

executed

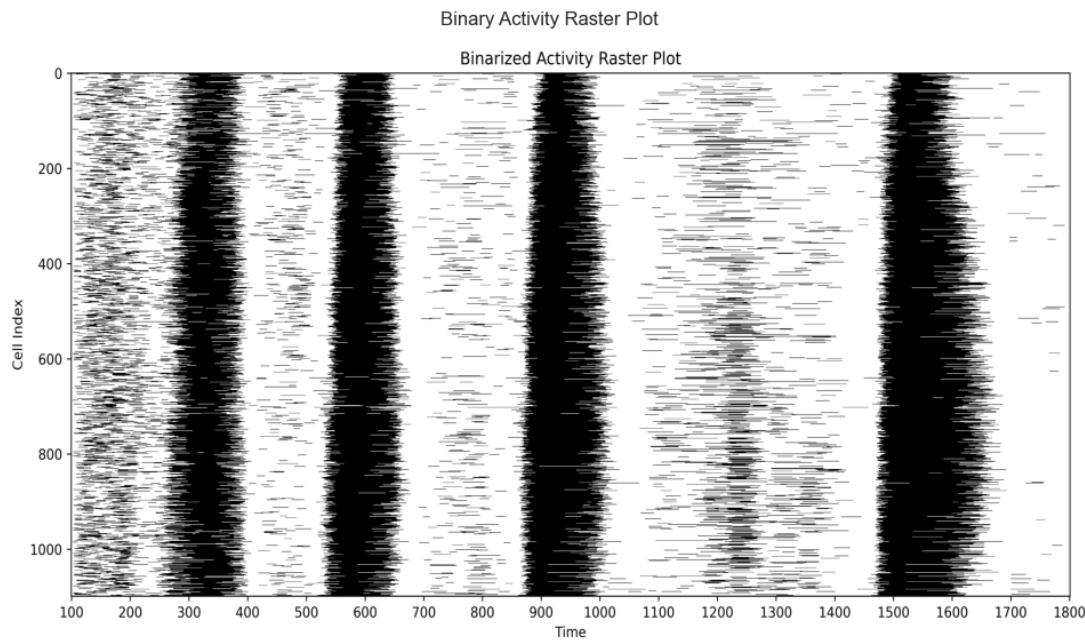
August 27, 2025

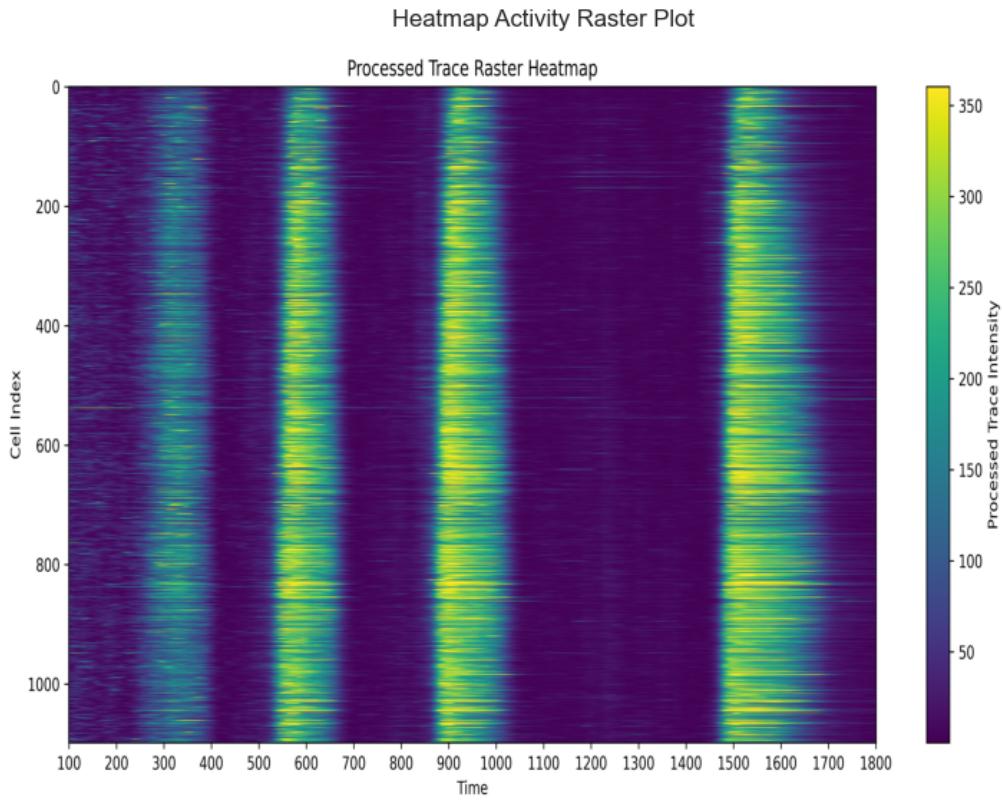
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





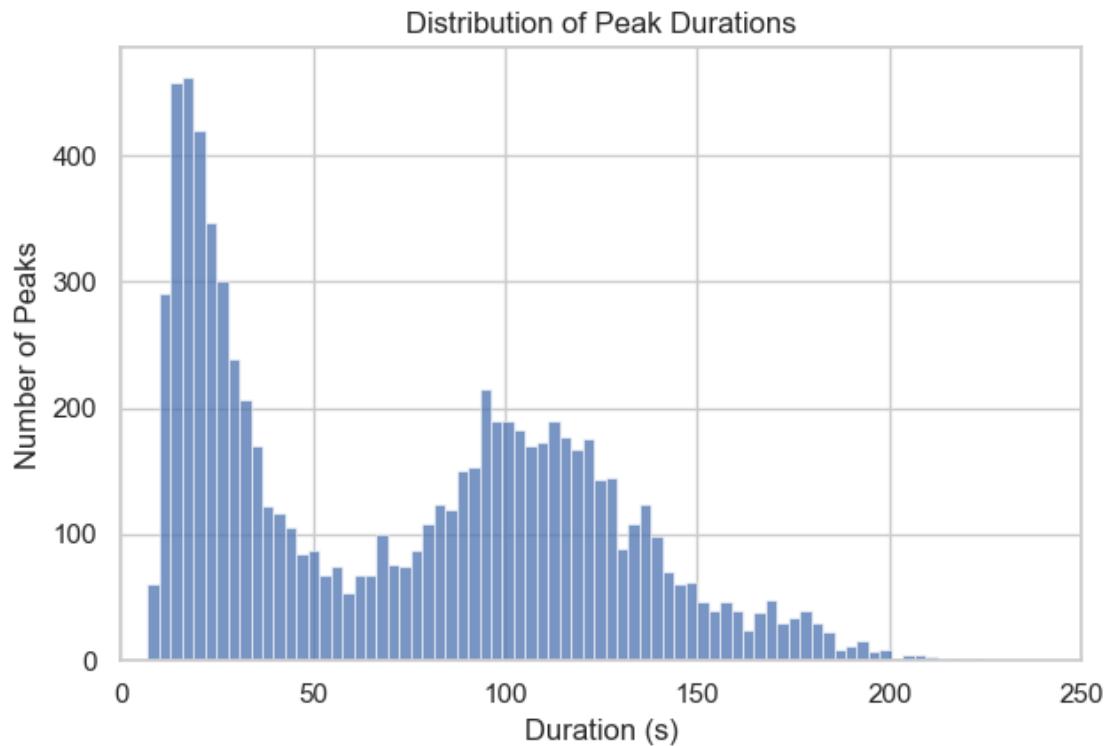
1.1.2 Peaks population

Total number of peaks: 8024

Total number of cells: 1099

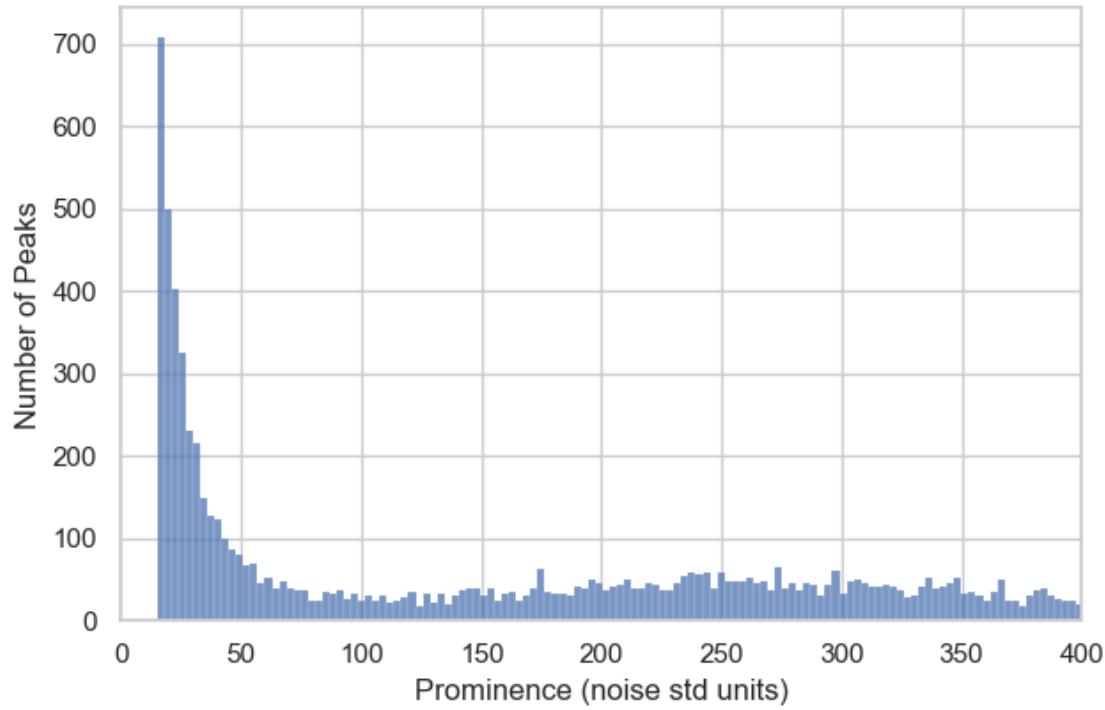
1.1.3 Peaks statistics

```
[2025-08-27 15:05:06] [INFO] calcium: plot_histogram: removed 0 outliers out of  
8024 on 'Duration (s)' (lower=-243, upper=380)
```

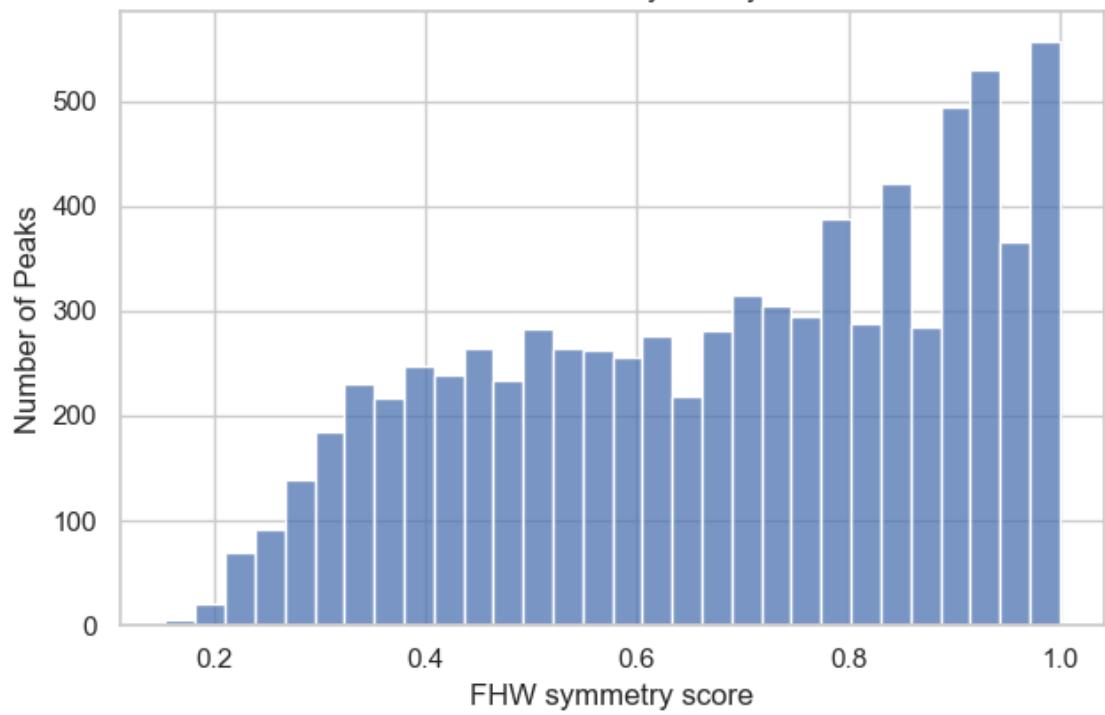


```
[2025-08-27 15:05:06] [INFO] calcium: plot_histogram: removed 0 outliers out of 8024 on 'Prominence (noise std units)' (lower=-725.8, upper=1032.6)
```

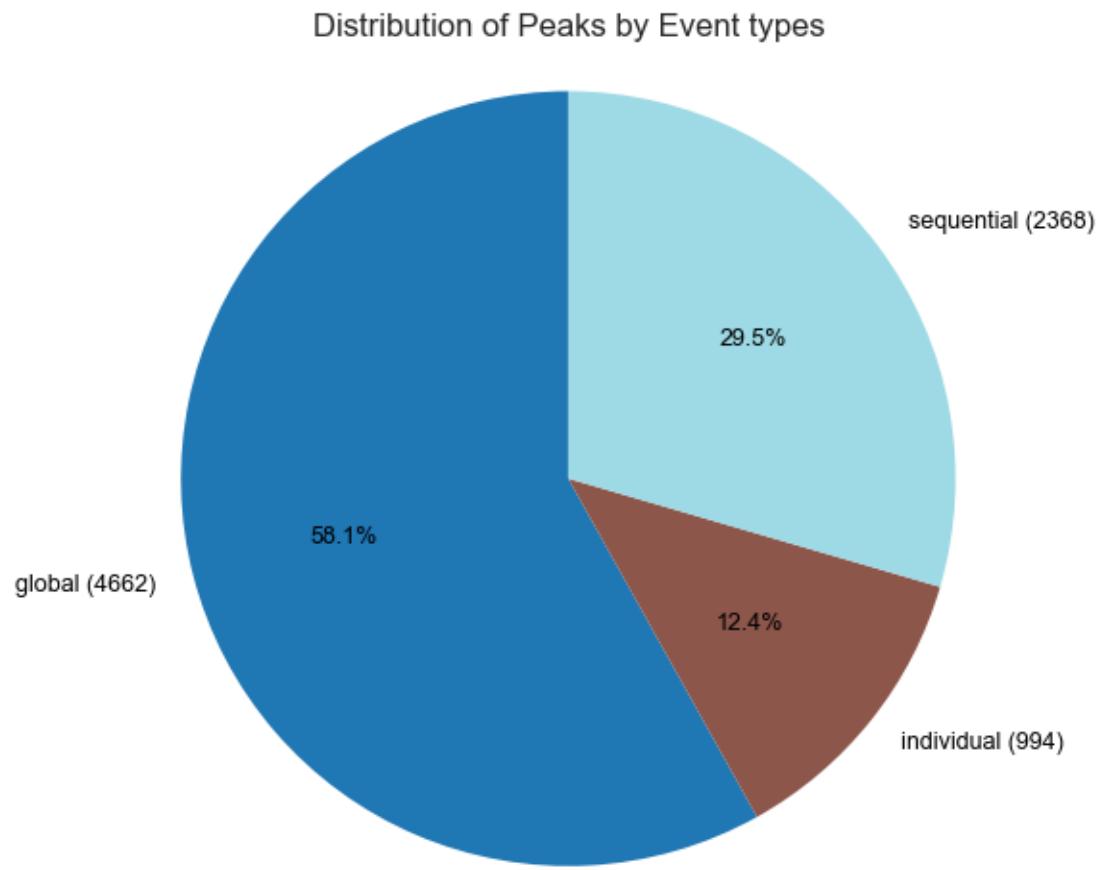
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

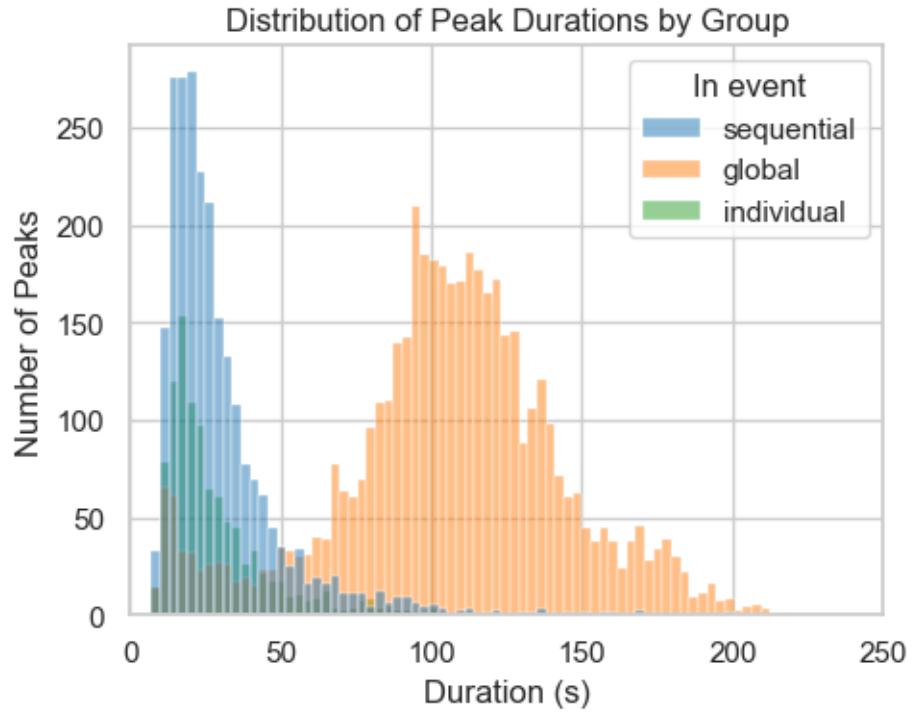


1.1.4 Distribution of peaks per event types

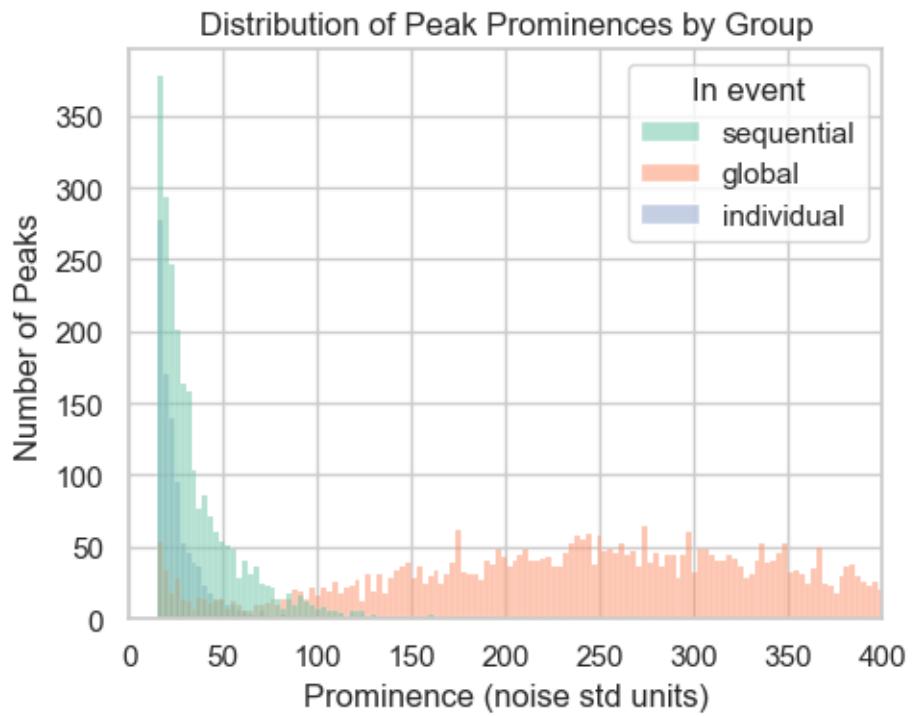


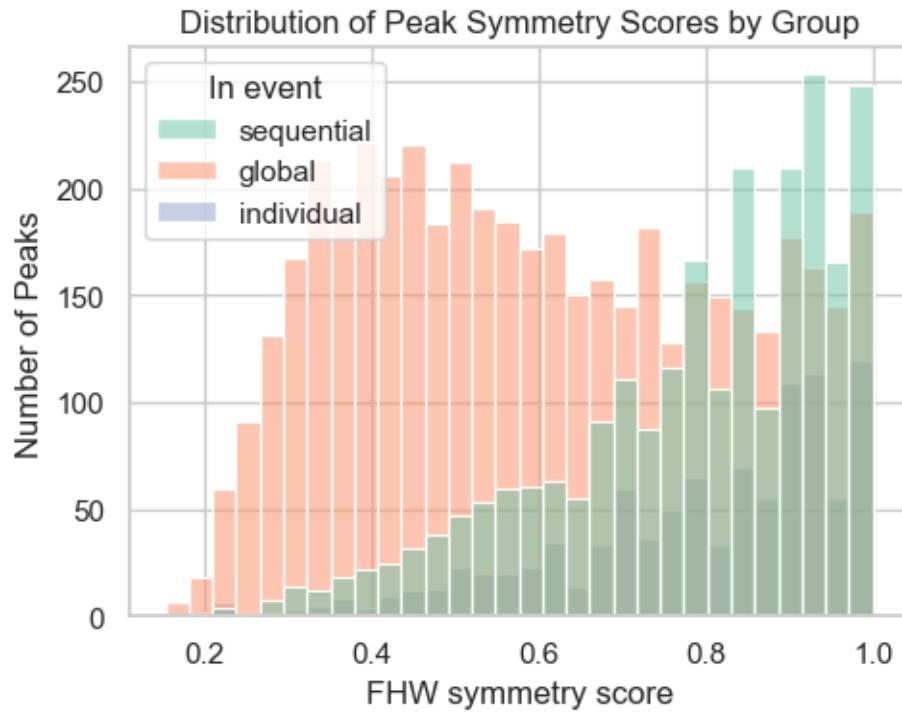
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:05:07] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 8024 on 'Duration (s)' (lower=-243, upper=380)
```



```
[2025-08-27 15:05:07] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 8024 on 'Prominence (noise std units)' (lower=-725.8, upper=1032.6)
```

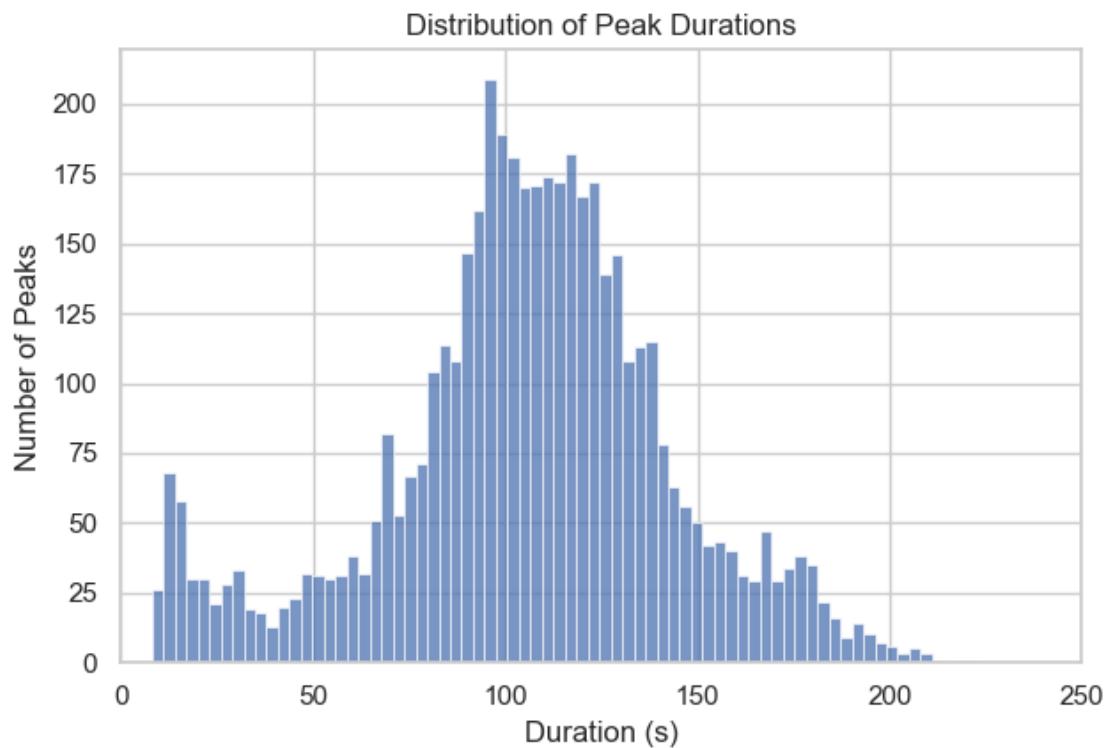




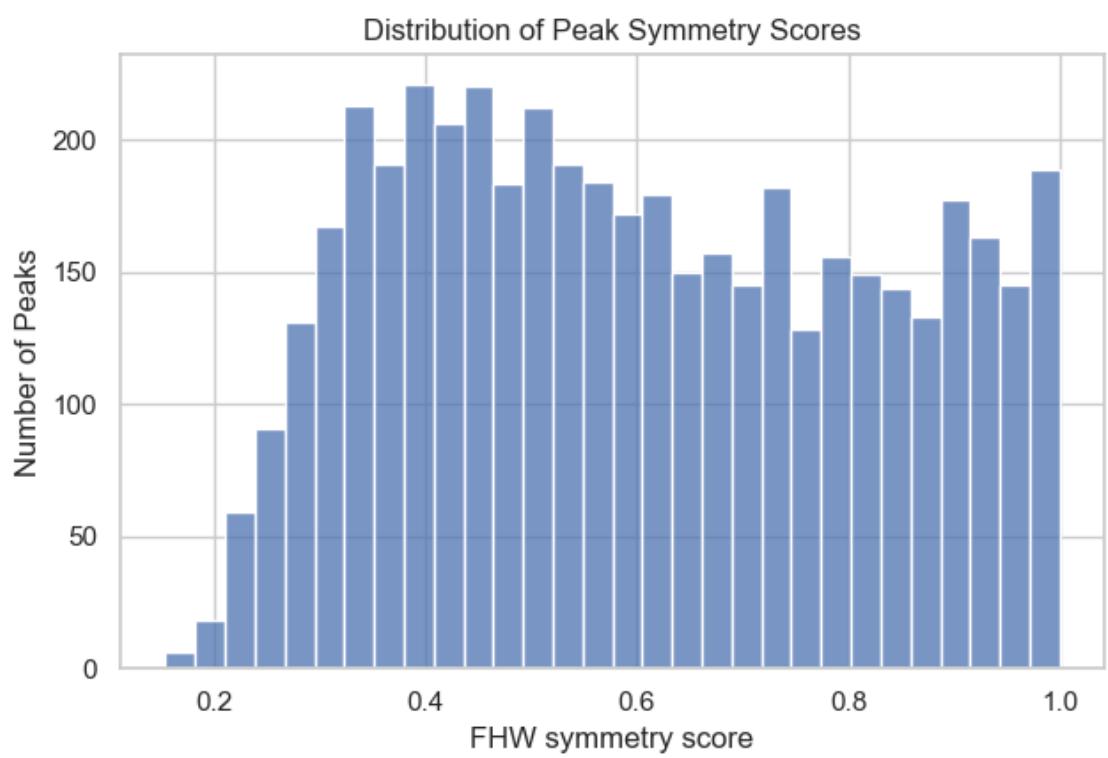
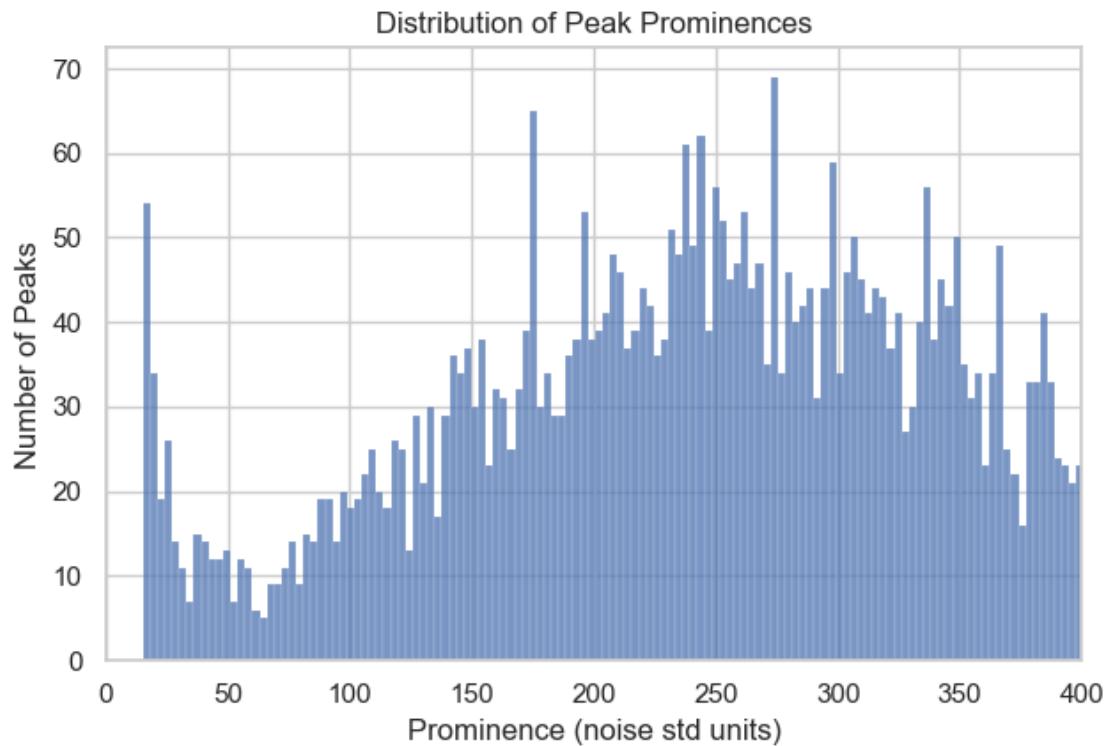
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:05:09] [INFO] calcium: plot_histogram: removed 1 outliers out of  
4662 on 'Duration (s)' (lower=-36, upper=251)
```

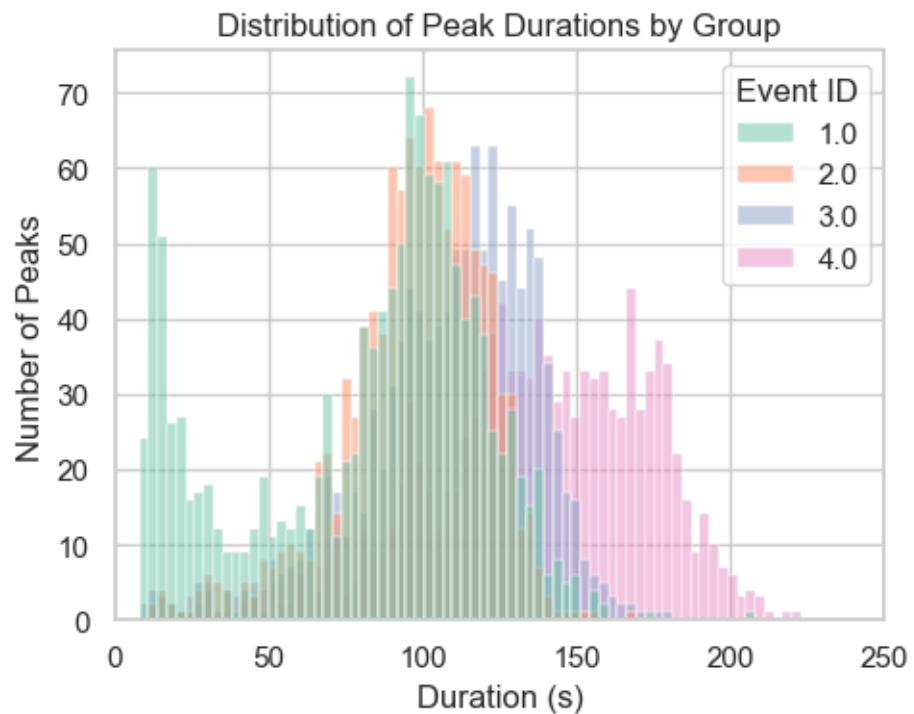


```
[2025-08-27 15:05:09] [INFO] calcium: plot_histogram: removed 1 outliers out of  
4662 on 'Prominence (noise std units)' (lower=-307.47, upper=823.72)
```

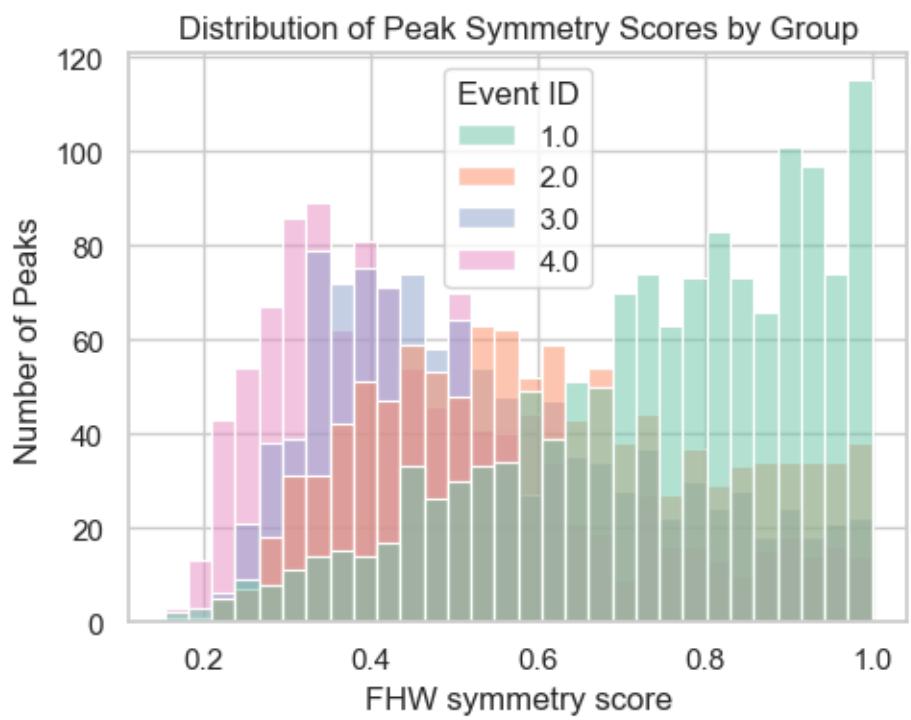
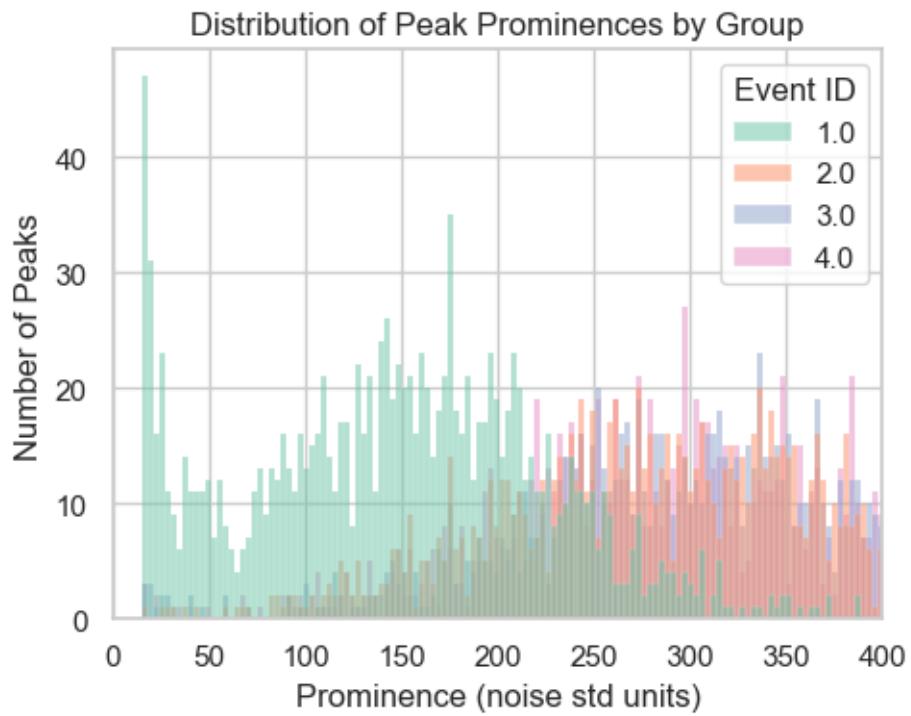


1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 15:05:10] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 4662 on 'Duration (s)' (lower=-36, upper=251)
```

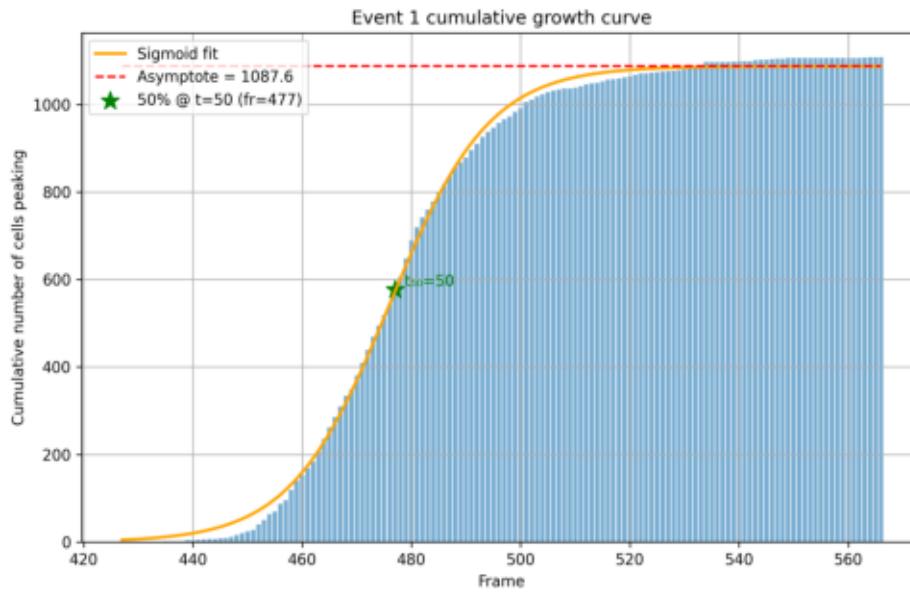


```
[2025-08-27 15:05:10] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 4662 on 'Prominence (noise std units)' (lower=-307.47, upper=823.72)
```

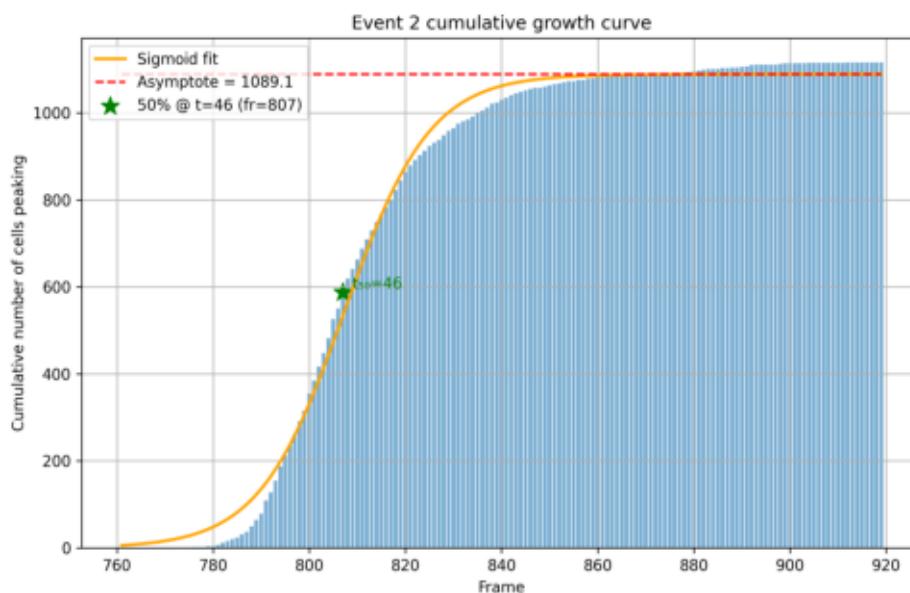


1.2.3 Kinetics of global events

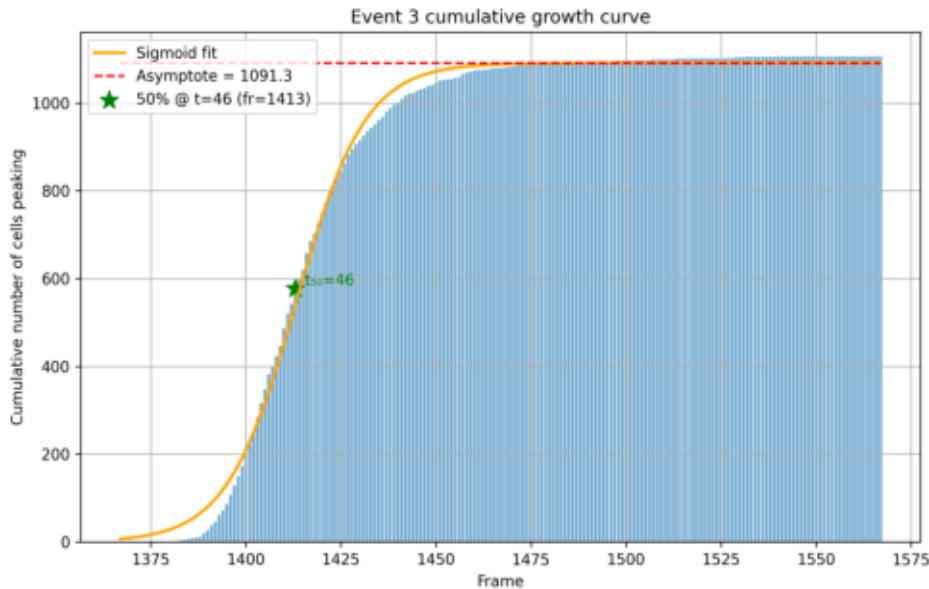
Event Activity Overlay (Event ID: 1)



Event Activity Overlay (Event ID: 2)

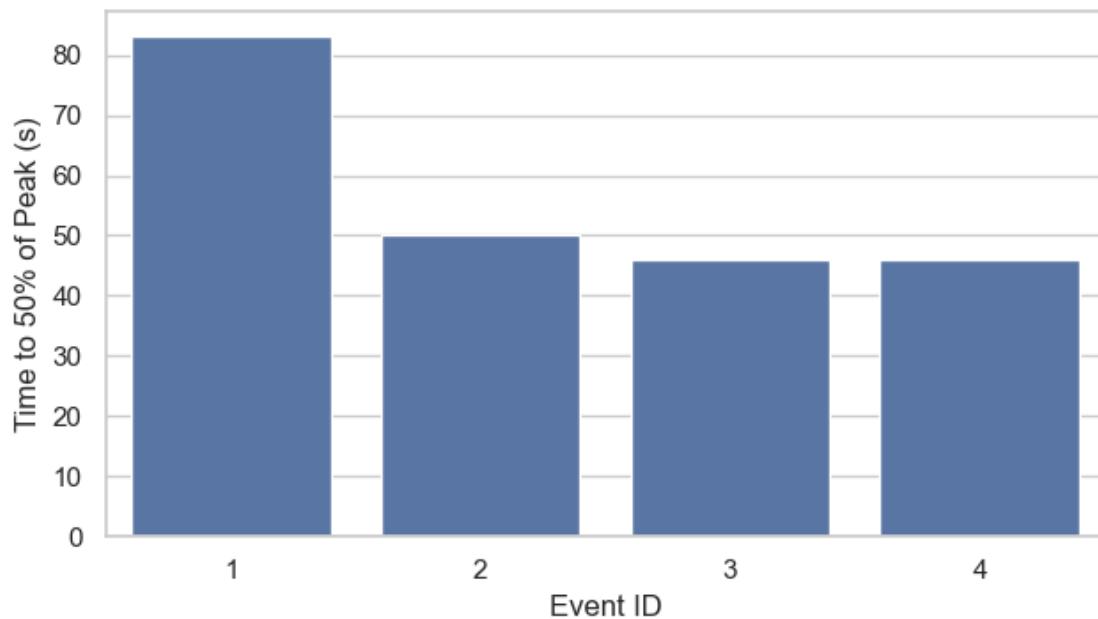


Event Activity Overlay (Event ID: 3)

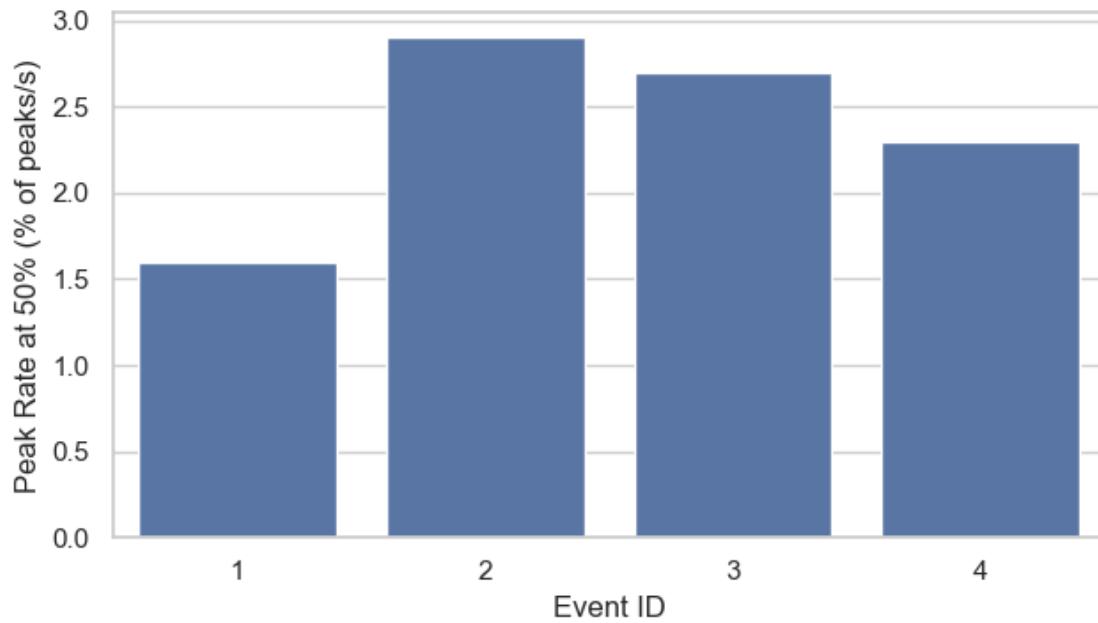


