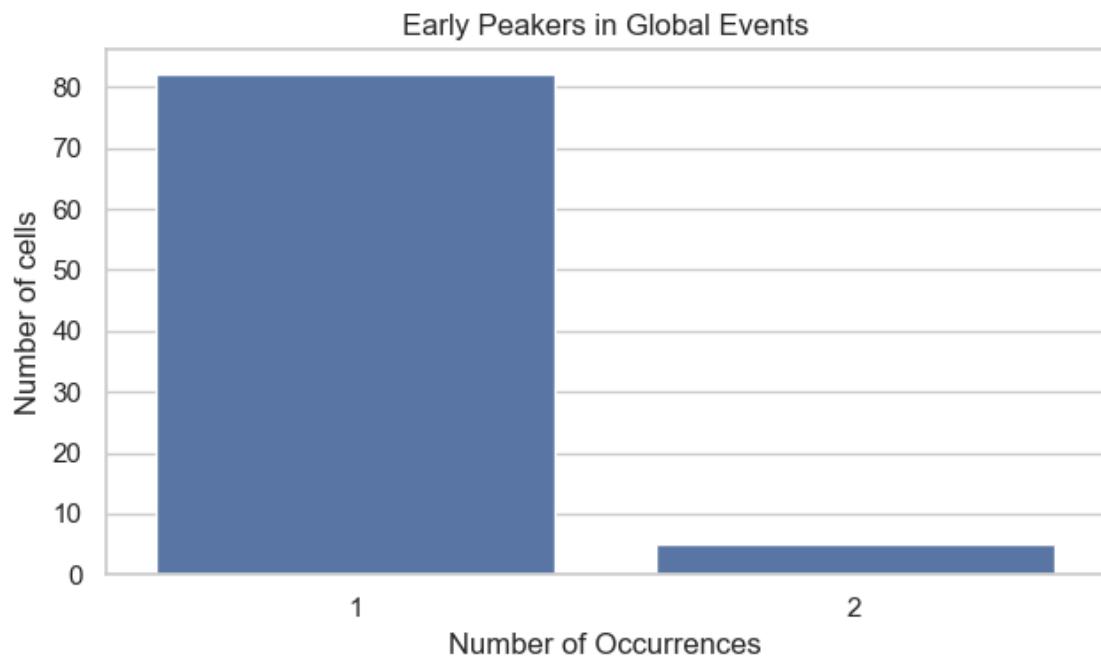
```
[2025-08-27 14:53:20] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 2 unique event IDs.
```

```
[2025-08-27 14:53:20] [INFO] calcium: Early peakers event-matrix: 87 cells x 2 events; black squares: 92
```

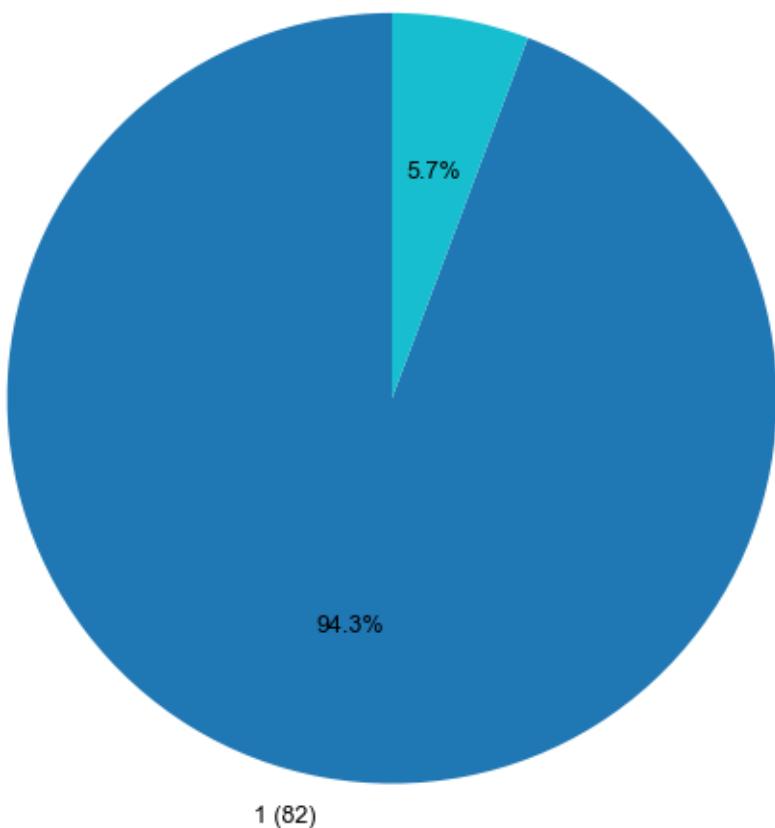


[2025-08-27 14:53:21] [INFO] calcium: Saved early peakers heatmap SVG to: early_peakers_heatmap.svg


```
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[1, 0],  
[1, 0],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1]])
```



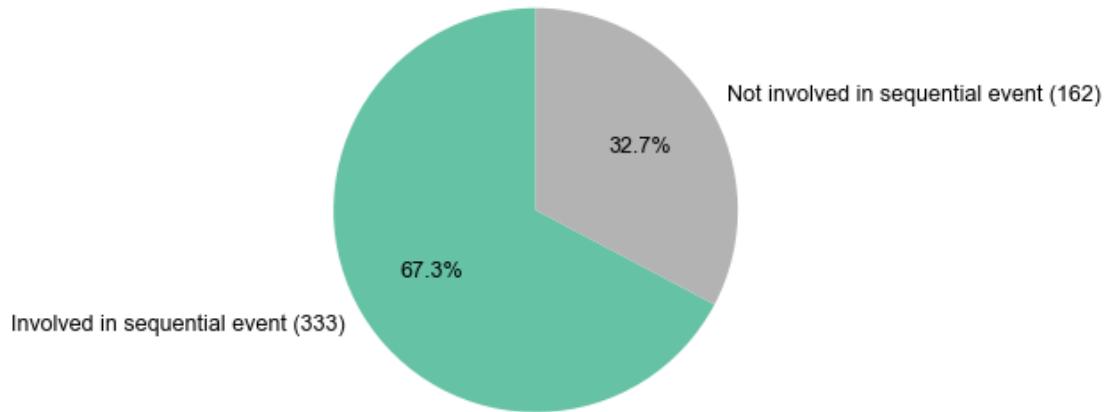
Distribution of Early Peakers in Global Events
2 (5)



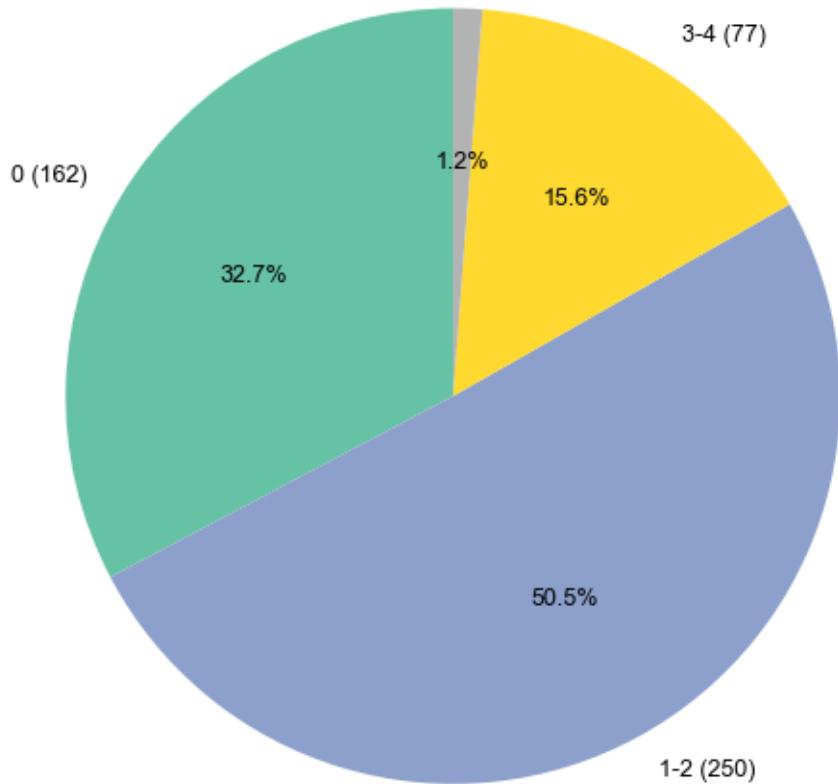
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

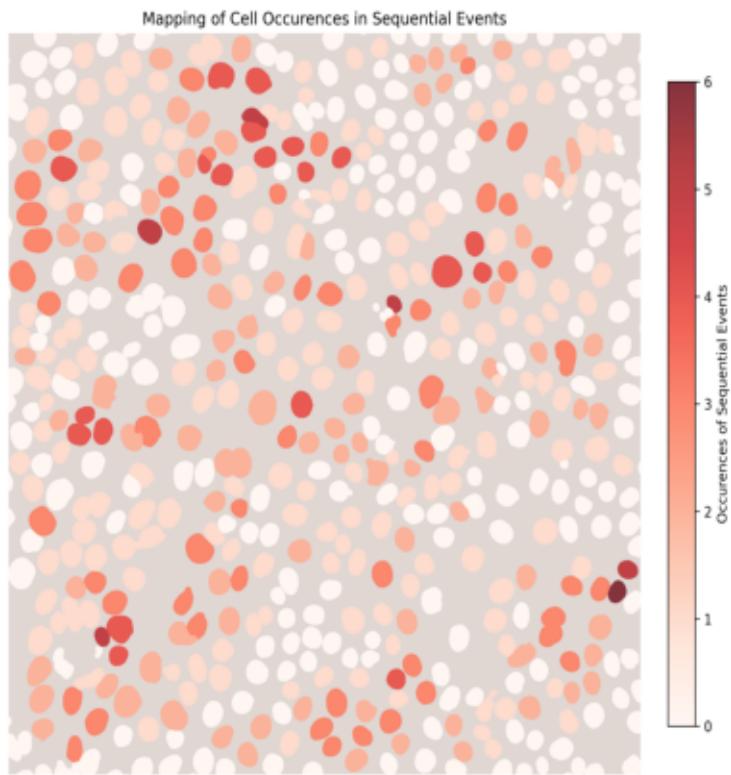
Distribution of Cells Involved in Sequential Events



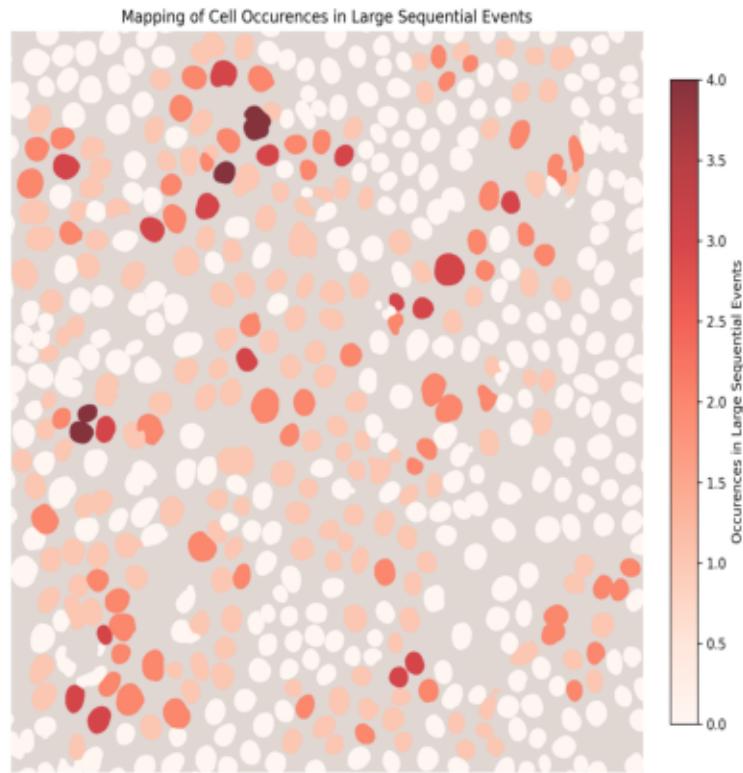
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (6)



Cell Mapping with Occurrences in Sequential Events Overlay

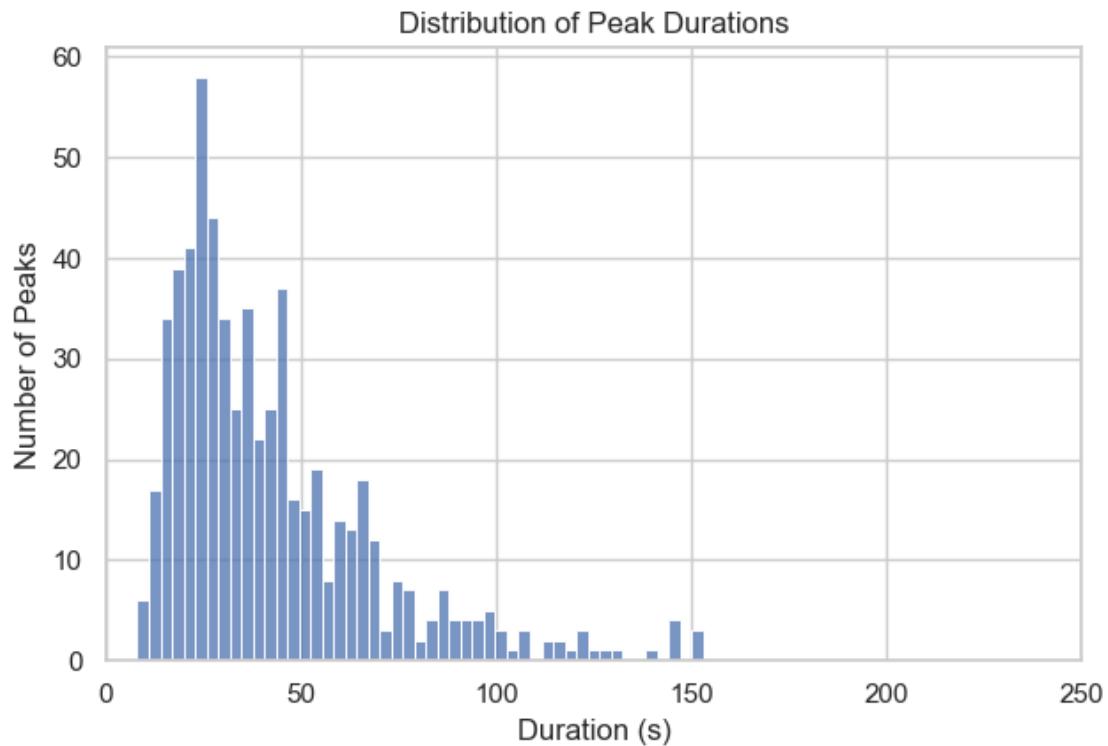


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



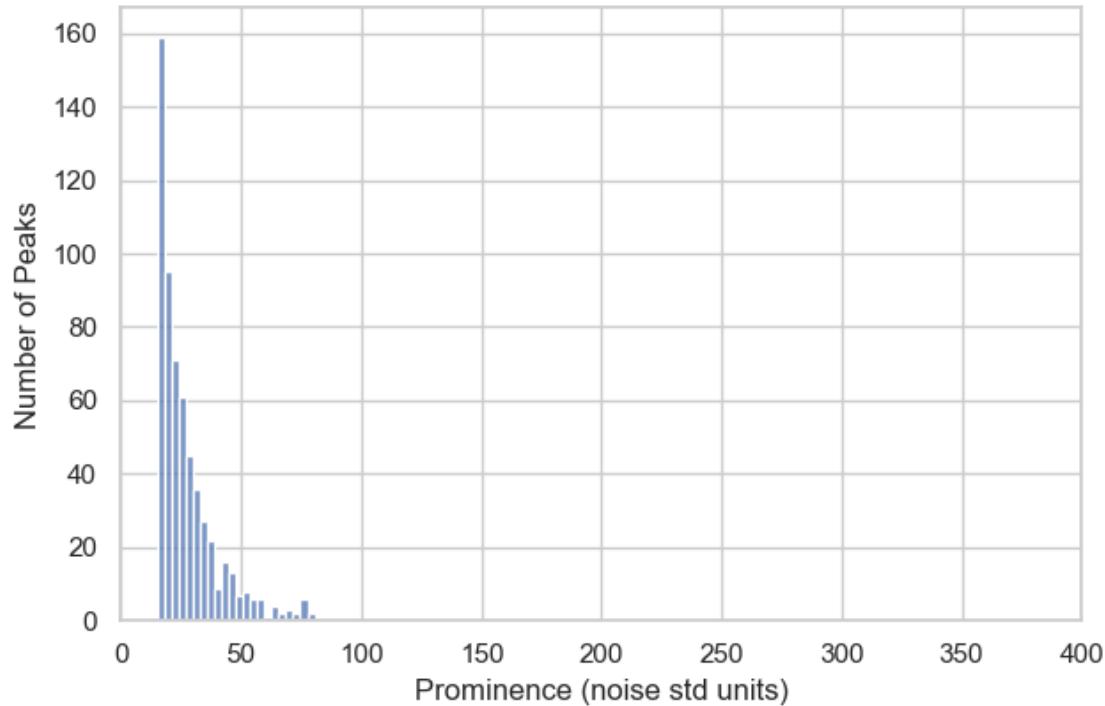
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:53:28] [INFO] calcium: plot_histogram: removed 13 outliers out of 619 on 'Duration (s)' (lower=-22.5, upper=163.5)
```

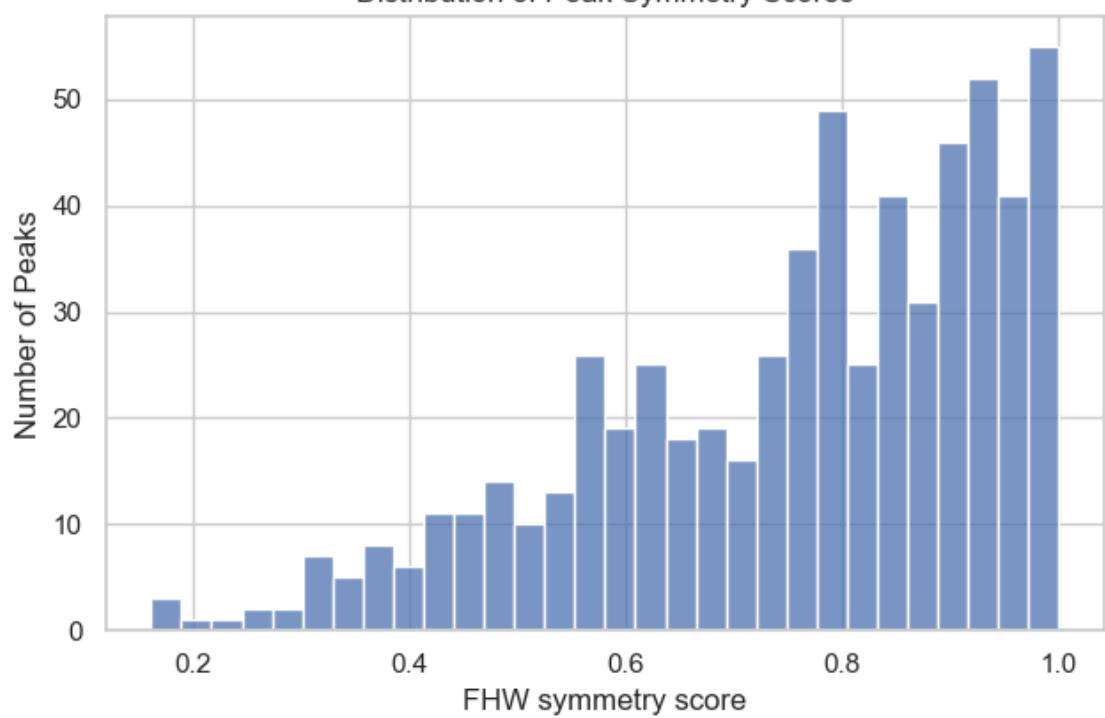


```
[2025-08-27 14:53:28] [INFO] calcium: plot_histogram: removed 18 outliers out of 619 on 'Prominence (noise std units)' (lower=-3.925, upper=83.375)
```

Distribution of Peak Prominences

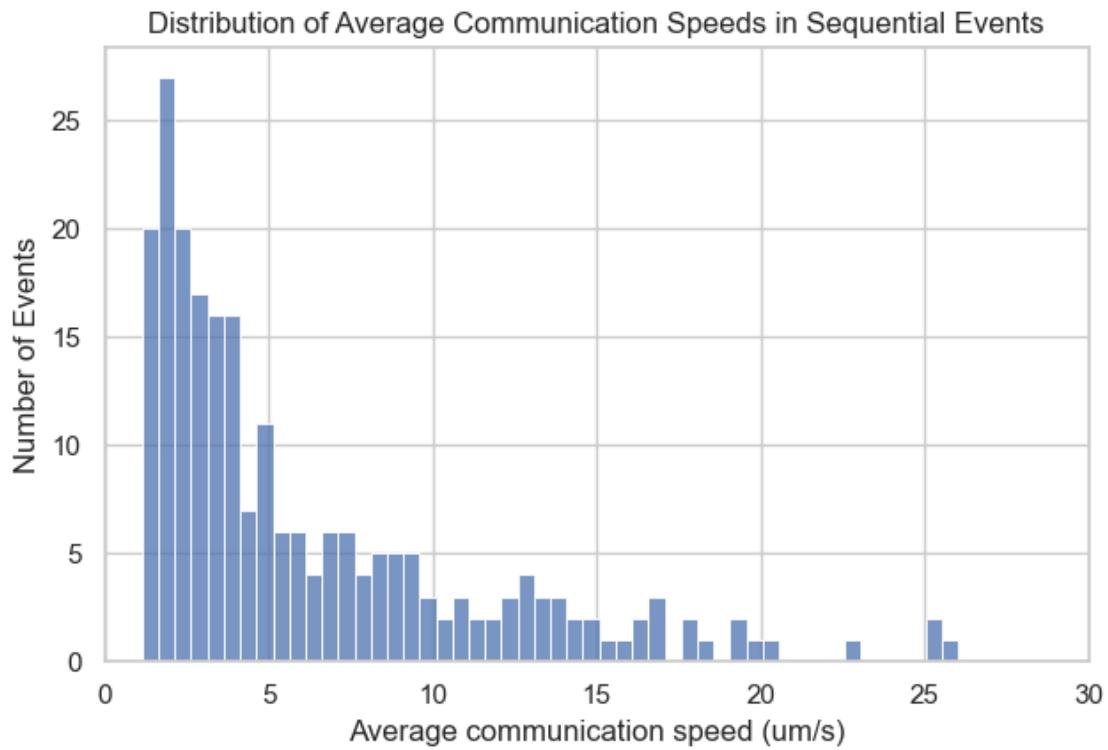


Distribution of Peak Symmetry Scores



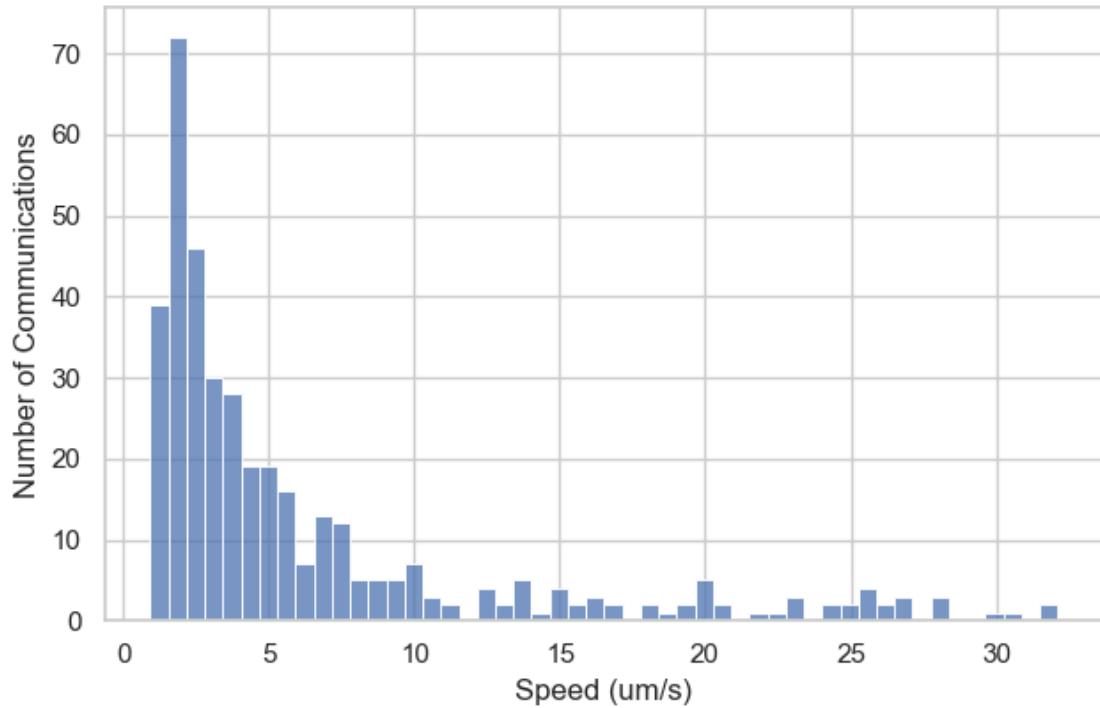
1.3.3 Cell-cell communication speed

[2025-08-27 14:53:29] [INFO] calcium: plot_histogram: removed 1 outliers out of 229 on 'Average communication speed (um/s)' (lower=-16.24, upper=27.3)

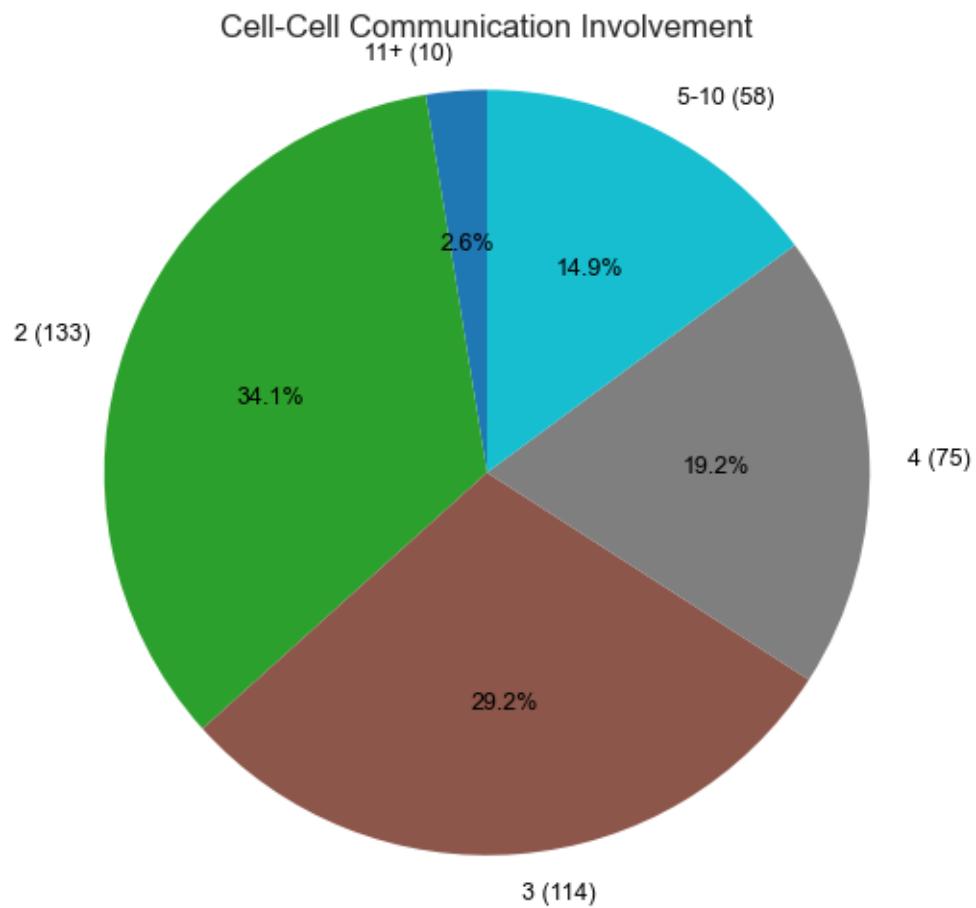


[2025-08-27 14:53:30] [INFO] calcium: plot_histogram: removed 2 outliers out of 390 on 'Speed (um/s)' (lower=-13.727, upper=33.703)

Distribution of Cell-Cell Communication Speeds

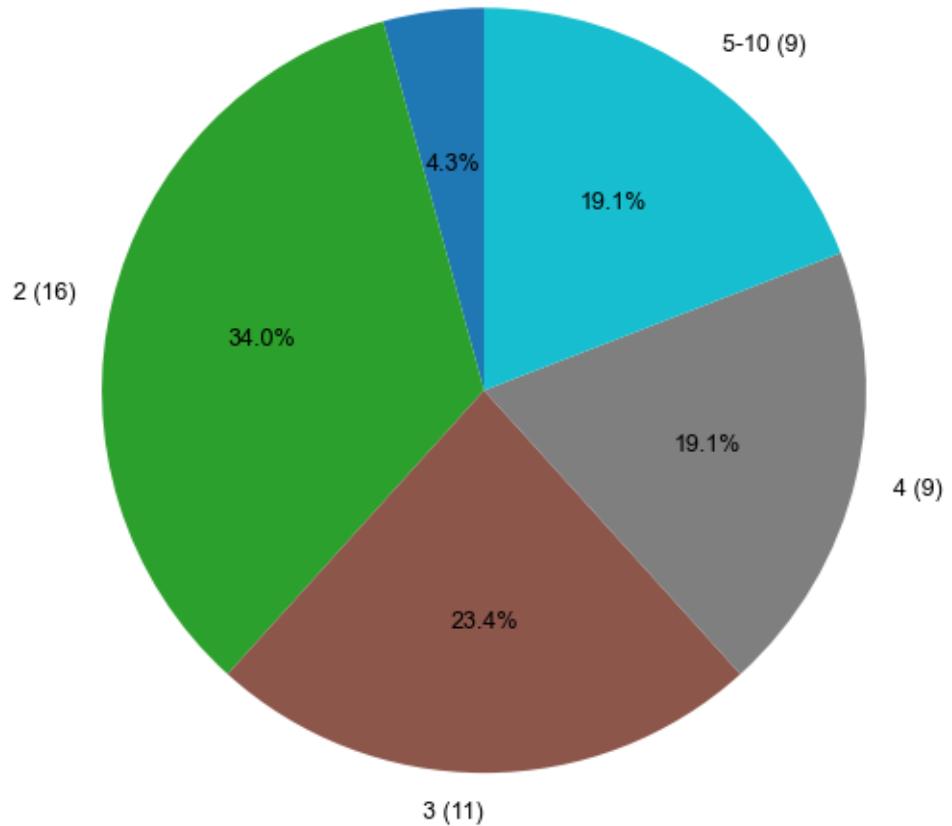


1.3.4 Double distribution in cell-cell communication speeds



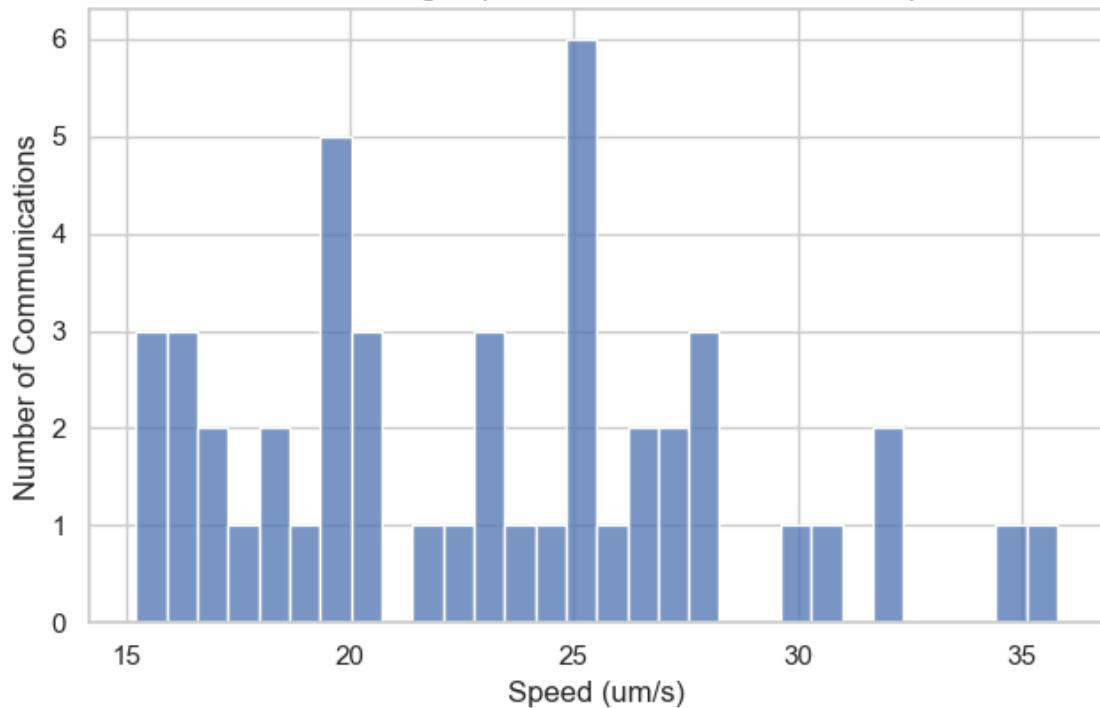
High Speed Cell-Cell Communication Involvement

11+ (2)



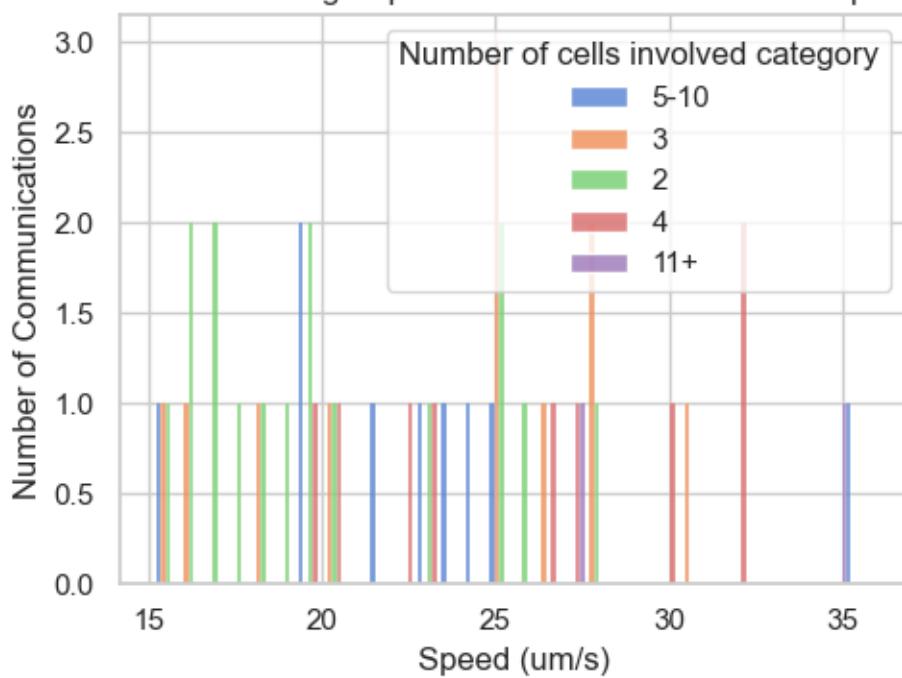
```
[2025-08-27 14:53:32] [INFO] calcium: plot_histogram: removed 0 outliers out of  
47 on 'Speed (um/s)' (lower=-1.97, upper=47.66)
```

Distribution of High Speed Cell-Cell Communication Speeds

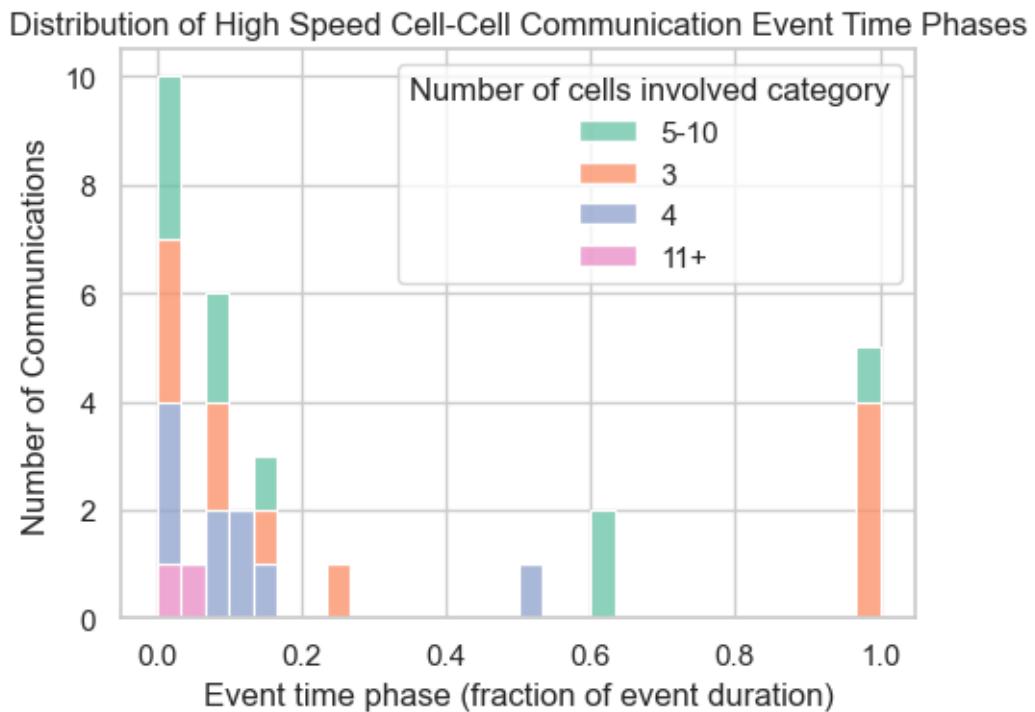


```
[2025-08-27 14:53:32] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 47 on 'Speed (um/s)' (lower=-1.97, upper=47.66)
```

Distribution of High Speed Cell-Cell Communication Speeds

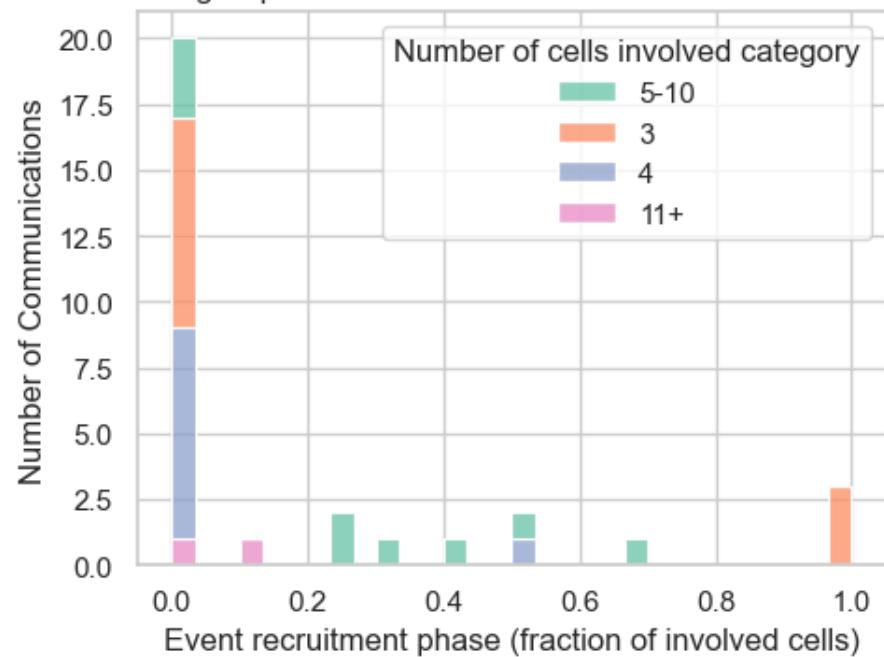


[2025-08-27 14:53:33] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 31 on 'Event time phase (fraction of event duration)' (lower=-1.125, upper=1.5)

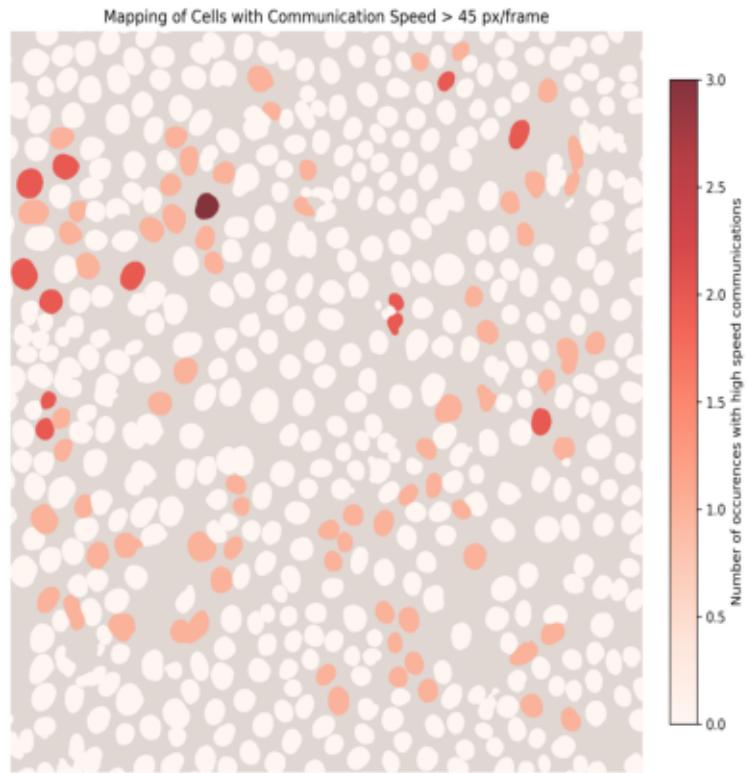


[2025-08-27 14:53:34] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 31 on 'Event recruitment phase (fraction of involved cells)' (lower=-0.87, upper=1.16)

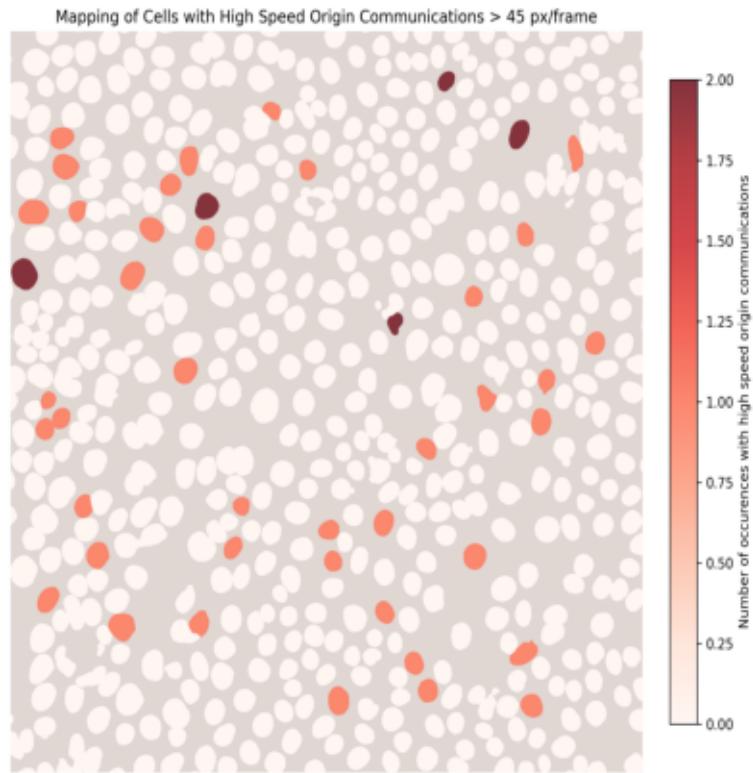
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
2	3015641225040	4	196	2
3	3015506571712	4	196	2
6	3015477177808	5	659	1
17	3015506565664	9	508	3
20	3015506561248	10	253	4
25	3015506566624	11	255	2
26	3015506573440	12	293	3
30	3015506565088	13	275	0
33	3015506572912	15	510	2
34	3015506566240	15	529	1
35	3015506569552	15	522	1
38	3015506573152	16	289	0

41	3015506571376	17	749	2
45	3015506563216	18	353	2
53	3015506574640	18	333	2
56	3015506574784	20	492	2
58	3015506567872	21	653	3
61	3015506571616	22	692	4
64	3015506563840	23	699	1
65	3015506572672	24	790	5
66	3015506571328	25	778	0
75	3015506571904	31	253	3
88	3015506560192	38	231	3
106	3015506572096	51	282	0
125	3015506559184	63	309	3
128	3015506574928	65	341	4
130	3015506563792	66	333	6
137	3015506564656	72	356	1
140	3015506574352	73	336	3
171	3015506572480	91	360	5
172	3015506572288	92	395	5
180	3015506570080	98	392	4
188	3015506570224	105	392	1
202	3015506568544	114	409	5
210	3015506568016	119	452	1
255	3015506563360	149	524	4
260	3015506562400	153	550	2
261	3015506562496	154	606	3
266	3015506561440	156	631	2
269	3015506562256	157	624	1
277	3015506561392	159	608	1
281	3015506561680	162	654	2
284	3015506560672	165	650	3
301	3015506567104	175	715	0
322	3015506562112	189	741	3
328	3015506560288	194	718	0
377	3015504476384	220	796	7

Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
2	179	2	221.0	221.0
3	160	2	221.0	222.0
6	646	1	258.0	258.0
17	518	2	329.0	329.0
20	306	2	1352.0	1352.0
25	289	1	226.0	226.0
26	334	0	203.0	203.0
30	308	0	178.0	178.0
33	529	1	179.0	180.0
34	551	0	180.0	180.0
35	510	2	179.0	179.0

38	307	0	17.0	17.0
41	731	2	260.0	260.0
45	395	2	240.0	240.0
53	343	3	237.0	238.0
56	524	2	277.0	277.0
58	648	2	969.0	969.0
61	698	3	1313.0	1313.0
64	710	2	190.0	190.0
65	762	3	1238.0	1238.0
66	768	2	163.0	163.0
75	210	4	933.0	935.0
88	192	3	811.0	812.0
106	254	0	23.0	24.0
125	333	5	917.0	918.0
128	307	5	771.0	772.0
130	298	5	1283.0	1284.0
137	329	1	287.0	288.0
140	354	2	300.0	301.0
171	380	3	1316.0	1317.0
172	382	3	906.0	908.0
180	413	6	1231.0	1232.0
188	413	2	211.0	212.0
202	442	4	1458.0	1459.0
210	464	1	177.0	178.0
255	549	5	901.0	902.0
260	585	0	256.0	257.0
261	584	2	702.0	703.0
266	617	4	1031.0	1032.0
269	596	1	239.0	240.0
277	621	2	913.0	914.0
281	610	3	1269.0	1271.0
284	649	5	1290.0	1291.0
301	675	0	15.0	17.0
322	721	4	1345.0	1346.0
328	720	0	13.0	16.0
377	806	3	1317.0	1319.0

	Duration (s)	Distance (um)	Speed (um/s)	\
2	0.0	24.53	24.53	
3	1.0	23.14	23.14	
6	0.0	15.60	15.60	
17	0.0	30.82	30.82	
20	0.0	35.79	35.79	
25	0.0	19.40	19.40	
26	0.0	25.24	25.24	
30	0.0	20.68	20.68	
33	1.0	19.67	19.67	
34	0.0	20.01	20.01	

35	0.0	15.90	15.90
38	0.0	30.18	30.18
41	0.0	20.70	20.70
45	0.0	34.74	34.74
53	1.0	26.93	26.93
56	0.0	27.95	27.95
58	0.0	24.06	24.06
61	0.0	22.45	22.45
64	0.0	19.79	19.79
65	0.0	20.24	20.24
66	0.0	25.41	25.41
75	2.0	36.86	18.43
88	1.0	23.27	23.27
106	1.0	19.20	19.20
125	1.0	32.12	32.12
128	1.0	19.72	19.72
130	1.0	26.53	26.53
137	1.0	24.87	24.87
140	1.0	16.18	16.18
171	1.0	17.93	17.93
172	2.0	36.02	18.01
180	1.0	28.10	28.10
188	1.0	28.10	28.10
202	1.0	26.04	26.04
210	1.0	22.94	22.94
255	1.0	25.28	25.28
260	1.0	25.38	25.38
261	1.0	15.22	15.22
266	1.0	21.66	21.66
269	1.0	27.12	27.12
277	1.0	32.10	32.10
281	2.0	33.20	16.60
284	1.0	25.35	25.35
301	2.0	34.11	17.06
322	1.0	26.25	26.25
328	3.0	48.29	16.10
377	2.0	31.97	15.99

	Event time phase (fraction of event duration) \	
2		0.00
3		0.14
6		0.00
17		0.00
20		0.62
25		NaN
26		0.00
30		0.00
33		0.07

34	0.07
35	0.00
38	0.00
41	0.00
45	0.06
53	0.02
56	1.00
58	1.00
61	0.00
64	NaN
65	NaN
66	NaN
75	0.25
88	0.14
106	NaN
125	0.50
128	0.12
130	0.09
137	1.00
140	1.00
171	NaN
172	NaN
180	1.00
188	NaN
202	NaN
210	NaN
255	NaN
260	0.07
261	NaN
266	0.61
269	0.12
277	0.07
281	NaN
284	0.14
301	NaN
322	0.08
328	NaN
377	NaN

	Event recruitment phase (fraction of involved cells)	dataset	\
2	0.00	20250501_IS08	
3	0.33	20250501_IS08	
6	0.00	20250501_IS08	
17	0.00	20250501_IS08	
20	0.40	20250501_IS08	
25	NaN	20250501_IS08	
26	0.00	20250501_IS08	
30	0.00	20250501_IS08	

33	0.25	20250501_IS08
34	0.25	20250501_IS08
35	0.00	20250501_IS08
38	0.00	20250501_IS08
41	0.00	20250501_IS08
45	0.11	20250501_IS08
53	0.00	20250501_IS08
56	0.00	20250501_IS08
58	0.67	20250501_IS08
61	0.00	20250501_IS08
64	NaN	20250501_IS08
65	NaN	20250501_IS08
66	NaN	20250501_IS08
75	0.00	20250501_IS08
88	0.00	20250501_IS08
106	NaN	20250501_IS08
125	0.50	20250501_IS08
128	0.00	20250501_IS08
130	0.00	20250501_IS08
137	1.00	20250501_IS08
140	1.00	20250501_IS08
171	NaN	20250501_IS08
172	NaN	20250501_IS08
180	1.00	20250501_IS08
188	NaN	20250501_IS08
202	NaN	20250501_IS08
210	NaN	20250501_IS08
255	NaN	20250501_IS08
260	0.00	20250501_IS08
261	NaN	20250501_IS08
266	0.50	20250501_IS08
269	0.00	20250501_IS08
277	0.00	20250501_IS08
281	NaN	20250501_IS08
284	0.00	20250501_IS08
301	NaN	20250501_IS08
322	0.00	20250501_IS08
328	NaN	20250501_IS08
377	NaN	20250501_IS08

Number of cells involved	category	Speed category
2	5-10	High speed
3	5-10	High speed
6	3	High speed
17	3	High speed
20	5-10	High speed
25	2	High speed
26	5-10	High speed

30	3	High speed
33	5-10	High speed
34	5-10	High speed
35	5-10	High speed
38	4	High speed
41	4	High speed
45	11+	High speed
53	11+	High speed
56	3	High speed
58	5-10	High speed
61	4	High speed
64	2	High speed
65	2	High speed
66	2	High speed
75	3	High speed
88	4	High speed
106	2	High speed
125	4	High speed
128	4	High speed
130	3	High speed
137	3	High speed
140	3	High speed
171	2	High speed
172	2	High speed
180	3	High speed
188	2	High speed
202	2	High speed
210	2	High speed
255	2	High speed
260	3	High speed
261	2	High speed
266	5-10	High speed
269	4	High speed
277	4	High speed
281	2	High speed
284	3	High speed
301	2	High speed
322	4	High speed
328	2	High speed
377	2	High speed

Speed category	High speed	Low speed
----------------	------------	-----------

Origin cell ID		
----------------	--	--

155	0	1
158	0	1
162	0	1
163	0	1
166	0	2

...
832	0	2	
834	0	3	
840	0	1	
841	0	1	
844	0	1	

[222 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
3	155	183.62	10.40	
5	158	390.00	11.05	
8	162	58.83	14.30	
9	163	149.50	14.62	
11	166	413.73	16.57	
..	
486	832	309.40	478.07	
487	834	255.12	480.03	
491	840	358.80	483.60	
492	841	188.50	485.55	
493	844	274.30	489.12	

	Number of peaks	Is active	Occurrences in global events	\
3	9	True	2	
5	6	True	2	
8	5	True	2	
9	3	True	2	
11	7	True	2	
..	
486	7	True	2	
487	5	True	2	
491	7	True	2	
492	4	True	2	
493	7	True	1	

	Occurrences in global events as early peaker	Early peaker event IDs	\
3	1	[1]	
5	1	[1]	
8	0	[]	
9	2	[1, 2]	
11	0	[]	
..	
486	0	[]	
487	0	[]	
491	0	[]	
492	0	[]	
493	0	[]	

```

Occurrences in sequential events \
3          2
5          2
8          1
9          1
11         1
..          ...
486         2
487         3
491         2
492         2
493         2

Occurrences in sequential events as origin \
3          1
5          1
8          1
9          0
11         1
..          ...
486         1
487         2
491         1
492         1
493         1

Occurrences in individual events  Peak frequency (Hz) Periodicity score \
3          3          0.0053      0.49
5          1          0.0035      0.56
8          2          0.0029      0.60
9          0          0.0018      0.74
11         4          0.0041      0.54
..          ...        ...
486         3          0.0041      0.57
487         0          0.0029      0.52
491         3          0.0041      0.66
492         0          0.0024      0.57
493         4          0.0041      0.54

Neighbor count    Neighbors (labels)      dataset \
3          4          [153,161,188,192] 20250501_IS08
5          3          [166,183,190]   20250501_IS08
8          4          [165,193,195,209] 20250501_IS08
9          4          [153,169,188,191] 20250501_IS08
11         5          [158,171,183,210,212] 20250501_IS08
..          ...
486         4          [805,814,822,845] 20250501_IS08
487         4          [790,817,822,844] 20250501_IS08

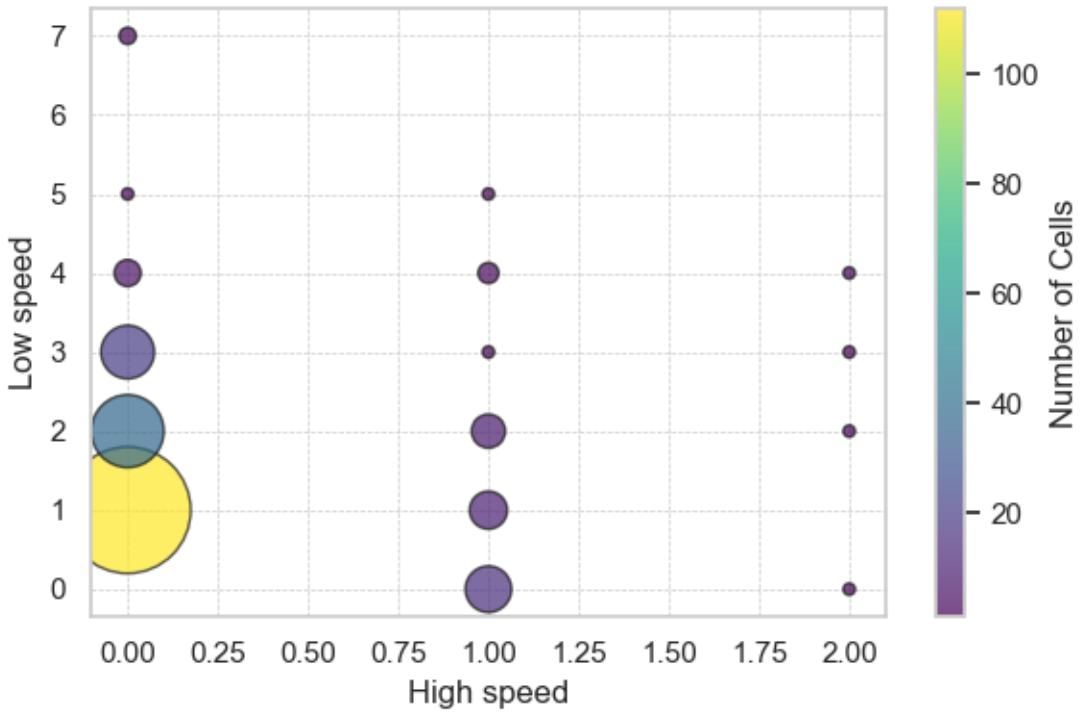
```

491	5	[812,814,821,837,845]	20250501_IS08
492	2	[813,824]	20250501_IS08
493	2	[822,834]	20250501_IS08

		Involved in sequential event Occurrences in sequential events category \	
3	Involved in sequential event		1-2
5	Involved in sequential event		1-2
8	Involved in sequential event		1-2
9	Involved in sequential event		1-2
11	Involved in sequential event		1-2
..
486	Involved in sequential event		1-2
487	Involved in sequential event		3-4
491	Involved in sequential event		1-2
492	Involved in sequential event		1-2
493	Involved in sequential event		1-2

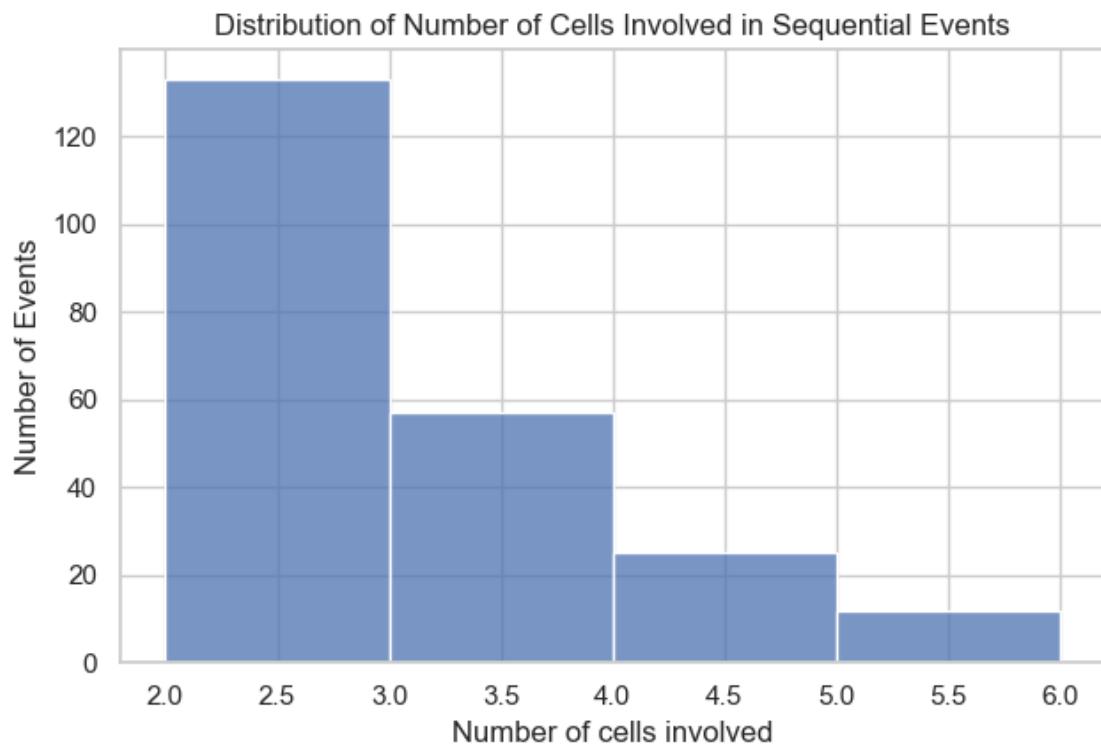
	High speed	Low speed
3	0.0	1.0
5	0.0	1.0
8	0.0	1.0
9	0.0	1.0
11	0.0	2.0
..
486	0.0	2.0
487	0.0	3.0
491	0.0	1.0
492	0.0	1.0
493	0.0	1.0

[219 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

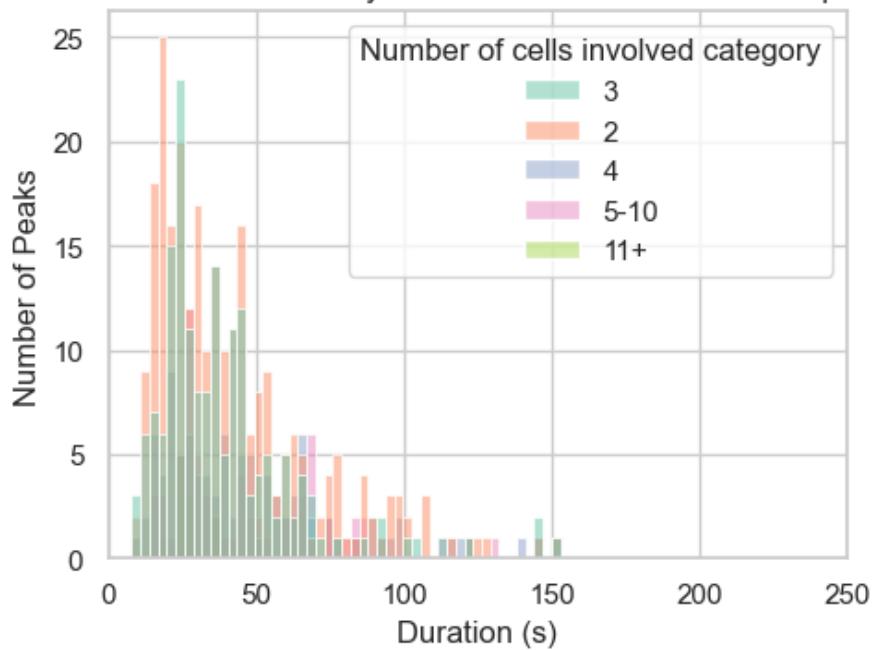
```
[2025-08-27 14:53:42] [INFO] calcium: plot_histogram: removed 2 outliers out of  
229 on 'Number of cells involved' (lower=-1, upper=6)
```



1.3.6 Influence of cell count per event on statistics

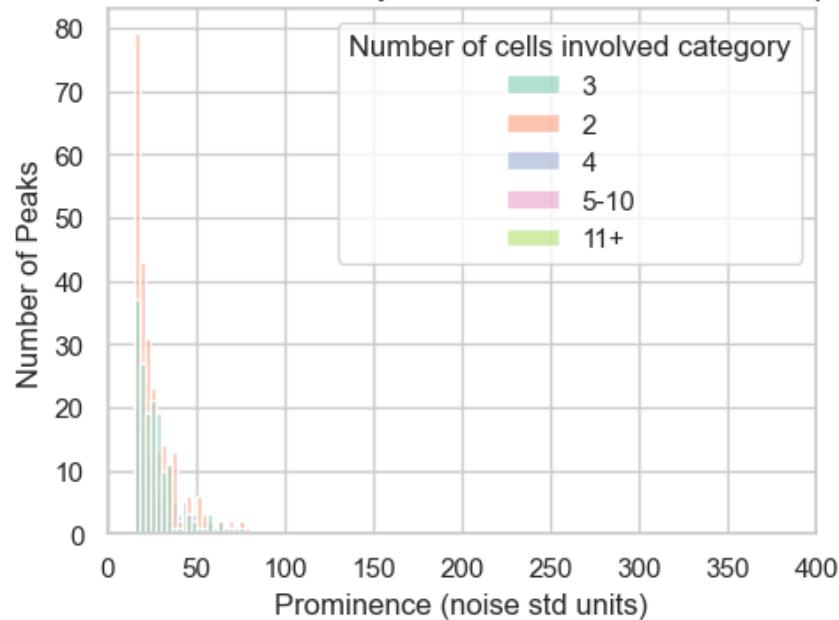
```
[2025-08-27 14:53:43] [INFO] calcium: plot_histogram_by_group: removed 13
outliers out of 619 on 'Duration (s)' (lower=-22.5, upper=163.5)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

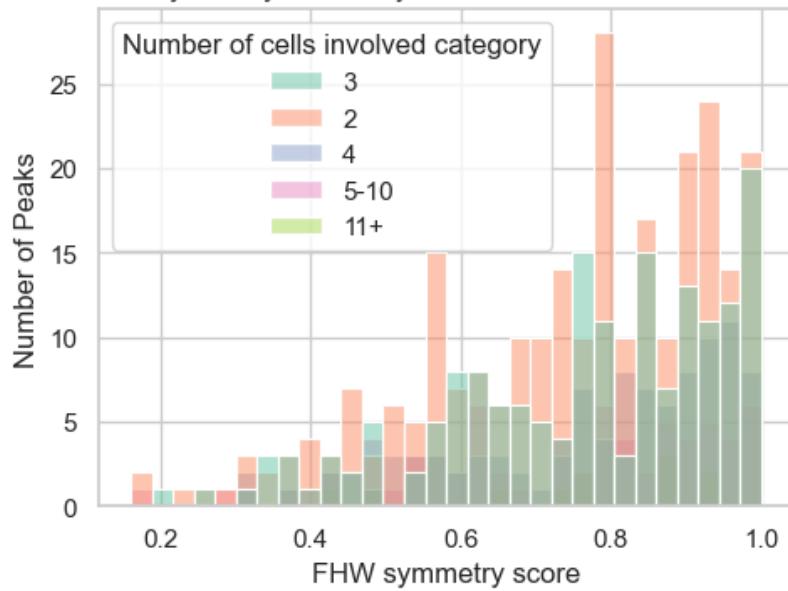


[2025-08-27 14:53:44] [INFO] calcium: plot_histogram_by_group: removed 18 outliers out of 619 on 'Prominence (noise std units)' (lower=-3.925, upper=83.375)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

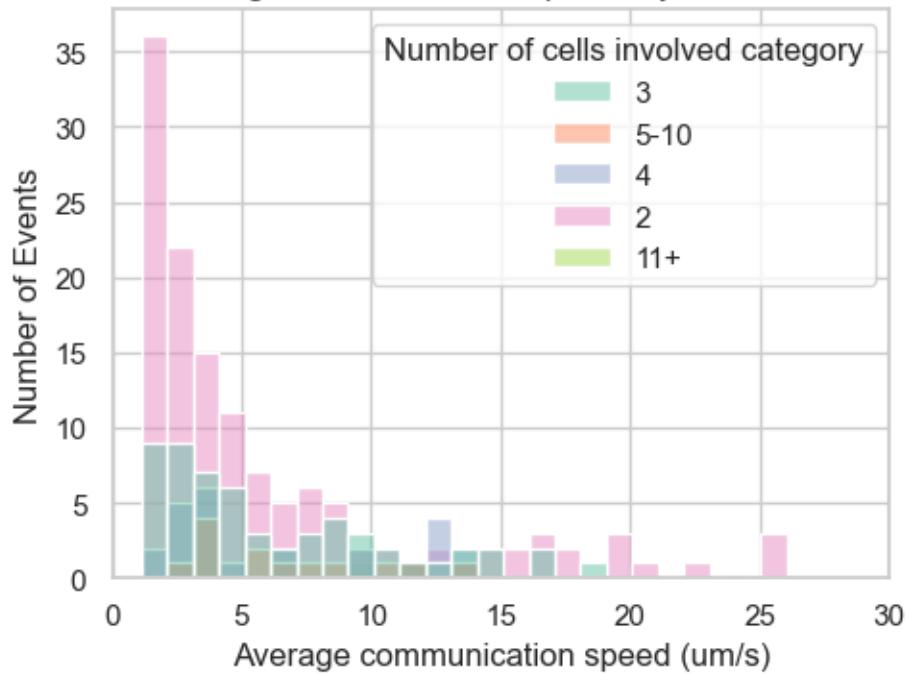


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



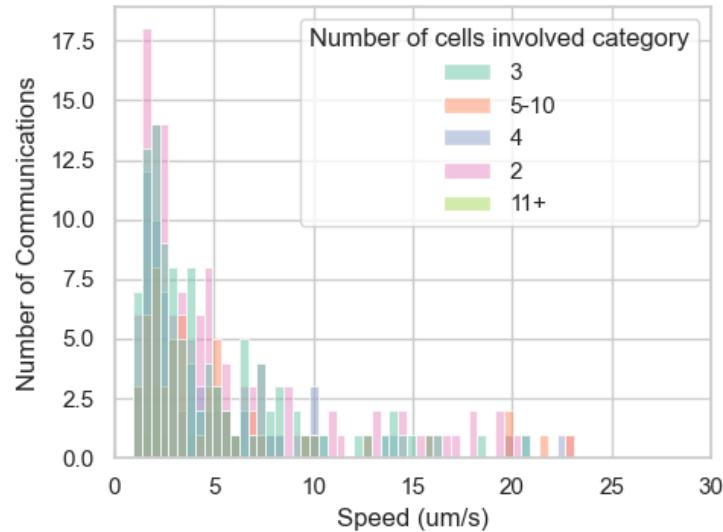
```
[2025-08-27 14:53:46] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 229 on 'Average communication speed (um/s)' (lower=-16.24, upper=27.3)
```

Distribution of Average Communication Speeds by Number of Cells Involved



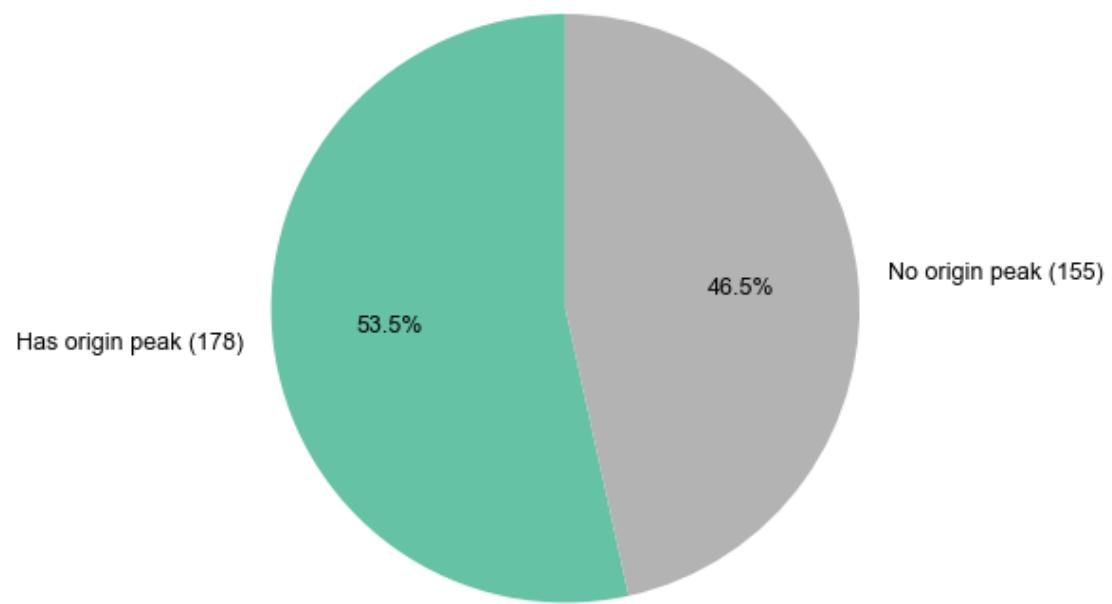
[2025-08-27 14:53:46] [INFO] calcium: plot_histogram_by_group: removed 23 outliers out of 390 on 'Speed (um/s)' (lower=-13.727, upper=23.162)

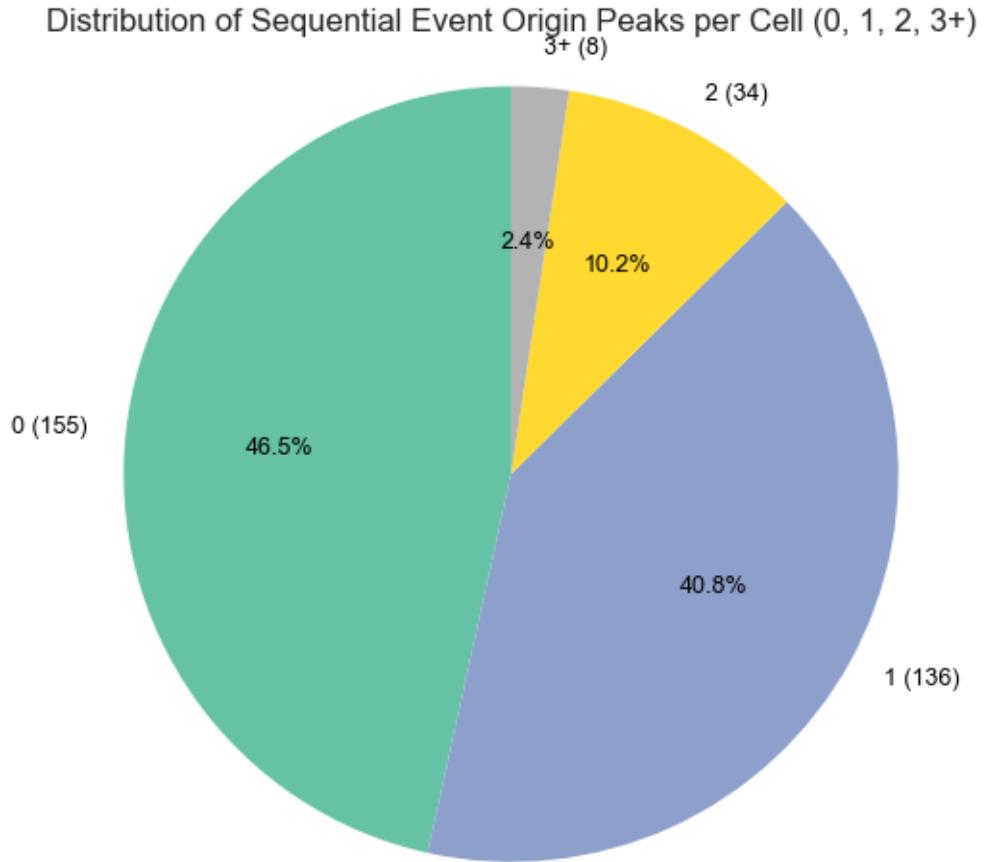
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

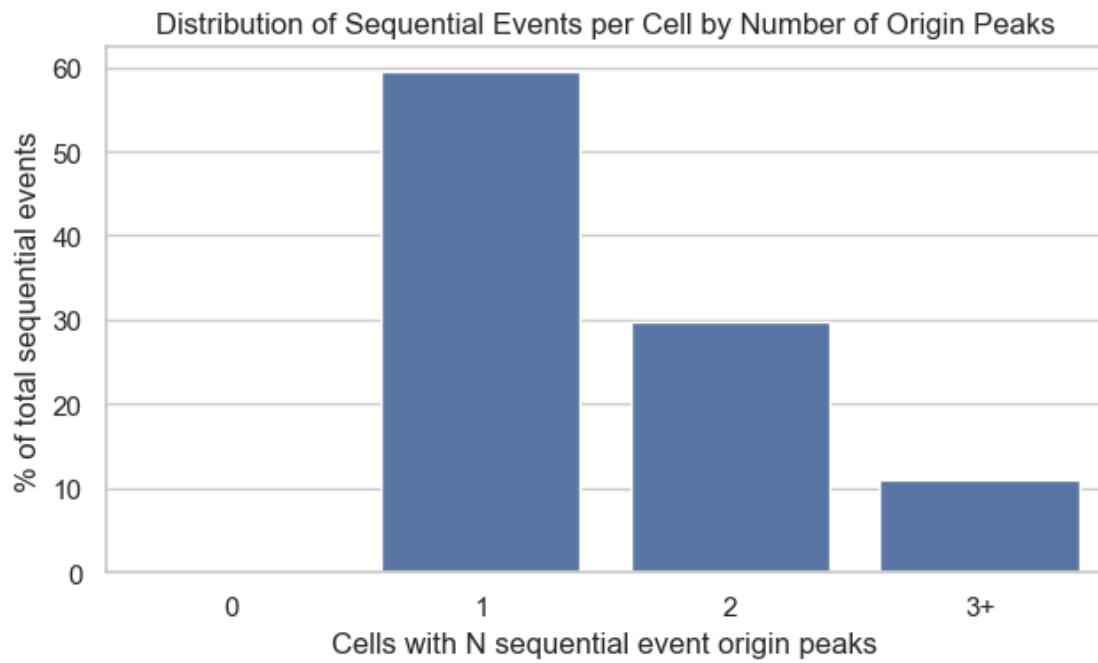
Distribution of Number of Sequential Event Origin Peaks per Cell





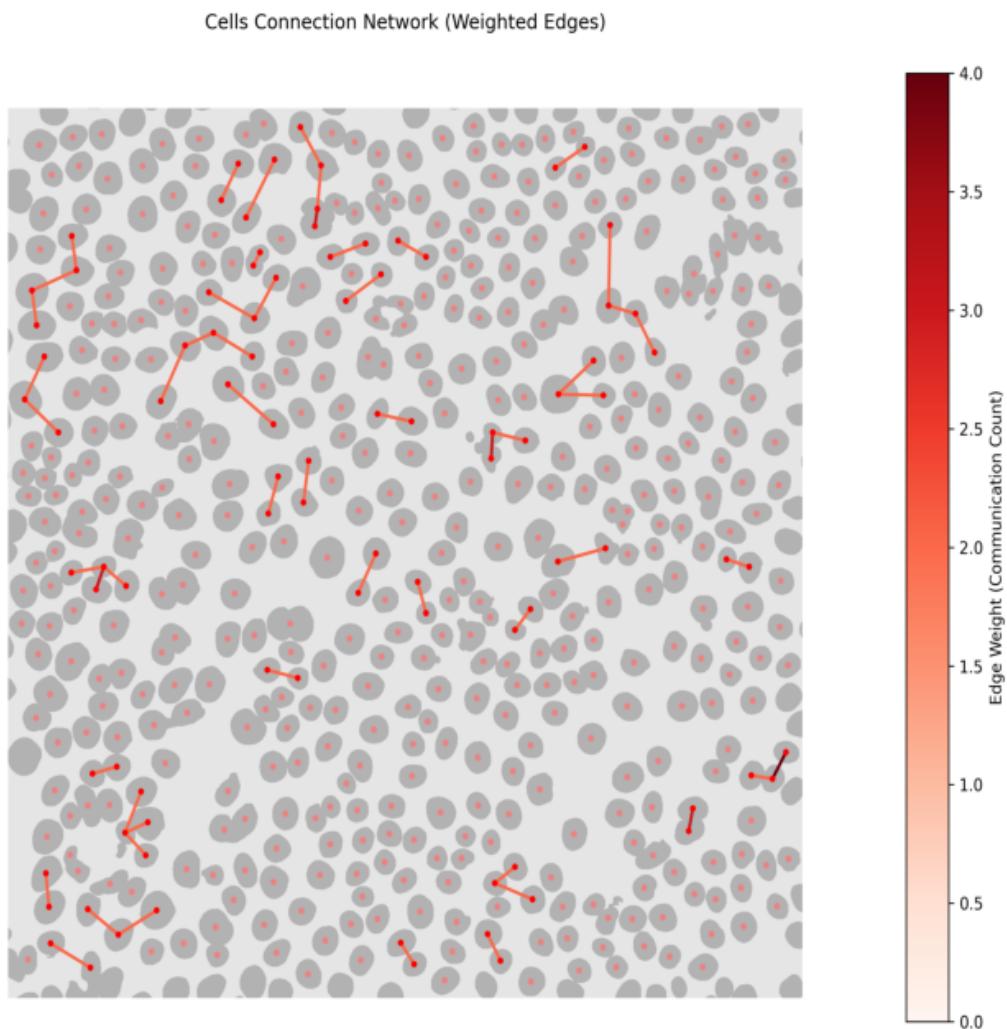
```
[2025-08-27 14:53:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250501\\Output\\IS08\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250501\\Output\\IS08\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'



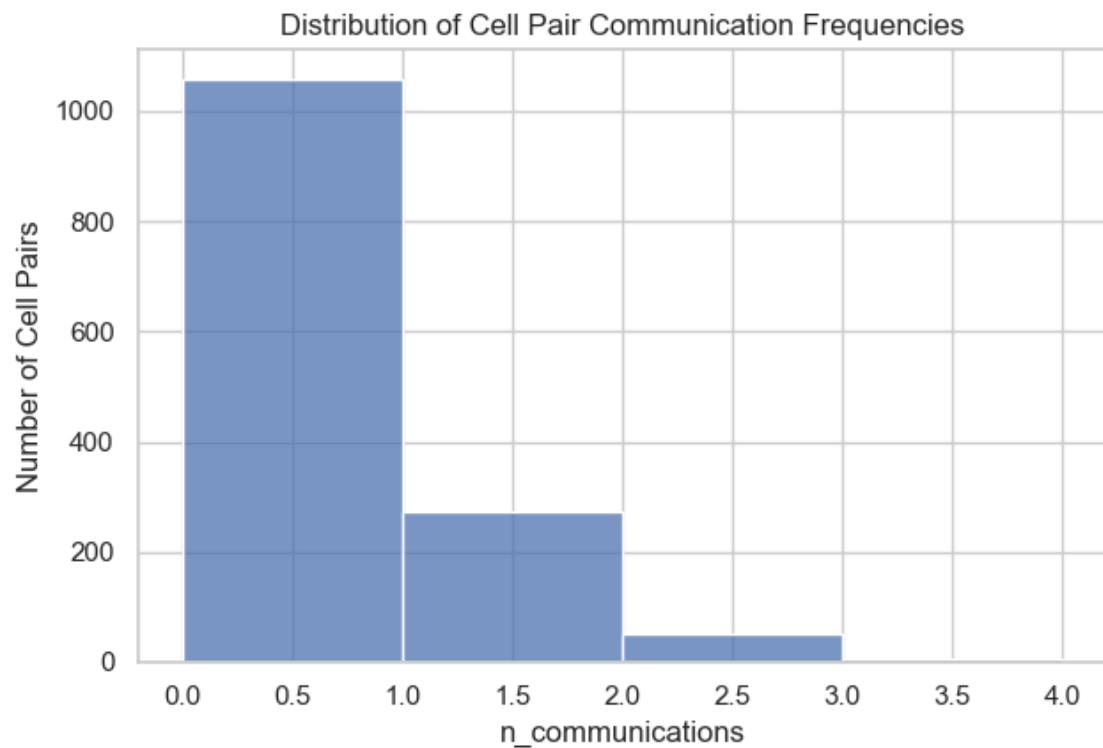
1.3.8 Connection network between cells

Cell Connection Network Graph



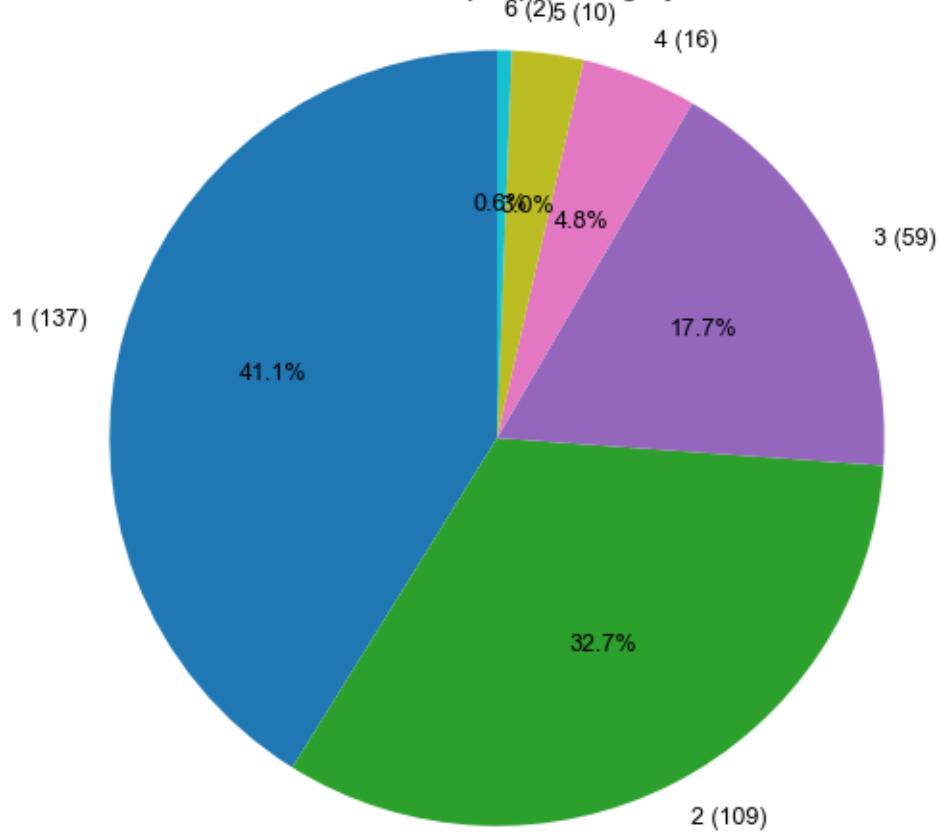
1.3.9 Pair/Trios with high communication networks

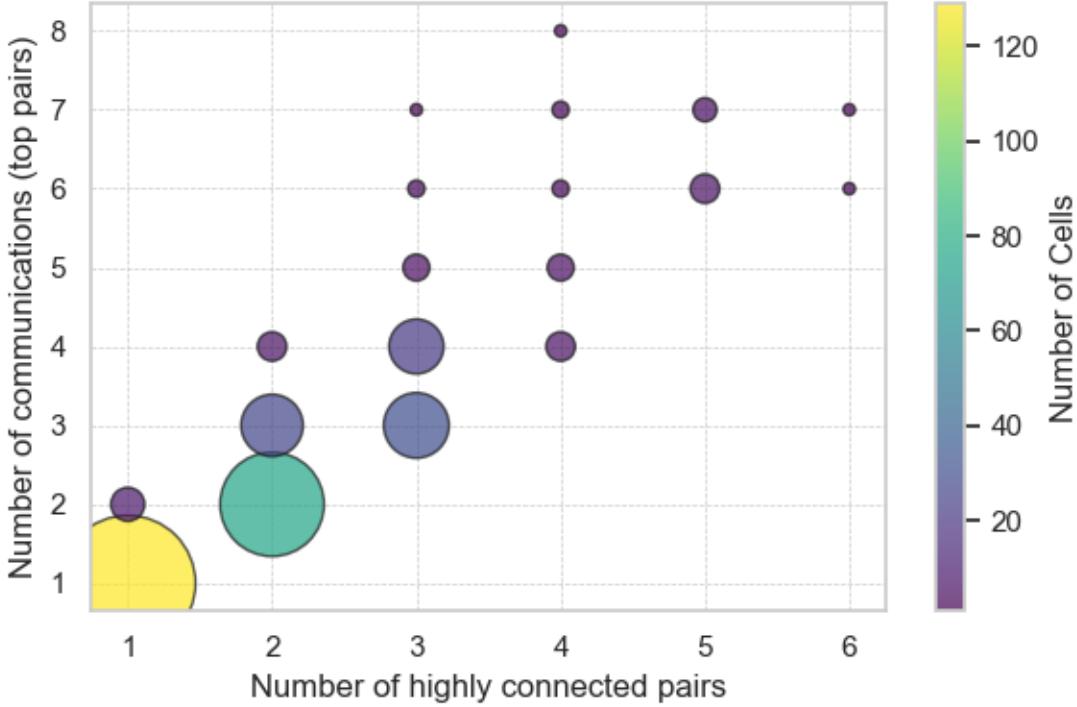
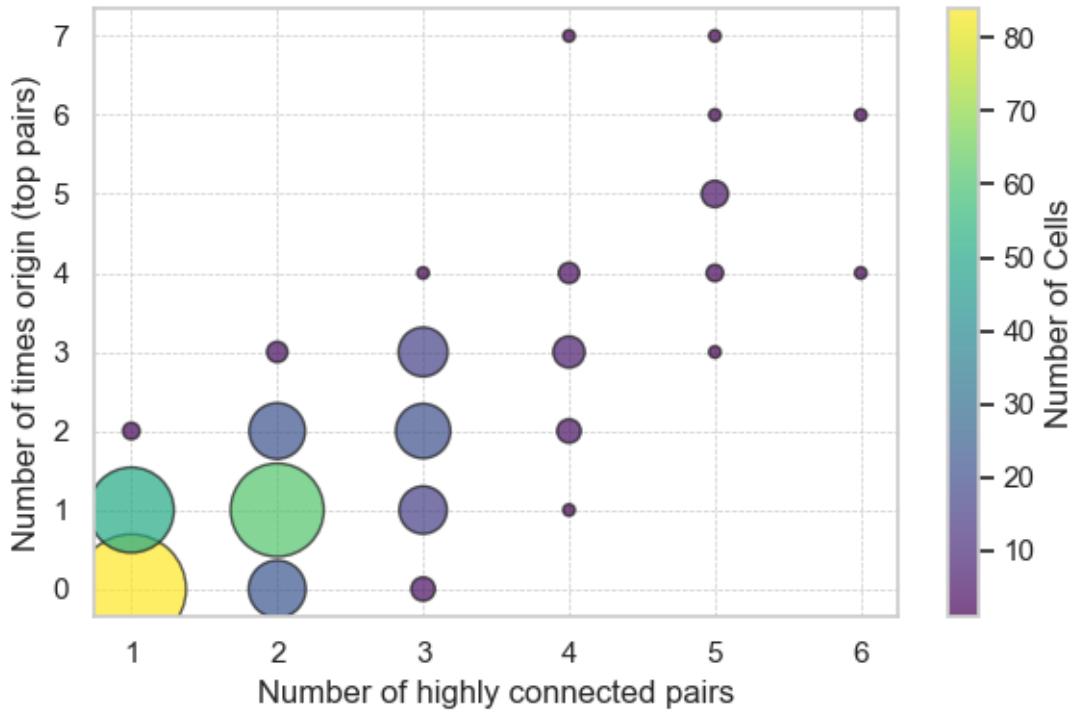
```
[2025-08-27 14:53:54] [INFO] calcium: build_neighbor_pair_stats: built 1387 pairs across 1 datasets (mean distance=24.02 um)
```

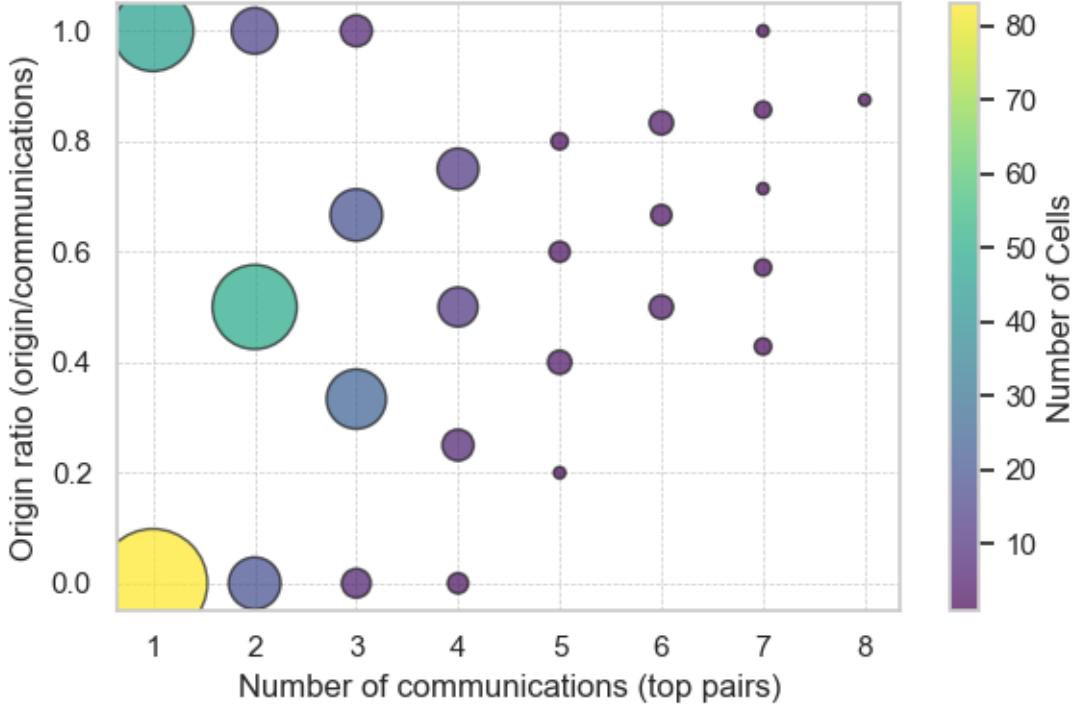
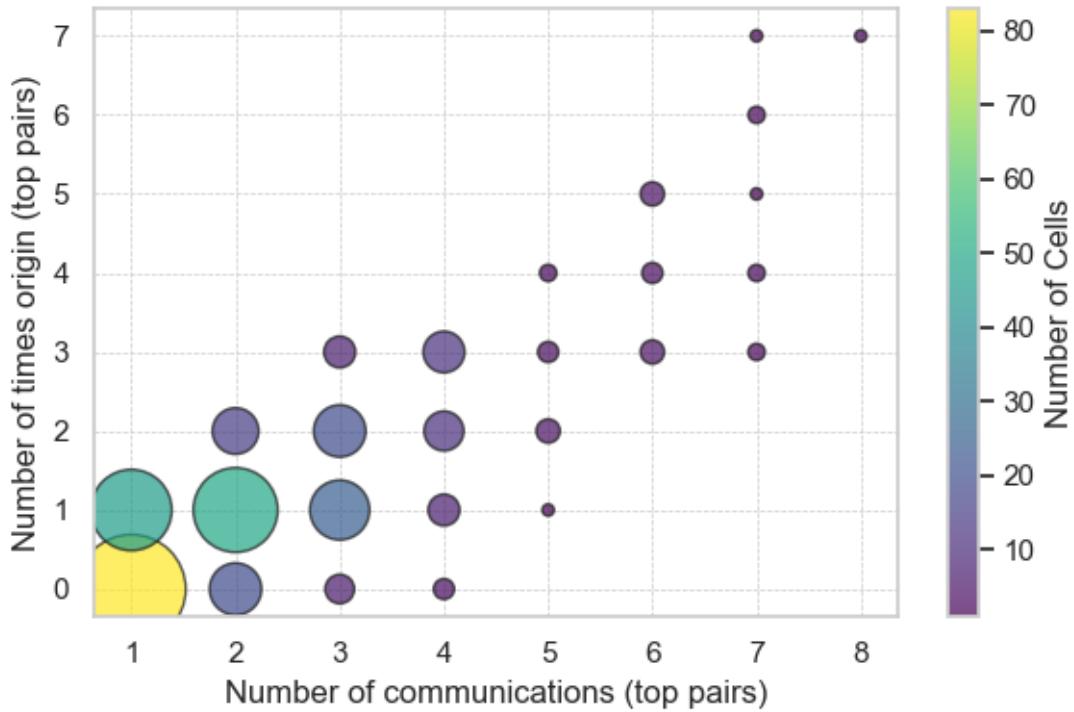


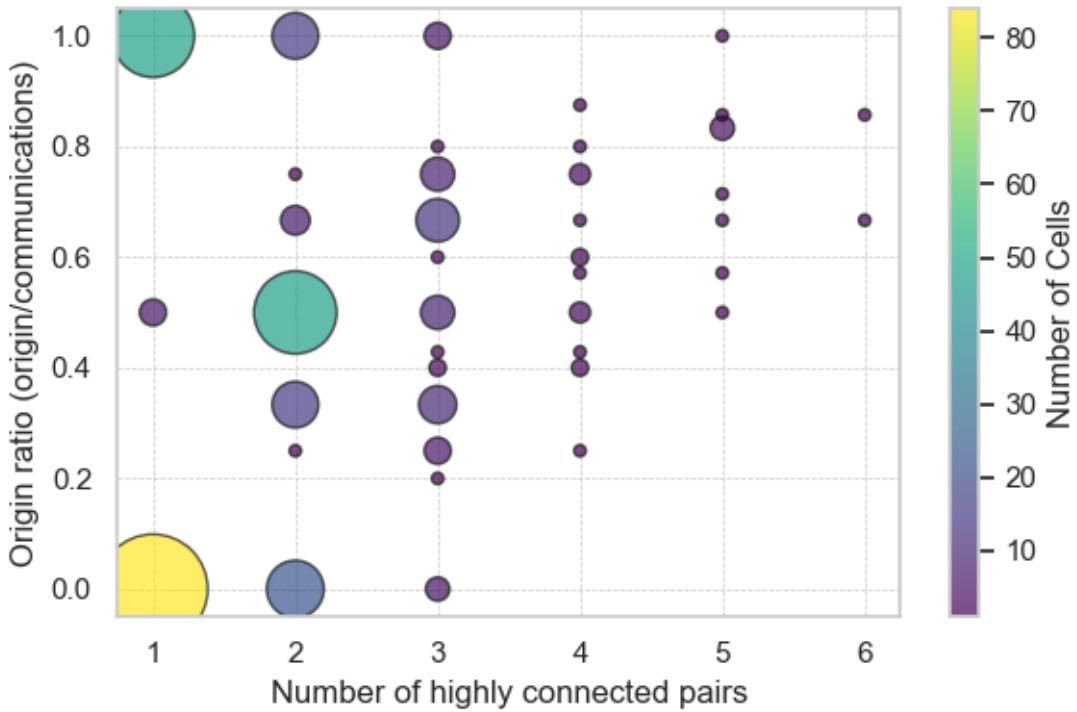
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=137 for Number of highly connected pairs=1

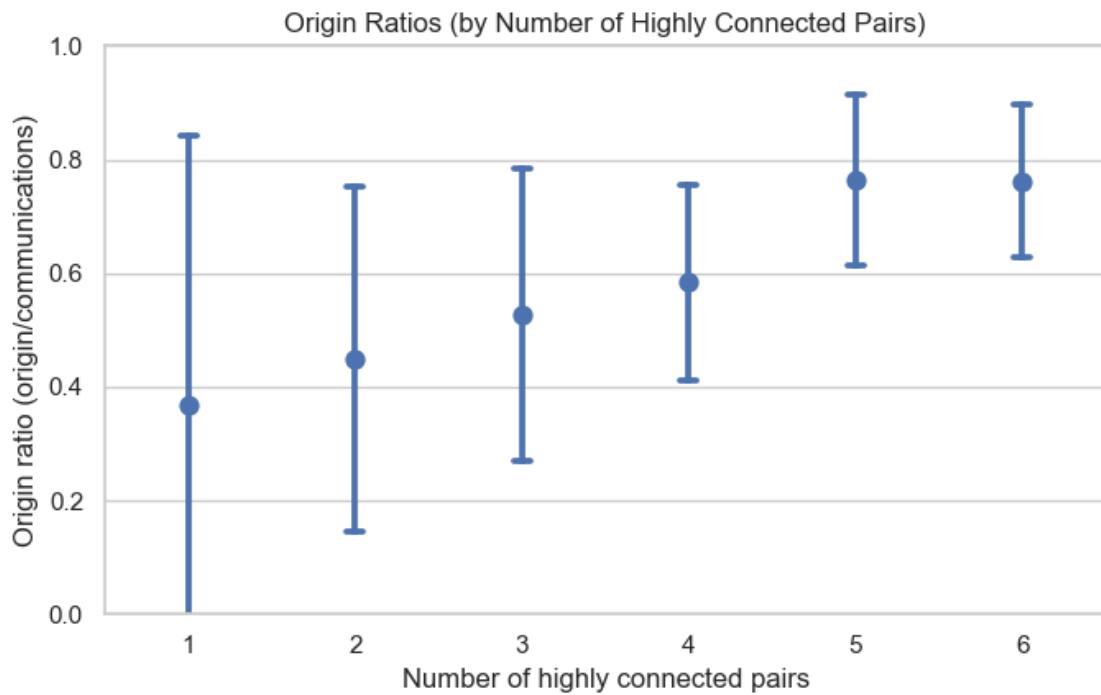
[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=109 for Number of highly connected pairs=2

[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=59 for Number of highly connected pairs=3

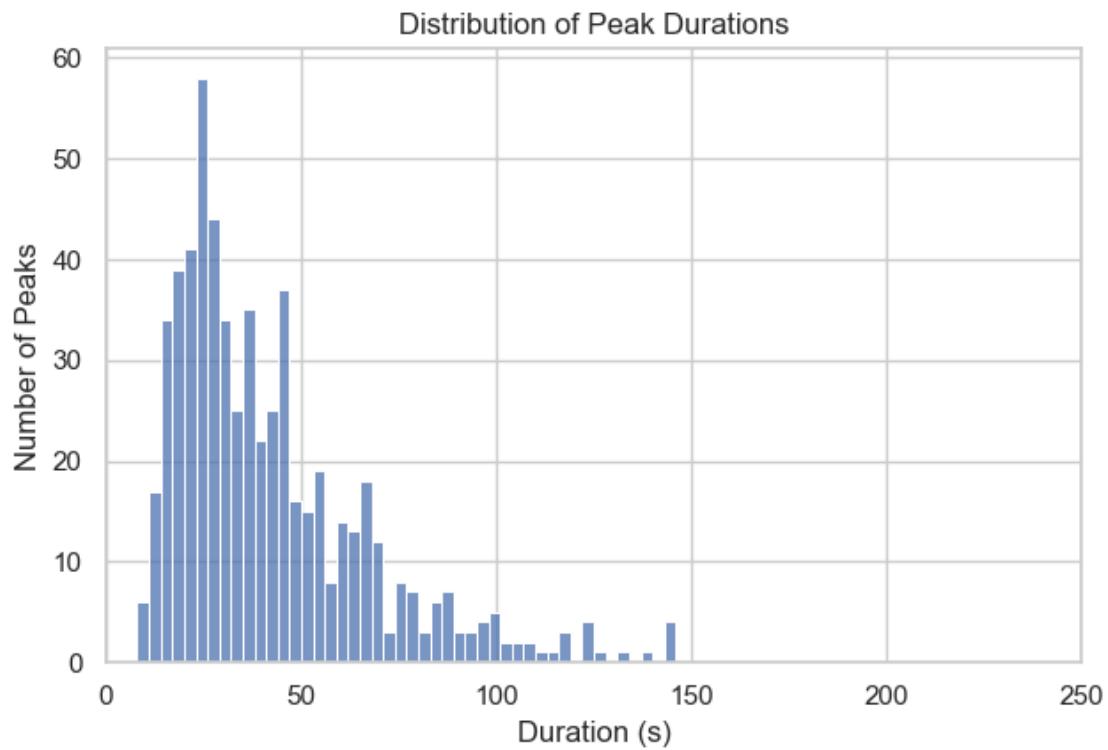
[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=16 for Number of highly connected pairs=4

[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=10 for Number of highly connected pairs=5

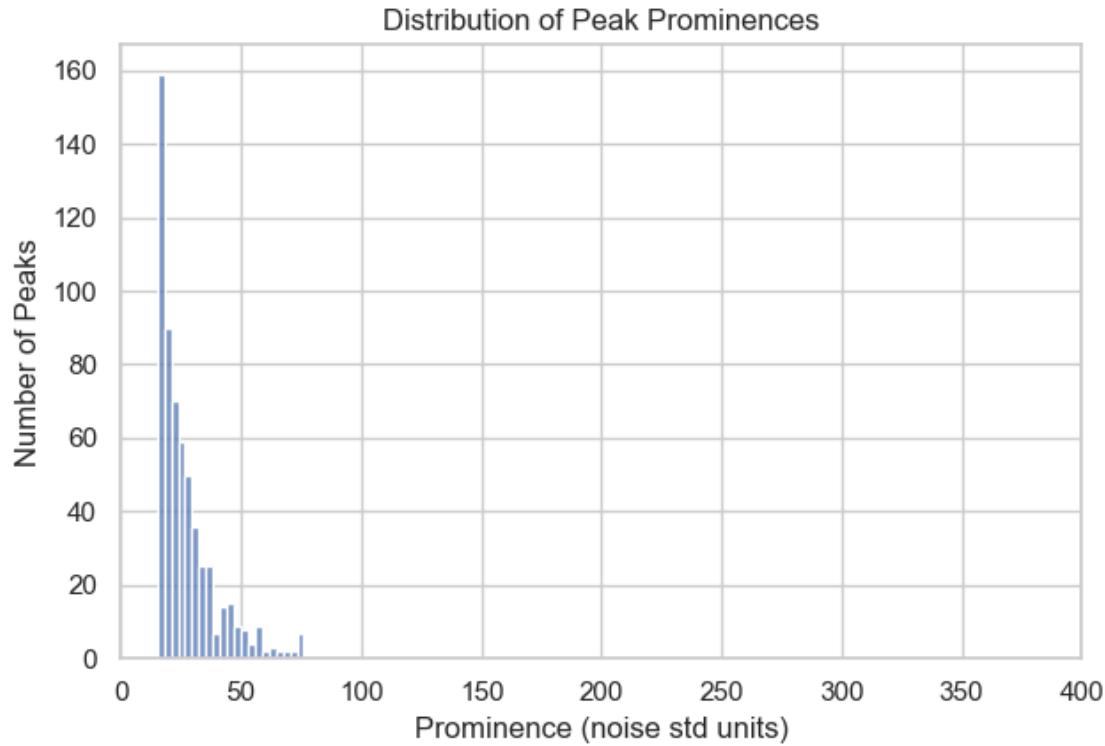
[2025-08-27 14:53:57] [INFO] calcium: plot_points_mean_std: N=2 for Number of highly connected pairs=6

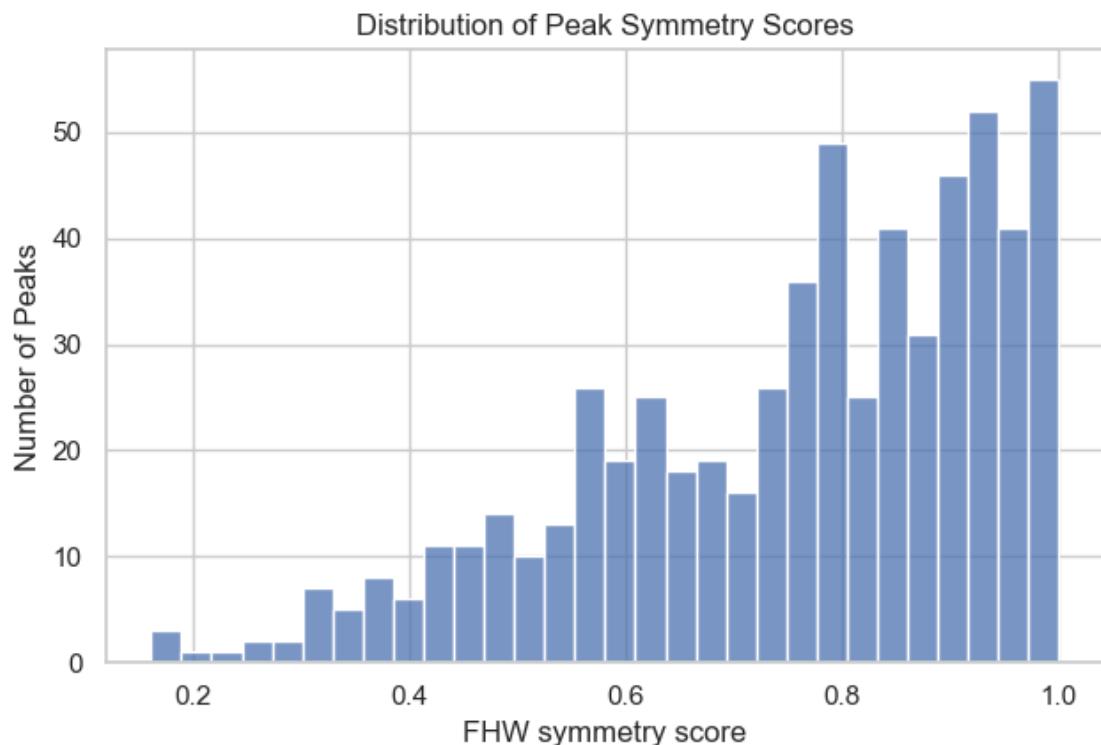


```
[2025-08-27 14:53:58] [INFO] calcium: plot_histogram: removed 16 outliers out of 619 on 'Duration (s)' (lower=-69, upper=148)
```

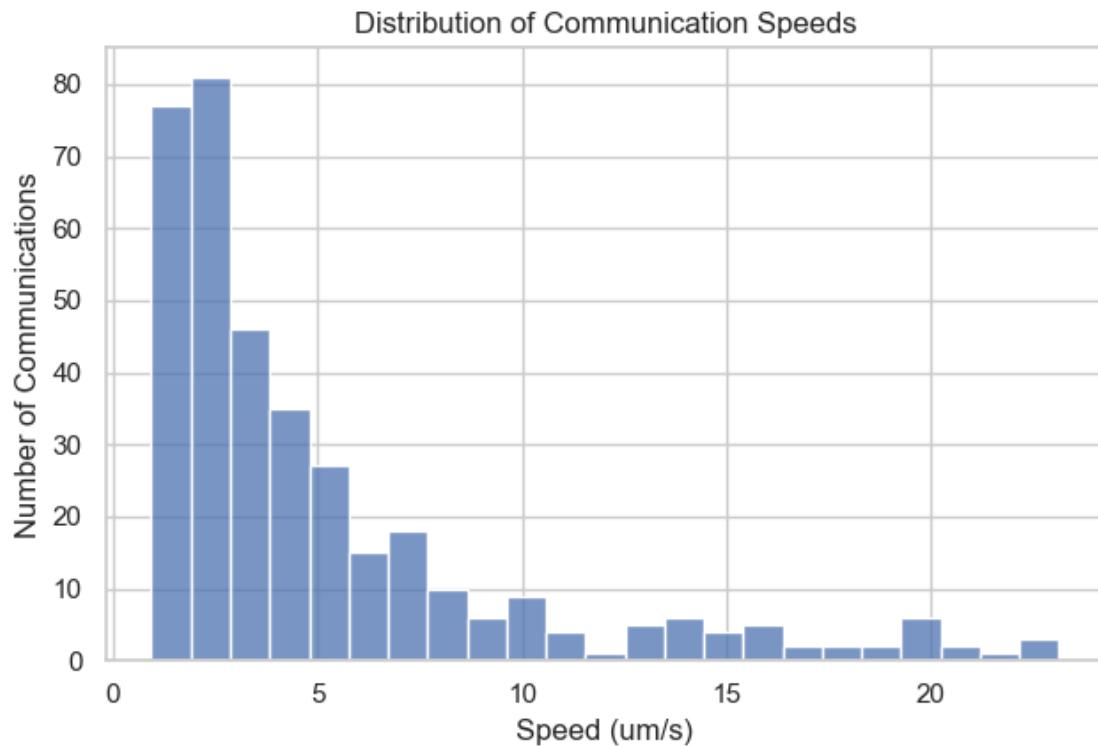


[2025-08-27 14:53:59] [INFO] calcium: plot_histogram: removed 21 outliers out of 619 on 'Prominence (noise std units)' (lower=-25.75, upper=76.1)

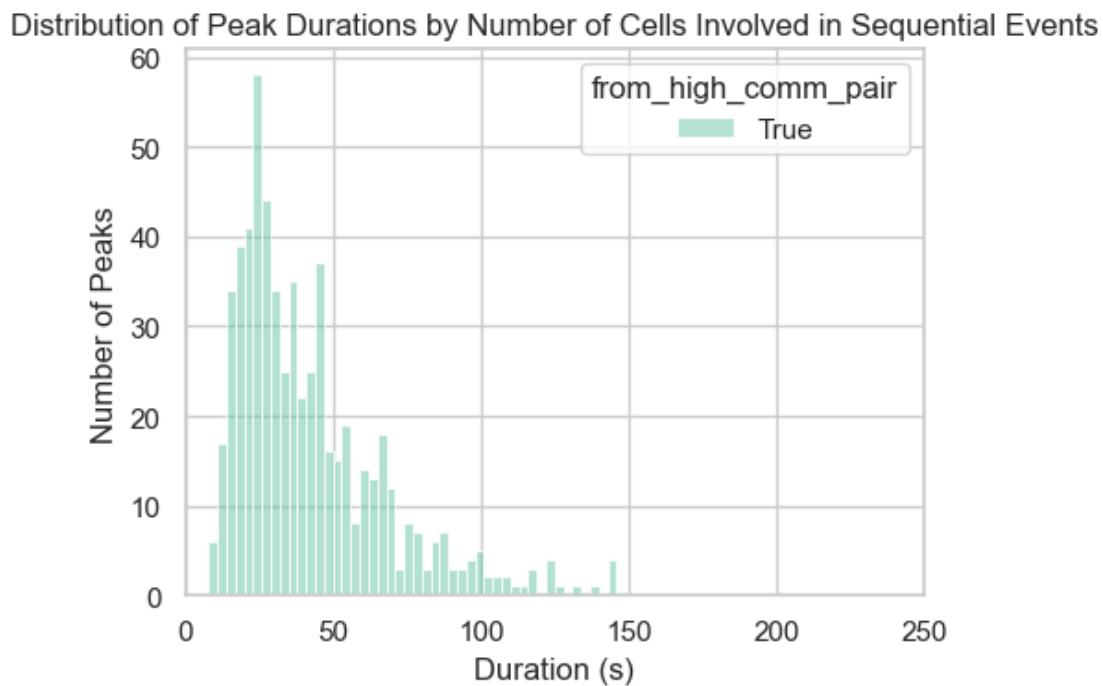




[2025-08-27 14:54:00] [INFO] calcium: plot_histogram: removed 23 outliers out of 390 on 'Speed (um/s)' (lower=-13.727, upper=23.162)

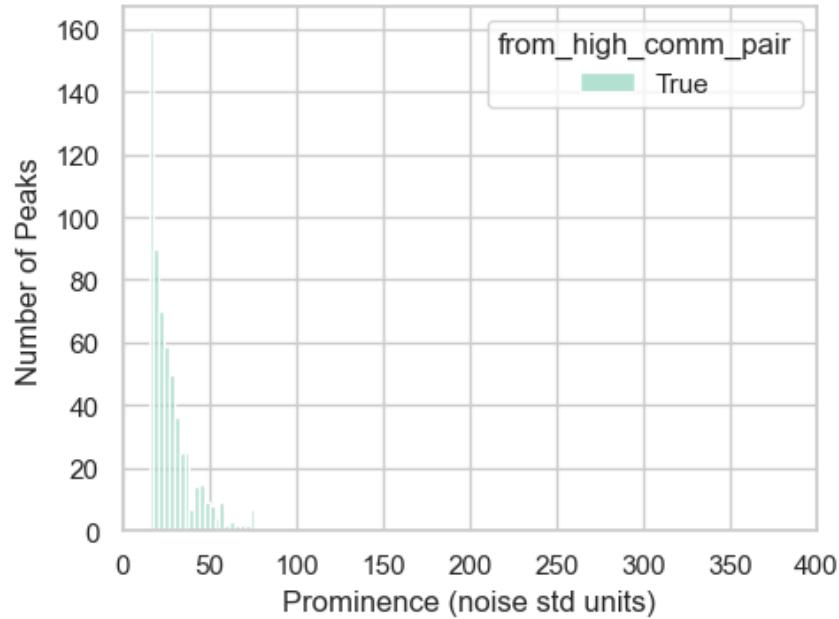


```
[2025-08-27 14:54:01] [INFO] calcium: plot_histogram_by_group: removed 16 outliers out of 619 on 'Duration (s)' (lower=-69, upper=148)
```

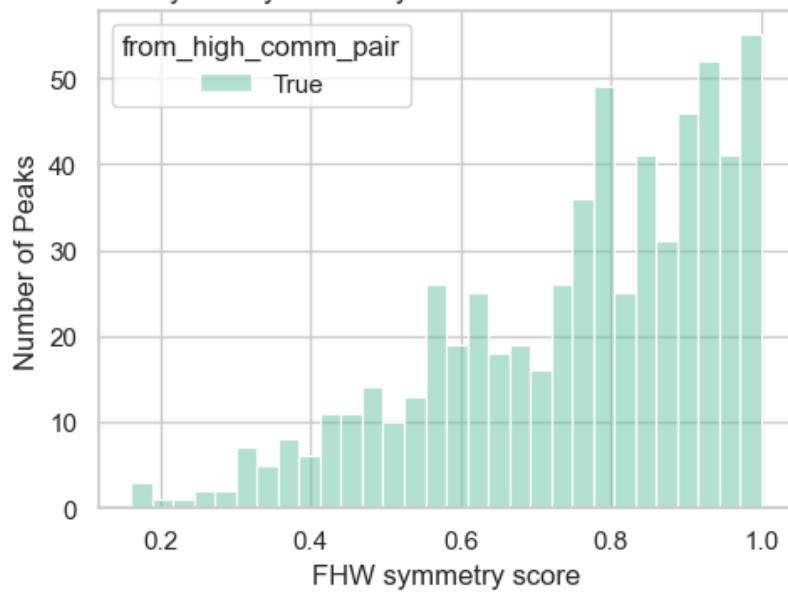


[2025-08-27 14:54:01] [INFO] calcium: plot_histogram_by_group: removed 21 outliers out of 619 on 'Prominence (noise std units)' (lower=-25.75, upper=76.1)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

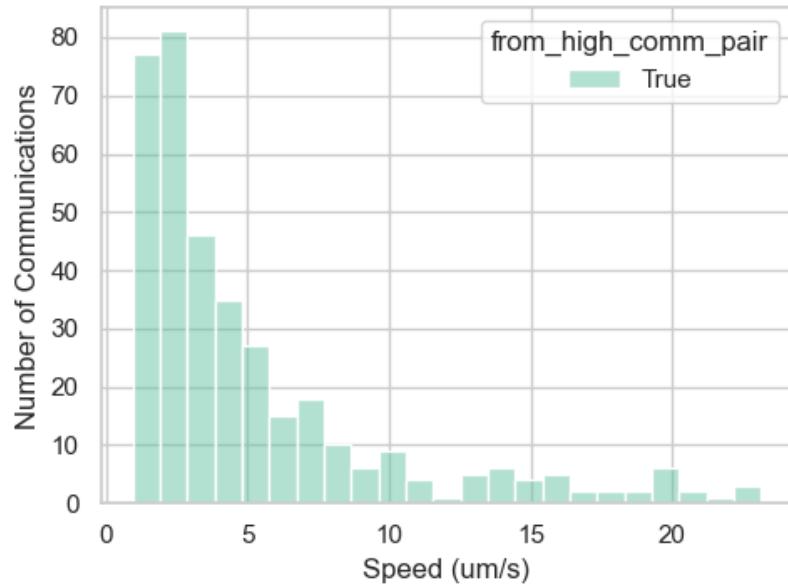


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 14:54:03] [INFO] calcium: plot_histogram_by_group: removed 23 outliers out of 390 on 'Speed (um/s)' (lower=-13.727, upper=23.162)

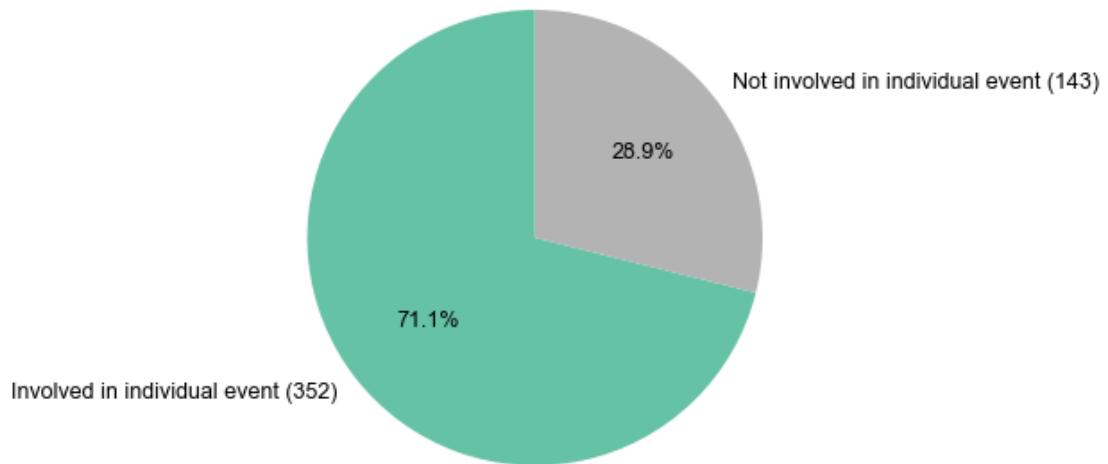
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



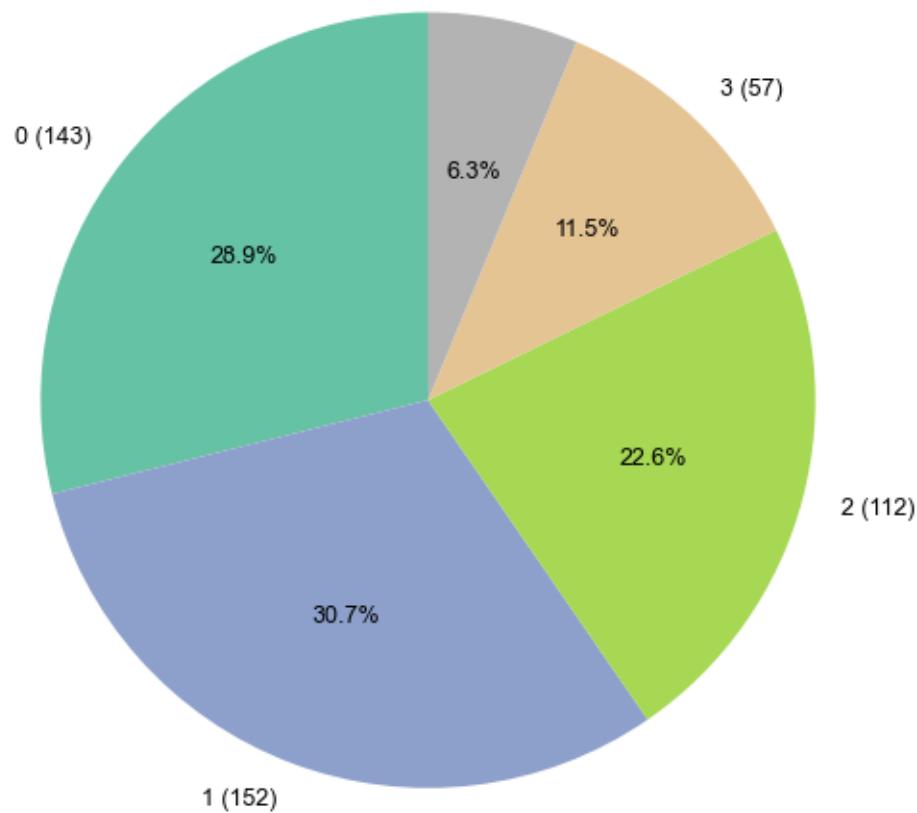
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

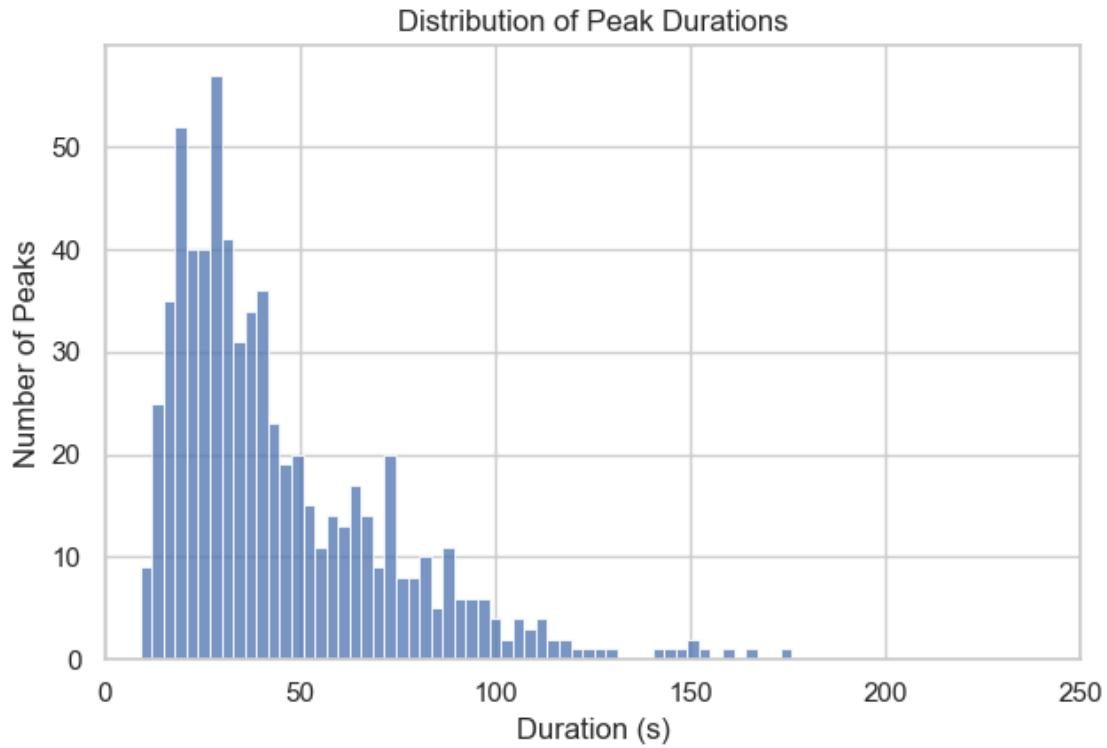


```
[2025-08-27 14:54:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250501\Output\IS08\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250501\\Output\\IS08\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

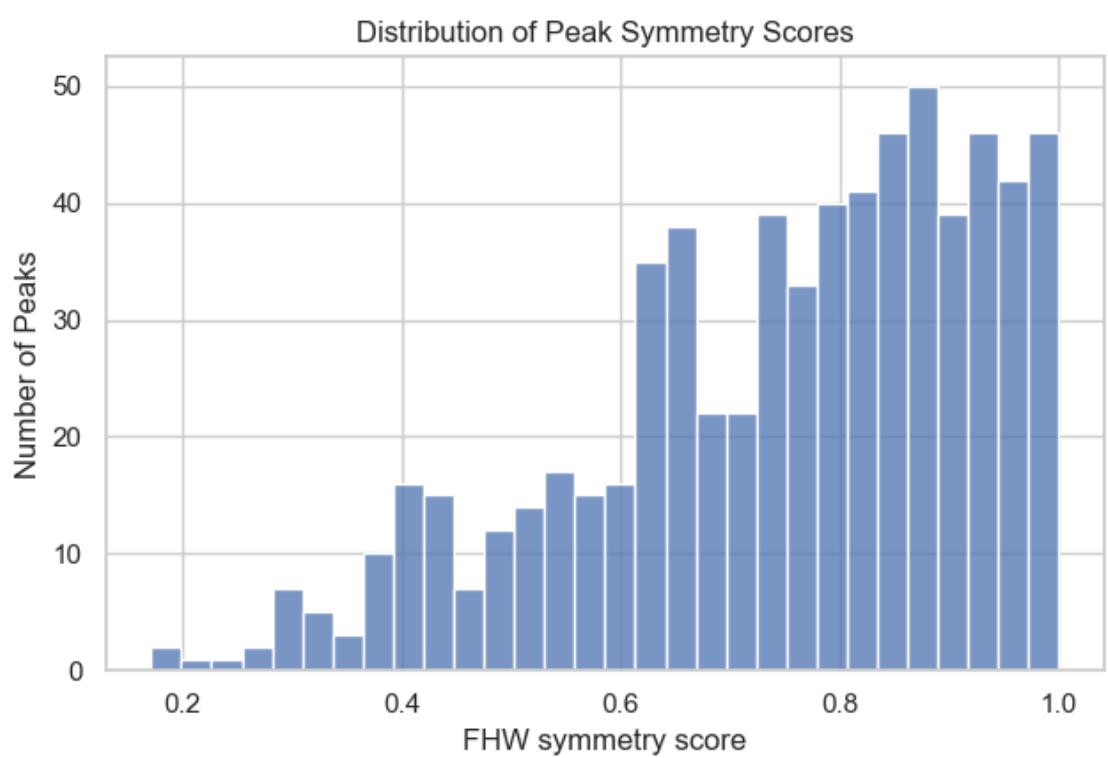
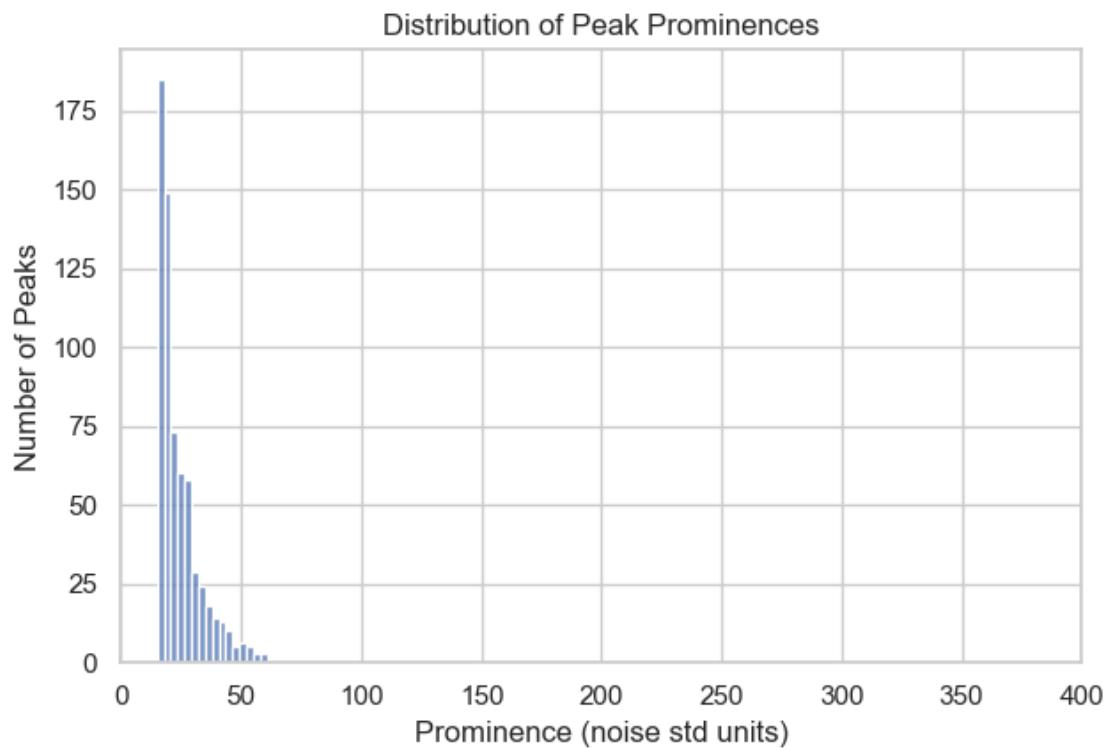
'D:\\Mateo\\20250501\\Output\\IS08\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

1.4.2 Peaks statistics in individual events

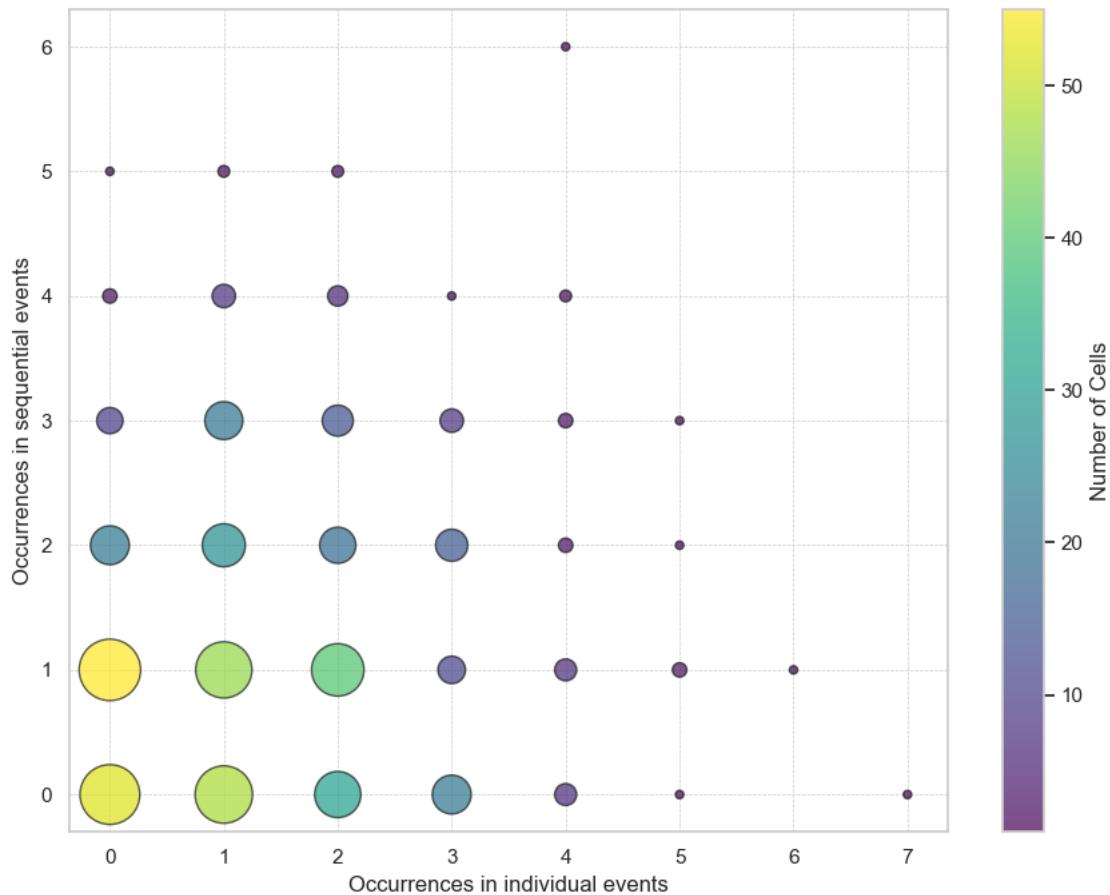
[2025-08-27 14:54:05] [INFO] calcium: plot_histogram: removed 13 outliers out of 682 on 'Duration (s)' (lower=-90, upper=176)



[2025-08-27 14:54:06] [INFO] calcium: plot_histogram: removed 27 outliers out of 682 on 'Prominence (noise std units)' (lower=-15.325, upper=61.5)



1.4.3 Correlation between event activity level & individual activity level

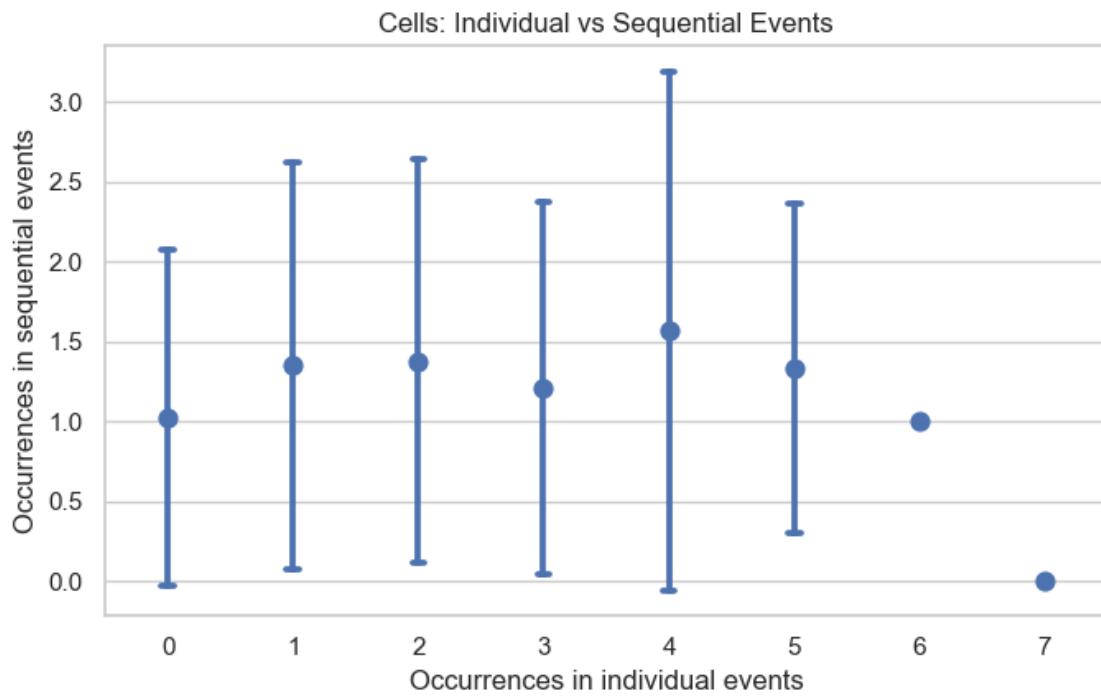


```
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: removed 0/495 outliers on 'Occurrences in sequential events' (lower=-6, upper=8)
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=143 for Occurrences in individual events=0
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=152 for Occurrences in individual events=1
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=112 for Occurrences in individual events=2
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=57 for Occurrences in individual events=3
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=23 for Occurrences in individual events=4
```

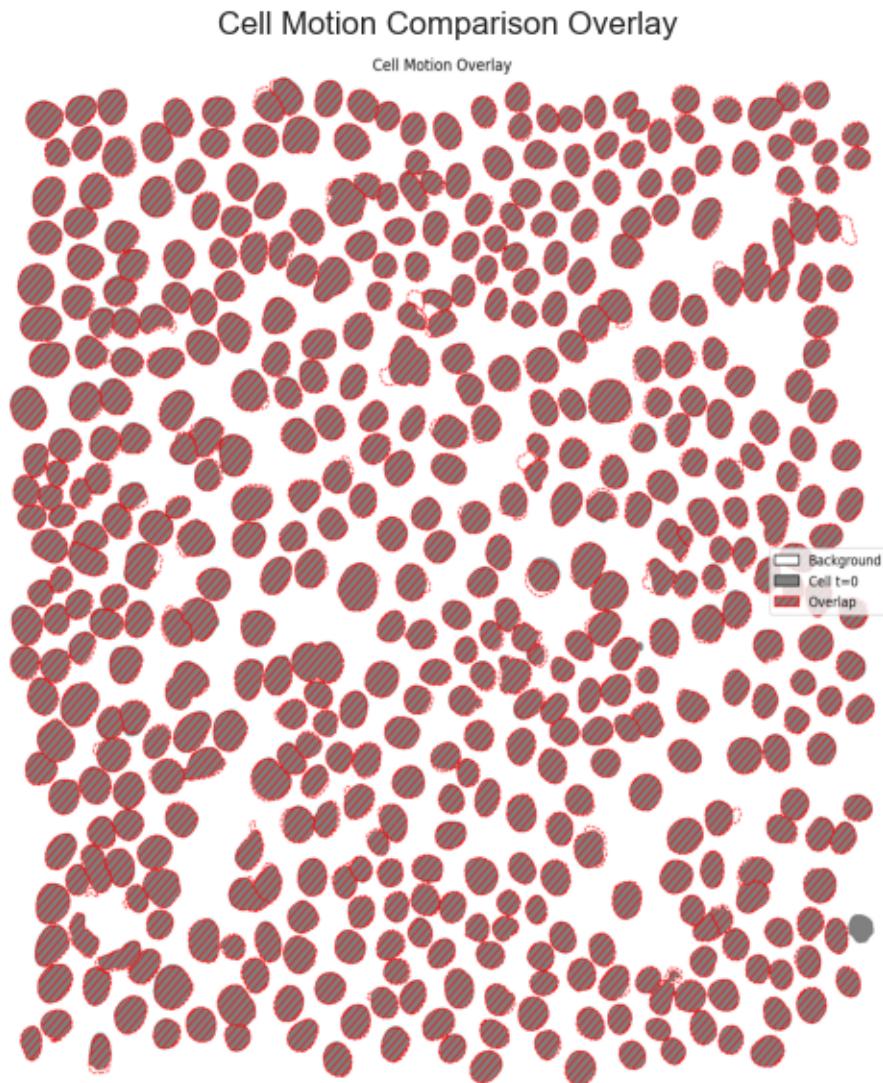
[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=6 for Occurrences in individual events=5

[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6

[2025-08-27 14:54:08] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=7



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 495
- Hoechst image taken at t=1801: 491
- Number of cells difference: absolute 4, relative 0.81%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 948197
- Pixels segmented as cell at t=1801: 955910
- Overlapping pixels between t=0 and t=1801: 911546 (95.75% of total)
- Pixels exclusive to t=0: 36651 (3.86% of total)
- Pixels exclusive to t=1801: 44364 (4.64% of total)

executed

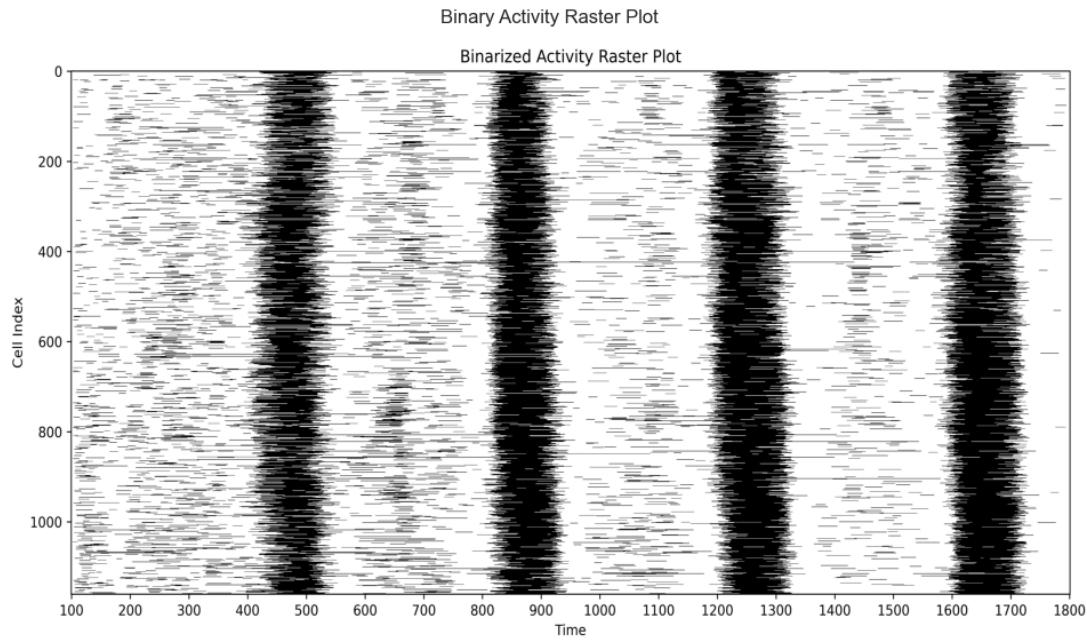
August 27, 2025

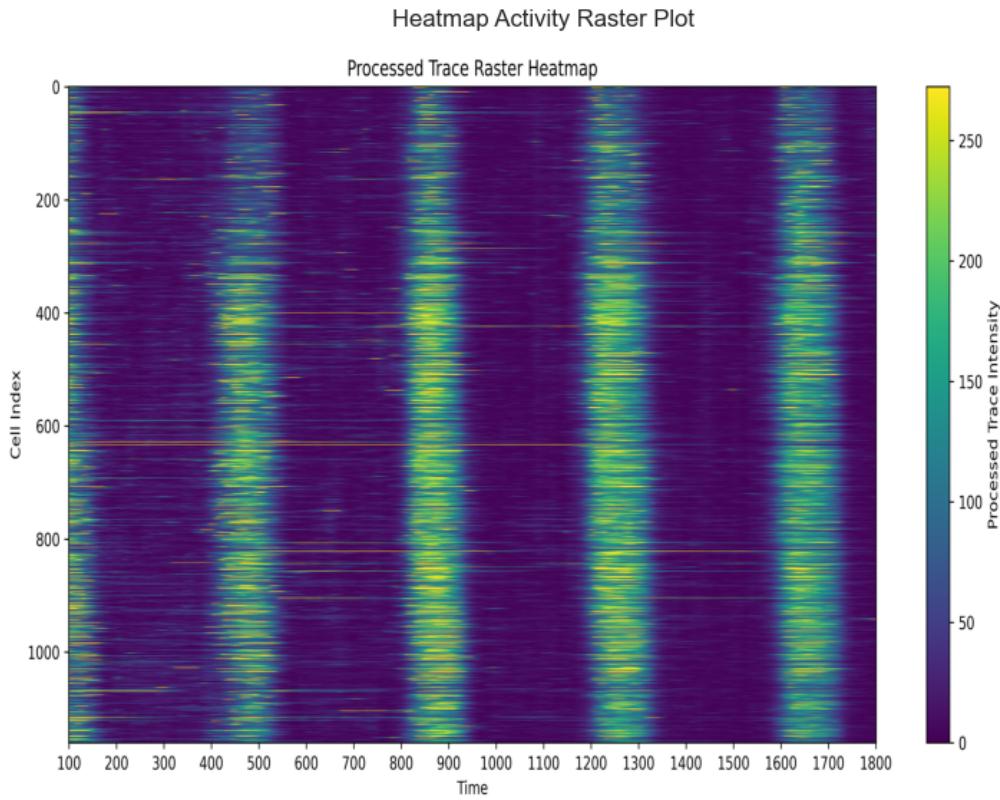
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





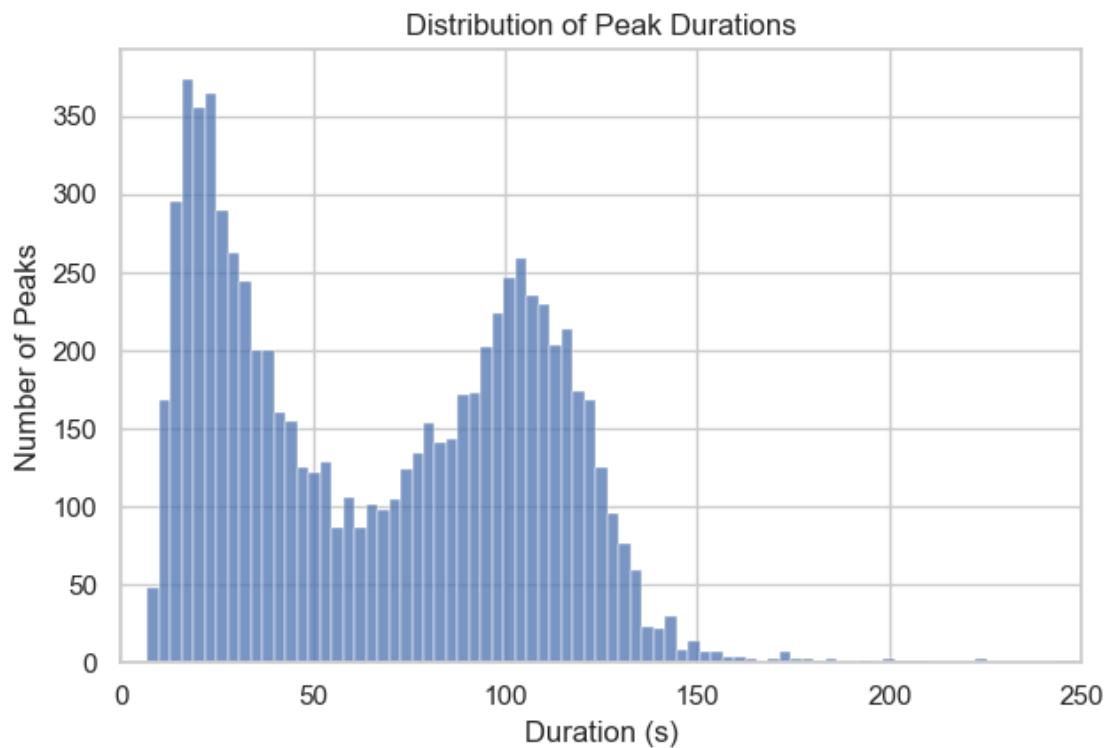
1.1.2 Peaks population

Total number of peaks: 7792

Total number of cells: 1161

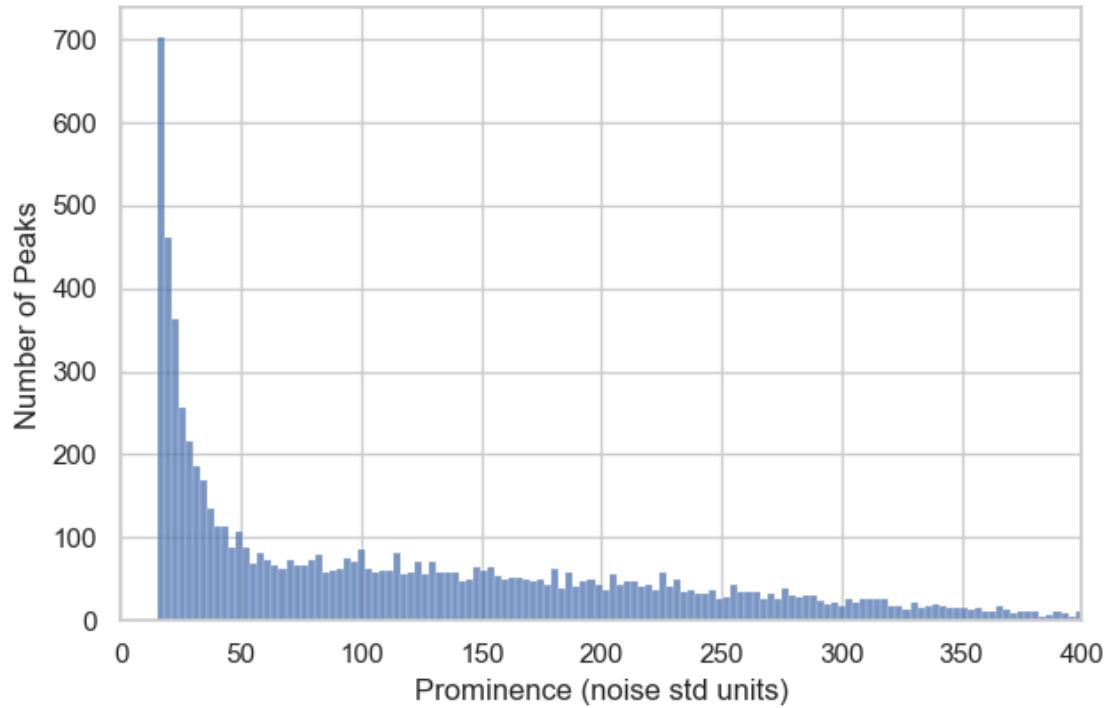
1.1.3 Peaks statistics

```
[2025-08-27 14:59:39] [INFO] calcium: plot_histogram: removed 9 outliers out of  
7792 on 'Duration (s)' (lower=-197, upper=328)
```

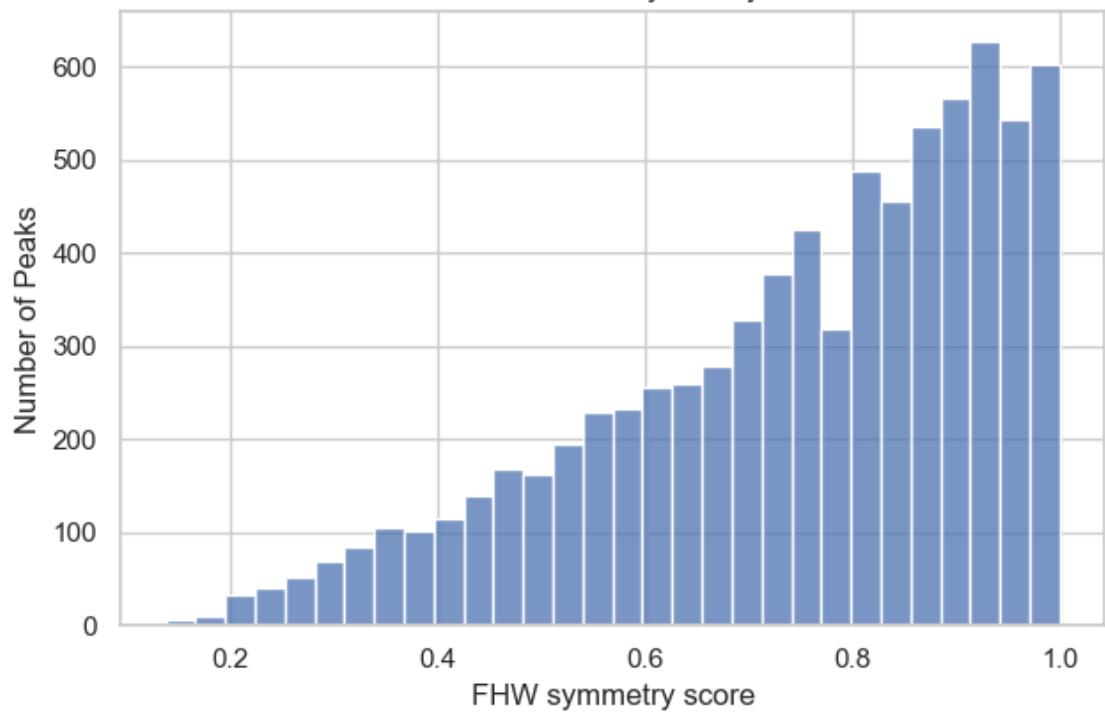


```
[2025-08-27 14:59:40] [INFO] calcium: plot_histogram: removed 4 outliers out of  
7792 on 'Prominence (noise std units)' (lower=-464.98, upper=688.1)
```

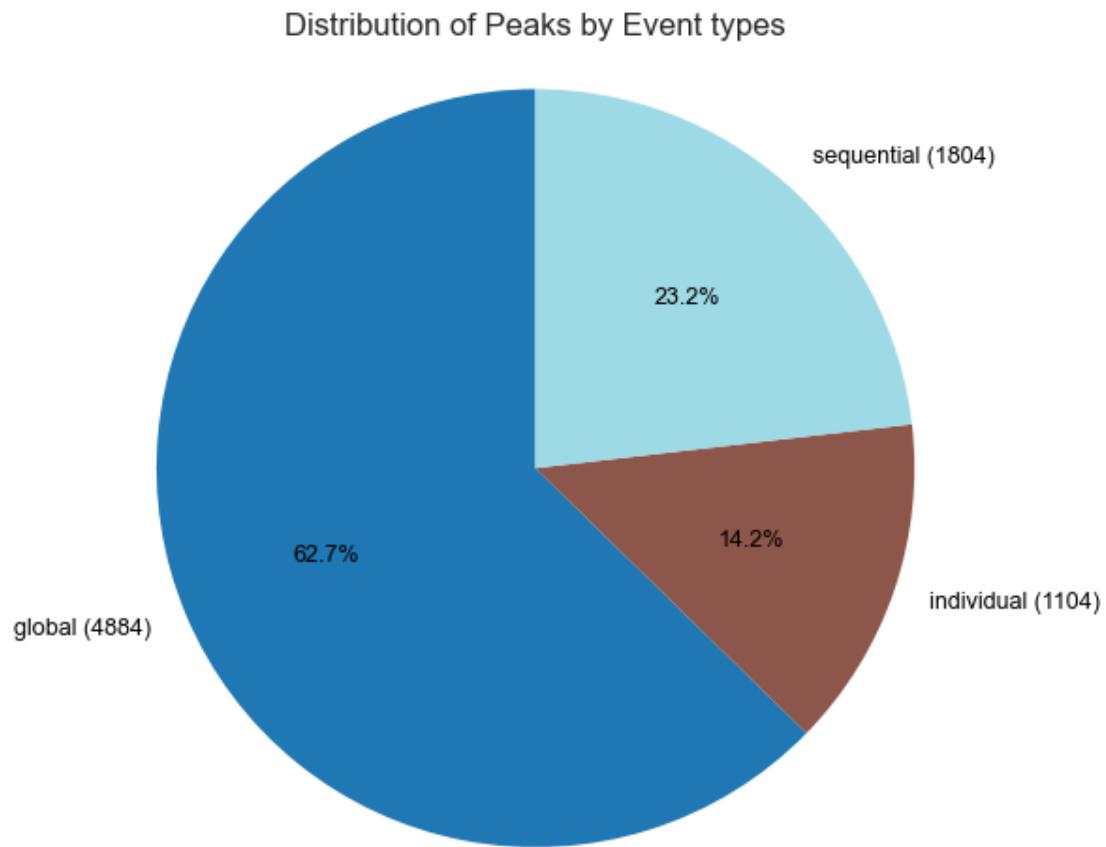
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

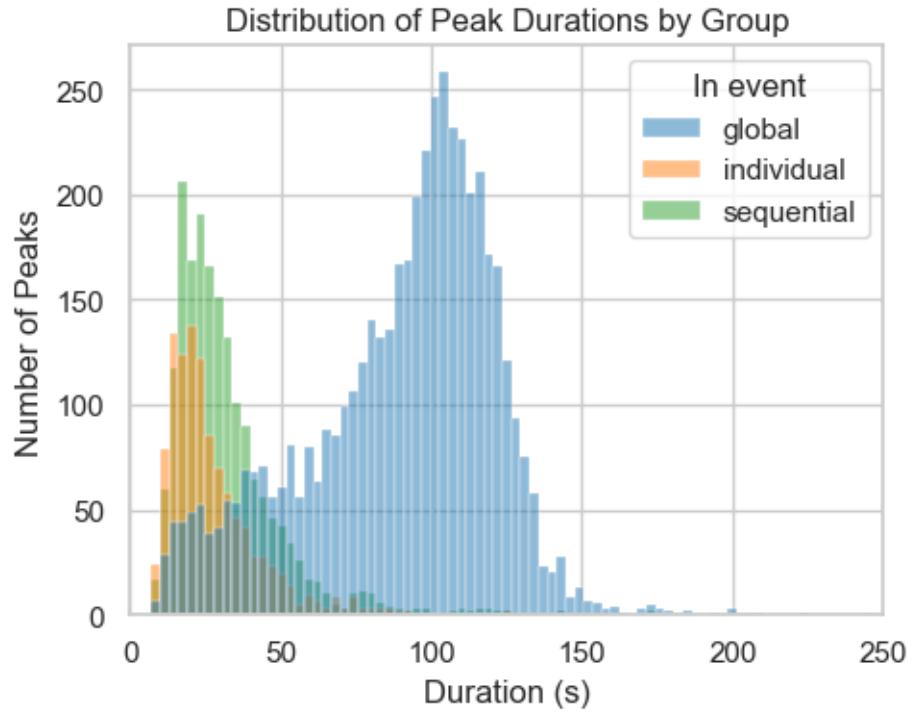


1.1.4 Distribution of peaks per event types

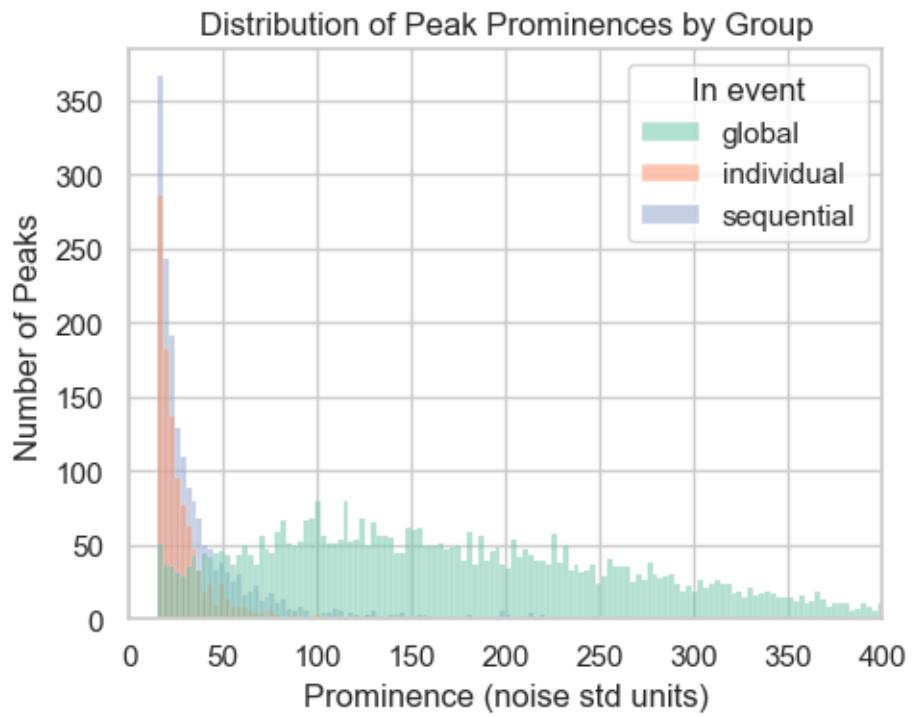


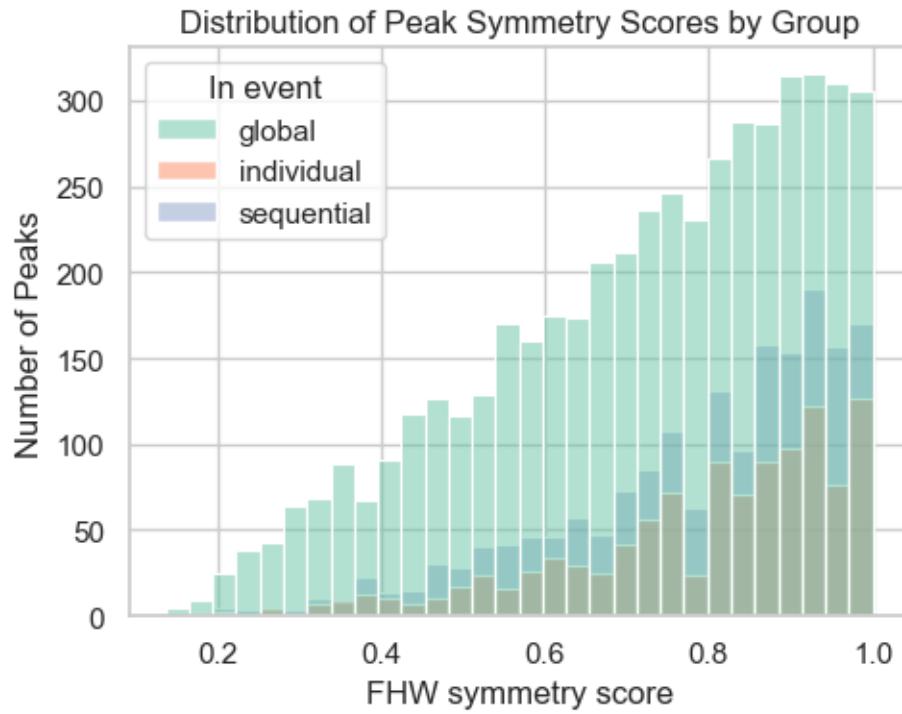
1.1.5 Peaks statistics per event types

```
[2025-08-27 14:59:41] [INFO] calcium: plot_histogram_by_group: removed 9 outliers out of 7792 on 'Duration (s)' (lower=-197, upper=328)
```



```
[2025-08-27 14:59:41] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 7792 on 'Prominence (noise std units)' (lower=-464.98, upper=688.1)
```

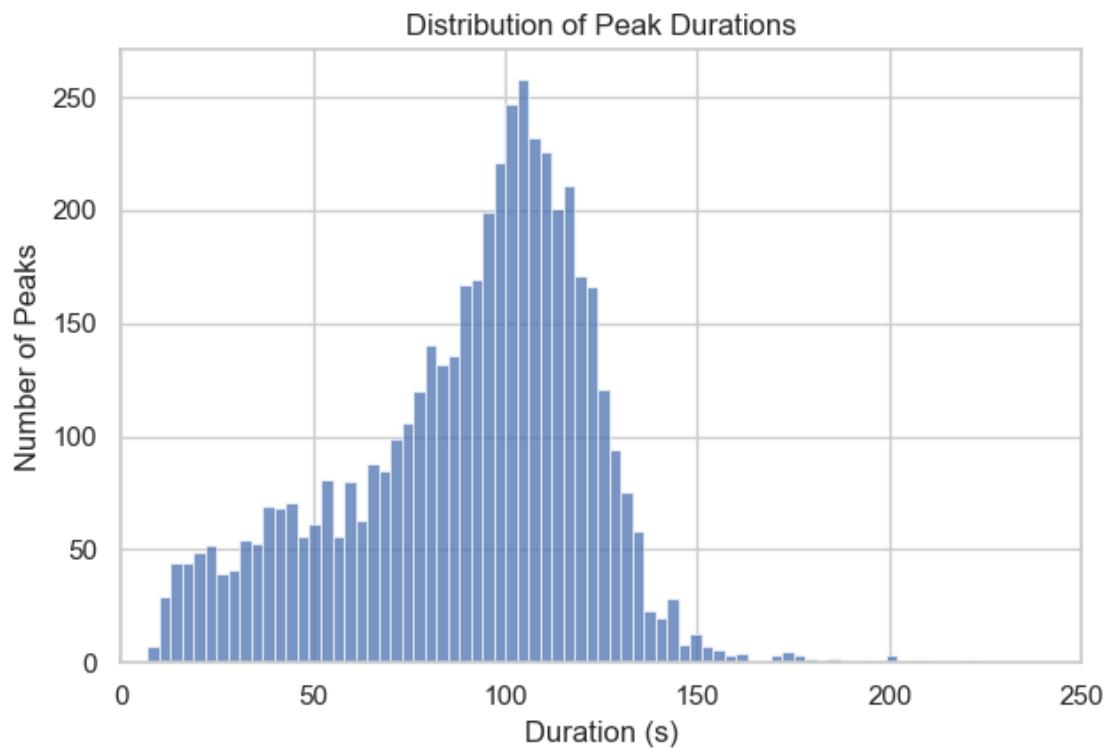




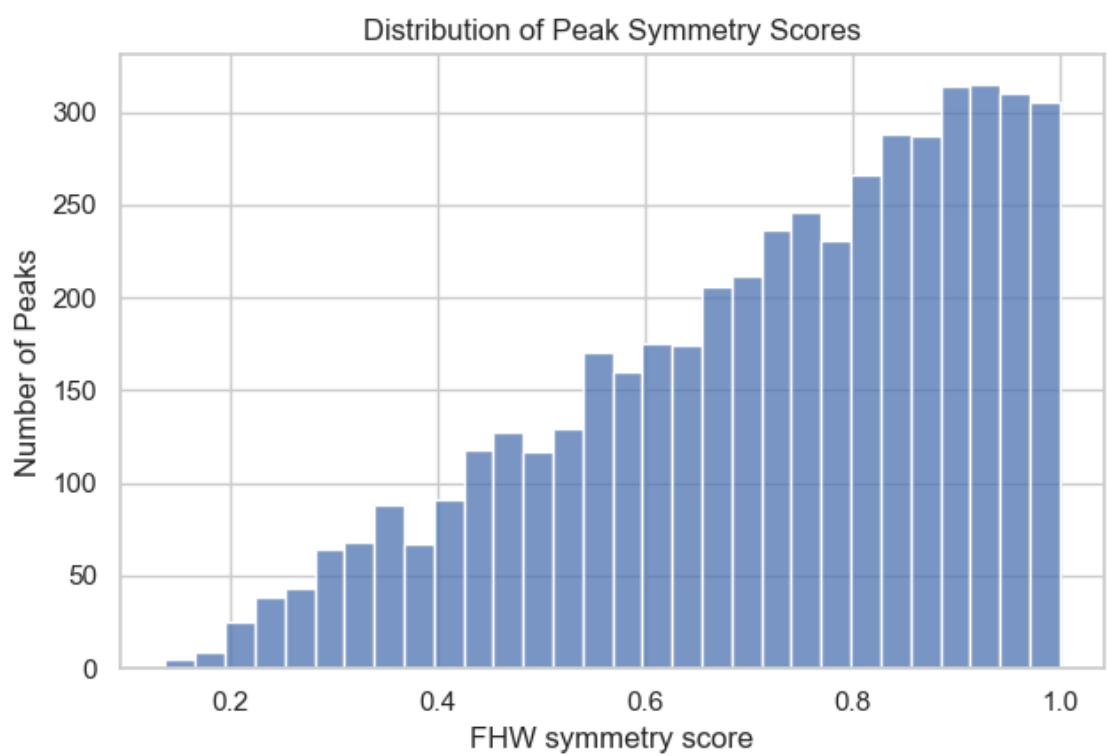
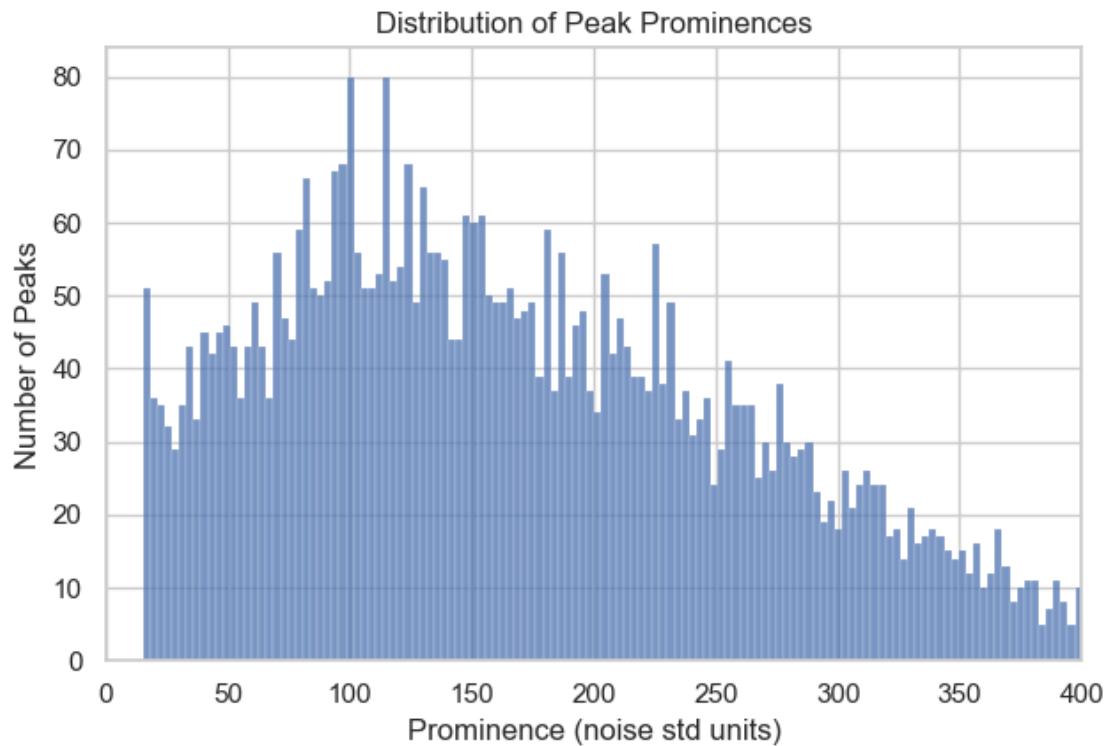
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 14:59:43] [INFO] calcium: plot_histogram: removed 10 outliers out of 4884 on 'Duration (s)' (lower=-56, upper=238)
```

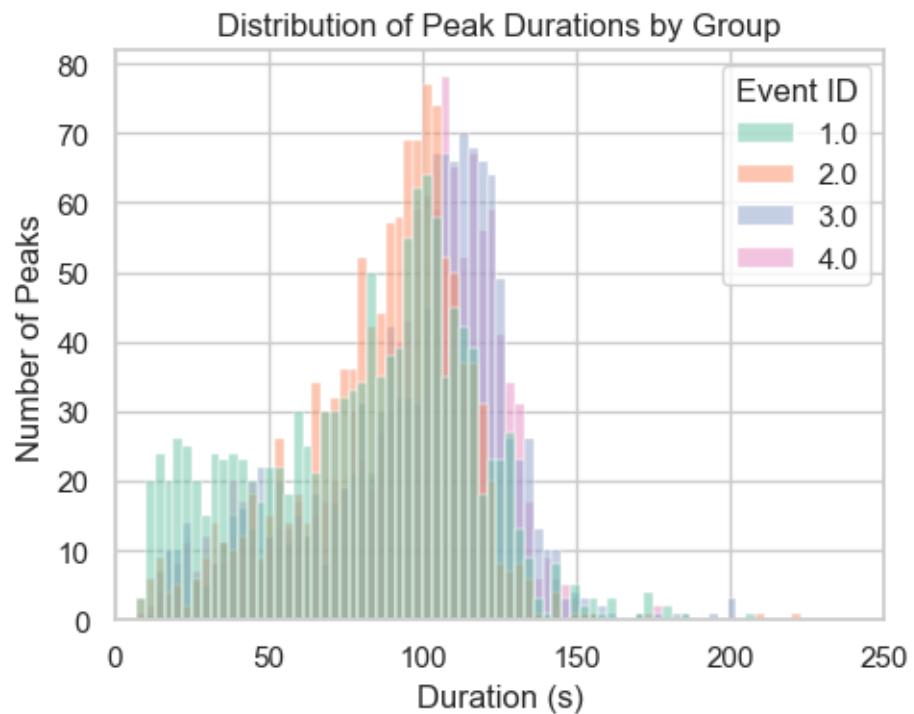


```
[2025-08-27 14:59:43] [INFO] calcium: plot_histogram: removed 4 outliers out of  
4884 on 'Prominence (noise std units)' (lower=-343.07, upper=681.2)
```

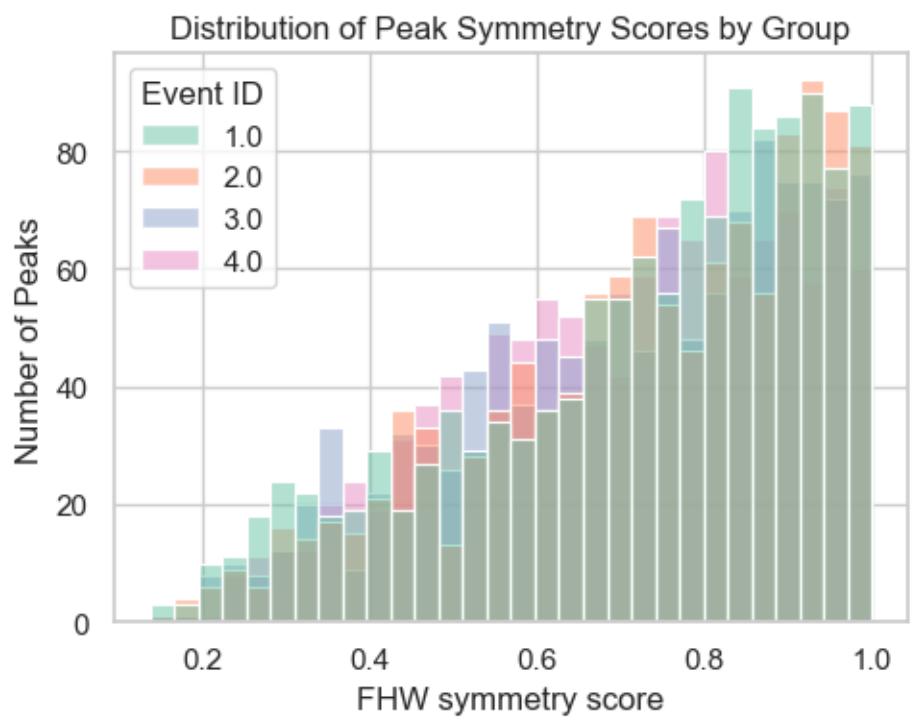
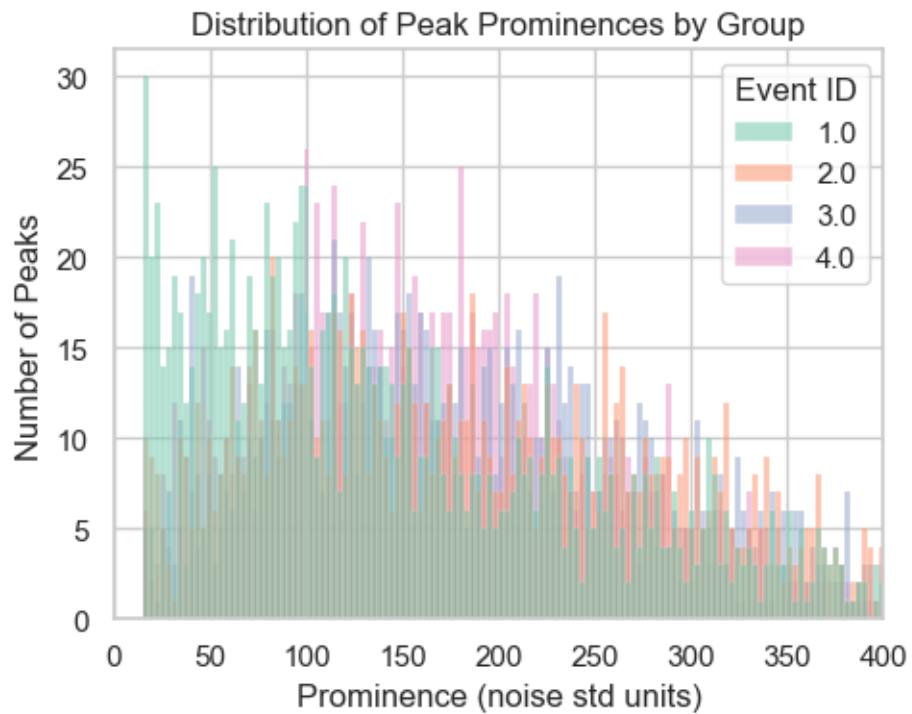


1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:59:43] [INFO] calcium: plot_histogram_by_group: removed 10 outliers out of 4884 on 'Duration (s)' (lower=-56, upper=238)

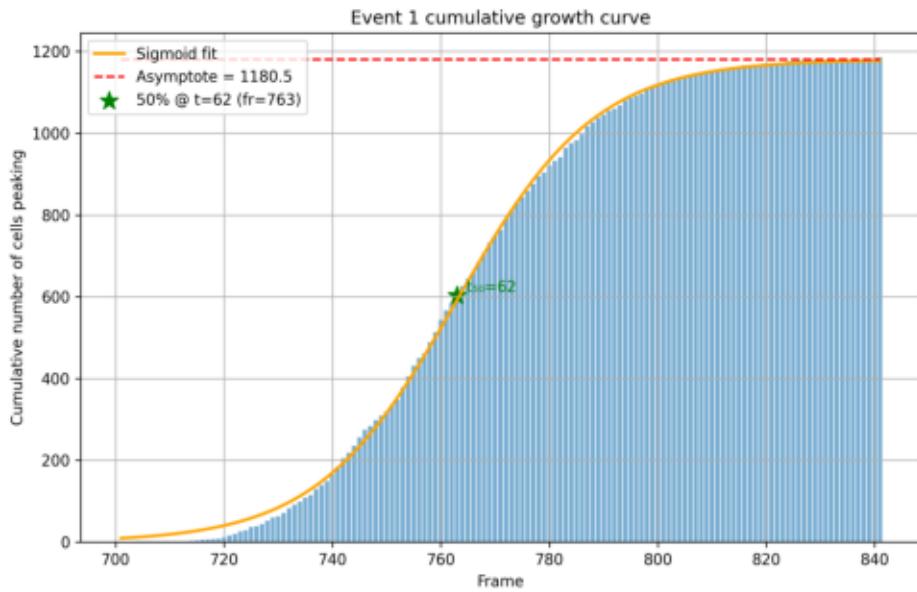


[2025-08-27 14:59:44] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 4884 on 'Prominence (noise std units)' (lower=-343.07, upper=681.2)

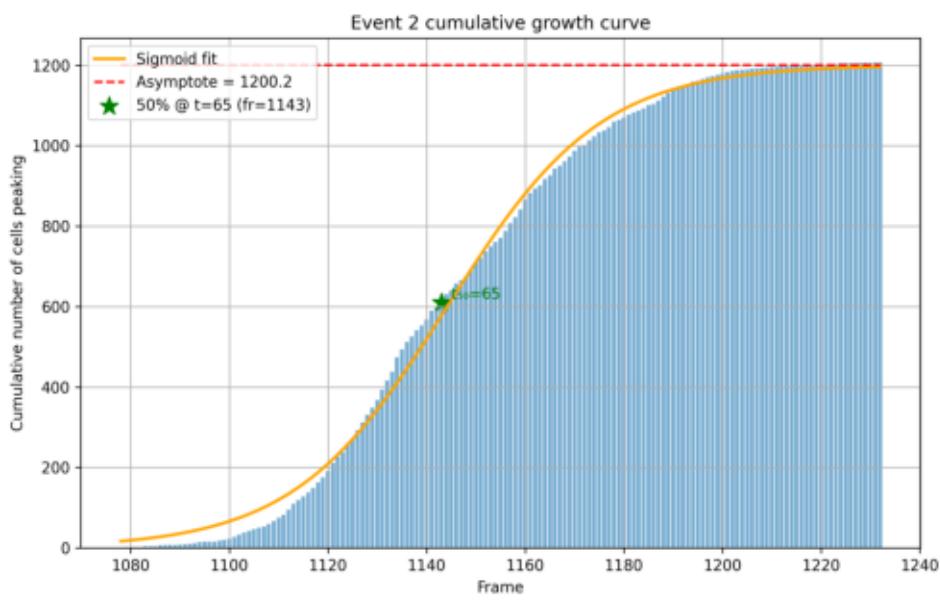


1.2.3 Kinetics of global events

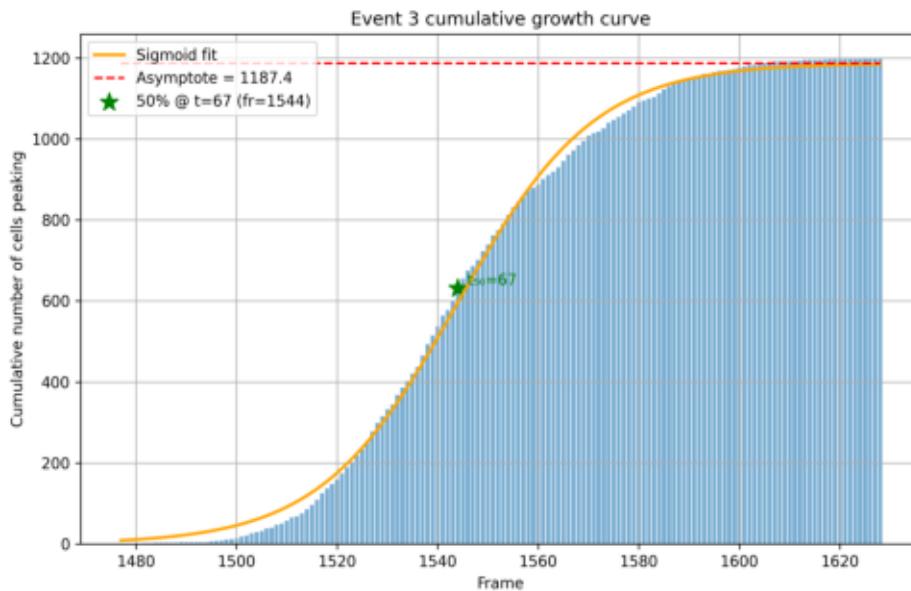
Event Activity Overlay (Event ID: 1)



Event Activity Overlay (Event ID: 2)

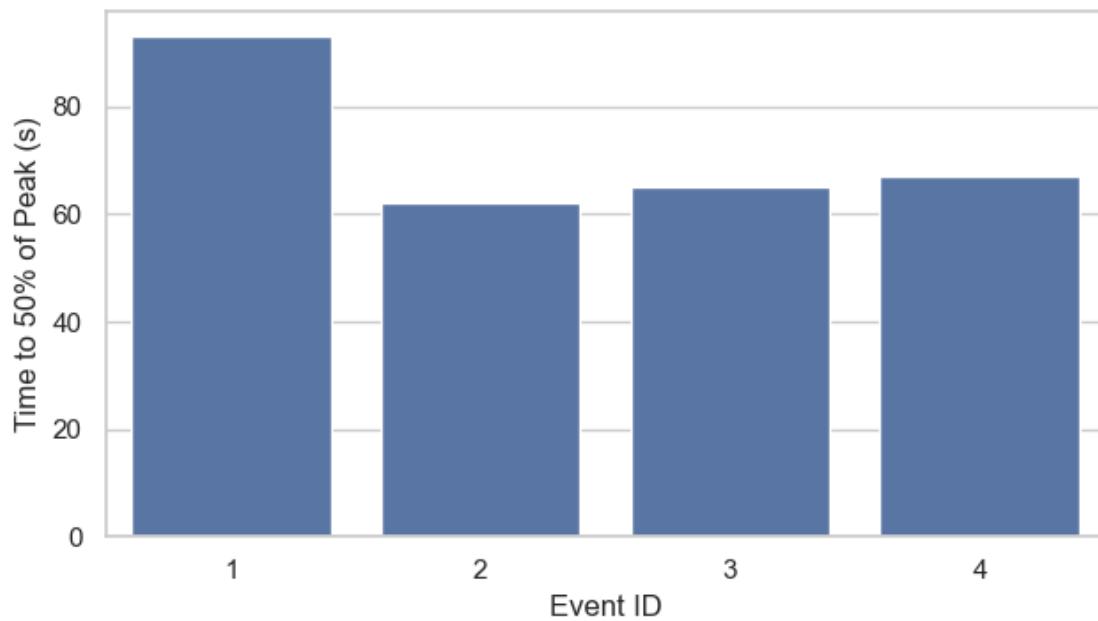


Event Activity Overlay (Event ID: 3)

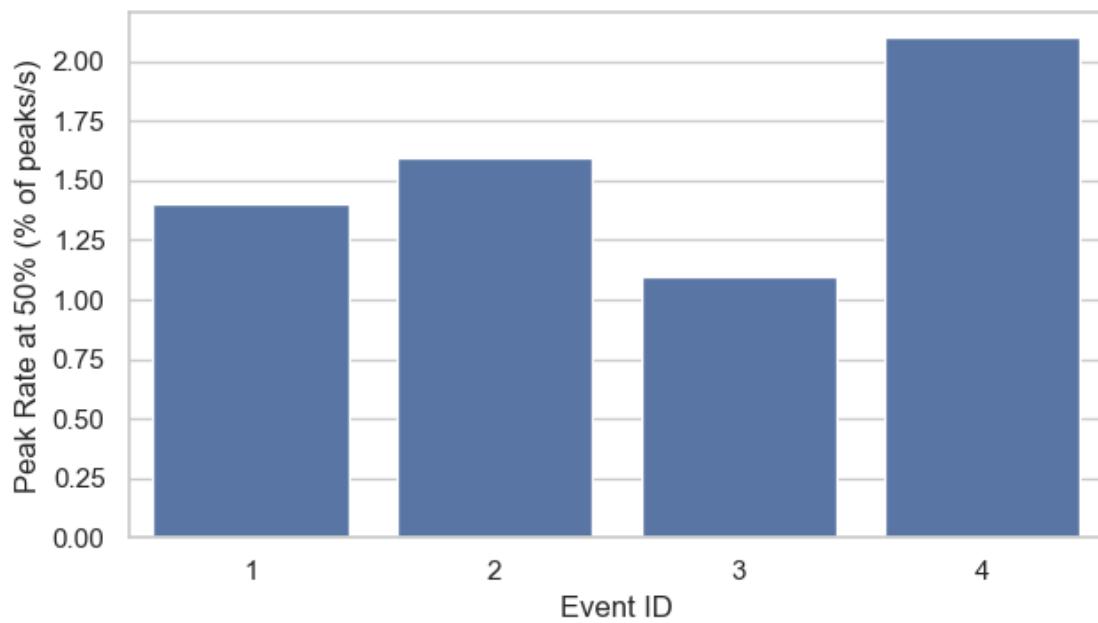


```
[2025-08-27 14:59:47] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\Output\\IS1\\events\\event-growth-
curve-4.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250618\\Output\\IS1\\events\\event-growth-curve-4.png'
```

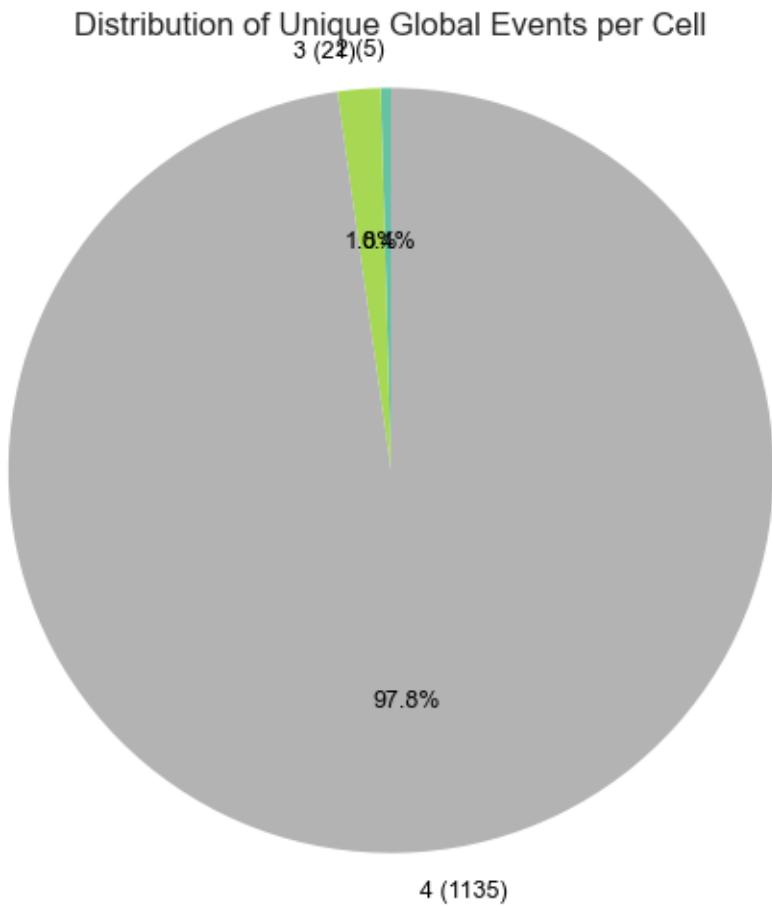
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

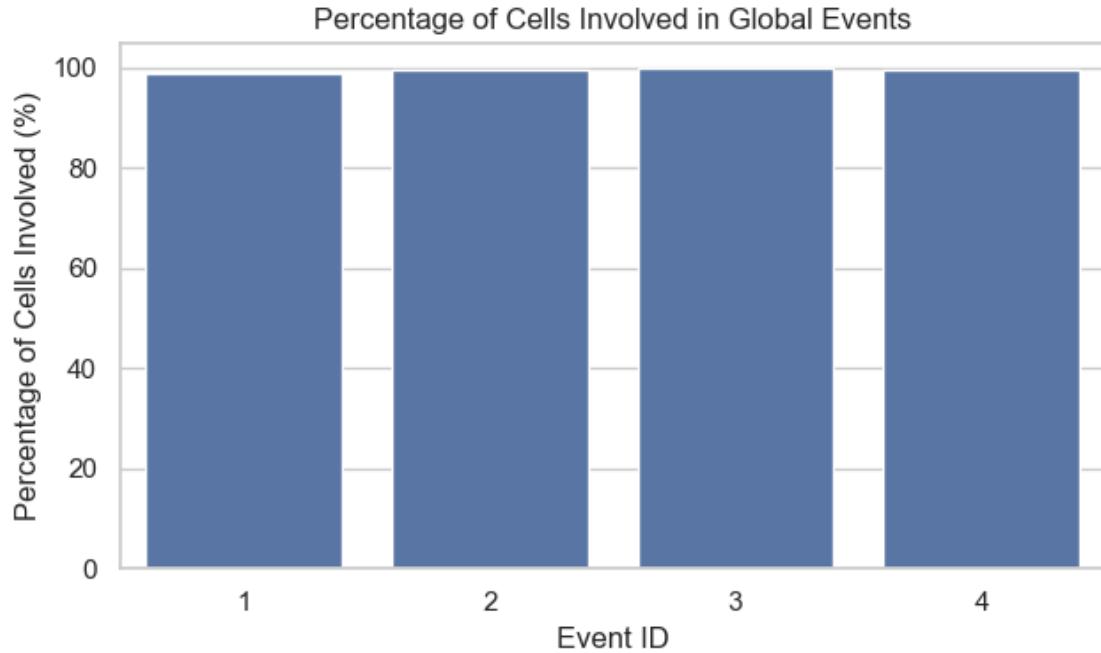


```
[2025-08-27 14:59:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS1\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250618\Output\IS1\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [381.0, 379.0, 399.0]
 Estimated periodicity: 0.977
 The global events exhibit a regular periodic pattern.
 Estimated frequency (1/mean interval): 0.003 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 14:59:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 14:59:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

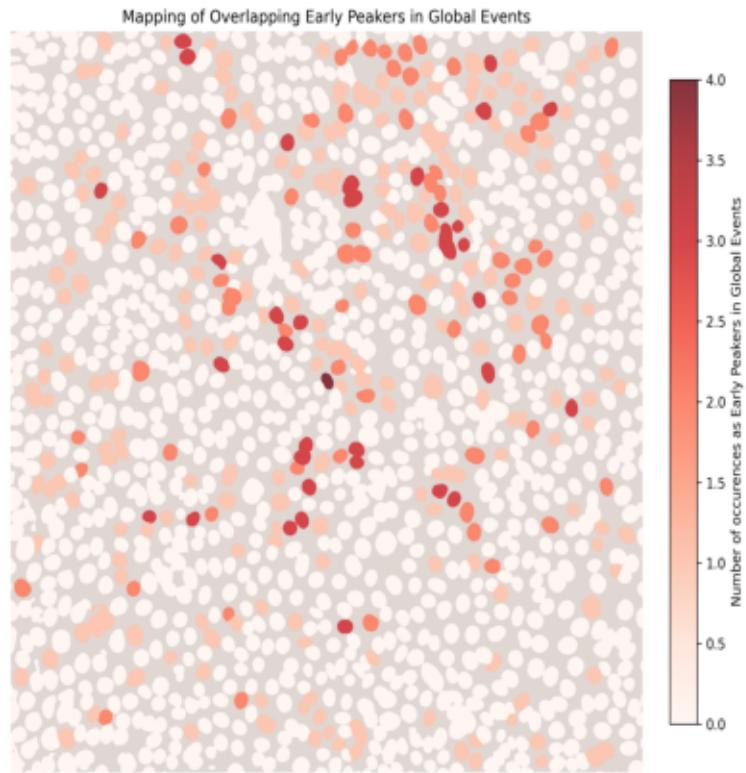
[2025-08-27 14:59:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()

```

```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

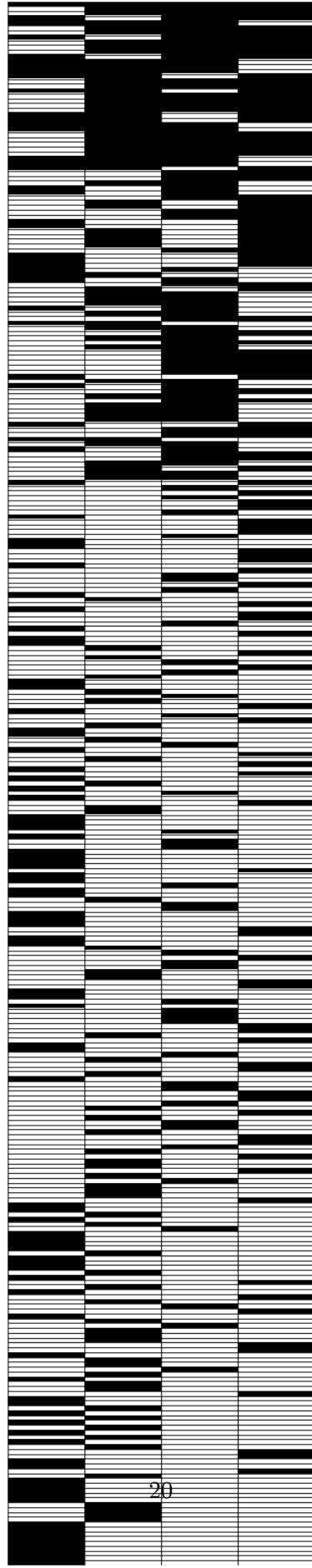
[2025-08-27 14:59:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



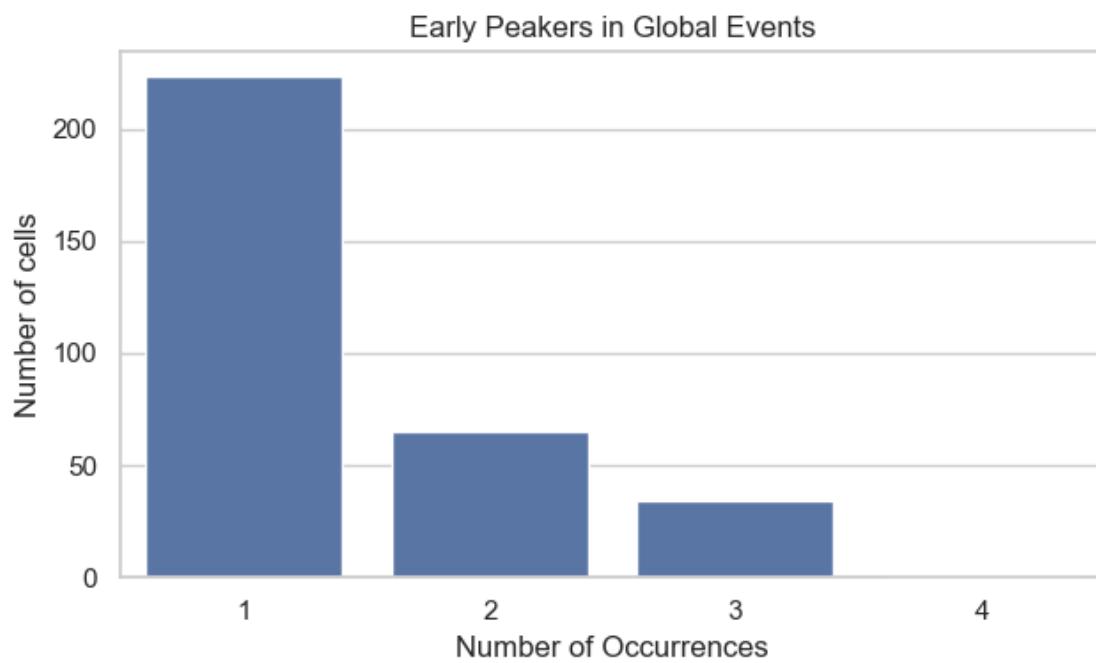
```
[2025-08-27 14:59:50] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 4 unique event IDs.
```

```
[2025-08-27 14:59:50] [INFO] calcium: Early peakers event-matrix: 323 cells x 4 events; black squares: 459
```

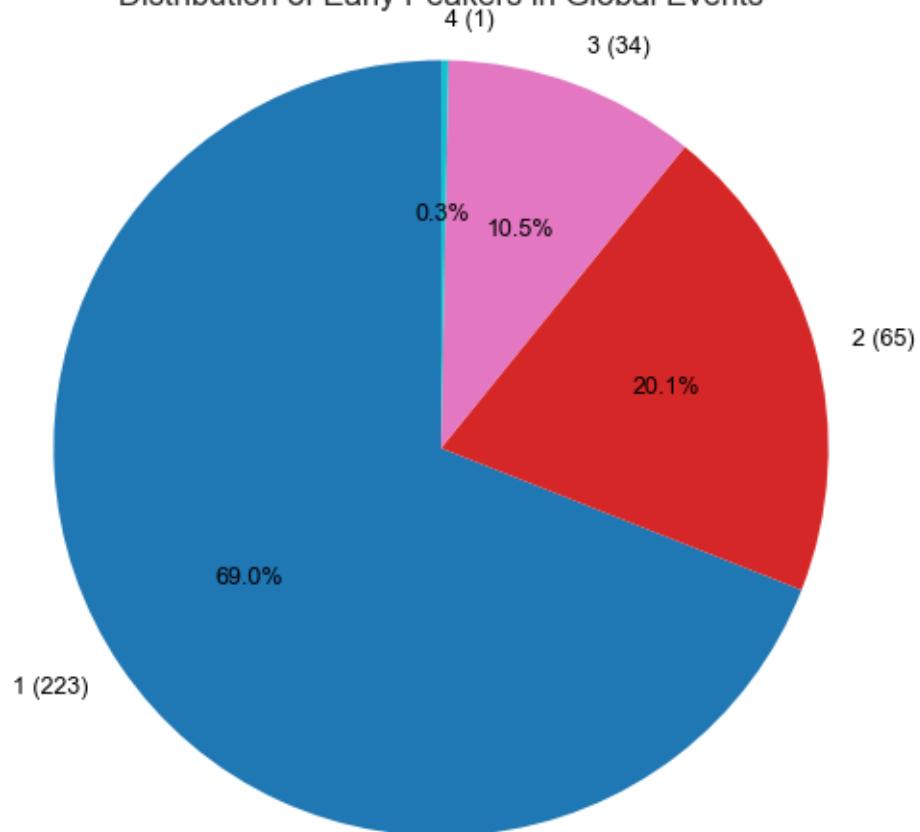


```
[2025-08-27 14:59:51] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 1, 1],  
           [0, 1, 1, 1],  
           [0, 1, 1, 1],  
           ...,  
           [1, 0, 0, 0],  
           [1, 0, 0, 0],  
           [1, 0, 0, 0]])
```



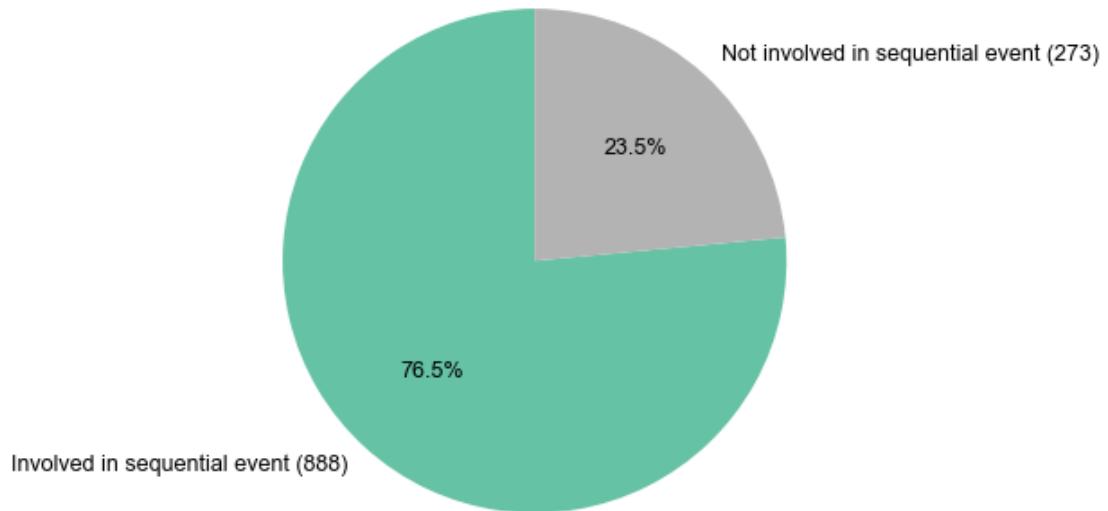
Distribution of Early Peakers in Global Events



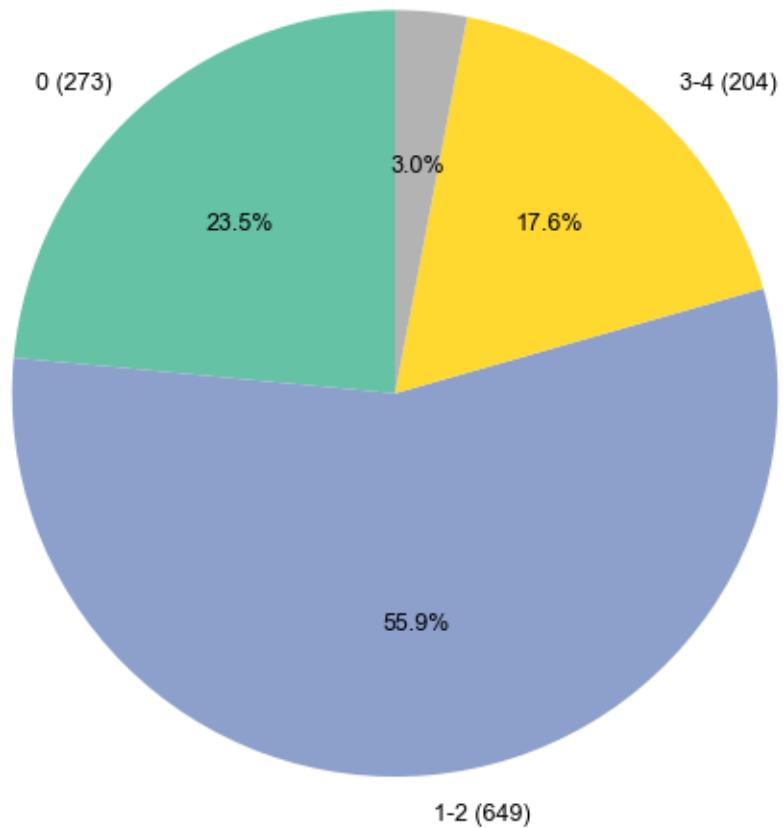
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

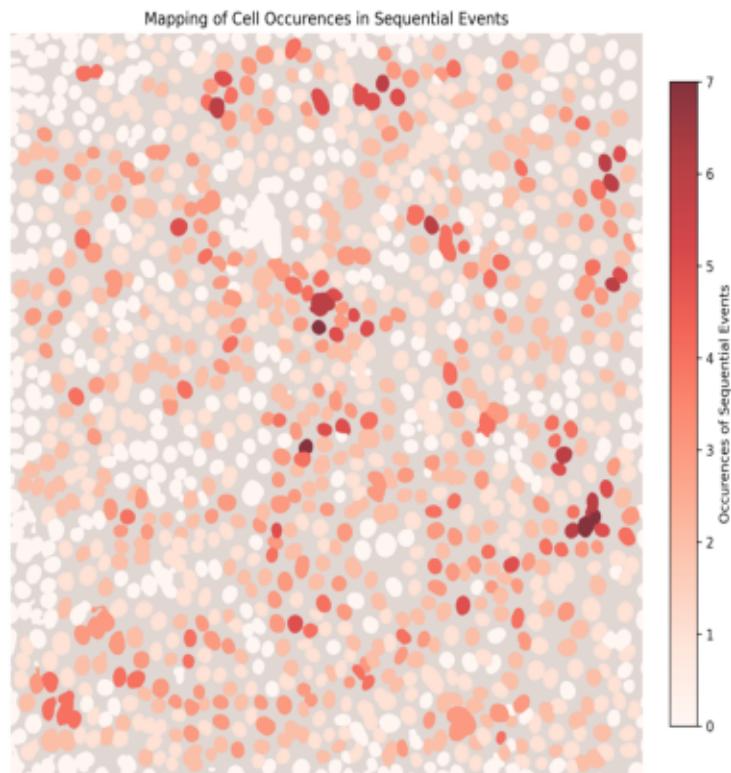
Distribution of Cells Involved in Sequential Events



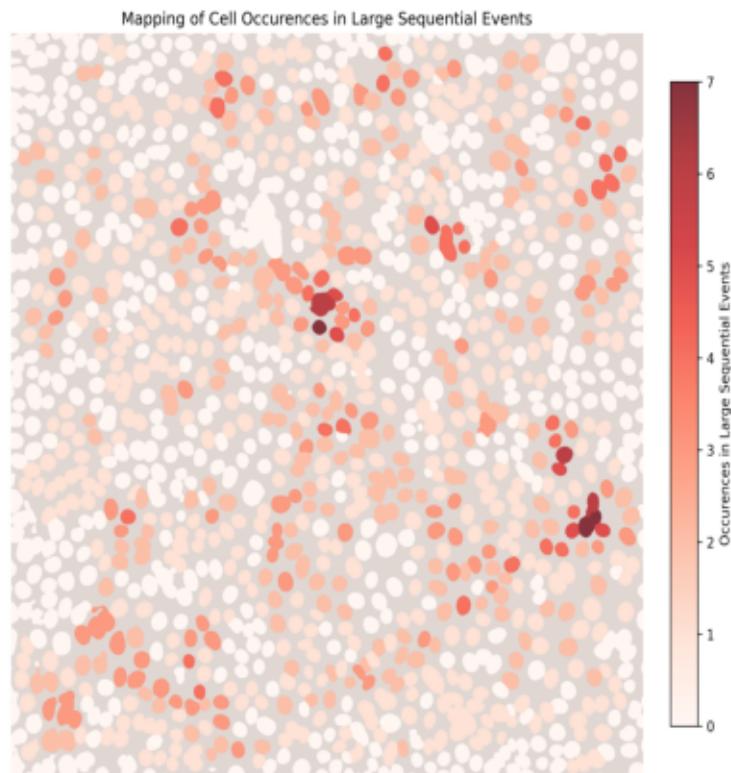
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (35)



