

executed

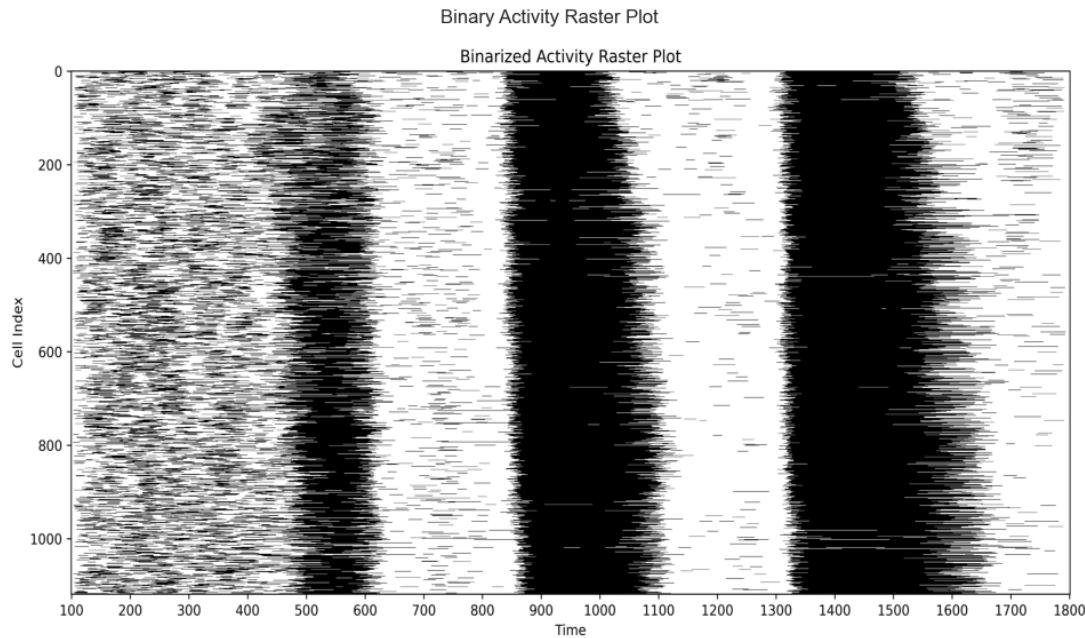
August 27, 2025

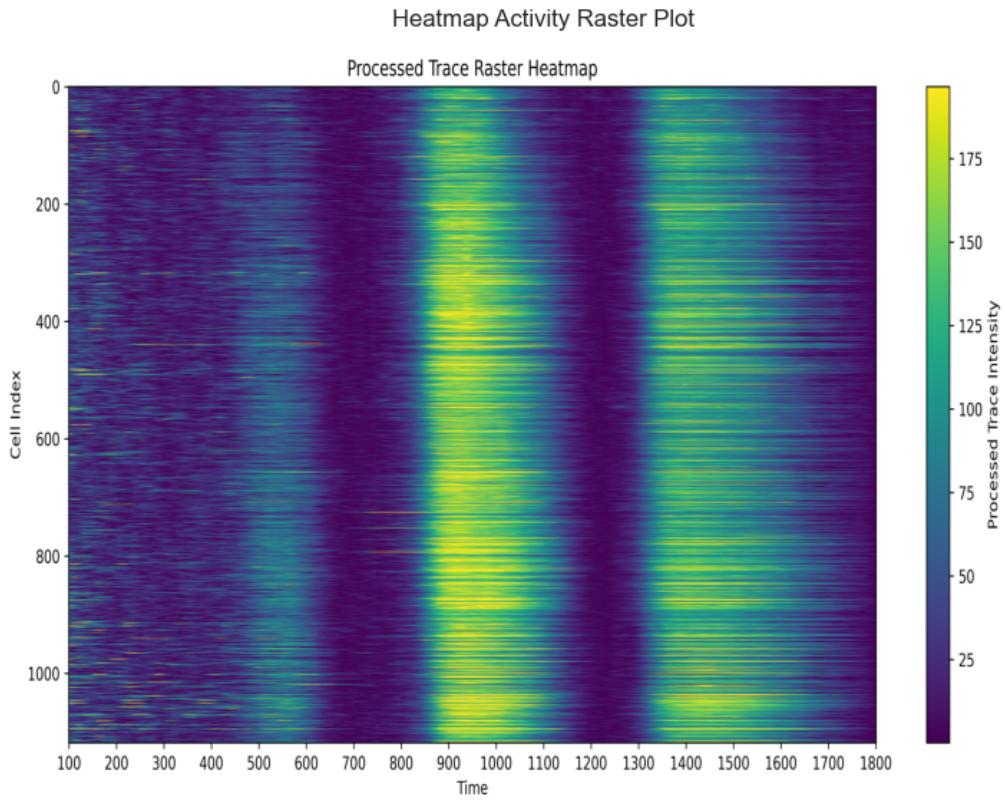
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





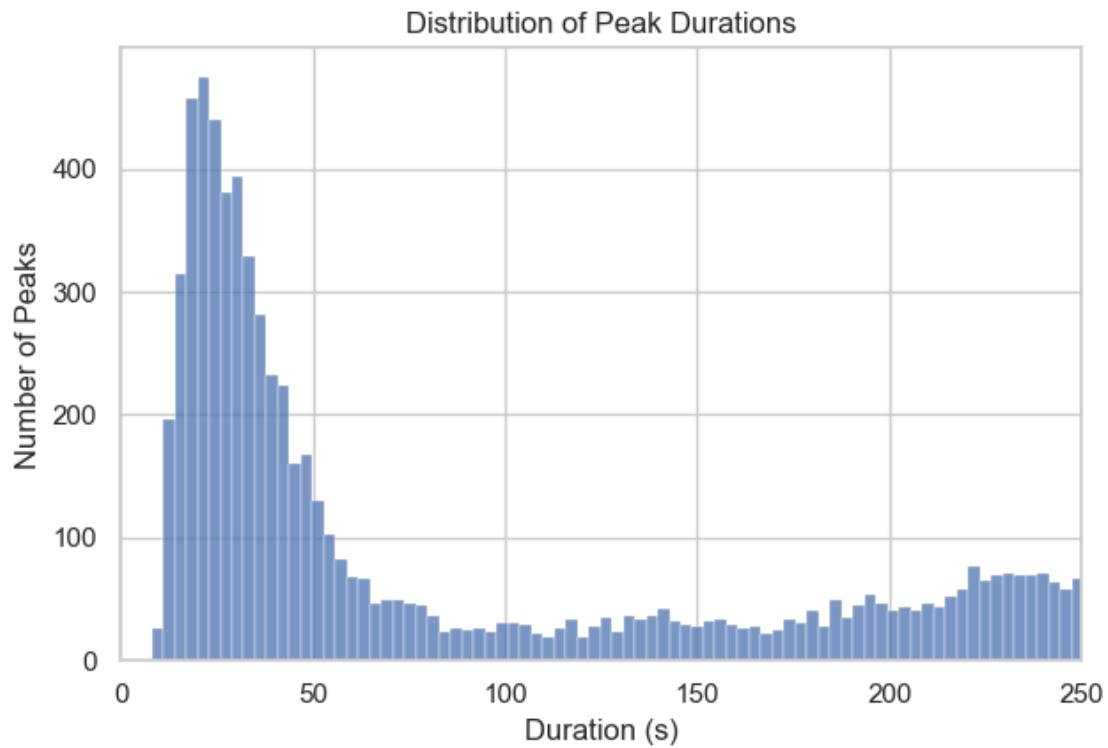
### 1.1.2 Peaks population

Total number of peaks: 7864

Total number of cells: 1119

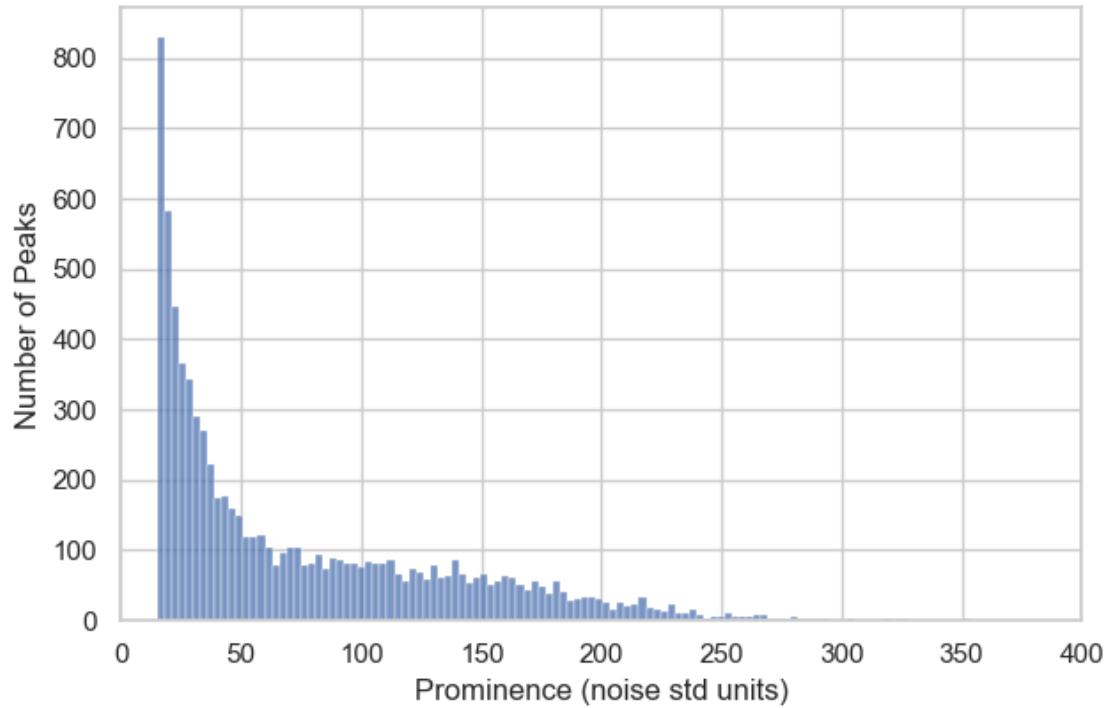
### 1.1.3 Peaks statistics

```
[2025-08-27 14:45:52] [INFO] calcium: plot_histogram: removed 0 outliers out of 7864 on 'Duration (s)' (lower=-472, upper=690)
```

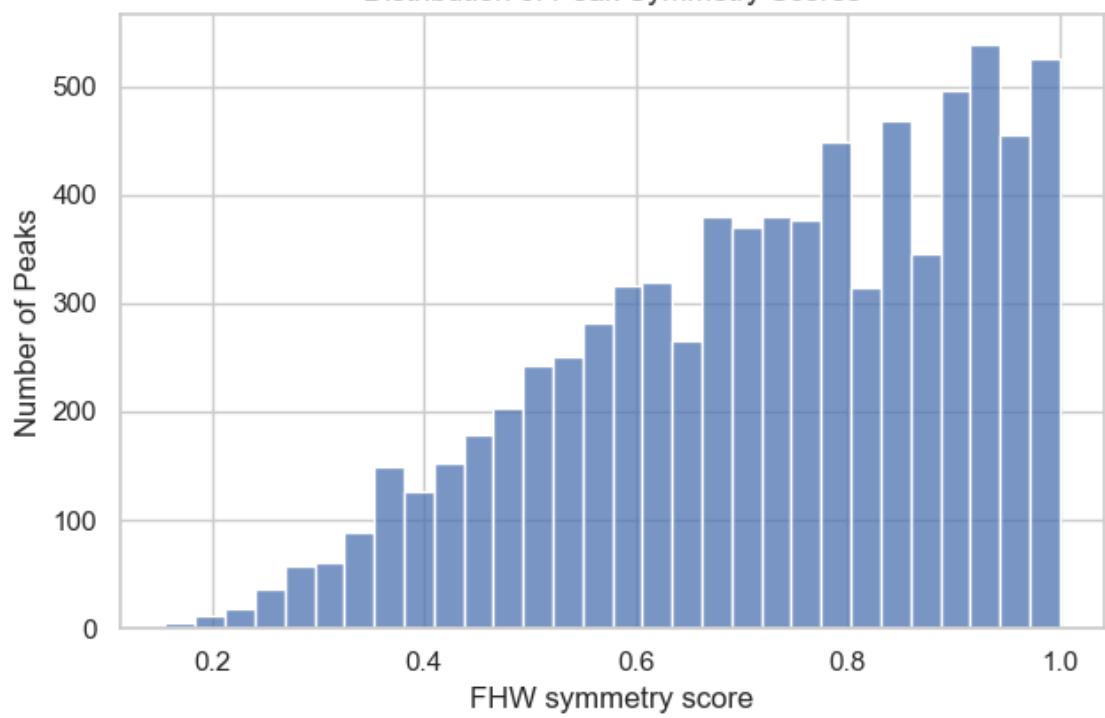


```
[2025-08-27 14:45:52] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7864 on 'Prominence (noise std units)' (lower=-239, upper=376.3)
```

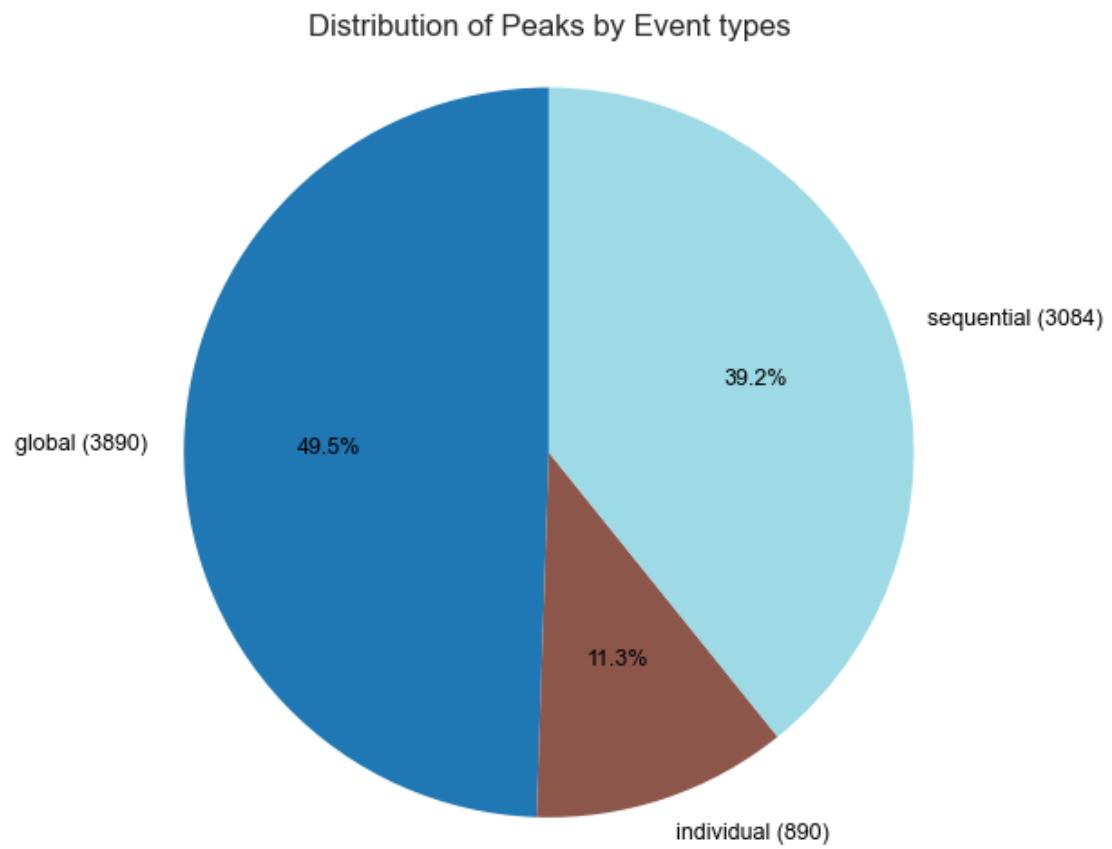
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

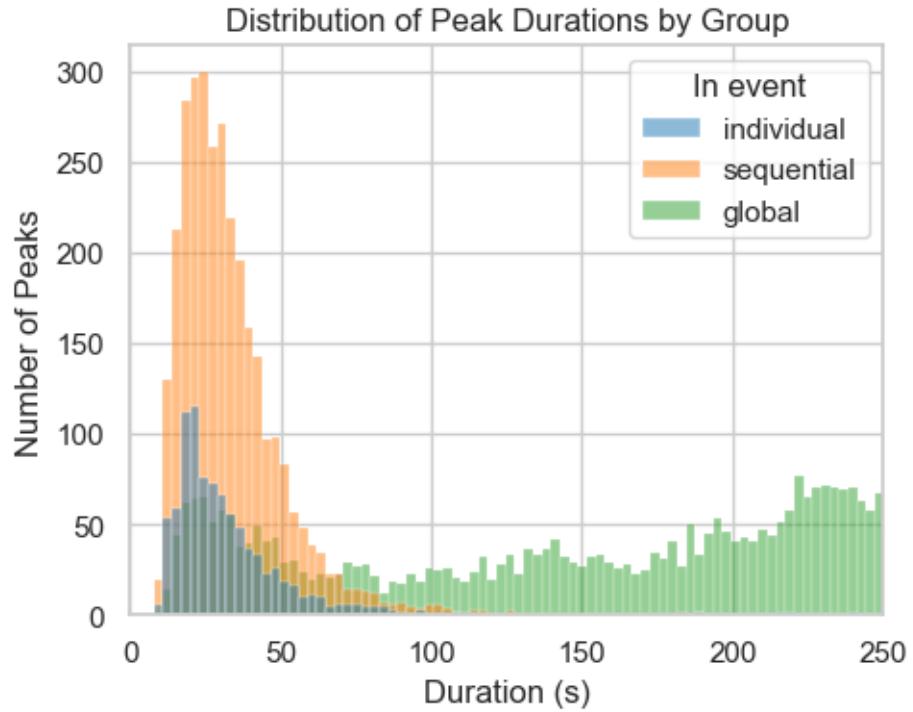


#### 1.1.4 Distribution of peaks per event types

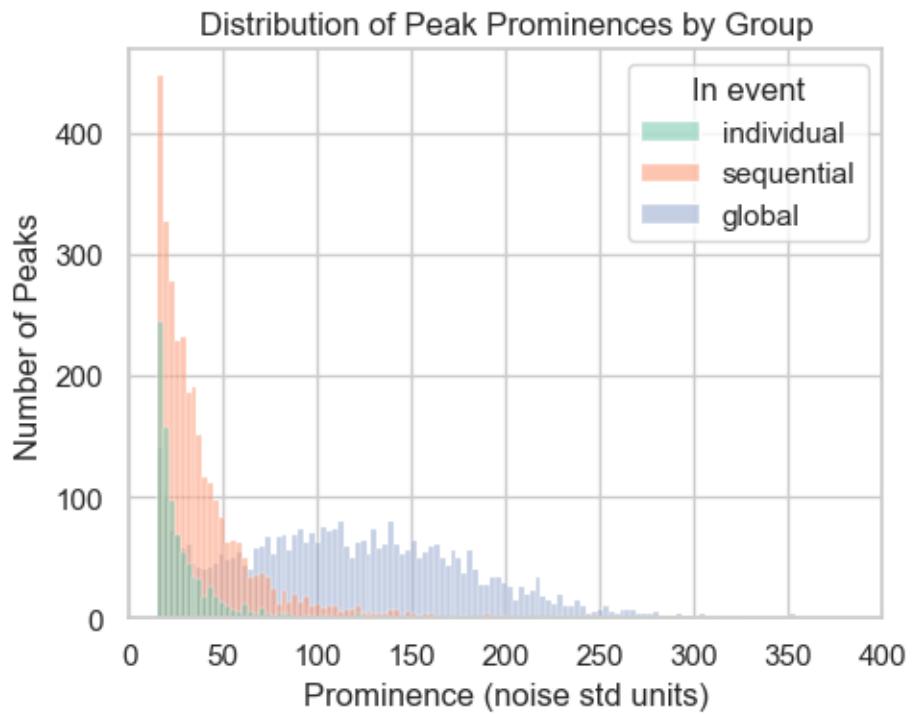


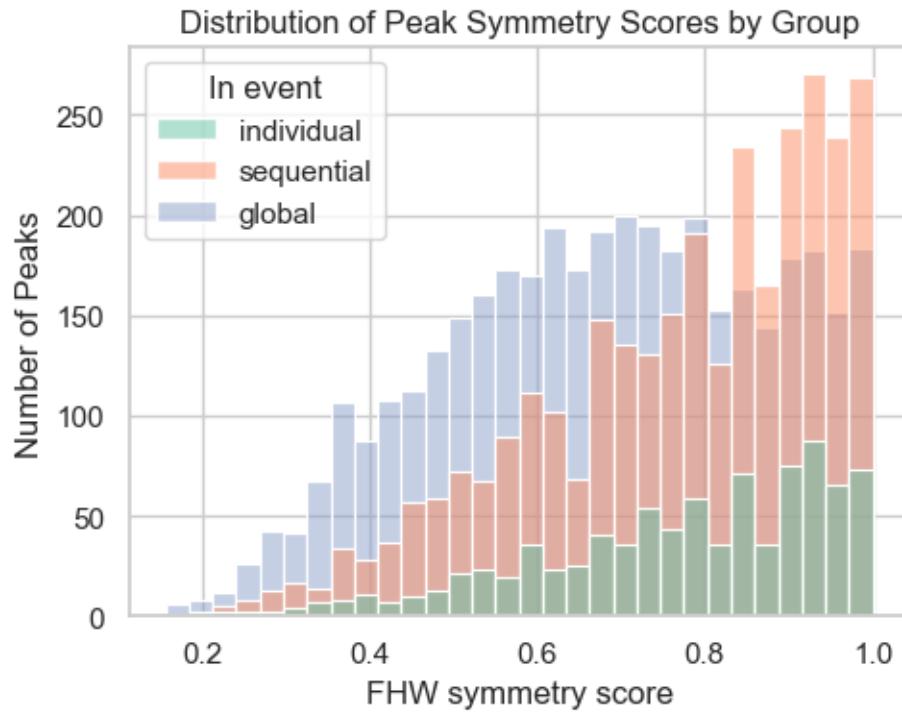
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 14:45:52] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7864 on 'Duration (s)' (lower=-472, upper=690)
```



```
[2025-08-27 14:45:53] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7864 on 'Prominence (noise std units)' (lower=-239, upper=376.3)
```

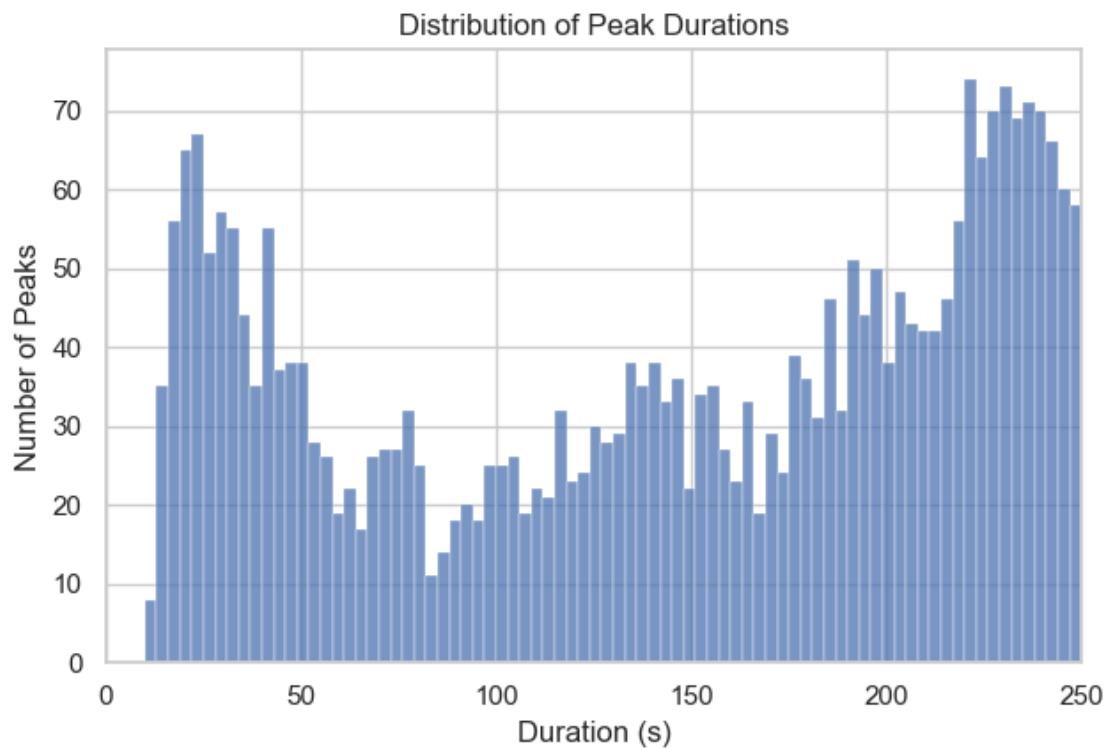




## 1.2 GLOBAL EVENTS

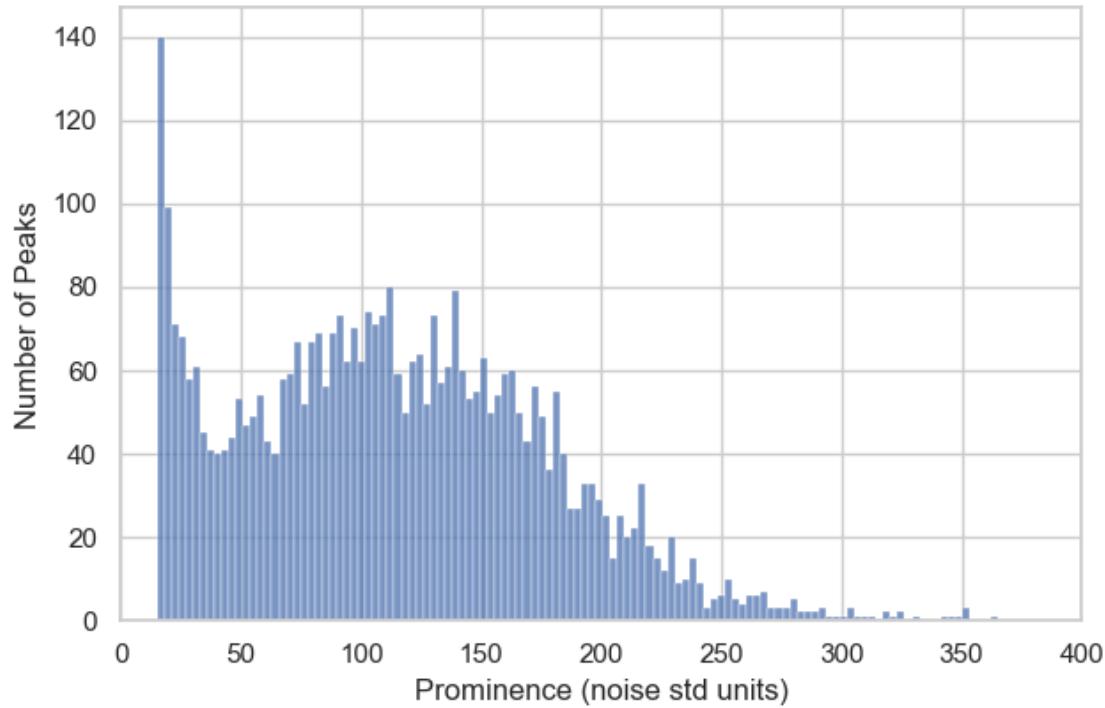
### 1.2.1 Peak statistics in global events

```
[2025-08-27 14:45:53] [INFO] calcium: plot_histogram: removed 0 outliers out of 3890 on 'Duration (s)' (lower=-344, upper=685)
```

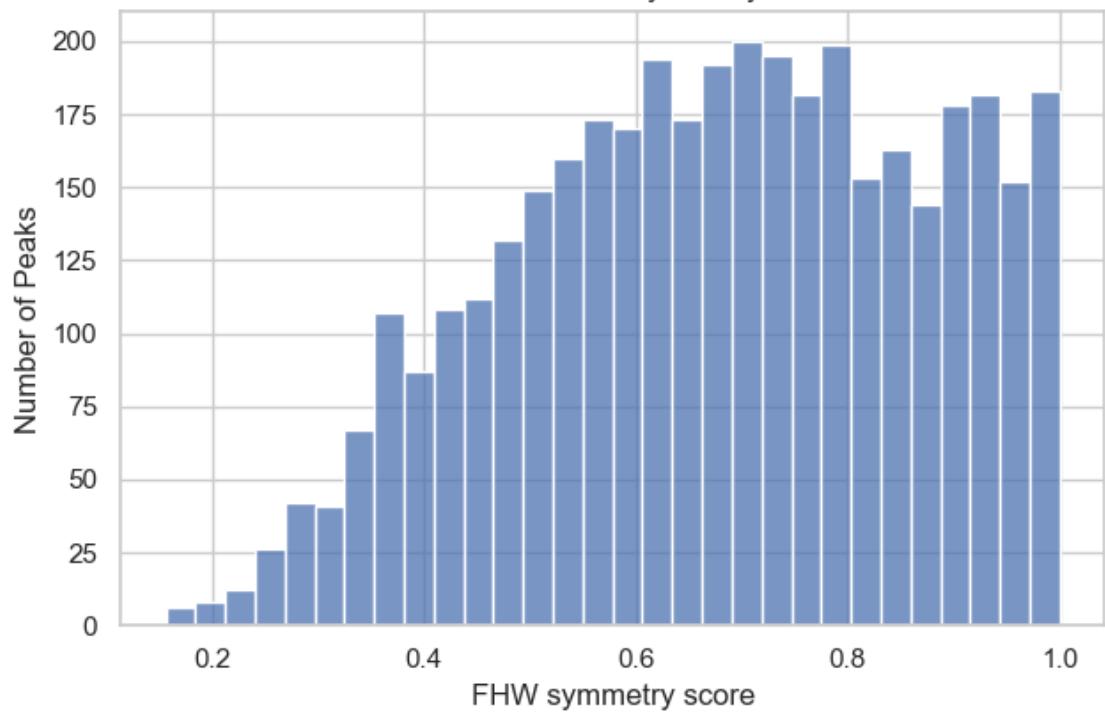


```
[2025-08-27 14:45:53] [INFO] calcium: plot_histogram: removed 0 outliers out of 3890 on 'Prominence (noise std units)' (lower=-213.92, upper=435.5)
```

Distribution of Peak Prominences

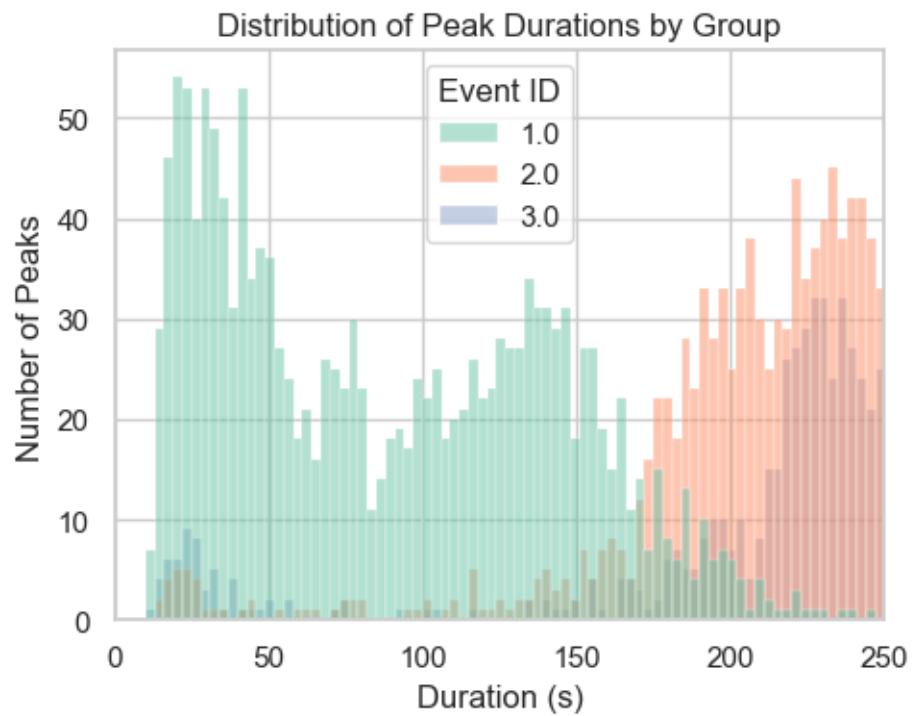


Distribution of Peak Symmetry Scores

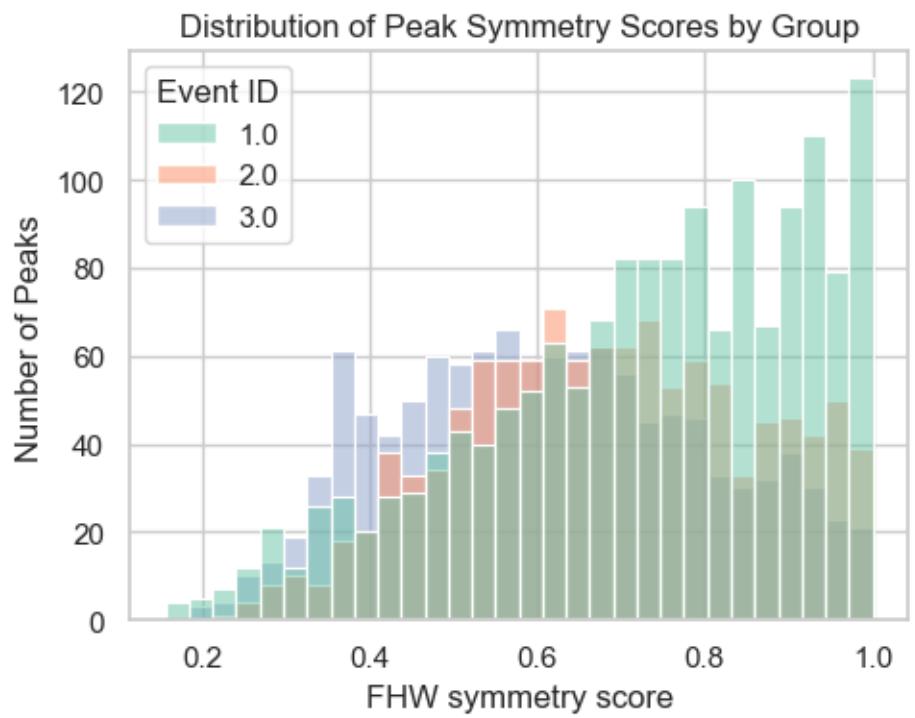
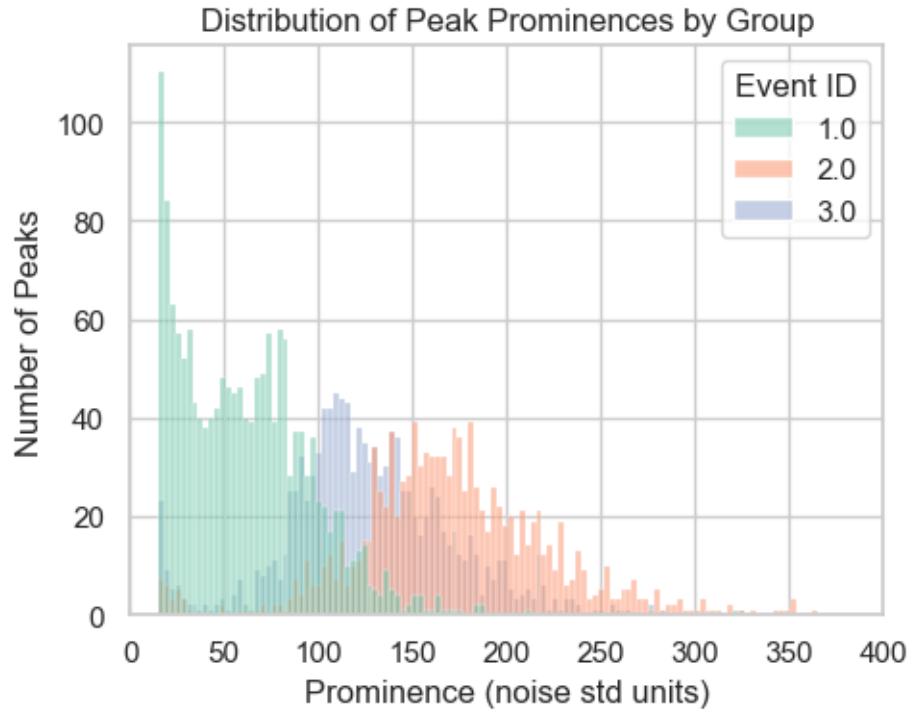


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:45:54] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 3890 on 'Duration (s)' (lower=-344, upper=685)

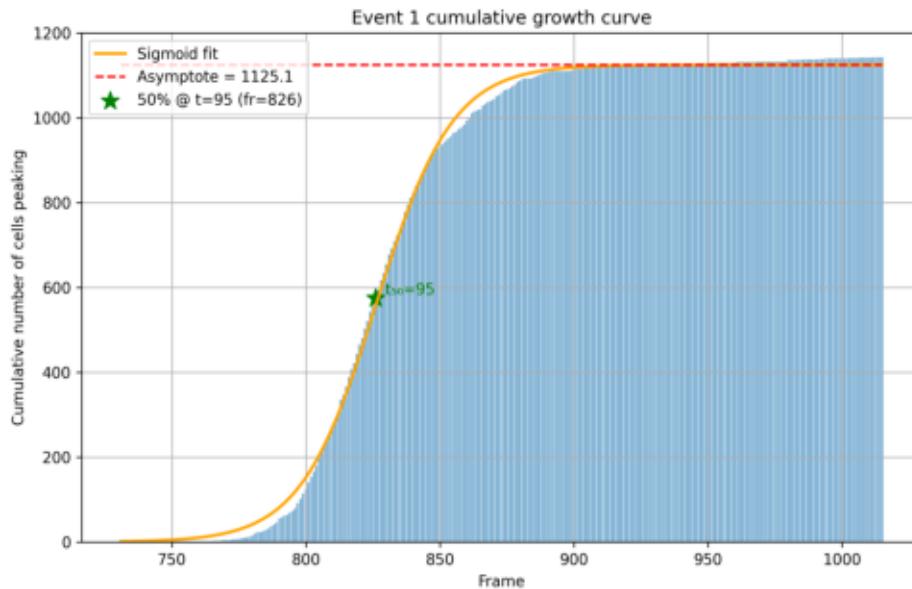


[2025-08-27 14:45:54] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 3890 on 'Prominence (noise std units)' (lower=-213.92, upper=435.5)

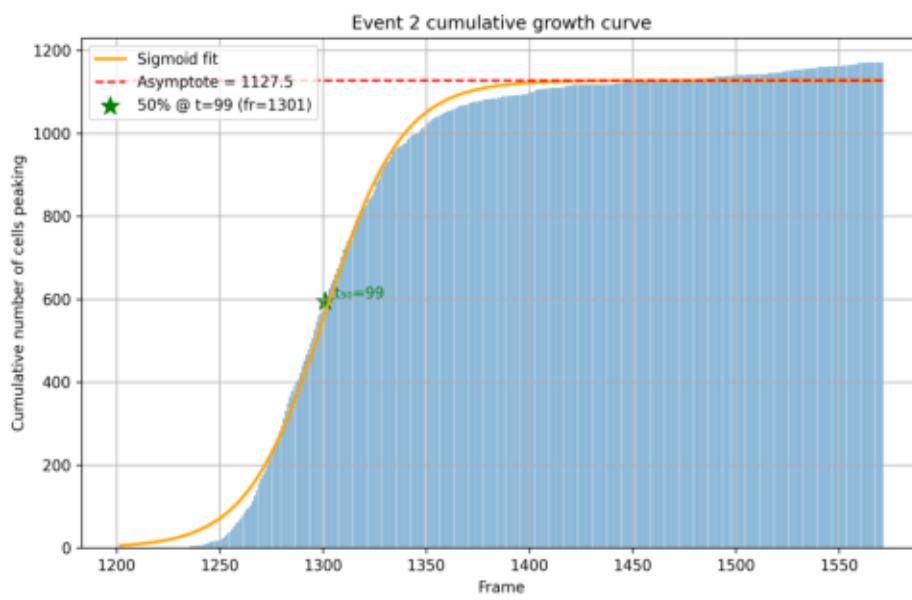


### 1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)



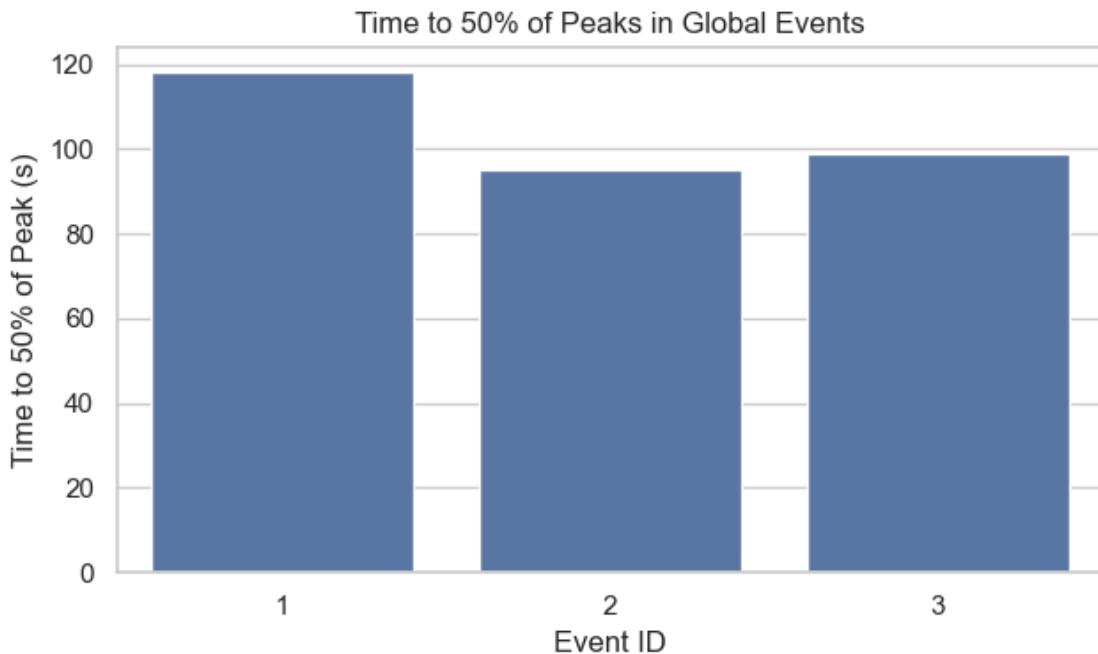
Event Activity Overlay (Event ID: 2)



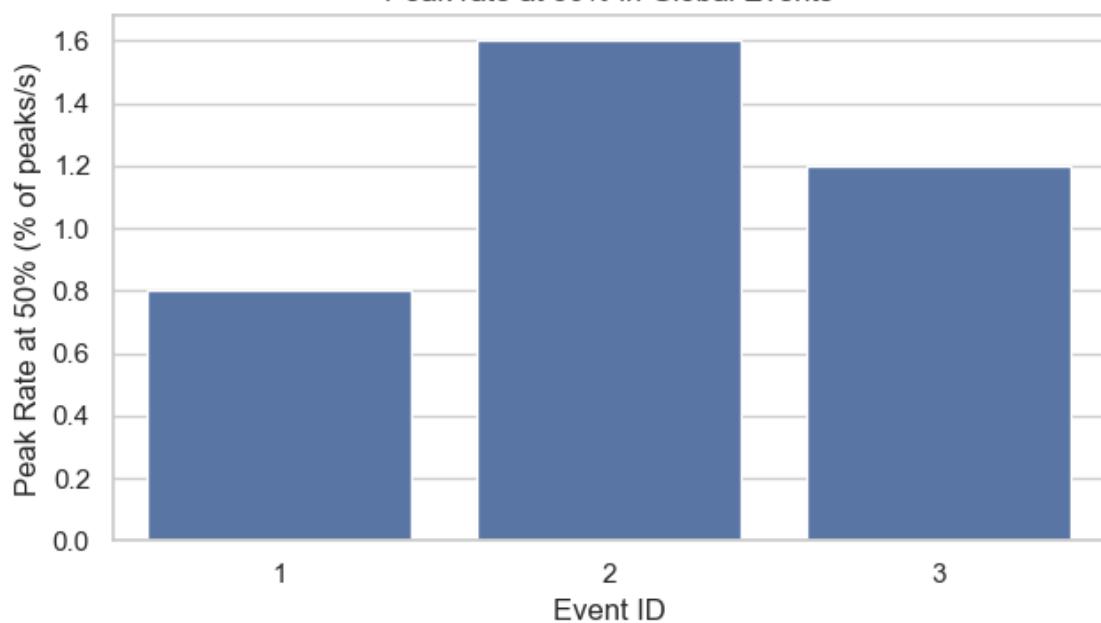
```

[2025-08-27 14:45:57] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS1\events\event-growth-curve-3.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250424\Output\IS1\events\event-growth-
curve-3.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\20250424\Output\IS1\events\event-growth-curve-3.png'

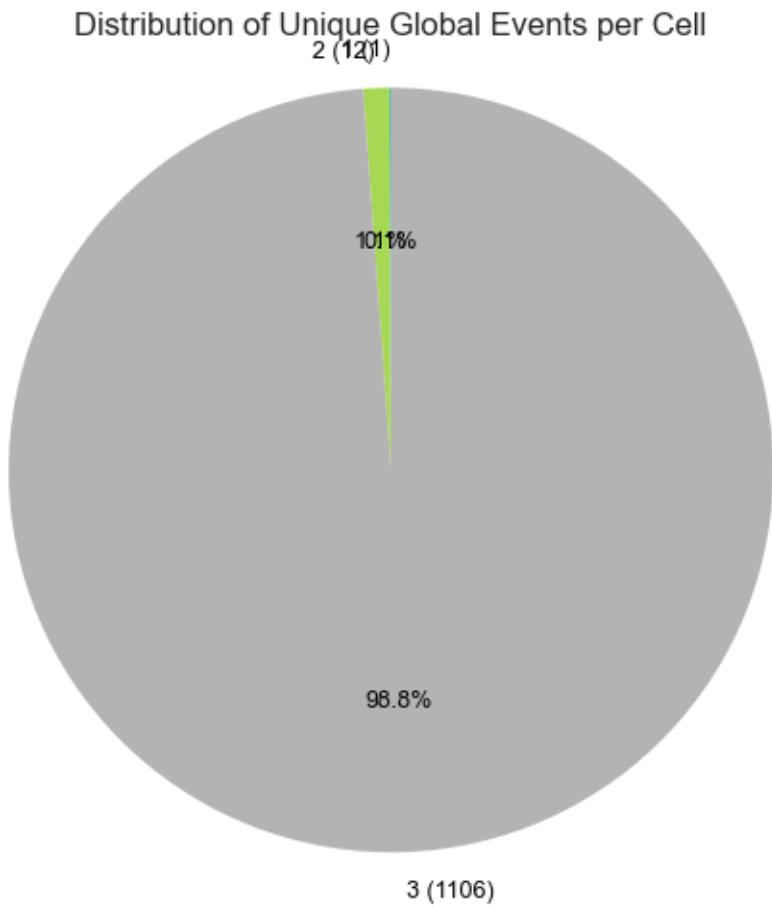
```



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

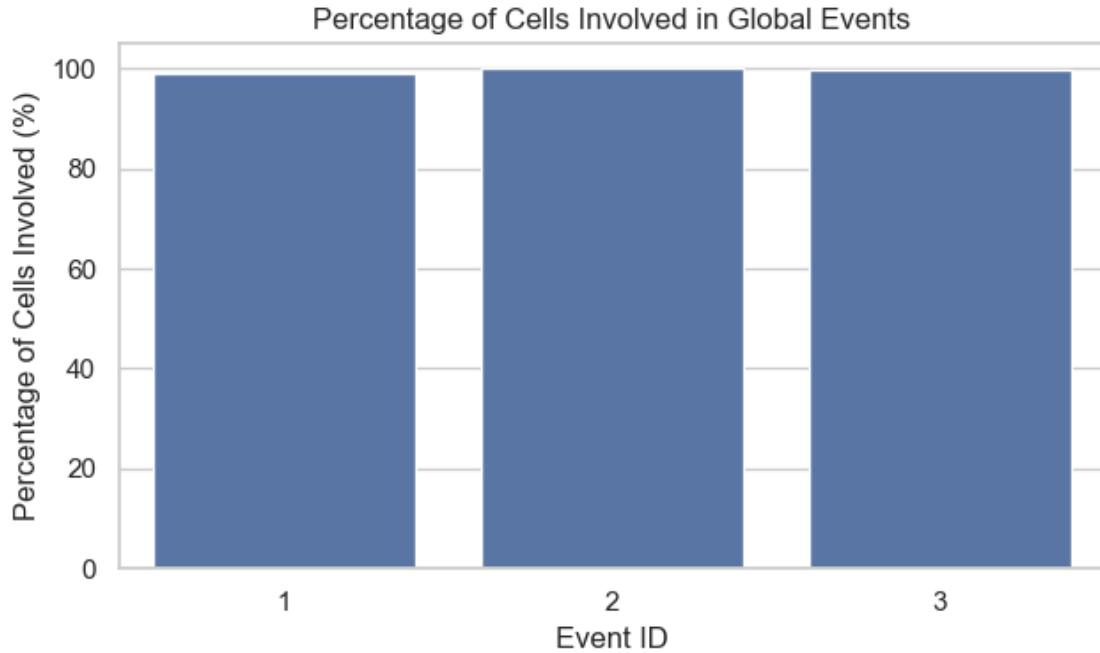


```
[2025-08-27 14:45:57] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS1\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250424\\\\Output\\\\IS1\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250424\Output\IS1\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [387.0, 433.0]

Estimated periodicity: 0.947

The global events exhibit a regular periodic pattern.

Estimated frequency (1/mean interval): 0.002 Hz

### 1.2.6 Early peakers in the events

```

[2025-08-27 14:45:58] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\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

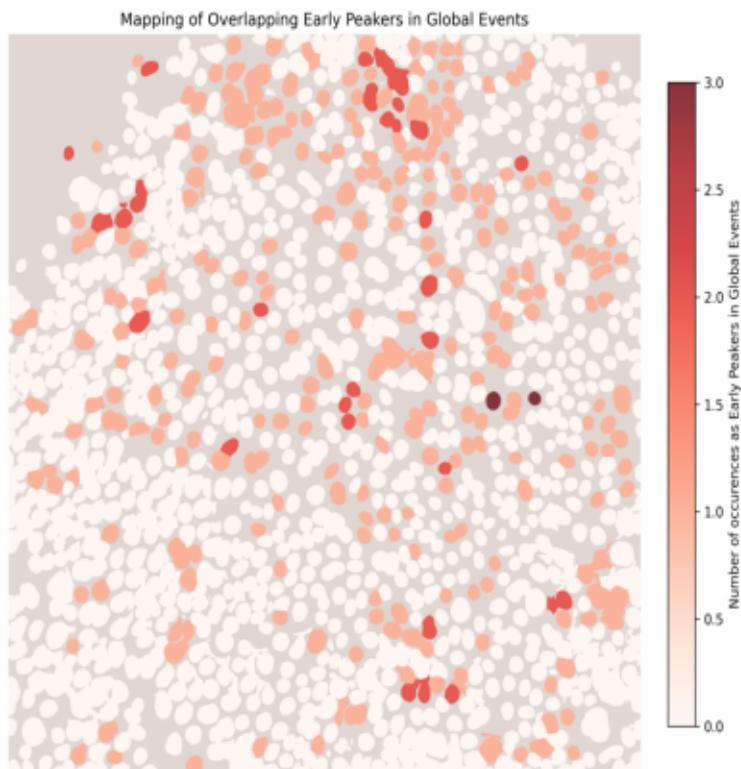
[2025-08-27 14:45:58] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS1\cell-mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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 14:45:58] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\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()

```

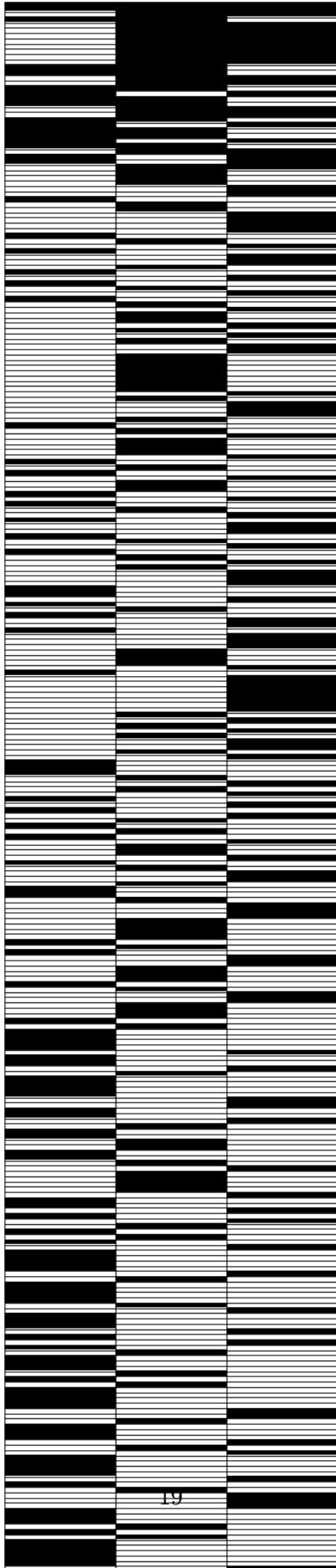
```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-  
packages\PIL\PngImagePlugin.py", line 757, in _open  
    raise SyntaxError(msg)  
SyntaxError: not a PNG file
```

## Cell Mapping with Occurrences in Global Events Overlay



```
[2025-08-27 14:45:59] [WARNING] calcium: 'total_events' is deprecated and  
ignored. Using 3 unique event IDs.
```

```
[2025-08-27 14:45:59] [INFO] calcium: Early peakers event-matrix: 298 cells x 3  
events; black squares: 332
```



[2025-08-27 14:46:00] [INFO] calcium: Saved early peakers heatmap SVG to: early\_peakers\_heatmap.svg



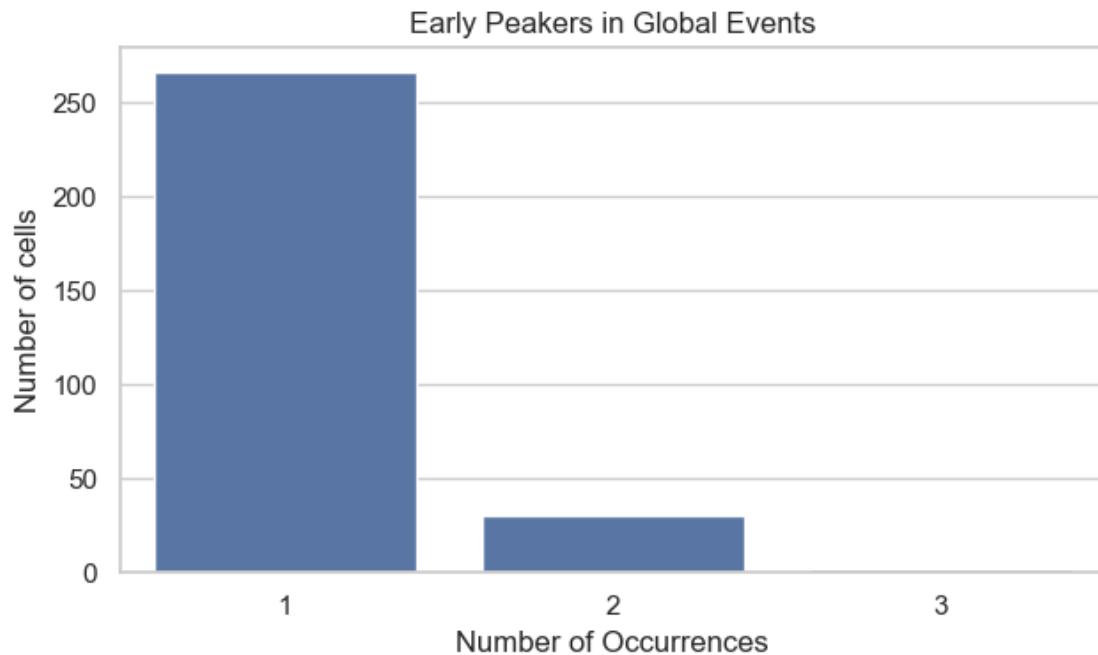




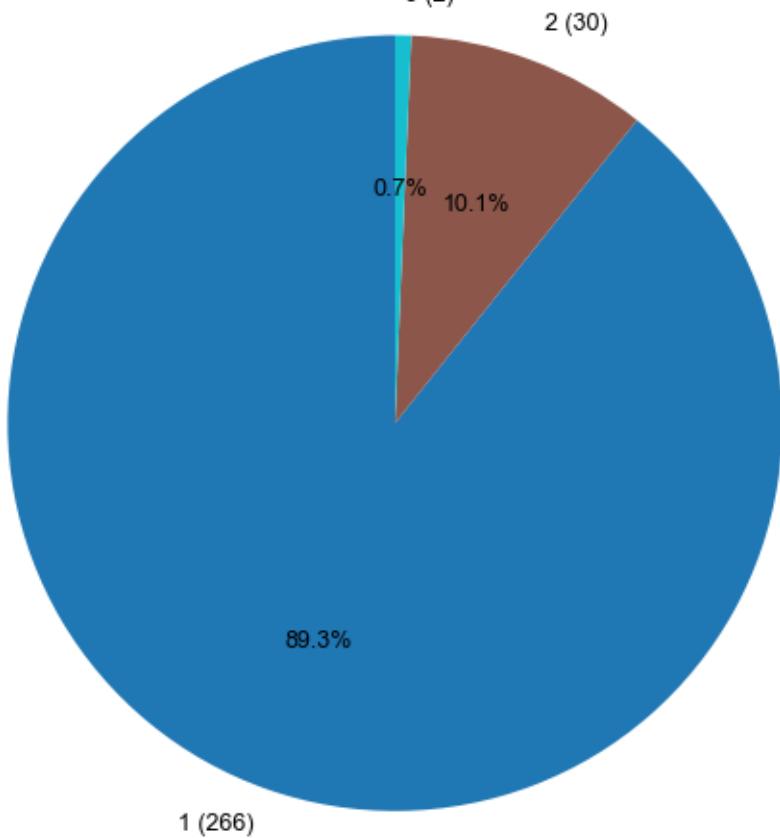
```
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```
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[1, 0, 0],  
[1, 0, 0],  
[1, 0, 0],  
[0, 0, 1]])
```

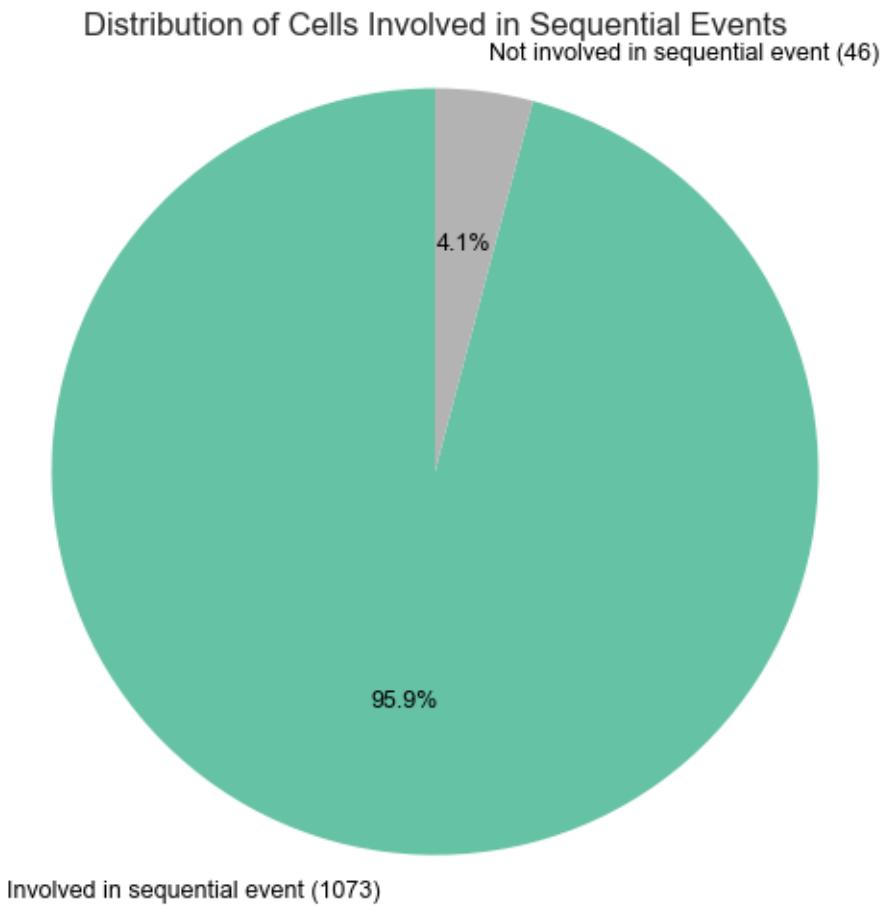


Distribution of Early Peakers in Global Events

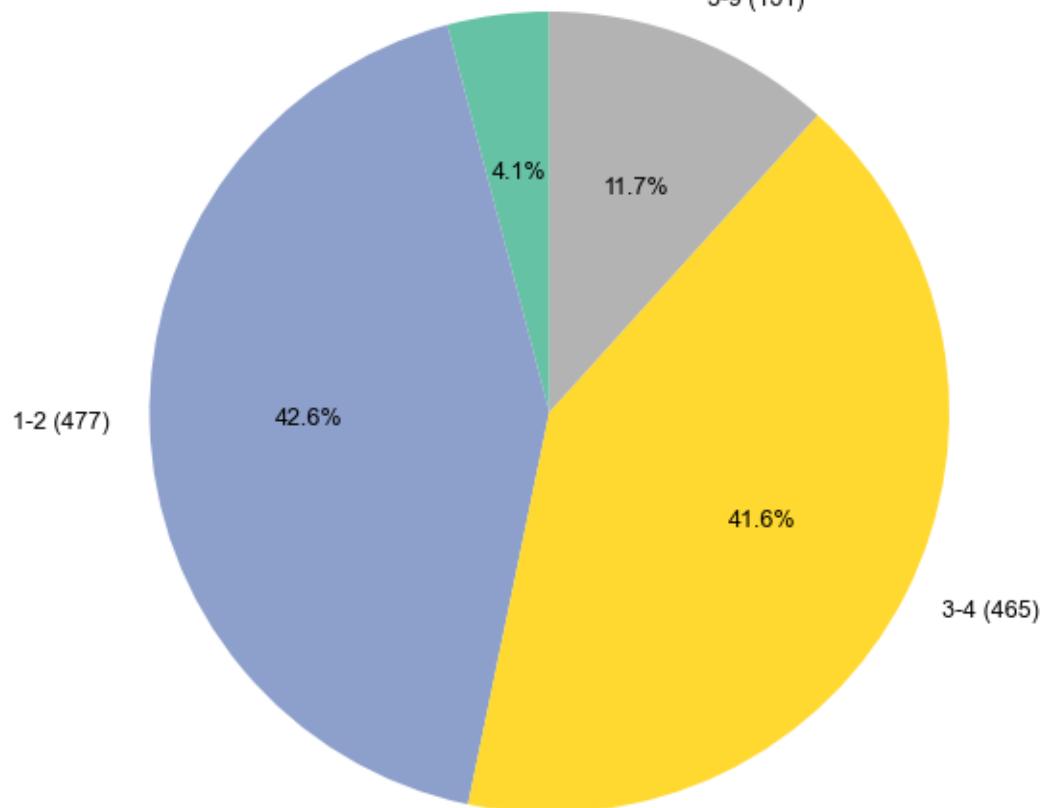


## 1.3 SEQUENTIAL EVENTS

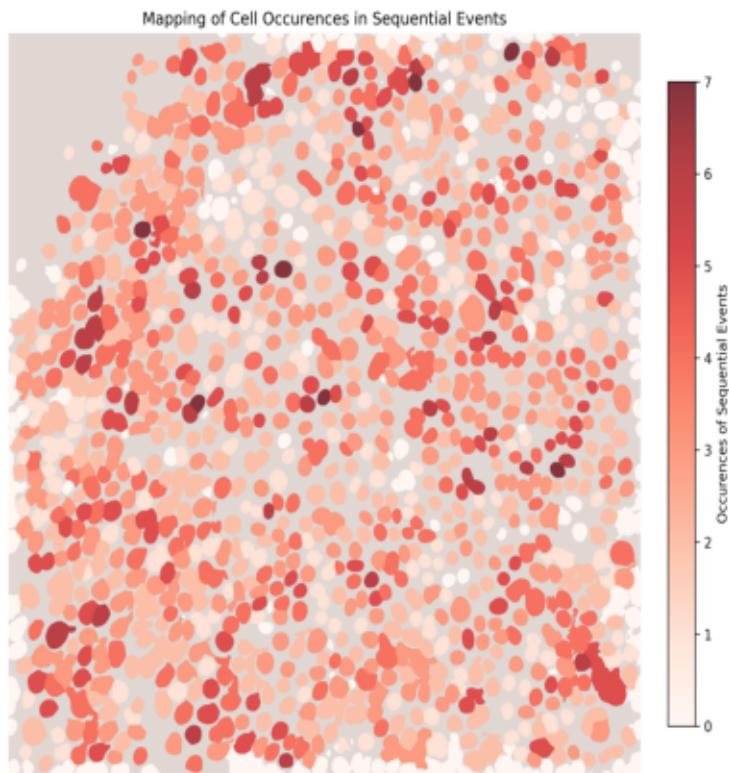
### 1.3.1 Cells Occurrences in sequential events



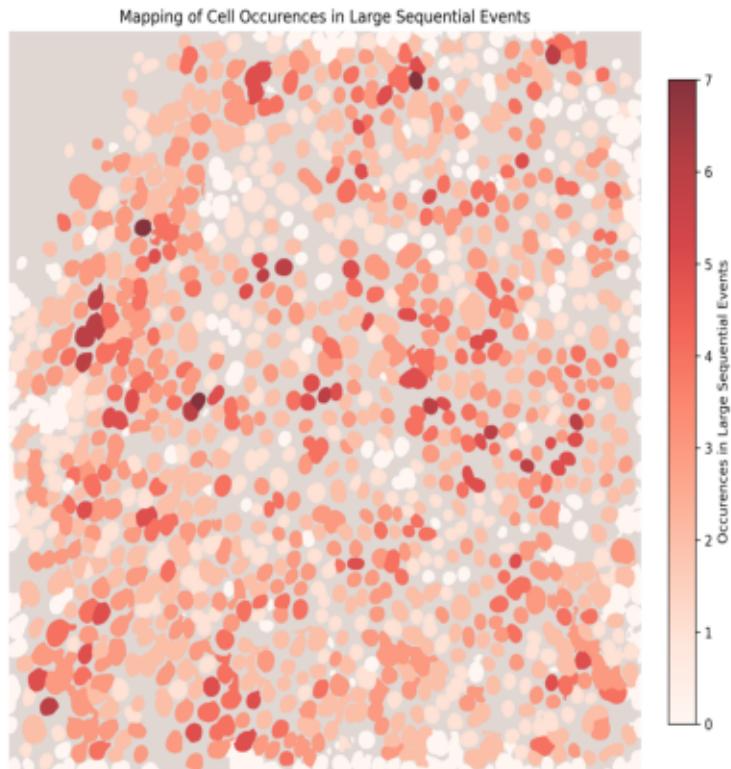
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

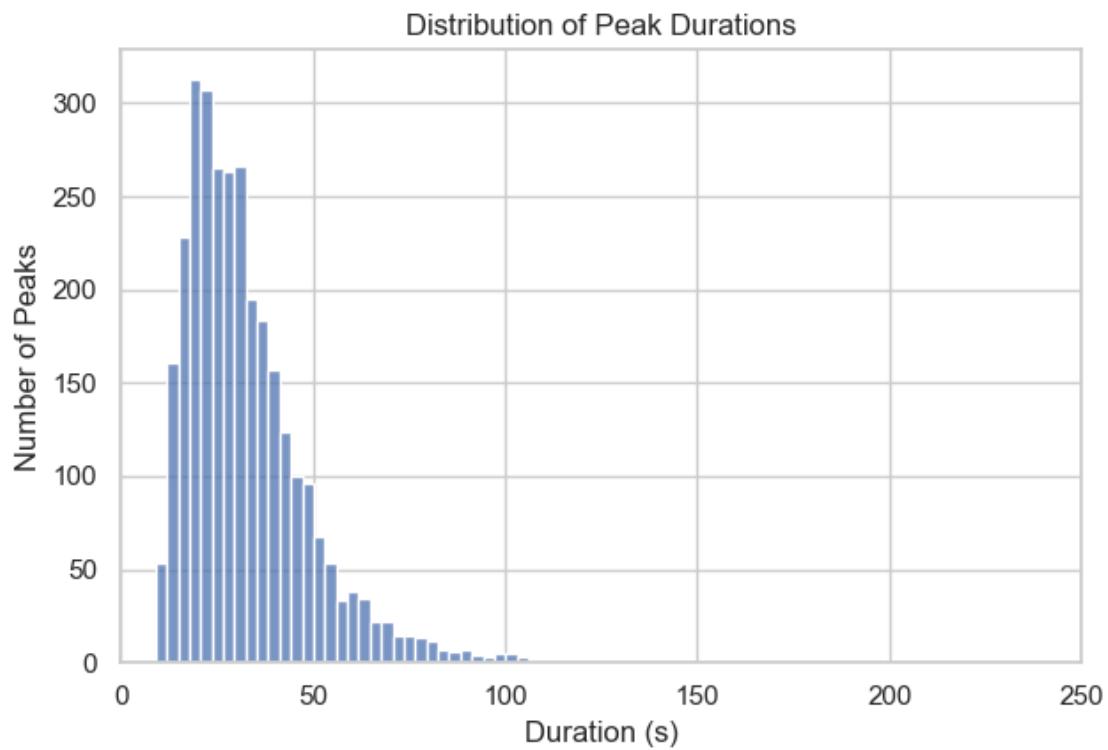


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

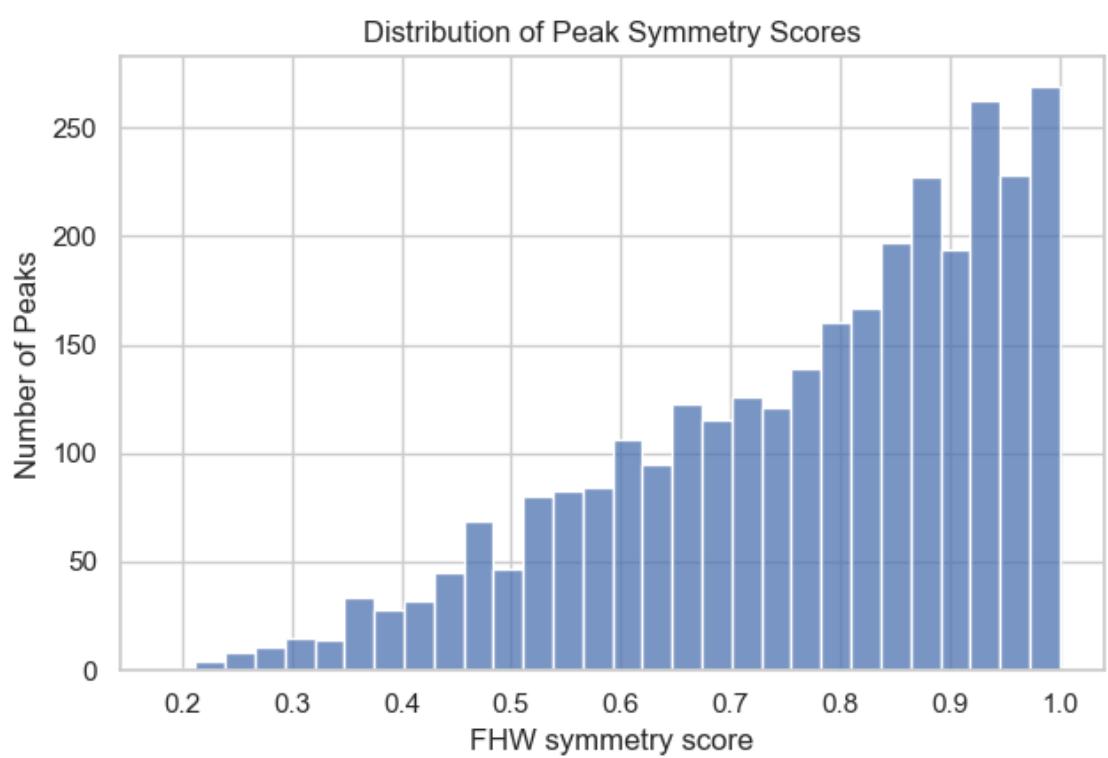
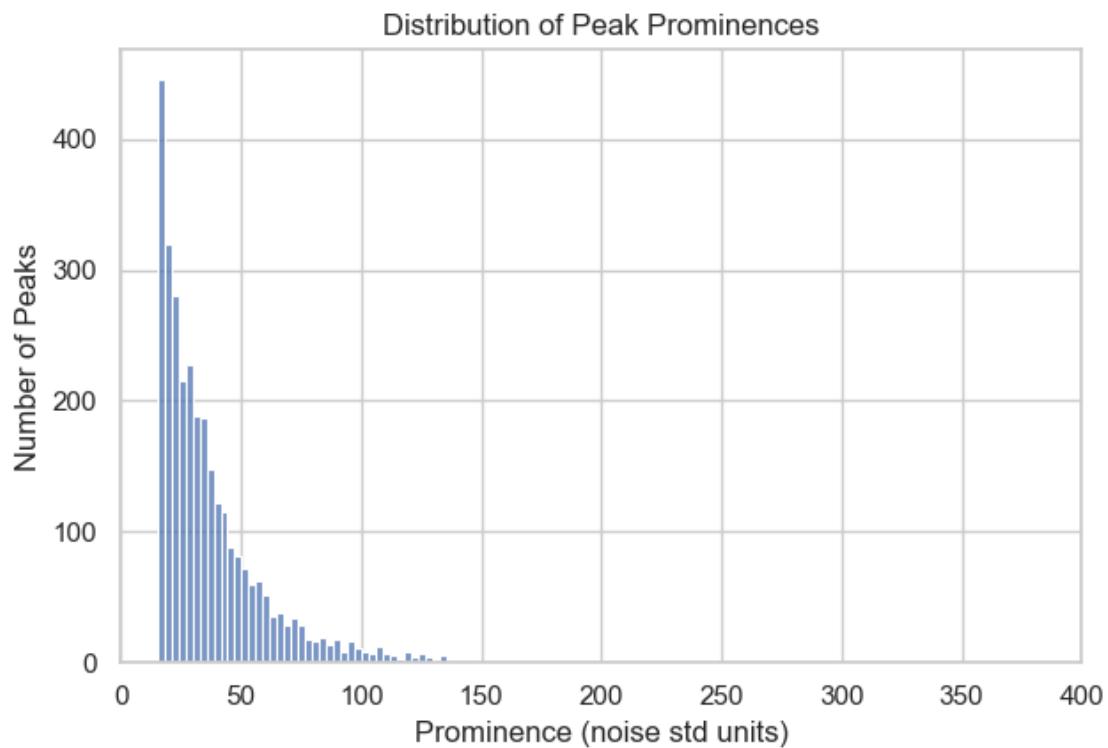


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:46:02] [INFO] calcium: plot_histogram: removed 9 outliers out of  
3084 on 'Duration (s)' (lower=-7.5, upper=106.5)
```

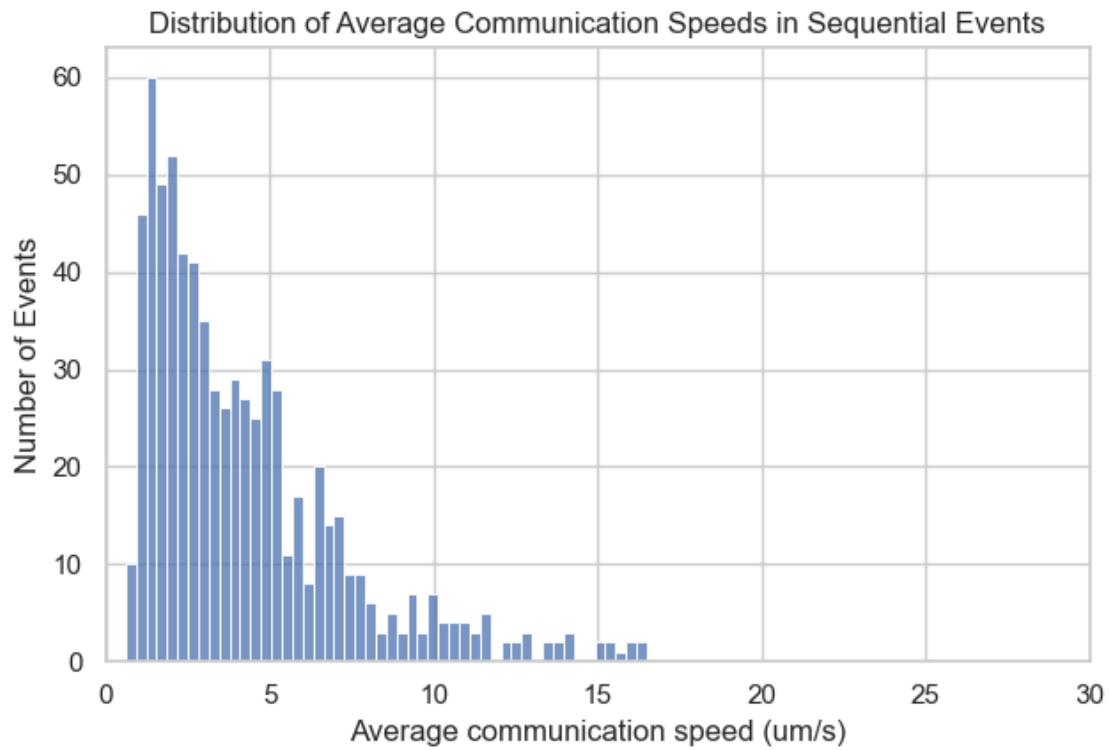


```
[2025-08-27 14:46:02] [INFO] calcium: plot_histogram: removed 54 outliers out of  
3084 on 'Prominence (noise std units)' (lower=-17.5, upper=136.1)
```



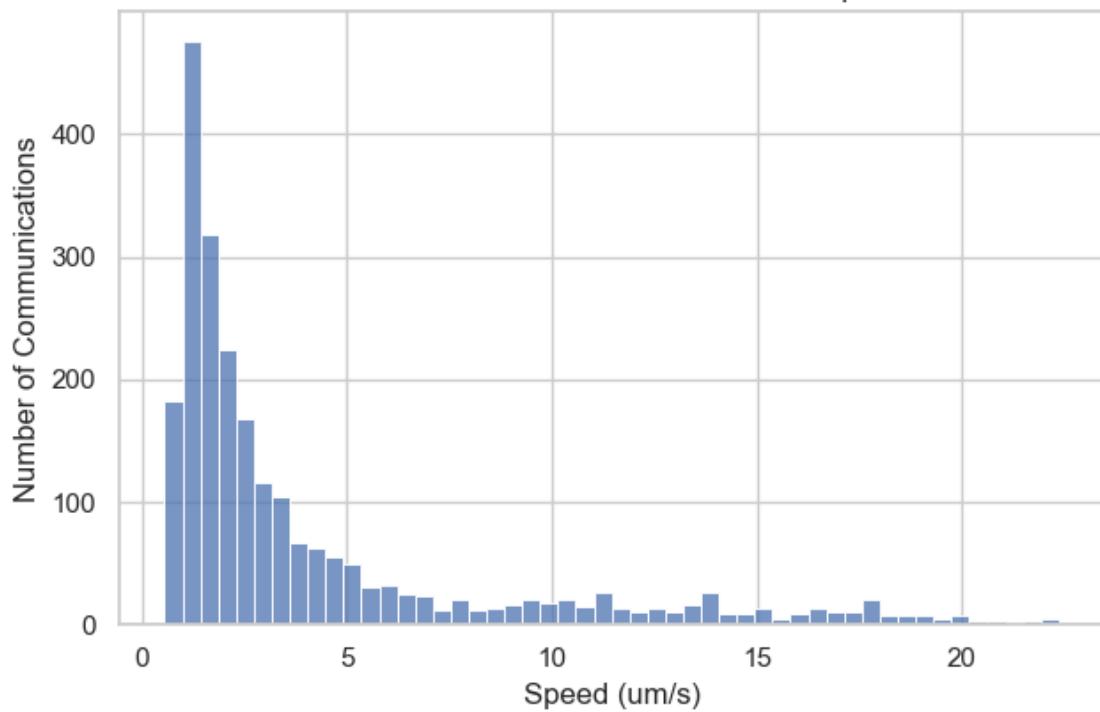
### 1.3.3 Cell-cell communication speed

[2025-08-27 14:46:03] [INFO] calcium: plot\_histogram: removed 8 outliers out of 717 on 'Average communication speed (um/s)' (lower=-8.97, upper=16.51)

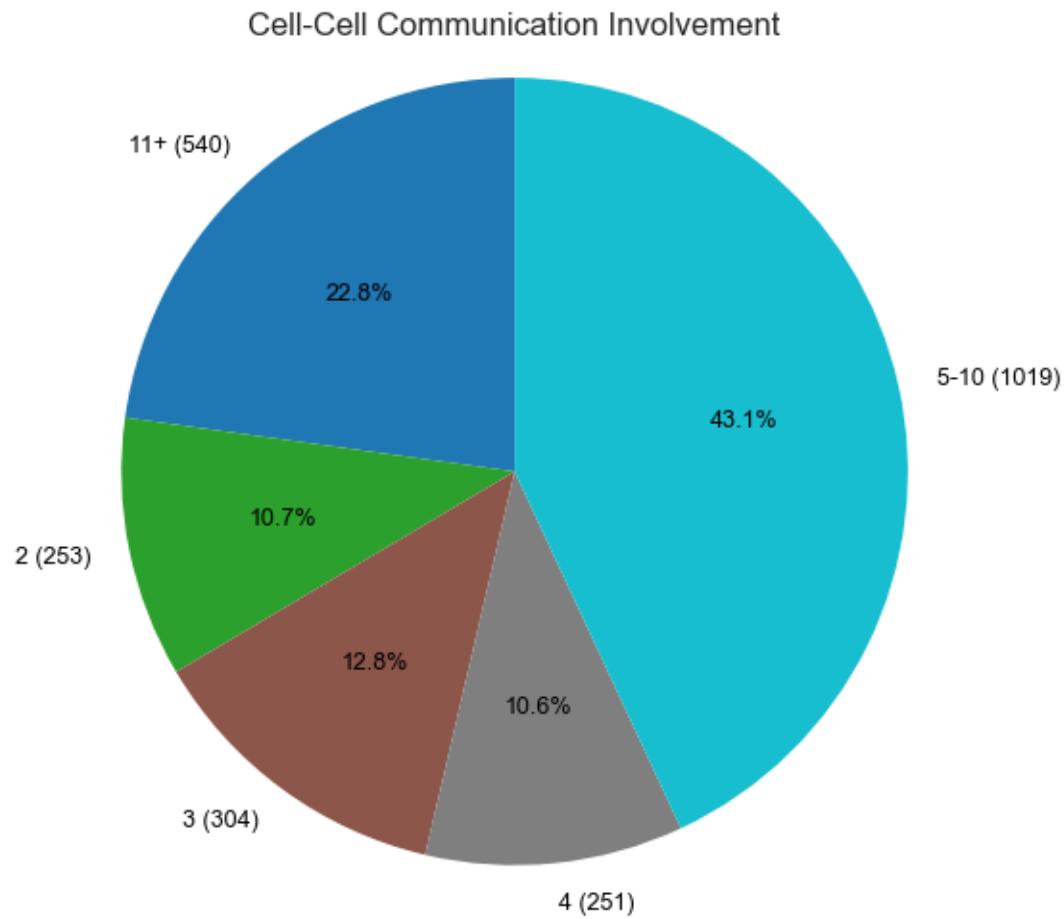


[2025-08-27 14:46:03] [INFO] calcium: plot\_histogram: removed 15 outliers out of 2367 on 'Speed (um/s)' (lower=-9.205, upper=22.52)

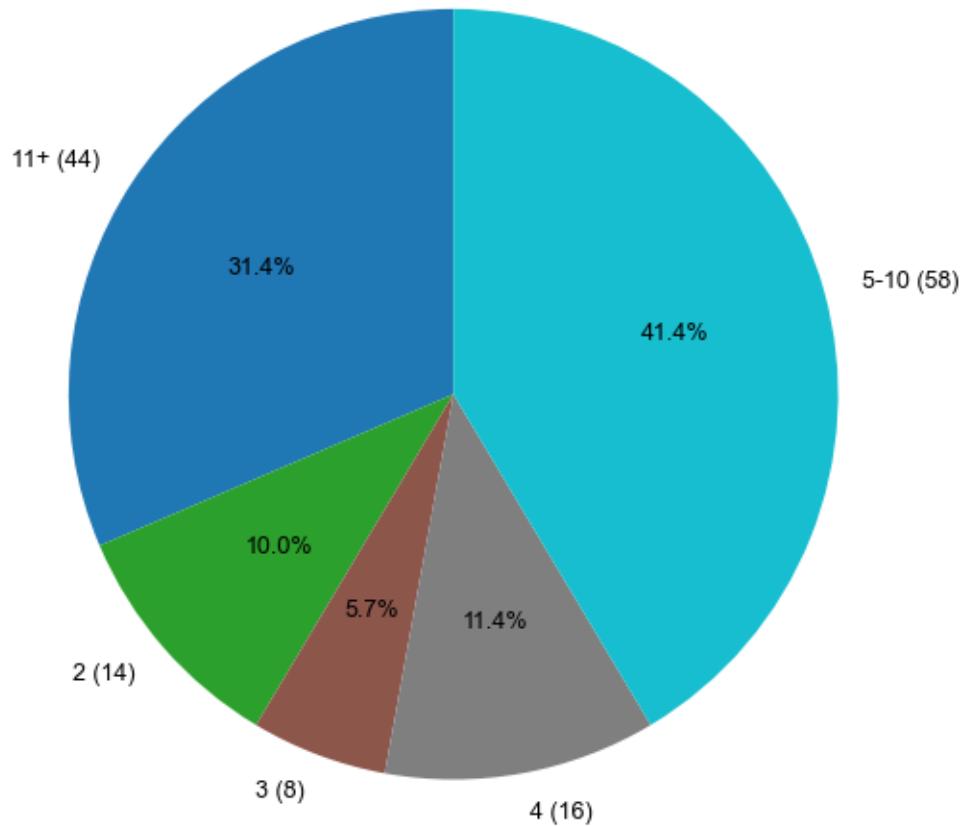
Distribution of Cell-Cell Communication Speeds



#### 1.3.4 Double distribution in cell-cell communication speeds

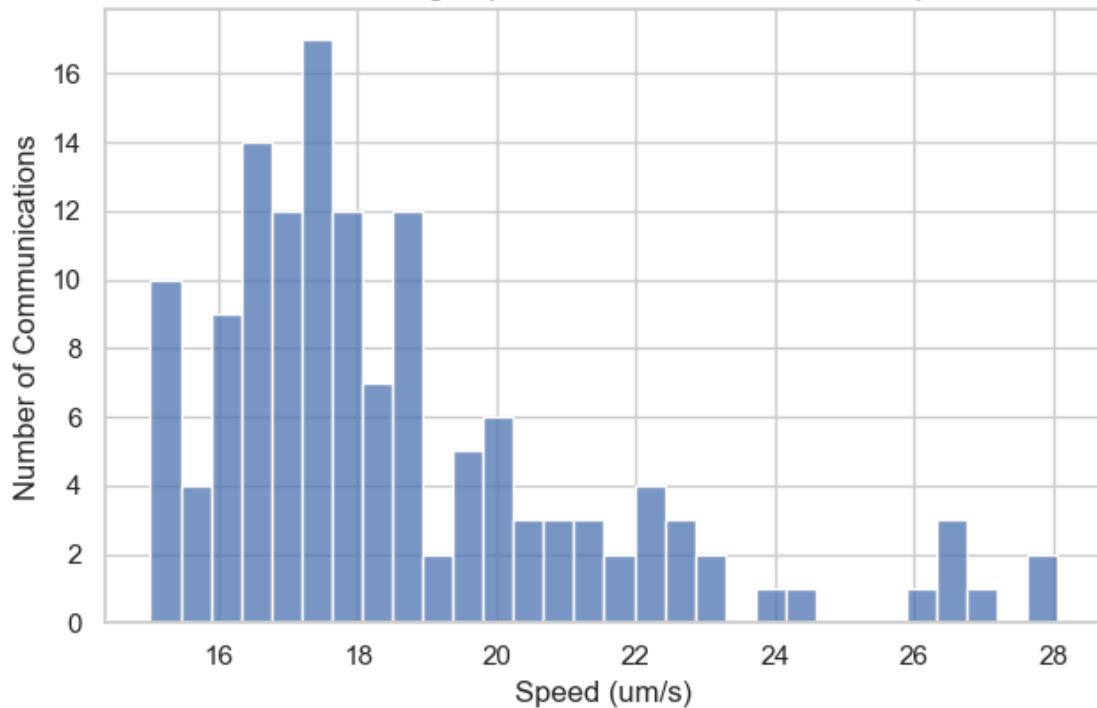


### High Speed Cell-Cell Communication Involvement

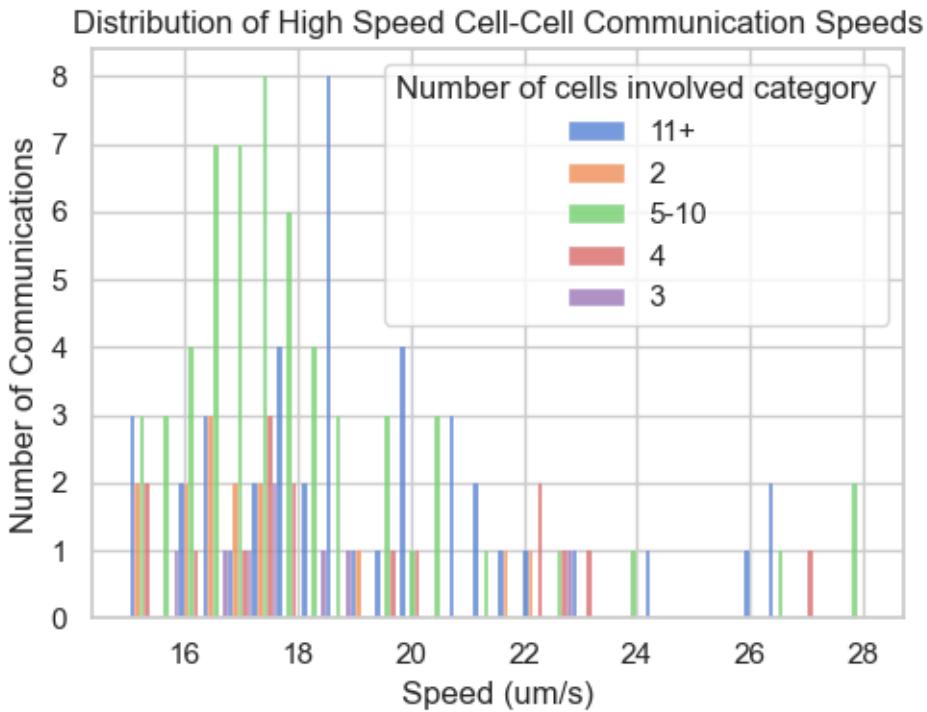


[2025-08-27 14:46:03] [INFO] calcium: plot\_histogram: removed 1 outliers out of 140 on 'Speed (um/s)' (lower=6.9625, upper=29.503)

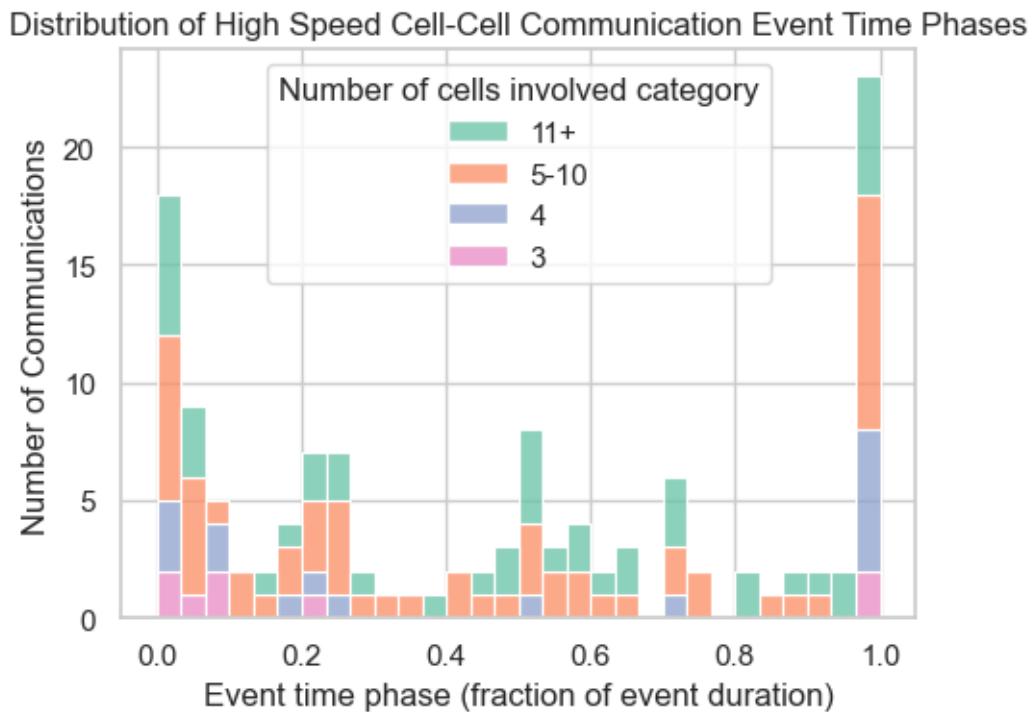
Distribution of High Speed Cell-Cell Communication Speeds



```
[2025-08-27 14:46:03] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 140 on 'Speed (um/s)' (lower=6.9625, upper=29.503)
```

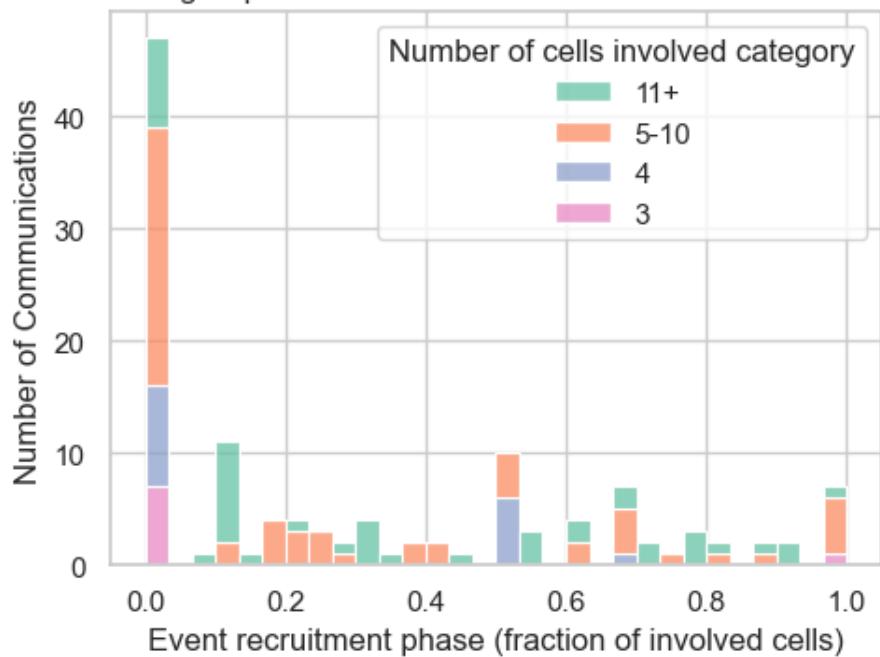


[2025-08-27 14:46:04] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 126 on 'Event time phase (fraction of event duration)' (lower=-2.04, upper=2.9475)

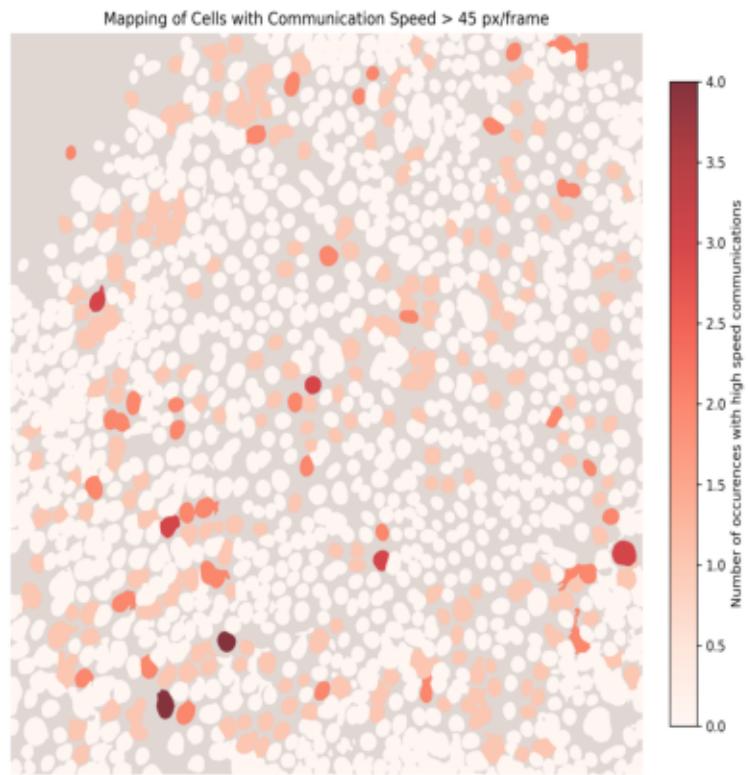


[2025-08-27 14:46:04] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 126 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.68, upper=2.24)

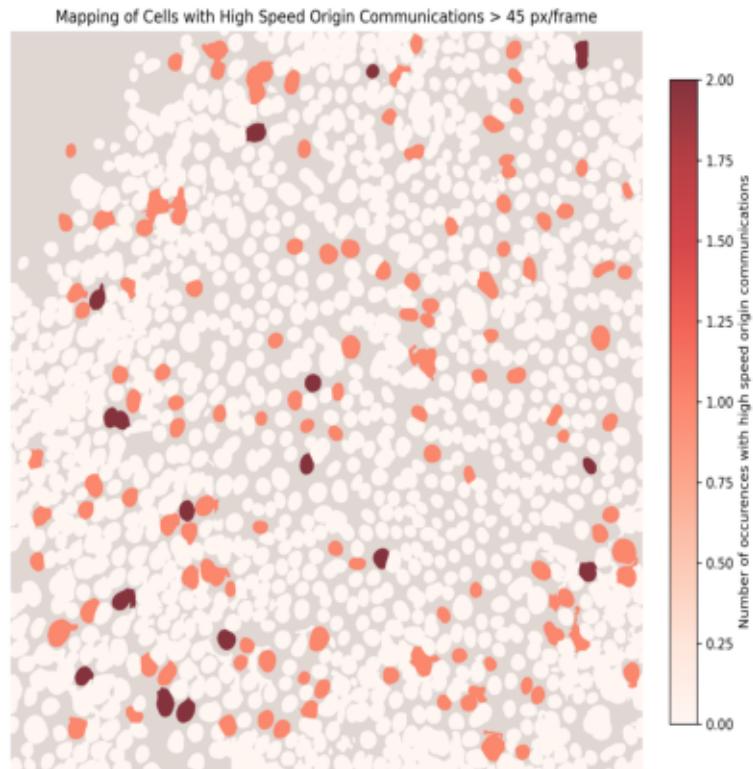
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	3015633520576	5	993		2
6	3015633522400	5	932		3
18	3015668256480	6	473		2
39	3015633520672	9	86		3
52	3015633534688	13	1447		1
...	...	...	...	...	...
2236	3015576737664	661	1437		3
2256	3015576737088	671	1402		6
2288	3015576734304	682	1418		0
2339	3015576736368	704	1445		0
2349	3015576741120	709	1490		0

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
5	932	3	169.0	169.0	
6	901	2	169.0	169.0	
18	433	1	209.0	209.0	
39	76	6	537.0	537.0	
52	1492	2	162.0	162.0	
...	...	...	...	...	
2236	1469	5	309.0	310.0	
2256	1382	7	1617.0	1618.0	
2288	1405	0	18.0	19.0	
2339	1475	1	56.0	57.0	
2349	1476	1	90.0	91.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
5	0.0	17.80	17.80		
6	0.0	16.28	16.28		
18	0.0	17.68	17.68		
39	0.0	16.44	16.44		
52	0.0	16.96	16.96		
...	...	...	...	...	
2236	1.0	17.95	17.95		
2256	1.0	16.86	16.86		
2288	1.0	16.79	16.79		
2339	1.0	18.75	18.75		
2349	1.0	17.19	17.19		
	Event time phase (fraction of event duration)	\			
5		1.00			
6		1.00			
18		0.55			
39		NaN			
52		0.65			
...		...			
2236		1.00			
2256		NaN			
2288		0.09			
2339		0.06			
2349		0.20			
	Event recruitment phase (fraction of involved cells)	dataset	\		
5		0.78	20250424_IS1		
6		0.78	20250424_IS1		
18		0.56	20250424_IS1		
39		NaN	20250424_IS1		
52		0.43	20250424_IS1		
...		...	...		
2236		1.00	20250424_IS1		
2256		NaN	20250424_IS1		

2288		0.00	20250424_IS1
2339		0.00	20250424_IS1
2349		0.00	20250424_IS1

Number of cells involved		category	Speed category
5		11+	High speed
6		11+	High speed
18		11+	High speed
39		2	High speed
52		5-10	High speed
...		...	...
2236		5-10	High speed
2256		2	High speed
2288		3	High speed
2339		3	High speed
2349		4	High speed

[140 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
73		0	1
74		0	2
75		0	1
78		0	4
79		0	1
...	...	...	...
1500		0	2
1502		0	2
1503		0	2
1504		0	1
1506		0	2

[871 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	73	367.57	6.17
1	74	138.45	6.50
2	75	283.07	6.50
5	78	435.50	7.15
6	79	320.12	8.12
...	...	...	...
1112	1500	237.25	488.80
1114	1502	218.72	489.45
1115	1503	368.23	489.78
1116	1504	414.70	489.12
1117	1506	28.93	491.40

Number of peaks Is active Occurrences in global events \

0	9	True	3
1	5	True	3
2	9	True	3
5	9	True	3
6	6	True	3
...	...	...	...
1112	10	True	3
1114	9	True	3
1115	6	True	3
1116	8	True	3
1117	5	True	3

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

0	0	[]
1	0	[]
2	1	[2]
5	0	[]
6	1	[3]
...	...	...
1112	0	[]
1114	0	[]
1115	0	[]
1116	0	[]
1117	0	[]

Occurrences in sequential events \

0	2
1	2
2	2
5	4
6	2
...	...
1112	3
1114	6
1115	2
1116	3
1117	2

Occurrences in sequential events as origin \

0	1
1	0
2	1
5	1
6	0
...	...
1112	0
1114	2
1115	1

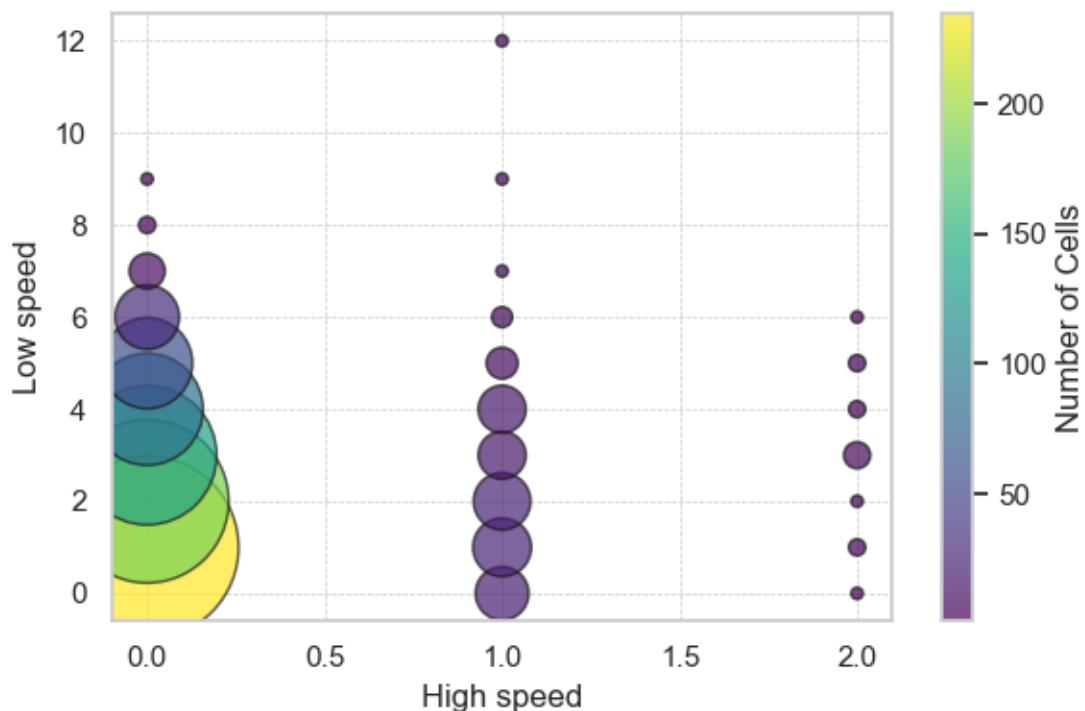
1116		1	
1117		1	
Occurrences in individual events Peak frequency (Hz) \			
0	4	0.0053	
1	0	0.0029	
2	2	0.0053	
5	1	0.0053	
6	0	0.0035	
...	...	...	
1112	3	0.0059	
1114	0	0.0053	
1115	1	0.0035	
1116	2	0.0047	
1117	0	0.0029	
Periodicity score Neighbor count Neighbors (labels) dataset \			
0	0.62	3	[82, 94, 99] 20250424_IS1
1	0.66	5	[86, 93, 97, 100, 105] 20250424_IS1
2	0.68	2	[95, 104] 20250424_IS1
5	0.62	3	[88, 90, 92] 20250424_IS1
6	0.60	4	[80, 89, 98, 108] 20250424_IS1
...	...	...	...
1112	0.46	3	[1470, 1480, 1502] 20250424_IS1
1114	0.49	4	[1465, 1480, 1486, 1500] 20250424_IS1
1115	0.61	2	[1463, 1479] 20250424_IS1
1116	0.58	2	[1476, 1490] 20250424_IS1
1117	0.68	4	[1450, 1456, 1483, 1487] 20250424_IS1
Involved in sequential event Occurrences in sequential events category \			
0	Involved in sequential event		1-2
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
...	...	...	...
1112	Involved in sequential event		3-4
1114	Involved in sequential event		5-9
1115	Involved in sequential event		1-2
1116	Involved in sequential event		3-4
1117	Involved in sequential event		1-2
High speed Low speed			
0	0.0	1.0	
1	0.0	2.0	
2	0.0	1.0	
5	0.0	4.0	
6	0.0	1.0	

```

...
1112      0.0      2.0
1114      0.0      2.0
1115      0.0      2.0
1116      0.0      1.0
1117      0.0      2.0

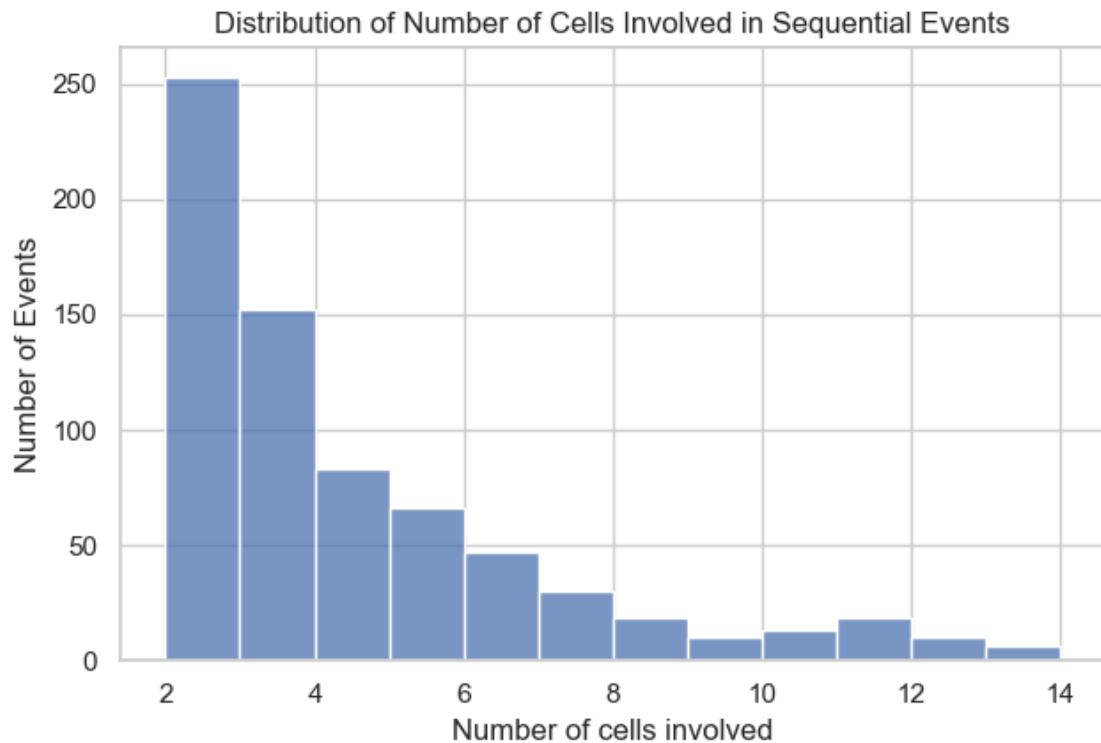
```

[871 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

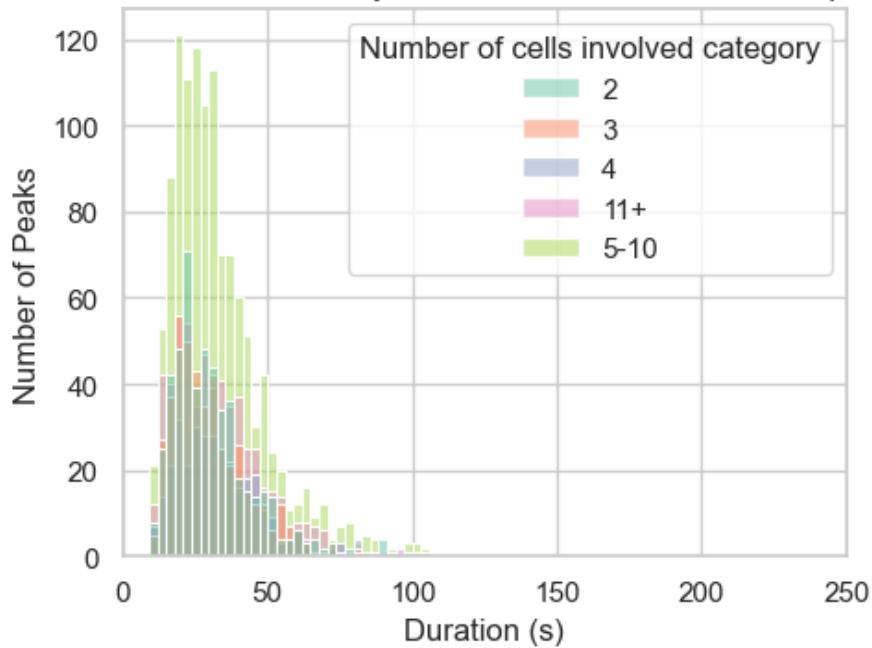
[2025-08-27 14:46:06] [INFO] calcium: plot\_histogram: removed 9 outliers out of 717 on 'Number of cells involved' (lower=-7, upper=14)



### 1.3.6 Influence of cell count per event on statistics

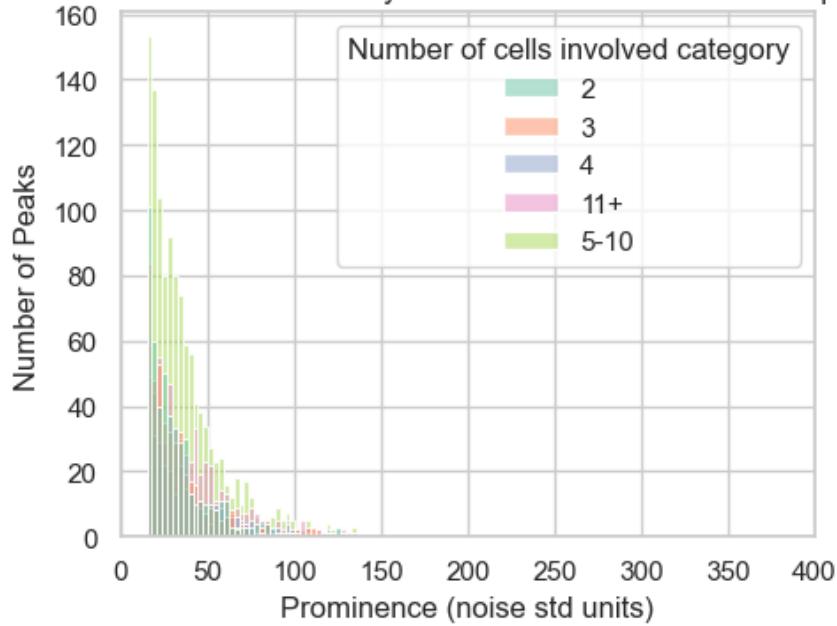
```
[2025-08-27 14:46:07] [INFO] calcium: plot_histogram_by_group: removed 9
outliers out of 3084 on 'Duration (s)' (lower=-7.5, upper=106.5)
```

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

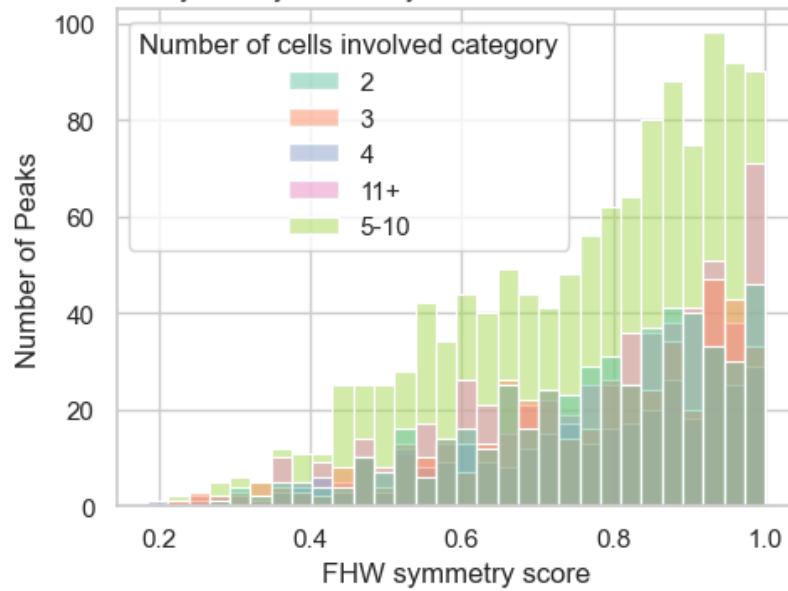


[2025-08-27 14:46:07] [INFO] calcium: plot\_histogram\_by\_group: removed 54 outliers out of 3084 on 'Prominence (noise std units)' (lower=-17.5, upper=136.1)

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

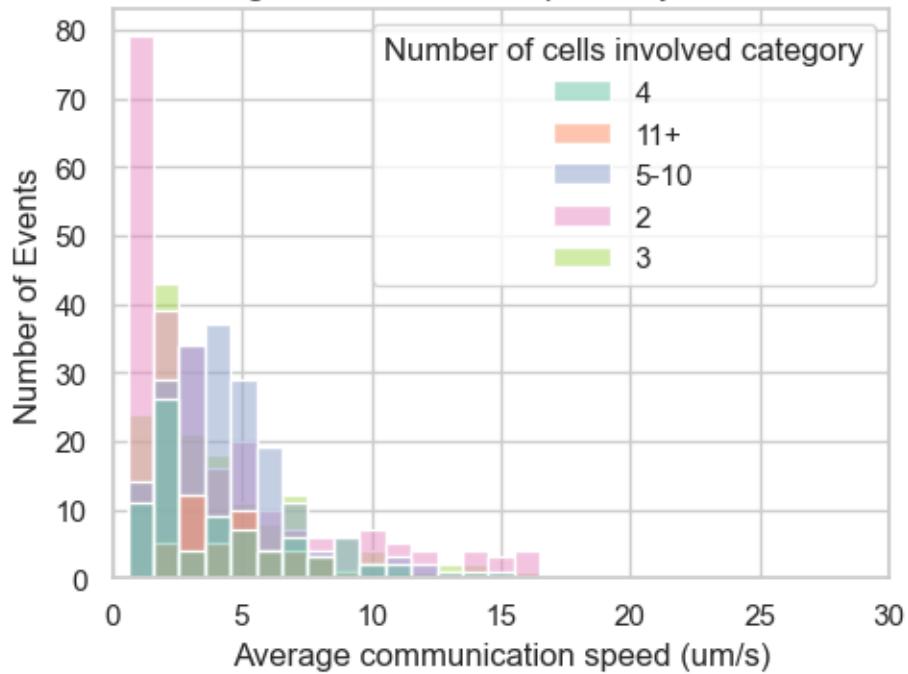


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

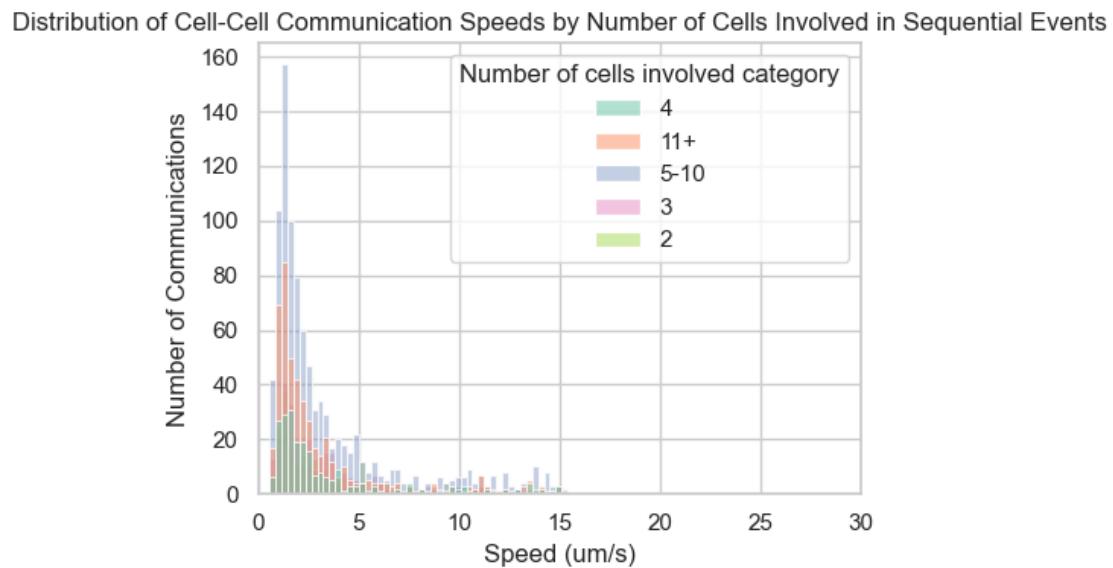


```
[2025-08-27 14:46:08] [INFO] calcium: plot_histogram_by_group: removed 8 outliers out of 717 on 'Average communication speed (um/s)' (lower=-8.97, upper=16.51)
```

Distribution of Average Communication Speeds by Number of Cells Involved

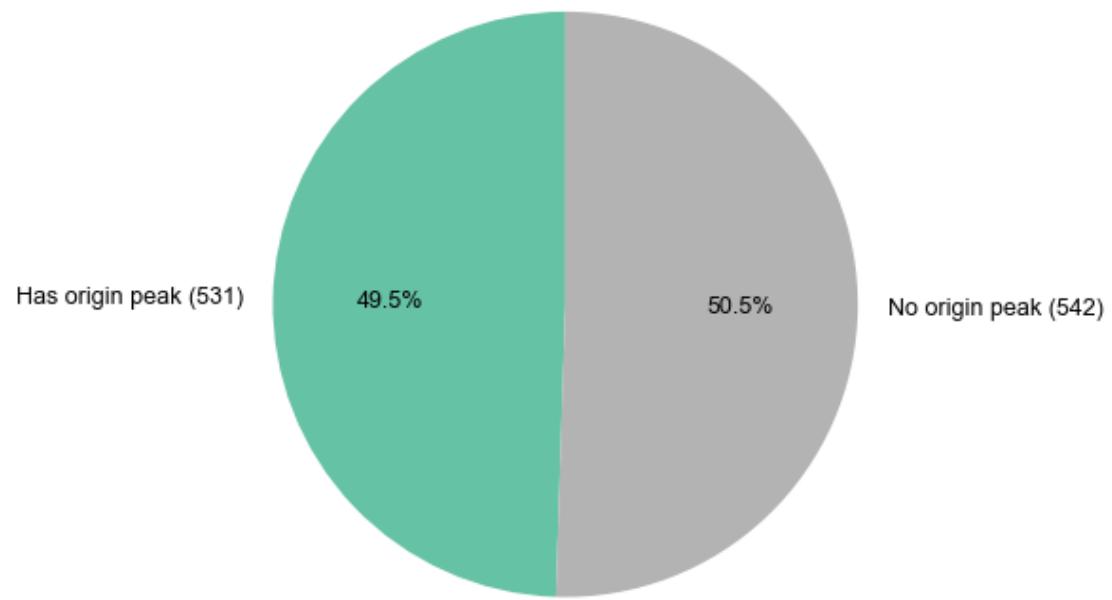


[2025-08-27 14:46:08] [INFO] calcium: plot\_histogram\_by\_group: removed 130 outliers out of 2367 on 'Speed (um/s)' (lower=-9.205, upper=15.47)

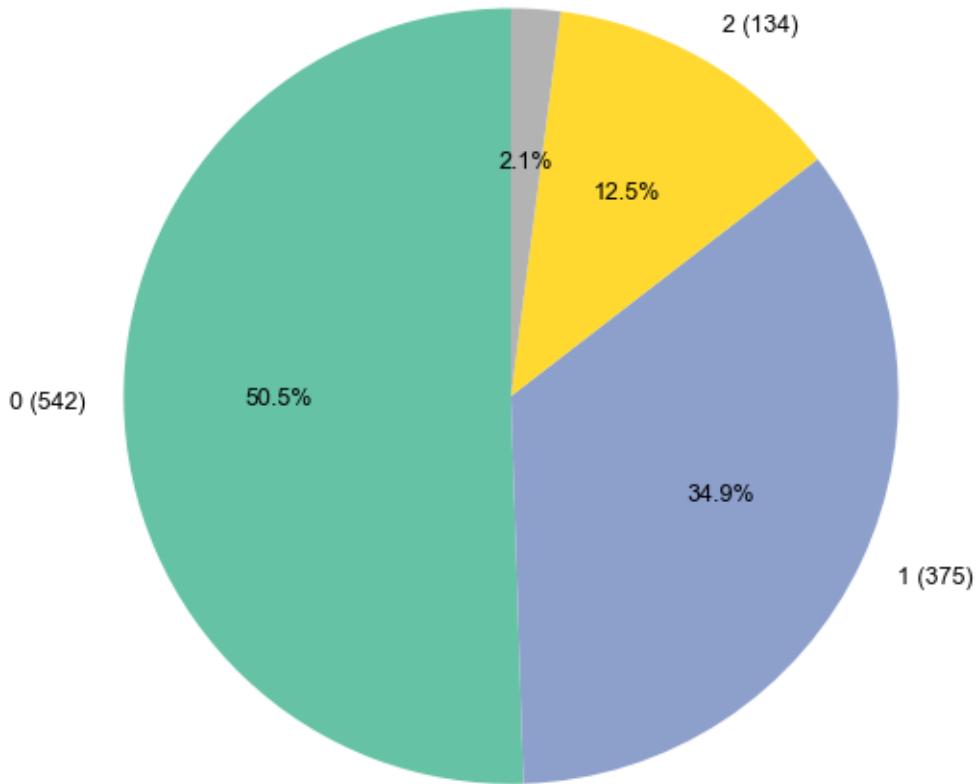


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

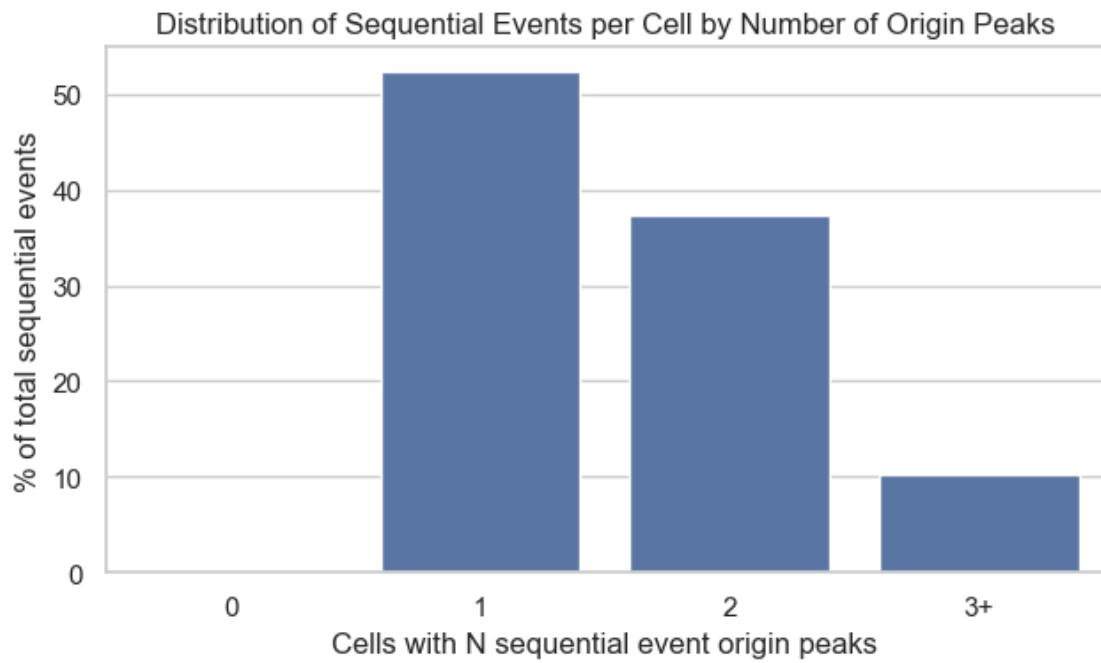


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



```
[2025-08-27 14:46:08] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS1\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\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:
```

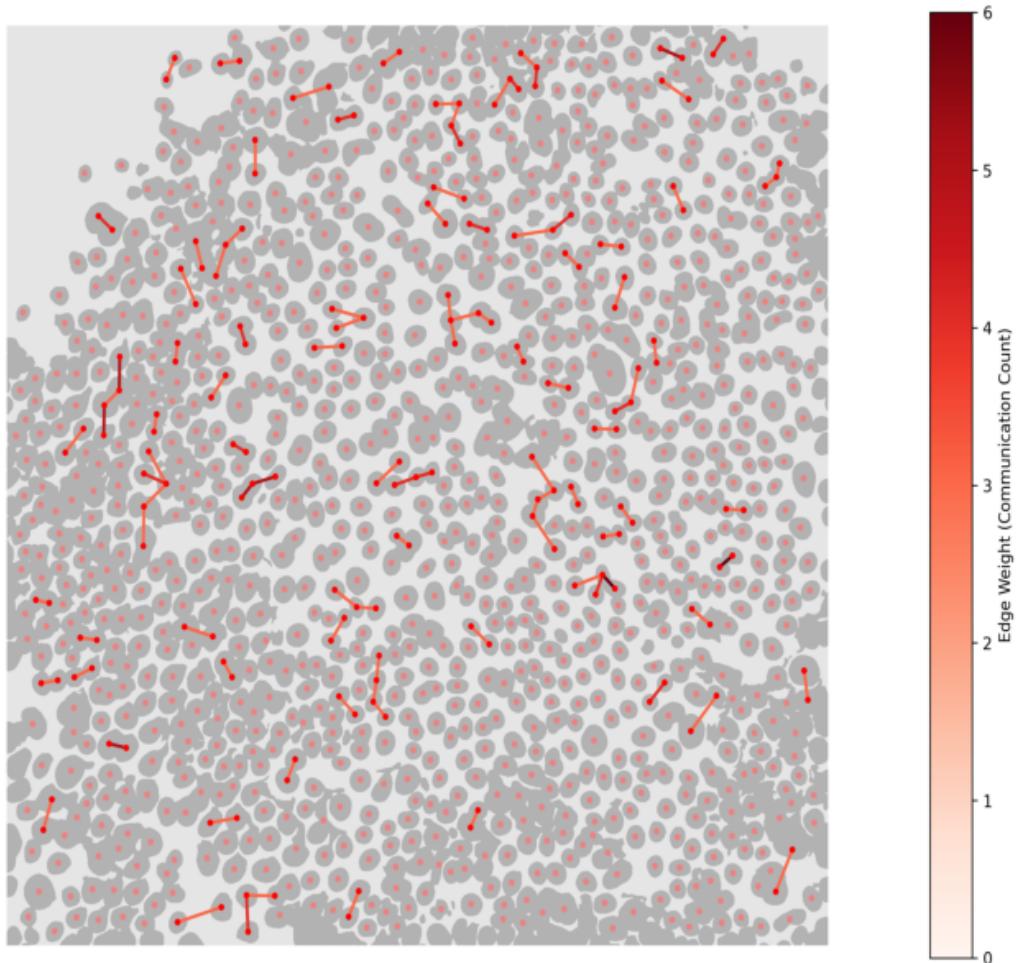
'D:\\Mateo\\20250424\\Output\\IS1\\cell-mapping\\cell\_Occurrences\_in\_origin\_seq\_events\_overlay.png'



### 1.3.8 Connection network between cells

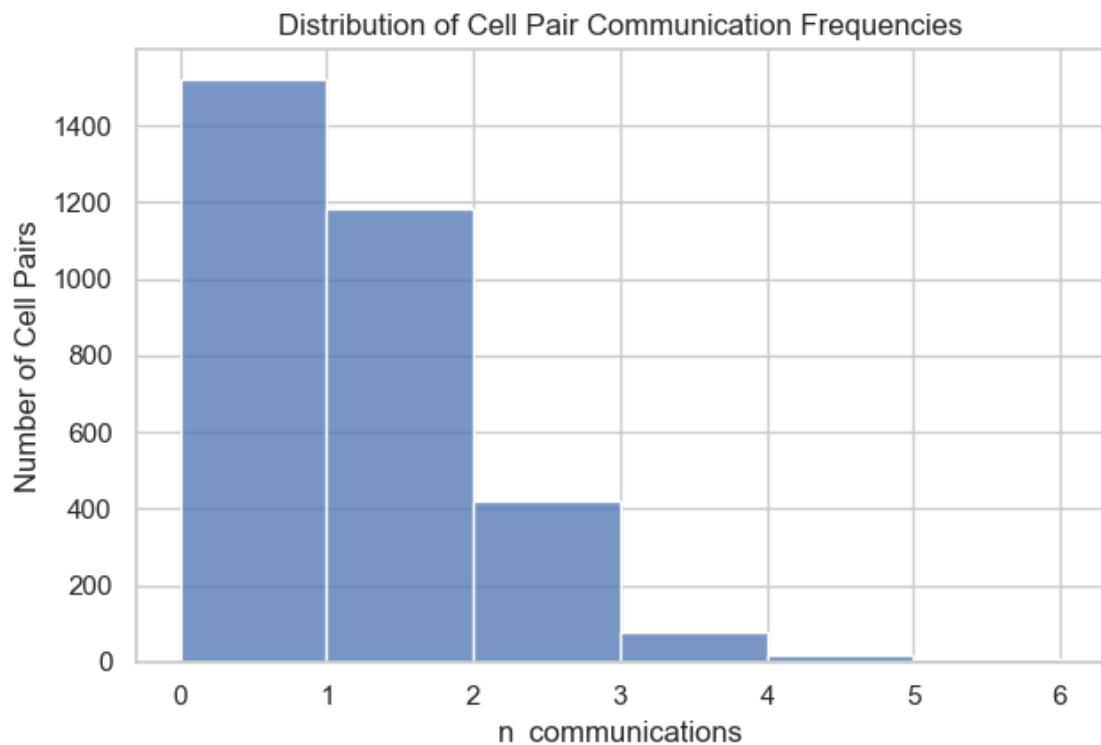
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



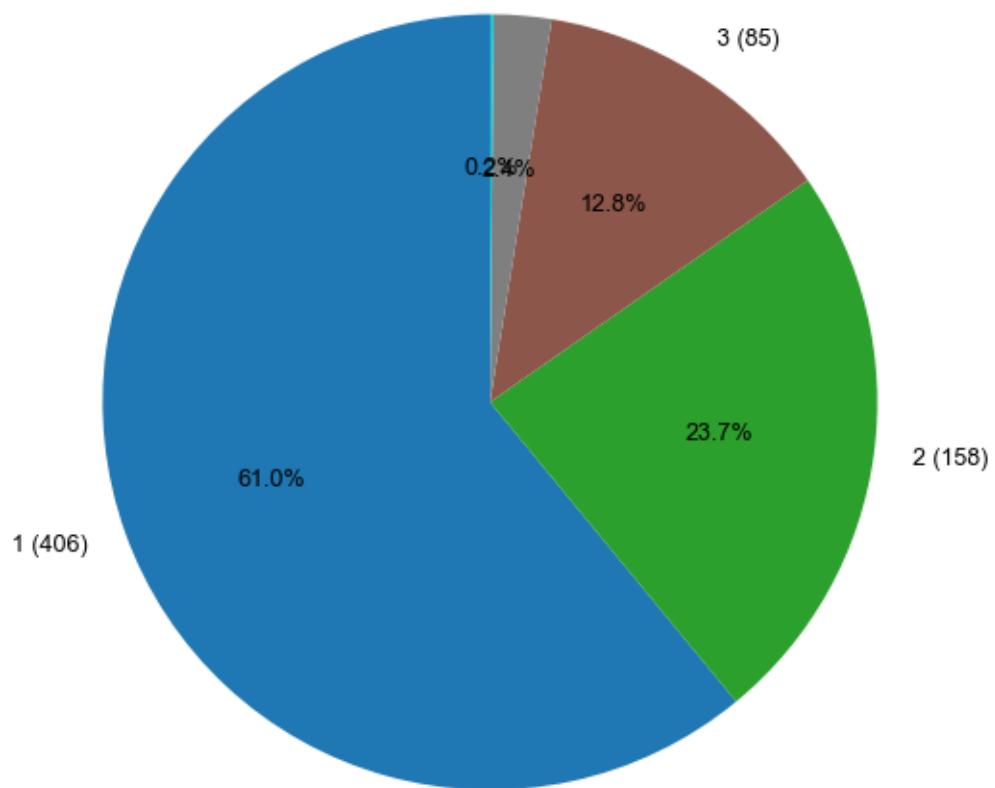
### 1.3.9 Pair/Trios with high communication networks

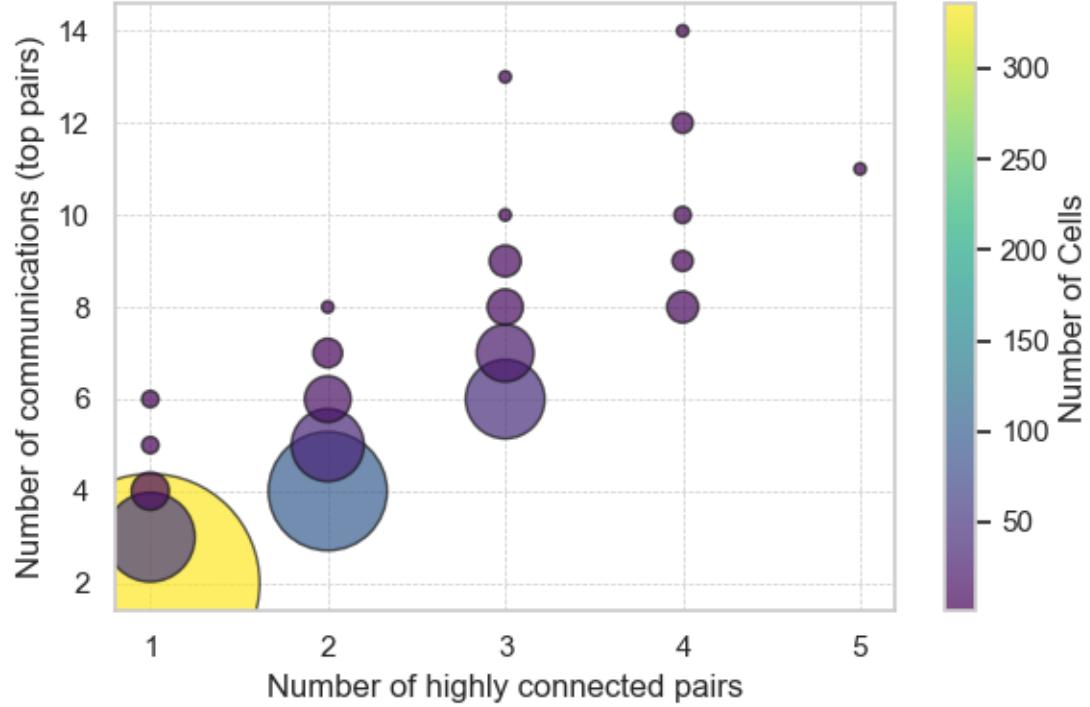
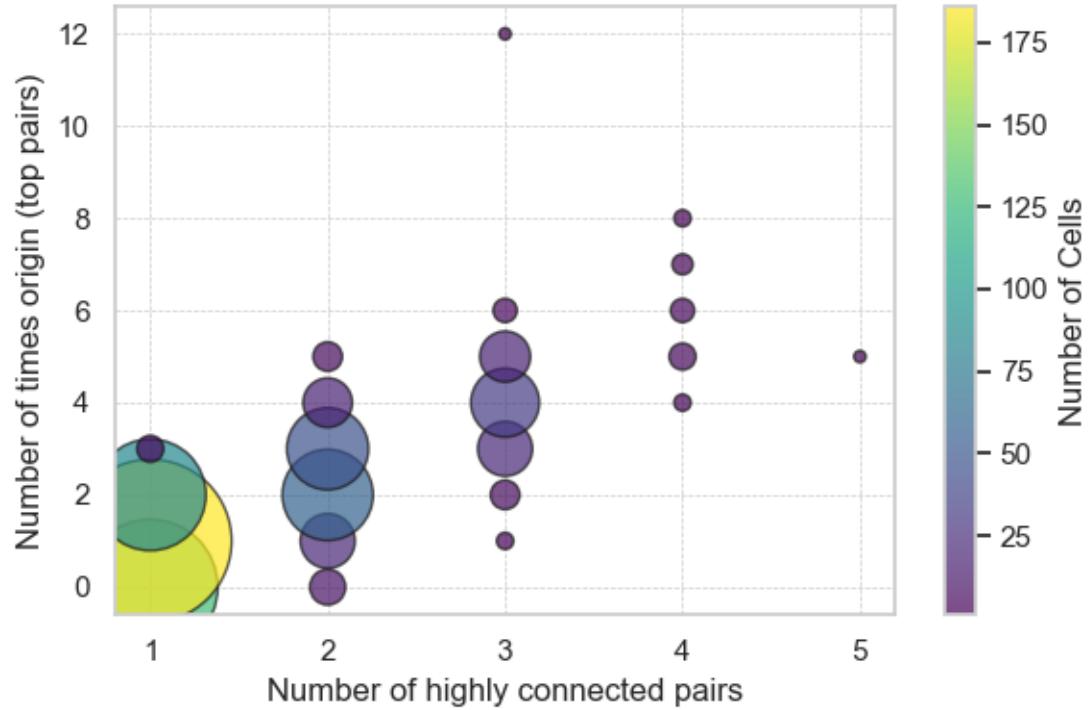
```
[2025-08-27 14:46:10] [INFO] calcium: build_neighbor_pair_stats: built 3227 pairs across 1 datasets (mean distance=15.91 um)
```

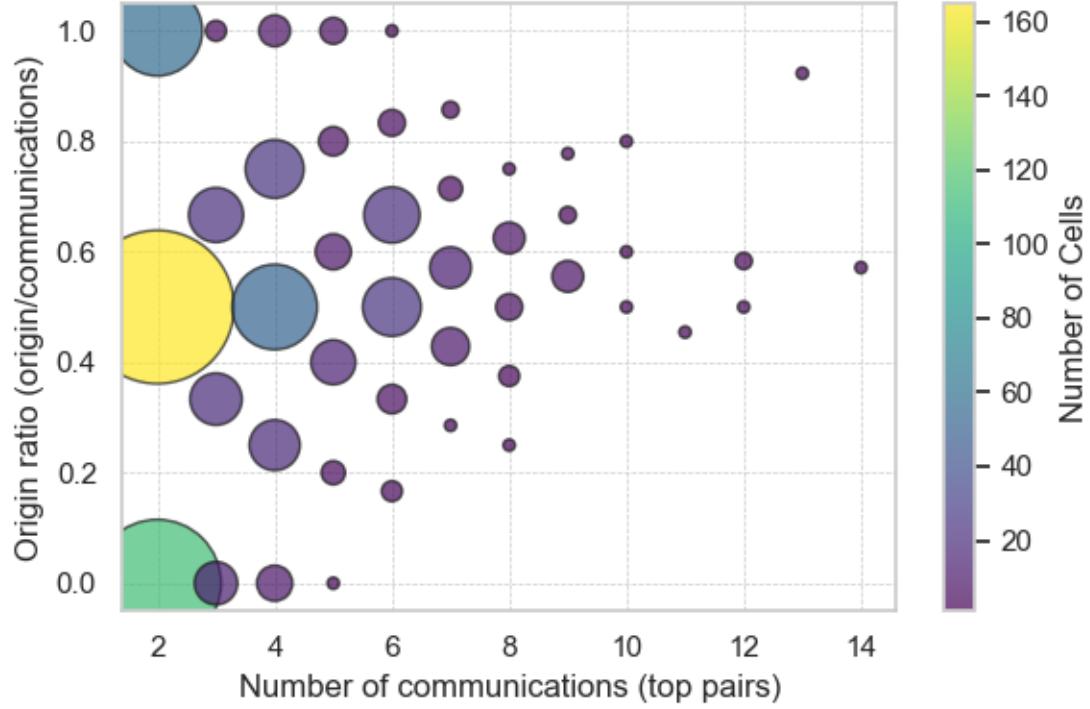
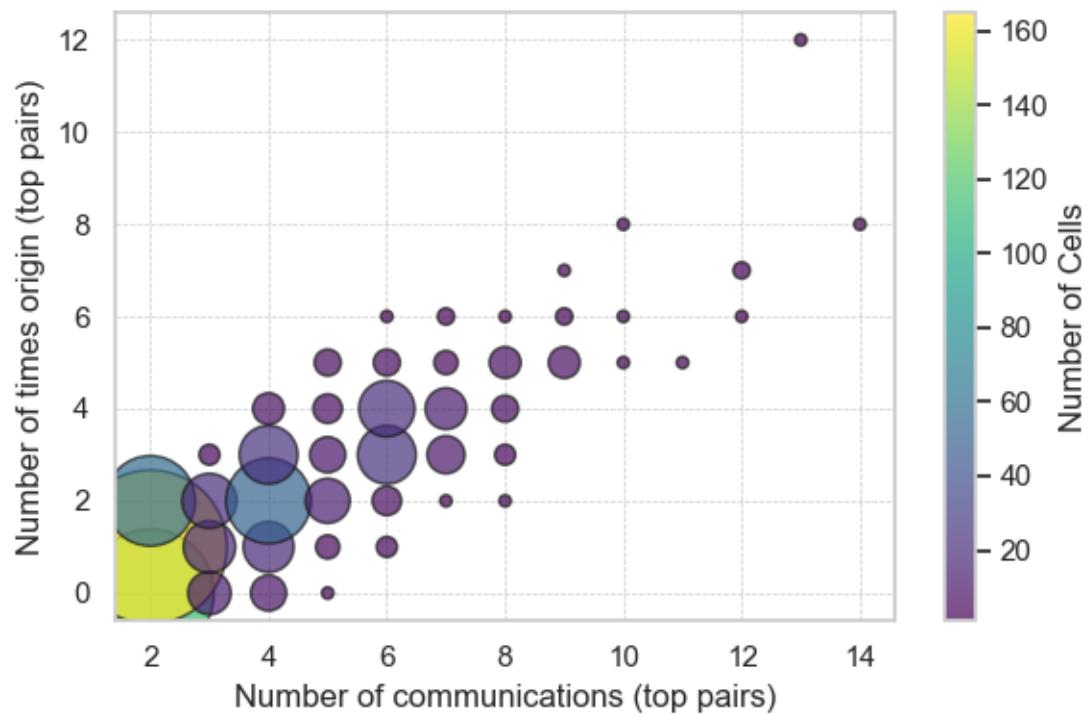


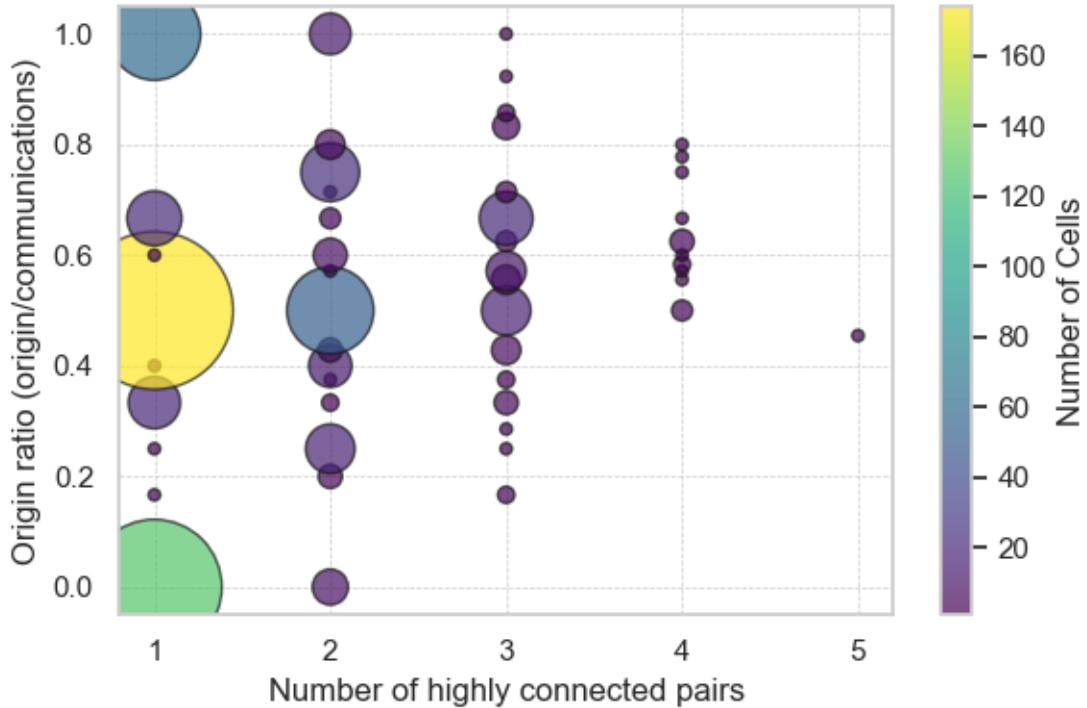
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected









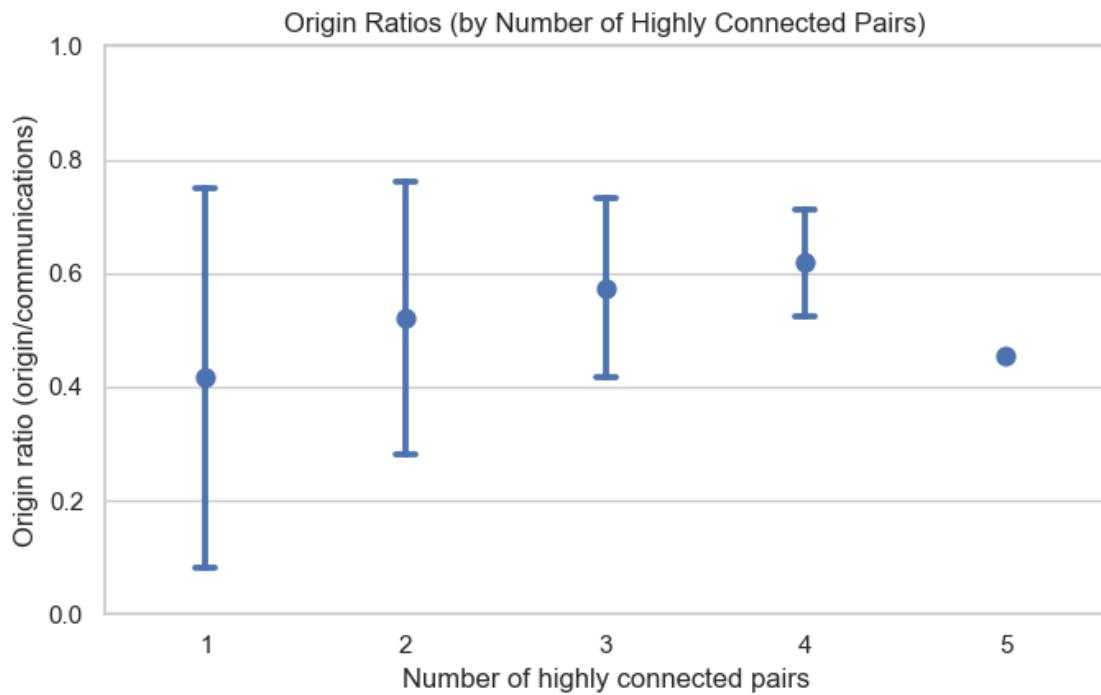
[2025-08-27 14:46:11] [INFO] calcium: plot\_points\_mean\_std: N=406 for Number of highly connected pairs=1

[2025-08-27 14:46:11] [INFO] calcium: plot\_points\_mean\_std: N=158 for Number of highly connected pairs=2

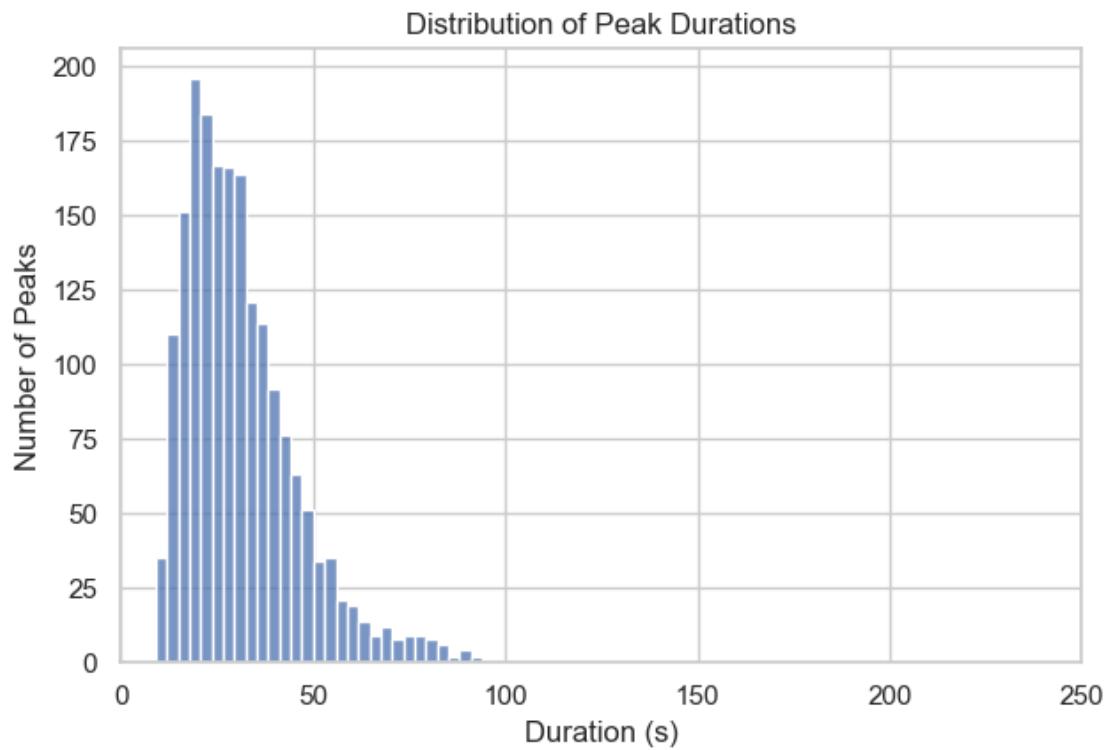
[2025-08-27 14:46:11] [INFO] calcium: plot\_points\_mean\_std: N=85 for Number of highly connected pairs=3

[2025-08-27 14:46:11] [INFO] calcium: plot\_points\_mean\_std: N=16 for Number of highly connected pairs=4

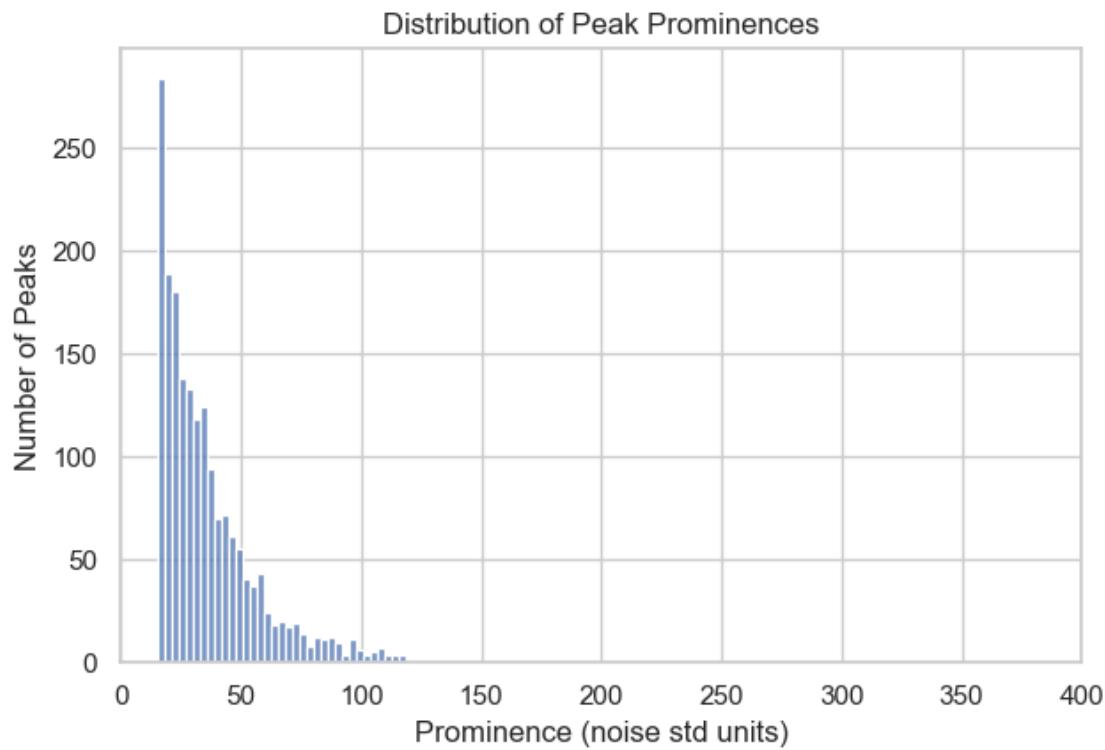
[2025-08-27 14:46:11] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=5

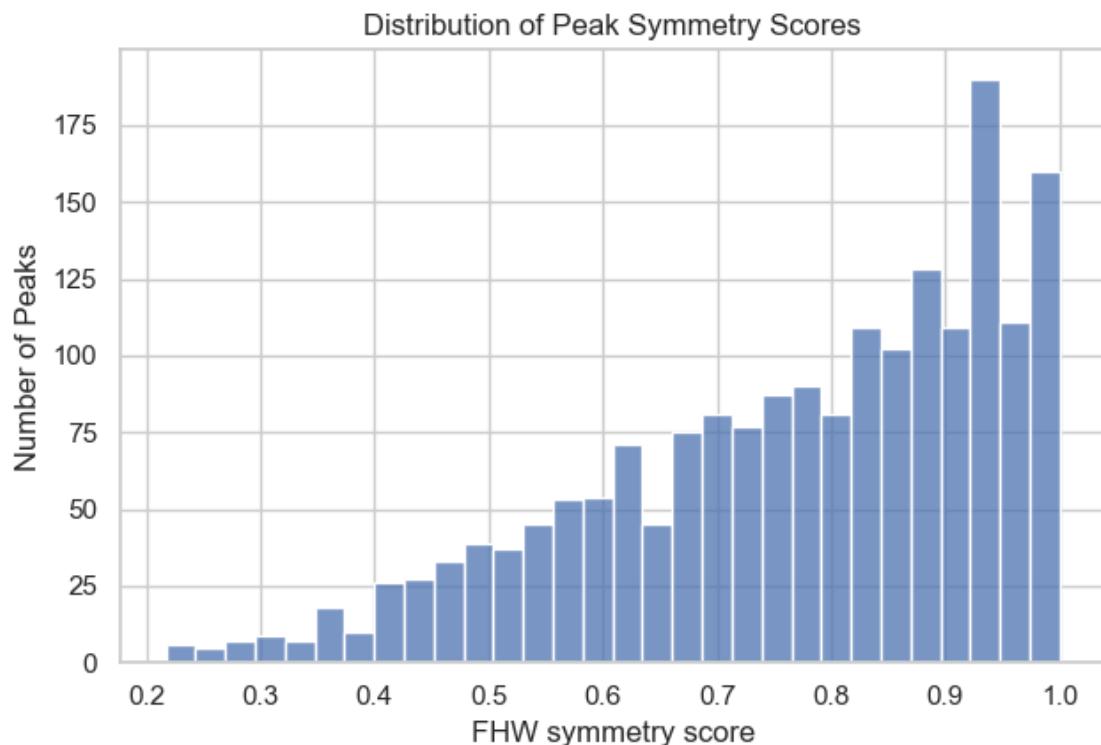


```
[2025-08-27 14:46:11] [INFO] calcium: plot_histogram: removed 10 outliers out of 1892 on 'Duration (s)' (lower=-37, upper=96)
```

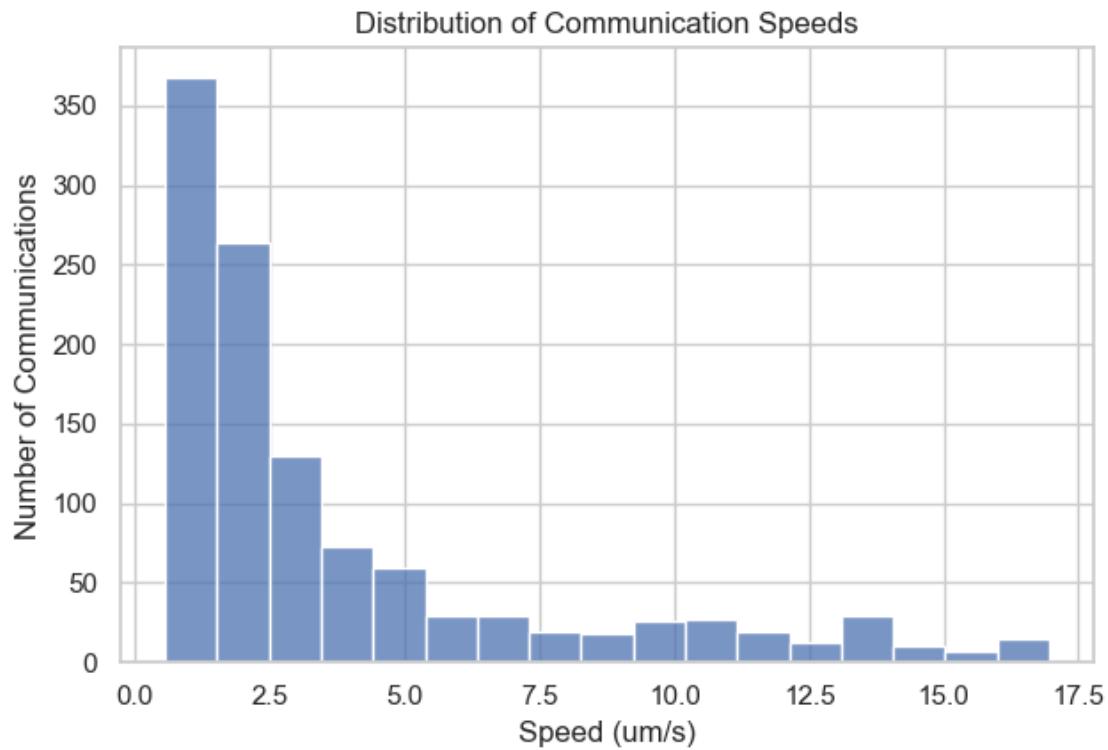


[2025-08-27 14:46:11] [INFO] calcium: plot\_histogram: removed 39 outliers out of 1892 on 'Prominence (noise std units)' (lower=-52.9, upper=119.47)

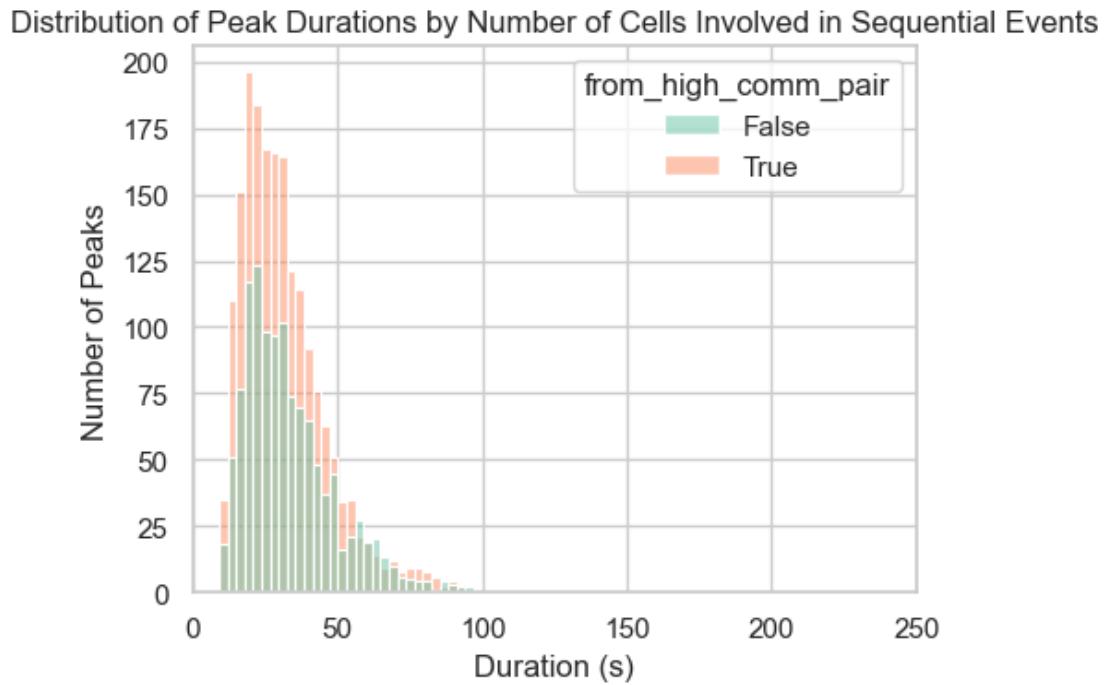




```
[2025-08-27 14:46:11] [INFO] calcium: plot_histogram: removed 49 outliers out of 1185 on 'Speed (um/s)' (lower=-10.39, upper=17.05)
```

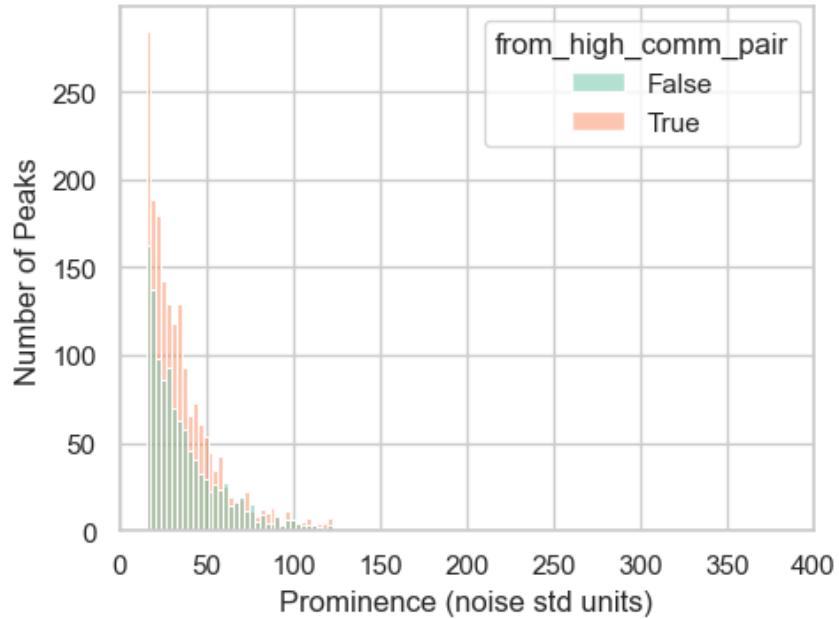


```
[2025-08-27 14:46:12] [INFO] calcium: plot_histogram_by_group: removed 22 outliers out of 3084 on 'Duration (s)' (lower=-36, upper=97)
```

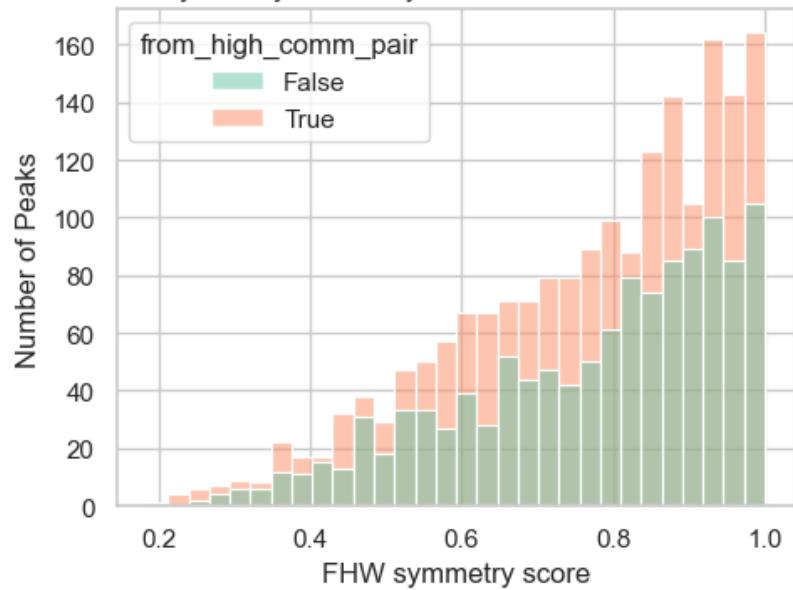


[2025-08-27 14:46:12] [INFO] calcium: plot\_histogram\_by\_group: removed 72 outliers out of 3084 on 'Prominence (noise std units)' (lower=-55.9, upper=123.3)

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

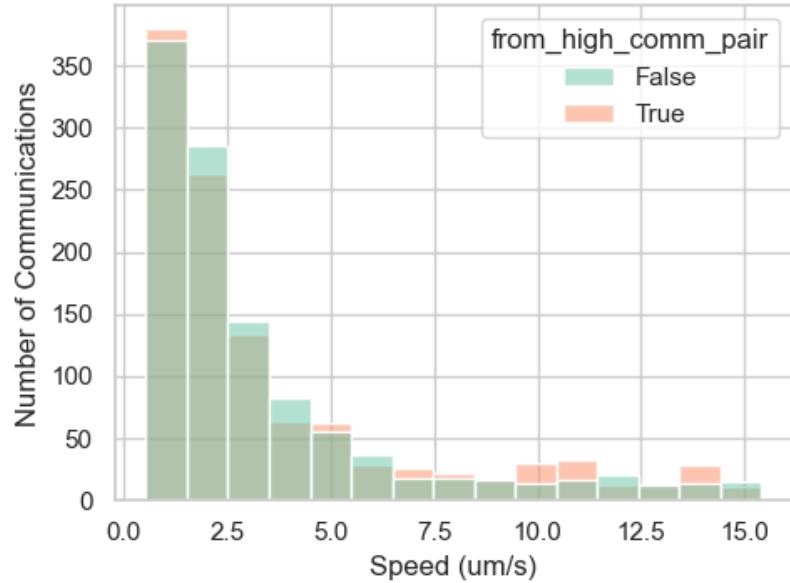


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 14:46:12] [INFO] calcium: plot\_histogram\_by\_group: removed 130 outliers out of 2367 on 'Speed (um/s)' (lower=-9.205, upper=15.47)

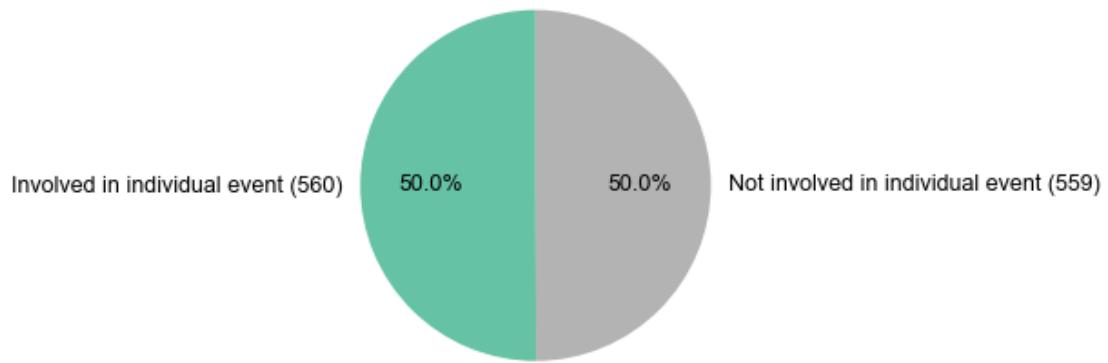
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events

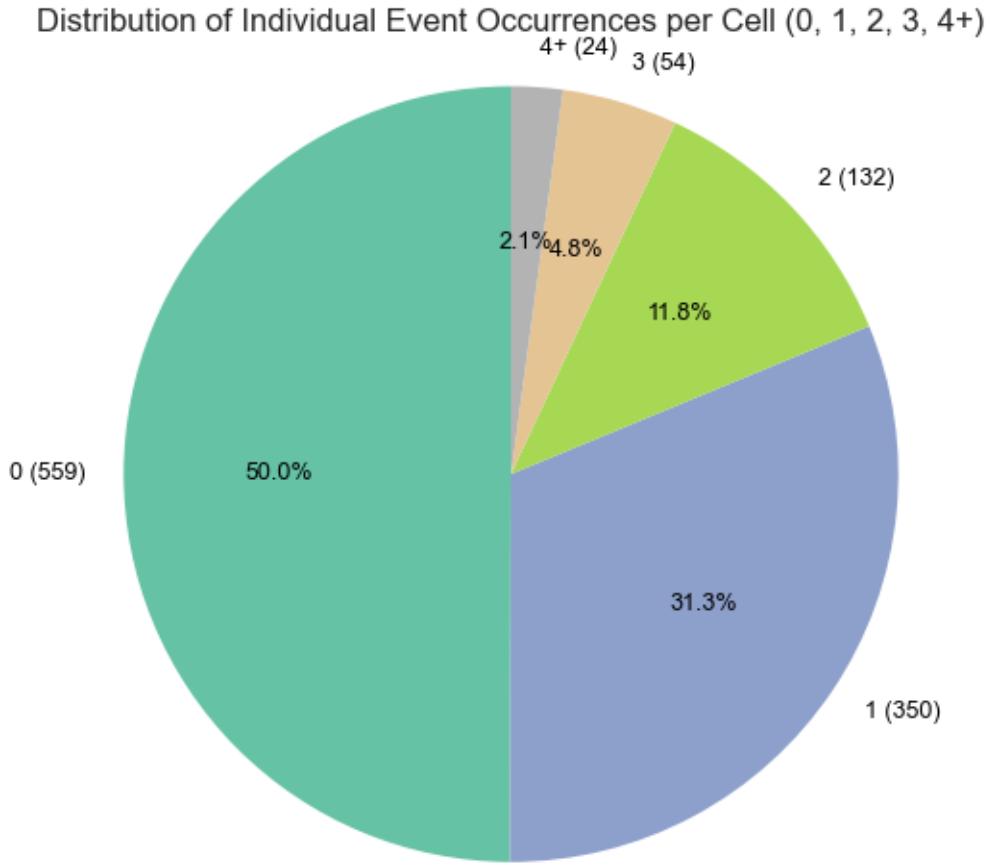


## 1.4 INDIVIDUAL EVENTS

### 1.4.1 Cells Occurrences in individual events

Distribution of Cells Involved in Individual Events



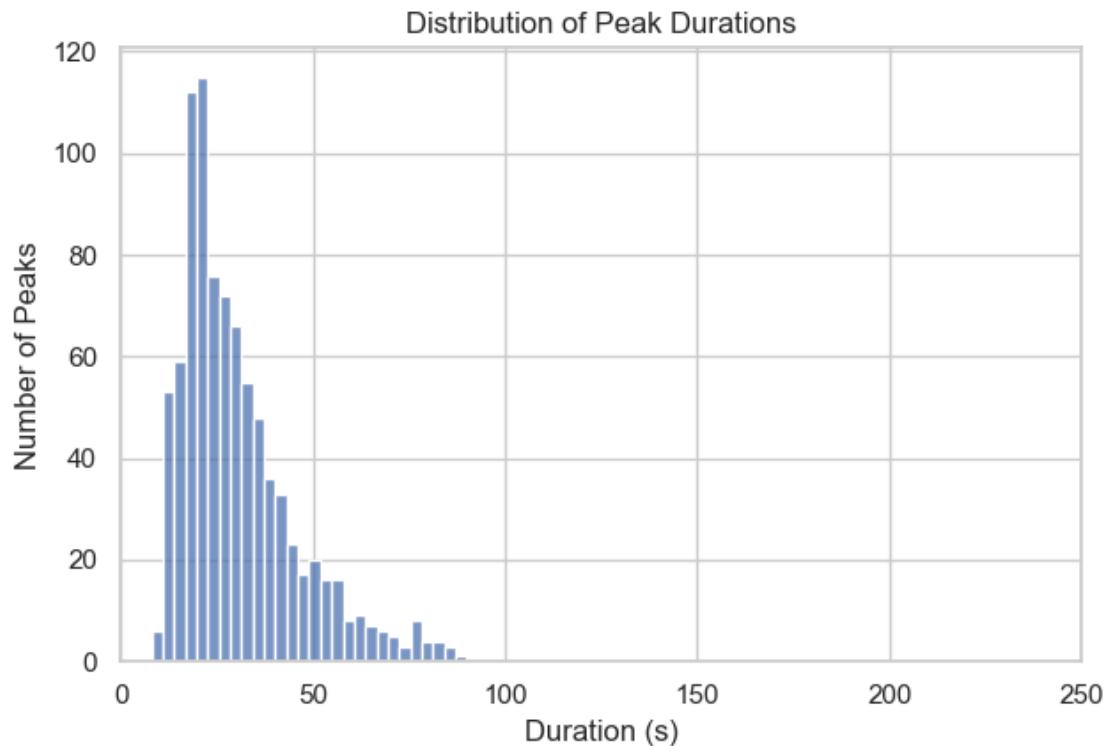