```
[2025-08-27 15:05:14] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\Output\\IS7\\events\\event-growth-
curve-4.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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\\IS7\\events\\event-growth-curve-4.png'
```

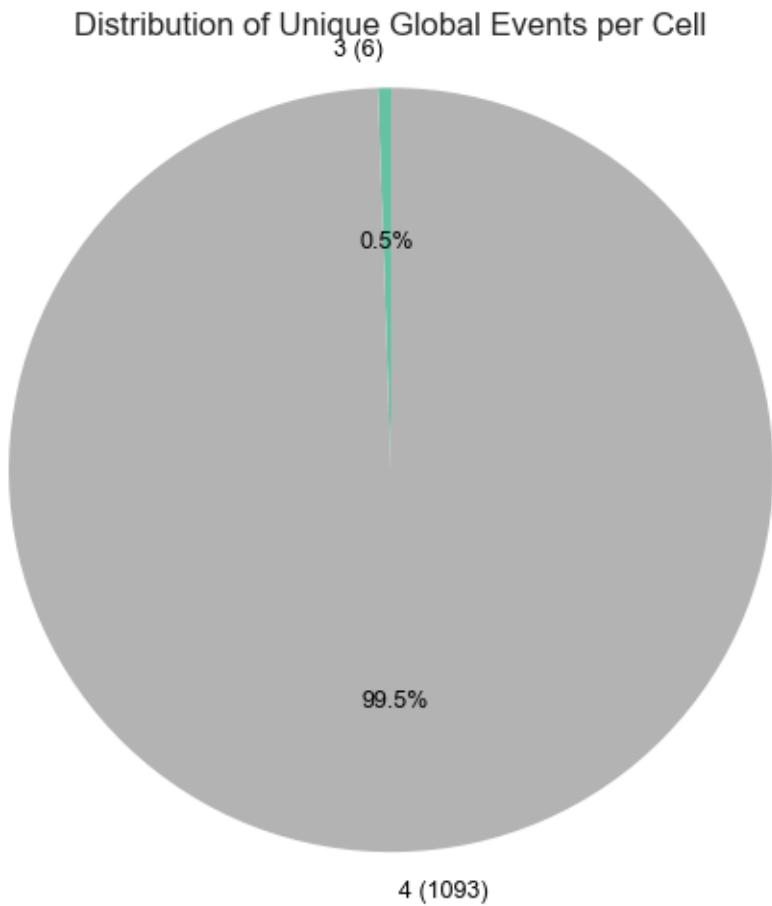
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



1.2.4 Cells Occurrences in global events

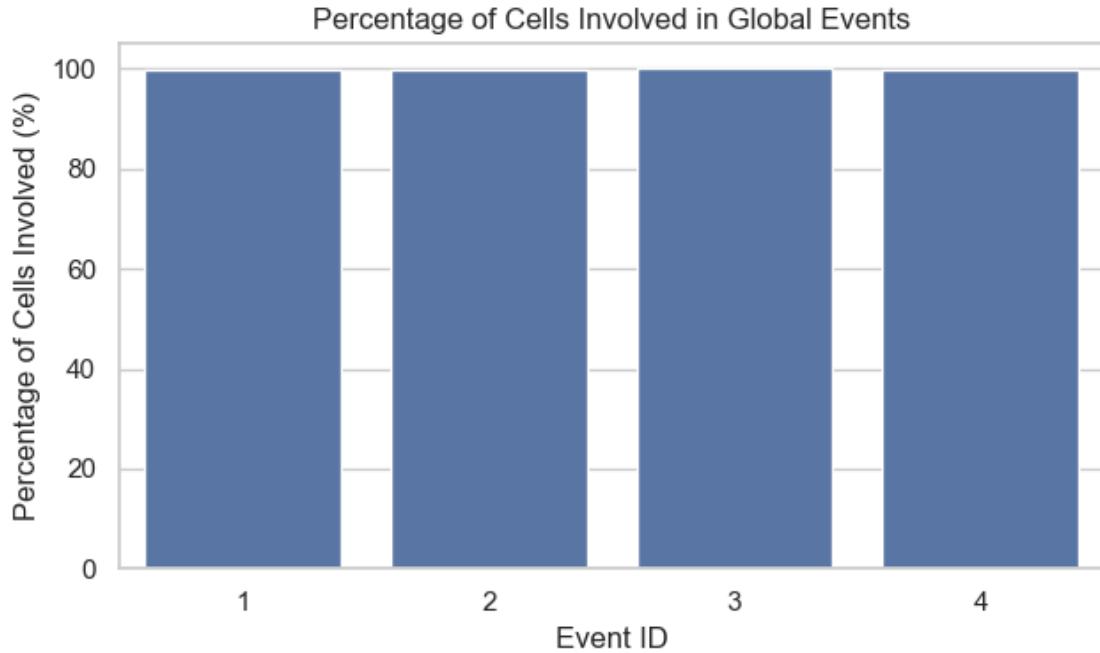


```
[2025-08-27 15:05:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS7\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\IS7\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [257.0, 336.0, 598.0]
Estimated periodicity: 0.731

1.2.6 Early peakers in the events

```

[2025-08-27 15:05:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\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

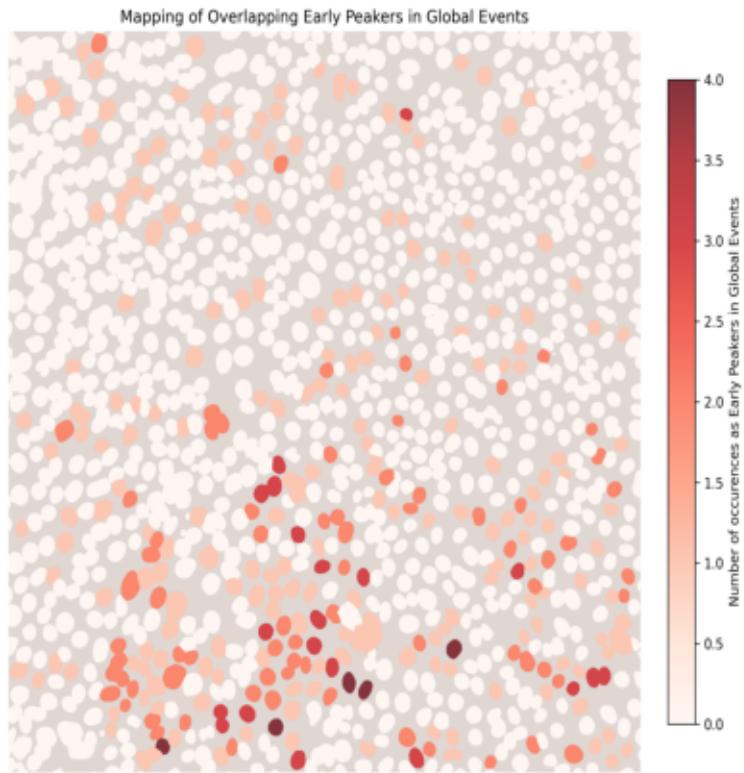
[2025-08-27 15:05:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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 15:05:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\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

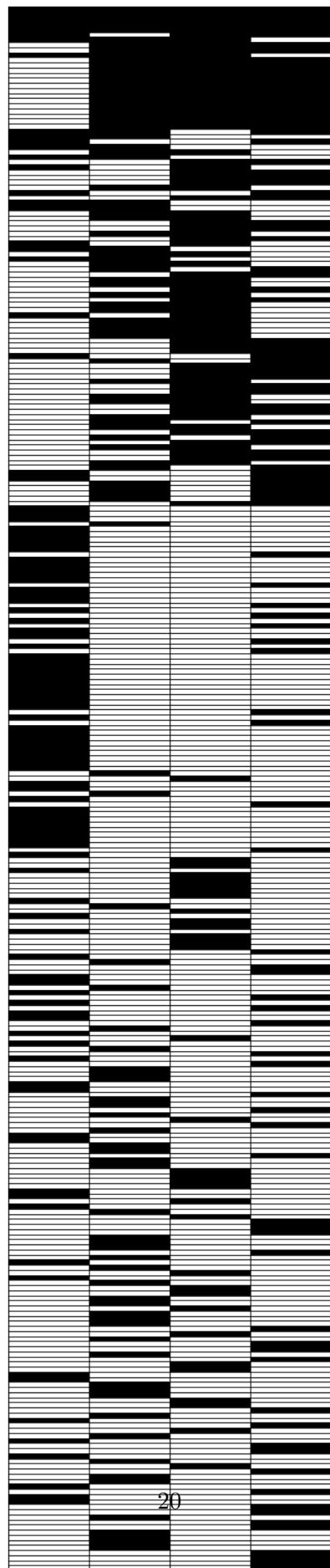
[2025-08-27 15:05:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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



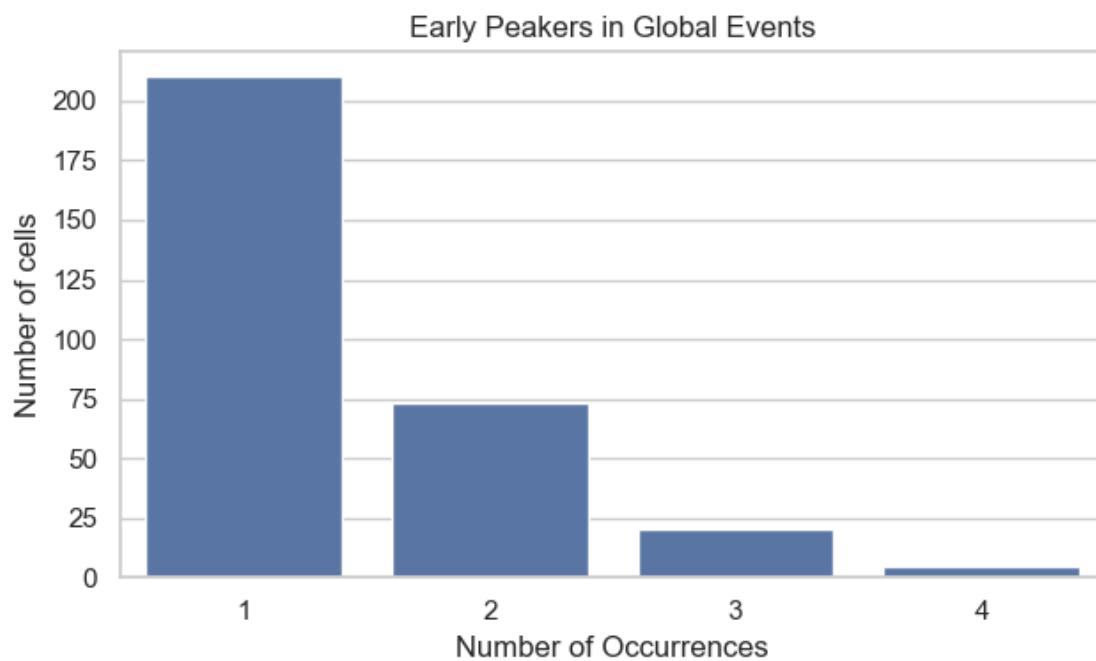
```
[2025-08-27 15:05:17] [WARNING] calcium: 'total_events' is deprecated and  
ignored. Using 4 unique event IDs.
```

```
[2025-08-27 15:05:17] [INFO] calcium: Early peakers event-matrix: 308 cells x 4  
events; black squares: 436
```

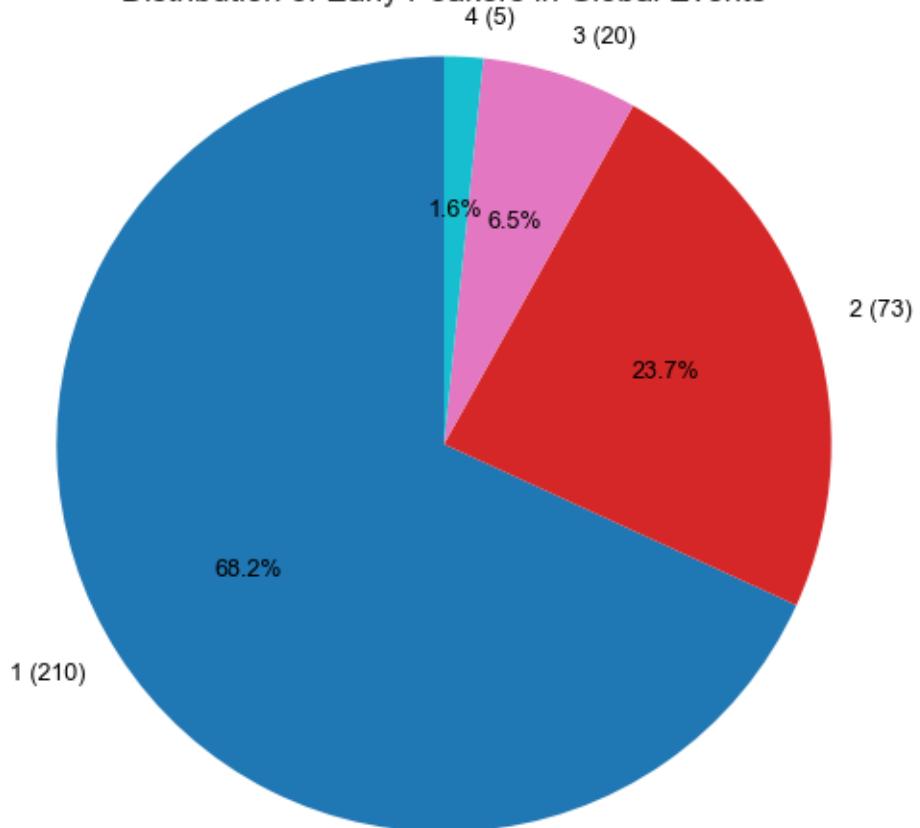


```
[2025-08-27 15:05:17] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

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

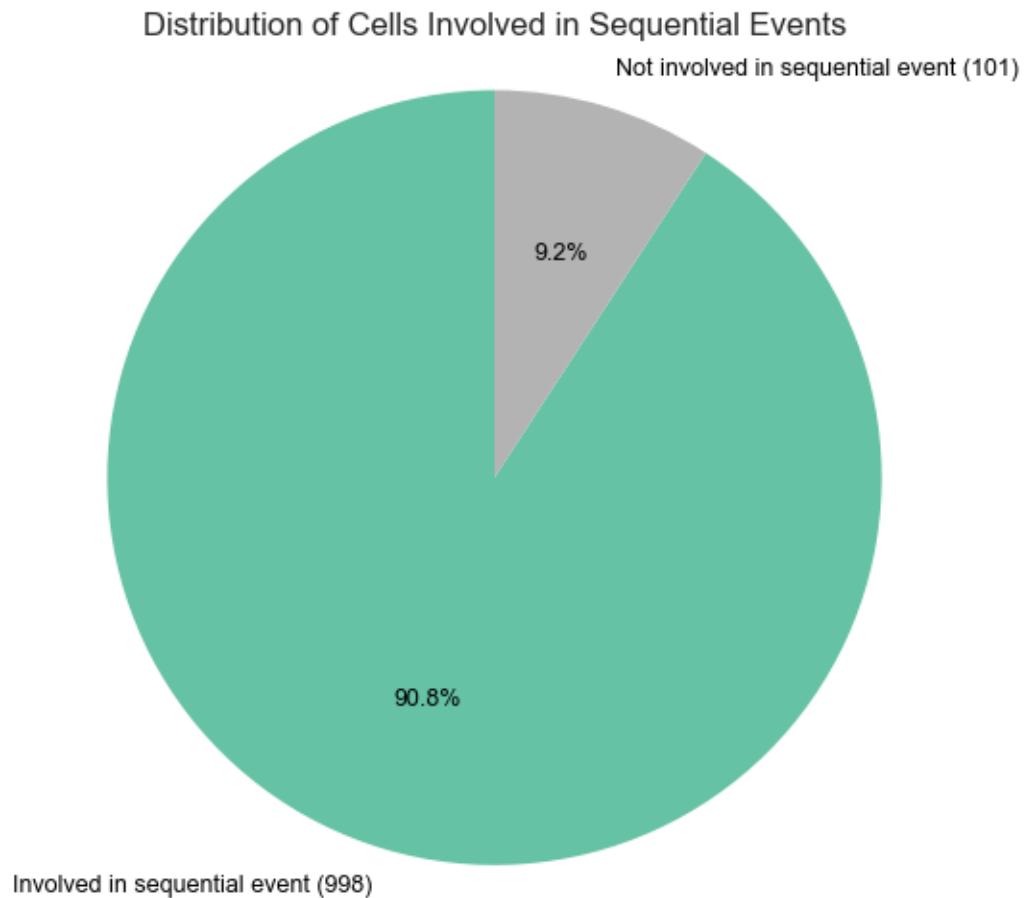


Distribution of Early Peakers in Global Events

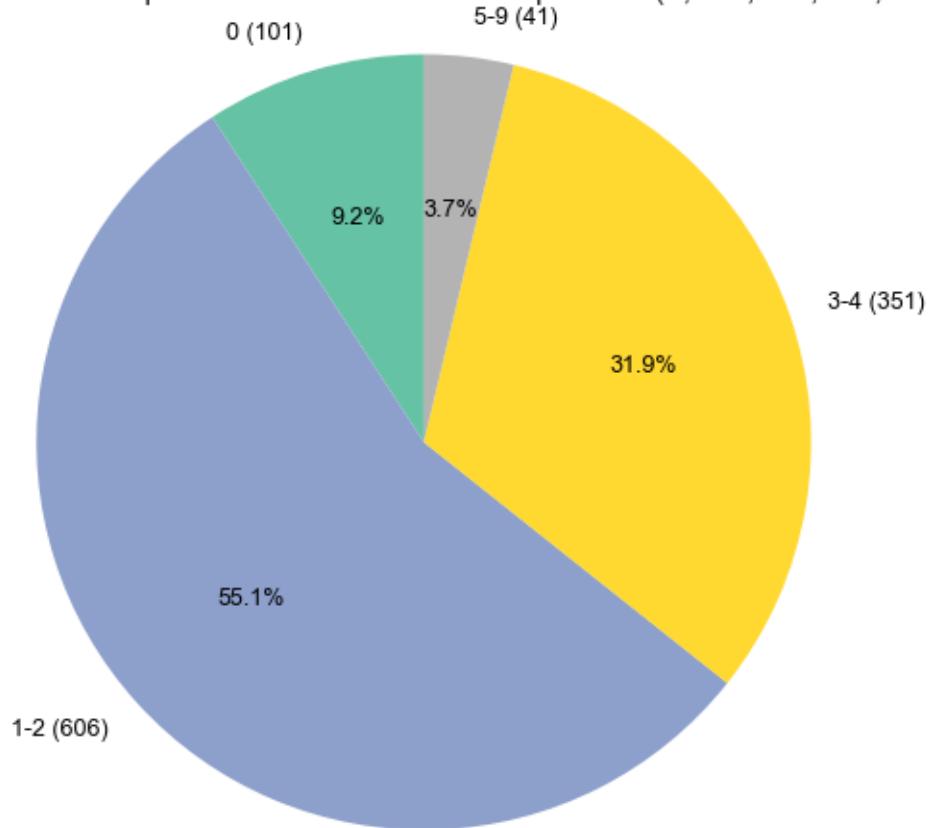


1.3 SEQUENTIAL EVENTS

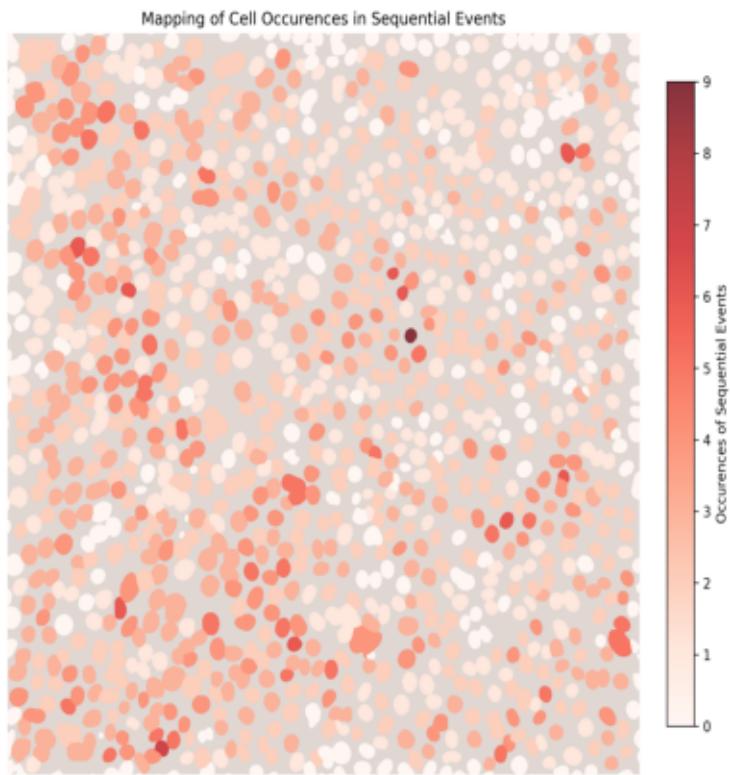
1.3.1 Cells Occurrences in sequential events



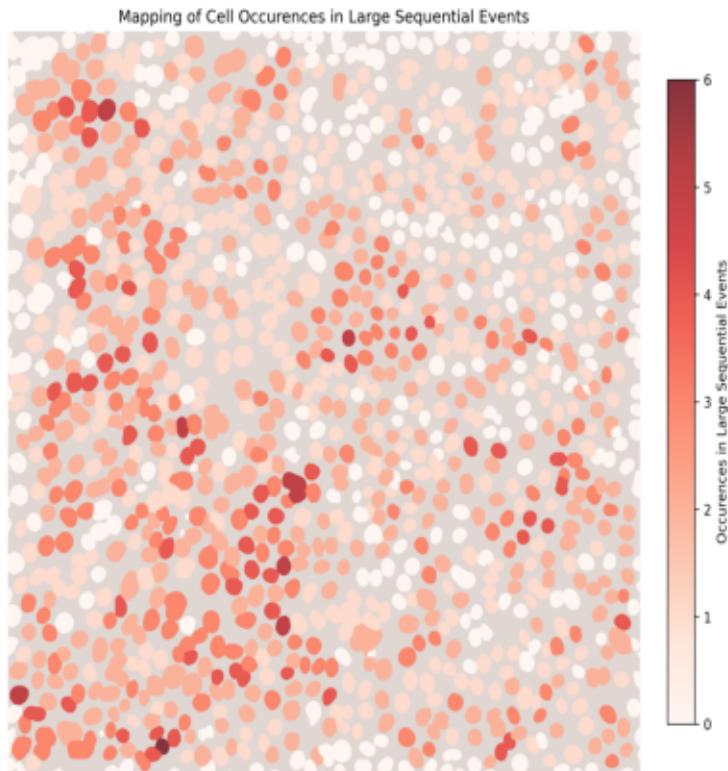
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



Cell Mapping with Occurrences in Sequential Events Overlay

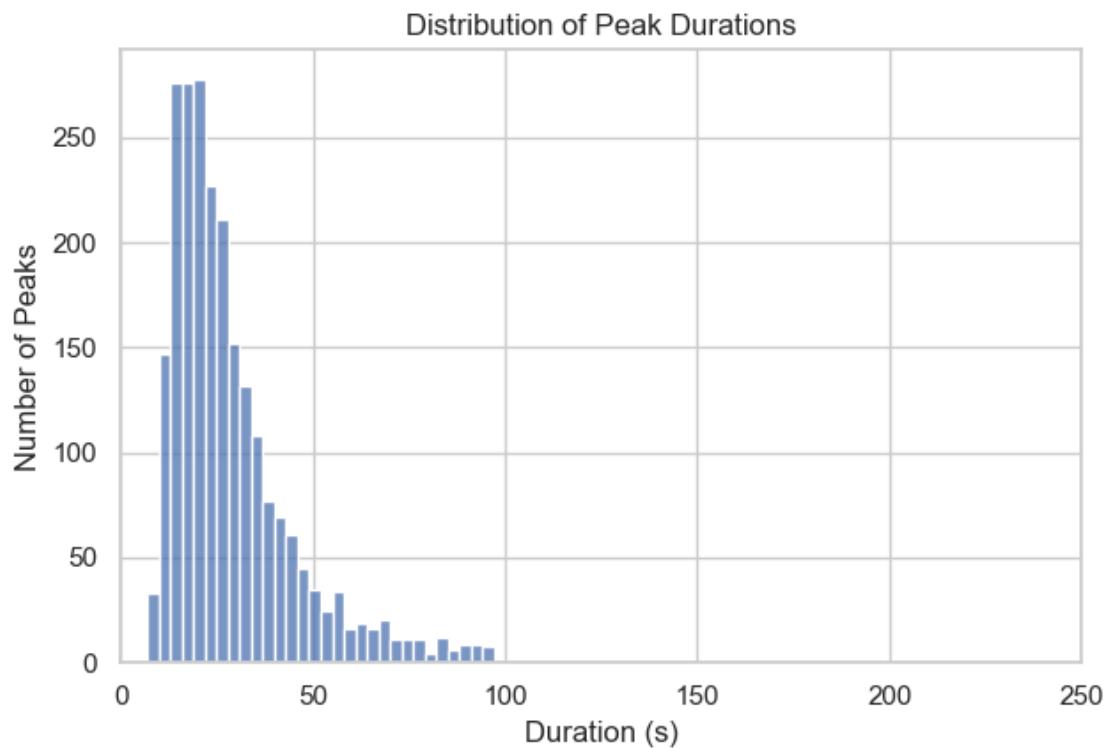


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

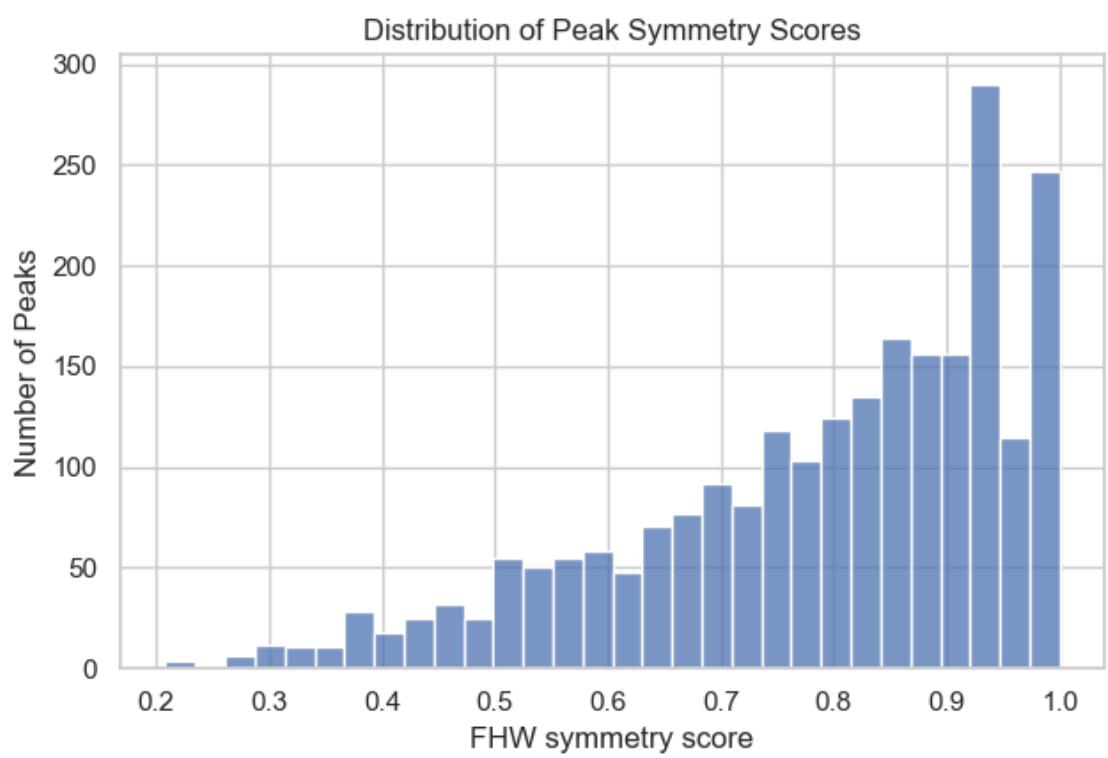
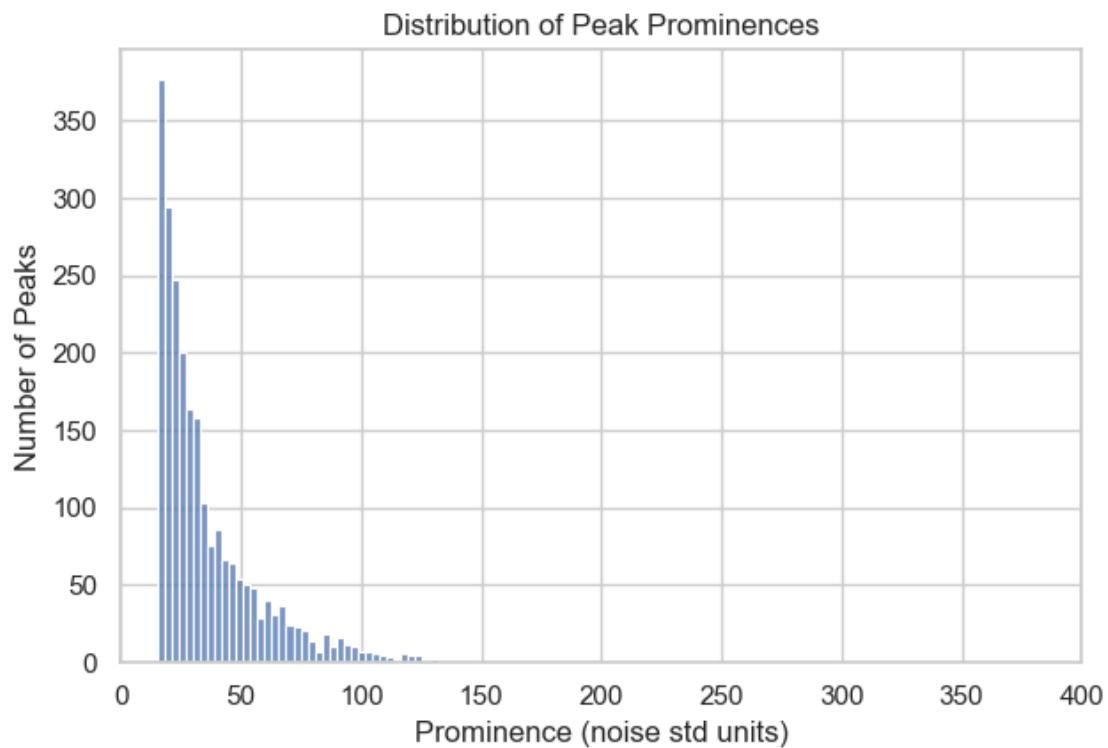


1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:05:21] [INFO] calcium: plot_histogram: removed 30 outliers out of  
2368 on 'Duration (s)' (lower=-10, upper=98)
```

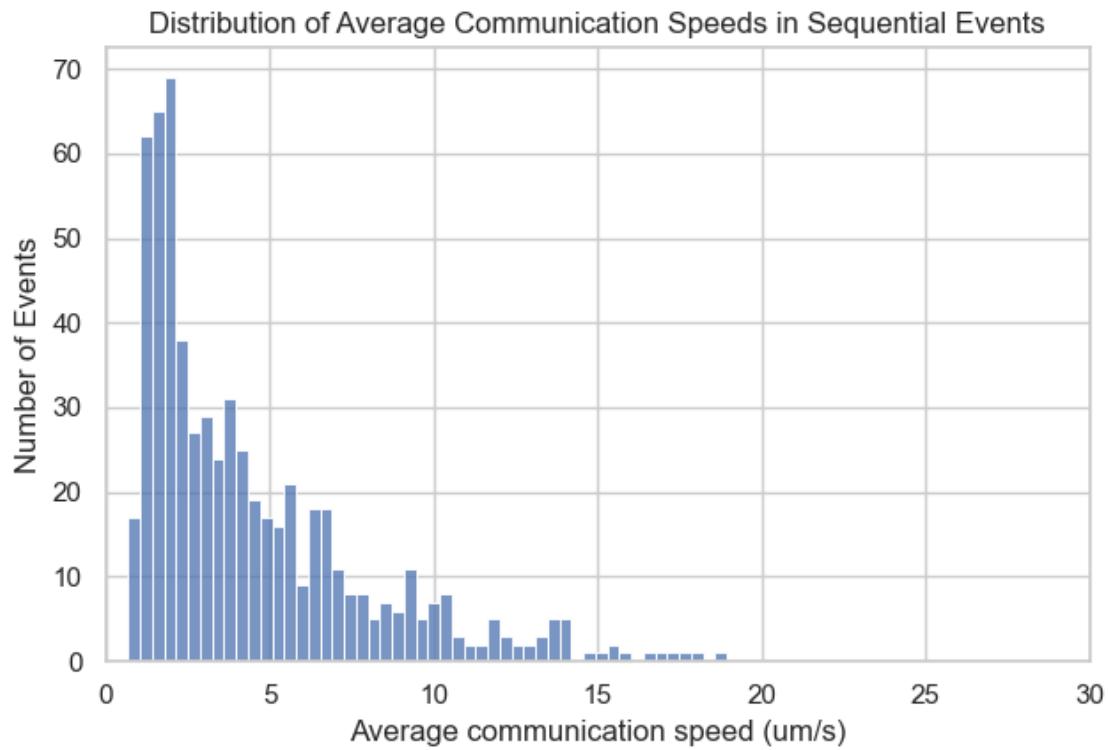


```
[2025-08-27 15:05:21] [INFO] calcium: plot_histogram: removed 36 outliers out of  
2368 on 'Prominence (noise std units)' (lower=-17.35, upper=132.05)
```

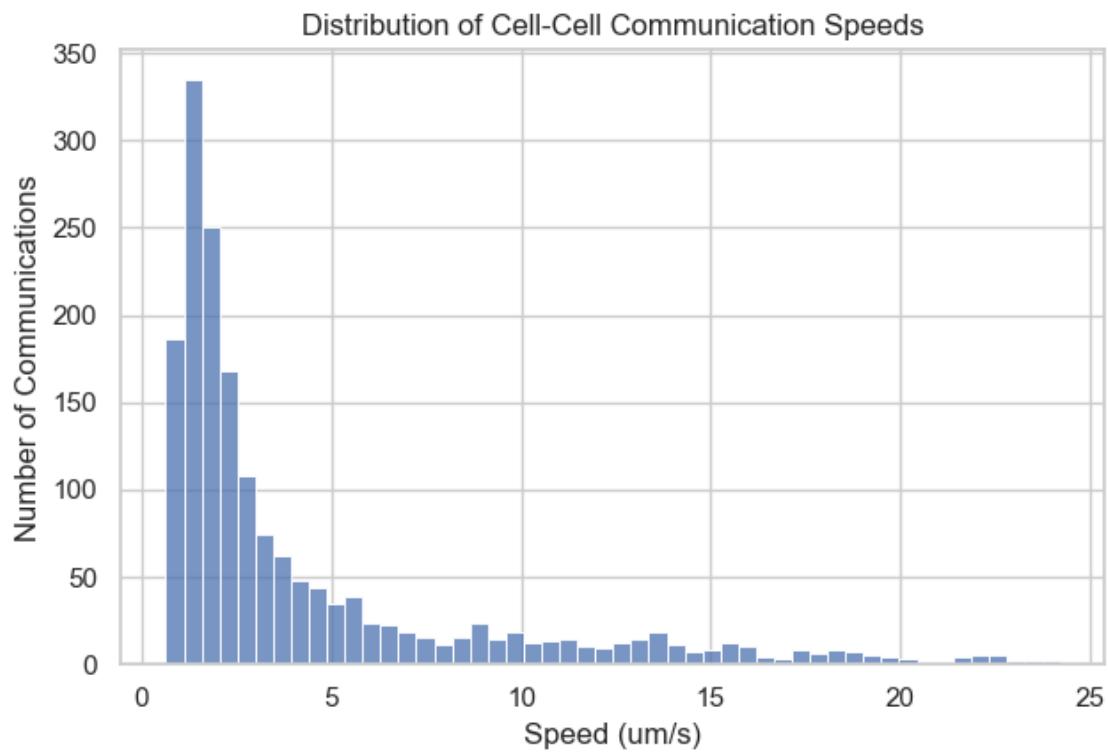


1.3.3 Cell-cell communication speed

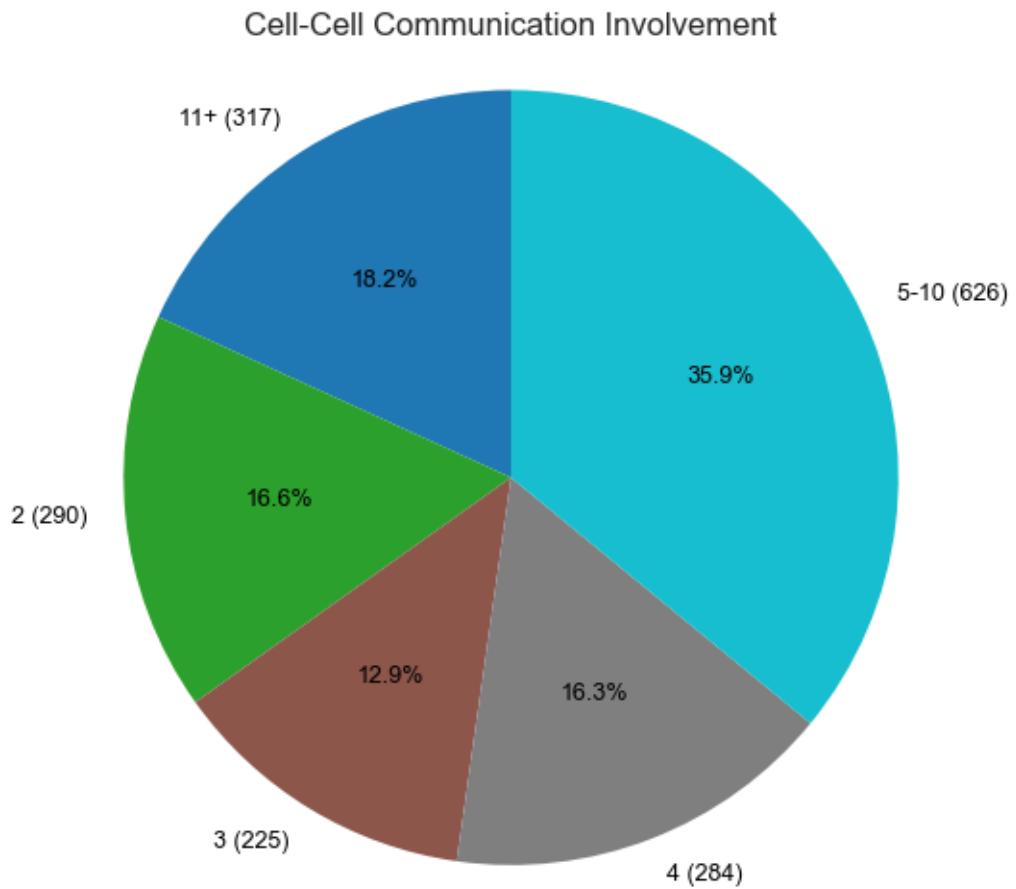
[2025-08-27 15:05:22] [INFO] calcium: plot_histogram: removed 2 outliers out of 626 on 'Average communication speed (um/s)' (lower=-11.085, upper=19.12)



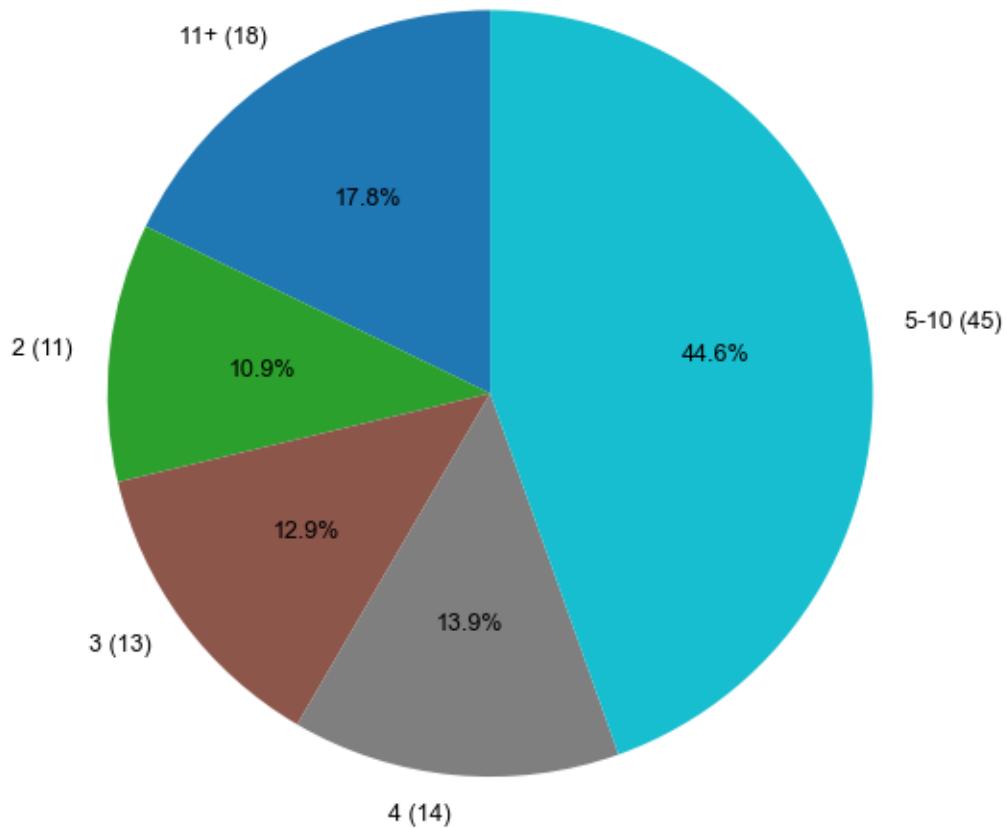
[2025-08-27 15:05:22] [INFO] calcium: plot_histogram: removed 4 outliers out of 1742 on 'Speed (um/s)' (lower=-10.172, upper=24.635)



1.3.4 Double distribution in cell-cell communication speeds

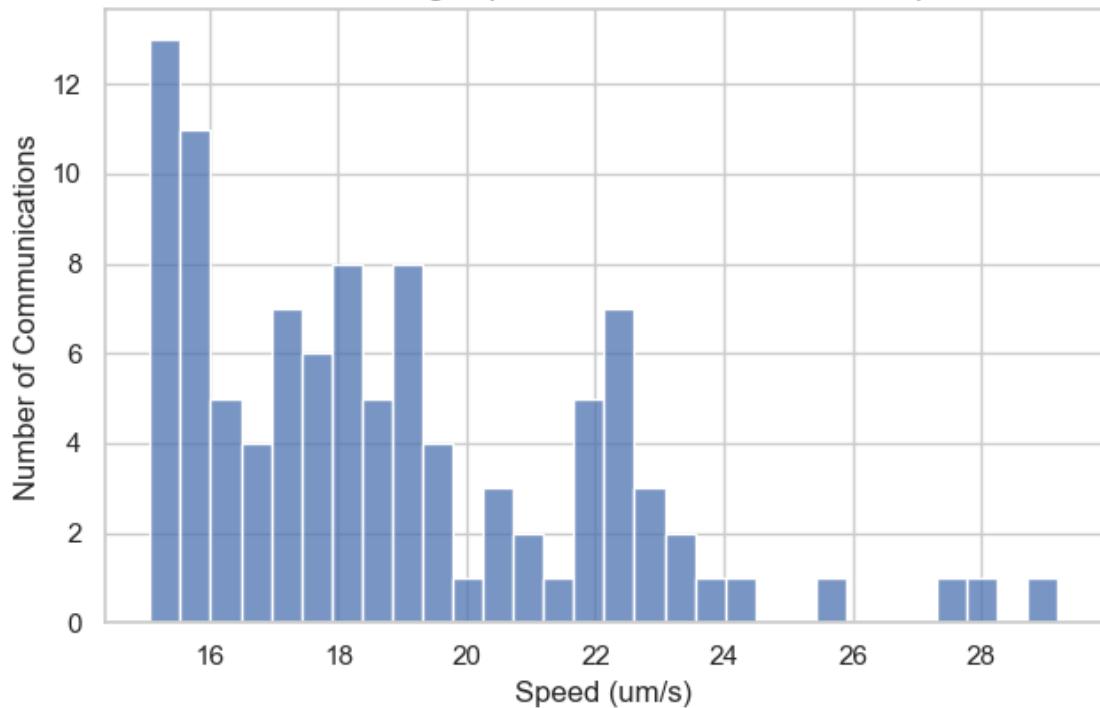


High Speed Cell-Cell Communication Involvement



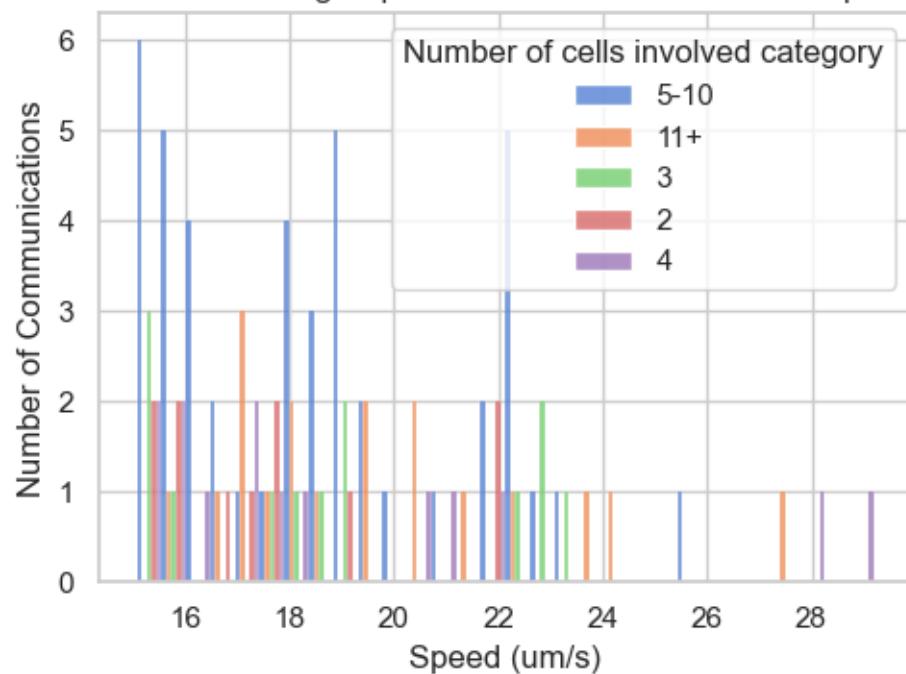
[2025-08-27 15:05:23] [INFO] calcium: plot_histogram: removed 0 outliers out of 101 on 'Speed (um/s)' (lower=2.16, upper=34.78)

Distribution of High Speed Cell-Cell Communication Speeds

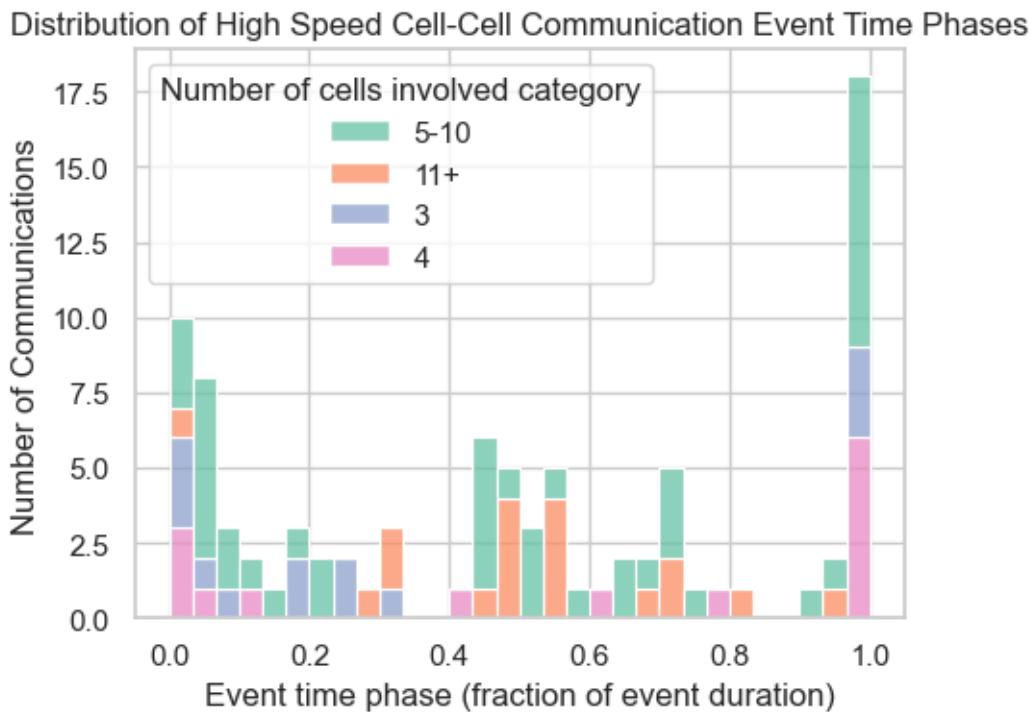