Cell Mapping with Occurrences in Sequential Events Overlay

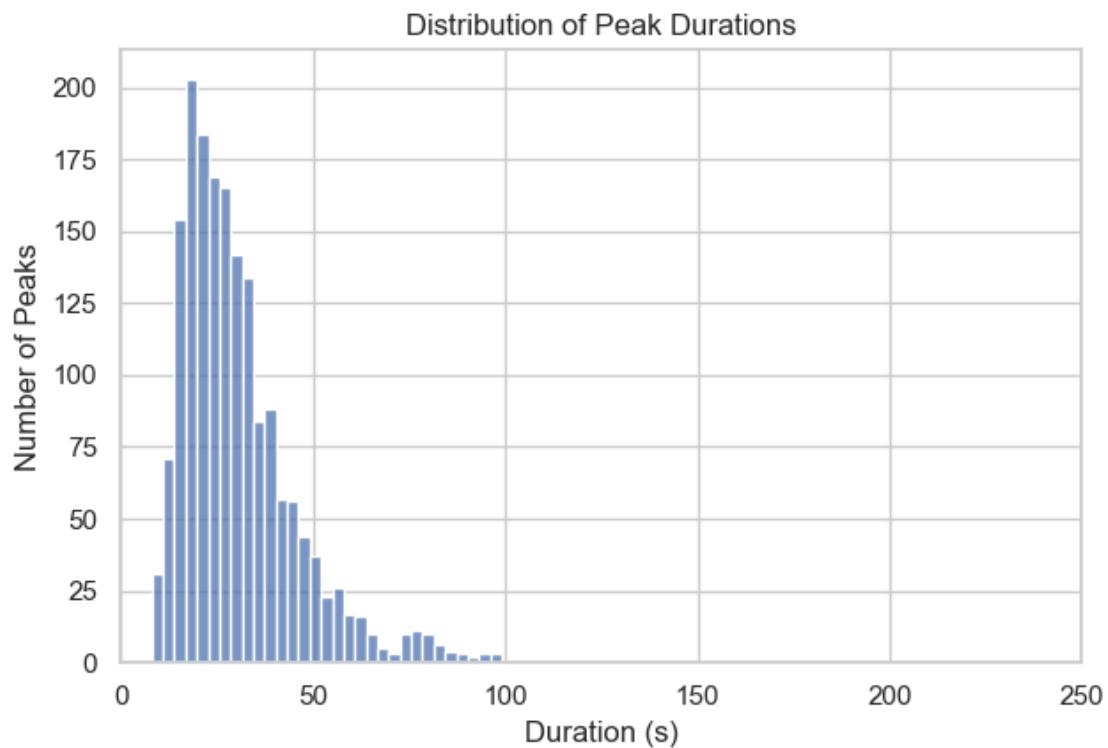


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



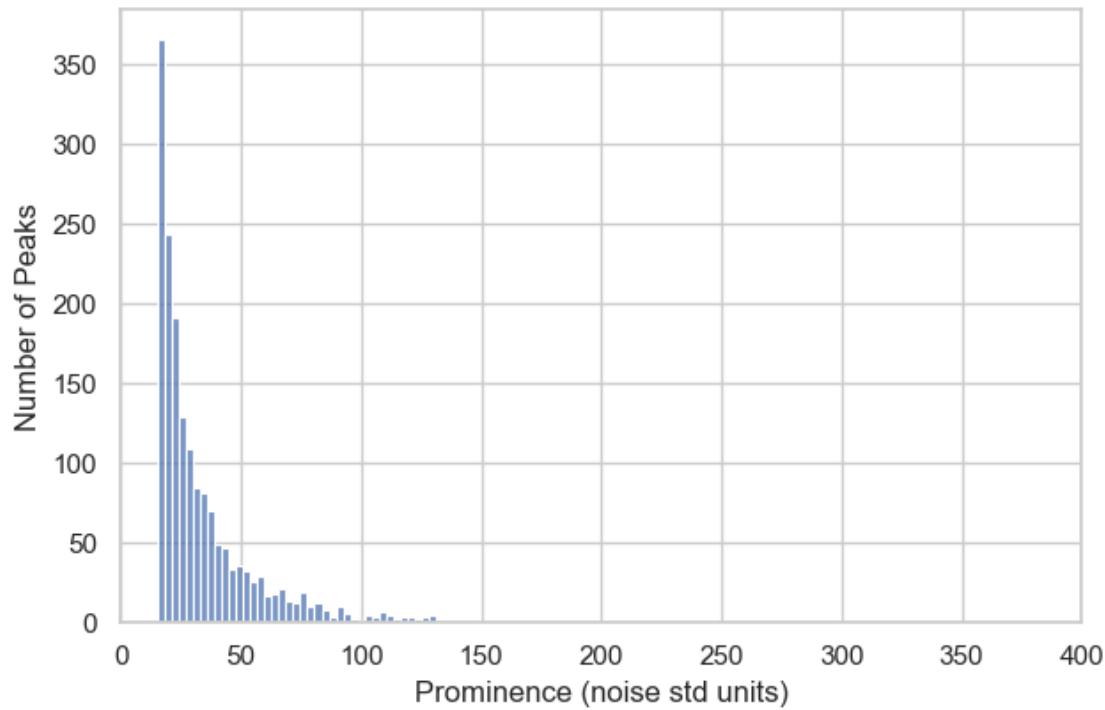
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:59:55] [INFO] calcium: plot_histogram: removed 33 outliers out of  
1804 on 'Duration (s)' (lower=-9.5, upper=104.5)
```

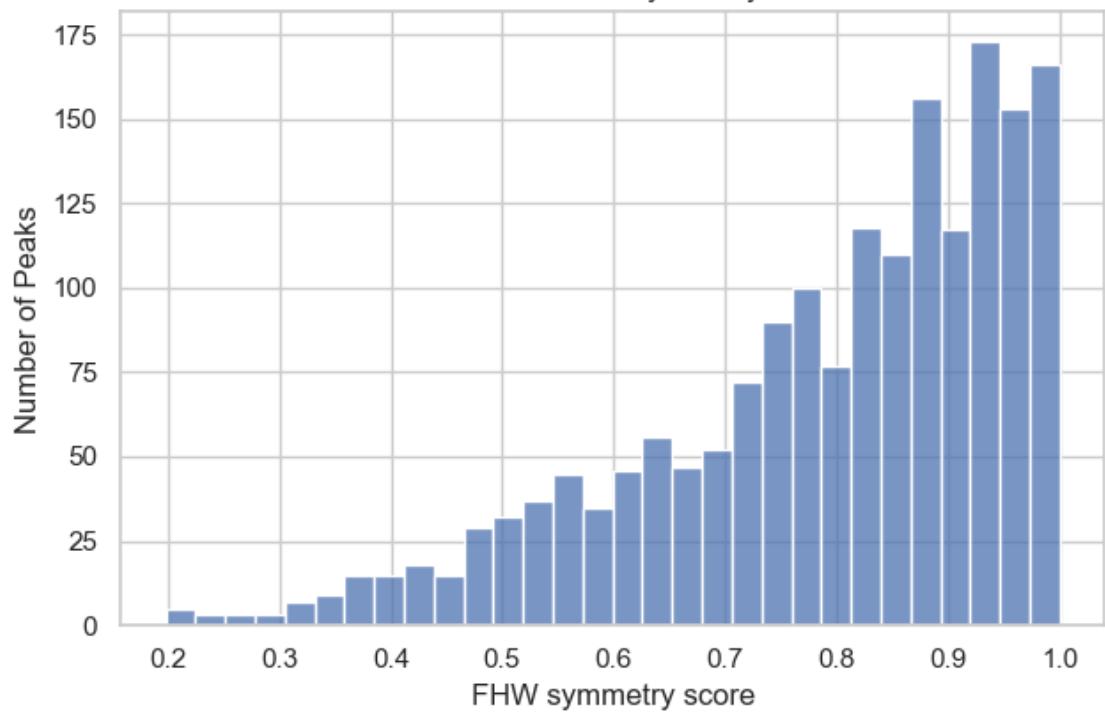


```
[2025-08-27 14:59:55] [INFO] calcium: plot_histogram: removed 85 outliers out of  
1804 on 'Prominence (noise std units)' (lower=-18.637, upper=131.51)
```

Distribution of Peak Prominences

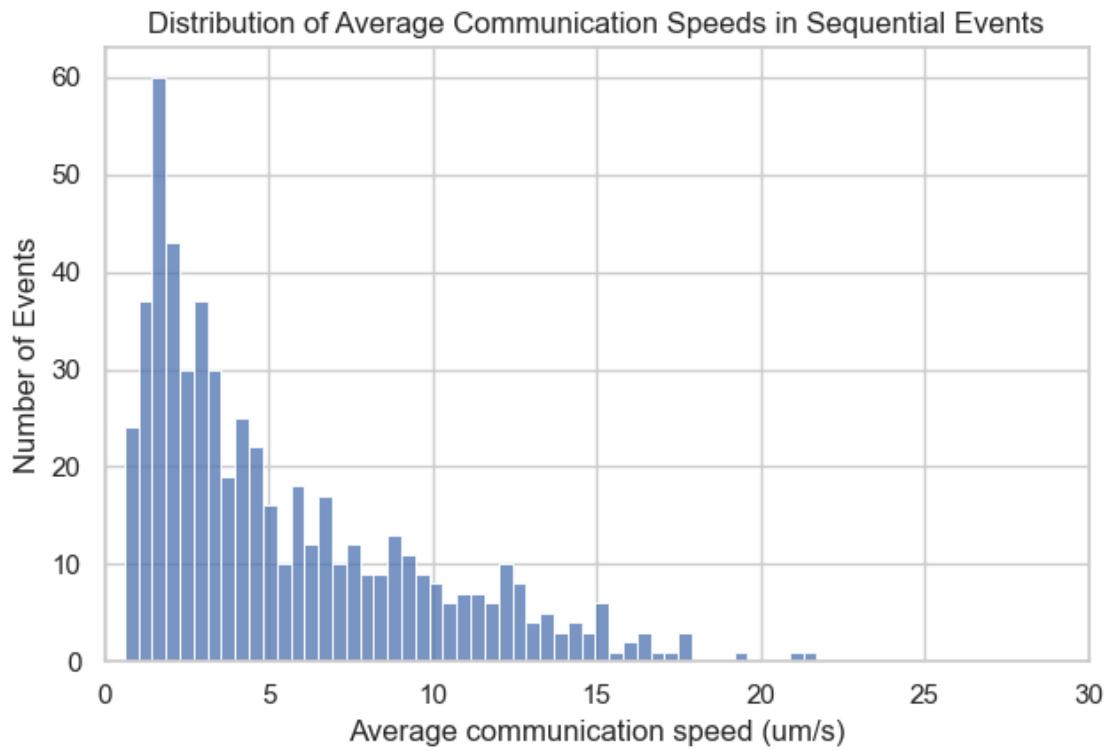


Distribution of Peak Symmetry Scores



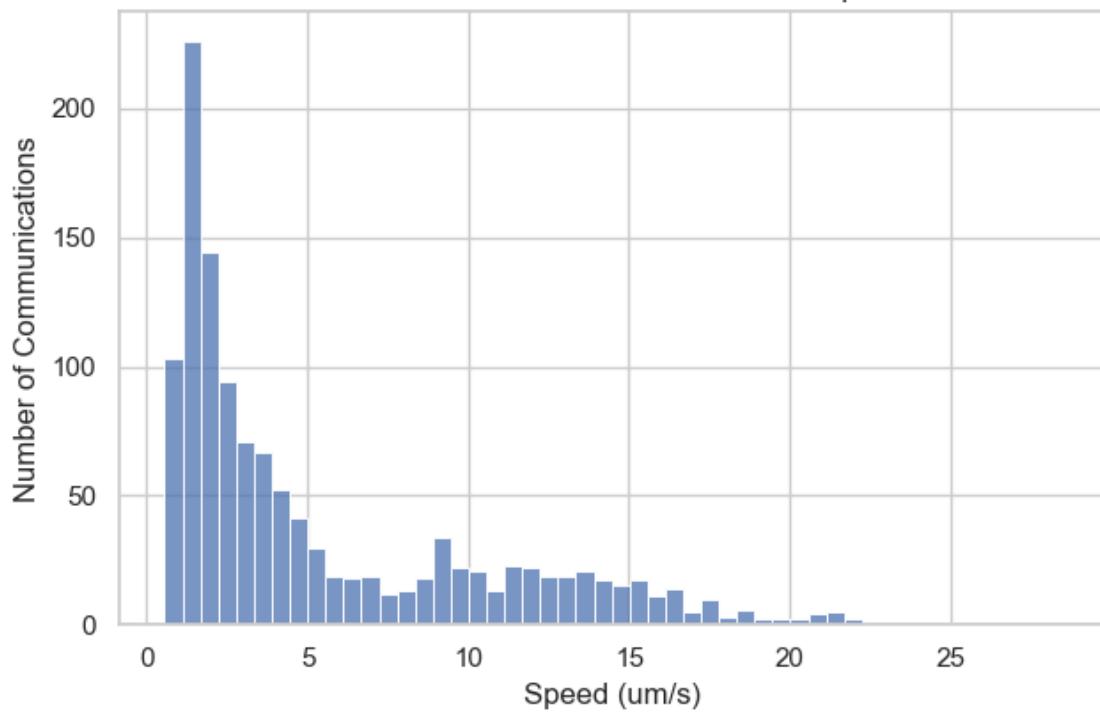
1.3.3 Cell-cell communication speed

```
[2025-08-27 14:59:55] [INFO] calcium: plot_histogram: removed 0 outliers out of  
564 on 'Average communication speed (um/s)' (lower=-15.005, upper=24.93)
```

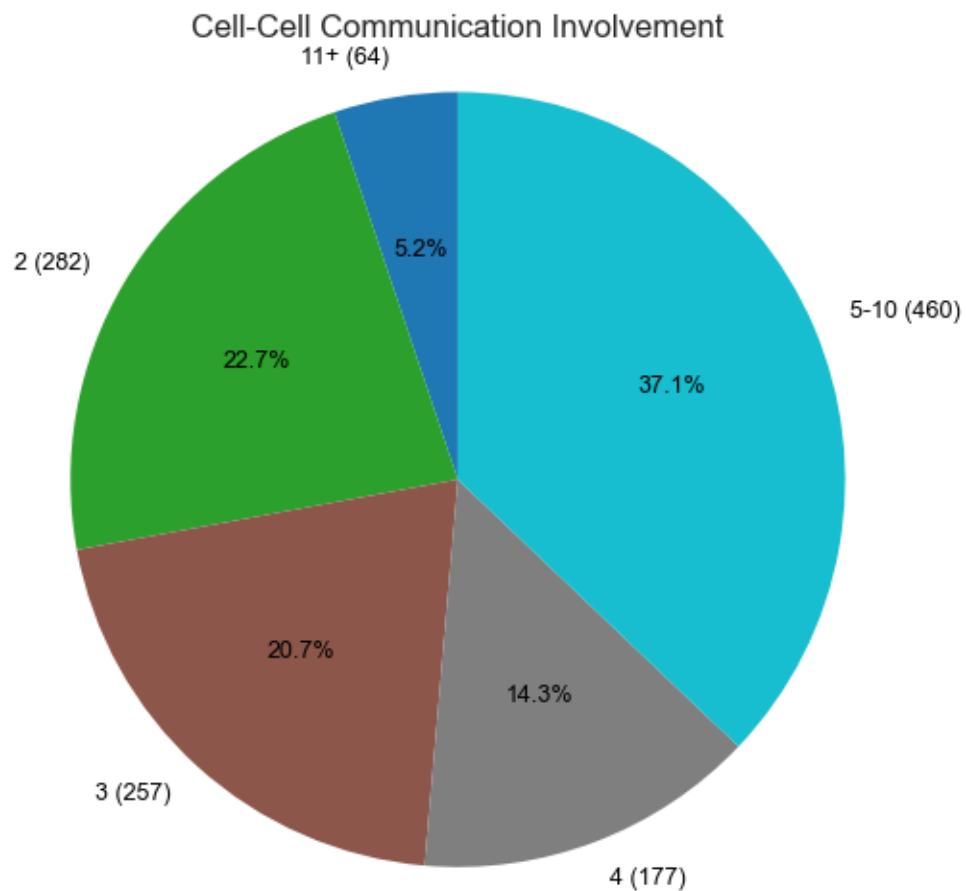


```
[2025-08-27 14:59:56] [INFO] calcium: plot_histogram: removed 0 outliers out of  
1240 on 'Speed (um/s)' (lower=-20.348, upper=45.578)
```

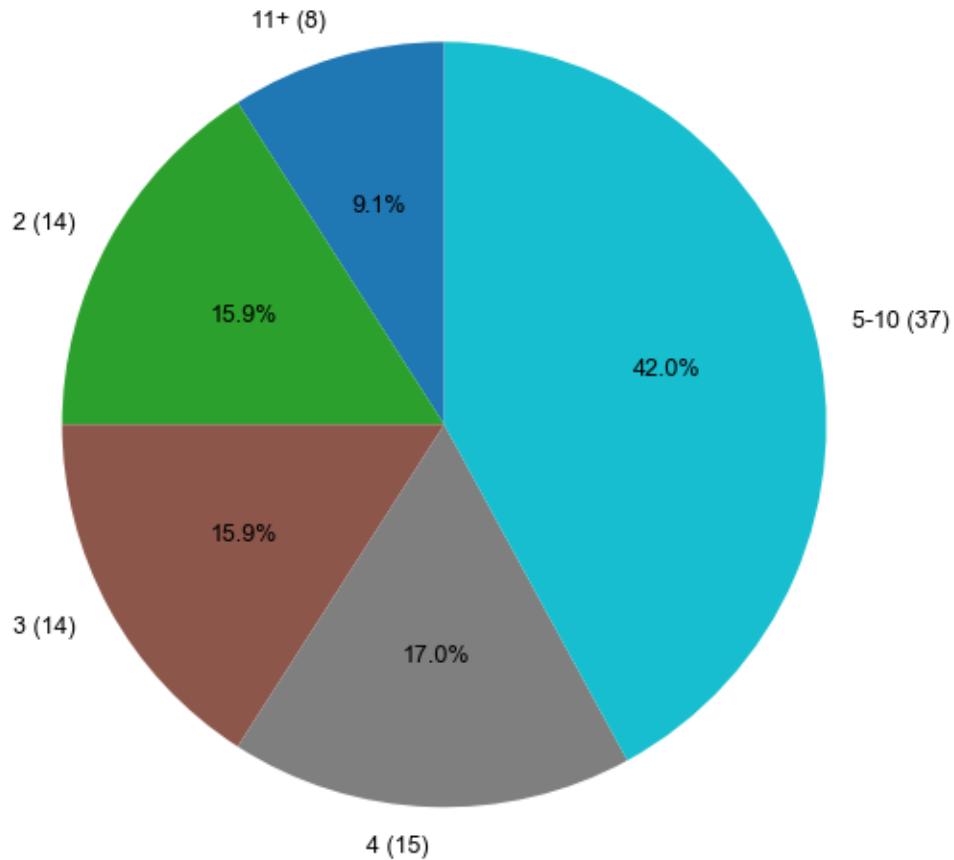
Distribution of Cell-Cell Communication Speeds



1.3.4 Double distribution in cell-cell communication speeds

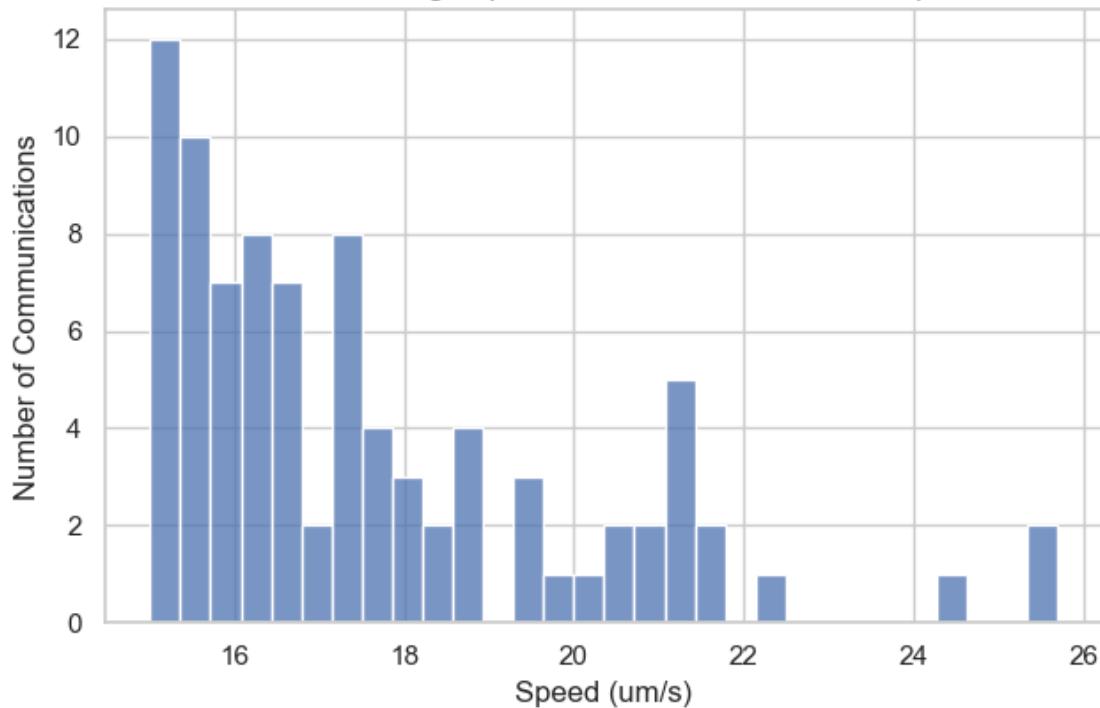


High Speed Cell-Cell Communication Involvement



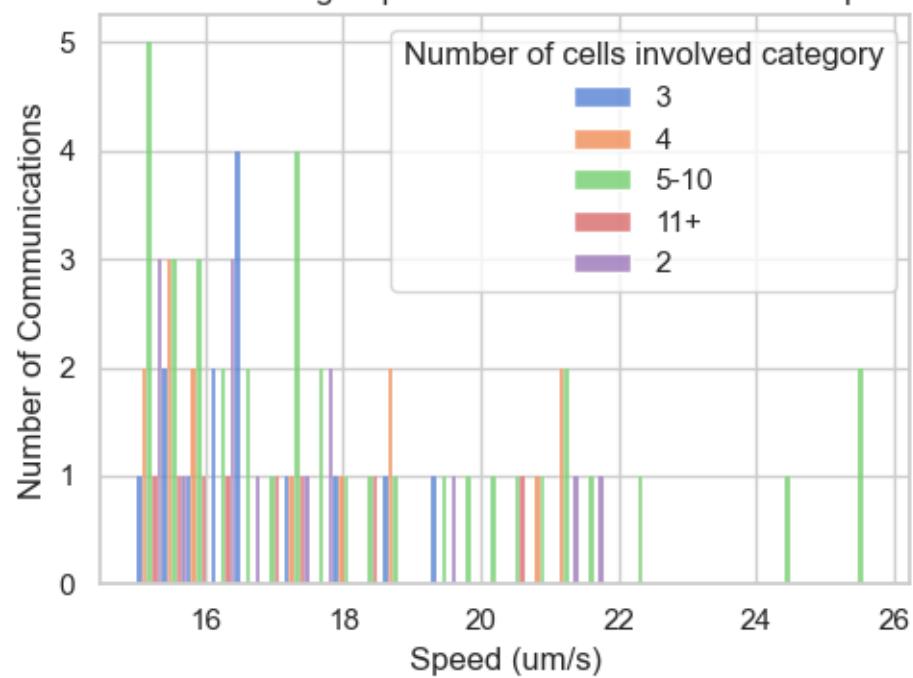
[2025-08-27 14:59:56] [INFO] calcium: plot_histogram: removed 1 outliers out of 88 on 'Speed (um/s)' (lower=6.4125, upper=28.182)

Distribution of High Speed Cell-Cell Communication Speeds

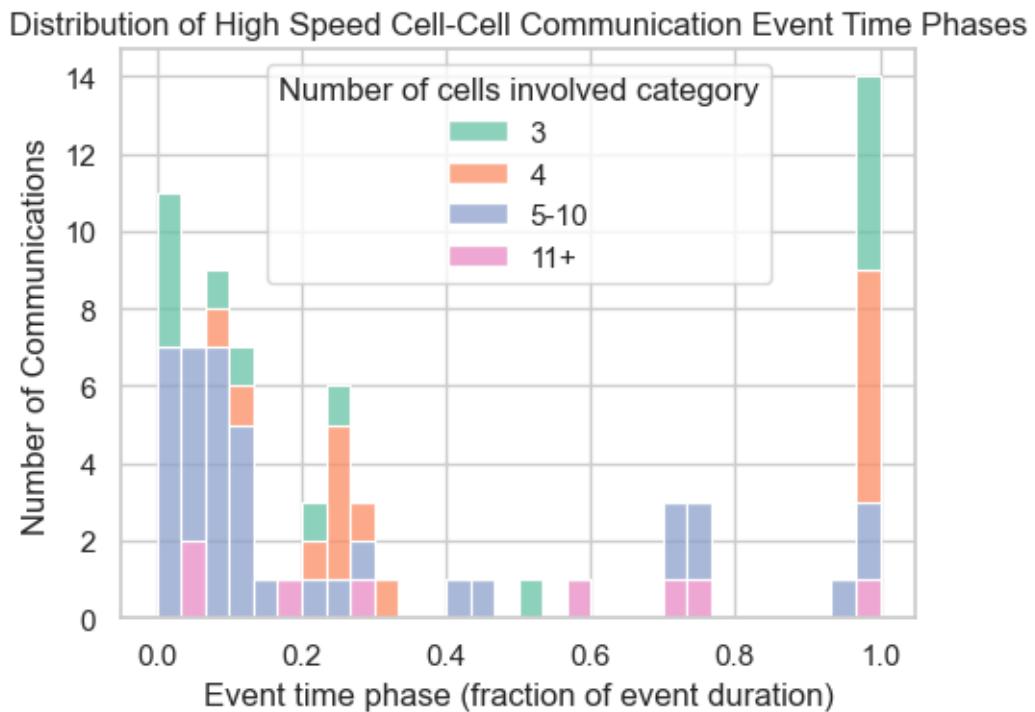


```
[2025-08-27 14:59:56] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 88 on 'Speed (um/s)' (lower=6.4125, upper=28.182)
```

Distribution of High Speed Cell-Cell Communication Speeds

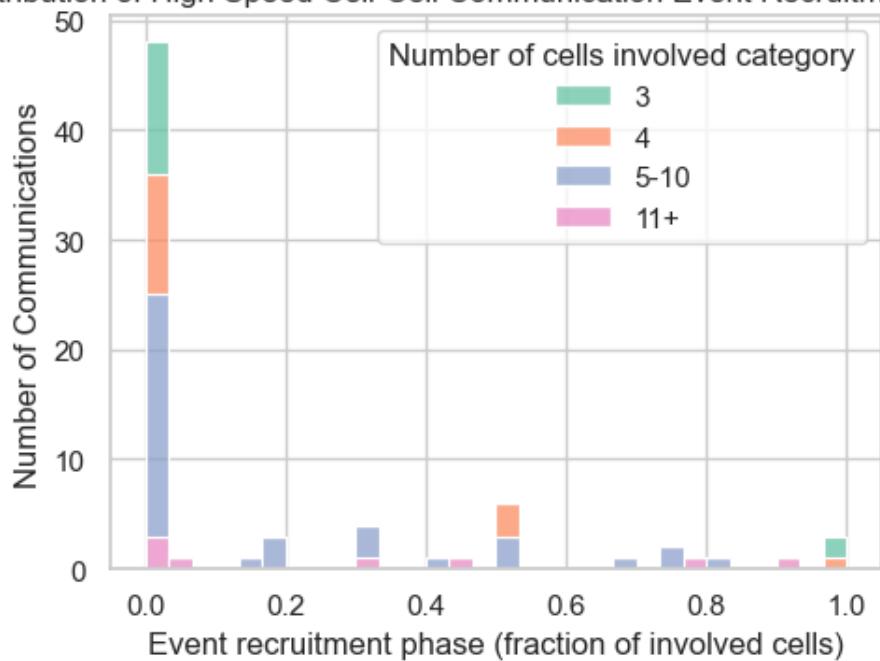


[2025-08-27 14:59:57] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 74 on 'Event time phase (fraction of event duration)' (lower=-1.85, upper=2.63)

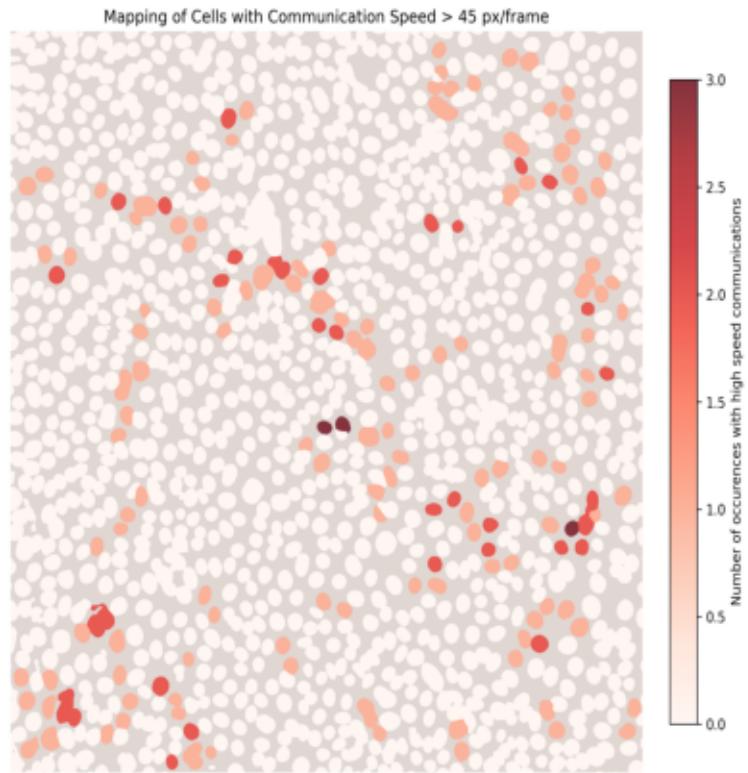


[2025-08-27 14:59:57] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 74 on 'Event recruitment phase (fraction of involved cells)' (lower=-0.99, upper=1.32)

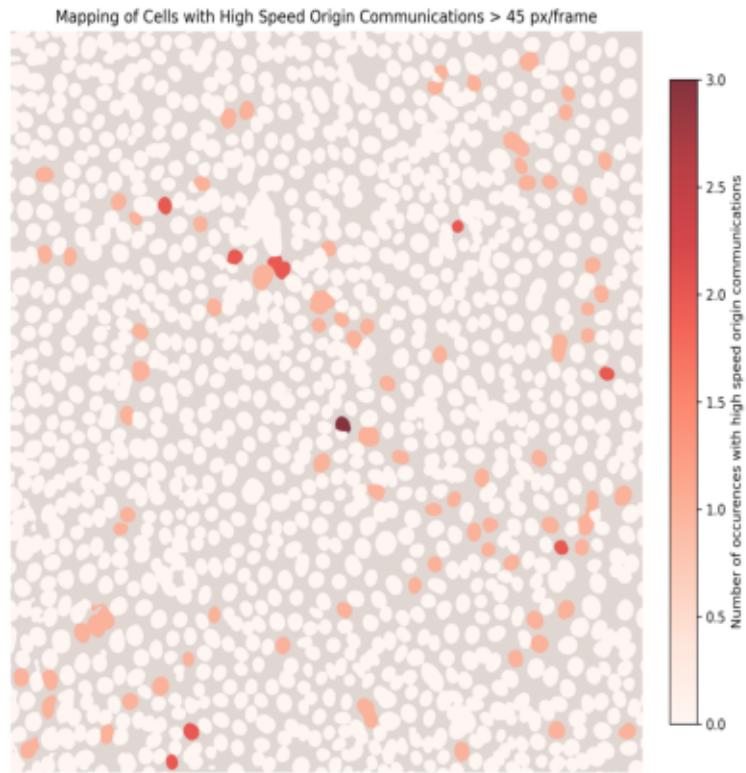
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
4	3015538601184	6	1676	6	
17	3015538598880	10	1272	2	
18	3015538590480	11	1563	0	
19	3015538593936	11	1530	0	
21	3015538591632	11	1479	1	
...	
1169	3015517823344	517	1726	1	
1170	3015517827712	517	1726	1	
1175	3015524066080	520	1604	0	
1188	3015524069824	527	1725	3	
1192	3015517824400	531	1721	0	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
4	1678	7	1382.0	1382.0	
17	1225	2	165.0	165.0	
18	1530	0	220.0	220.0	
19	1445	1	220.0	220.0	
21	1514	1	221.0	221.0	
...	
1169	1686	1	100.0	101.0	
1170	1776	1	100.0	101.0	
1175	1657	0	31.0	32.0	
1188	1675	2	927.0	928.0	
1192	1681	0	188.0	189.0	
	Duration (s)	Distance (um)	Speed (um/s)		\
4	0.0	15.36	15.36		
17	0.0	16.03	16.03		
18	0.0	21.37	21.37		
19	0.0	25.70	25.70		
21	0.0	15.23	15.23		
...		
1169	1.0	15.69	15.69		
1170	1.0	20.94	20.94		
1175	1.0	16.25	16.25		
1188	1.0	16.75	16.75		
1192	1.0	15.44	15.44		
	Event time phase (fraction of event duration)				\
4			1.00		
17			1.00		
18			0.00		
19			0.00		
21			0.08		
...			...		
1169			0.25		
1170			0.25		
1175			0.07		
1188			NaN		
1192			NaN		
	Event recruitment phase (fraction of involved cells)		dataset		\
4		0.0	20250618_IS1		
17		0.0	20250618_IS1		
18		0.0	20250618_IS1		
19		0.0	20250618_IS1		
21		0.5	20250618_IS1		
...			
1169		0.0	20250618_IS1		
1170		0.0	20250618_IS1		

1175		0.0	20250618_IS1
1188		NaN	20250618_IS1
1192		NaN	20250618_IS1

	Number of cells involved	category	Speed category
4		3	High speed
17		4	High speed
18		5-10	High speed
19		5-10	High speed
21		5-10	High speed
...
1169		4	High speed
1170		4	High speed
1175		3	High speed
1188		2	High speed
1192		2	High speed

[88 rows x 16 columns]

Speed category	High speed	Low speed
Origin cell ID		
194	0	1
202	0	1
204	0	4
214	0	1
218	0	1
...
1793	0	1
1794	0	1
1796	0	3
1797	2	0
1798	0	1

[621 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	194	108.23	5.85
6	202	323.05	8.78
8	204	222.62	9.75
16	214	338.00	12.35
19	218	295.43	13.33
...
1154	1793	366.93	491.07
1155	1794	419.25	491.40
1156	1796	451.43	491.40
1157	1797	127.08	491.73
1158	1798	145.93	492.38

Number of peaks Is active Occurrences in global events \

0	6	True	4
6	7	True	4
8	8	True	4
16	8	True	4
19	12	True	4
...
1154	7	True	4
1155	7	True	4
1156	6	True	4
1157	6	True	4
1158	6	True	4

Occurrences in global events as early peaker Early peaker event IDs \

0	0	[]
6	2	[3, 4]
8	0	[]
16	0	[]
19	2	[1, 3]
...
1154	1	[1]
1155	1	[1]
1156	0	[]
1157	0	[]
1158	0	[]

Occurrences in sequential events \

0	1
6	1
8	4
16	2
19	3
...	...
1154	1
1155	1
1156	2
1157	1
1158	2

Occurrences in sequential events as origin \

0	1
6	1
8	2
16	0
19	1
...	...
1154	1
1155	1
1156	2

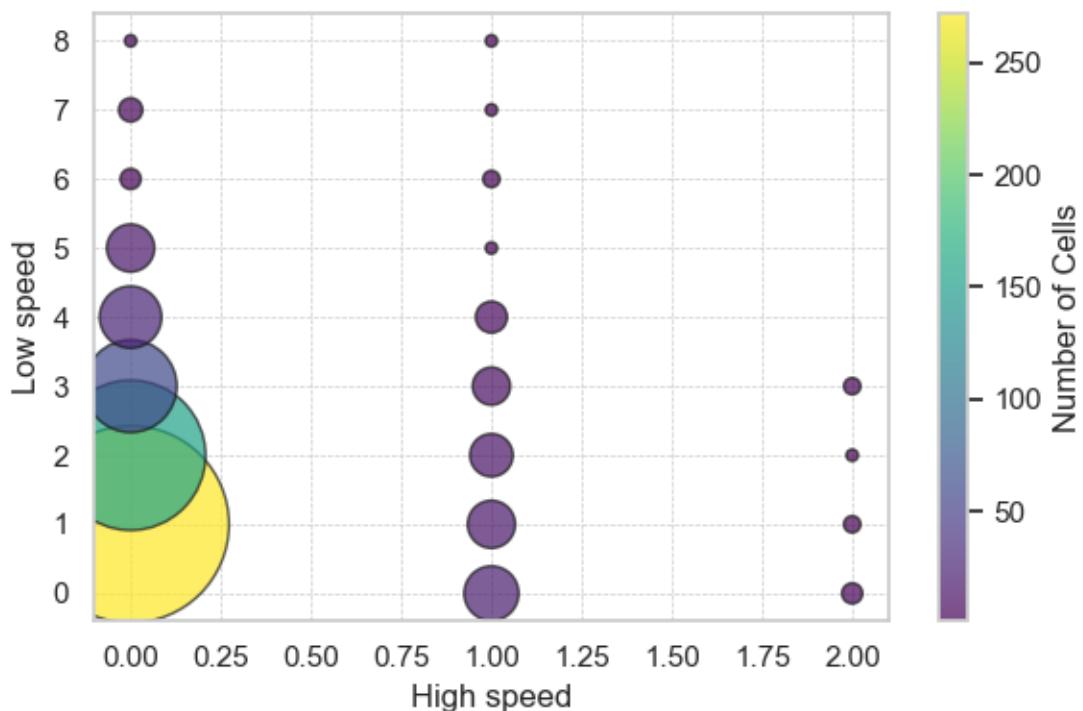
1157		1		
1158		1		
Occurrences in individual events Peak frequency (Hz) \				
0		1	0.0035	
6		1	0.0041	
8		0	0.0047	
16		2	0.0047	
19		2	0.0071	
...	
1154		1	0.0041	
1155		1	0.0041	
1156		0	0.0035	
1157		1	0.0035	
1158		0	0.0035	
Periodicity score Neighbor count Neighbors (labels) dataset \				
0	0.77	4	[199,212,226,241]	20250618_IS1
6	0.66	3	[214,221,247]	20250618_IS1
8	0.63	3	[222,224,256]	20250618_IS1
16	0.78	4	[202,242,247,253]	20250618_IS1
19	0.53	4	[209,221,246,273]	20250618_IS1
...
1154	0.60	2	[1751,1774]	20250618_IS1
1155	0.67	3	[1752,1768,1791]	20250618_IS1
1156	0.74	4	[1729,1765,1785,1804]	20250618_IS1
1157	0.75	4	[1766,1770,1782,1798]	20250618_IS1
1158	0.72	3	[1770,1776,1797]	20250618_IS1
Involved in sequential event Occurrences in sequential events category \				
0	Involved in sequential event			1-2
6	Involved in sequential event			1-2
8	Involved in sequential event			3-4
16	Involved in sequential event			1-2
19	Involved in sequential event			3-4
...
1154	Involved in sequential event			1-2
1155	Involved in sequential event			1-2
1156	Involved in sequential event			1-2
1157	Involved in sequential event			1-2
1158	Involved in sequential event			1-2
High speed Low speed				
0	0.0	1.0		
6	0.0	1.0		
8	0.0	4.0		
16	0.0	1.0		
19	0.0	1.0		

```

...
1154      0.0      1.0
1155      0.0      1.0
1156      0.0      3.0
1157      2.0      0.0
1158      0.0      1.0

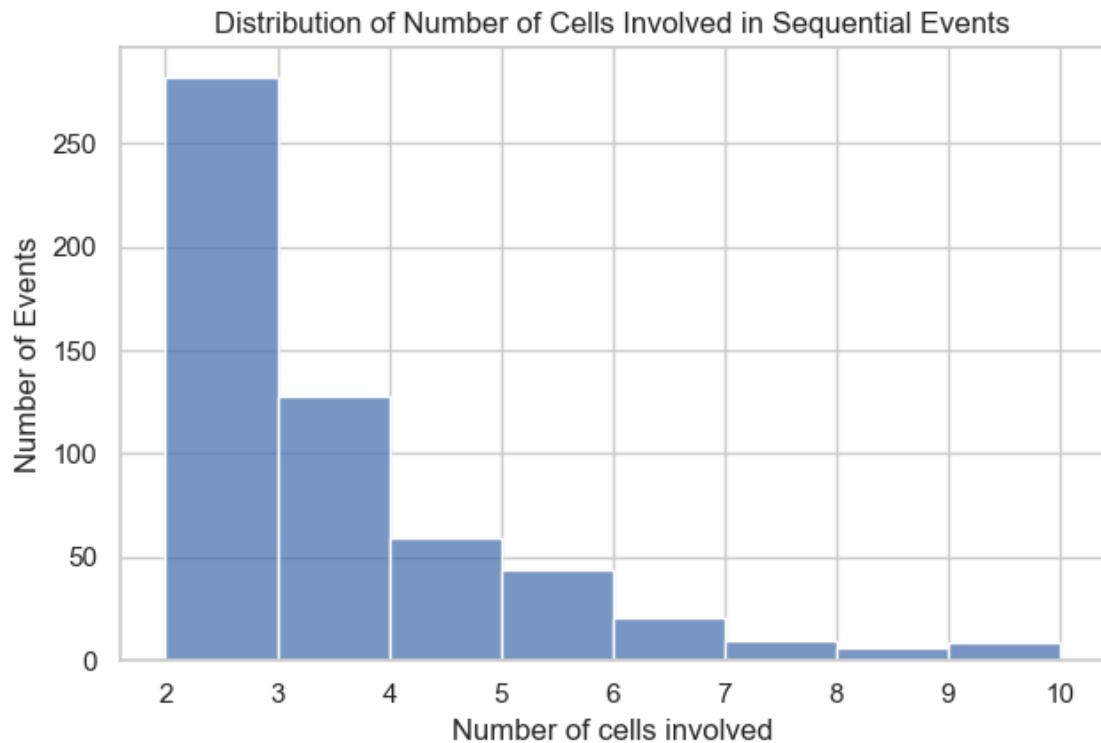
```

[621 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

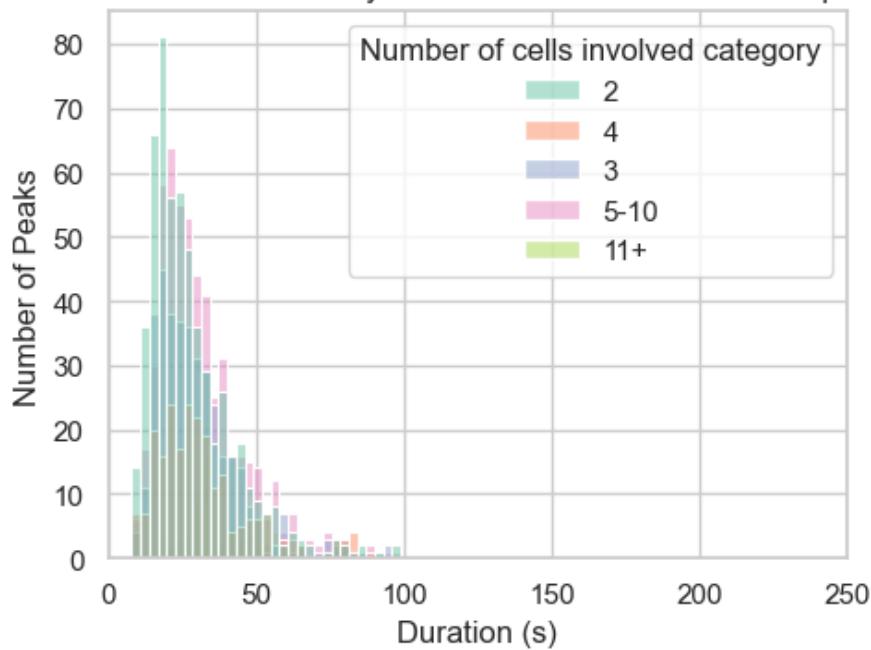
[2025-08-27 14:59:59] [INFO] calcium: plot_histogram: removed 5 outliers out of 564 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

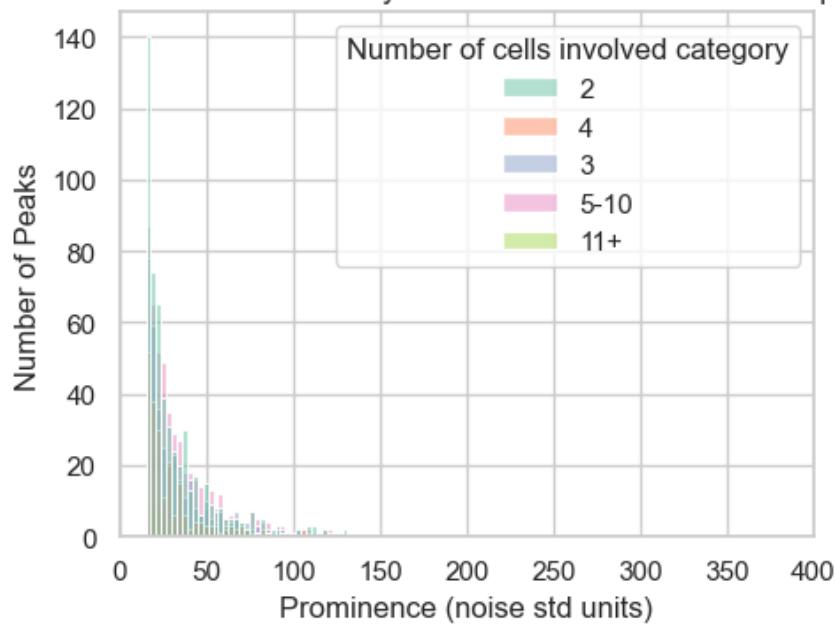
```
[2025-08-27 14:59:59] [INFO] calcium: plot_histogram_by_group: removed 33 outliers out of 1804 on 'Duration (s)' (lower=-9.5, upper=104.5)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

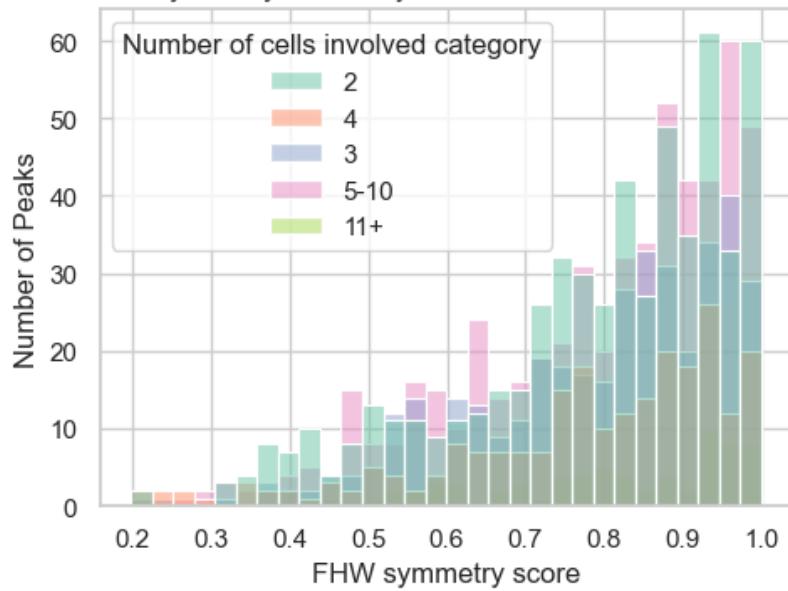


[2025-08-27 15:00:00] [INFO] calcium: plot_histogram_by_group: removed 85 outliers out of 1804 on 'Prominence (noise std units)' (lower=-18.637, upper=131.51)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

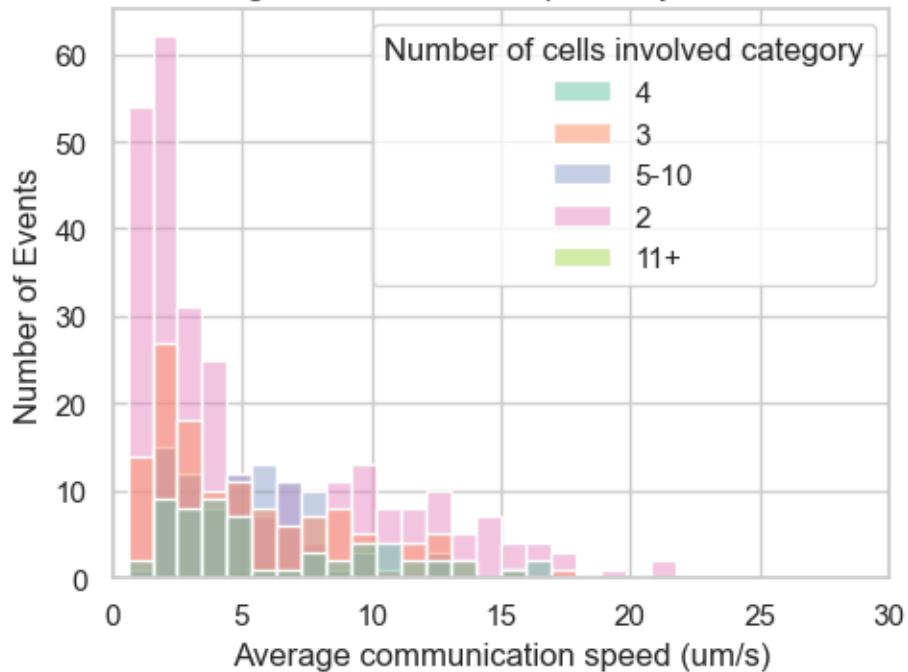


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



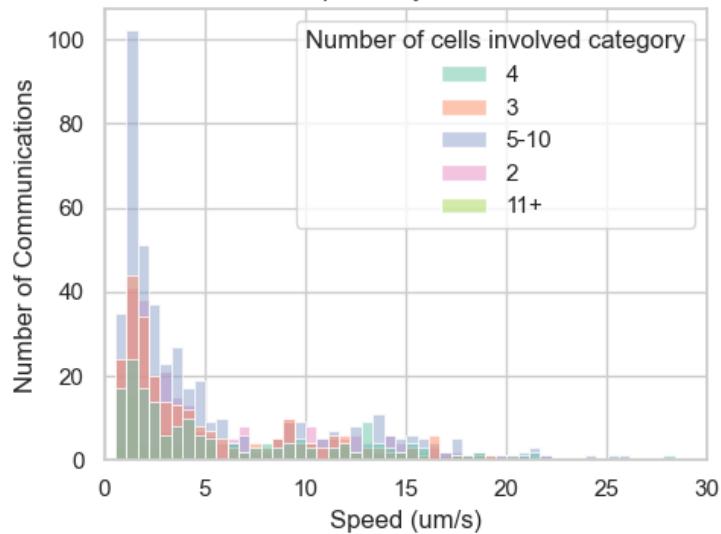
```
[2025-08-27 15:00:01] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 564 on 'Average communication speed (um/s)' (lower=-15.005, upper=24.93)
```

Distribution of Average Communication Speeds by Number of Cells Involved



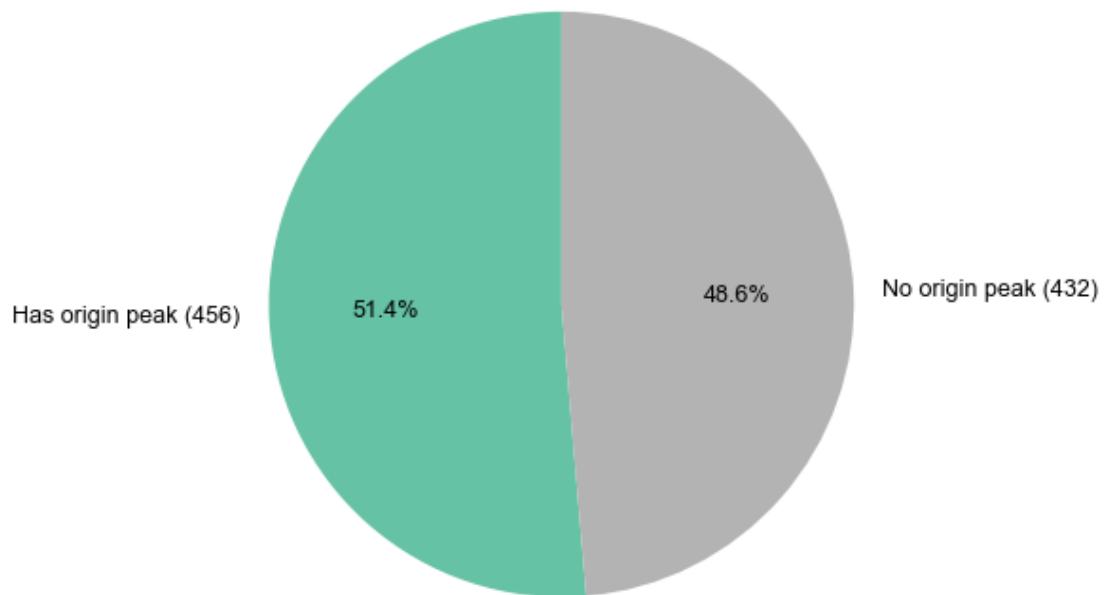
```
[2025-08-27 15:00:01] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1240 on 'Speed (um/s)' (lower=-20.348, upper=30.928)
```

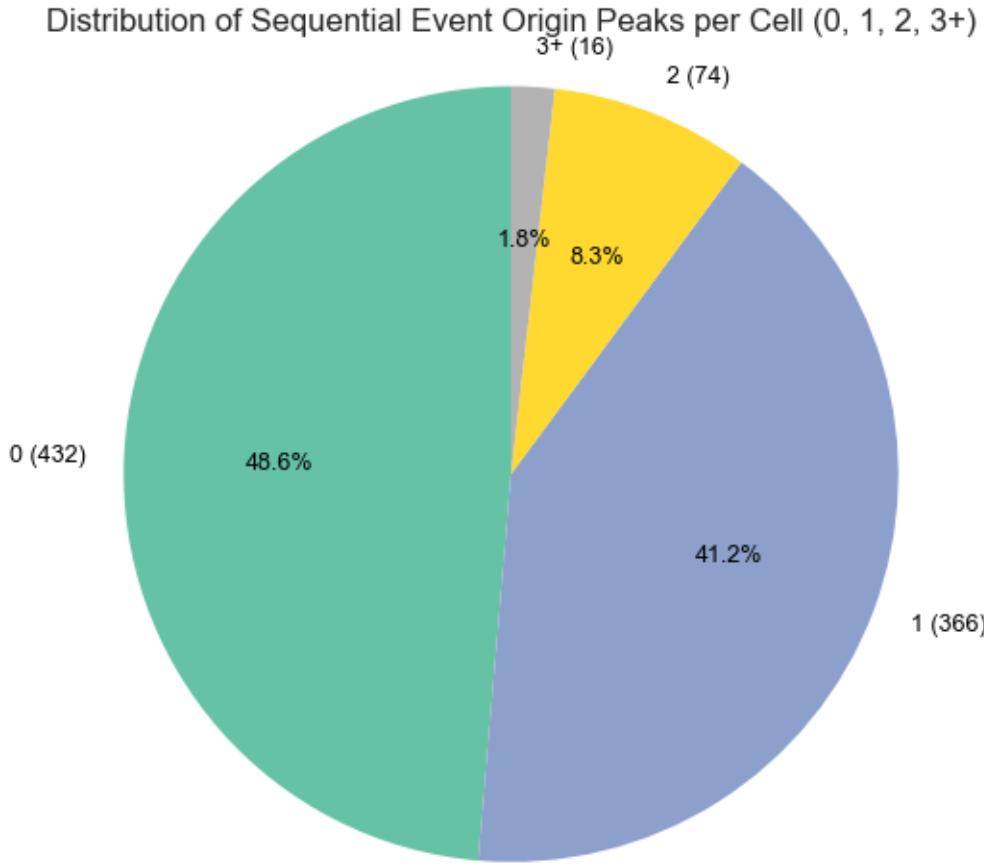
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

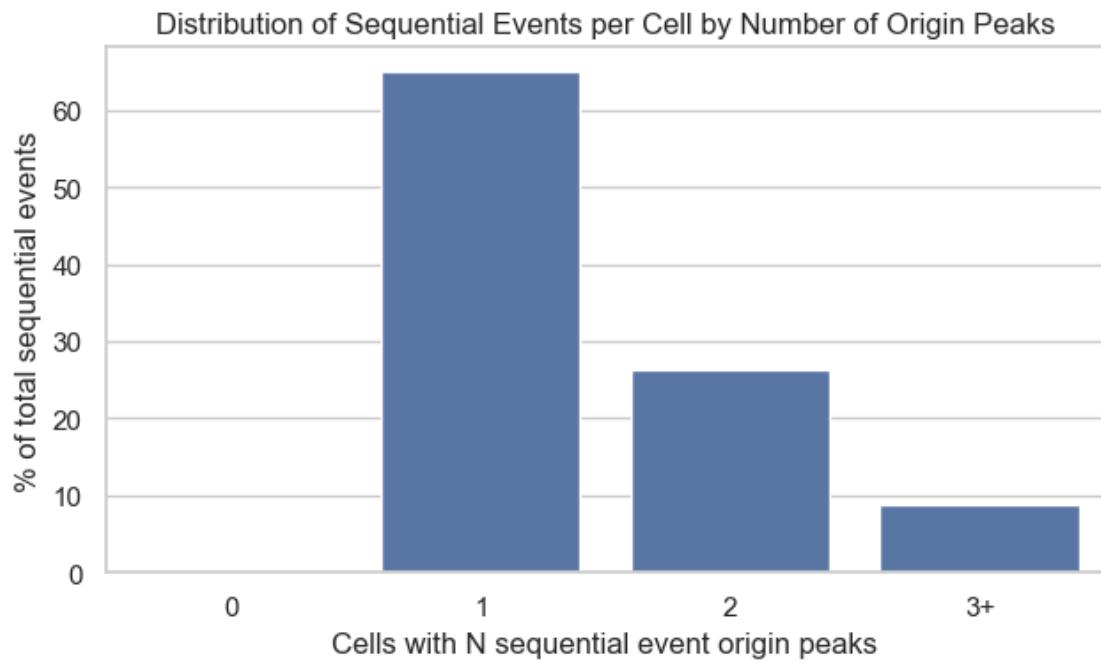
Distribution of Number of Sequential Event Origin Peaks per Cell





```
[2025-08-27 15:00:03] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS1\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

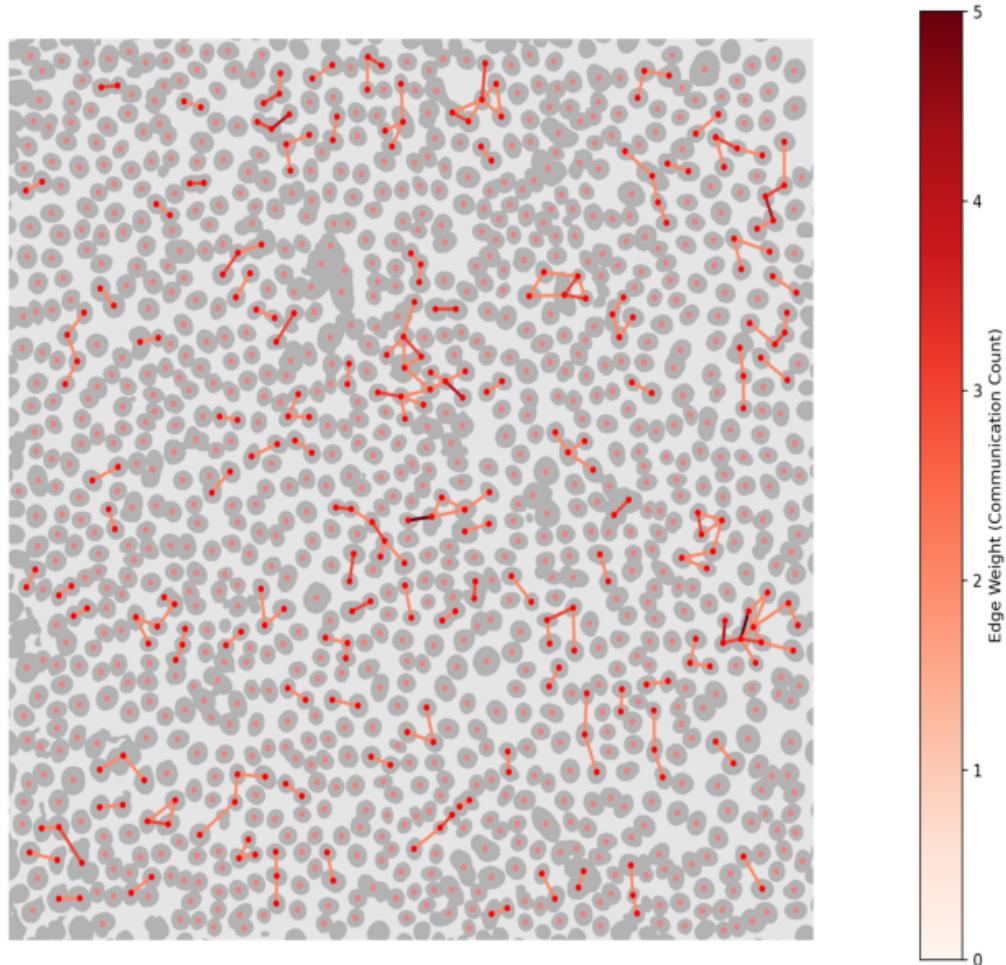
'D:\\Mateo\\20250618\\Output\\IS1\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'



1.3.8 Connection network between cells

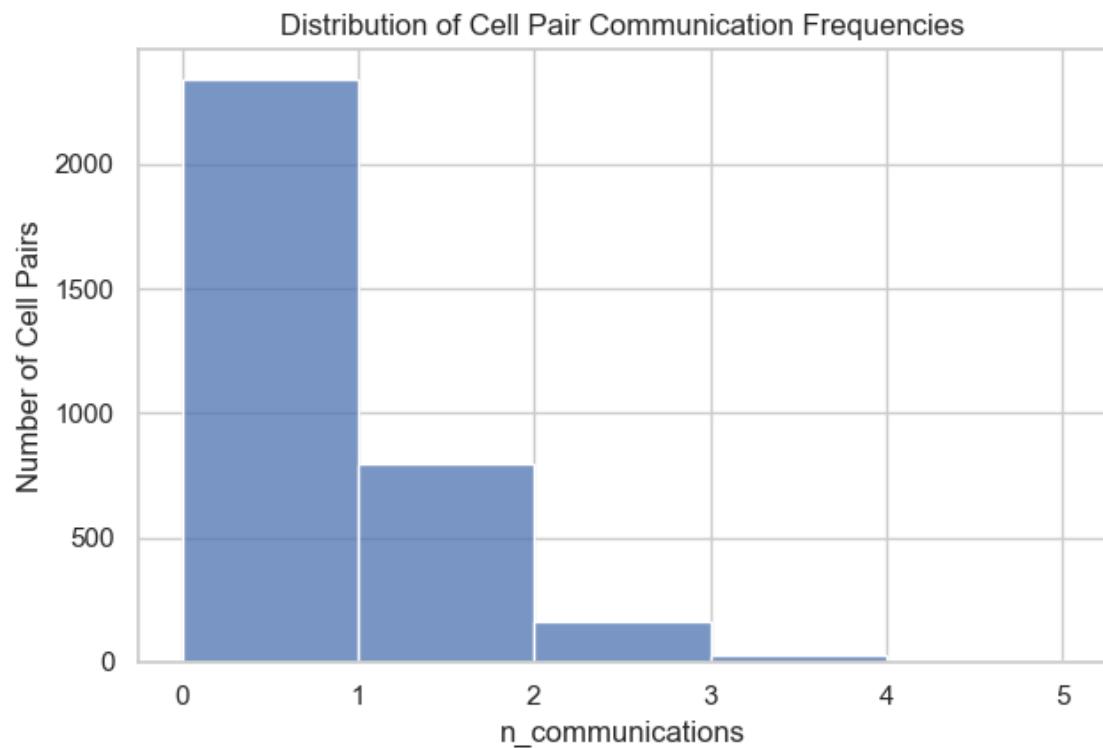
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



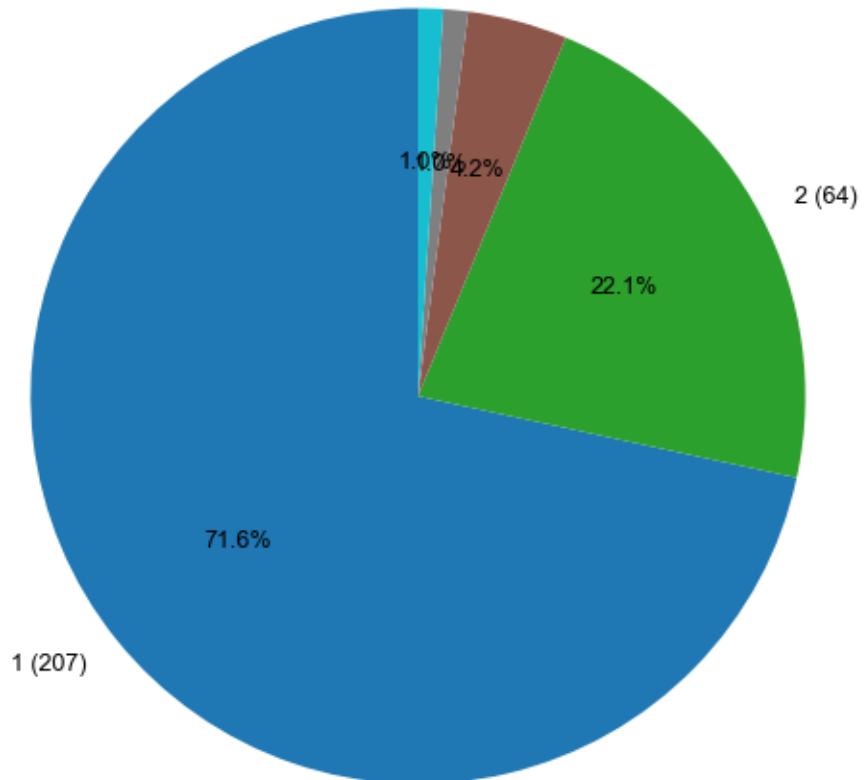
1.3.9 Pair/Trios with high communication networks

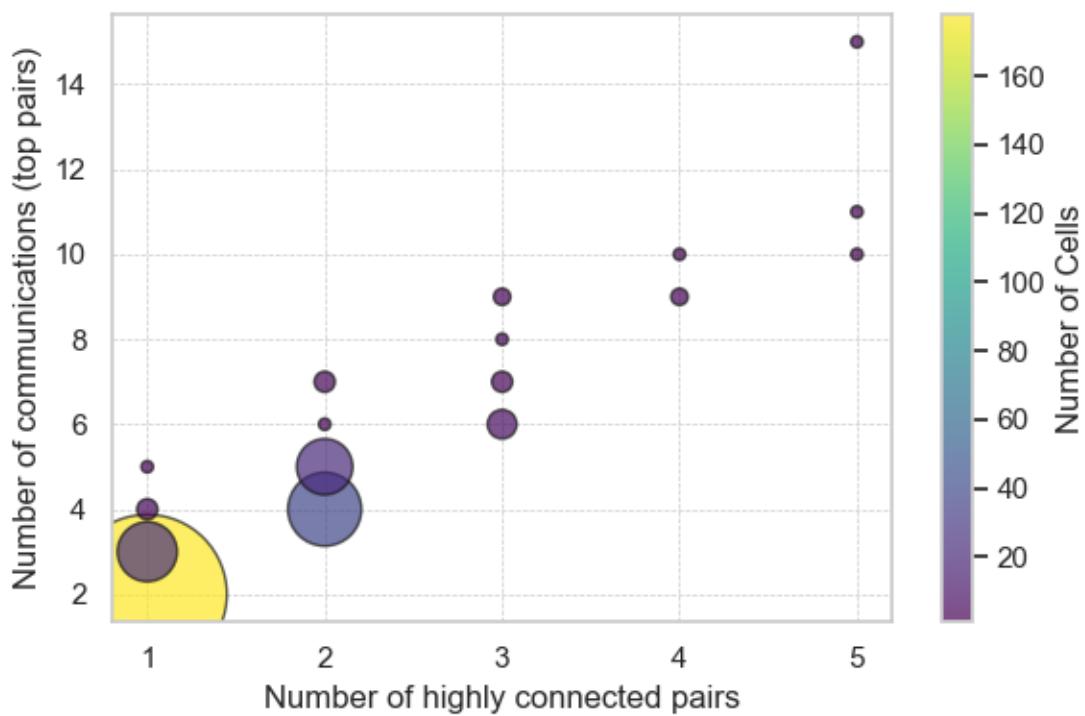
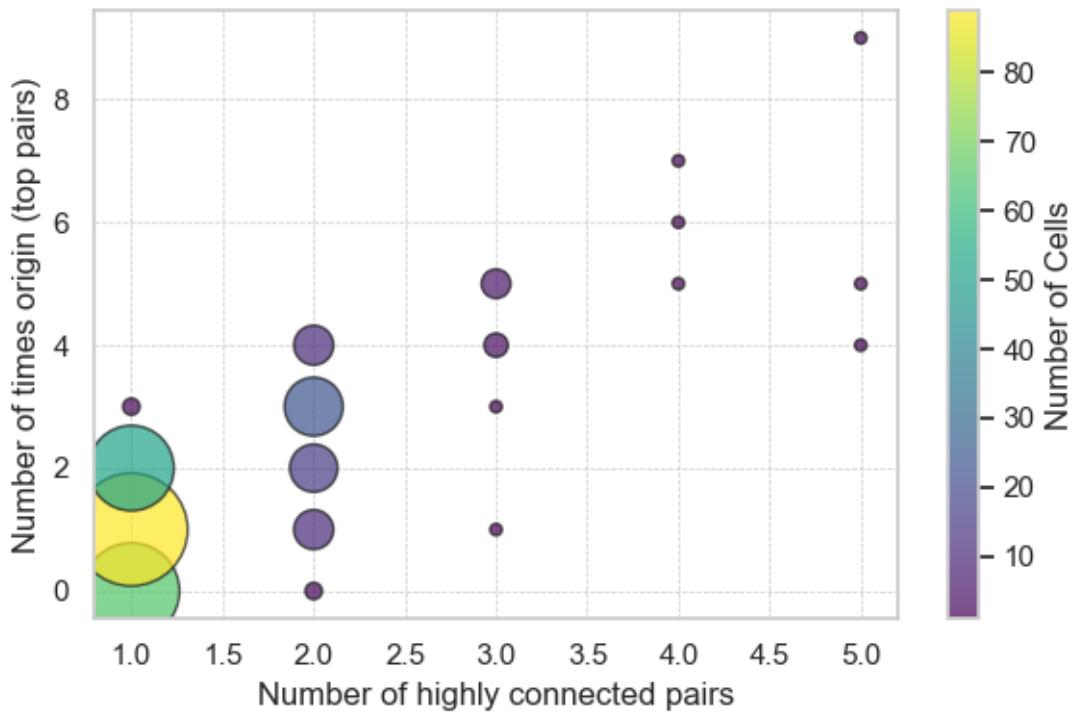
```
[2025-08-27 15:00:05] [INFO] calcium: build_neighbor_pair_stats: built 3337 pairs across 1 datasets (mean distance=15.99 um)
```

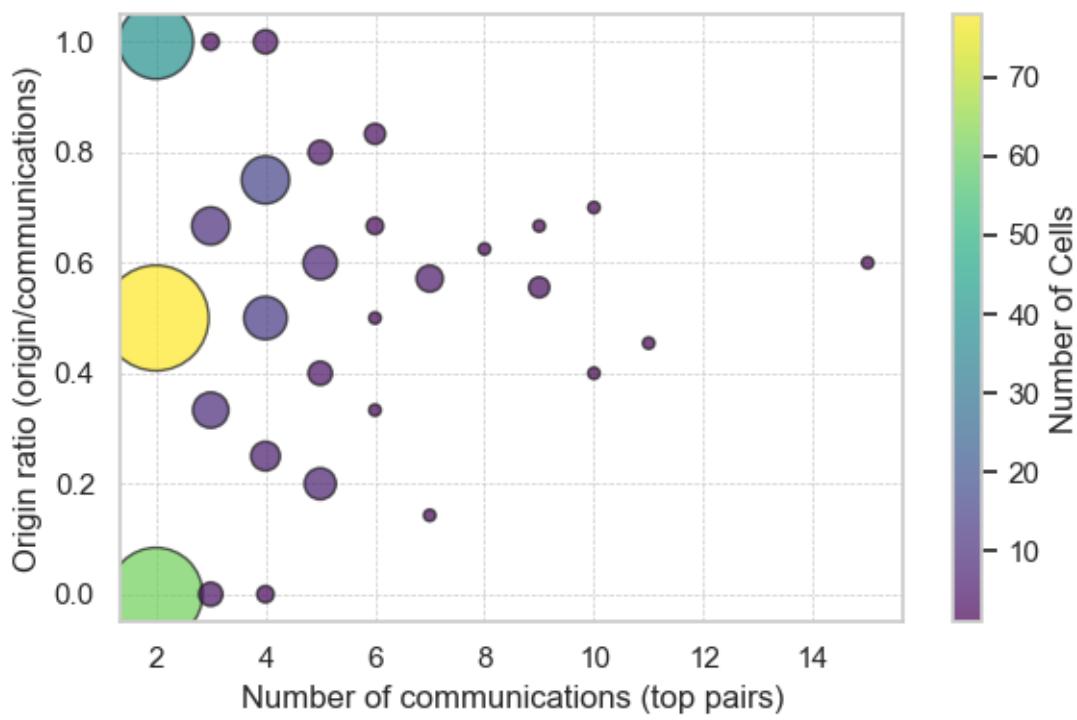
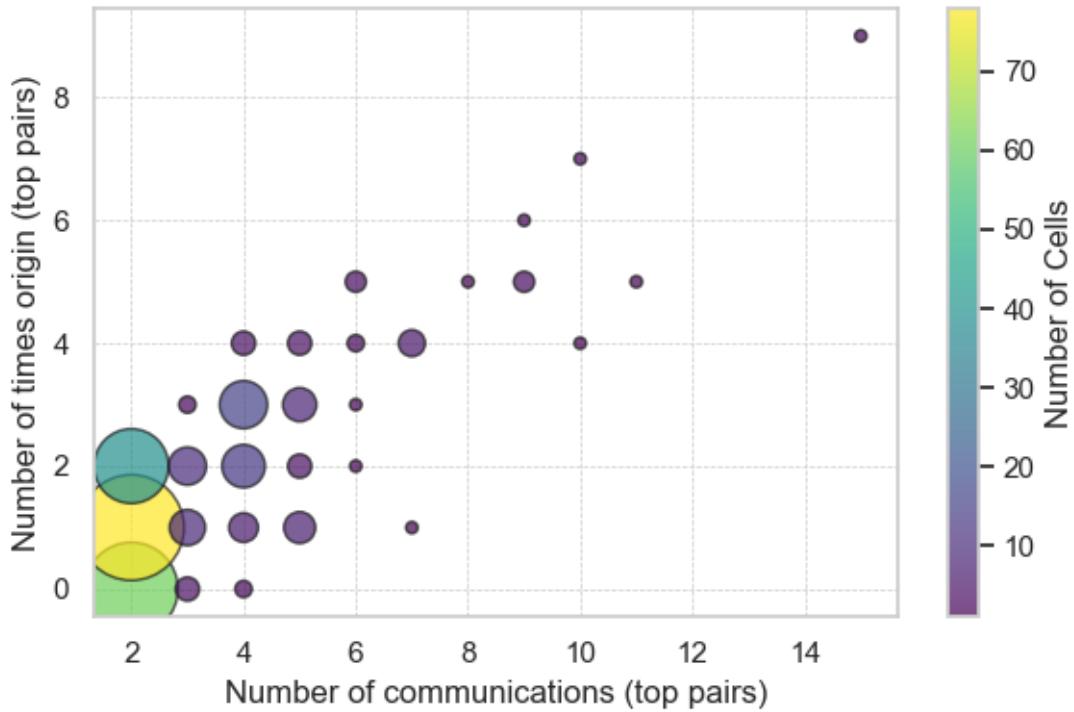


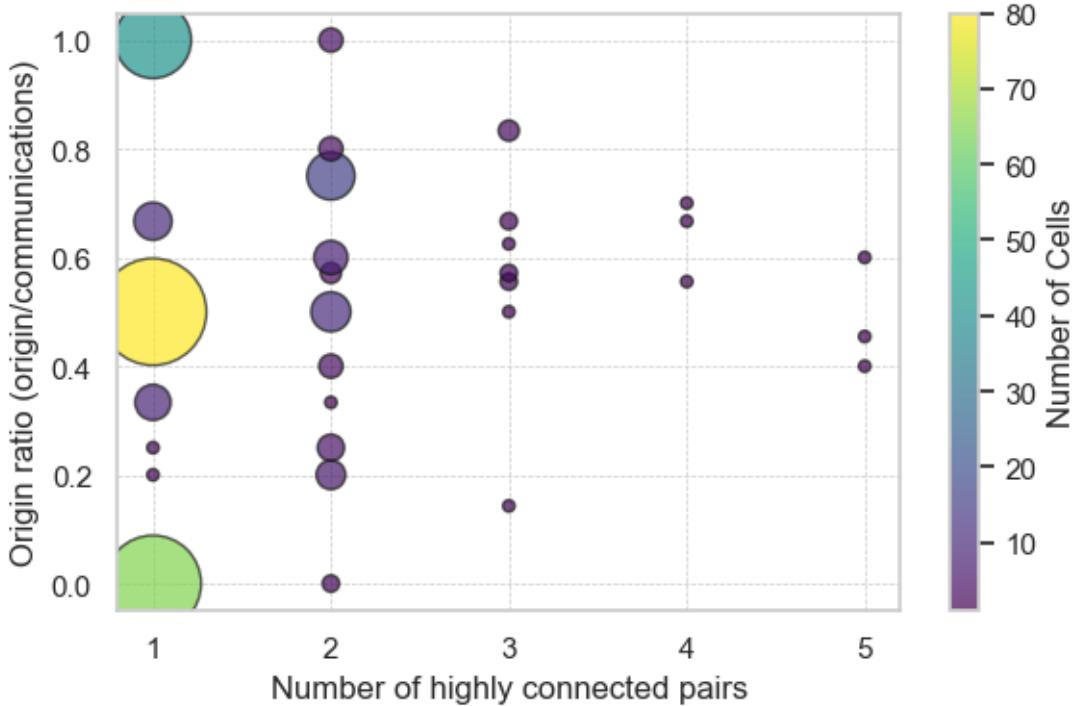
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected
5 (3)(3) 3 (12)









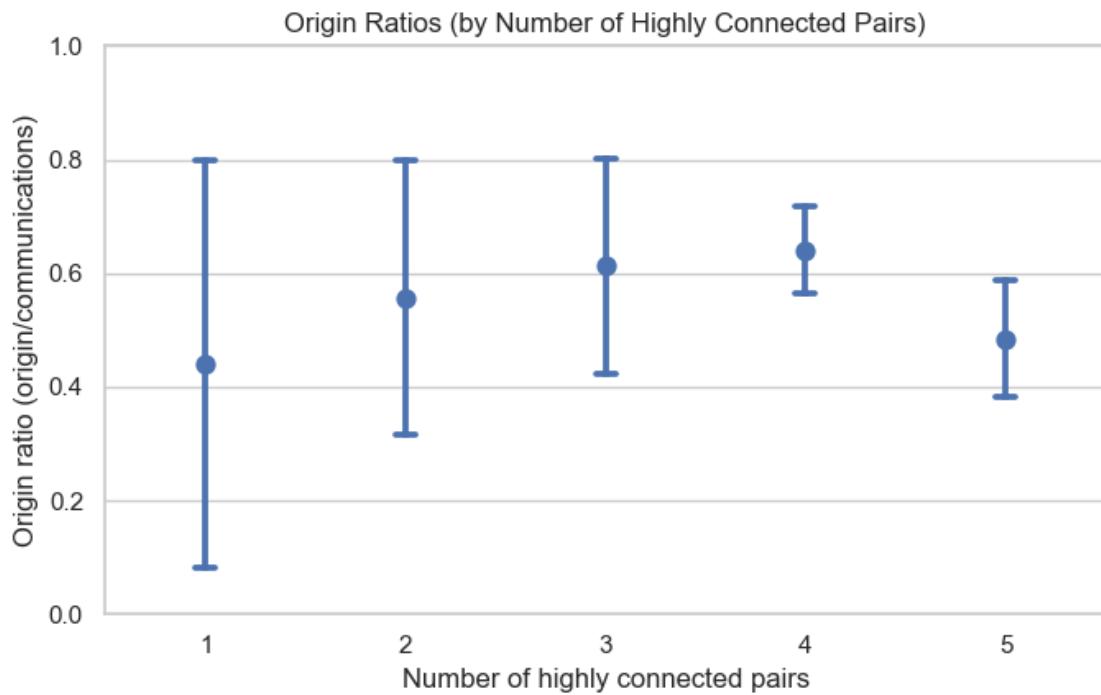
[2025-08-27 15:00:06] [INFO] calcium: plot_points_mean_std: N=207 for Number of highly connected pairs=1

[2025-08-27 15:00:06] [INFO] calcium: plot_points_mean_std: N=64 for Number of highly connected pairs=2

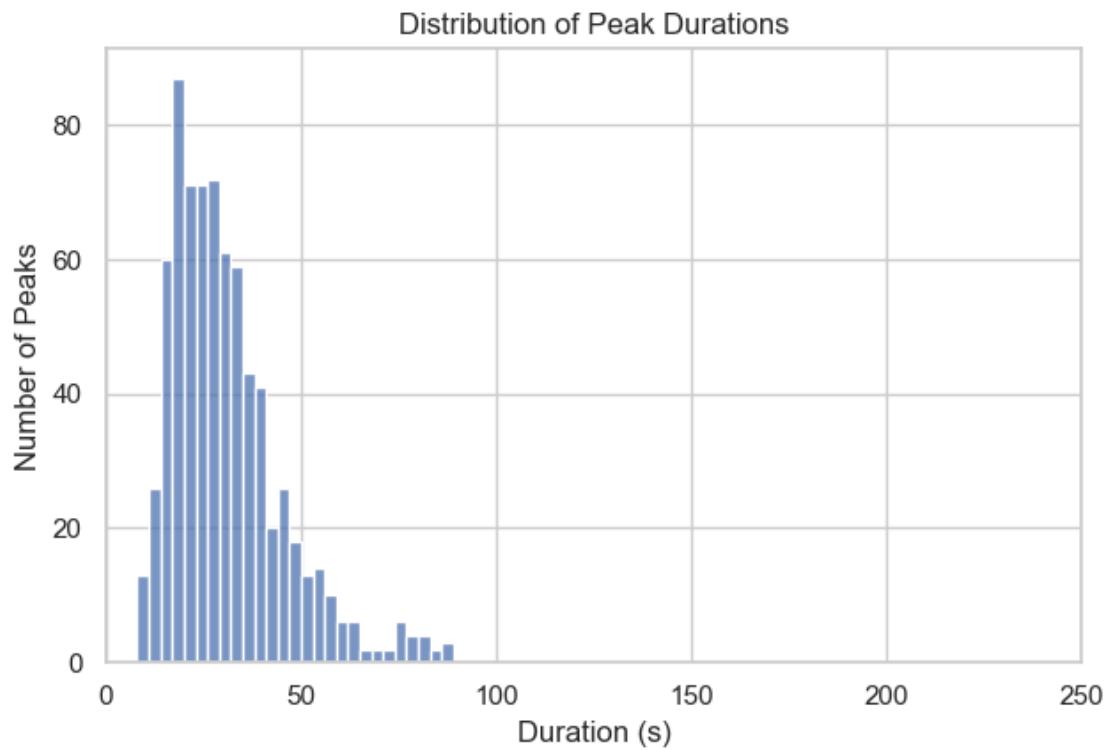
[2025-08-27 15:00:06] [INFO] calcium: plot_points_mean_std: N=12 for Number of highly connected pairs=3

[2025-08-27 15:00:06] [INFO] calcium: plot_points_mean_std: N=3 for Number of highly connected pairs=4

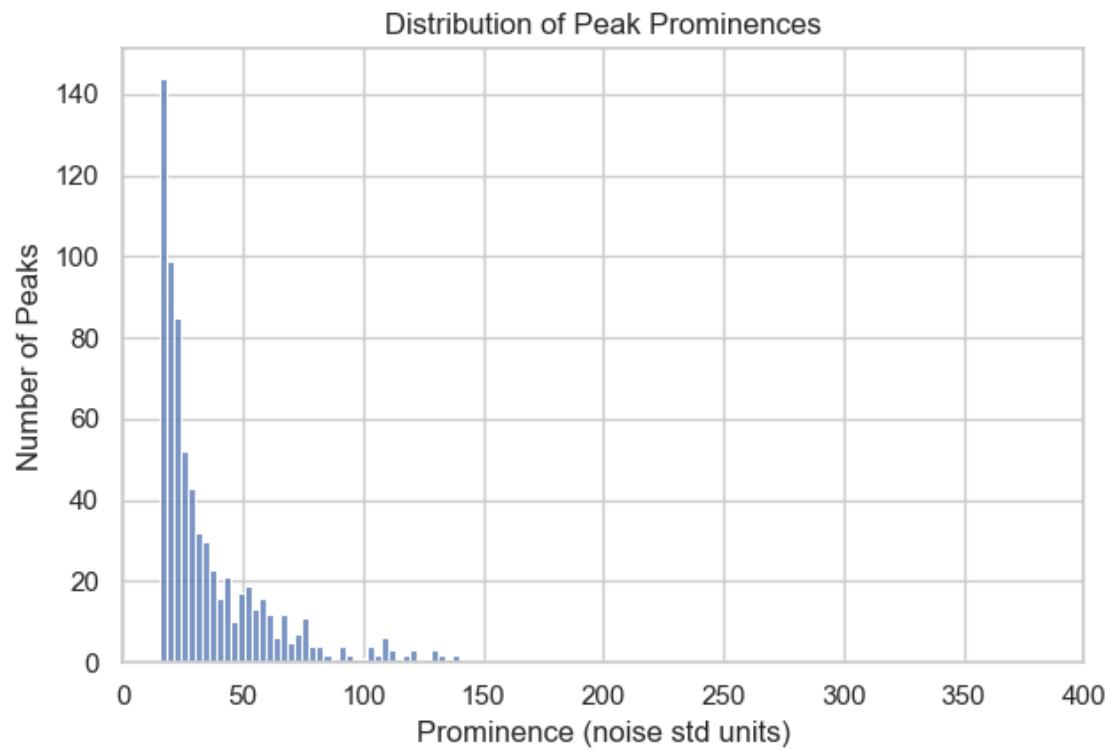
[2025-08-27 15:00:06] [INFO] calcium: plot_points_mean_std: N=3 for Number of highly connected pairs=5

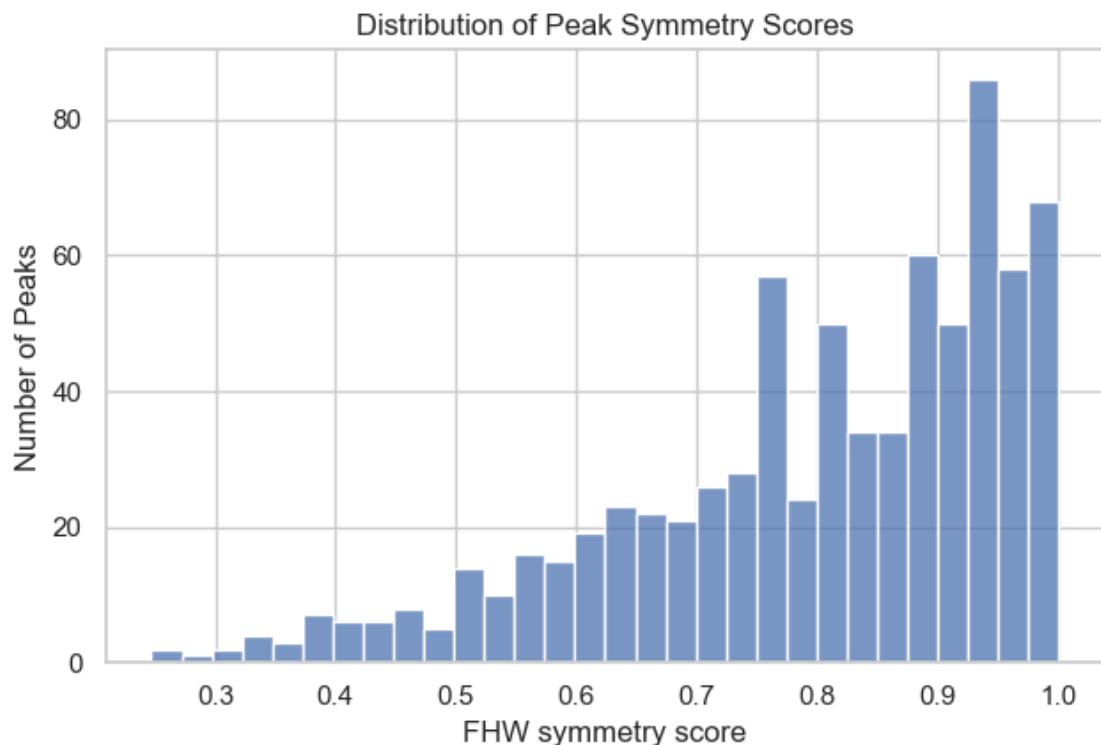


```
[2025-08-27 15:00:07] [INFO] calcium: plot_histogram: removed 17 outliers out of 759 on 'Duration (s)' (lower=-34, upper=92)
```

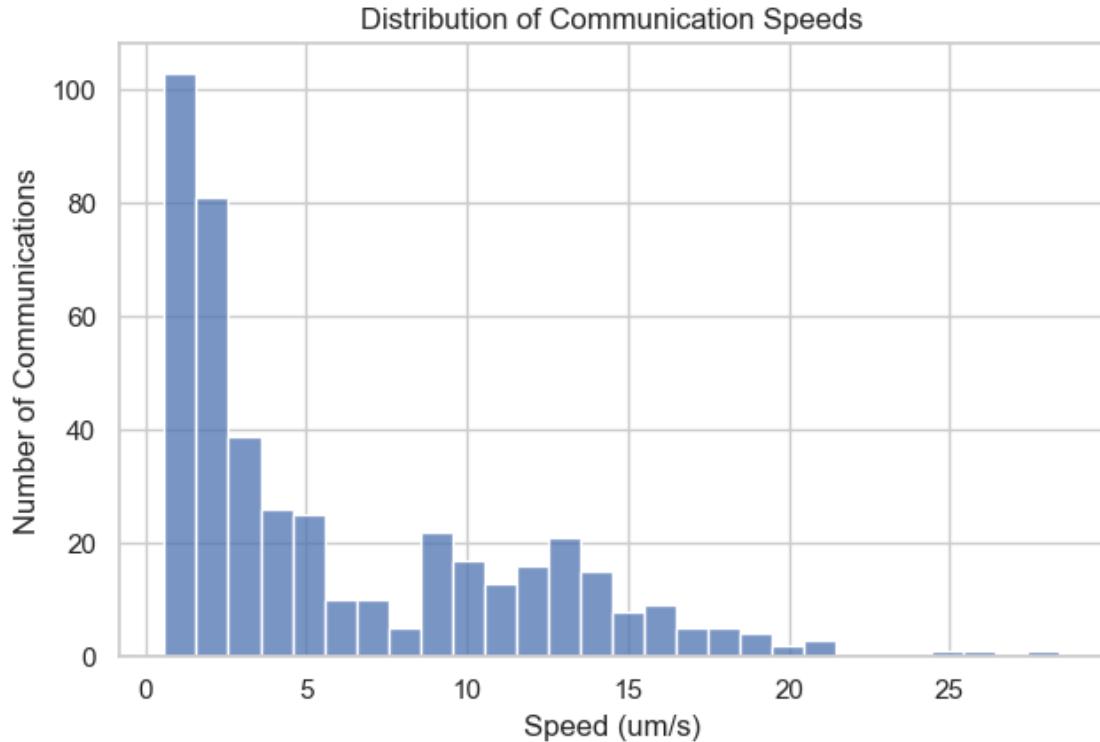


[2025-08-27 15:00:07] [INFO] calcium: plot_histogram: removed 37 outliers out of 759 on 'Prominence (noise std units)' (lower=-71.2, upper=140.2)

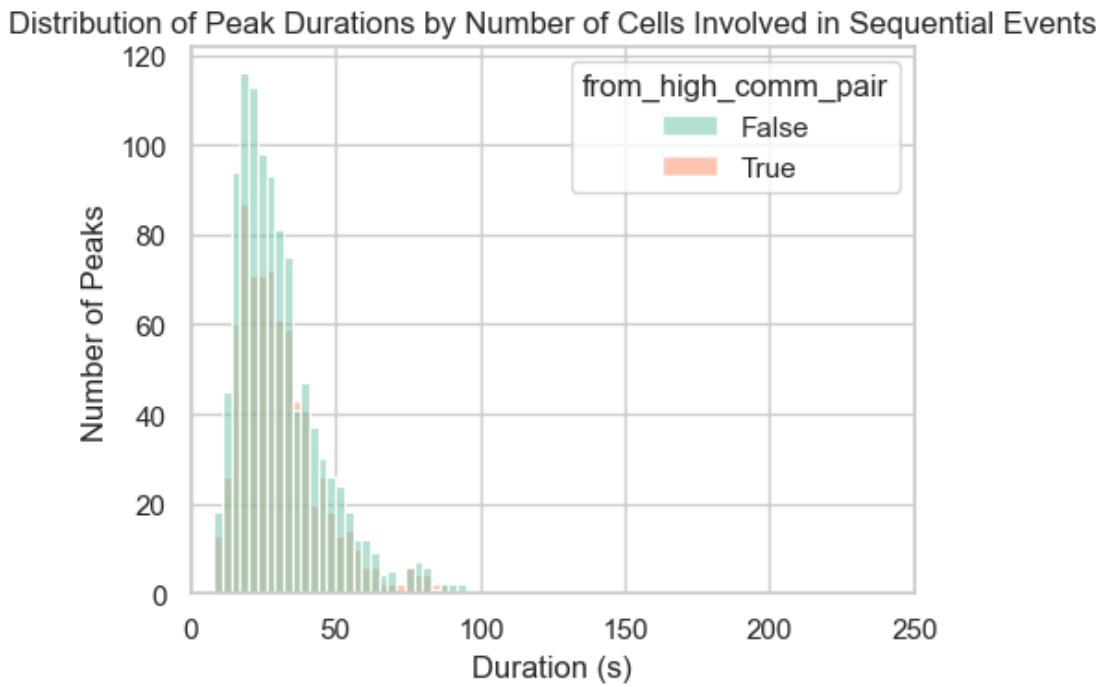




```
[2025-08-27 15:00:07] [INFO] calcium: plot_histogram: removed 0 outliers out of 442 on 'Speed (um/s)' (lower=-23.777, upper=35.583)
```

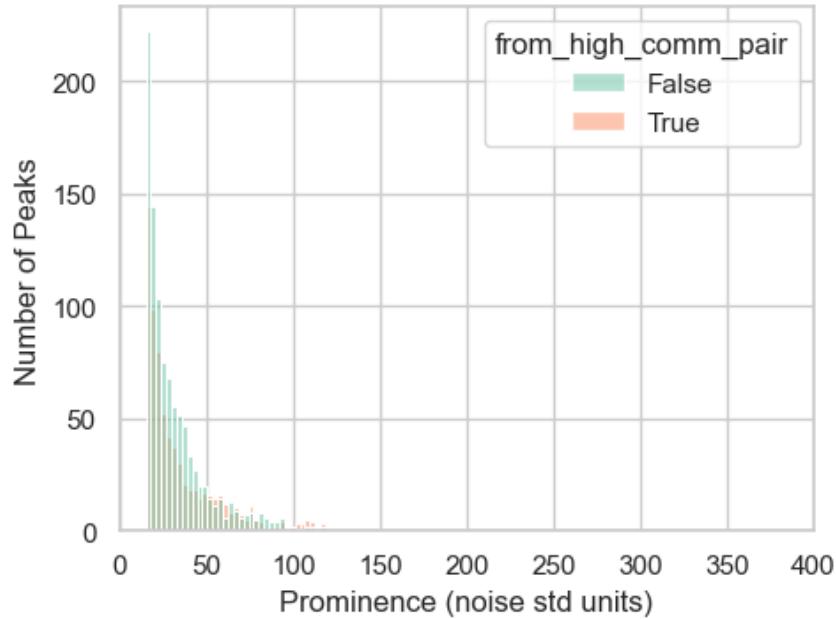


```
[2025-08-27 15:00:08] [INFO] calcium: plot_histogram_by_group: removed 38 outliers out of 1804 on 'Duration (s)' (lower=-38, upper=95)
```

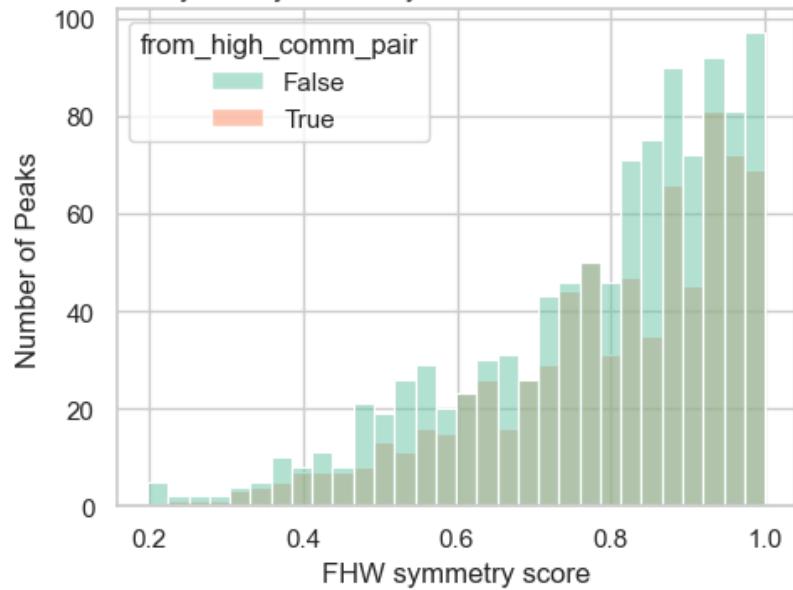


[2025-08-27 15:00:08] [INFO] calcium: plot_histogram_by_group: removed 98 outliers out of 1804 on 'Prominence (noise std units)' (lower=-56.175, upper=119)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

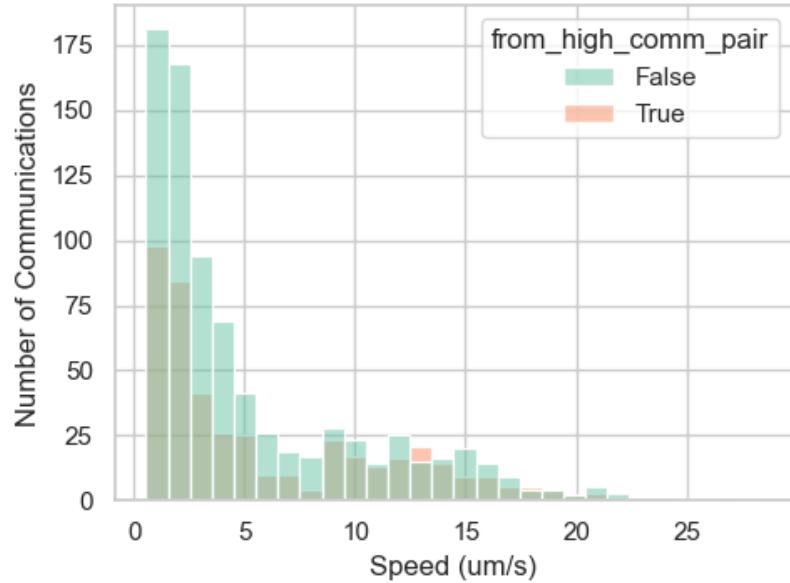


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:00:08] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1240 on 'Speed (um/s)' (lower=-20.348, upper=30.928)
```

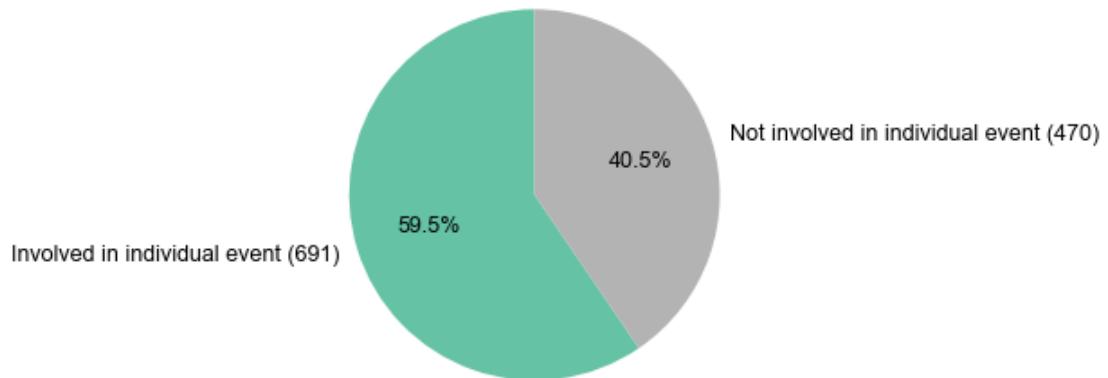
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

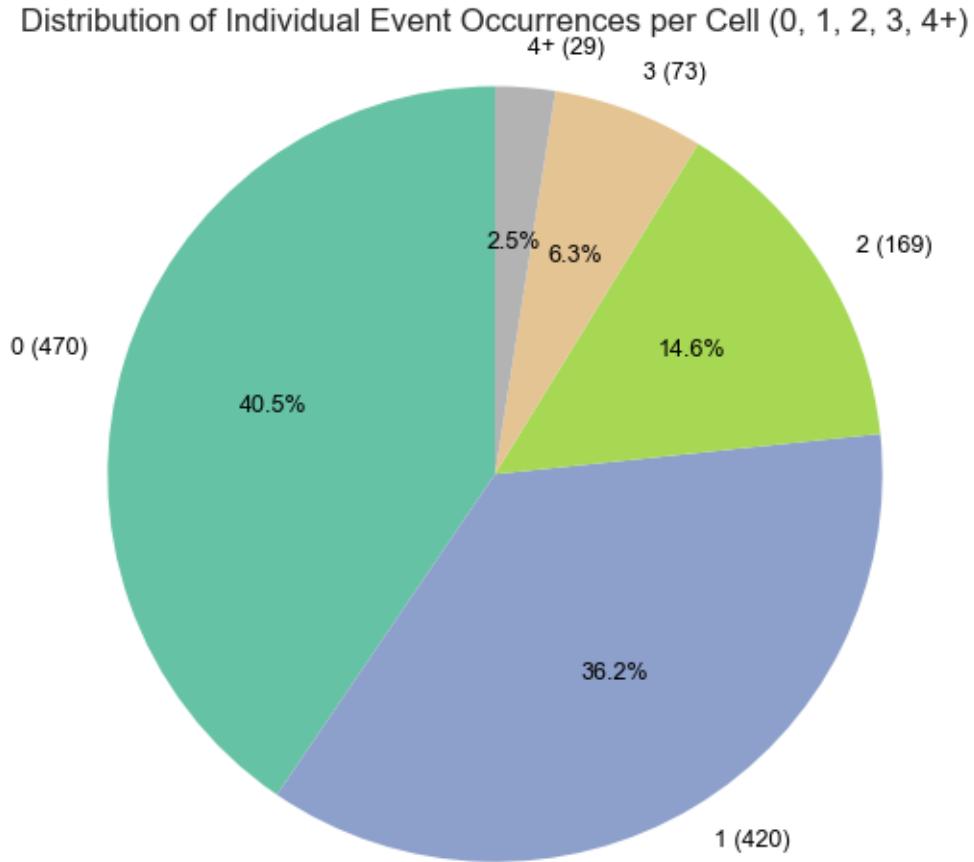


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



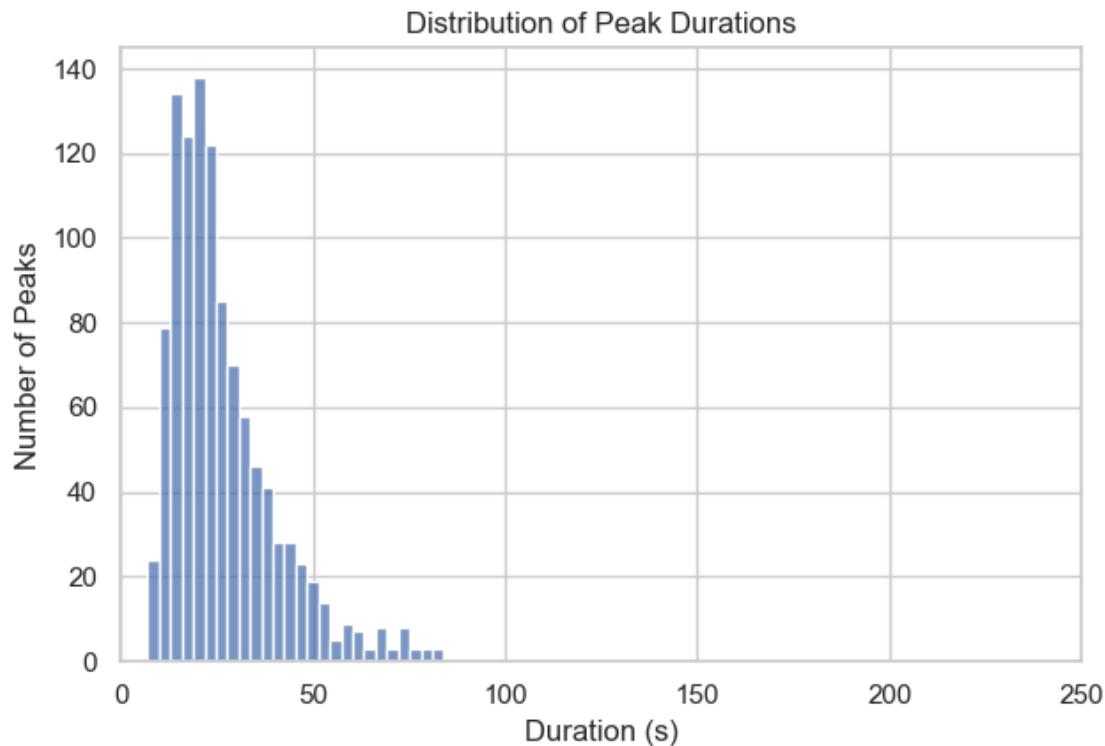


```
[2025-08-27 15:00:09] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS1\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS1\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

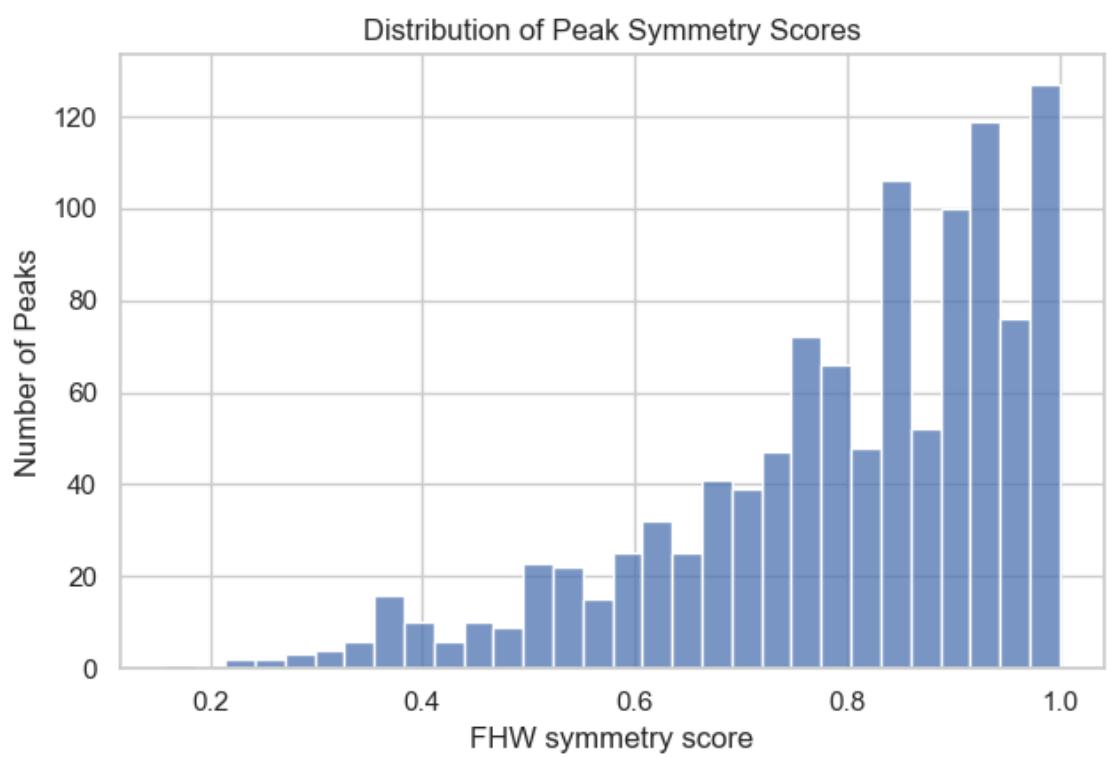
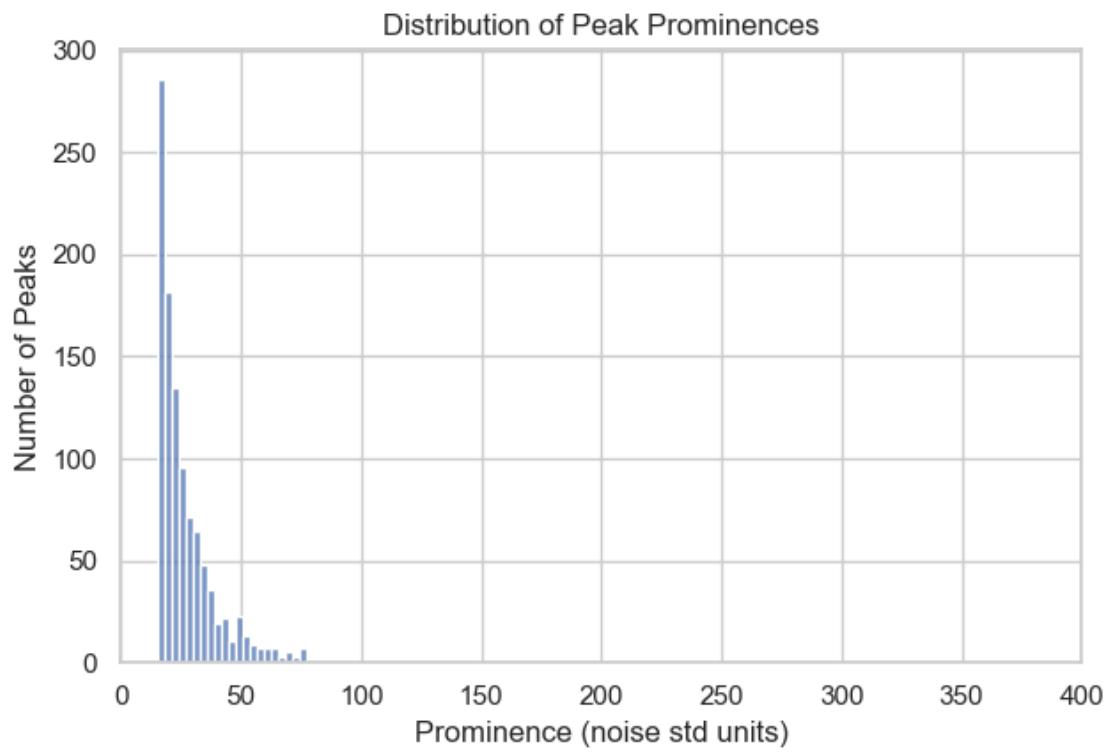
'D:\\Mateo\\20250618\\Output\\IS1\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

1.4.2 Peaks statistics in individual events

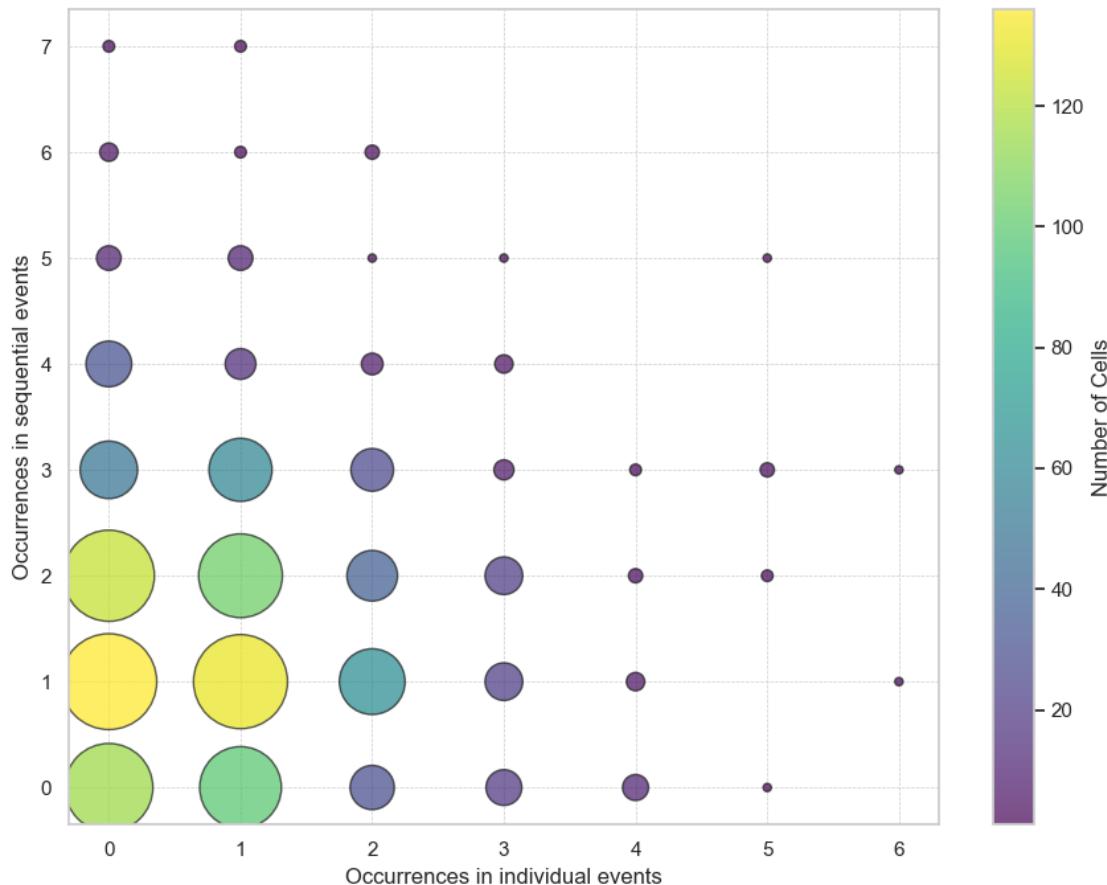
[2025-08-27 15:00:09] [INFO] calcium: plot_histogram: removed 19 outliers out of 1104 on 'Duration (s)' (lower=-35, upper=84)



[2025-08-27 15:00:09] [INFO] calcium: plot_histogram: removed 50 outliers out of 1104 on 'Prominence (noise std units)' (lower=-26.6, upper=77)



1.4.3 Correlation between event activity level & individual activity level



[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: removed 14/1161 outliers on 'Occurrences in sequential events' (lower=-2, upper=5)

[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=463 for Occurrences in individual events=0

[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=416 for Occurrences in individual events=1

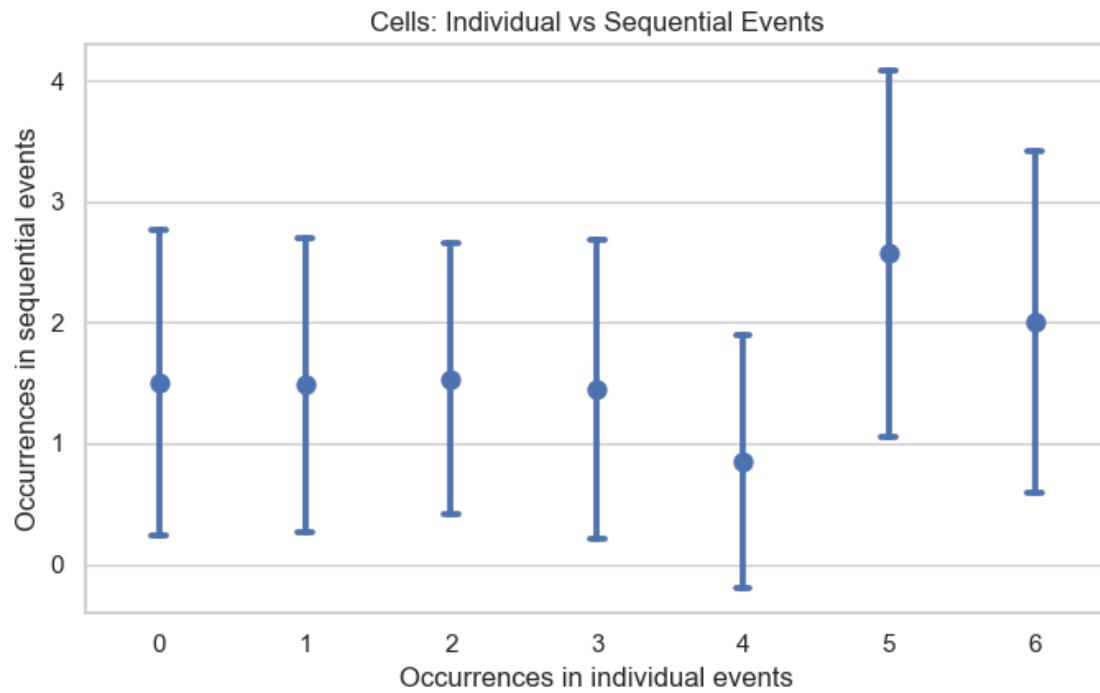
[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=166 for Occurrences in individual events=2

[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=73 for Occurrences in individual events=3

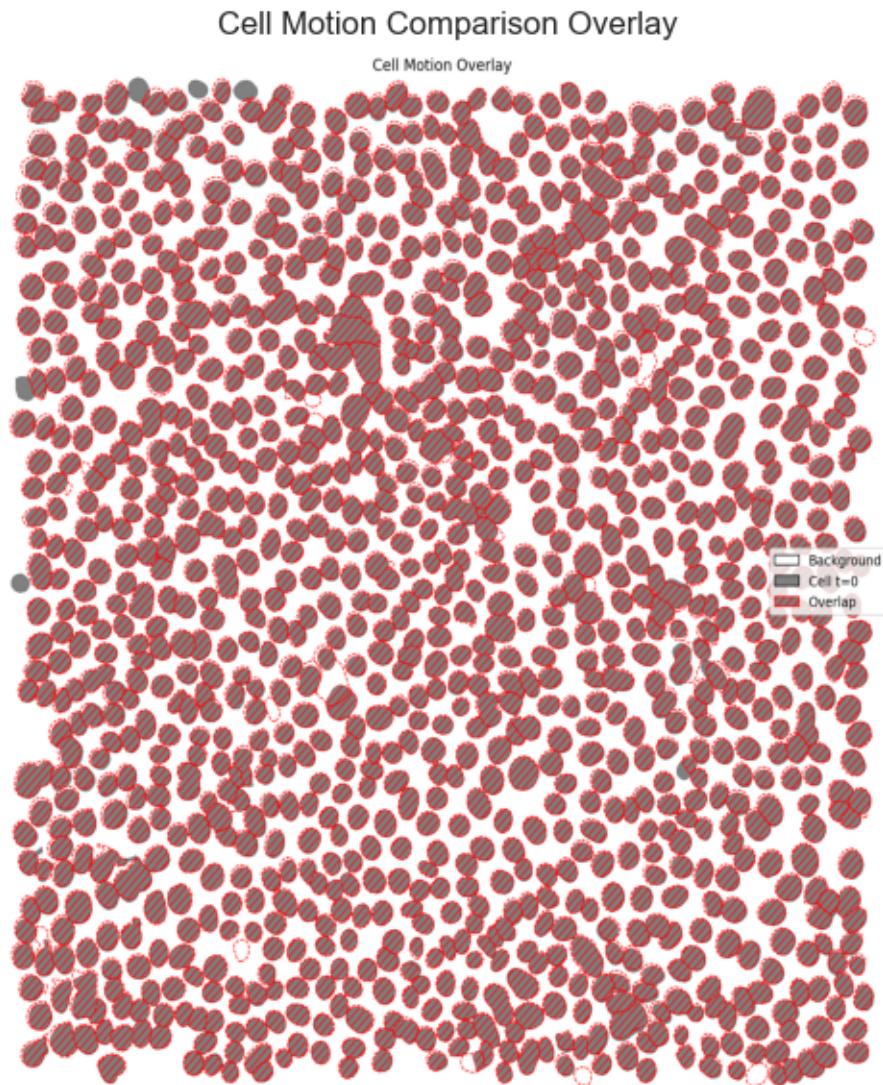
[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=20 for Occurrences in individual events=4

[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=7 for Occurrences in individual events=5

[2025-08-27 15:00:10] [INFO] calcium: plot_points_mean_std: N=2 for Occurrences in individual events=6



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1161
- Hoechst image taken at t=1801: 1160
- Number of cells difference: absolute 1, relative 0.09%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1182638
- Pixels segmented as cell at t=1801: 1209431
- Overlapping pixels between t=0 and t=1801: 1094218 (91.49% of total)
- Pixels exclusive to t=0: 88420 (7.48% of total)
- Pixels exclusive to t=1801: 115213 (9.53% of total)

executed

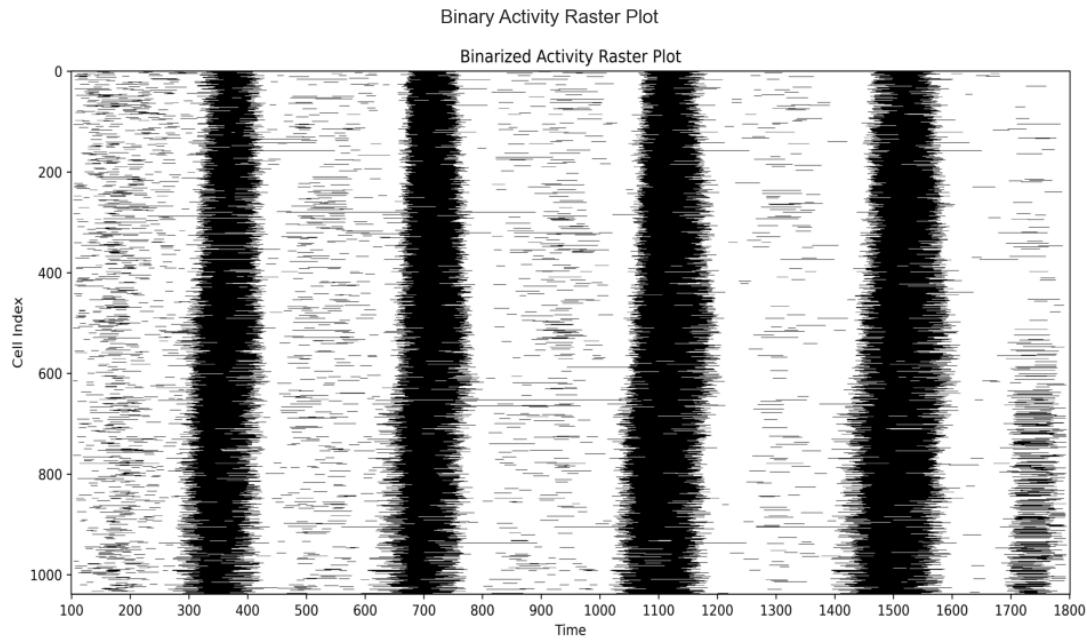
August 27, 2025

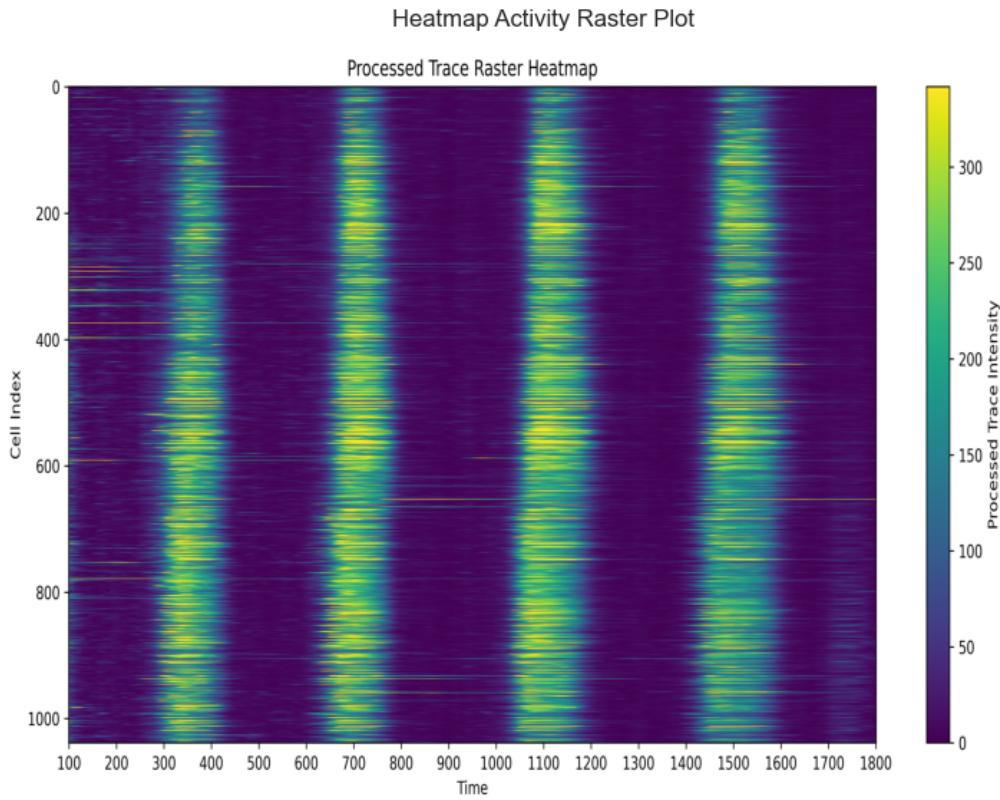
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





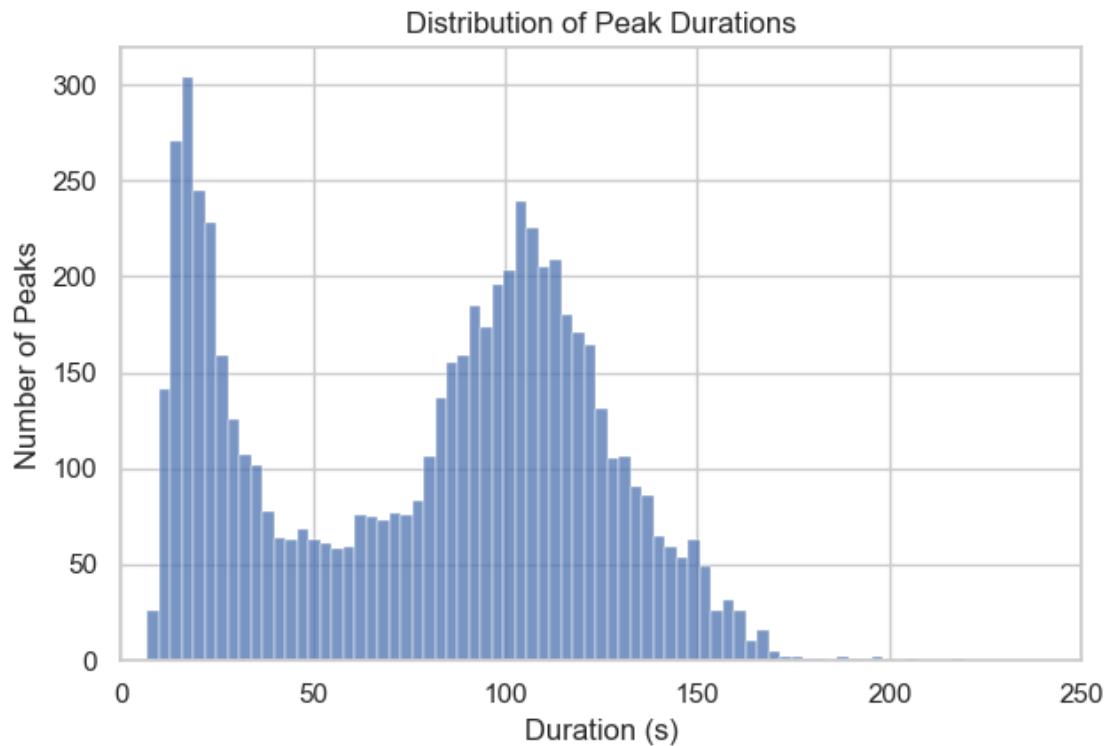
1.1.2 Peaks population

Total number of peaks: 6334

Total number of cells: 1039

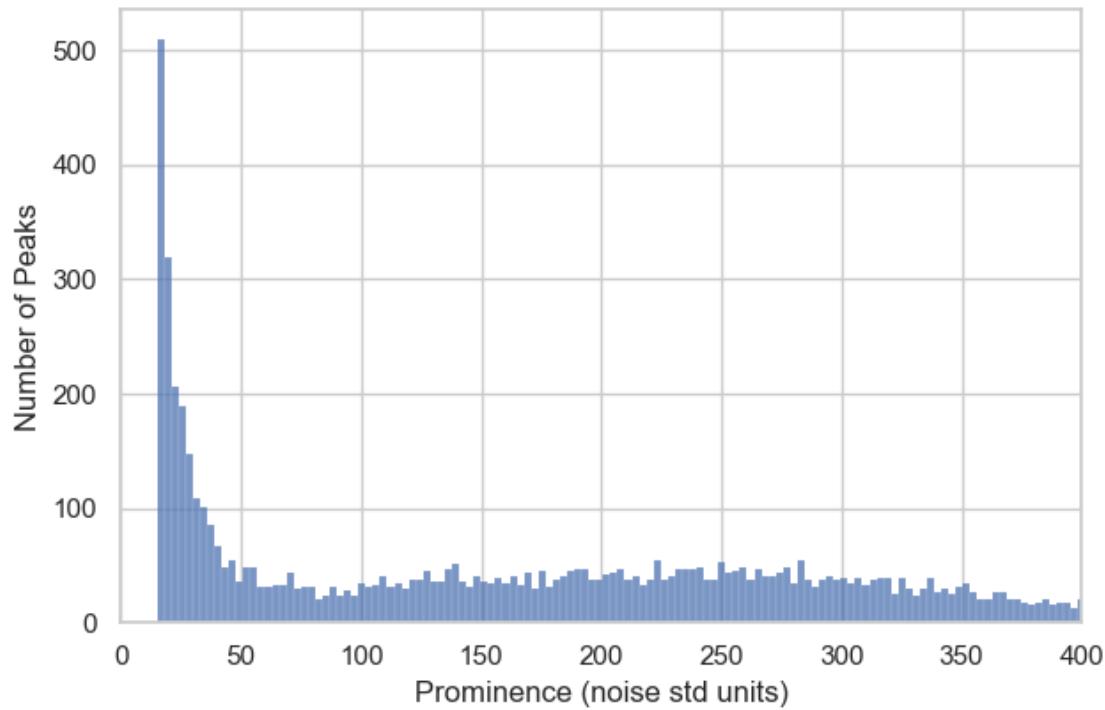
1.1.3 Peaks statistics

```
[2025-08-27 15:00:38] [INFO] calcium: plot_histogram: removed 1 outliers out of  
6334 on 'Duration (s)' (lower=-207, upper=353)
```

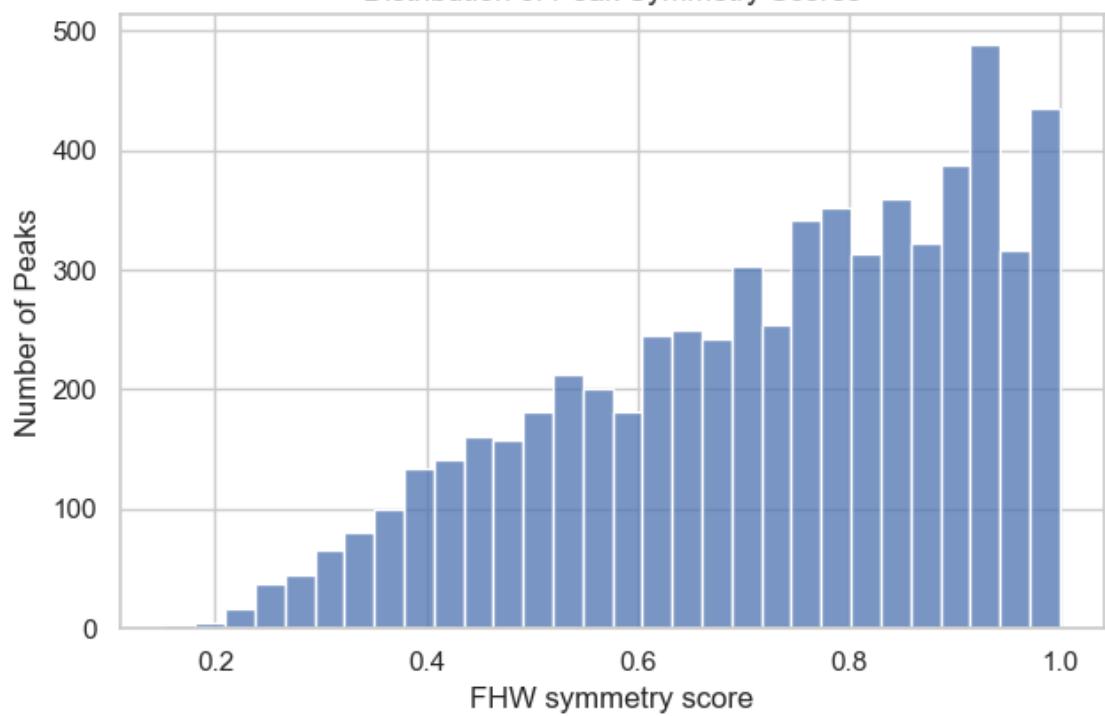


```
[2025-08-27 15:00:38] [INFO] calcium: plot_histogram: removed 0 outliers out of  
6334 on 'Prominence (noise std units)' (lower=-684.3, upper=996.4)
```

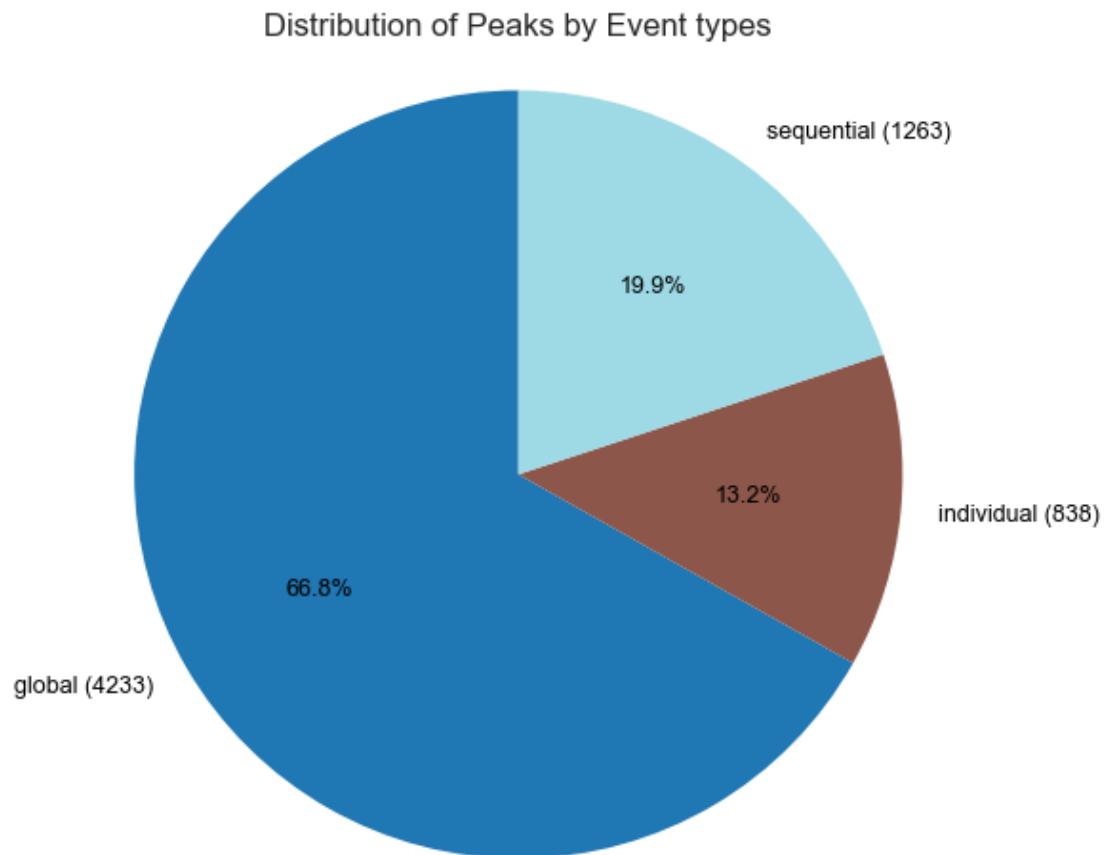
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

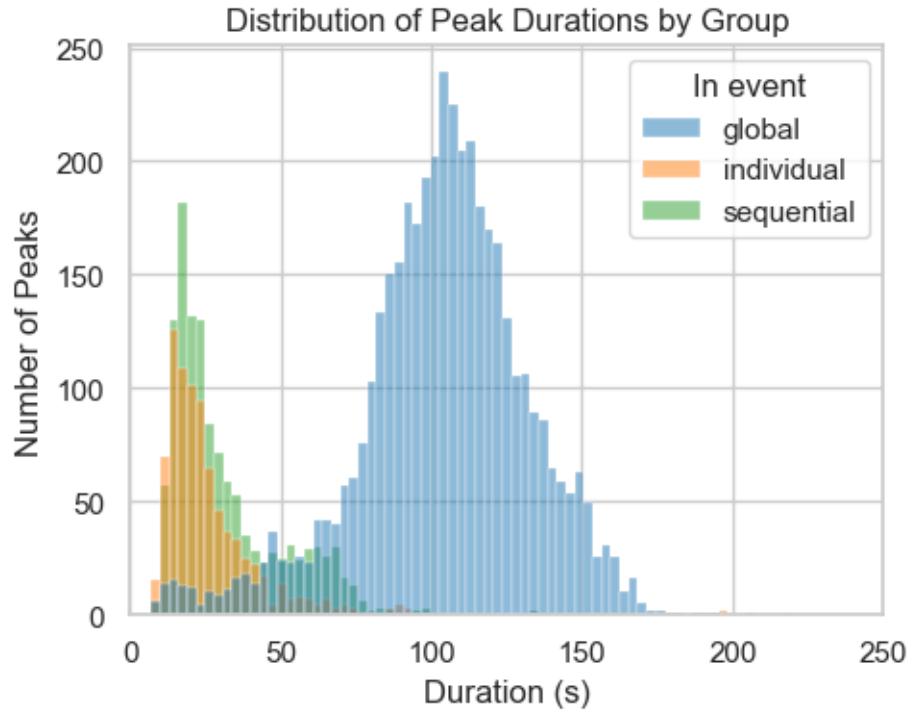


1.1.4 Distribution of peaks per event types

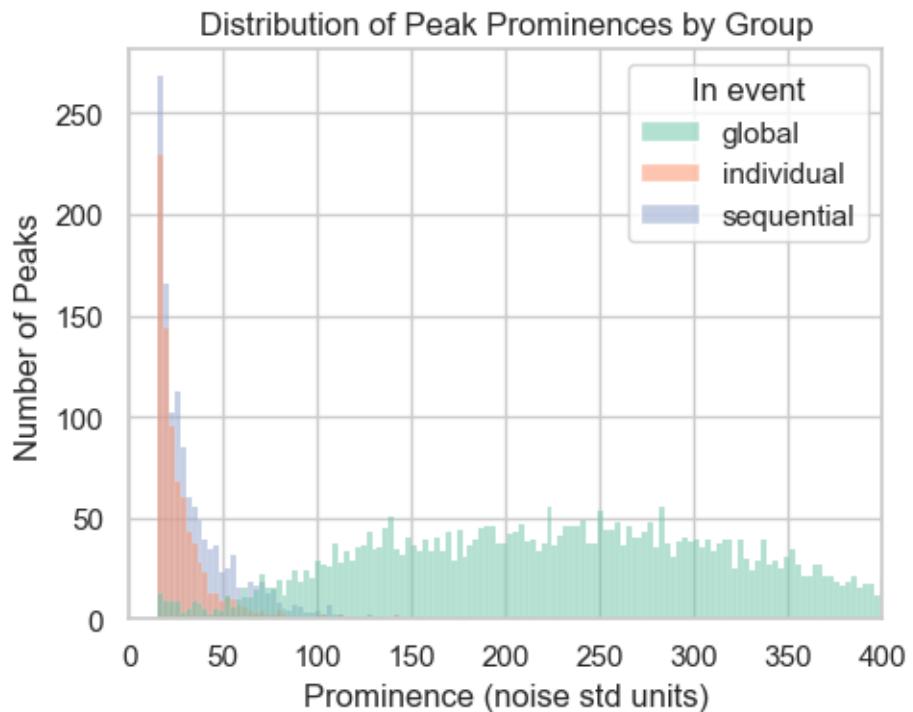


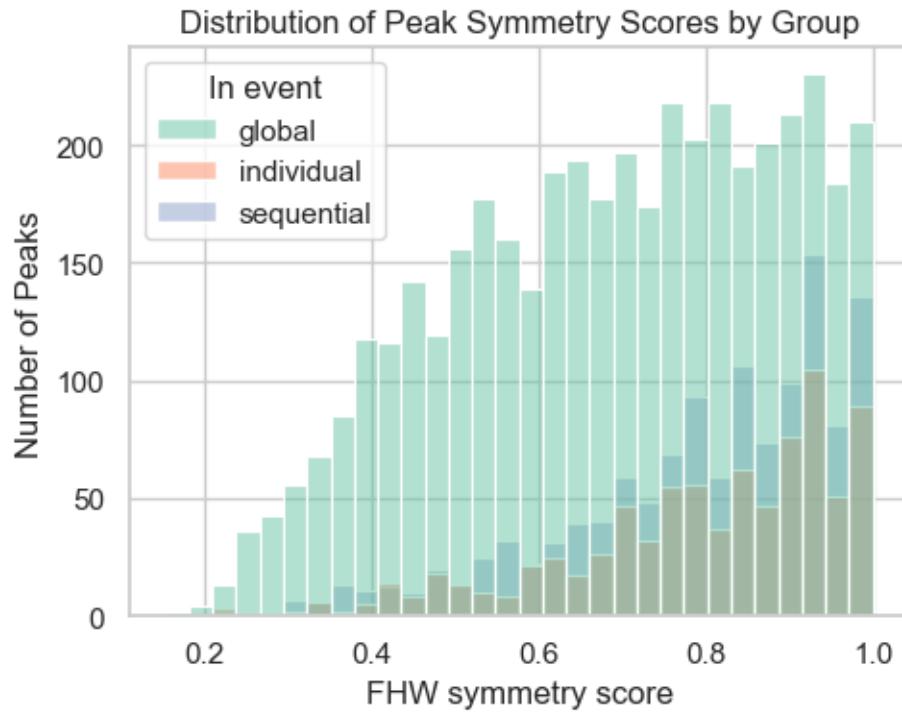
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:00:39] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 6334 on 'Duration (s)' (lower=-207, upper=353)
```



```
[2025-08-27 15:00:39] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 6334 on 'Prominence (noise std units)' (lower=-684.3, upper=996.4)
```

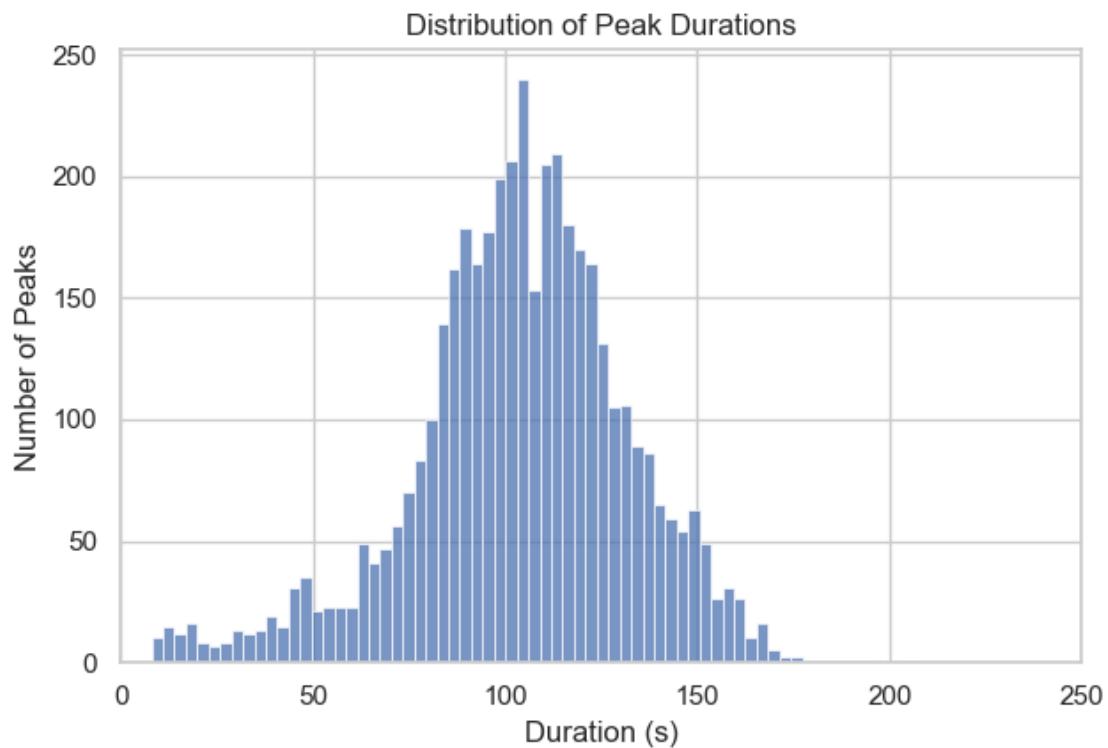




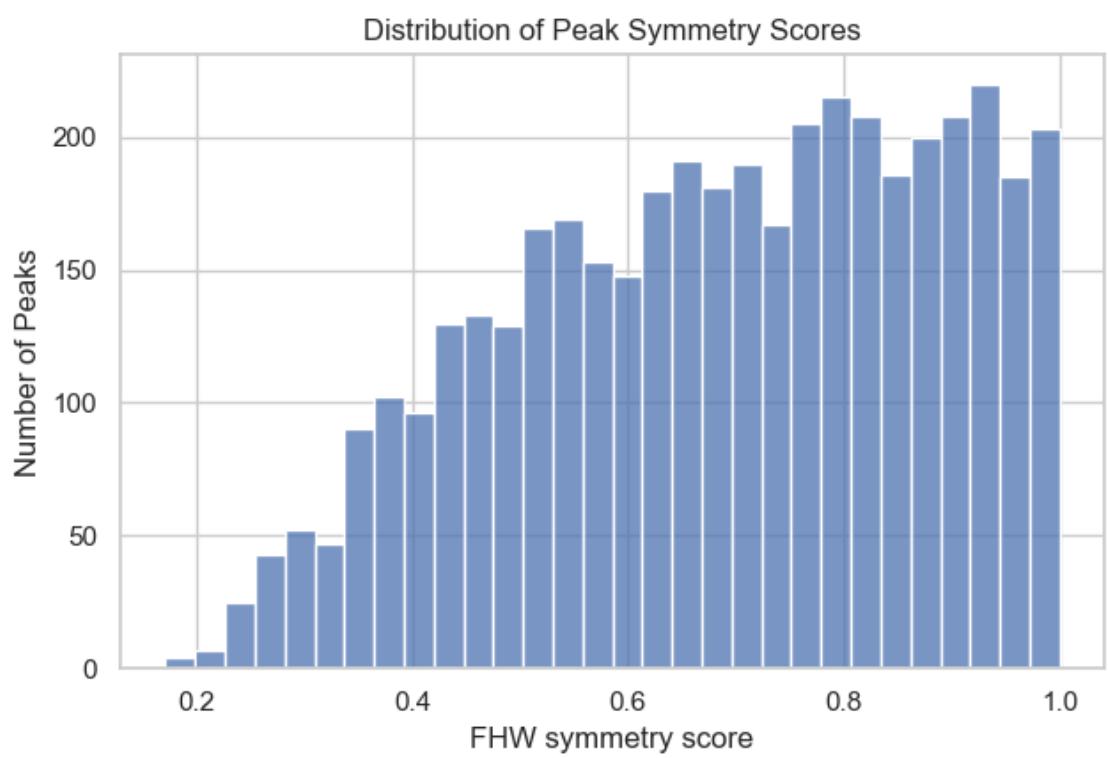
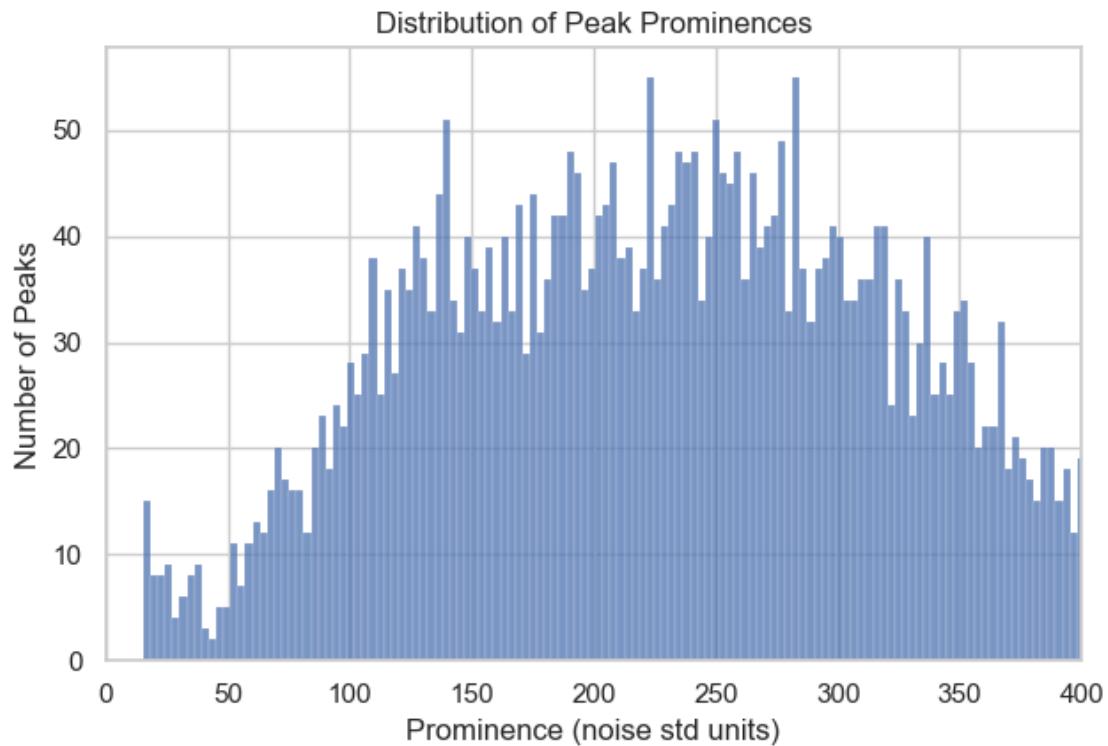
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:00:40] [INFO] calcium: plot_histogram: removed 5 outliers out of 4233 on 'Duration (s)' (lower=-7, upper=217)
```

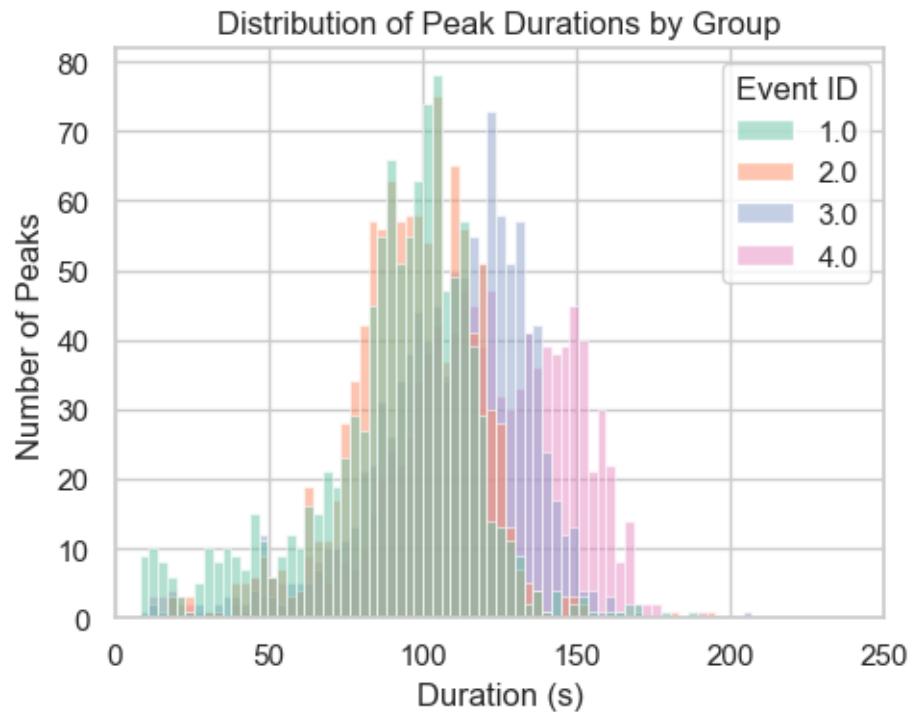


```
[2025-08-27 15:00:40] [INFO] calcium: plot_histogram: removed 9 outliers out of  
4233 on 'Prominence (noise std units)' (lower=-307.5, upper=784.5)
```

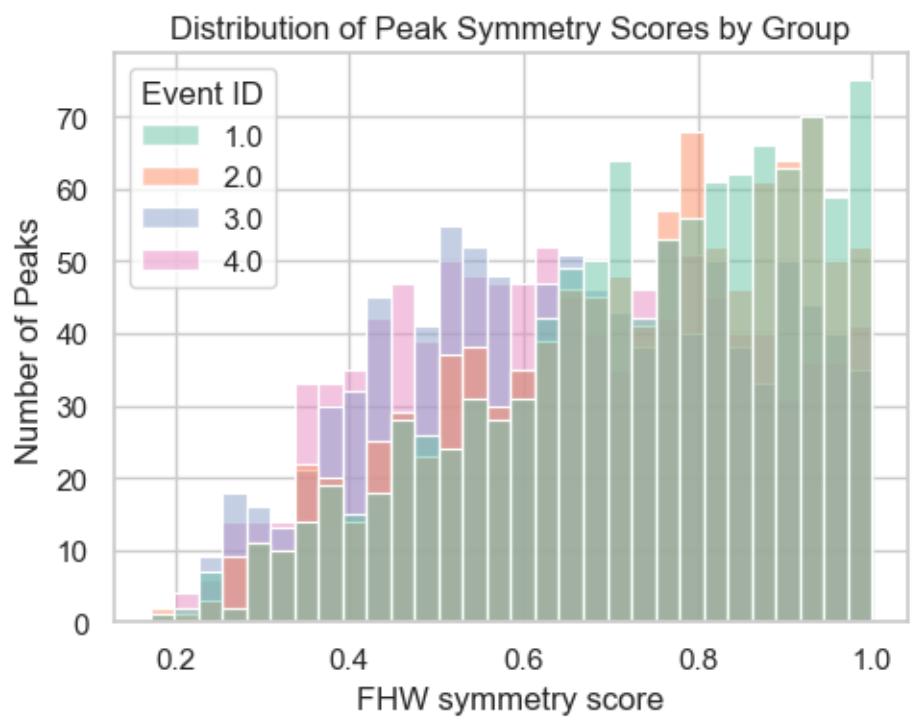
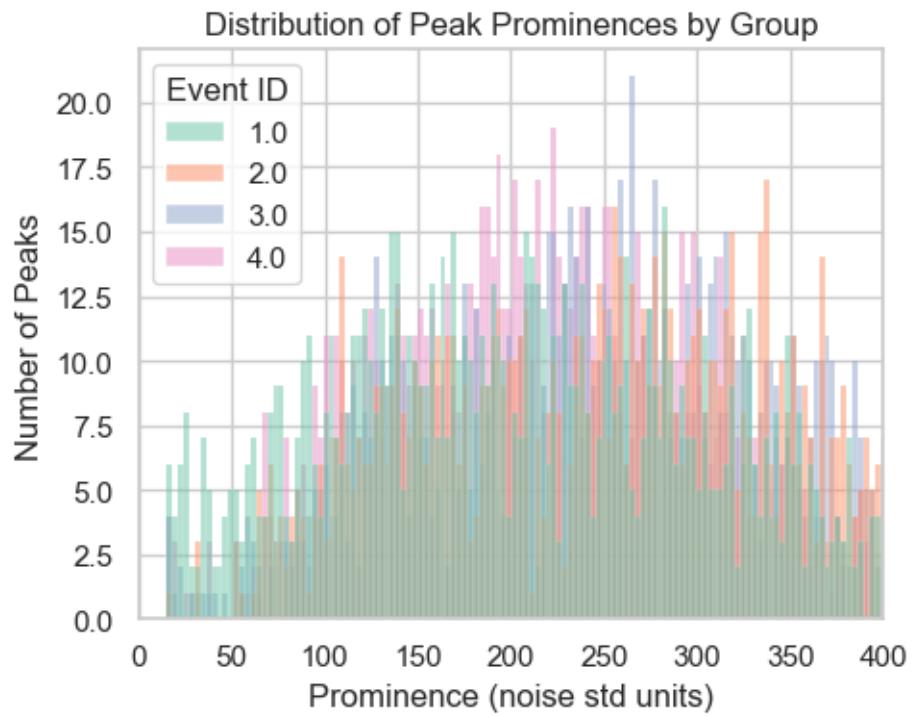


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:00:41] [INFO] calcium: plot_histogram_by_group: removed 5 outliers out of 4233 on 'Duration (s)' (lower=-7, upper=217)

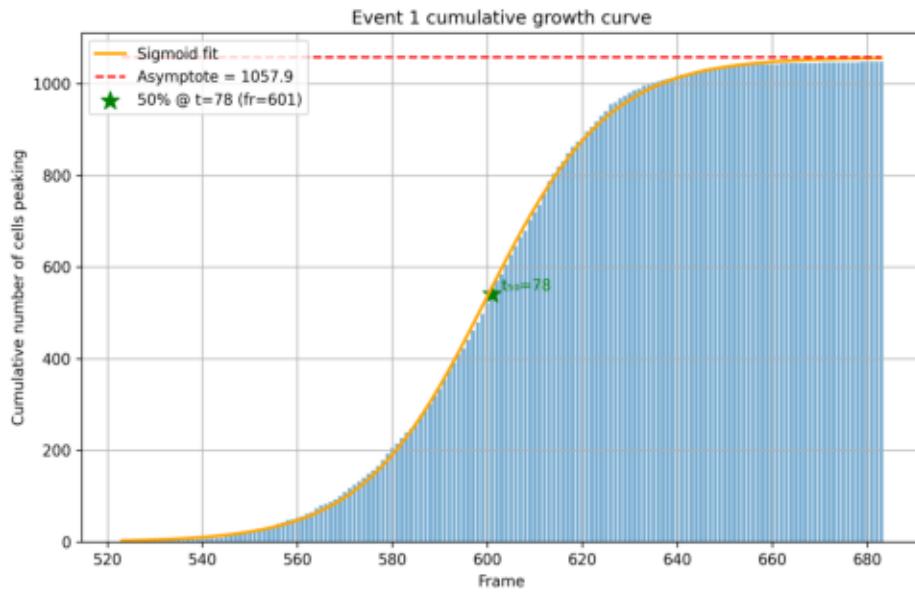


[2025-08-27 15:00:41] [INFO] calcium: plot_histogram_by_group: removed 9 outliers out of 4233 on 'Prominence (noise std units)' (lower=-307.5, upper=784.5)

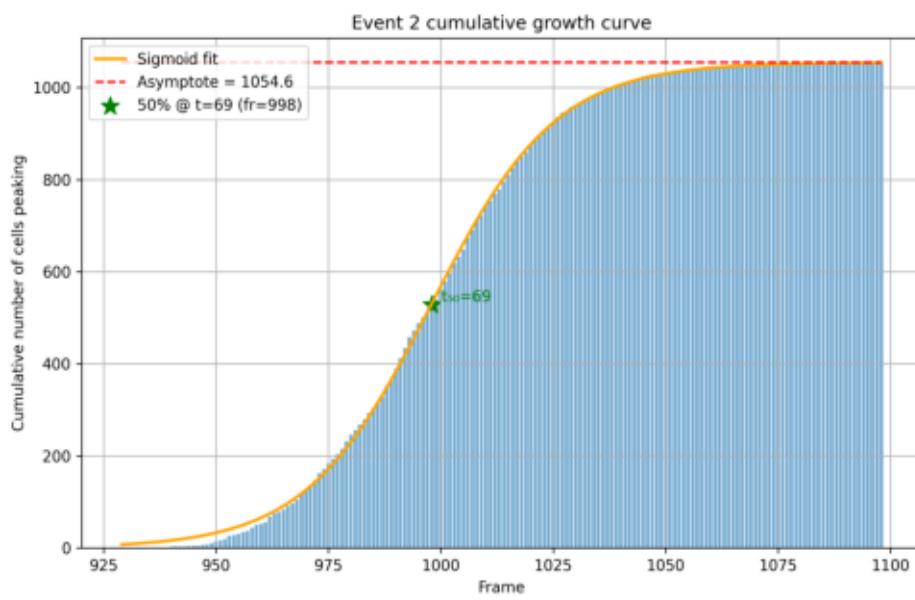


1.2.3 Kinetics of global events

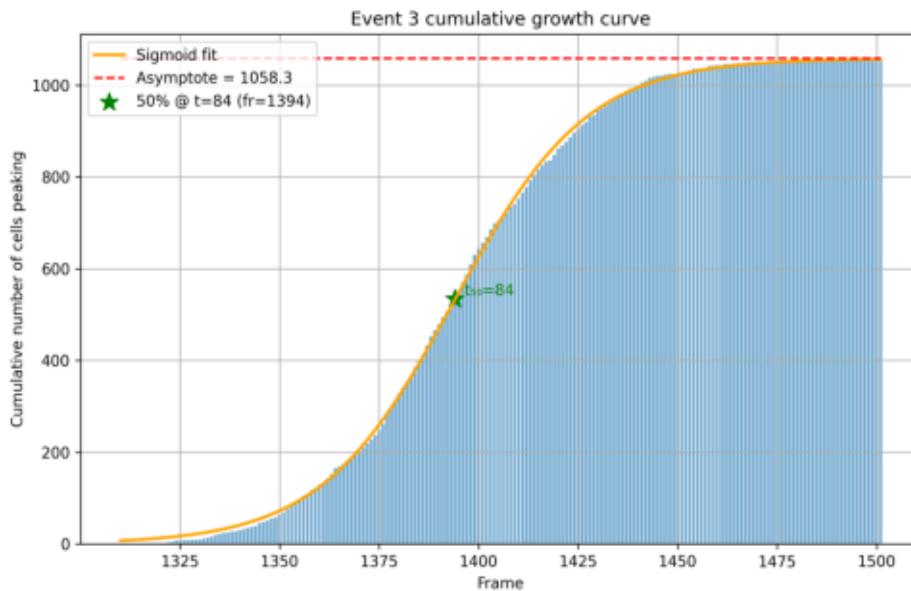
Event Activity Overlay (Event ID: 1)



Event Activity Overlay (Event ID: 2)

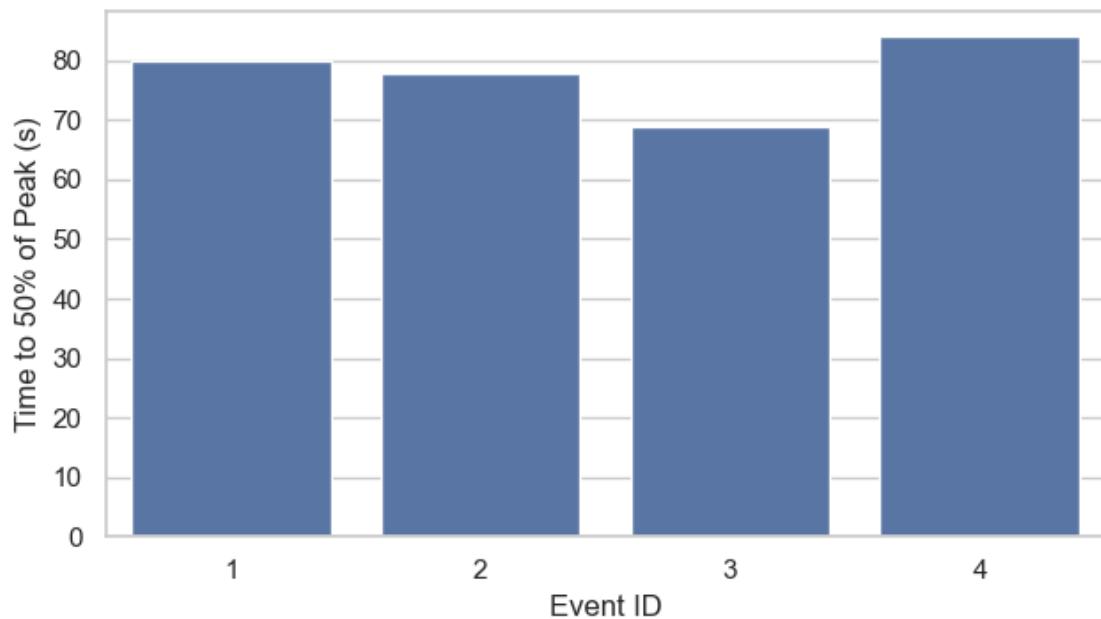


Event Activity Overlay (Event ID: 3)

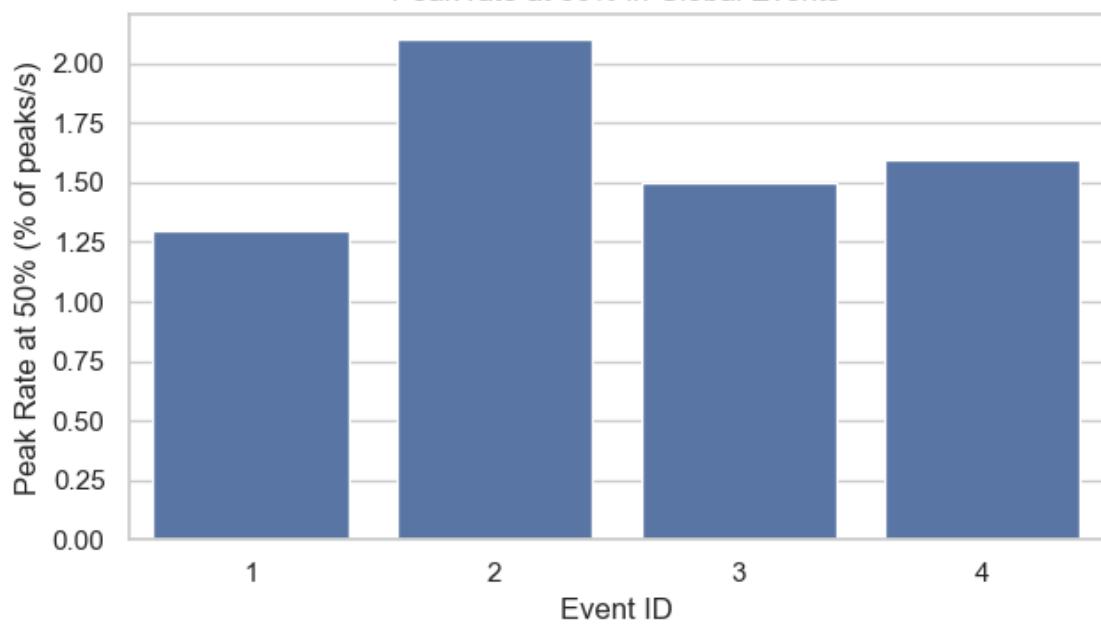


```
[2025-08-27 15:00:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\\\Output\\\\IS2\\\\events\\\\event-growth-
curve-4.png'
Traceback (most recent call last):
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\src\\calcium_activity_characterizatio
n\\analysis\\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\.venv\\lib\\site-
packages\\matplotlib\\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\.venv\\lib\\site-
packages\\PIL\\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250618\\\\Output\\\\IS2\\\\events\\\\event-growth-curve-4.png'
```

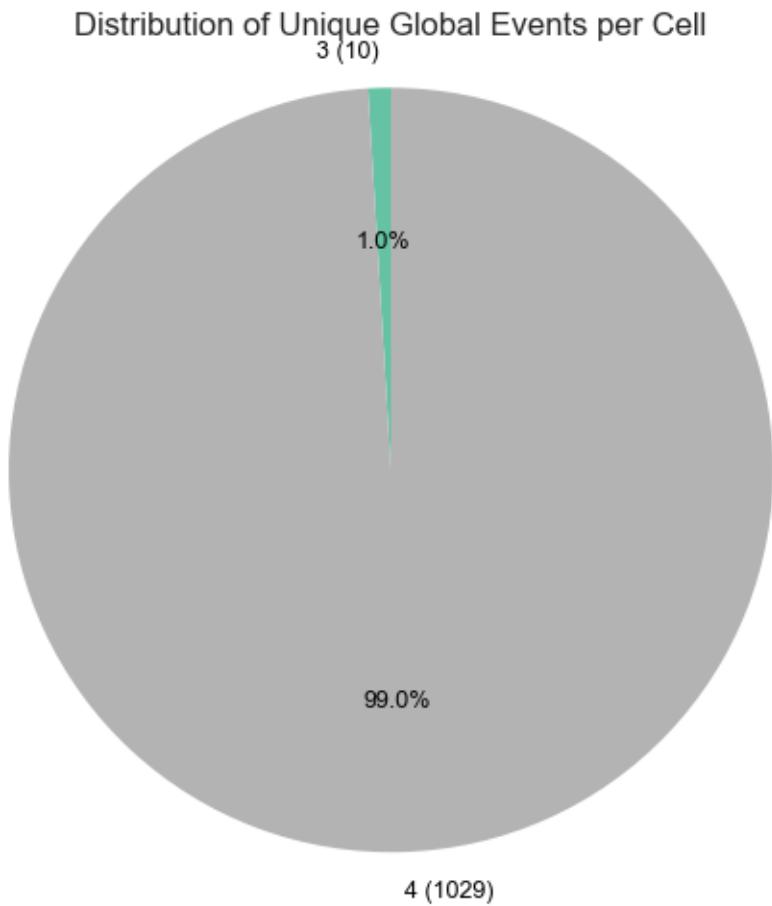
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

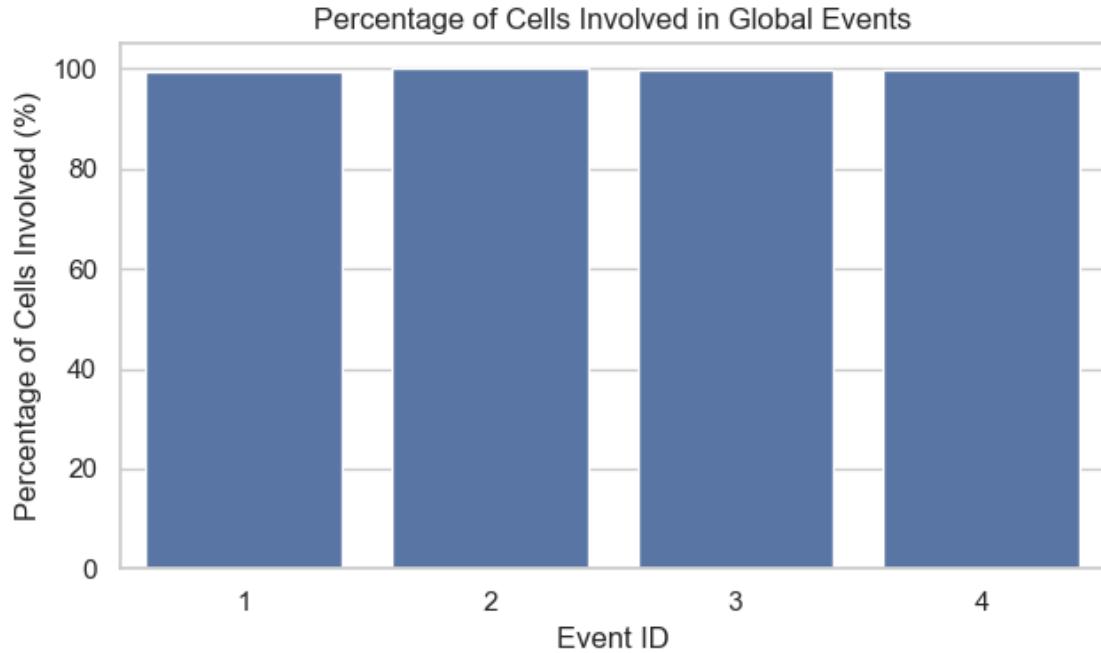


```
[2025-08-27 15:00:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS2\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250618\Output\IS2\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [340.0, 410.0, 398.0]
 Estimated periodicity: 0.926
 The global events exhibit a regular periodic pattern.
 Estimated frequency (1/mean interval): 0.003 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 15:00:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:00:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

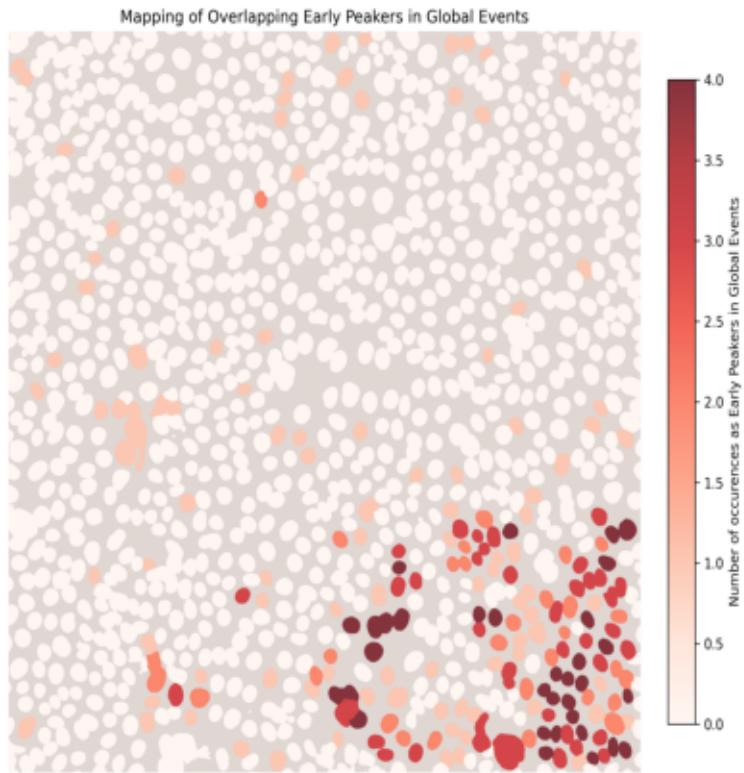
[2025-08-27 15:00:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()

```

```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

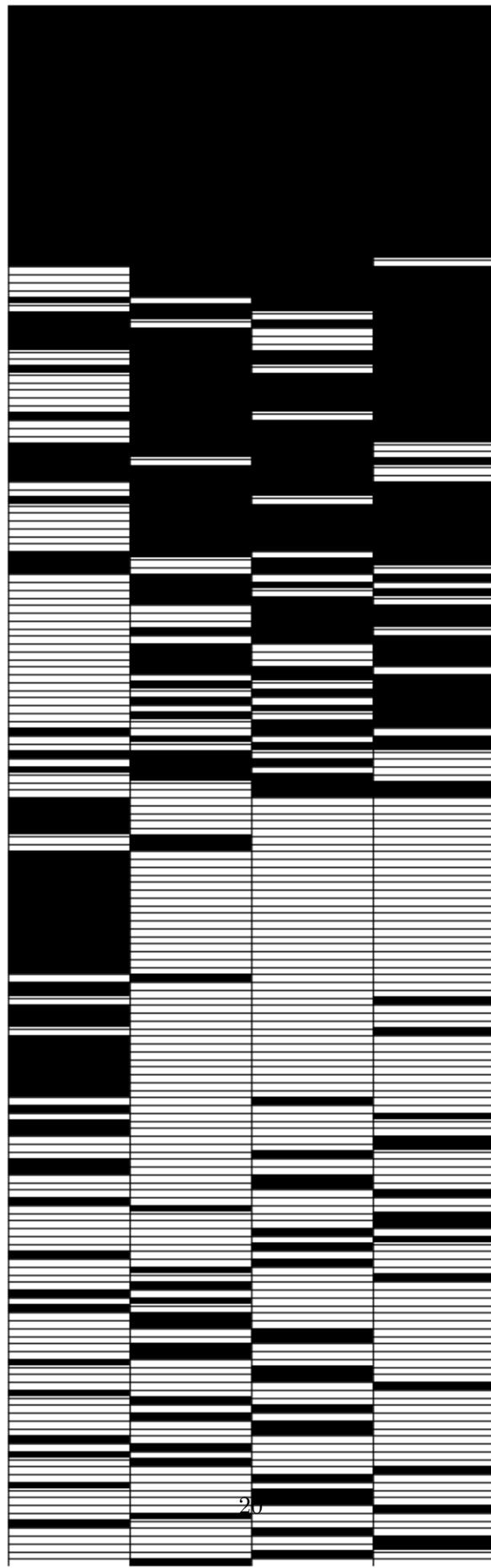
[2025-08-27 15:00:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



[2025-08-27 15:00:46] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 4 unique event IDs.

[2025-08-27 15:00:46] [INFO] calcium: Early peakers event-matrix: 203 cells x 4 events; black squares: 412



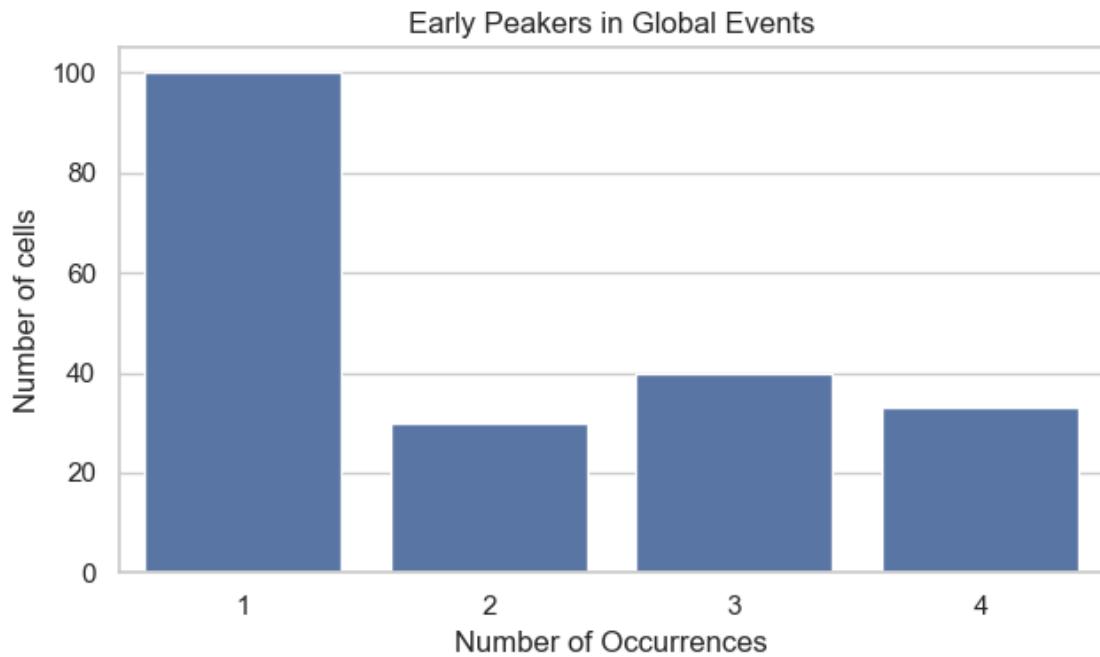
[2025-08-27 15:00:47] [INFO] calcium: Saved early peakers heatmap SVG to: early_peakers_heatmap.svg

```
[1, 1, 0, 1],  
[1, 1, 0, 1],  
[1, 1, 0, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[1, 1, 0, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[1, 1, 0, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[1, 1, 1, 0],  
[1, 1, 1, 0],  
[1, 0, 1, 1],  
[1, 1, 1, 0],  
[1, 1, 1, 0],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[0, 1, 1, 1],  
[1, 1, 0, 1],  
[0, 1, 1, 1],  
[1, 0, 1, 0],  
[0, 1, 0, 1],  
[0, 1, 1, 0],  
[0, 1, 0, 1],  
[0, 0, 1, 1],  
[0, 0, 1, 1],  
[0, 1, 1, 0],  
[0, 0, 1, 1],  
[0, 1, 0, 1],  
[0, 1, 0, 1],  
[0, 1, 0, 1],  
[0, 1, 1, 0],  
[0, 0, 1, 1],  
[0, 1, 0, 1],
```

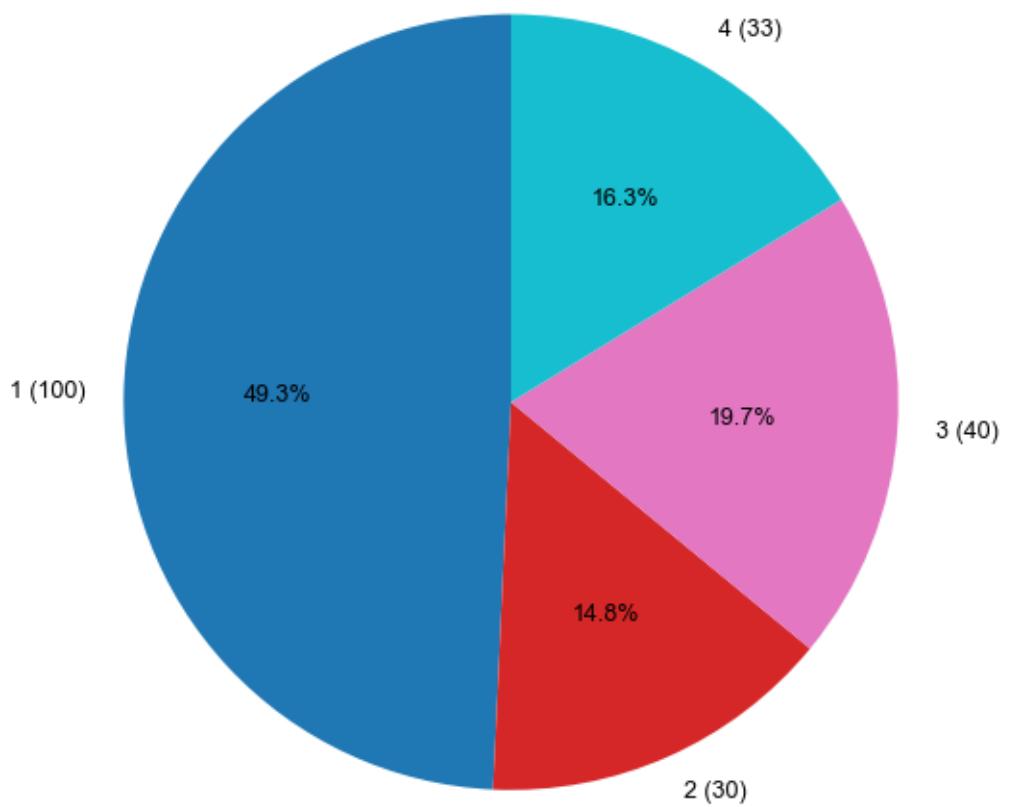


```
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[1, 0, 0, 0],  
[0, 0, 0, 1],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[0, 0, 1, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[0, 0, 0, 1],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[0, 0, 0, 1],  
[0, 1, 0, 0],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[0, 1, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[0, 1, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 0, 1],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[0, 0, 1, 0]
```

```
[0, 1, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[0, 0, 0, 1],  
[0, 0, 1, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[0, 0, 1, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[0, 0, 1, 0],  
[0, 1, 0, 0]])
```



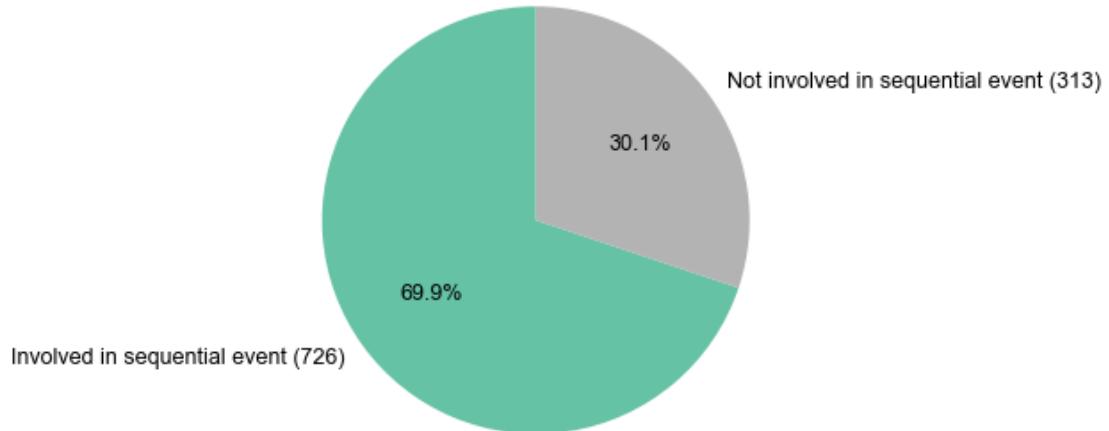
Distribution of Early Peakers in Global Events



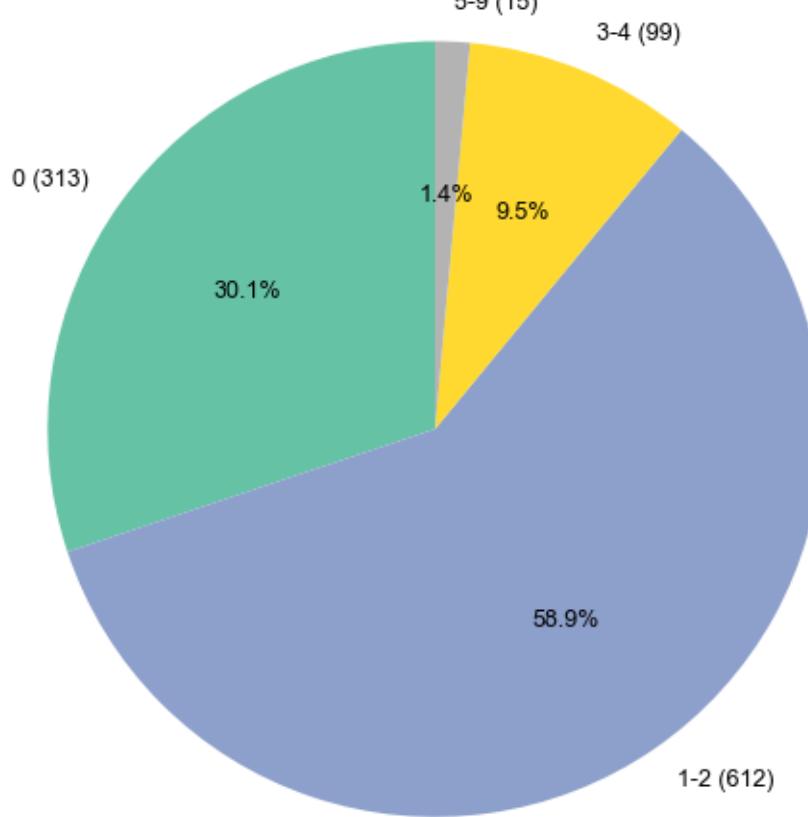
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

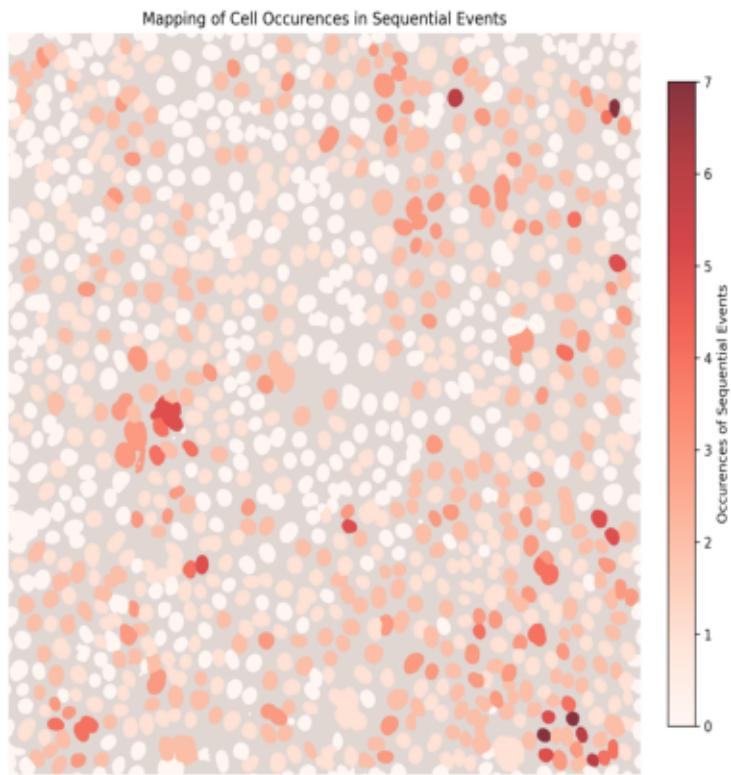
Distribution of Cells Involved in Sequential Events



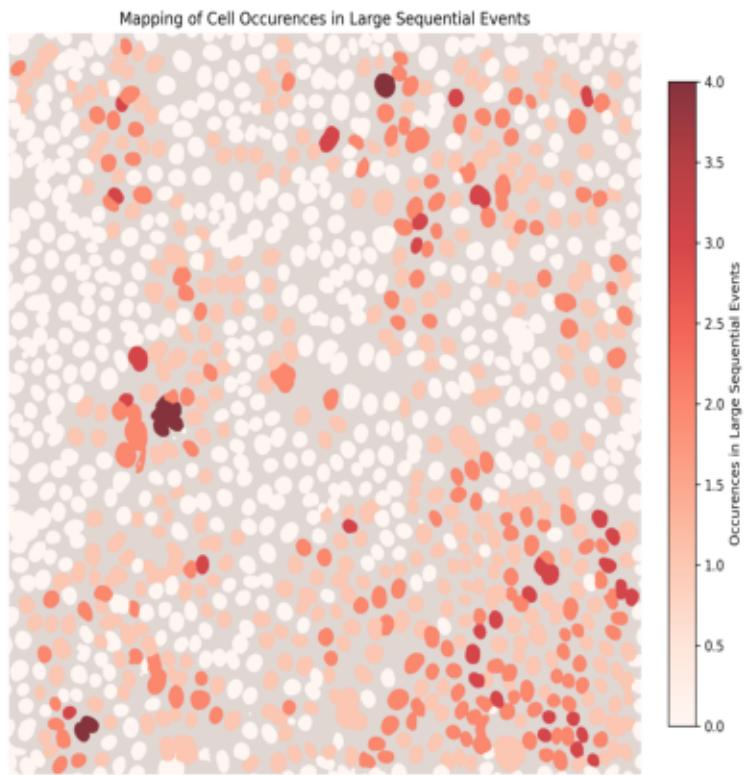
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

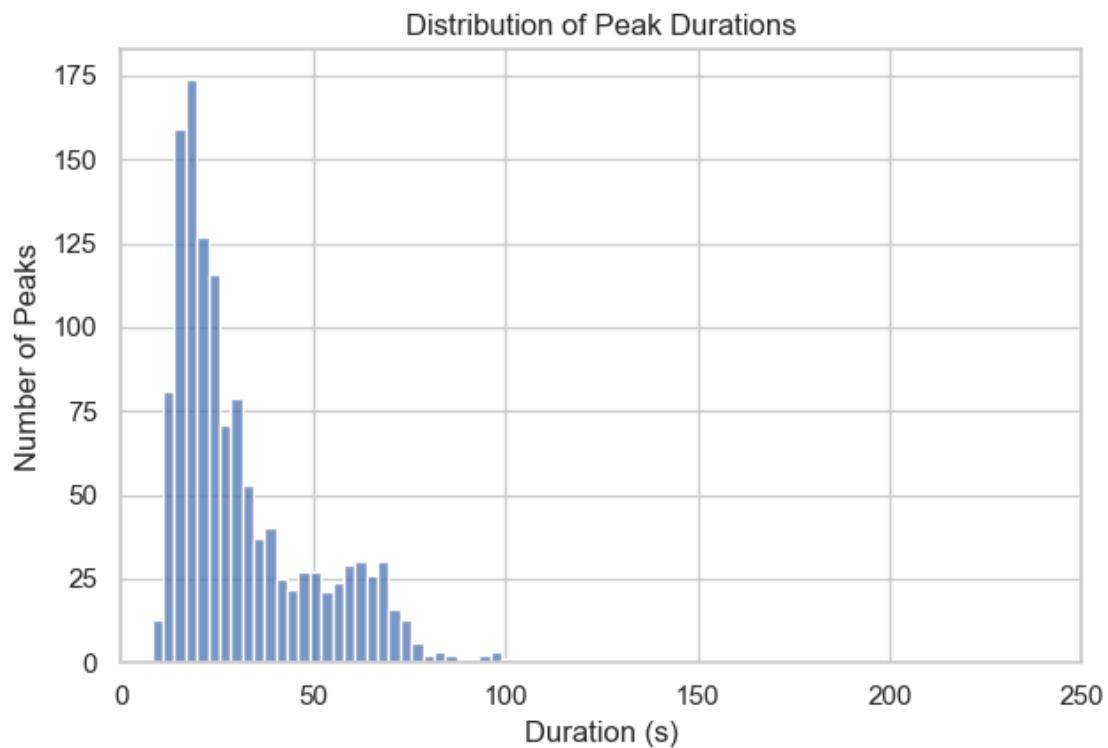


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

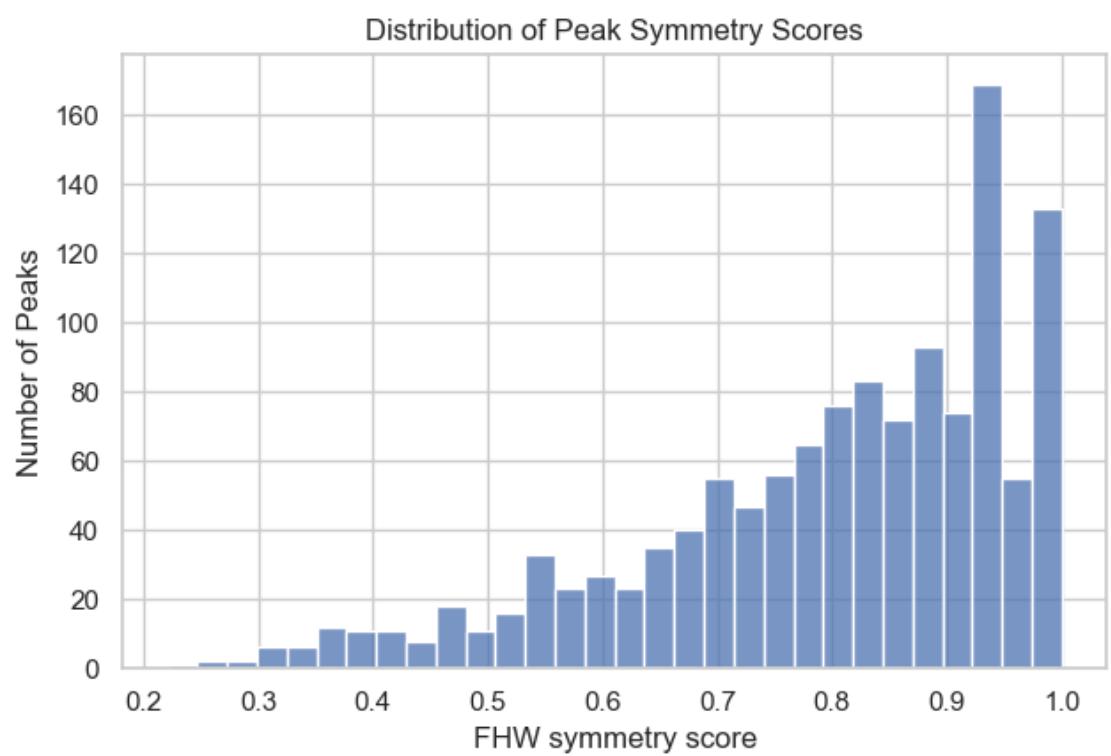
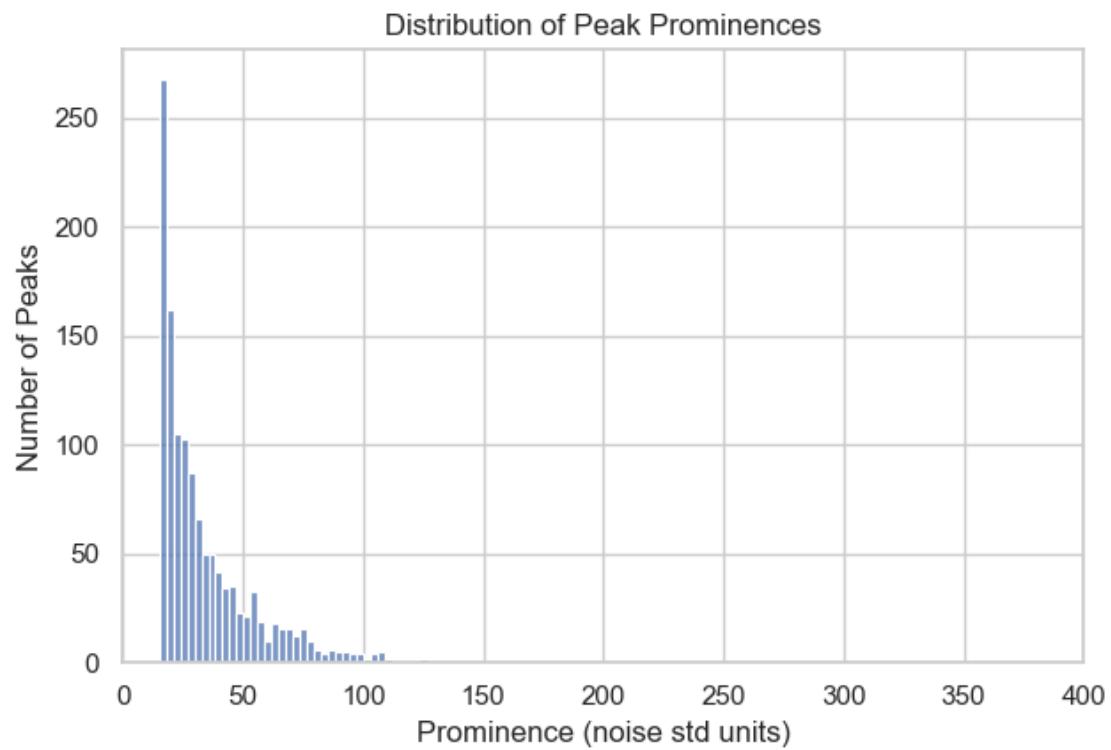


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:00:49] [INFO] calcium: plot_histogram: removed 4 outliers out of  
1263 on 'Duration (s)' (lower=-15, upper=117)
```

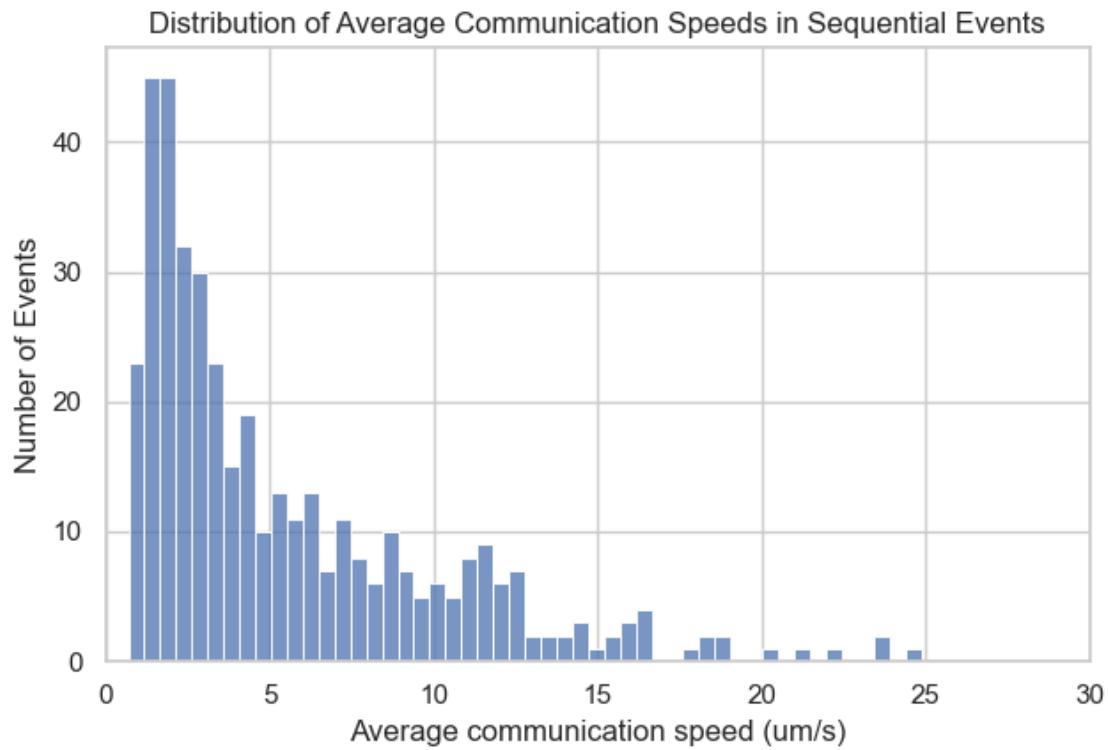


```
[2025-08-27 15:00:49] [INFO] calcium: plot_histogram: removed 14 outliers out of  
1263 on 'Prominence (noise std units)' (lower=-17.225, upper=127.07)
```



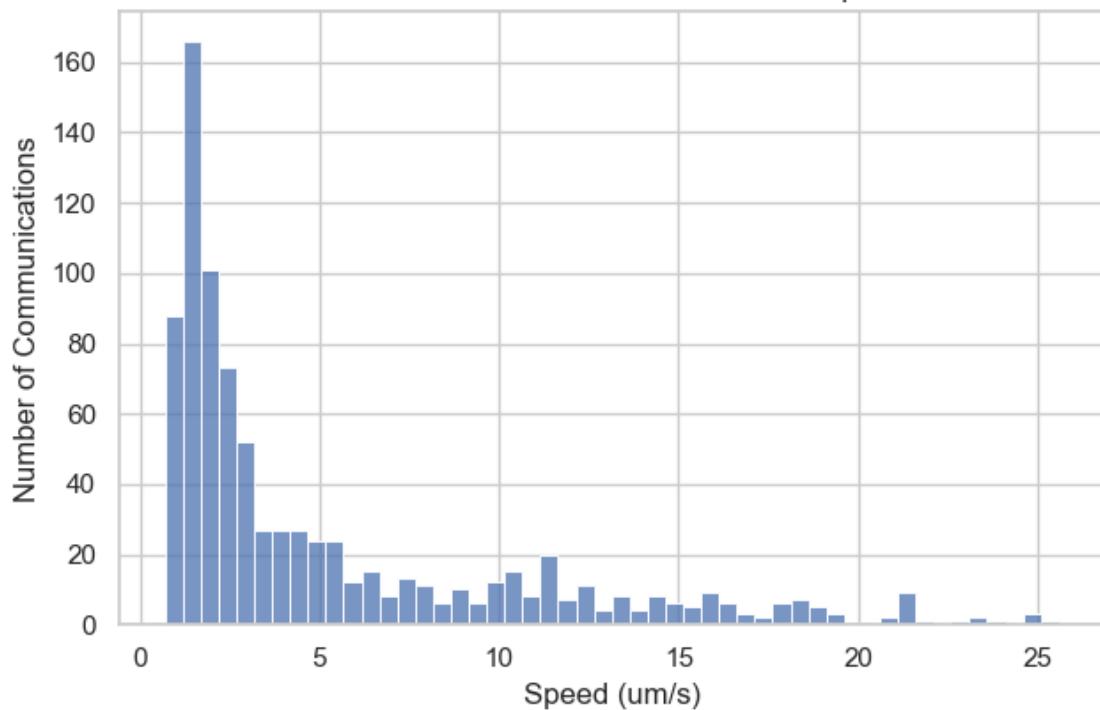
1.3.3 Cell-cell communication speed

```
[2025-08-27 15:00:50] [INFO] calcium: plot_histogram: removed 0 outliers out of  
404 on 'Average communication speed (um/s)' (lower=-15.433, upper=25.378)
```

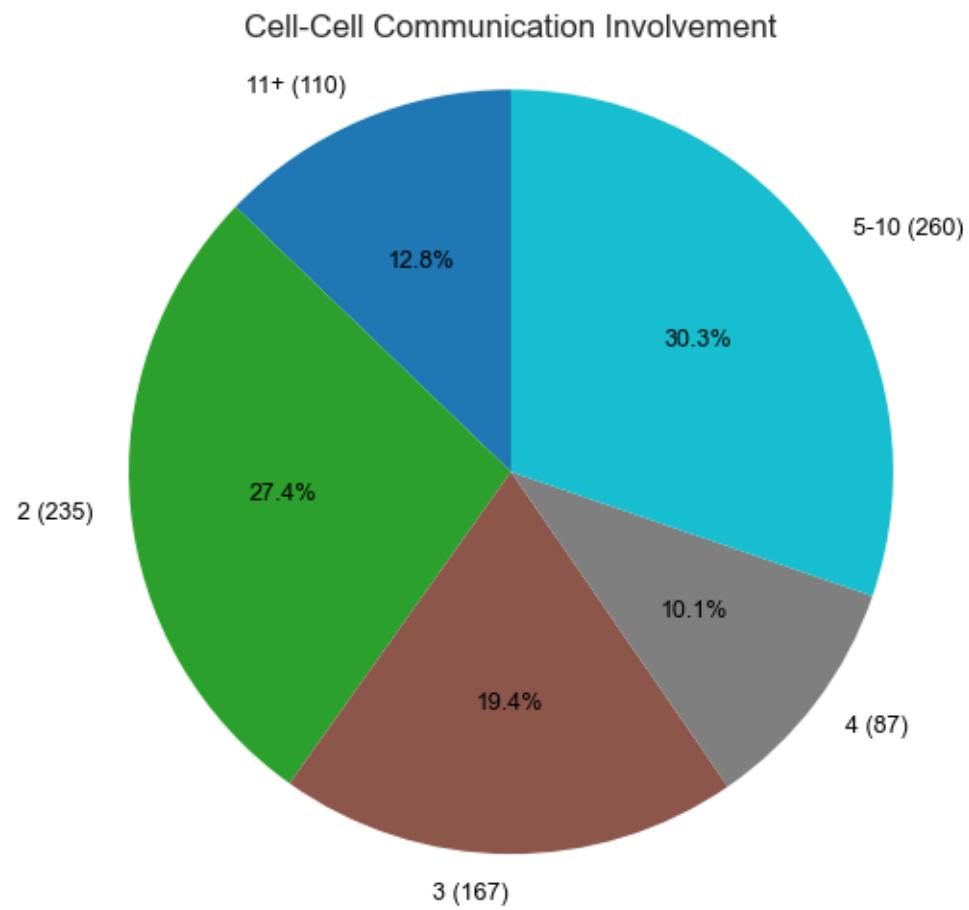


```
[2025-08-27 15:00:50] [INFO] calcium: plot_histogram: removed 0 outliers out of  
859 on 'Speed (um/s)' (lower=-15.265, upper=35.18)
```

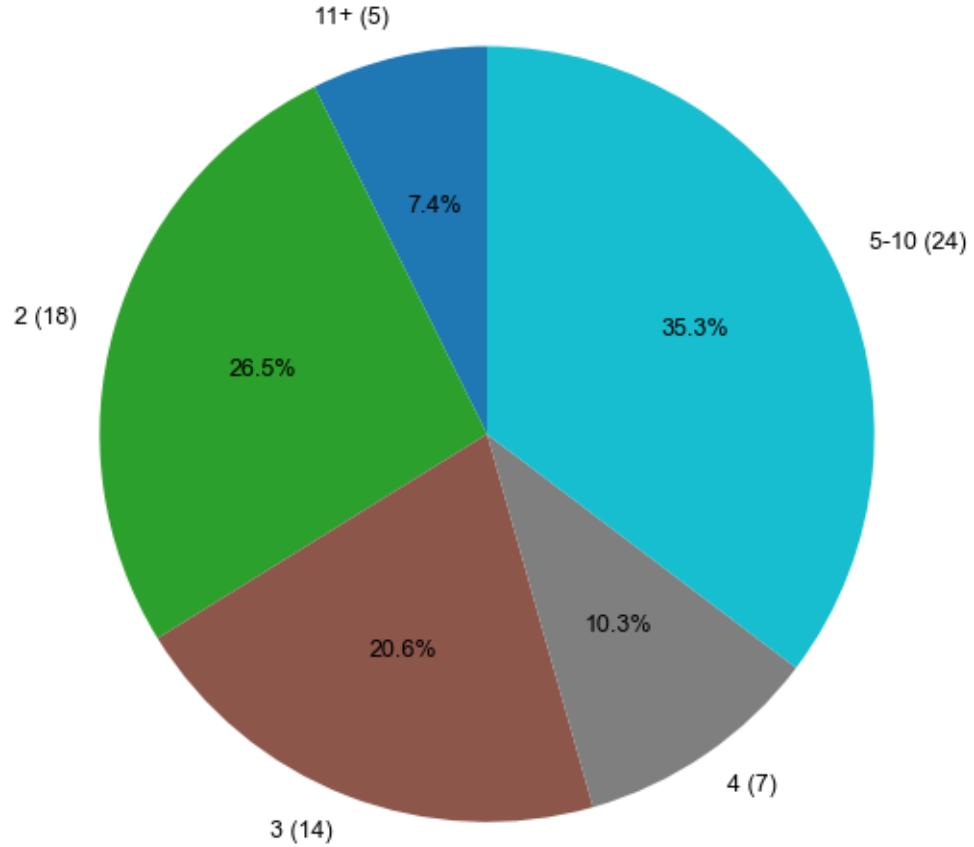
Distribution of Cell-Cell Communication Speeds



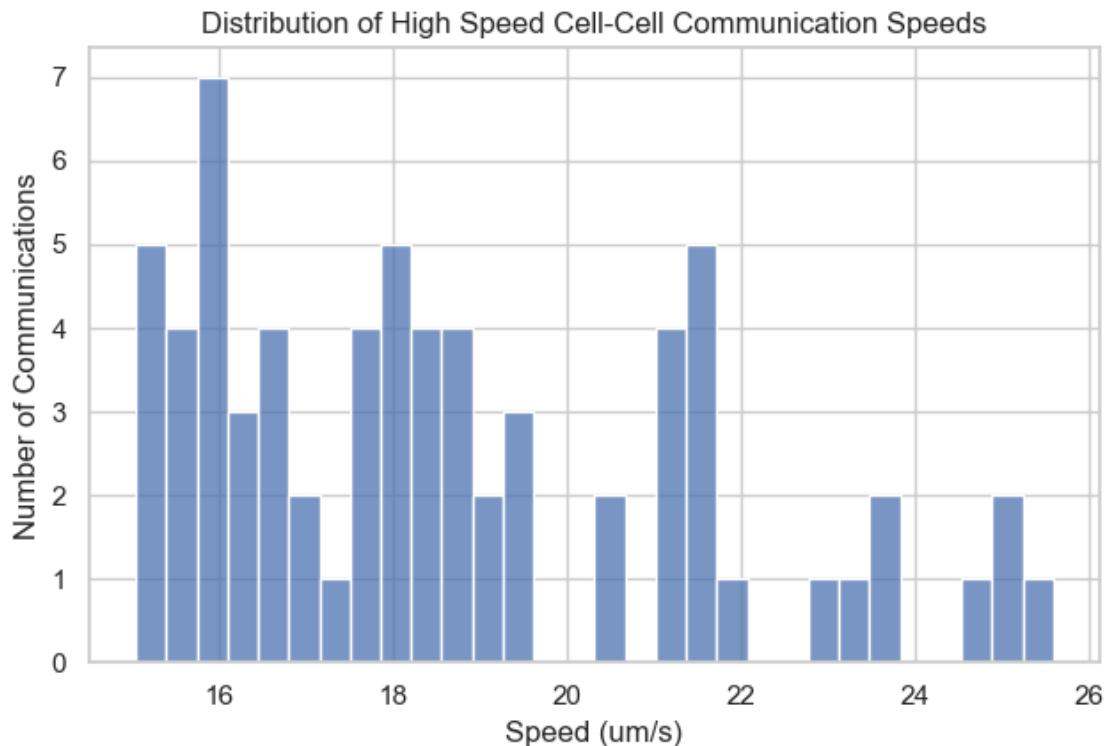
1.3.4 Double distribution in cell-cell communication speeds



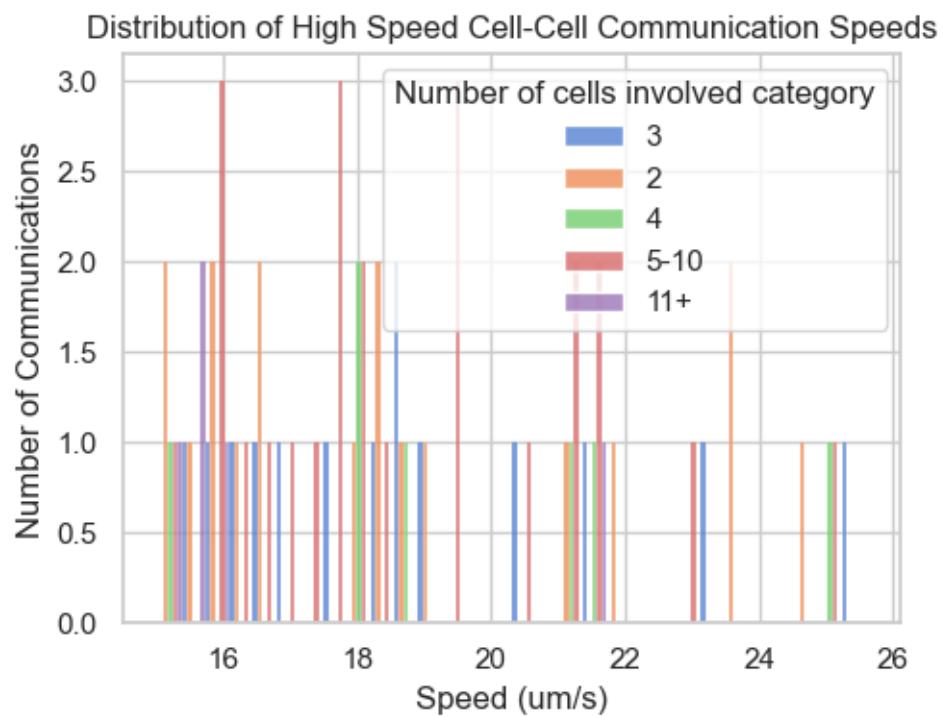
High Speed Cell-Cell Communication Involvement



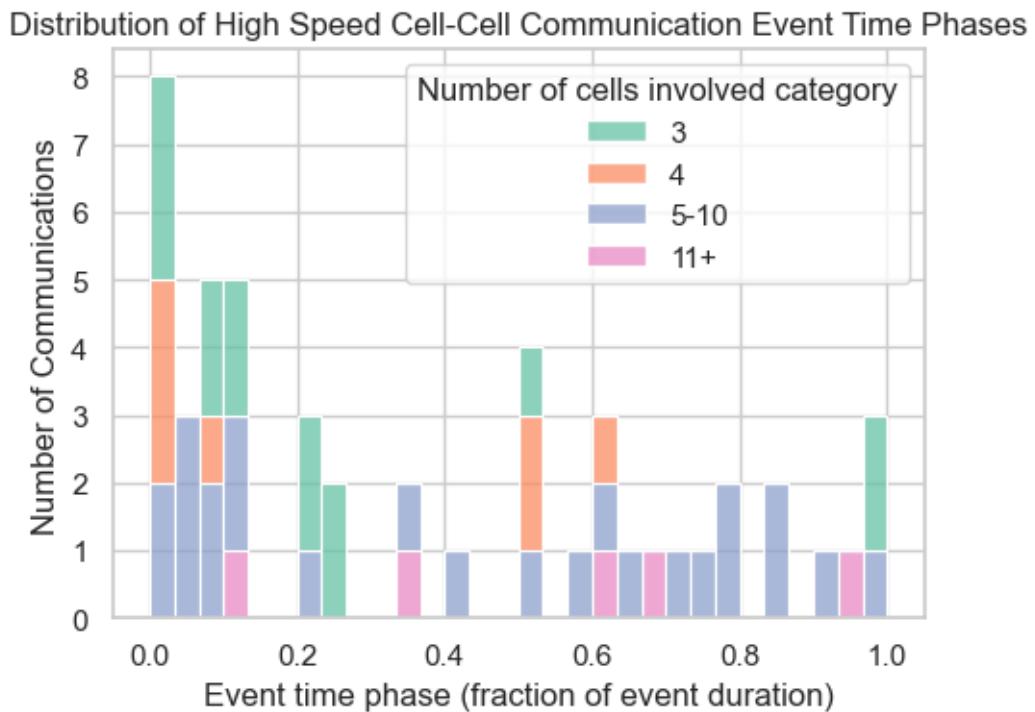
[2025-08-27 15:00:50] [INFO] calcium: plot_histogram: removed 0 outliers out of 68 on 'Speed (um/s)' (lower=1.82, upper=35.718)