```
[2025-08-27 14:46:13] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS1\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS1\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\20250424\\Output\\IS1\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

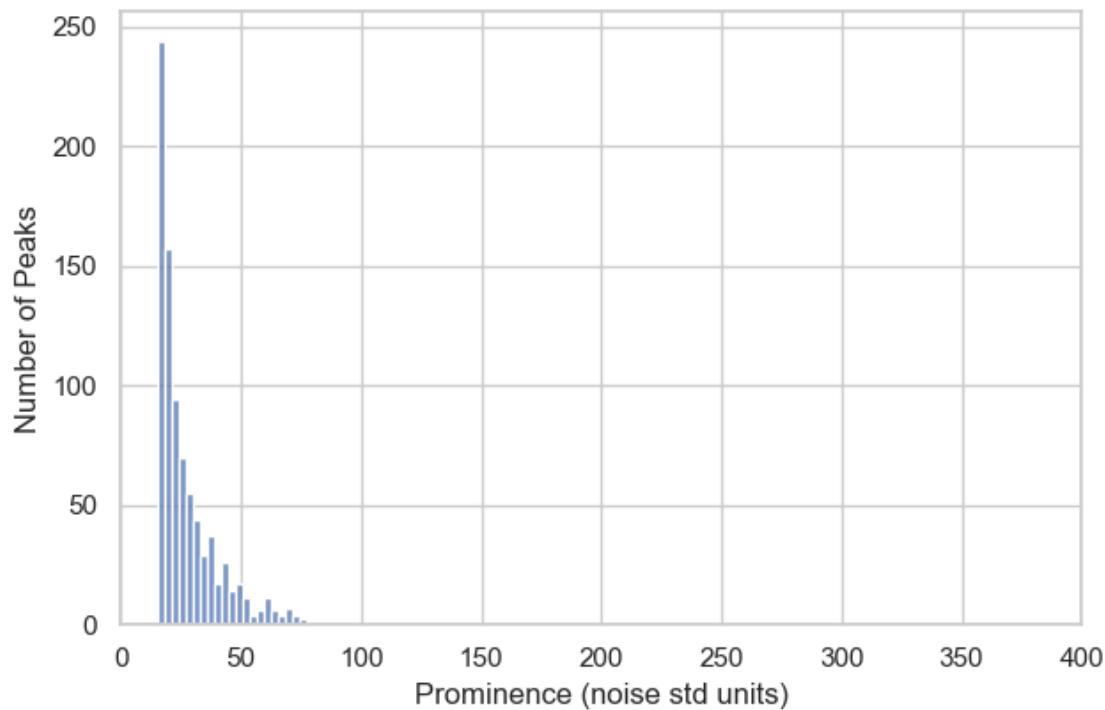
#### 1.4.2 Peaks statistics in individual events

[2025-08-27 14:46:13] [INFO] calcium: plot\_histogram: removed 9 outliers out of 890 on 'Duration (s)' (lower=-38, upper=95)

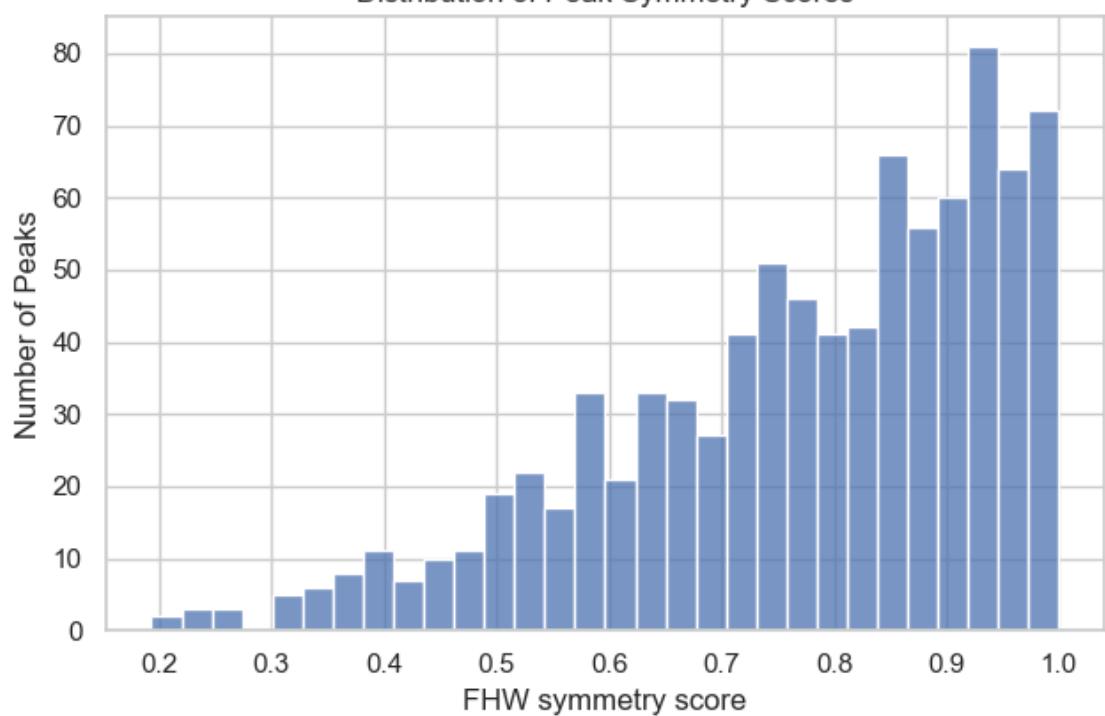


[2025-08-27 14:46:13] [INFO] calcium: plot\_histogram: removed 31 outliers out of 890 on 'Prominence (noise std units)' (lower=-28.2, upper=78.9)

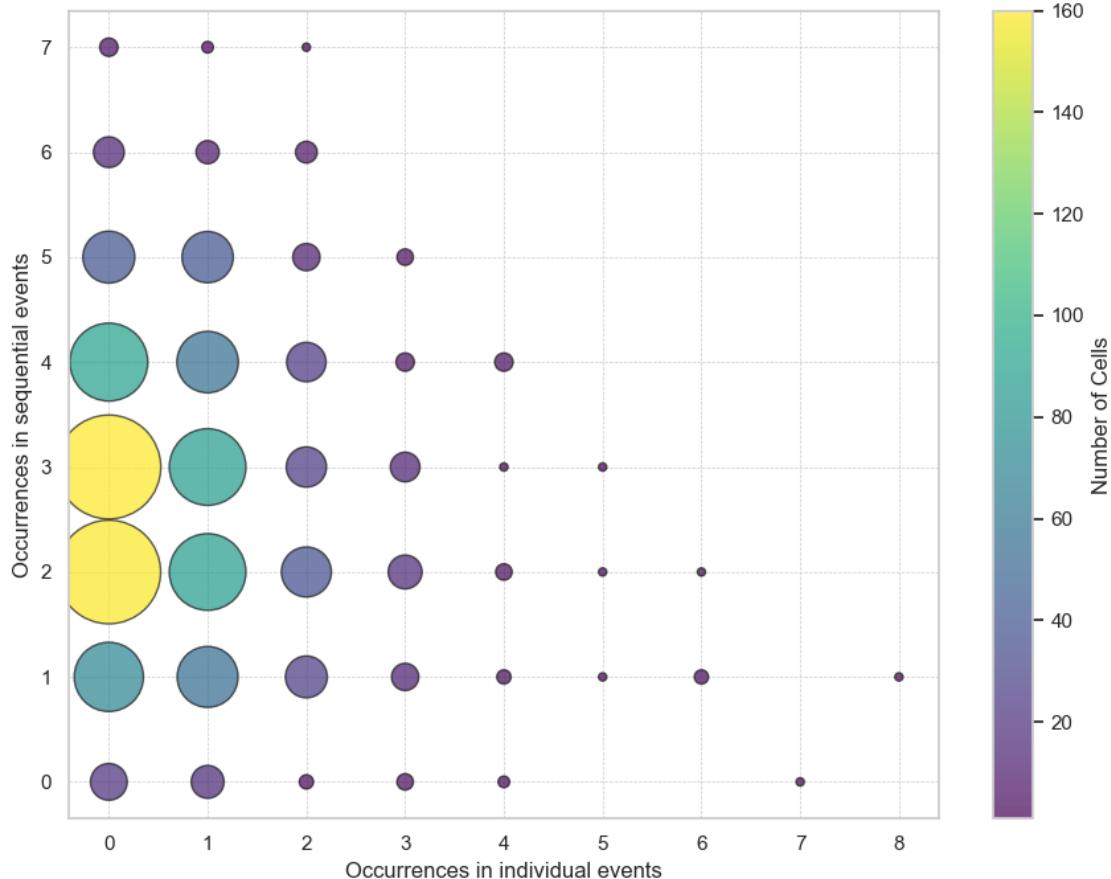
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



### 1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 14:46:13] [INFO] calcium: plot_points_mean_std: removed 0/1119 outliers on 'Occurrences in sequential events' (lower=-4, upper=10)
```

```
[2025-08-27 14:46:14] [INFO] calcium: plot_points_mean_std: N=559 for Occurrences in individual events=0
```

```
[2025-08-27 14:46:14] [INFO] calcium: plot_points_mean_std: N=350 for Occurrences in individual events=1
```

```
[2025-08-27 14:46:14] [INFO] calcium: plot_points_mean_std: N=132 for Occurrences in individual events=2
```

```
[2025-08-27 14:46:14] [INFO] calcium: plot_points_mean_std: N=54 for Occurrences in individual events=3
```

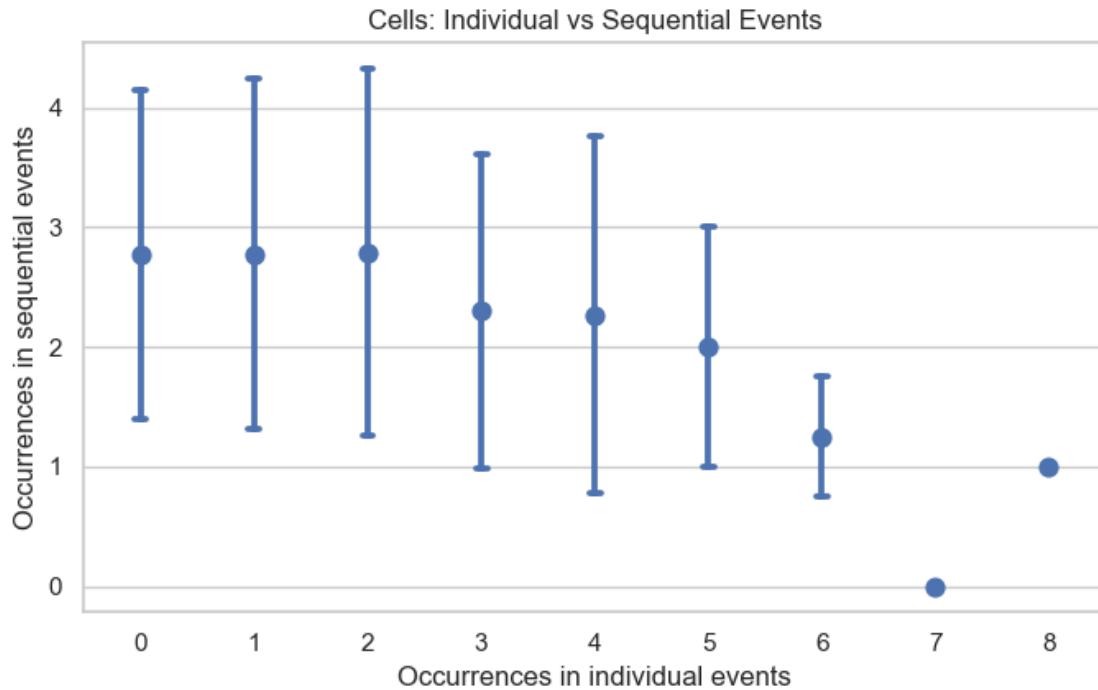
```
[2025-08-27 14:46:14] [INFO] calcium: plot_points_mean_std: N=15 for Occurrences in individual events=4
```

[2025-08-27 14:46:14] [INFO] calcium: plot\_points\_mean\_std: N=3 for Occurrences in individual events=5

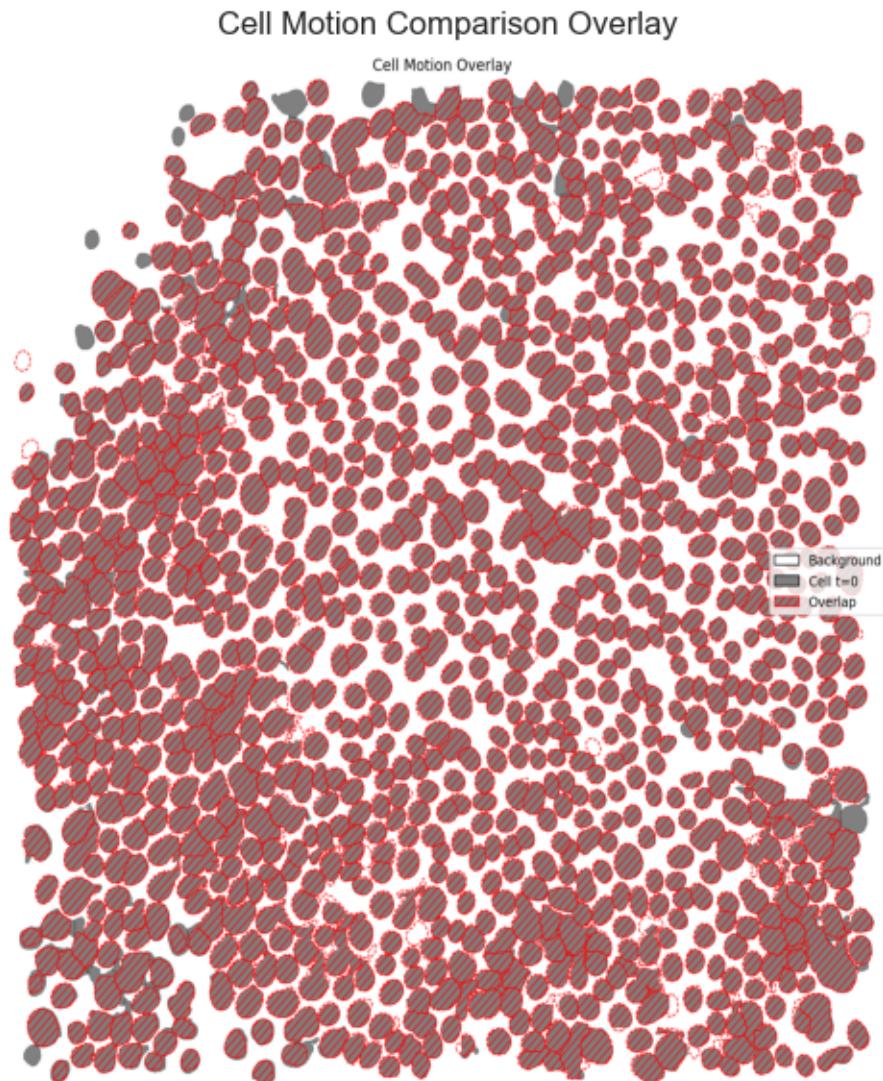
[2025-08-27 14:46:14] [INFO] calcium: plot\_points\_mean\_std: N=4 for Occurrences in individual events=6

[2025-08-27 14:46:14] [INFO] calcium: plot\_points\_mean\_std: N=1 for Occurrences in individual events=7

[2025-08-27 14:46:14] [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: 1119
- Hoechst image taken at t=1801: 1093
- Number of cells difference: absolute 26, relative 2.35%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1293761
- Pixels segmented as cell at t=1801: 1304452
- Overlapping pixels between t=0 and t=1801: 1223832 (94.21% of total)
- Pixels exclusive to t=0: 69929 (5.41% of total)
- Pixels exclusive to t=1801: 80620 (6.18% of total)

executed

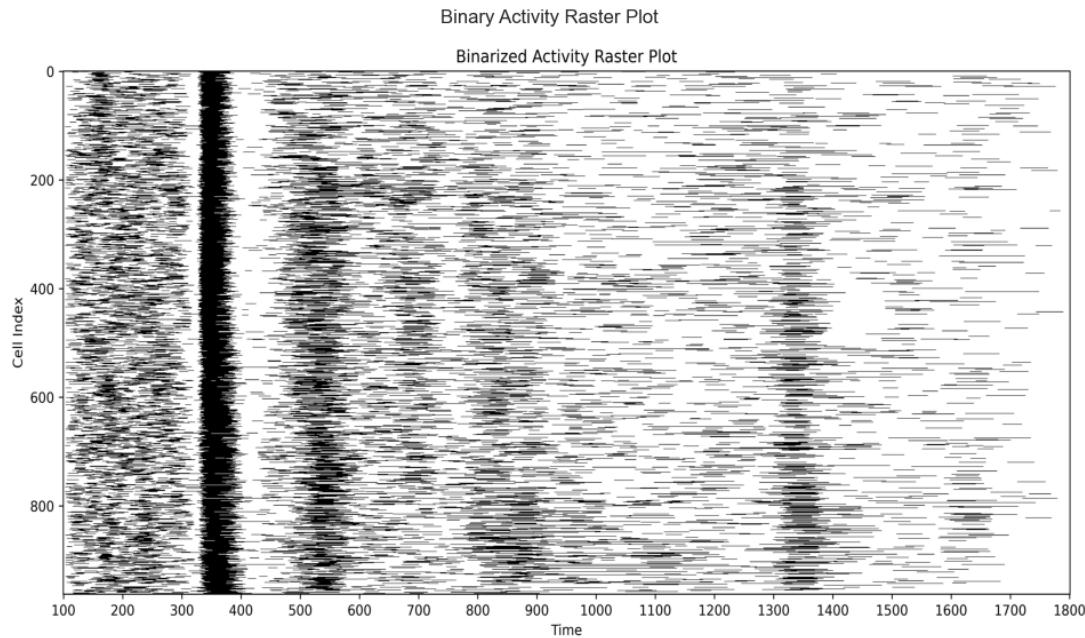
August 27, 2025

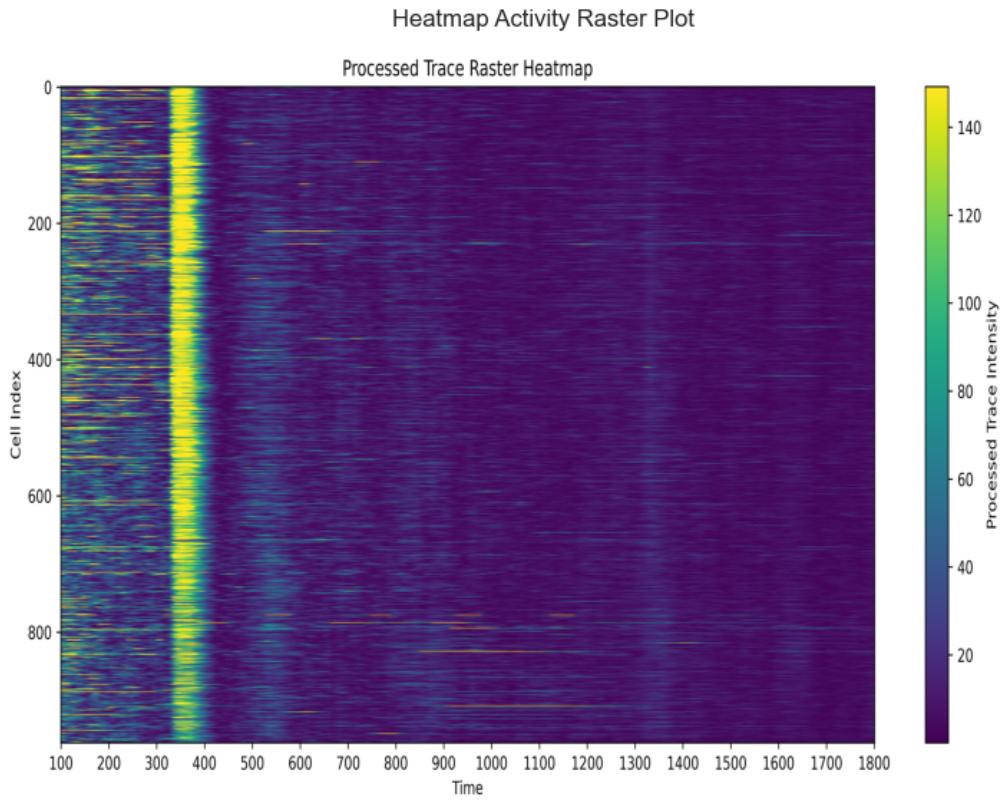
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





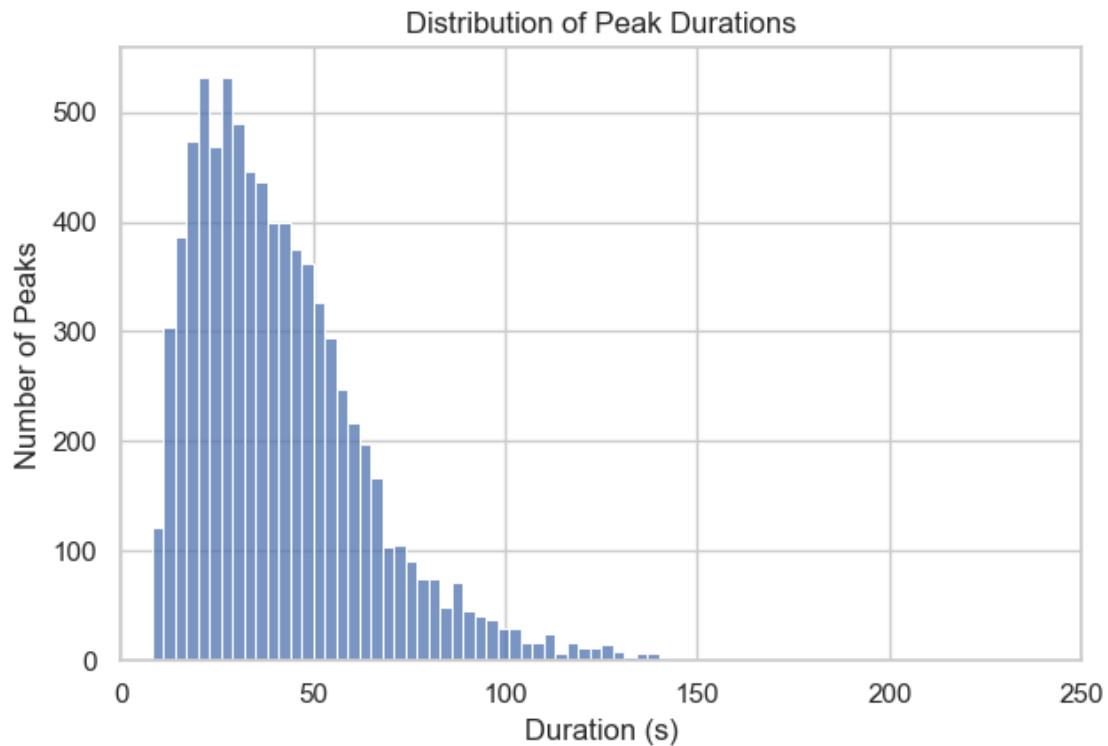
### 1.1.2 Peaks population

Total number of peaks: 8127

Total number of cells: 963

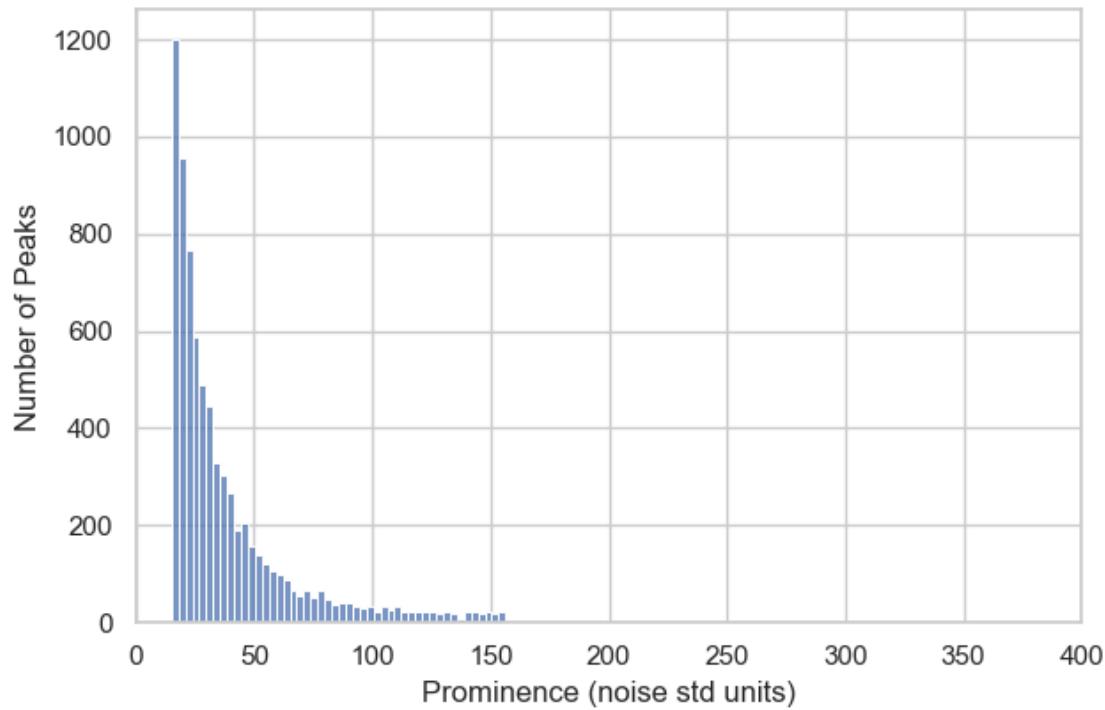
### 1.1.3 Peaks statistics

```
[2025-08-27 14:46:45] [INFO] calcium: plot_histogram: removed 59 outliers out of  
8127 on 'Duration (s)' (lower=-63, upper=140)
```

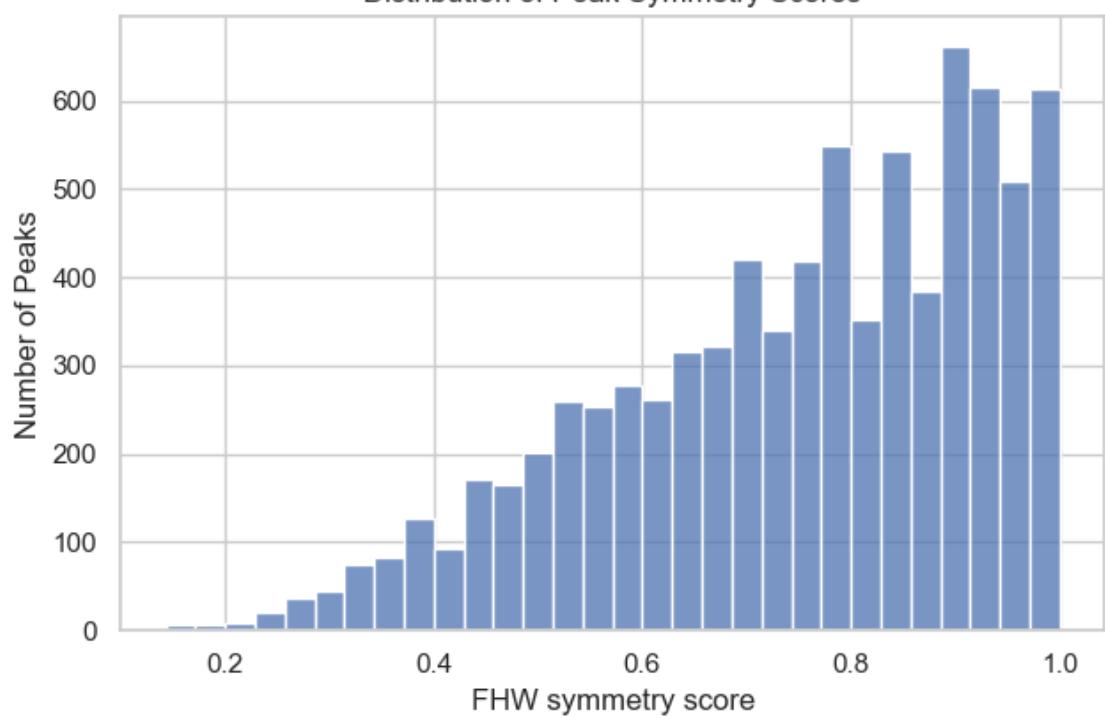


```
[2025-08-27 14:46:45] [INFO] calcium: plot_histogram: removed 673 outliers out  
of 8127 on 'Prominence (noise std units)' (lower=-81.5, upper=156.5)
```

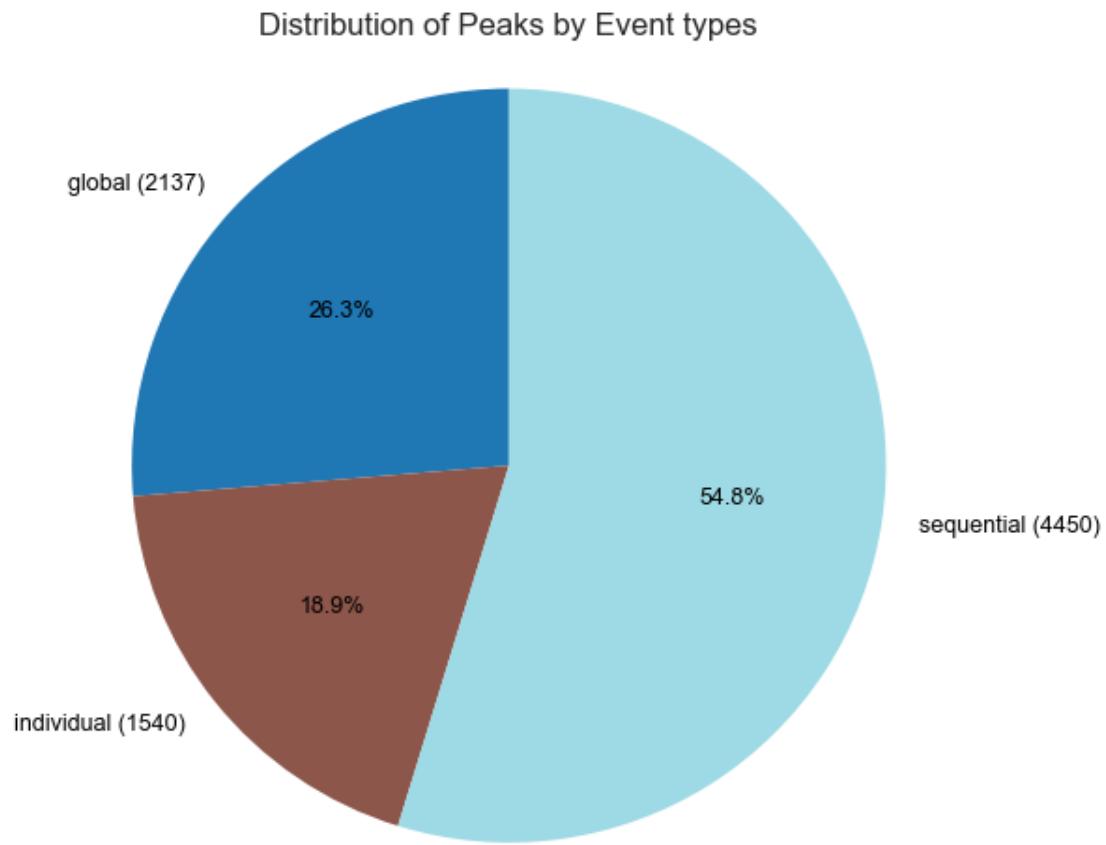
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

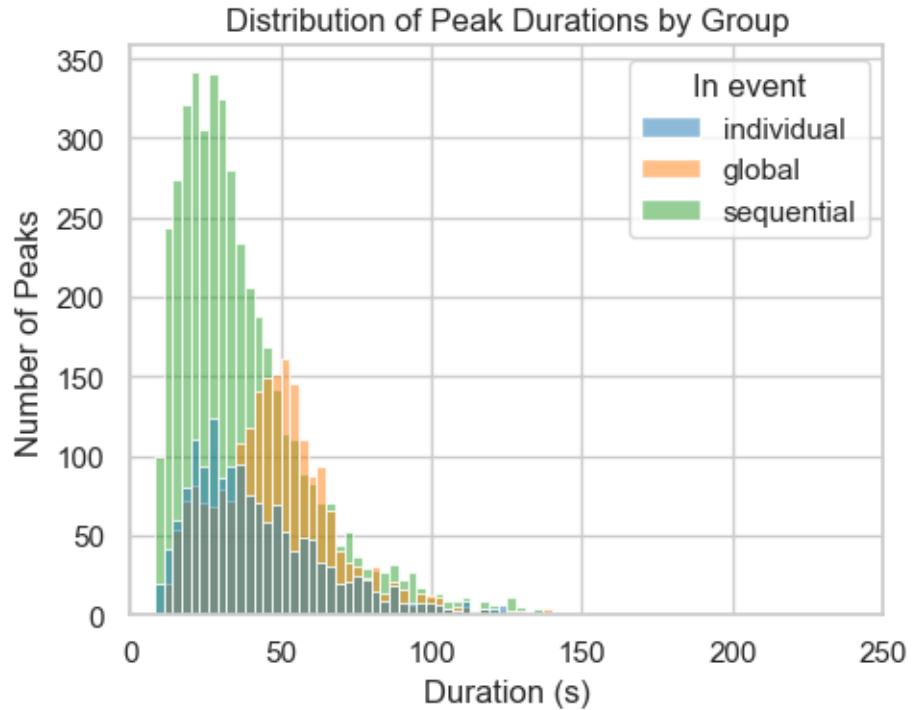


#### 1.1.4 Distribution of peaks per event types

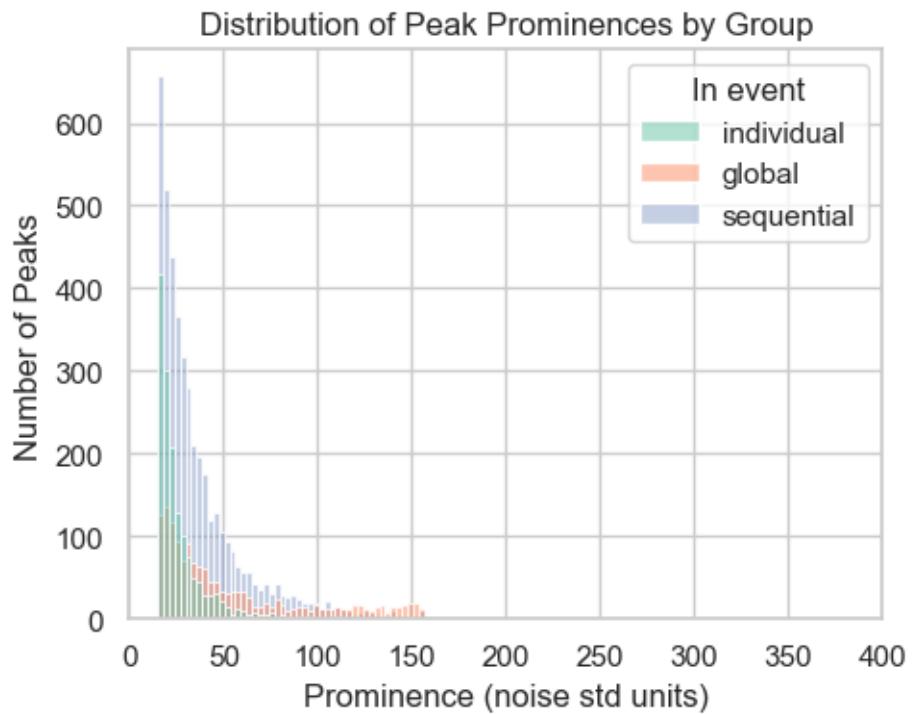


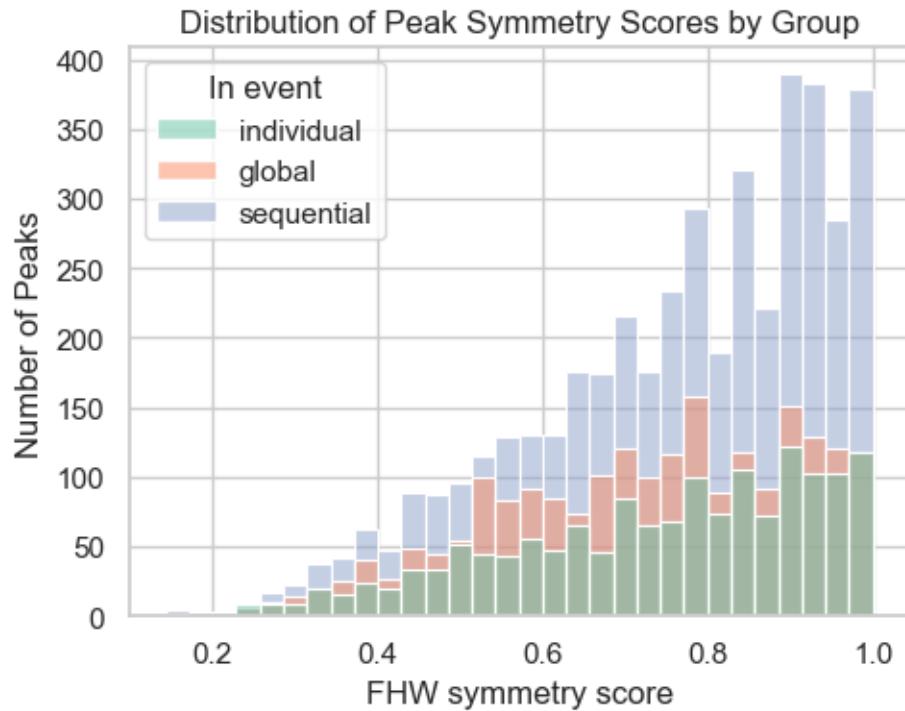
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 14:46:45] [INFO] calcium: plot_histogram_by_group: removed 59 outliers out of 8127 on 'Duration (s)' (lower=-63, upper=140)
```



```
[2025-08-27 14:46:45] [INFO] calcium: plot_histogram_by_group: removed 673 outliers out of 8127 on 'Prominence (noise std units)' (lower=-81.5, upper=156.5)
```

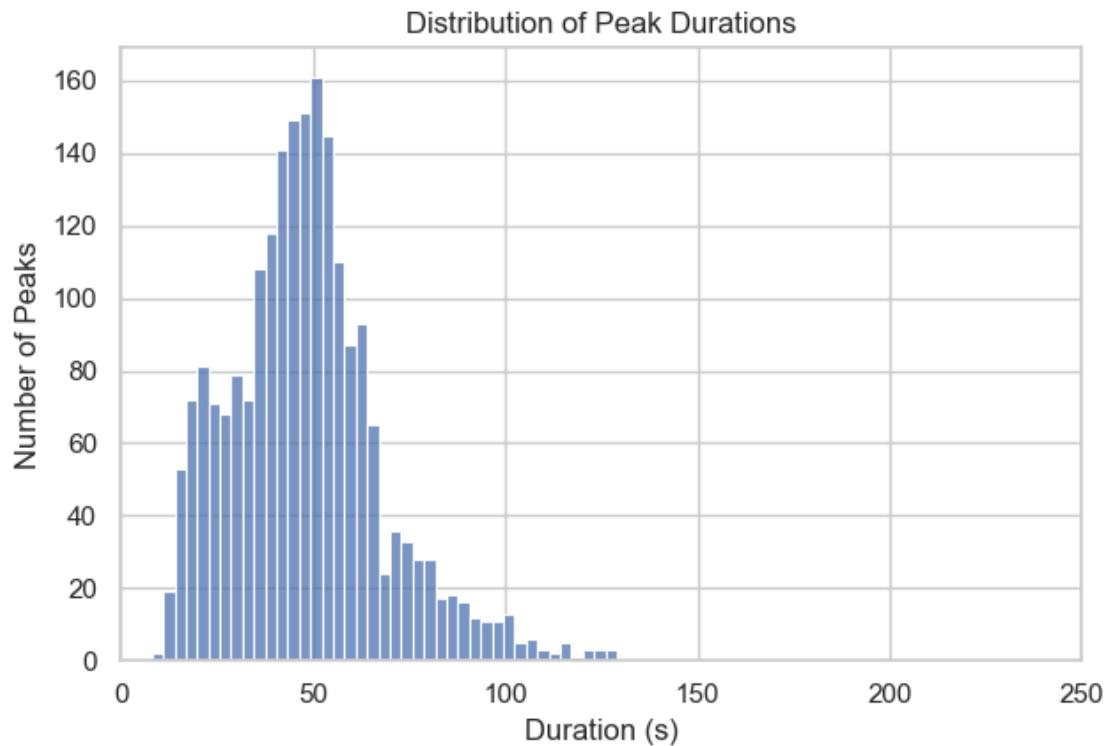




## 1.2 GLOBAL EVENTS

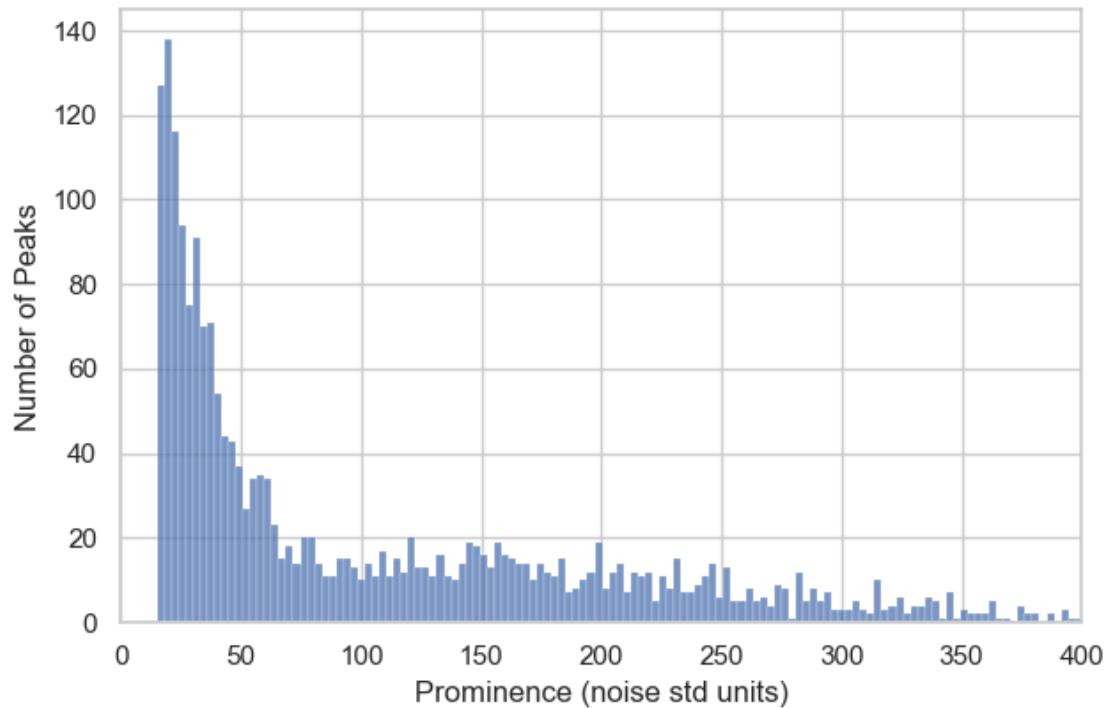
### 1.2.1 Peak statistics in global events

```
[2025-08-27 14:46:46] [INFO] calcium: plot_histogram: removed 14 outliers out of 2137 on 'Duration (s)' (lower=-37, upper=131)
```

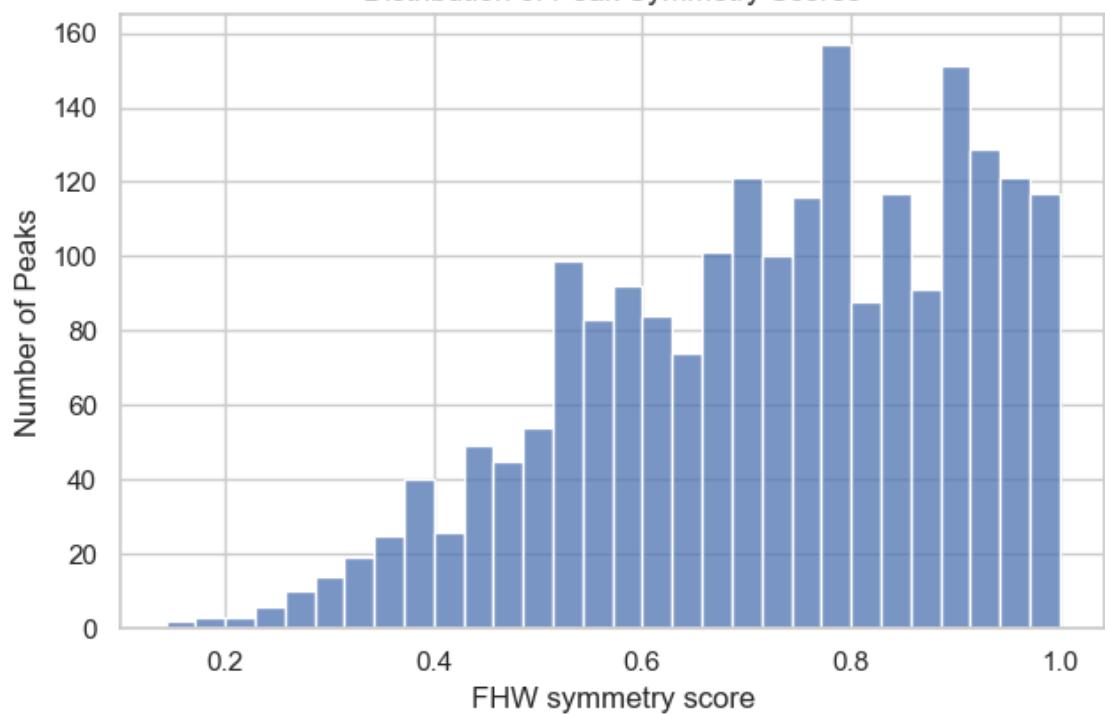


```
[2025-08-27 14:46:46] [INFO] calcium: plot_histogram: removed 3 outliers out of  
2137 on 'Prominence (noise std units)' (lower=-380.4, upper=575.8)
```

Distribution of Peak Prominences

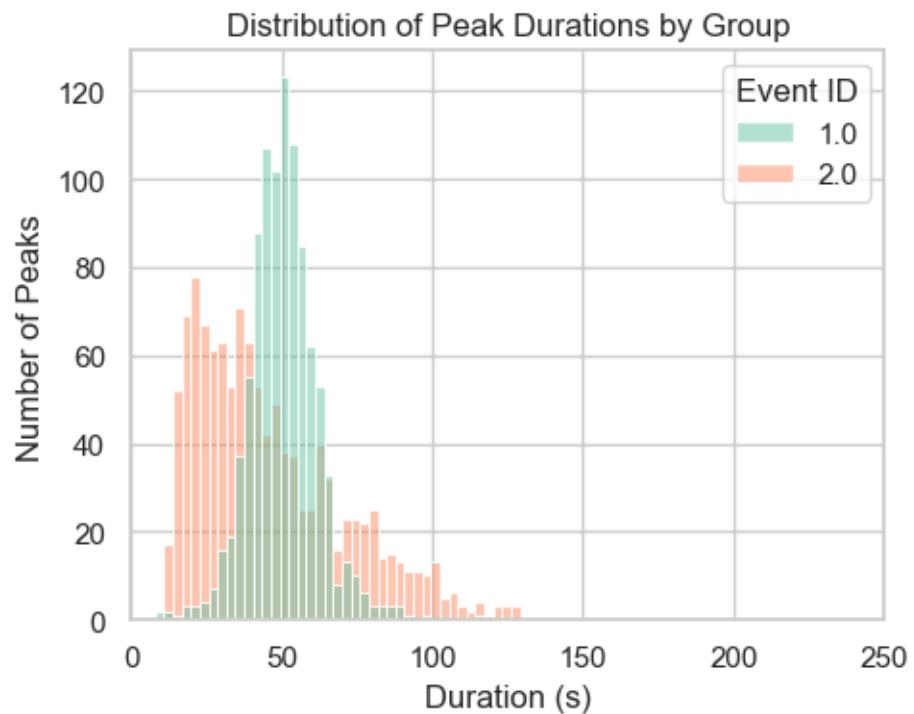


Distribution of Peak Symmetry Scores

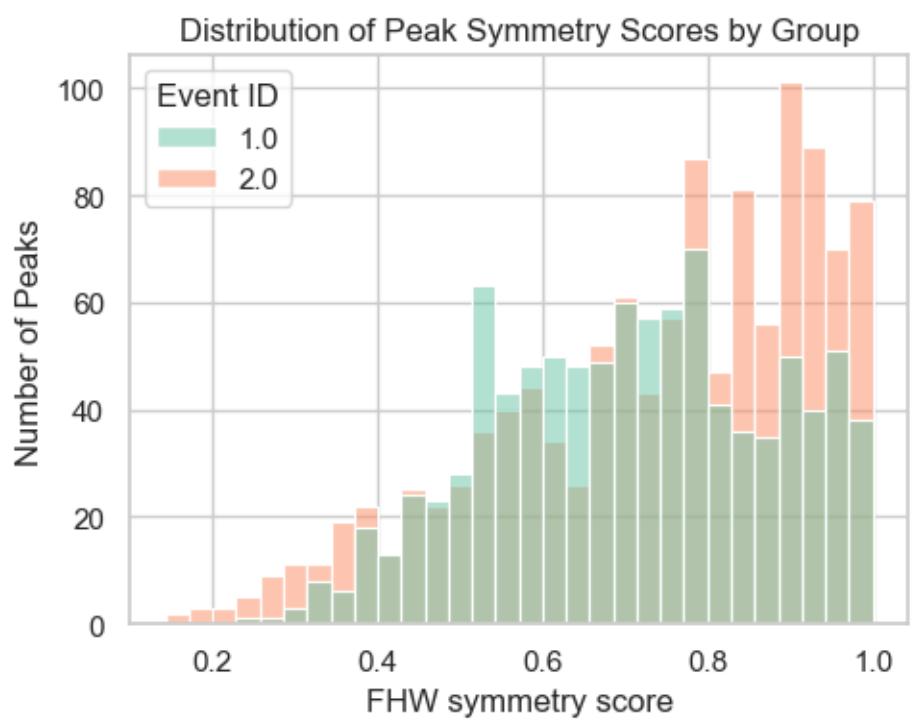
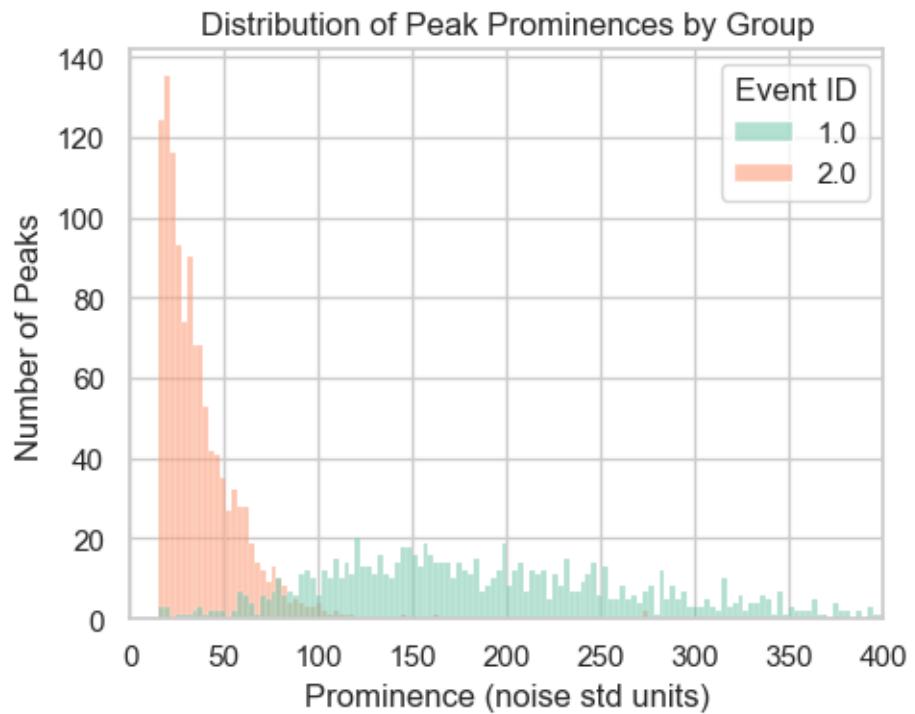


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:46:46] [INFO] calcium: plot\_histogram\_by\_group: removed 14 outliers out of 2137 on 'Duration (s)' (lower=-37, upper=131)

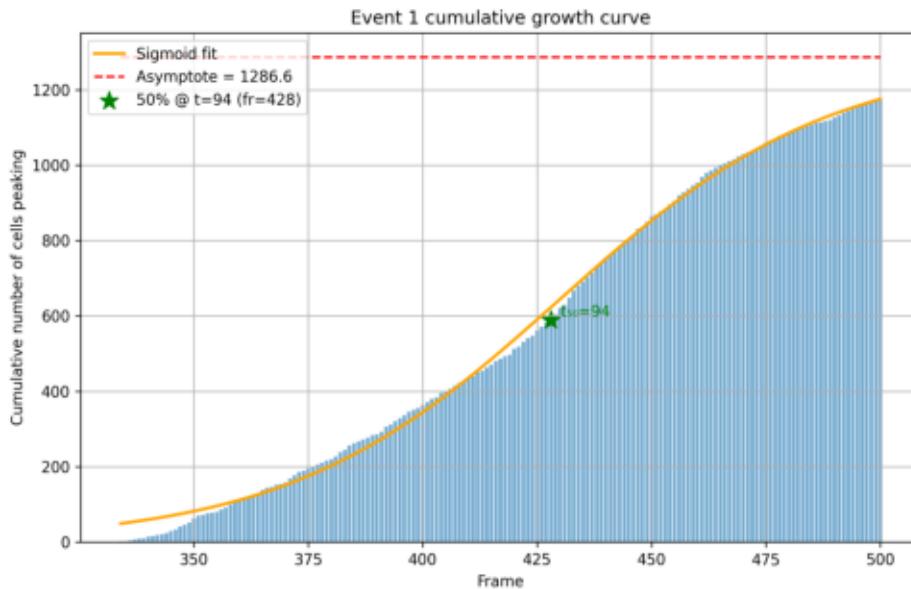


[2025-08-27 14:46:47] [INFO] calcium: plot\_histogram\_by\_group: removed 3 outliers out of 2137 on 'Prominence (noise std units)' (lower=-380.4, upper=575.8)



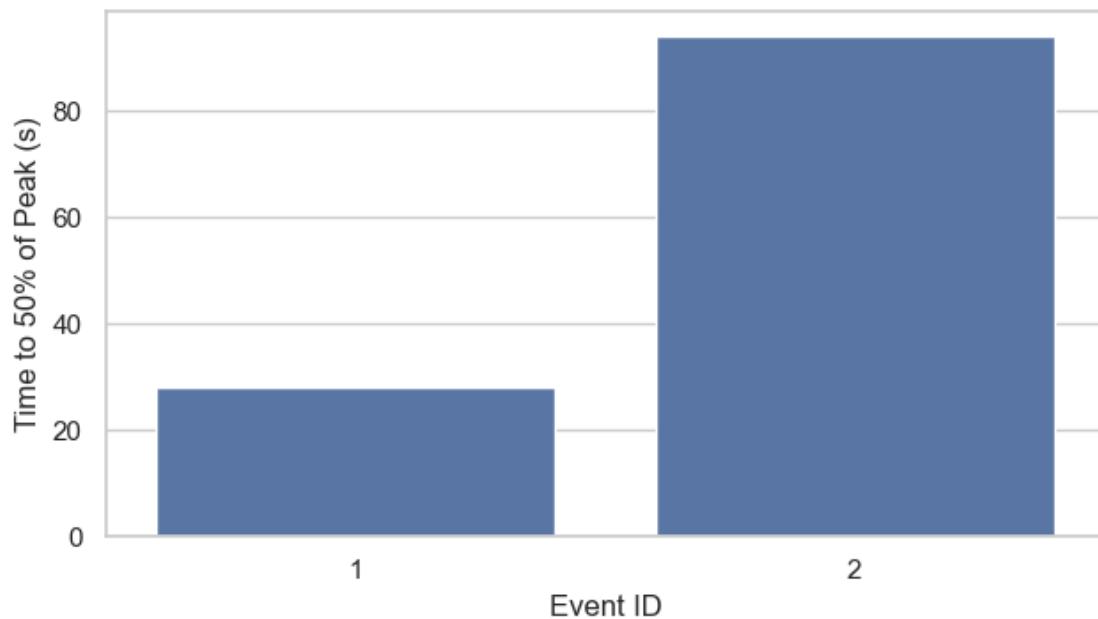
### 1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)

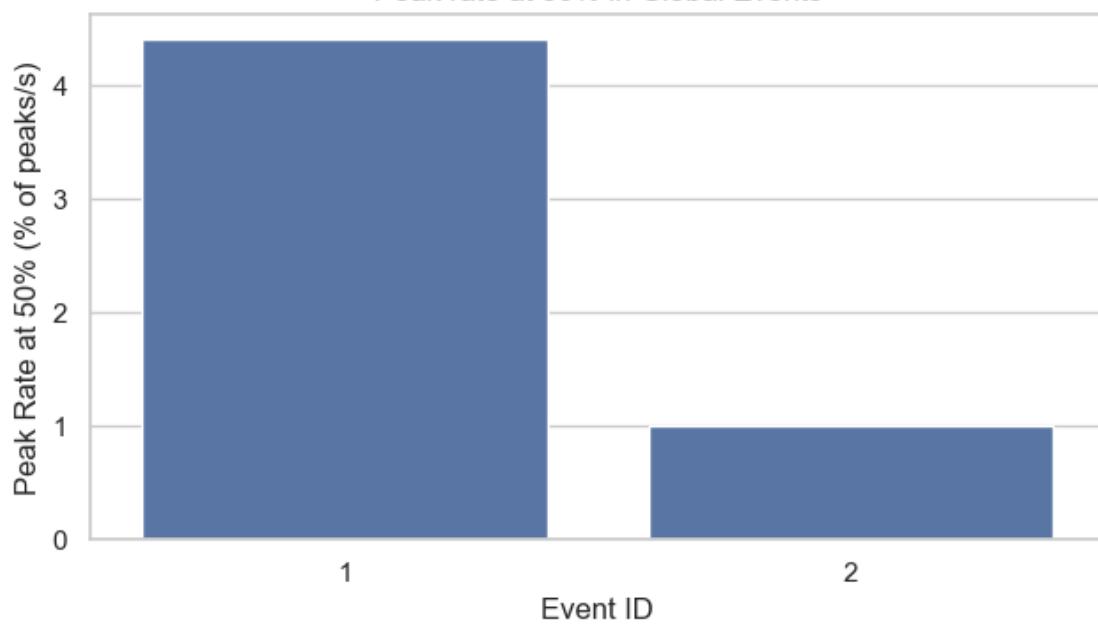


```
[2025-08-27 14:46:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\events\event-growth-curve-2.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250424\\Output\\IS3\\events\\event-growth-
curve-2.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250424\\Output\\IS3\\events\\event-growth-curve-2.png'
```

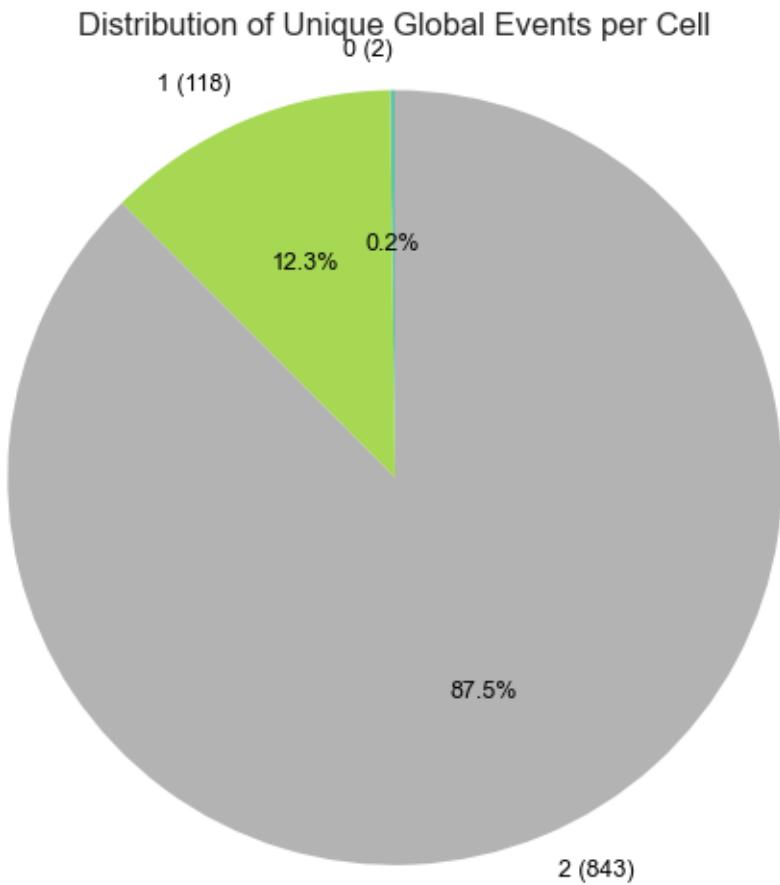
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

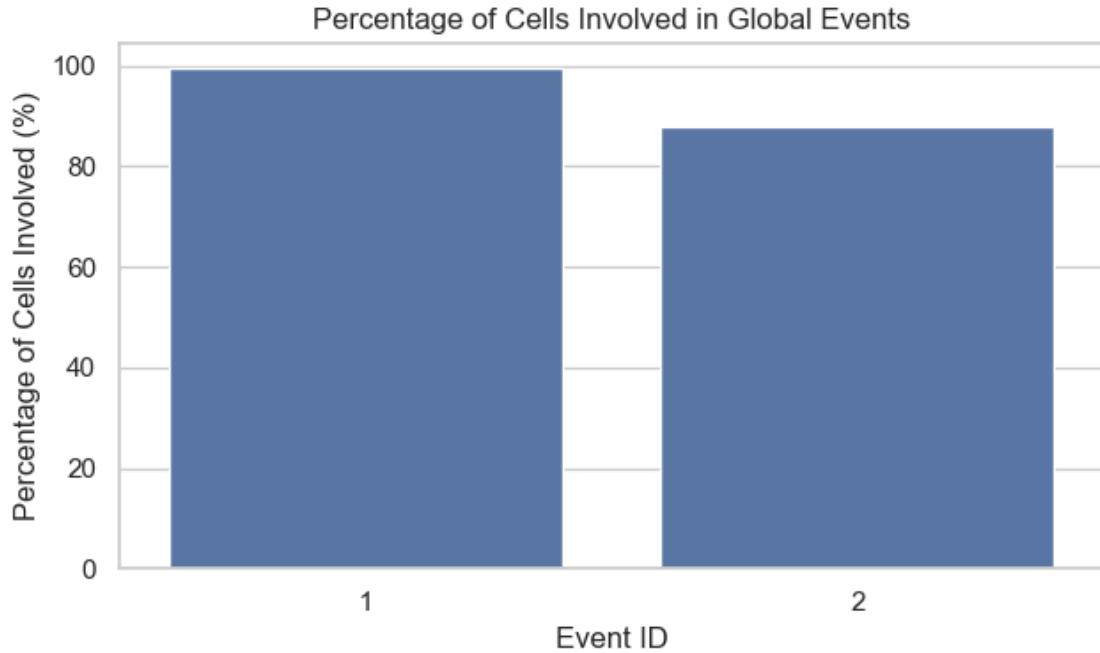


```
[2025-08-27 14:46:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250424\\\\Output\\\\IS3\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250424\Output\IS3\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [184.0]

### 1.2.6 Early peakers in the events

```

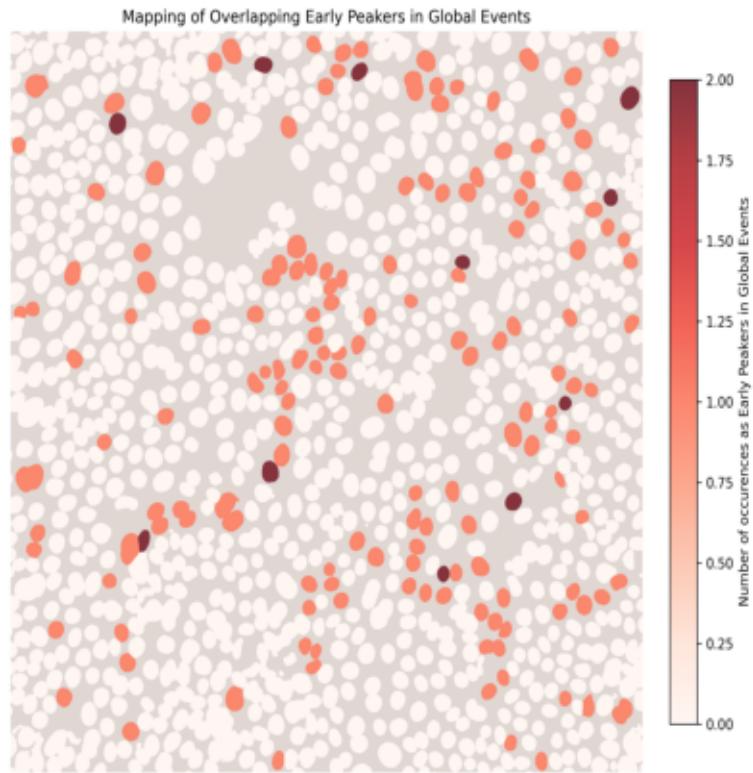
[2025-08-27 14:46:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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

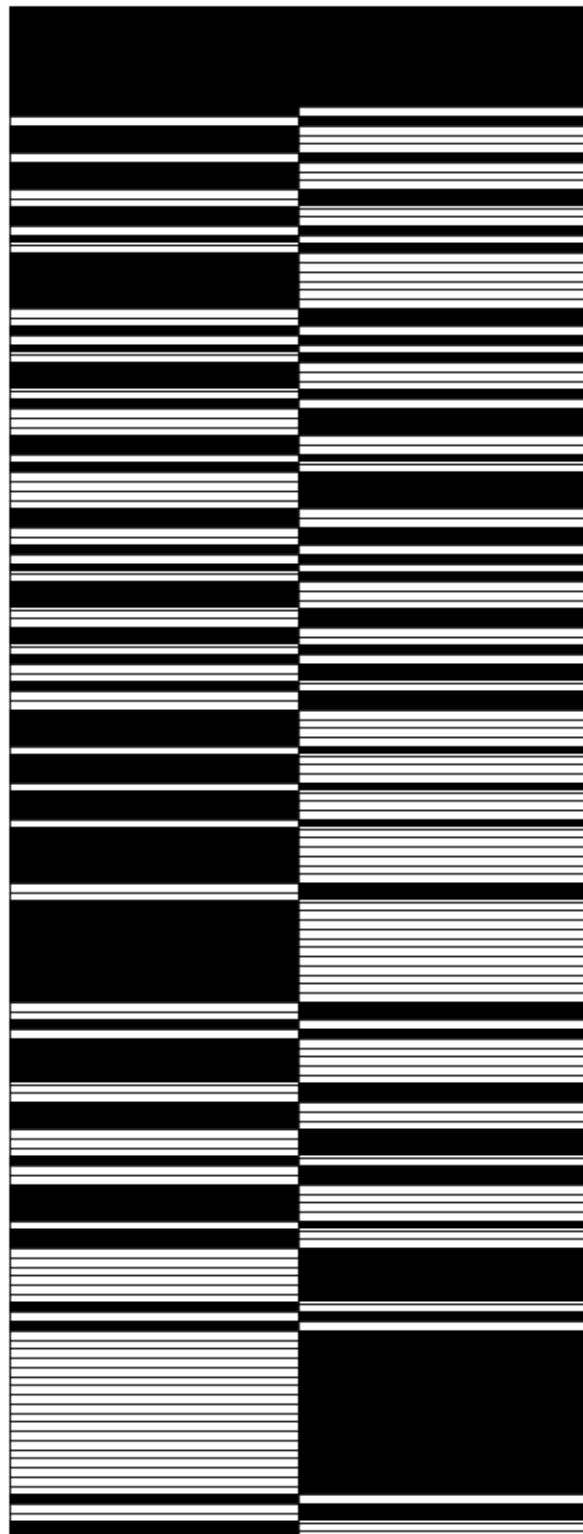
[2025-08-27 14:46:48] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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
```

## Cell Mapping with Occurrences in Global Events Overlay



```
[2025-08-27 14:46:49] [WARNING] calcium: 'total_events' is deprecated and  
ignored. Using 2 unique event IDs.
```

```
[2025-08-27 14:46:49] [INFO] calcium: Early peakers event-matrix: 168 cells x 2  
events; black squares: 179
```



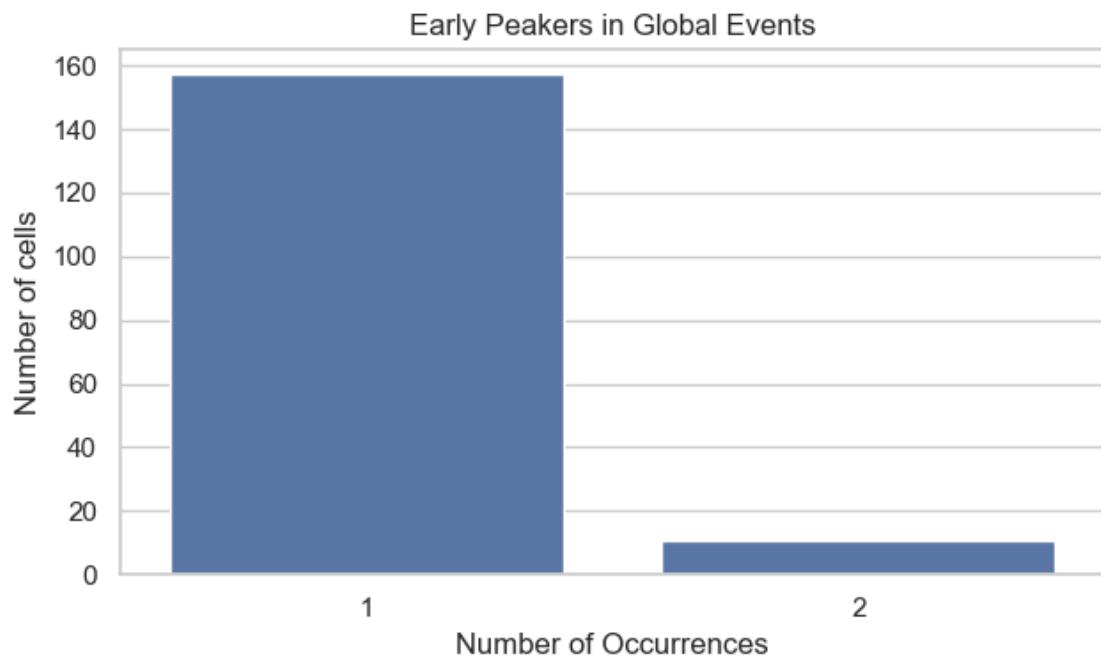
[2025-08-27 14:46:50] [INFO] calcium: Saved early peakers heatmap SVG to:

early\_peakers\_heatmap.svg

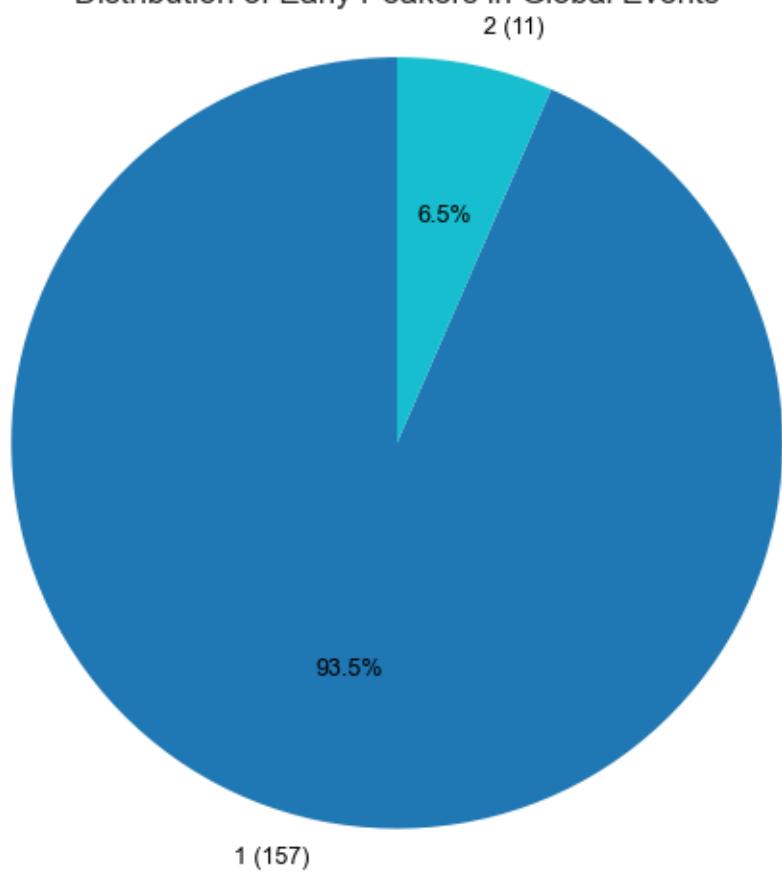
```
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
[0, 1],  
[0, 1],  
[1, 0],  
[1, 0],  
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[0,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





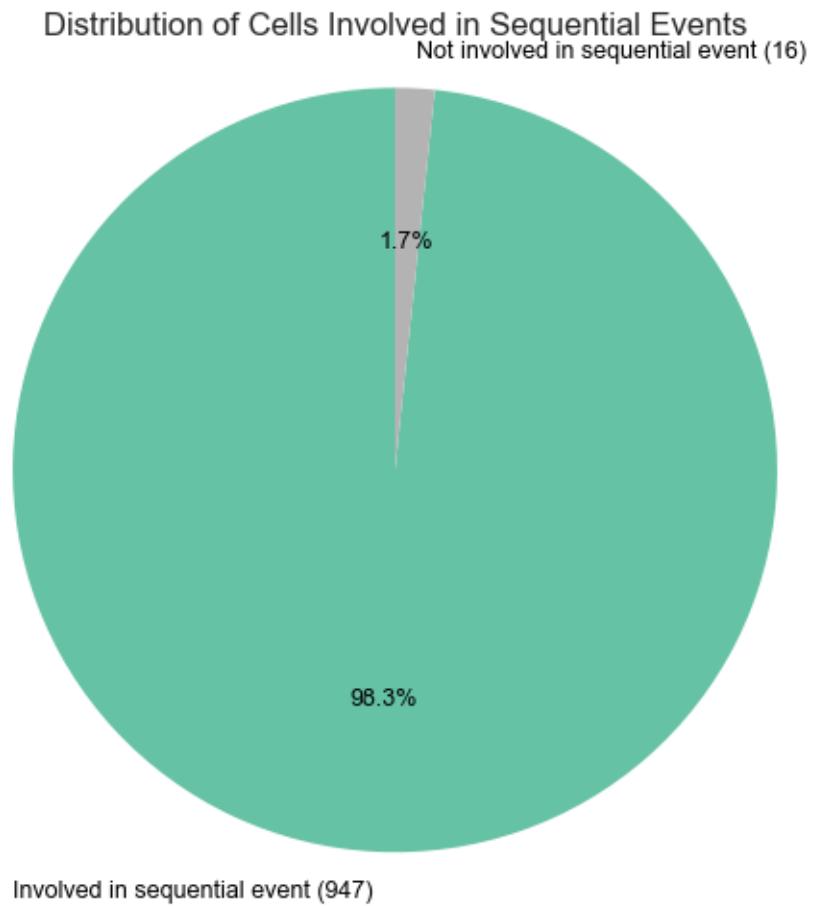


Distribution of Early Peakers in Global Events

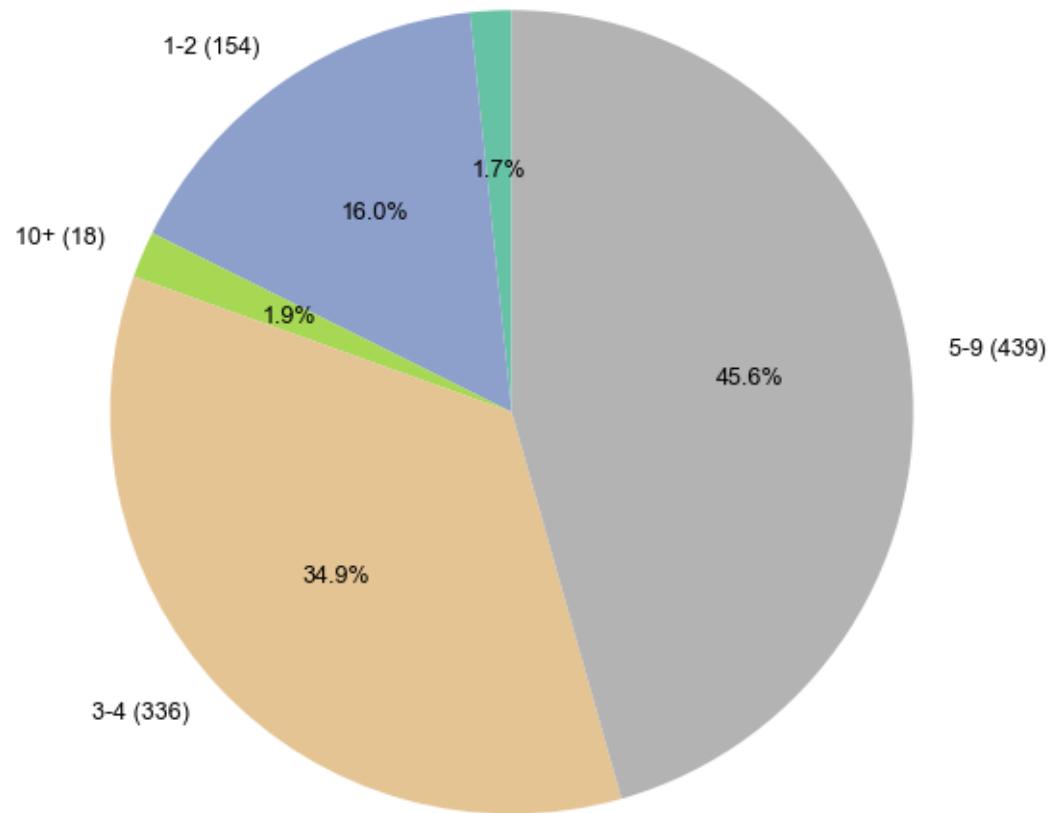


## 1.3 SEQUENTIAL EVENTS

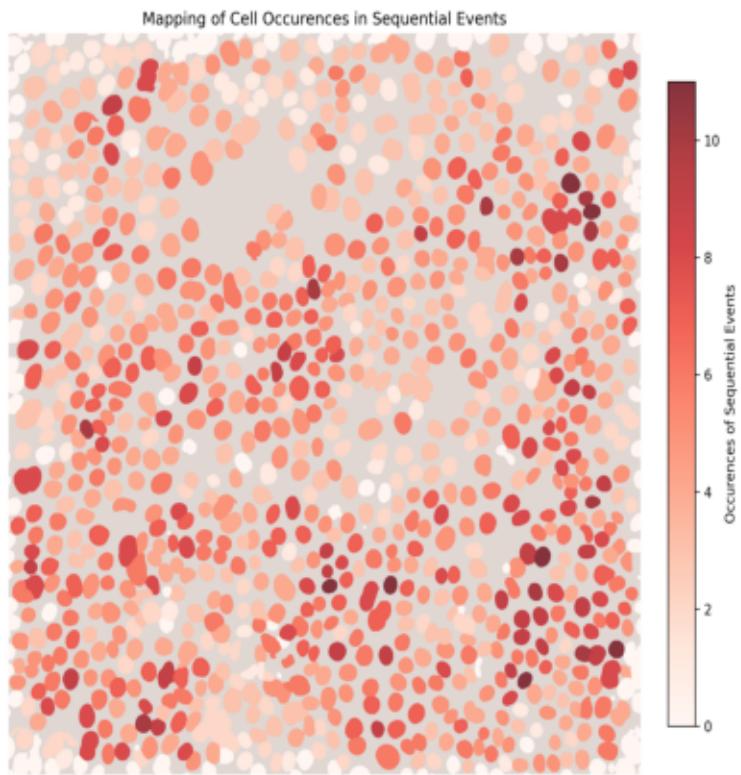
### 1.3.1 Cells Occurrences in sequential events



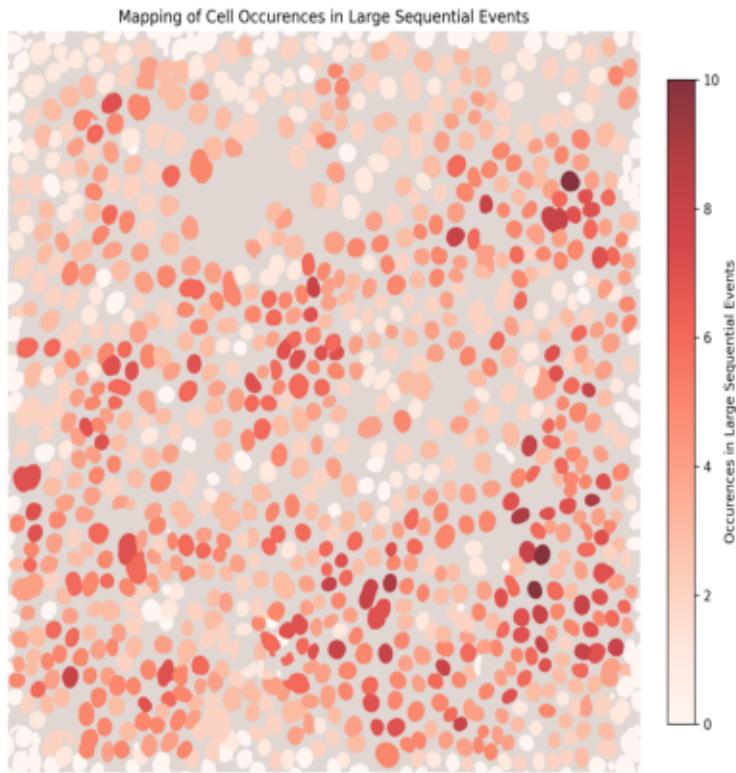
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

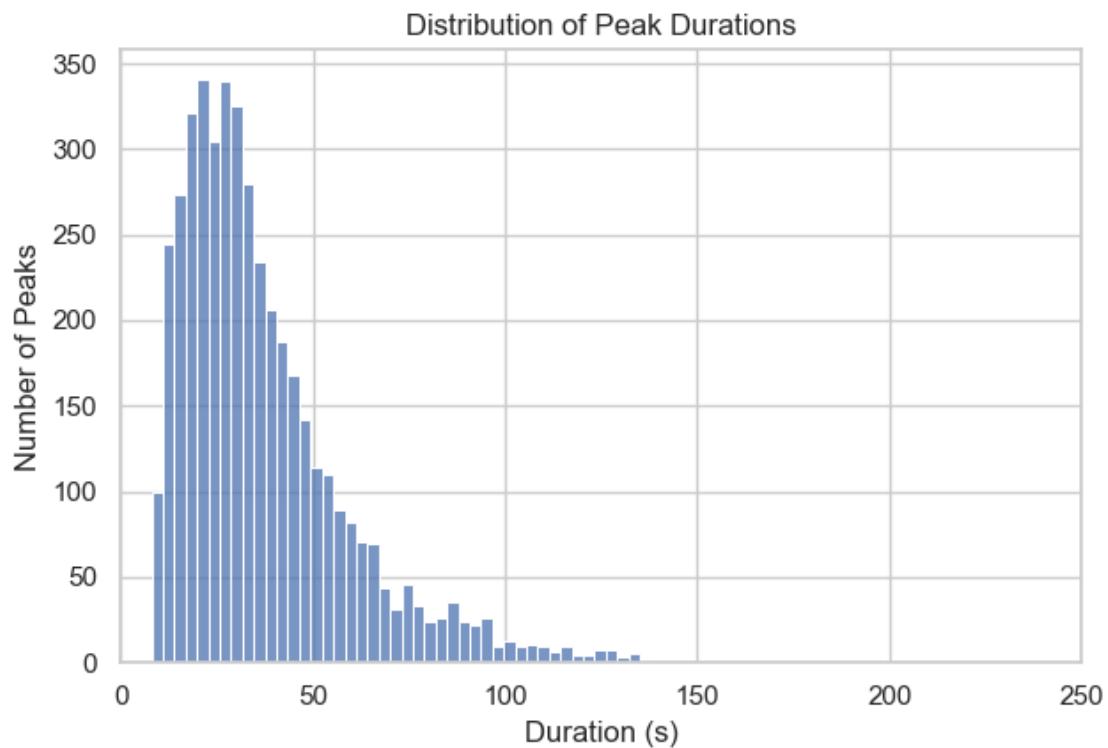


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



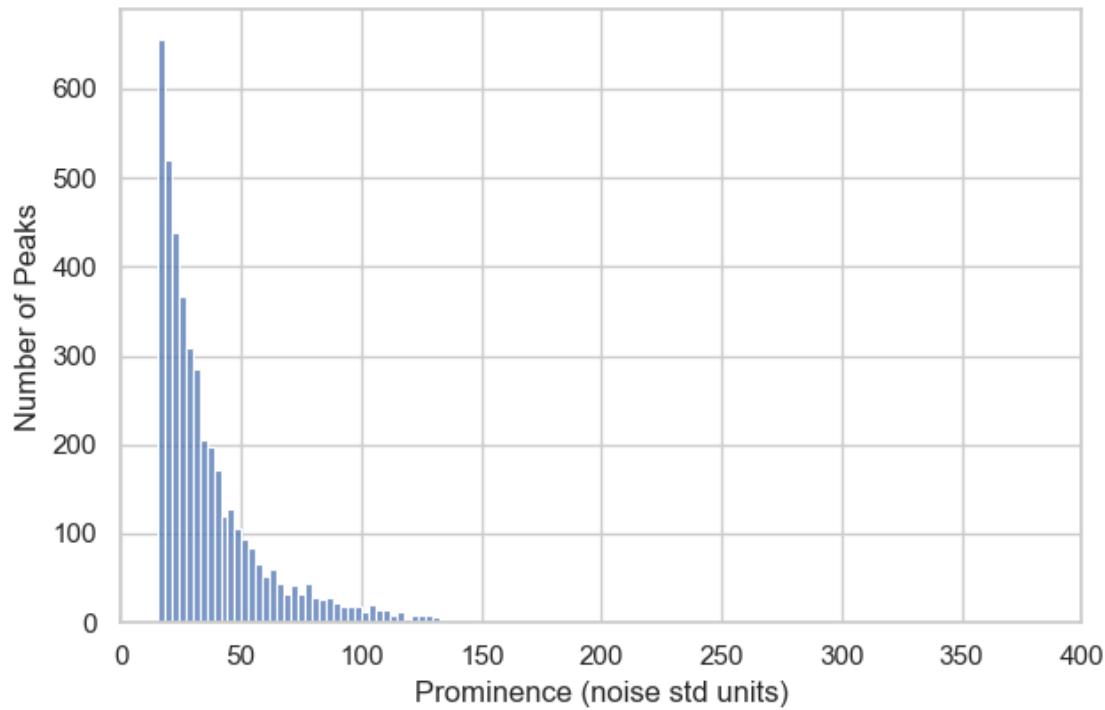
### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:46:52] [INFO] calcium: plot_histogram: removed 36 outliers out of 4450 on 'Duration (s)' (lower=-18, upper=138)
```

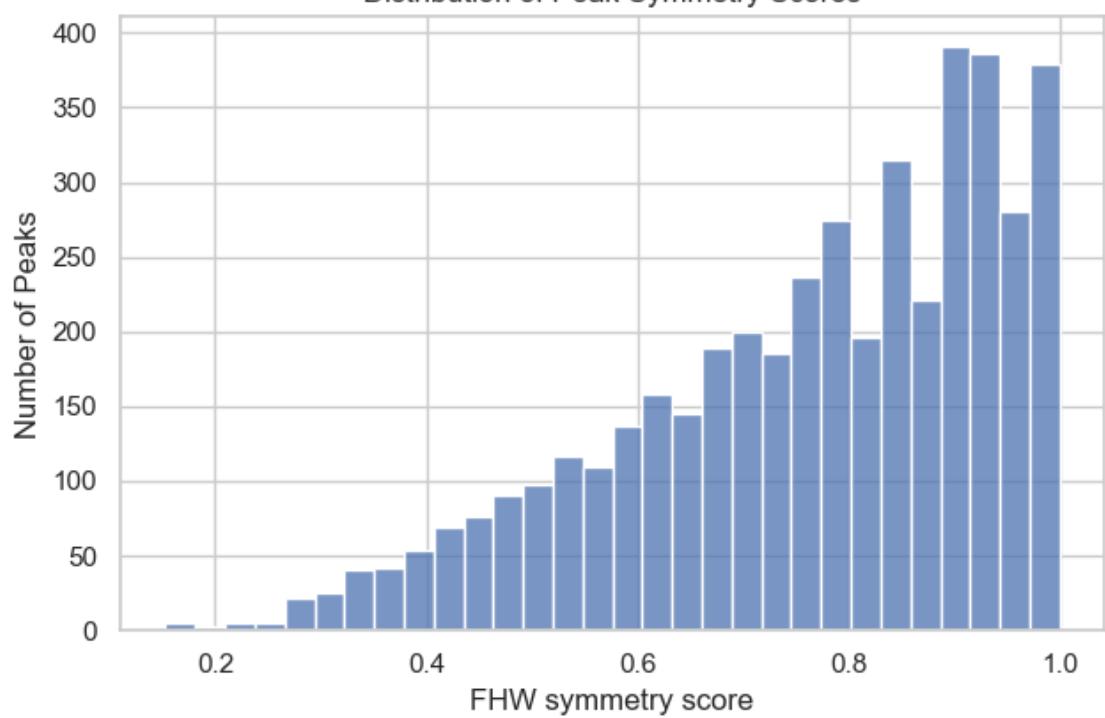


```
[2025-08-27 14:46:52] [INFO] calcium: plot_histogram: removed 116 outliers out  
of 4450 on 'Prominence (noise std units)' (lower=-17.45, upper=134.35)
```

Distribution of Peak Prominences

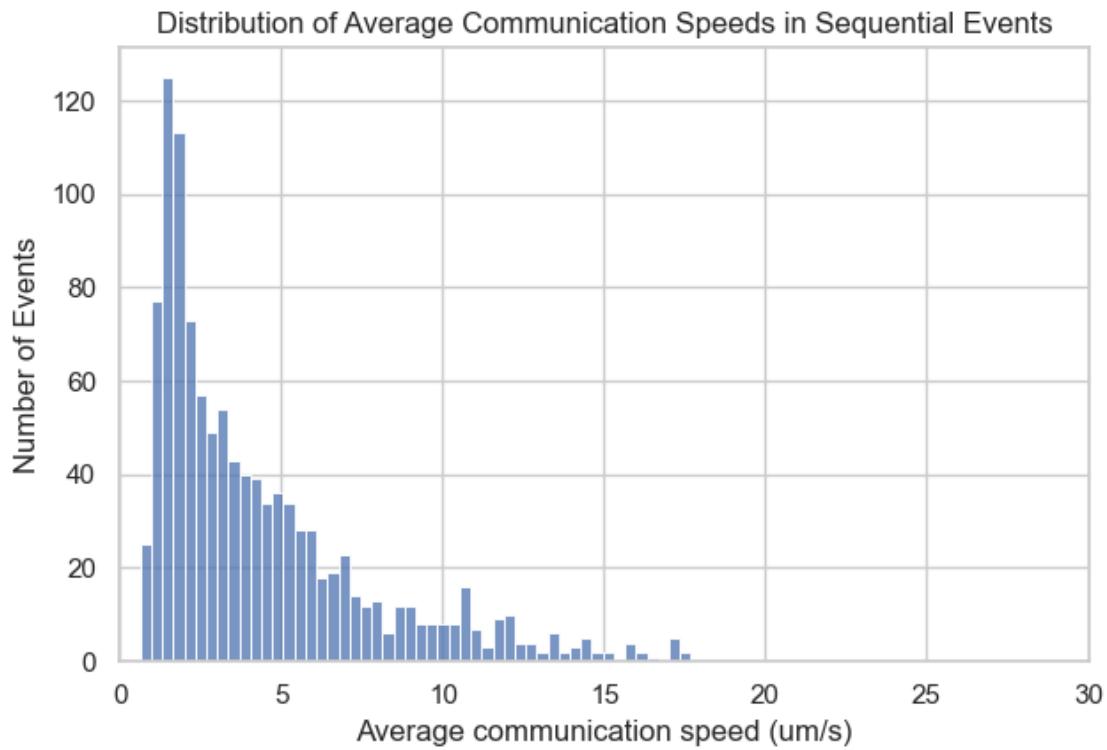


Distribution of Peak Symmetry Scores



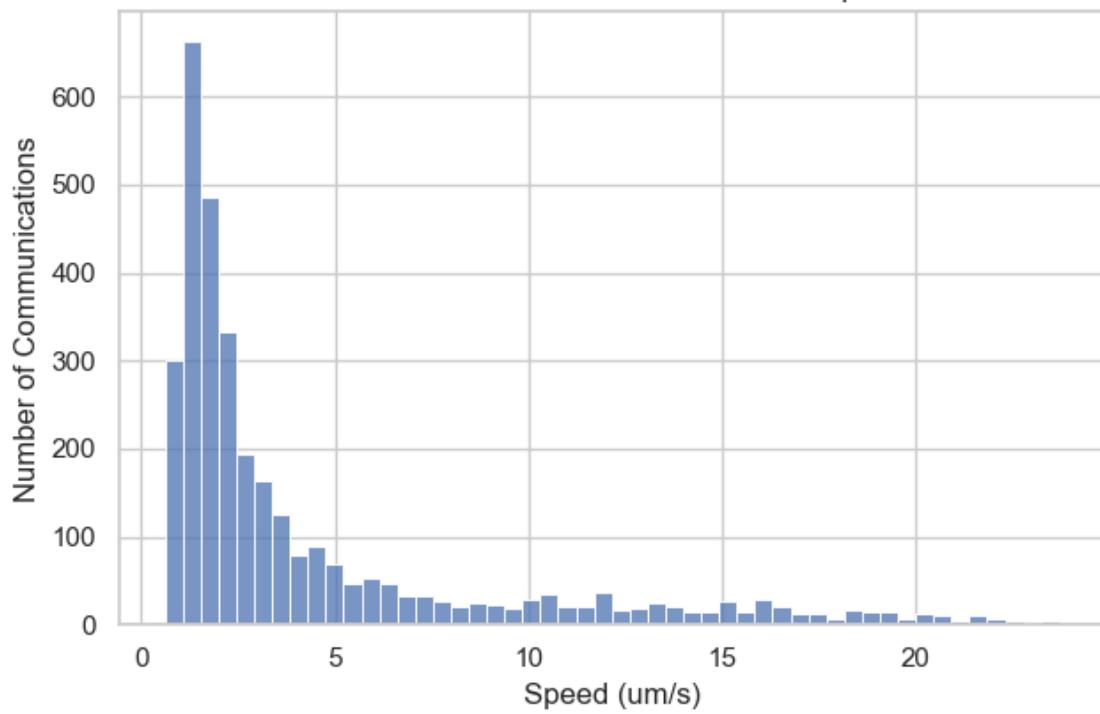
### 1.3.3 Cell-cell communication speed

[2025-08-27 14:46:52] [INFO] calcium: plot\_histogram: removed 19 outliers out of 1124 on 'Average communication speed (um/s)' (lower=-10.43, upper=18.13)

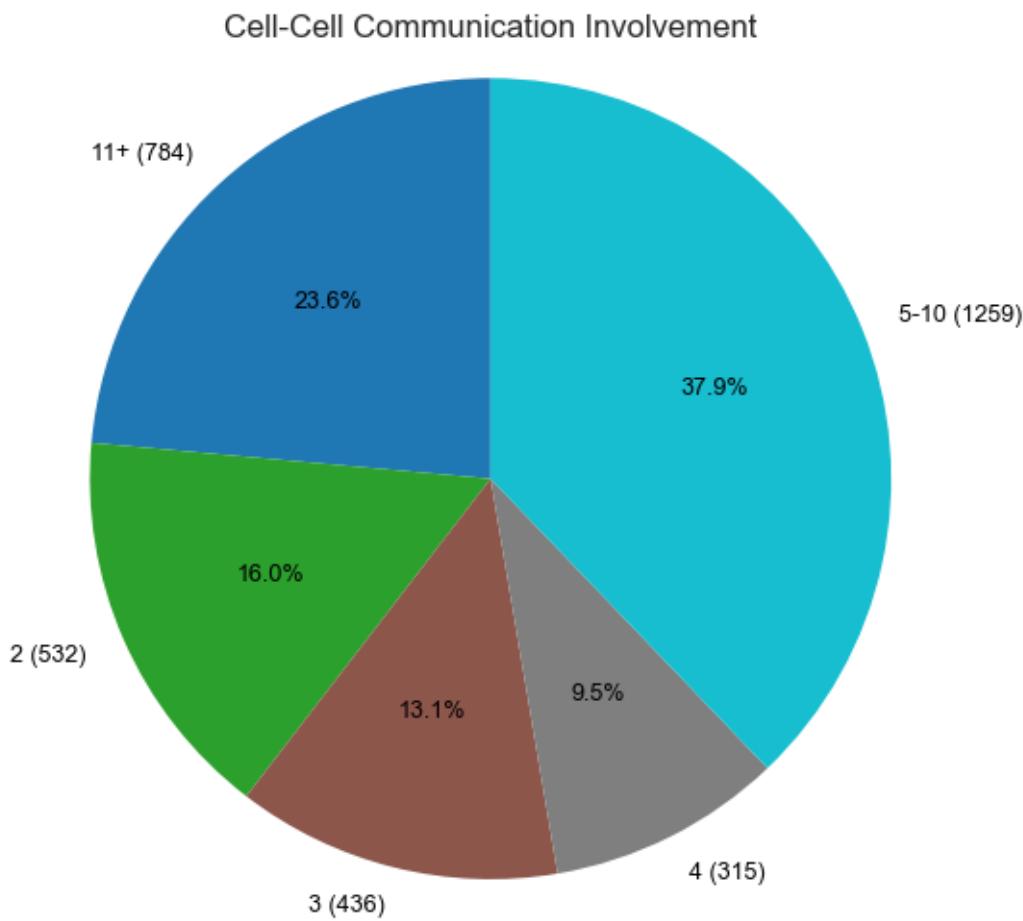


[2025-08-27 14:46:53] [INFO] calcium: plot\_histogram: removed 26 outliers out of 3326 on 'Speed (um/s)' (lower=-9.72, upper=23.76)

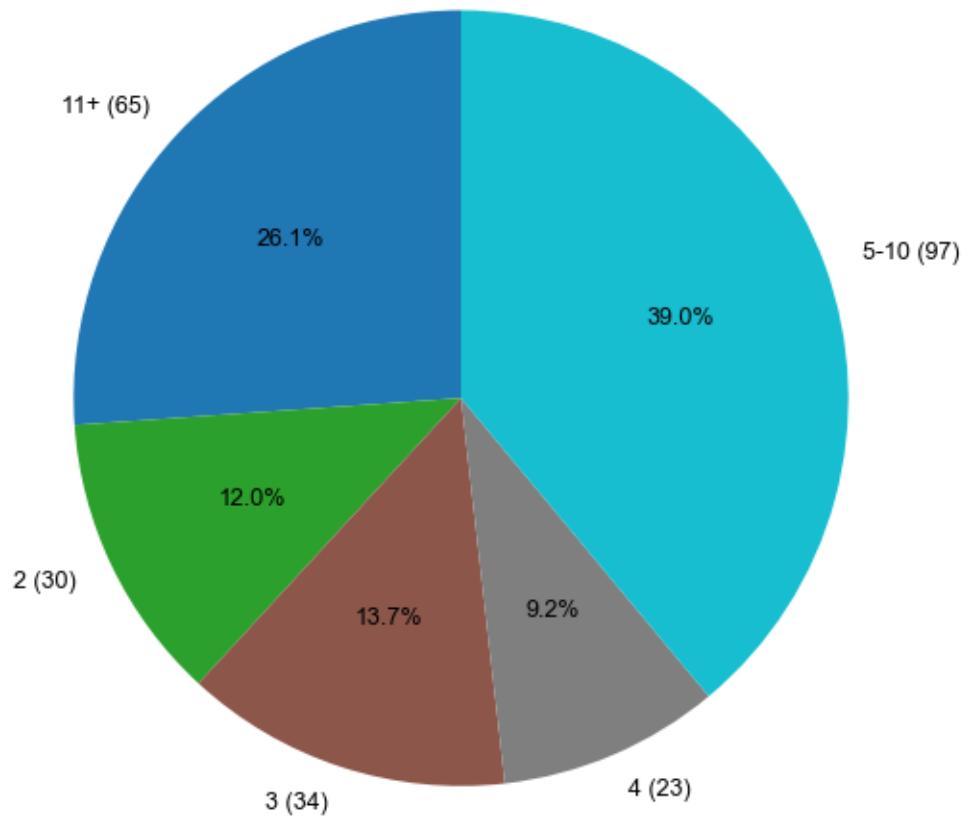
Distribution of Cell-Cell Communication Speeds



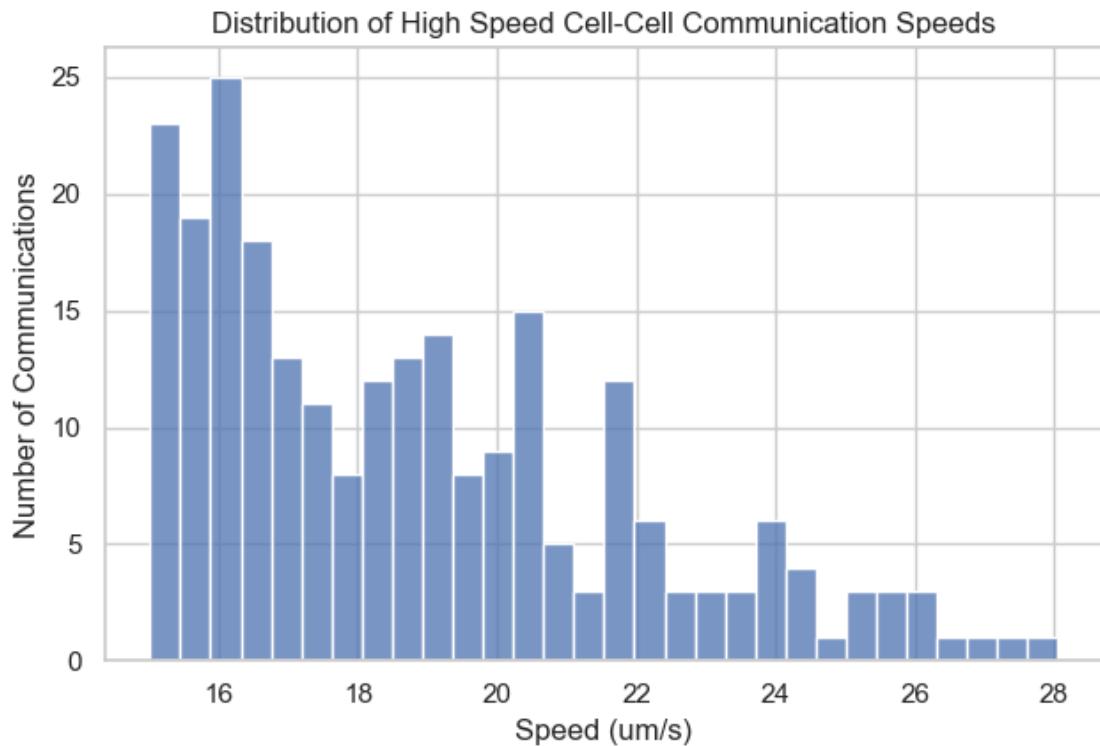
#### 1.3.4 Double distribution in cell-cell communication speeds



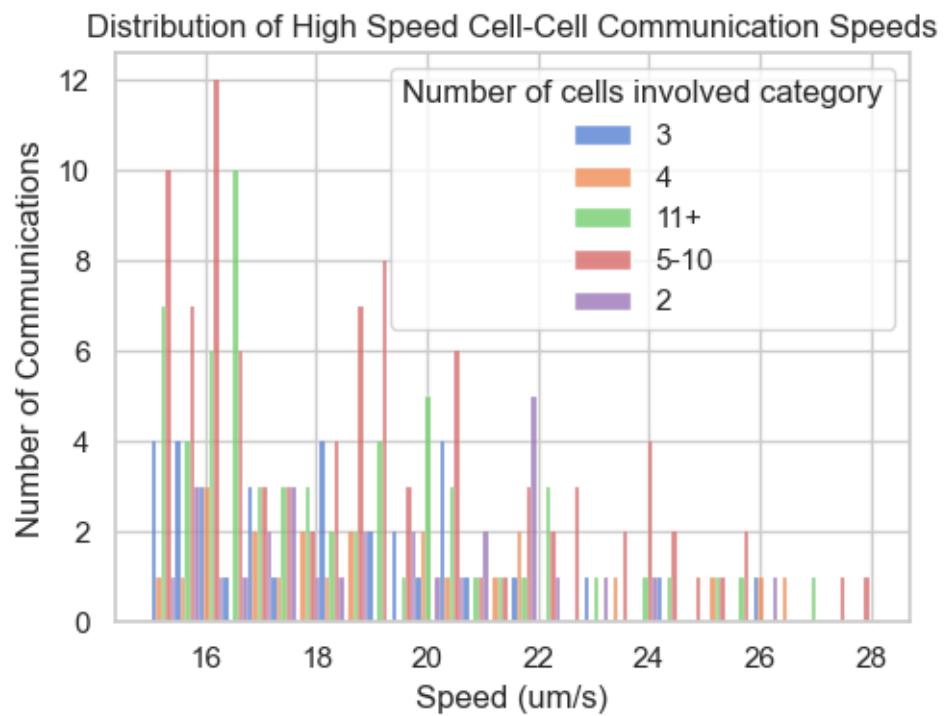
### High Speed Cell-Cell Communication Involvement



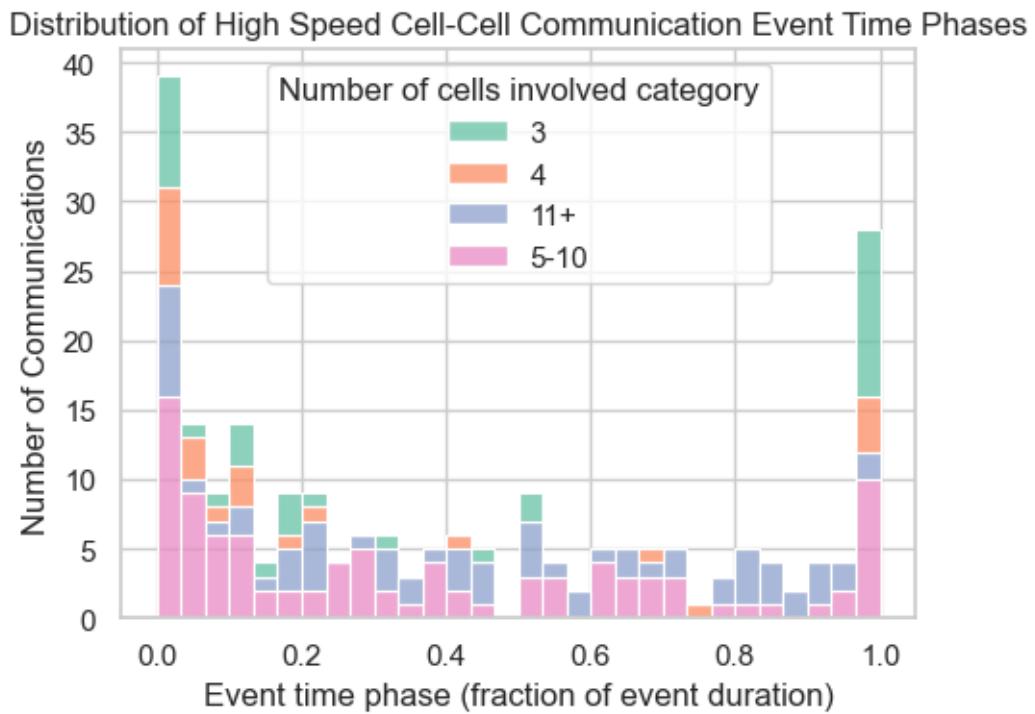
[2025-08-27 14:46:53] [INFO] calcium: plot\_histogram: removed 2 outliers out of 249 on 'Speed (um/s)' (lower=3.08, upper=33.81)



```
[2025-08-27 14:46:53] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 249 on 'Speed (um/s)' (lower=3.08, upper=33.81)
```

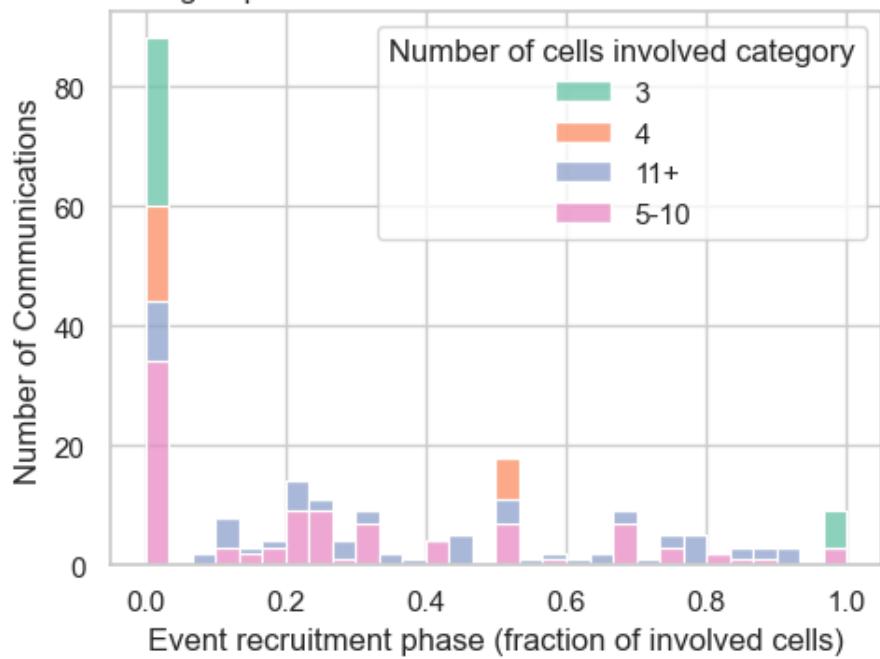


```
[2025-08-27 14:46:53] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 219 on 'Event time phase (fraction of event duration)' (lower=-1.815, upper=2.595)
```

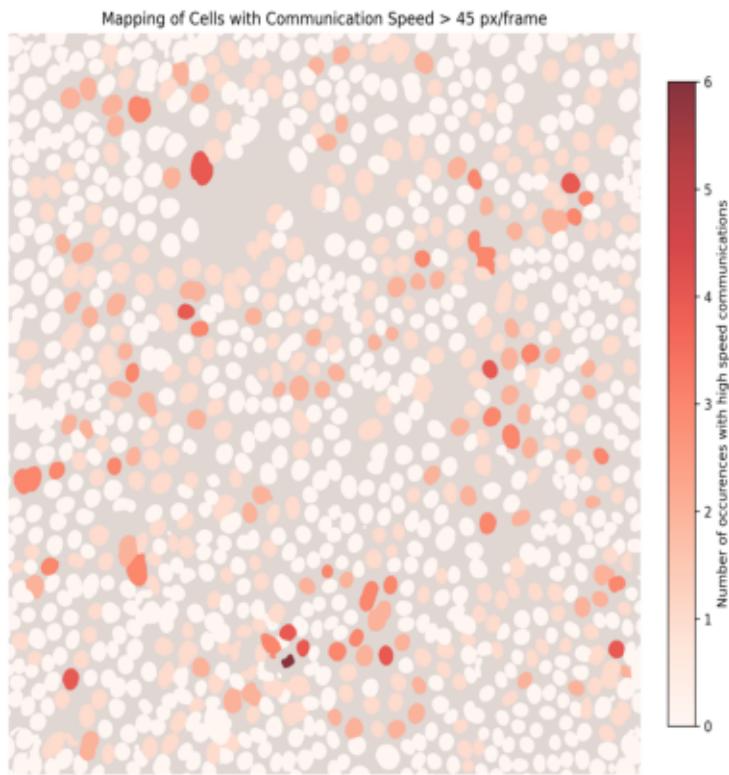


```
[2025-08-27 14:46:54] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 219 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)
```

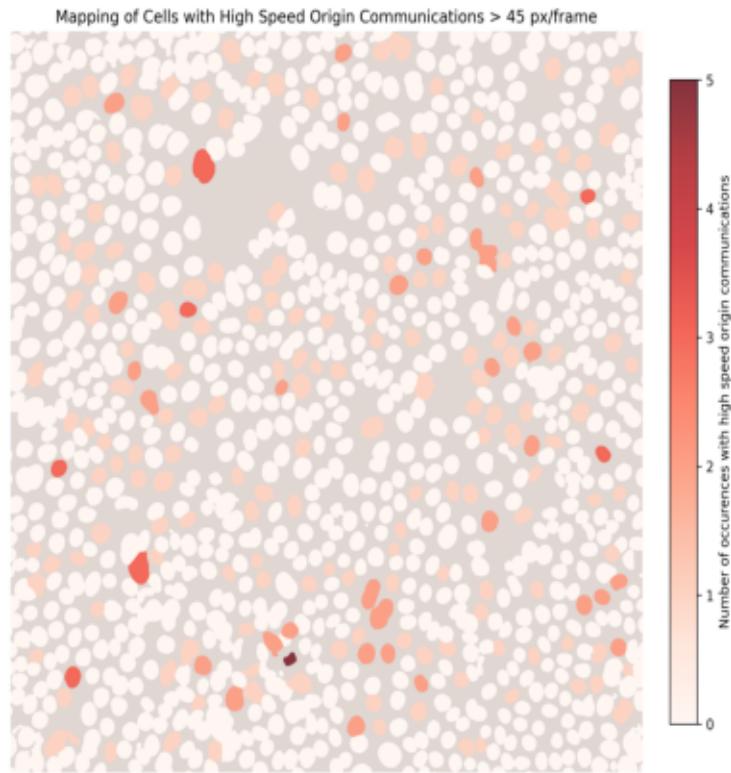
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	3015469175264	3	411	5	
3	3015469174160	4	1404	11	
9	3015469180400	6	1224	1	
23	3015469181888	7	602	0	
24	3015469184816	7	595	0	
...	...	...	...	...	
3130	3015542972256	1017	1446	7	
3138	3015542976960	1021	1451	7	
3224	3015557019776	1058	1555	0	
3268	3015557020544	1085	1482	0	
3304	3015480062736	1107	1544	0	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
0	450	5	707.0	707.0	
3	1449	9	1236.0	1236.0	
9	1171	1	62.0	62.0	
23	640	0	20.0	20.0	
24	592	0	10.0	10.0	
...	...	...	...	...	
3130	1406	8	582.0	583.0	
3138	1483	3	911.0	912.0	
3224	1531	0	19.0	20.0	
3268	1516	0	23.0	24.0	
3304	1585	1	56.0	57.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
0	0.0	20.46	20.46		
3	0.0	26.25	26.25		
9	0.0	16.46	16.46		
23	0.0	15.99	15.99		
24	0.0	15.36	15.36		
...	...	...	...	...	
3130	1.0	16.78	16.78		
3138	1.0	18.51	18.51		
3224	1.0	16.24	16.24		
3268	1.0	17.11	17.11		
3304	1.0	15.23	15.23		
	Event time phase (fraction of event duration)	\			
0		0.00			
3		0.75			
9		0.20			
23		0.29			
24		0.00			
...		...			
3130		0.17			
3138		0.65			
3224		0.11			
3268		NaN			
3304		0.06			
	Event recruitment phase (fraction of involved cells)	dataset	\		
0		0.00	20250424_IS3		
3		0.00	20250424_IS3		
9		0.00	20250424_IS3		
23		0.18	20250424_IS3		
24		0.00	20250424_IS3		
...		...	...		
3130		0.00	20250424_IS3		
3138		0.67	20250424_IS3		

3224		0.00	20250424_IS3
3268		NaN	20250424_IS3
3304		0.00	20250424_IS3

	Number of cells involved	category	Speed category
0		3	High speed
3		4	High speed
9		11+	High speed
23		11+	High speed
24		11+	High speed
...		...	...
3130		3	High speed
3138		5-10	High speed
3224		5-10	High speed
3268		2	High speed
3304		3	High speed

[249 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
197		1	2
202		0	1
203		0	2
205		0	2
207		0	4
...	...	...	...
1576		0	4
1577		0	2
1578		0	2
1584		0	1
1585		0	2

[861 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	197	307.45	9.75
2	202	239.20	8.78
3	203	65.33	10.08
4	205	186.88	10.08
5	207	474.18	10.40
..	...	...	...
956	1574	264.23	490.10
958	1576	418.93	491.40
959	1577	430.30	491.40
961	1584	403.65	492.70
962	1585	362.70	493.35

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

0	10	True	2
2	9	True	2
3	3	True	1
4	6	True	1
5	11	True	2
..	..	..	..
956	9	True	2
958	9	True	2
959	8	True	2
961	7	True	2
962	12	True	2

Occurrences in global events as early peaker Early peaker event IDs \		
0	0	[]
2	1	[1]
3	0	[]
4	0	[]
5	1	[2]
..	..	..
956	0	[]
958	1	[1]
959	0	[]
961	0	[]
962	0	[]

Occurrences in sequential events \	
0	4
2	2
3	1
4	4
5	6
..	..
956	2
958	5
959	5
961	4
962	3

Occurrences in sequential events as origin \	
0	1
2	1
3	1
4	2
5	2
..	..
956	1
958	3
959	2

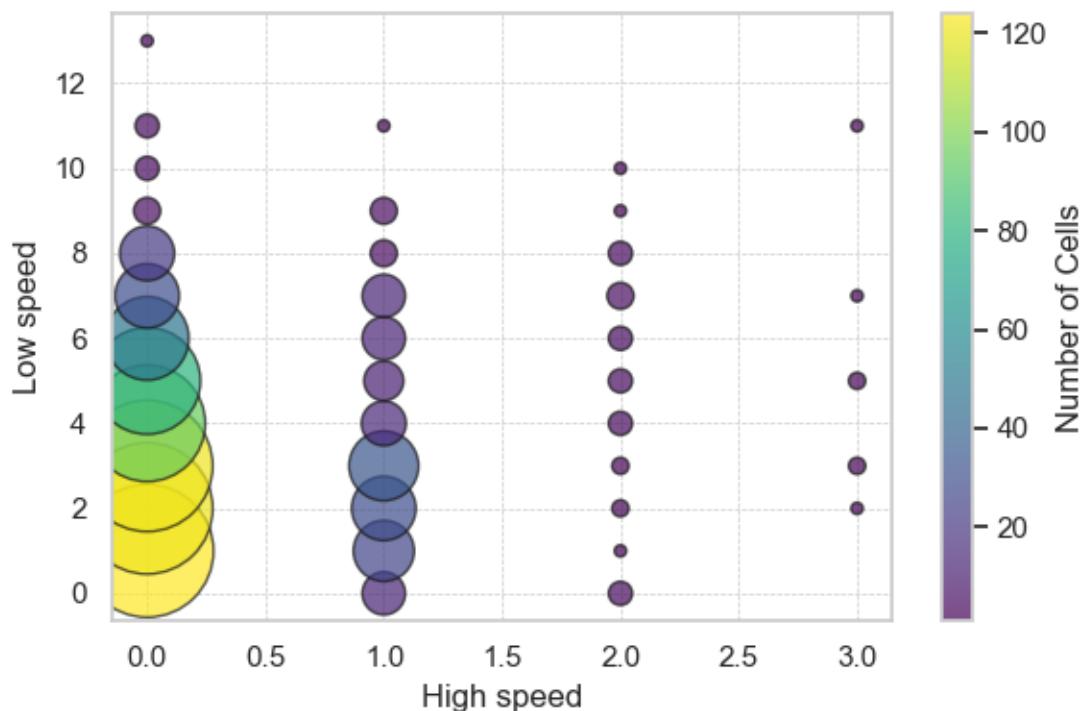
961		1	
962		1	
Occurrences in individual events Peak frequency (Hz) Periodicity score \			
0	4	0.0059	0.76
2	4	0.0053	0.73
3	1	0.0018	0.67
4	1	0.0035	0.70
5	2	0.0065	0.66
..	...	...	...
956	4	0.0053	0.62
958	1	0.0053	0.62
959	1	0.0047	0.59
961	1	0.0041	0.82
962	6	0.0071	0.57
Neighbor count Neighbors (labels) dataset \			
0	4	[213, 226, 267, 274]	20250424_IS3
2	3	[211, 232, 248]	20250424_IS3
3	4	[216, 219, 225, 231]	20250424_IS3
4	4	[208, 215, 234, 260]	20250424_IS3
5	4	[221, 240, 250, 251]	20250424_IS3
..	...	...	...
956	2	[1526, 1539]	20250424_IS3
958	4	[1530, 1535, 1577, 1584]	20250424_IS3
959	3	[1530, 1565, 1576]	20250424_IS3
961	4	[1535, 1538, 1576, 1578]	20250424_IS3
962	2	[1544, 1546]	20250424_IS3
Involved in sequential event Occurrences in sequential events category \			
0	Involved in sequential event		3-4
2	Involved in sequential event		1-2
3	Involved in sequential event		1-2
4	Involved in sequential event		3-4
5	Involved in sequential event		5-9
..	...	...	...
956	Involved in sequential event		1-2
958	Involved in sequential event		5-9
959	Involved in sequential event		5-9
961	Involved in sequential event		3-4
962	Involved in sequential event		3-4
High speed Low speed			
0	1.0	2.0	
2	0.0	1.0	
3	0.0	2.0	
4	0.0	2.0	
5	0.0	4.0	

```

...
956      0.0      1.0
958      0.0      4.0
959      0.0      2.0
961      0.0      1.0
962      0.0      2.0

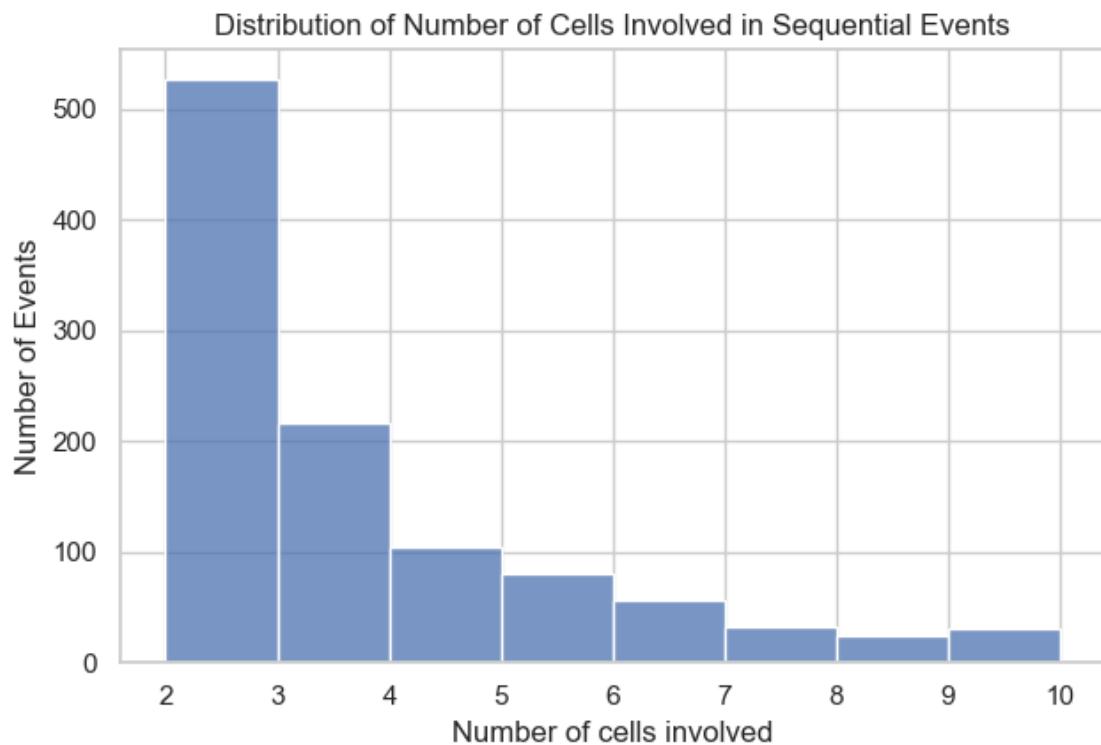
```

[857 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

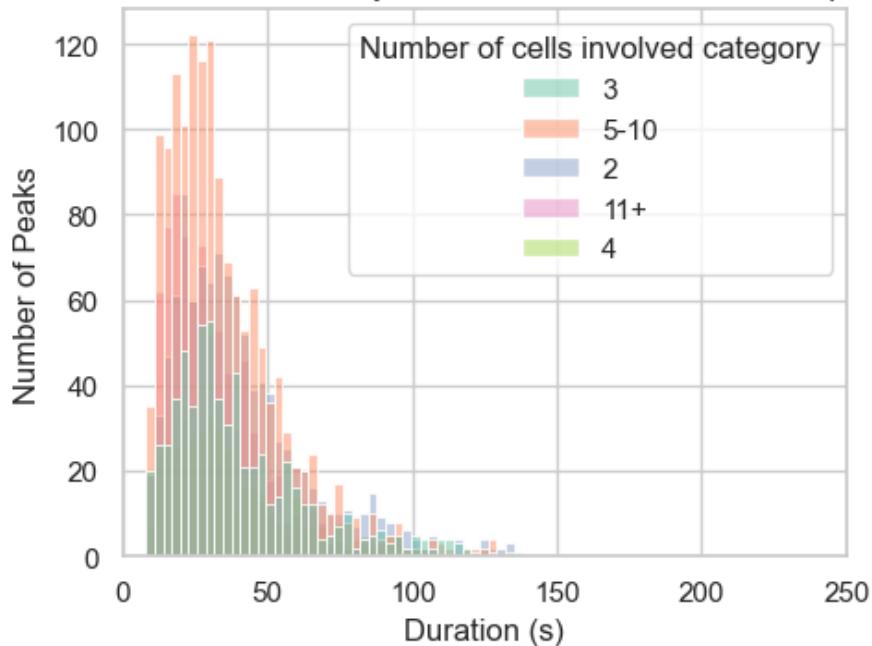
[2025-08-27 14:46:56] [INFO] calcium: plot\_histogram: removed 51 outliers out of 1124 on 'Number of cells involved' (lower=-4, upper=10)



### 1.3.6 Influence of cell count per event on statistics

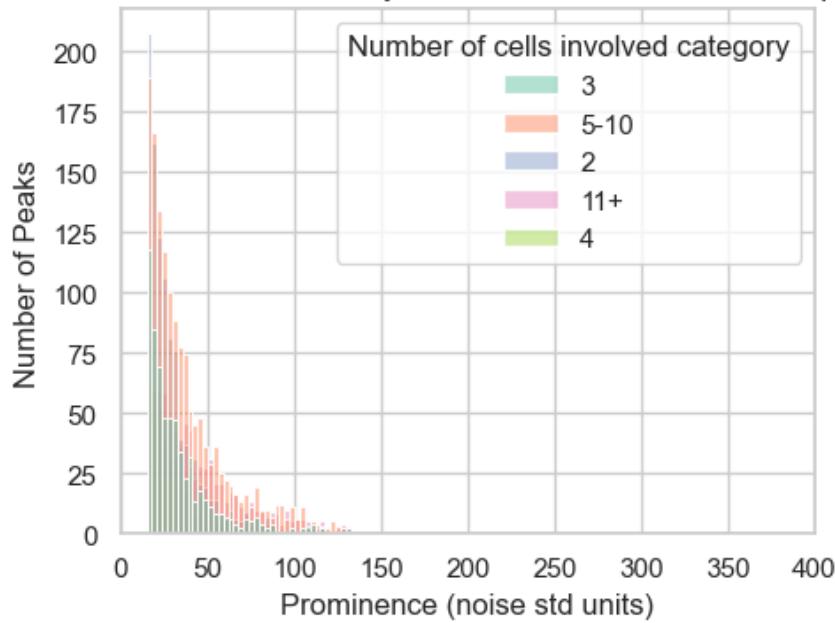
```
[2025-08-27 14:46:56] [INFO] calcium: plot_histogram_by_group: removed 36 outliers out of 4450 on 'Duration (s)' (lower=-18, upper=138)
```

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

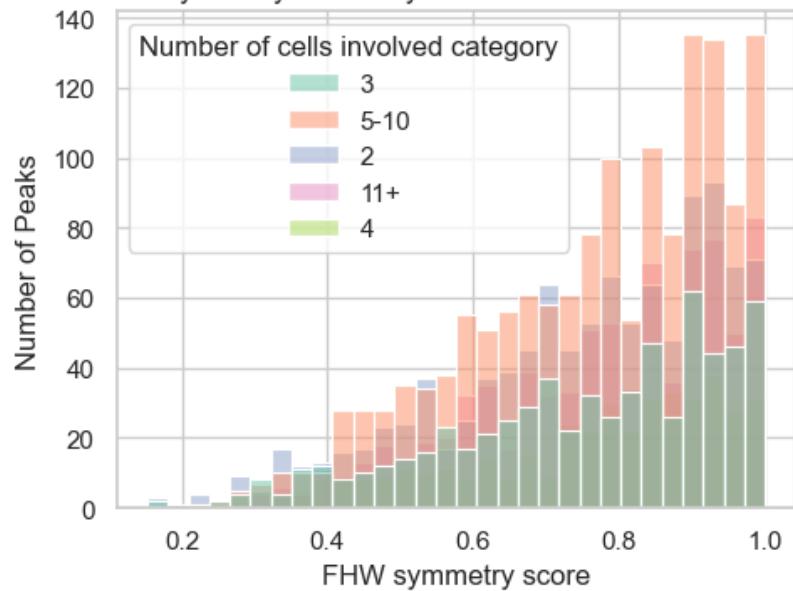


```
[2025-08-27 14:46:57] [INFO] calcium: plot_histogram_by_group: removed 116 outliers out of 4450 on 'Prominence (noise std units)' (lower=-17.45, upper=134.35)
```

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

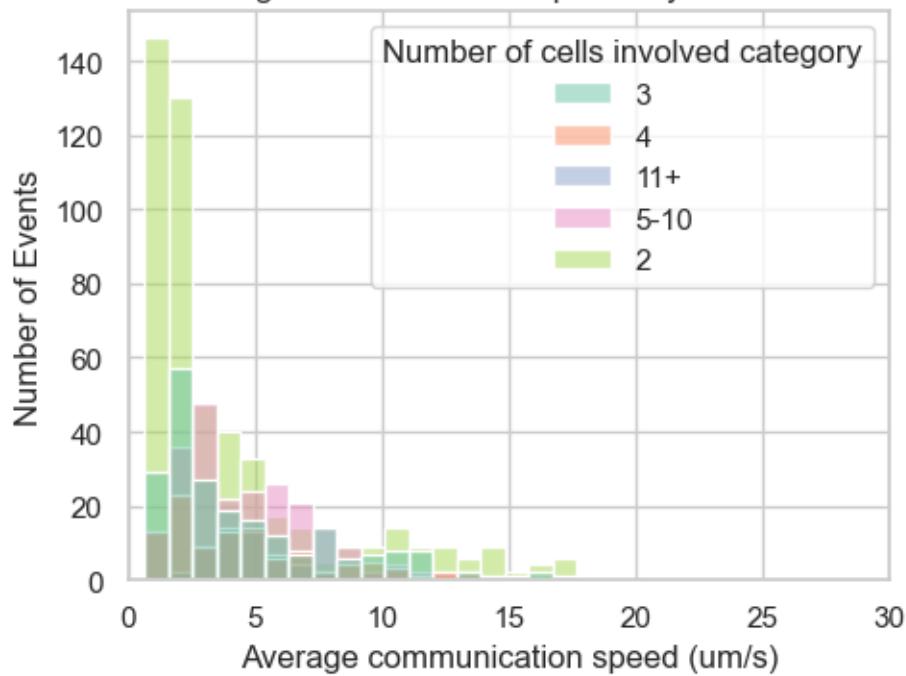


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



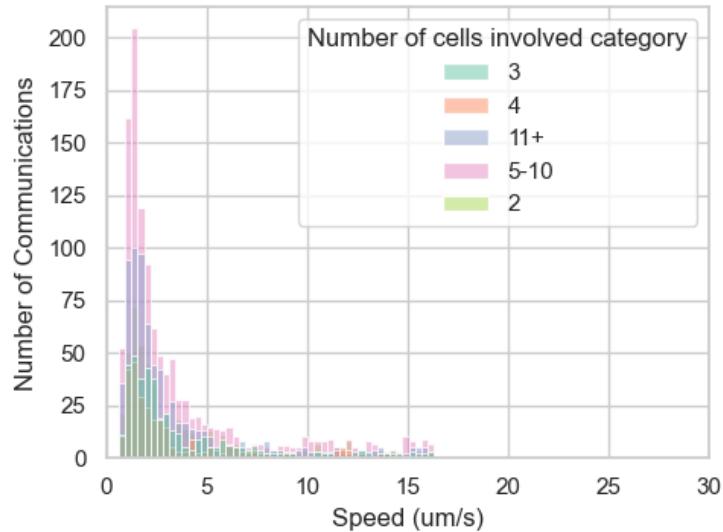
```
[2025-08-27 14:46:57] [INFO] calcium: plot_histogram_by_group: removed 19 outliers out of 1124 on 'Average communication speed (um/s)' (lower=-10.43, upper=18.13)
```

Distribution of Average Communication Speeds by Number of Cells Involved



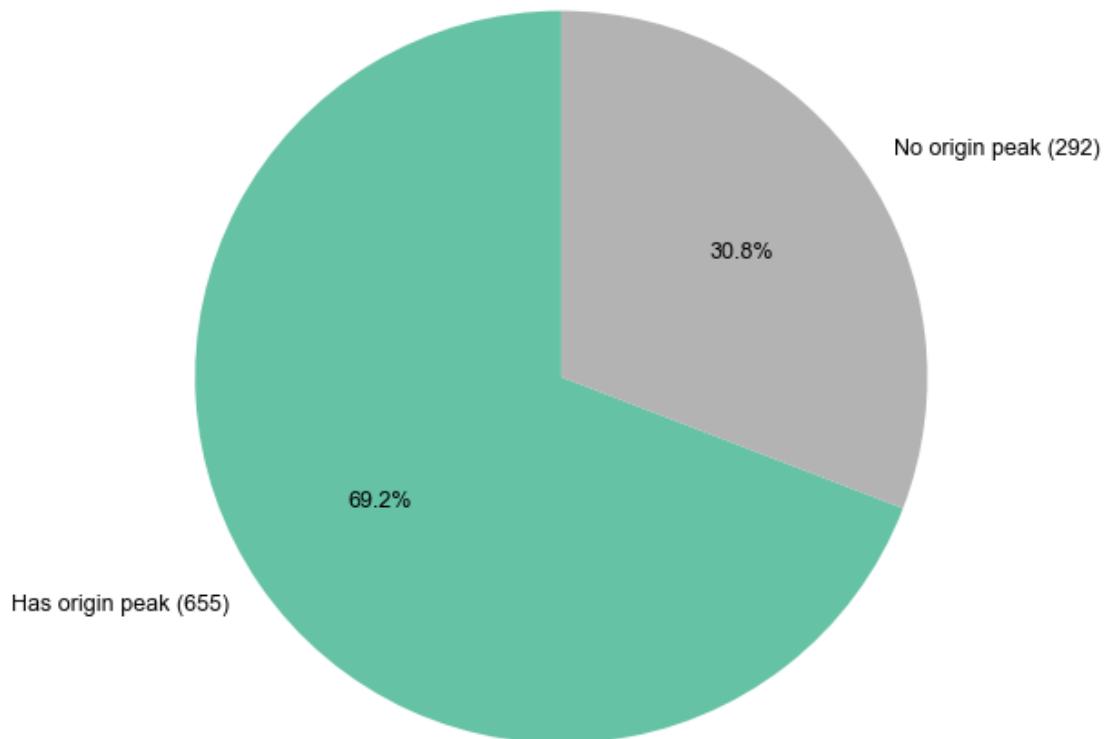
[2025-08-27 14:46:57] [INFO] calcium: plot\_histogram\_by\_group: removed 182 outliers out of 3326 on 'Speed (um/s)' (lower=-9.72, upper=16.32)

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

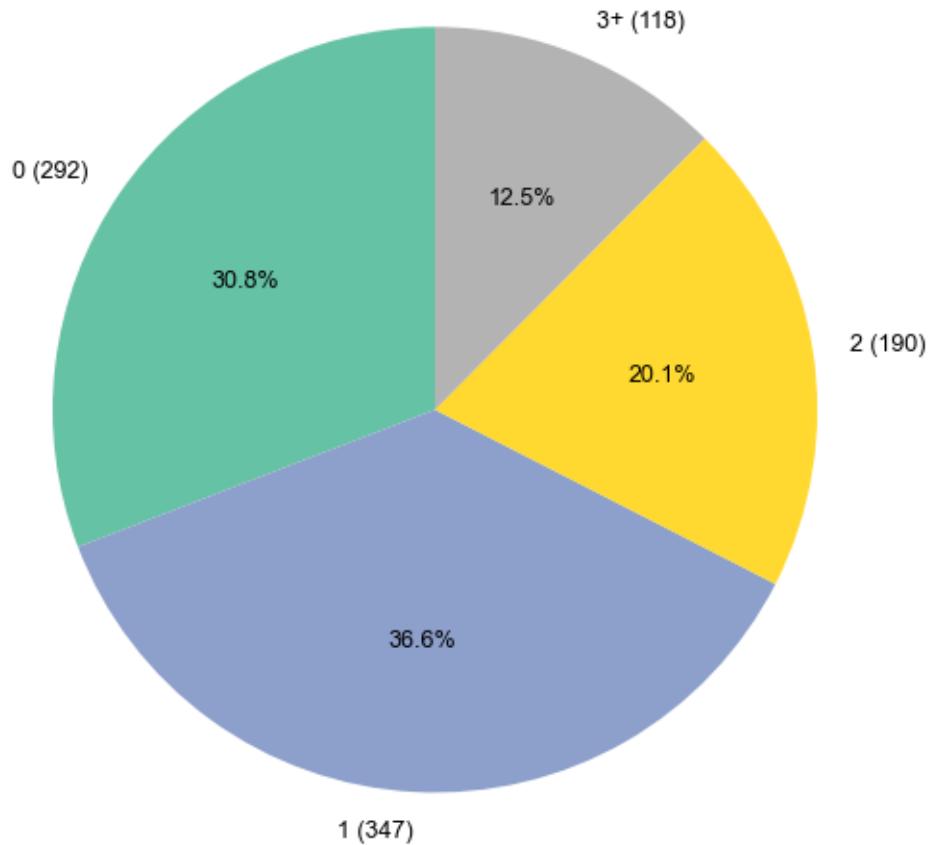


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

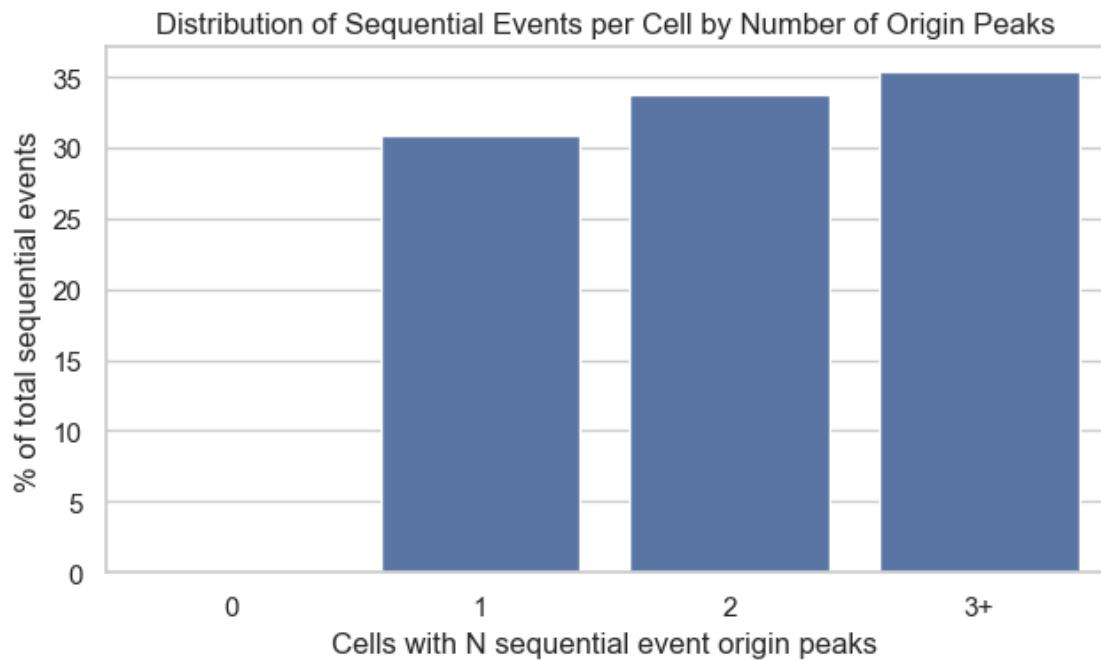


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)

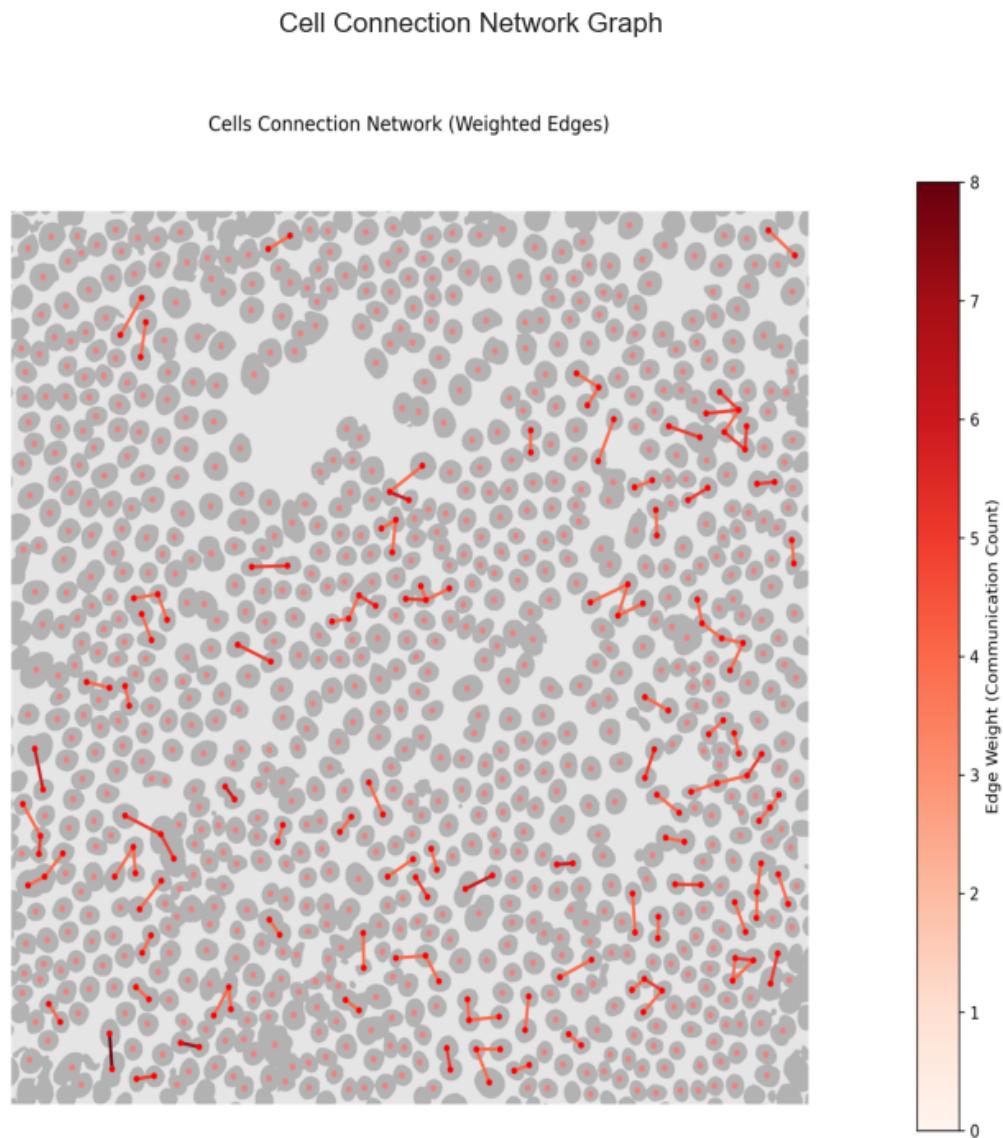


```
[2025-08-27 14:46:58] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS3\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (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\\20250424\\Output\\IS3\\cell-mapping\\cell\_Occurrences\_in\_origin\_seq\_events\_overlay.png'

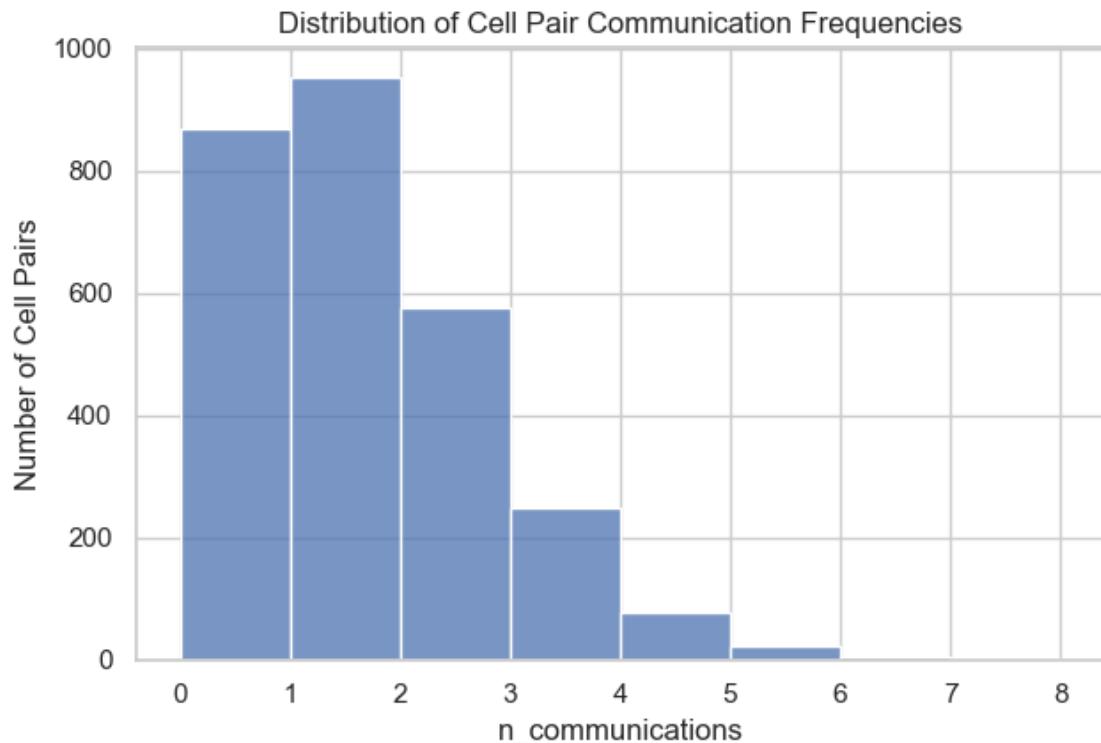


### 1.3.8 Connection network between cells



### 1.3.9 Pair/Trios with high communication networks

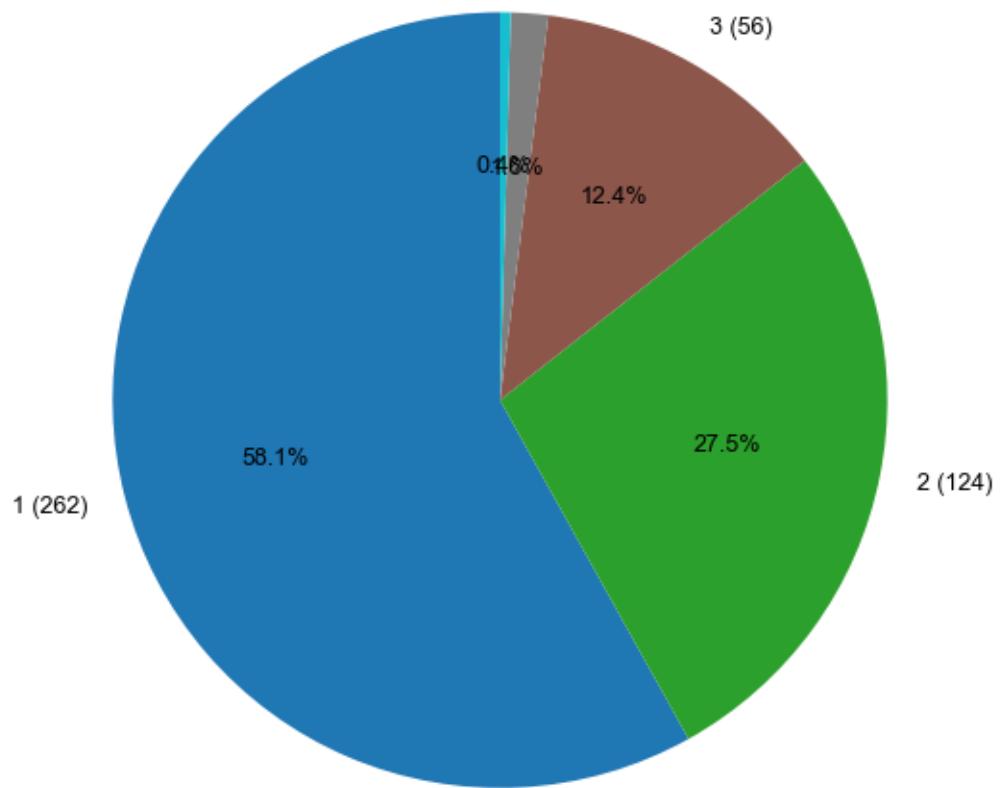
```
[2025-08-27 14:46:59] [INFO] calcium: build_neighbor_pair_stats: built 2754 pairs across 1 datasets (mean distance=17.47 um)
```

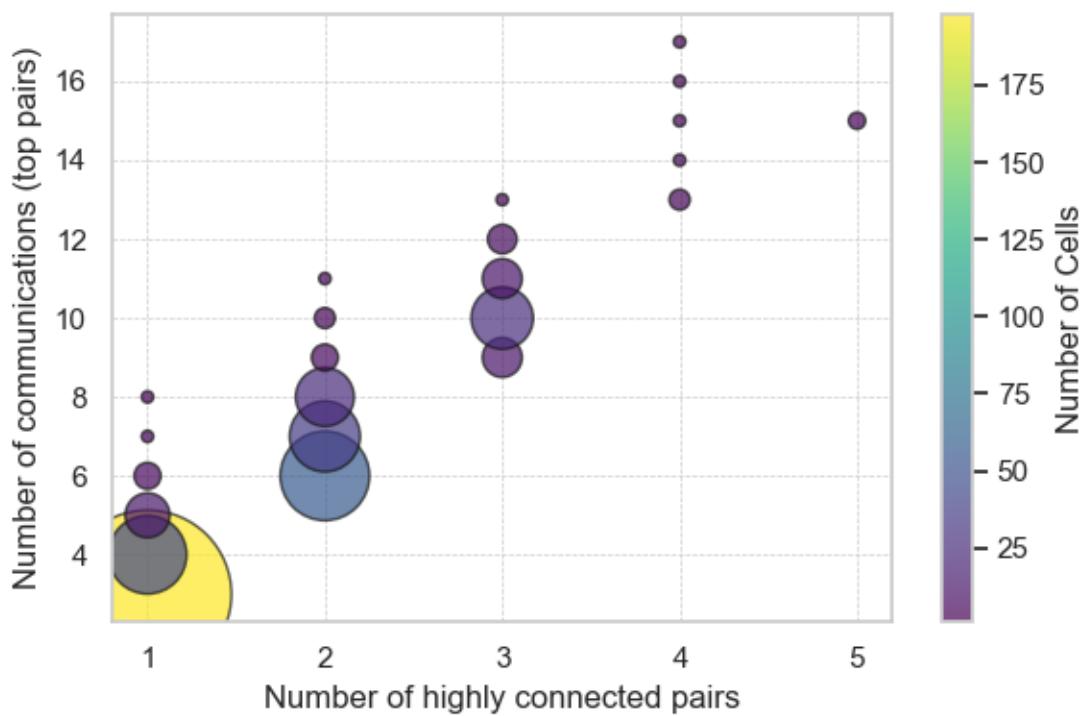
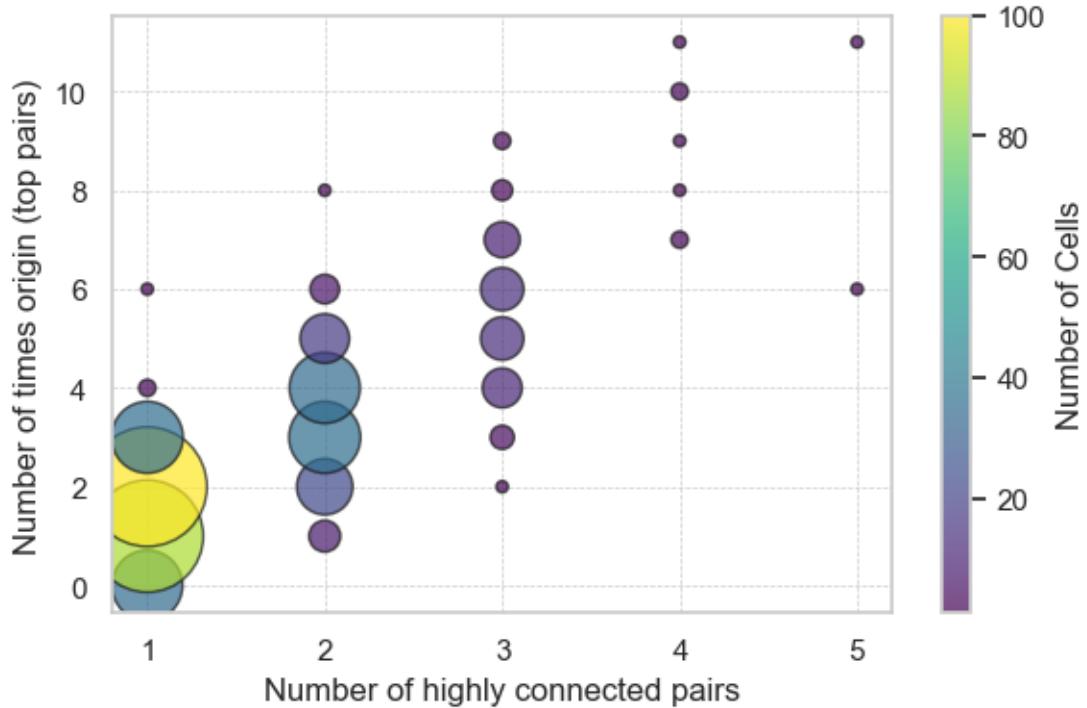


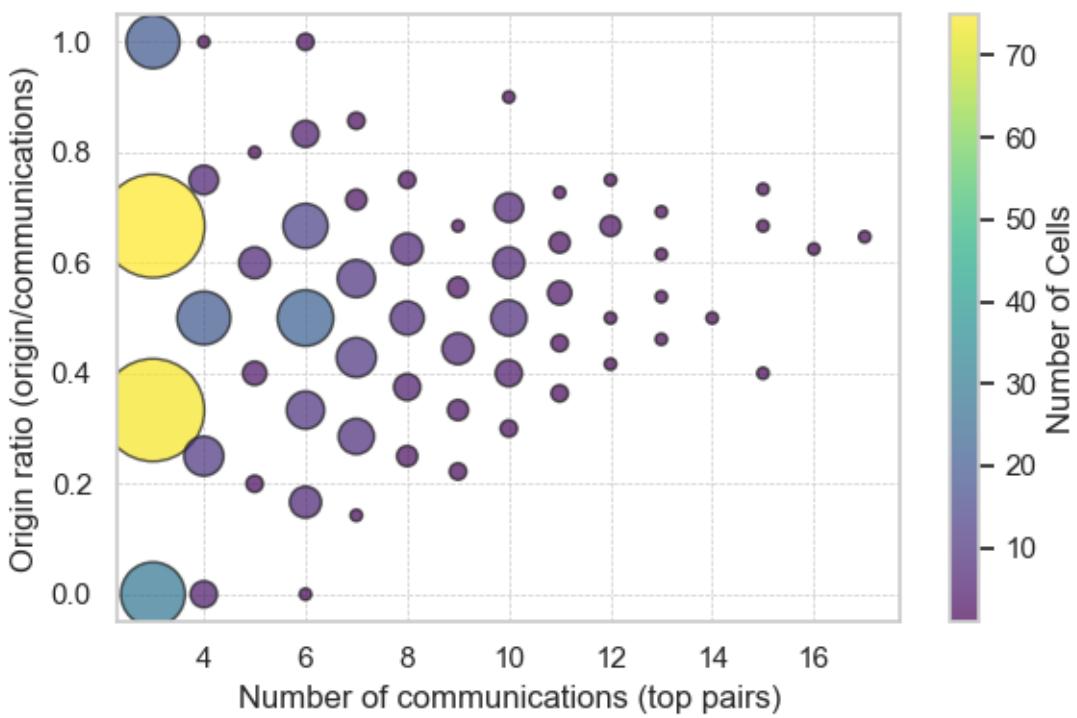
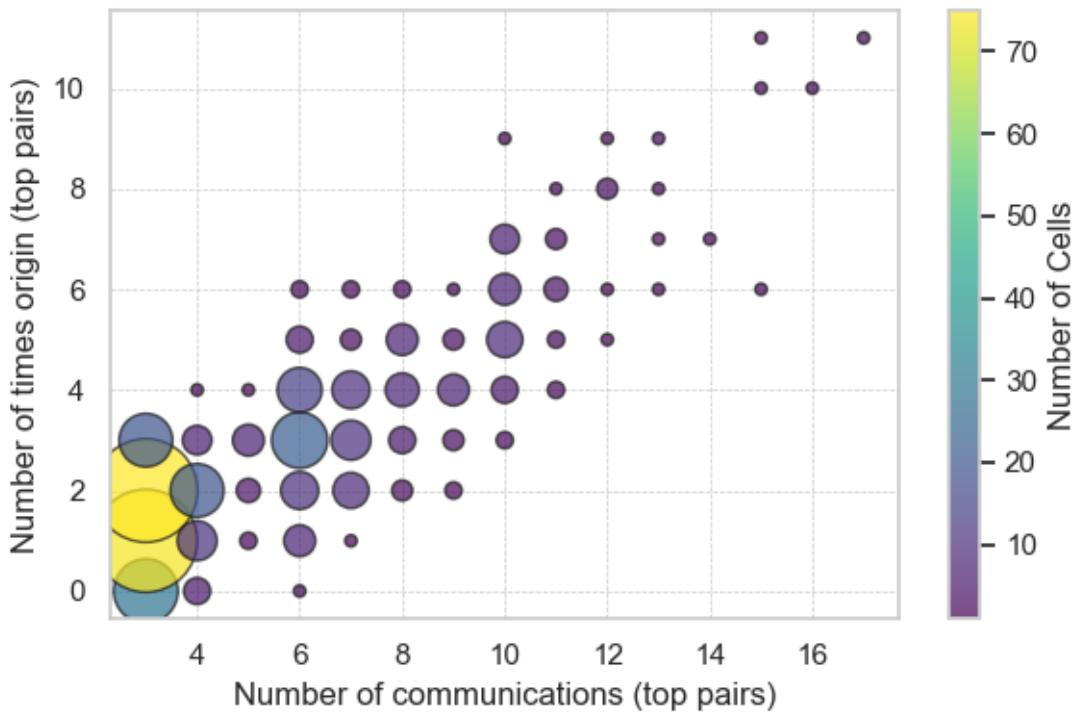
95th percentile threshold: 3.0

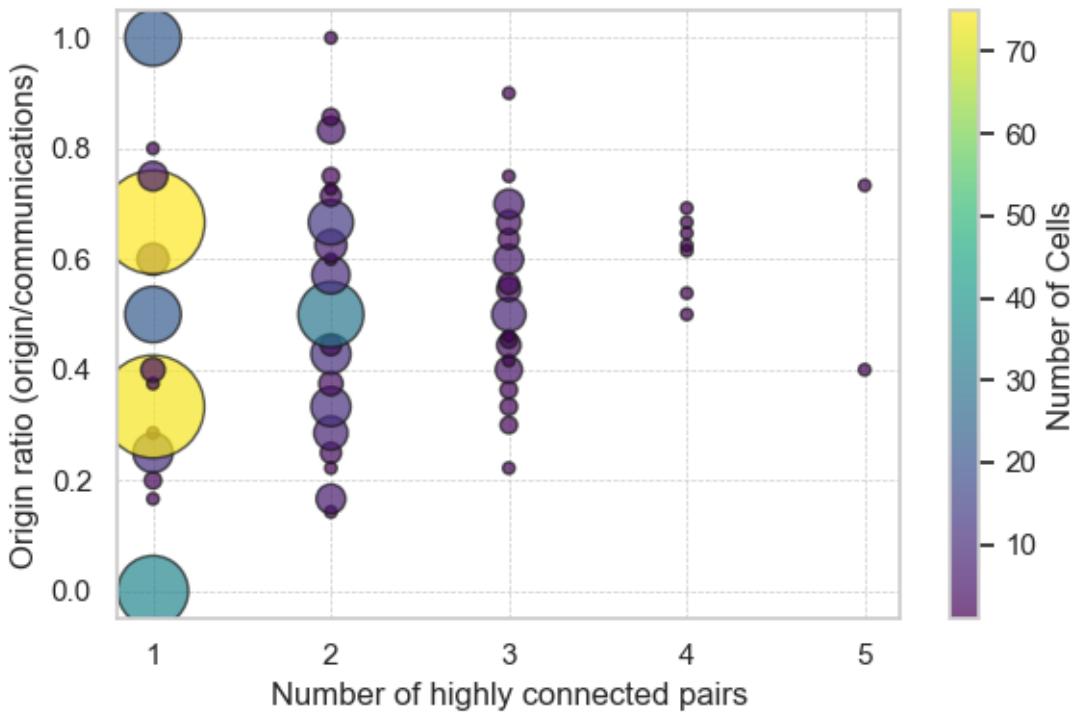
Cells involved in multiple pairs highly connected

5 (4)(7)









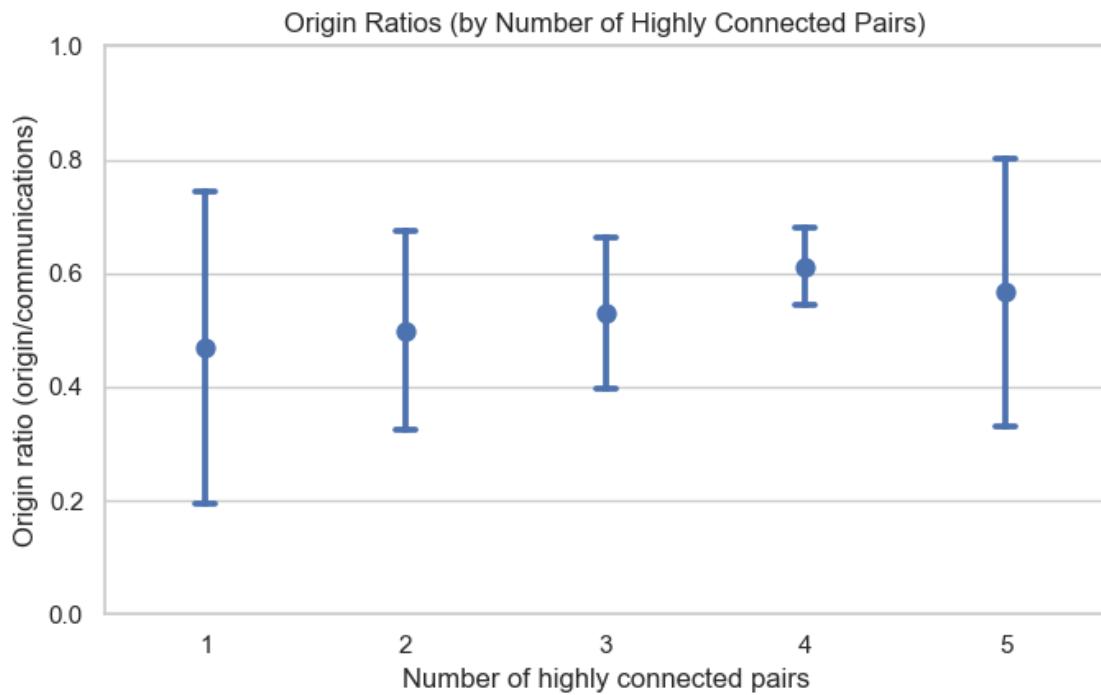
[2025-08-27 14:47:00] [INFO] calcium: plot\_points\_mean\_std: N=262 for Number of highly connected pairs=1

[2025-08-27 14:47:00] [INFO] calcium: plot\_points\_mean\_std: N=124 for Number of highly connected pairs=2

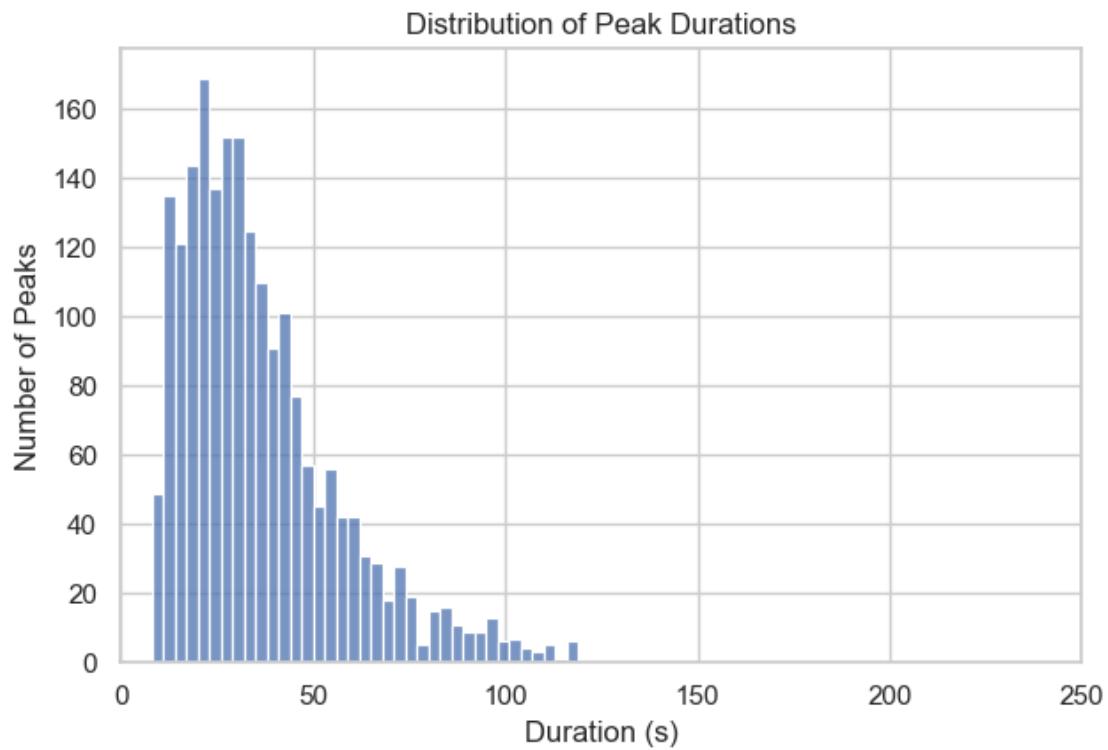
[2025-08-27 14:47:00] [INFO] calcium: plot\_points\_mean\_std: N=56 for Number of highly connected pairs=3

[2025-08-27 14:47:00] [INFO] calcium: plot\_points\_mean\_std: N=7 for Number of highly connected pairs=4

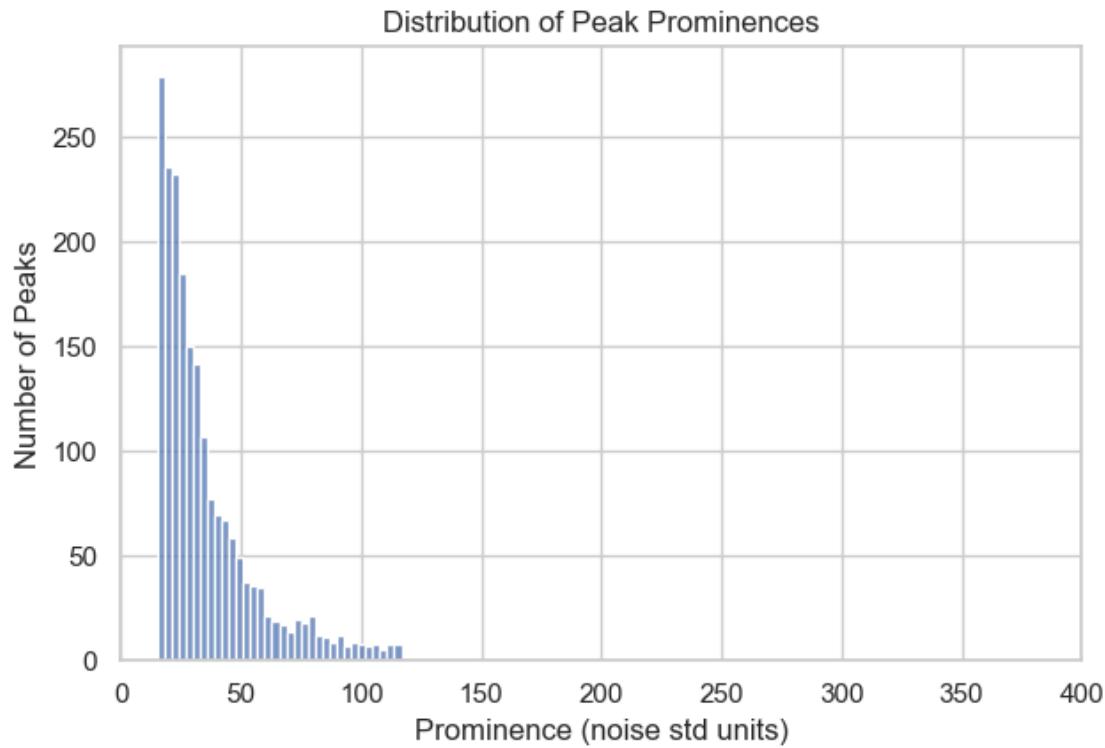
[2025-08-27 14:47:00] [INFO] calcium: plot\_points\_mean\_std: N=2 for Number of highly connected pairs=5