```
[2025-08-27 15:05:23] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 101 on 'Speed (um/s)' (lower=2.16, upper=34.78)
```

Distribution of High Speed Cell-Cell Communication Speeds

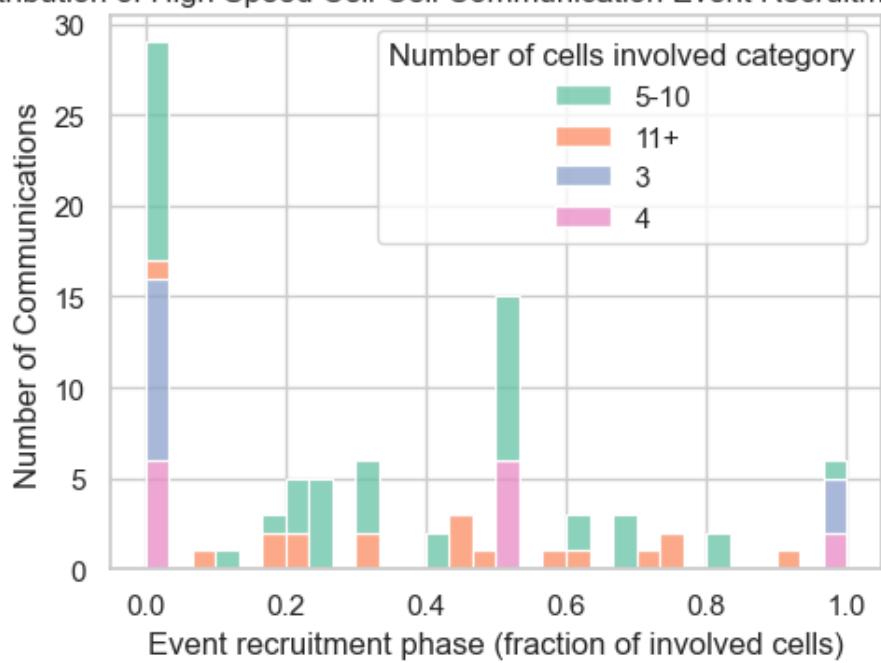


[2025-08-27 15:05:23] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 90 on 'Event time phase (fraction of event duration)' (lower=-1.85, upper=2.7525)

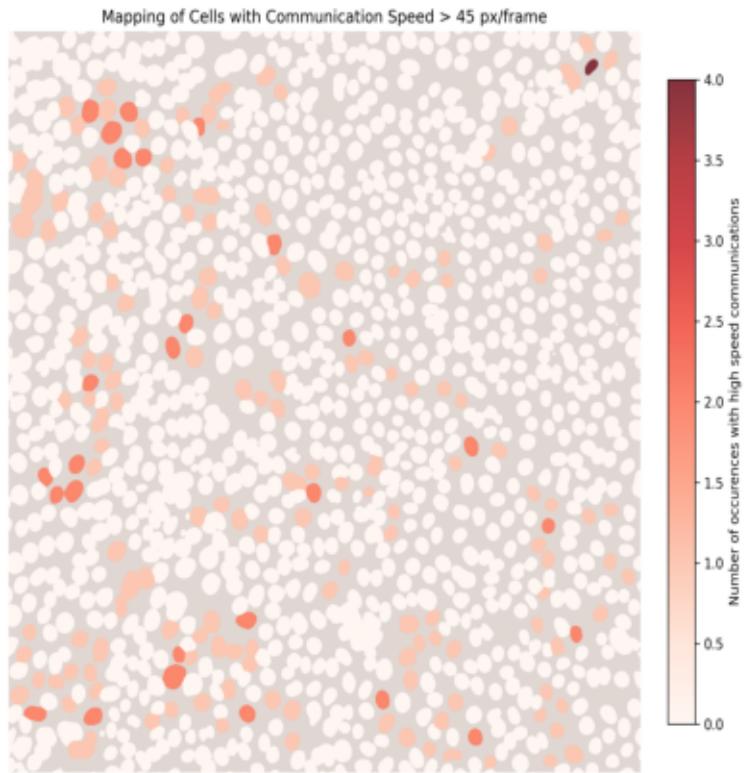


[2025-08-27 15:05:24] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 90 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)

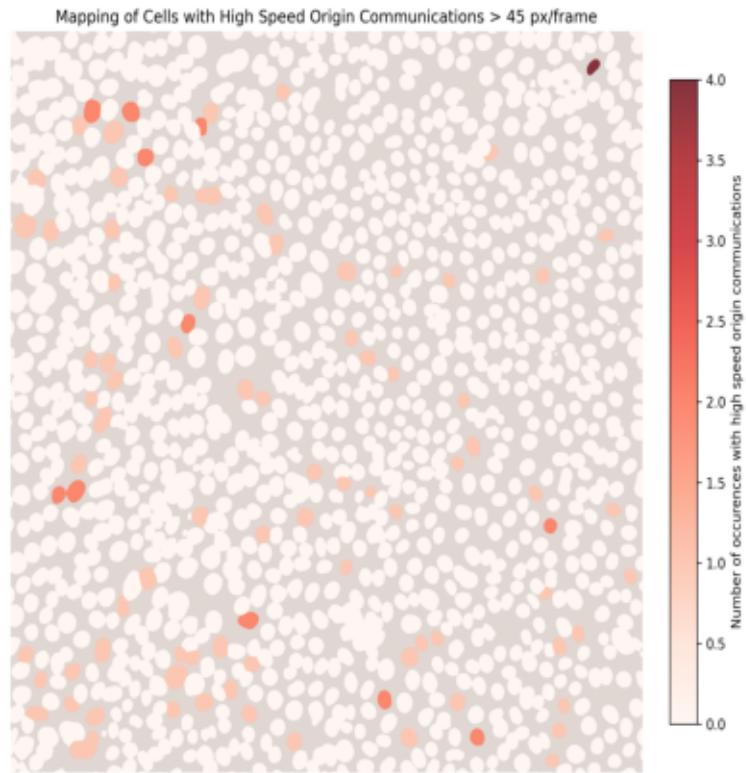
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



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	\
30	3015667824048	9	701	1	
46	3015557010416	10	708	1	
53	3015667817808	11	790	1	
57	3015667810464	11	842	1	
59	3015607129888	11	955	0	
...	
1665	3015668116800	585	1611	4	
1691	3015504390864	599	1676	5	
1701	3015668109648	605	1606	4	
1708	3015668121504	607	1722	0	
1741	3015668113872	630	1676	0	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
30	655	0	60.0	60.0	
46	752	0	103.0	104.0	
53	762	0	77.0	77.0	
57	860	0	63.0	63.0	
59	959	0	59.0	59.0	
...	
1665	1584	8	1213.0	1214.0	
1691	1727	6	1215.0	1216.0	
1701	1639	4	630.0	631.0	
1708	1710	0	19.0	20.0	
1741	1714	0	46.0	47.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
30	0.0	15.08	15.08		
46	1.0	17.36	17.36		
53	0.0	23.78	23.78		
57	0.0	18.30	18.30		
59	0.0	19.52	19.52		
...	
1665	1.0	15.54	15.54		
1691	1.0	20.29	20.29		
1701	1.0	16.82	16.82		
1708	1.0	19.00	19.00		
1741	1.0	21.81	21.81		
	Event time phase (fraction of event duration)	\			
30		0.51			
46		0.56			
53		0.82			
57		0.56			
59		0.49			
...		...			
1665		NaN			
1691		0.10			
1701		0.17			
1708		0.05			
1741		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
30		0.50	20250618_IS7		
46		0.57	20250618_IS7		
53		0.93	20250618_IS7		
57		0.47	20250618_IS7		
59		0.20	20250618_IS7		
...			
1665		NaN	20250618_IS7		
1691		0.00	20250618_IS7		

1701		0.00	20250618_IS7
1708		0.00	20250618_IS7
1741		NaN	20250618_IS7

	Number of cells involved	category	Speed category
30		5-10	High speed
46		11+	High speed
53		11+	High speed
57		11+	High speed
59		11+	High speed
...
1665		2	High speed
1691		4	High speed
1701		5-10	High speed
1708		5-10	High speed
1741		2	High speed

[101 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
198		0	1
199		0	2
201		0	2
204		0	1
207		0	2
...
1717		0	1
1721		0	1
1722		1	0
1727		0	2
1728		0	1

[767 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	198	373.43		7.15
1	199	71.17		7.80
2	201	456.30		8.12
4	204	303.55		9.10
7	207	146.90		10.08
...
1090	1717	243.43		488.15
1093	1721	228.47		490.43
1094	1722	427.70		490.75
1097	1727	380.25		491.73
1098	1728	19.50		492.38

Number of peaks Is active Occurrences in global events \

0	6	True	4
1	9	True	4
2	9	True	4
4	5	True	4
7	10	True	4
...
1090	7	True	4
1093	10	True	4
1094	6	True	4
1097	8	True	4
1098	6	True	4

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

0	0	[]
1	2	[1, 2]
2	0	[]
4	0	[]
7	1	[1]
...
1090	0	[]
1093	3	[1, 2, 4]
1094	0	[]
1097	2	[3, 4]
1098	0	[]

Occurrences in sequential events \

0	1
1	3
2	3
4	1
7	2
...	...
1090	2
1093	1
1094	1
1097	3
1098	1

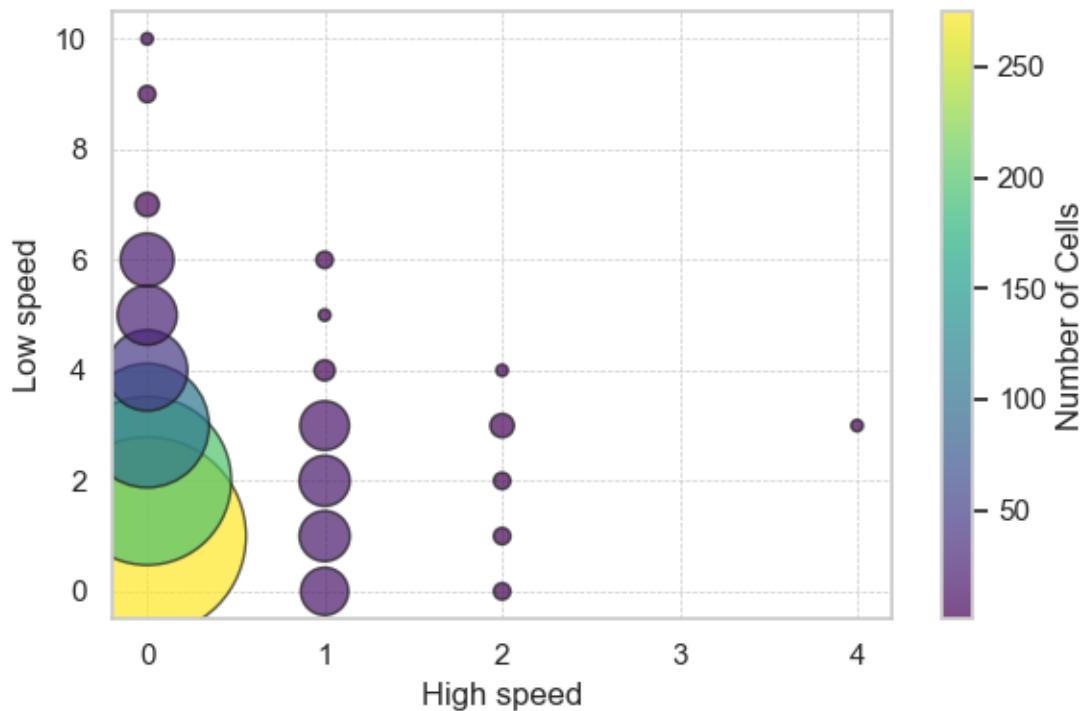
Occurrences in sequential events as origin \

0	0
1	2
2	1
4	1
7	2
...	...
1090	1
1093	1
1094	1

1097		2		
1098		1		
Occurrences in individual events Peak frequency (Hz) \				
0		1	0.0035	
1		1	0.0053	
2		2	0.0053	
4		0	0.0029	
7		2	0.0059	
...	
1090		0	0.0041	
1093		3	0.0059	
1094		1	0.0035	
1097		1	0.0047	
1098		0	0.0035	
Periodicity score Neighbor count Neighbors (labels) \				
0	0.58	4	[206,227,238,264]	
1	0.50	3	[217,236,248]	
2	0.51	2	[216,245]	
4	0.66	2	[229,246]	
7	0.59	3	[237,243,257]	
...	
1090	0.53	5	[1620,1652,1682,1713,1721]	
1093	0.63	3	[1682,1712,1717]	
1094	0.62	4	[1659,1680,1687,1710]	
1097	0.56	2	[1676,1707]	
1098	0.69	2	[1697,1708]	
dataset Involved in sequential event \				
0	20250618_IS7	Involved in sequential event		
1	20250618_IS7	Involved in sequential event		
2	20250618_IS7	Involved in sequential event		
4	20250618_IS7	Involved in sequential event		
7	20250618_IS7	Involved in sequential event		
...	
1090	20250618_IS7	Involved in sequential event		
1093	20250618_IS7	Involved in sequential event		
1094	20250618_IS7	Involved in sequential event		
1097	20250618_IS7	Involved in sequential event		
1098	20250618_IS7	Involved in sequential event		
Occurrences in sequential events category High speed Low speed				
0		1-2	0.0	1.0
1		3-4	0.0	2.0
2		3-4	0.0	2.0
4		1-2	0.0	1.0
7		1-2	0.0	2.0

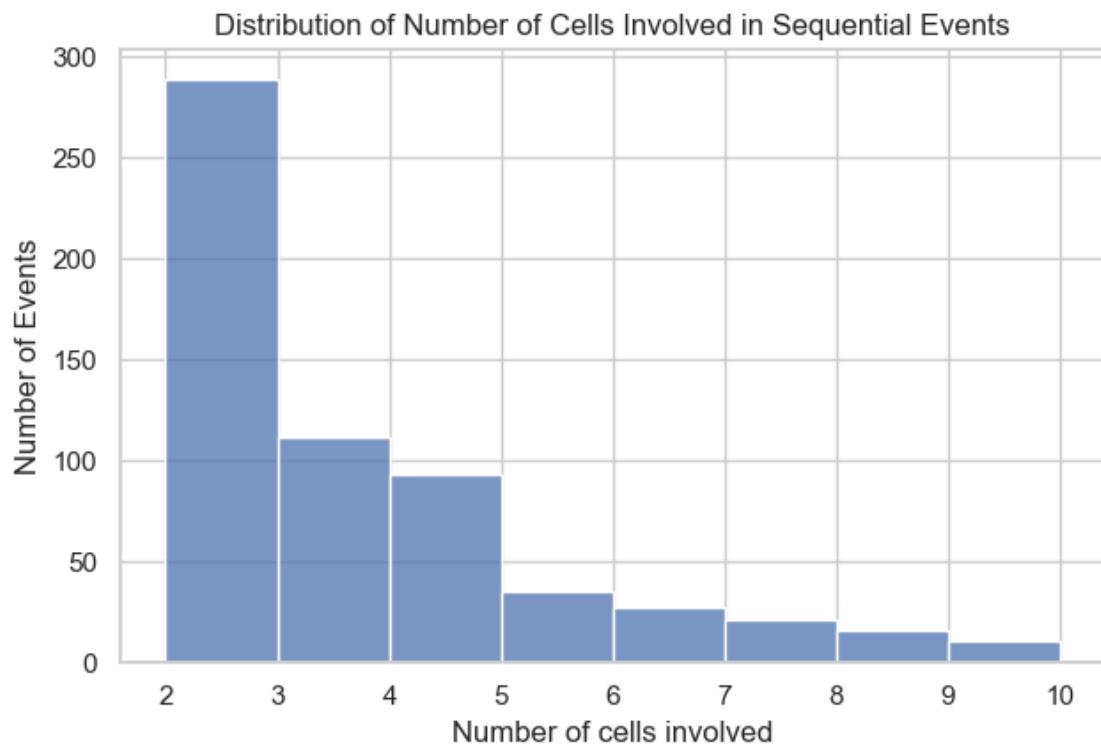
...				
1090		1-2	0.0	1.0
1093		1-2	0.0	1.0
1094		1-2	1.0	0.0
1097		3-4	0.0	2.0
1098		1-2	0.0	1.0

[767 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

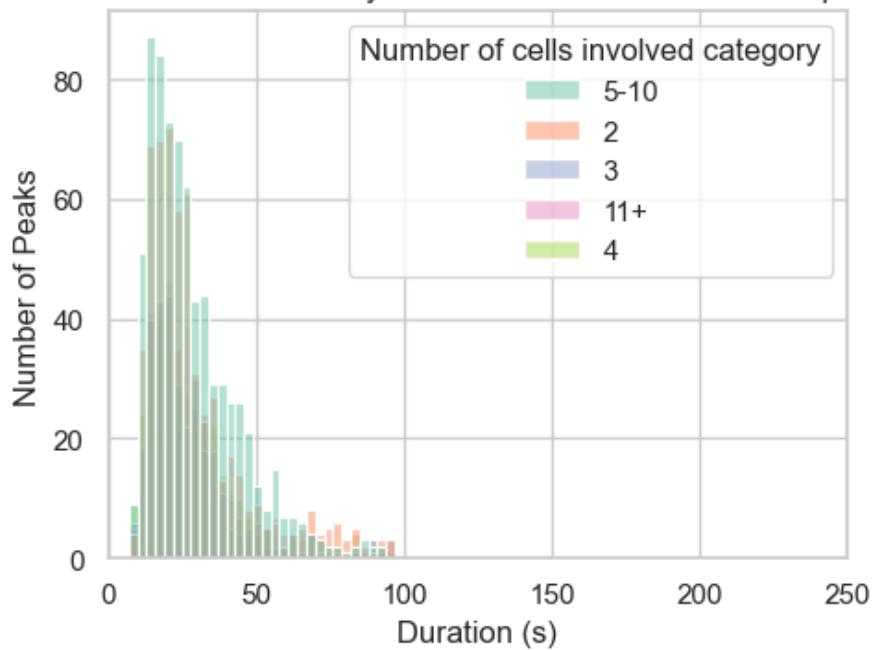
[2025-08-27 15:05:28] [INFO] calcium: plot_histogram: removed 22 outliers out of 626 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

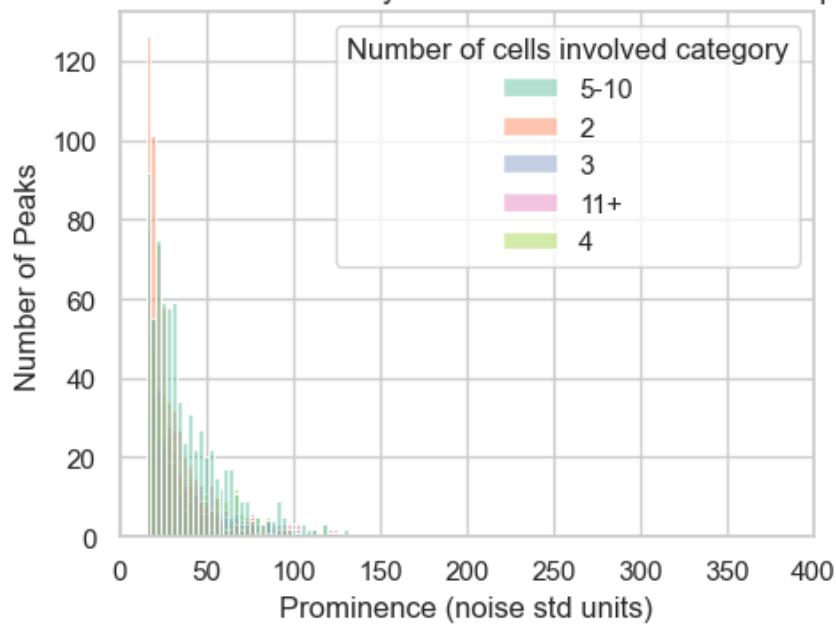
```
[2025-08-27 15:05:29] [INFO] calcium: plot_histogram_by_group: removed 30 outliers out of 2368 on 'Duration (s)' (lower=-10, upper=98)
```

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

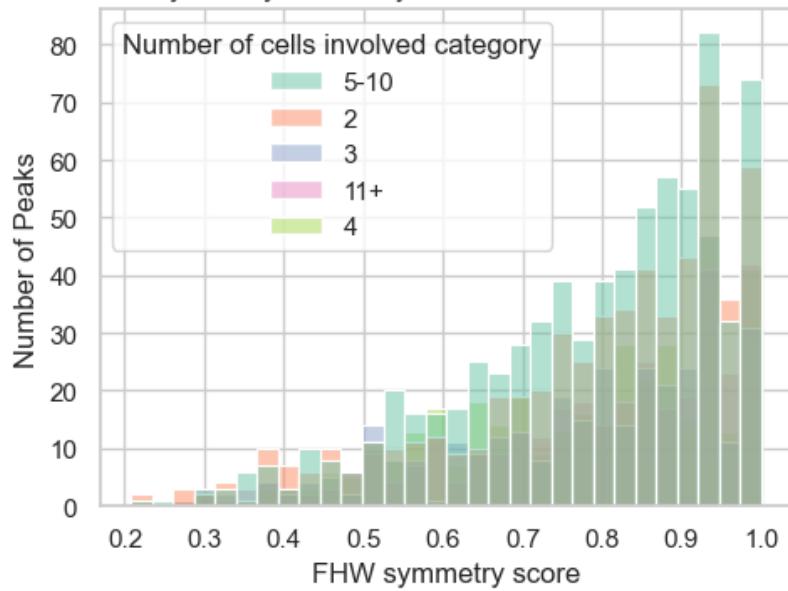


```
[2025-08-27 15:05:29] [INFO] calcium: plot_histogram_by_group: removed 36 outliers out of 2368 on 'Prominence (noise std units)' (lower=-17.35, upper=132.05)
```

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

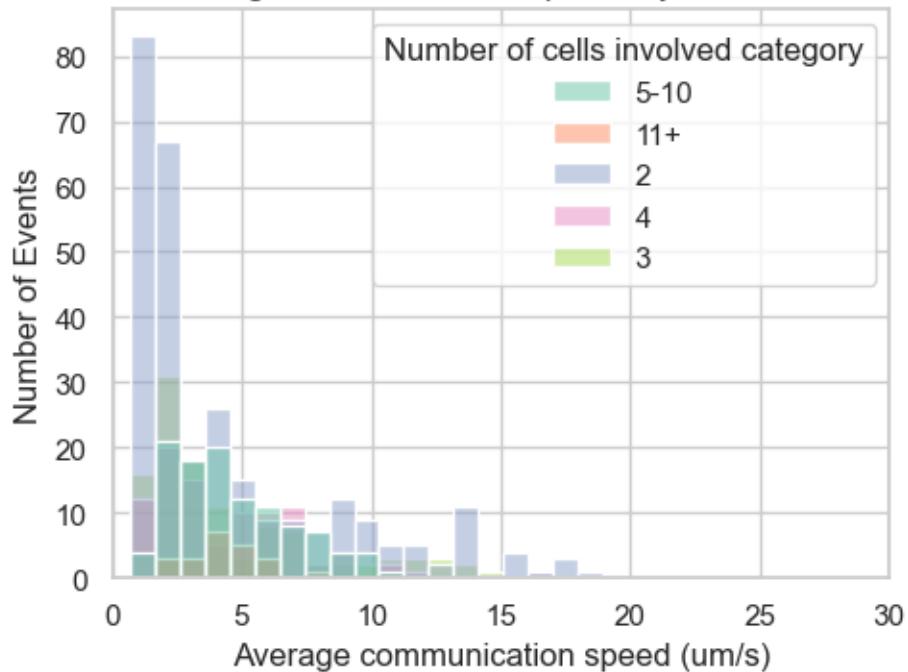


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



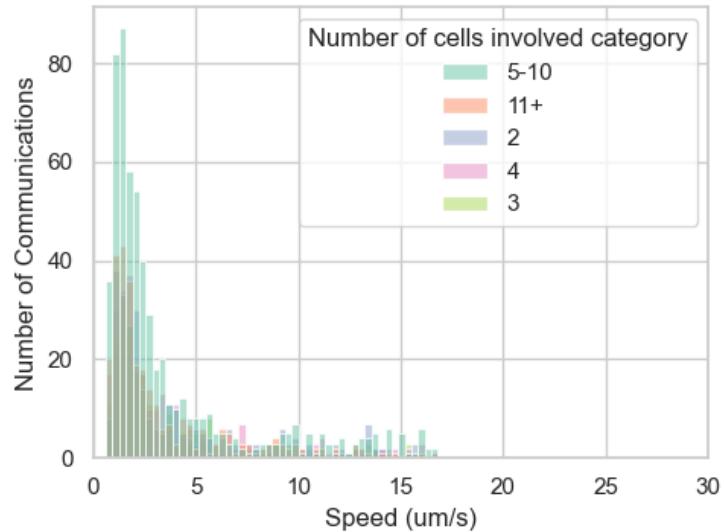
```
[2025-08-27 15:05:30] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 626 on 'Average communication speed (um/s)' (lower=-11.085, upper=19.12)
```

Distribution of Average Communication Speeds by Number of Cells Involved



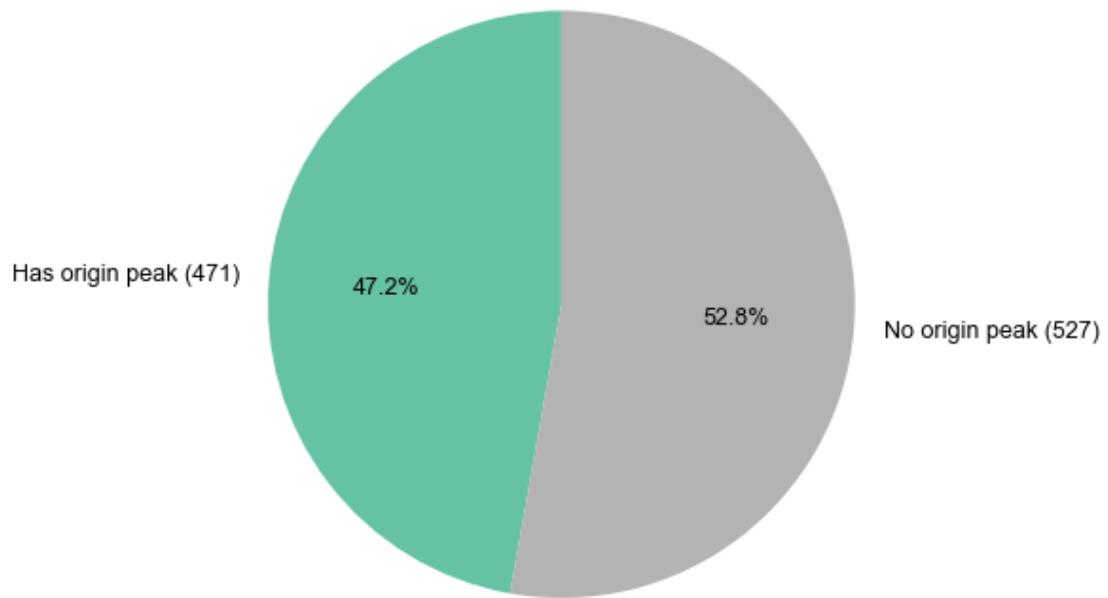
[2025-08-27 15:05:31] [INFO] calcium: plot_histogram_by_group: removed 68 outliers out of 1742 on 'Speed (um/s)' (lower=-10.172, upper=16.9)

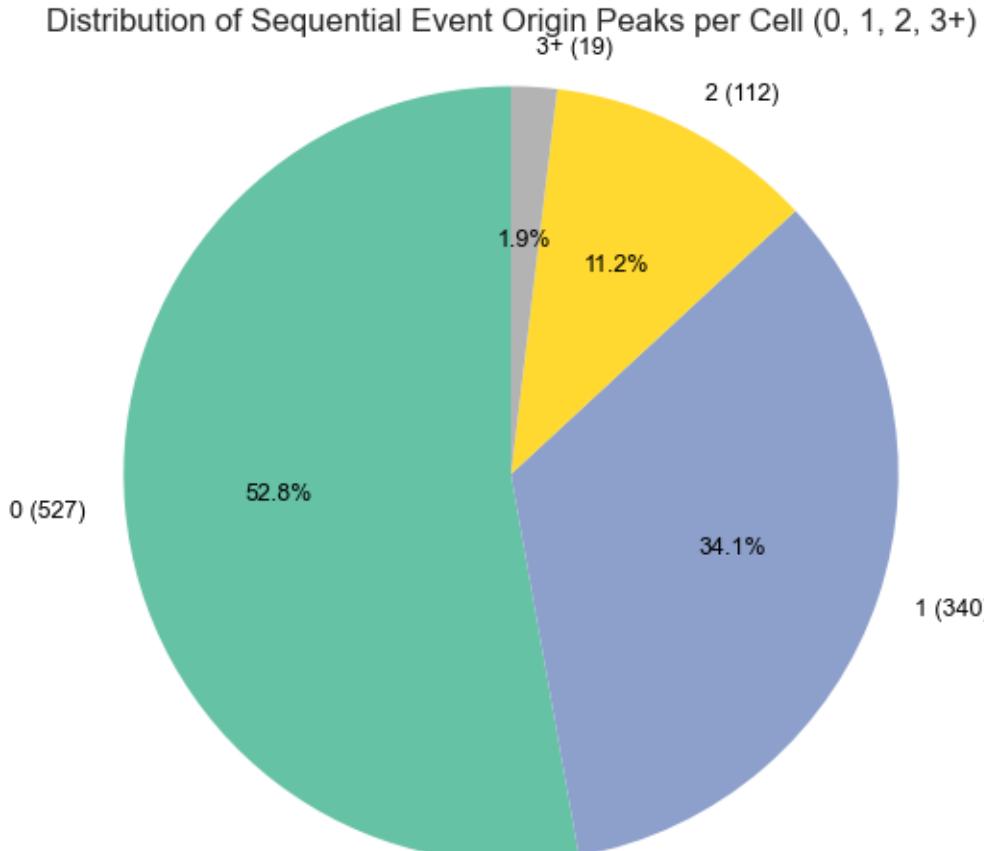
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

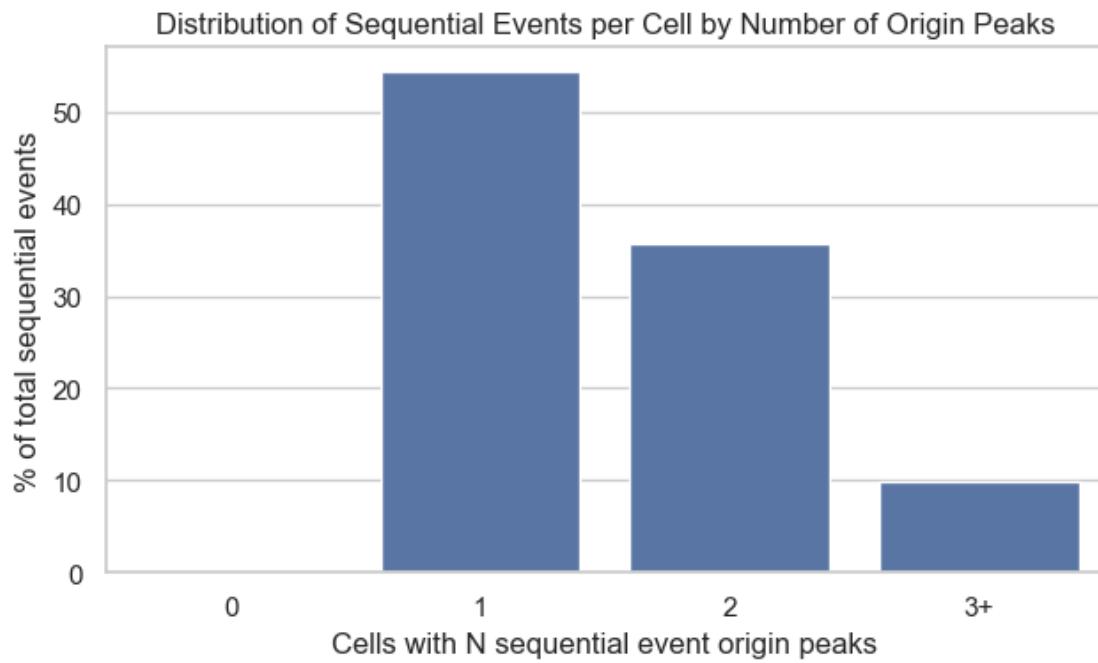
Distribution of Number of Sequential Event Origin Peaks per Cell



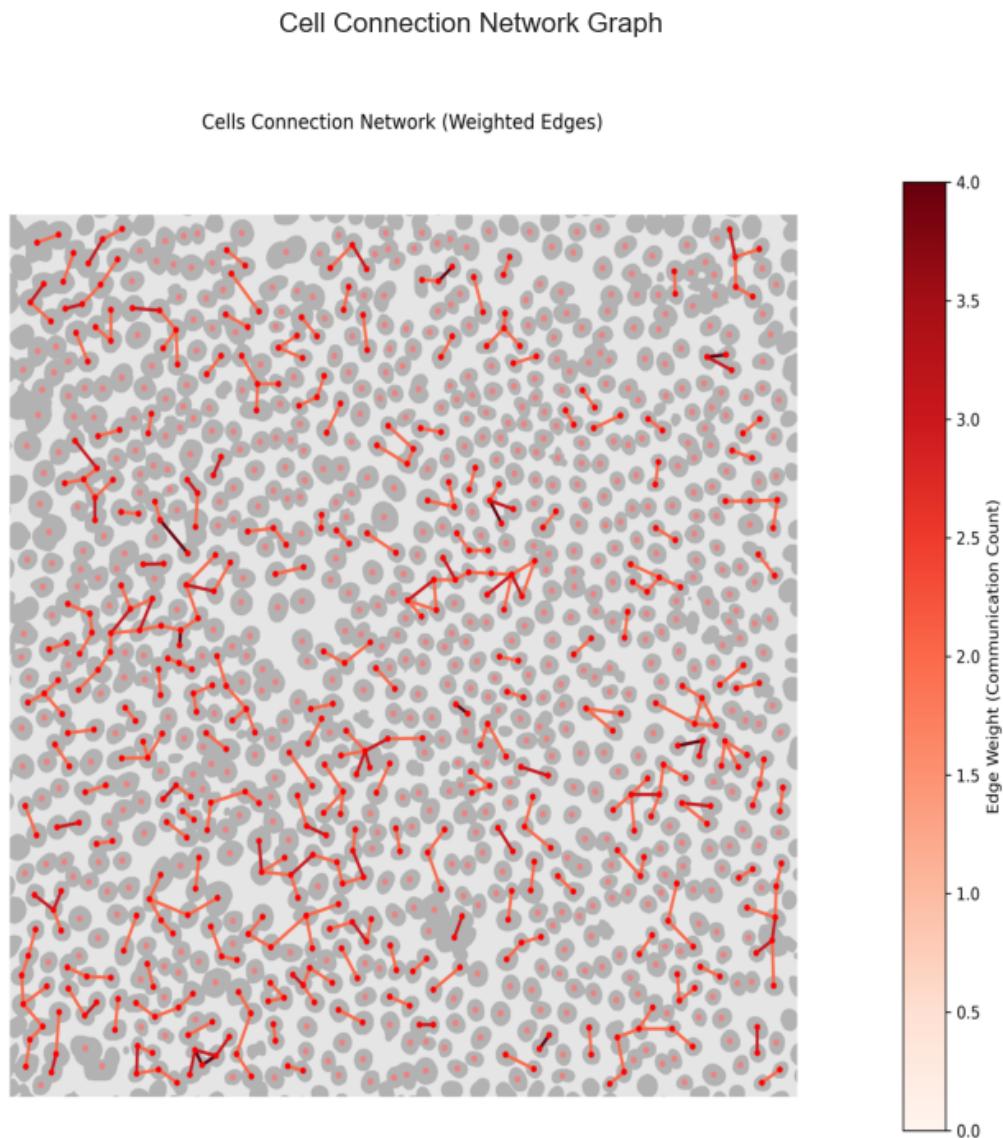


```
[2025-08-27 15:05:32] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS7\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (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\\20250618\\Output\\IS7\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'

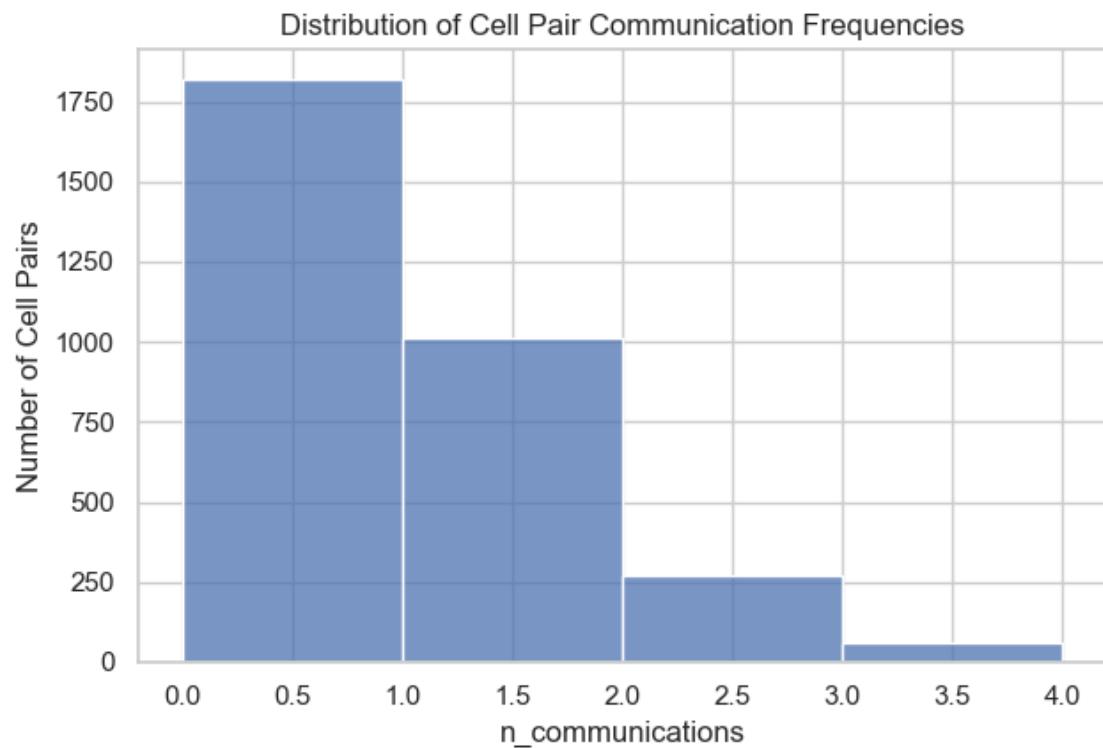


1.3.8 Connection network between cells



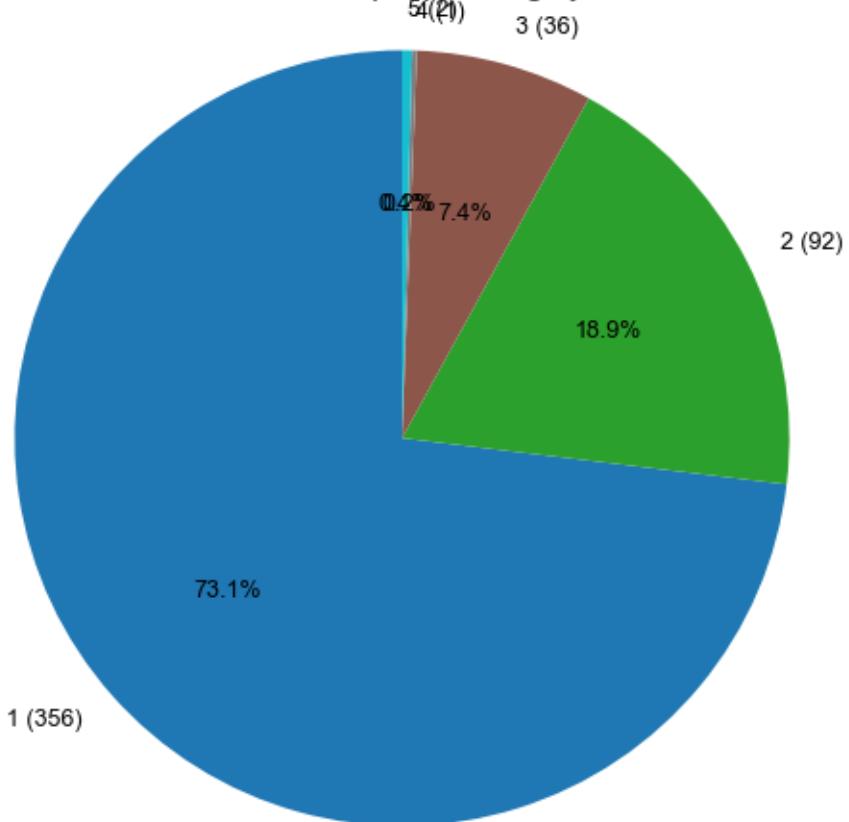
1.3.9 Pair/Trios with high communication networks

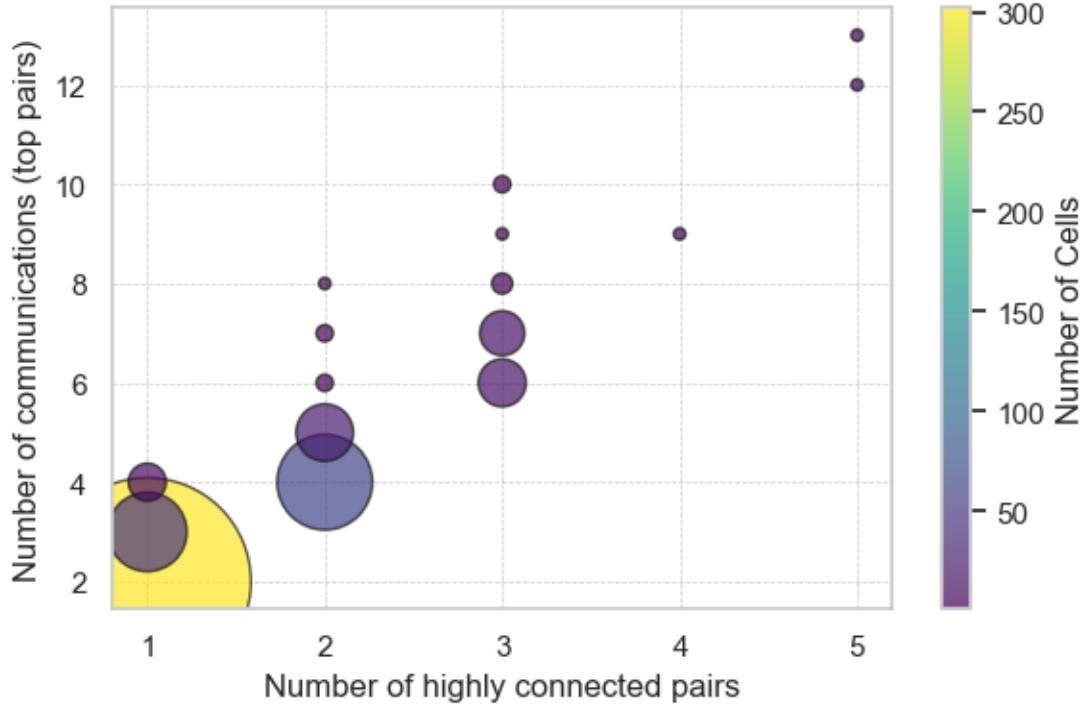
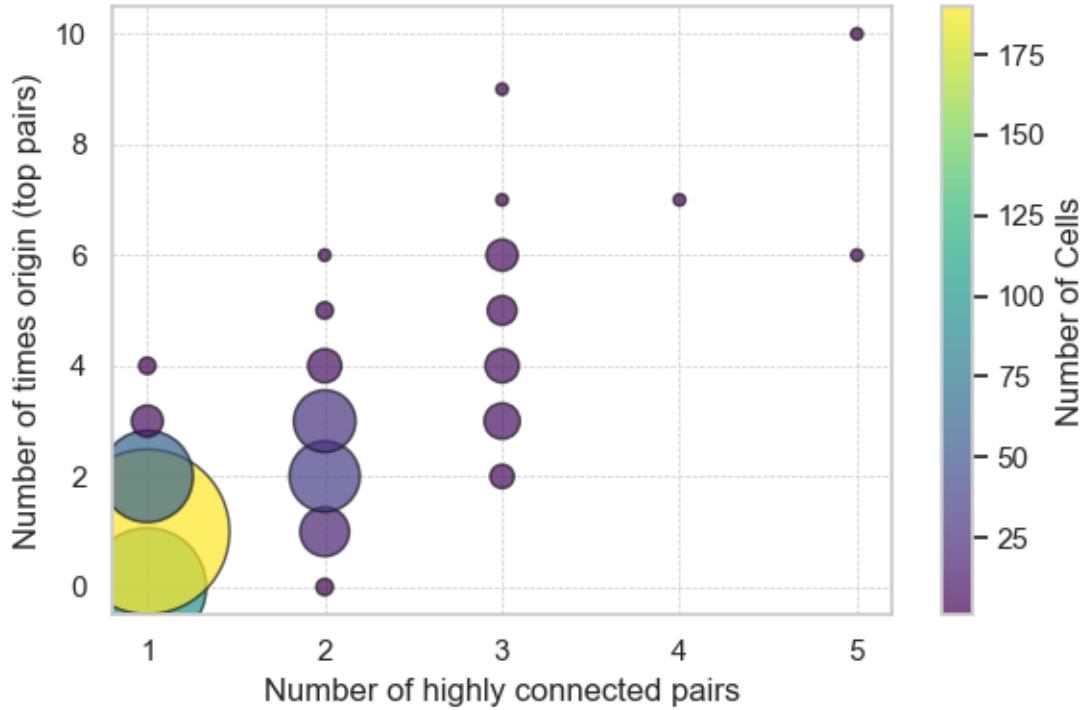
```
[2025-08-27 15:05:34] [INFO] calcium: build_neighbor_pair_stats: built 3162 pairs across 1 datasets (mean distance=16.33 um)
```