```
[2025-08-27 15:00:50] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 68 on 'Speed (um/s)' (lower=1.82, upper=35.718)
```

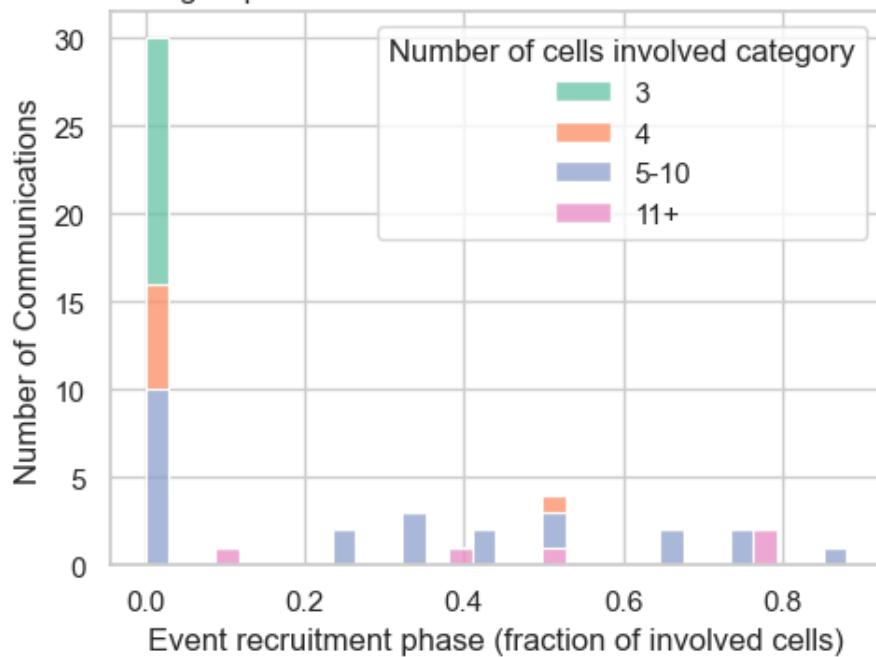


```
[2025-08-27 15:00:51] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 50 on 'Event time phase (fraction of event duration)' (lower=-1.5675, upper=2.2825)
```

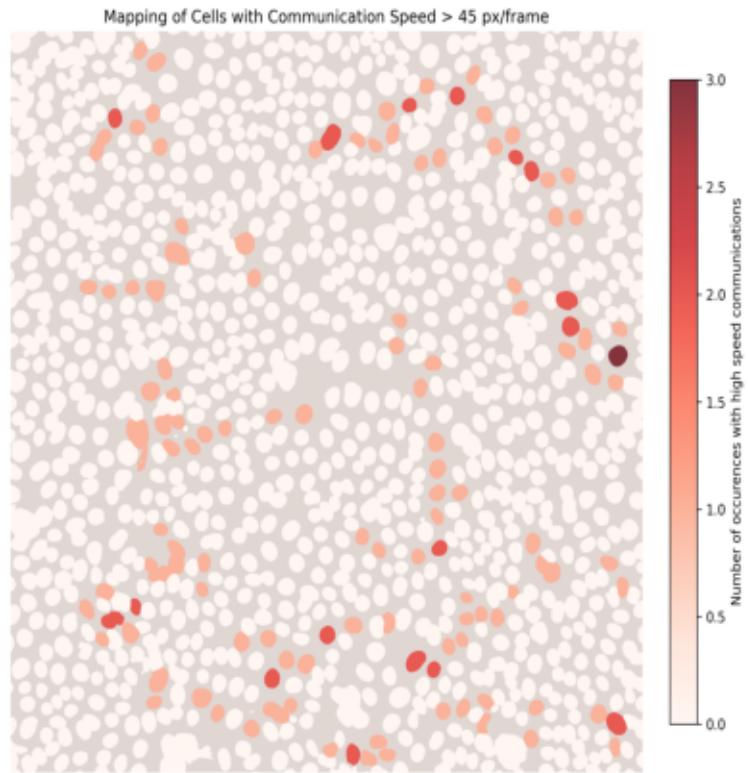


```
[2025-08-27 15:00:51] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 50 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.2675, upper=1.69)
```

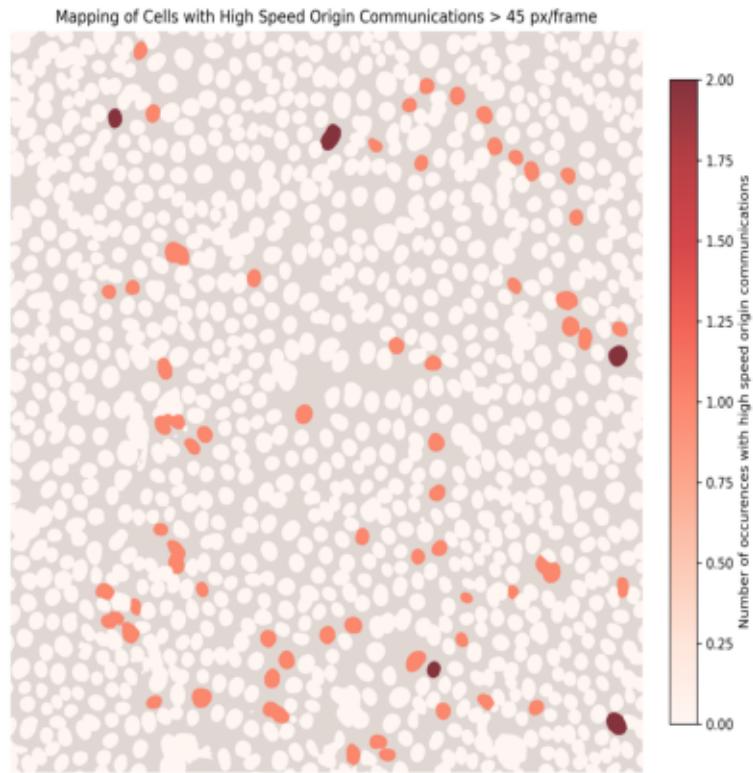
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
0	3015480673040	5	703	0	
27	3015480672944	11	1614	0	
30	3015480672560	13	542	1	
33	3015480677456	14	1699	0	
35	3015500604768	14	1725	0	
..	
753	3015543248240	351	1470	6	
767	3015543242960	357	1465	5	
777	3015500599248	360	1666	5	
814	3015500609664	378	1604	0	
843	3015500602944	395	1727	6	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
0	650	0	17.0	17.0	
27	1562	0	31.0	31.0	
30	516	1	109.0	109.0	
33	1725	0	87.0	87.0	
35	1716	0	87.0	88.0	
..	
753	1480	5	757.0	758.0	
767	1526	4	1191.0	1192.0	
777	1638	4	1607.0	1608.0	
814	1635	0	89.0	90.0	
843	1739	5	1607.0	1608.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
0	0.0	18.93	18.93		
27	0.0	15.06	15.06		
30	0.0	15.28	15.28		
33	0.0	21.55	21.55		
35	1.0	17.85	17.85		
..		
753	1.0	21.25	21.25		
767	1.0	25.59	25.59		
777	1.0	15.41	15.41		
814	1.0	16.40	16.40		
843	1.0	15.49	15.49		
	Event time phase (fraction of event duration)	\			
0		0.00			
27		NaN			
30		0.60			
33		0.77			
35		0.85			
..		...			
753		NaN			
767		0.50			
777		0.13			
814		0.09			
843		0.25			
	Event recruitment phase (fraction of involved cells)	dataset	\		
0		0.00	20250618_IS2		
27		NaN	20250618_IS2		
30		0.00	20250618_IS2		
33		0.25	20250618_IS2		
35		0.75	20250618_IS2		
..			
753		NaN	20250618_IS2		
767		0.00	20250618_IS2		

777		0.09	20250618_IS2
814		0.00	20250618_IS2
843		0.00	20250618_IS2

	Number of cells involved	category	Speed category
0		3	High speed
27		2	High speed
30		4	High speed
33		5-10	High speed
35		5-10	High speed
..	
753		2	High speed
767		3	High speed
777		11+	High speed
814		3	High speed
843		3	High speed

[68 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
266		0	1
267		0	1
270		0	1
271		0	1
278		0	1
..	
1740		0	2
1741		0	1
1744		0	1
1746		0	1
1747		0	2

[486 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	266	217.43	7.48
3	267	255.45	7.48
5	270	350.03	8.45
6	271	91.98	8.45
10	278	299.32	10.72
..
1033	1740	212.55	490.75
1034	1741	249.60	491.07
1036	1744	190.78	491.73
1037	1746	449.80	491.73
1038	1747	39.98	492.38

Number of peaks Is active Occurrences in global events \

2	6	True	4
3	10	True	4
5	11	True	4
6	6	True	4
10	8	True	4
...
1033	7	True	4
1034	5	True	4
1036	5	True	4
1037	8	True	4
1038	8	True	4

Occurrences in global events as early peaker Early peaker event IDs \

2	0	[]
3	1	[1]
5	1	[1]
6	0	[]
10	0	[]
...
1033	1	[3]
1034	0	[]
1036	0	[]
1037	1	[2]
1038	0	[]

Occurrences in sequential events \

2	2	
3	2	
5	1	
6	2	
10	2	
...	...	
1033	1	
1034	1	
1036	1	
1037	2	
1038	2	

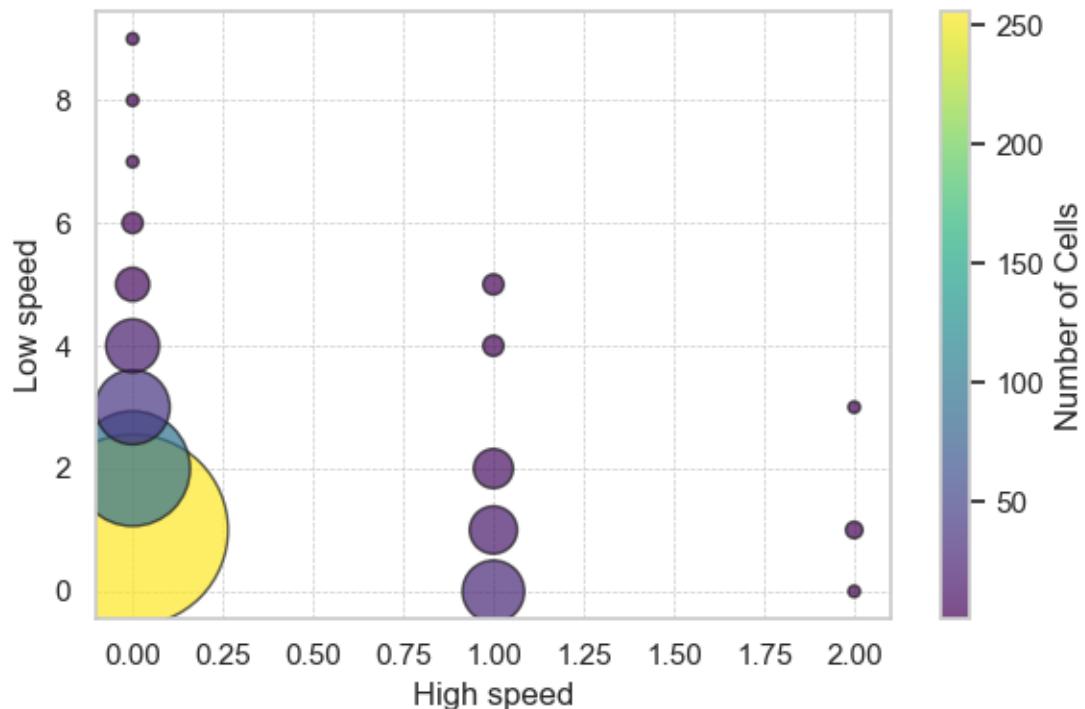
Occurrences in sequential events as origin \

2	1	
3	1	
5	1	
6	1	
10	1	
...	...	
1033	0	
1034	1	
1036	1	

1037			1	
1038			1	
Occurrences in individual events Peak frequency (Hz) \				
2		0	0.0035	
3		3	0.0059	
5		4	0.0065	
6		0	0.0035	
10		2	0.0047	
...	
1033		2	0.0041	
1034		0	0.0029	
1036		0	0.0029	
1037		2	0.0047	
1038		2	0.0047	
Periodicity score Neighbor count Neighbors (labels) \				
2	0.65	3	[281,282,318]	
3	0.67	4	[272,290,293,350]	
5	0.59	4	[269,298,315,340]	
6	0.68	2	[284,286]	
10	0.68	3	[280,300,307]	
...	
1033	0.67	4	[1677,1679,1719,1744]	
1034	0.88	2	[1705,1716]	
1036	0.88	5	[1671,1679,1710,1736,1740]	
1037	0.79	3	[1704,1735,1737]	
1038	0.64	4	[1690,1707,1730,1734]	
dataset Involved in sequential event \				
2	20250618_IS2	Involved in sequential event		
3	20250618_IS2	Involved in sequential event		
5	20250618_IS2	Involved in sequential event		
6	20250618_IS2	Involved in sequential event		
10	20250618_IS2	Involved in sequential event		
...	
1033	20250618_IS2	Involved in sequential event		
1034	20250618_IS2	Involved in sequential event		
1036	20250618_IS2	Involved in sequential event		
1037	20250618_IS2	Involved in sequential event		
1038	20250618_IS2	Involved in sequential event		
Occurrences in sequential events category High speed Low speed				
2		1-2	0.0	1.0
3		1-2	0.0	1.0
5		1-2	0.0	1.0
6		1-2	0.0	1.0
10		1-2	0.0	1.0

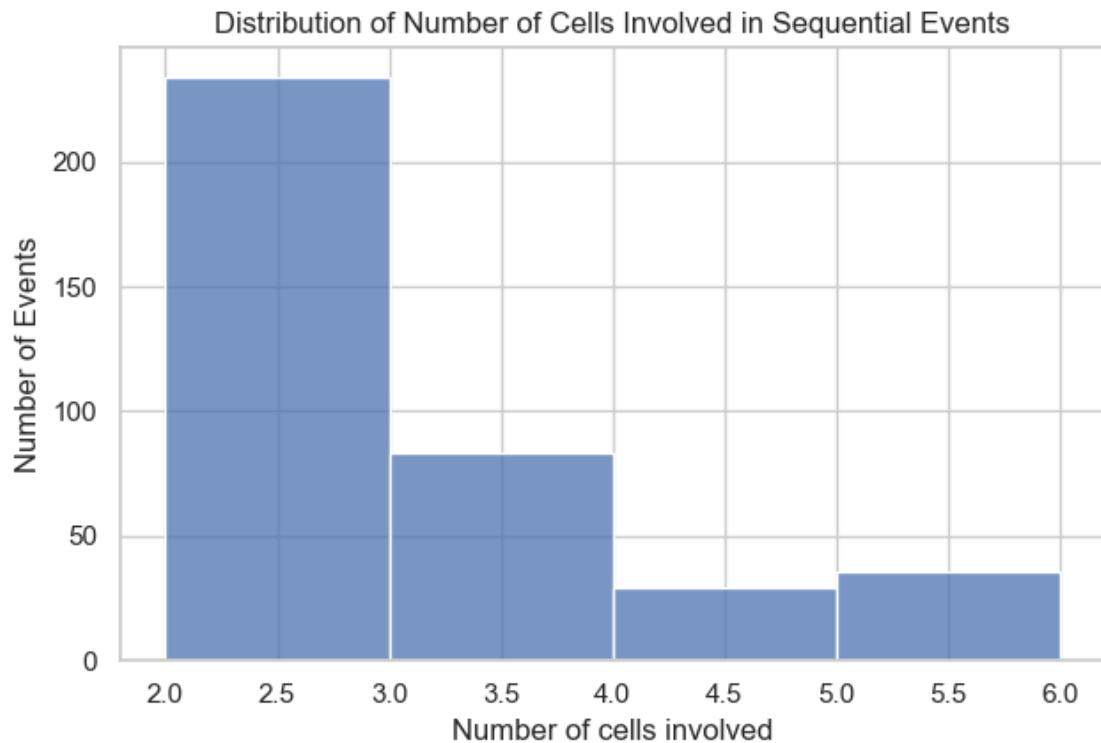
...				
1033		1-2	0.0	2.0
1034		1-2	0.0	1.0
1036		1-2	0.0	1.0
1037		1-2	0.0	1.0
1038		1-2	0.0	2.0

[486 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

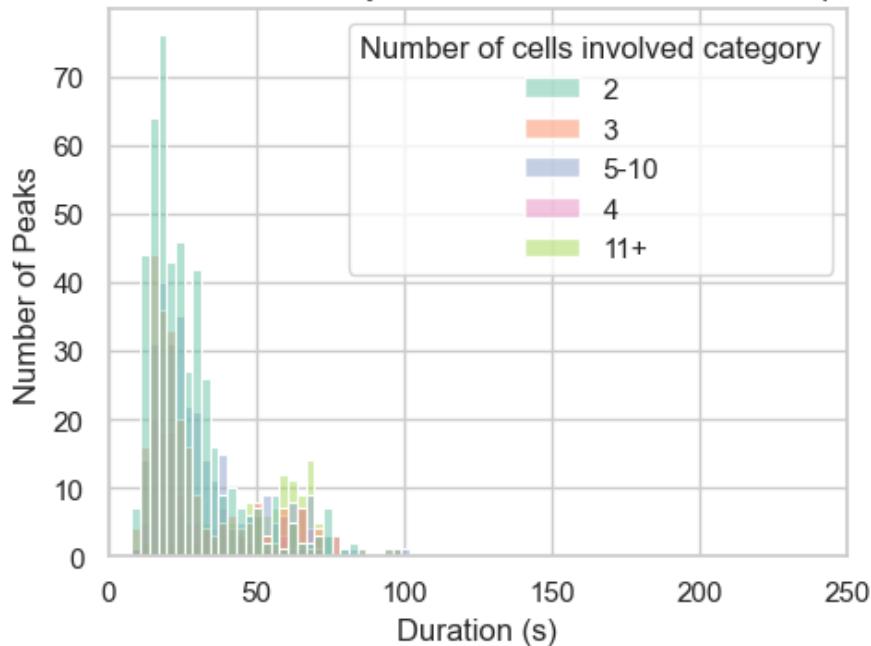
[2025-08-27 15:00:53] [INFO] calcium: plot_histogram: removed 22 outliers out of 404 on 'Number of cells involved' (lower=-1, upper=6)



1.3.6 Influence of cell count per event on statistics

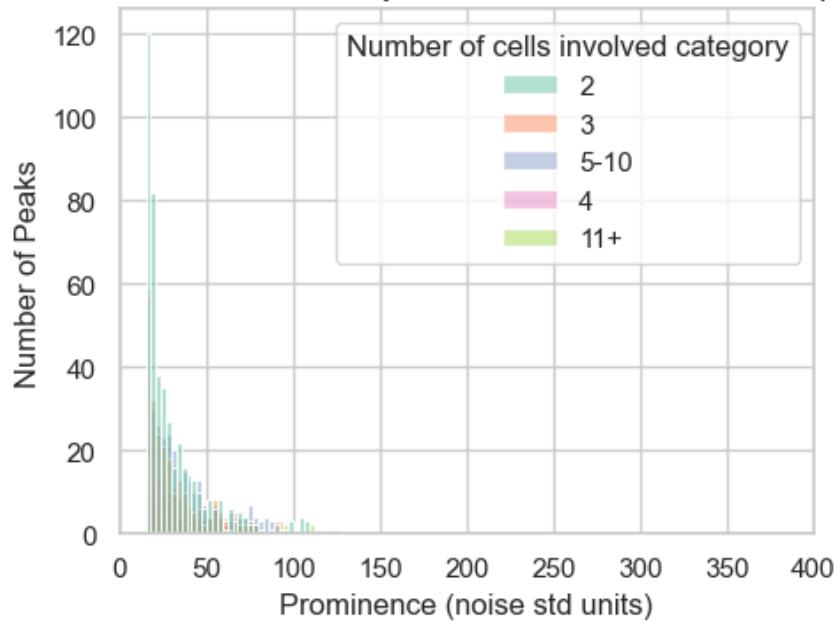
```
[2025-08-27 15:00:53] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 1263 on 'Duration (s)' (lower=-15, upper=117)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

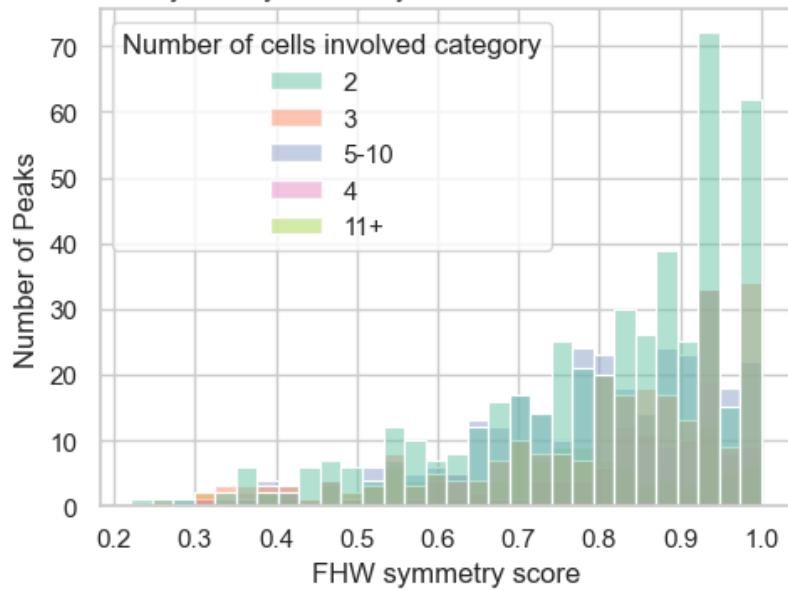


[2025-08-27 15:00:54] [INFO] calcium: plot_histogram_by_group: removed 14 outliers out of 1263 on 'Prominence (noise std units)' (lower=-17.225, upper=127.07)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

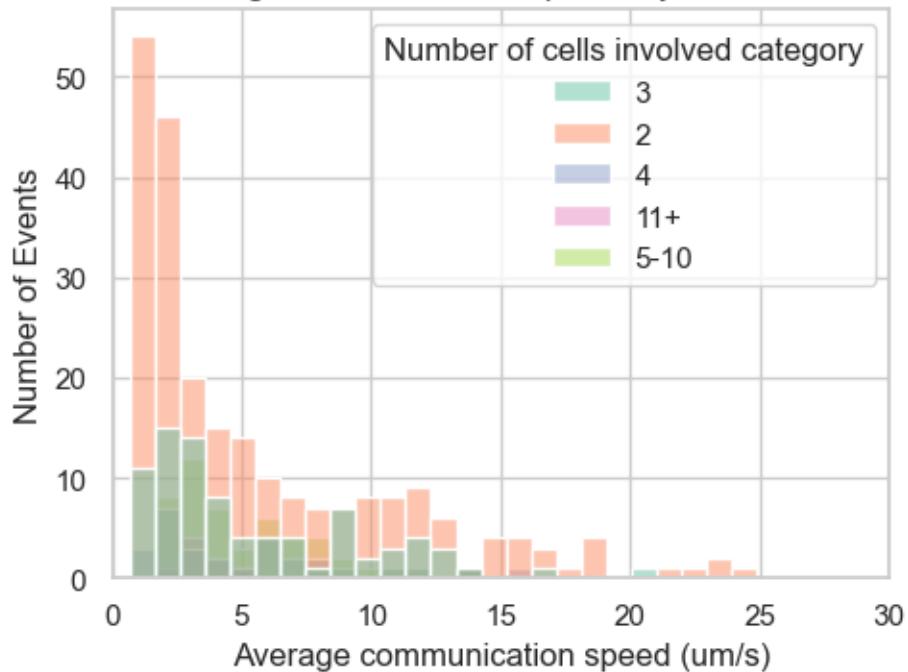


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



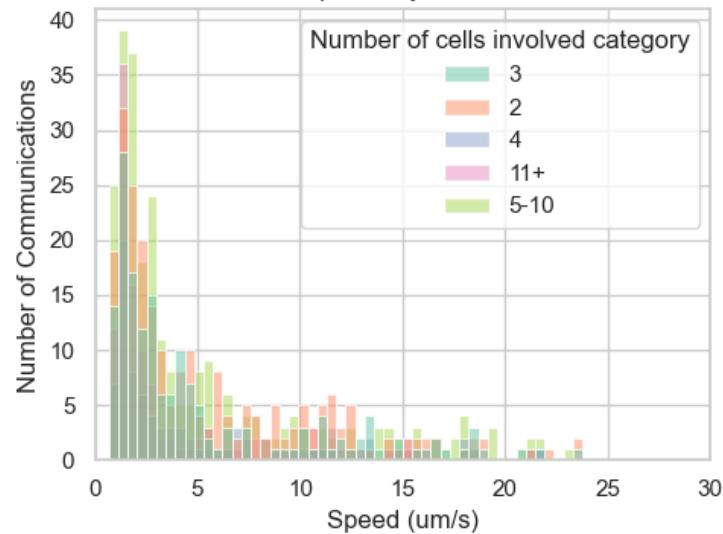
```
[2025-08-27 15:00:54] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 404 on 'Average communication speed (um/s)' (lower=-15.433, upper=25.378)
```

Distribution of Average Communication Speeds by Number of Cells Involved



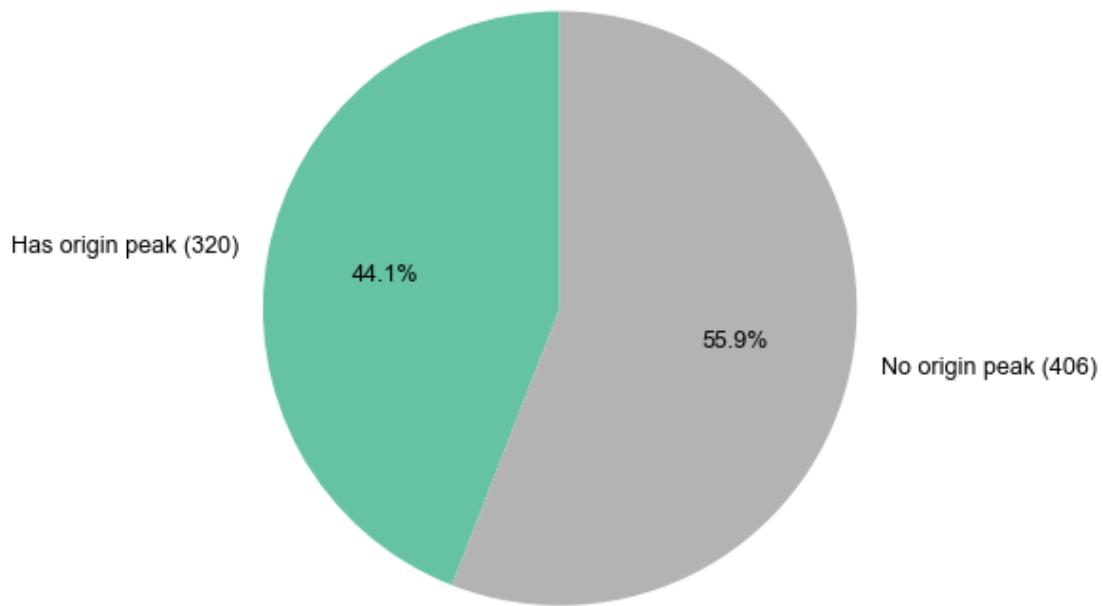
[2025-08-27 15:00:55] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 859 on 'Speed (um/s)' (lower=-15.265, upper=23.97)

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events

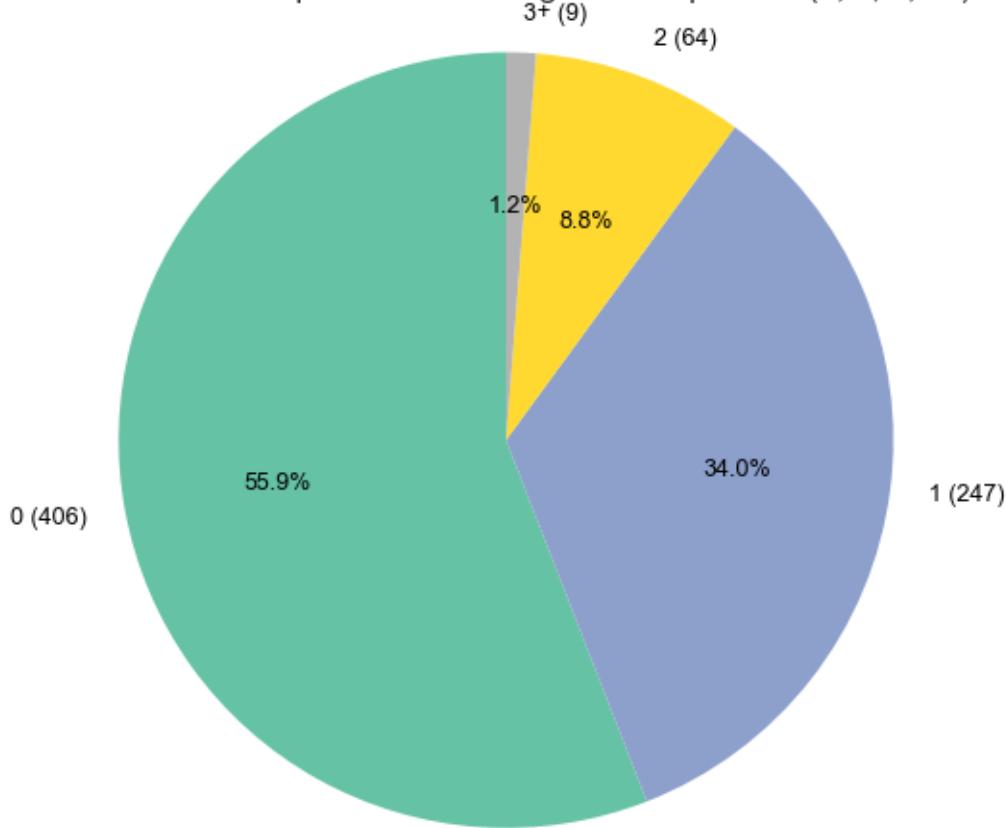


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

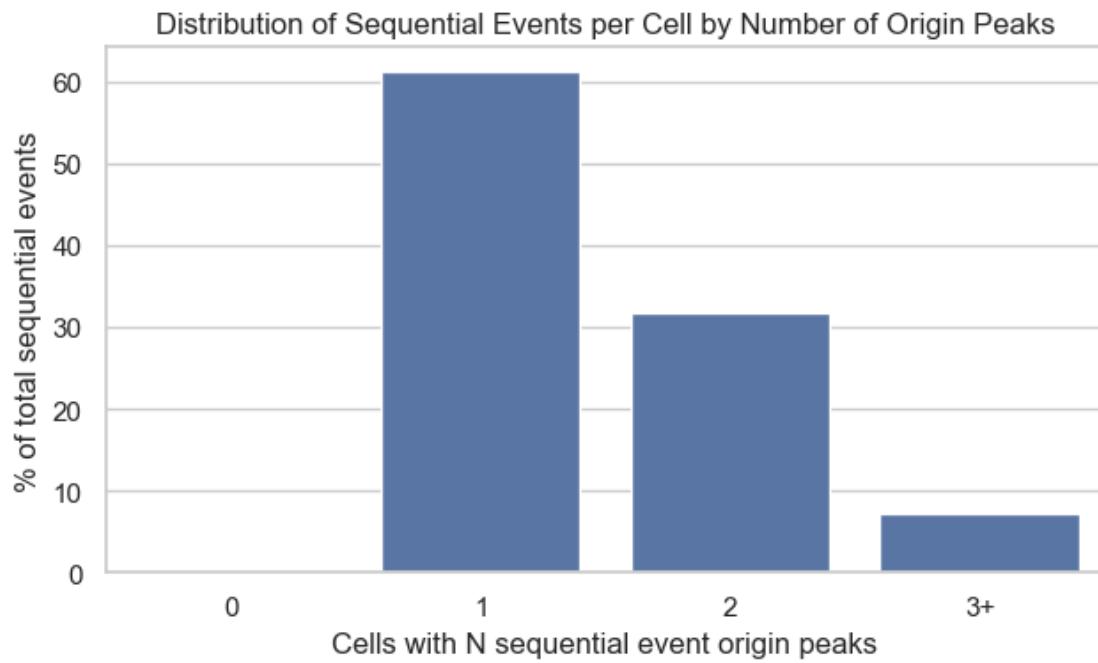


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



```
[2025-08-27 15:00:55] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS2\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

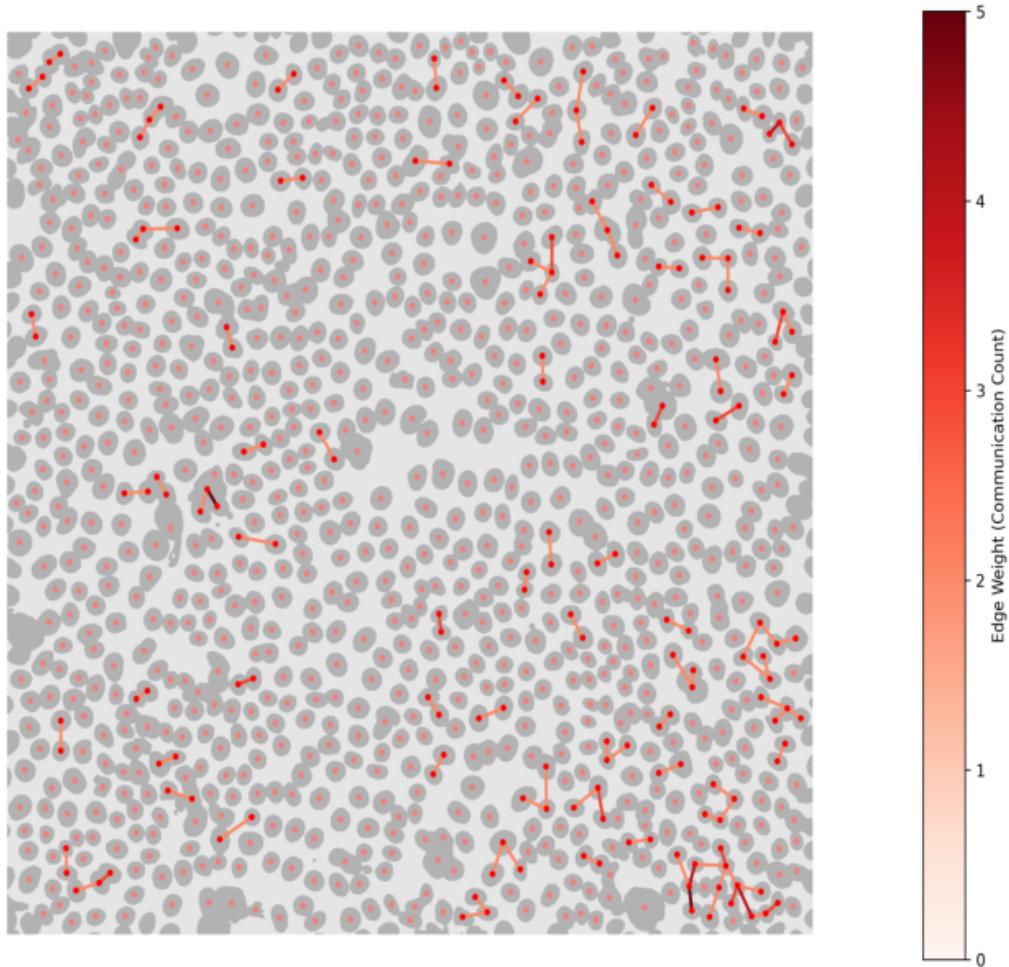
'D:\\Mateo\\20250618\\Output\\IS2\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'



1.3.8 Connection network between cells

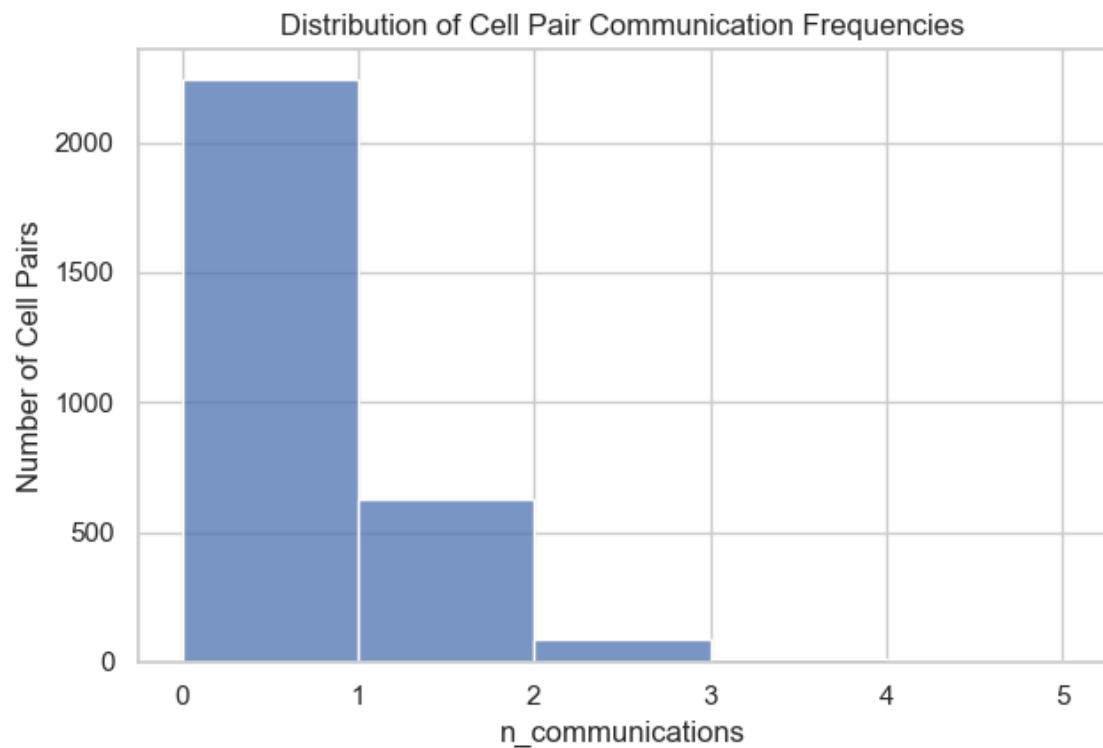
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



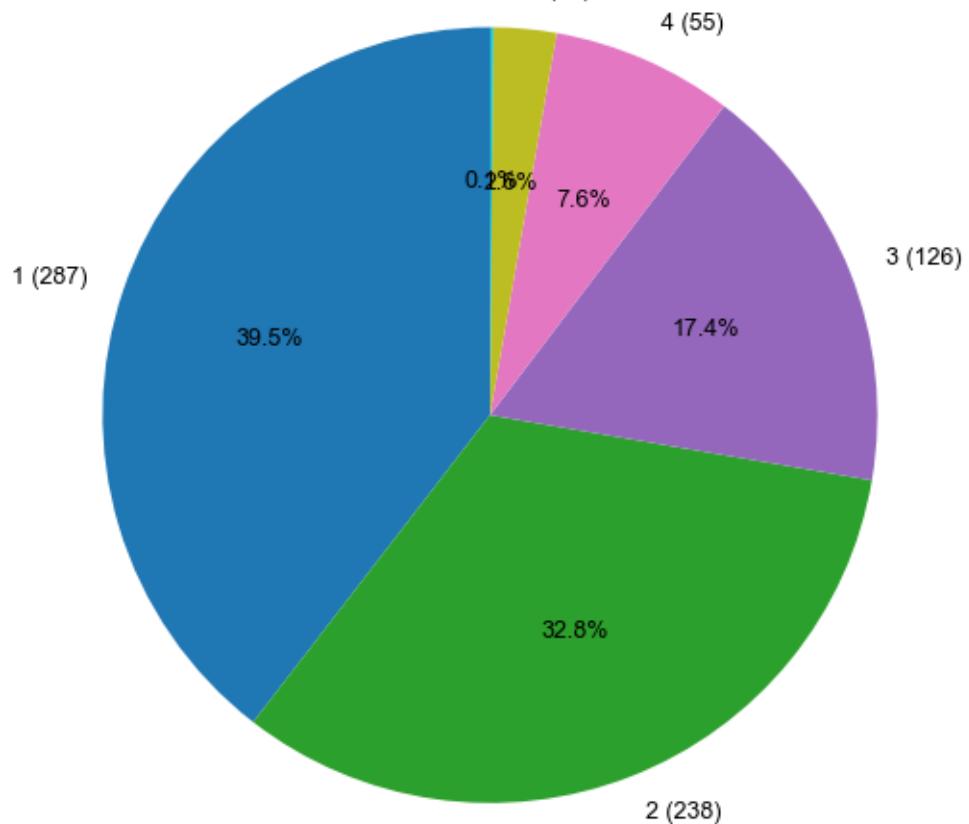
1.3.9 Pair/Trios with high communication networks

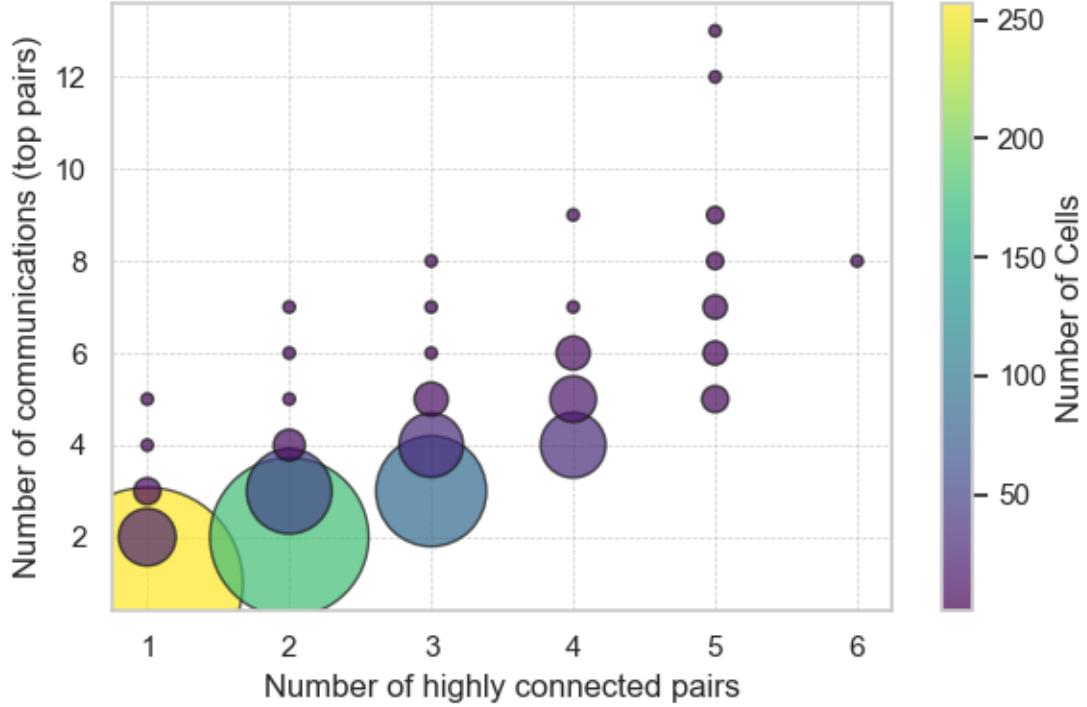
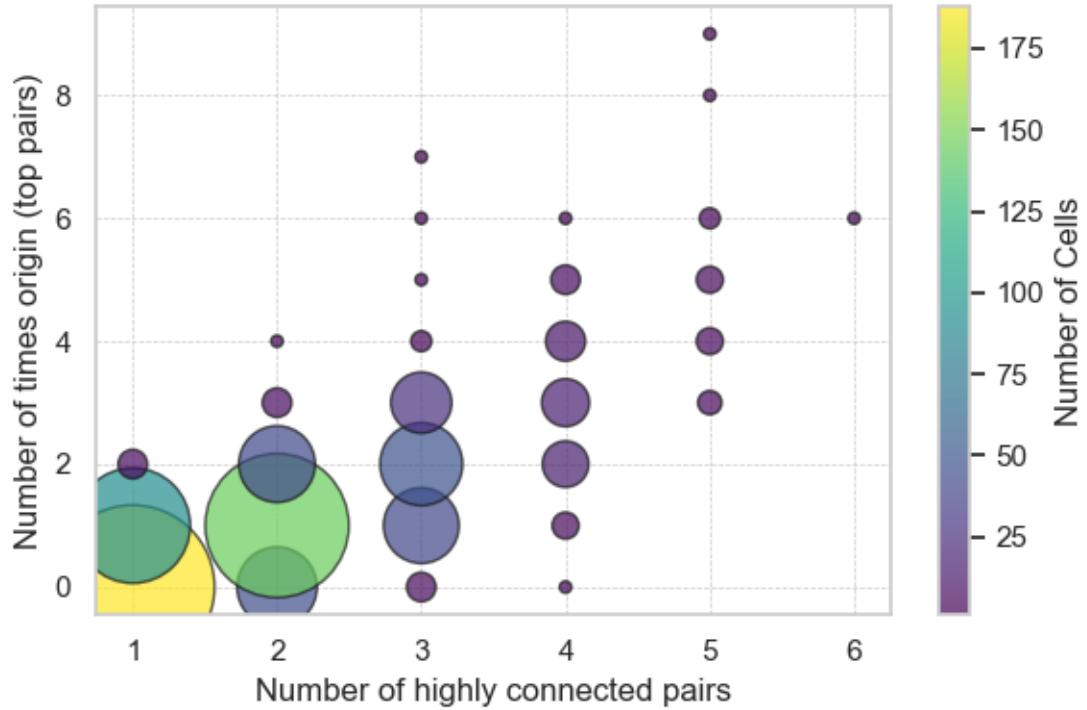
[2025-08-27 15:00:57] [INFO] calcium: build_neighbor_pair_stats: built 2975 pairs across 1 datasets (mean distance=16.85 um)

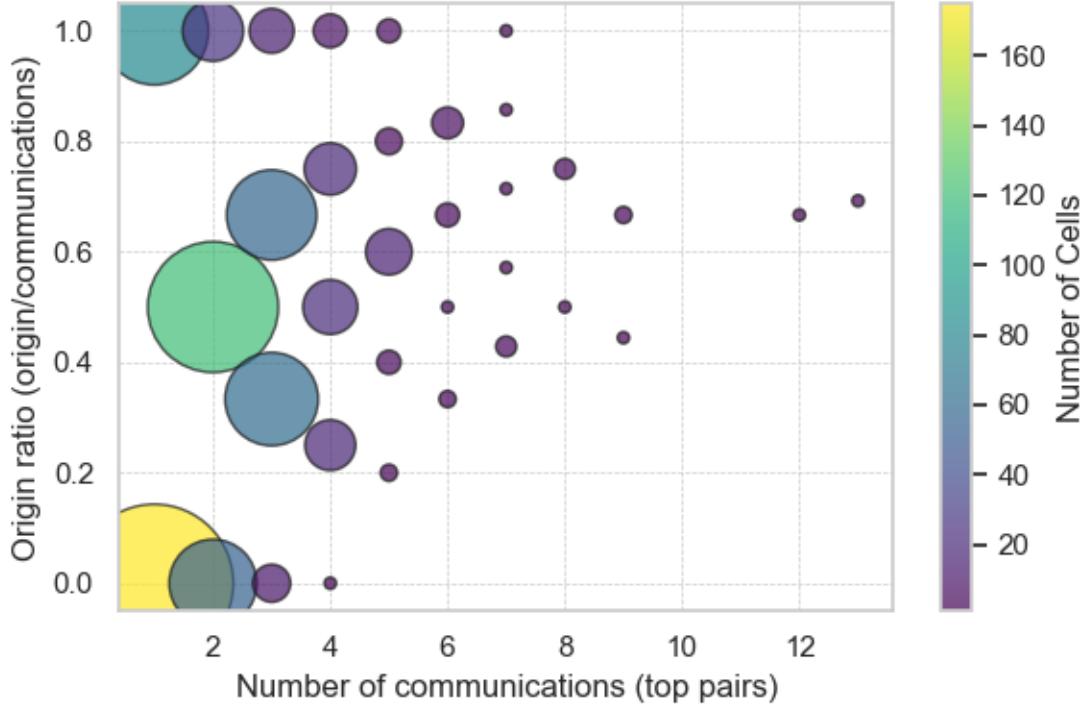
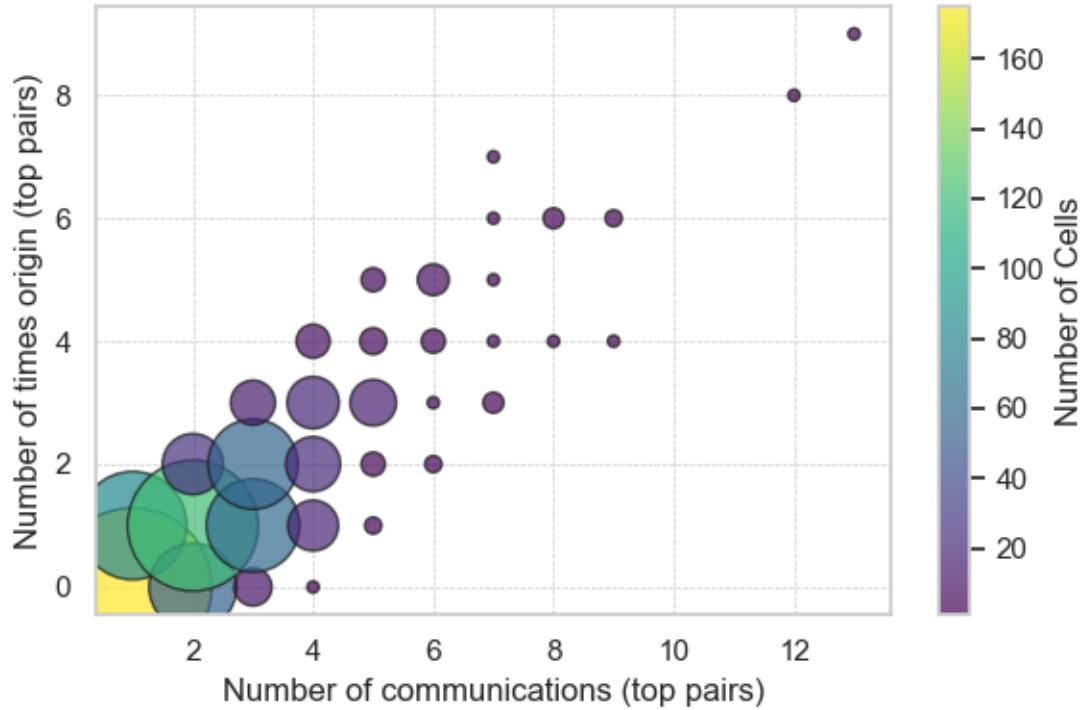


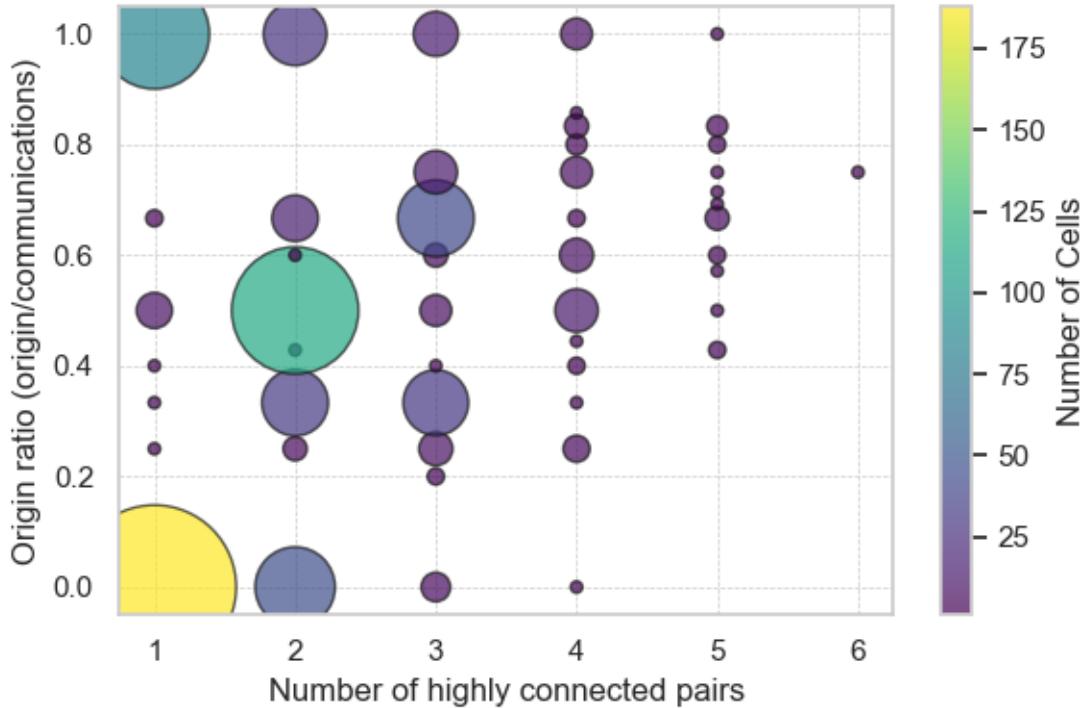
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=287 for Number of highly connected pairs=1

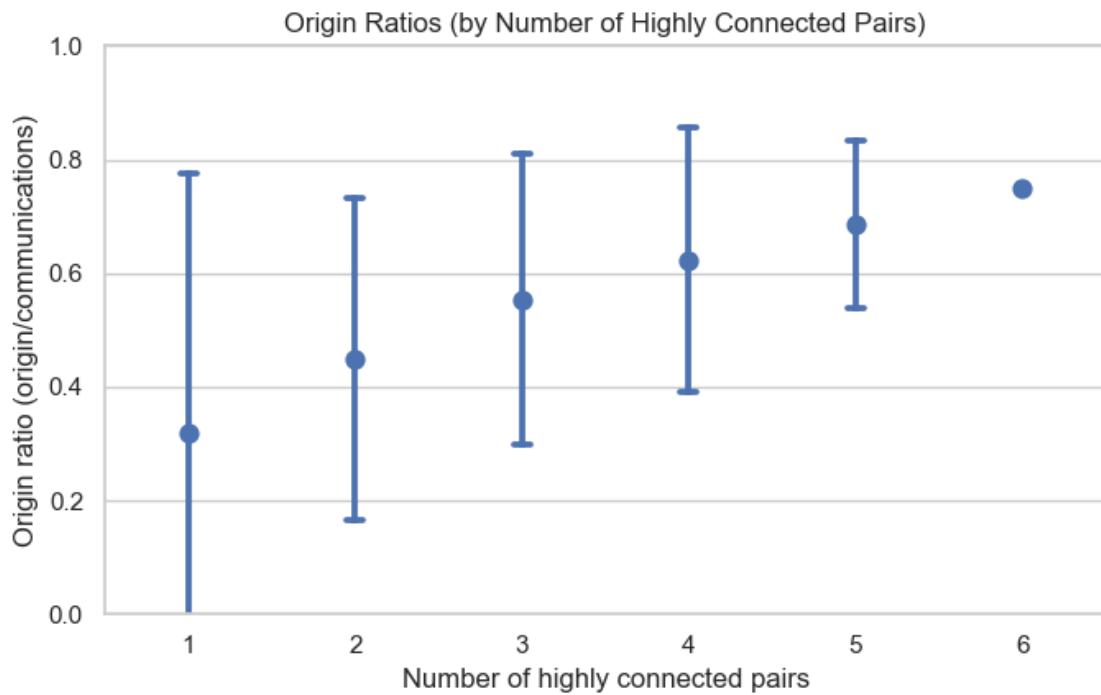
[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=238 for Number of highly connected pairs=2

[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=126 for Number of highly connected pairs=3

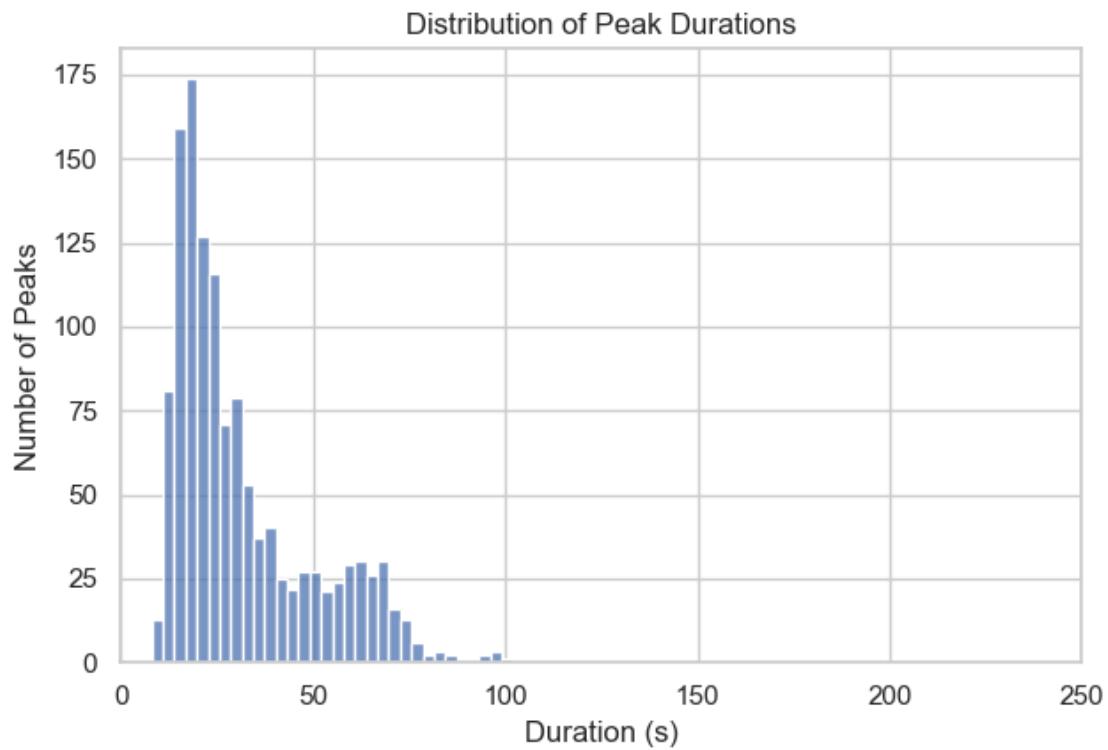
[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=55 for Number of highly connected pairs=4

[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=19 for Number of highly connected pairs=5

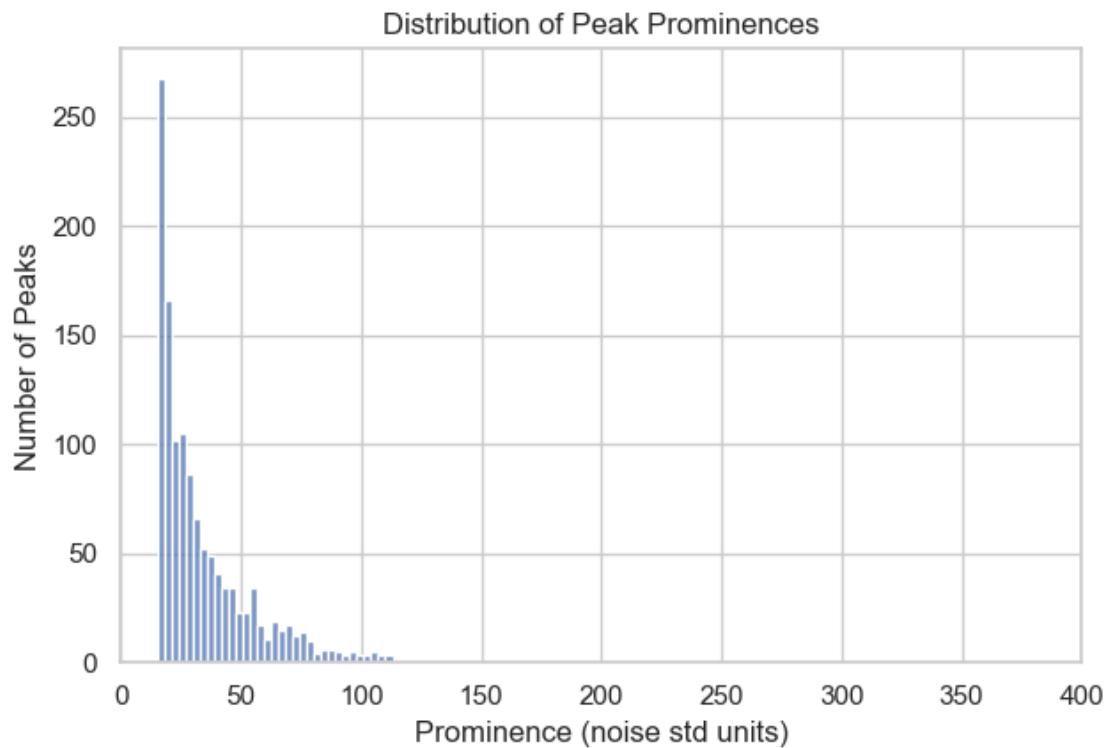
[2025-08-27 15:00:58] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=6

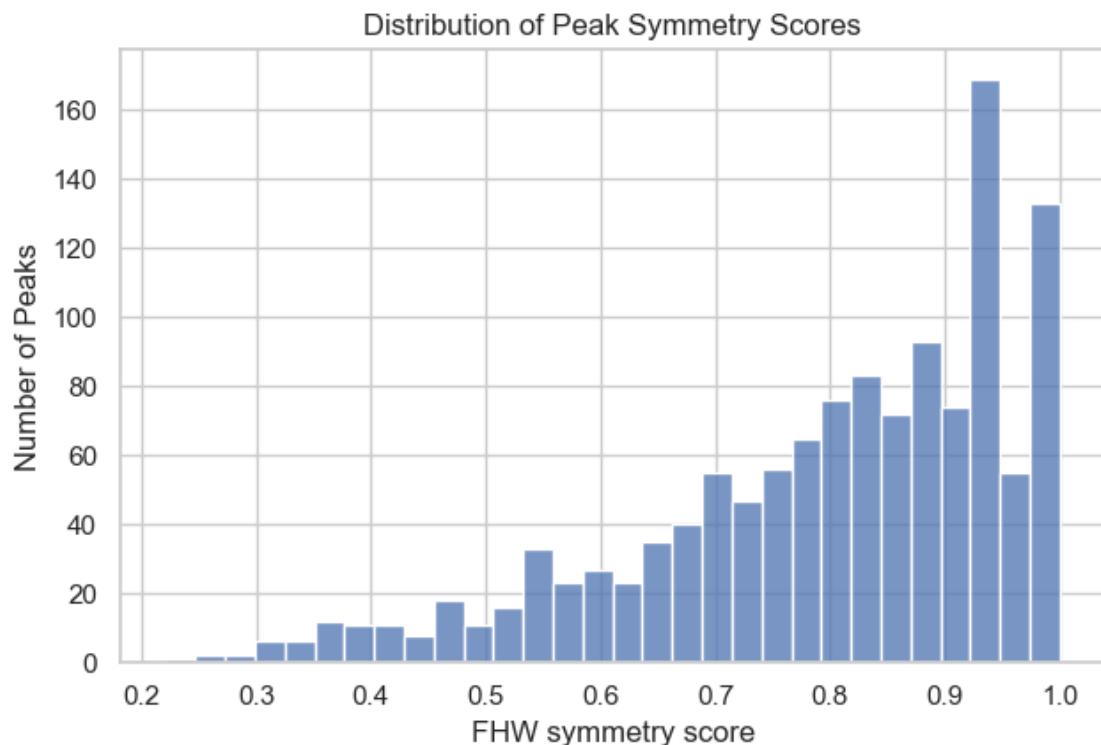


```
[2025-08-27 15:00:58] [INFO] calcium: plot_histogram: removed 4 outliers out of 1263 on 'Duration (s)' (lower=-48, upper=106)
```

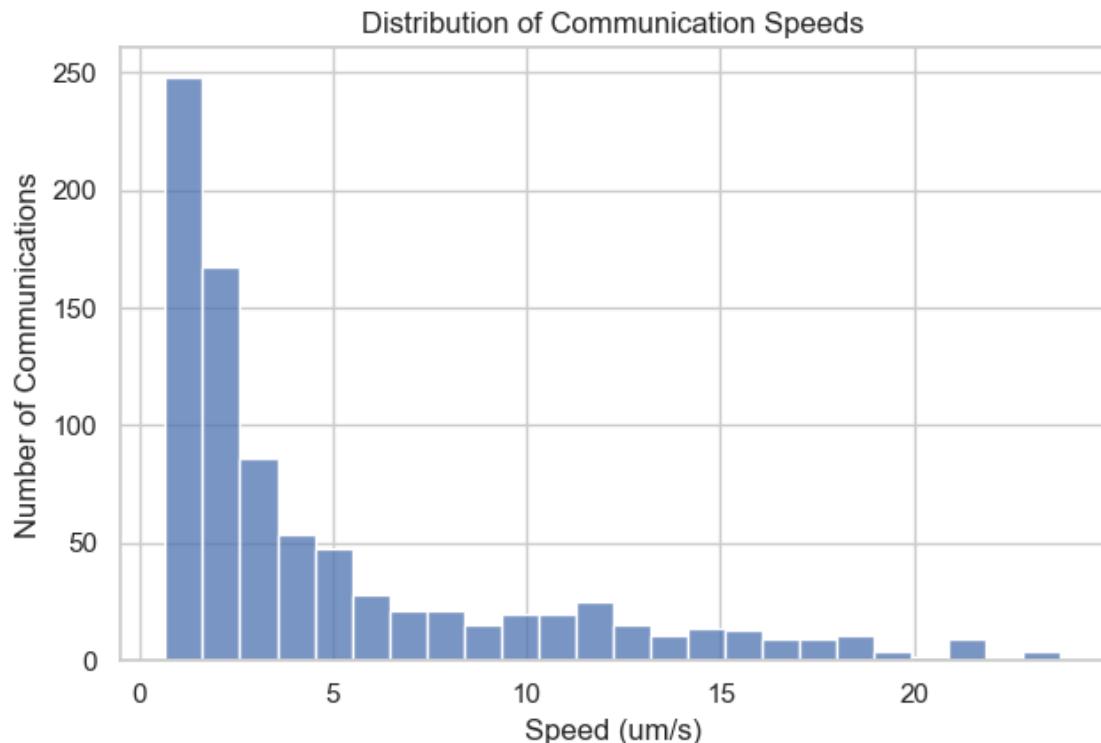


[2025-08-27 15:00:58] [INFO] calcium: plot_histogram: removed 19 outliers out of 1263 on 'Prominence (noise std units)' (lower=-53.3, upper=115.05)

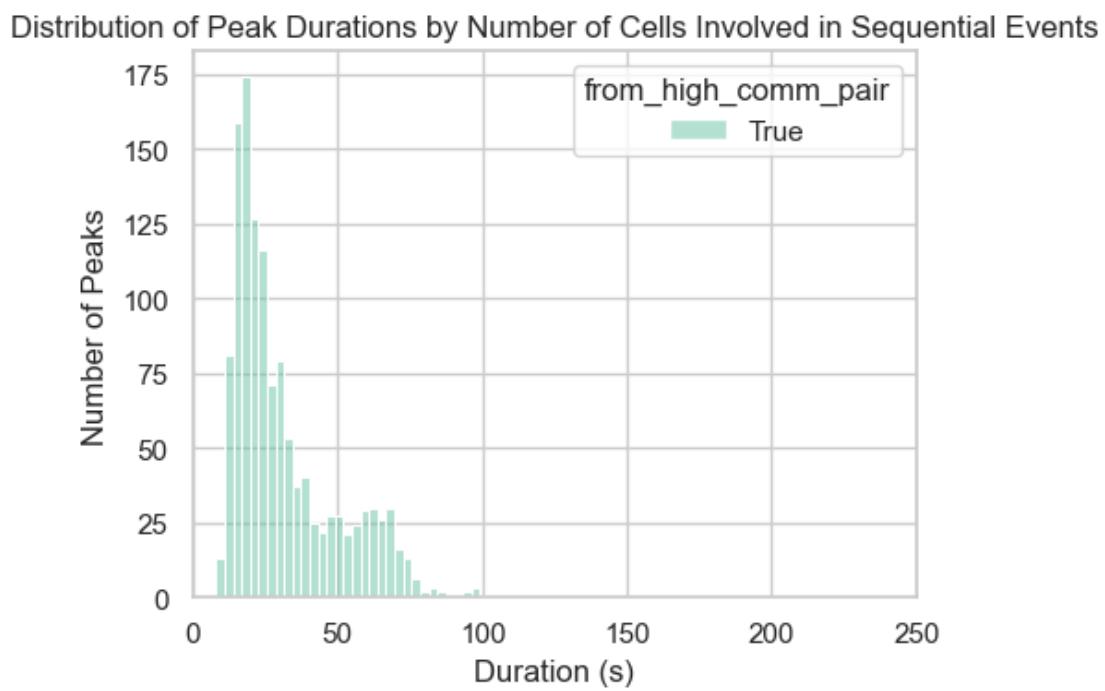




```
[2025-08-27 15:00:59] [INFO] calcium: plot_histogram: removed 4 outliers out of 859 on 'Speed (um/s)' (lower=-15.265, upper=23.97)
```

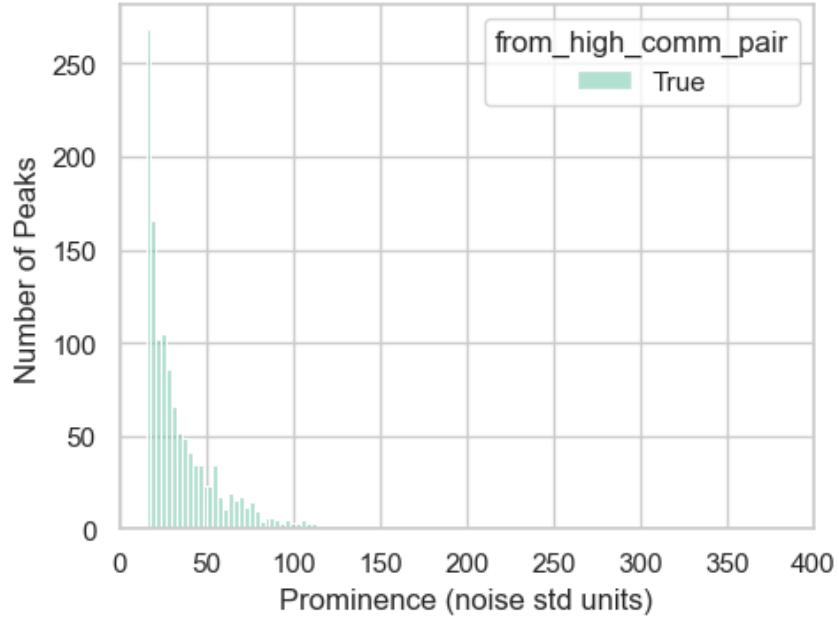


```
[2025-08-27 15:00:59] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 1263 on 'Duration (s)' (lower=-48, upper=106)
```

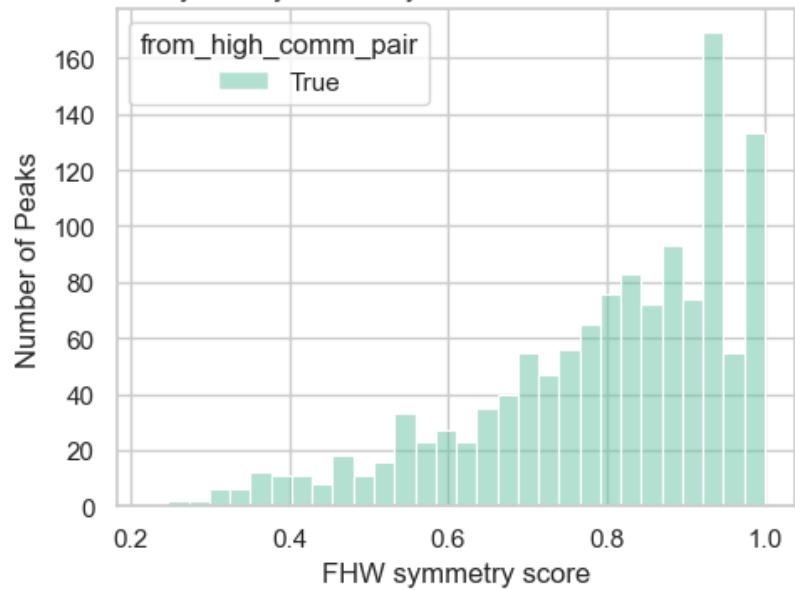


```
[2025-08-27 15:00:59] [INFO] calcium: plot_histogram_by_group: removed 19 outliers out of 1263 on 'Prominence (noise std units)' (lower=-53.3, upper=115.05)
```

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

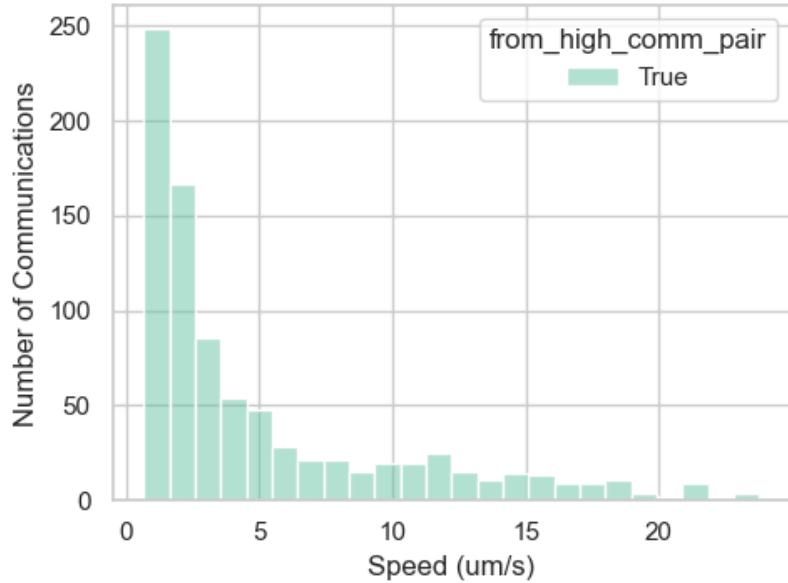


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:00:59] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 859 on 'Speed (um/s)' (lower=-15.265, upper=23.97)

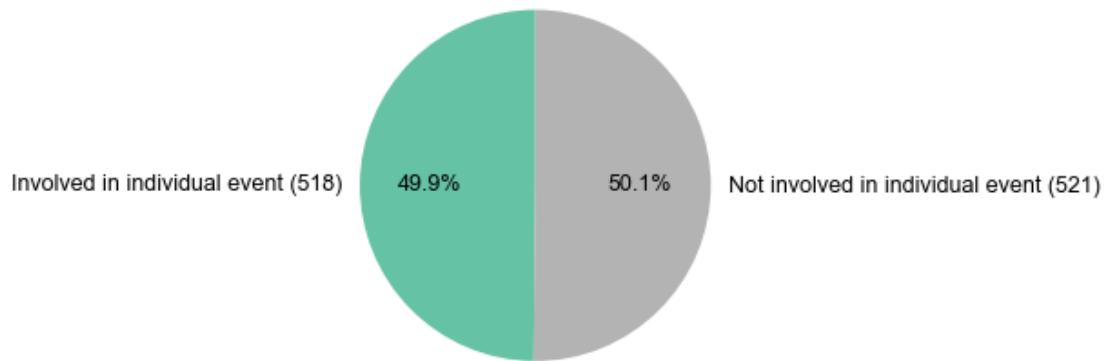
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

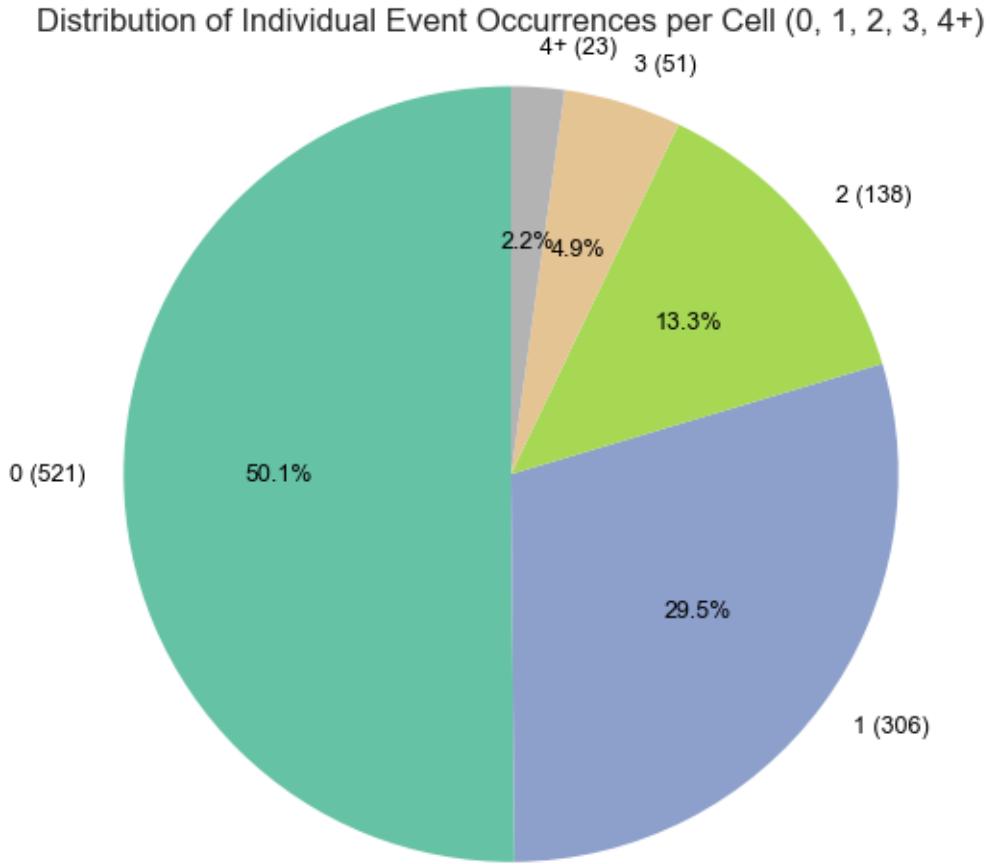


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



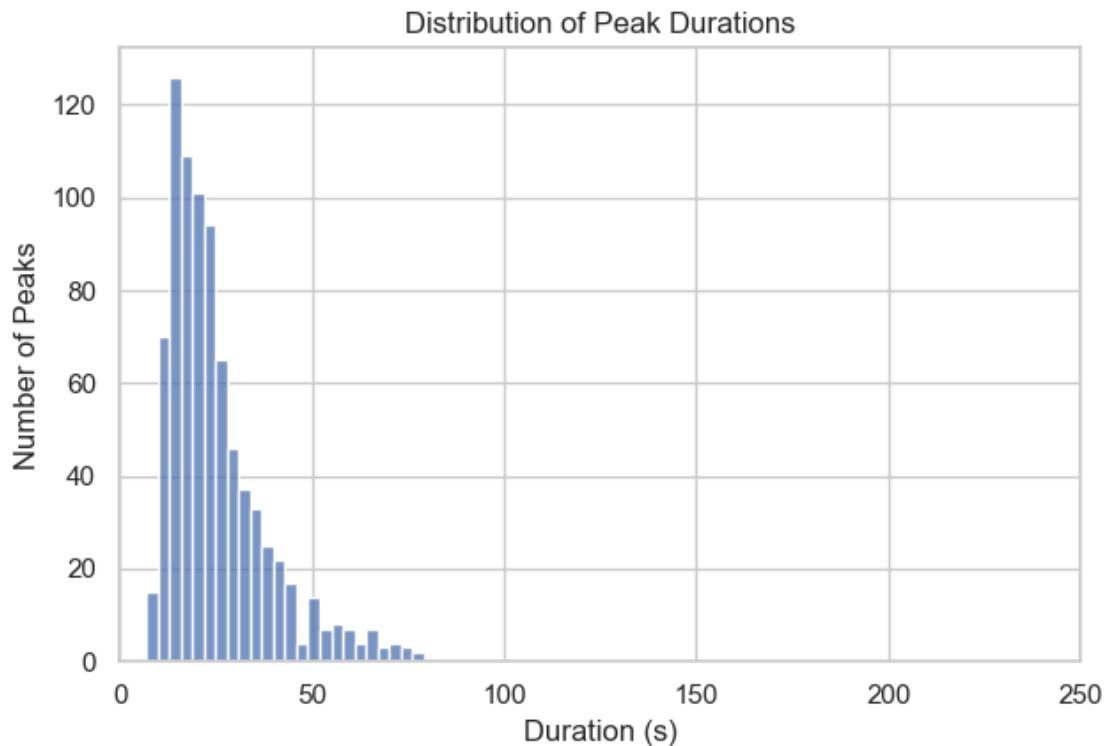


```
[2025-08-27 15:01:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS2\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS2\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250618\\Output\\IS2\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

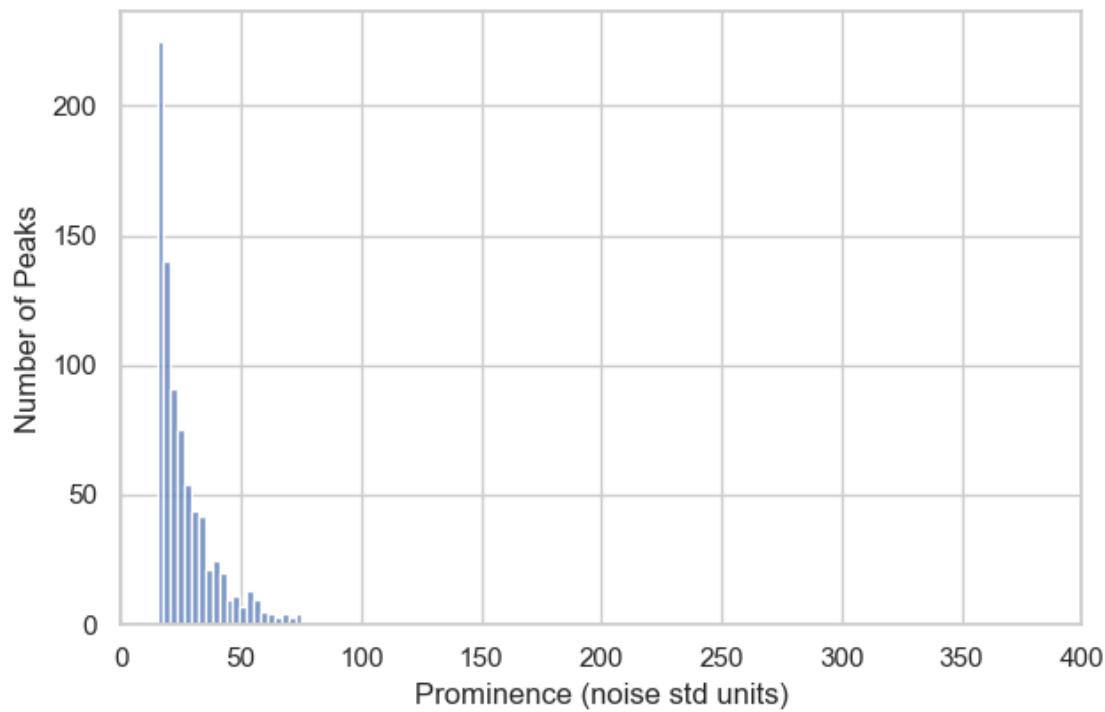
1.4.2 Peaks statistics in individual events

[2025-08-27 15:01:00] [INFO] calcium: plot_histogram: removed 15 outliers out of 838 on 'Duration (s)' (lower=-33, upper=79)

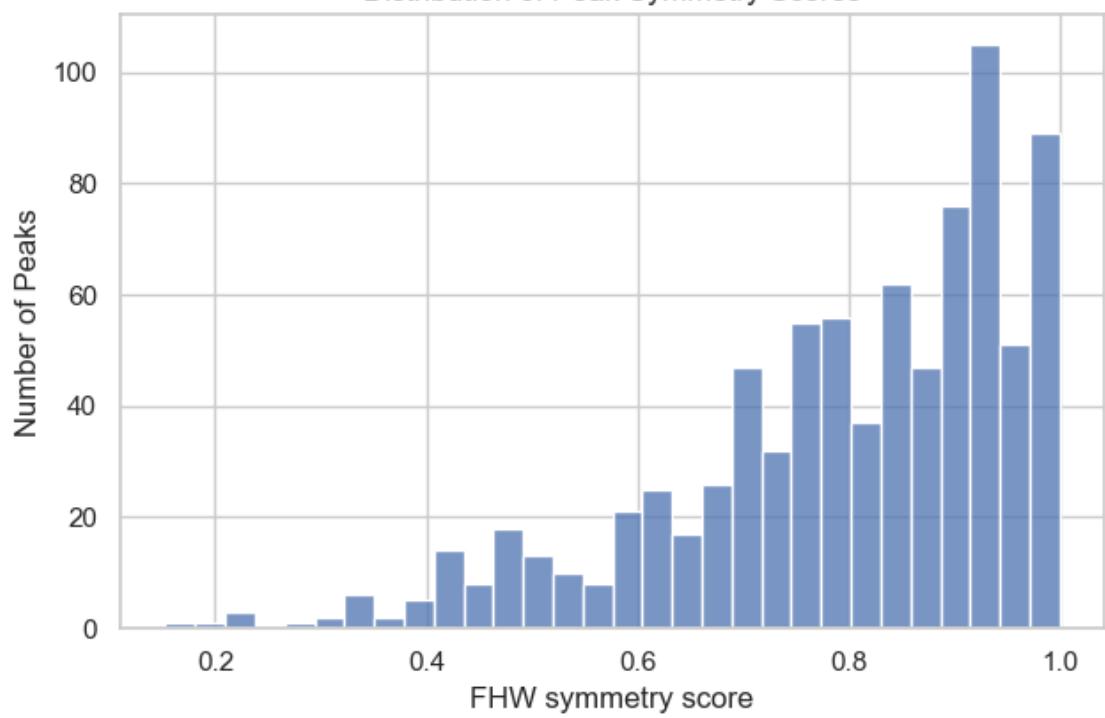


[2025-08-27 15:01:00] [INFO] calcium: plot_histogram: removed 27 outliers out of 838 on 'Prominence (noise std units)' (lower=-26.125, upper=75.9)

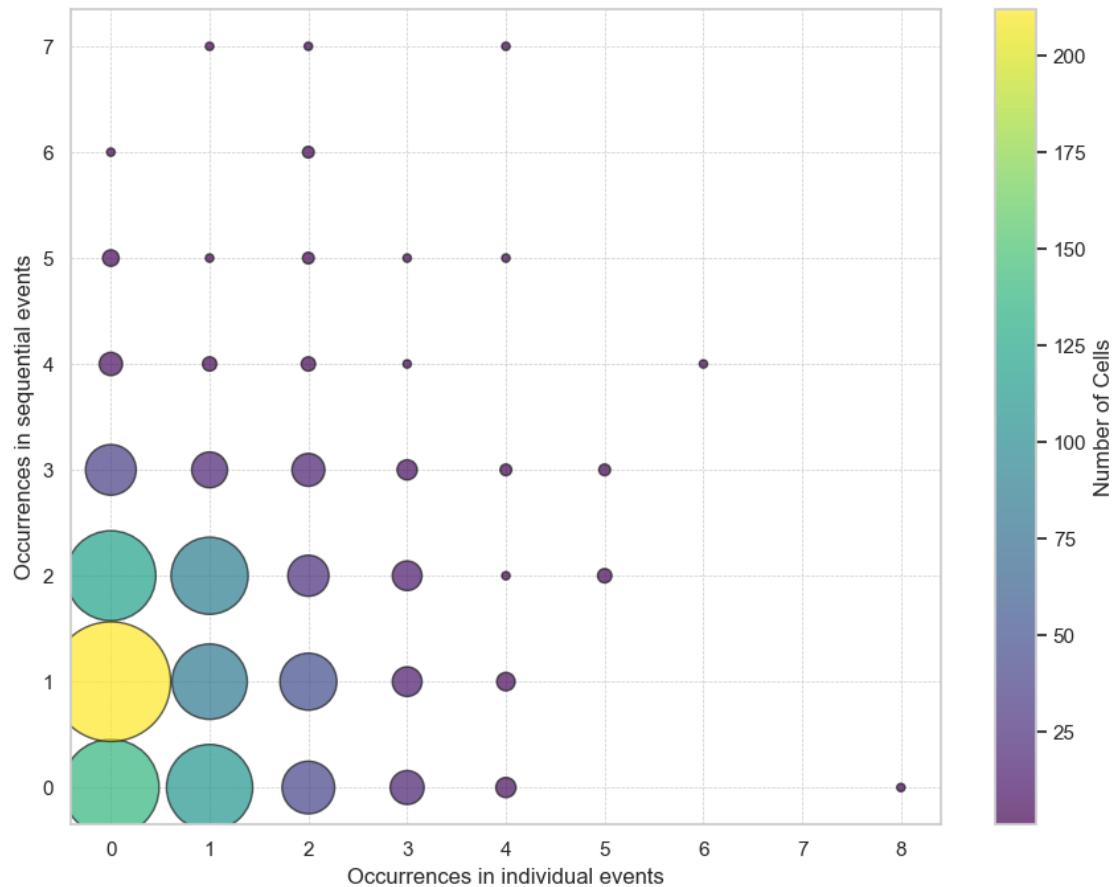
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: removed 0/1039 outliers on 'Occurrences in sequential events' (lower=-6, upper=8)
```

```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=521 for Occurrences in individual events=0
```

```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=306 for Occurrences in individual events=1
```

```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=138 for Occurrences in individual events=2
```

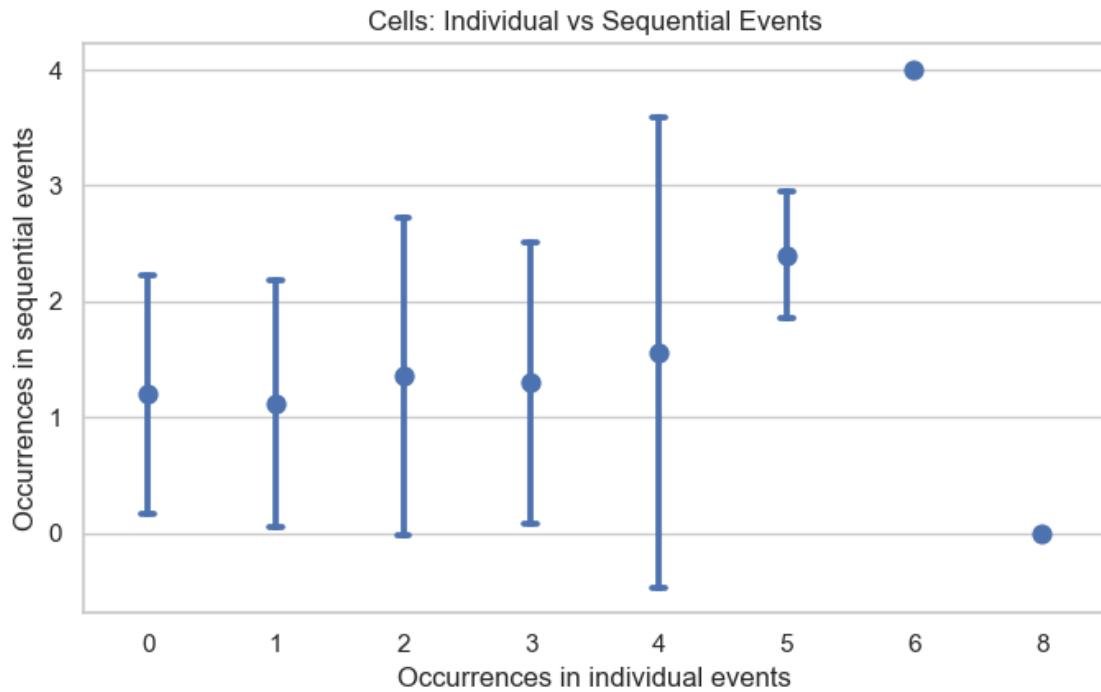
```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=51 for Occurrences in individual events=3
```

```
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=16 for Occurrences in individual events=4
```

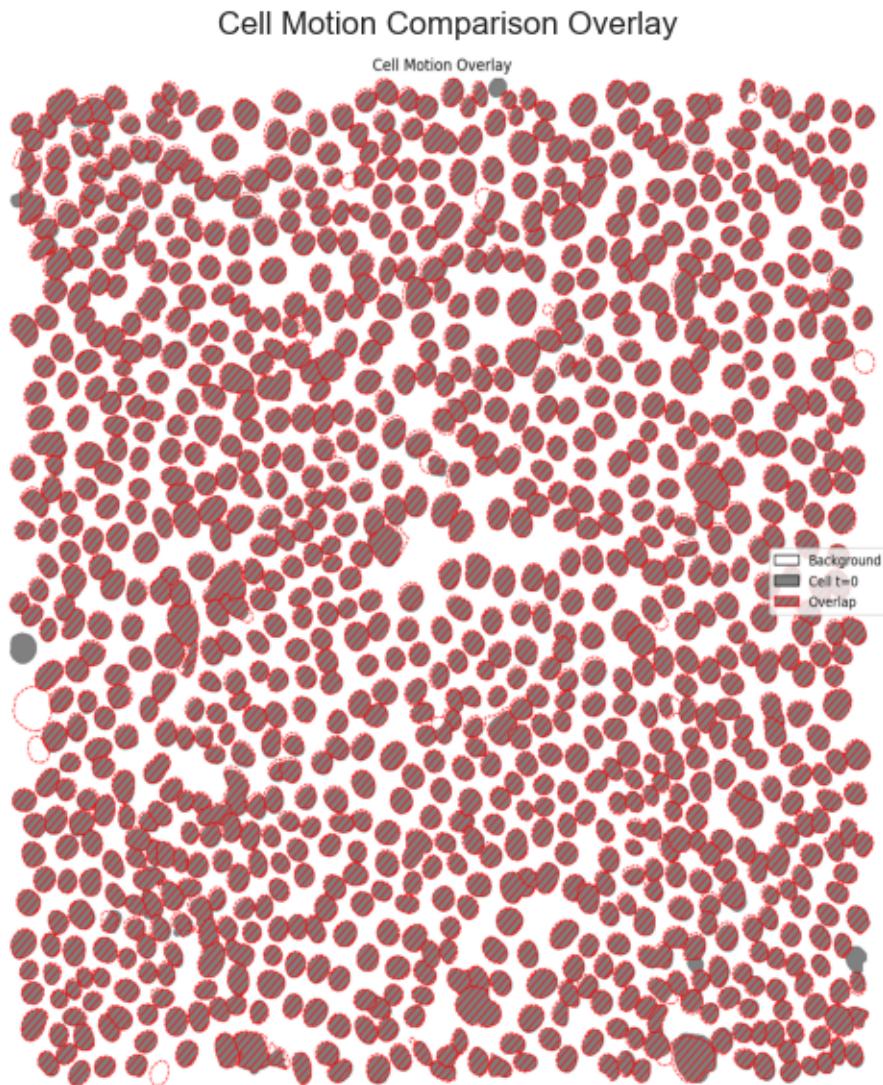
[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=5 for Occurrences in individual events=5

[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6

[2025-08-27 15:01:01] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=8



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1039
- Hoechst image taken at t=1801: 1036
- Number of cells difference: absolute 3, relative 0.29%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1120835
- Pixels segmented as cell at t=1801: 1137563
- Overlapping pixels between t=0 and t=1801: 1044188 (92.47% of total)
- Pixels exclusive to t=0: 76647 (6.84% of total)
- Pixels exclusive to t=1801: 93375 (8.21% of total)

executed

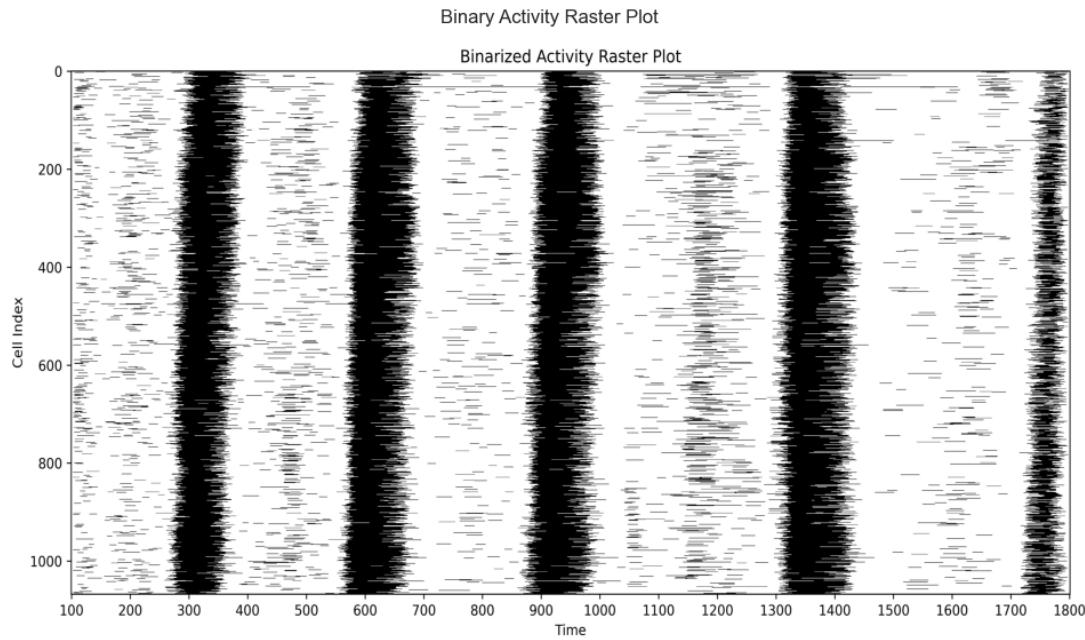
August 27, 2025

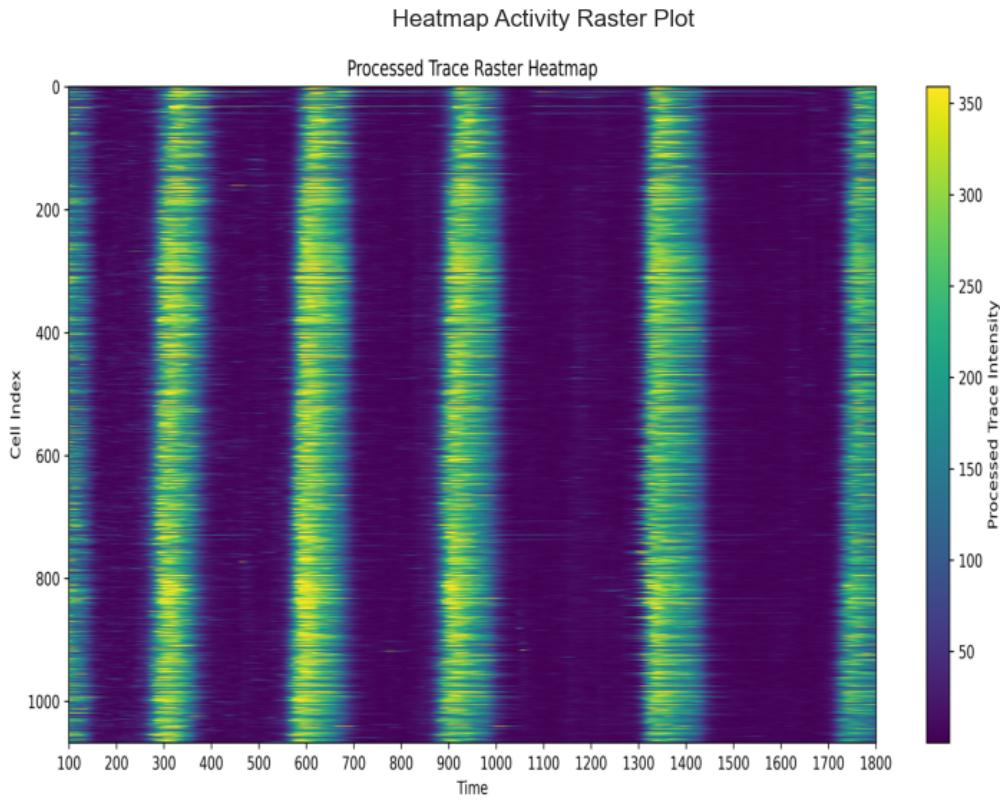
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





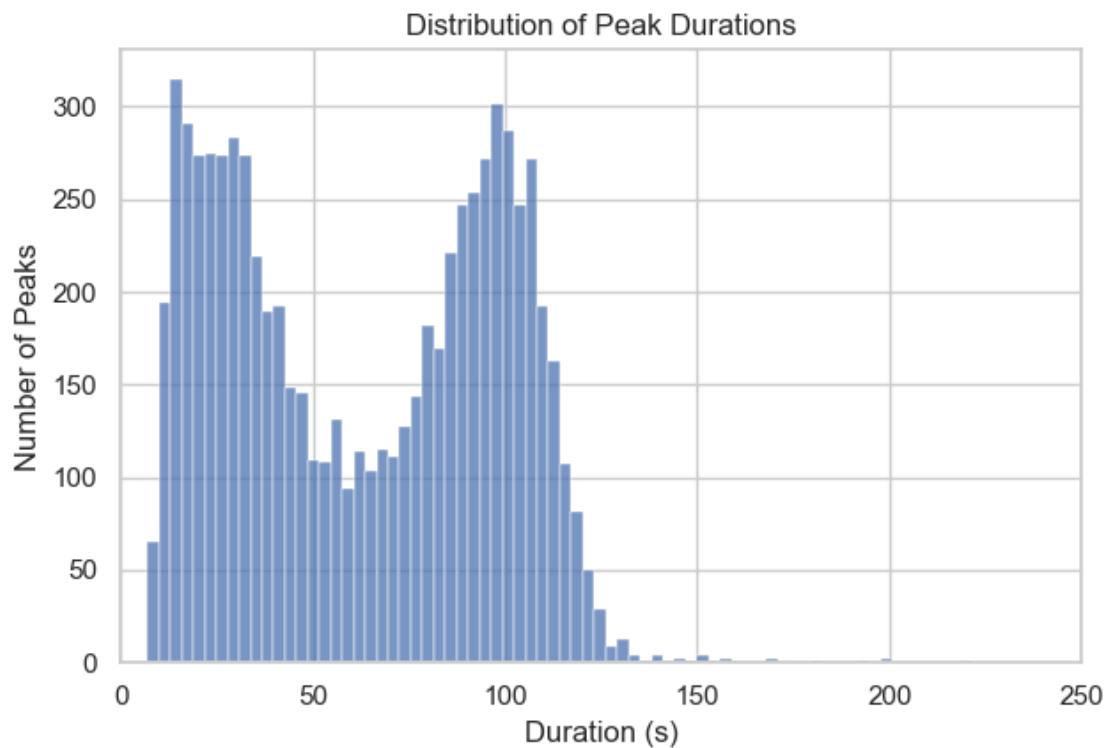
1.1.2 Peaks population

Total number of peaks: 7420

Total number of cells: 1068

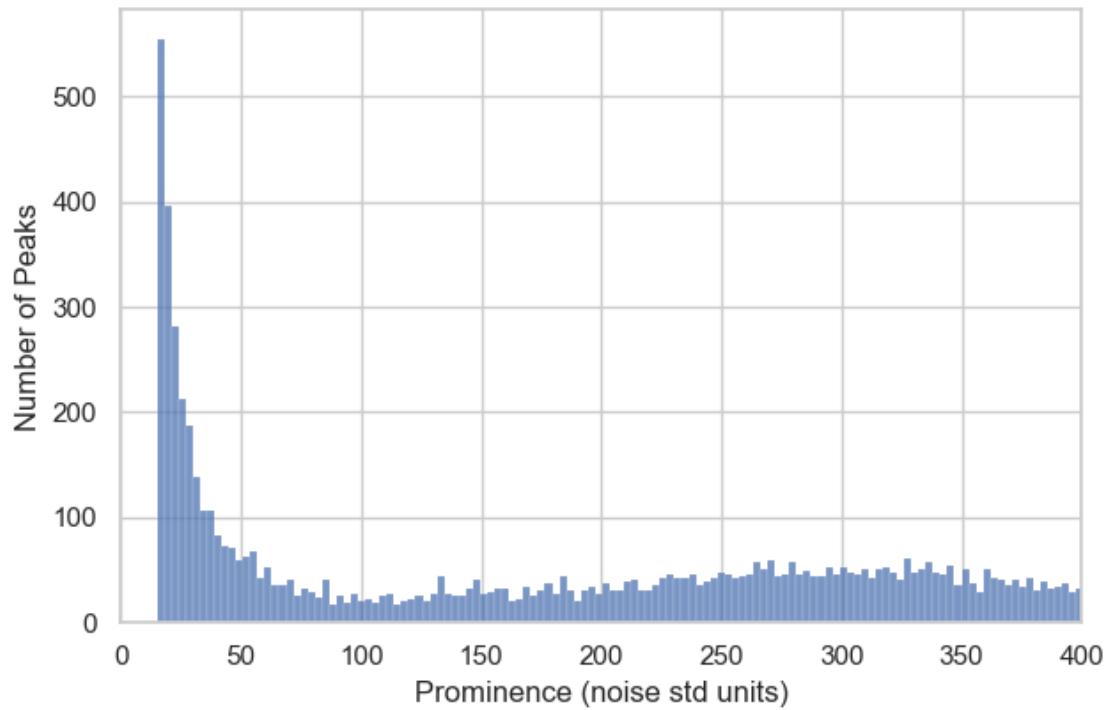
1.1.3 Peaks statistics

```
[2025-08-27 15:07:37] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7420 on 'Duration (s)' (lower=-172, upper=297)
```

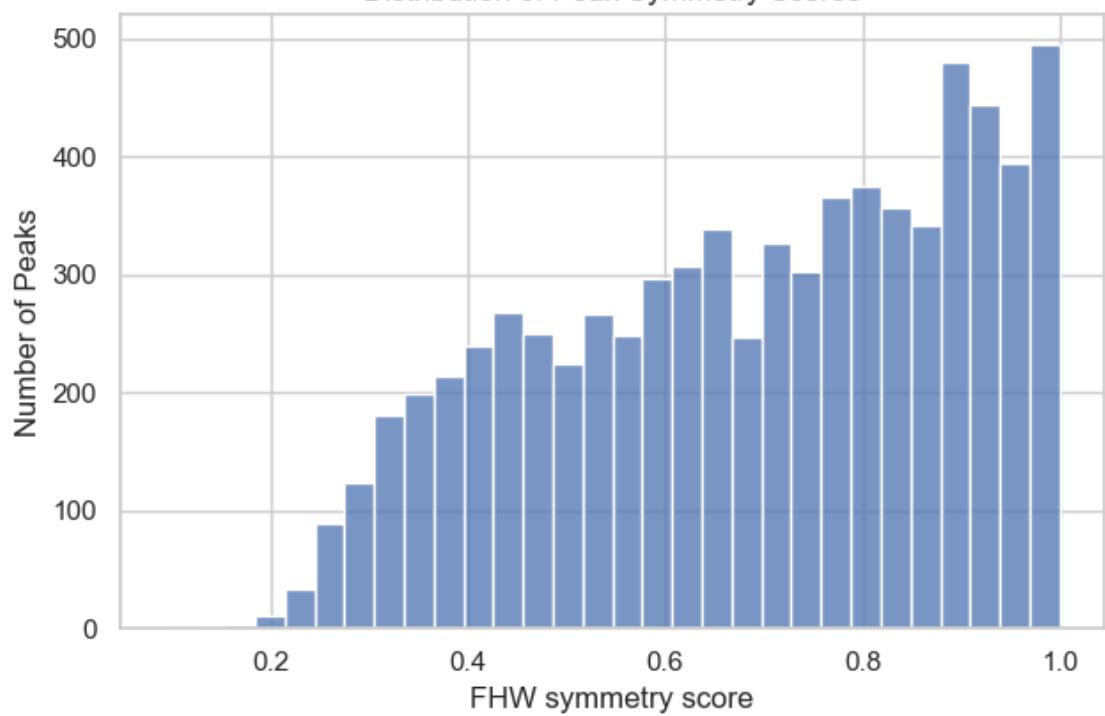


```
[2025-08-27 15:07:37] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7420 on 'Prominence (noise std units)' (lower=-818.67, upper=1173.7)
```

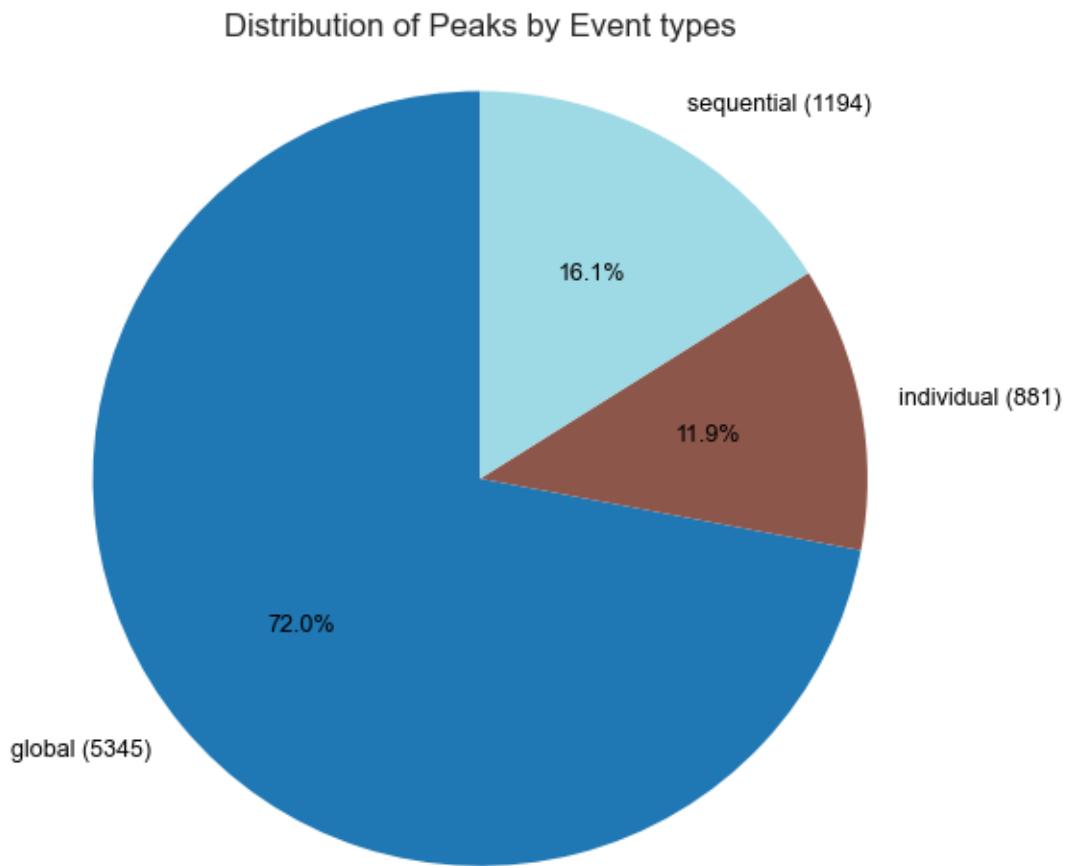
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

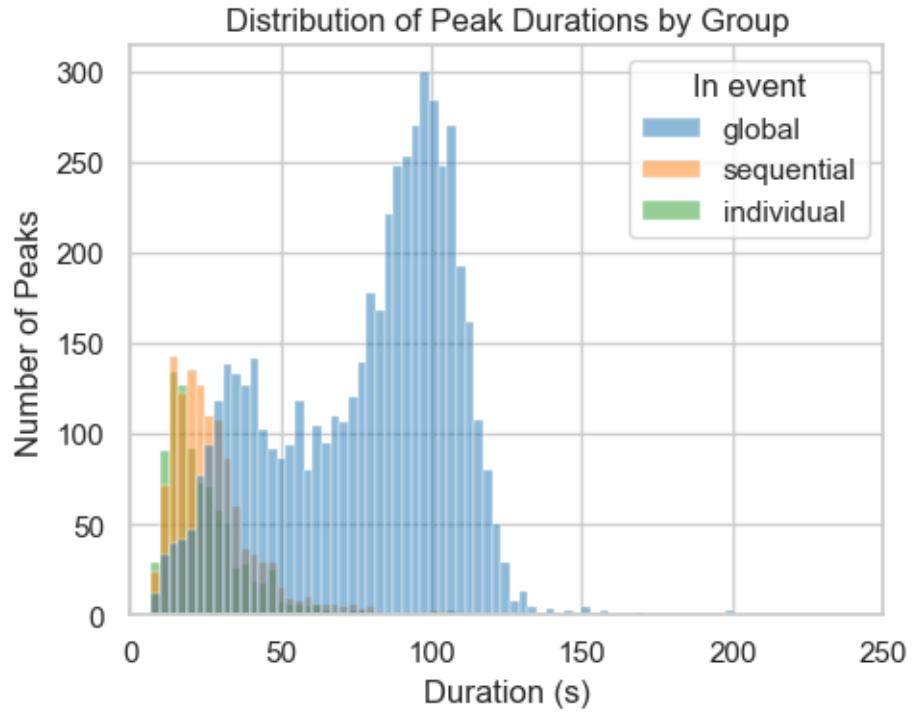


1.1.4 Distribution of peaks per event types

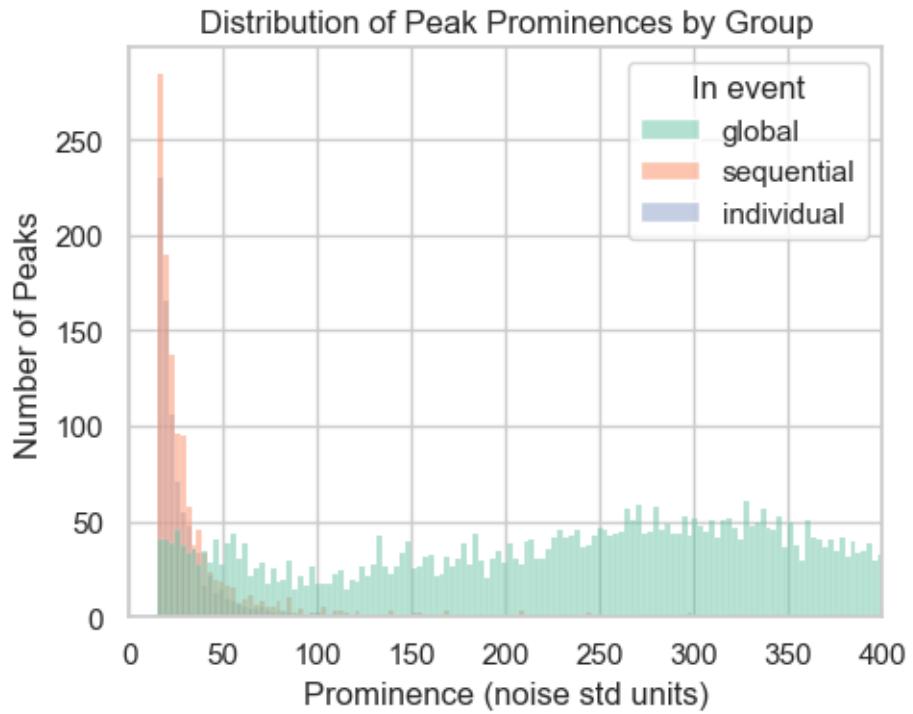


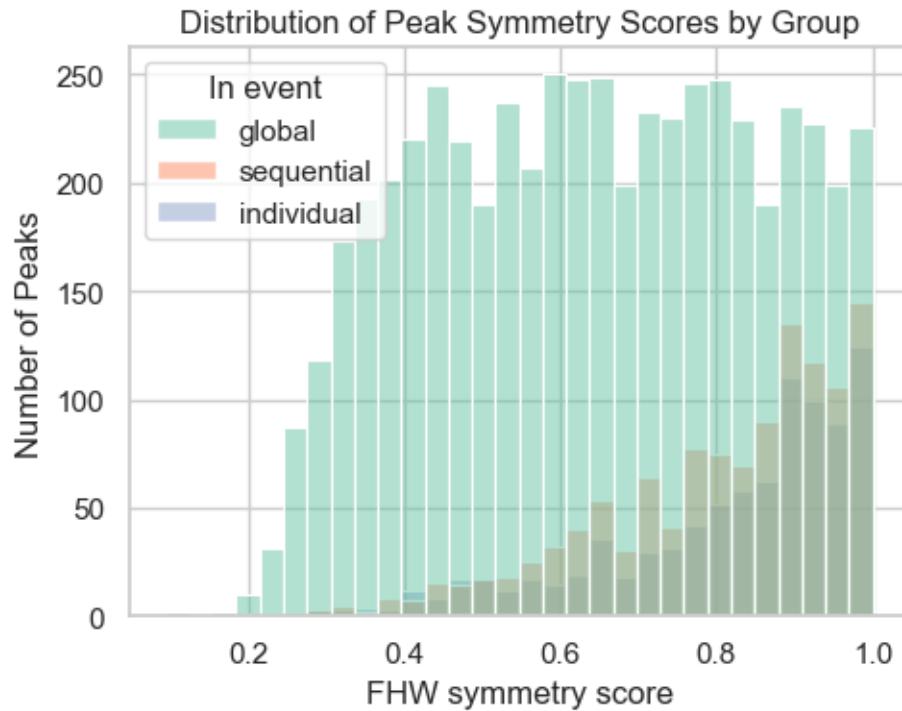
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:07:37] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7420 on 'Duration (s)' (lower=-172, upper=297)
```



```
[2025-08-27 15:07:38] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7420 on 'Prominence (noise std units)' (lower=-818.67, upper=1173.7)
```

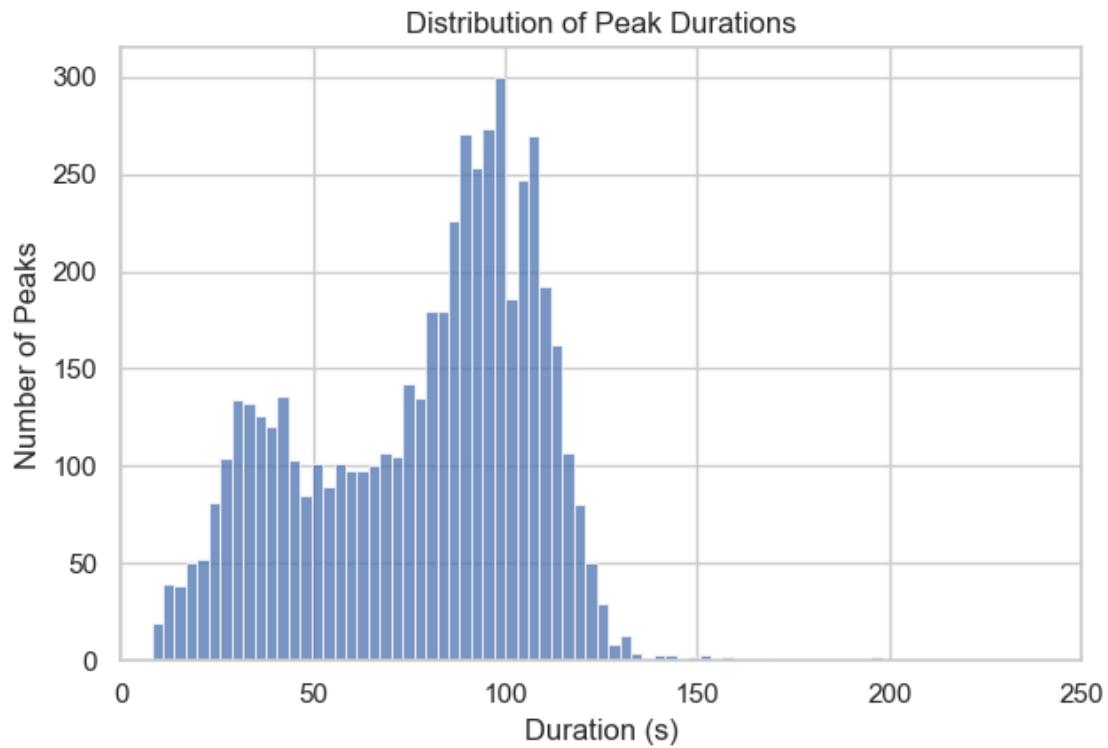




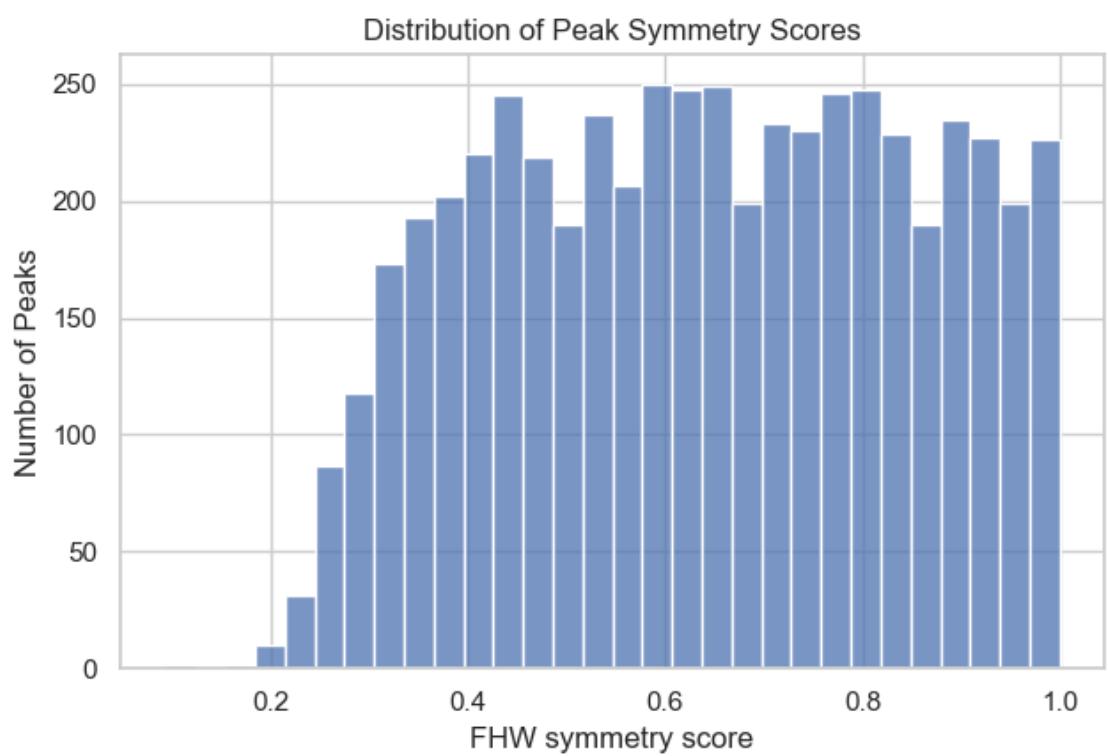
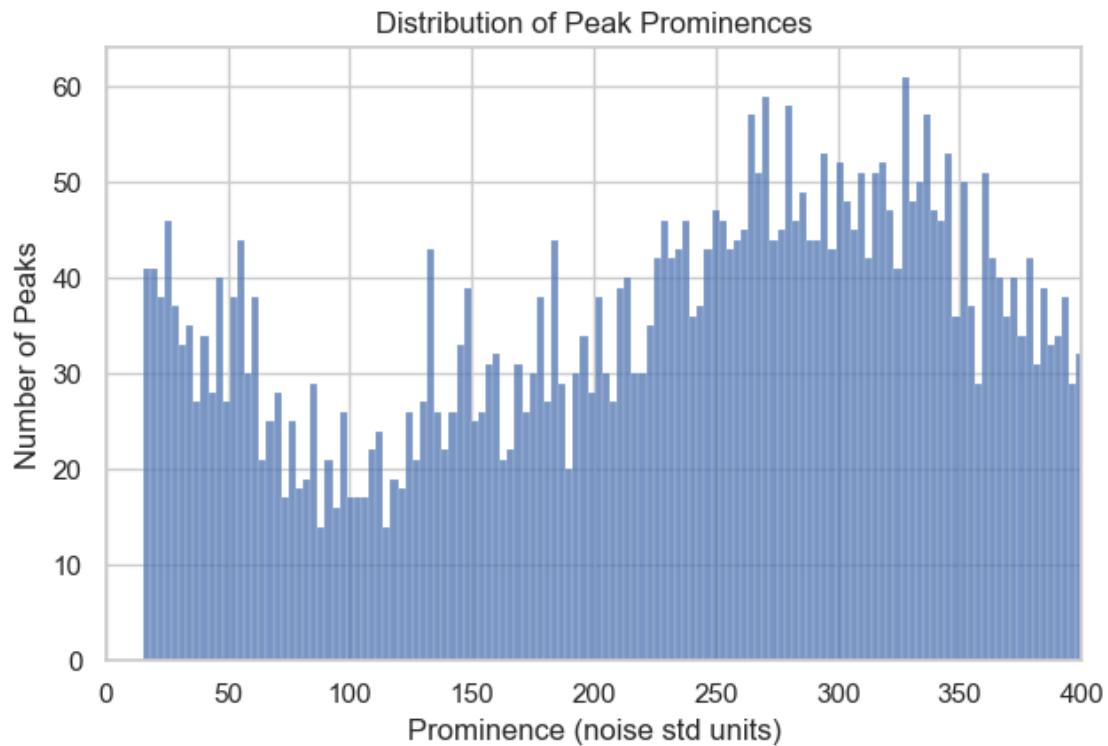
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:07:38] [INFO] calcium: plot_histogram: removed 1 outliers out of 5345 on 'Duration (s)' (lower=-91, upper=245)
```

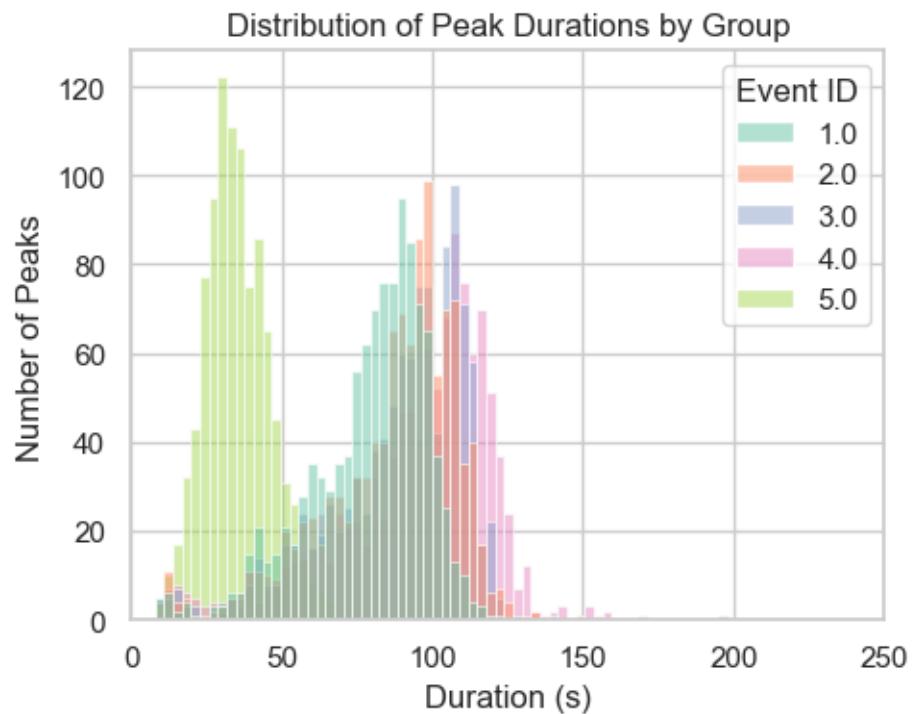


```
[2025-08-27 15:07:39] [INFO] calcium: plot_histogram: removed 0 outliers out of  
5345 on 'Prominence (noise std units)' (lower=-413.8, upper=924.6)
```

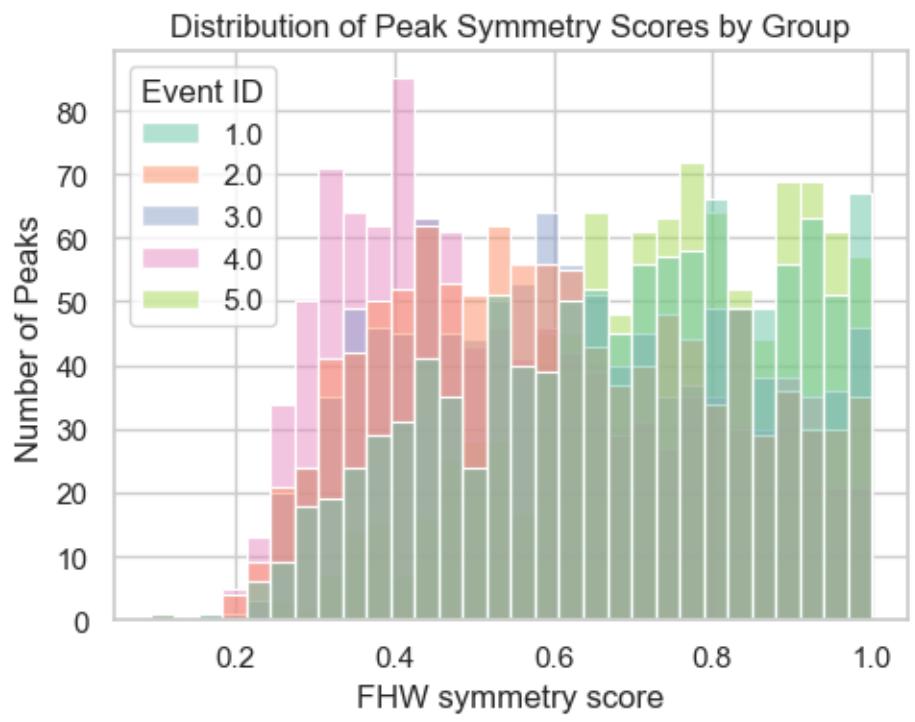
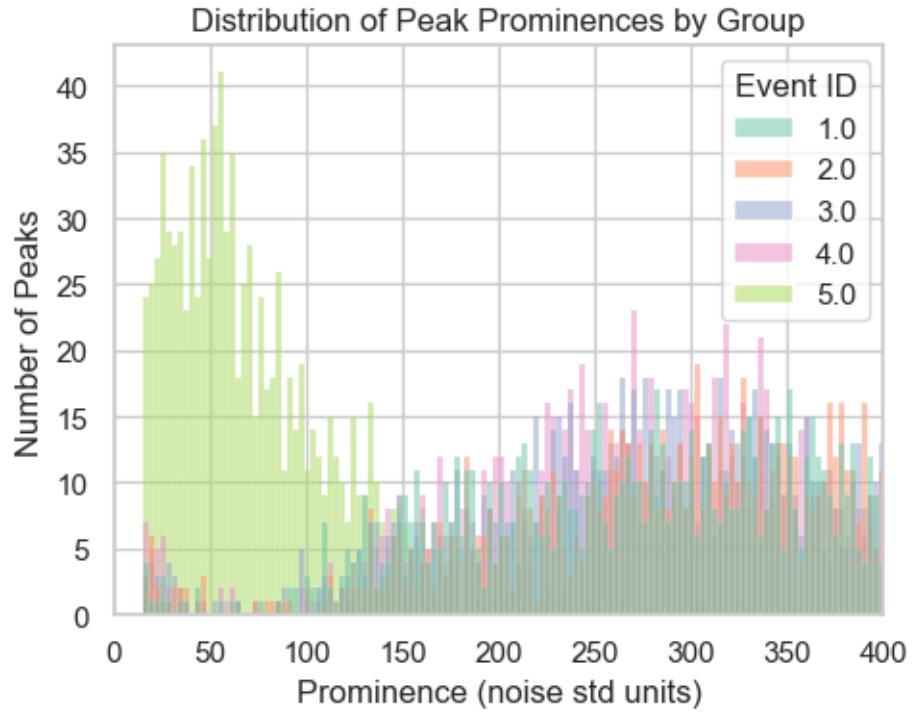


1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 15:07:39] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 5345 on 'Duration (s)' (lower=-91, upper=245)
```

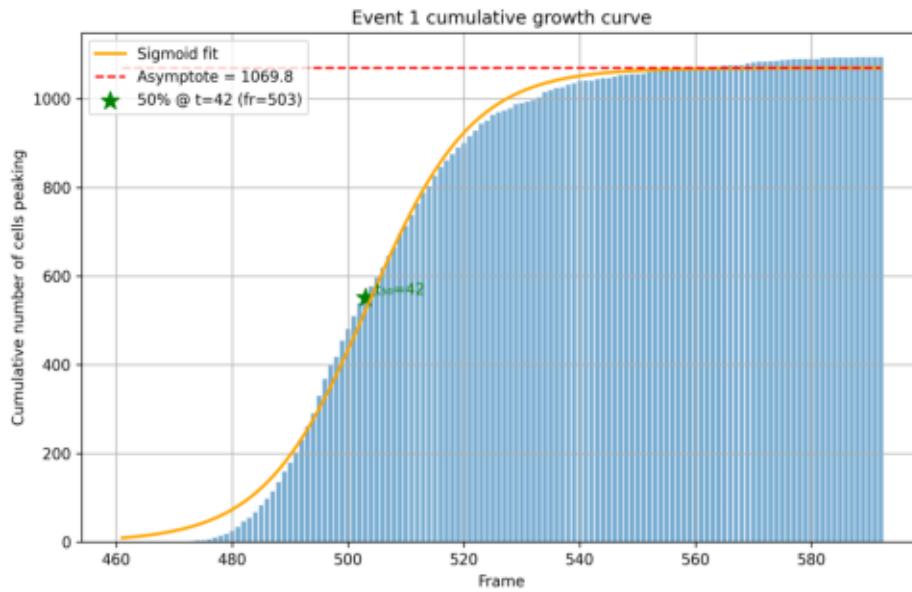


```
[2025-08-27 15:07:39] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5345 on 'Prominence (noise std units)' (lower=-413.8, upper=924.6)
```

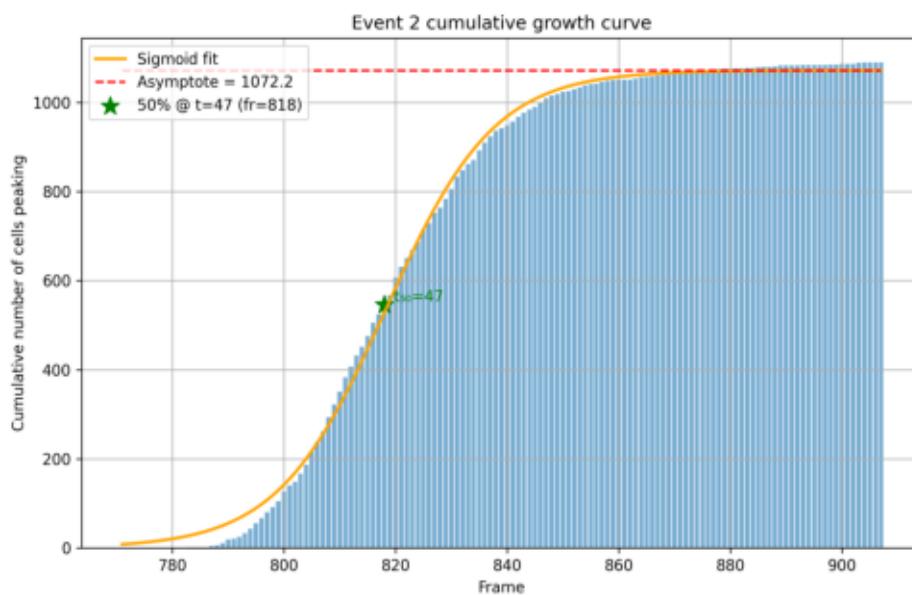


1.2.3 Kinetics of global events

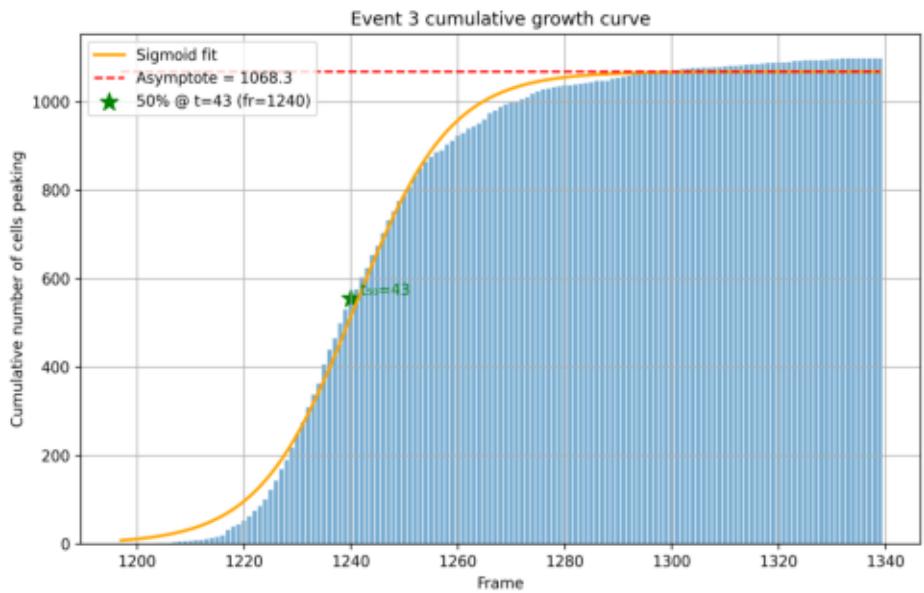
Event Activity Overlay (Event ID: 1)



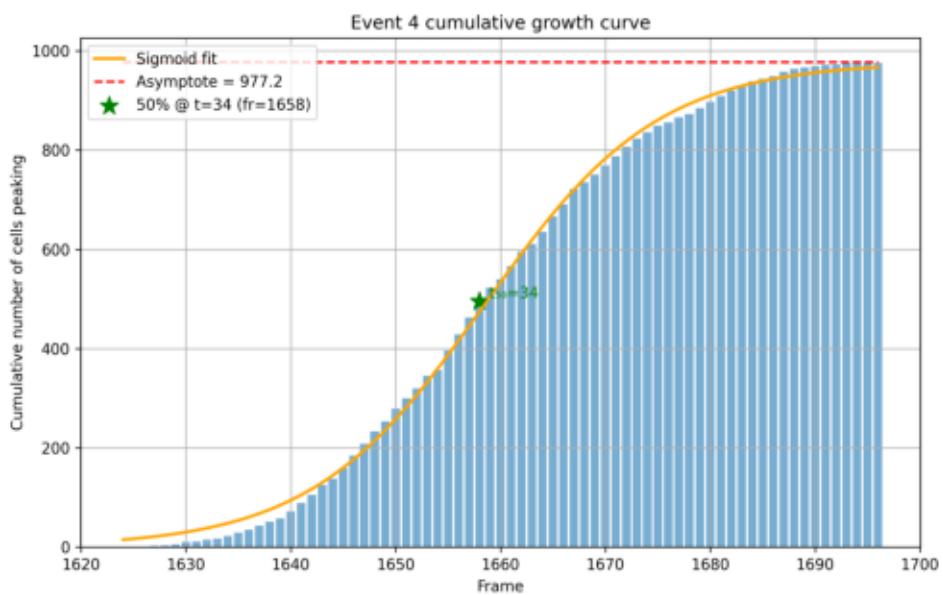
Event Activity Overlay (Event ID: 2)



Event Activity Overlay (Event ID: 3)



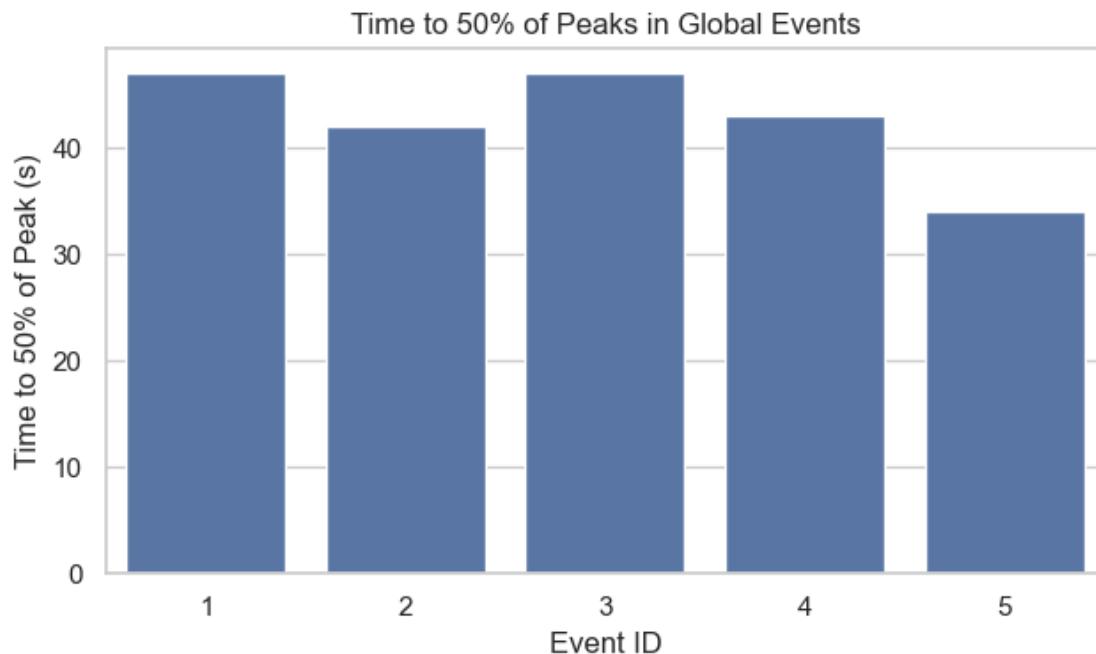
Event Activity Overlay (Event ID: 4)

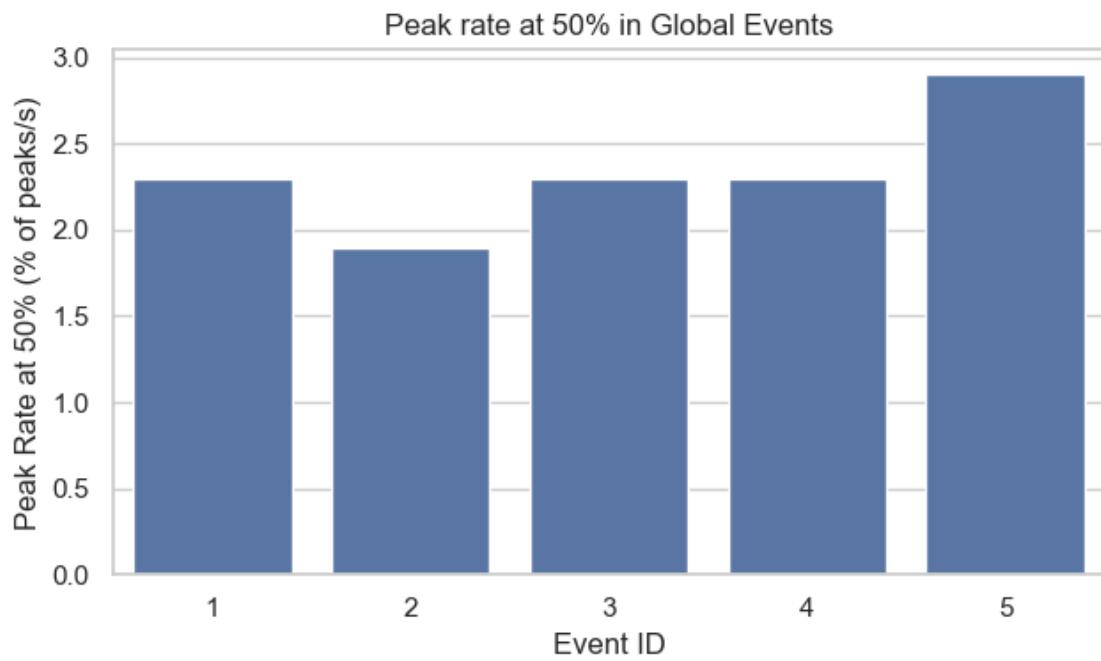


```

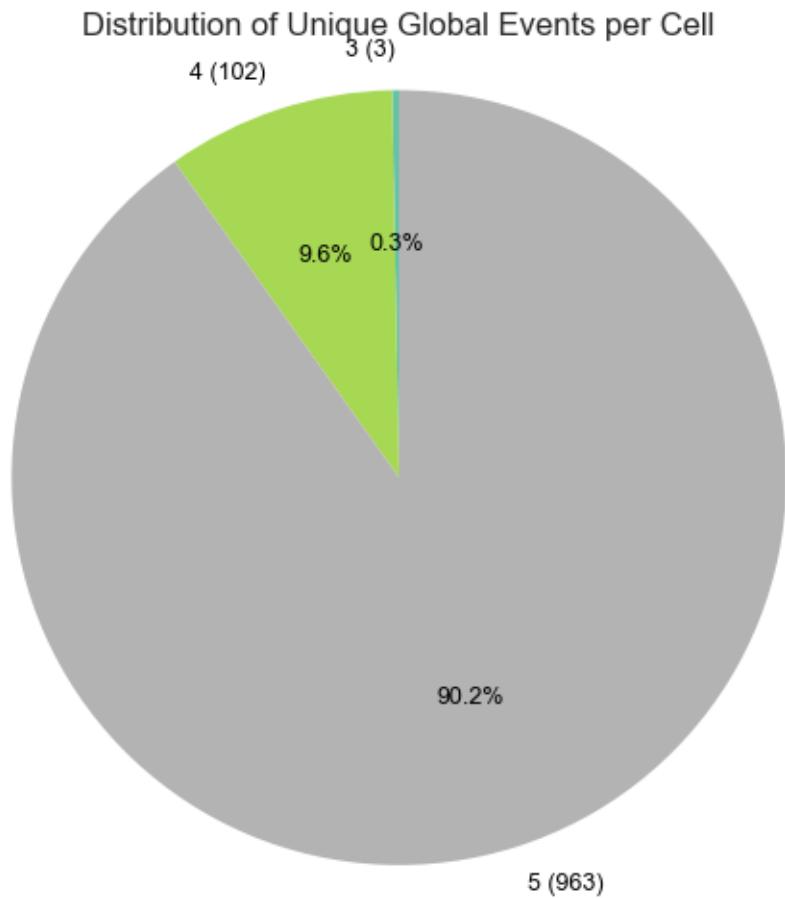
[2025-08-27 15:07:43] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\events\event-growth-curve-5.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250624\\Output\\IS05\\events\\event-
growth-curve-5.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250624\\Output\\IS05\\events\\event-growth-curve-5.png'

```





1.2.4 Cells Occurrences in global events

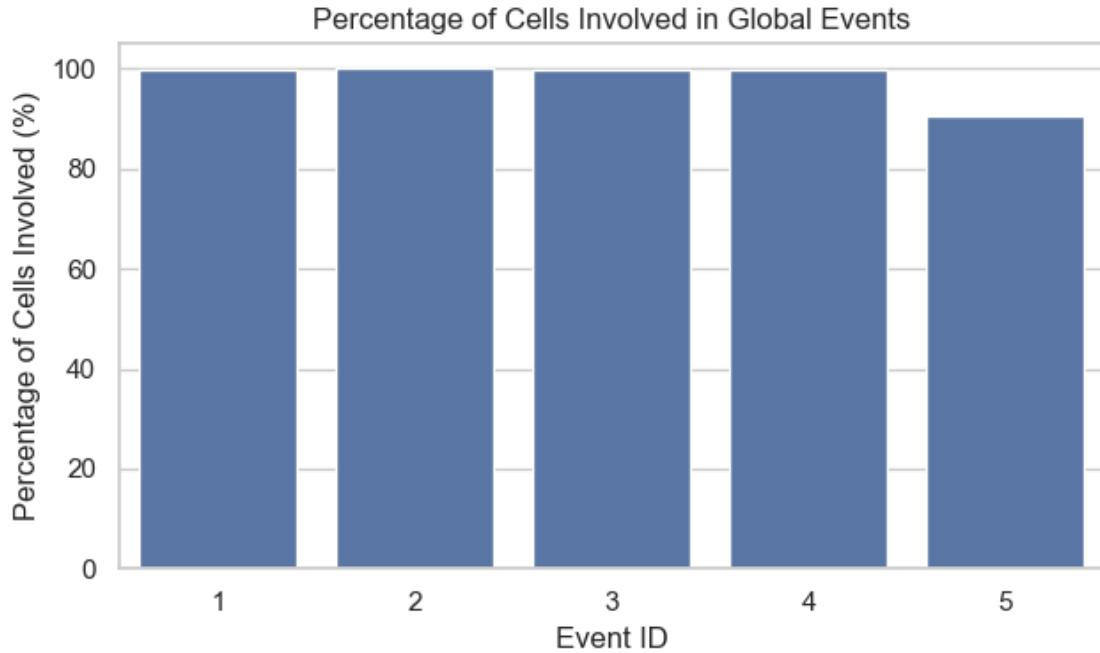


```
[2025-08-27 15:07:43] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250624\\\\Output\\\\IS05\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250624\Output\IS05\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [291.0, 316.0, 418.0, 418.0]
 Estimated periodicity: 0.862
 The global events exhibit a regular periodic pattern.
 Estimated frequency (1/mean interval): 0.003 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 15:07:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:07:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:07:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-

```

```

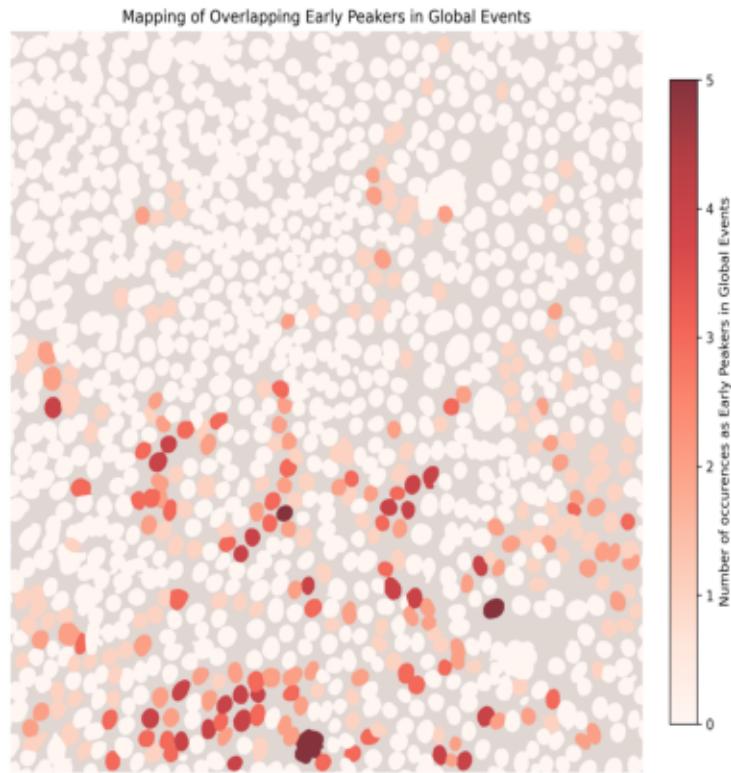
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:07:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:07:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

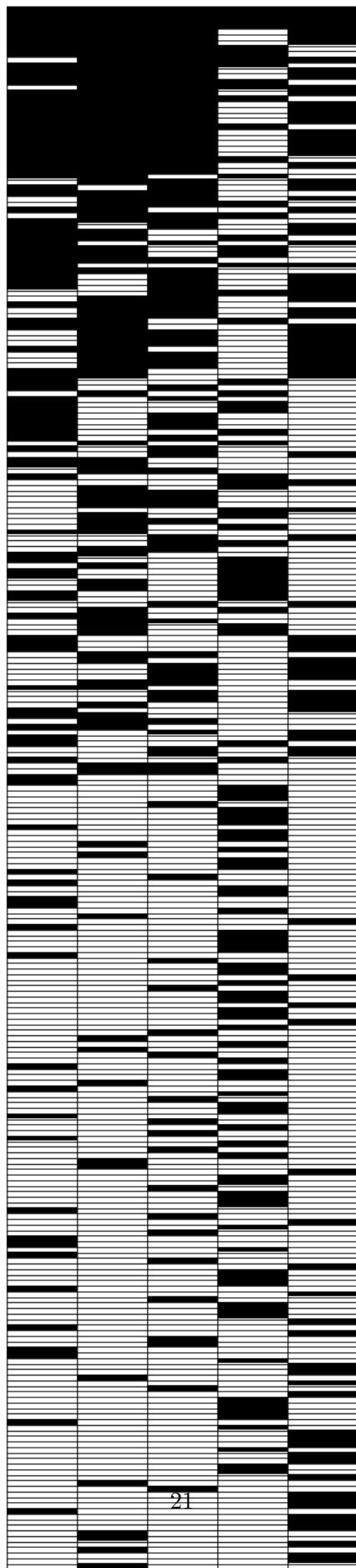
```

Cell Mapping with Occurrences in Global Events Overlay



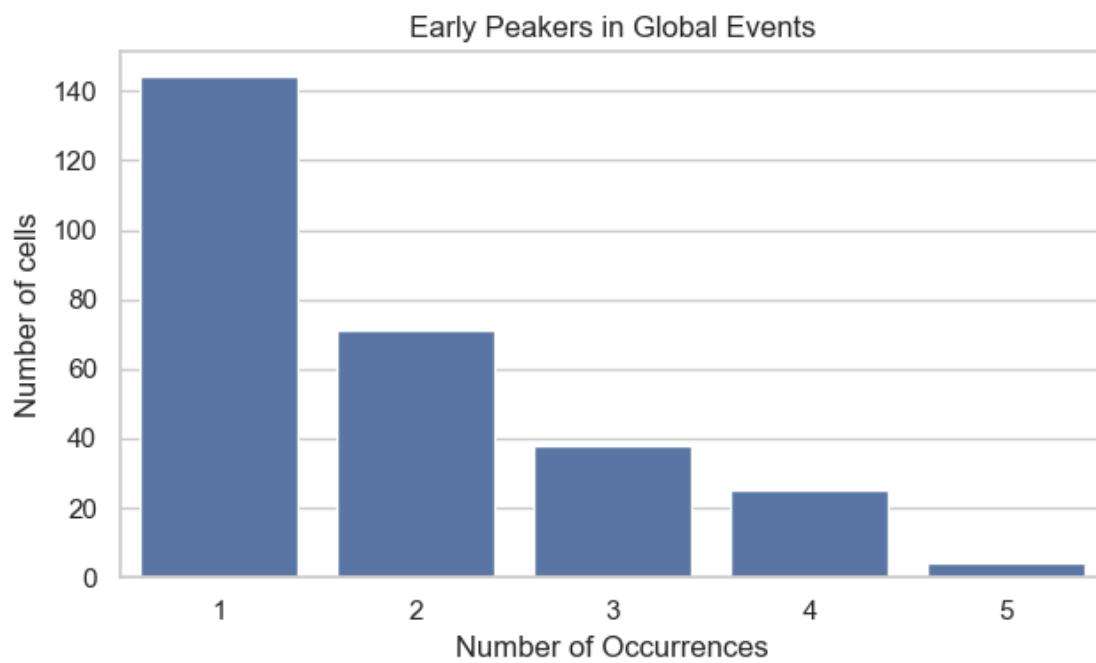
[2025-08-27 15:07:45] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 5 unique event IDs.

[2025-08-27 15:07:45] [INFO] calcium: Early peakers event-matrix: 282 cells x 5 events; black squares: 520

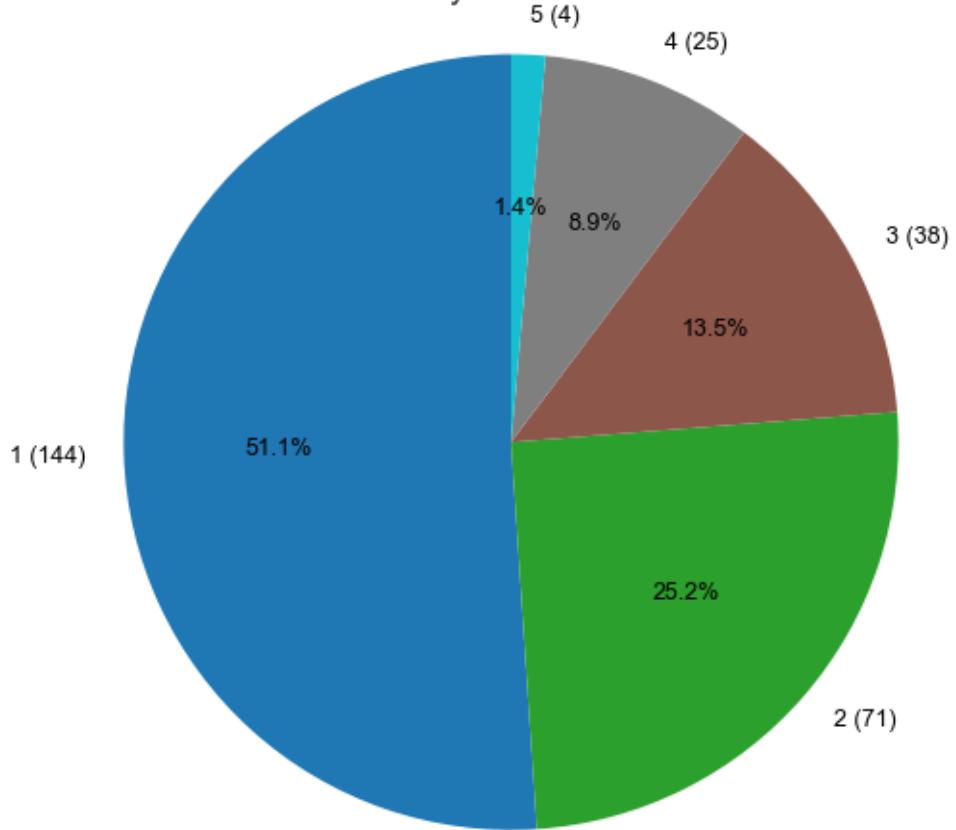


```
[2025-08-27 15:07:45] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 1, 1, 1],  
           [1, 1, 1, 1, 1],  
           [1, 1, 1, 1, 1],  
           ...,  
           [0, 0, 0, 0, 1],  
           [0, 1, 0, 0, 0],  
           [0, 0, 1, 0, 0]])
```



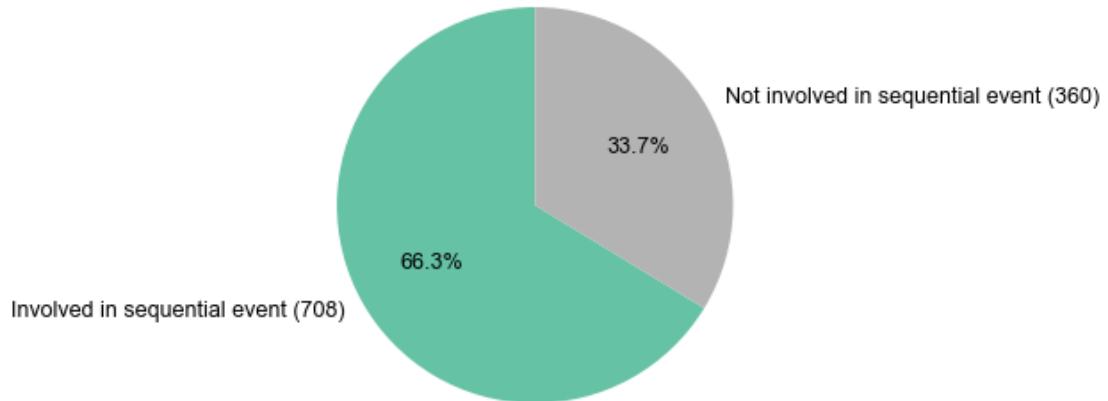
Distribution of Early Peakers in Global Events



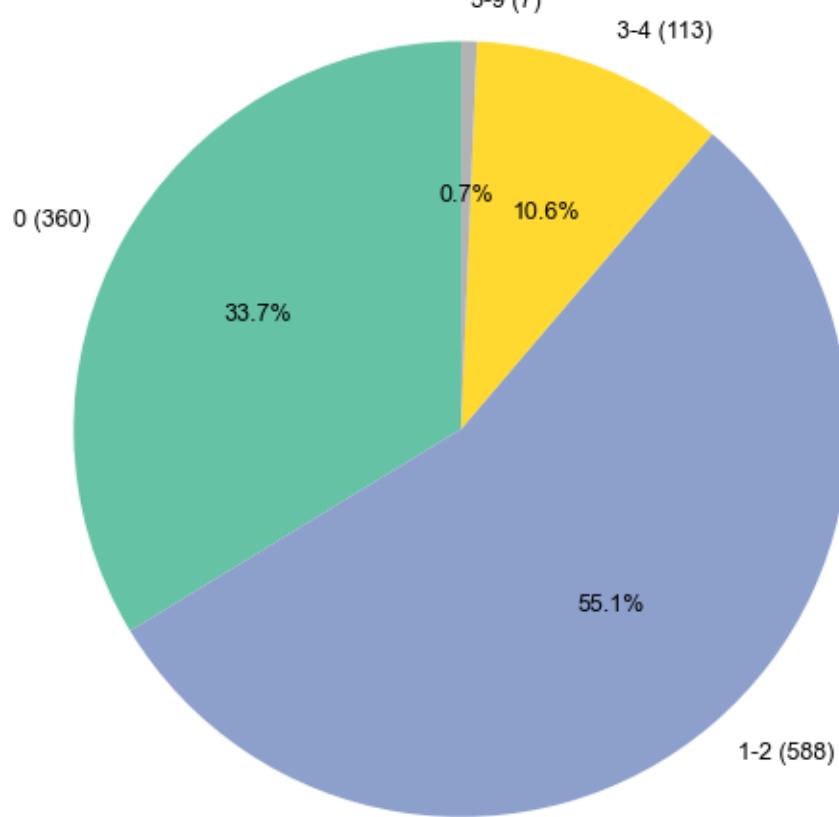
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

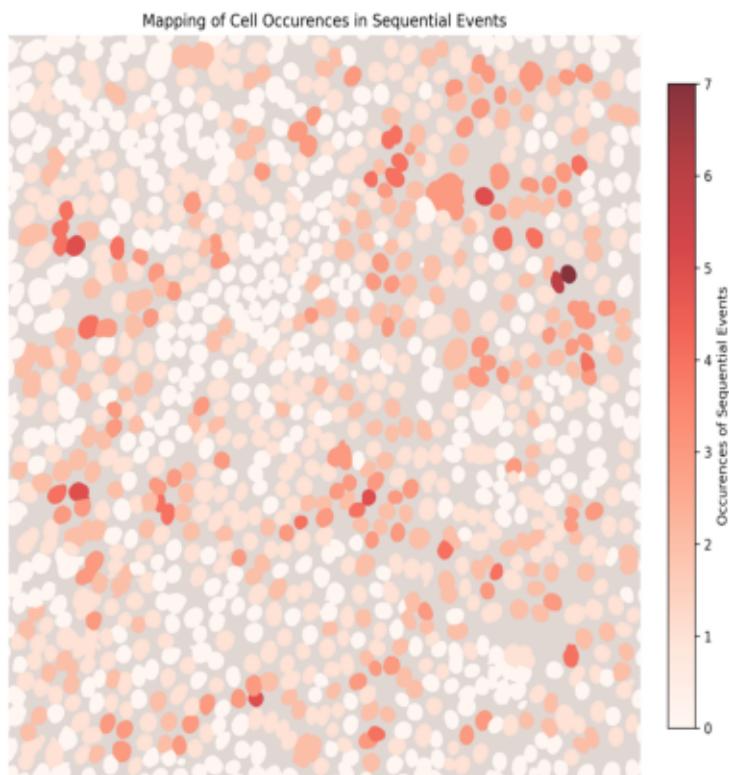
Distribution of Cells Involved in Sequential Events



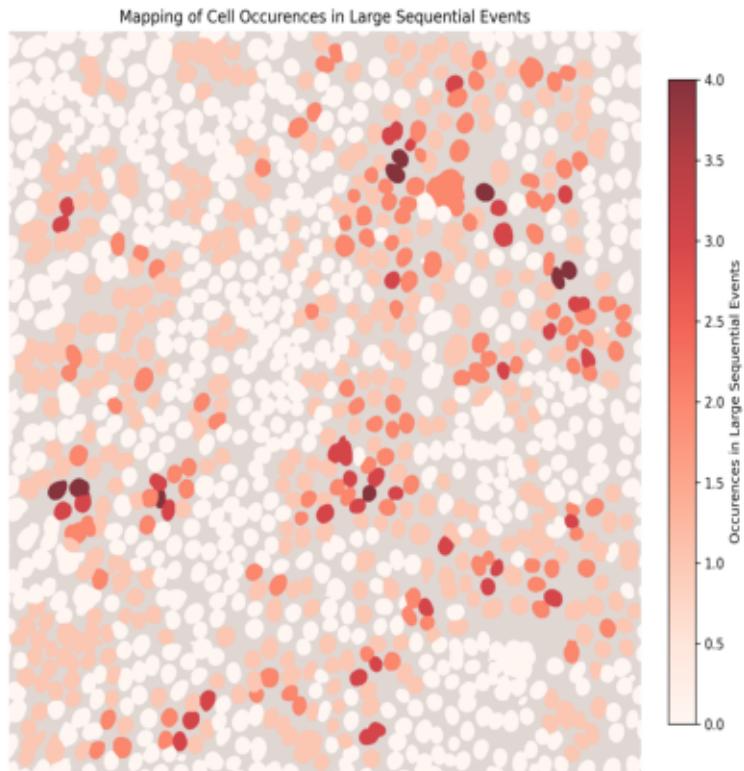
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

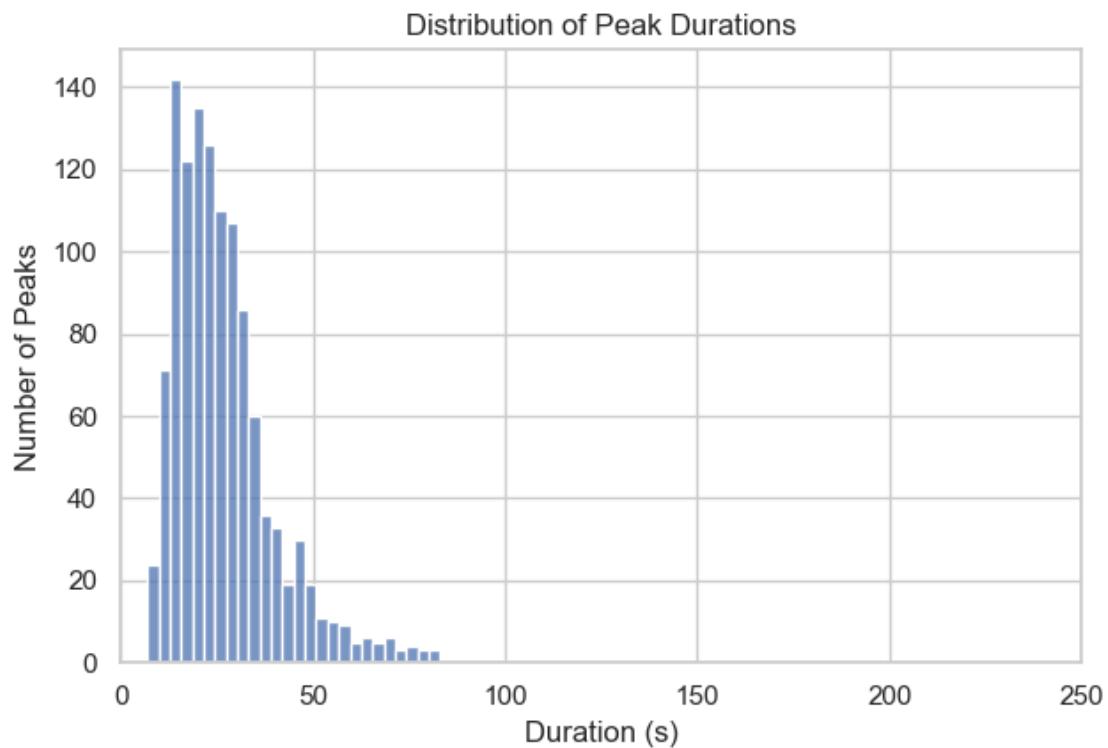


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



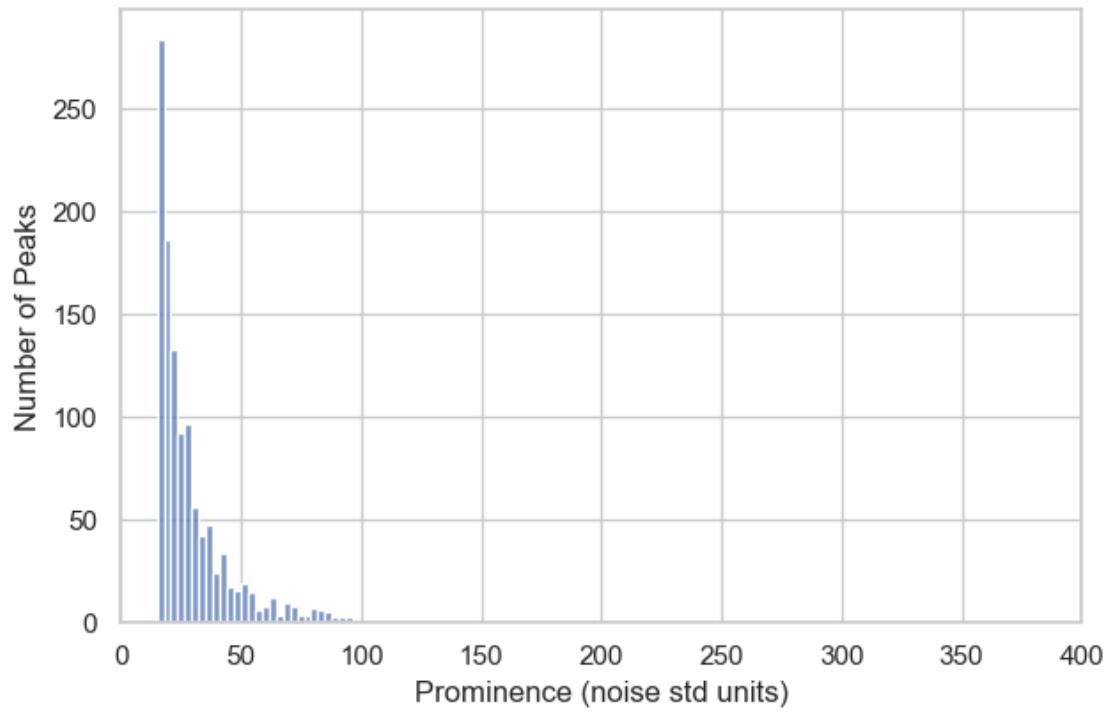
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:07:48] [INFO] calcium: plot_histogram: removed 9 outliers out of 1194 on 'Duration (s)' (lower=-6.625, upper=87.875)
```

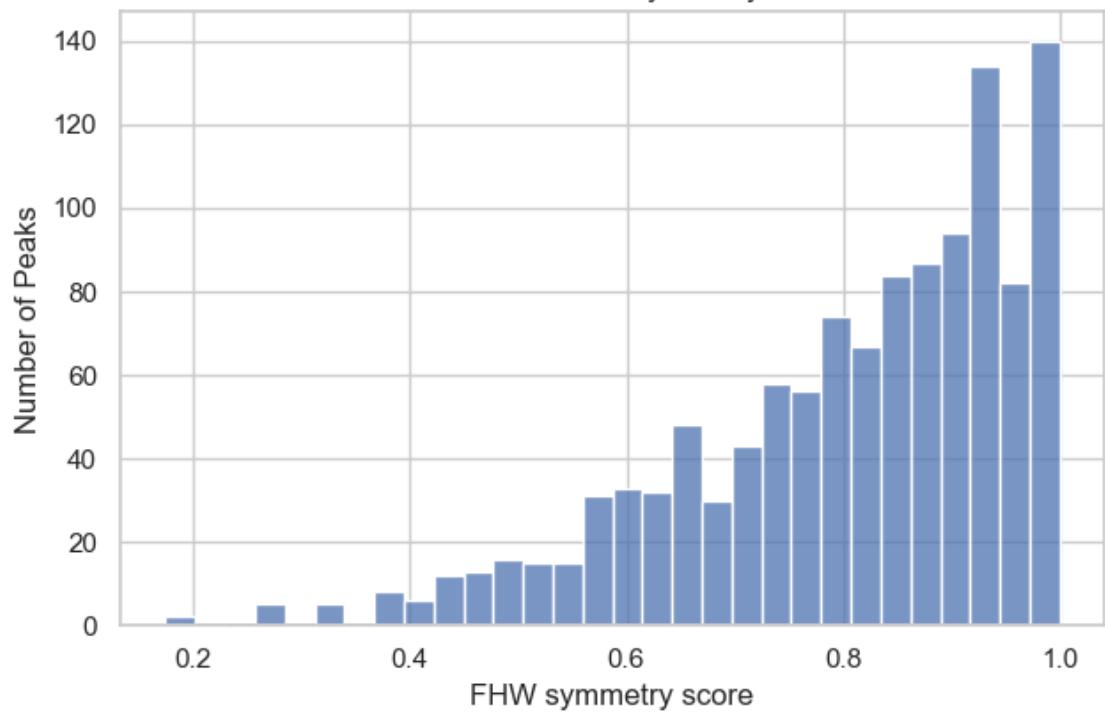


```
[2025-08-27 15:07:48] [INFO] calcium: plot_histogram: removed 48 outliers out of 1194 on 'Prominence (noise std units)' (lower=-8.275, upper=97.625)
```

Distribution of Peak Prominences

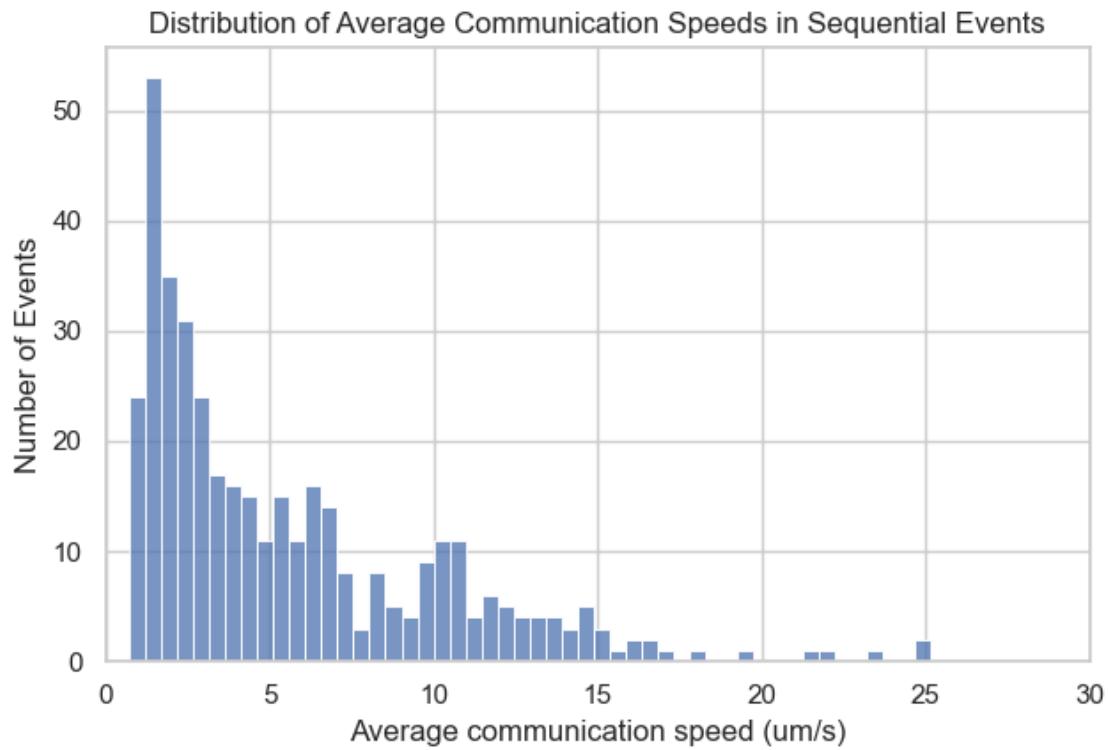


Distribution of Peak Symmetry Scores

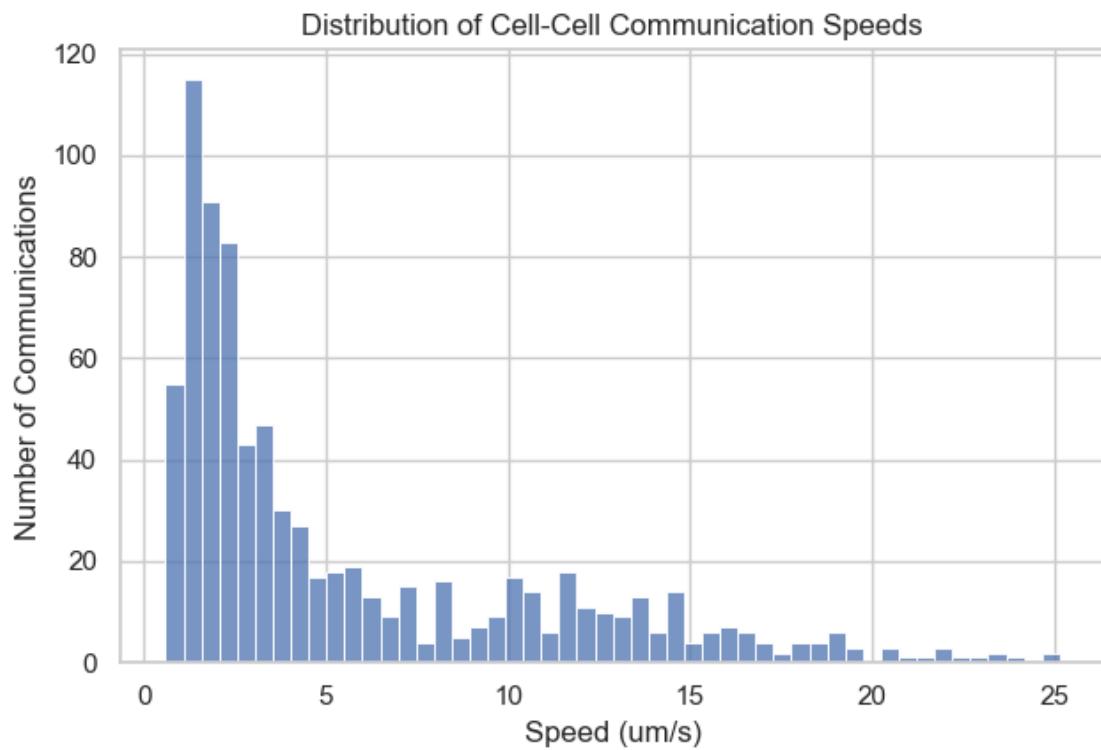


1.3.3 Cell-cell communication speed

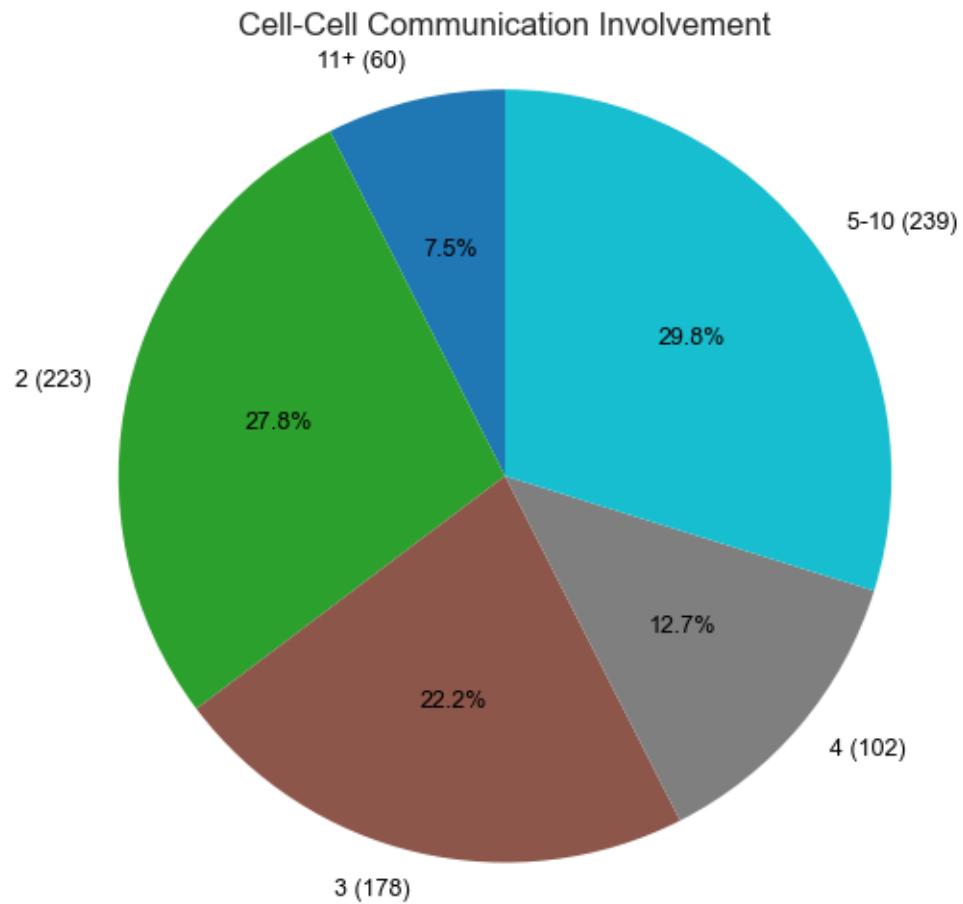
[2025-08-27 15:07:48] [INFO] calcium: plot_histogram: removed 0 outliers out of 392 on 'Average communication speed (um/s)' (lower=-16.23, upper=26.278)



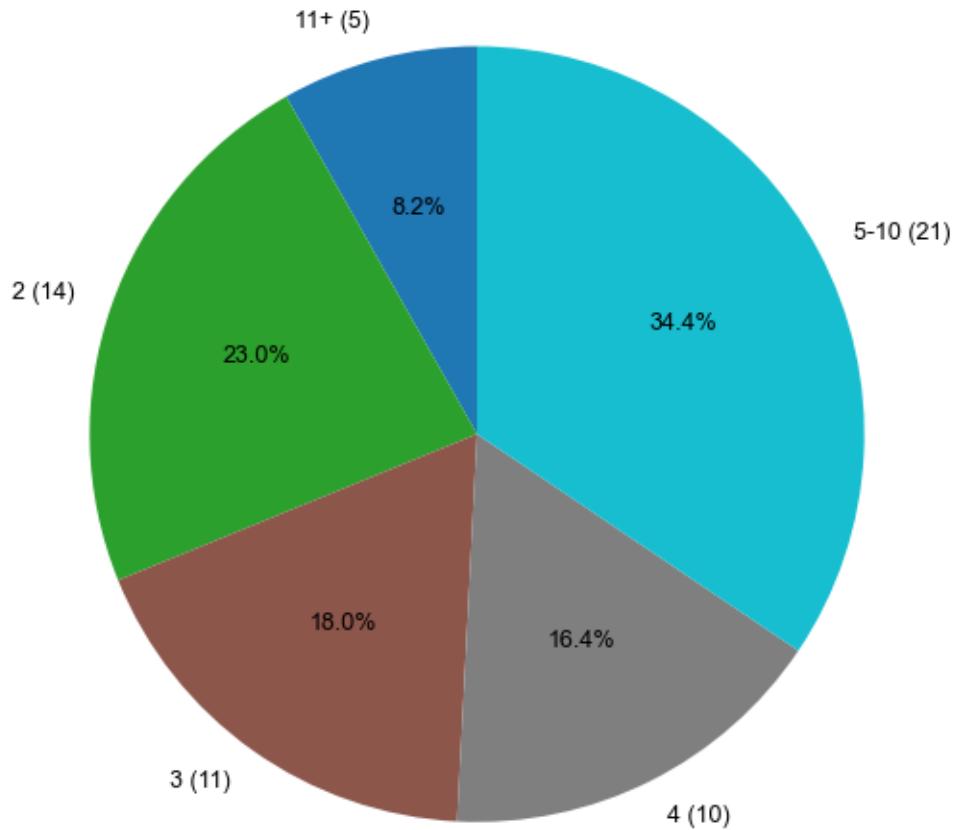
[2025-08-27 15:07:48] [INFO] calcium: plot_histogram: removed 0 outliers out of 802 on 'Speed (um/s)' (lower=-18.145, upper=41.48)



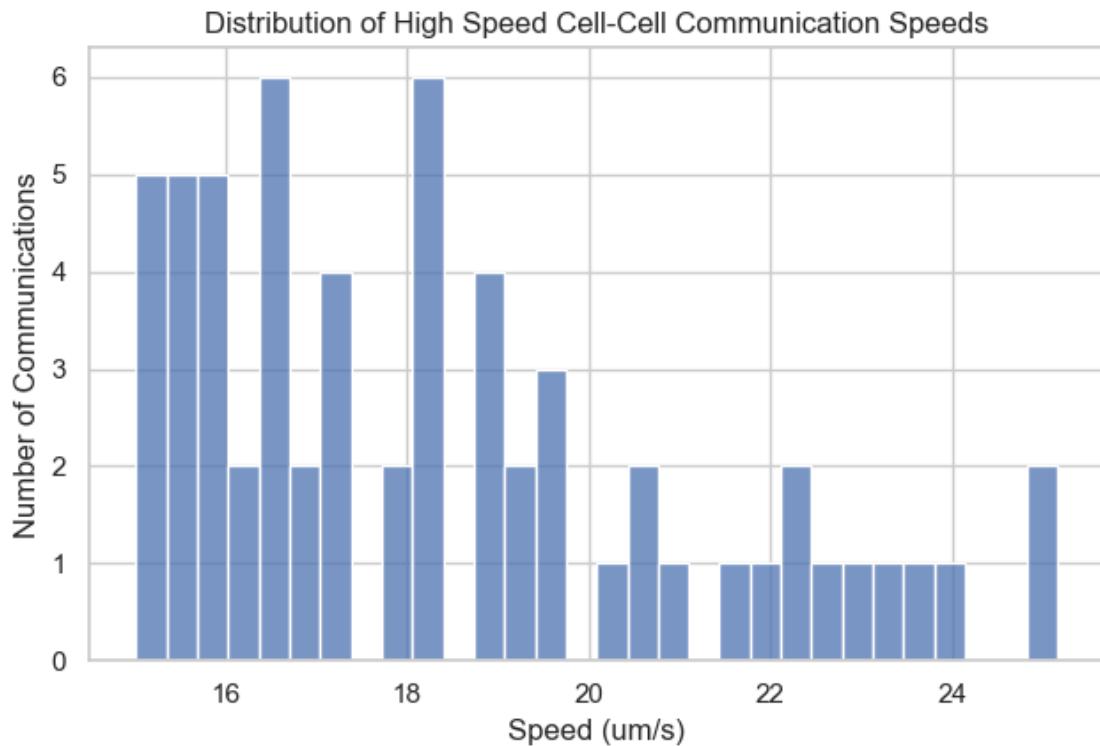
1.3.4 Double distribution in cell-cell communication speeds



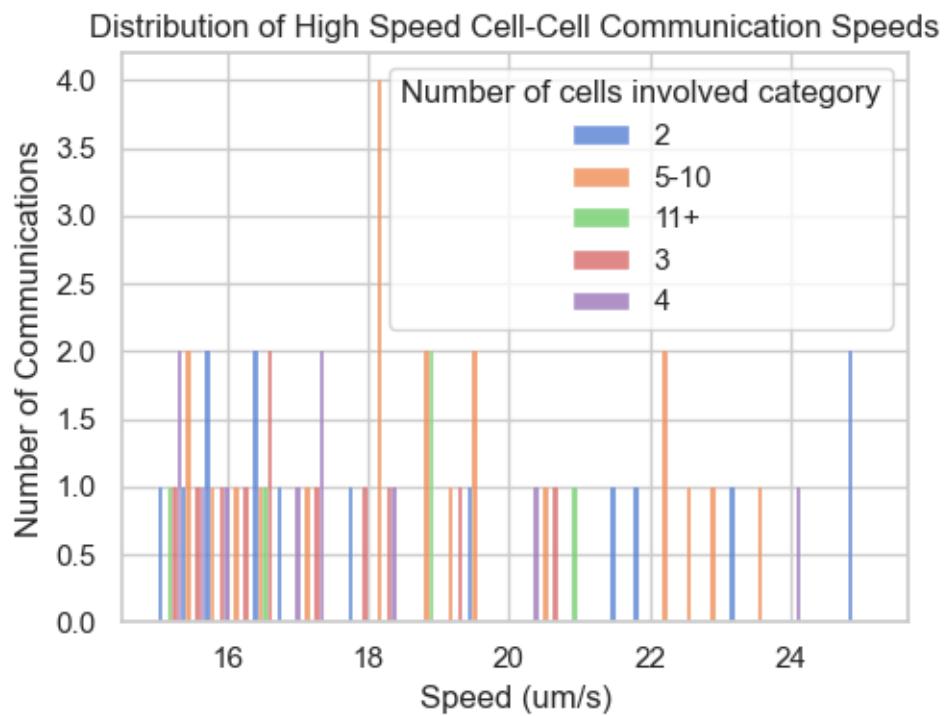
High Speed Cell-Cell Communication Involvement



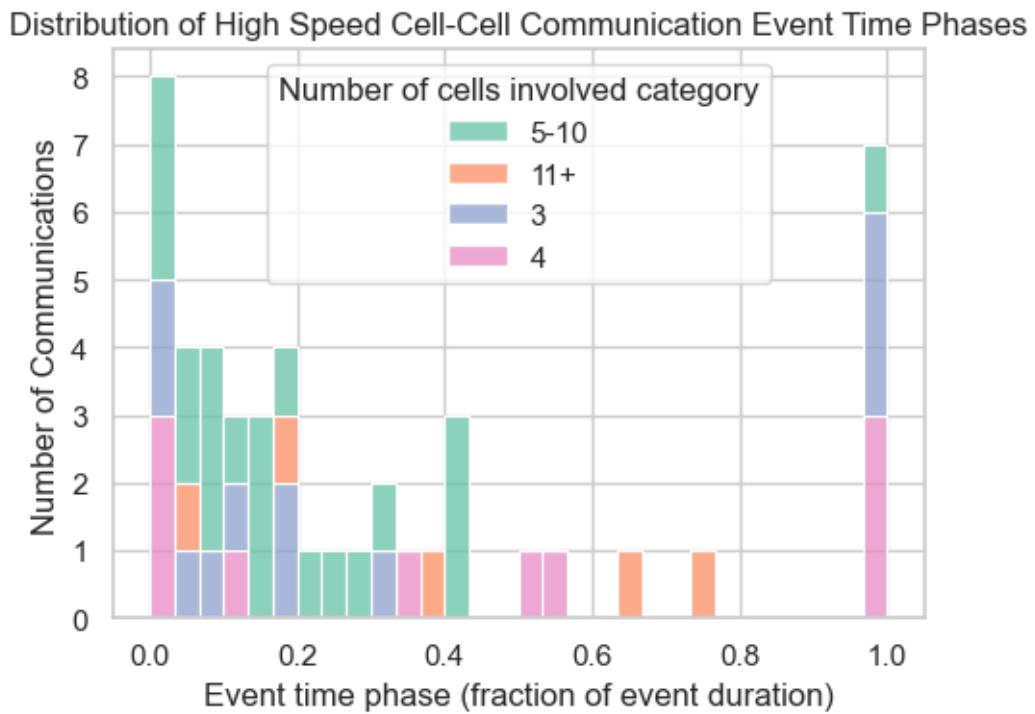
[2025-08-27 15:07:49] [INFO] calcium: plot_histogram: removed 0 outliers out of 61 on 'Speed (um/s)' (lower=4.98, upper=30.81)



```
[2025-08-27 15:07:49] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 61 on 'Speed (um/s)' (lower=4.98, upper=30.81)
```

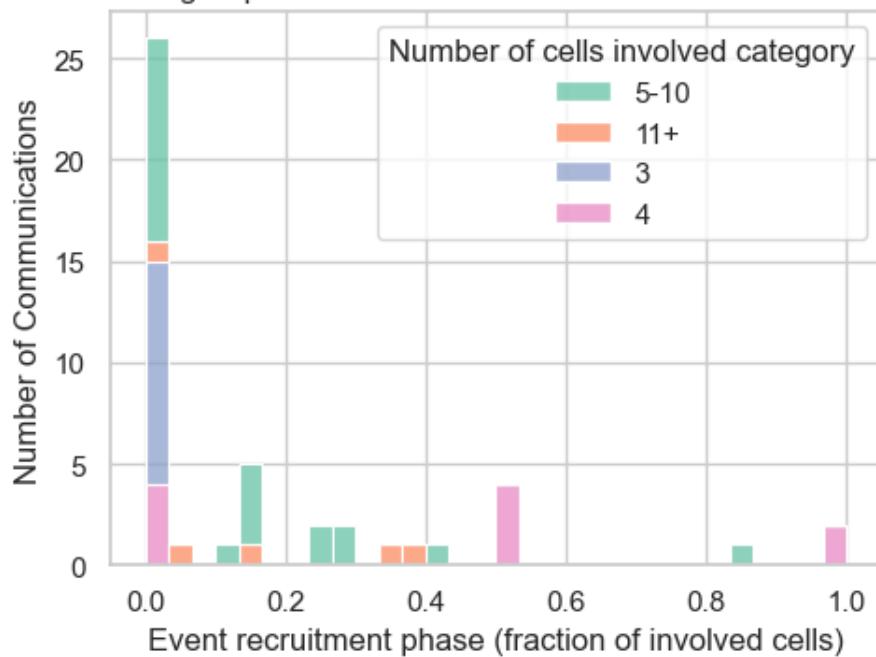


[2025-08-27 15:07:49] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 47 on 'Event time phase (fraction of event duration)' (lower=-0.985, upper=1.465)

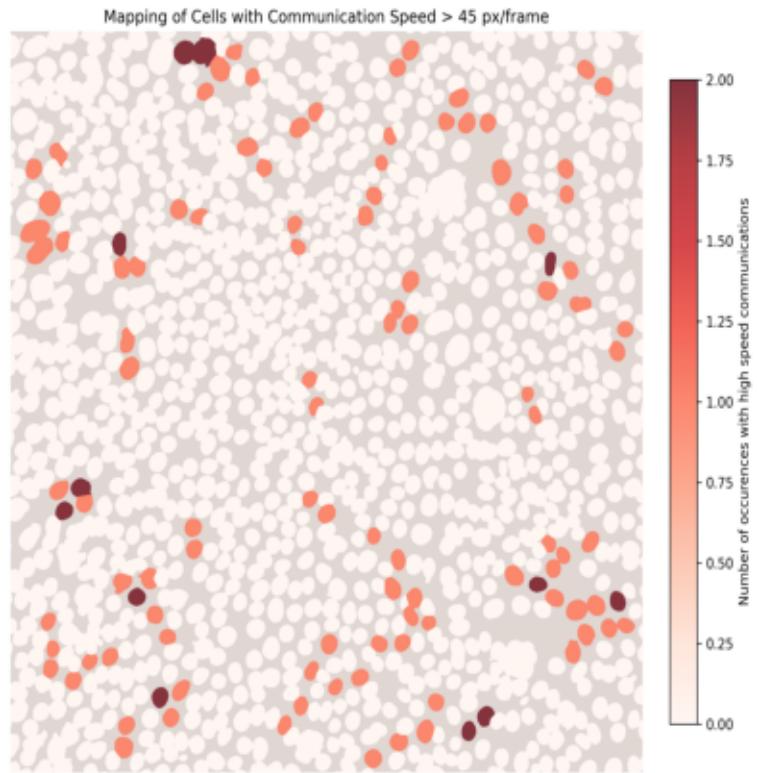


[2025-08-27 15:07:49] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 47 on 'Event recruitment phase (fraction of involved cells)' (lower=-0.81, upper=1.08)

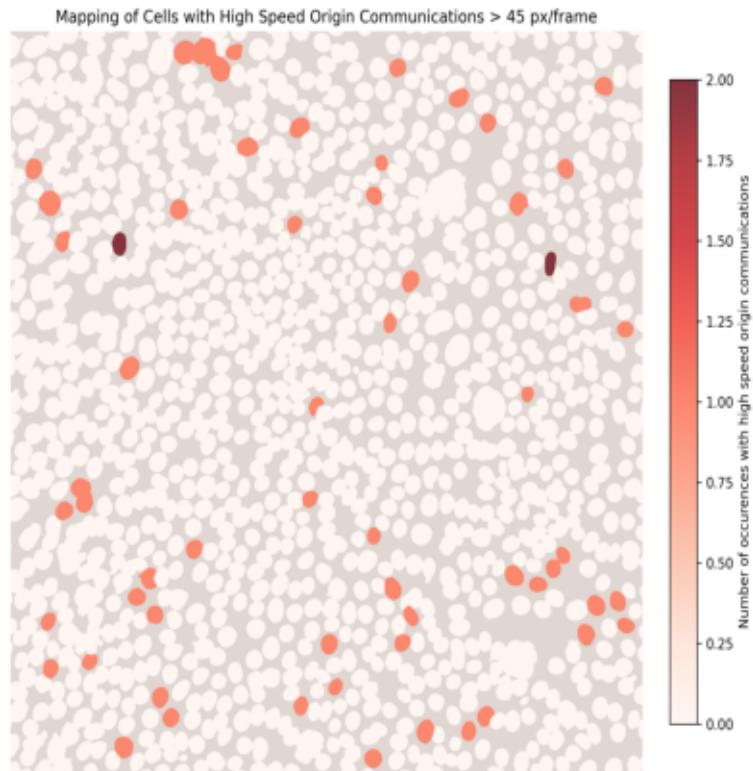
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
4	2016651333824	7	261	2	
6	2016651339536	8	255	5	
8	2016651341360	8	263	3	
12	2018409376608	8	285	2	
13	2016651334544	9	282	6	
..	
753	2016632060752	367	1597	1	
758	2016632058688	370	1626	0	
767	2016632050192	374	1572	5	
770	2016632046256	376	1623	2	
783	2016632051008	384	1656	7	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
4	255	3	684.0	684.0	
6	261	4	996.0	996.0	
8	305	4	992.0	992.0	
12	332	4	989.0	990.0	
13	256	6	1562.0	1562.0	
..	\
753	1557	2	384.0	385.0	
758	1566	1	80.0	81.0	
767	1615	4	1057.0	1058.0	
770	1593	1	371.0	372.0	
783	1616	9	1438.0	1439.0	
	Duration (s)	Distance (um)	Speed (um/s)		\
4	0.0	15.94	15.94		
6	0.0	15.94	15.94		
8	0.0	22.14	22.14		
12	1.0	19.24	19.24		
13	0.0	15.69	15.69		
..		
753	1.0	16.05	16.05		
758	1.0	21.55	21.55		
767	1.0	18.38	18.38		
770	1.0	16.45	16.45		
783	1.0	15.12	15.12		
	Event time phase (fraction of event duration)		\		
4			NaN		
6			1.00		
8			0.43		
12			0.14		
13			0.00		
..			...		
753			0.12		
758			NaN		
767			0.17		
770			NaN		
783			NaN		
	Event recruitment phase (fraction of involved cells)	dataset	\		
4		NaN	20250624_IS05		
6		0.86	20250624_IS05		
8		0.29	20250624_IS05		
12		0.00	20250624_IS05		
13		0.00	20250624_IS05		
..			
753		0.00	20250624_IS05		
758		NaN	20250624_IS05		

767		0.00	20250624_IS05
770		NaN	20250624_IS05
783		NaN	20250624_IS05

	Number of cells involved	category	Speed category
4		2	High speed
6		5-10	High speed
8		5-10	High speed
12		5-10	High speed
13		5-10	High speed
..	
753		3	High speed
758		2	High speed
767		5-10	High speed
770		2	High speed
783		2	High speed

[61 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
247		0	1
254		0	1
255		1	0
256		0	2
261		1	0
..	
1661		0	4
1663		0	1
1671		0	2
1675		1	0
1682		0	1

[440 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
3	247	341.90		8.78
8	254	195.97		11.70
9	255	152.75		13.33
10	256	315.57		12.35
14	261	136.83		13.97
..
1047	1661	69.23		483.60
1049	1663	35.75		483.60
1056	1671	230.75		487.18
1059	1675	286.00		489.45
1065	1682	99.45		491.73

Number of peaks Is active Occurrences in global events \

3	9	True	5
8	7	True	5
9	7	True	3
10	8	True	5
14	7	True	4
...
1047	9	True	5
1049	6	True	5
1056	8	True	5
1059	8	True	5
1065	7	True	5

Occurrences in global events as early peaker Early peaker event IDs \

3	1	[1]
8	0	[]
9	0	[]
10	0	[]
14	0	[]
...
1047	0	[]
1049	0	[]
1056	5	[1, 2, 3, 4, 5]
1059	0	[]
1065	0	[]

Occurrences in sequential events \

3	2
8	1
9	2
10	1
14	2
...	...
1047	2
1049	1
1056	2
1059	2
1065	1

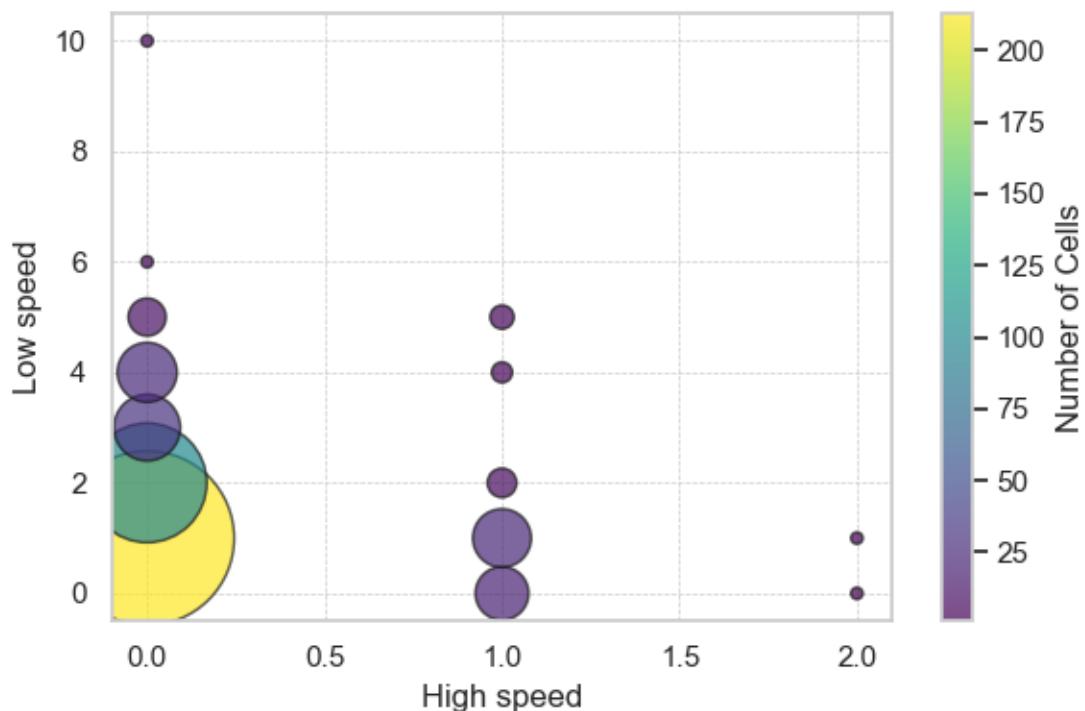
Occurrences in sequential events as origin \

3	0
8	1
9	0
10	0
14	1
...	...
1047	2
1049	1
1056	1

1059		1	
1065		1	
Occurrences in individual events Peak frequency (Hz) \			
3		1	0.0053
8		1	0.0041
9		2	0.0041
10		1	0.0047
14		1	0.0041
...
1047		2	0.0053
1049		0	0.0035
1056		1	0.0047
1059		1	0.0047
1065		1	0.0041
Periodicity score Neighbor count Neighbors (labels) \			
3	0.62	3	[260,265,297]
8	0.71	4	[257,263,289,305]
9	0.71	4	[253,261,285,300]
10	0.70	5	[246,265,282,290,309]
14	0.68	3	[255,269,300]
...
1047	0.62	5	[1601,1625,1656,1662,1680]
1049	0.77	5	[1581,1586,1631,1649,1662]
1056	0.61	3	[1636,1642,1683]
1059	0.61	5	[1622,1637,1647,1665,1678]
1065	0.74	4	[1639,1656,1667,1680]
dataset Involved in sequential event \			
3	20250624_IS05	Involved in sequential event	
8	20250624_IS05	Involved in sequential event	
9	20250624_IS05	Involved in sequential event	
10	20250624_IS05	Involved in sequential event	
14	20250624_IS05	Involved in sequential event	
...
1047	20250624_IS05	Involved in sequential event	
1049	20250624_IS05	Involved in sequential event	
1056	20250624_IS05	Involved in sequential event	
1059	20250624_IS05	Involved in sequential event	
1065	20250624_IS05	Involved in sequential event	
Occurrences in sequential events category High speed Low speed			
3		1-2	0.0
8		1-2	0.0
9		1-2	1.0
10		1-2	0.0
14		1-2	1.0

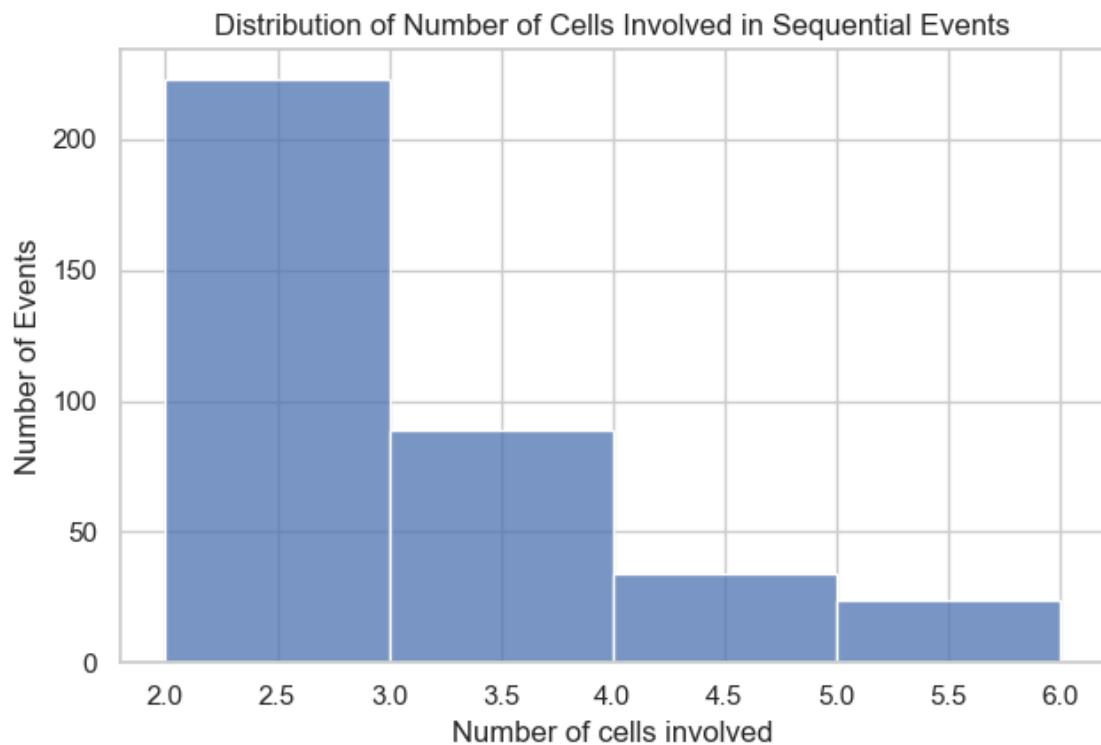
...
1047	1-2	0.0	4.0
1049	1-2	0.0	1.0
1056	1-2	0.0	2.0
1059	1-2	1.0	0.0
1065	1-2	0.0	1.0

[440 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

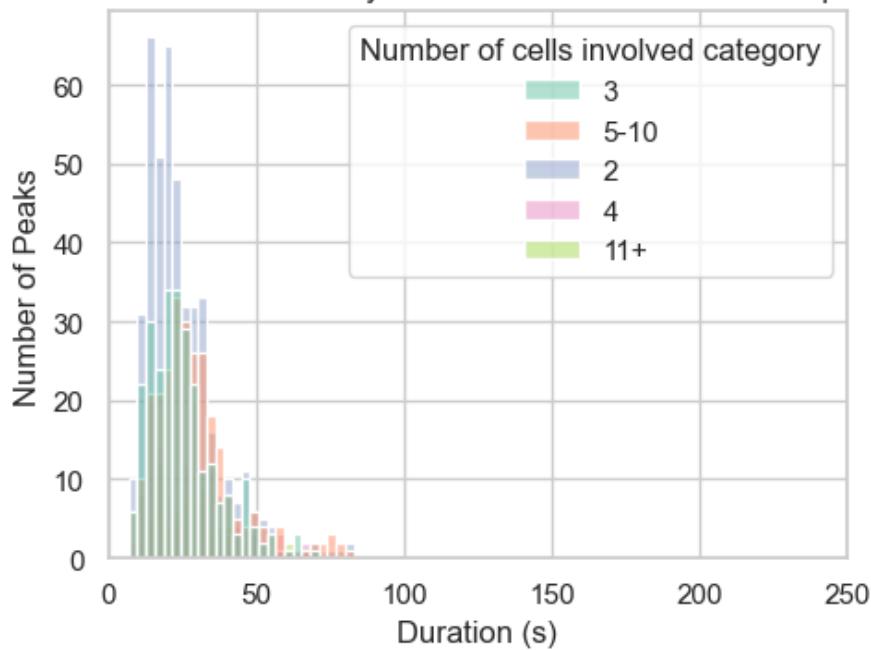
[2025-08-27 15:07:52] [INFO] calcium: plot_histogram: removed 22 outliers out of 392 on 'Number of cells involved' (lower=-1, upper=6)



1.3.6 Influence of cell count per event on statistics

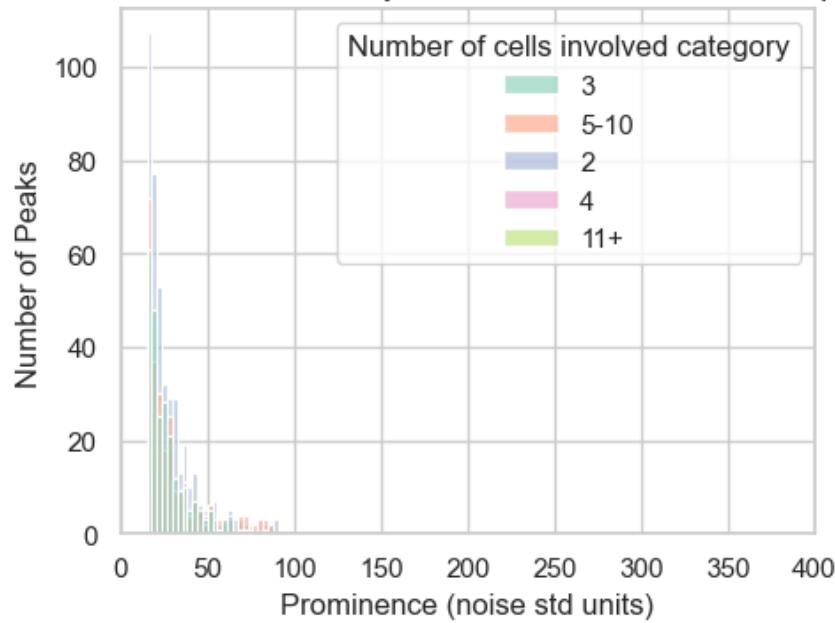
```
[2025-08-27 15:07:52] [INFO] calcium: plot_histogram_by_group: removed 9 outliers out of 1194 on 'Duration (s)' (lower=-6.625, upper=87.875)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