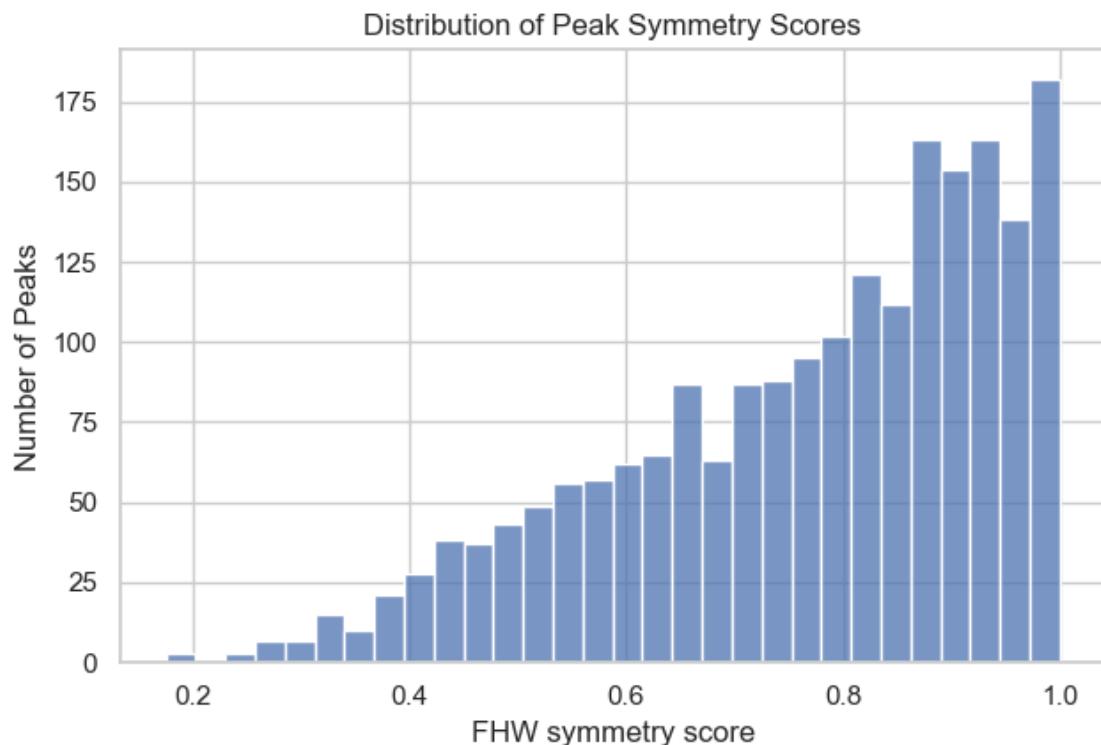


```
[2025-08-27 14:47:00] [INFO] calcium: plot_histogram: removed 16 outliers out of 2056 on 'Duration (s)' (lower=-54, upper=121)
```

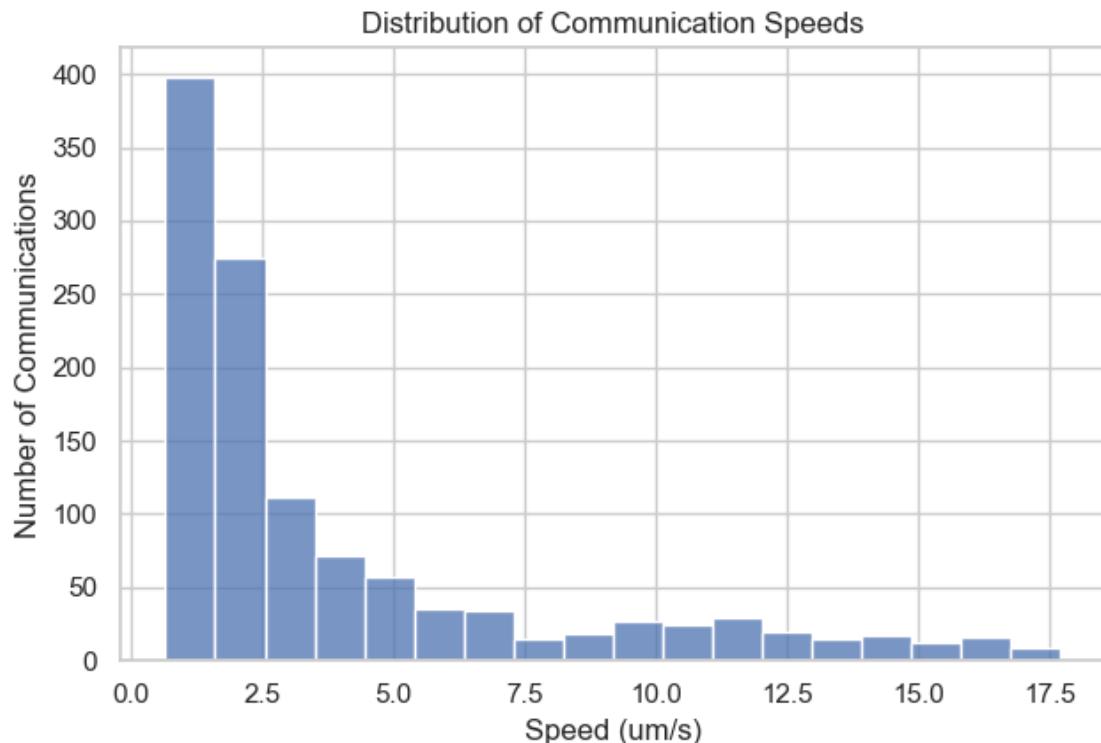


[2025-08-27 14:47:01] [INFO] calcium: plot\_histogram: removed 61 outliers out of 2056 on 'Prominence (noise std units)' (lower=-51.1, upper=116.9)

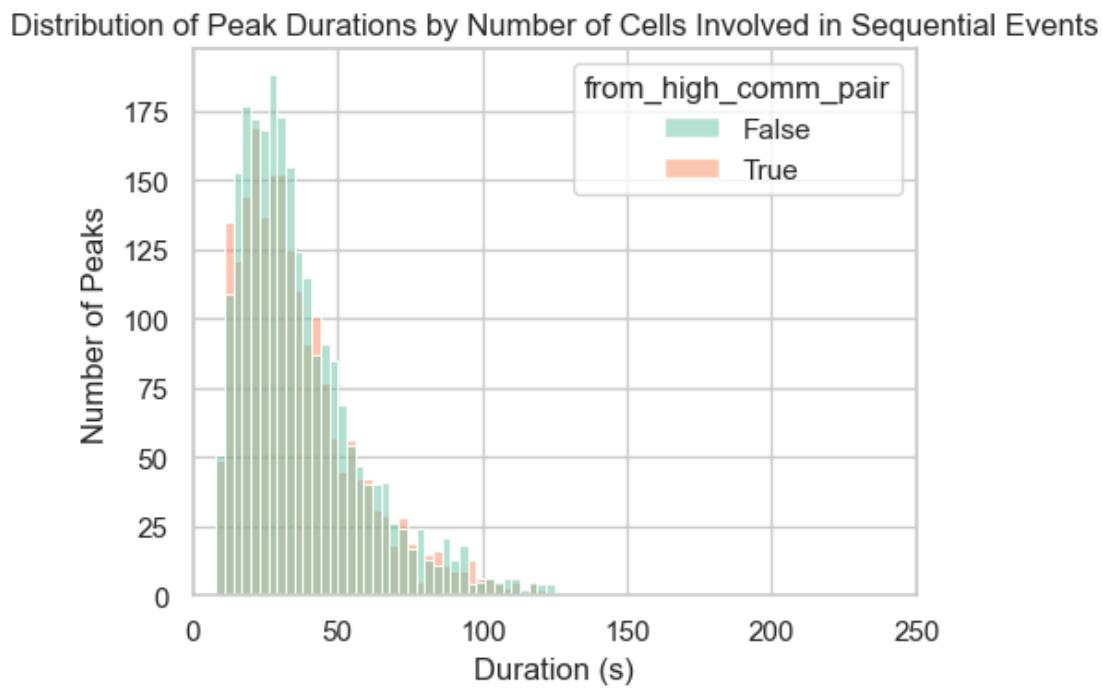




```
[2025-08-27 14:47:01] [INFO] calcium: plot_histogram: removed 38 outliers out of 1223 on 'Speed (um/s)' (lower=-10.88, upper=17.82)
```

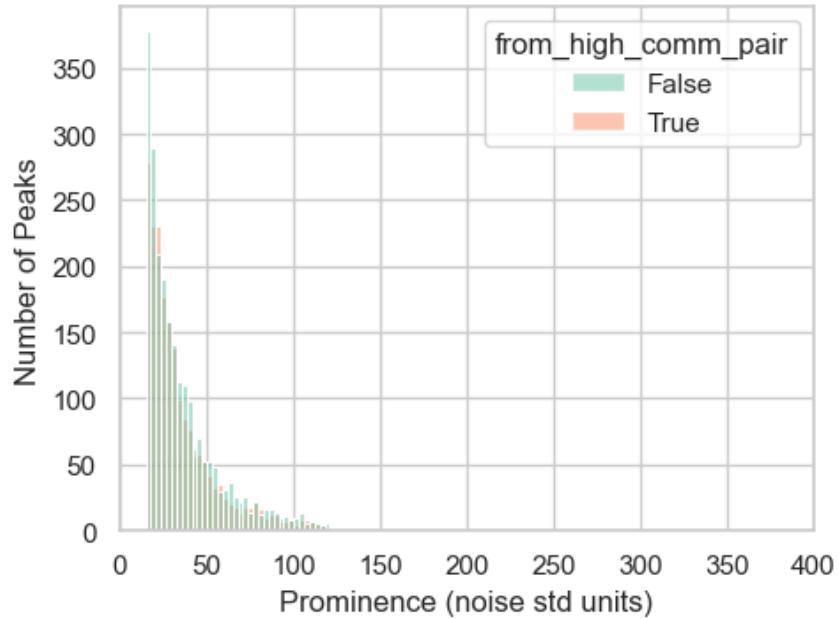


```
[2025-08-27 14:47:01] [INFO] calcium: plot_histogram_by_group: removed 56 outliers out of 4450 on 'Duration (s)' (lower=-57, upper=125)
```

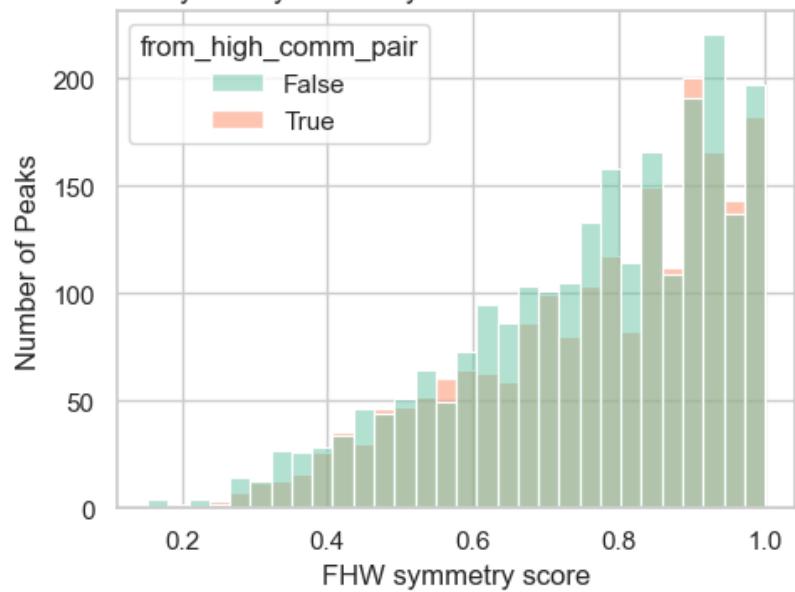


[2025-08-27 14:47:01] [INFO] calcium: plot\_histogram\_by\_group: removed 146 outliers out of 4450 on 'Prominence (noise std units)' (lower=-55.4, upper=121.7)

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

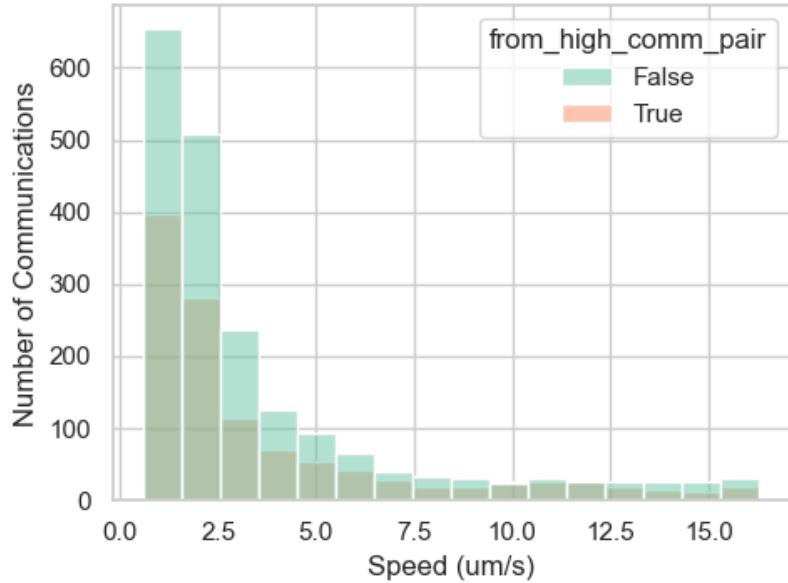


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 14:47:01] [INFO] calcium: plot_histogram_by_group: removed 182 outliers out of 3326 on 'Speed (um/s)' (lower=-9.72, upper=16.32)
```

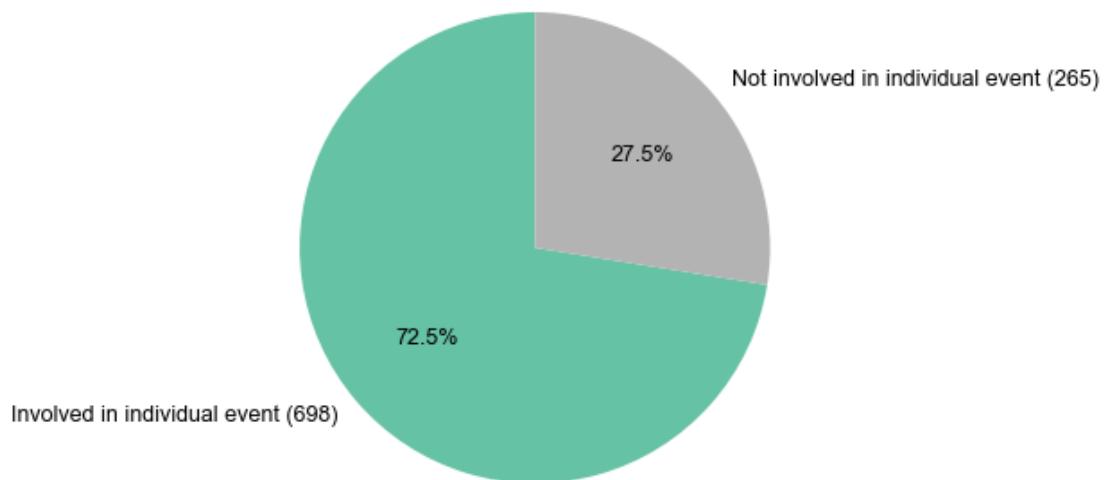
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



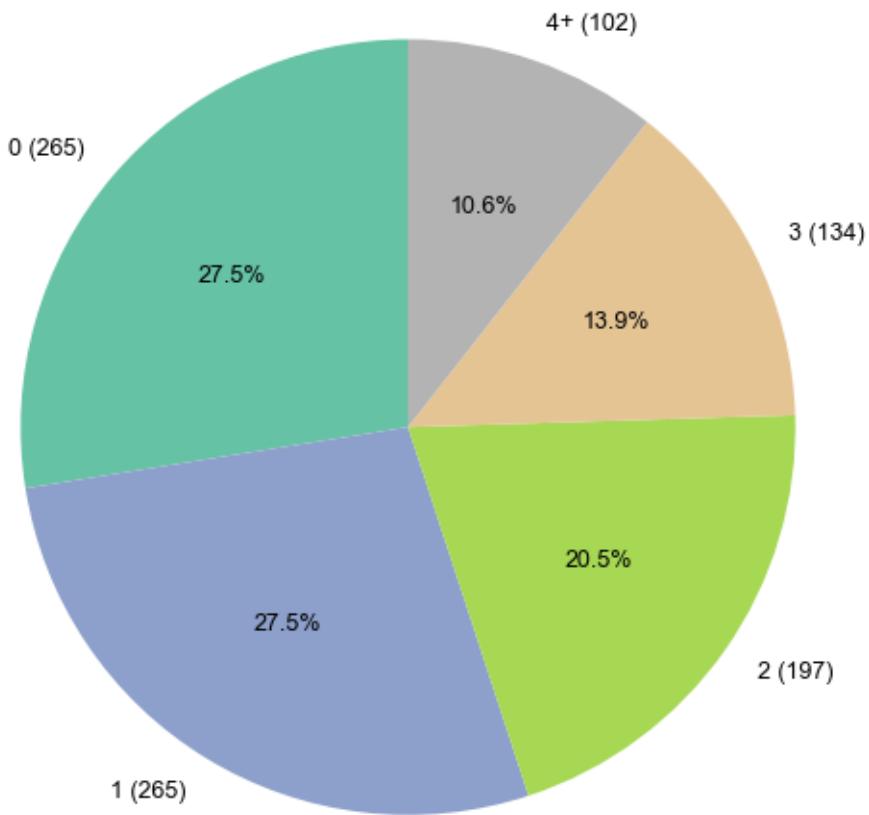
## 1.4 INDIVIDUAL EVENTS

### 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+)

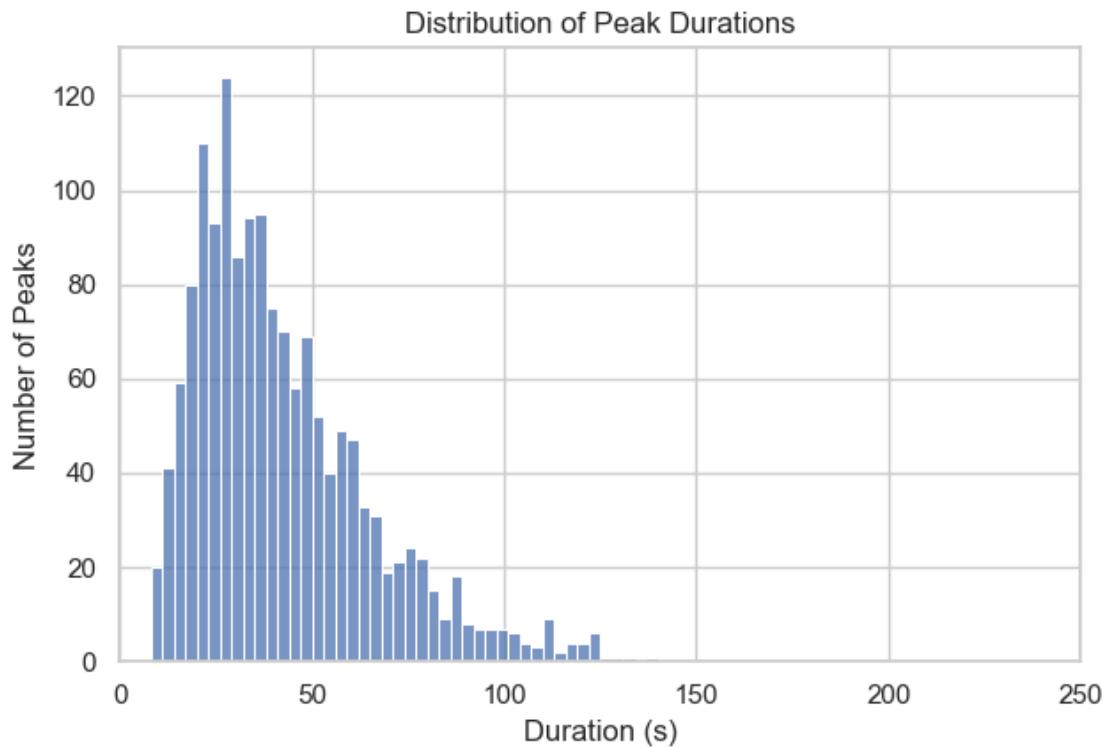


```
[2025-08-27 14:47:02] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS3\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS3\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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:
```

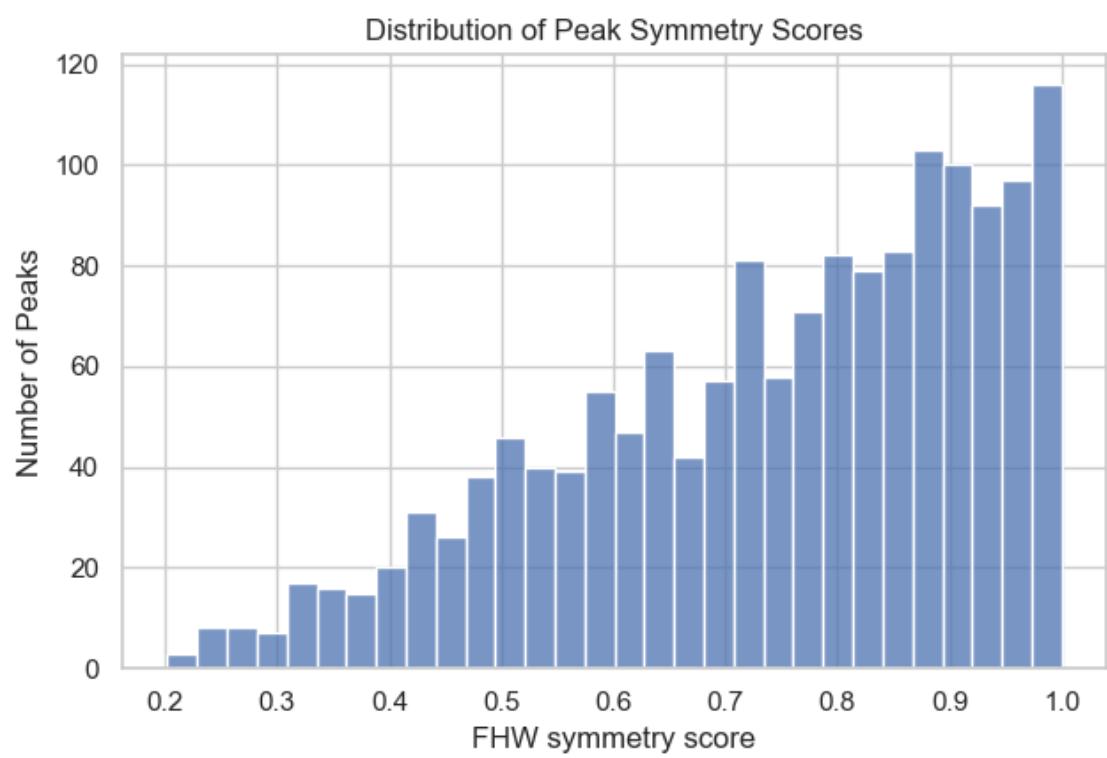
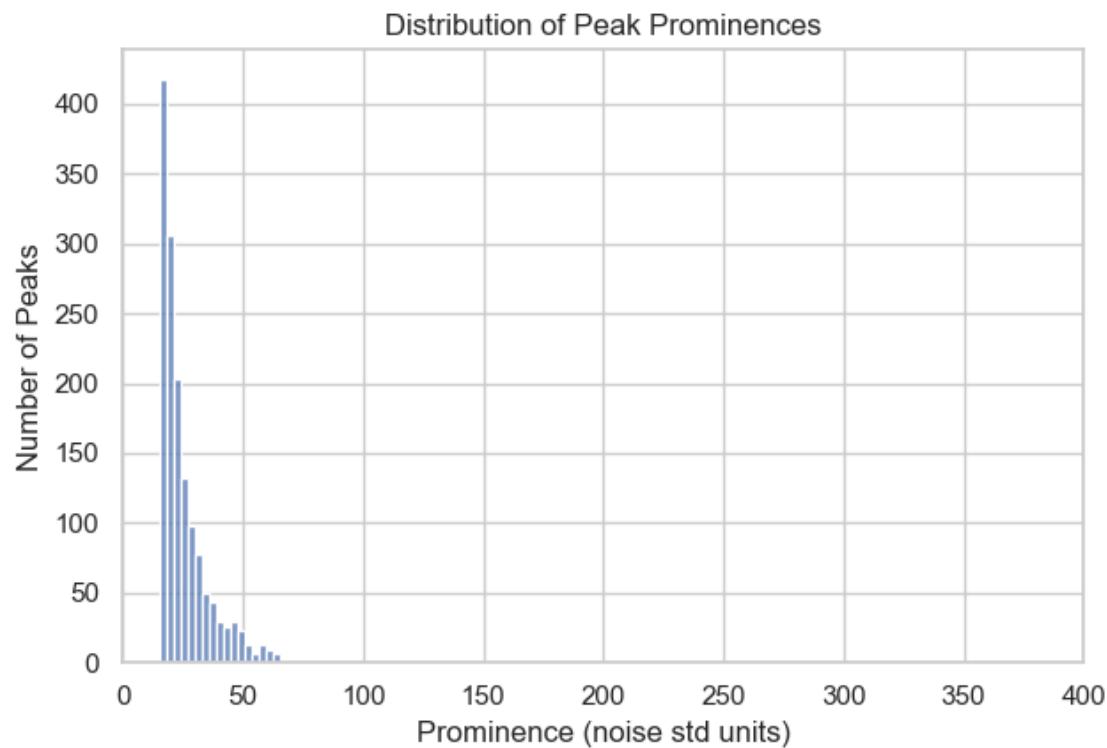
'D:\\Mateo\\20250424\\Output\\IS3\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

#### 1.4.2 Peaks statistics in individual events

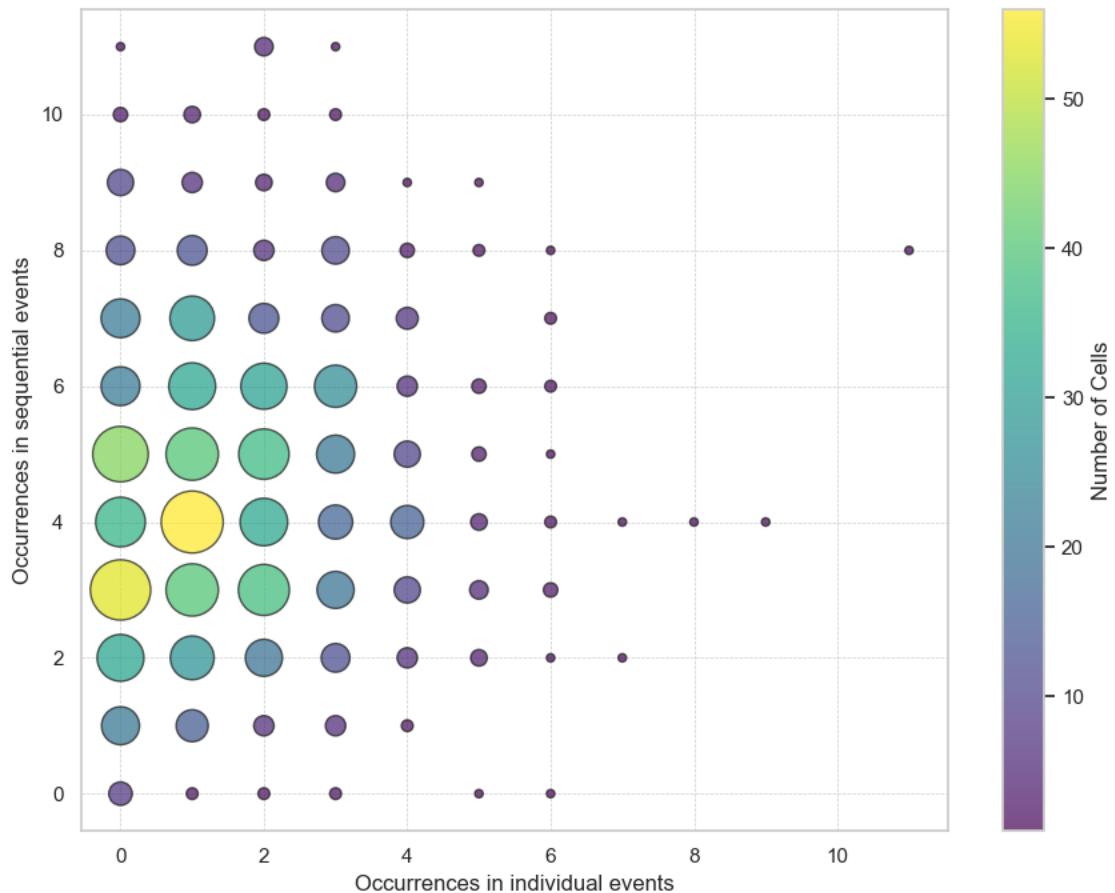
[2025-08-27 14:47:02] [INFO] calcium: plot\_histogram: removed 15 outliers out of 1540 on 'Duration (s)' (lower=-65, upper=145)



[2025-08-27 14:47:02] [INFO] calcium: plot\_histogram: removed 55 outliers out of 1540 on 'Prominence (noise std units)' (lower=-18.7, upper=66)



### 1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: removed 0/963 outliers on 'Occurrences in sequential events' (lower=-6, upper=15)
```

```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: N=265 for Occurrences in individual events=0
```

```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: N=265 for Occurrences in individual events=1
```

```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: N=197 for Occurrences in individual events=2
```

```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: N=134 for Occurrences in individual events=3
```

```
[2025-08-27 14:47:03] [INFO] calcium: plot_points_mean_std: N=61 for Occurrences in individual events=4
```

[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=23 for Occurrences in individual events=5

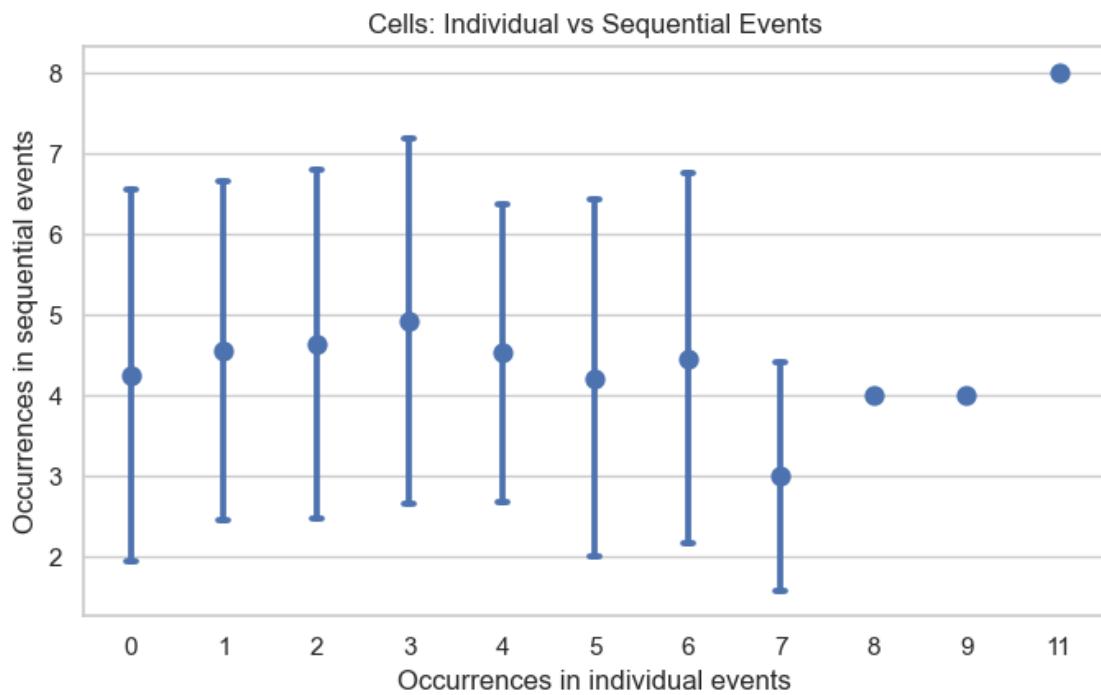
[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=13 for Occurrences in individual events=6

[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=2 for Occurrences in individual events=7

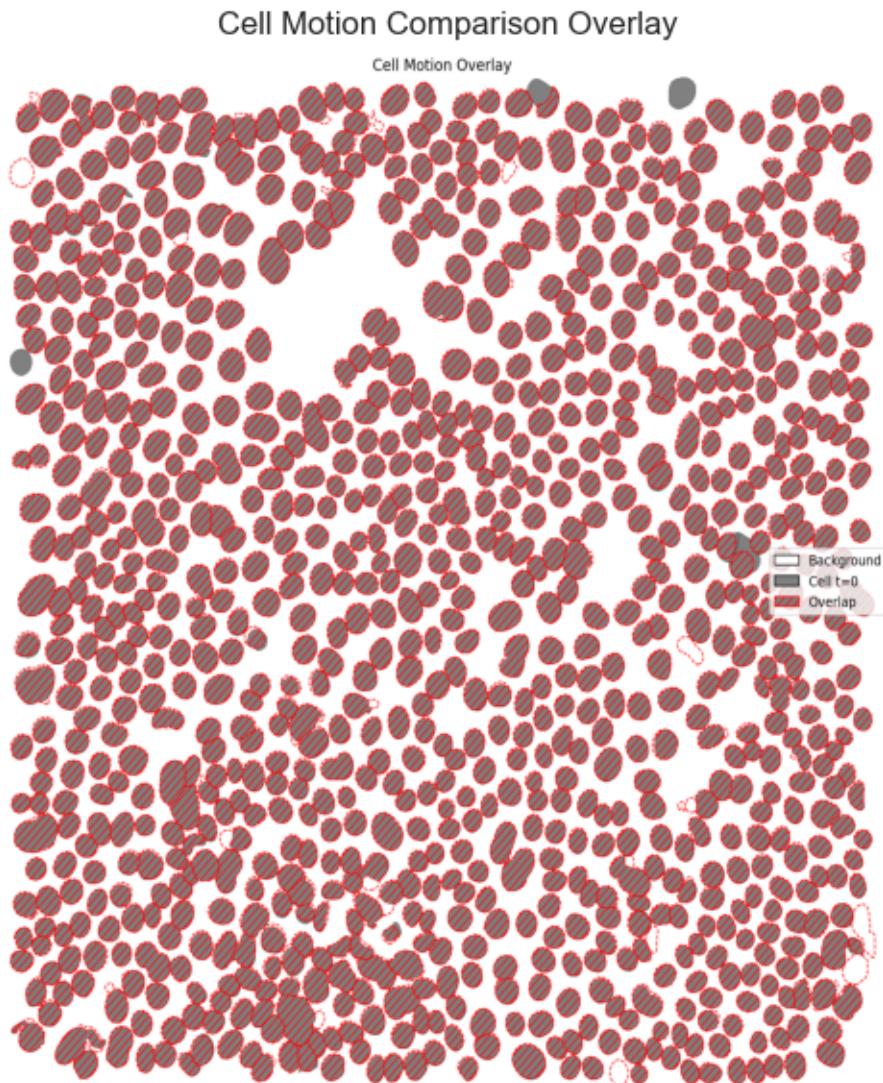
[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=1 for Occurrences in individual events=8

[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=1 for Occurrences in individual events=9

[2025-08-27 14:47:03] [INFO] calcium: plot\_points\_mean\_std: N=1 for Occurrences in individual events=11



## 1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 963
- Hoechst image taken at t=1801: 952
- Number of cells difference: absolute 11, relative 1.15%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1139883
- Pixels segmented as cell at t=1801: 1159509
- Overlapping pixels between t=0 and t=1801: 1088142 (94.65% of total)
- Pixels exclusive to t=0: 51741 (4.54% of total)
- Pixels exclusive to t=1801: 71367 (6.16% of total)

executed

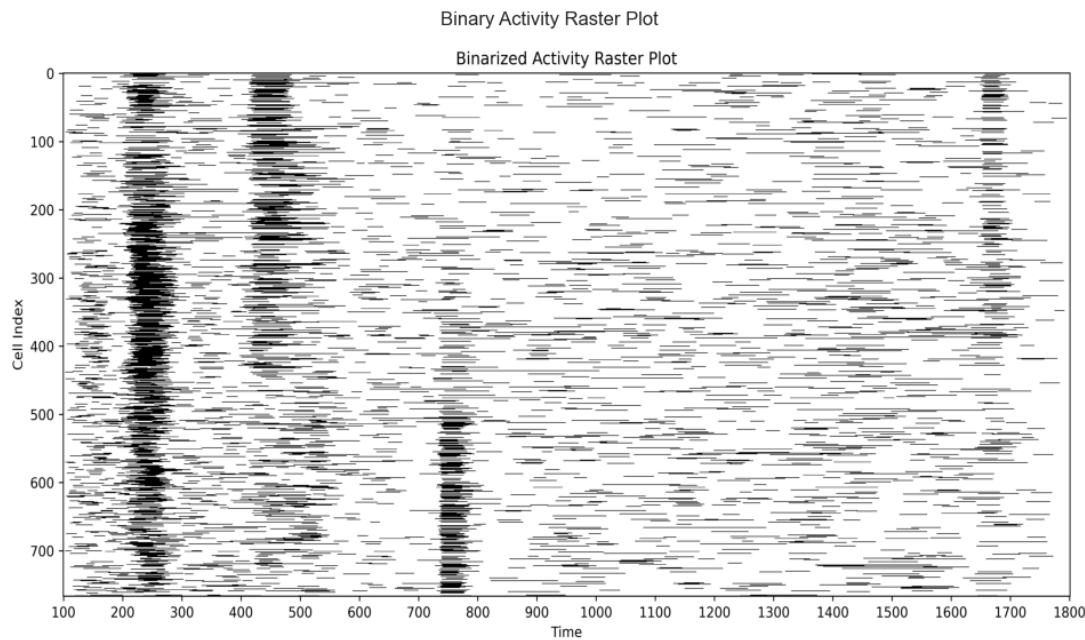
August 27, 2025

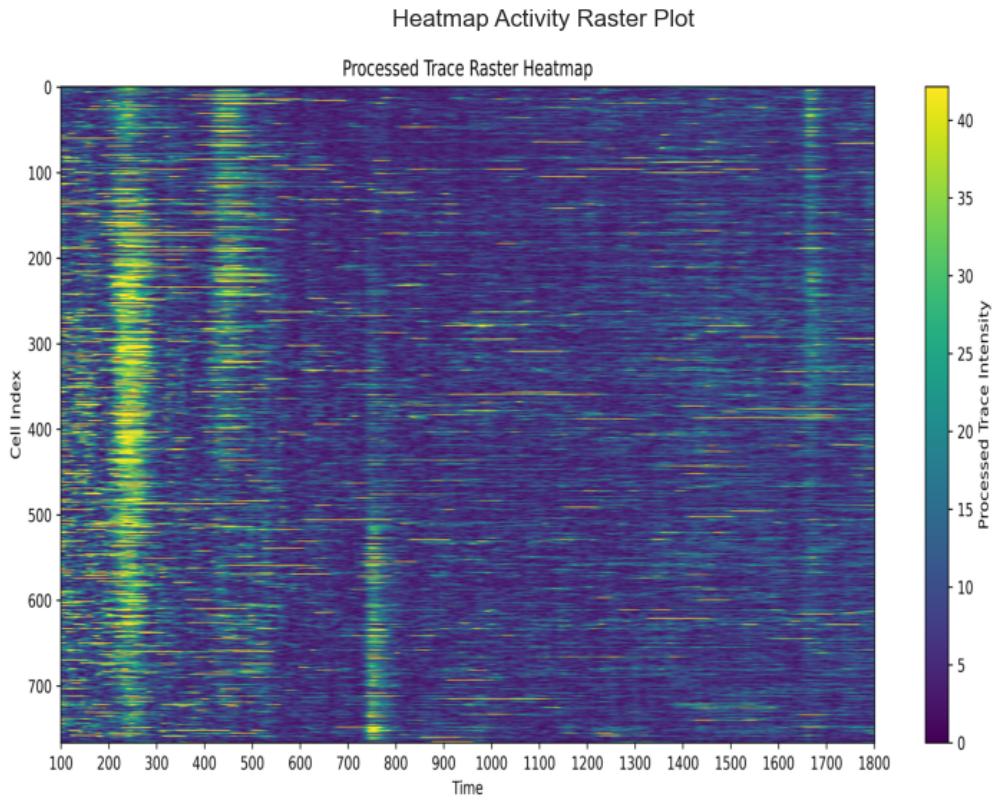
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





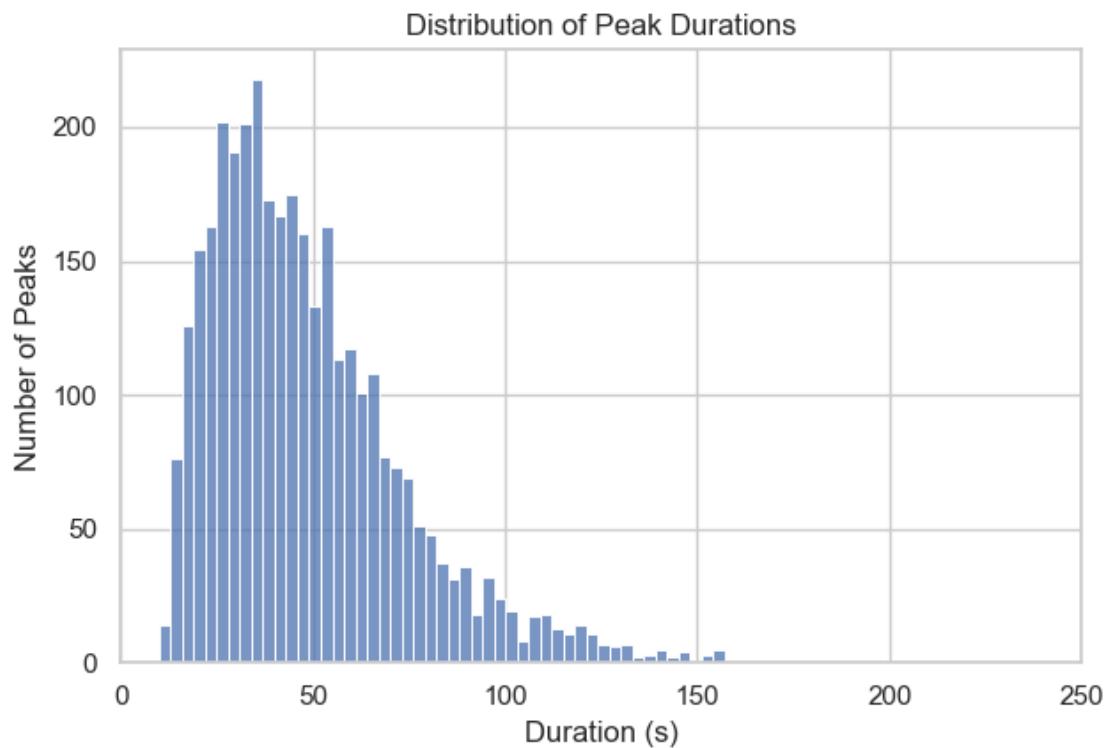
### 1.1.2 Peaks population

Total number of peaks: 3436

Total number of cells: 767

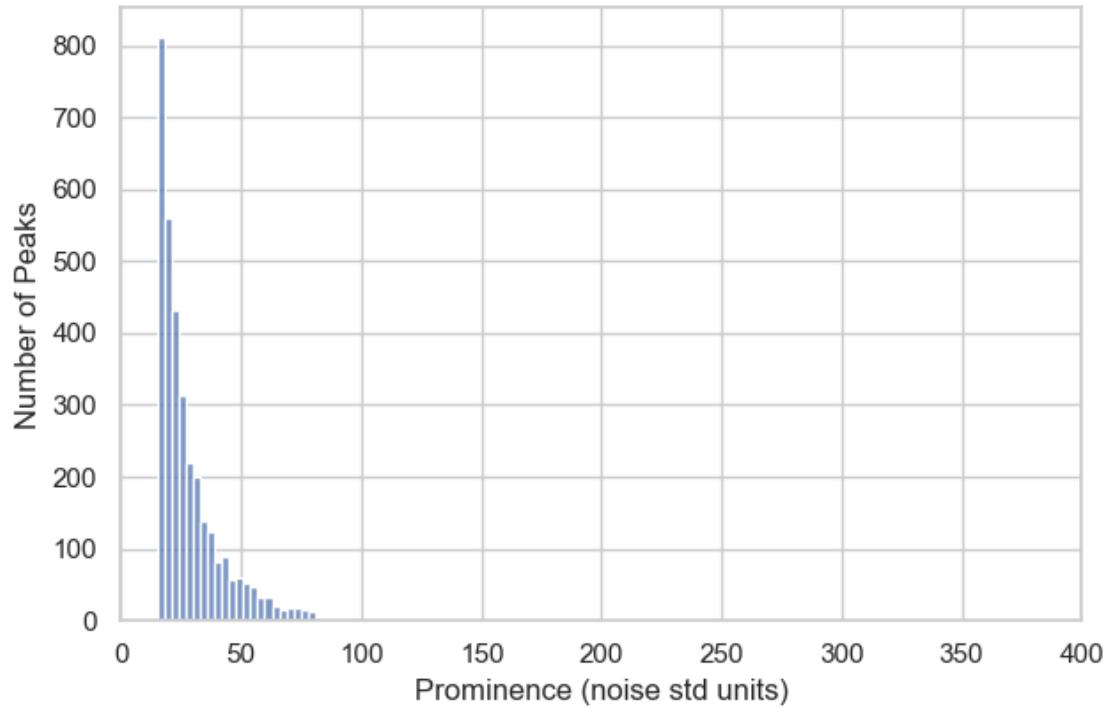
### 1.1.3 Peaks statistics

```
[2025-08-27 14:47:29] [INFO] calcium: plot_histogram: removed 29 outliers out of  
3436 on 'Duration (s)' (lower=-67, upper=157)
```

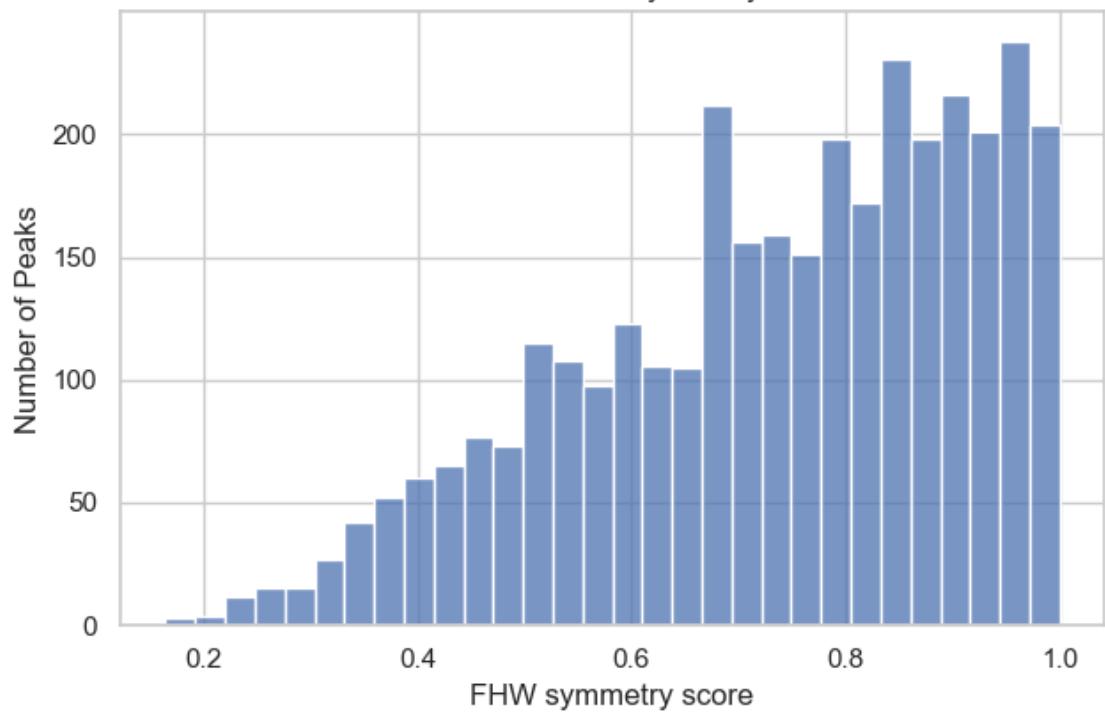


```
[2025-08-27 14:47:29] [INFO] calcium: plot_histogram: removed 86 outliers out of  
3436 on 'Prominence (noise std units)' (lower=-29, upper=80.9)
```

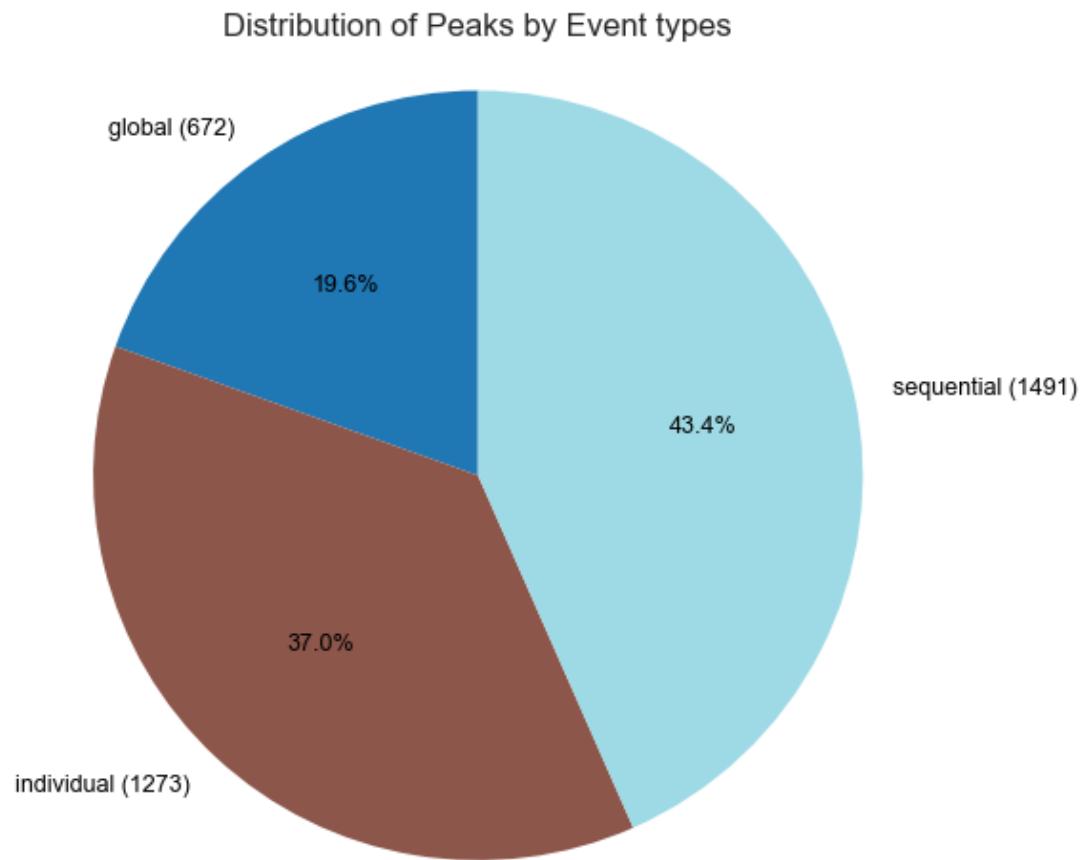
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

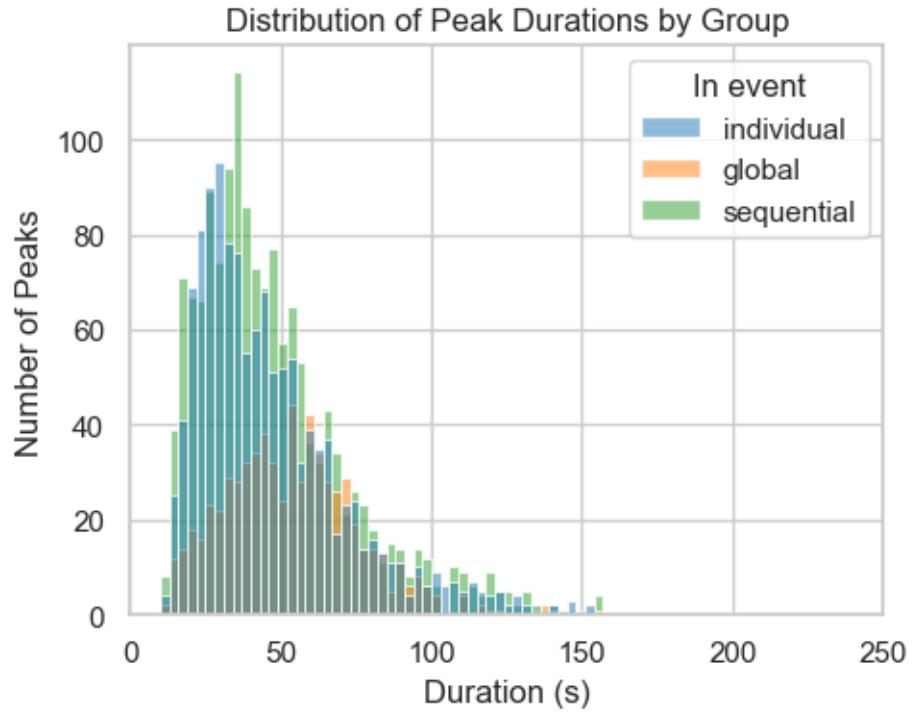


#### 1.1.4 Distribution of peaks per event types

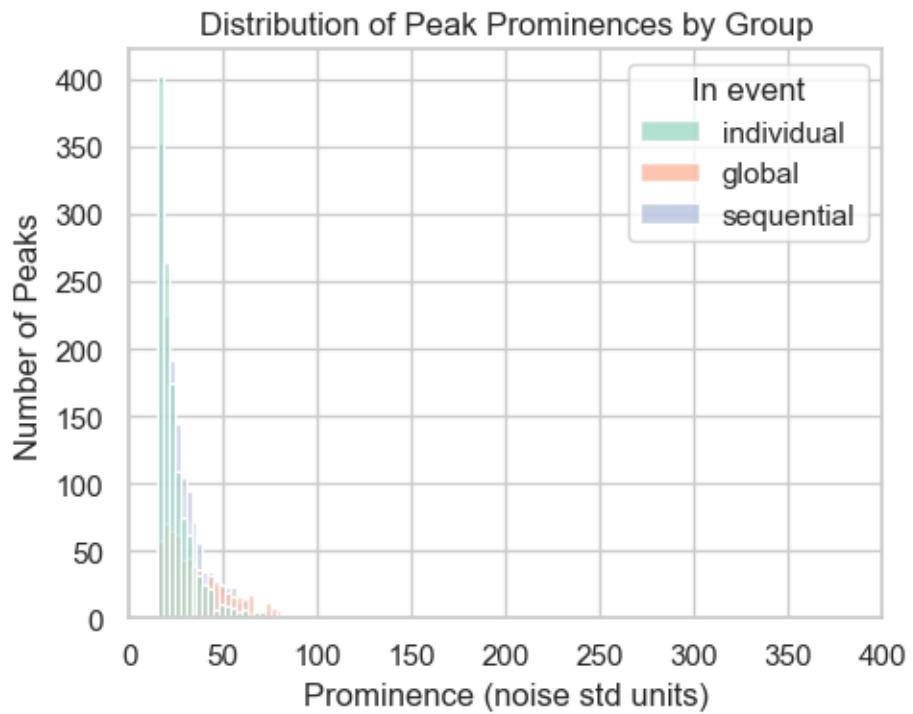


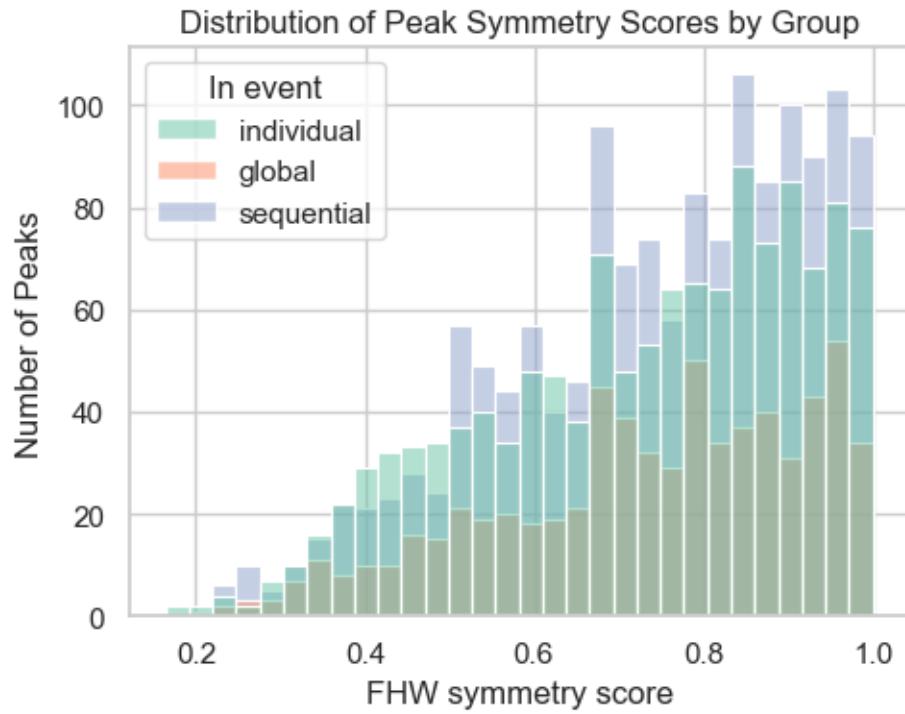
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 14:47:29] [INFO] calcium: plot_histogram_by_group: removed 29 outliers out of 3436 on 'Duration (s)' (lower=-67, upper=157)
```



```
[2025-08-27 14:47:30] [INFO] calcium: plot_histogram_by_group: removed 86 outliers out of 3436 on 'Prominence (noise std units)' (lower=-29, upper=80.9)
```

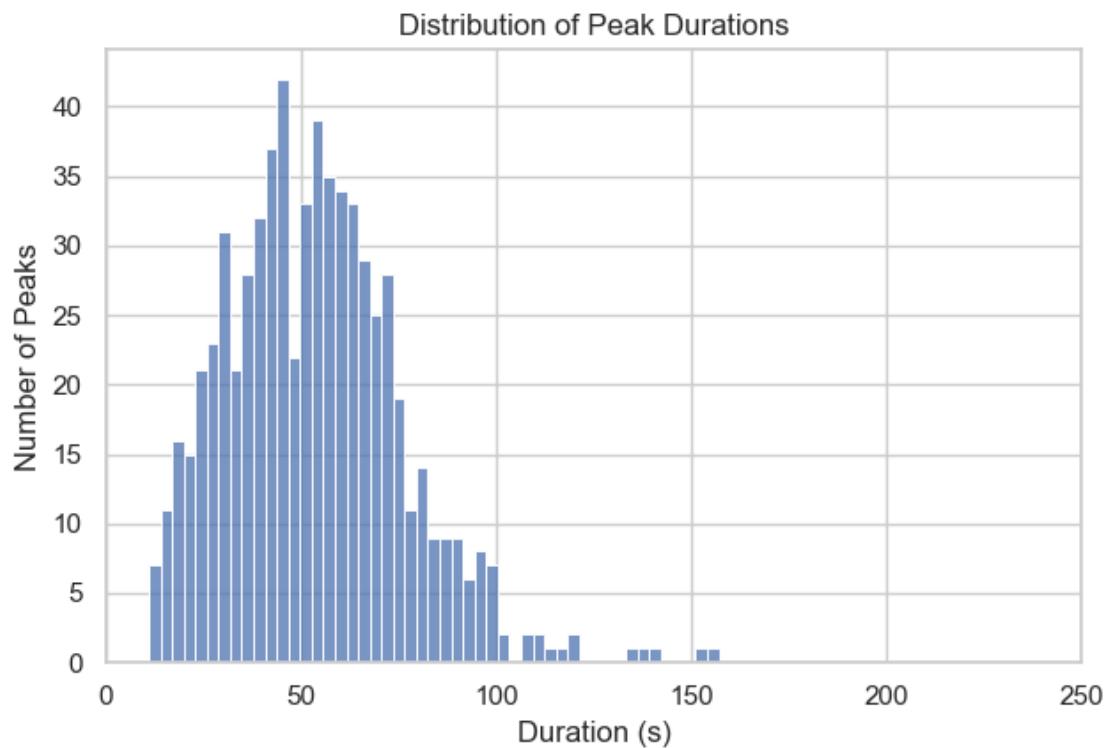




## 1.2 GLOBAL EVENTS

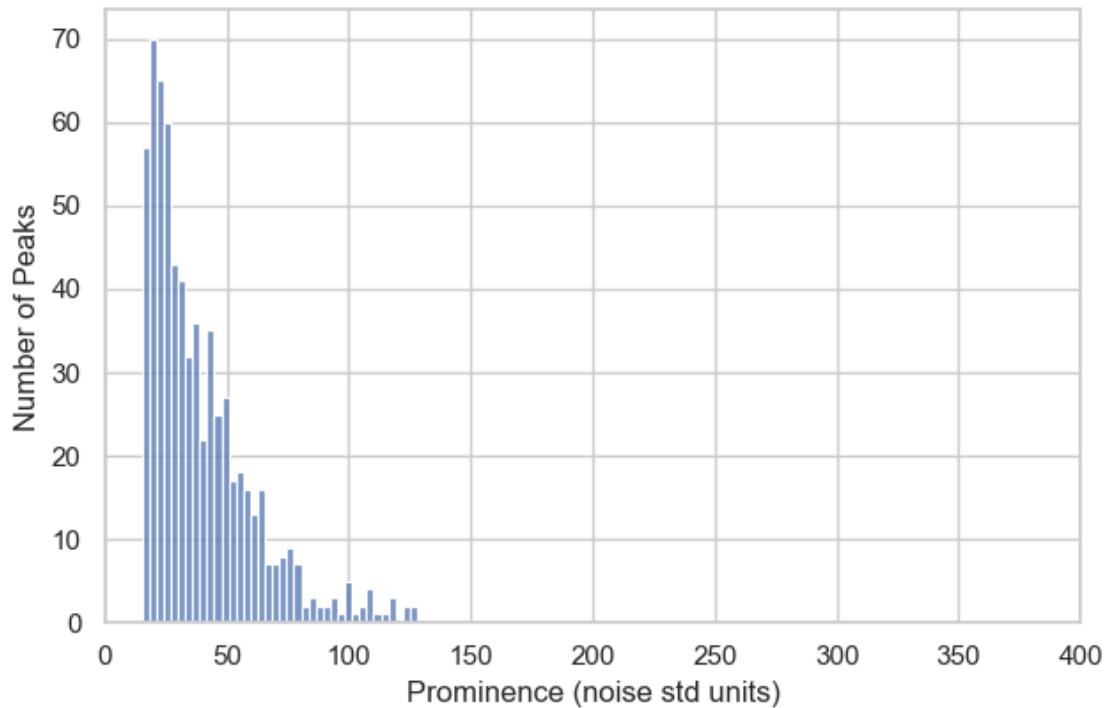
### 1.2.1 Peak statistics in global events

```
[2025-08-27 14:47:30] [INFO] calcium: plot_histogram: removed 3 outliers out of 672 on 'Duration (s)' (lower=-53, upper=157)
```

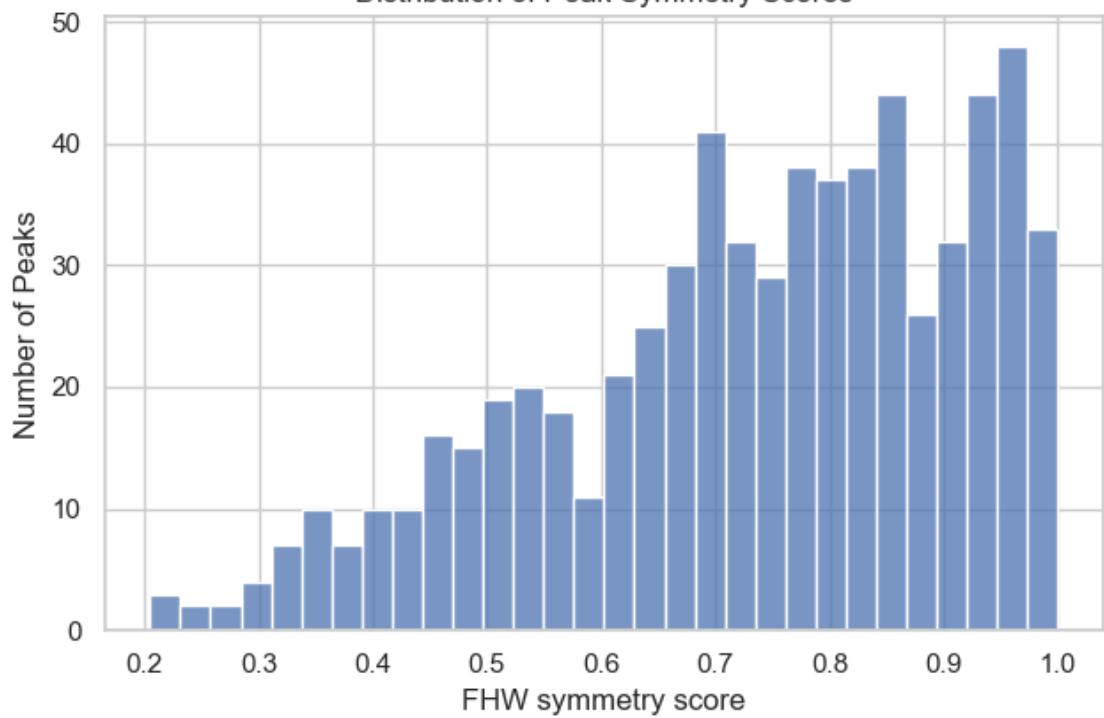


```
[2025-08-27 14:47:30] [INFO] calcium: plot_histogram: removed 7 outliers out of  
672 on 'Prominence (noise std units)' (lower=-57.375, upper=129.88)
```

Distribution of Peak Prominences

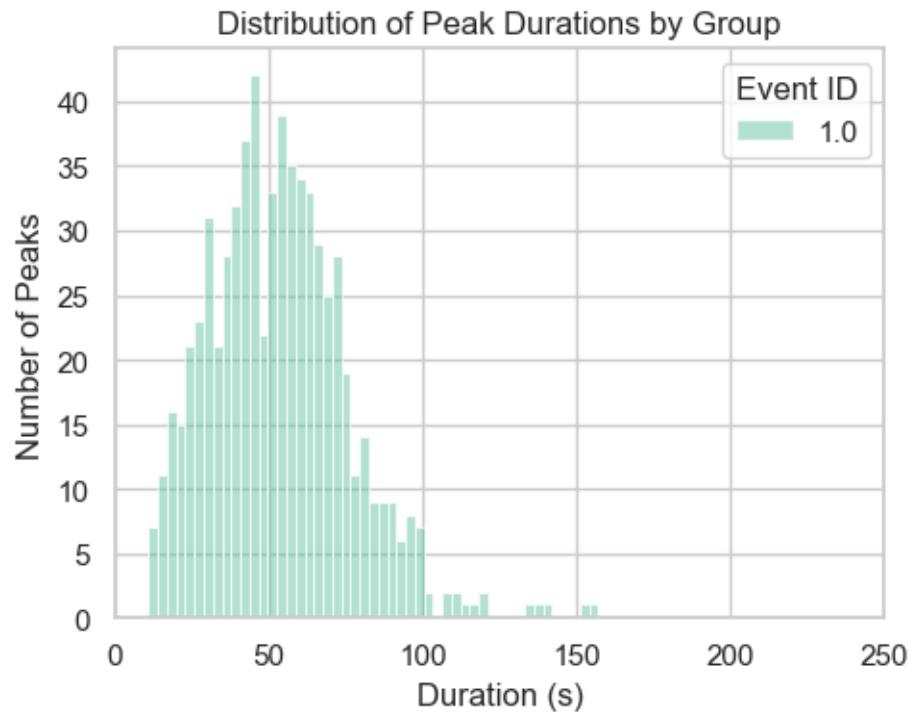


Distribution of Peak Symmetry Scores

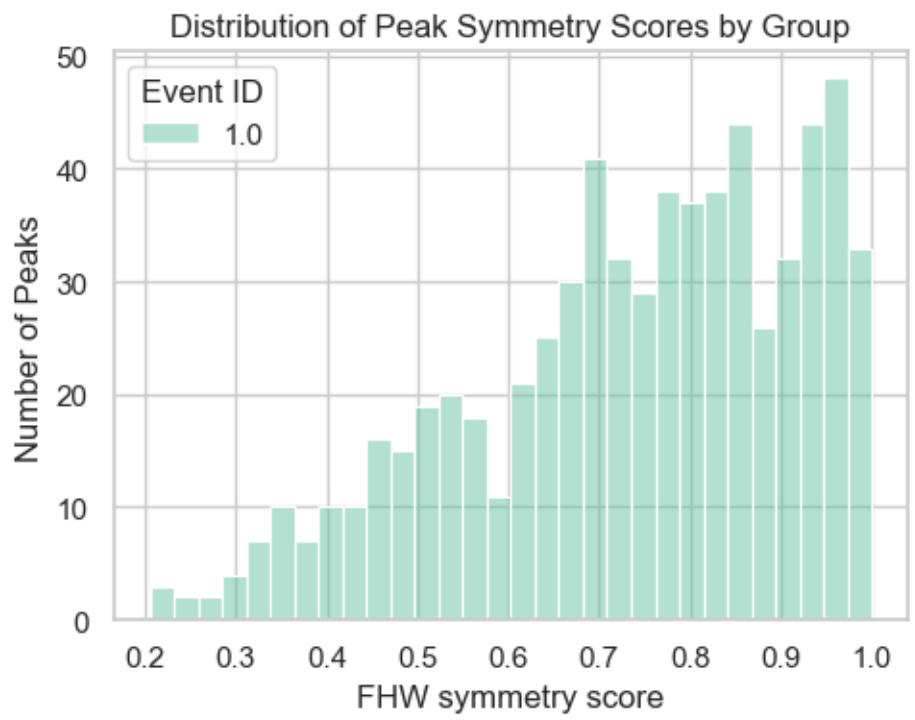
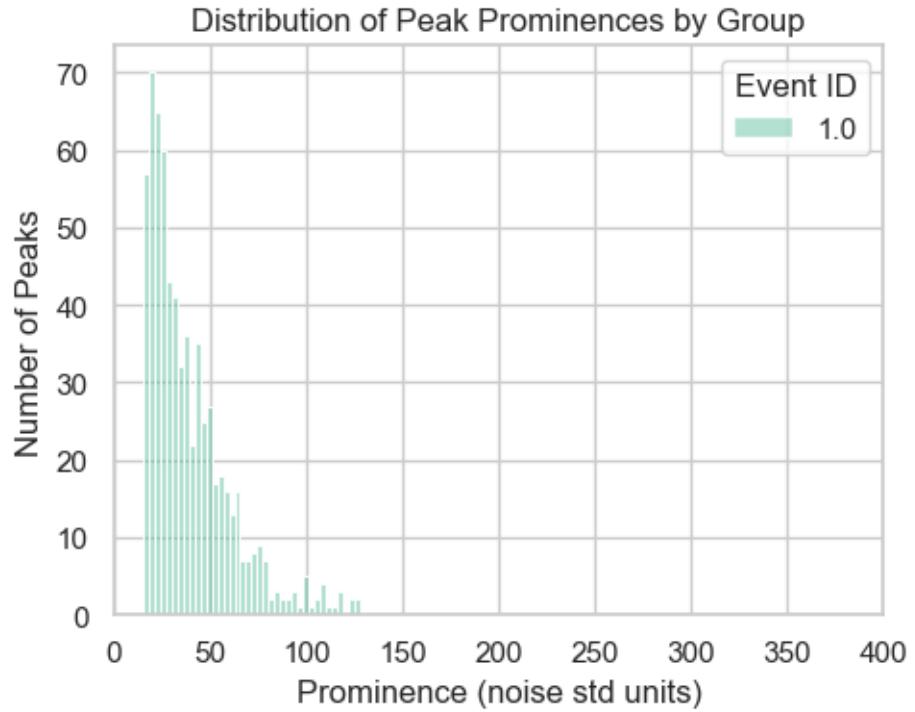


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 14:47:30] [INFO] calcium: plot\_histogram\_by\_group: removed 3 outliers out of 672 on 'Duration (s)' (lower=-53, upper=157)

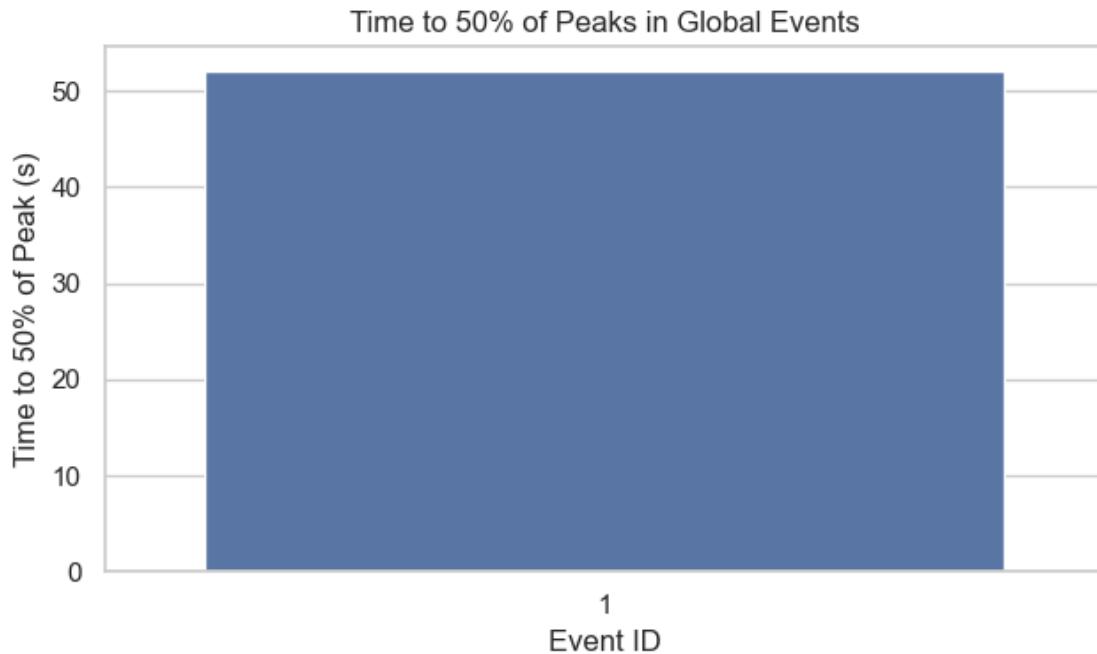


[2025-08-27 14:47:31] [INFO] calcium: plot\_histogram\_by\_group: removed 7 outliers out of 672 on 'Prominence (noise std units)' (lower=-57.375, upper=129.88)

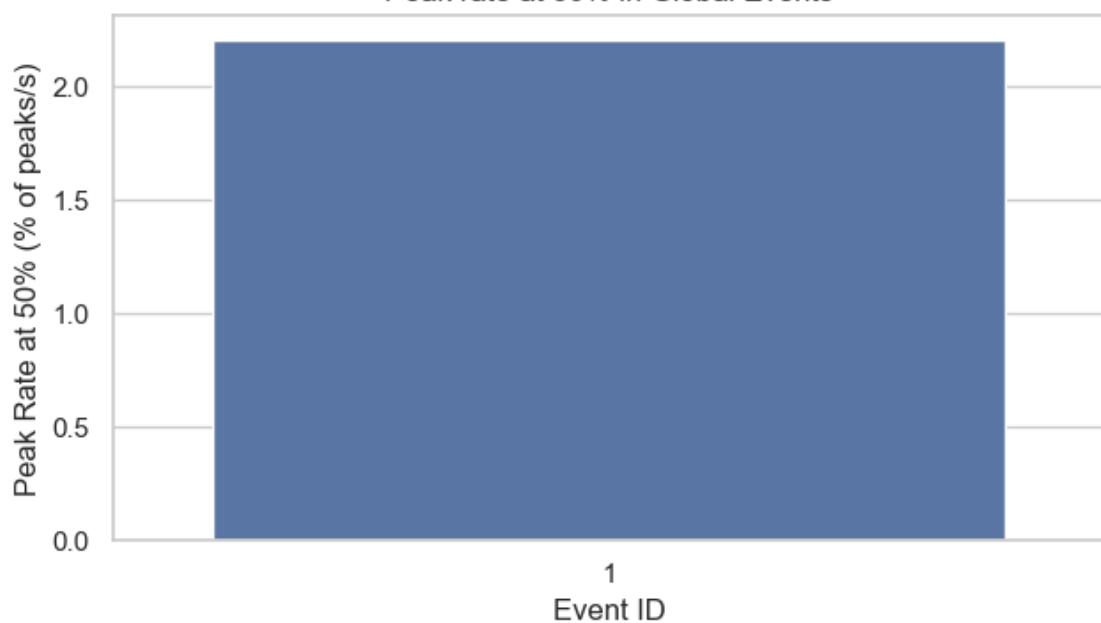


### 1.2.3 Kinetics of global events

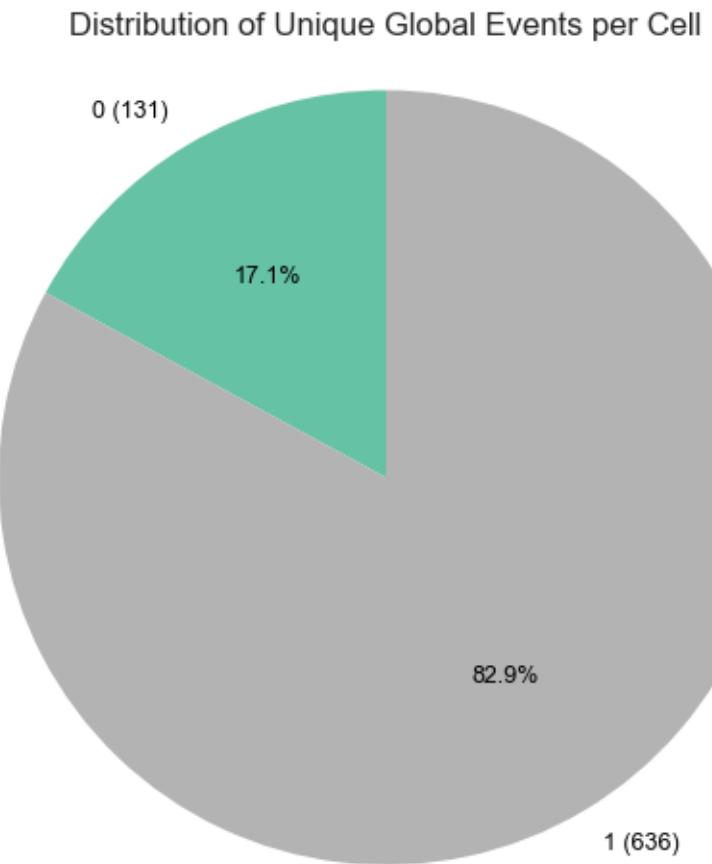
```
[2025-08-27 14:47:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS5\events\event-growth-curve-1.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250424\Output\IS5\events\event-growth-
curve-1.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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\20250424\Output\IS5\events\event-growth-curve-1.png'
```



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

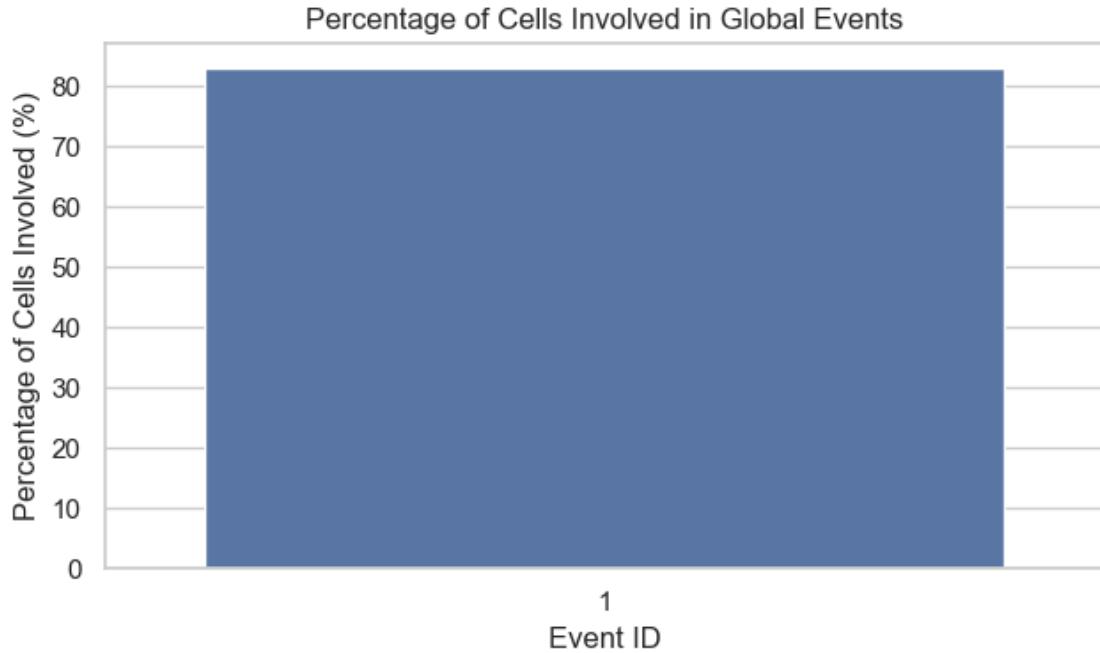


```
[2025-08-27 14:47:31] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250424\\\\Output\\\\IS5\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250424\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: []

### 1.2.6 Early peakers in the events

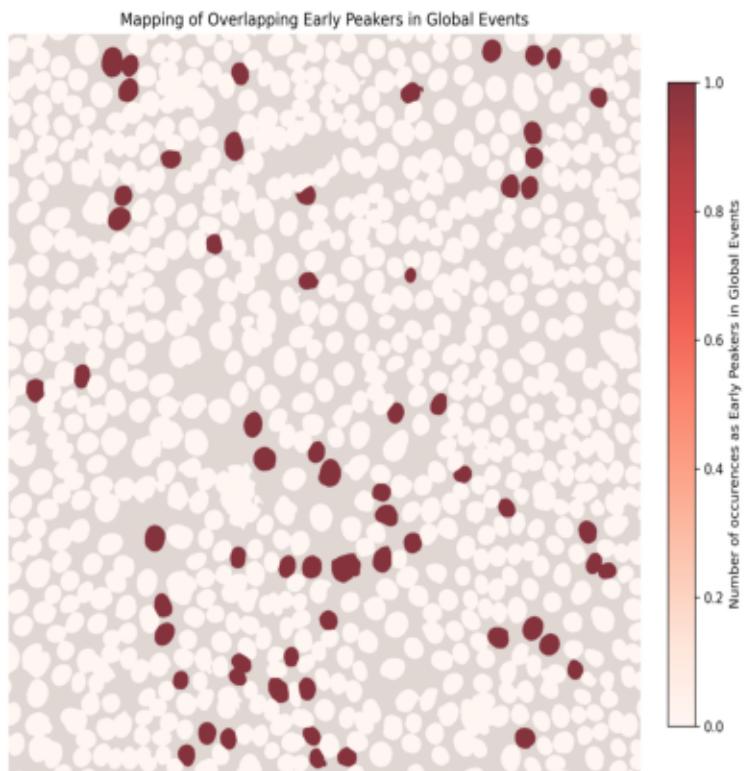
```

[2025-08-27 14:47:32] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\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_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 14:47:32] [WARNING] calcium: 'total\_events' is deprecated and ignored. Using 1 unique event IDs.

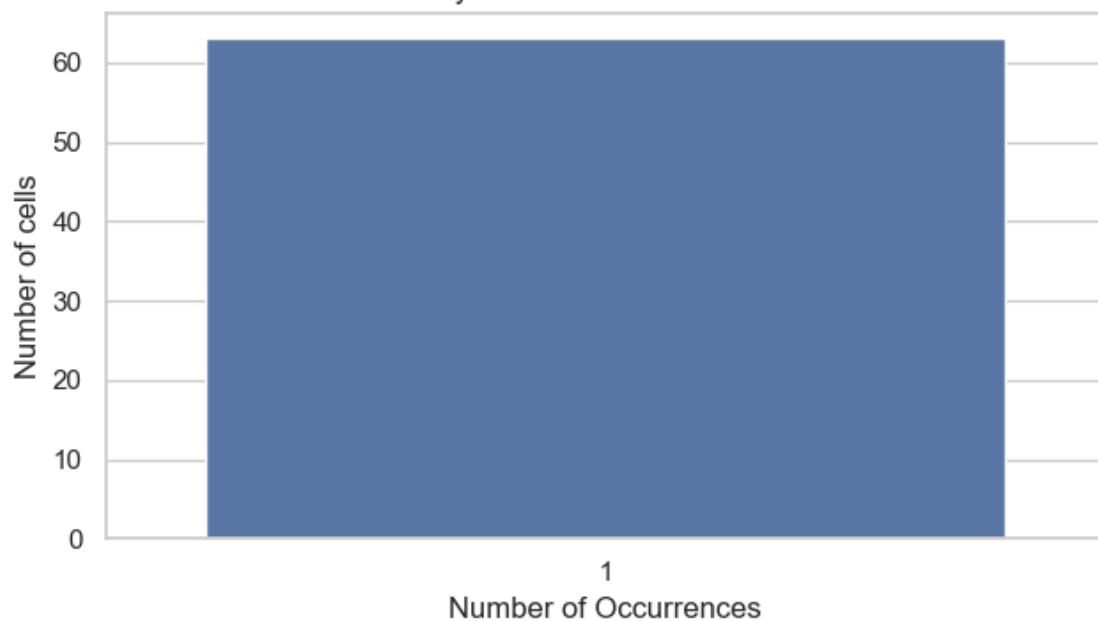
[2025-08-27 14:47:32] [INFO] calcium: Early peakers event-matrix: 63 cells x 1 events; black squares: 63



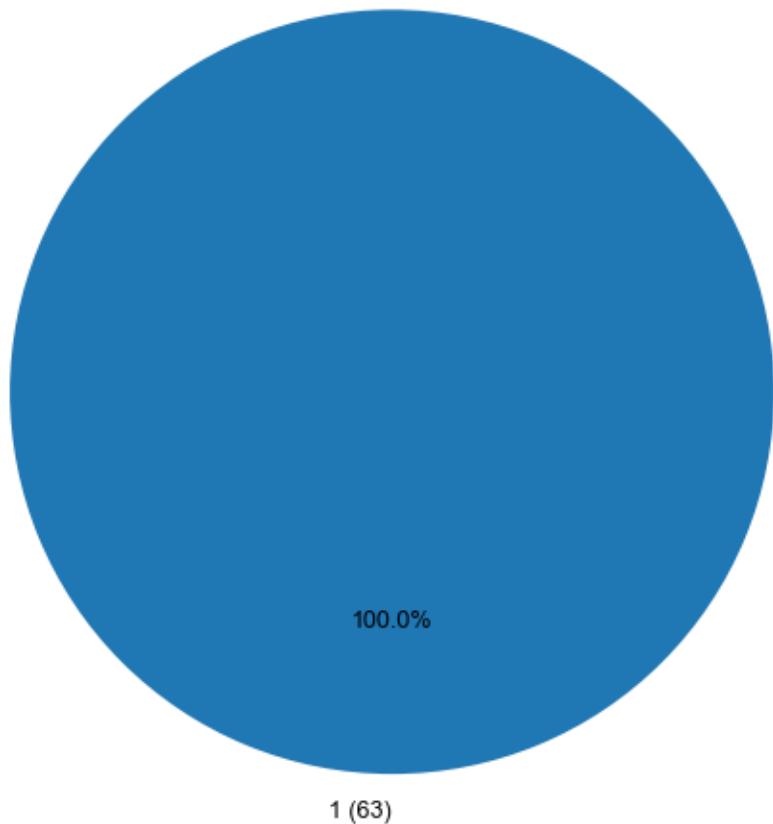
[2025-08-27 14:47:33] [INFO] calcium: Saved early peakers heatmap SVG to: early\_peakers\_heatmap.svg



Early Peakers in Global Events



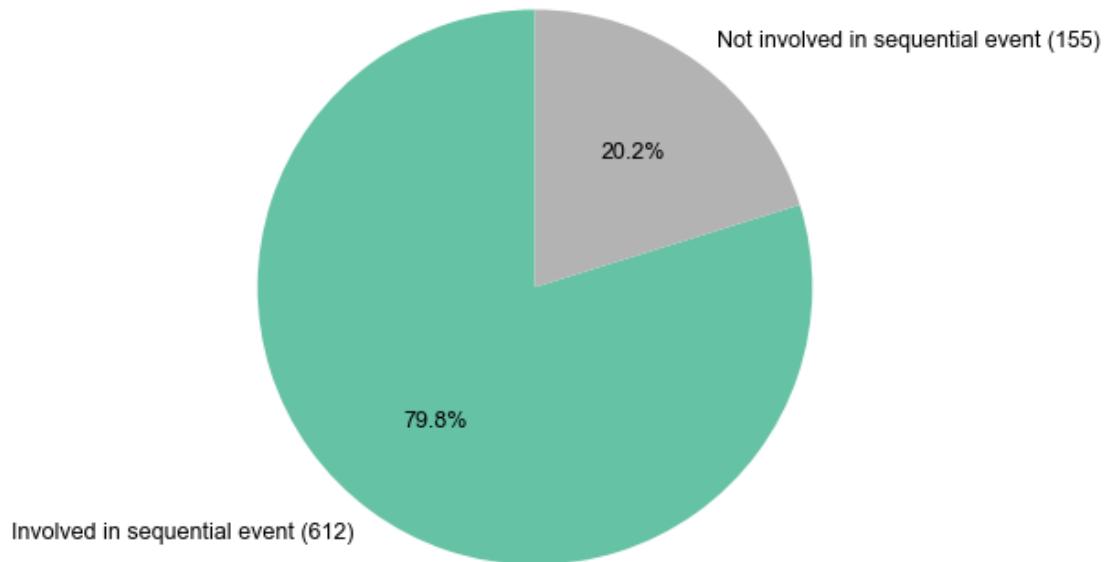
Distribution of Early Peakers in Global Events



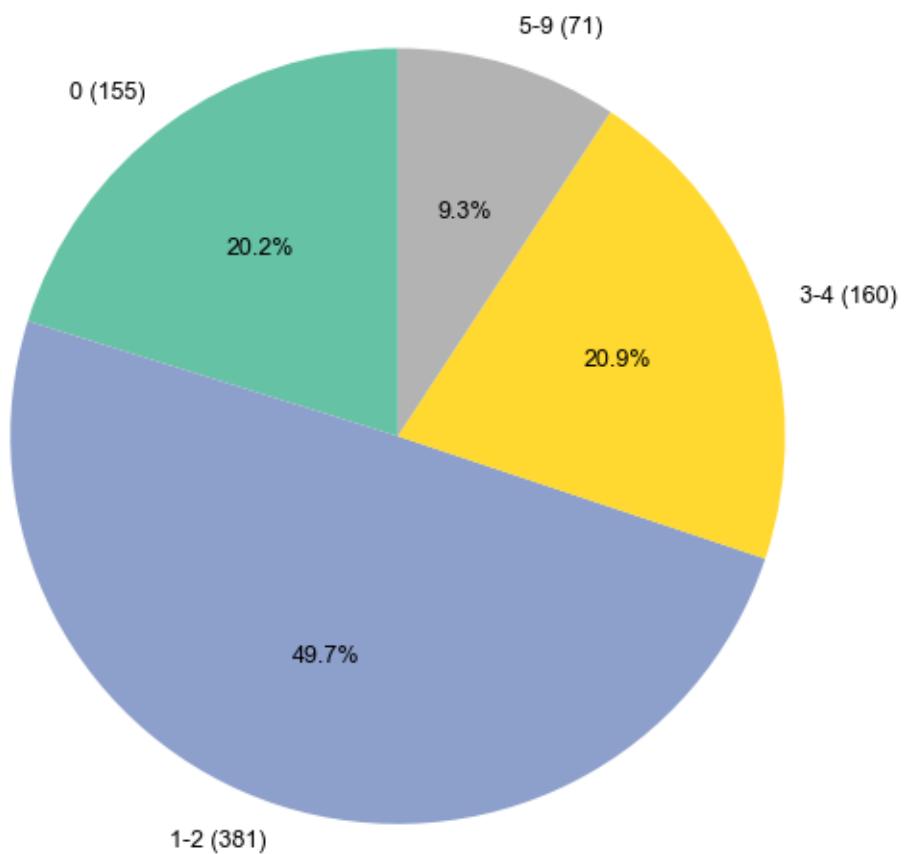
## 1.3 SEQUENTIAL EVENTS

### 1.3.1 Cells Occurrences in sequential events

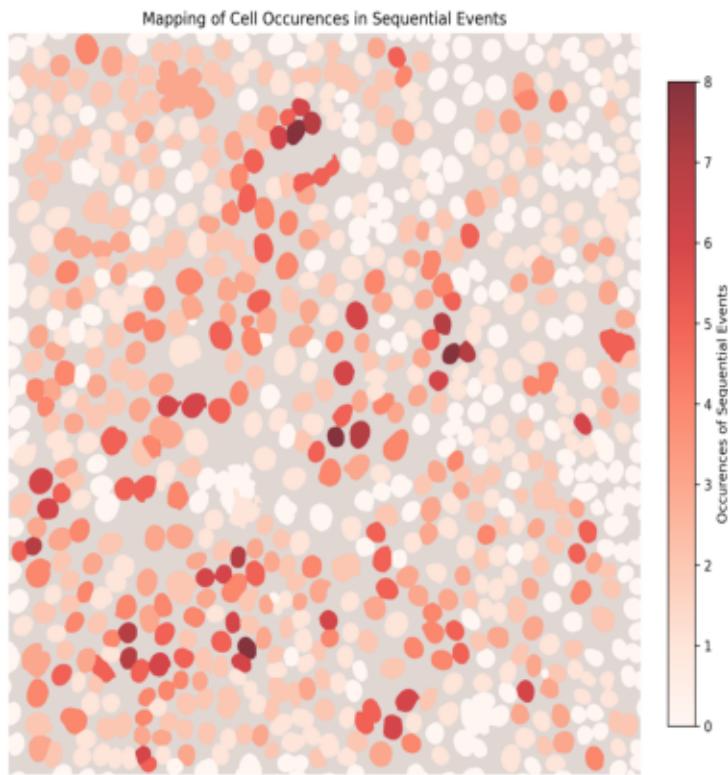
Distribution of Cells Involved in Sequential Events



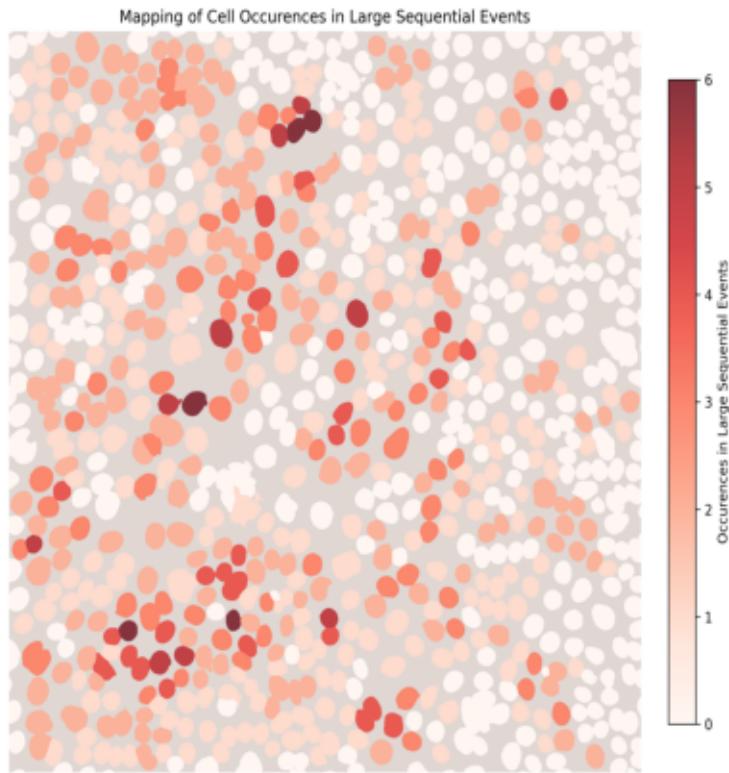
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

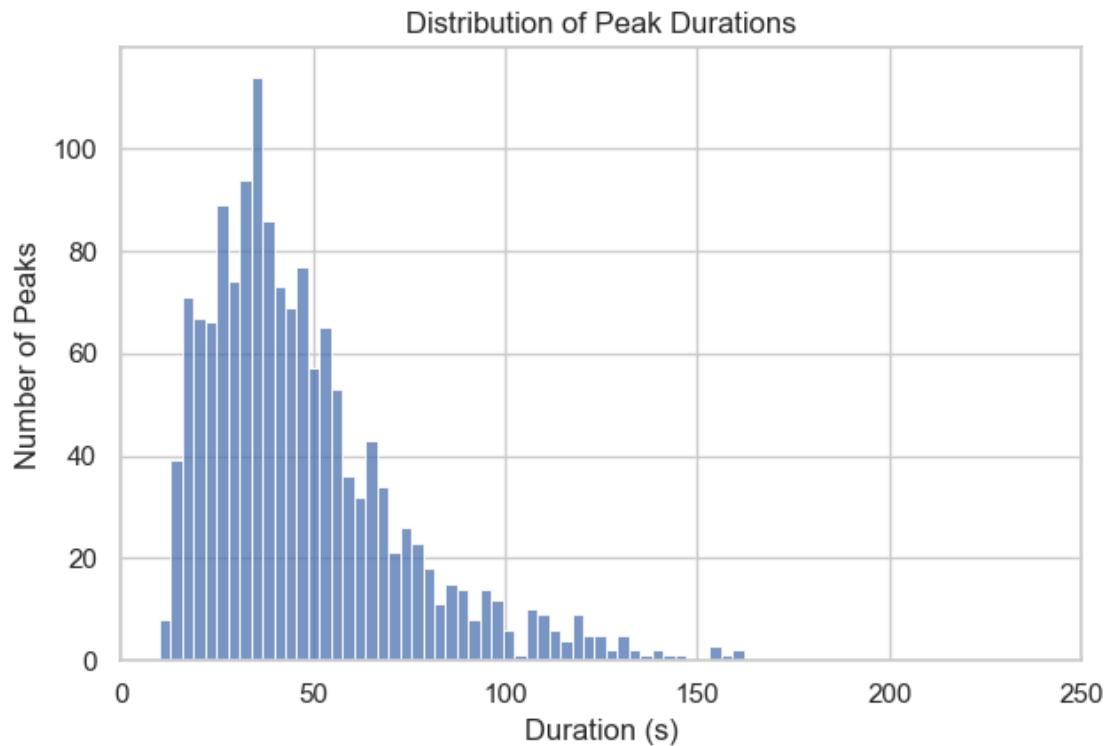


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

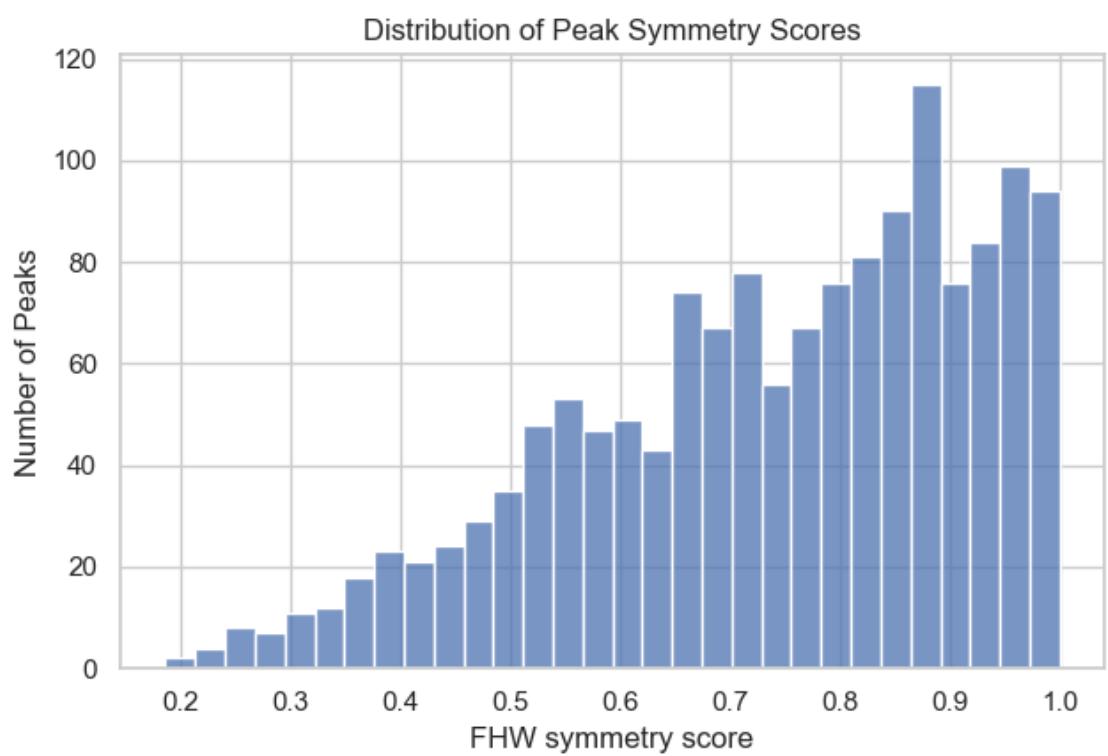
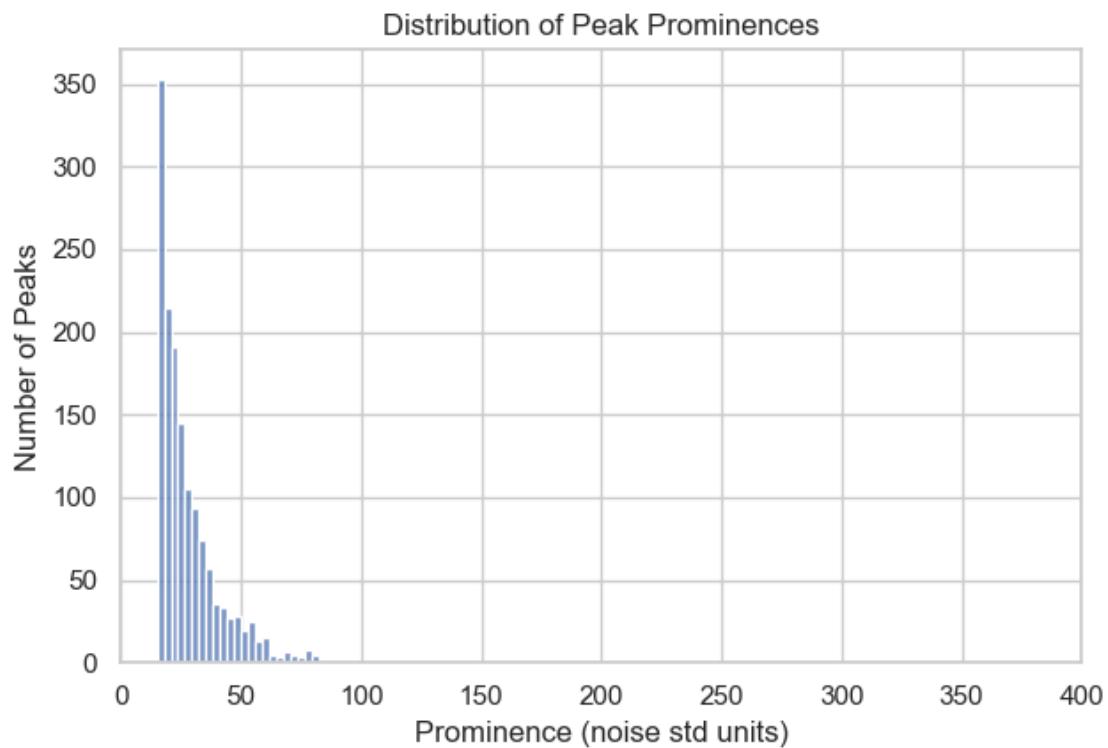


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:47:35] [INFO] calcium: plot_histogram: removed 7 outliers out of  
1491 on 'Duration (s)' (lower=-16, upper=164)
```

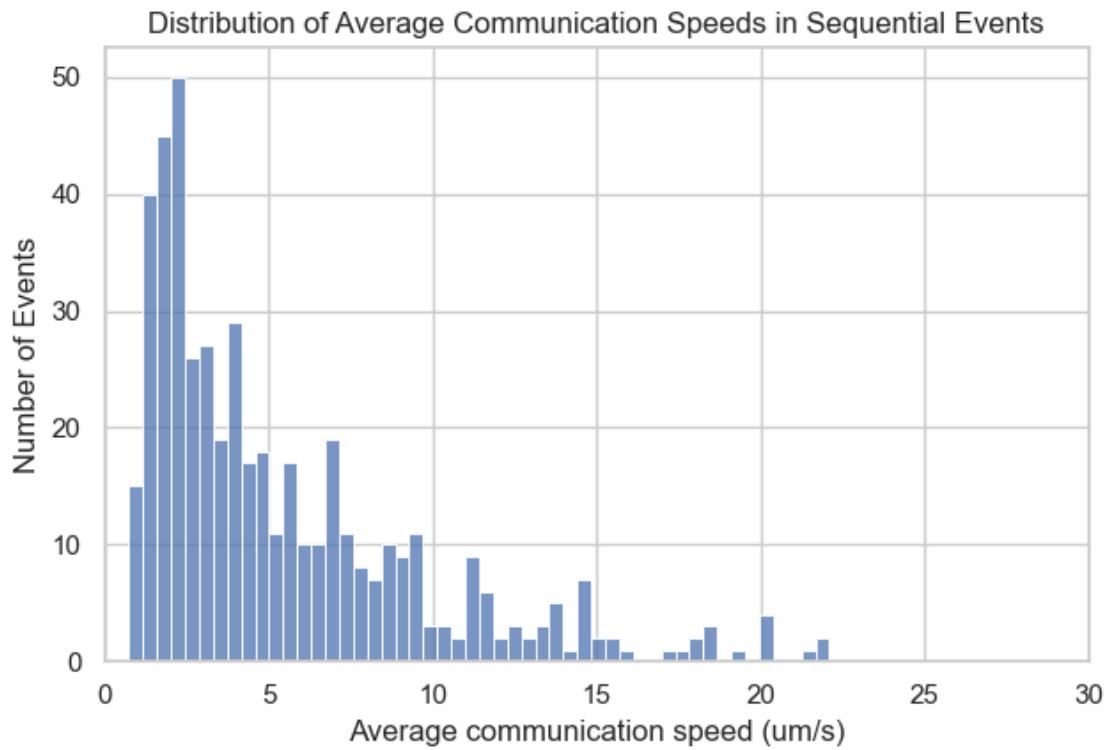


```
[2025-08-27 14:47:35] [INFO] calcium: plot_histogram: removed 28 outliers out of  
1491 on 'Prominence (noise std units)' (lower=-4.225, upper=85.475)
```

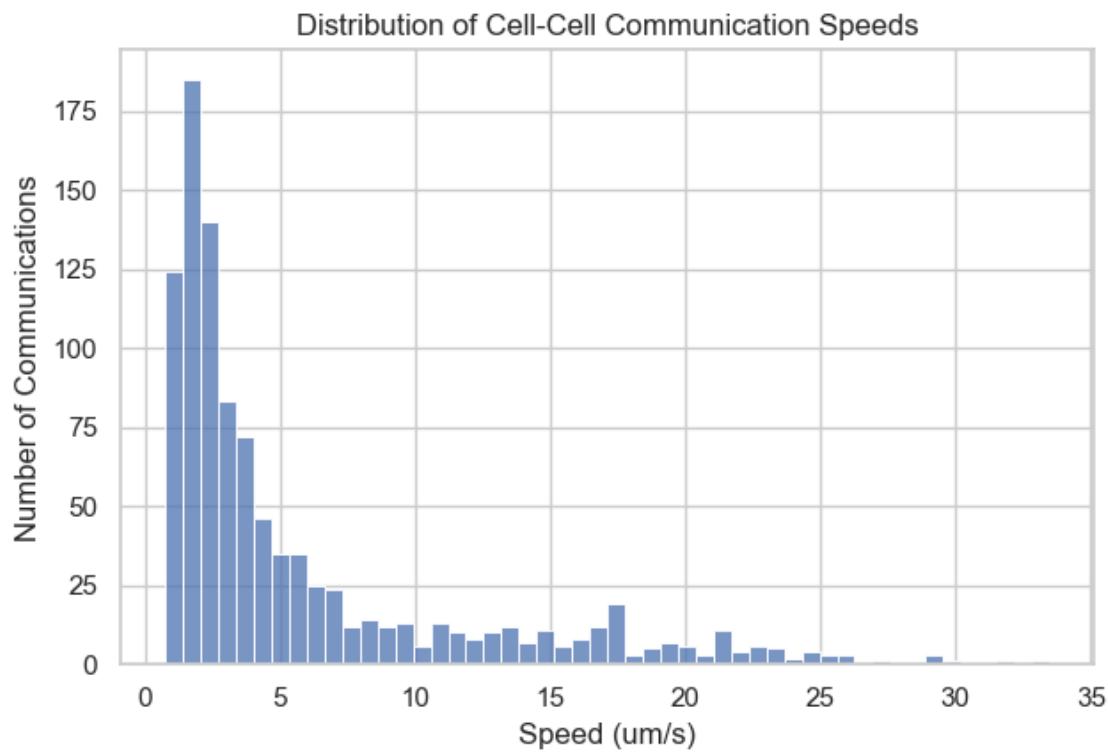


### 1.3.3 Cell-cell communication speed

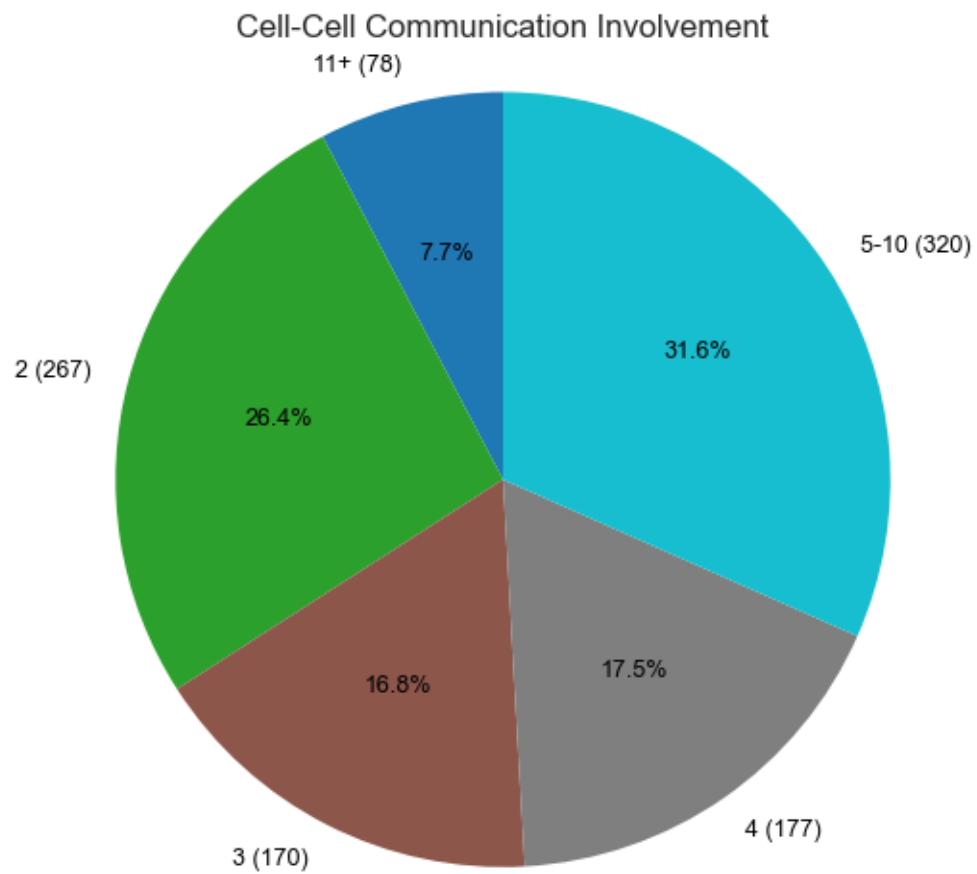
[2025-08-27 14:47:35] [INFO] calcium: plot\_histogram: removed 4 outliers out of 479 on 'Average communication speed (um/s)' (lower=-13.09, upper=22.68)



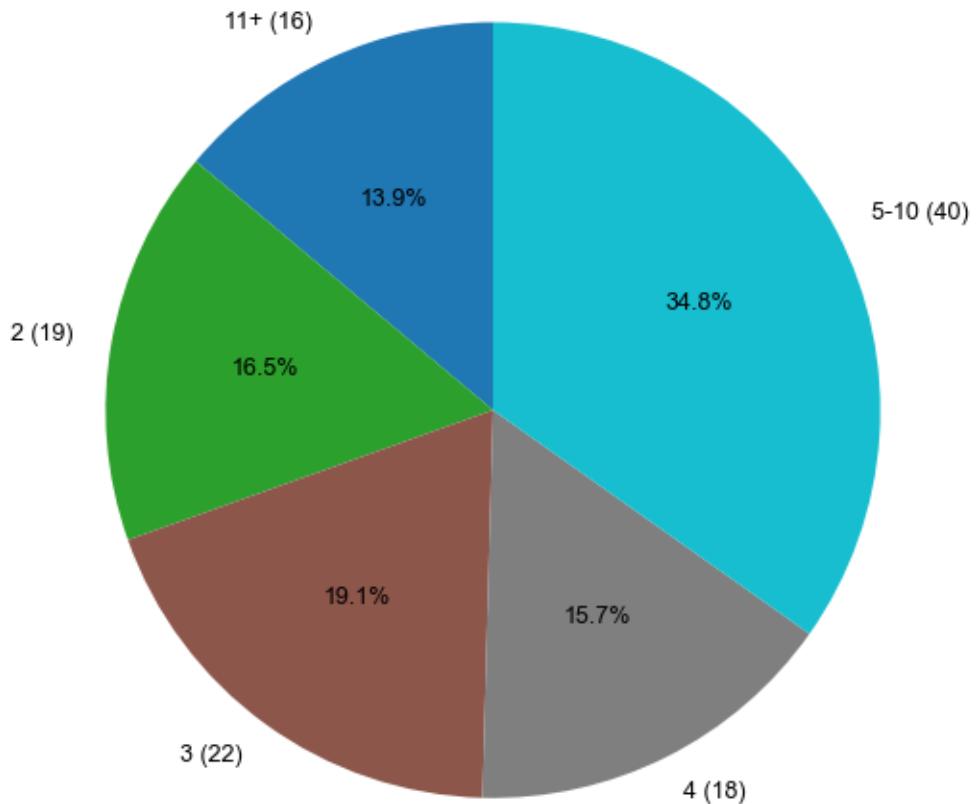
[2025-08-27 14:47:36] [INFO] calcium: plot\_histogram: removed 1 outliers out of 1012 on 'Speed (um/s)' (lower=-14.08, upper=33.53)



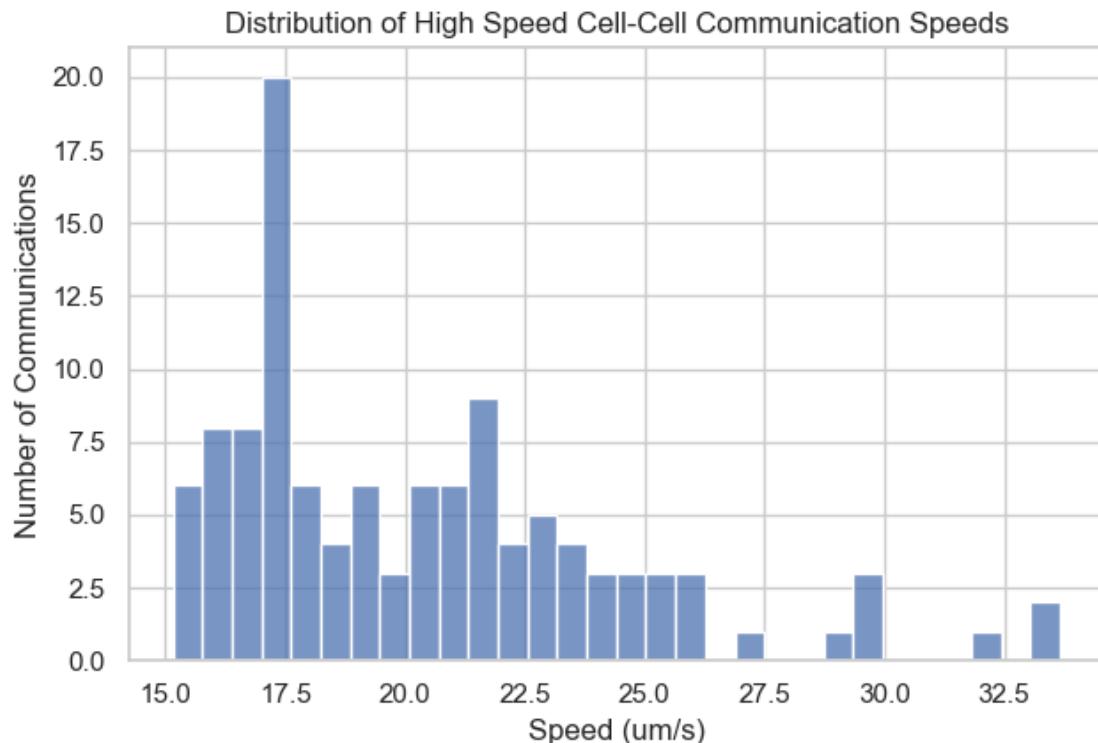
#### 1.3.4 Double distribution in cell-cell communication speeds



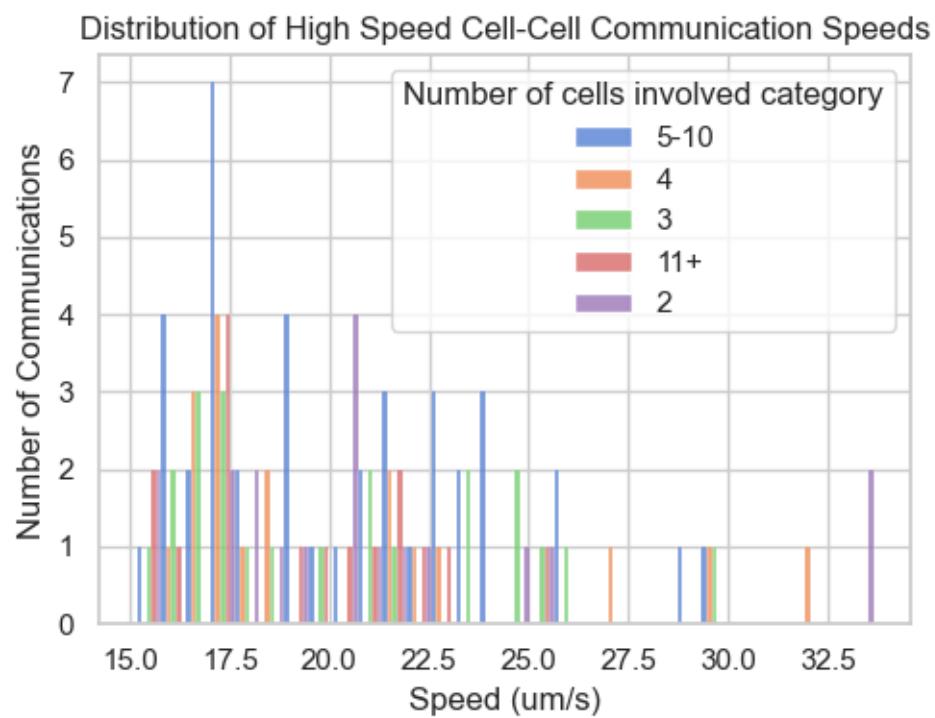
### High Speed Cell-Cell Communication Involvement



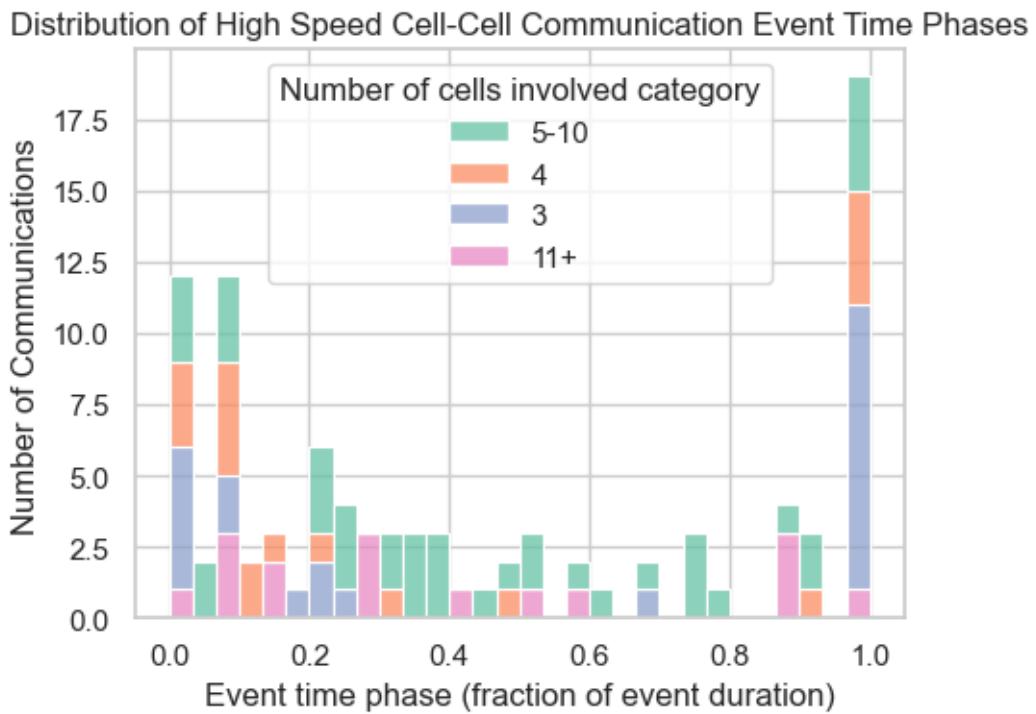
```
[2025-08-27 14:47:36] [INFO] calcium: plot_histogram: removed 0 outliers out of  
115 on 'Speed (um/s)' (lower=0.99, upper=38.72)
```



```
[2025-08-27 14:47:36] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 115 on 'Speed (um/s)' (lower=0.99, upper=38.72)
```

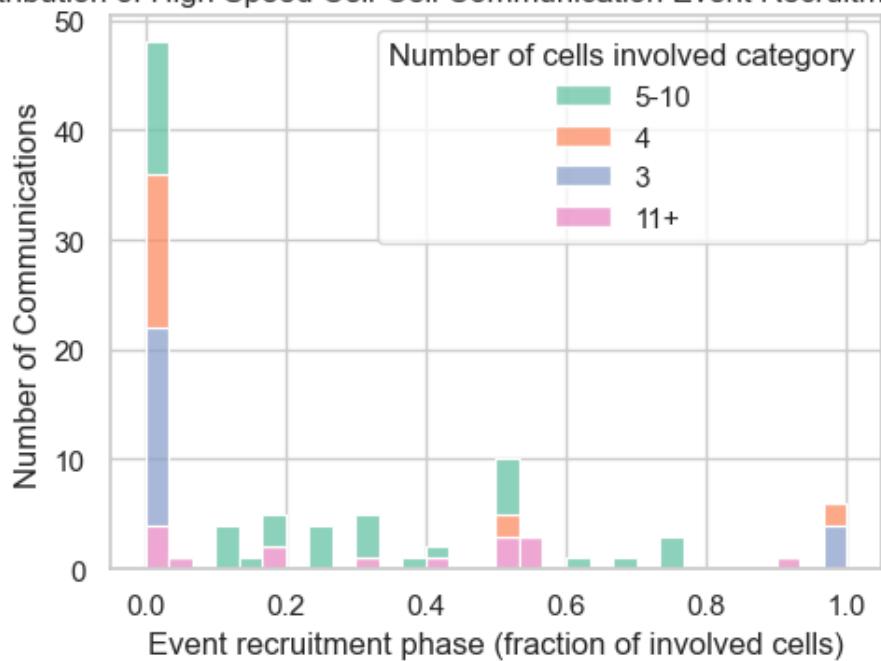


[2025-08-27 14:47:36] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 96 on 'Event time phase (fraction of event duration)' (lower=-2.29, upper=3.2575)

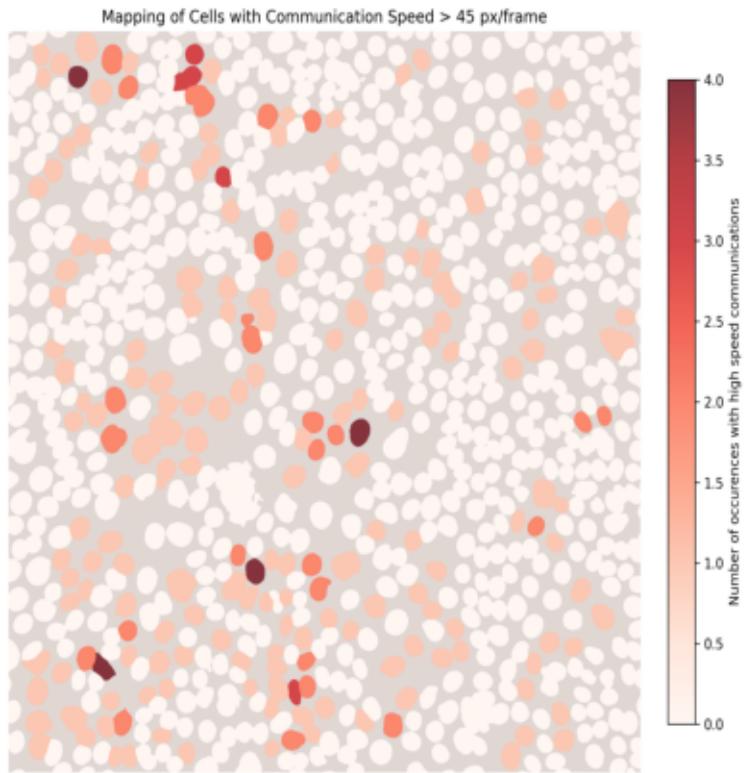


[2025-08-27 14:47:37] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 96 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)

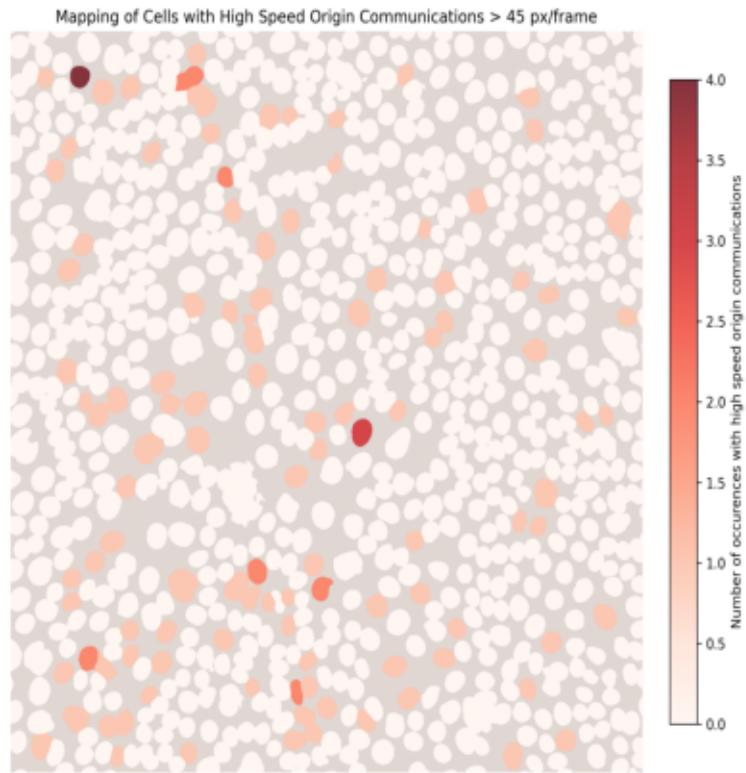
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	\
4	3015667554368	3	267	4	
5	3015667554512	3	267	4	
7	3015667563296	3	293	2	
8	3015667562576	3	285	3	
18	3015667553024	5	1186	2	
..	...	...	...	...	
949	3015558058704	440	1233	4	
979	3015477193616	459	1237	4	
981	3015477193424	460	1200	8	
991	3015477191504	465	1286	4	
995	3015477191024	466	1293	7	

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
4	217	5	1563.0	1564.0	
5	247	3	1563.0	1564.0	
7	285	3	1566.0	1566.0	
8	244	5	1566.0	1566.0	
18	1144	3	220.0	220.0	
..	...	...	...	...	...
949	1188	5	871.0	873.0	
979	1244	6	649.0	650.0	
981	1244	7	806.0	807.0	
991	1259	3	650.0	651.0	
995	1260	5	1564.0	1565.0	
	Duration (s)	Distance (um)	Speed (um/s)		\
4	1.0	21.07	21.07		
5	1.0	16.50	16.50		
7	0.0	21.65	21.65		
8	0.0	16.95	16.95		
18	0.0	18.41	18.41		
..	...	...	...		
949	2.0	34.00	17.00		
979	1.0	23.22	23.22		
981	1.0	21.29	21.29		
991	1.0	22.86	22.86		
995	1.0	17.56	17.56		
	Event time phase (fraction of event duration)				\
4		0.25			
5		0.25			
7		0.75			
8		0.75			
18		0.00			
..		...			
949		0.22			
979		0.07			
981		NaN			
991		0.05			
995		NaN			
	Event recruitment phase (fraction of involved cells)		dataset		\
4		0.0	20250424_IS5		
5		0.0	20250424_IS5		
7		0.5	20250424_IS5		
8		0.5	20250424_IS5		
18		0.0	20250424_IS5		
..		...	...		
949		0.0	20250424_IS5		
979		0.0	20250424_IS5		

981		NaN	20250424_IS5
991		0.0	20250424_IS5
995		NaN	20250424_IS5

	Number of cells involved	category	Speed category
4		5-10	High speed
5		5-10	High speed
7		5-10	High speed
8		5-10	High speed
18		4	High speed
..		..	..
949		4	High speed
979		3	High speed
981		2	High speed
991		5-10	High speed
995		2	High speed

[115 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
213		0	1
214		0	1
217		0	2
220		0	2
222		0	1
..		..	..
1294		0	1
1296		0	1
1297		1	1
1303		0	1
1304		0	1

[446 rows x 2 columns]

	Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	214	290.23	9.75	
4	217	61.43	10.40	
6	220	168.68	11.05	
9	223	241.47	12.03	
13	230	146.58	15.28	
..	..	..	..	
758	1293	396.50	487.82	
759	1294	462.48	487.82	
761	1296	243.43	488.15	
765	1303	431.60	491.40	
766	1304	110.83	492.38	

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

2	9	True	1
4	6	True	1
6	4	True	0
9	4	True	1
13	7	True	0
..	..	..	..
758	8	True	1
759	9	True	1
761	3	True	1
765	5	True	1
766	7	True	1

Occurrences in global events as early peaker			Early peaker event IDs \
2	9	0	[]
4	6	0	[]
6	4	0	[]
9	4	0	[]
13	7	0	[]
..	..	..	..
758	8	0	[]
759	9	0	[]
761	3	1	[1]
765	5	0	[]
766	7	0	[]

Occurrences in sequential events \	
2	3
4	4
6	2
9	1
13	2
..	..
758	1
759	4
761	2
765	1
766	5

Occurrences in sequential events as origin \	
2	1
4	2
6	1
9	1
13	0
..	..
758	1
759	1
761	1

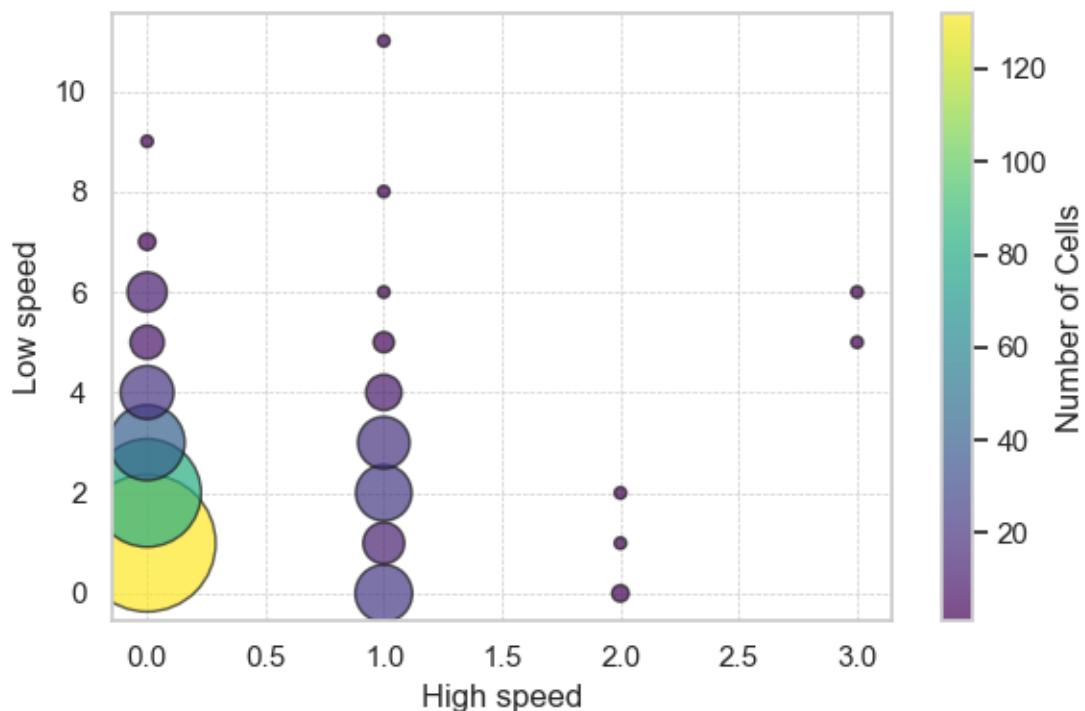
765		1		
766		1		
	Occurrences in individual events	Peak frequency (Hz)	Periodicity score	\
2	5	0.0053	0.67	
4	1	0.0035	0.64	
6	2	0.0024	0.55	
9	2	0.0024	0.59	
13	5	0.0041	0.66	
..	...	...	...	...
758	6	0.0047	0.66	
759	4	0.0053	0.50	
761	0	0.0018	0.85	
765	3	0.0029	0.60	
766	1	0.0041	0.63	
	Neighbor count	Neighbors (labels)	dataset	\
2	3	[231,245,270]	20250424_IS5	
4	3	[238,247,267]	20250424_IS5	
6	4	[230,254,255,275]	20250424_IS5	
9	3	[221,236,260]	20250424_IS5	
13	4	[220,222,254,265]	20250424_IS5	
..	...	...	...	...
758	3	[1222,1260,1276]	20250424_IS5	
759	5	[1249,1254,1266,1273,1303]	20250424_IS5	
761	4	[1257,1270,1291,1301]	20250424_IS5	
765	3	[1266,1271,1294]	20250424_IS5	
766	3	[1284,1285,1295]	20250424_IS5	
	Involved in sequential event	Occurrences in sequential events	category	\
2	Involved in sequential event		3-4	
4	Involved in sequential event		3-4	
6	Involved in sequential event		1-2	
9	Involved in sequential event		1-2	
13	Involved in sequential event		1-2	
..	...	...	...	...
758	Involved in sequential event		1-2	
759	Involved in sequential event		3-4	
761	Involved in sequential event		1-2	
765	Involved in sequential event		1-2	
766	Involved in sequential event		5-9	
	High speed	Low speed		
2	0.0	1.0		
4	0.0	2.0		
6	0.0	2.0		
9	0.0	1.0		
13	1.0	0.0		

```

...     ...     ...
758     1.0     0.0
759     0.0     1.0
761     0.0     1.0
765     0.0     1.0
766     0.0     1.0

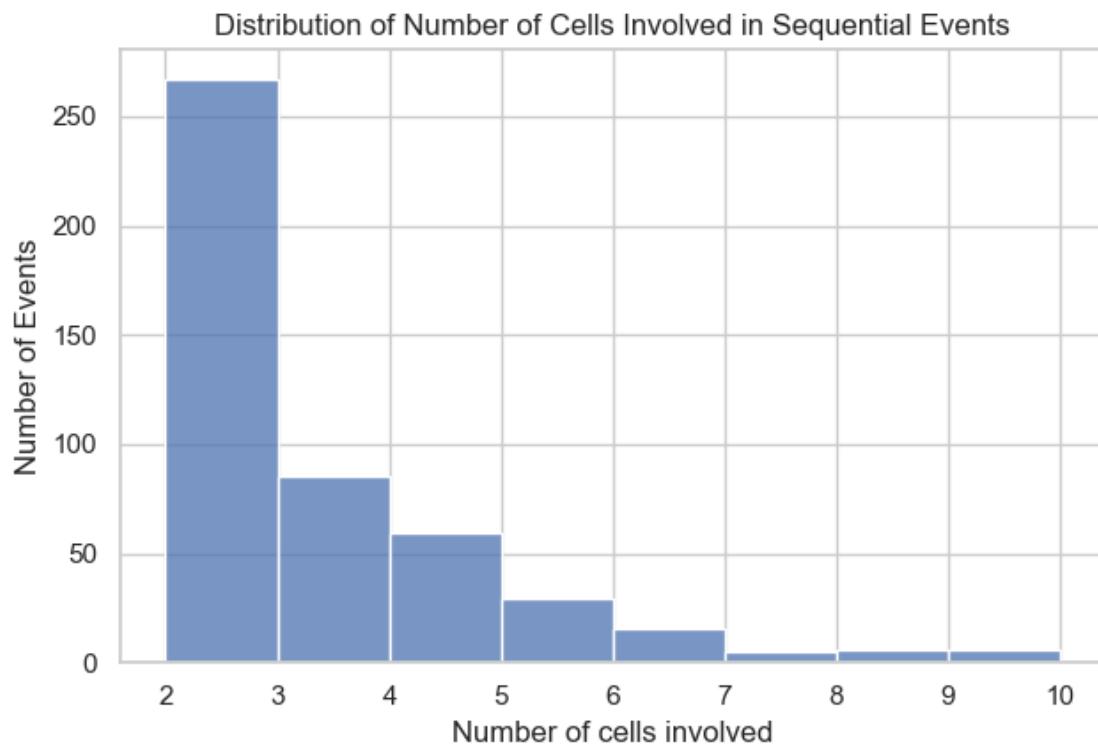
```

[393 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

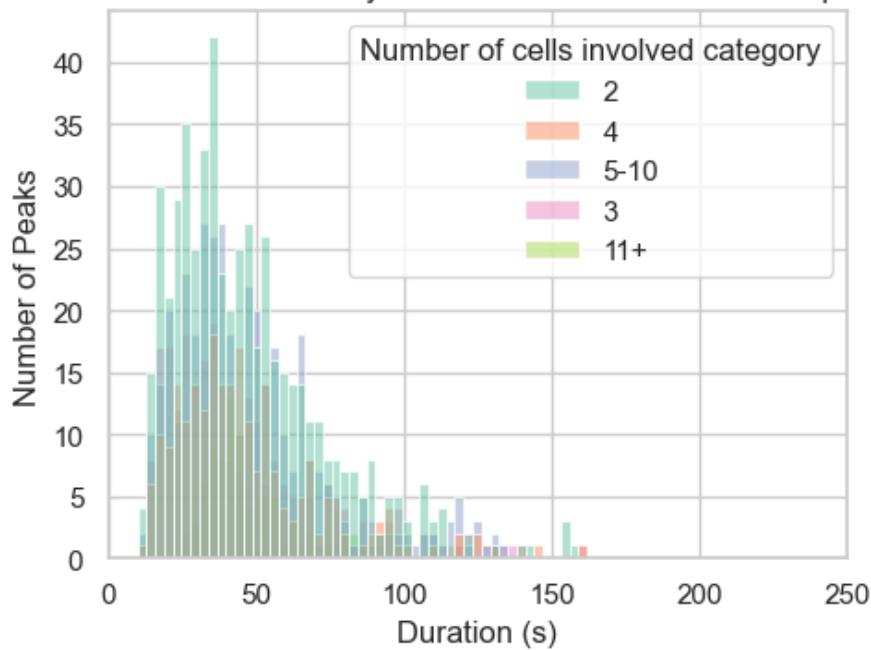
[2025-08-27 14:47:39] [INFO] calcium: plot\_histogram: removed 6 outliers out of 479 on 'Number of cells involved' (lower=-4, upper=10)



### 1.3.6 Influence of cell count per event on statistics

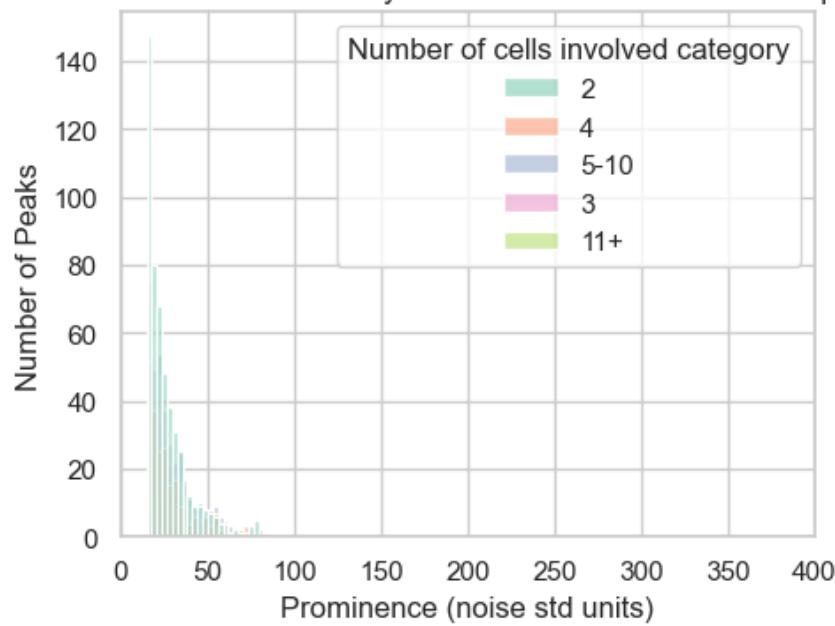
```
[2025-08-27 14:47:39] [INFO] calcium: plot_histogram_by_group: removed 7 outliers out of 1491 on 'Duration (s)' (lower=-16, upper=164)
```

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

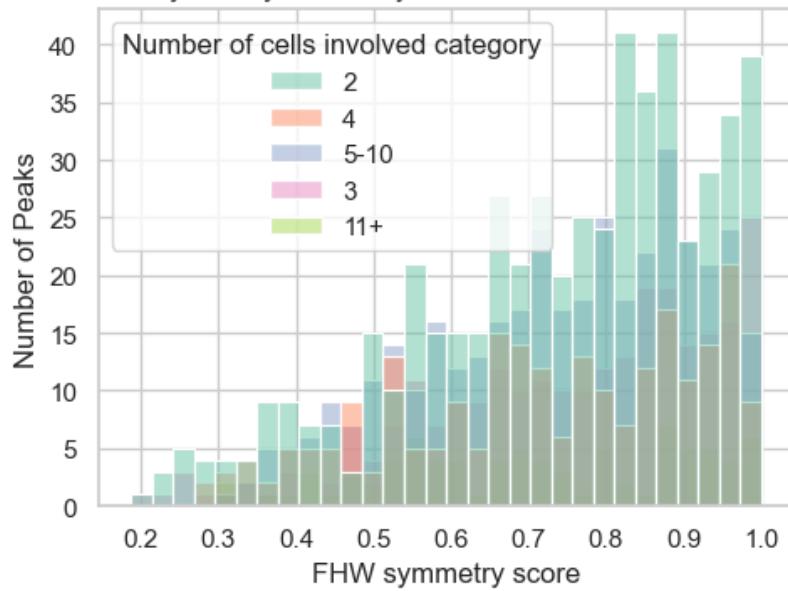


```
[2025-08-27 14:47:40] [INFO] calcium: plot_histogram_by_group: removed 28 outliers out of 1491 on 'Prominence (noise std units)' (lower=-4.225, upper=85.475)
```

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

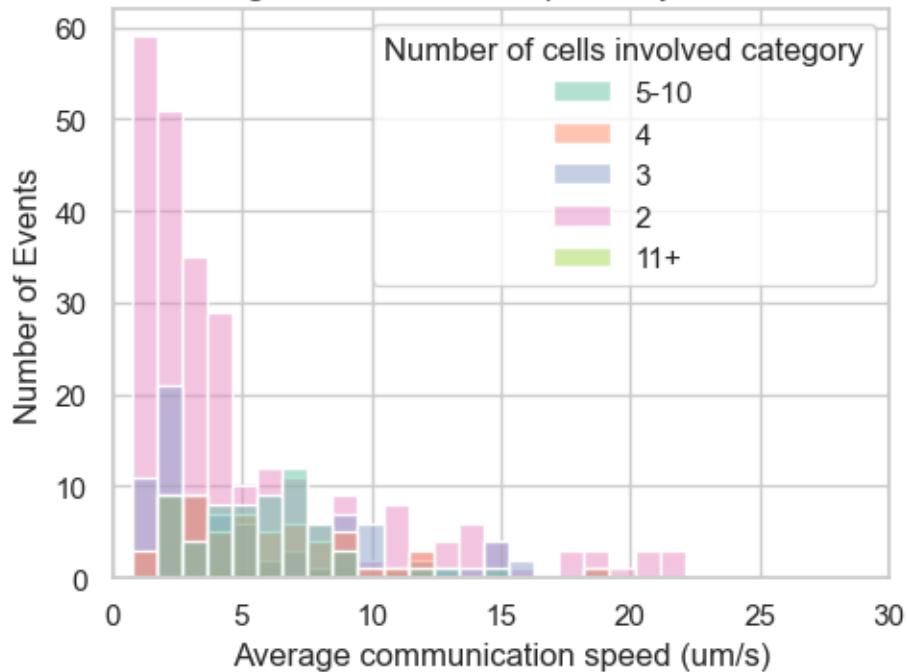


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

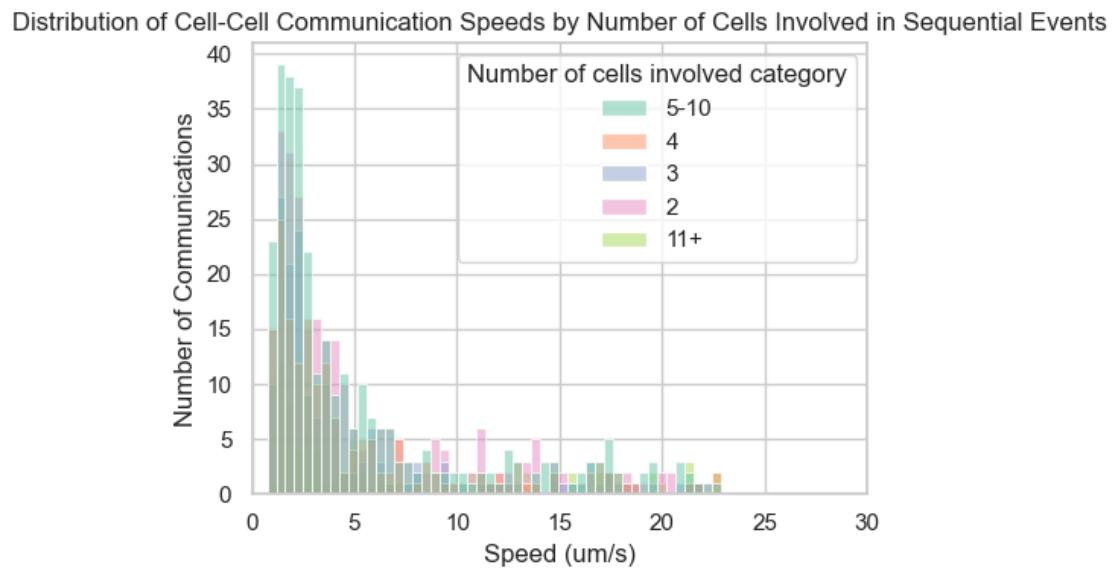


```
[2025-08-27 14:47:40] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 479 on 'Average communication speed (um/s)' (lower=-13.09, upper=22.68)
```

Distribution of Average Communication Speeds by Number of Cells Involved

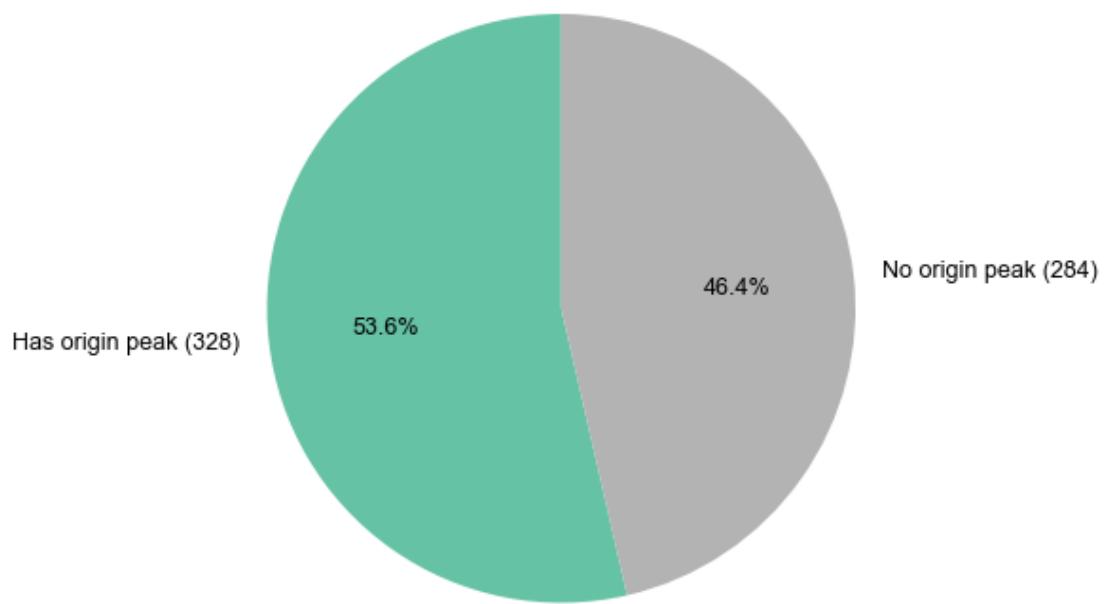


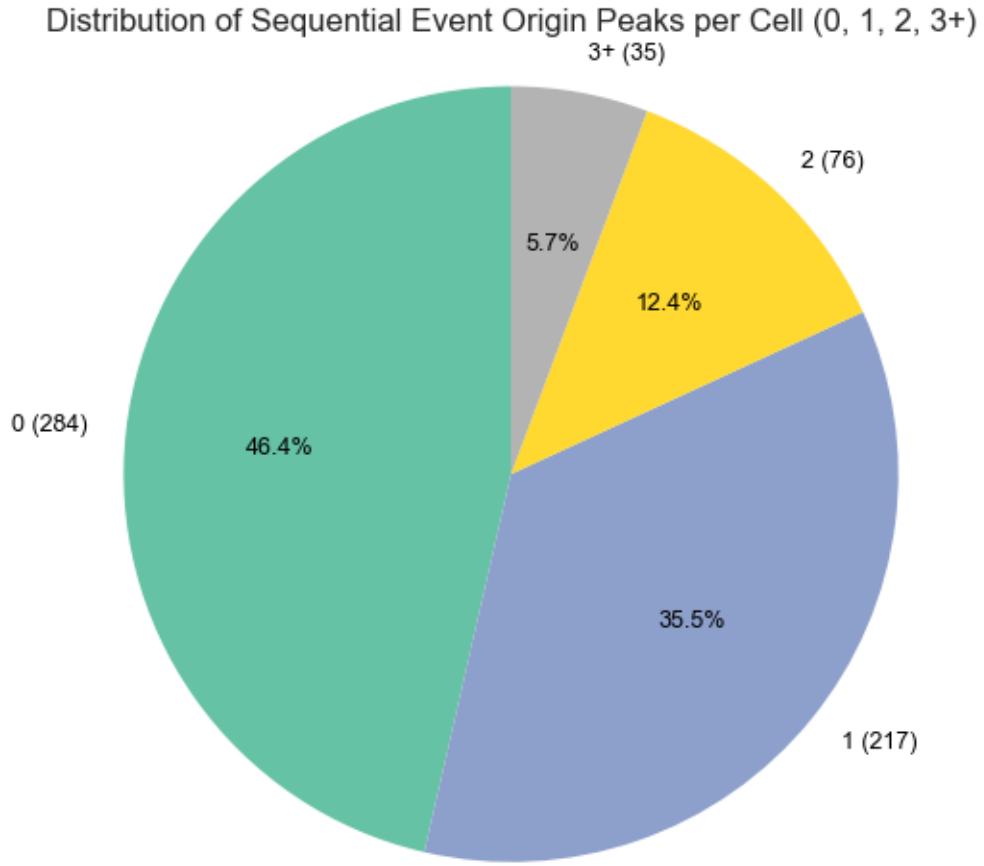
[2025-08-27 14:47:41] [INFO] calcium: plot\_histogram\_by\_group: removed 26 outliers out of 1012 on 'Speed (um/s)' (lower=-14.08, upper=22.95)



### 1.3.7 Cells Occurrences as origin in sequential events

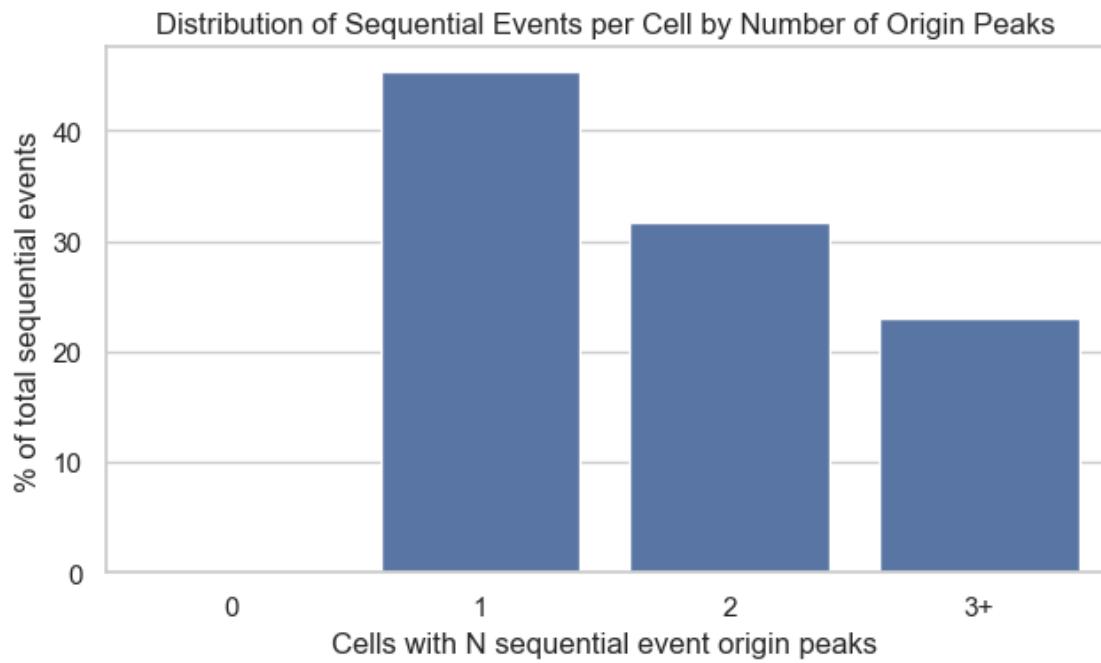
Distribution of Number of Sequential Event Origin Peaks per Cell





```
[2025-08-27 14:47:41] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS5\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\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:
```

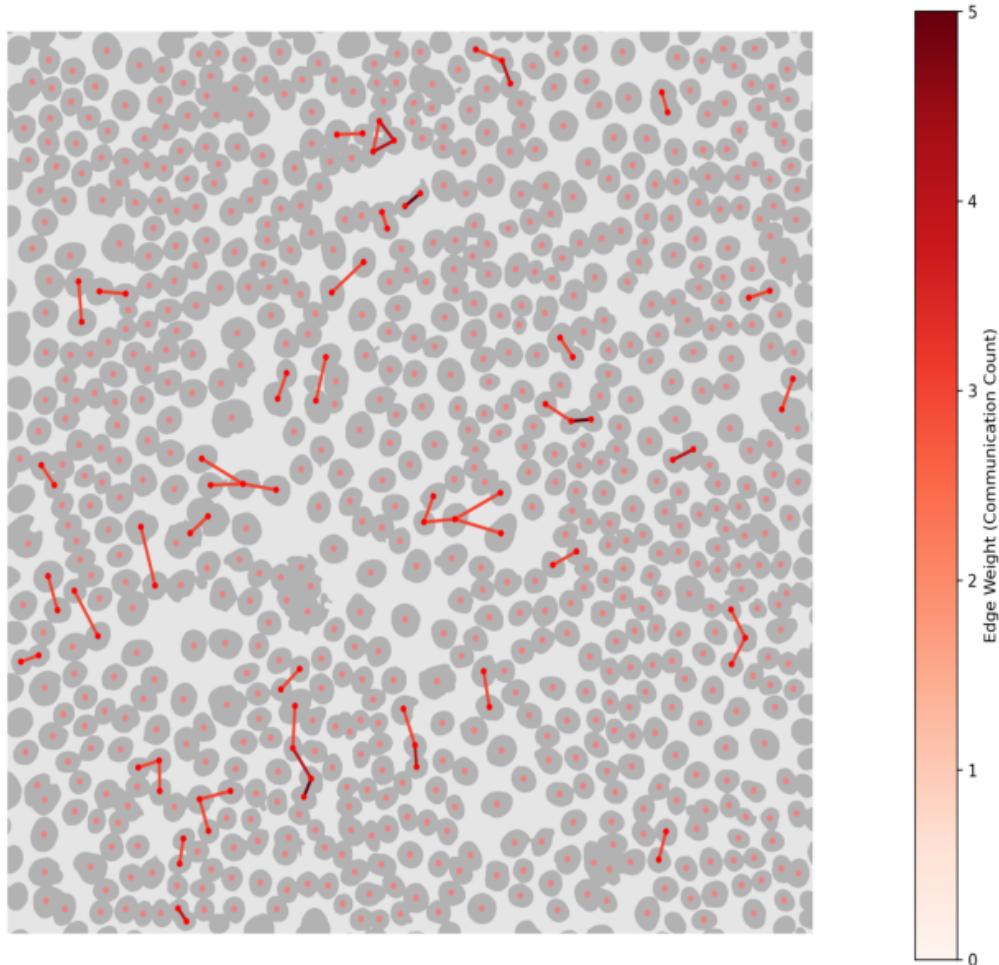
'D:\\Mateo\\20250424\\Output\\IS5\\cell-mapping\\cell\_Occurrences\_in\_origin\_seq\_events\_overlay.png'



### 1.3.8 Connection network between cells

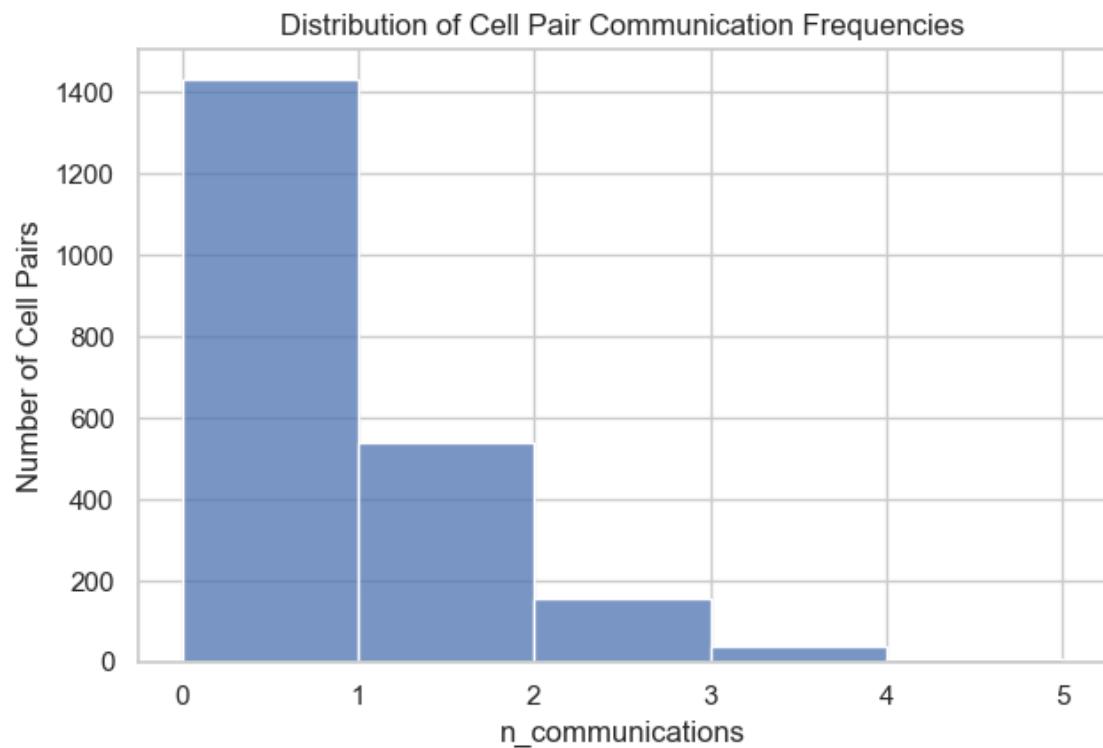
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



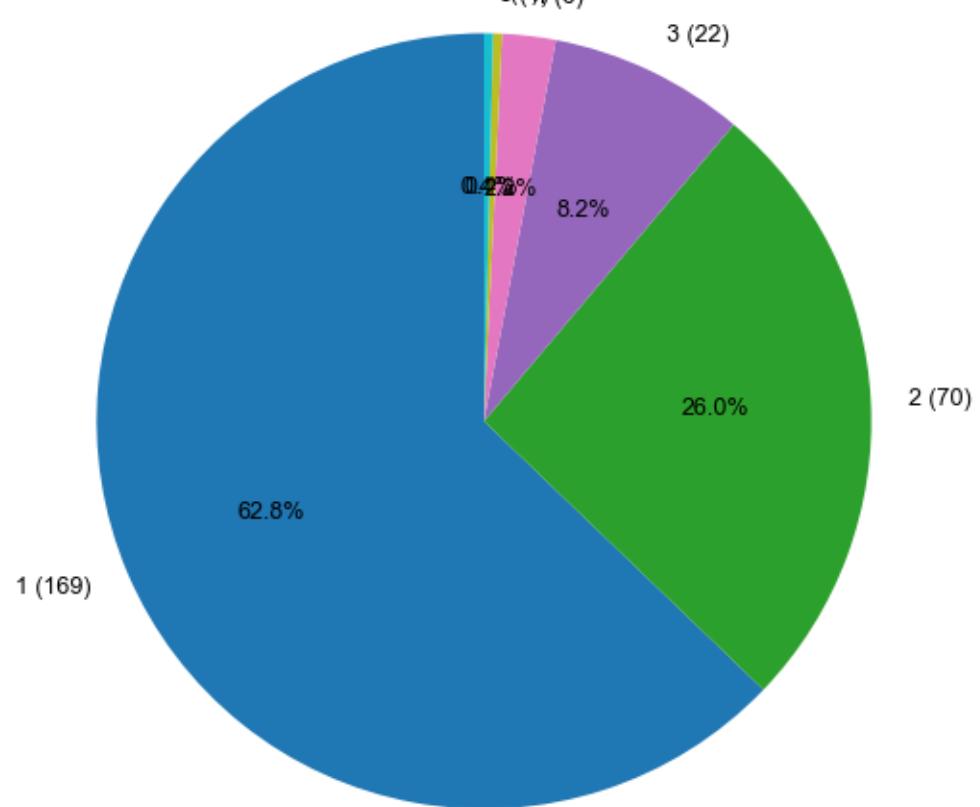
### 1.3.9 Pair/Trios with high communication networks

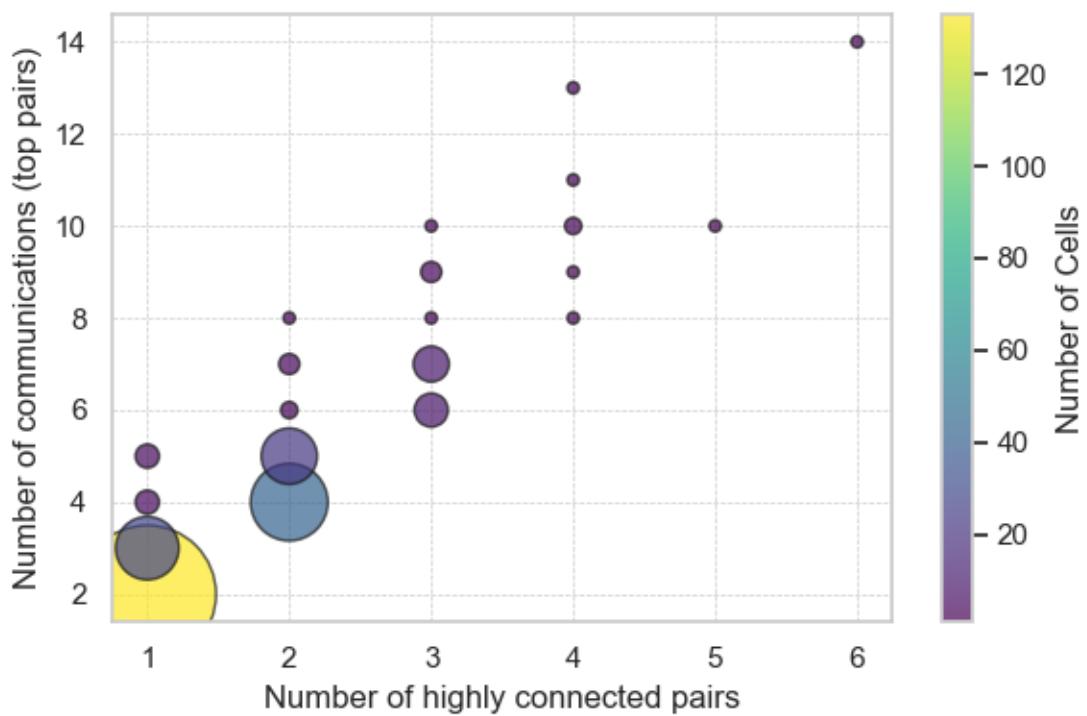
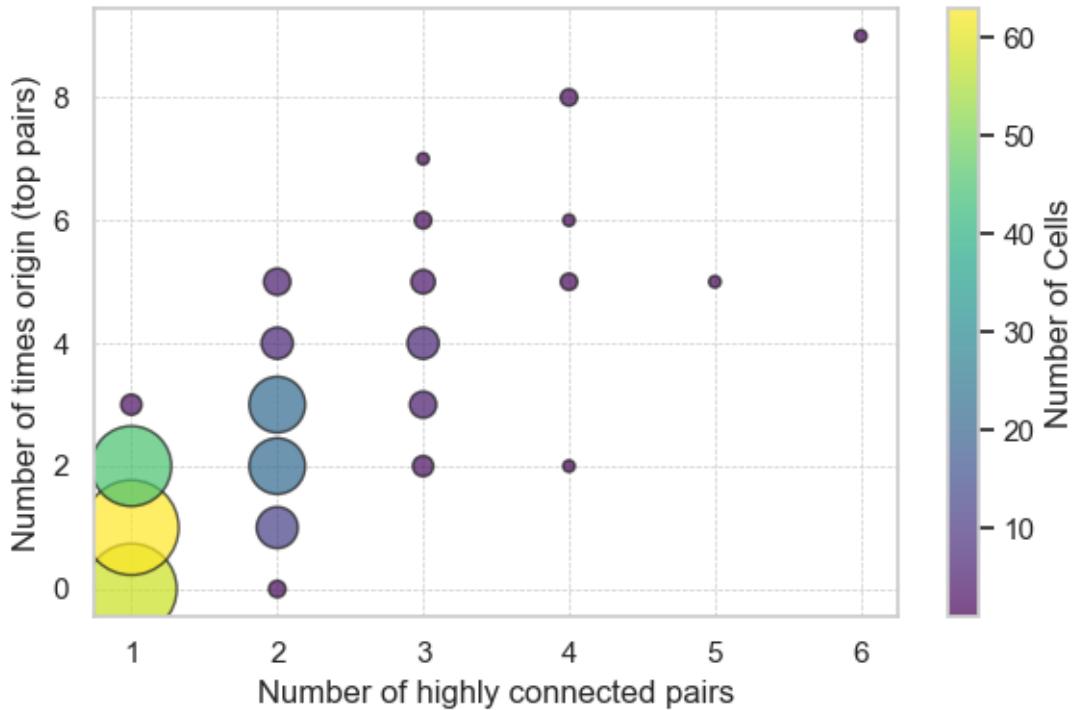
```
[2025-08-27 14:47:43] [INFO] calcium: build_neighbor_pair_stats: built 2176 pairs across 1 datasets (mean distance=19.46 um)
```

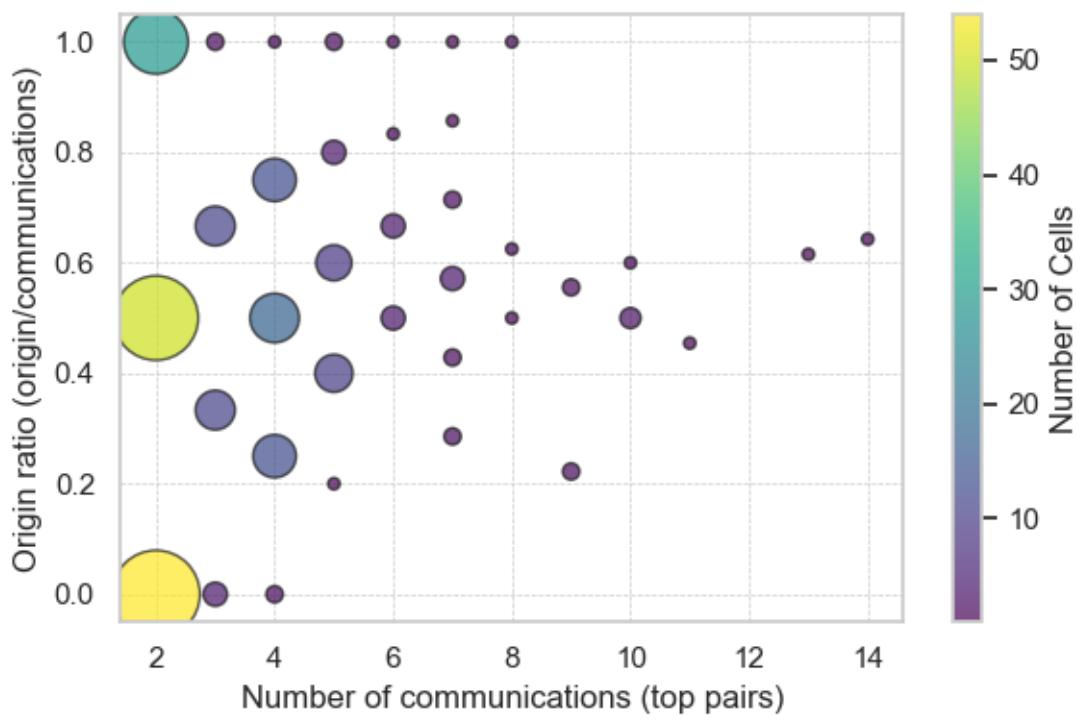
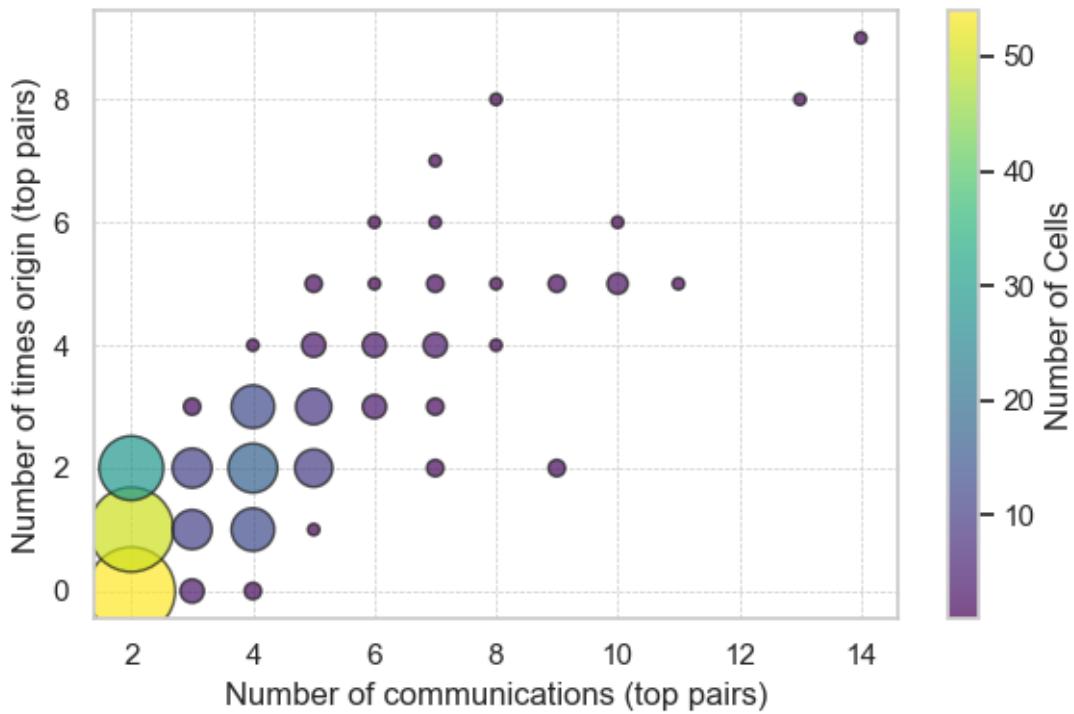