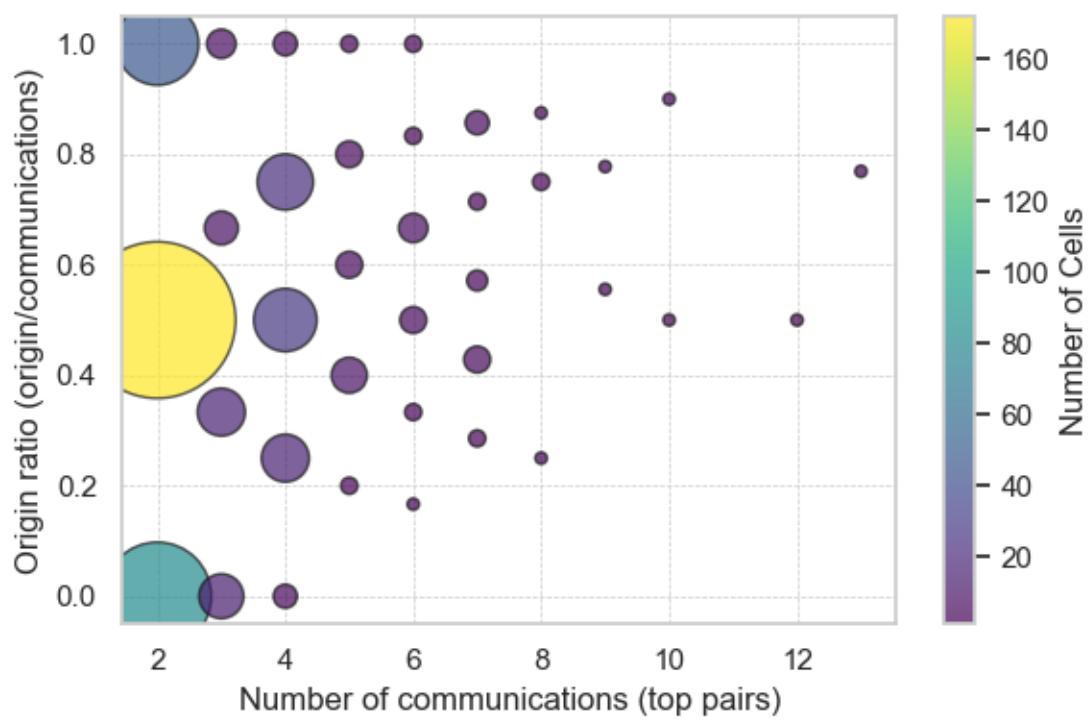
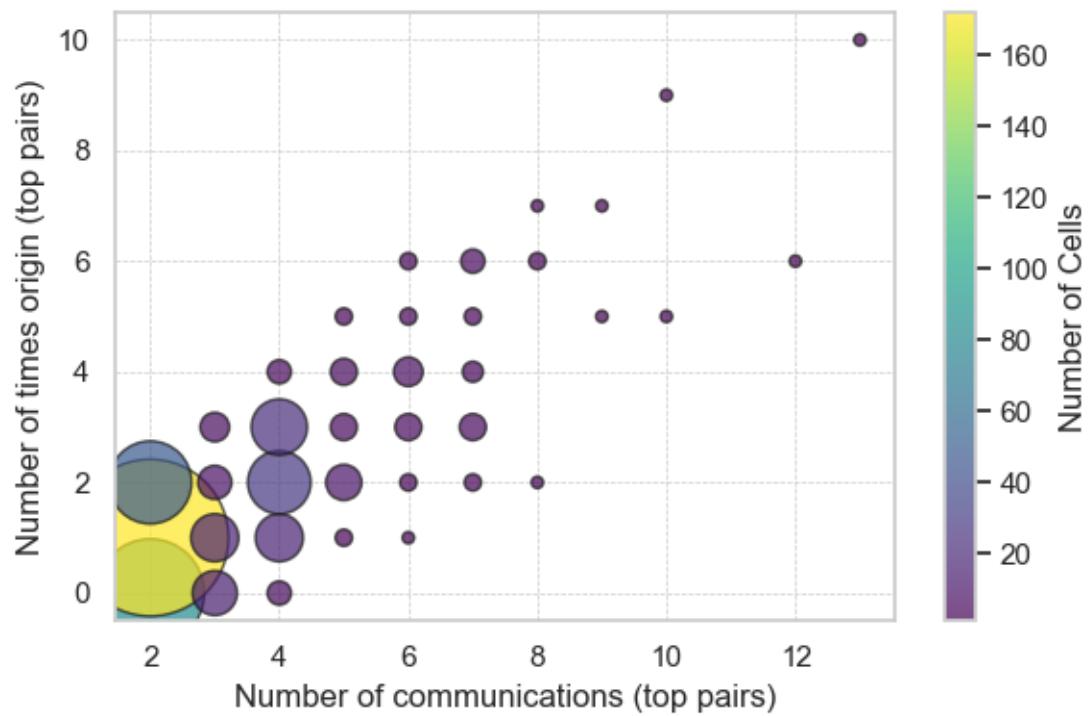


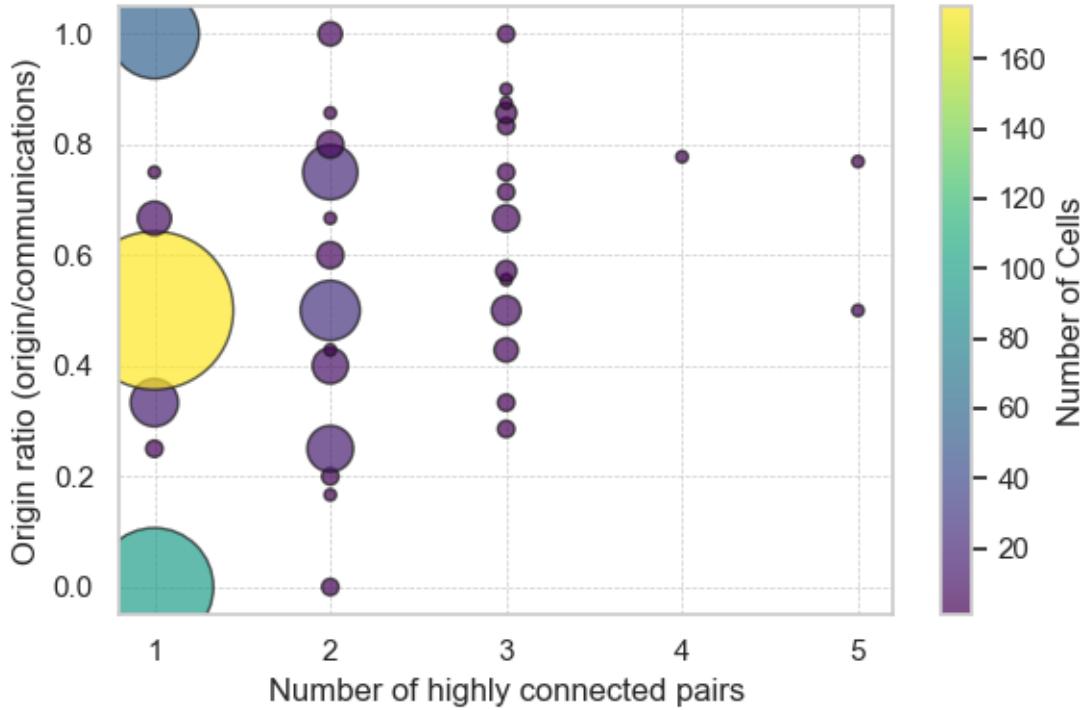
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected









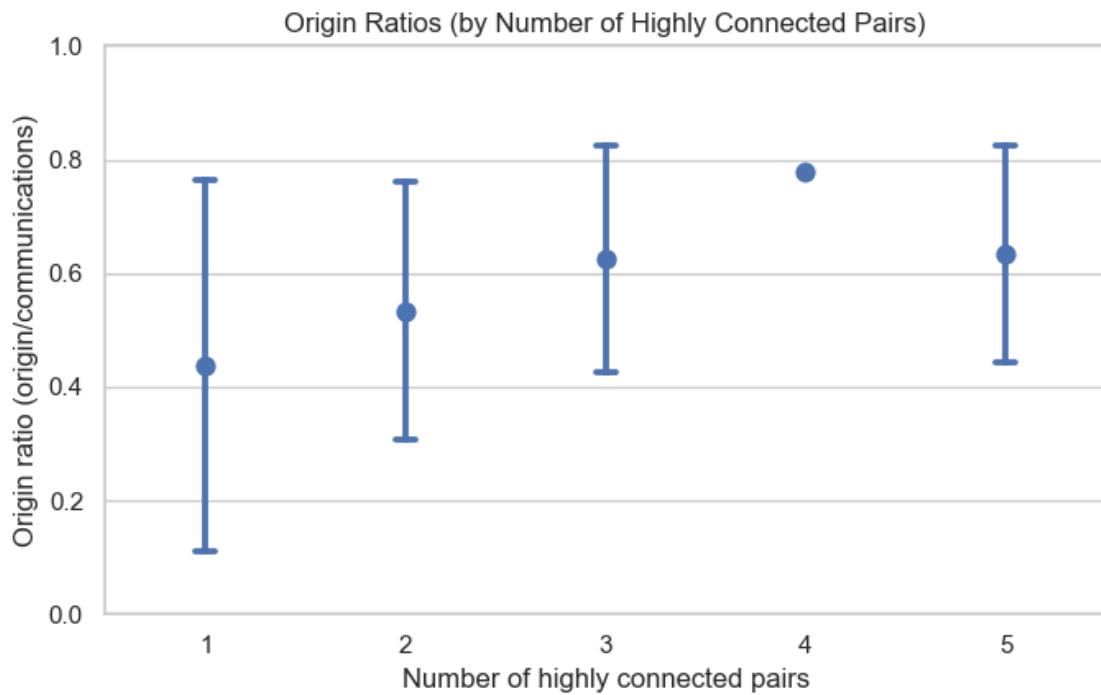
[2025-08-27 15:05:36] [INFO] calcium: plot_points_mean_std: N=356 for Number of highly connected pairs=1

[2025-08-27 15:05:36] [INFO] calcium: plot_points_mean_std: N=92 for Number of highly connected pairs=2

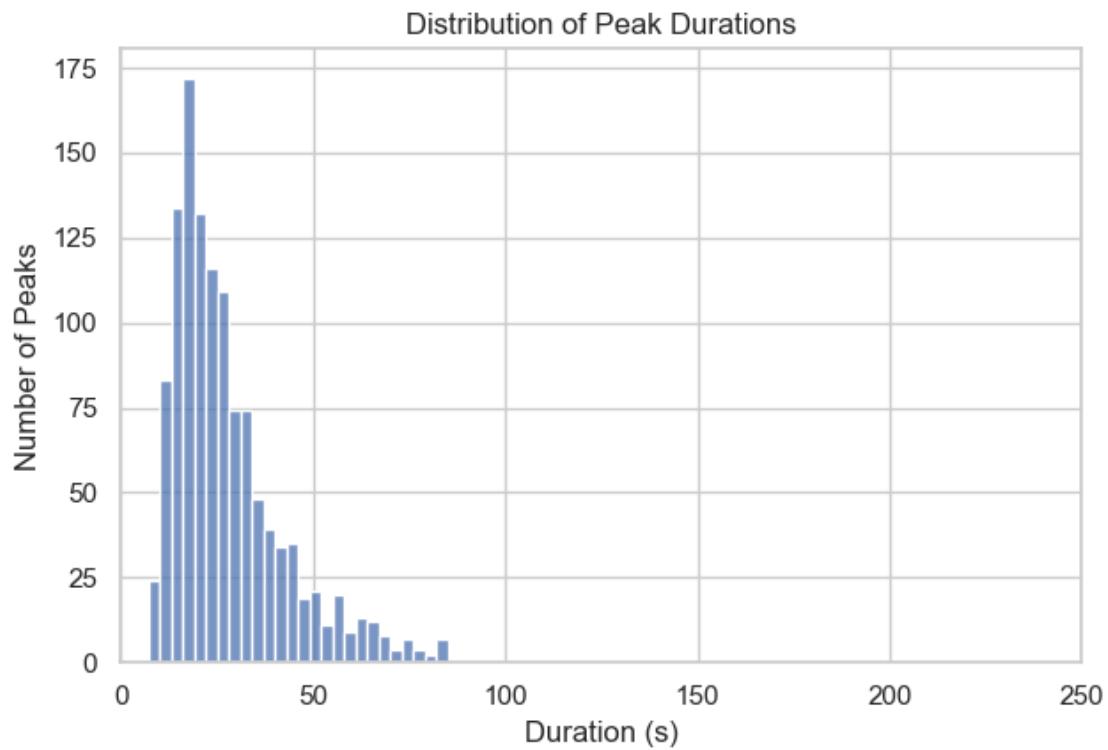
[2025-08-27 15:05:36] [INFO] calcium: plot_points_mean_std: N=36 for Number of highly connected pairs=3

[2025-08-27 15:05:36] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=4

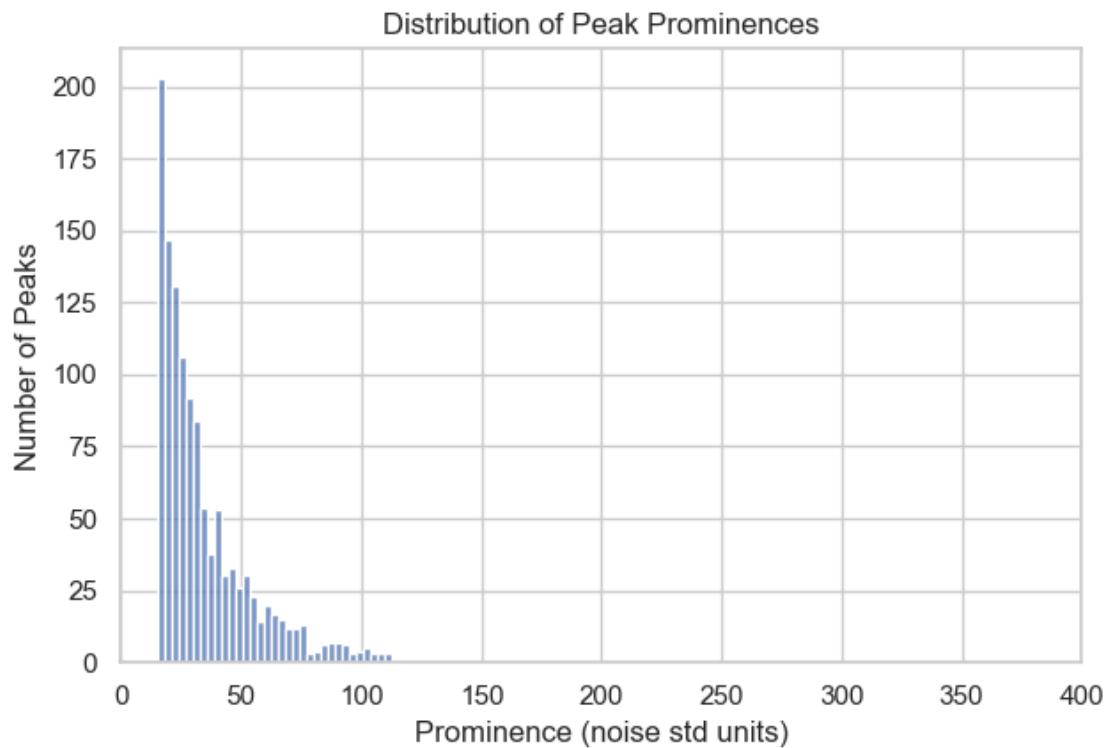
[2025-08-27 15:05:36] [INFO] calcium: plot_points_mean_std: N=2 for Number of highly connected pairs=5

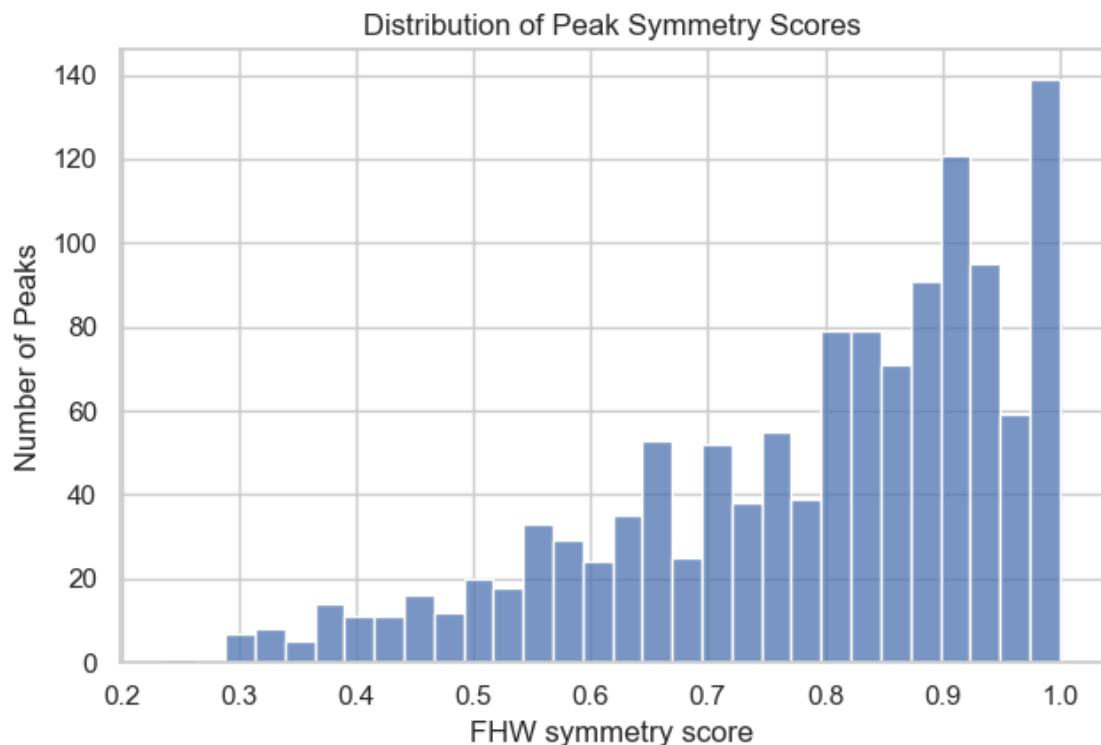


```
[2025-08-27 15:05:36] [INFO] calcium: plot_histogram: removed 29 outliers out of 1240 on 'Duration (s)' (lower=-34, upper=85)
```

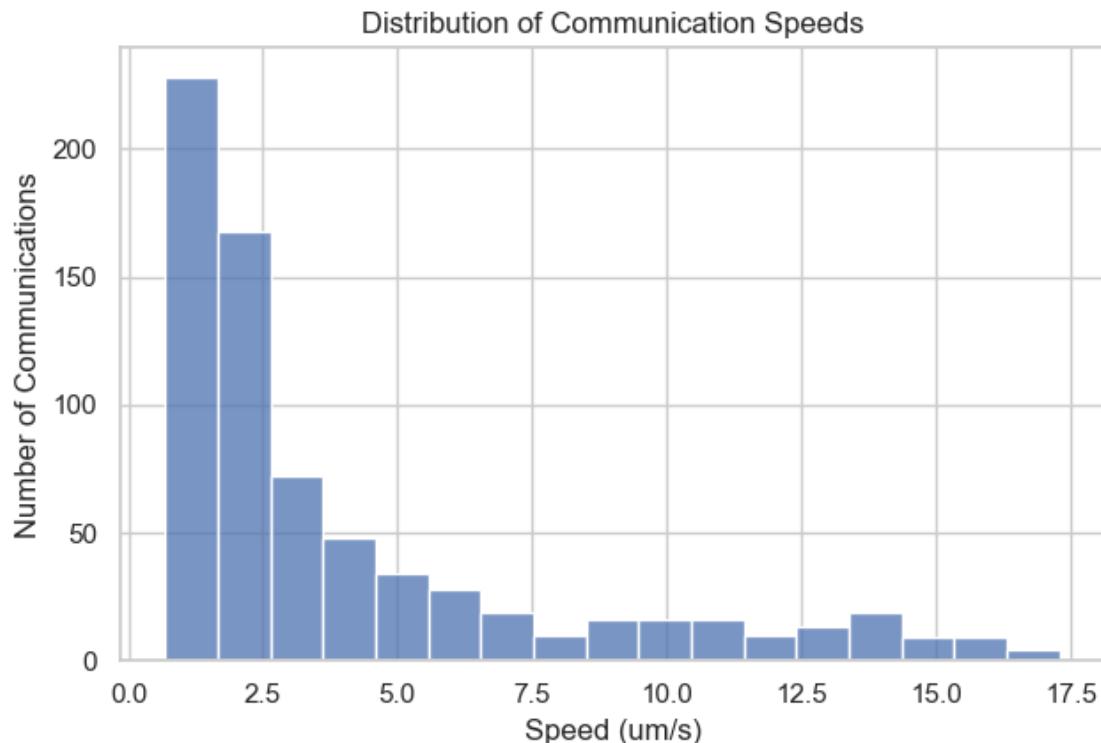


[2025-08-27 15:05:37] [INFO] calcium: plot_histogram: removed 33 outliers out of 1240 on 'Prominence (noise std units)' (lower=-50.175, upper=113.8)

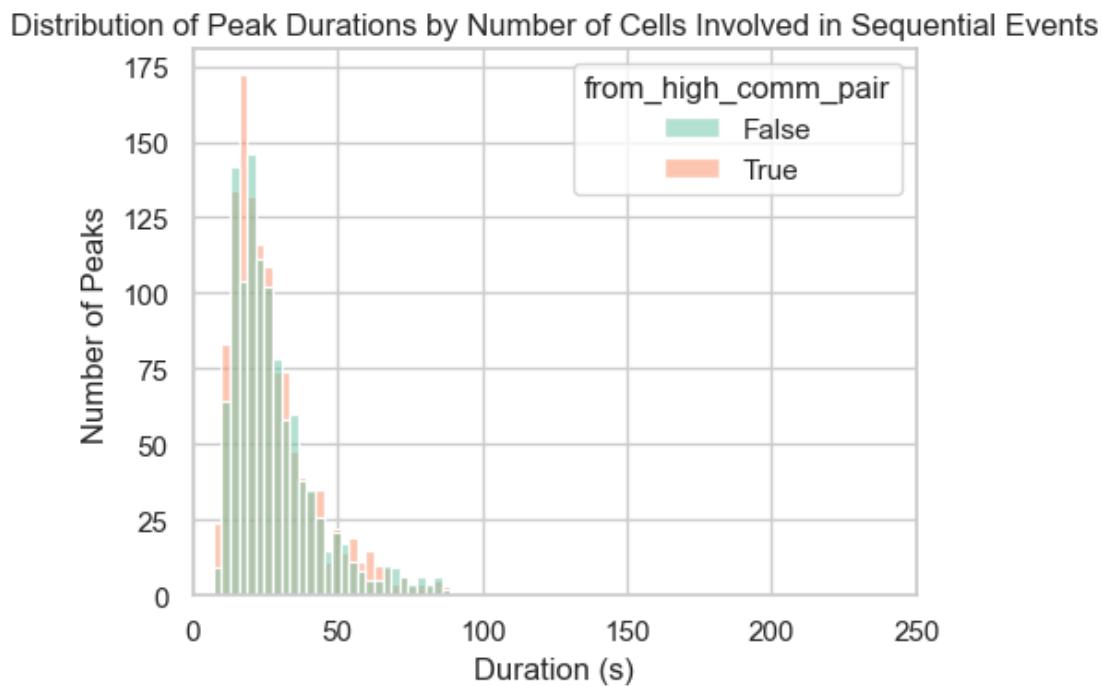




[2025-08-27 15:05:37] [INFO] calcium: plot_histogram: removed 12 outliers out of 731 on 'Speed (um/s)' (lower=-10.46, upper=17.4)

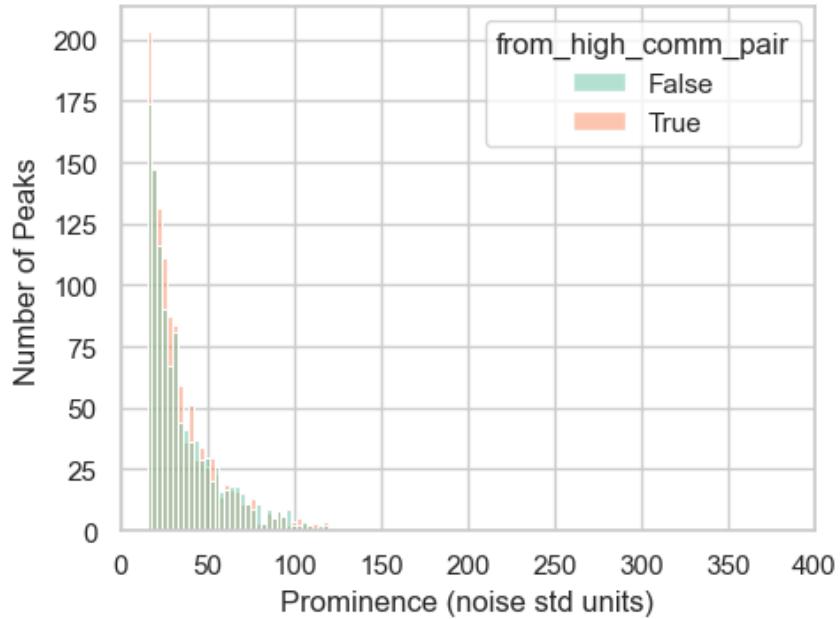


```
[2025-08-27 15:05:37] [INFO] calcium: plot_histogram_by_group: removed 52 outliers out of 2368 on 'Duration (s)' (lower=-37, upper=89)
```

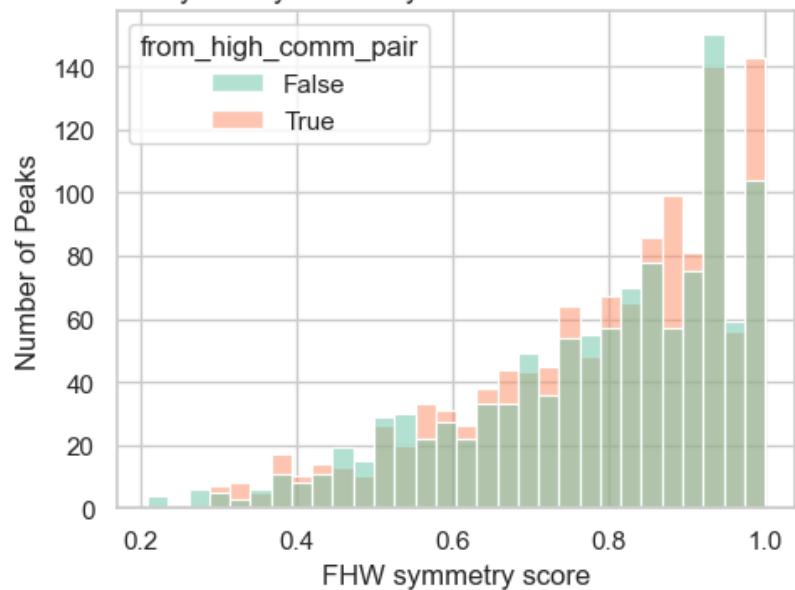


[2025-08-27 15:05:38] [INFO] calcium: plot_histogram_by_group: removed 50 outliers out of 2368 on 'Prominence (noise std units)' (lower=-54.7, upper=119.6)

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

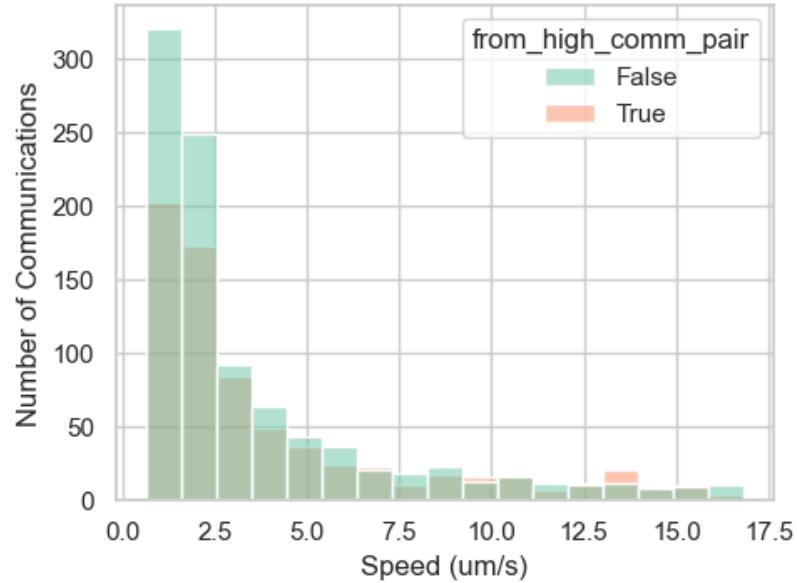


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:05:38] [INFO] calcium: plot_histogram_by_group: removed 68 outliers out of 1742 on 'Speed (um/s)' (lower=-10.172, upper=16.9)

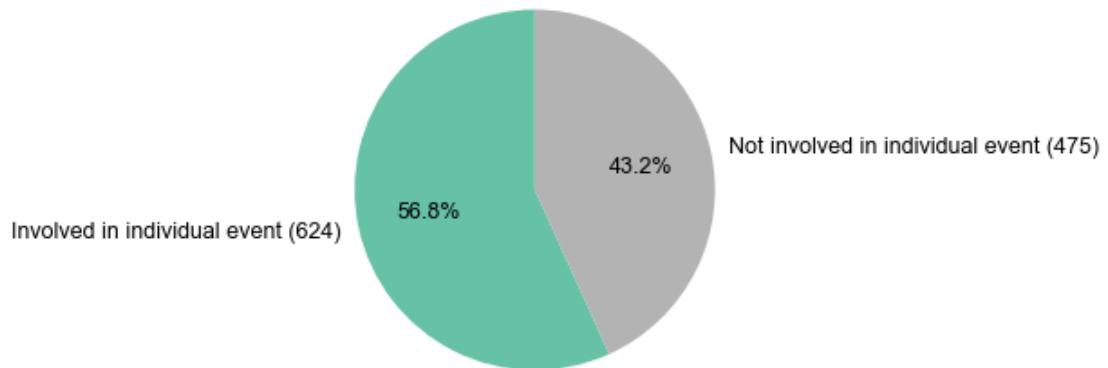
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

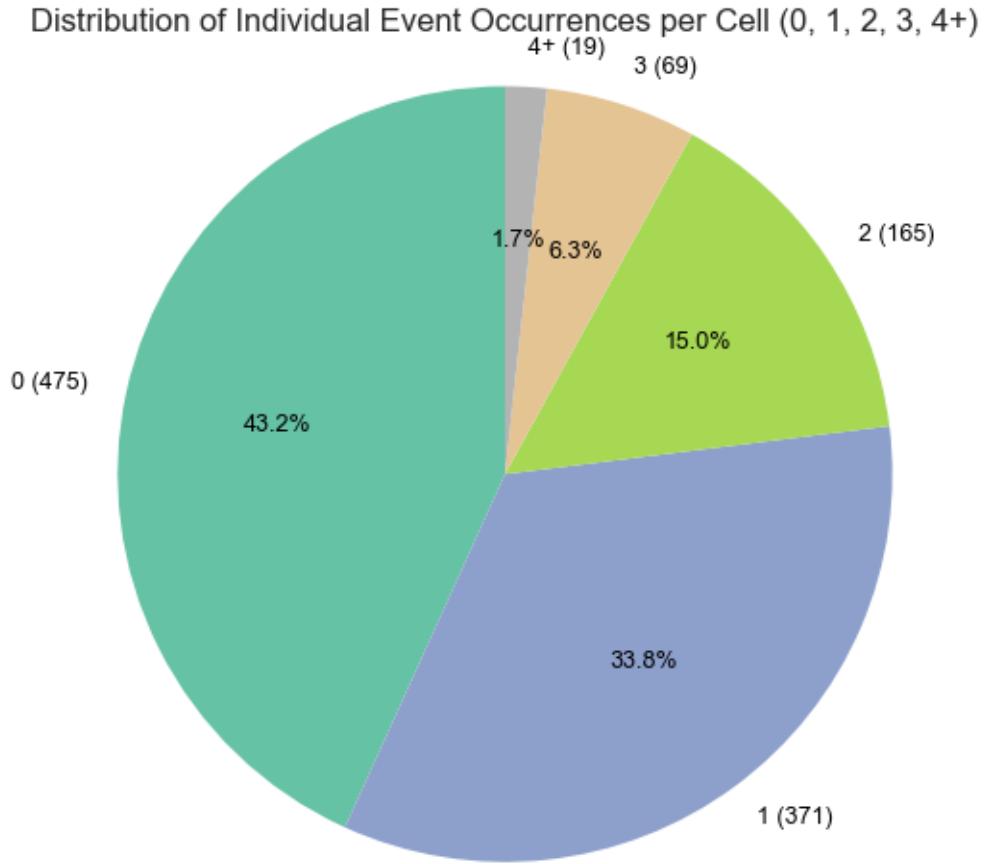


1.4 INDIVIDUAL EVENTS

1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



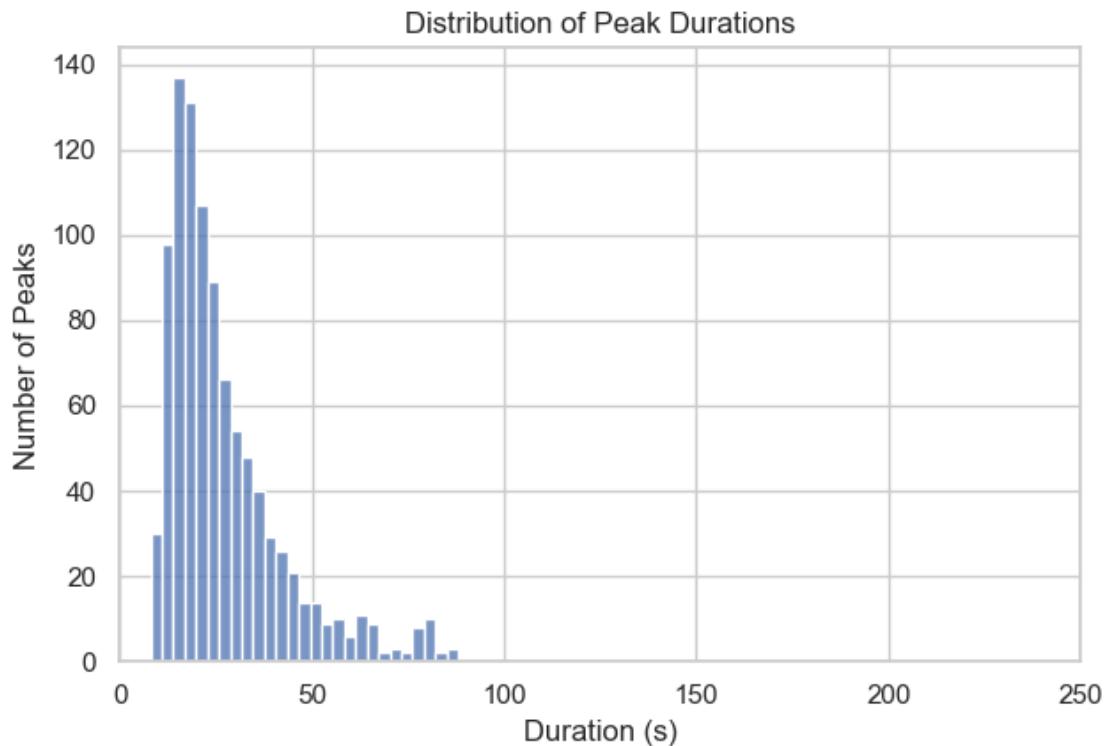


```
[2025-08-27 15:05:39] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS7\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS7\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\IS7\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

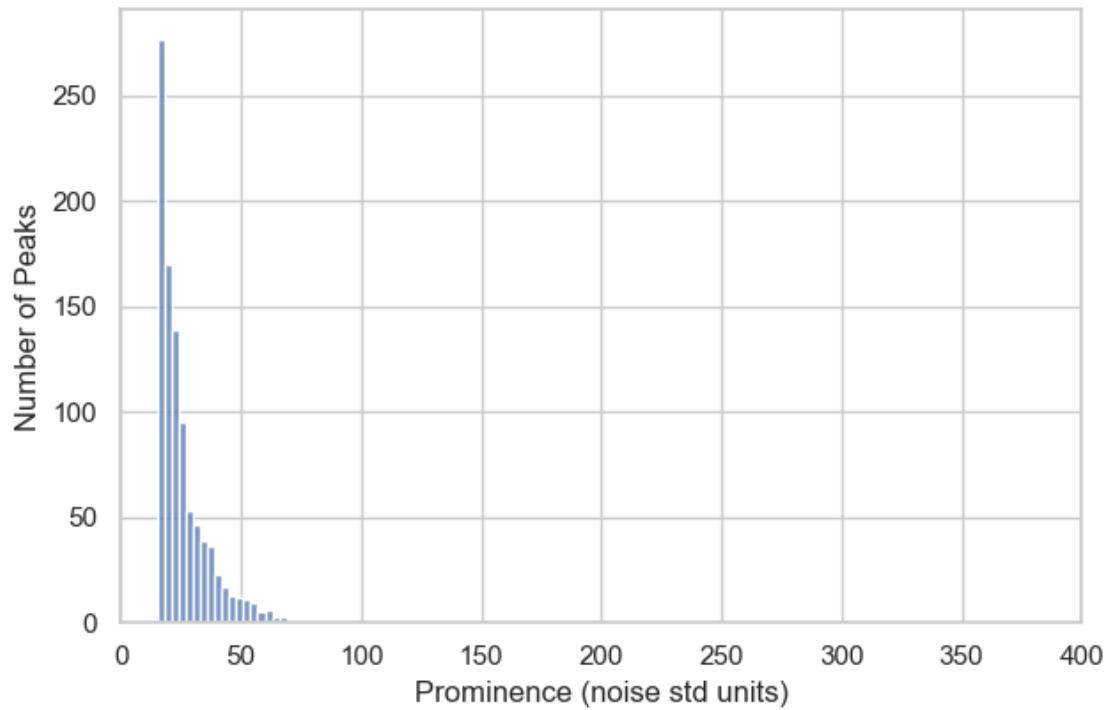
1.4.2 Peaks statistics in individual events

[2025-08-27 15:05:39] [INFO] calcium: plot_histogram: removed 15 outliers out of 994 on 'Duration (s)' (lower=-38, upper=88)

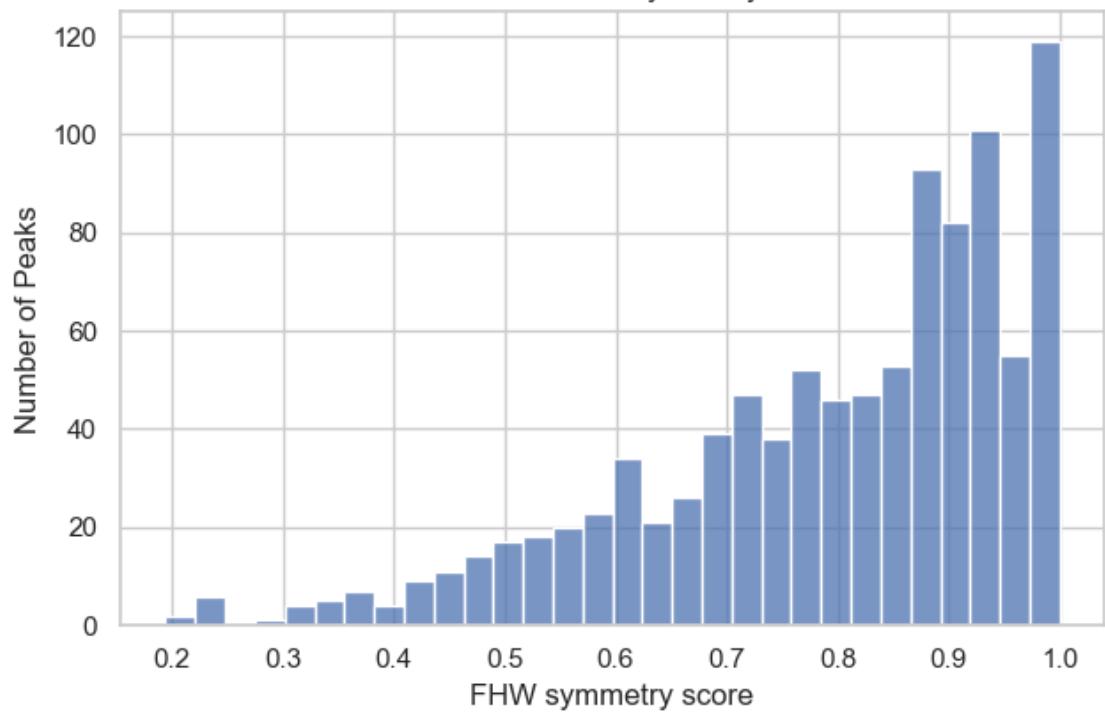


[2025-08-27 15:05:40] [INFO] calcium: plot_histogram: removed 37 outliers out of 994 on 'Prominence (noise std units)' (lower=-21.85, upper=70.025)

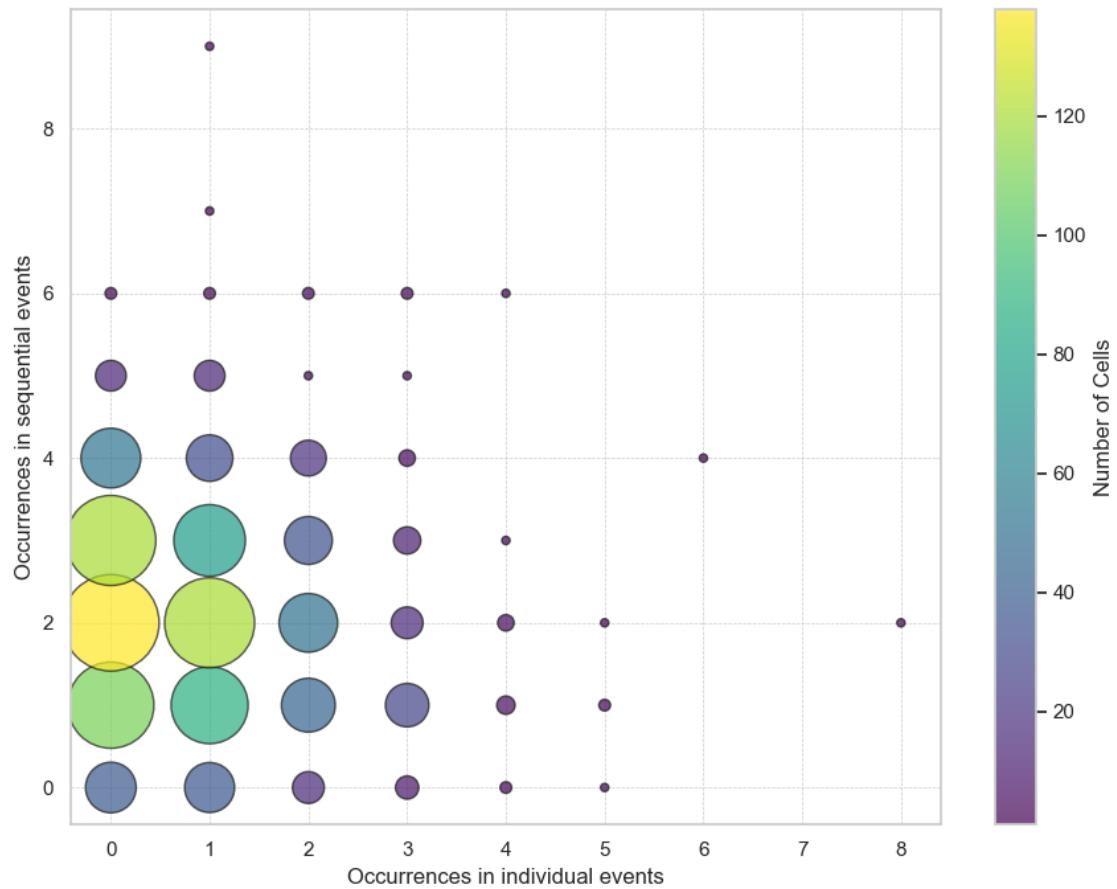
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



1.4.3 Correlation between event activity level & individual activity level



[2025-08-27 15:05:40] [INFO] calcium: plot_points_mean_std: removed 0/1099 outliers on 'Occurrences in sequential events' (lower=-5, upper=9)

[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=475 for Occurrences in individual events=0

[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=371 for Occurrences in individual events=1

[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=165 for Occurrences in individual events=2

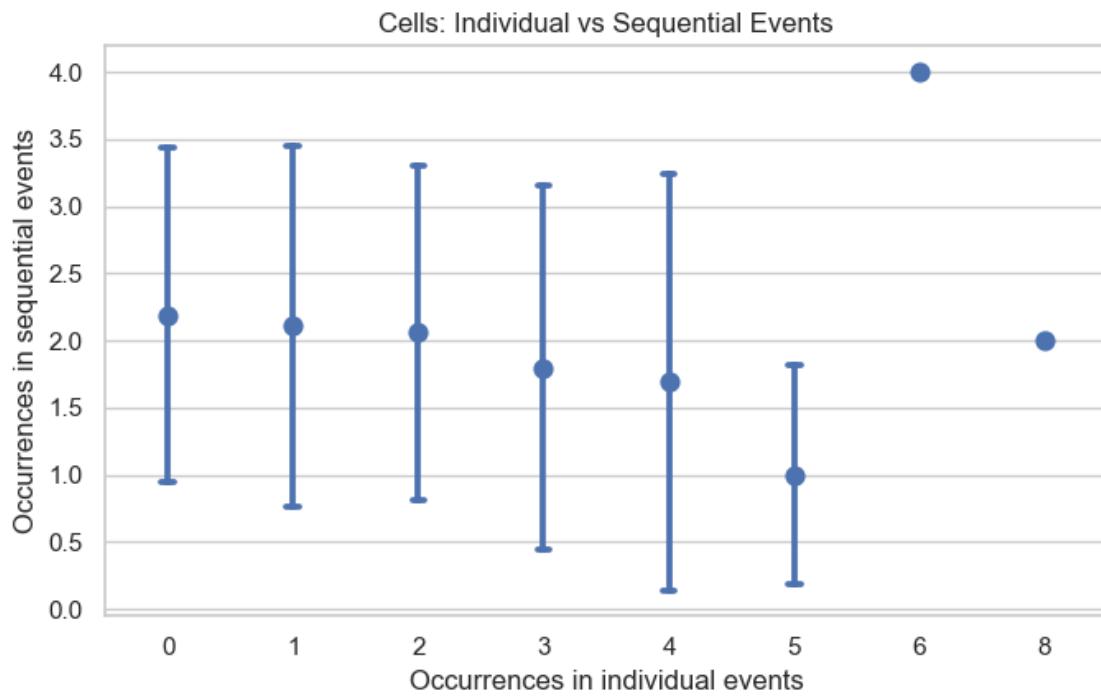
[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=69 for Occurrences in individual events=3

[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=13 for Occurrences in individual events=4

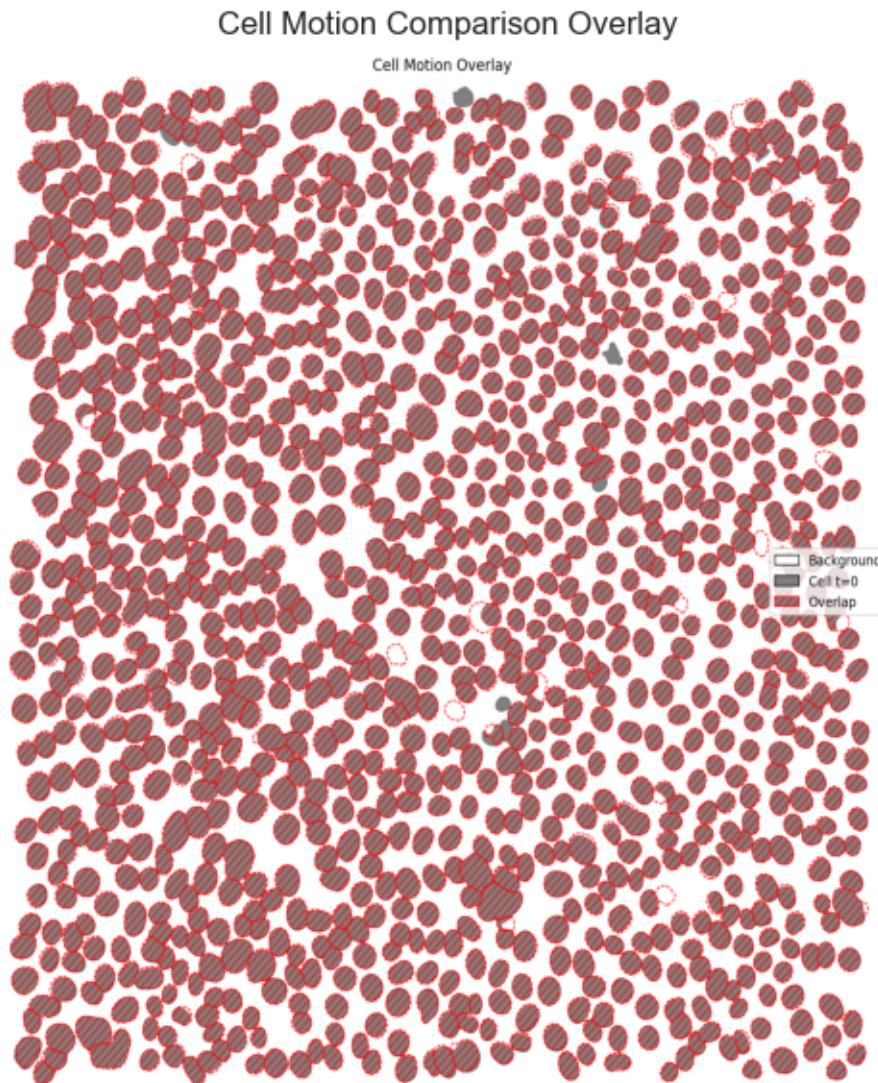
[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=4 for Occurrences in individual events=5

[2025-08-27 15:05:41] [INFO] calcium: plot_points_mean_std: N=1 for Occurrences in individual events=6

[2025-08-27 15:05:41] [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: 1099
- Hoechst image taken at t=1801: 1097
- Number of cells difference: absolute 2, relative 0.18%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1154787
- Pixels segmented as cell at t=1801: 1165303
- Overlapping pixels between t=0 and t=1801: 1097029 (94.57% of total)
- Pixels exclusive to t=0: 57758 (5.00% of total)
- Pixels exclusive to t=1801: 68274 (5.86% of total)

executed

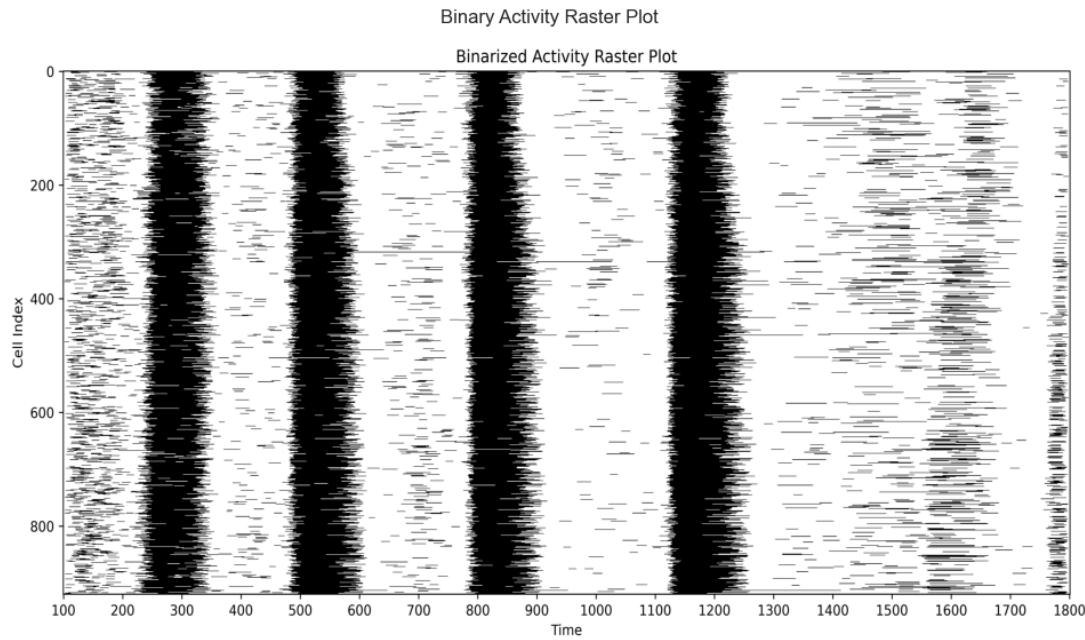
August 27, 2025

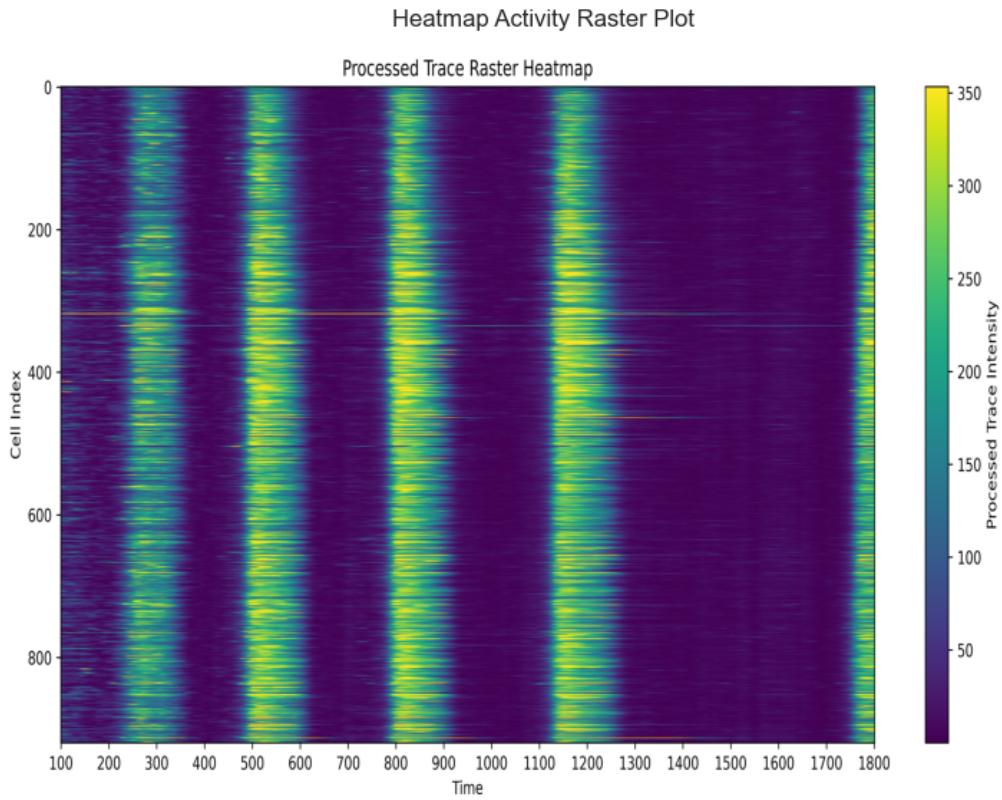
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot





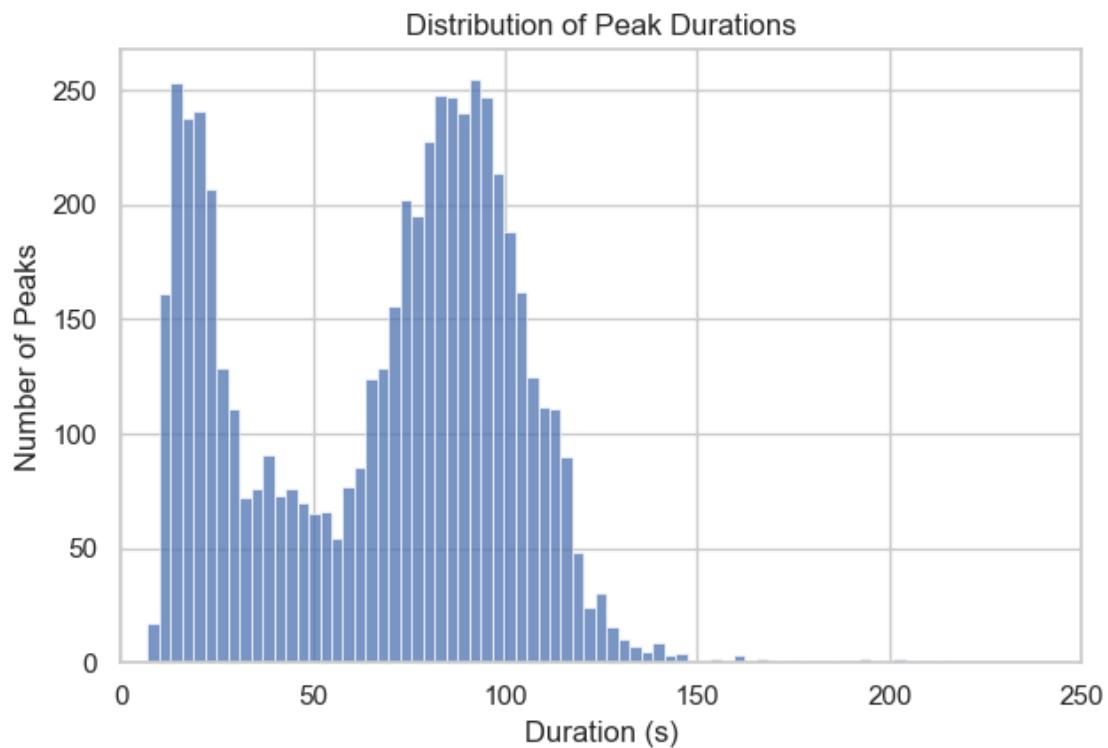
1.1.2 Peaks population

Total number of peaks: 5611

Total number of cells: 920

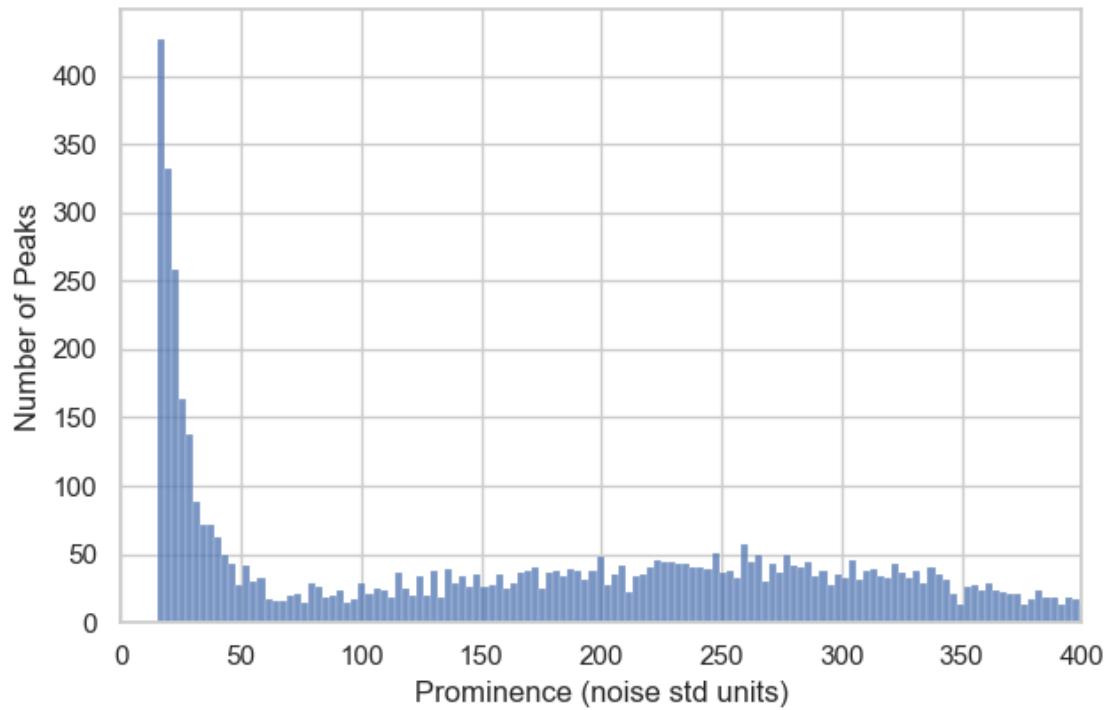
1.1.3 Peaks statistics