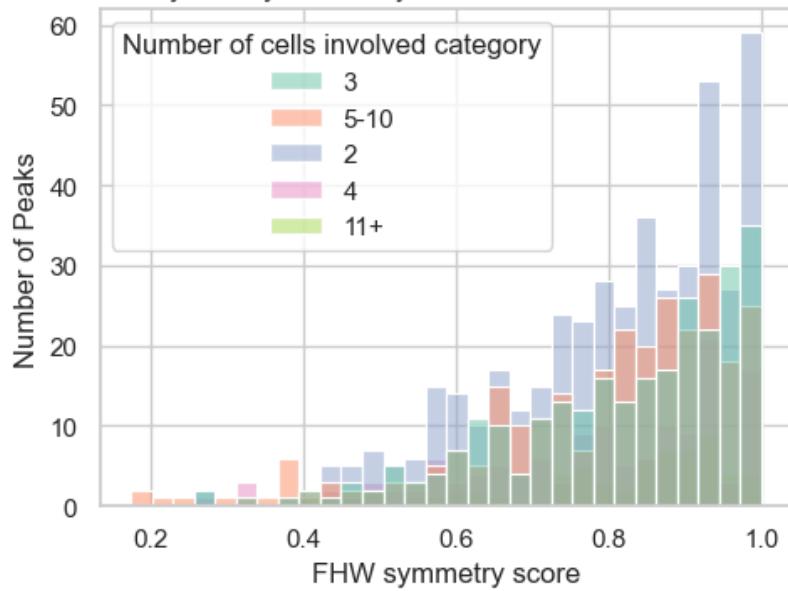


[2025-08-27 15:07:52] [INFO] calcium: plot_histogram_by_group: removed 48 outliers out of 1194 on 'Prominence (noise std units)' (lower=-8.275, upper=97.625)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

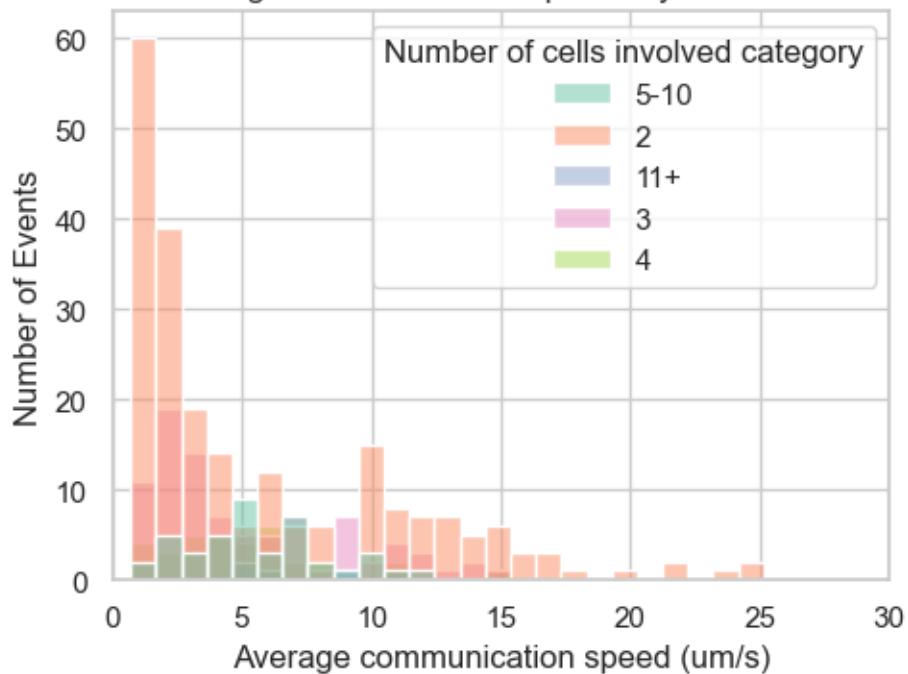


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

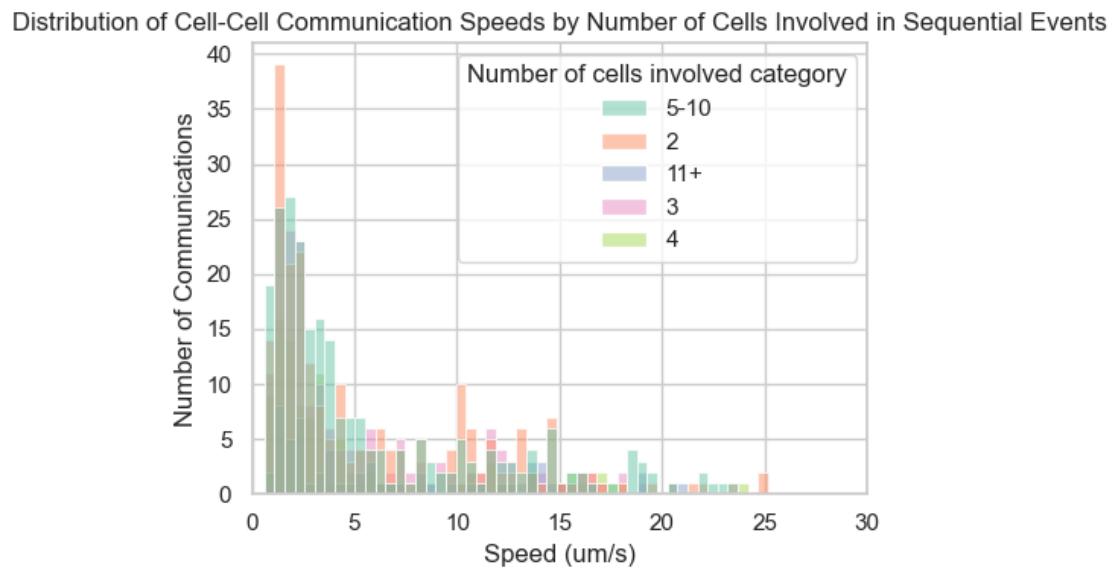


```
[2025-08-27 15:07:52] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 392 on 'Average communication speed (um/s)' (lower=-16.23, upper=26.278)
```

Distribution of Average Communication Speeds by Number of Cells Involved

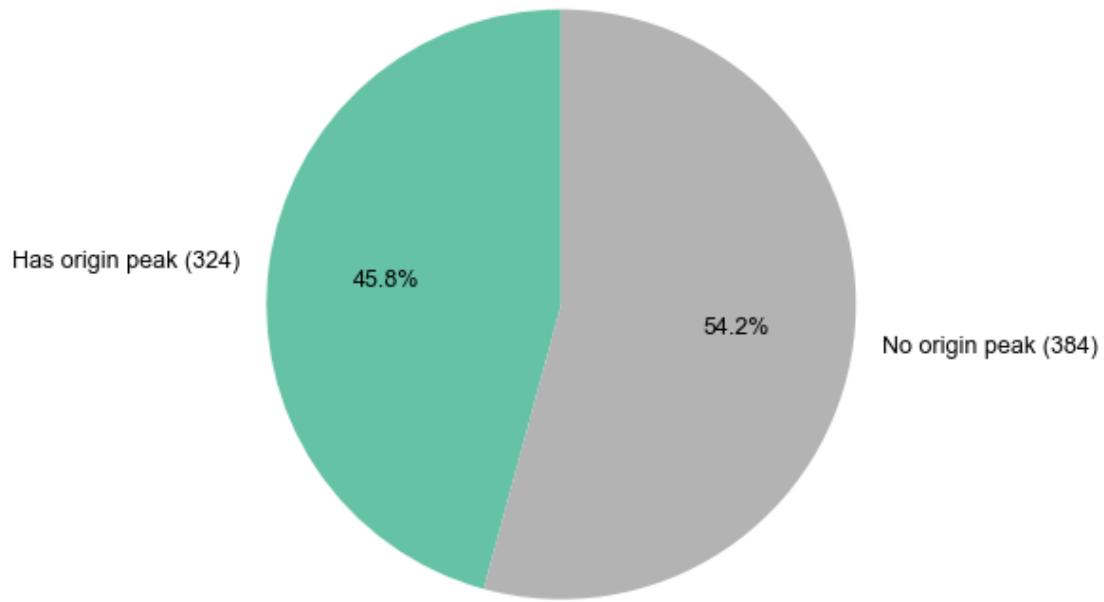


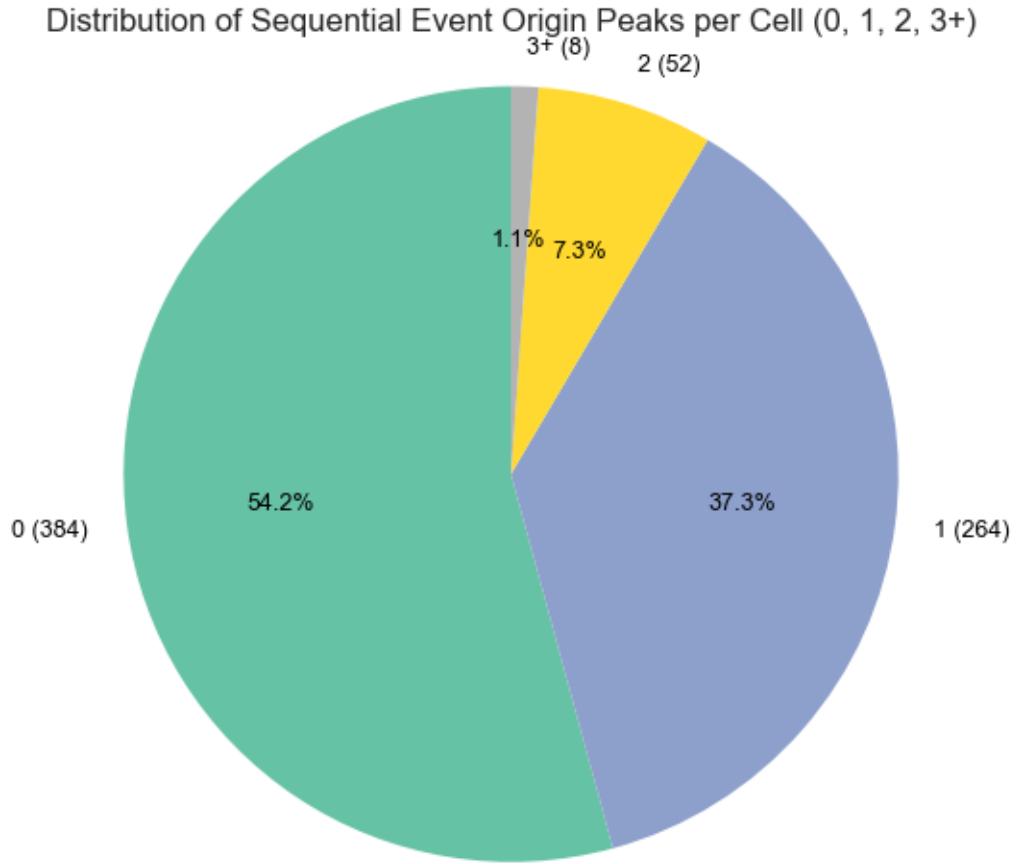
[2025-08-27 15:07:53] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 802 on 'Speed (um/s)' (lower=-18.145, upper=28.23)



1.3.7 Cells Occurrences as origin in sequential events

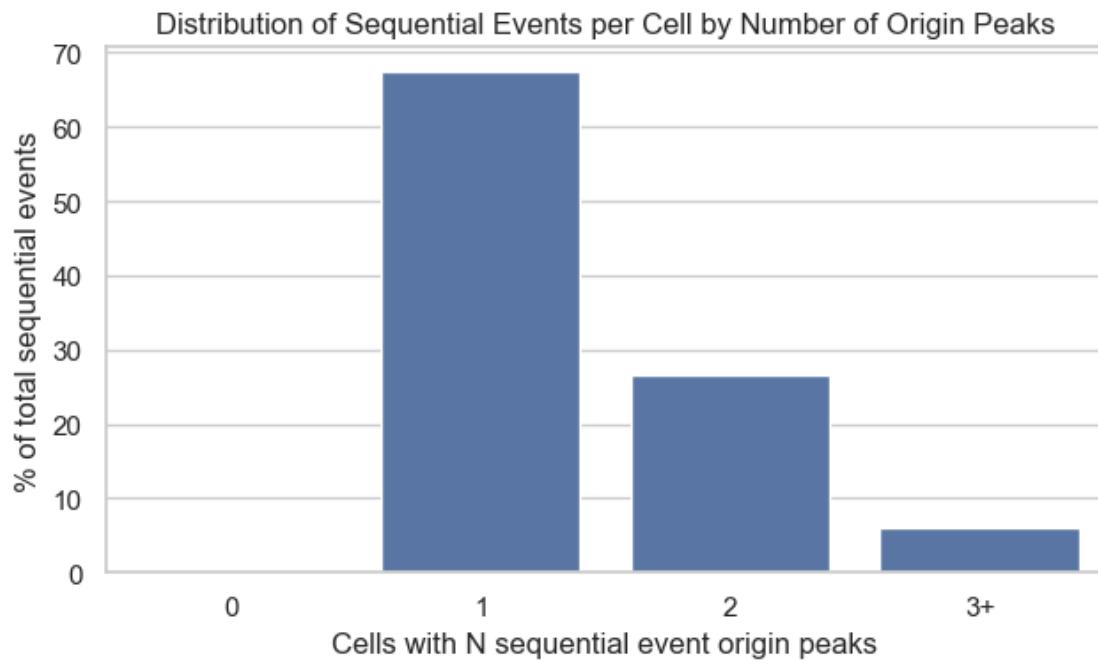
Distribution of Number of Sequential Event Origin Peaks per Cell



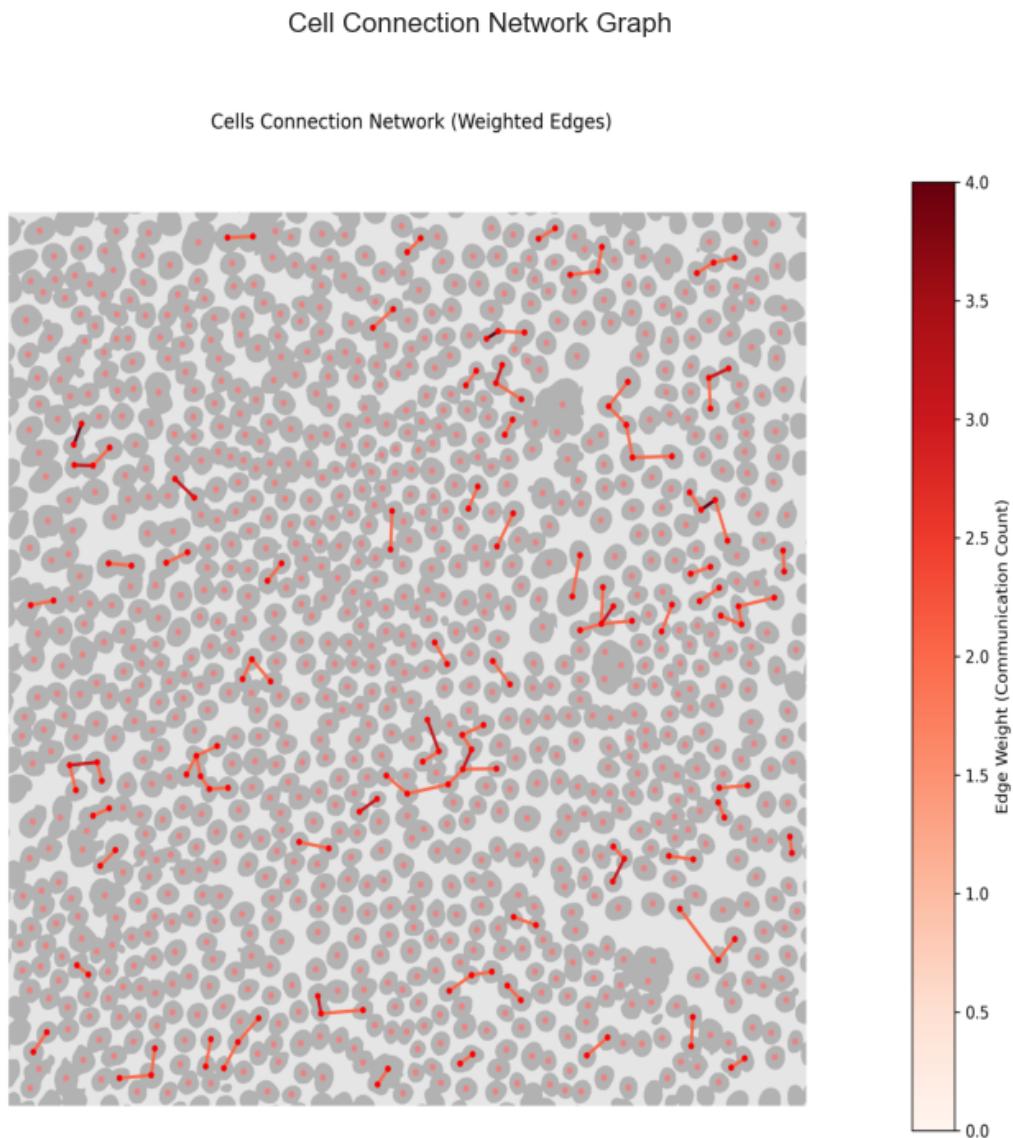


```
[2025-08-27 15:07:53] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS05\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250624\\Output\\IS05\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'

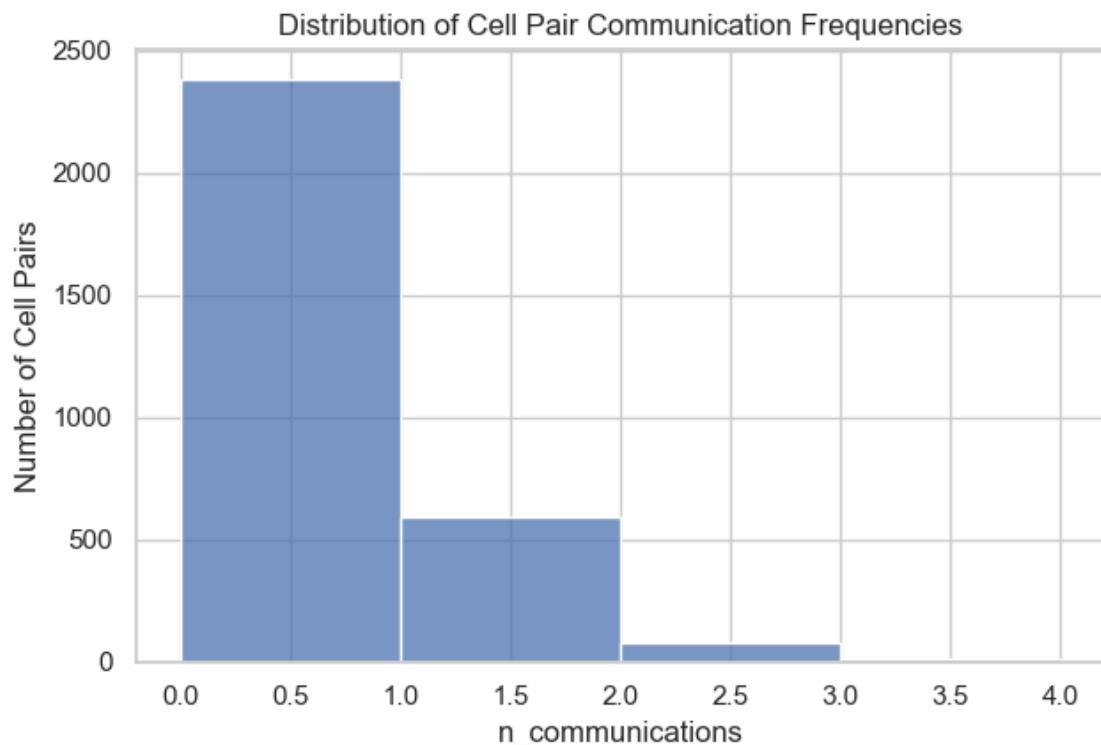


1.3.8 Connection network between cells



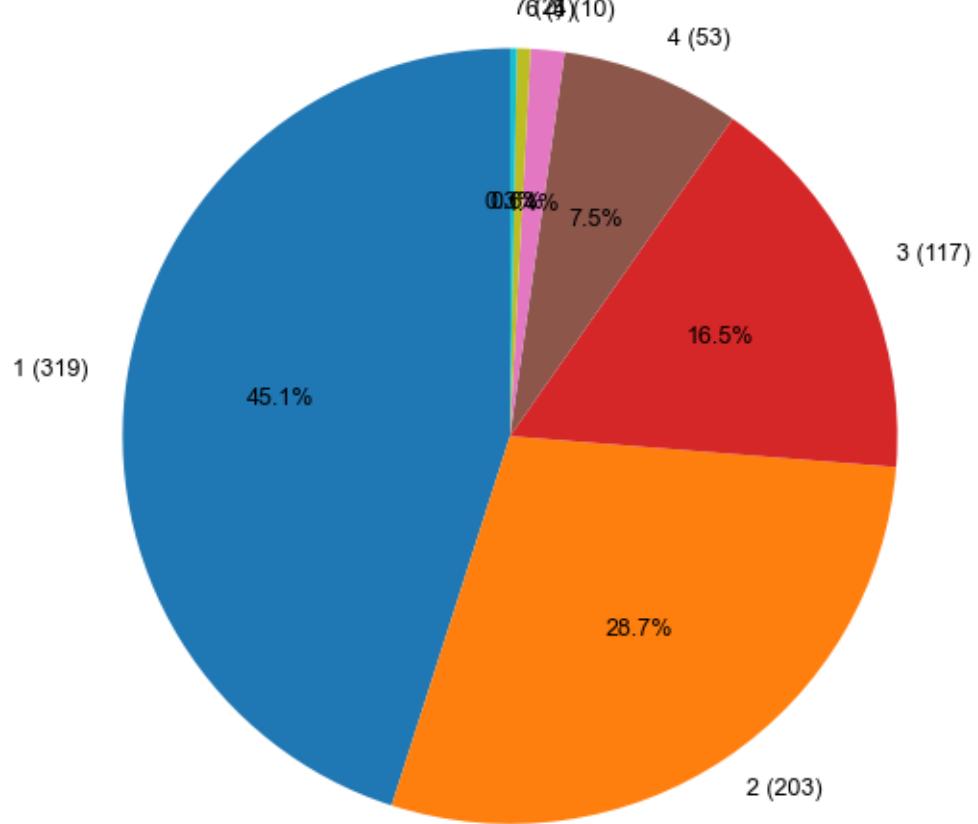
1.3.9 Pair/Trios with high communication networks

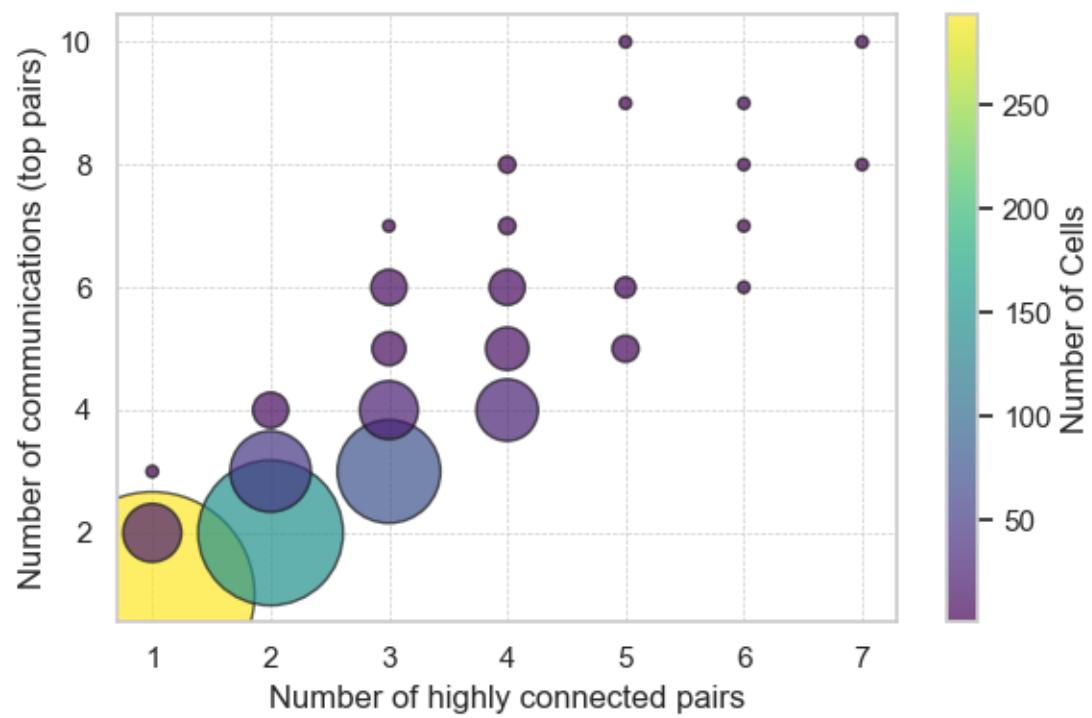
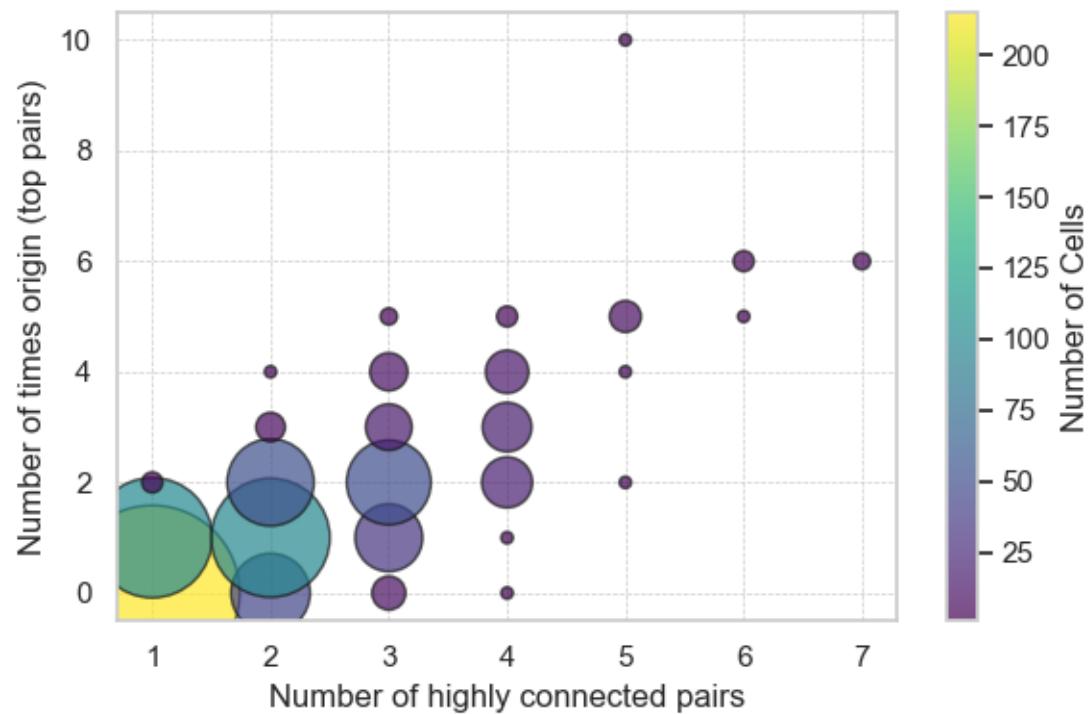
```
[2025-08-27 15:07:55] [INFO] calcium: build_neighbor_pair_stats: built 3070 pairs across 1 datasets (mean distance=16.53 um)
```

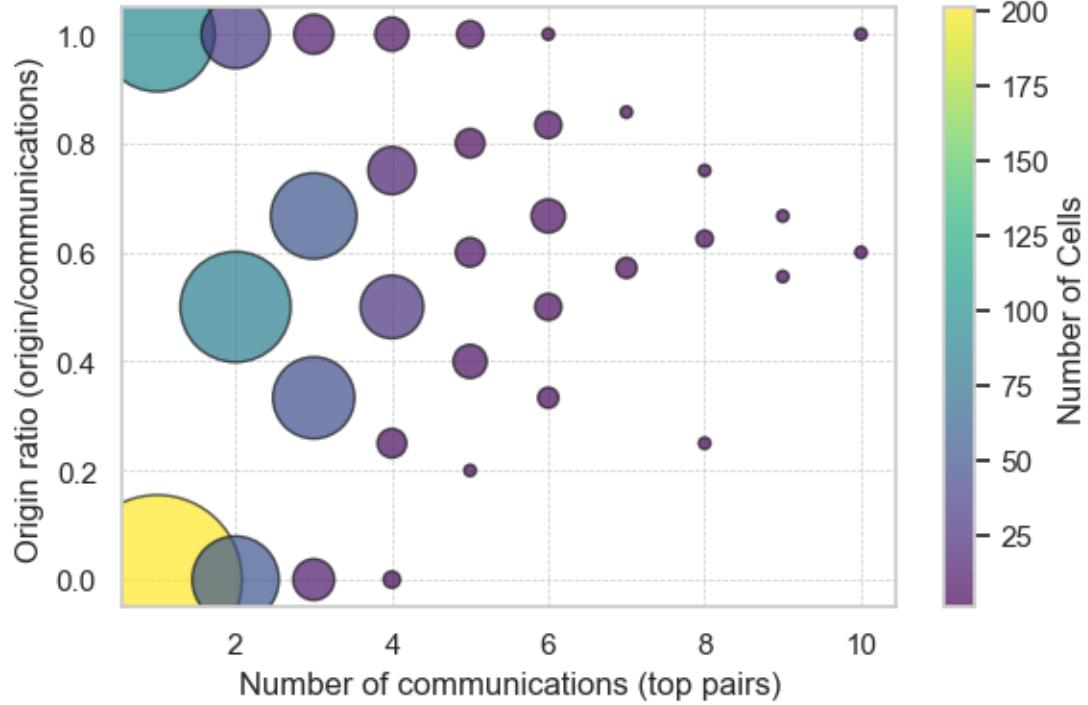
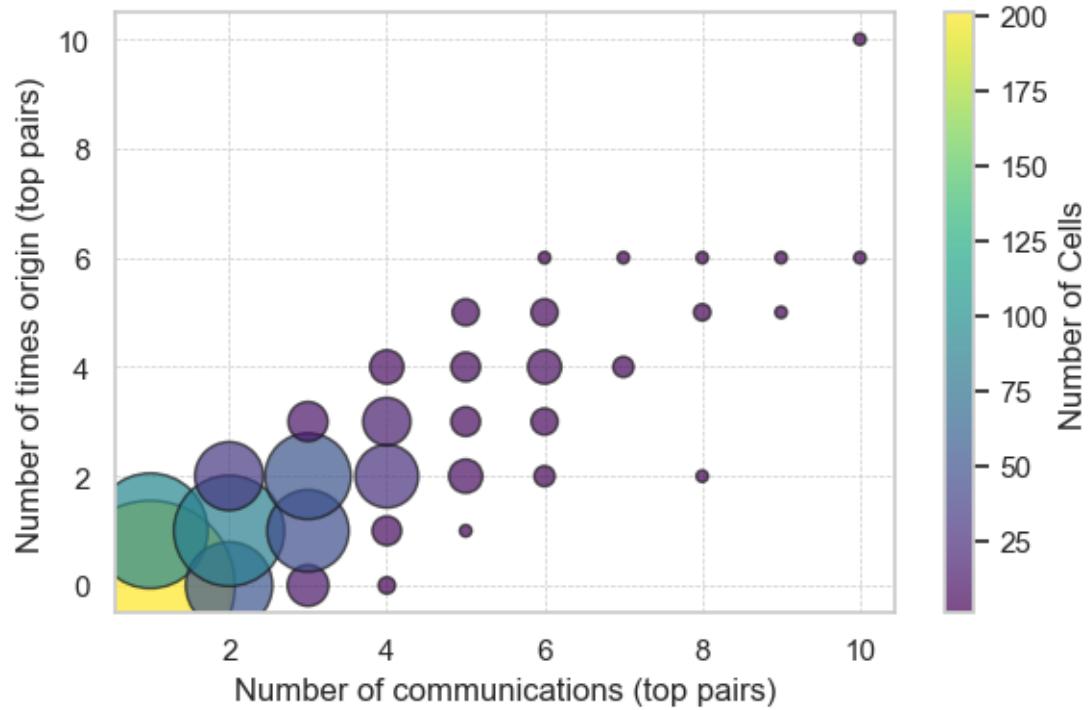


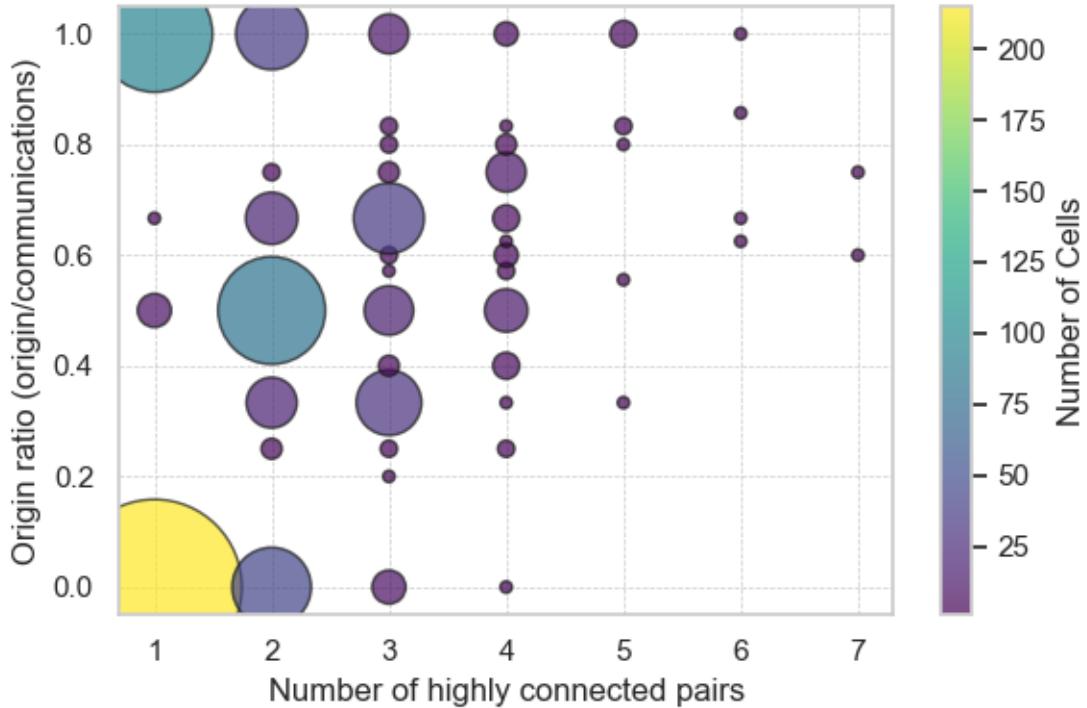
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=319 for Number of highly connected pairs=1

[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=203 for Number of highly connected pairs=2

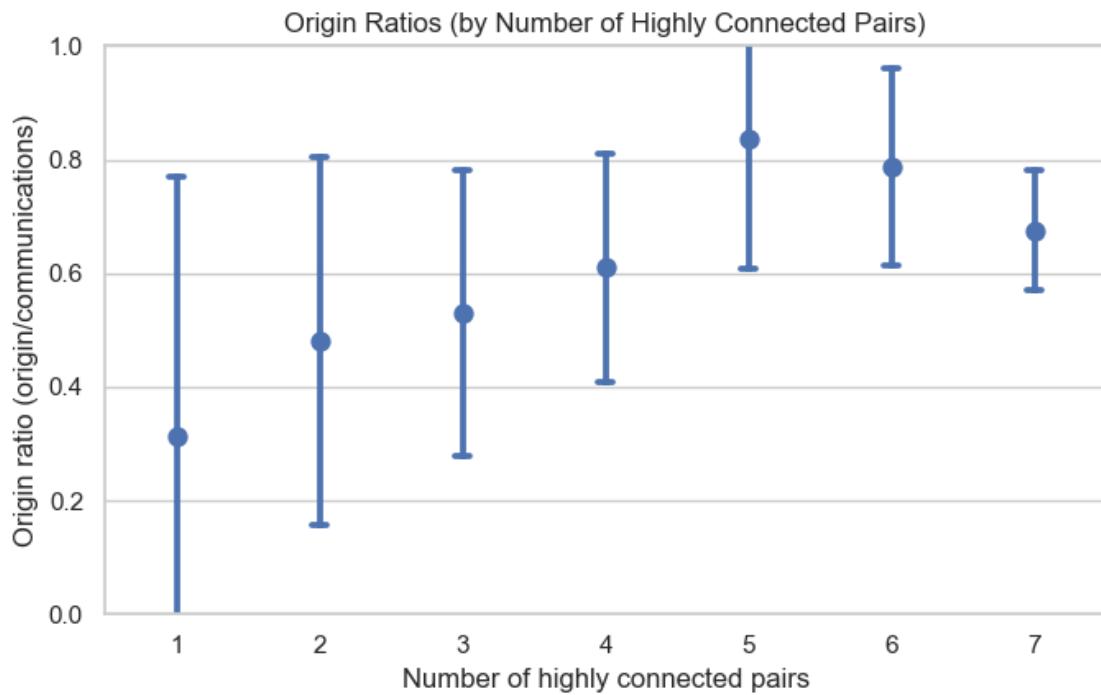
[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=117 for Number of highly connected pairs=3

[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=53 for Number of highly connected pairs=4

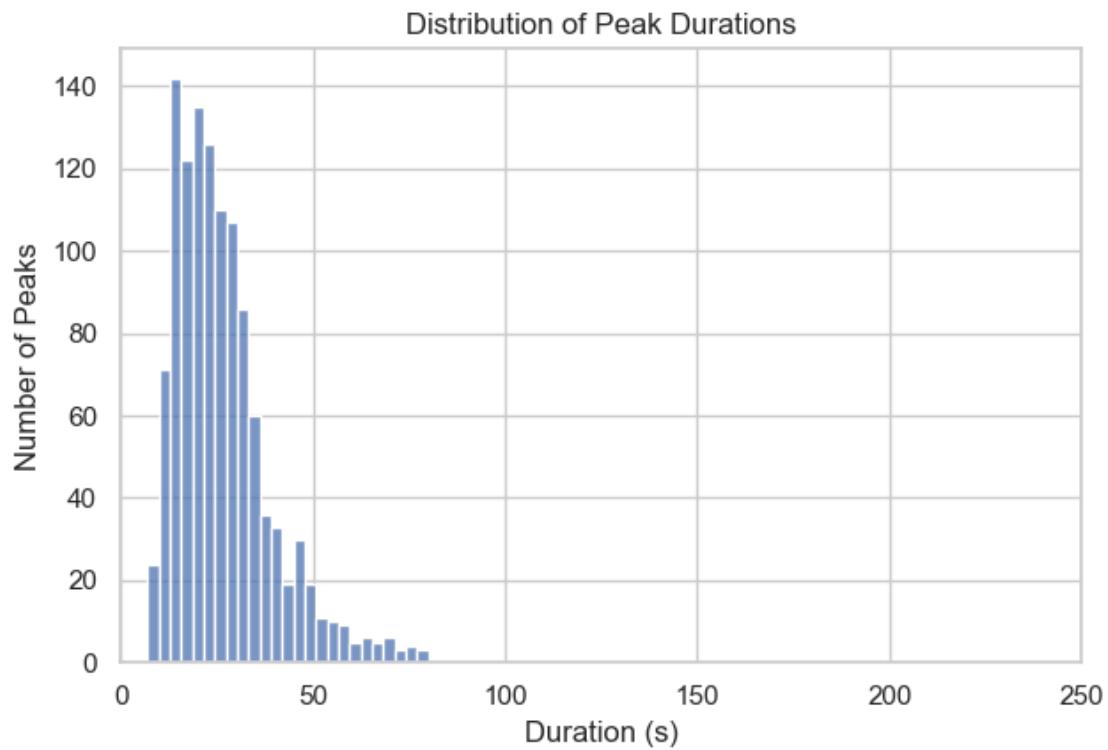
[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=10 for Number of highly connected pairs=5

[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=4 for Number of highly connected pairs=6

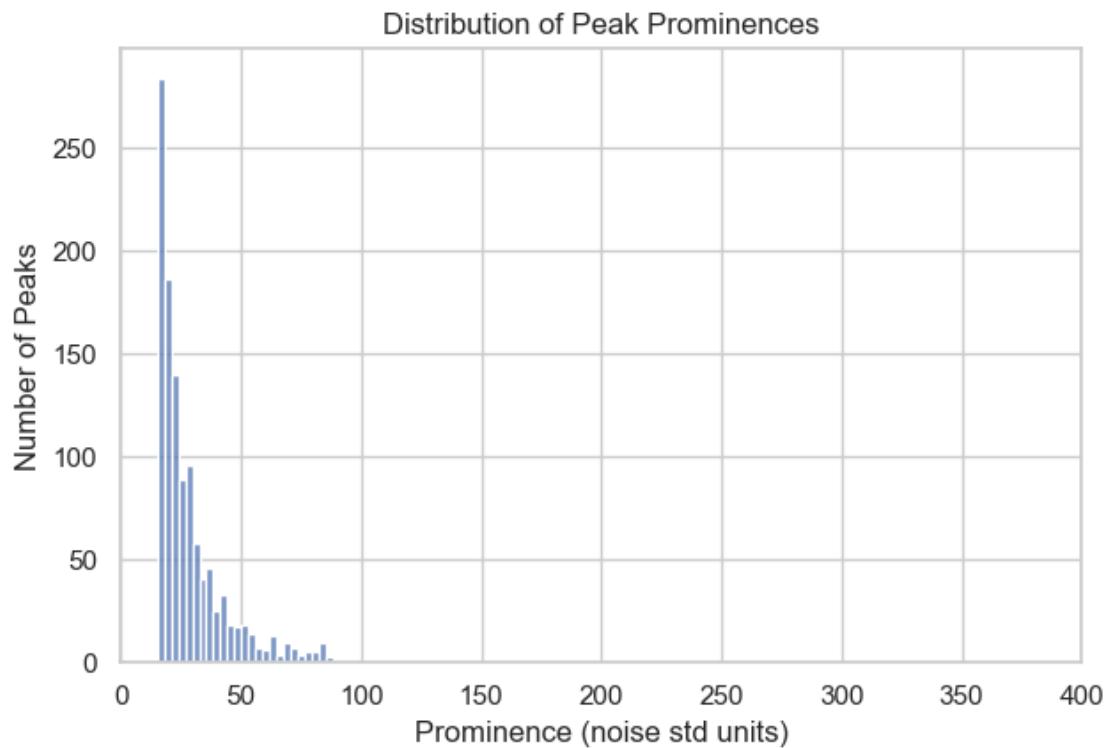
[2025-08-27 15:07:56] [INFO] calcium: plot_points_mean_std: N=2 for Number of highly connected pairs=7

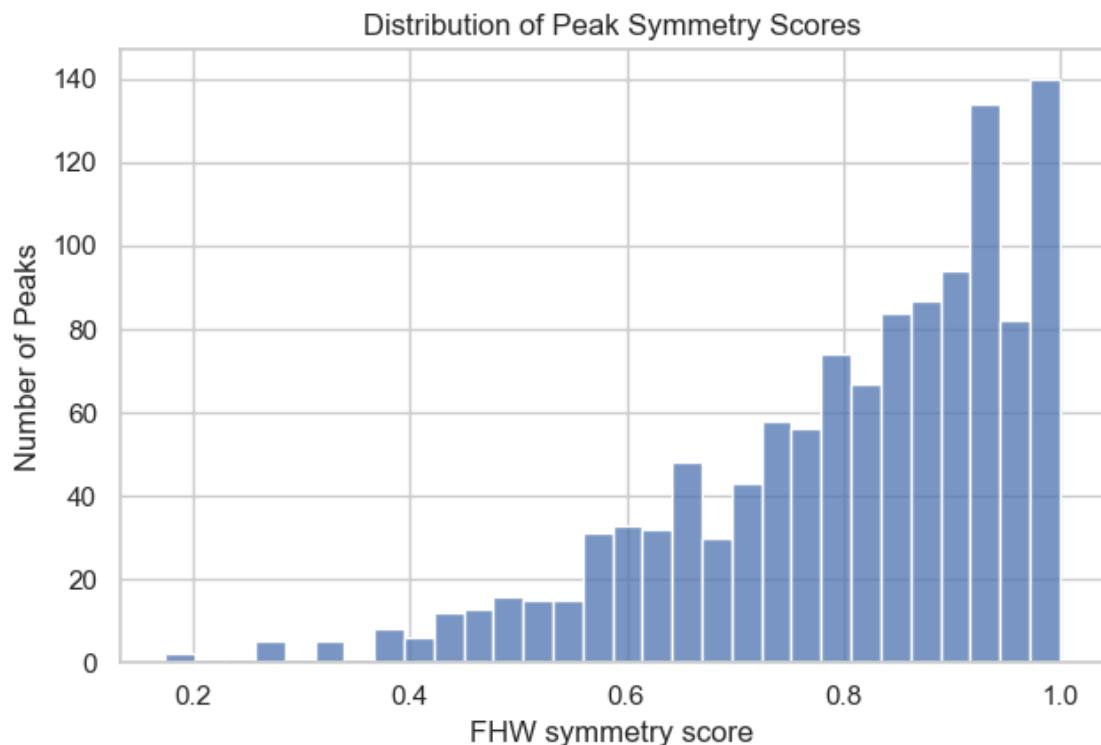


[2025-08-27 15:07:56] [INFO] calcium: plot_histogram: removed 12 outliers out of 1194 on 'Duration (s)' (lower=-30.25, upper=80)

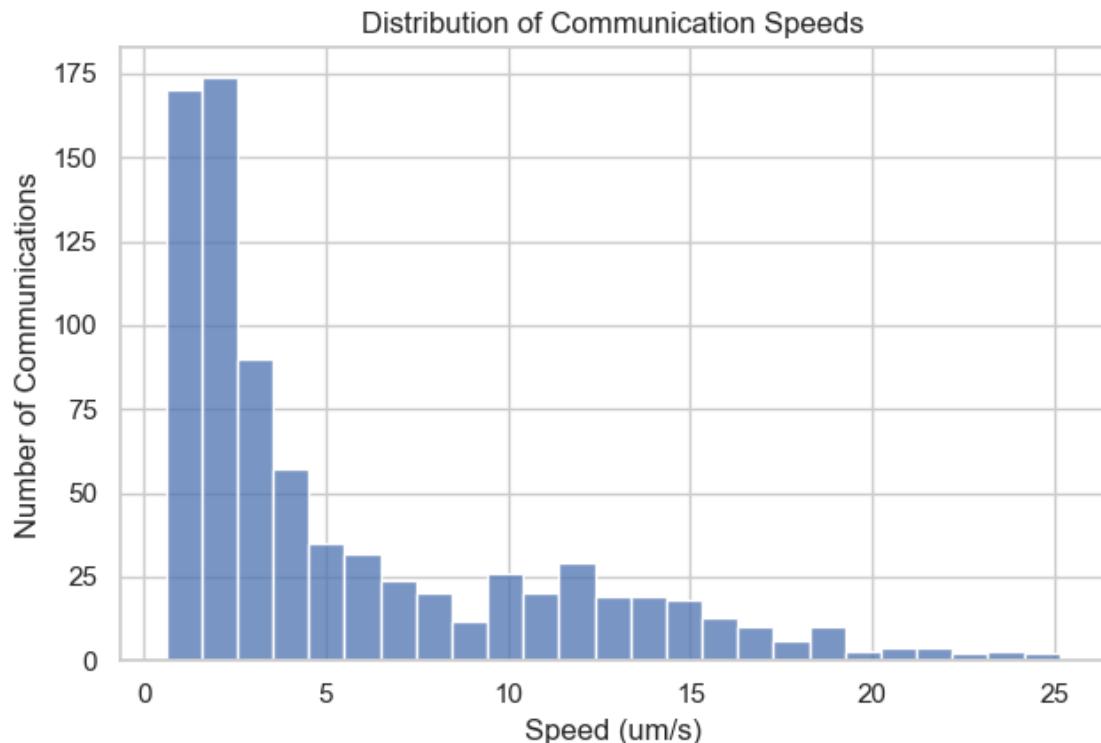


[2025-08-27 15:07:56] [INFO] calcium: plot_histogram: removed 55 outliers out of 1194 on 'Prominence (noise std units)' (lower=-34.75, upper=88.8)

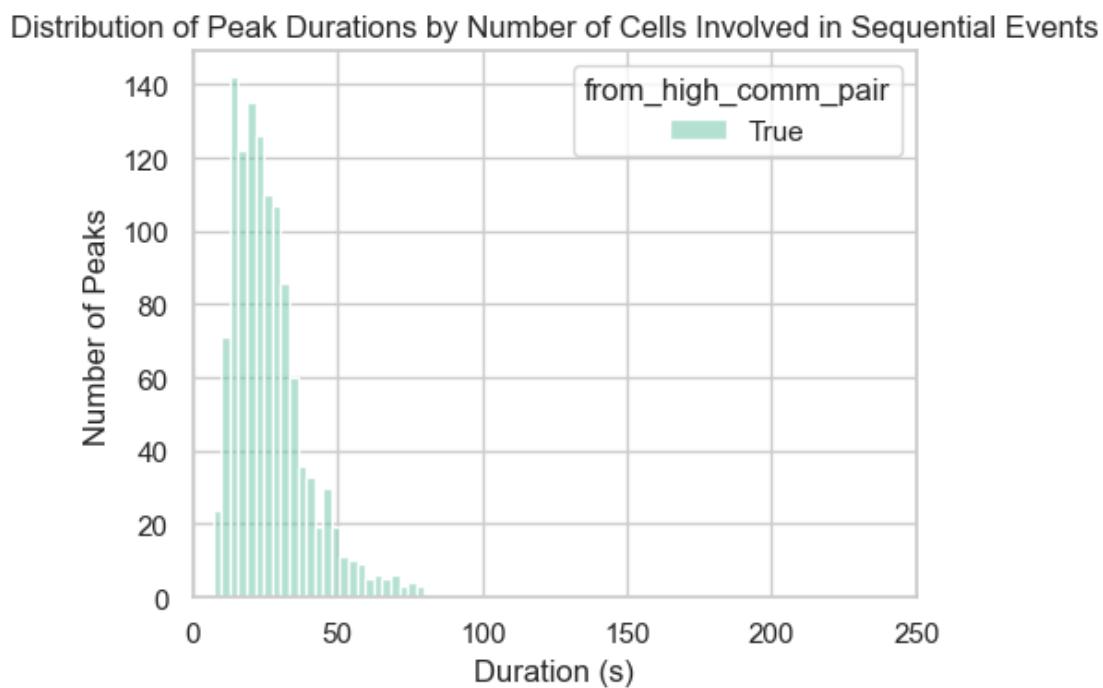




```
[2025-08-27 15:07:56] [INFO] calcium: plot_histogram: removed 0 outliers out of 802 on 'Speed (um/s)' (lower=-18.145, upper=28.23)
```

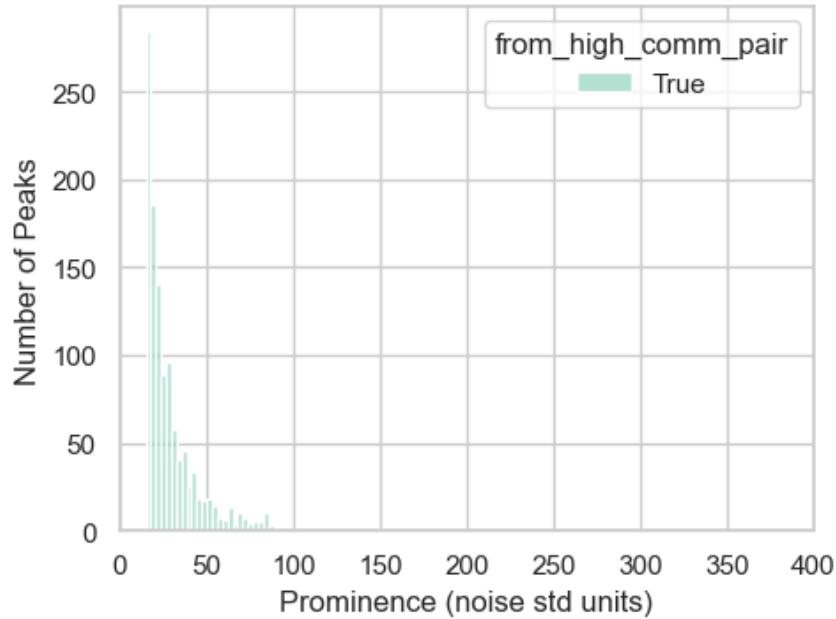


```
[2025-08-27 15:07:56] [INFO] calcium: plot_histogram_by_group: removed 12 outliers out of 1194 on 'Duration (s)' (lower=-30.25, upper=80)
```

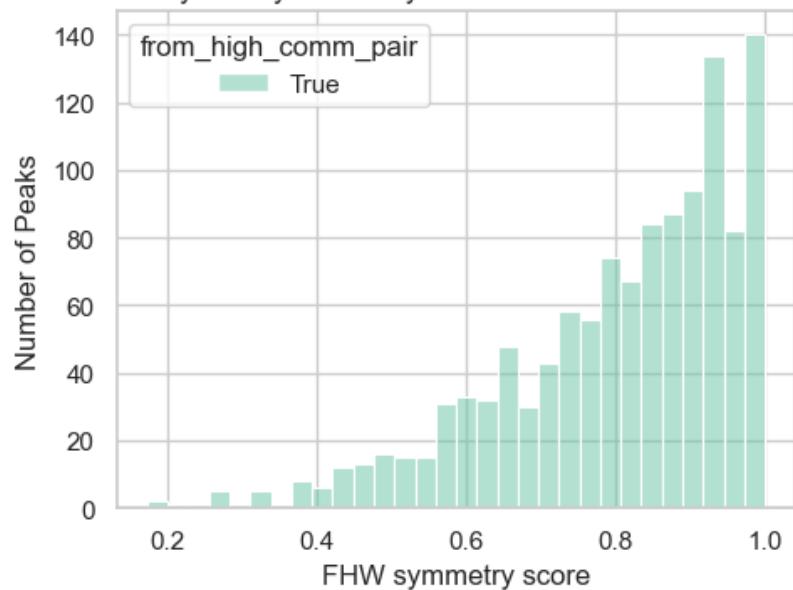


[2025-08-27 15:07:56] [INFO] calcium: plot_histogram_by_group: removed 55 outliers out of 1194 on 'Prominence (noise std units)' (lower=-34.75, upper=88.8)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

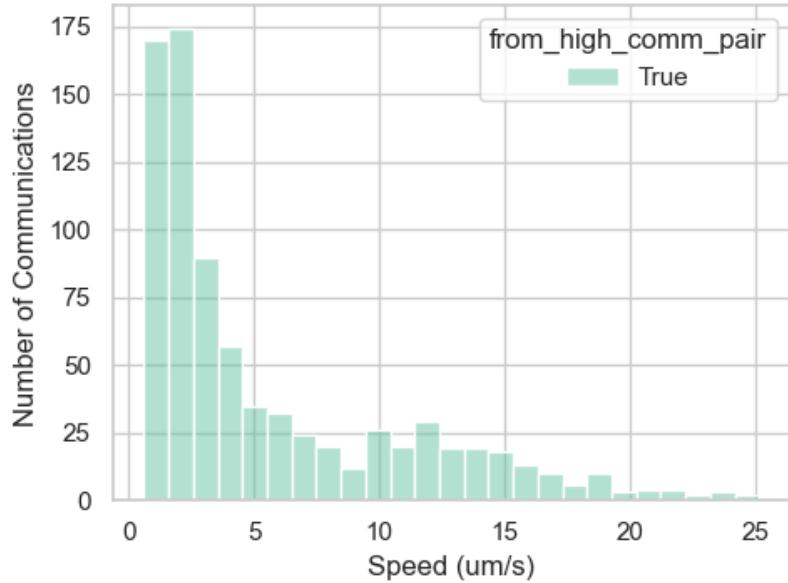


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:07:57] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 802 on 'Speed (um/s)' (lower=-18.145, upper=28.23)
```

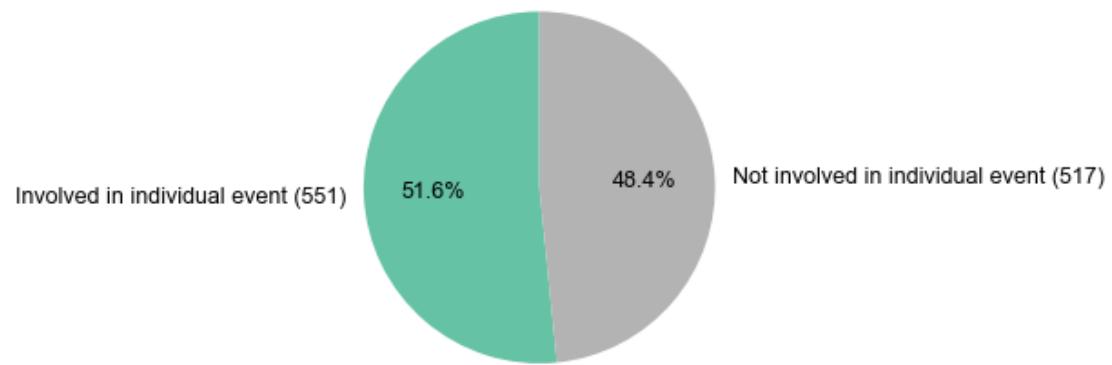
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

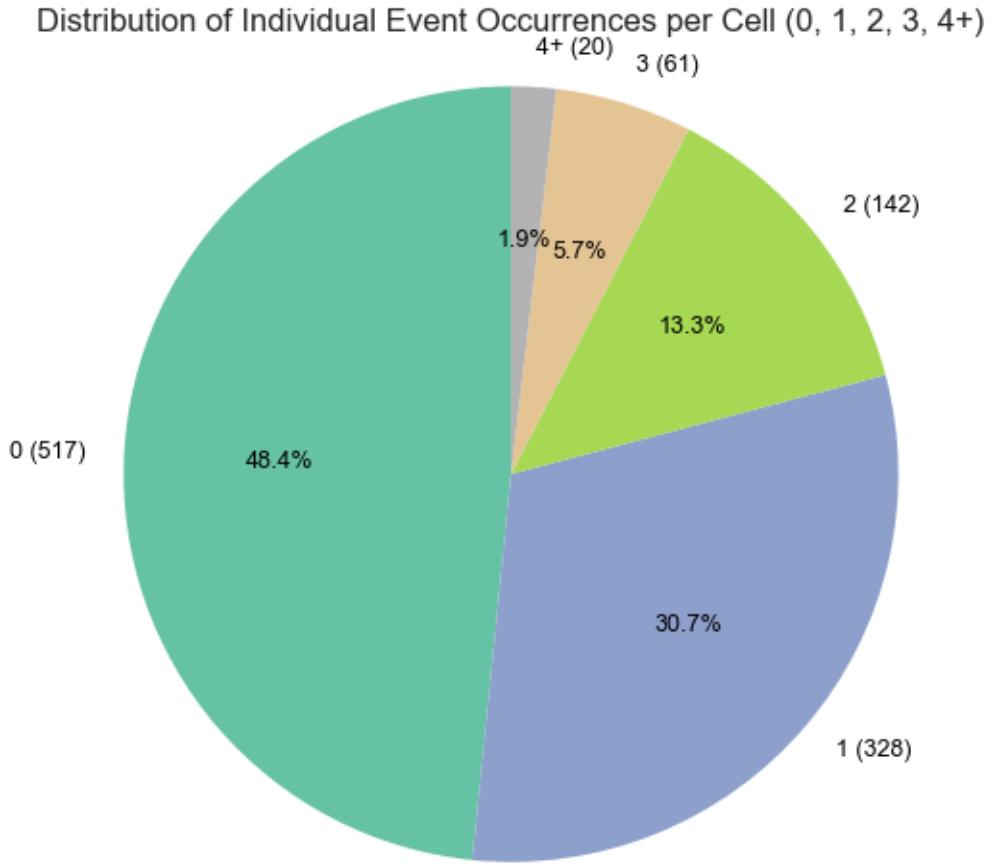


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



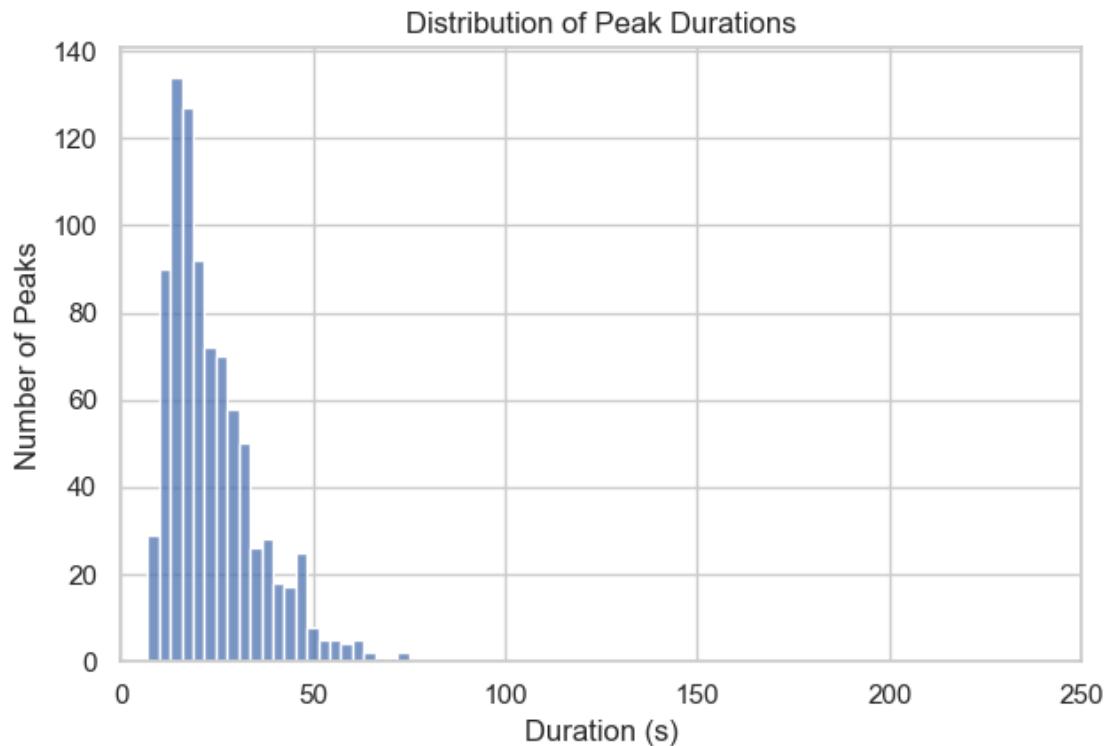


```
[2025-08-27 15:07:57] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS05\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS05\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

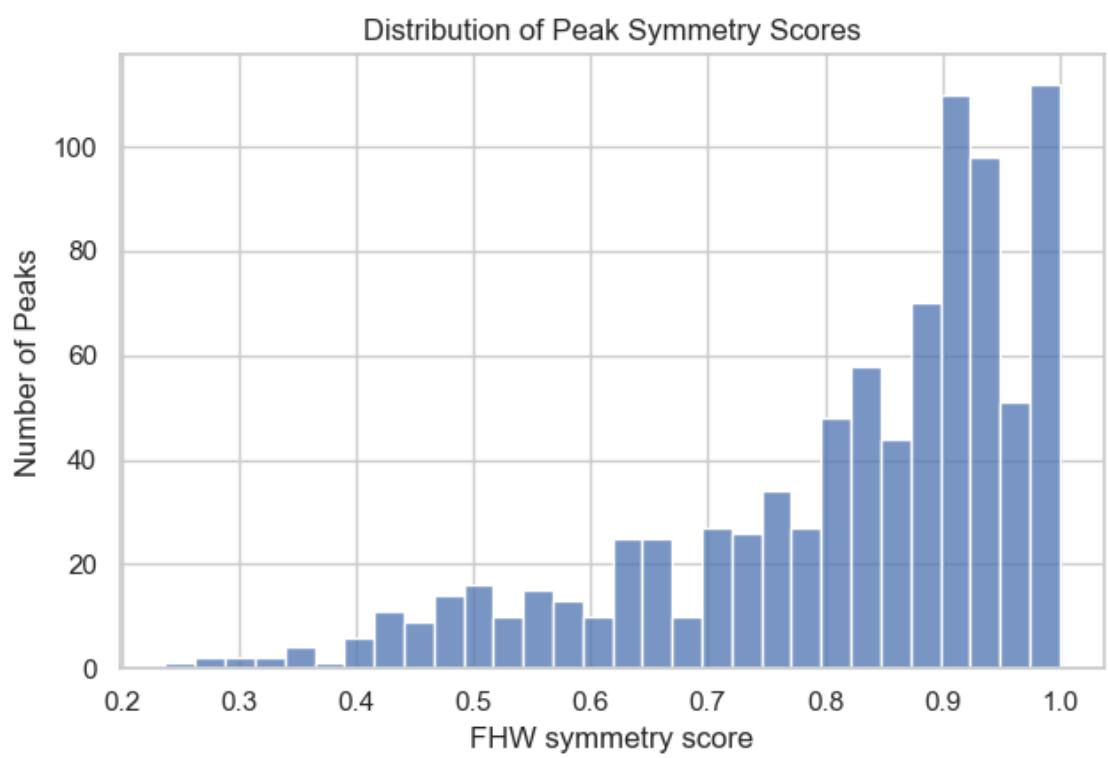
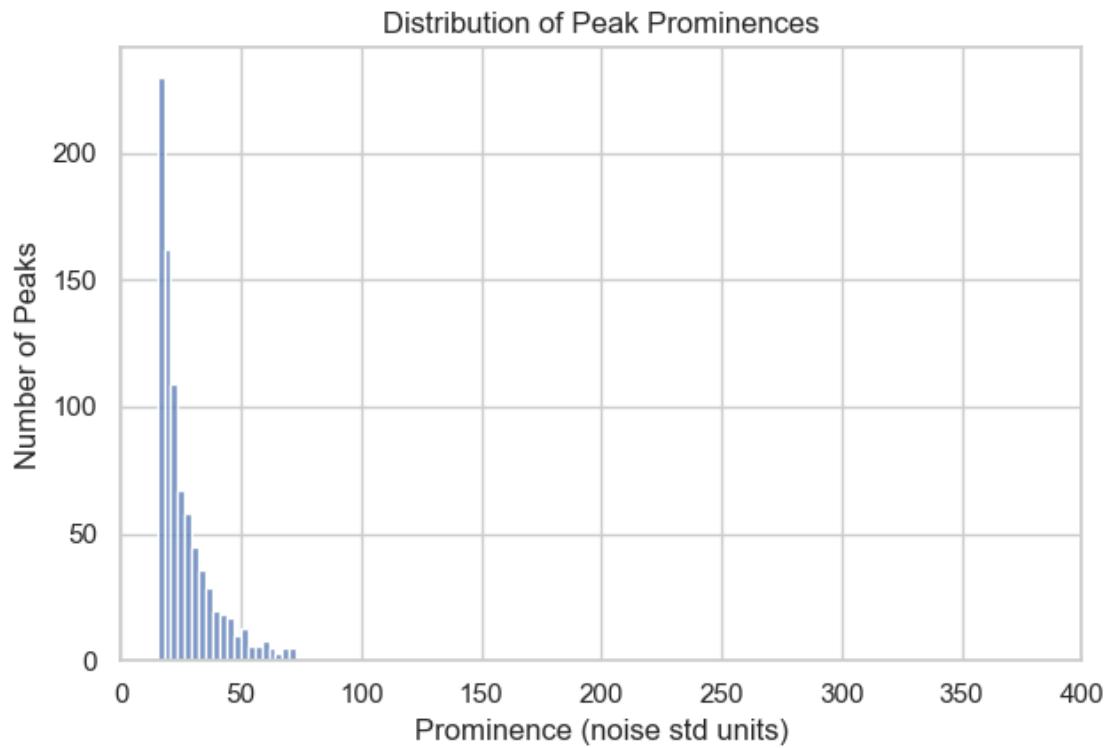
```
'D:\\Mateo\\20250624\\Output\\IS05\\cell-  
mapping\\cell_occurrences_in_individual_events_overlay.png'
```

1.4.2 Peaks statistics in individual events

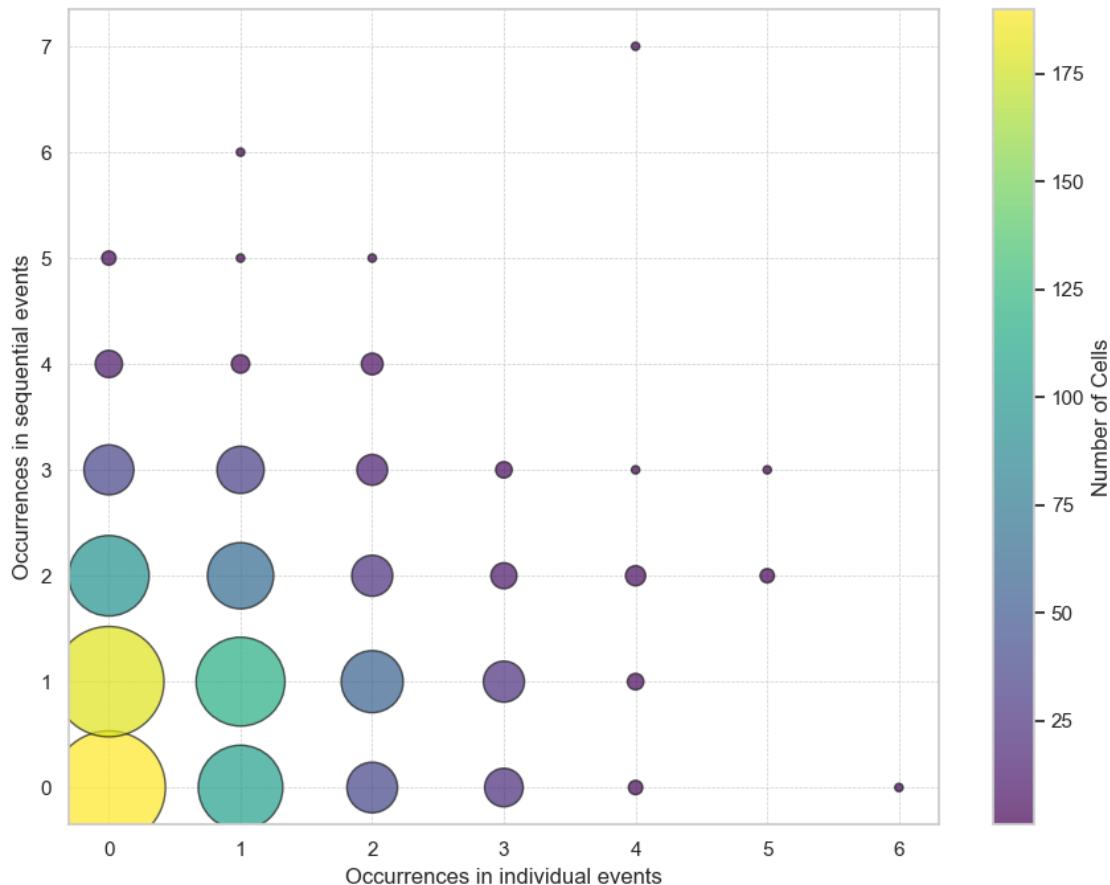
```
[2025-08-27 15:07:57] [INFO] calcium: plot_histogram: removed 12 outliers out of  
881 on 'Duration (s)' (lower=-30, upper=75)
```



```
[2025-08-27 15:07:57] [INFO] calcium: plot_histogram: removed 29 outliers out of  
881 on 'Prominence (noise std units)' (lower=-24.8, upper=74.6)
```



1.4.3 Correlation between event activity level & individual activity level



[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: removed 0/1068 outliers on 'Occurrences in sequential events' (lower=-6, upper=8)

[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=517 for Occurrences in individual events=0

[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=328 for Occurrences in individual events=1

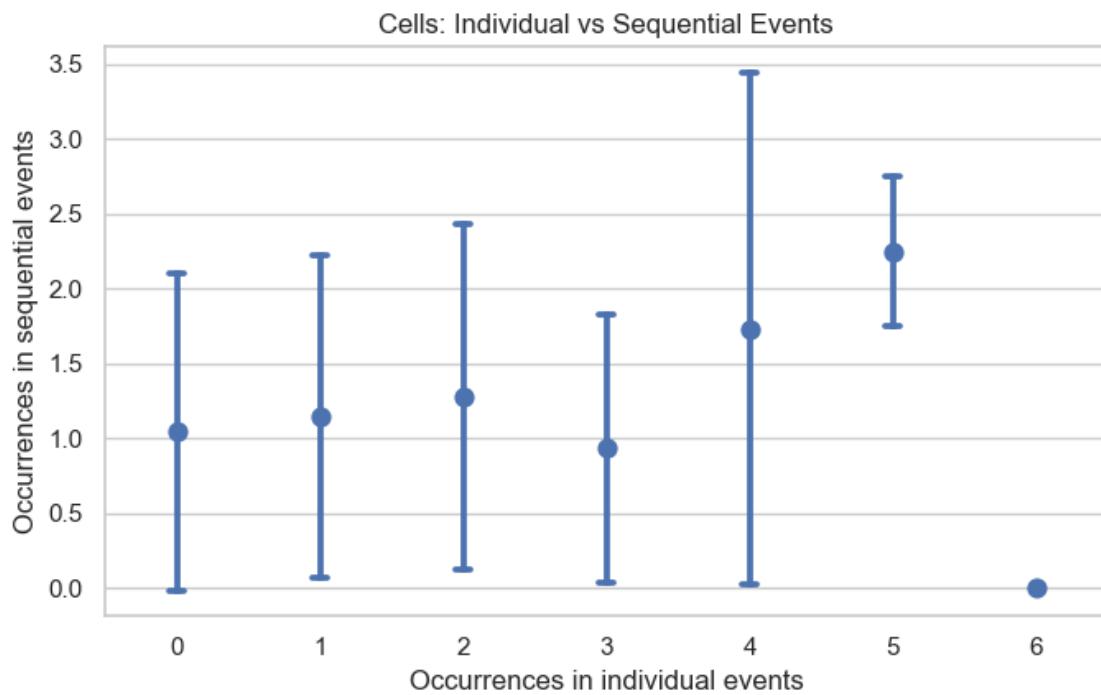
[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=142 for Occurrences in individual events=2

[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=61 for Occurrences in individual events=3

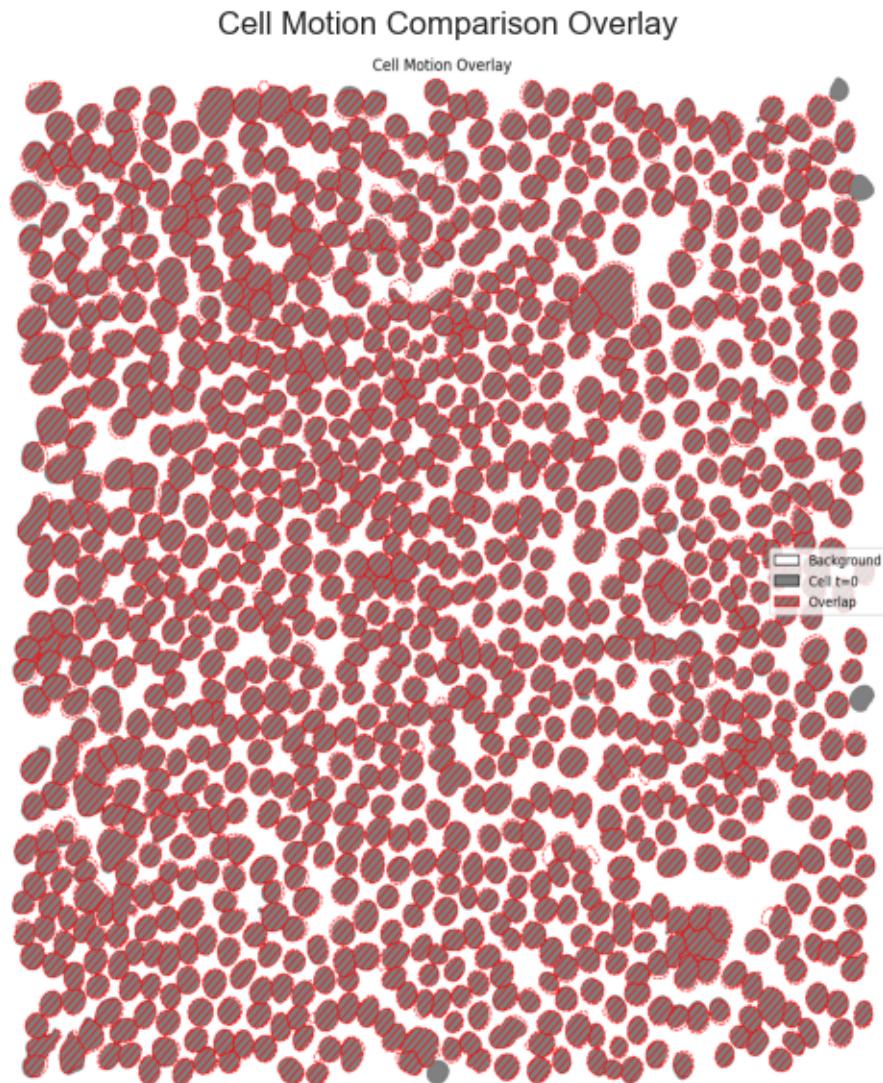
[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=15 for Occurrences in individual events=4

[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=4 for Occurrences in individual events=5

[2025-08-27 15:07:58] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1068
- Hoechst image taken at t=1801: 1057
- Number of cells difference: absolute 11, relative 1.03%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1325895
- Pixels segmented as cell at t=1801: 1354825
- Overlapping pixels between t=0 and t=1801: 1262081 (94.16% of total)
- Pixels exclusive to t=0: 63814 (4.81% of total)
- Pixels exclusive to t=1801: 92744 (6.84% of total)

executed

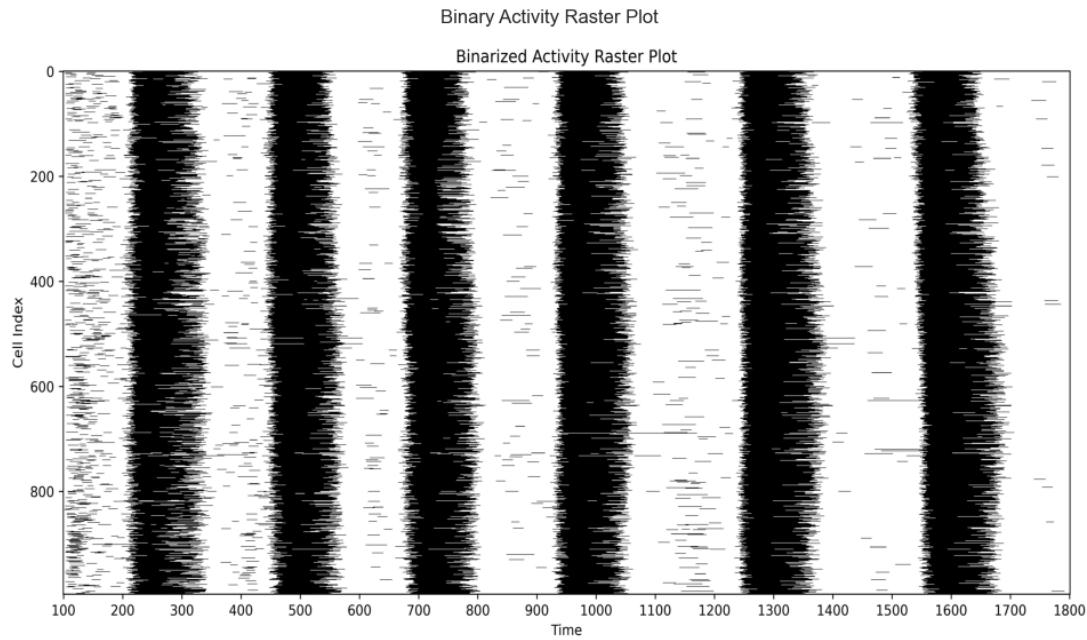
August 27, 2025

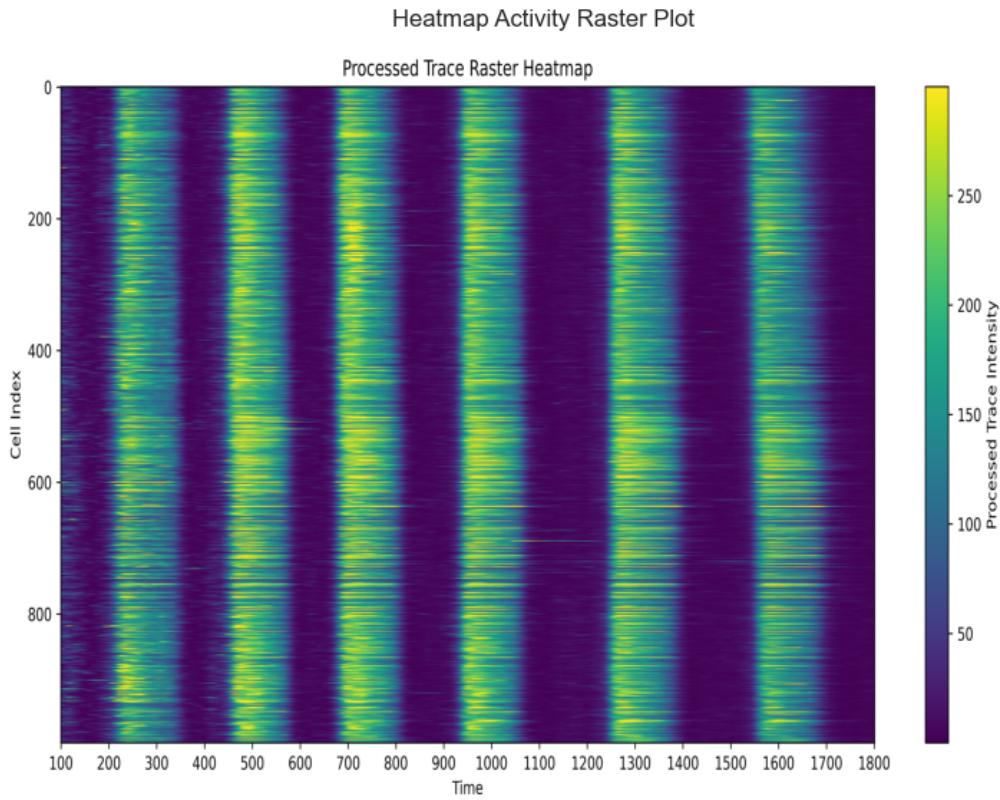
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





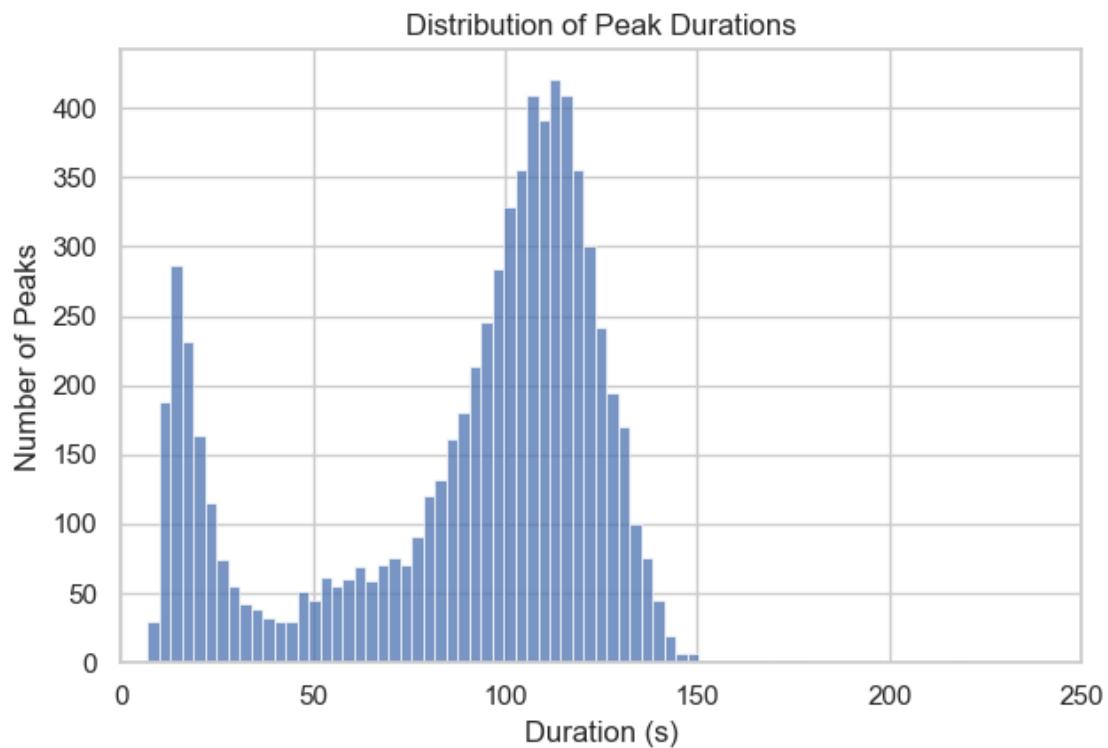
1.1.2 Peaks population

Total number of peaks: 7200

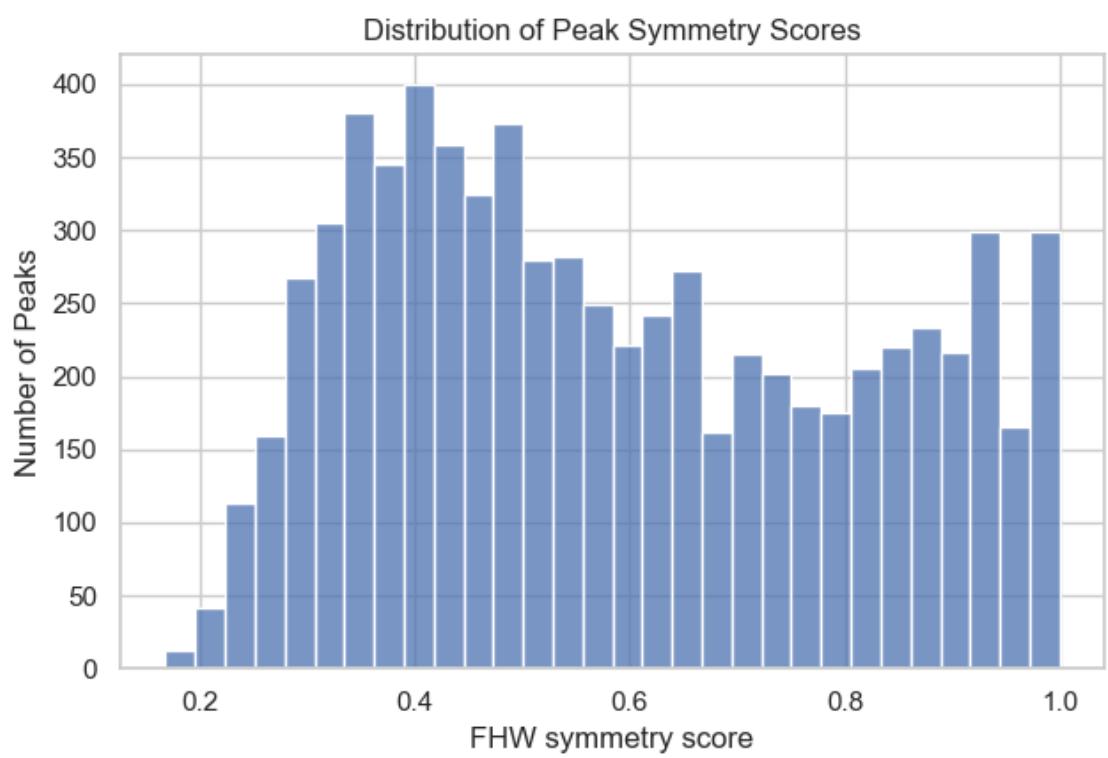
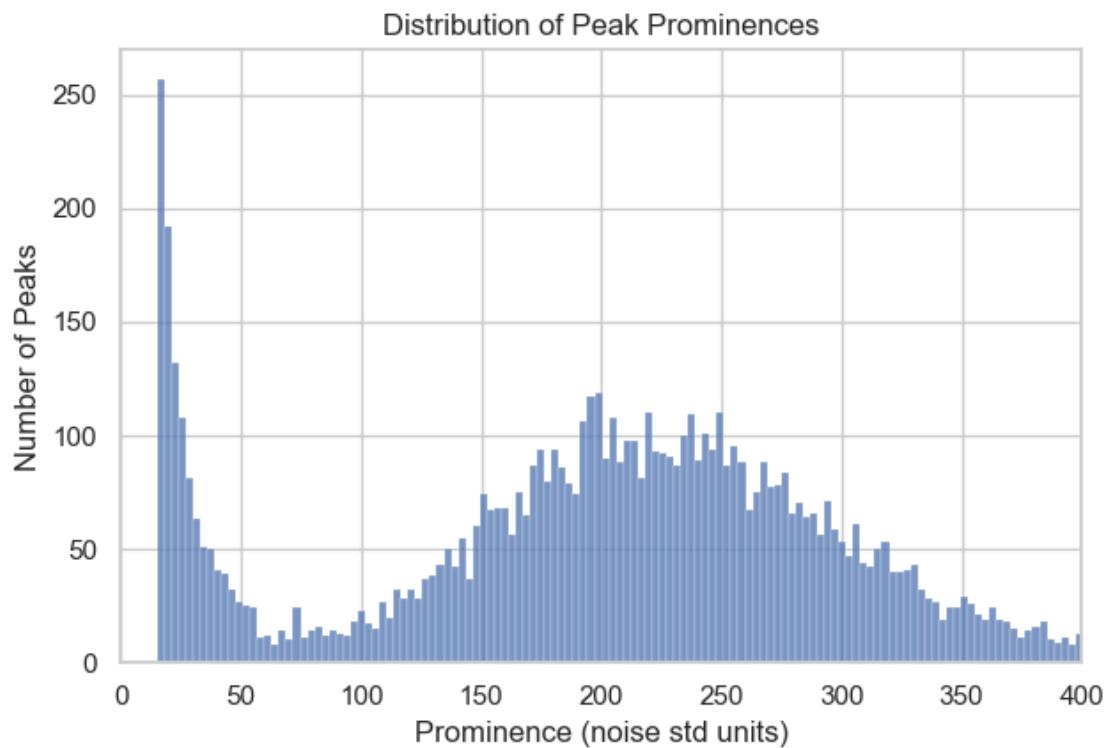
Total number of cells: 996

1.1.3 Peaks statistics

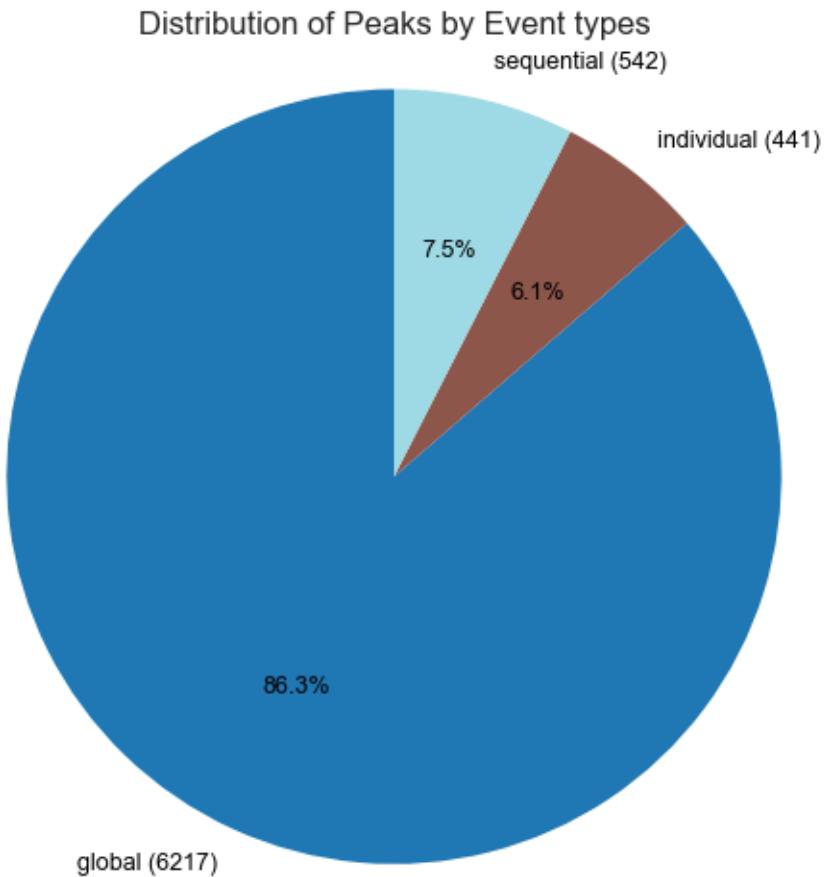
```
[2025-08-27 15:08:23] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7200 on 'Duration (s)' (lower=-65, upper=250)
```



```
[2025-08-27 15:08:24] [INFO] calcium: plot_histogram: removed 3 outliers out of  
7200 on 'Prominence (noise std units)' (lower=-228.2, upper=639.1)
```

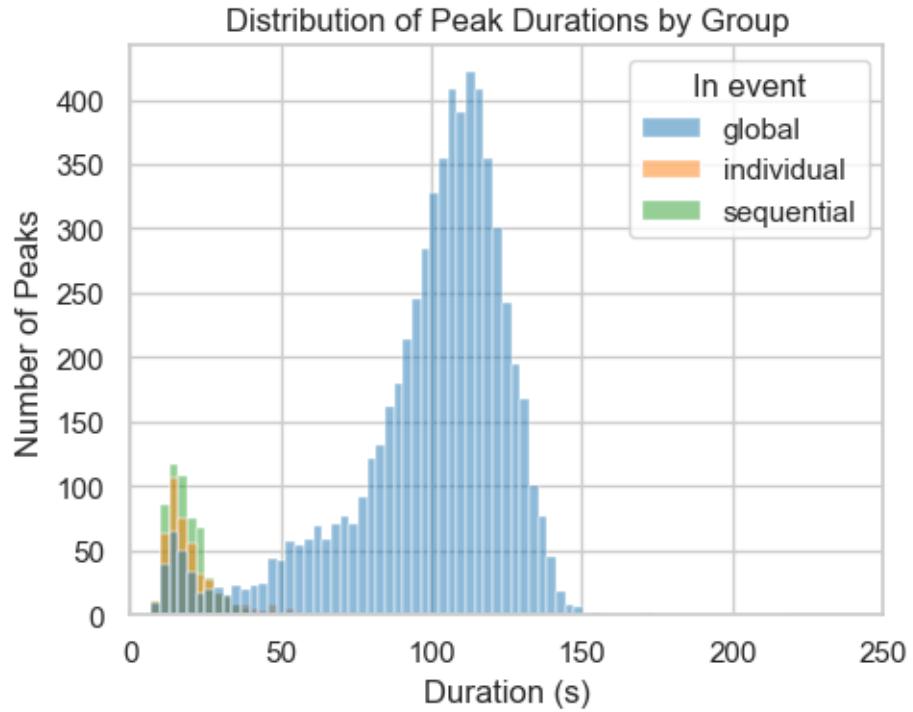


1.1.4 Distribution of peaks per event types

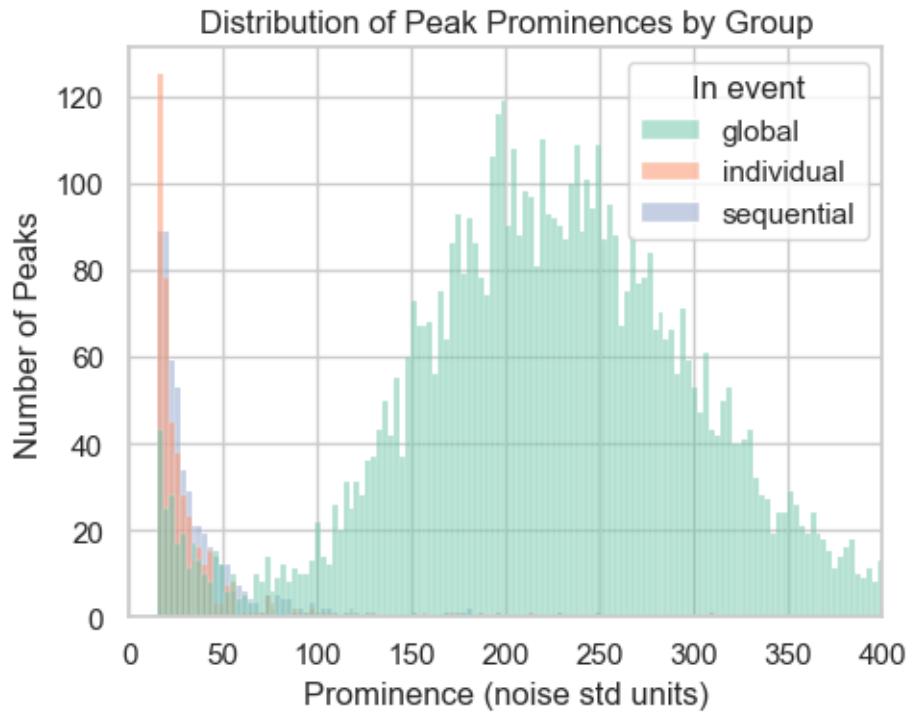


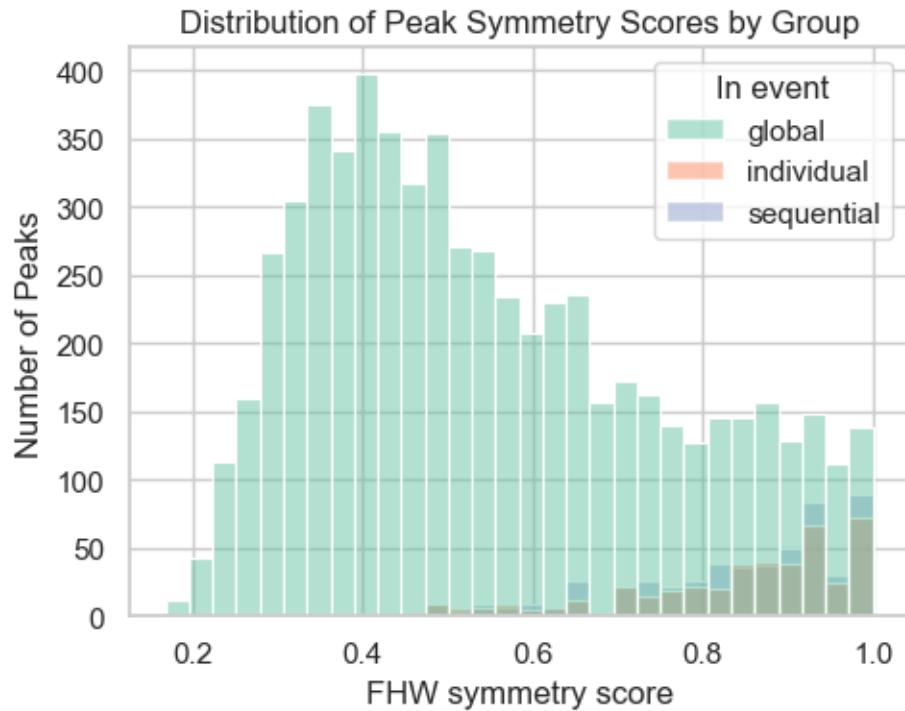
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:08:24] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7200 on 'Duration (s)' (lower=-65, upper=250)
```



```
[2025-08-27 15:08:24] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 7200 on 'Prominence (noise std units)' (lower=-228.2, upper=639.1)
```

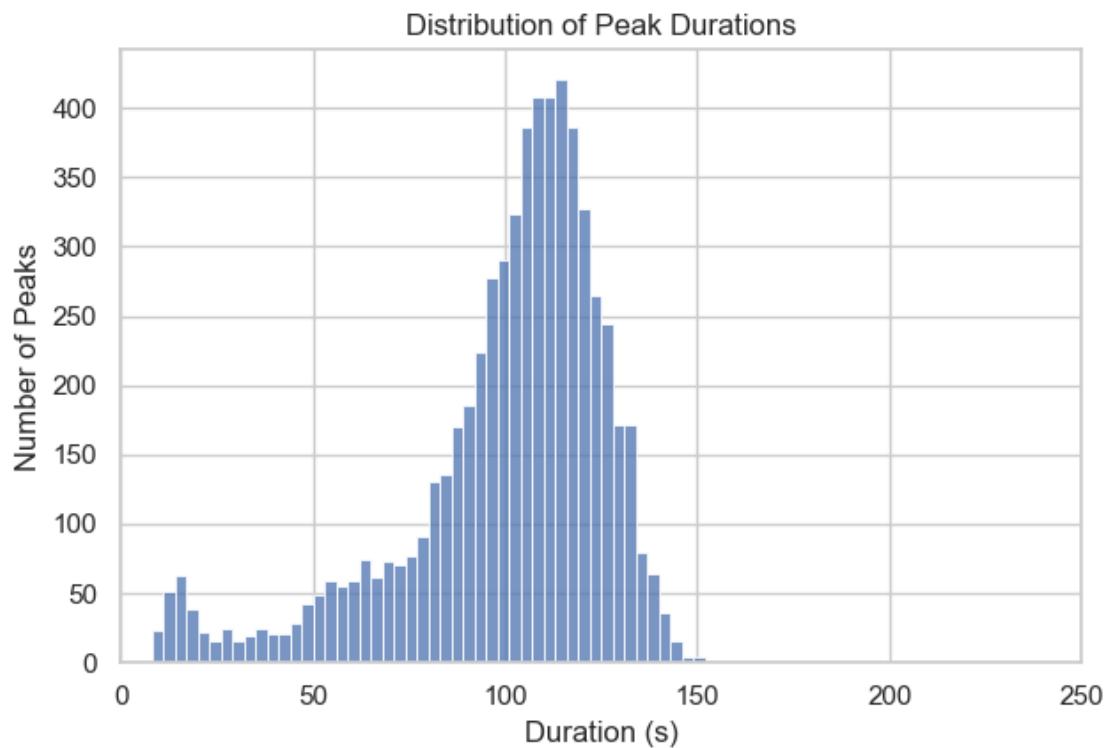




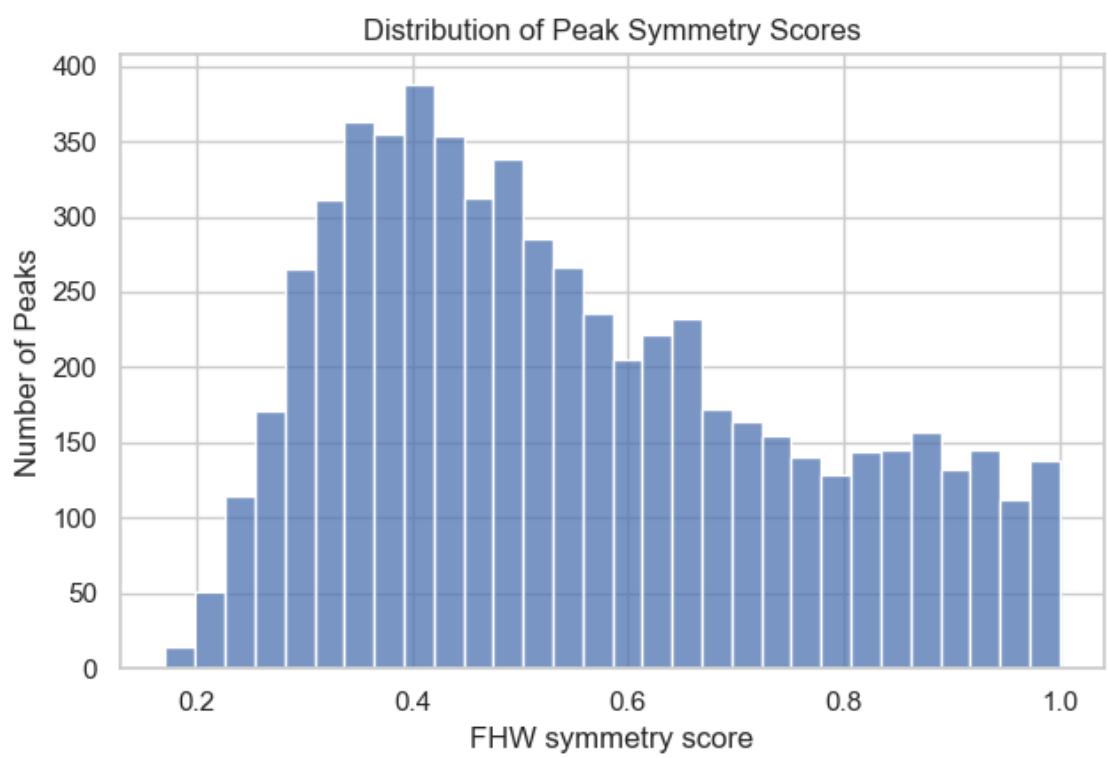
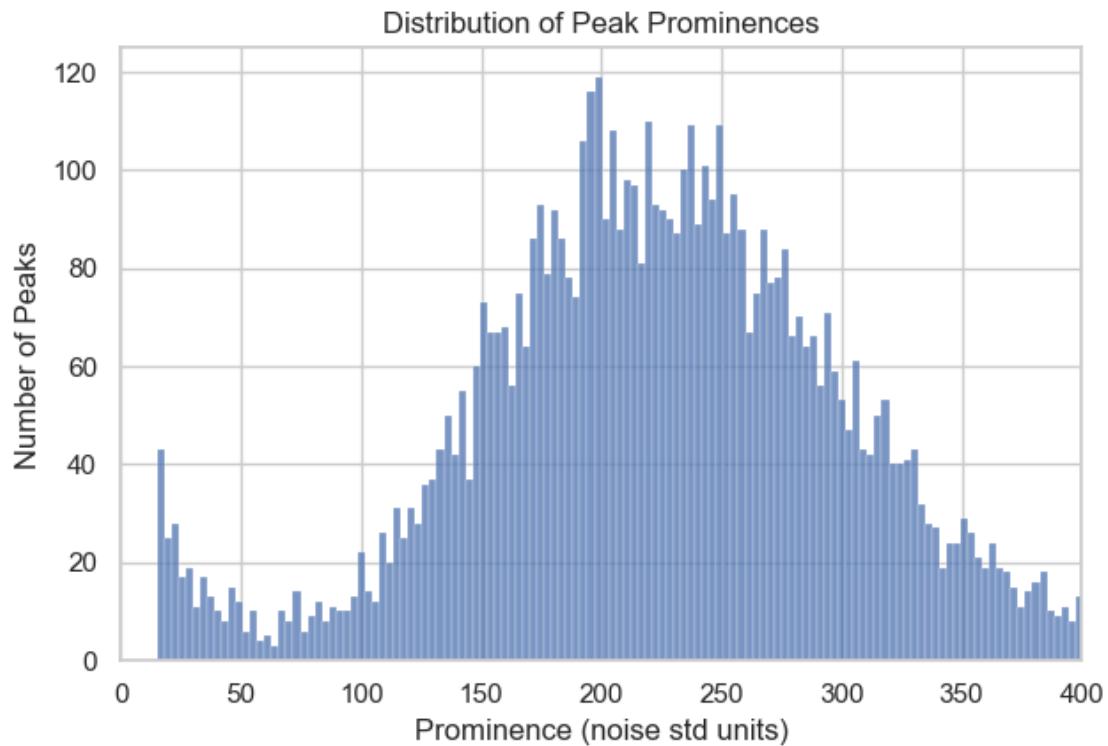
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:08:25] [INFO] calcium: plot_histogram: removed 1 outliers out of  
6217 on 'Duration (s)' (lower=5, upper=201)
```

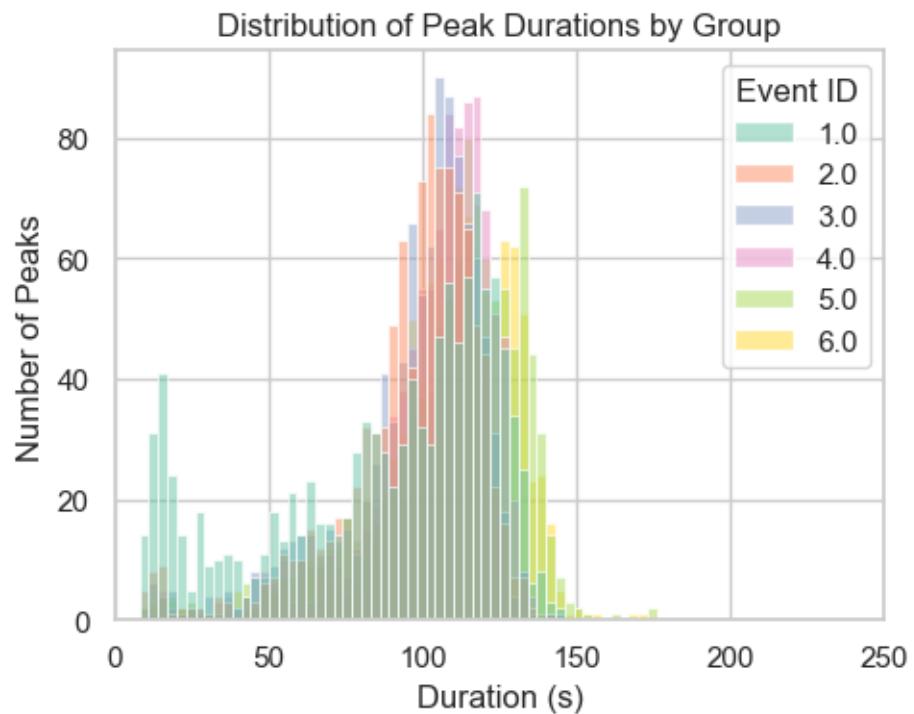


```
[2025-08-27 15:08:25] [INFO] calcium: plot_histogram: removed 3 outliers out of  
6217 on 'Prominence (noise std units)' (lower=-126.6, upper=579)
```

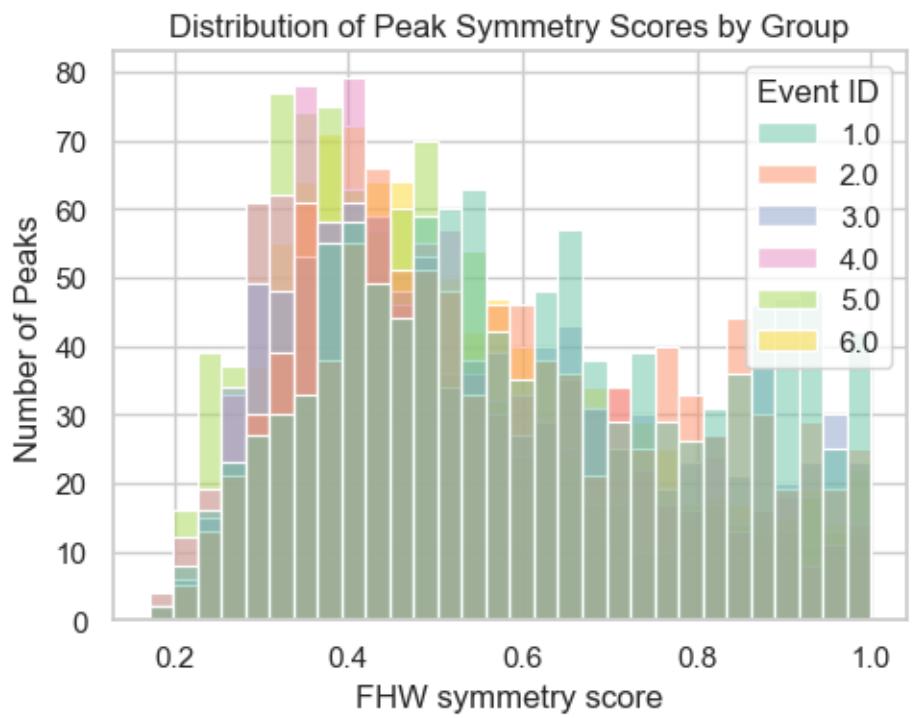
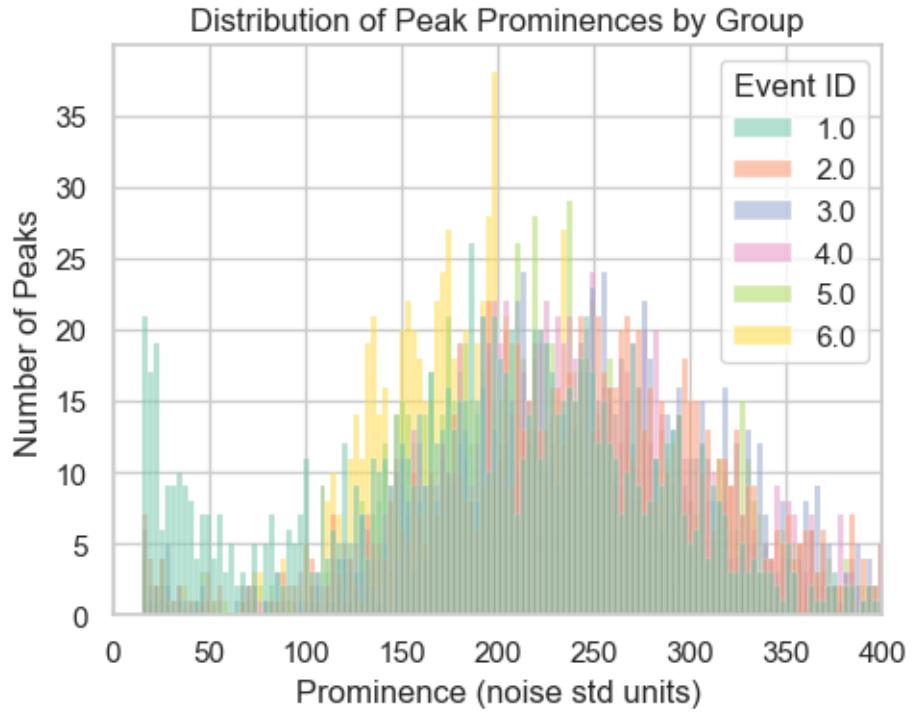


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:08:26] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 6217 on 'Duration (s)' (lower=5, upper=201)

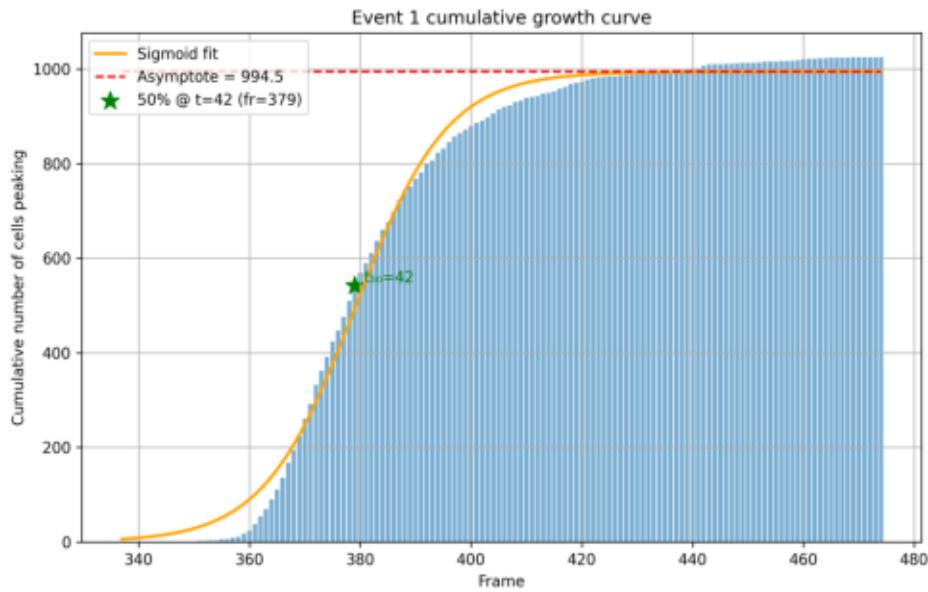


[2025-08-27 15:08:26] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 6217 on 'Prominence (noise std units)' (lower=-126.6, upper=579)

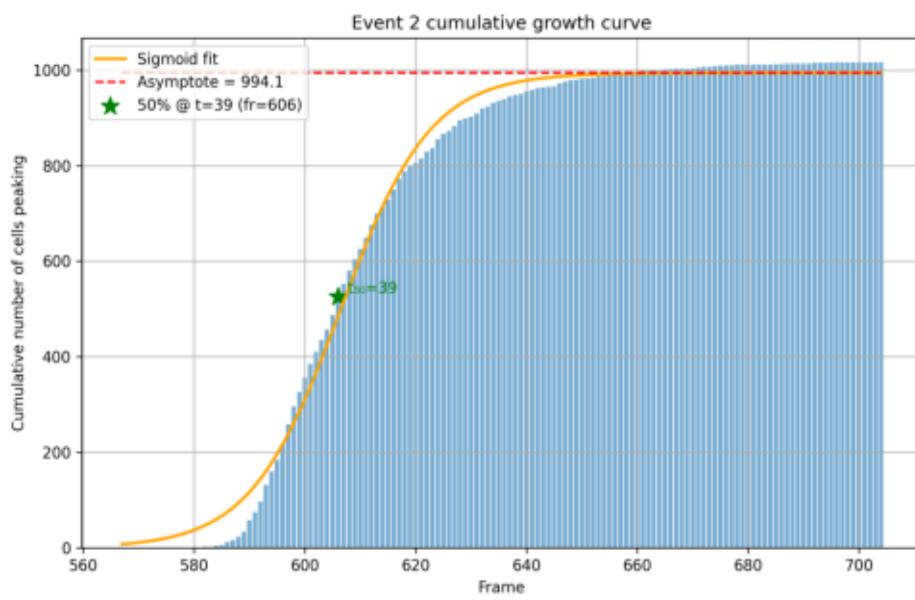


1.2.3 Kinetics of global events

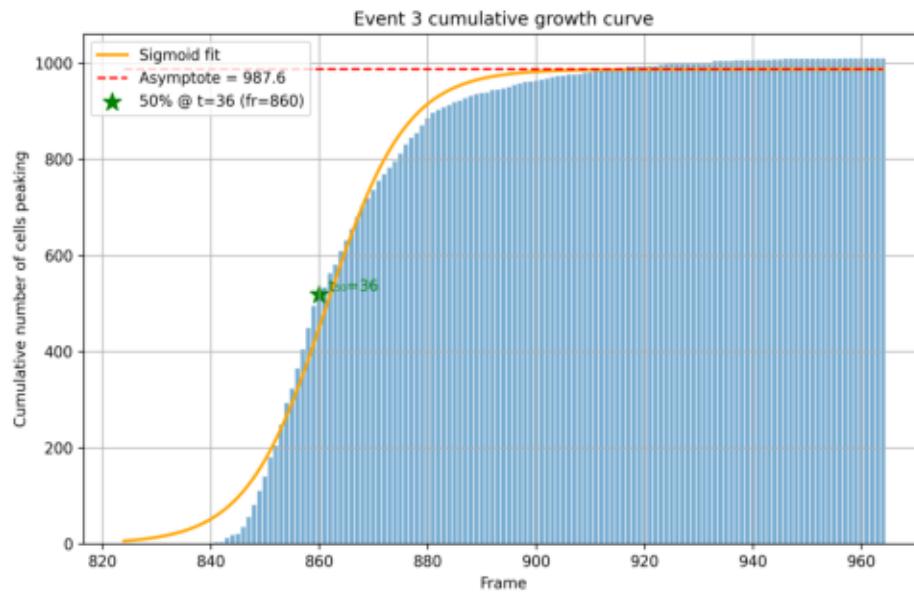
Event Activity Overlay (Event ID: 1)



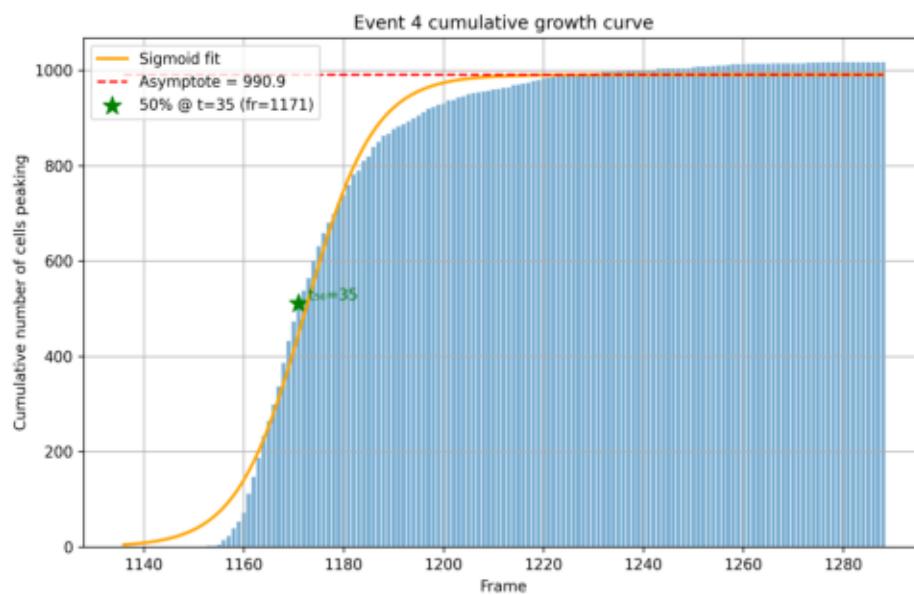
Event Activity Overlay (Event ID: 2)



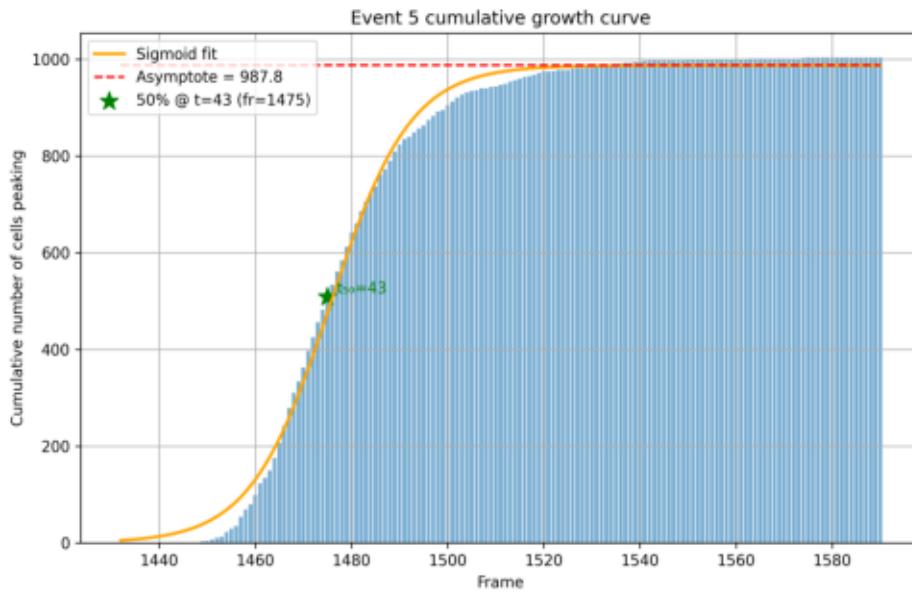
Event Activity Overlay (Event ID: 3)



Event Activity Overlay (Event ID: 4)

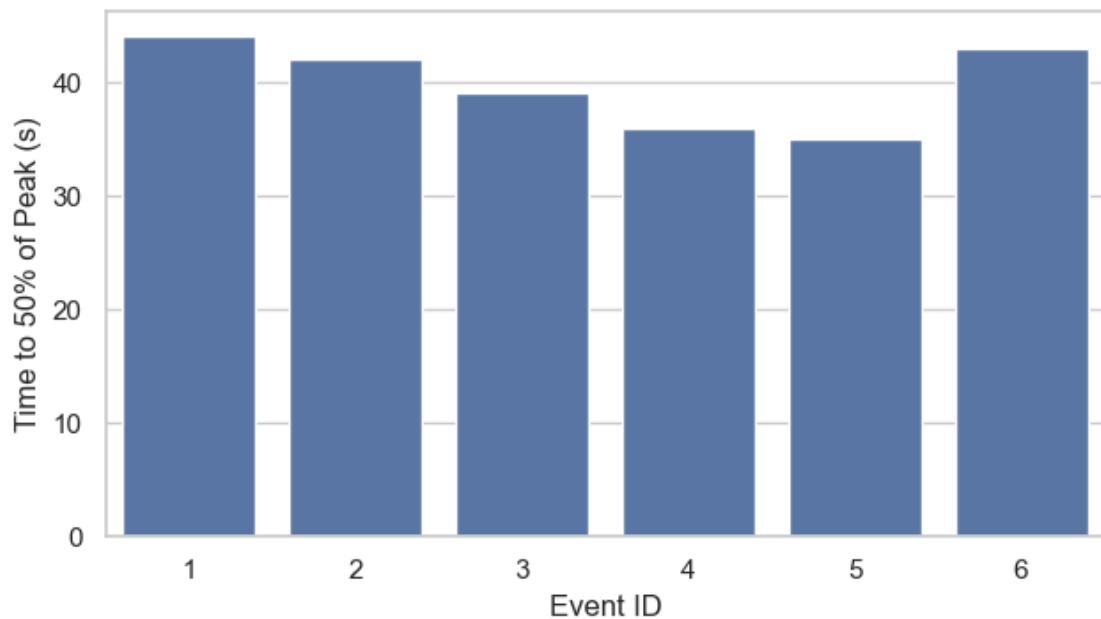


Event Activity Overlay (Event ID: 5)

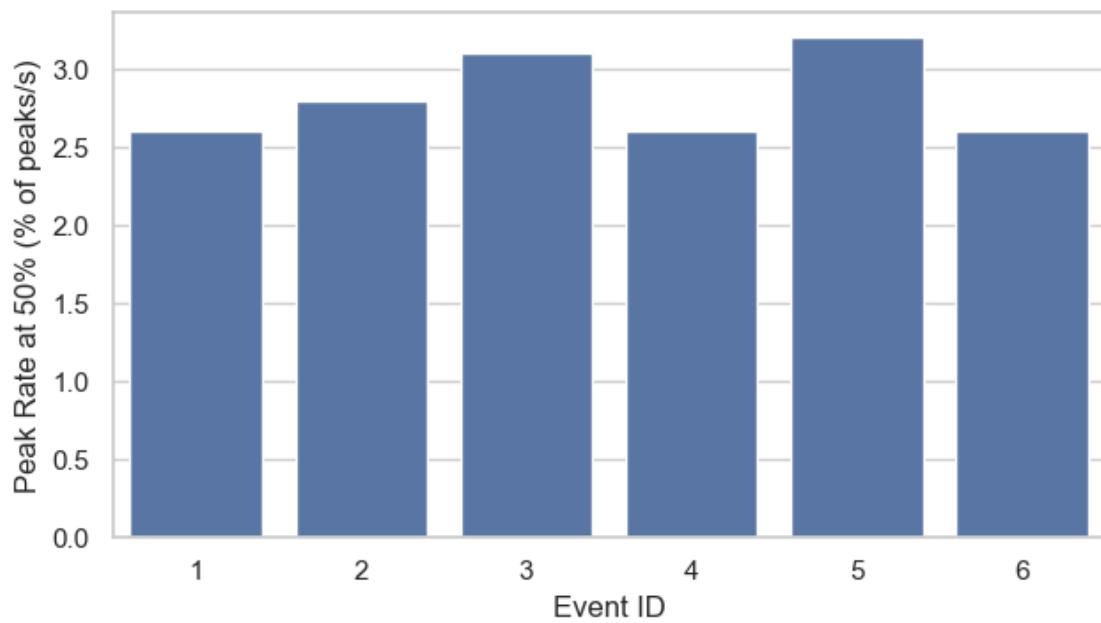


```
[2025-08-27 15:08:30] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\events\event-growth-curve-6.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250624\Output\IS06\events\event-
growth-curve-6.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250624\Output\IS06\events\event-growth-curve-6.png'
```

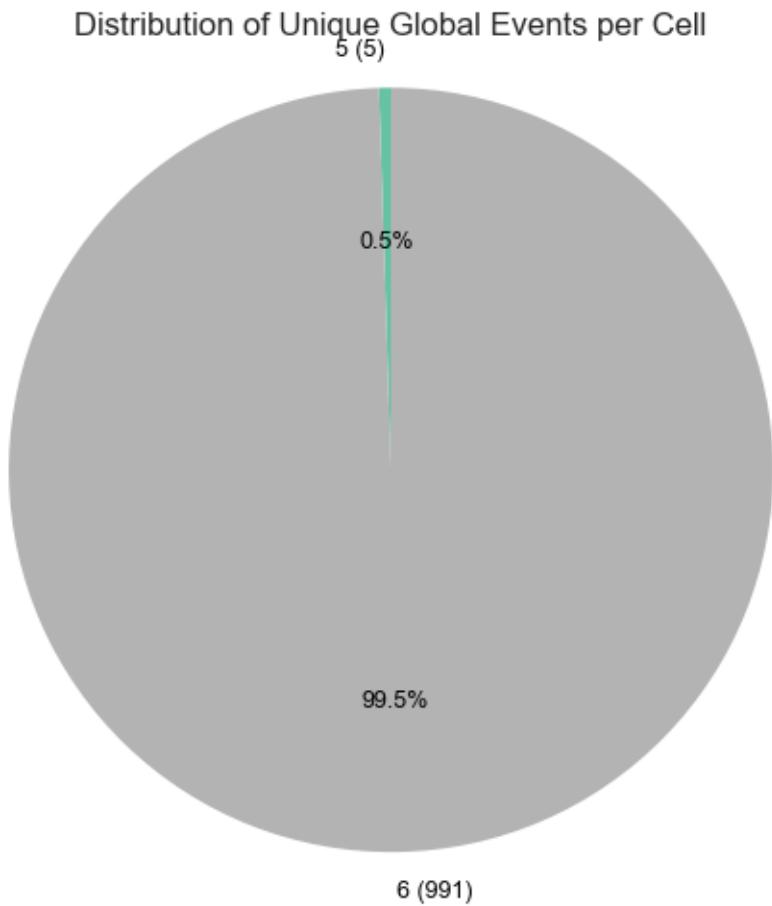
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

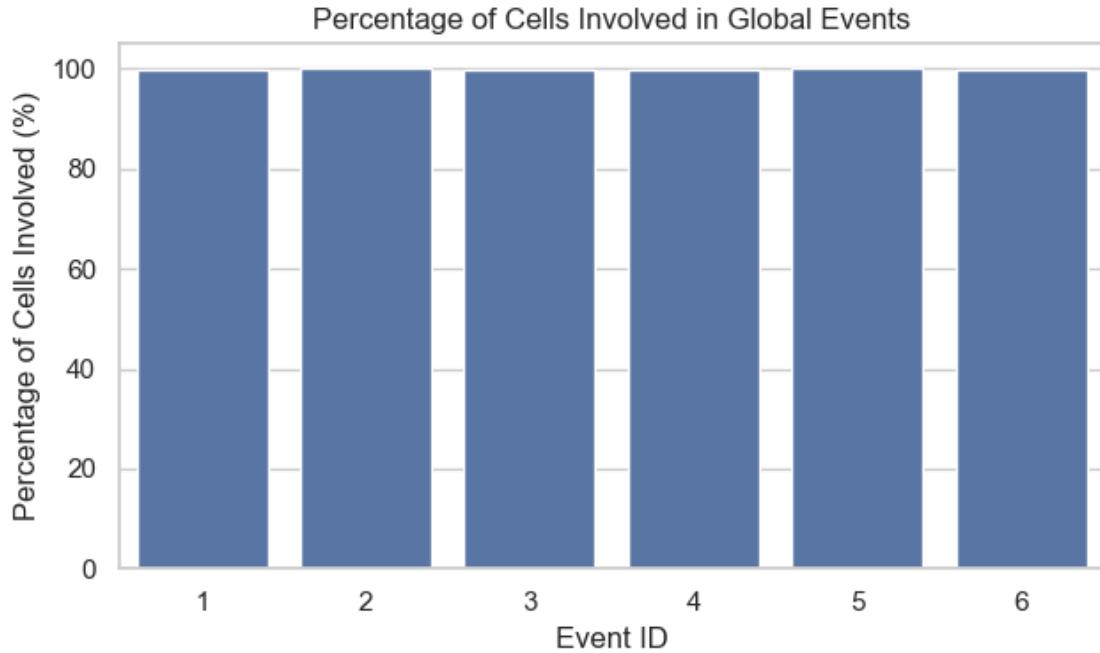


```
[2025-08-27 15:08:30] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250624\\\\Output\\\\IS06\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250624\Output\IS06\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [242.0, 227.0, 253.0, 312.0, 303.0]
Estimated periodicity: 0.888
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.004 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-

```

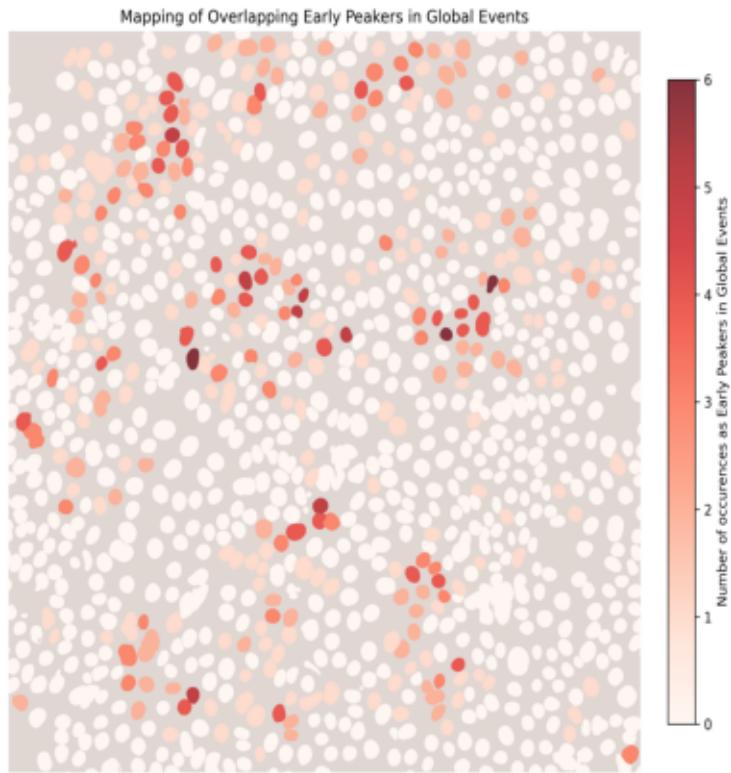
```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

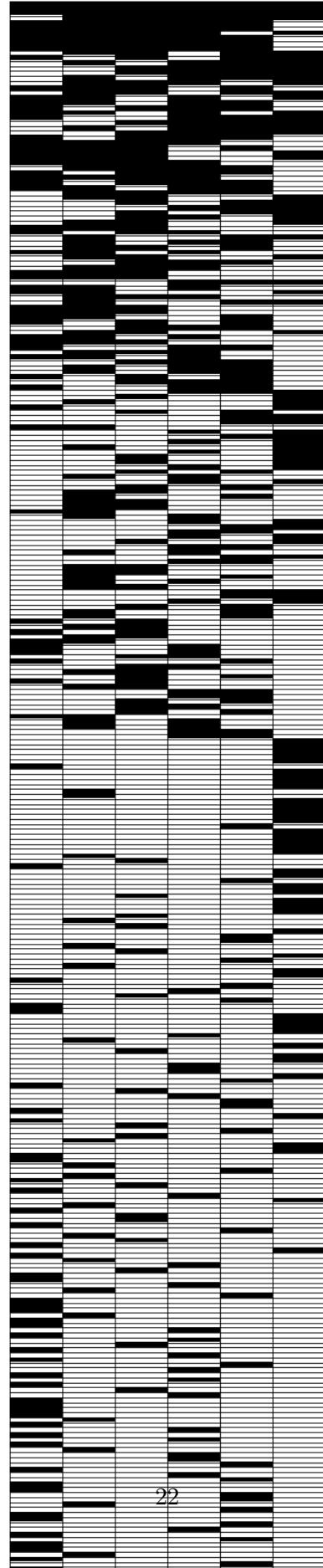
```
[2025-08-27 15:08:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\global_events\global_event_6_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



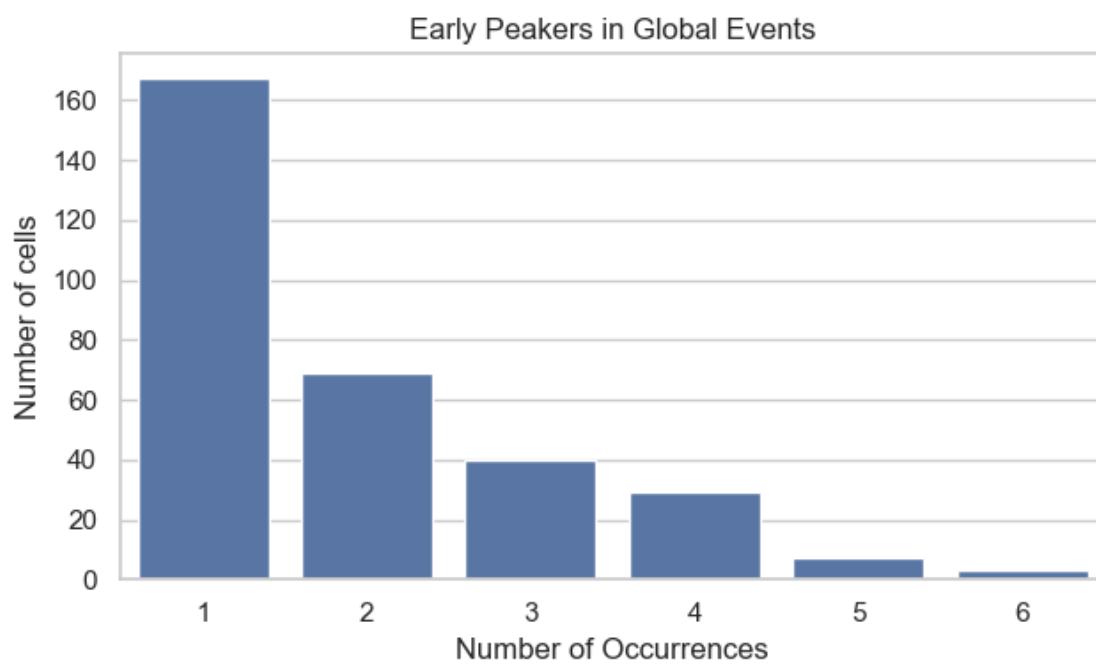
[2025-08-27 15:08:32] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 6 unique event IDs.

[2025-08-27 15:08:32] [INFO] calcium: Early peakers event-matrix: 315 cells x 6 events; black squares: 594

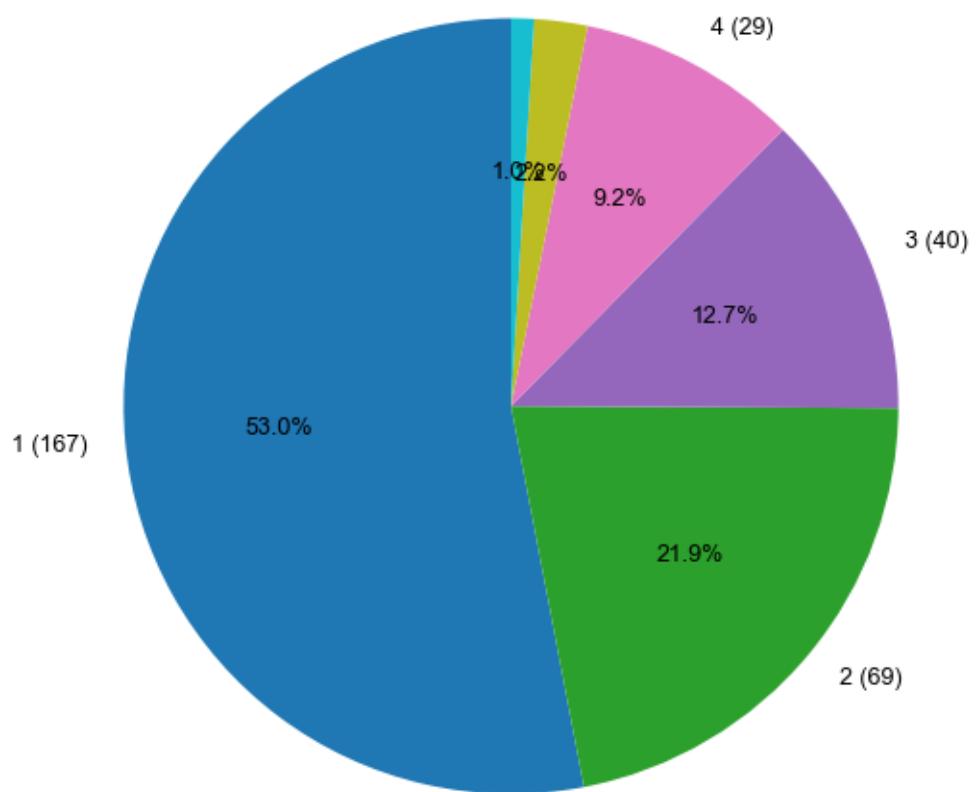


```
[2025-08-27 15:08:32] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 1, 1, 1, 1],  
           [1, 1, 1, 1, 1, 1],  
           [1, 1, 1, 1, 1, 1],  
           ...,  
           [1, 0, 0, 0, 0, 0],  
           [0, 0, 0, 0, 1, 0],  
           [1, 0, 0, 0, 0, 0]])
```



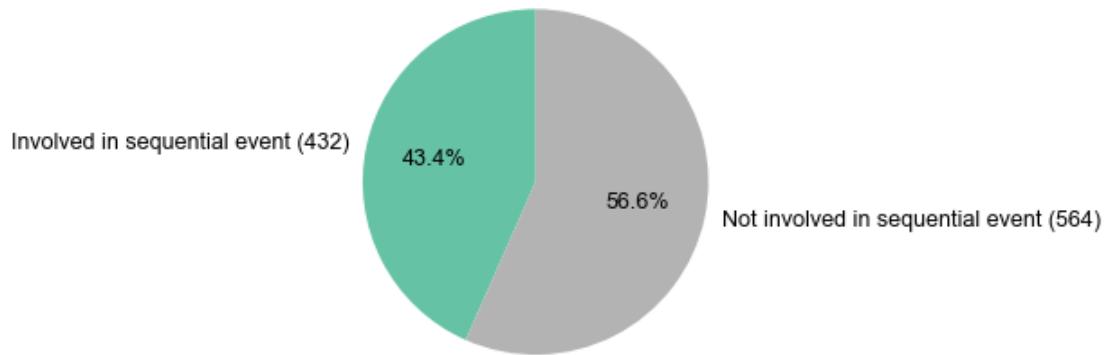
Distribution of Early Peakers in Global Events
6 (35%)



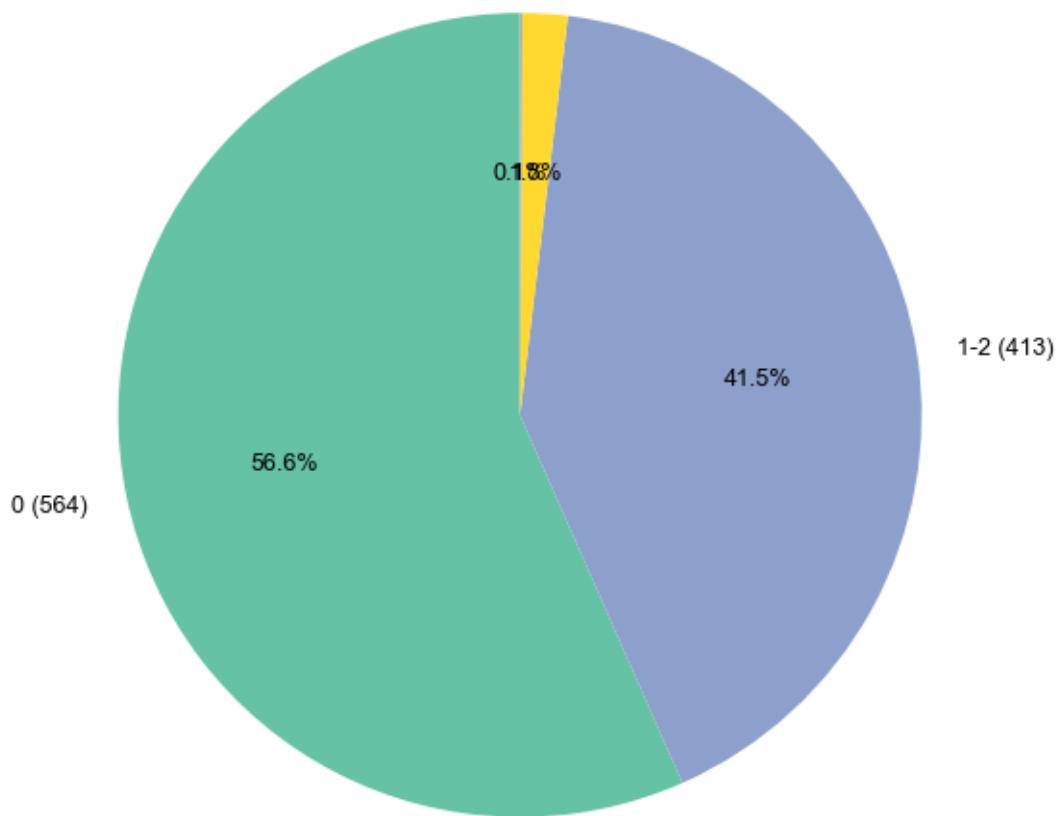
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

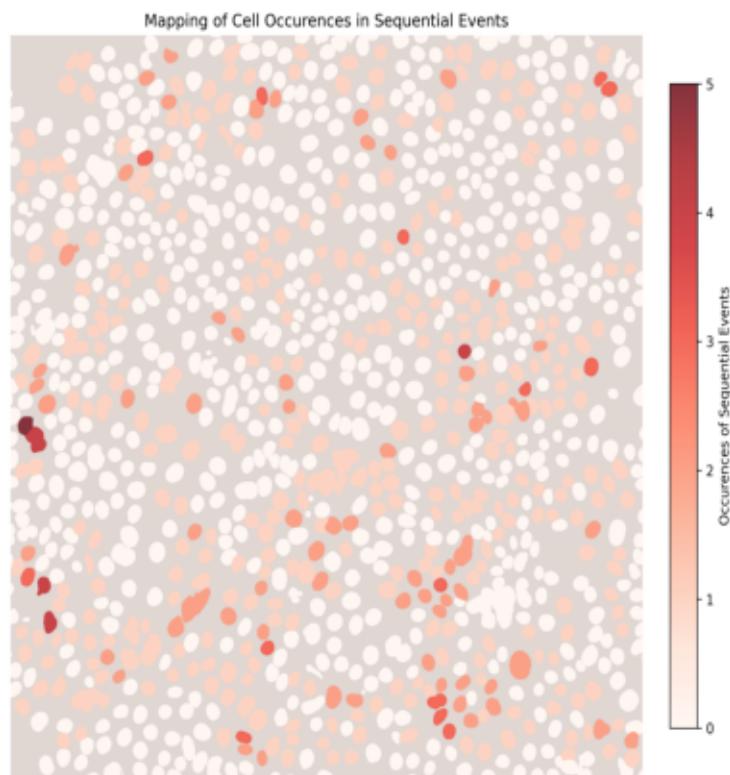
Distribution of Cells Involved in Sequential Events



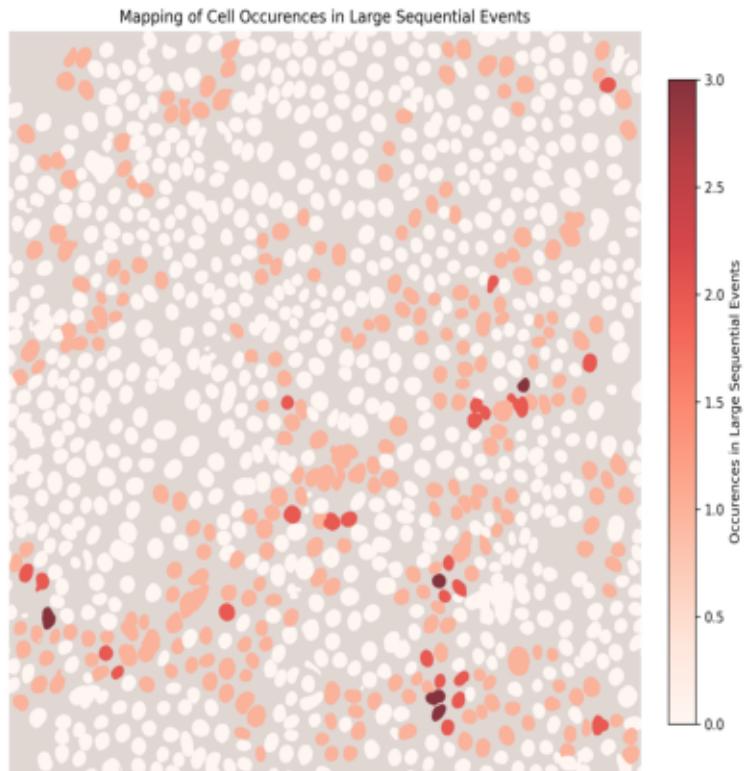
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

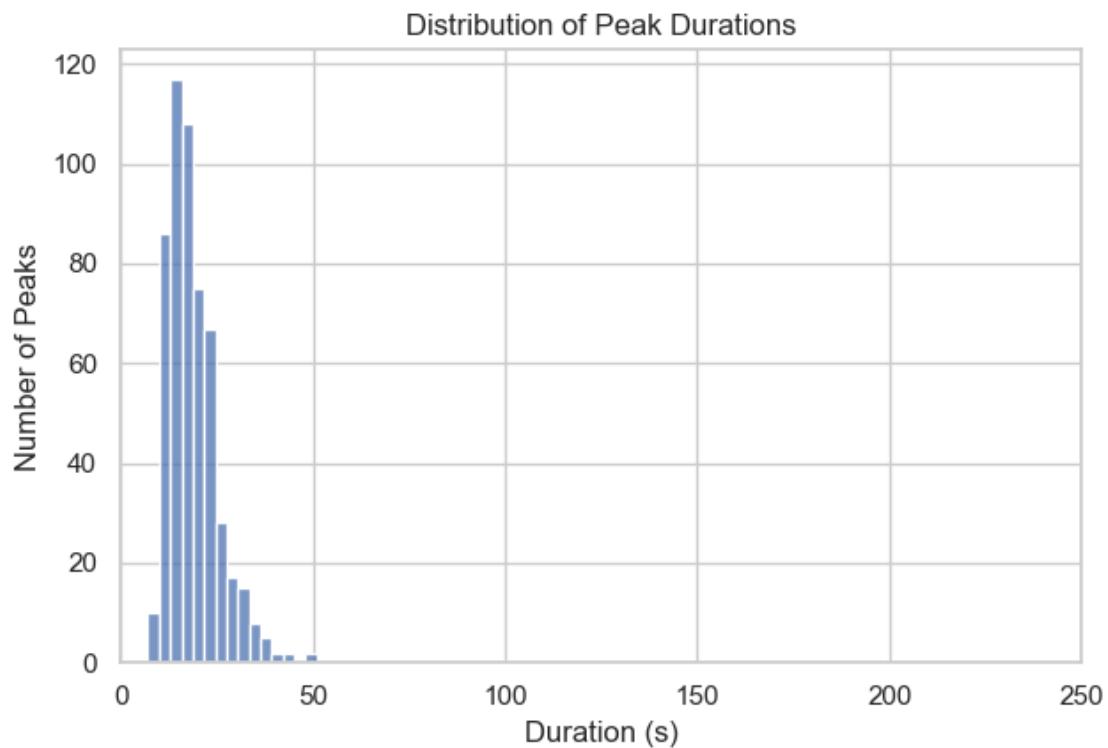


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



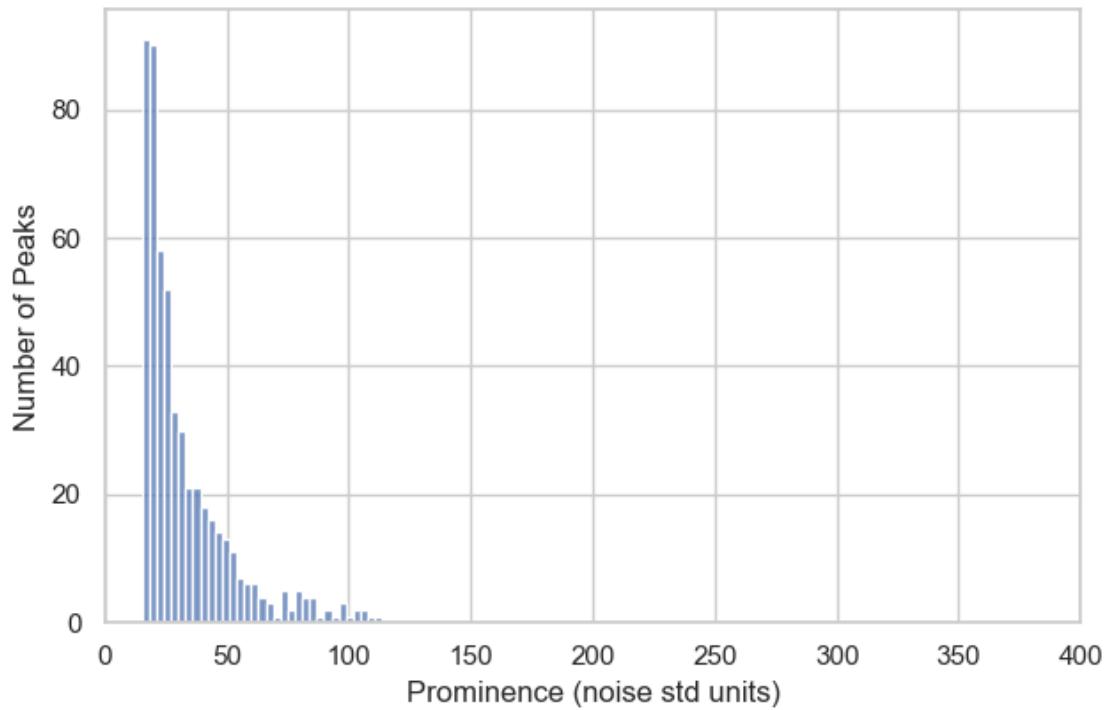
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:08:35] [INFO] calcium: plot_histogram: removed 0 outliers out of 542 on 'Duration (s)' (lower=-0.5, upper=53.5)
```

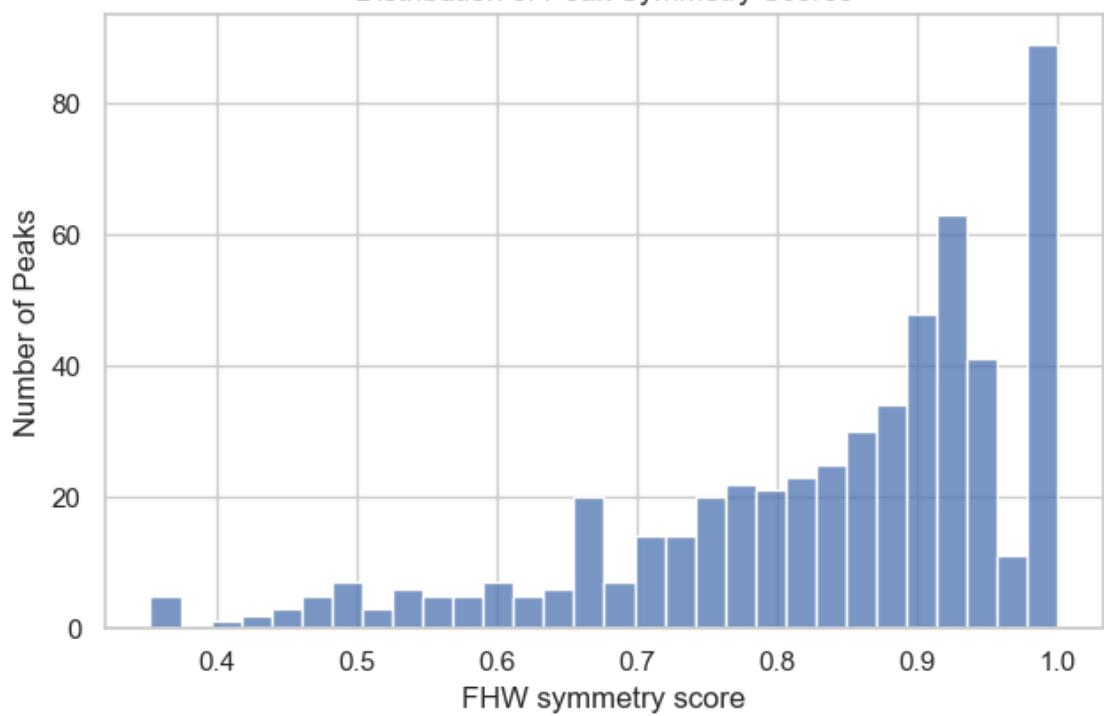


```
[2025-08-27 15:08:35] [INFO] calcium: plot_histogram: removed 13 outliers out of 542 on 'Prominence (noise std units)' (lower=-12.338, upper=114.71)
```

Distribution of Peak Prominences

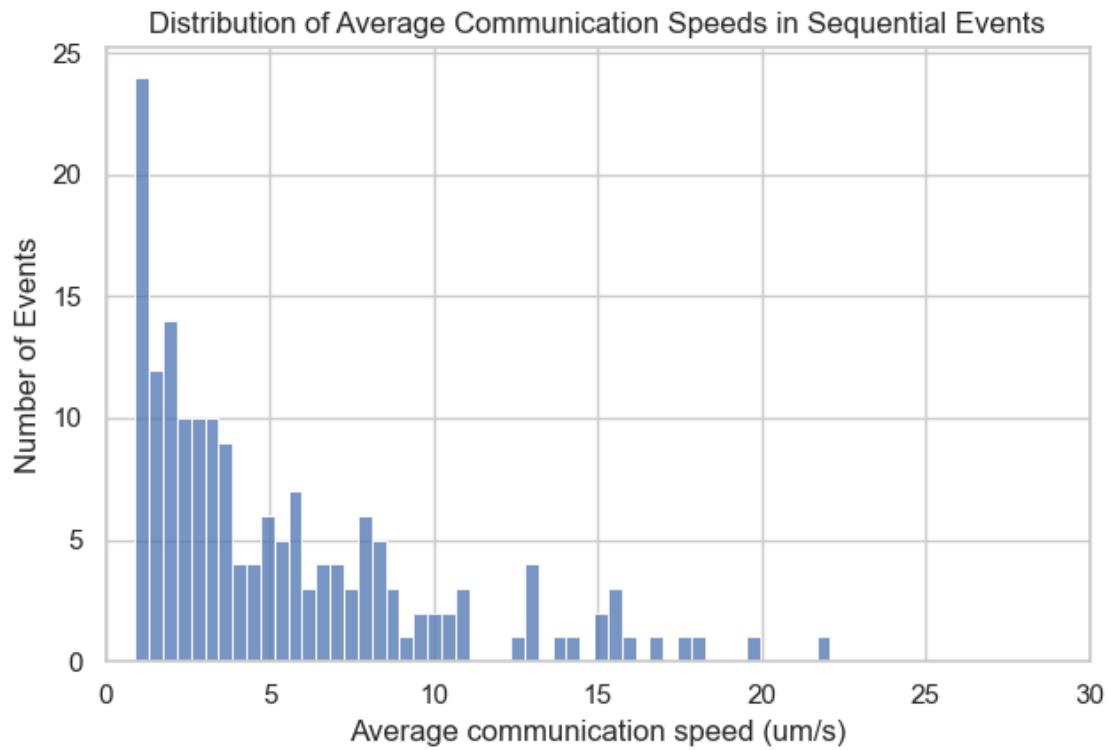


Distribution of Peak Symmetry Scores



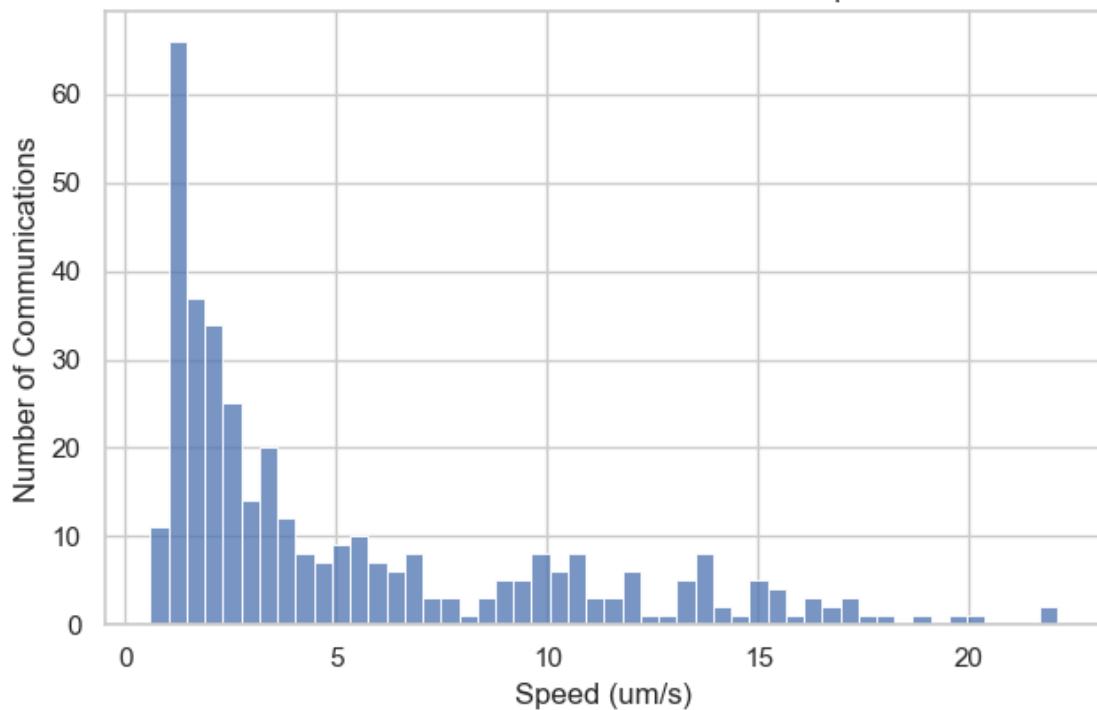
1.3.3 Cell-cell communication speed

[2025-08-27 15:08:35] [INFO] calcium: plot_histogram: removed 0 outliers out of 171 on 'Average communication speed (um/s)' (lower=-15.015, upper=24.605)

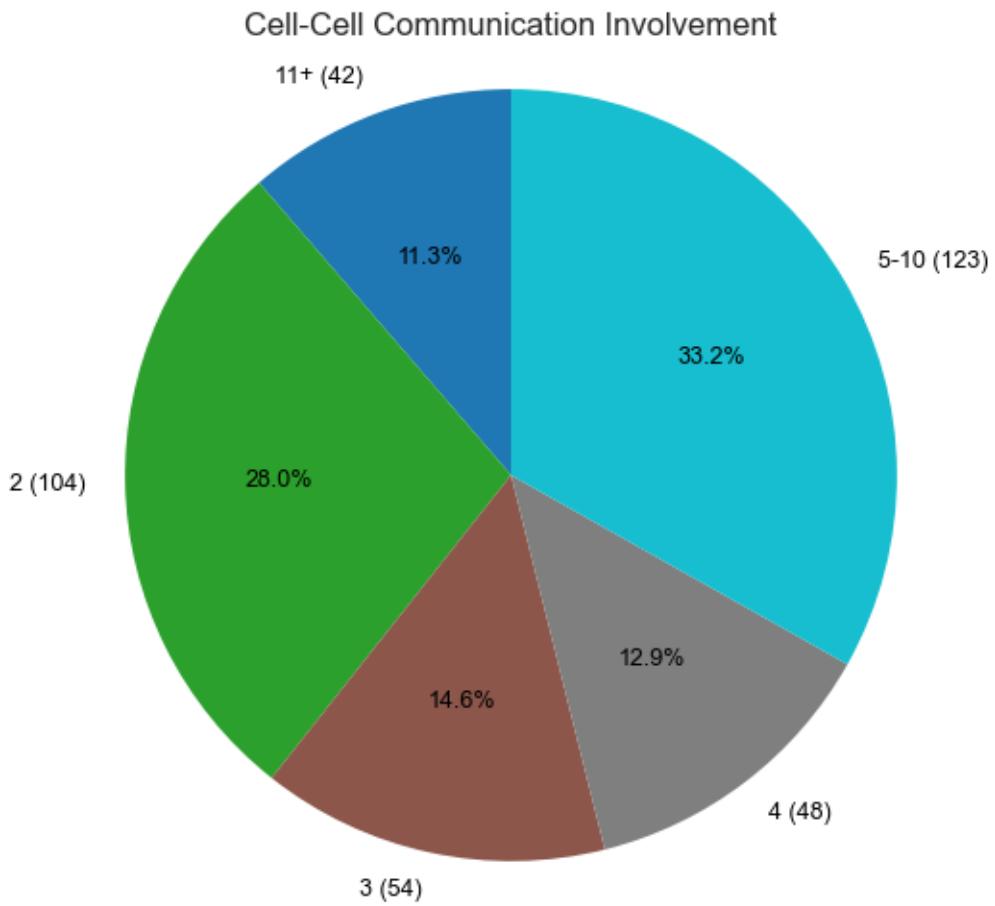


[2025-08-27 15:08:36] [INFO] calcium: plot_histogram: removed 0 outliers out of 371 on 'Speed (um/s)' (lower=-16.335, upper=37.62)

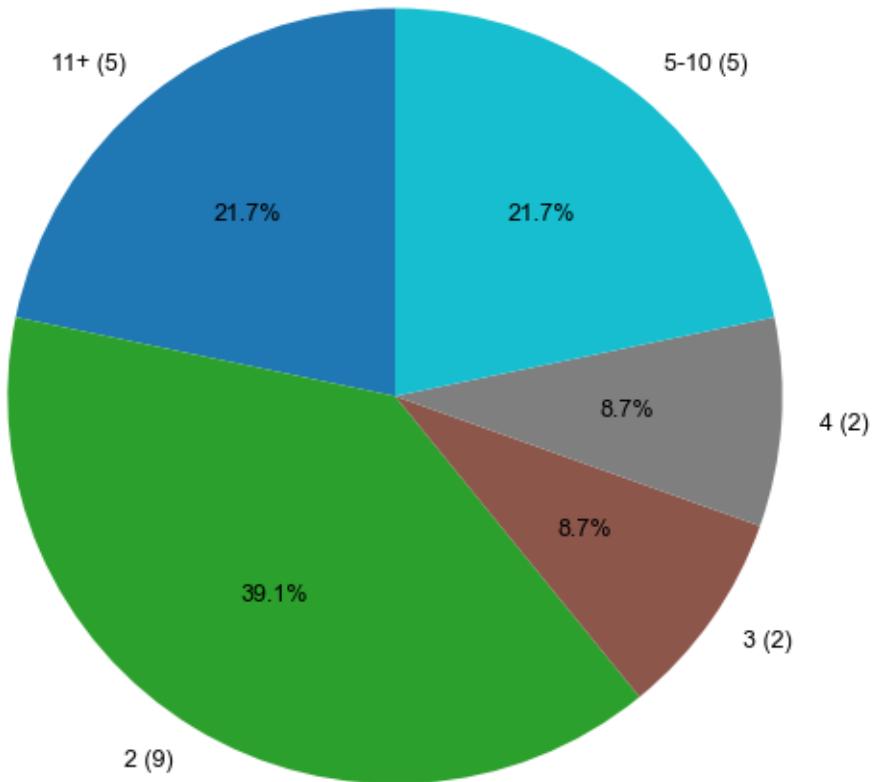
Distribution of Cell-Cell Communication Speeds



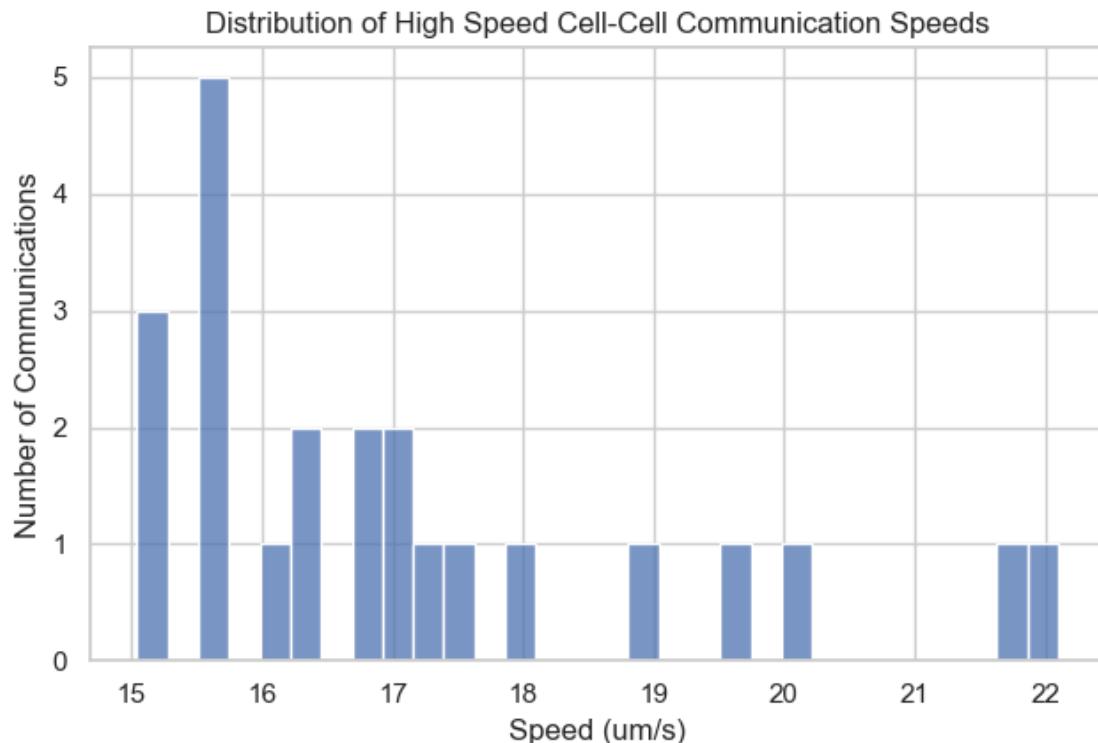
1.3.4 Double distribution in cell-cell communication speeds



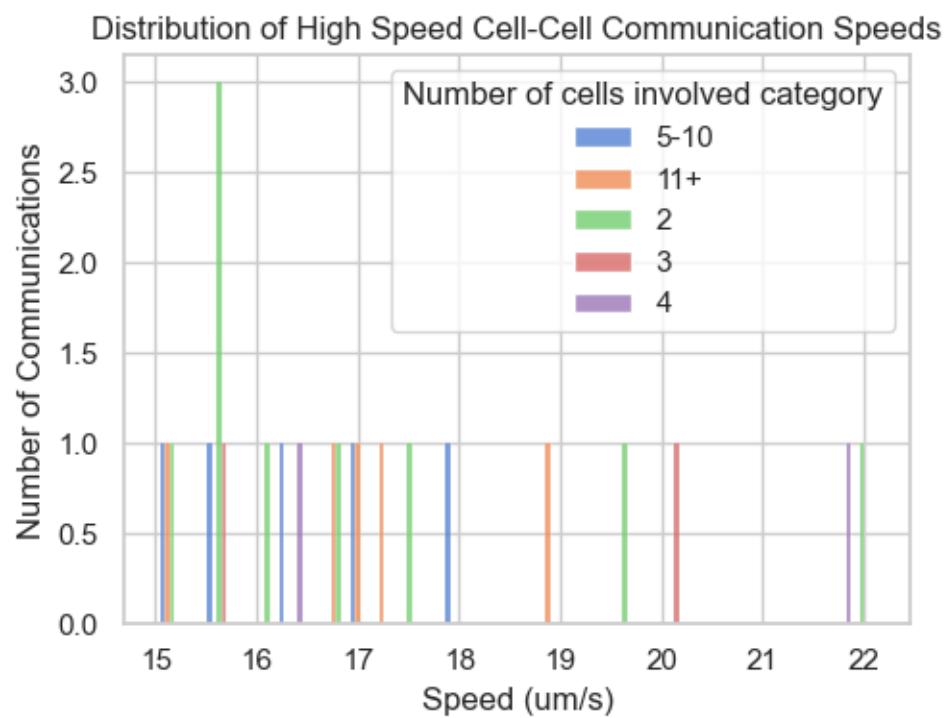
High Speed Cell-Cell Communication Involvement



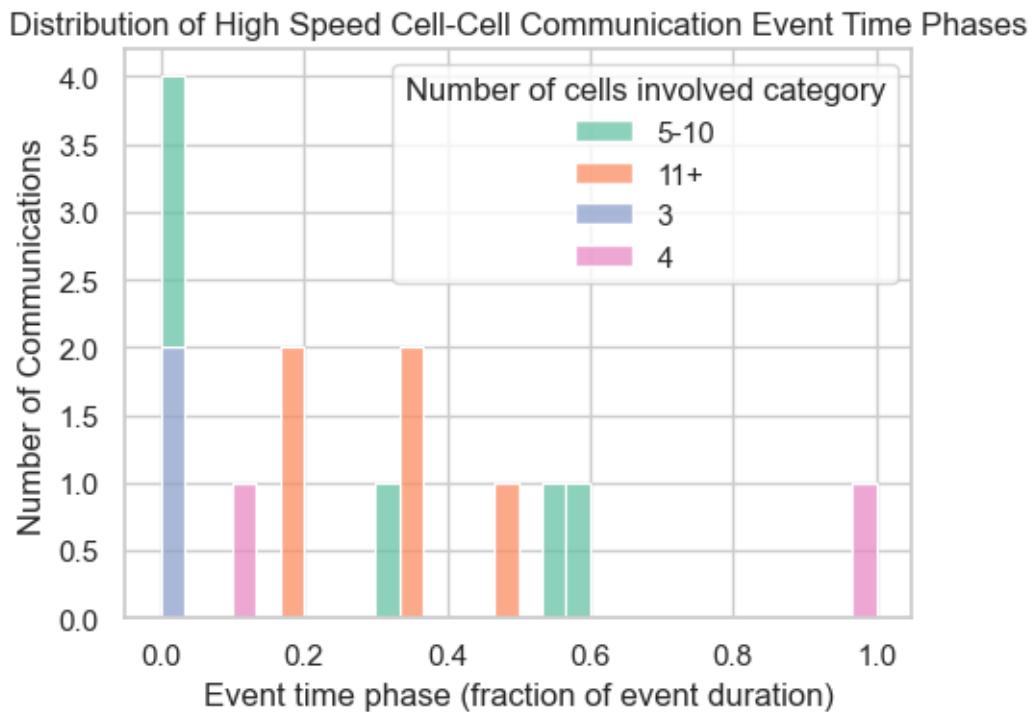
[2025-08-27 15:08:36] [INFO] calcium: plot_histogram: removed 0 outliers out of 23 on 'Speed (um/s)' (lower=9.29, upper=24.095)



```
[2025-08-27 15:08:36] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 23 on 'Speed (um/s)' (lower=9.29, upper=24.095)
```

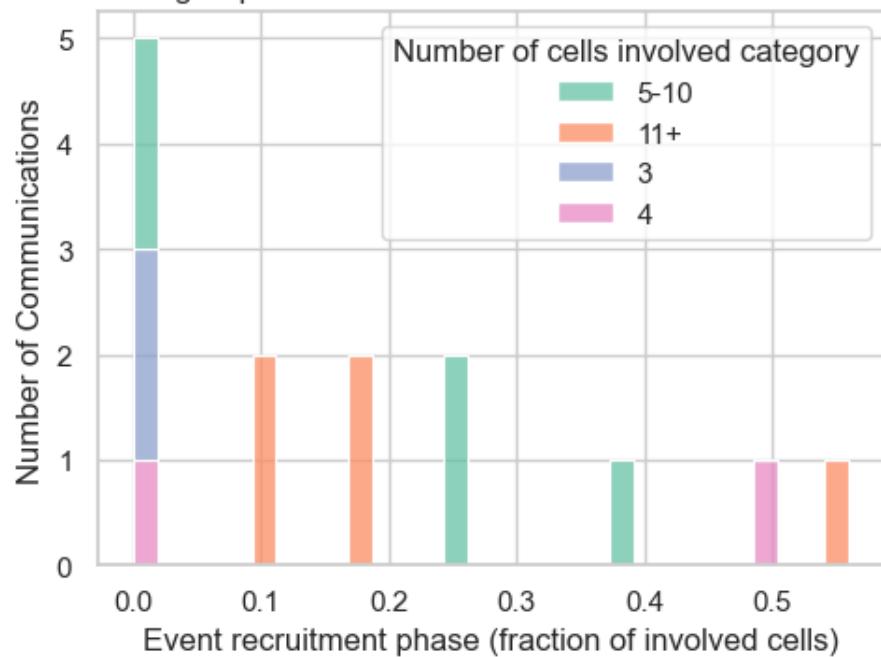


```
[2025-08-27 15:08:37] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 14 on 'Event time phase (fraction of event duration)' (lower=-1.2225, upper=1.7)
```

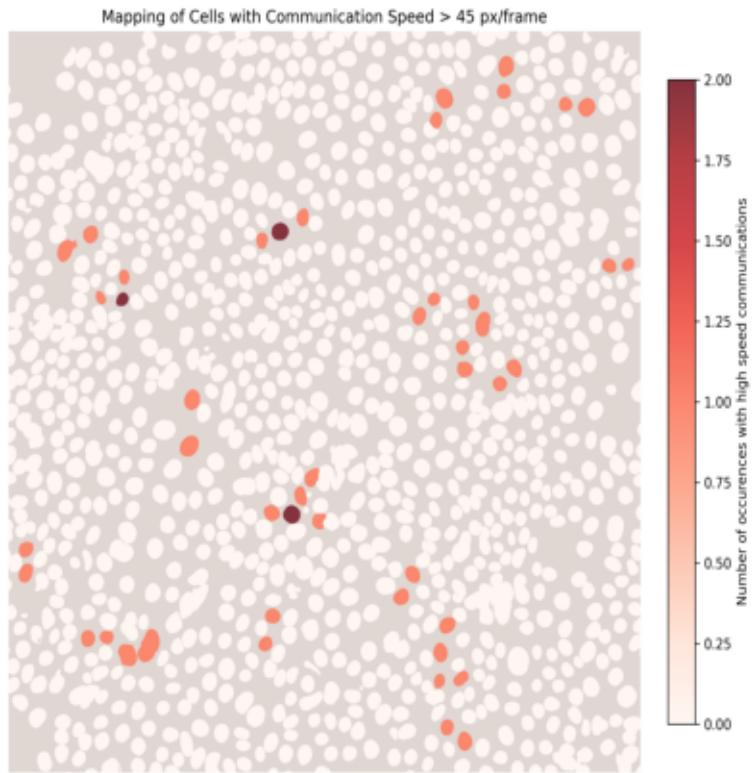


```
[2025-08-27 15:08:37] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 14 on 'Event recruitment phase (fraction of involved cells)' (lower=-0.75, upper=1)
```

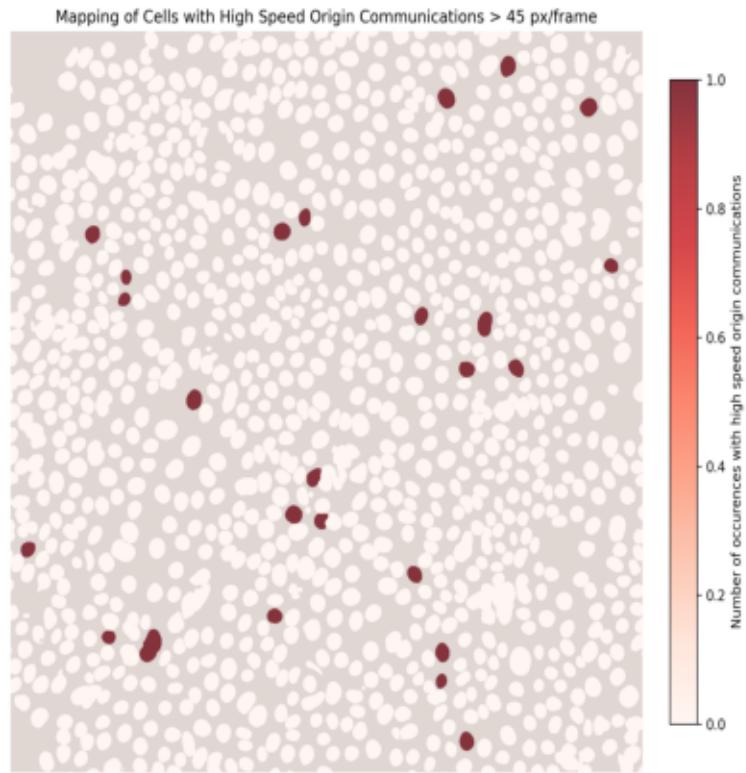
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
10	2016915897552	10	919	0
11	2016915896544	10	848	0
18	2016915886752	11	88	0
26	2016915893856	12	449	0
27	2016915889776	12	495	0
35	2016915886368	13	369	0
50	2016915882720	17	1316	0
54	2016915896064	17	1222	0
70	2016915882144	20	1150	0
83	2016915888096	24	341	0
84	2016915897408	24	360	0
105	2016915883968	30	934	0

117	2016915883200	37	1035	6
137	2016915896496	53	161	0
139	2016915897936	55	142	0
180	2016915897504	80	553	0
185	2016915890544	82	535	0
204	2016915883296	91	646	1
220	2016915891312	101	645	5
240	2016915895344	115	702	2
297	2016915581504	142	987	4
310	2016915584144	150	1166	2
328	2016915580304	156	1106	1

Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
10	916	0	26.0	26.0
11	883	0	18.0	18.0
18	132	0	10.0	10.0
26	495	0	19.0	20.0
27	494	0	20.0	20.0
35	397	0	12.0	12.0
50	1293	0	18.0	18.0
54	1216	0	18.0	18.0
70	1174	0	29.0	29.0
83	360	0	11.0	11.0
84	383	0	11.0	11.0
105	919	1	51.0	51.0
117	1075	6	685.0	685.0
137	155	0	86.0	87.0
139	179	0	46.0	47.0
180	507	0	54.0	55.0
185	498	0	18.0	19.0
204	600	2	82.0	83.0
220	673	8	1037.0	1038.0
240	790	2	284.0	286.0
297	1032	7	748.0	749.0
310	1122	1	317.0	318.0
328	1153	1	81.0	82.0

Duration (s)	Distance (um)	Speed (um/s)	\
10	0.0	15.63	15.63
11	0.0	15.15	15.15
18	0.0	16.98	16.98
26	1.0	15.04	15.04
27	0.0	16.95	16.95
35	0.0	22.10	22.10
50	0.0	16.86	16.86
54	0.0	17.30	17.30
70	0.0	17.88	17.88
83	0.0	20.21	20.21

84	0.0	15.58	15.58
105	0.0	21.86	21.86
117	0.0	17.62	17.62
137	1.0	16.73	16.73
139	1.0	16.14	16.14
180	1.0	16.42	16.42
185	1.0	16.32	16.32
204	1.0	15.08	15.08
220	1.0	15.65	15.65
240	2.0	31.28	15.64
297	1.0	15.60	15.60
310	1.0	18.93	18.93
328	1.0	19.64	19.64

Event time phase (fraction of event duration) \	
10	0.57
11	0.00
18	0.00
26	0.18
27	0.18
35	NaN
50	0.35
54	0.35
70	0.56
83	0.00
84	0.00
105	1.00
117	NaN
137	NaN
139	NaN
180	0.12
185	0.30
204	NaN
220	NaN
240	NaN
297	NaN
310	0.48
328	NaN

Event recruitment phase (fraction of involved cells)		dataset \
10	0.25	20250624_IS06
11	0.00	20250624_IS06
18	0.00	20250624_IS06
26	0.17	20250624_IS06
27	0.17	20250624_IS06
35	NaN	20250624_IS06
50	0.11	20250624_IS06
54	0.11	20250624_IS06

70	0.25	20250624_IS06
83	0.00	20250624_IS06
84	0.00	20250624_IS06
105	0.50	20250624_IS06
117	NaN	20250624_IS06
137	NaN	20250624_IS06
139	NaN	20250624_IS06
180	0.00	20250624_IS06
185	0.38	20250624_IS06
204	NaN	20250624_IS06
220	NaN	20250624_IS06
240	NaN	20250624_IS06
297	NaN	20250624_IS06
310	0.56	20250624_IS06
328	NaN	20250624_IS06

Number of cells involved	category	Speed category
10	5-10	High speed
11	5-10	High speed
18	5-10	High speed
26	11+	High speed
27	11+	High speed
35	2	High speed
50	11+	High speed
54	11+	High speed
70	5-10	High speed
83	3	High speed
84	3	High speed
105	4	High speed
117	2	High speed
137	2	High speed
139	2	High speed
180	4	High speed
185	5-10	High speed
204	2	High speed
220	2	High speed
240	2	High speed
297	2	High speed
310	11+	High speed
328	2	High speed

Speed category High speed Low speed

Origin cell ID

68	0	1
70	0	1
71	0	1
74	0	1
88	1	1

...
1324		0	4
1330		0	1
1331		0	1
1332		0	1
1333		0	1

[250 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um) \
8	68	358.80	11.70
10	70	346.78	12.03
11	71	174.53	12.03
14	74	468.32	12.68
25	88	392.60	23.40
..
972	1324	374.07	482.30
978	1330	269.10	485.88
979	1331	218.72	486.20
980	1332	254.48	486.20
981	1333	491.07	486.53

	Number of peaks	Is active	Occurrences in global events \
8	7	True	6
10	7	True	6
11	8	True	6
14	9	True	6
25	8	True	6
..
972	7	True	6
978	9	True	6
979	7	True	6
980	7	True	6
981	9	True	6

	Occurrences in global events as early peaker	Early peaker event IDs \
8	2	[5, 6]
10	1	[6]
11	1	[6]
14	0	[]
25	0	[]
..
972	0	[]
978	0	[]
979	0	[]
980	0	[]
981	3	[4, 5, 6]

```

Occurrences in sequential events \
8 1
10 1
11 1
14 1
25 1
.. ...
972 1
978 1
979 1
980 1
981 1

Occurrences in sequential events as origin \
8 1
10 0
11 1
14 1
25 1
.. ...
972 1
978 1
979 1
980 0
981 1

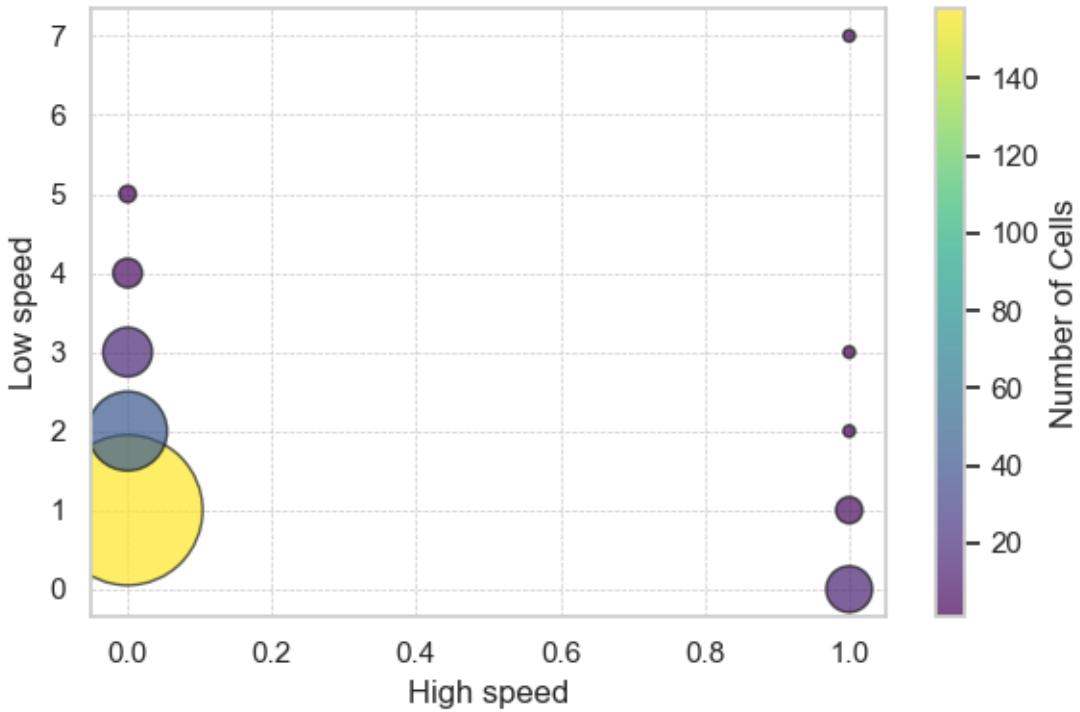
Occurrences in individual events Peak frequency (Hz) Periodicity score \
8 0 0.0041 0.75
10 0 0.0041 0.74
11 0 0.0047 0.72
14 1 0.0053 0.64
25 1 0.0047 0.67
.. ...
972 0 0.0041 ...
978 1 0.0053 ...
979 0 0.0041 ...
980 0 0.0041 ...
981 2 0.0053 ...

Neighbor count Neighbors (labels) dataset \
8 3 [70,87,100] 20250624_IS06
10 4 [68,75,100,107] 20250624_IS06
11 4 [59,63,94,104] 20250624_IS06
14 3 [83,85,108] 20250624_IS06
25 4 [80,87,120,132] 20250624_IS06
.. ...
972 ... ...
978 5 [1271,1278,1310,1316,1341] 20250624_IS06
978 4 [1290,1301,1326,1332] 20250624_IS06

```

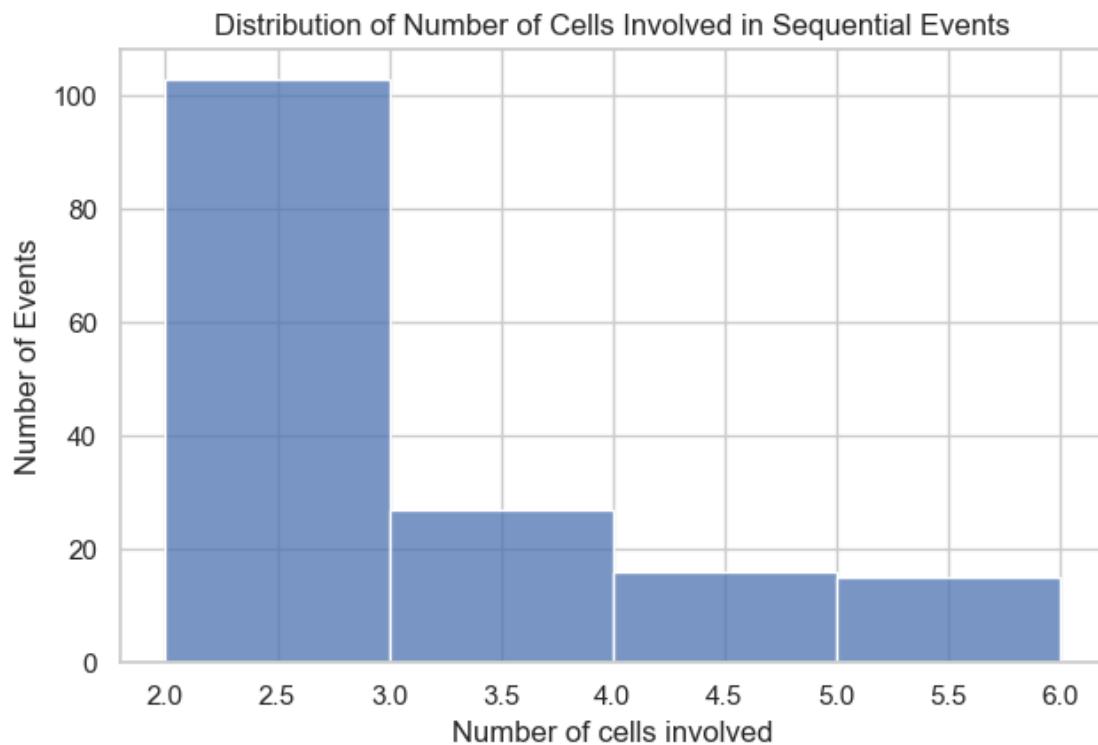
979	4	[1309, 1317, 1334, 1336]	20250624_IS06	
980	4	[1290, 1313, 1330, 1336]	20250624_IS06	
981	2	[1312, 1322]	20250624_IS06	
		Involved in sequential event	Occurrences in sequential events category \	
8		Involved in sequential event		1-2
10		Involved in sequential event		1-2
11		Involved in sequential event		1-2
14		Involved in sequential event		1-2
25		Involved in sequential event		1-2
..	
972		Involved in sequential event		1-2
978		Involved in sequential event		1-2
979		Involved in sequential event		1-2
980		Involved in sequential event		1-2
981		Involved in sequential event		1-2
		High speed Low speed		
8		0.0 1.0		
10		0.0 1.0		
11		0.0 1.0		
14		0.0 1.0		
25		1.0 1.0		
..	
972		0.0 4.0		
978		0.0 1.0		
979		0.0 1.0		
980		0.0 1.0		
981		0.0 1.0		

[250 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

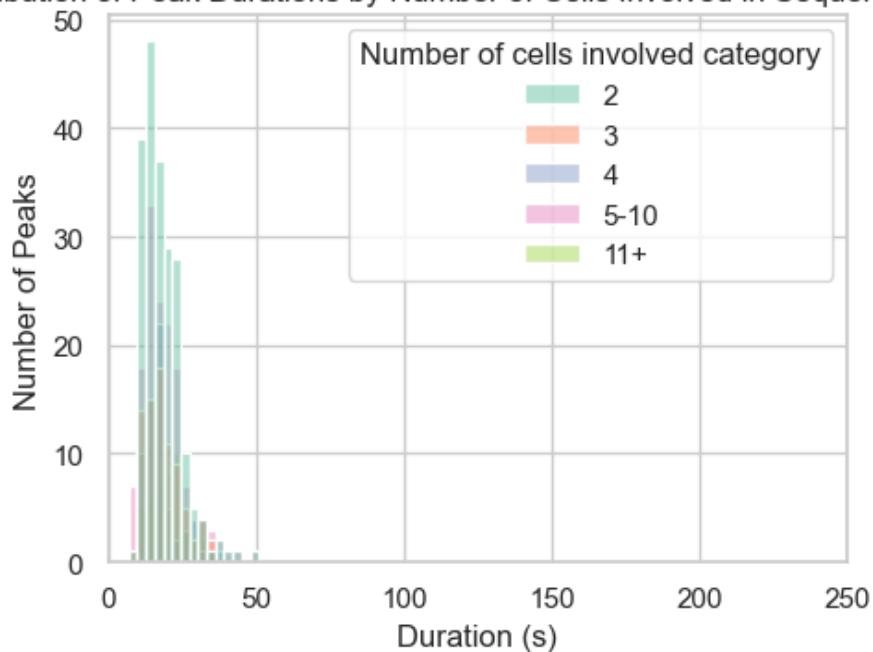
```
[2025-08-27 15:08:39] [INFO] calcium: plot_histogram: removed 10 outliers out of  
171 on 'Number of cells involved' (lower=-1, upper=6)
```



1.3.6 Influence of cell count per event on statistics

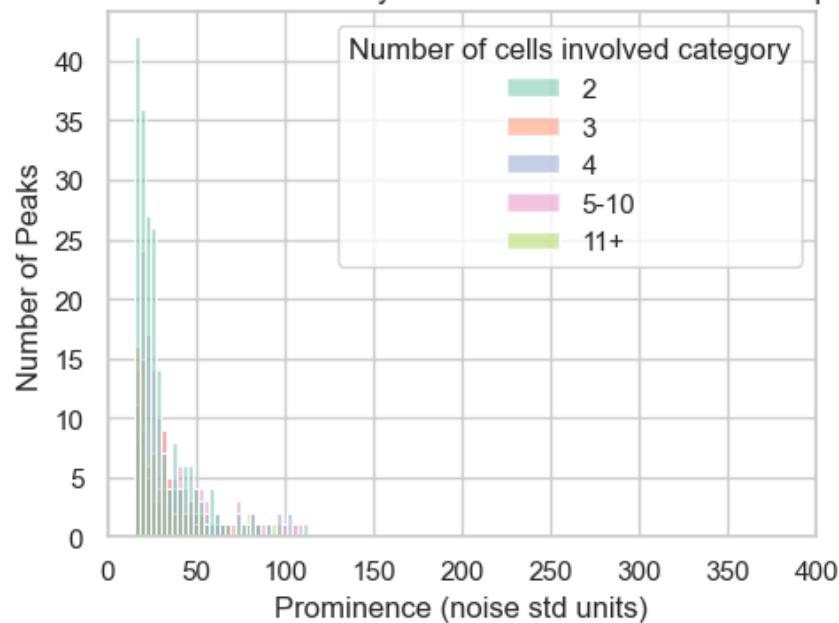
```
[2025-08-27 15:08:40] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 542 on 'Duration (s)' (lower=-0.5, upper=53.5)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

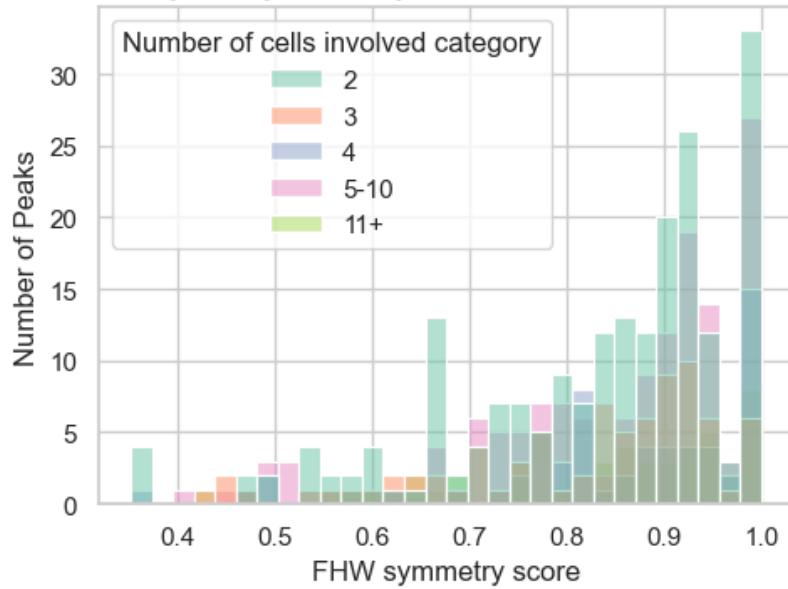


[2025-08-27 15:08:40] [INFO] calcium: plot_histogram_by_group: removed 13 outliers out of 542 on 'Prominence (noise std units)' (lower=-12.338, upper=114.71)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

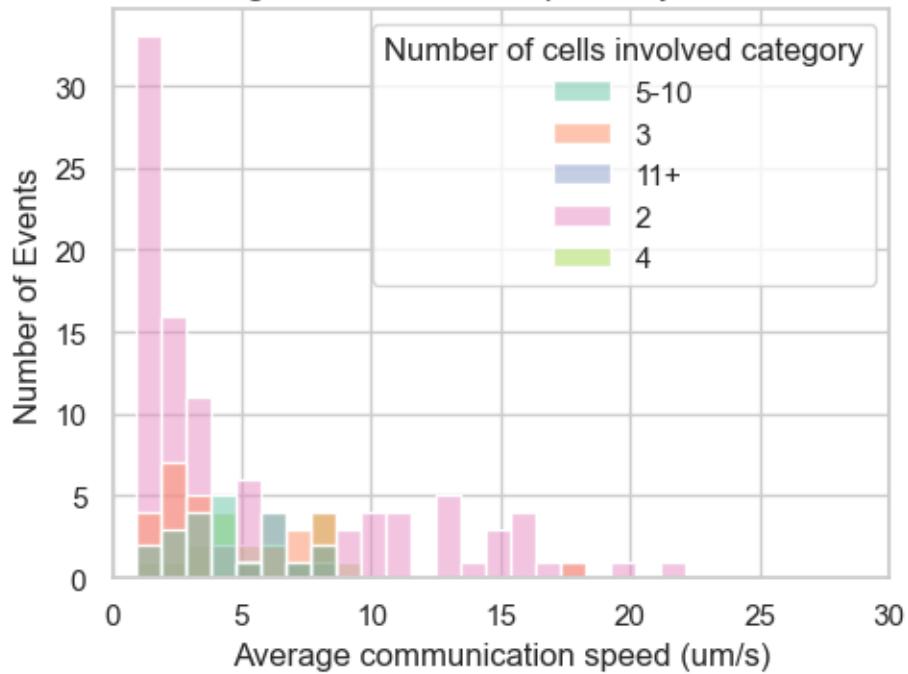


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

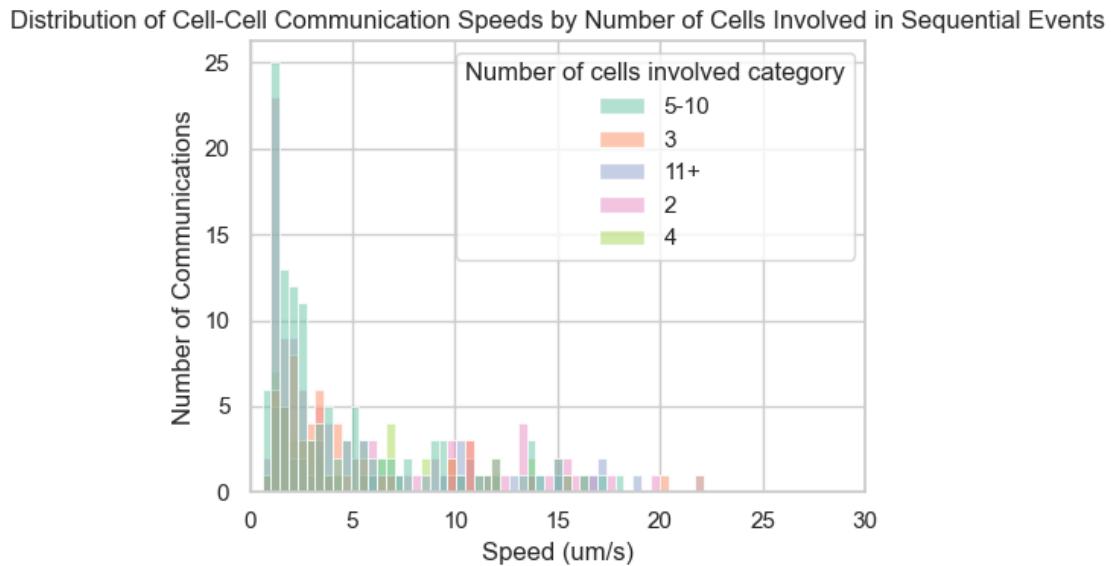


```
[2025-08-27 15:08:40] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 171 on 'Average communication speed (um/s)' (lower=-15.015, upper=24.605)
```

Distribution of Average Communication Speeds by Number of Cells Involved

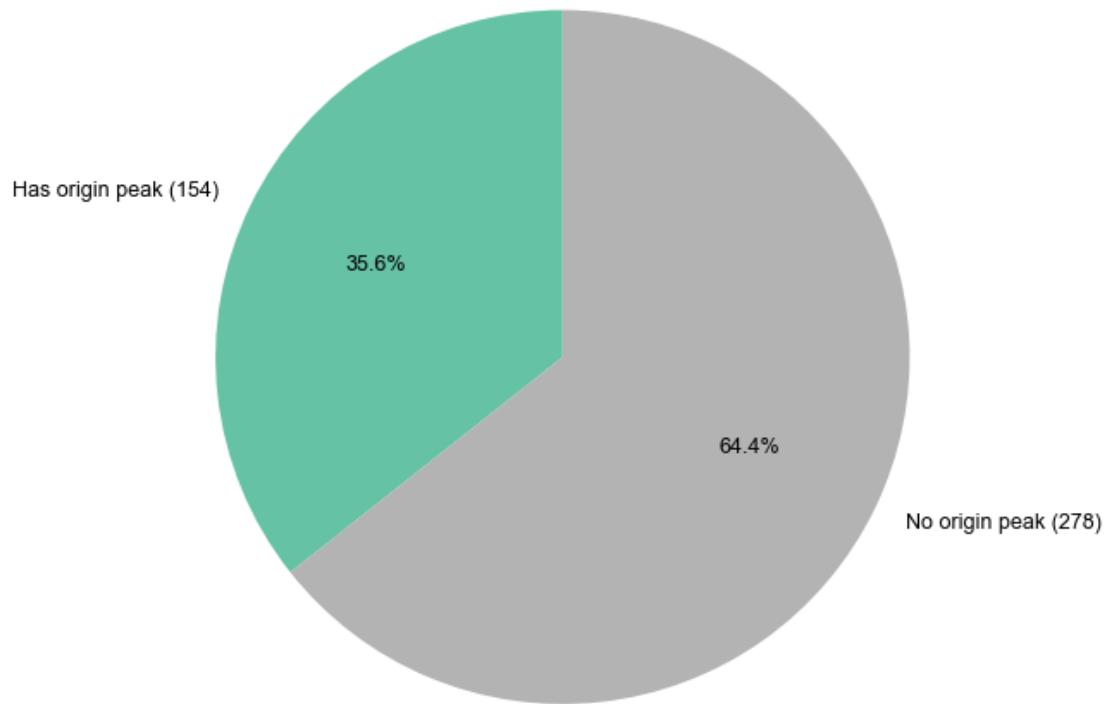