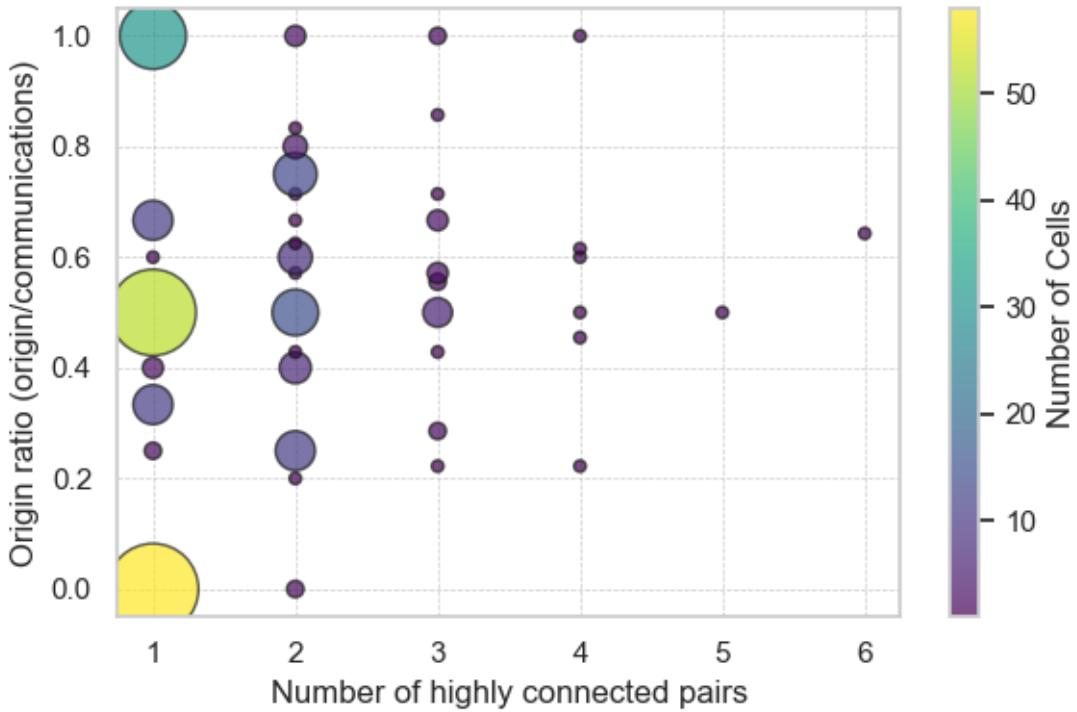
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected









[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=169 for Number of highly connected pairs=1

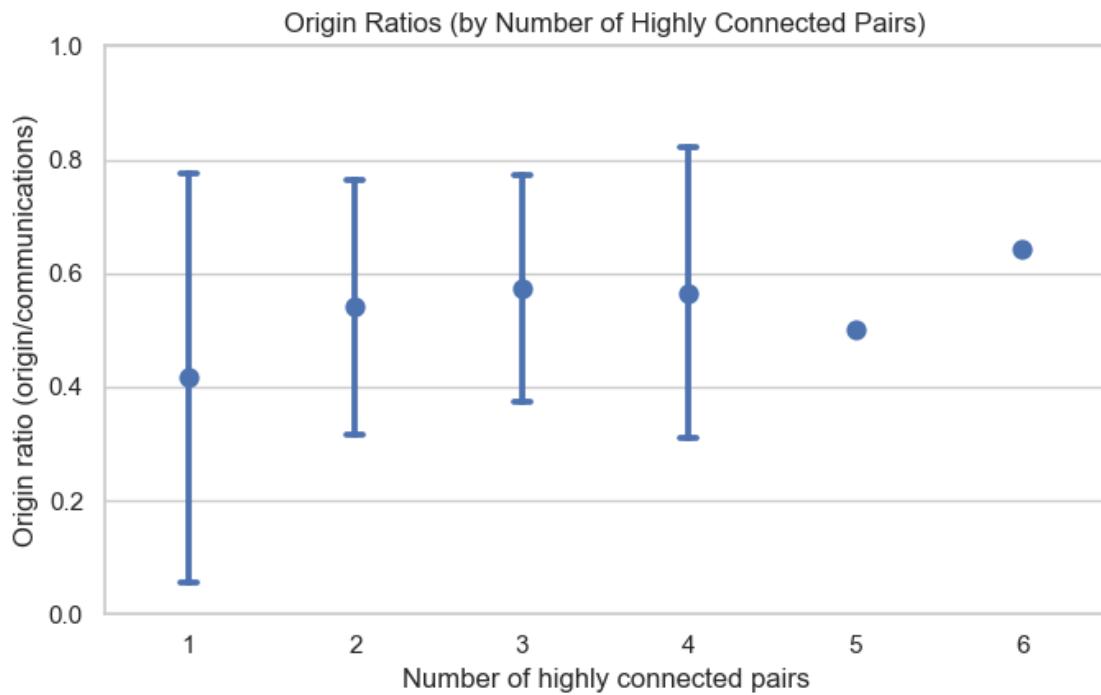
[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=70 for Number of highly connected pairs=2

[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=22 for Number of highly connected pairs=3

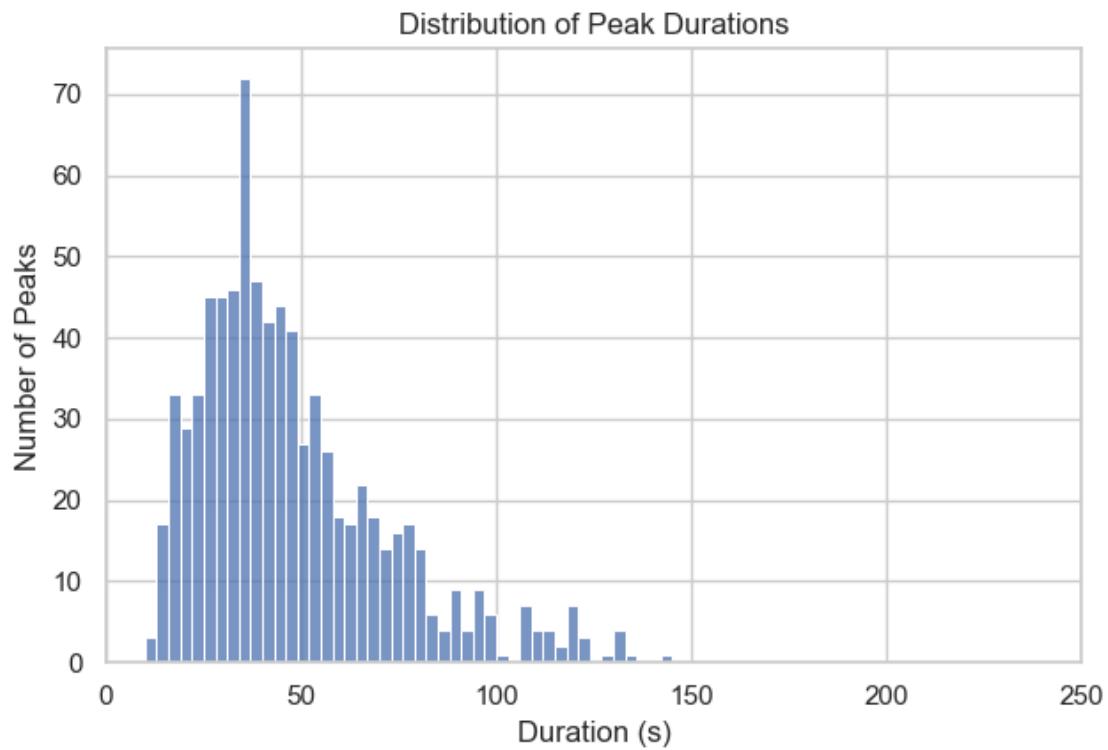
[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=6 for Number of highly connected pairs=4

[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=5

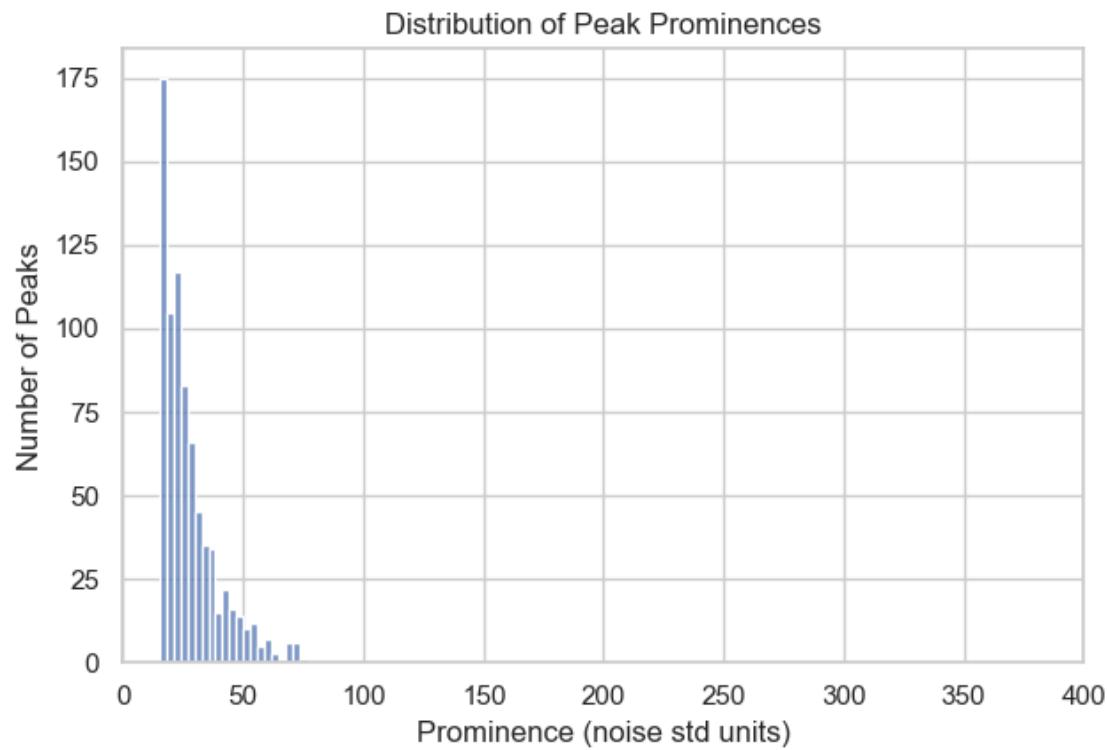
[2025-08-27 14:47:44] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=6

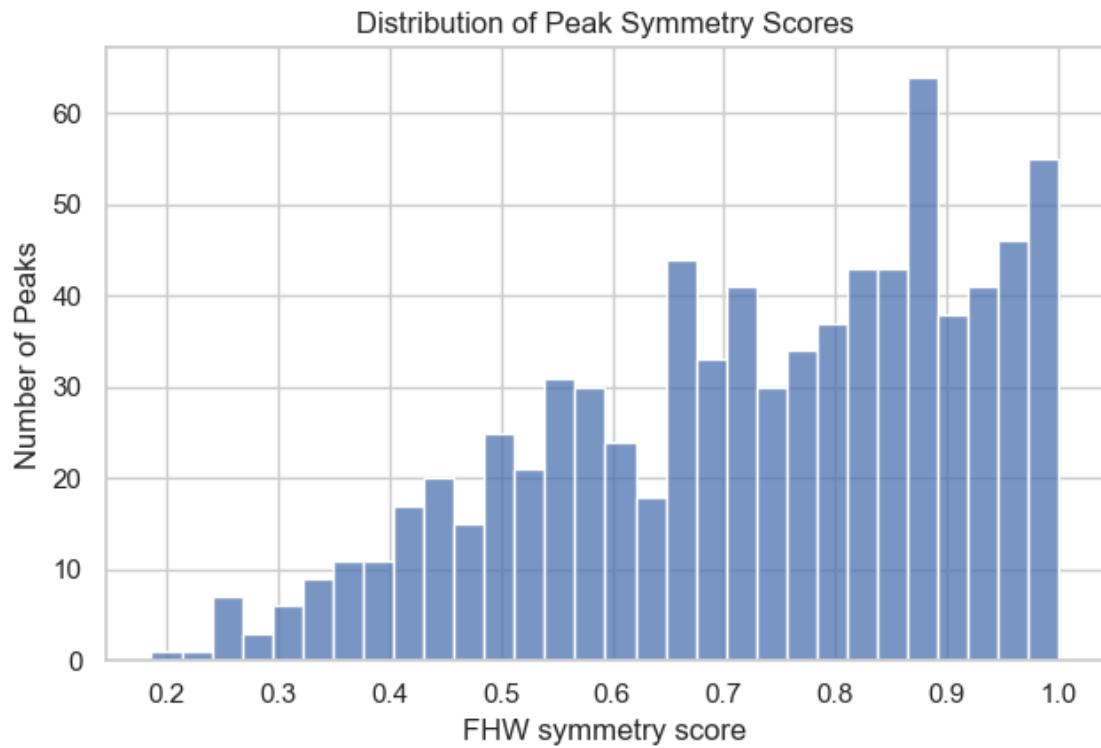


```
[2025-08-27 14:47:44] [INFO] calcium: plot_histogram: removed 7 outliers out of 799 on 'Duration (s)' (lower=-57, upper=146)
```

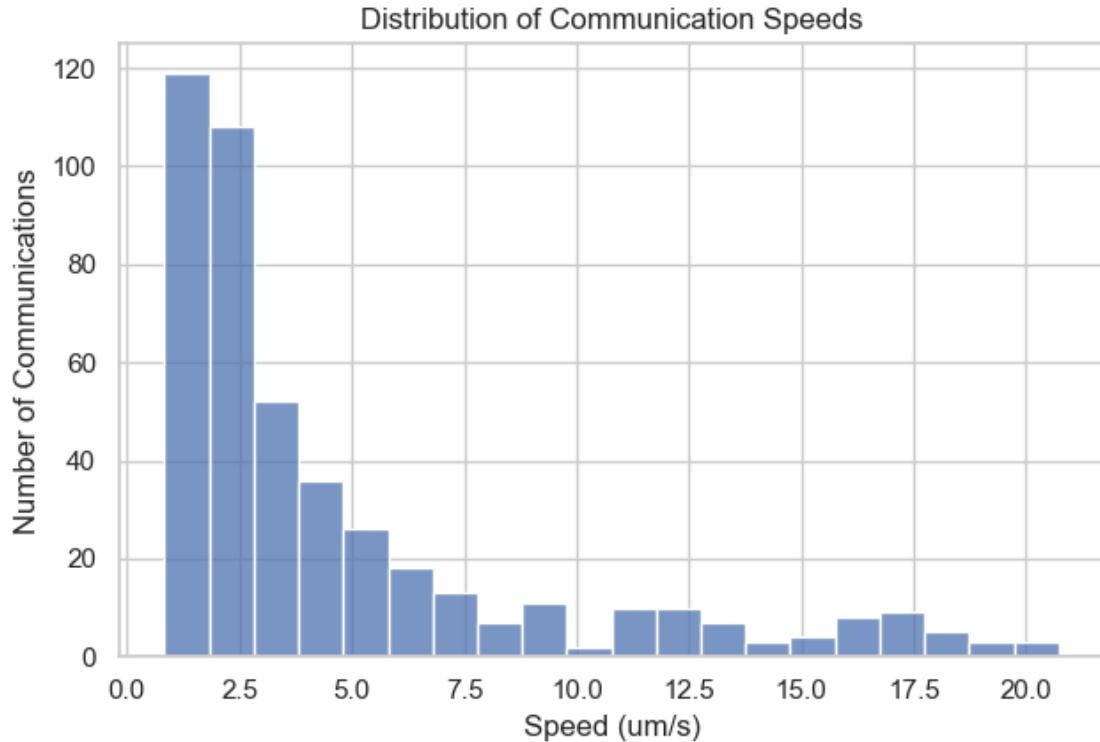


[2025-08-27 14:47:44] [INFO] calcium: plot\_histogram: removed 22 outliers out of 799 on 'Prominence (noise std units)' (lower=-25.5, upper=77.05)

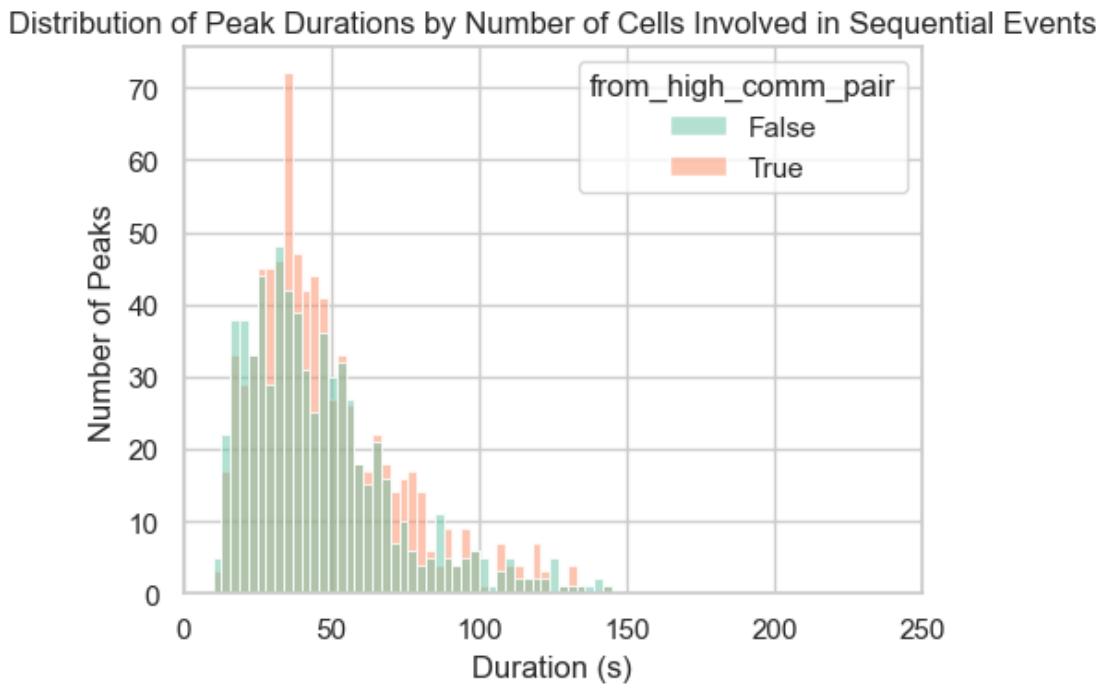




```
[2025-08-27 14:47:44] [INFO] calcium: plot_histogram: removed 19 outliers out of 473 on 'Speed (um/s)' (lower=-12.61, upper=21.06)
```

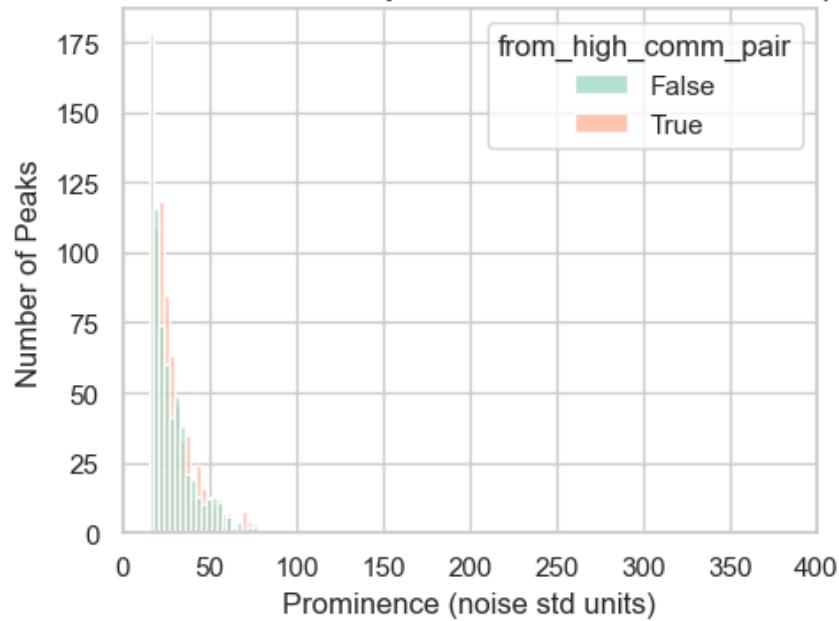


```
[2025-08-27 14:47:44] [INFO] calcium: plot_histogram_by_group: removed 13 outliers out of 1491 on 'Duration (s)' (lower=-61, upper=149)
```

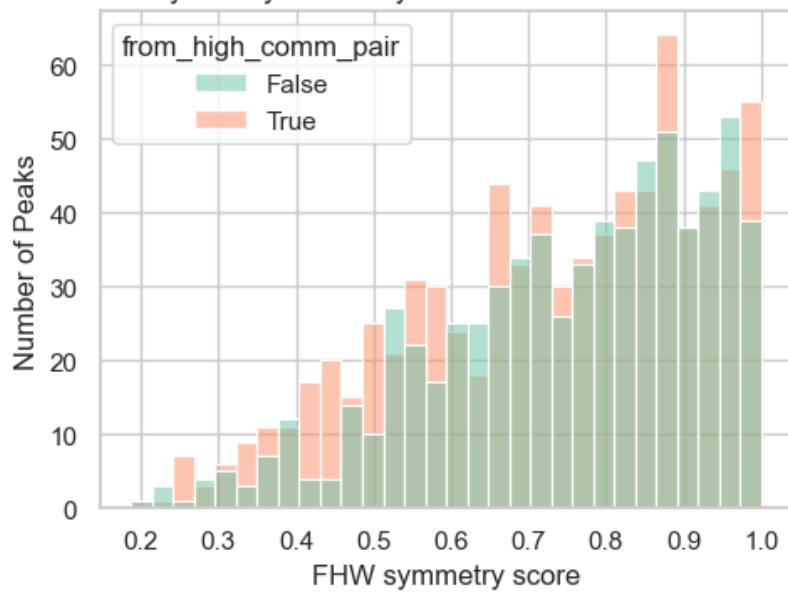


[2025-08-27 14:47:45] [INFO] calcium: plot\_histogram\_by\_group: removed 35 outliers out of 1491 on 'Prominence (noise std units)' (lower=-26.65, upper=78)

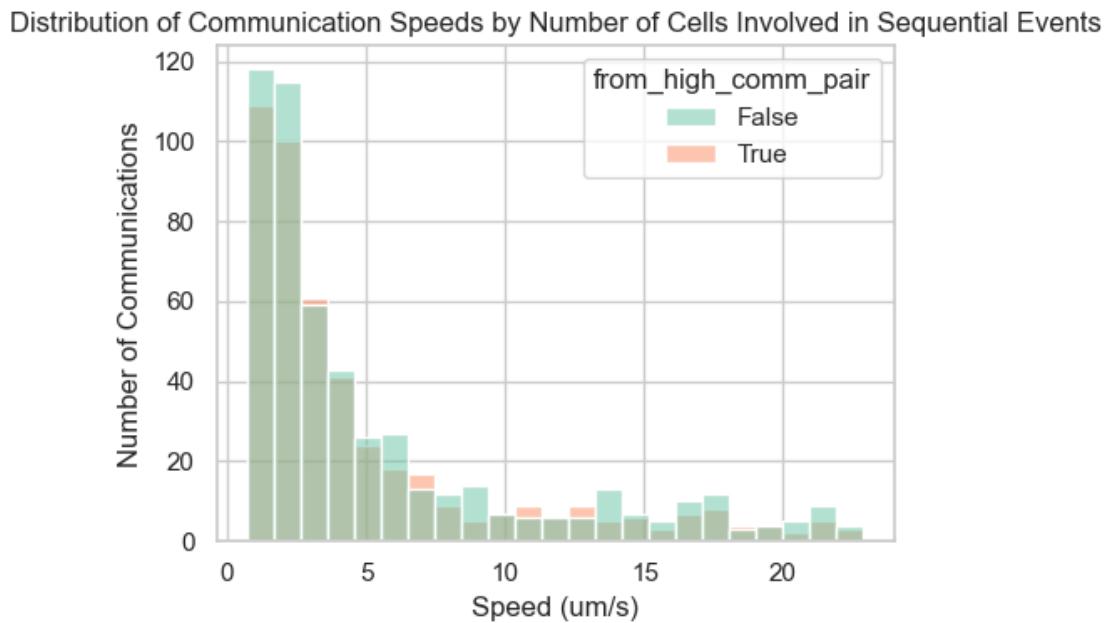
Distribution of Peak Prominences by Number of Cells Involved in Sequential Events



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



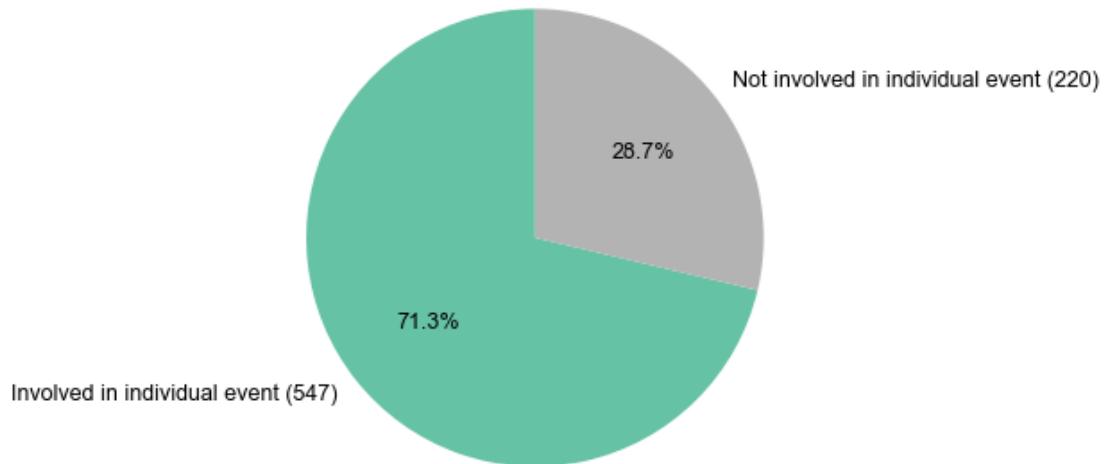
[2025-08-27 14:47:45] [INFO] calcium: plot\_histogram\_by\_group: removed 26 outliers out of 1012 on 'Speed (um/s)' (lower=-14.08, upper=22.95)



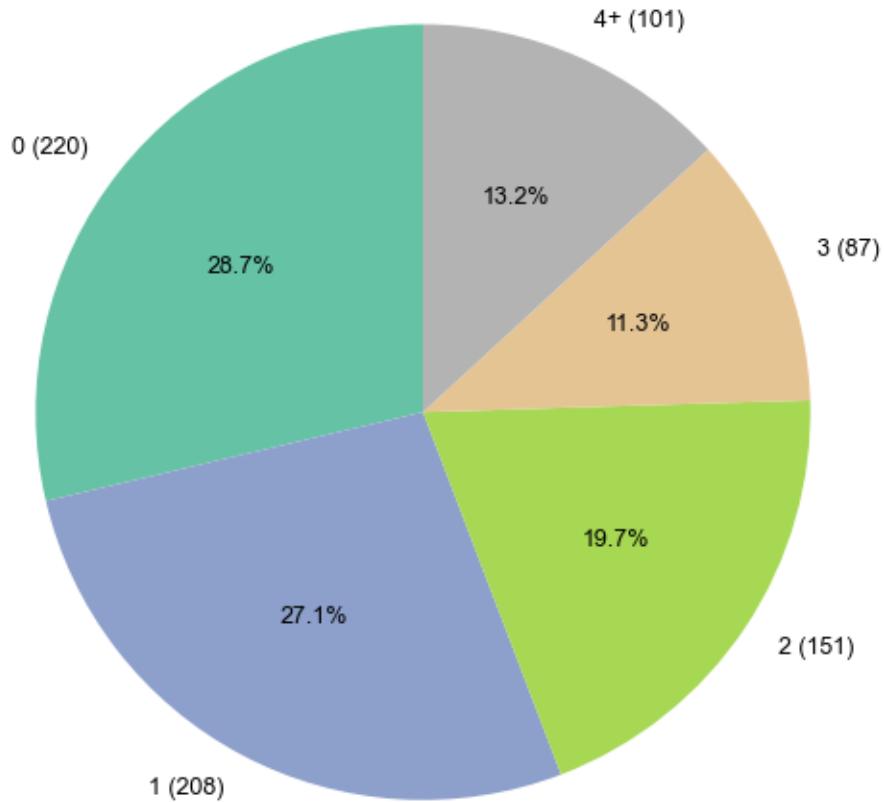
## 1.4 INDIVIDUAL EVENTS

### 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+)

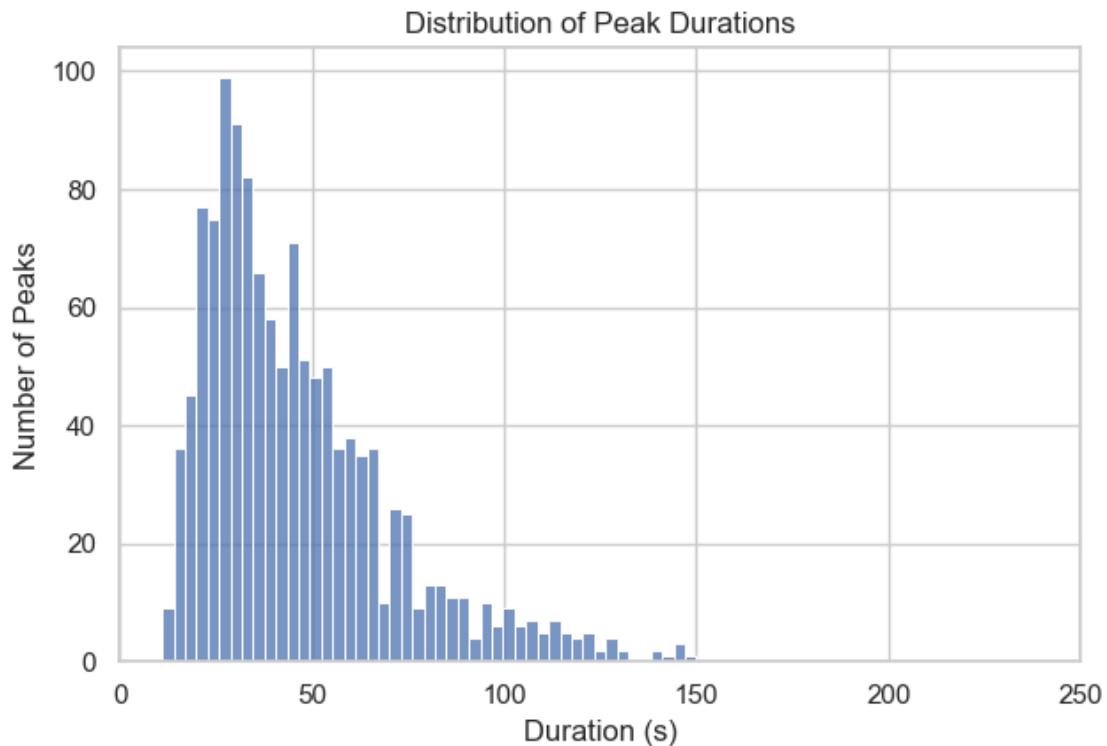


```
[2025-08-27 14:47:45] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS5\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS5\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\20250424\\Output\\IS5\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

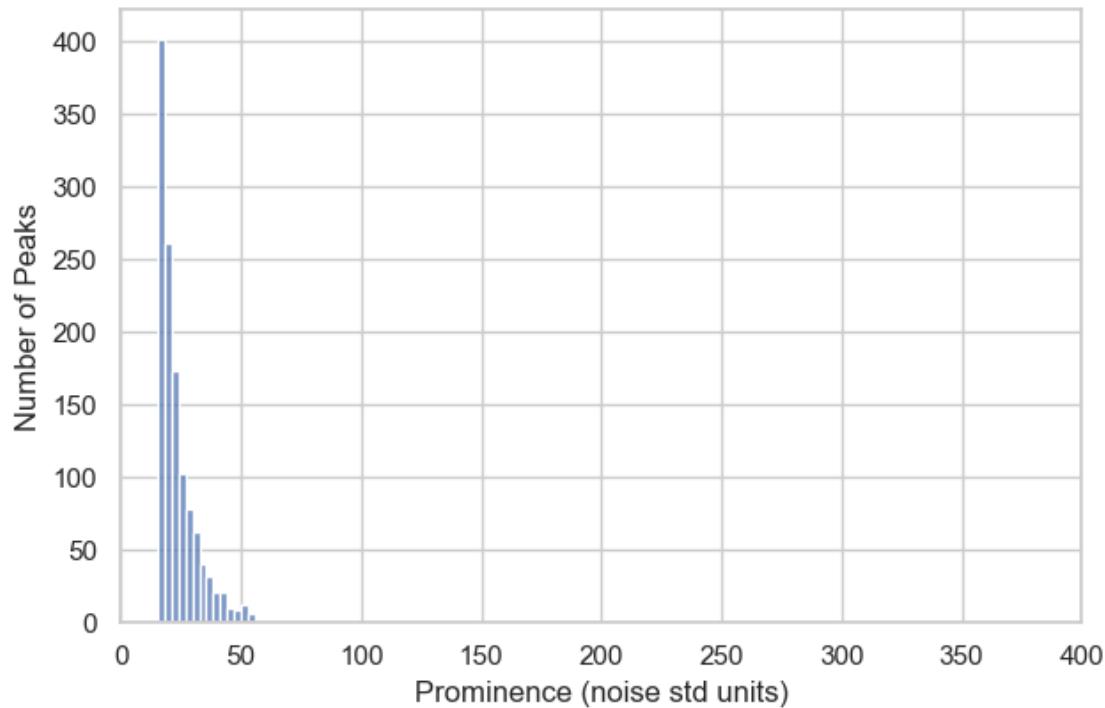
#### 1.4.2 Peaks statistics in individual events

[2025-08-27 14:47:46] [INFO] calcium: plot\_histogram: removed 19 outliers out of 1273 on 'Duration (s)' (lower=-65, upper=152)

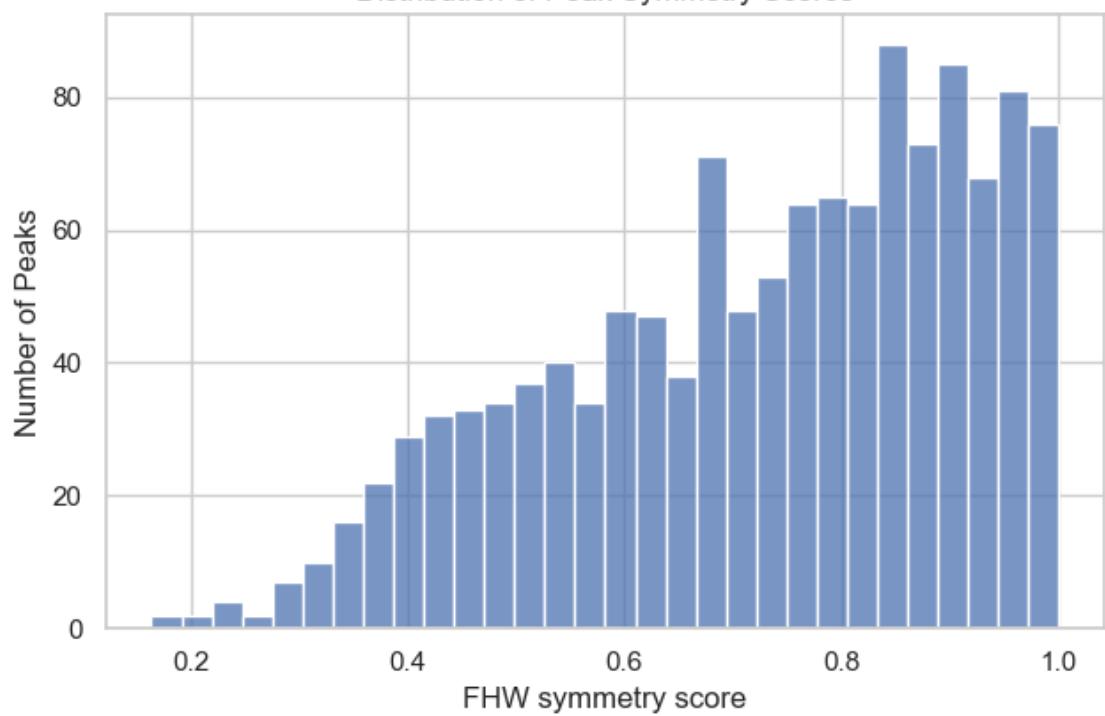


[2025-08-27 14:47:46] [INFO] calcium: plot\_histogram: removed 42 outliers out of 1273 on 'Prominence (noise std units)' (lower=-12.2, upper=56.4)

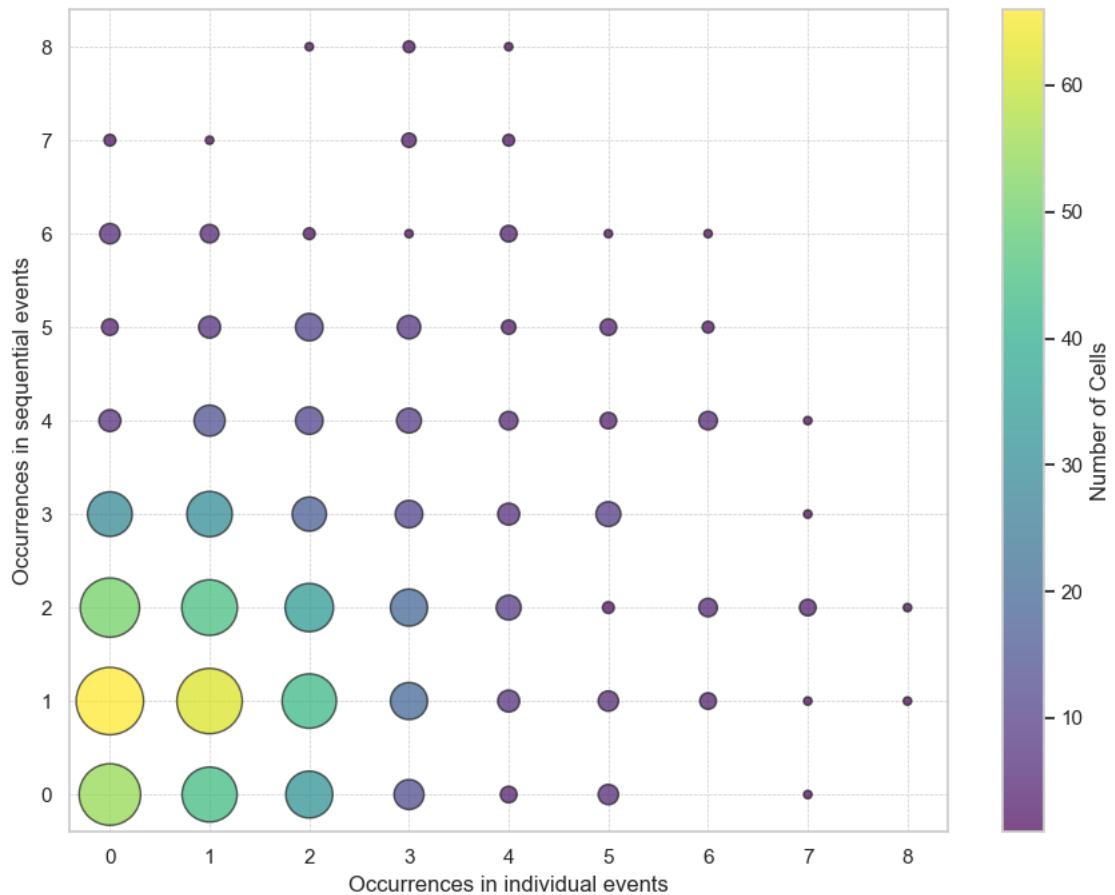
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores



### 1.4.3 Correlation between event activity level & individual activity level



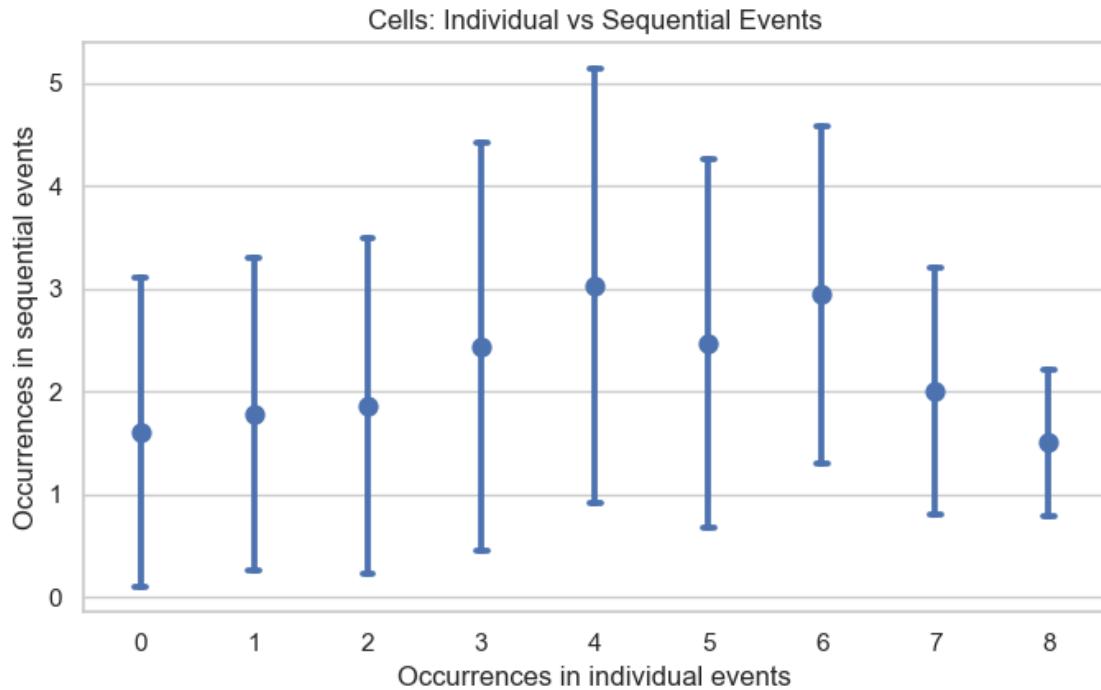
```
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: removed 0/767 outliers on 'Occurrences in sequential events' (lower=-5, upper=9)
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: N=220 for Occurrences in individual events=0
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: N=208 for Occurrences in individual events=1
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: N=151 for Occurrences in individual events=2
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: N=87 for Occurrences in individual events=3
[2025-08-27 14:47:46] [INFO] calcium: plot_points_mean_std: N=42 for Occurrences in individual events=4
```

[2025-08-27 14:47:46] [INFO] calcium: plot\_points\_mean\_std: N=32 for Occurrences in individual events=5

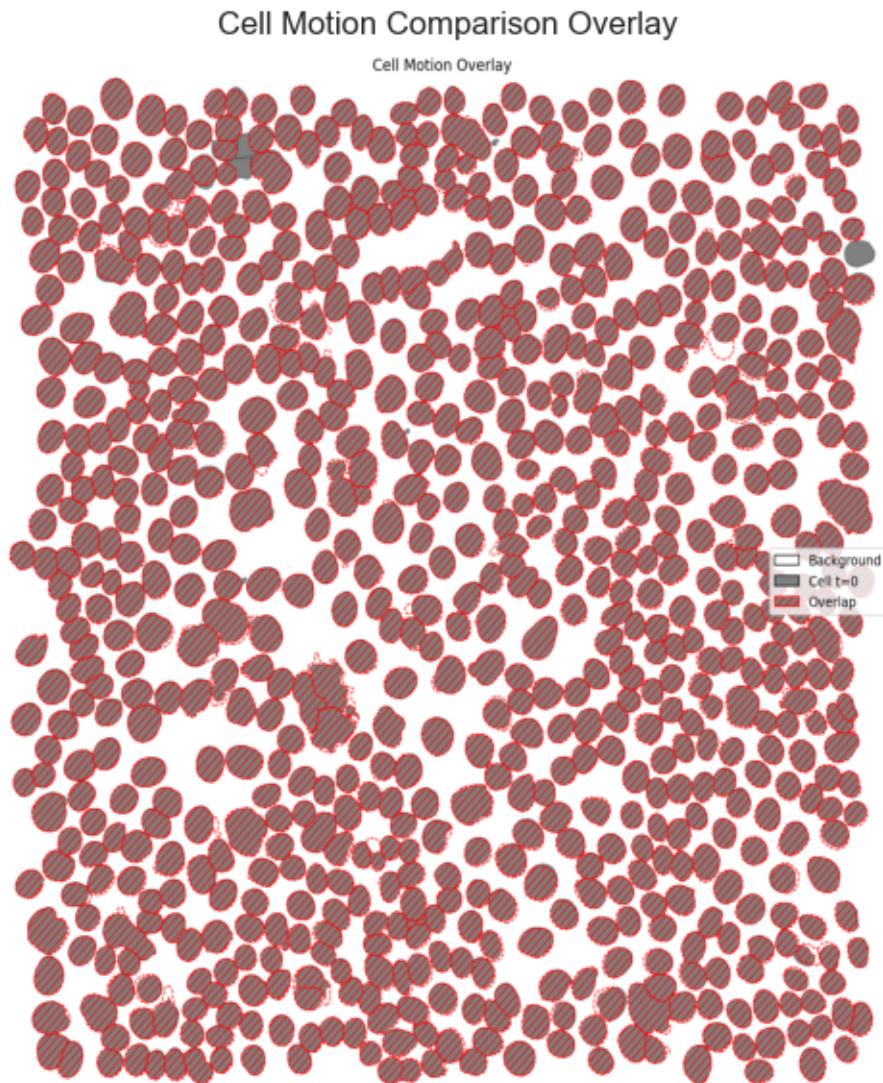
[2025-08-27 14:47:46] [INFO] calcium: plot\_points\_mean\_std: N=17 for Occurrences in individual events=6

[2025-08-27 14:47:46] [INFO] calcium: plot\_points\_mean\_std: N=8 for Occurrences in individual events=7

[2025-08-27 14:47:46] [INFO] calcium: plot\_points\_mean\_std: N=2 for Occurrences in individual events=8



## 1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 767
- Hoechst image taken at t=1801: 758
- Number of cells difference: absolute 9, relative 1.18%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1263715
- Pixels segmented as cell at t=1801: 1245863
- Overlapping pixels between t=0 and t=1801: 1201272 (95.73% of total)
- Pixels exclusive to t=0: 62443 (4.94% of total)
- Pixels exclusive to t=1801: 44591 (3.58% of total)

executed

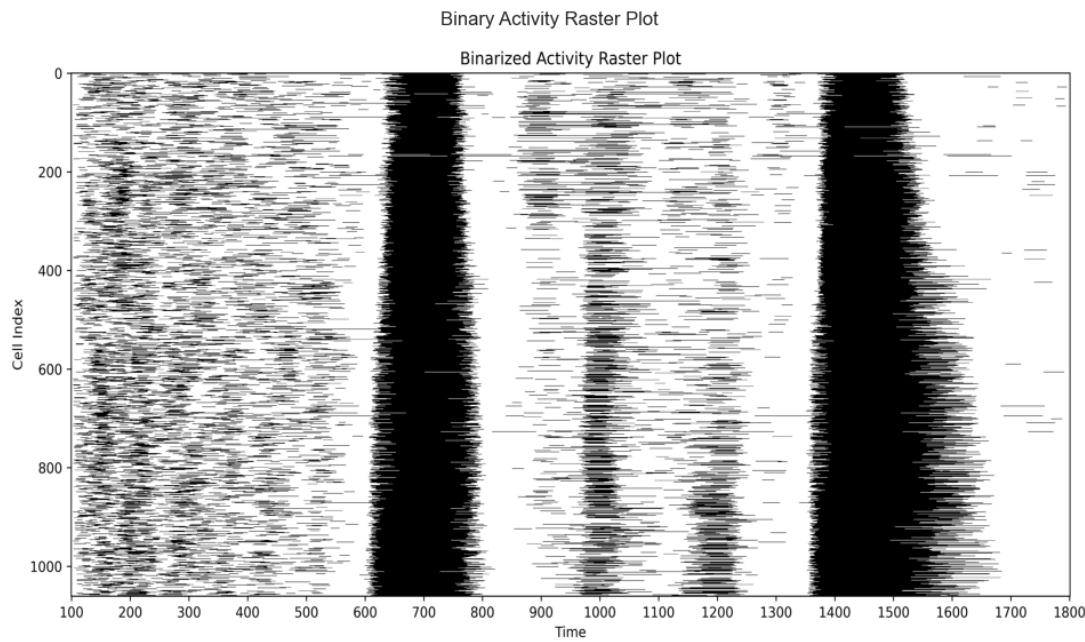
August 27, 2025

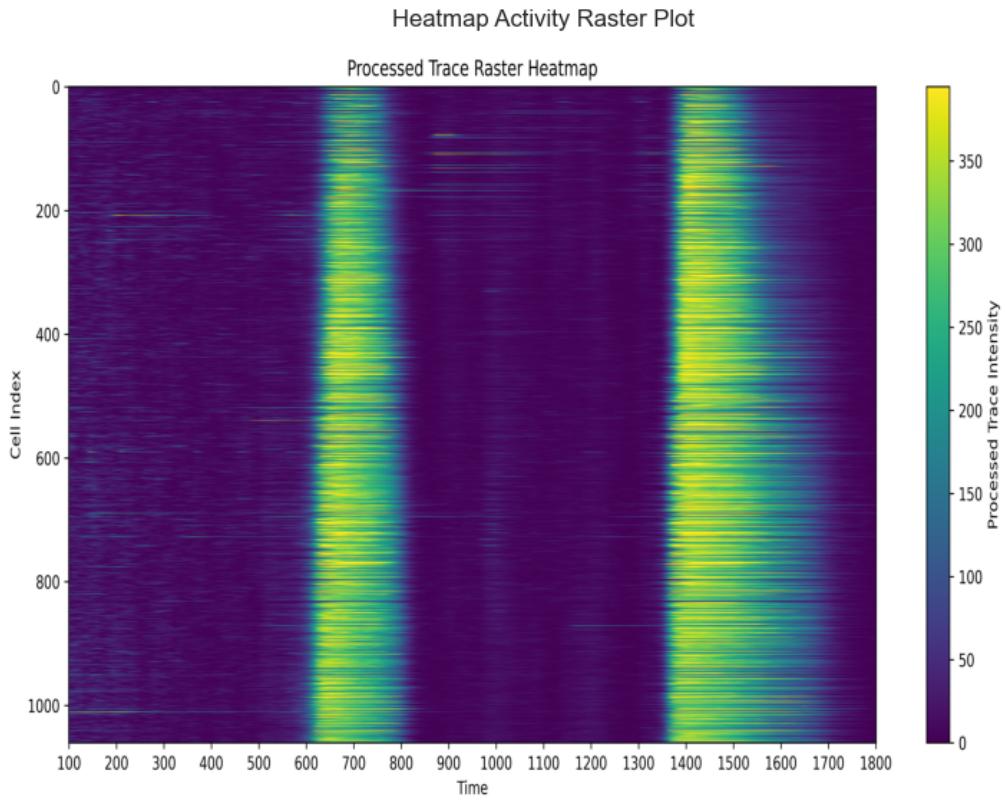
## 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

### 1.0.1 Initialization

#### 1.1 POPULATION

##### 1.1.1 Binary & Heatmap Raster Plot





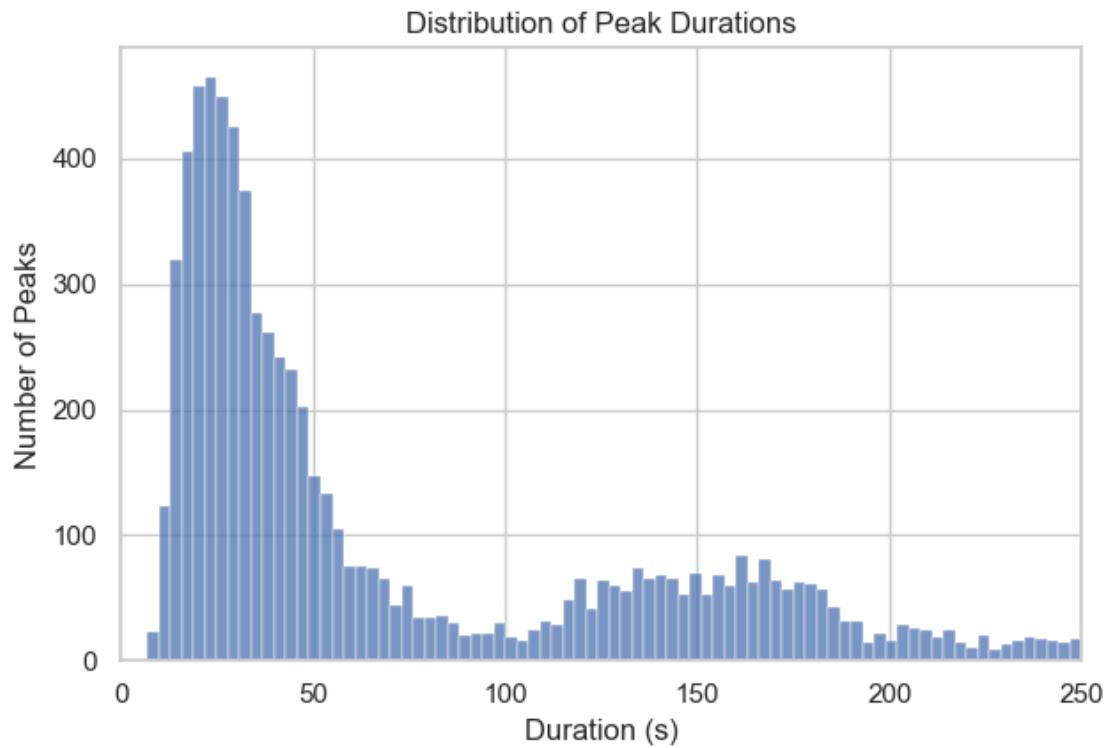
### 1.1.2 Peaks population

Total number of peaks: 7463

Total number of cells: 1061

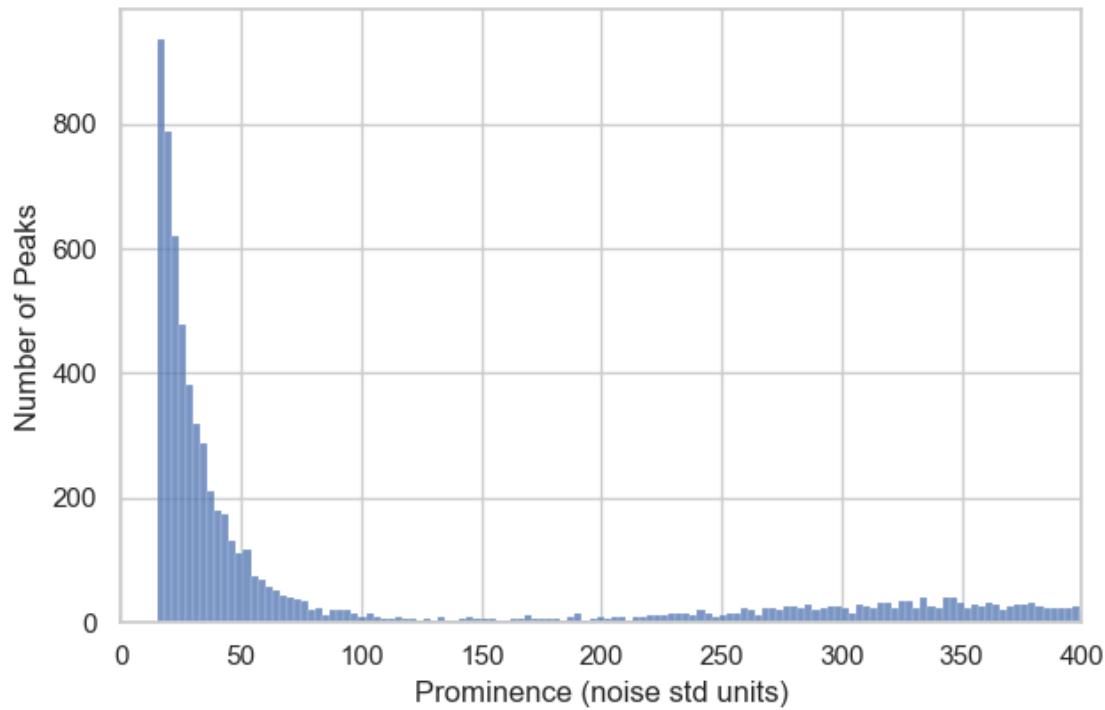
### 1.1.3 Peaks statistics

```
[2025-08-27 14:48:14] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7463 on 'Duration (s)' (lower=-279.5, upper=431)
```

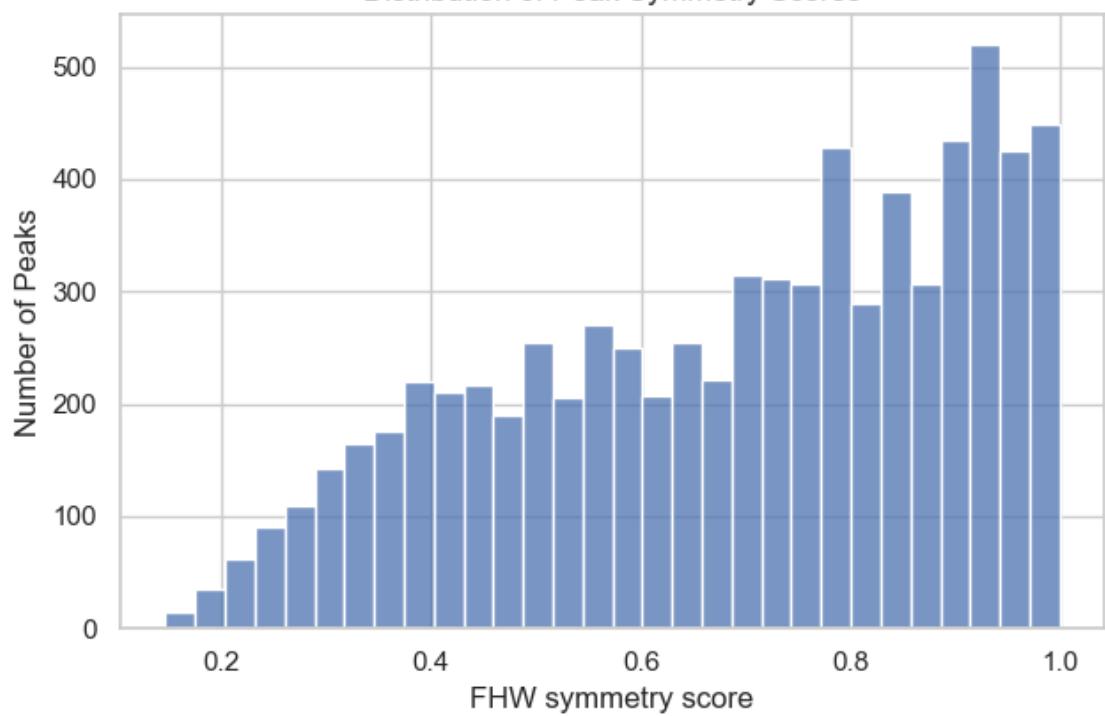


```
[2025-08-27 14:48:14] [INFO] calcium: plot_histogram: removed 1 outliers out of  
7463 on 'Prominence (noise std units)' (lower=-606.55, upper=858.9)
```

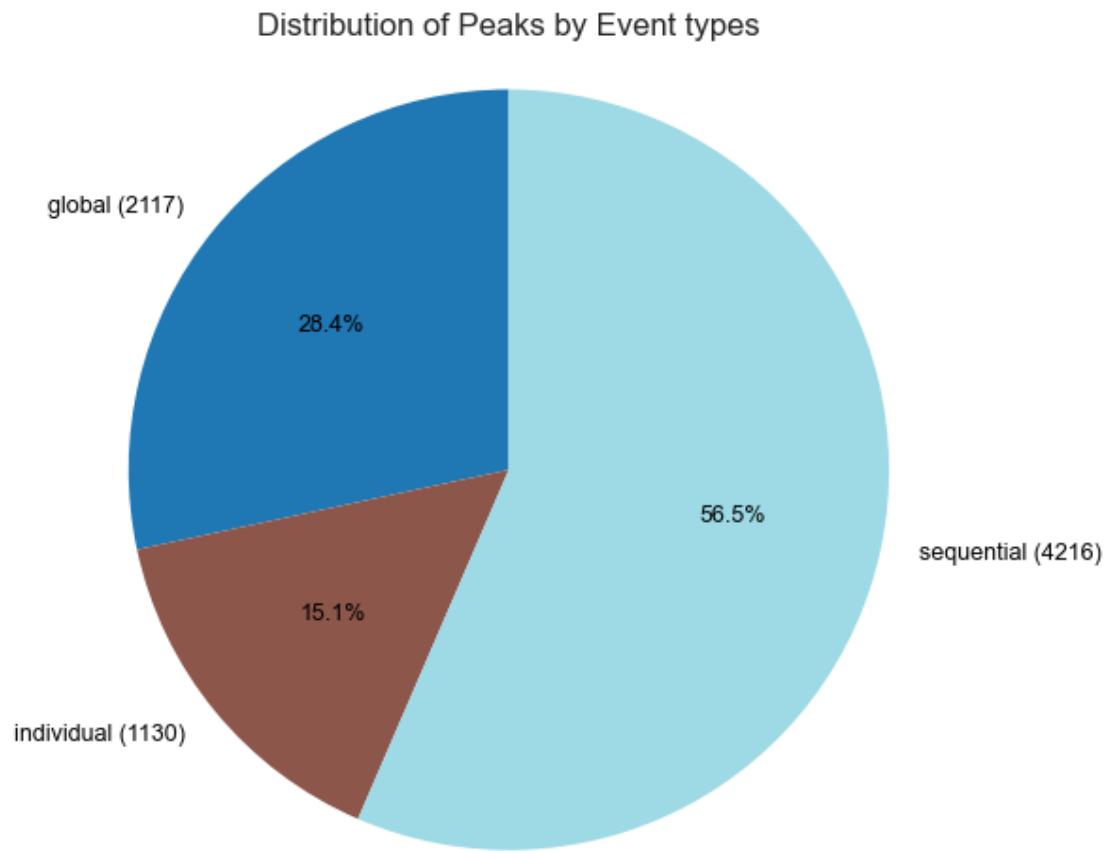
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

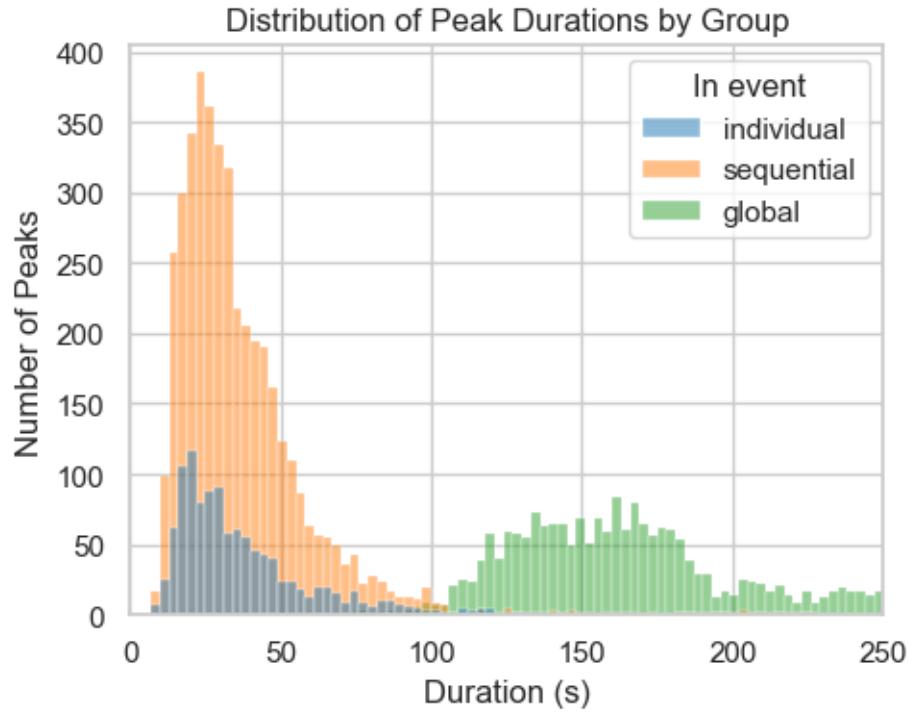


#### 1.1.4 Distribution of peaks per event types

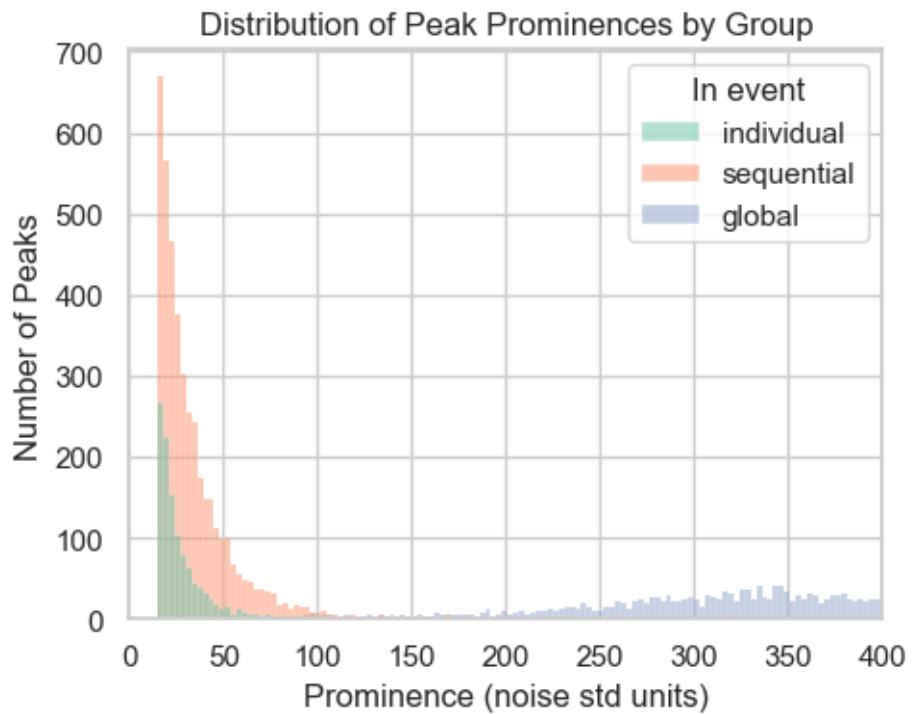


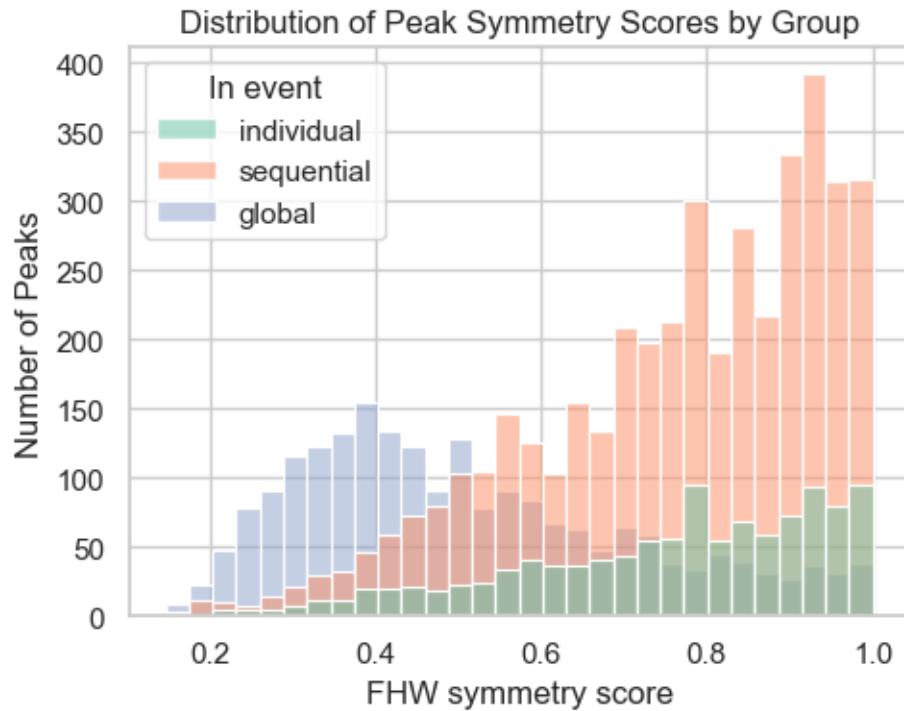
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 14:48:15] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 7463 on 'Duration (s)' (lower=-279.5, upper=431)
```



```
[2025-08-27 14:48:15] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 7463 on 'Prominence (noise std units)' (lower=-606.55, upper=858.9)
```

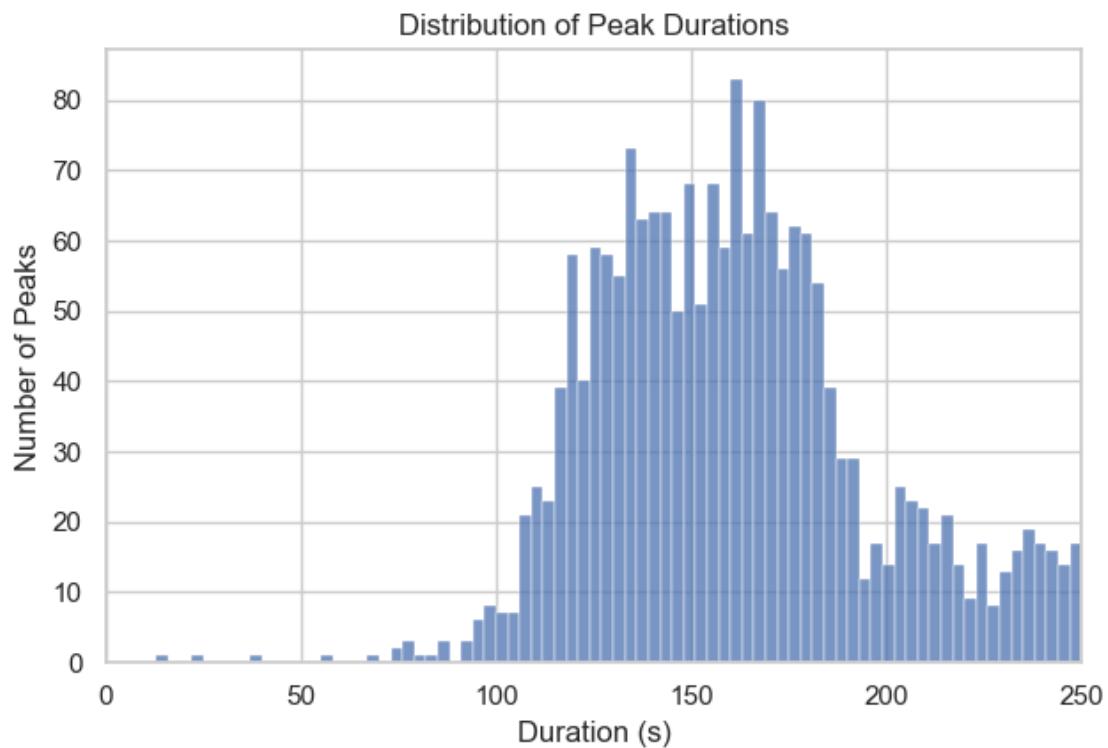




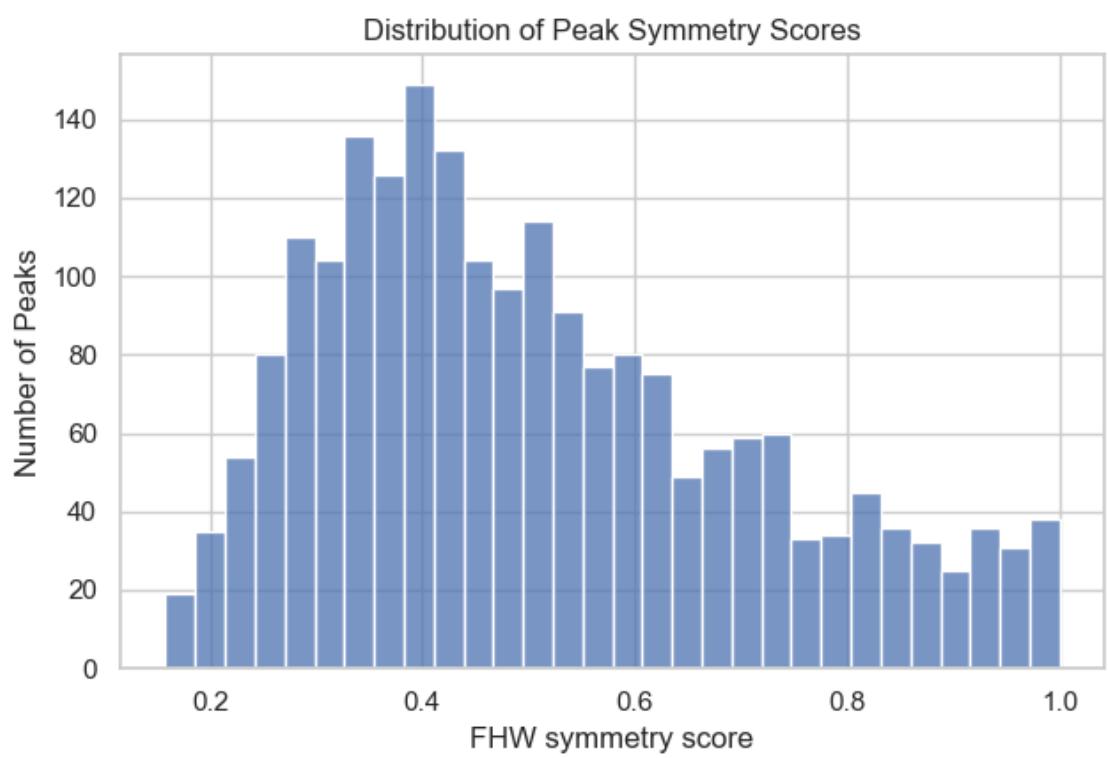
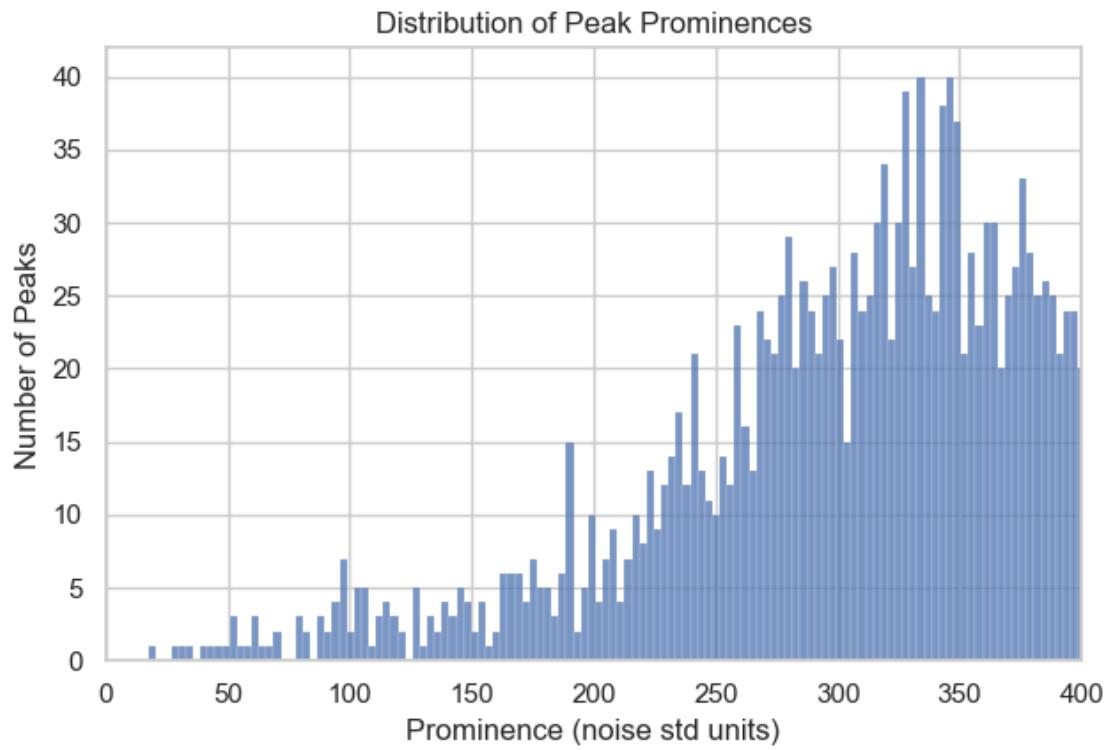
## 1.2 GLOBAL EVENTS

### 1.2.1 Peak statistics in global events

```
[2025-08-27 14:48:16] [INFO] calcium: plot_histogram: removed 0 outliers out of 2117 on 'Duration (s)' (lower=-25, upper=353)
```

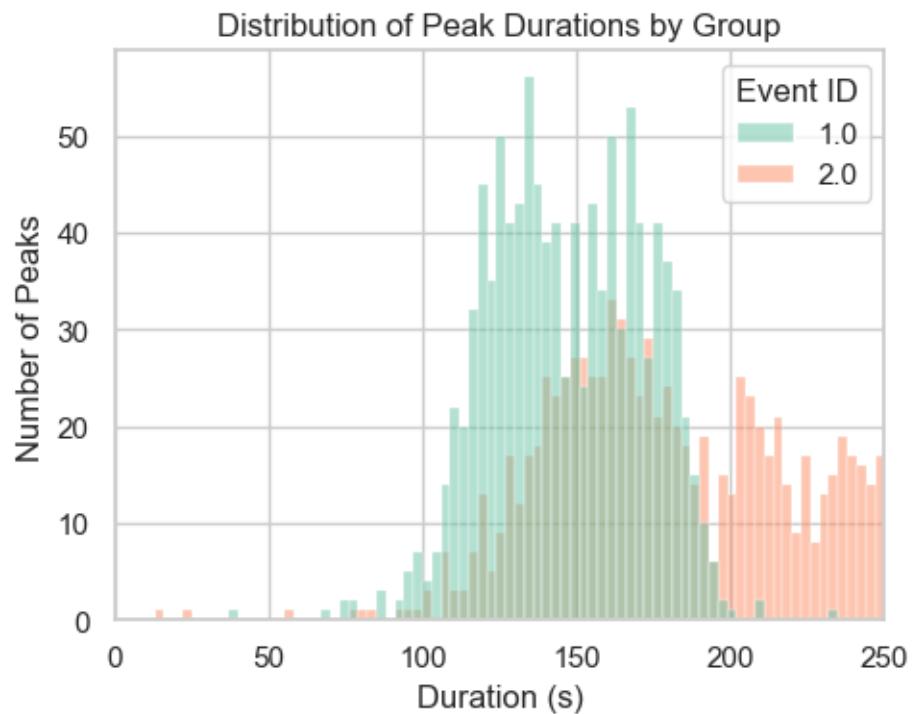


```
[2025-08-27 14:48:17] [INFO] calcium: plot_histogram: removed 2 outliers out of  
2117 on 'Prominence (noise std units)' (lower=-72.2, upper=745.4)
```

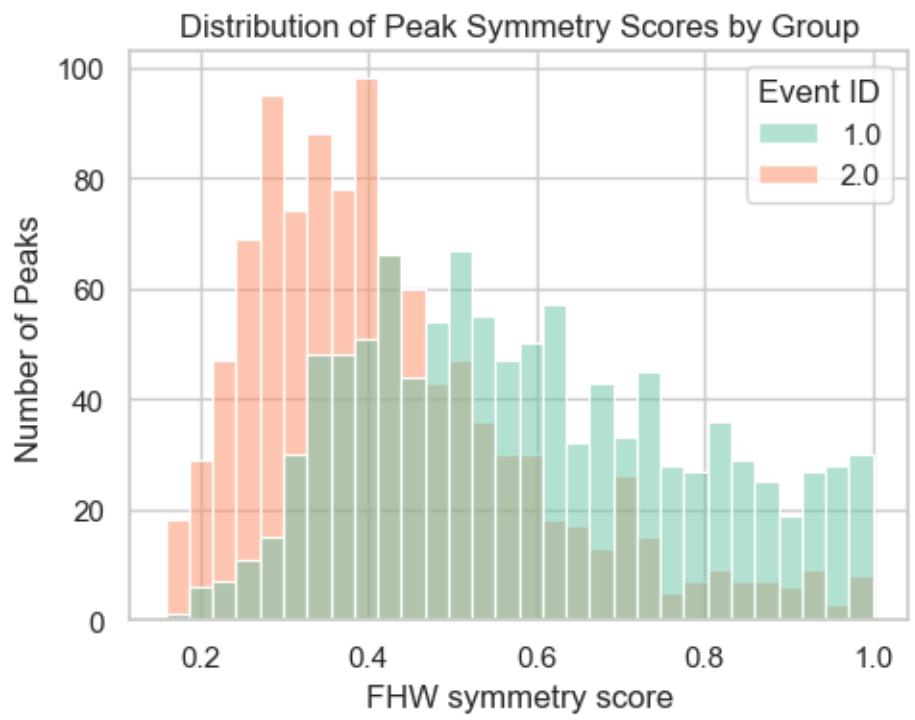
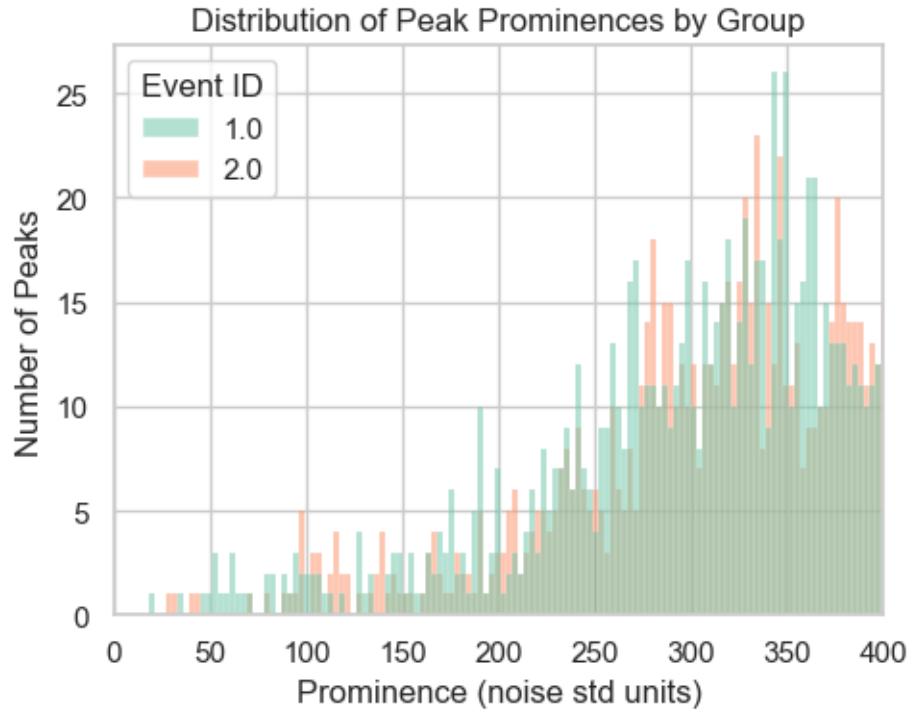


### 1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 14:48:17] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 2117 on 'Duration (s)' (lower=-25, upper=353)
```

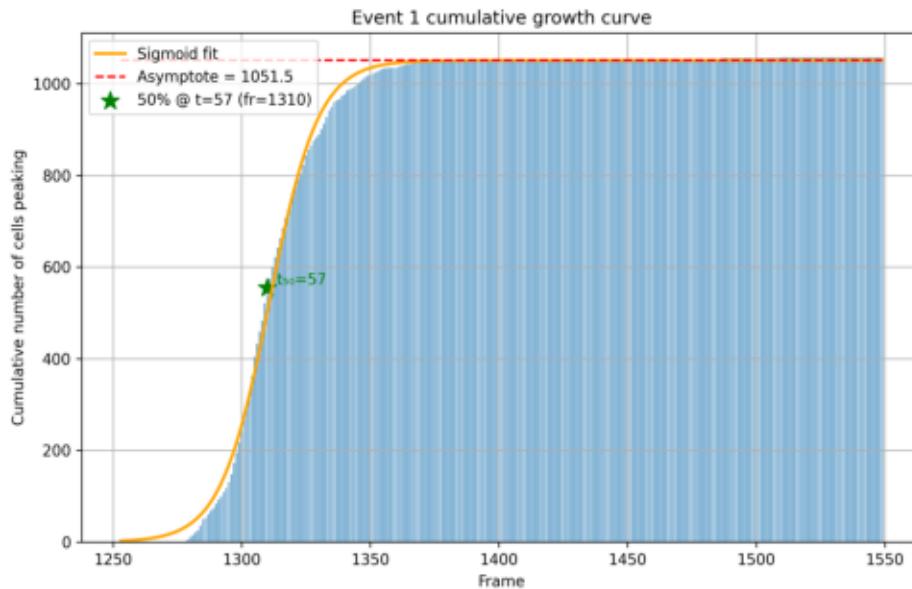


```
[2025-08-27 14:48:17] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 2117 on 'Prominence (noise std units)' (lower=-72.2, upper=745.4)
```



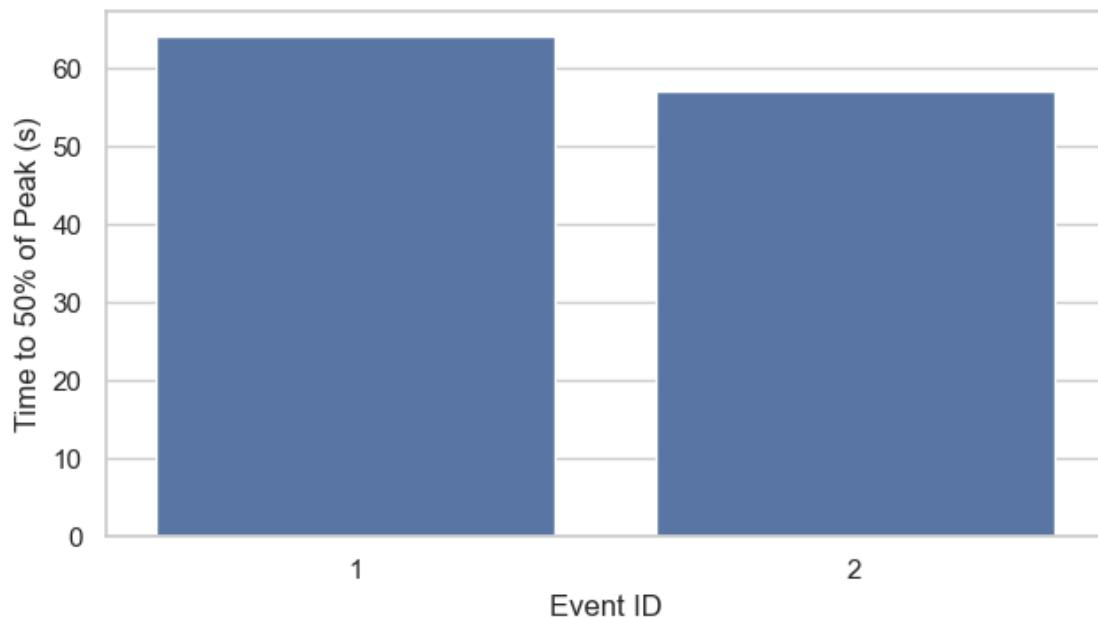
### 1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)

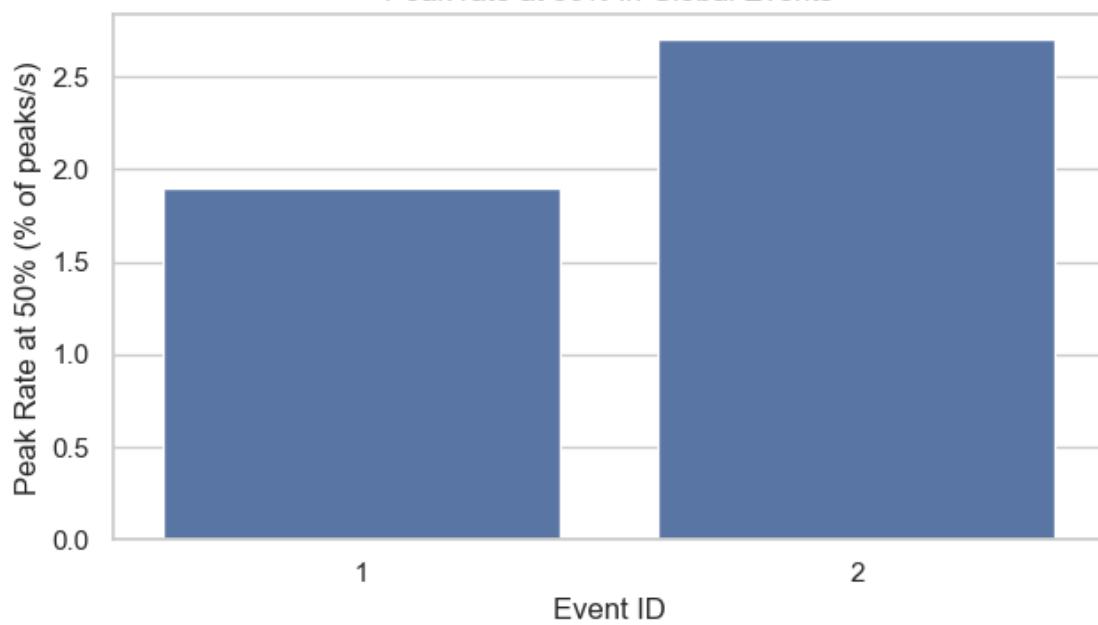


```
[2025-08-27 14:48:19] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\events\event-growth-curve-2.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250424\\Output\\IS7\\events\\event-growth-
curve-2.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250424\\Output\\IS7\\events\\event-growth-curve-2.png'
```

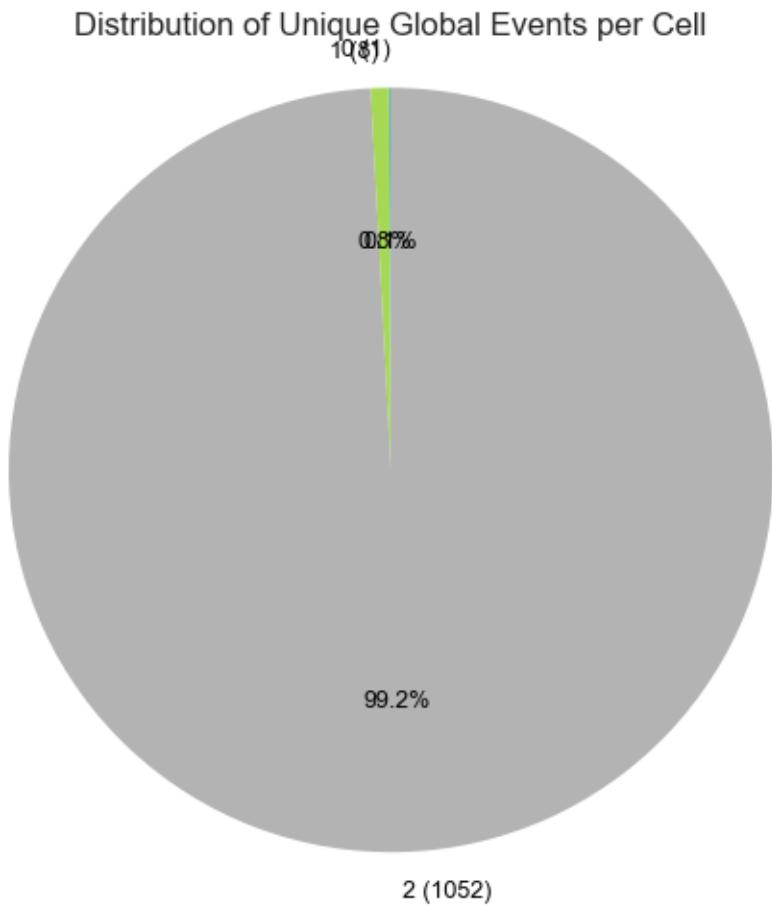
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

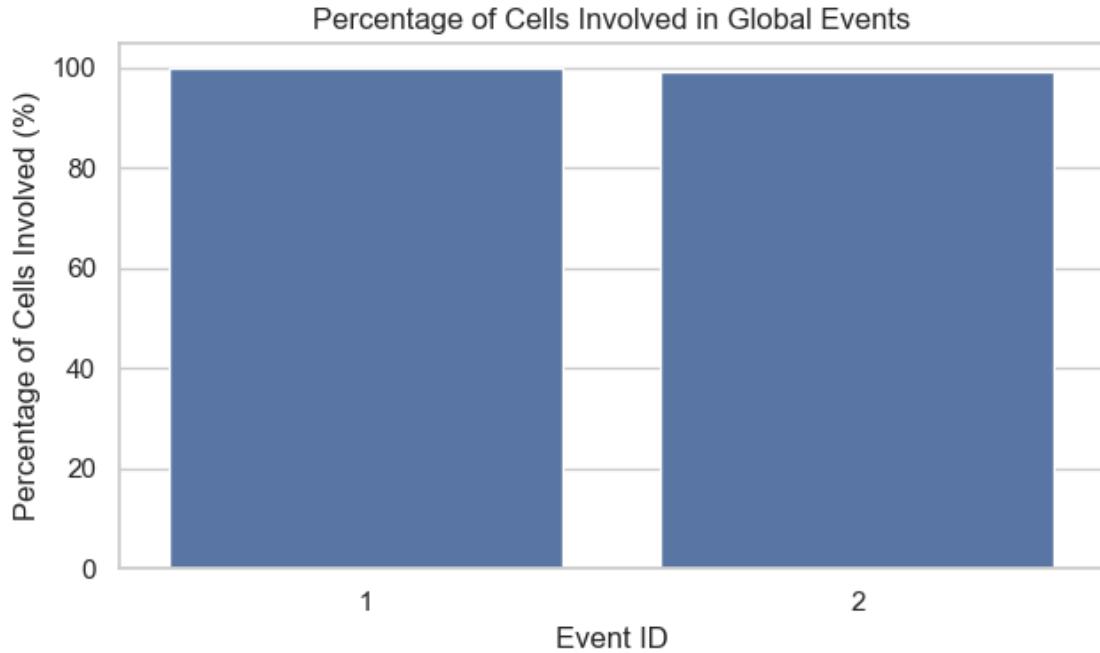


```
[2025-08-27 14:48:19] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250424\\\\Output\\\\IS7\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250424\Output\IS7\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [733.0]

### 1.2.6 Early peakers in the events

```

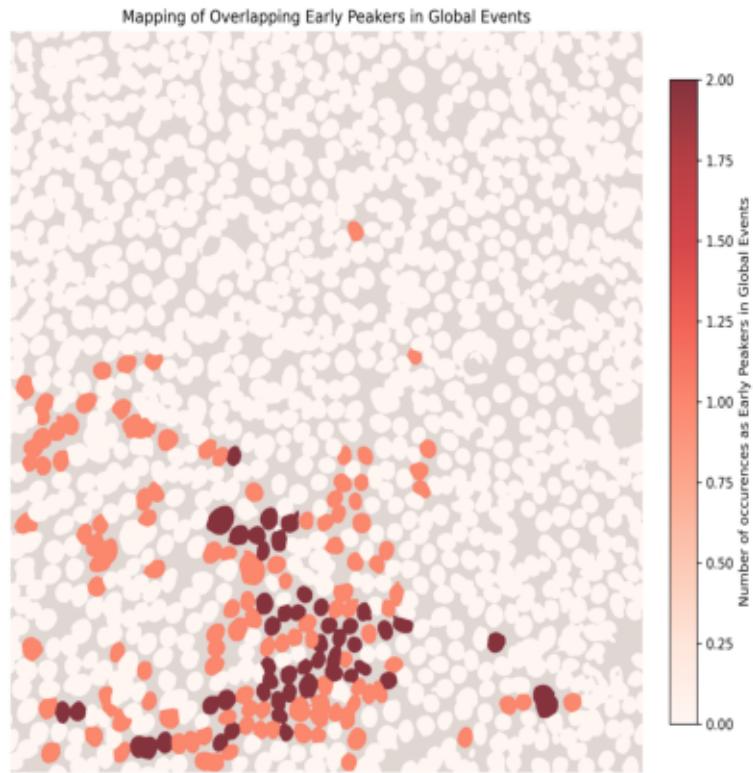
[2025-08-27 14:48:19] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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

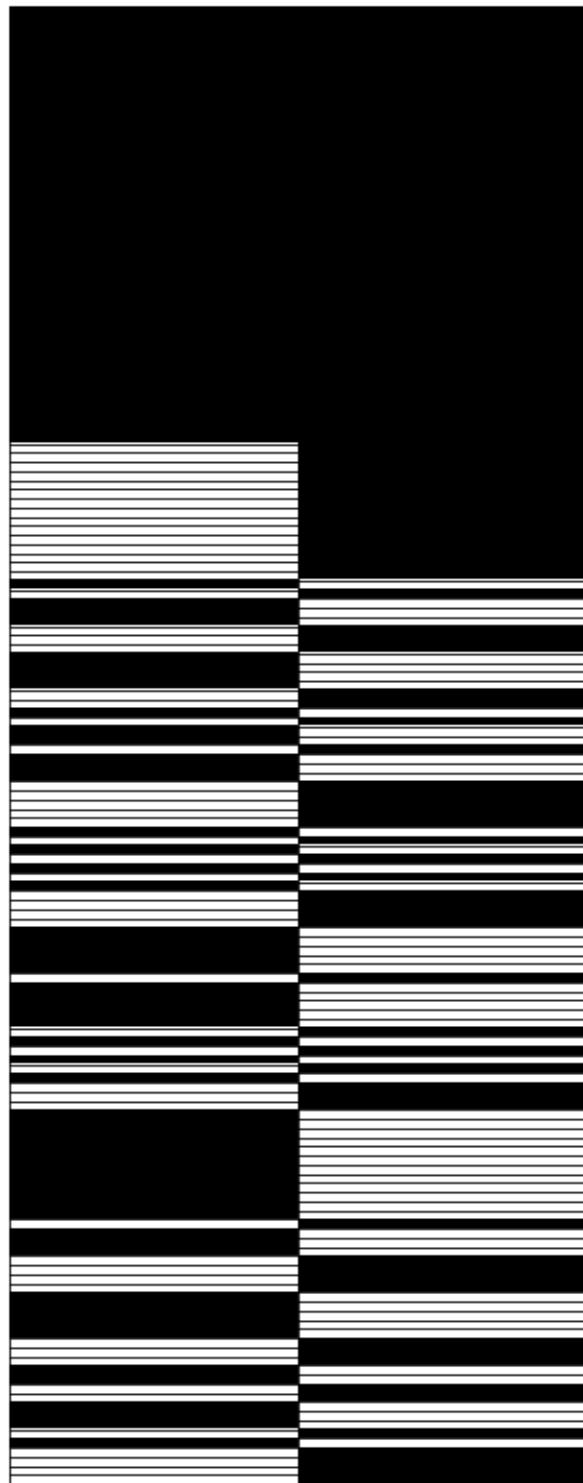
[2025-08-27 14:48:20] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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
```

## Cell Mapping with Occurrences in Global Events Overlay



```
[2025-08-27 14:48:21] [WARNING] calcium: 'total_events' is deprecated and  
ignored. Using 2 unique event IDs.
```

```
[2025-08-27 14:48:21] [INFO] calcium: Early peakers event-matrix: 162 cells x 2  
events; black squares: 210
```



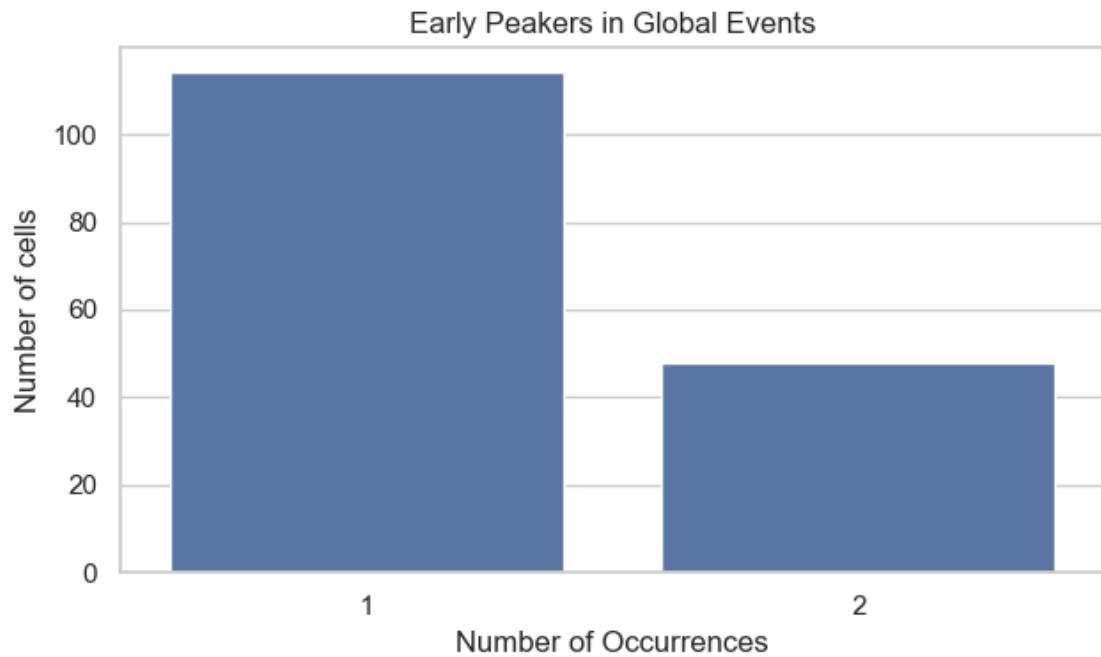
[2025-08-27 14:48:21] [INFO] calcium: Saved early peakers heatmap SVG to:  
early\_peakers\_heatmap.svg



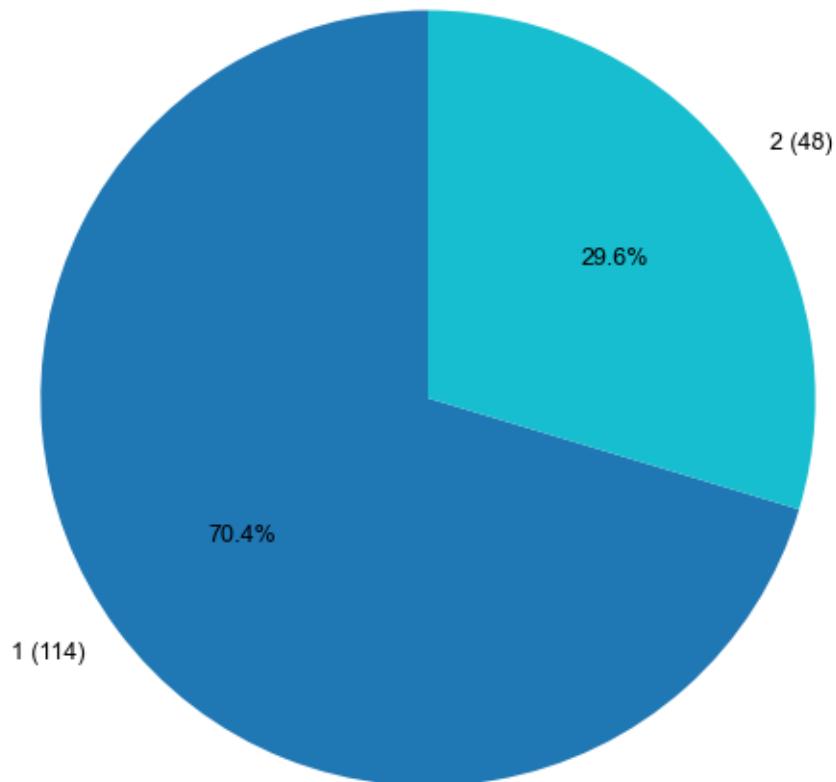
```
[1, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
[0, 1],  
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[0, 1],  
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[0, 1],  
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[0, 1],  
[1, 0],  
[0, 1],  
[1, 0],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



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

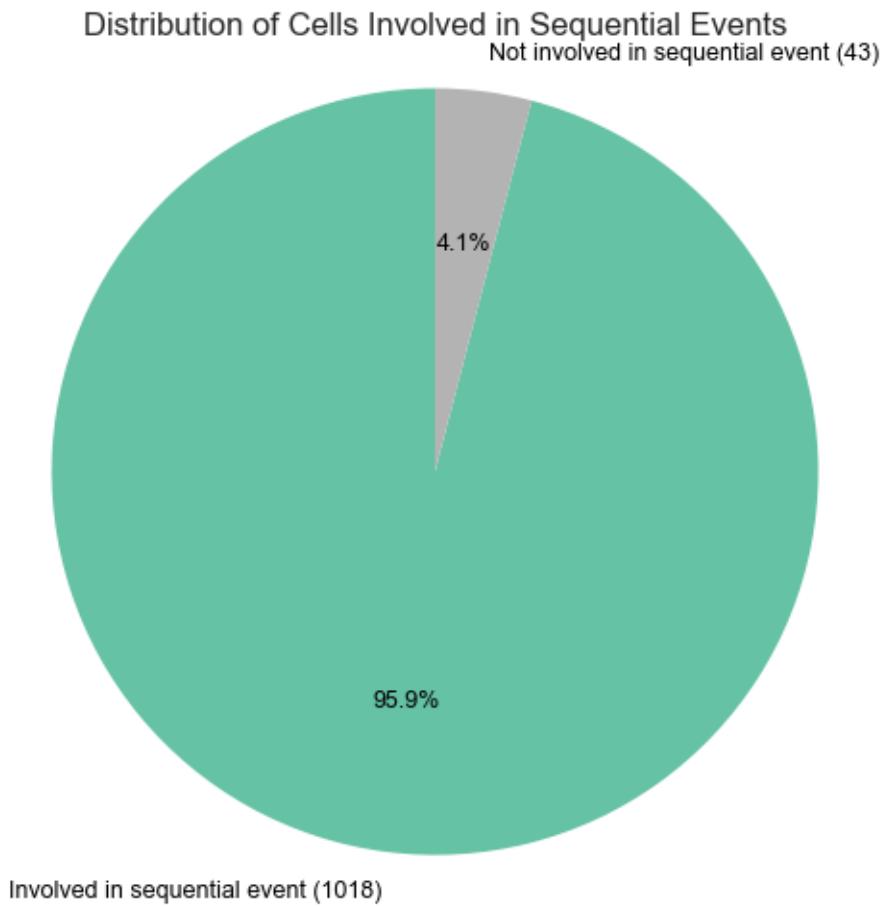


Distribution of Early Peakers in Global Events

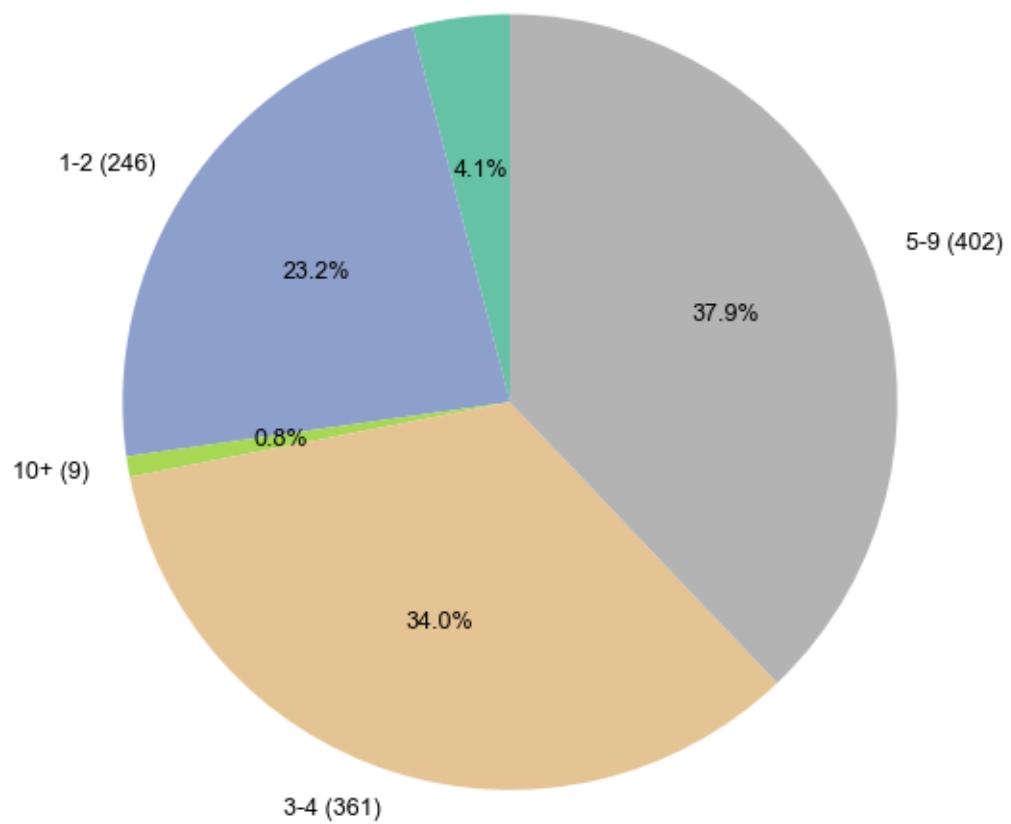


## 1.3 SEQUENTIAL EVENTS

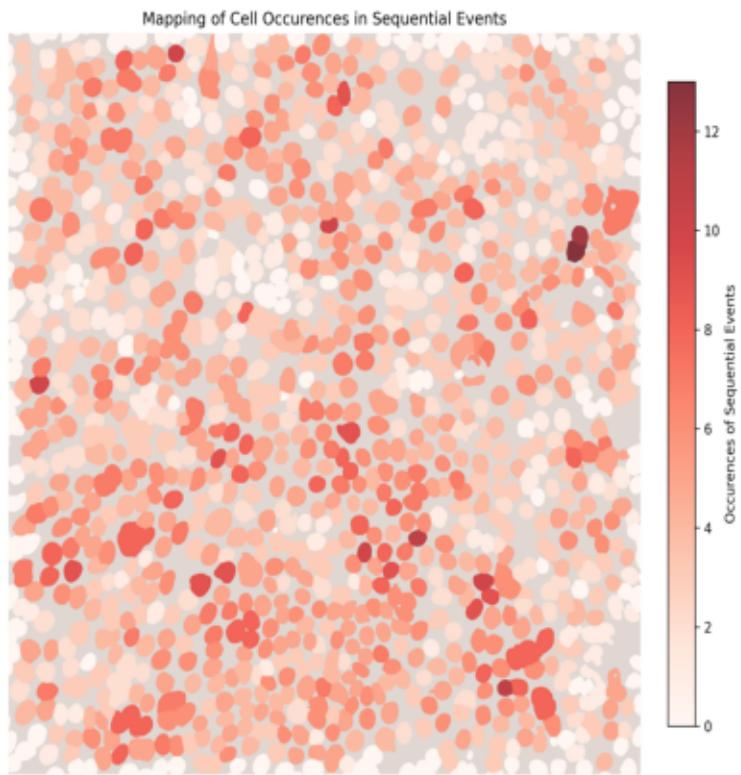
### 1.3.1 Cells Occurrences in sequential events



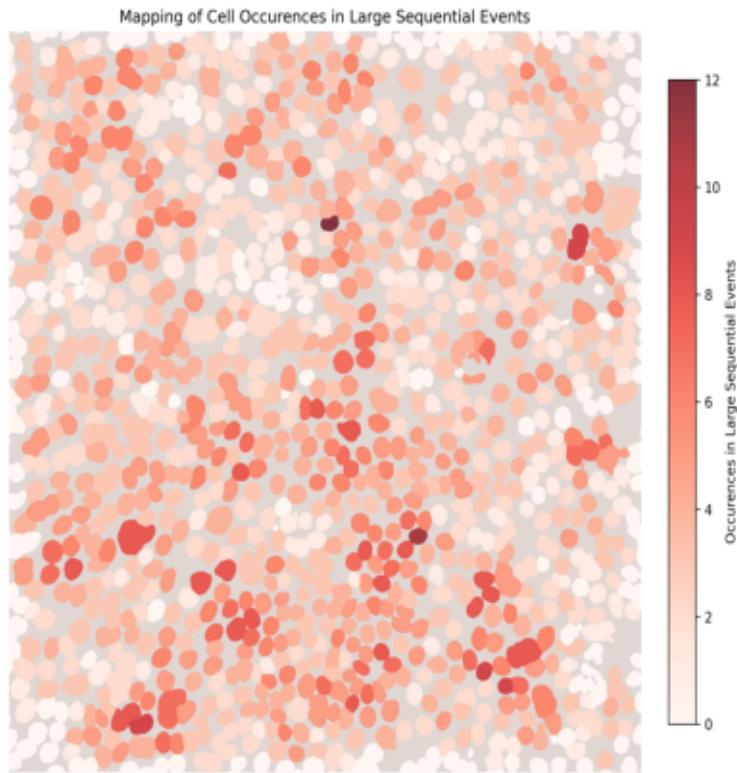
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

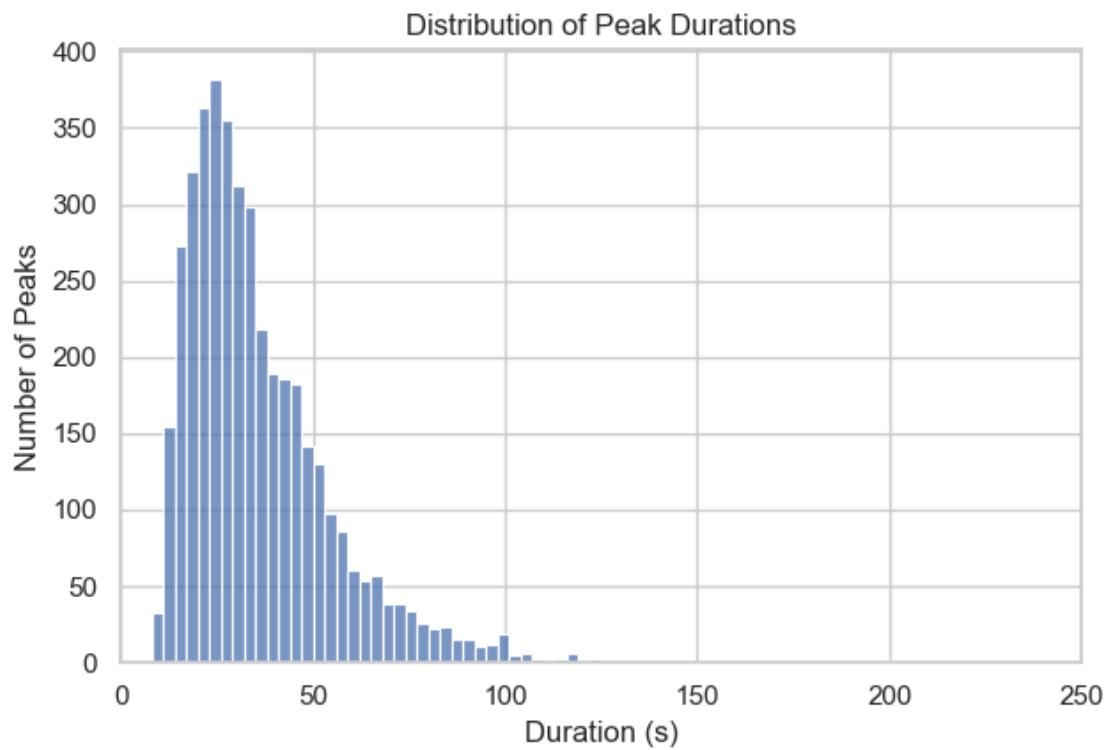


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

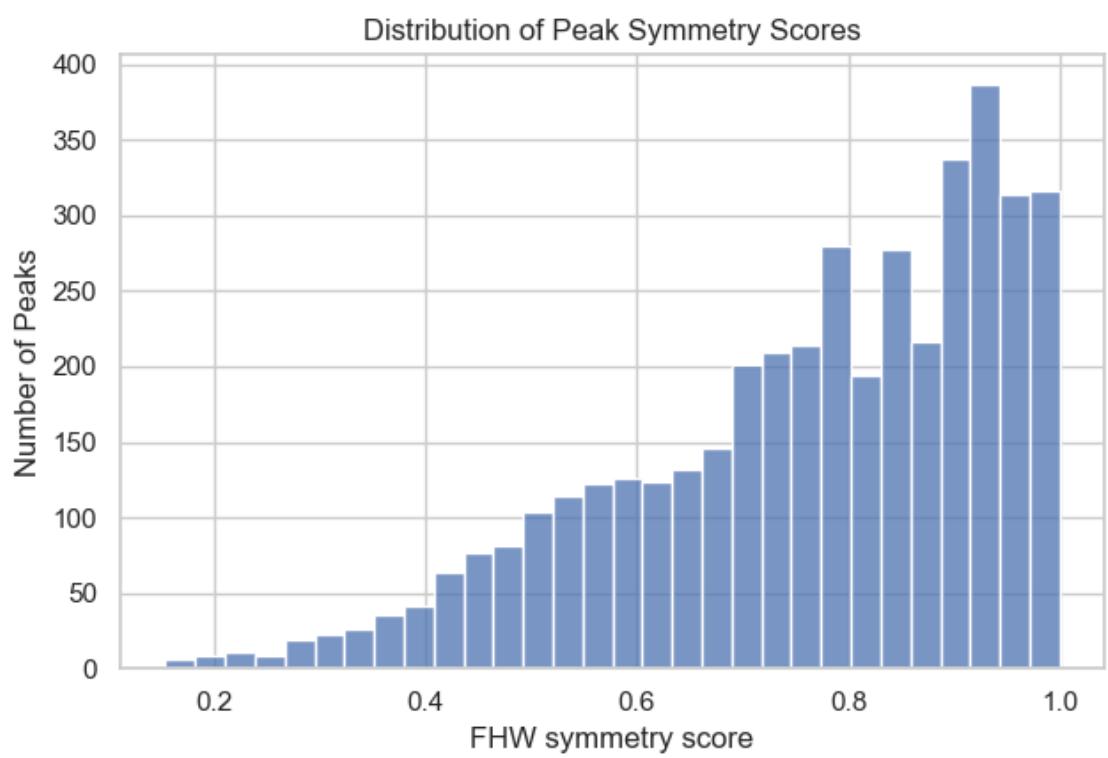
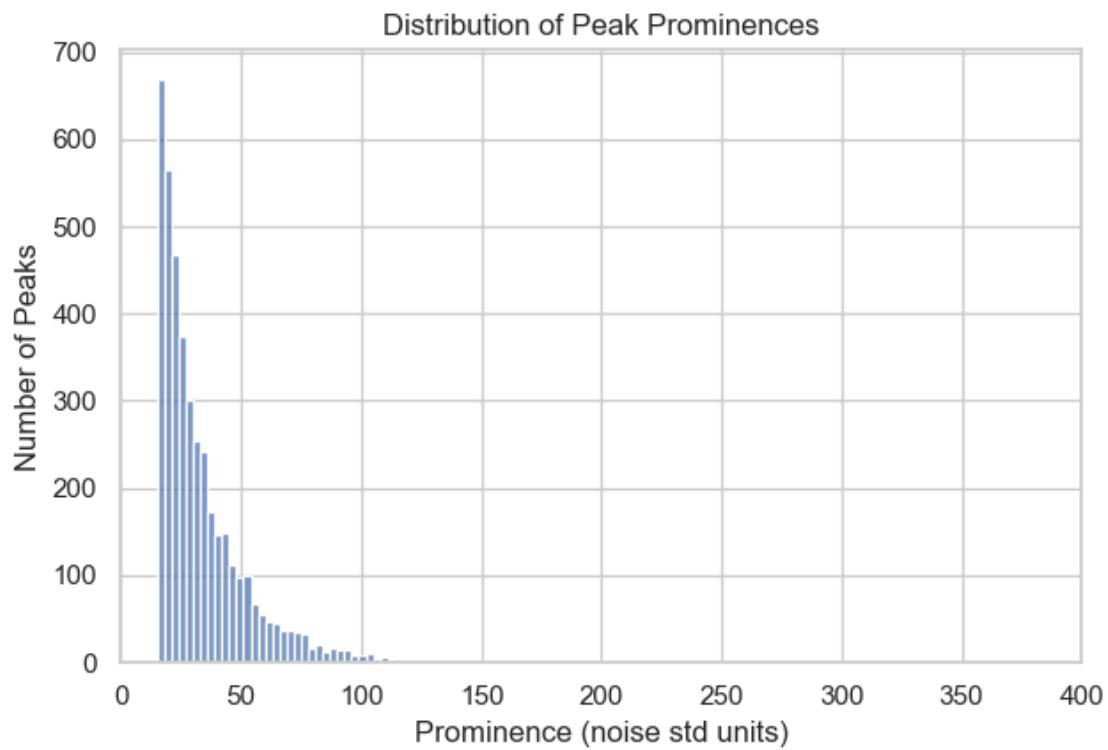


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 14:48:23] [INFO] calcium: plot_histogram: removed 41 outliers out of  
4216 on 'Duration (s)' (lower=-12.5, upper=125.5)
```

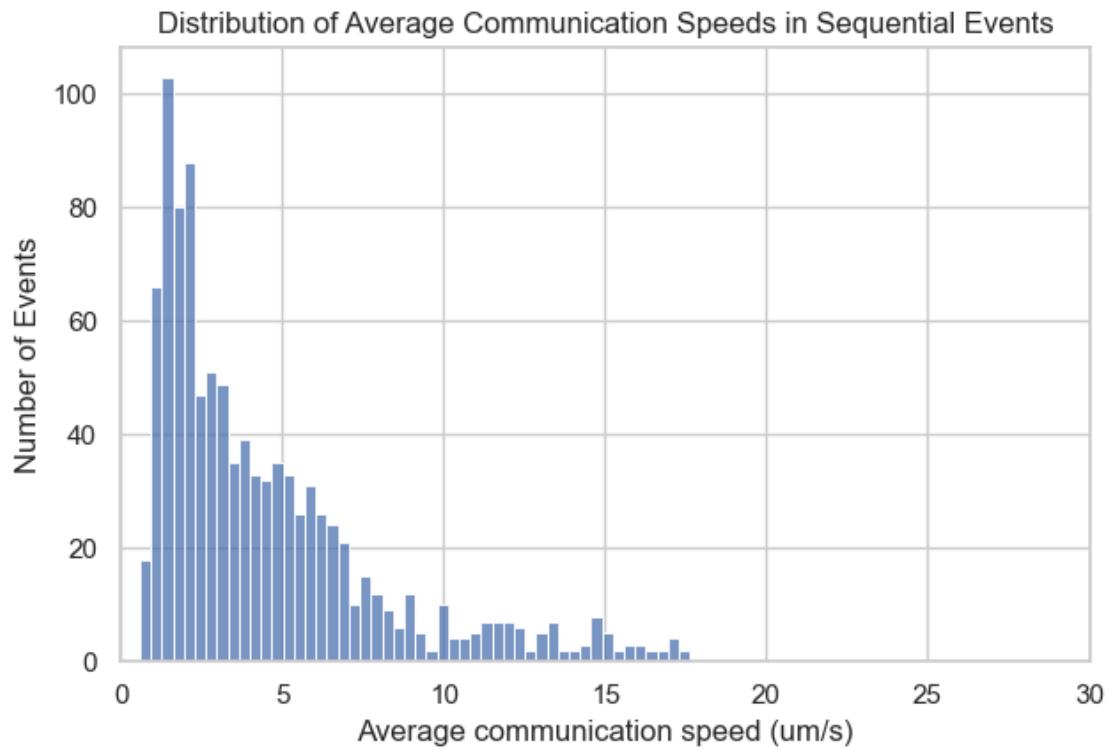


```
[2025-08-27 14:48:24] [INFO] calcium: plot_histogram: removed 67 outliers out of  
4216 on 'Prominence (noise std units)' (lower=-12.5, upper=117.1)
```

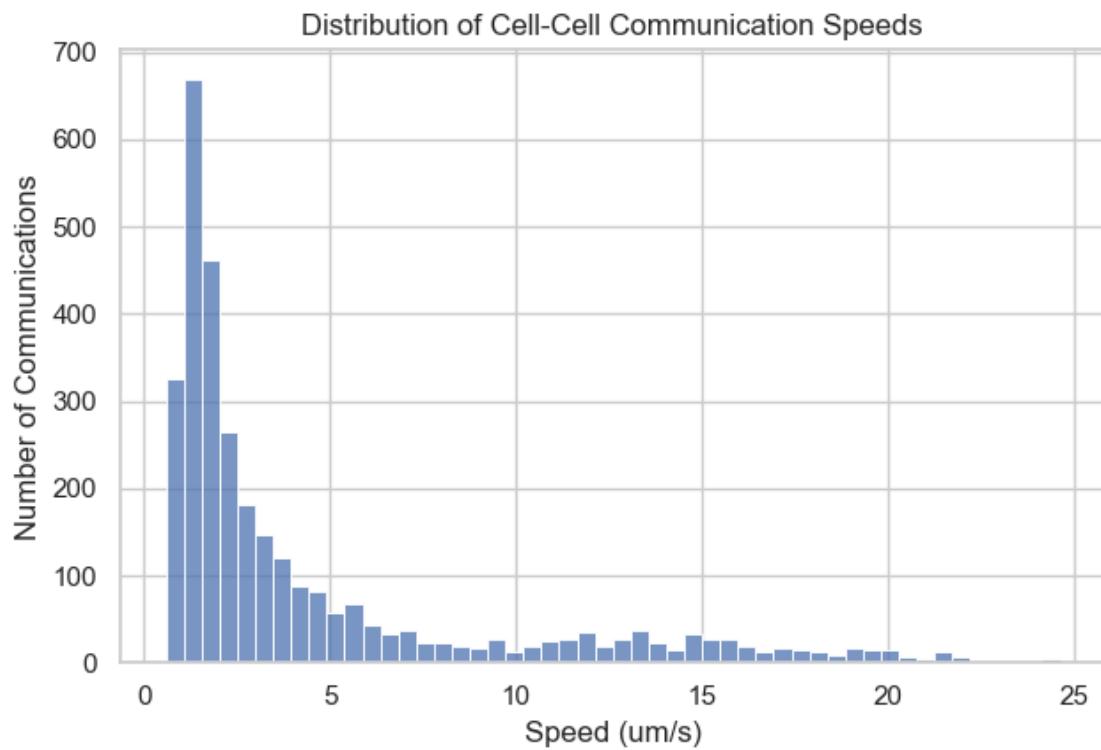


### 1.3.3 Cell-cell communication speed

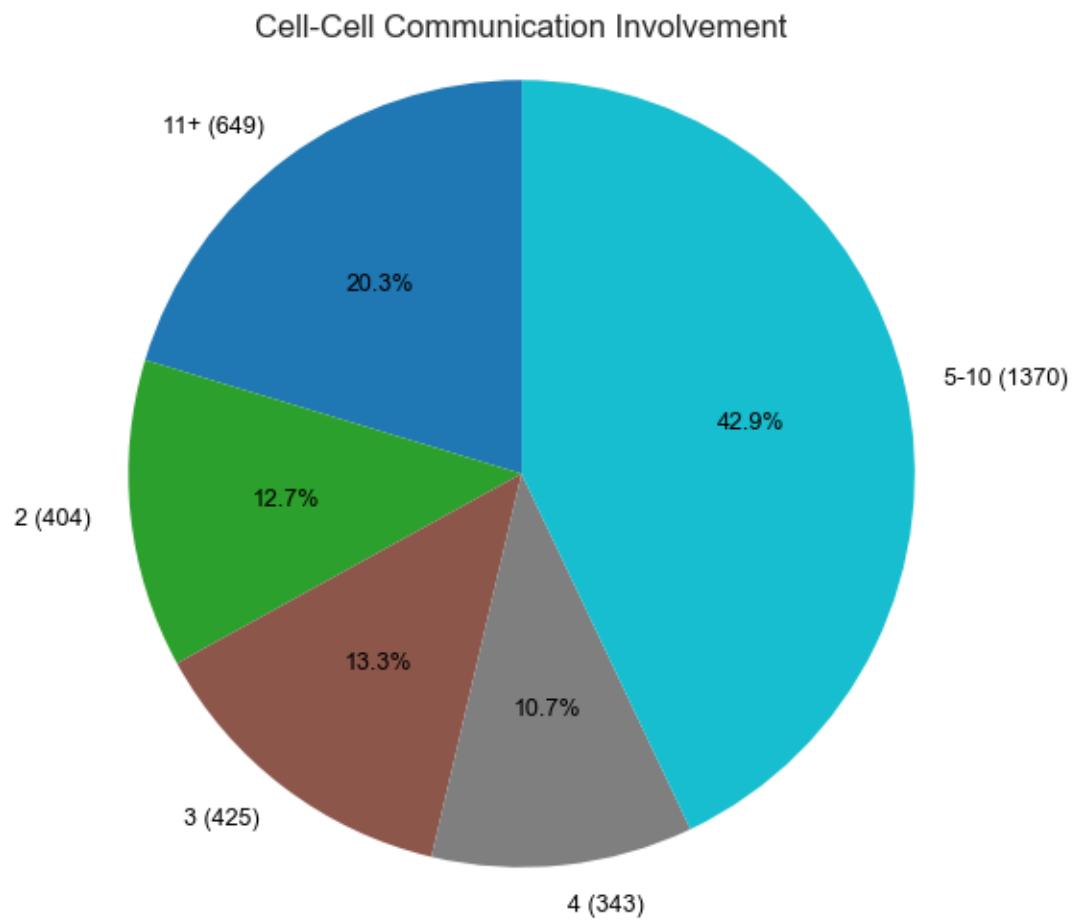
[2025-08-27 14:48:24] [INFO] calcium: plot\_histogram: removed 15 outliers out of 1025 on 'Average communication speed (um/s)' (lower=-10.56, upper=18.56)



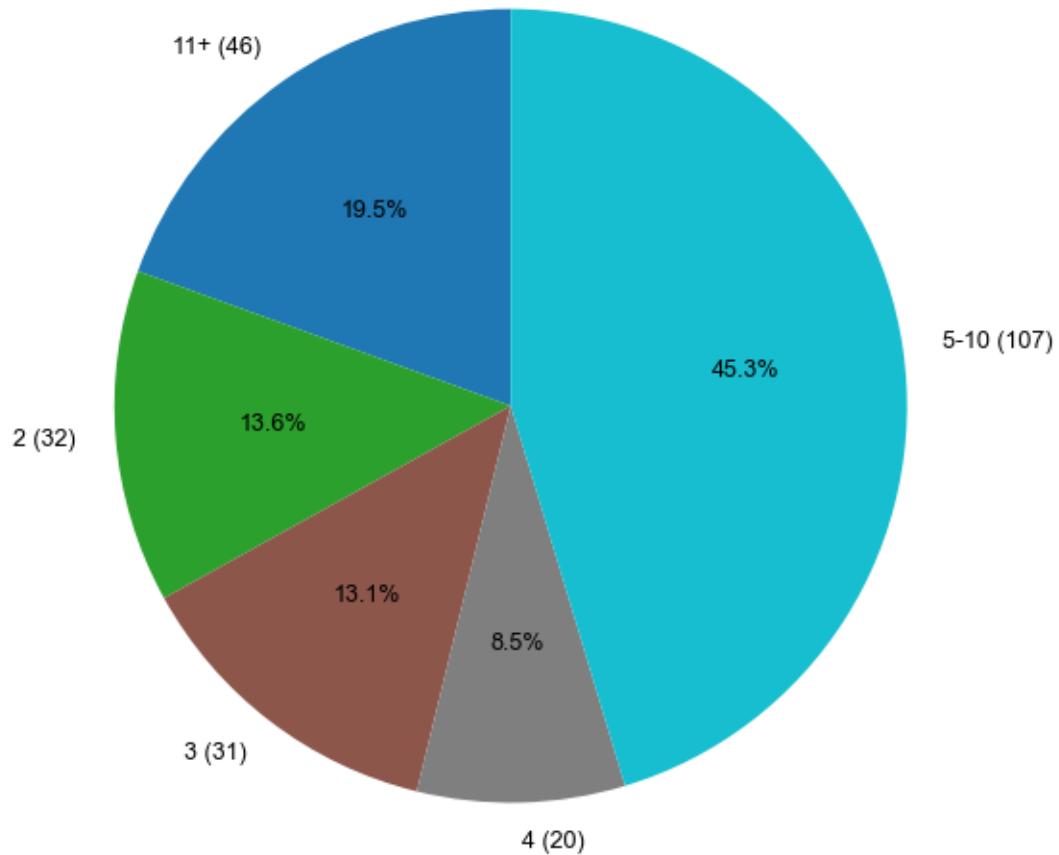
[2025-08-27 14:48:24] [INFO] calcium: plot\_histogram: removed 10 outliers out of 3191 on 'Speed (um/s)' (lower=-10.5, upper=25.23)



#### 1.3.4 Double distribution in cell-cell communication speeds

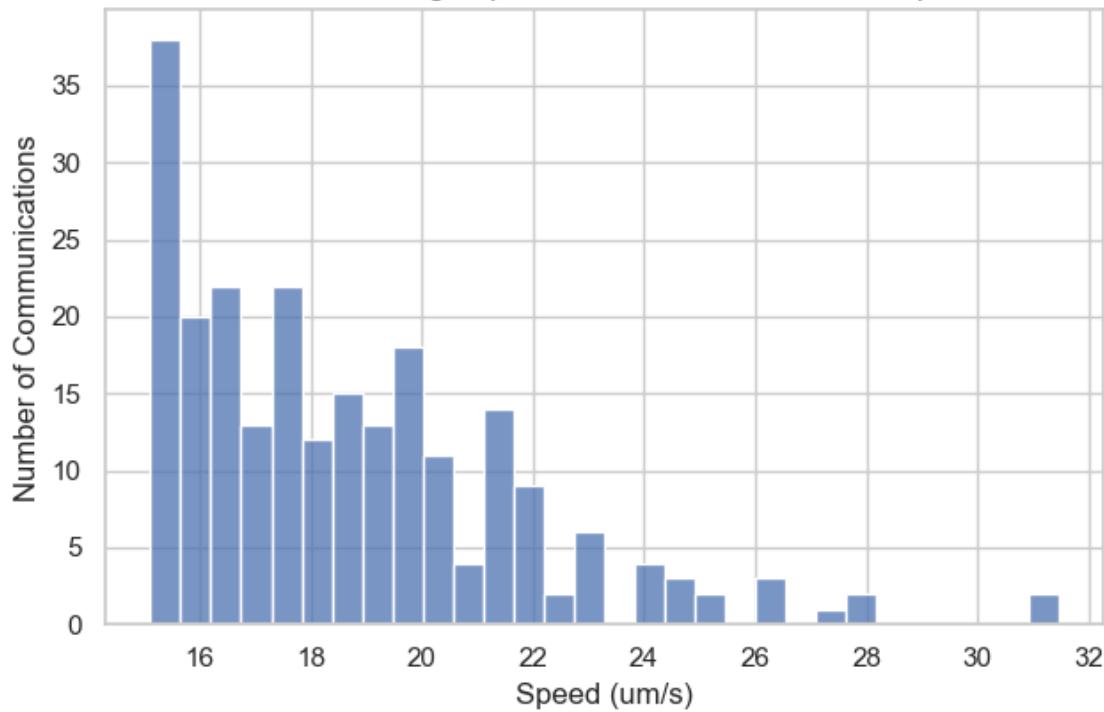


### High Speed Cell-Cell Communication Involvement



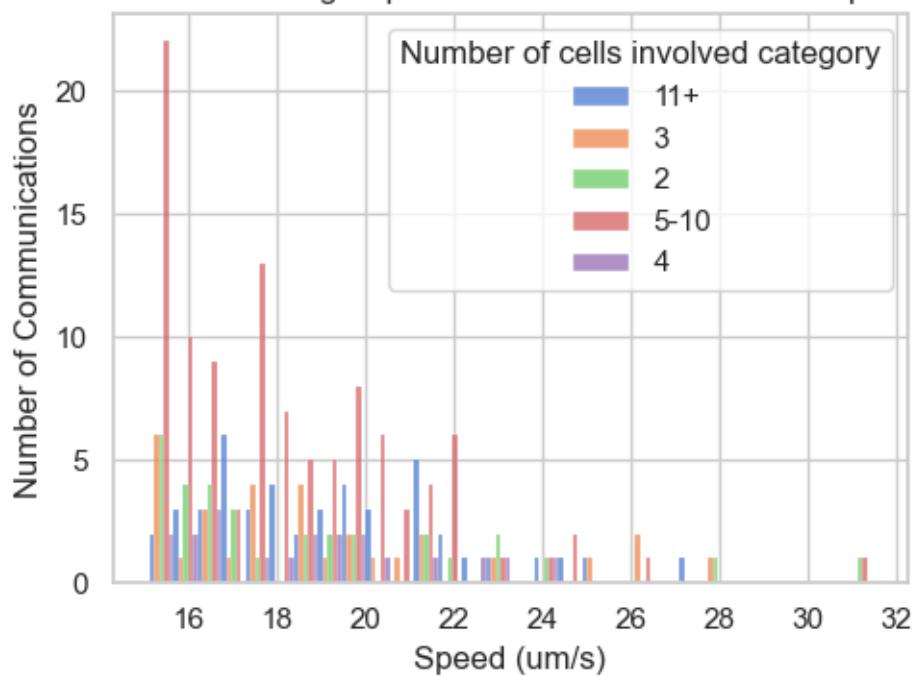
[2025-08-27 14:48:25] [INFO] calcium: plot\_histogram: removed 0 outliers out of 236 on 'Speed (um/s)' (lower=4.4, upper=32.068)

Distribution of High Speed Cell-Cell Communication Speeds

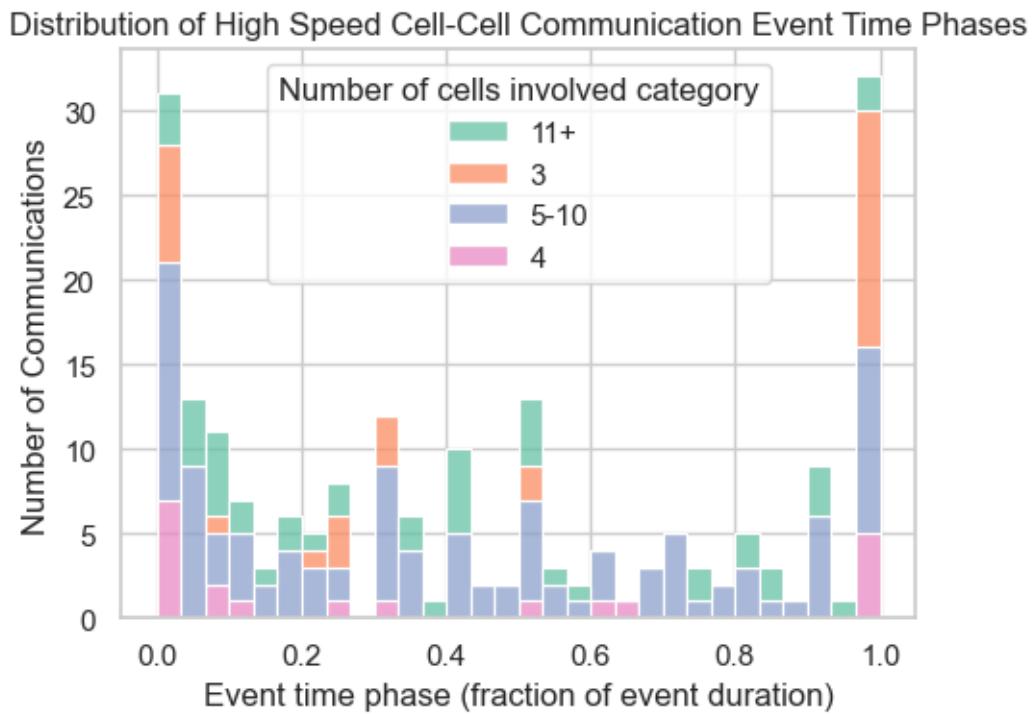


```
[2025-08-27 14:48:25] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 236 on 'Speed (um/s)' (lower=4.4, upper=32.068)
```

Distribution of High Speed Cell-Cell Communication Speeds

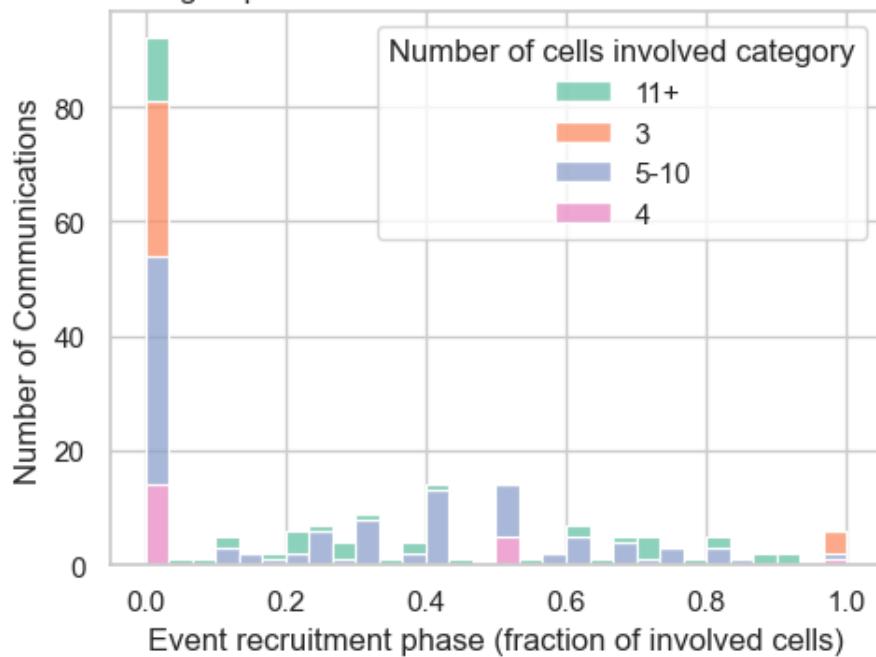


[2025-08-27 14:48:25] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 204 on 'Event time phase (fraction of event duration)' (lower=-2.0575, upper=2.93)

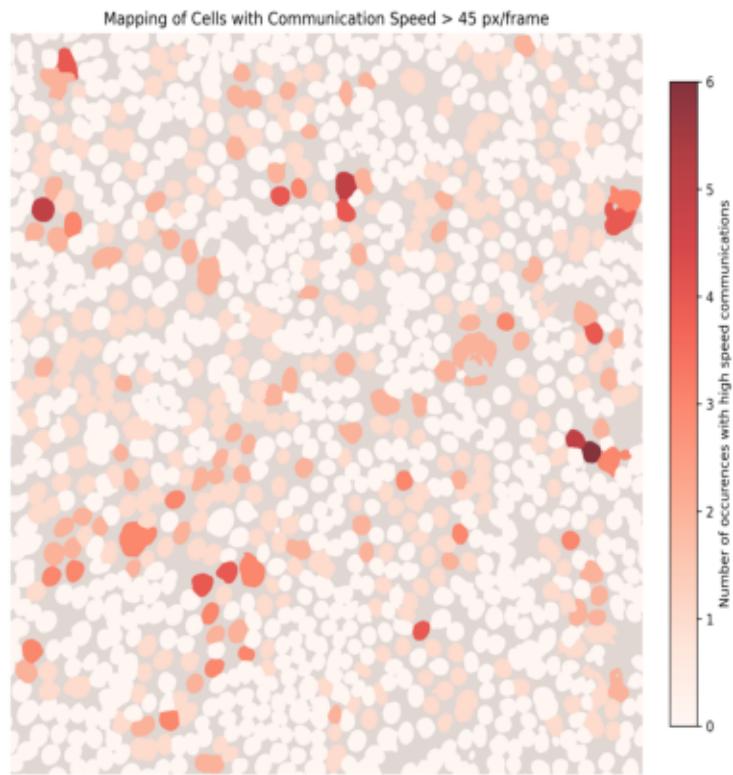


[2025-08-27 14:48:25] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 204 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)

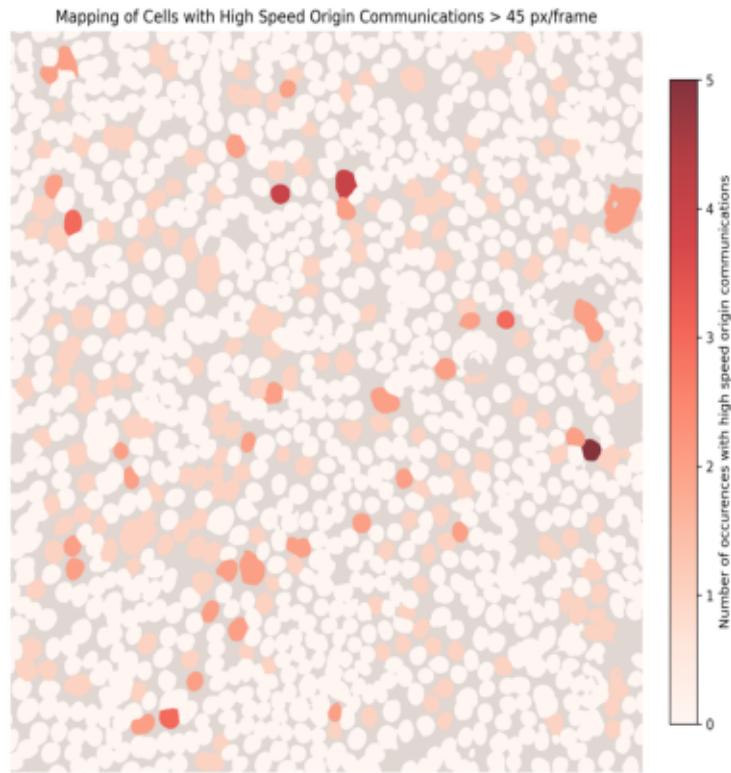
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	3015504590976	3	1512		0
17	3015504584736	4	553		0
21	3015506983952	4	622		1
23	3015506970176	4	562		0
36	3015504580800	6	1113		0
...	...	...	...	...	
2967	3015569152736	916	1627		3
2998	3015569147408	926	1604		0
3051	3015569151776	951	1613		5
3140	3015518339424	991	1655		1
3186	3015518349936	1023	1660		7

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
0	1529	0	13.0	13.0	
17	570	0	84.0	84.0	
21	643	1	89.0	89.0	
23	541	0	74.0	74.0	
36	1153	2	123.0	123.0	
...	...	...	...	...	
2967	1570	3	143.0	144.0	
2998	1550	0	72.0	73.0	
3051	1578	3	465.0	466.0	
3140	1646	1	100.0	101.0	
3186	1716	8	1097.0	1098.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
0	0.0	19.71	19.71		
17	0.0	16.61	16.61		
21	0.0	19.63	19.63		
23	0.0	17.02	17.02		
36	0.0	23.26	23.26		
...	...	...	...	...	
2967	1.0	19.80	19.80		
2998	1.0	19.08	19.08		
3051	1.0	15.63	15.63		
3140	1.0	15.22	15.22		
3186	1.0	17.24	17.24		
	Event time phase (fraction of event duration)	\			
0		0.00			
17		0.37			
21		0.51			
23		0.09			
36		0.90			
...		...			
2967		0.74			
2998		1.00			
3051		NaN			
3140		NaN			
3186		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
0		0.00	20250424_IS7		
17		0.23	20250424_IS7		
21		0.69	20250424_IS7		
23		0.00	20250424_IS7		
36		0.88	20250424_IS7		
...		...	...		
2967		0.80	20250424_IS7		
2998		1.00	20250424_IS7		

3051		NaN	20250424_IS7
3140		NaN	20250424_IS7
3186		NaN	20250424_IS7

	Number of cells involved	category	Speed category
0		11+	High speed
17		11+	High speed
21		11+	High speed
23		11+	High speed
36		11+	High speed
...		...	...
2967		11+	High speed
2998		3	High speed
3051		2	High speed
3140		2	High speed
3186		2	High speed

[236 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
265		0	4
266		0	2
270		1	0
274		0	1
276		0	2
...	...	...	...
1709		0	3
1716		0	3
1717		0	1
1718		0	2
1720		1	1

[898 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	265	247.00	7.48
3	266	273.00	8.12
5	270	405.93	8.12
8	274	65.98	9.43
9	276	284.38	10.72
...	...	...	...
1053	1709	226.53	486.20
1055	1716	256.43	487.82
1056	1717	349.05	490.75
1057	1718	470.28	490.43
1058	1720	156.65	491.73

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

2	11	True	2
3	10	True	2
5	7	True	2
8	4	True	2
9	5	True	2
...	...	...	...
1053	10	True	2
1055	10	True	2
1056	7	True	2
1057	8	True	2
1058	8	True	2

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

2	0	[]
3	0	[]
5	0	[]
8	0	[]
9	0	[]
...	...	...
1053	0	[]
1055	0	[]
1056	0	[]
1057	0	[]
1058	1	[2]

Occurrences in sequential events \

2	6
3	4
5	4
8	1
9	3
...	...
1053	5
1055	5
1056	3
1057	4
1058	3

Occurrences in sequential events as origin \

2	2
3	2
5	0
8	1
9	1
...	...
1053	1
1055	0
1056	1

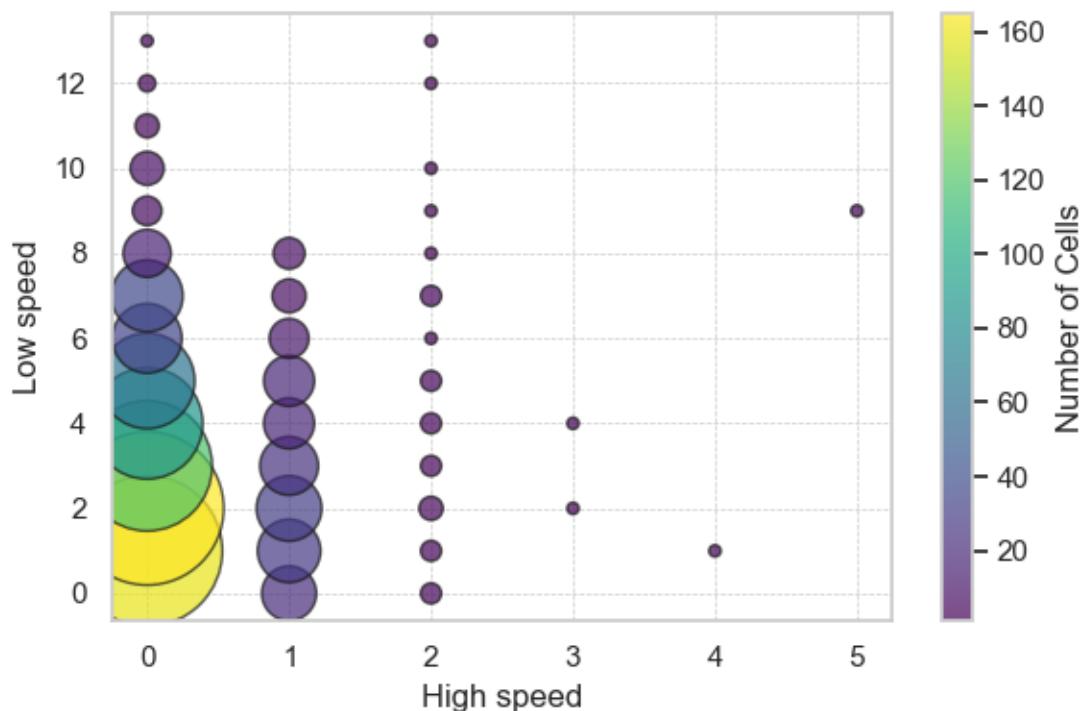
1057		2	
1058		1	
	Occurrences in individual events	Peak frequency (Hz)	\
2	2	0.0065	
3	4	0.0059	
5	1	0.0041	
8	1	0.0024	
9	0	0.0029	
...	...	...	
1053	3	0.0059	
1055	3	0.0059	
1056	2	0.0041	
1057	2	0.0047	
1058	3	0.0047	
	Periodicity score	Neighbor count	Neighbors (labels) dataset \
2	0.62	3	[289,310,322] 20250424_IS7
3	0.61	3	[276,310,312] 20250424_IS7
5	0.45	4	[293,294,303,326] 20250424_IS7
8	0.80	3	[280,315,320] 20250424_IS7
9	0.79	5	[266,300,312,327,335] 20250424_IS7
...	...	...	...
1053	0.58	4	[1664,1665,1700,1702] 20250424_IS7
1055	0.57	4	[1660,1680,1700,1721] 20250424_IS7
1056	0.62	2	[1677,1697] 20250424_IS7
1057	0.51	4	[1655,1666,1693,1701] 20250424_IS7
1058	0.69	4	[1674,1687,1689,1708] 20250424_IS7
	Involved in sequential event	Occurrences in sequential events	category \
2	Involved in sequential event		5-9
3	Involved in sequential event		3-4
5	Involved in sequential event		3-4
8	Involved in sequential event		1-2
9	Involved in sequential event		3-4
...	...	...	...
1053	Involved in sequential event		5-9
1055	Involved in sequential event		5-9
1056	Involved in sequential event		3-4
1057	Involved in sequential event		3-4
1058	Involved in sequential event		3-4
	High speed	Low speed	
2	0.0	4.0	
3	0.0	2.0	
5	1.0	0.0	
8	0.0	1.0	
9	0.0	2.0	

```

...
1053      0.0      3.0
1055      0.0      3.0
1056      0.0      1.0
1057      0.0      2.0
1058      1.0      1.0

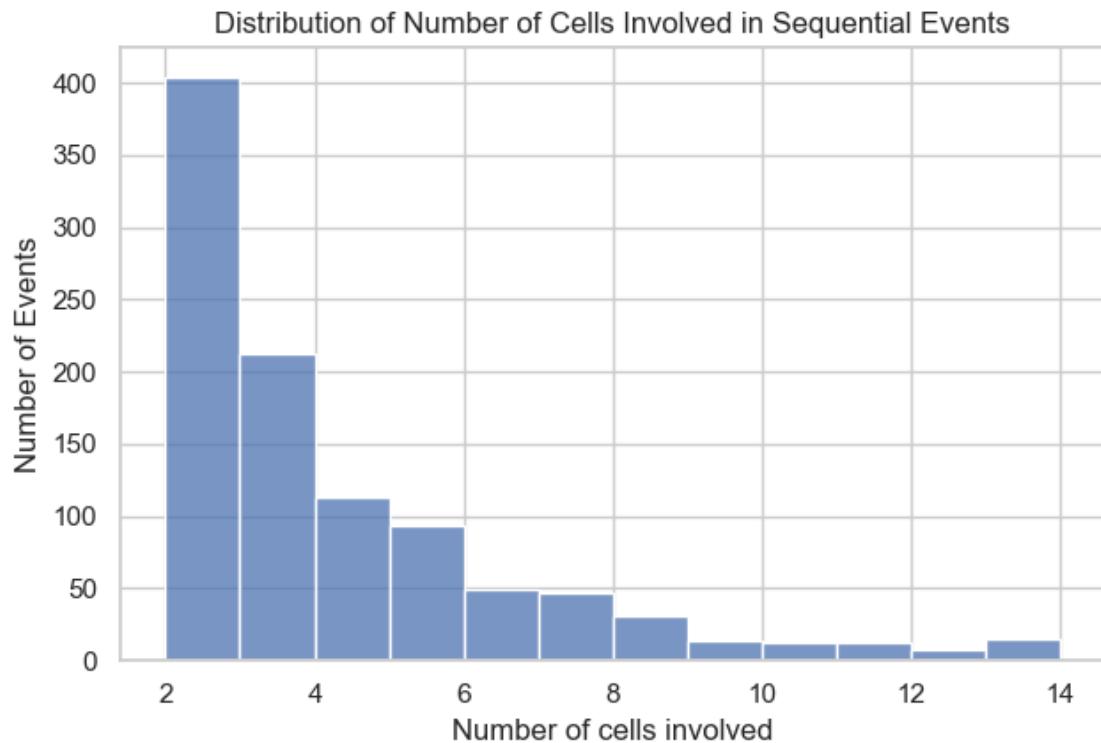
```

[898 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

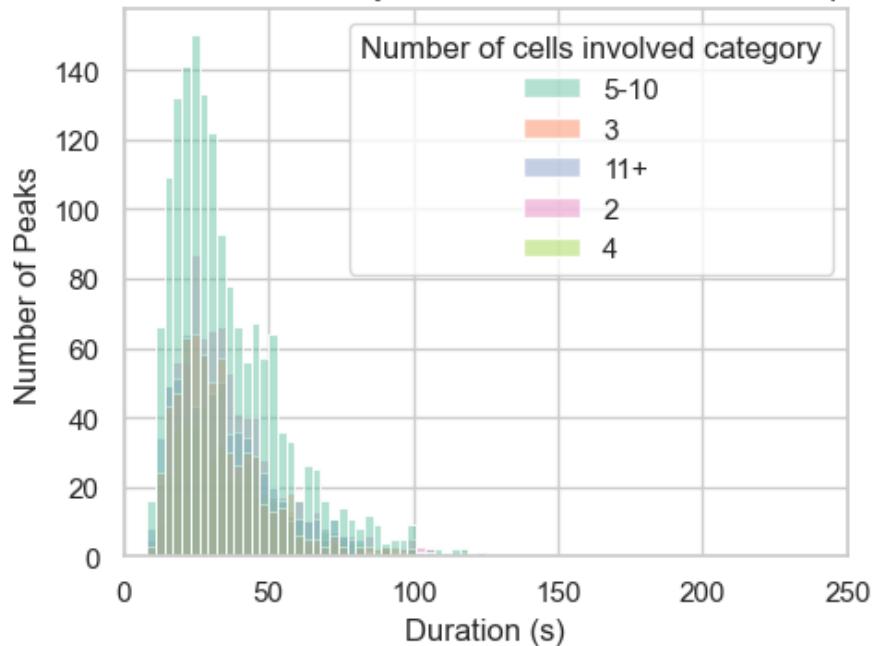
[2025-08-27 14:48:28] [INFO] calcium: plot\_histogram: removed 13 outliers out of 1025 on 'Number of cells involved' (lower=-7, upper=14)



### 1.3.6 Influence of cell count per event on statistics

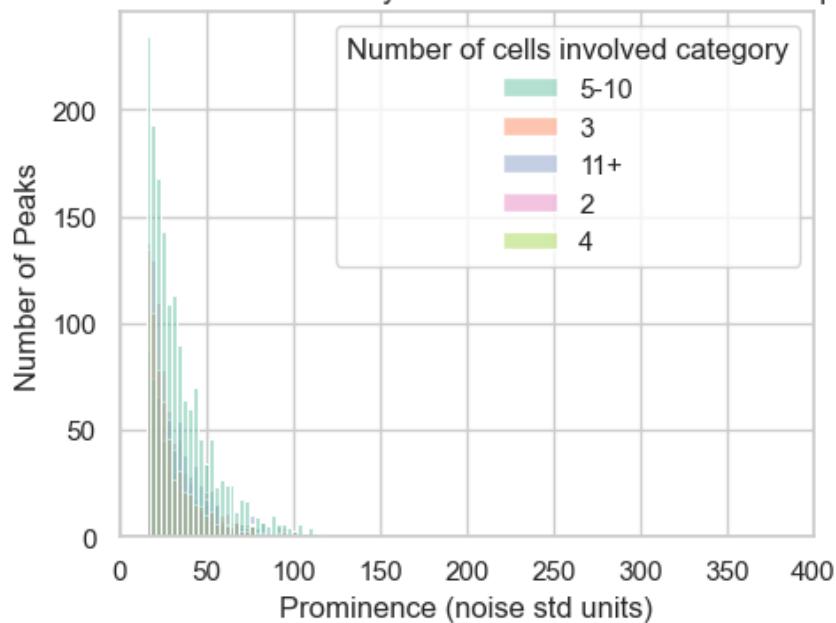
```
[2025-08-27 14:48:28] [INFO] calcium: plot_histogram_by_group: removed 41
outliers out of 4216 on 'Duration (s)' (lower=-12.5, upper=125.5)
```

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

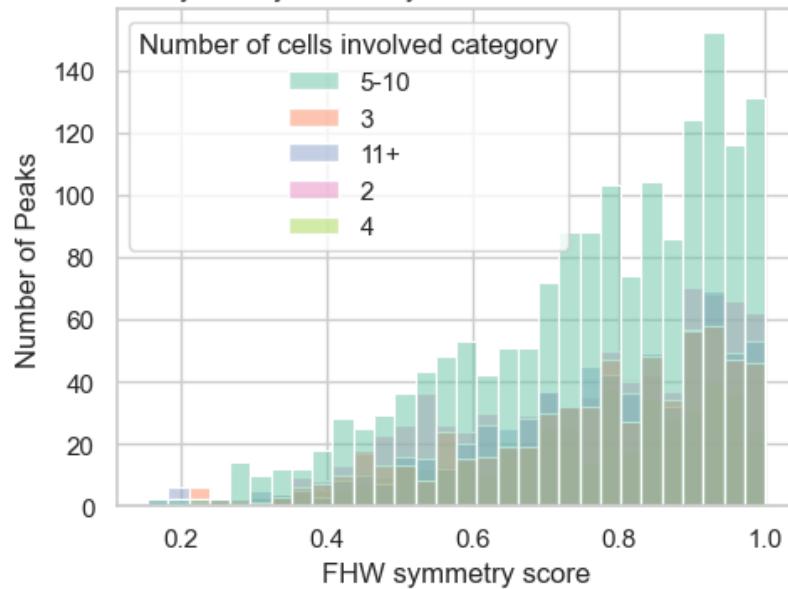


```
[2025-08-27 14:48:29] [INFO] calcium: plot_histogram_by_group: removed 67 outliers out of 4216 on 'Prominence (noise std units)' (lower=-12.5, upper=117.1)
```

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

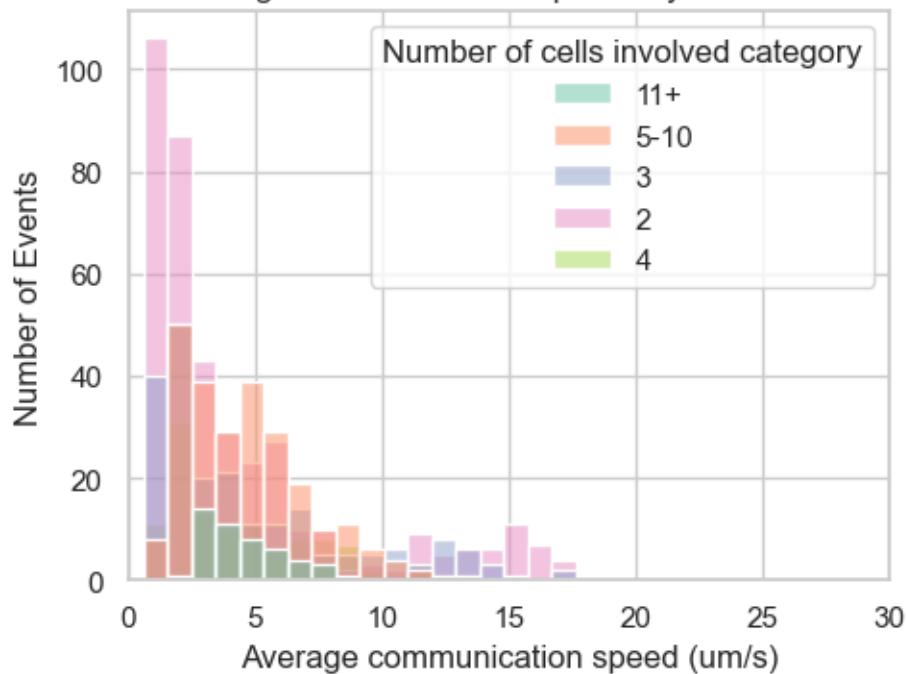


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events

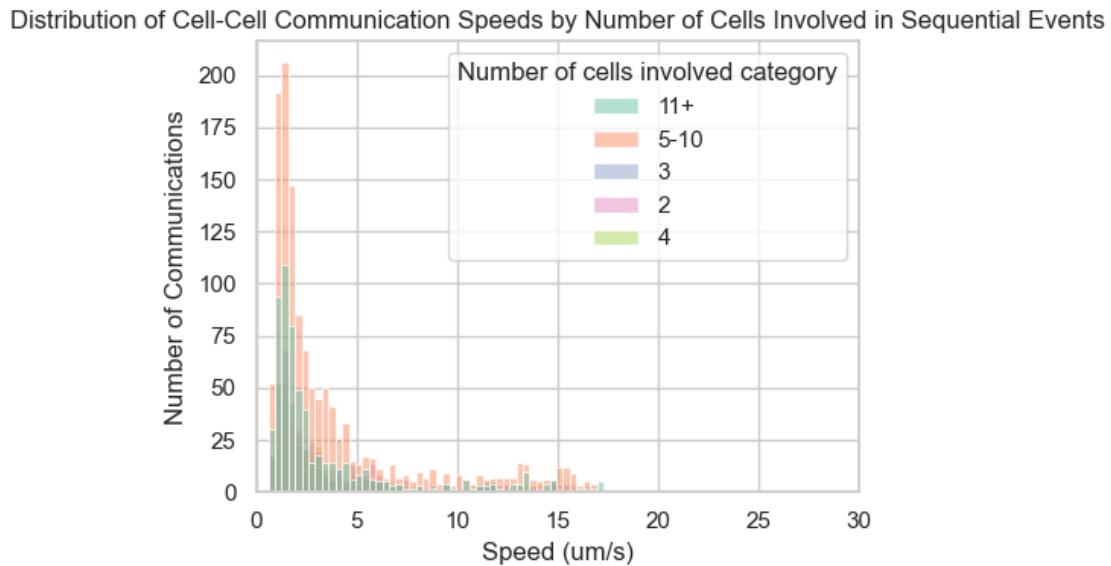


```
[2025-08-27 14:48:29] [INFO] calcium: plot_histogram_by_group: removed 15 outliers out of 1025 on 'Average communication speed (um/s)' (lower=-10.56, upper=18.56)
```

Distribution of Average Communication Speeds by Number of Cells Involved

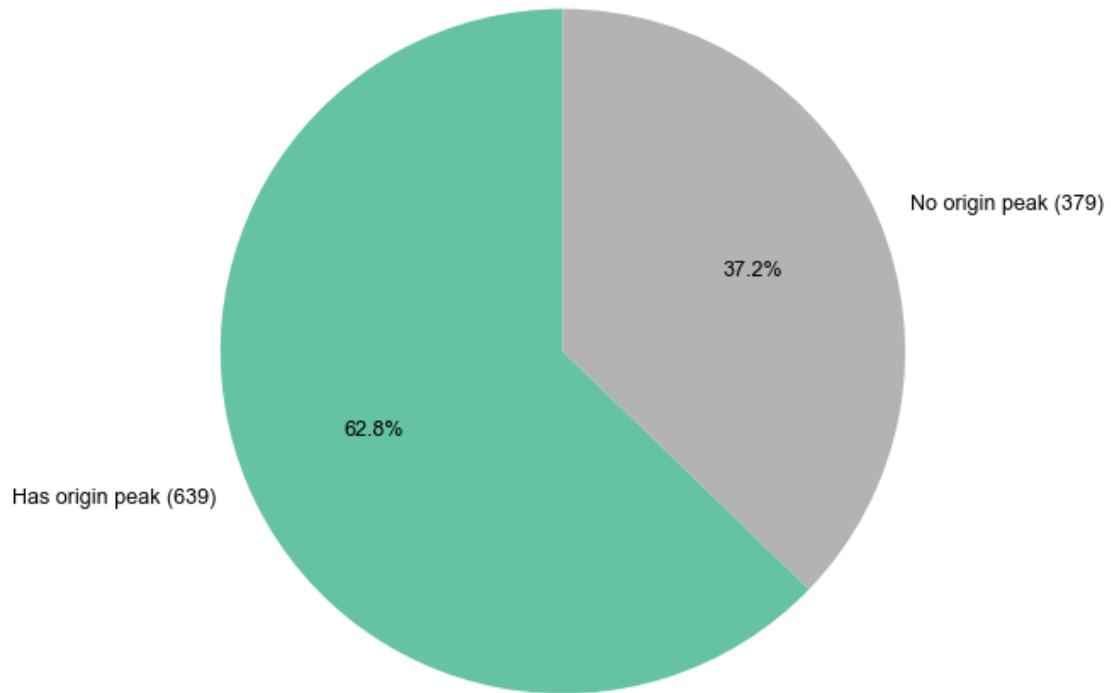


[2025-08-27 14:48:30] [INFO] calcium: plot\_histogram\_by\_group: removed 143 outliers out of 3191 on 'Speed (um/s)' (lower=-10.5, upper=17.29)

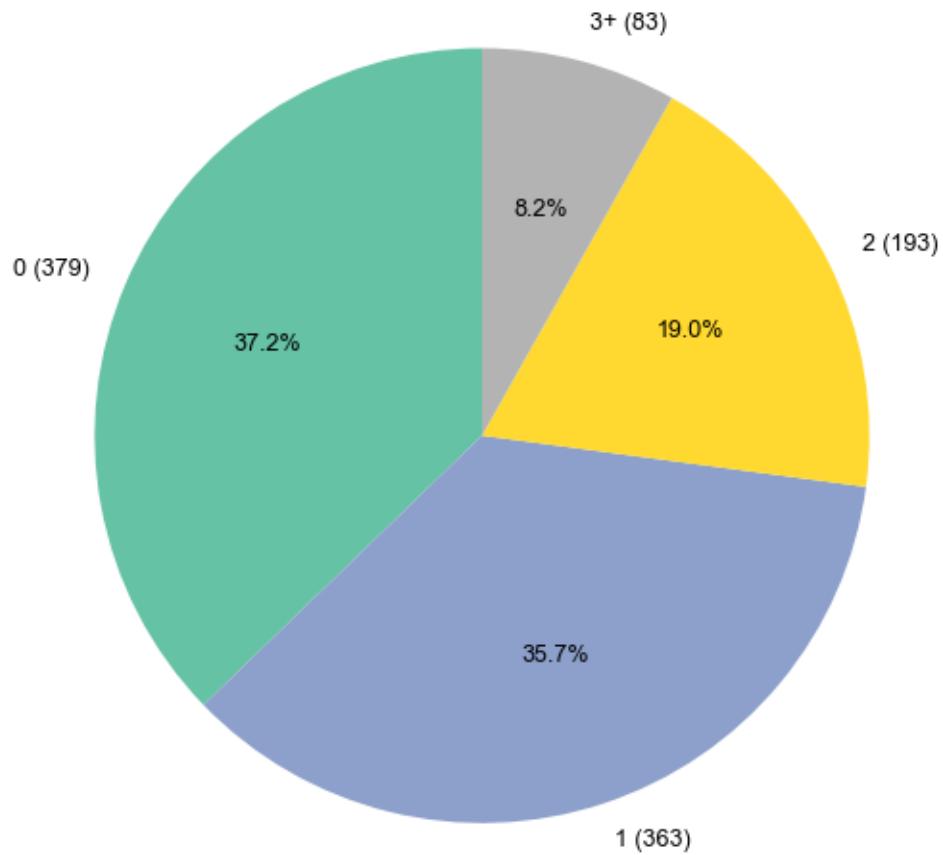


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

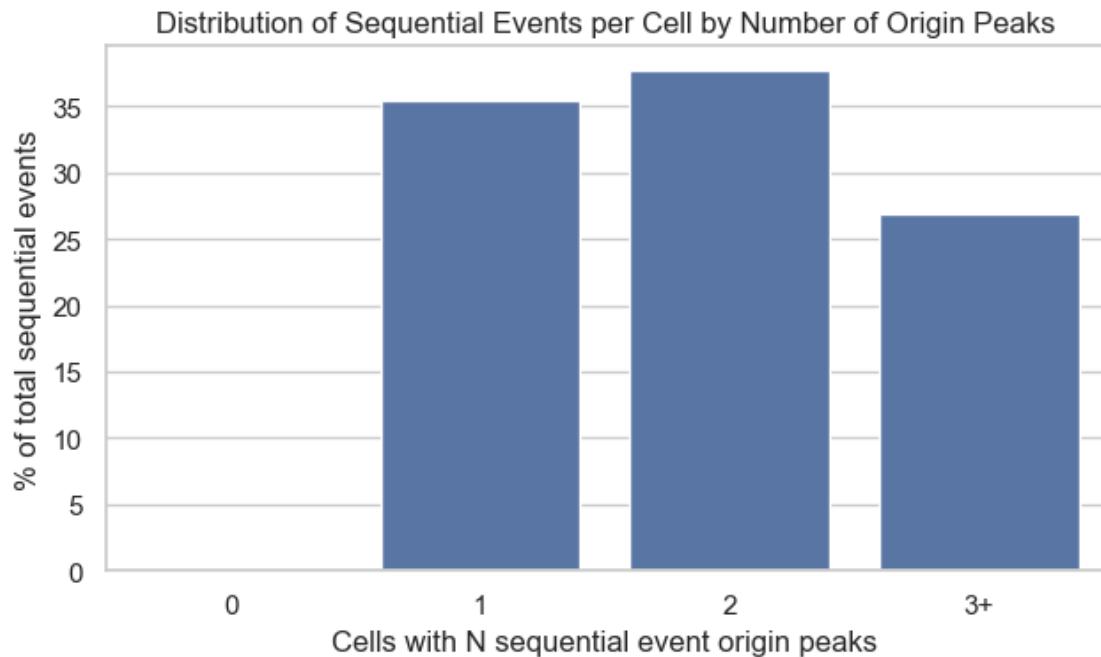


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)