```
[2025-08-27 15:06:47] [INFO] calcium: plot_histogram: removed 1 outliers out of  
5611 on 'Duration (s)' (lower=-150, upper=277)
```

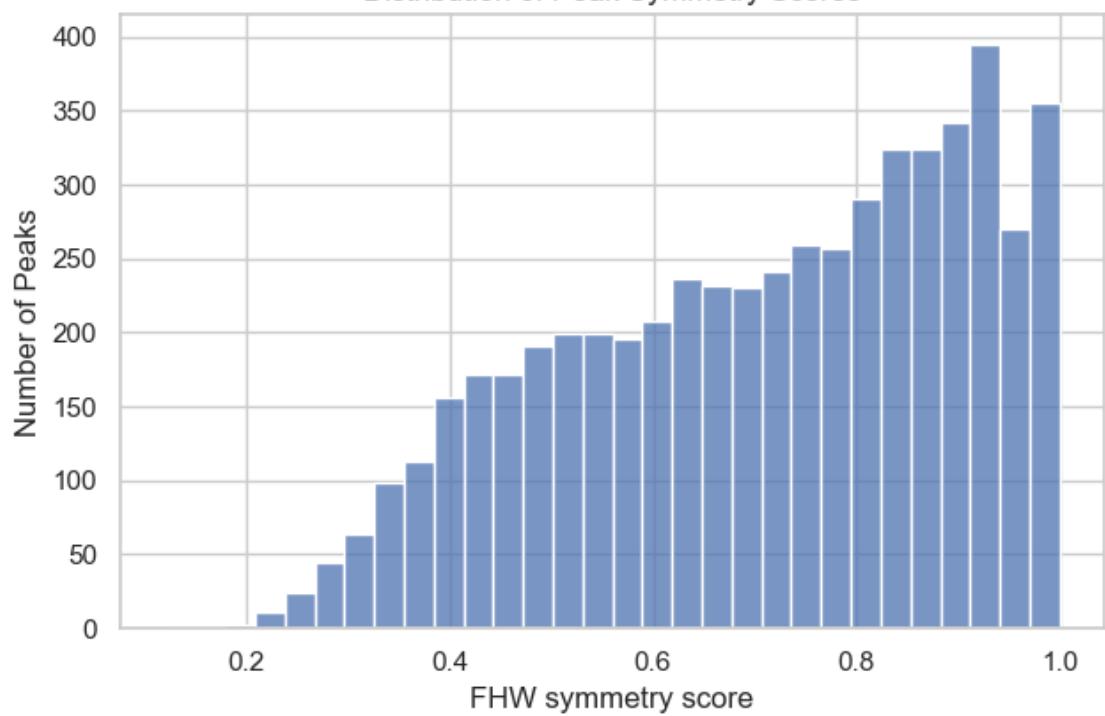


```
[2025-08-27 15:06:47] [INFO] calcium: plot_histogram: removed 0 outliers out of  
5611 on 'Prominence (noise std units)' (lower=-709.1, upper=1022)
```

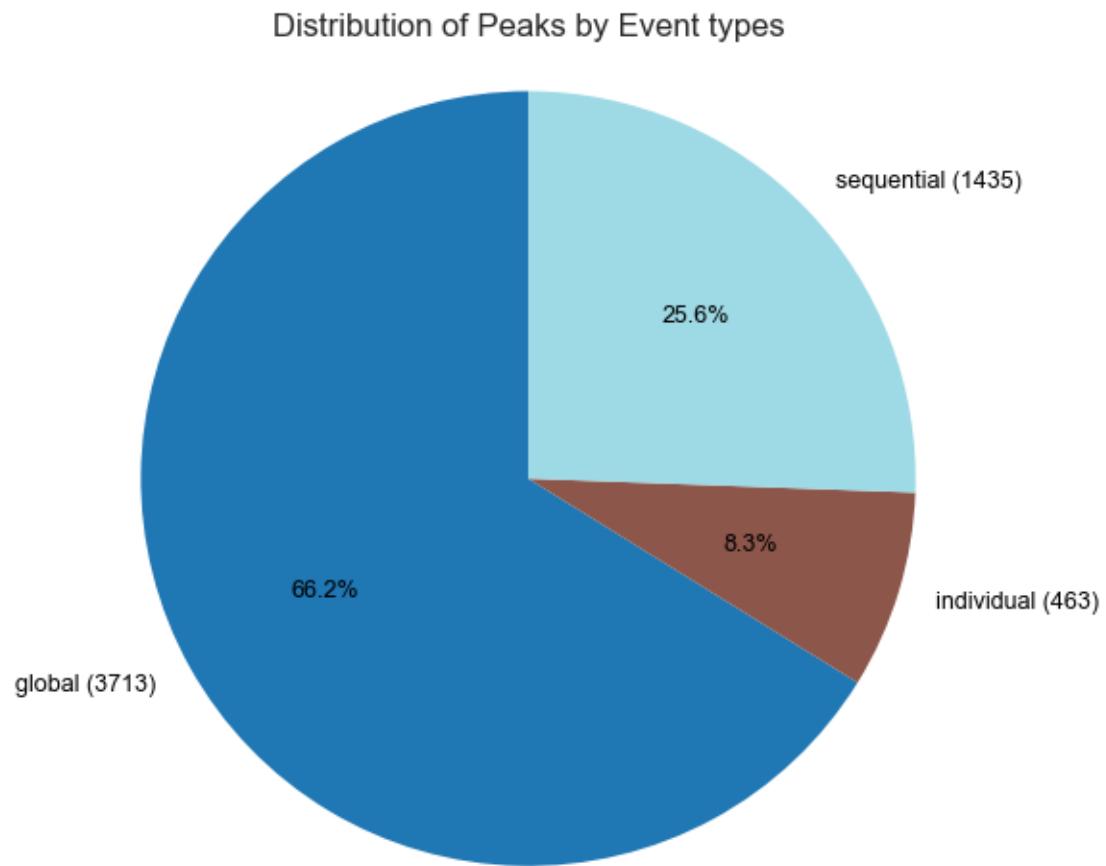
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

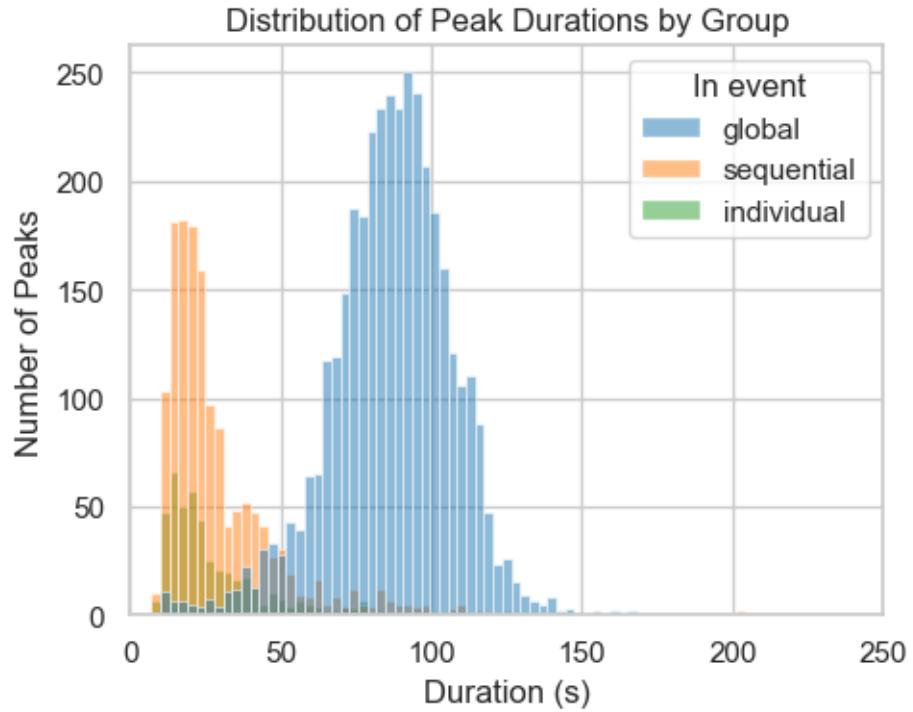


1.1.4 Distribution of peaks per event types

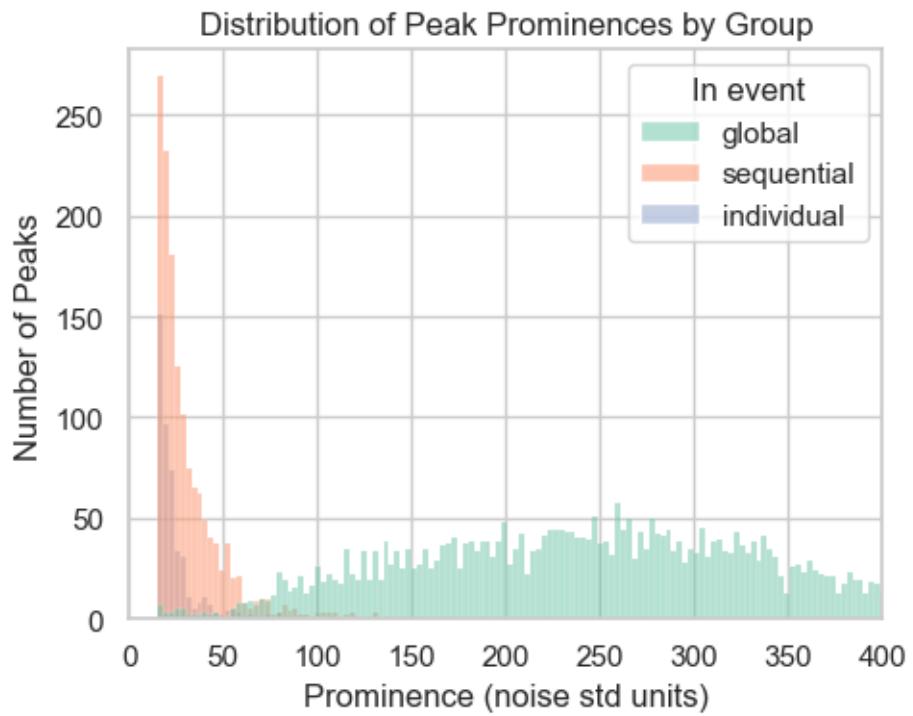


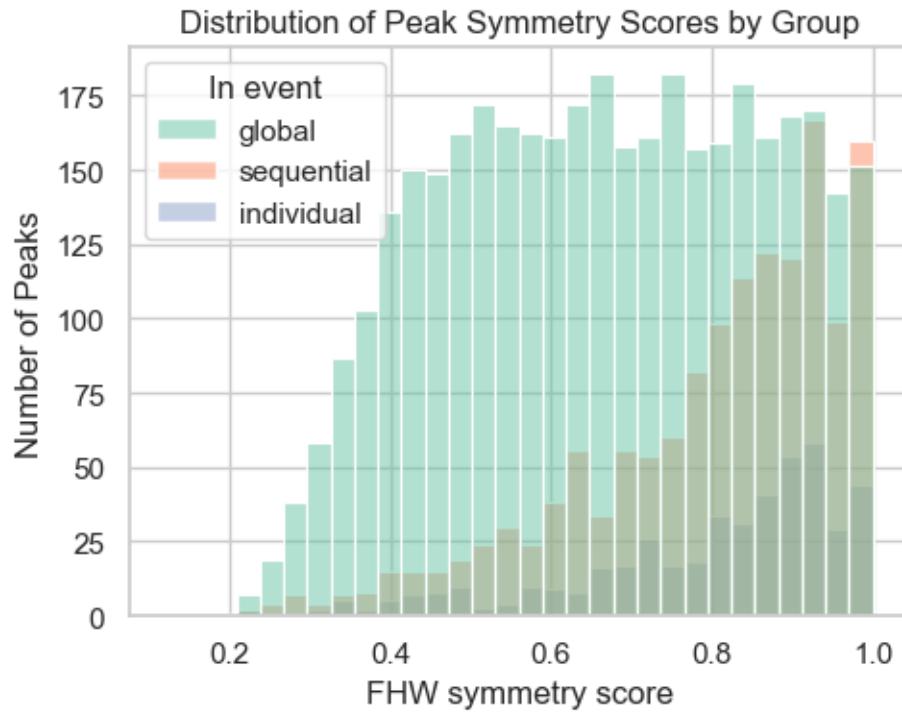
1.1.5 Peaks statistics per event types

```
[2025-08-27 15:06:48] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 5611 on 'Duration (s)' (lower=-150, upper=277)
```



```
[2025-08-27 15:06:48] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5611 on 'Prominence (noise std units)' (lower=-709.1, upper=1022)
```

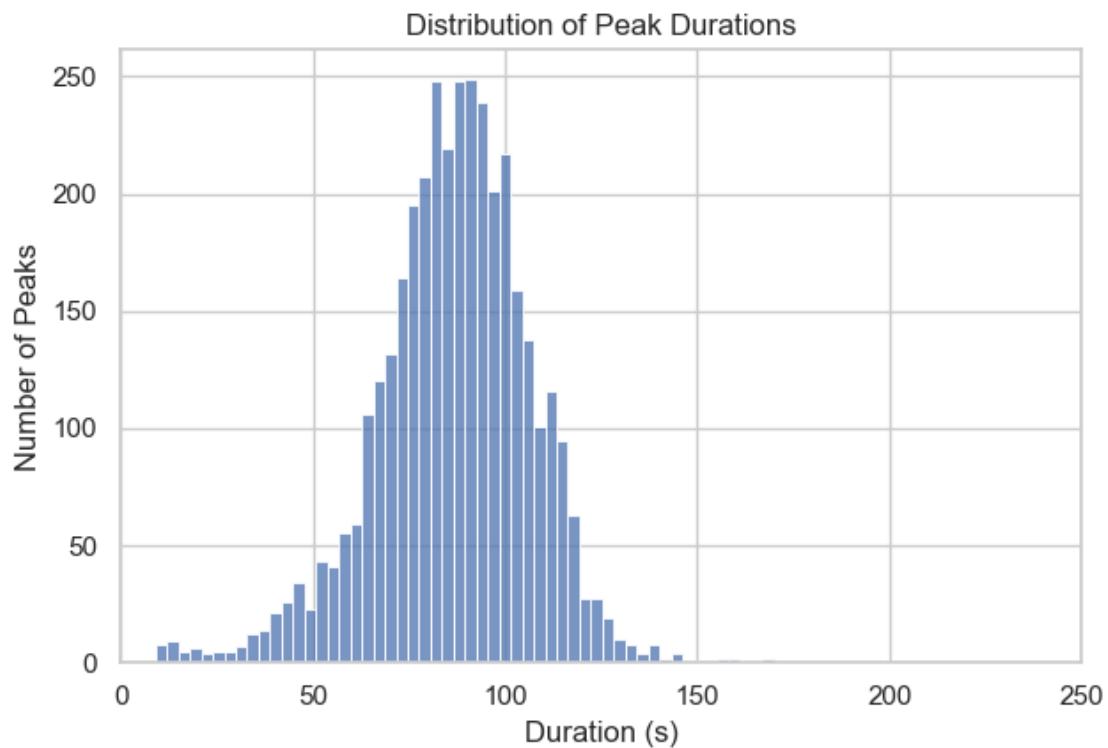




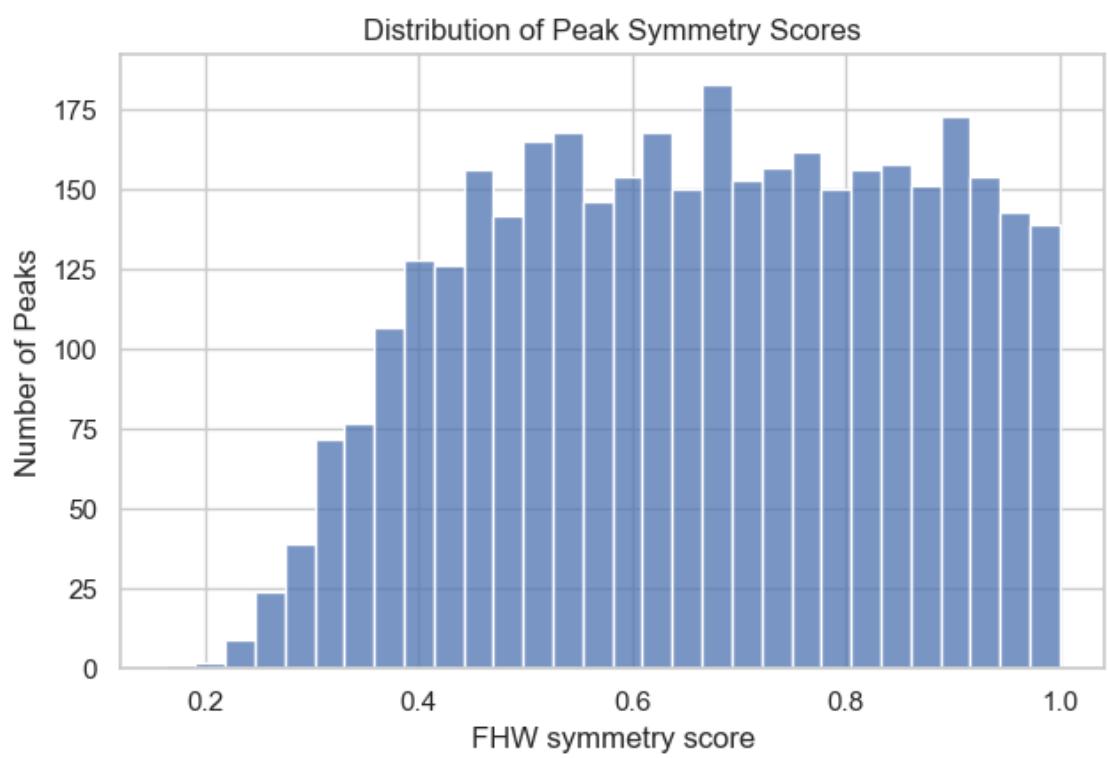
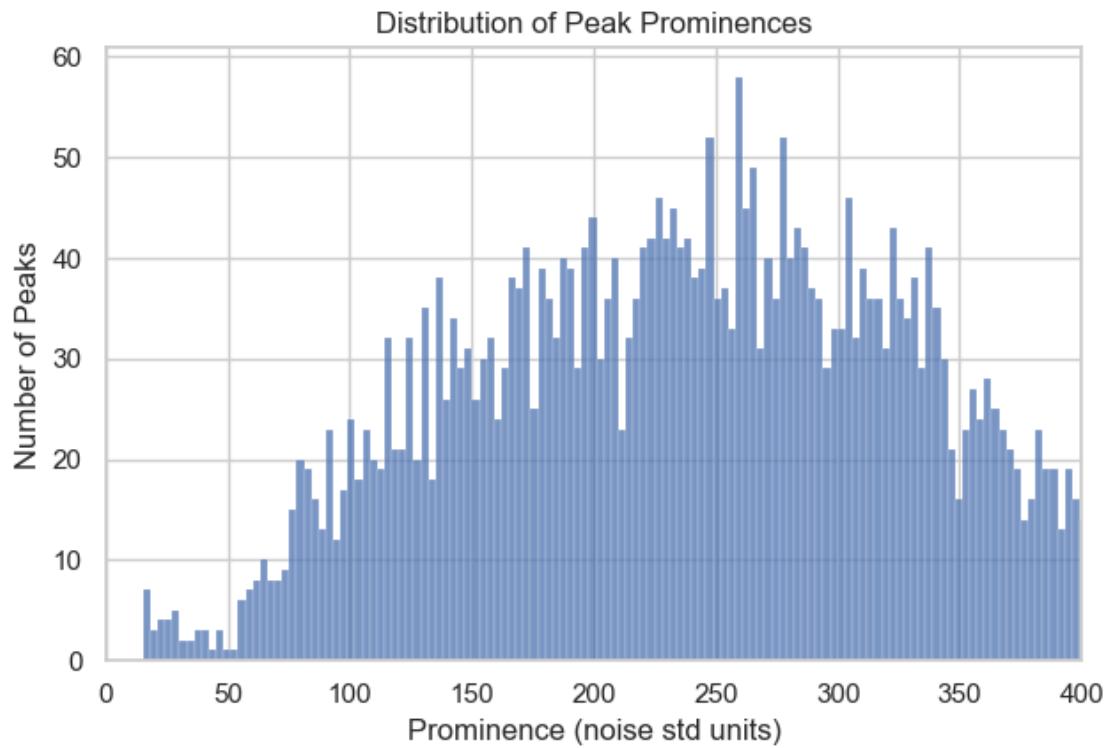
1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-27 15:06:49] [INFO] calcium: plot_histogram: removed 2 outliers out of  
3713 on 'Duration (s)' (lower=3, upper=171)
```

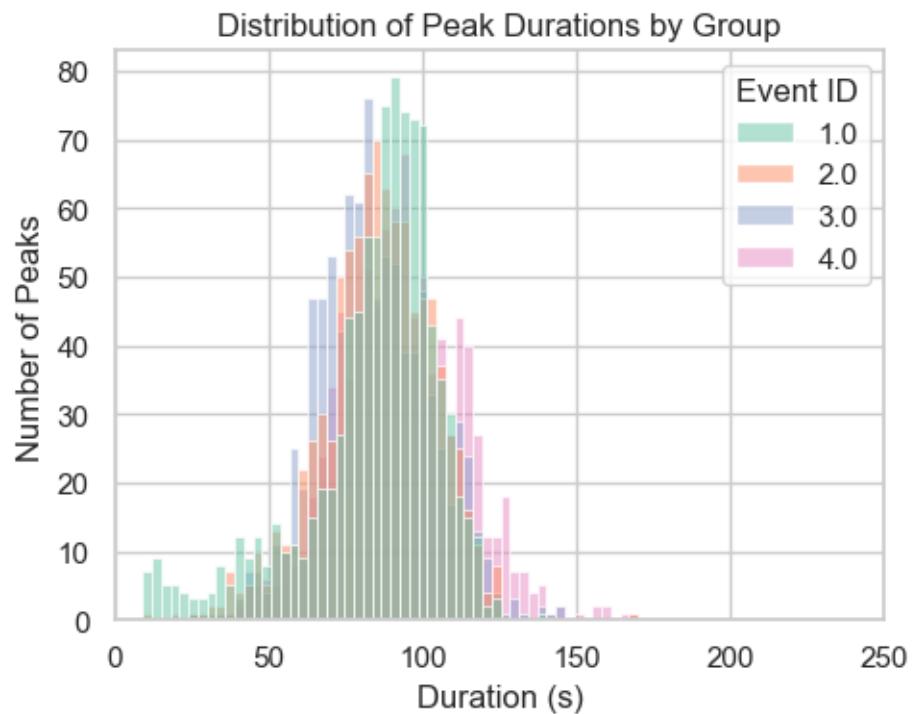


```
[2025-08-27 15:06:49] [INFO] calcium: plot_histogram: removed 0 outliers out of  
3713 on 'Prominence (noise std units)' (lower=-258.9, upper=751.9)
```

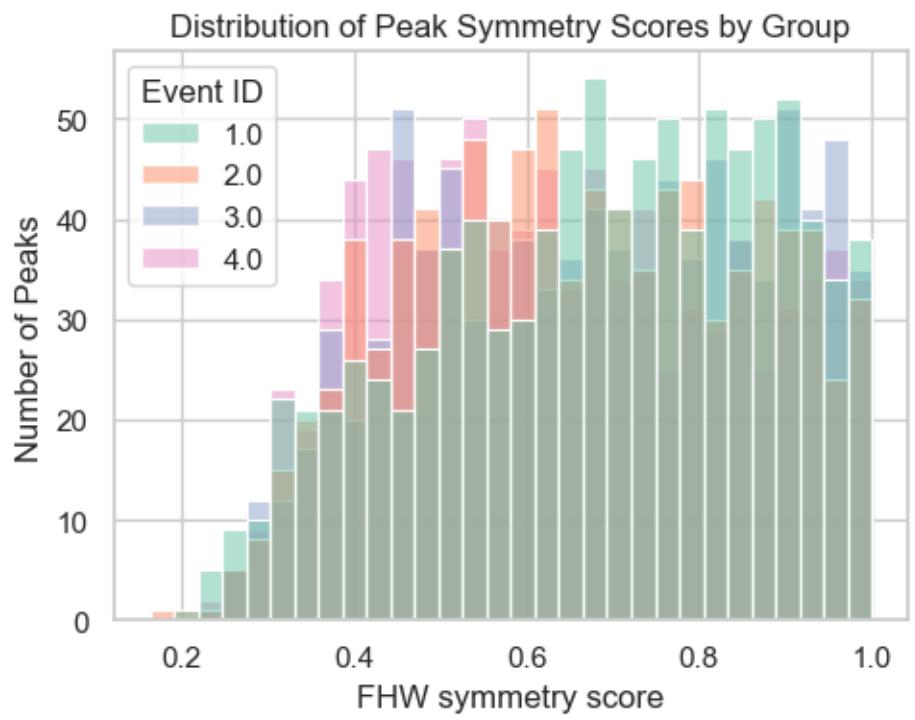
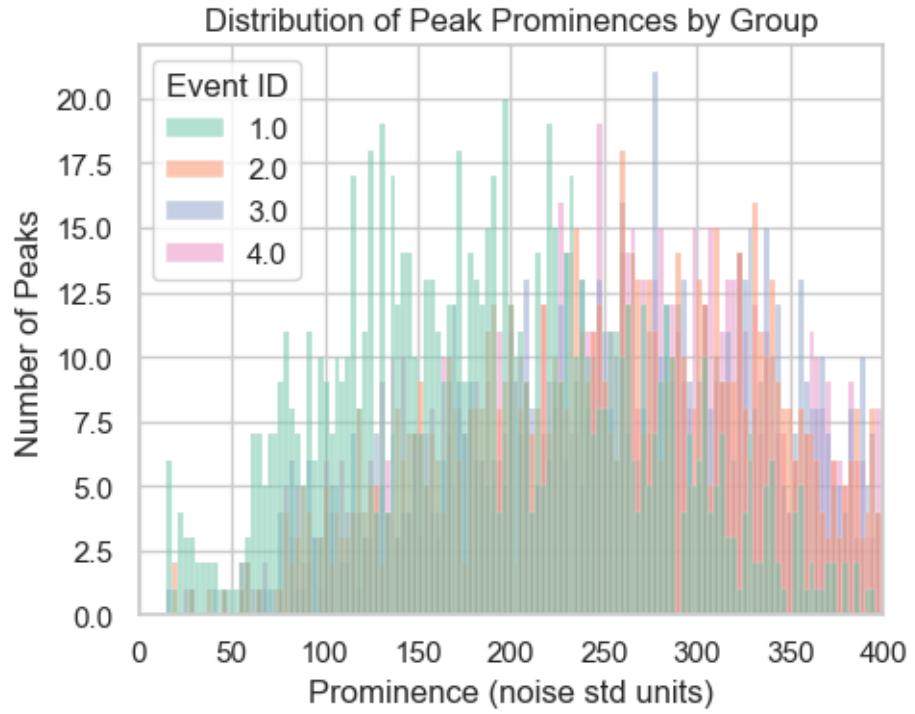


1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:06:50] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 3713 on 'Duration (s)' (lower=3, upper=171)

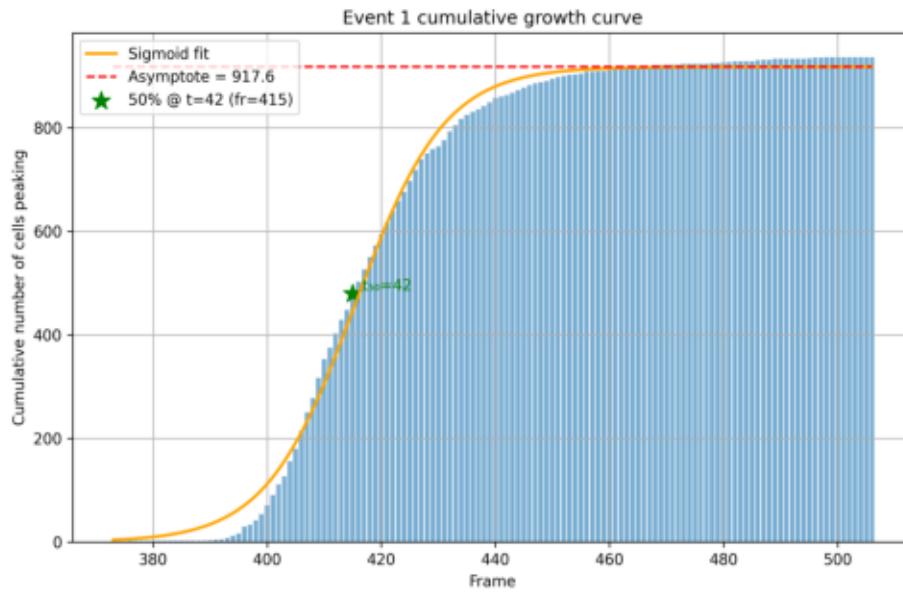


[2025-08-27 15:06:50] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 3713 on 'Prominence (noise std units)' (lower=-258.9, upper=751.9)

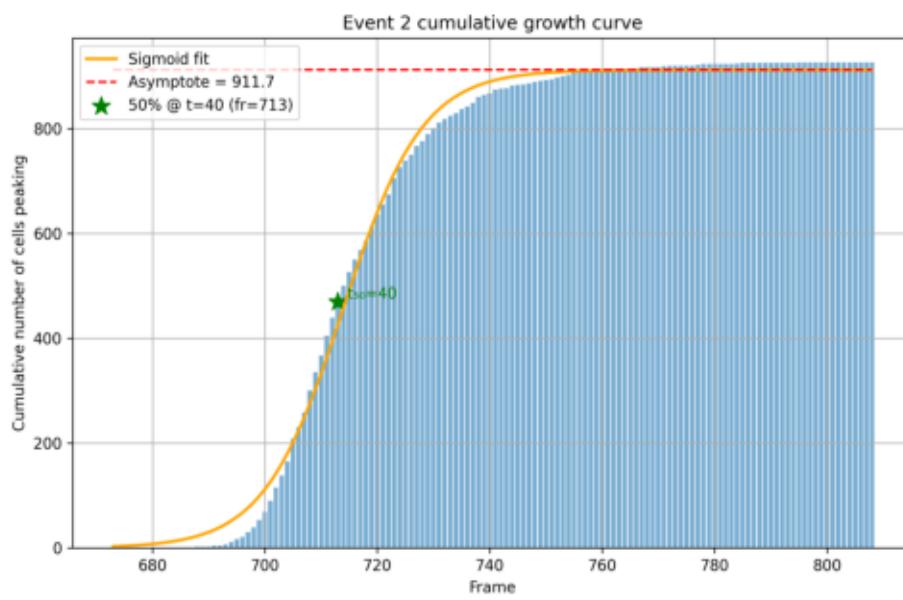


1.2.3 Kinetics of global events

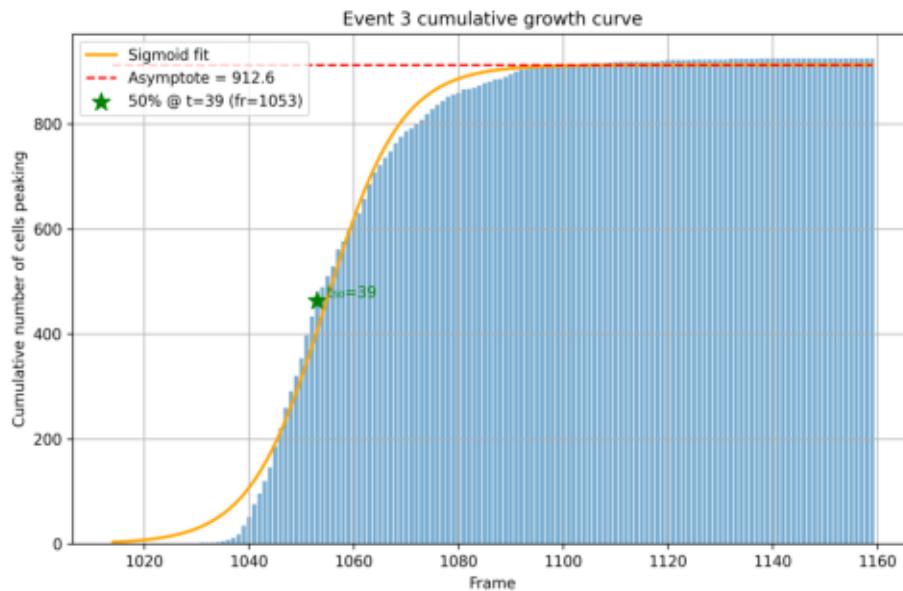
Event Activity Overlay (Event ID: 1)



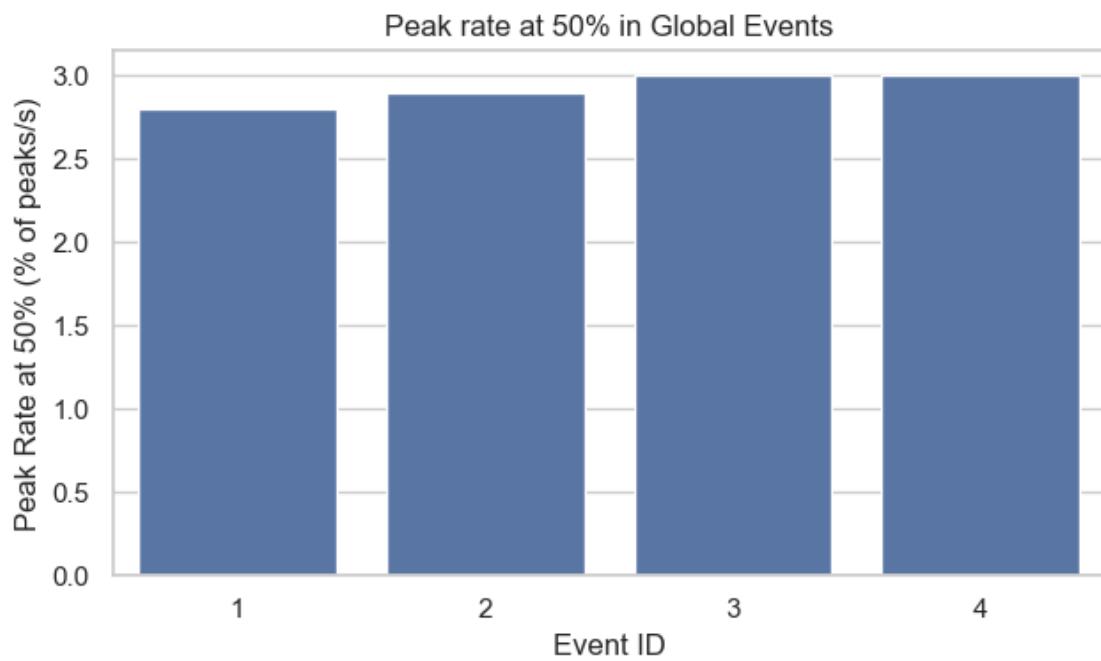
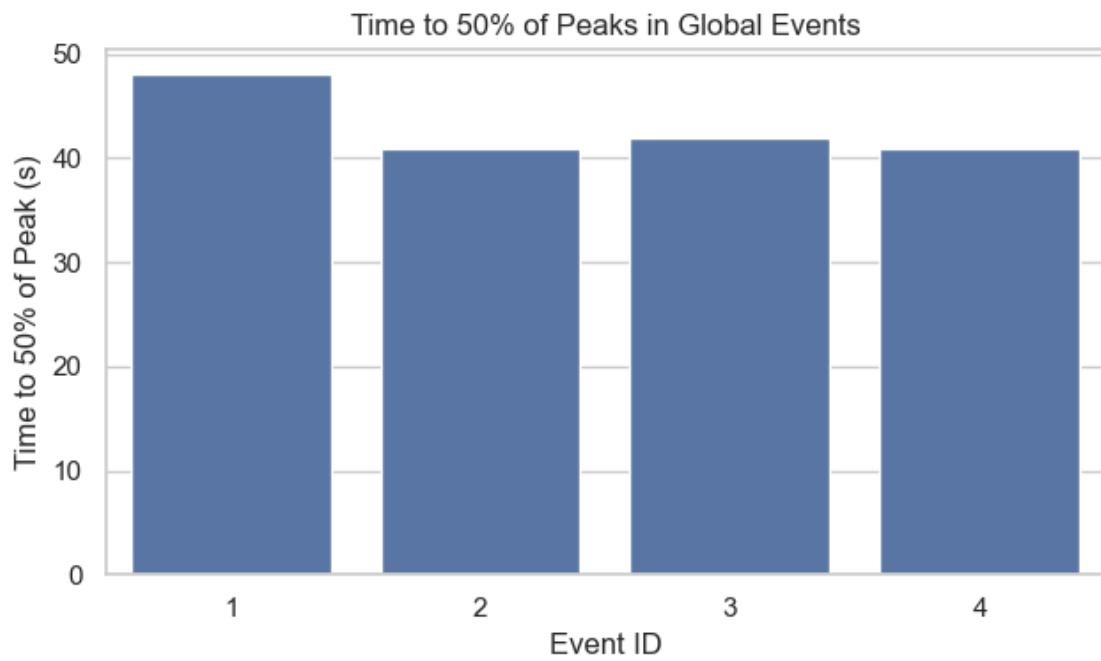
Event Activity Overlay (Event ID: 2)