```
[2025-08-27 15:08:41] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 371 on 'Speed (um/s)' (lower=-16.335, upper=25.63)
```

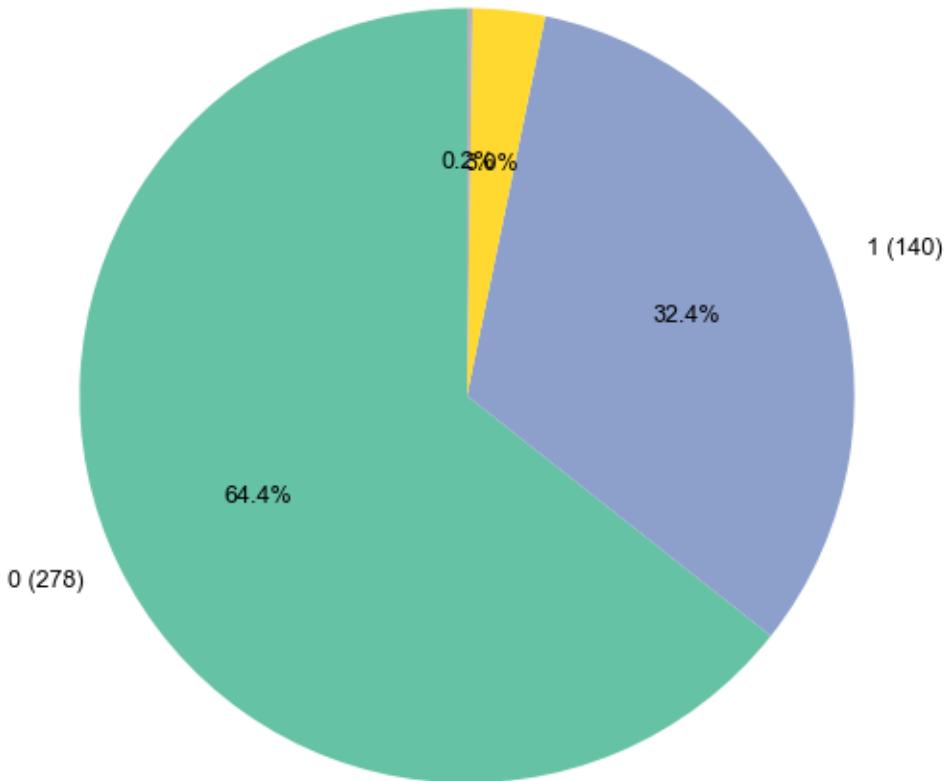


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

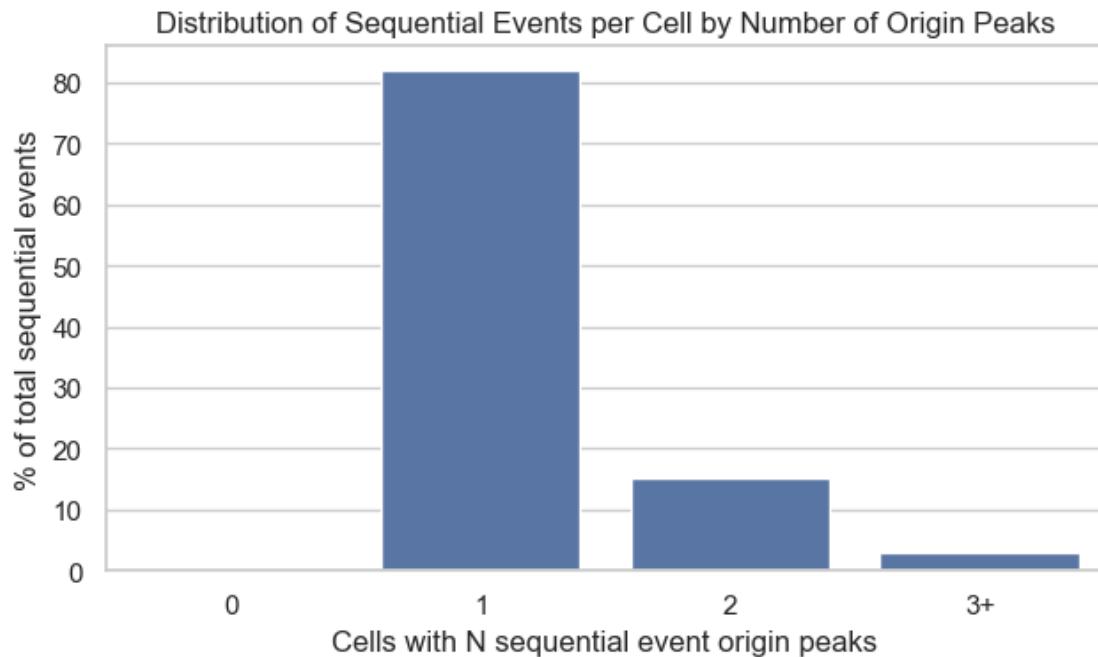


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)

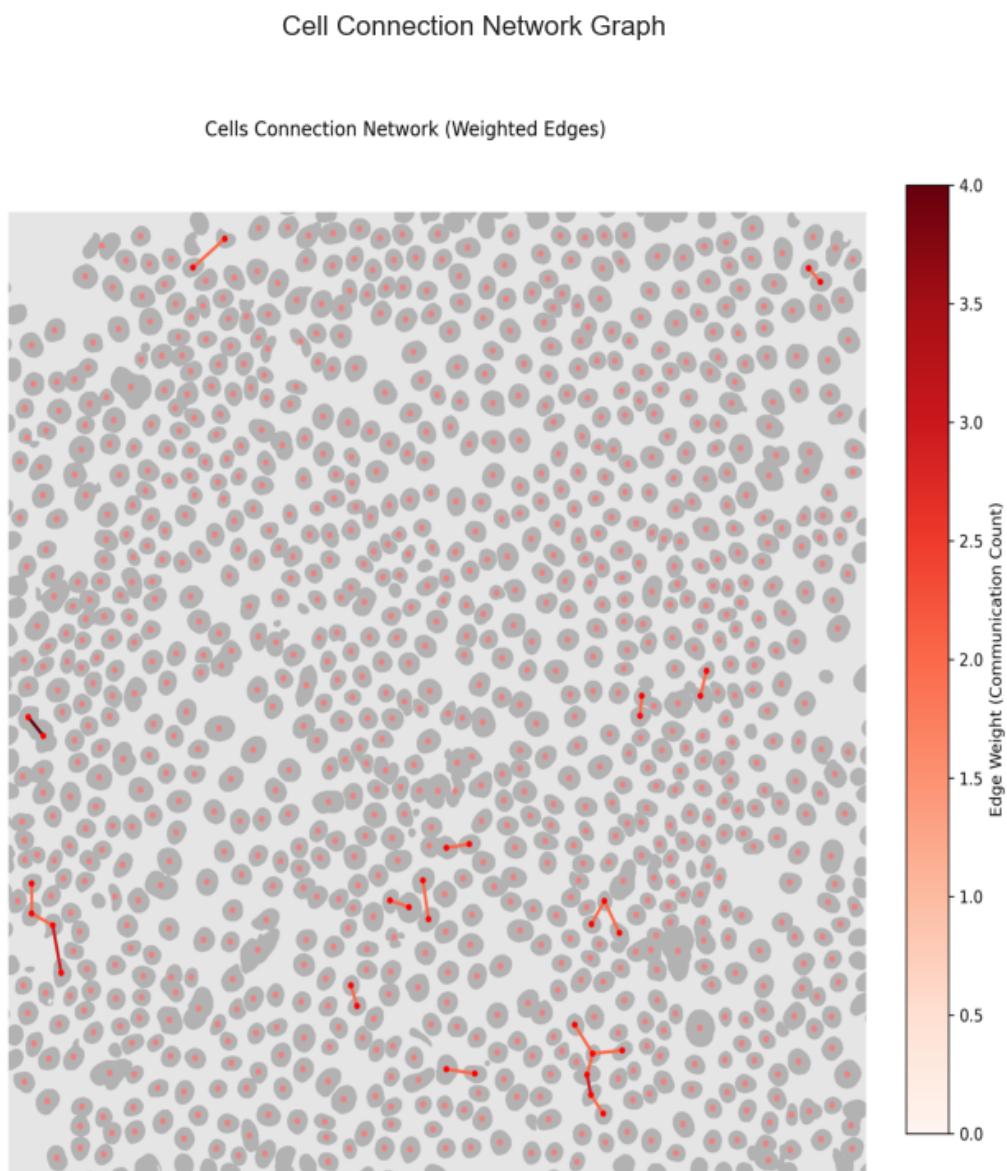


```
[2025-08-27 15:08:41] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS06\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
```

```
packages\PIL\ImageFile.py", line 132, in __init__  
    self.fp = open(fp, "rb")  
FileNotFoundException: [Errno 2] No such file or directory:  
'D:\\Mateo\\20250624\\Output\\IS06\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```

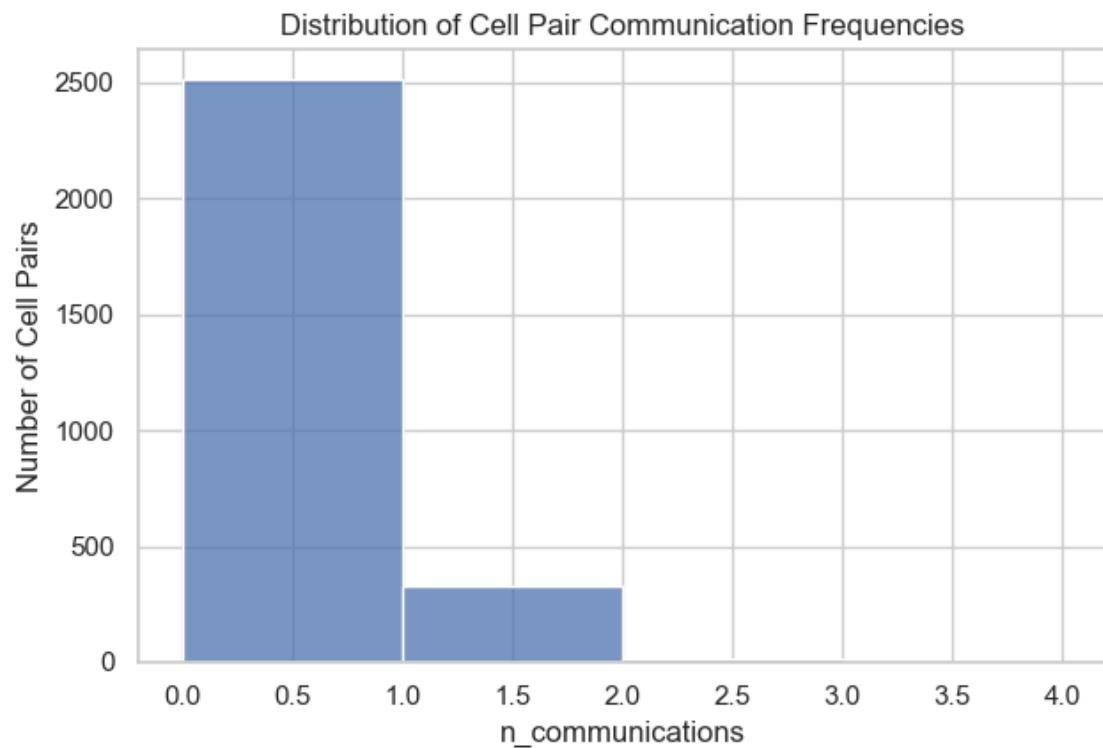


1.3.8 Connection network between cells



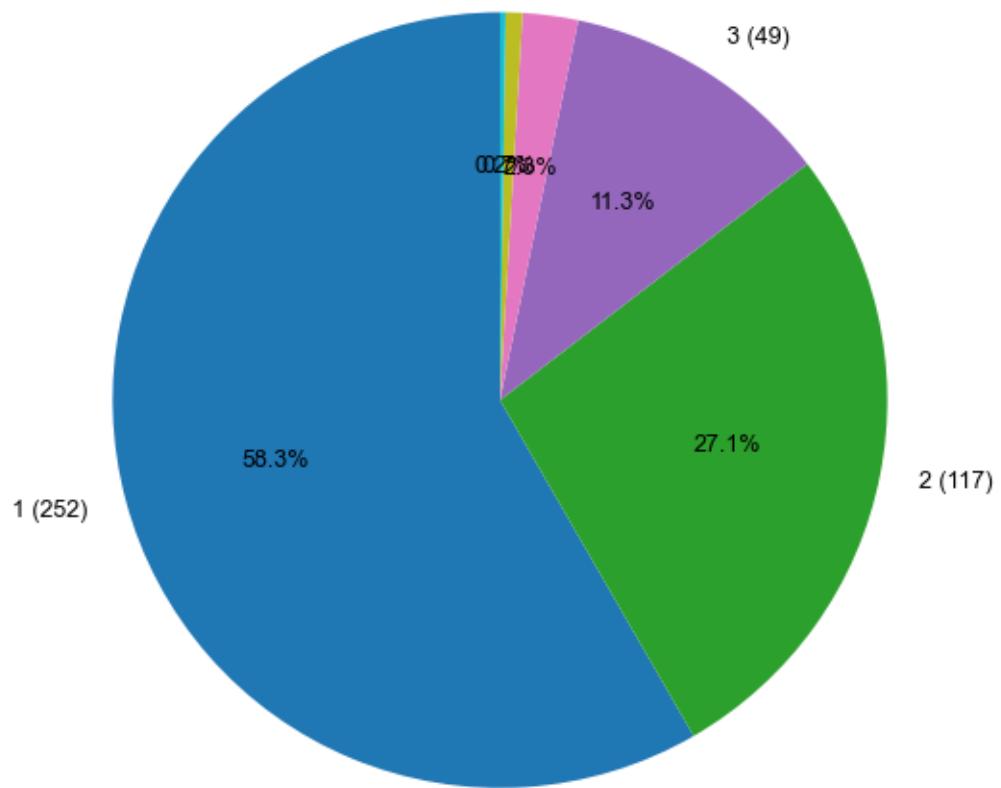
1.3.9 Pair/Trios with high communication networks

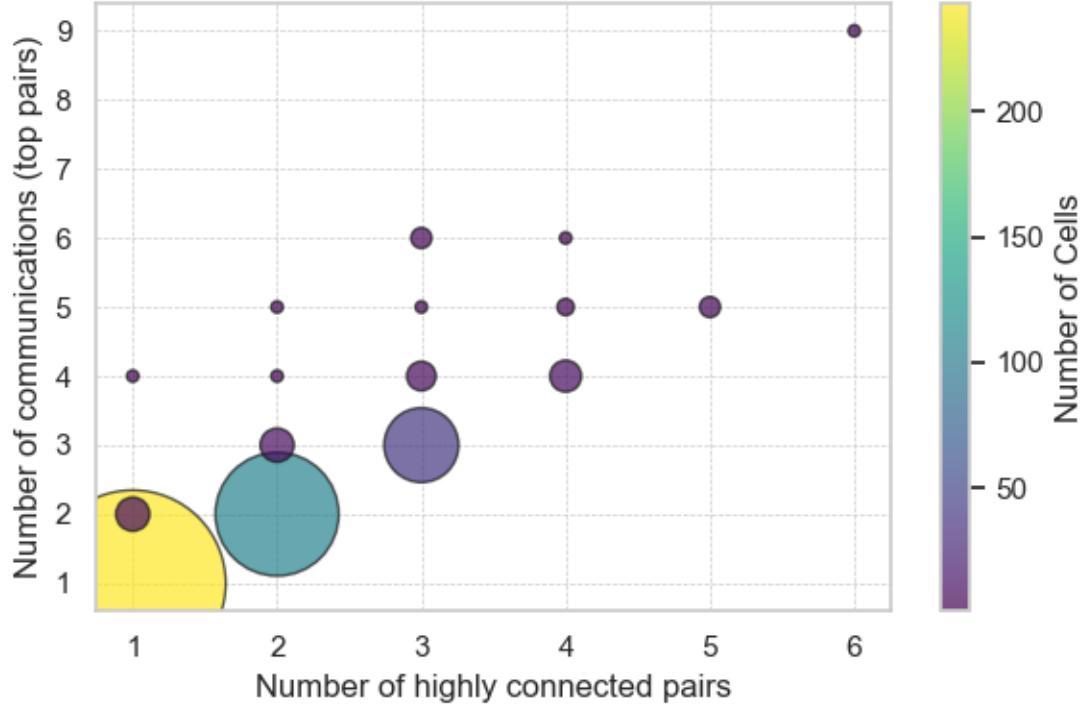
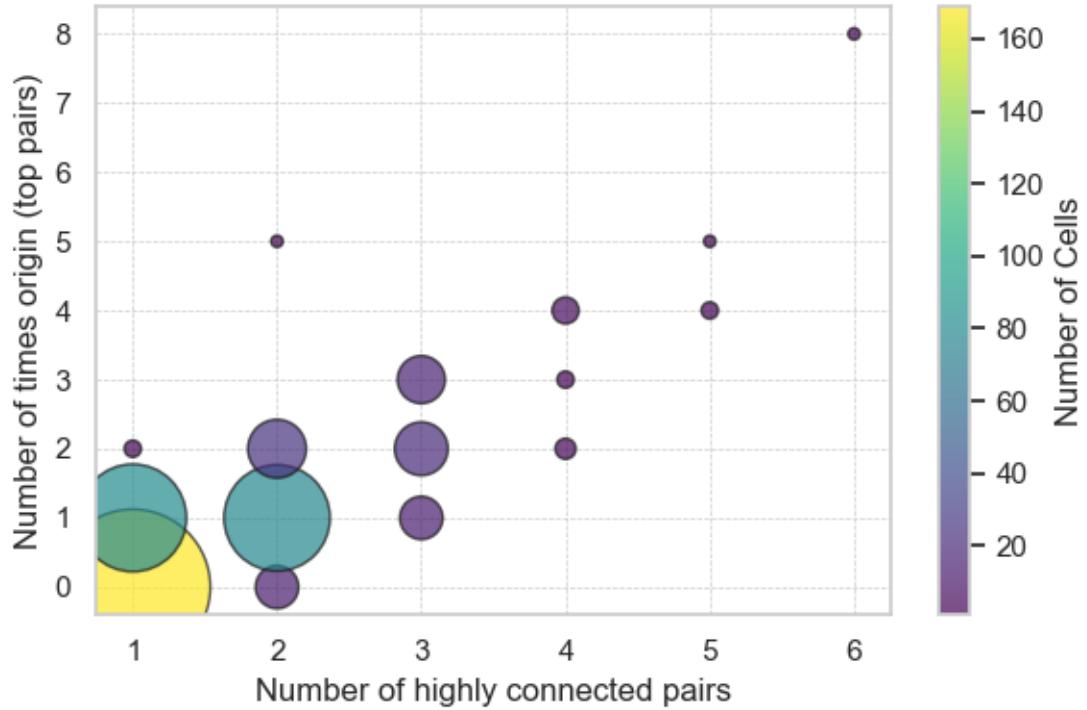
```
[2025-08-27 15:08:44] [INFO] calcium: build_neighbor_pair_stats: built 2863 pairs across 1 datasets (mean distance=17.11 um)
```

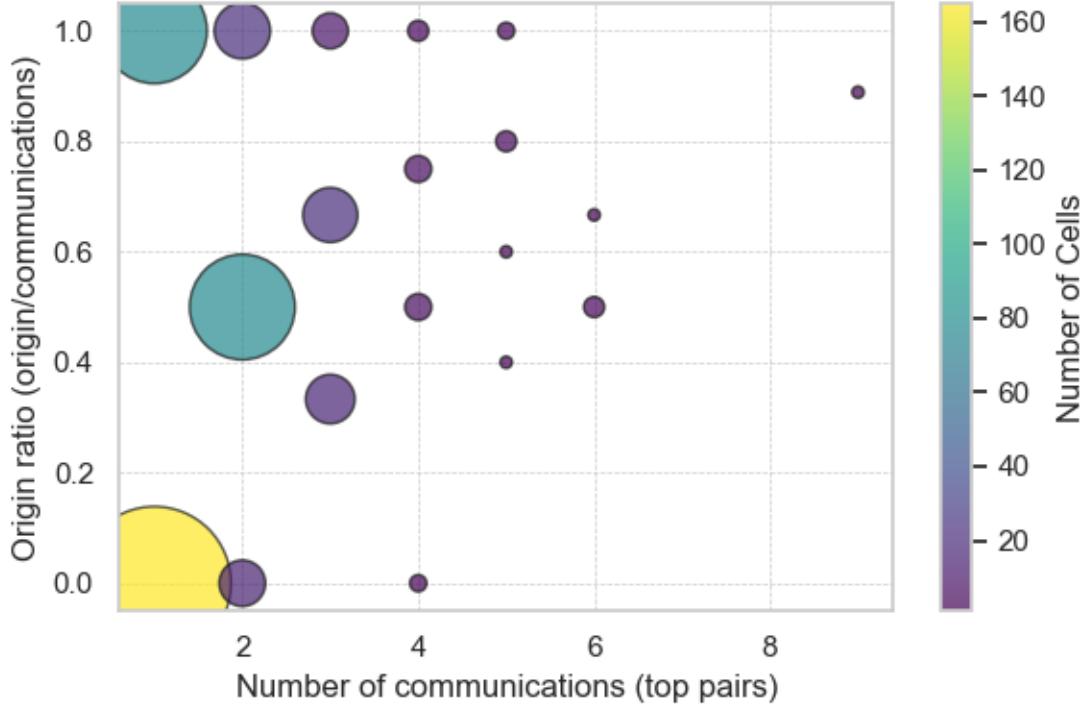
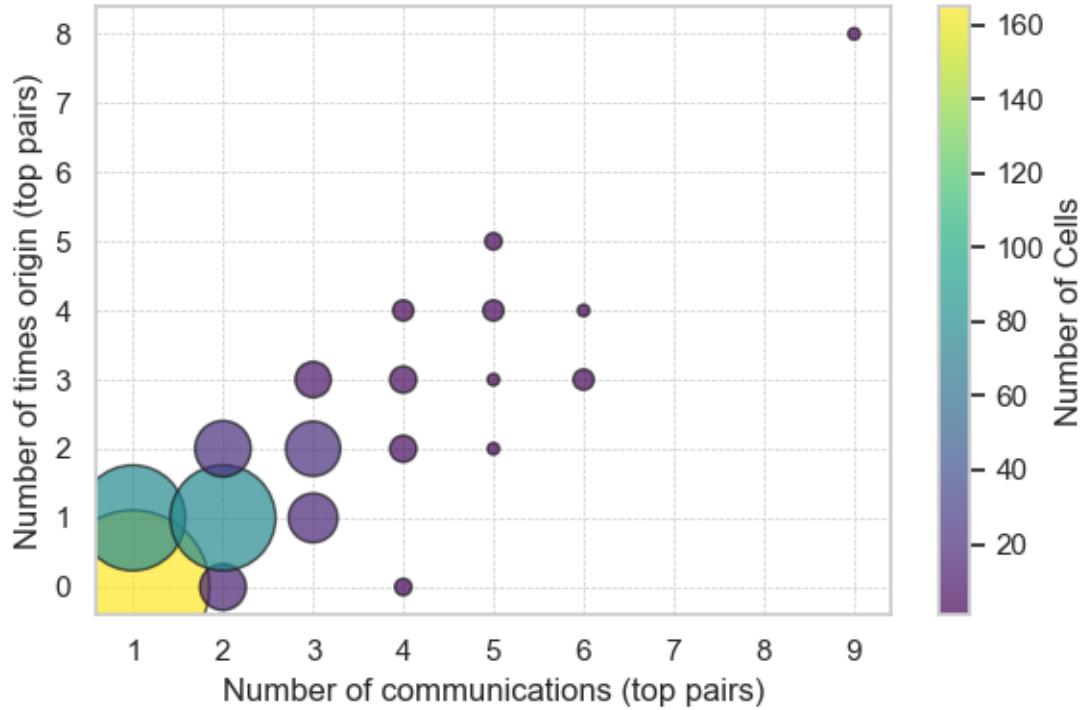


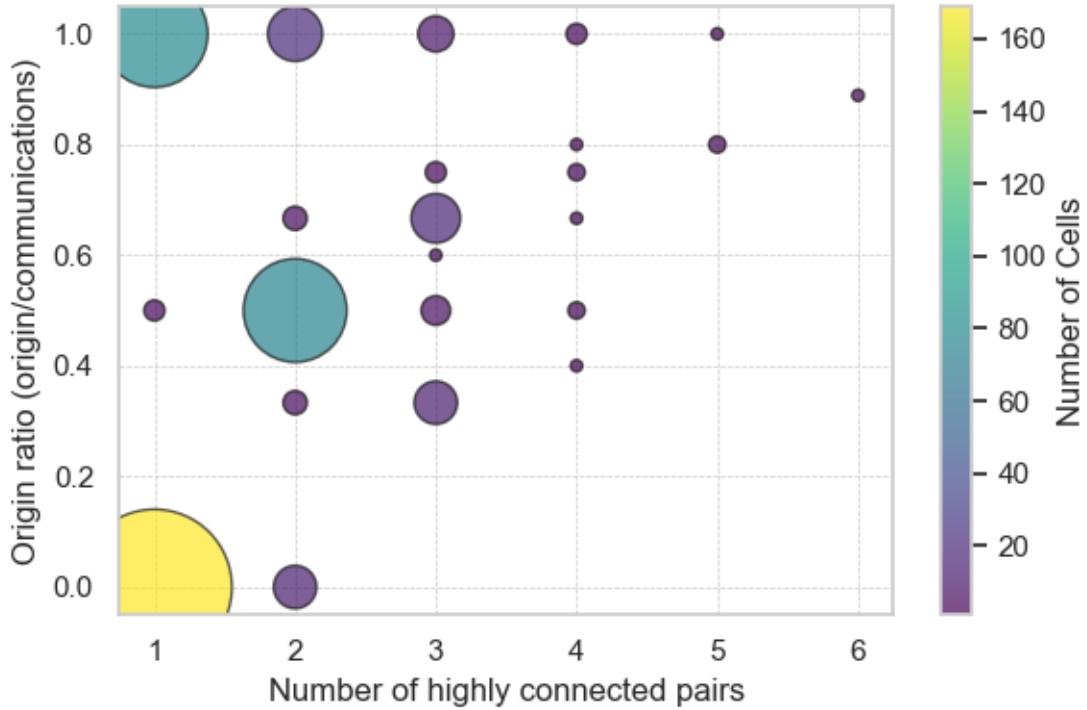
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=252 for Number of highly connected pairs=1

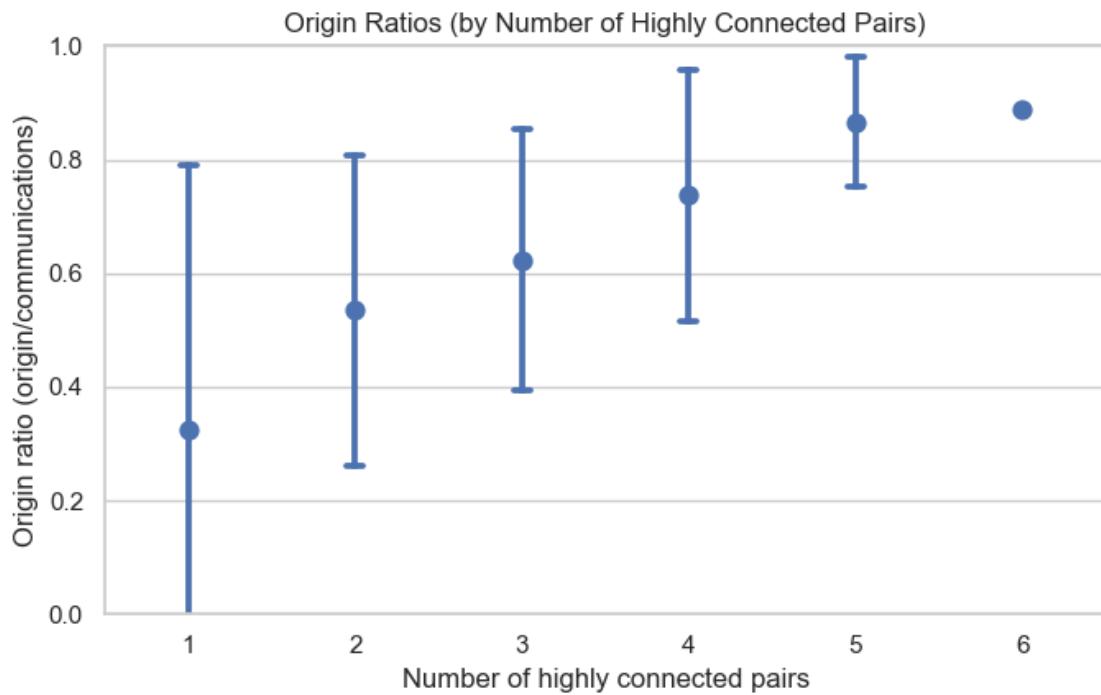
[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=117 for Number of highly connected pairs=2

[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=49 for Number of highly connected pairs=3

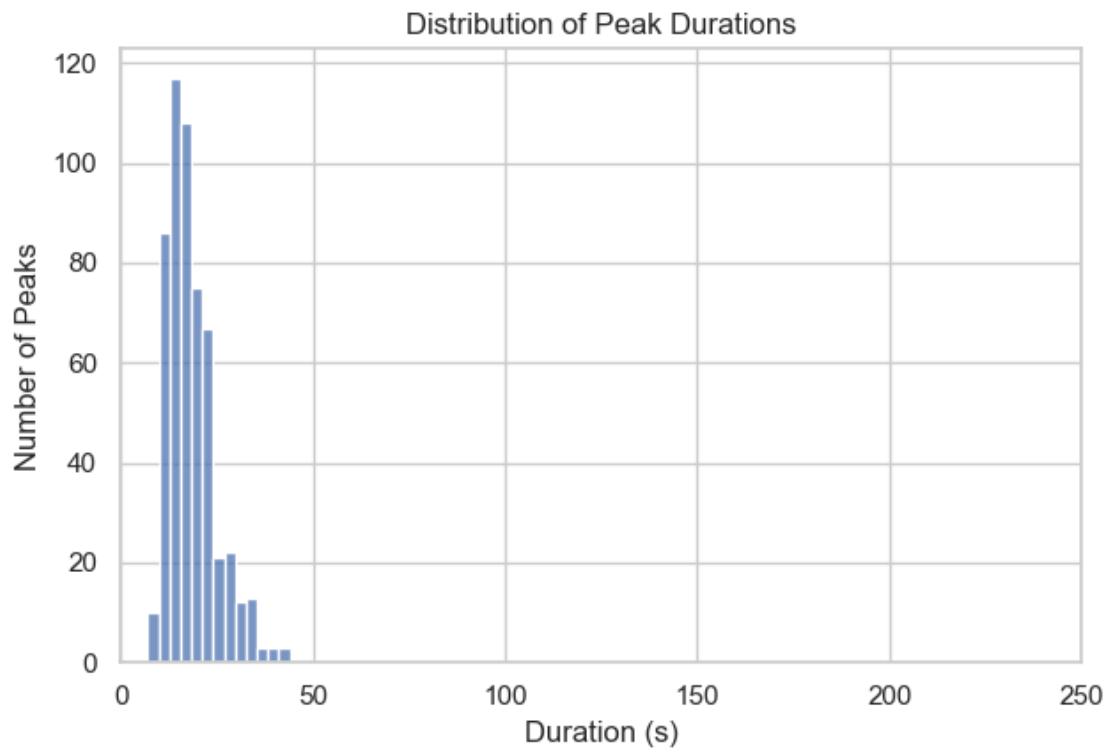
[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=10 for Number of highly connected pairs=4

[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=3 for Number of highly connected pairs=5

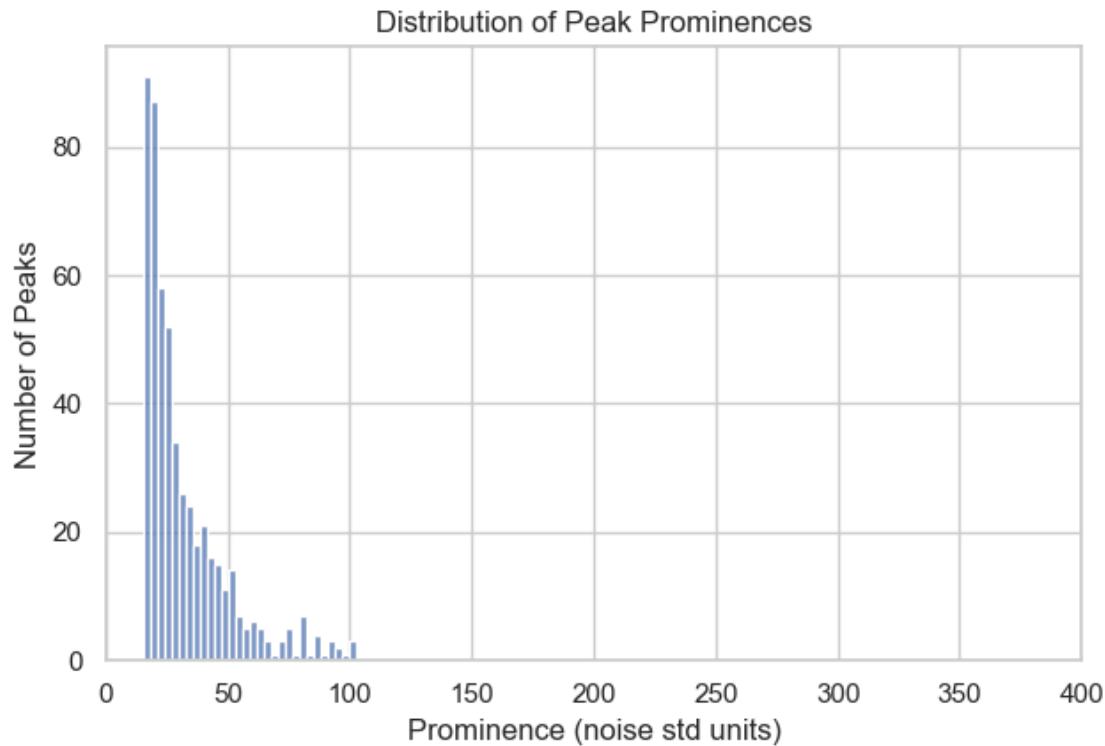
[2025-08-27 15:08:45] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=6

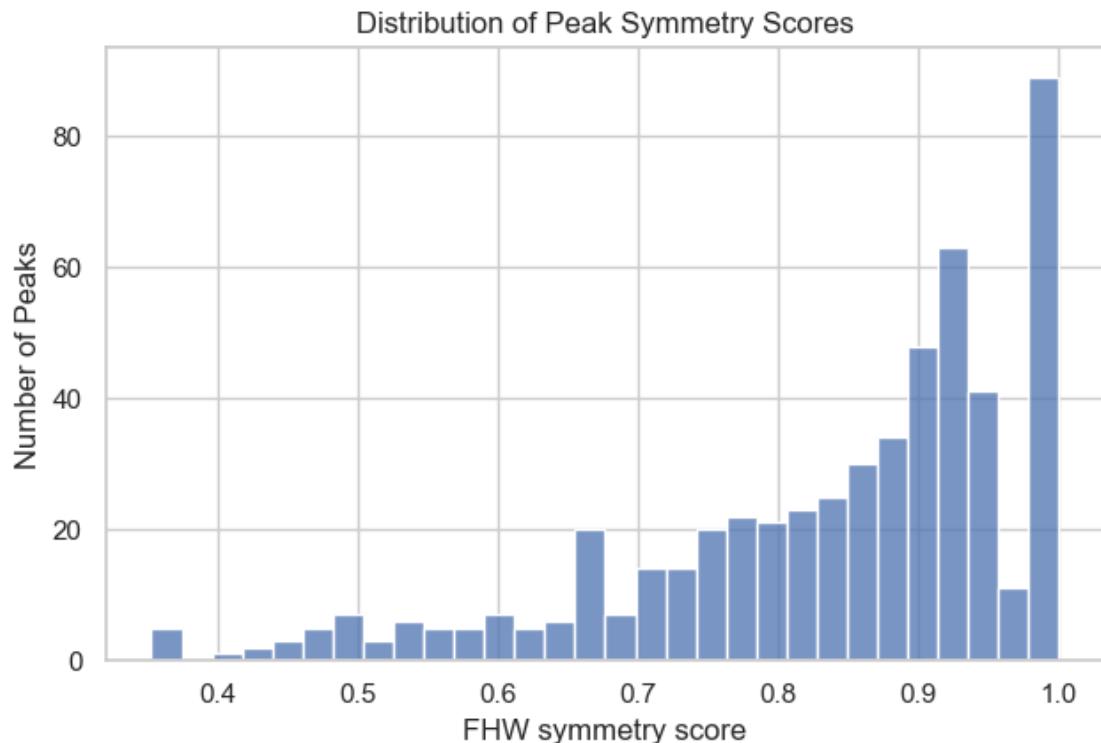


```
[2025-08-27 15:08:46] [INFO] calcium: plot_histogram: removed 2 outliers out of 542 on 'Duration (s)' (lower=-14, upper=49)
```

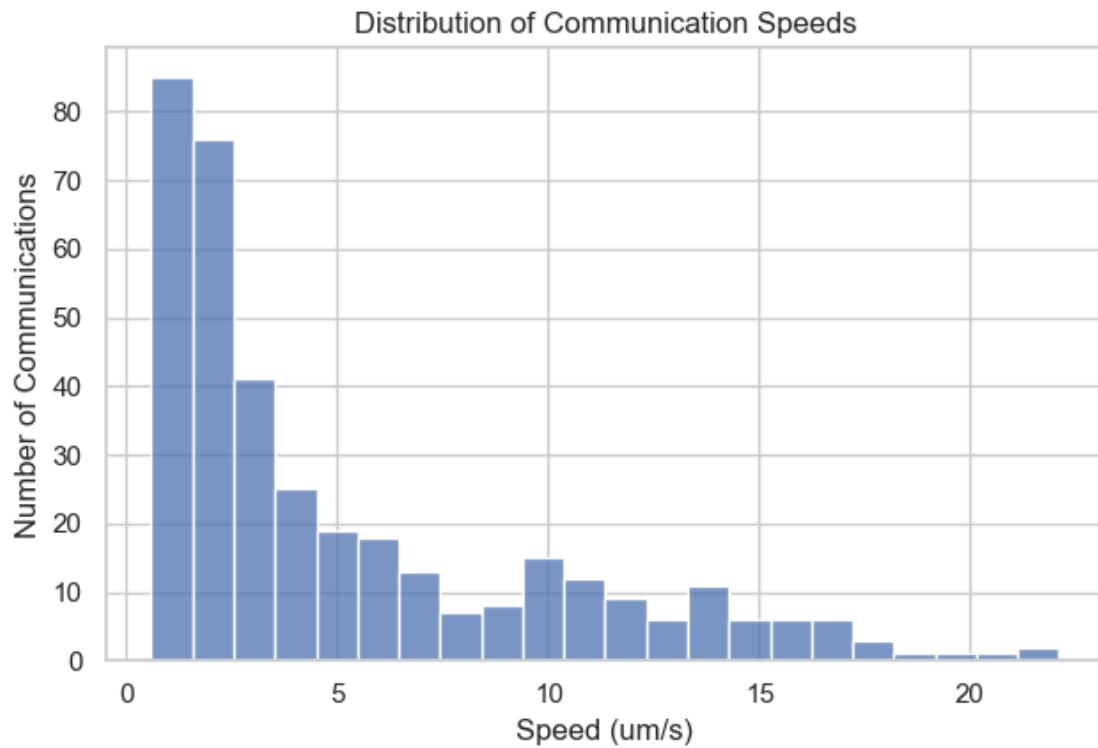


[2025-08-27 15:08:46] [INFO] calcium: plot_histogram: removed 17 outliers out of 542 on 'Prominence (noise std units)' (lower=-44.1, upper=104.13)

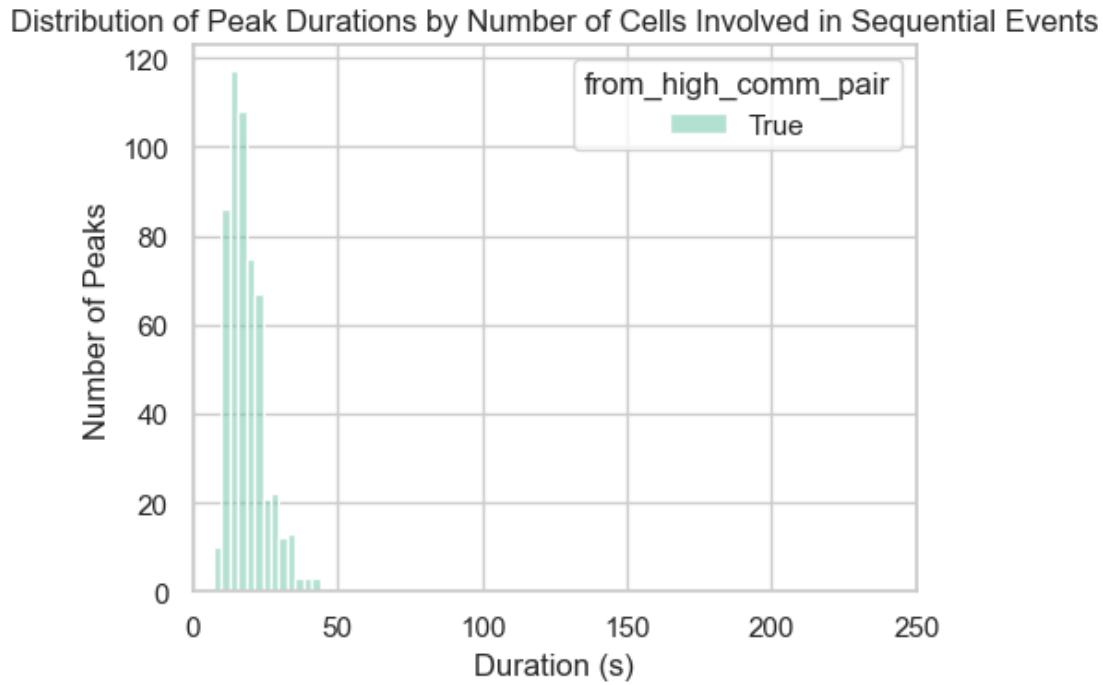




```
[2025-08-27 15:08:46] [INFO] calcium: plot_histogram: removed 0 outliers out of 371 on 'Speed (um/s)' (lower=-16.335, upper=25.63)
```

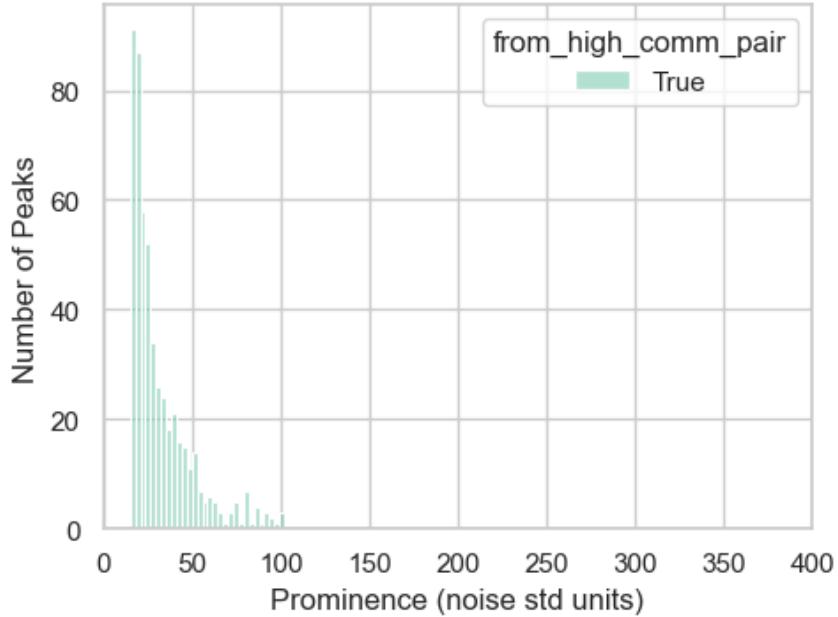


```
[2025-08-27 15:08:46] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 542 on 'Duration (s)' (lower=-14, upper=49)
```

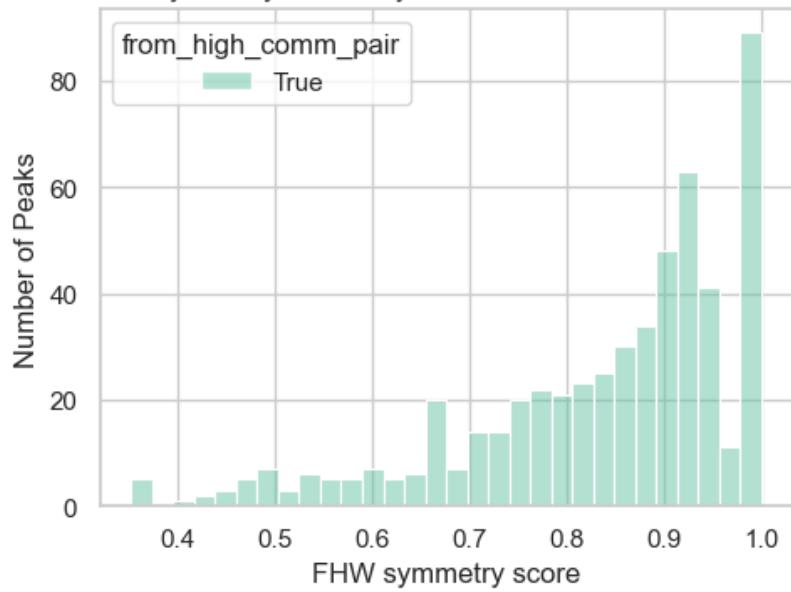


[2025-08-27 15:08:46] [INFO] calcium: plot_histogram_by_group: removed 17 outliers out of 542 on 'Prominence (noise std units)' (lower=-44.1, upper=104.13)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

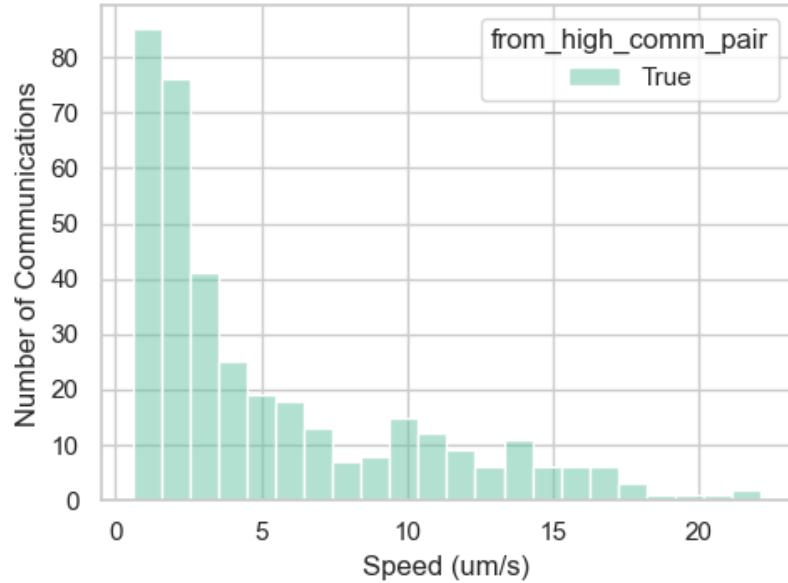


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:08:47] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 371 on 'Speed (um/s)' (lower=-16.335, upper=25.63)

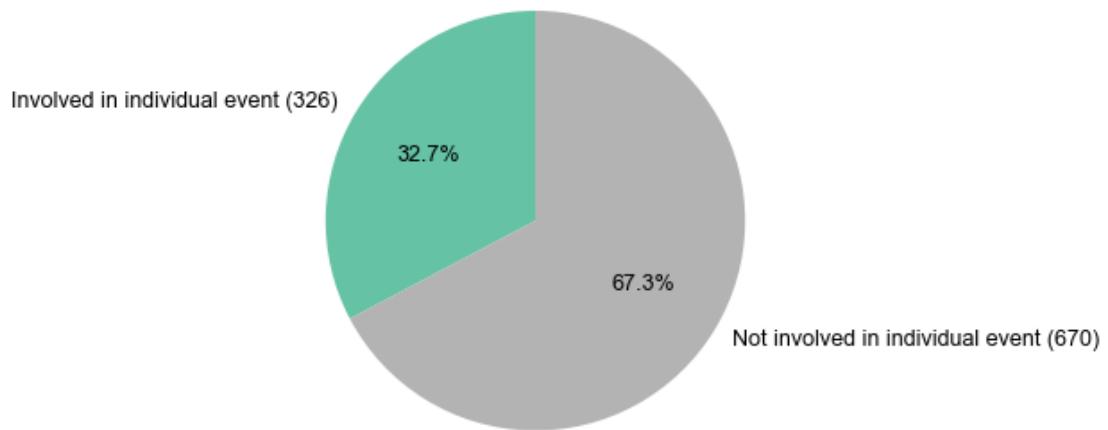
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



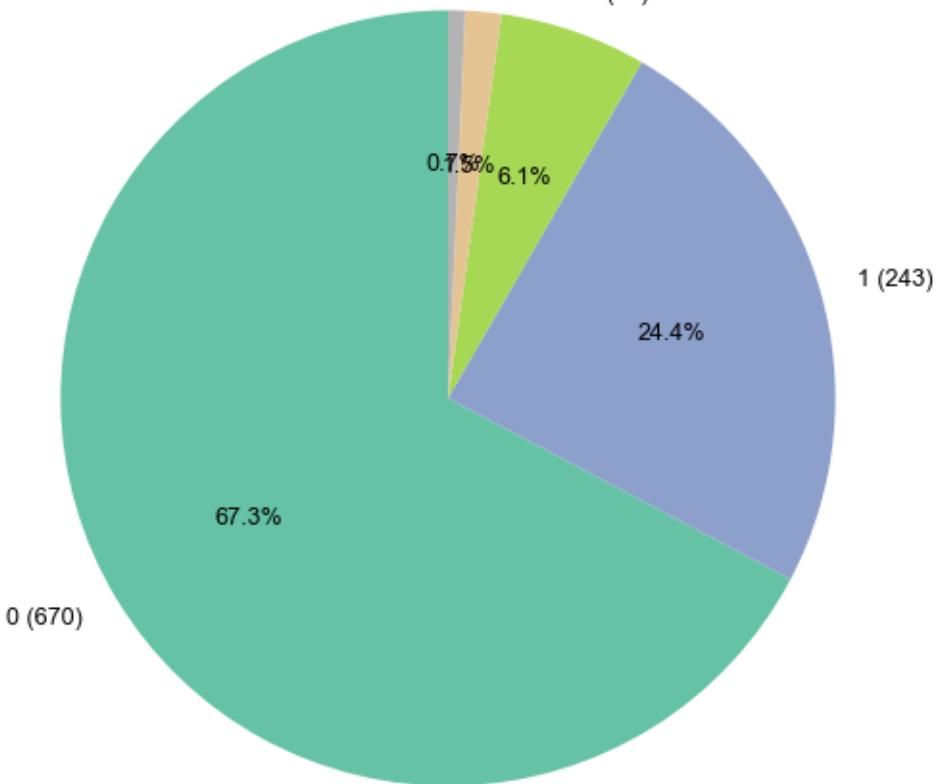
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

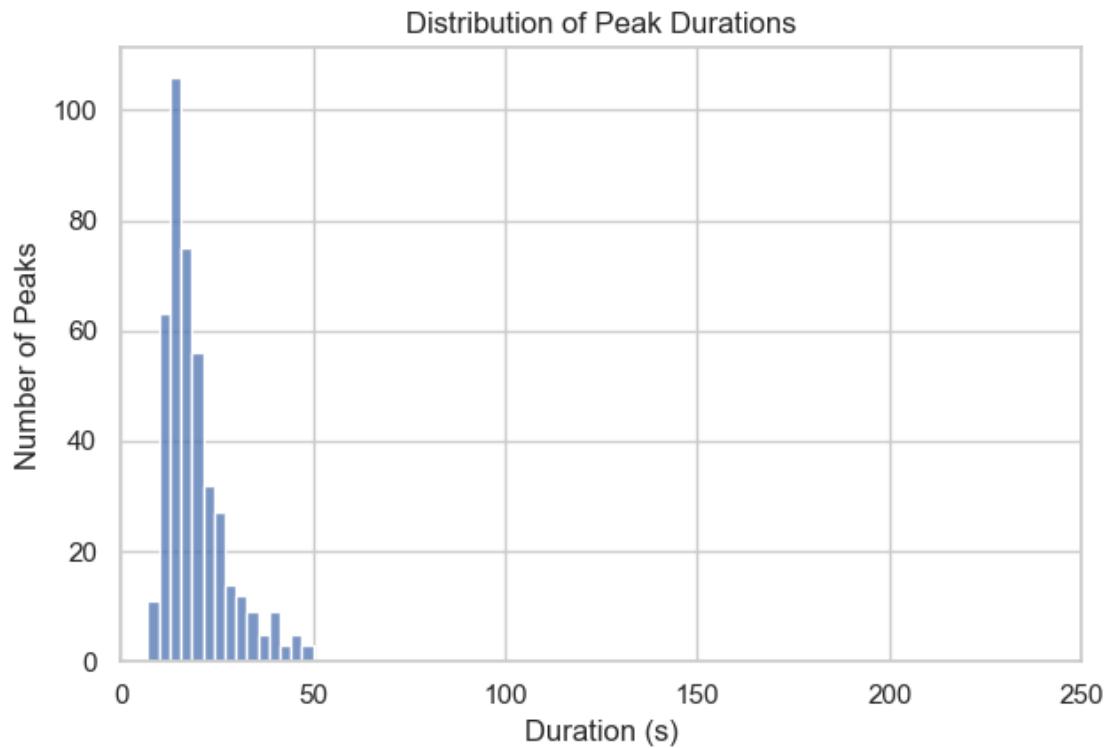


```
[2025-08-27 15:08:47] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS06\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS06\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

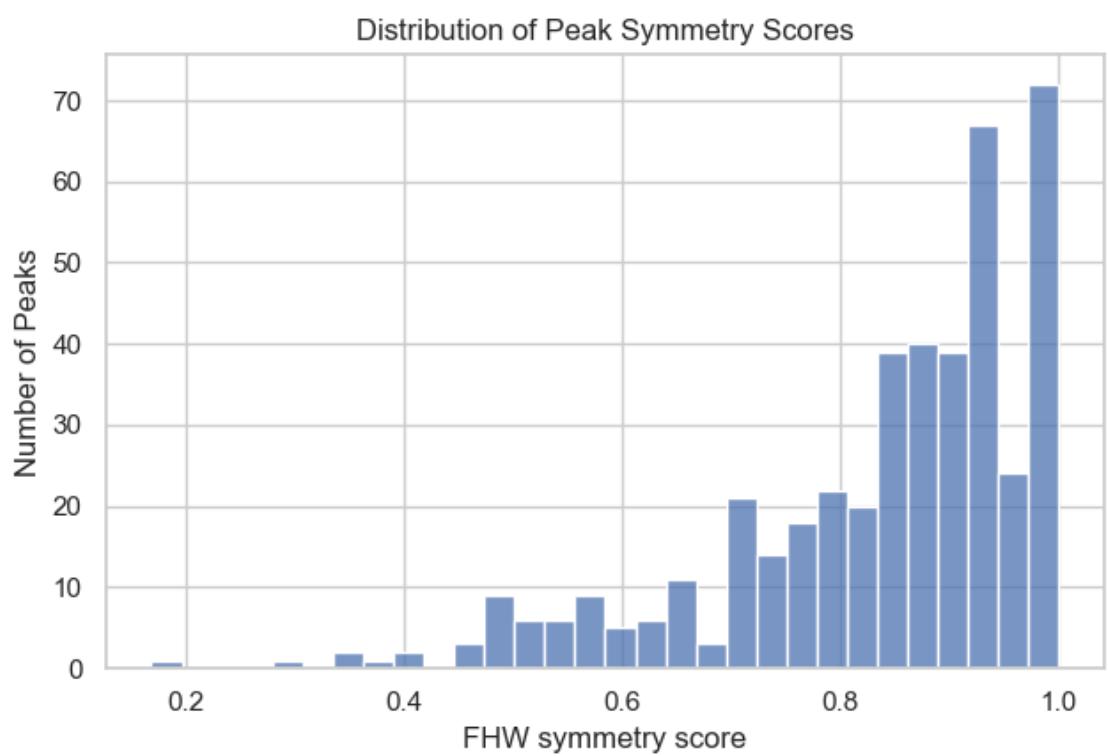
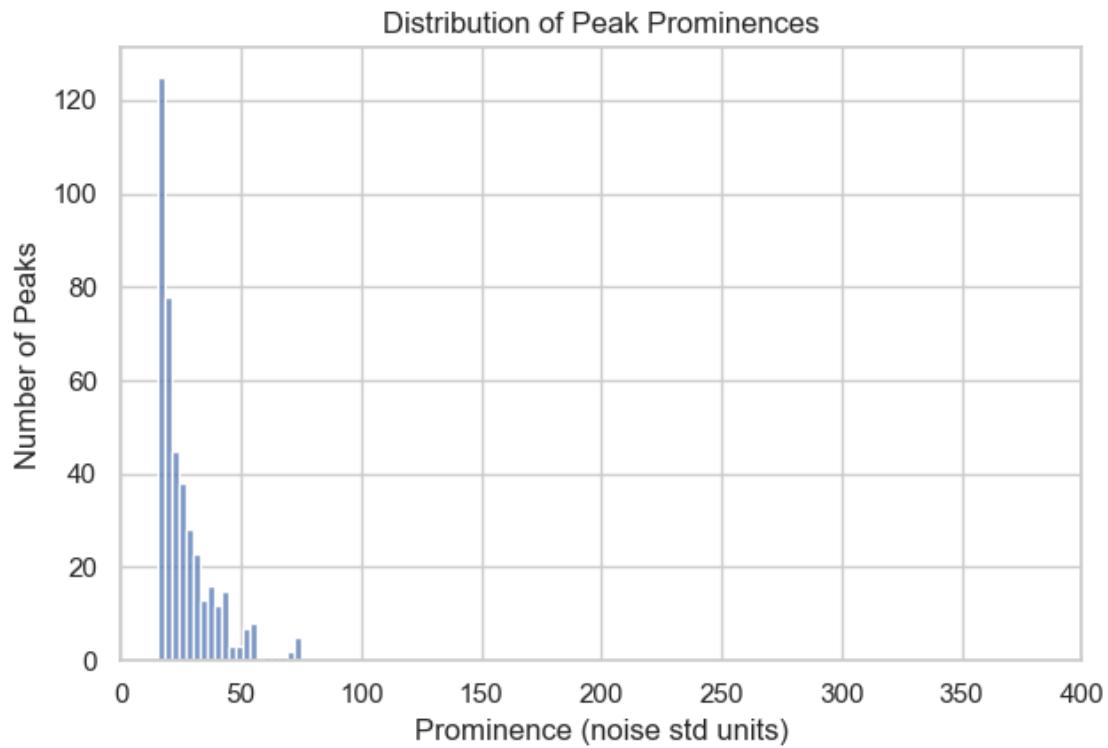
'D:\\Mateo\\20250624\\Output\\IS06\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

1.4.2 Peaks statistics in individual events

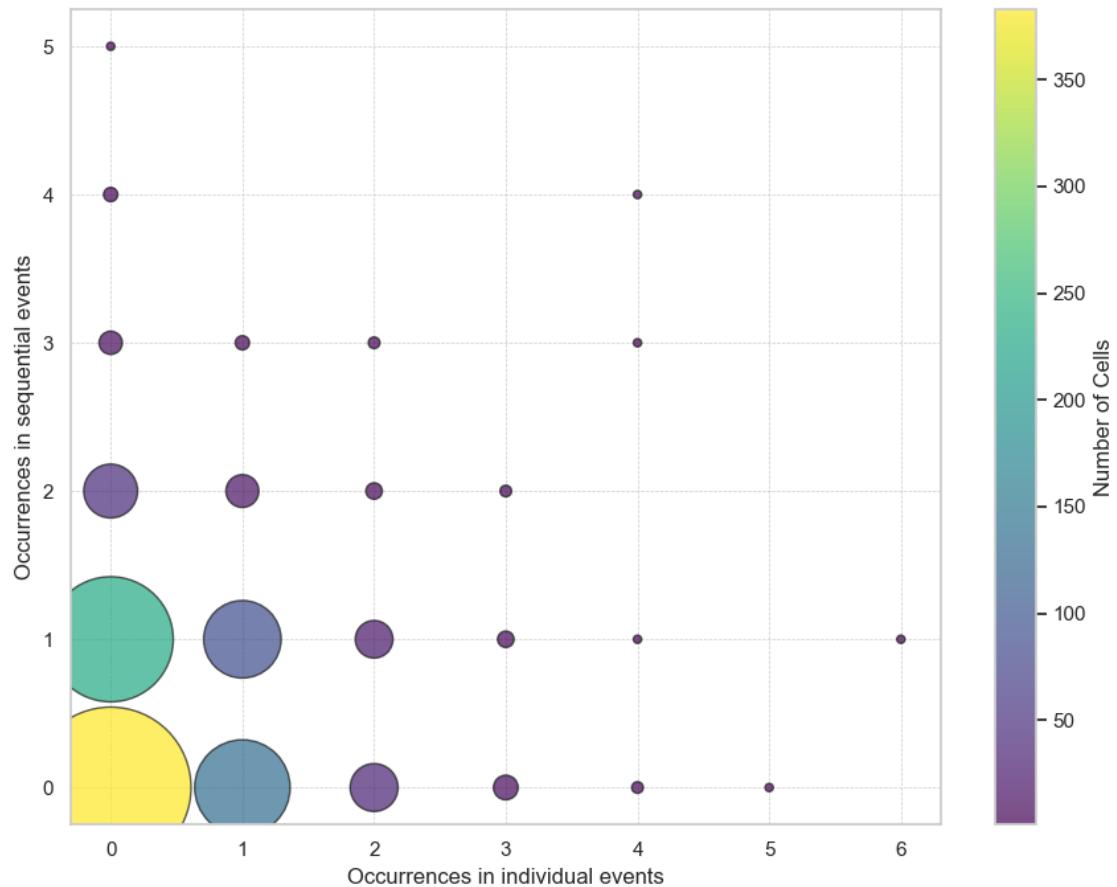
[2025-08-27 15:08:47] [INFO] calcium: plot_histogram: removed 11 outliers out of 441 on 'Duration (s)' (lower=-13, upper=50)



[2025-08-27 15:08:47] [INFO] calcium: plot_histogram: removed 17 outliers out of 441 on 'Prominence (noise std units)' (lower=-26.7, upper=76.2)



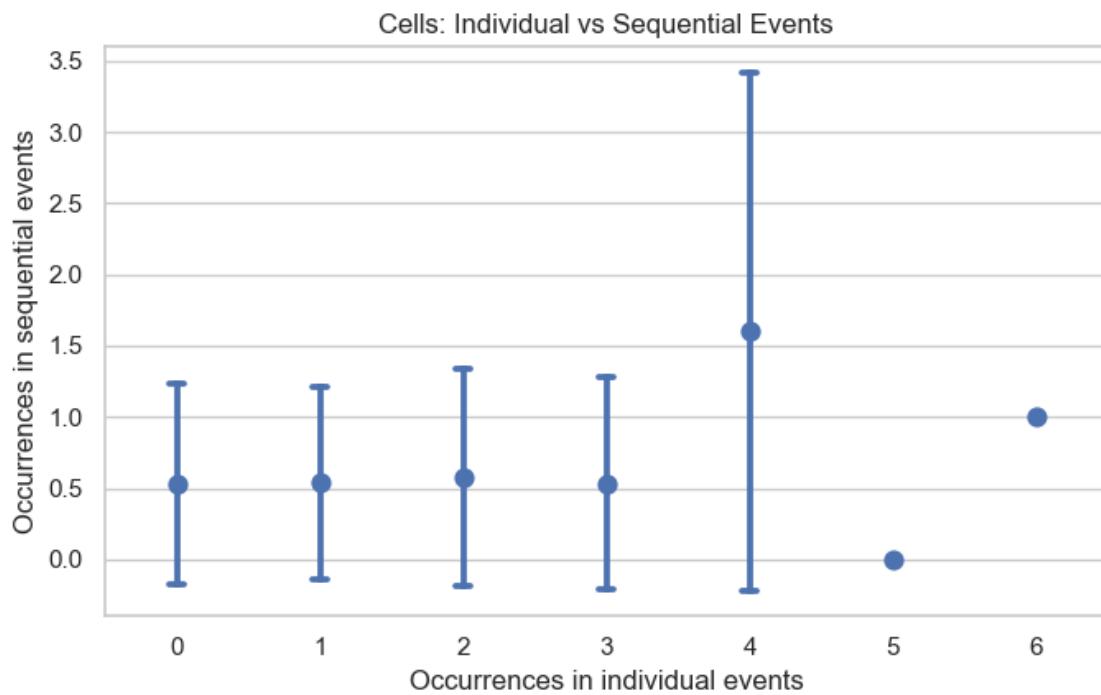
1.4.3 Correlation between event activity level & individual activity level



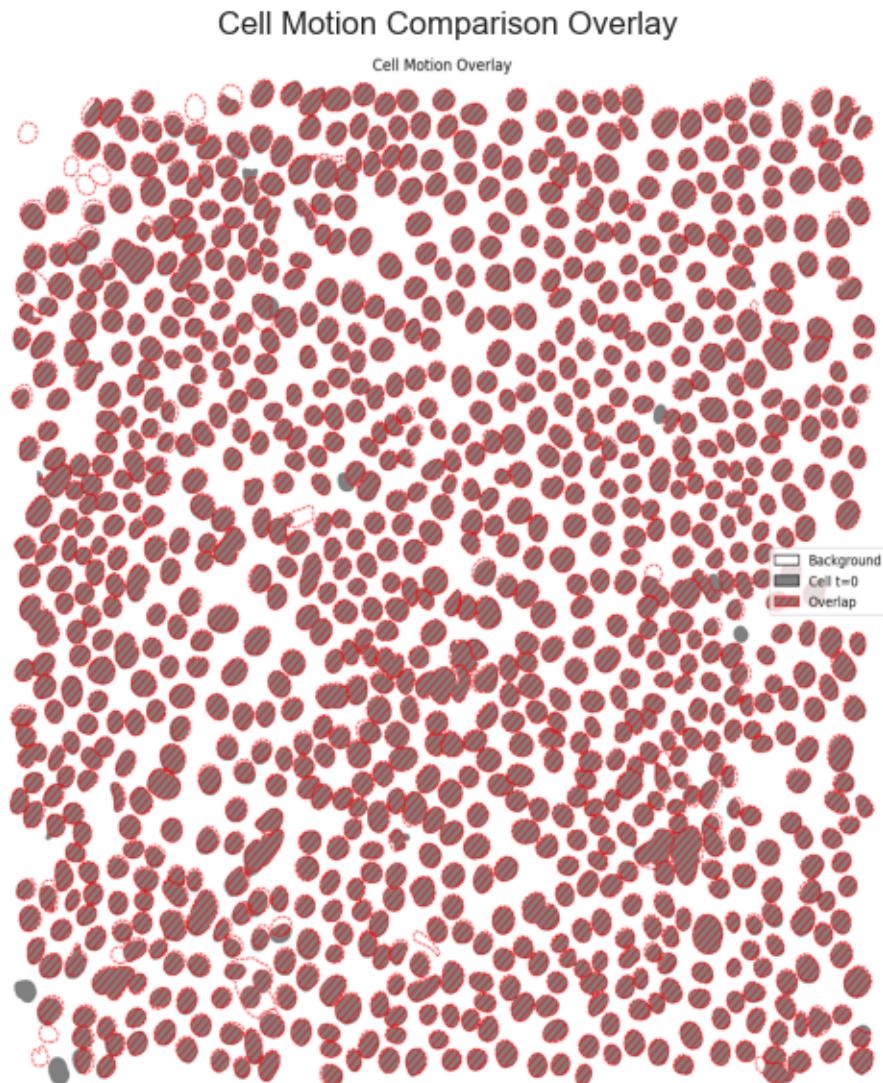
```
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: removed 1/996 outliers on 'Occurrences in sequential events' (lower=-3, upper=4)
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=669 for Occurrences in individual events=0
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=243 for Occurrences in individual events=1
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=61 for Occurrences in individual events=2
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=15 for Occurrences in individual events=3
[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=5 for Occurrences in individual events=4
```

[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=5

[2025-08-27 15:08:48] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 996
- Hoechst image taken at t=1801: 989
- Number of cells difference: absolute 7, relative 0.70%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 970478
- Pixels segmented as cell at t=1801: 968409
- Overlapping pixels between t=0 and t=1801: 891662 (91.98% of total)
- Pixels exclusive to t=0: 78816 (8.12% of total)
- Pixels exclusive to t=1801: 76747 (7.92% of total)

executed

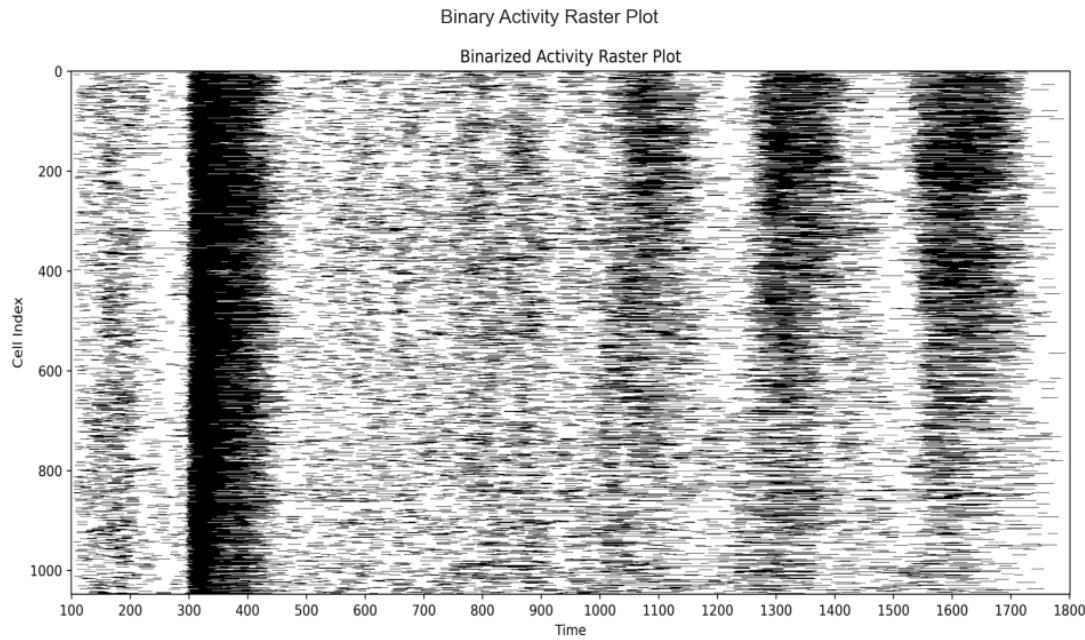
August 27, 2025

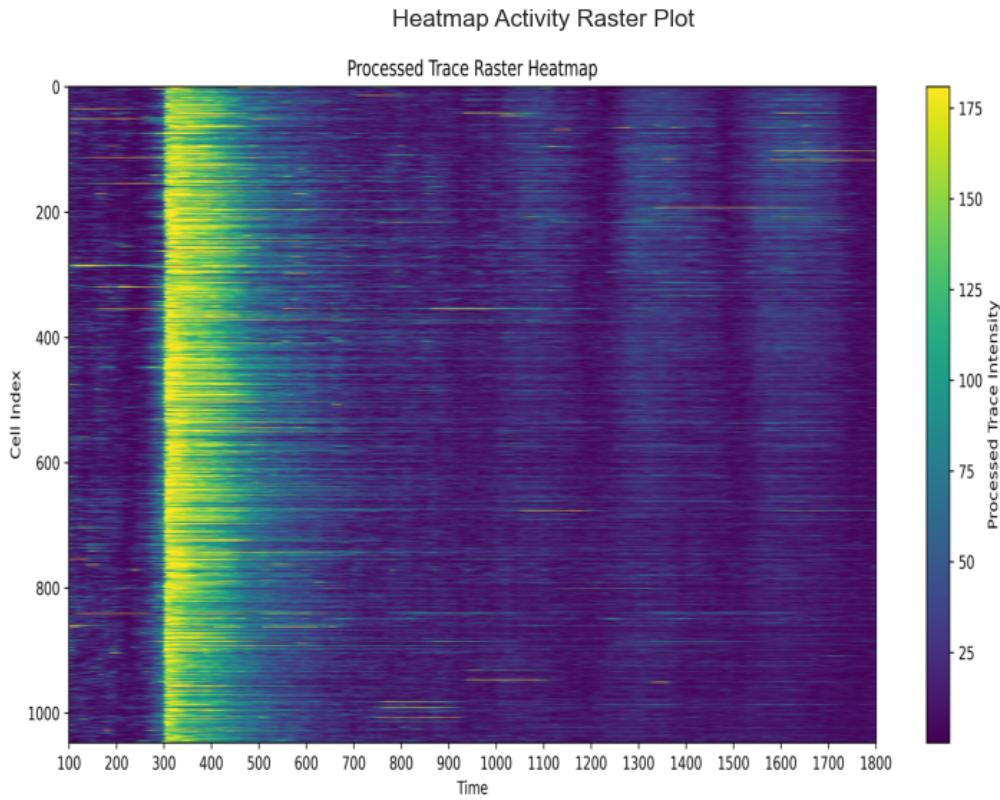
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





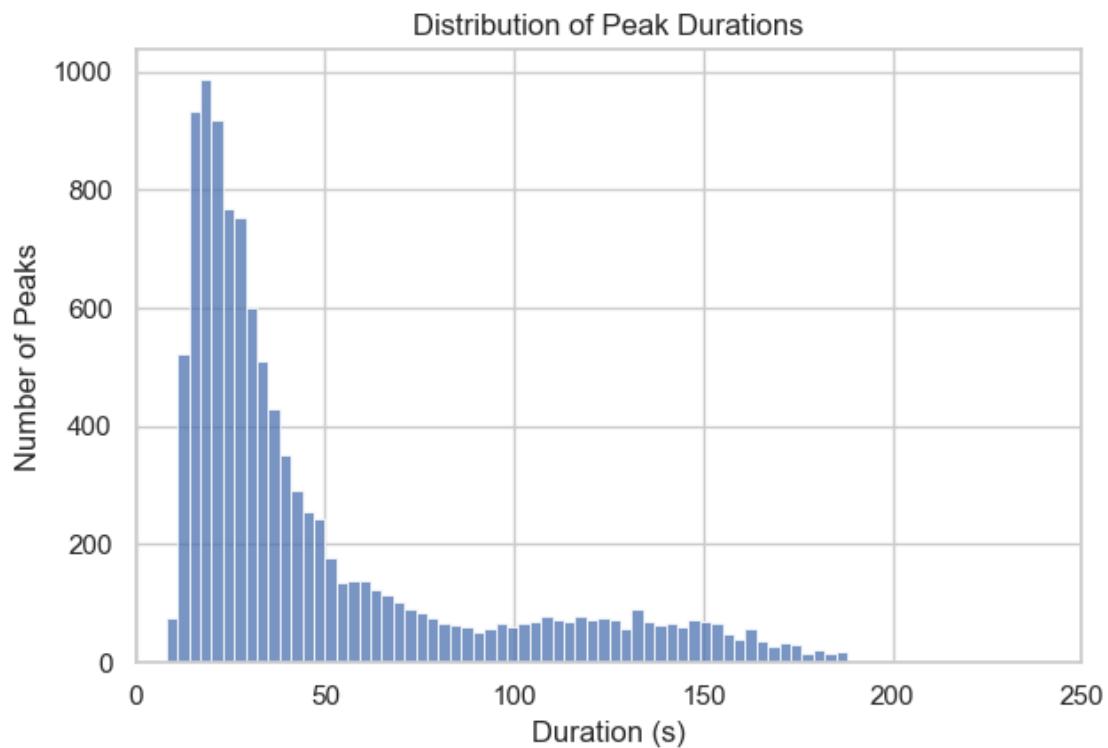
1.1.2 Peaks population

Total number of peaks: 11008

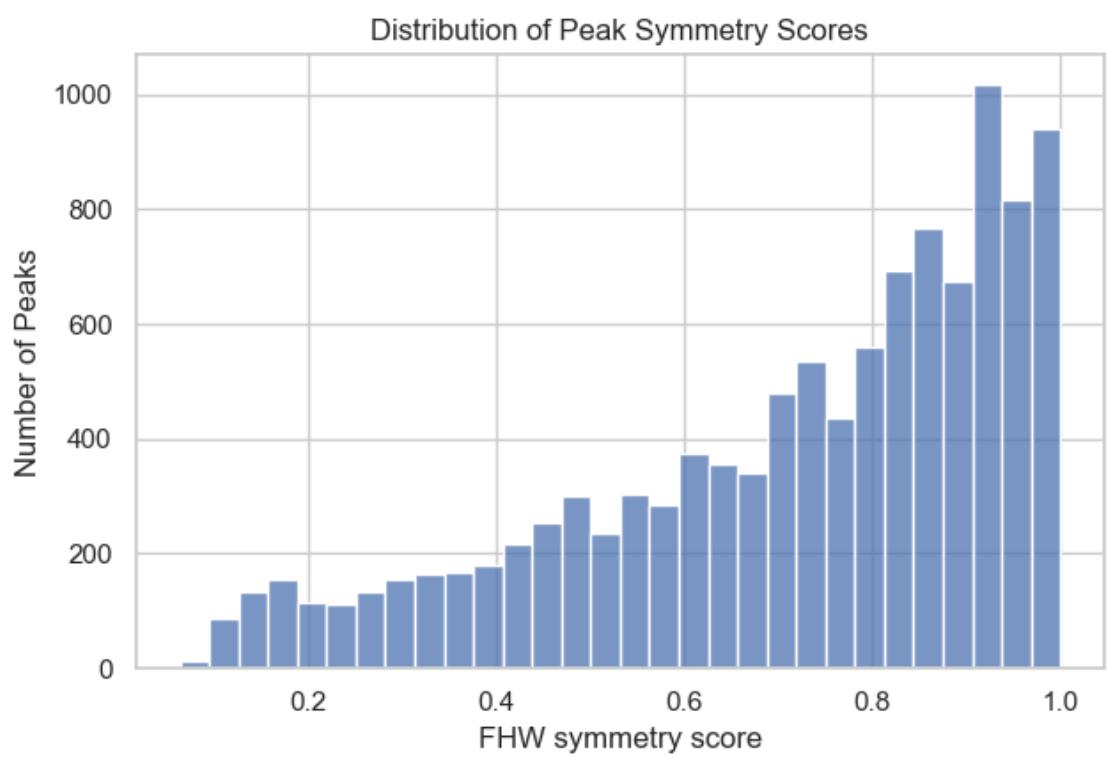
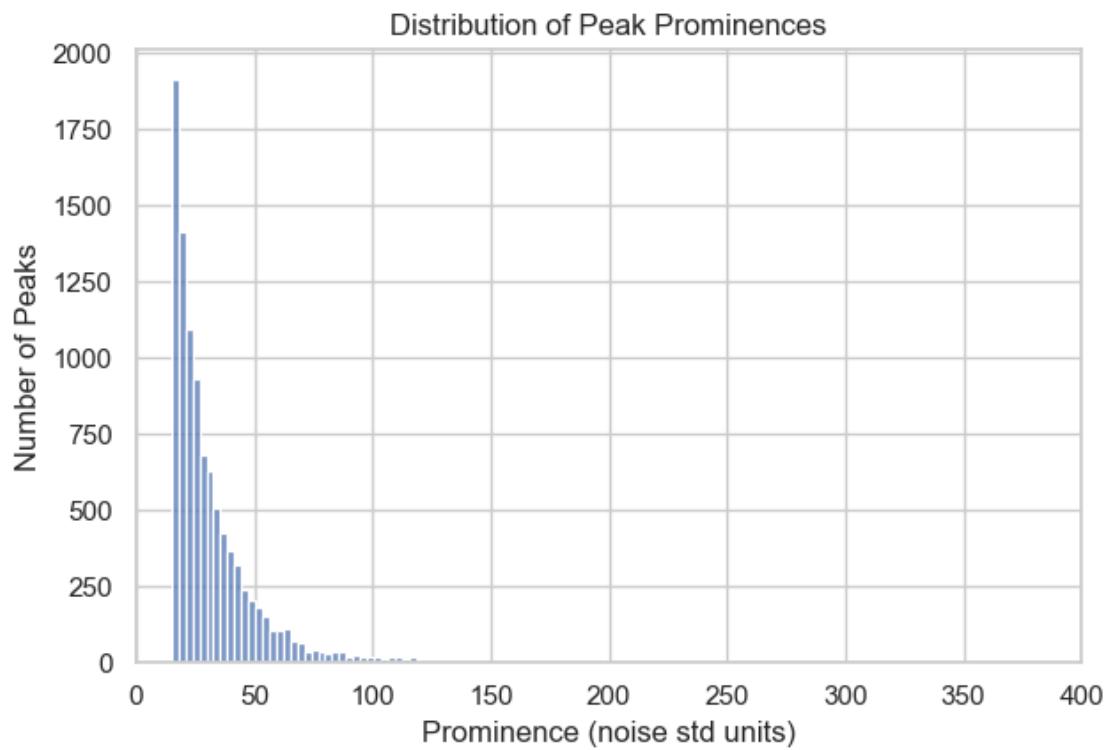
Total number of cells: 1048

1.1.3 Peaks statistics

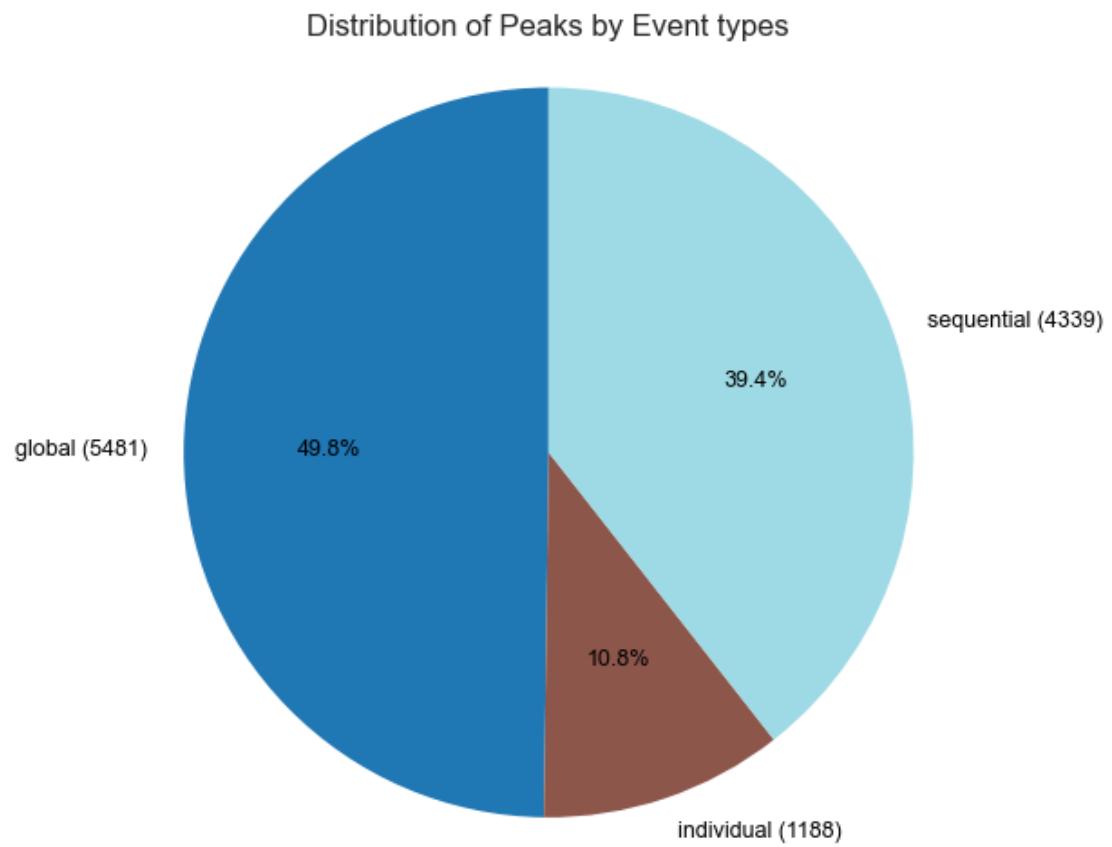
```
[2025-08-27 15:13:44] [INFO] calcium: plot_histogram: removed 133 outliers out  
of 11008 on 'Duration (s)' (lower=-106, upper=188)
```



```
[2025-08-27 15:13:44] [INFO] calcium: plot_histogram: removed 1101 outliers out  
of 11008 on 'Prominence (noise std units)' (lower=-54.5, upper=118.4)
```

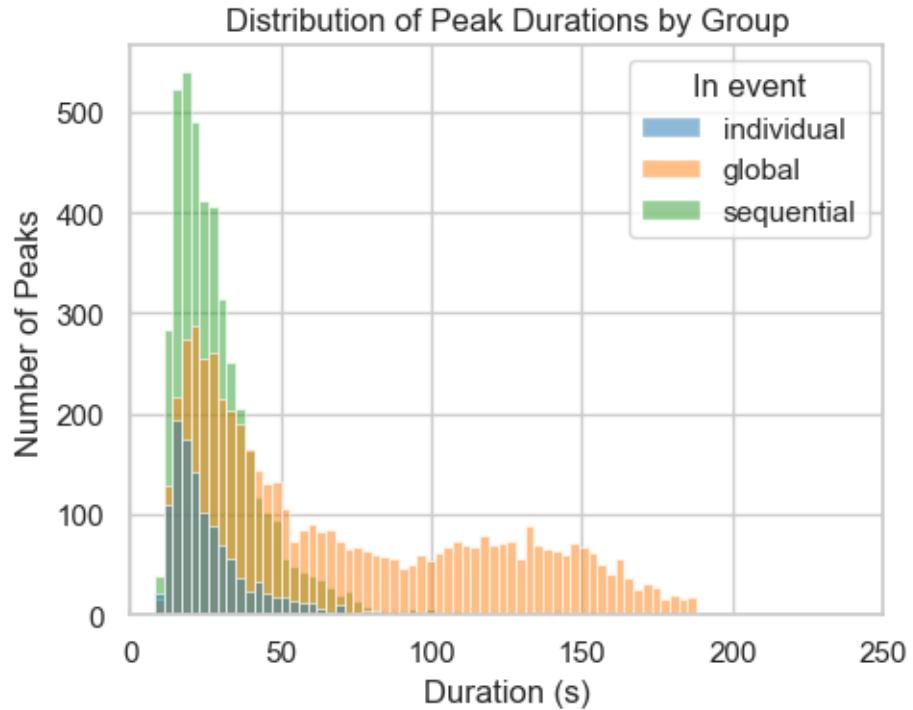


1.1.4 Distribution of peaks per event types

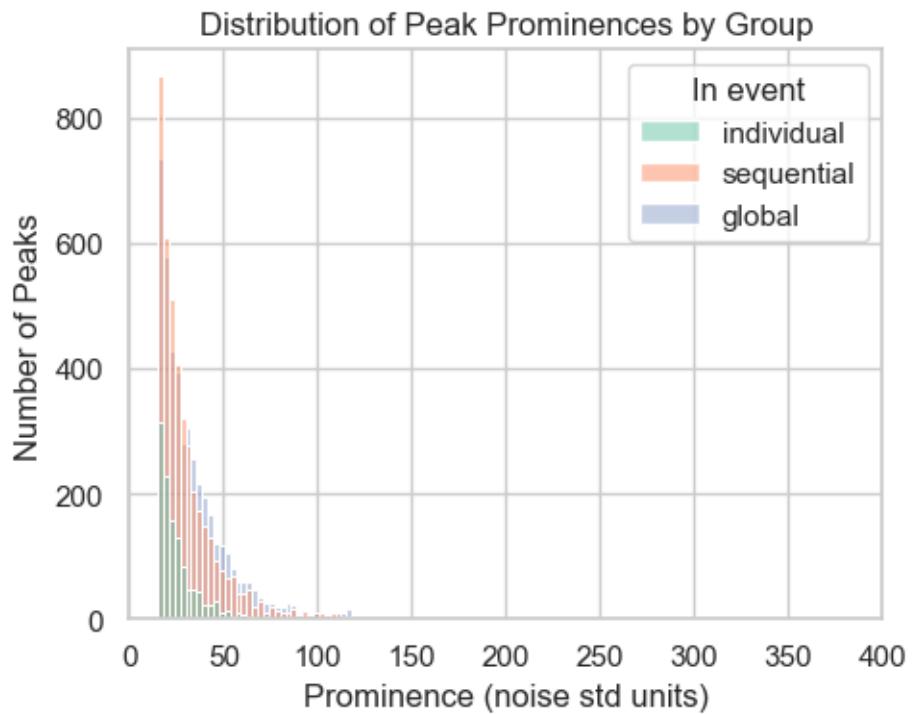


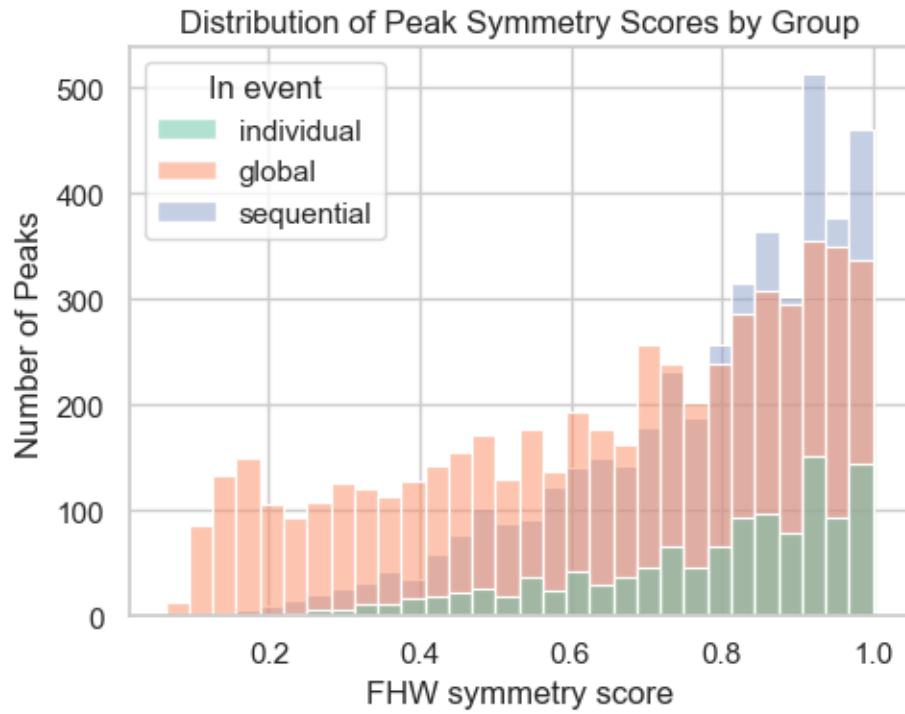
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:13:44] [INFO] calcium: plot_histogram_by_group: removed 133 outliers out of 11008 on 'Duration (s)' (lower=-106, upper=188)
```



```
[2025-08-27 15:13:45] [INFO] calcium: plot_histogram_by_group: removed 1101 outliers out of 11008 on 'Prominence (noise std units)' (lower=-54.5, upper=118.4)
```

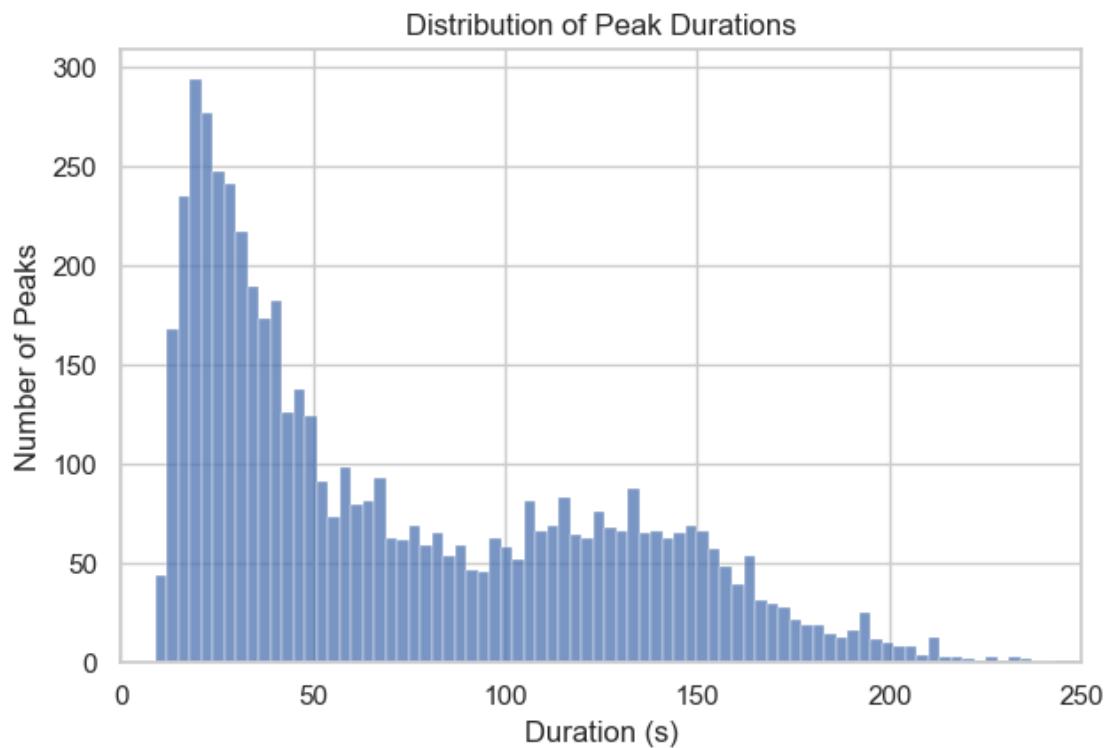




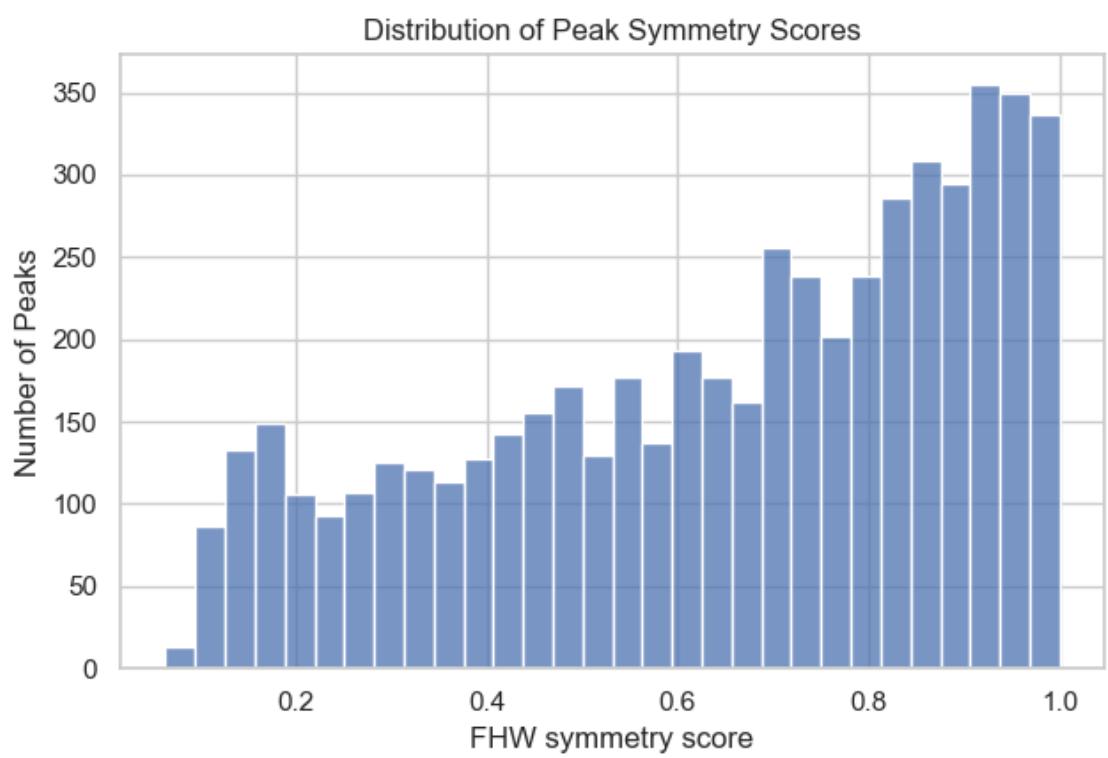
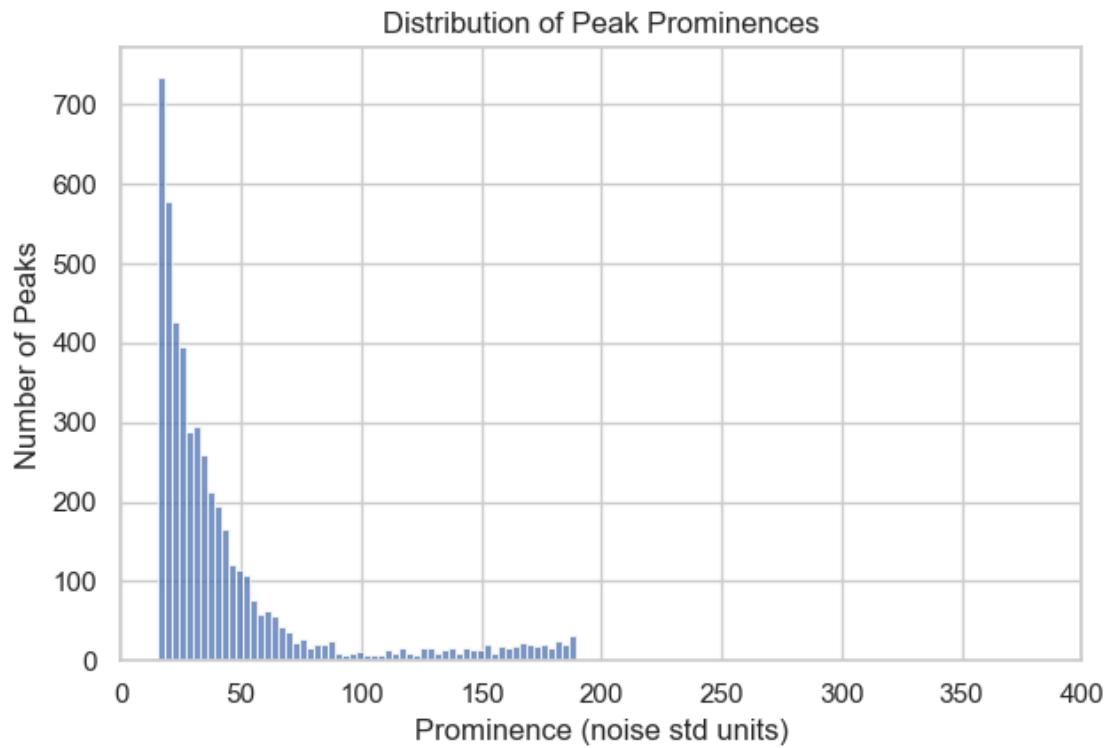
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:13:45] [INFO] calcium: plot_histogram: removed 0 outliers out of 5481 on 'Duration (s)' (lower=-230, upper=372)
```

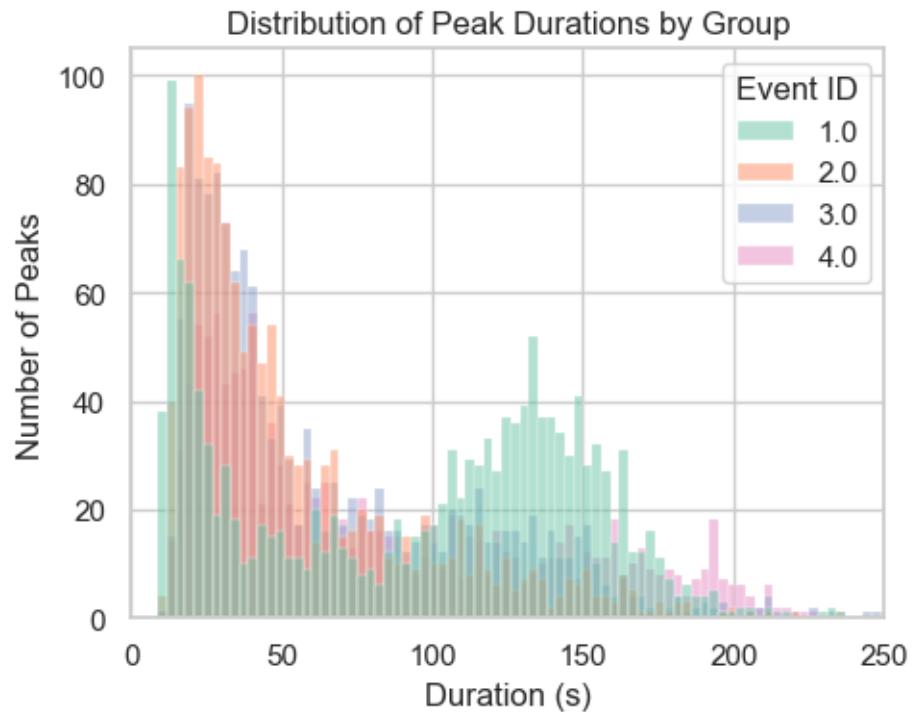


```
[2025-08-27 15:13:45] [INFO] calcium: plot_histogram: removed 628 outliers out  
of 5481 on 'Prominence (noise std units)' (lower=-105.7, upper=190.4)
```

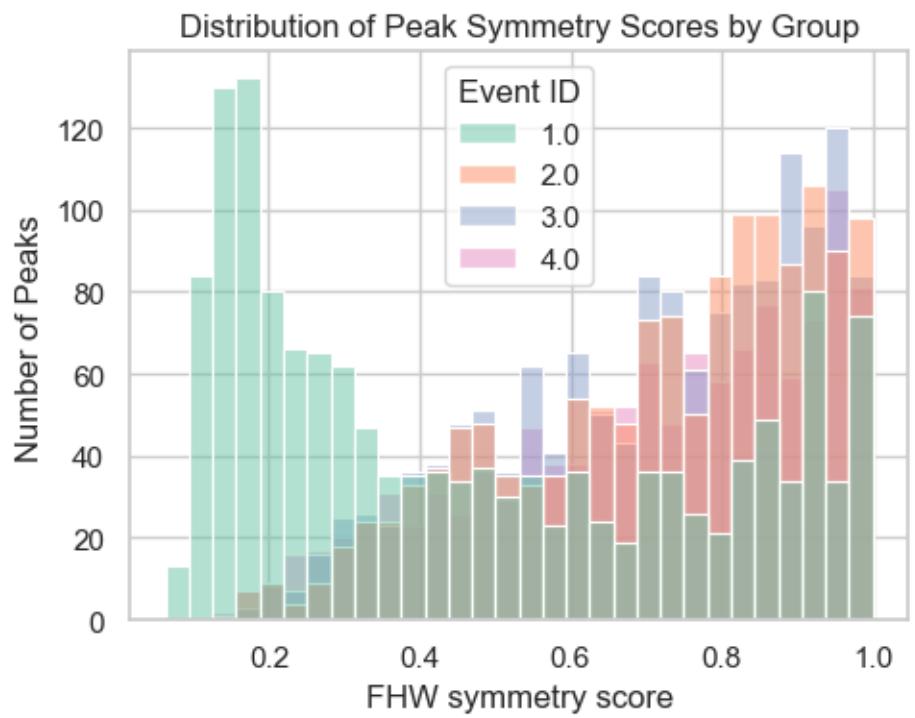
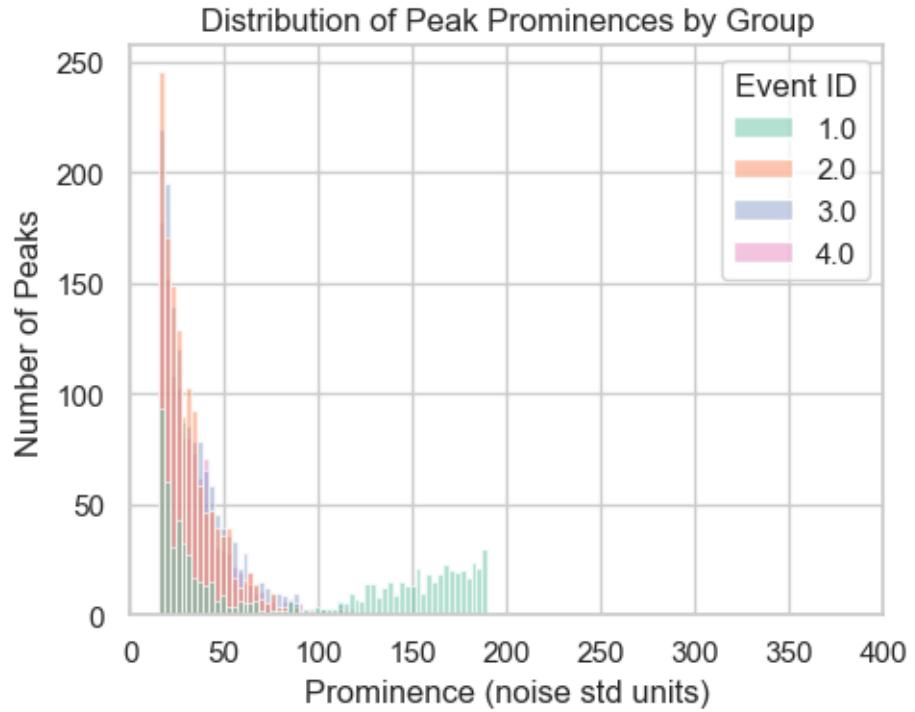


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:13:46] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5481 on 'Duration (s)' (lower=-230, upper=372)

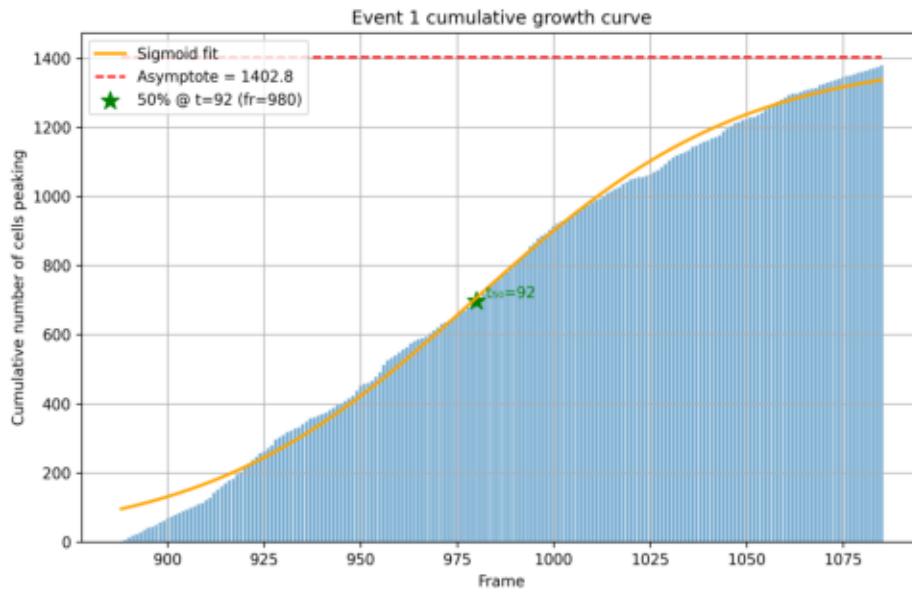


[2025-08-27 15:13:46] [INFO] calcium: plot_histogram_by_group: removed 628 outliers out of 5481 on 'Prominence (noise std units)' (lower=-105.7, upper=190.4)

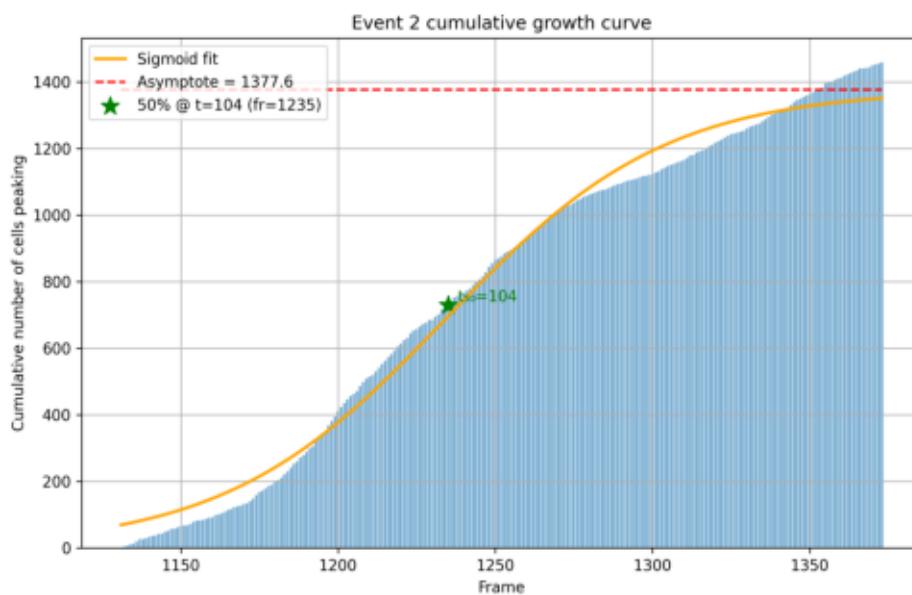


1.2.3 Kinetics of global events

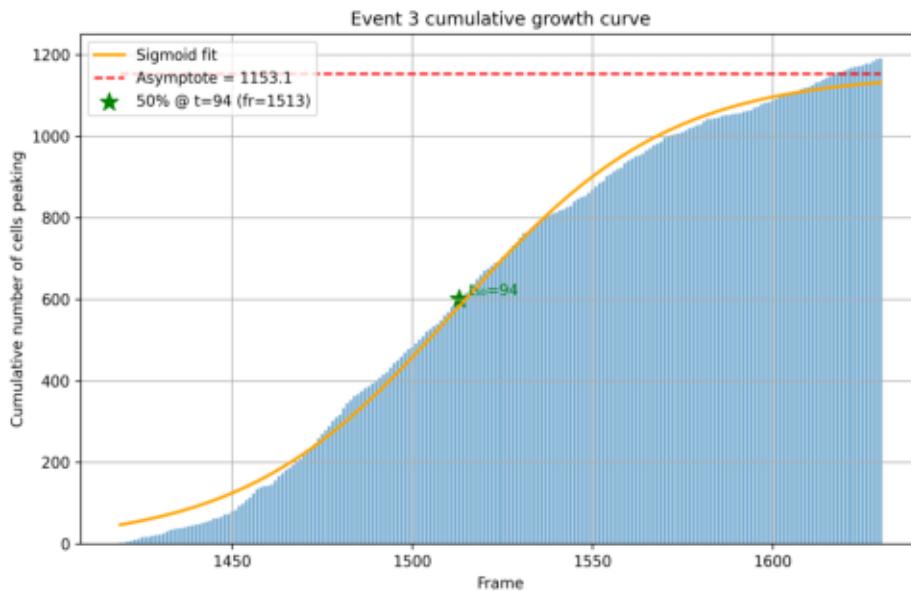
Event Activity Overlay (Event ID: 1)



Event Activity Overlay (Event ID: 2)

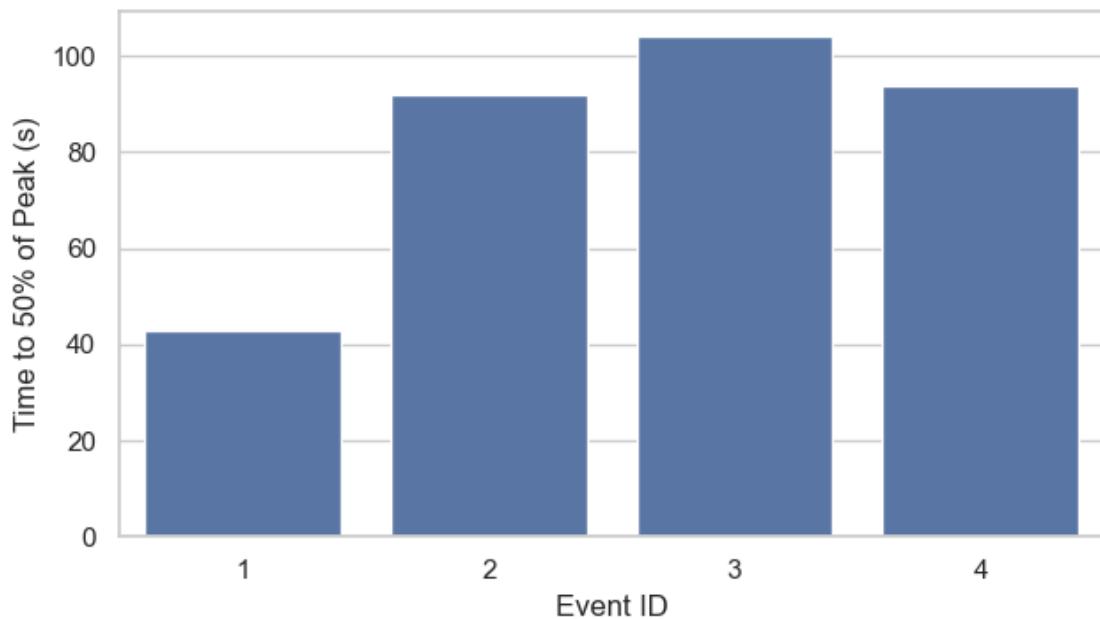


Event Activity Overlay (Event ID: 3)

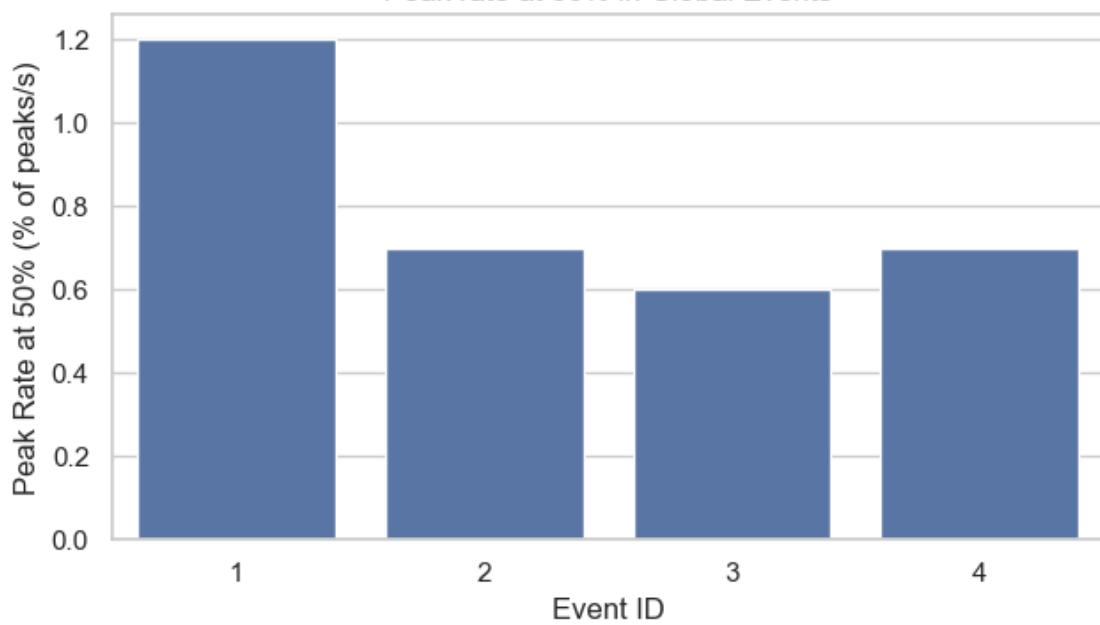


```
[2025-08-27 15:13:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250701\\\\Output\\\\IS2\\\\events\\\\event-growth-
curve-4.png'
Traceback (most recent call last):
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\src\\calcium_activity_characterizatio
n\\analysis\\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\.venv\\lib\\site-
packages\\matplotlib\\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\\Users\\poseidon\\OneDrive\\Documents\\01_ETHZ\\Master_Degree\\Spring_Semest
er_2025\\Master_Thesis\\Coding\\Image_analysis\\.venv\\lib\\site-
packages\\PIL\\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250701\\\\Output\\\\IS2\\\\events\\\\event-growth-curve-4.png'
```

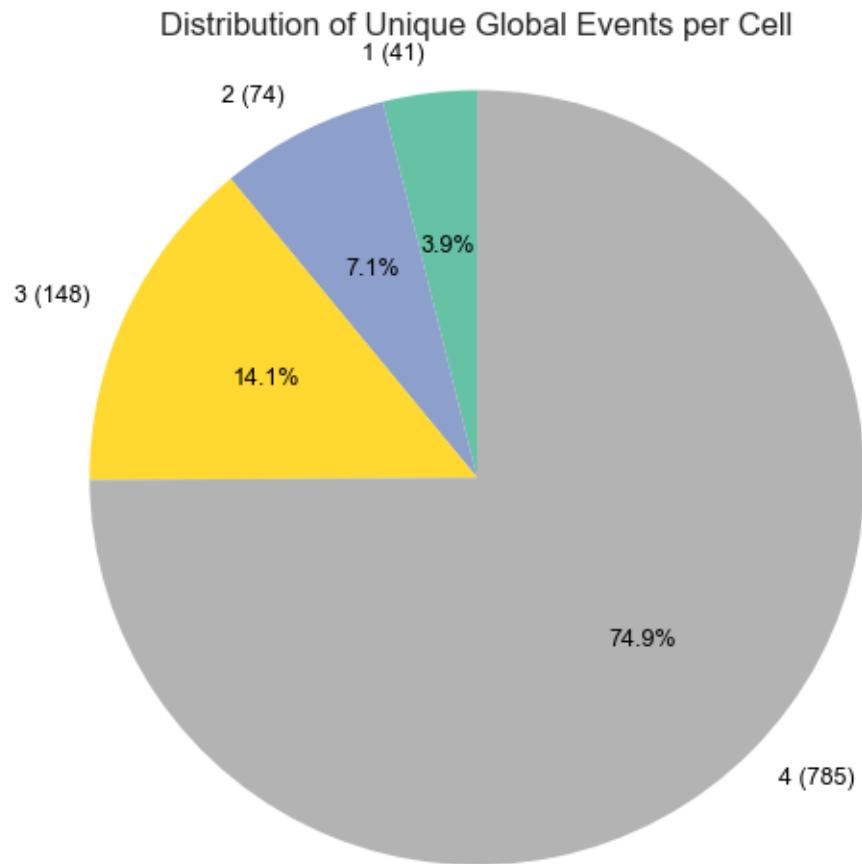
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

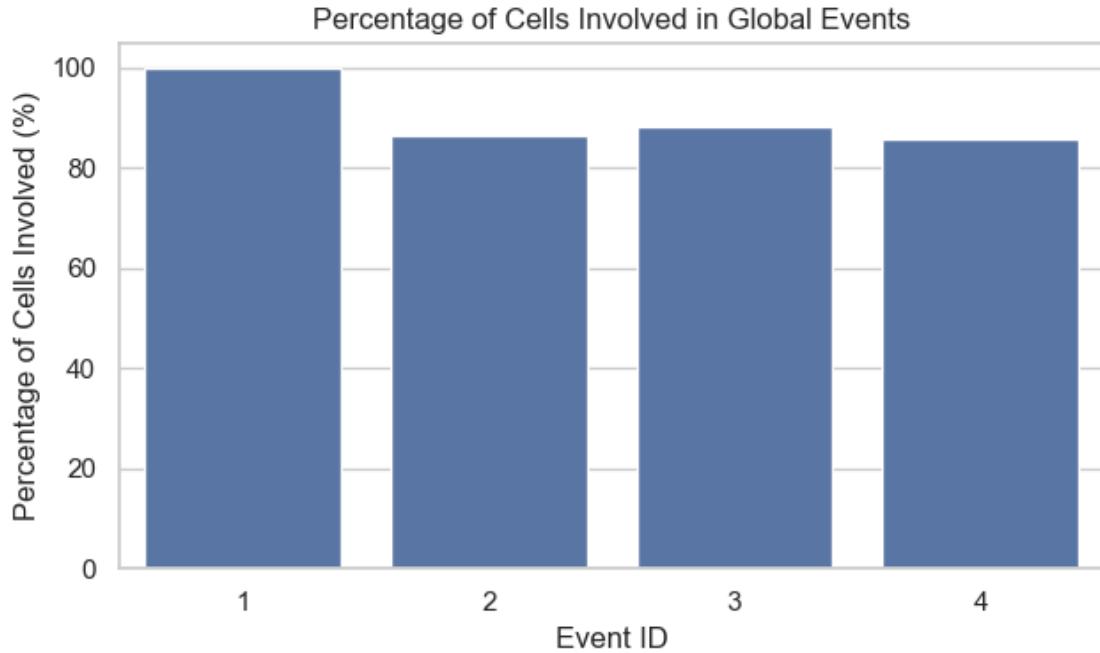


```
[2025-08-27 15:13:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250701\\\\Output\\\\IS2\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\IS2\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [754.0, 233.0, 288.0]
Estimated periodicity: 0.645

1.2.6 Early peakers in the events

```

[2025-08-27 15:13:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-

```

```

packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:13:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

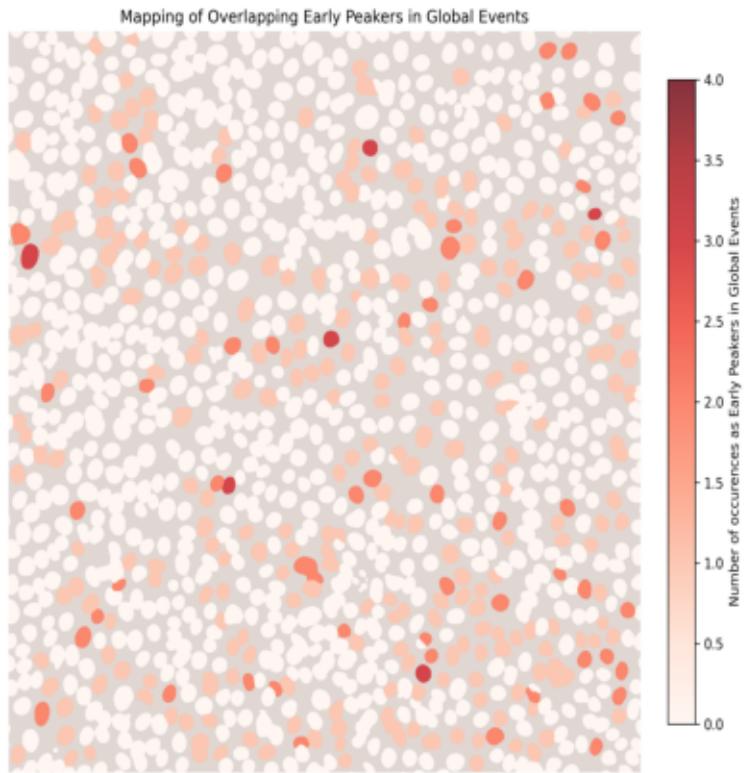
[2025-08-27 15:13:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)

```

```
    raise SyntaxError(msg)
SyntaxError: not a PNG file

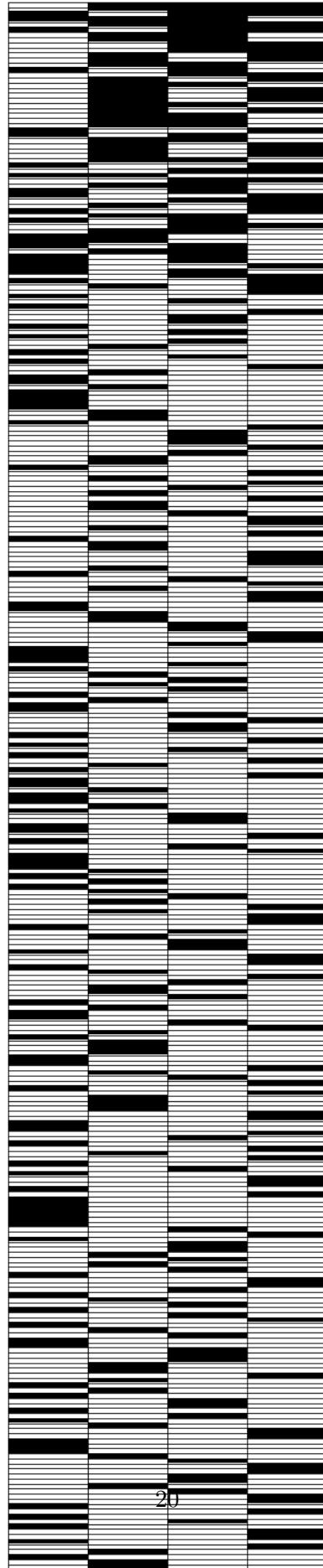
[2025-08-27 15:13:50] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



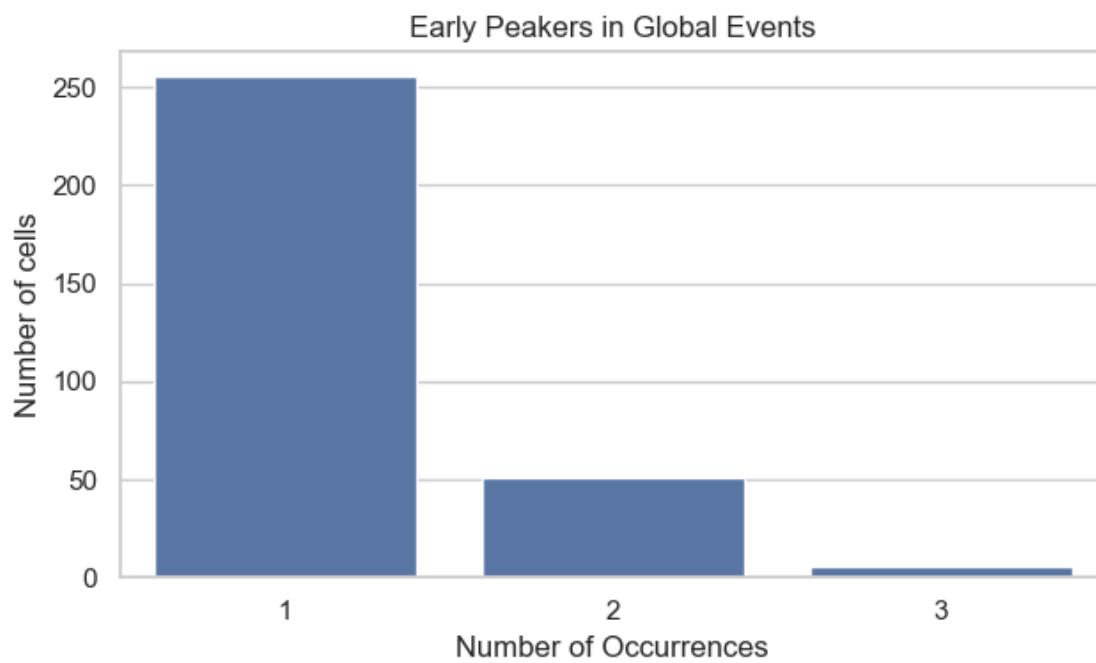
[2025-08-27 15:13:50] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 4 unique event IDs.

[2025-08-27 15:13:50] [INFO] calcium: Early peakers event-matrix: 312 cells x 4 events; black squares: 375

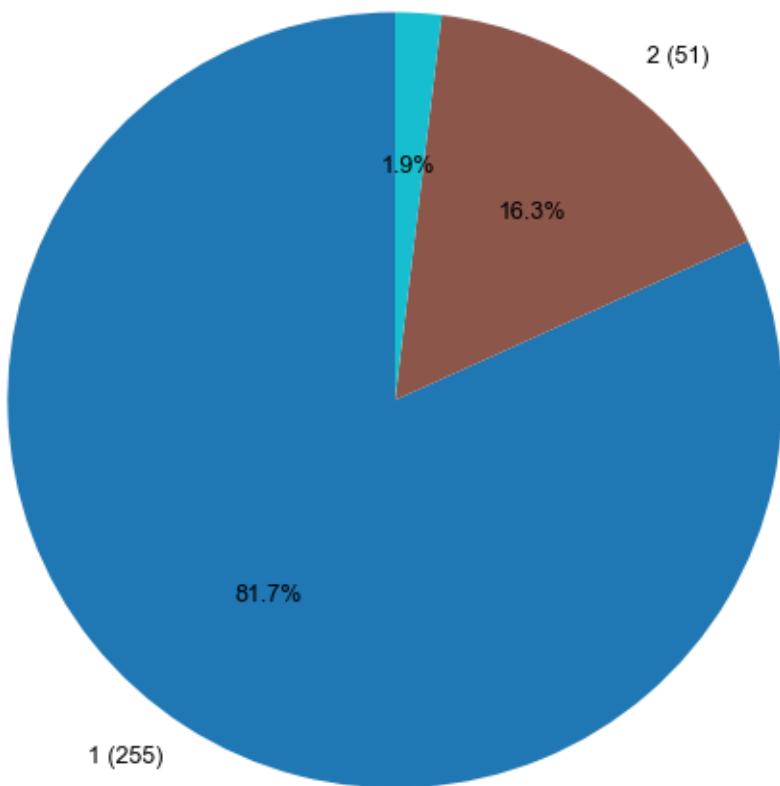


```
[2025-08-27 15:13:51] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[0, 1, 1, 1],  
           [0, 1, 1, 1],  
           [1, 0, 1, 1],  
           ...,  
           [0, 1, 0, 0],  
           [0, 1, 0, 0],  
           [1, 0, 0, 0]])
```

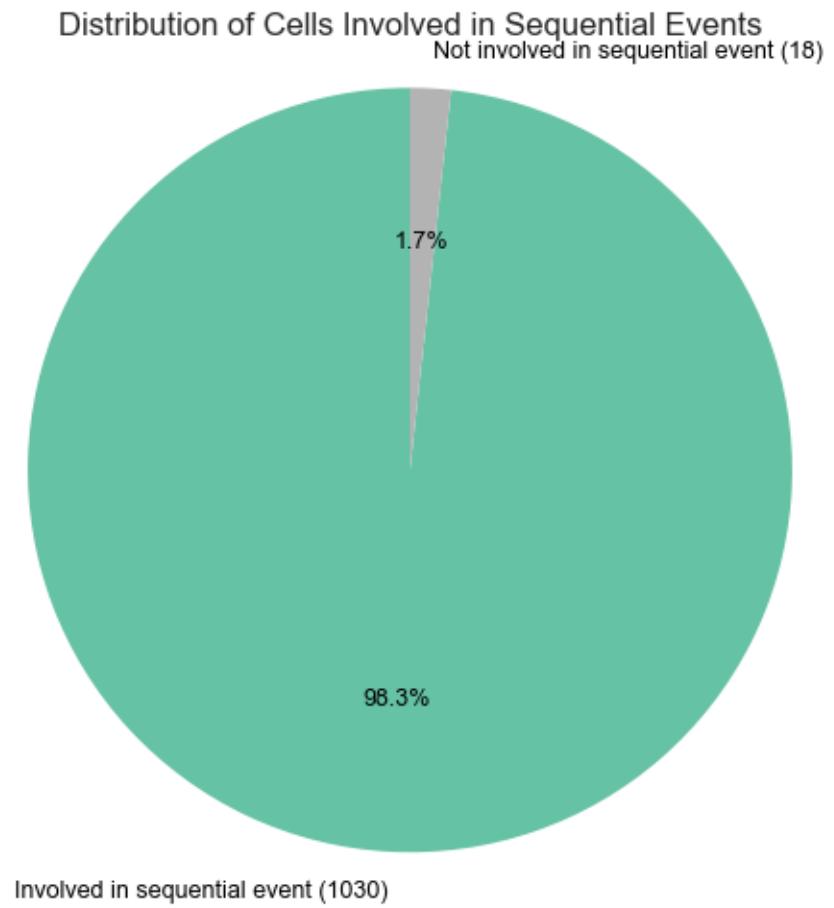


Distribution of Early Peakers in Global Events
3 (6)

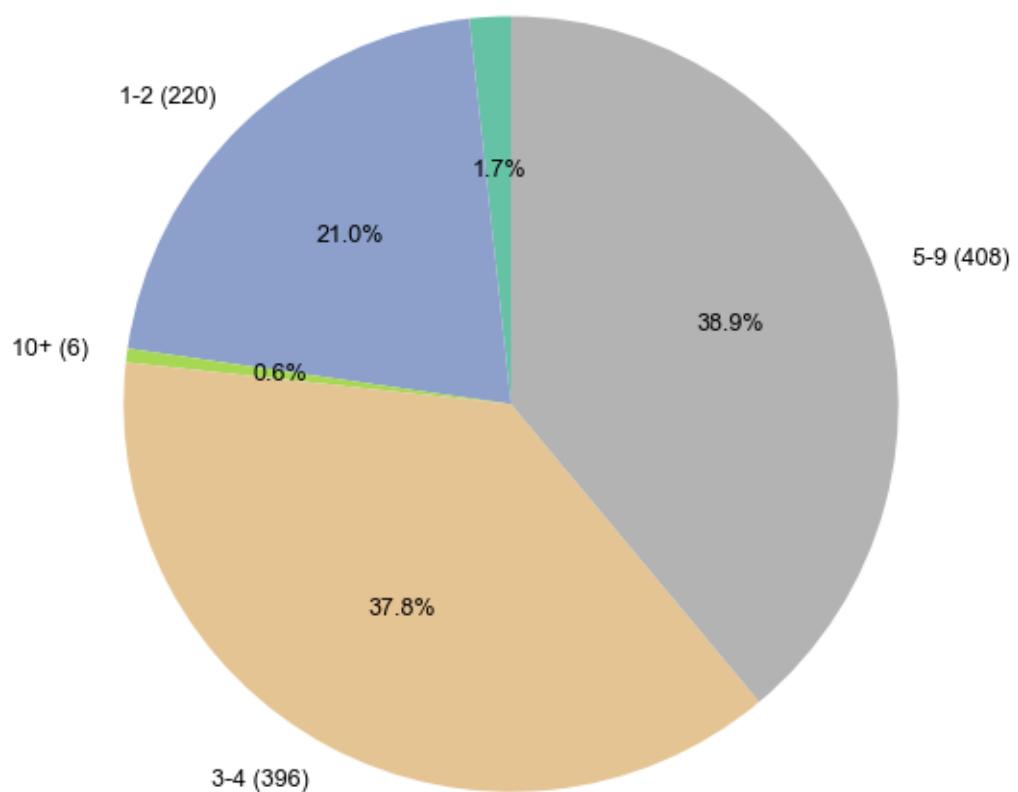


1.3 SEQUENTIAL EVENTS

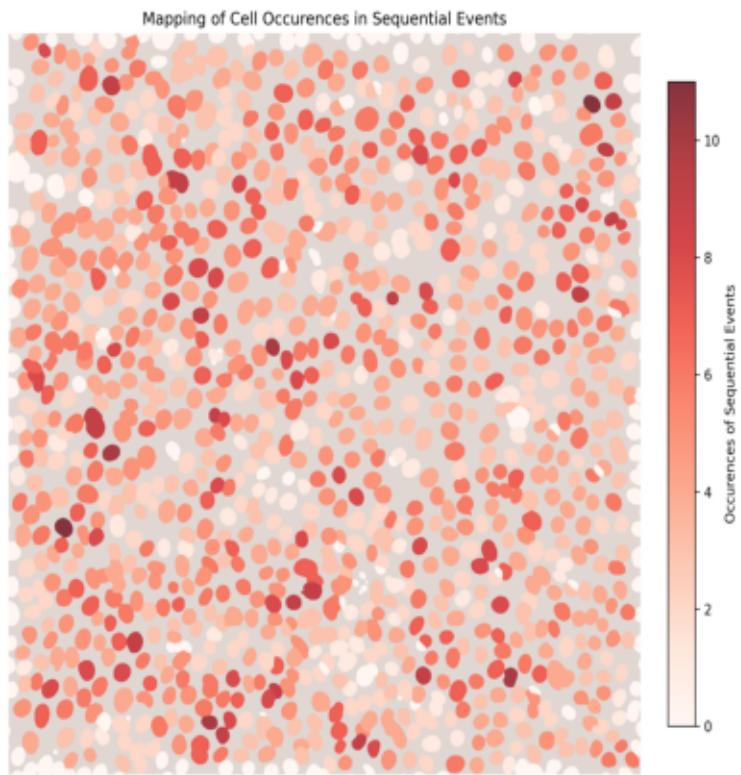
1.3.1 Cells Occurrences in sequential events



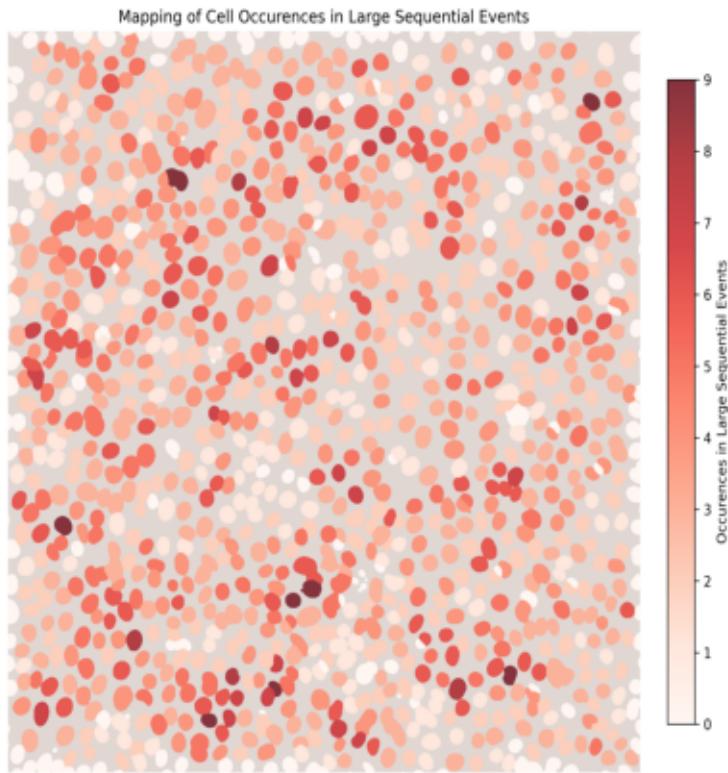
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

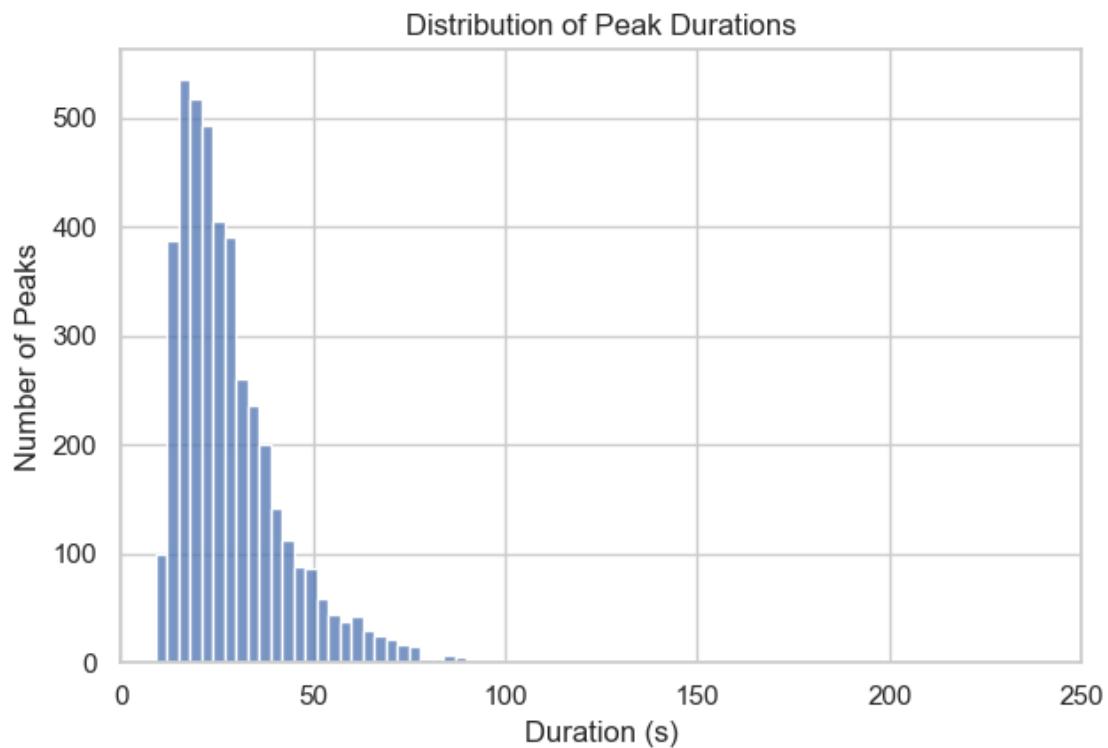


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

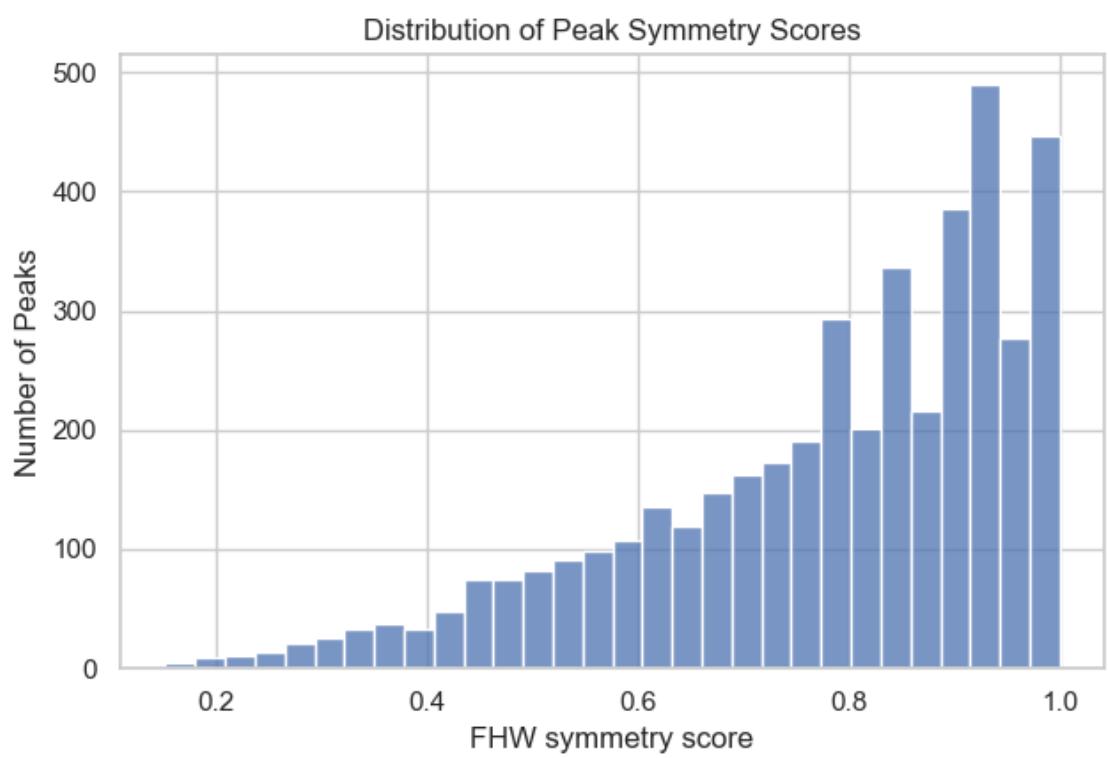
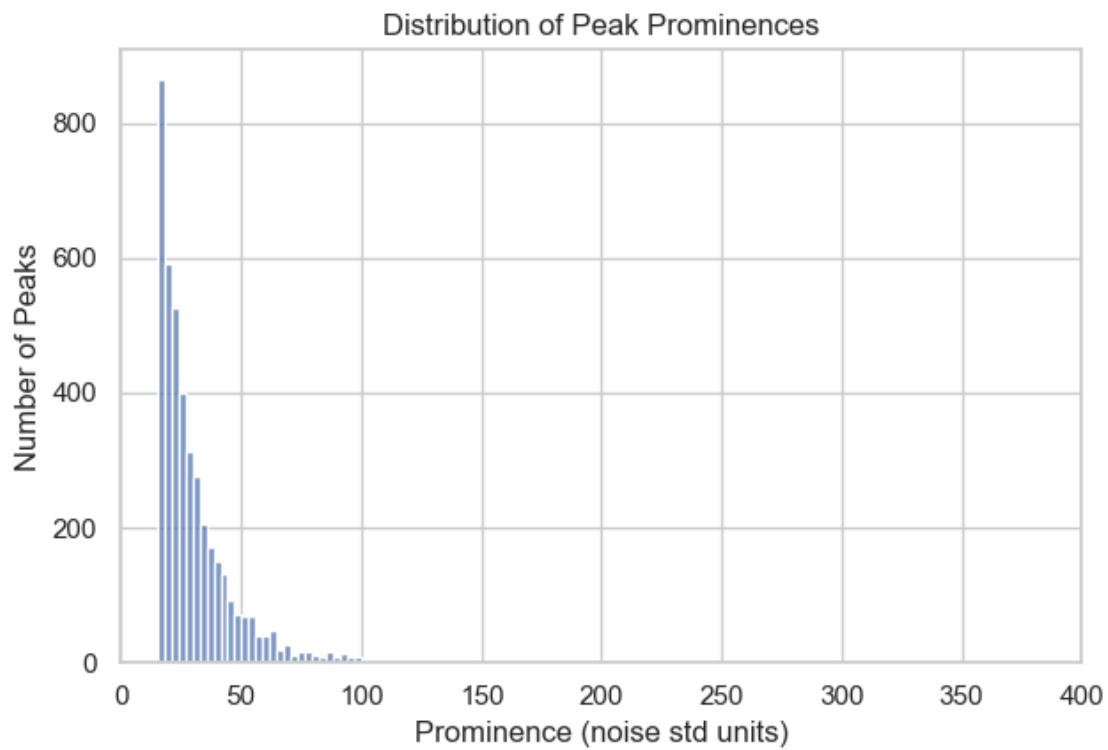


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:13:53] [INFO] calcium: plot_histogram: removed 74 outliers out of  
4339 on 'Duration (s)' (lower=-6, upper=90)
```

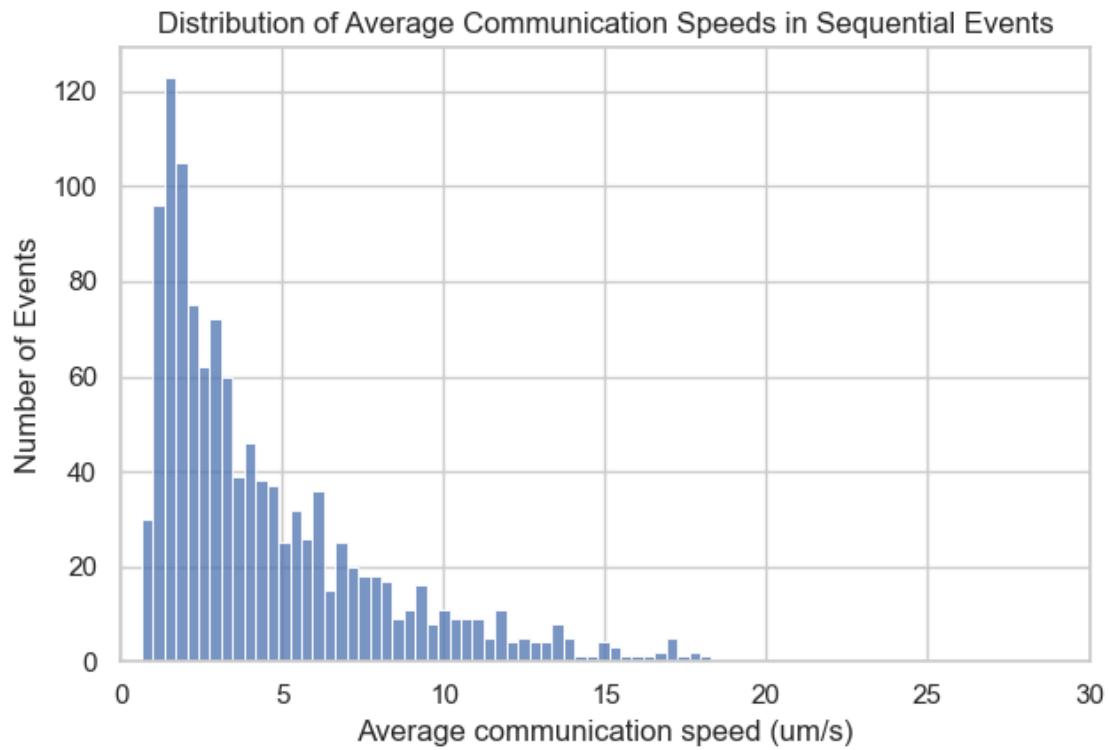


```
[2025-08-27 15:13:53] [INFO] calcium: plot_histogram: removed 113 outliers out  
of 4339 on 'Prominence (noise std units)' (lower=-8.25, upper=100.35)
```



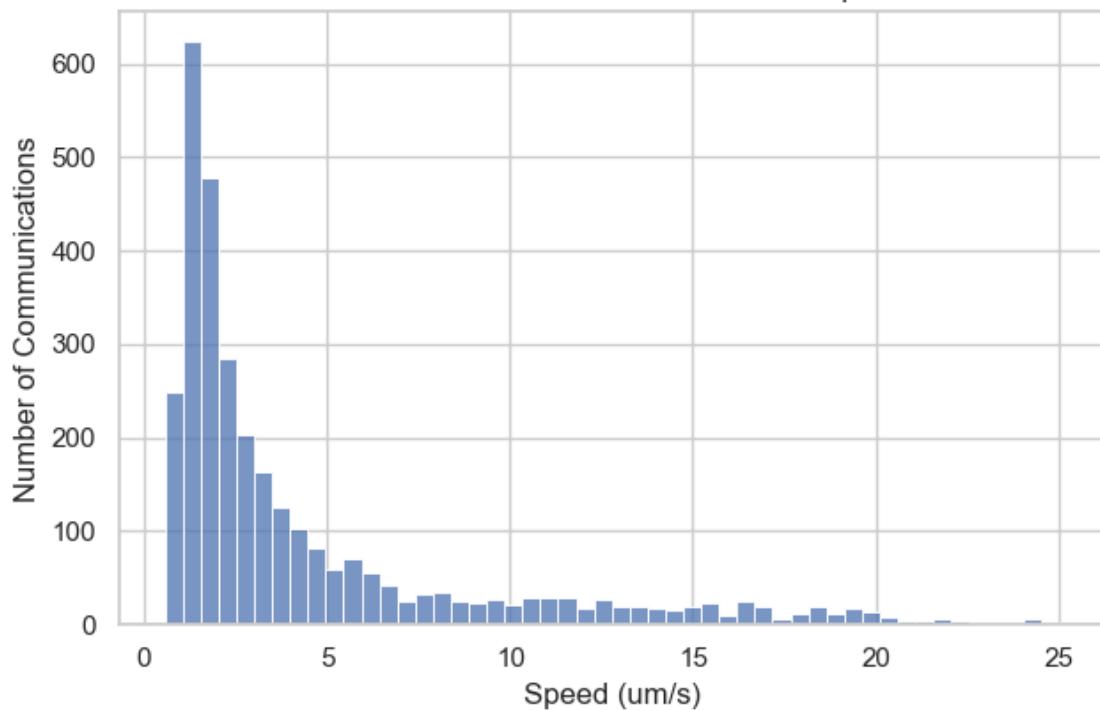
1.3.3 Cell-cell communication speed

```
[2025-08-27 15:13:54] [INFO] calcium: plot_histogram: removed 9 outliers out of  
1175 on 'Average communication speed (um/s)' (lower=-10.67, upper=18.59)
```

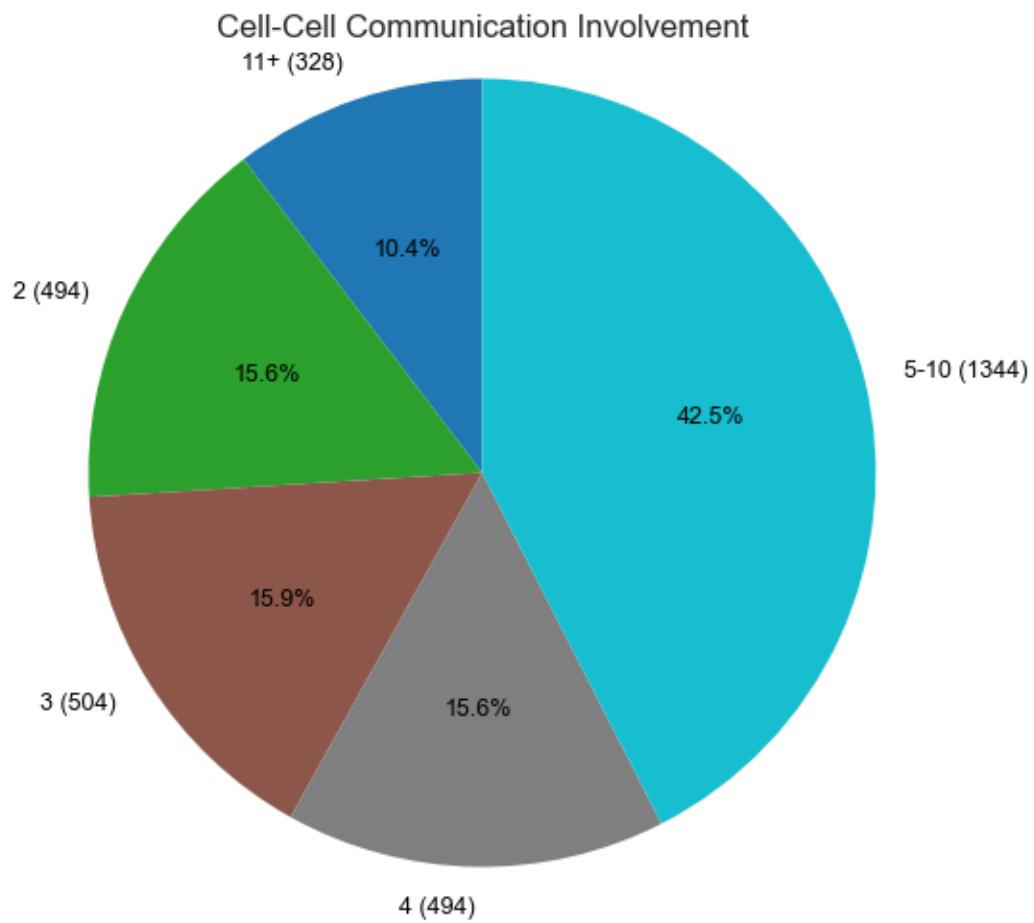


```
[2025-08-27 15:13:54] [INFO] calcium: plot_histogram: removed 11 outliers out of  
3164 on 'Speed (um/s)' (lower=-10.49, upper=25.42)
```

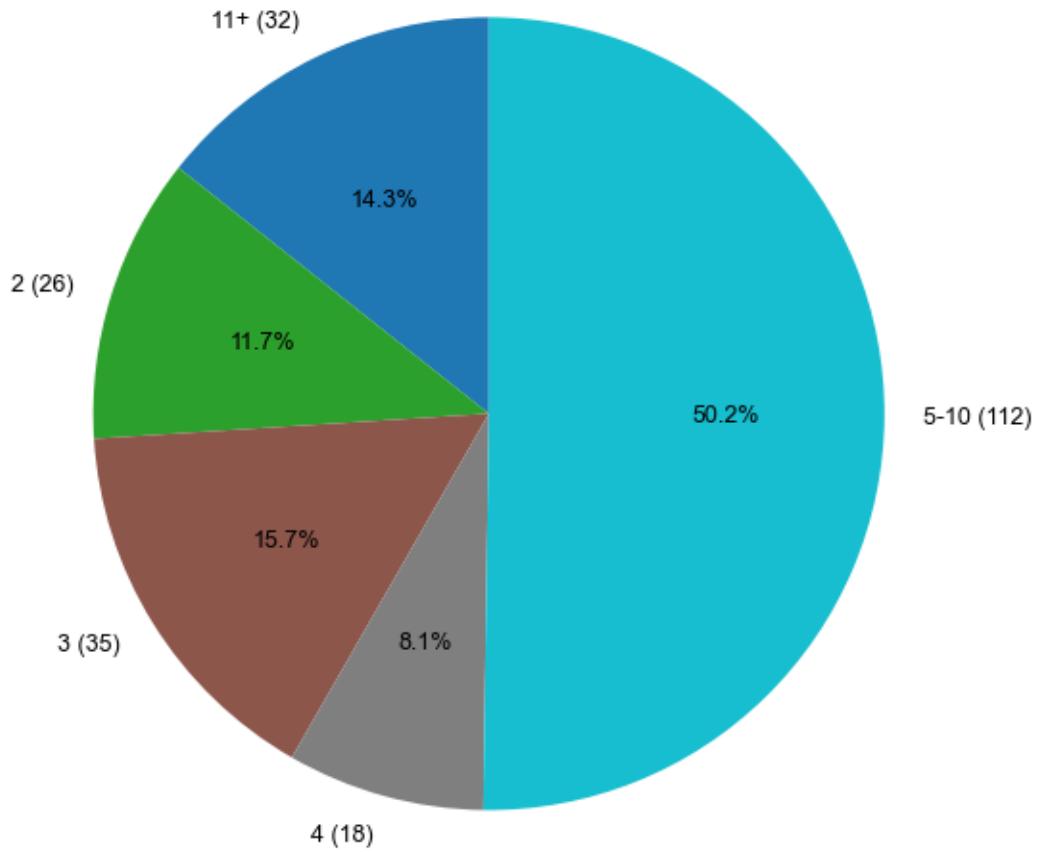
Distribution of Cell-Cell Communication Speeds



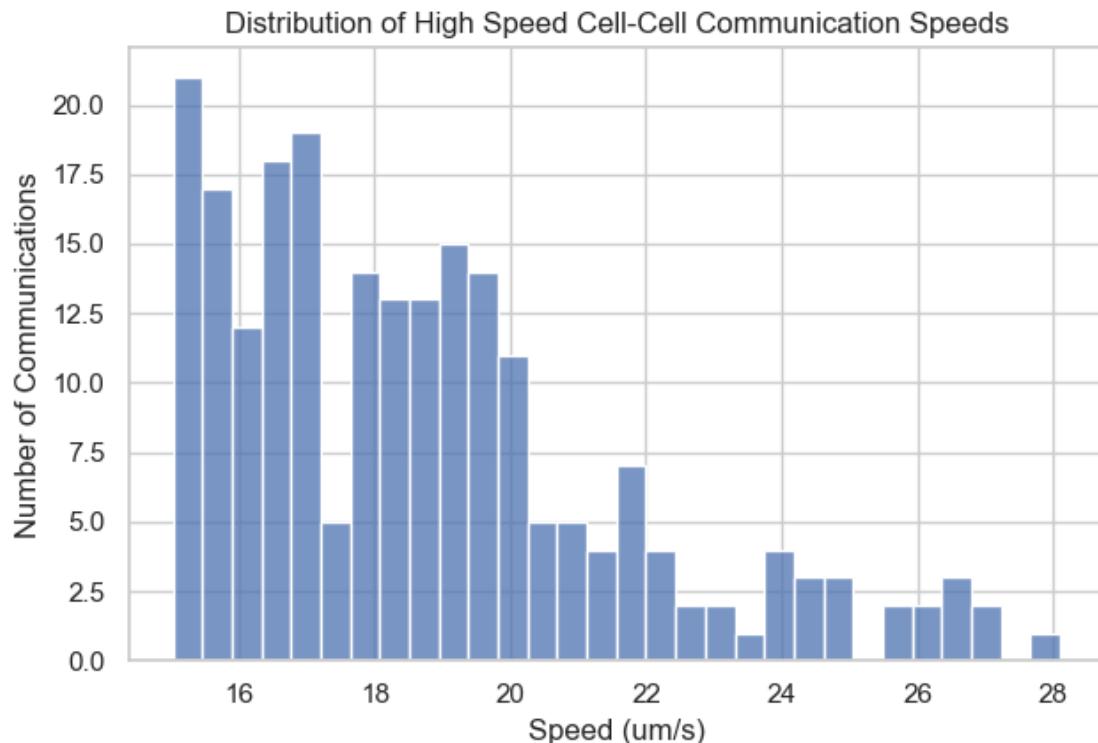
1.3.4 Double distribution in cell-cell communication speeds



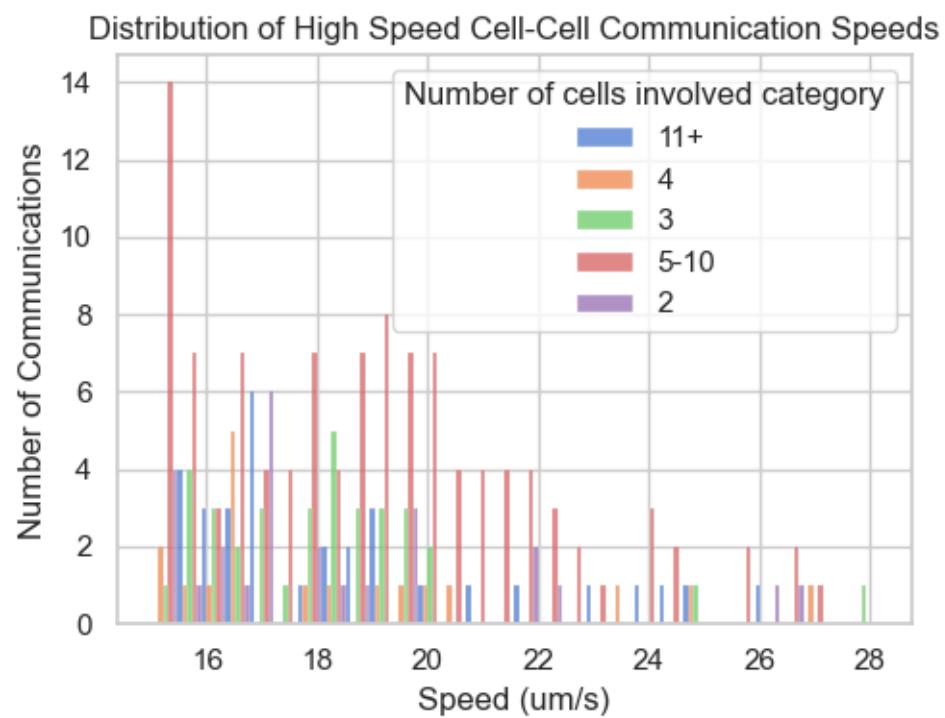
High Speed Cell-Cell Communication Involvement



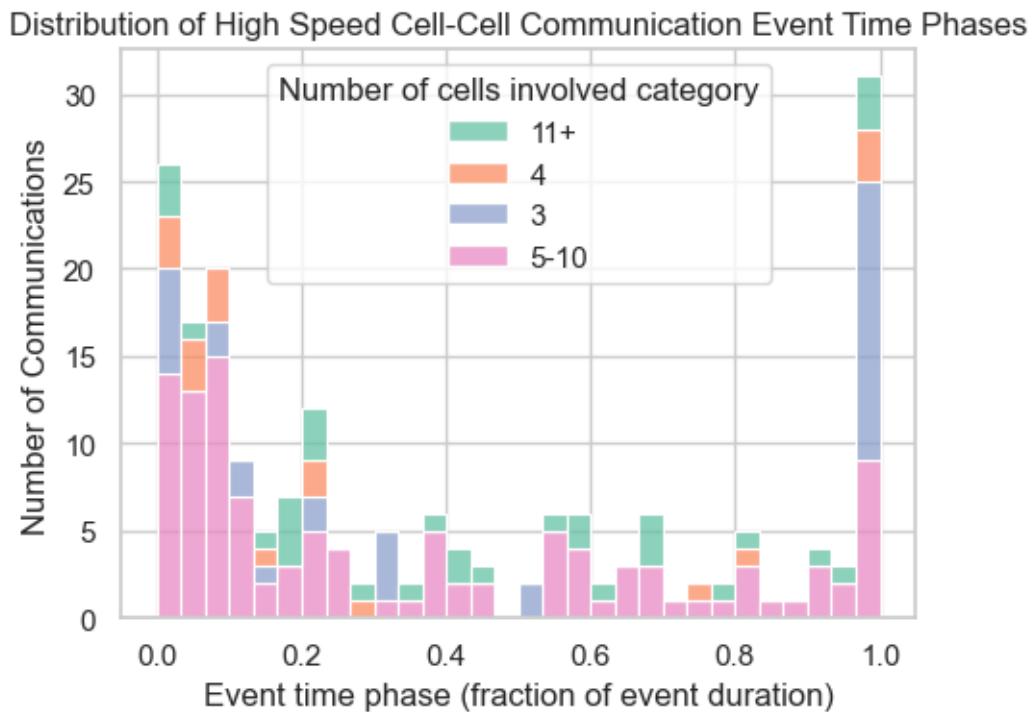
[2025-08-27 15:13:54] [INFO] calcium: plot_histogram: removed 1 outliers out of 223 on 'Speed (um/s)' (lower=5.545, upper=30.99)



```
[2025-08-27 15:13:55] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 223 on 'Speed (um/s)' (lower=5.545, upper=30.99)
```

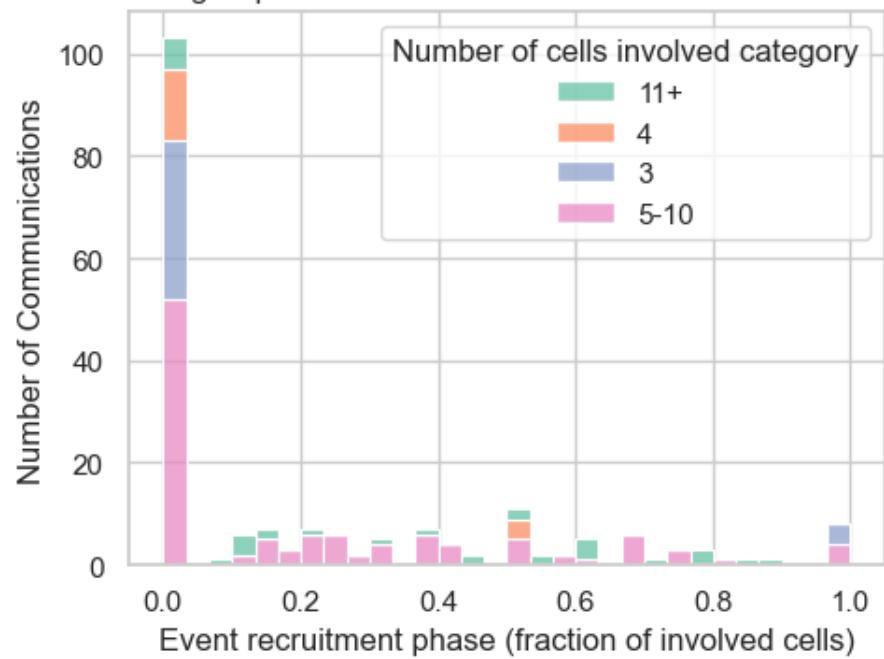


[2025-08-27 15:13:55] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 197 on 'Event time phase (fraction of event duration)' (lower=-1.78, upper=2.56)

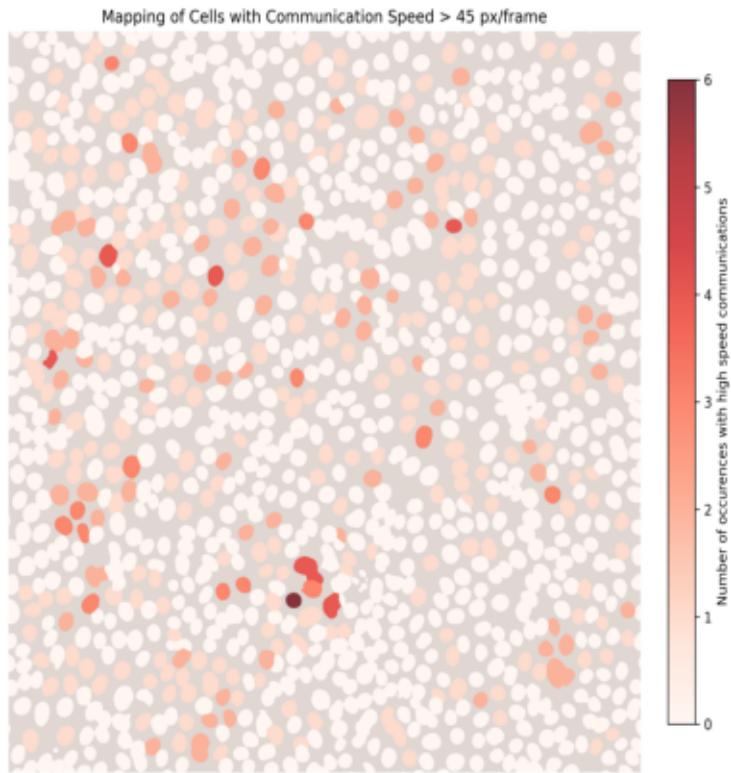


[2025-08-27 15:13:55] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 197 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.2, upper=1.6)

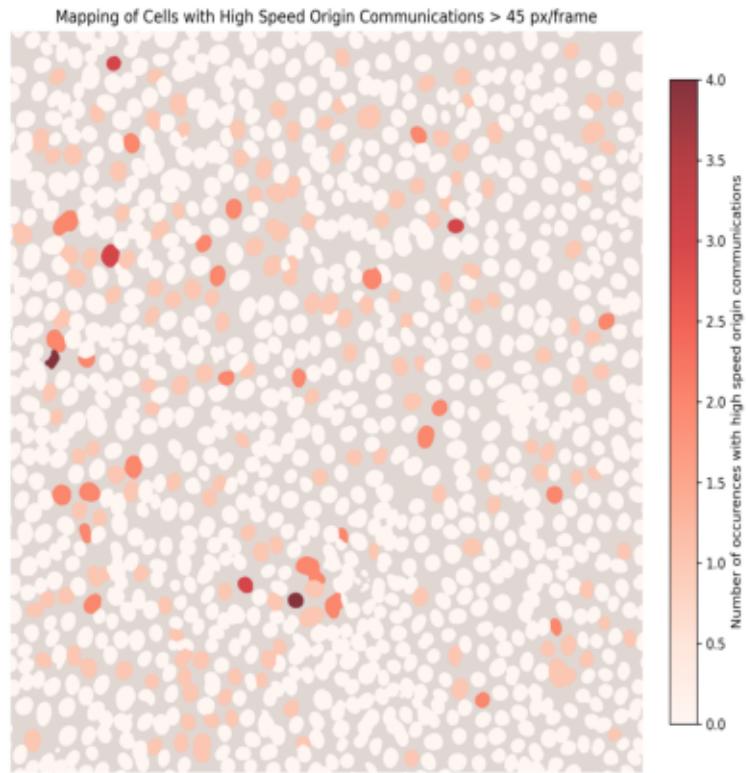
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
2	2016994518608	6	642		2
15	2016994508912	8	1226		3
29	2016784339520	10	595		4
30	2016784614592	10	555		4
41	2018409056912	10	789		2
...	
3056	2016916181184	1116	1608		7
3101	2016916190352	1136	1735		4
3116	2016916188624	1144	1693		0
3135	2016996240992	1156	1651		7
3136	2016996231680	1156	1717		6

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
2	662	2	487.0	487.0	
15	1215	8	554.0	554.0	
29	607	5	684.0	684.0	
30	521	4	685.0	686.0	
41	740	8	653.0	654.0	
...	
3056	1646	4	846.0	847.0	
3101	1675	3	611.0	612.0	
3116	1683	0	30.0	31.0	
3135	1717	6	735.0	736.0	
3136	1720	7	736.0	737.0	
	Duration (s)	Distance (um)	Speed (um/s)		\
2	0.0	25.00	25.00		
15	0.0	16.34	16.34		
29	0.0	18.37	18.37		
30	1.0	18.79	18.79		
41	1.0	19.07	19.07		
...	
3056	1.0	19.70	19.70		
3101	1.0	24.80	24.80		
3116	1.0	28.10	28.10		
3135	1.0	19.80	19.80		
3136	1.0	16.64	16.64		
	Event time phase (fraction of event duration)				\
2			0.17		
15			0.80		
29			0.79		
30			0.83		
41			0.17		
...			...		
3056			NaN		
3101			0.03		
3116			1.00		
3135			0.14		
3136			0.29		
	Event recruitment phase (fraction of involved cells)		dataset		\
2		0.11	20250701_IS2		
15		0.00	20250701_IS2		
29		0.52	20250701_IS2		
30		0.86	20250701_IS2		
41		0.10	20250701_IS2		
...			
3056		NaN	20250701_IS2		
3101		0.00	20250701_IS2		

3116		1.00	20250701_IS2
3135		0.00	20250701_IS2
3136		0.50	20250701_IS2

	Number of cells involved	category	Speed category
2		11+	High speed
15		4	High speed
29		11+	High speed
30		11+	High speed
41		11+	High speed
...
3056		2	High speed
3101		4	High speed
3116		3	High speed
3135		4	High speed
3136		4	High speed

[223 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
248		0	2
251		0	2
255		0	2
258		0	3
259		0	1
...
1738		0	5
1741		0	1
1742		0	4
1744		0	3
1745		0	1

[923 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	248	17.23		5.85
1	251	97.83		5.53
2	255	362.70		9.75
4	258	141.38		10.08
5	259	189.15		11.05
...
1041	1738	90.03		491.40
1044	1741	253.50		492.05
1045	1742	352.62		491.73
1046	1744	369.53		492.70
1047	1745	394.88		492.38

Number of peaks	Is active	Occurrences in global events	\
-----------------	-----------	------------------------------	---

0	18	True	4
1	12	True	4
2	10	True	4
4	8	True	4
5	7	True	4
...
1041	17	True	4
1044	12	True	4
1045	11	True	2
1046	10	True	2
1047	5	True	2

Occurrences in global events as early peaker Early peaker event IDs \

0	0	[]
1	1	[4]
2	0	[]
4	0	[]
5	0	[]
...
1041	0	[]
1044	0	[]
1045	0	[]
1046	1	[1]
1047	0	[]

Occurrences in sequential events \

0	5
1	5
2	2
4	3
5	2
...	...
1041	3
1044	2
1045	6
1046	4
1047	1

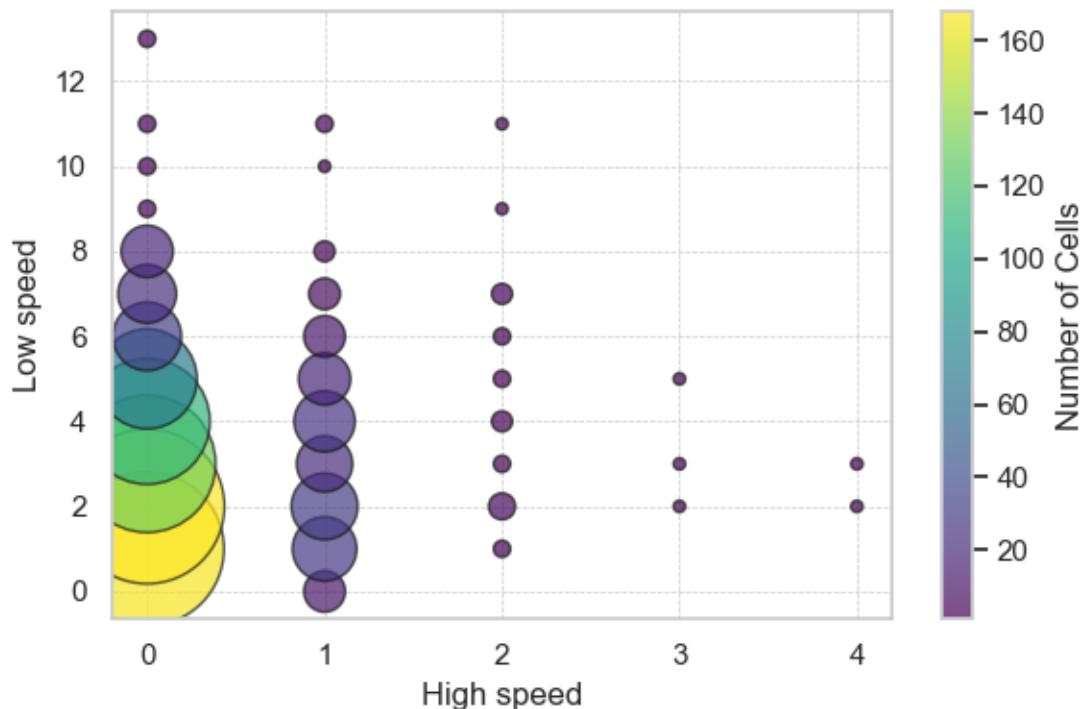
Occurrences in sequential events as origin \

0	2
1	1
2	1
4	1
5	1
...	...
1041	3
1044	1
1045	2

1046			3	
1047			1	
	Occurrences in individual events	Peak frequency (Hz)	\	
0	7	0.0110		
1	1	0.0071		
2	2	0.0059		
4	1	0.0047		
5	1	0.0041		
...	
1041	9	0.0100		
1044	4	0.0071		
1045	3	0.0065		
1046	4	0.0059		
1047	1	0.0029		
	Periodicity score	Neighbor count	Neighbors (labels)	\
0	0.57	2	[262,292]	
1	0.70	3	[264,284,293]	
2	0.73	4	[272,273,313,315]	
4	0.73	3	[276,277,289]	
5	0.72	3	[276,283,298]	
...	
1041	0.64	4	[1682,1694,1713,1739]	
1044	0.73	3	[1690,1702,1737]	
1045	0.65	5	[1685,1695,1697,1740,1744]	
1046	0.57	3	[1695,1727,1742]	
1047	0.48	2	[1706,1727]	
	dataset	Involved in sequential event	\	
0	20250701_IS2	Involved in sequential event		
1	20250701_IS2	Involved in sequential event		
2	20250701_IS2	Involved in sequential event		
4	20250701_IS2	Involved in sequential event		
5	20250701_IS2	Involved in sequential event		
...	
1041	20250701_IS2	Involved in sequential event		
1044	20250701_IS2	Involved in sequential event		
1045	20250701_IS2	Involved in sequential event		
1046	20250701_IS2	Involved in sequential event		
1047	20250701_IS2	Involved in sequential event		
	Occurrences in sequential events	category	High speed	Low speed
0		5-9	0.0	2.0
1		5-9	0.0	2.0
2		1-2	0.0	2.0
4		3-4	0.0	3.0
5		1-2	0.0	1.0

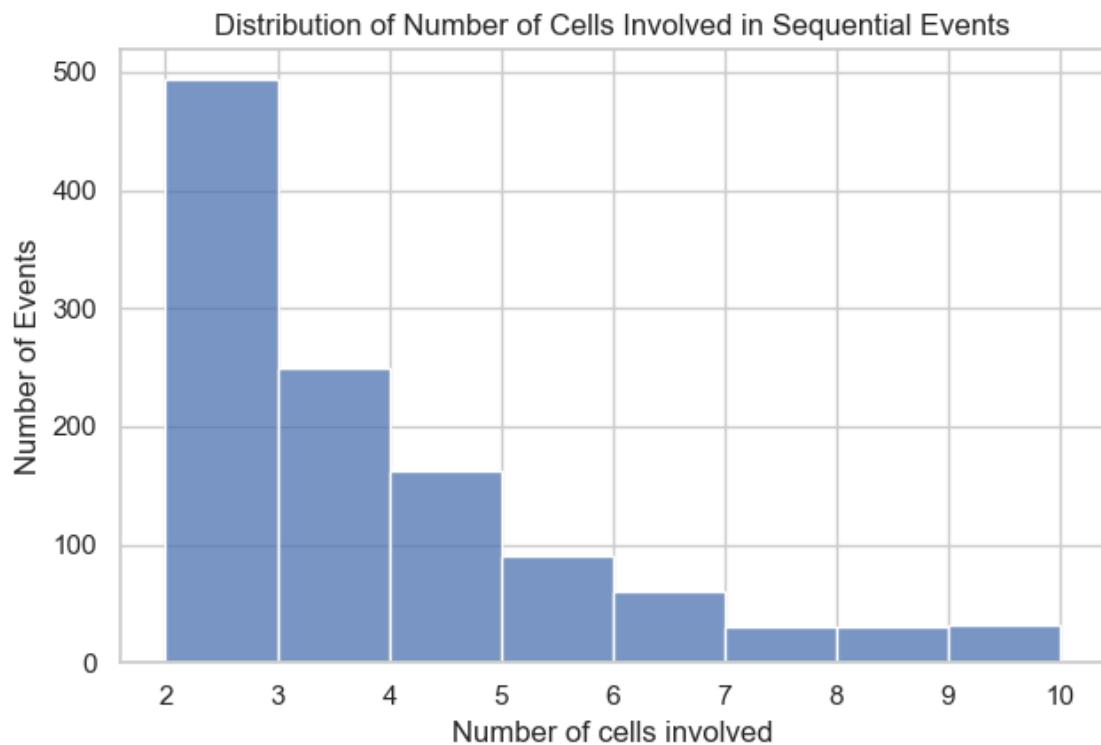
...
1041	3-4	0.0	5.0
1044	1-2	0.0	1.0
1045	5-9	0.0	4.0
1046	3-4	0.0	3.0
1047	1-2	0.0	1.0

[921 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

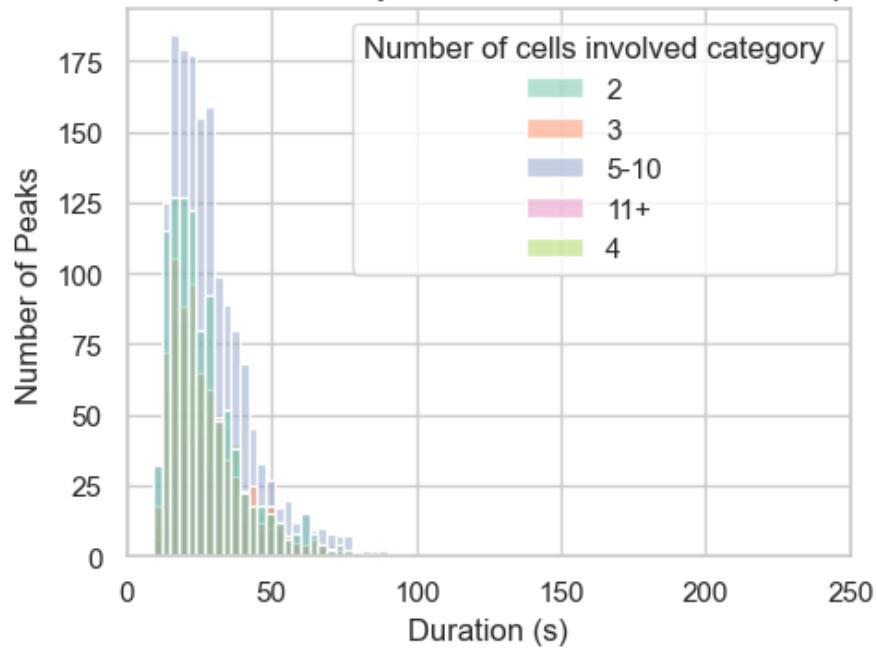
[2025-08-27 15:13:57] [INFO] calcium: plot_histogram: removed 26 outliers out of 1175 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

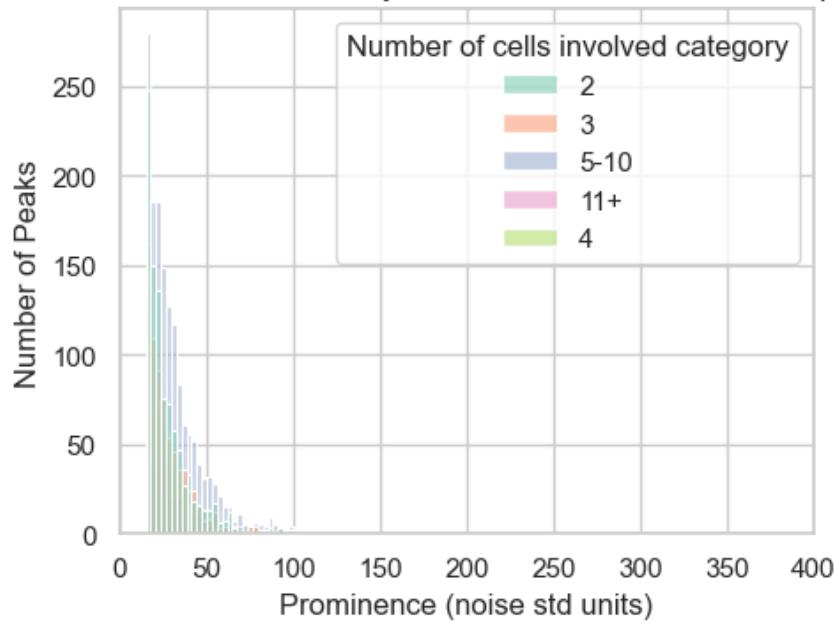
```
[2025-08-27 15:13:58] [INFO] calcium: plot_histogram_by_group: removed 74 outliers out of 4339 on 'Duration (s)' (lower=-6, upper=90)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

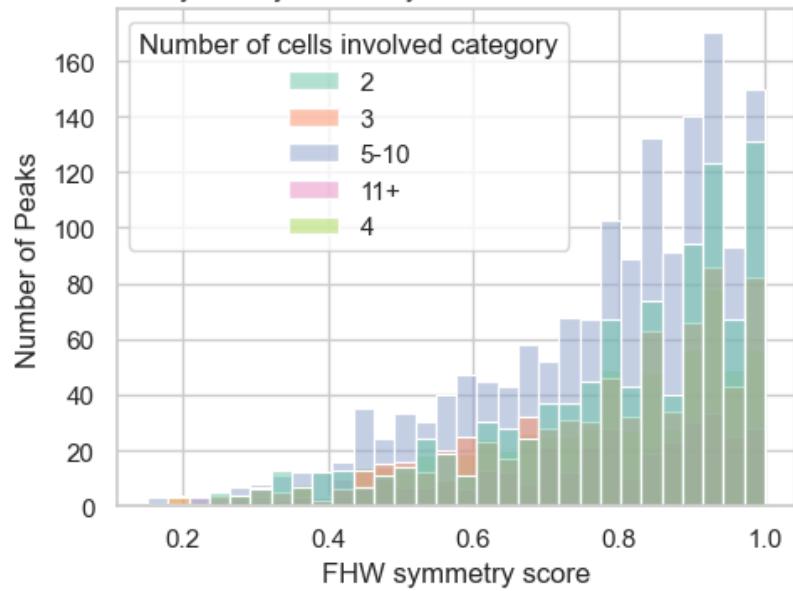


```
[2025-08-27 15:13:58] [INFO] calcium: plot_histogram_by_group: removed 113 outliers out of 4339 on 'Prominence (noise std units)' (lower=-8.25, upper=100.35)
```

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

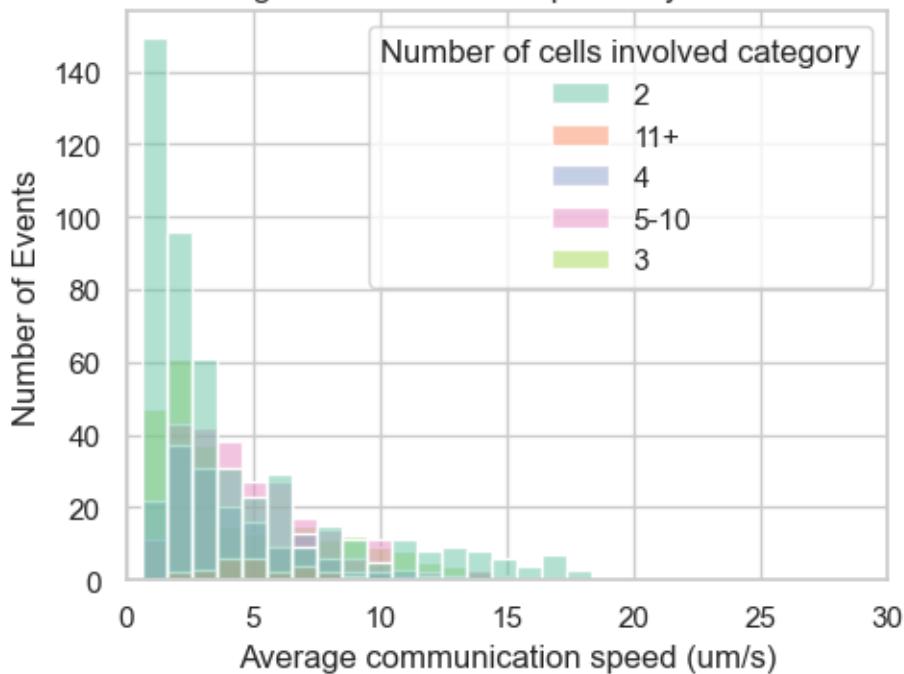


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

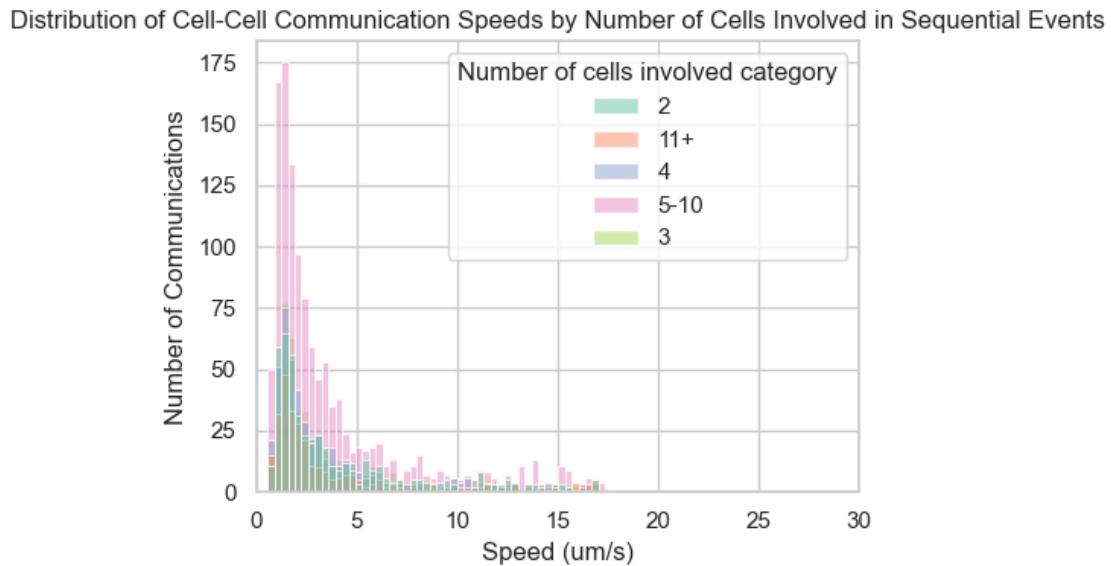


```
[2025-08-27 15:13:58] [INFO] calcium: plot_histogram_by_group: removed 9
outliers out of 1175 on 'Average communication speed (um/s)' (lower=-10.67,
upper=18.59)
```

Distribution of Average Communication Speeds by Number of Cells Involved

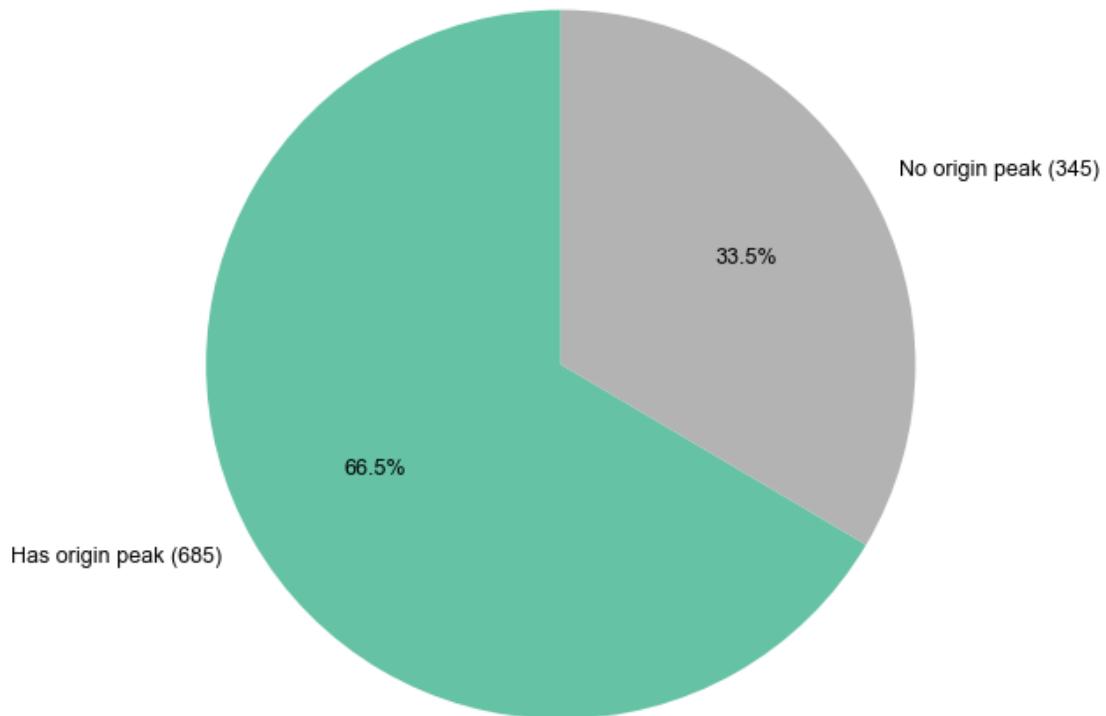


[2025-08-27 15:13:59] [INFO] calcium: plot_histogram_by_group: removed 132 outliers out of 3164 on 'Speed (um/s)' (lower=-10.49, upper=17.44)

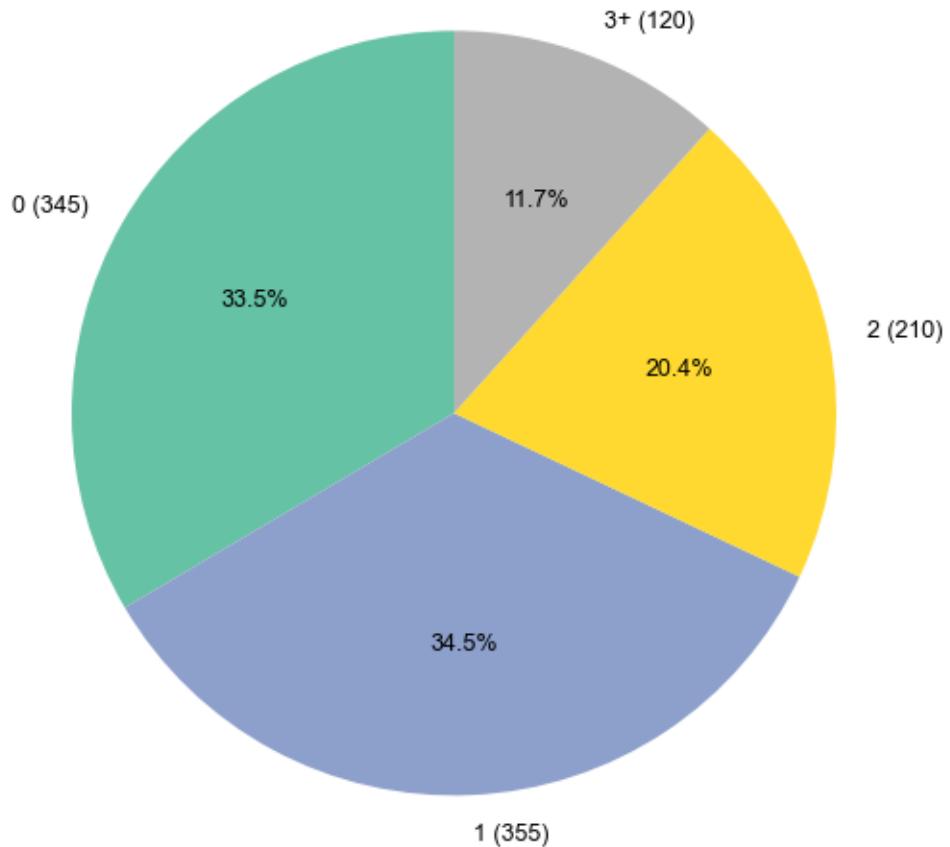


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

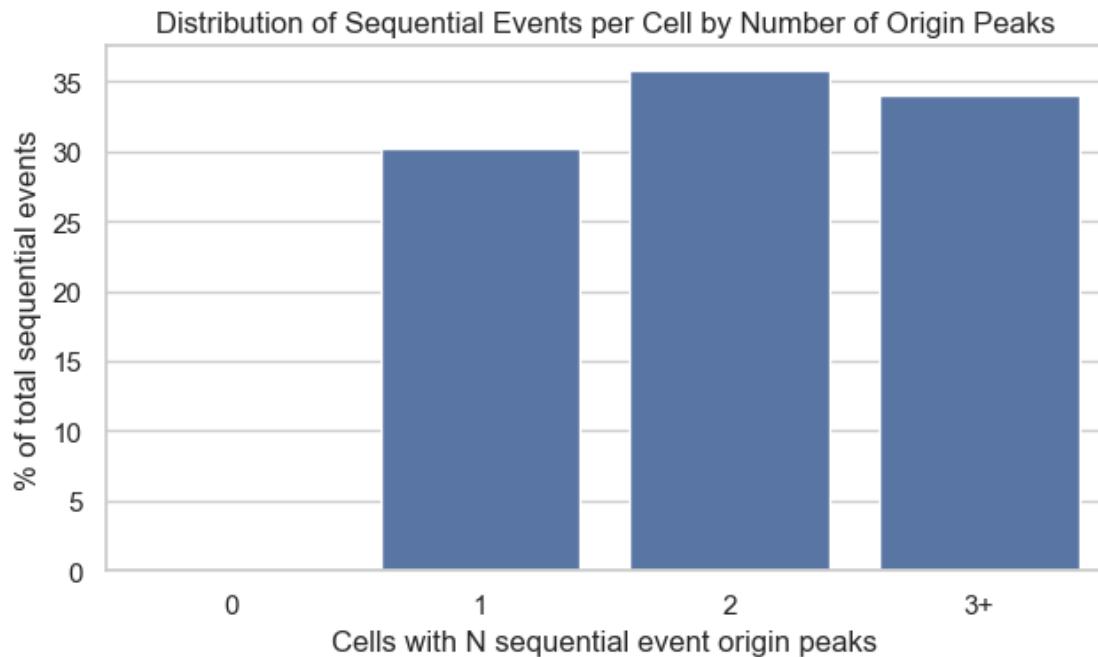


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



```
[2025-08-27 15:13:59] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250701\\Output\\IS2\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
```

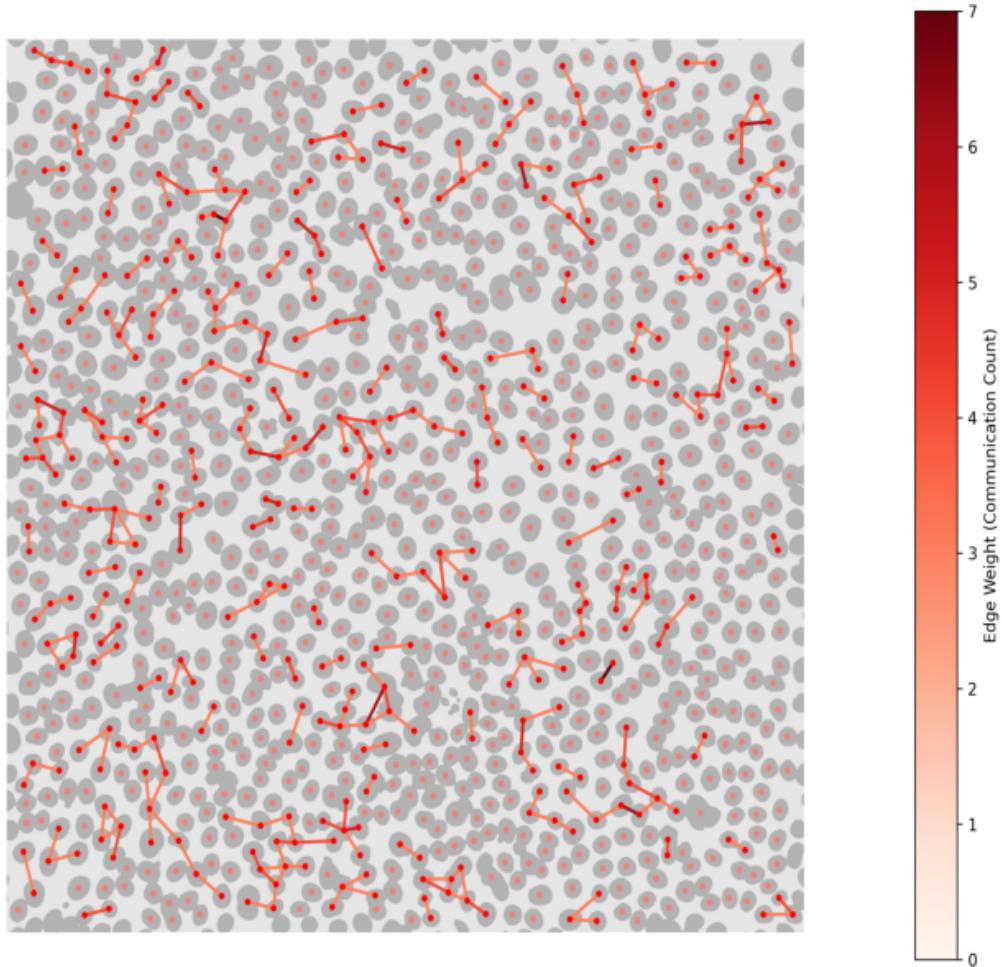
```
packages\PIL\ImageFile.py", line 132, in __init__  
    self.fp = open(fp, "rb")  
FileNotFoundError: [Errno 2] No such file or directory:  
'D:\\Mateo\\20250701\\Output\\IS2\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```



1.3.8 Connection network between cells

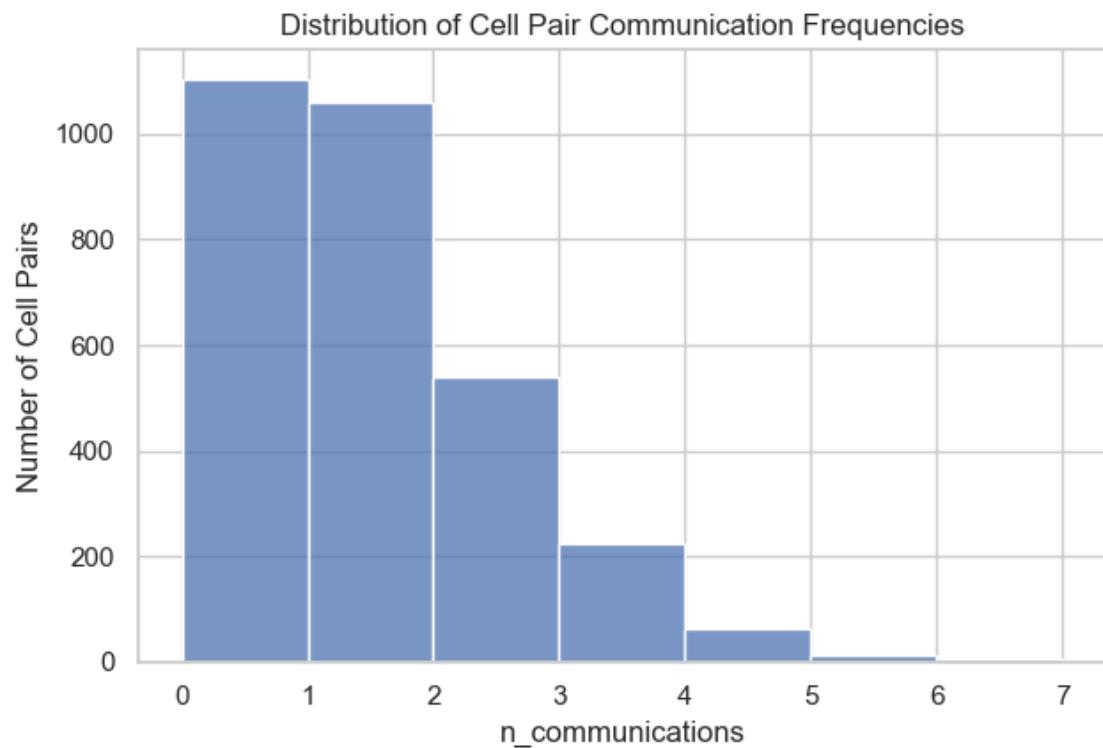
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



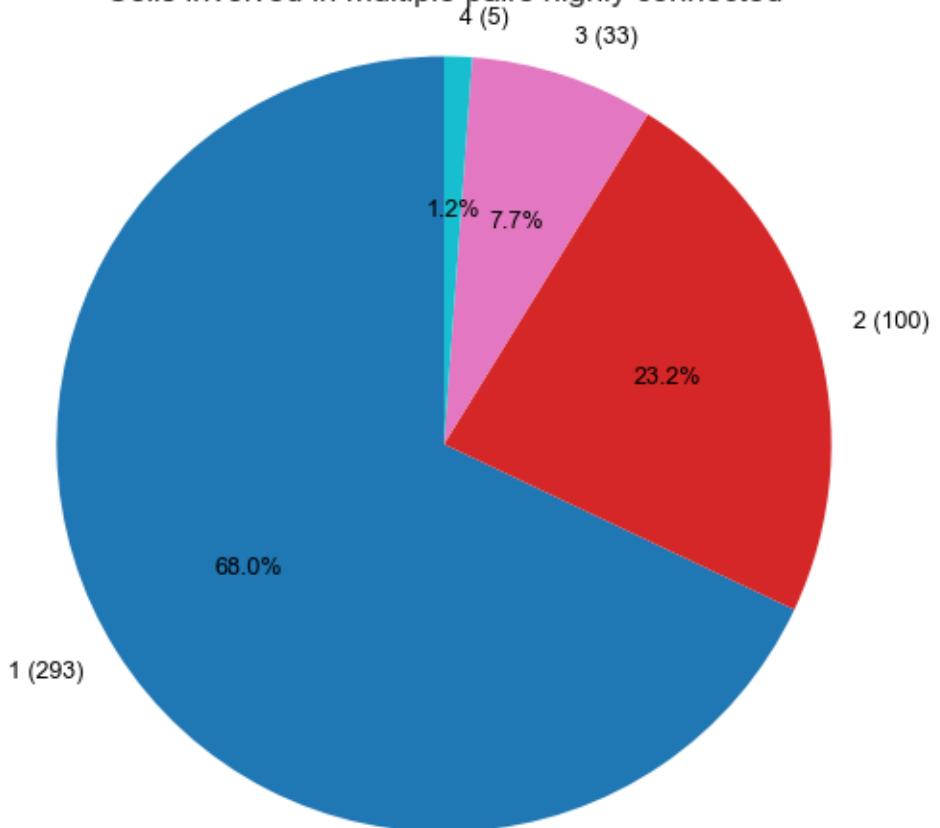
1.3.9 Pair/Trios with high communication networks

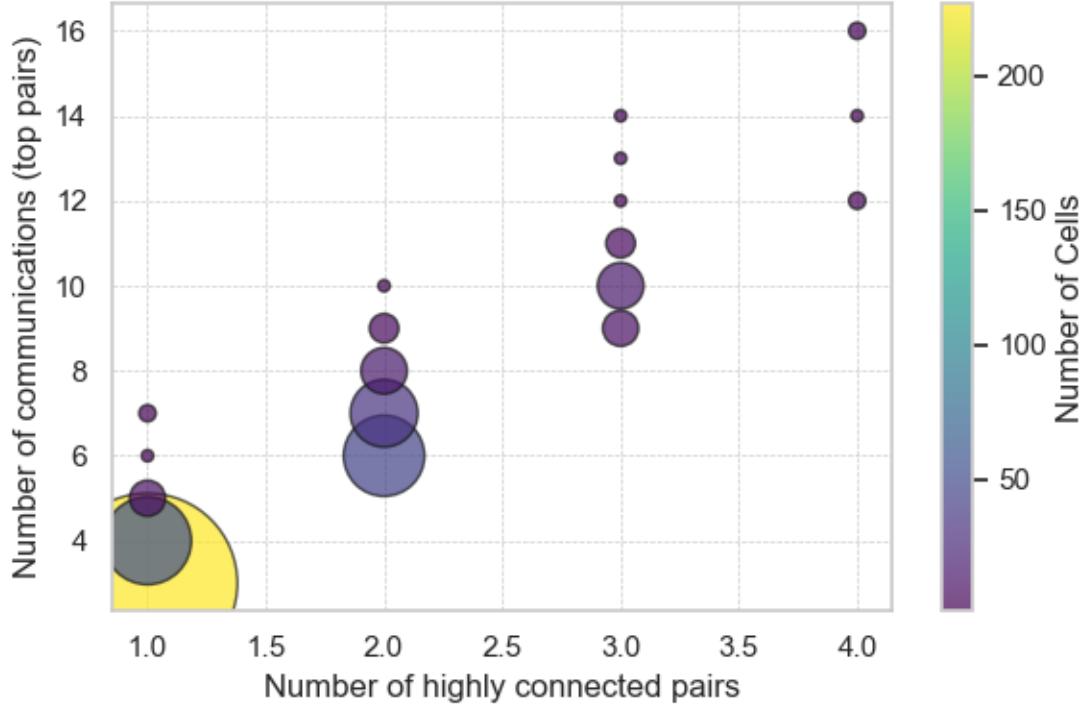
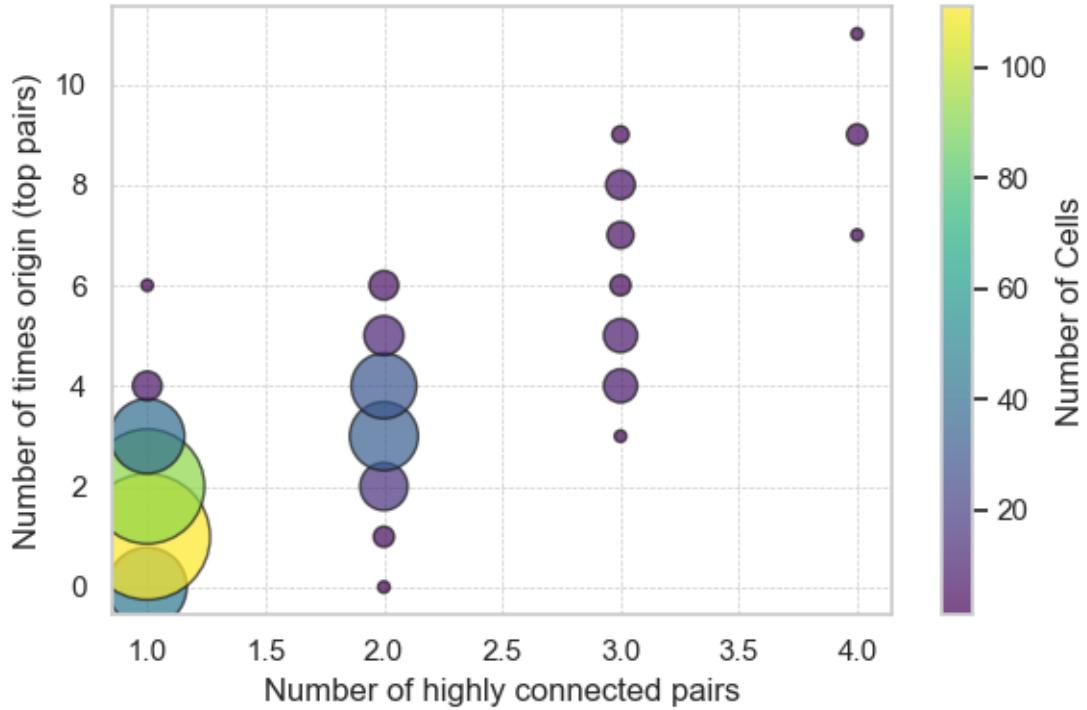
```
[2025-08-27 15:14:01] [INFO] calcium: build_neighbor_pair_stats: built 3009  
pairs across 1 datasets (mean distance=16.79 um)
```

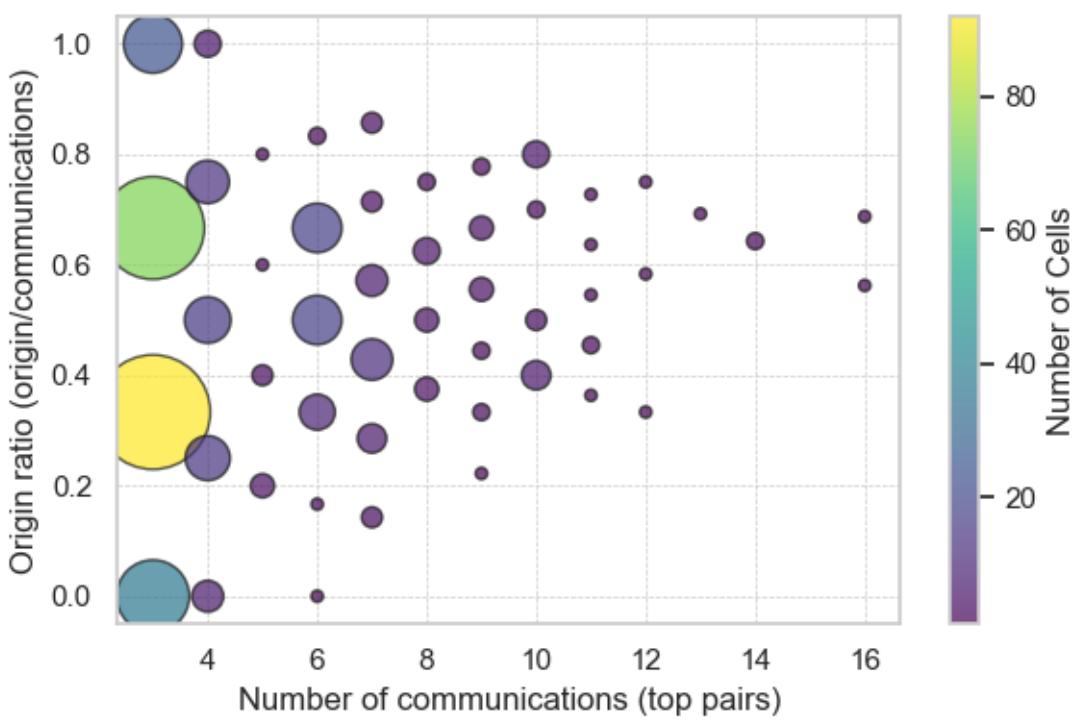
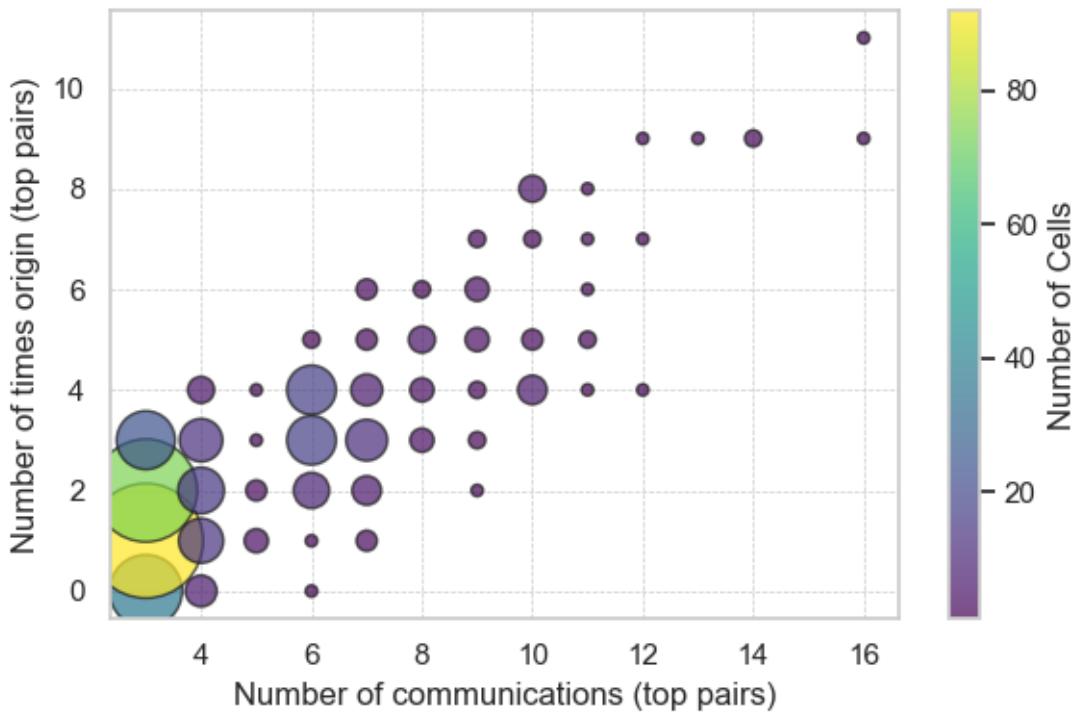