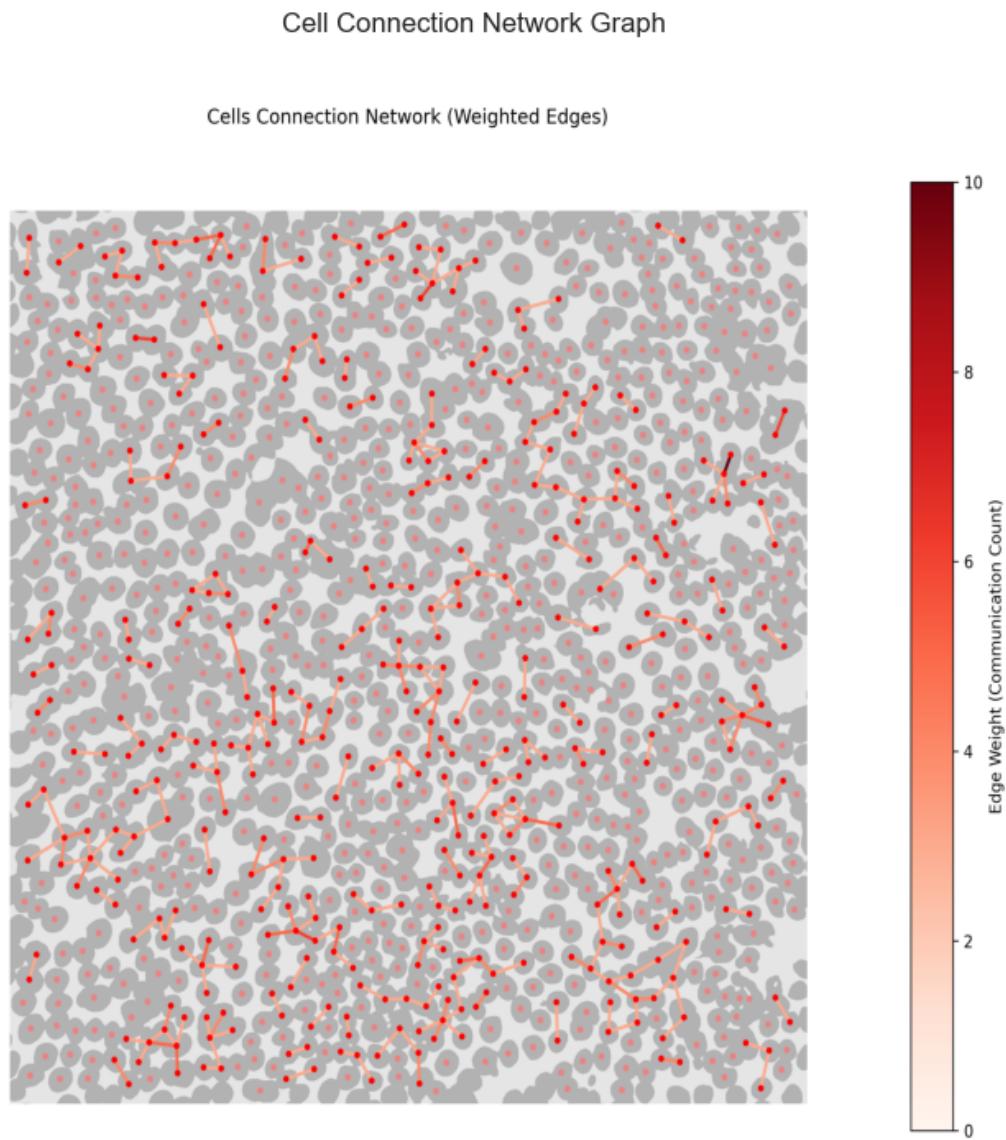


```
[2025-08-27 14:48:30] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS7\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_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\\20250424\\Output\\IS7\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```

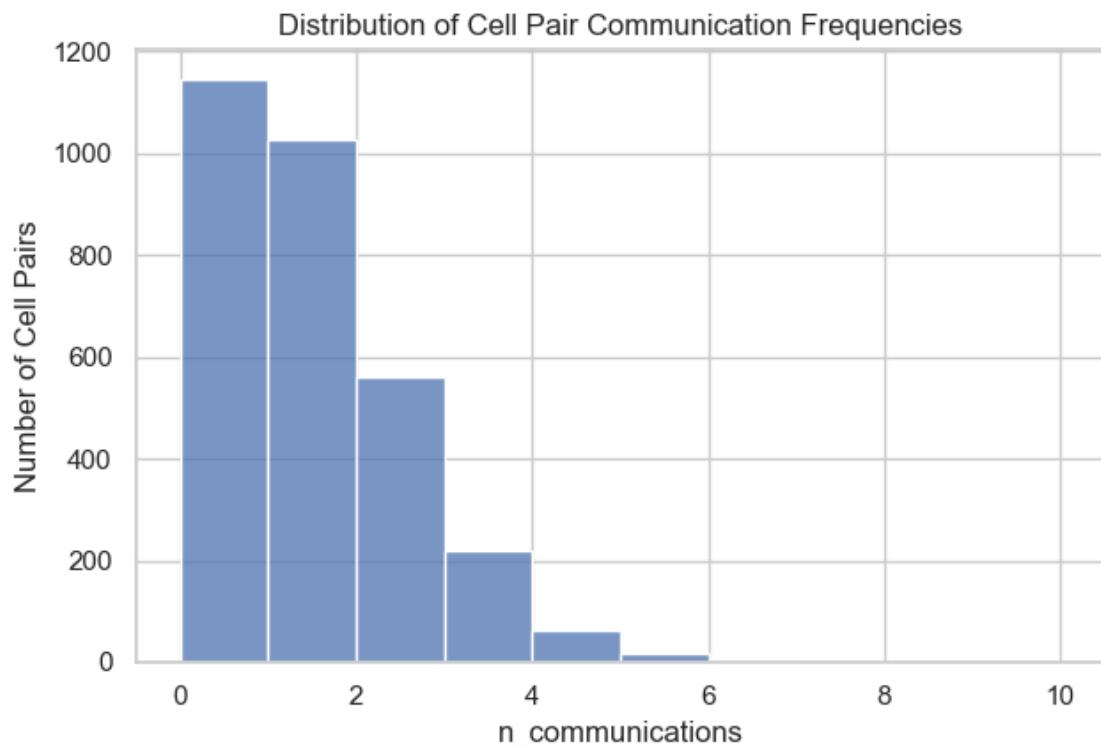


### 1.3.8 Connection network between cells



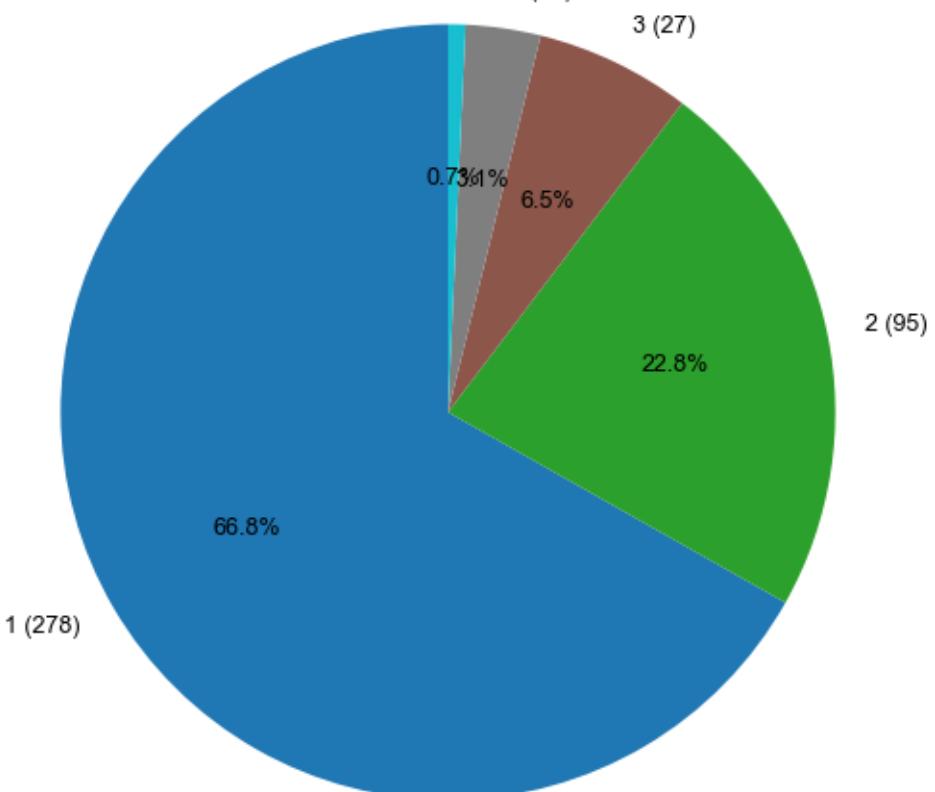
### 1.3.9 Pair/Trios with high communication networks

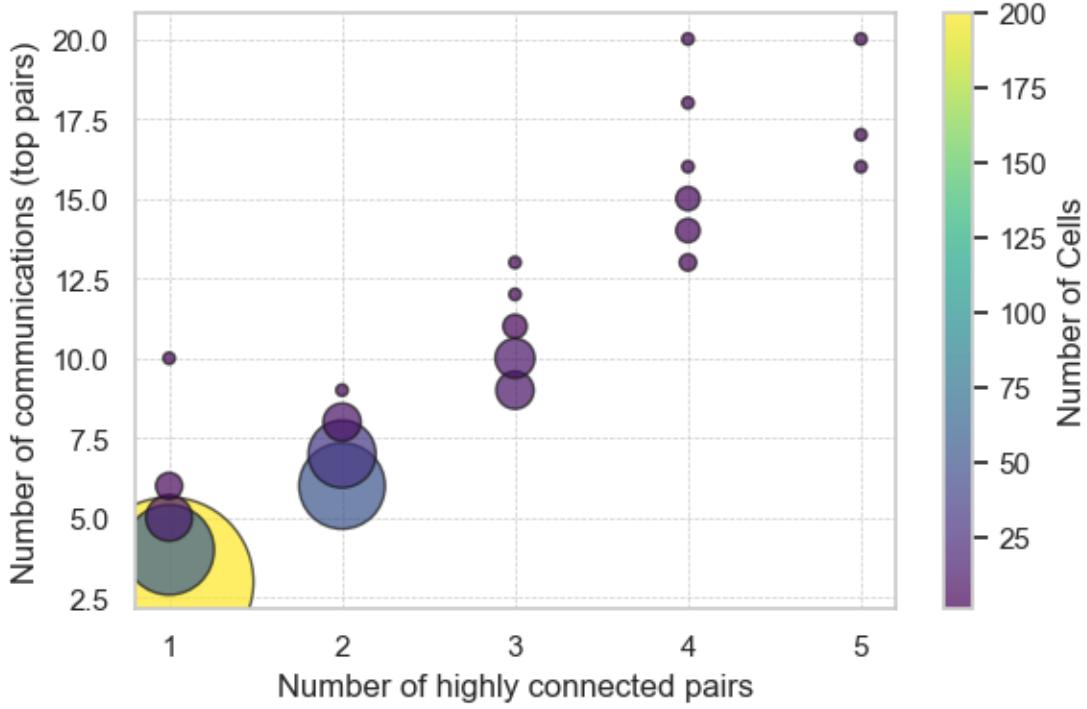
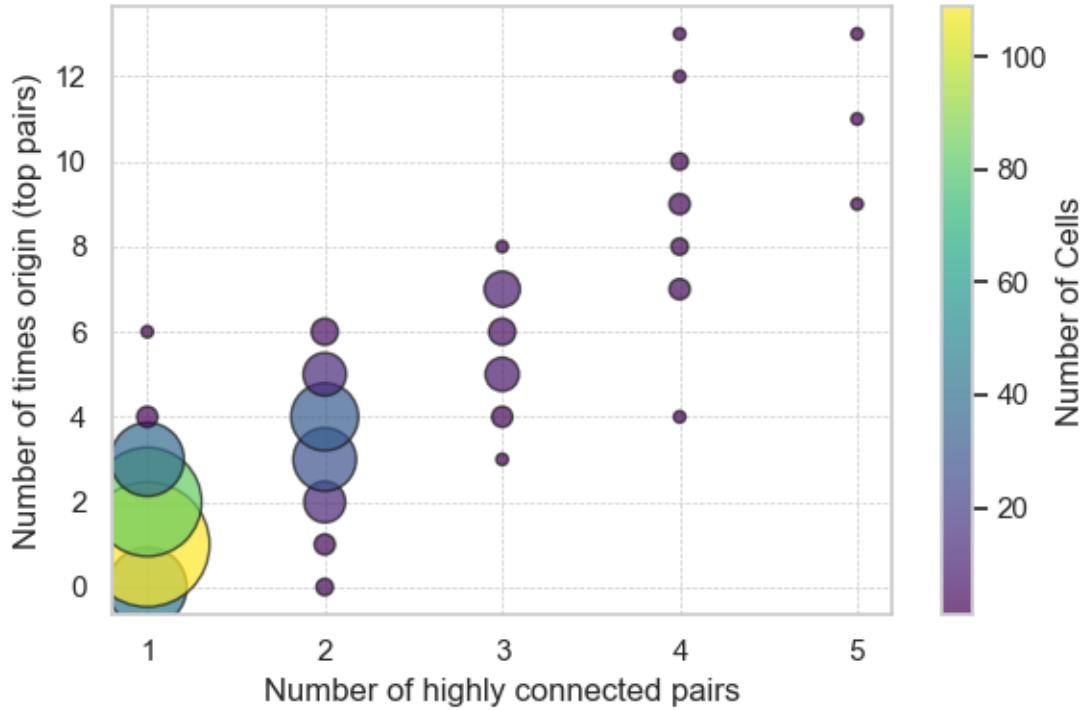
```
[2025-08-27 14:48:32] [INFO] calcium: build_neighbor_pair_stats: built 3041 pairs across 1 datasets (mean distance=16.53 um)
```

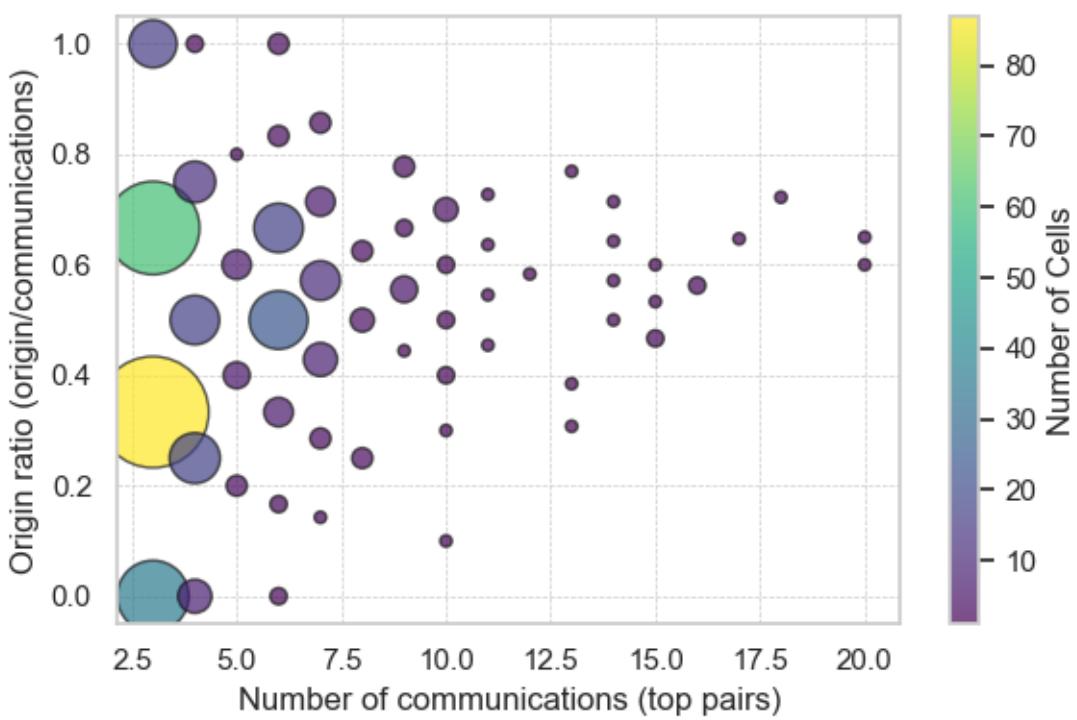
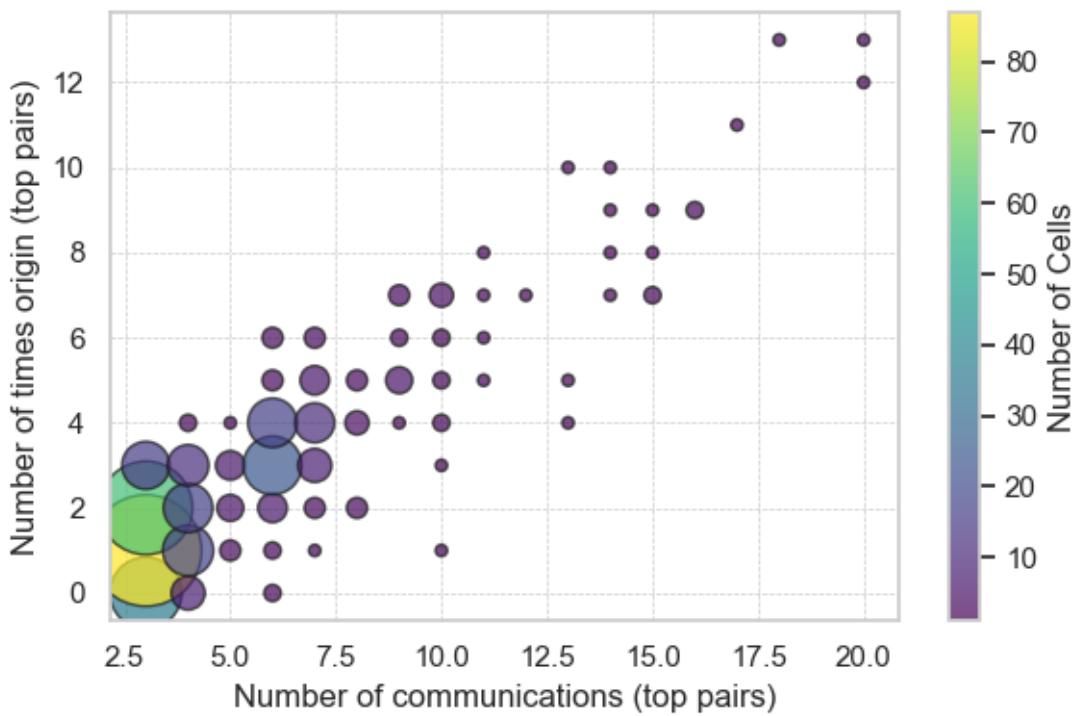


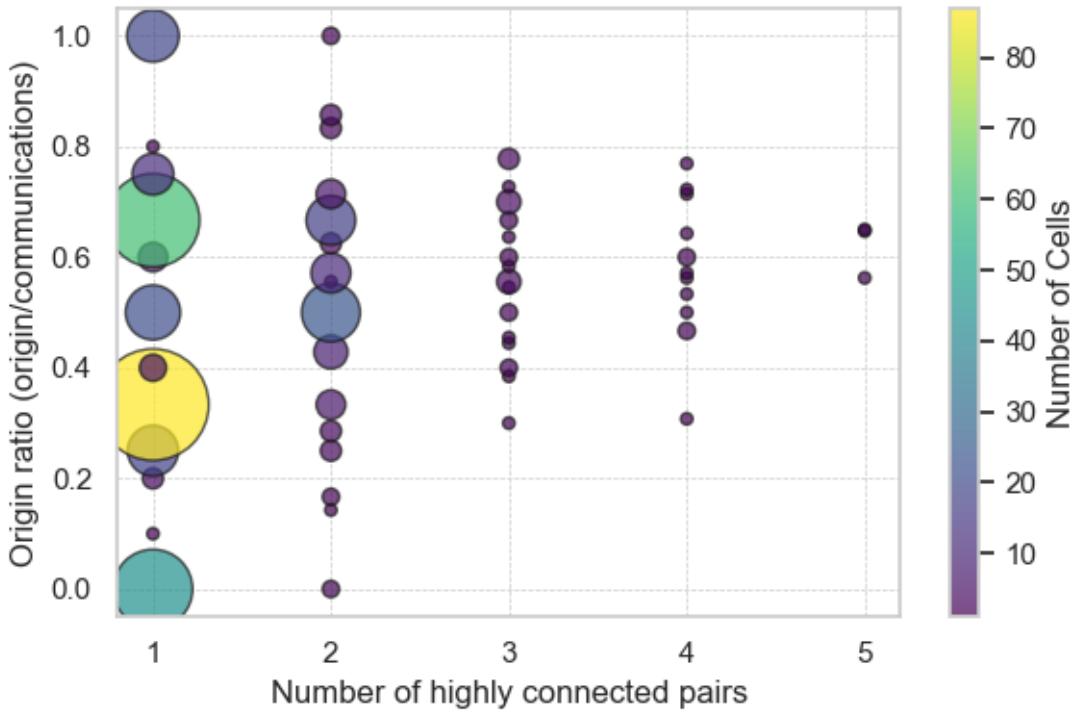
95th percentile threshold: 3.0

Cells involved in multiple pairs highly connected









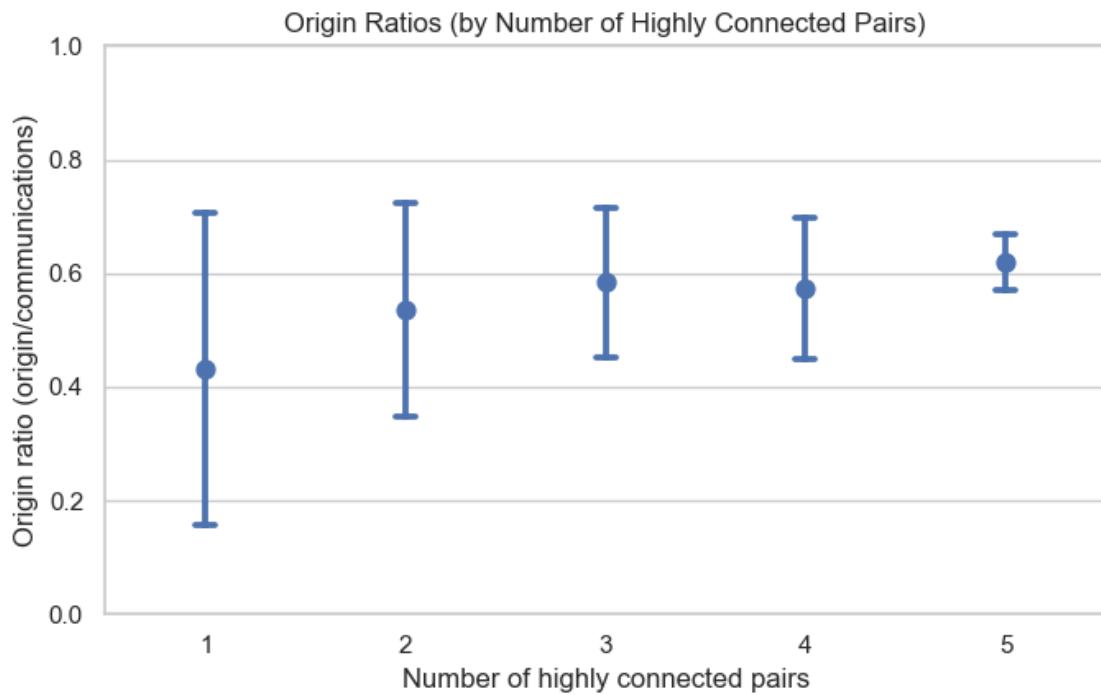
[2025-08-27 14:48:33] [INFO] calcium: plot\_points\_mean\_std: N=278 for Number of highly connected pairs=1

[2025-08-27 14:48:33] [INFO] calcium: plot\_points\_mean\_std: N=95 for Number of highly connected pairs=2

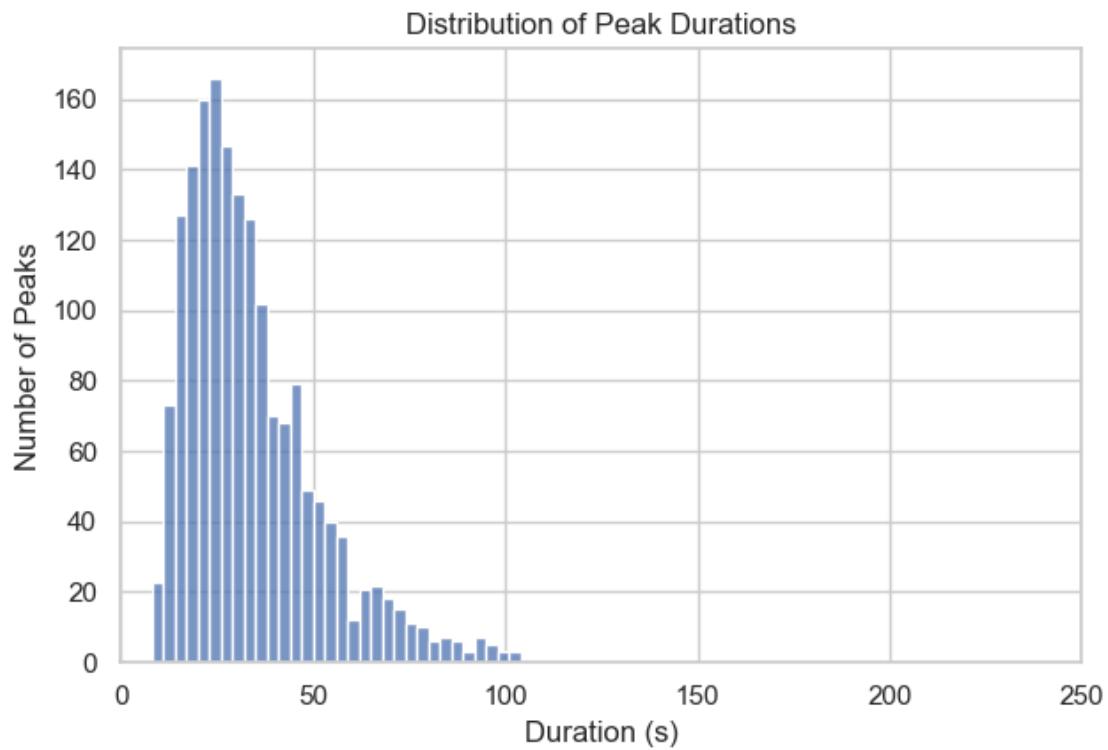
[2025-08-27 14:48:33] [INFO] calcium: plot\_points\_mean\_std: N=27 for Number of highly connected pairs=3

[2025-08-27 14:48:33] [INFO] calcium: plot\_points\_mean\_std: N=13 for Number of highly connected pairs=4

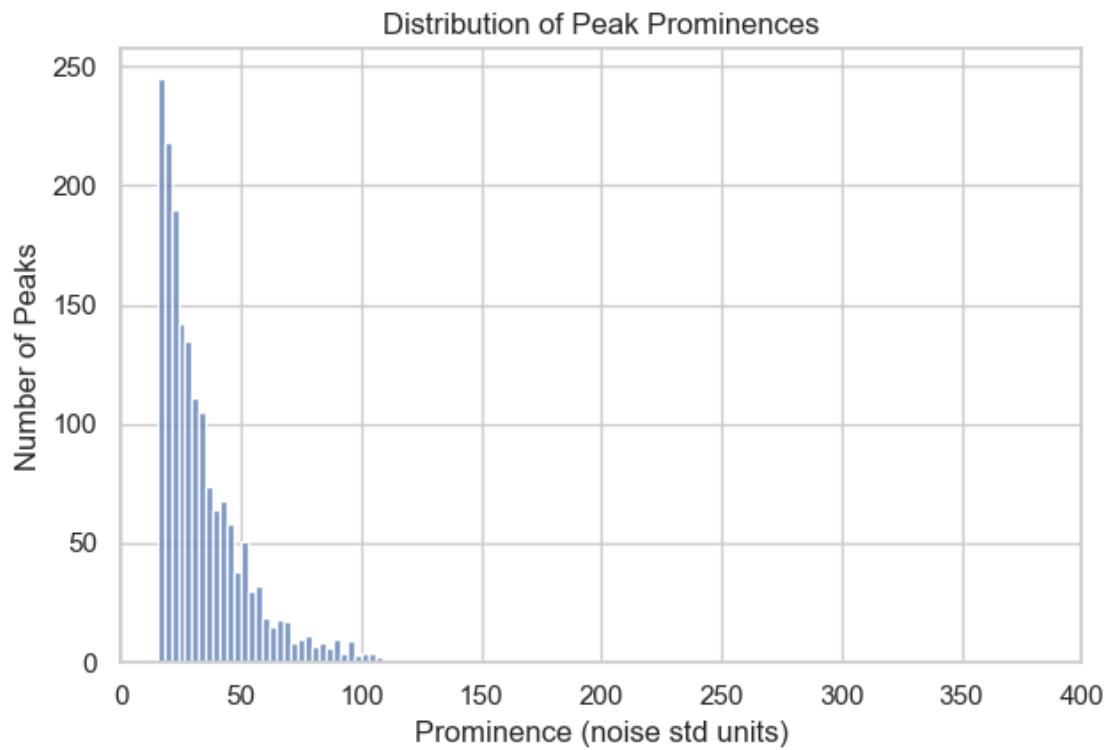
[2025-08-27 14:48:33] [INFO] calcium: plot\_points\_mean\_std: N=3 for Number of highly connected pairs=5

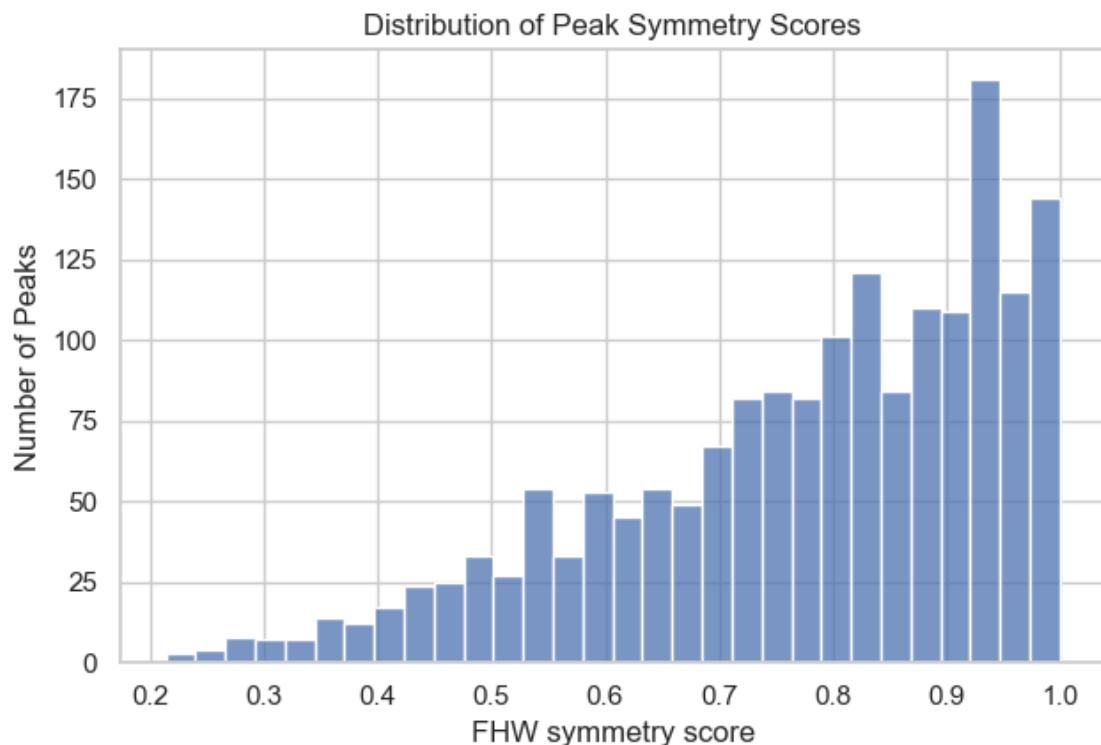


```
[2025-08-27 14:48:33] [INFO] calcium: plot_histogram: removed 14 outliers out of 1749 on 'Duration (s)' (lower=-42, upper=105)
```

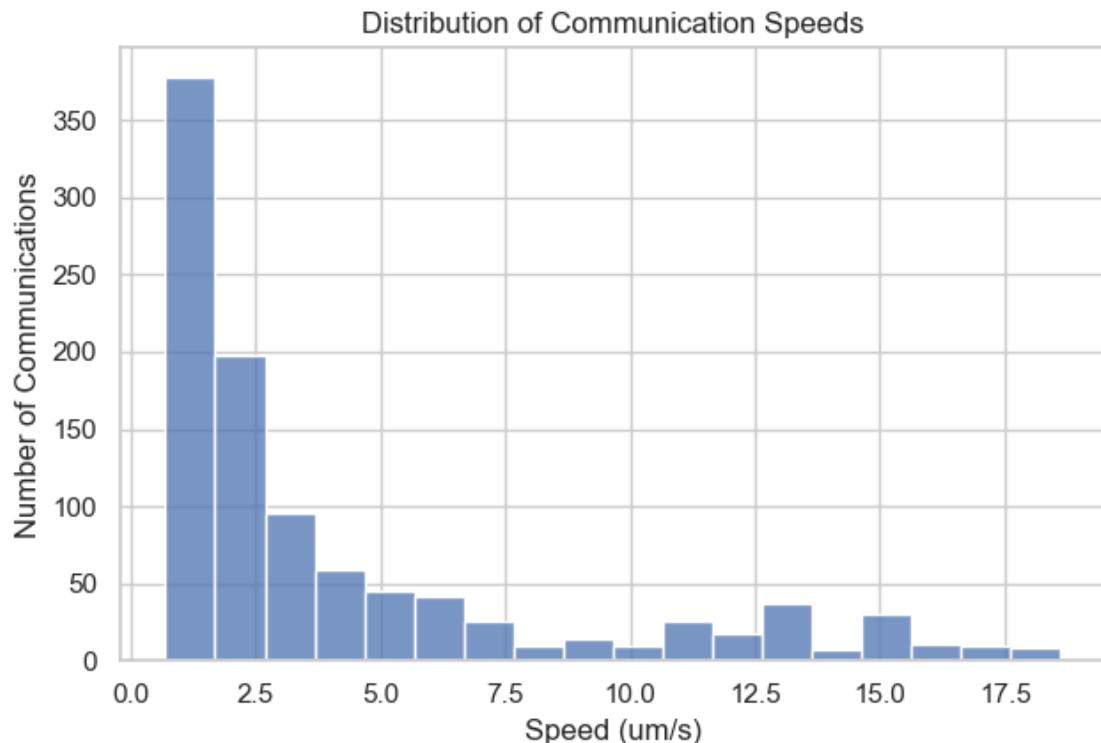


[2025-08-27 14:48:33] [INFO] calcium: plot\_histogram: removed 33 outliers out of 1749 on 'Prominence (noise std units)' (lower=-46.4, upper=109.7)

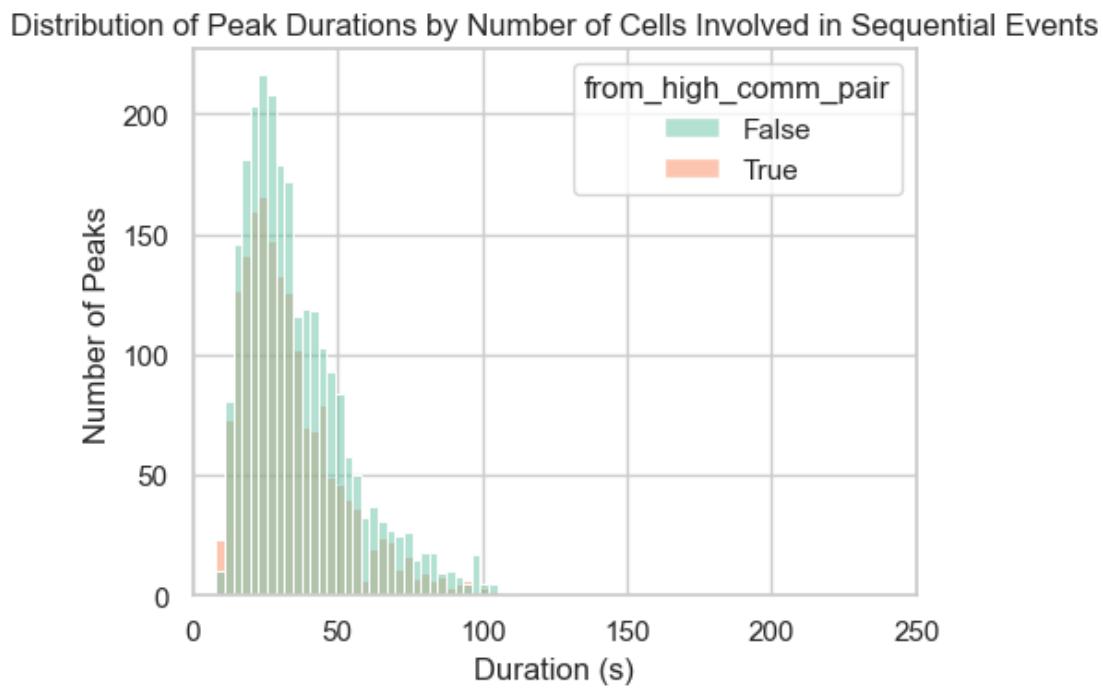




```
[2025-08-27 14:48:34] [INFO] calcium: plot_histogram: removed 19 outliers out of 1043 on 'Speed (um/s)' (lower=-11.64, upper=18.81)
```

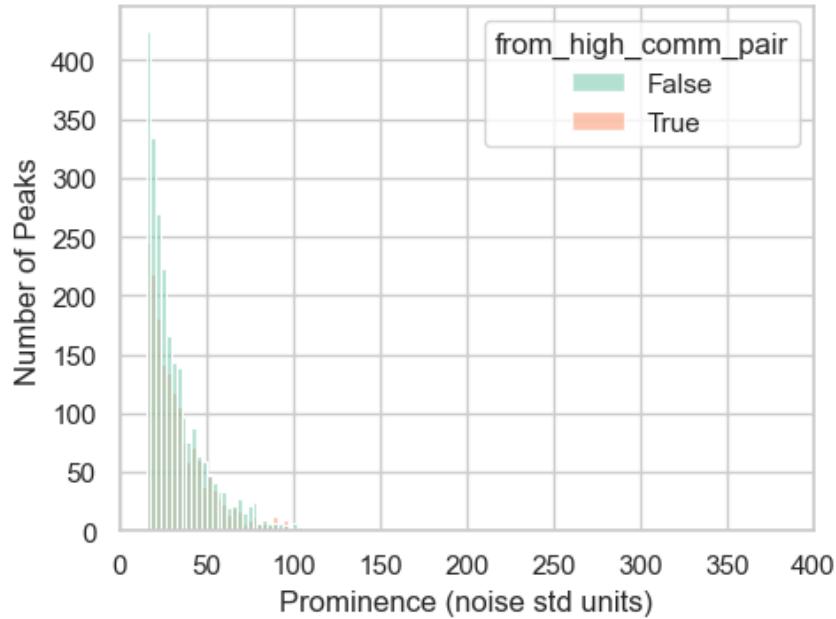


```
[2025-08-27 14:48:34] [INFO] calcium: plot_histogram_by_group: removed 51 outliers out of 4216 on 'Duration (s)' (lower=-47, upper=114)
```

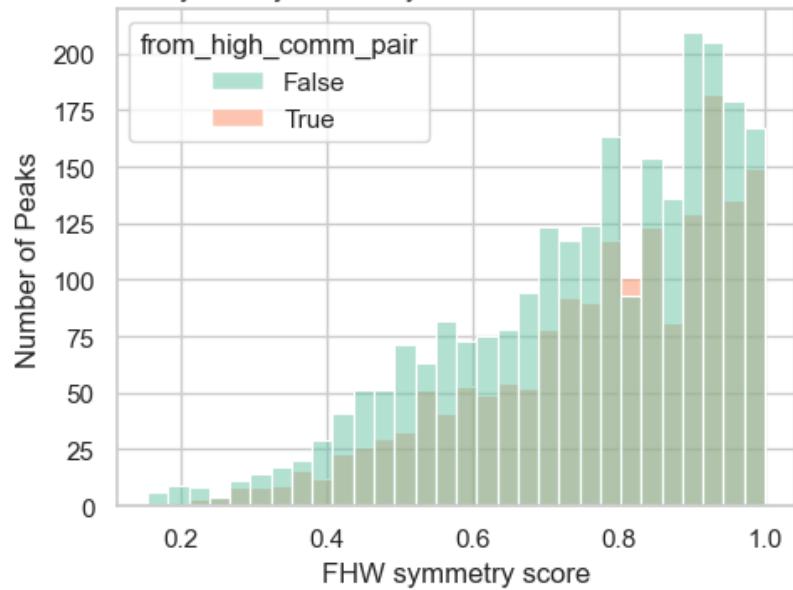


[2025-08-27 14:48:34] [INFO] calcium: plot\_histogram\_by\_group: removed 84 outliers out of 4216 on 'Prominence (noise std units)' (lower=-44.9, upper=106.3)

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

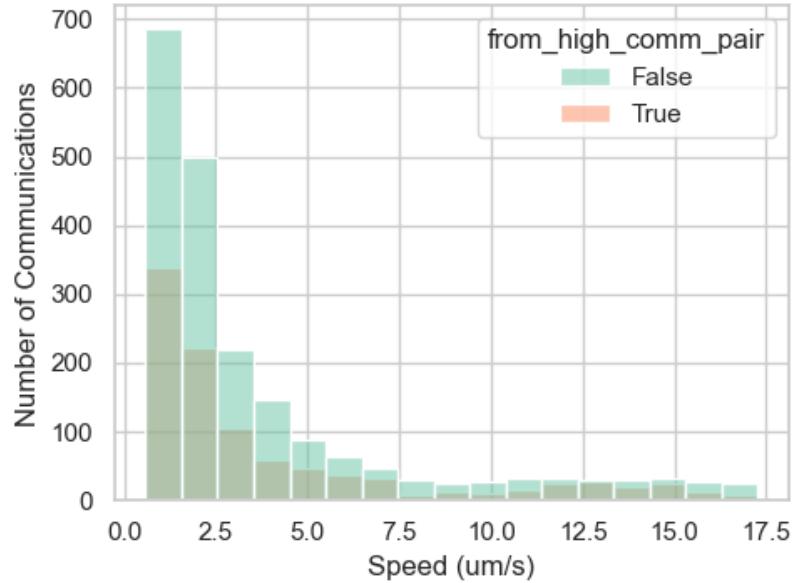


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 14:48:34] [INFO] calcium: plot\_histogram\_by\_group: removed 143 outliers out of 3191 on 'Speed (um/s)' (lower=-10.5, upper=17.29)

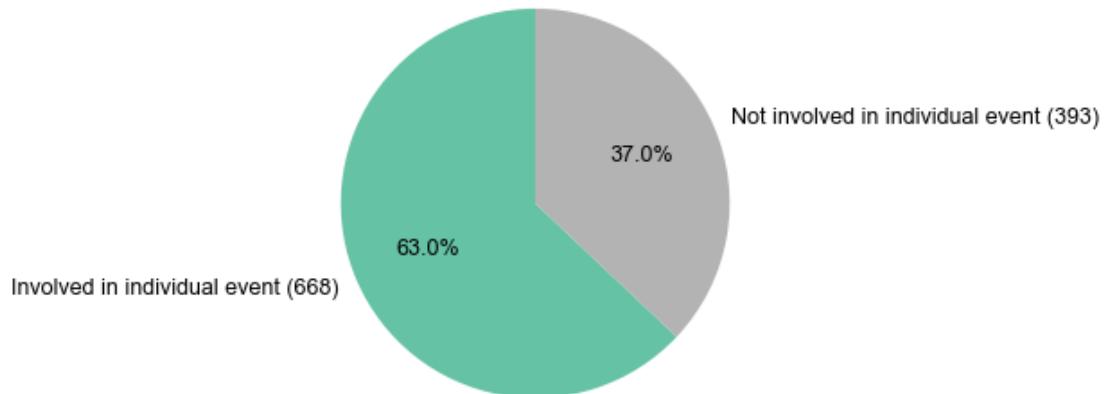
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



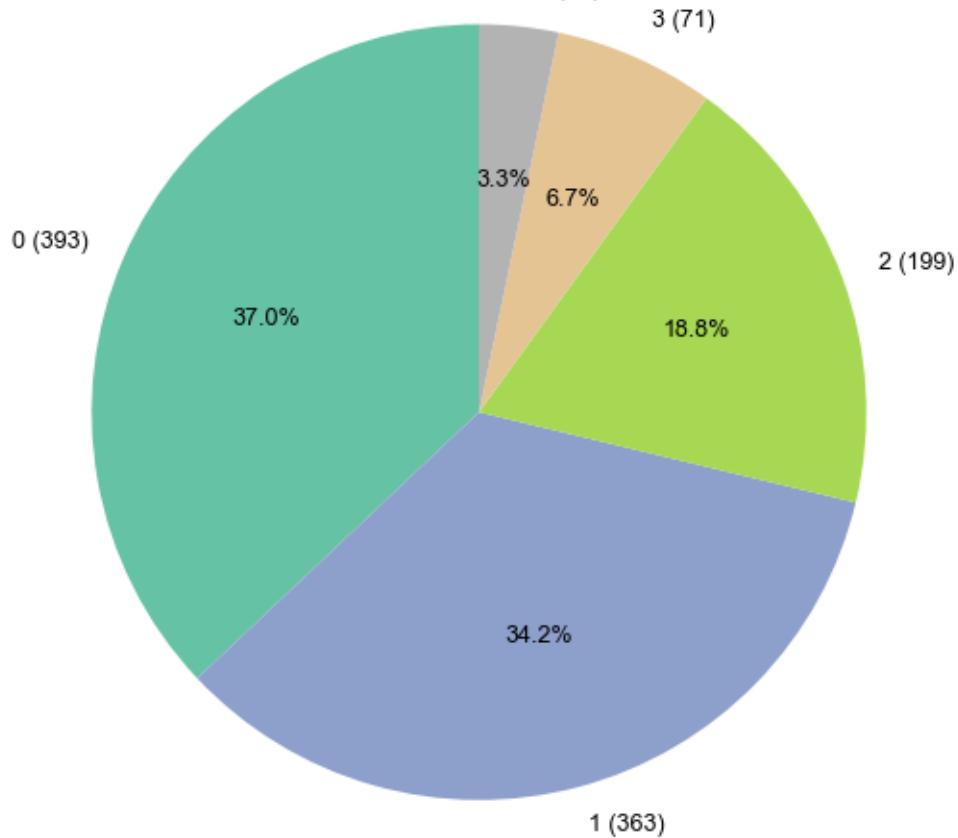
## 1.4 INDIVIDUAL EVENTS

### 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+)

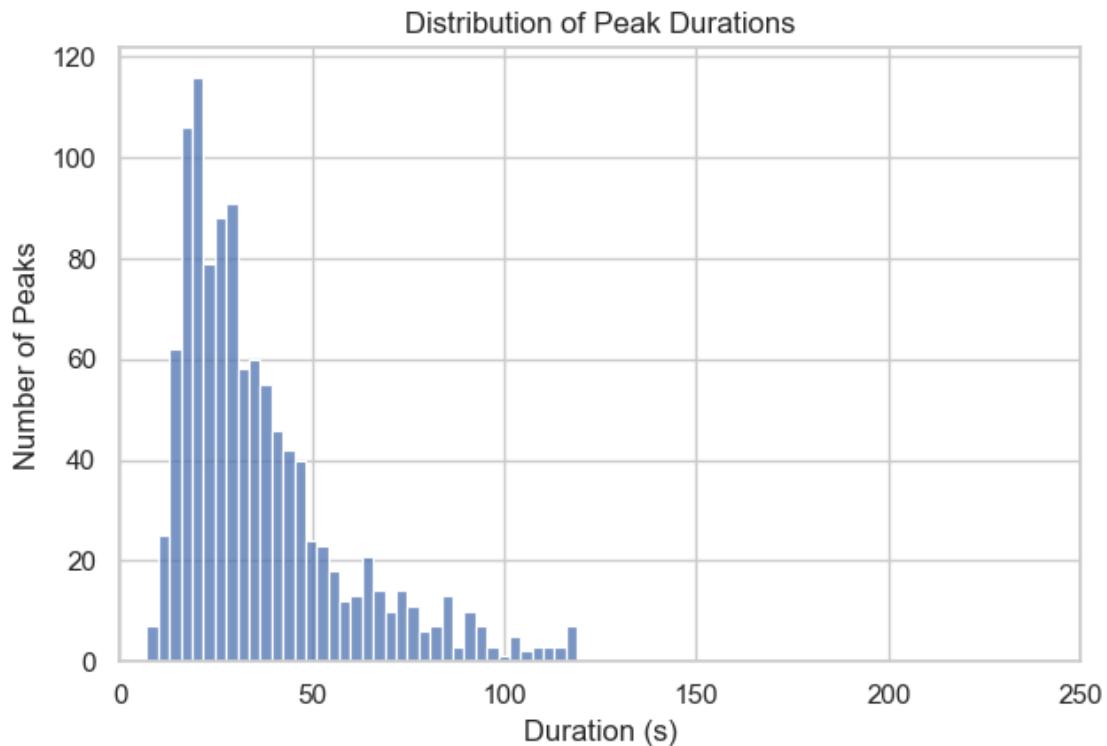


```
[2025-08-27 14:48:35] [ERROR] calcium: Failed to read image
'D:\Mateo\20250424\Output\IS7\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250424\\Output\\IS7\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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:
```

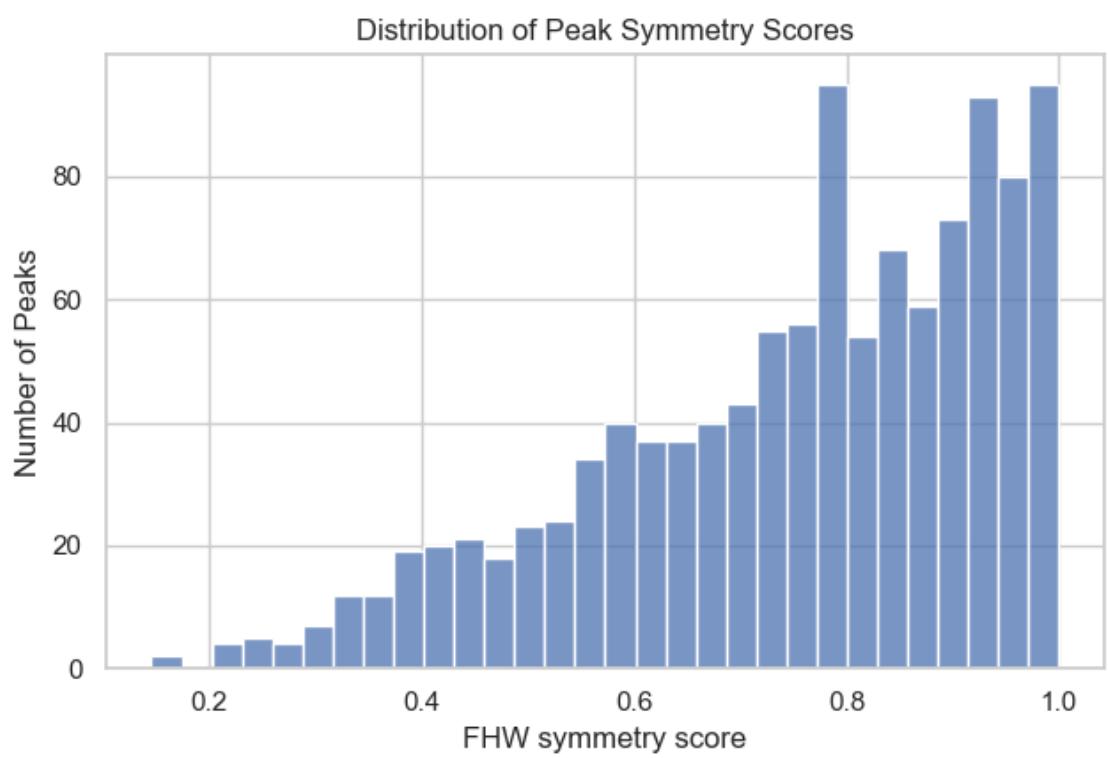
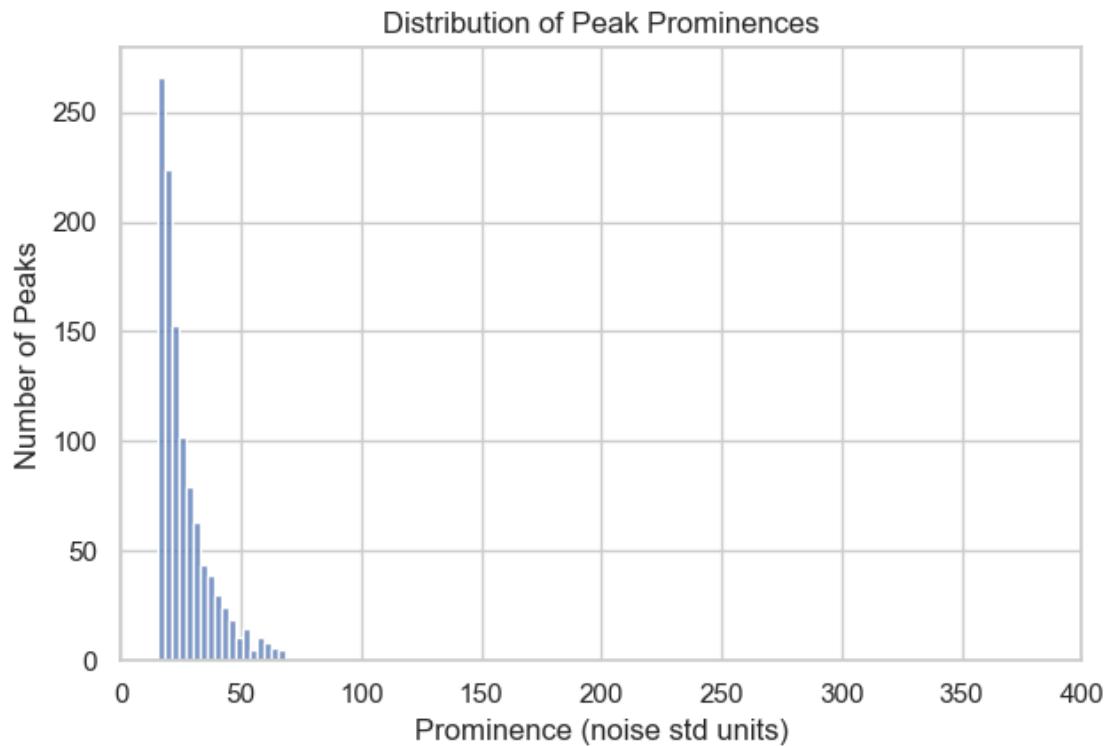
'D:\\Mateo\\20250424\\Output\\IS7\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

#### 1.4.2 Peaks statistics in individual events

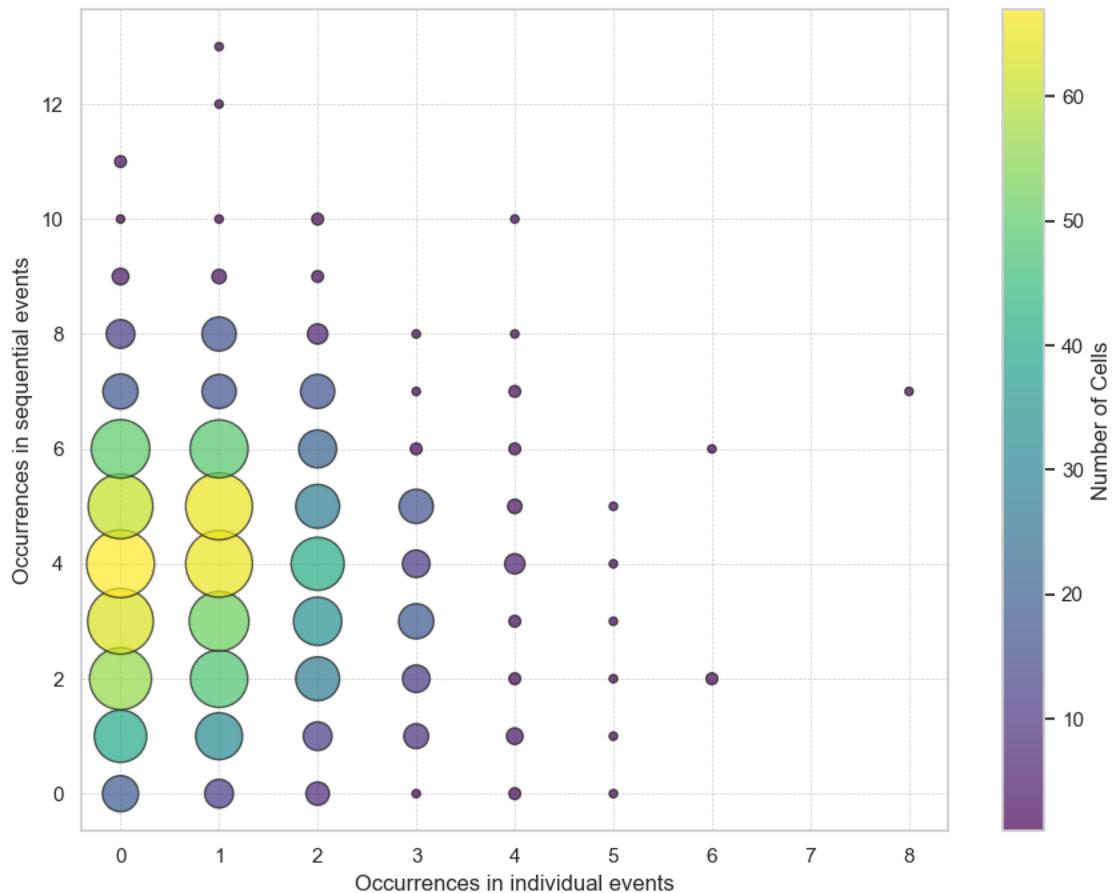
[2025-08-27 14:48:35] [INFO] calcium: plot\_histogram: removed 22 outliers out of 1130 on 'Duration (s)' (lower=-54, upper=121)



[2025-08-27 14:48:35] [INFO] calcium: plot\_histogram: removed 26 outliers out of 1130 on 'Prominence (noise std units)' (lower=-20.6, upper=69.7)



### 1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: removed 0/1061 outliers on 'Occurrences in sequential events' (lower=-7, upper=14)
```

```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: N=393 for Occurrences in individual events=0
```

```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: N=363 for Occurrences in individual events=1
```

```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: N=199 for Occurrences in individual events=2
```

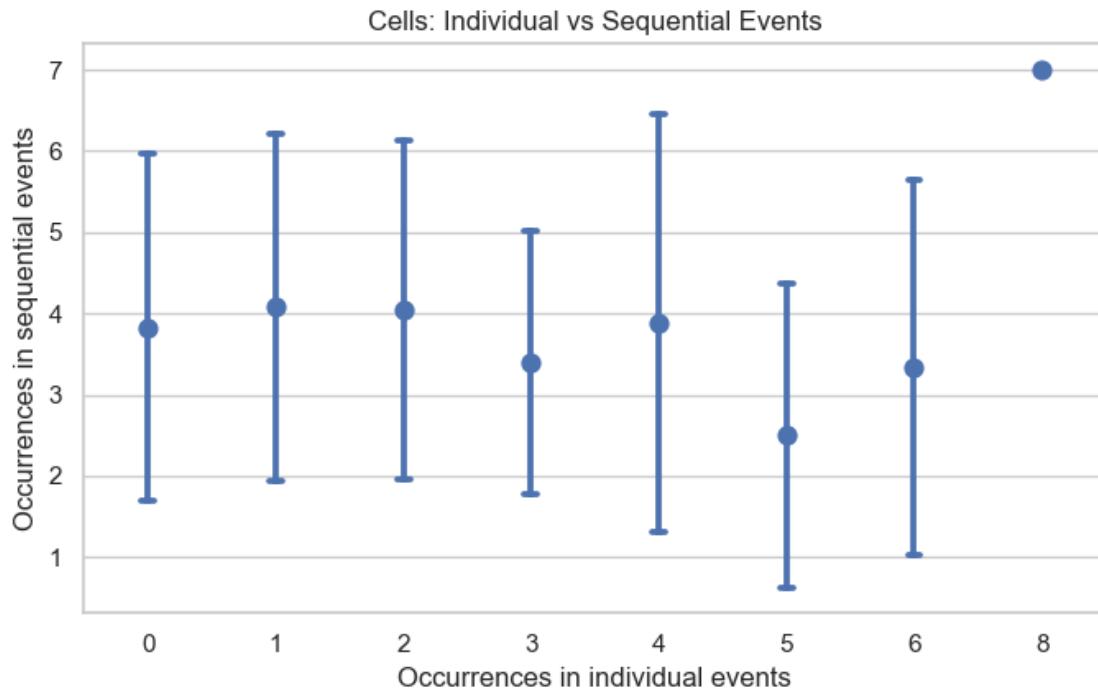
```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: N=71 for Occurrences in individual events=3
```

```
[2025-08-27 14:48:36] [INFO] calcium: plot_points_mean_std: N=25 for Occurrences in individual events=4
```

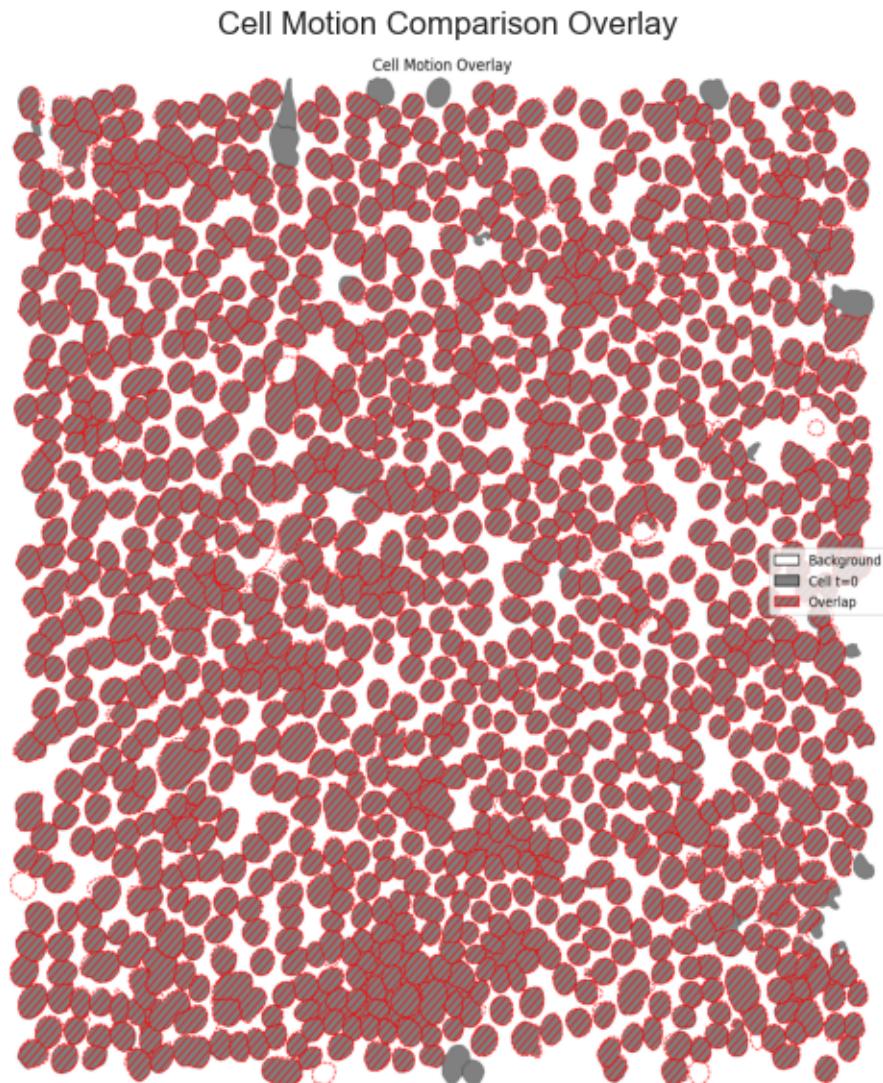
[2025-08-27 14:48:36] [INFO] calcium: plot\_points\_mean\_std: N=6 for Occurrences in individual events=5

[2025-08-27 14:48:36] [INFO] calcium: plot\_points\_mean\_std: N=3 for Occurrences in individual events=6

[2025-08-27 14:48:36] [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: 1061
- Hoechst image taken at t=1801: 1039
- Number of cells difference: absolute 22, relative 2.10%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1485545
- Pixels segmented as cell at t=1801: 1465963
- Overlapping pixels between t=0 and t=1801: 1405013 (95.21% of total)
- Pixels exclusive to t=0: 80532 (5.42% of total)
- Pixels exclusive to t=1801: 60950 (4.16% of total)

executed

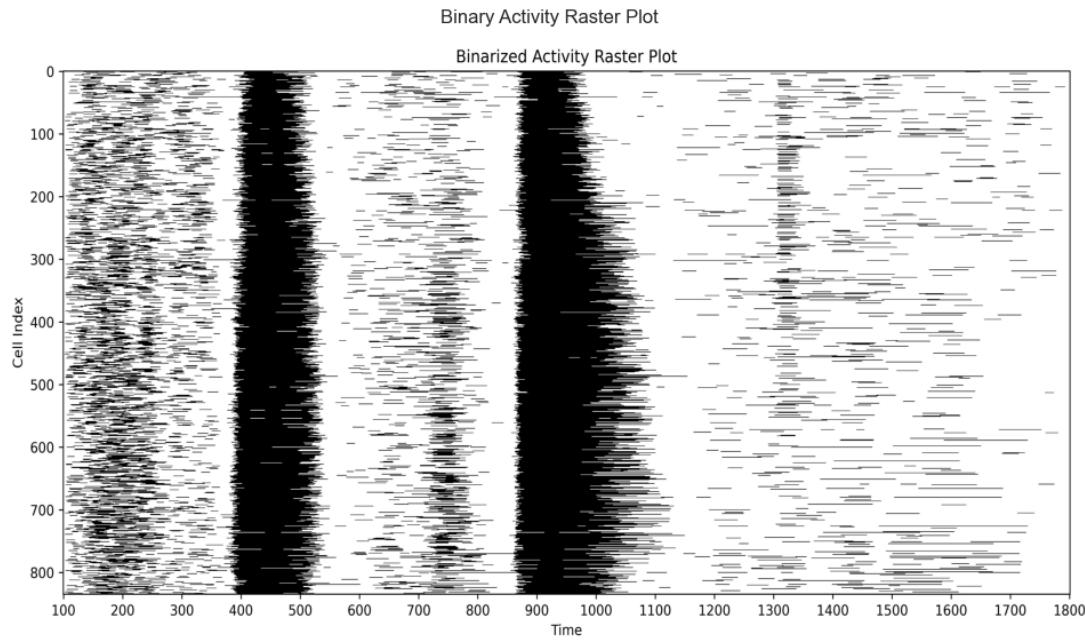
August 27, 2025

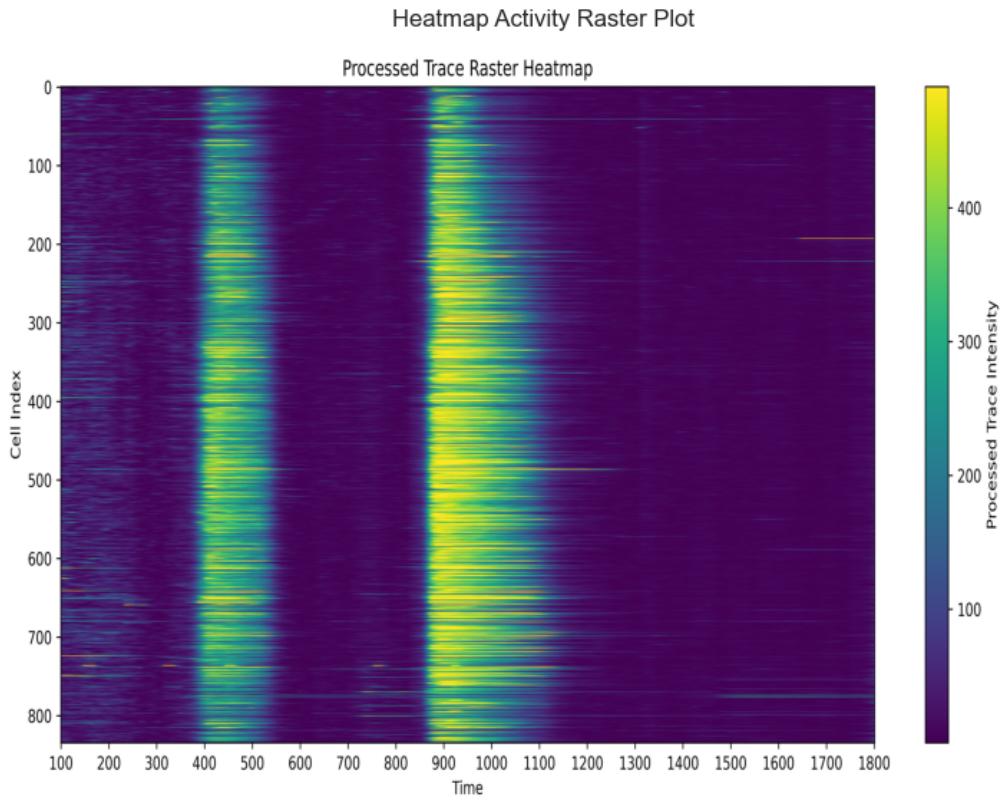
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





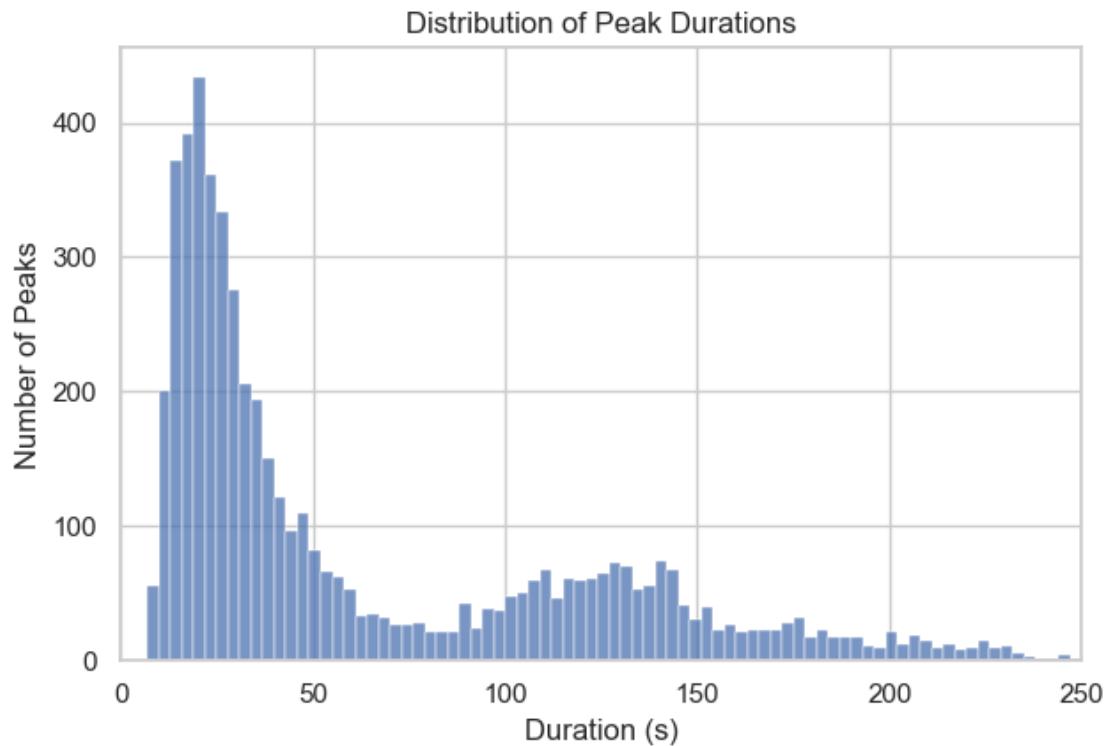
### 1.1.2 Peaks population

Total number of peaks: 5456

Total number of cells: 835

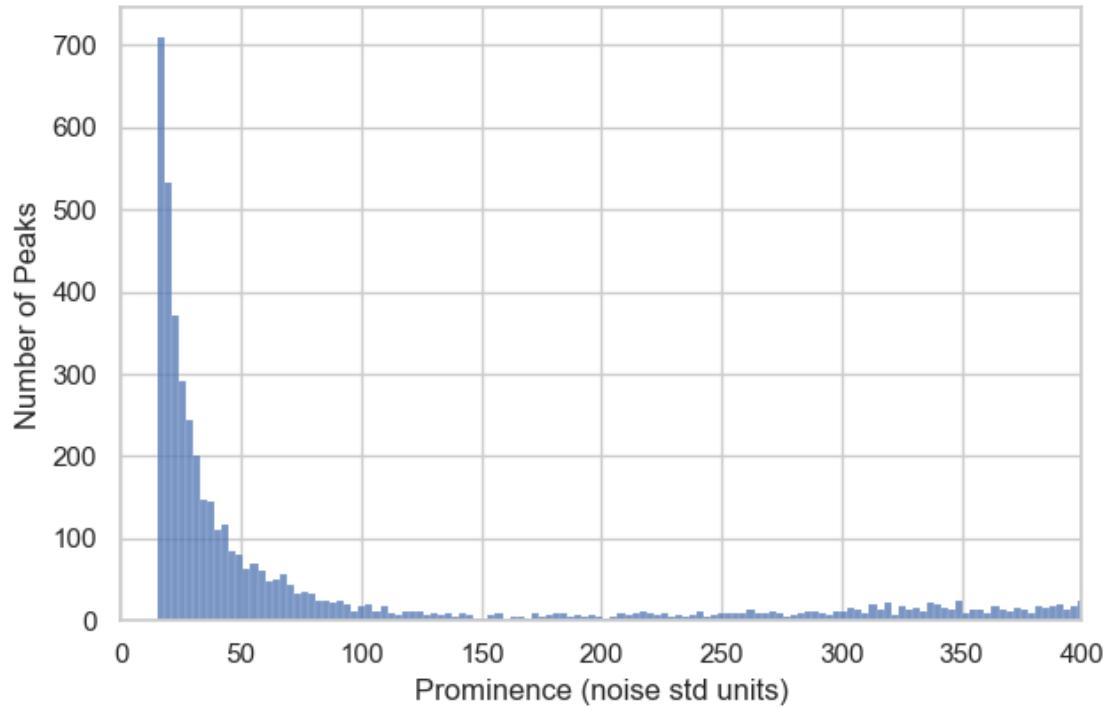
### 1.1.3 Peaks statistics

```
[2025-08-27 15:03:09] [INFO] calcium: plot_histogram: removed 0 outliers out of  
5456 on 'Duration (s)' (lower=-237.75, upper=366)
```

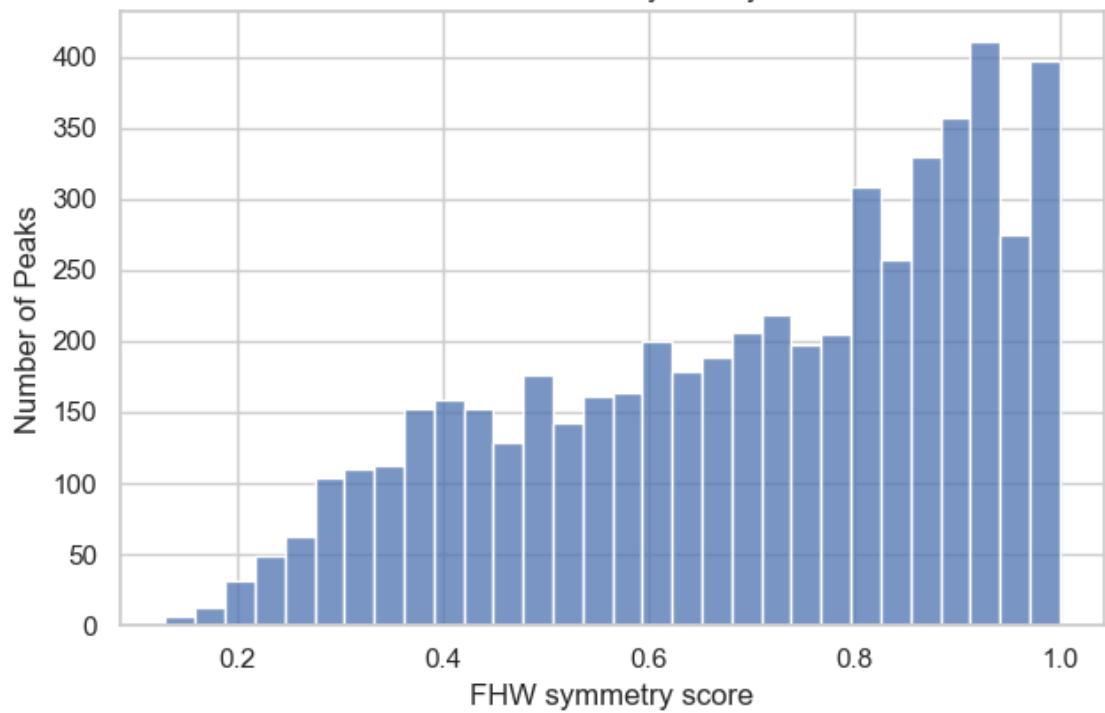


```
[2025-08-27 15:03:09] [INFO] calcium: plot_histogram: removed 1 outliers out of  
5456 on 'Prominence (noise std units)' (lower=-723.35, upper=1015.1)
```

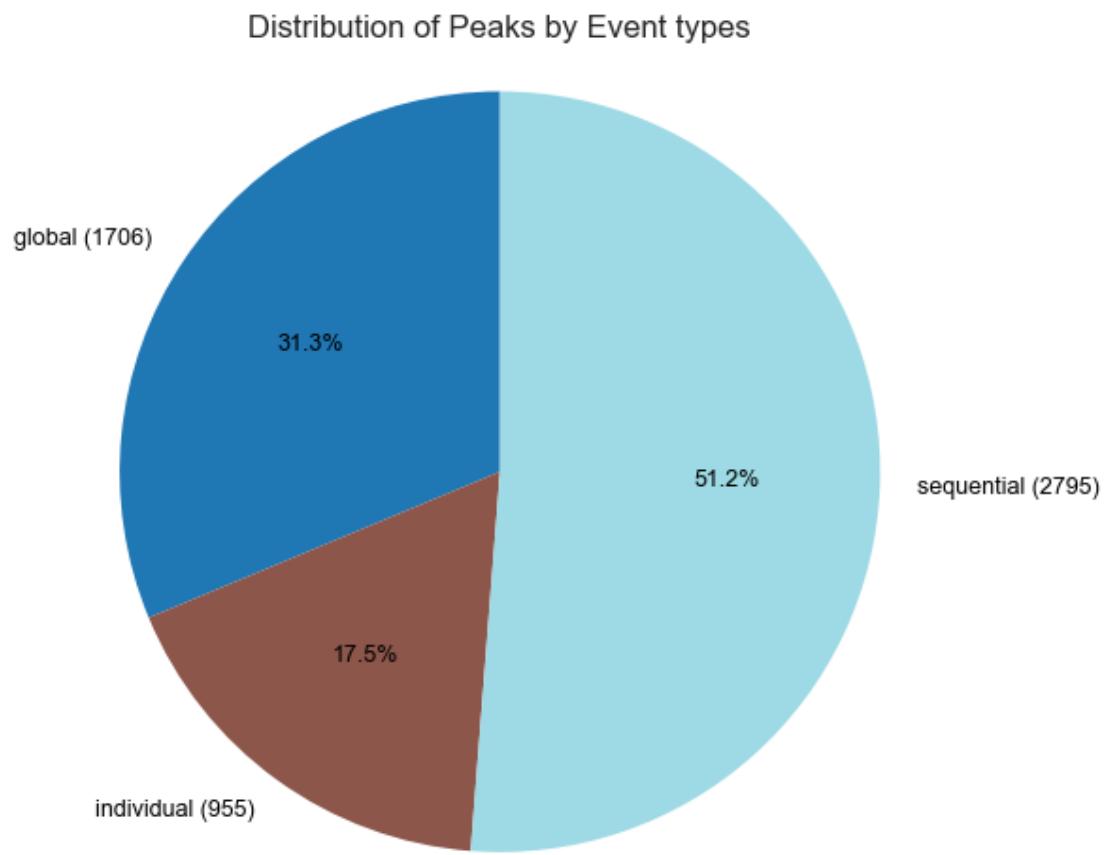
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

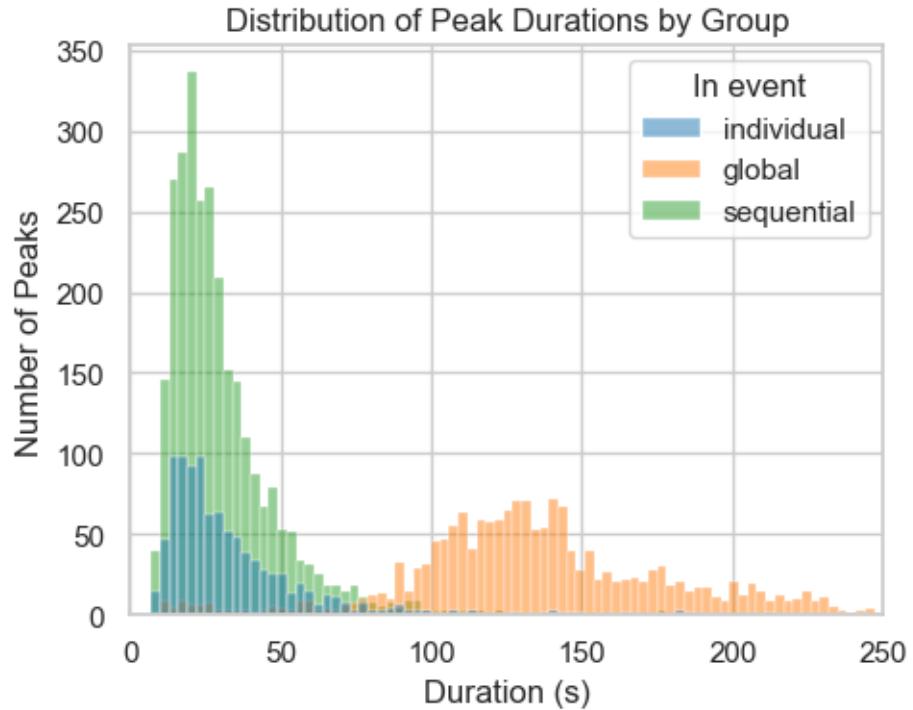


#### 1.1.4 Distribution of peaks per event types

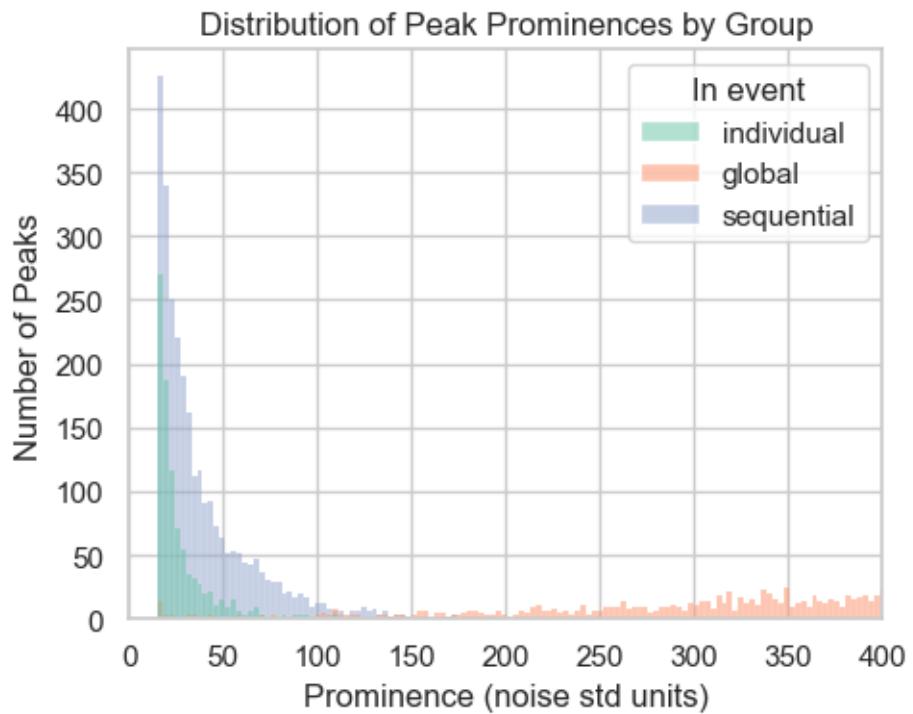


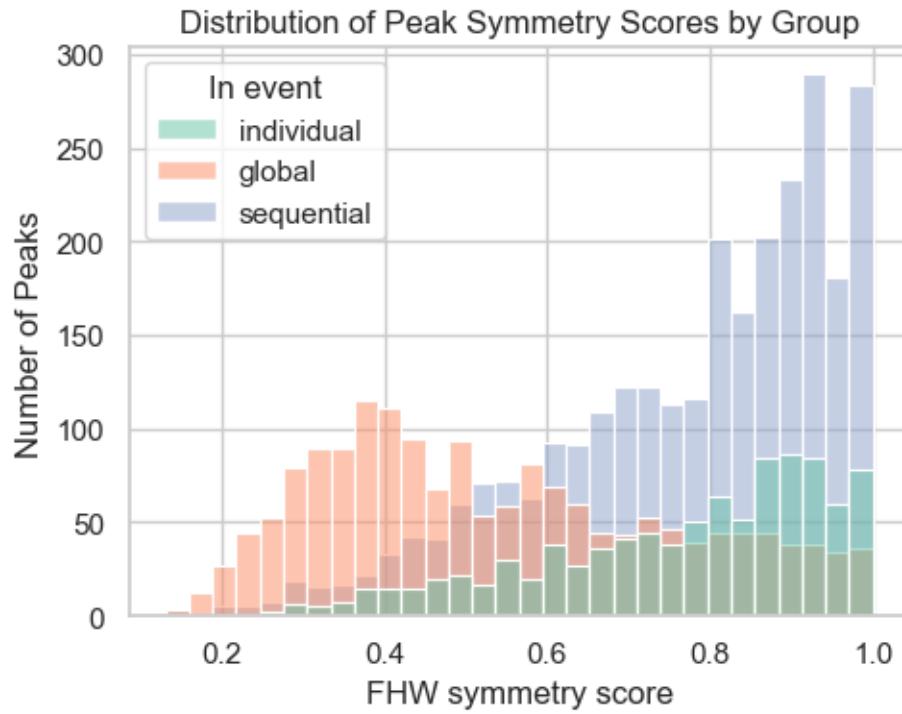
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 15:03:10] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 5456 on 'Duration (s)' (lower=-237.75, upper=366)
```



```
[2025-08-27 15:03:10] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 5456 on 'Prominence (noise std units)' (lower=-723.35, upper=1015.1)
```

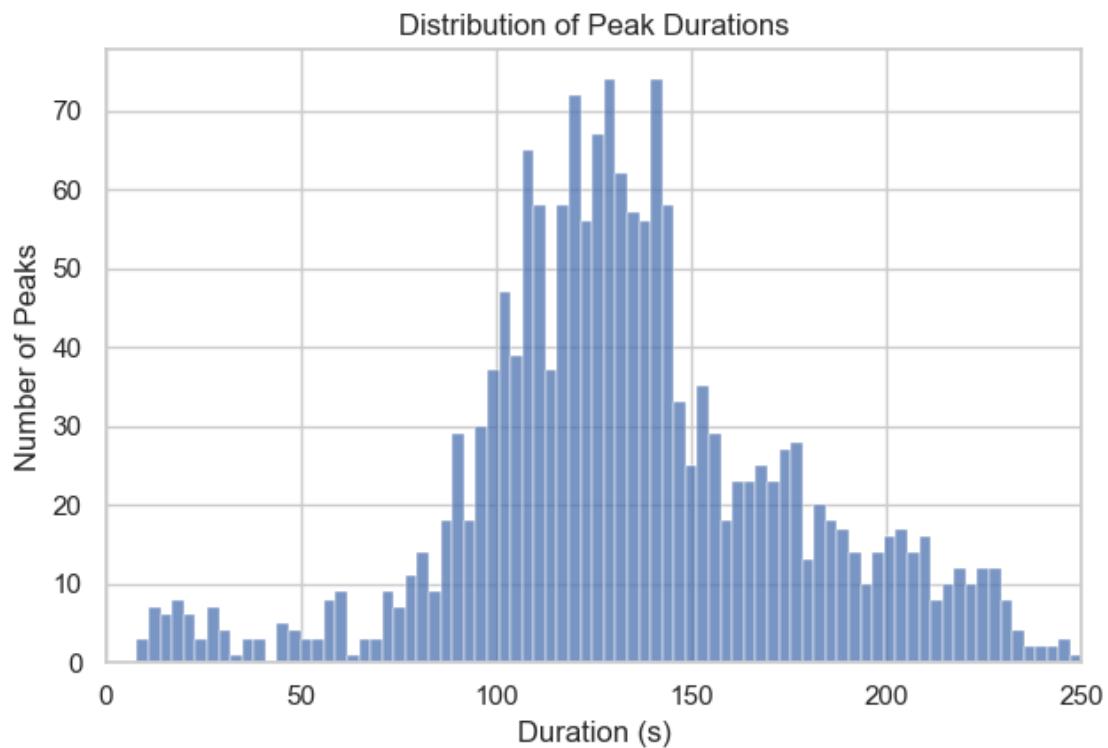




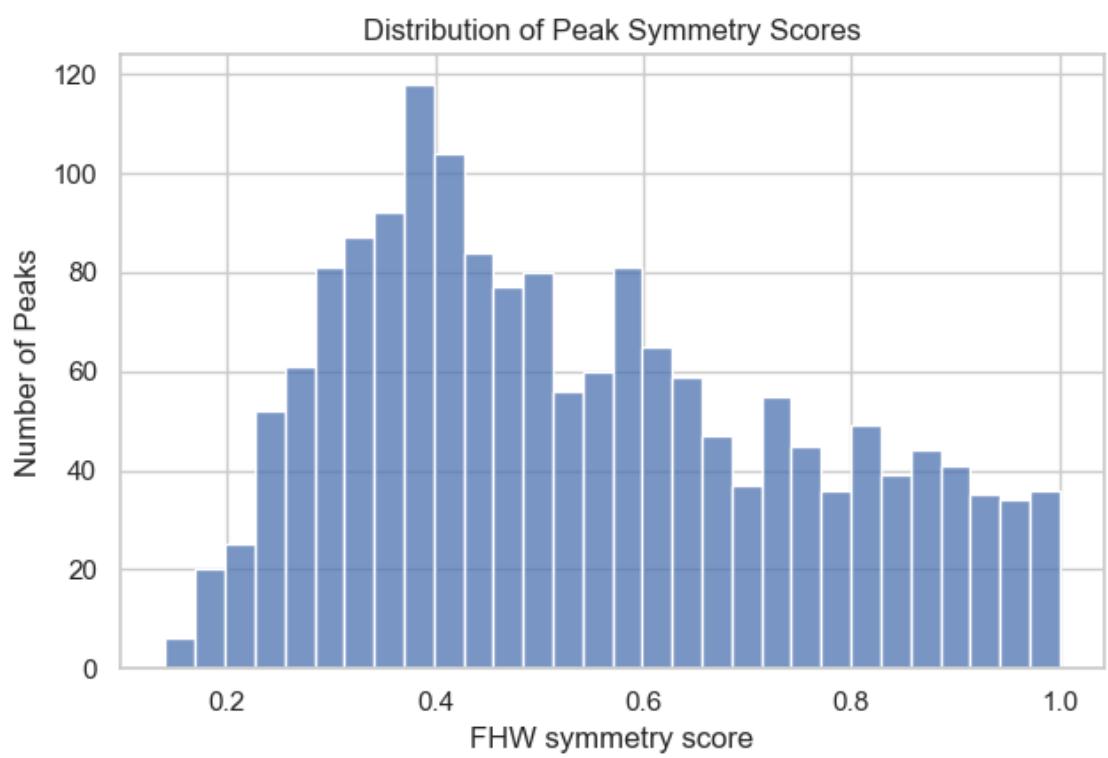
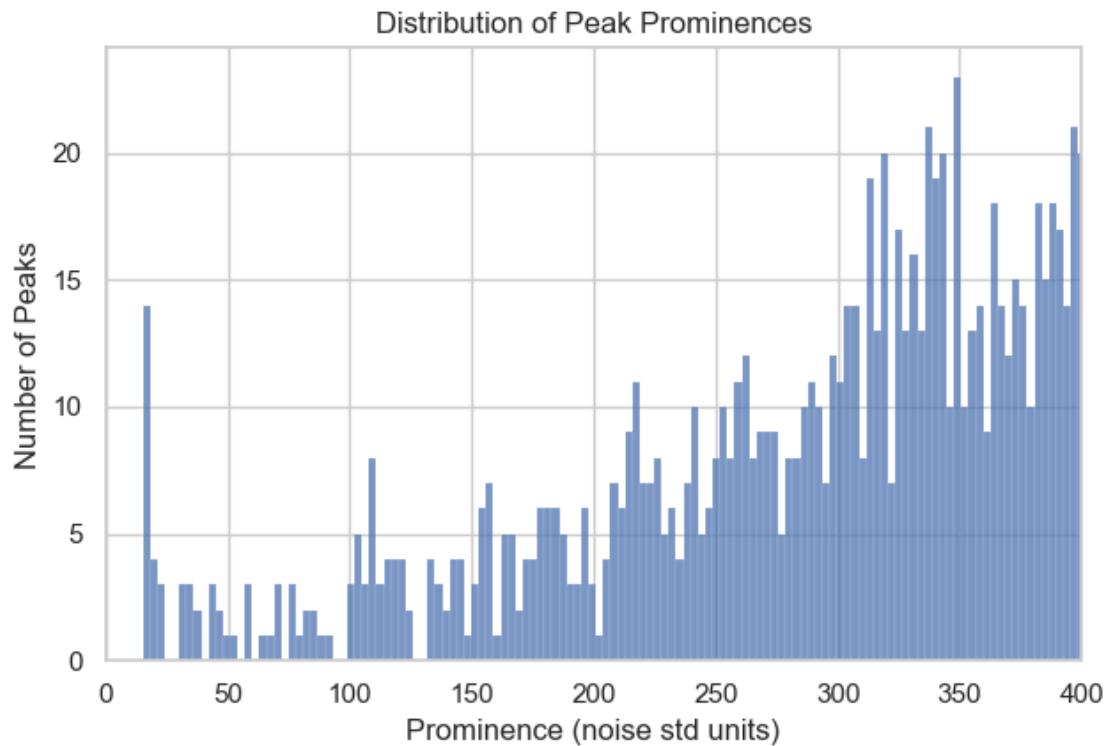
## 1.2 GLOBAL EVENTS

### 1.2.1 Peak statistics in global events

```
[2025-08-27 15:03:12] [INFO] calcium: plot_histogram: removed 0 outliers out of  
1706 on 'Duration (s)' (lower=-34, upper=302)
```

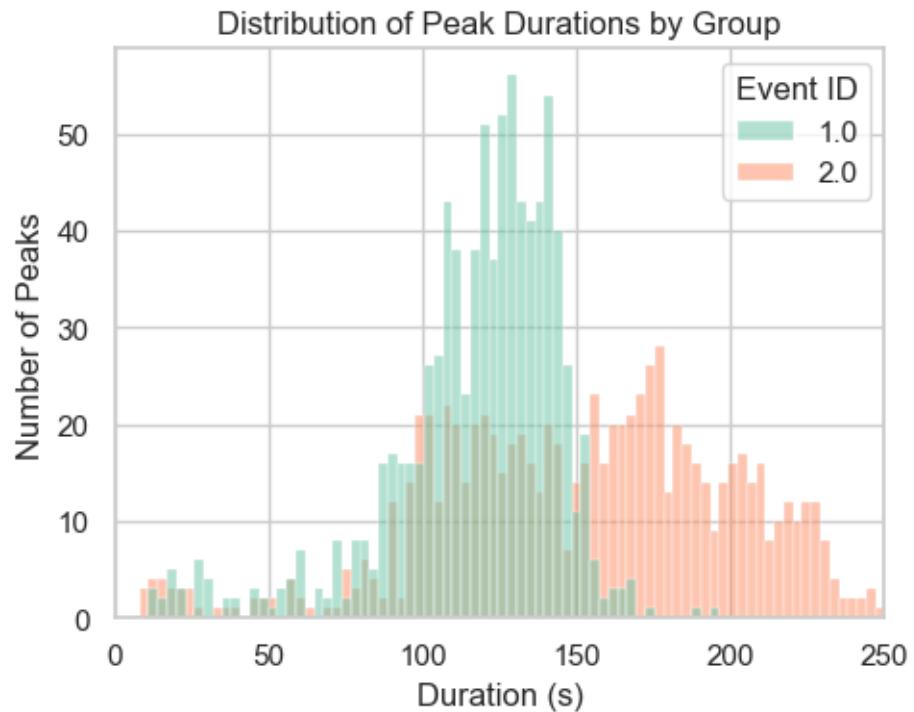


```
[2025-08-27 15:03:12] [INFO] calcium: plot_histogram: removed 1 outliers out of  
1706 on 'Prominence (noise std units)' (lower=-265, upper=1042.4)
```

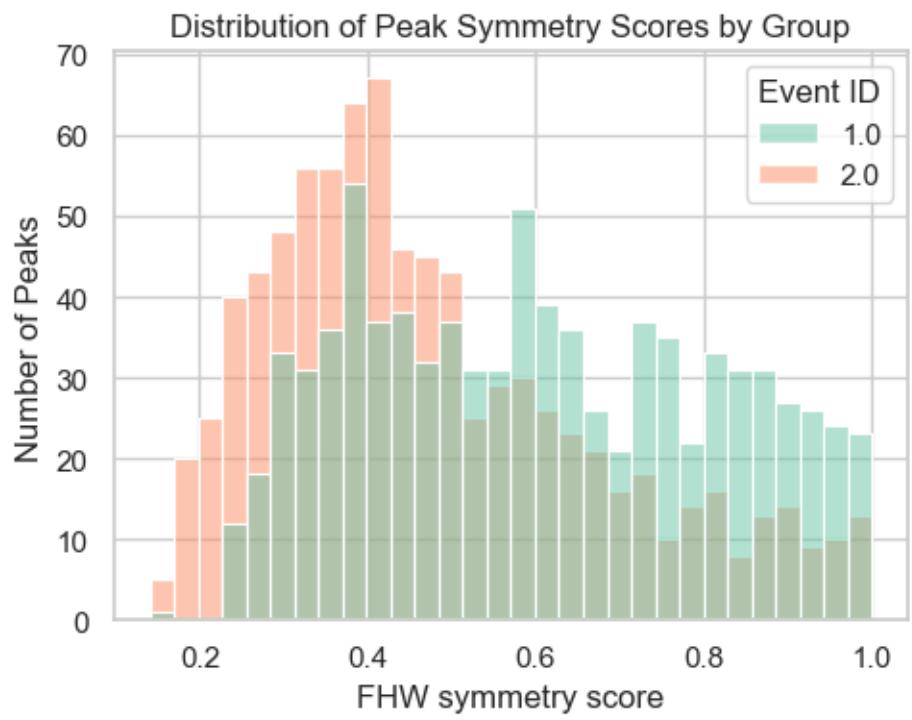
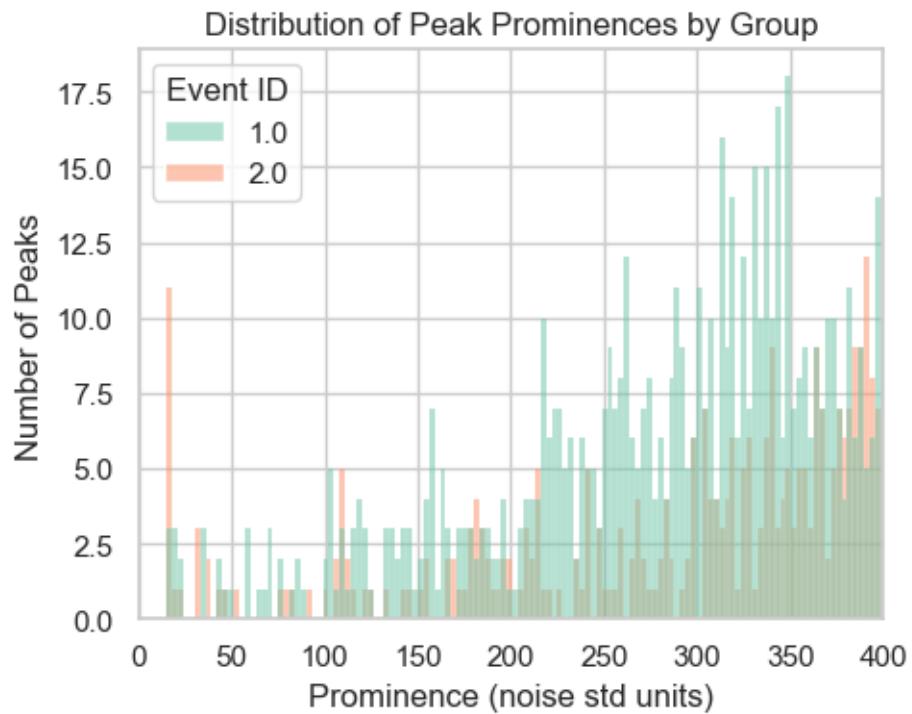


### 1.2.2 Peak statistics in global event per event ID

```
[2025-08-27 15:03:13] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 1706 on 'Duration (s)' (lower=-34, upper=302)
```

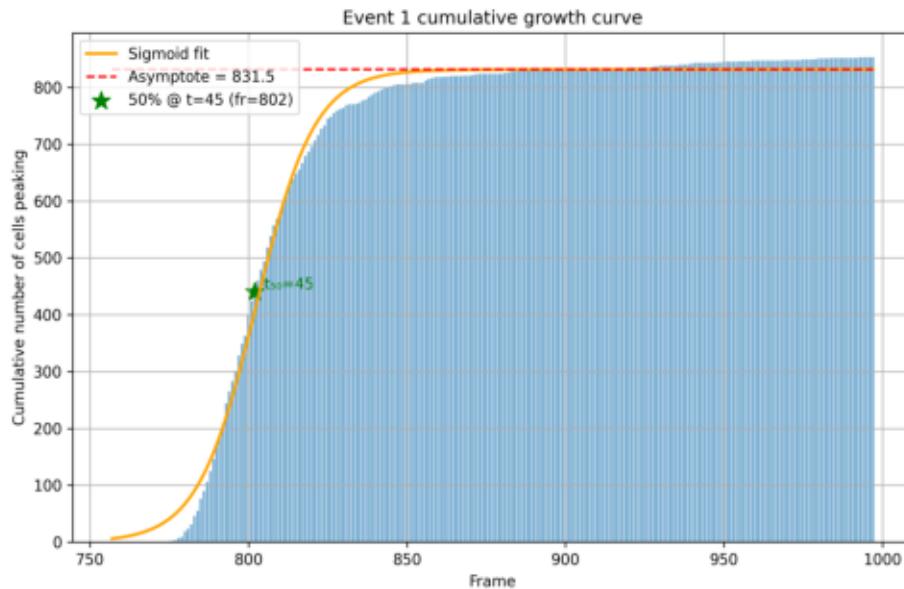


```
[2025-08-27 15:03:13] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 1706 on 'Prominence (noise std units)' (lower=-265, upper=1042.4)
```



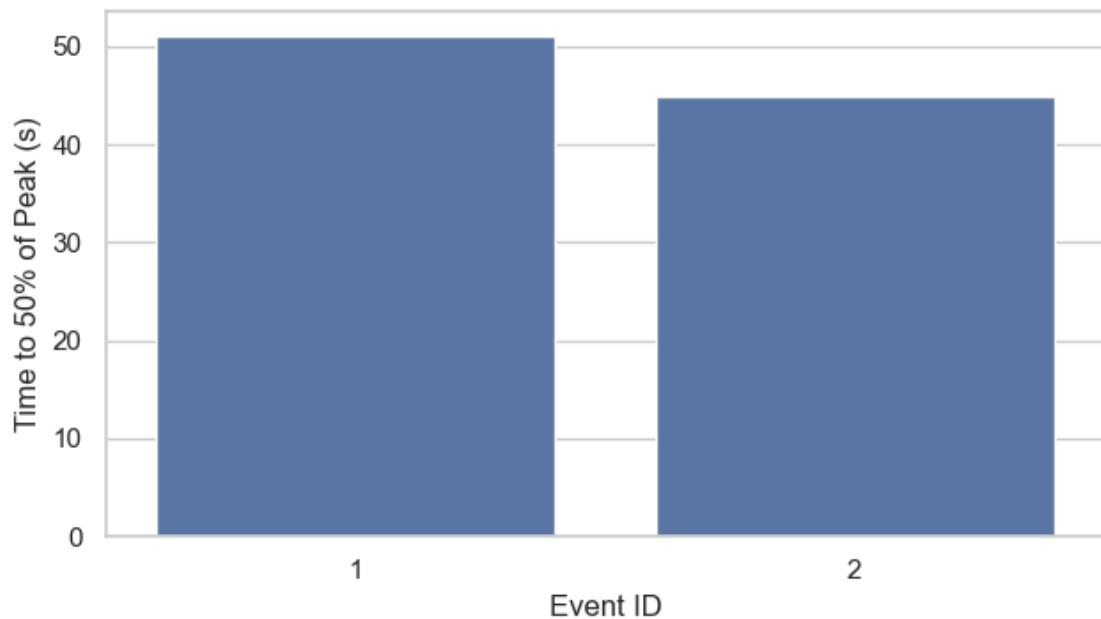
### 1.2.3 Kinetics of global events

Event Activity Overlay (Event ID: 1)

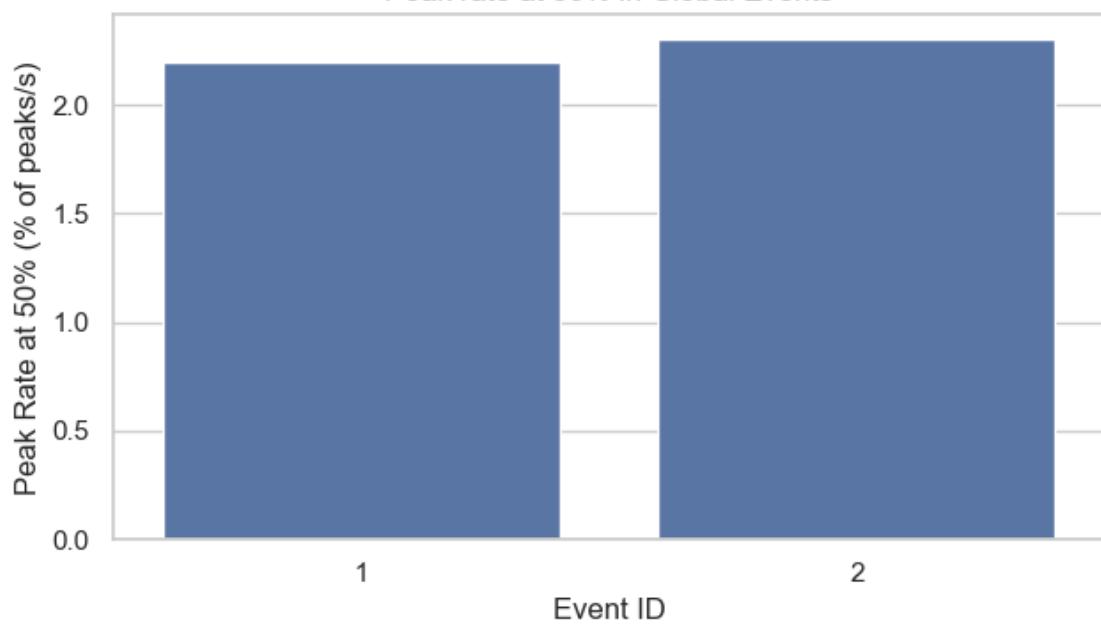


```
[2025-08-27 15:03:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\events\event-growth-curve-2.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\Output\\IS5\\events\\event-growth-
curve-2.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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")
FileNotFoundException: [Errno 2] No such file or directory:
'D:\\Mateo\\20250618\\Output\\IS5\\events\\event-growth-curve-2.png'
```

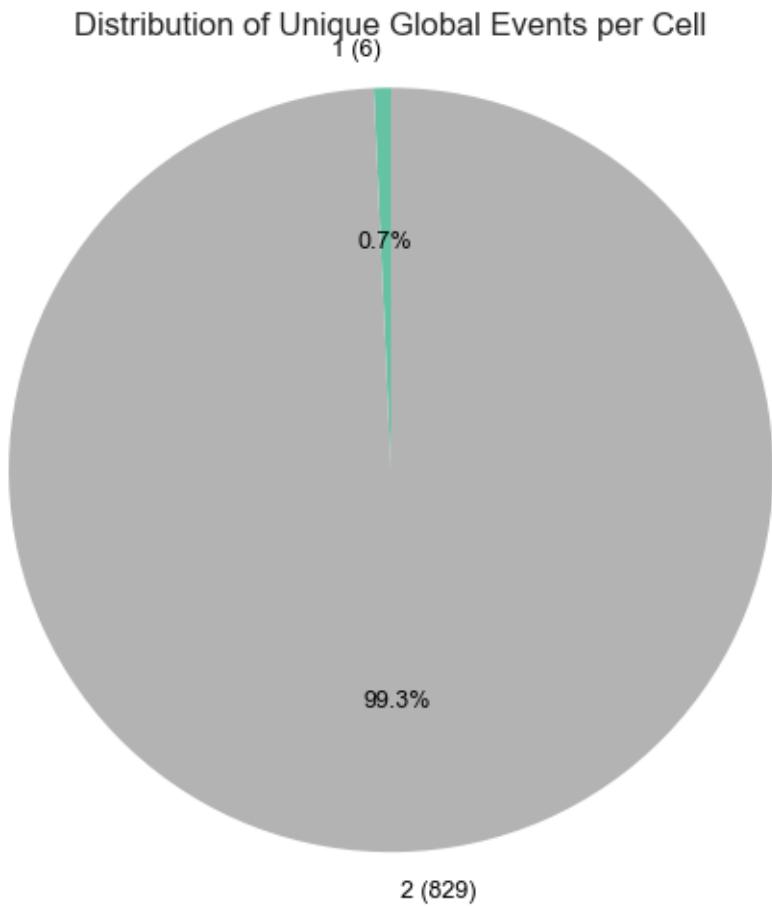
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

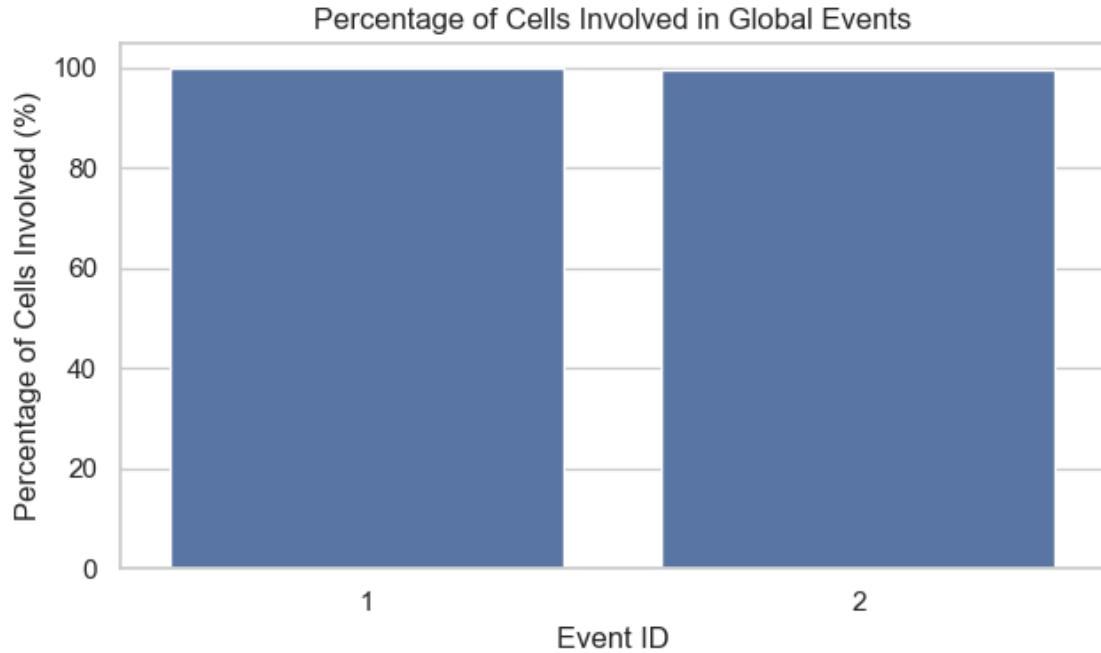


```
[2025-08-27 15:03:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS5\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250618\Output\IS5\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [466.0]

### 1.2.6 Early peakers in the events

```

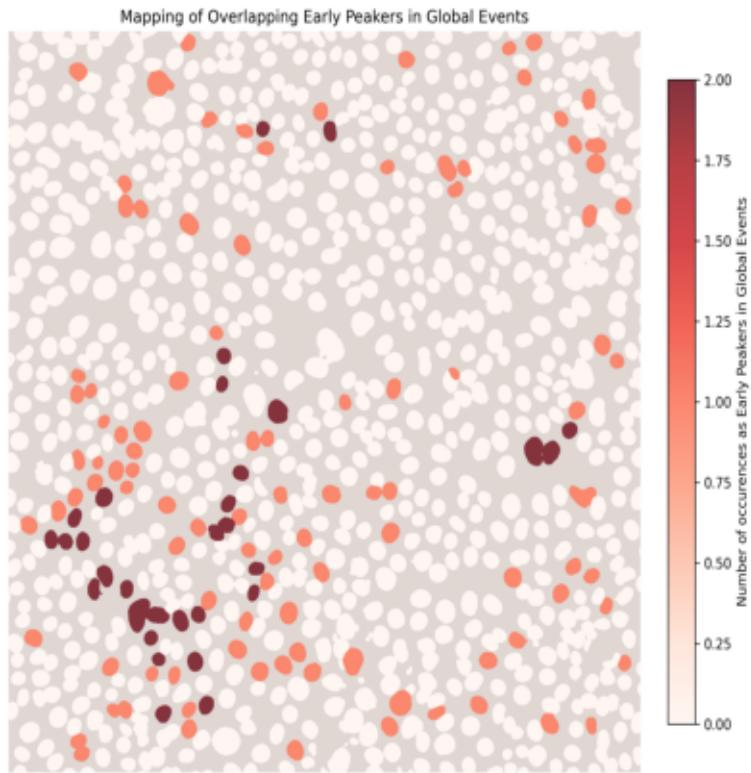
[2025-08-27 15:03:17] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\cell-
mapping\global_events\global_event_1_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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

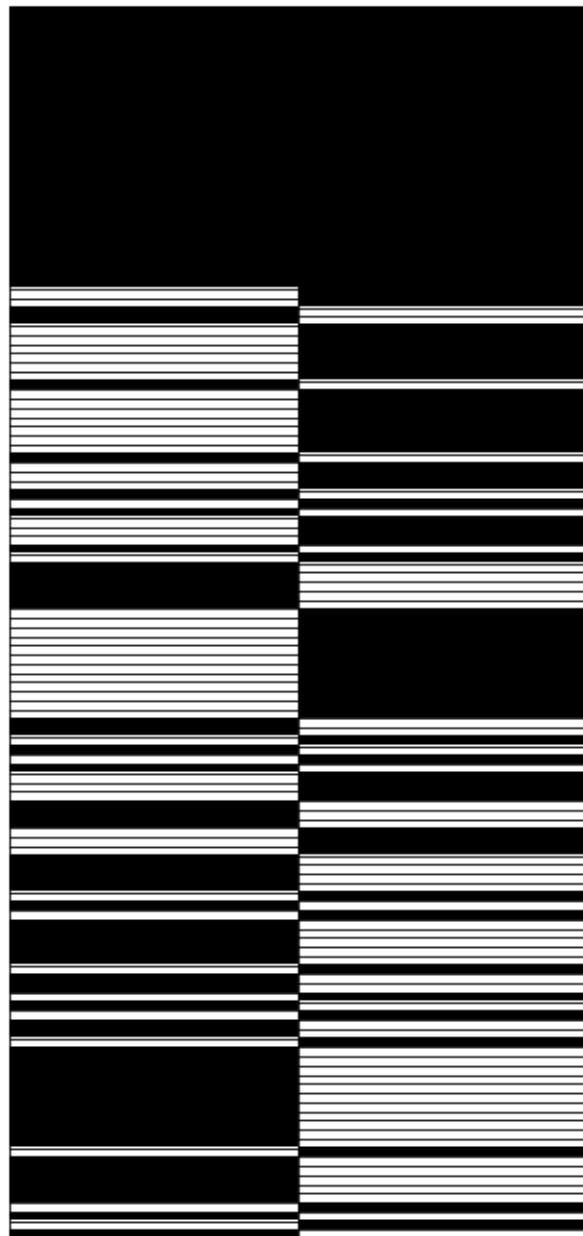
[2025-08-27 15:03:17] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\cell-
mapping\global_events\global_event_2_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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
```

## Cell Mapping with Occurrences in Global Events Overlay



```
[2025-08-27 15:03:18] [WARNING] calcium: 'total_events' is deprecated and  
ignored. Using 2 unique event IDs.
```

```
[2025-08-27 15:03:18] [INFO] calcium: Early peakers event-matrix: 135 cells x 2  
events; black squares: 166
```

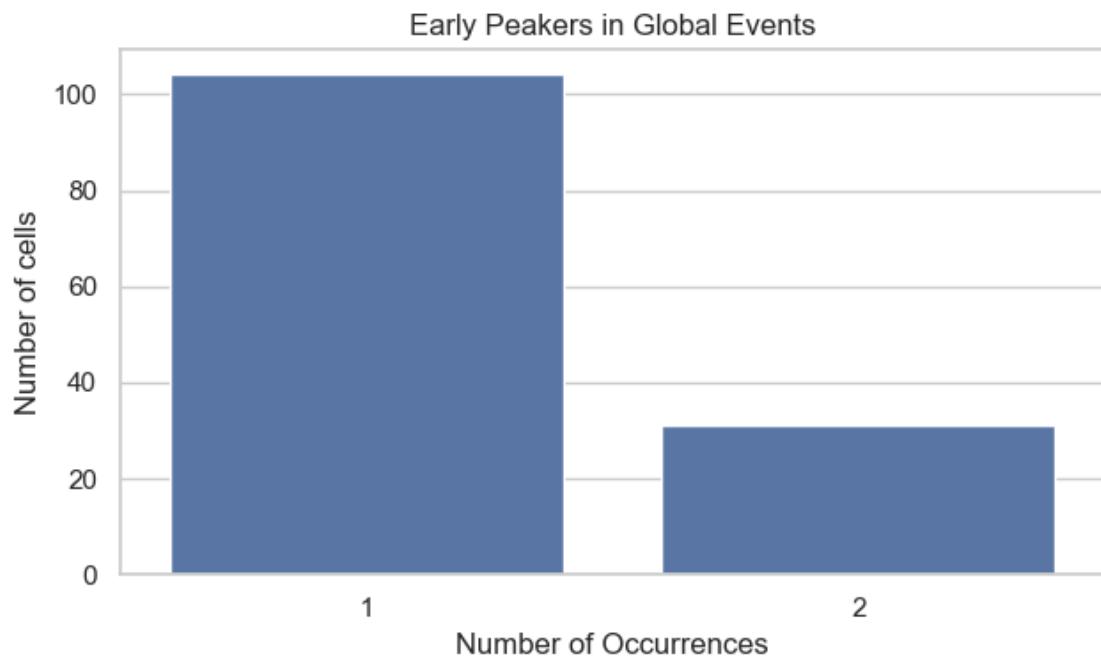


[2025-08-27 15:03:19] [INFO] calcium: Saved early peakers heatmap SVG to: early\_peakers\_heatmap.svg

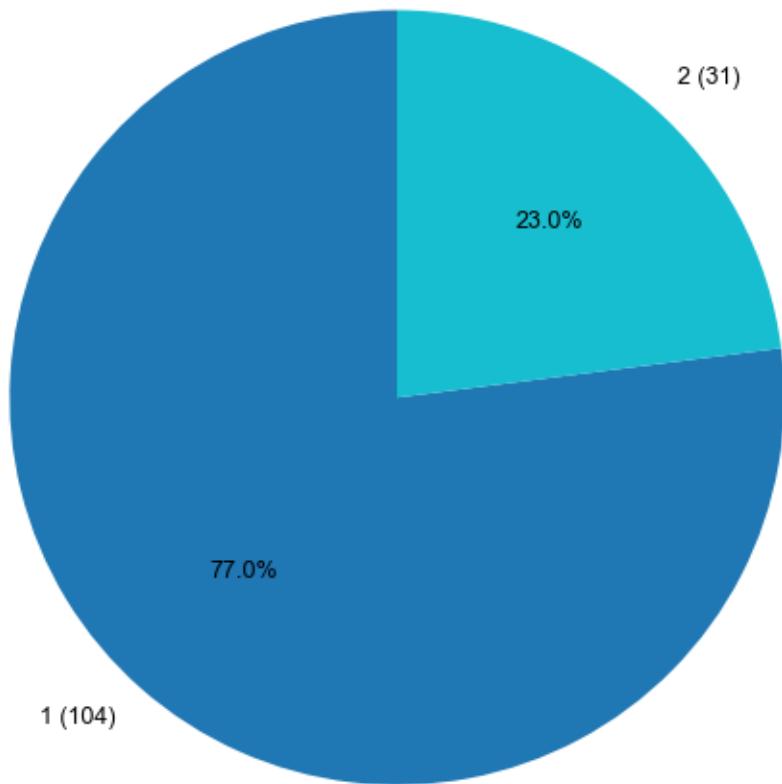






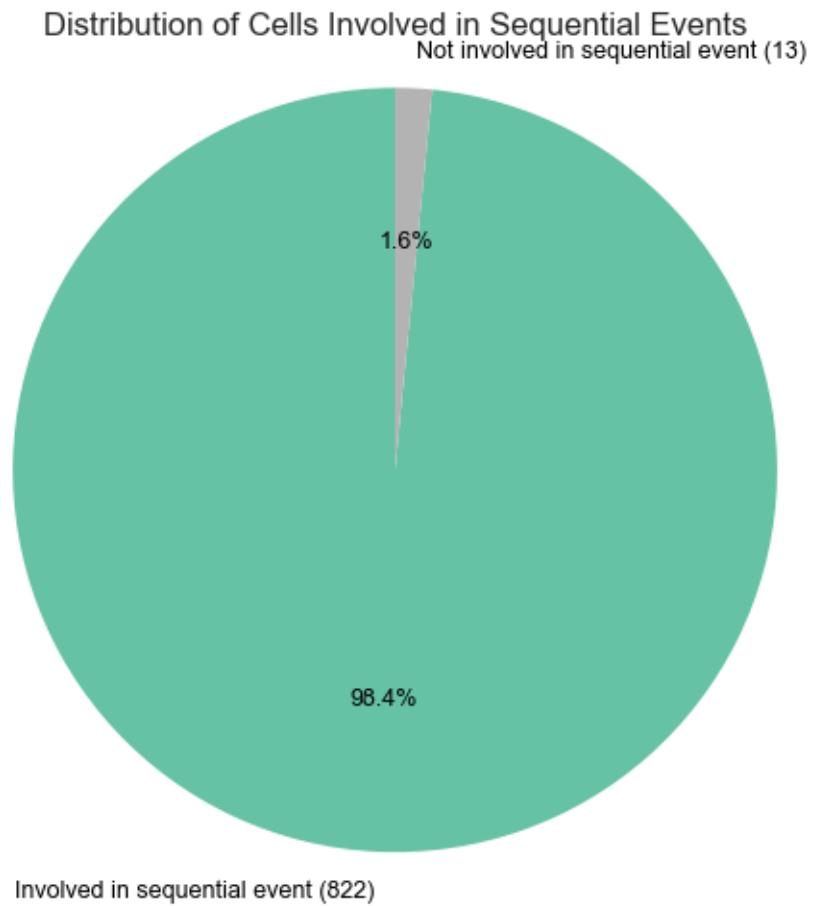


Distribution of Early Peakers in Global Events

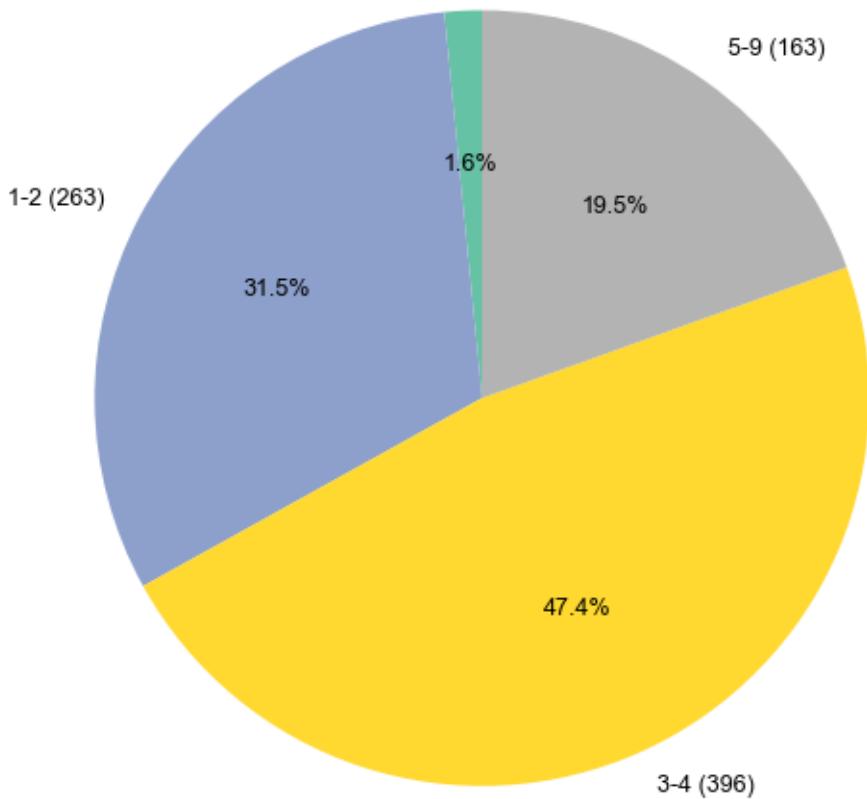


## 1.3 SEQUENTIAL EVENTS

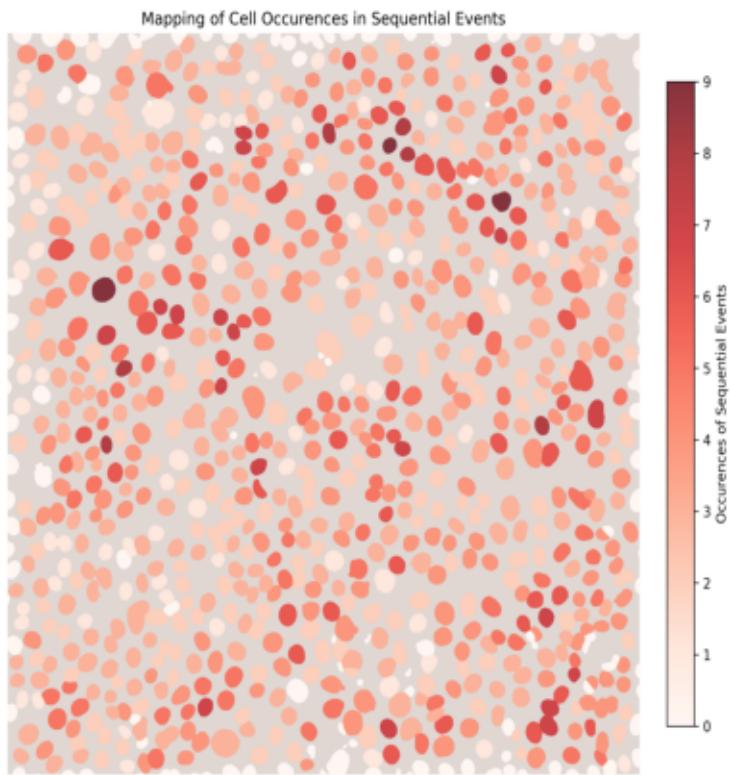
### 1.3.1 Cells Occurrences in sequential events



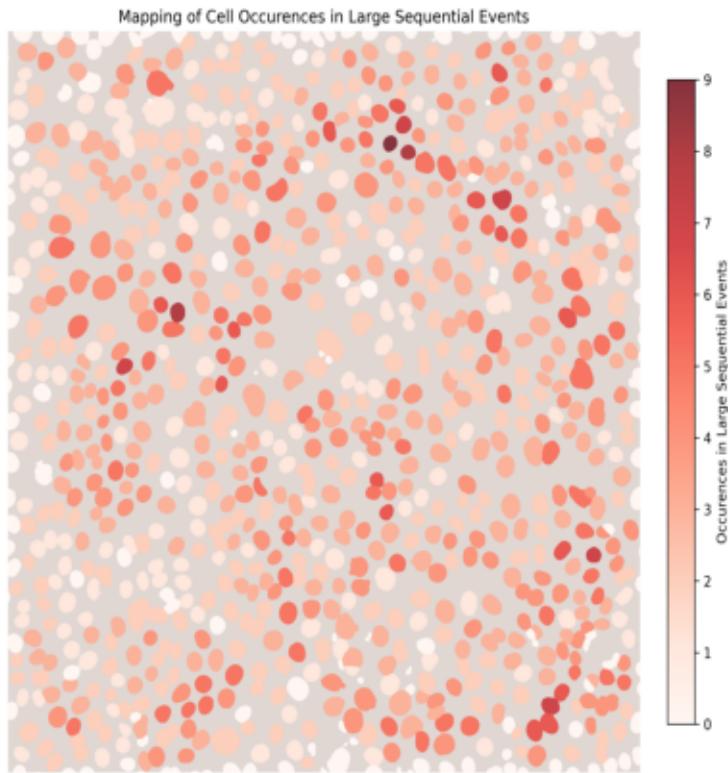
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

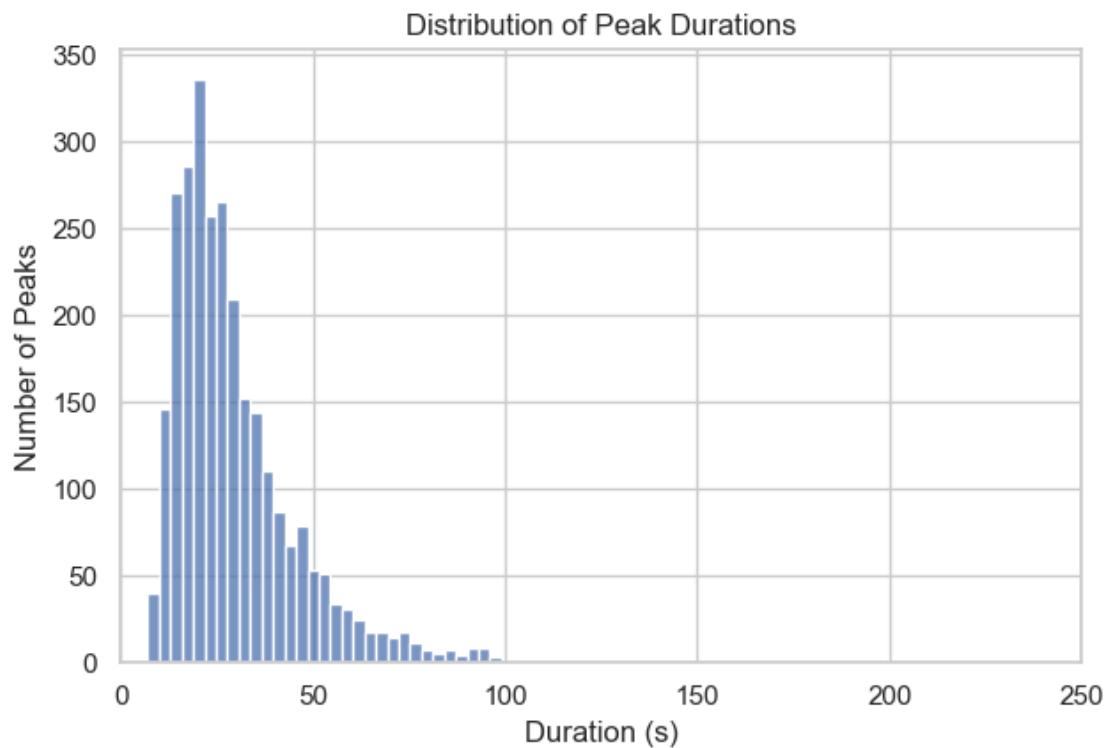


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

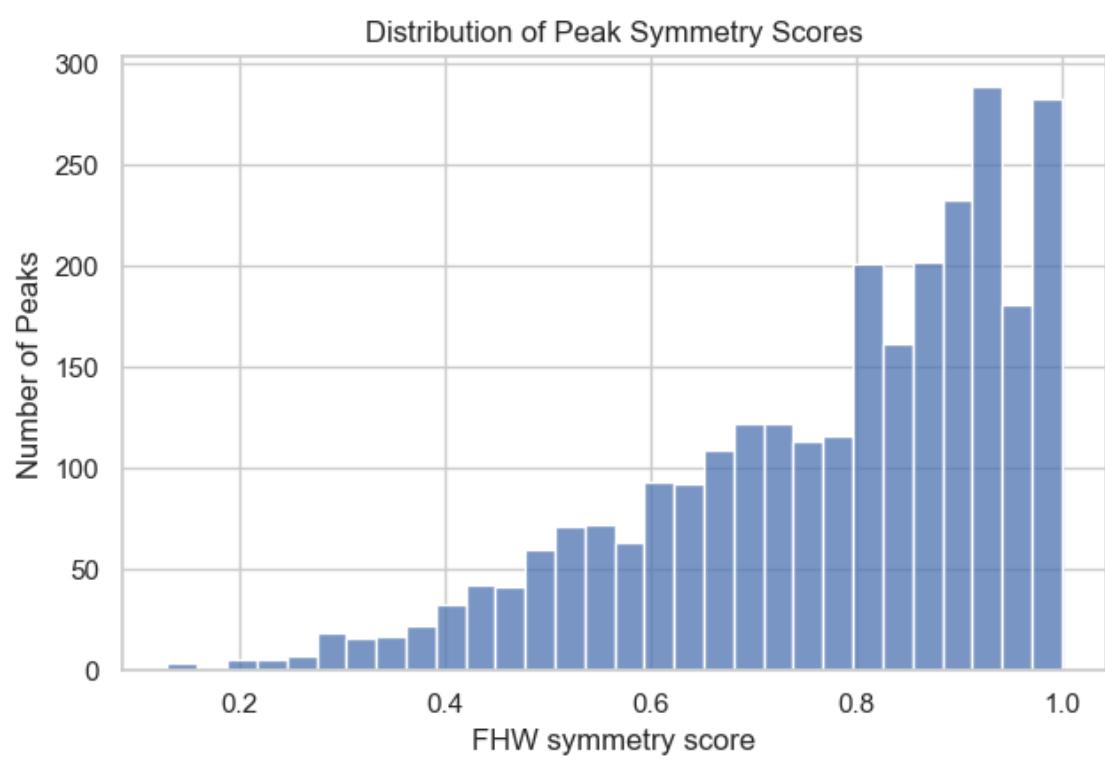
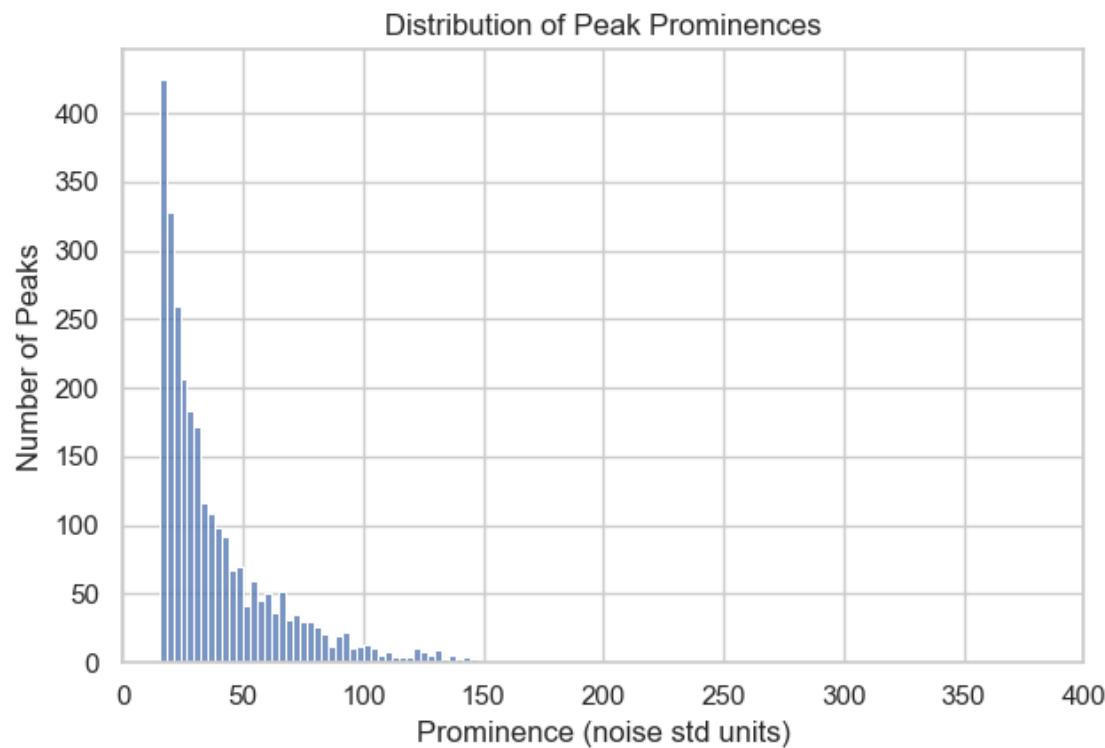


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:03:22] [INFO] calcium: plot_histogram: removed 32 outliers out of  
2795 on 'Duration (s)' (lower=-9, upper=99)
```

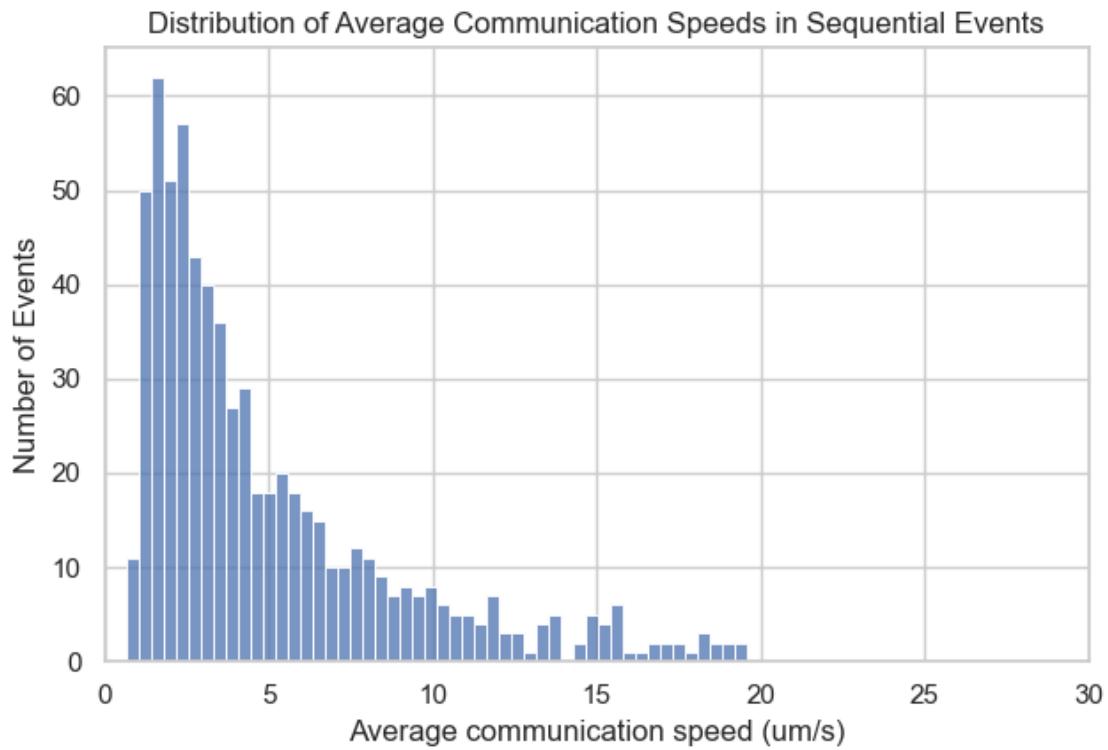


```
[2025-08-27 15:03:23] [INFO] calcium: plot_histogram: removed 36 outliers out of  
2795 on 'Prominence (noise std units)' (lower=-22.475, upper=148.82)
```

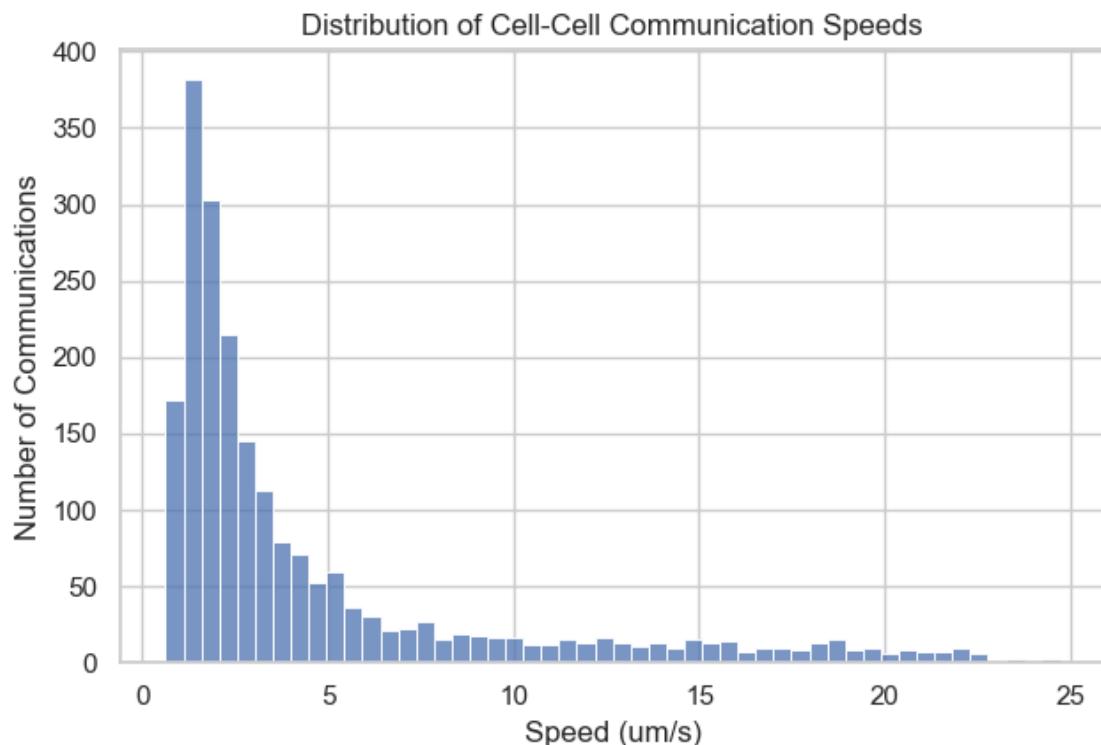


### 1.3.3 Cell-cell communication speed

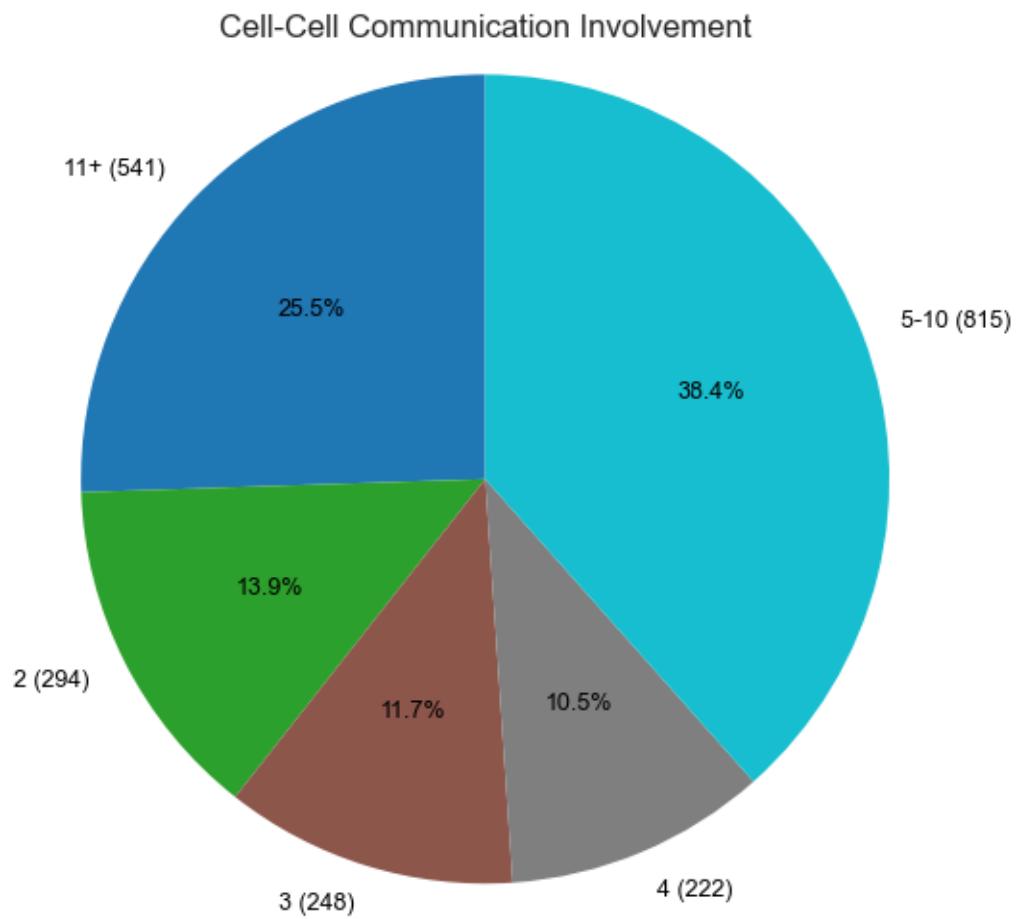
[2025-08-27 15:03:23] [INFO] calcium: plot\_histogram: removed 4 outliers out of 675 on 'Average communication speed (um/s)' (lower=-11.335, upper=20.095)



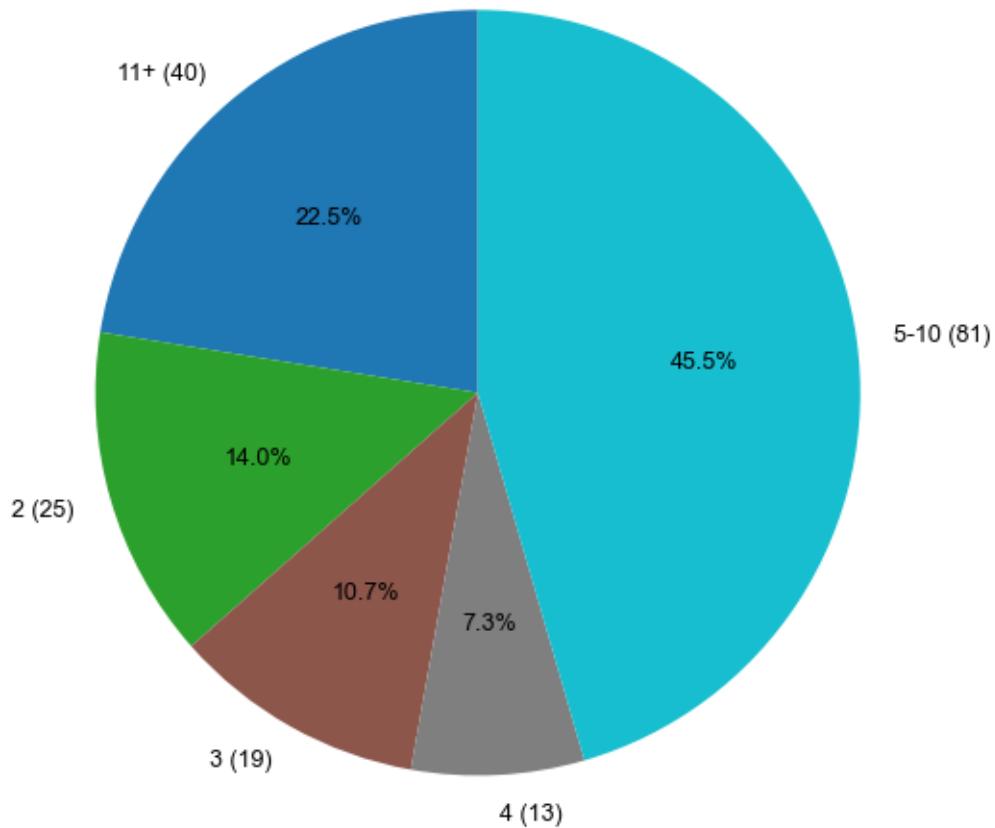
[2025-08-27 15:03:23] [INFO] calcium: plot\_histogram: removed 16 outliers out of 2120 on 'Speed (um/s)' (lower=-10.02, upper=24.72)



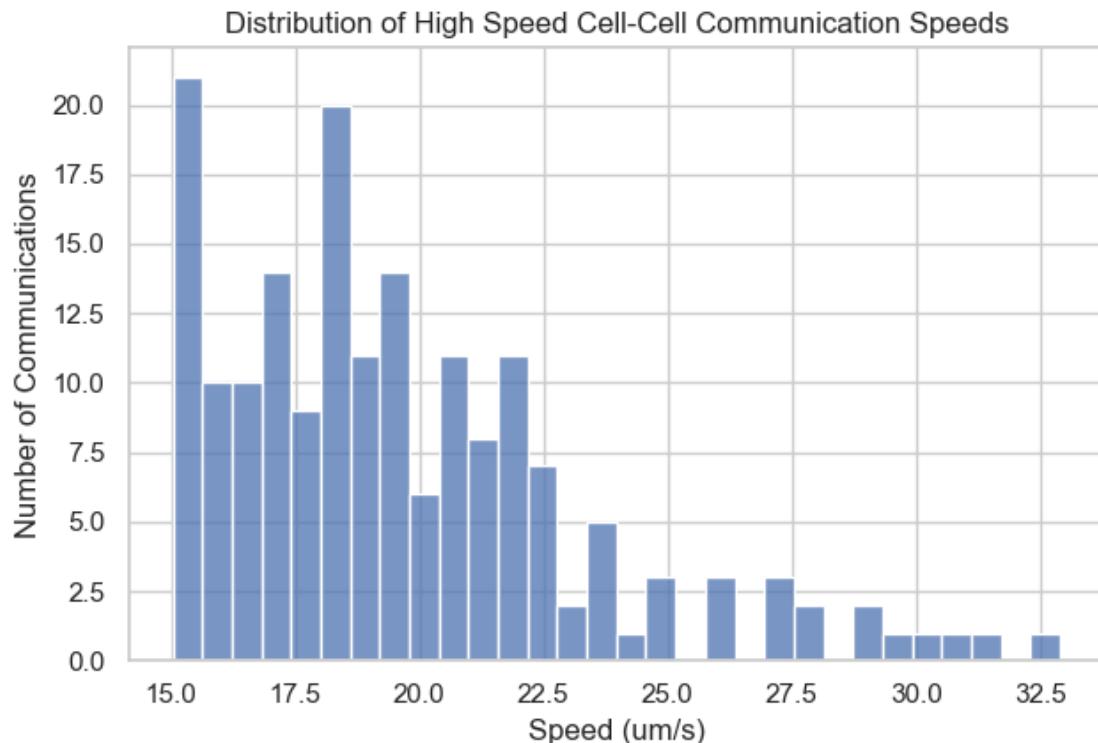
#### 1.3.4 Double distribution in cell-cell communication speeds



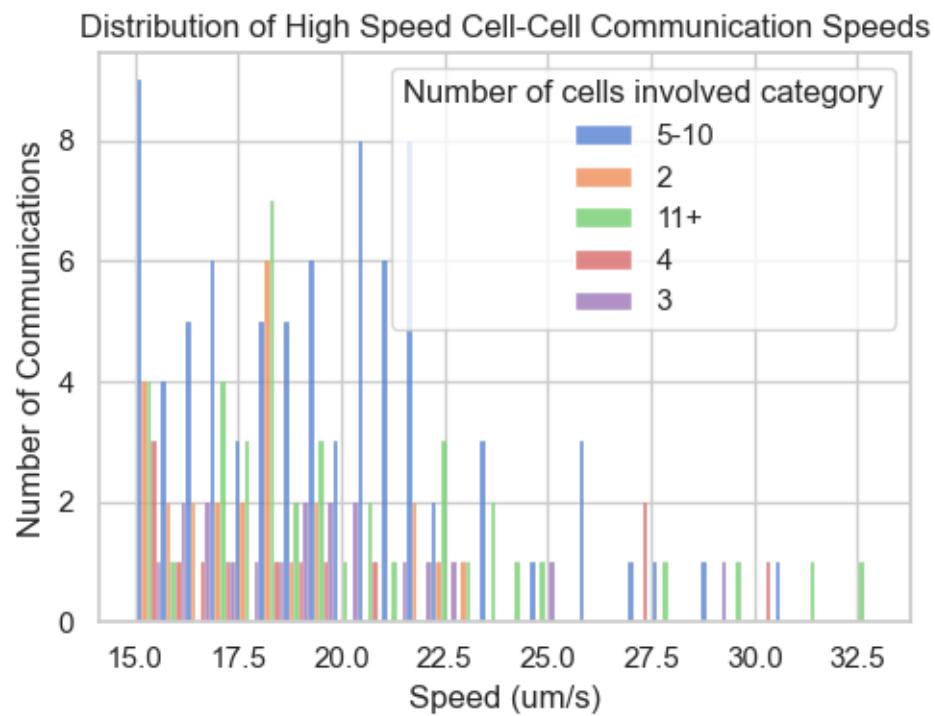
### High Speed Cell-Cell Communication Involvement



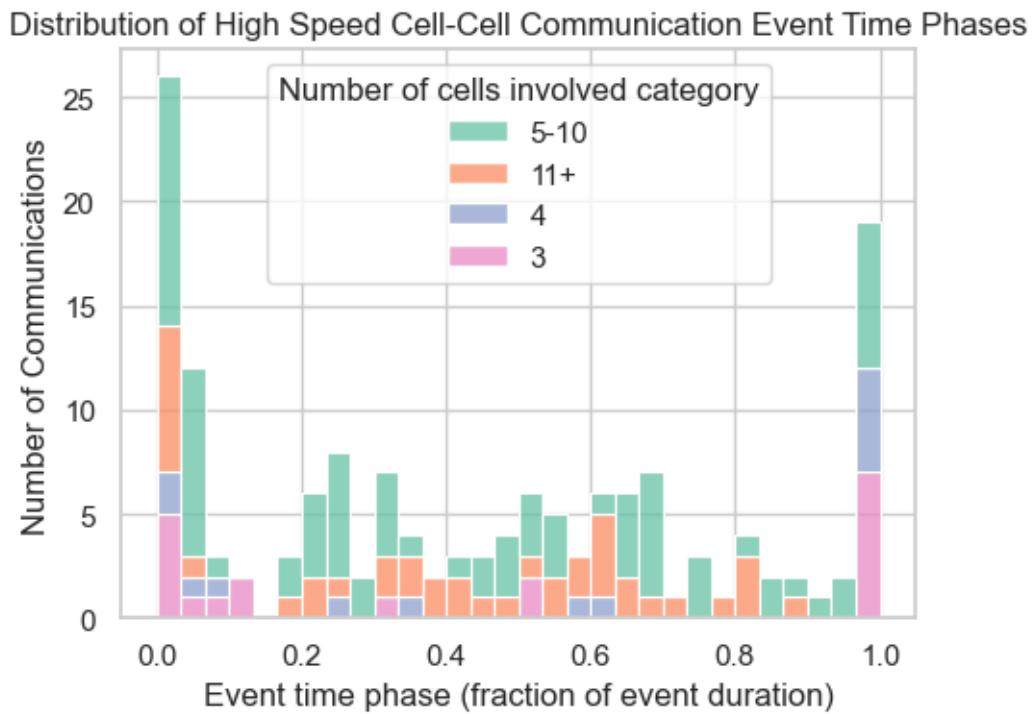
```
[2025-08-27 15:03:24] [INFO] calcium: plot_histogram: removed 0 outliers out of 178 on 'Speed (um/s)' (lower=3.6075, upper=34.722)
```



```
[2025-08-27 15:03:24] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 178 on 'Speed (um/s)' (lower=3.6075, upper=34.722)
```

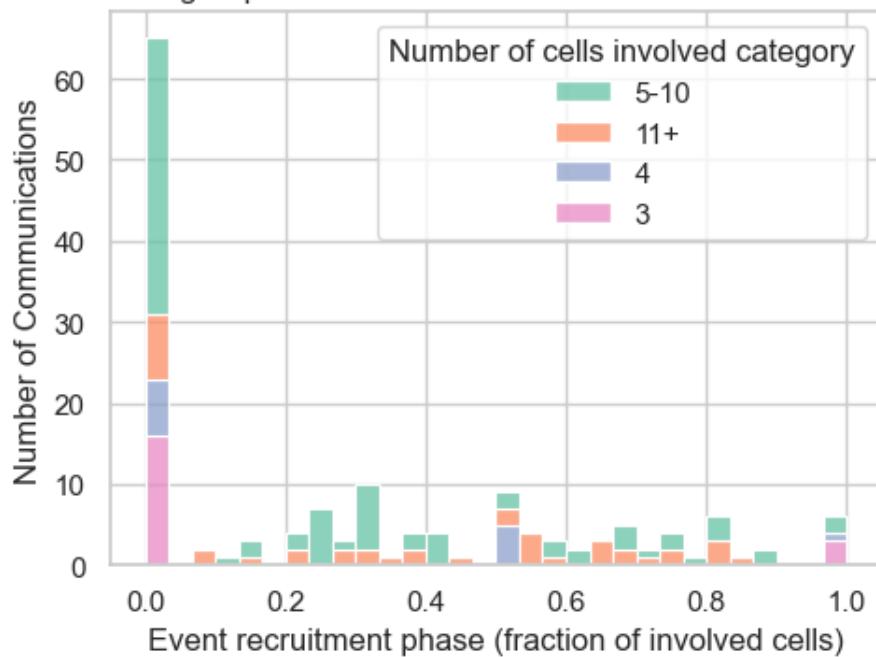


[2025-08-27 15:03:24] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 153 on 'Event time phase (fraction of event duration)' (lower=-1.76, upper=2.51)

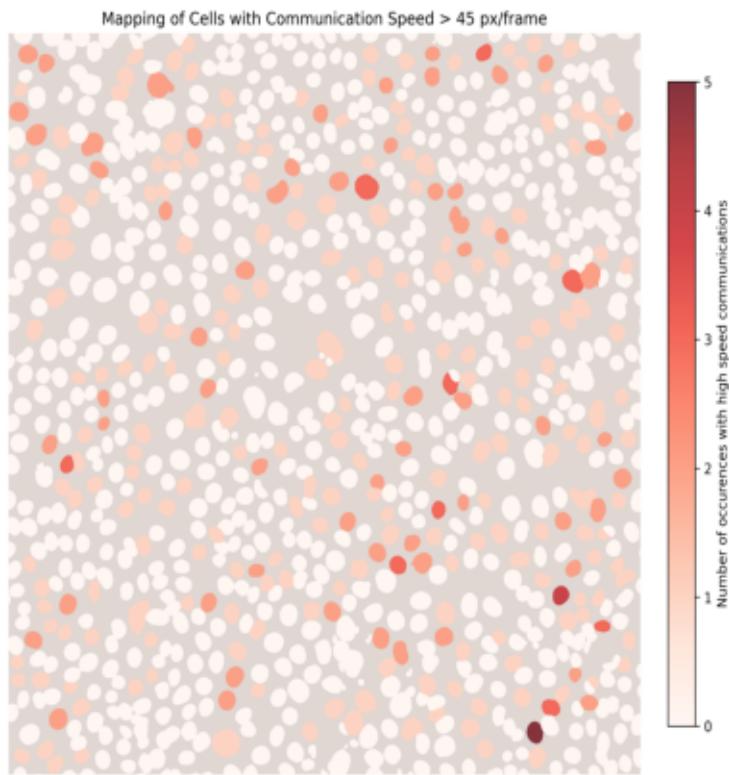


[2025-08-27 15:03:24] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 153 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.62, upper=2.16)

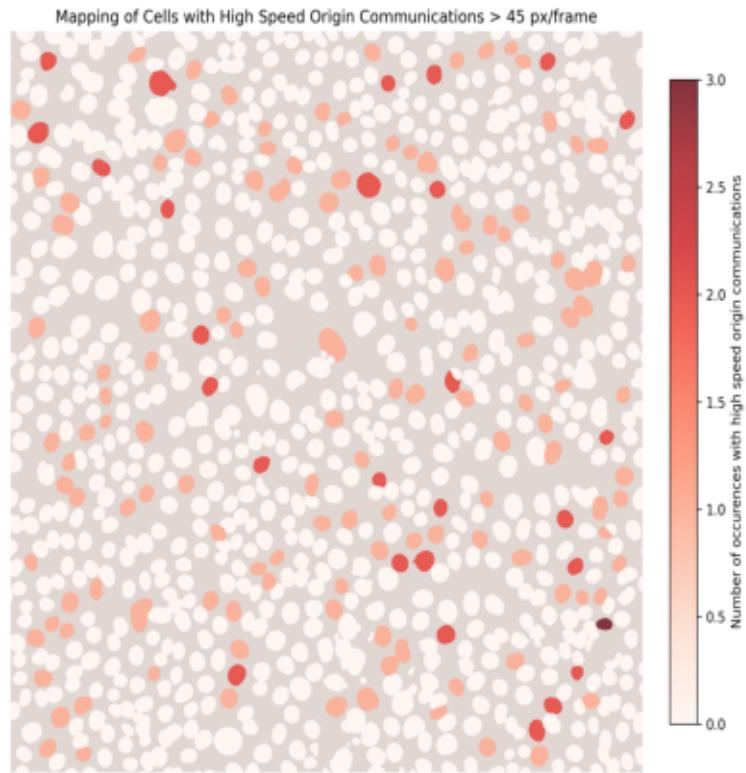
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	\
3	3015509613856	3	281	5
5	3015504031376	3	232	9
18	3015509621104	7	344	0
57	3015509607088	11	811	2
63	3015509606512	12	249	1
...	...	...	...	...
1981	3015516046720	604	1273	4
1998	3015516051760	612	1257	3
2018	3015516057520	618	1305	9
2044	3015516059344	632	1294	3
2112	3015516057280	671	1376	3

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
3	317	7	1218.0	1218.0	
5	268	6	1215.0	1215.0	
18	370	1	205.0	205.0	
57	776	2	136.0	136.0	
63	222	2	136.0	136.0	
...	...	...	...	...	
1981	1301	2	642.0	643.0	
1998	1256	2	190.0	191.0	
2018	1346	6	1315.0	1316.0	
2044	1328	5	551.0	552.0	
2112	1388	3	599.0	600.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
3	0.0	17.78	17.78		
5	0.0	15.65	15.65		
18	0.0	15.87	15.87		
57	0.0	17.23	17.23		
63	0.0	22.24	22.24		
...	...	...	...	...	
1981	1.0	22.63	22.63		
1998	1.0	17.55	17.55		
2018	1.0	24.72	24.72		
2044	1.0	17.40	17.40		
2112	1.0	19.00	19.00		
	Event time phase (fraction of event duration)	\			
3		0.94			
5		0.75			
18		1.00			
57		0.00			
63		0.87			
...		...			
1981		0.02			
1998		NaN			
2018		0.12			
2044		0.23			
2112		NaN			
	Event recruitment phase (fraction of involved cells)	dataset	\		
3		0.33	20250618_IS5		
5		0.00	20250618_IS5		
18		0.50	20250618_IS5		
57		0.00	20250618_IS5		
63		0.62	20250618_IS5		
...		...	...		
1981		0.00	20250618_IS5		
1998		NaN	20250618_IS5		

2018		0.00	20250618_IS5
2044		0.33	20250618_IS5
2112		NaN	20250618_IS5

	Number of cells involved	category	Speed category
3		5-10	High speed
5		5-10	High speed
18		5-10	High speed
57		5-10	High speed
63		5-10	High speed
...		...	...
1981		5-10	High speed
1998		2	High speed
2018		3	High speed
2044		5-10	High speed
2112		2	High speed

[178 rows x 16 columns]

Speed category	High speed	Low speed
Origin cell ID		
217	0	1
219	0	1
220	0	4
223	0	3
224	1	3
...	...	...
1398	0	1
1403	0	1
1404	0	1
1406	0	1
1408	0	1

[702 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
2	217	414.70	7.15
3	219	198.90	9.10
4	220	304.20	9.10
6	223	45.50	10.72
7	224	395.20	11.05
..	...	...	...
829	1398	74.10	488.80
831	1403	486.85	491.73
832	1404	36.40	491.73
833	1406	236.28	492.38
834	1408	94.25	493.35

Number of peaks Is active Occurrences in global events \

2	6	True	2
3	5	True	2
4	6	True	2
6	7	True	2
7	11	True	2
..	..	..	..
829	5	True	2
831	6	True	2
832	6	True	2
833	8	True	2
834	4	True	2

Occurrences in global events as early peaker			Early peaker event IDs \
2		1	[2]
3		0	[]
4		0	[]
6		0	[]
7		1	[1]
..		..	..
829		0	[]
831		0	[]
832		0	[]
833		0	[]
834		0	[]

Occurrences in sequential events \	
2	3
3	2
4	2
6	4
7	6
..	..
829	2
831	1
832	3
833	4
834	1

Occurrences in sequential events as origin \	
2	0
3	0
4	2
6	1
7	2
..	..
829	1
831	1
832	0

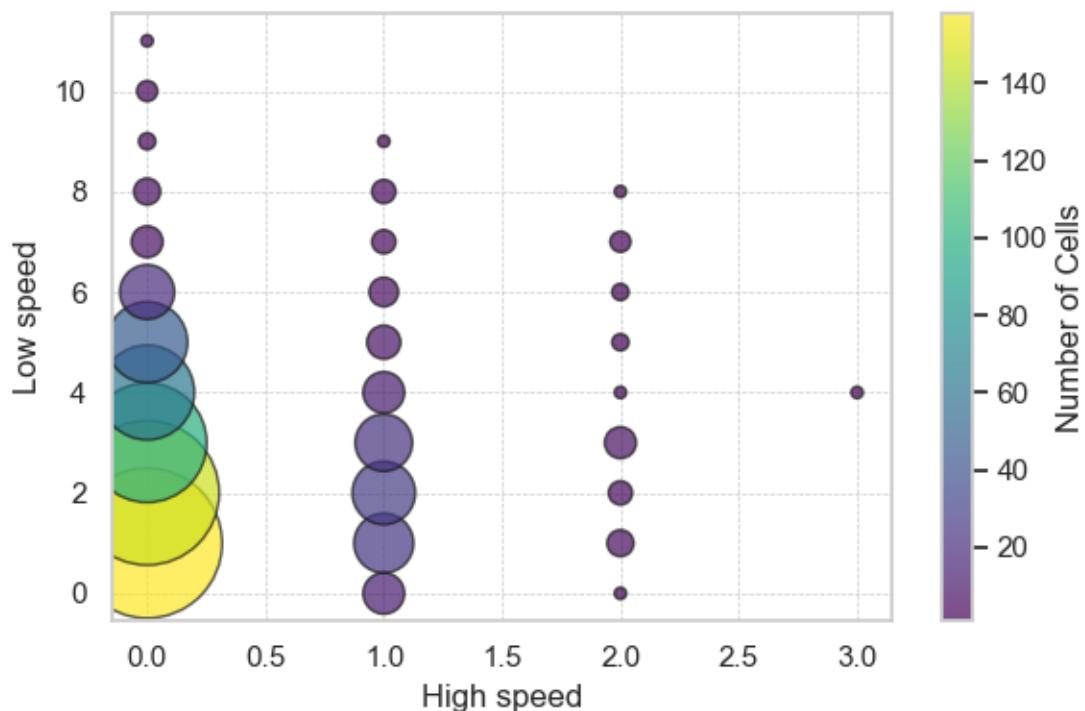
833		1		
834		1		
	Occurrences in individual events	Peak frequency (Hz)	Periodicity score	\
2	1	0.0035	0.65	
3	1	0.0029	0.64	
4	2	0.0035	0.65	
6	0	0.0041	0.53	
7	3	0.0065	0.63	
..	...	...	...	...
829	1	0.0029	0.60	
831	3	0.0035	0.58	
832	1	0.0035	0.61	
833	1	0.0047	0.68	
834	1	0.0024	0.59	
	Neighbor count	Neighbors (labels)	dataset	\
2	3	[224, 248, 249]	20250618_IS5	
3	3	[226, 241, 267]	20250618_IS5	
4	3	[232, 243, 281]	20250618_IS5	
6	3	[225, 247, 261]	20250618_IS5	
7	4	[217, 228, 248, 263]	20250618_IS5	
..	..	..	..	..
829	4	[1354, 1372, 1386, 1408]	20250618_IS5	
831	3	[1349, 1363, 1396]	20250618_IS5	
832	3	[1365, 1376, 1386]	20250618_IS5	
833	2	[1346, 1378]	20250618_IS5	
834	3	[1372, 1398, 1401]	20250618_IS5	
	Involved in sequential event	Occurrences in sequential events	category	\
2	Involved in sequential event		3-4	
3	Involved in sequential event		1-2	
4	Involved in sequential event		1-2	
6	Involved in sequential event		3-4	
7	Involved in sequential event		5-9	
..	..	..	..	..
829	Involved in sequential event		1-2	
831	Involved in sequential event		1-2	
832	Involved in sequential event		3-4	
833	Involved in sequential event		3-4	
834	Involved in sequential event		1-2	
	High speed	Low speed		
2	0.0	1.0		
3	0.0	1.0		
4	0.0	4.0		
6	0.0	3.0		
7	1.0	3.0		

```

...
829      0.0      1.0
831      0.0      1.0
832      0.0      1.0
833      0.0      1.0
834      0.0      1.0