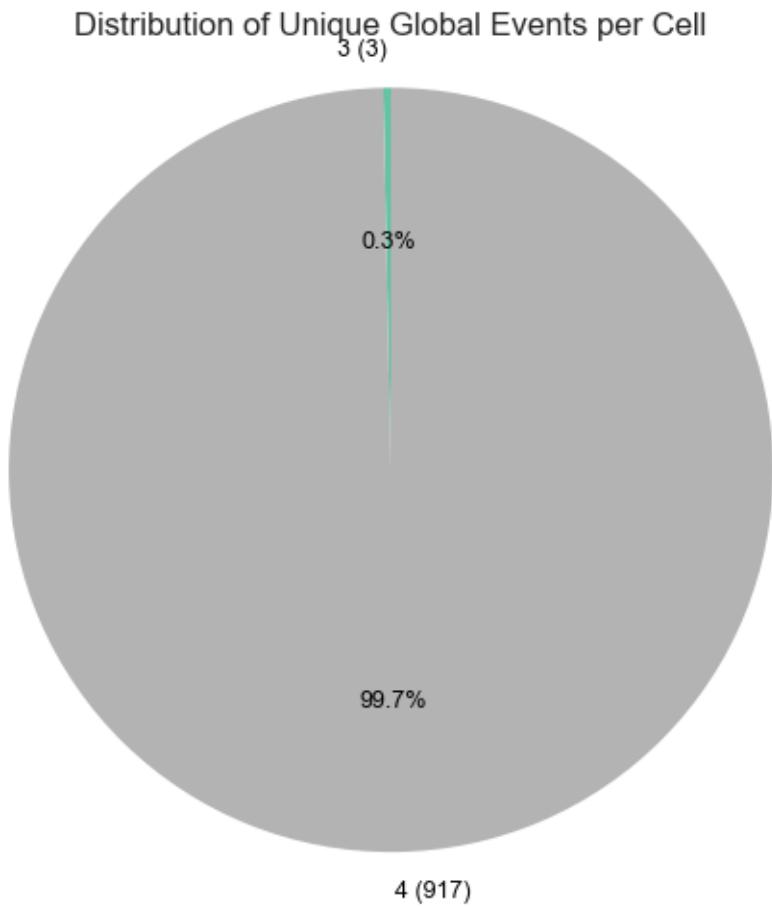
Event Activity Overlay (Event ID: 3)



```
[2025-08-27 15:06:53] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\\\Output\\\\IS8\\\\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\\\\IS8\\\\events\\\\event-growth-curve-4.png'
```



1.2.4 Cells Occurrences in global events

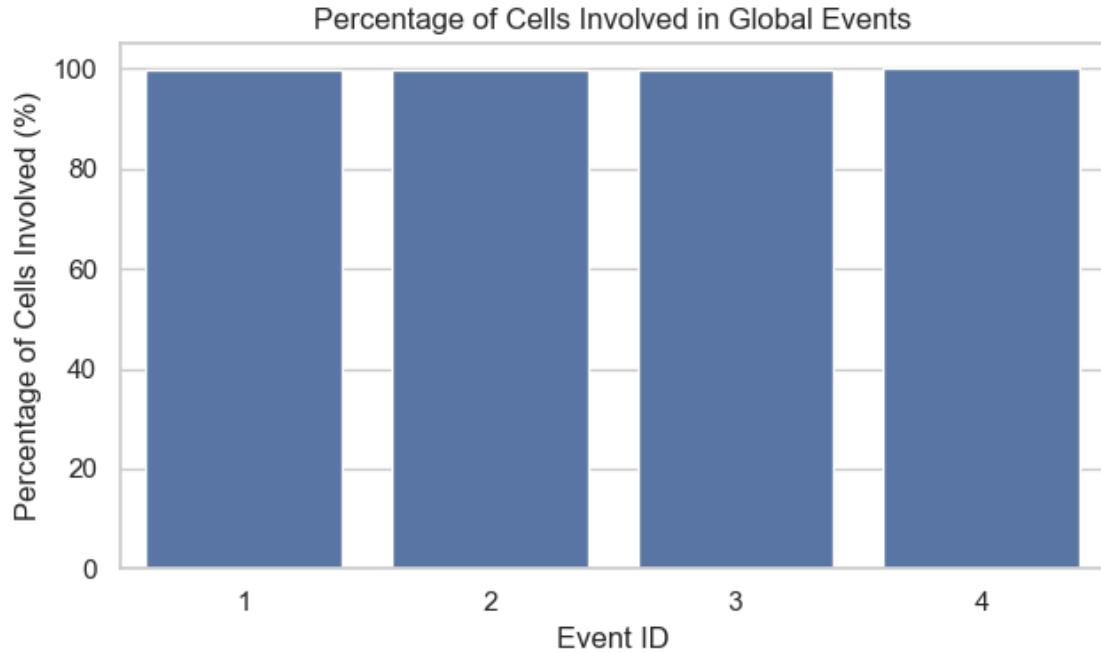


```
[2025-08-27 15:06:53] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS8\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\IS8\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



1.2.5 Inter-event interval analysis

Intervals between global event peaks: [244.0, 297.0, 346.0]
 Estimated periodicity: 0.877
 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 15:06:54] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\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 15:06:54] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\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

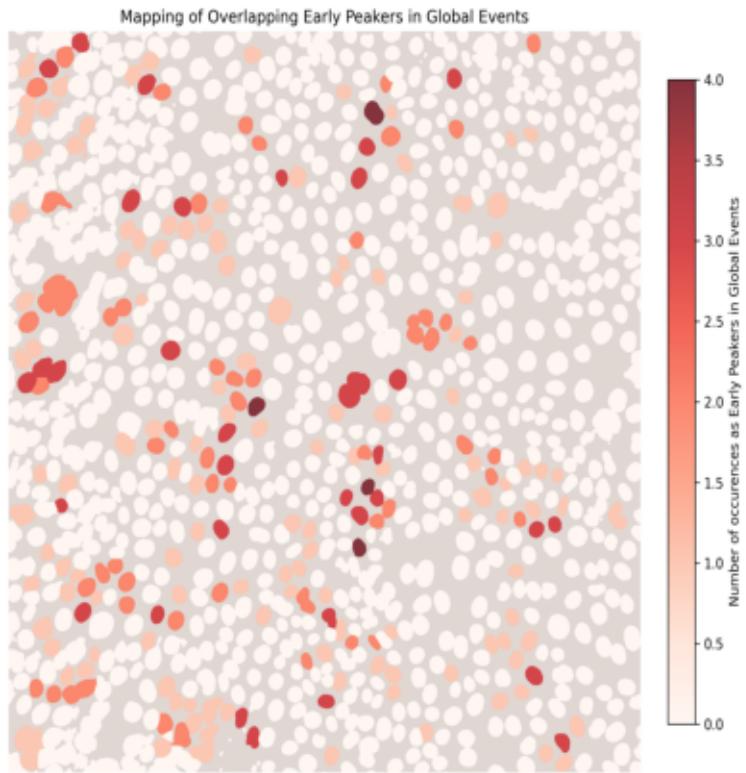
[2025-08-27 15:06:54] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\cell-mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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

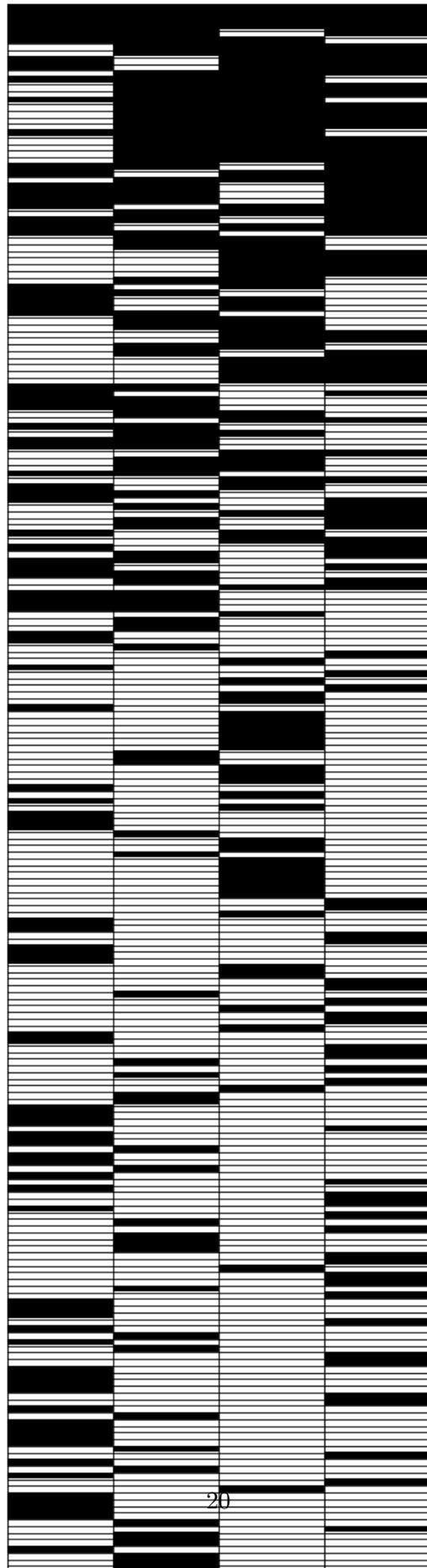
[2025-08-27 15:06:54] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\cell-
mapping\global_events\global_event_4_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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 15:06:55] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 4 unique event IDs.

[2025-08-27 15:06:55] [INFO] calcium: Early peakers event-matrix: 235 cells x 4 events; black squares: 365



```
[2025-08-27 15:06:55] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

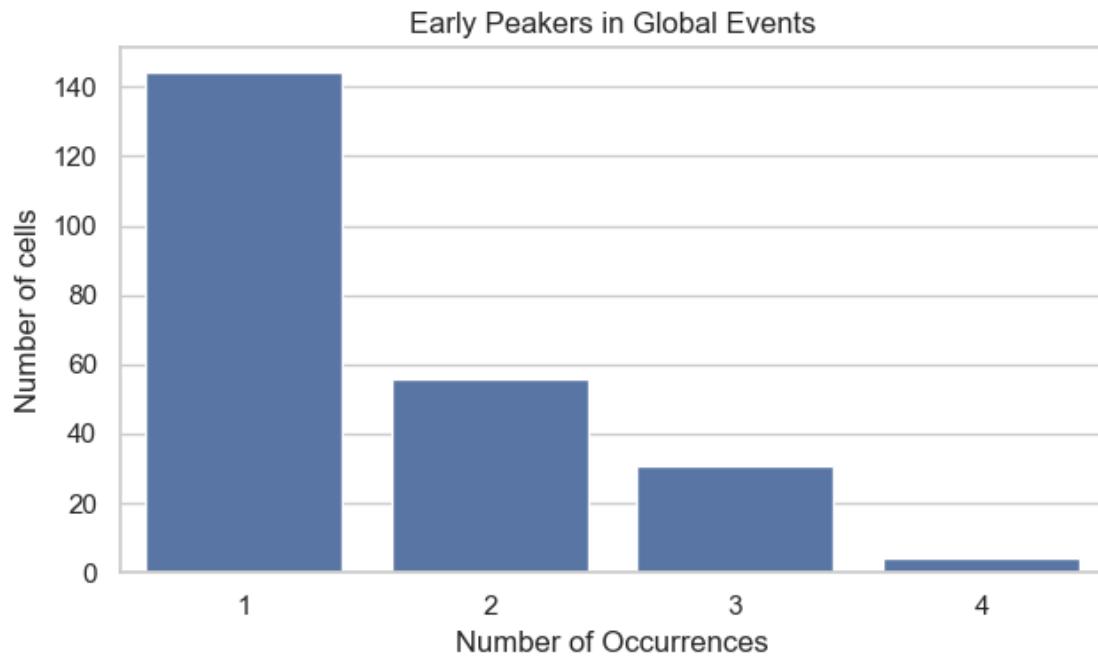
```
[19]: array([[1, 1, 1, 1],  
           [1, 1, 1, 1],  
           [1, 1, 1, 1],  
           [1, 1, 1, 1],  
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           [1, 1, 1, 0],  
           [0, 1, 1, 1],  
           [0, 1, 1, 1],  
           [1, 0, 1, 1],  
           [1, 0, 1, 1], 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



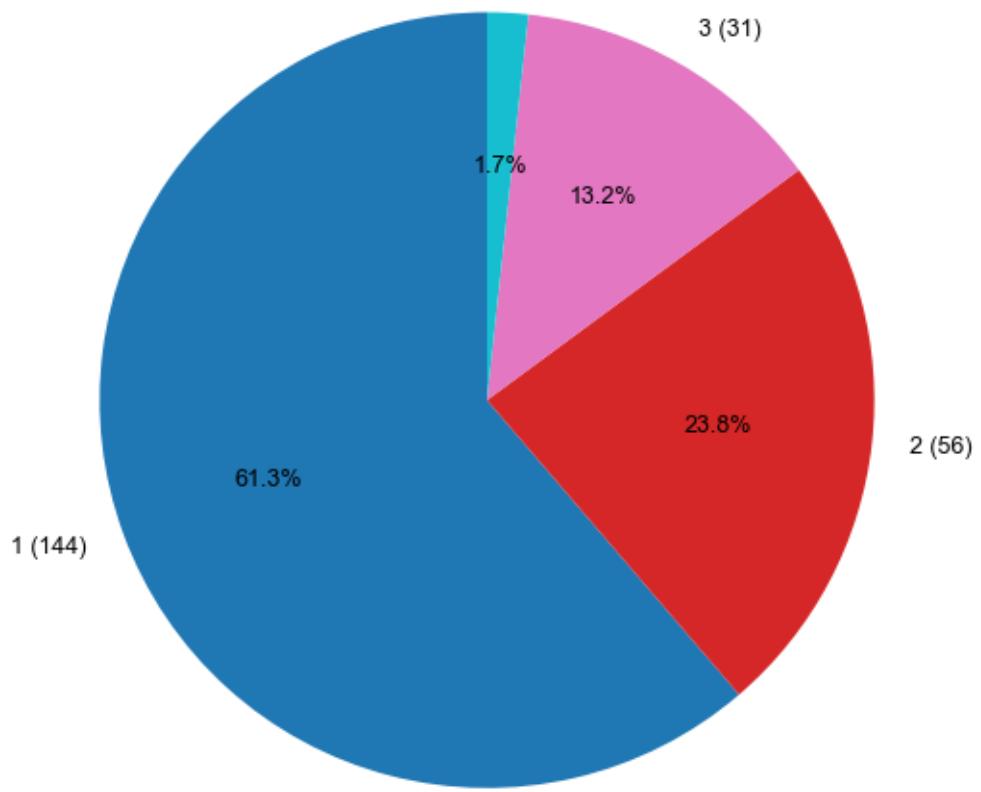
```
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```

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

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



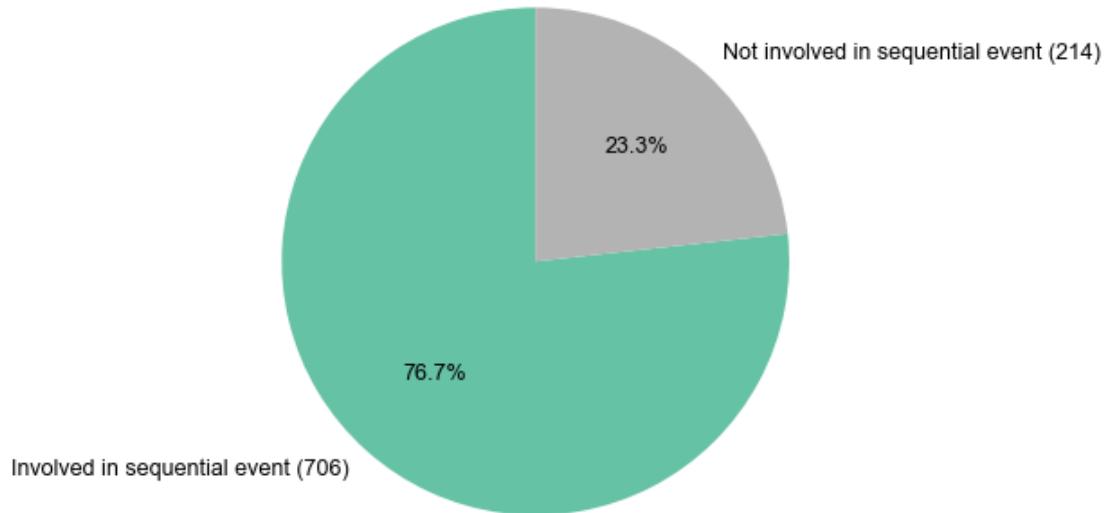
Distribution of Early Peakers in Global Events
4 (4)



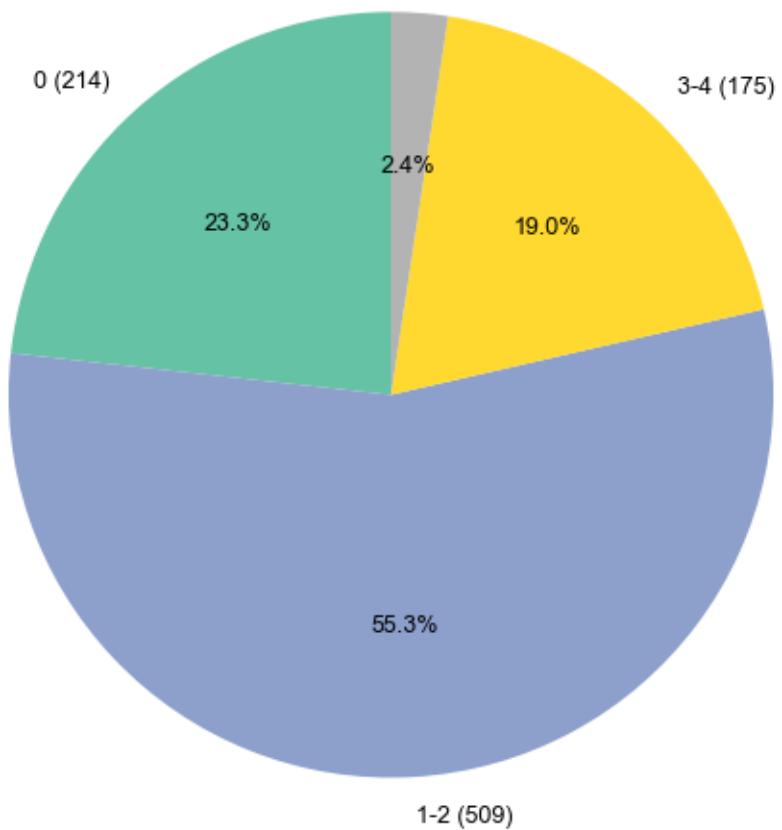
1.3 SEQUENTIAL EVENTS

1.3.1 Cells Occurrences in sequential events

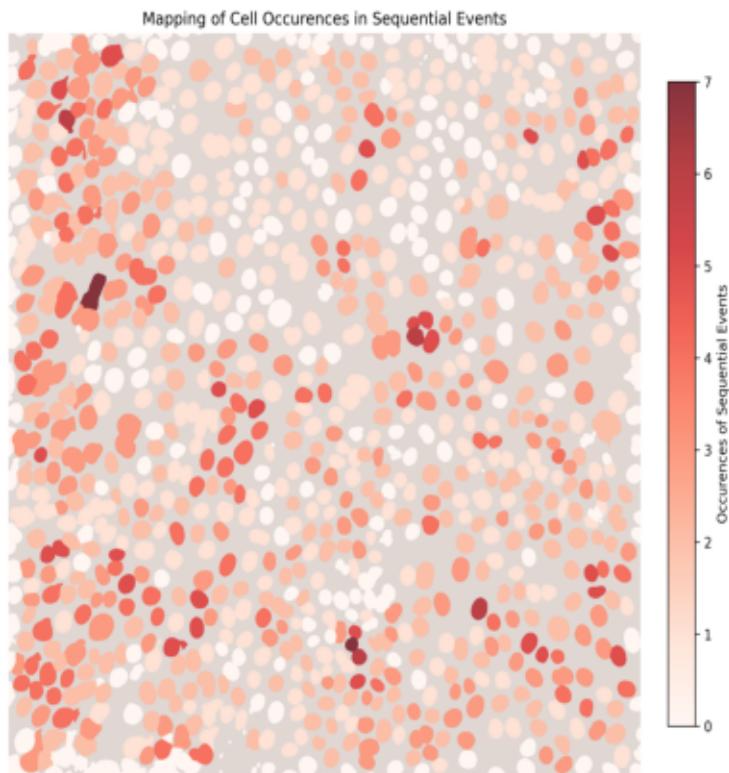
Distribution of Cells Involved in Sequential Events



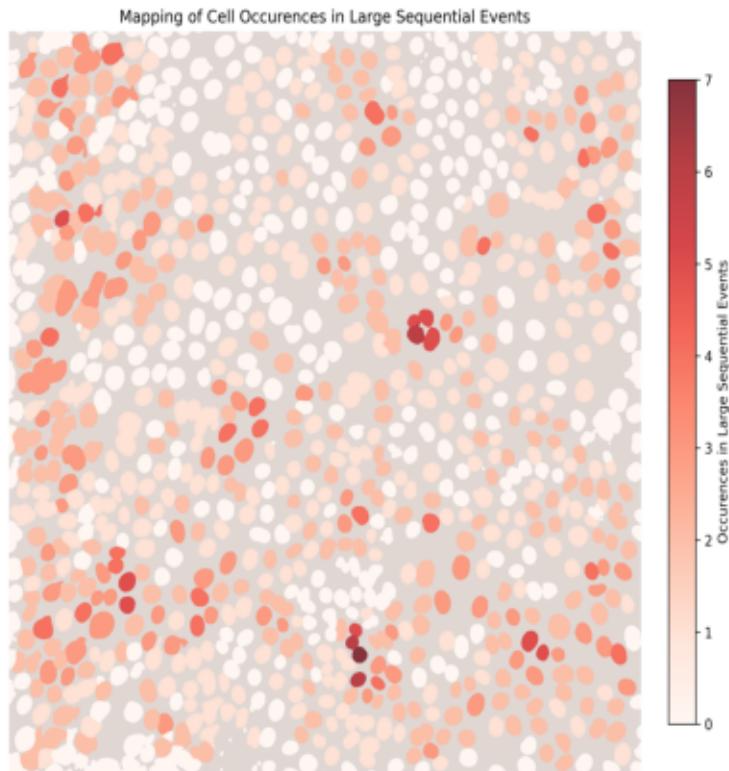
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (22)



Cell Mapping with Occurrences in Sequential Events Overlay

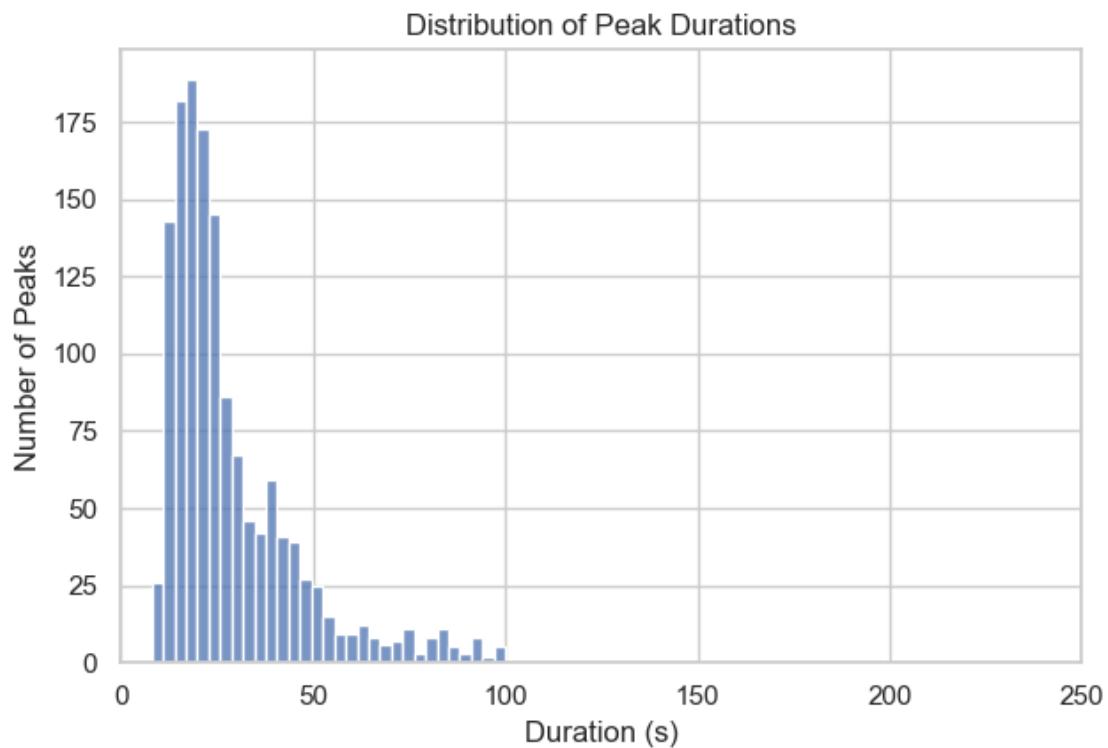


Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



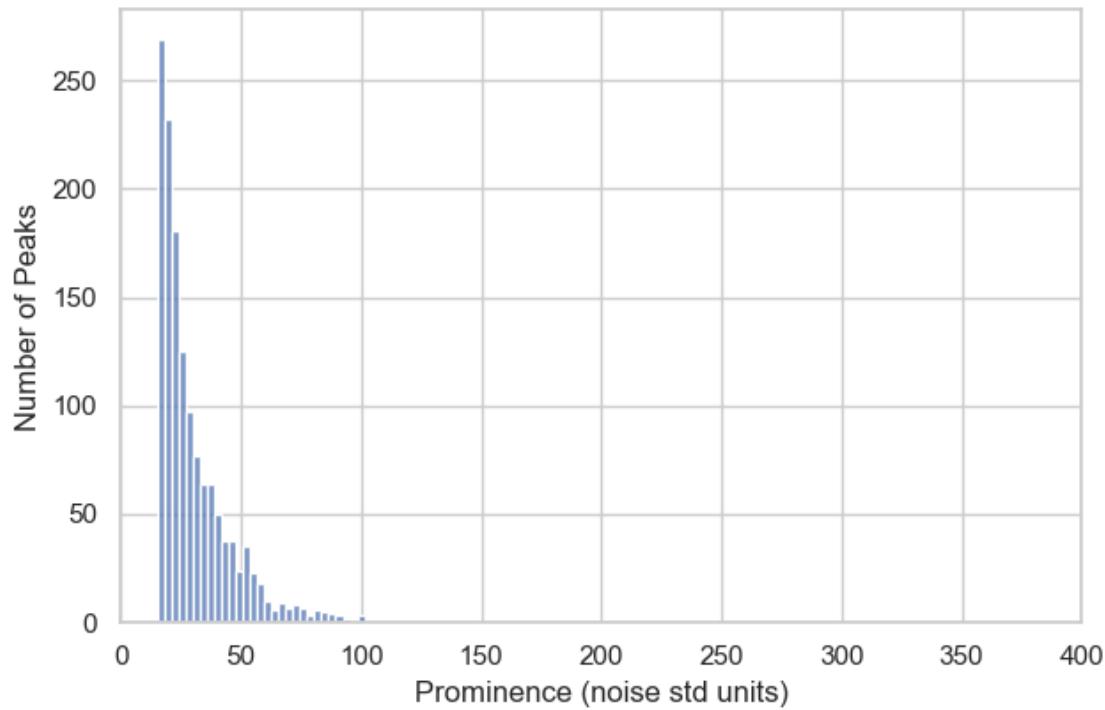
1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:06:58] [INFO] calcium: plot_histogram: removed 23 outliers out of  
1435 on 'Duration (s)' (lower=-11.5, upper=102.5)
```

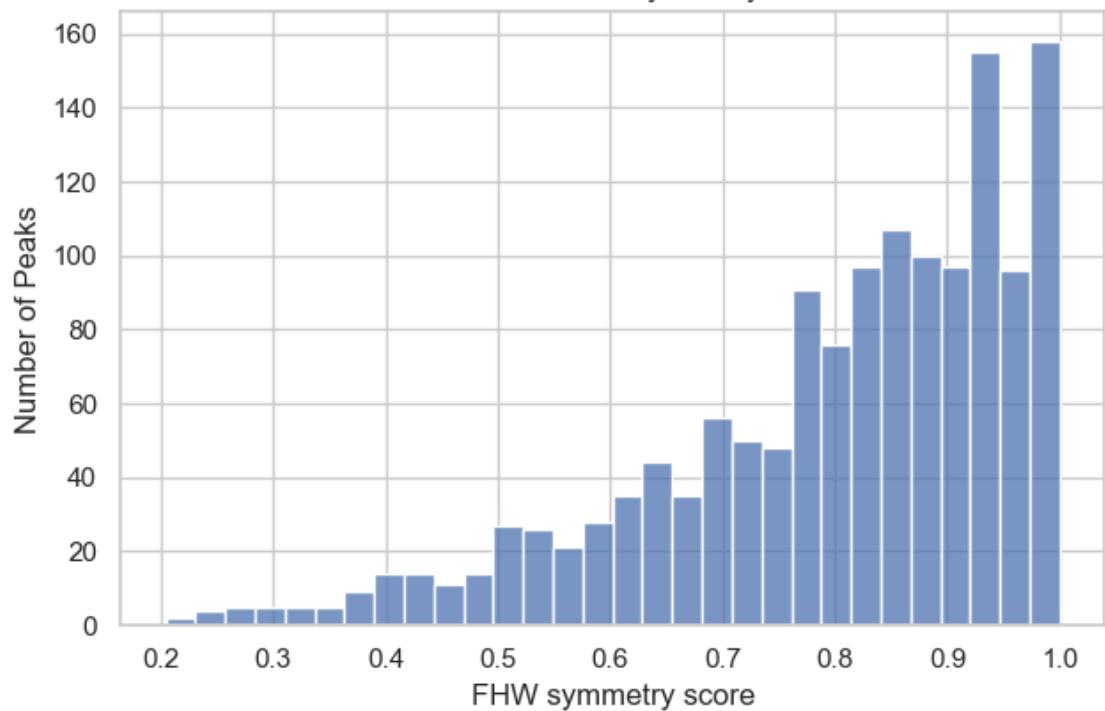


```
[2025-08-27 15:06:58] [INFO] calcium: plot_histogram: removed 26 outliers out of  
1435 on 'Prominence (noise std units)' (lower=-8.75, upper=102.25)
```

Distribution of Peak Prominences

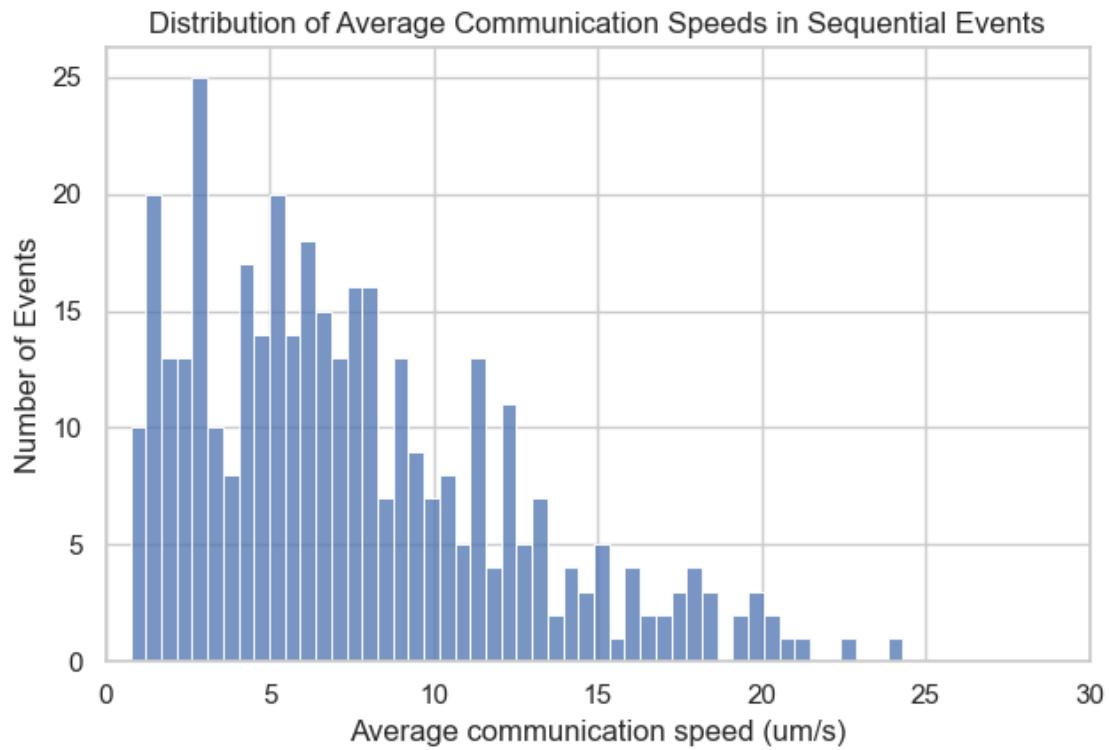


Distribution of Peak Symmetry Scores

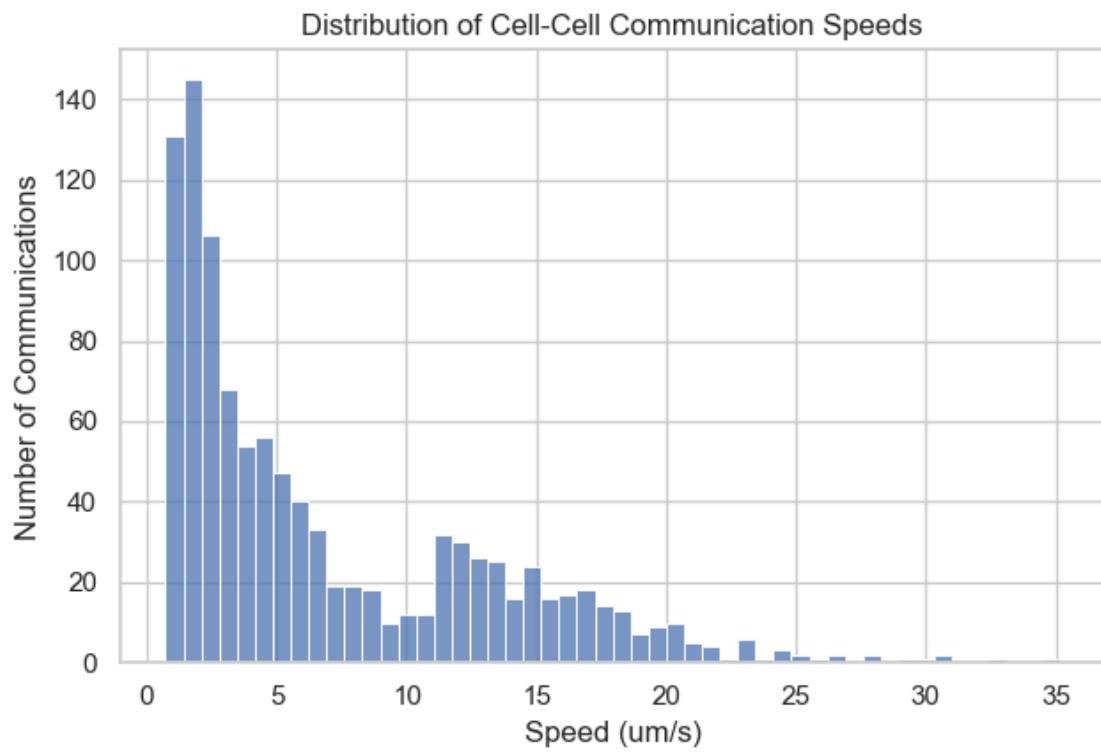


1.3.3 Cell-cell communication speed

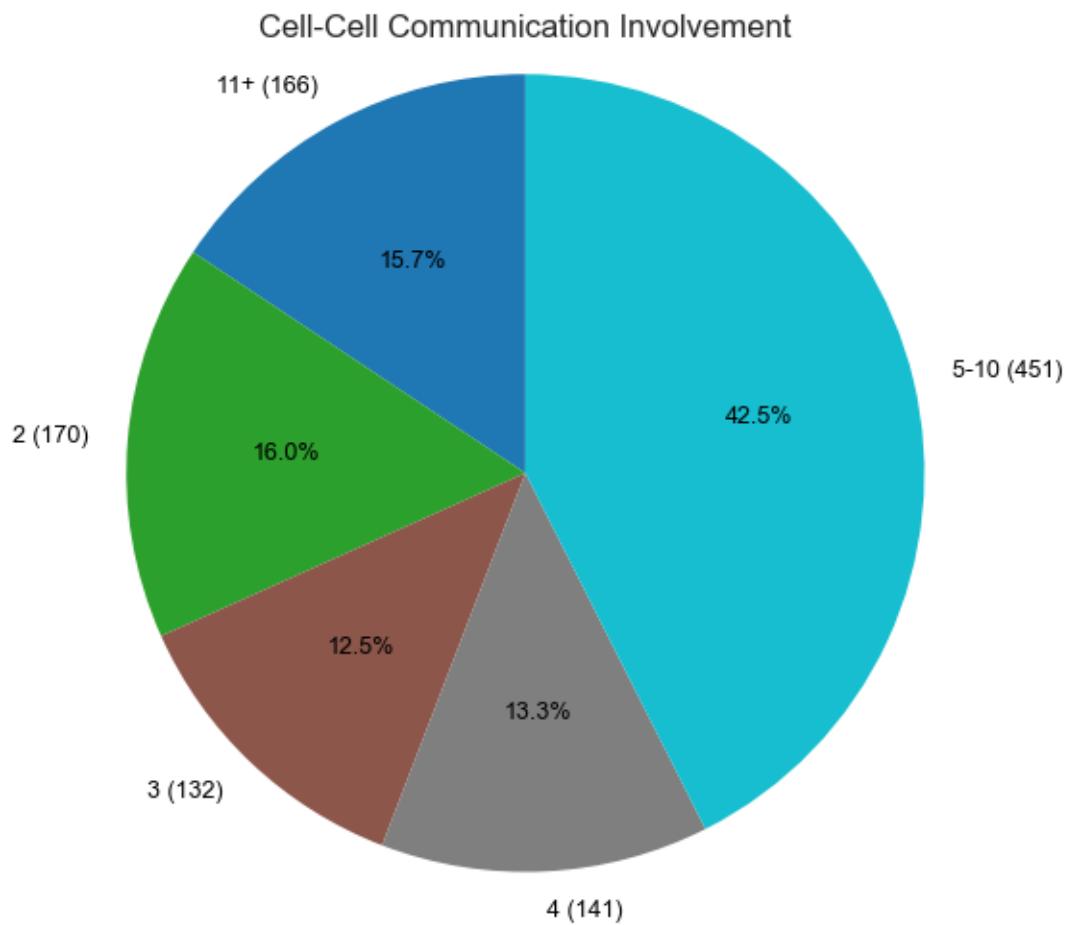
[2025-08-27 15:06:58] [INFO] calcium: plot_histogram: removed 0 outliers out of 375 on 'Average communication speed (um/s)' (lower=-15.56, upper=29.625)



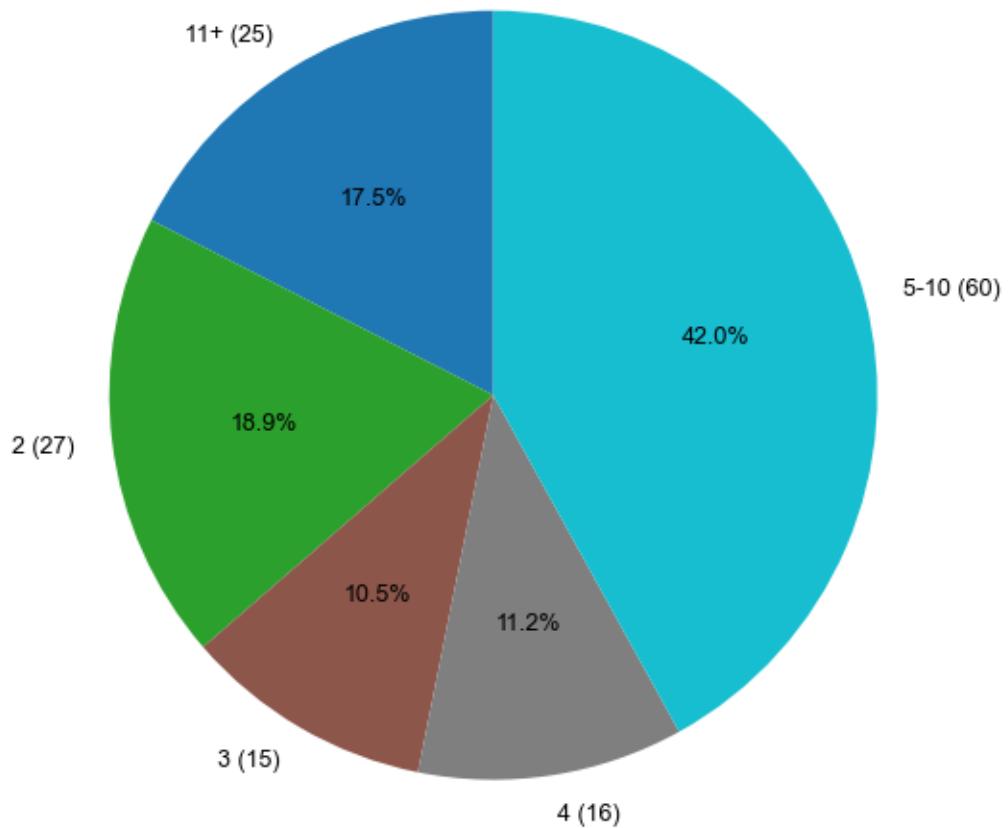
[2025-08-27 15:06:59] [INFO] calcium: plot_histogram: removed 0 outliers out of 1060 on 'Speed (um/s)' (lower=-26.75, upper=59.56)



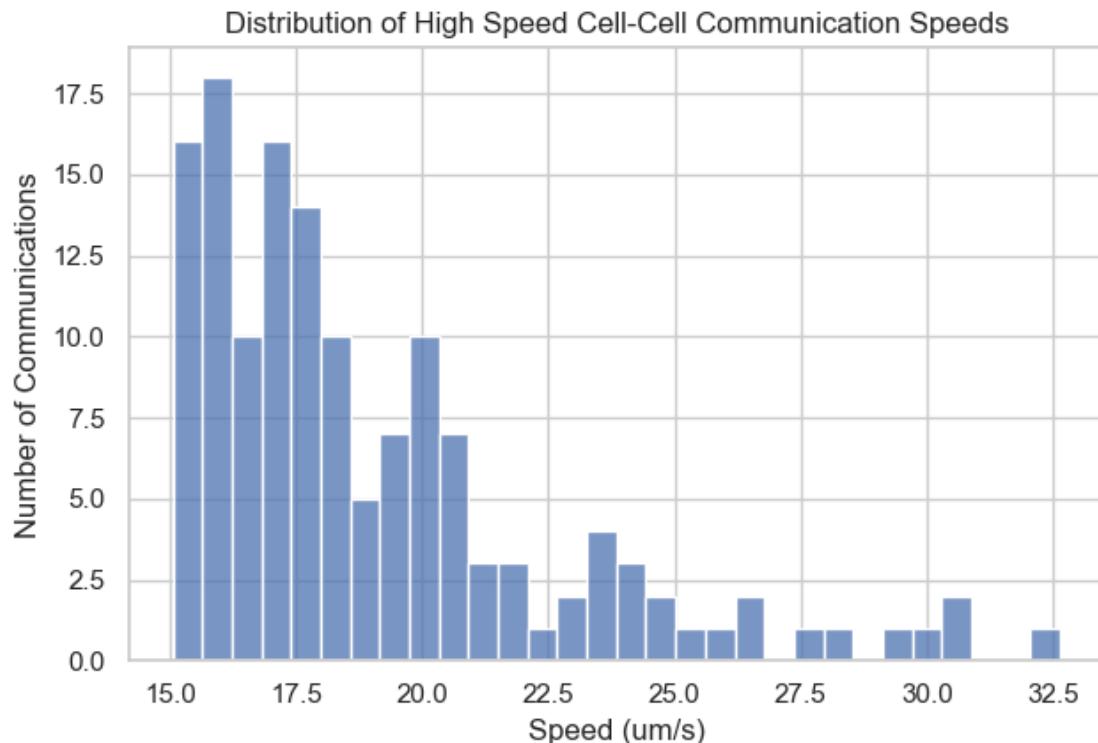
1.3.4 Double distribution in cell-cell communication speeds



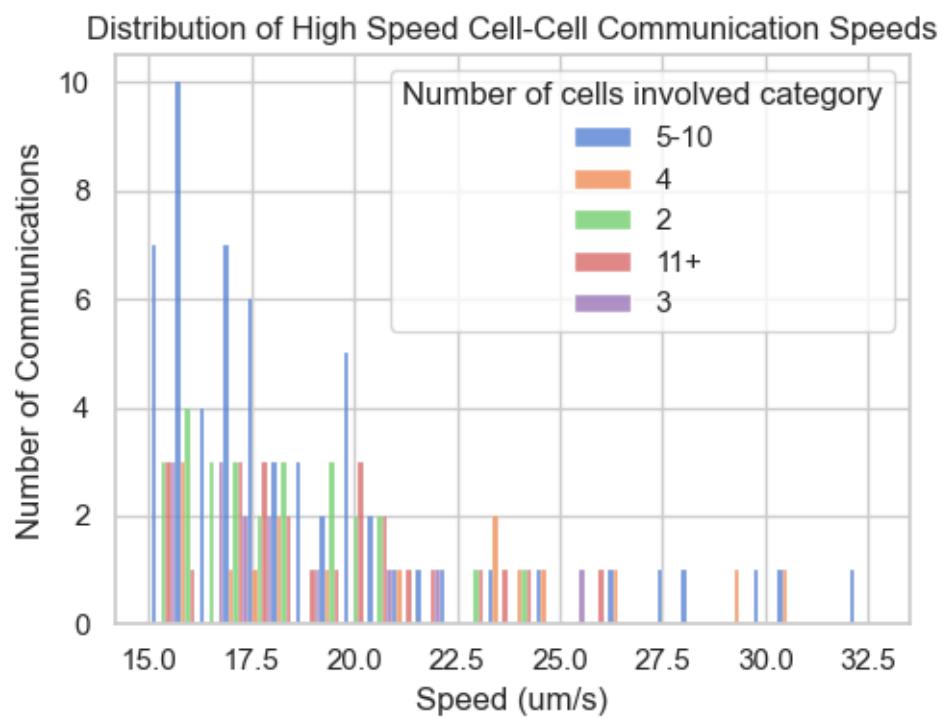
High Speed Cell-Cell Communication Involvement



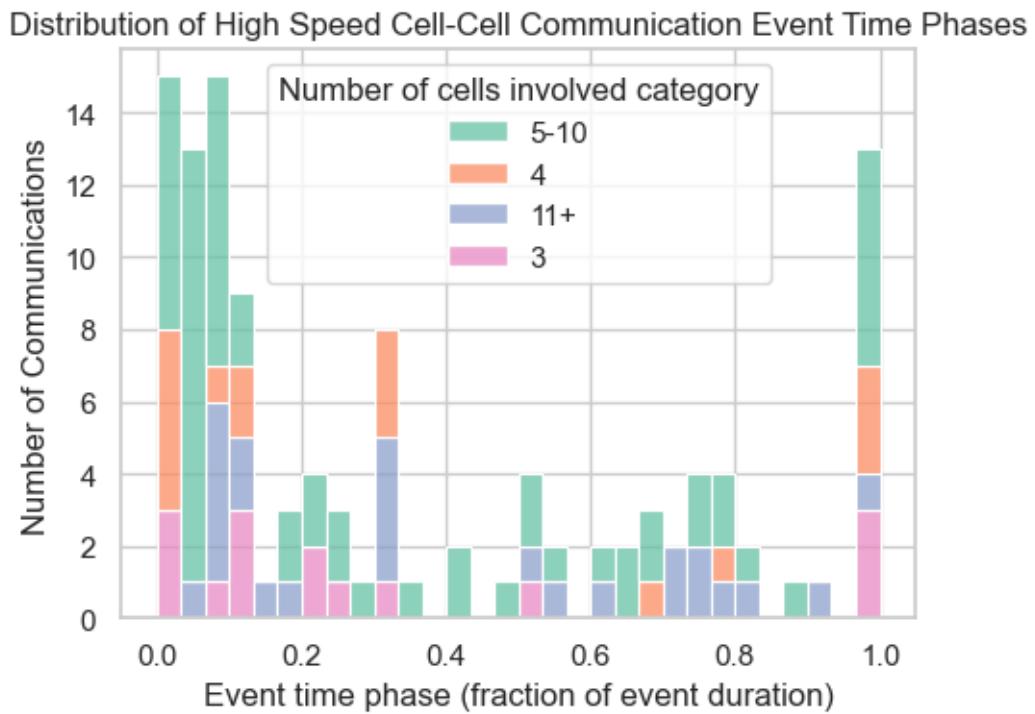
[2025-08-27 15:06:59] [INFO] calcium: plot_histogram: removed 1 outliers out of 143 on 'Speed (um/s)' (lower=3.7, upper=33.1)