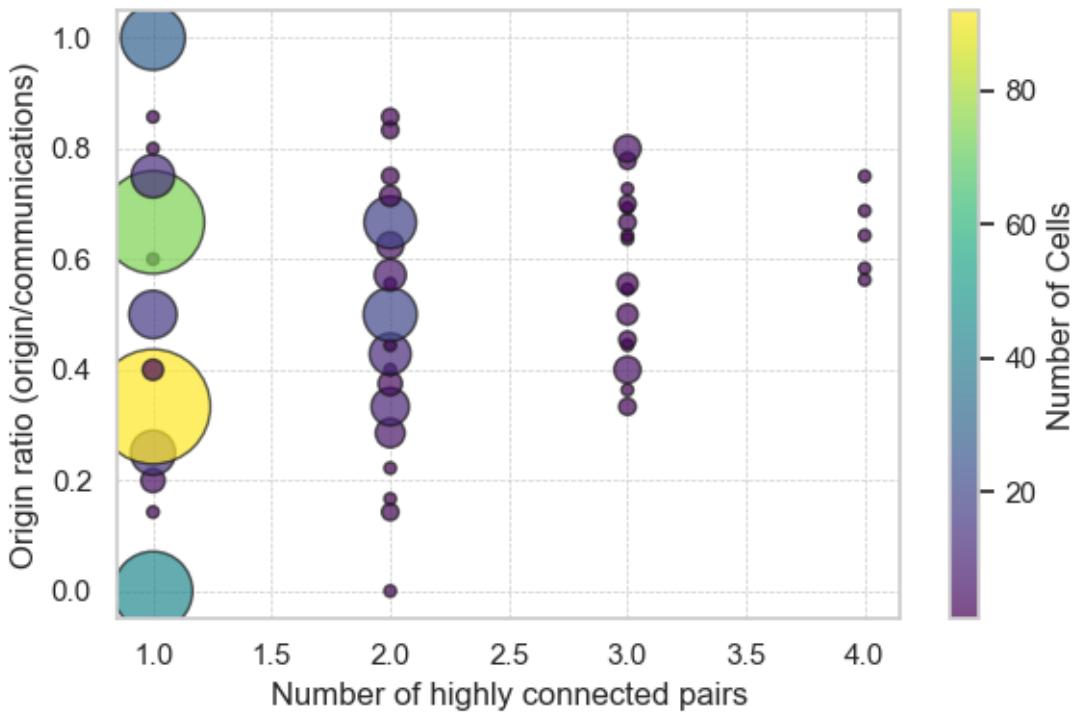
95th percentile threshold: 3.0

Cells involved in multiple pairs highly connected







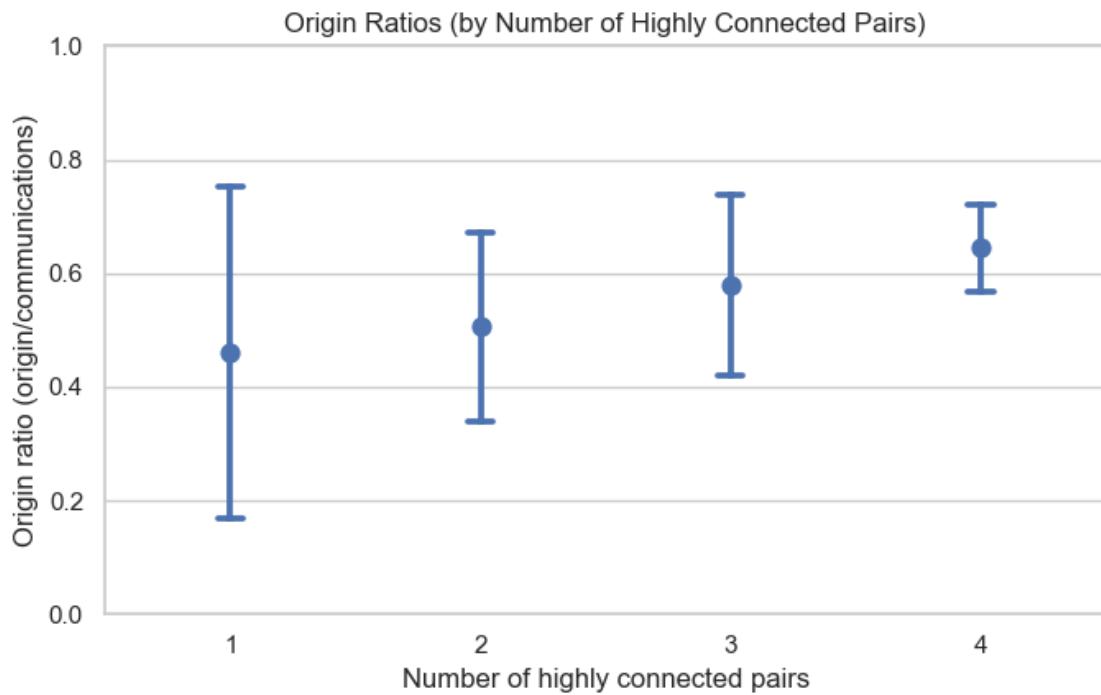


[2025-08-27 15:14:02] [INFO] calcium: plot_points_mean_std: N=293 for Number of highly connected pairs=1

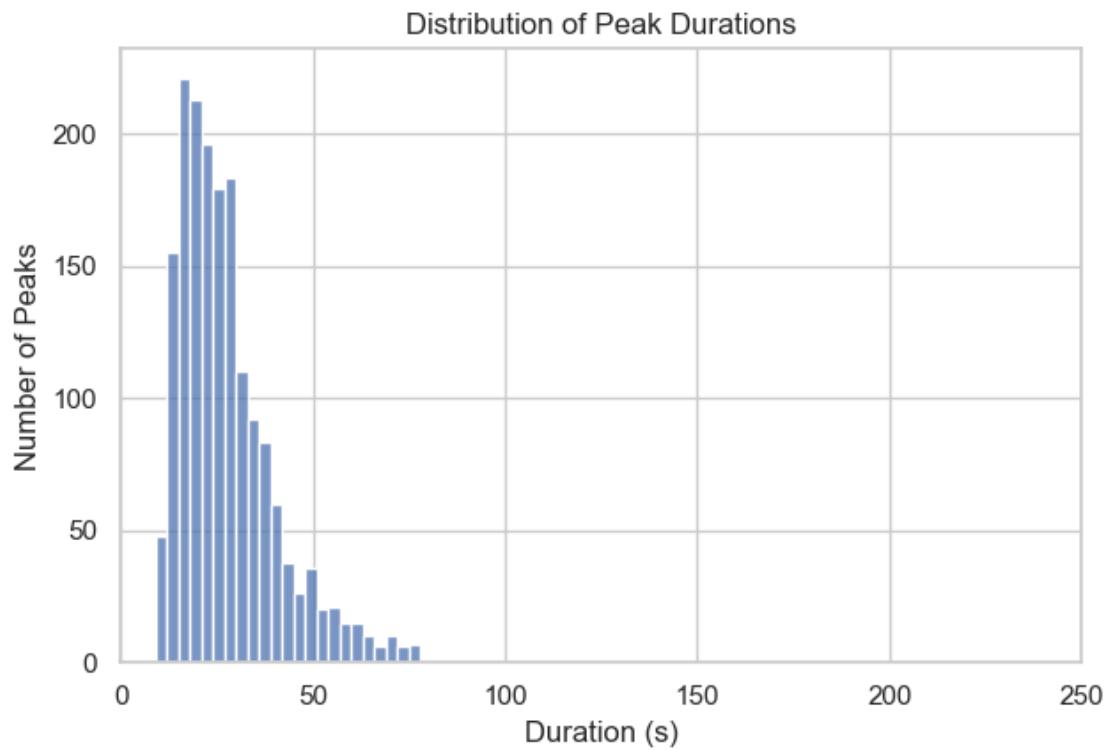
[2025-08-27 15:14:02] [INFO] calcium: plot_points_mean_std: N=100 for Number of highly connected pairs=2

[2025-08-27 15:14:02] [INFO] calcium: plot_points_mean_std: N=33 for Number of highly connected pairs=3

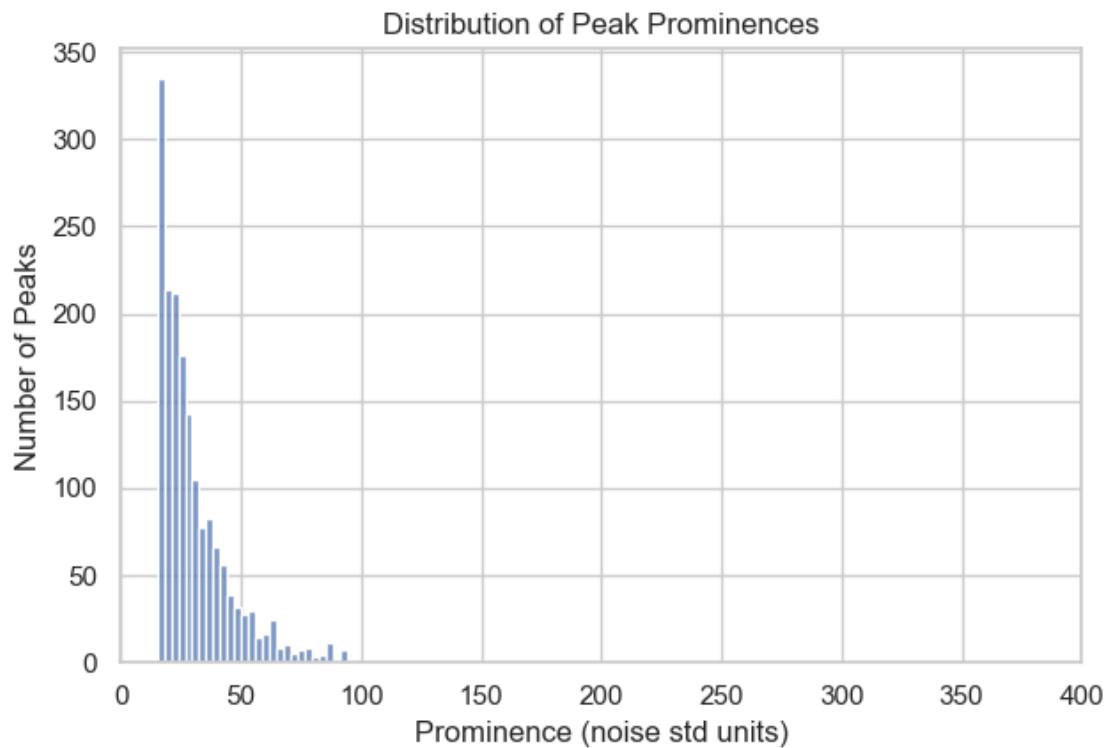
[2025-08-27 15:14:02] [INFO] calcium: plot_points_mean_std: N=5 for Number of highly connected pairs=4

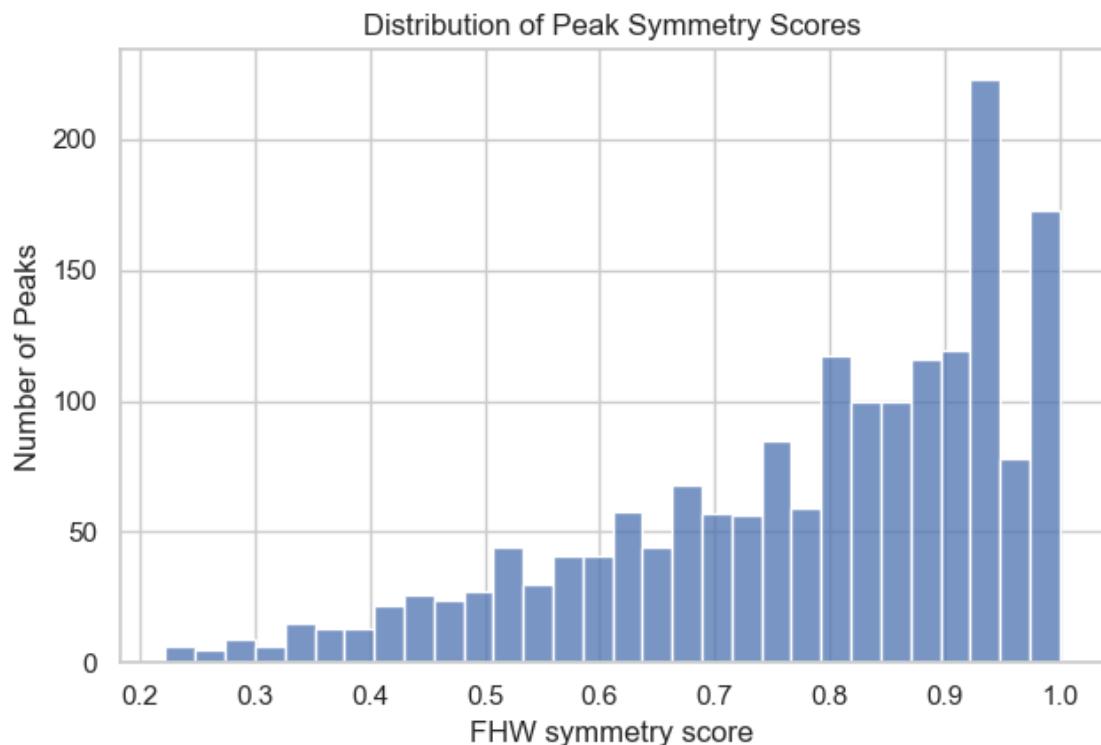


```
[2025-08-27 15:14:02] [INFO] calcium: plot_histogram: removed 25 outliers out of 1775 on 'Duration (s)' (lower=-27, upper=78)
```

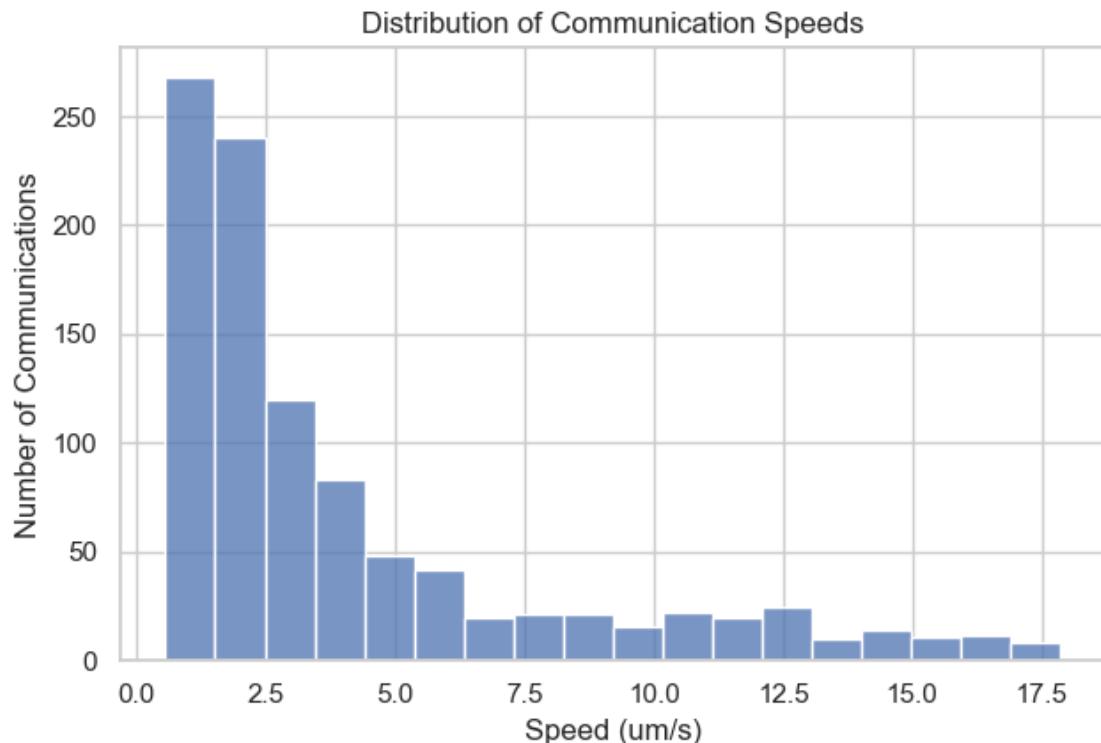


[2025-08-27 15:14:02] [INFO] calcium: plot_histogram: removed 60 outliers out of 1775 on 'Prominence (noise std units)' (lower=-36.85, upper=94.4)

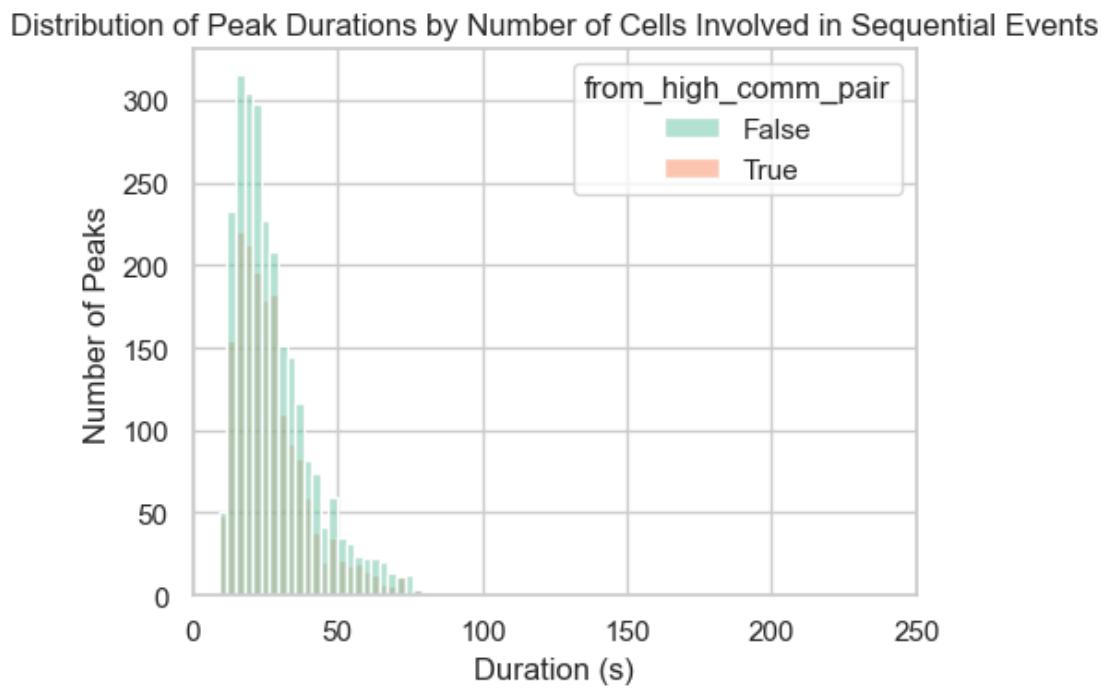




```
[2025-08-27 15:14:02] [INFO] calcium: plot_histogram: removed 25 outliers out of 1026 on 'Speed (um/s)' (lower=-10.935, upper=18.08)
```

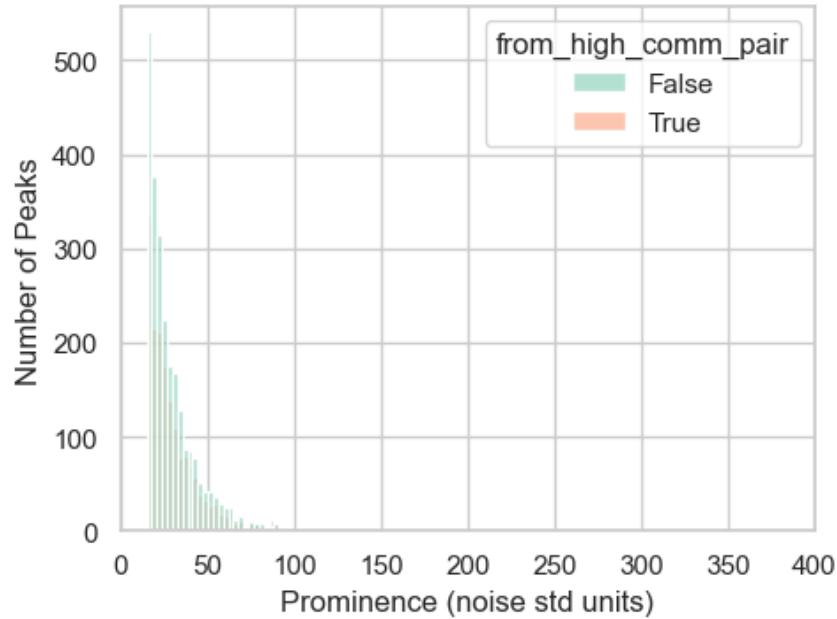


[2025-08-27 15:14:02] [INFO] calcium: plot_histogram_by_group: removed 85 outliers out of 4339 on 'Duration (s)' (lower=-30, upper=82)

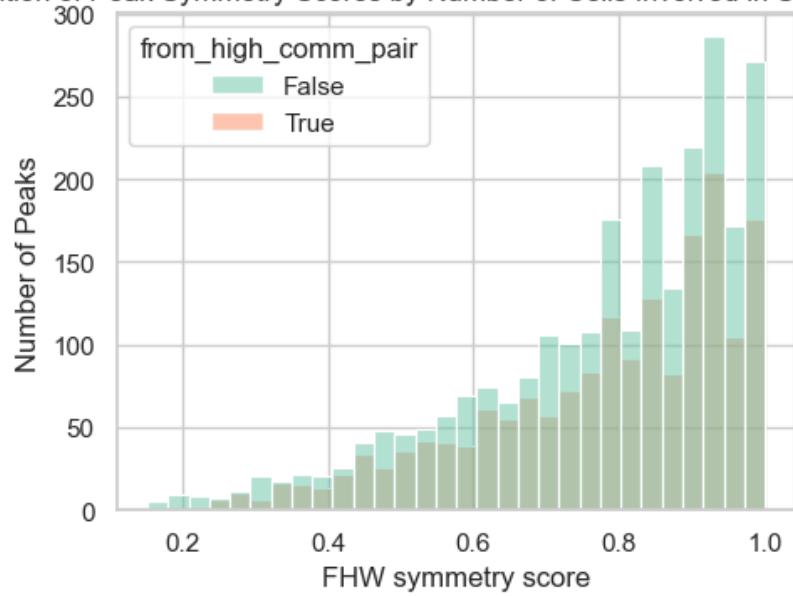


[2025-08-27 15:14:02] [INFO] calcium: plot_histogram_by_group: removed 143 outliers out of 4339 on 'Prominence (noise std units)' (lower=-35.4, upper=91.3)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

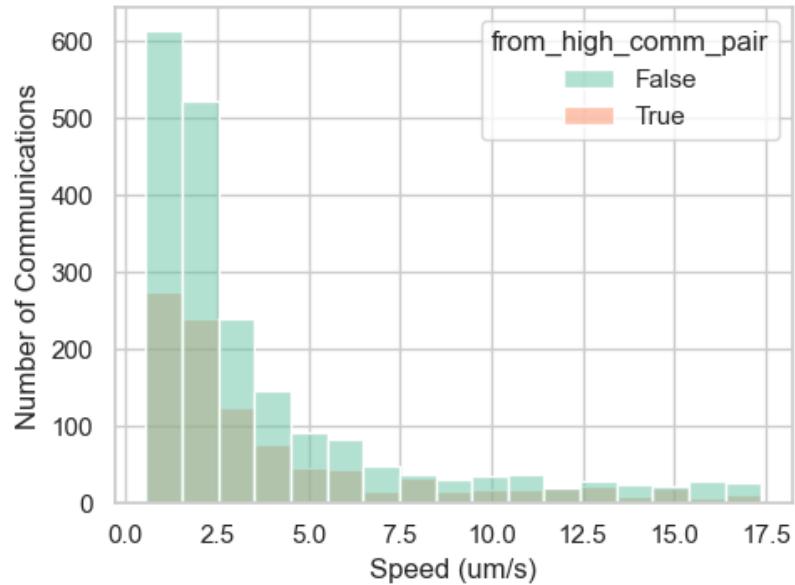


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:14:03] [INFO] calcium: plot_histogram_by_group: removed 132 outliers out of 3164 on 'Speed (um/s)' (lower=-10.49, upper=17.44)

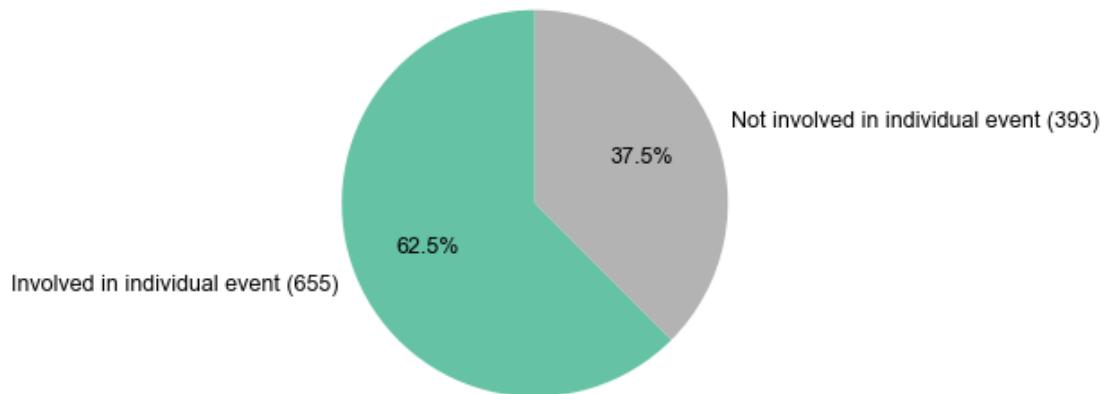
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



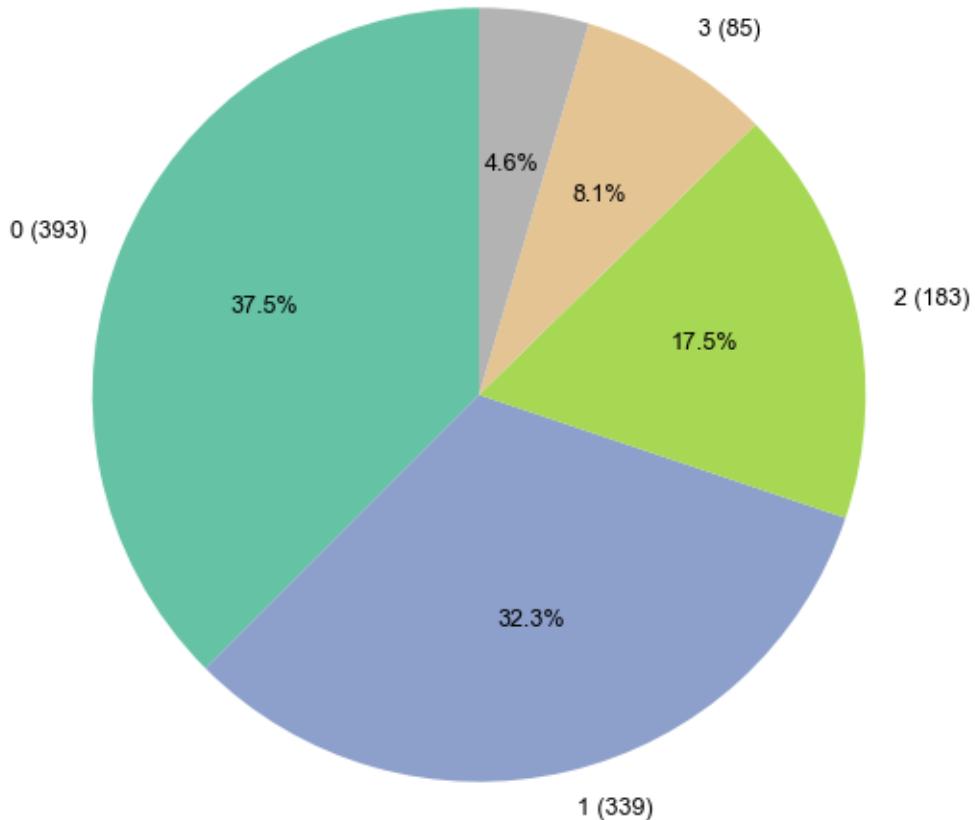
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

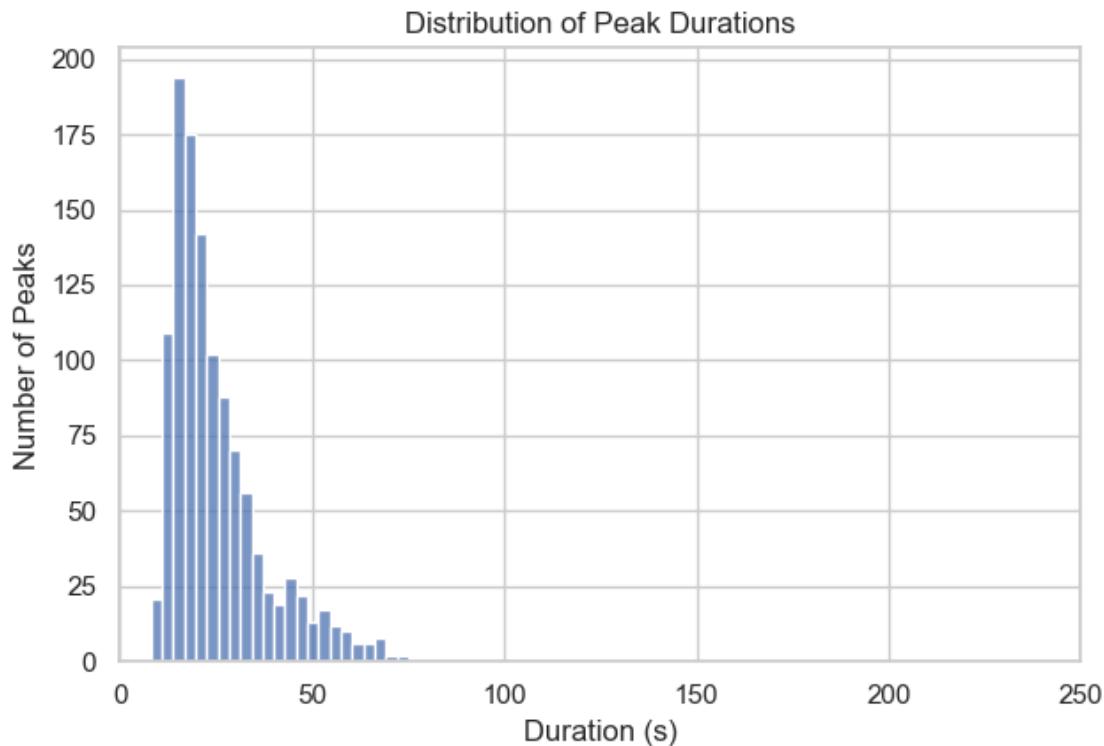


```
[2025-08-27 15:14:03] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS2\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250701\\Output\\IS2\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250701\\Output\\IS2\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

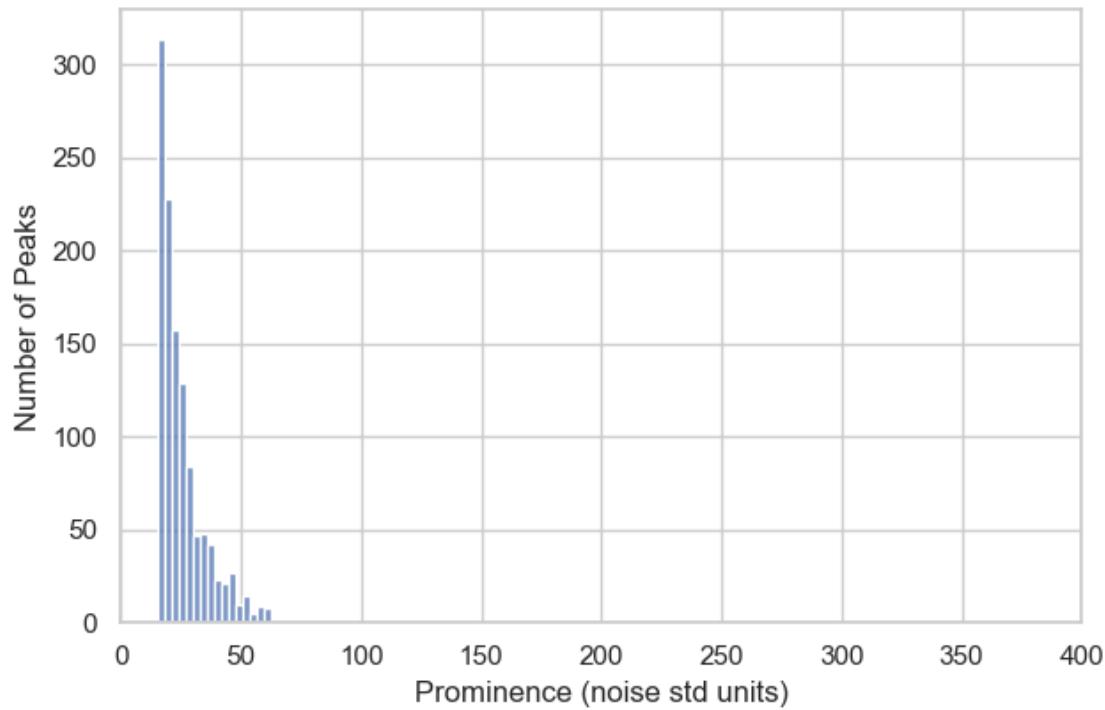
1.4.2 Peaks statistics in individual events

[2025-08-27 15:14:03] [INFO] calcium: plot_histogram: removed 27 outliers out of 1188 on 'Duration (s)' (lower=-29, upper=76)

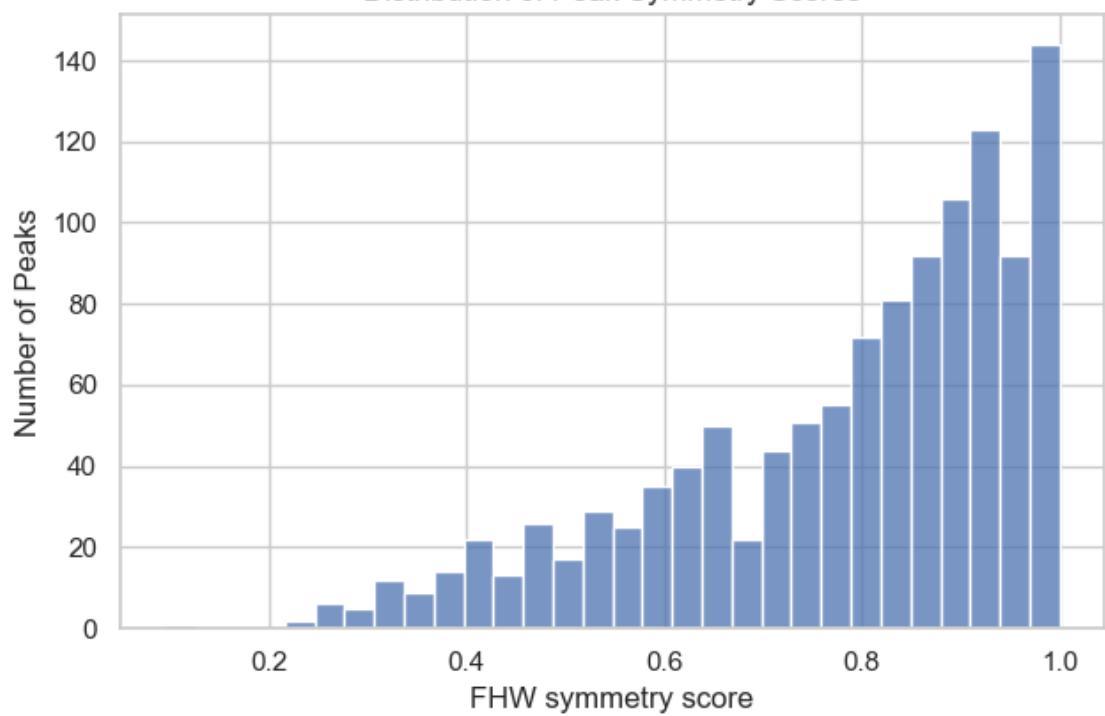


[2025-08-27 15:14:04] [INFO] calcium: plot_histogram: removed 22 outliers out of 1188 on 'Prominence (noise std units)' (lower=-15.9, upper=62.5)

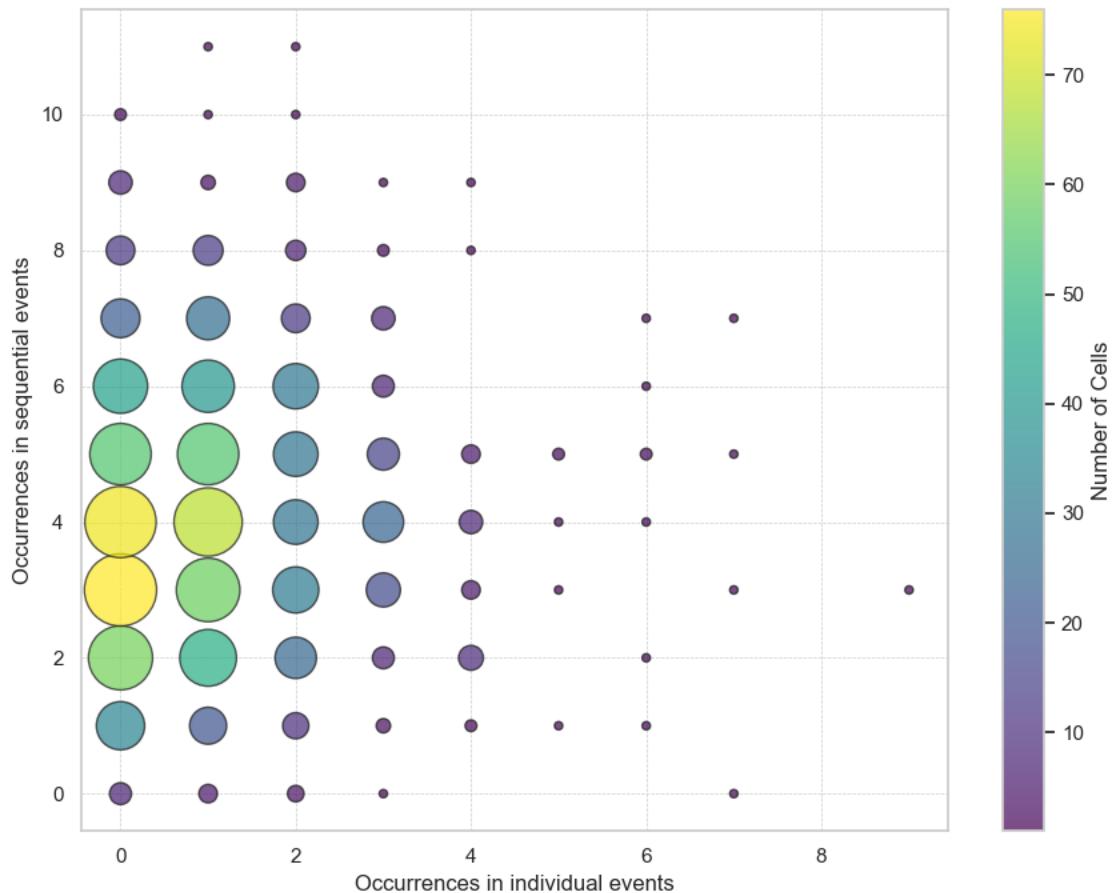
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: removed 0/1048 outliers on 'Occurrences in sequential events' (lower=-3, upper=11)
```

```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=393 for Occurrences in individual events=0
```

```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=339 for Occurrences in individual events=1
```

```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=183 for Occurrences in individual events=2
```

```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=85 for Occurrences in individual events=3
```

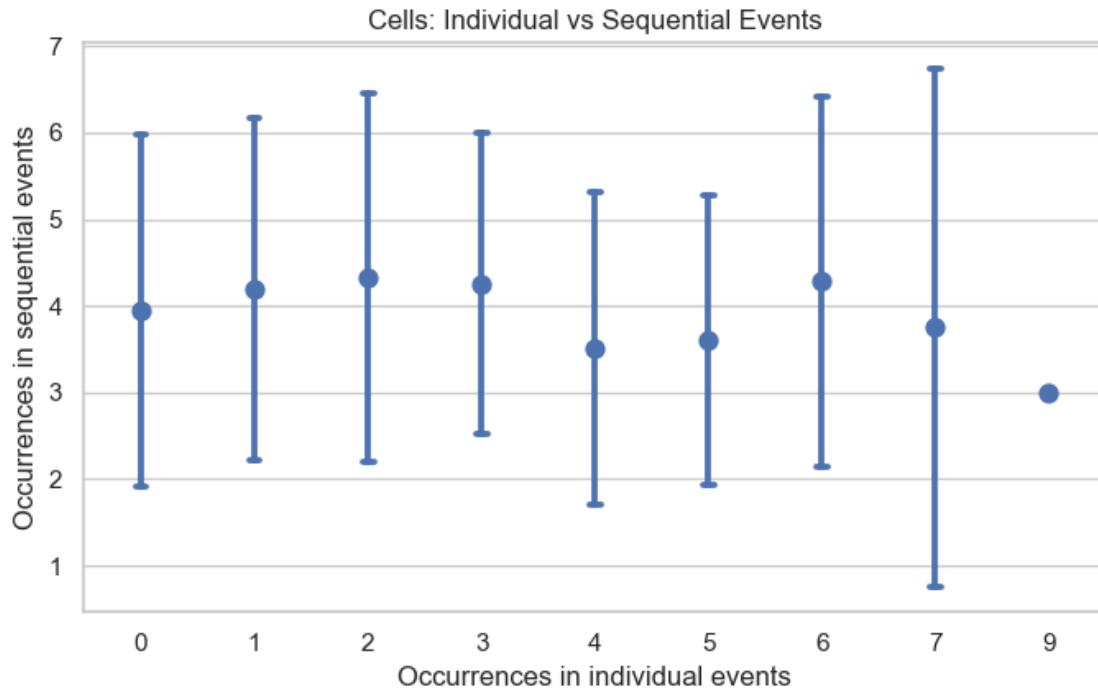
```
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=31 for Occurrences in individual events=4
```

[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=5 for Occurrences in individual events=5

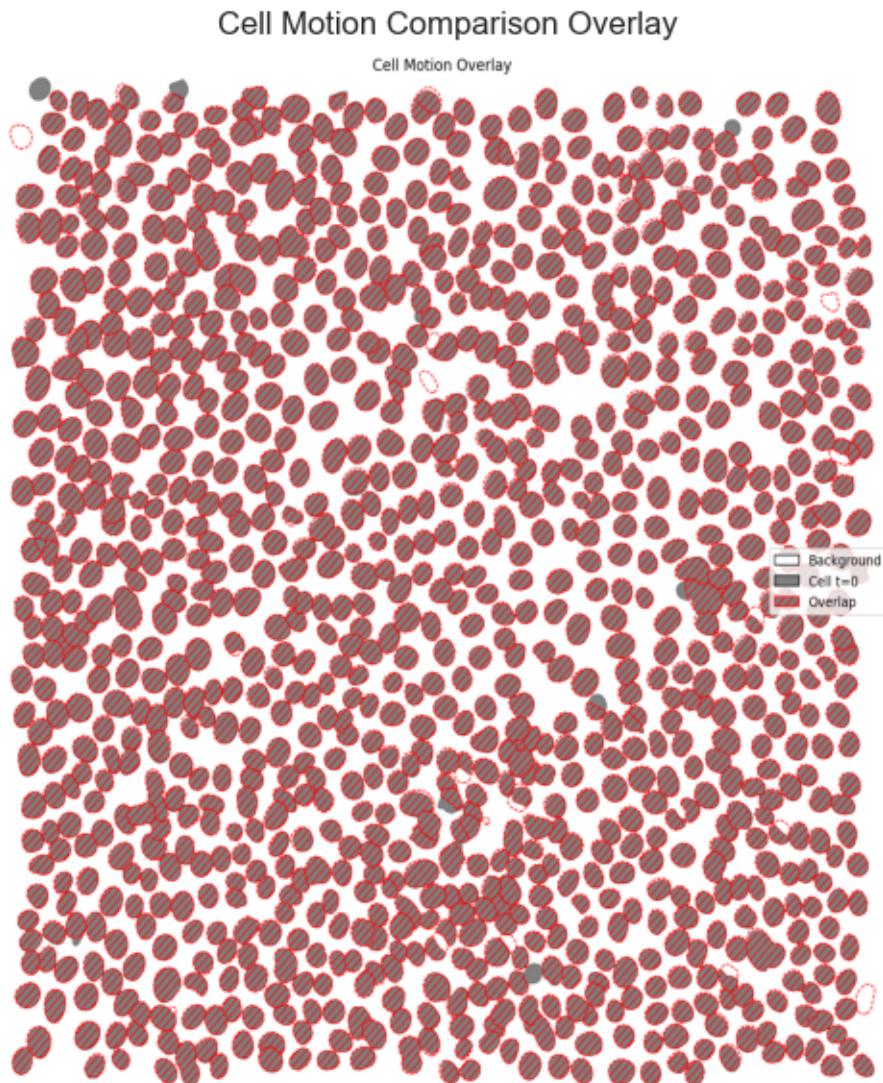
[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=7 for Occurrences in individual events=6

[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=4 for Occurrences in individual events=7

[2025-08-27 15:14:04] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=9



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1048
- Hoechst image taken at t=1801: 1052
- Number of cells difference: absolute 4, relative 0.38%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1151067
- Pixels segmented as cell at t=1801: 1152501
- Overlapping pixels between t=0 and t=1801: 1090633 (94.69% of total)
- Pixels exclusive to t=0: 60434 (5.25% of total)
- Pixels exclusive to t=1801: 61868 (5.37% of total)

executed

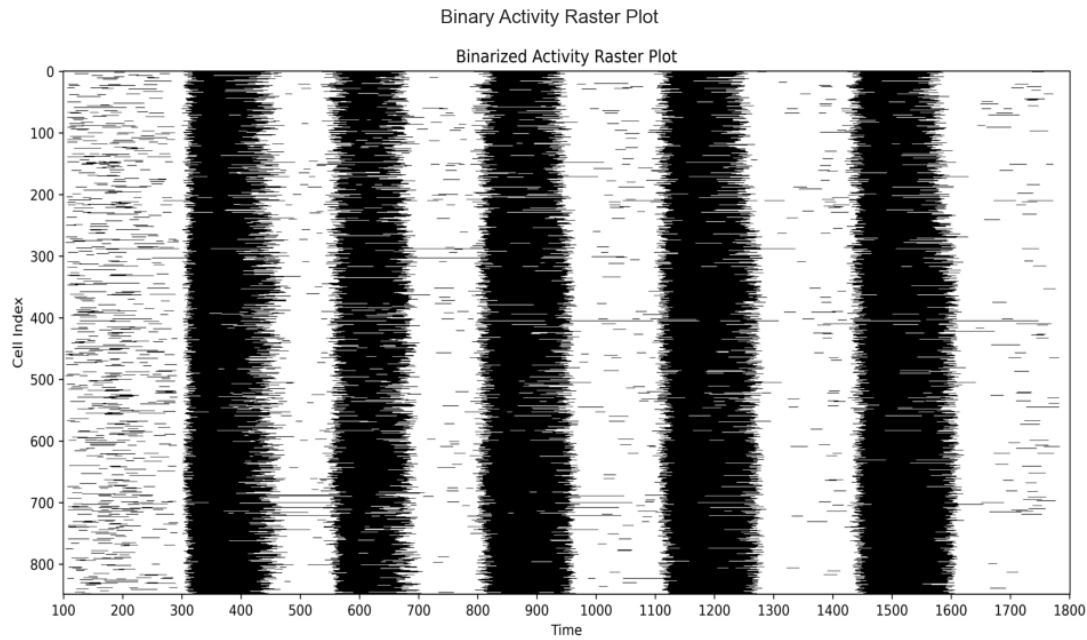
August 27, 2025

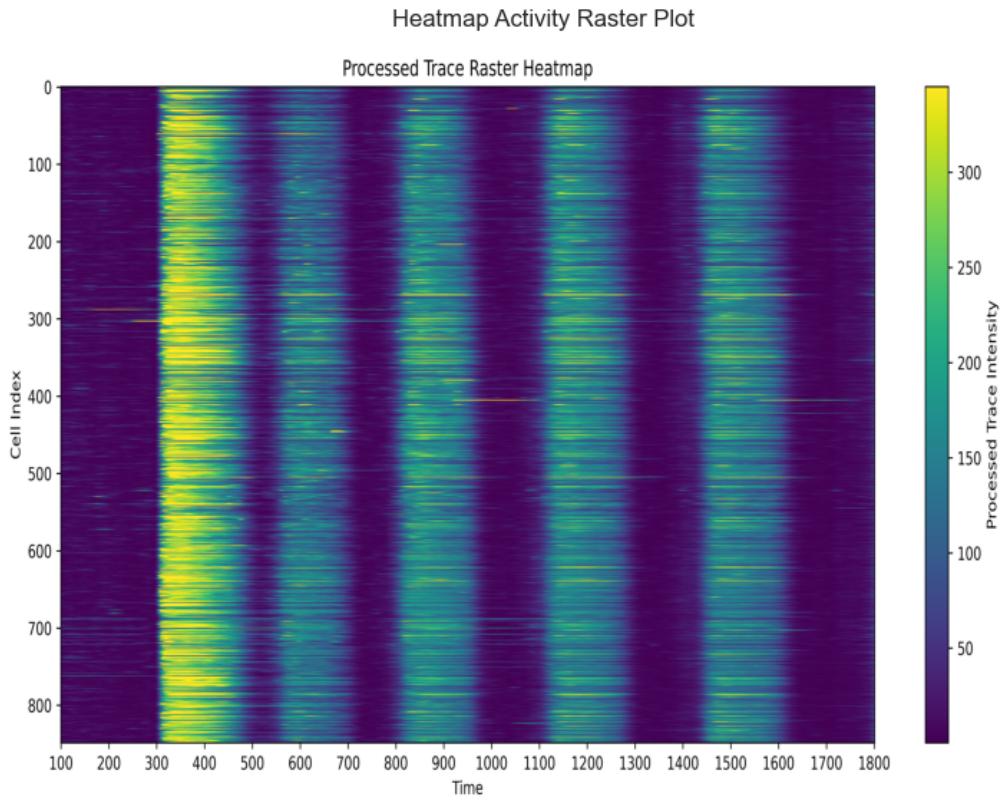
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





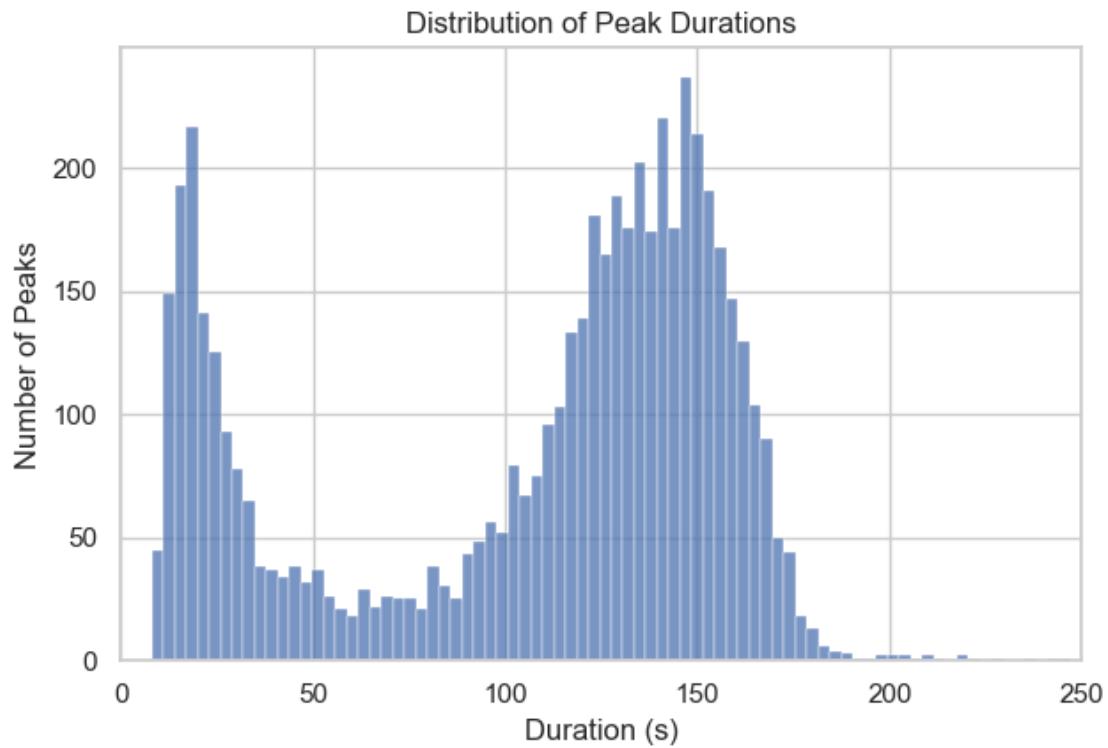
1.1.2 Peaks population

Total number of peaks: 5448

Total number of cells: 849

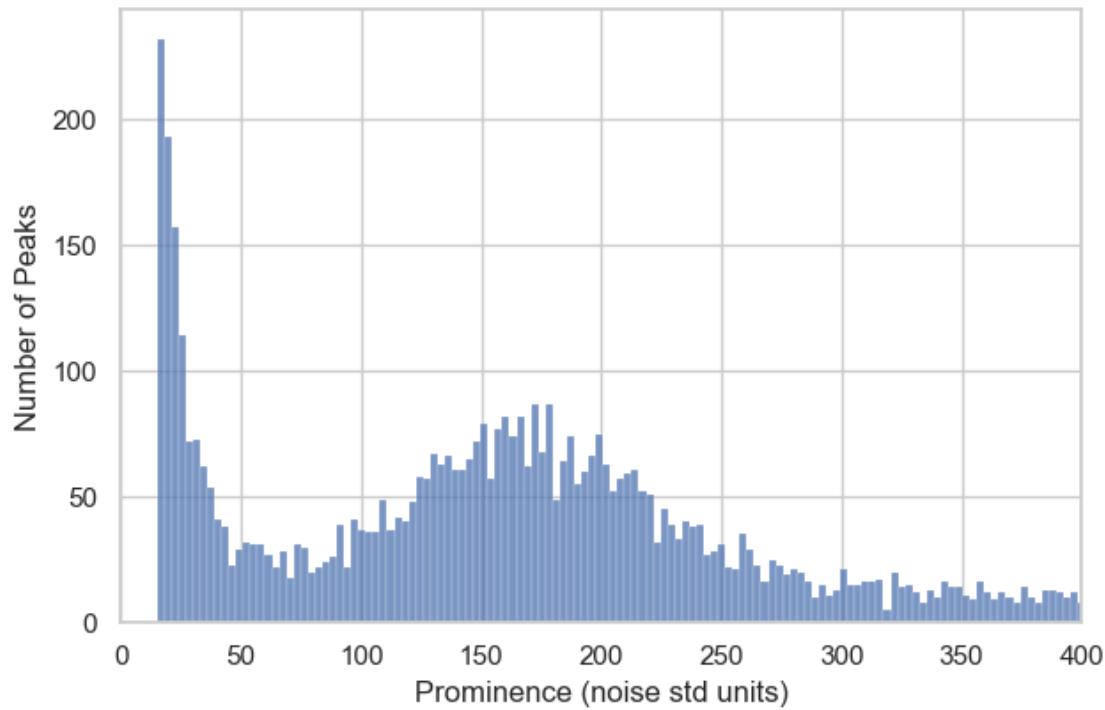
1.1.3 Peaks statistics

```
[2025-08-27 15:14:31] [INFO] calcium: plot_histogram: removed 0 outliers out of 5448 on 'Duration (s)' (lower=-206, upper=410)
```

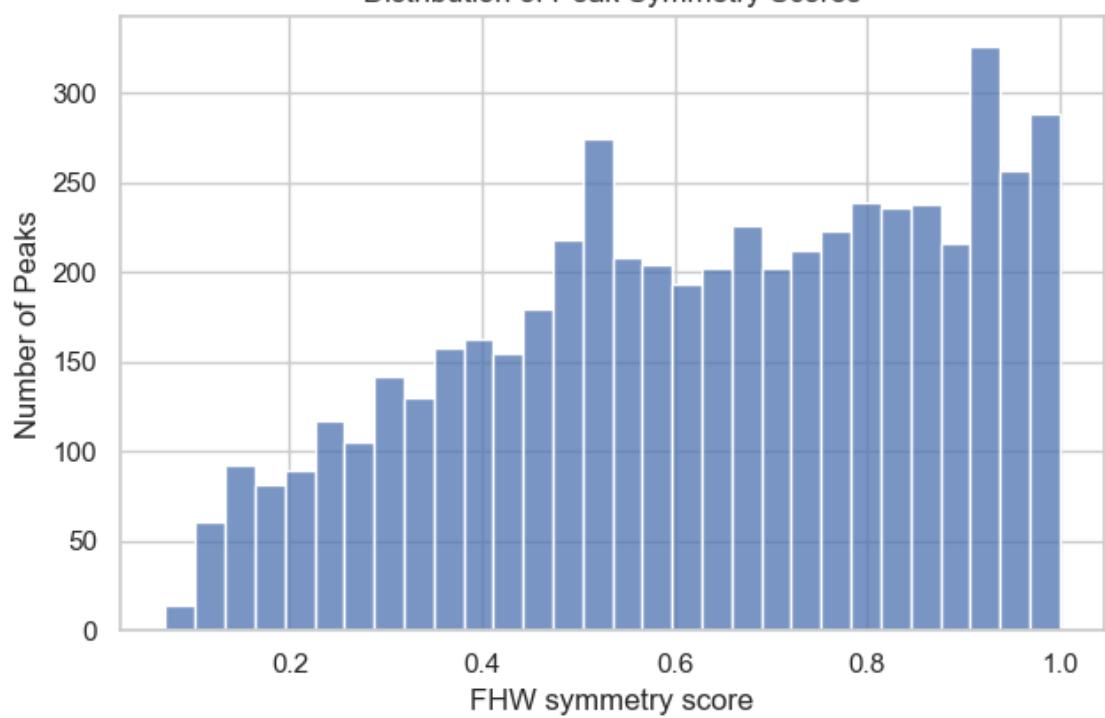


```
[2025-08-27 15:14:31] [INFO] calcium: plot_histogram: removed 7 outliers out of  
5448 on 'Prominence (noise std units)' (lower=-351.48, upper=660.2)
```

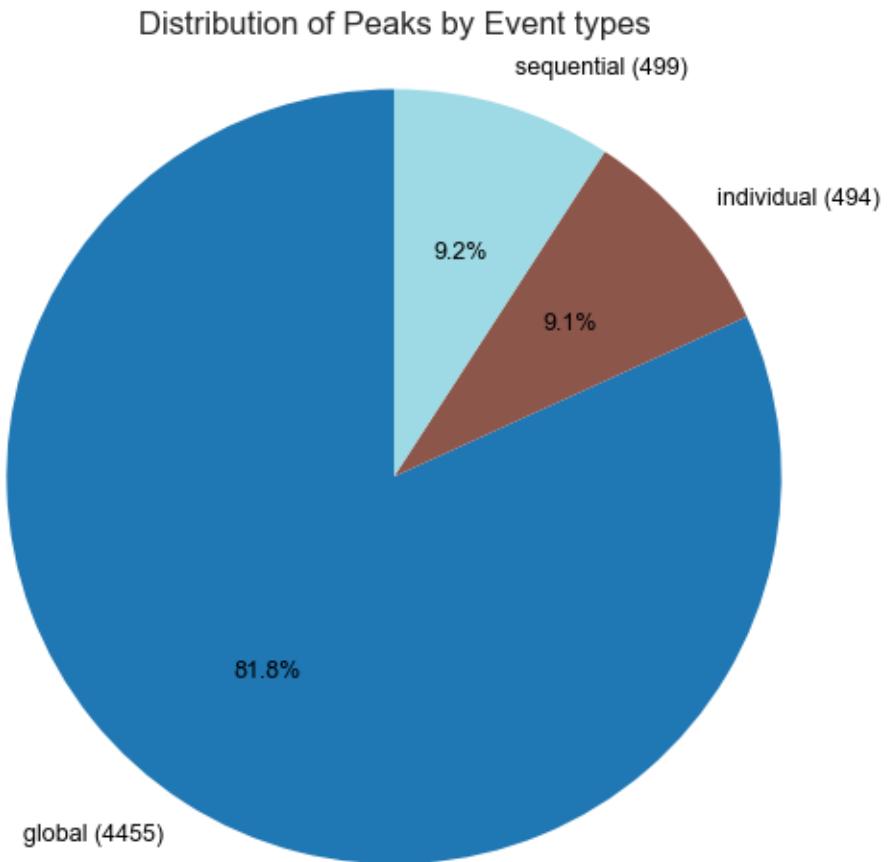
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

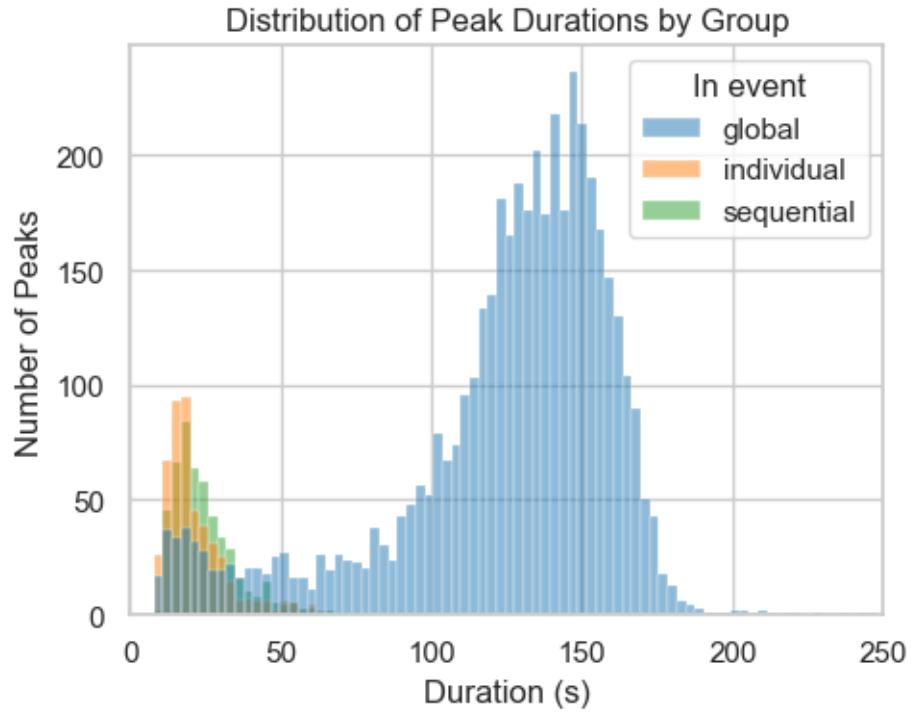


1.1.4 Distribution of peaks per event types

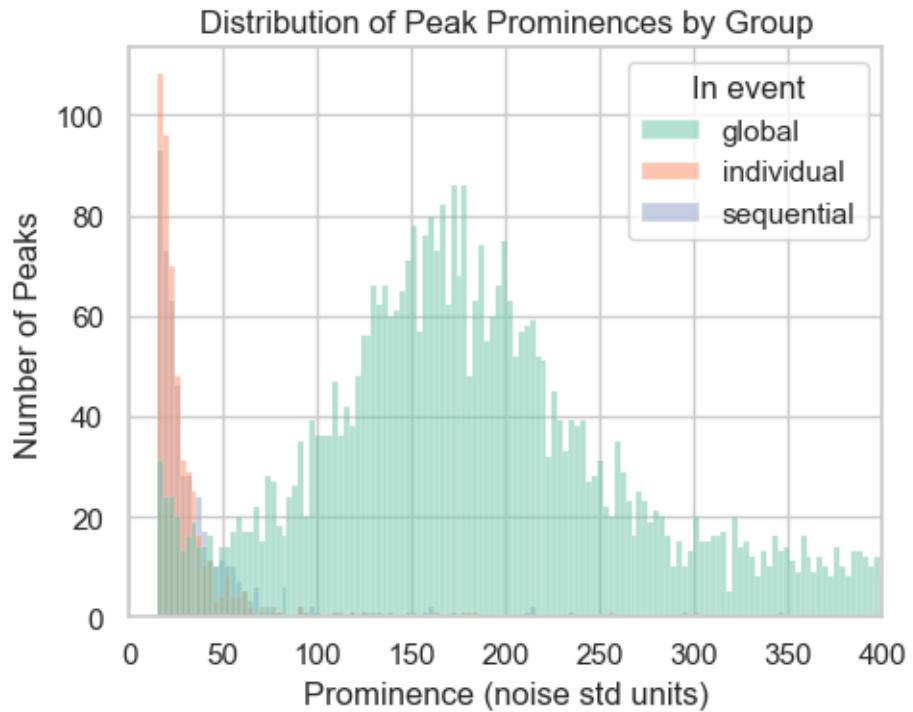


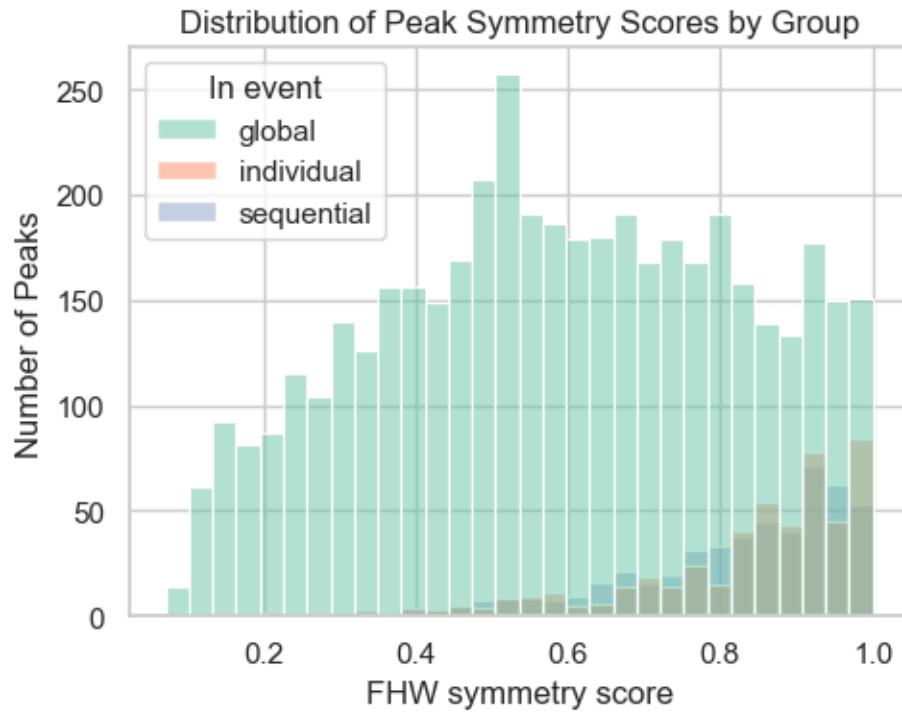
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:14:32] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5448 on 'Duration (s)' (lower=-206, upper=410)
```



```
[2025-08-27 15:14:32] [INFO] calcium: plot_histogram_by_group: removed 7 outliers out of 5448 on 'Prominence (noise std units)' (lower=-351.48, upper=660.2)
```

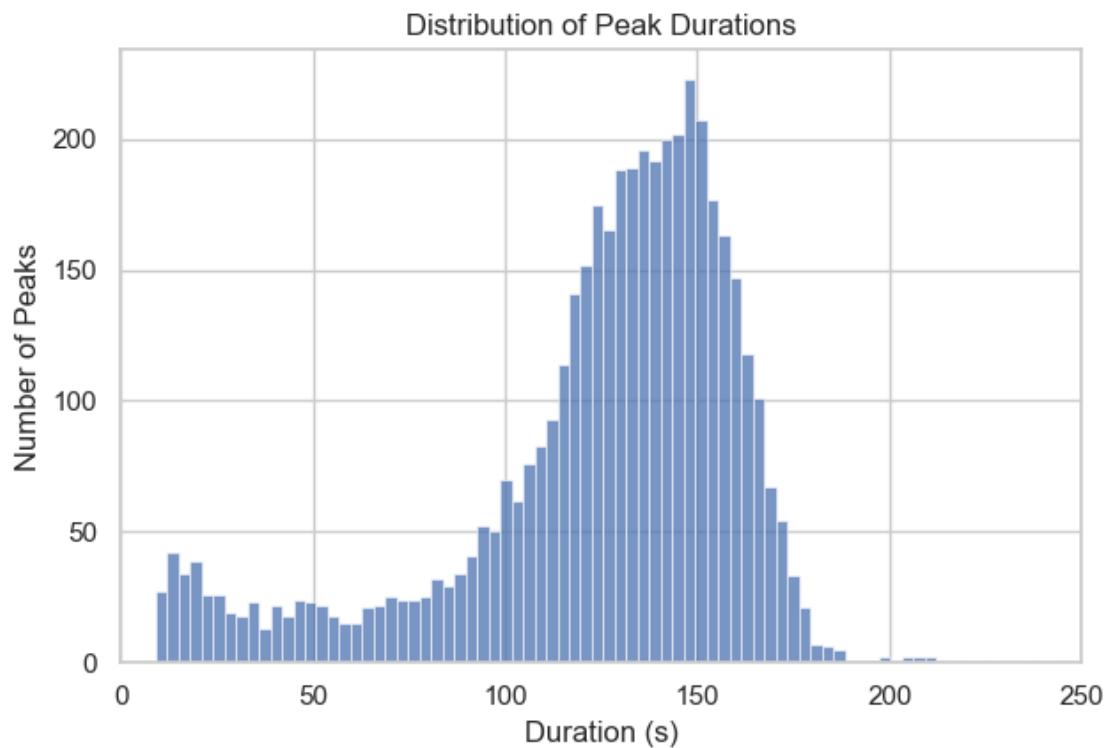




1.2 GLOBAL EVENTS

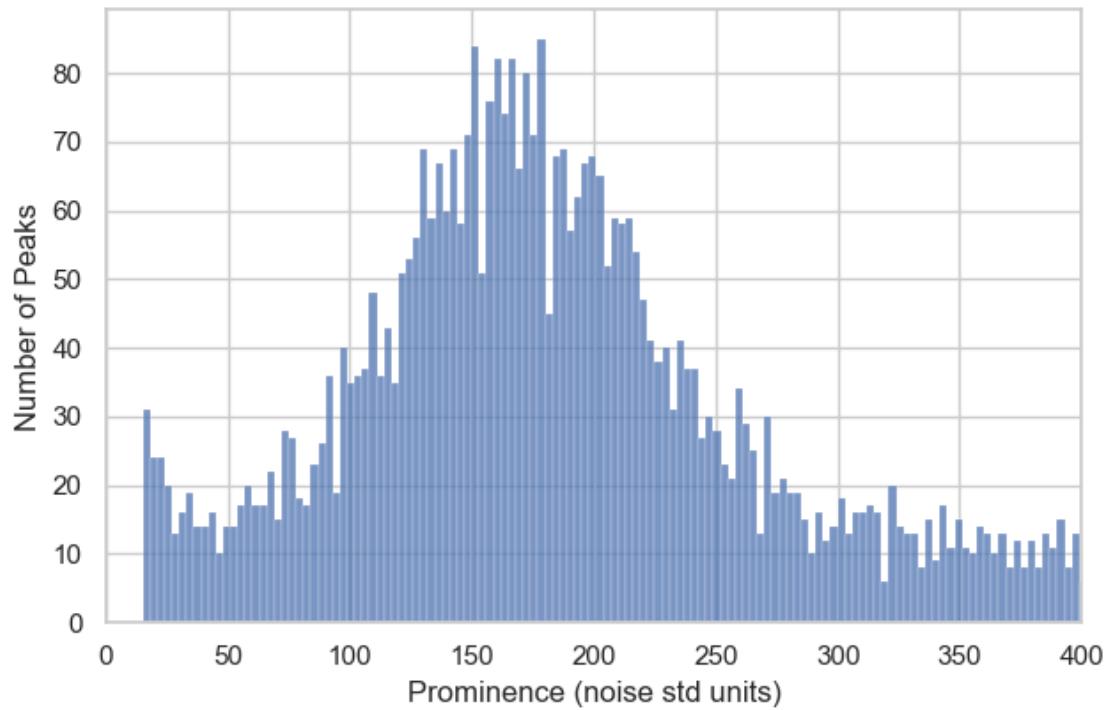
1.2.1 Peak statistics in global events

```
[2025-08-27 15:14:33] [INFO] calcium: plot_histogram: removed 7 outliers out of 4455 on 'Duration (s)' (lower=-6, upper=267)
```

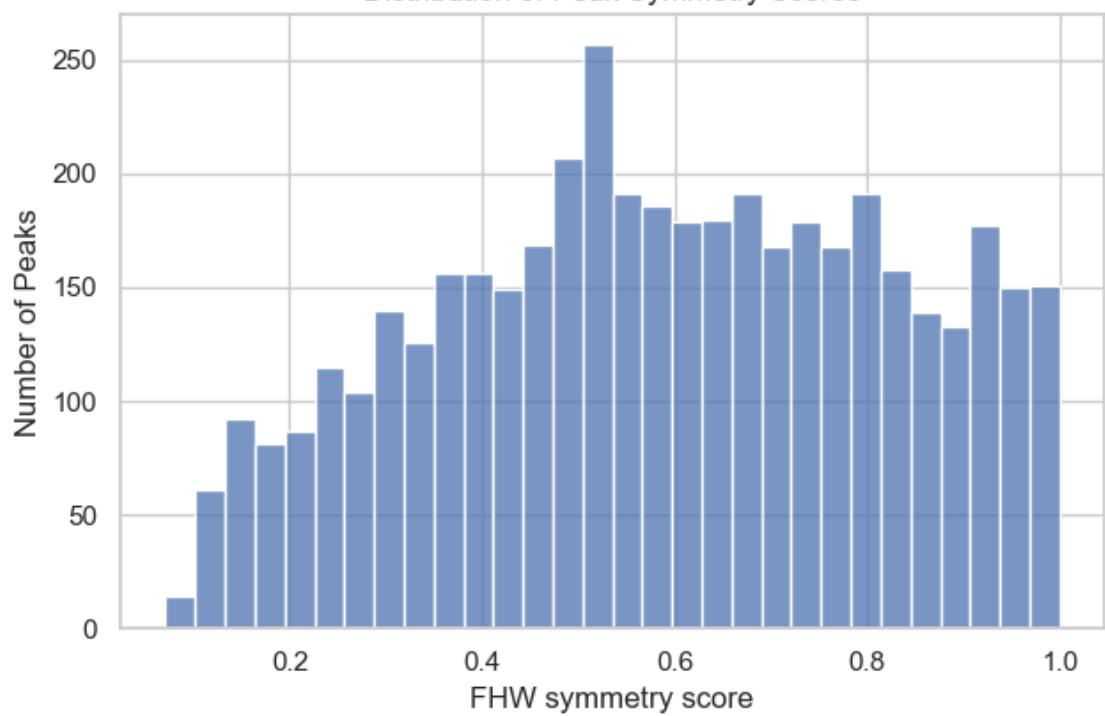


```
[2025-08-27 15:14:33] [INFO] calcium: plot_histogram: removed 25 outliers out of  
4455 on 'Prominence (noise std units)' (lower=-207.75, upper=589.2)
```

Distribution of Peak Prominences

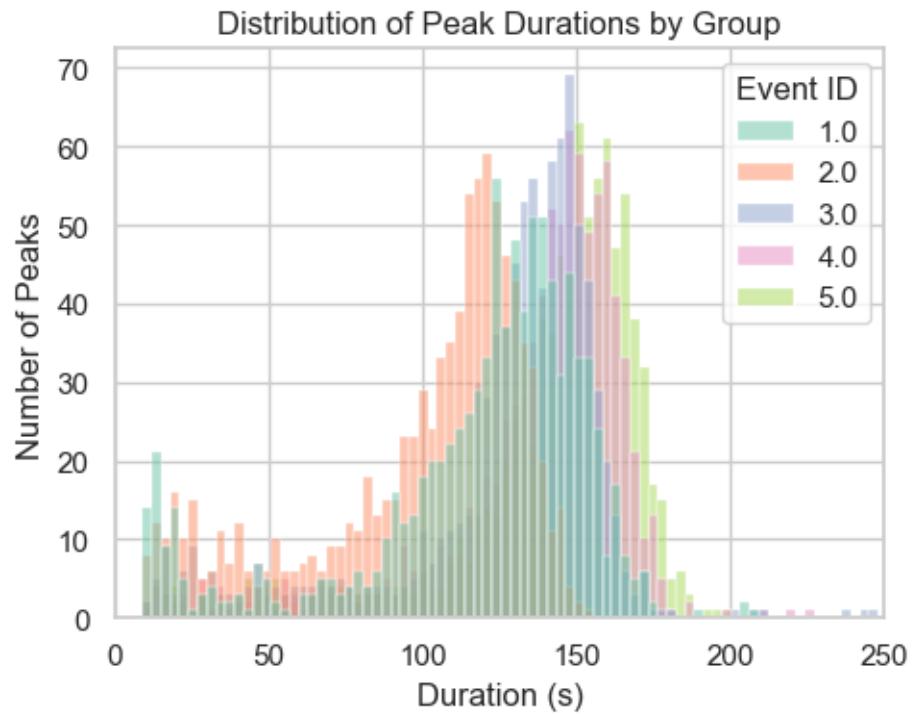


Distribution of Peak Symmetry Scores

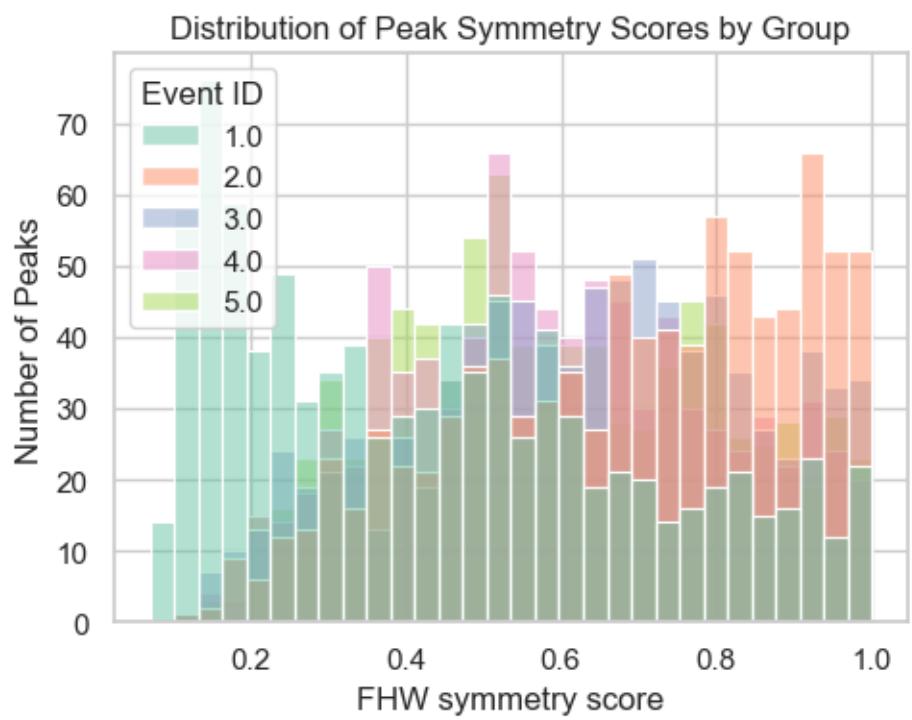
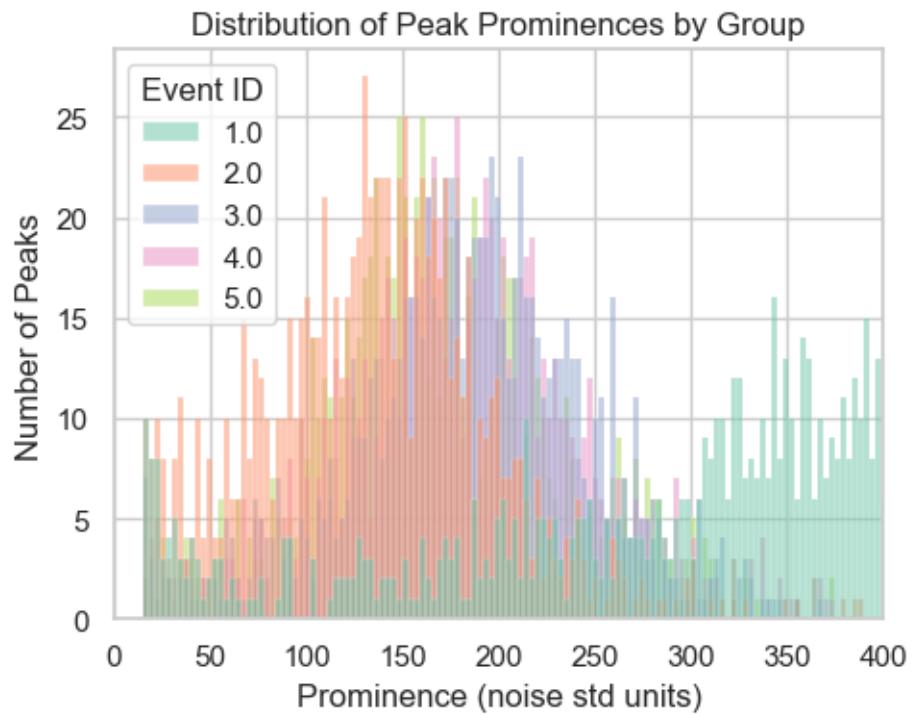


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:14:33] [INFO] calcium: plot_histogram_by_group: removed 7 outliers out of 4455 on 'Duration (s)' (lower=-6, upper=267)

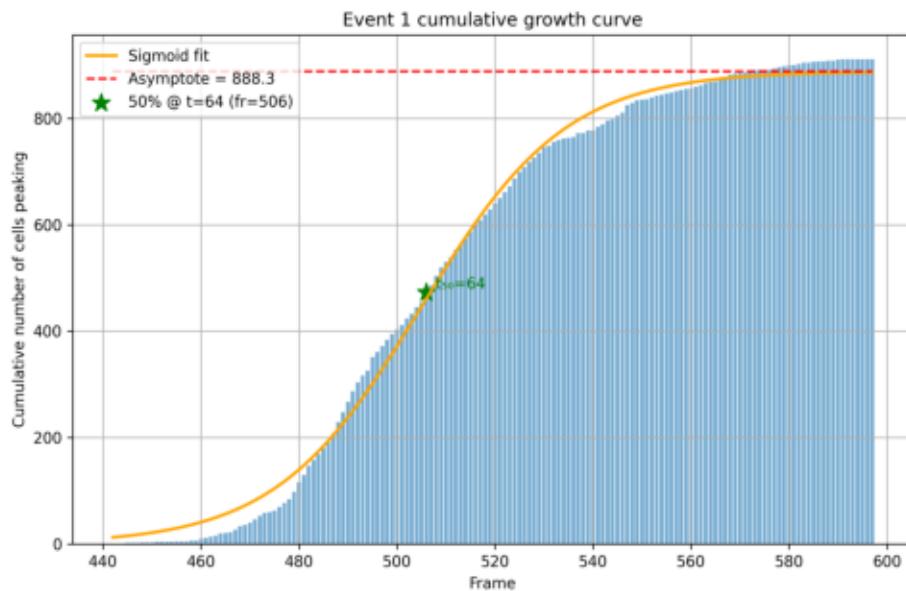


[2025-08-27 15:14:34] [INFO] calcium: plot_histogram_by_group: removed 25 outliers out of 4455 on 'Prominence (noise std units)' (lower=-207.75, upper=589.2)

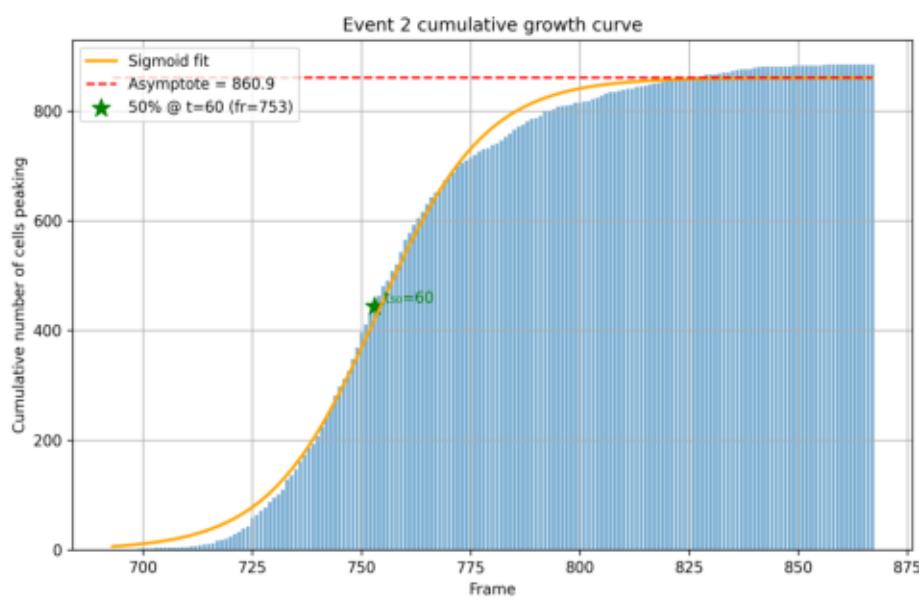


1.2.3 Kinetics of global events

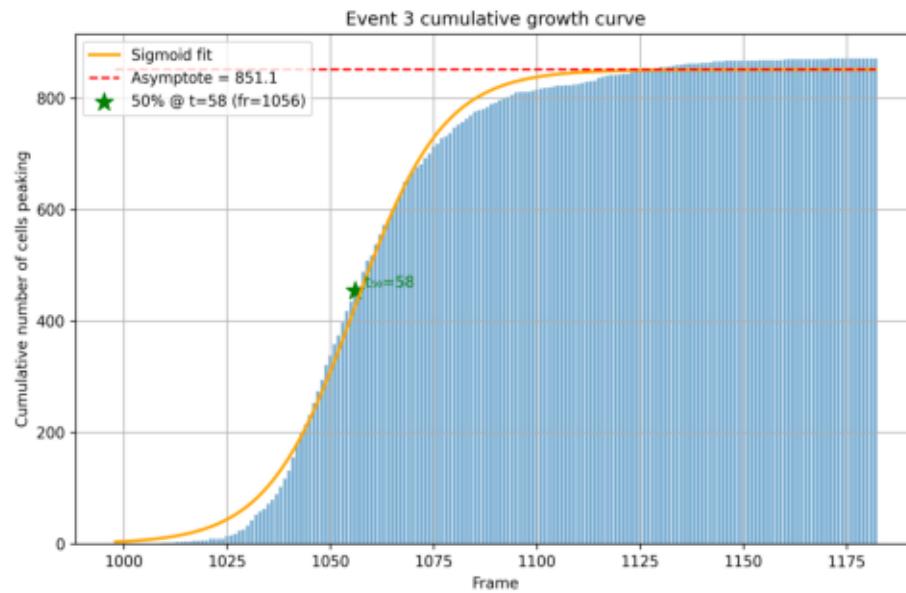
Event Activity Overlay (Event ID: 1)



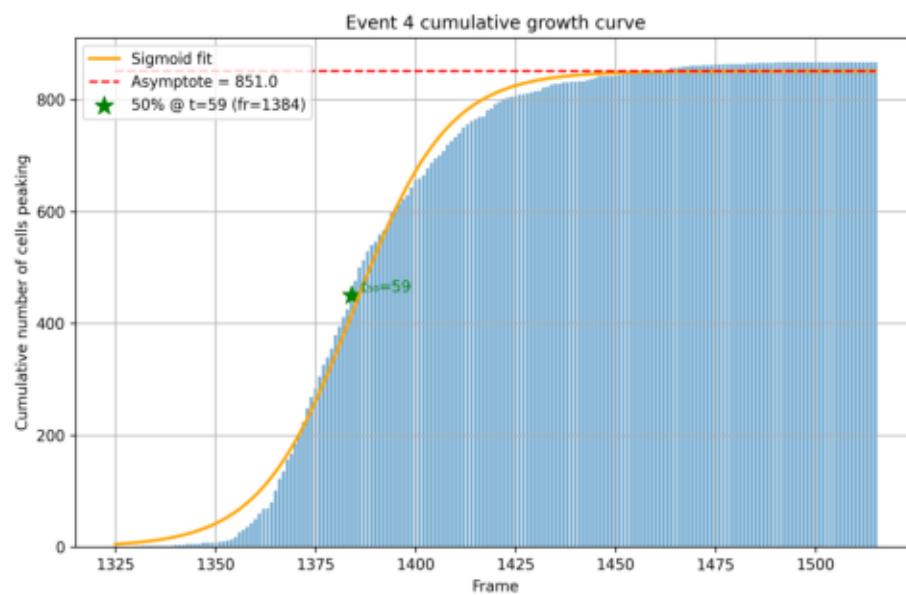
Event Activity Overlay (Event ID: 2)



Event Activity Overlay (Event ID: 3)



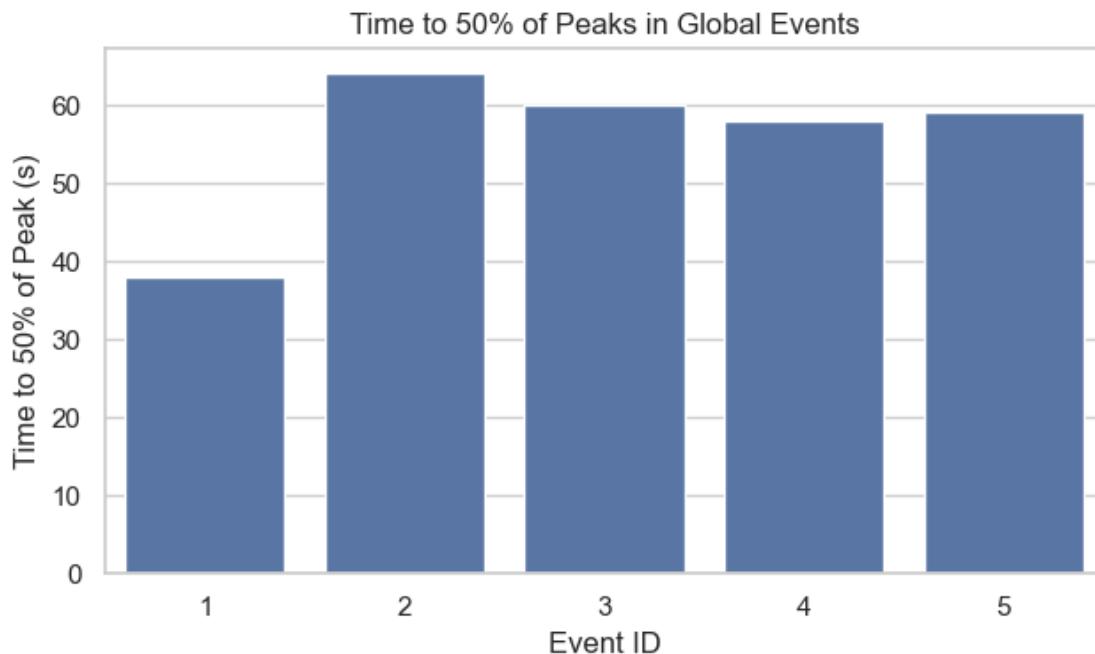
Event Activity Overlay (Event ID: 4)



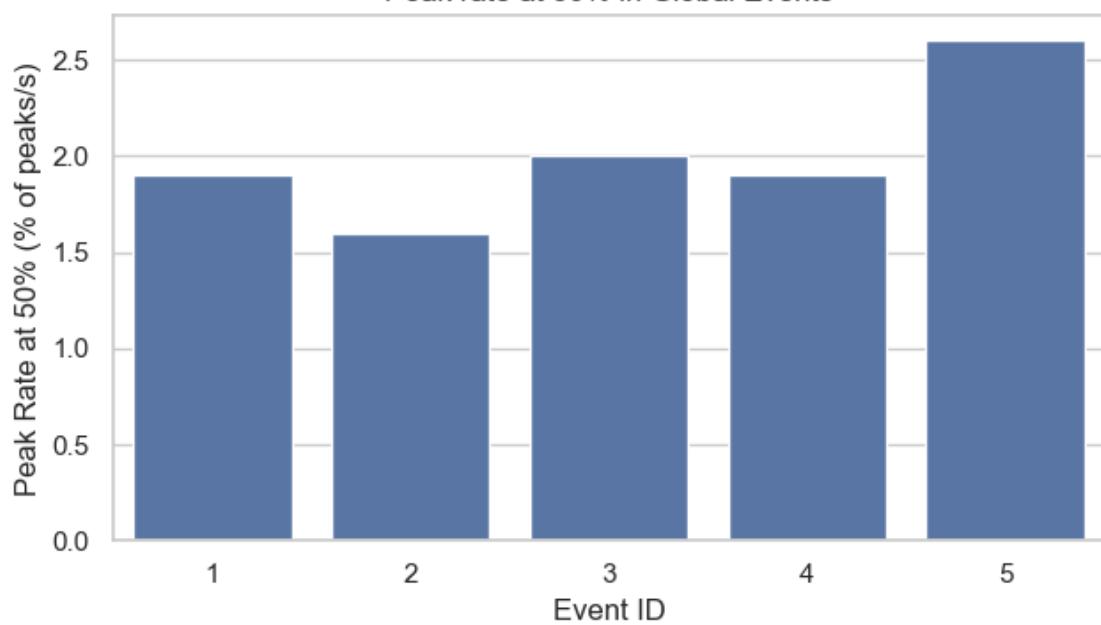
```

[2025-08-27 15:14:37] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\events\event-growth-curve-5.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250701\\Output\\IS3\\events\\event-growth-
curve-5.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\\Mateo\\20250701\\Output\\IS3\\events\\event-growth-curve-5.png'

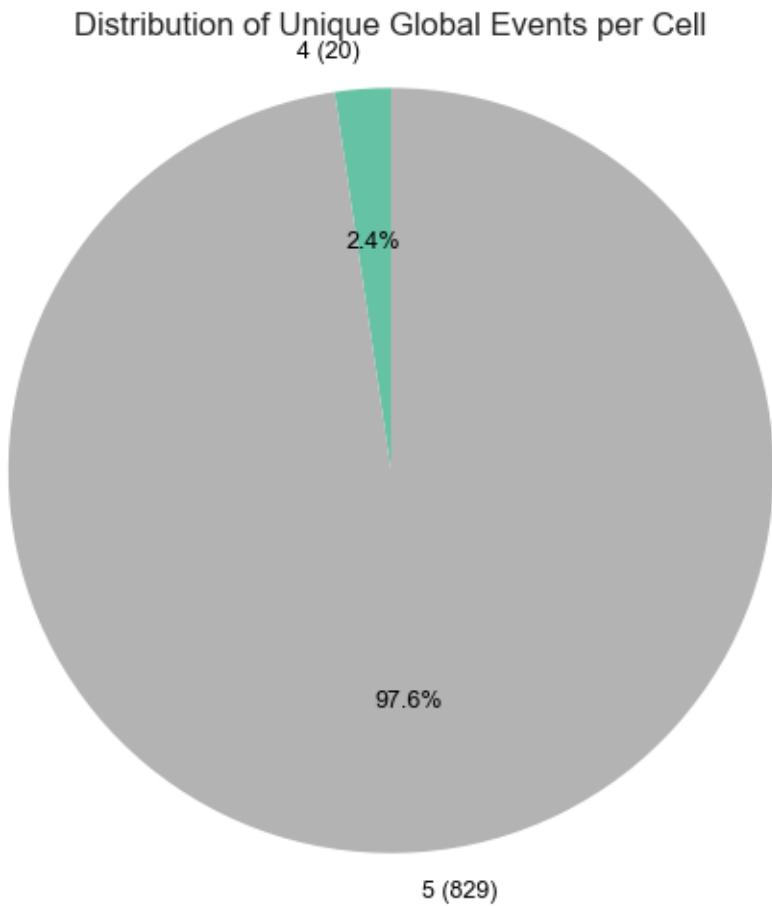
```



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

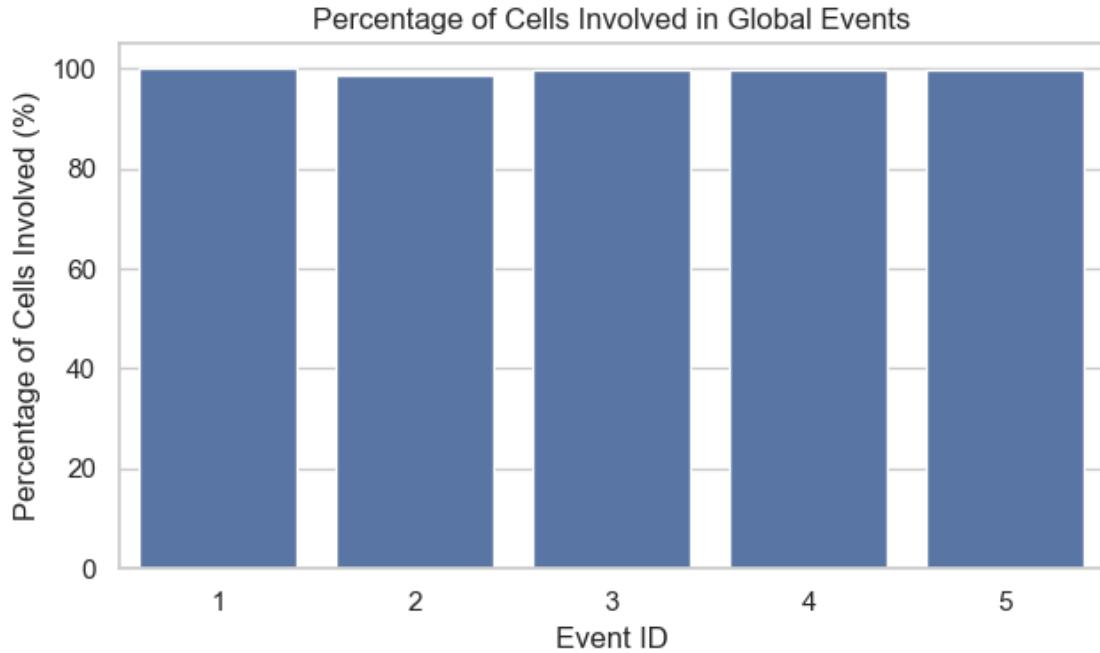


```
[2025-08-27 15:14:38] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250701\\\\Output\\\\IS3\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\IS3\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [250.0, 246.0, 309.0, 328.0]
 Estimated periodicity: 0.887
 The global events exhibit a regular periodic pattern.
 Estimated frequency (1/mean interval): 0.004 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 15:14:38] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:14:39] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:14:39] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()

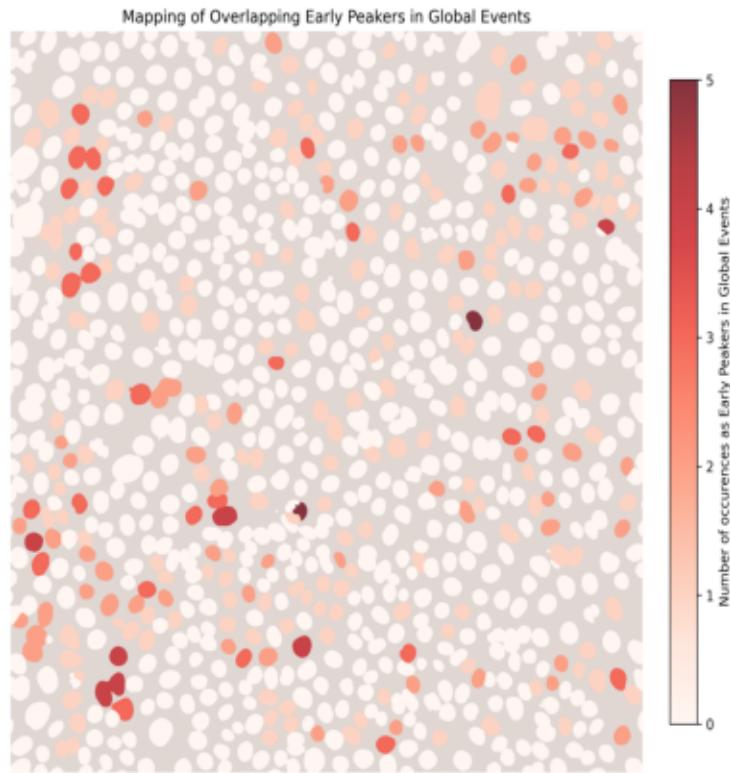
```

```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:14:39] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

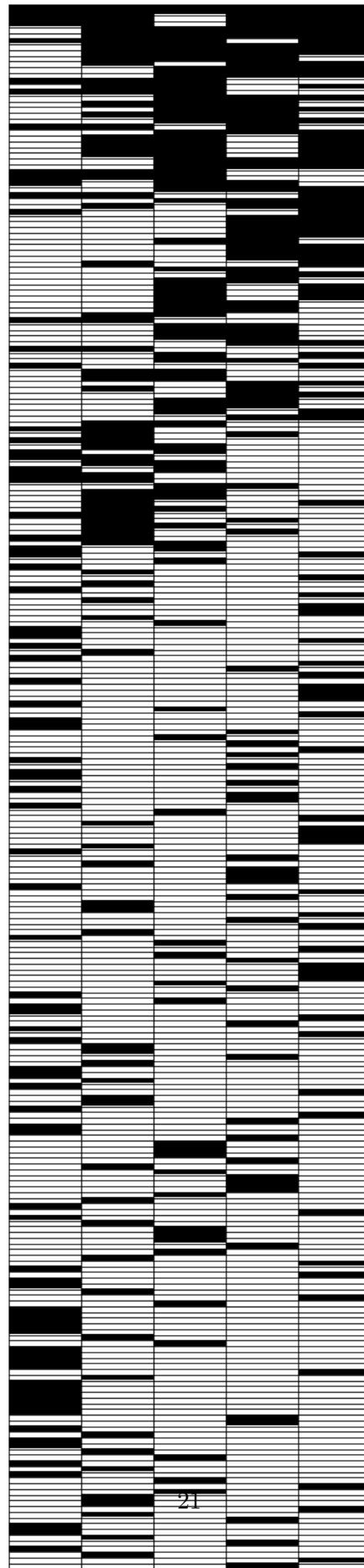
[2025-08-27 15:14:39] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



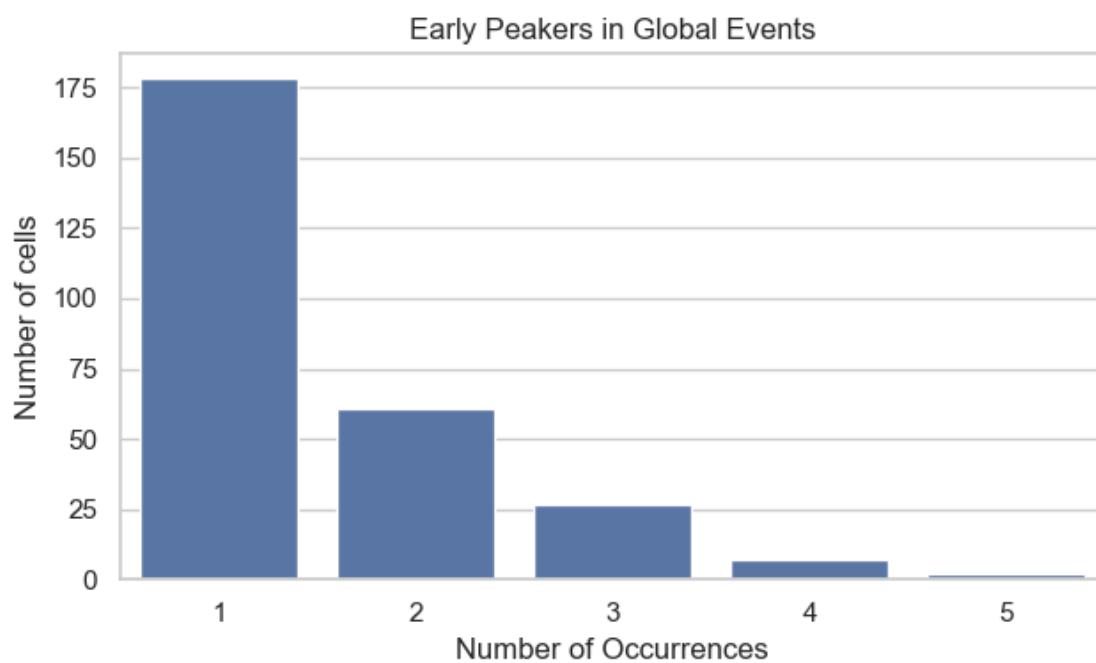
```
[2025-08-27 15:14:40] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 5 unique event IDs.
```

```
[2025-08-27 15:14:40] [INFO] calcium: Early peakers event-matrix: 275 cells x 5 events; black squares: 419
```

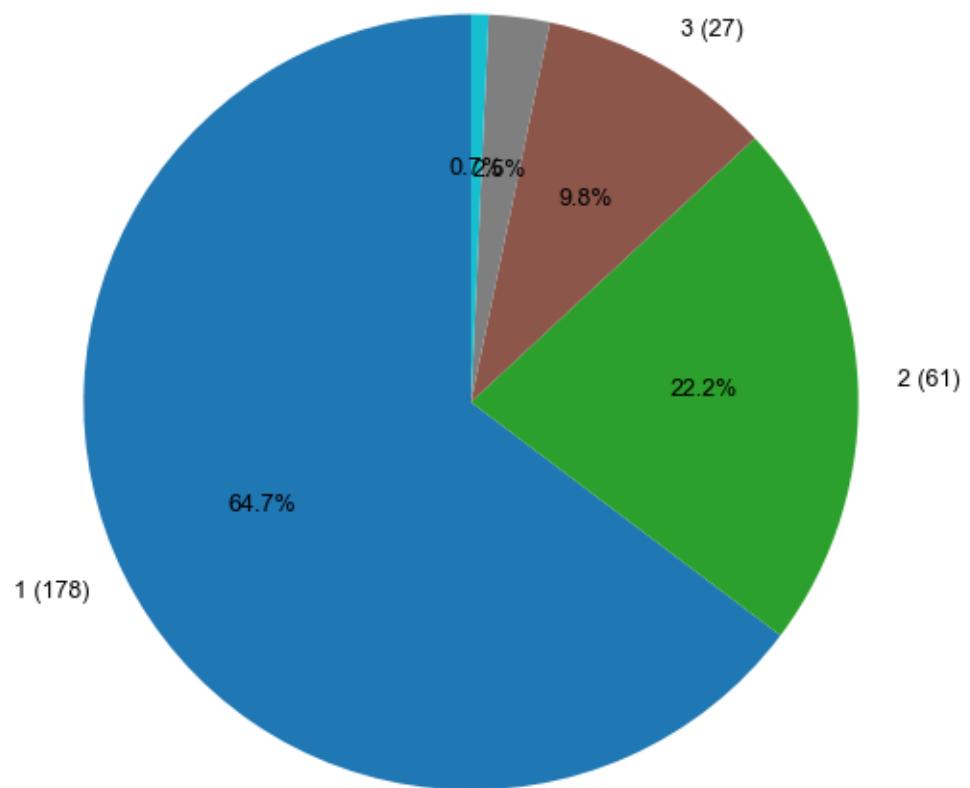


```
[2025-08-27 15:14:40] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 1, 1, 1],  
           [1, 1, 1, 1, 1],  
           [1, 1, 0, 1, 1],  
           ...,  
           [0, 0, 0, 0, 1],  
           [0, 0, 0, 1, 0],  
           [0, 0, 0, 1, 0]])
```



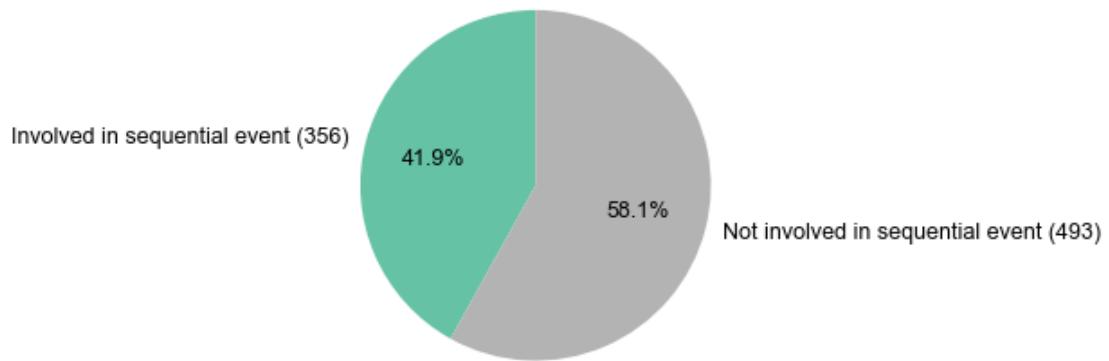
Distribution of Early Peakers in Global Events
5 (24%)



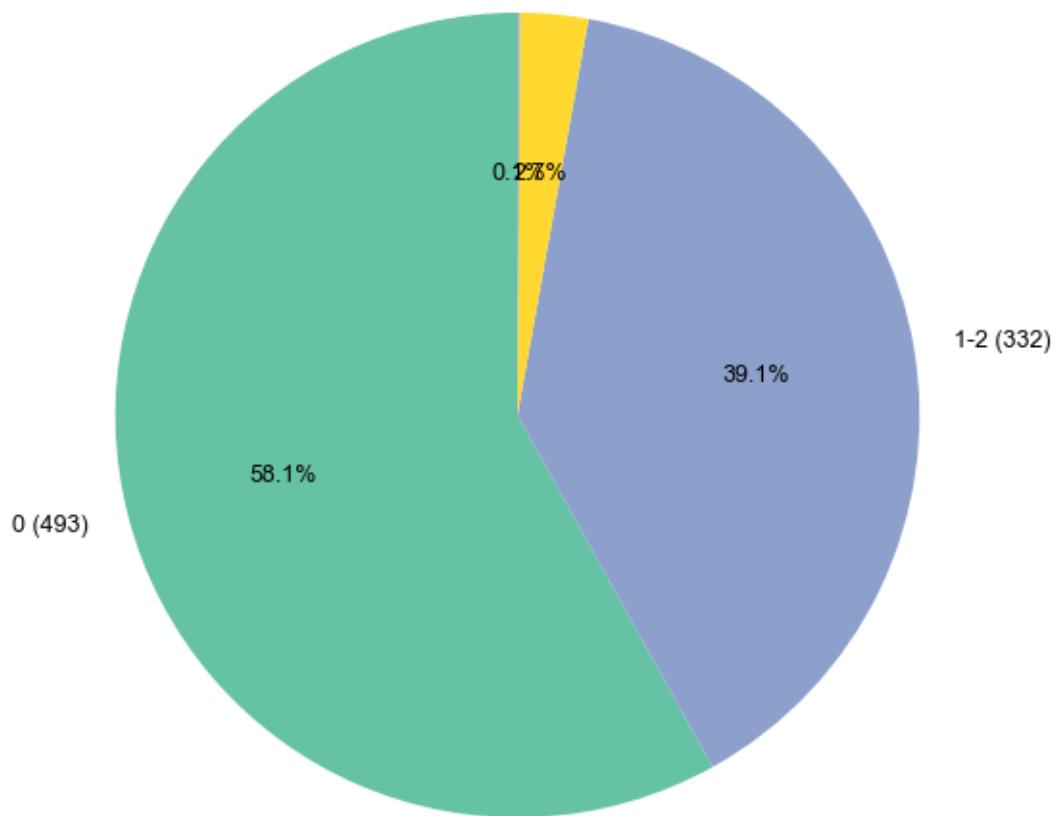
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

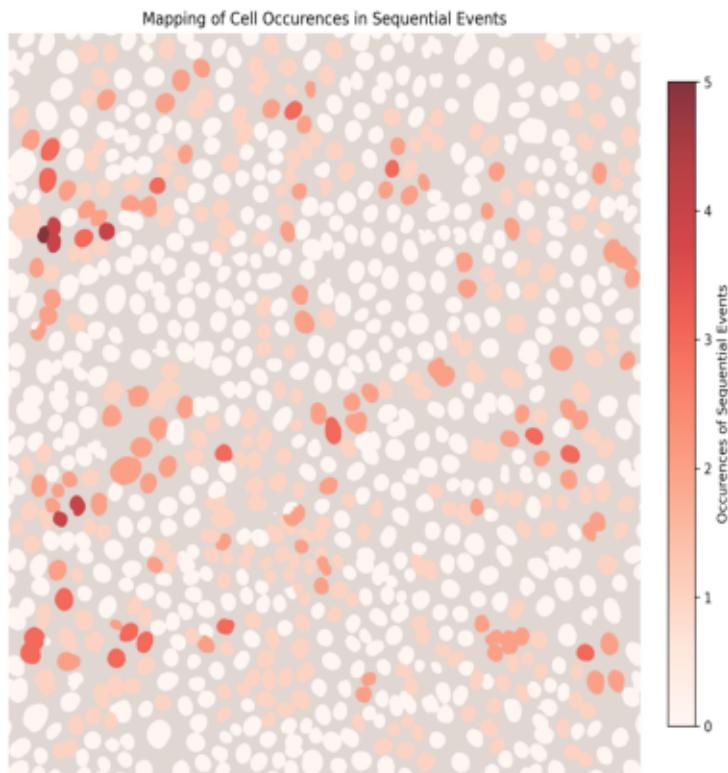
Distribution of Cells Involved in Sequential Events



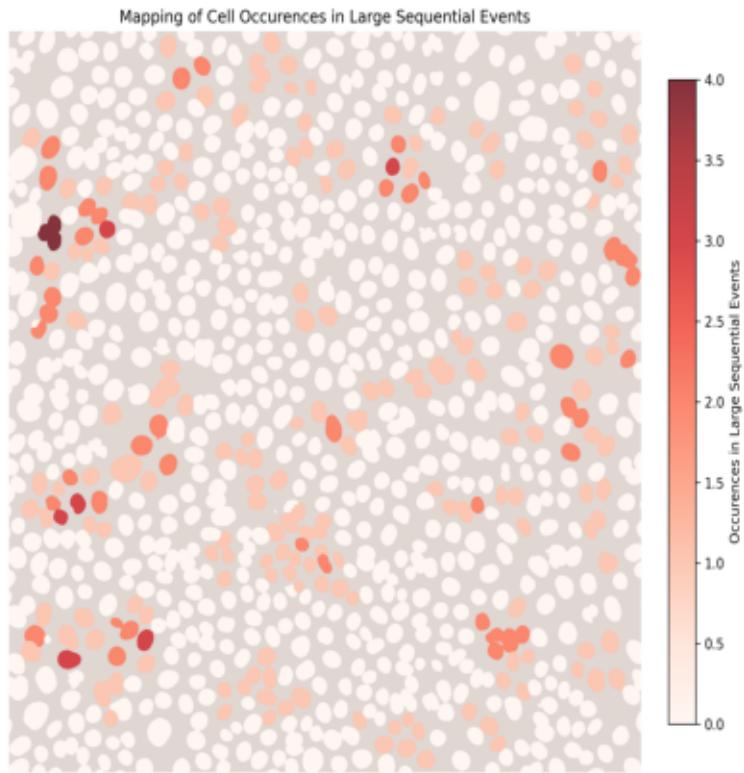
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

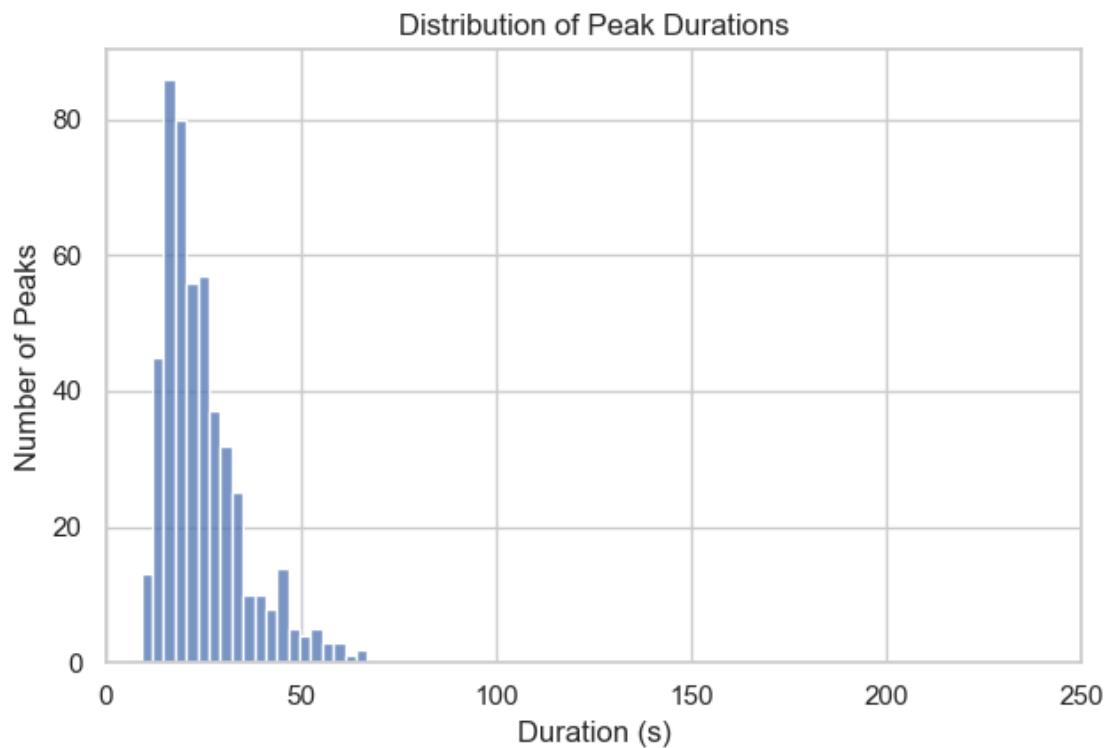


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



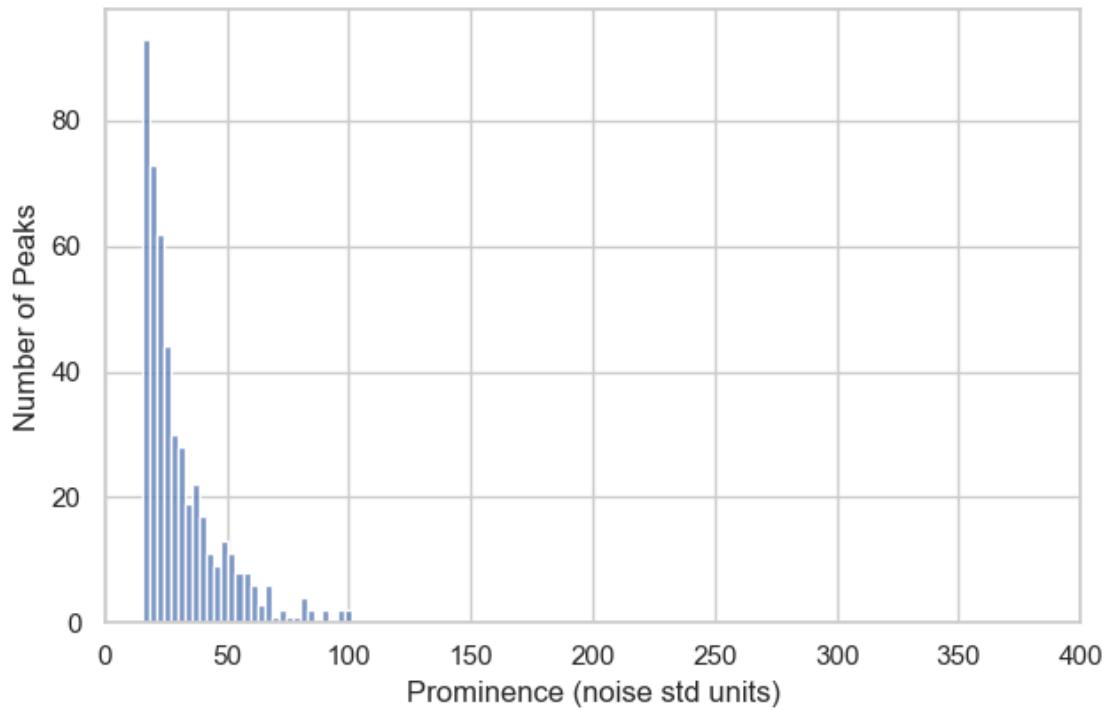
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:14:43] [INFO] calcium: plot_histogram: removed 3 outliers out of 499 on 'Duration (s)' (lower=-1.75, upper=73.25)
```

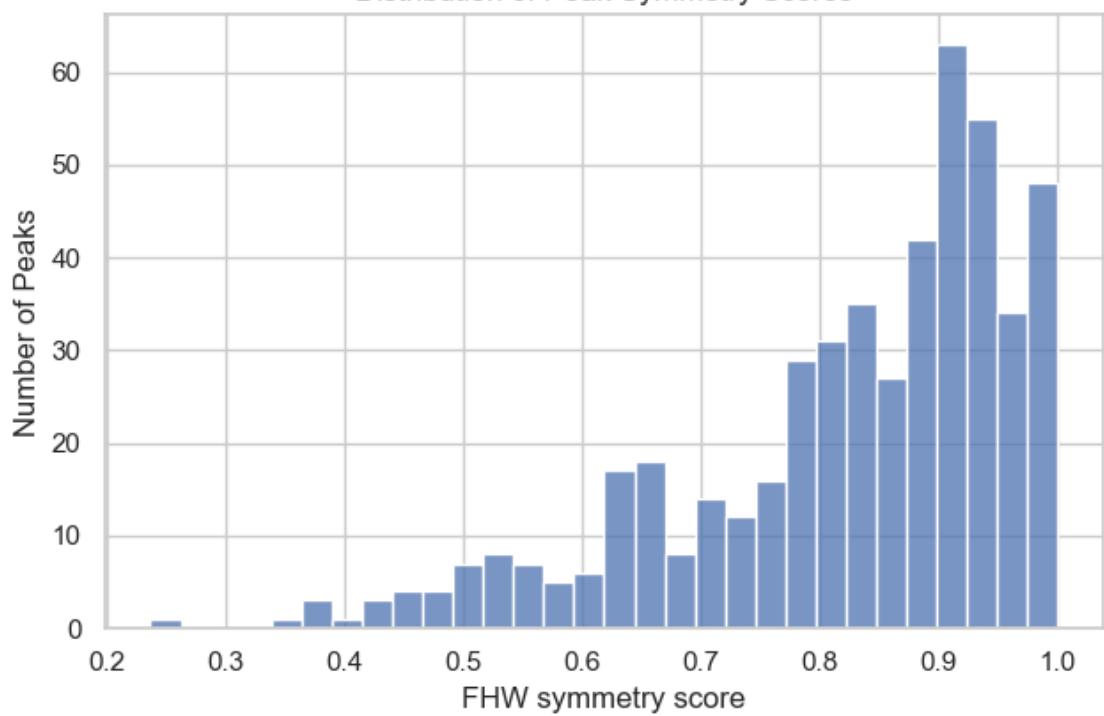


```
[2025-08-27 15:14:43] [INFO] calcium: plot_histogram: removed 19 outliers out of 499 on 'Prominence (noise std units)' (lower=-10.2, upper=108)
```

Distribution of Peak Prominences

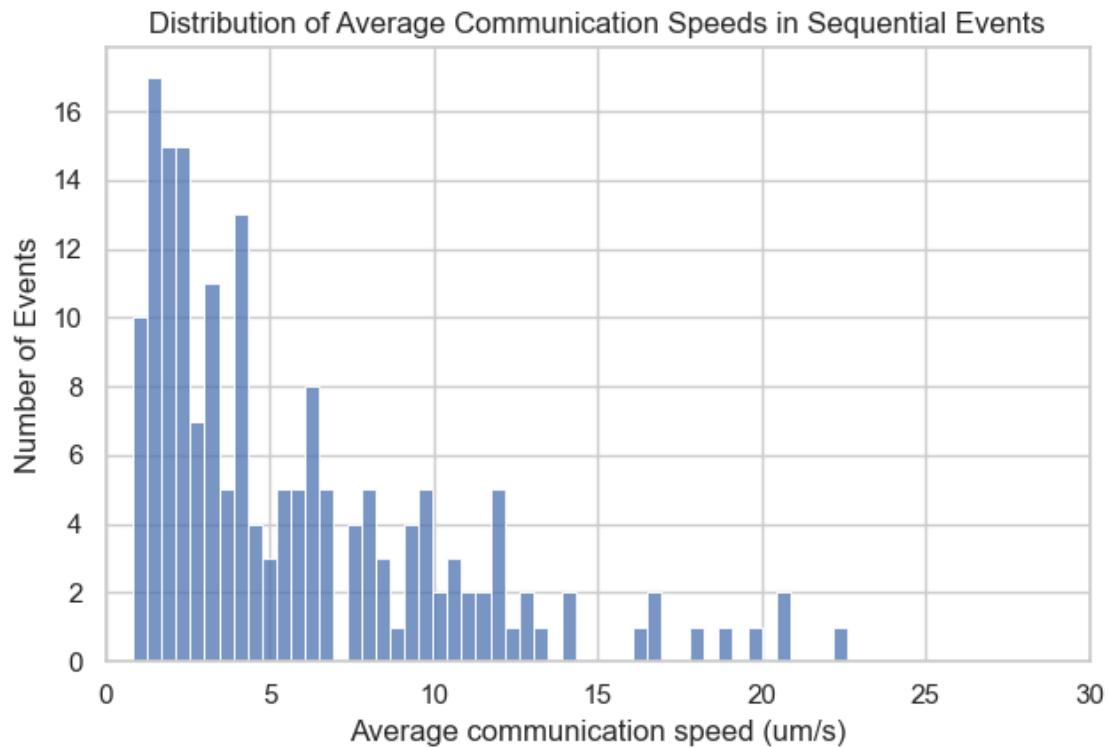


Distribution of Peak Symmetry Scores



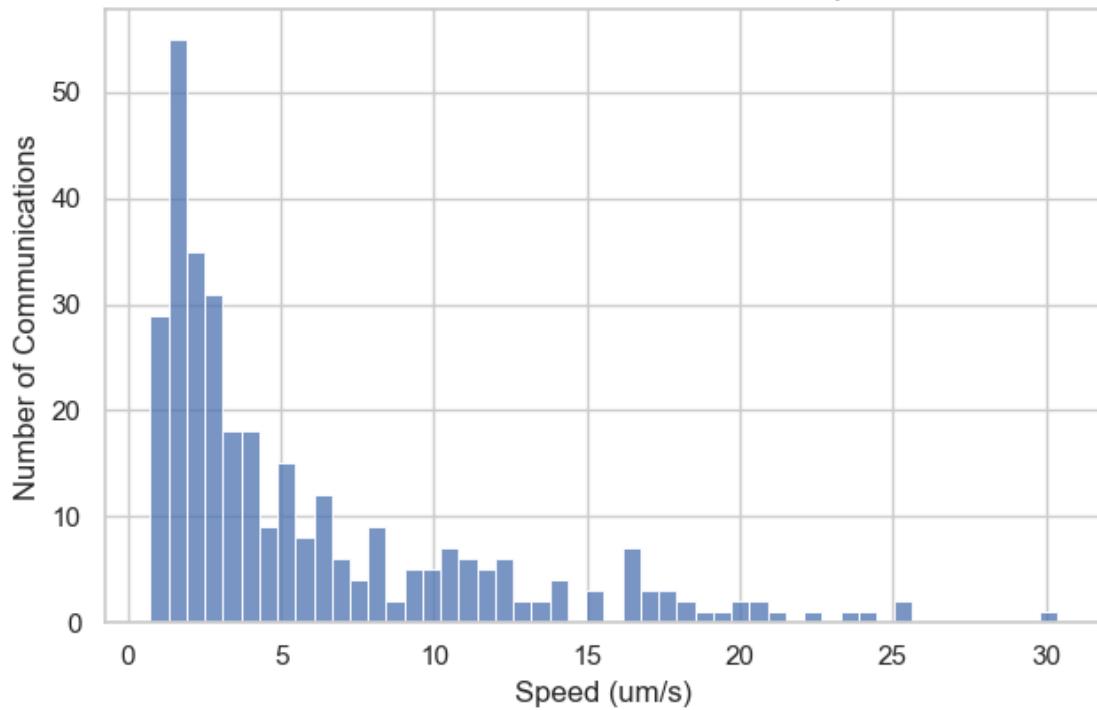
1.3.3 Cell-cell communication speed

[2025-08-27 15:14:44] [INFO] calcium: plot_histogram: removed 1 outliers out of 175 on 'Average communication speed (um/s)' (lower=-15.155, upper=25.375)

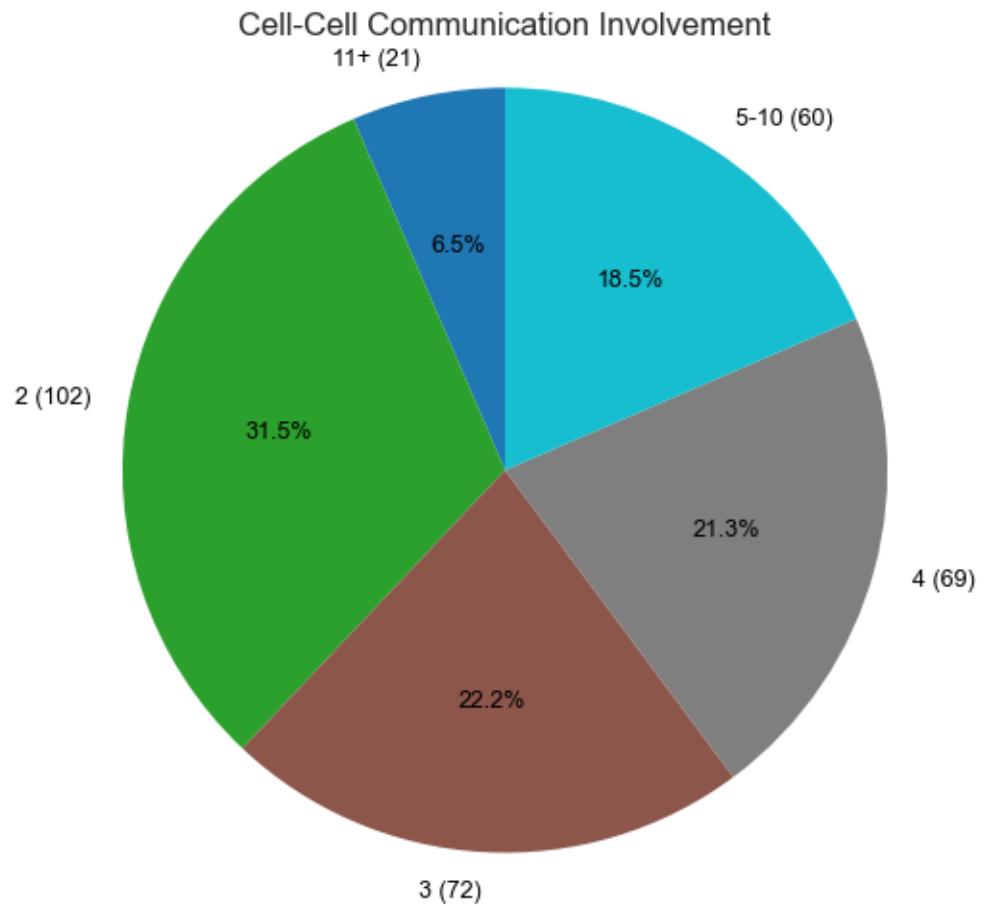


[2025-08-27 15:14:44] [INFO] calcium: plot_histogram: removed 0 outliers out of 324 on 'Speed (um/s)' (lower=-16.428, upper=38.45)

Distribution of Cell-Cell Communication Speeds

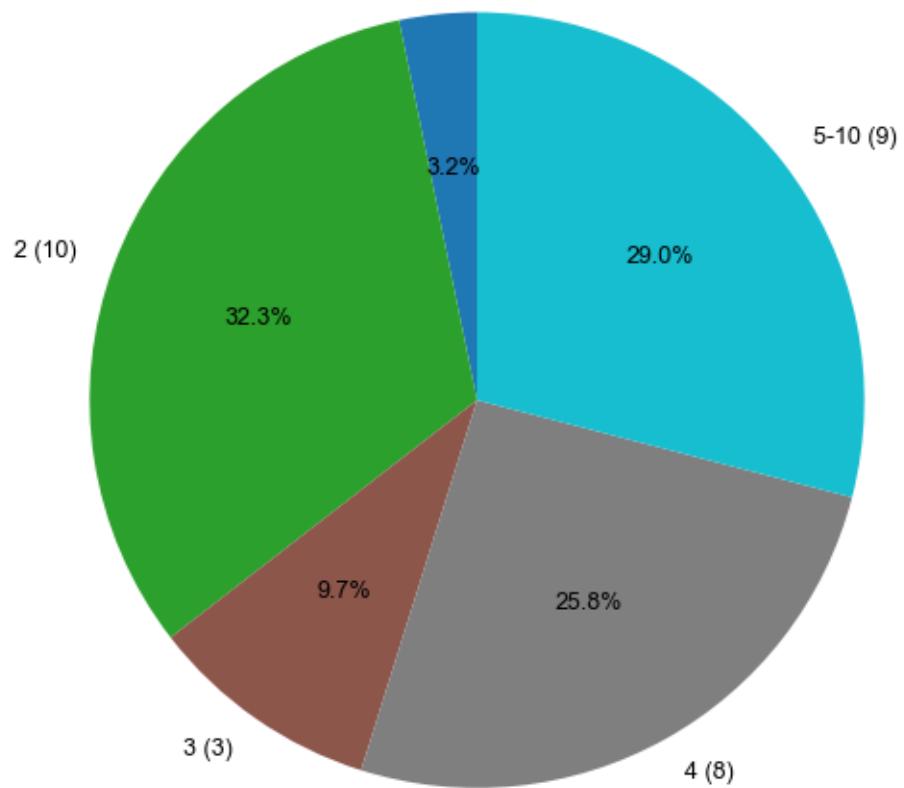


1.3.4 Double distribution in cell-cell communication speeds

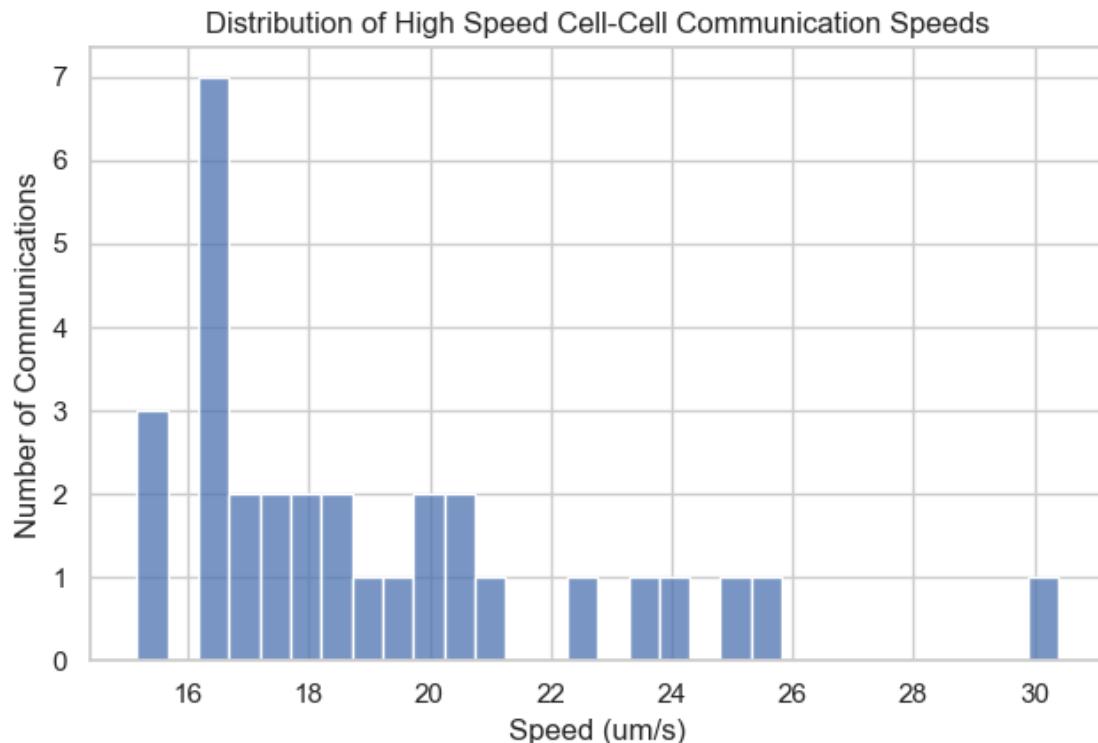


High Speed Cell-Cell Communication Involvement

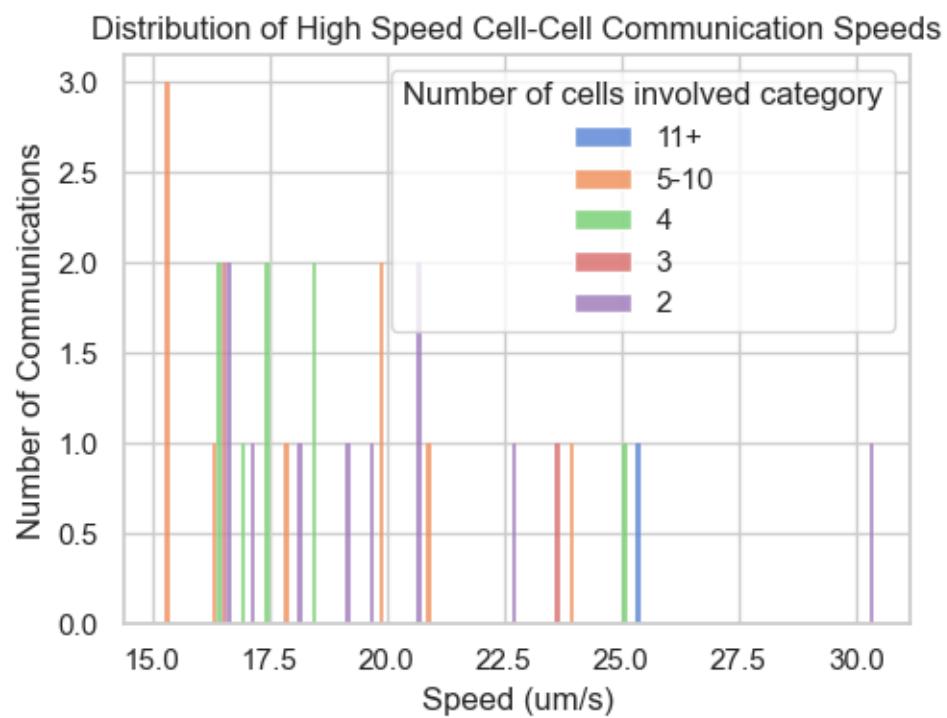
11+ (1)



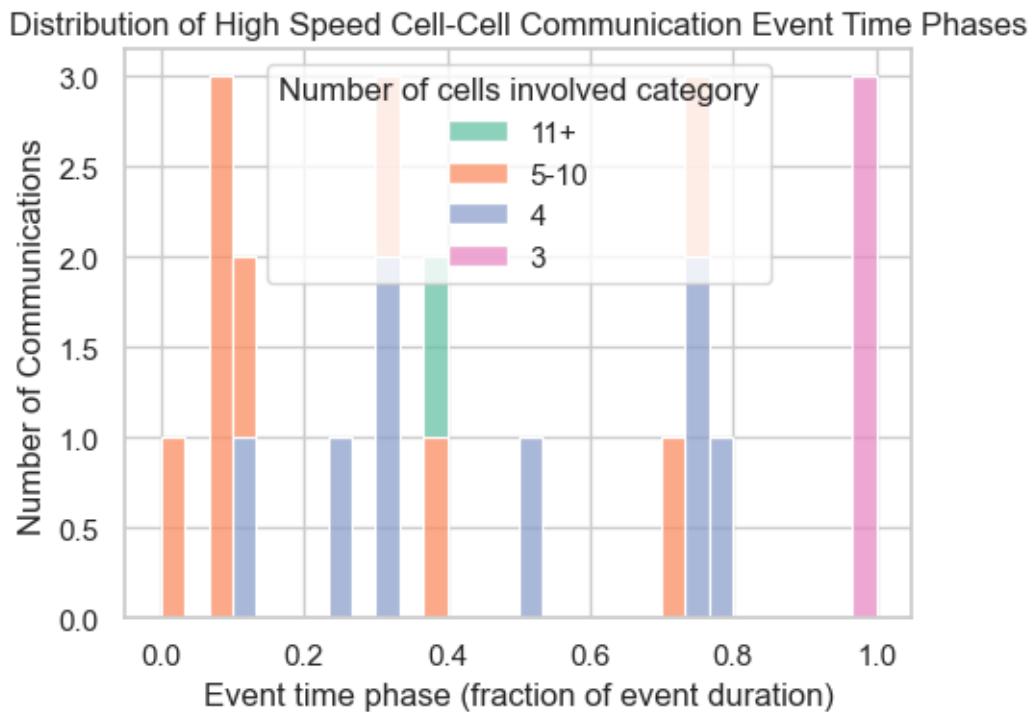
[2025-08-27 15:14:44] [INFO] calcium: plot_histogram: removed 0 outliers out of 31 on 'Speed (um/s)' (lower=5.115, upper=32.1)



```
[2025-08-27 15:14:45] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 31 on 'Speed (um/s)' (lower=5.115, upper=32.1)
```

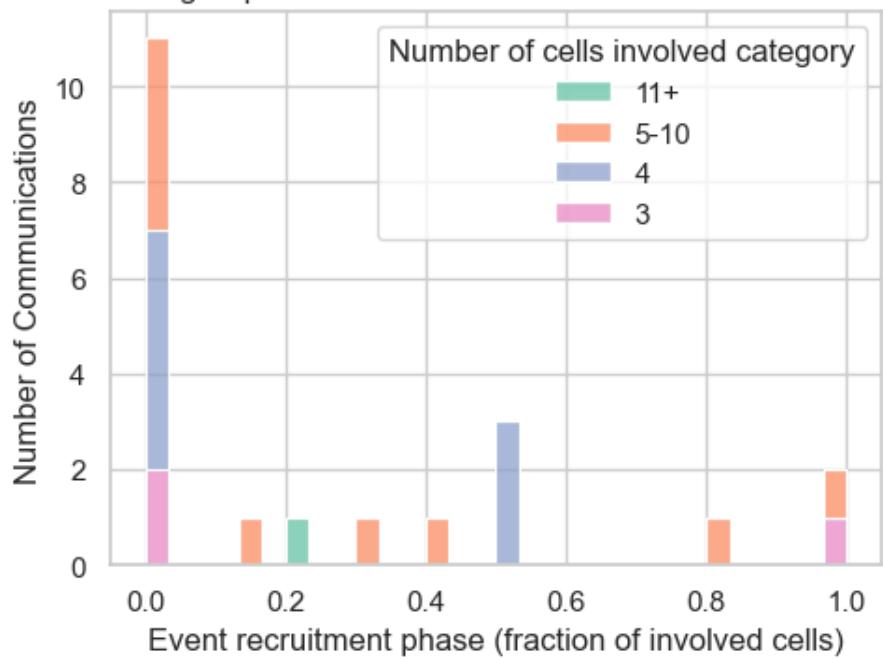


```
[2025-08-27 15:14:45] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 21 on 'Event time phase (fraction of event duration)' (lower=-1.77, upper=2.64)
```

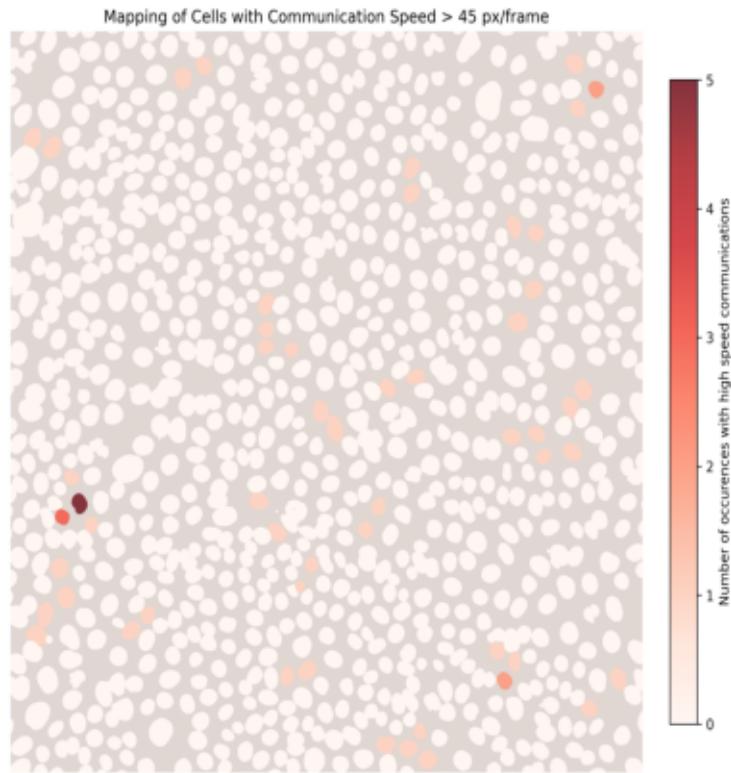


```
[2025-08-27 15:14:45] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 21 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)
```

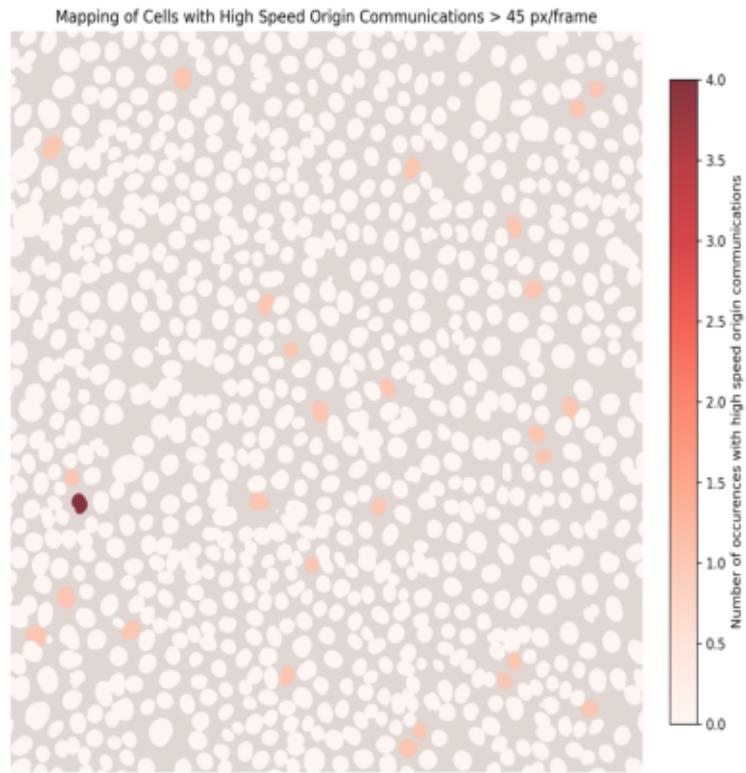
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
3	2016987886736	7	965	0
12	2016987874160	8	323	0
13	2016987886352	8	297	0
17	2016987875120	9	280	1
27	2016987877184	12	1246	0
28	2016535632128	12	1279	0
33	2016535635392	13	1192	0
42	2016987875264	16	387	2
47	2016987882512	18	420	0
52	2016987873392	20	615	0
59	2016535627568	22	1396	0
61	2016535626032	22	1366	0

71	2016987889376	27	814	6
76	2016987888896	29	978	0
86	2016987877328	33	972	8
88	2016987879392	35	972	12
89	2016987880400	35	972	12
163	2016987880016	83	512	6
179	2016987873776	93	638	0
184	2016987885392	96	713	0
186	2016987888080	97	807	0
193	2016987880736	100	775	0
215	2016987875360	116	849	3
222	2016987873872	121	889	0
244	2016987878384	131	924	7
245	2016987876656	131	972	15
263	2016535637408	142	1086	0
265	2016535630400	144	1140	1
277	2016535626176	151	1206	0
306	2016535629488	167	1267	1
309	2016535626416	170	1330	0

Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
3	1023	0	82.0	82.0
12	297	0	17.0	18.0
13	260	0	18.0	18.0
17	264	1	65.0	65.0
27	1279	0	67.0	67.0
28	1228	0	67.0	68.0
33	1175	0	110.0	111.0
42	370	2	181.0	181.0
47	461	1	80.0	81.0
52	666	0	60.0	60.0
59	1390	0	37.0	38.0
61	1413	0	28.0	29.0
71	842	7	1654.0	1654.0
76	1016	0	103.0	103.0
86	994	4	979.0	979.0
88	994	6	1298.0	1299.0
89	1005	6	1298.0	1299.0
163	529	4	1291.0	1292.0
179	681	0	93.0	94.0
184	703	1	162.0	163.0
186	778	0	35.0	36.0
193	761	0	75.0	76.0
215	852	2	376.0	377.0
222	883	0	9.0	10.0
244	972	15	1619.0	1620.0
245	994	8	1620.0	1621.0
263	1124	0	89.0	90.0

265	1092	2	184.0	185.0
277	1171	0	100.0	101.0
306	1263	0	184.0	185.0
309	1272	1	93.0	94.0

	Duration (s)	Distance (um)	Speed (um/s)	\
3	0.0	25.62	25.62	
12	1.0	19.81	19.81	
13	0.0	23.90	23.90	
17	0.0	18.32	18.32	
27	0.0	15.16	15.16	
28	1.0	20.98	20.98	
33	1.0	16.65	16.65	
42	0.0	16.60	16.60	
47	1.0	17.23	17.23	
52	0.0	25.16	25.16	
59	1.0	17.74	17.74	
61	1.0	20.14	20.14	
71	0.0	16.55	16.55	
76	0.0	18.75	18.75	
86	0.0	16.68	16.68	
88	1.0	16.68	16.68	
89	1.0	17.40	17.40	
163	1.0	17.82	17.82	
179	1.0	16.90	16.90	
184	1.0	20.57	20.57	
186	1.0	15.20	15.20	
193	1.0	23.44	23.44	
215	1.0	19.57	19.57	
222	1.0	22.61	22.61	
244	1.0	18.41	18.41	
245	1.0	16.68	16.68	
263	1.0	17.06	17.06	
265	1.0	20.50	20.50	
277	1.0	15.41	15.41	
306	1.0	16.40	16.40	
309	1.0	30.39	30.39	

	Event time phase (fraction of event duration)	\
3	0.38	
12	0.07	
13	0.07	
17	0.75	
27	0.00	
28	0.12	
33	0.33	
42	1.00	
47	0.11	

52	0.75
59	0.73
61	0.38
71	1.00
76	NaN
86	NaN
88	0.33
89	0.33
163	NaN
179	NaN
184	NaN
186	0.07
193	1.00
215	NaN
222	NaN
244	0.25
245	0.50
263	0.79
265	NaN
277	0.76
306	NaN
309	NaN

	Event recruitment phase (fraction of involved cells)	dataset	\
3	0.20	20250701_IS3	
12	0.00	20250701_IS3	
13	0.00	20250701_IS3	
17	0.00	20250701_IS3	
27	0.00	20250701_IS3	
28	0.14	20250701_IS3	
33	0.33	20250701_IS3	
42	0.00	20250701_IS3	
47	0.50	20250701_IS3	
52	0.00	20250701_IS3	
59	0.80	20250701_IS3	
61	0.40	20250701_IS3	
71	0.00	20250701_IS3	
76	NaN	20250701_IS3	
86	NaN	20250701_IS3	
88	0.00	20250701_IS3	
89	0.00	20250701_IS3	
163	NaN	20250701_IS3	
179	NaN	20250701_IS3	
184	NaN	20250701_IS3	
186	0.00	20250701_IS3	
193	1.00	20250701_IS3	
215	NaN	20250701_IS3	
222	NaN	20250701_IS3	

244		0.00	20250701_IS3
245		0.50	20250701_IS3
263		0.50	20250701_IS3
265		NaN	20250701_IS3
277		1.00	20250701_IS3
306		NaN	20250701_IS3
309		NaN	20250701_IS3

Number of cells involved	category	Speed category
3	11+	High speed
12	5-10	High speed
13	5-10	High speed
17	4	High speed
27	5-10	High speed
28	5-10	High speed
33	5-10	High speed
42	3	High speed
47	4	High speed
52	4	High speed
59	5-10	High speed
61	5-10	High speed
71	3	High speed
76	2	High speed
86	2	High speed
88	4	High speed
89	4	High speed
163	2	High speed
179	2	High speed
184	2	High speed
186	5-10	High speed
193	3	High speed
215	2	High speed
222	2	High speed
244	4	High speed
245	4	High speed
263	4	High speed
265	2	High speed
277	5-10	High speed
306	2	High speed
309	2	High speed

Speed category High speed Low speed

Origin cell ID

228	0	1
233	0	1
241	0	1
253	0	1
257	0	2

...
1389	0	1	
1390	0	1	
1392	0	1	
1396	1	0	
1408	0	1	

[214 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	228	419.25	7.80	
6	233	257.07	10.72	
11	241	62.40	13.00	
20	253	460.85	18.20	
22	257	195.00	20.48	
..	
824	1389	386.10	479.70	
825	1390	296.07	480.03	
826	1392	49.08	480.68	
830	1396	313.62	482.62	
841	1408	455.65	489.12	

	Number of peaks	Is active	Occurrences in global events	\
2	6	True	5	
6	6	True	5	
11	8	True	5	
20	7	True	5	
22	7	True	5	
..	
824	7	True	5	
825	6	True	5	
826	6	True	5	
830	8	True	5	
841	6	True	5	

	Occurrences in global events as early peaker	Early peaker event IDs	\
2	0	[]	
6	0	[]	
11	0	[]	
20	1	[2]	
22	0	[]	
..	
824	0	[]	
825	3	[2, 4, 5]	
826	1	[4]	
830	0	[]	
841	0	[]	

```

Occurrences in sequential events \
2 1
6 1
11 1
20 1
22 1
.. ...
824 1
825 1
826 1
830 1
841 1

Occurrences in sequential events as origin \
2 1
6 1
11 1
20 1
22 1
.. ...
824 1
825 0
826 1
830 0
841 1

Occurrences in individual events Peak frequency (Hz) Periodicity score \
2 0 0.0035 0.79
6 0 0.0035 0.77
11 1 0.0047 0.65
20 0 0.0041 0.65
22 1 0.0041 0.66
.. ... ...
824 1 0.0041 0.68
825 0 0.0035 0.83
826 0 0.0035 0.79
830 2 0.0047 0.66
841 0 0.0035 0.76

Neighbor count Neighbors (labels) dataset \
2 [237,263] 20250701_IS3
6 [251,252,269,283,288] 20250701_IS3
11 [243,256,272] 20250701_IS3
20 [223,260,265,297] 20250701_IS3
22 [227,247,274,275,290] 20250701_IS3
.. ...
824 5 [1327,1355,1373,1394,1407] 20250701_IS3
825 6 [1342,1345,1360,1372,1396,1410] 20250701_IS3

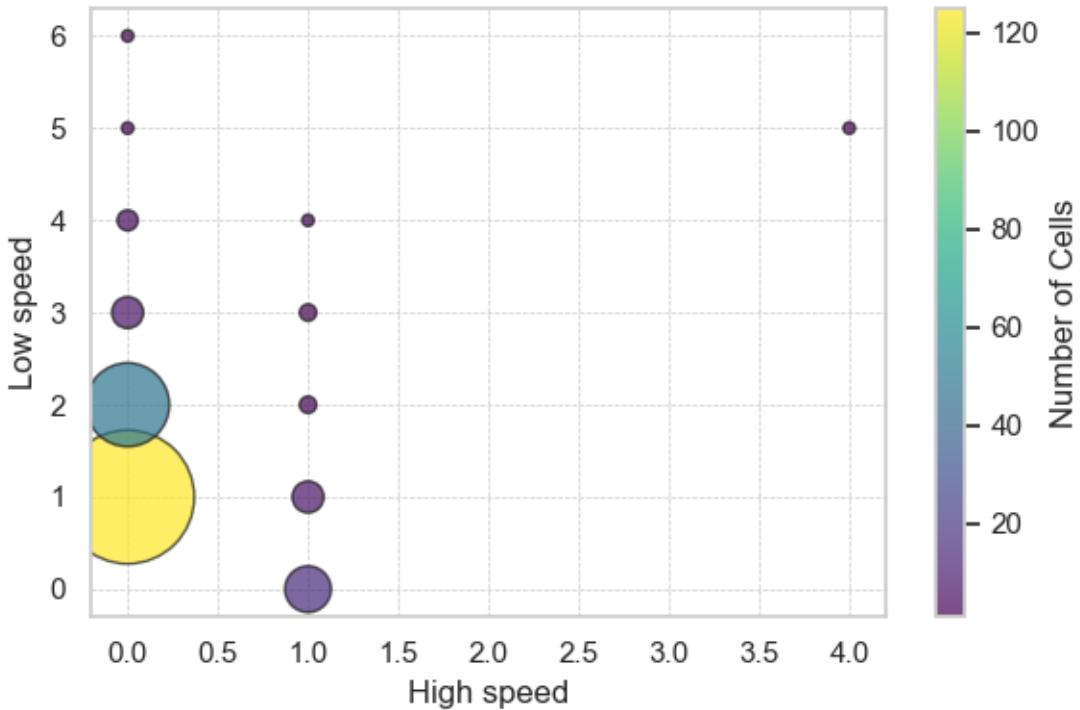
```

826	5	[1350,1362,1378,1395,1405]	20250701_IS3
830	5	[1343,1360,1366,1390,1413]	20250701_IS3
841	4	[1358,1364,1397,1403]	20250701_IS3

		Involved in sequential event Occurrences in sequential events category \	
2	Involved in sequential event		1-2
6	Involved in sequential event		1-2
11	Involved in sequential event		1-2
20	Involved in sequential event		1-2
22	Involved in sequential event		1-2
..	
824	Involved in sequential event		1-2
825	Involved in sequential event		1-2
826	Involved in sequential event		1-2
830	Involved in sequential event		1-2
841	Involved in sequential event		1-2

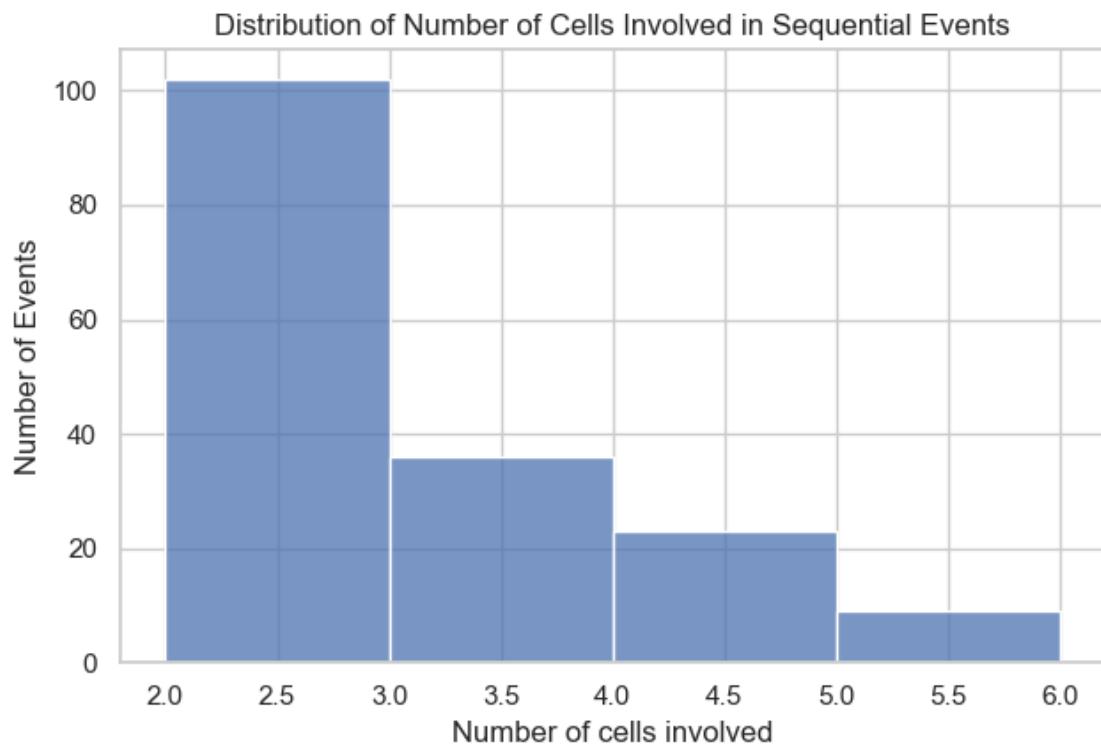
	High speed	Low speed
2	0.0	1.0
6	0.0	1.0
11	0.0	1.0
20	0.0	1.0
22	0.0	2.0
..
824	0.0	1.0
825	0.0	1.0
826	0.0	1.0
830	1.0	0.0
841	0.0	1.0

[214 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

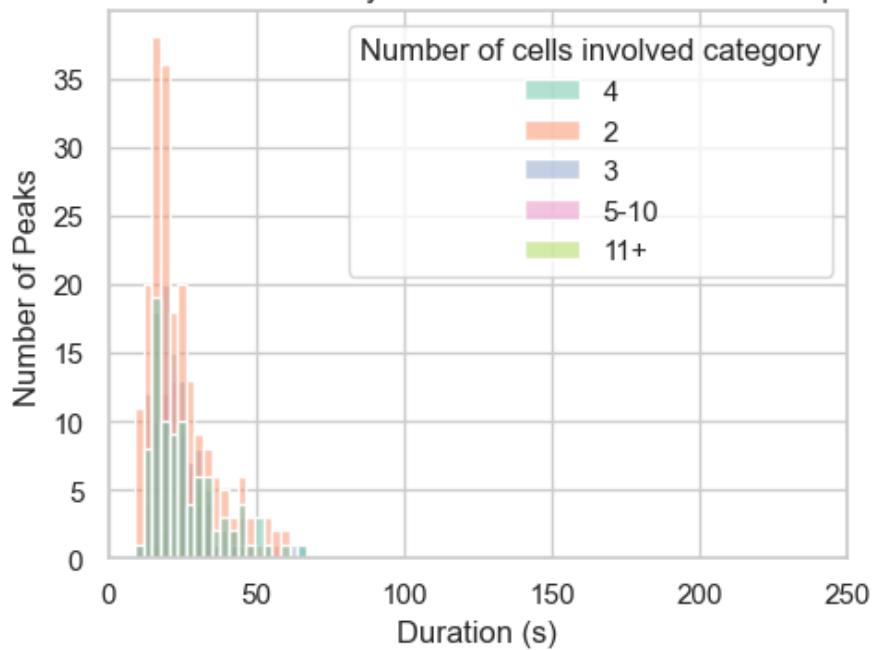
[2025-08-27 15:14:47] [INFO] calcium: plot_histogram: removed 5 outliers out of 175 on 'Number of cells involved' (lower=-1, upper=6)



1.3.6 Influence of cell count per event on statistics

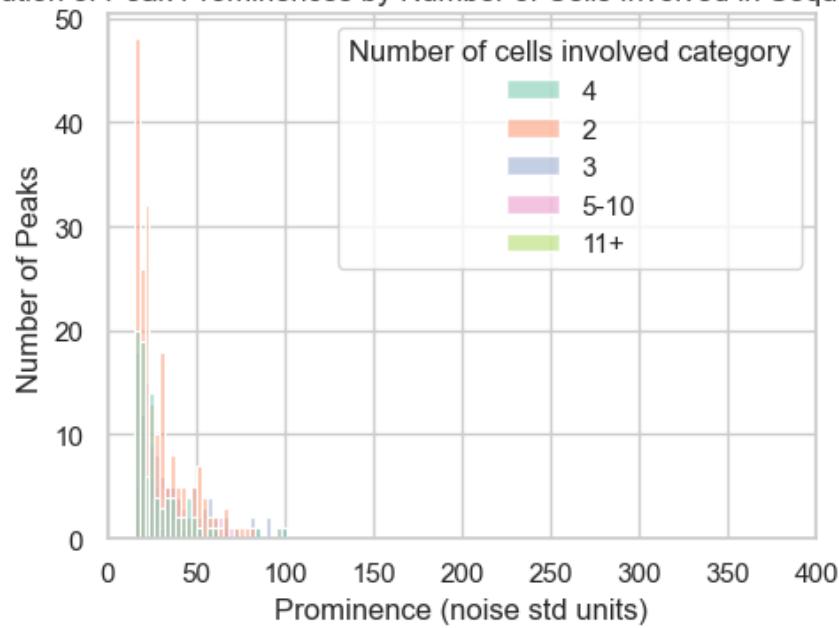
```
[2025-08-27 15:14:48] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 499 on 'Duration (s)' (lower=-1.75, upper=73.25)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

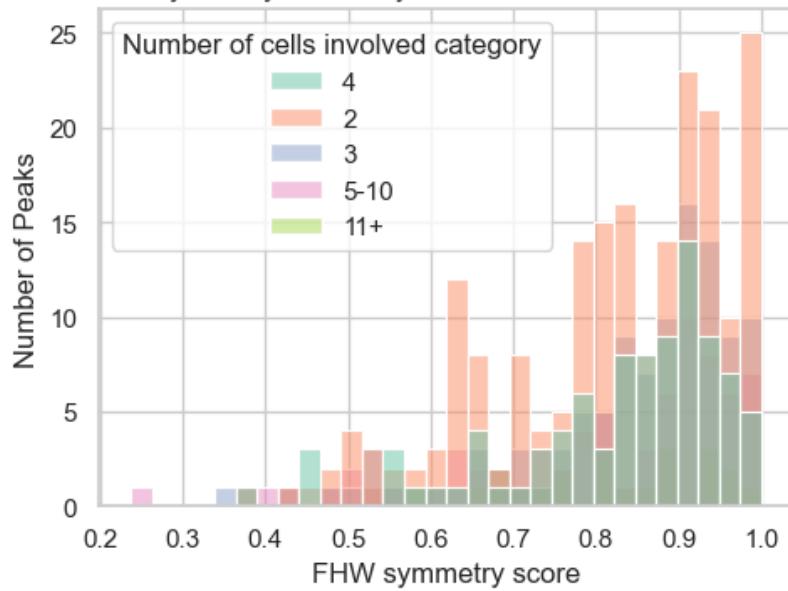


[2025-08-27 15:14:48] [INFO] calcium: plot_histogram_by_group: removed 19 outliers out of 499 on 'Prominence (noise std units)' (lower=-10.2, upper=108)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

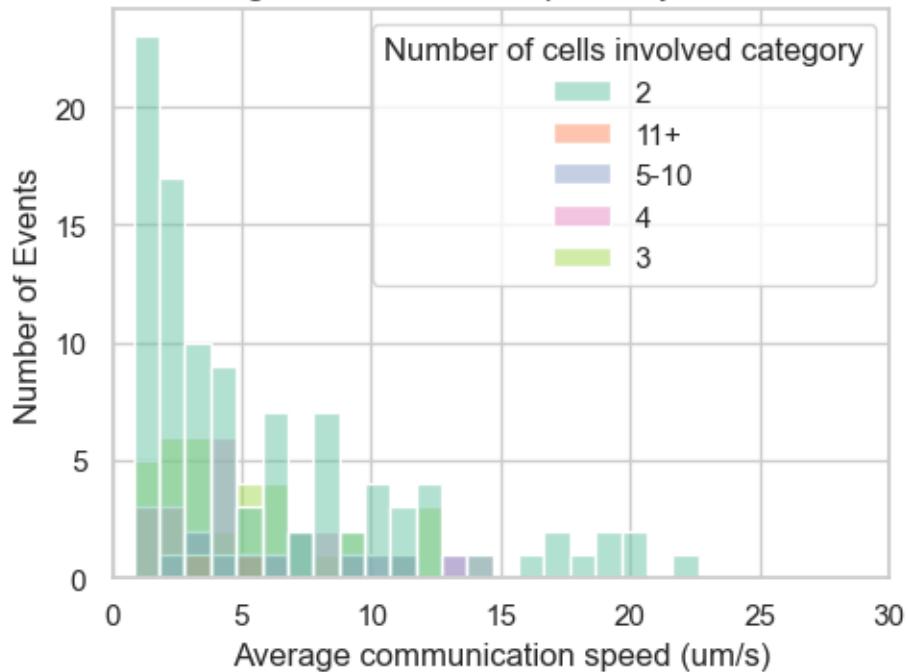


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



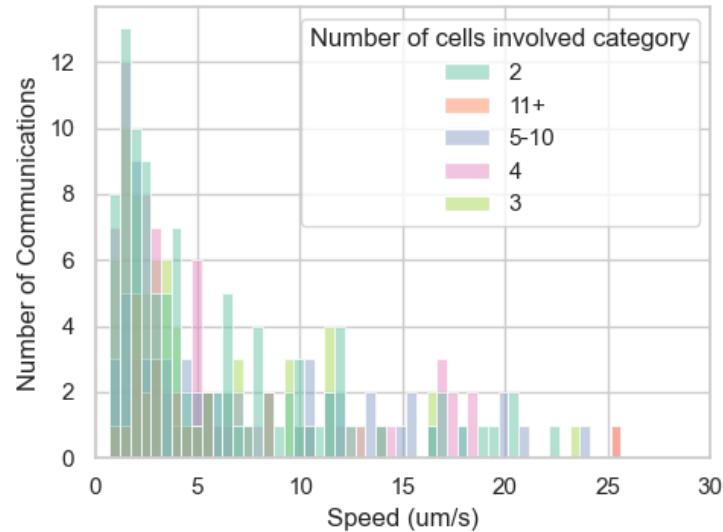
```
[2025-08-27 15:14:48] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 175 on 'Average communication speed (um/s)' (lower=-15.155, upper=25.375)
```

Distribution of Average Communication Speeds by Number of Cells Involved



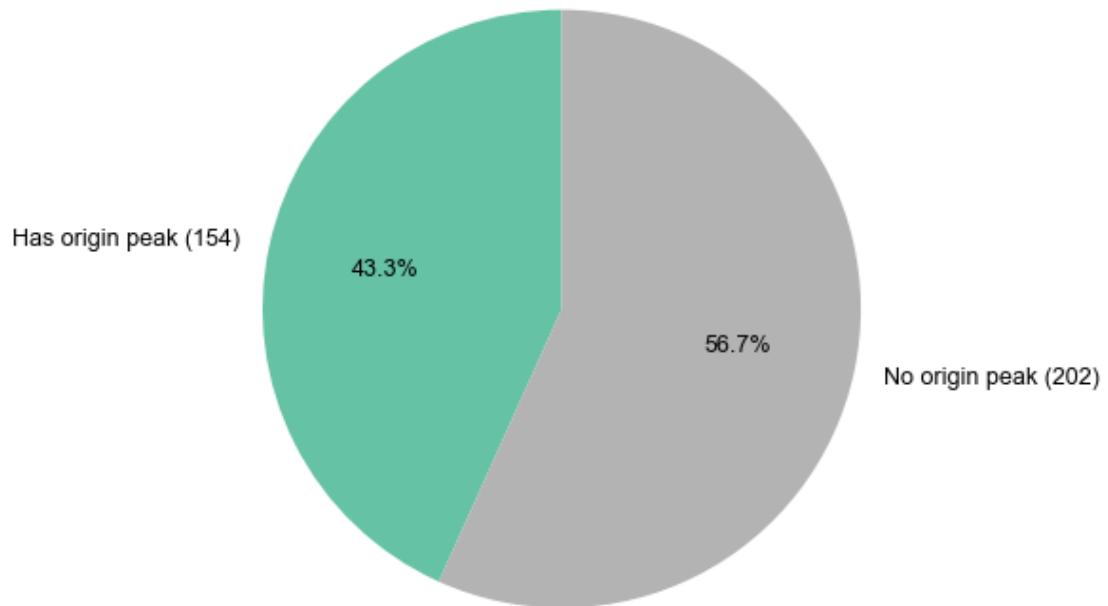
[2025-08-27 15:14:49] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 324 on 'Speed (um/s)' (lower=-16.428, upper=26.255)

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events

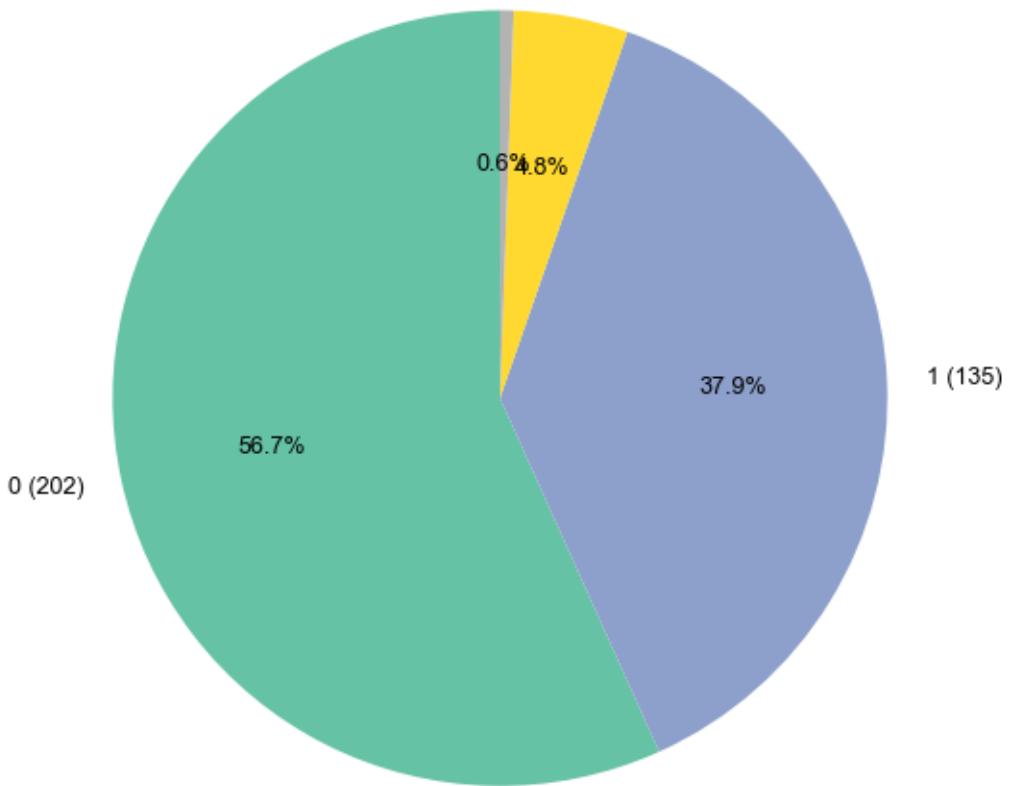


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

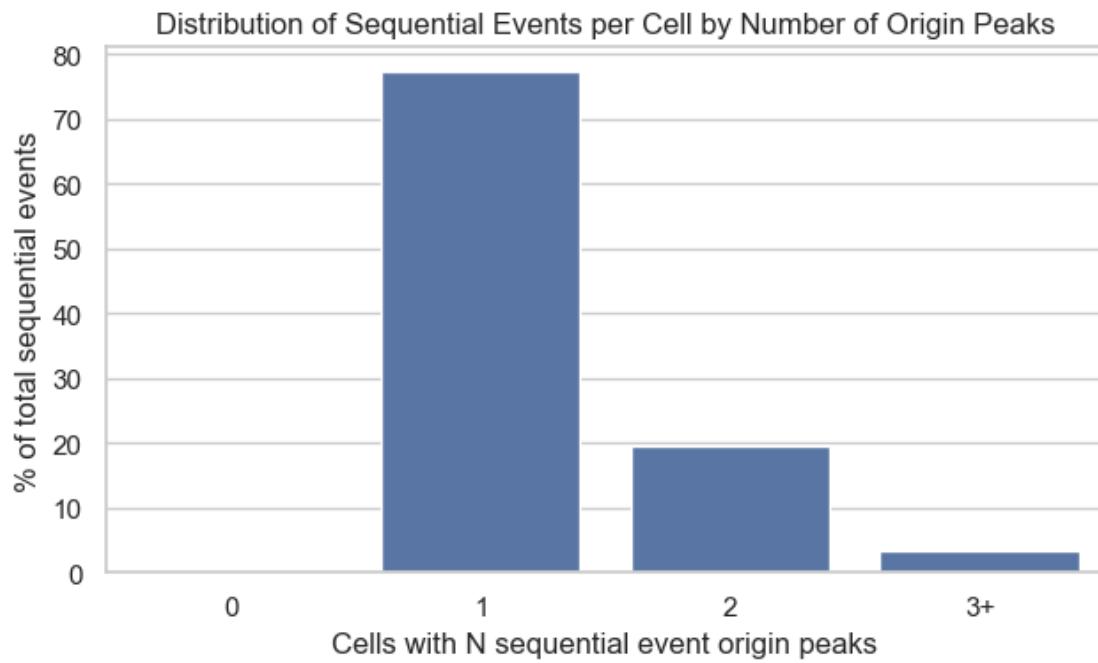


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (2) 2 (17)



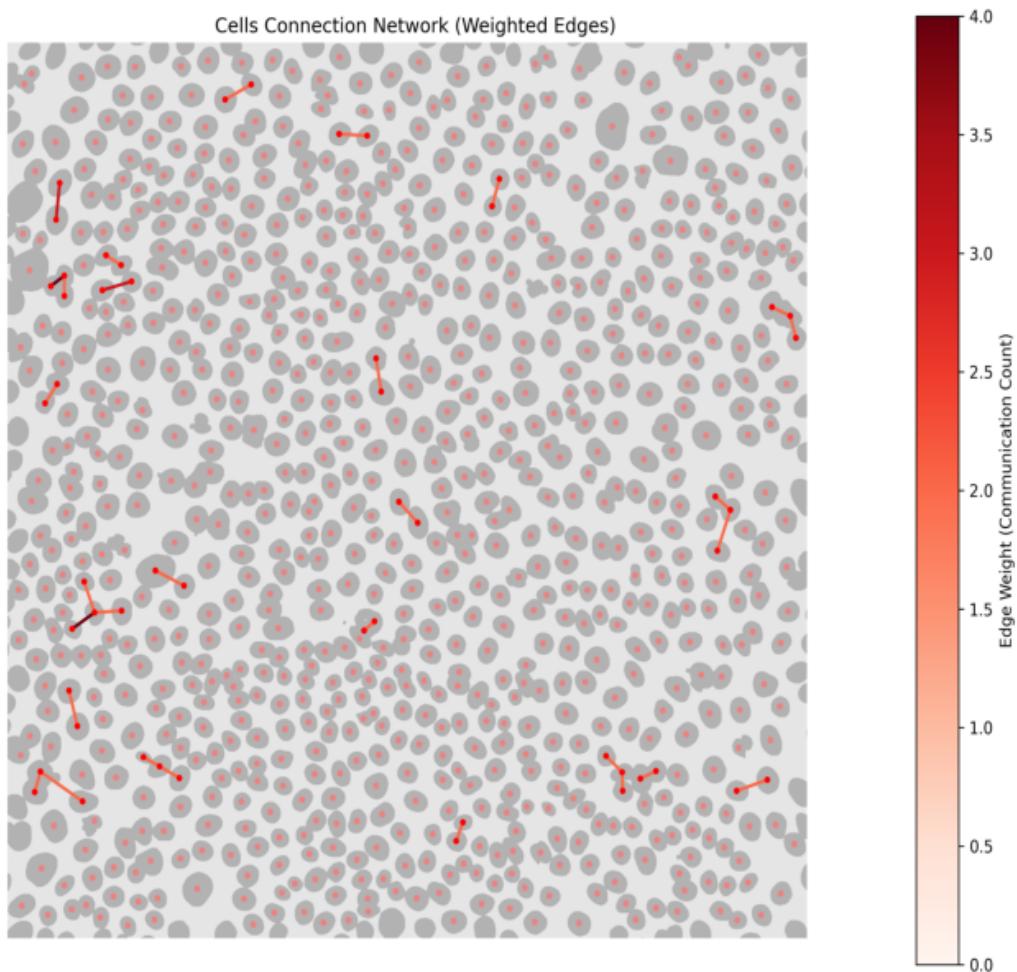
```
[2025-08-27 15:14:49] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\\\20250701\\\\Output\\\\IS3\\\\cell-
mapping\\\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250701\\Output\\IS3\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'



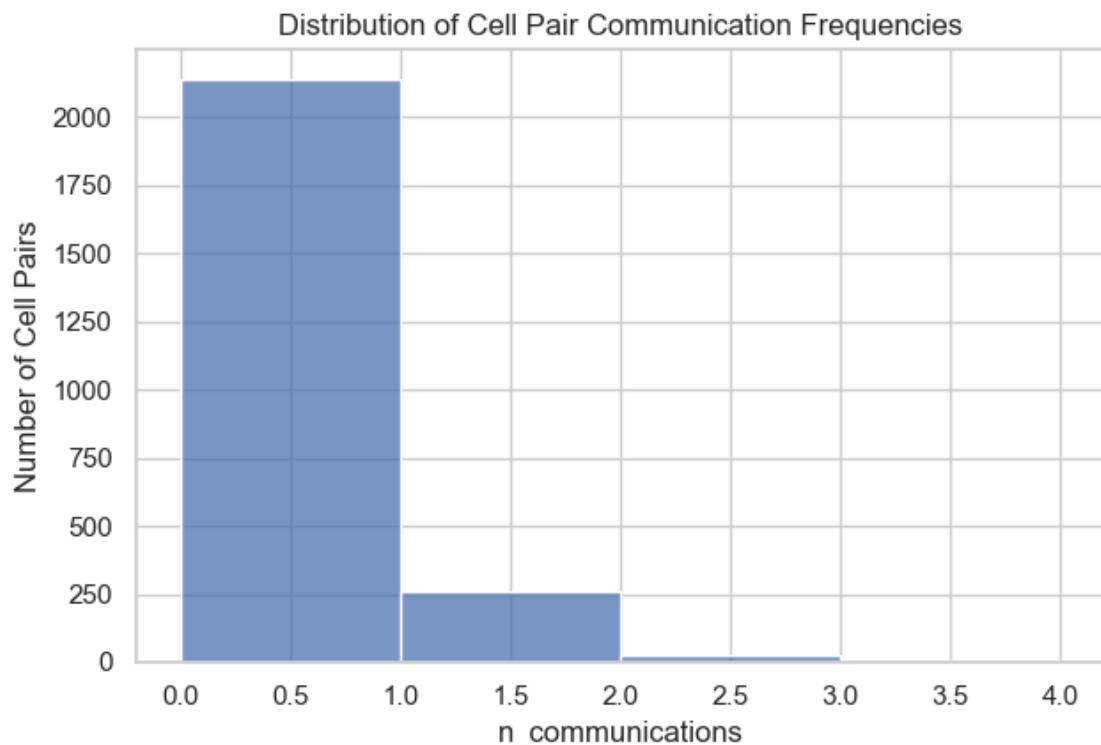
1.3.8 Connection network between cells

Cell Connection Network Graph



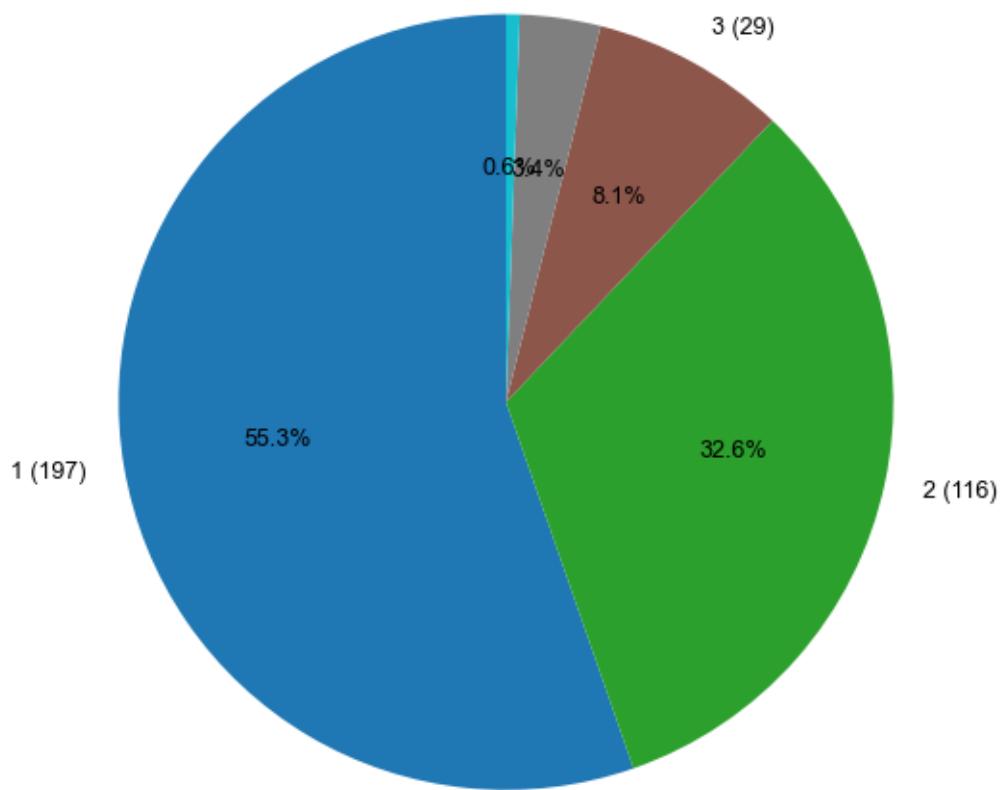
1.3.9 Pair/Trios with high communication networks

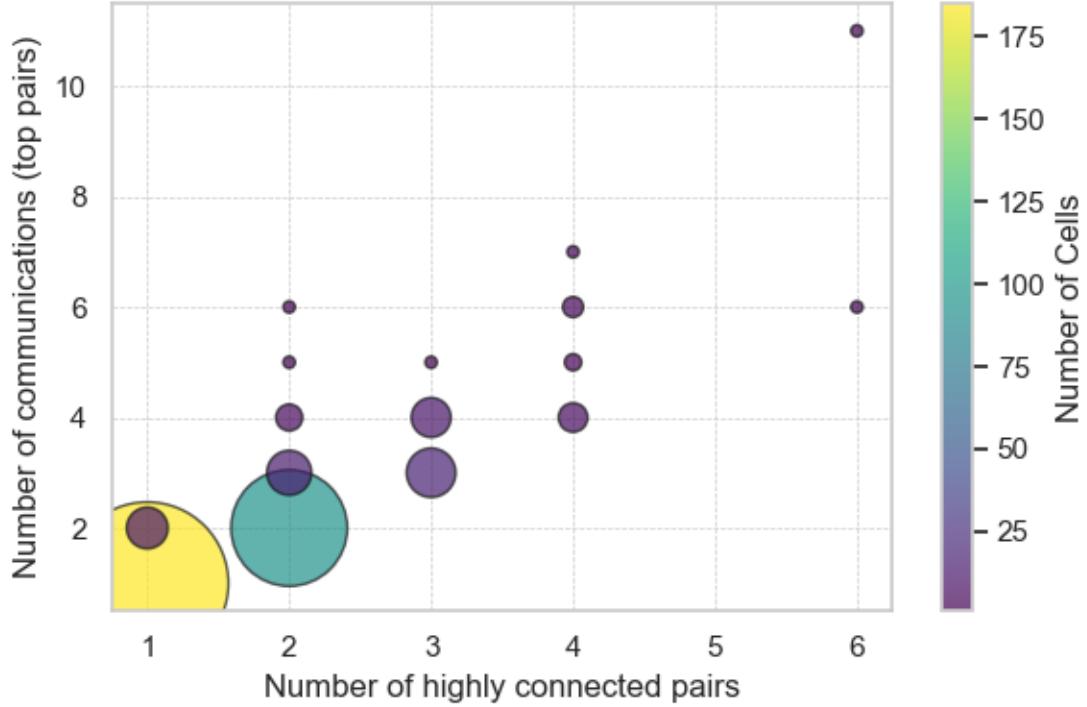
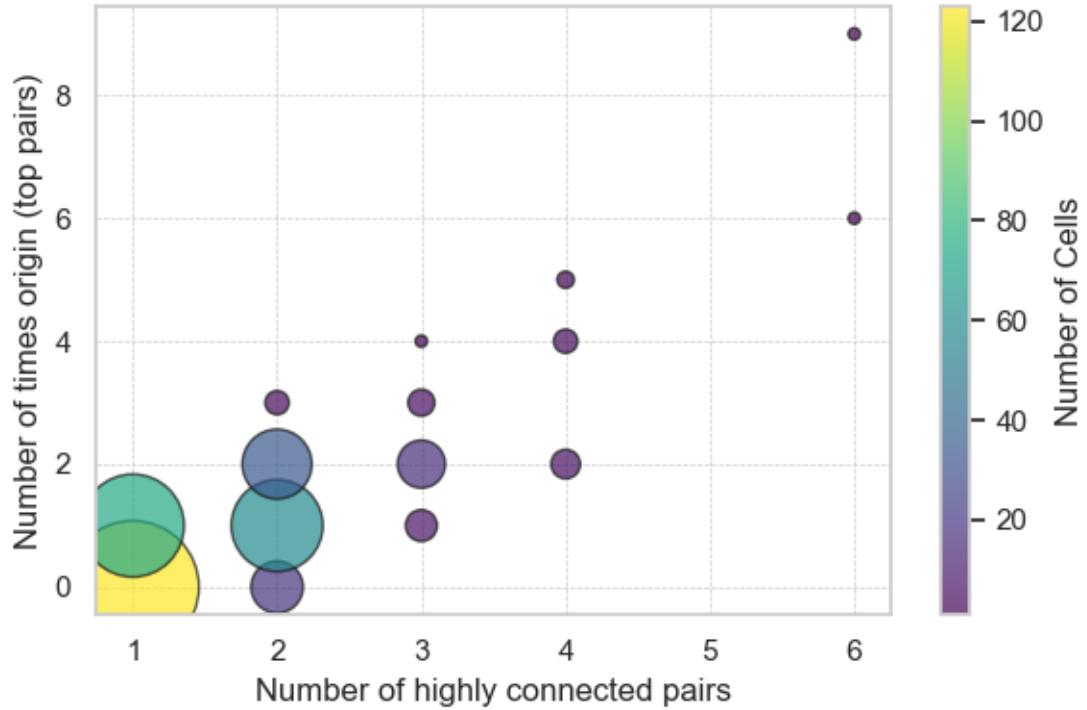
```
[2025-08-27 15:14:51] [INFO] calcium: build_neighbor_pair_stats: built 2428 pairs across 1 datasets (mean distance=18.55 um)
```

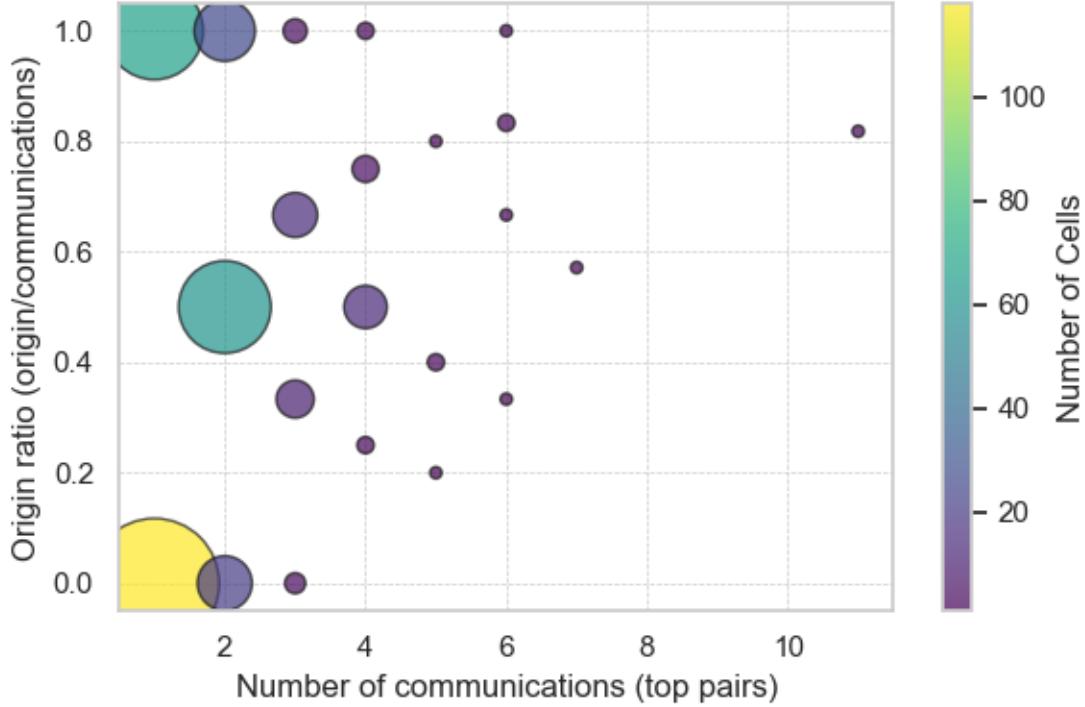
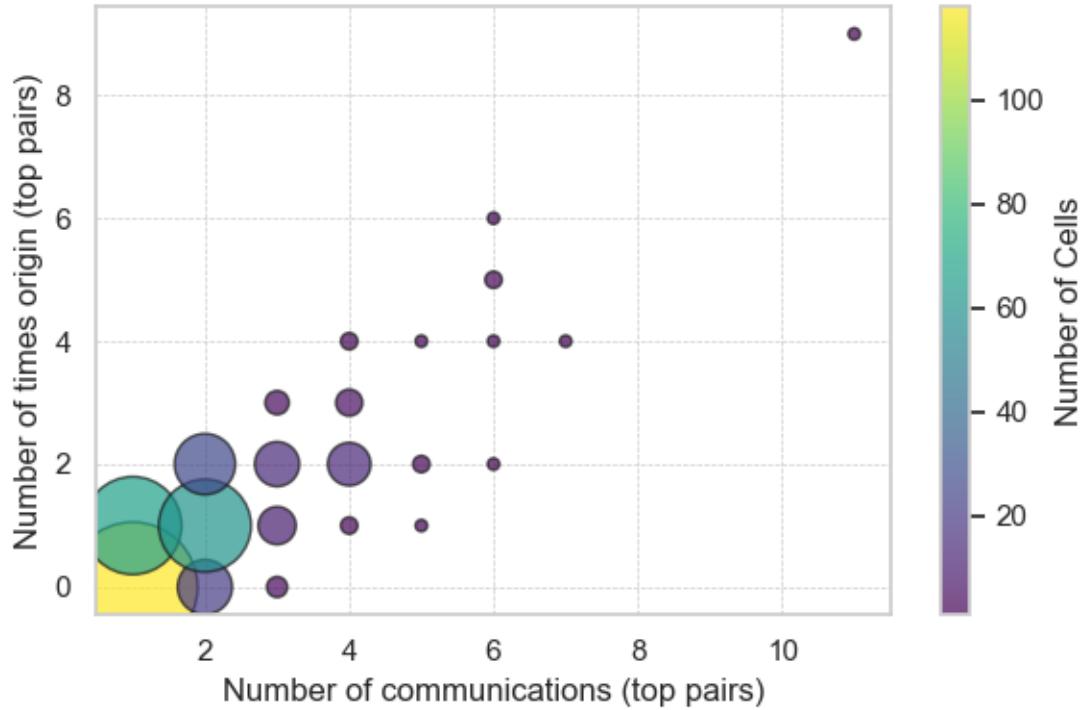


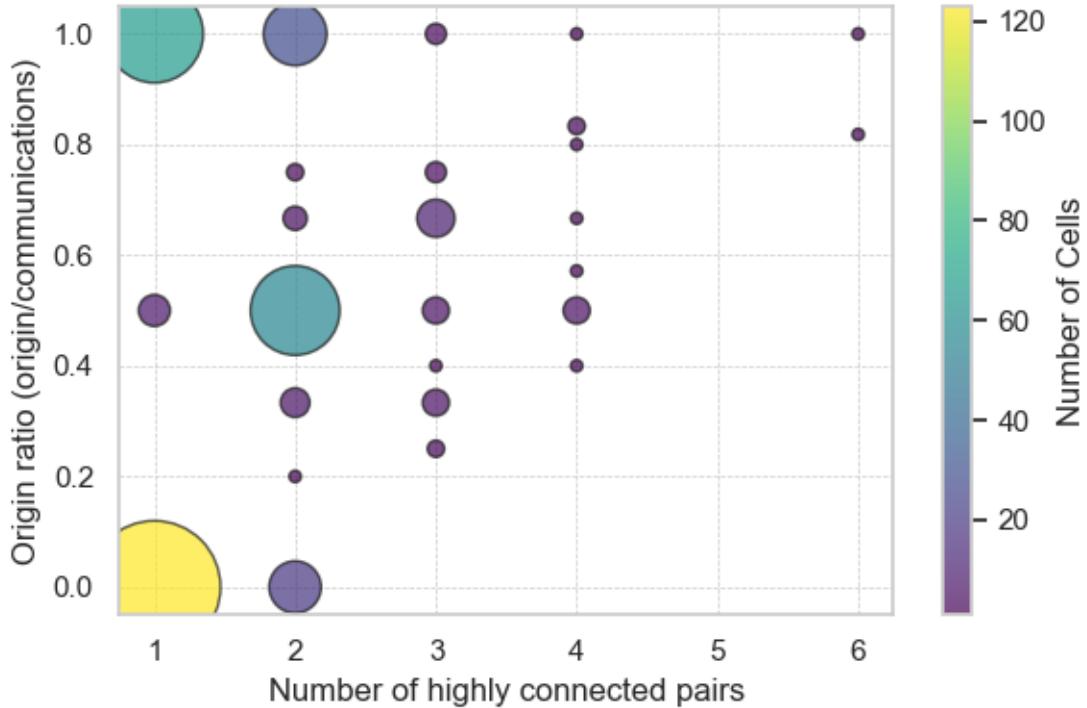
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









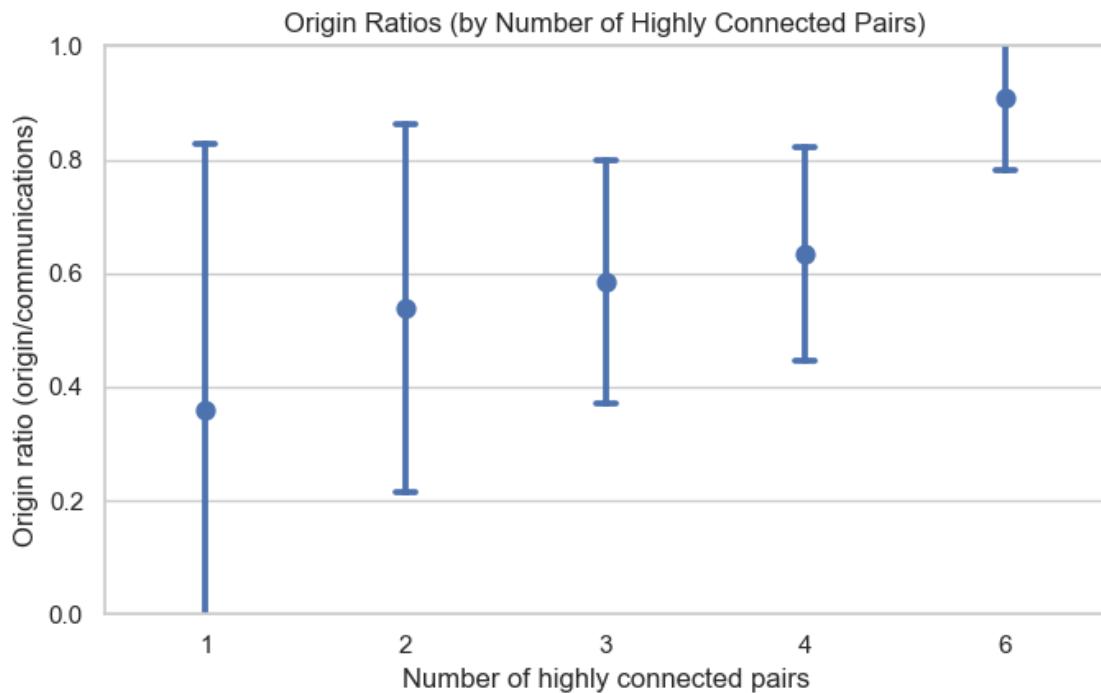
[2025-08-27 15:14:51] [INFO] calcium: plot_points_mean_std: N=197 for Number of highly connected pairs=1

[2025-08-27 15:14:51] [INFO] calcium: plot_points_mean_std: N=116 for Number of highly connected pairs=2

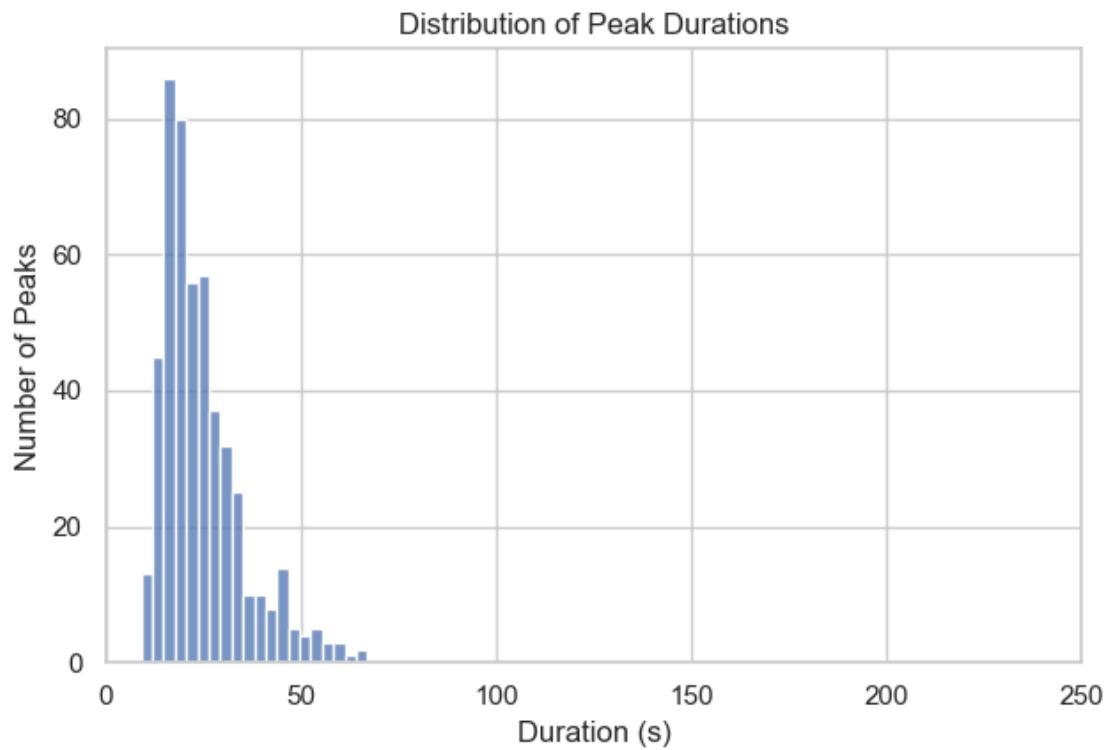
[2025-08-27 15:14:51] [INFO] calcium: plot_points_mean_std: N=29 for Number of highly connected pairs=3

[2025-08-27 15:14:51] [INFO] calcium: plot_points_mean_std: N=12 for Number of highly connected pairs=4

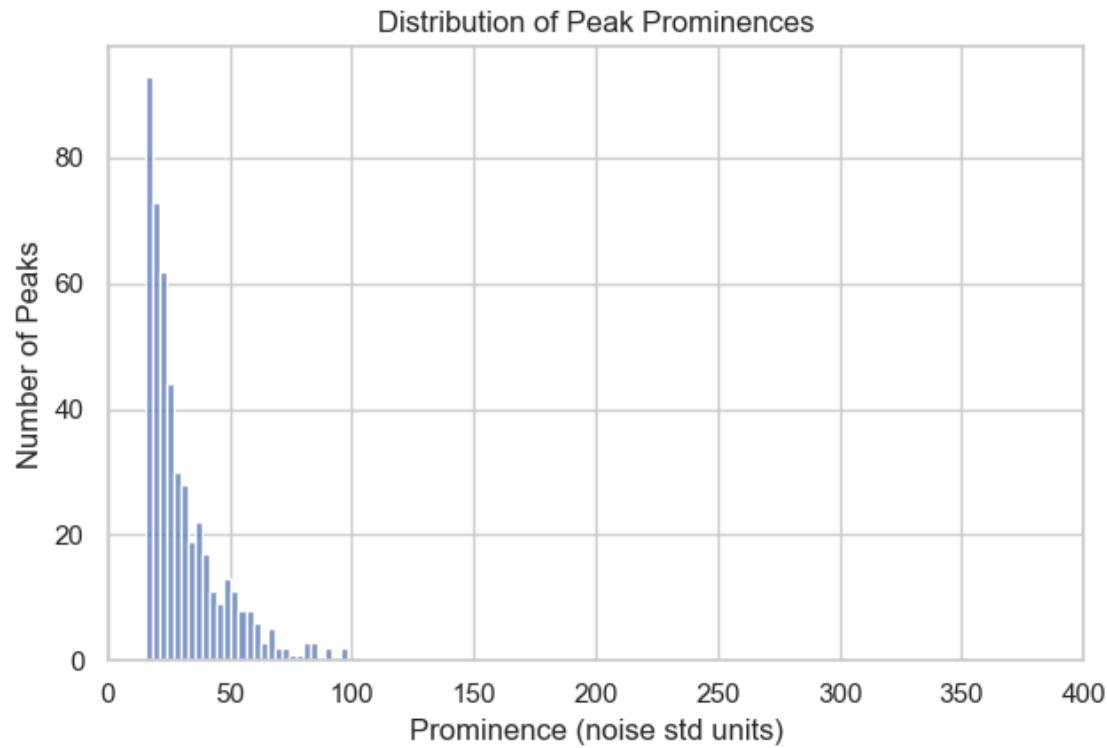
[2025-08-27 15:14:51] [INFO] calcium: plot_points_mean_std: N=2 for Number of highly connected pairs=6

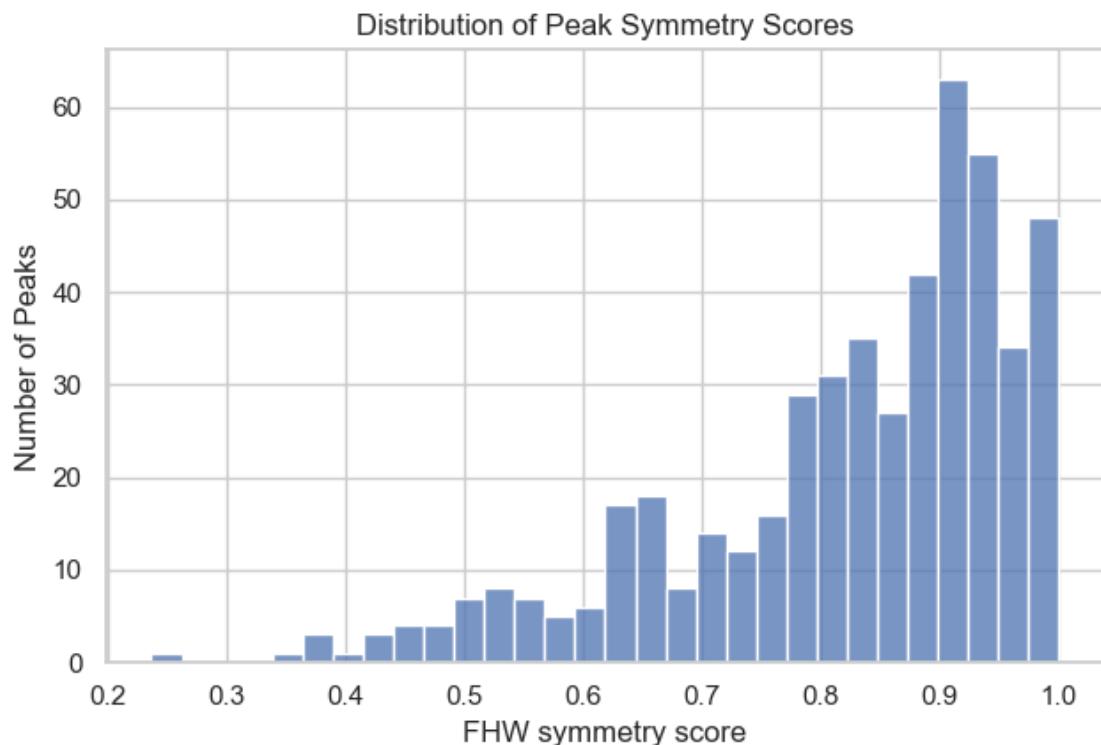