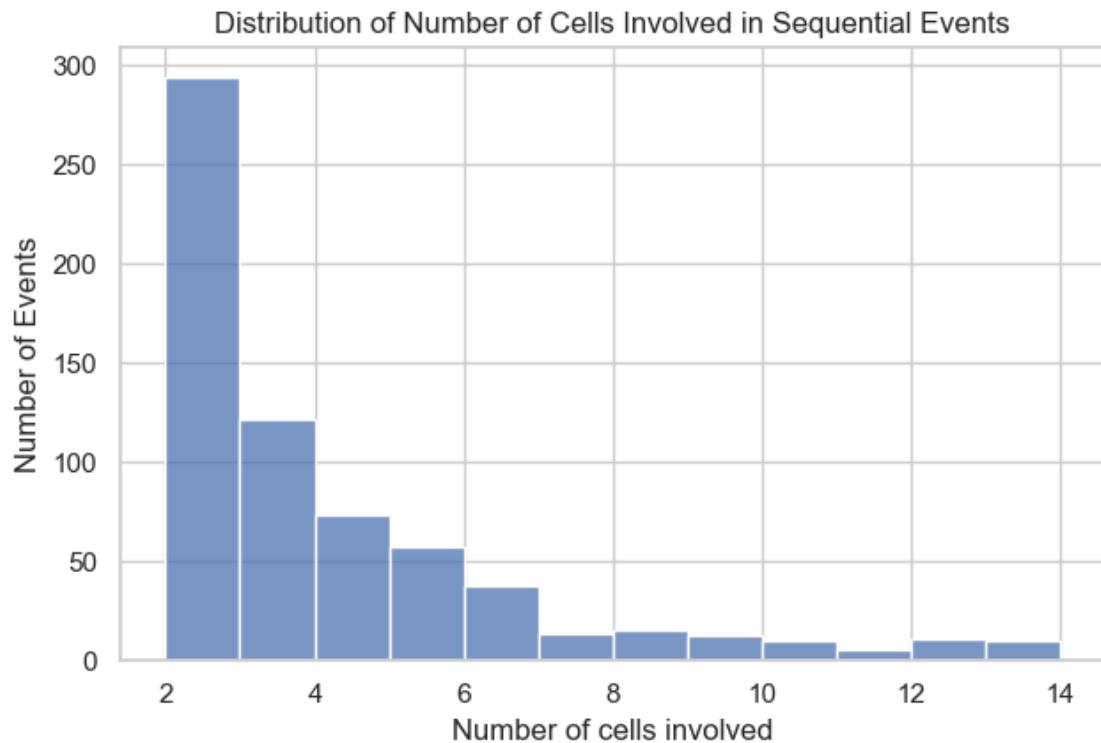
```

[702 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

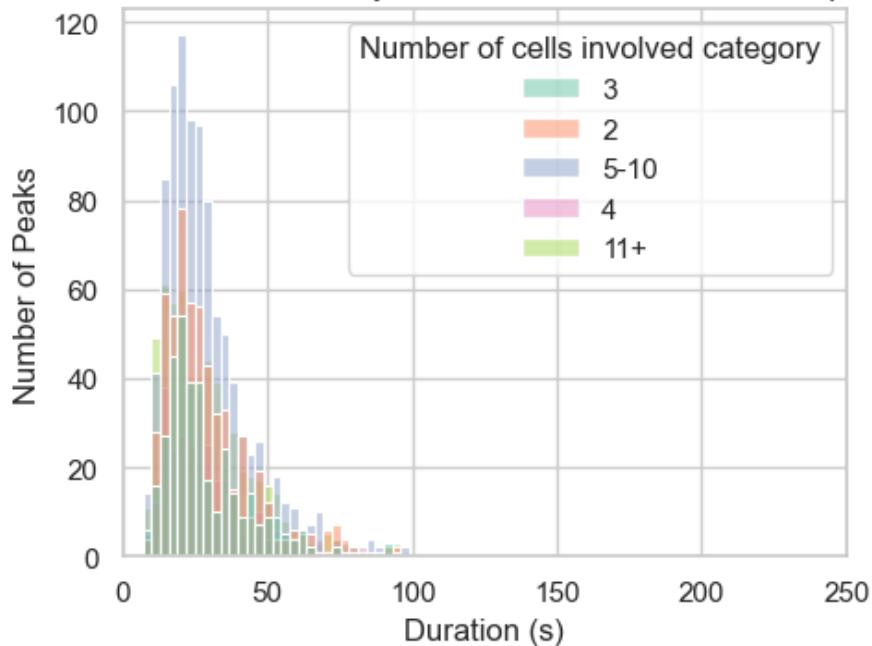
[2025-08-27 15:03:27] [INFO] calcium: plot\_histogram: removed 12 outliers out of 675 on 'Number of cells involved' (lower=-7, upper=14)



### 1.3.6 Influence of cell count per event on statistics

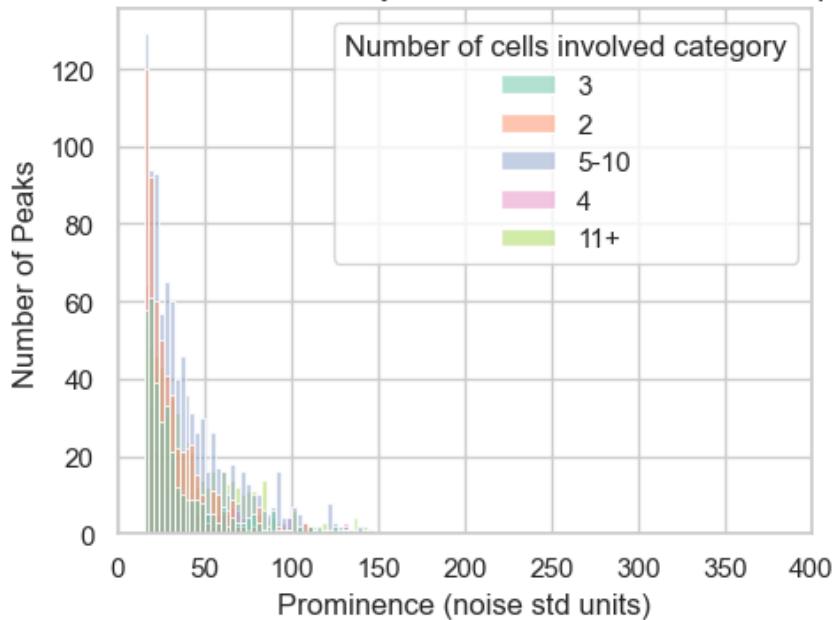
```
[2025-08-27 15:03:27] [INFO] calcium: plot_histogram_by_group: removed 32 outliers out of 2795 on 'Duration (s)' (lower=-9, upper=99)
```

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

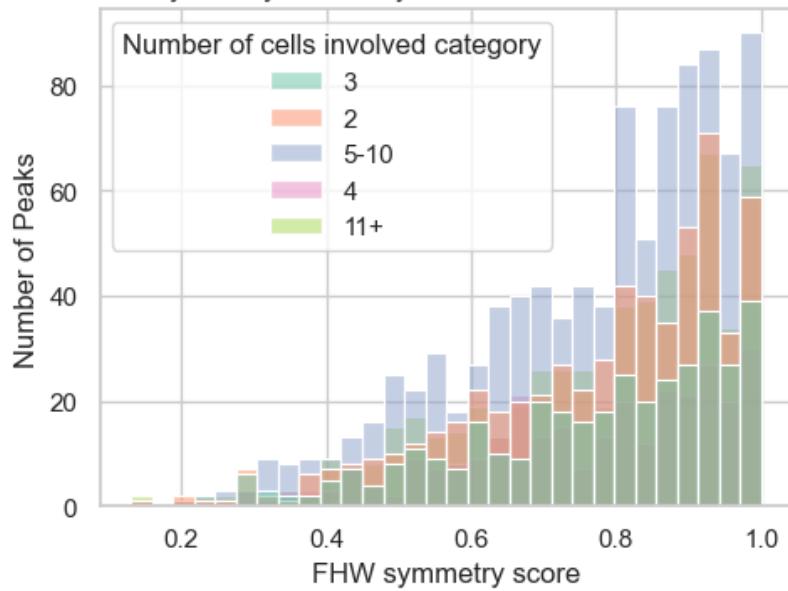


```
[2025-08-27 15:03:27] [INFO] calcium: plot_histogram_by_group: removed 36 outliers out of 2795 on 'Prominence (noise std units)' (lower=-22.475, upper=148.82)
```

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

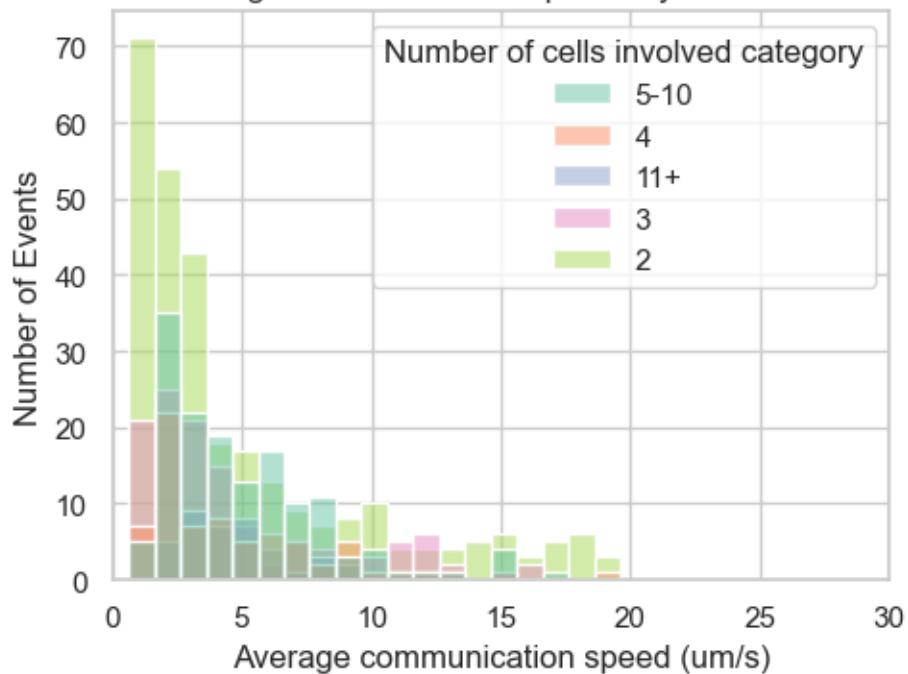


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



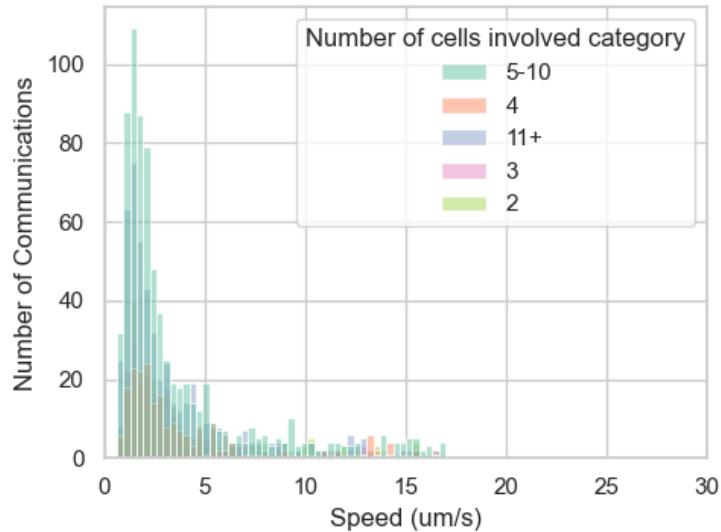
```
[2025-08-27 15:03:28] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 675 on 'Average communication speed (um/s)' (lower=-11.335, upper=20.095)
```

Distribution of Average Communication Speeds by Number of Cells Involved



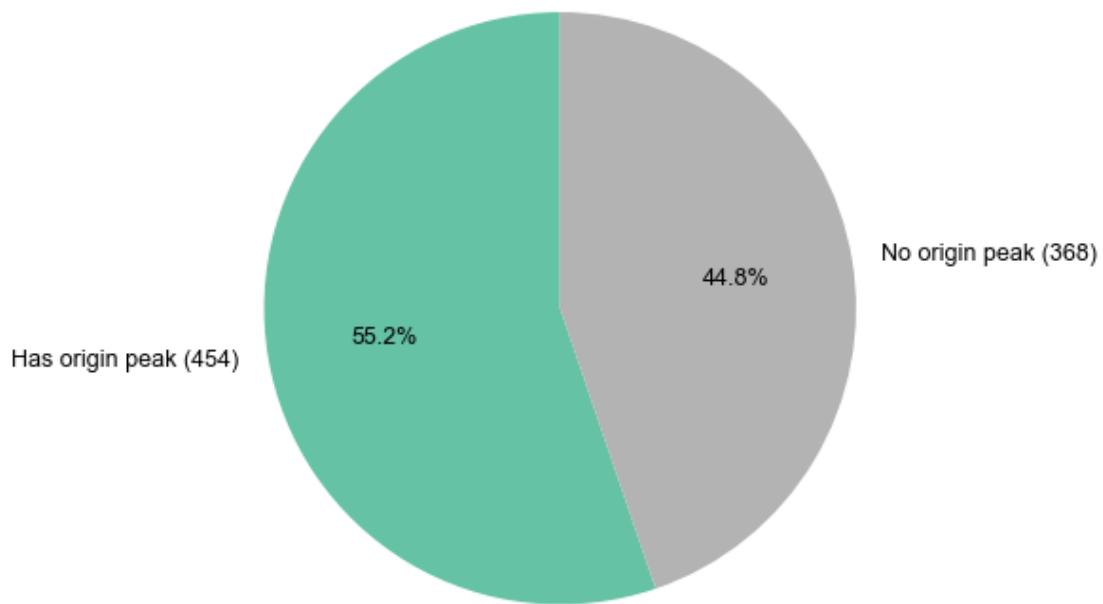
[2025-08-27 15:03:28] [INFO] calcium: plot\_histogram\_by\_group: removed 132 outliers out of 2120 on 'Speed (um/s)' (lower=-10.02, upper=17)

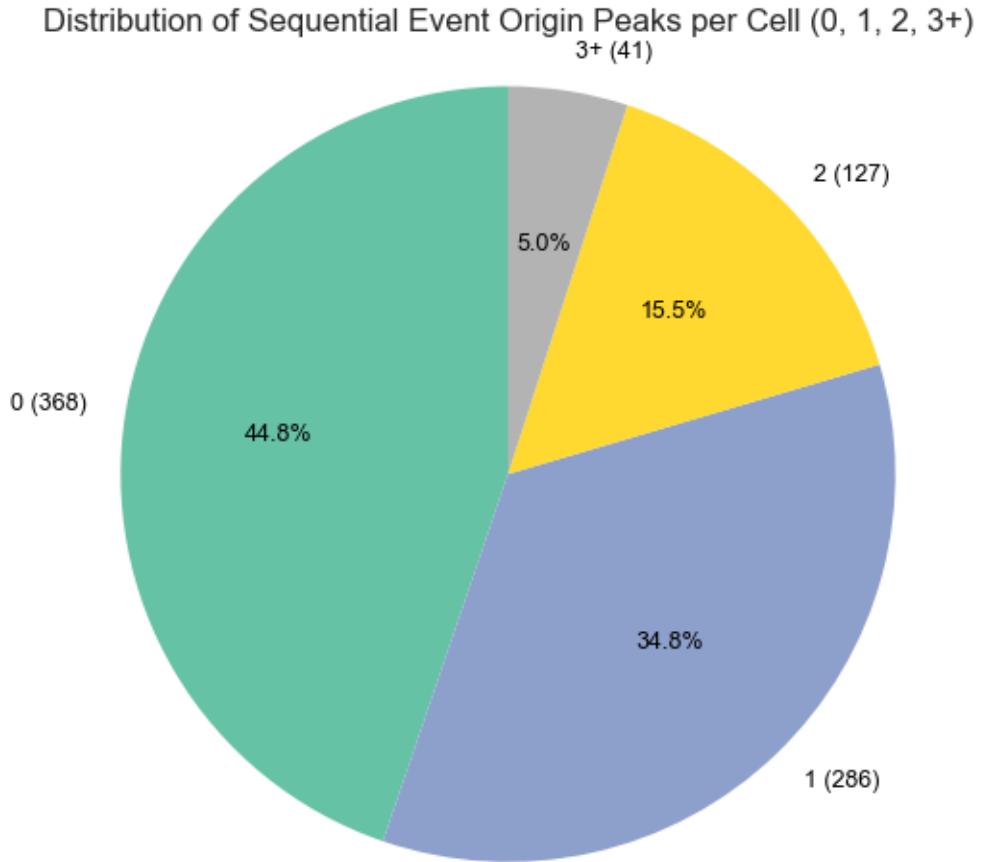
Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events



### 1.3.7 Cells Occurrences as origin in sequential events

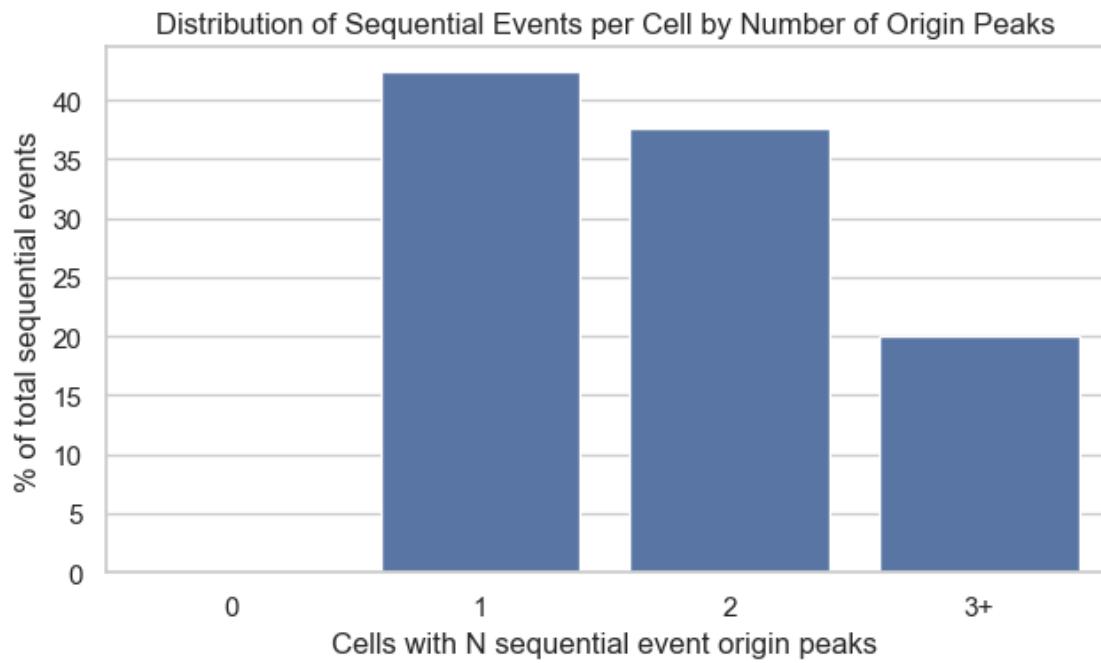
Distribution of Number of Sequential Event Origin Peaks per Cell





```
[2025-08-27 15:03:29] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\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:
```

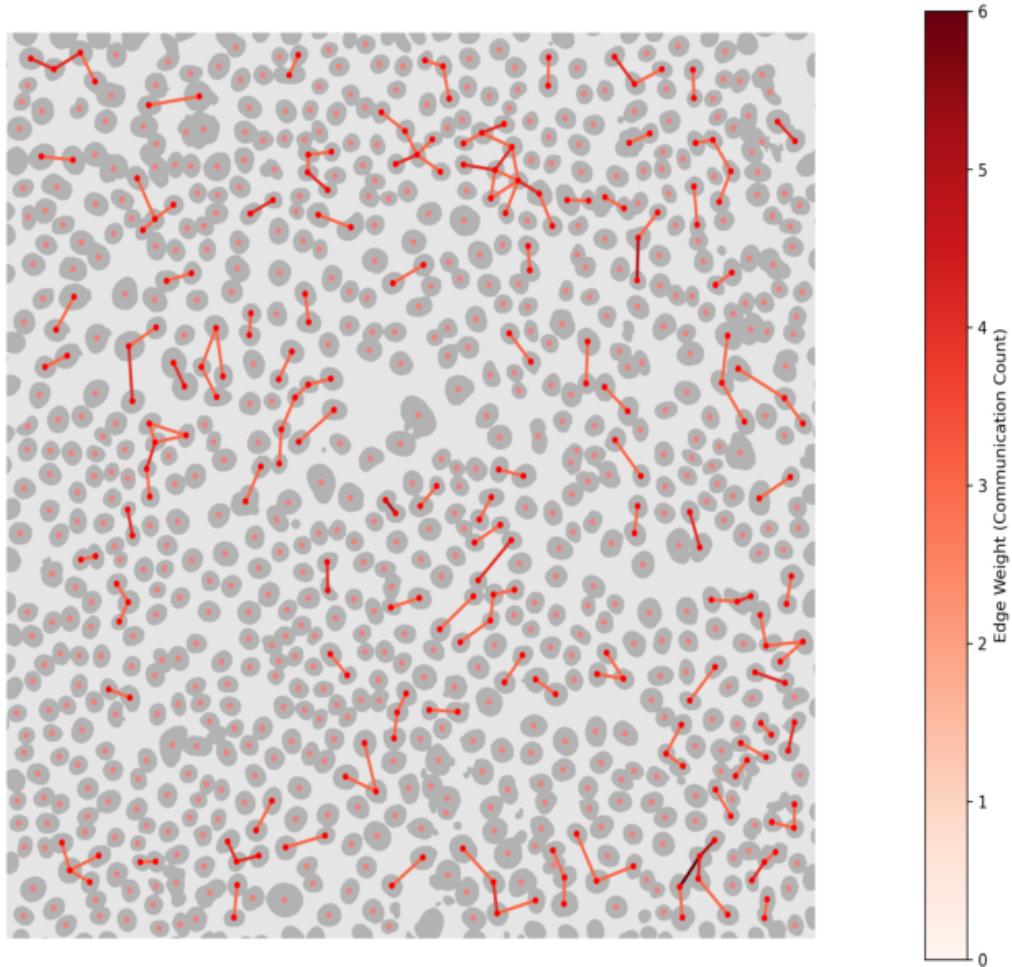
'D:\\Mateo\\20250618\\Output\\IS5\\cell-mapping\\cell\_Occurrences\_in\_origin\_seq\_events\_overlay.png'



### 1.3.8 Connection network between cells

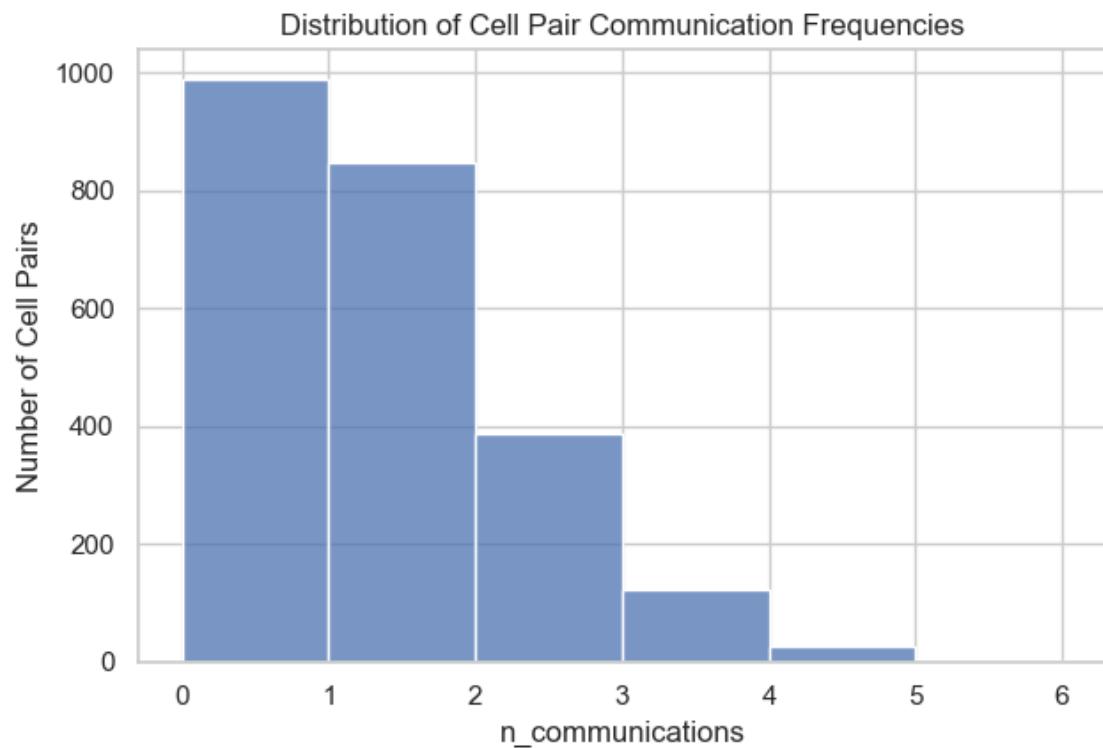
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



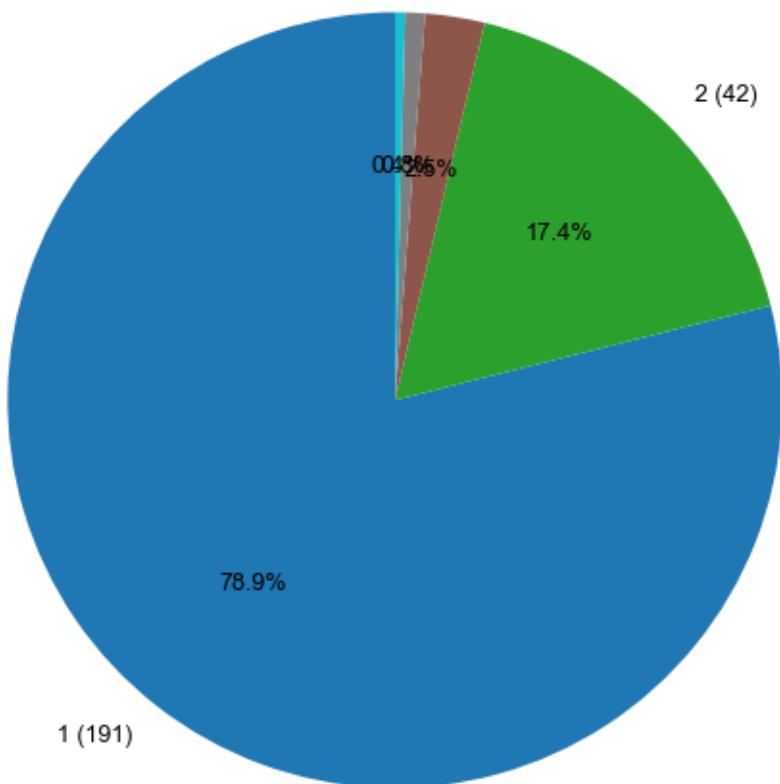
### 1.3.9 Pair/Trios with high communication networks

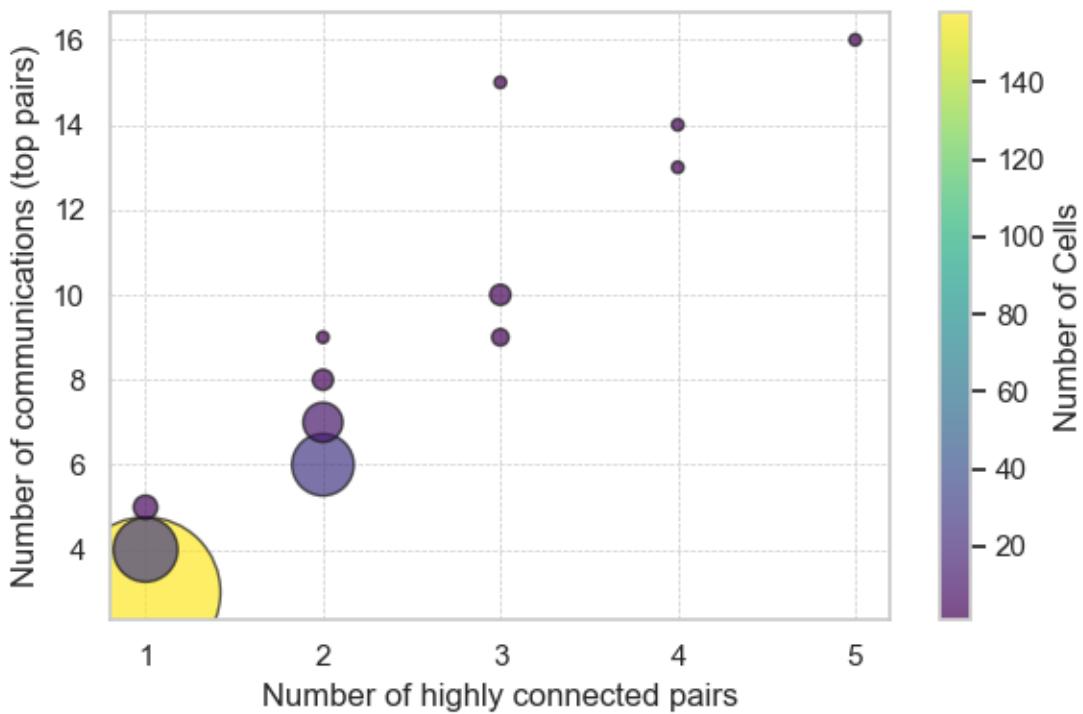
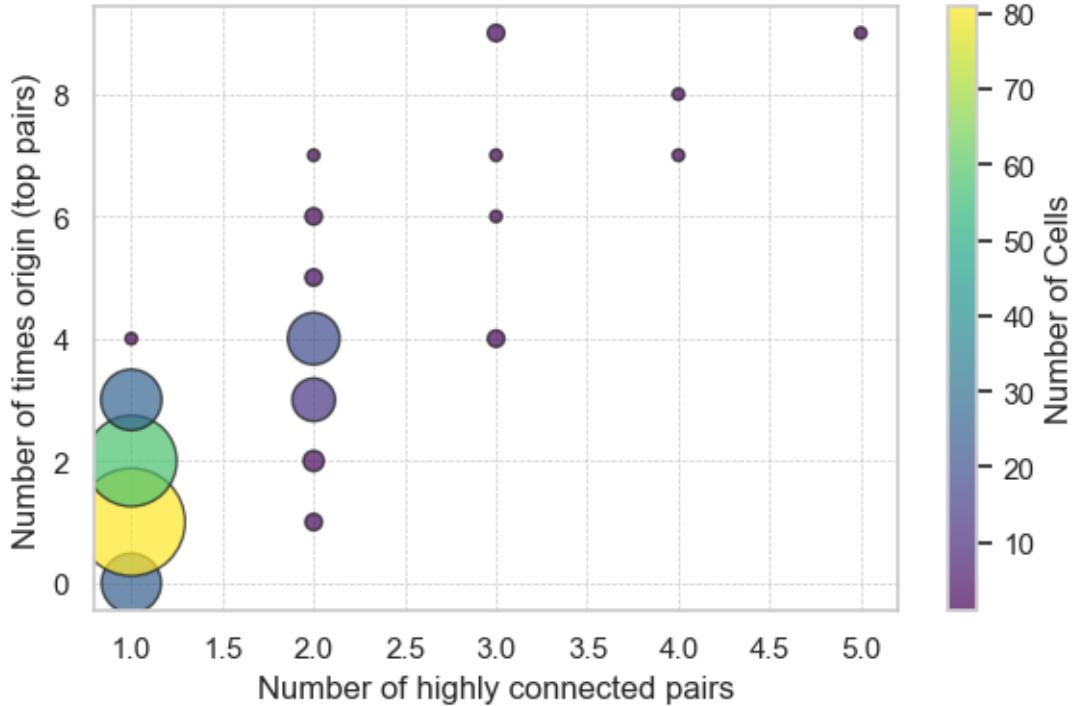
```
[2025-08-27 15:03:31] [INFO] calcium: build_neighbor_pair_stats: built 2379 pairs across 1 datasets (mean distance=18.81 um)
```

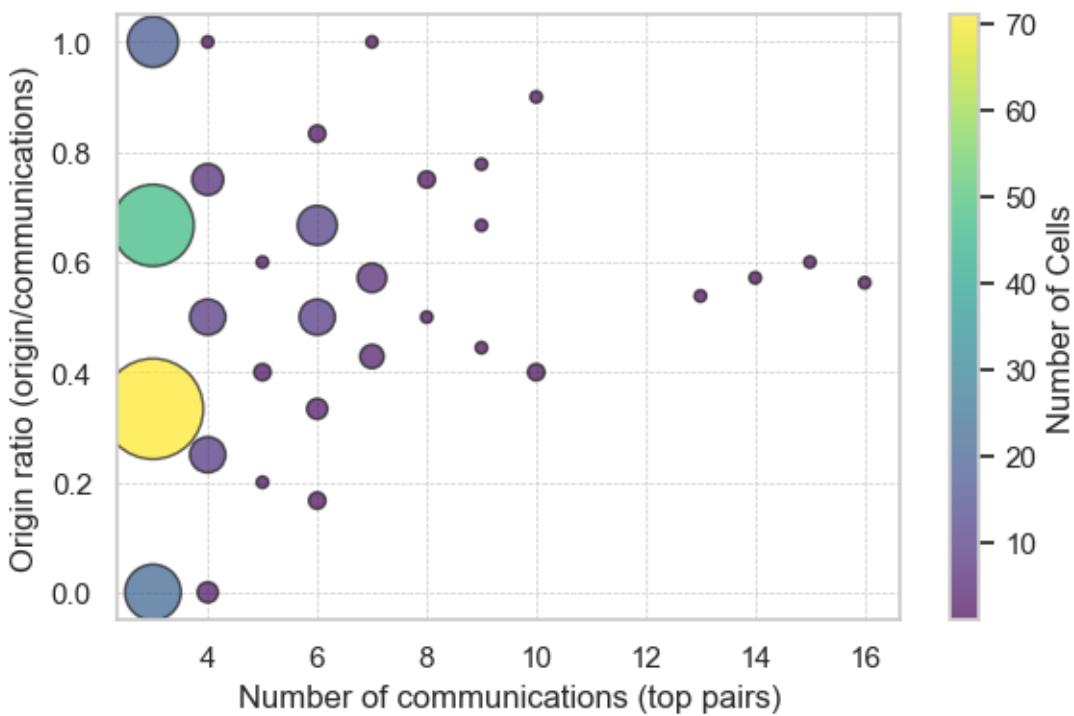
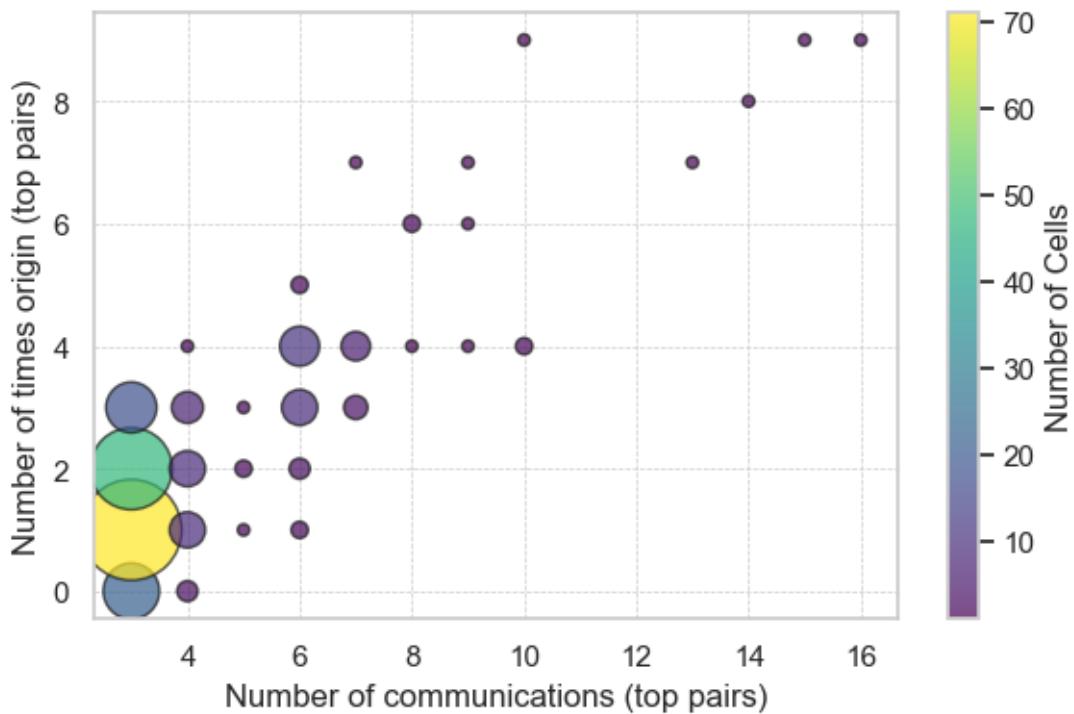


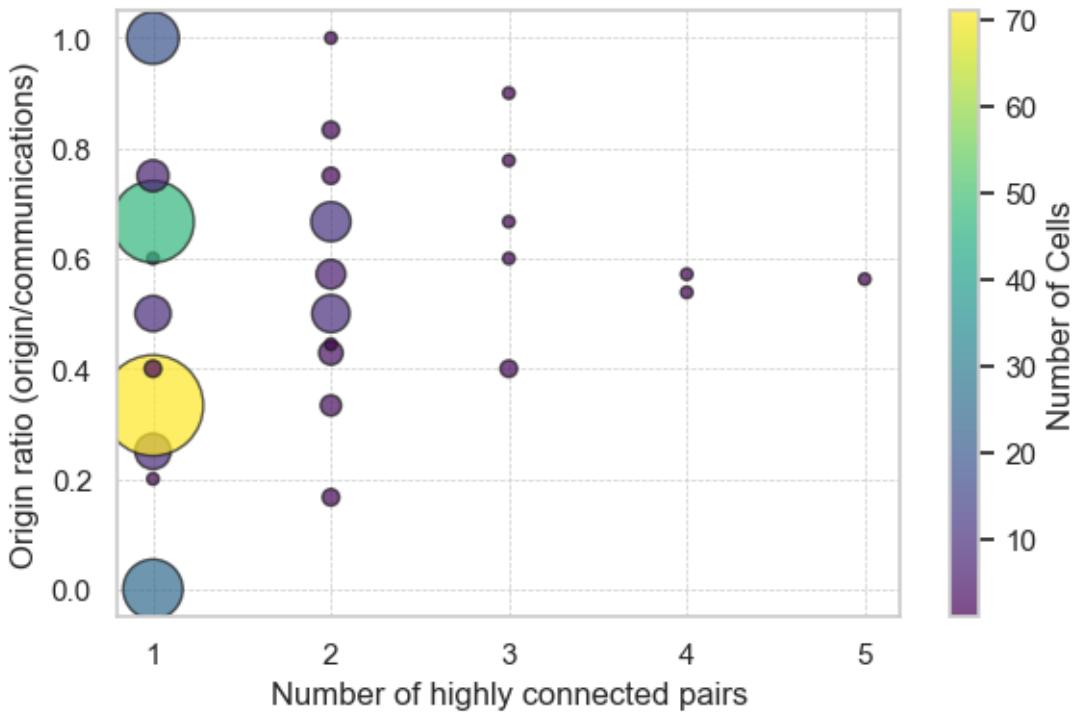
95th percentile threshold: 3.0

Cells involved in multiple pairs highly connected  
541(23%)









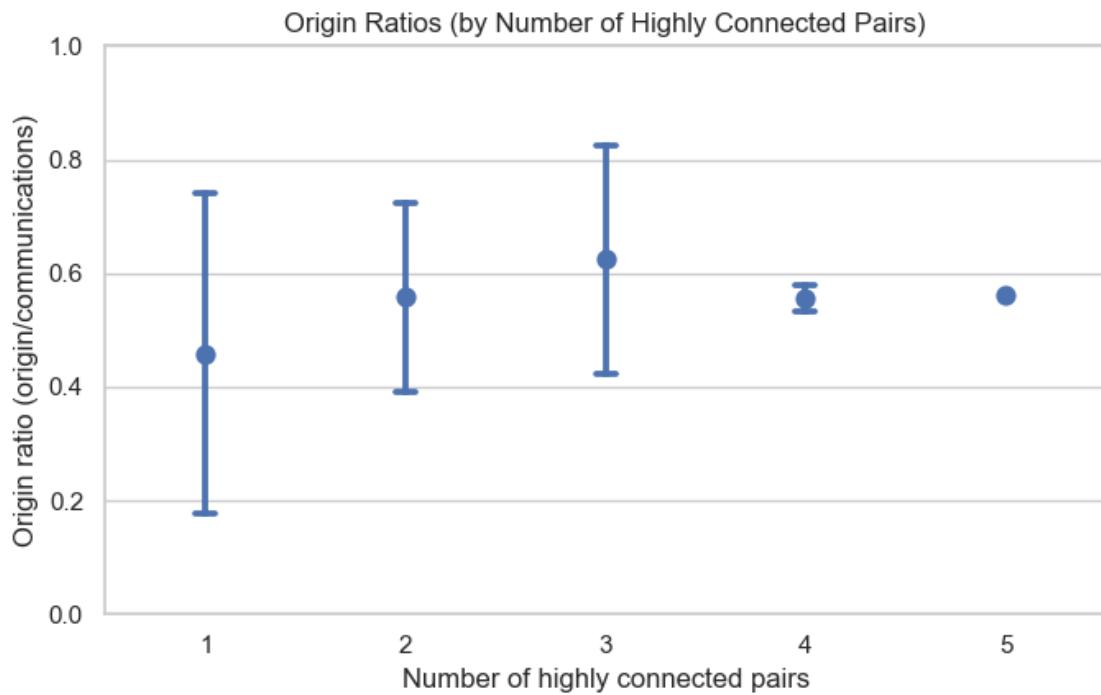
[2025-08-27 15:03:32] [INFO] calcium: plot\_points\_mean\_std: N=191 for Number of highly connected pairs=1

[2025-08-27 15:03:32] [INFO] calcium: plot\_points\_mean\_std: N=42 for Number of highly connected pairs=2

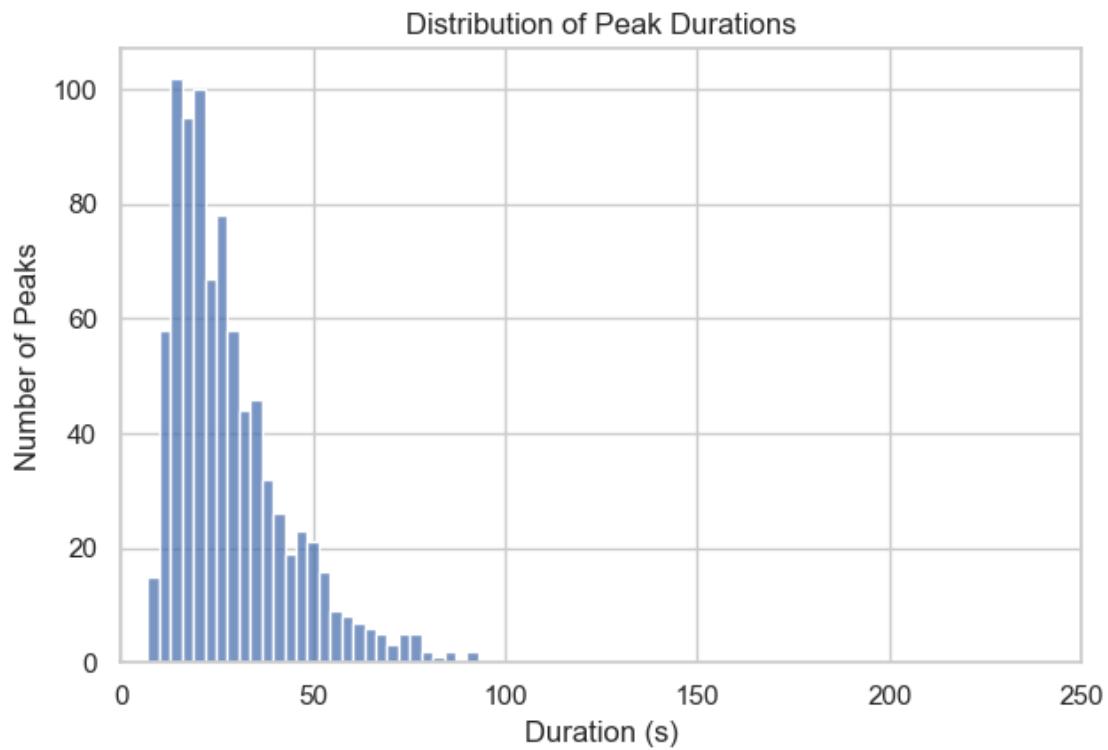
[2025-08-27 15:03:32] [INFO] calcium: plot\_points\_mean\_std: N=6 for Number of highly connected pairs=3

[2025-08-27 15:03:32] [INFO] calcium: plot\_points\_mean\_std: N=2 for Number of highly connected pairs=4

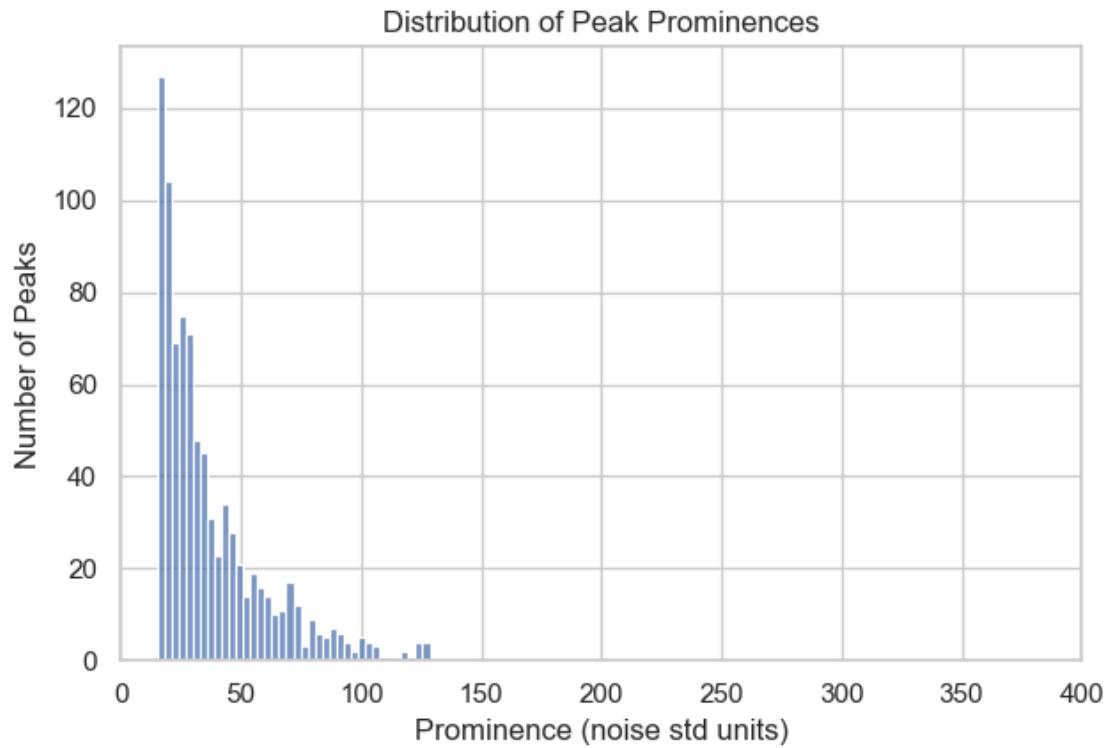
[2025-08-27 15:03:32] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=5

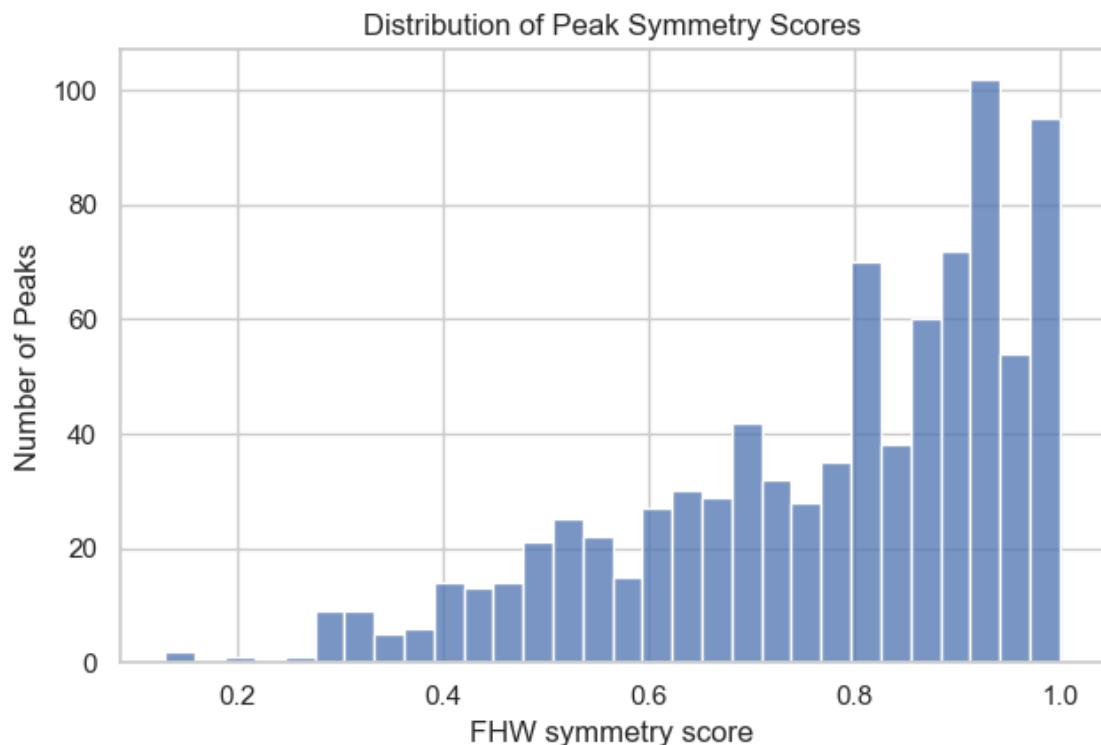


```
[2025-08-27 15:03:32] [INFO] calcium: plot_histogram: removed 16 outliers out of 871 on 'Duration (s)' (lower=-40, upper=93)
```

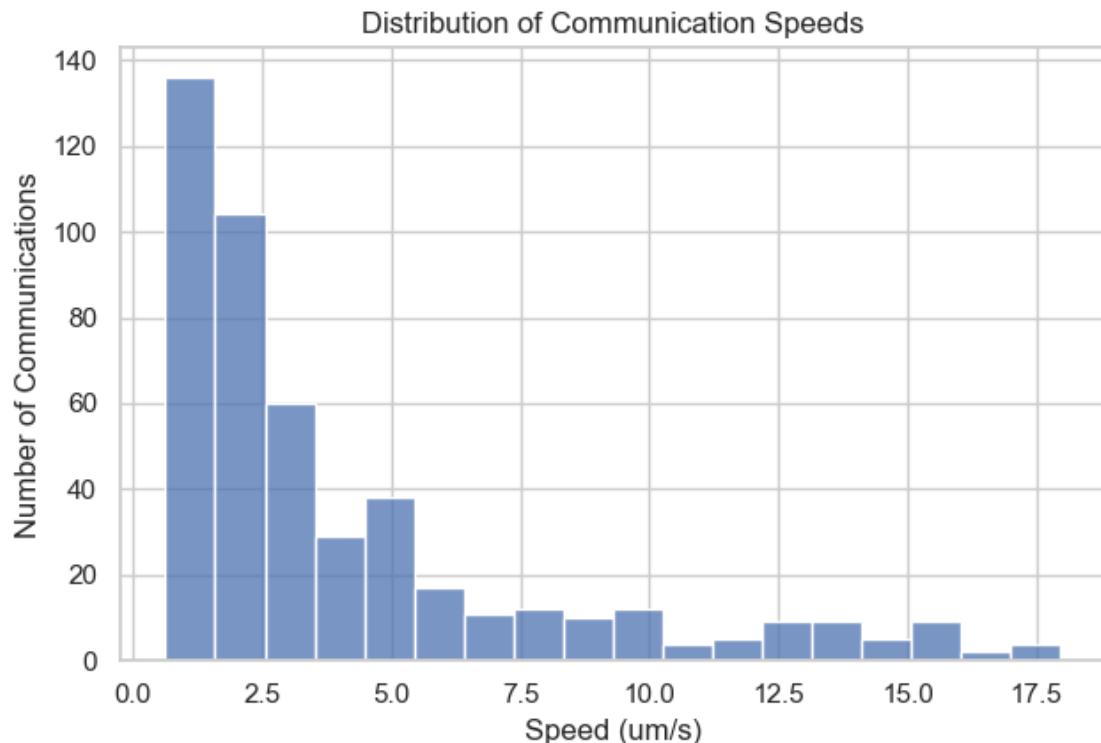


[2025-08-27 15:03:32] [INFO] calcium: plot\_histogram: removed 14 outliers out of 871 on 'Prominence (noise std units)' (lower=-61.1, upper=129.3)

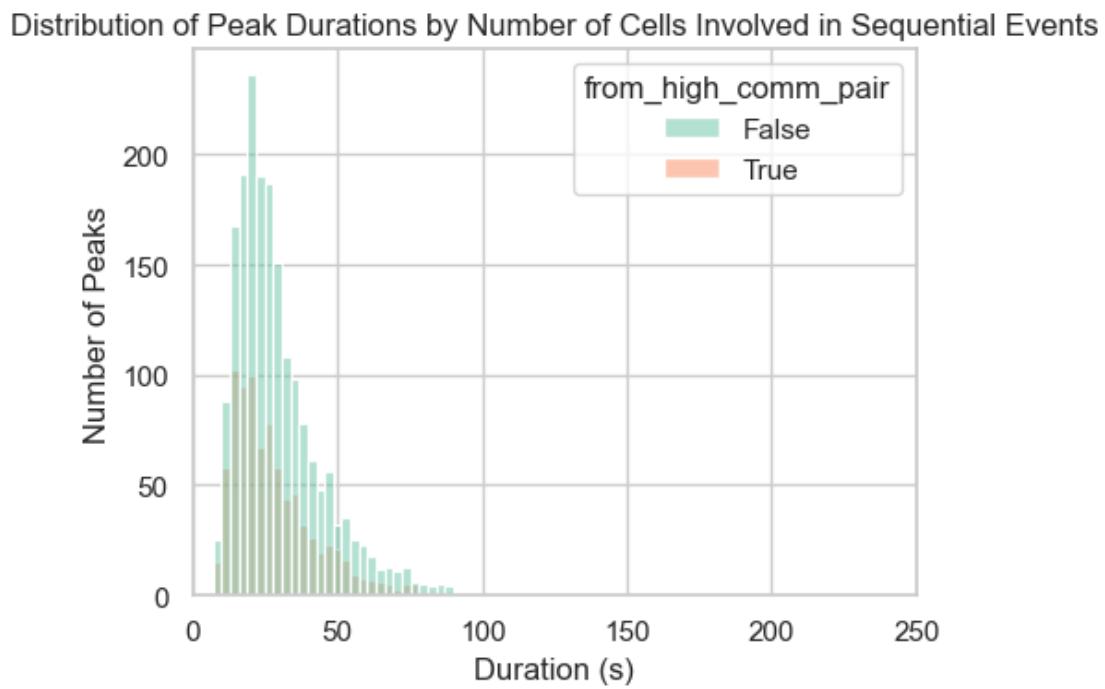




```
[2025-08-27 15:03:32] [INFO] calcium: plot_histogram: removed 18 outliers out of 494 on 'Speed (um/s)' (lower=-11.19, upper=18.472)
```

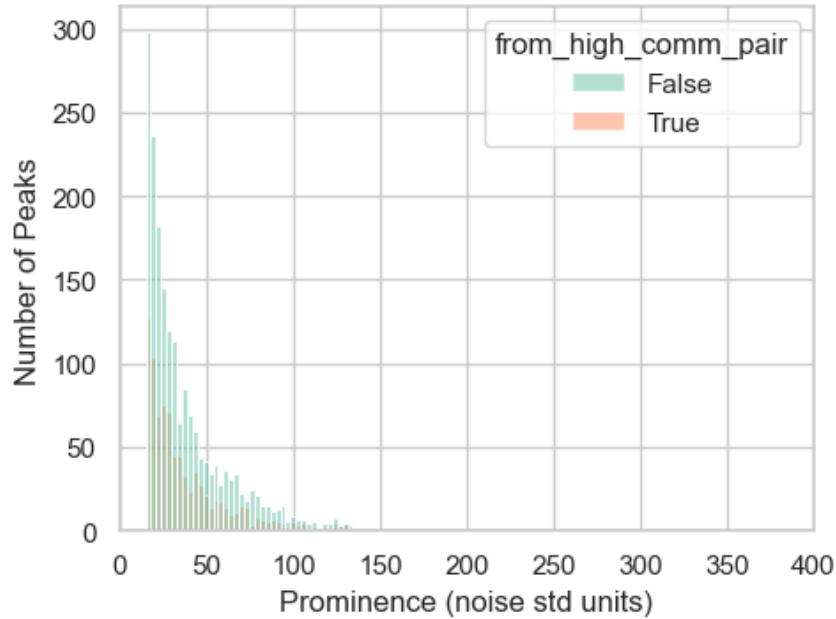


```
[2025-08-27 15:03:33] [INFO] calcium: plot_histogram_by_group: removed 51 outliers out of 2795 on 'Duration (s)' (lower=-36, upper=90)
```

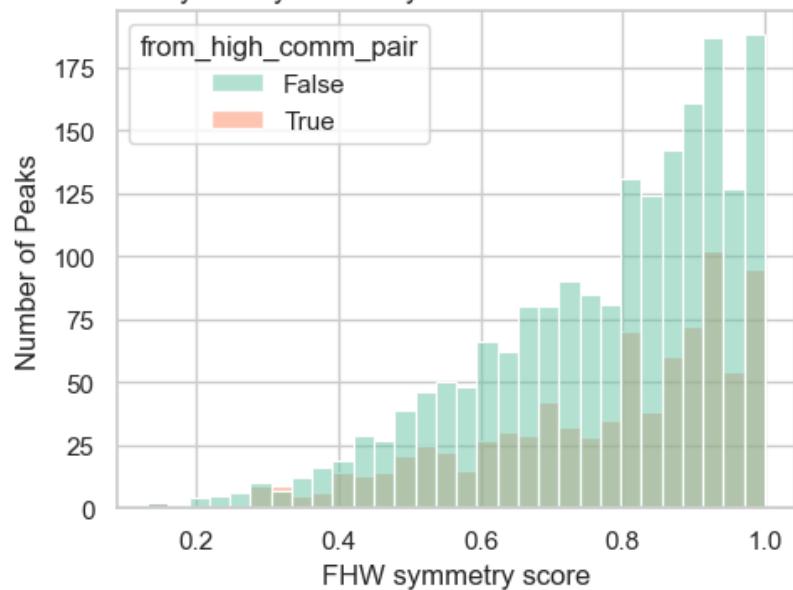


[2025-08-27 15:03:33] [INFO] calcium: plot\_histogram\_by\_group: removed 52 outliers out of 2795 on 'Prominence (noise std units)' (lower=-65.3, upper=134.55)

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

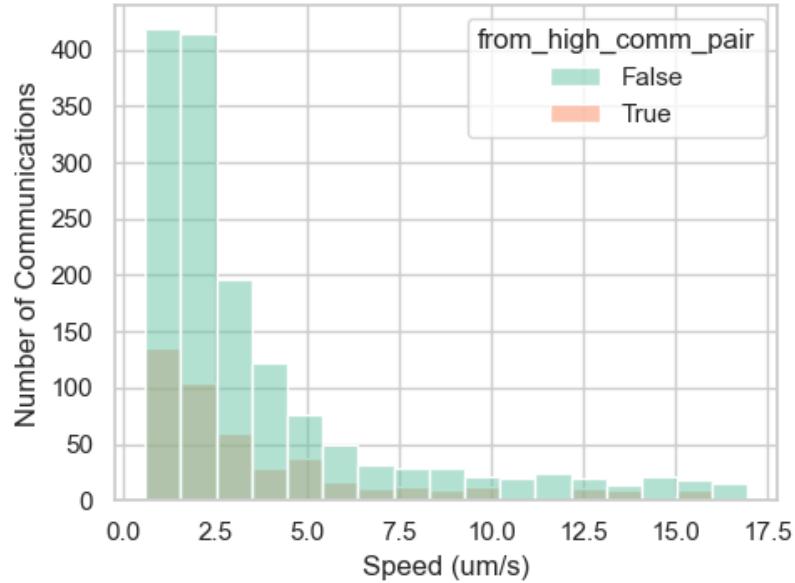


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:03:33] [INFO] calcium: plot_histogram_by_group: removed 132 outliers out of 2120 on 'Speed (um/s)' (lower=-10.02, upper=17)
```

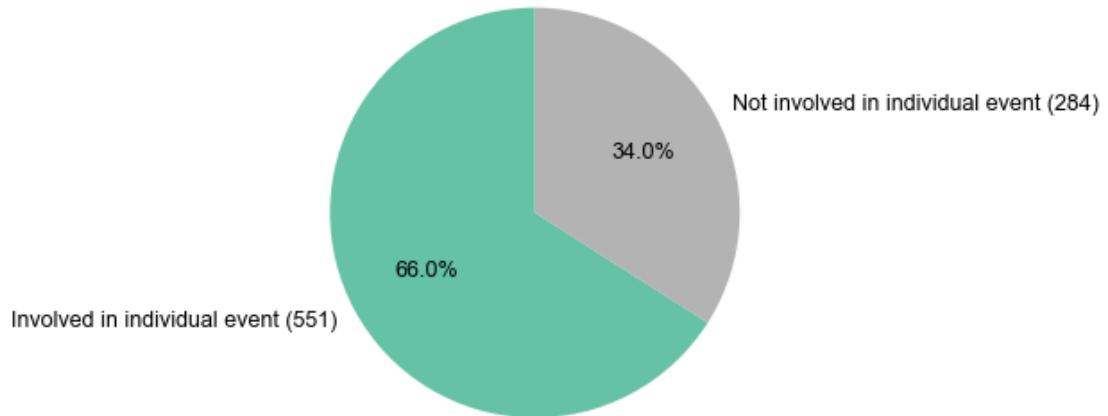
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



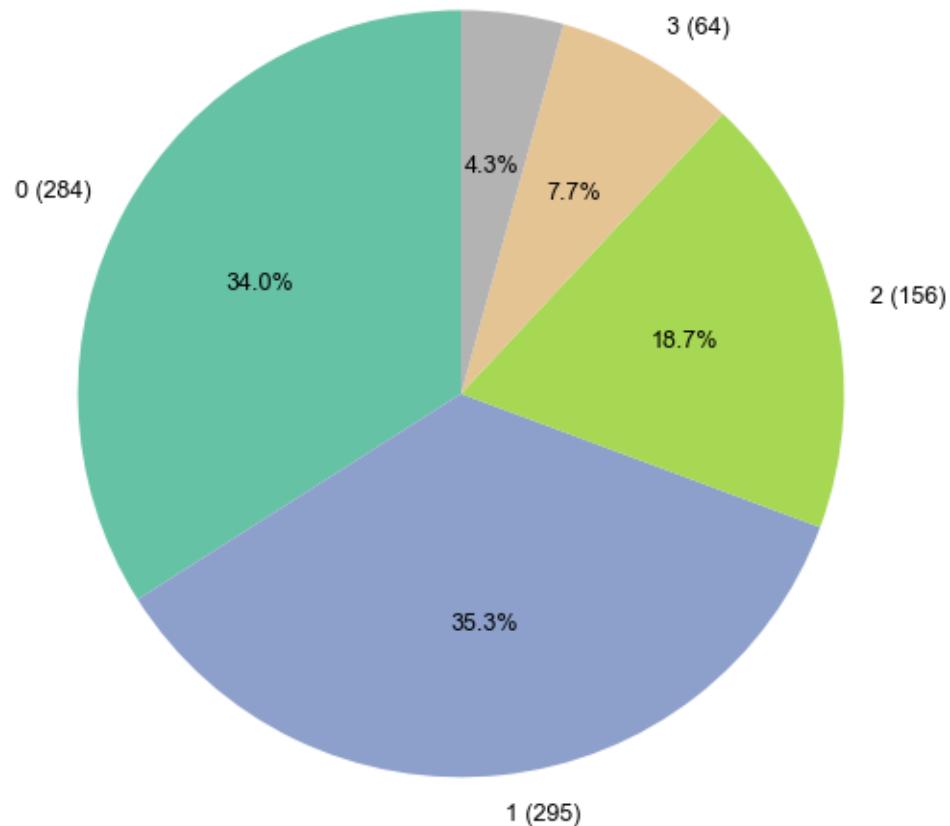
## 1.4 INDIVIDUAL EVENTS

### 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+)

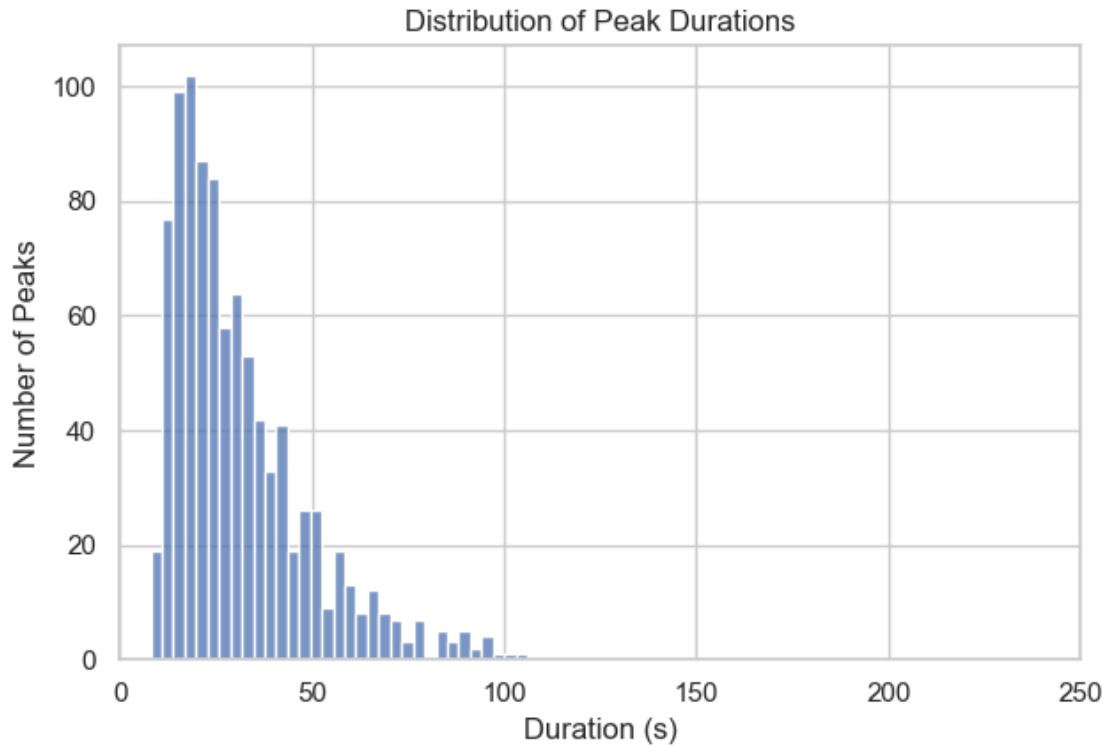


```
[2025-08-27 15:03:34] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS5\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS5\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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:
```

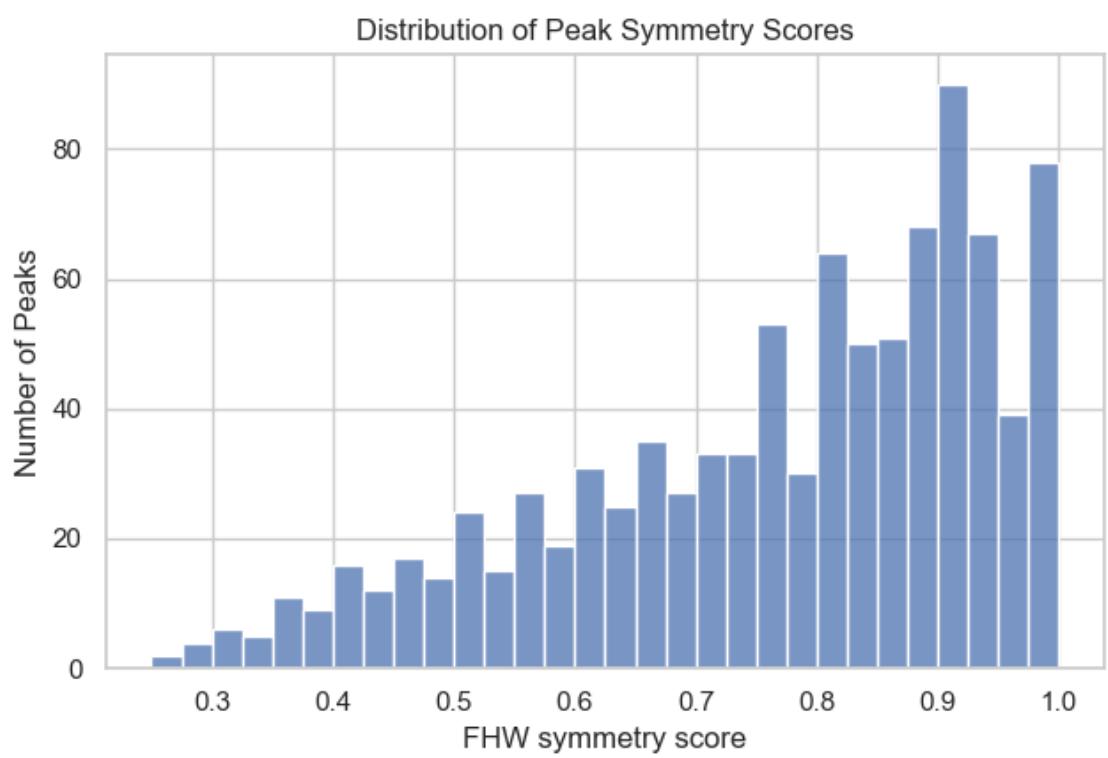
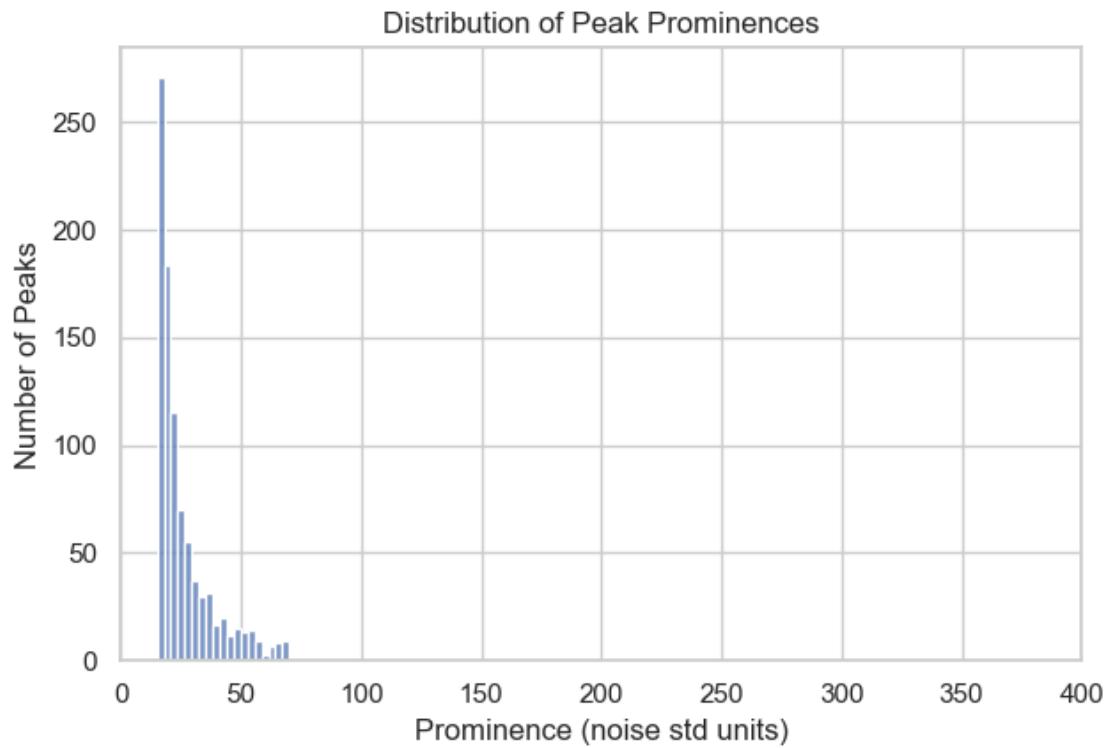
'D:\\Mateo\\20250618\\Output\\IS5\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

#### 1.4.2 Peaks statistics in individual events

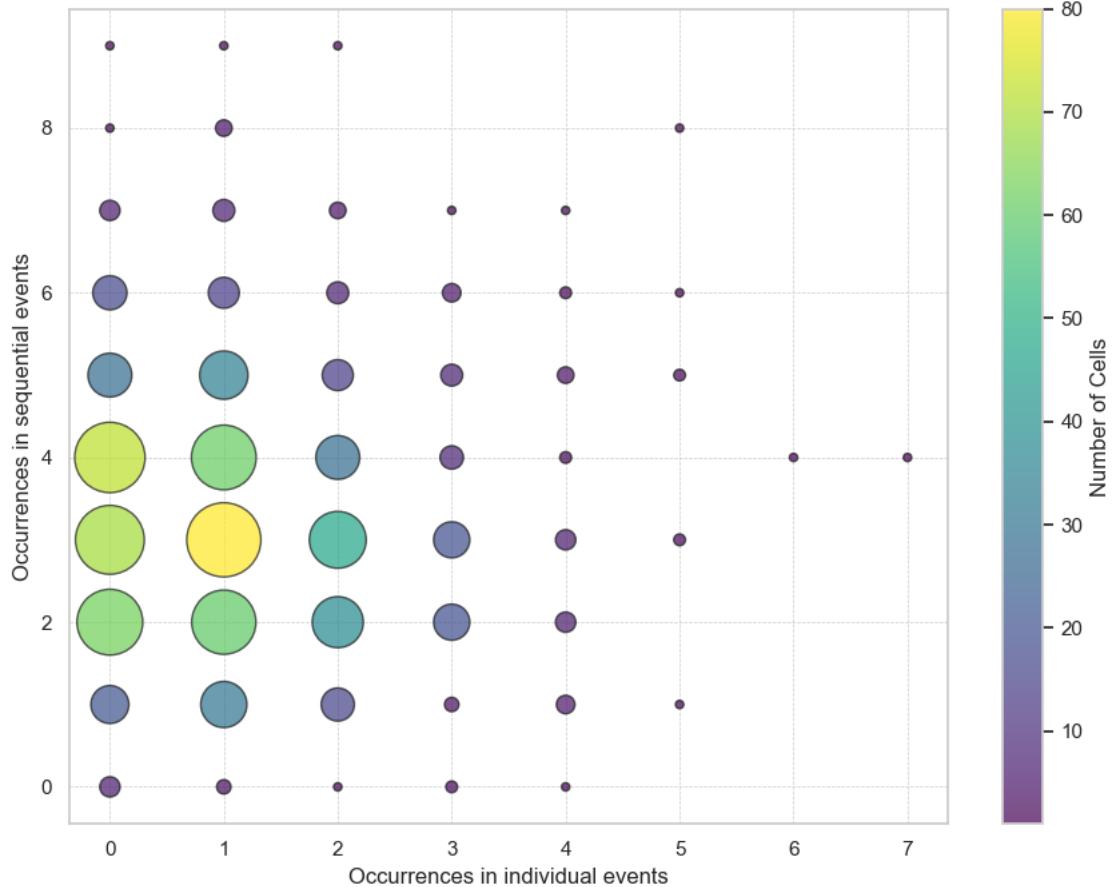
[2025-08-27 15:03:34] [INFO] calcium: plot\_histogram: removed 17 outliers out of 955 on 'Duration (s)' (lower=-48, upper=106)



[2025-08-27 15:03:34] [INFO] calcium: plot\_histogram: removed 35 outliers out of 955 on 'Prominence (noise std units)' (lower=-22.7, upper=71.1)



### 1.4.3 Correlation between event activity level & individual activity level



[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: removed 0/835 outliers on 'Occurrences in sequential events' (lower=-4, upper=10)

[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=284 for Occurrences in individual events=0

[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=295 for Occurrences in individual events=1

[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=156 for Occurrences in individual events=2

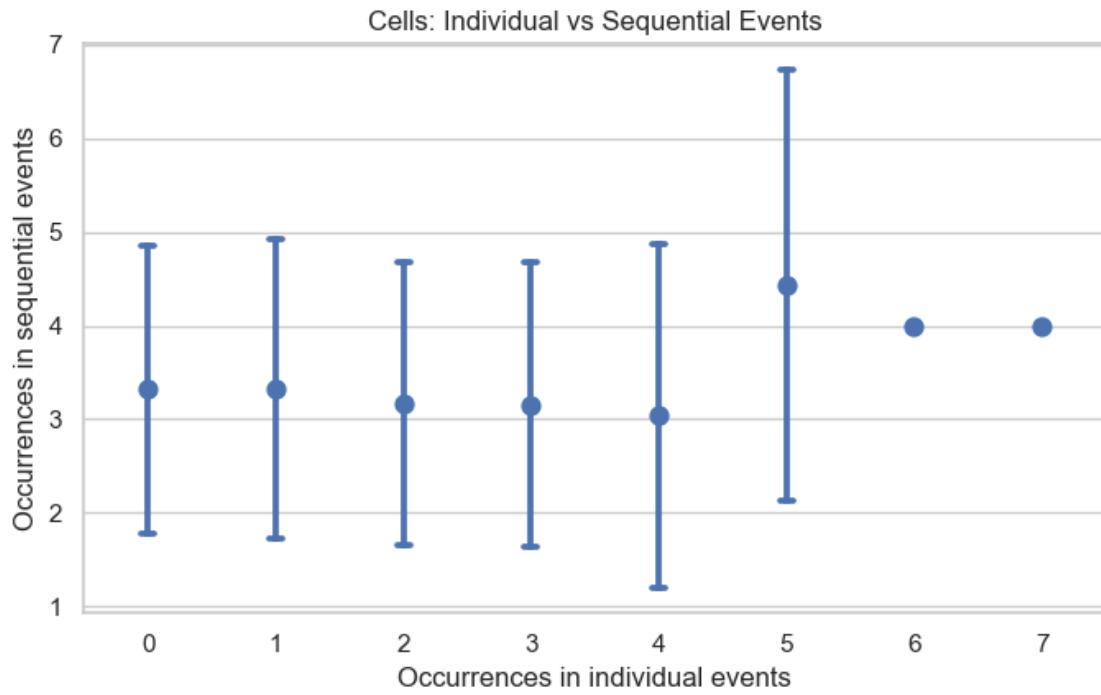
[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=64 for Occurrences in individual events=3

[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=27 for Occurrences in individual events=4

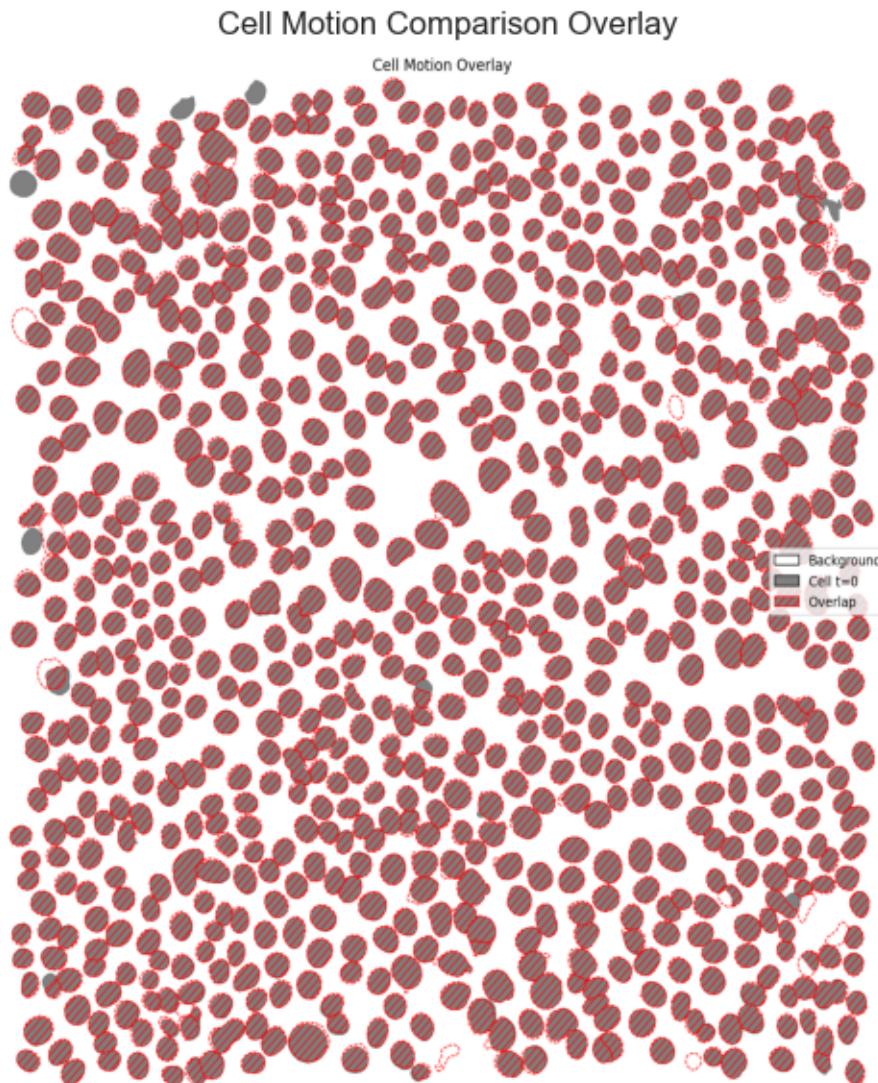
[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=7 for Occurrences in individual events=5

[2025-08-27 15:03:35] [INFO] calcium: plot\_points\_mean\_std: N=1 for Occurrences in individual events=6

[2025-08-27 15:03:35] [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: 835
- Hoechst image taken at t=1801: 833
- Number of cells difference: absolute 2, relative 0.24%

### Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 980579
- Pixels segmented as cell at t=1801: 988403
- Overlapping pixels between t=0 and t=1801: 926003 (94.06% of total)
- Pixels exclusive to t=0: 54576 (5.57% of total)
- Pixels exclusive to t=1801: 62400 (6.31% of total)

executed

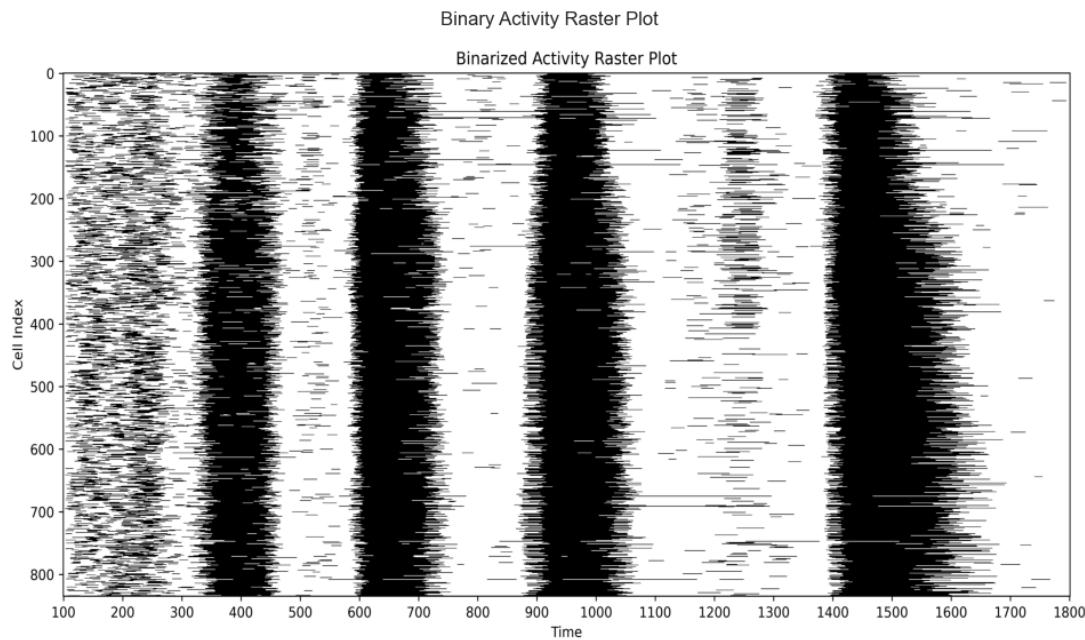
August 27, 2025

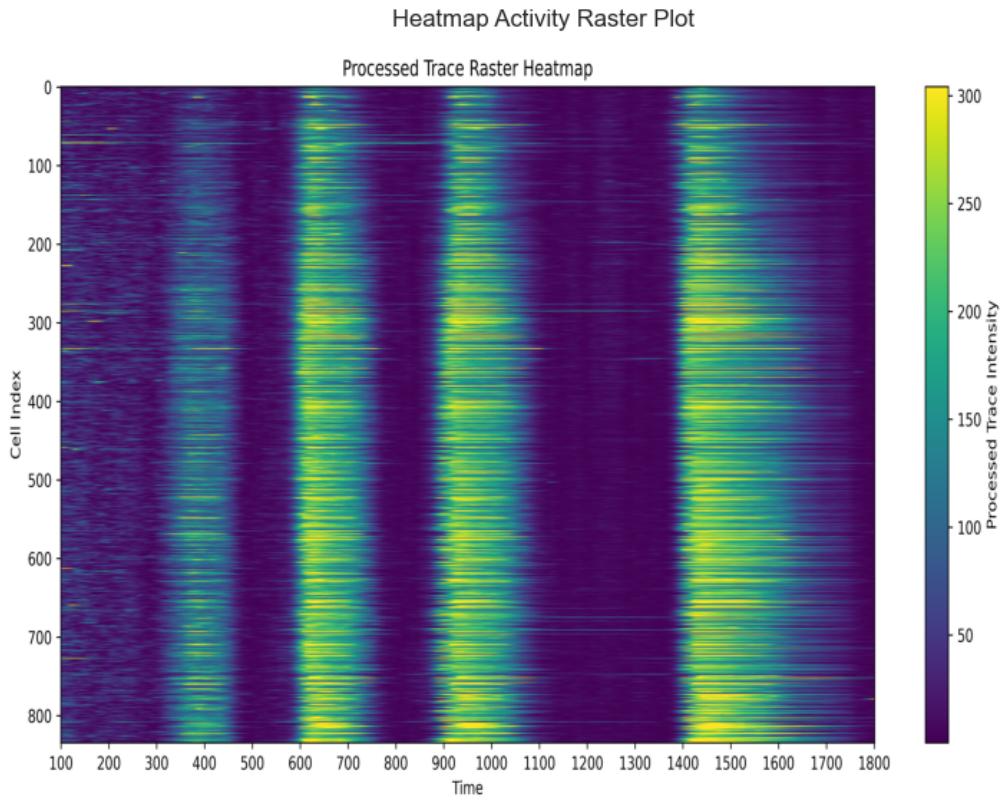
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





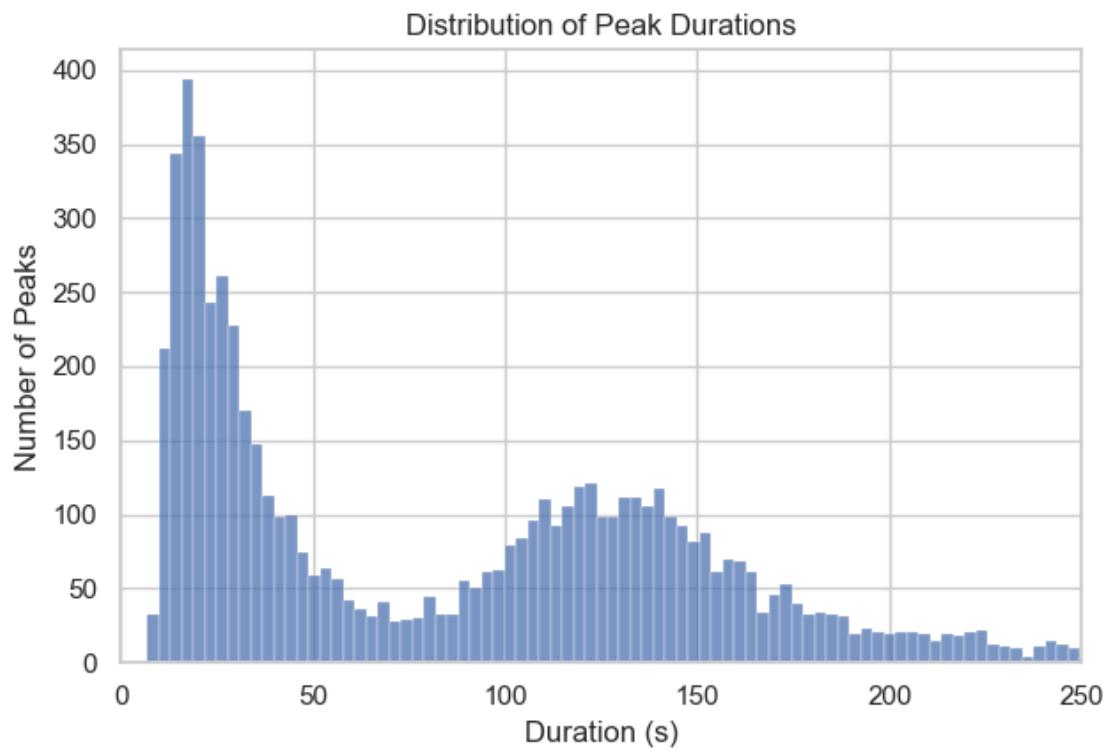
### 1.1.2 Peaks population

Total number of peaks: 6280

Total number of cells: 835

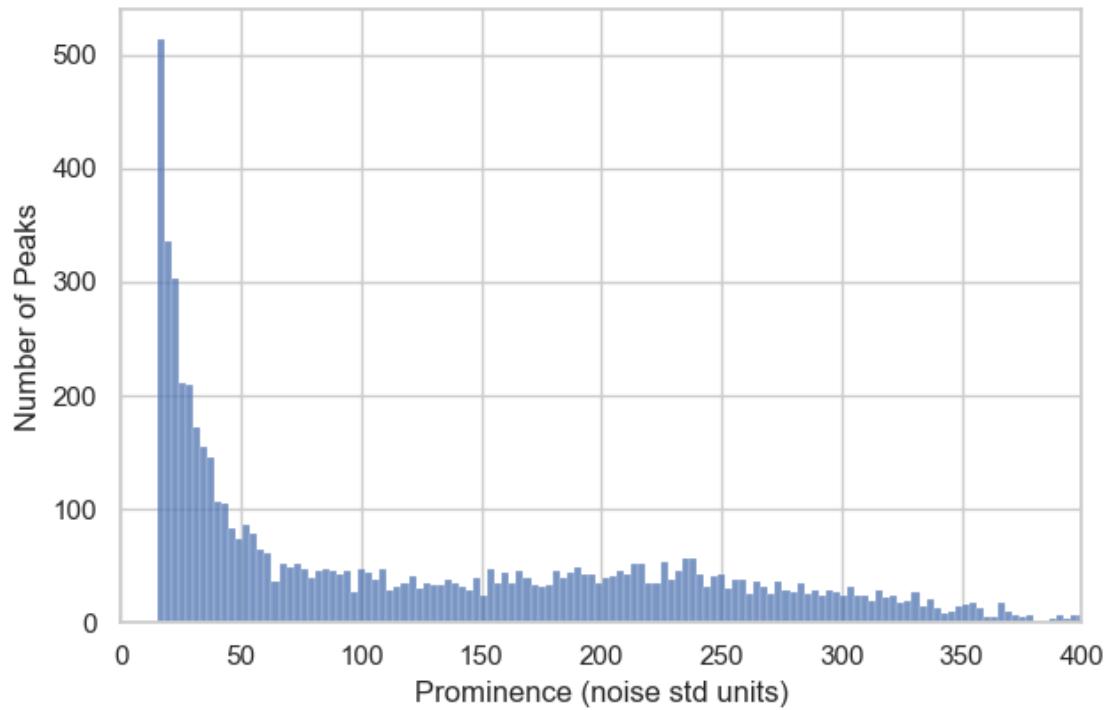
### 1.1.3 Peaks statistics

```
[2025-08-27 15:04:07] [INFO] calcium: plot_histogram: removed 0 outliers out of  
6280 on 'Duration (s)' (lower=-306, upper=464)
```

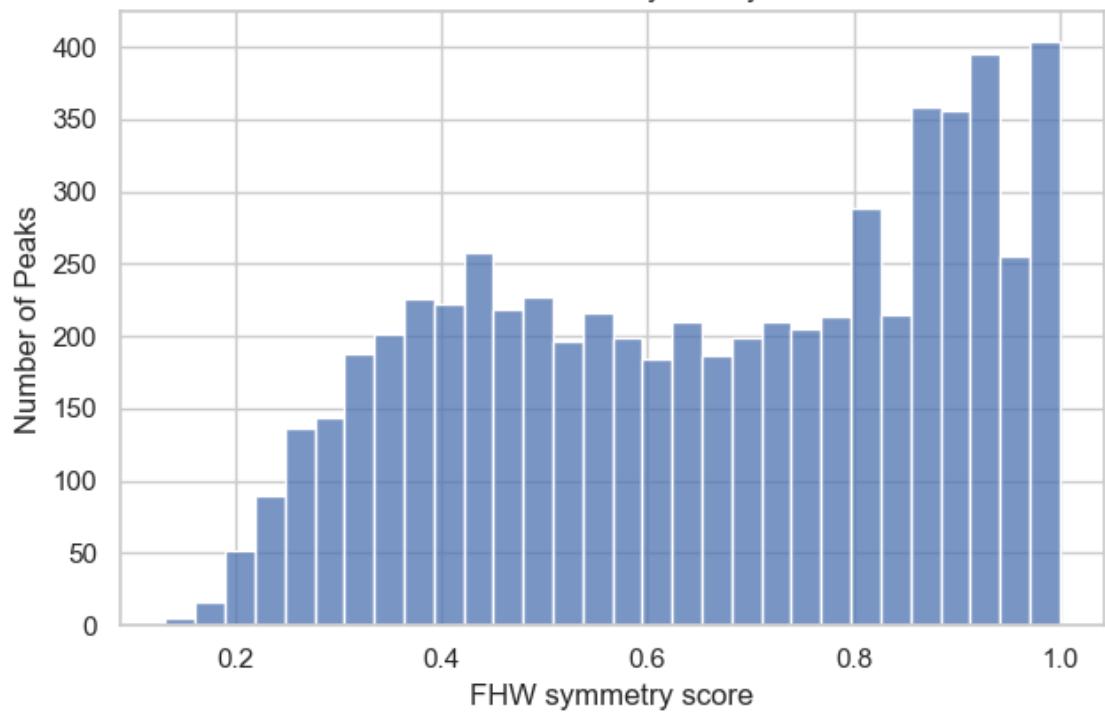


```
[2025-08-27 15:04:07] [INFO] calcium: plot_histogram: removed 0 outliers out of  
6280 on 'Prominence (noise std units)' (lower=-524.88, upper=769.6)
```

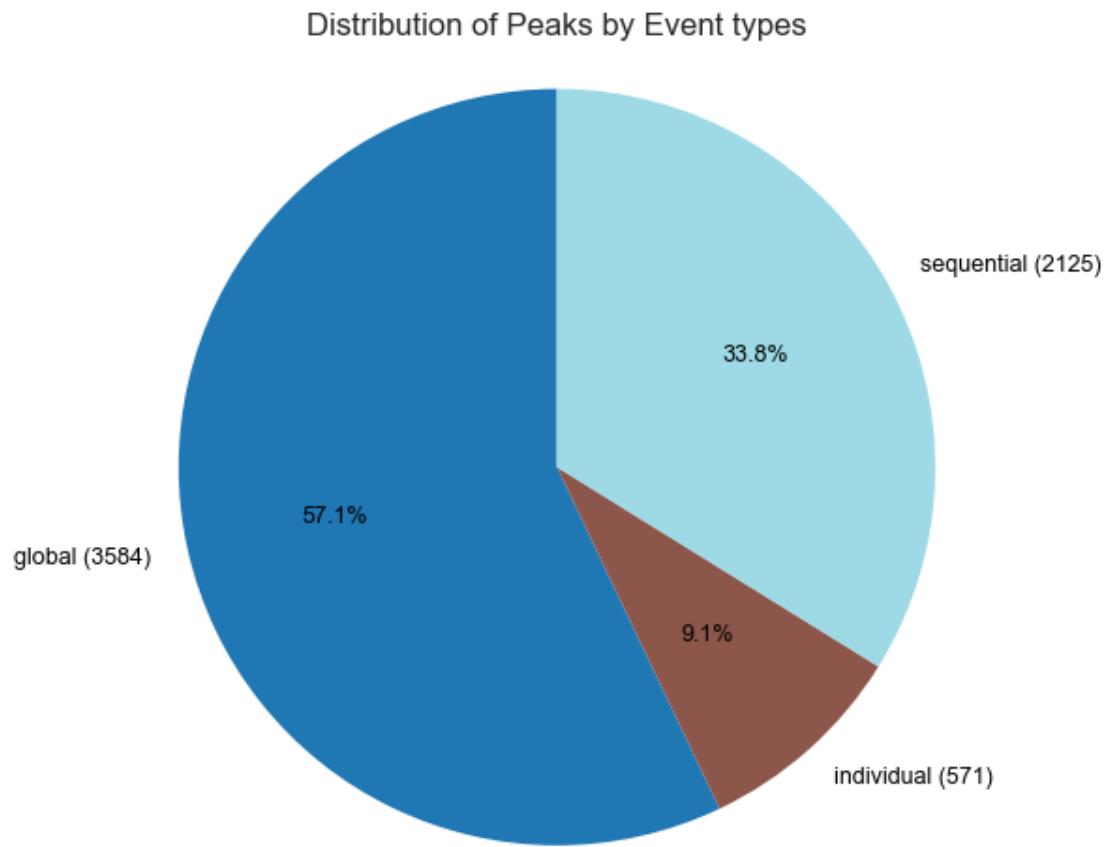
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

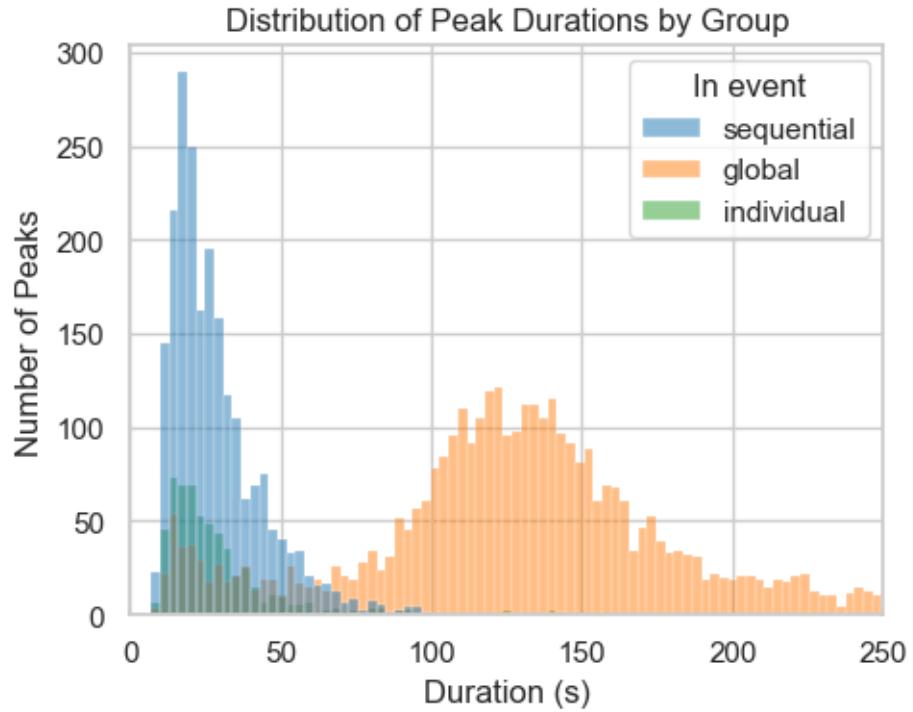


#### 1.1.4 Distribution of peaks per event types

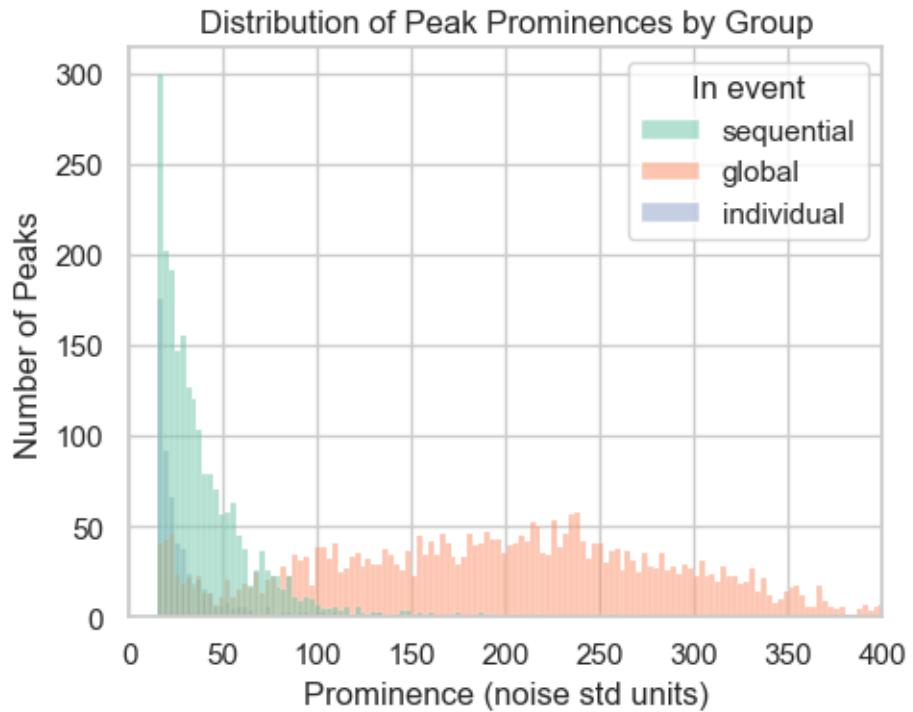


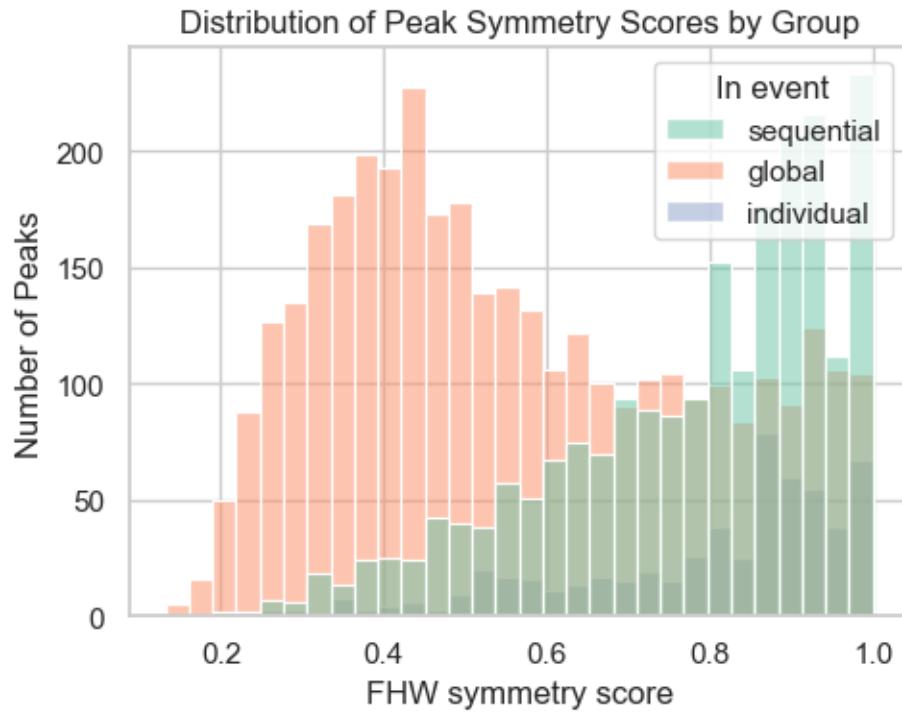
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 15:04:08] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 6280 on 'Duration (s)' (lower=-306, upper=464)
```



```
[2025-08-27 15:04:08] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 6280 on 'Prominence (noise std units)' (lower=-524.88, upper=769.6)
```

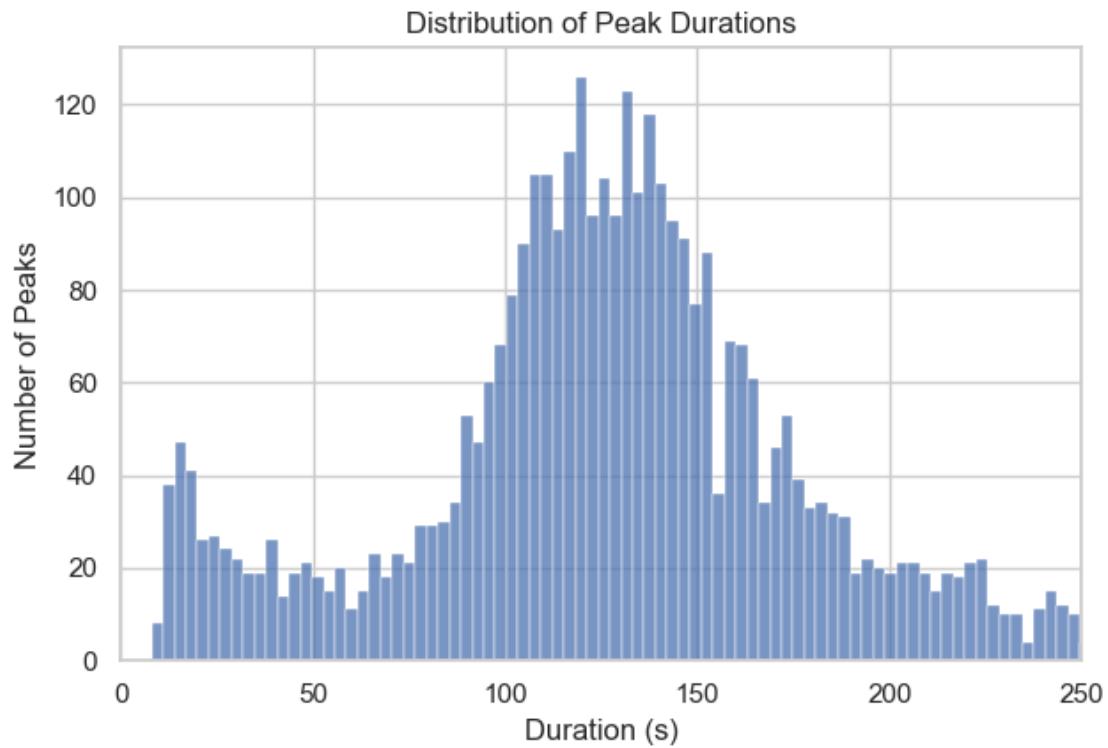




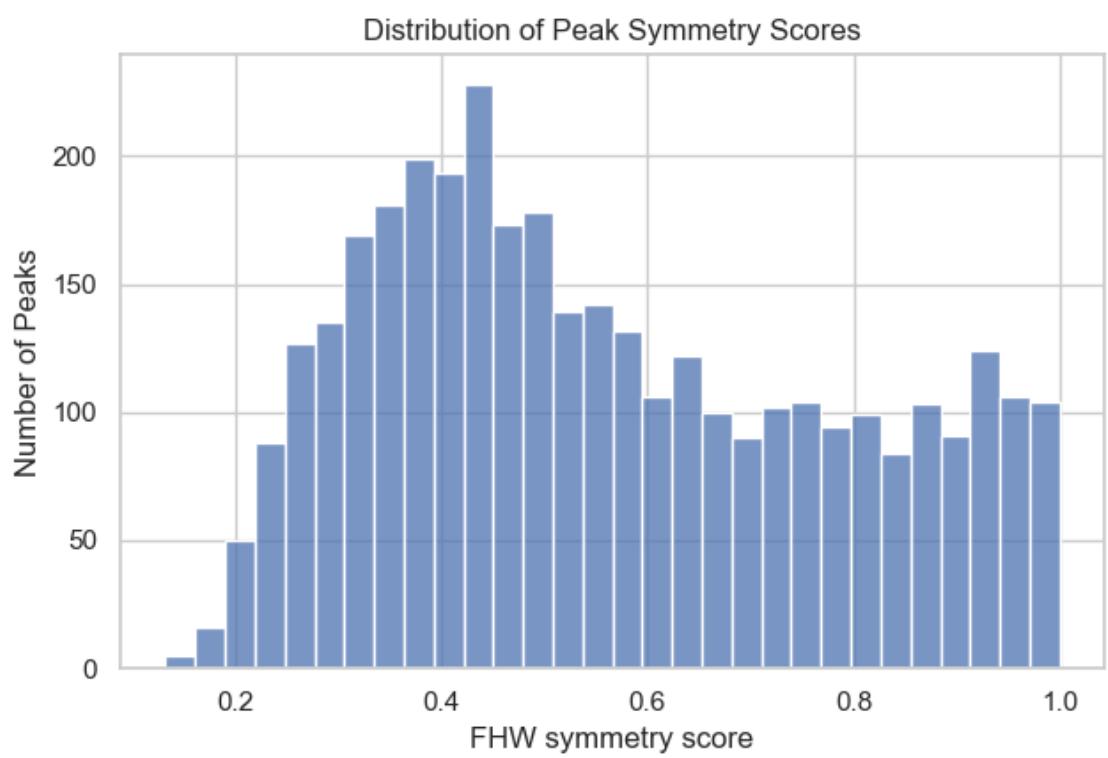
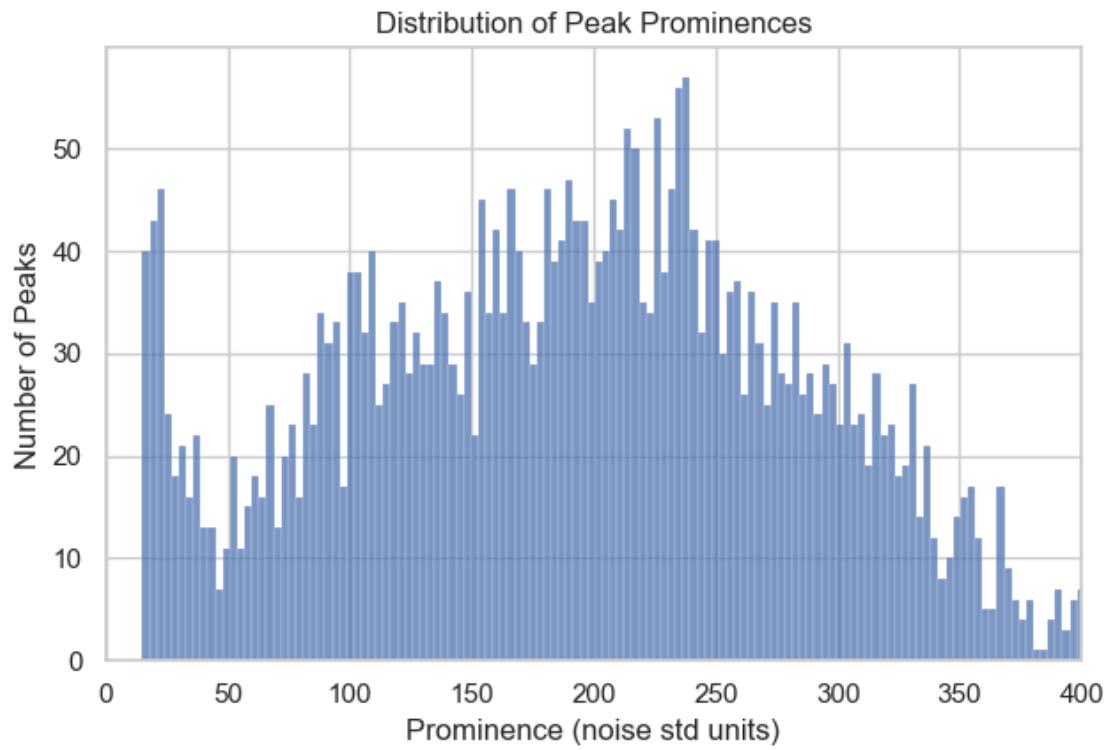
## 1.2 GLOBAL EVENTS

### 1.2.1 Peak statistics in global events

```
[2025-08-27 15:04:09] [INFO] calcium: plot_histogram: removed 5 outliers out of 3584 on 'Duration (s)' (lower=-60, upper=318)
```

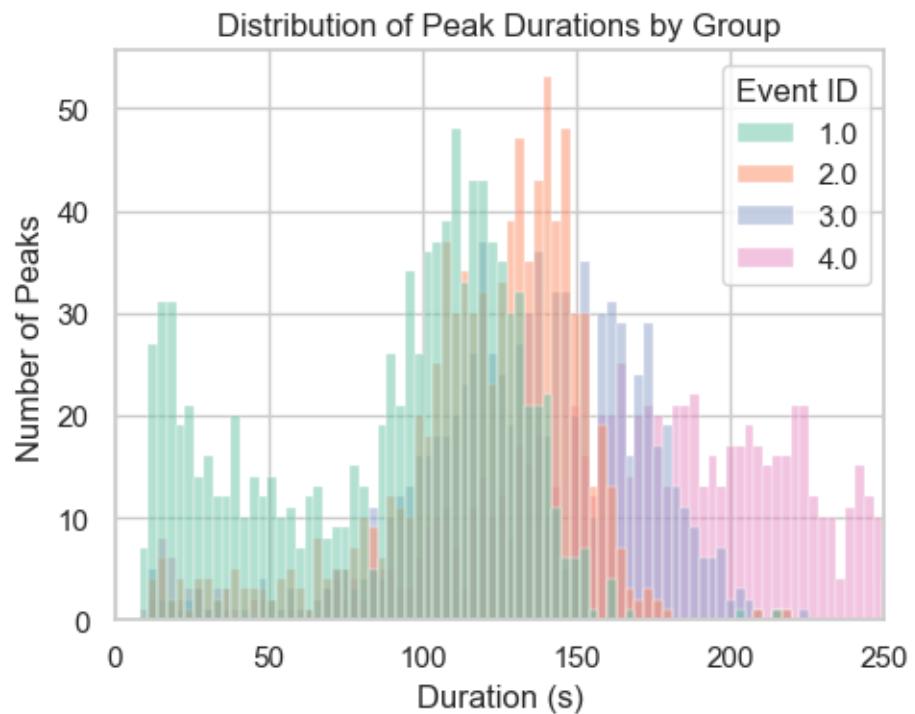


```
[2025-08-27 15:04:09] [INFO] calcium: plot_histogram: removed 0 outliers out of  
3584 on 'Prominence (noise std units)' (lower=-293.38, upper=680.85)
```

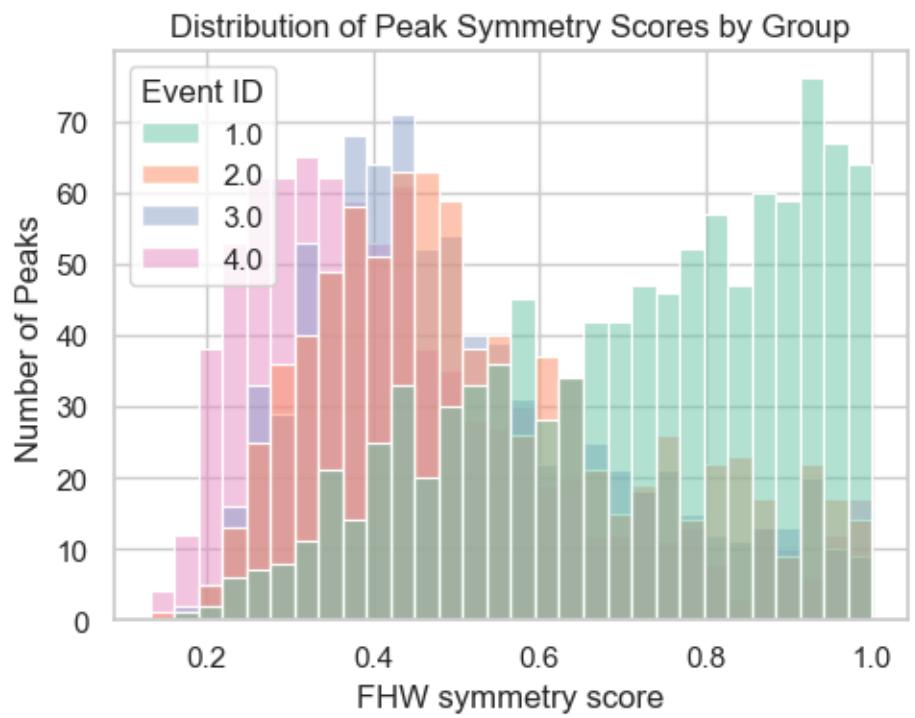
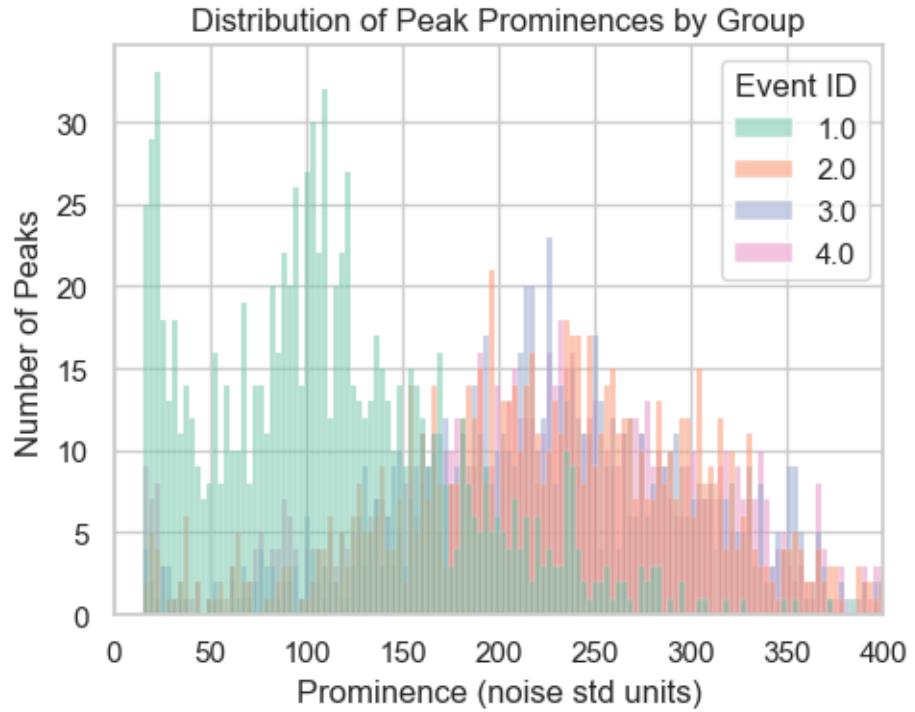


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:04:10] [INFO] calcium: plot\_histogram\_by\_group: removed 5 outliers out of 3584 on 'Duration (s)' (lower=-60, upper=318)

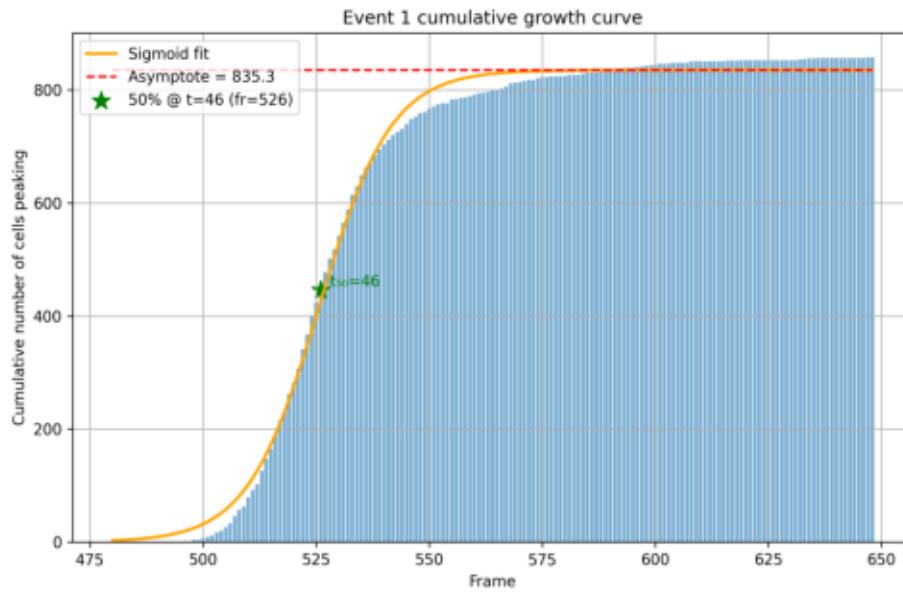


[2025-08-27 15:04:11] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 3584 on 'Prominence (noise std units)' (lower=-293.38, upper=680.85)

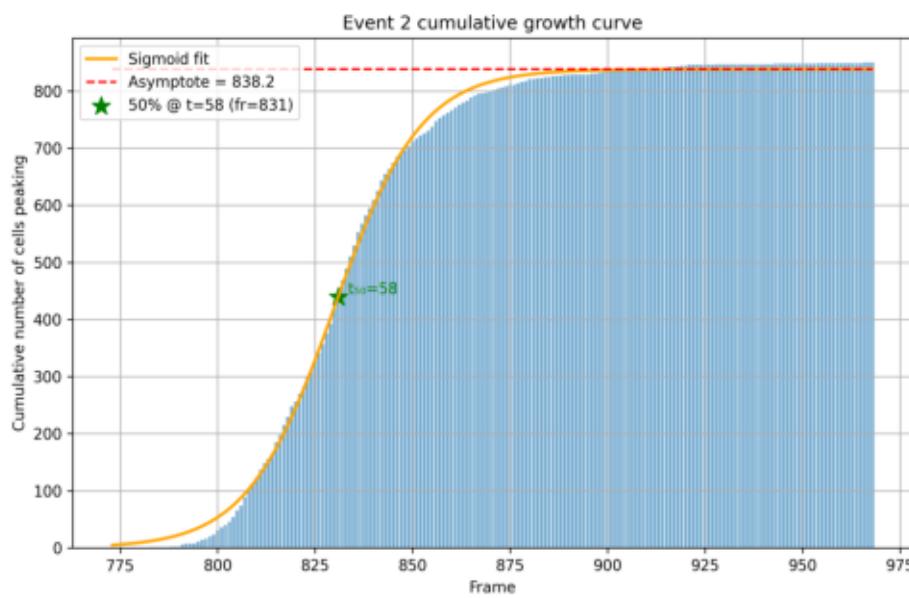


### 1.2.3 Kinetics of global events

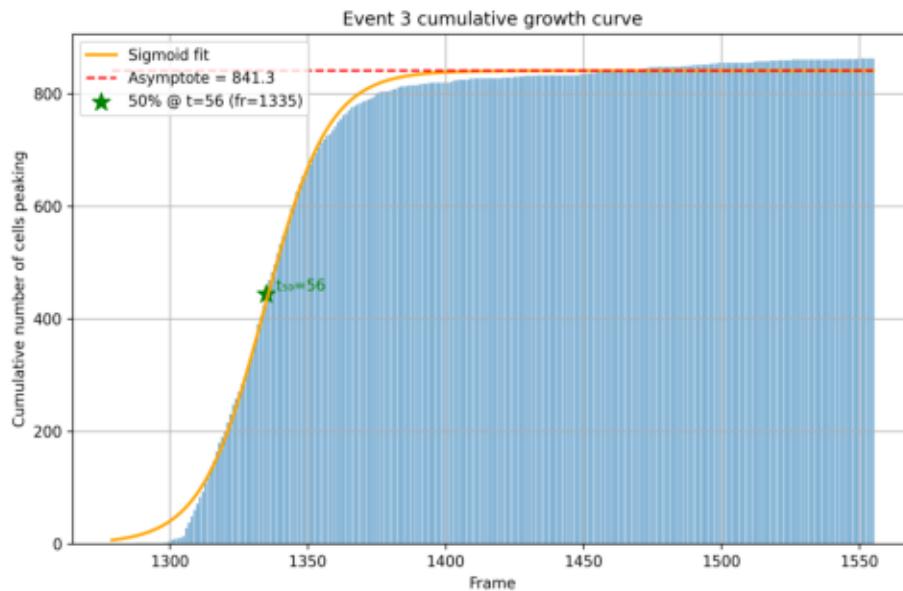
Event Activity Overlay (Event ID: 1)



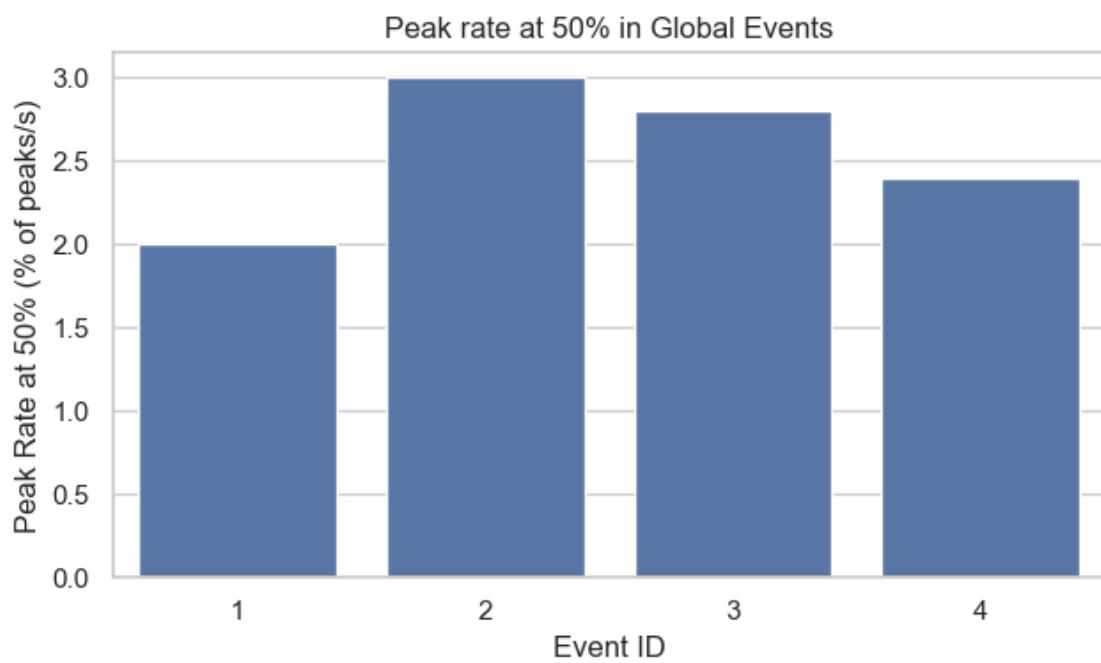
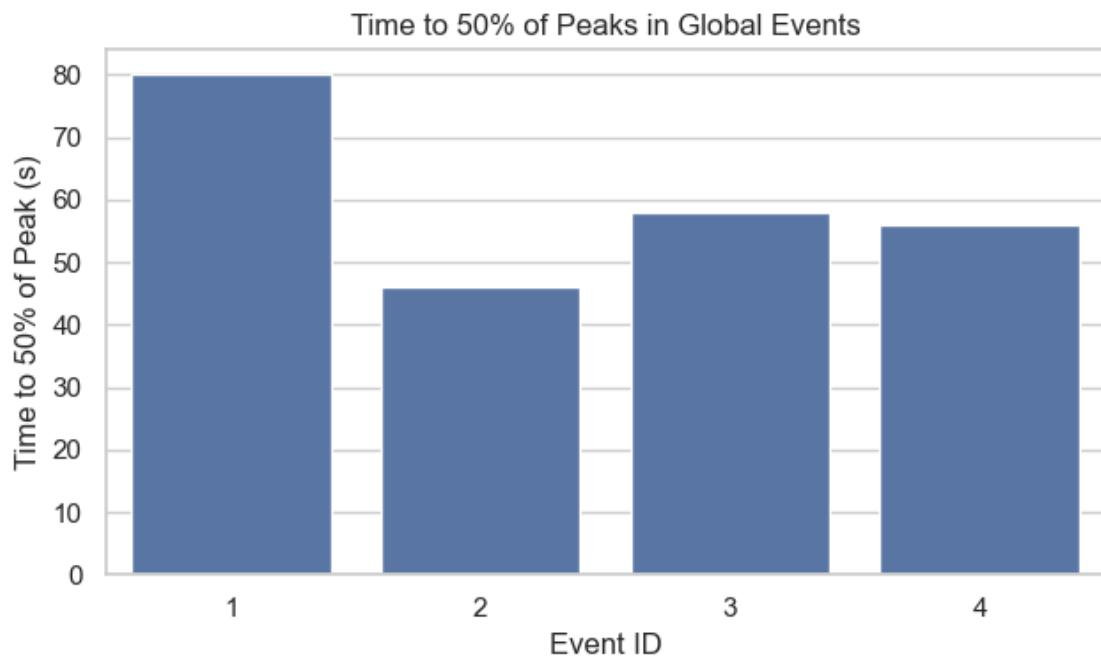
Event Activity Overlay (Event ID: 2)



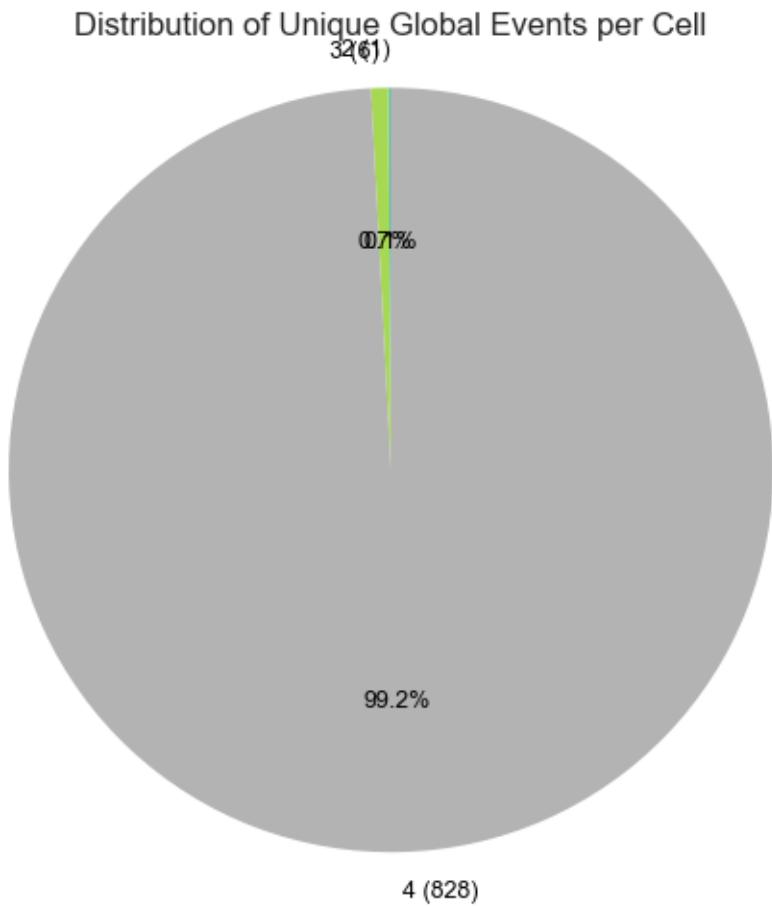
### Event Activity Overlay (Event ID: 3)



```
[2025-08-27 15:04:14] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS6\events\event-growth-curve-4.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250618\\Output\\IS6\\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\\IS6\\events\\event-growth-curve-4.png'
```



#### 1.2.4 Cells Occurrences in global events

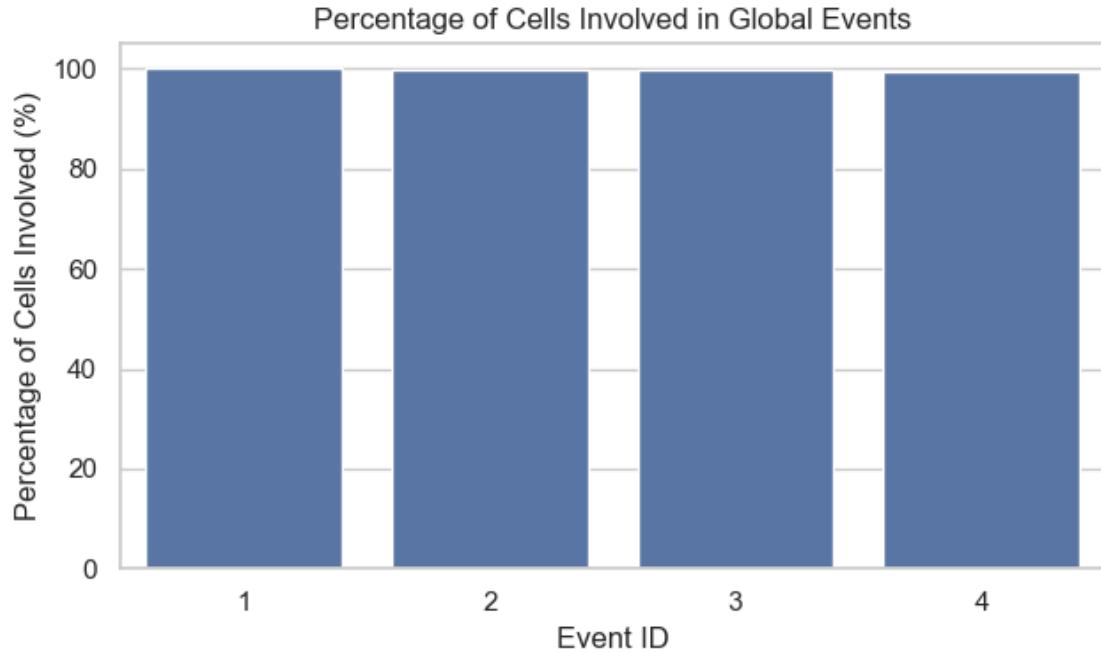


```
[2025-08-27 15:04:14] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS6\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250618\\\\Output\\\\IS6\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\20250618\Output\IS6\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [240.0, 303.0, 513.0]  
Estimated periodicity: 0.751

### 1.2.6 Early peakers in the events

```

[2025-08-27 15:04:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\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 15:04:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\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

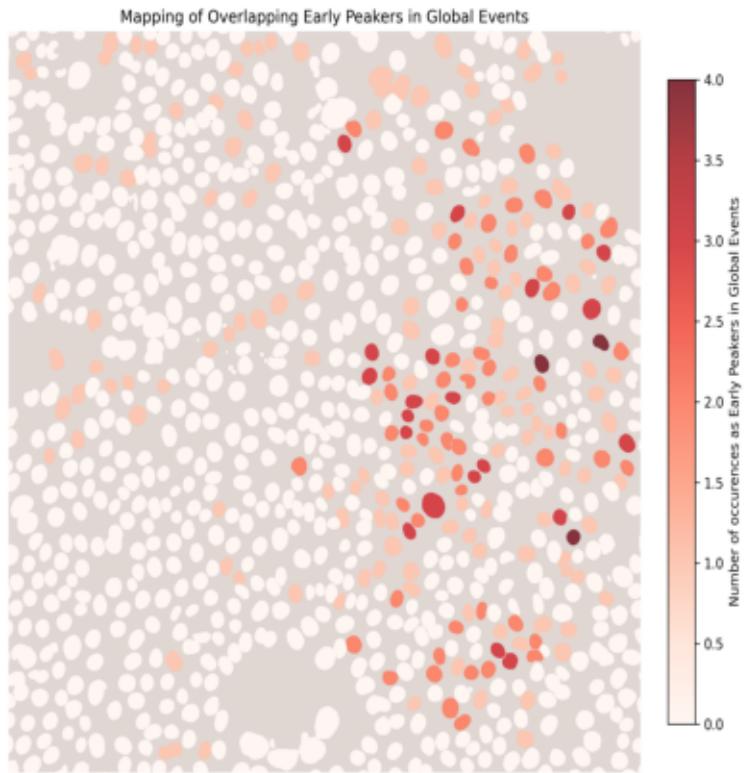
[2025-08-27 15:04:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS6\cell-
mapping\global_events\global_event_3_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\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)

```

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

[2025-08-27 15:04:15] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\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
```

## Cell Mapping with Occurrences in Global Events Overlay



[2025-08-27 15:04:16] [WARNING] calcium: 'total\_events' is deprecated and ignored. Using 4 unique event IDs.

[2025-08-27 15:04:16] [INFO] calcium: Early peakers event-matrix: 226 cells x 4 events; black squares: 332



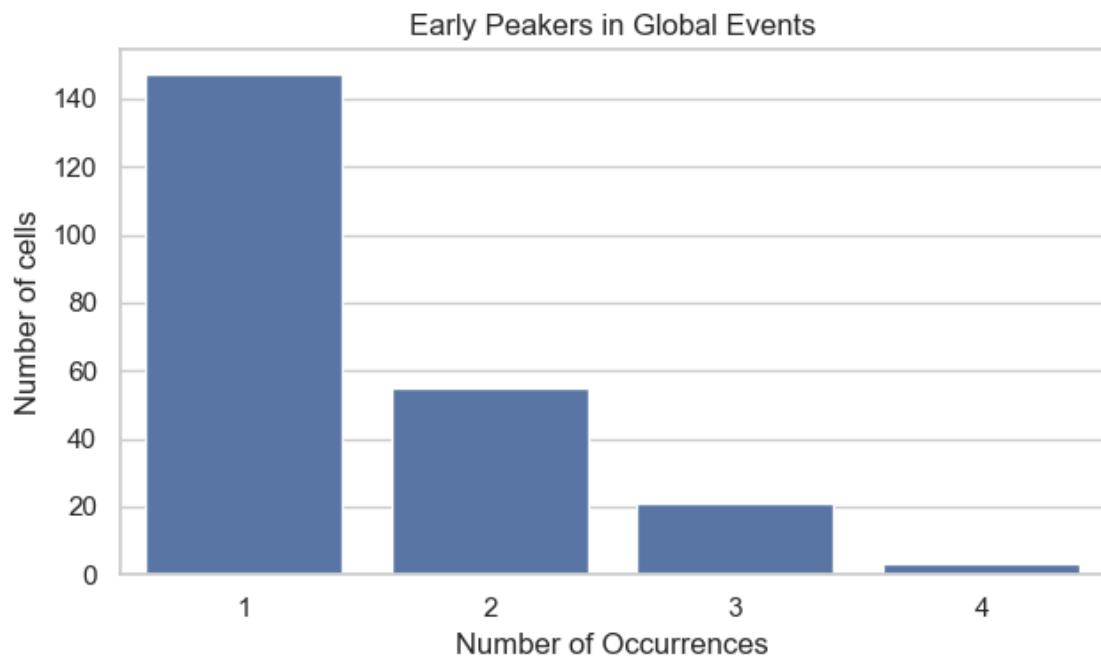
[2025-08-27 15:04:16] [INFO] calcium: Saved early peakers heatmap SVG to: early\_peakers\_heatmap.svg



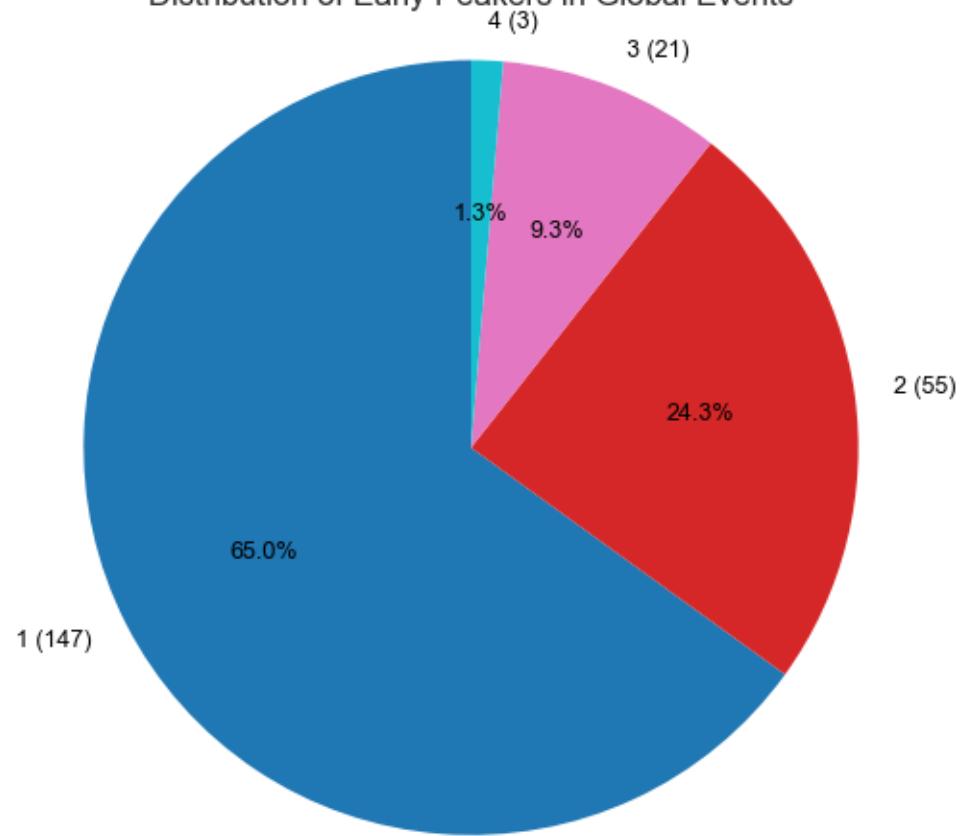
```
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 0, 1],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 1, 0],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[0, 0, 0, 1],  
[1, 0, 0, 0],  
[0, 1, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[1, 0, 0, 0],  
[0, 0, 0, 1],  
[0, 0, 0,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



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

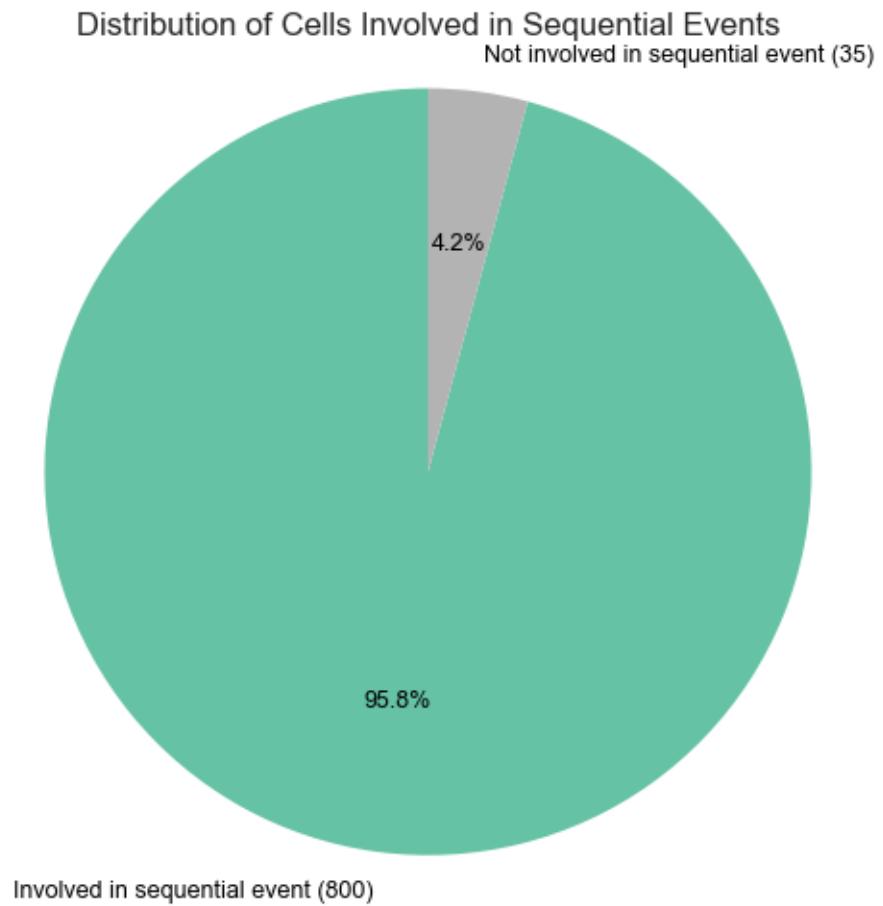


Distribution of Early Peakers in Global Events

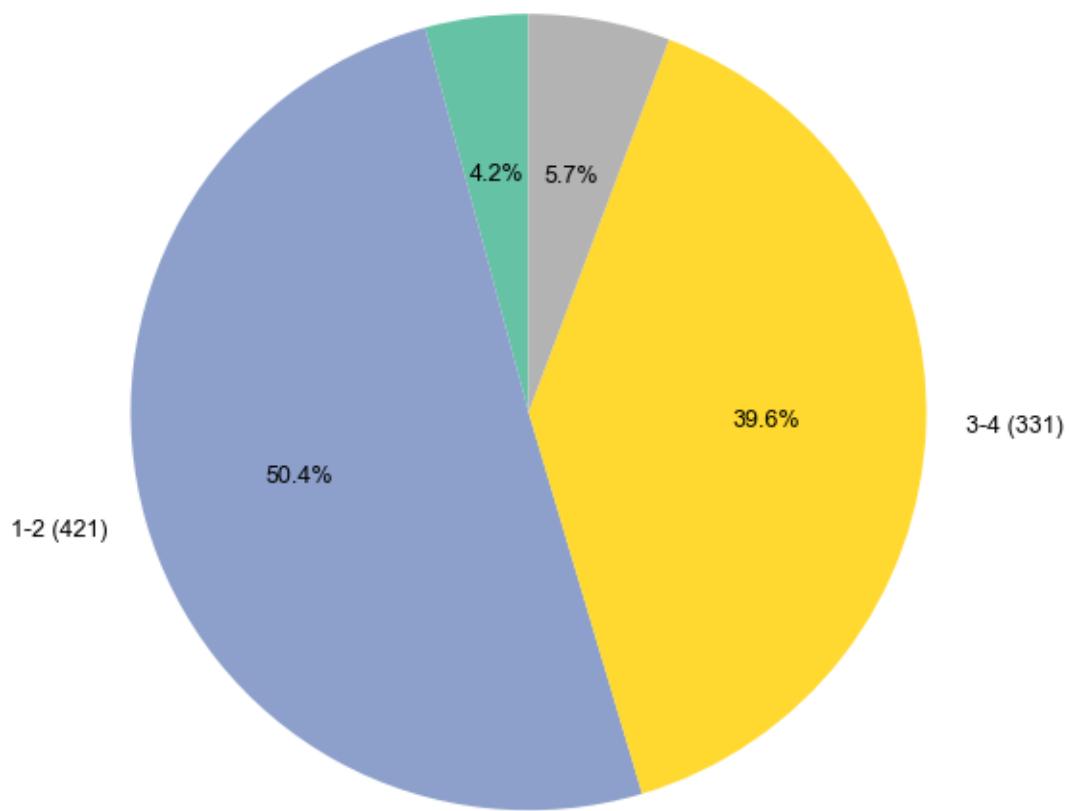


## 1.3 SEQUENTIAL EVENTS

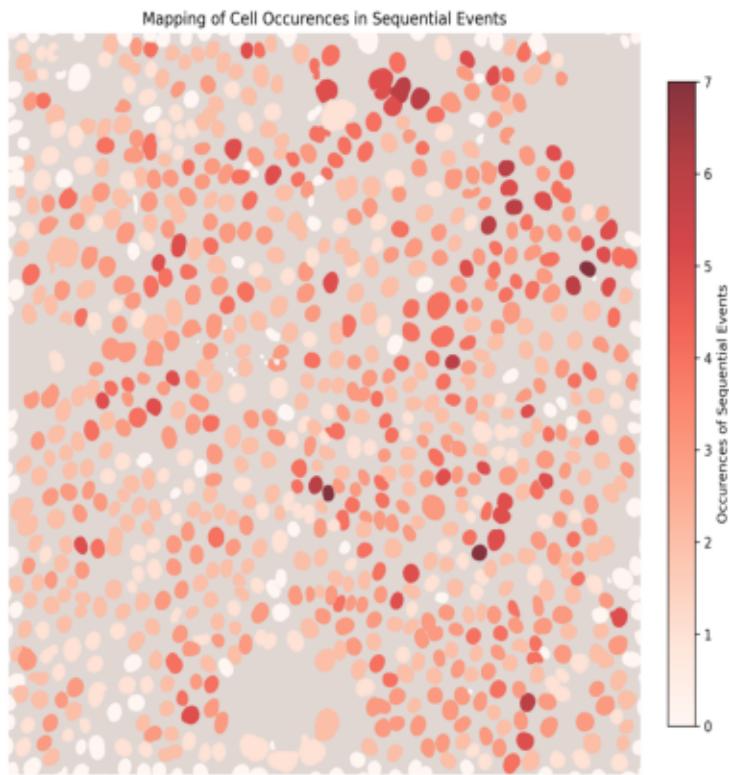
### 1.3.1 Cells Occurrences in sequential events



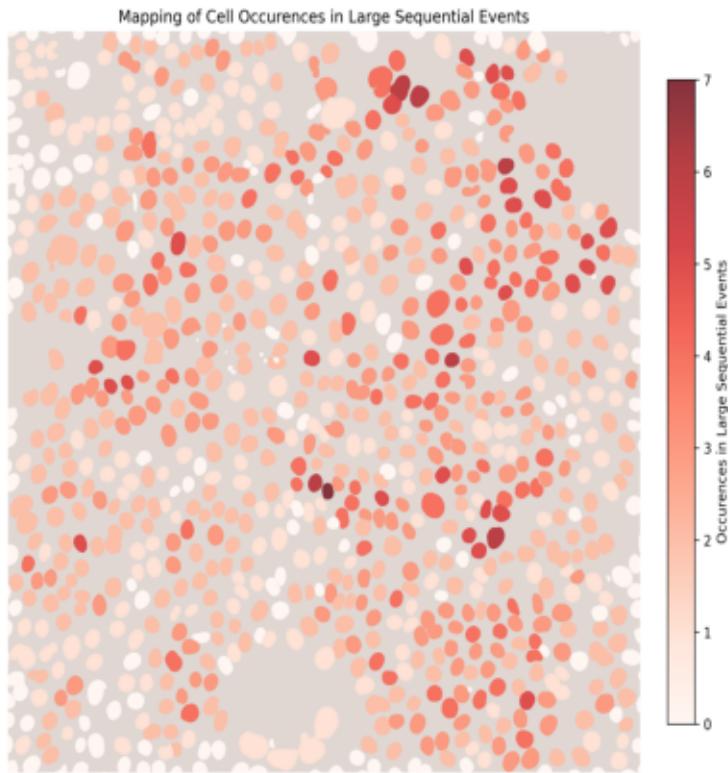
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

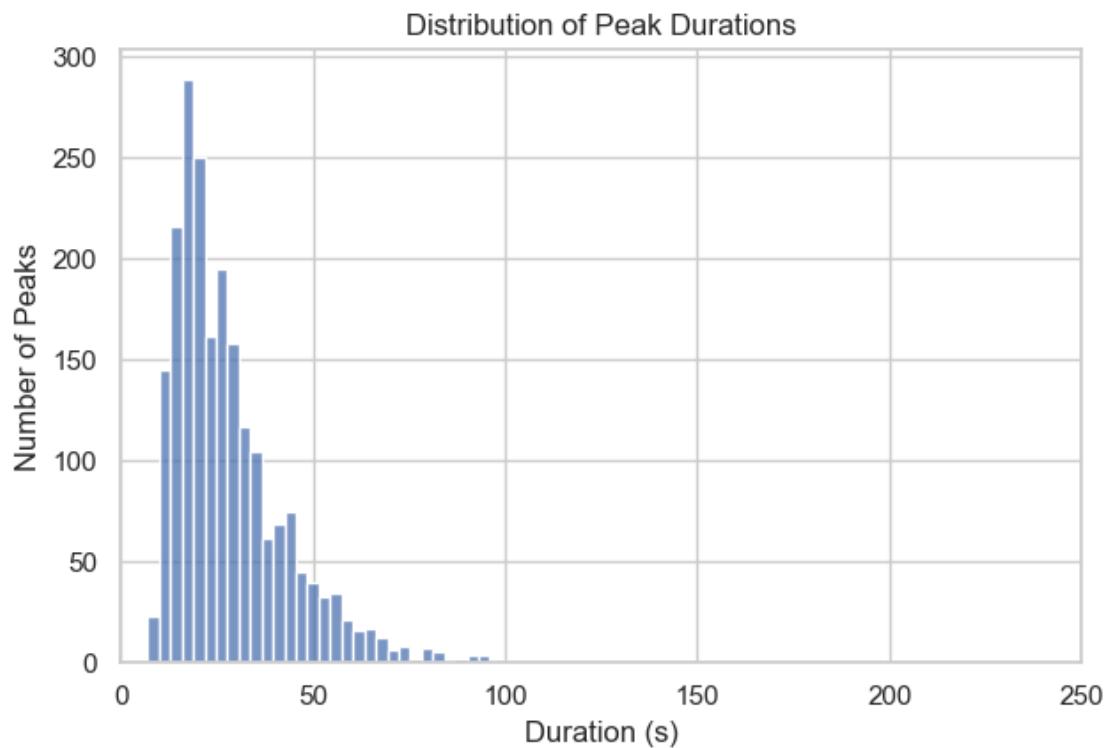


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)



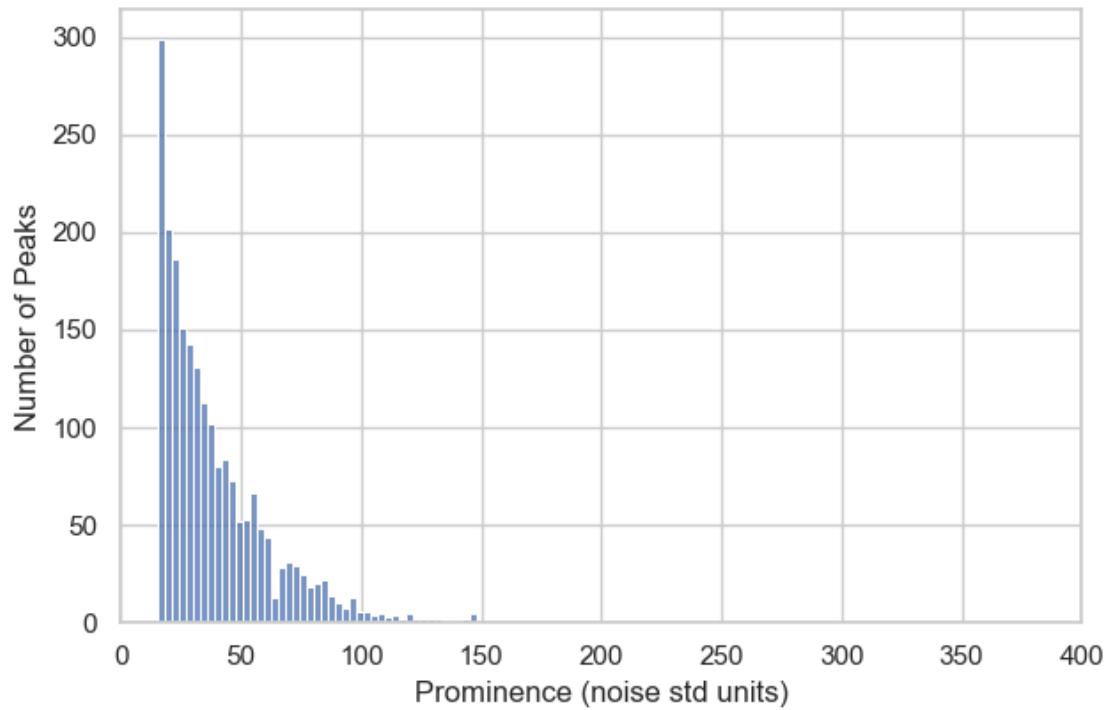
### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:04:19] [INFO] calcium: plot_histogram: removed 2 outliers out of  
2125 on 'Duration (s)' (lower=-10, upper=98)
```

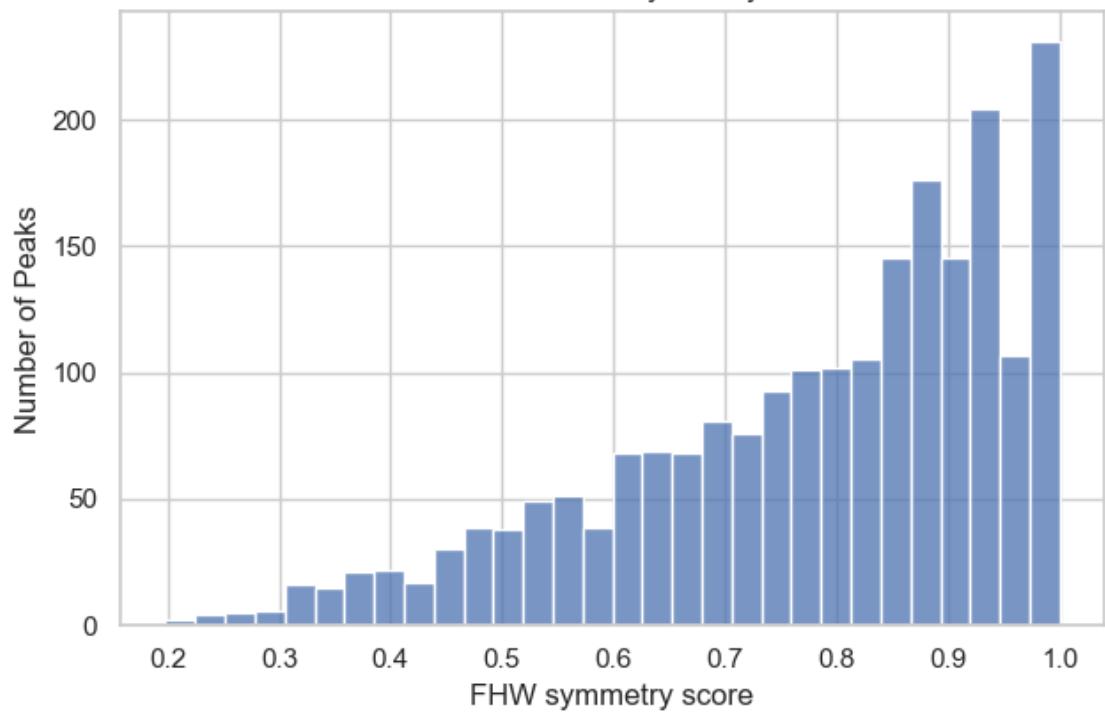


```
[2025-08-27 15:04:19] [INFO] calcium: plot_histogram: removed 17 outliers out of  
2125 on 'Prominence (noise std units)' (lower=-21.05, upper=148.75)
```

Distribution of Peak Prominences

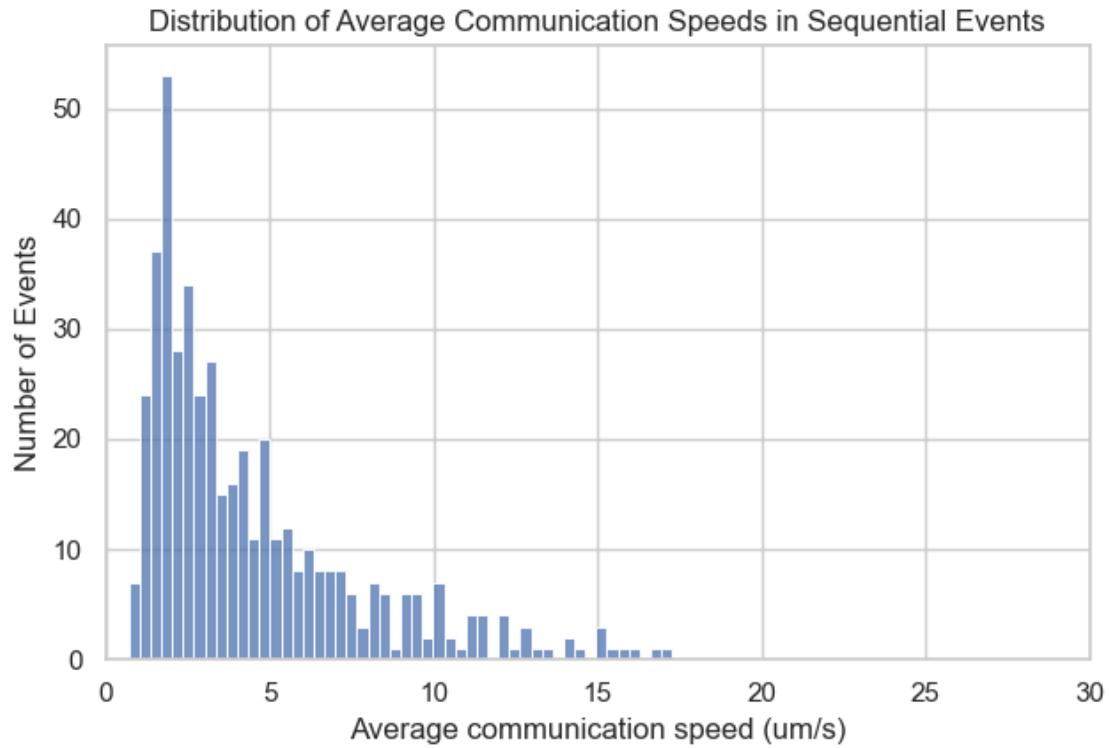


Distribution of Peak Symmetry Scores



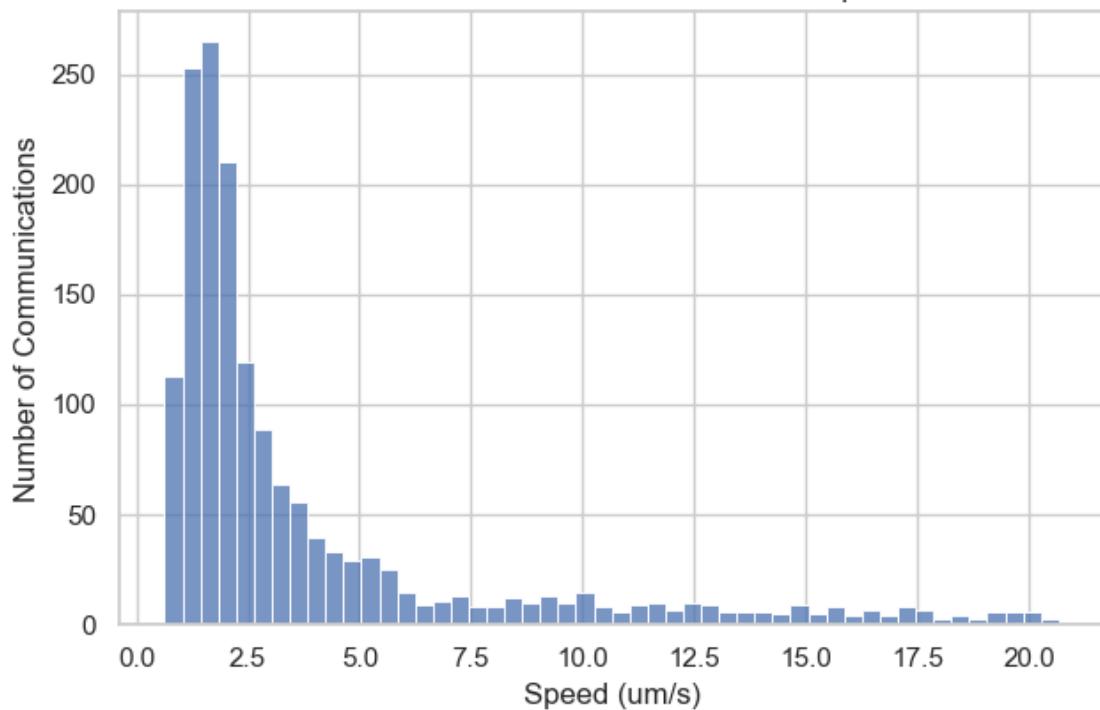
### 1.3.3 Cell-cell communication speed

[2025-08-27 15:04:19] [INFO] calcium: plot\_histogram: removed 6 outliers out of 462 on 'Average communication speed (um/s)' (lower=-10.1, upper=18.093)

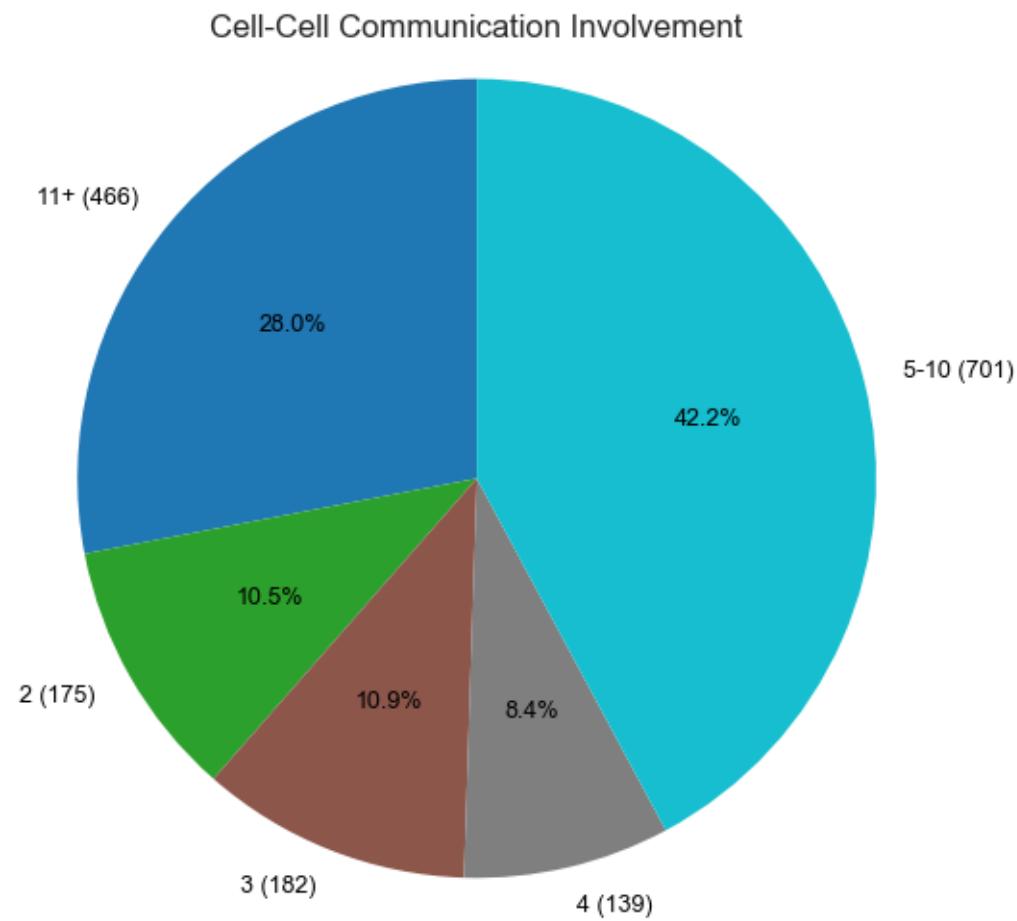


[2025-08-27 15:04:20] [INFO] calcium: plot\_histogram: removed 47 outliers out of 1663 on 'Speed (um/s)' (lower=-8.12, upper=20.77)

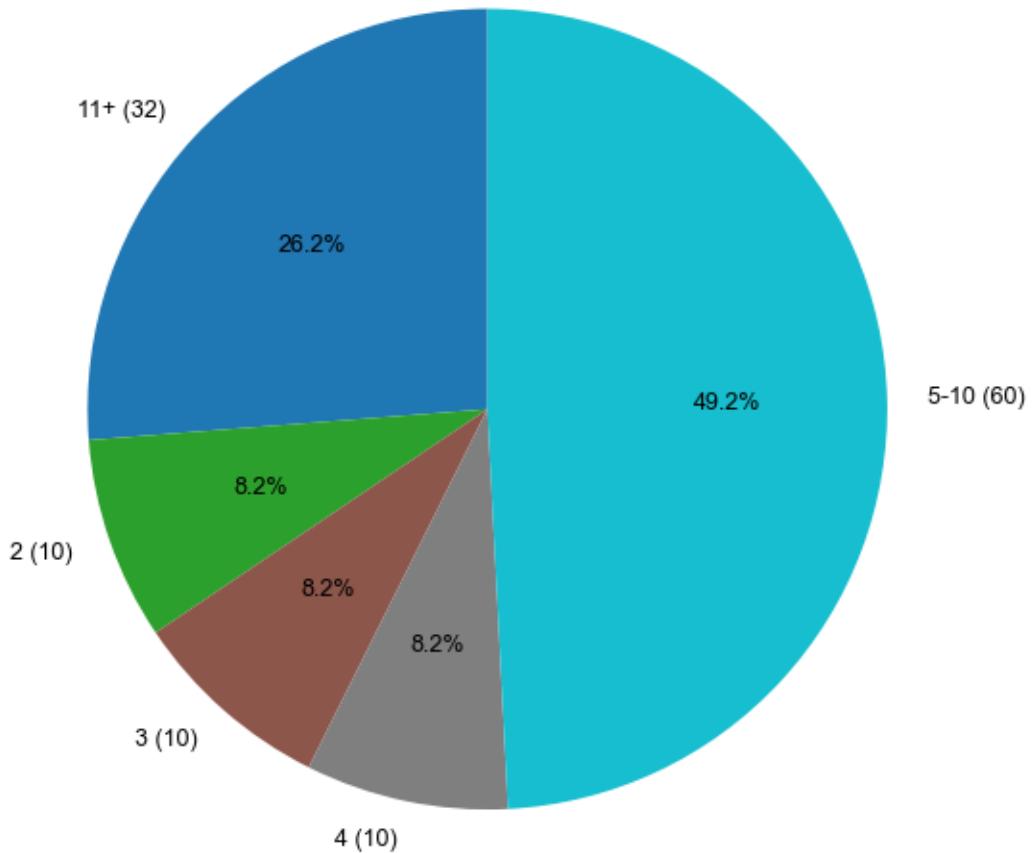
Distribution of Cell-Cell Communication Speeds



#### 1.3.4 Double distribution in cell-cell communication speeds

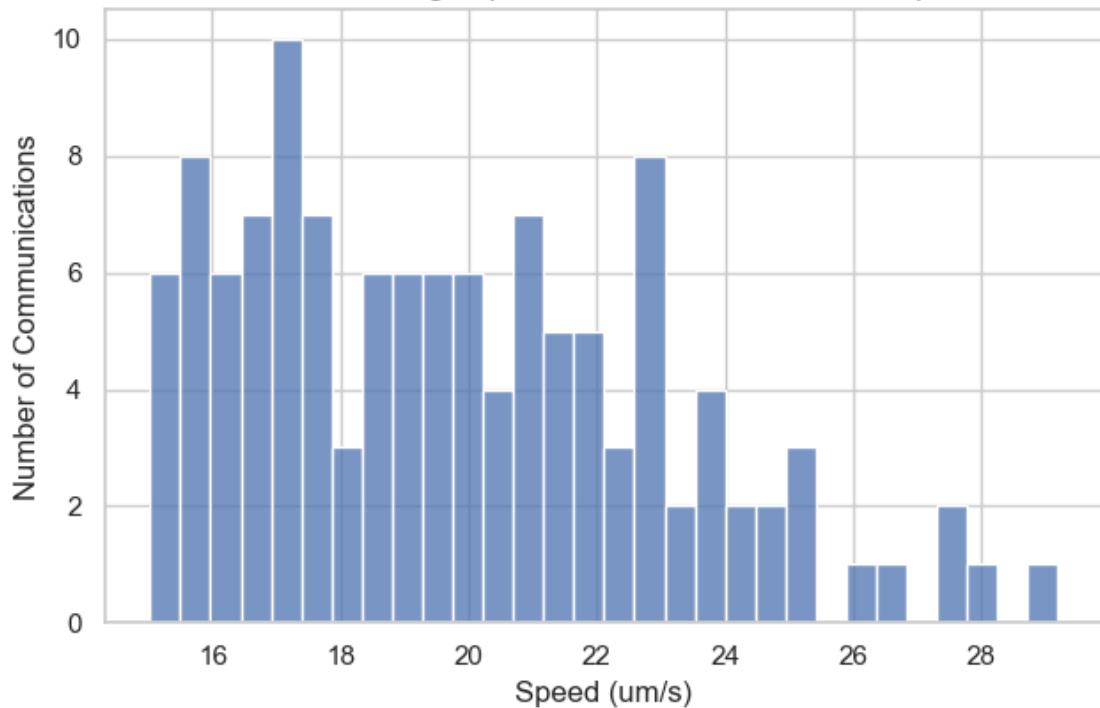


### High Speed Cell-Cell Communication Involvement



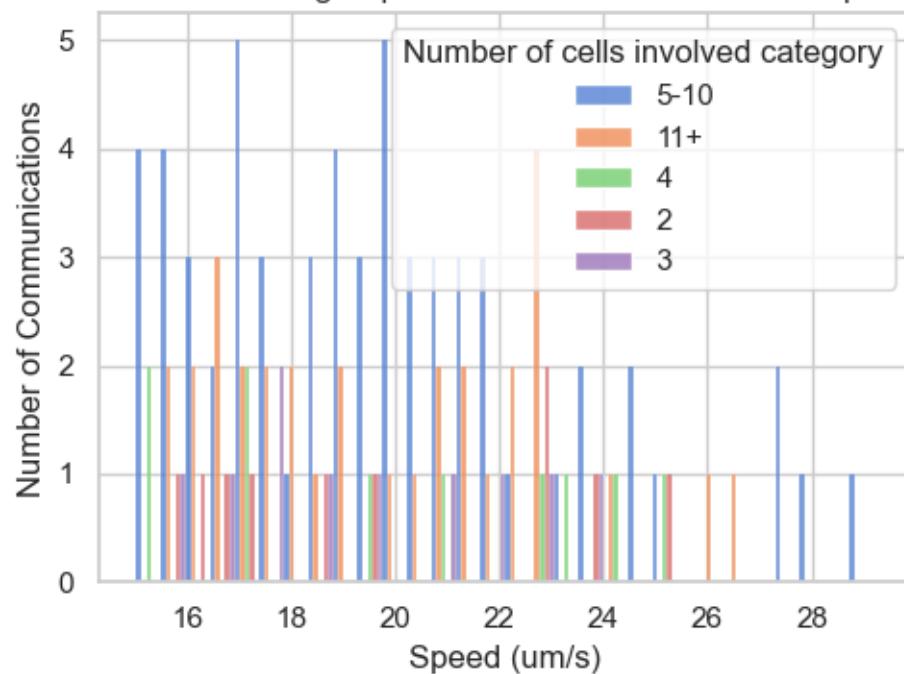
```
[2025-08-27 15:04:20] [INFO] calcium: plot_histogram: removed 0 outliers out of  
122 on 'Speed (um/s)' (lower=2.435, upper=36.84)
```

Distribution of High Speed Cell-Cell Communication Speeds

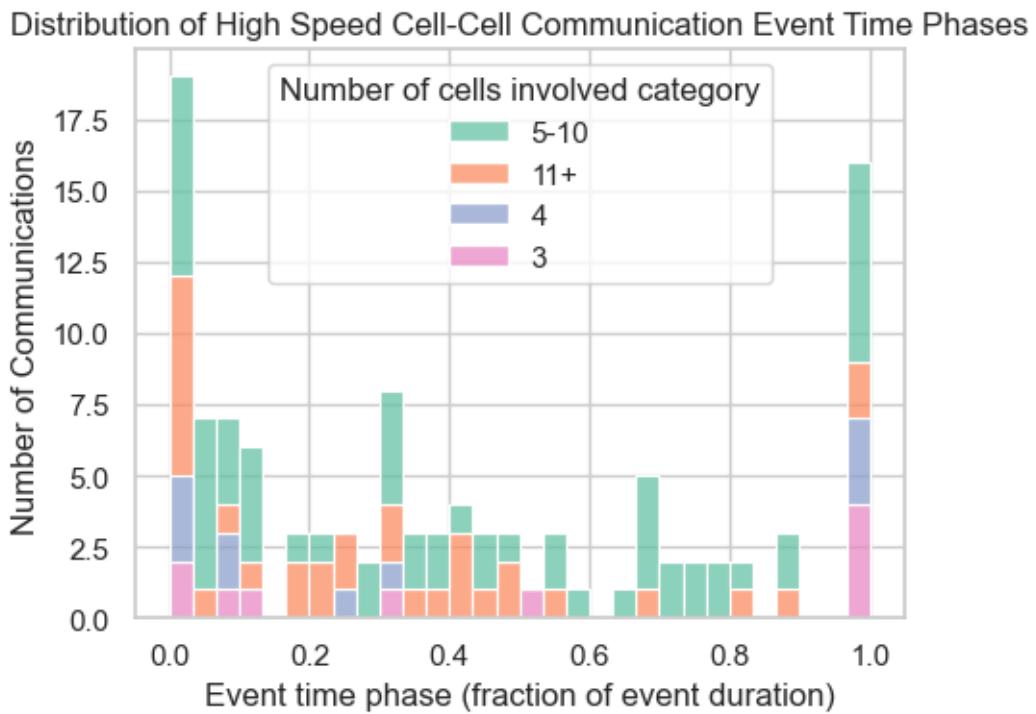