```
[2025-08-27 15:06:59] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 143 on 'Speed (um/s)' (lower=3.7, upper=33.1)
```

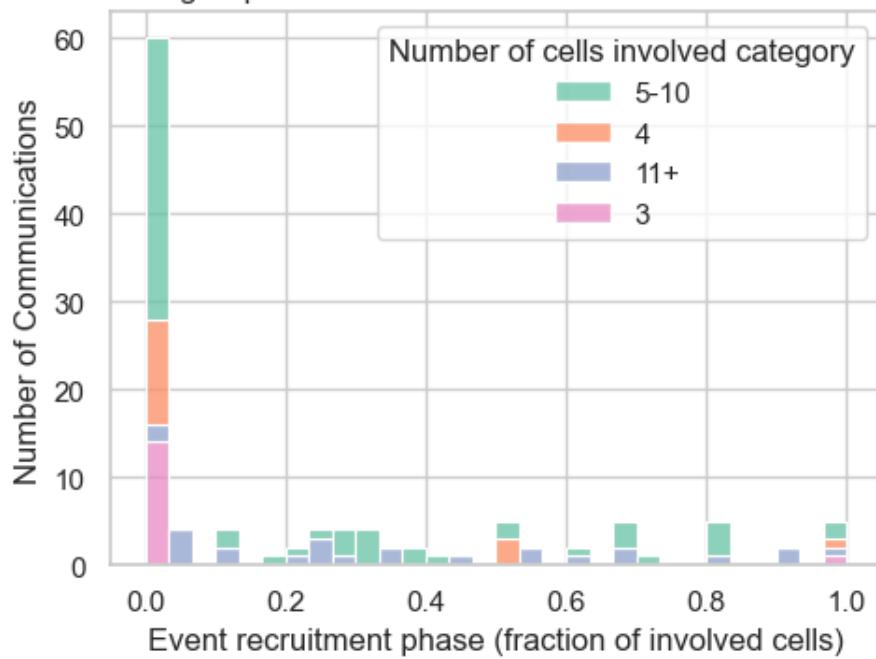


[2025-08-27 15:06:59] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 116 on 'Event time phase (fraction of event duration)' (lower=-1.73, upper=2.47)

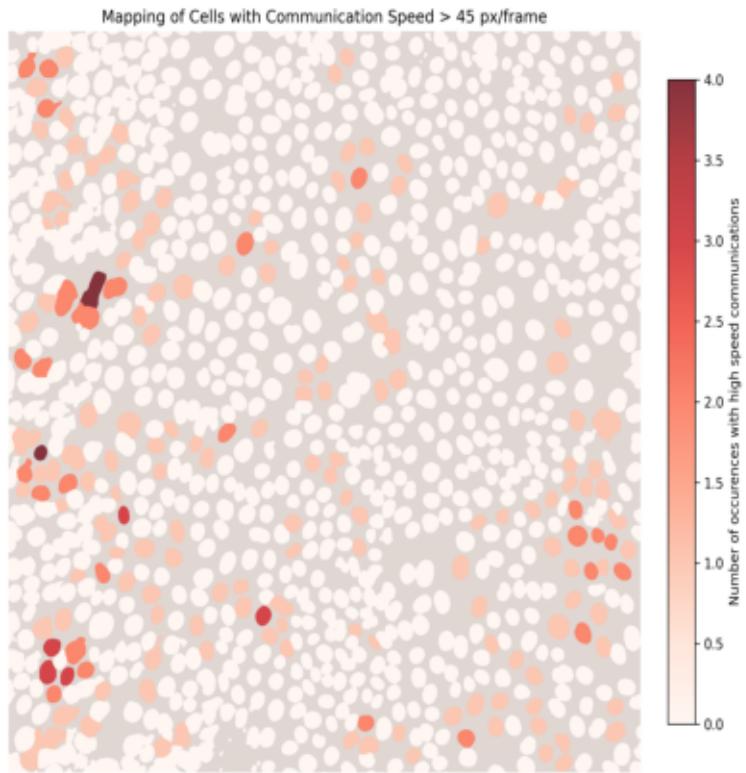


[2025-08-27 15:07:00] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 116 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.155, upper=1.54)

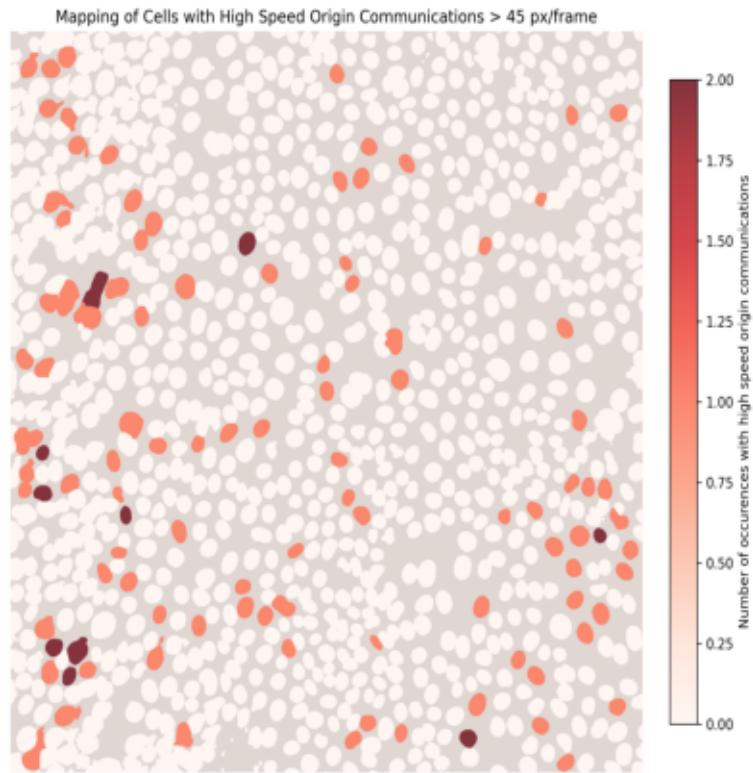
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



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	\
5	1756976004544	5	421	0	
6	1756975994080	5	447	0	
17	1757038088240	8	973	0	
22	1757038088864	10	226	6	
27	1757038087760	13	1389	0	
...	
1007	1757125895904	355	1284	6	
1037	1757013912128	367	1423	0	
1040	1757013910064	368	1393	5	
1044	1757013904208	370	1390	1	
1053	1757013908768	374	1438	1	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
5	447	0	18.0	18.0	
6	456	0	18.0	19.0	
17	952	0	53.0	54.0	
22	205	4	1396.0	1396.0	
27	1412	0	25.0	26.0	
...	
1007	1305	7	1427.0	1428.0	
1037	1382	0	24.0	25.0	
1040	1423	6	1416.0	1417.0	
1044	1388	1	71.0	72.0	
1053	1401	1	101.0	102.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
5	0.0	17.34	17.34		
6	1.0	15.17	15.17		
17	1.0	21.49	21.49		
22	0.0	20.67	20.67		
27	1.0	24.36	24.36		
...	
1007	1.0	20.83	20.83		
1037	1.0	15.49	15.49		
1040	1.0	16.32	16.32		
1044	1.0	15.98	15.98		
1053	1.0	15.83	15.83		
	Event time phase (fraction of event duration)	\			
5		0.21			
6		0.25			
17		0.33			
22		NaN			
27		0.33			
...		...			
1007		0.33			
1037		1.00			
1040		0.10			
1044		1.00			
1053		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
5		0.00	20250618_IS8		
6		0.29	20250618_IS8		
17		0.00	20250618_IS8		
22		NaN	20250618_IS8		
27		0.00	20250618_IS8		
...			
1007		0.00	20250618_IS8		
1037		1.00	20250618_IS8		

1040		0.00	20250618_IS8
1044		1.00	20250618_IS8
1053		NaN	20250618_IS8

	Number of cells involved	category	Speed category
5		5-10	High speed
6		5-10	High speed
17		4	High speed
22		2	High speed
27		4	High speed
...
1007		3	High speed
1037		3	High speed
1040		3	High speed
1044		4	High speed
1053		2	High speed

[143 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
187		0	2
196		0	1
205		0	1
208		0	1
217		0	2
...
1438		2	0
1444		0	2
1445		0	1
1447		0	2
1451		0	1

[490 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	187	414.38	7.80
7	196	117.65	10.08
13	205	81.25	14.62
15	208	433.55	15.60
23	217	408.53	18.53
..
909	1438	484.25	486.53
914	1444	28.28	489.12
915	1445	283.07	490.43
916	1447	18.85	485.55
917	1451	438.43	492.38

Number of peaks Is active Occurrences in global events \

2	6	True	4
7	5	True	4
13	6	True	4
15	5	True	4
23	6	True	4
..
909	8	True	4
914	8	True	4
915	5	True	4
916	8	True	4
917	6	True	4

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

2	0	[]
7	3	[1, 2, 4]
13	0	[]
15	0	[]
23	0	[]
..
909	2	[1, 2]
914	2	[1, 2]
915	0	[]
916	2	[1, 2]
917	0	[]

Occurrences in sequential events \

2	2
7	1
13	2
15	1
23	2
..	..
909	4
914	4
915	1
916	4
917	1

Occurrences in sequential events as origin \

2	2
7	1
13	0
15	1
23	0
..	..
909	2
914	2
915	1

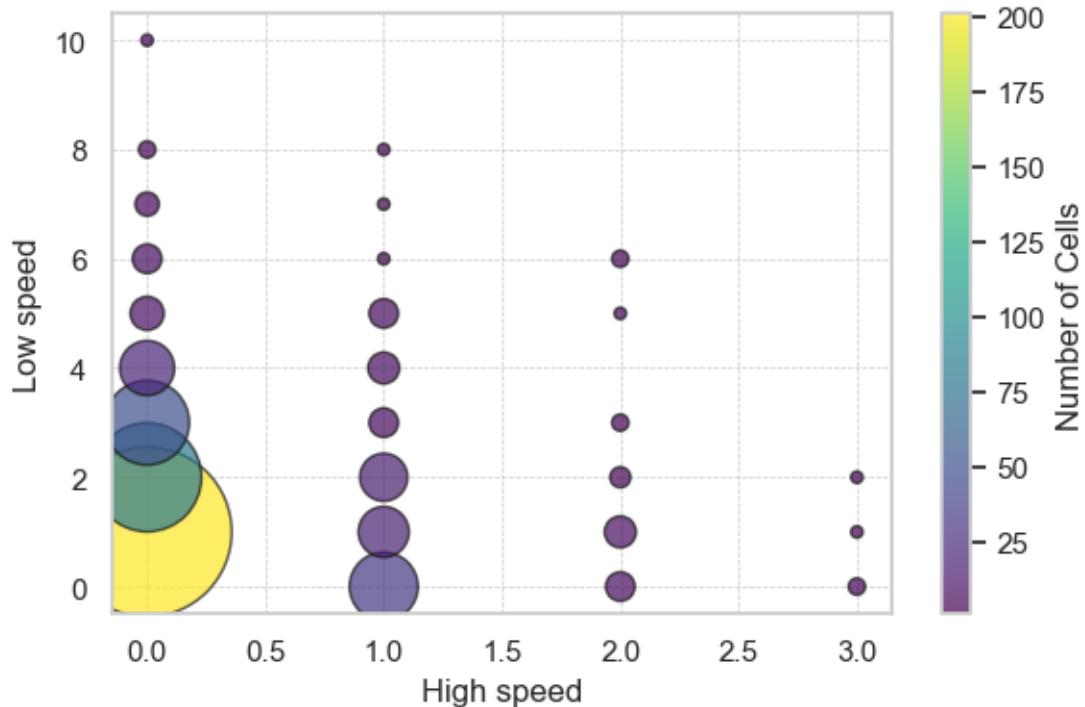
916		2	
917		1	
	Occurrences in individual events	Peak frequency (Hz)	Periodicity score \
2	0	0.0035	0.68
7	0	0.0029	0.74
13	0	0.0035	0.82
15	0	0.0029	0.72
23	0	0.0035	0.67
..
909	0	0.0047	0.59
914	0	0.0047	0.58
915	0	0.0029	0.75
916	0	0.0047	0.56
917	1	0.0035	0.69
	Neighbor count	Neighbors (labels)	dataset \
2	3	[208, 217, 232]	20250618_IS8
7	4	[199, 200, 221, 248]	20250618_IS8
13	4	[200, 226, 238, 257]	20250618_IS8
15	5	[187, 198, 228, 232, 260]	20250618_IS8
23	5	[187, 227, 232, 241, 261]	20250618_IS8
..
909	1	[1401]	20250618_IS8
914	3	[1409, 1439, 1447]	20250618_IS8
915	2	[1416, 1423]	20250618_IS8
916	3	[1409, 1414, 1444]	20250618_IS8
917	2	[1418, 1433]	20250618_IS8
	Involved in sequential event	Occurrences in sequential events	category \
2	Involved in sequential event		1-2
7	Involved in sequential event		1-2
13	Involved in sequential event		1-2
15	Involved in sequential event		1-2
23	Involved in sequential event		1-2
..
909	Involved in sequential event		3-4
914	Involved in sequential event		3-4
915	Involved in sequential event		1-2
916	Involved in sequential event		3-4
917	Involved in sequential event		1-2
	High speed	Low speed	
2	0.0	2.0	
7	0.0	1.0	
13	0.0	1.0	
15	0.0	1.0	
23	0.0	2.0	

```

...
909      2.0      0.0
914      0.0      2.0
915      0.0      1.0
916      0.0      2.0
917      0.0      1.0

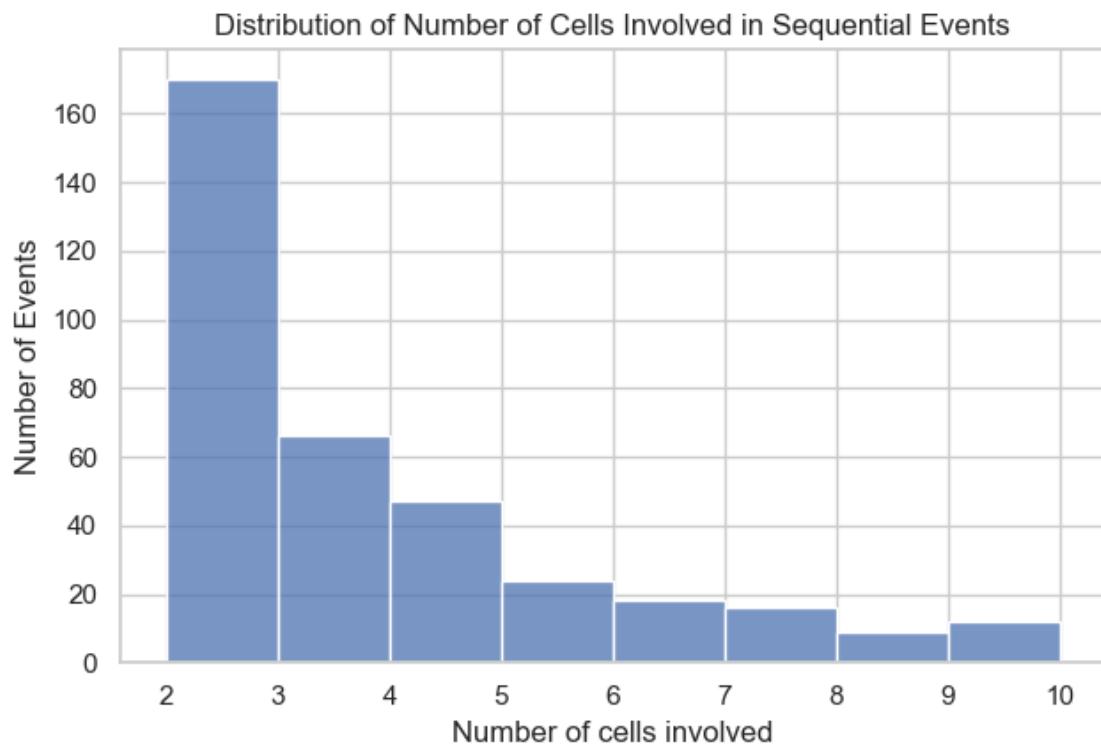
```

[490 rows x 20 columns]



1.3.5 Number of cells involved per sequential events

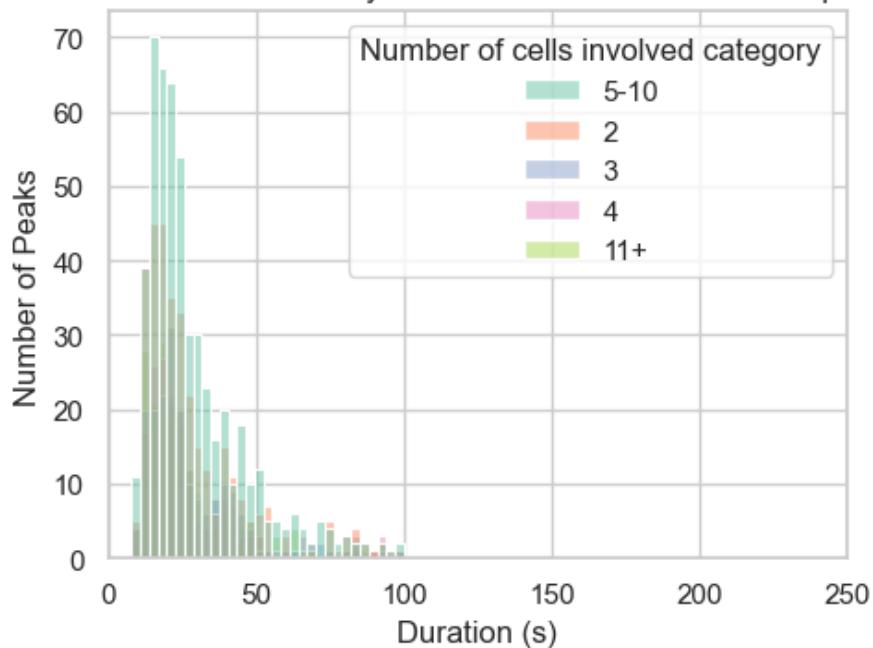
[2025-08-27 15:07:02] [INFO] calcium: plot_histogram: removed 13 outliers out of 375 on 'Number of cells involved' (lower=-4, upper=10)



1.3.6 Influence of cell count per event on statistics

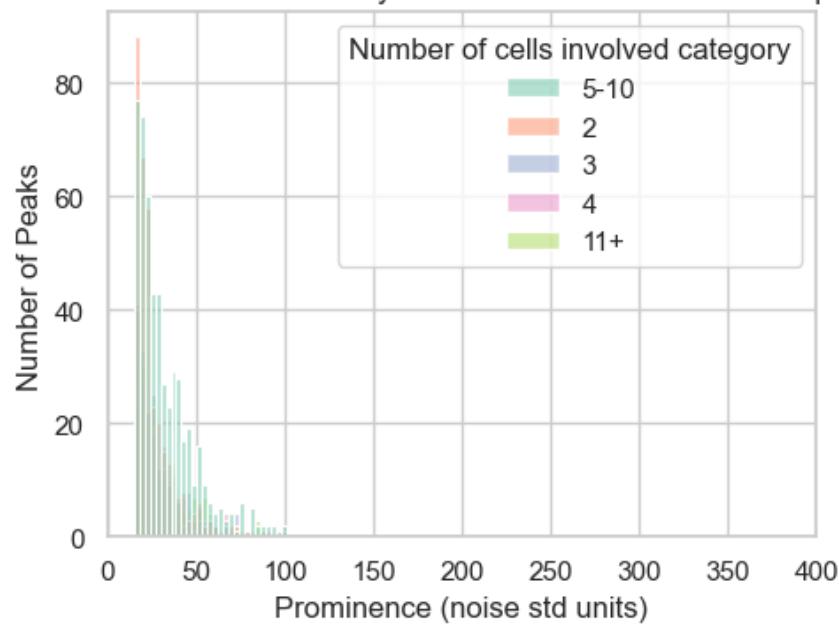
```
[2025-08-27 15:07:03] [INFO] calcium: plot_histogram_by_group: removed 23
outliers out of 1435 on 'Duration (s)' (lower=-11.5, upper=102.5)
```

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

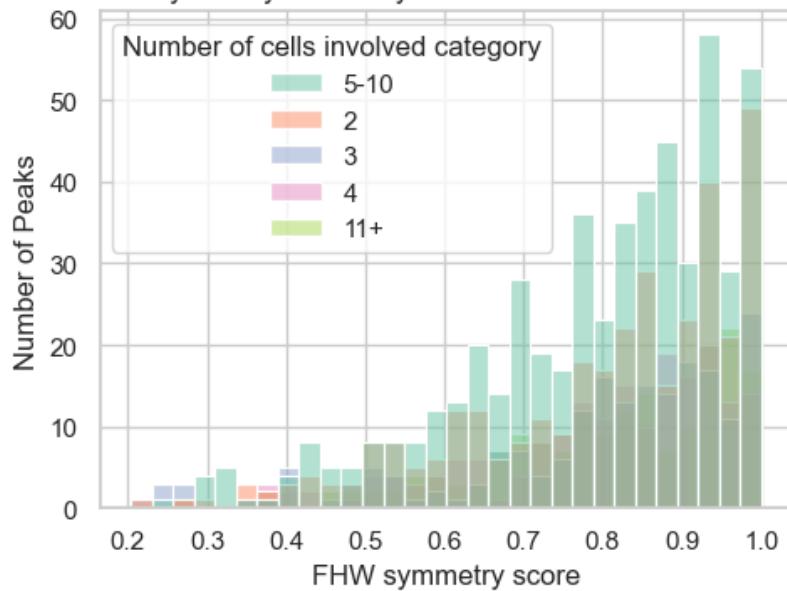


[2025-08-27 15:07:03] [INFO] calcium: plot_histogram_by_group: removed 26 outliers out of 1435 on 'Prominence (noise std units)' (lower=-8.75, upper=102.25)

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

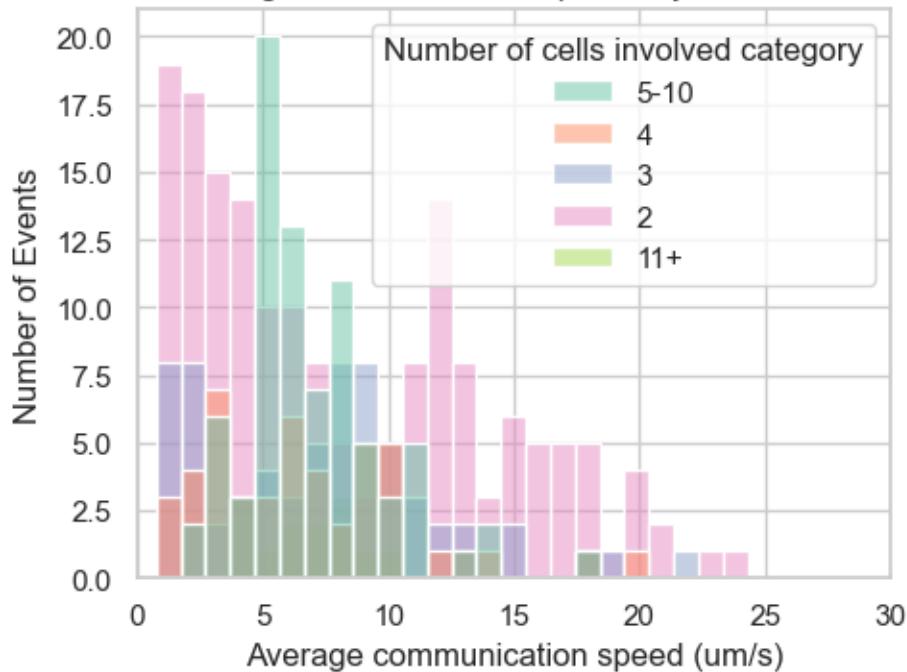


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



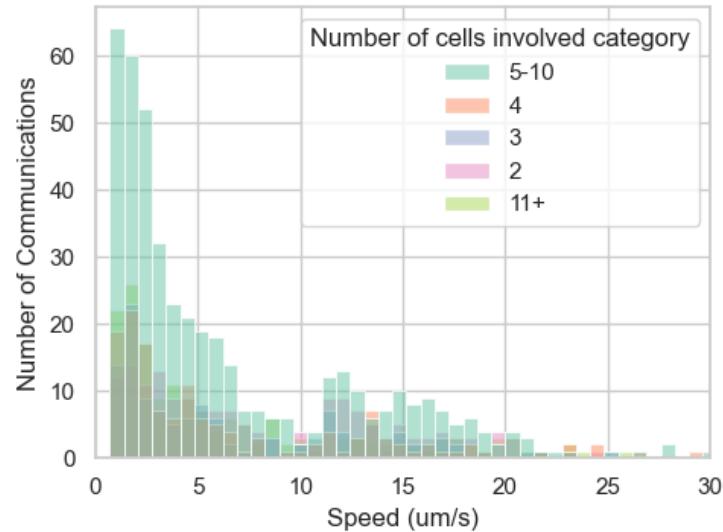
```
[2025-08-27 15:07:04] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 375 on 'Average communication speed (um/s)' (lower=-15.56, upper=29.625)
```

Distribution of Average Communication Speeds by Number of Cells Involved



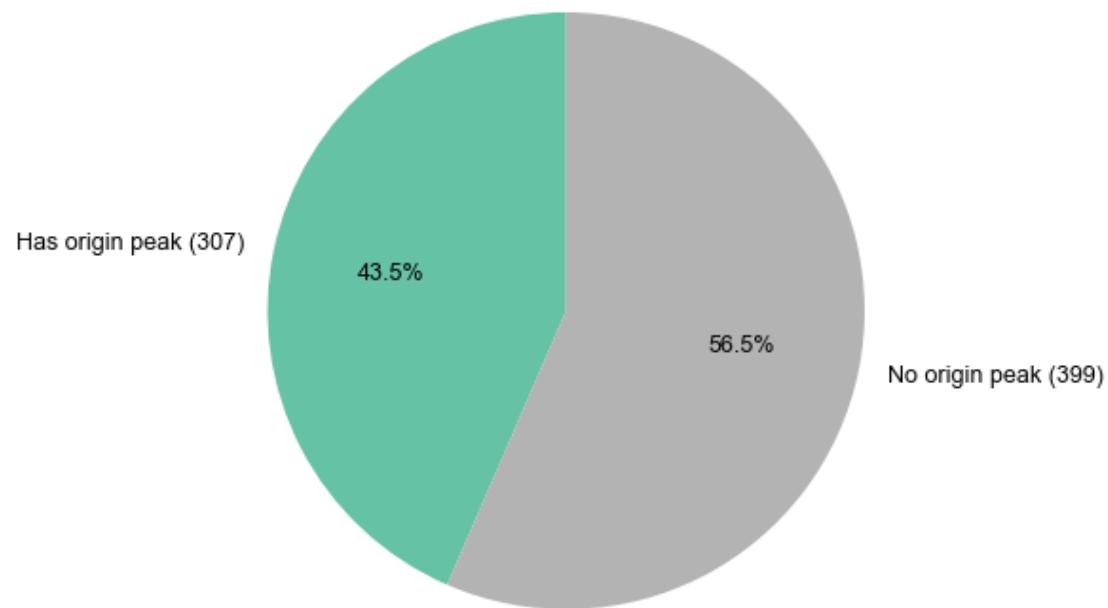
[2025-08-27 15:07:04] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1060 on 'Speed (um/s)' (lower=-26.75, upper=40.38)

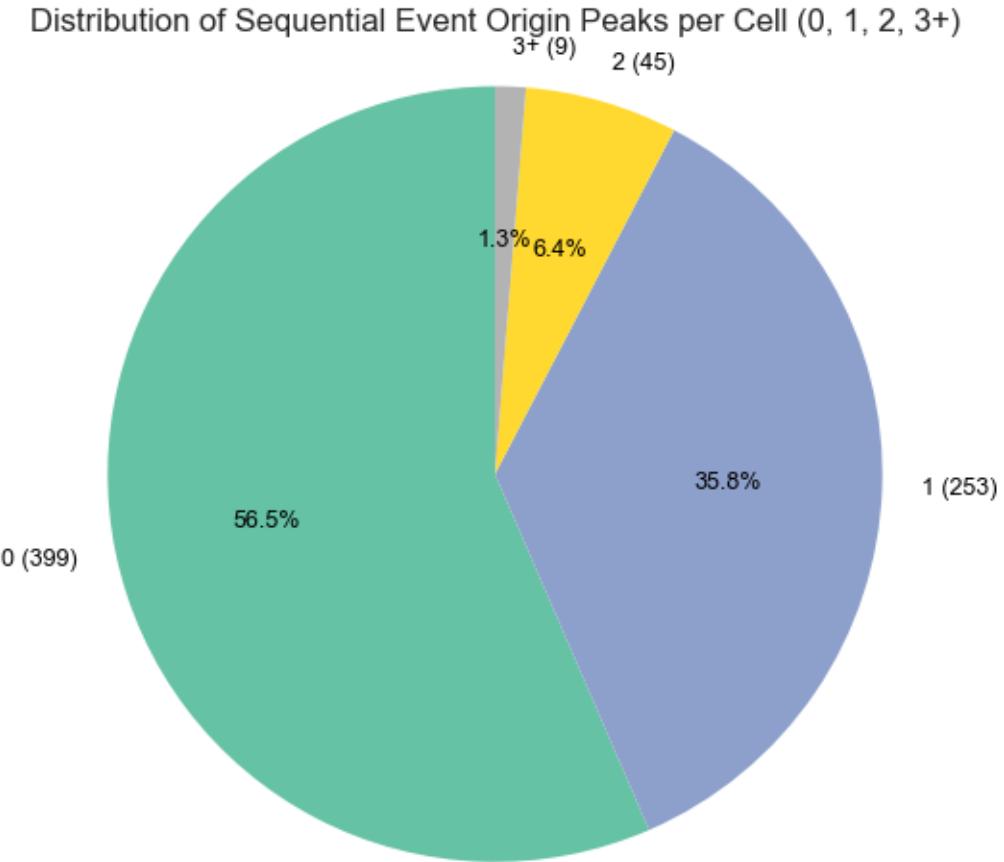
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



1.3.7 Cells Occurrences as origin in sequential events

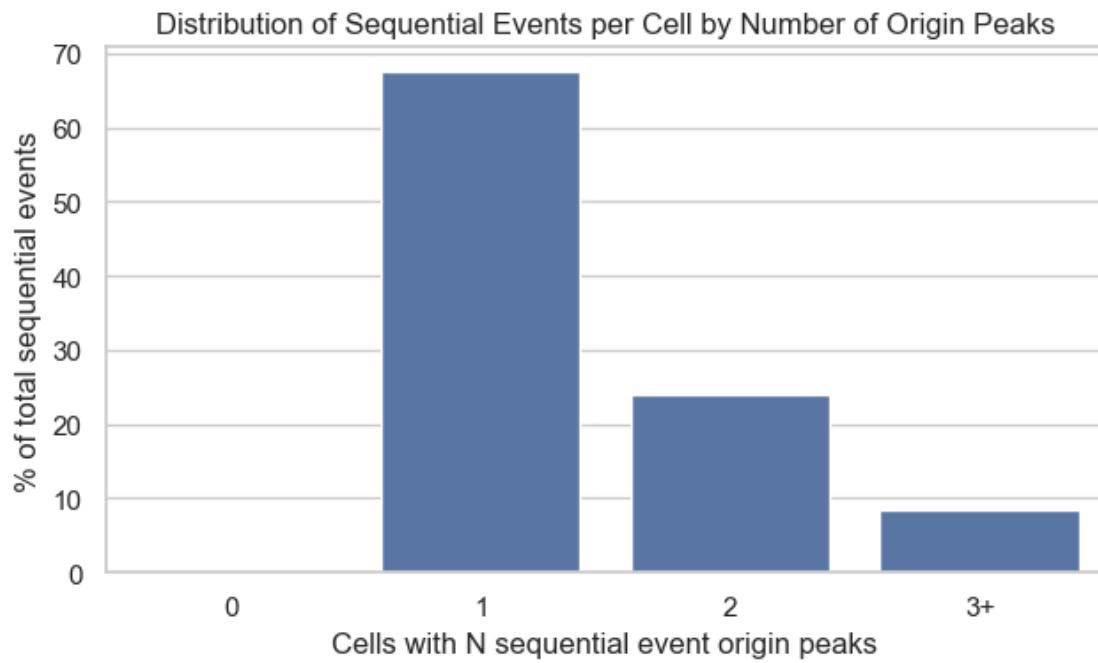
Distribution of Number of Sequential Event Origin Peaks per Cell



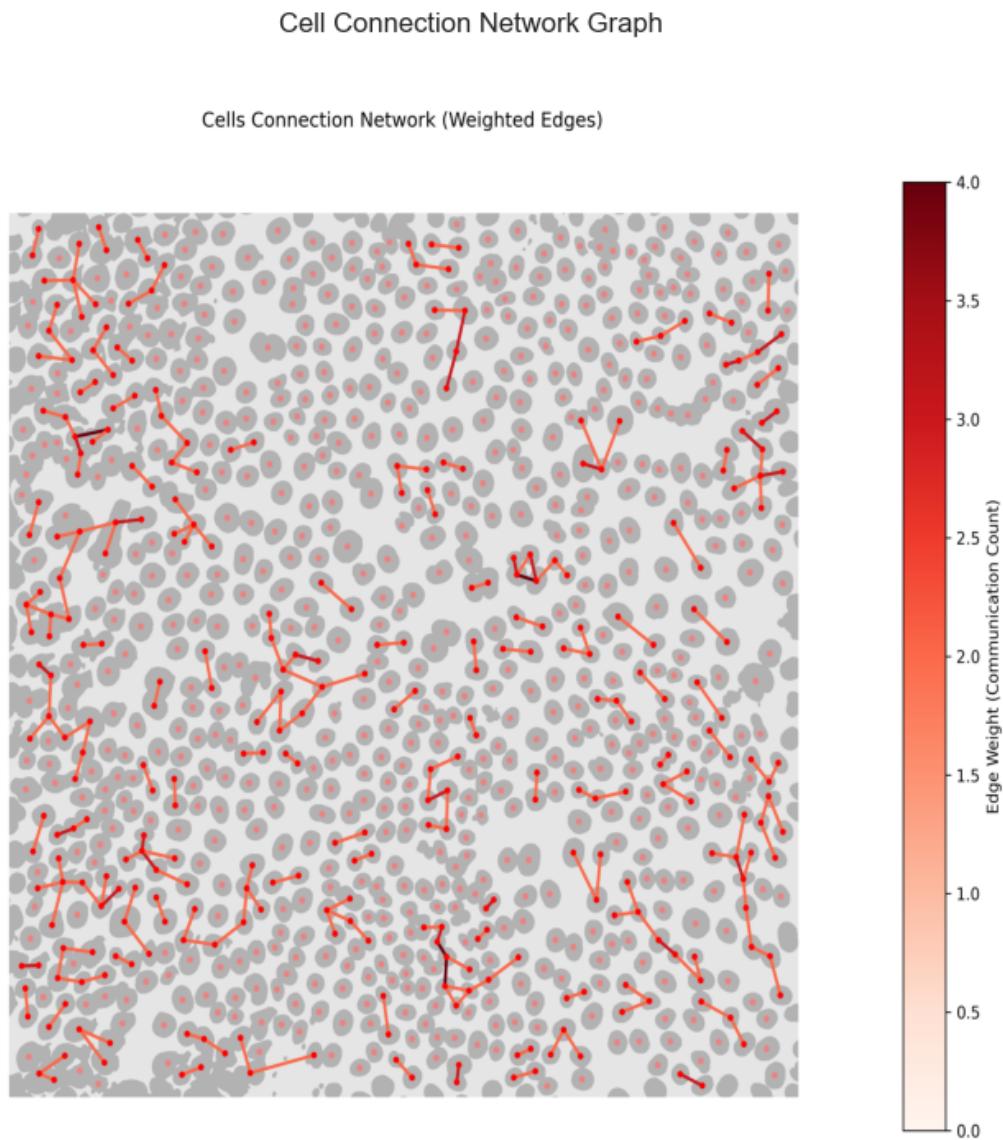


```
[2025-08-27 15:07:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS8\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (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\\IS8\\cell-mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'

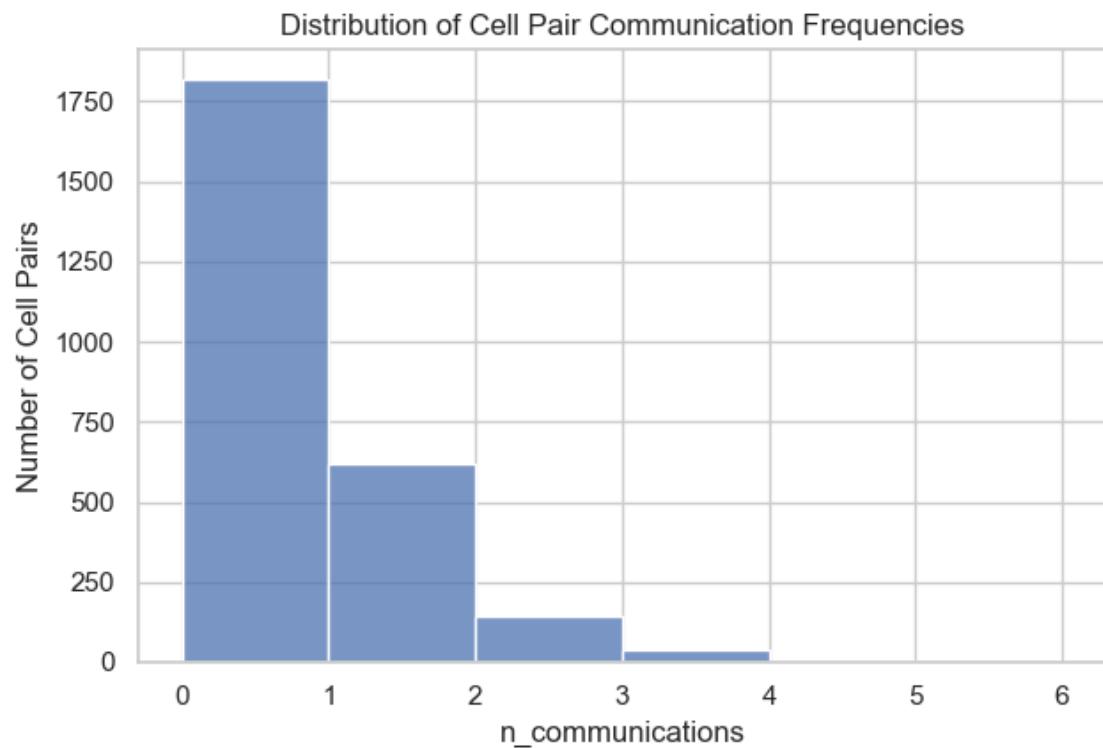


1.3.8 Connection network between cells



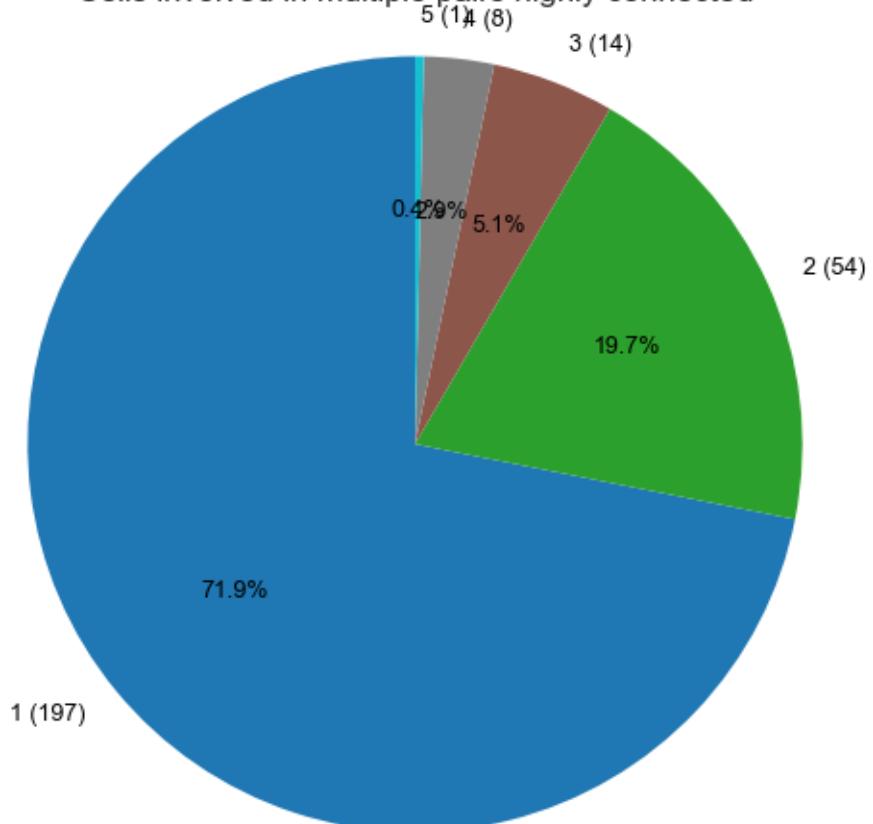
1.3.9 Pair/Trios with high communication networks

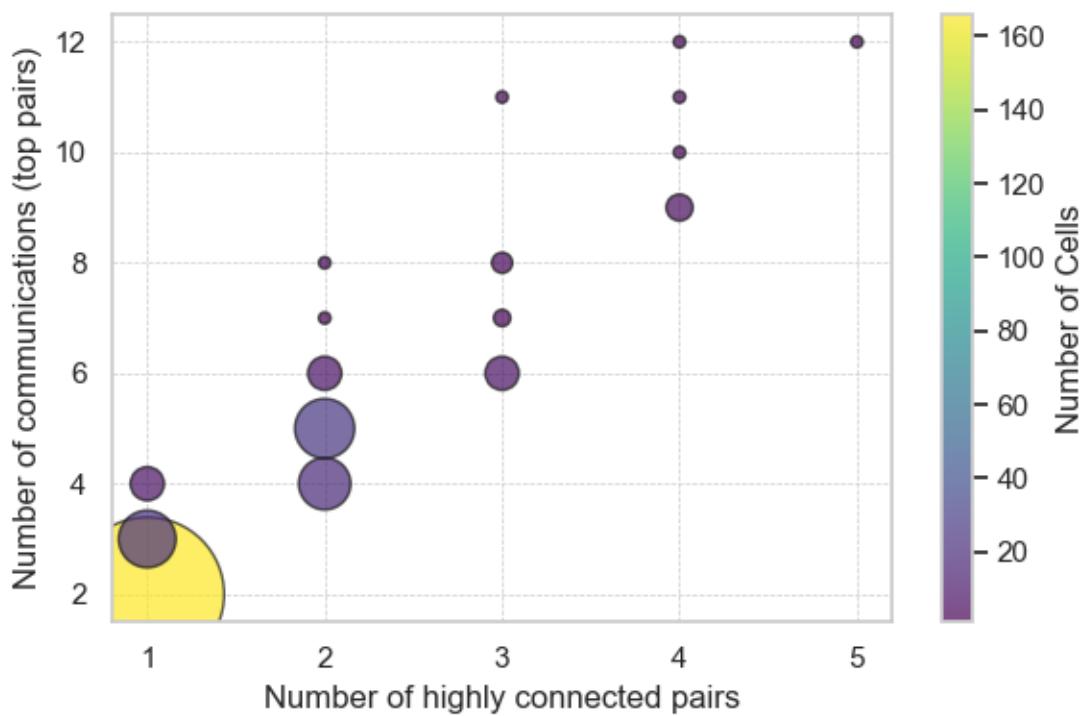
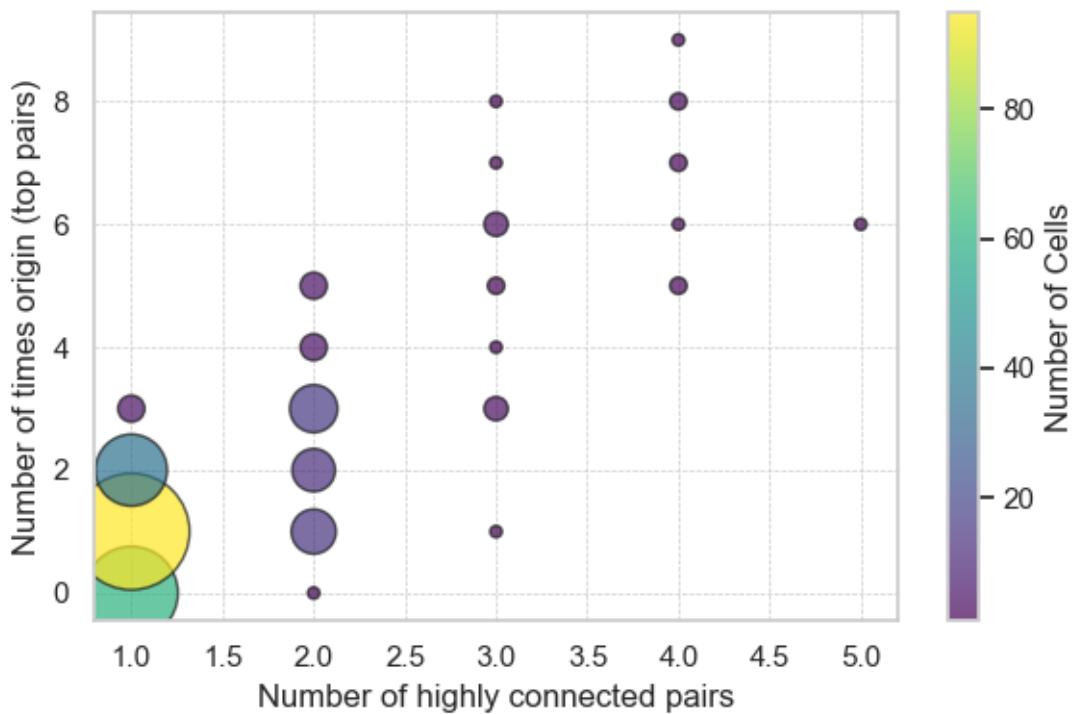
```
[2025-08-27 15:07:06] [INFO] calcium: build_neighbor_pair_stats: built 2629 pairs across 1 datasets (mean distance=17.77 um)
```