```
[2025-08-27 15:14:52] [INFO] calcium: plot_histogram: removed 3 outliers out of 499 on 'Duration (s)' (lower=-20.5, upper=67)
```



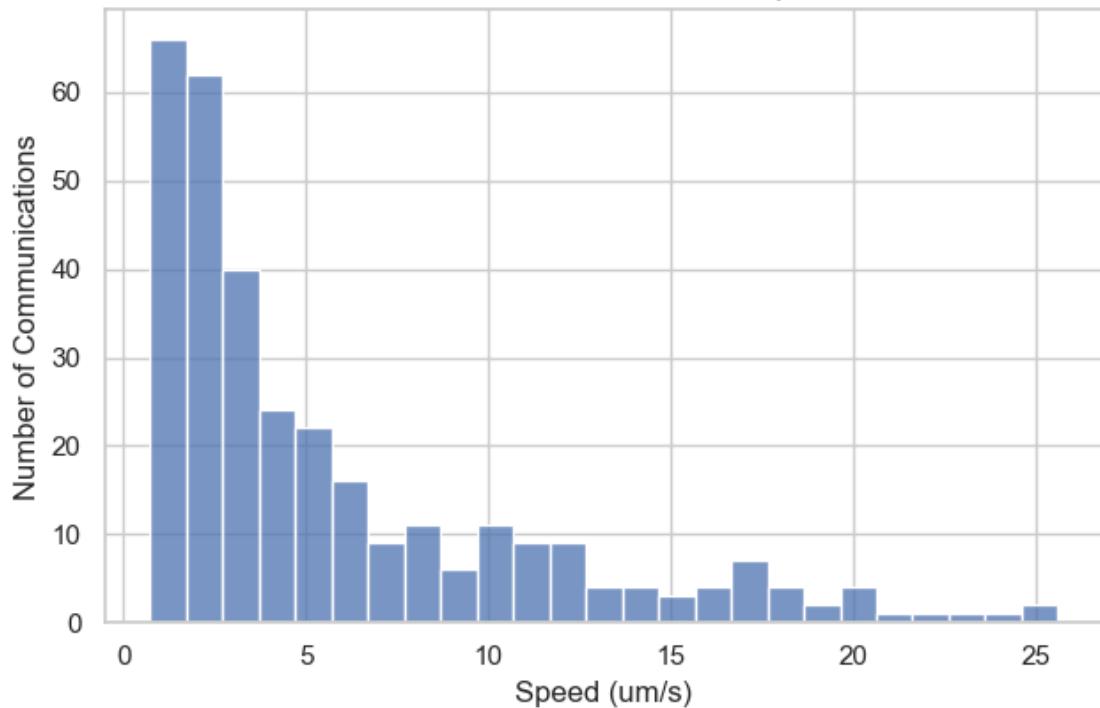
[2025-08-27 15:14:52] [INFO] calcium: plot_histogram: removed 21 outliers out of 499 on 'Prominence (noise std units)' (lower=-39.75, upper=98.15)





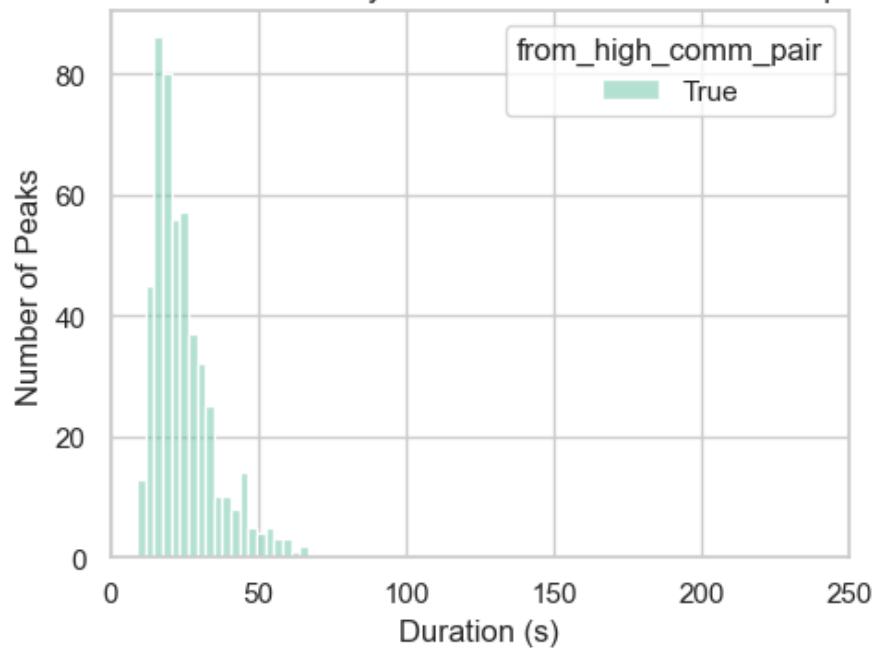
[2025-08-27 15:14:52] [INFO] calcium: plot_histogram: removed 1 outliers out of 324 on 'Speed (um/s)' (lower=-16.428, upper=26.255)

Distribution of Communication Speeds



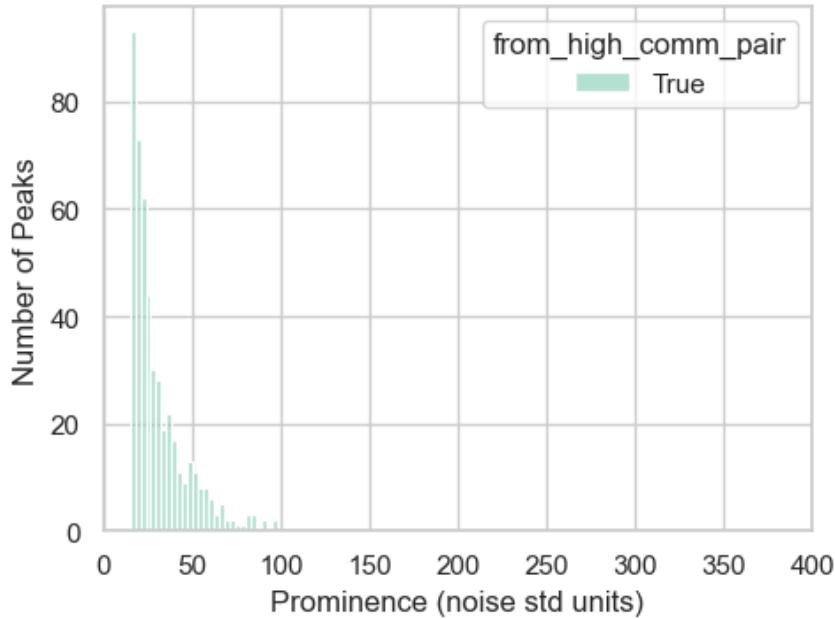
```
[2025-08-27 15:14:52] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 499 on 'Duration (s)' (lower=-20.5, upper=67)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

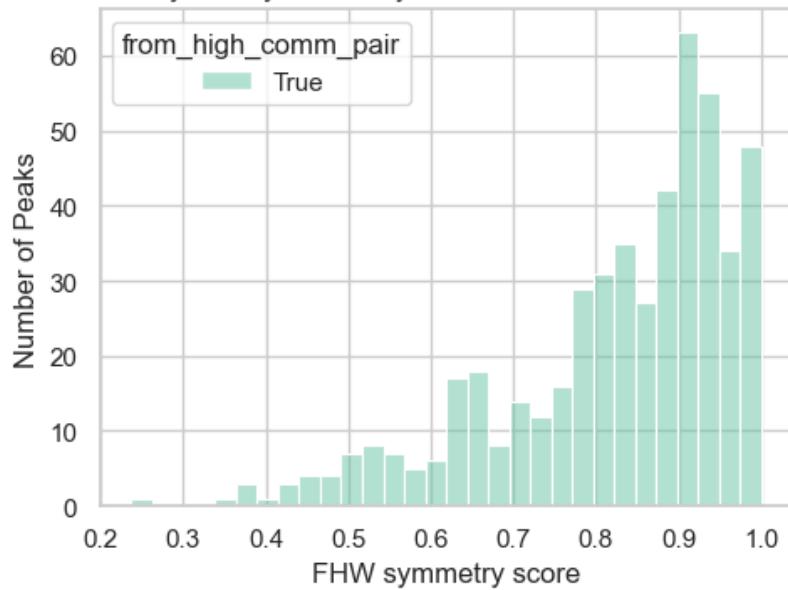


[2025-08-27 15:14:52] [INFO] calcium: plot_histogram_by_group: removed 21 outliers out of 499 on 'Prominence (noise std units)' (lower=-39.75, upper=98.15)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

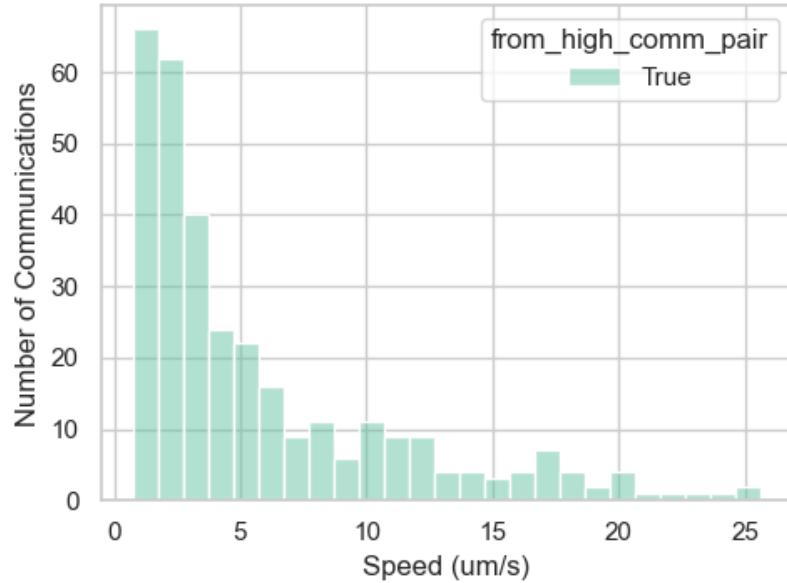


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:14:53] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 324 on 'Speed (um/s)' (lower=-16.428, upper=26.255)
```

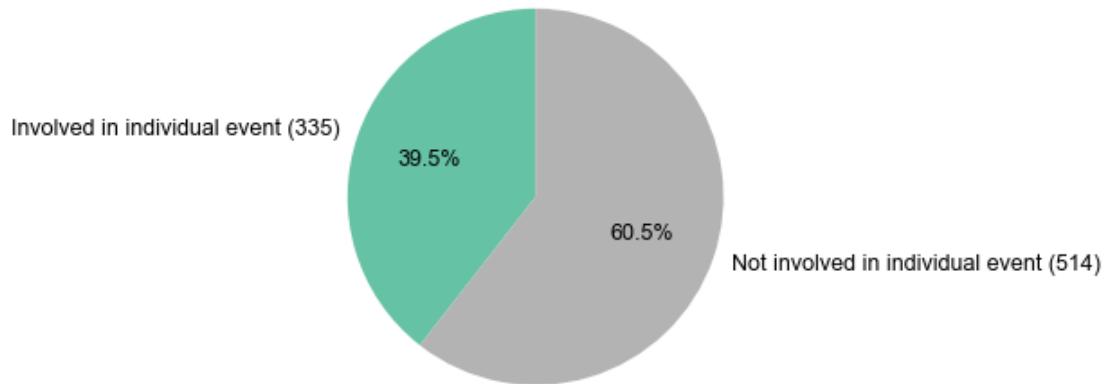
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



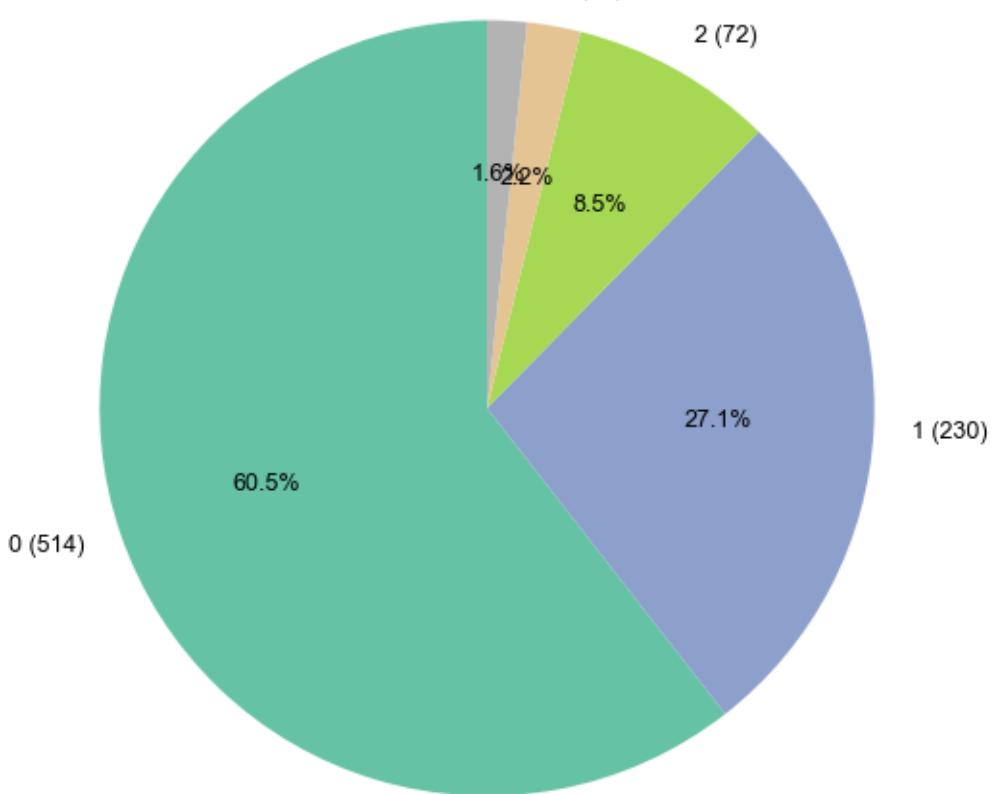
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

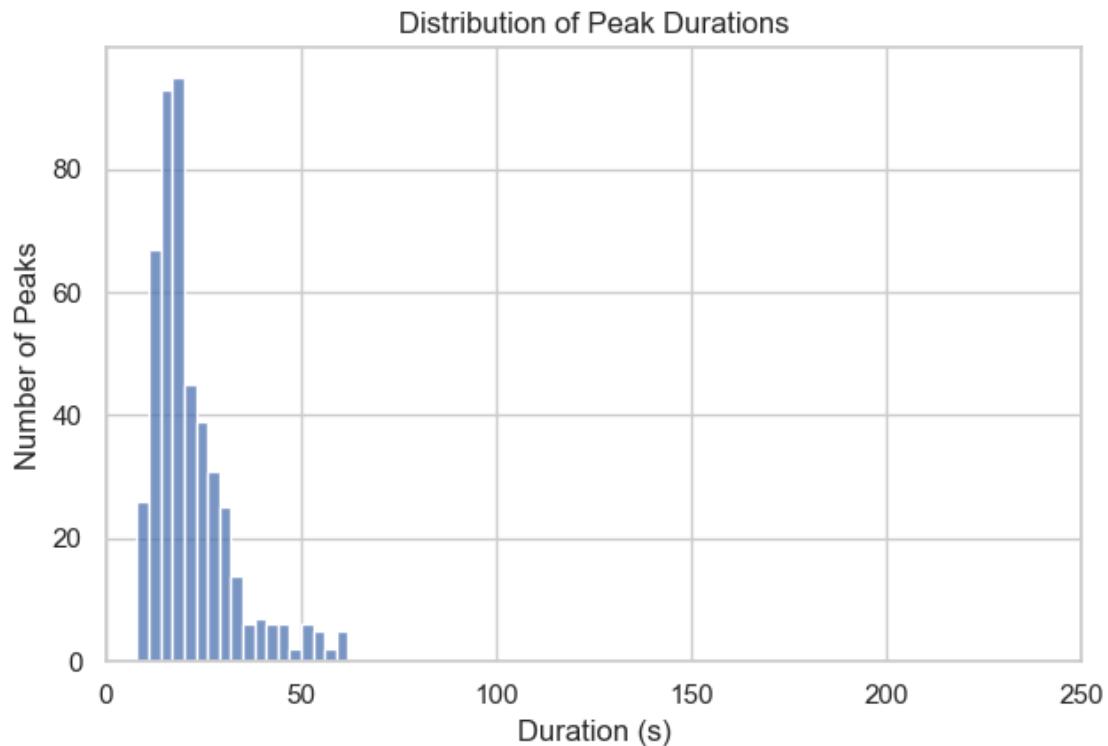


```
[2025-08-27 15:14:53] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS3\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\\\20250701\\\\Output\\\\IS3\\\\cell-
mapping\\\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
```

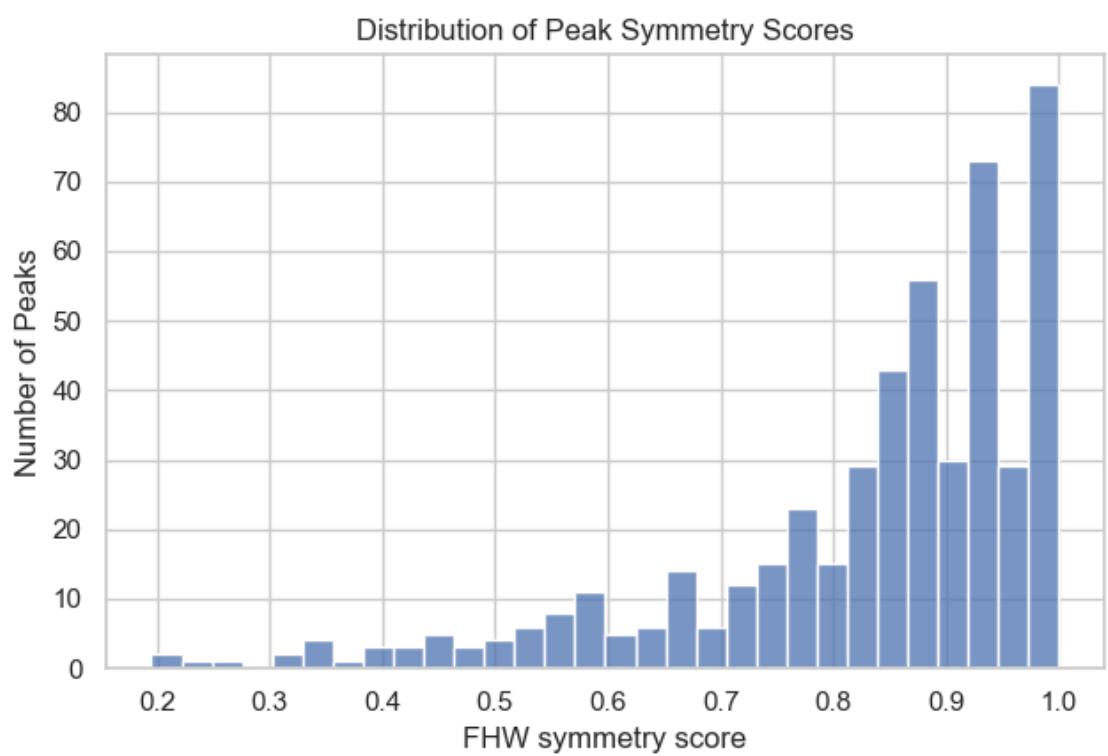
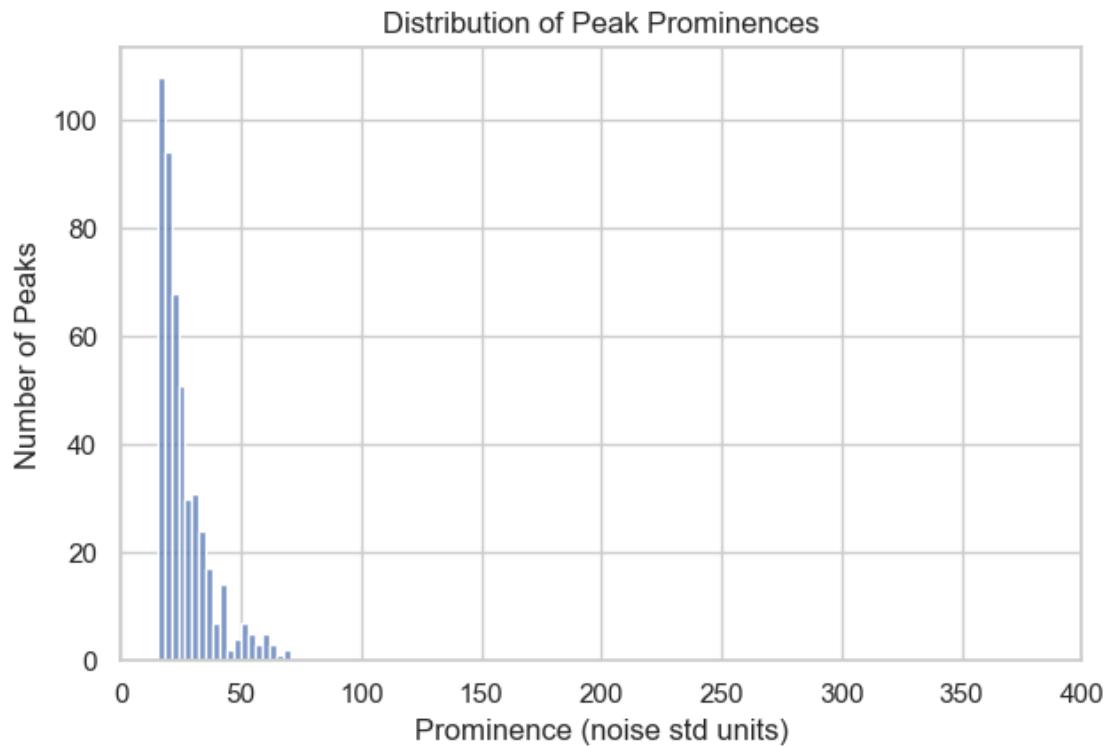
'D:\\Mateo\\20250701\\Output\\IS3\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

1.4.2 Peaks statistics in individual events

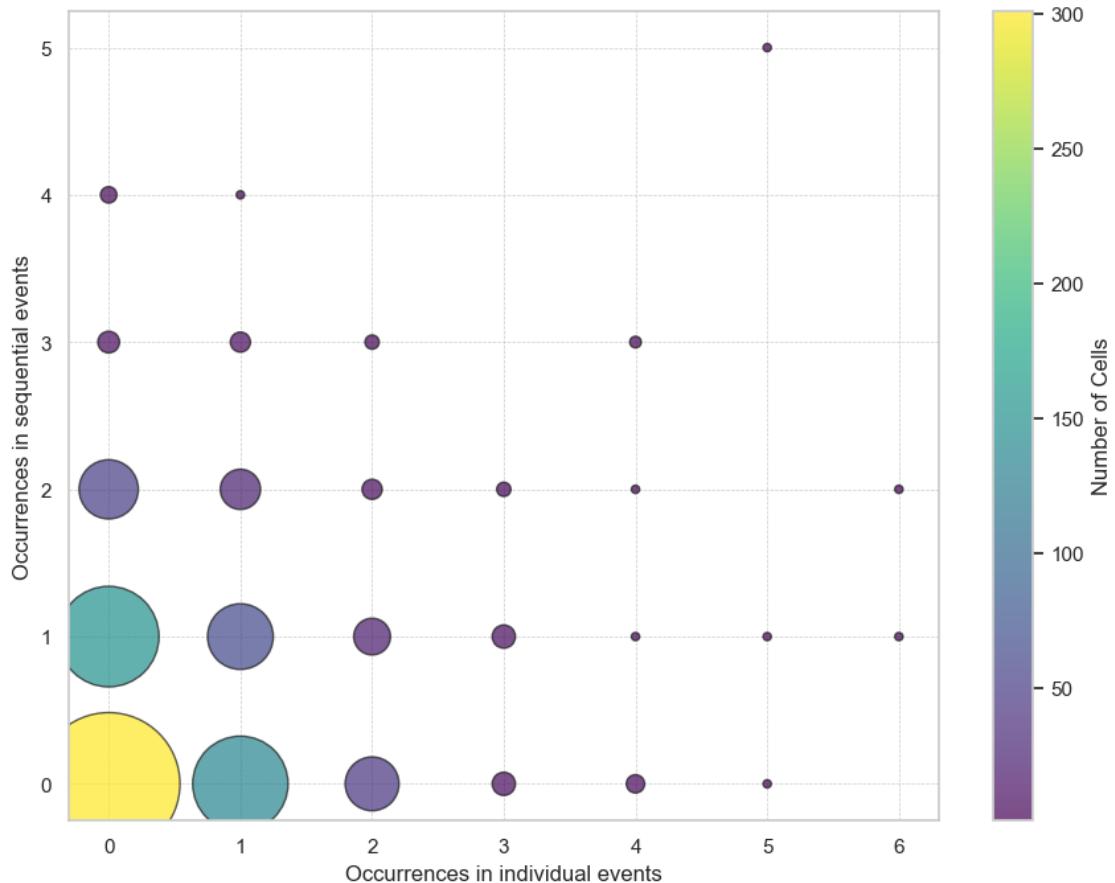
[2025-08-27 15:14:53] [INFO] calcium: plot_histogram: removed 14 outliers out of 494 on 'Duration (s)' (lower=-22, upper=62)



[2025-08-27 15:14:53] [INFO] calcium: plot_histogram: removed 18 outliers out of 494 on 'Prominence (noise std units)' (lower=-21.525, upper=71.4)



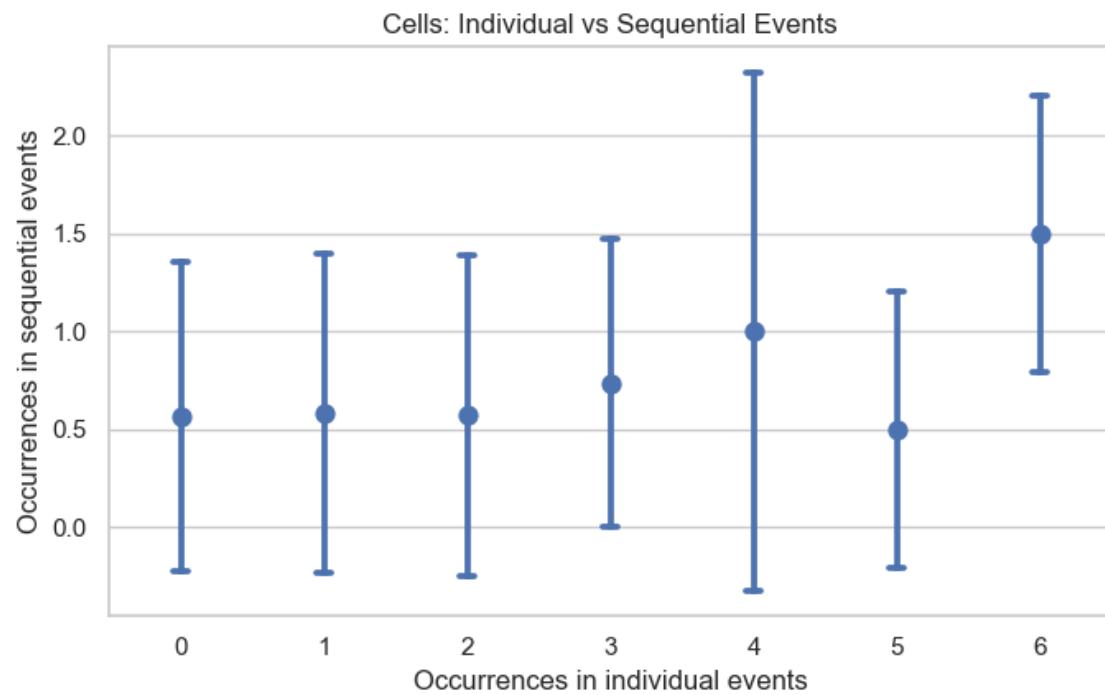
1.4.3 Correlation between event activity level & individual activity level



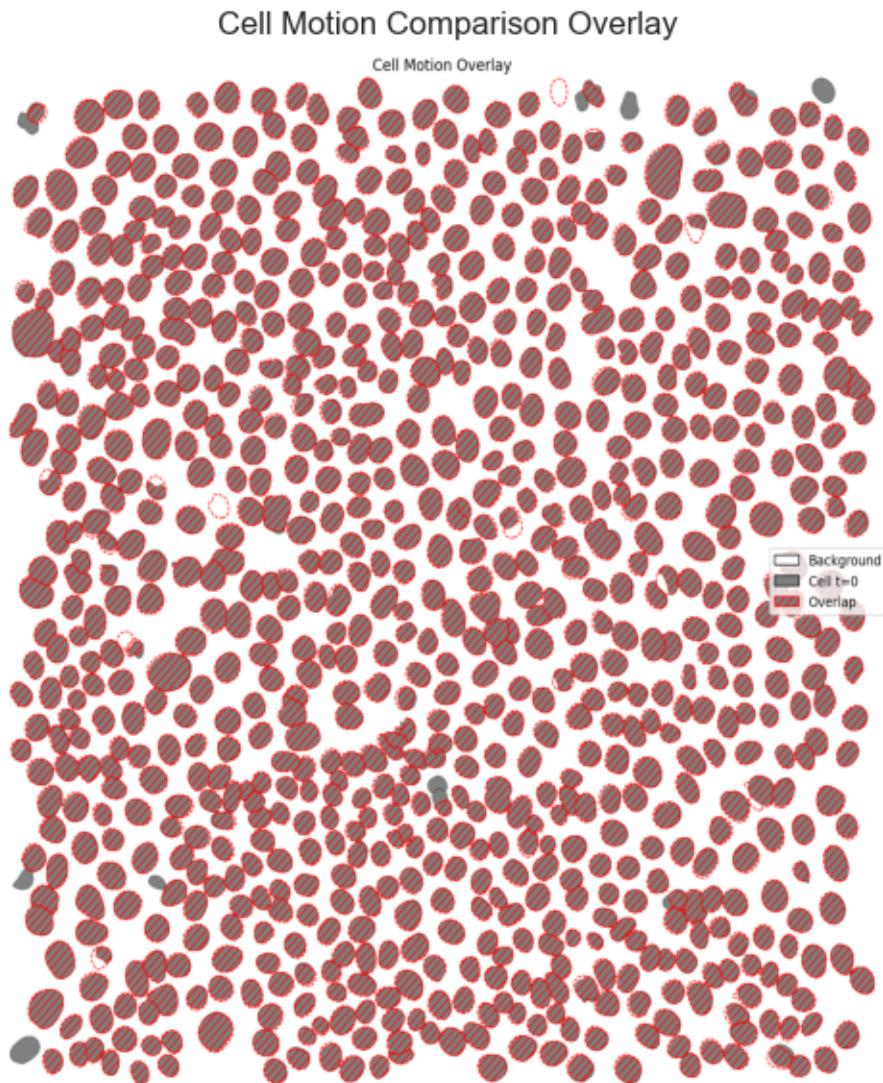
```
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: removed 1/849 outliers on 'Occurrences in sequential events' (lower=-3, upper=4)
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=514 for Occurrences in individual events=0
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=230 for Occurrences in individual events=1
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=72 for Occurrences in individual events=2
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=19 for Occurrences in individual events=3
[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=9 for Occurrences in individual events=4
```

[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=2 for Occurrences in individual events=5

[2025-08-27 15:14:54] [INFO] calcium: plot_points_mean_std: N=2 for Occurrences in individual events=6



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 849
- Hoechst image taken at t=1801: 843
- Number of cells difference: absolute 6, relative 0.71%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1015681
- Pixels segmented as cell at t=1801: 1017630
- Overlapping pixels between t=0 and t=1801: 960001 (94.43% of total)
- Pixels exclusive to t=0: 55680 (5.48% of total)
- Pixels exclusive to t=1801: 57629 (5.66% of total)

executed

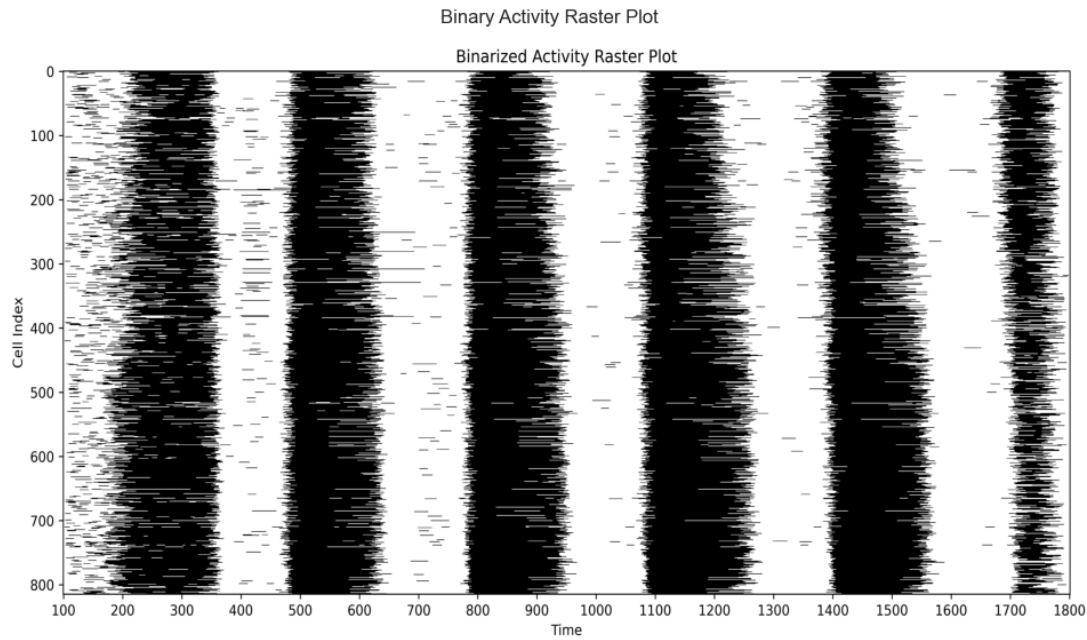
August 27, 2025

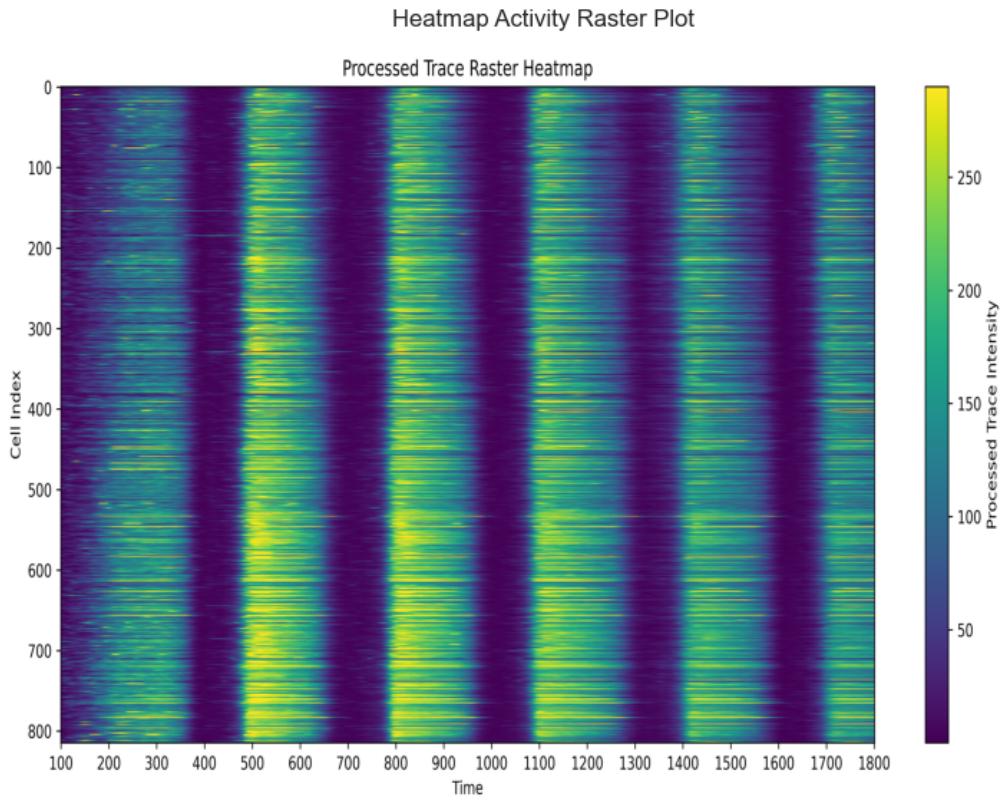
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





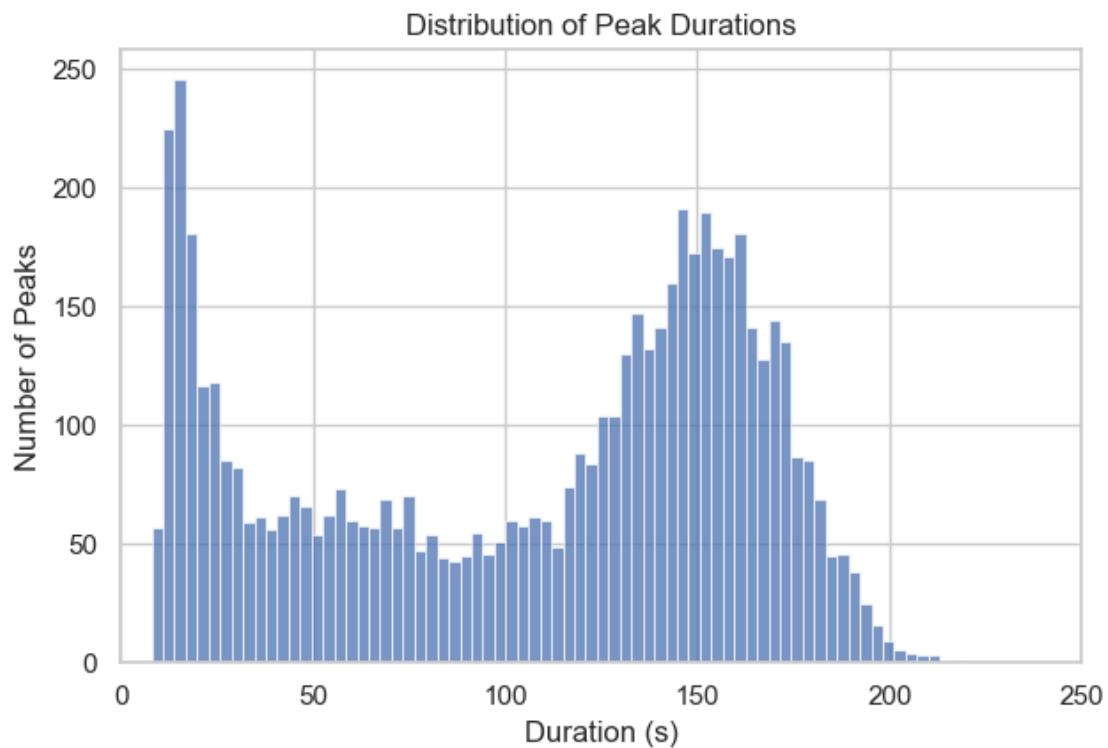
1.1.2 Peaks population

Total number of peaks: 5947

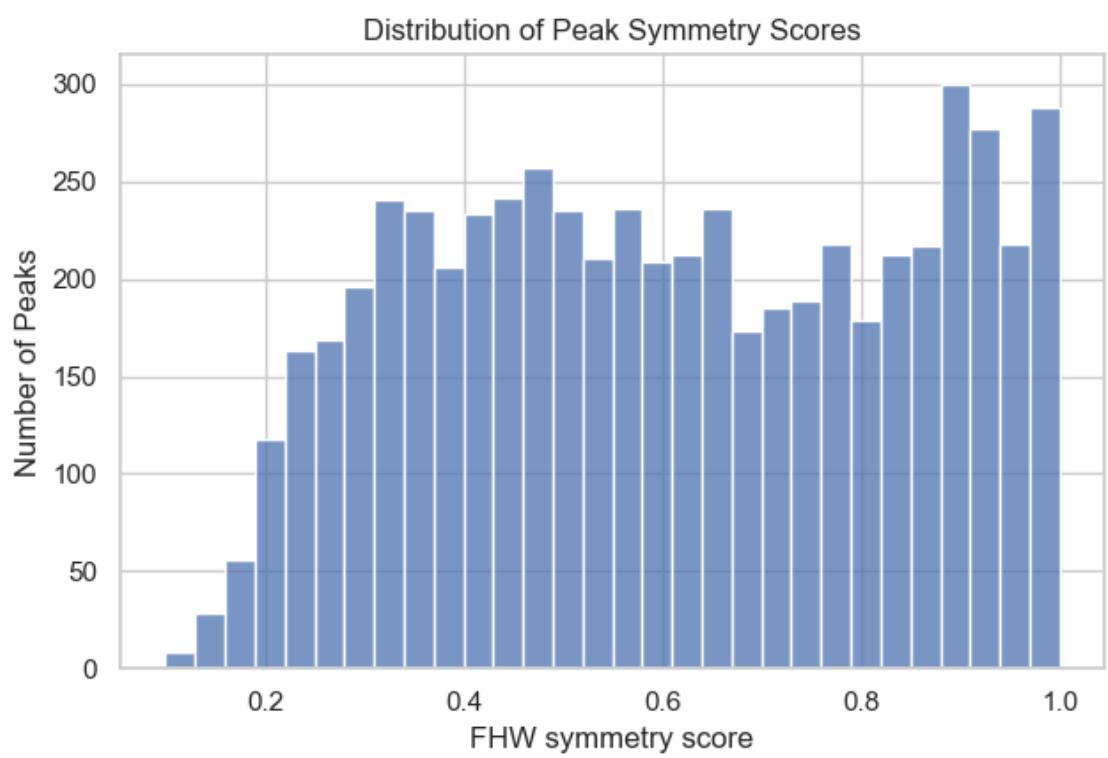
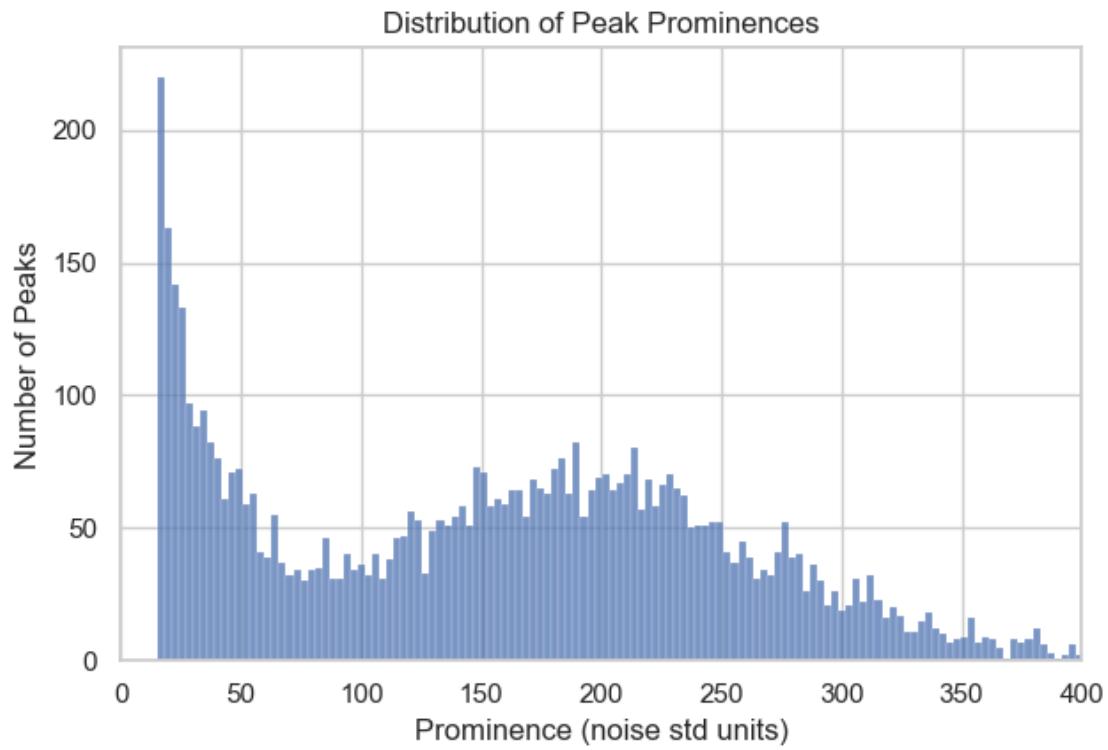
Total number of cells: 815

1.1.3 Peaks statistics

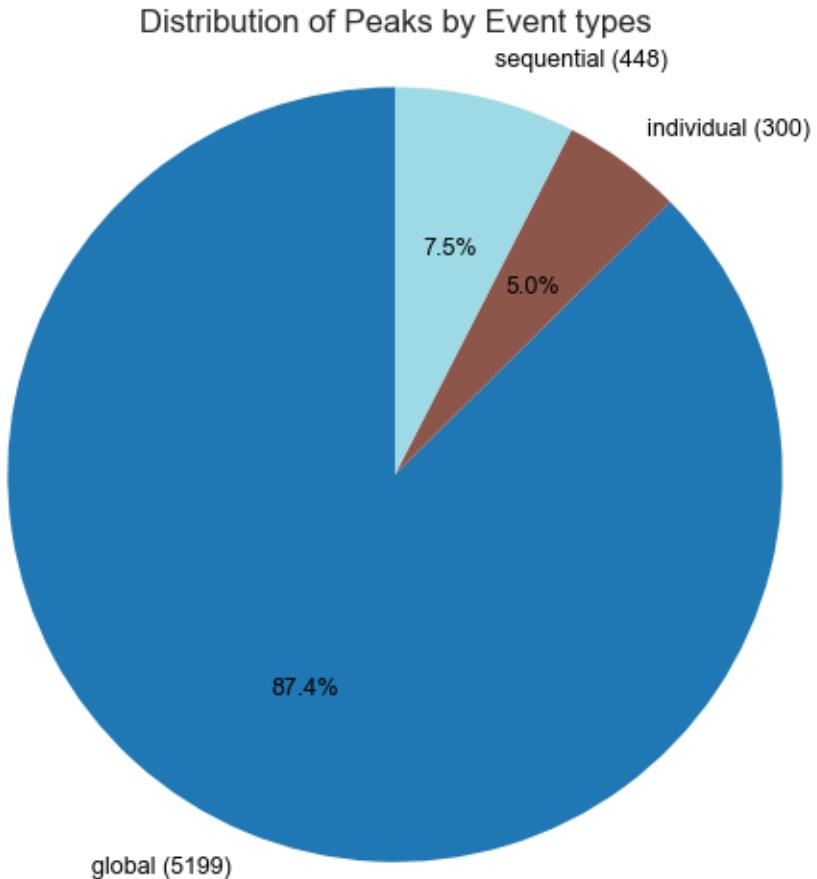
```
[2025-08-27 15:16:06] [INFO] calcium: plot_histogram: removed 0 outliers out of  
5947 on 'Duration (s)' (lower=-262, upper=466)
```



```
[2025-08-27 15:16:06] [INFO] calcium: plot_histogram: removed 2 outliers out of  
5947 on 'Prominence (noise std units)' (lower=-437.2, upper=726.55)
```

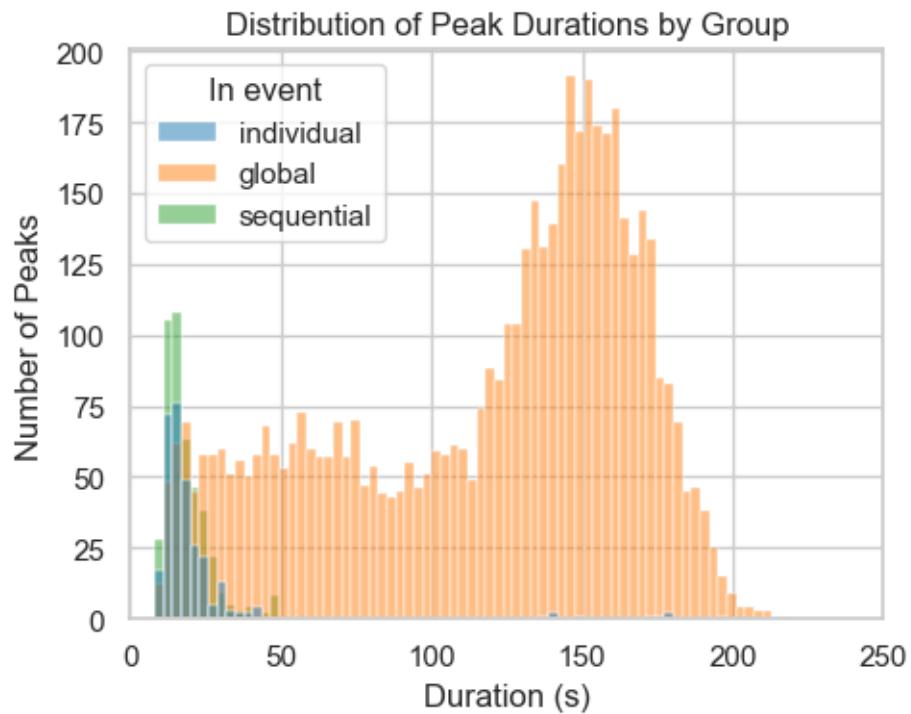


1.1.4 Distribution of peaks per event types

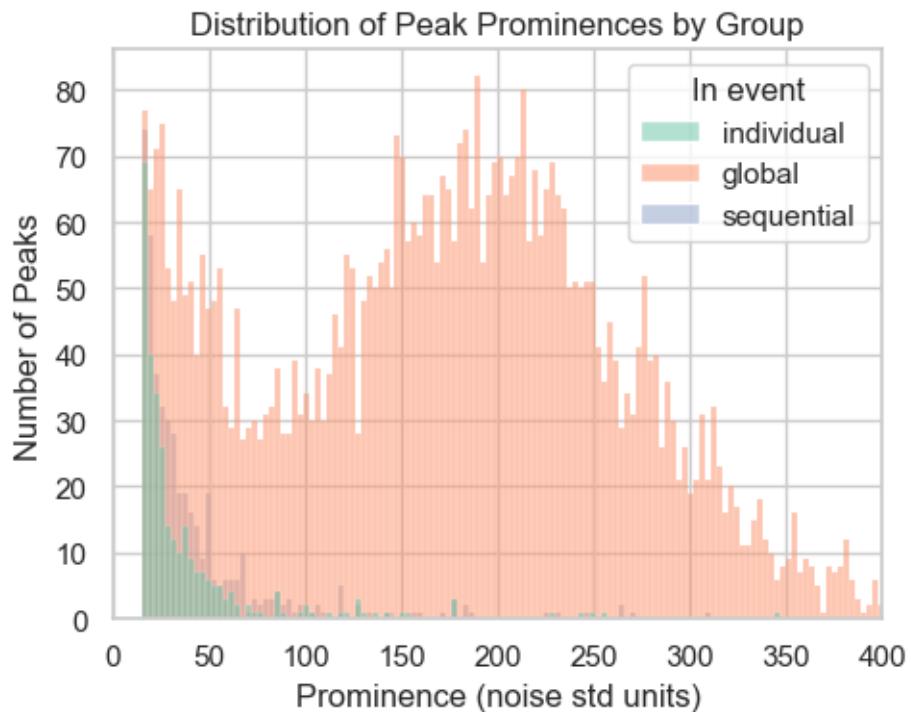


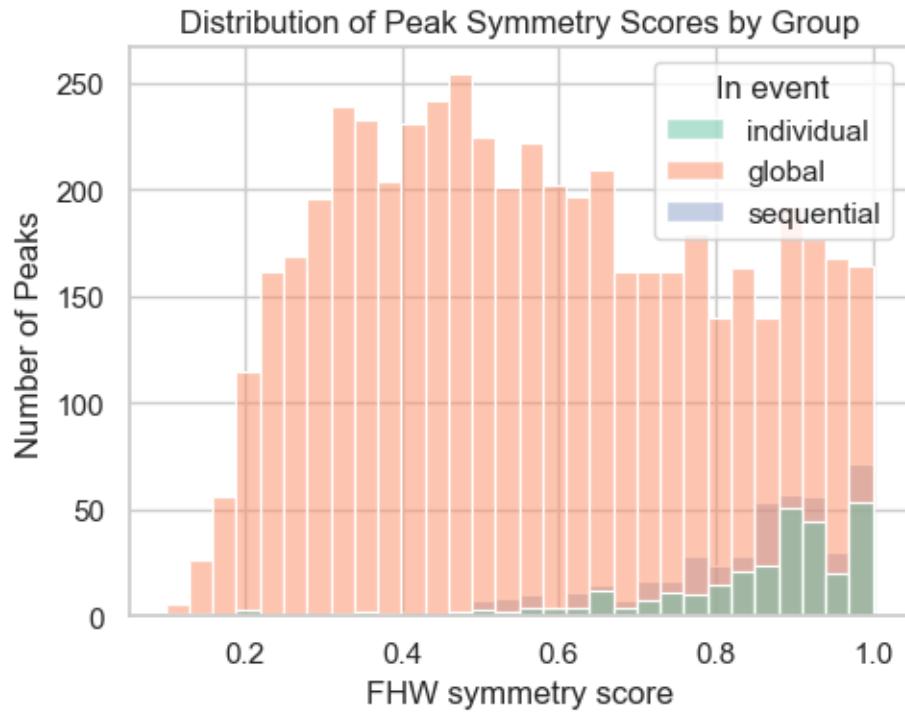
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:16:07] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5947 on 'Duration (s)' (lower=-262, upper=466)
```



[2025-08-27 15:16:07] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 5947 on 'Prominence (noise std units)' (lower=-437.2, upper=726.55)

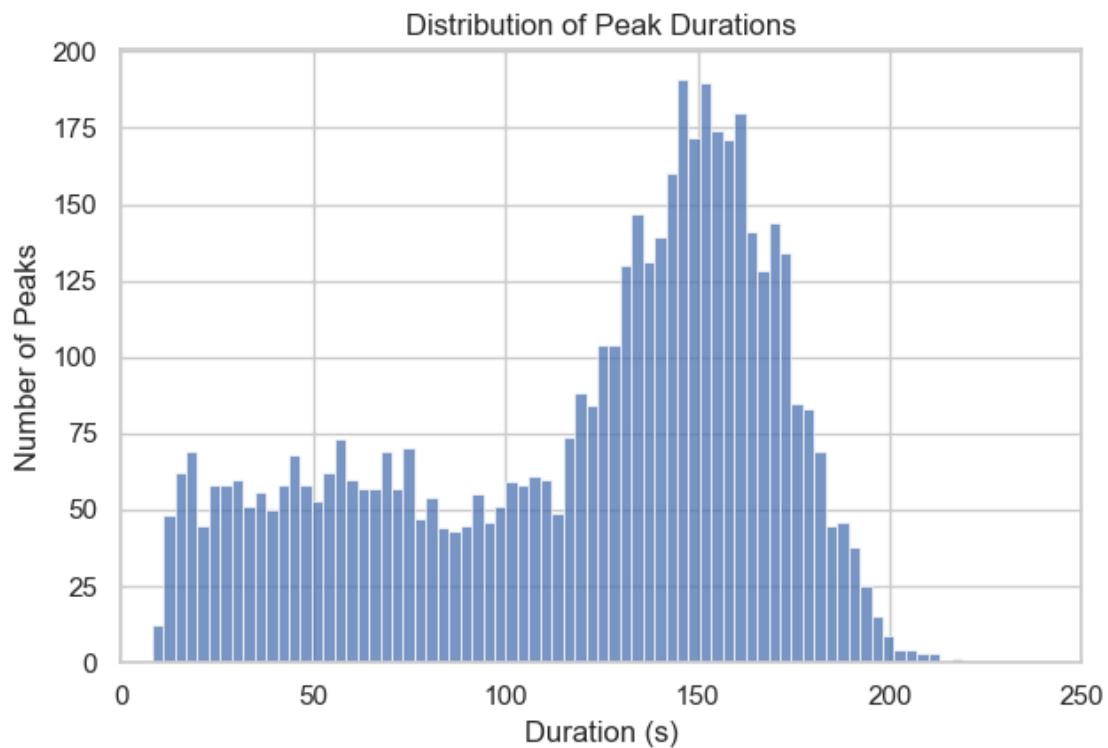




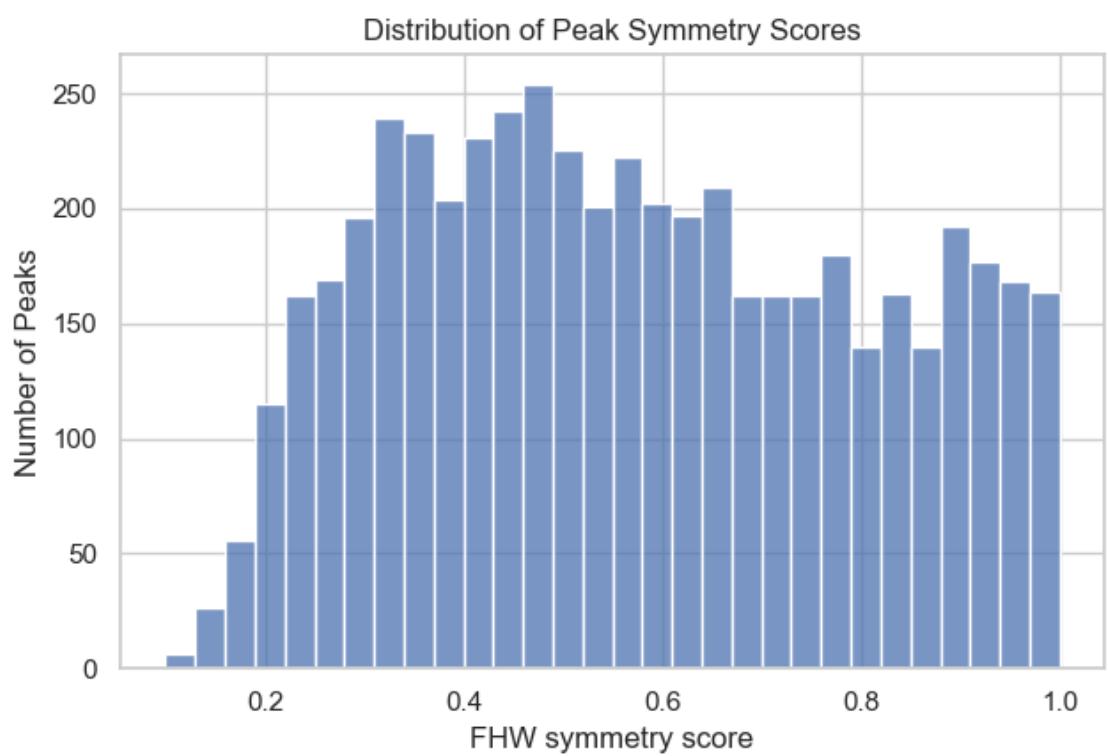
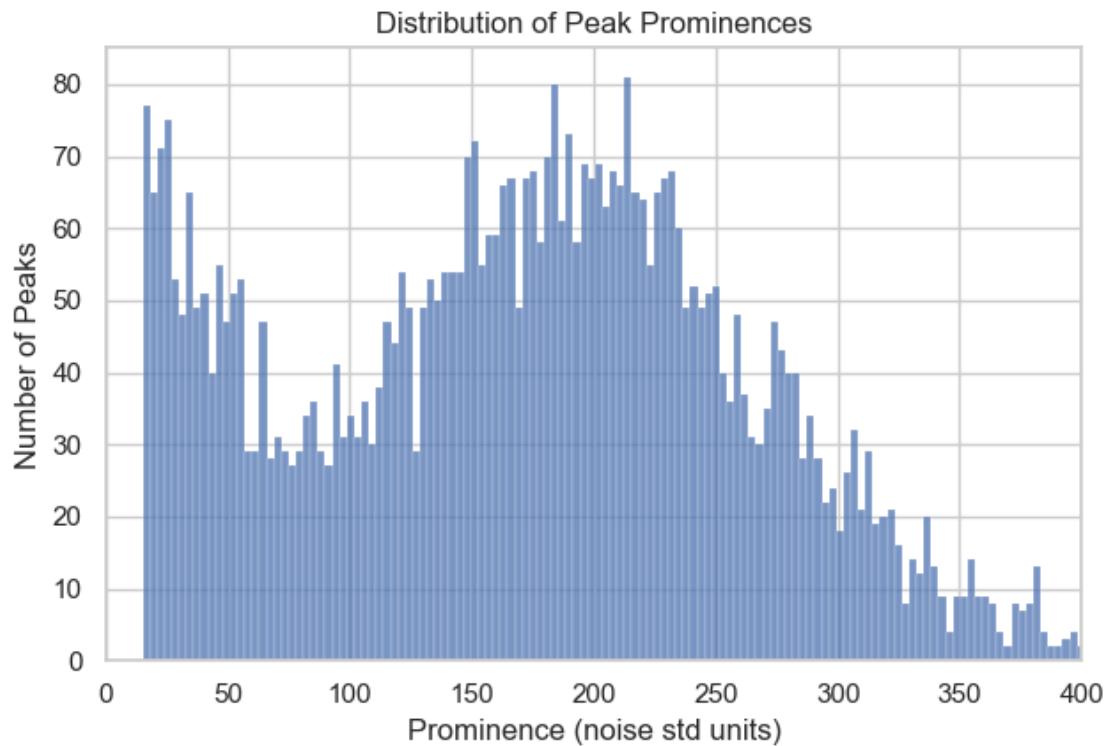
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:16:08] [INFO] calcium: plot_histogram: removed 0 outliers out of 5199 on 'Duration (s)' (lower=-167, upper=400)
```

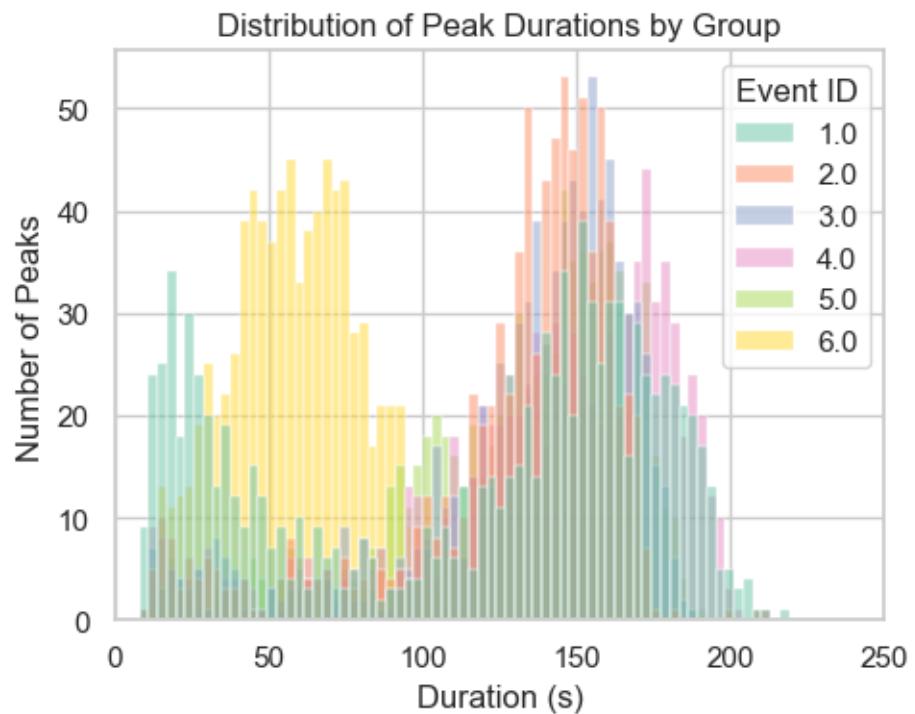


```
[2025-08-27 15:16:08] [INFO] calcium: plot_histogram: removed 5 outliers out of  
5199 on 'Prominence (noise std units)' (lower=-293, upper=632.05)
```

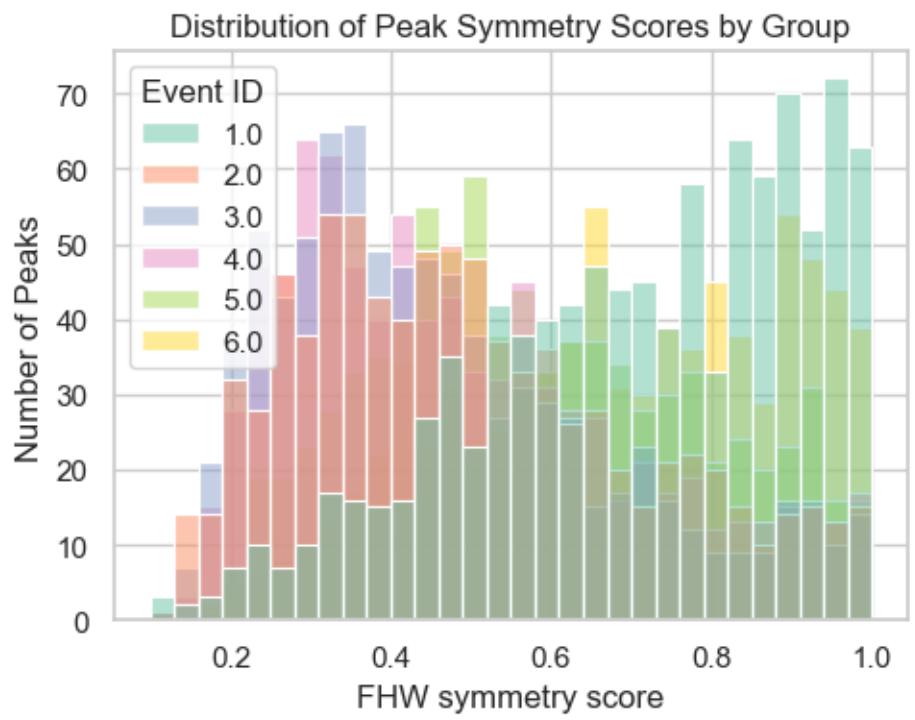
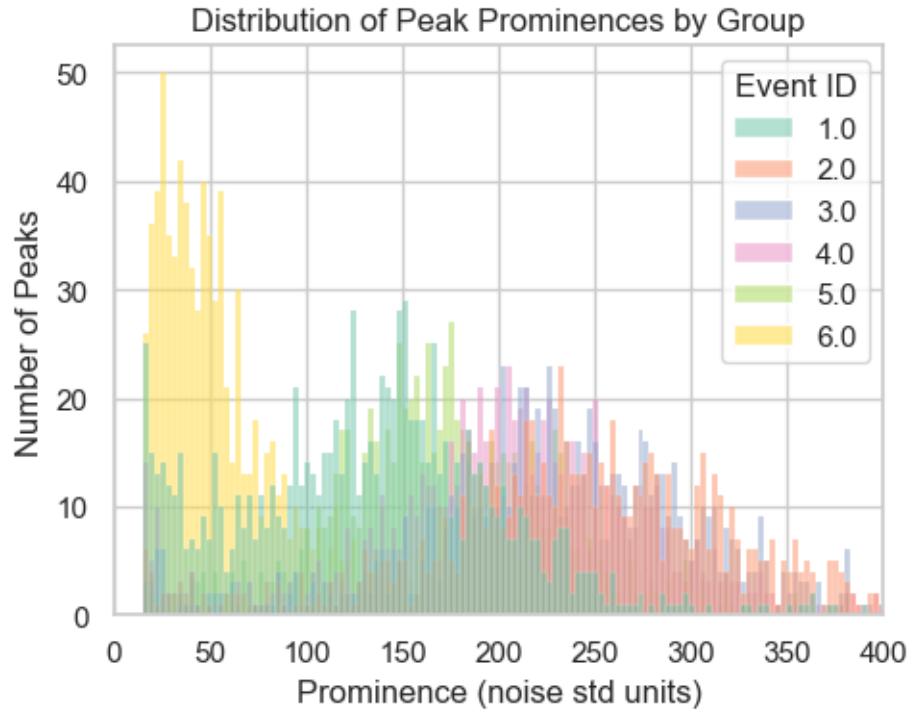


1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 15:16:08] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5199 on 'Duration (s)' (lower=-167, upper=400)
```

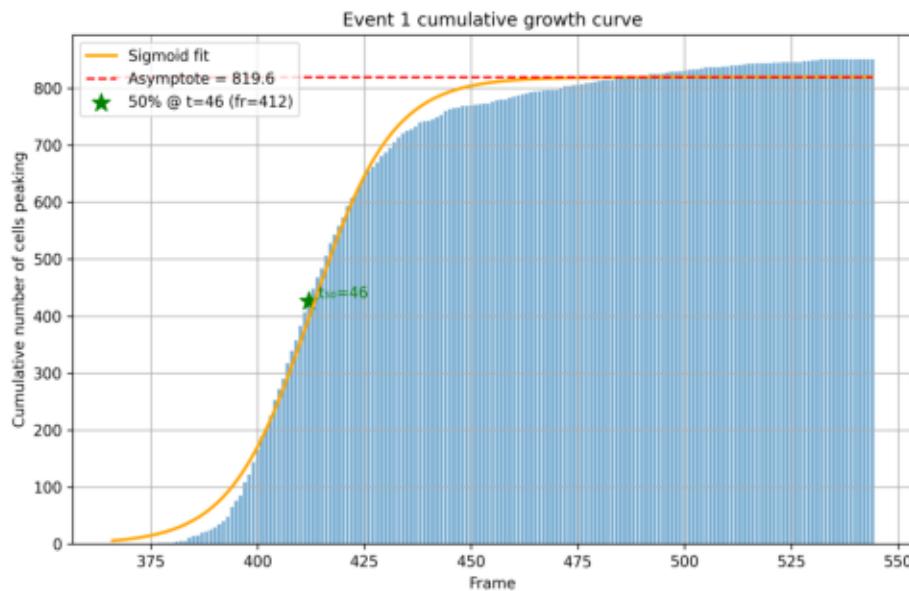


```
[2025-08-27 15:16:09] [INFO] calcium: plot_histogram_by_group: removed 5 outliers out of 5199 on 'Prominence (noise std units)' (lower=-293, upper=632.05)
```

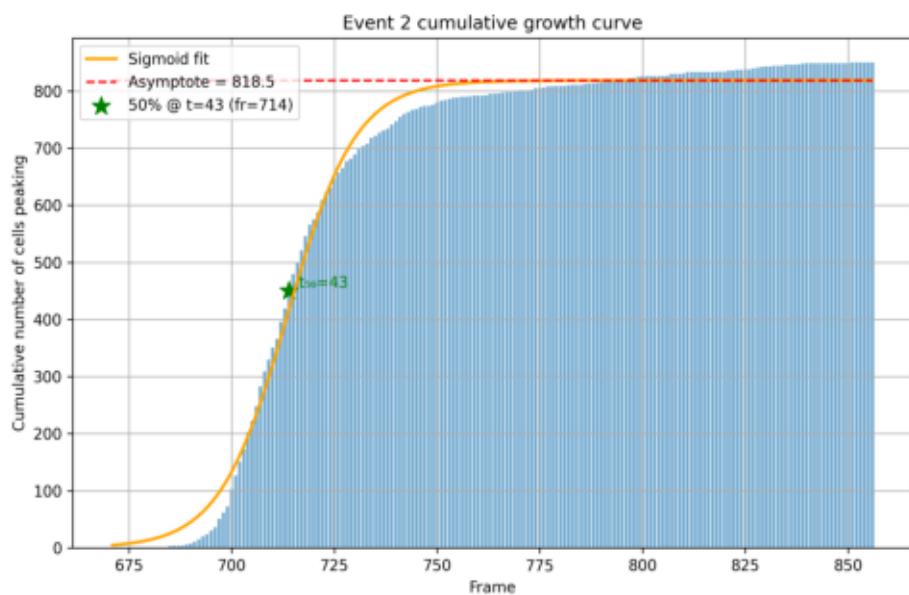


1.2.3 Kinetics of global events

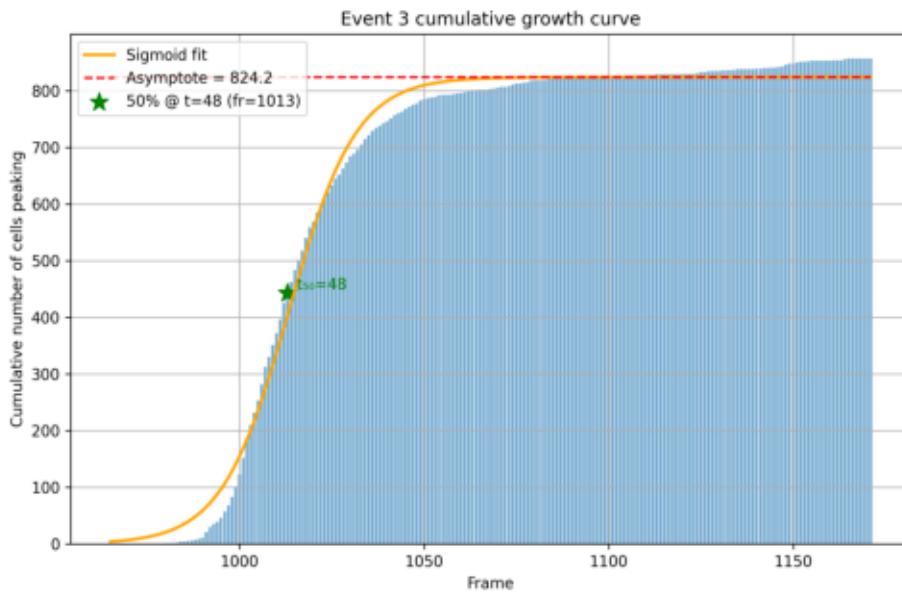
Event Activity Overlay (Event ID: 1)



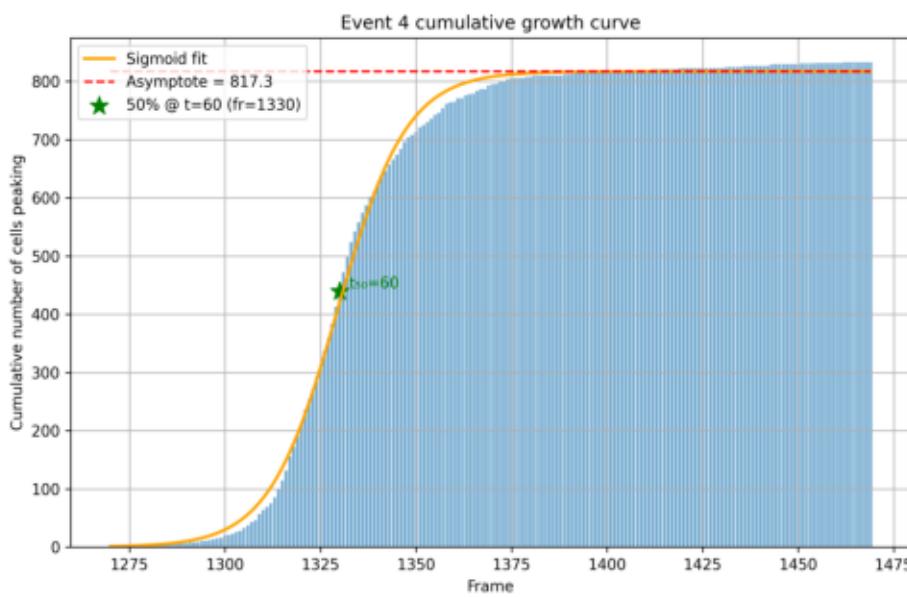
Event Activity Overlay (Event ID: 2)



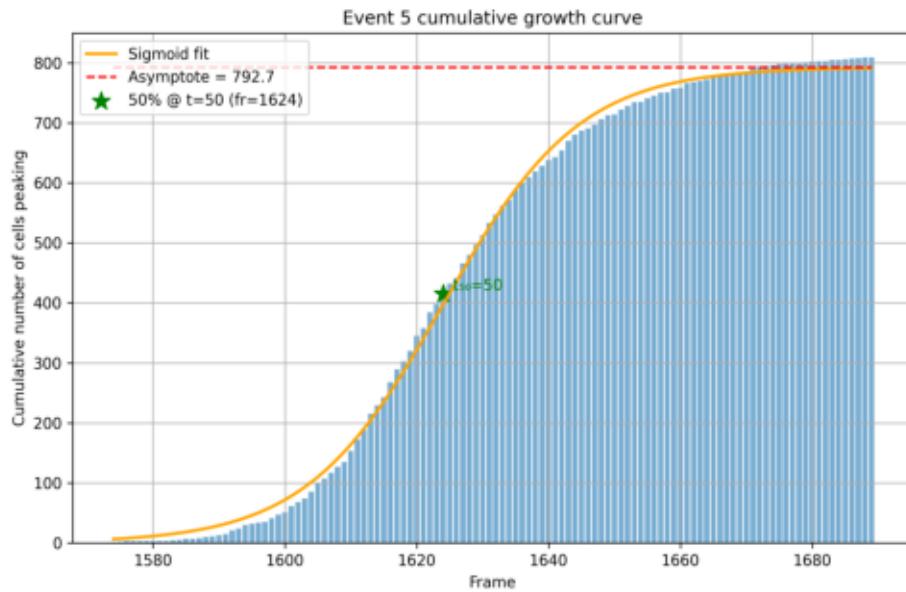
Event Activity Overlay (Event ID: 3)



Event Activity Overlay (Event ID: 4)

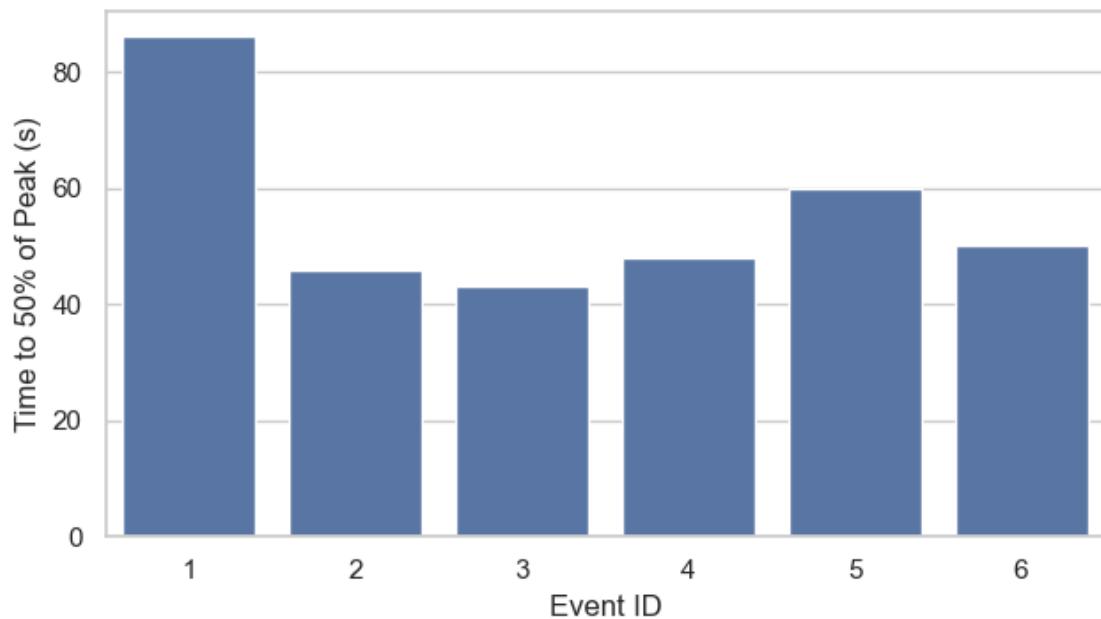


Event Activity Overlay (Event ID: 5)

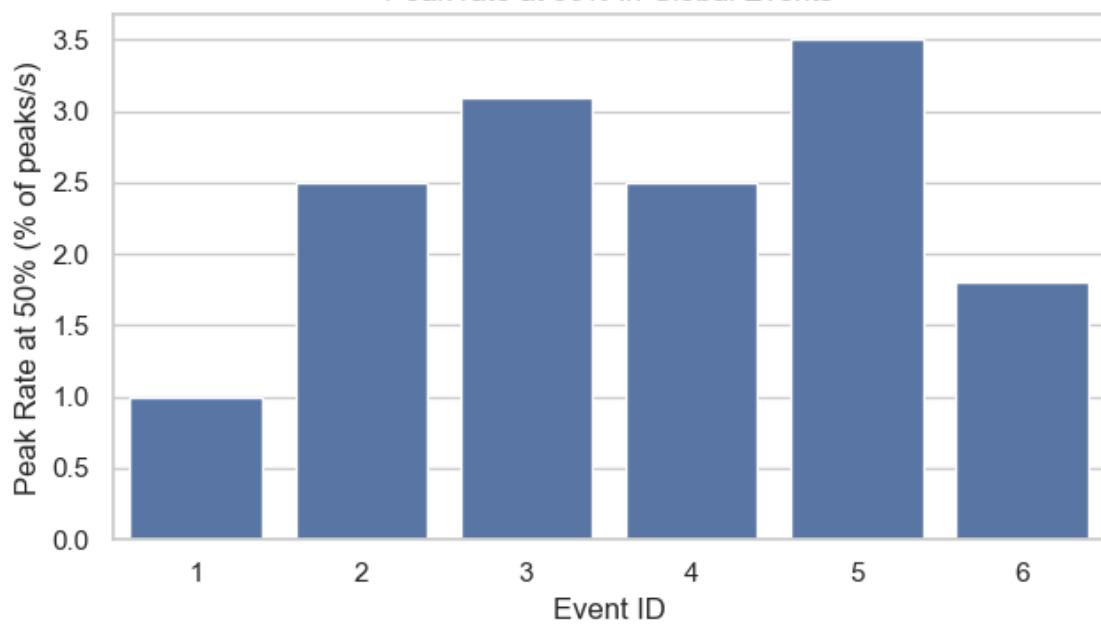


```
[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\events\event-growth-curve-6.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250701\Output\\IS5\\events\\event-growth-
curve-6.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\\IS5\\events\\event-growth-curve-6.png'
```

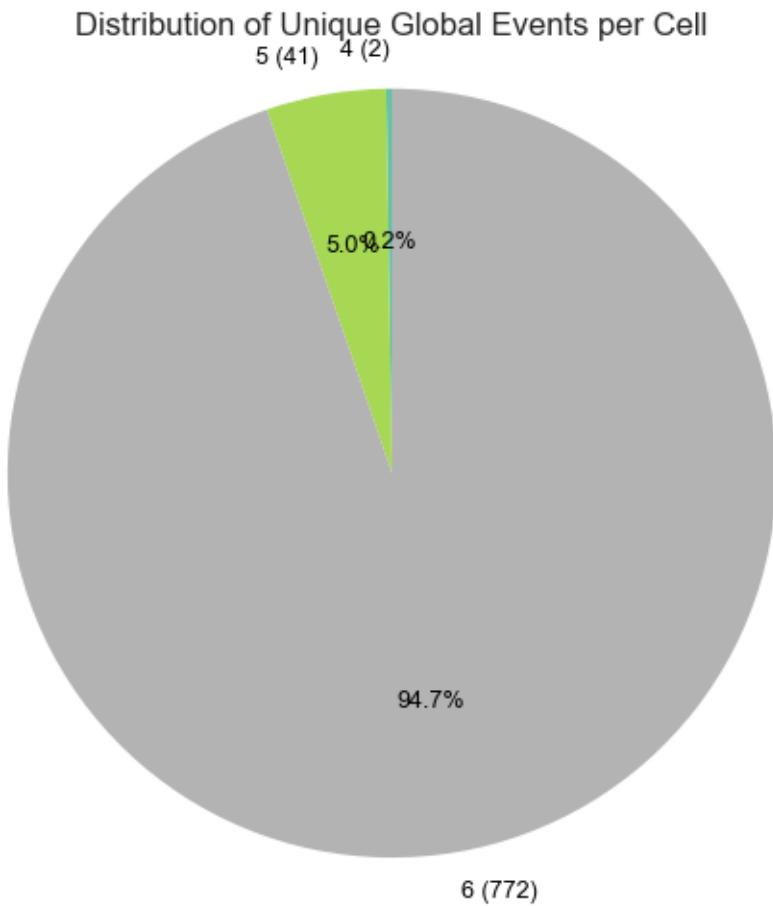
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

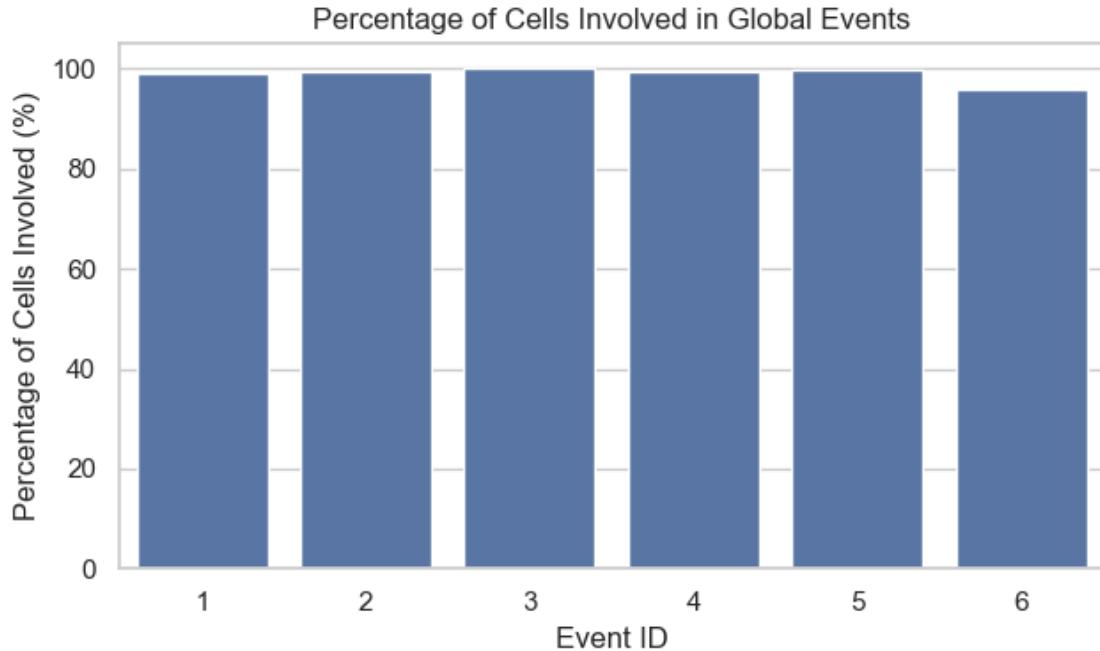


```
[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250701\\\\Output\\\\IS5\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [208.0, 302.0, 294.0, 314.0, 301.0]
Estimated periodicity: 0.881
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.004 Hz

1.2.6 Early peakers in the events

```

[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:

```

```

  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()

```

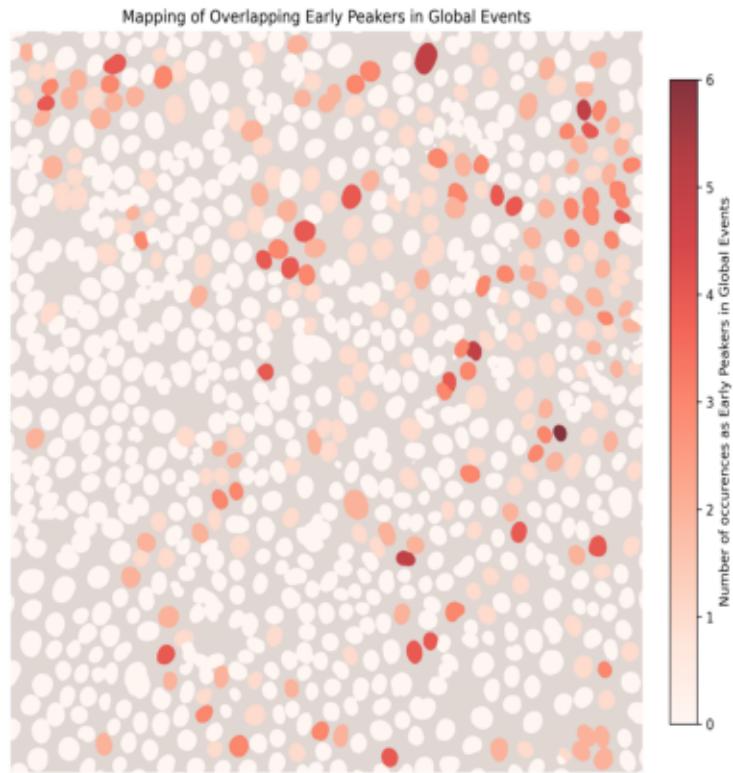
```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:16:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

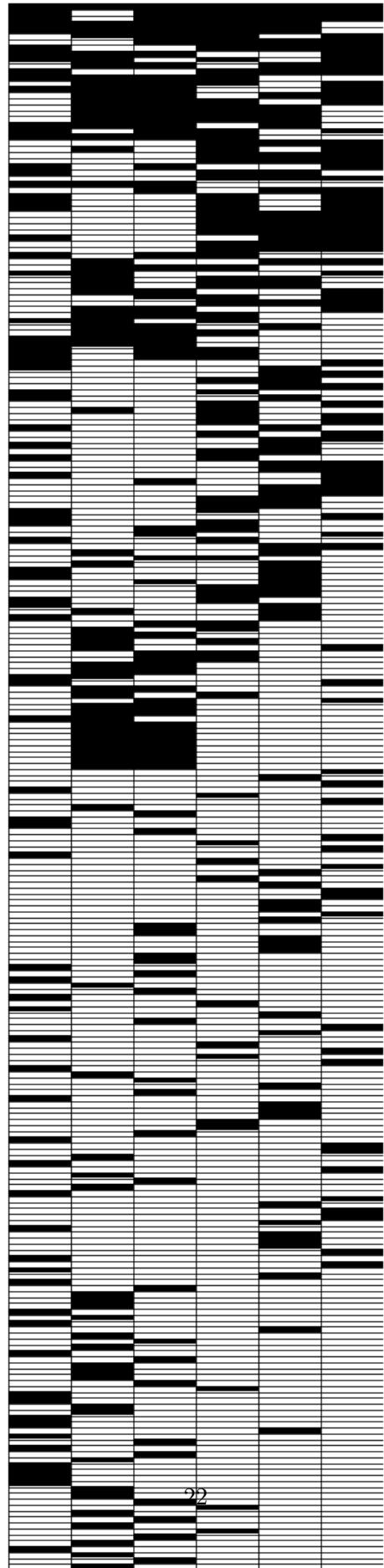
```
[2025-08-27 15:16:14] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\global_events\global_event_6_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



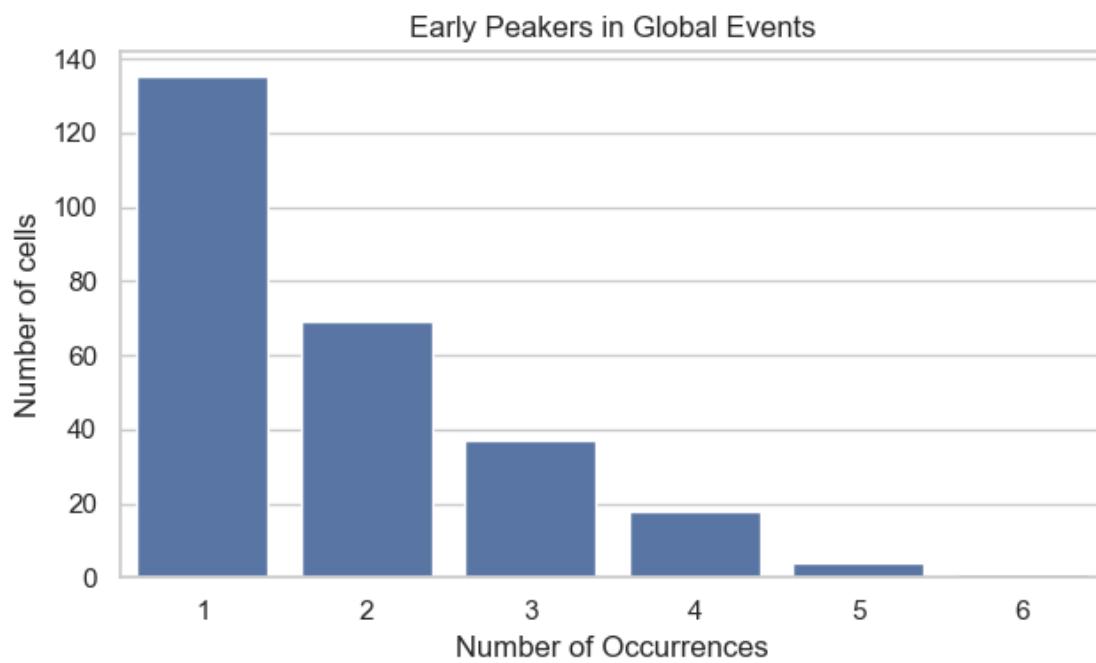
```
[2025-08-27 15:16:14] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 6 unique event IDs.
```

```
[2025-08-27 15:16:14] [INFO] calcium: Early peakers event-matrix: 264 cells x 6 events; black squares: 482
```

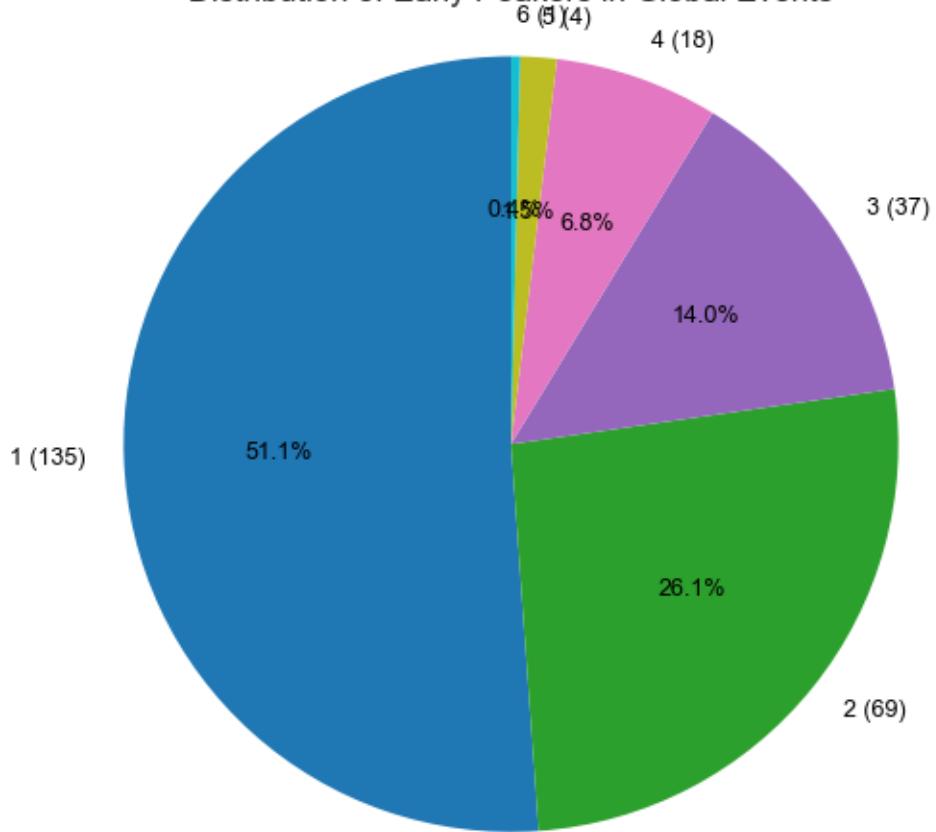


```
[2025-08-27 15:16:15] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 1, 1, 1, 1],  
           [1, 0, 1, 1, 1, 1],  
           [1, 0, 1, 1, 1, 1],  
           ...,  
           [0, 1, 0, 0, 0, 0],  
           [0, 0, 1, 0, 0, 0],  
           [0, 1, 0, 0, 0, 0]])
```



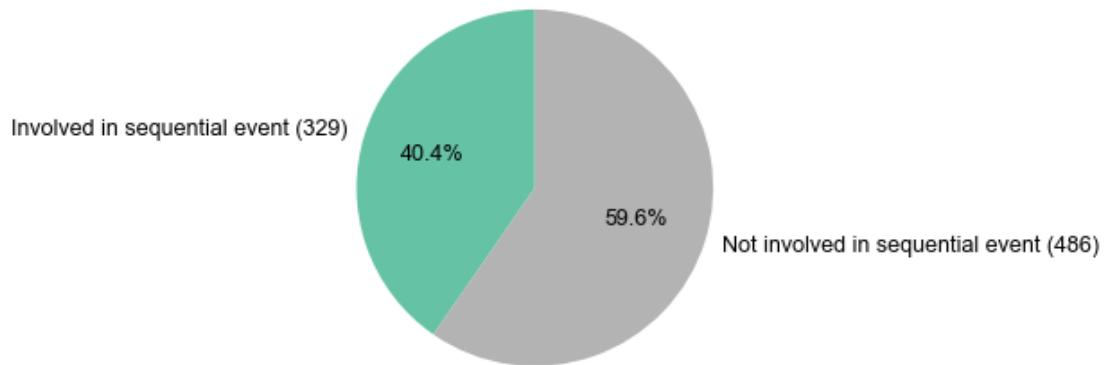
Distribution of Early Peakers in Global Events



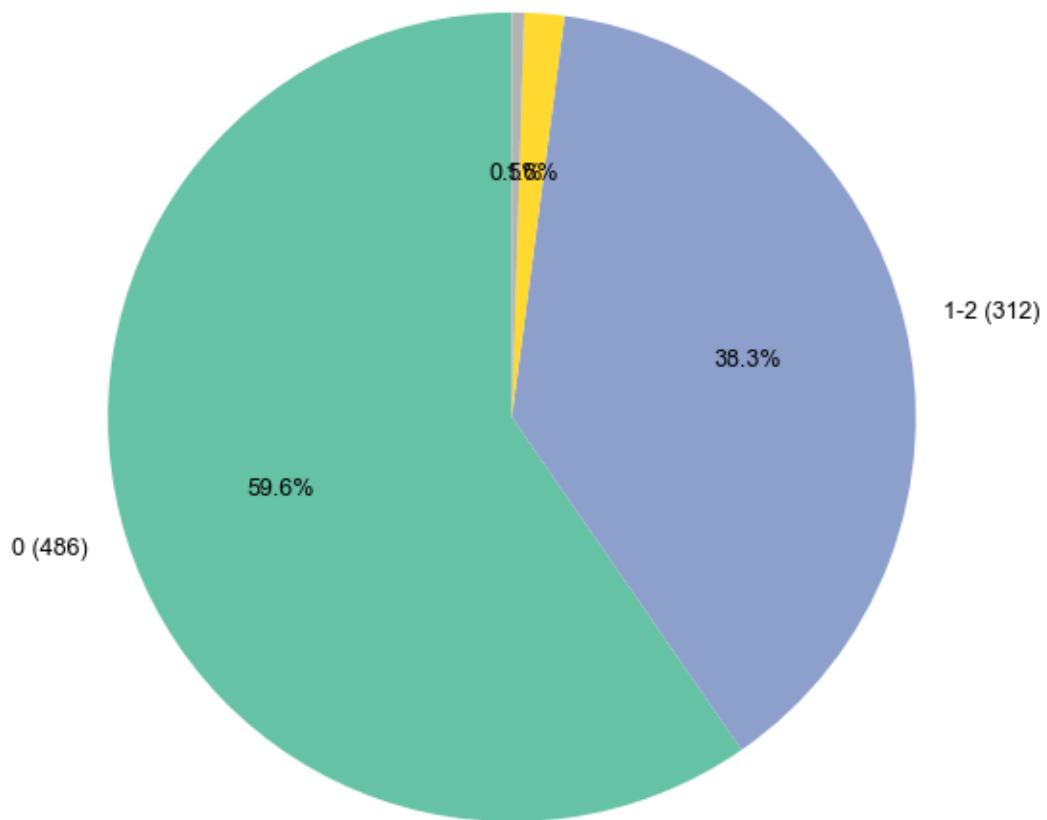
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

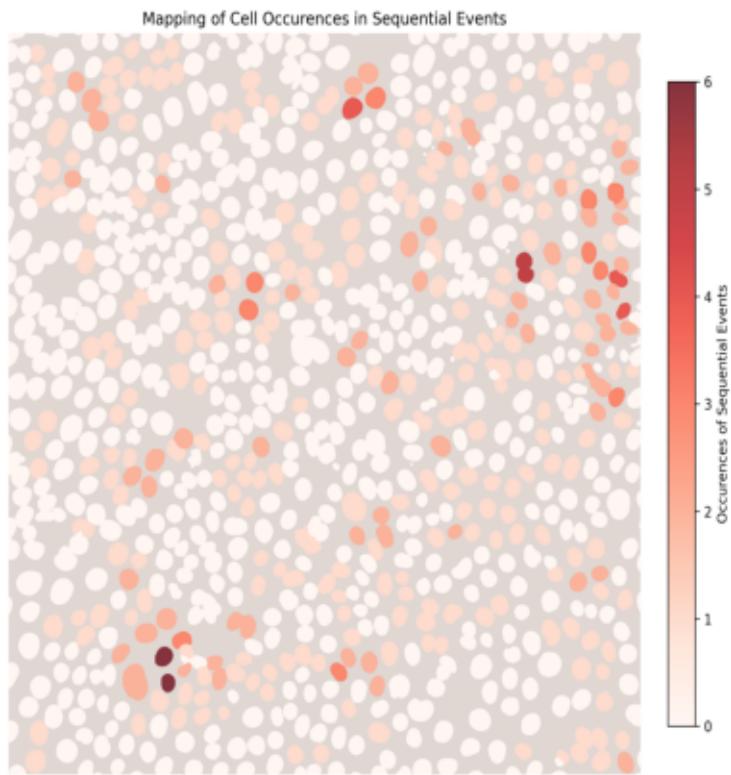
Distribution of Cells Involved in Sequential Events



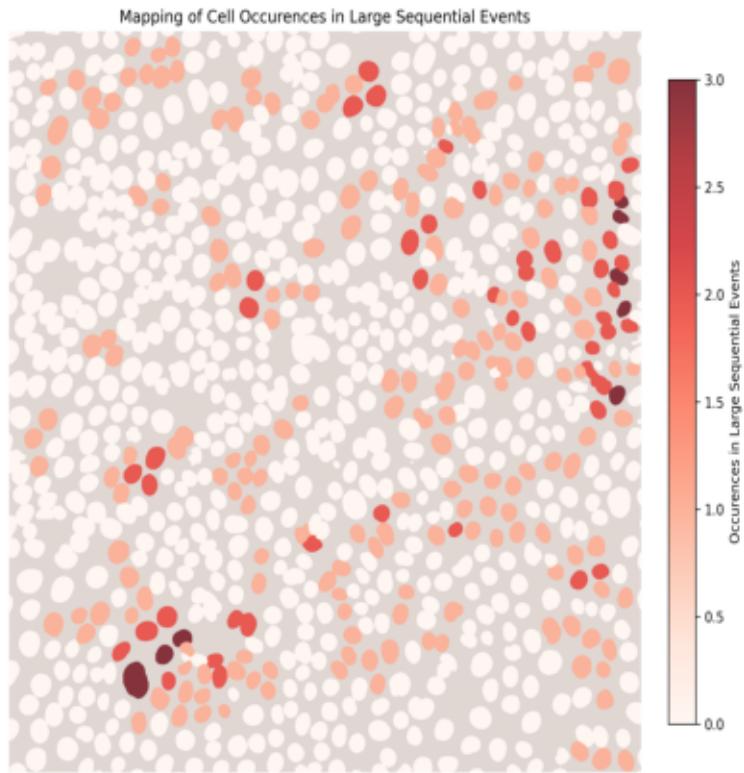
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

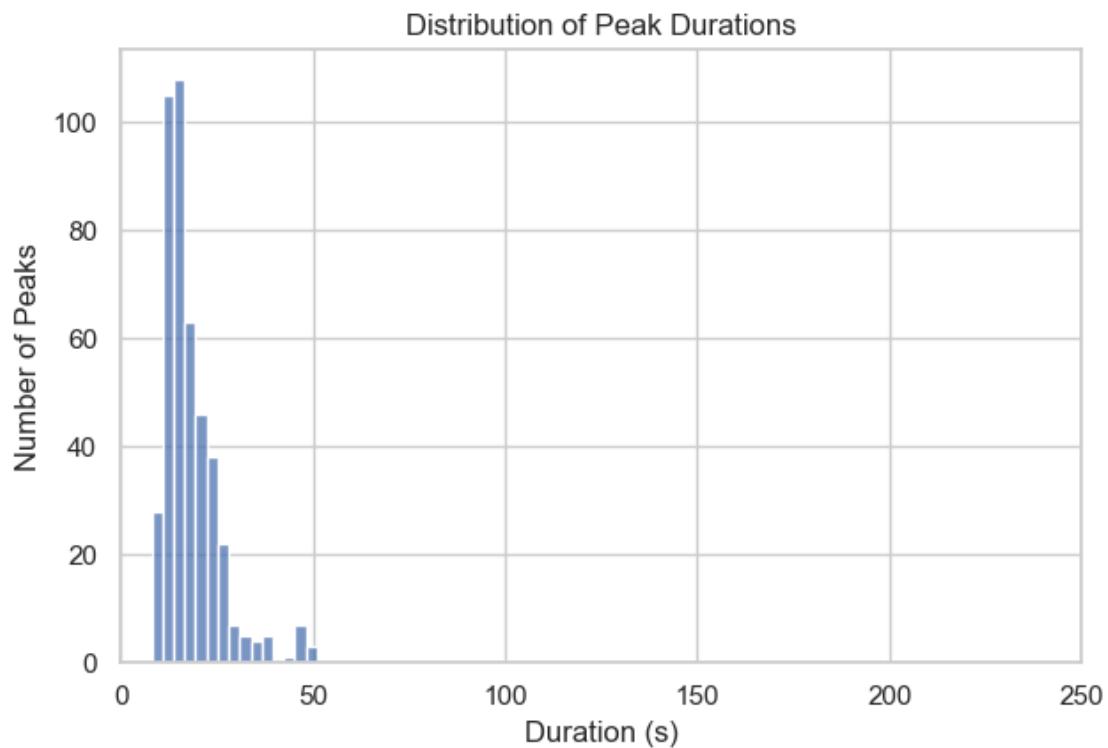


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

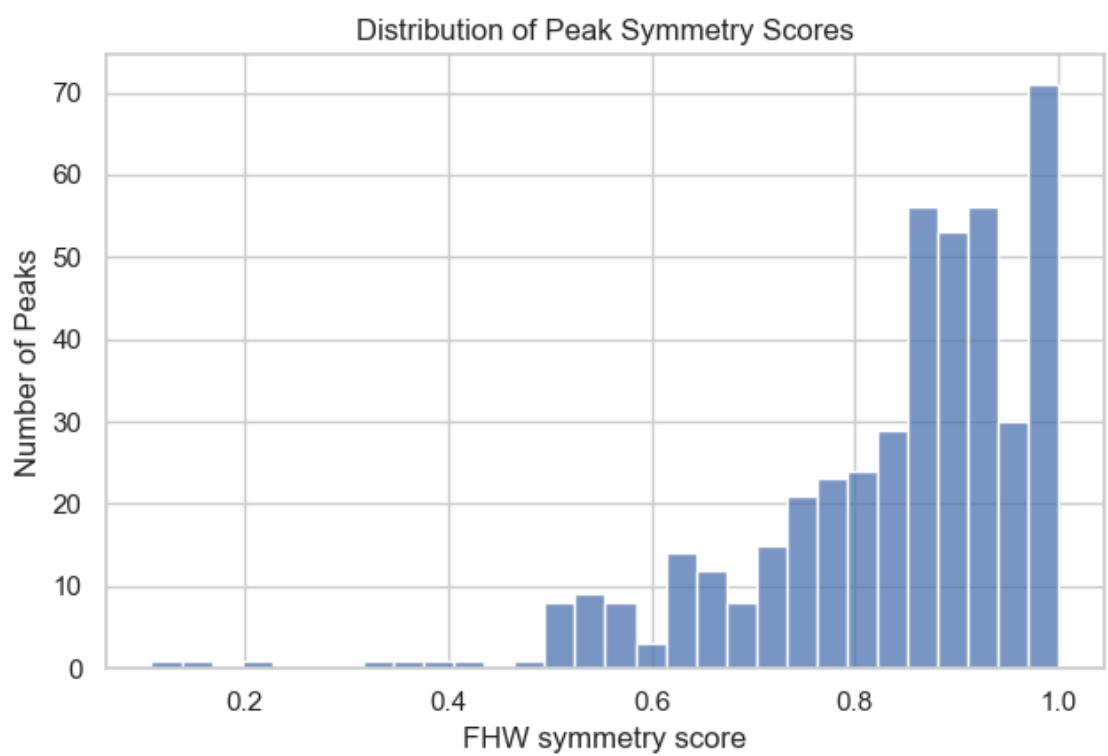
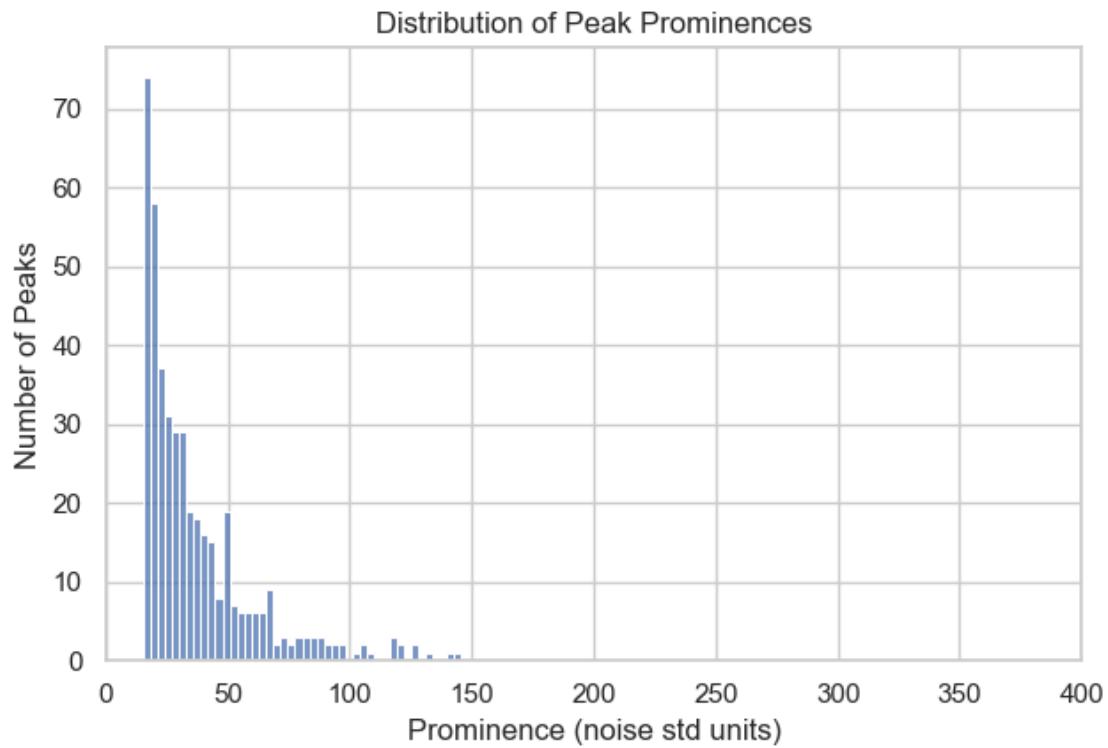


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:16:17] [INFO] calcium: plot_histogram: removed 6 outliers out of 448 on 'Duration (s)' (lower=-0.5, upper=53.5)
```

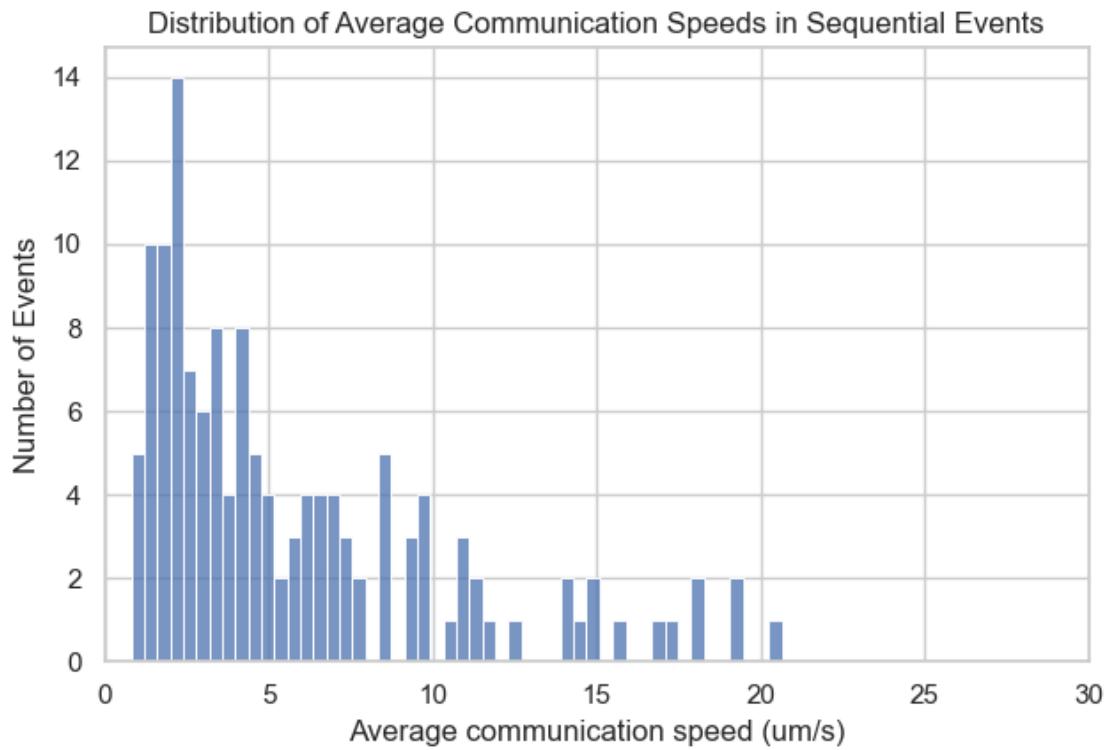


```
[2025-08-27 15:16:17] [INFO] calcium: plot_histogram: removed 16 outliers out of 448 on 'Prominence (noise std units)' (lower=-22.487, upper=146.26)
```



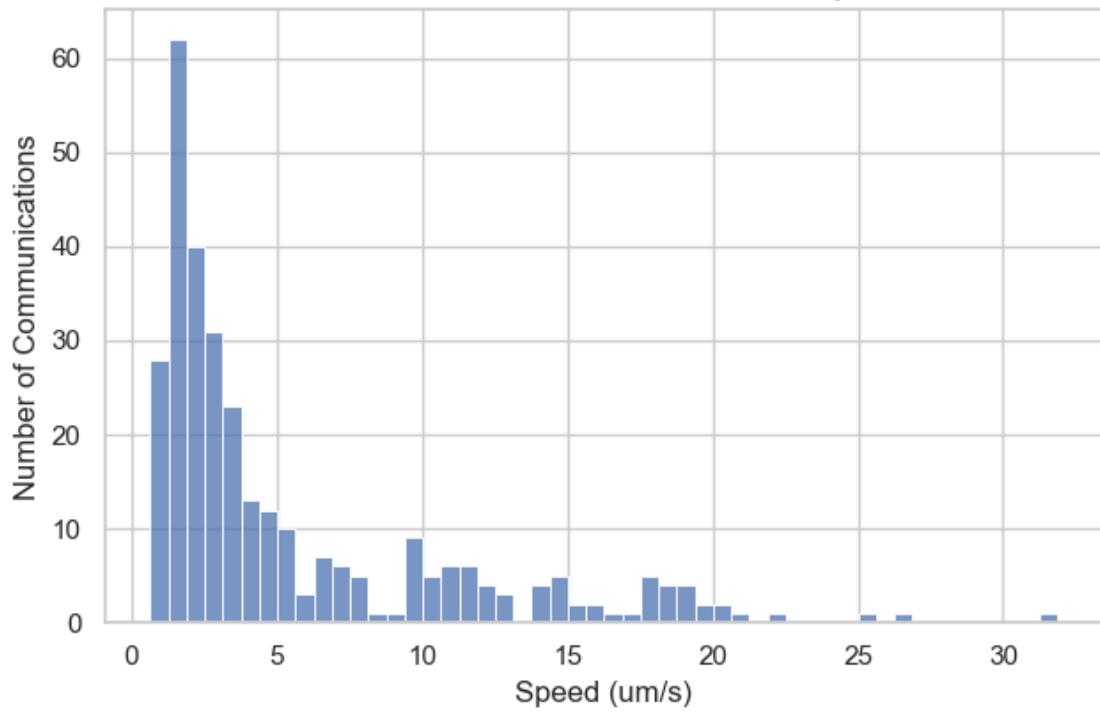
1.3.3 Cell-cell communication speed

```
[2025-08-27 15:16:18] [INFO] calcium: plot_histogram: removed 0 outliers out of  
136 on 'Average communication speed (um/s)' (lower=-13.89, upper=23.77)
```

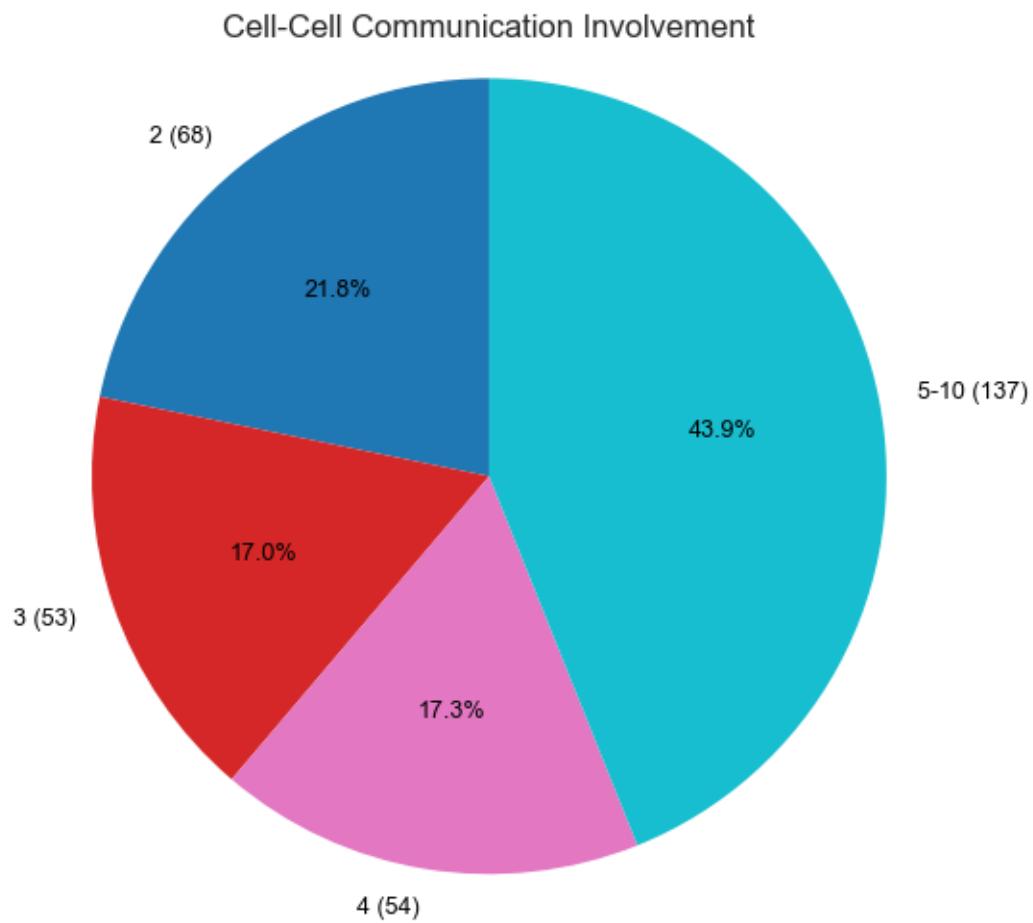


```
[2025-08-27 15:16:18] [INFO] calcium: plot_histogram: removed 0 outliers out of  
312 on 'Speed (um/s)' (lower=-15.378, upper=35.945)
```

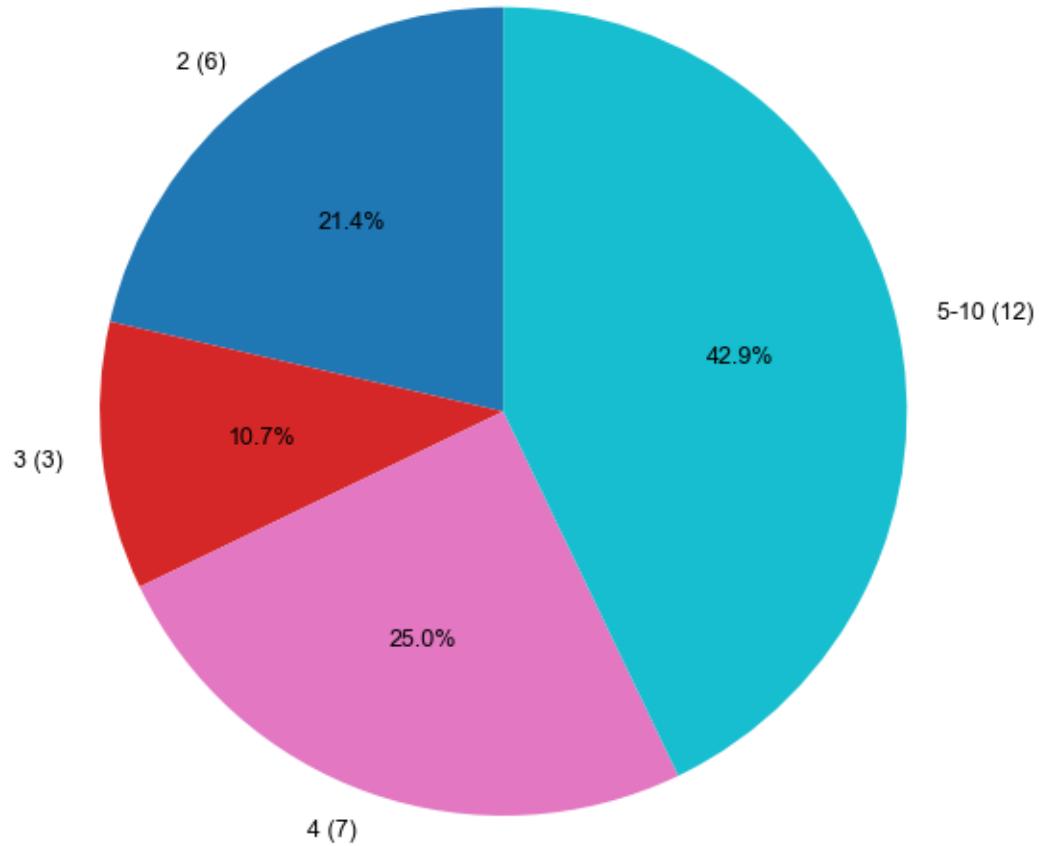
Distribution of Cell-Cell Communication Speeds



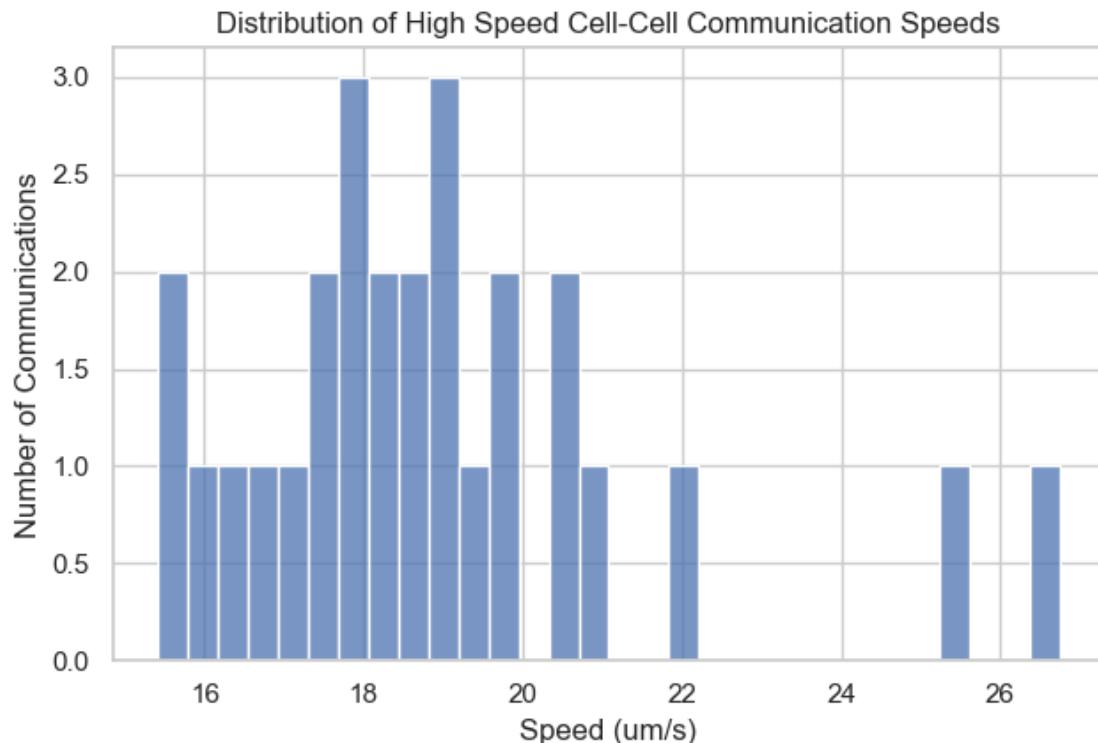
1.3.4 Double distribution in cell-cell communication speeds



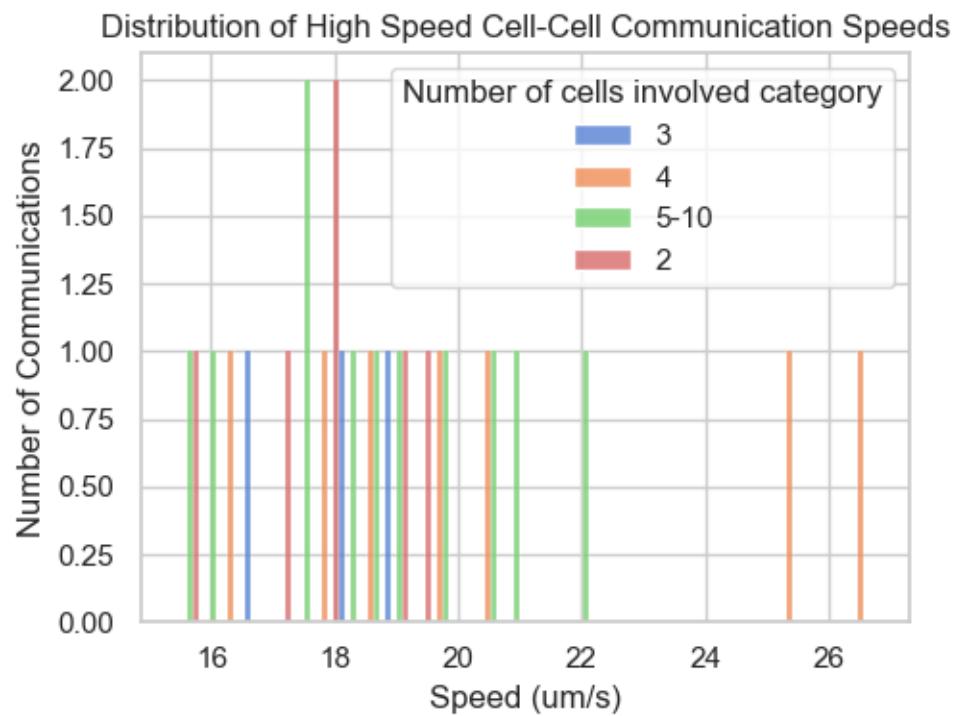
High Speed Cell-Cell Communication Involvement



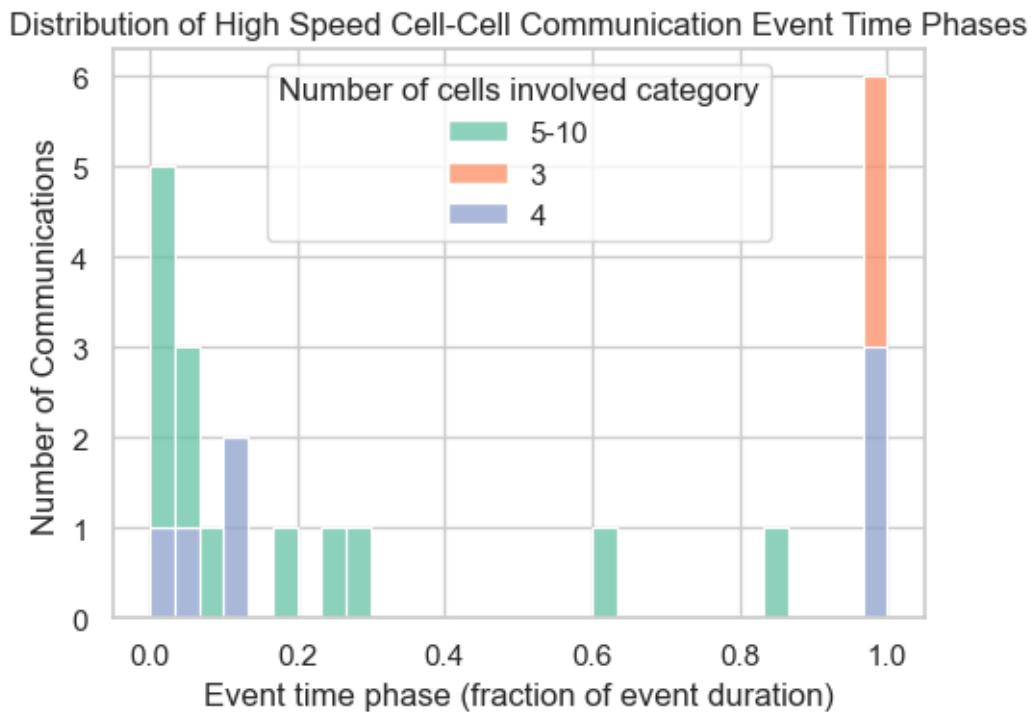
[2025-08-27 15:16:18] [INFO] calcium: plot_histogram: removed 1 outliers out of 28 on 'Speed (um/s)' (lower=10.275, upper=27.408)



```
[2025-08-27 15:16:18] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 28 on 'Speed (um/s)' (lower=10.275, upper=27.408)
```

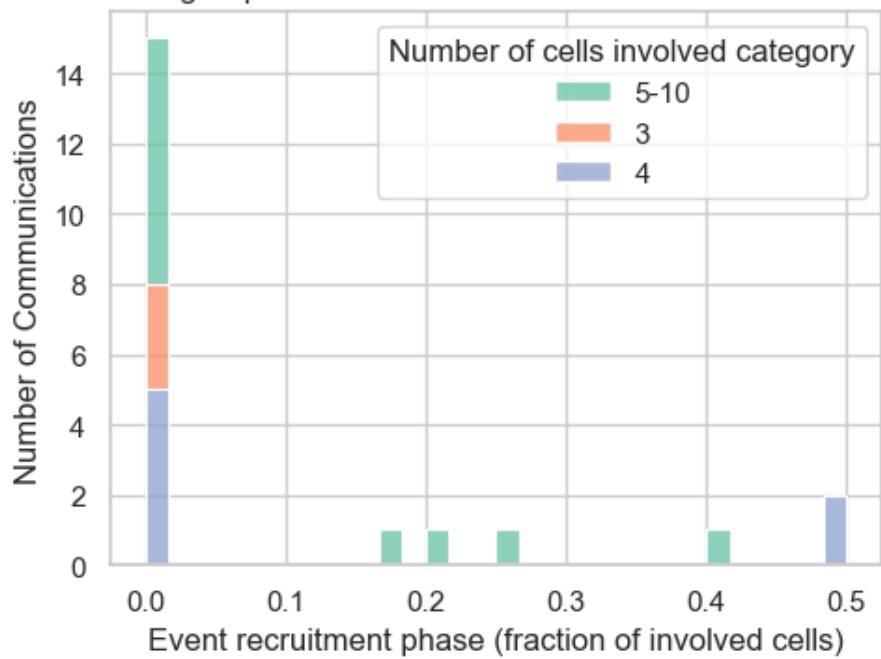


```
[2025-08-27 15:16:19] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 22 on 'Event time phase (fraction of event duration)' (lower=-2.7175, upper=3.7225)
```

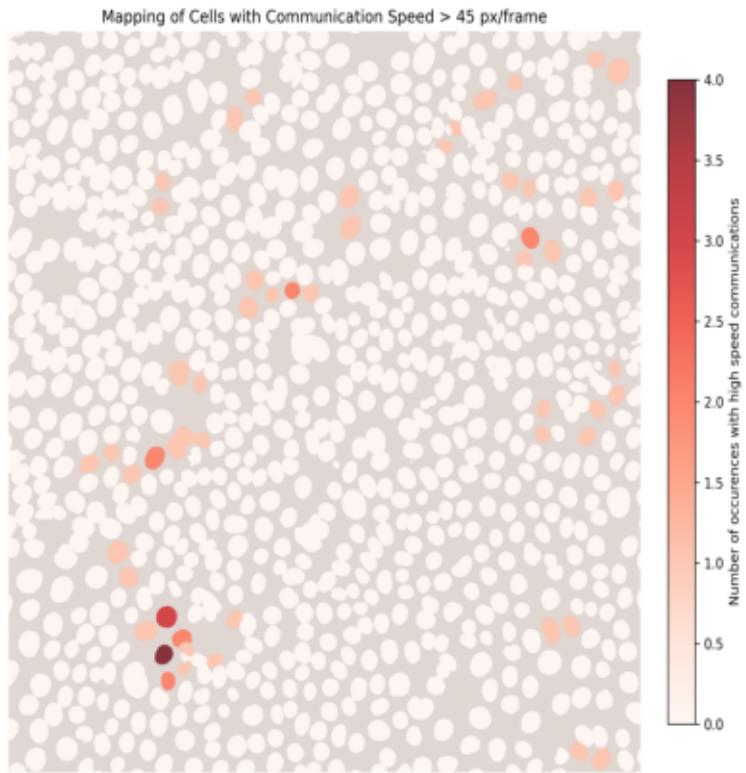


```
[2025-08-27 15:16:19] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 22 on 'Event recruitment phase (fraction of involved cells)' (lower=-0.5775, upper=0.77)
```

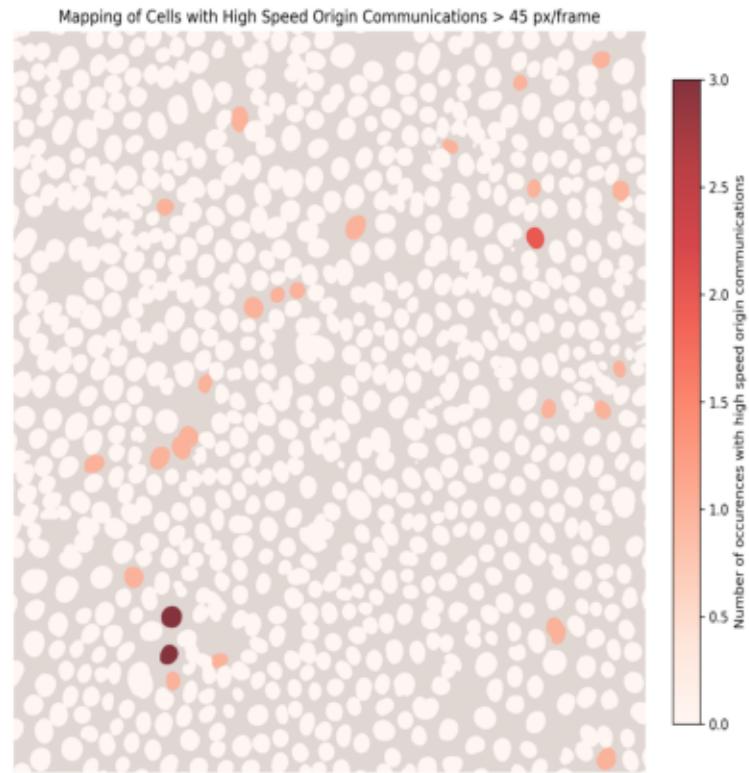
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
1	2016663475232	7	1179		0
8	2016663480176	8	459		0
17	2016663473648	11	222		0
19	2016663482960	12	1119		1
20	2016921046848	12	1119		1
21	2016921048528	12	1119		1
27	2016663485840	14	1171		0
28	2016663482336	14	1171		0
35	2016663479552	16	1310		0
36	2016663478448	17	314		0
40	2016663477200	18	501		0
45	2016663472640	19	262		1

47	2016663484736	21	592	0
55	2016663478544	24	873	0
56	2016663476528	25	786	0
63	2016663483104	28	1209	8
71	2016663484496	30	720	2
75	2016663481808	33	1056	0
89	2016663478256	36	787	1
93	2016663478160	37	1171	13
131	2016663473600	55	423	1
138	2016663483440	58	490	0
145	2016663470432	62	429	1
181	2016663480512	79	613	4
207	2016663472448	94	747	0
226	2016663477776	104	849	0
227	2016663483632	104	862	0
284	2016921051216	126	1133	0

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
1	1120	0	15.0	15.0	
8	415	1	42.0	42.0	
17	243	1	67.0	68.0	
19	1171	2	93.0	93.0	
20	1137	1	93.0	94.0	
21	1144	2	93.0	94.0	
27	1144	0	6.0	7.0	
28	1158	0	6.0	7.0	
35	1301	0	50.0	50.0	
36	281	0	26.0	26.0	
40	522	1	87.0	88.0	
45	286	1	311.0	312.0	
47	583	0	35.0	36.0	
55	855	1	74.0	74.0	
56	825	0	61.0	61.0	
63	1189	3	340.0	340.0	
71	765	4	316.0	317.0	
75	1016	0	11.0	11.0	
89	826	1	81.0	81.0	
93	1209	13	957.0	957.0	
131	413	1	59.0	60.0	
138	437	0	14.0	15.0	
145	442	1	73.0	74.0	
181	569	5	630.0	631.0	
207	731	1	85.0	86.0	
226	862	0	22.0	23.0	
227	890	0	23.0	24.0	
284	1130	0	21.0	22.0	

Duration (s) Distance (um) Speed (um/s) \

1	0.0	31.89	31.89
8	0.0	16.73	16.73
17	1.0	18.91	18.91
19	0.0	25.45	25.45
20	1.0	18.51	18.51
21	1.0	17.98	17.98
27	1.0	18.23	18.23
28	1.0	18.61	18.61
35	0.0	18.30	18.30
36	0.0	20.91	20.91
40	1.0	19.92	19.92
45	1.0	26.74	26.74
47	1.0	15.87	15.87
55	0.0	19.21	19.21
56	0.0	17.25	17.25
63	0.0	15.50	15.50
71	1.0	17.63	17.63
75	0.0	18.89	18.89
89	0.0	19.77	19.77
93	0.0	17.91	17.91
131	1.0	15.42	15.42
138	1.0	20.50	20.50
145	1.0	21.93	21.93
181	1.0	19.16	19.16
207	1.0	17.93	17.93
226	1.0	17.58	17.58
227	1.0	20.57	20.57
284	1.0	16.25	16.25

Event time phase (fraction of event duration) \	
1	0.19
8	1.00
17	1.00
19	0.00
20	1.00
21	1.00
27	0.03
28	0.03
35	1.00
36	0.00
40	1.00
45	0.12
47	0.05
55	NaN
56	NaN
63	NaN
71	0.08
75	0.00

89	0.61
93	NaN
131	0.04
138	0.11
145	0.85
181	NaN
207	NaN
226	0.26
227	0.29
284	0.06

	Event recruitment phase (fraction of involved cells)	dataset \
1	0.17	20250701_IS5
8	0.00	20250701_IS5
17	0.00	20250701_IS5
19	0.00	20250701_IS5
20	0.50	20250701_IS5
21	0.50	20250701_IS5
27	0.00	20250701_IS5
28	0.00	20250701_IS5
35	0.00	20250701_IS5
36	0.00	20250701_IS5
40	0.00	20250701_IS5
45	0.00	20250701_IS5
47	0.00	20250701_IS5
55	NaN	20250701_IS5
56	NaN	20250701_IS5
63	NaN	20250701_IS5
71	0.00	20250701_IS5
75	0.00	20250701_IS5
89	0.25	20250701_IS5
93	NaN	20250701_IS5
131	0.00	20250701_IS5
138	0.00	20250701_IS5
145	0.80	20250701_IS5
181	NaN	20250701_IS5
207	NaN	20250701_IS5
226	0.20	20250701_IS5
227	0.40	20250701_IS5
284	0.00	20250701_IS5

	Number of cells involved	category	Speed category
1	5-10	High speed	
8	3	High speed	
17	3	High speed	
19	4	High speed	
20	4	High speed	
21	4	High speed	

27	5-10	High speed
28	5-10	High speed
35	3	High speed
36	5-10	High speed
40	4	High speed
45	4	High speed
47	5-10	High speed
55	2	High speed
56	2	High speed
63	2	High speed
71	5-10	High speed
75	5-10	High speed
89	5-10	High speed
93	2	High speed
131	5-10	High speed
138	4	High speed
145	5-10	High speed
181	2	High speed
207	2	High speed
226	5-10	High speed
227	5-10	High speed
284	4	High speed

Speed category	High speed	Low speed
----------------	------------	-----------

Origin cell ID

210	0	1
216	0	2
222	1	1
230	0	1
246	0	3
...
1299	0	1
1302	0	1
1310	1	0
1312	0	1
1314	0	2

[199 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
5	210	22.75	13.33
10	216	117.65	15.60
16	222	464.10	18.85
22	230	82.23	22.10
31	246	108.23	28.60
..
805	1299	406.57	483.28
808	1302	246.68	484.90
812	1310	468.00	489.78

813	1312	21.12	490.10
814	1314	487.18	491.07

	Number of peaks	Is active	Occurrences in global events	\
5	7	True	6	
10	9	True	6	
16	11	True	6	
22	9	True	6	
31	7	True	6	
..	
805	7	True	6	
808	8	True	6	
812	7	True	6	
813	7	True	6	
814	7	True	4	

	Occurrences in global events as early peaker	Early peaker event IDs	\
5	0	[]	
10	1	[6]	
16	2	[5, 6]	
22	4	[2, 3, 4, 6]	
31	0	[]	
..	
805	1	[2]	
808	0	[]	
812	2	[2, 3]	
813	0	[]	
814	0	[]	

	Occurrences in sequential events	\
5	1	
10	1	
16	1	
22	1	
31	1	
..	...	
805	1	
808	1	
812	1	
813	1	
814	2	

	Occurrences in sequential events as origin	\
5	1	
10	0	
16	1	
22	1	
31	1	

..
 805 1
 808 1
 812 0
 813 1
 814 2

	Occurrences in individual events	Peak frequency (Hz)	Periodicity score	\
5	0	0.0041	0.78	
10	1	0.0053	0.71	
16	3	0.0065	0.61	
22	0	0.0053	0.64	
31	0	0.0041	0.78	
..
805	0	0.0041	0.77	
808	1	0.0047	0.66	
812	0	0.0041	0.76	
813	0	0.0041	0.76	
814	1	0.0041	0.65	

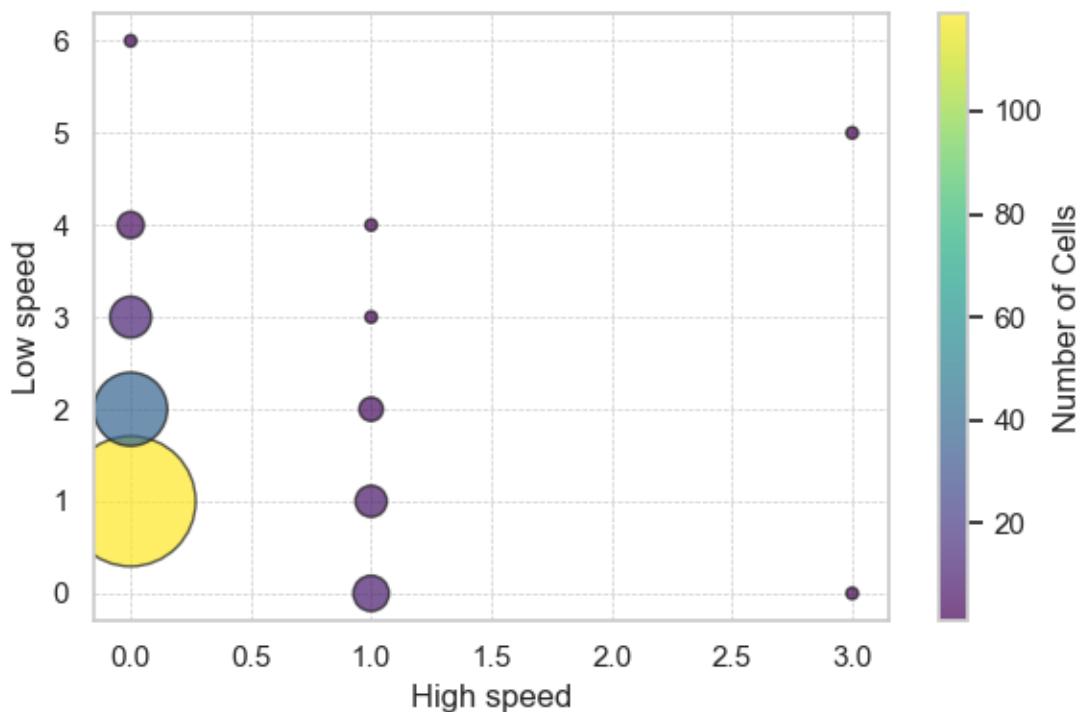
	Neighbor count	Neighbors (labels)	dataset	\
5	4	[212, 218, 240, 245]	20250701_IS5	
10	5	[207, 208, 241, 246, 252]	20250701_IS5	
16	2	[243, 248]	20250701_IS5	
22	4	[207, 234, 251, 264]	20250701_IS5	
31	5	[207, 216, 251, 252, 279]	20250701_IS5	
..
805	3	[1262, 1298, 1306]	20250701_IS5	
808	3	[1271, 1279, 1305]	20250701_IS5	
812	4	[1281, 1283, 1301, 1314]	20250701_IS5	
813	2	[1272, 1295]	20250701_IS5	
814	2	[1283, 1310]	20250701_IS5	

	Involved in sequential event	Occurrences in sequential events category	\
5	Involved in sequential event	1-2	
10	Involved in sequential event	1-2	
16	Involved in sequential event	1-2	
22	Involved in sequential event	1-2	
31	Involved in sequential event	1-2	
..
805	Involved in sequential event	1-2	
808	Involved in sequential event	1-2	
812	Involved in sequential event	1-2	
813	Involved in sequential event	1-2	
814	Involved in sequential event	1-2	

	High speed	Low speed	
5	0.0	1.0	

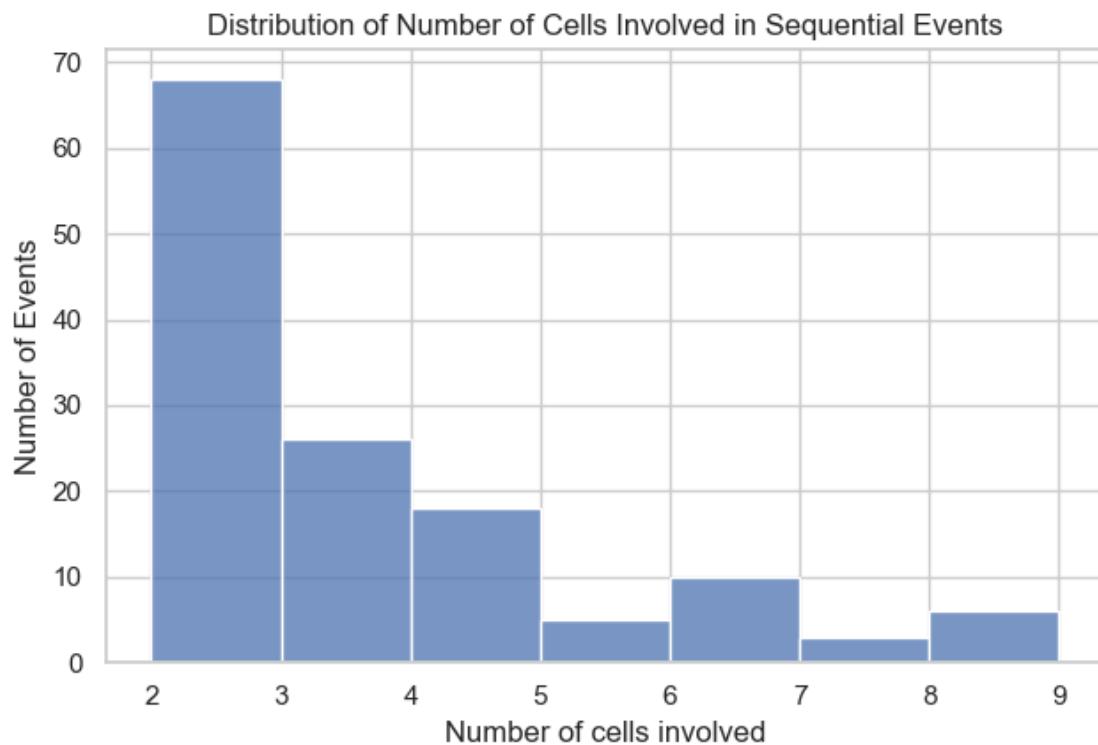
10	0.0	2.0
16	1.0	1.0
22	0.0	1.0
31	0.0	3.0
..
805	0.0	1.0
808	0.0	1.0
812	1.0	0.0
813	0.0	1.0
814	0.0	2.0

[199 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

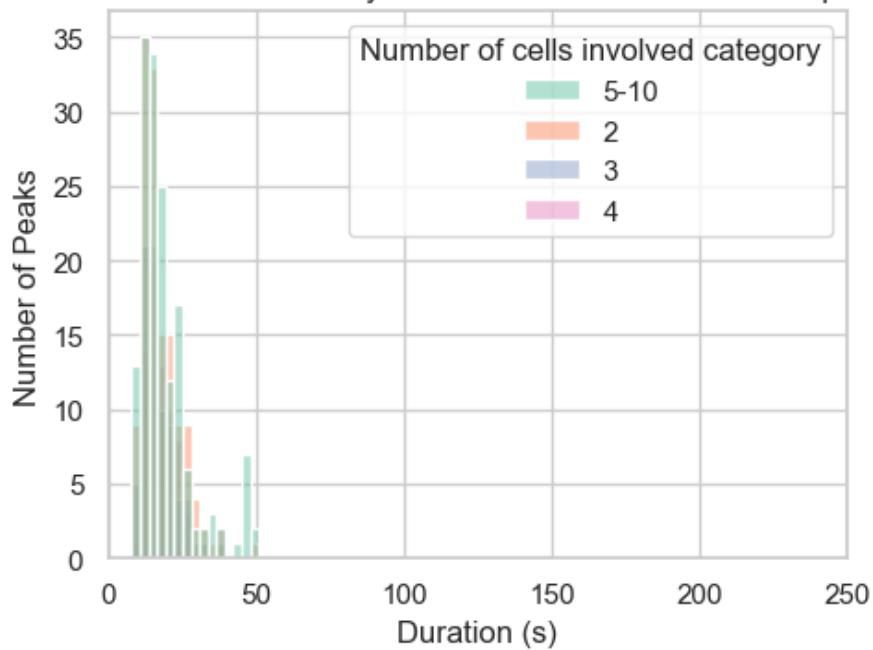
[2025-08-27 15:16:21] [INFO] calcium: plot_histogram: removed 0 outliers out of 136 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

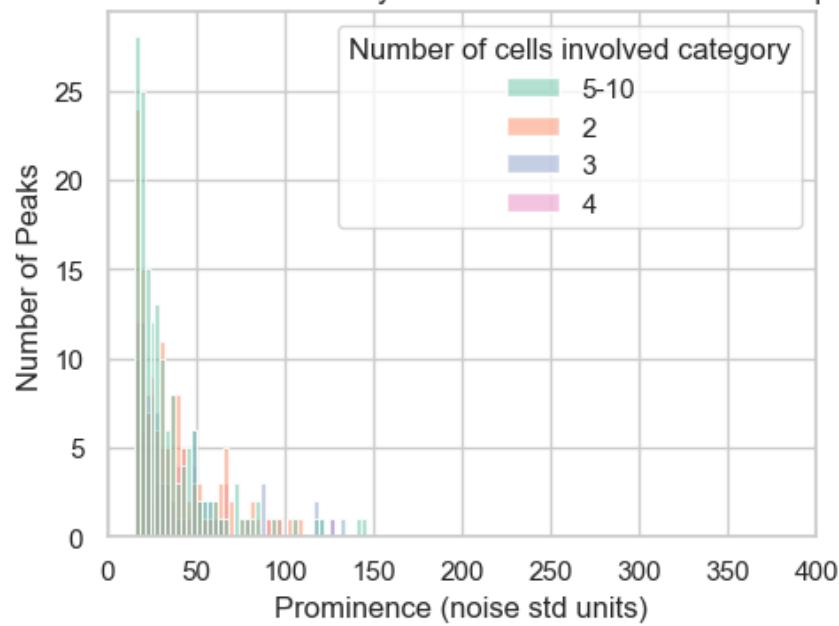
```
[2025-08-27 15:16:21] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 448 on 'Duration (s)' (lower=-0.5, upper=53.5)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

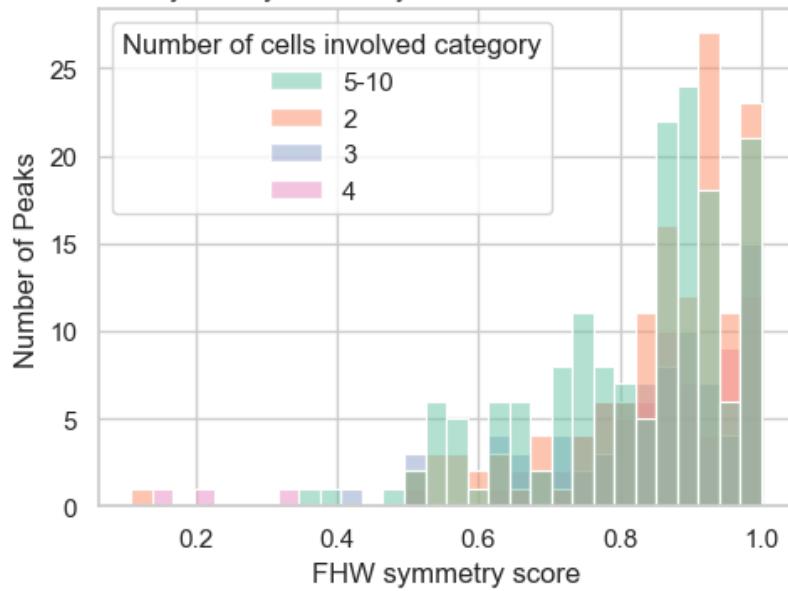


[2025-08-27 15:16:22] [INFO] calcium: plot_histogram_by_group: removed 16 outliers out of 448 on 'Prominence (noise std units)' (lower=-22.487, upper=146.26)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

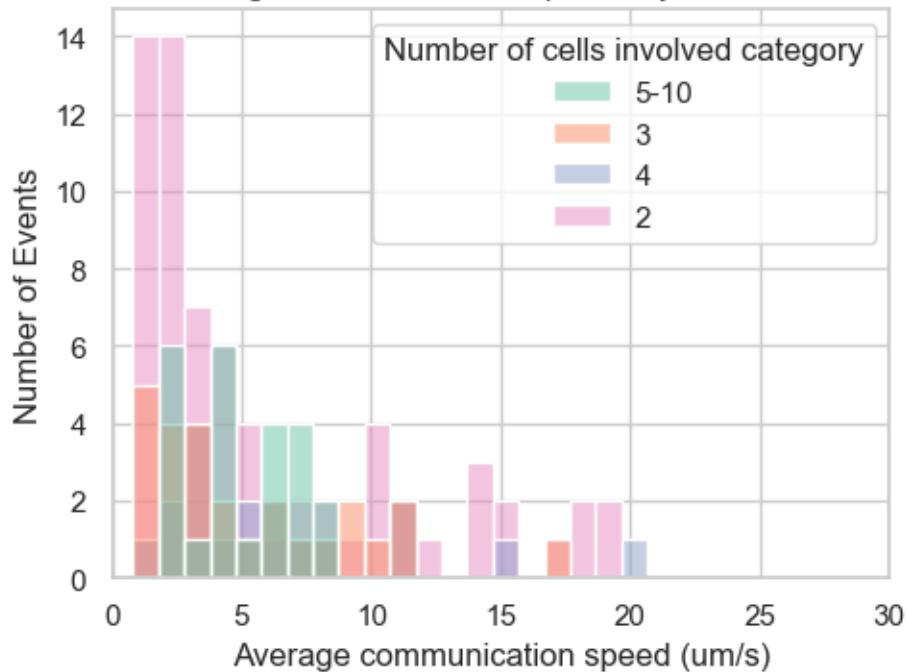


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



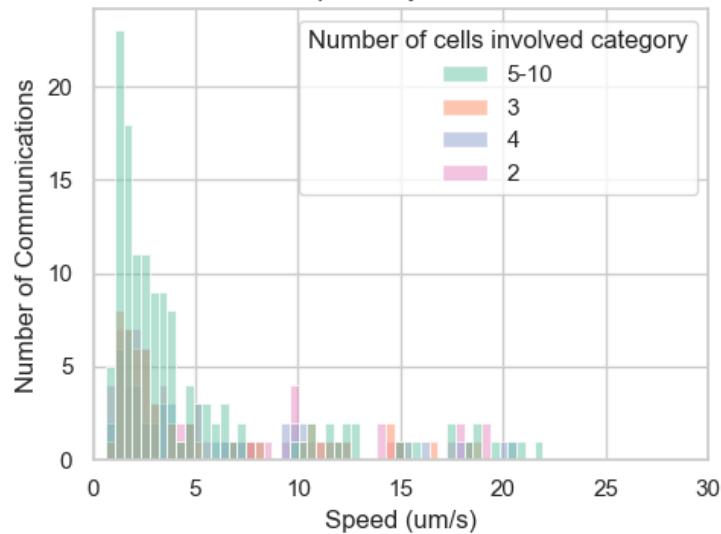
```
[2025-08-27 15:16:22] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 136 on 'Average communication speed (um/s)' (lower=-13.89, upper=23.77)
```

Distribution of Average Communication Speeds by Number of Cells Involved



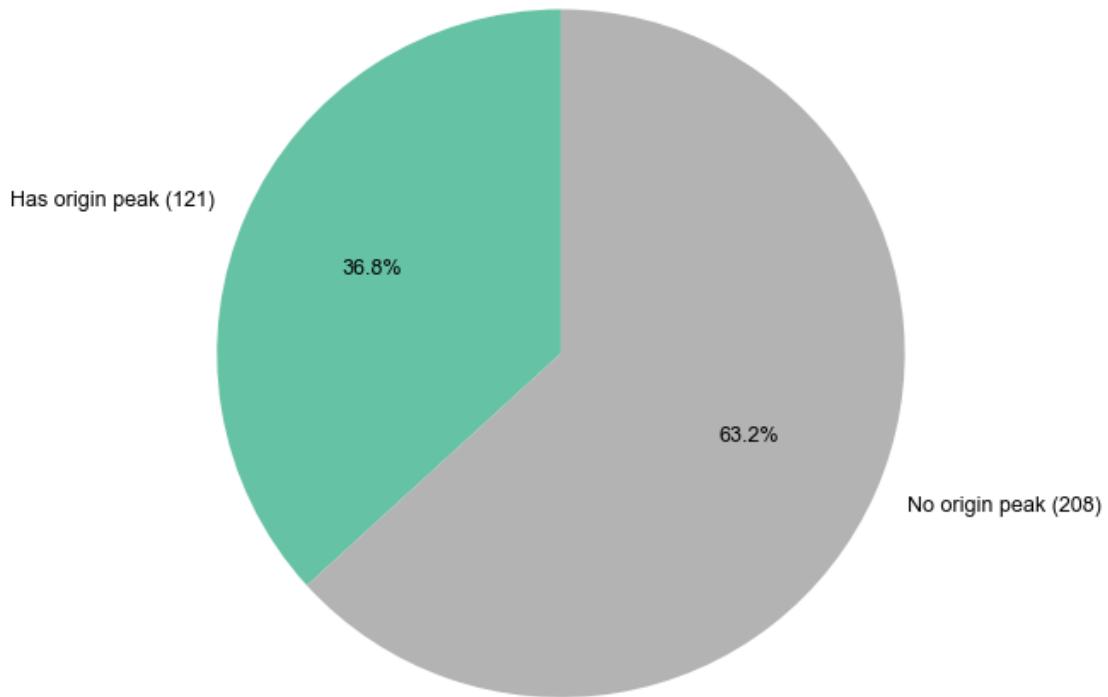
[2025-08-27 15:16:22] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 312 on 'Speed (um/s)' (lower=-15.378, upper=24.54)

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events

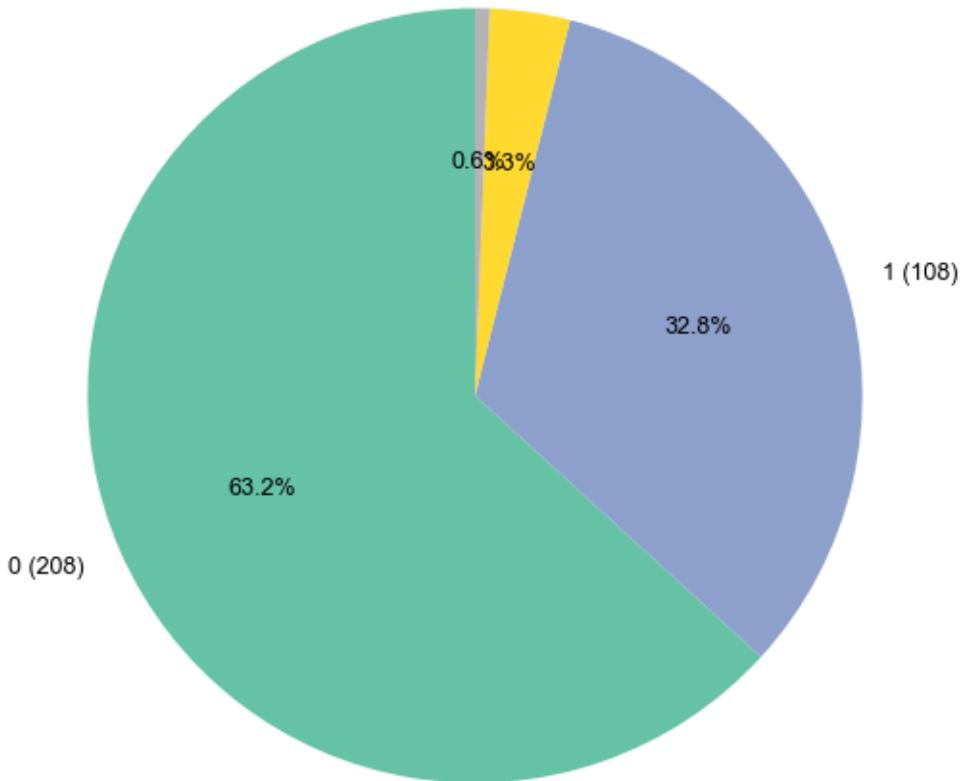


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

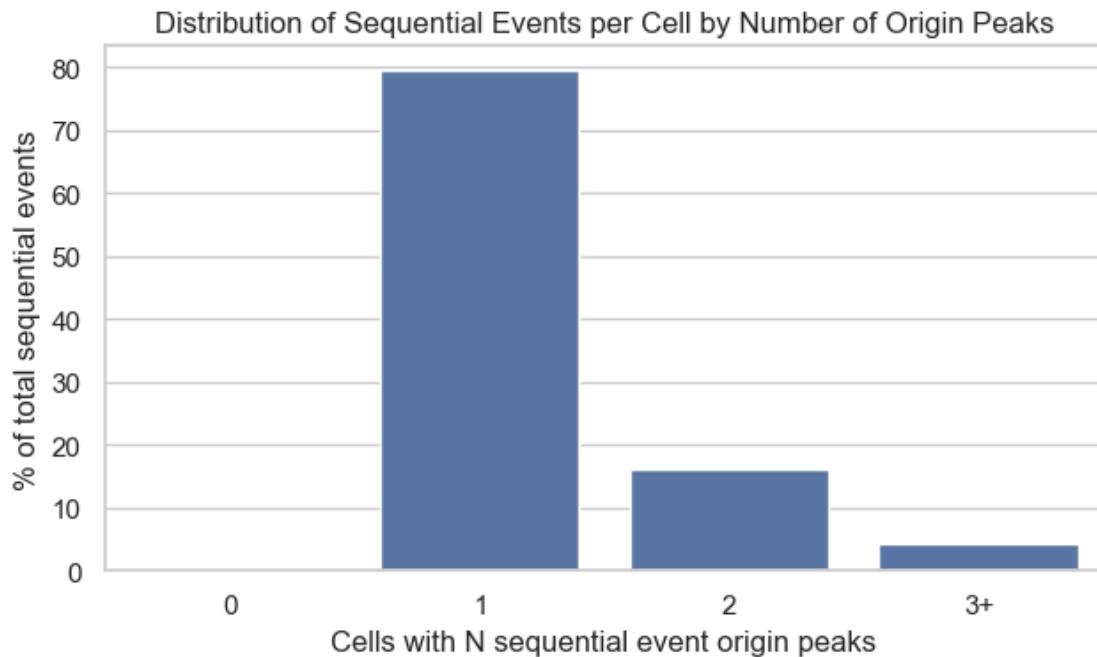


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (2) (11)



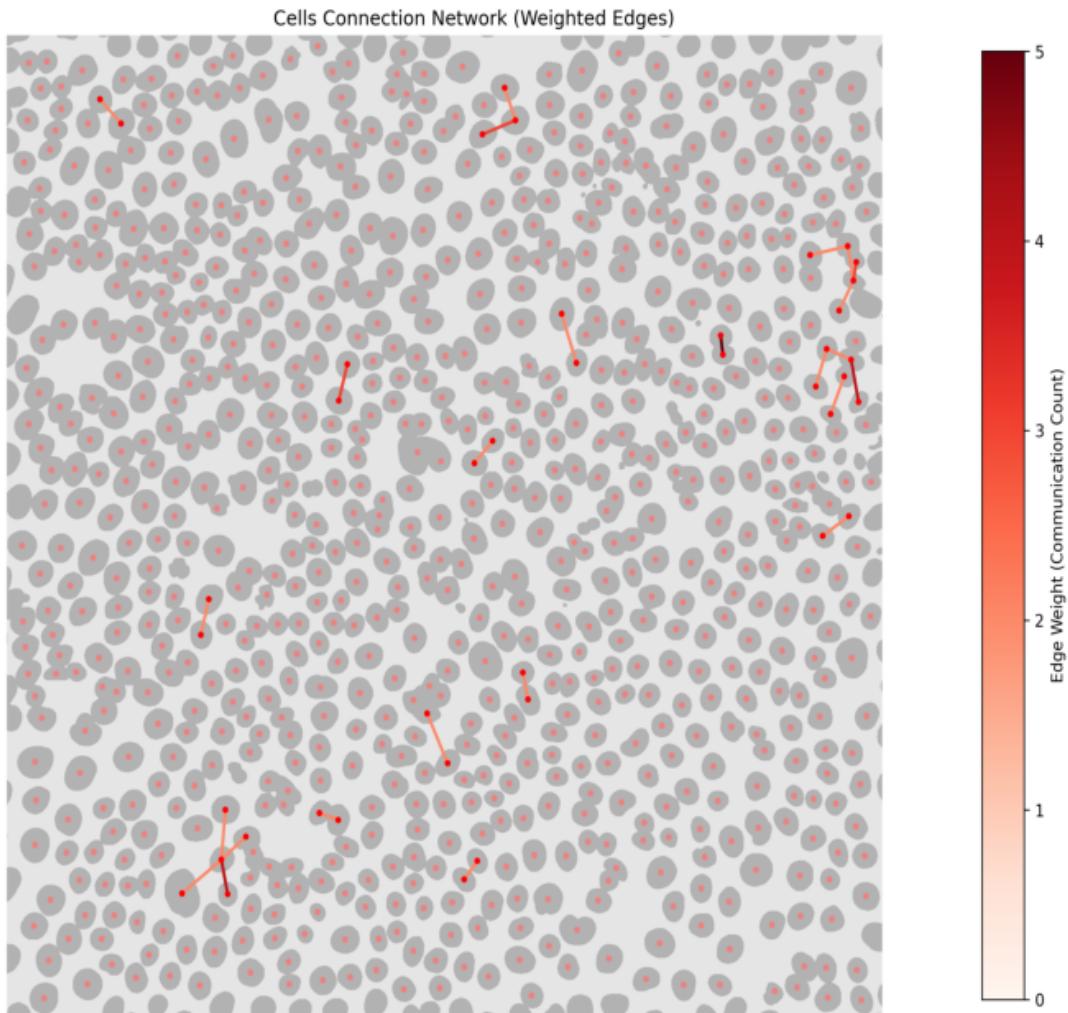
```
[2025-08-27 15:16:23] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250701\\Output\\IS5\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
```

```
packages\PIL\ImageFile.py", line 132, in __init__  
    self.fp = open(fp, "rb")  
FileNotFoundException: [Errno 2] No such file or directory:  
'D:\\Mateo\\20250701\\Output\\IS5\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```



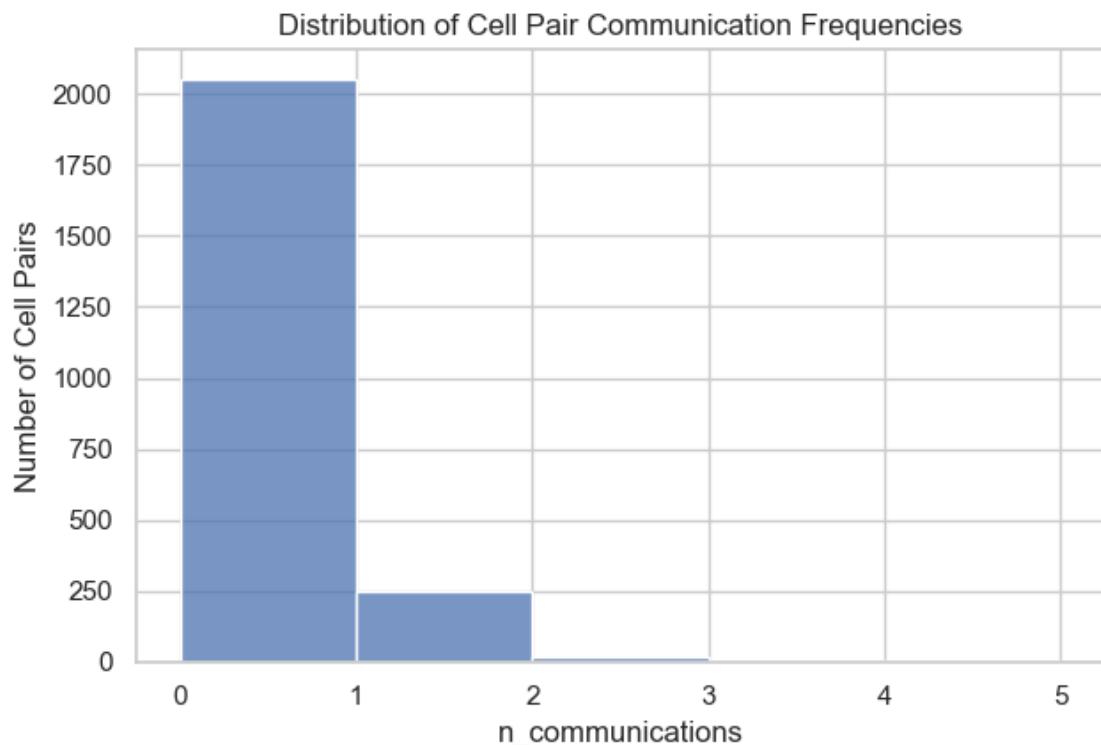
1.3.8 Connection network between cells

Cell Connection Network Graph



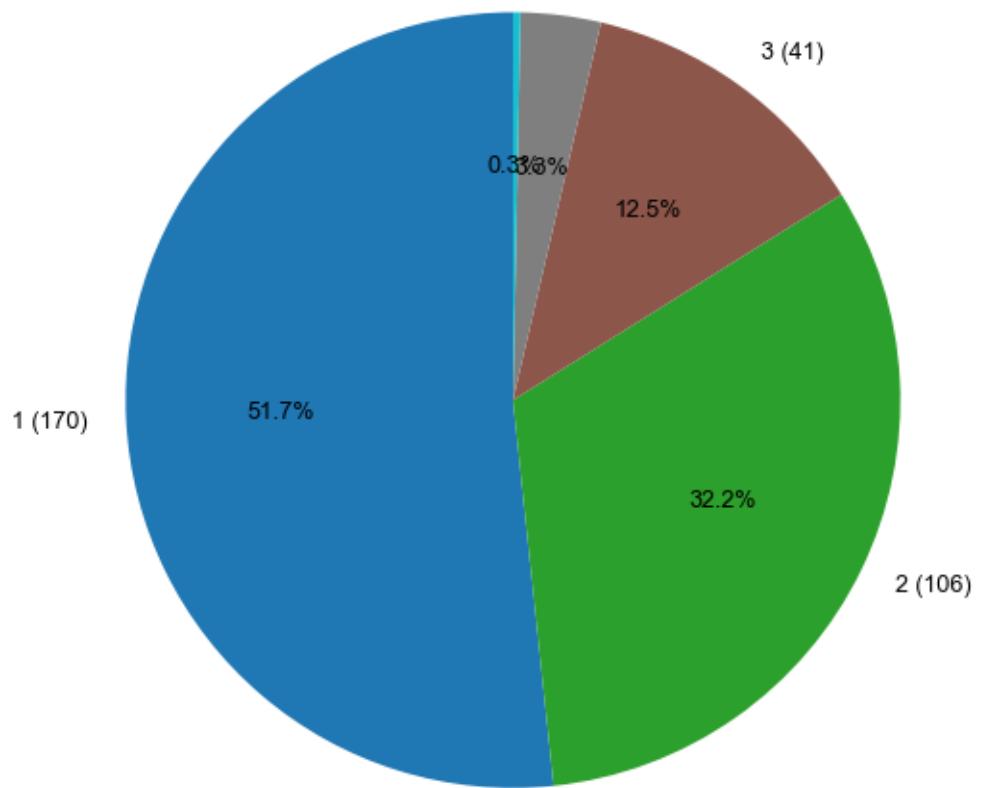
1.3.9 Pair/Trios with high communication networks

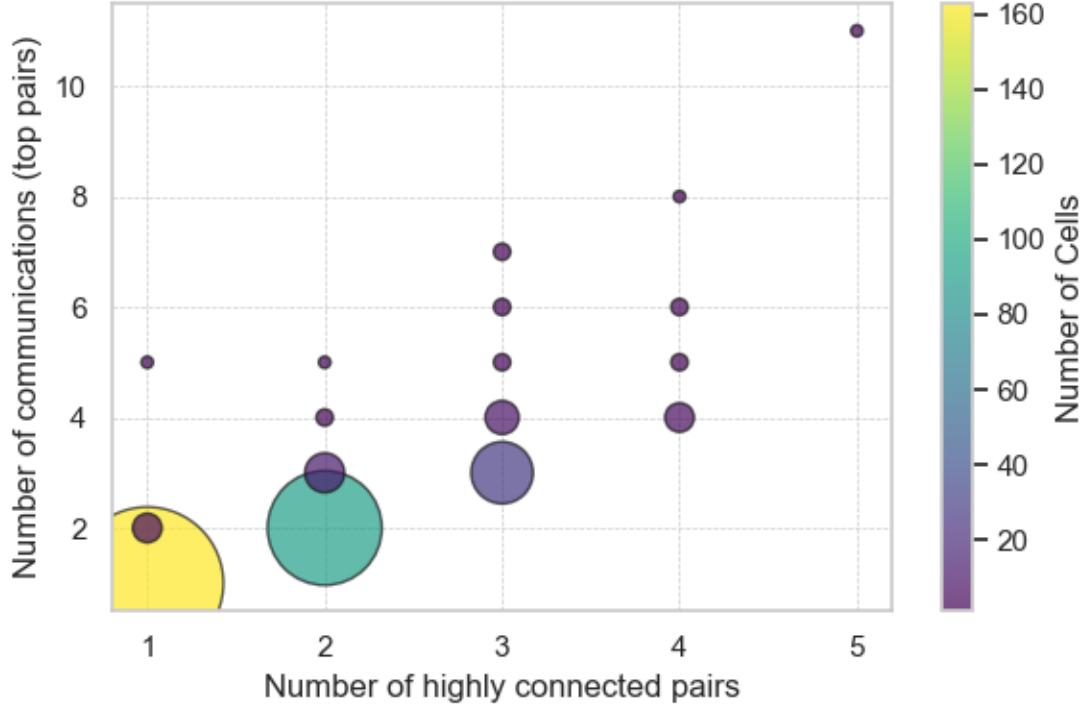
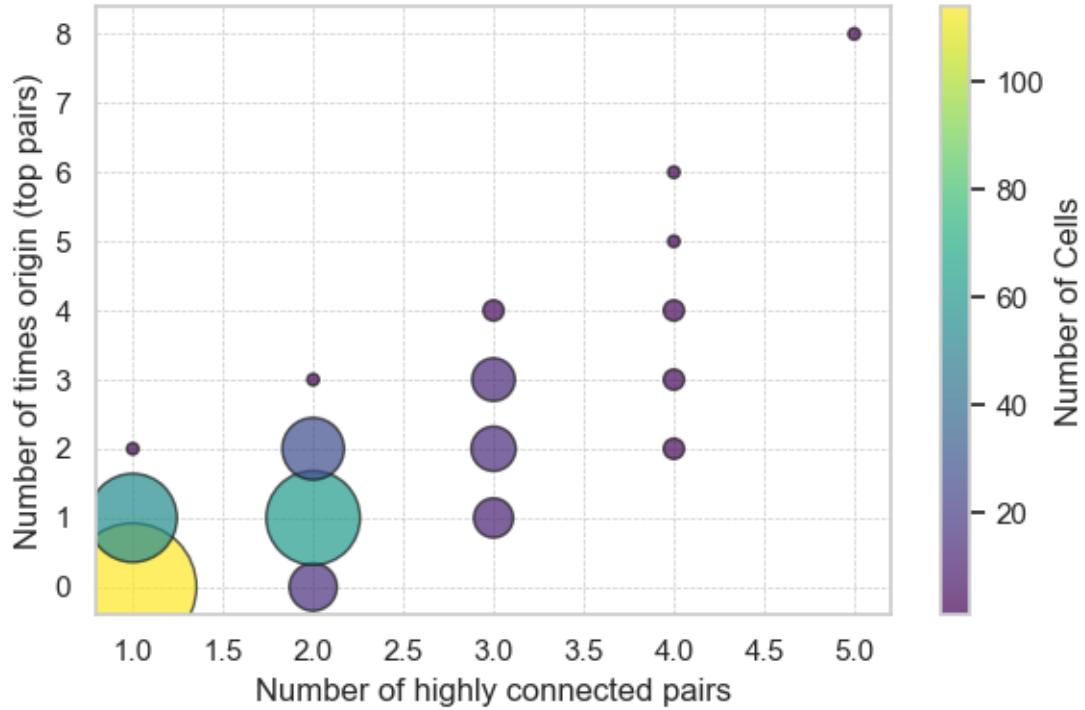
```
[2025-08-27 15:16:25] [INFO] calcium: build_neighbor_pair_stats: built 2328 pairs across 1 datasets (mean distance=18.85 um)
```

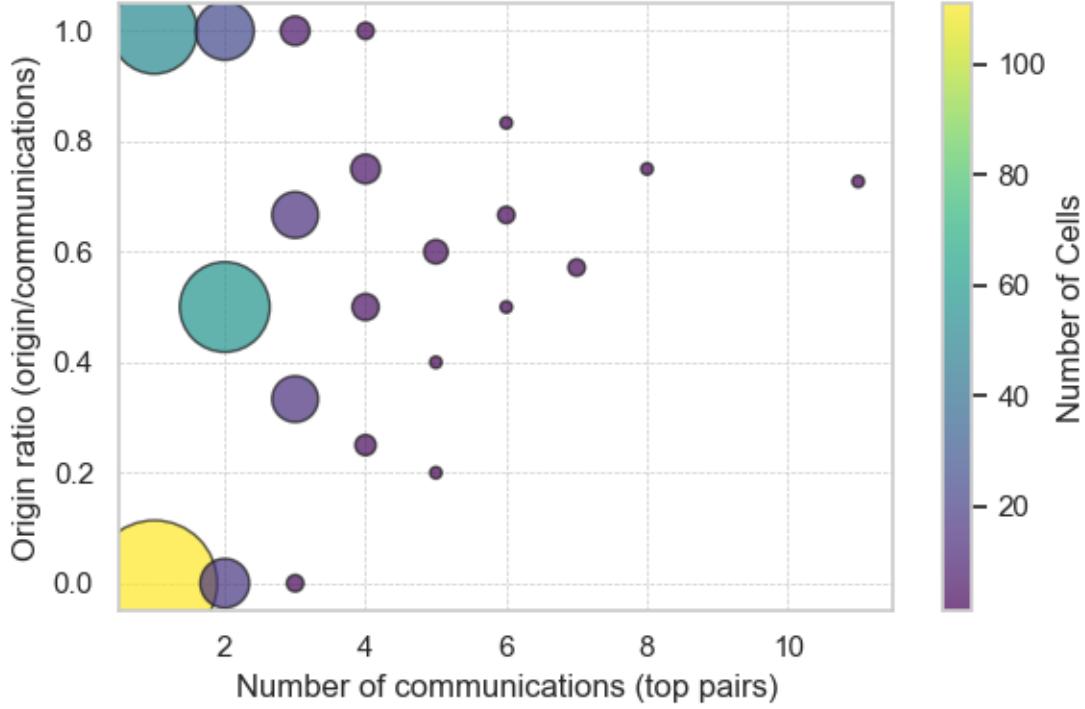
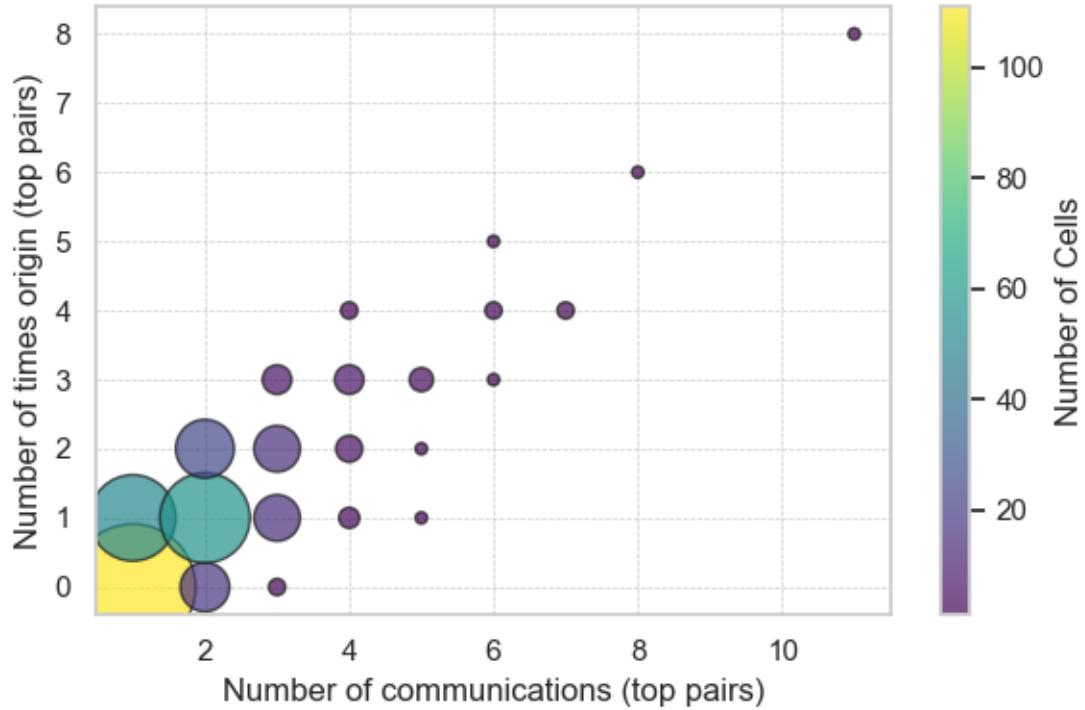


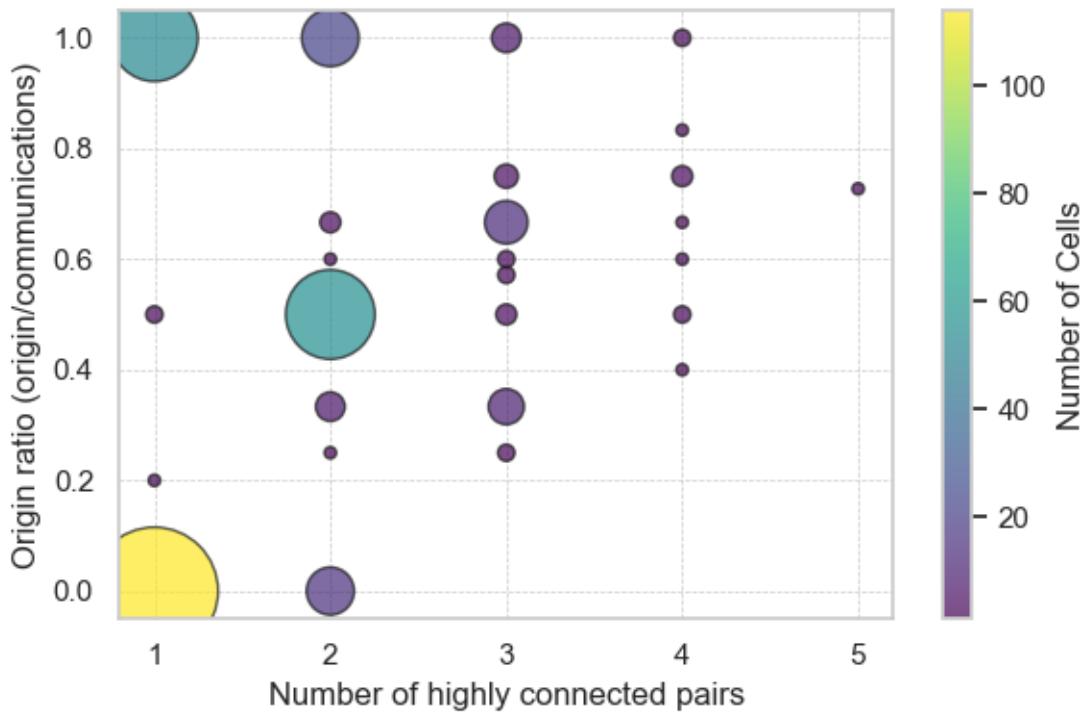
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









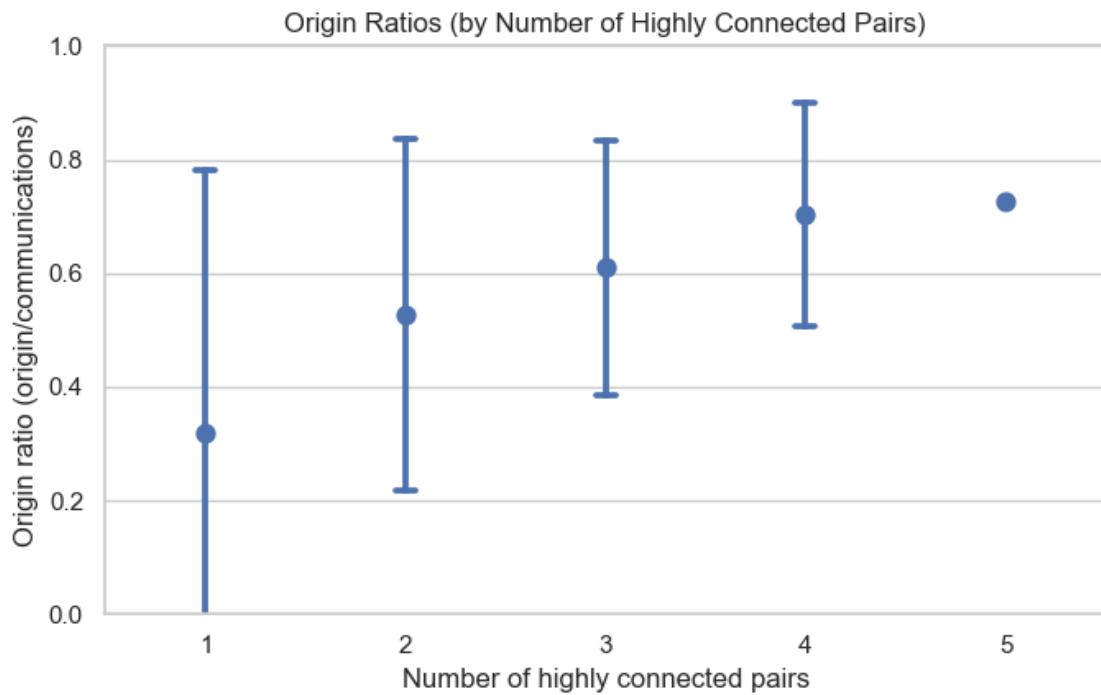
[2025-08-27 15:16:25] [INFO] calcium: plot_points_mean_std: N=170 for Number of highly connected pairs=1

[2025-08-27 15:16:25] [INFO] calcium: plot_points_mean_std: N=106 for Number of highly connected pairs=2

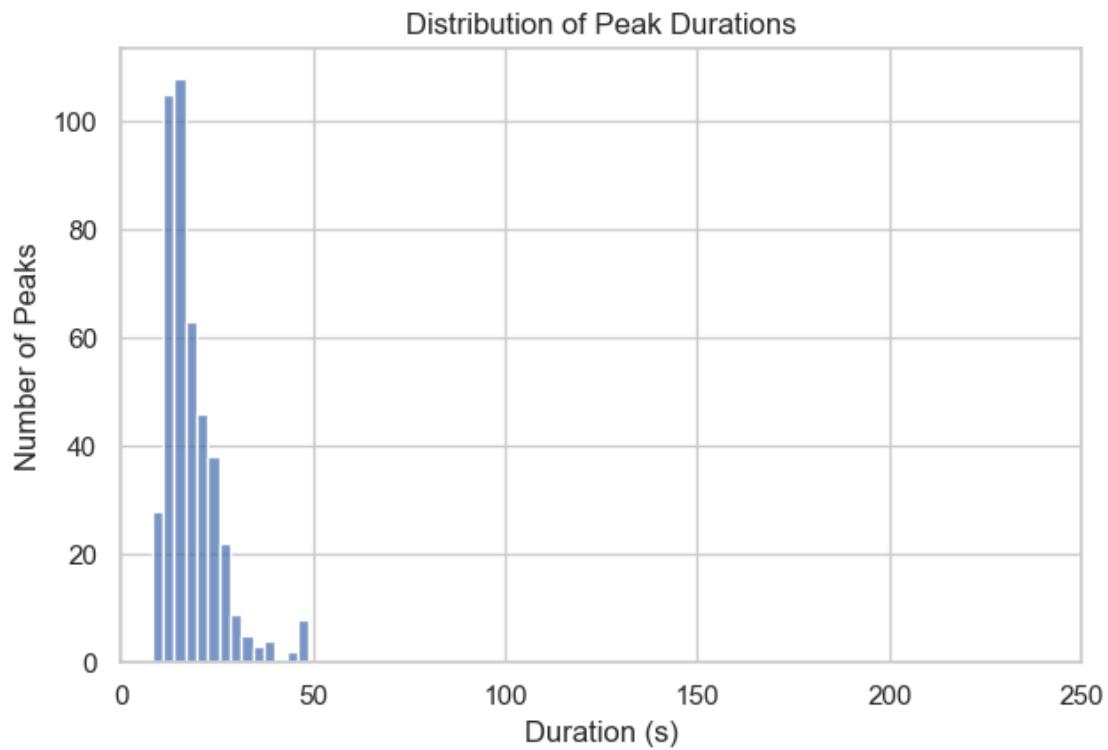
[2025-08-27 15:16:25] [INFO] calcium: plot_points_mean_std: N=41 for Number of highly connected pairs=3

[2025-08-27 15:16:25] [INFO] calcium: plot_points_mean_std: N=11 for Number of highly connected pairs=4

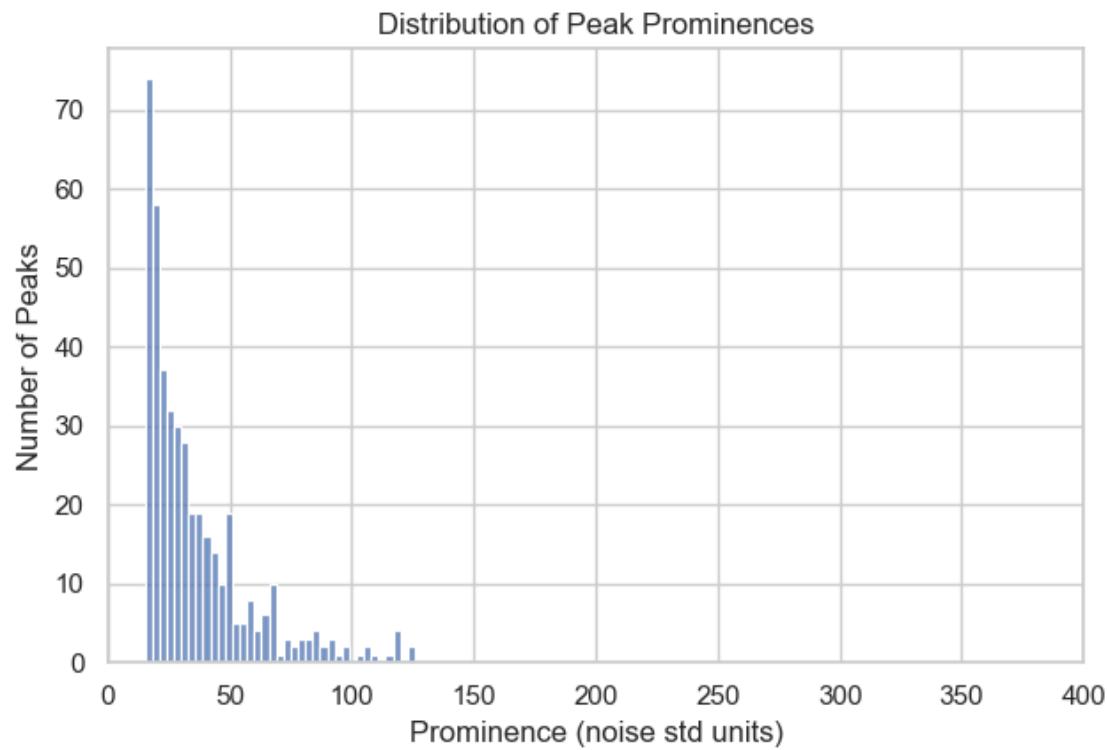
[2025-08-27 15:16:25] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=5

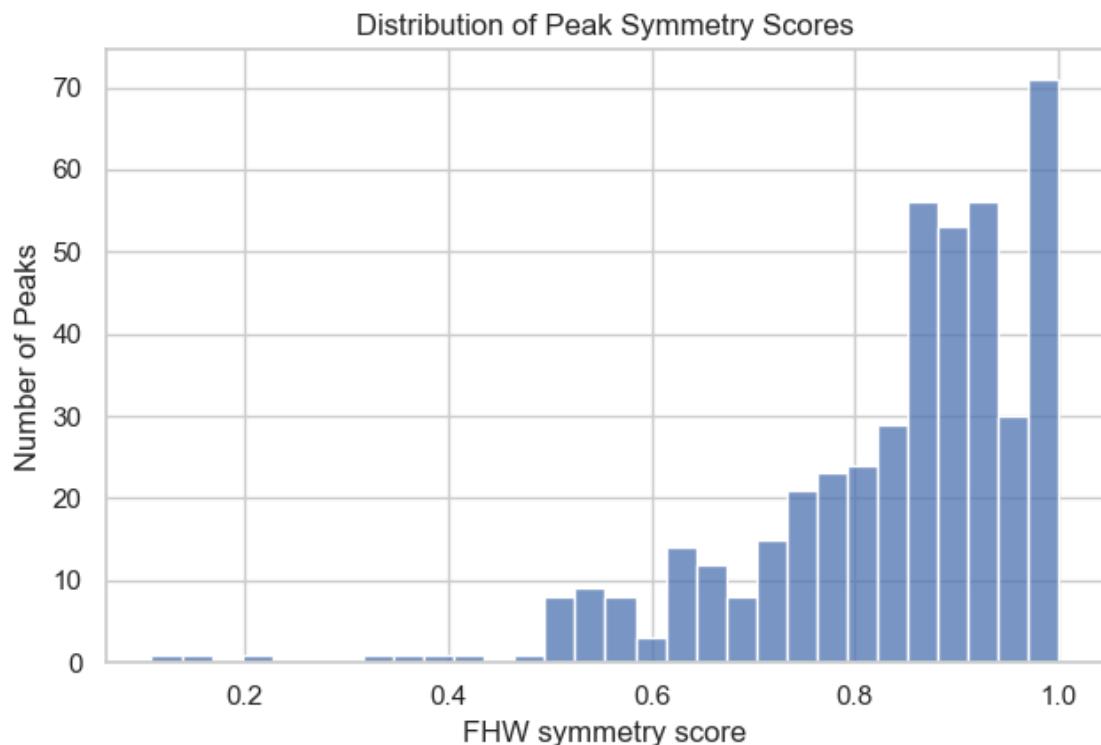


```
[2025-08-27 15:16:26] [INFO] calcium: plot_histogram: removed 7 outliers out of 448 on 'Duration (s)' (lower=-14, upper=49)
```

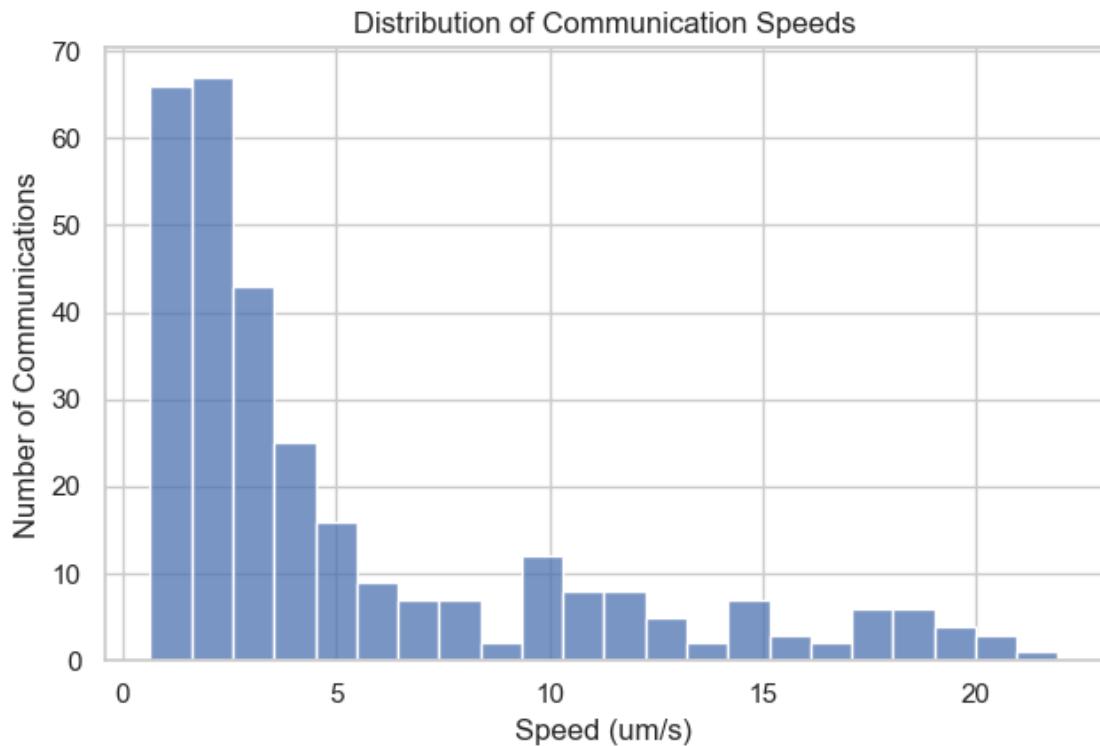


[2025-08-27 15:16:26] [INFO] calcium: plot_histogram: removed 19 outliers out of 448 on 'Prominence (noise std units)' (lower=-64.675, upper=132.2)

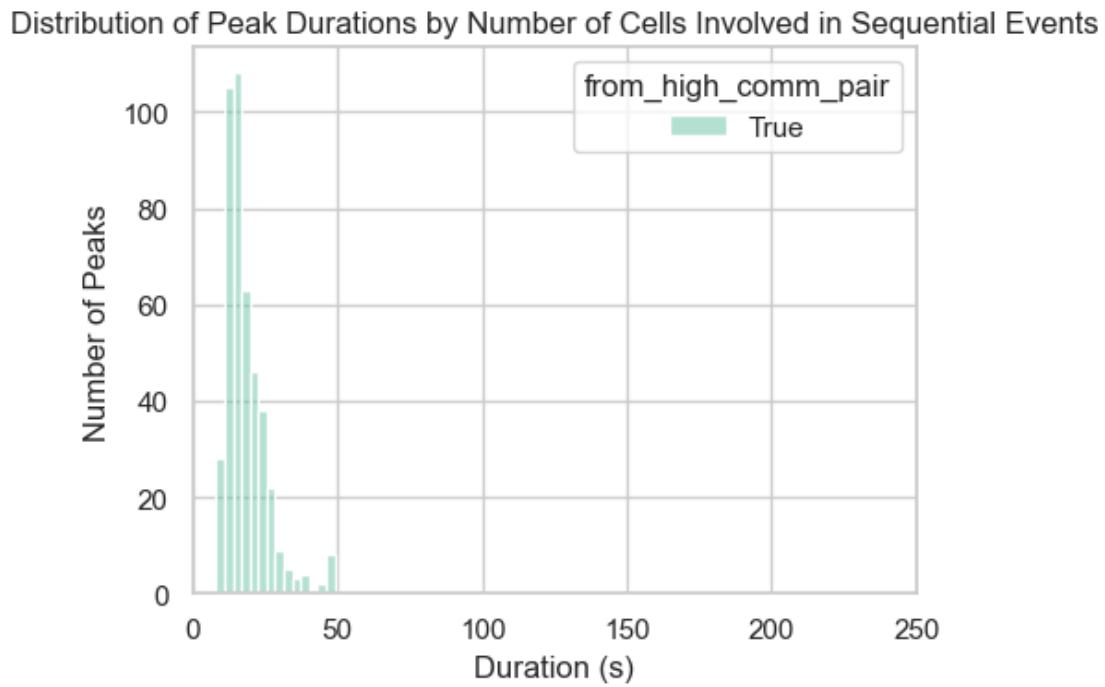




```
[2025-08-27 15:16:26] [INFO] calcium: plot_histogram: removed 3 outliers out of 312 on 'Speed (um/s)' (lower=-15.378, upper=24.54)
```

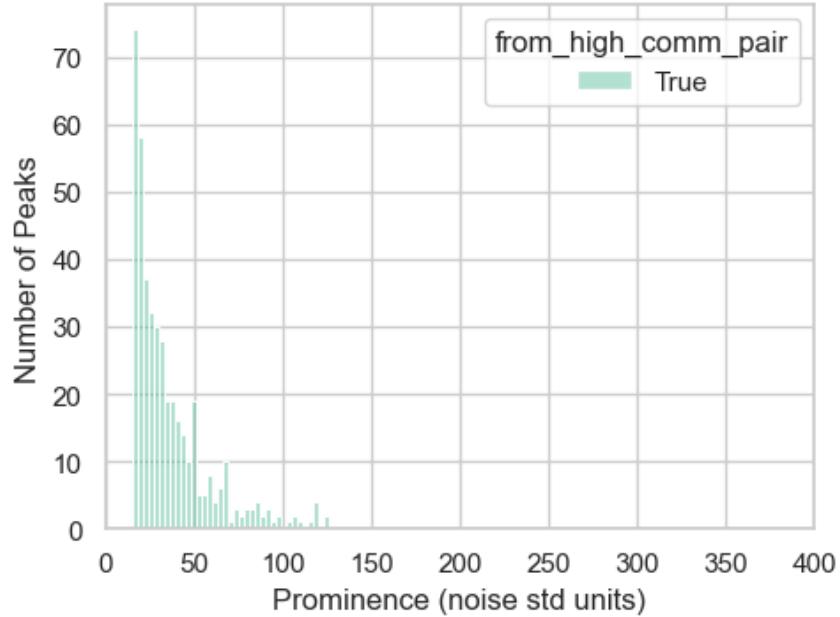


```
[2025-08-27 15:16:26] [INFO] calcium: plot_histogram_by_group: removed 7 outliers out of 448 on 'Duration (s)' (lower=-14, upper=49)
```

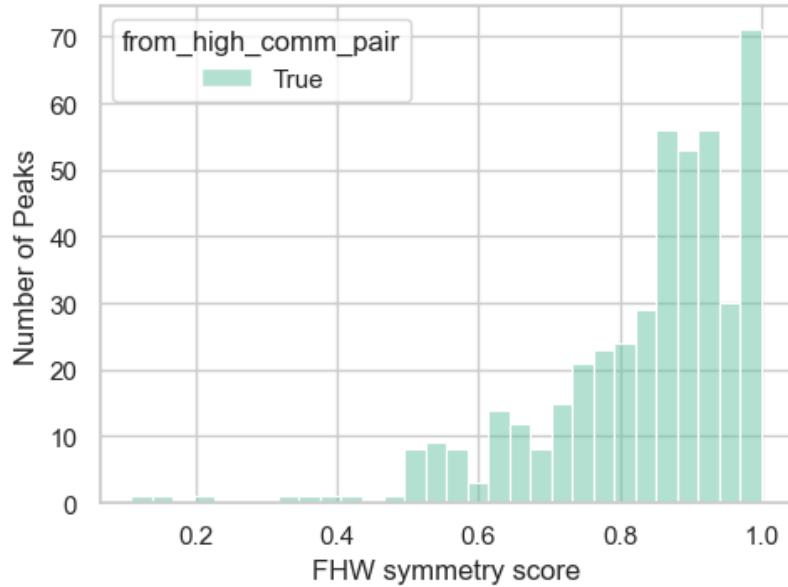


```
[2025-08-27 15:16:26] [INFO] calcium: plot_histogram_by_group: removed 19 outliers out of 448 on 'Prominence (noise std units)' (lower=-64.675, upper=132.2)
```

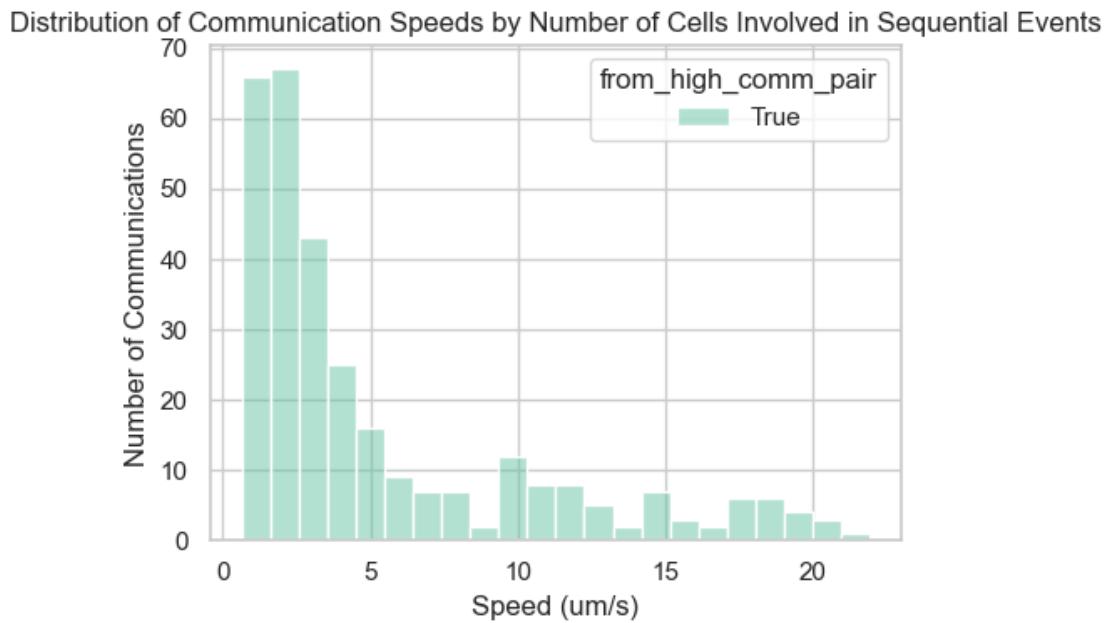
Distribution of Peak Prominences by Number of Cells Involved in Sequential Events



Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



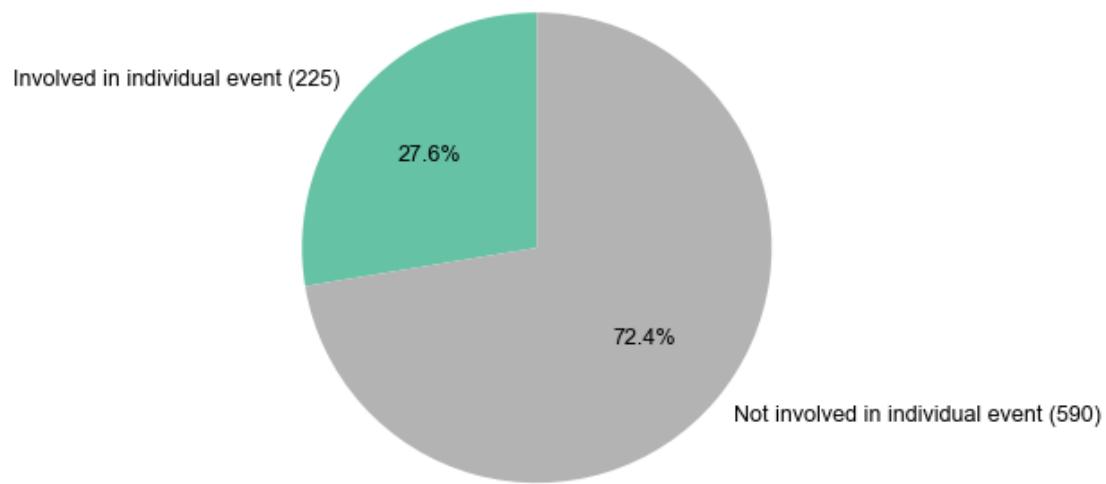
[2025-08-27 15:16:26] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 312 on 'Speed (um/s)' (lower=-15.378, upper=24.54)