```
[2025-08-27 15:04:20] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 122 on 'Speed (um/s)' (lower=2.435, upper=36.84)
```

Distribution of High Speed Cell-Cell Communication Speeds

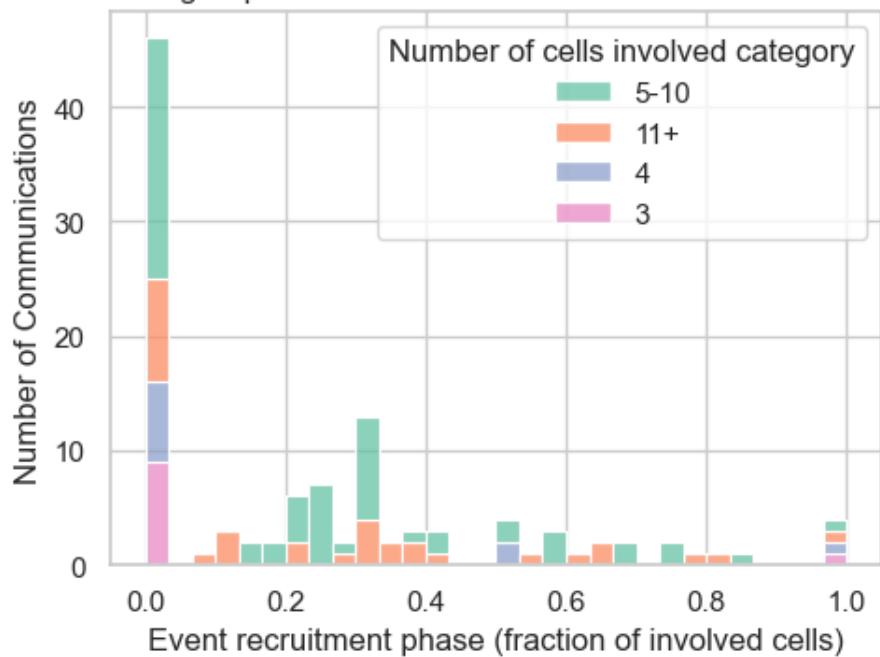


[2025-08-27 15:04:21] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 112 on 'Event time phase (fraction of event duration)' (lower=-1.7675, upper=2.52)

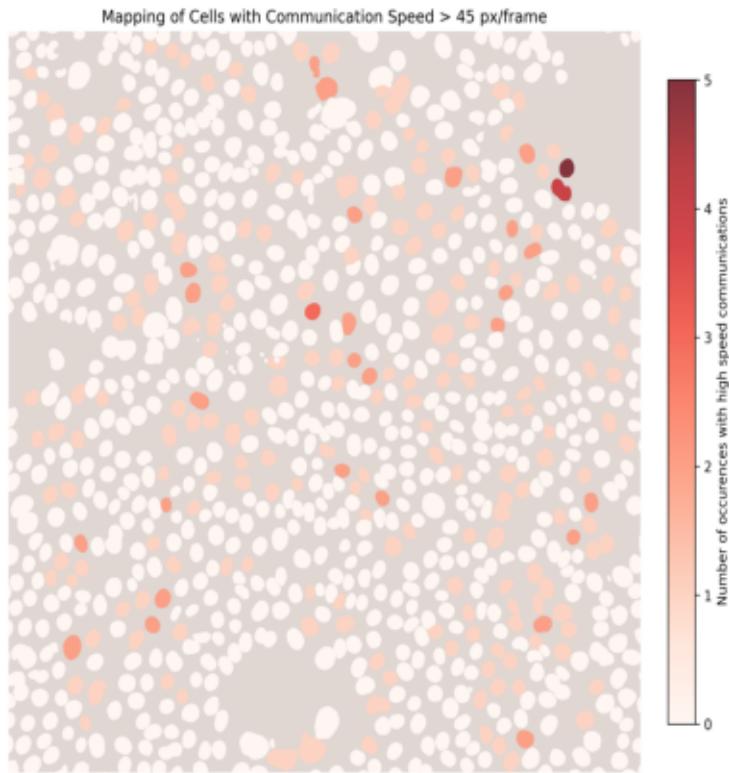


[2025-08-27 15:04:21] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 112 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.0725, upper=1.43)

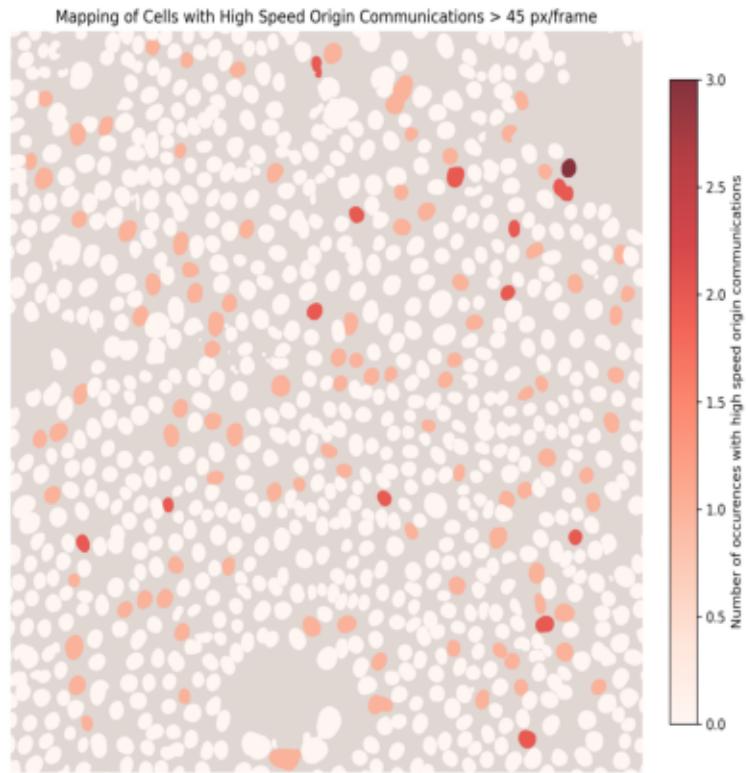
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	\
16	3015530755888	6	470		1
41	3015530749600	9	609		2
43	3015530743600	9	645		2
45	3015475878912	9	519		2
46	3015475885968	9	558		1
...	...	...	...	...	
1523	3015498428048	405	1111		0
1530	3015498430832	411	1154		6
1556	3015498417296	424	1128		1
1607	3015507250720	440	1264		3
1651	3015507257632	459	1335		1

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
16	418	1	108.0	108.0	
41	558	1	157.0	157.0	
43	616	1	154.0	154.0	
45	507	1	158.0	159.0	
46	519	2	157.0	158.0	
...	...	...	...	...	
1523	1108	0	32.0	33.0	
1530	1114	8	1134.0	1135.0	
1556	1187	2	101.0	102.0	
1607	1262	5	737.0	738.0	
1651	1375	1	68.0	69.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
16	0.0	25.16	25.16		
41	0.0	26.60	26.60		
43	0.0	21.37	21.37		
45	1.0	22.82	22.82		
46	1.0	16.00	16.00		
...	...	...	...	...	
1523	1.0	16.28	16.28		
1530	1.0	15.85	15.85		
1556	1.0	22.83	22.83		
1607	1.0	16.57	16.57		
1651	1.0	18.59	18.59		
	Event time phase (fraction of event duration)	\			
16		0.00			
41		0.31			
43		0.26			
45		0.35			
46		0.33			
...		...			
1523		NaN			
1530		NaN			
1556		NaN			
1607		1.00			
1651		0.08			
	Event recruitment phase (fraction of involved cells)	dataset	\		
16		0.00	20250618_IS6		
41		0.22	20250618_IS6		
43		0.09	20250618_IS6		
45		0.39	20250618_IS6		
46		0.35	20250618_IS6		
...		...	...		
1523		NaN	20250618_IS6		
1530		NaN	20250618_IS6		

1556		NaN	20250618_IS6
1607		1.00	20250618_IS6
1651		0.00	20250618_IS6

	Number of cells involved	category	Speed category
16		5-10	High speed
41		11+	High speed
43		11+	High speed
45		11+	High speed
46		11+	High speed
...	...	...	...
1523		2	High speed
1530		2	High speed
1556		2	High speed
1607		3	High speed
1651		3	High speed

[122 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
189		0	3
195		0	2
197		0	1
198		1	3
199		0	1
...	...	...	...
1367		0	1
1371		0	2
1372		1	1
1374		0	1
1375		0	2

[644 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
0	189	207.03	6.83
3	195	100.42	9.10
5	197	343.20	9.75
6	198	111.80	10.72
7	199	160.88	10.72
..	...	...	...
827	1367	433.23	488.80
830	1371	412.43	489.45
831	1372	216.78	489.45
833	1374	482.30	490.75
834	1375	396.82	491.40

Number of peaks Is active Occurrences in global events \

0	11	True	4
3	11	True	4
5	6	True	4
6	10	True	4
7	10	True	4
..	..	..	..
827	6	True	4
830	7	True	4
831	7	True	4
833	8	True	4
834	8	True	4

Occurrences in global events as early peaker			Early peaker event IDs
0		1	[1]
3		1	[1]
5		1	[1]
6		1	[1]
7		0	[]
..	..	..	..
827		0	[]
830		0	[]
831		0	[]
833		0	[]
834		0	[]

Occurrences in sequential events		
0		2
3		3
5		1
6		4
7		2
..	..	..
827		1
830		2
831		1
833		1
834		4

Occurrences in sequential events as origin		
0		1
3		1
5		1
6		2
7		1
..	..	..
827		0
830		0
831		1

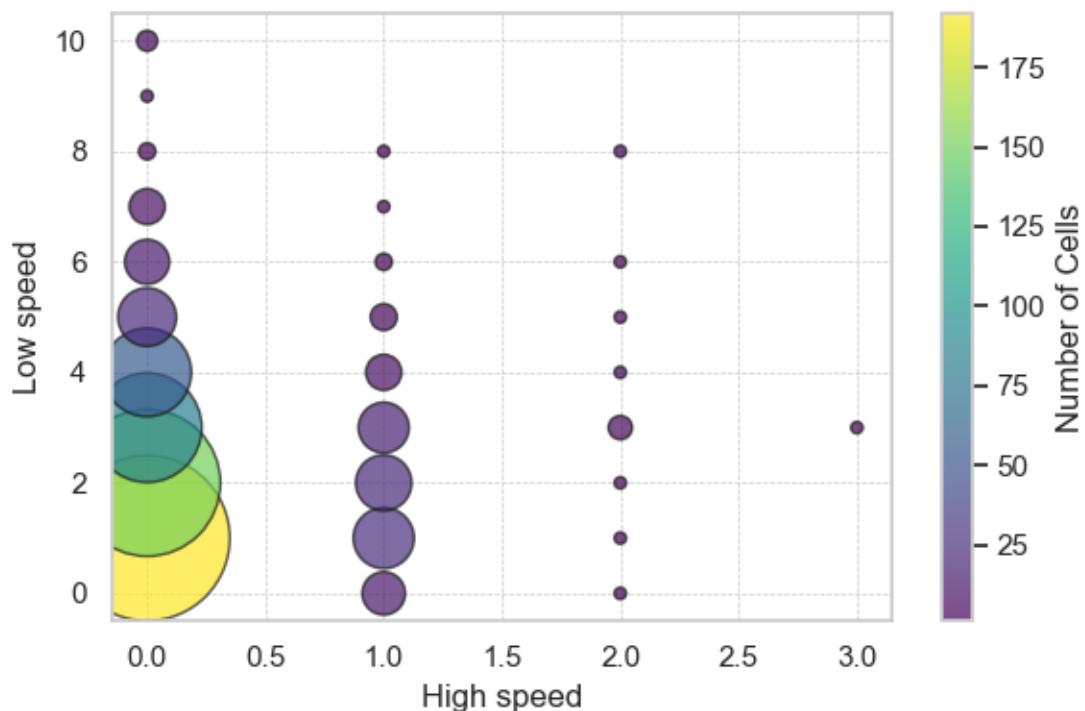
833		1	
834		1	
Occurrences in individual events Peak frequency (Hz) Periodicity score \			
0	3	0.0065	0.66
3	2	0.0065	0.49
5	0	0.0035	0.60
6	1	0.0059	0.52
7	3	0.0059	0.58
..	...	...	...
827	0	0.0035	0.62
830	0	0.0041	0.55
831	2	0.0041	0.67
833	2	0.0047	0.63
834	0	0.0047	0.53
Neighbor count Neighbors (labels) dataset \			
0	4	[200,207,230,243]	20250618_IS6
3	3	[198,217,223]	20250618_IS6
5	5	[213,220,226,259,264]	20250618_IS6
6	3	[195,206,223]	20250618_IS6
7	2	[208,219]	20250618_IS6
..	..	..	..
827	4	[1309,1321,1366,1371]	20250618_IS6
830	4	[1321,1335,1367,1375]	20250618_IS6
831	3	[1313,1342,1360]	20250618_IS6
833	2	[1339,1340]	20250618_IS6
834	4	[1335,1352,1371,1373]	20250618_IS6
Involved in sequential event Occurrences in sequential events category \			
0	Involved in sequential event		1-2
3	Involved in sequential event		3-4
5	Involved in sequential event		1-2
6	Involved in sequential event		3-4
7	Involved in sequential event		1-2
..	..	..	..
827	Involved in sequential event		1-2
830	Involved in sequential event		1-2
831	Involved in sequential event		1-2
833	Involved in sequential event		1-2
834	Involved in sequential event		3-4
High speed Low speed			
0	0.0	3.0	
3	0.0	2.0	
5	0.0	1.0	
6	1.0	3.0	
7	0.0	1.0	

```

...
827      0.0      1.0
830      0.0      2.0
831      1.0      1.0
833      0.0      1.0
834      0.0      2.0

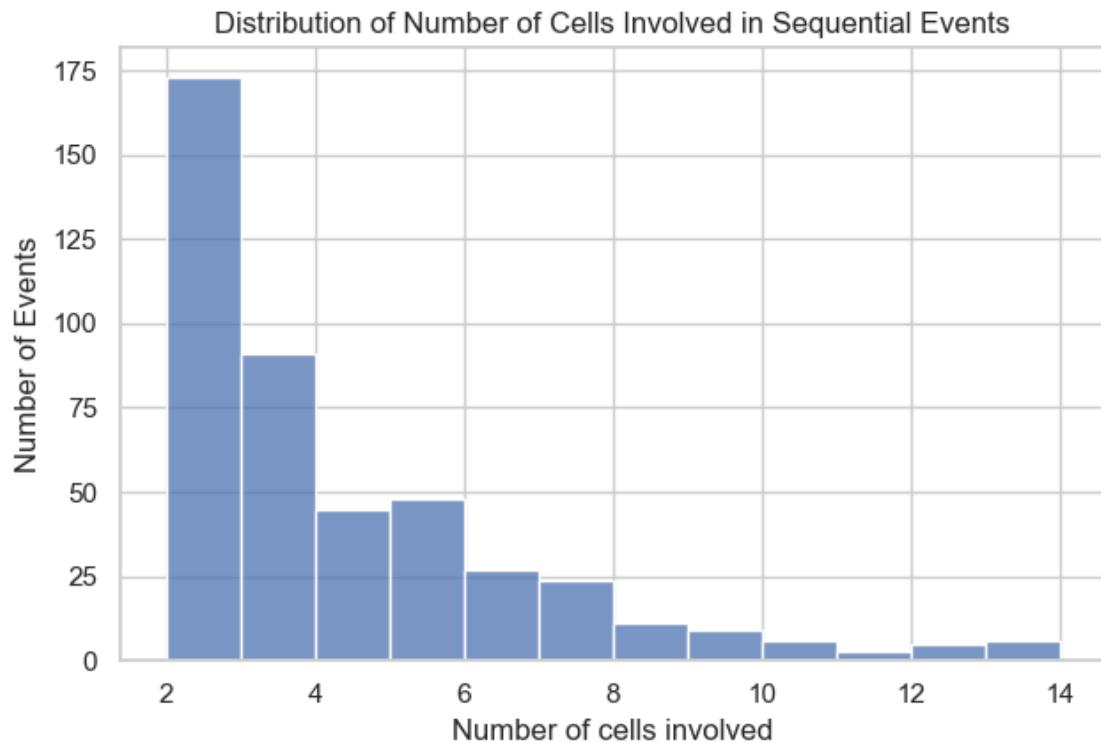
```

[644 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

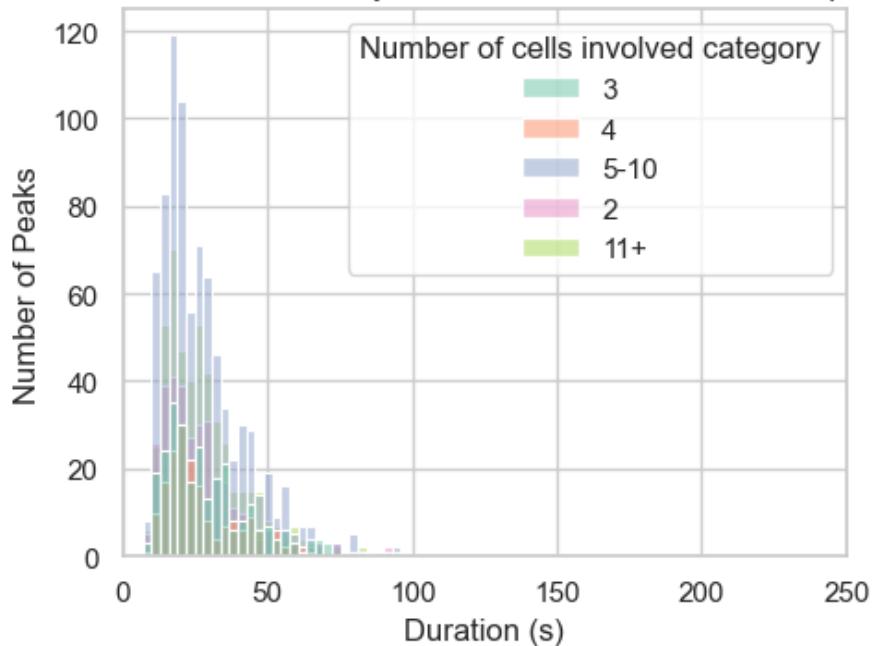
[2025-08-27 15:04:24] [INFO] calcium: plot\_histogram: removed 14 outliers out of 462 on 'Number of cells involved' (lower=-7, upper=14)



### 1.3.6 Influence of cell count per event on statistics

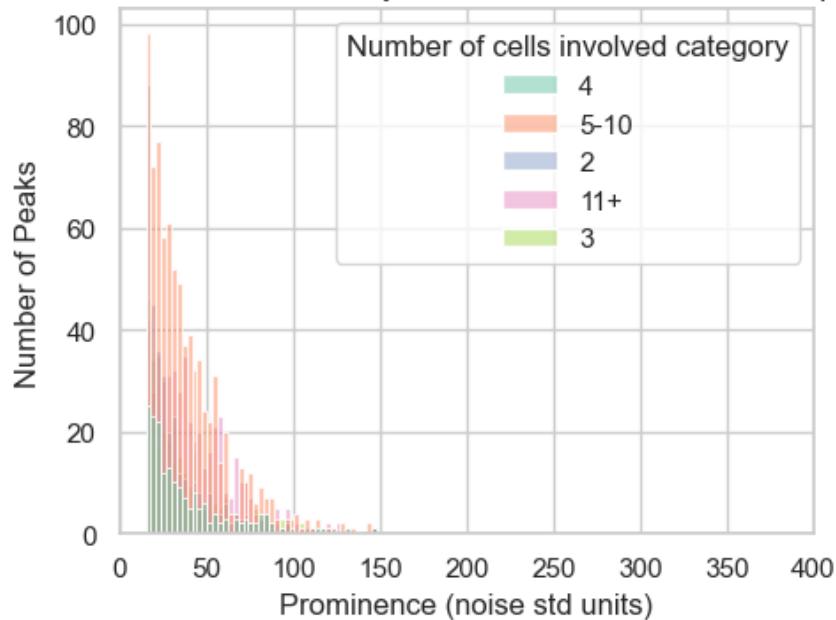
```
[2025-08-27 15:04:24] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 2125 on 'Duration (s)' (lower=-10, upper=98)
```

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

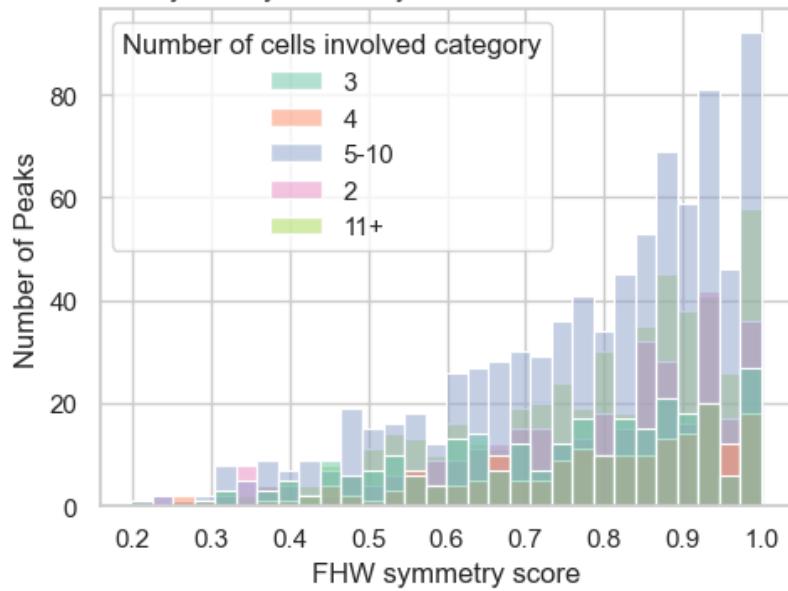


```
[2025-08-27 15:04:24] [INFO] calcium: plot_histogram_by_group: removed 17 outliers out of 2125 on 'Prominence (noise std units)' (lower=-21.05, upper=148.75)
```

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

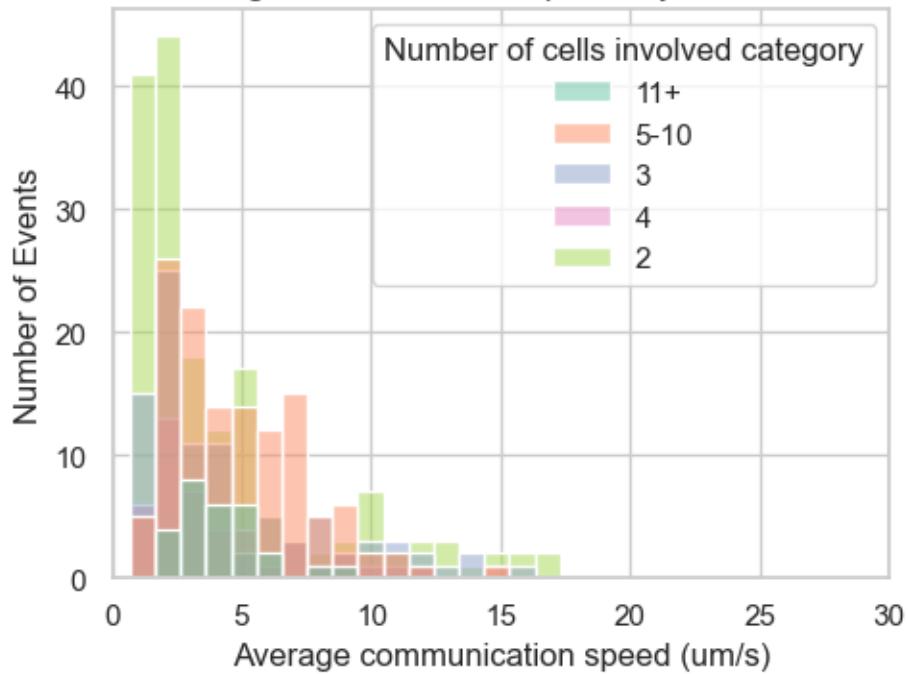


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



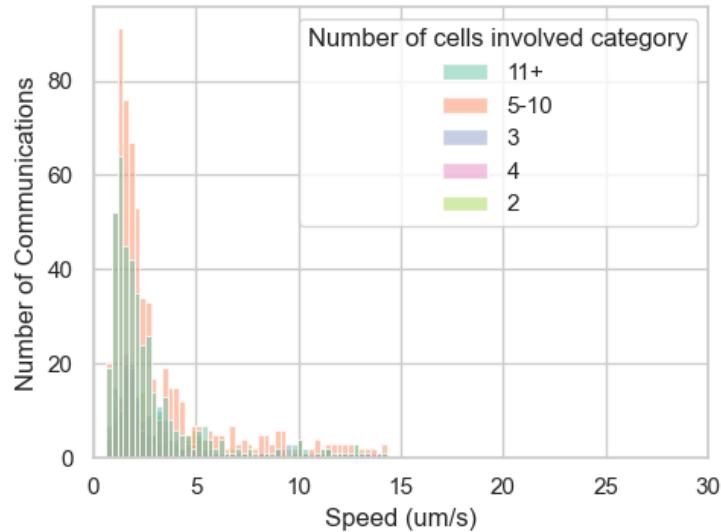
```
[2025-08-27 15:04:25] [INFO] calcium: plot_histogram_by_group: removed 6 outliers out of 462 on 'Average communication speed (um/s)' (lower=-10.1, upper=18.093)
```

Distribution of Average Communication Speeds by Number of Cells Involved



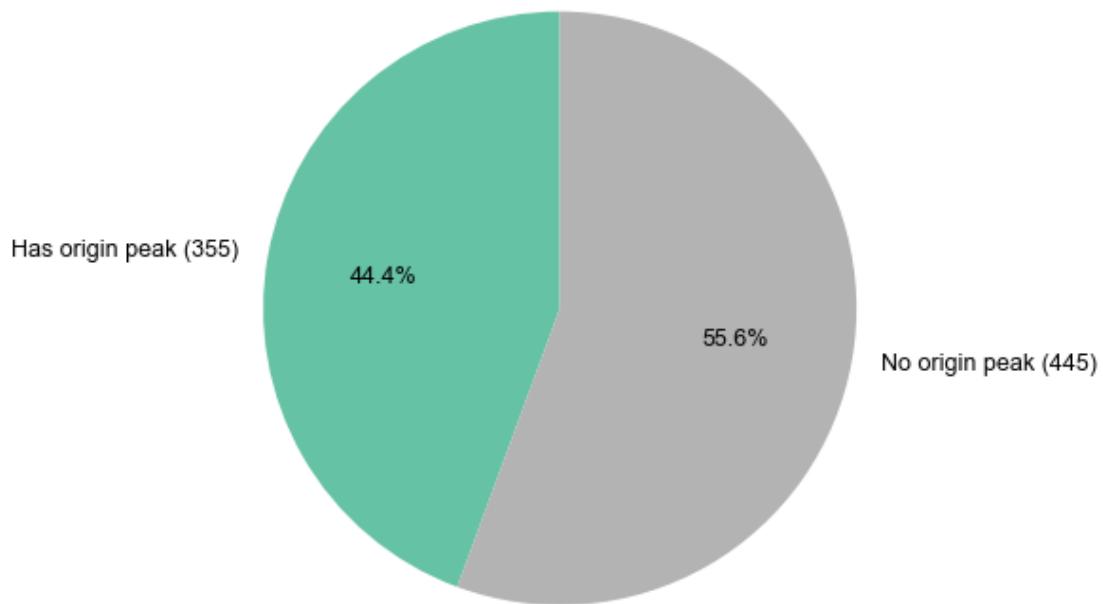
[2025-08-27 15:04:25] [INFO] calcium: plot\_histogram\_by\_group: removed 134 outliers out of 1663 on 'Speed (um/s)' (lower=-8.12, upper=14.35)

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

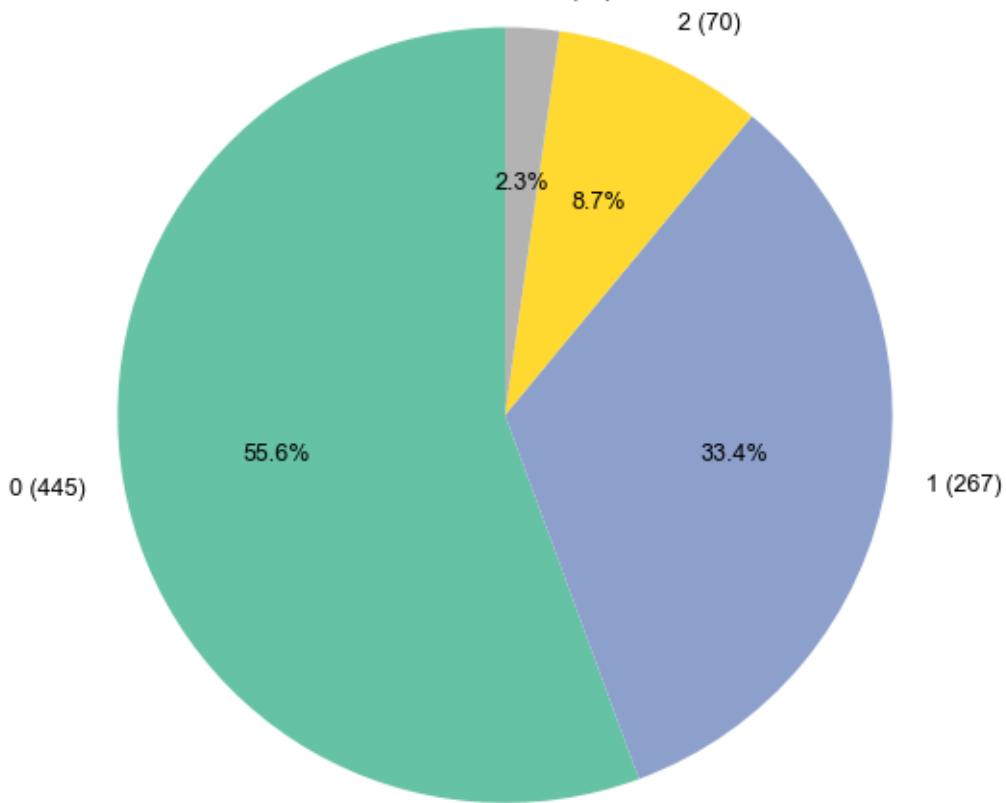


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

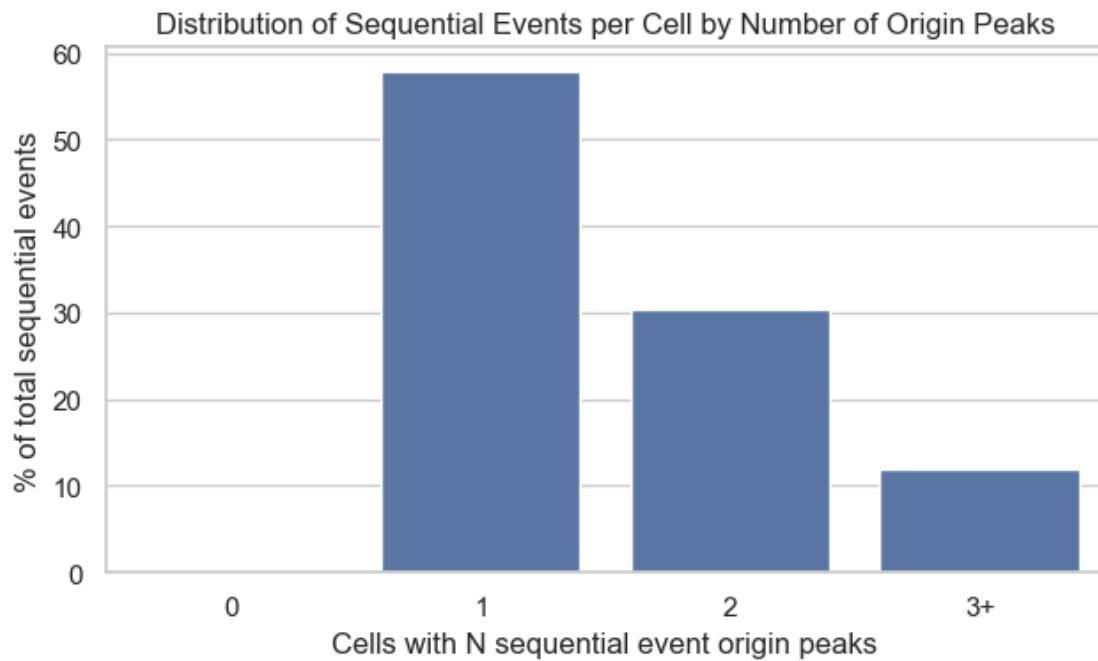


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



```
[2025-08-27 15:04:26] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS6\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\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:
```

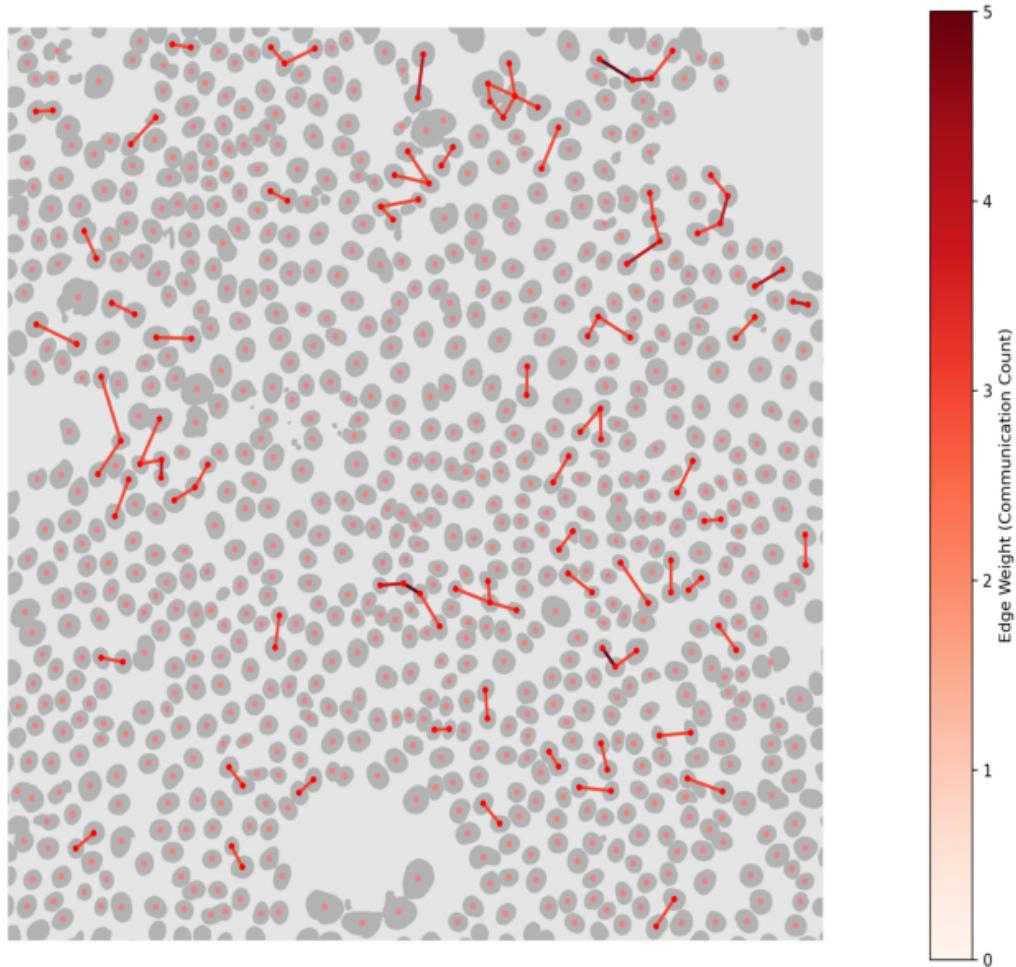
'D:\\Mateo\\20250618\\Output\\IS6\\cell-mapping\\cell\_Occurrences\_in\_origin\_seq\_events\_overlay.png'



### 1.3.8 Connection network between cells

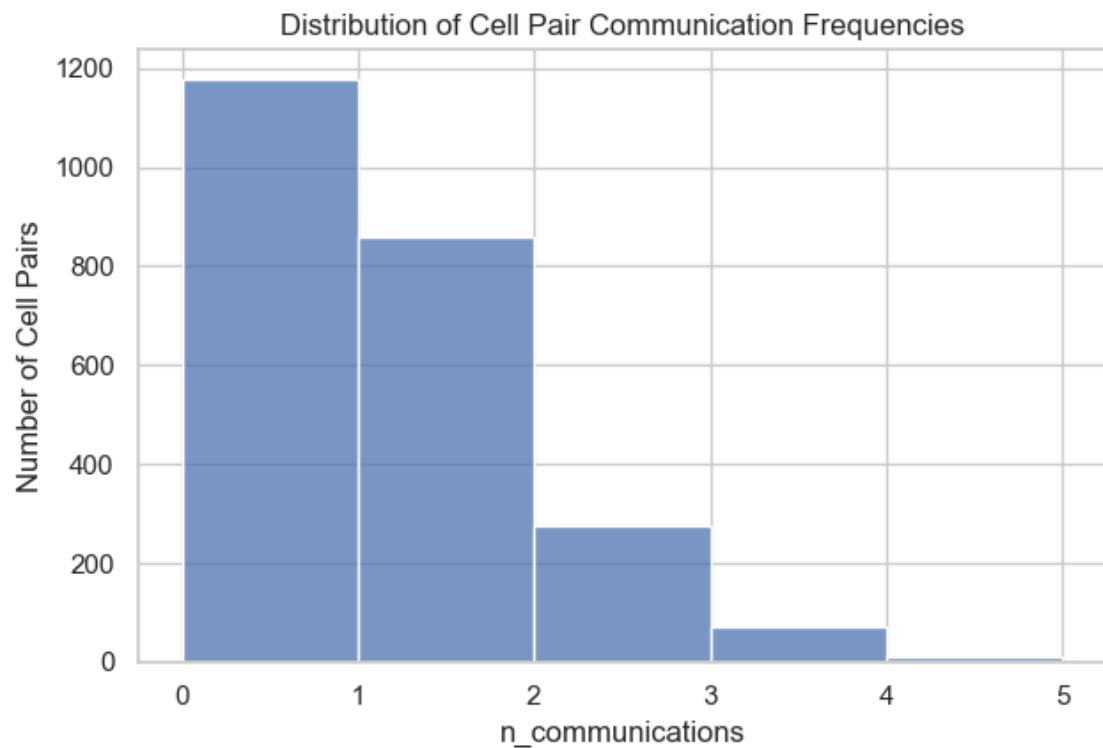
Cell Connection Network Graph

Cells Connection Network (Weighted Edges)



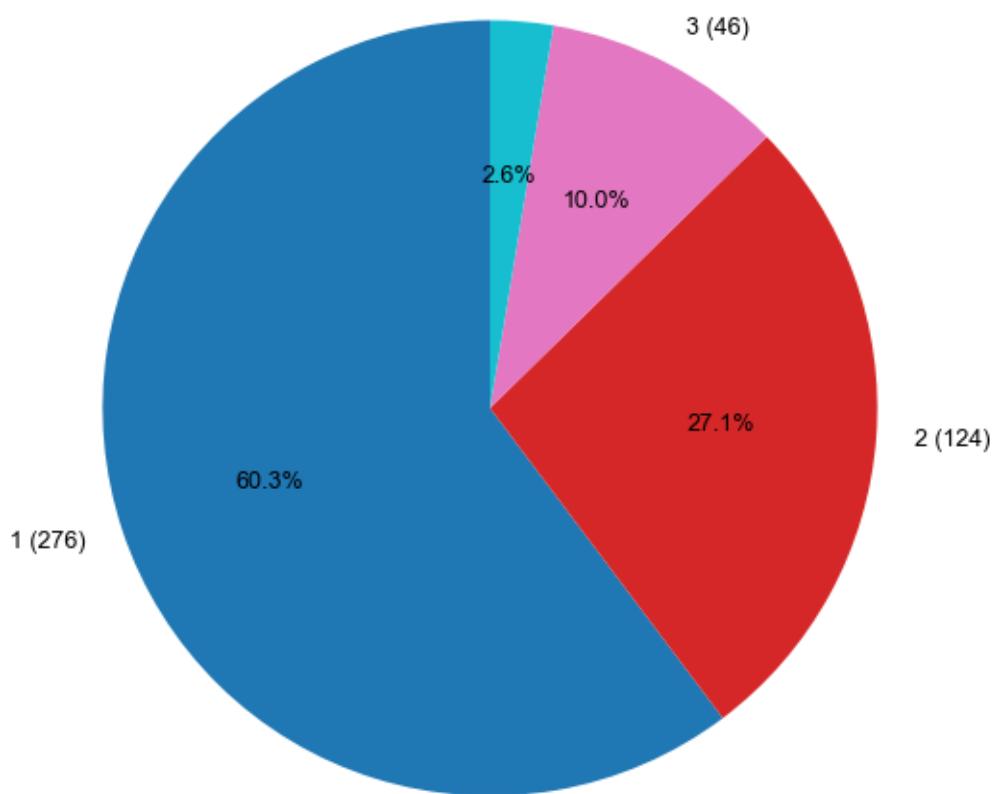
### 1.3.9 Pair/Trios with high communication networks

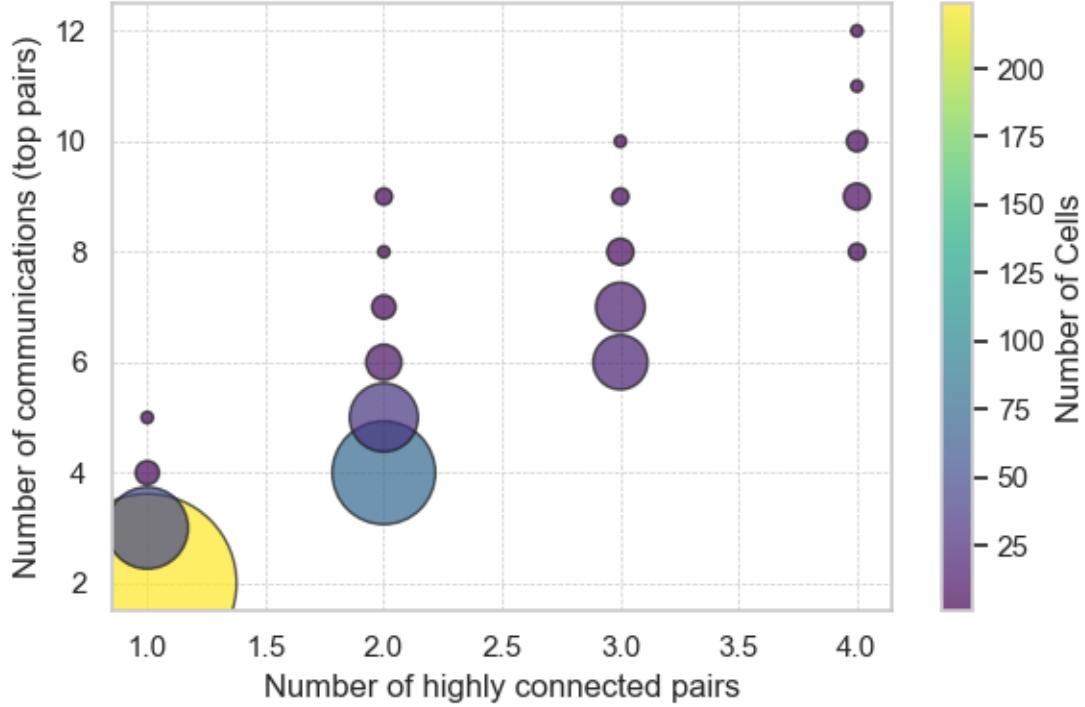
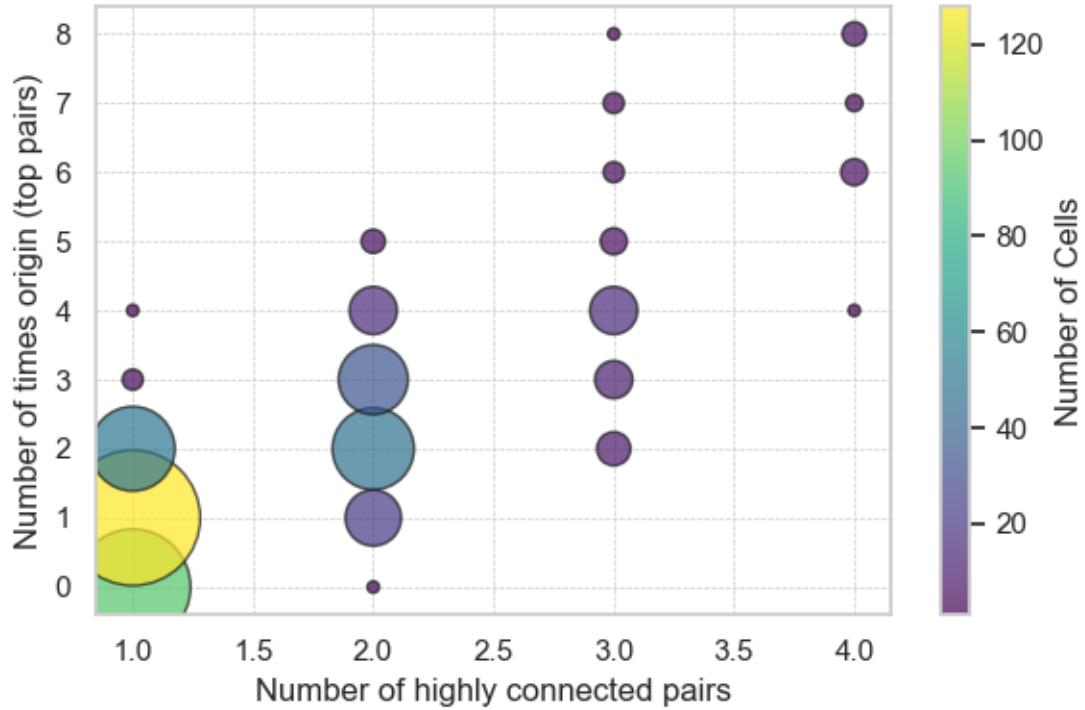
```
[2025-08-27 15:04:27] [INFO] calcium: build_neighbor_pair_stats: built 2391  
pairs across 1 datasets (mean distance=18.56 um)
```

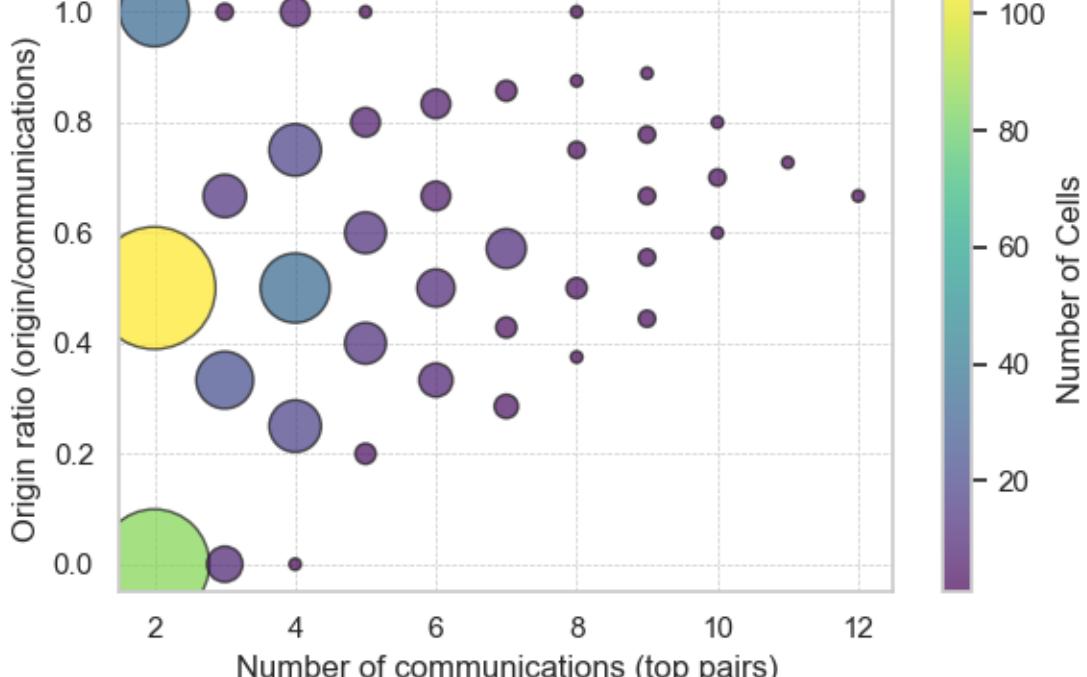
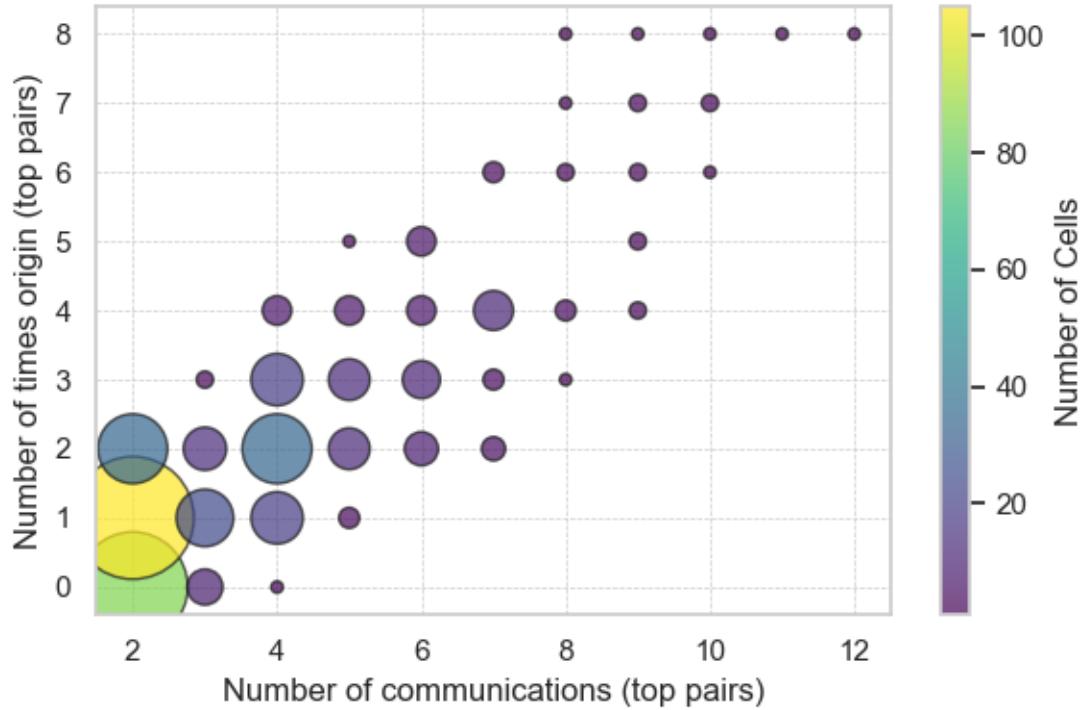


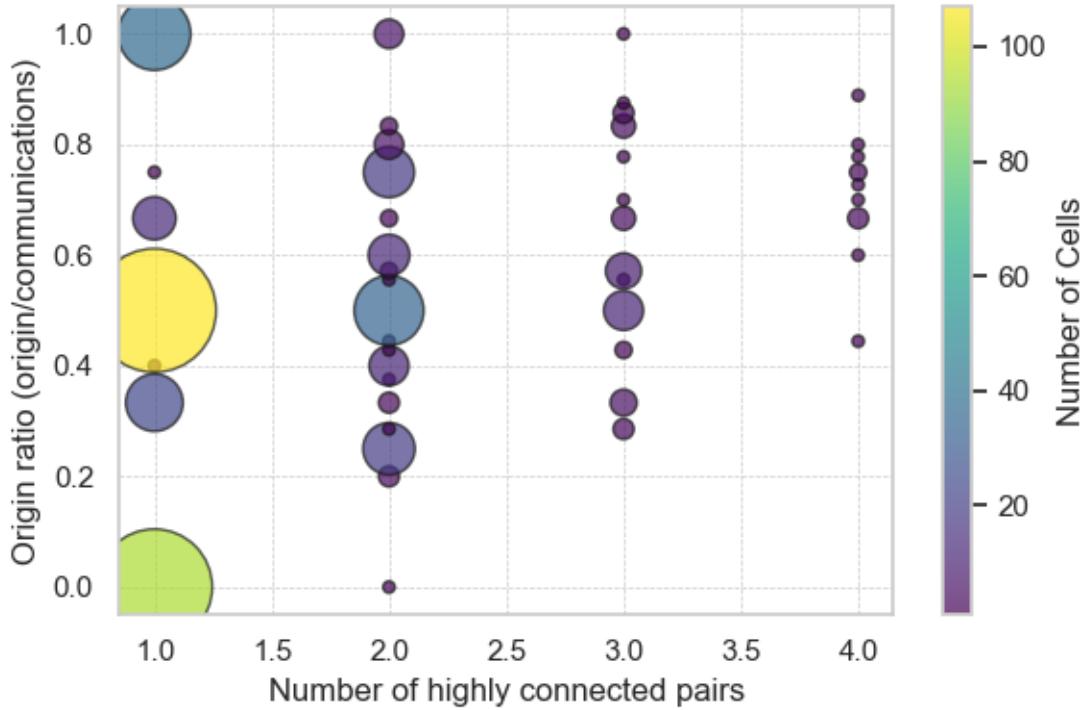
95th percentile threshold: 2.0

Cells involved in multiple pairs highly connected  
4 (12)







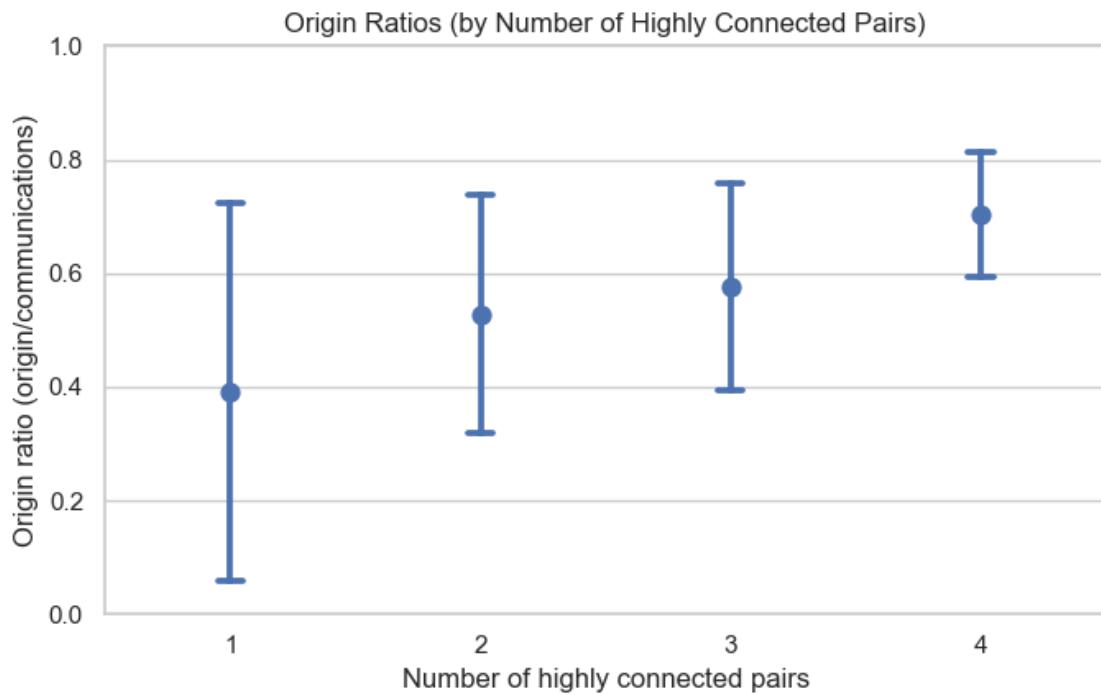


[2025-08-27 15:04:28] [INFO] calcium: plot\_points\_mean\_std: N=276 for Number of highly connected pairs=1

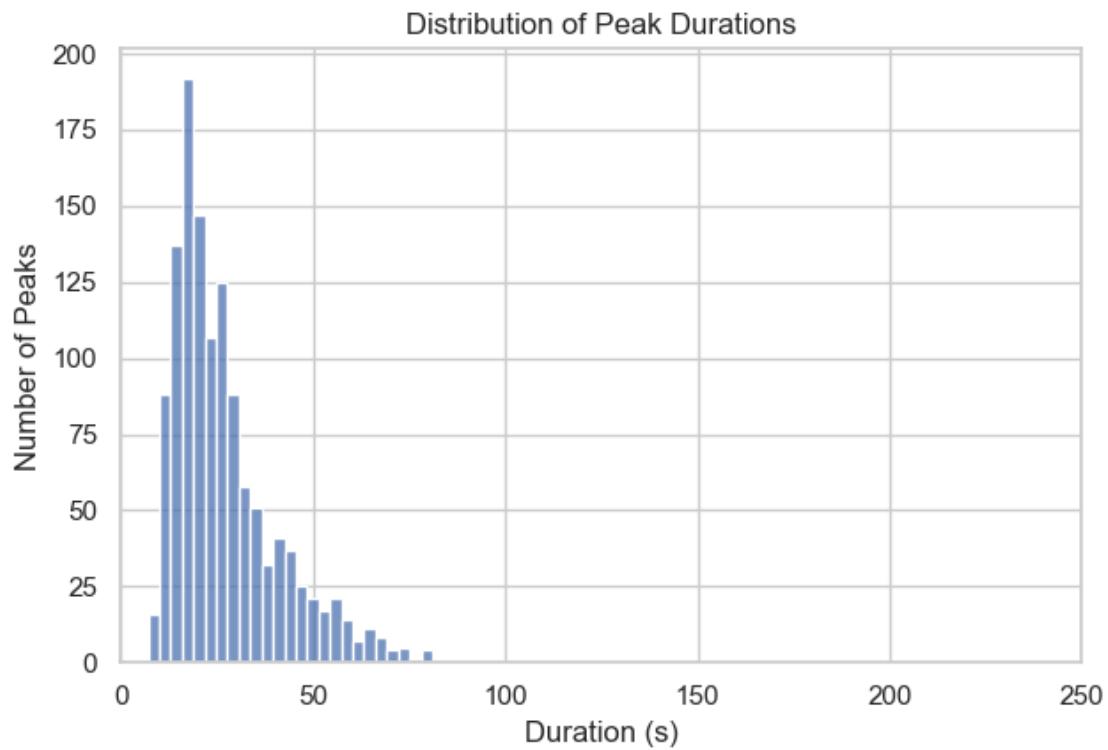
[2025-08-27 15:04:28] [INFO] calcium: plot\_points\_mean\_std: N=124 for Number of highly connected pairs=2

[2025-08-27 15:04:28] [INFO] calcium: plot\_points\_mean\_std: N=46 for Number of highly connected pairs=3

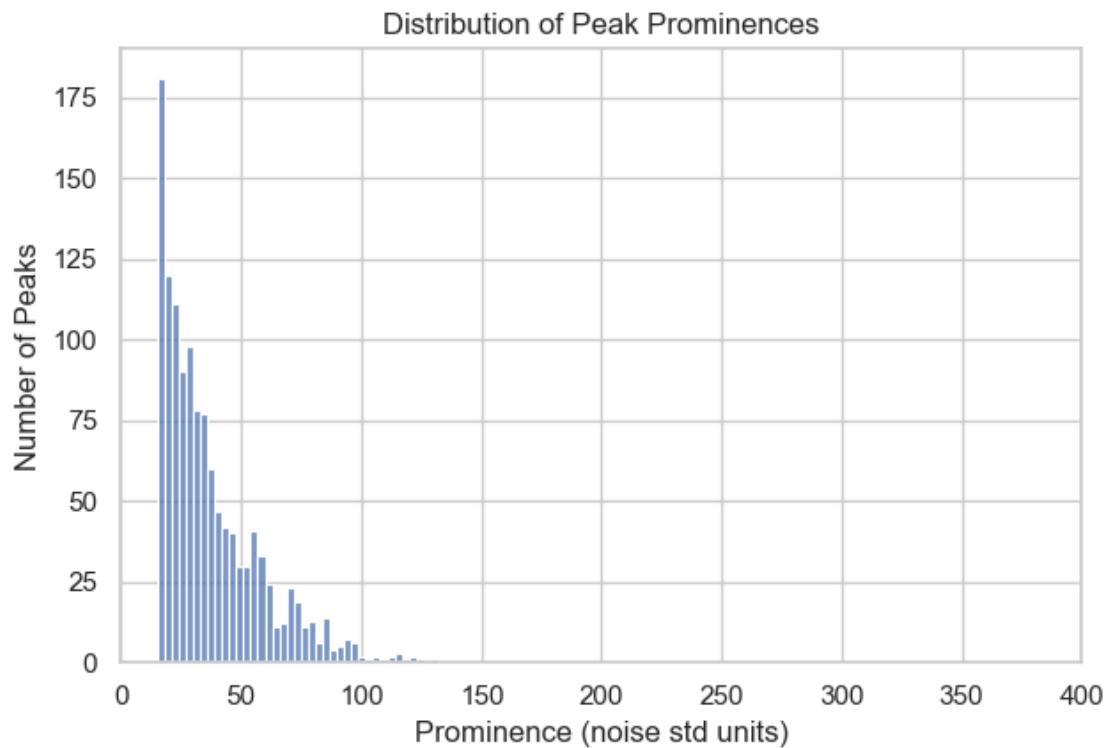
[2025-08-27 15:04:28] [INFO] calcium: plot\_points\_mean\_std: N=12 for Number of highly connected pairs=4

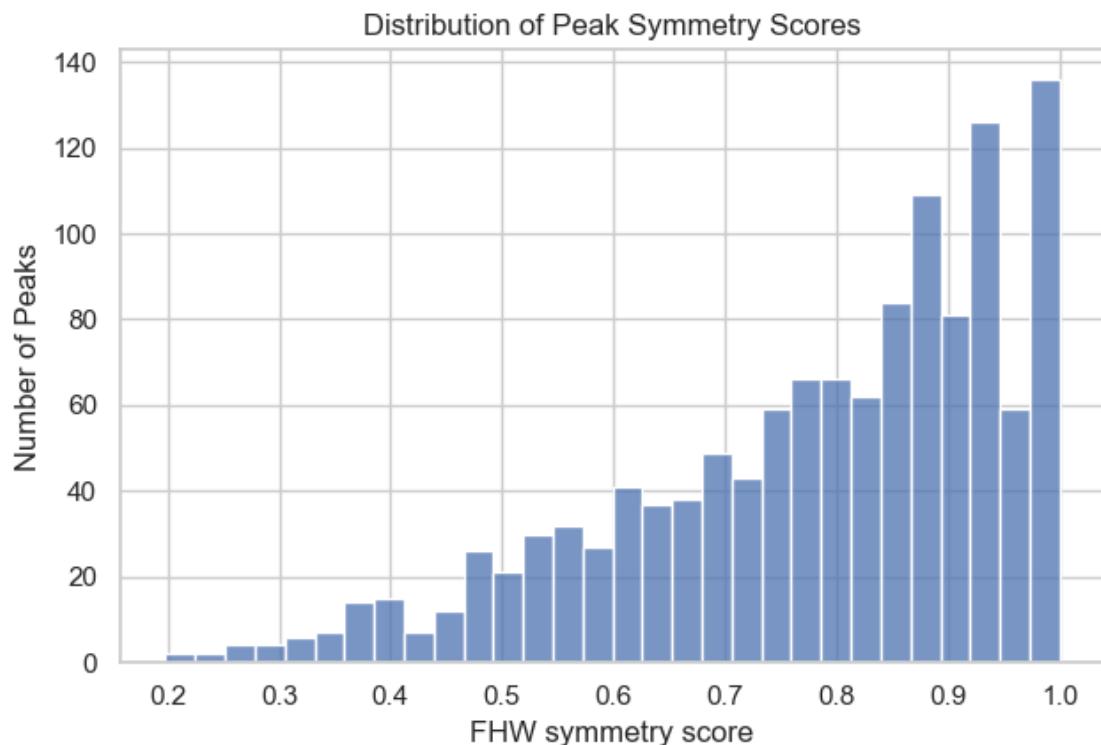


```
[2025-08-27 15:04:29] [INFO] calcium: plot_histogram: removed 8 outliers out of 1265 on 'Duration (s)' (lower=-31, upper=81)
```

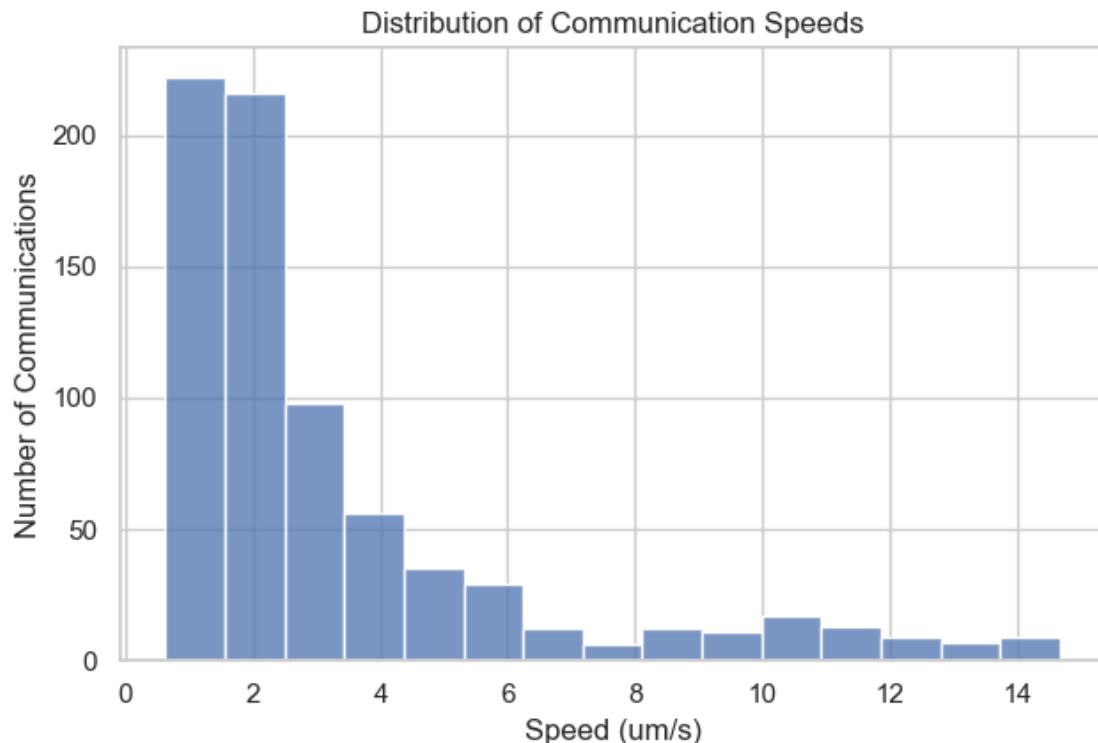


[2025-08-27 15:04:29] [INFO] calcium: plot\_histogram: removed 16 outliers out of 1265 on 'Prominence (noise std units)' (lower=-63.2, upper=133.5)

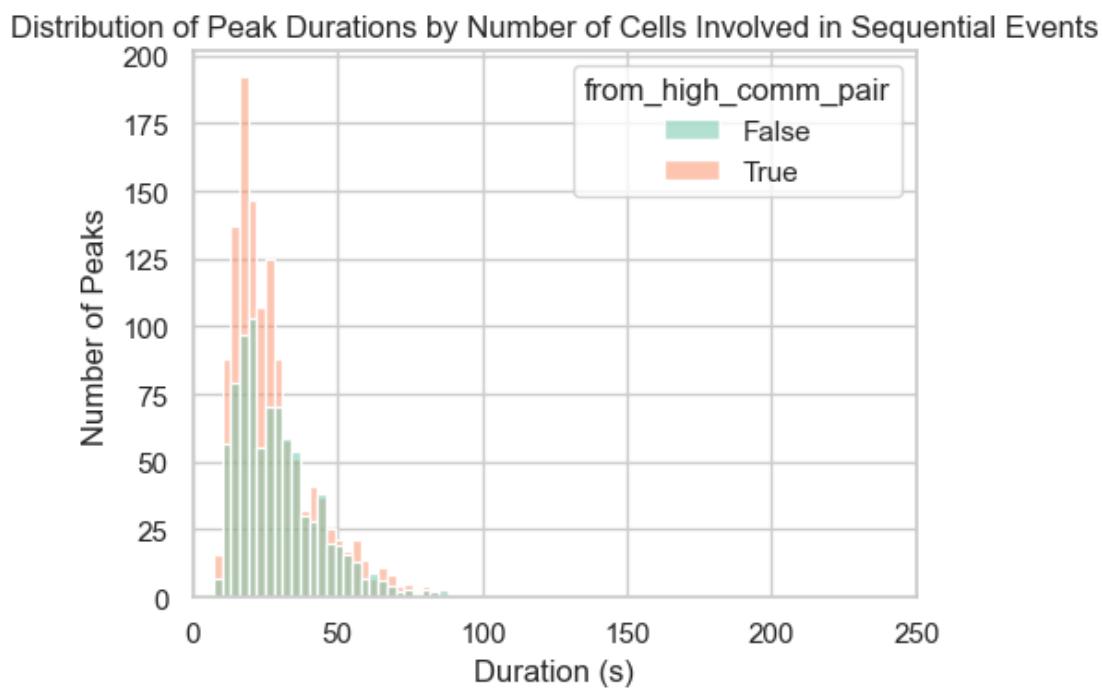




```
[2025-08-27 15:04:29] [INFO] calcium: plot_histogram: removed 53 outliers out of 805 on 'Speed (um/s)' (lower=-8.44, upper=14.73)
```

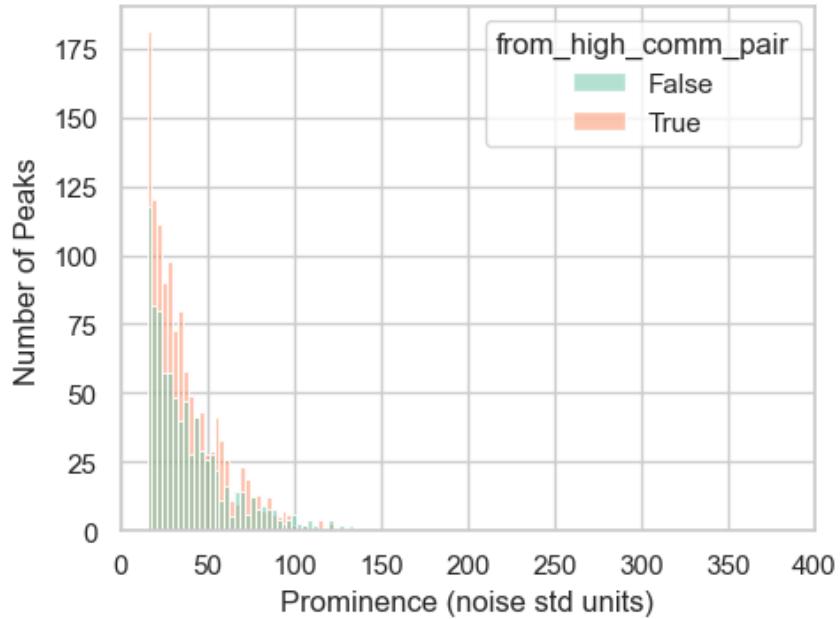


```
[2025-08-27 15:04:29] [INFO] calcium: plot_histogram_by_group: removed 10 outliers out of 2125 on 'Duration (s)' (lower=-37, upper=89)
```

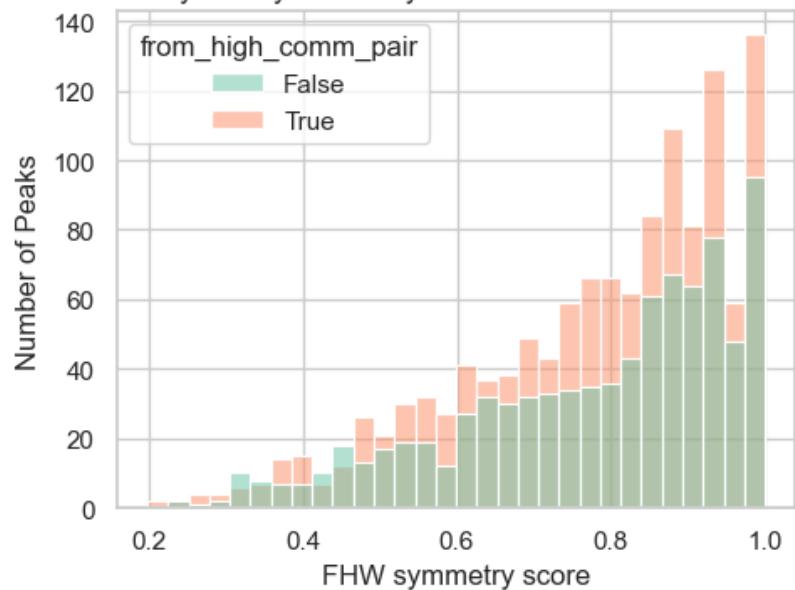


[2025-08-27 15:04:29] [INFO] calcium: plot\_histogram\_by\_group: removed 24 outliers out of 2125 on 'Prominence (noise std units)' (lower=-63.5, upper=134.6)

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

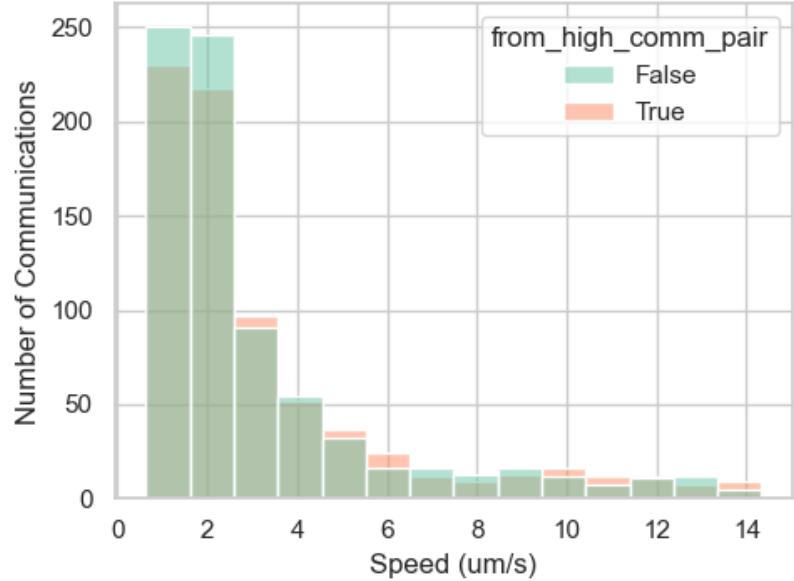


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:04:30] [INFO] calcium: plot\_histogram\_by\_group: removed 134 outliers out of 1663 on 'Speed (um/s)' (lower=-8.12, upper=14.35)

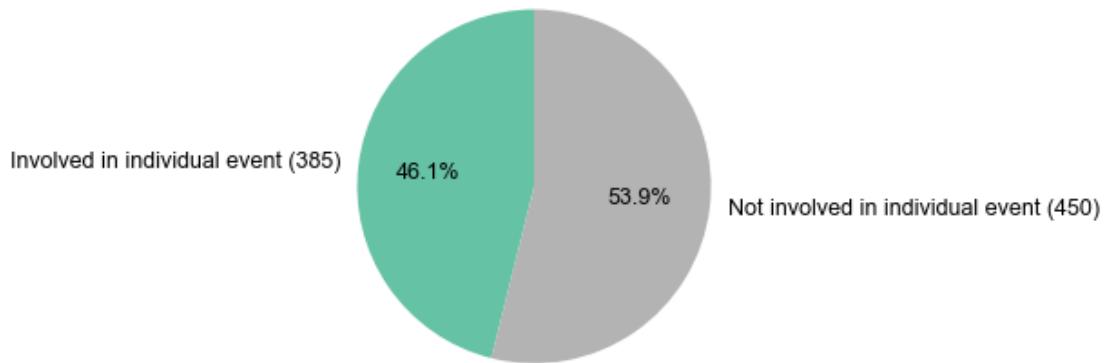
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



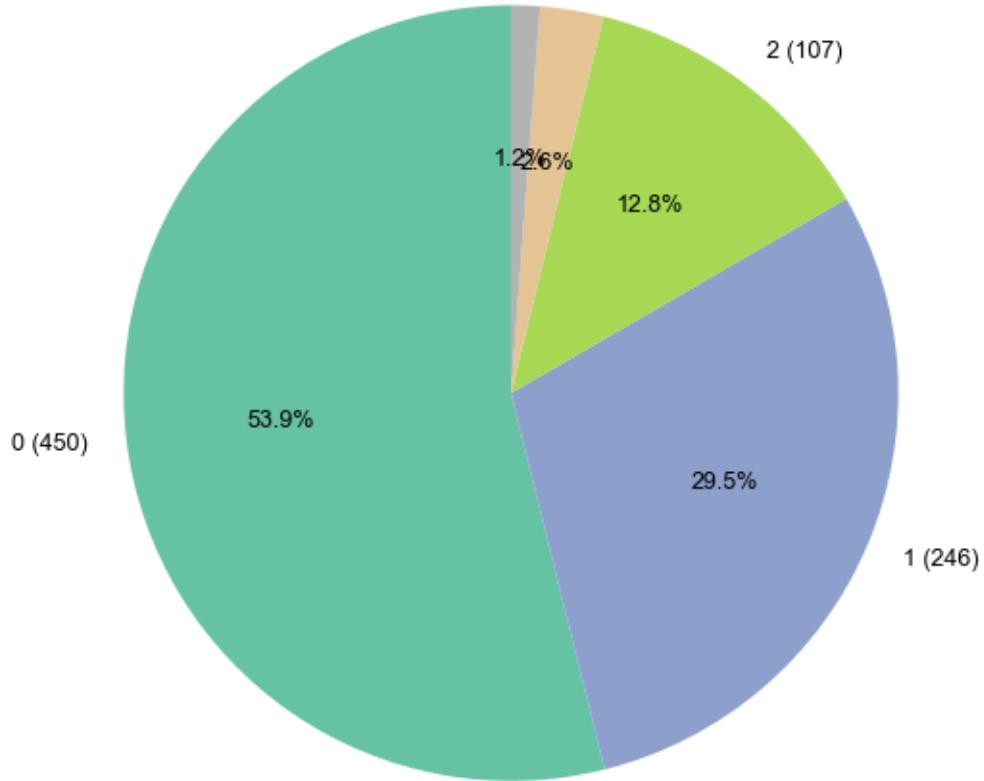
## 1.4 INDIVIDUAL EVENTS

### 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+)

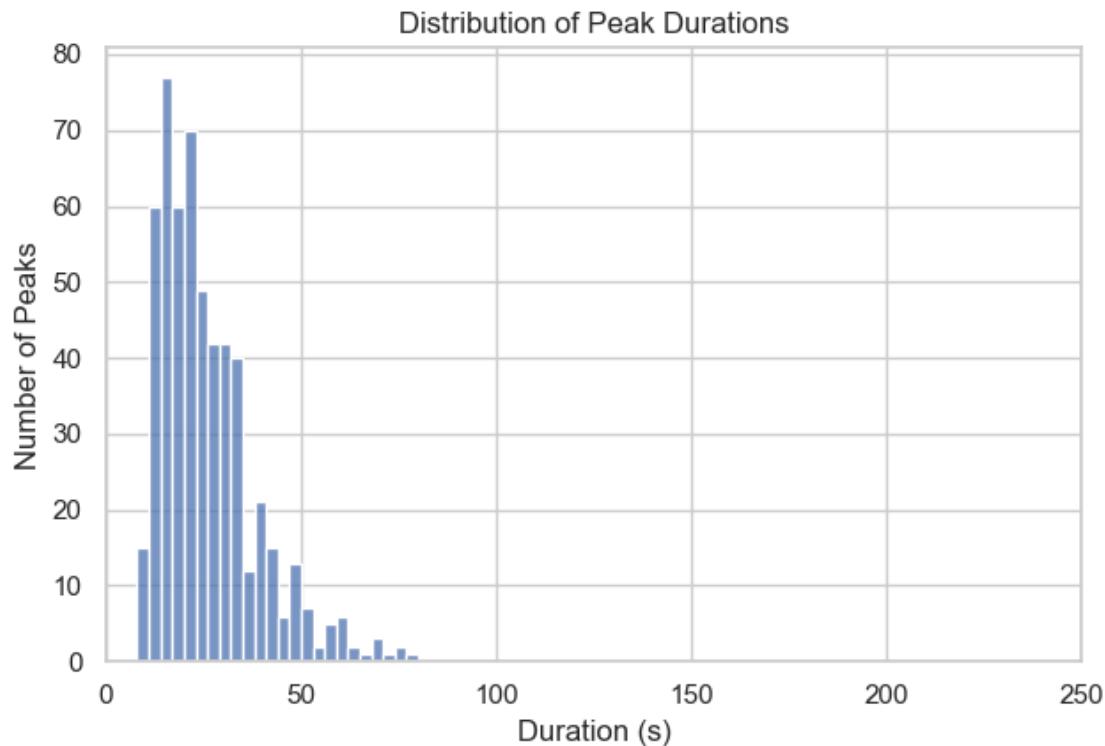


```
[2025-08-27 15:04:30] [ERROR] calcium: Failed to read image
'D:\Mateo\20250618\Output\IS6\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250618\\Output\\IS6\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\20250618\\Output\\IS6\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

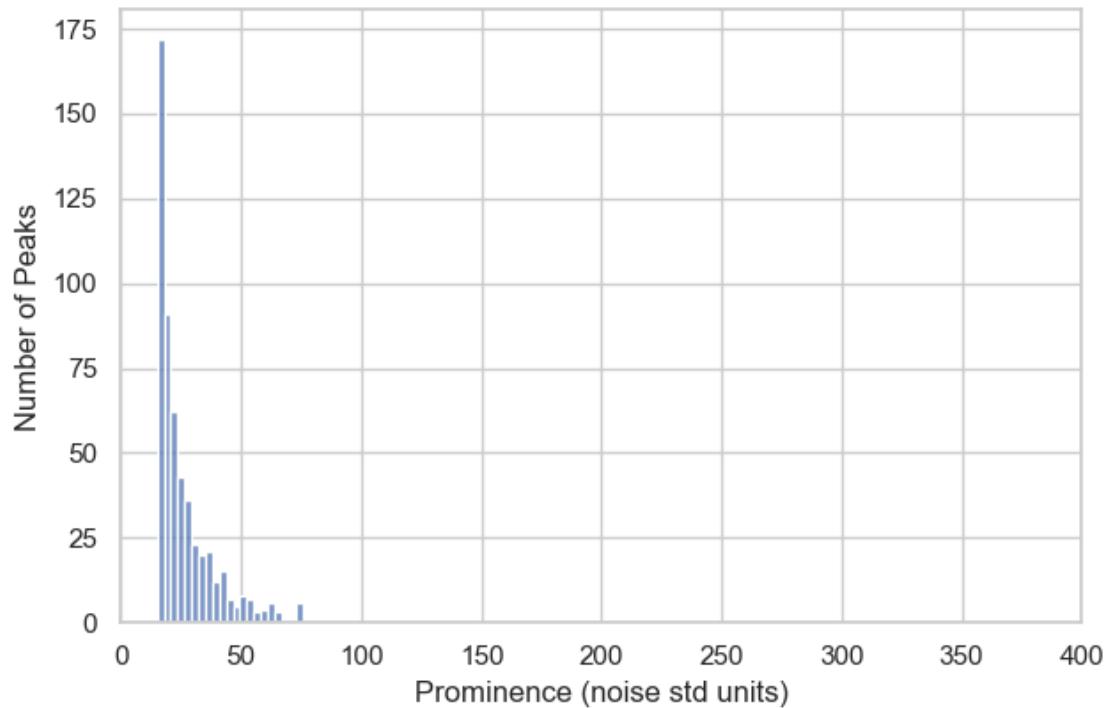
#### 1.4.2 Peaks statistics in individual events

[2025-08-27 15:04:31] [INFO] calcium: plot\_histogram: removed 19 outliers out of 571 on 'Duration (s)' (lower=-32, upper=80)

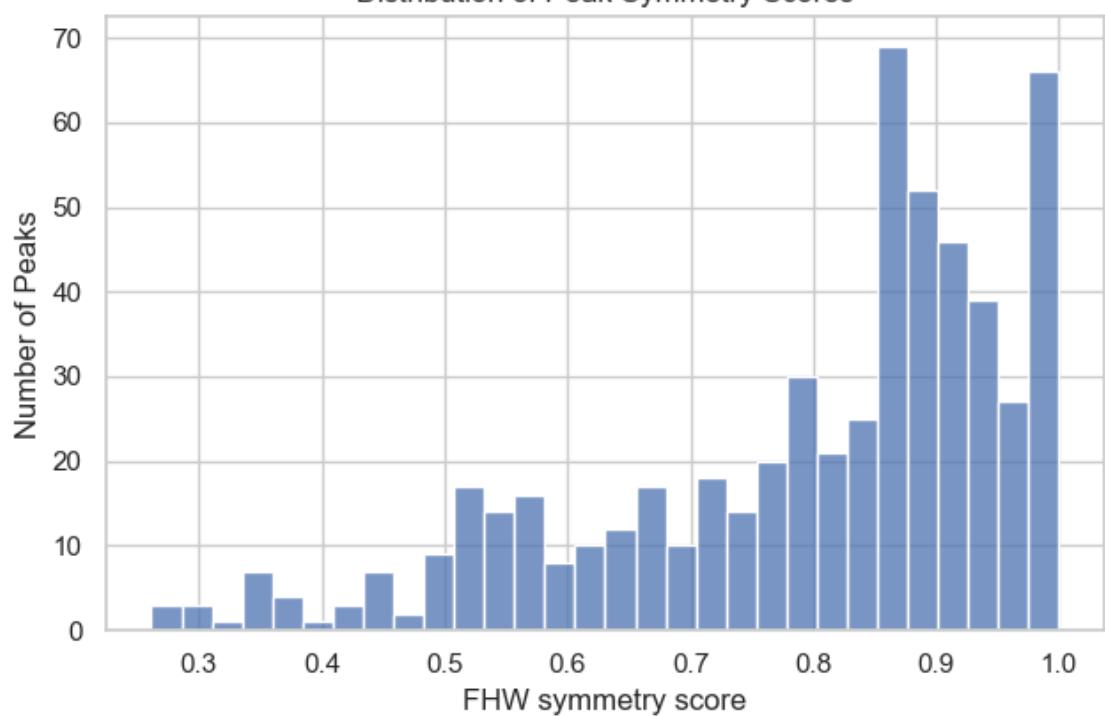


[2025-08-27 15:04:31] [INFO] calcium: plot\_histogram: removed 27 outliers out of 571 on 'Prominence (noise std units)' (lower=-27.9, upper=77.8)

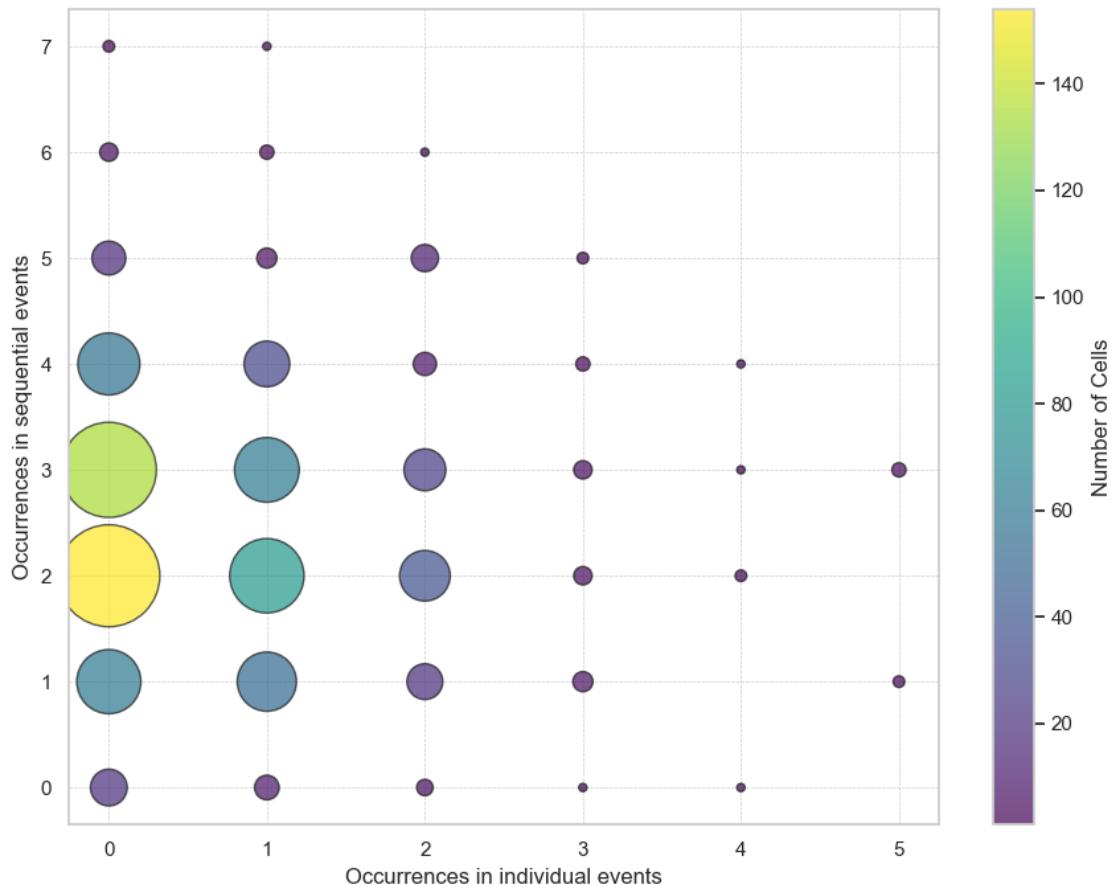
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

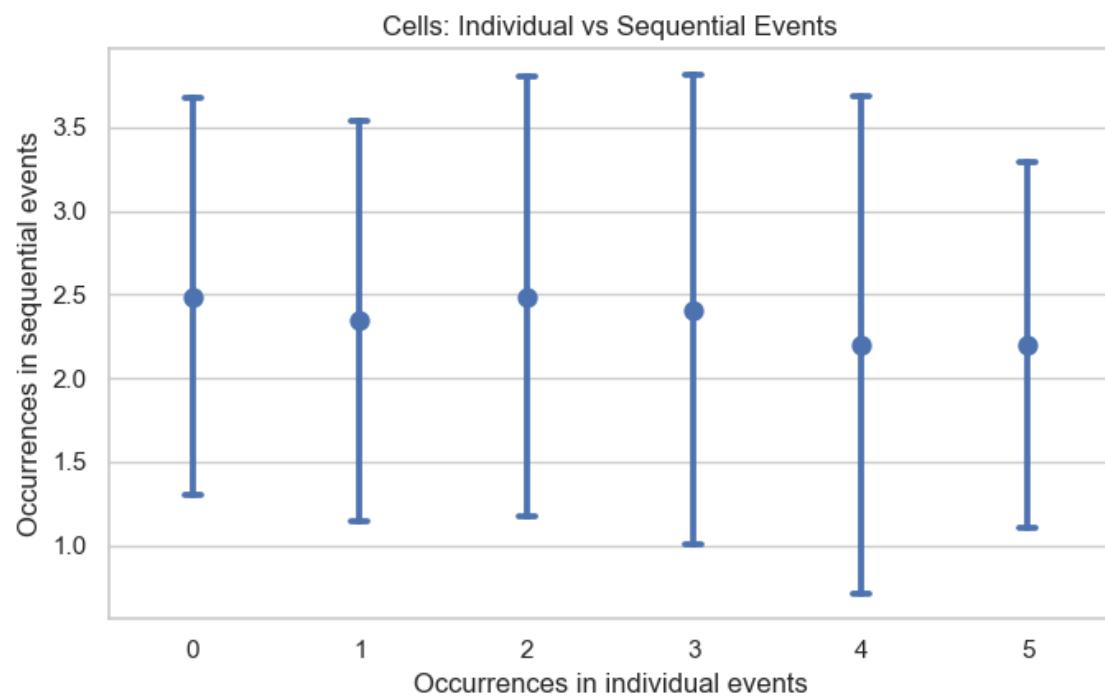


### 1.4.3 Correlation between event activity level & individual activity level

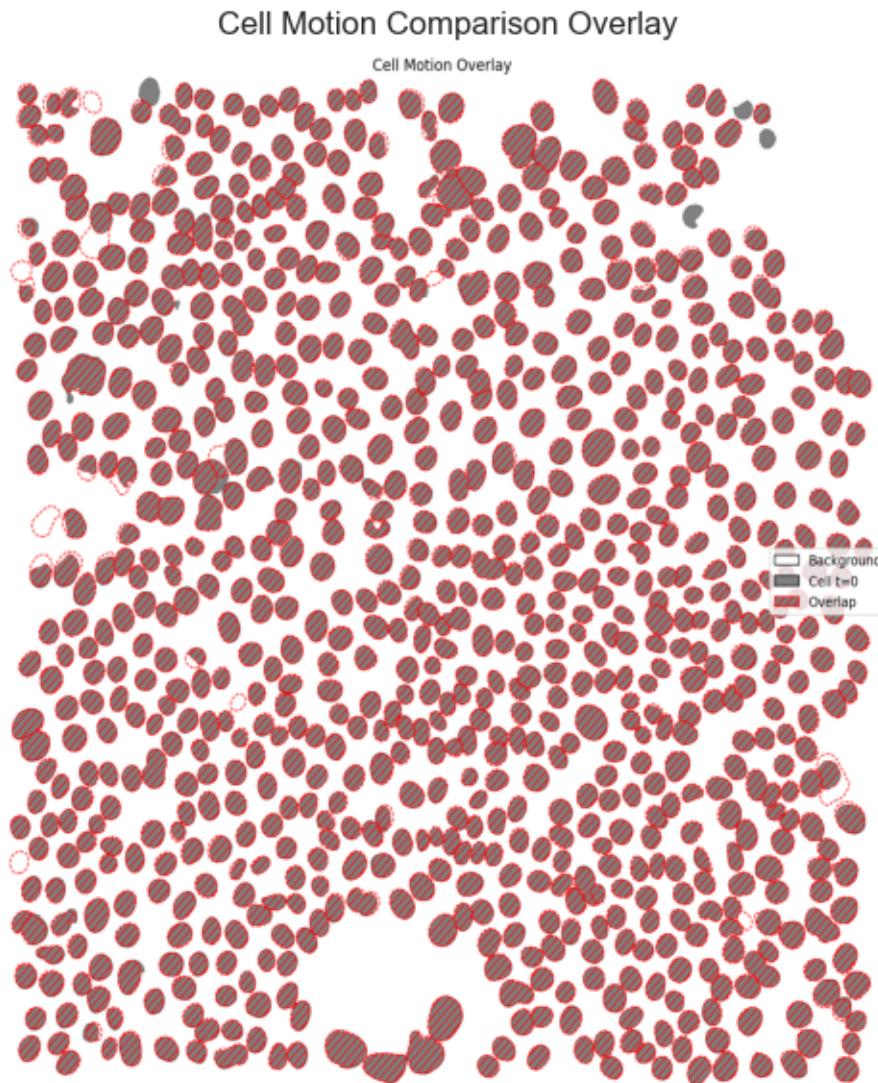


```
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: removed 3/835 outliers on 'Occurrences in sequential events' (lower=-1, upper=6)
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: N=448 for Occurrences in individual events=0
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: N=245 for Occurrences in individual events=1
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: N=107 for Occurrences in individual events=2
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: N=22 for Occurrences in individual events=3
[2025-08-27 15:04:32] [INFO] calcium: plot_points_mean_std: N=5 for Occurrences in individual events=4
```

[2025-08-27 15:04:32] [INFO] calcium: plot\_points\_mean\_std: N=5 for Occurrences in individual events=5



## 1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 835
- Hoechst image taken at t=1801: 835
- Number of cells difference: absolute 0, relative 0.00%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 898429
- Pixels segmented as cell at t=1801: 885314
- Overlapping pixels between t=0 and t=1801: 838380 (94.00% of total)
- Pixels exclusive to t=0: 60049 (6.68% of total)
- Pixels exclusive to t=1801: 46934 (5.30% of total)

executed

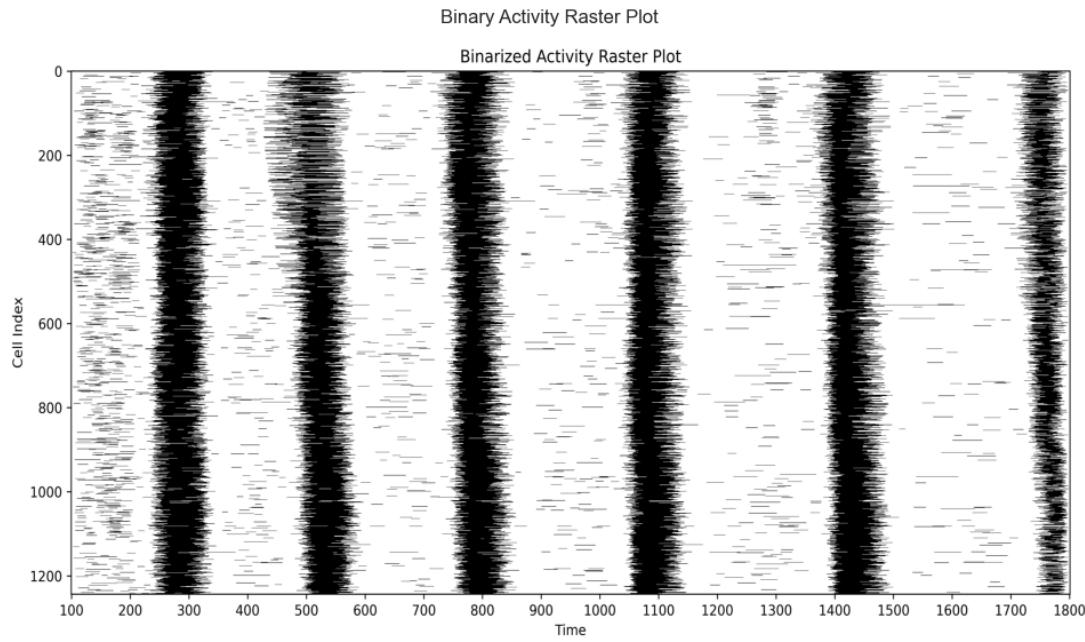
August 27, 2025

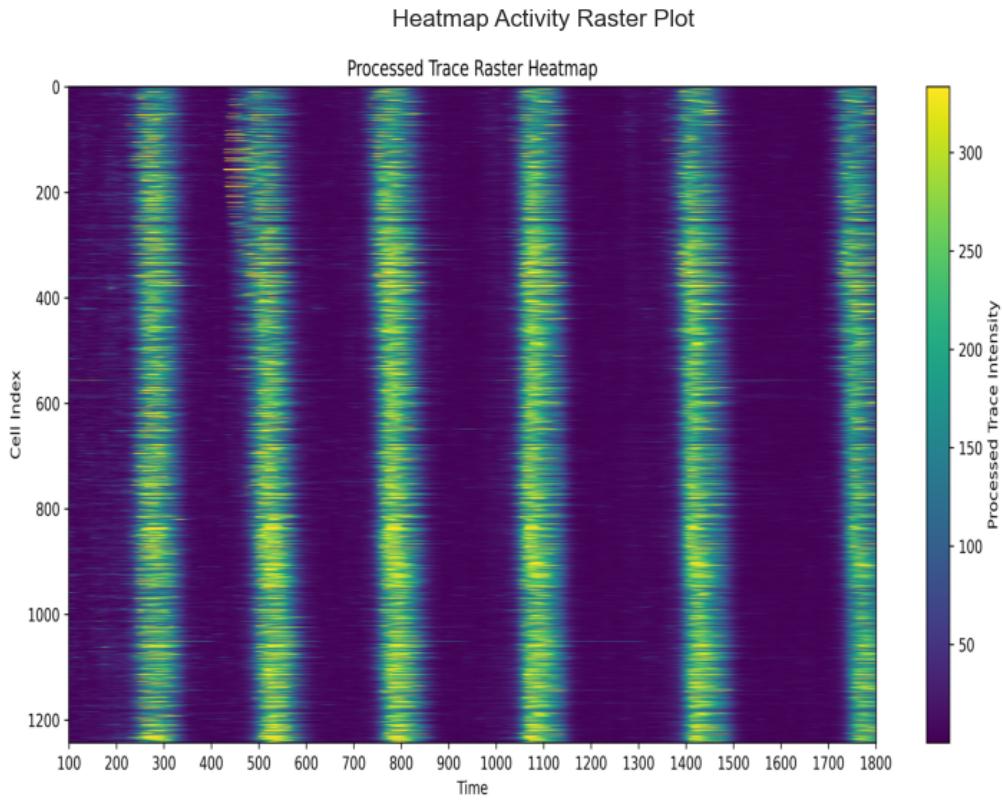
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





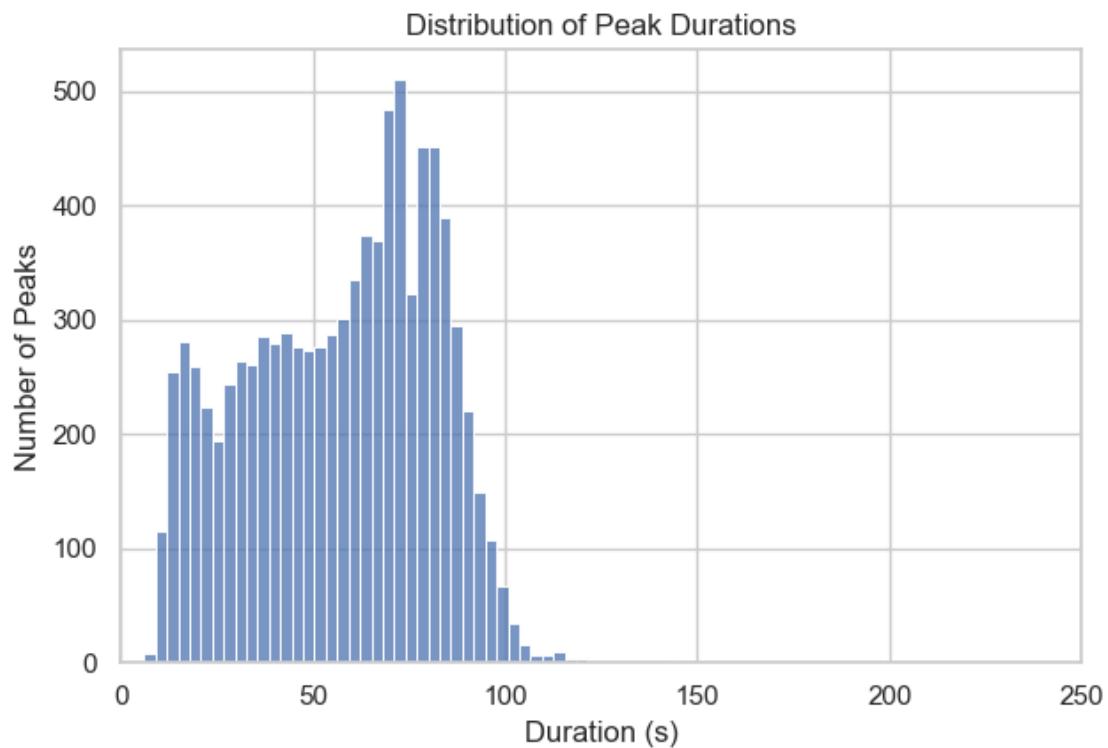
### 1.1.2 Peaks population

Total number of peaks: 8988

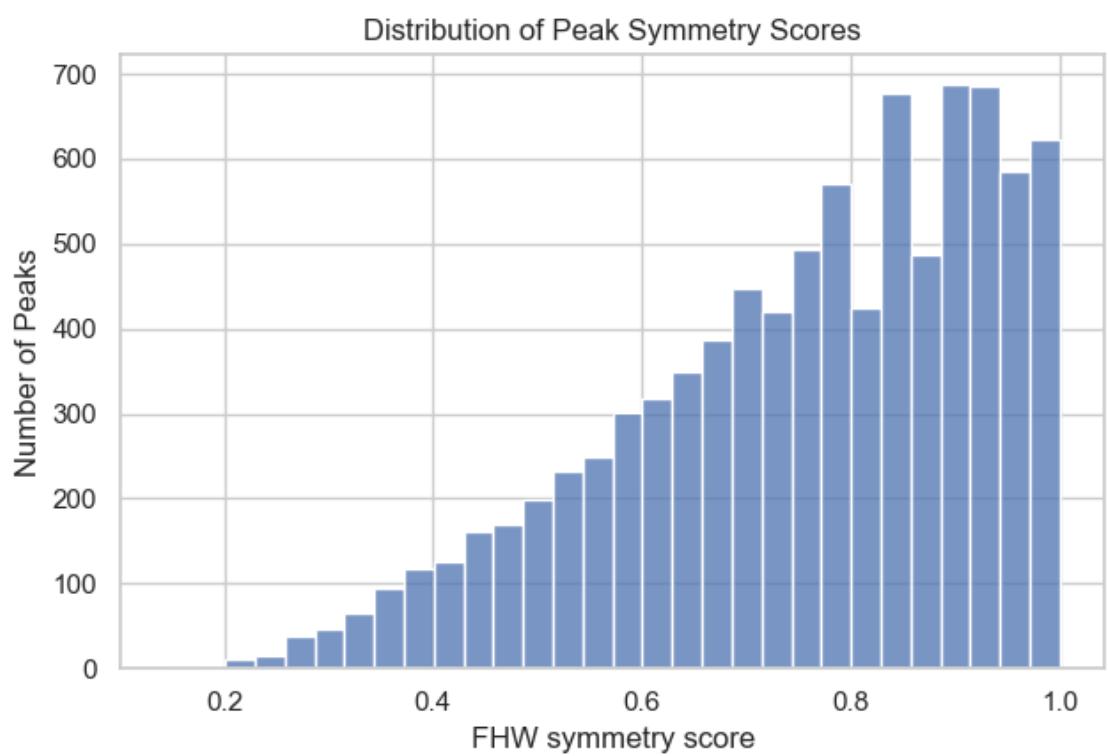
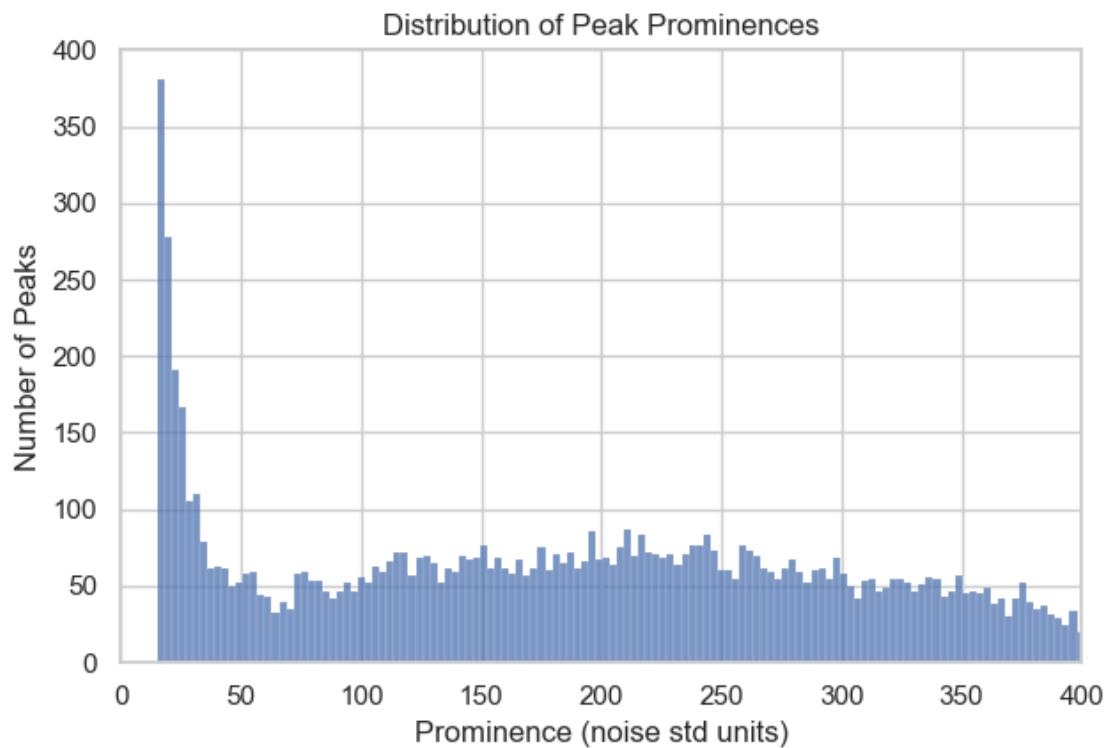
Total number of cells: 1244

### 1.1.3 Peaks statistics

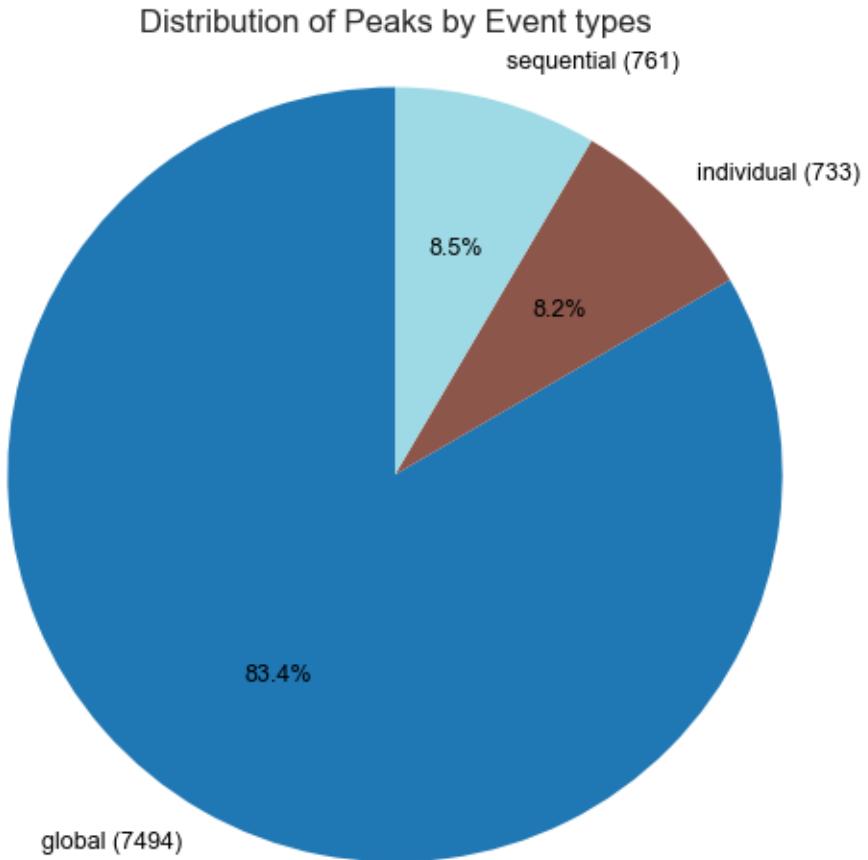
```
[2025-08-27 15:10:55] [INFO] calcium: plot_histogram: removed 1 outliers out of  
8988 on 'Duration (s)' (lower=-80, upper=193)
```



```
[2025-08-27 15:10:55] [INFO] calcium: plot_histogram: removed 2 outliers out of  
8988 on 'Prominence (noise std units)' (lower=-523.8, upper=911.38)
```

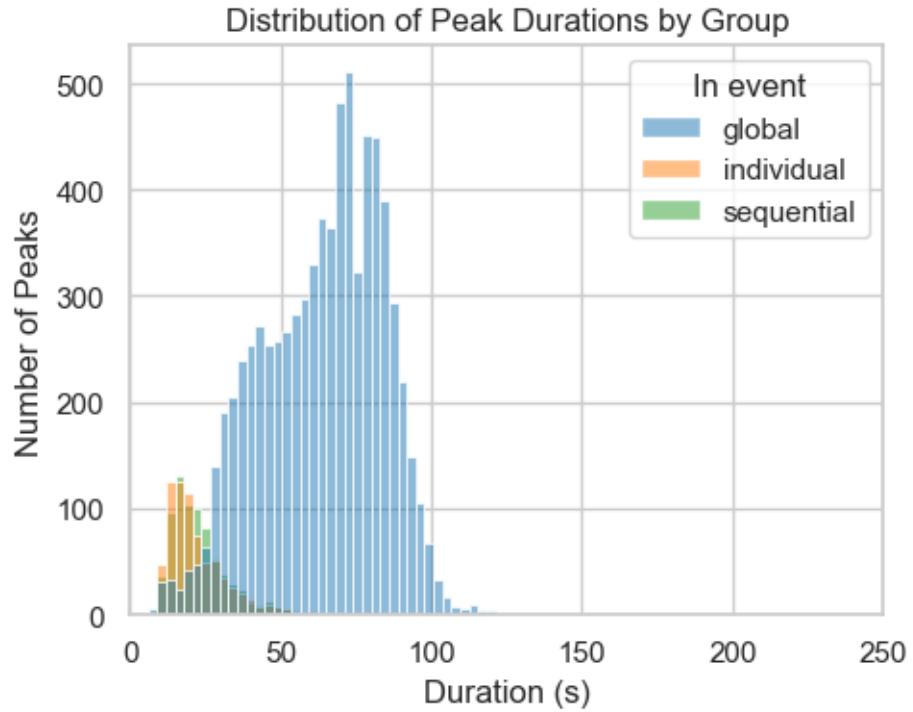


#### 1.1.4 Distribution of peaks per event types

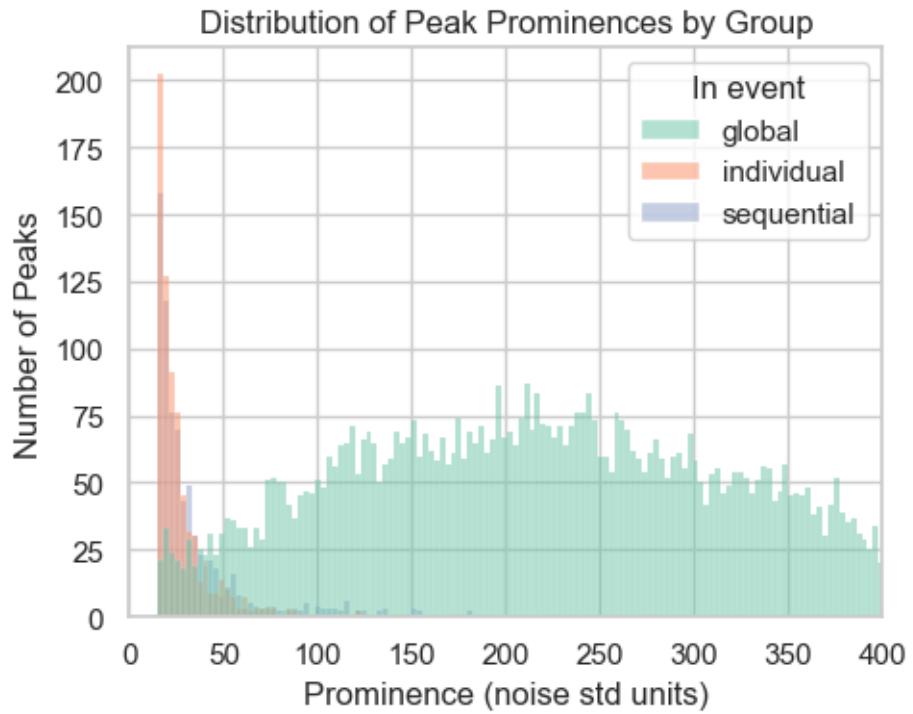


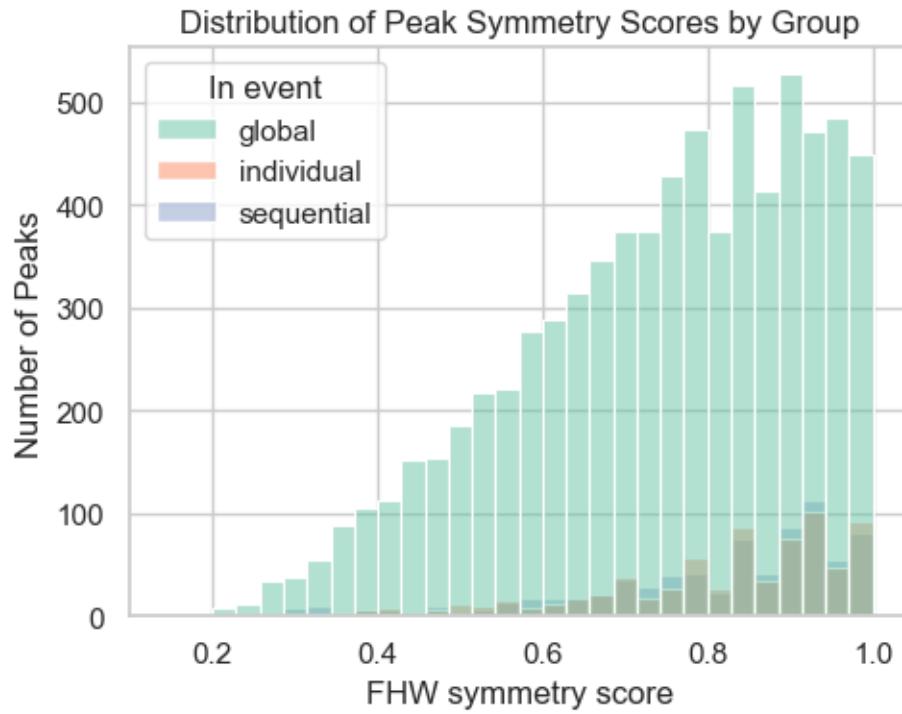
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 15:10:56] [INFO] calcium: plot_histogram_by_group: removed 1 outliers out of 8988 on 'Duration (s)' (lower=-80, upper=193)
```



```
[2025-08-27 15:10:56] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 8988 on 'Prominence (noise std units)' (lower=-523.8, upper=911.38)
```

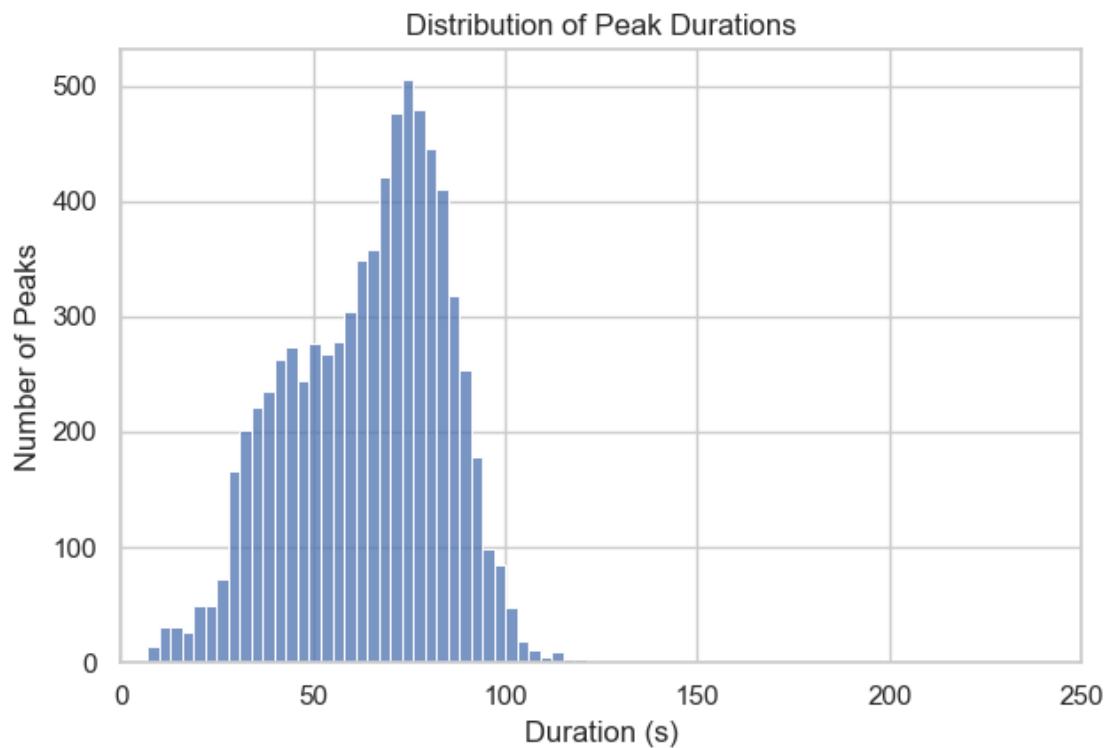




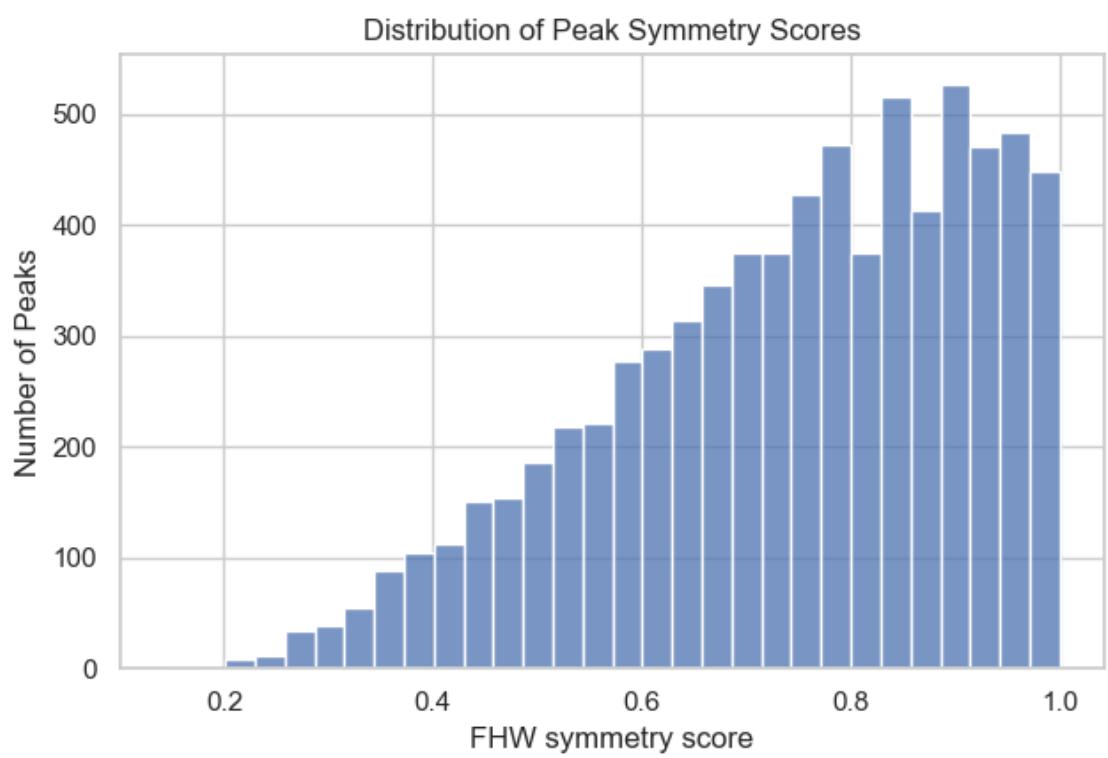
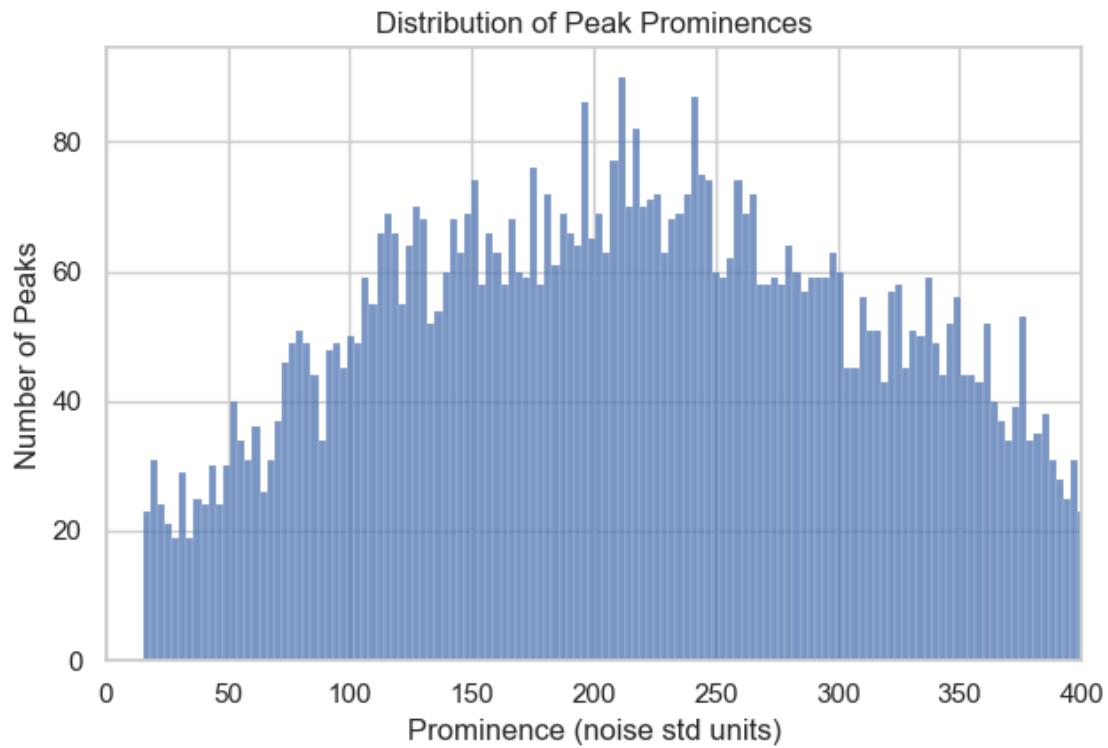
## 1.2 GLOBAL EVENTS

### 1.2.1 Peak statistics in global events

```
[2025-08-27 15:10:57] [INFO] calcium: plot_histogram: removed 0 outliers out of 7494 on 'Duration (s)' (lower=-45, upper=172)
```

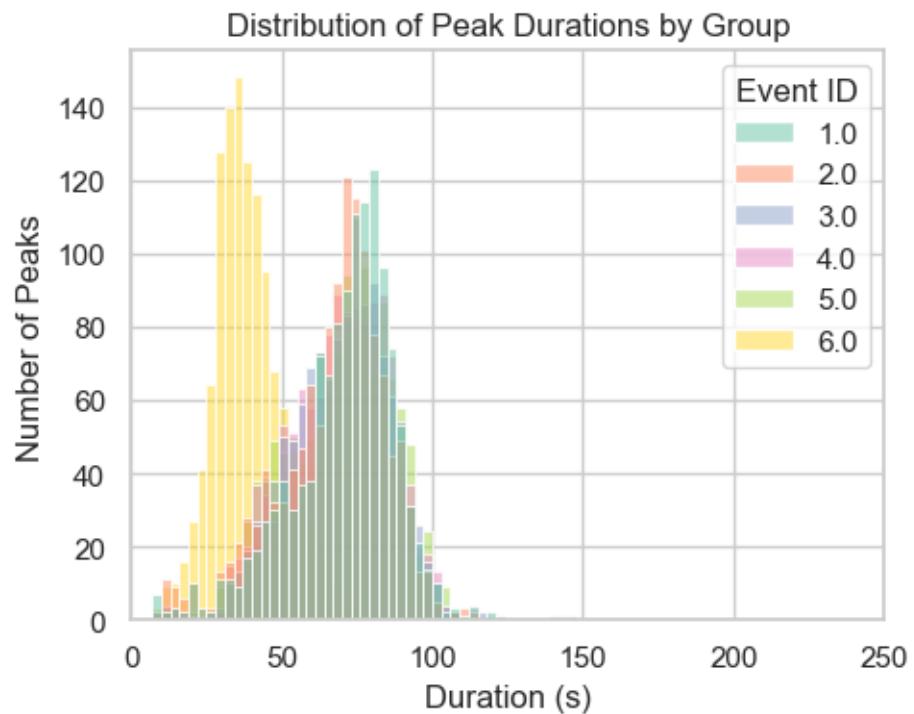


```
[2025-08-27 15:10:58] [INFO] calcium: plot_histogram: removed 0 outliers out of  
7494 on 'Prominence (noise std units)' (lower=-371.2, upper=832.8)
```

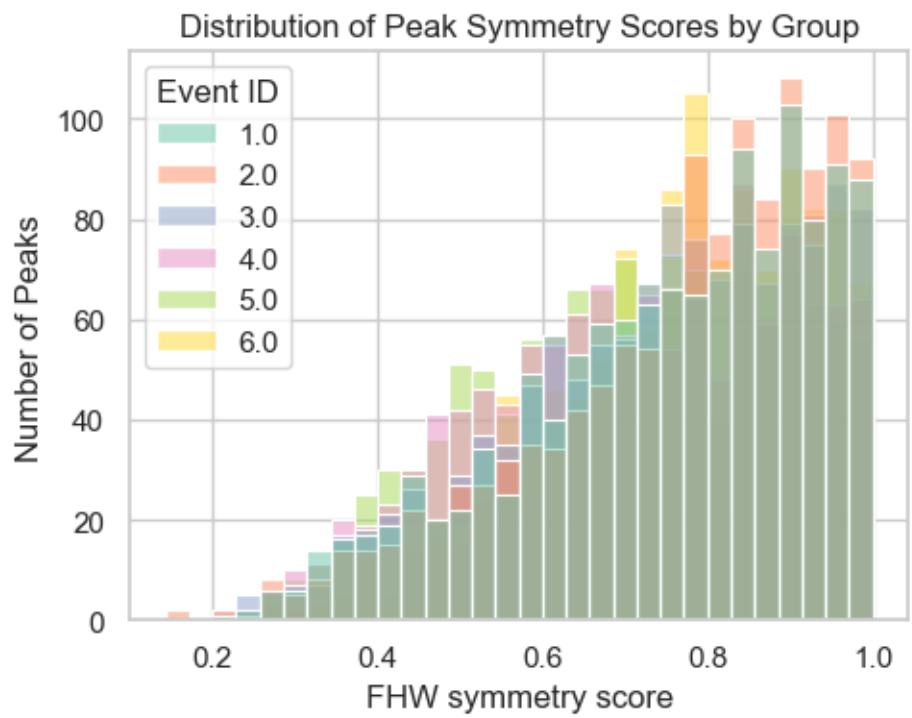
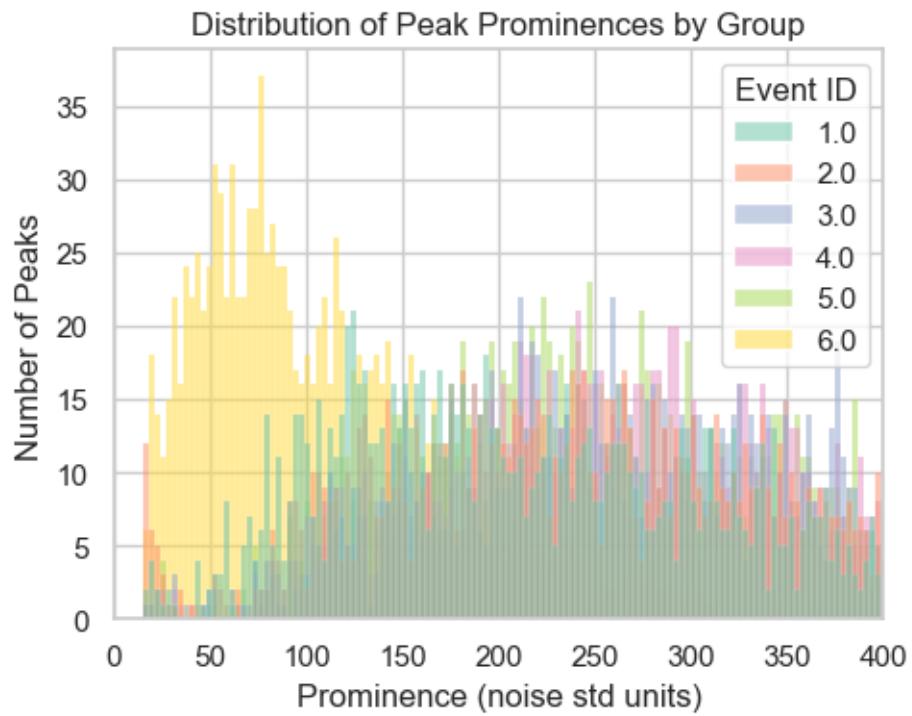


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:10:58] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 7494 on 'Duration (s)' (lower=-45, upper=172)

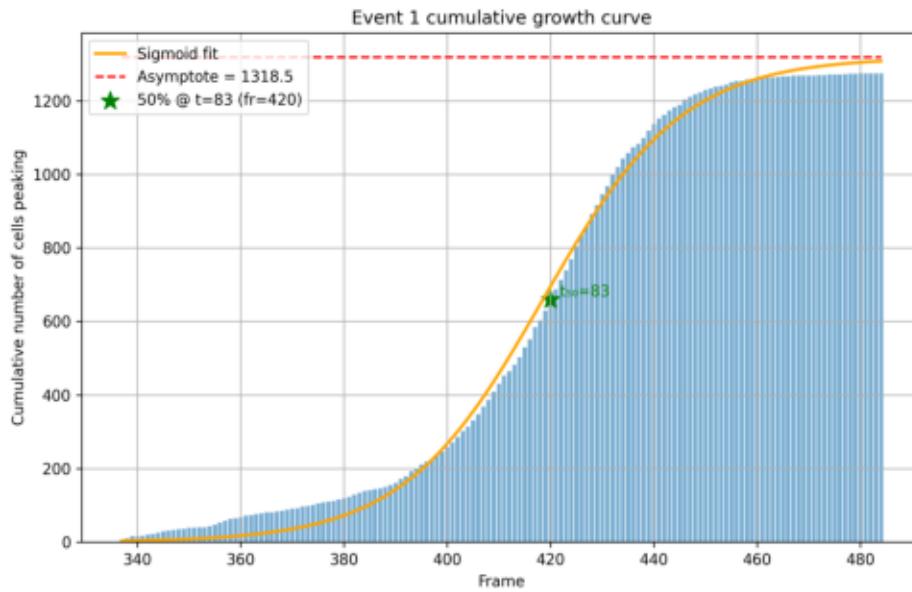


[2025-08-27 15:10:59] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 7494 on 'Prominence (noise std units)' (lower=-371.2, upper=832.8)

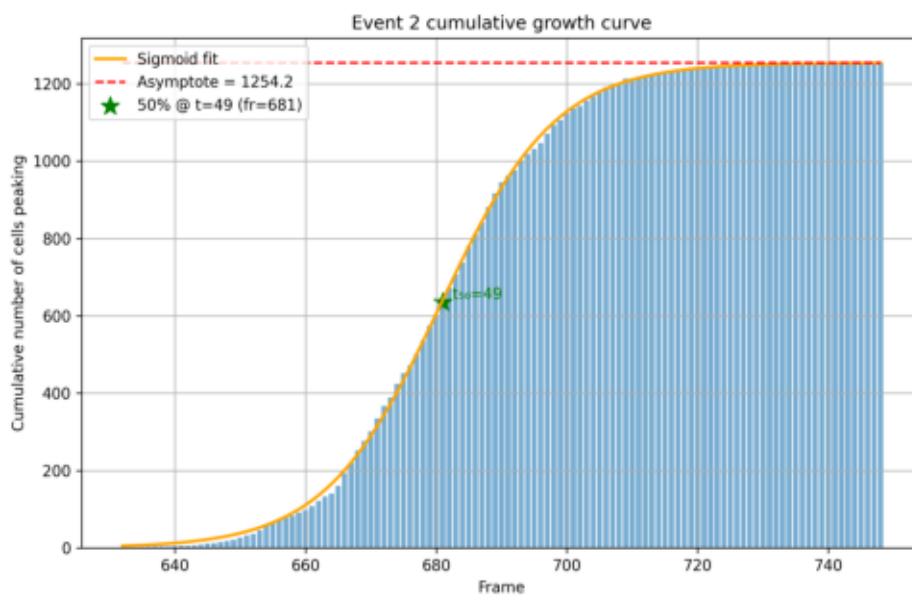


### 1.2.3 Kinetics of global events

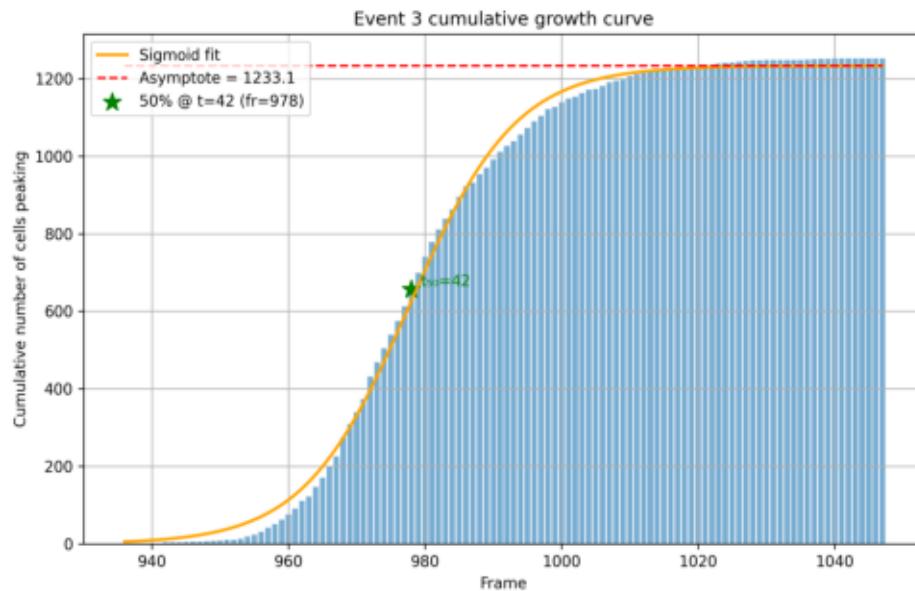
Event Activity Overlay (Event ID: 1)



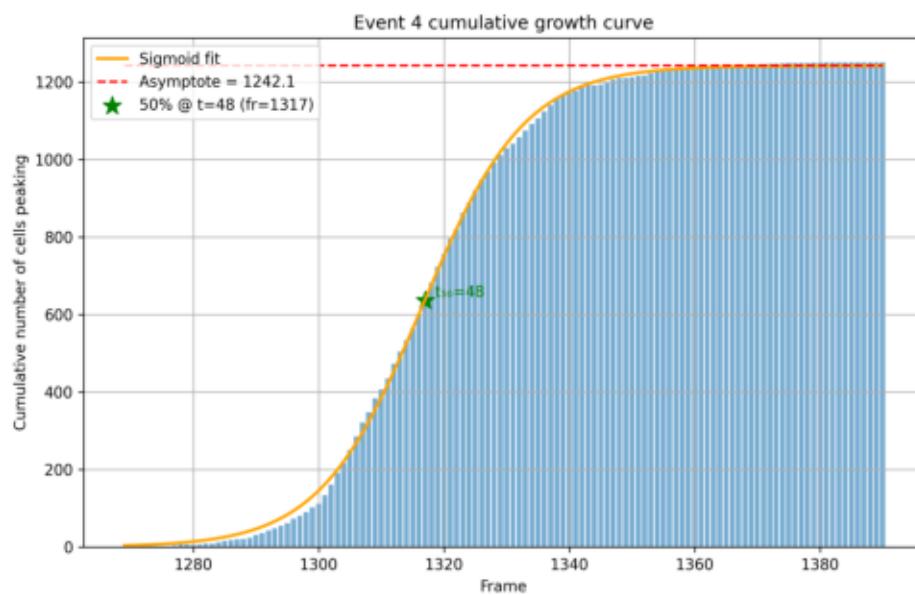
Event Activity Overlay (Event ID: 2)



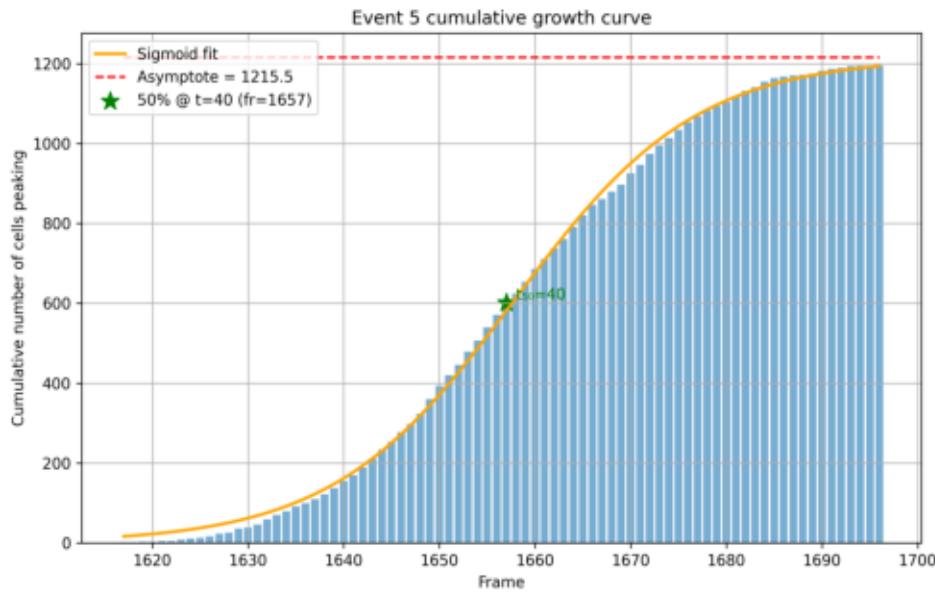
### Event Activity Overlay (Event ID: 3)



### Event Activity Overlay (Event ID: 4)

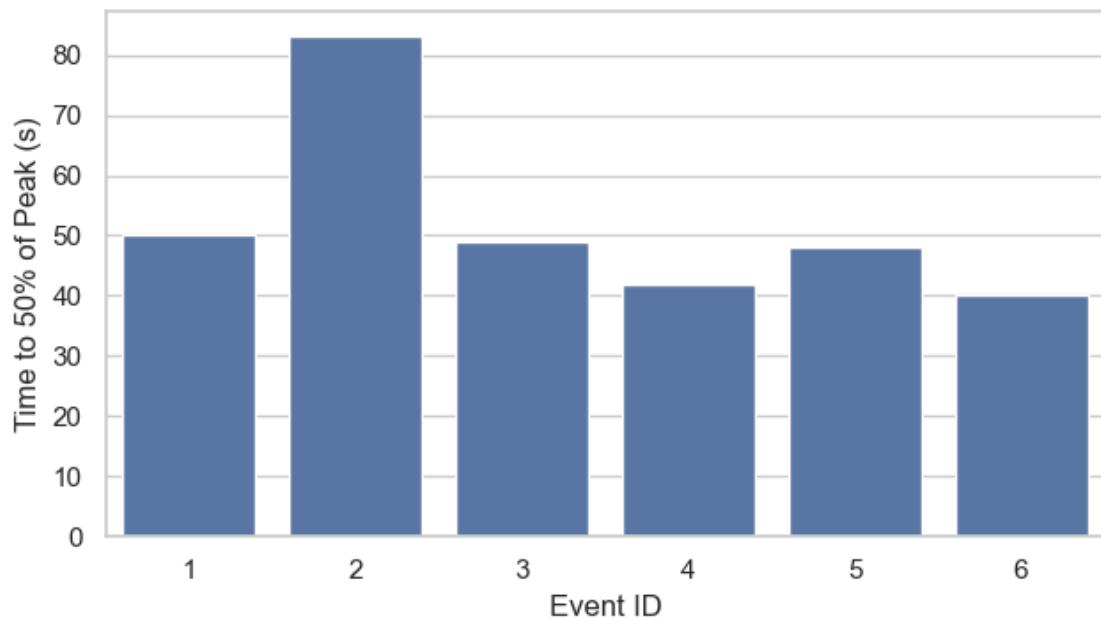


## Event Activity Overlay (Event ID: 5)

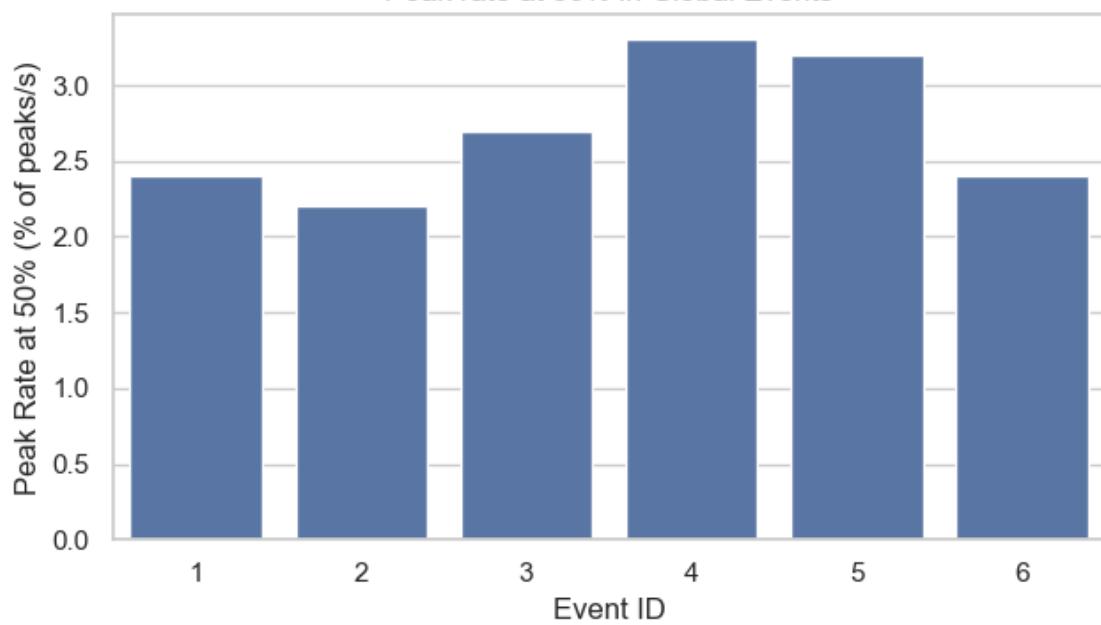


```
[2025-08-27 15:11:04] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\events\event-growth-curve-6.png': [Errno 2] No
such file or directory: 'D:\Mateo\20250624\Output\IS09\events\event-
growth-curve-6.png'
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
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\IS09\events\event-growth-curve-6.png'
```

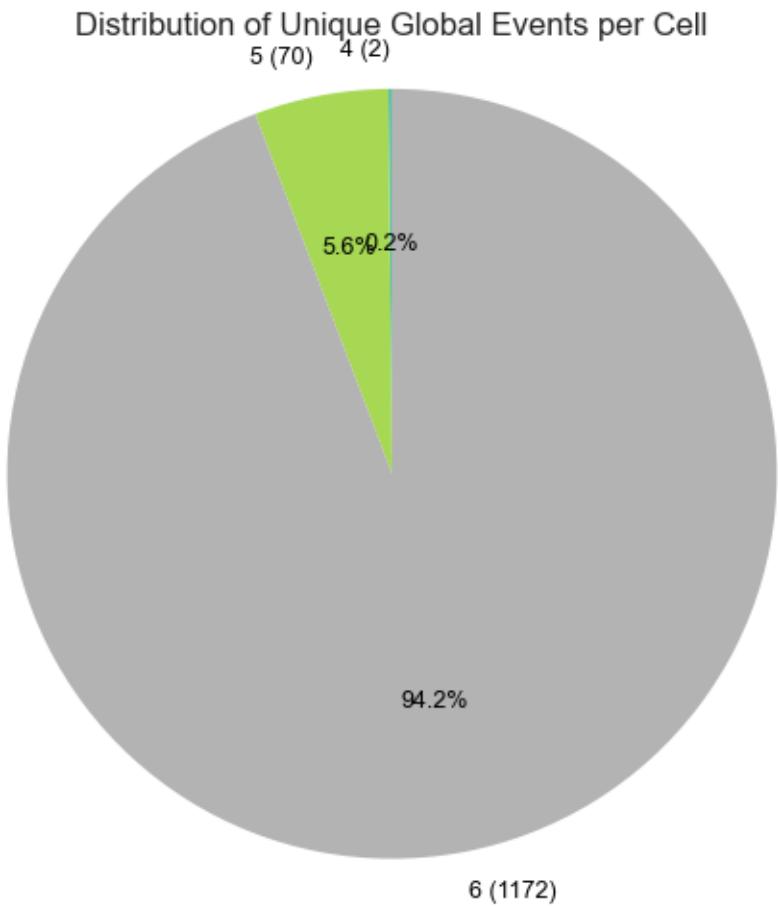
Time to 50% of Peaks in Global Events



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

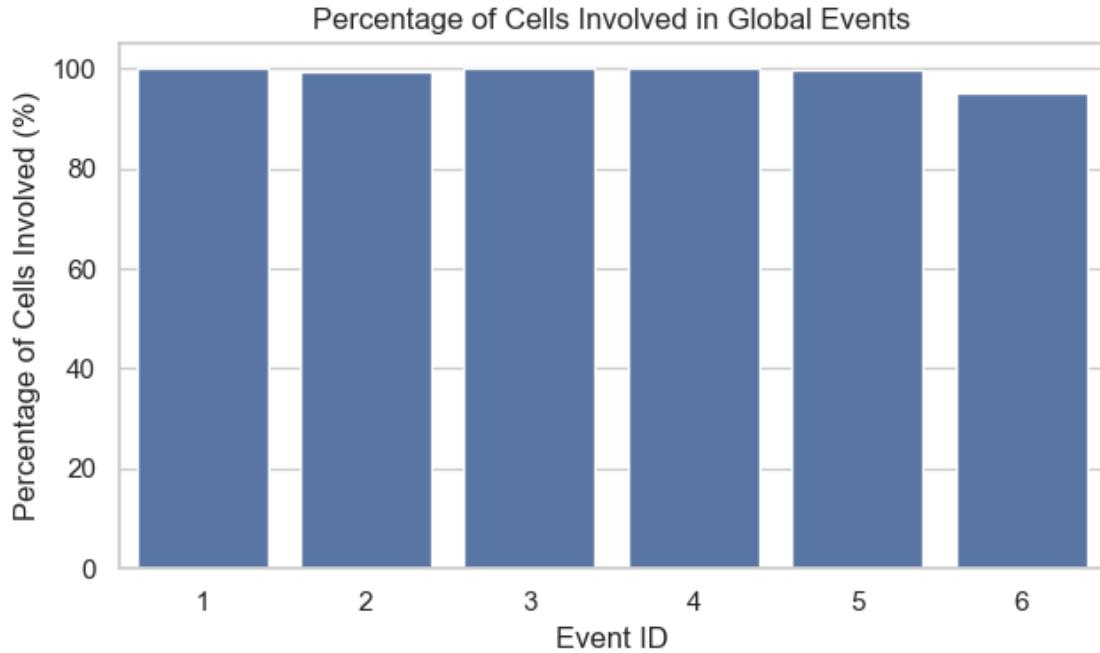


```
[2025-08-27 15:11:04] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250624\\\\Output\\\\IS09\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\IS09\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [237.0, 265.0, 298.0, 337.0, 344.0]  
 Estimated periodicity: 0.878  
 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 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\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 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\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 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\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-

```

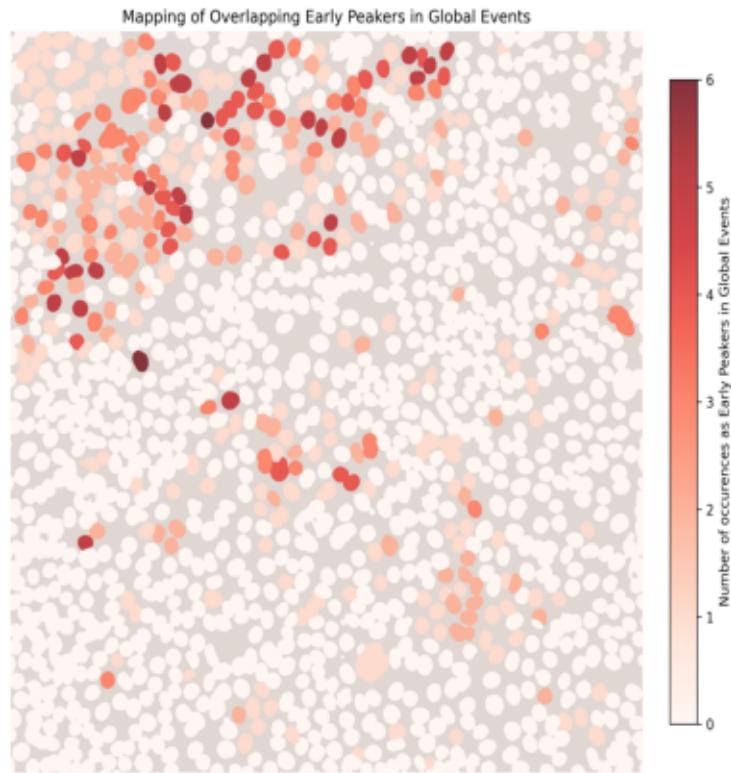
```
er_2025\Master_Thesis\Coding\Image_analysis\.venv\lib\site-
packages\PIL\PngImagePlugin.py", line 757, in _open
    raise SyntaxError(msg)
SyntaxError: not a PNG file

[2025-08-27 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\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 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\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
```

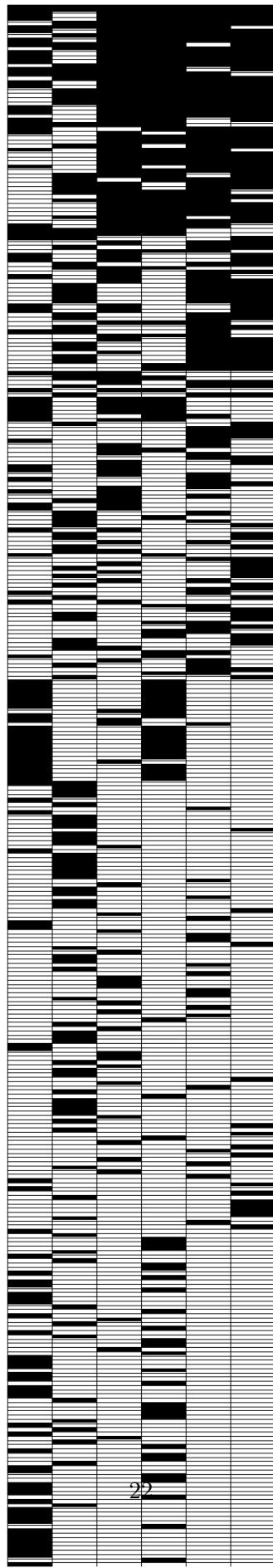
```
[2025-08-27 15:11:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\cell-
mapping\global_events\global_event_6_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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



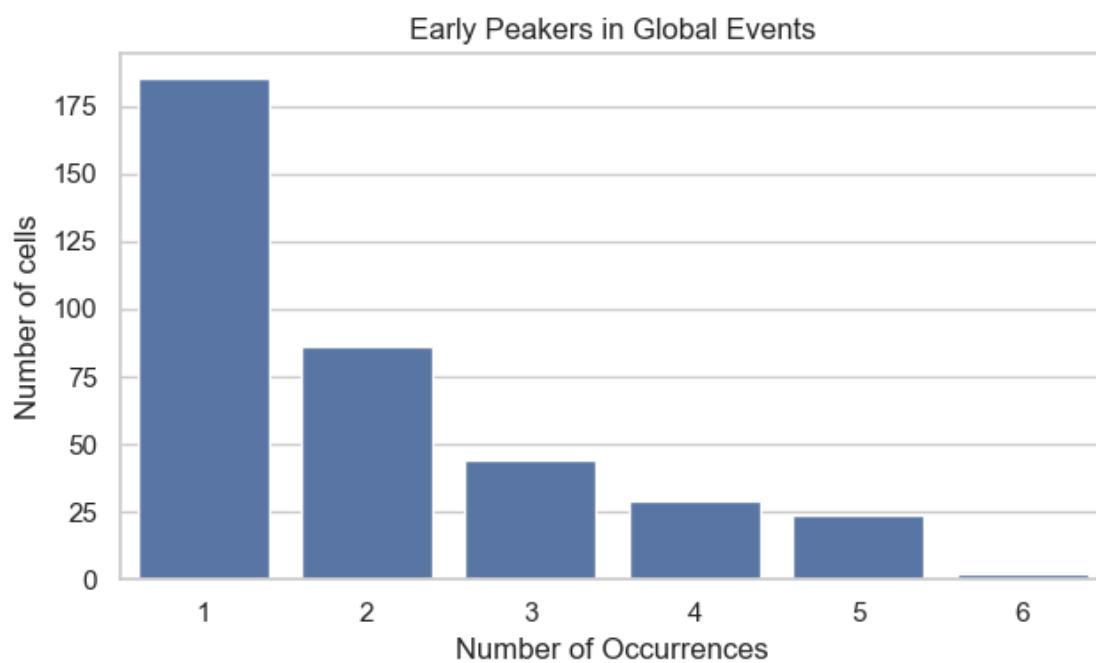
[2025-08-27 15:11:06] [WARNING] calcium: 'total\_events' is deprecated and ignored. Using 6 unique event IDs.