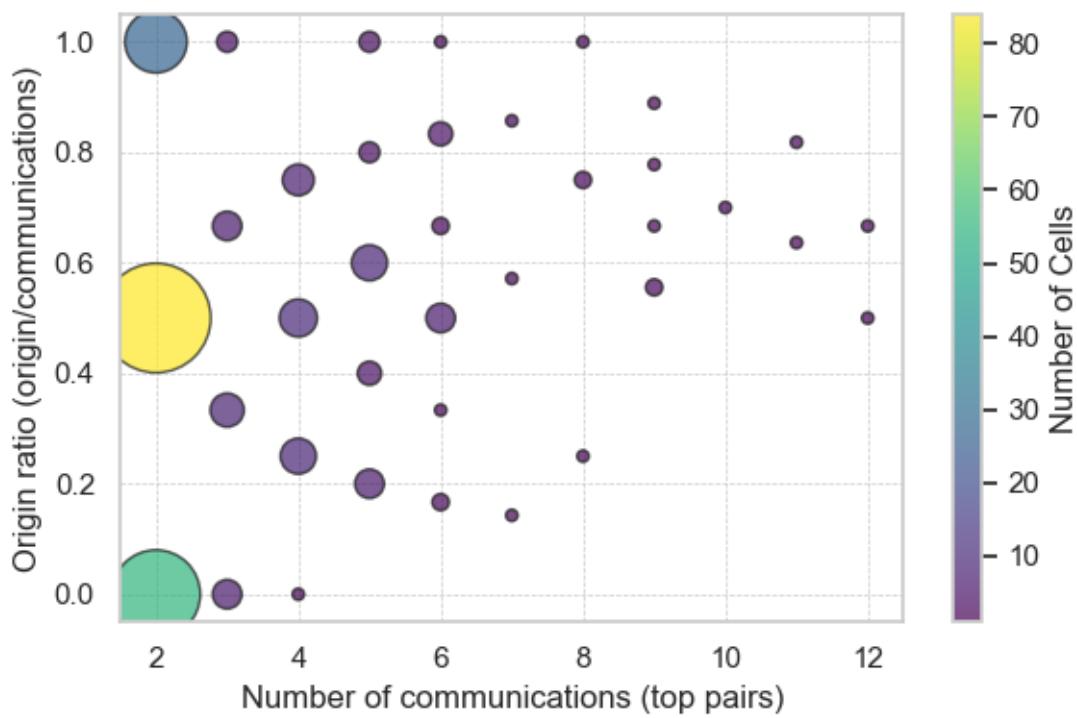
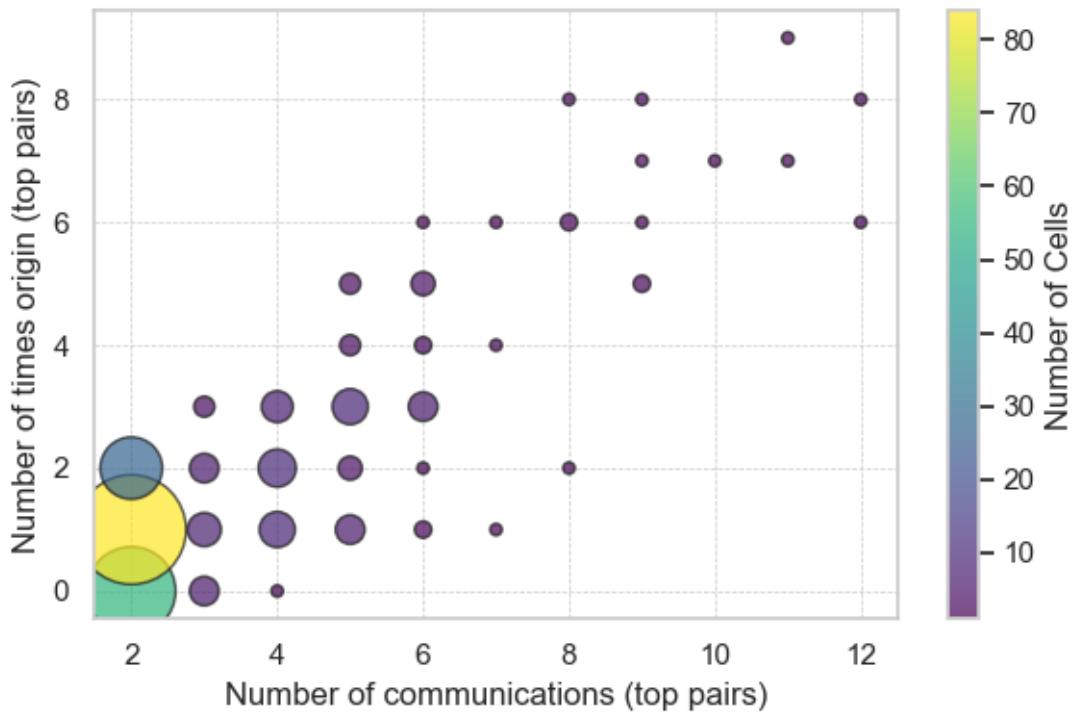


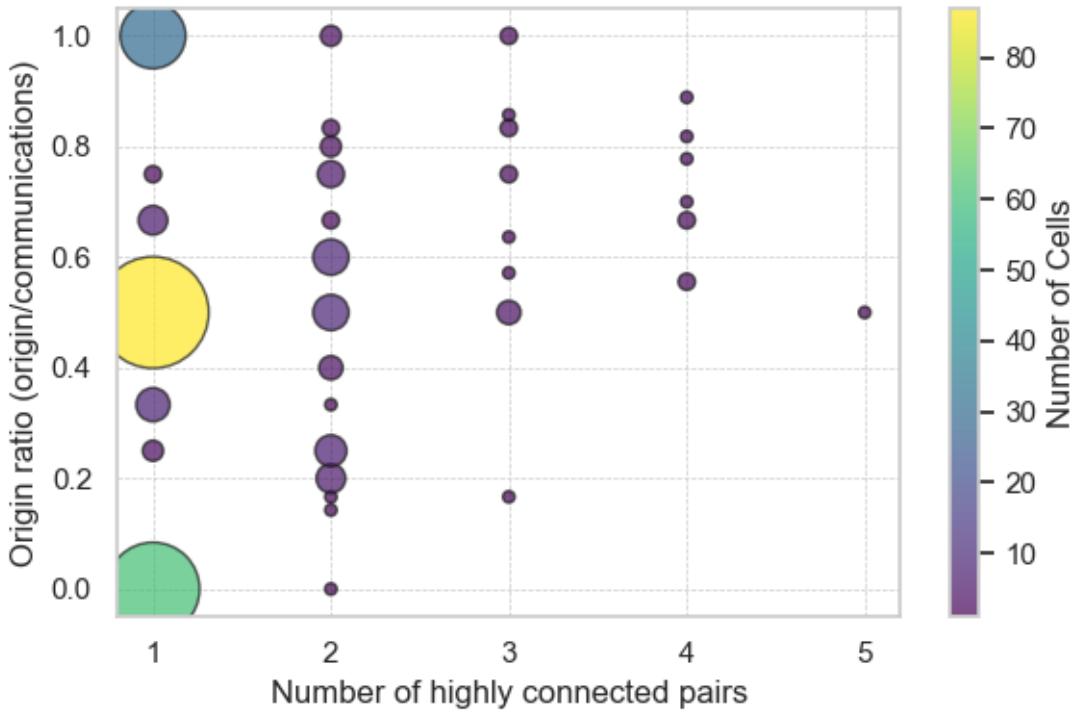
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected









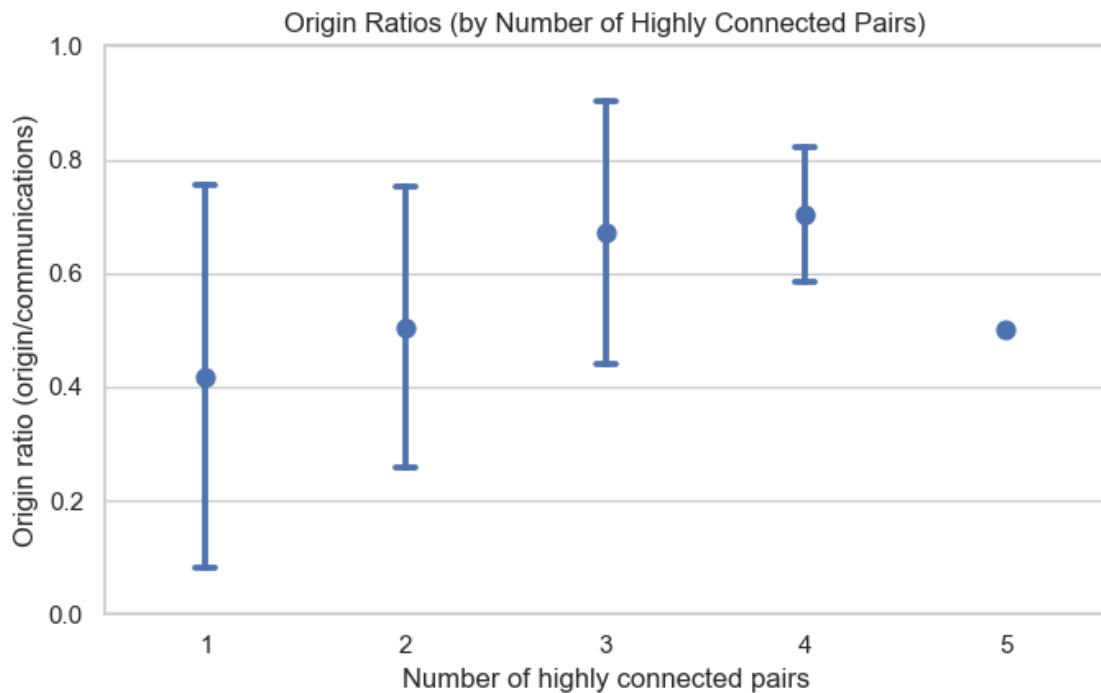
[2025-08-27 15:07:07] [INFO] calcium: plot_points_mean_std: N=197 for Number of highly connected pairs=1

[2025-08-27 15:07:07] [INFO] calcium: plot_points_mean_std: N=54 for Number of highly connected pairs=2

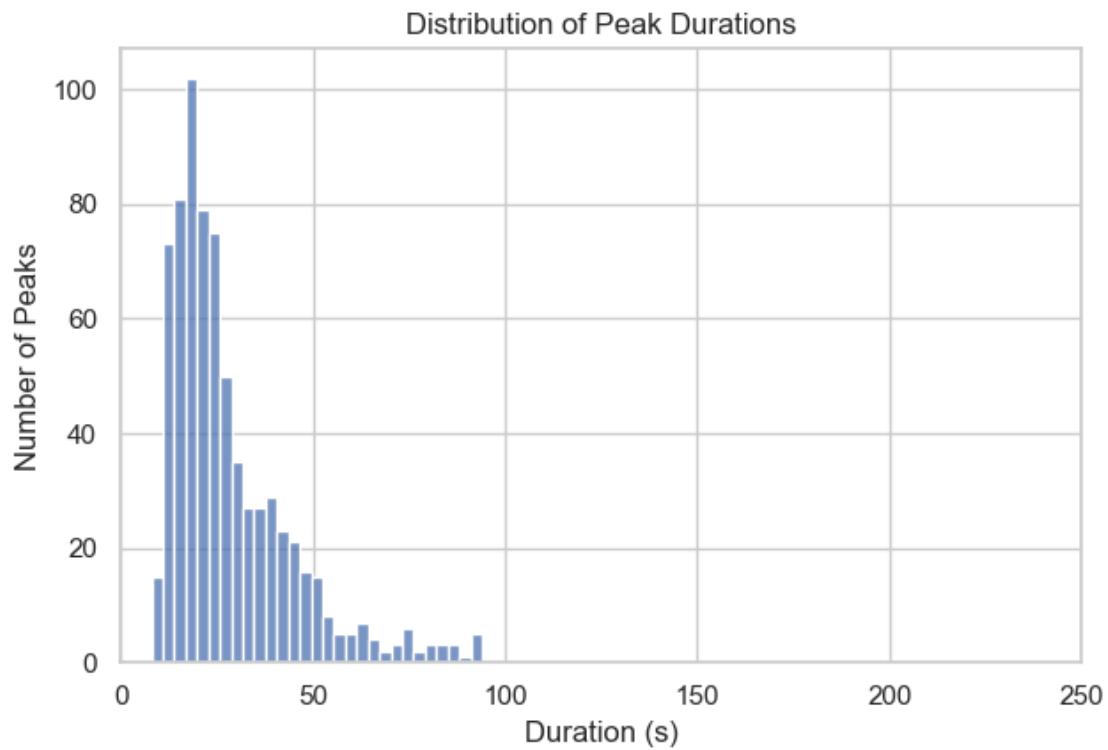
[2025-08-27 15:07:07] [INFO] calcium: plot_points_mean_std: N=14 for Number of highly connected pairs=3

[2025-08-27 15:07:07] [INFO] calcium: plot_points_mean_std: N=8 for Number of highly connected pairs=4

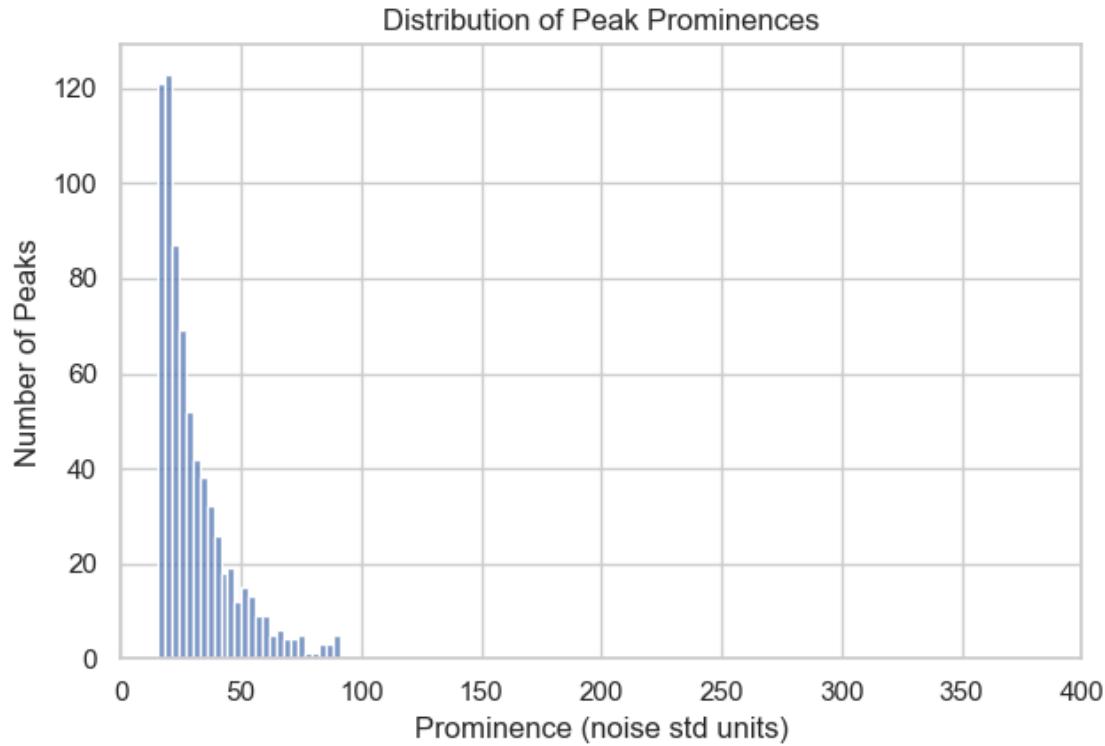
[2025-08-27 15:07:07] [INFO] calcium: plot_points_mean_std: N=1 for Number of highly connected pairs=5

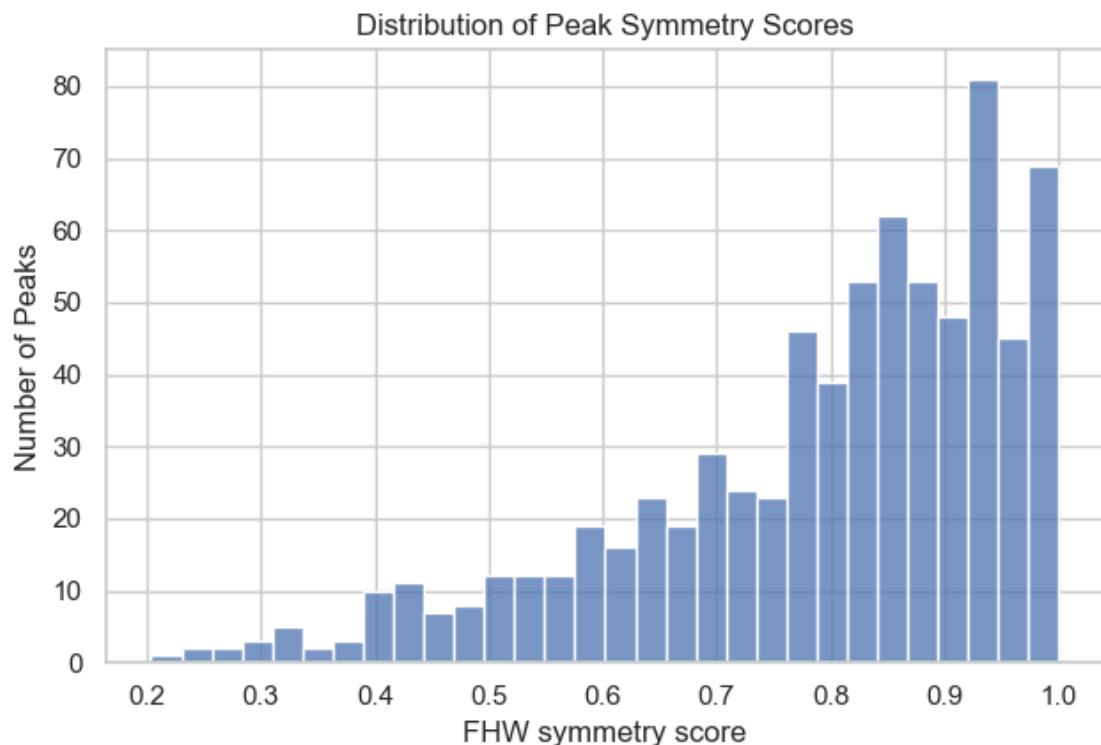


```
[2025-08-27 15:07:07] [INFO] calcium: plot_histogram: removed 14 outliers out of 739 on 'Duration (s)' (lower=-41.5, upper=95)
```

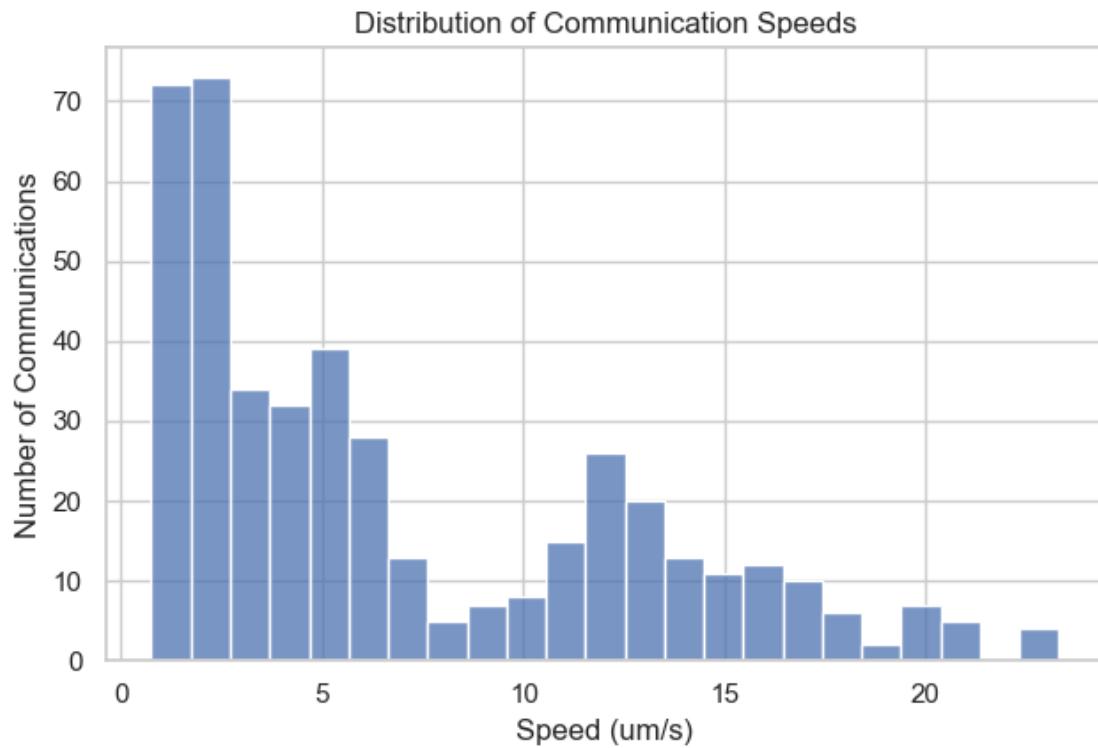


[2025-08-27 15:07:08] [INFO] calcium: plot_histogram: removed 17 outliers out of 739 on 'Prominence (noise std units)' (lower=-36, upper=93.15)

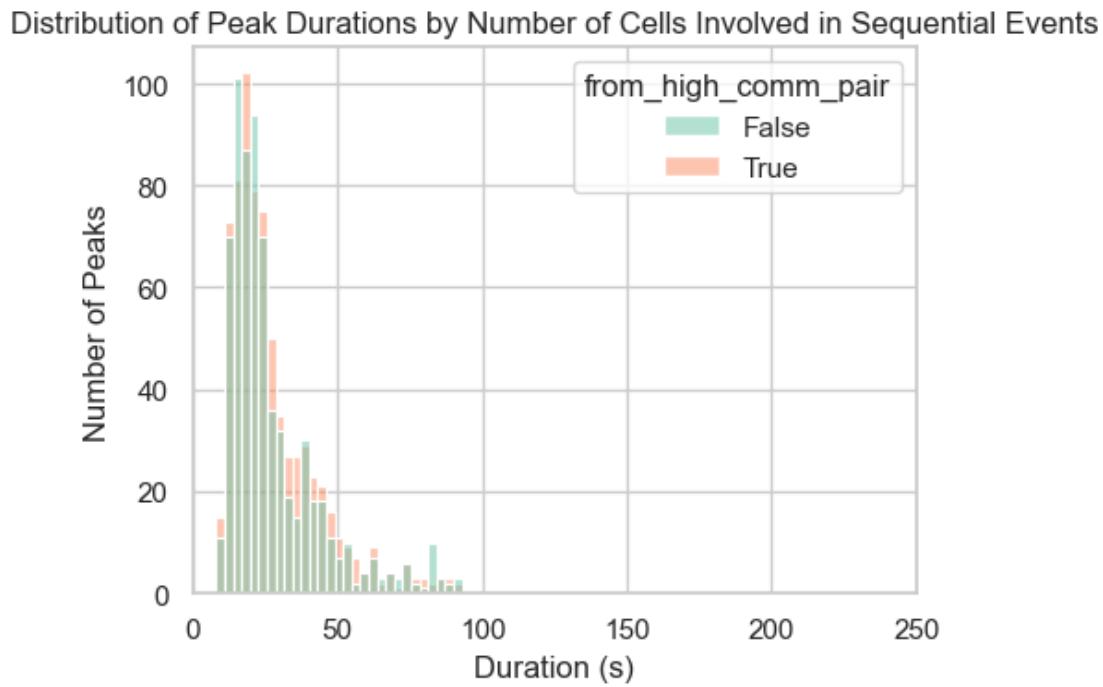




```
[2025-08-27 15:07:08] [INFO] calcium: plot_histogram: removed 0 outliers out of 442 on 'Speed (um/s)' (lower=-27.585, upper=41.627)
```

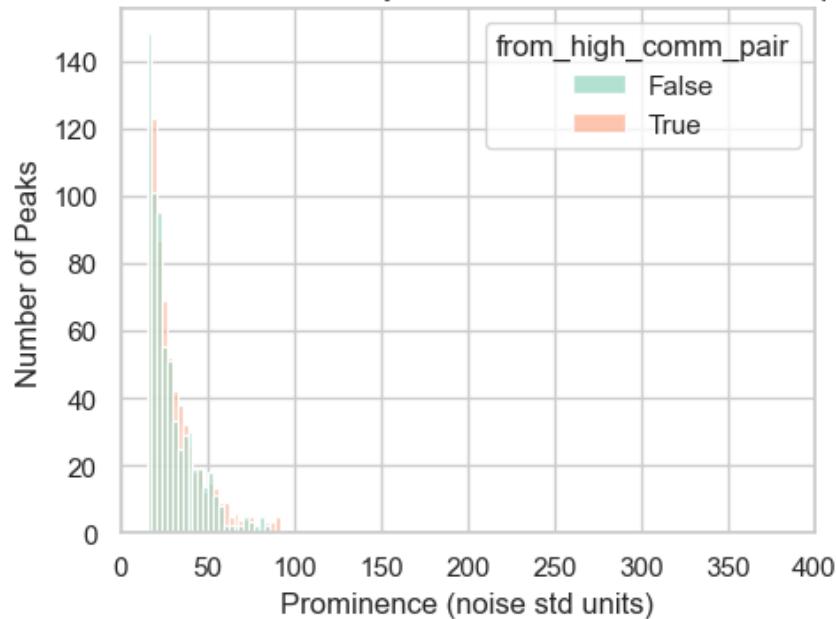


```
[2025-08-27 15:07:08] [INFO] calcium: plot_histogram_by_group: removed 34 outliers out of 1435 on 'Duration (s)' (lower=-40, upper=93)
```

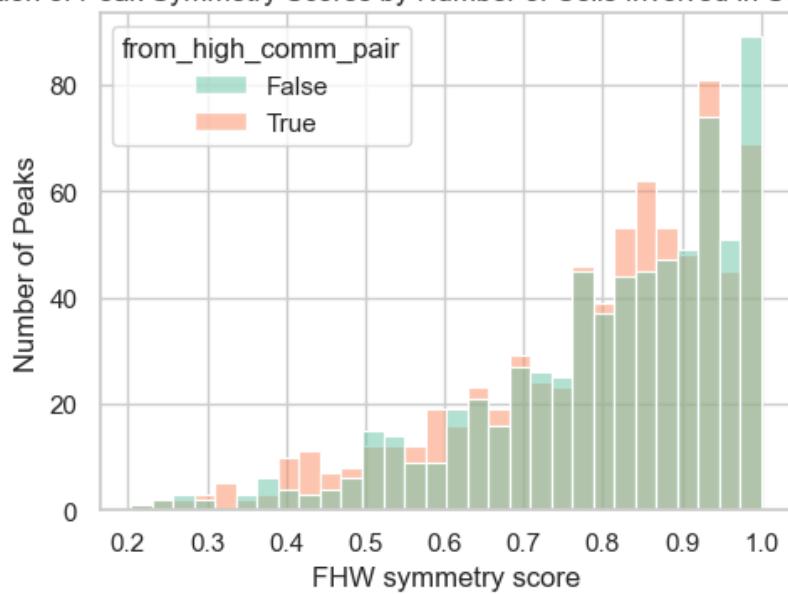


[2025-08-27 15:07:08] [INFO] calcium: plot_histogram_by_group: removed 32 outliers out of 1435 on 'Prominence (noise std units)' (lower=-36.5, upper=93)

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

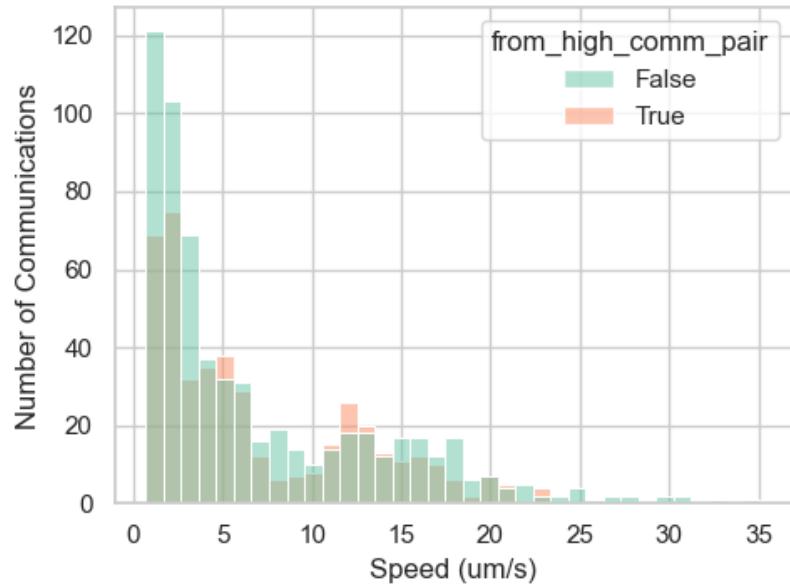


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:07:09] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1060 on 'Speed (um/s)' (lower=-26.75, upper=40.38)
```

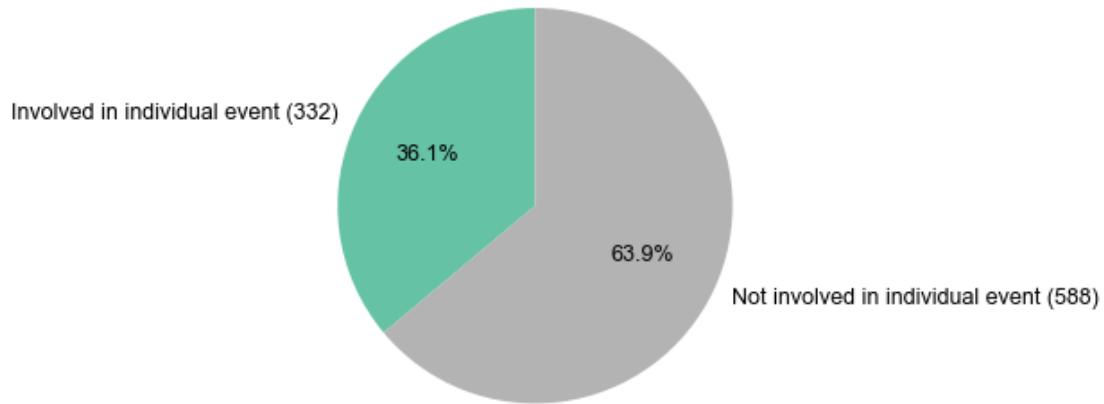
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



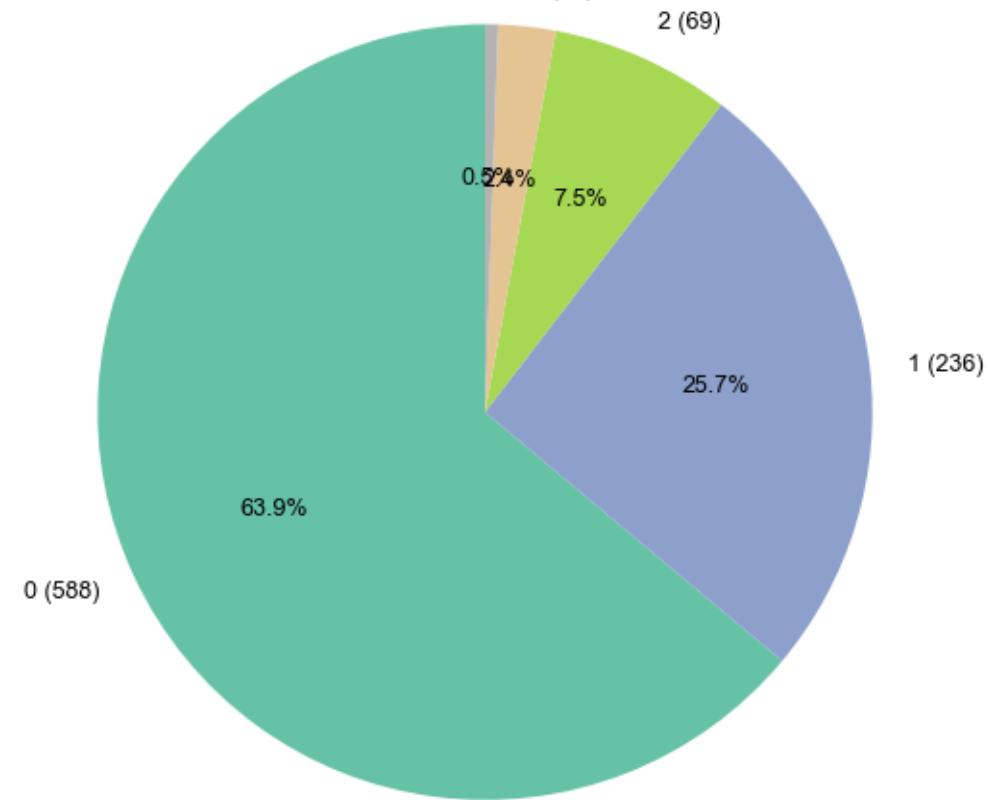
1.4 INDIVIDUAL EVENTS

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+)

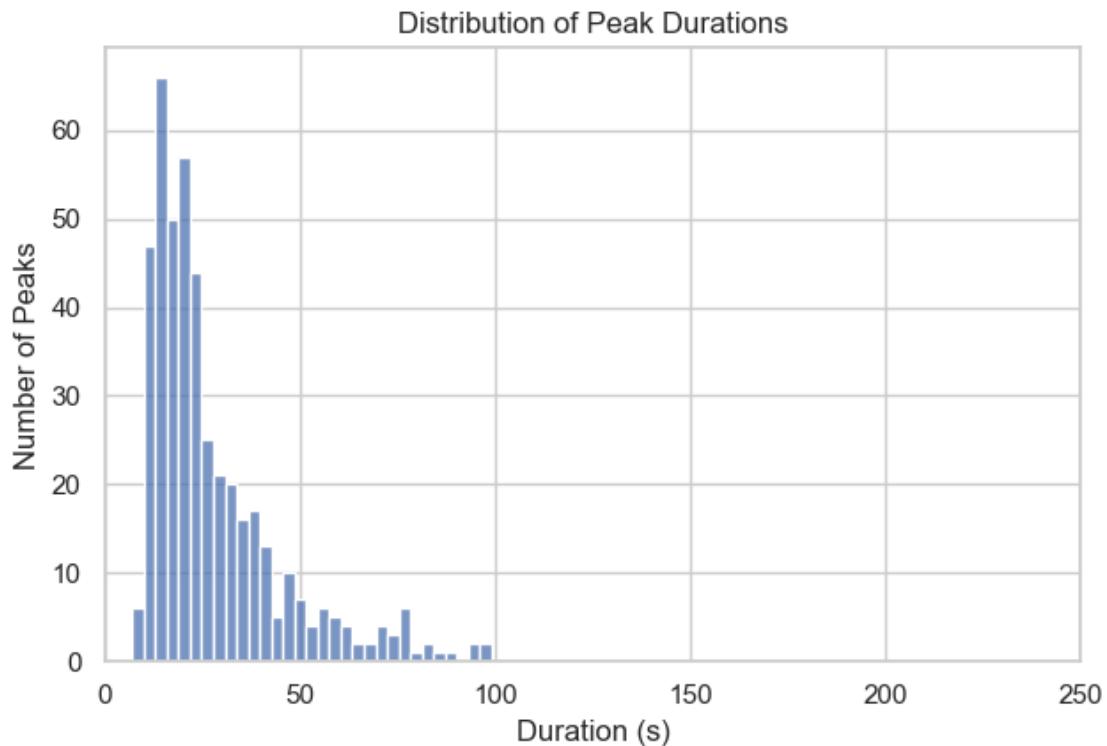


```
[2025-08-27 15:07:09] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS8\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS8\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\IS8\\cell-mapping\\cell_occurrences_in_individual_events_overlay.png'

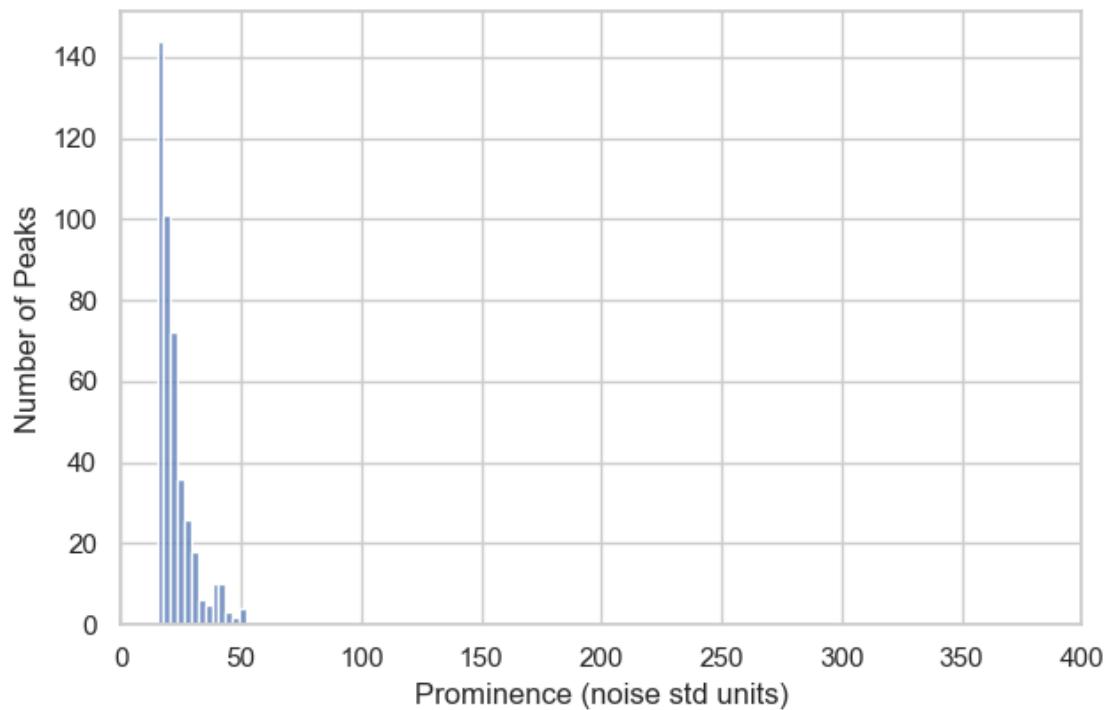
1.4.2 Peaks statistics in individual events

[2025-08-27 15:07:09] [INFO] calcium: plot_histogram: removed 14 outliers out of 463 on 'Duration (s)' (lower=-48, upper=99)

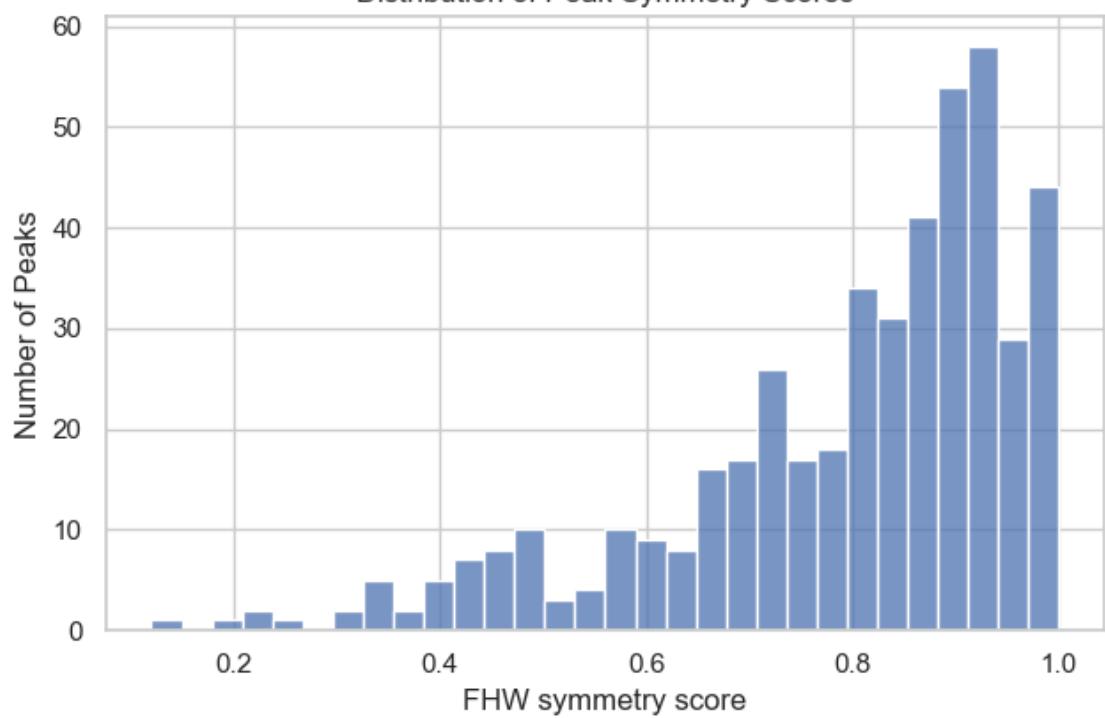


[2025-08-27 15:07:09] [INFO] calcium: plot_histogram: removed 26 outliers out of 463 on 'Prominence (noise std units)' (lower=-9.05, upper=52.2)

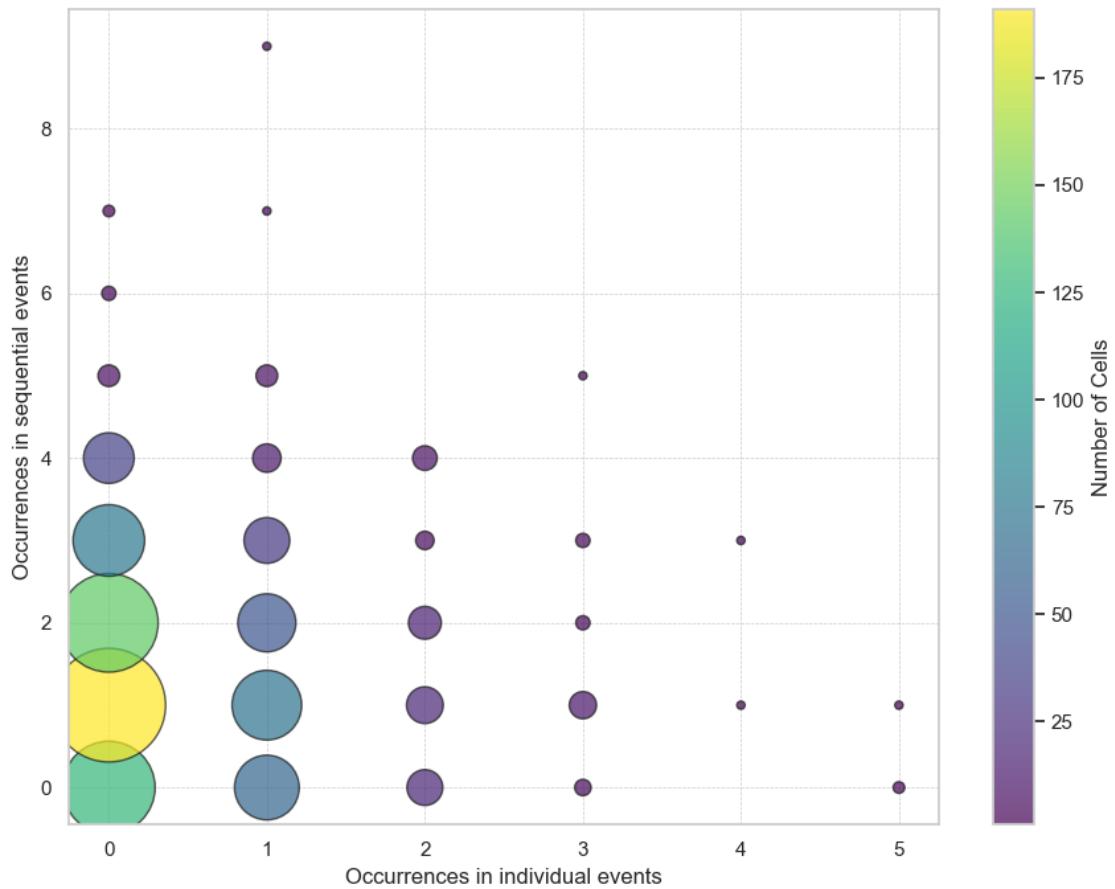
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

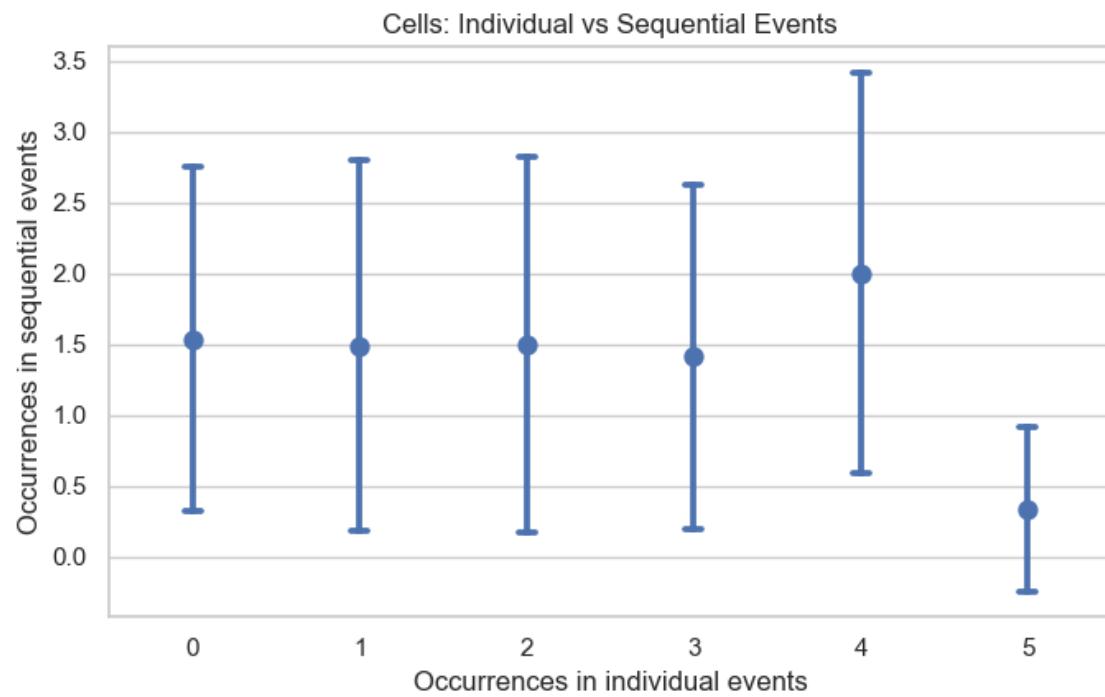


1.4.3 Correlation between event activity level & individual activity level

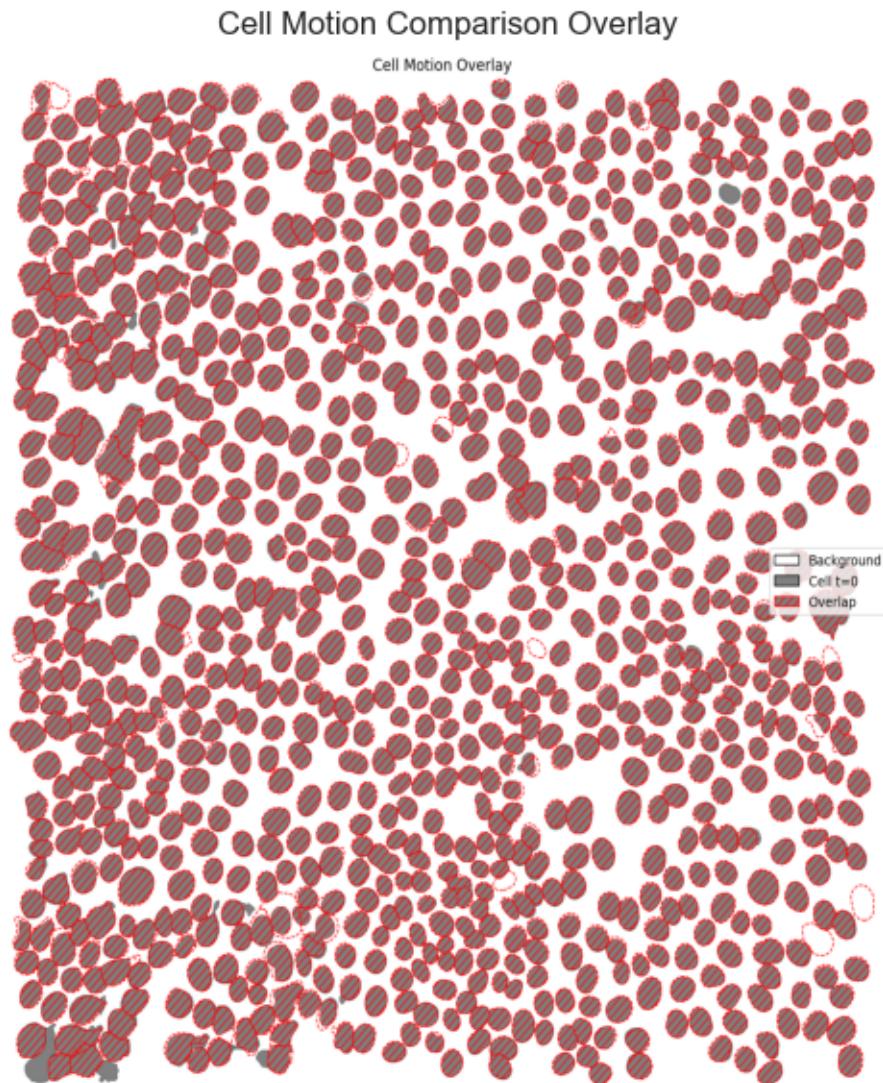


```
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: removed 7/920 outliers on 'Occurrences in sequential events' (lower=-2, upper=5)
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: N=583 for Occurrences in individual events=0
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: N=234 for Occurrences in individual events=1
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: N=69 for Occurrences in individual events=2
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: N=22 for Occurrences in individual events=3
[2025-08-27 15:07:10] [INFO] calcium: plot_points_mean_std: N=2 for Occurrences in individual events=4
```

[2025-08-27 15:07:10] [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: 920
- Hoechst image taken at t=1801: 921
- Number of cells difference: absolute 1, relative 0.11%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1113306
- Pixels segmented as cell at t=1801: 1095985
- Overlapping pixels between t=0 and t=1801: 1034988 (93.69% of total)
- Pixels exclusive to t=0: 78318 (7.03% of total)
- Pixels exclusive to t=1801: 60997 (5.56% of total)