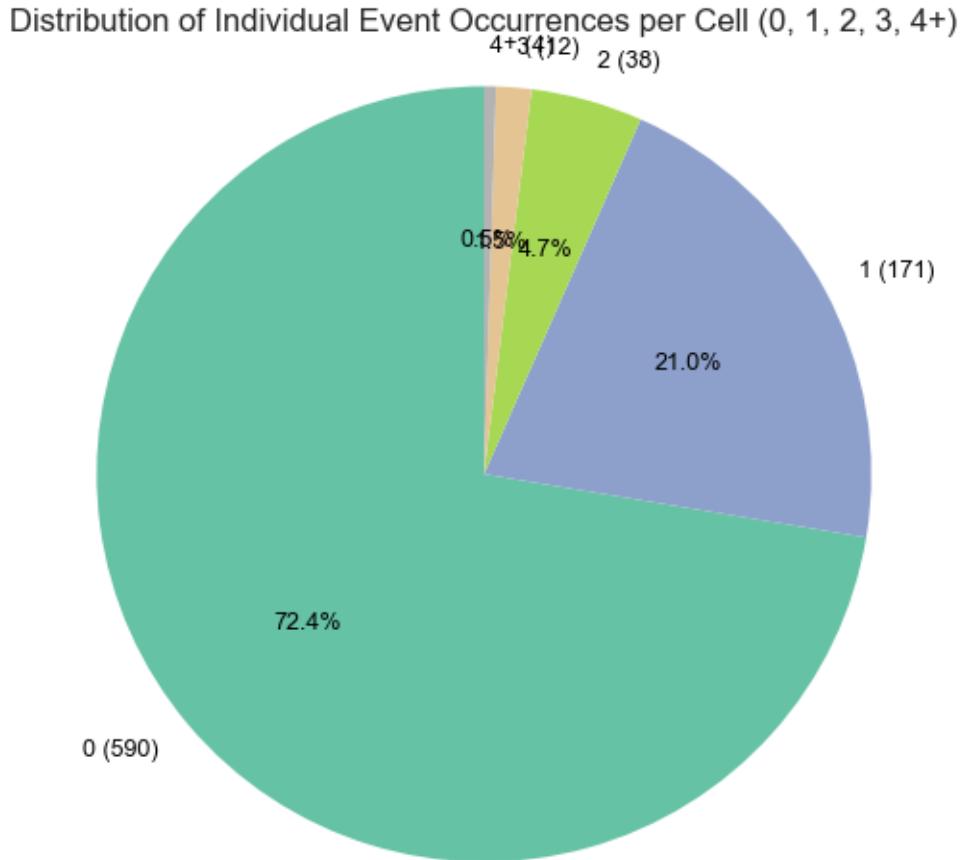


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



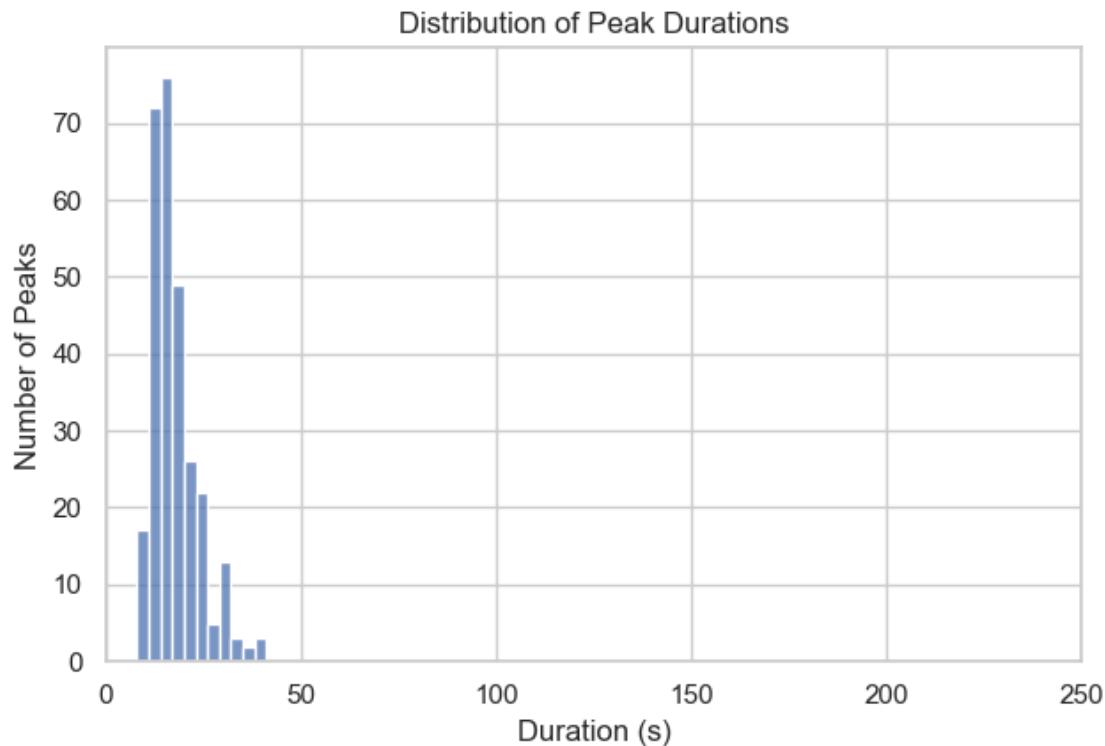


```
[2025-08-27 15:16:27] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS5\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\\\20250701\\\\Output\\\\IS5\\\\cell-
mapping\\\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250701\\Output\\IS5\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

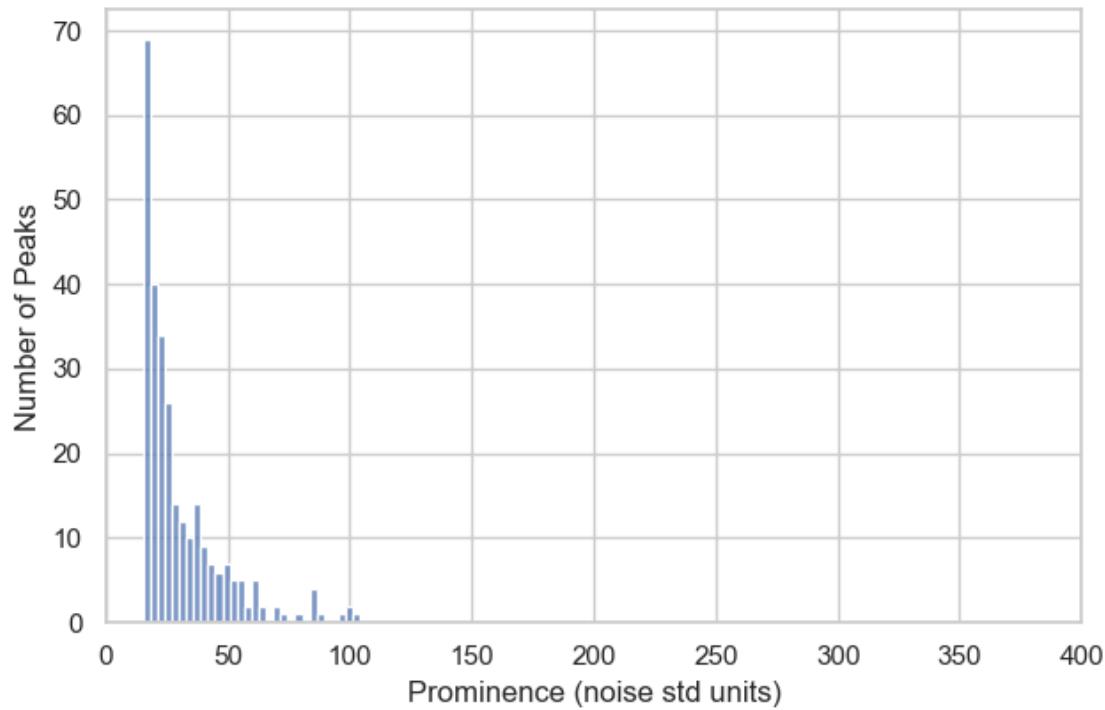
1.4.2 Peaks statistics in individual events

[2025-08-27 15:16:27] [INFO] calcium: plot_histogram: removed 12 outliers out of 300 on 'Duration (s)' (lower=-8, upper=41)

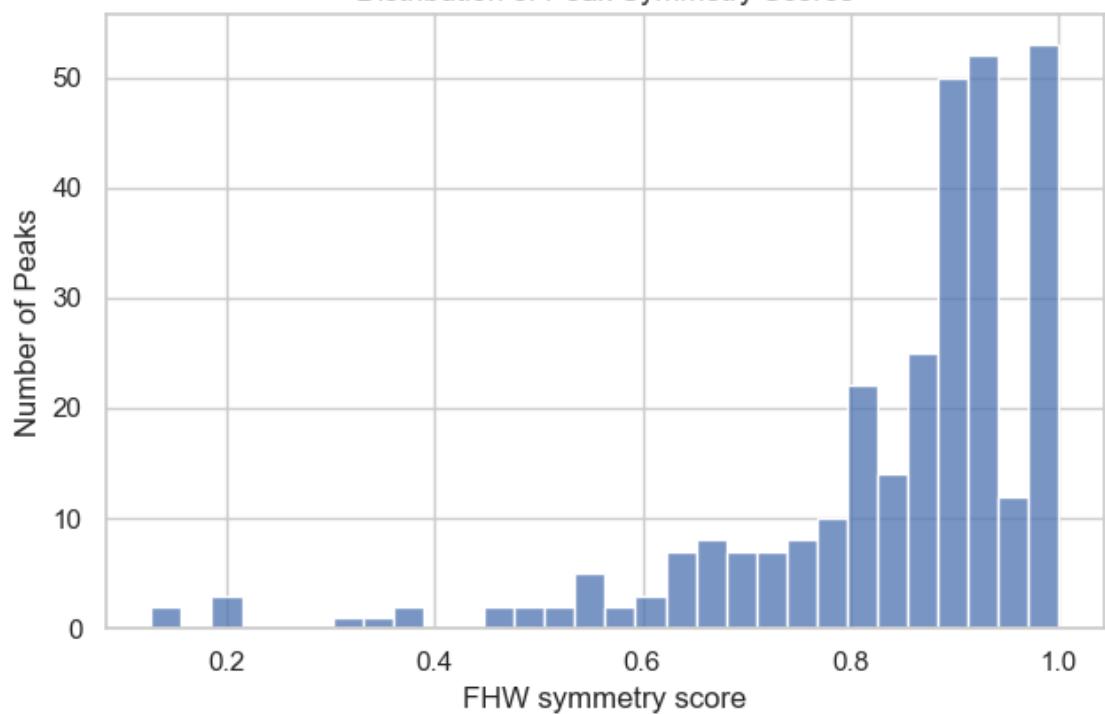


[2025-08-27 15:16:27] [INFO] calcium: plot_histogram: removed 20 outliers out of 300 on 'Prominence (noise std units)' (lower=-47.15, upper=106.15)

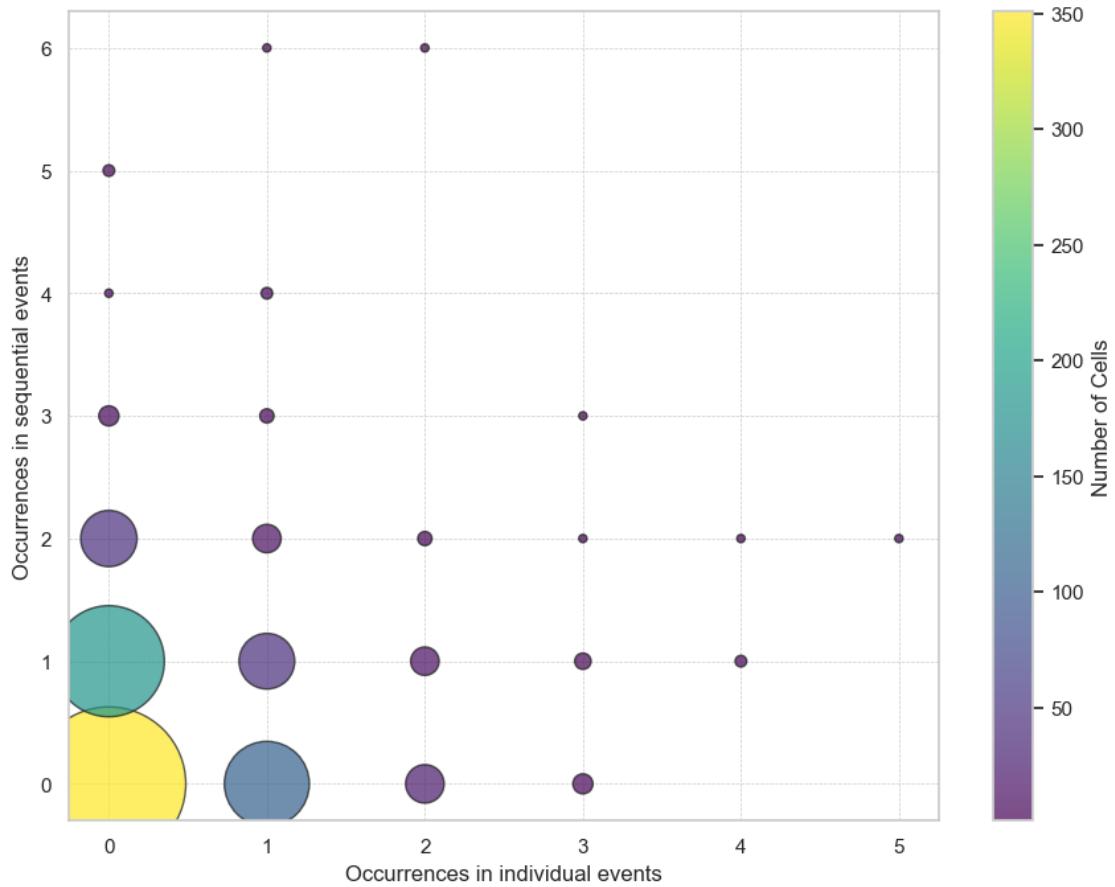
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

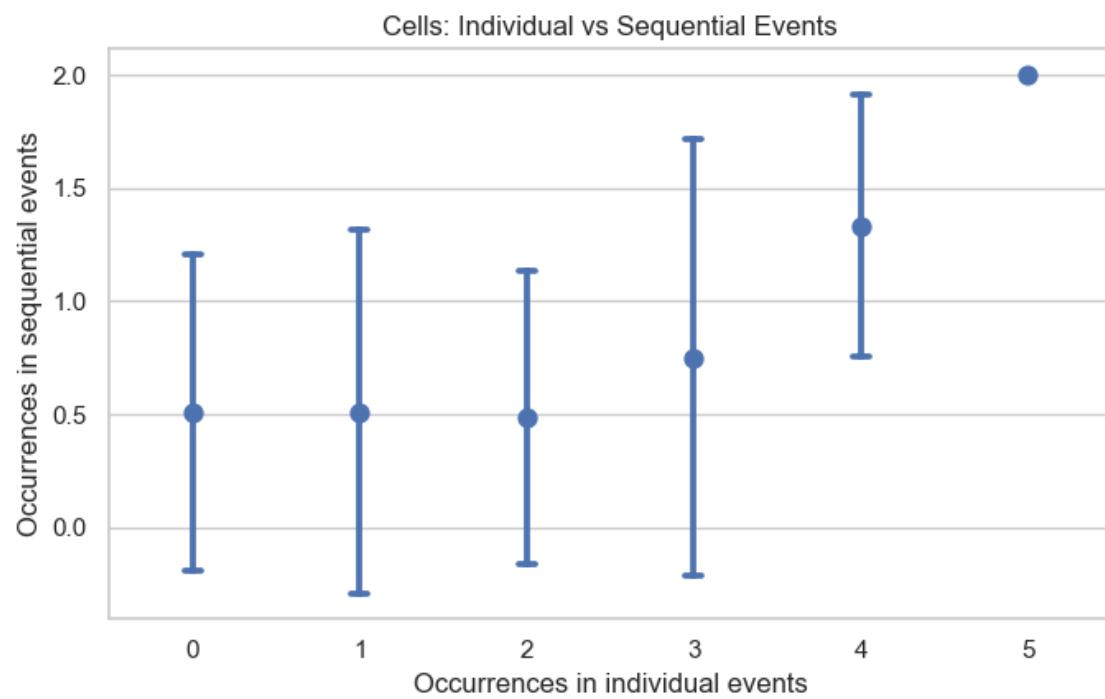


1.4.3 Correlation between event activity level & individual activity level

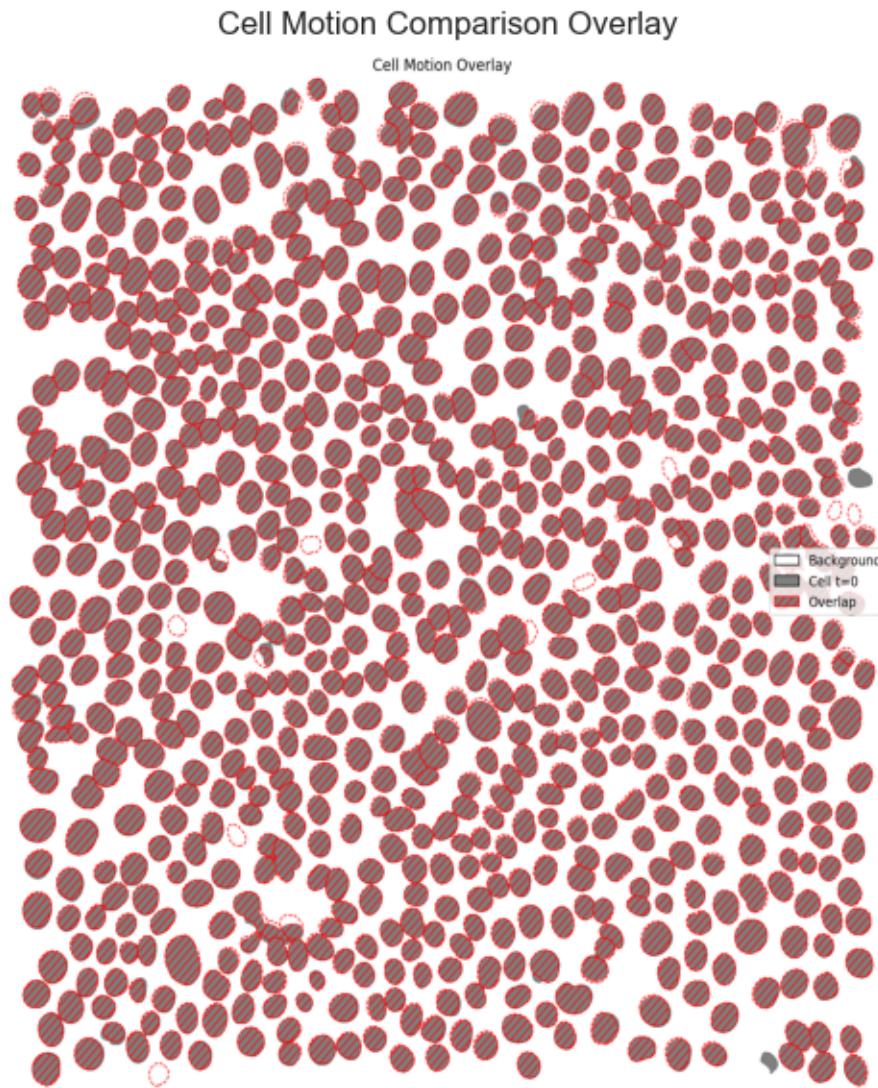


```
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: removed 4/815 outliers on 'Occurrences in sequential events' (lower=-3, upper=4)
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=588 for Occurrences in individual events=0
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=170 for Occurrences in individual events=1
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=37 for Occurrences in individual events=2
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=12 for Occurrences in individual events=3
[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=3 for Occurrences in individual events=4
```

[2025-08-27 15:16:28] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=5



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 815
- Hoechst image taken at t=1801: 814
- Number of cells difference: absolute 1, relative 0.12%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1093317
- Pixels segmented as cell at t=1801: 1056837
- Overlapping pixels between t=0 and t=1801: 1007903 (93.75% of total)
- Pixels exclusive to t=0: 85414 (7.81% of total)
- Pixels exclusive to t=1801: 48934 (4.63% of total)

executed

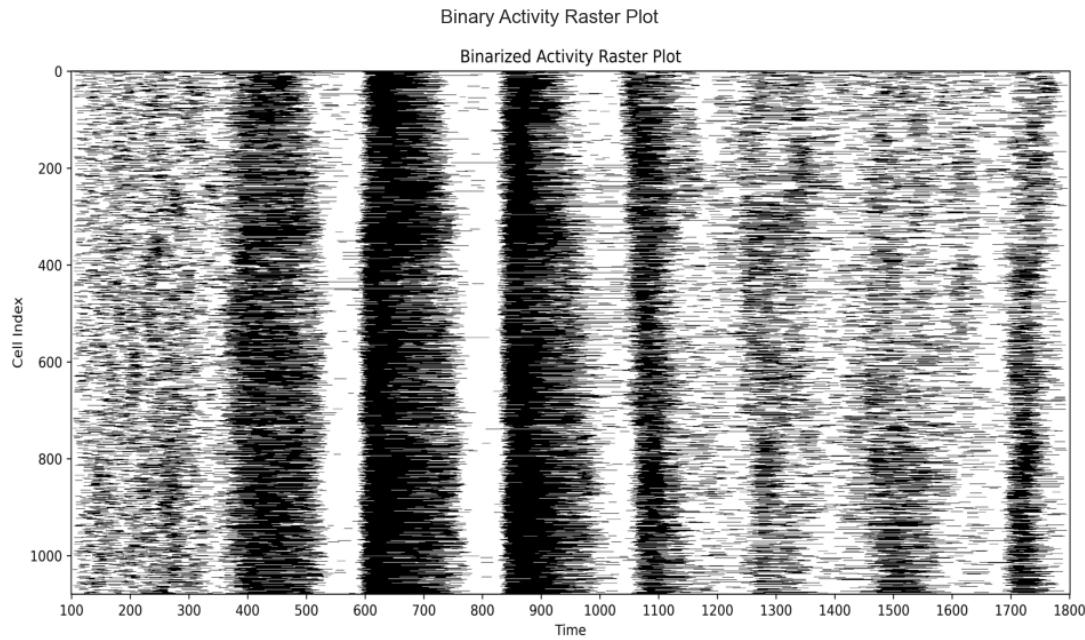
August 27, 2025

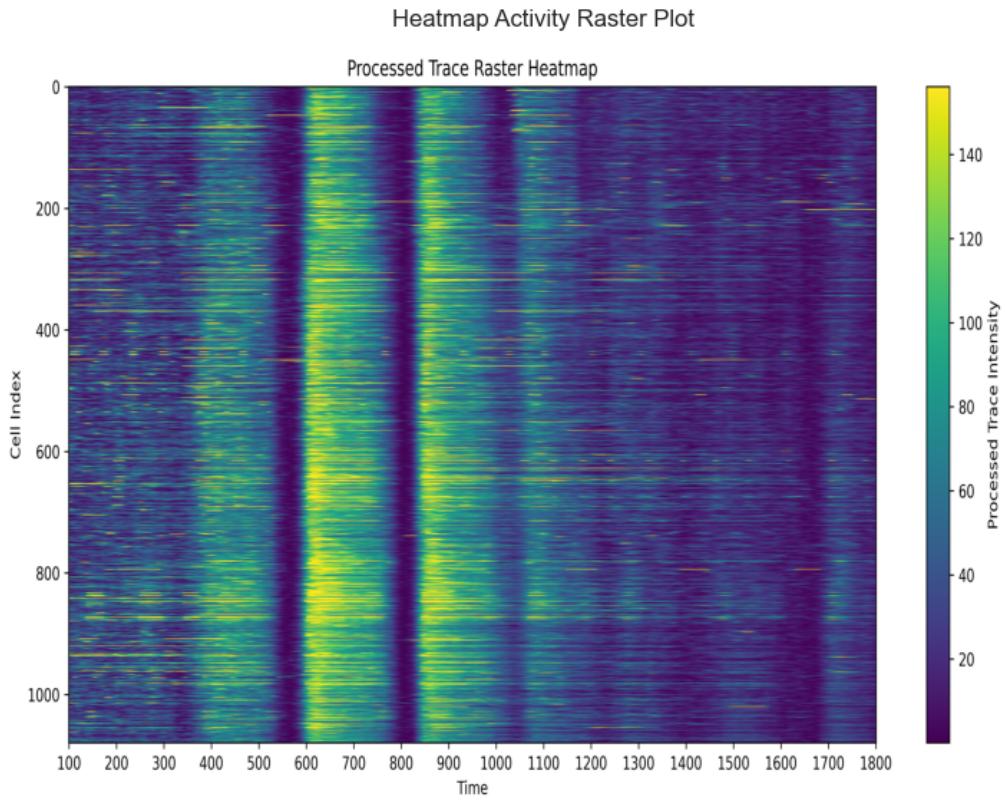
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





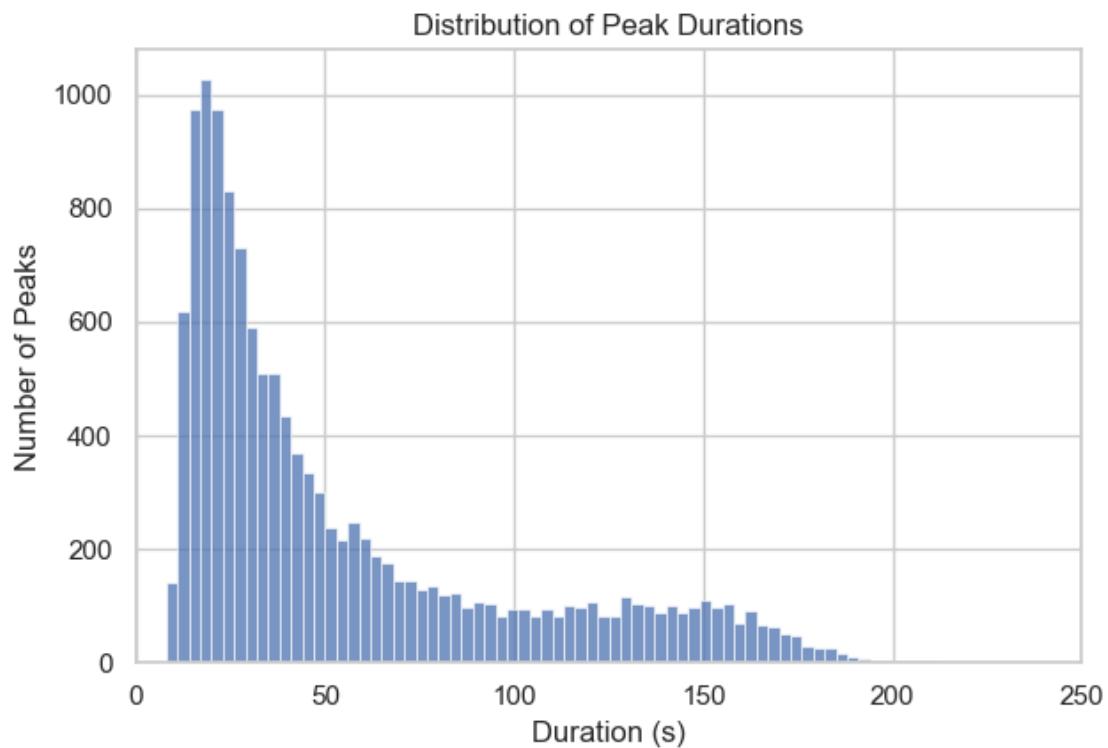
1.1.2 Peaks population

Total number of peaks: 13260

Total number of cells: 1080

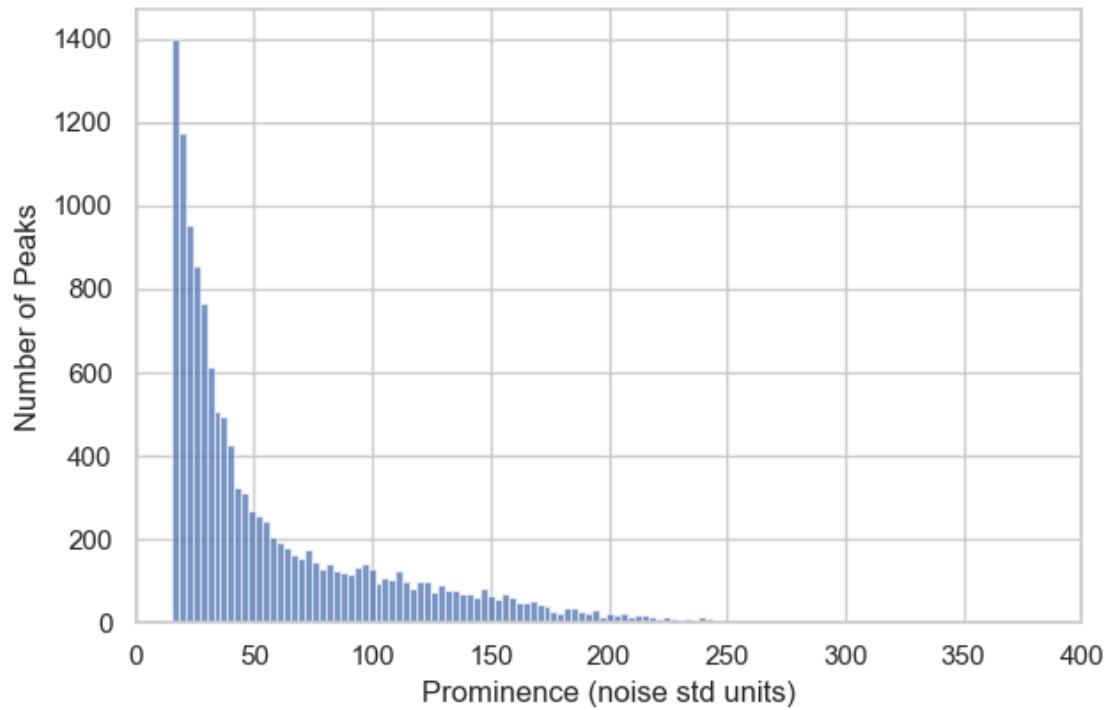
1.1.3 Peaks statistics

```
[2025-08-27 15:16:53] [INFO] calcium: plot_histogram: removed 13 outliers out of  
13260 on 'Duration (s)' (lower=-138, upper=233)
```

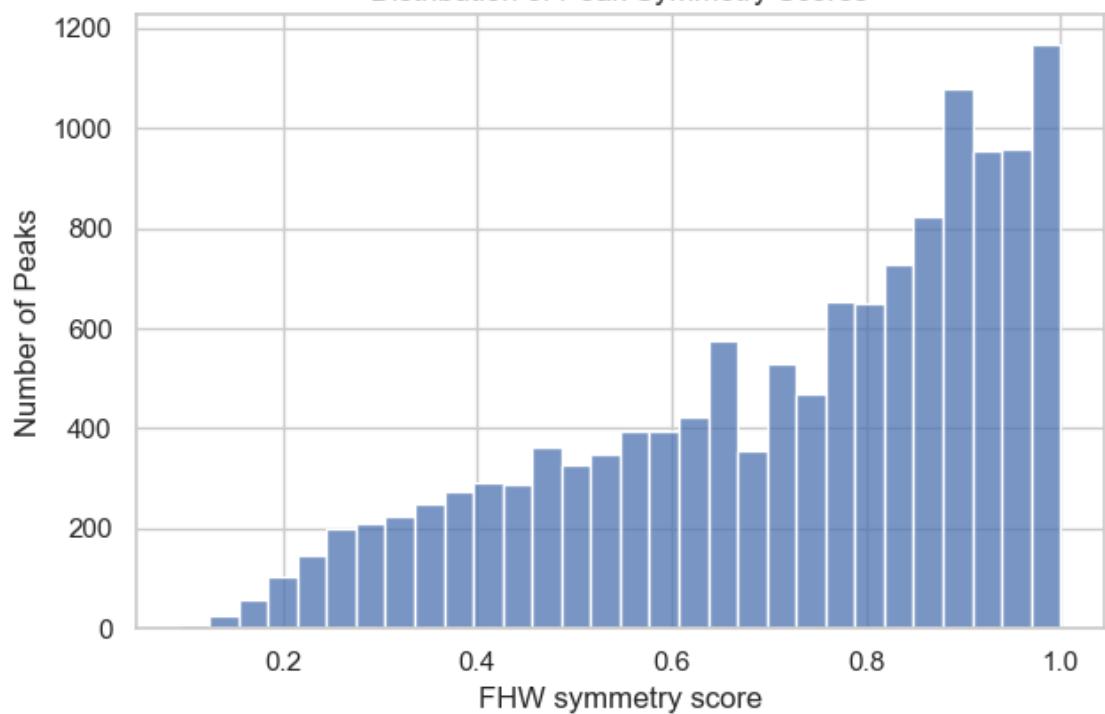


```
[2025-08-27 15:16:53] [INFO] calcium: plot_histogram: removed 122 outliers out  
of 13260 on 'Prominence (noise std units)' (lower=-149, upper=252.8)
```

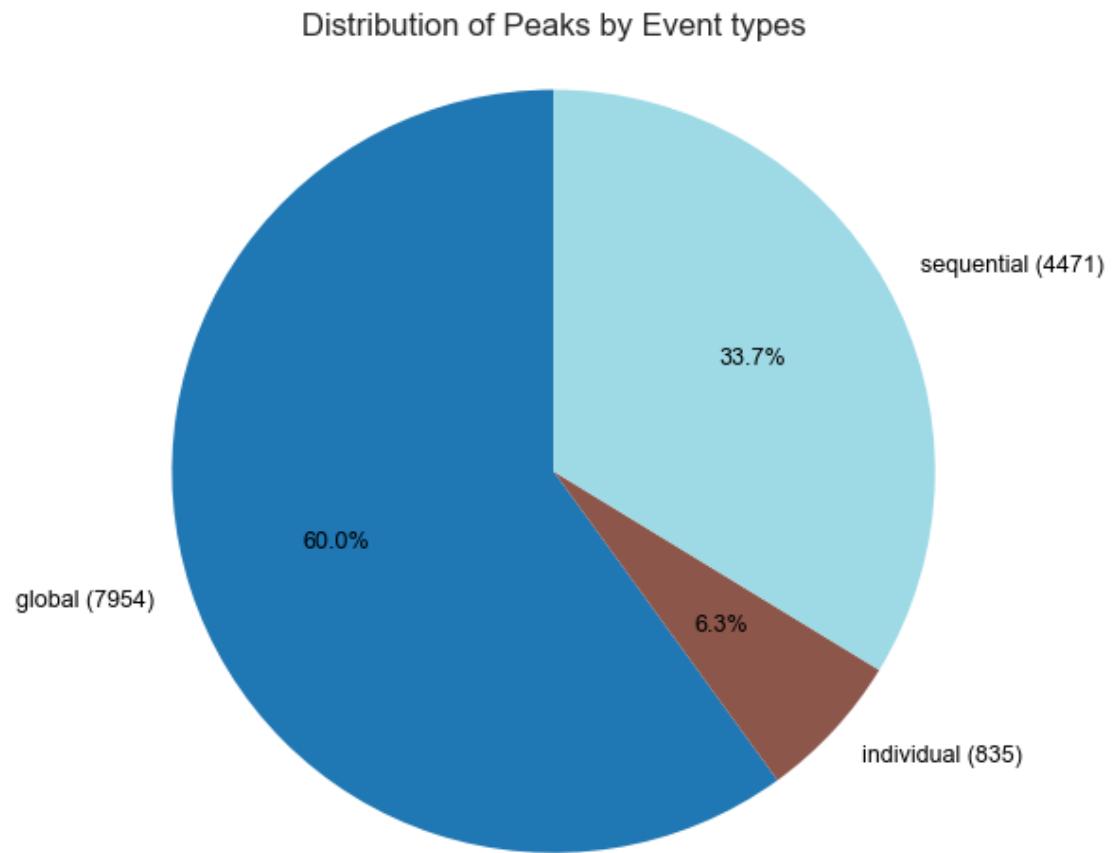
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

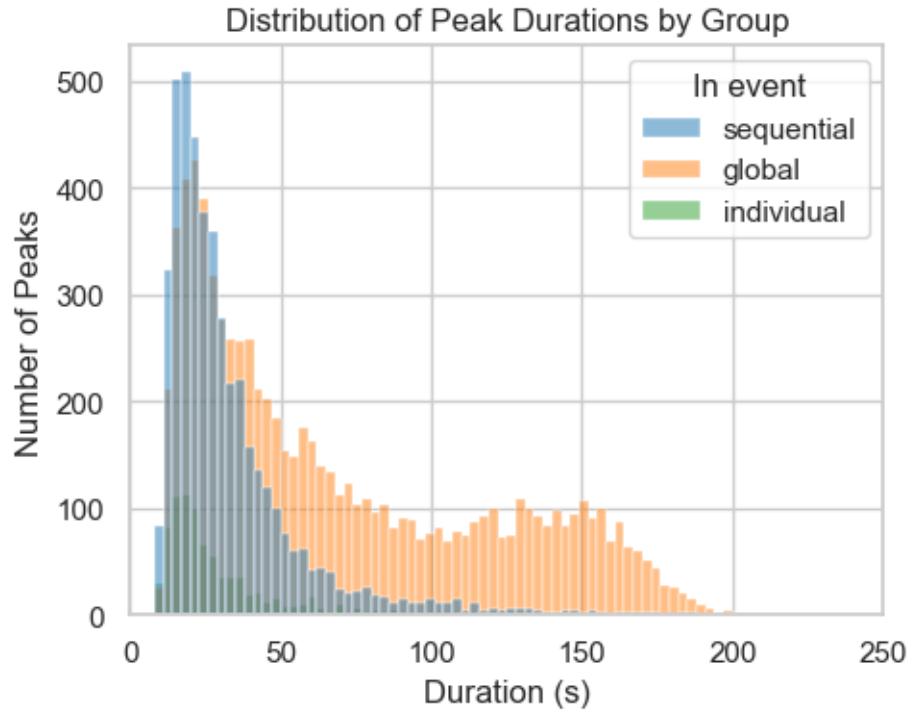


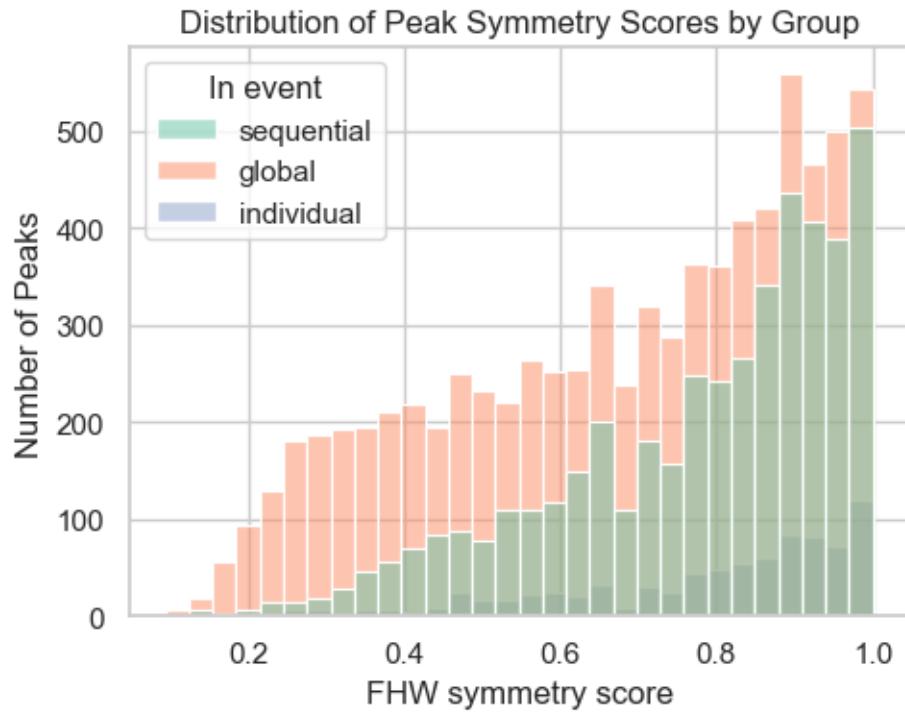
1.1.4 Distribution of peaks per event types



1.1.5 Peaks statistics per event types

```
[2025-08-27 15:16:53] [INFO] calcium: plot_histogram_by_group: removed 13
outliers out of 13260 on 'Duration (s)' (lower=-138, upper=233)
```

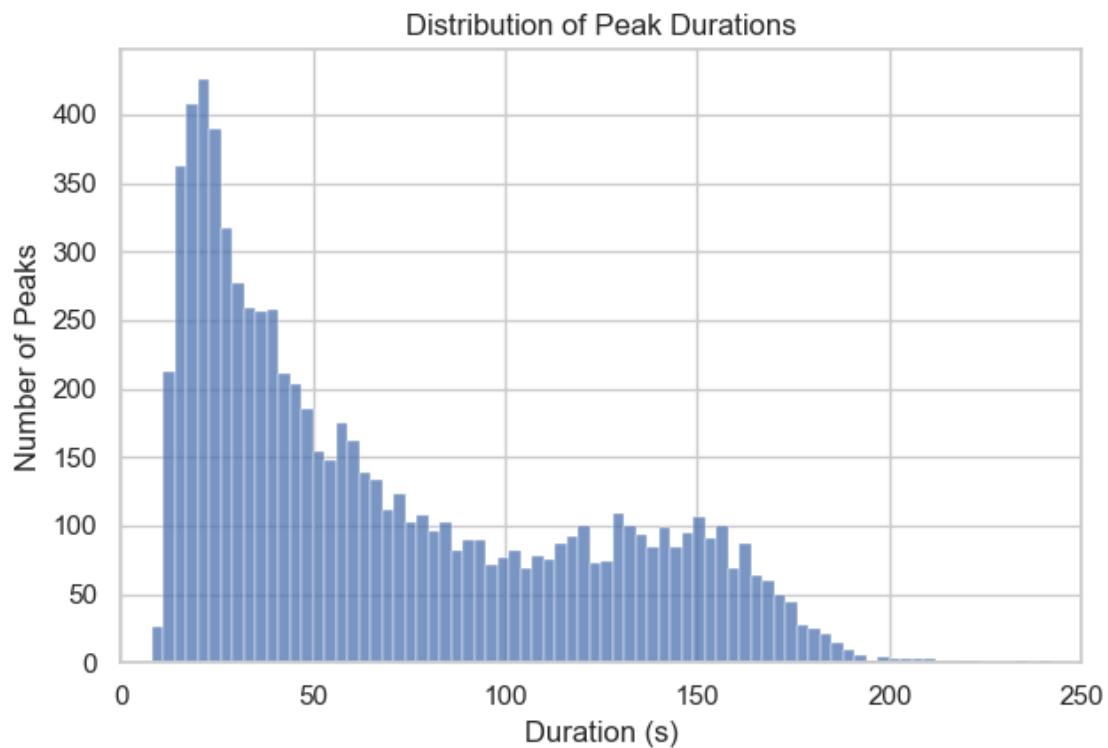




1.2 GLOBAL EVENTS

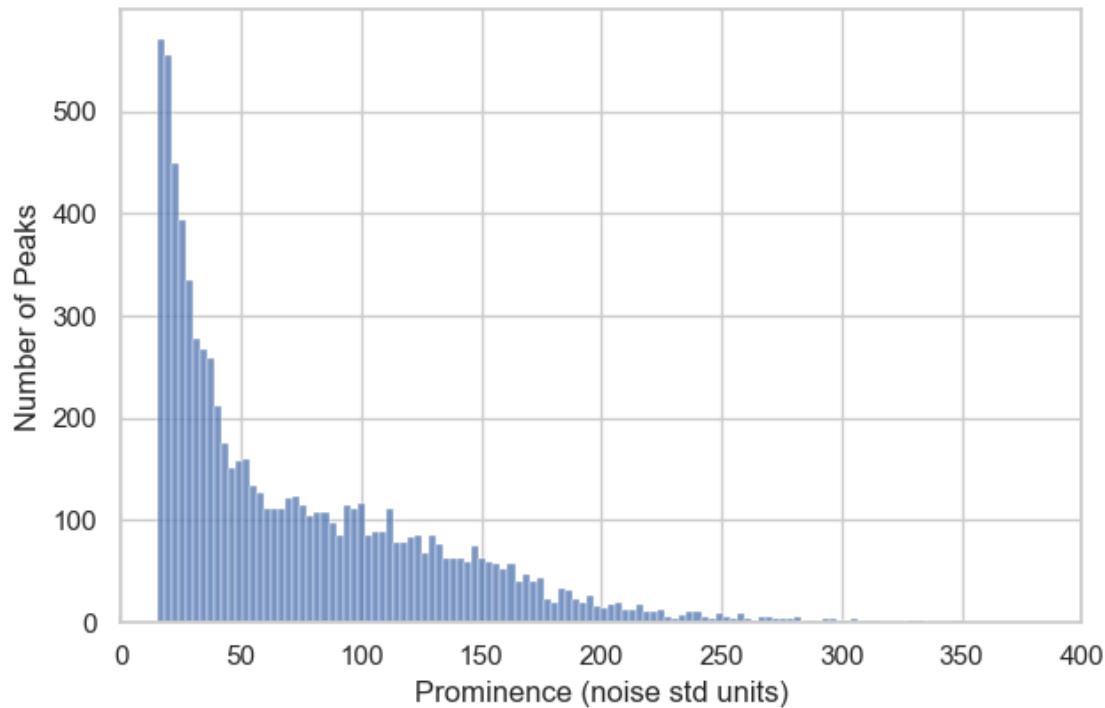
1.2.1 Peak statistics in global events

```
[2025-08-27 15:16:54] [INFO] calcium: plot_histogram: removed 0 outliers out of 7954 on 'Duration (s)' (lower=-219, upper=355)
```

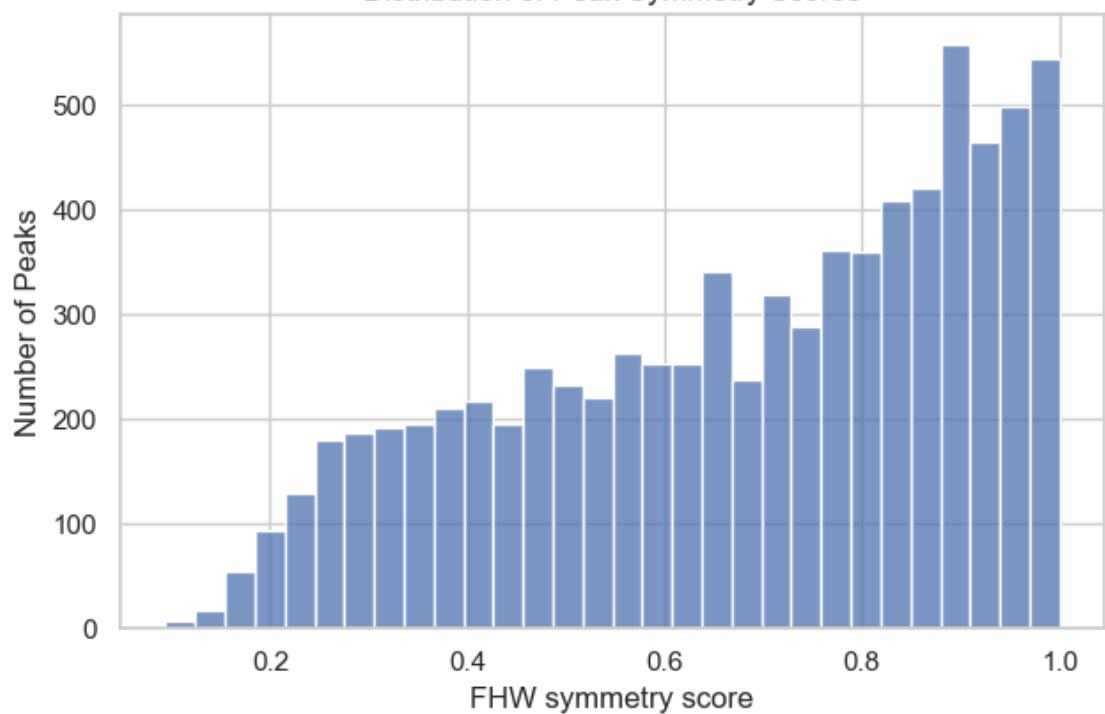


```
[2025-08-27 15:16:54] [INFO] calcium: plot_histogram: removed 16 outliers out of  
7954 on 'Prominence (noise std units)' (lower=-216.73, upper=352.2)
```

Distribution of Peak Prominences

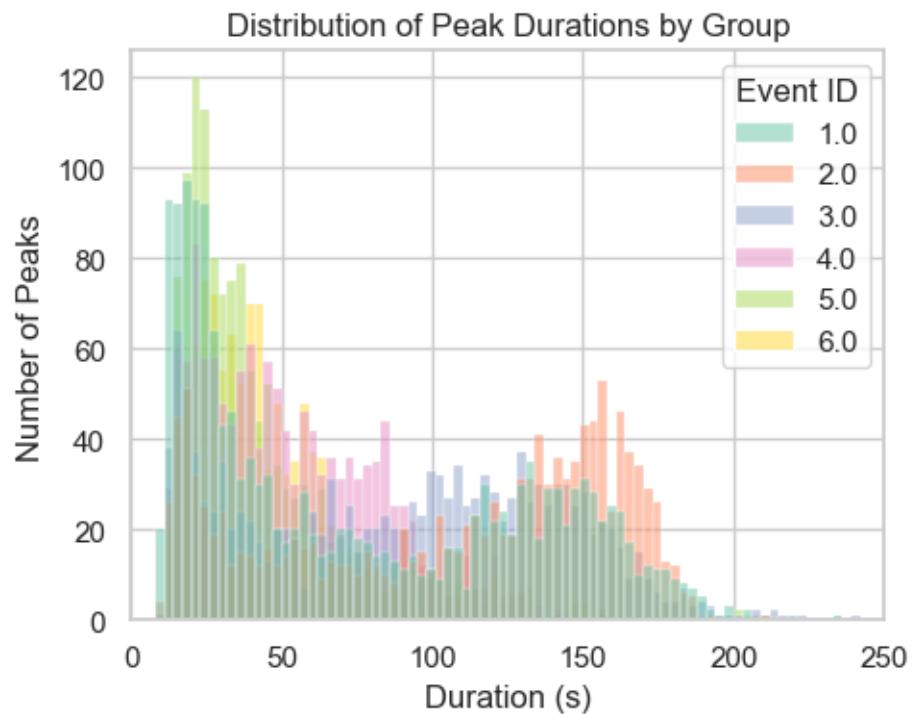


Distribution of Peak Symmetry Scores

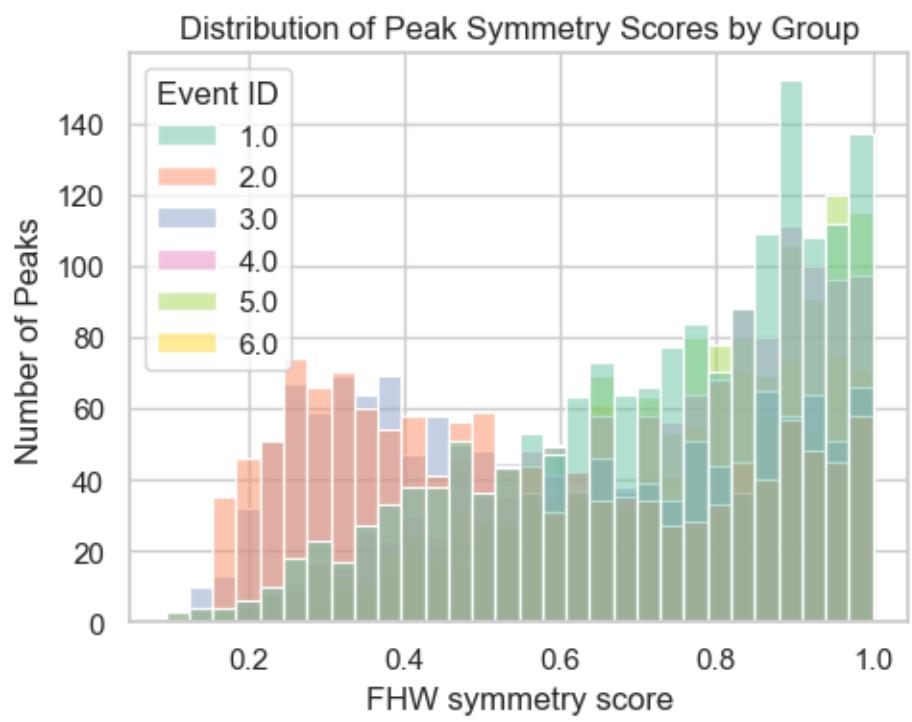
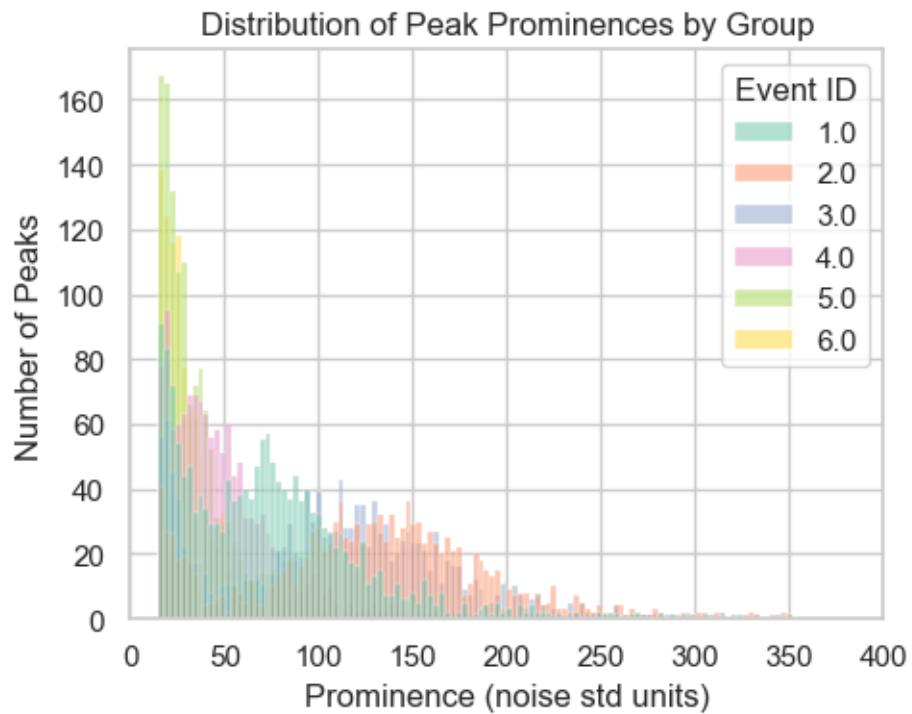


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:16:55] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7954 on 'Duration (s)' (lower=-219, upper=355)

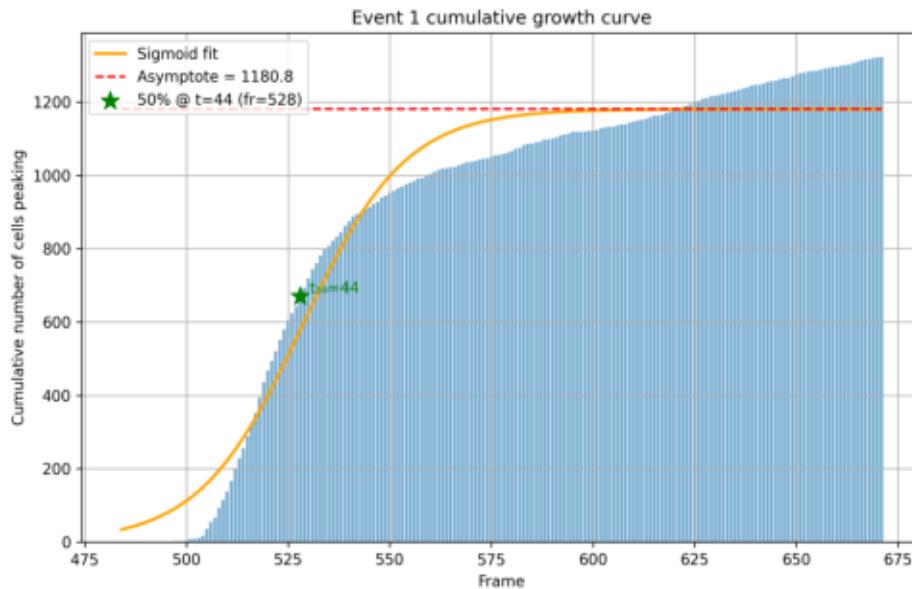


[2025-08-27 15:16:55] [INFO] calcium: plot_histogram_by_group: removed 16 outliers out of 7954 on 'Prominence (noise std units)' (lower=-216.73, upper=352.2)

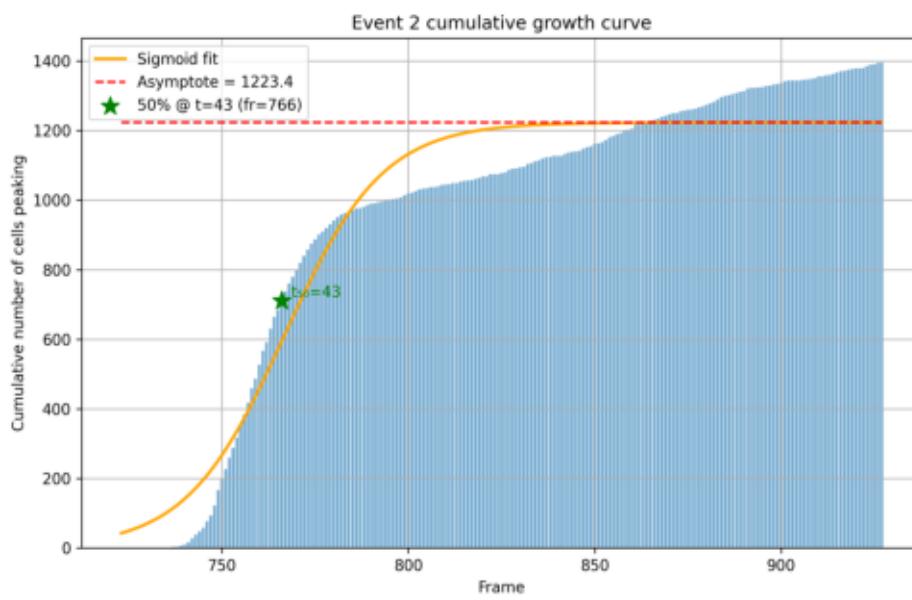


1.2.3 Kinetics of global events

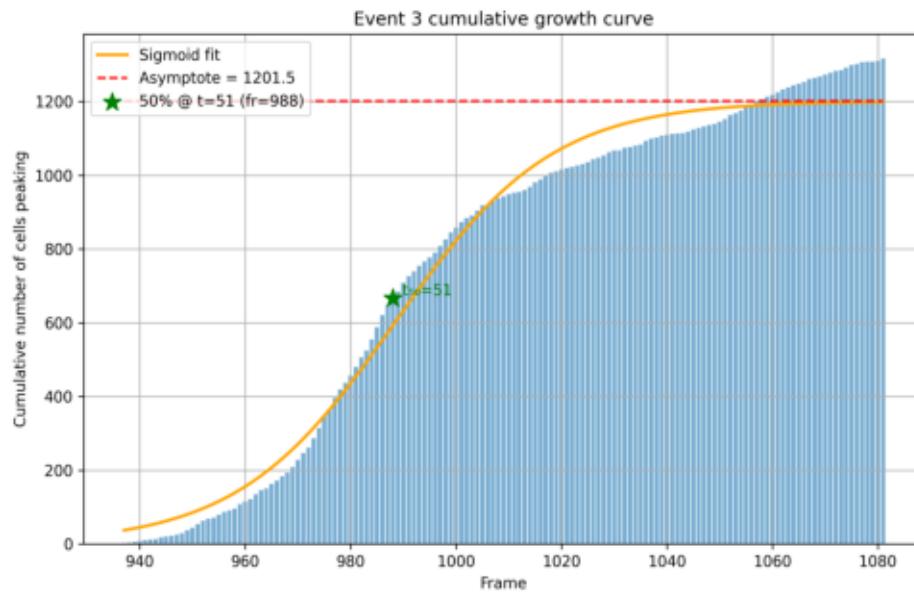
Event Activity Overlay (Event ID: 1)



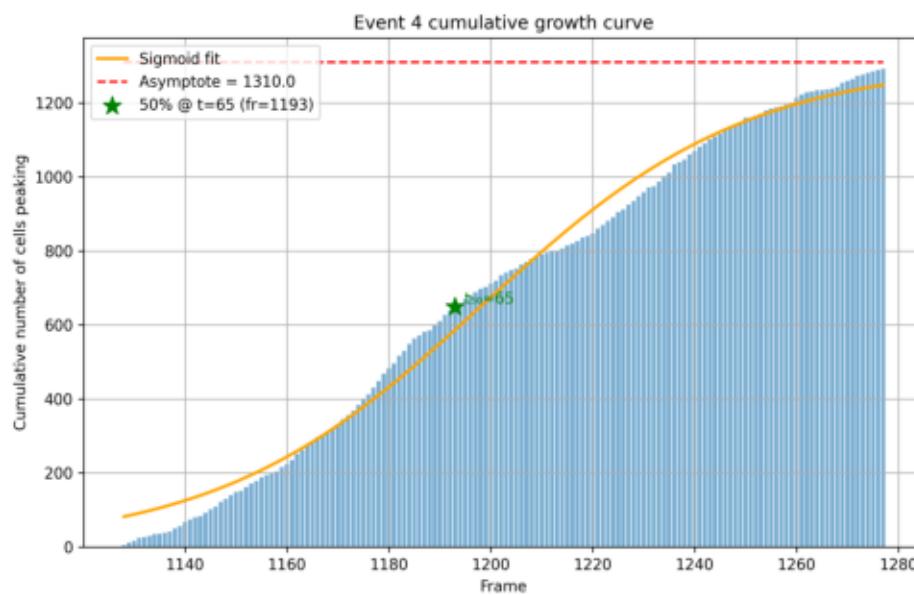
Event Activity Overlay (Event ID: 2)



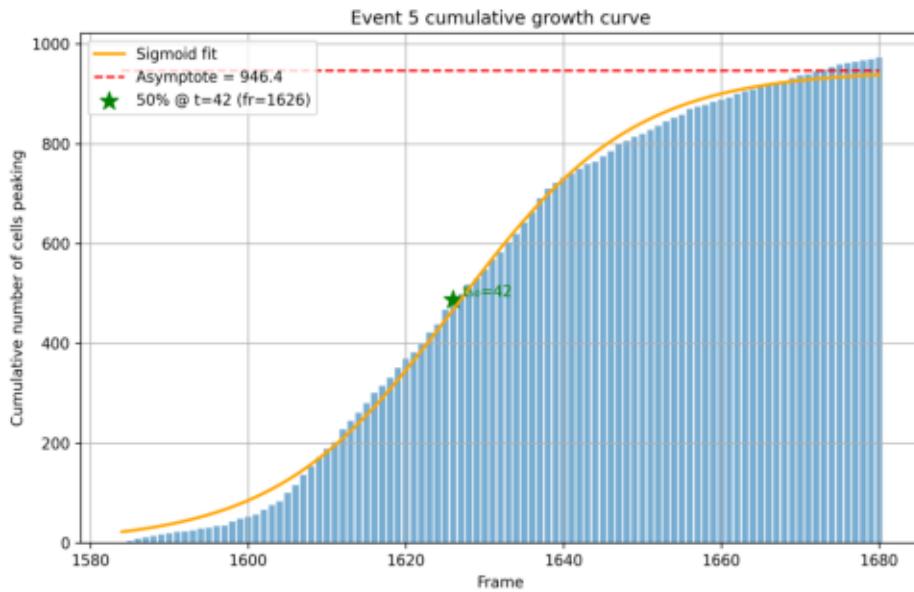
Event Activity Overlay (Event ID: 3)



Event Activity Overlay (Event ID: 4)

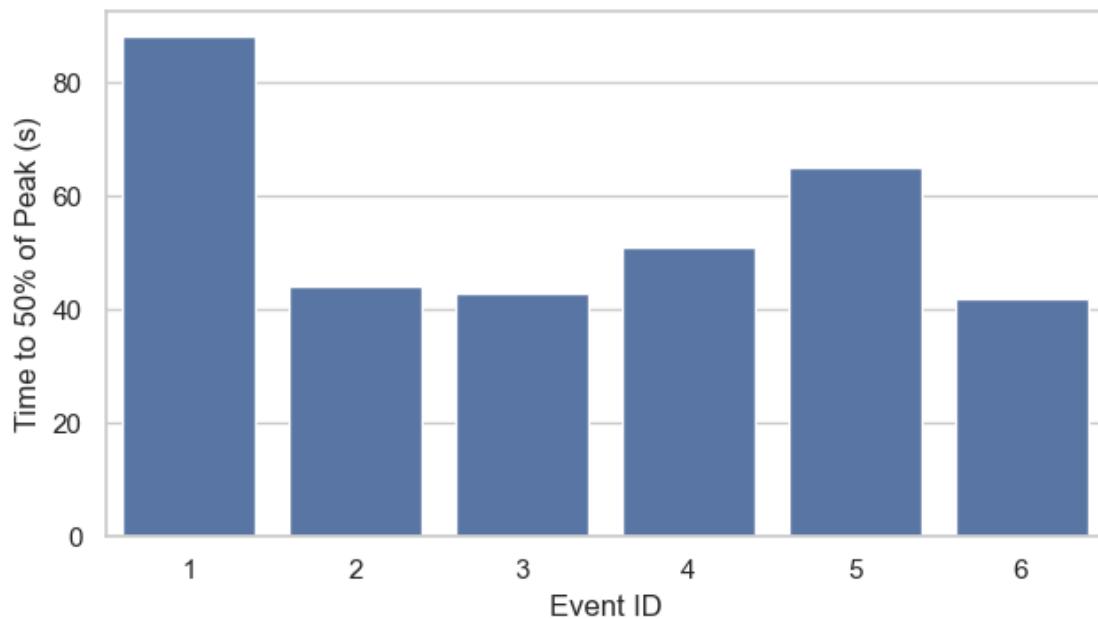


Event Activity Overlay (Event ID: 5)

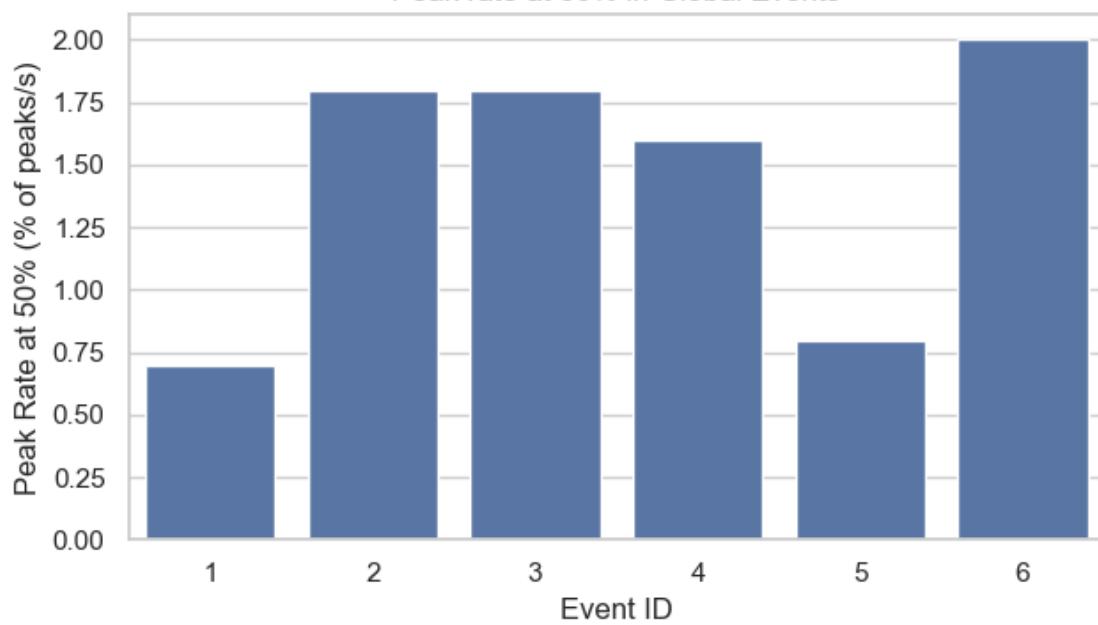


```
[2025-08-27 15:16:59] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\events\event-growth-curve-6.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250701\Output\\IS6\\events\\event-growth-
curve-6.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\\IS6\\events\\event-growth-curve-6.png'
```

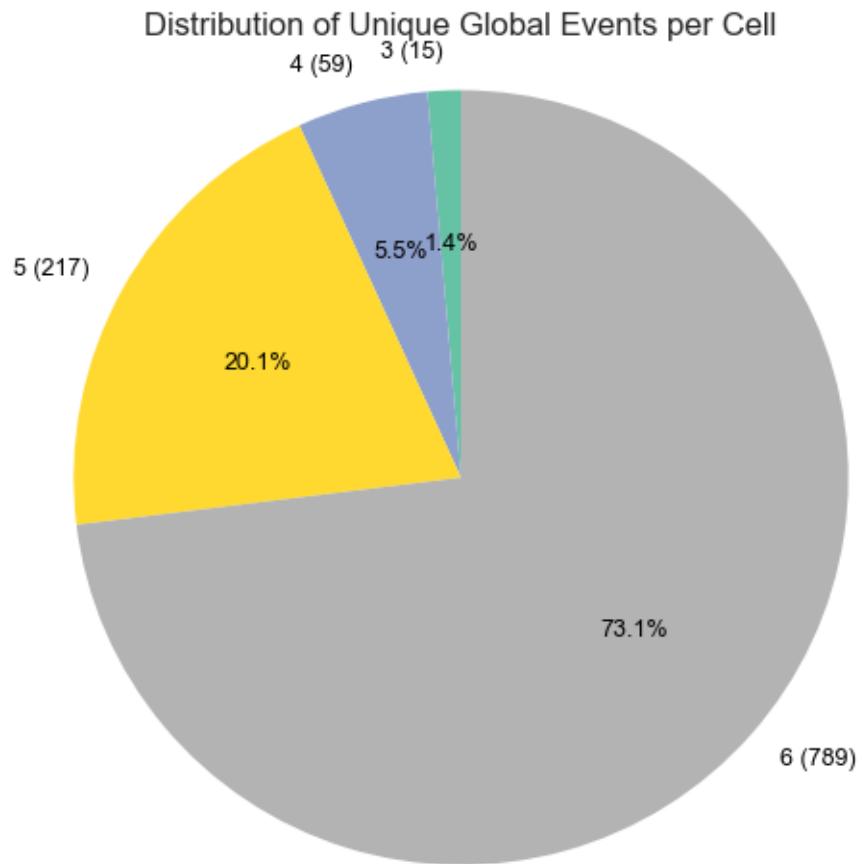
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

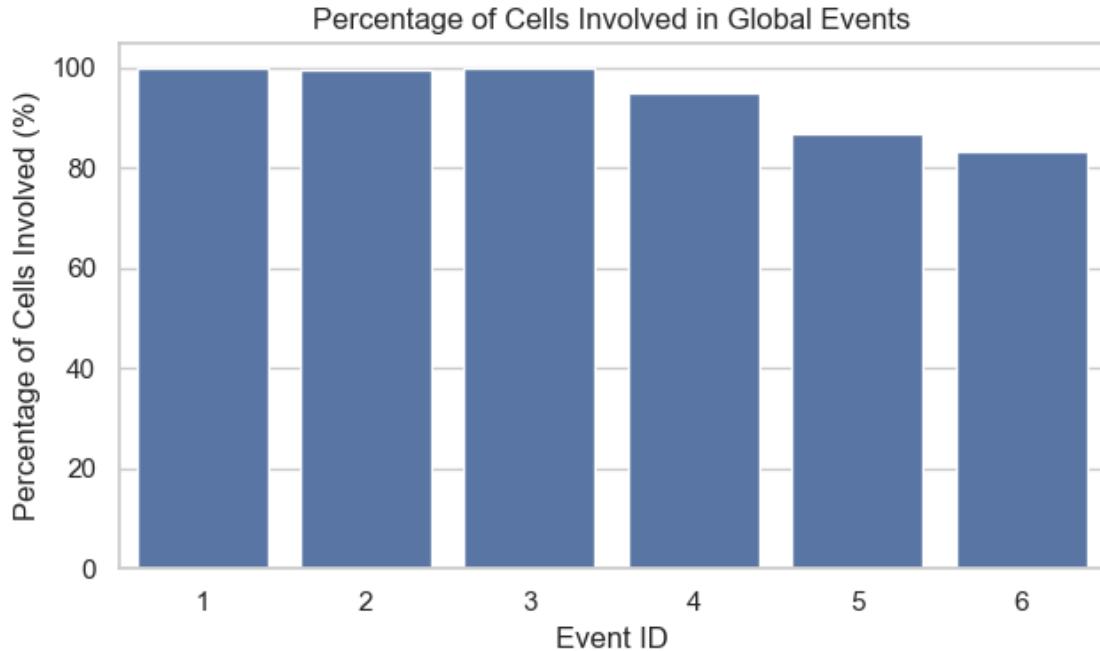


```
[2025-08-27 15:16:59] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250701\\\\Output\\\\IS6\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
```

```

    self.fp = open(fp, "rb")
FileNotFoundError: [Errno 2] No such file or directory:
'D:\Mateo\20250701\Output\IS6\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [211.0, 237.0, 217.0, 196.0, 448.0]
Estimated periodicity: 0.736

1.2.6 Early peakers in the events

```

[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-

```

```
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
```

```
    raise SyntaxError(msg)
SyntaxError: not a PNG file

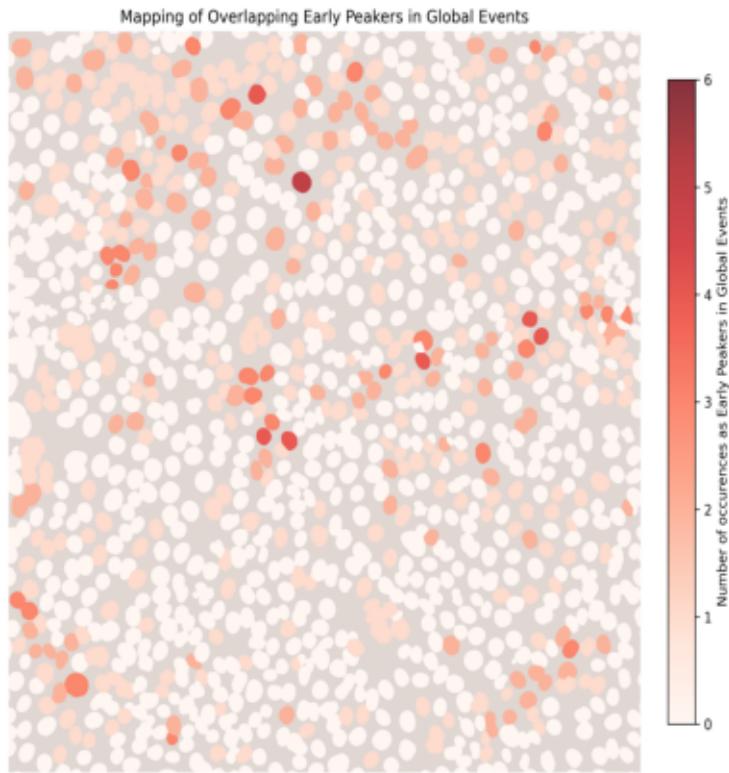
[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:17:00] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
```

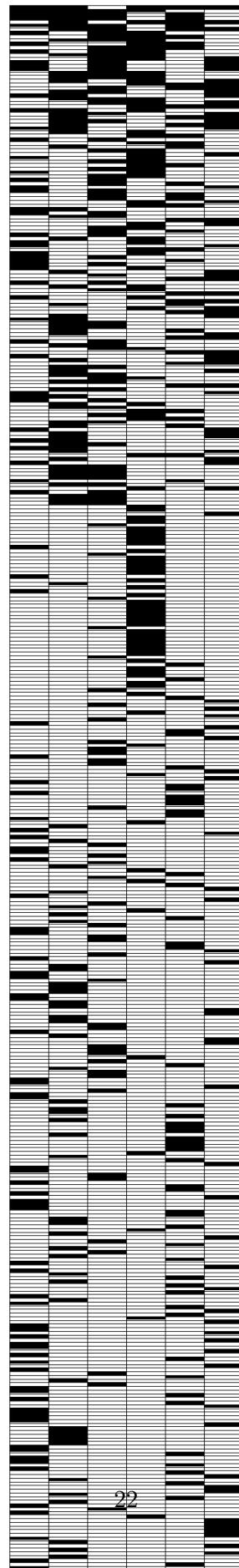
```
mapping\global_events\global_event_6_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\ImageFile.py", line 144, in __init__
    self._open()
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file
```

Cell Mapping with Occurrences in Global Events Overlay



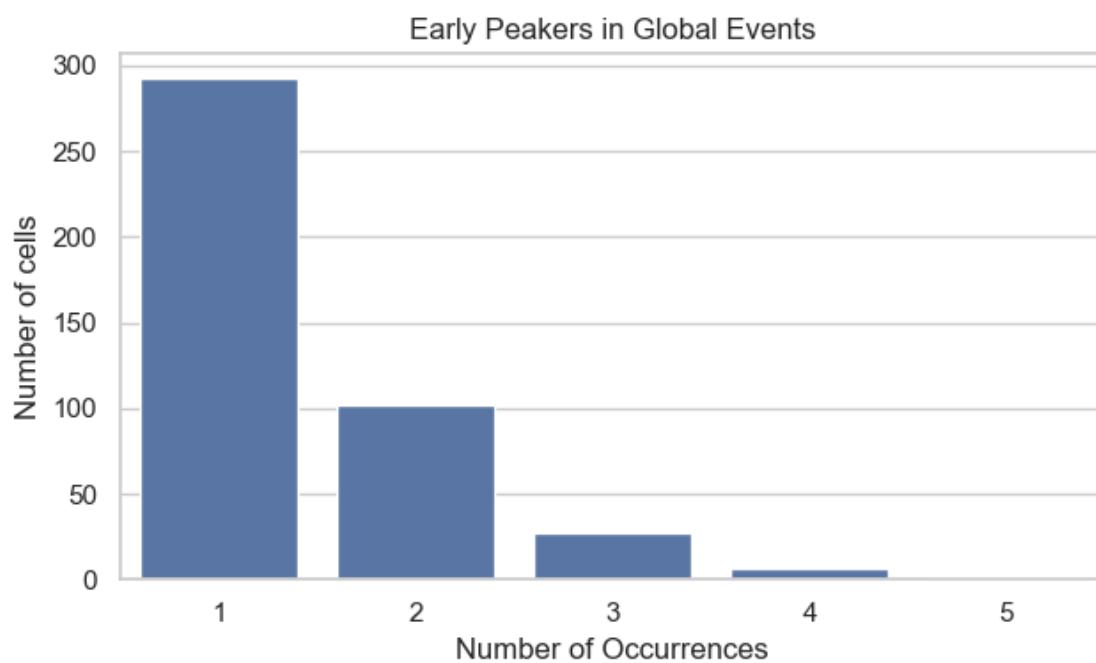
```
[2025-08-27 15:17:01] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 6 unique event IDs.
```

```
[2025-08-27 15:17:01] [INFO] calcium: Early peakers event-matrix: 428 cells x 6 events; black squares: 606
```

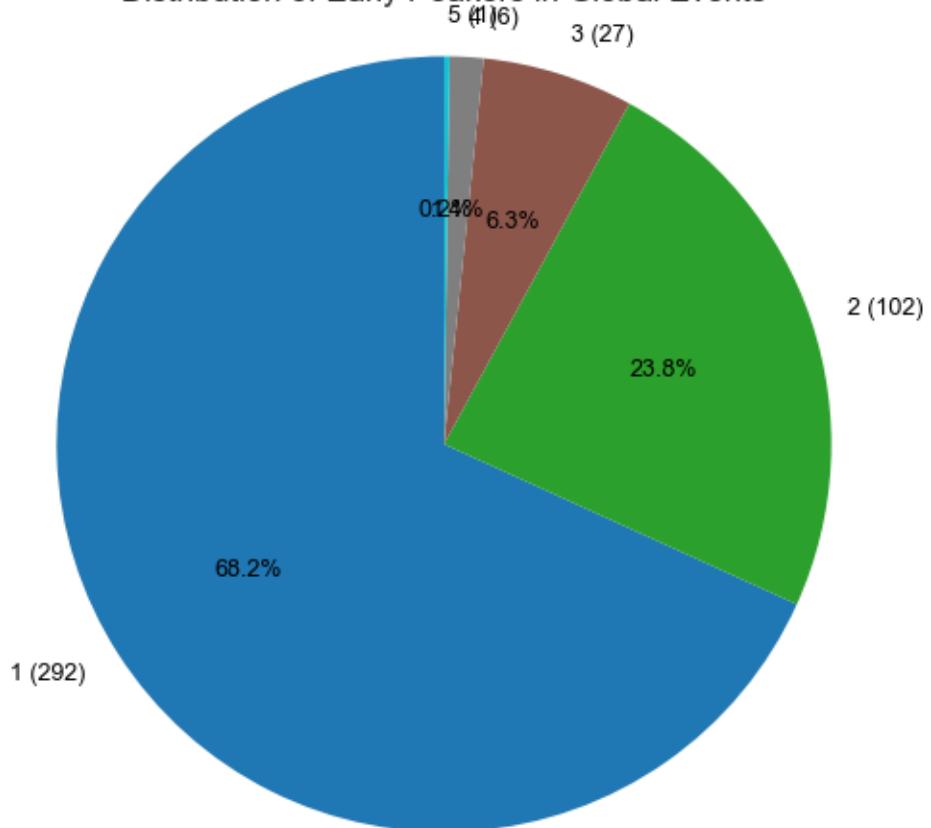


```
[2025-08-27 15:17:02] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

```
[19]: array([[1, 1, 0, 1, 1, 1],  
           [1, 1, 1, 1, 0, 0],  
           [1, 1, 1, 0, 1, 0],  
           ...,  
           [1, 0, 0, 0, 0, 0],  
           [0, 0, 0, 0, 1, 0],  
           [1, 0, 0, 0, 0, 0]])
```

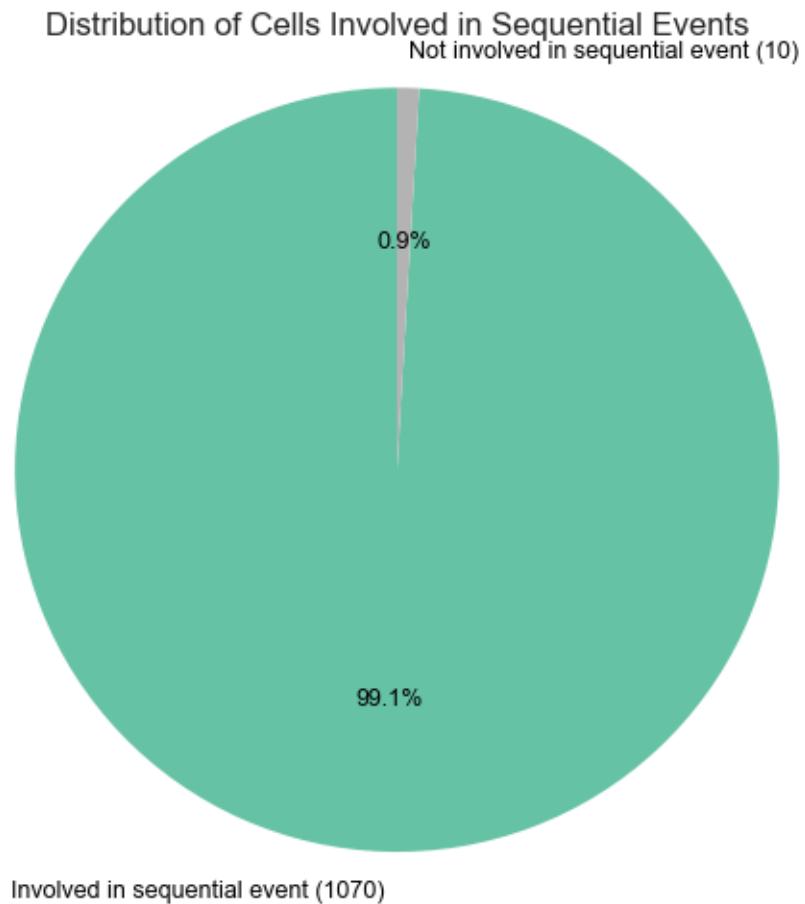


Distribution of Early Peakers in Global Events

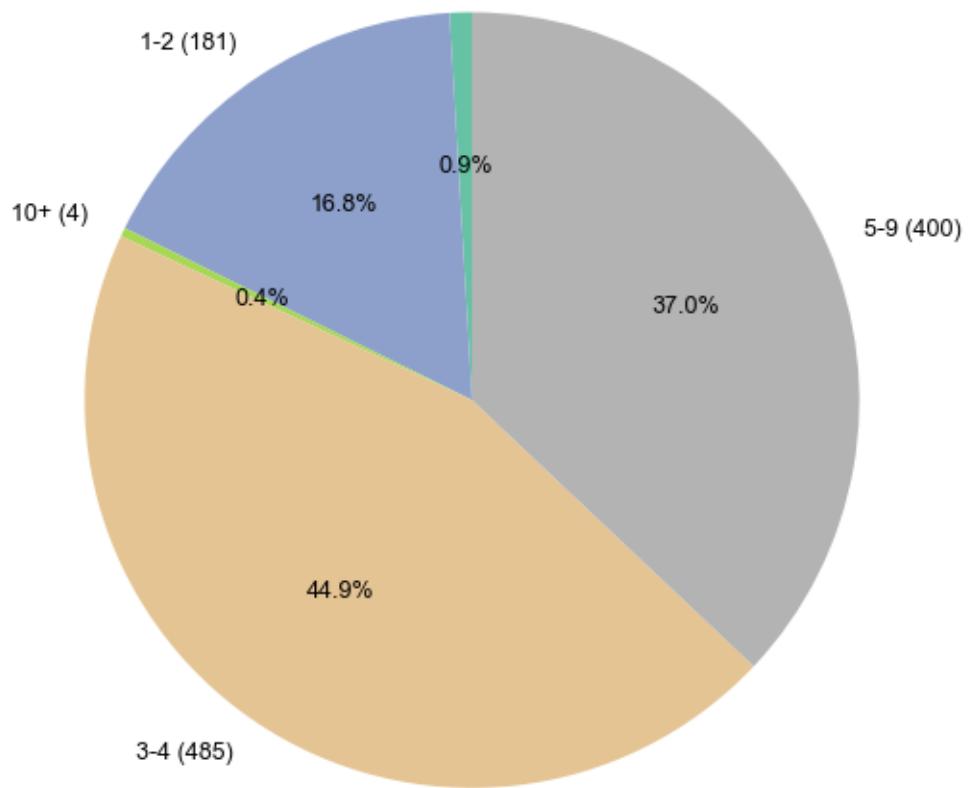


1.3 SEQUENTIAL EVENTS

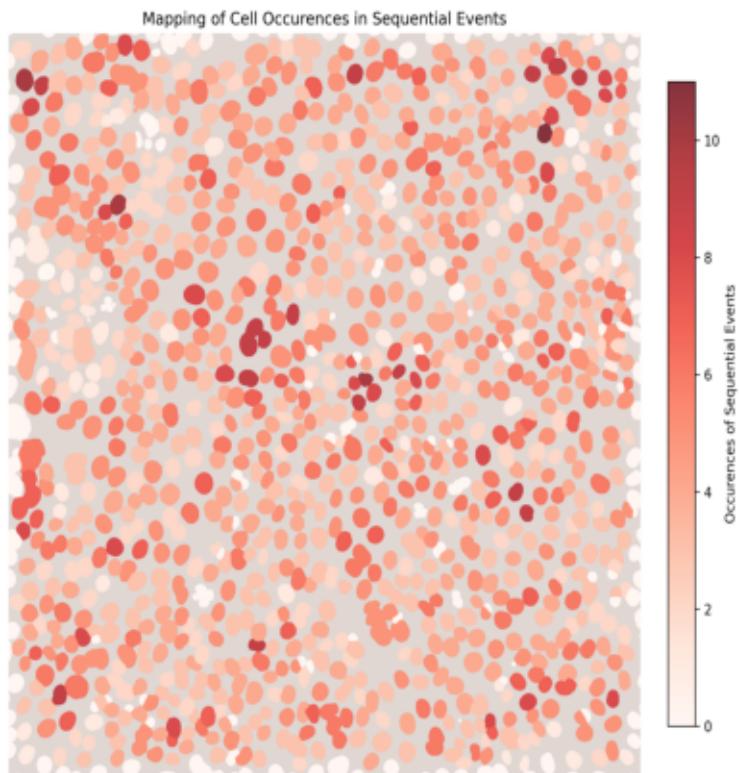
1.3.1 Cells Occurrences in sequential events



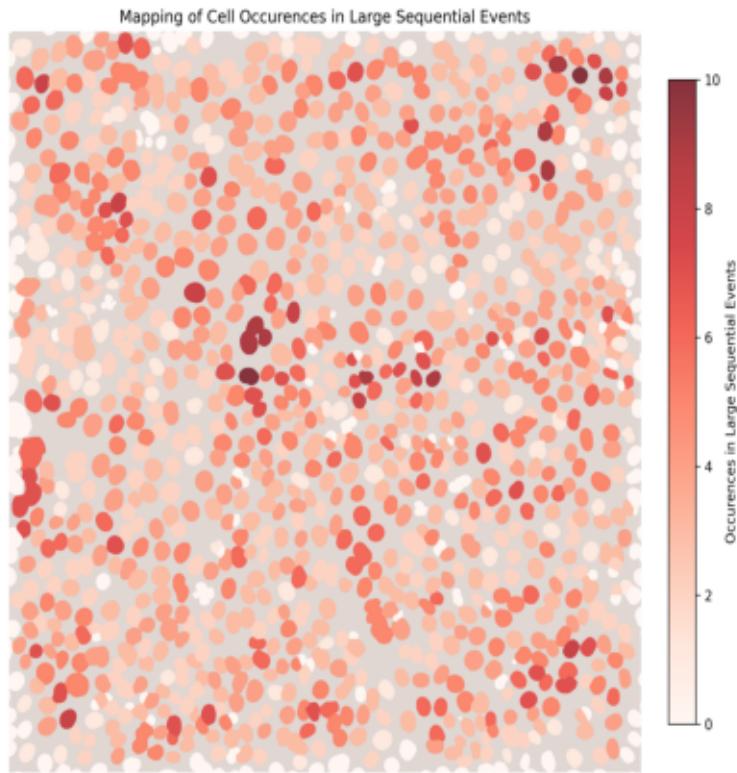
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

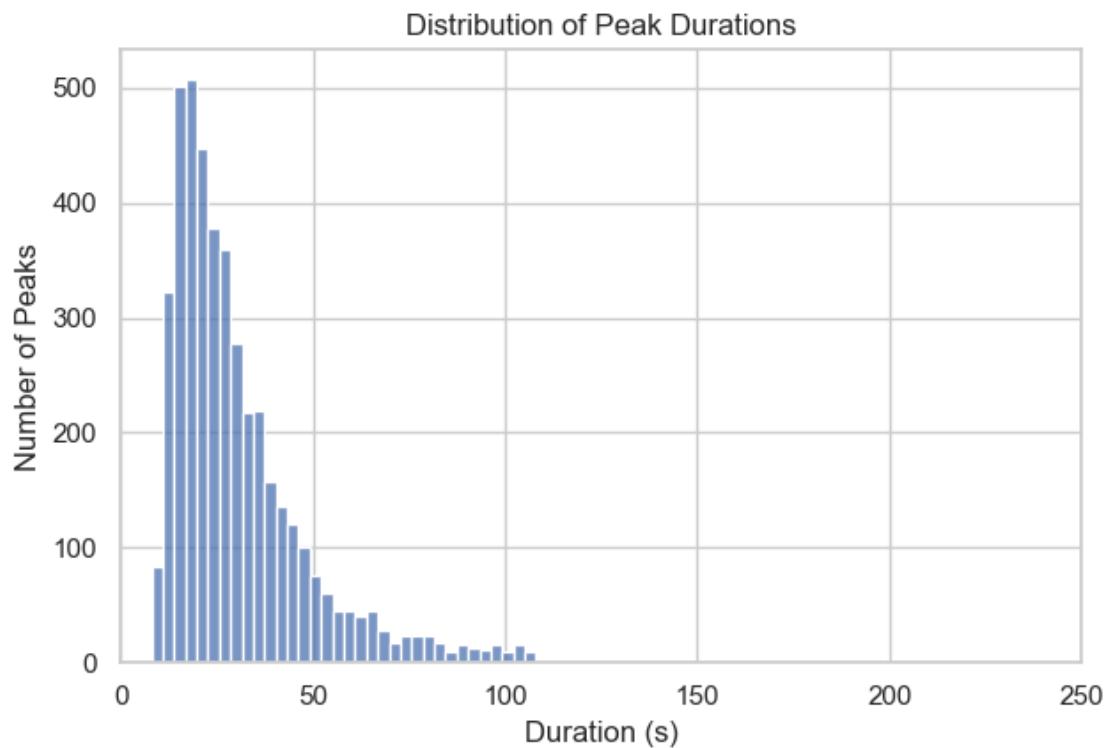


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

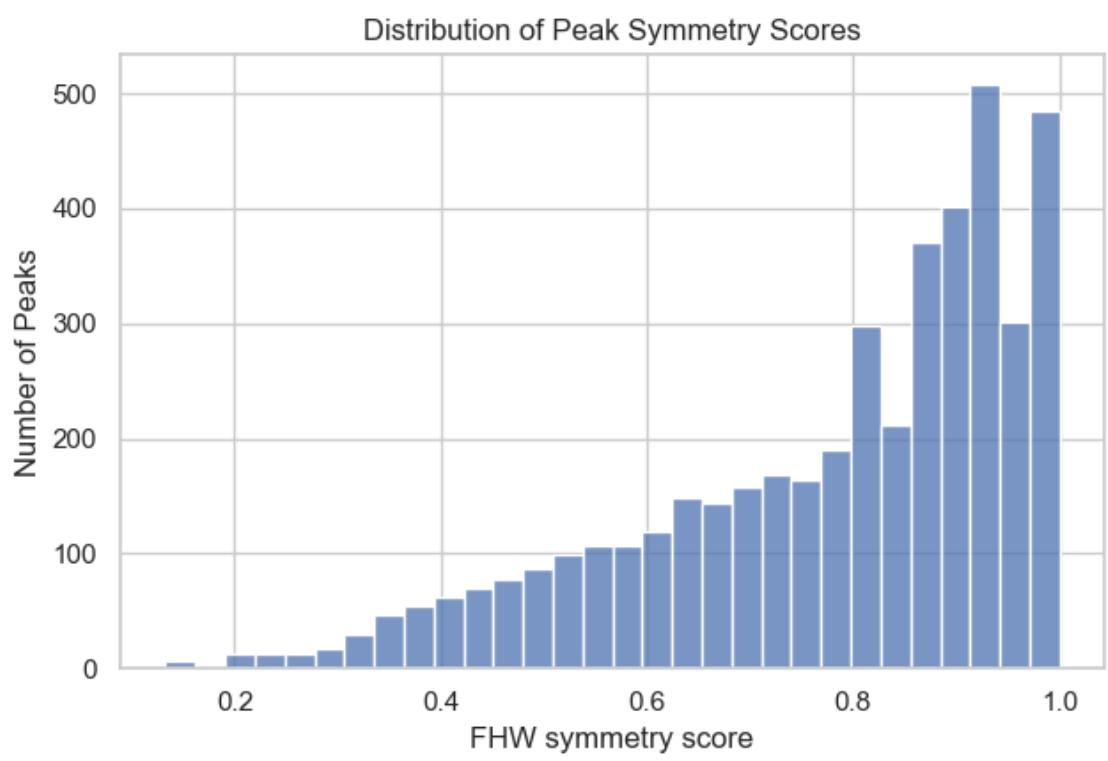
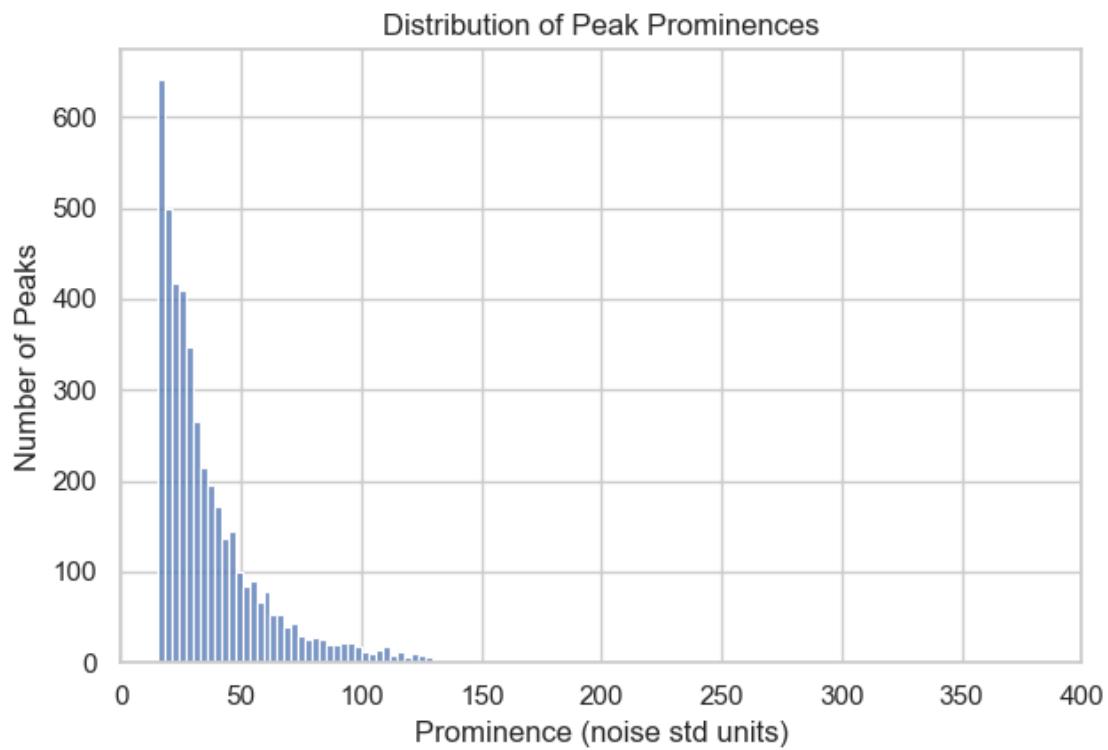


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:17:04] [INFO] calcium: plot_histogram: removed 98 outliers out of 4471 on 'Duration (s)' (lower=-12, upper=108)
```

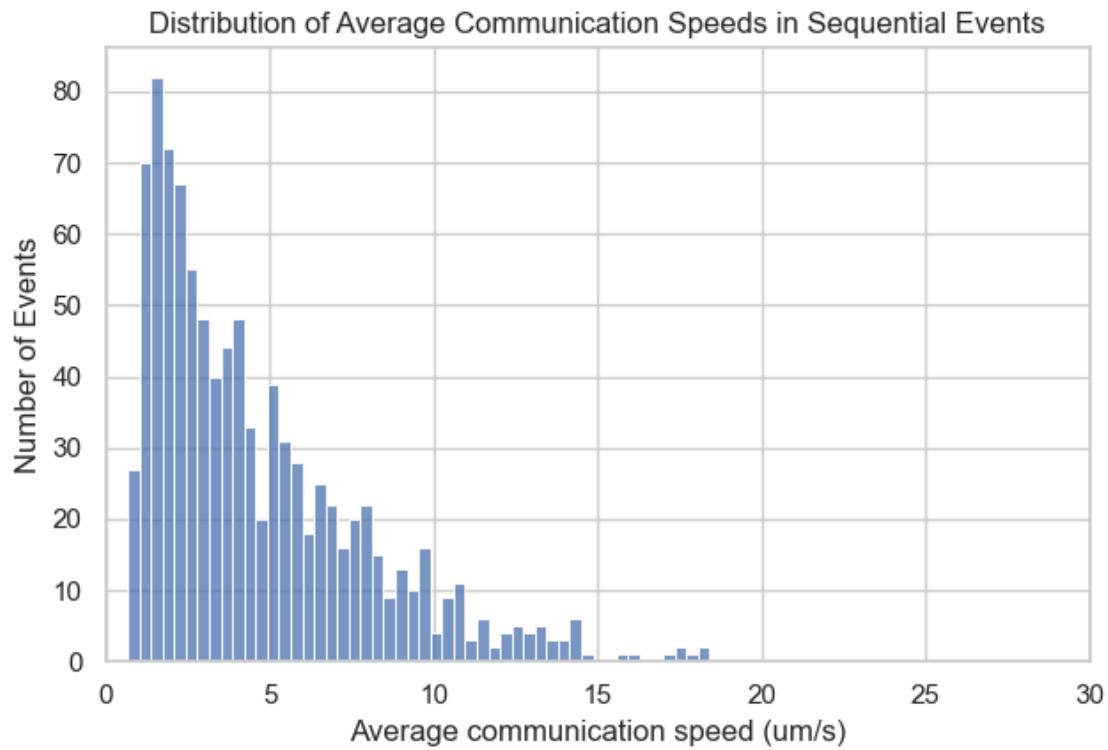


```
[2025-08-27 15:17:04] [INFO] calcium: plot_histogram: removed 107 outliers out  
of 4471 on 'Prominence (noise std units)' (lower=-16.2, upper=131.4)
```



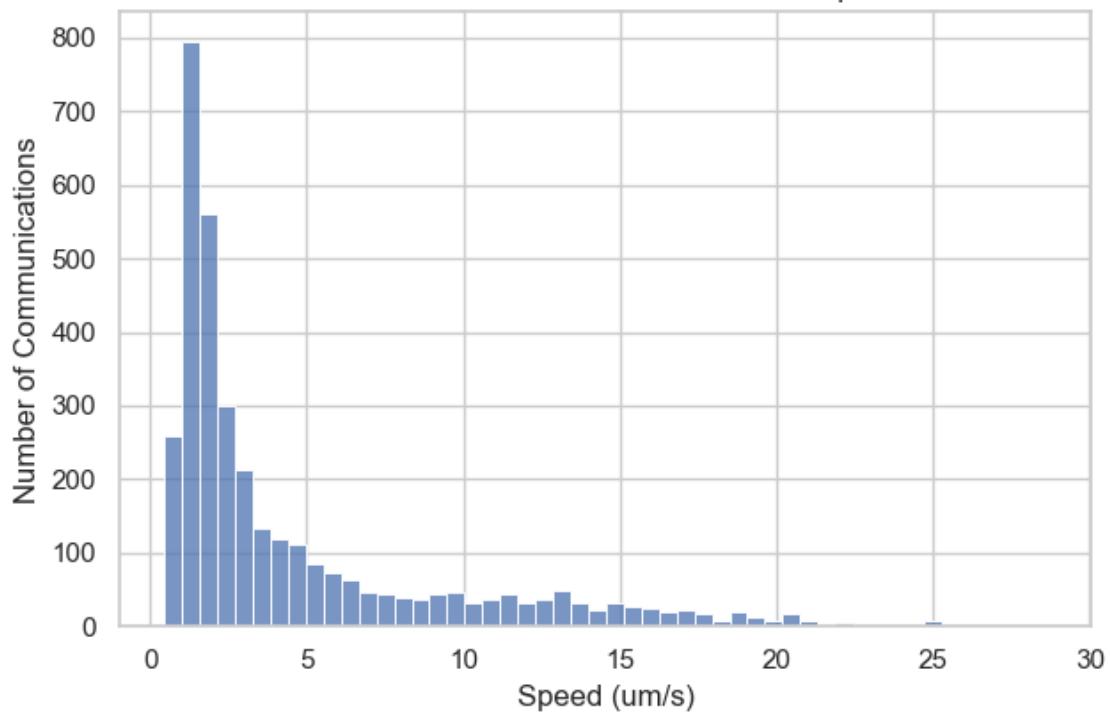
1.3.3 Cell-cell communication speed

[2025-08-27 15:17:04] [INFO] calcium: plot_histogram: removed 4 outliers out of 968 on 'Average communication speed (um/s)' (lower=-11.02, upper=19.447)

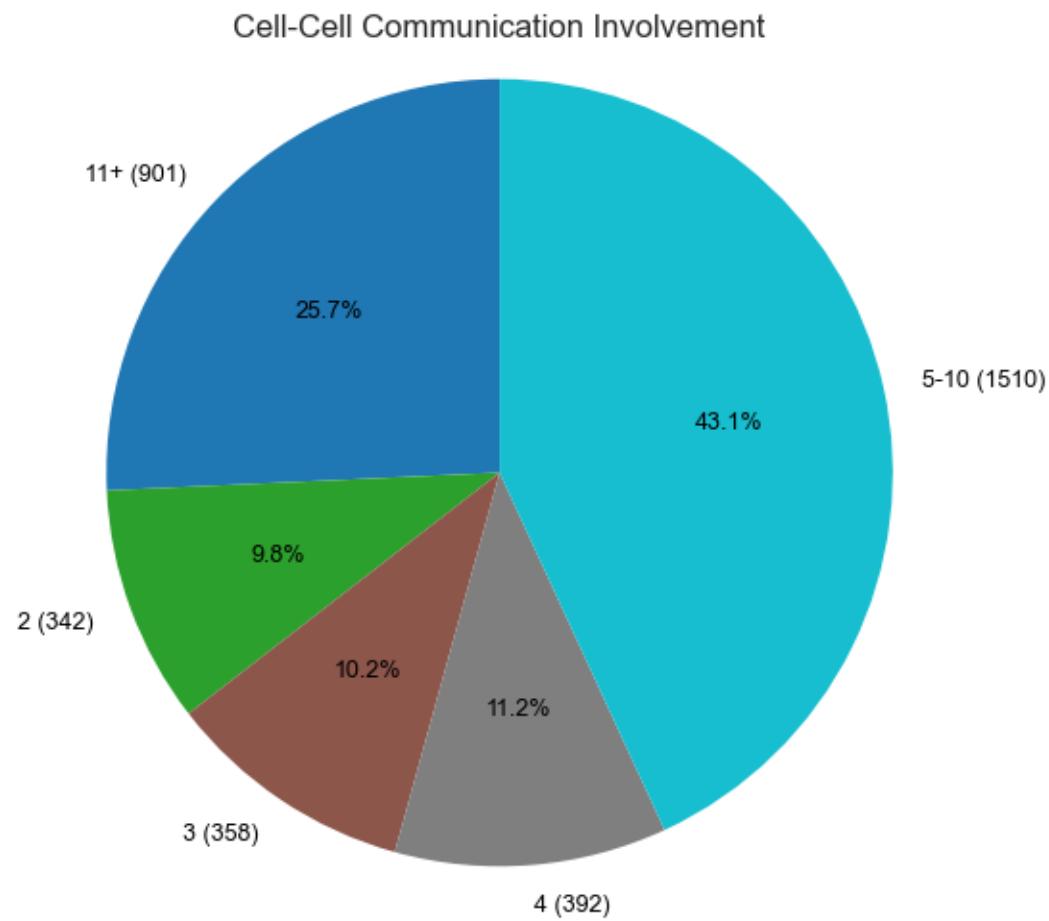


[2025-08-27 15:17:05] [INFO] calcium: plot_histogram: removed 6 outliers out of 3503 on 'Speed (um/s)' (lower=-12.165, upper=28.65)

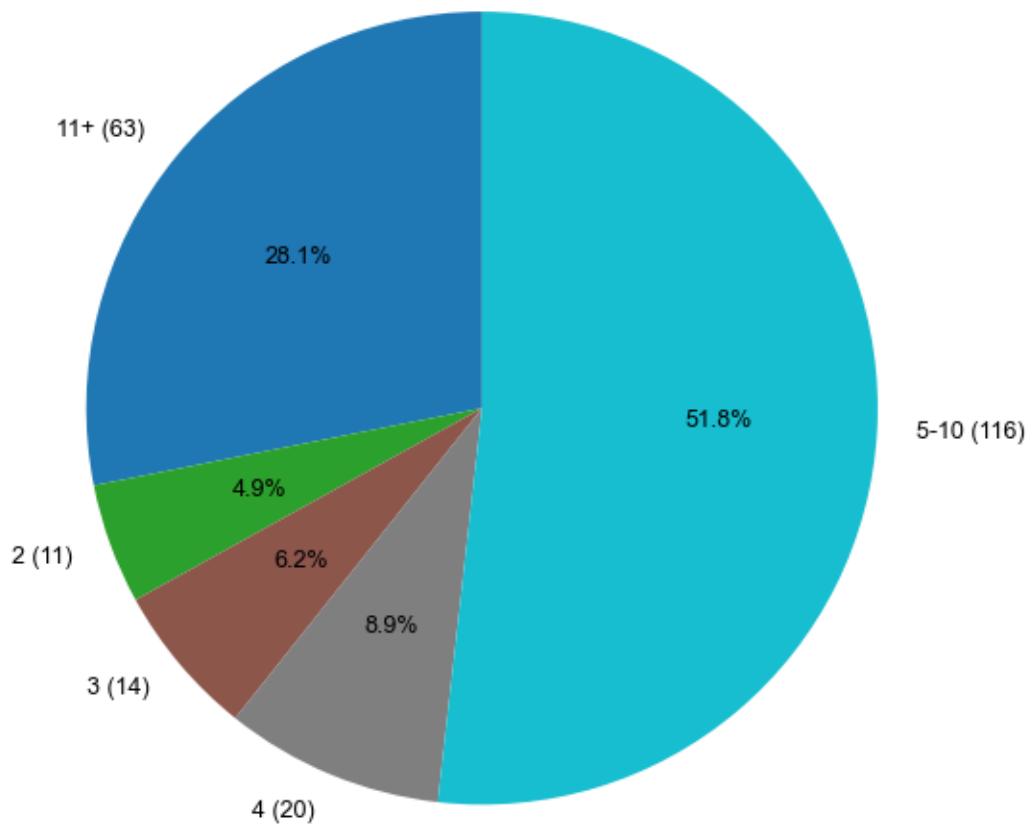
Distribution of Cell-Cell Communication Speeds



1.3.4 Double distribution in cell-cell communication speeds

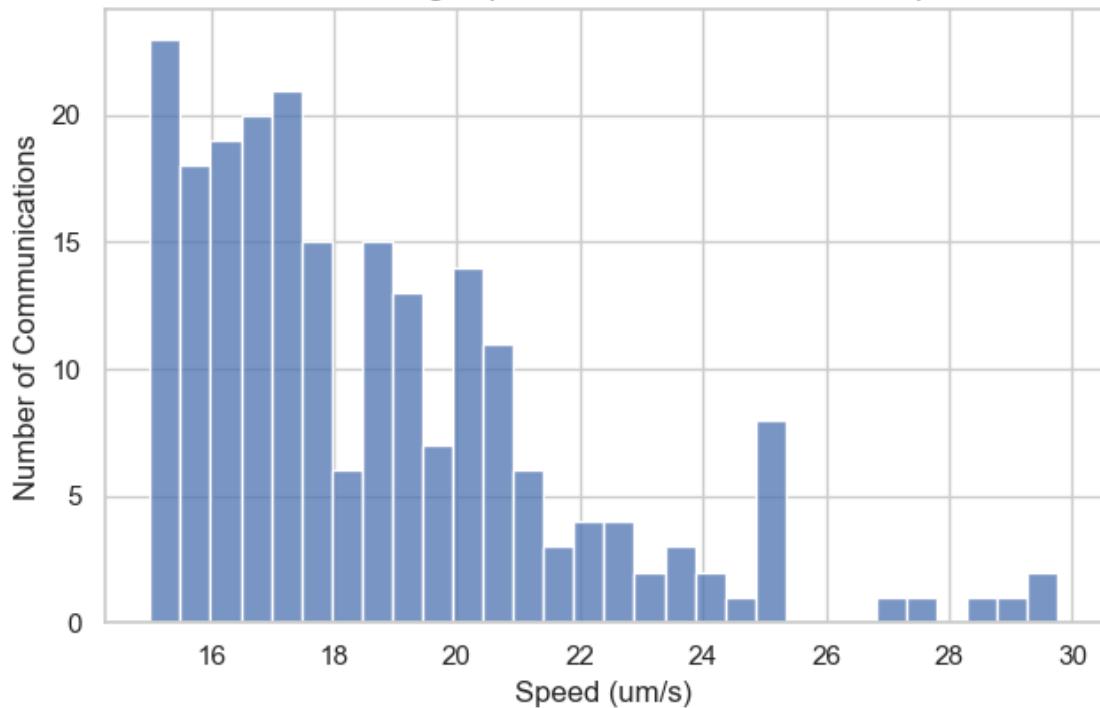


High Speed Cell-Cell Communication Involvement



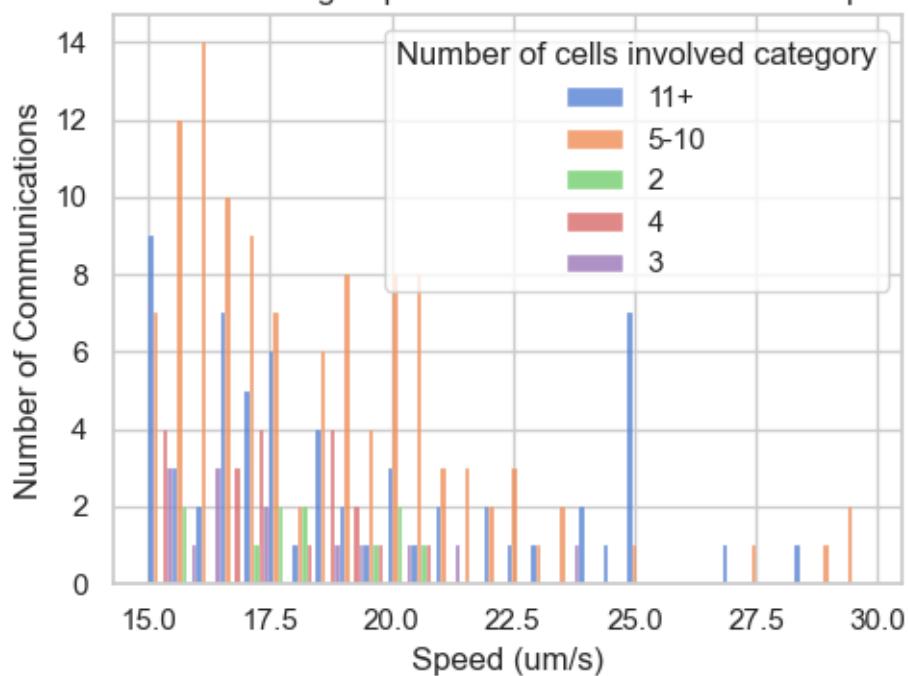
[2025-08-27 15:17:05] [INFO] calcium: plot_histogram: removed 3 outliers out of 224 on 'Speed (um/s)' (lower=4.3725, upper=32.337)

Distribution of High Speed Cell-Cell Communication Speeds

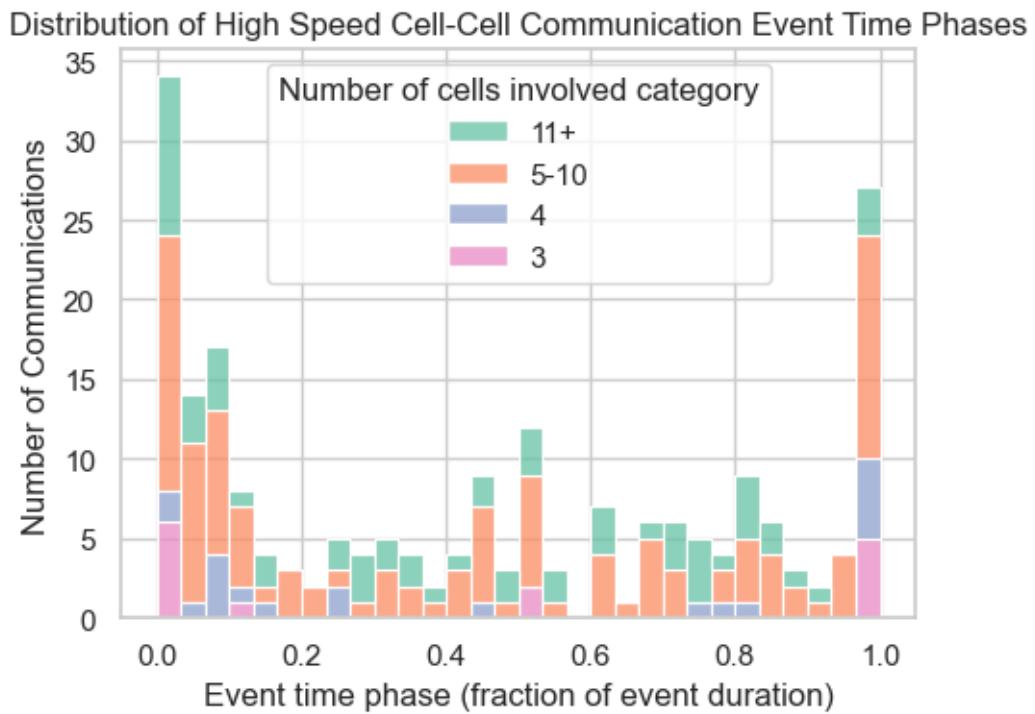


```
[2025-08-27 15:17:05] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 224 on 'Speed (um/s)' (lower=4.3725, upper=32.337)
```

Distribution of High Speed Cell-Cell Communication Speeds

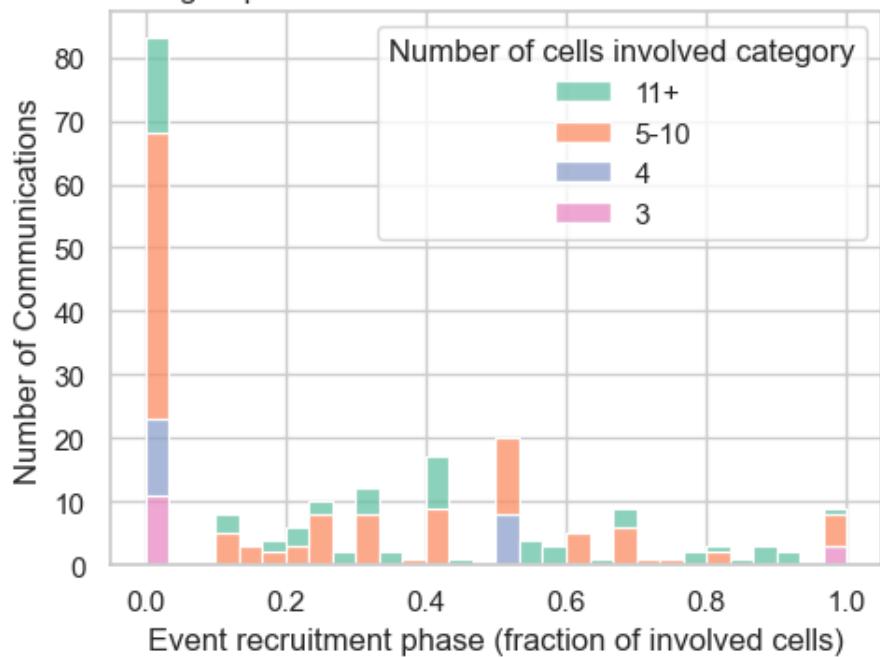


[2025-08-27 15:17:06] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 213 on 'Event time phase (fraction of event duration)' (lower=-1.99, upper=2.84)

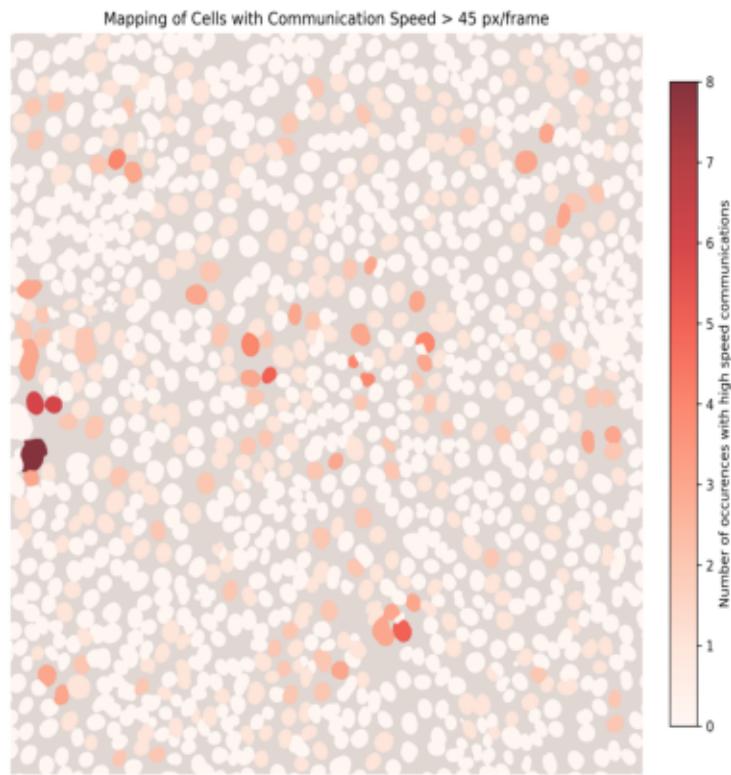


[2025-08-27 15:17:06] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 213 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)

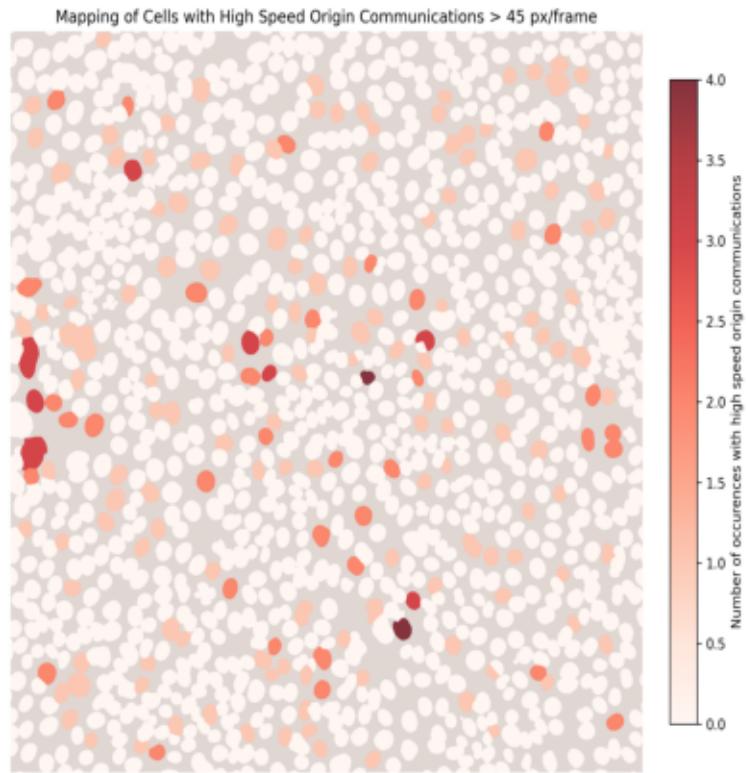
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



Cell Mapping with High Speed Cells Overlay



Cell Mapping with High Speed Origin Cells Overlay



	Communication ID	Event ID	Origin cell ID	Origin cell peak ID	\
12	2016568408912	8	547	0	
41	2018680340096	11	757	2	
48	2018680326944	12	867	2	
50	2018680326656	12	952	2	
51	2018680339952	12	952	2	
...	
3379	2018409056576	912	1614	2	
3382	2018409054704	913	1701	3	
3400	2018409056288	917	1674	8	
3426	2016987874688	930	1717	1	
3502	2016581384128	974	1758	3	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
12	570	0	25.0	26.0	
41	768	1	141.0	141.0	
48	952	2	135.0	135.0	
50	1000	2	135.0	135.0	
51	1016	2	135.0	135.0	
...	
3379	1628	1	172.0	173.0	
3382	1640	3	169.0	170.0	
3400	1630	6	1106.0	1107.0	
3426	1685	1	88.0	89.0	
3502	1790	3	235.0	236.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
12	1.0	20.35	20.35		
41	0.0	16.32	16.32		
48	0.0	24.13	24.13		
50	0.0	18.59	18.59		
51	0.0	22.25	22.25		
...	
3379	1.0	18.37	18.37		
3382	1.0	16.90	16.90		
3400	1.0	16.55	16.55		
3426	1.0	16.59	16.59		
3502	1.0	17.67	17.67		
	Event time phase (fraction of event duration)	\			
12		0.16			
41		1.00			
48		0.72			
50		0.72			
51		0.72			
...		...			
3379		0.25			
3382		0.14			
3400		1.00			
3426		0.05			
3502		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
12		0.21	20250701_IS6		
41		0.67	20250701_IS6		
48		0.56	20250701_IS6		
50		0.56	20250701_IS6		
51		0.56	20250701_IS6		
...			
3379		0.50	20250701_IS6		
3382		0.00	20250701_IS6		

3400		1.00	20250701_IS6
3426		0.00	20250701_IS6
3502		NaN	20250701_IS6

	Number of cells involved	category	Speed category
12		11+	High speed
41		5-10	High speed
48		11+	High speed
50		11+	High speed
51		11+	High speed
...
3379		4	High speed
3382		4	High speed
3400		5-10	High speed
3426		5-10	High speed
3502		2	High speed

[224 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
247		0	1
250		0	5
253		0	1
254		0	2
255		0	2
...
1781		0	1
1785		1	1
1787		0	2
1790		0	1
1791		0	1

[969 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	247	72.80		5.53
2	250	91.65		7.48
3	253	230.10		8.45
4	254	209.30		8.78
5	255	368.55		9.43
...
1074	1781	59.48		488.80
1076	1785	286.00		490.10
1077	1787	359.45		491.40
1078	1790	229.45		492.05
1079	1791	407.23		491.73

Number of peaks Is active Occurrences in global events \

0	11	True	5
2	19	True	6
3	17	True	6
4	17	True	6
5	15	True	6
...
1074	11	True	5
1076	16	True	6
1077	11	True	6
1078	10	True	5
1079	10	True	6
Occurrences in global events as early peaker Early peaker event IDs \			
0		1	[4]
2		2	[2, 4]
3		2	[4, 5]
4		1	[4]
5		2	[1, 3]
...
1074		0	[]
1076		1	[1]
1077		0	[]
1078		0	[]
1079		0	[]
Occurrences in sequential events \			
0		5	
2		8	
3		3	
4		3	
5		3	
...	
1074		3	
1076		4	
1077		2	
1078		2	
1079		1	
Occurrences in sequential events as origin \			
0		1	
2		3	
3		1	
4		2	
5		1	
...	
1074		1	
1076		2	
1077		1	

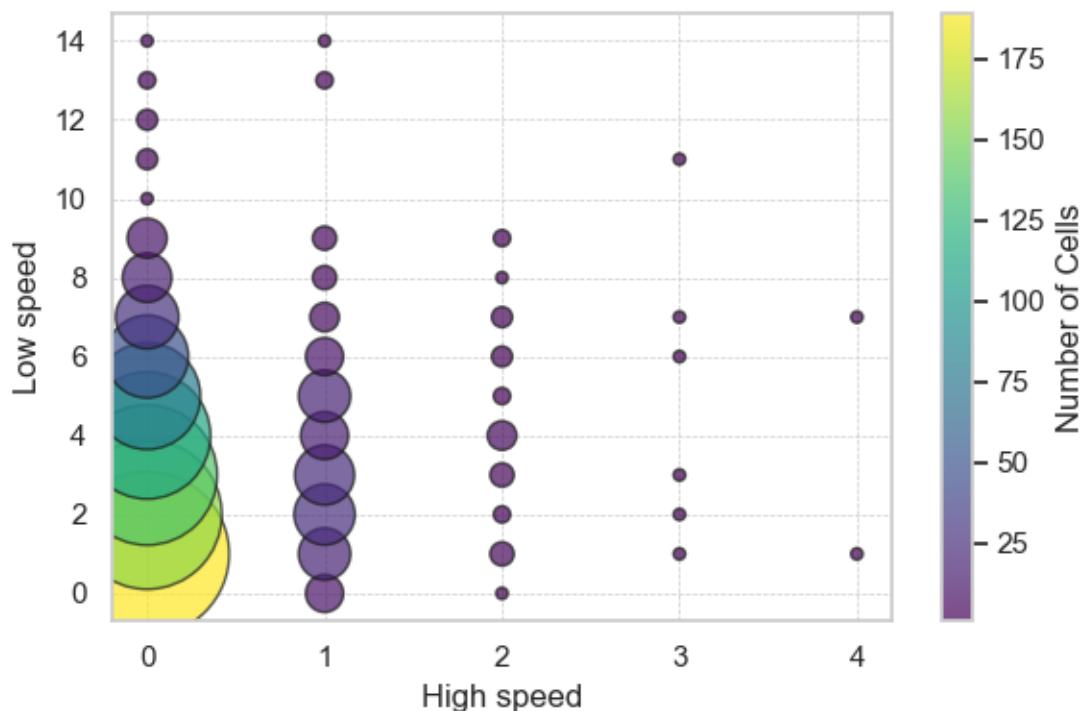
1078		0	
1079		1	
Occurrences in individual events Peak frequency (Hz) \			
0	1	0.0065	
2	1	0.0110	
3	3	0.0100	
4	3	0.0100	
5	1	0.0088	
...
1074	3	0.0065	
1076	3	0.0094	
1077	2	0.0065	
1078	3	0.0059	
1079	1	0.0059	
Periodicity score Neighbor count Neighbors (labels) dataset \			
0	0.71	2	[274,288] 20250701_IS6
2	0.61	3	[266,274,311] 20250701_IS6
3	0.61	3	[259,264,296] 20250701_IS6
4	0.66	3	[264,277,292] 20250701_IS6
5	0.69	3	[280,294,299] 20250701_IS6
...
1074	0.57	3	[1730,1745,1771] 20250701_IS6
1076	0.60	2	[1733,1741] 20250701_IS6
1077	0.72	3	[1748,1756,1768] 20250701_IS6
1078	0.59	2	[1750,1758] 20250701_IS6
1079	0.76	3	[1735,1746,1773] 20250701_IS6
Involved in sequential event Occurrences in sequential events category \			
0	Involved in sequential event		5-9
2	Involved in sequential event		5-9
3	Involved in sequential event		3-4
4	Involved in sequential event		3-4
5	Involved in sequential event		3-4
...
1074	Involved in sequential event		3-4
1076	Involved in sequential event		3-4
1077	Involved in sequential event		1-2
1078	Involved in sequential event		1-2
1079	Involved in sequential event		1-2
High speed Low speed			
0	0.0	1.0	
2	0.0	5.0	
3	0.0	1.0	
4	0.0	2.0	
5	0.0	2.0	

```

...
1074      0.0      1.0
1076      1.0      1.0
1077      0.0      2.0
1078      0.0      1.0
1079      0.0      1.0

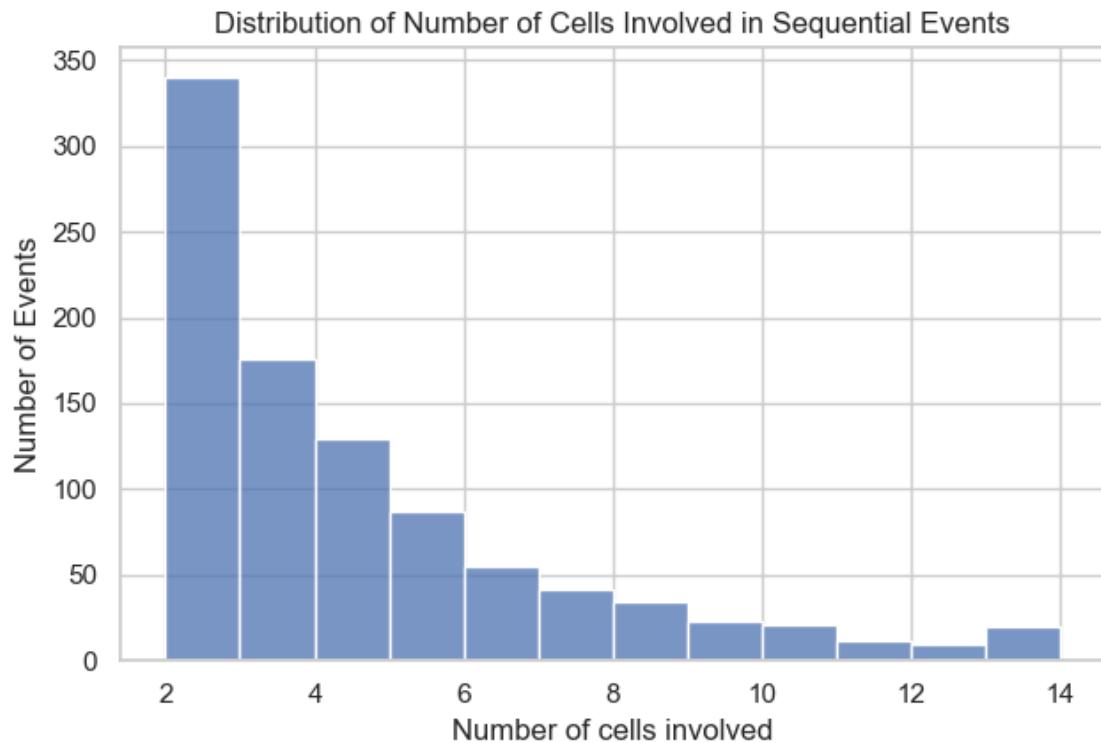
```

[969 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

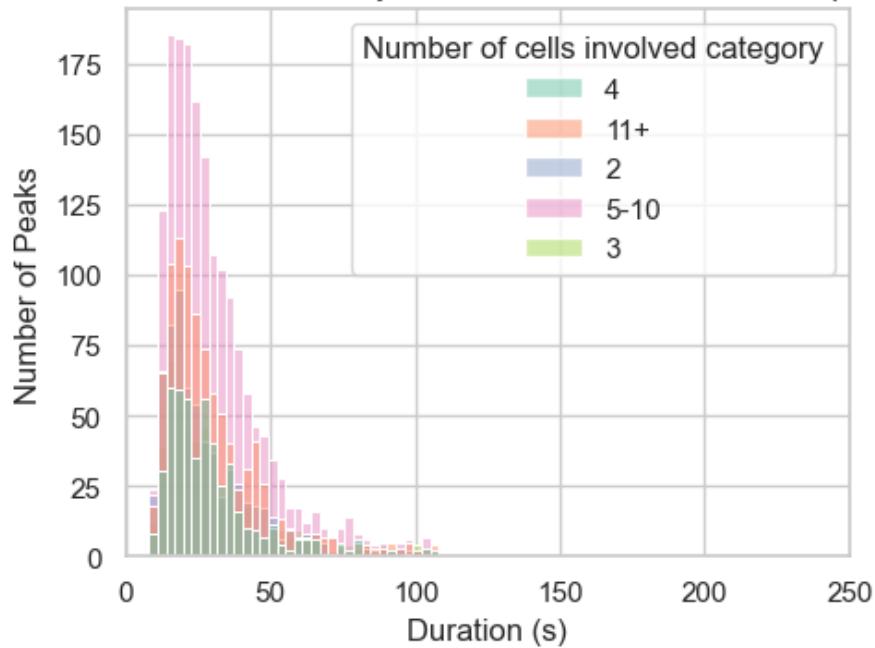
[2025-08-27 15:17:08] [INFO] calcium: plot_histogram: removed 19 outliers out of 968 on 'Number of cells involved' (lower=-7, upper=14)



1.3.6 Influence of cell count per event on statistics

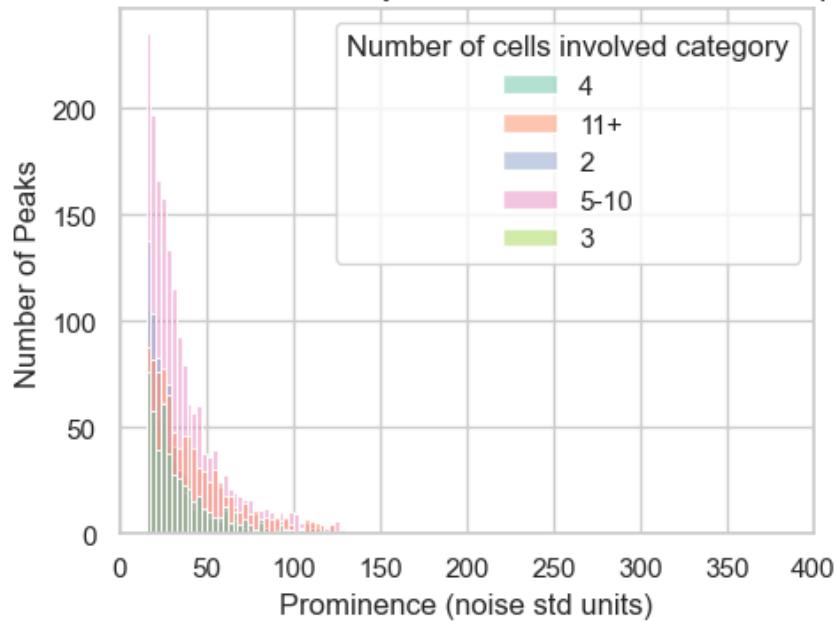
```
[2025-08-27 15:17:08] [INFO] calcium: plot_histogram_by_group: removed 98
outliers out of 4471 on 'Duration (s)' (lower=-12, upper=108)
```

Distribution of Peak Durations by Number of Cells Involved in Sequential Events

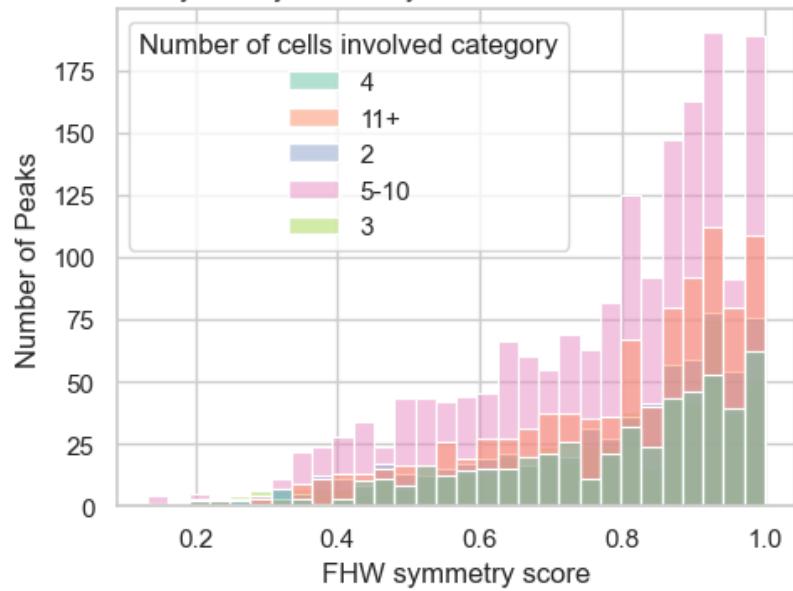


```
[2025-08-27 15:17:09] [INFO] calcium: plot_histogram_by_group: removed 107 outliers out of 4471 on 'Prominence (noise std units)' (lower=-16.2, upper=131.4)
```

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

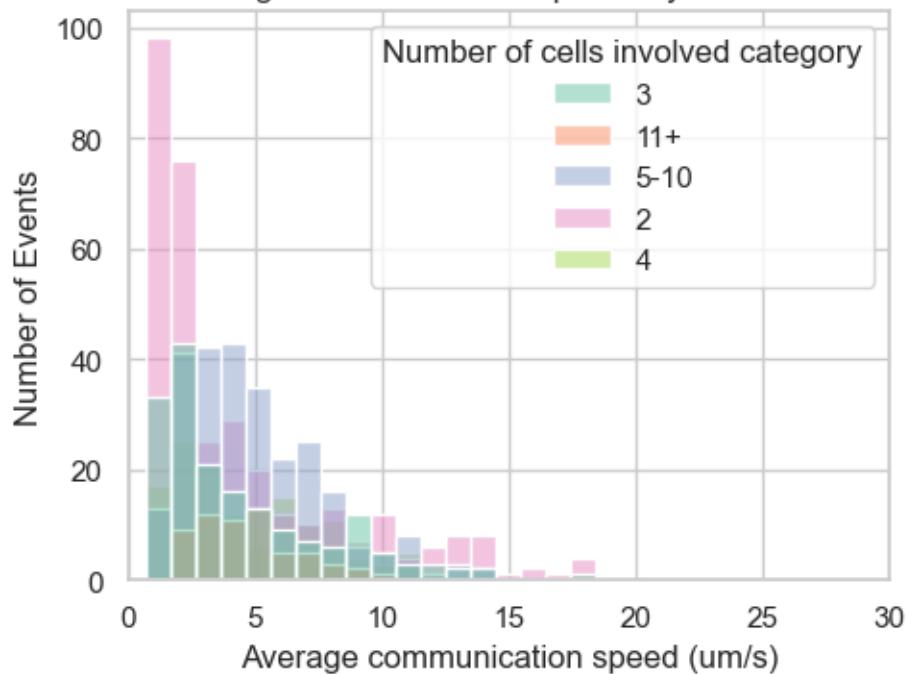


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



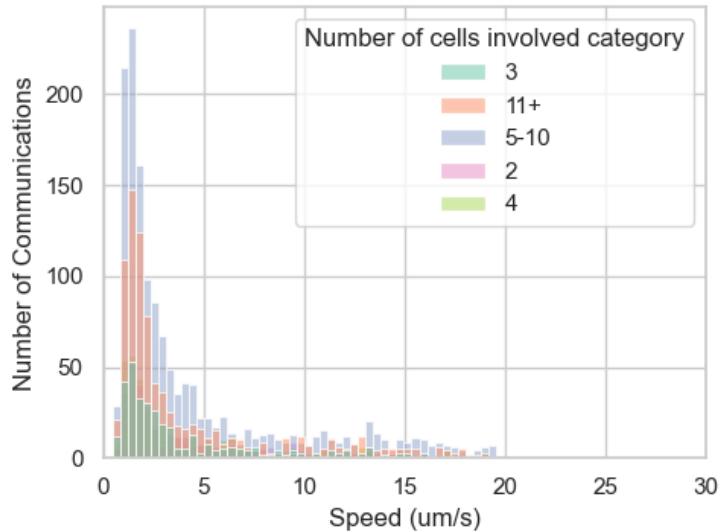
```
[2025-08-27 15:17:09] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 968 on 'Average communication speed (um/s)' (lower=-11.02, upper=19.447)
```

Distribution of Average Communication Speeds by Number of Cells Involved



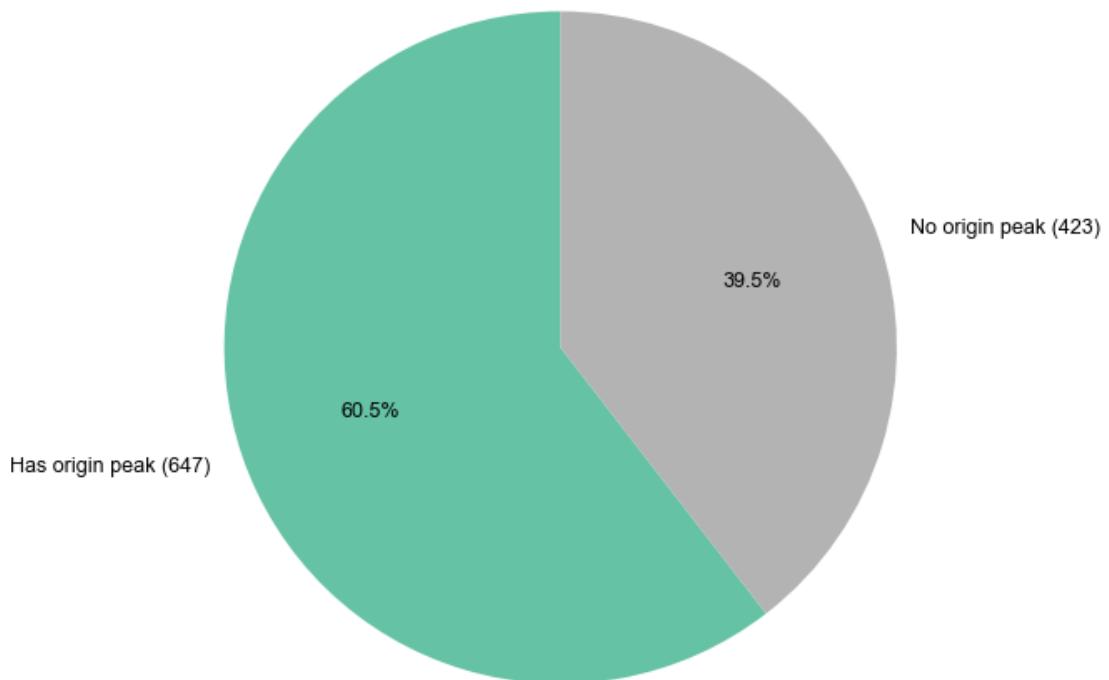
[2025-08-27 15:17:09] [INFO] calcium: plot_histogram_by_group: removed 71 outliers out of 3503 on 'Speed (um/s)' (lower=-12.165, upper=19.58)

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events

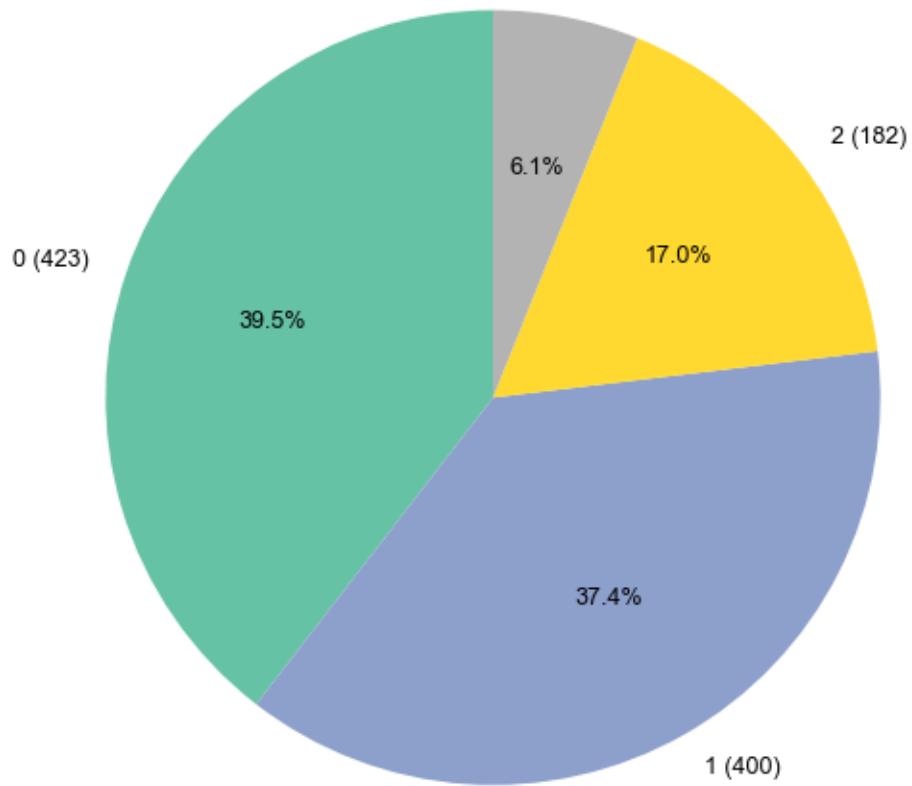


1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

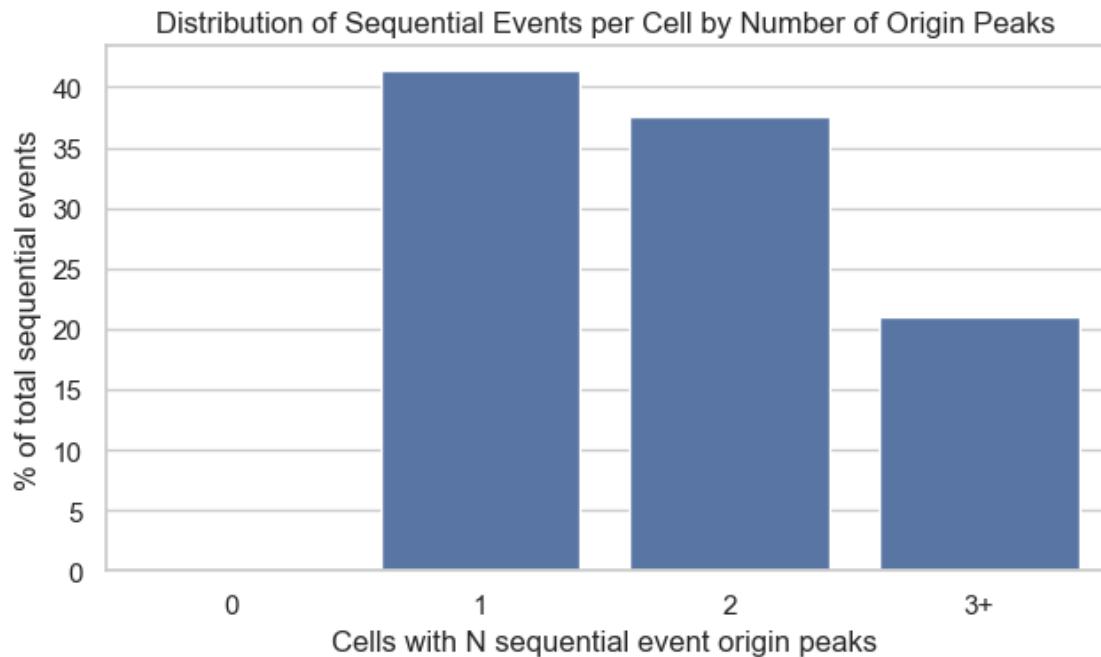


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



```
[2025-08-27 15:17:10] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250701\\Output\\IS6\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
```

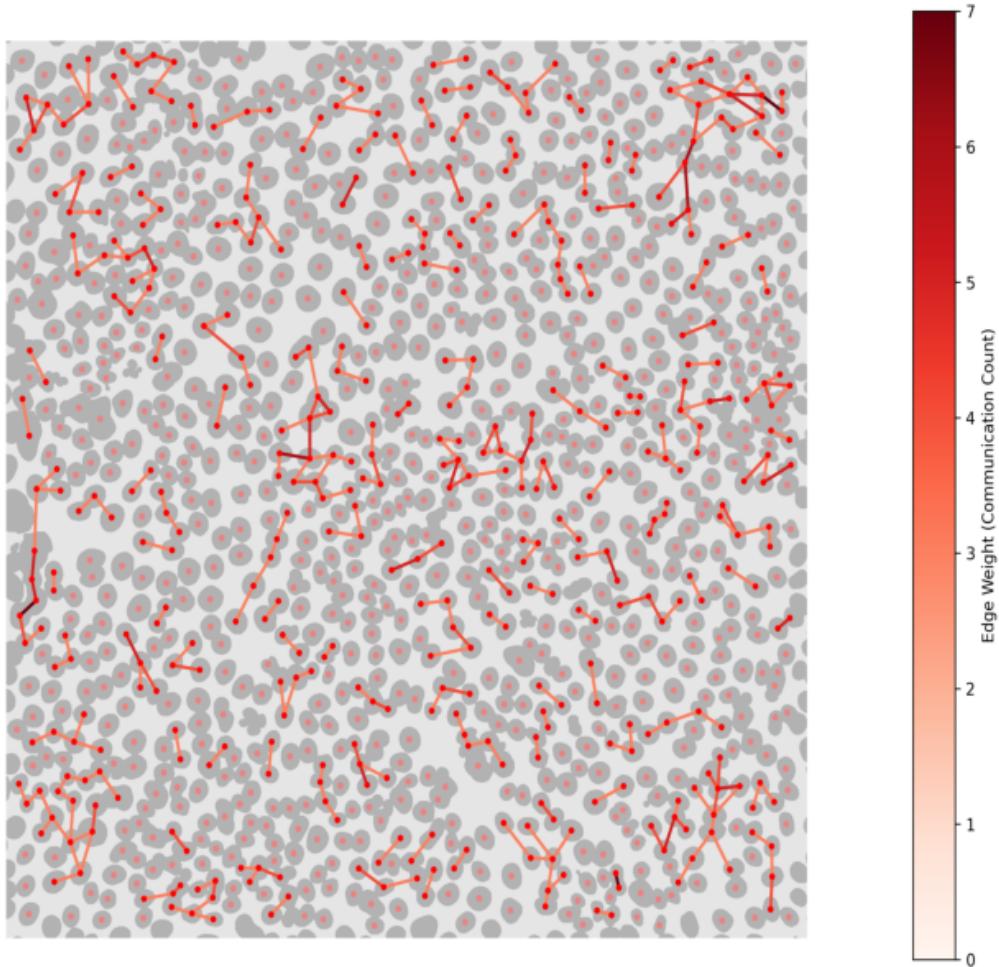
```
packages\PIL\ImageFile.py", line 132, in __init__  
    self.fp = open(fp, "rb")  
FileNotFoundException: [Errno 2] No such file or directory:  
'D:\Mateo\20250701\Output\\IS6\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```



1.3.8 Connection network between cells

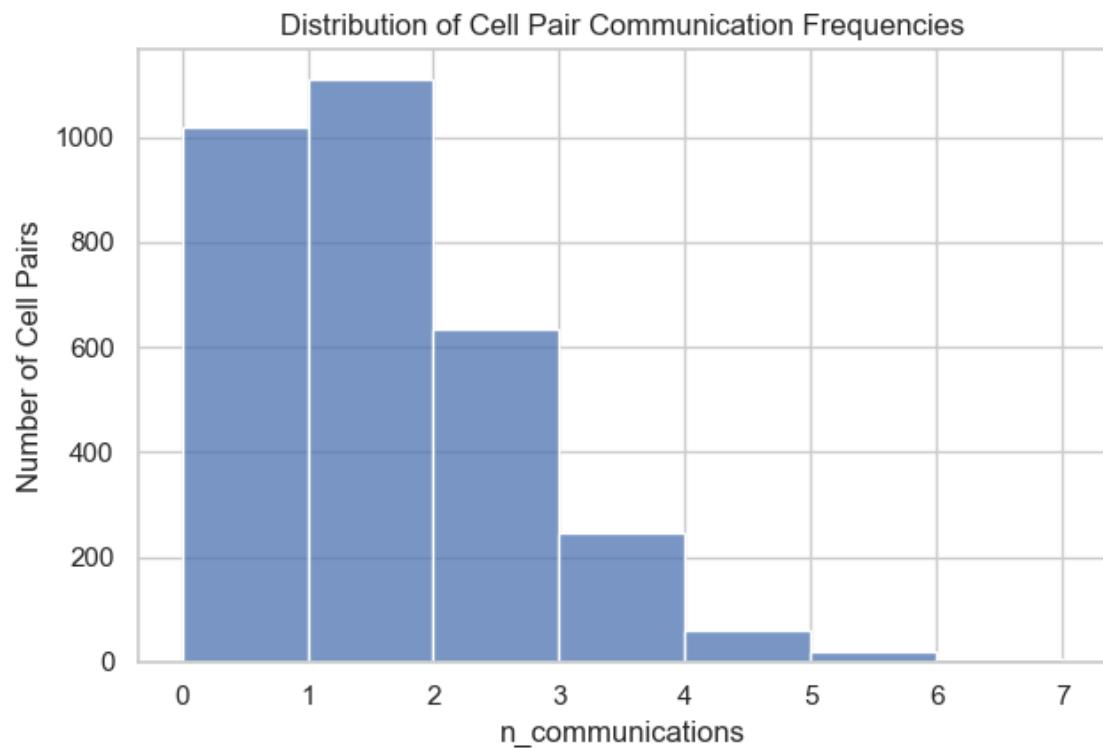
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



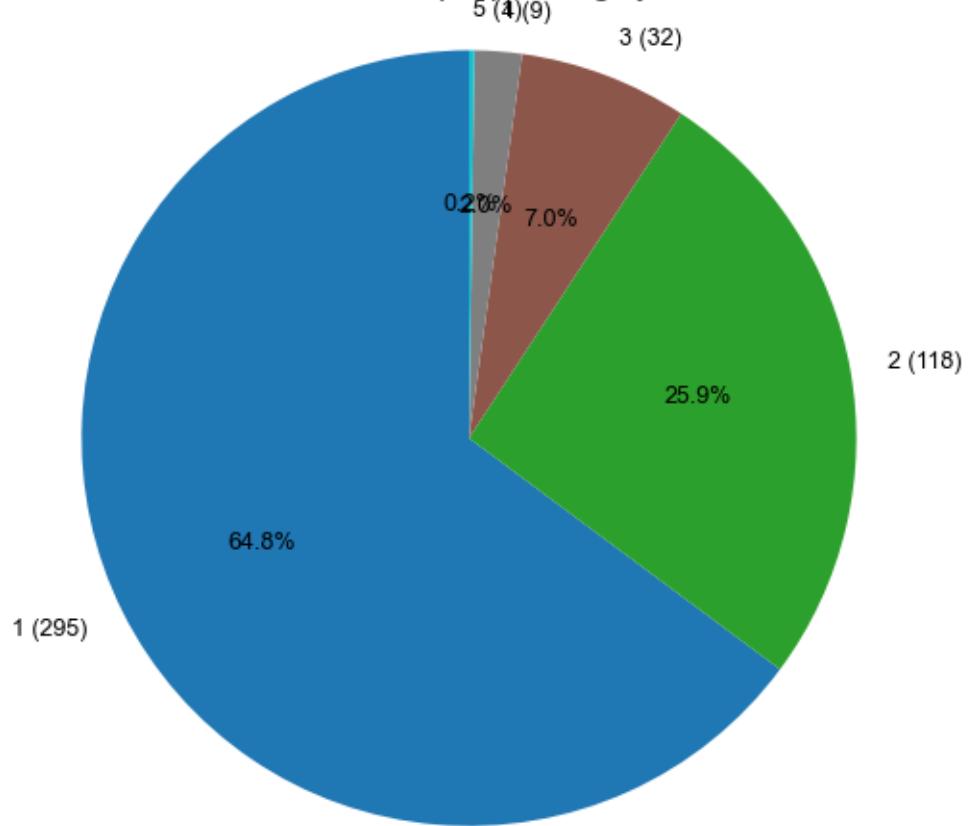
1.3.9 Pair/Trios with high communication networks

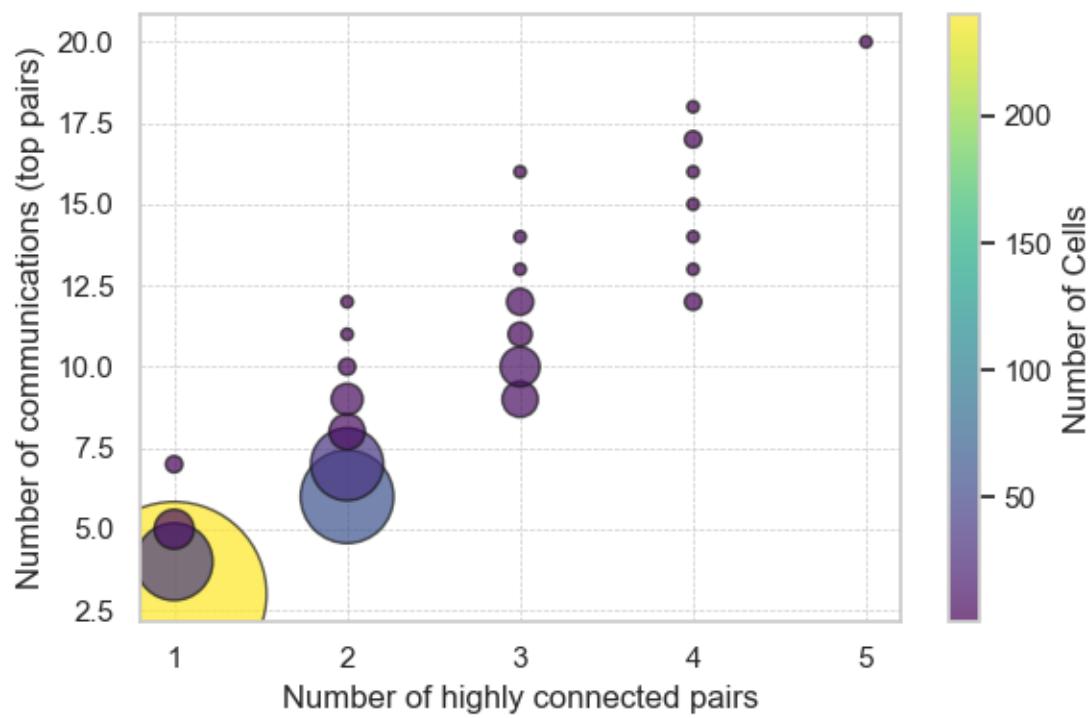
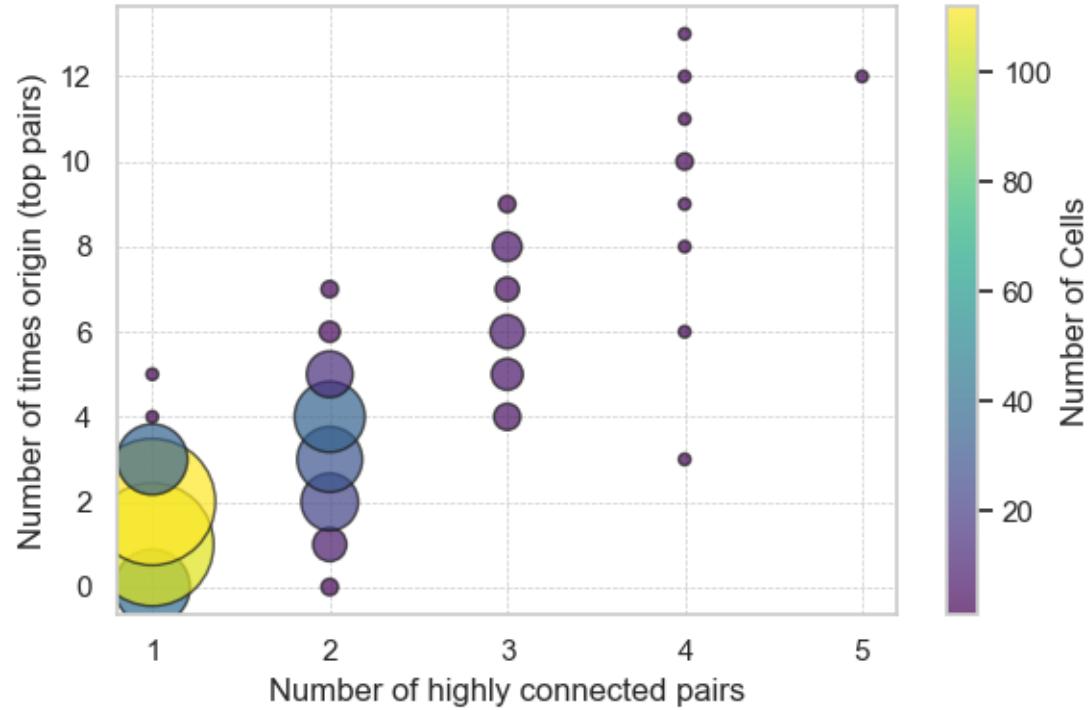
```
[2025-08-27 15:17:12] [INFO] calcium: build_neighbor_pair_stats: built 3097  
pairs across 1 datasets (mean distance=16.52 um)
```

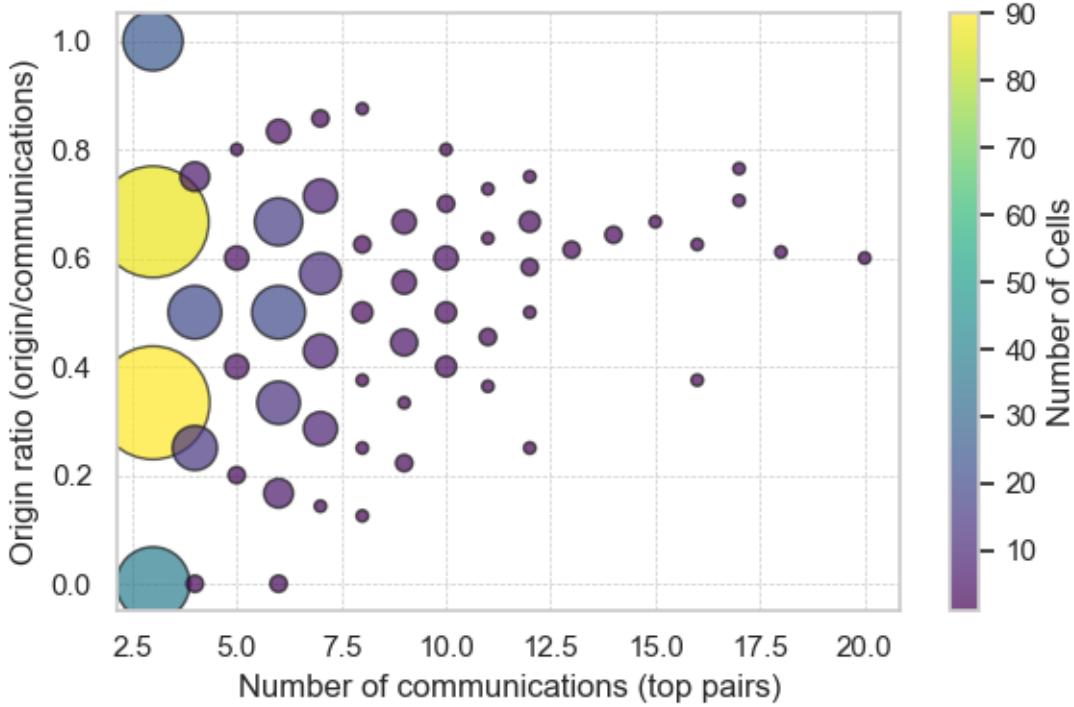
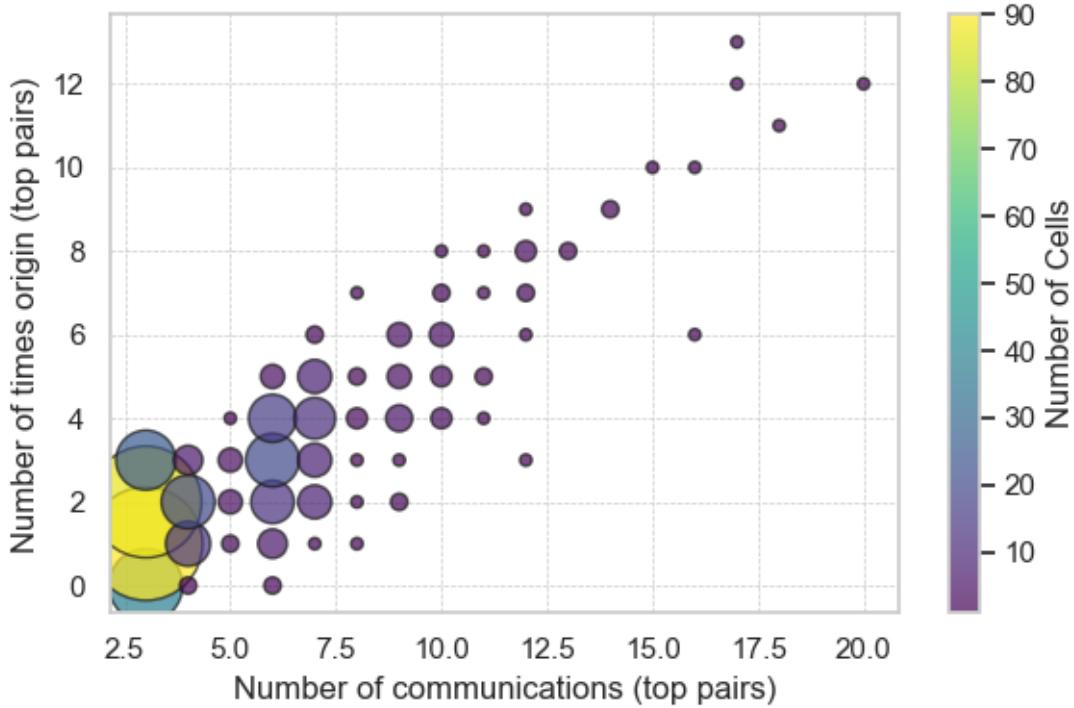


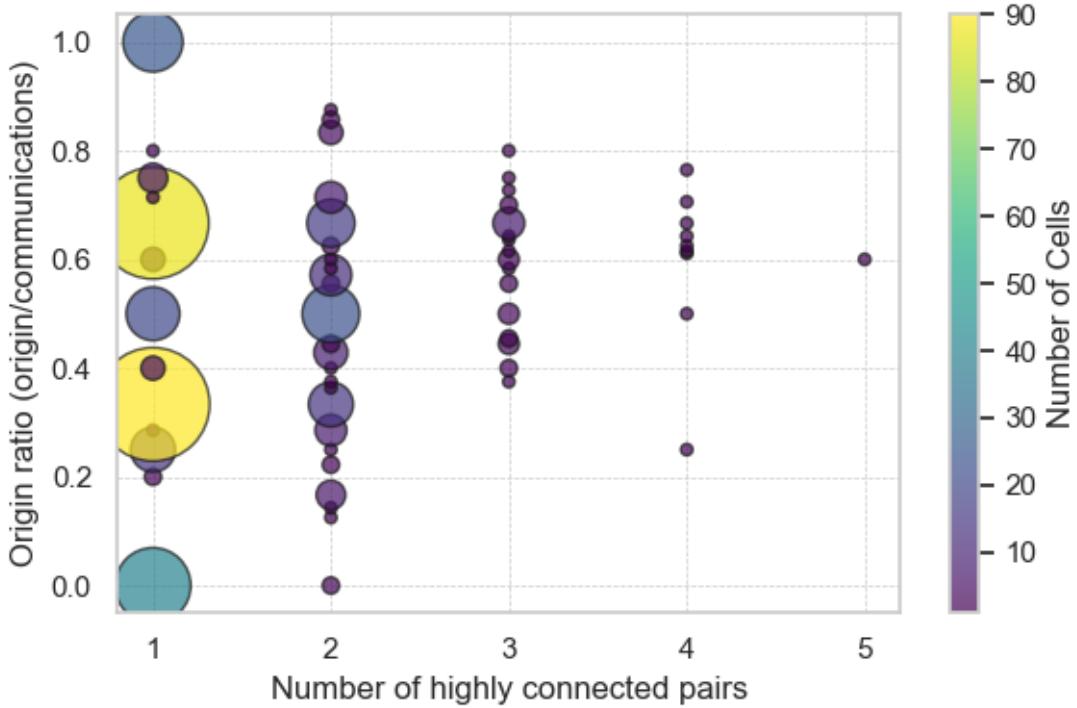
95th percentile threshold: 3.0

Cells involved in multiple pairs highly connected









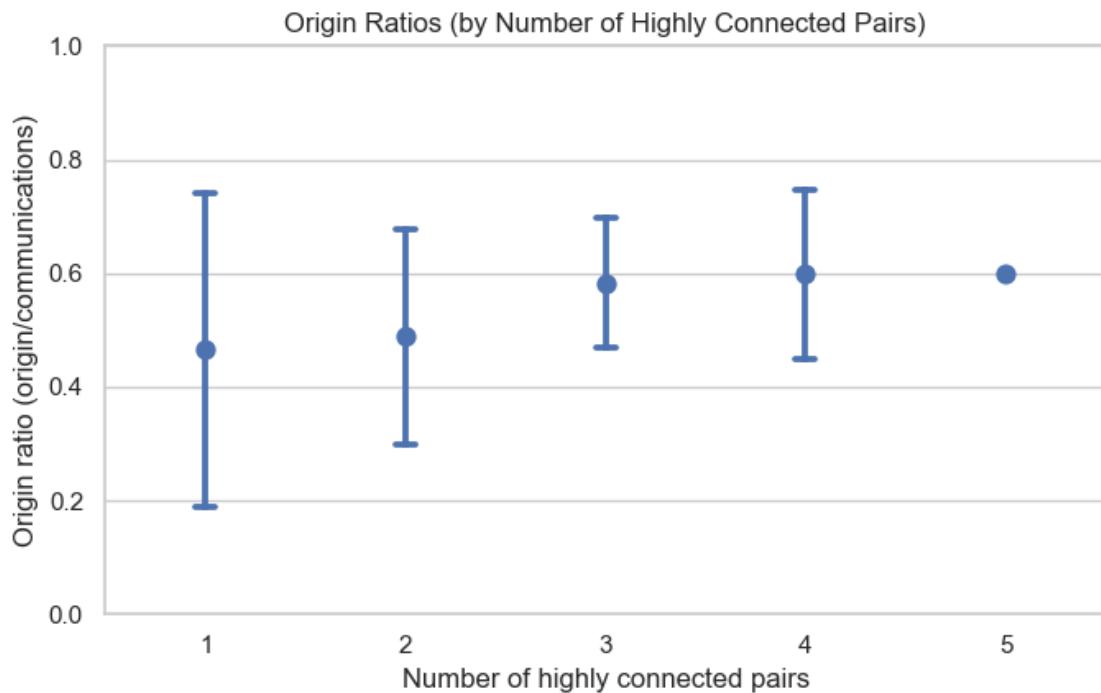
[2025-08-27 15:17:12] [INFO] calcium: plot_points_mean_std: N=295 for Number of highly connected pairs=1

[2025-08-27 15:17:12] [INFO] calcium: plot_points_mean_std: N=118 for Number of highly connected pairs=2

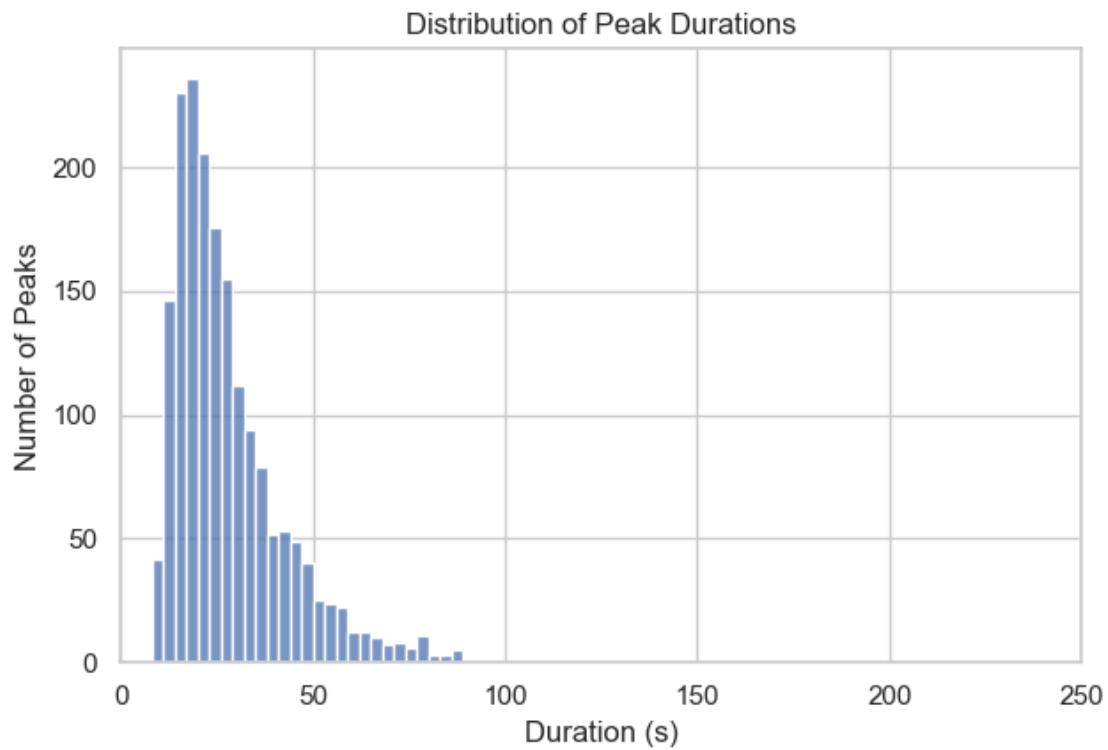
[2025-08-27 15:17:12] [INFO] calcium: plot_points_mean_std: N=32 for Number of highly connected pairs=3

[2025-08-27 15:17:12] [INFO] calcium: plot_points_mean_std: N=9 for Number of highly connected pairs=4

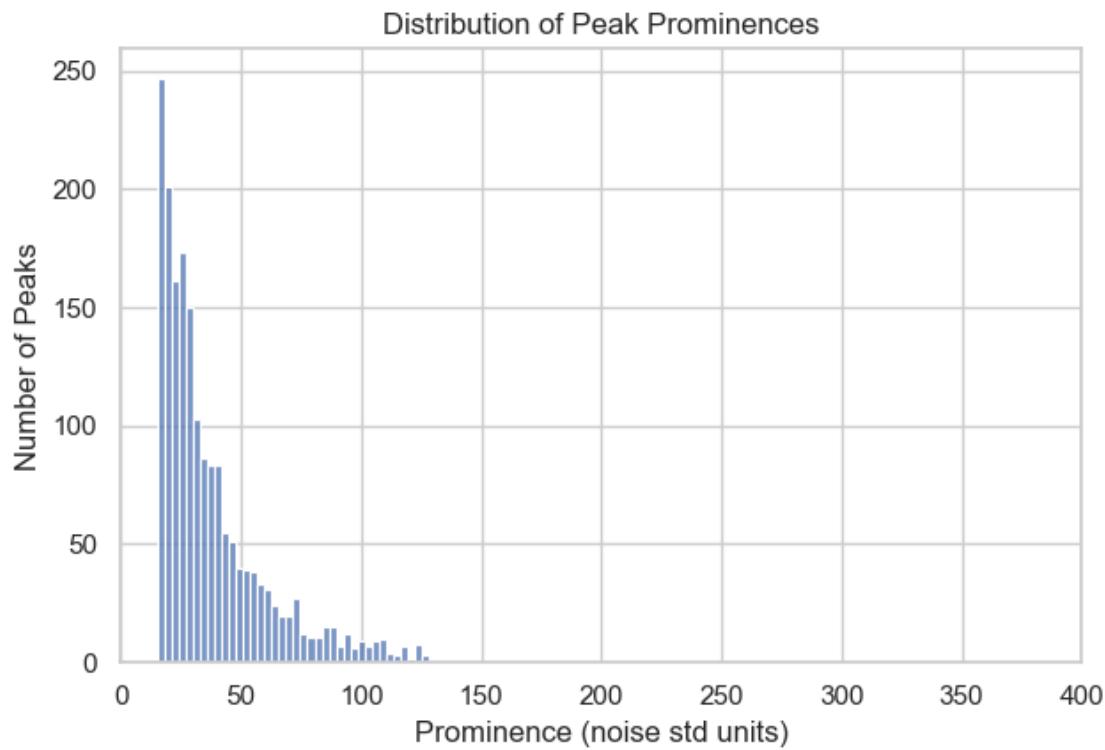
[2025-08-27 15:17:12] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=5

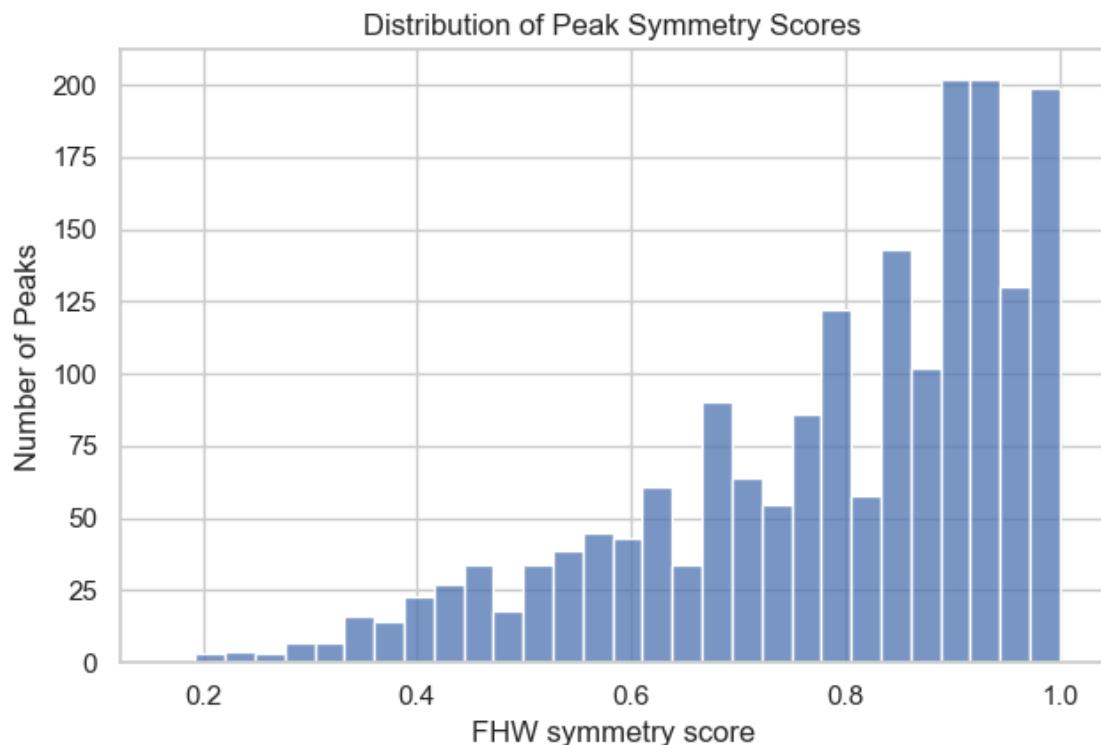


```
[2025-08-27 15:17:13] [INFO] calcium: plot_histogram: removed 48 outliers out of 1866 on 'Duration (s)' (lower=-37, upper=89)
```

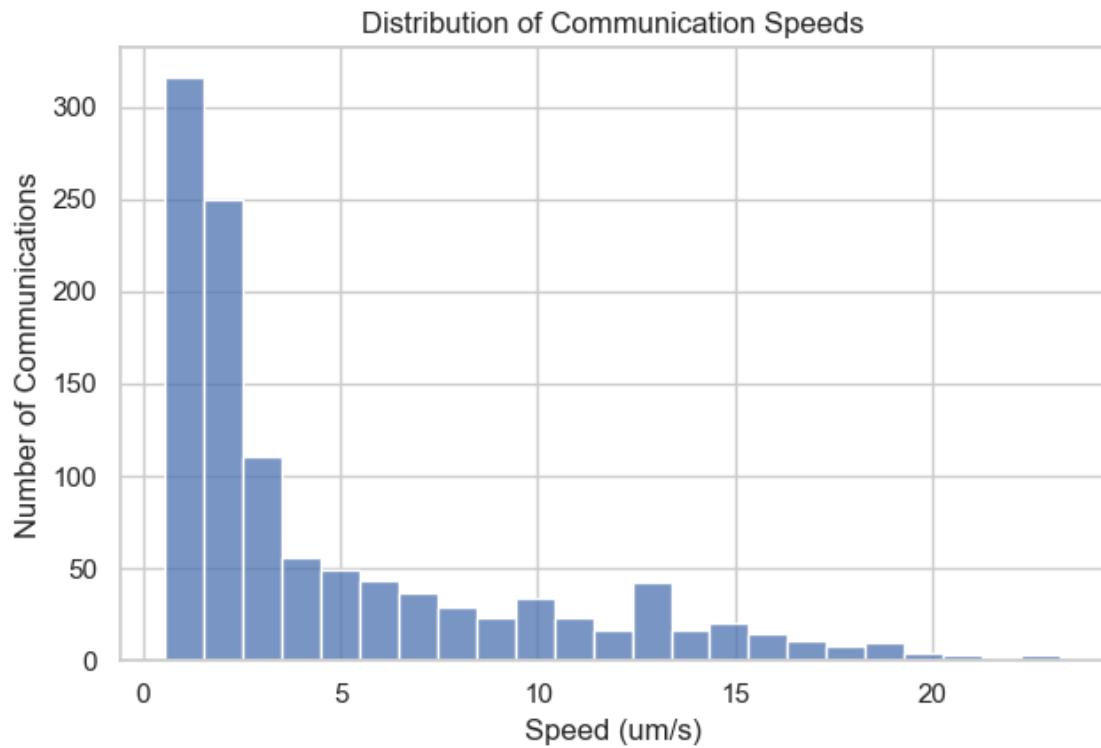


[2025-08-27 15:17:13] [INFO] calcium: plot_histogram: removed 50 outliers out of 1866 on 'Prominence (noise std units)' (lower=-59.5, upper=128.8)

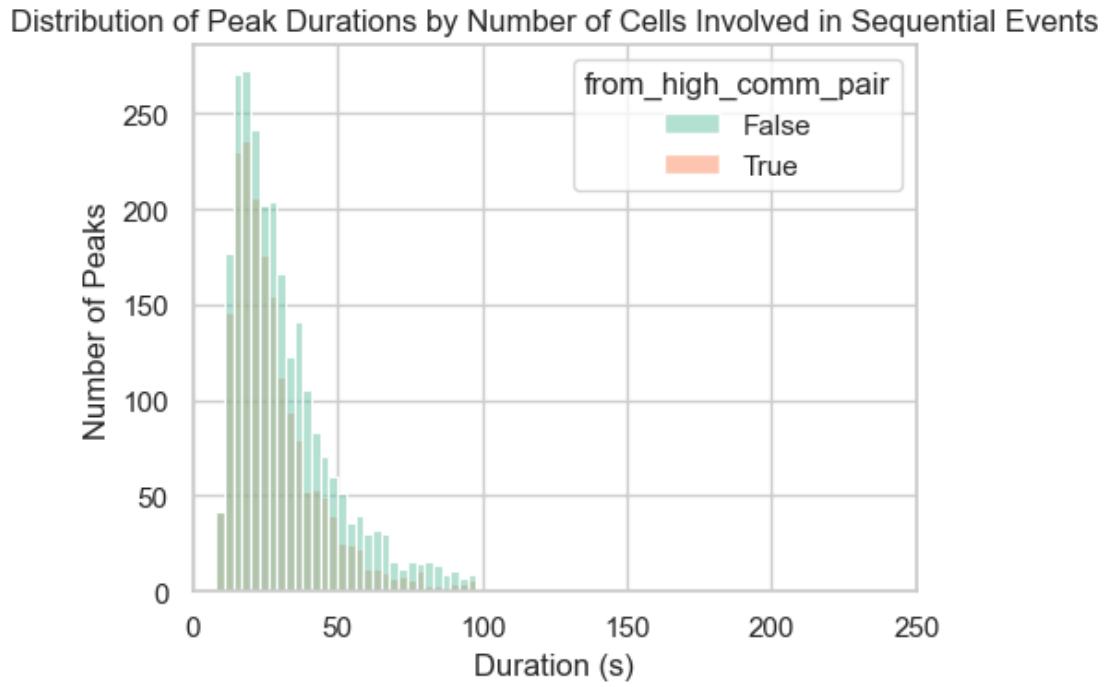




```
[2025-08-27 15:17:13] [INFO] calcium: plot_histogram: removed 5 outliers out of 1126 on 'Speed (um/s)' (lower=-14.905, upper=23.263)
```

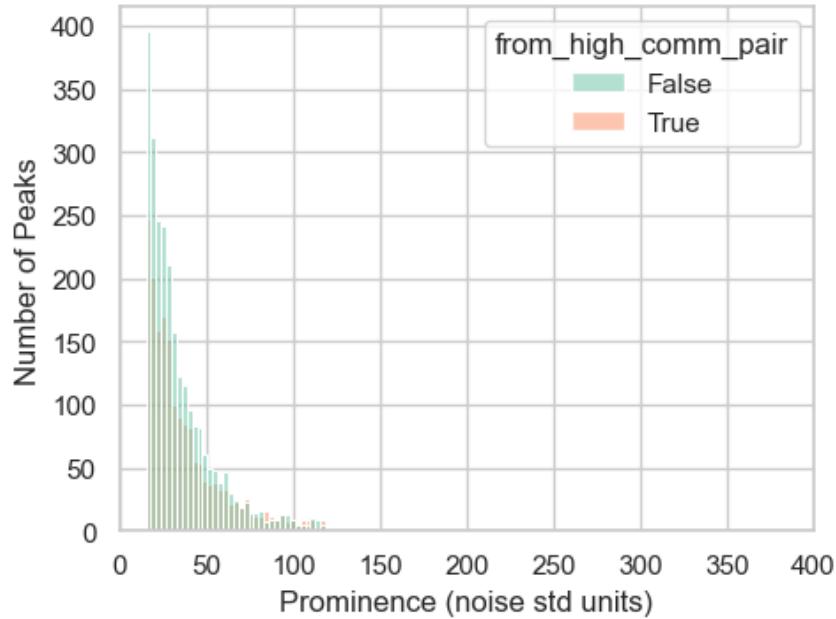


```
[2025-08-27 15:17:13] [INFO] calcium: plot_histogram_by_group: removed 139 outliers out of 4471 on 'Duration (s)' (lower=-42, upper=98)
```

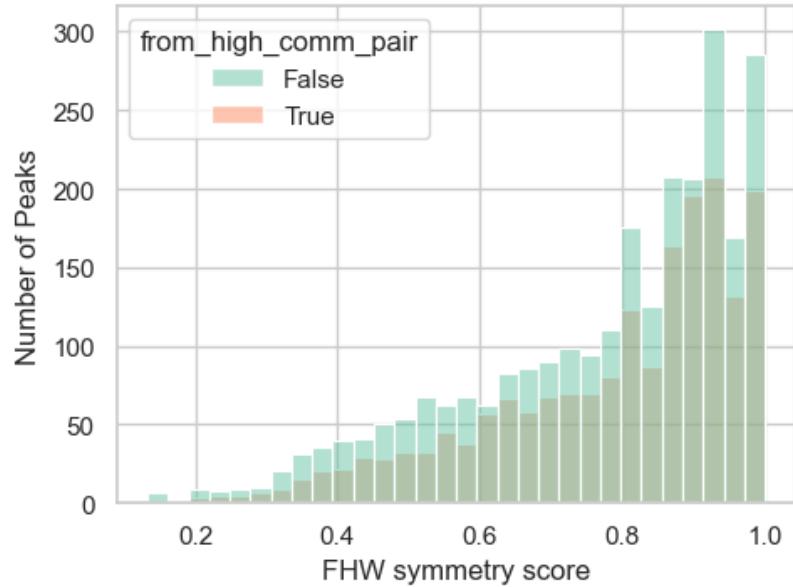


[2025-08-27 15:17:13] [INFO] calcium: plot_histogram_by_group: removed 134 outliers out of 4471 on 'Prominence (noise std units)' (lower=-53.1, upper=119.1)

Distribution of Peak Prominences by Number of Cells Involved in Sequential Events

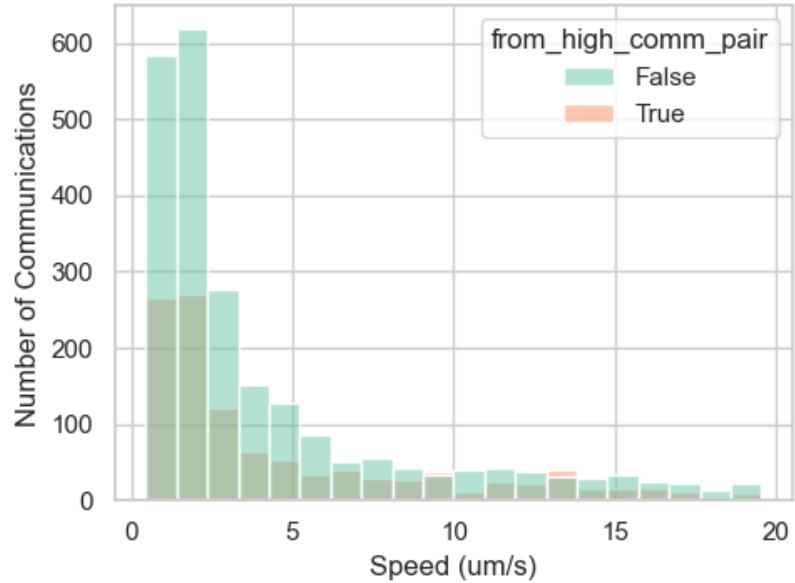


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:17:14] [INFO] calcium: plot_histogram_by_group: removed 71 outliers out of 3503 on 'Speed (um/s)' (lower=-12.165, upper=19.58)

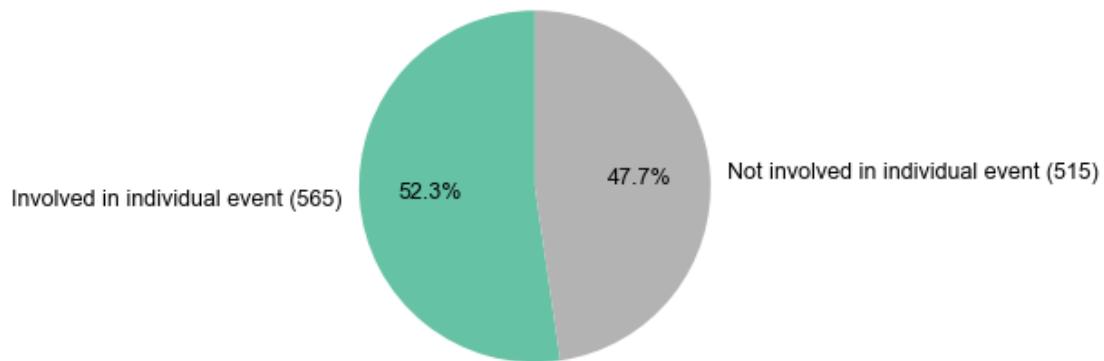
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



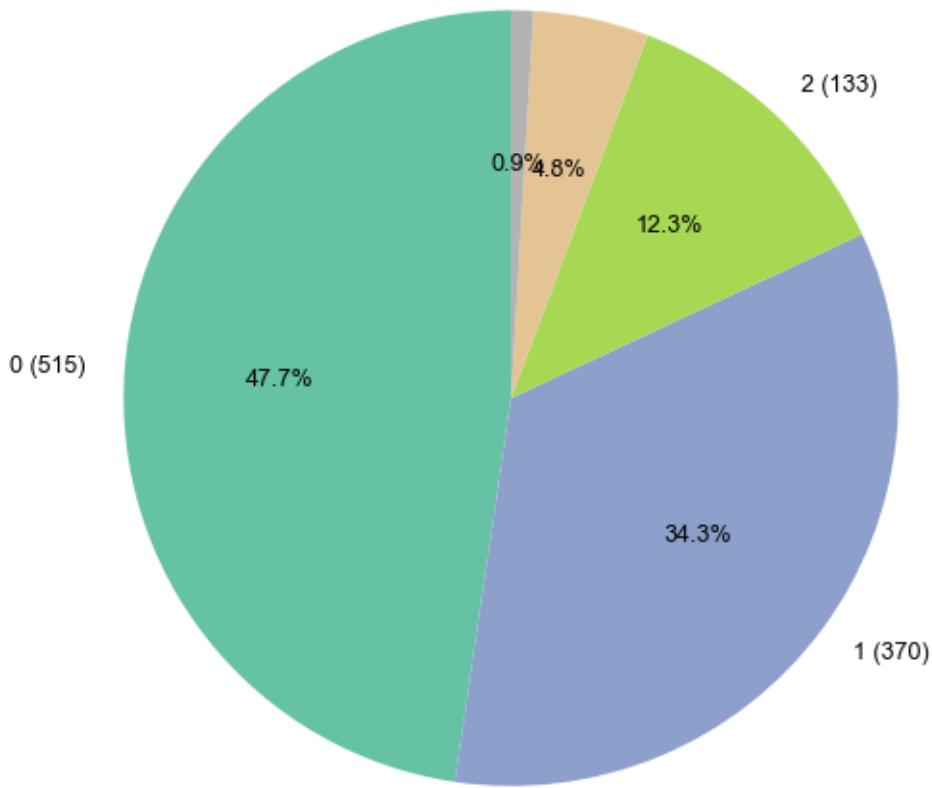
1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



Distribution of Individual Event Occurrences per Cell (0, 1, 2, 3, 4+)

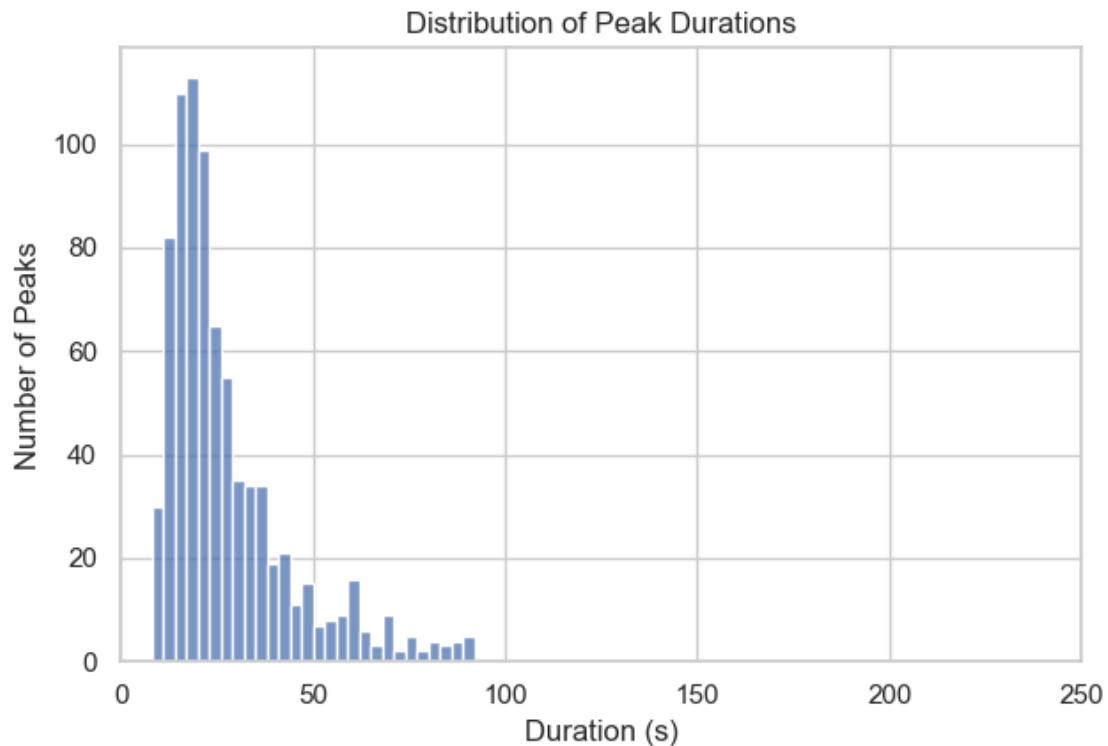


```
[2025-08-27 15:17:14] [ERROR] calcium: Failed to read image
'D:\Mateo\20250701\Output\IS6\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\\\20250701\\\\Output\\\\IS6\\\\cell-
mapping\\\\cell_occurrences_in_individual_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
n\analysis\visualizers.py", line 243, in visualize_image
    img = imread(img_path)
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\matplotlib\image.py", line 1512, in imread
    with img_open(fname) as image:
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\ImageFile.py", line 132, in __init__
    self.fp = open(fp, "rb")
FileNotFoundException: [Errno 2] No such file or directory:
```

'D:\\Mateo\\20250701\\Output\\IS6\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

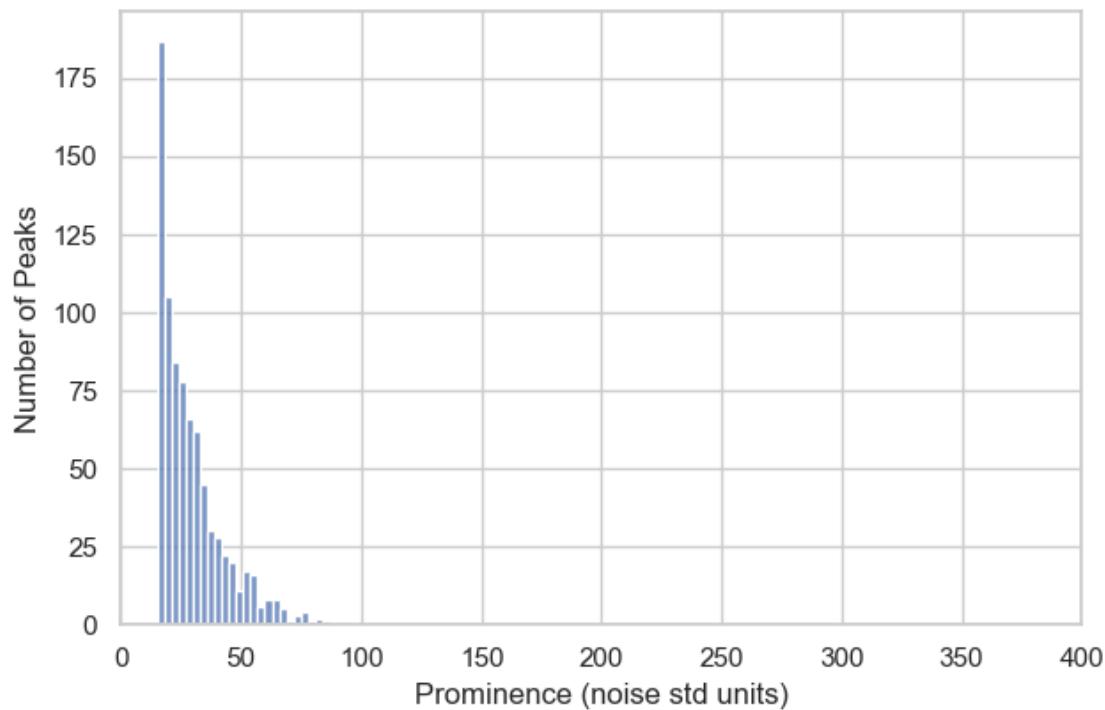
1.4.2 Peaks statistics in individual events

[2025-08-27 15:17:14] [INFO] calcium: plot_histogram: removed 29 outliers out of 835 on 'Duration (s)' (lower=-41, upper=92)

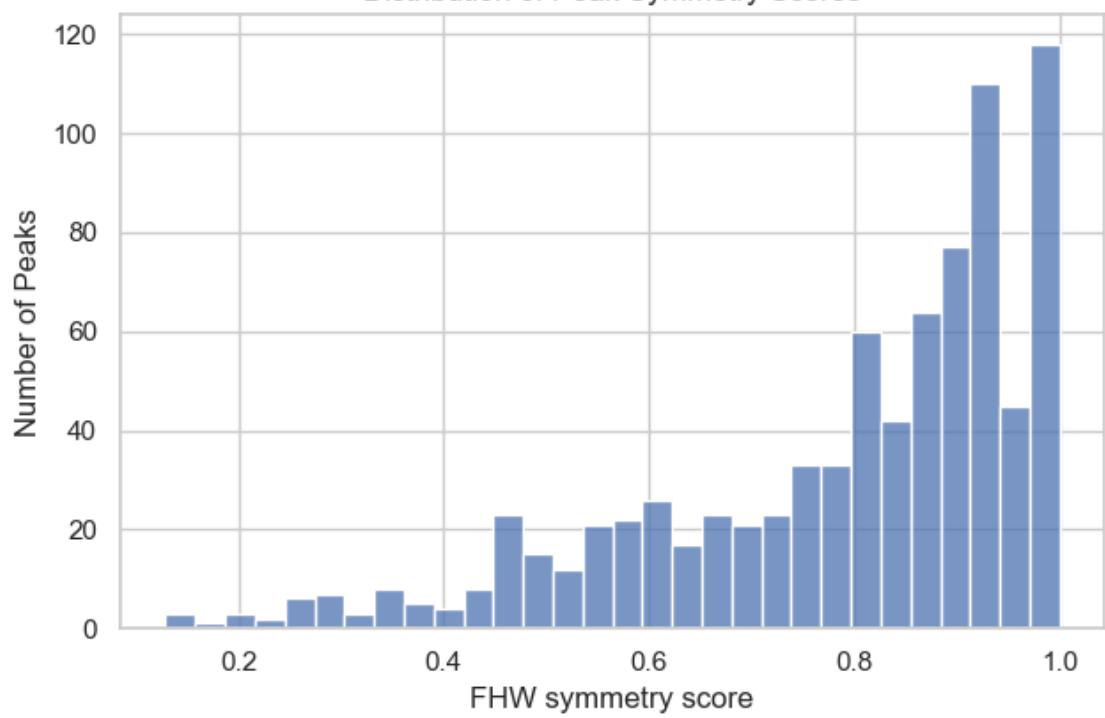


[2025-08-27 15:17:15] [INFO] calcium: plot_histogram: removed 25 outliers out of 835 on 'Prominence (noise std units)' (lower=-32.95, upper=87.45)

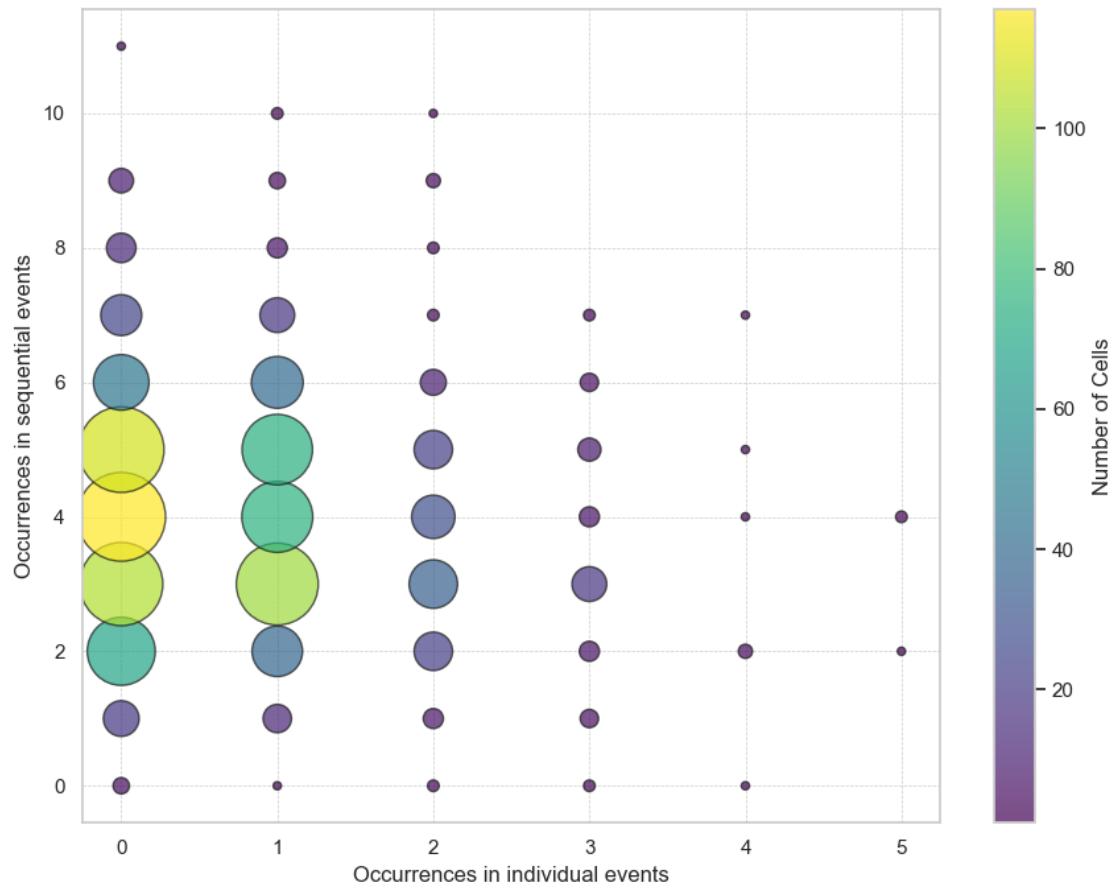
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: removed 0/1080 outliers on 'Occurrences in sequential events' (lower=-3, upper=11)
```

```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=515 for Occurrences in individual events=0
```

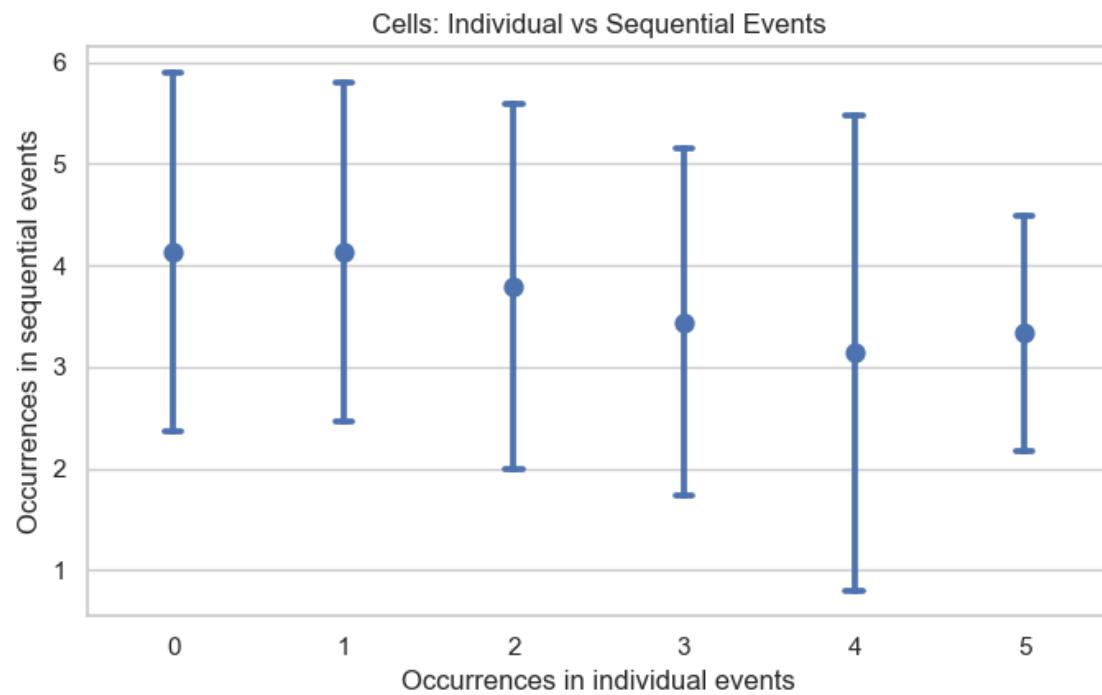
```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=370 for Occurrences in individual events=1
```

```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=133 for Occurrences in individual events=2
```

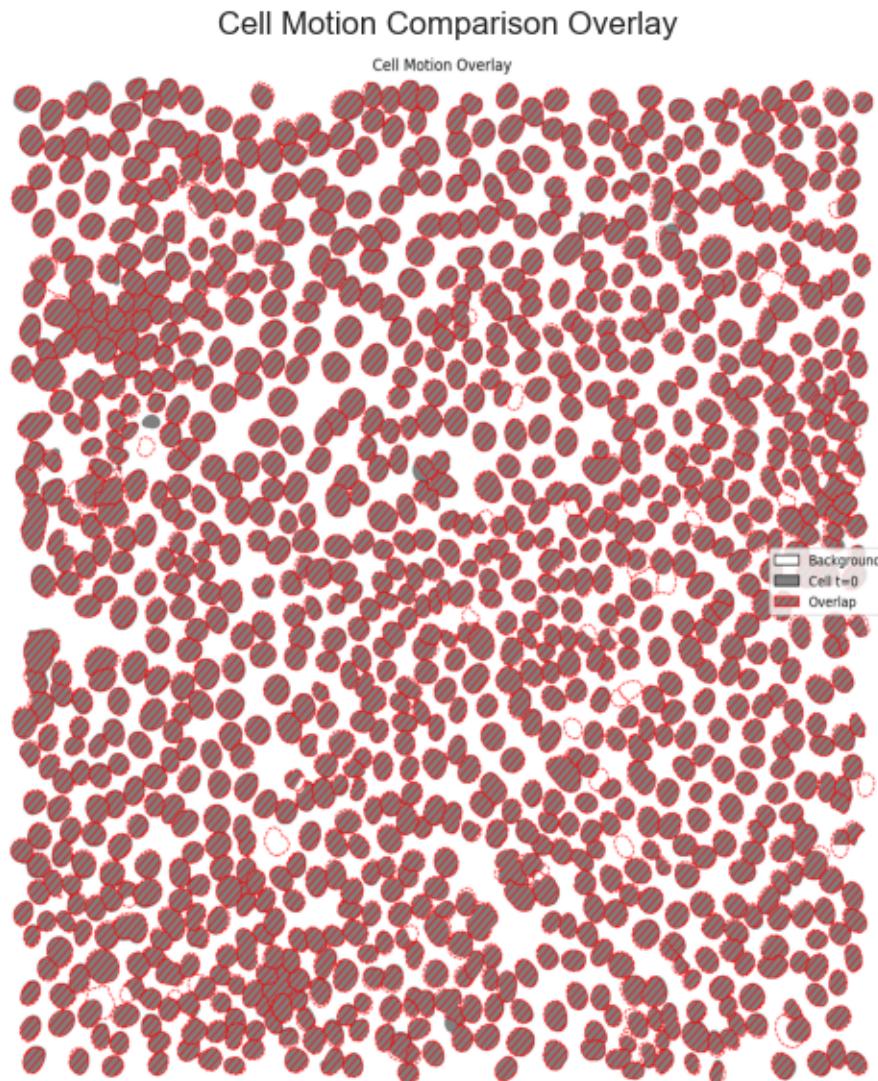
```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=52 for Occurrences in individual events=3
```

```
[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=7 for Occurrences in individual events=4
```

[2025-08-27 15:17:15] [INFO] calcium: plot_points_mean_std: N=3 for Occurrences in individual events=5



1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1080
- Hoechst image taken at t=1801: 1086
- Number of cells difference: absolute 6, relative 0.55%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1201430
- Pixels segmented as cell at t=1801: 1208512
- Overlapping pixels between t=0 and t=1801: 1128961 (93.69% of total)
- Pixels exclusive to t=0: 72469 (6.03% of total)
- Pixels exclusive to t=1801: 79551 (6.58% of total)