[2025-08-27 15:11:06] [INFO] calcium: Early peakers event-matrix: 370 cells x 6 events; black squares: 737

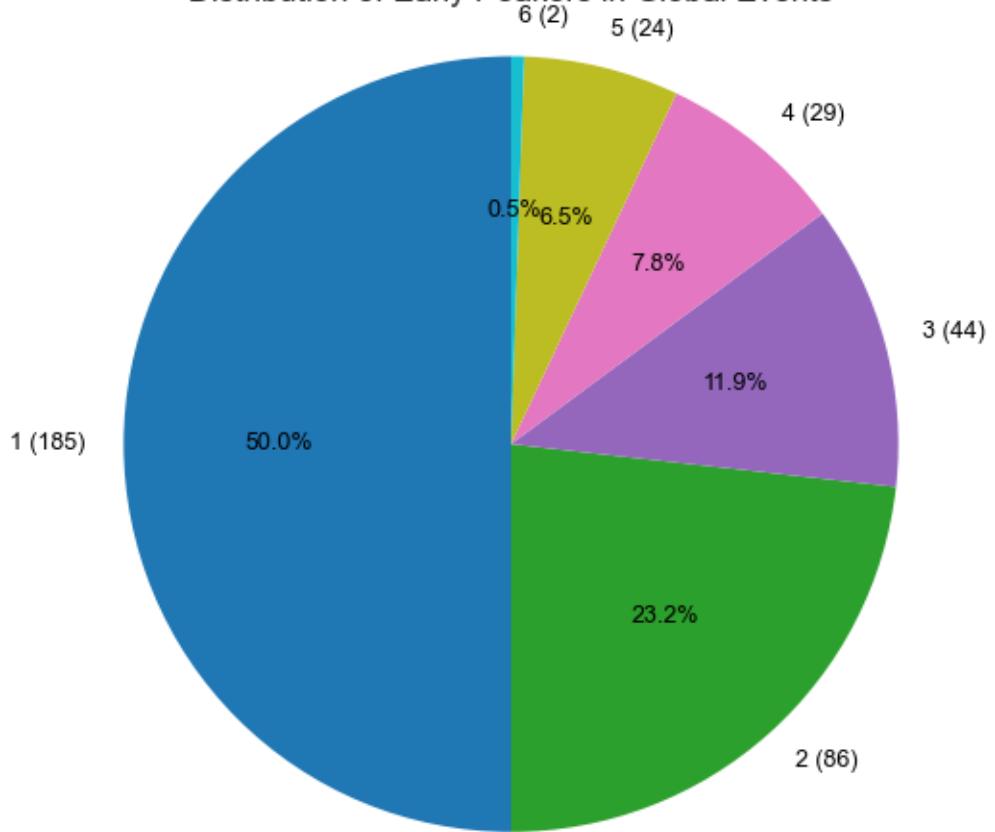


```
[2025-08-27 15:11:07] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

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



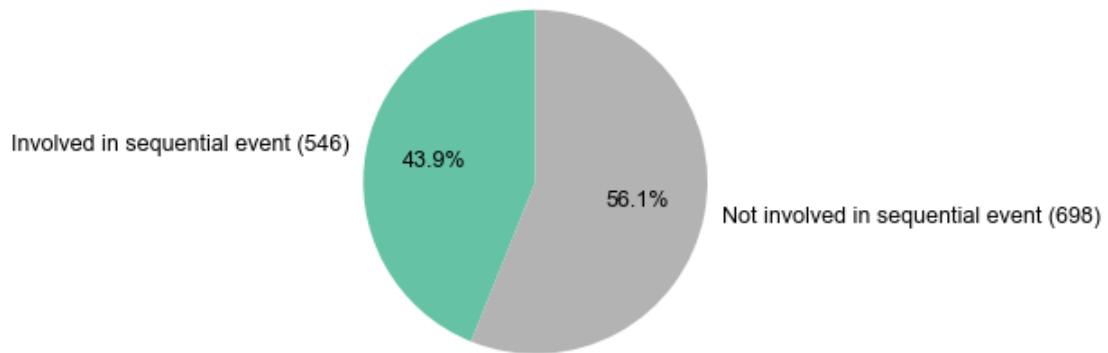
Distribution of Early Peakers in Global Events



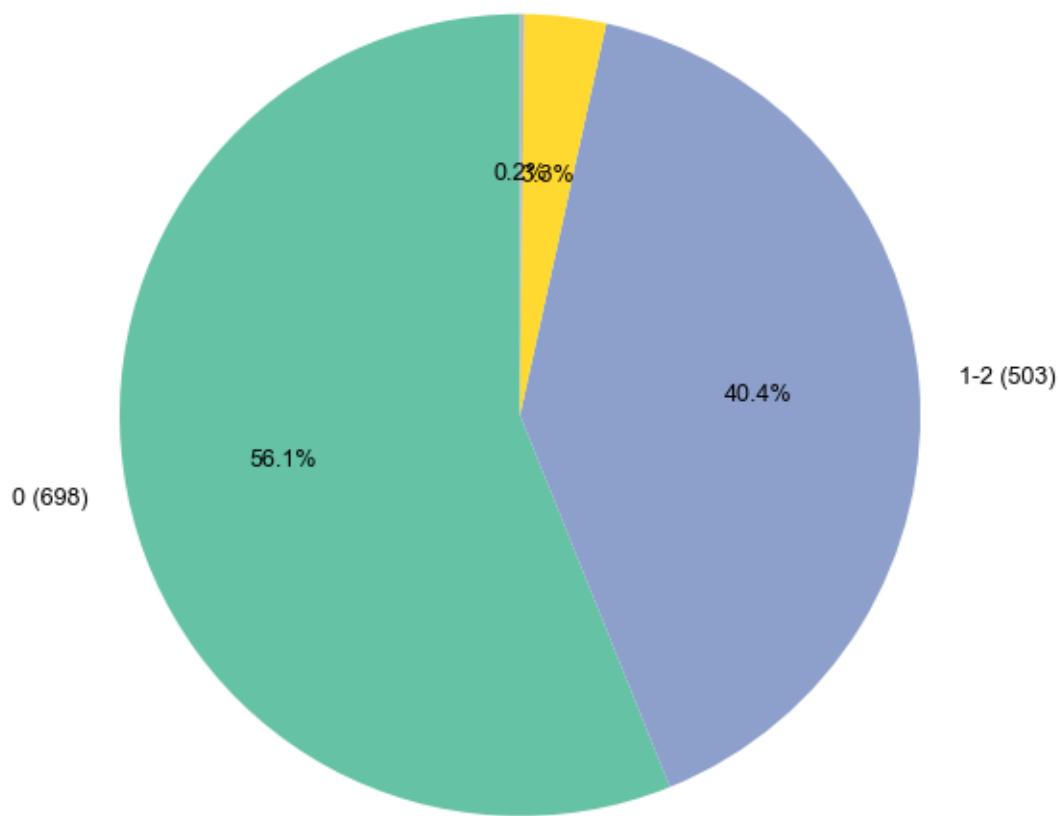
## 1.3 SEQUENTIAL EVENTS

### 1.3.1 Cells Occurrences in sequential events

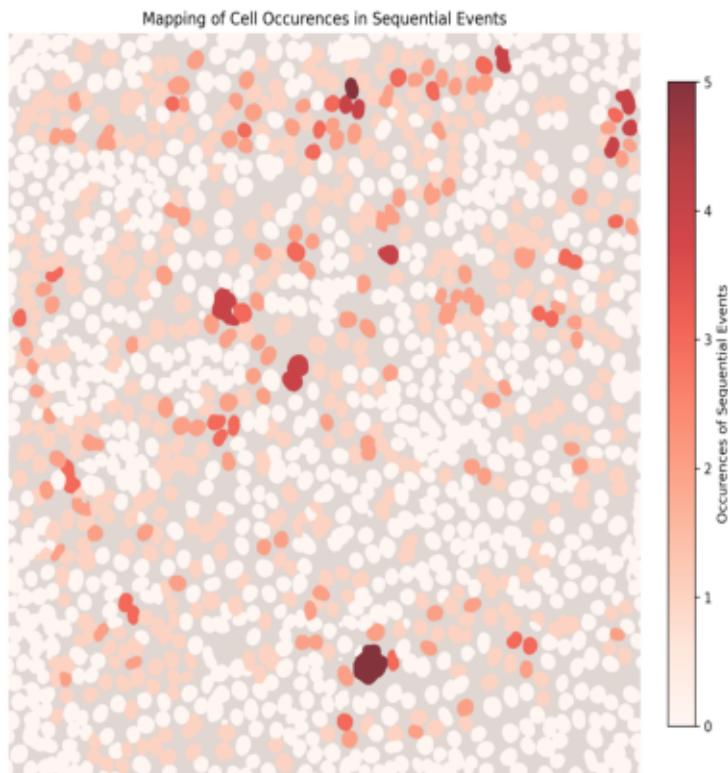
Distribution of Cells Involved in Sequential Events



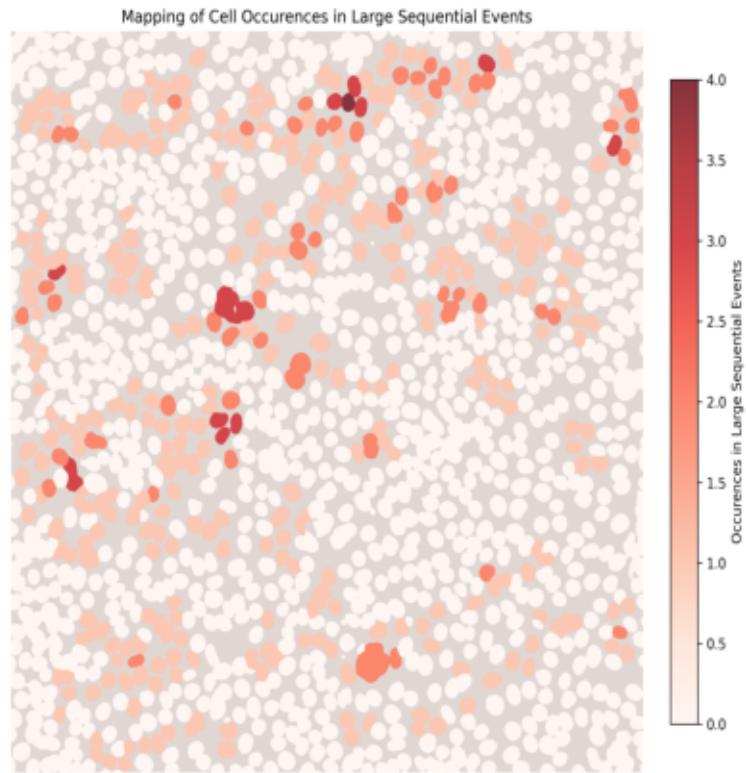
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

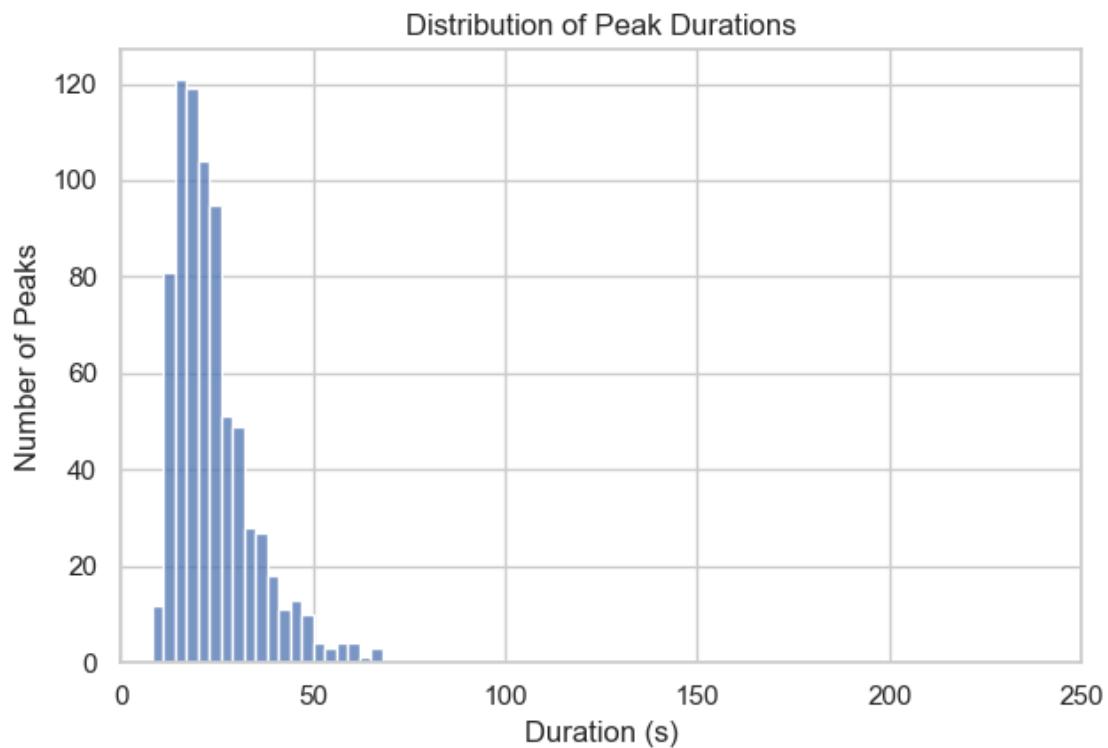


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

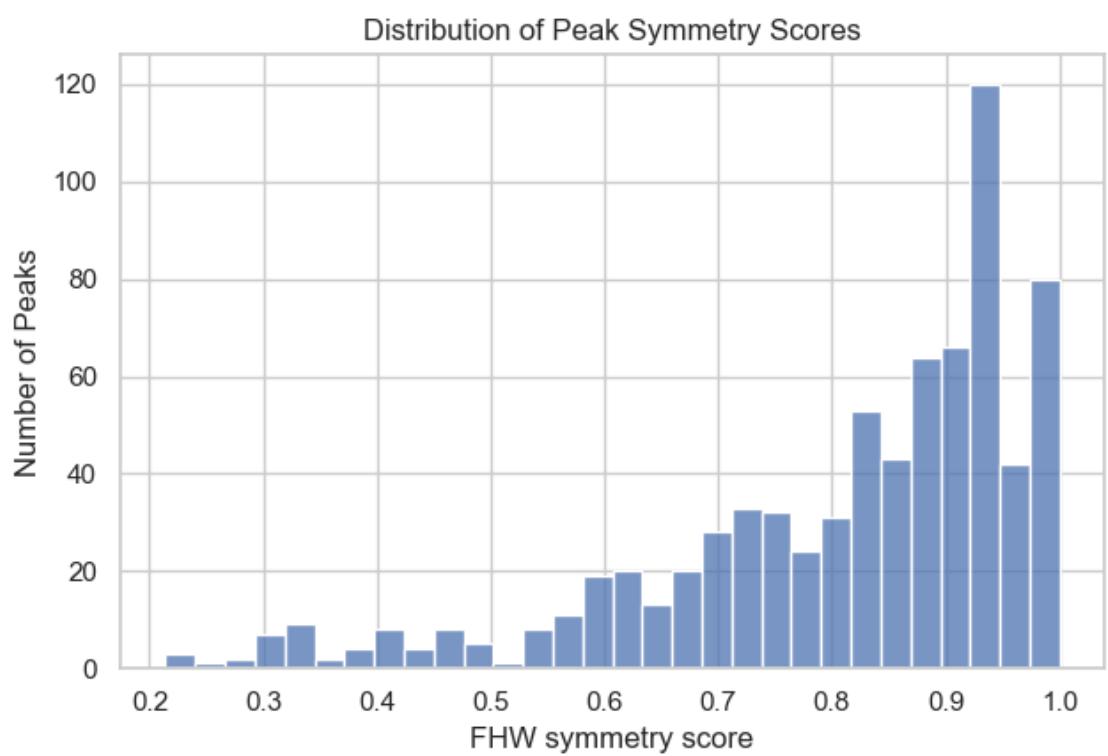
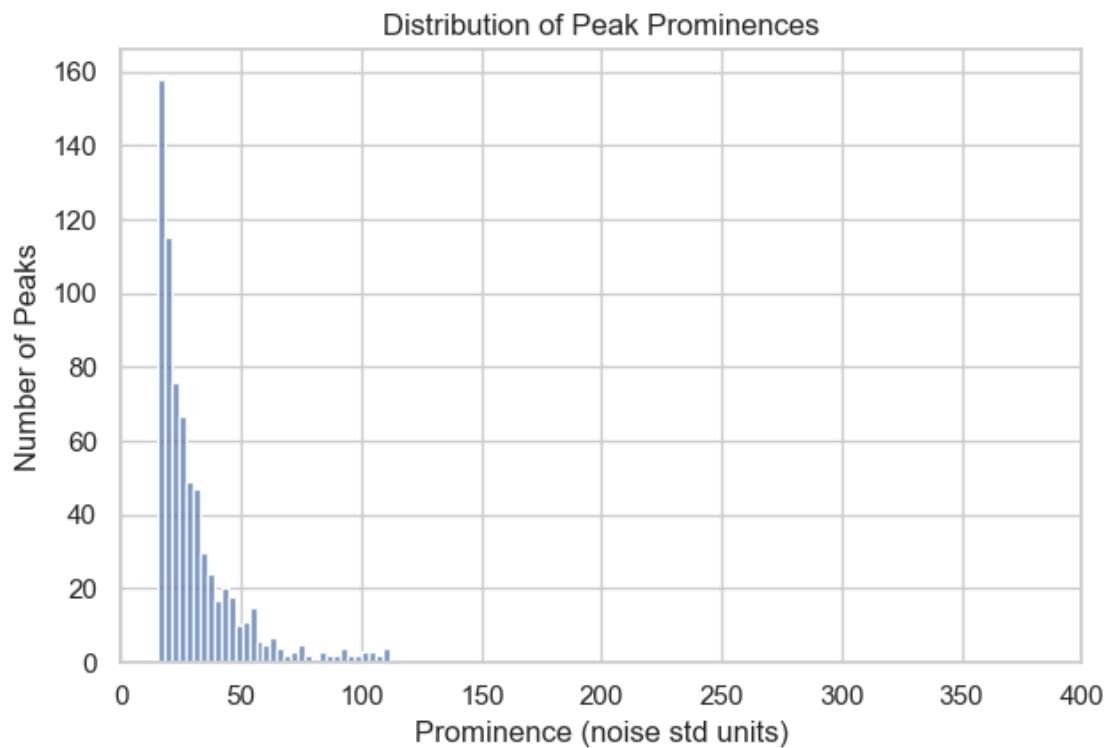


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:11:09] [INFO] calcium: plot_histogram: removed 3 outliers out of  
761 on 'Duration (s)' (lower=-2, upper=70)
```

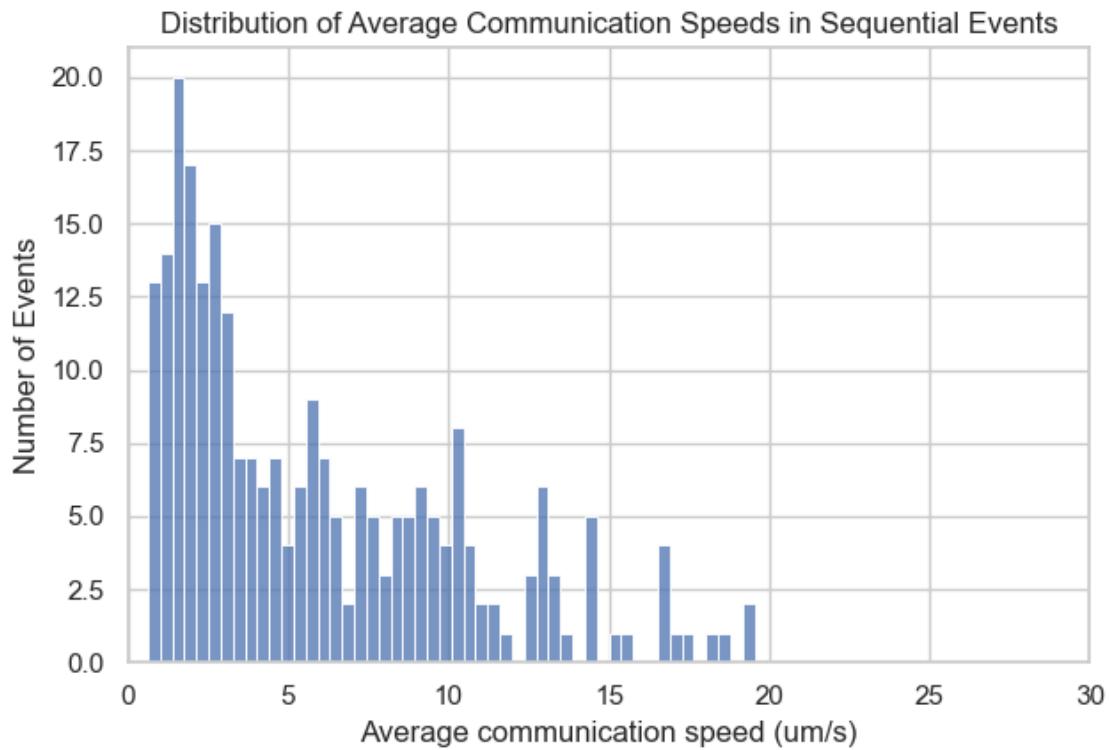


```
[2025-08-27 15:11:09] [INFO] calcium: plot_histogram: removed 42 outliers out of  
761 on 'Prominence (noise std units)' (lower=-12.5, upper=112.3)
```

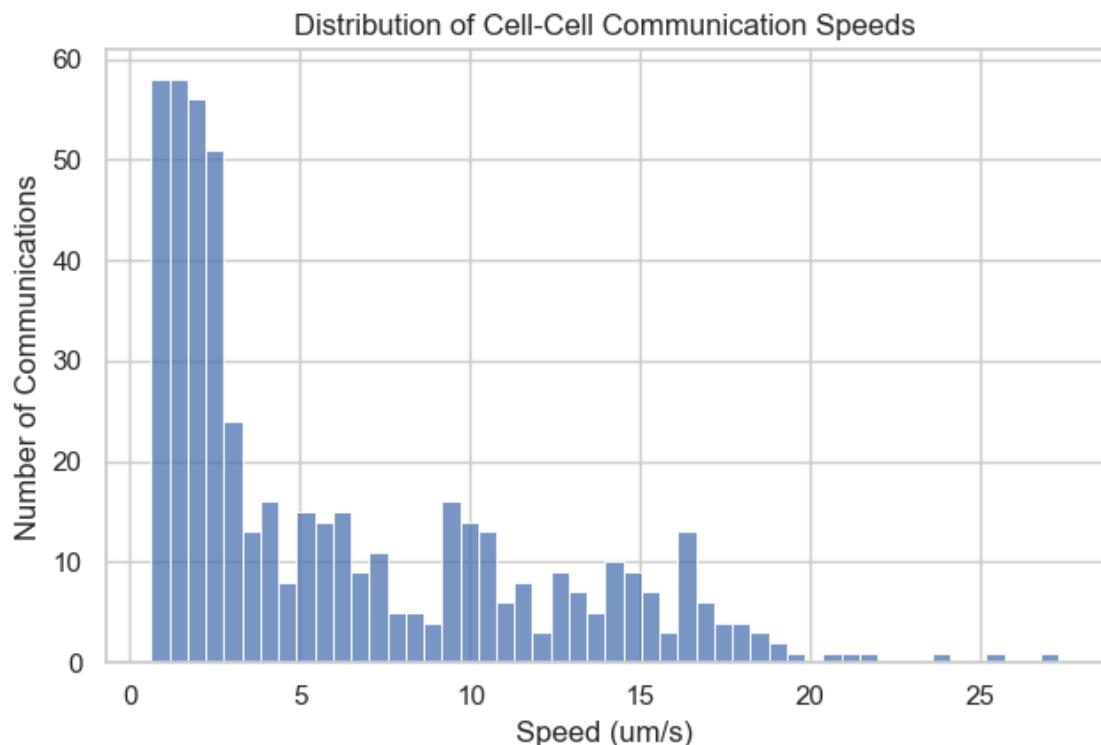


### 1.3.3 Cell-cell communication speed

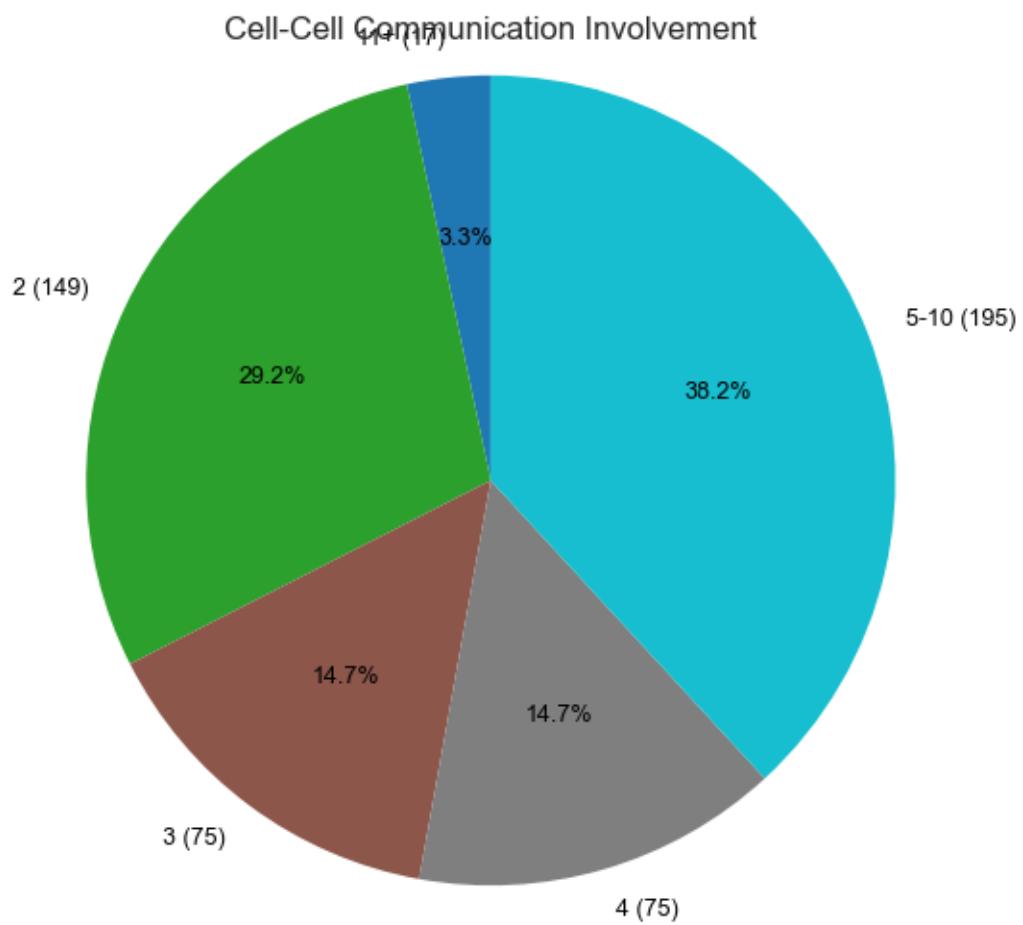
```
[2025-08-27 15:11:10] [INFO] calcium: plot_histogram: removed 0 outliers out of  
250 on 'Average communication speed (um/s)' (lower=-18.125, upper=29.055)
```



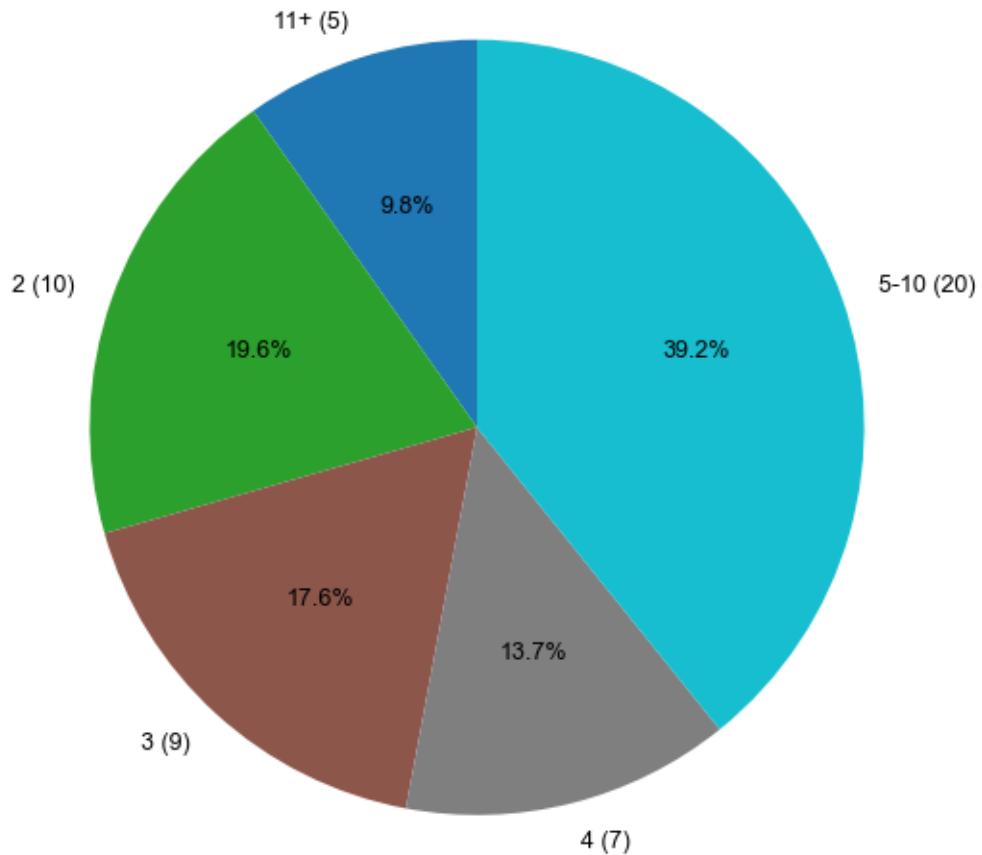
```
[2025-08-27 15:11:10] [INFO] calcium: plot_histogram: removed 0 outliers out of  
511 on 'Speed (um/s)' (lower=-22.545, upper=50.4)
```



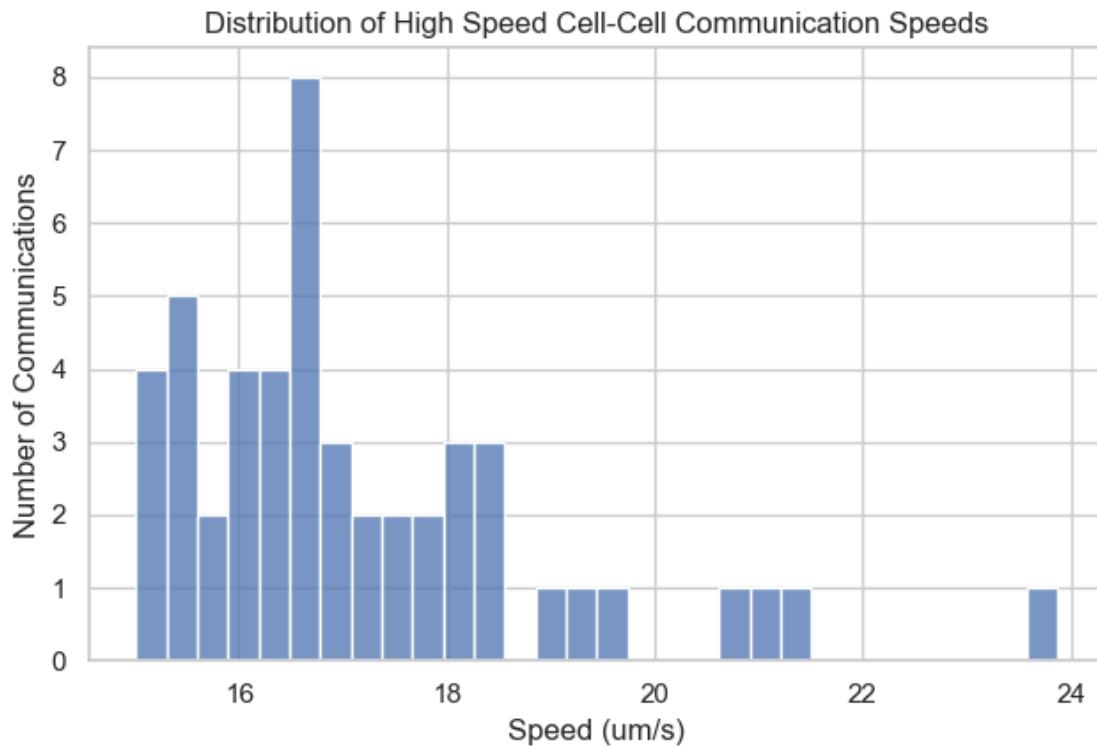
#### 1.3.4 Double distribution in cell-cell communication speeds



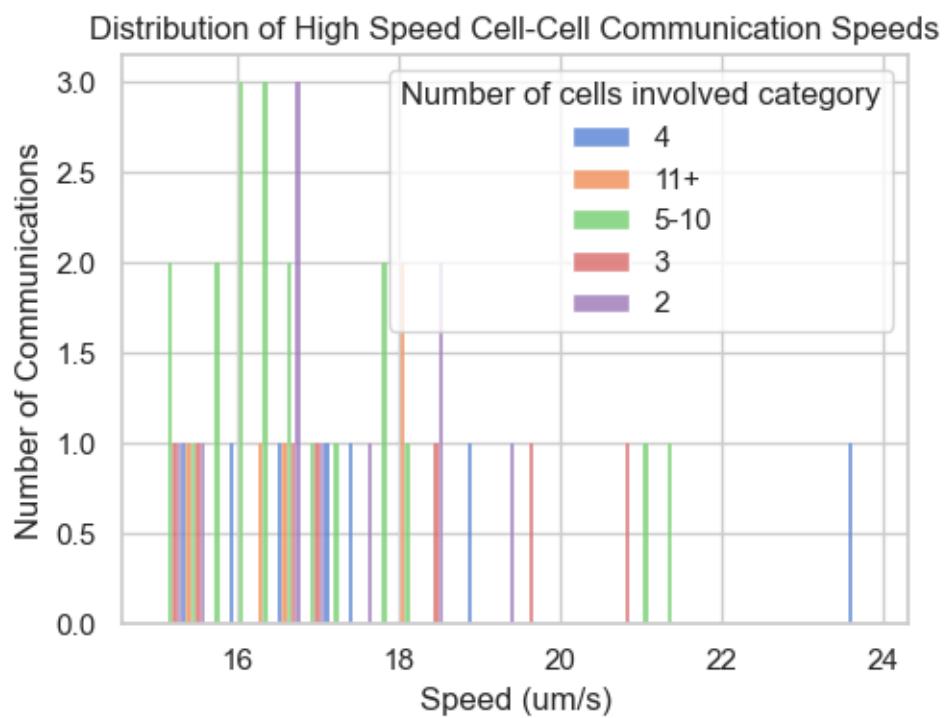
### High Speed Cell-Cell Communication Involvement



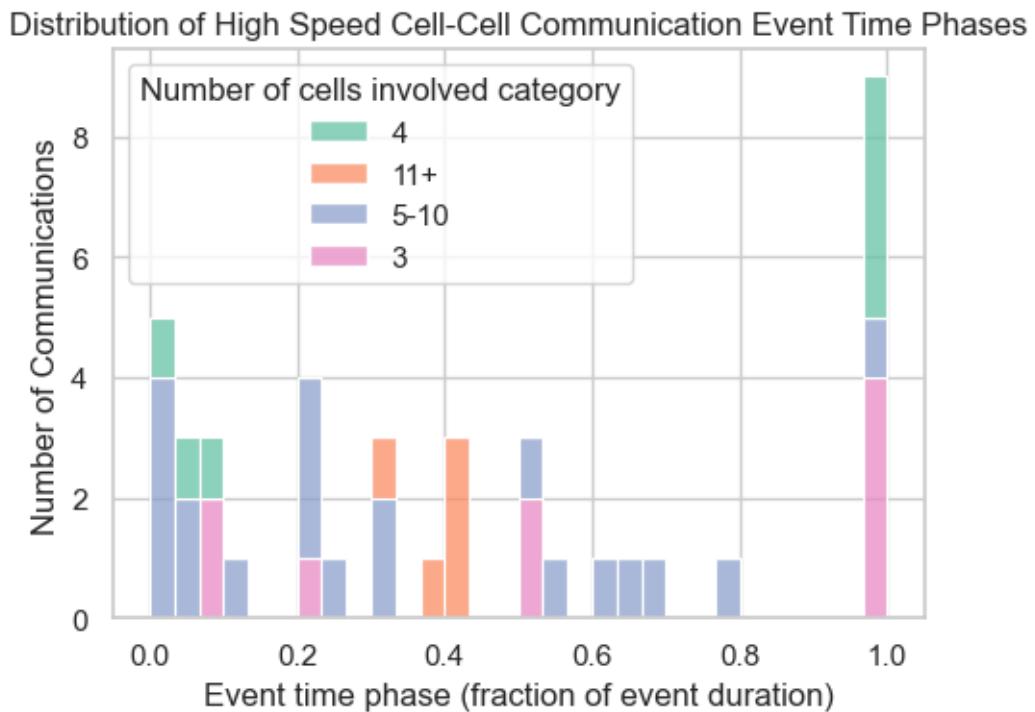
[2025-08-27 15:11:10] [INFO] calcium: plot\_histogram: removed 2 outliers out of 51 on 'Speed (um/s)' (lower=10.21, upper=24.07)



```
[2025-08-27 15:11:11] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 51 on 'Speed (um/s)' (lower=10.21, upper=24.07)
```

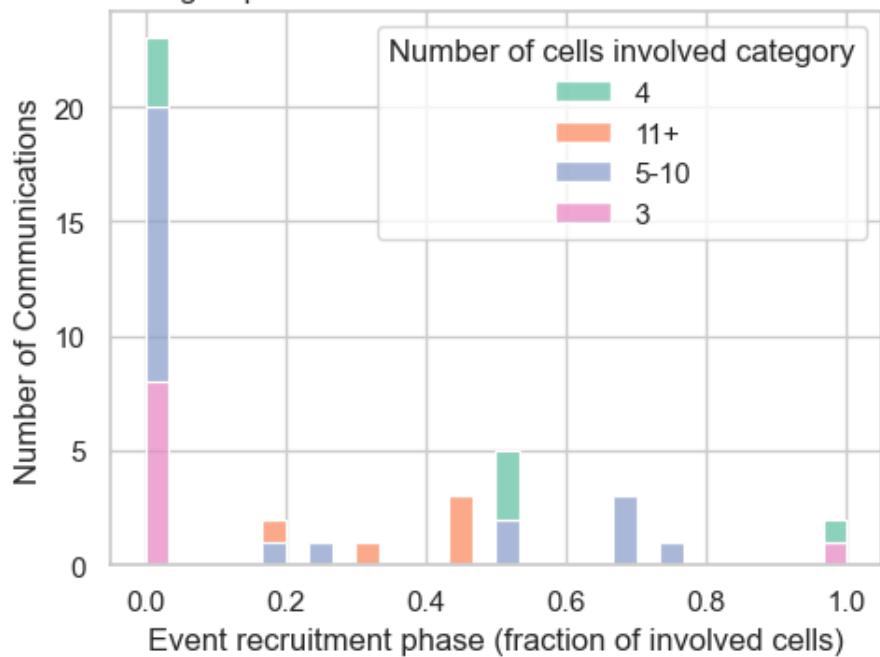


```
[2025-08-27 15:11:11] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 41 on 'Event time phase (fraction of event duration)' (lower=-1.65, upper=2.41)
```

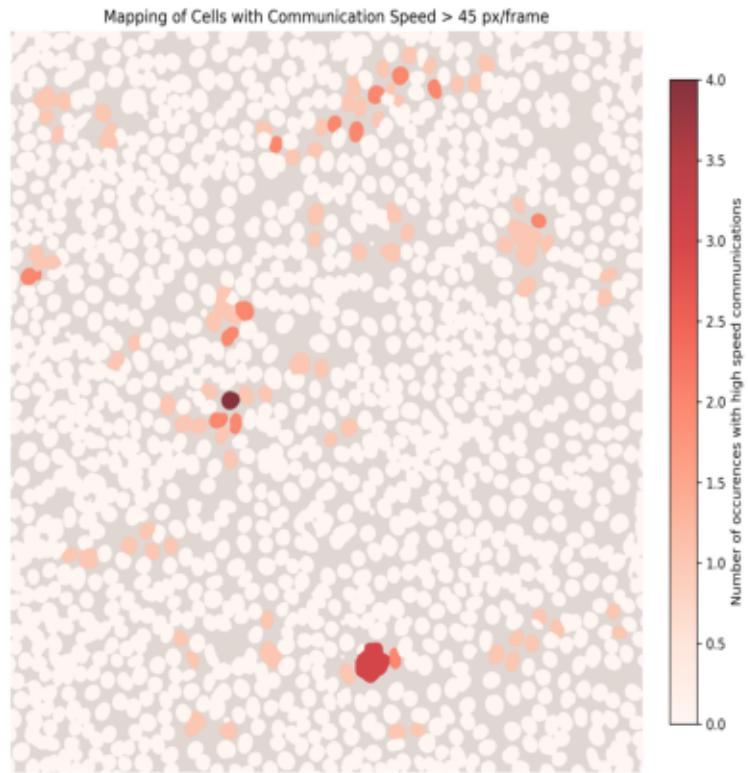


```
[2025-08-27 15:11:11] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 41 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.5, upper=2)
```

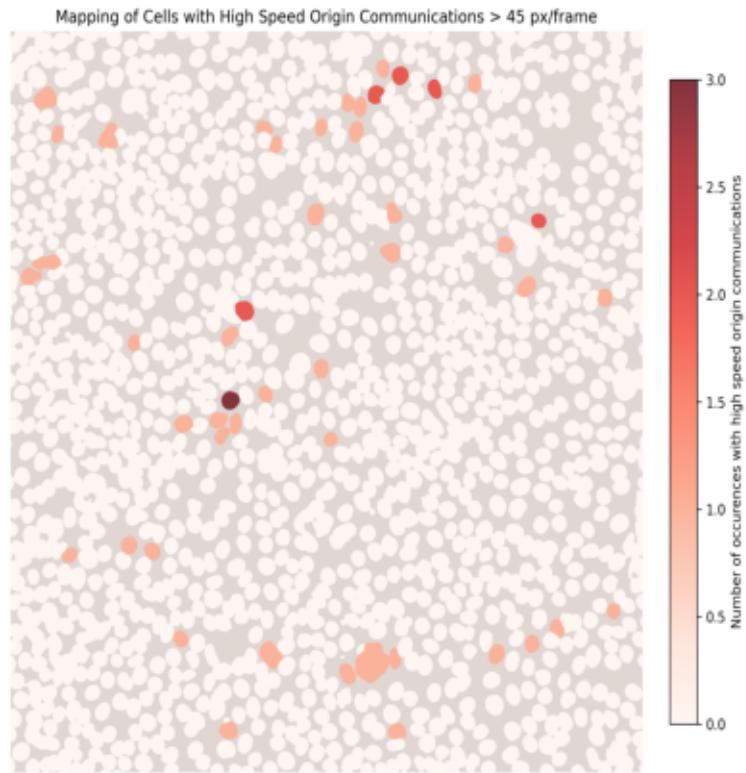
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	\
1	2016590730560	7	411		0
12	2016590729696	12	417		7
13	2016590737616	12	476		5
17	2016590731040	12	338		6
18	2016590740256	12	380		4
21	2016590736944	12	380		4
28	2016590726096	13	373		8
30	2016590735456	13	362		6
32	2016590739296	13	373		8
37	2016590727104	15	742		0
38	2016590728784	16	338		0
45	2016524951872	19	1203		5

48	2016590737280	20	832	0
51	2016590734112	21	1713	0
57	2016590731184	22	1171	0
74	2016590737520	25	471	0
75	2016590735024	25	506	0
85	2016590725712	27	669	0
90	2016590731616	30	497	1
113	2016590739872	38	781	0
114	2016524945536	38	810	0
117	2016590738528	40	887	0
119	2016590728016	40	887	0
127	2016590731472	42	1163	0
128	2016524954992	42	1114	0
129	2016524956528	42	1169	0
131	2016590739200	43	1485	0
144	2016524952112	47	950	1
148	2016590735120	48	1114	1
149	2016590737088	48	1114	1
166	2016590735408	52	1470	1
223	2016524944192	81	468	0
255	2016524945728	104	664	0
262	2016524943952	108	683	0
264	2016524945152	108	683	0
277	2016524945824	118	754	2
295	2016524946784	130	859	0
329	2016524949280	147	1030	0
344	2016524949376	158	965	0
367	2016524954752	170	1099	0
379	2016524954944	179	1210	2
455	2016524949952	221	1639	0
461	2016524952064	225	1686	1
463	2016524950624	226	1749	0
468	2016524952736	229	1750	0
481	2016524953648	237	1782	0
482	2016524953552	237	1797	0
483	2016524954224	238	1727	0
485	2016524953456	239	1769	1
500	2016587906208	249	1931	0
504	2016587904816	251	1935	4

Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
1	456	0	30.0	31.0
12	476	5	1181.0	1181.0
13	456	5	1181.0	1181.0
17	293	4	1181.0	1181.0
18	370	8	1179.0	1180.0
21	446	5	1179.0	1179.0
28	365	5	1182.0	1183.0

30	314	6	1183.0	1183.0
32	322	6	1182.0	1183.0
37	713	0	52.0	52.0
38	399	0	52.0	52.0
45	1264	5	887.0	888.0
48	765	0	53.0	53.0
51	1762	0	74.0	74.0
57	1127	0	46.0	46.0
74	506	0	29.0	30.0
75	539	0	30.0	30.0
85	711	0	81.0	81.0
90	429	0	86.0	86.0
113	810	0	98.0	98.0
114	757	0	98.0	99.0
117	851	0	12.0	13.0
119	950	0	12.0	12.0
127	1177	0	23.0	23.0
128	1091	0	24.0	25.0
129	1114	0	23.0	24.0
131	1474	0	54.0	54.0
144	915	2	70.0	71.0
148	1169	1	73.0	73.0
149	1163	1	73.0	73.0
166	1438	2	325.0	325.0
223	517	0	30.0	31.0
255	725	1	60.0	61.0
262	648	0	49.0	50.0
264	738	0	49.0	50.0
277	751	0	103.0	104.0
295	805	0	58.0	59.0
329	1021	0	50.0	51.0
344	1012	0	92.0	93.0
367	1102	0	103.0	104.0
379	1184	2	575.0	576.0
455	1697	0	51.0	52.0
461	1649	2	312.0	313.0
463	1658	0	58.0	59.0
468	1714	0	17.0	18.0
481	1769	0	14.0	15.0
482	1782	0	13.0	14.0
483	1770	0	63.0	64.0
485	1782	1	73.0	74.0
500	1913	0	46.0	47.0
504	1929	7	886.0	887.0

	Duration (s)	Distance (um)	Speed (um/s)	\
1	1.0	17.62	17.62	
12	0.0	16.57	16.57	

13	0.0	18.09	18.09
17	0.0	15.41	15.41
18	1.0	18.09	18.09
21	0.0	16.33	16.33
28	1.0	18.17	18.17
30	0.0	16.14	16.14
32	1.0	16.40	16.40
37	0.0	16.57	16.57
38	0.0	16.93	16.93
45	1.0	17.20	17.20
48	0.0	21.45	21.45
51	0.0	16.77	16.77
57	0.0	17.70	17.70
74	1.0	15.02	15.02
75	0.0	15.78	15.78
85	0.0	16.85	16.85
90	0.0	16.56	16.56
113	0.0	16.41	16.41
114	1.0	16.56	16.56
117	1.0	15.55	15.55
119	0.0	21.01	21.01
127	0.0	15.14	15.14
128	1.0	17.69	17.69
129	1.0	16.16	16.16
131	0.0	15.45	15.45
144	1.0	15.80	15.80
148	0.0	16.16	16.16
149	0.0	16.32	16.32
166	0.0	17.49	17.49
223	1.0	16.03	16.03
255	1.0	16.95	16.95
262	1.0	19.02	19.02
264	1.0	16.73	16.73
277	1.0	25.35	25.35
295	1.0	15.55	15.55
329	1.0	17.15	17.15
344	1.0	18.44	18.44
367	1.0	15.29	15.29
379	1.0	16.61	16.61
455	1.0	15.01	15.01
461	1.0	15.44	15.44
463	1.0	23.87	23.87
468	1.0	19.20	19.20
481	1.0	18.38	18.38
482	1.0	20.70	20.70
483	1.0	19.44	19.44
485	1.0	18.38	18.38
500	1.0	27.30	27.30

504 1.0 16.63 16.63

	Event time phase (fraction of event duration)	\
1		1.00
12		0.42
13		0.42
17		0.42
18		0.37
21		0.32
28		0.20
30		0.20
32		0.20
37		1.00
38		NaN
45		1.00
48		1.00
51		0.77
57		0.64
74		0.33
75		0.33
85		1.00
90		NaN
113		0.56
114		0.67
117		0.12
119		0.00
127		0.00
128		0.50
129		0.25
131		0.00
144		0.05
148		0.00
149		0.00
166		NaN
223		0.09
255		0.06
262		1.00
264		1.00
277		0.20
295		NaN
329		0.62
344		NaN
367		NaN
379		NaN
455		0.07
461		1.00
463		0.05
468		NaN

481		1.00	
482		0.50	
483		0.07	
485		NaN	
500		0.50	
504		NaN	
Event recruitment phase (fraction of involved cells) \ dataset			
1		0.50	20250624_IS09
12		0.44	20250624_IS09
13		0.44	20250624_IS09
17		0.44	20250624_IS09
18		0.31	20250624_IS09
21		0.19	20250624_IS09
28		0.00	20250624_IS09
30		0.00	20250624_IS09
32		0.00	20250624_IS09
37		0.00	20250624_IS09
38		NaN	20250624_IS09
45		1.00	20250624_IS09
48		0.67	20250624_IS09
51		0.50	20250624_IS09
57		0.67	20250624_IS09
74		0.00	20250624_IS09
75		0.00	20250624_IS09
85		0.00	20250624_IS09
90		NaN	20250624_IS09
113		0.00	20250624_IS09
114		0.67	20250624_IS09
117		0.17	20250624_IS09
119		0.00	20250624_IS09
127		0.00	20250624_IS09
128		0.75	20250624_IS09
129		0.50	20250624_IS09
131		0.00	20250624_IS09
144		0.00	20250624_IS09
148		0.00	20250624_IS09
149		0.00	20250624_IS09
166		NaN	20250624_IS09
223		0.00	20250624_IS09
255		0.00	20250624_IS09
262		0.50	20250624_IS09
264		0.50	20250624_IS09
277		0.00	20250624_IS09
295		NaN	20250624_IS09
329		0.25	20250624_IS09
344		NaN	20250624_IS09
367		NaN	20250624_IS09

379		NaN	20250624_IS09
455		0.00	20250624_IS09
461		0.00	20250624_IS09
463		0.00	20250624_IS09
468		NaN	20250624_IS09
481		1.00	20250624_IS09
482		0.00	20250624_IS09
483		0.00	20250624_IS09
485		NaN	20250624_IS09
500		0.00	20250624_IS09
504		NaN	20250624_IS09

	Number of cells involved	category	Speed category
1		4	High speed
12		11+	High speed
13		11+	High speed
17		11+	High speed
18		11+	High speed
21		11+	High speed
28		5-10	High speed
30		5-10	High speed
32		5-10	High speed
37		3	High speed
38		2	High speed
45		4	High speed
48		5-10	High speed
51		5-10	High speed
57		5-10	High speed
74		5-10	High speed
75		5-10	High speed
85		3	High speed
90		2	High speed
113		5-10	High speed
114		5-10	High speed
117		5-10	High speed
119		5-10	High speed
127		5-10	High speed
128		5-10	High speed
129		5-10	High speed
131		4	High speed
144		5-10	High speed
148		5-10	High speed
149		5-10	High speed
166		2	High speed
223		4	High speed
255		5-10	High speed
262		4	High speed
264		4	High speed

277	3	High speed
295	2	High speed
329	5-10	High speed
344	2	High speed
367	2	High speed
379	2	High speed
455	3	High speed
461	3	High speed
463	4	High speed
468	2	High speed
481	3	High speed
482	3	High speed
483	3	High speed
485	2	High speed
500	3	High speed
504	2	High speed

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

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

281	0	4
293	0	1
299	0	1
307	0	1
309	0	1
...	...	...
1963	0	1
1965	0	1
1973	0	2
1976	0	1
1988	0	2

[321 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
12	281	388.38	12.03
21	293	314.60	15.93
25	299	79.30	16.90
31	307	390.65	20.15
33	309	128.05	20.48
...	...	...	...
1209	1963	116.03	479.70
1211	1965	105.30	480.03
1216	1973	93.28	481.98
1219	1976	145.60	483.60
1229	1988	66.95	487.18

Number of peaks	Is active	Occurrences in global events	\
12	True	6	
21	True	6	

25	10	True	6
31	10	True	6
33	7	True	4
...	...	...	...
1209	8	True	6
1211	6	True	5
1216	6	True	5
1219	7	True	6
1229	6	True	5

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

12	1	[1]
21	5	[1, 3, 4, 5, 6]
25	1	[2]
31	0	[]
33	4	[1, 2, 3, 4]
...	...	...
1209	0	[]
1211	0	[]
1216	0	[]
1219	0	[]
1229	0	[]

Occurrences in sequential events \

12	4
21	1
25	1
31	4
33	1
...	...
1209	1
1211	1
1216	1
1219	1
1229	1

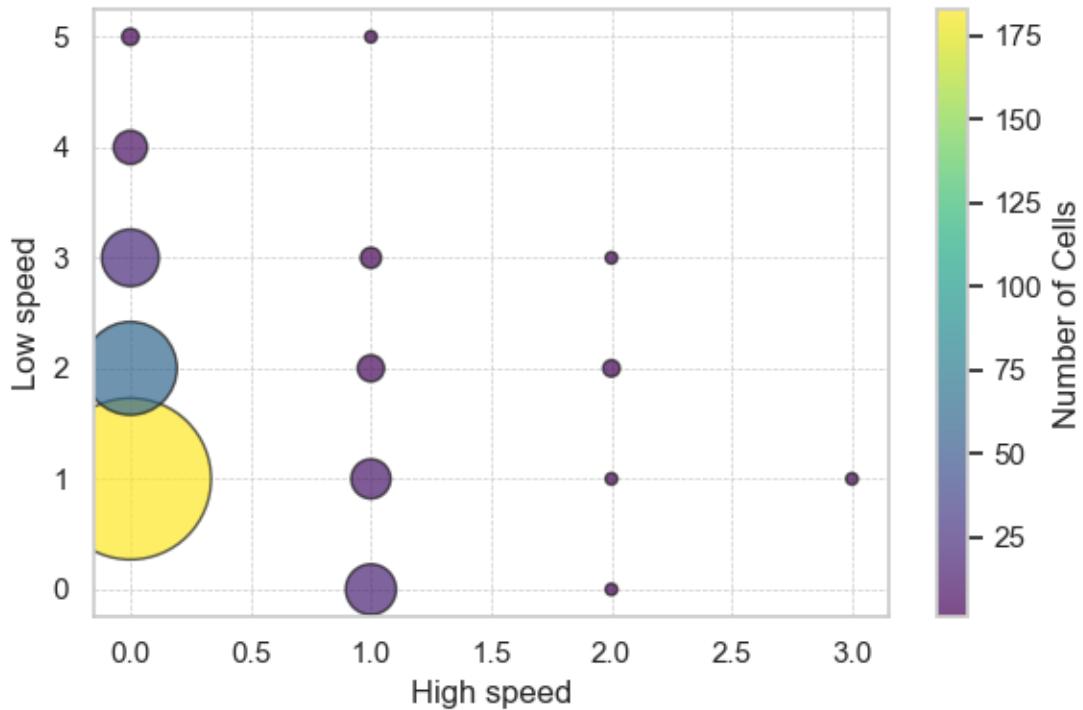
Occurrences in sequential events as origin \

12	3
21	0
25	1
31	1
33	1
...	...
1209	0
1211	0
1216	1
1219	1
1229	1

	Occurrences in individual events	Peak frequency (Hz)	\
12	2	0.0071	
21	0	0.0041	
25	3	0.0059	
31	0	0.0059	
33	1	0.0041	
...	...	...	
1209	1	0.0047	
1211	0	0.0035	
1216	0	0.0035	
1219	0	0.0041	
1229	0	0.0035	
Periodicity score	Neighbor count	Neighbors (labels)	\
12	0.66	3	[307,314,320]
21	0.77	4	[288,296,338,344]
25	0.65	5	[276,284,324,341,354]
31	0.63	4	[281,314,320,359]
33	0.73	4	[301,315,363,369]
...	...	...	...
1209	0.71	4	[1910,1939,1965,1989]
1211	0.73	4	[1910,1937,1963,1973]
1216	0.73	5	[1937,1941,1965,1974,2010]
1219	0.74	6	[1913,1931,1939,1975,1989,2003]
1229	0.80	4	[1952,1974,1987,2001]
dataset	Involved in sequential event	\	
12	20250624_IS09	Involved in sequential event	
21	20250624_IS09	Involved in sequential event	
25	20250624_IS09	Involved in sequential event	
31	20250624_IS09	Involved in sequential event	
33	20250624_IS09	Involved in sequential event	
...	...	...	
1209	20250624_IS09	Involved in sequential event	
1211	20250624_IS09	Involved in sequential event	
1216	20250624_IS09	Involved in sequential event	
1219	20250624_IS09	Involved in sequential event	
1229	20250624_IS09	Involved in sequential event	
Occurrences in sequential events category	High speed	Low speed	
12	3-4	0.0	4.0
21	1-2	0.0	1.0
25	1-2	0.0	1.0
31	3-4	0.0	1.0
33	1-2	0.0	1.0
...	...	...	
1209	1-2	0.0	1.0

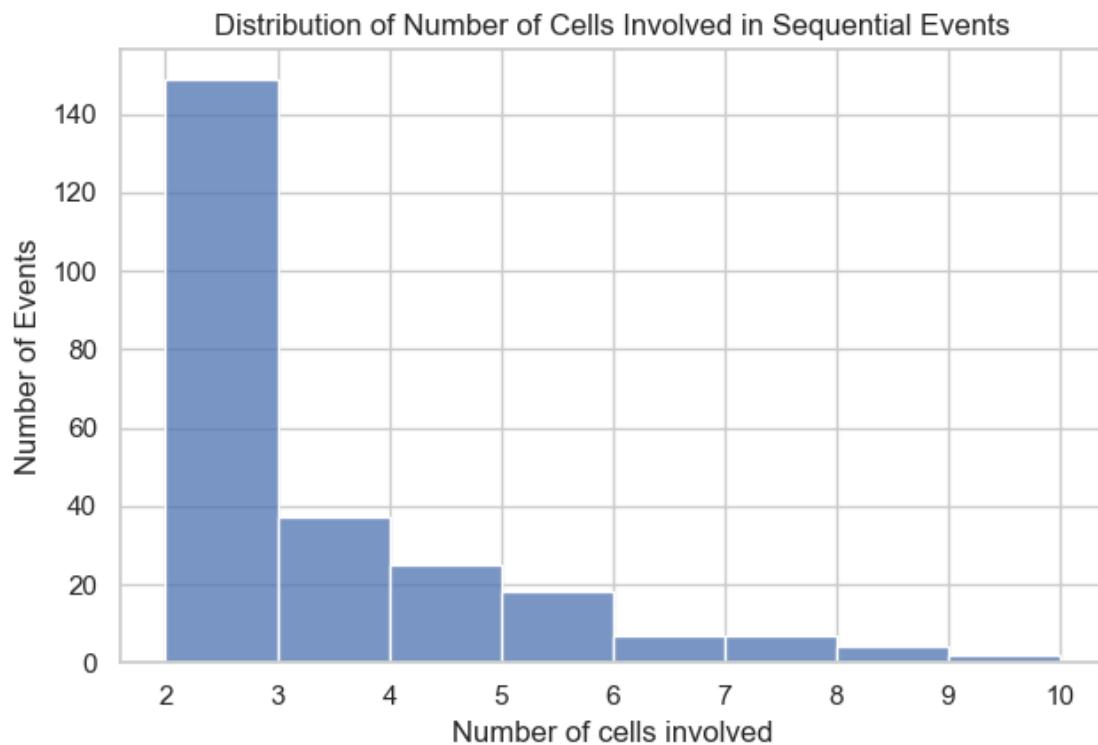
1211	1-2	0.0	1.0
1216	1-2	0.0	2.0
1219	1-2	0.0	1.0
1229	1-2	0.0	2.0

[321 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

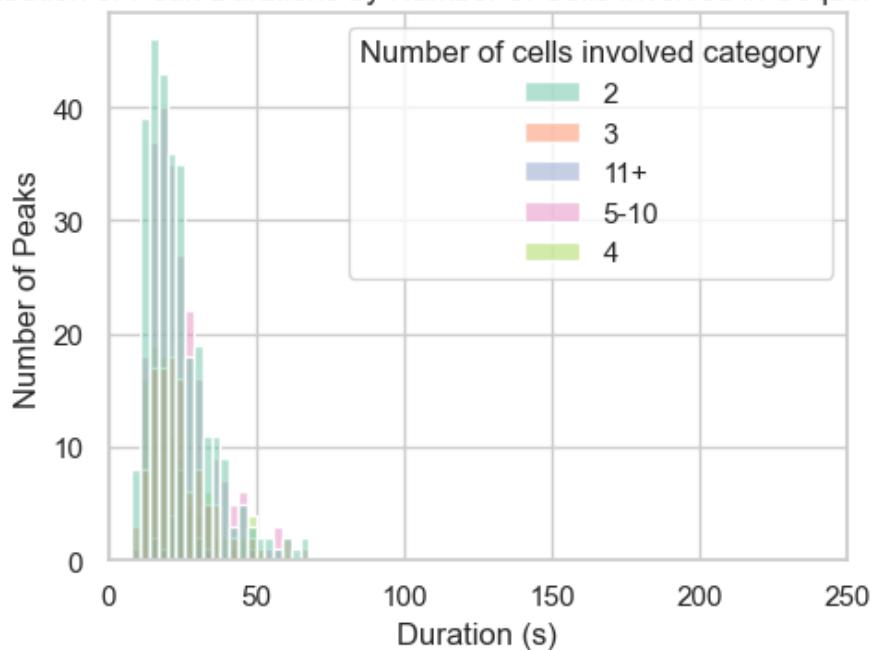
[2025-08-27 15:11:14] [INFO] calcium: plot\_histogram: removed 1 outliers out of 250 on 'Number of cells involved' (lower=-4, upper=10)



### 1.3.6 Influence of cell count per event on statistics

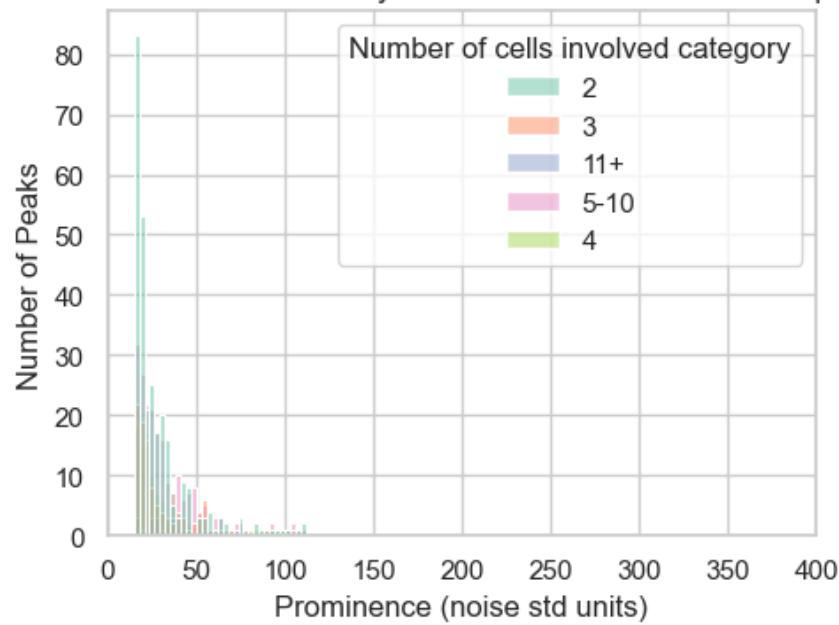
```
[2025-08-27 15:11:14] [INFO] calcium: plot_histogram_by_group: removed 3 outliers out of 761 on 'Duration (s)' (lower=-2, upper=70)
```

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

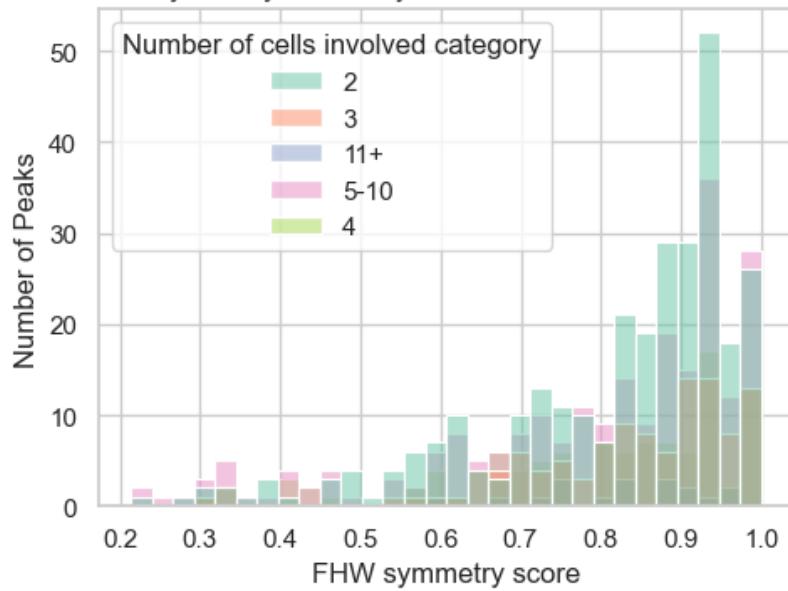


[2025-08-27 15:11:14] [INFO] calcium: plot\_histogram\_by\_group: removed 42 outliers out of 761 on 'Prominence (noise std units)' (lower=-12.5, upper=112.3)

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

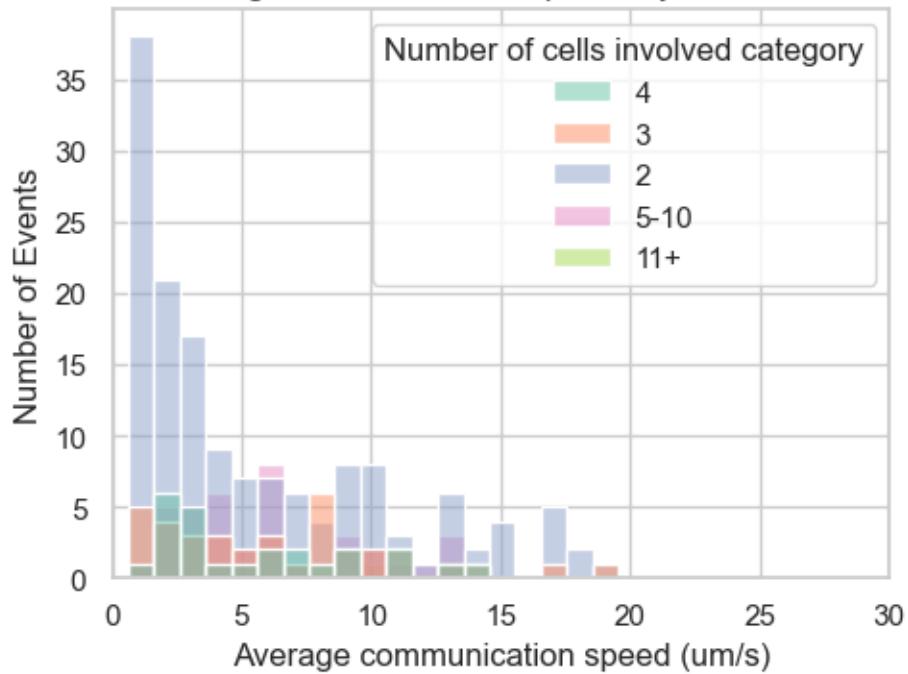


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



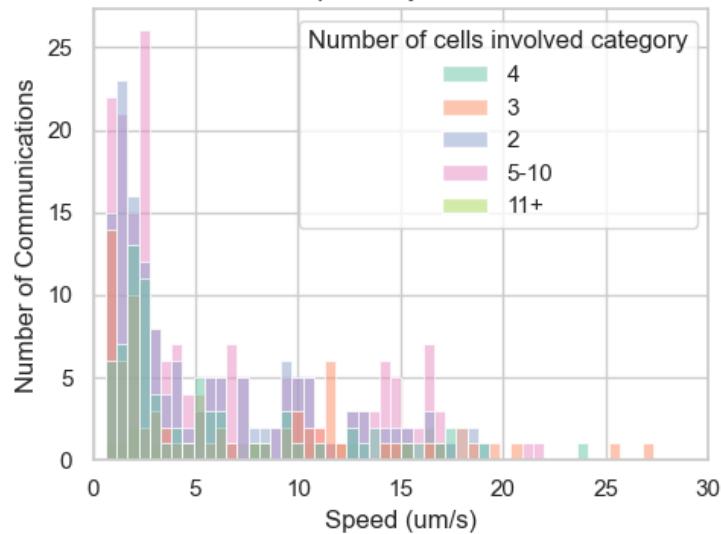
```
[2025-08-27 15:11:15] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 250 on 'Average communication speed (um/s)' (lower=-18.125, upper=29.055)
```

Distribution of Average Communication Speeds by Number of Cells Involved



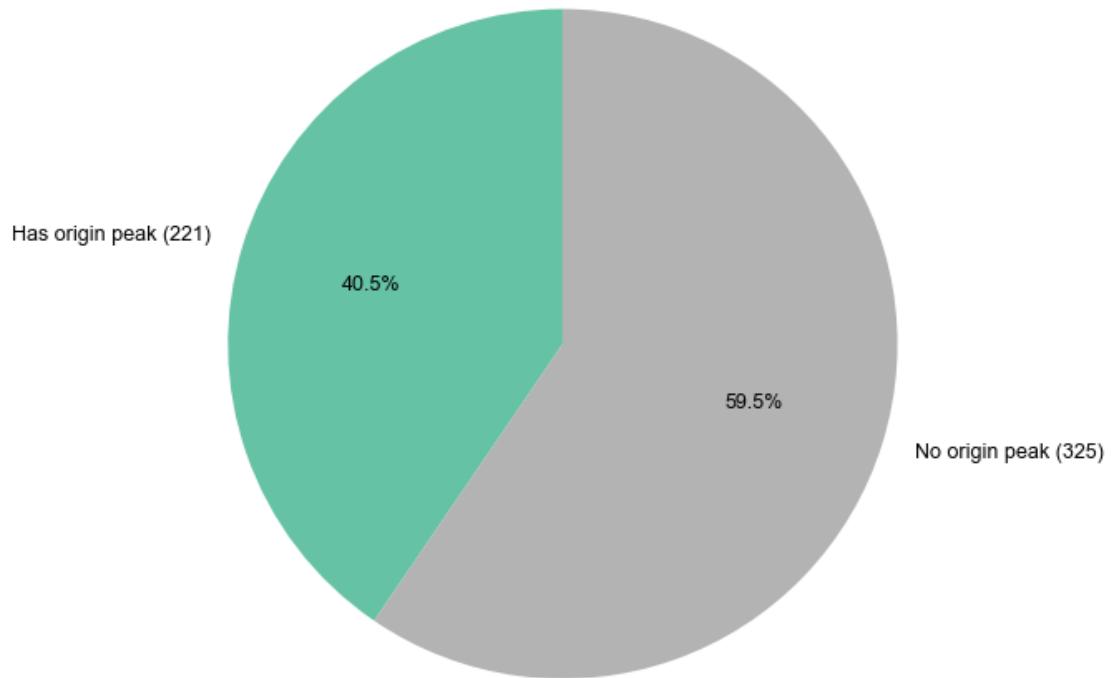
[2025-08-27 15:11:15] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 511 on 'Speed (um/s)' (lower=-22.545, upper=34.19)

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

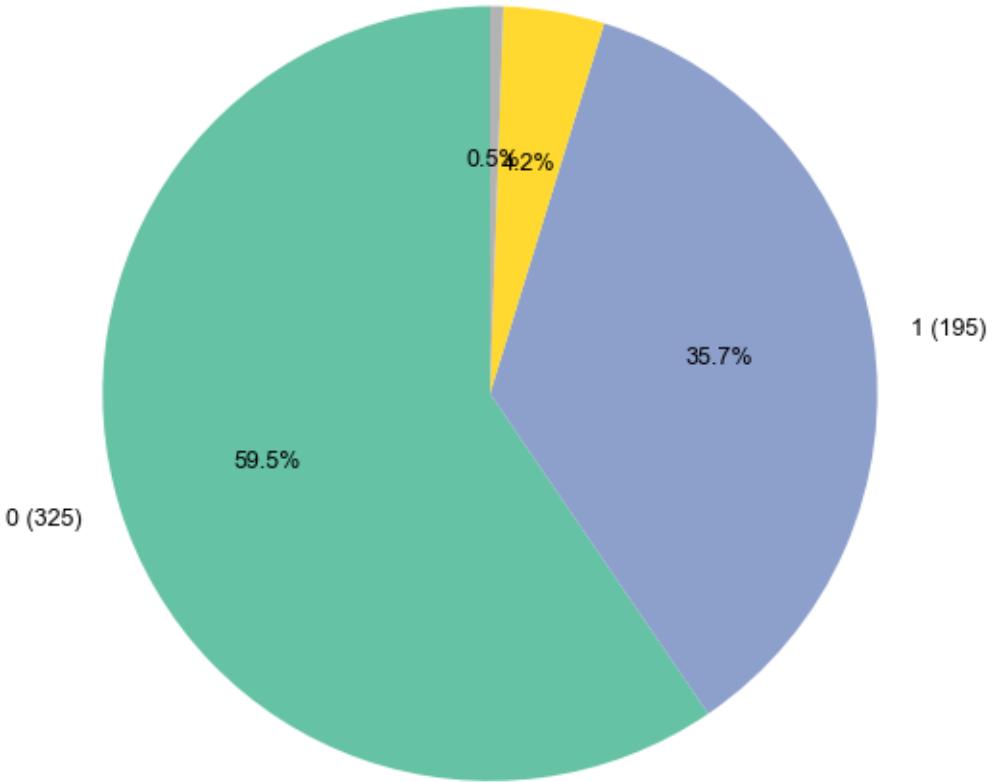


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

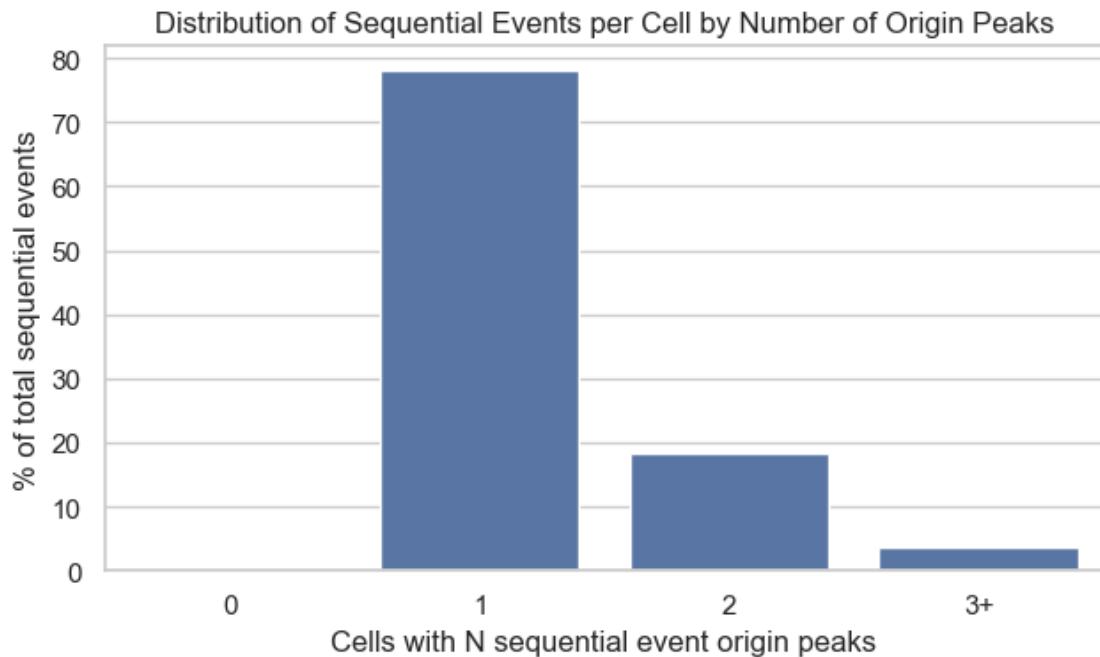


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)  
3+ (3) 2 (23)



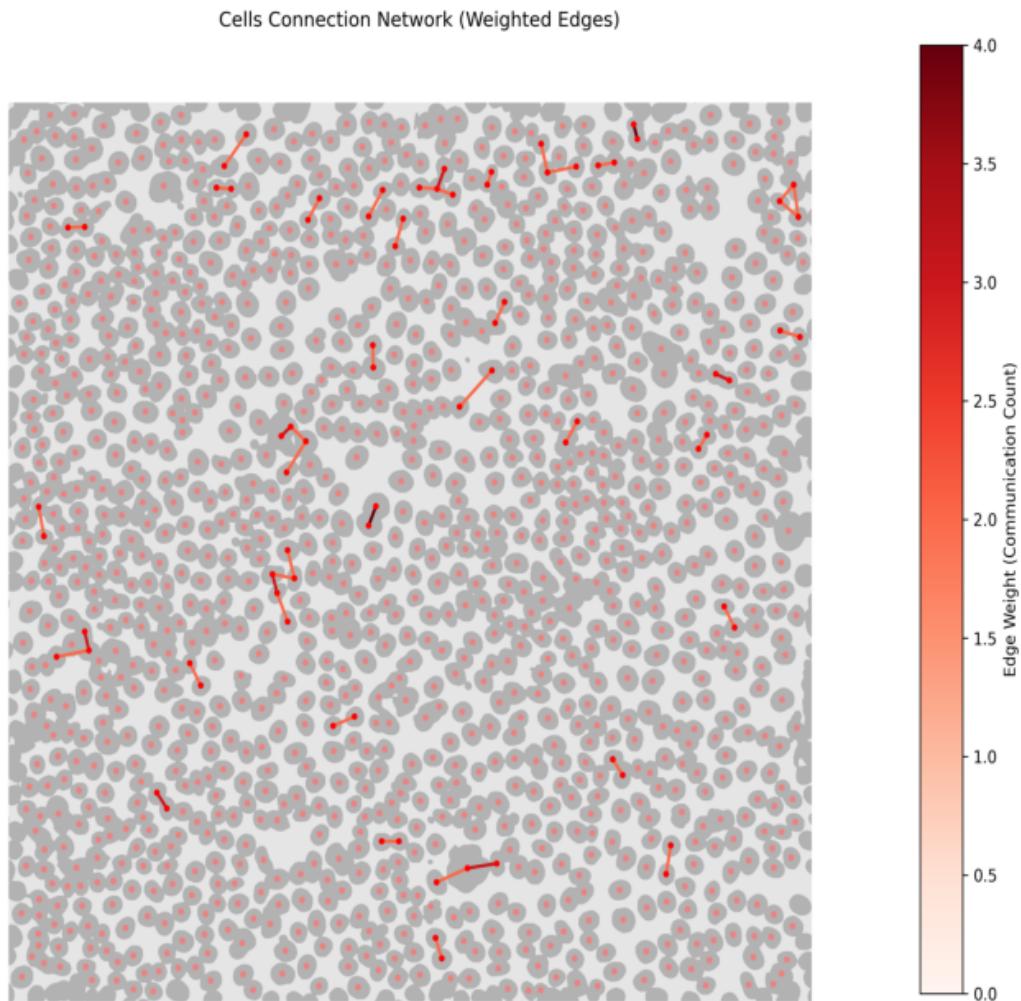
```
[2025-08-27 15:11:16] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS09\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (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\\20250624\\Output\\IS09\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```



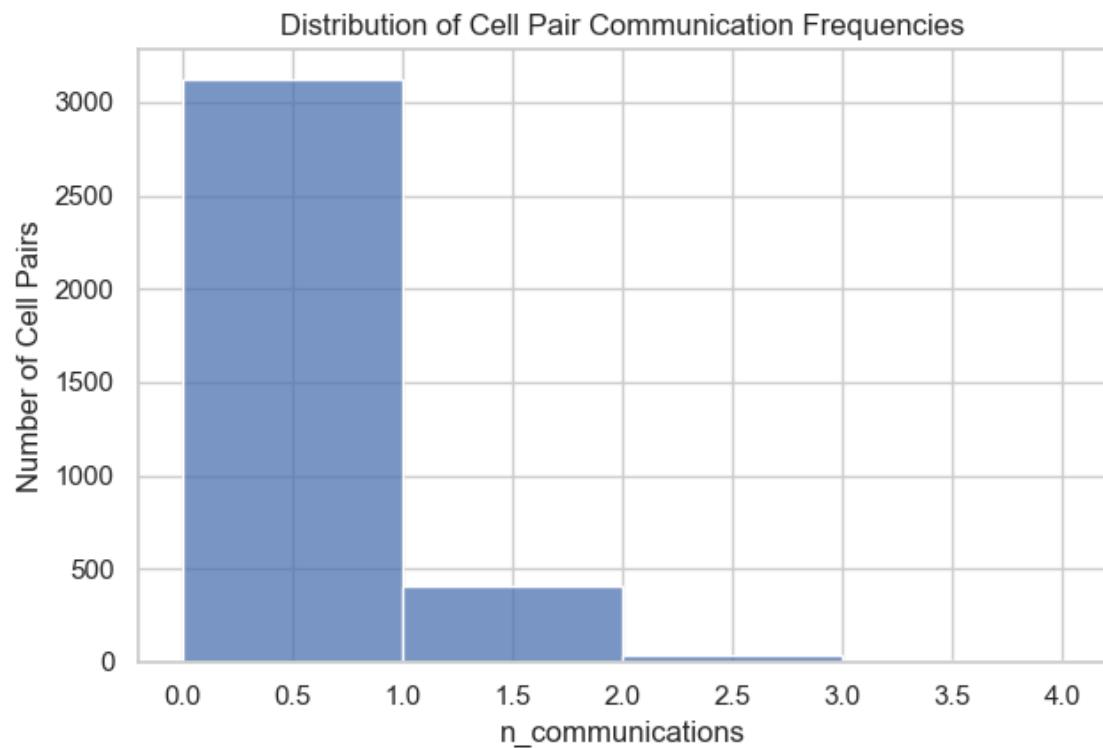
### 1.3.8 Connection network between cells

Cell Connection Network Graph



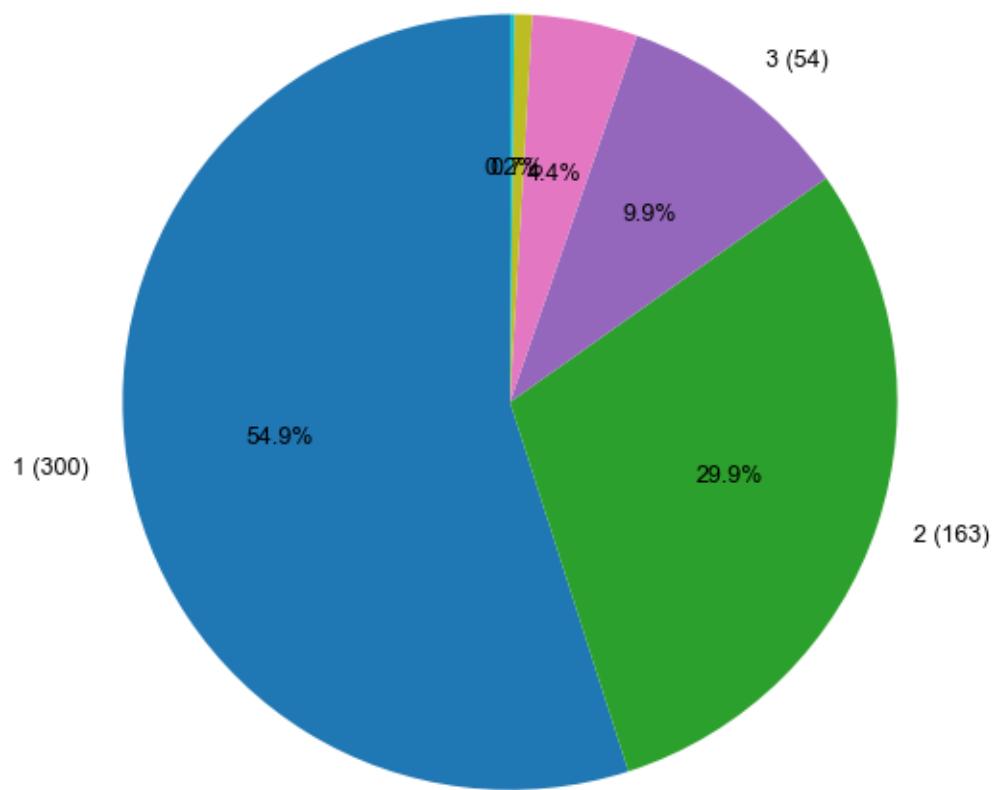
### 1.3.9 Pair/Trios with high communication networks

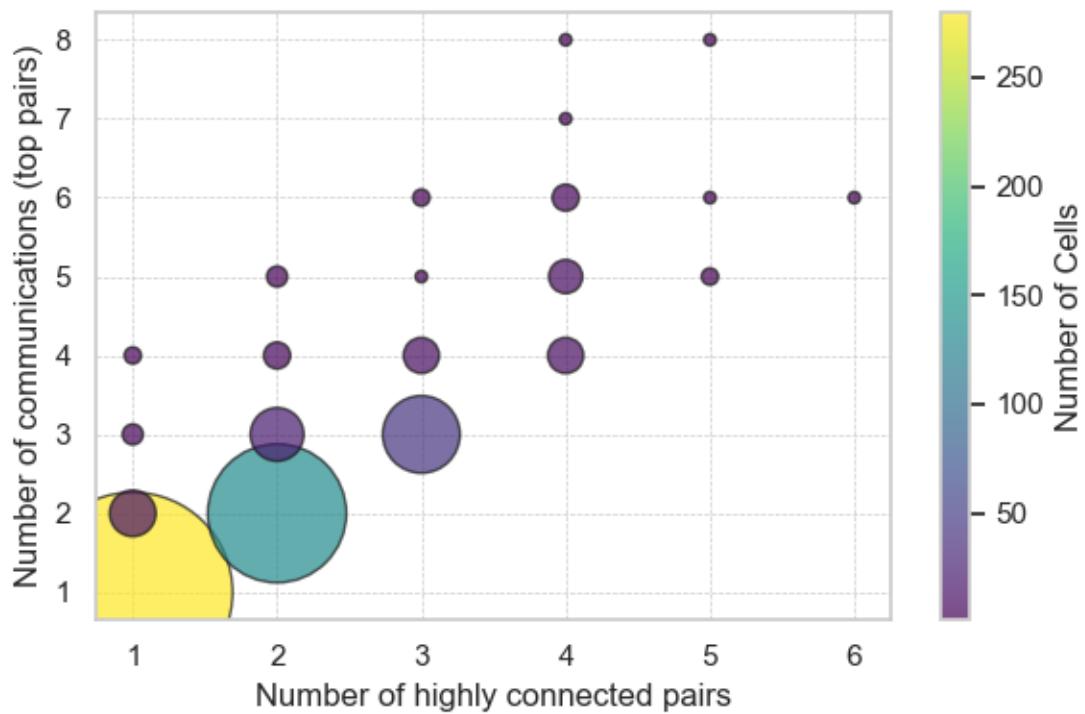
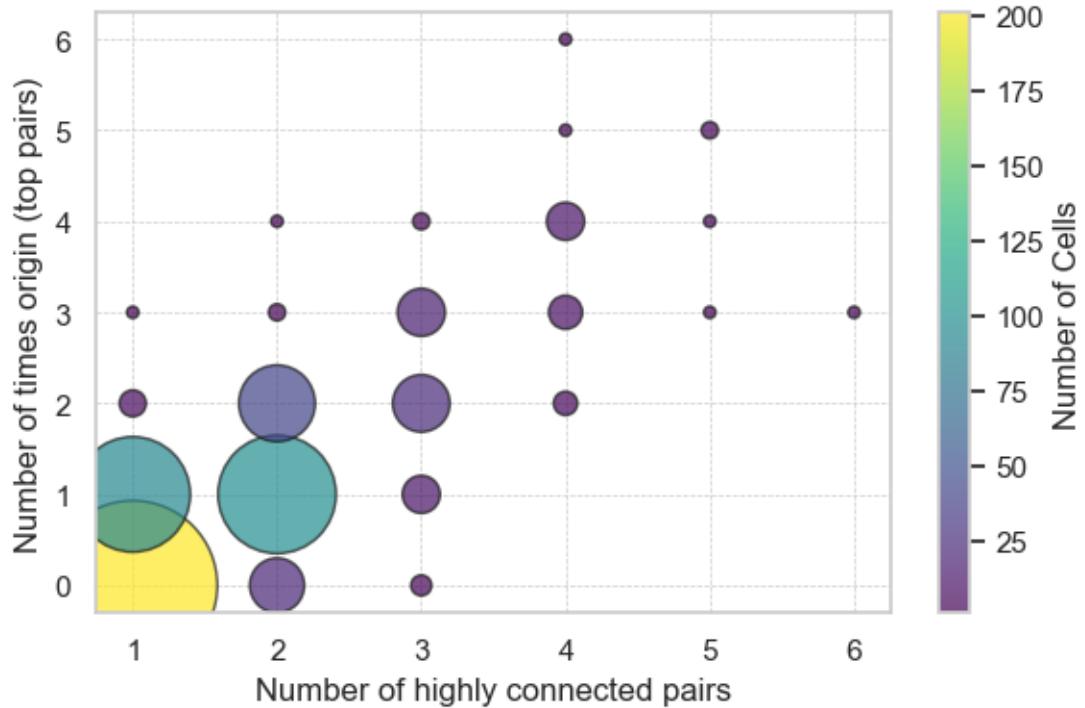
```
[2025-08-27 15:11:17] [INFO] calcium: build_neighbor_pair_stats: built 3578 pairs across 1 datasets (mean distance=15.37 um)
```

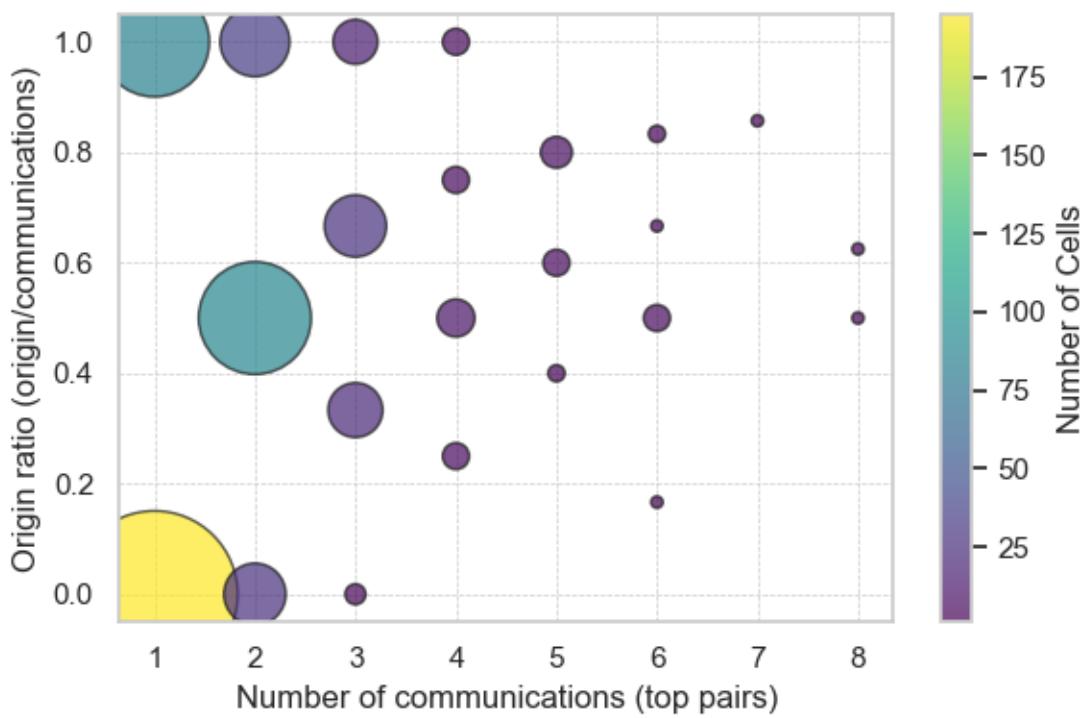
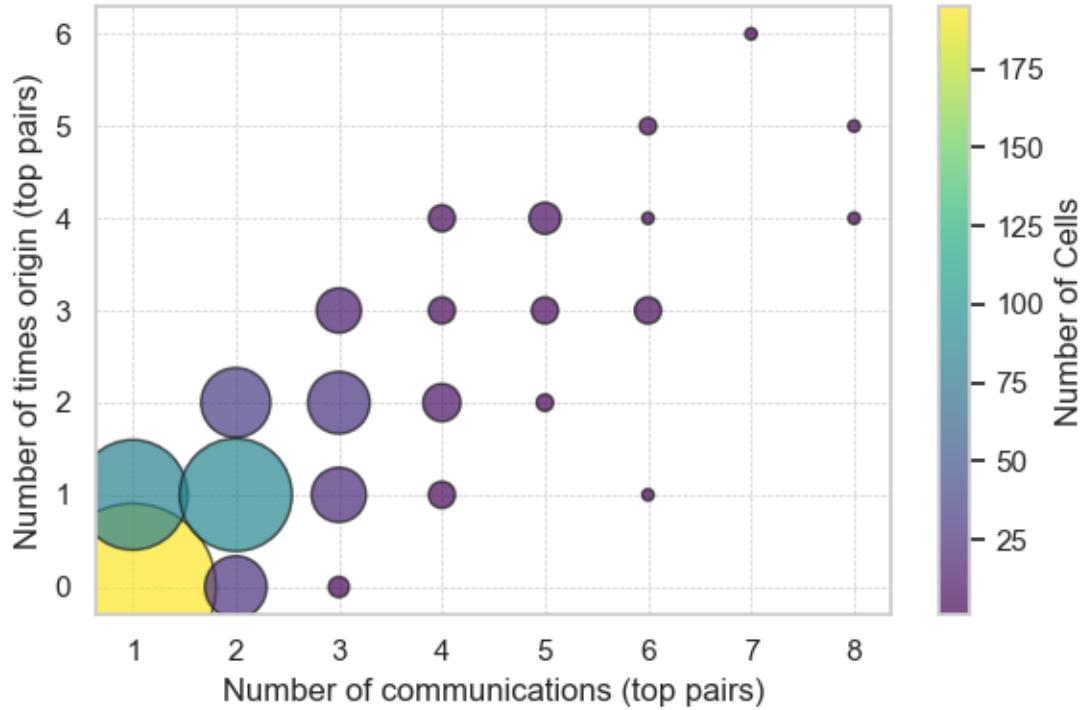


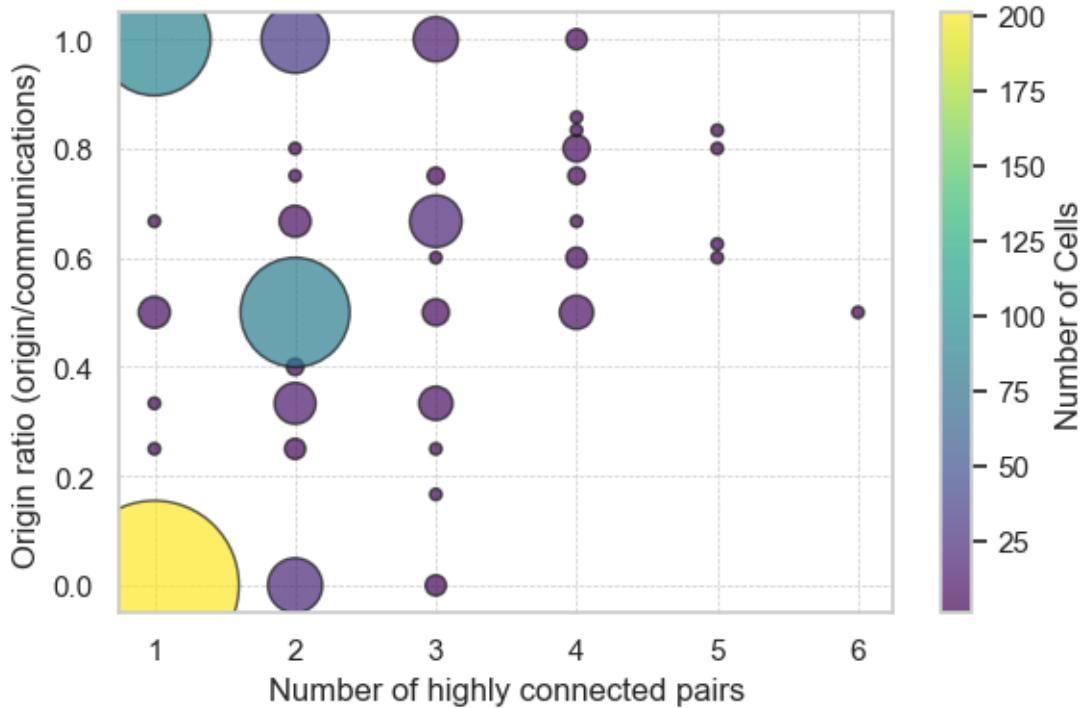
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=300 for Number of highly connected pairs=1

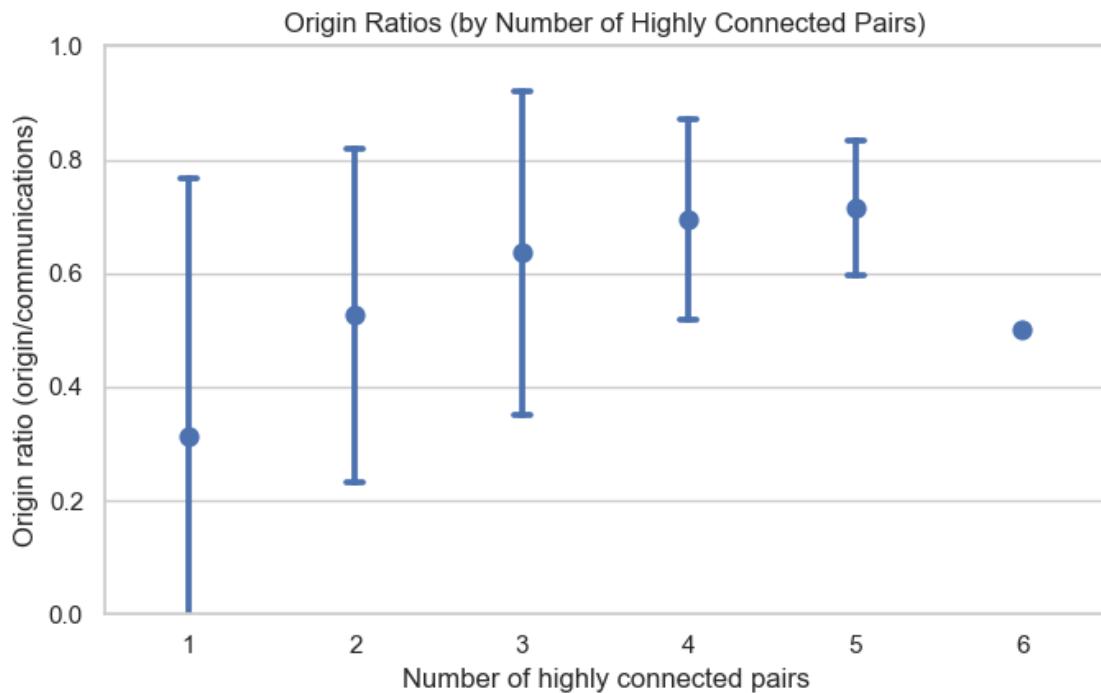
[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=163 for Number of highly connected pairs=2

[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=54 for Number of highly connected pairs=3

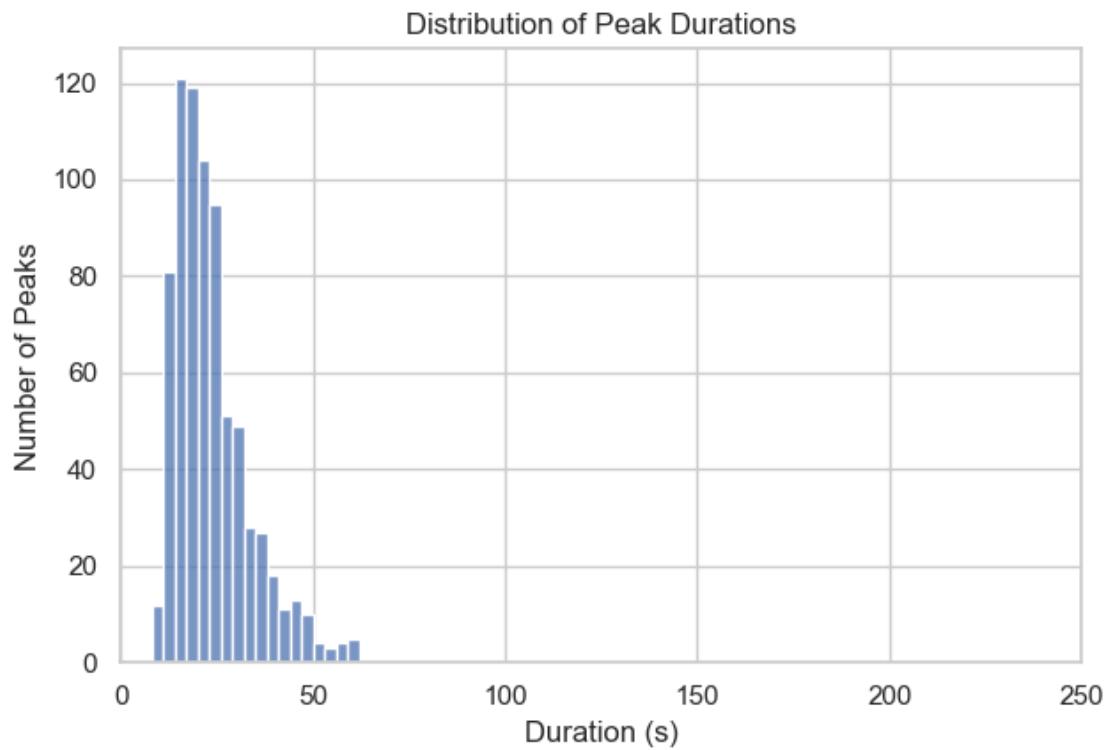
[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=24 for Number of highly connected pairs=4

[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=4 for Number of highly connected pairs=5

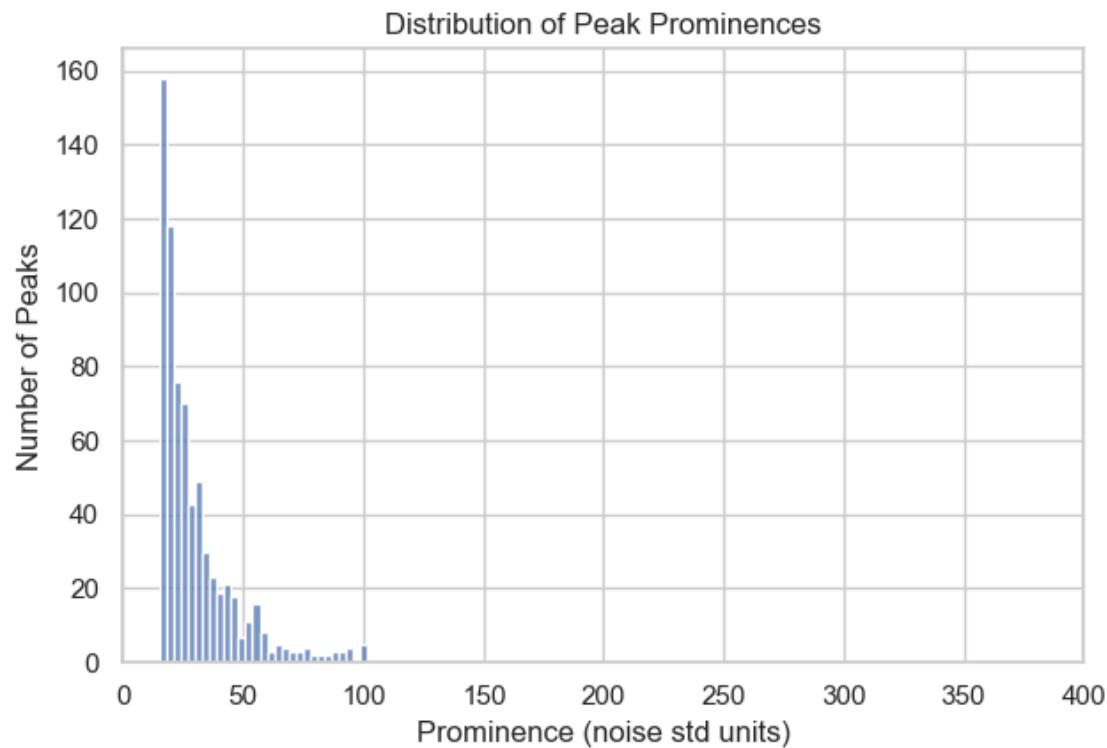
[2025-08-27 15:11:19] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=6

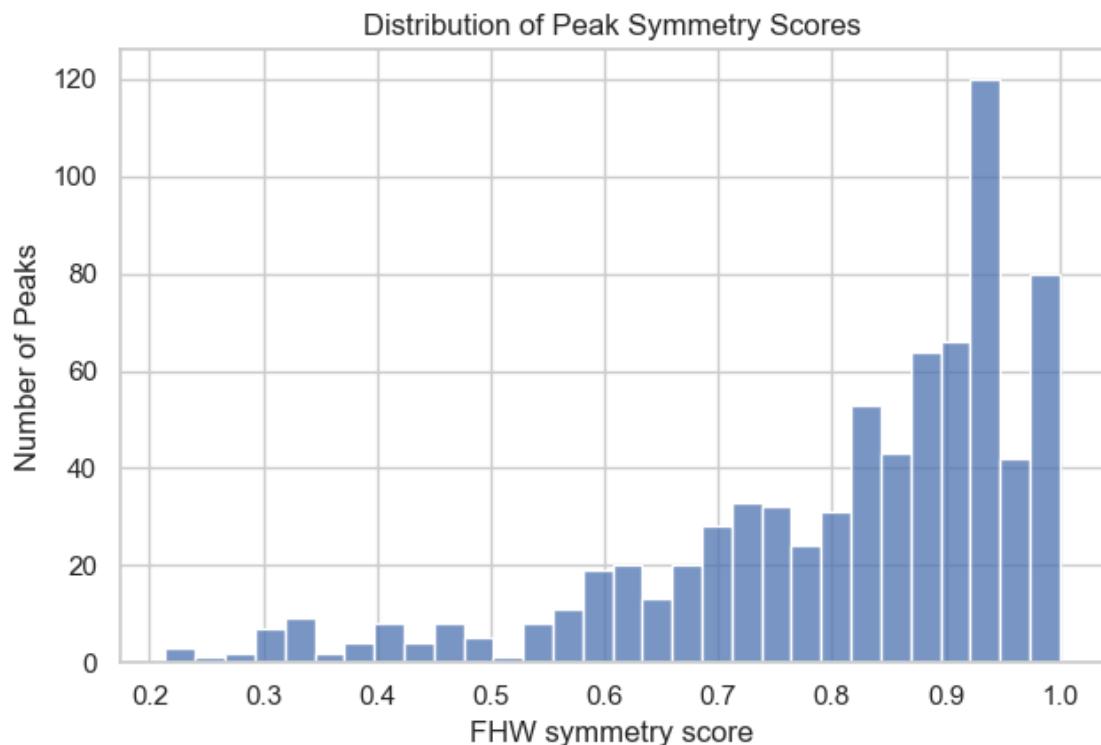


```
[2025-08-27 15:11:19] [INFO] calcium: plot_histogram: removed 6 outliers out of 761 on 'Duration (s)' (lower=-20, upper=64)
```

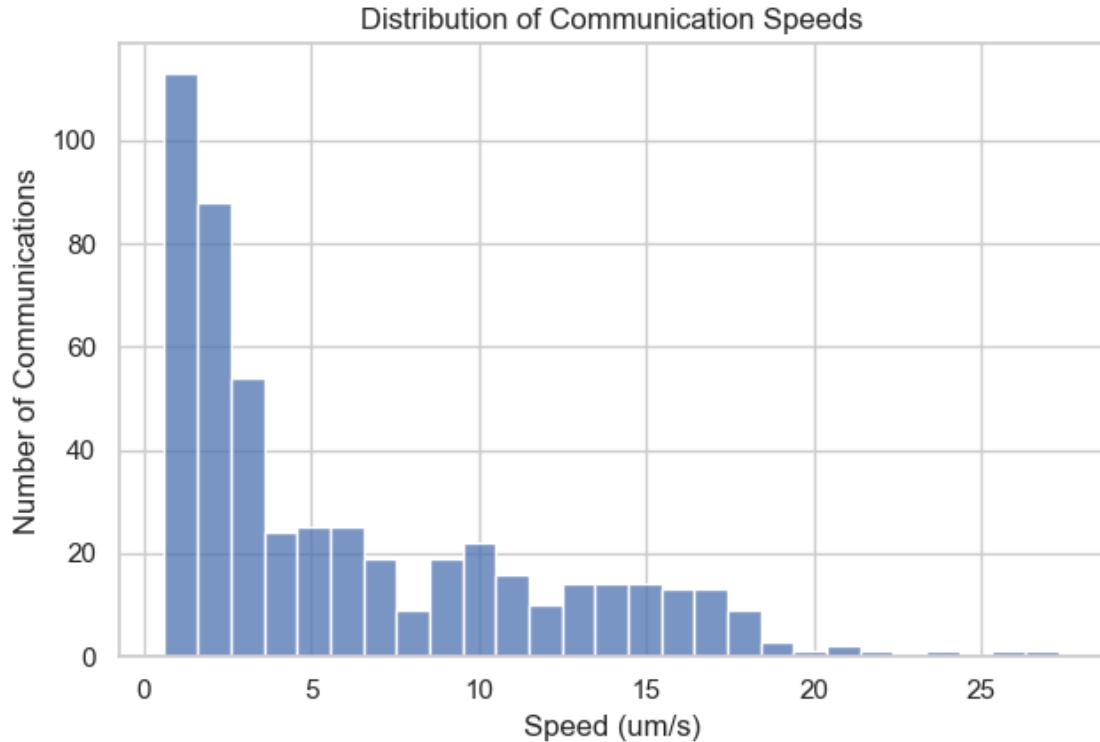


[2025-08-27 15:11:19] [INFO] calcium: plot\_histogram: removed 51 outliers out of 761 on 'Prominence (noise std units)' (lower=-43.7, upper=101.9)



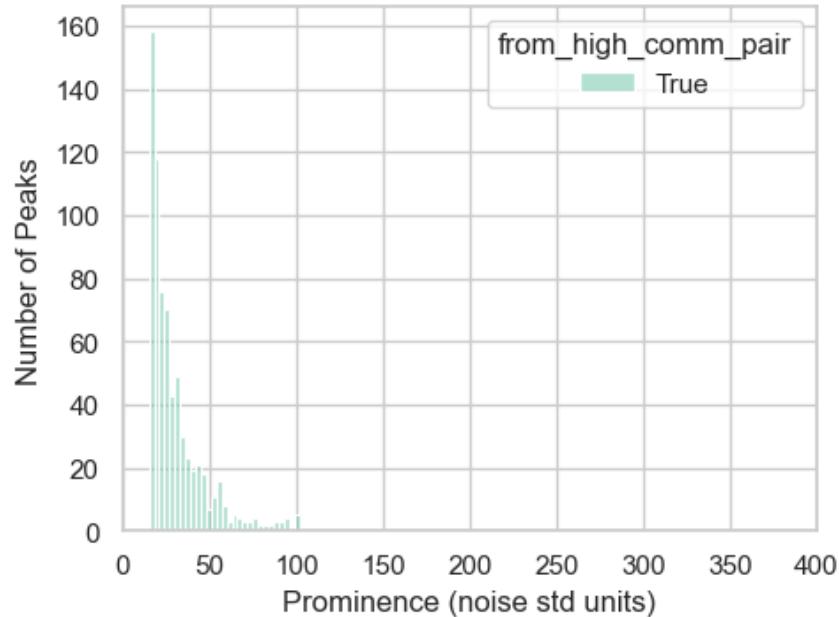


```
[2025-08-27 15:11:19] [INFO] calcium: plot_histogram: removed 0 outliers out of 511 on 'Speed (um/s)' (lower=-22.545, upper=34.19)
```

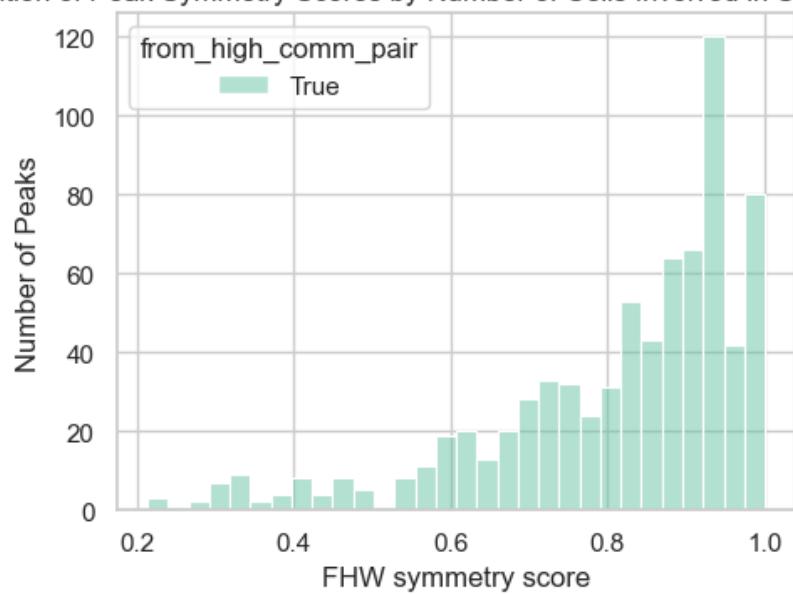


[2025-08-27 15:11:20] [INFO] calcium: plot\_histogram\_by\_group: removed 51 outliers out of 761 on 'Prominence (noise std units)' (lower=-43.7, upper=101.9)

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

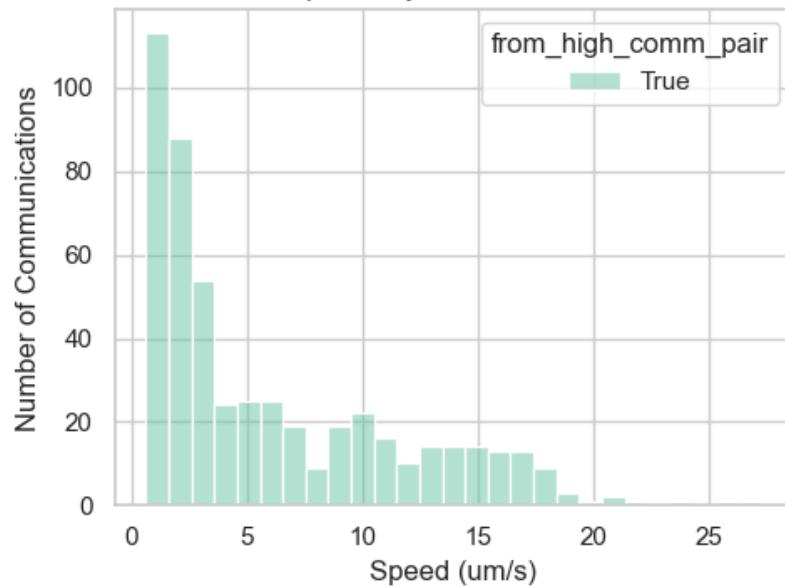


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



```
[2025-08-27 15:11:20] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 511 on 'Speed (um/s)' (lower=-22.545, upper=34.19)
```

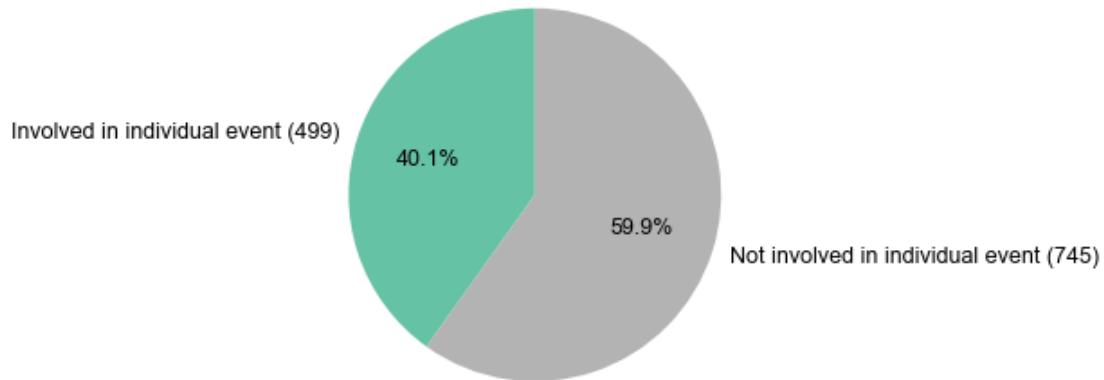
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



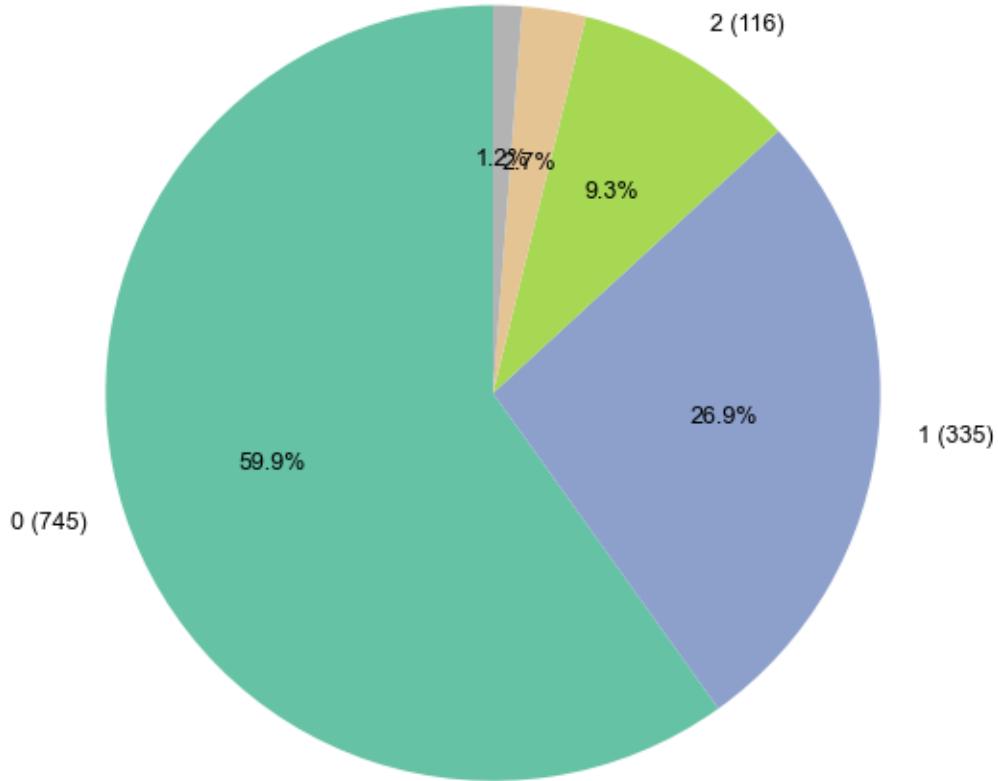
## 1.4 INDIVIDUAL EVENTS

### 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+)  
4+ (15)(33)

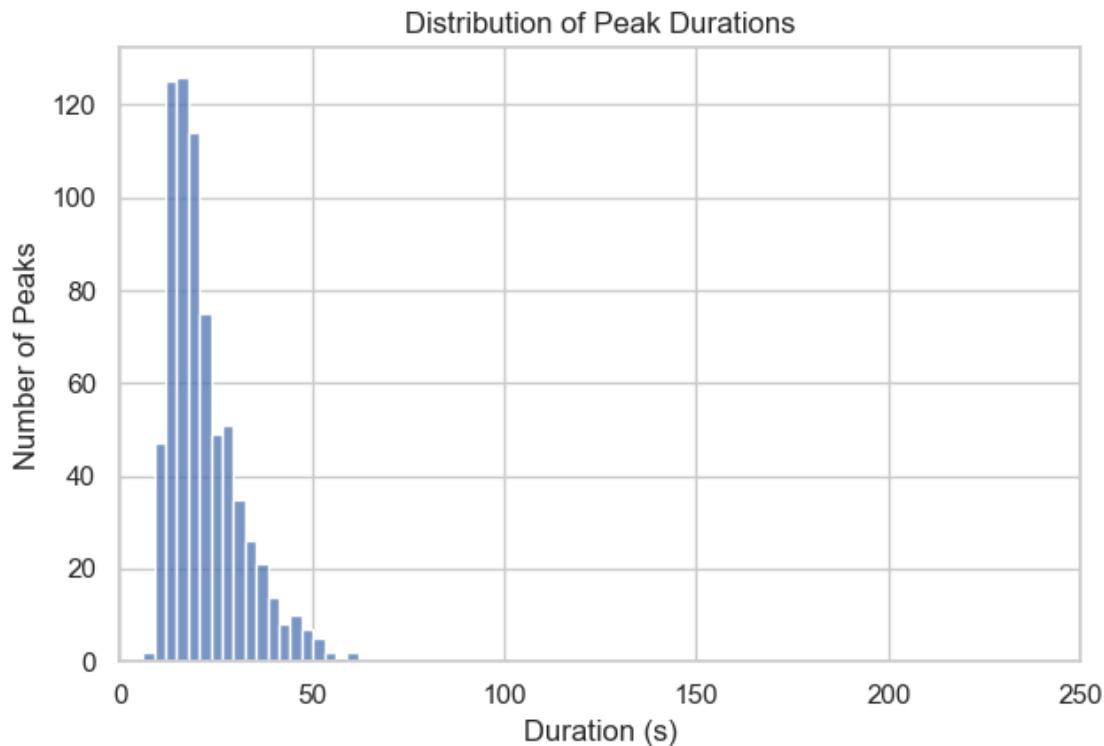


```
[2025-08-27 15:11:21] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS09\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS09\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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\\20250624\\Output\\IS09\\cell-  
mapping\\cell_occurrences_in_individual_events_overlay.png'
```

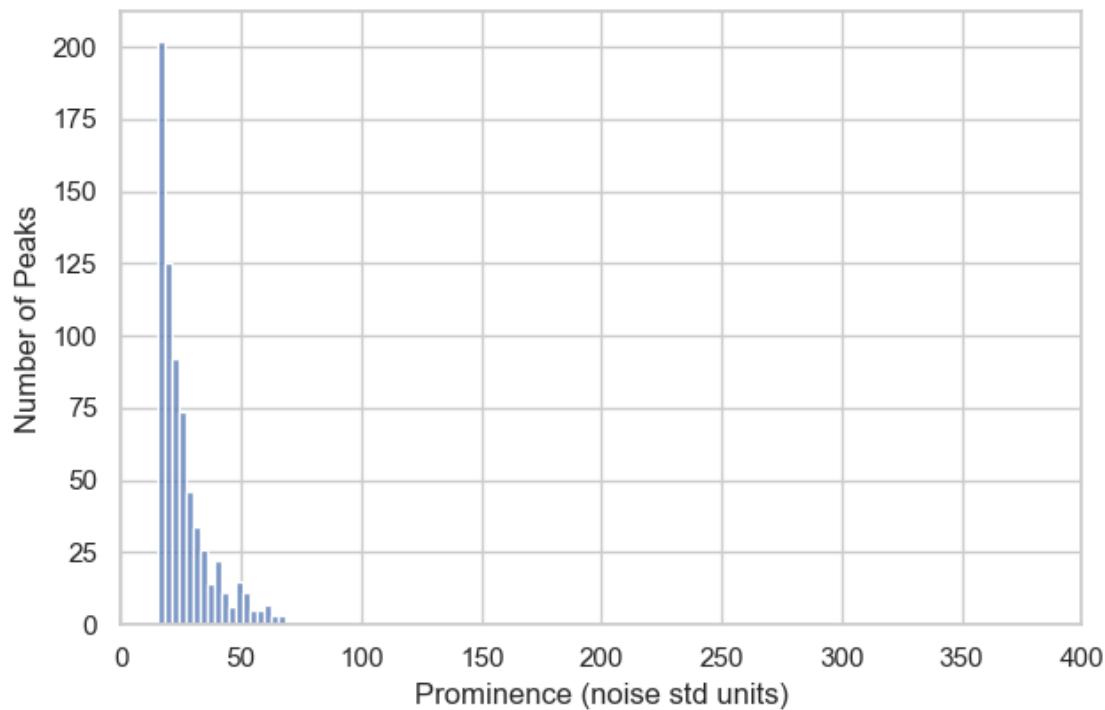
#### 1.4.2 Peaks statistics in individual events

```
[2025-08-27 15:11:21] [INFO] calcium: plot_histogram: removed 13 outliers out of  
733 on 'Duration (s)' (lower=-21, upper=63)
```

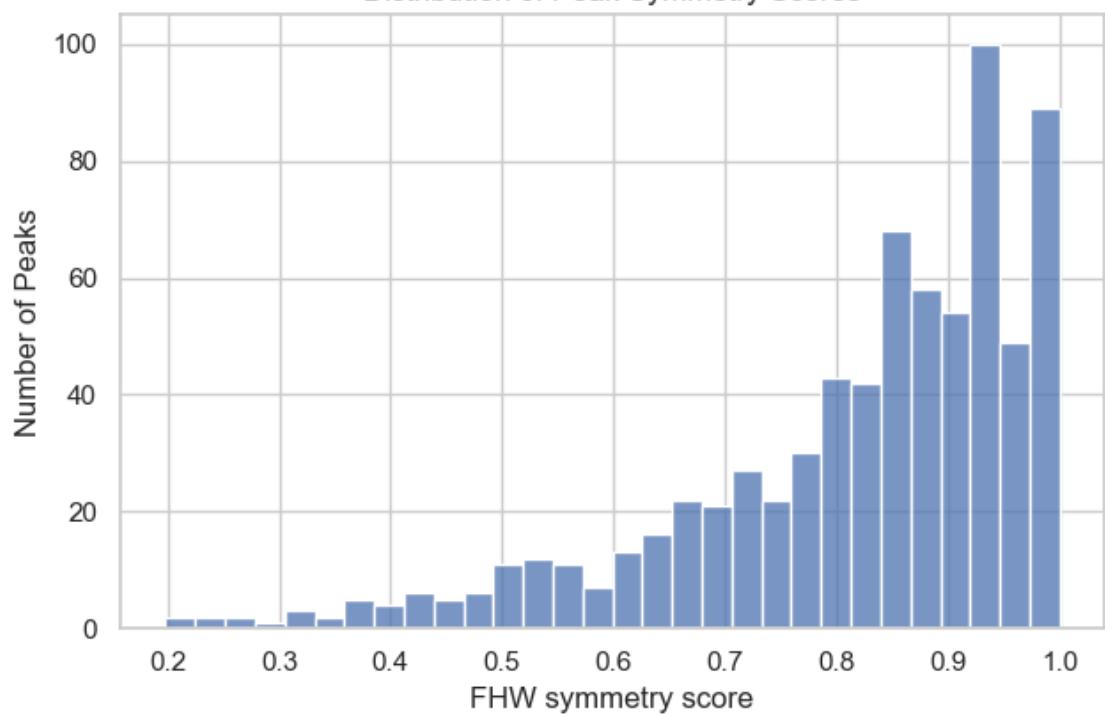


```
[2025-08-27 15:11:21] [INFO] calcium: plot_histogram: removed 32 outliers out of  
733 on 'Prominence (noise std units)' (lower=-20.7, upper=68.9)
```

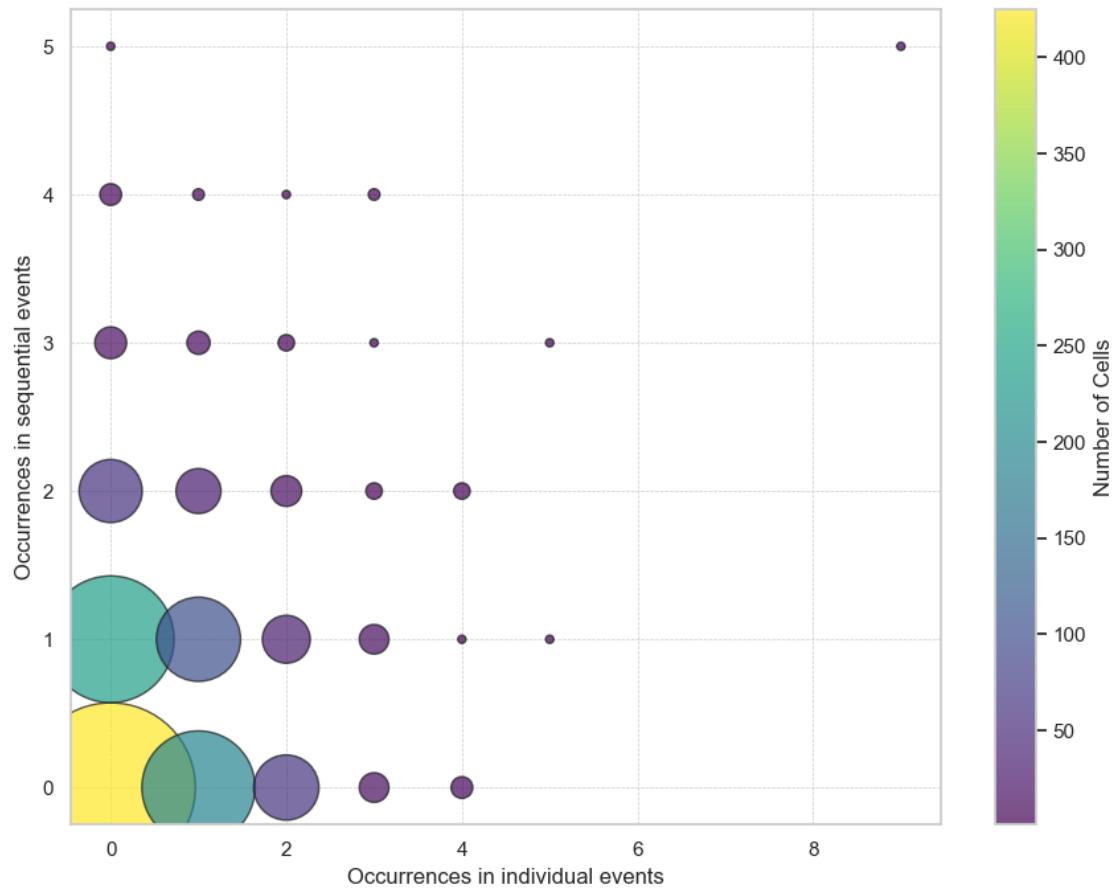
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

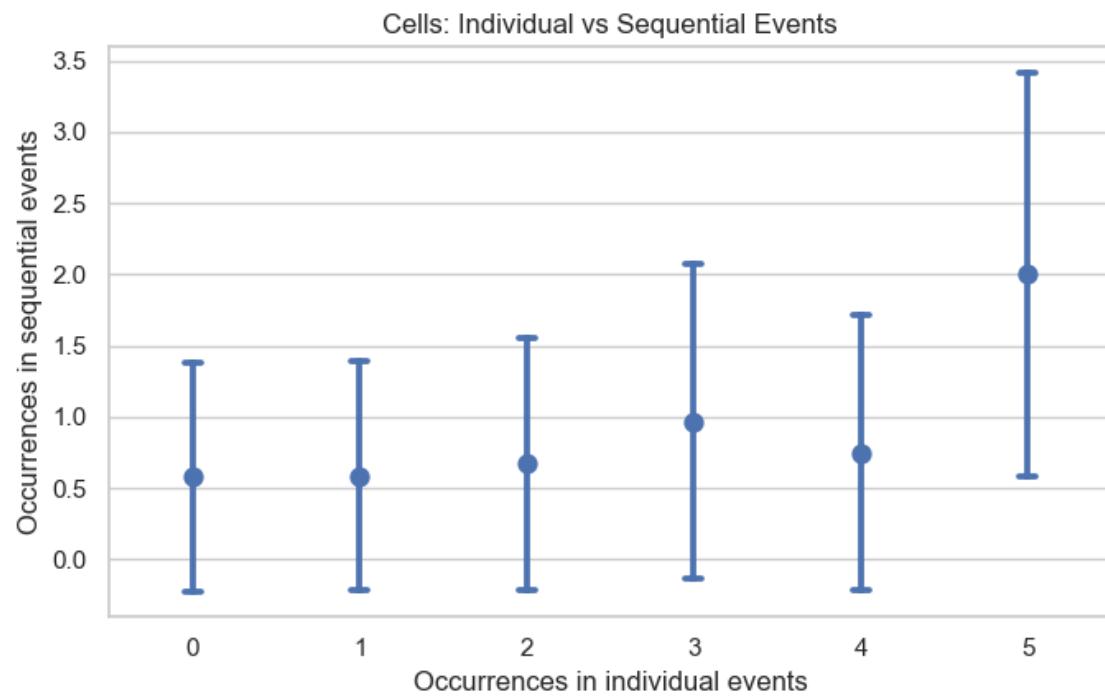


### 1.4.3 Correlation between event activity level & individual activity level

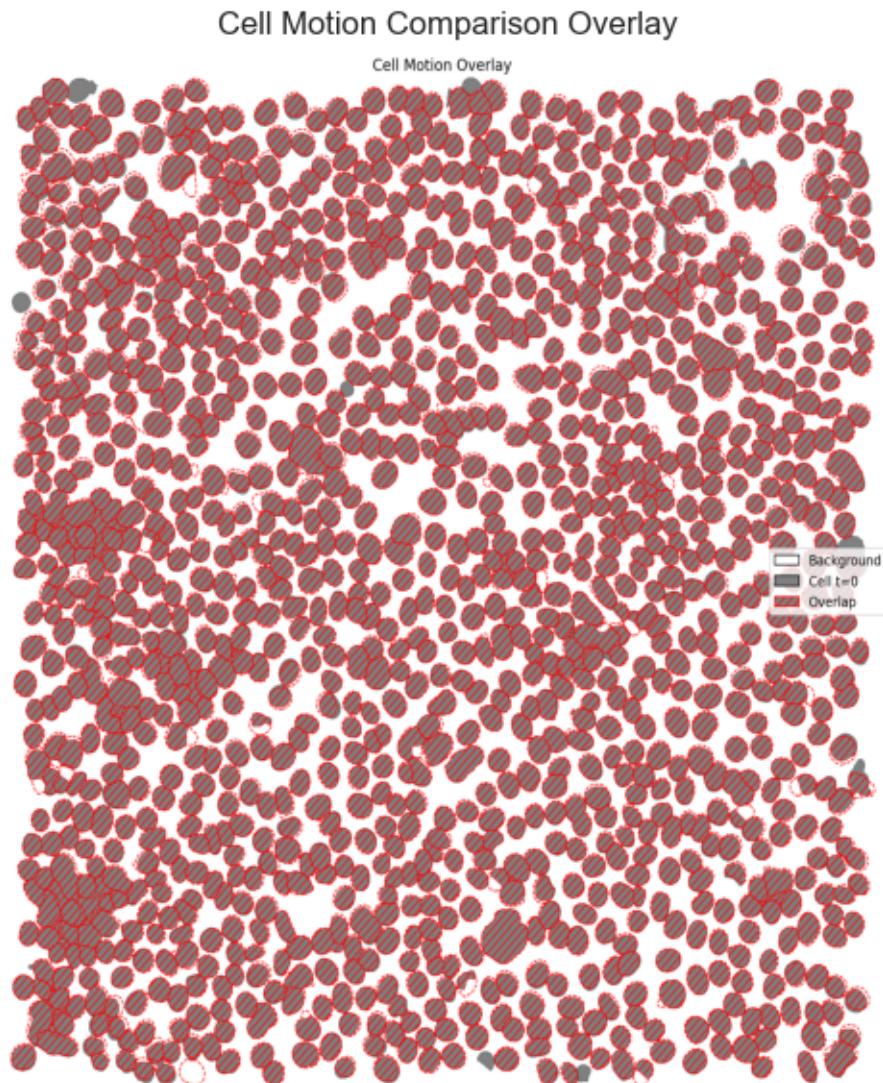


```
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: removed 2/1244 outliers on 'Occurrences in sequential events' (lower=-3, upper=4)
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: N=744 for Occurrences in individual events=0
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: N=335 for Occurrences in individual events=1
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: N=116 for Occurrences in individual events=2
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: N=33 for Occurrences in individual events=3
[2025-08-27 15:11:21] [INFO] calcium: plot_points_mean_std: N=12 for Occurrences in individual events=4
```

[2025-08-27 15:11:21] [INFO] calcium: plot\_points\_mean\_std: N=2 for Occurrences in individual events=5



## 1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at  $t=0$ : 1244
- Hoechst image taken at  $t=1801$ : 1232
- Number of cells difference: absolute 12, relative 0.97%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at  $t=0$ : 1313958
- Pixels segmented as cell at  $t=1801$ : 1327533
- Overlapping pixels between  $t=0$  and  $t=1801$ : 1224596 (92.72% of total)
- Pixels exclusive to  $t=0$ : 89362 (6.80% of total)
- Pixels exclusive to  $t=1801$ : 102937 (7.75% of total)

executed

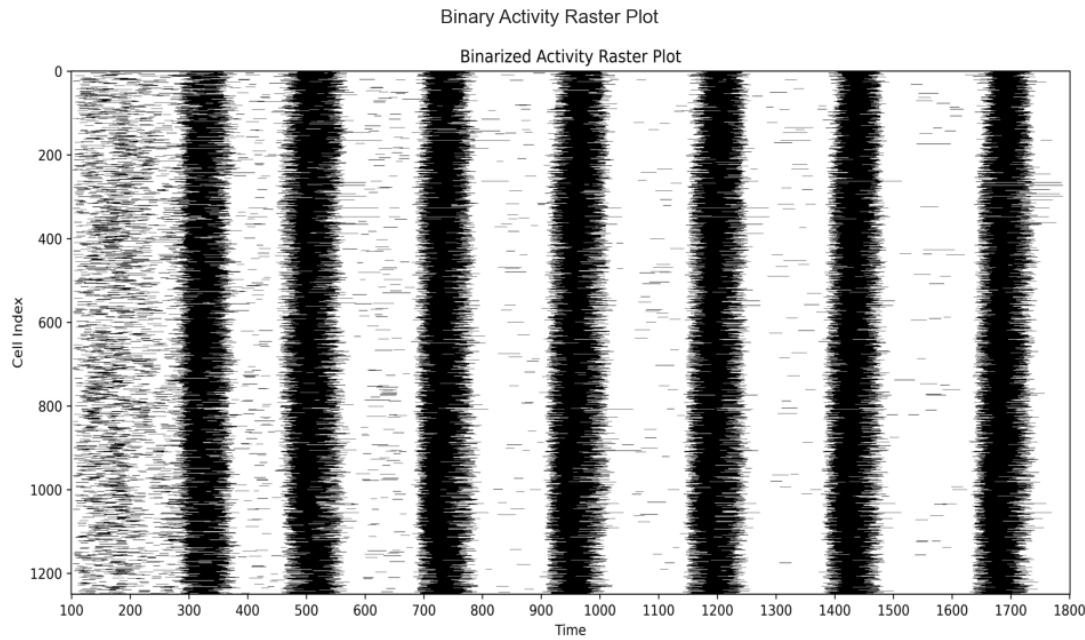
August 27, 2025

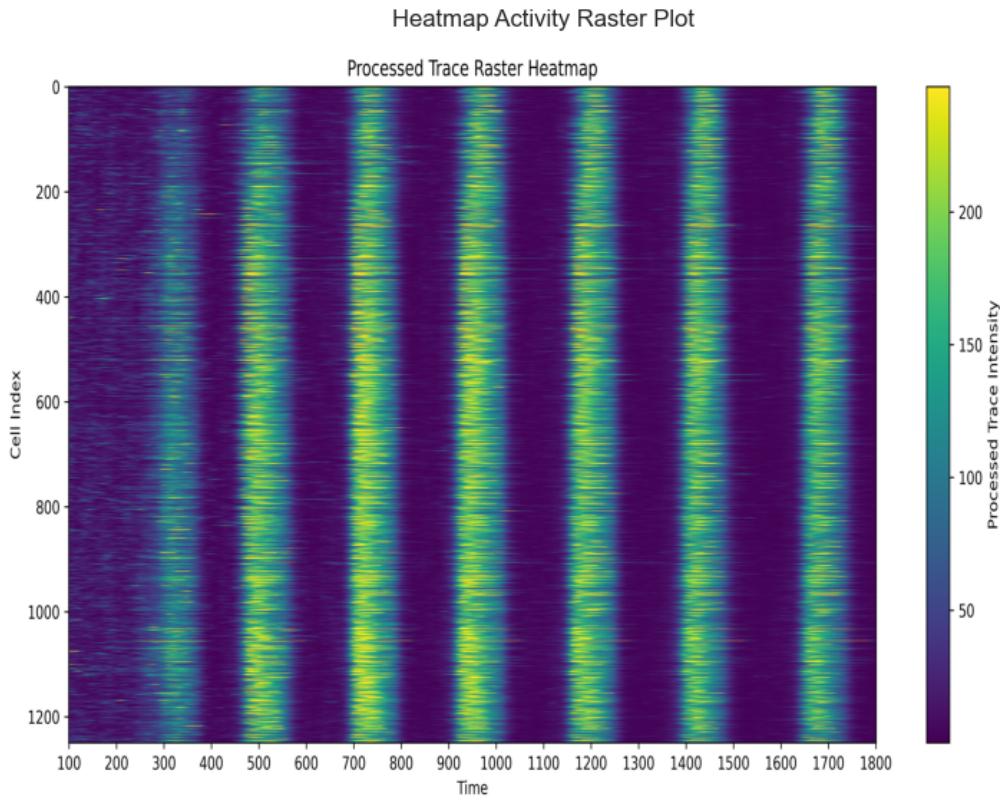
# 1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

## 1.0.1 Initialization

### 1.1 POPULATION

#### 1.1.1 Binary & Heatmap Raster Plot





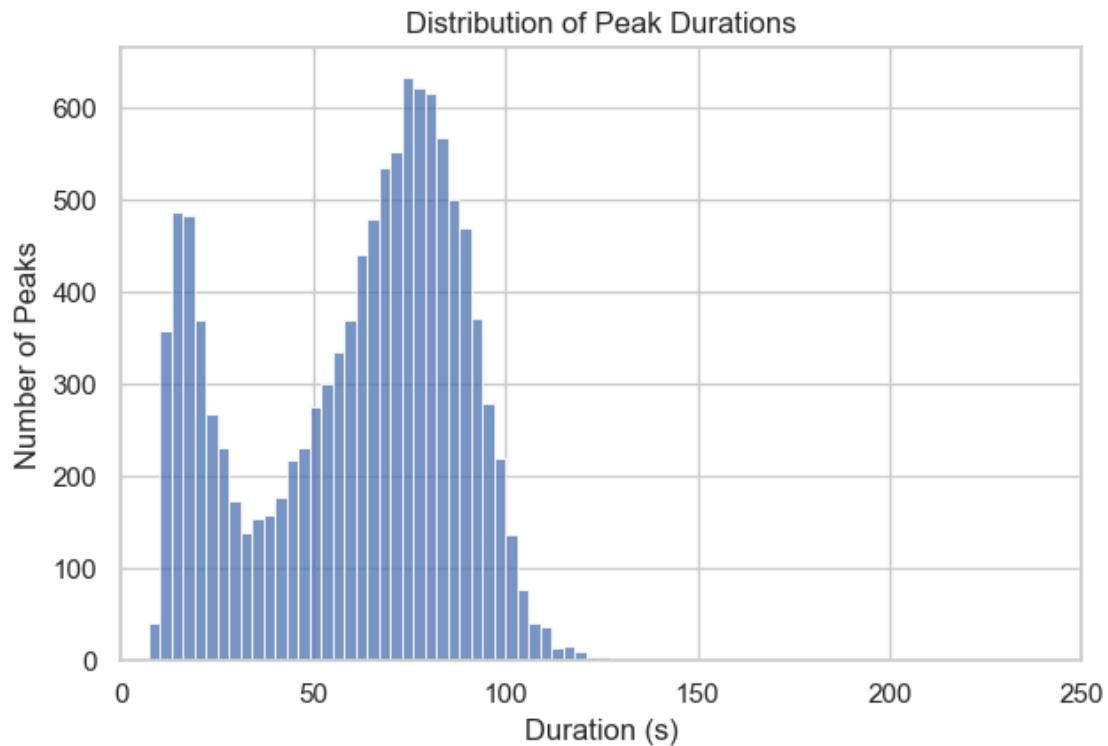
### 1.1.2 Peaks population

Total number of peaks: 11414

Total number of cells: 1250

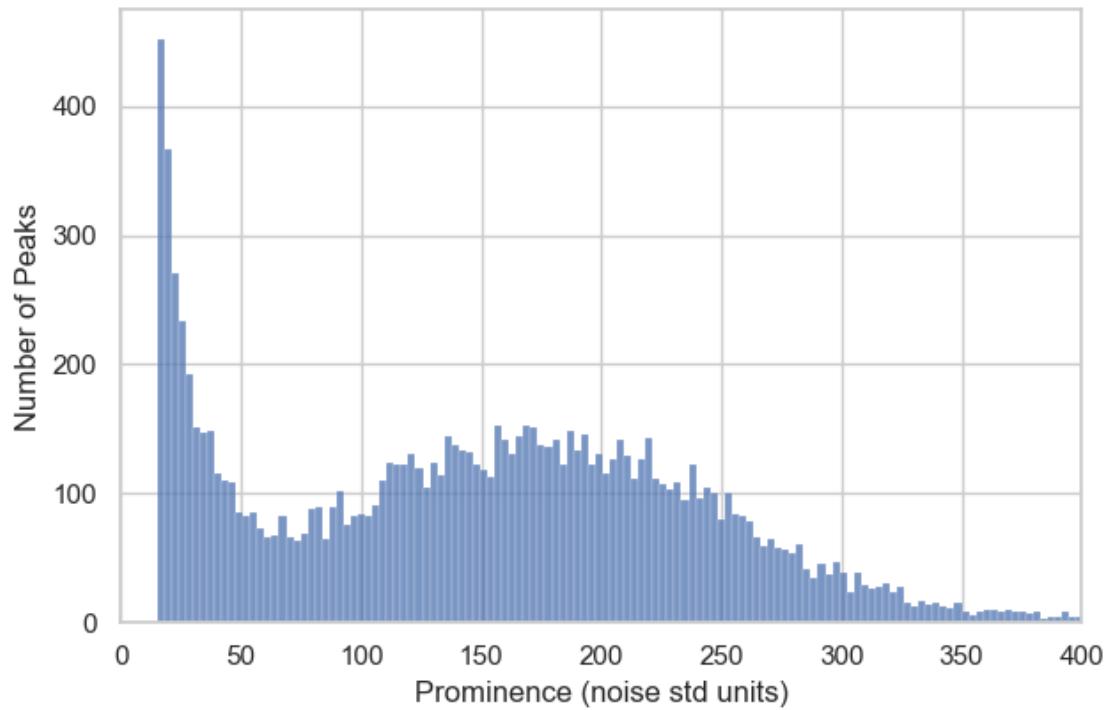
### 1.1.3 Peaks statistics

```
[2025-08-27 15:11:55] [INFO] calcium: plot_histogram: removed 0 outliers out of 11414 on 'Duration (s)' (lower=-87, upper=207)
```

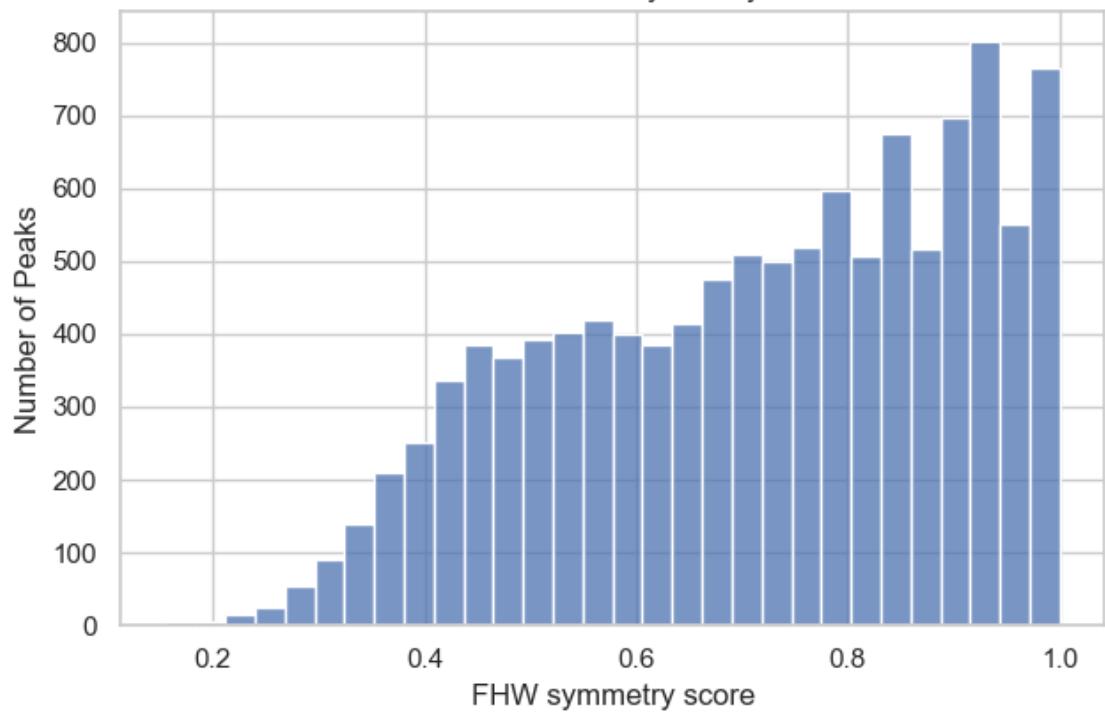


```
[2025-08-27 15:11:55] [INFO] calcium: plot_histogram: removed 2 outliers out of  
11414 on 'Prominence (noise std units)' (lower=-366.1, upper=651)
```

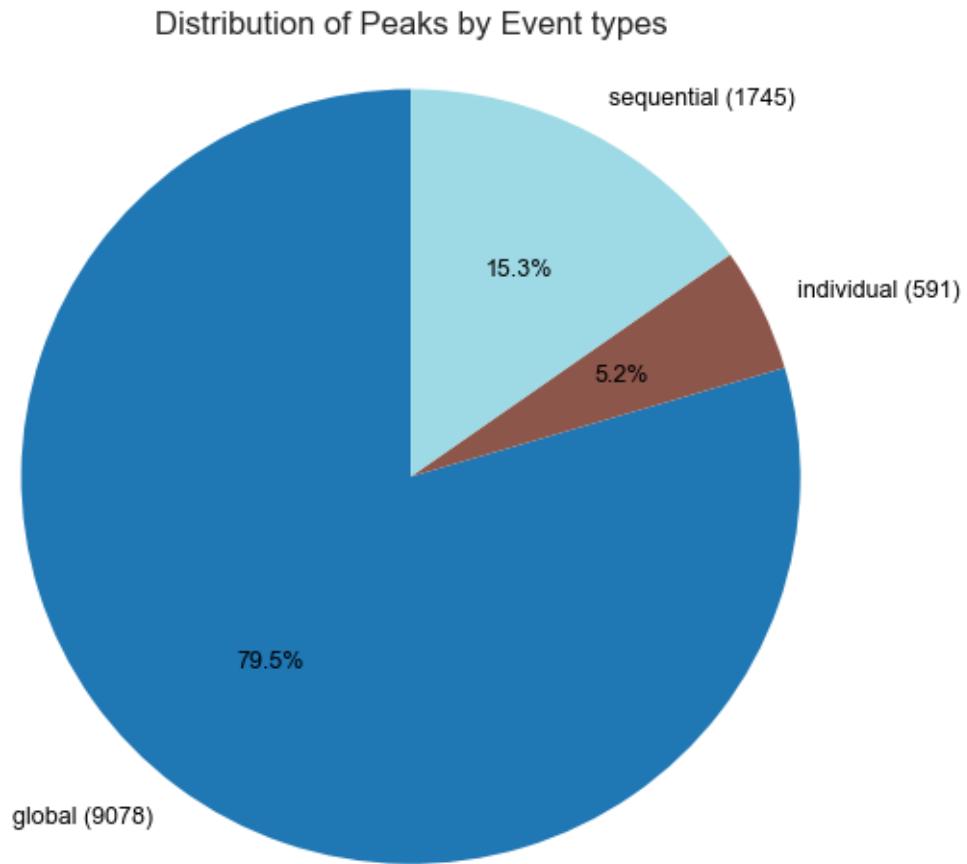
Distribution of Peak Prominences



Distribution of Peak Symmetry Scores

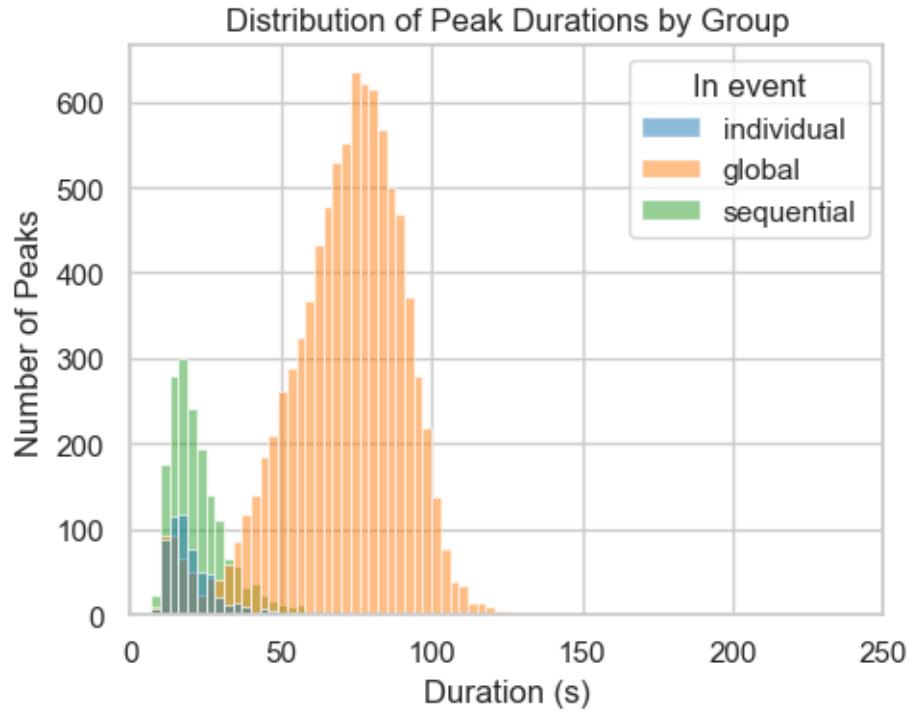


#### 1.1.4 Distribution of peaks per event types

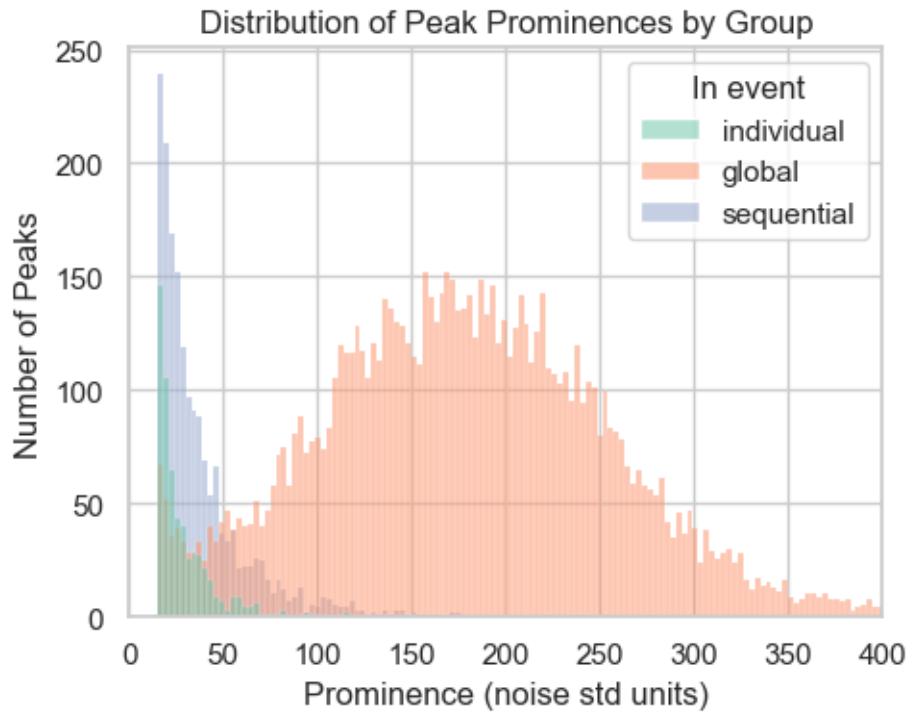


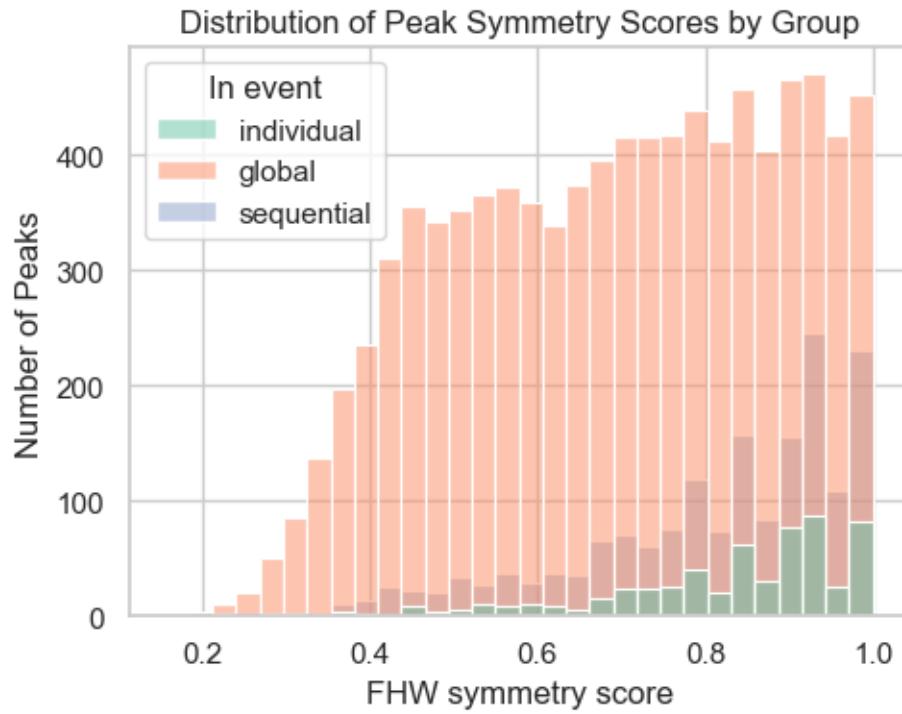
#### 1.1.5 Peaks statistics per event types

```
[2025-08-27 15:11:56] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 11414 on 'Duration (s)' (lower=-87, upper=207)
```



```
[2025-08-27 15:11:56] [INFO] calcium: plot_histogram_by_group: removed 2 outliers out of 11414 on 'Prominence (noise std units)' (lower=-366.1, upper=651)
```

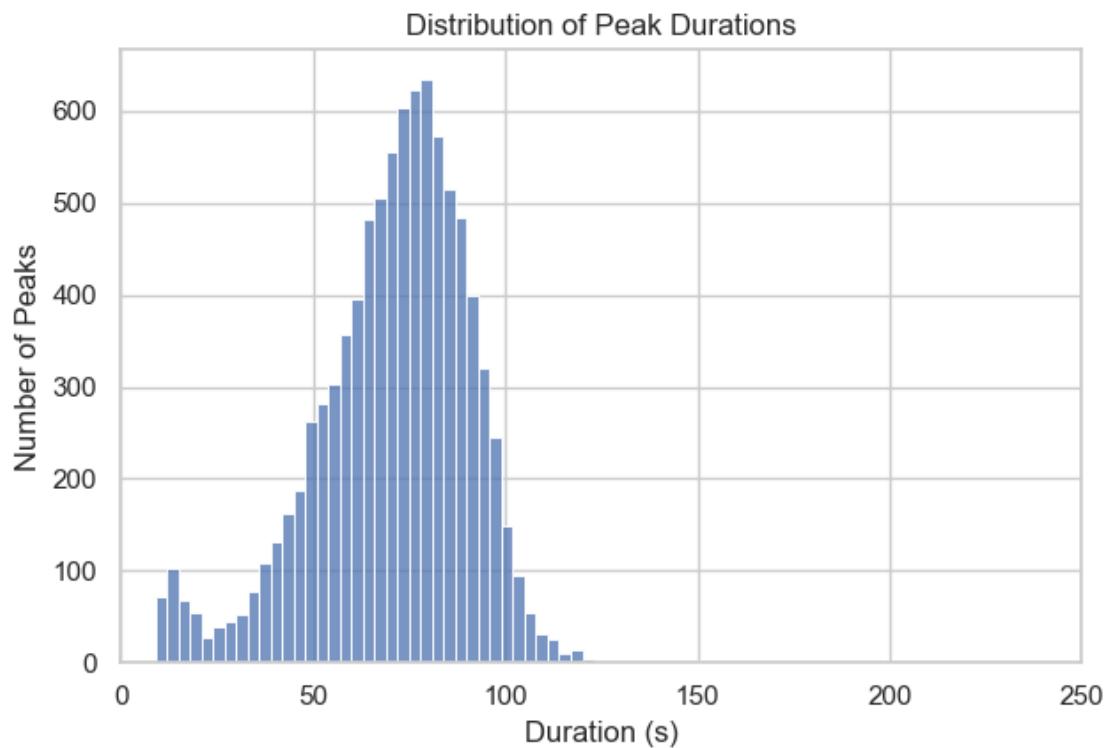




## 1.2 GLOBAL EVENTS

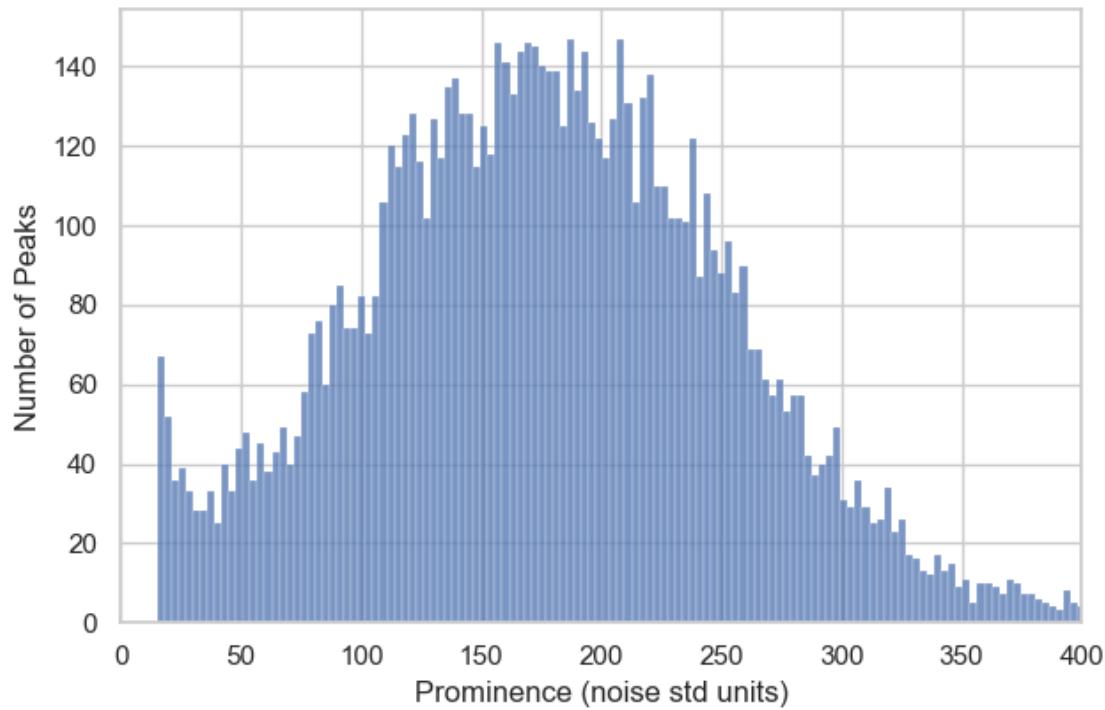
### 1.2.1 Peak statistics in global events

```
[2025-08-27 15:11:58] [INFO] calcium: plot_histogram: removed 2 outliers out of  
9078 on 'Duration (s)' (lower=-16, upper=159)
```

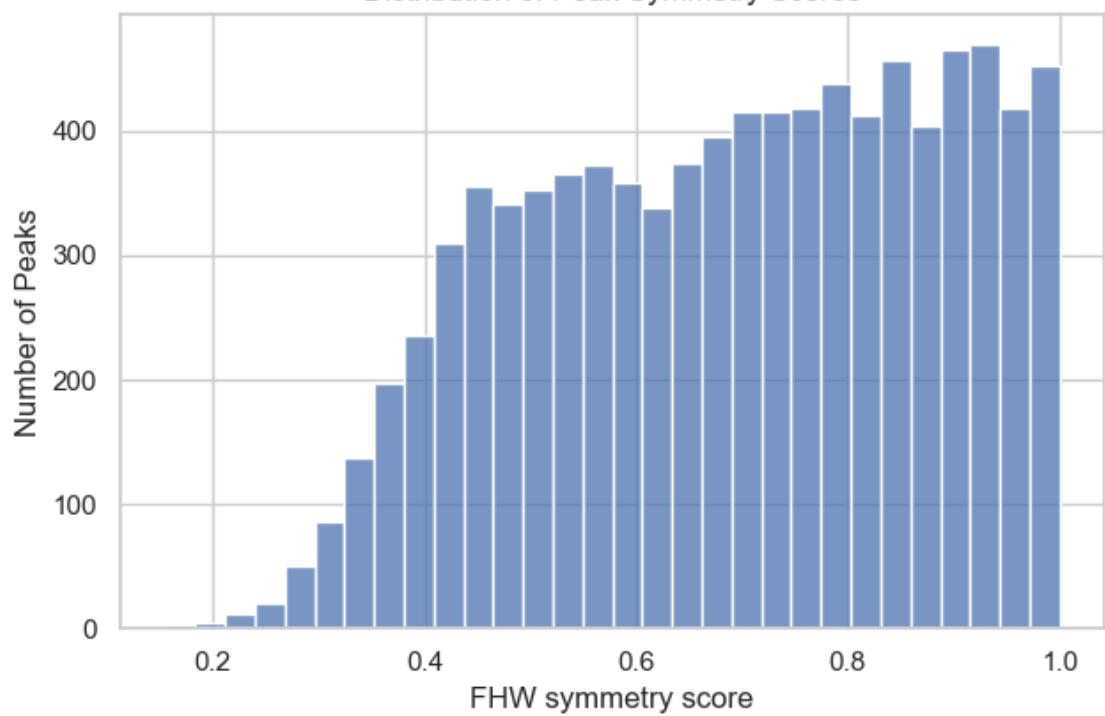


```
[2025-08-27 15:11:58] [INFO] calcium: plot_histogram: removed 9 outliers out of 9078 on 'Prominence (noise std units)' (lower=-190.8, upper=544.9)
```

Distribution of Peak Prominences

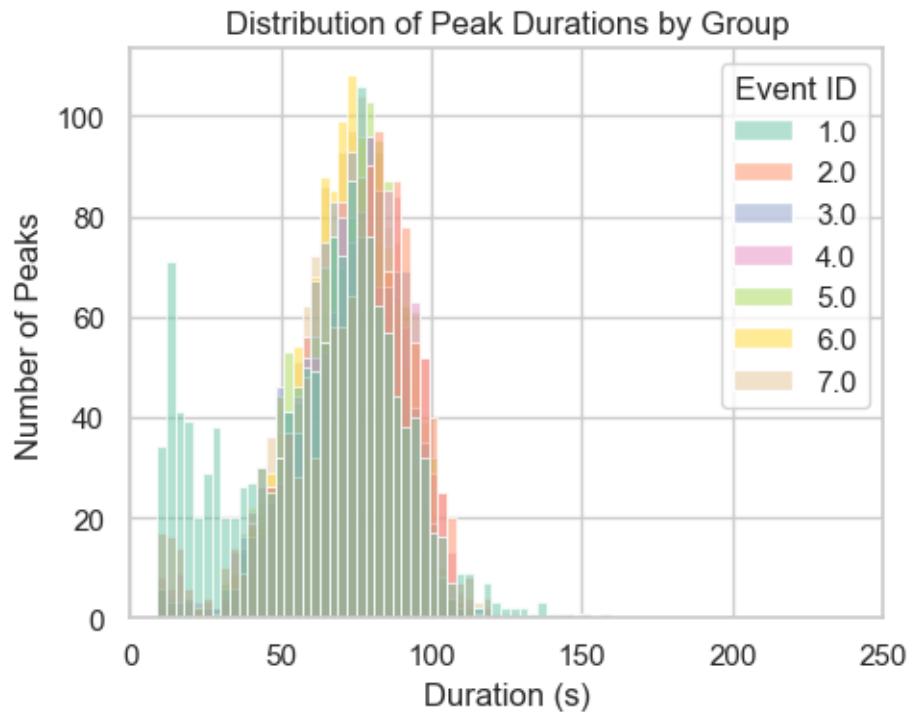


Distribution of Peak Symmetry Scores

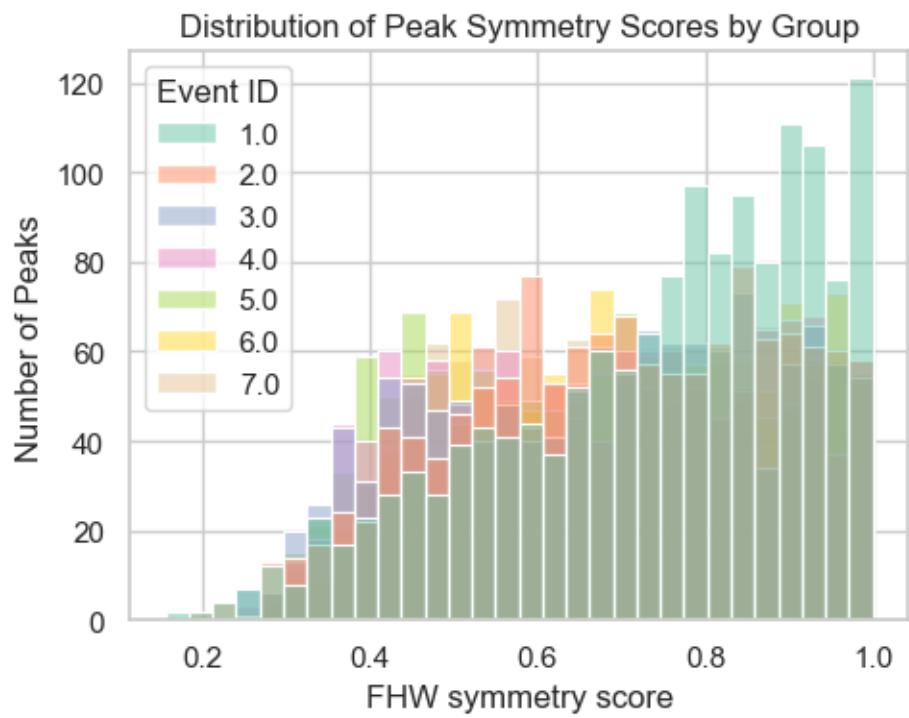
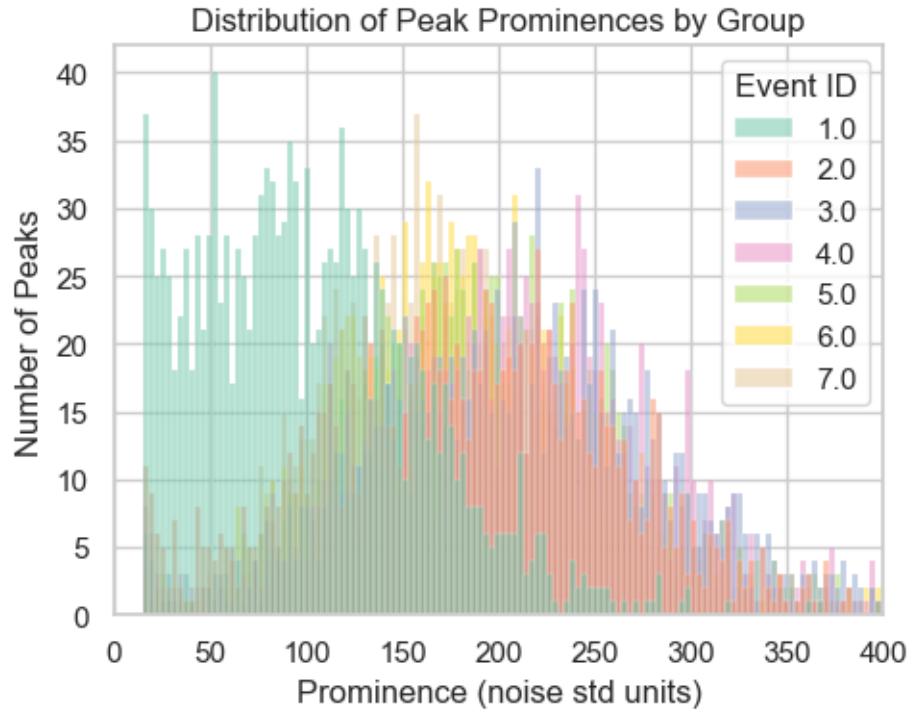


### 1.2.2 Peak statistics in global event per event ID

[2025-08-27 15:11:58] [INFO] calcium: plot\_histogram\_by\_group: removed 2 outliers out of 9078 on 'Duration (s)' (lower=-16, upper=159)

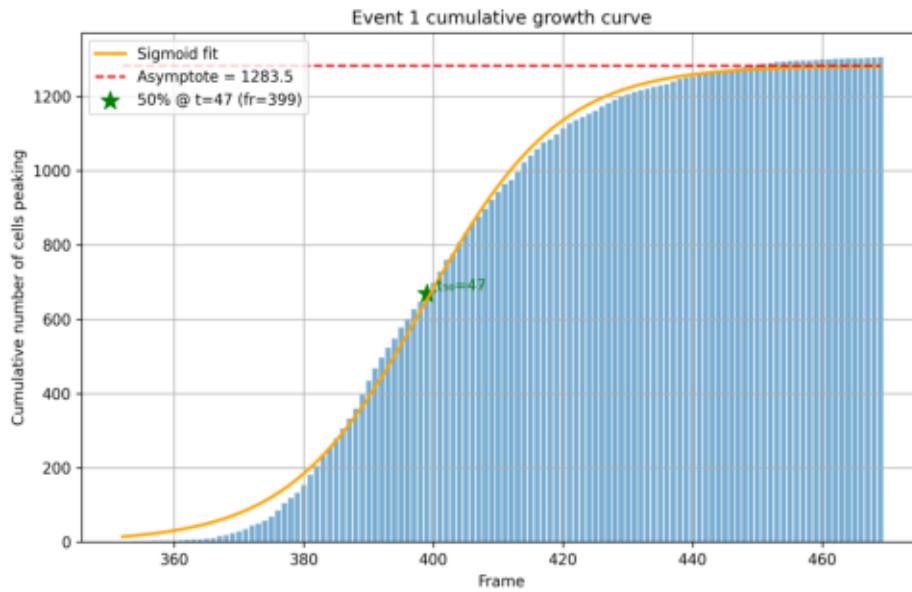


[2025-08-27 15:11:59] [INFO] calcium: plot\_histogram\_by\_group: removed 9 outliers out of 9078 on 'Prominence (noise std units)' (lower=-190.8, upper=544.9)

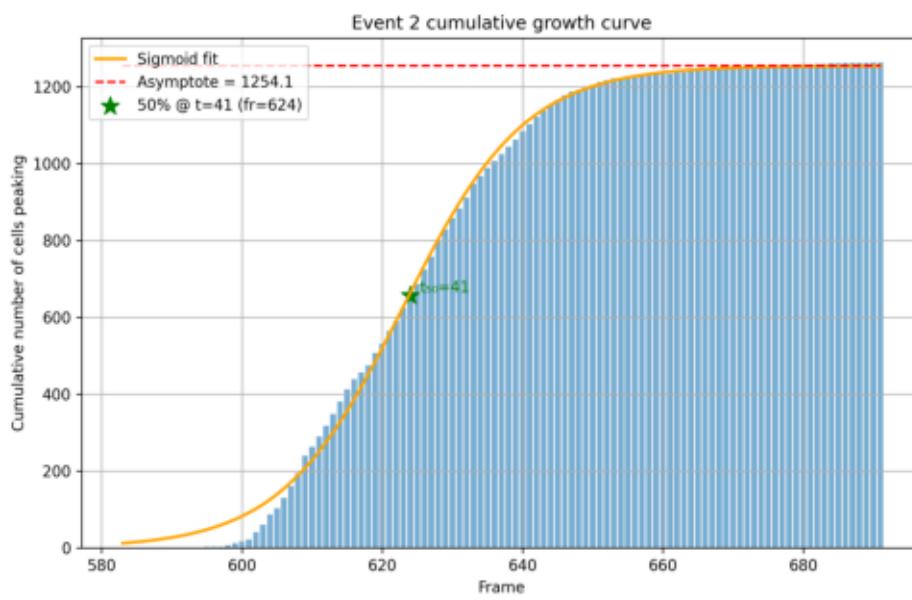


### 1.2.3 Kinetics of global events

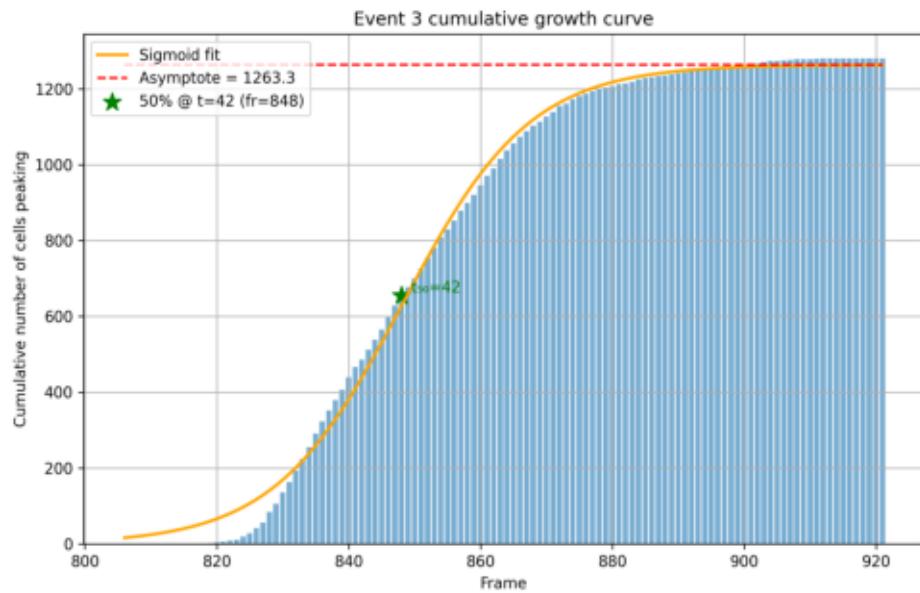
Event Activity Overlay (Event ID: 1)



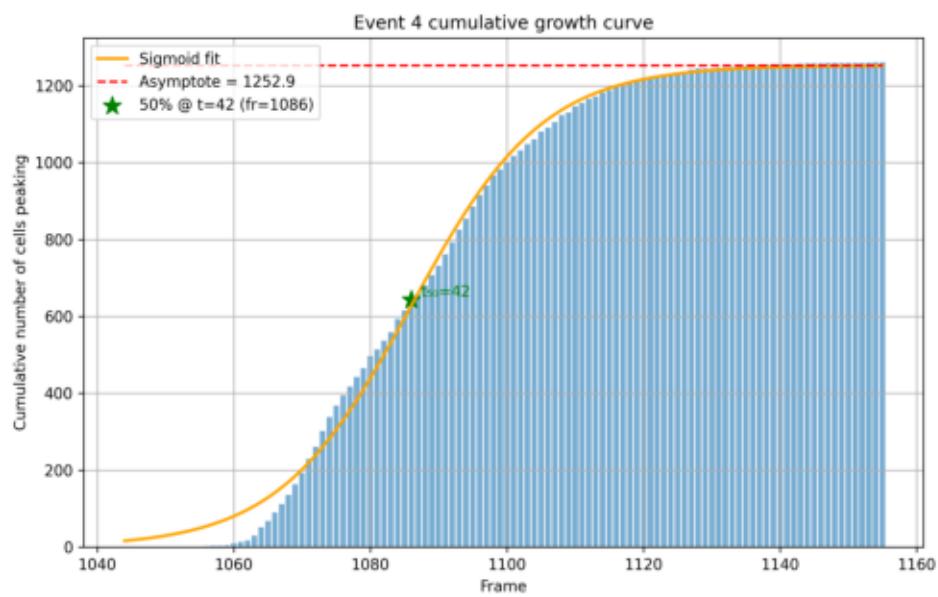
Event Activity Overlay (Event ID: 2)



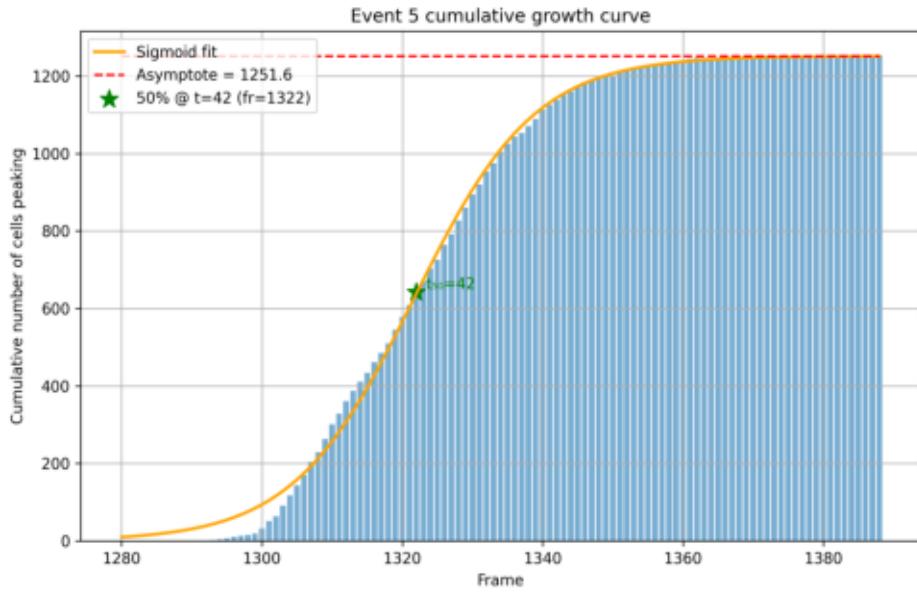
### Event Activity Overlay (Event ID: 3)



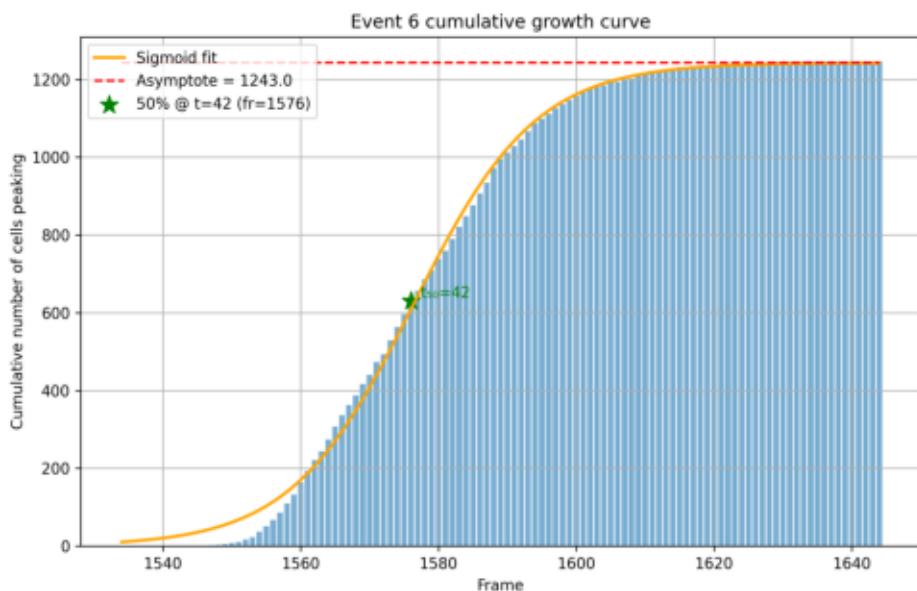
### Event Activity Overlay (Event ID: 4)



### Event Activity Overlay (Event ID: 5)



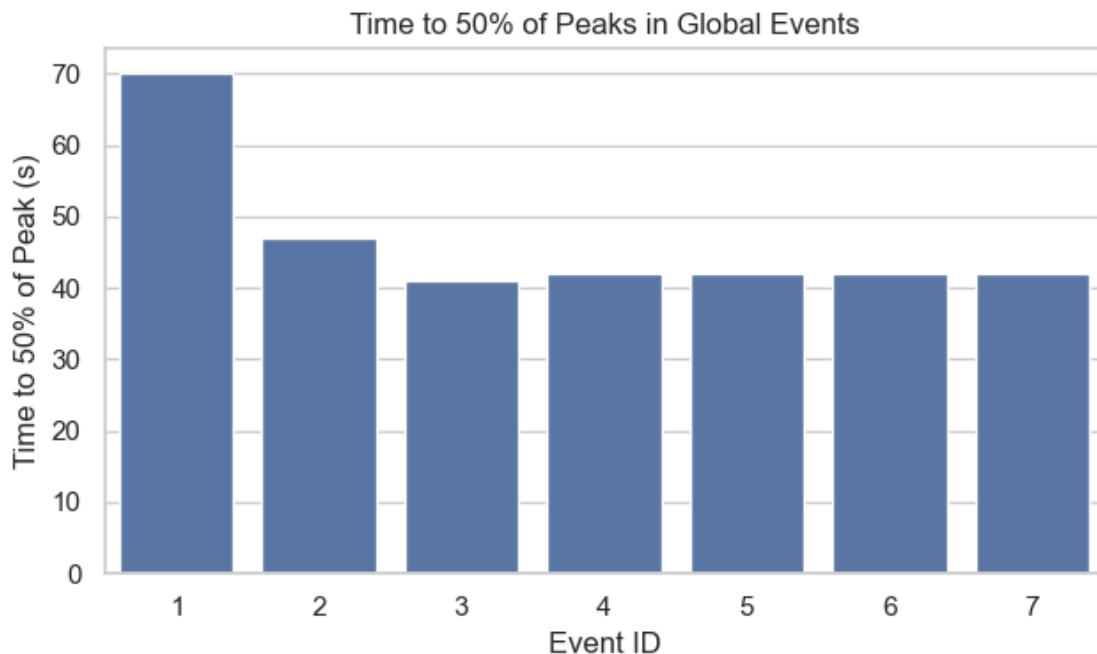
### Event Activity Overlay (Event ID: 6)



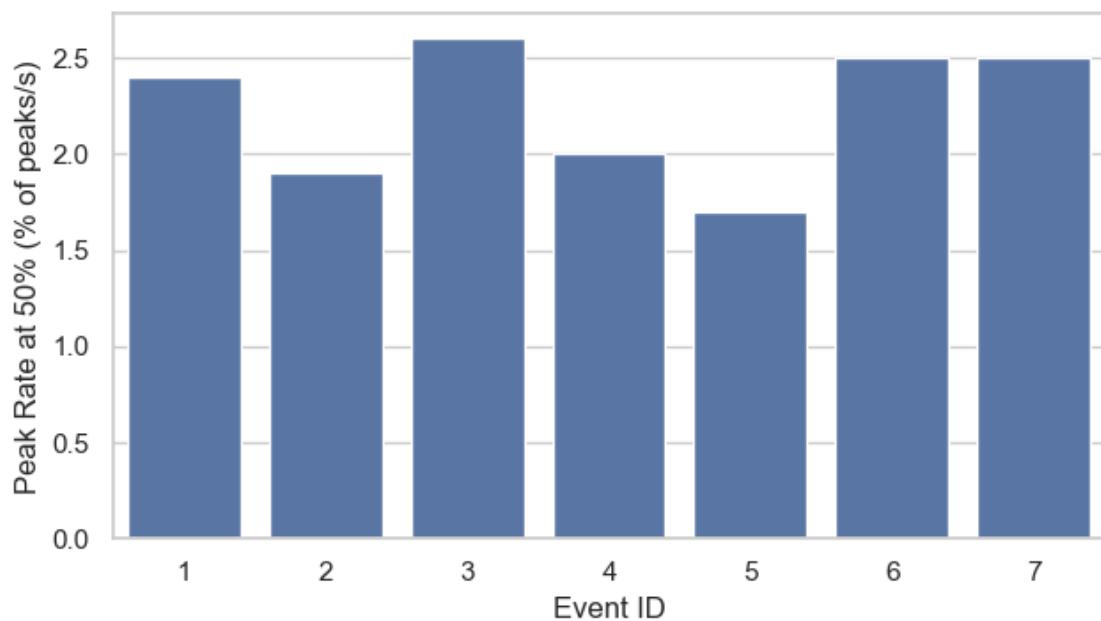
```

[2025-08-27 15:12:05] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\events\event-growth-curve-7.png': [Errno 2] No
such file or directory: 'D:\\Mateo\\20250624\\Output\\IS10\\events\\event-
growth-curve-7.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\\IS10\\events\\event-growth-curve-7.png'

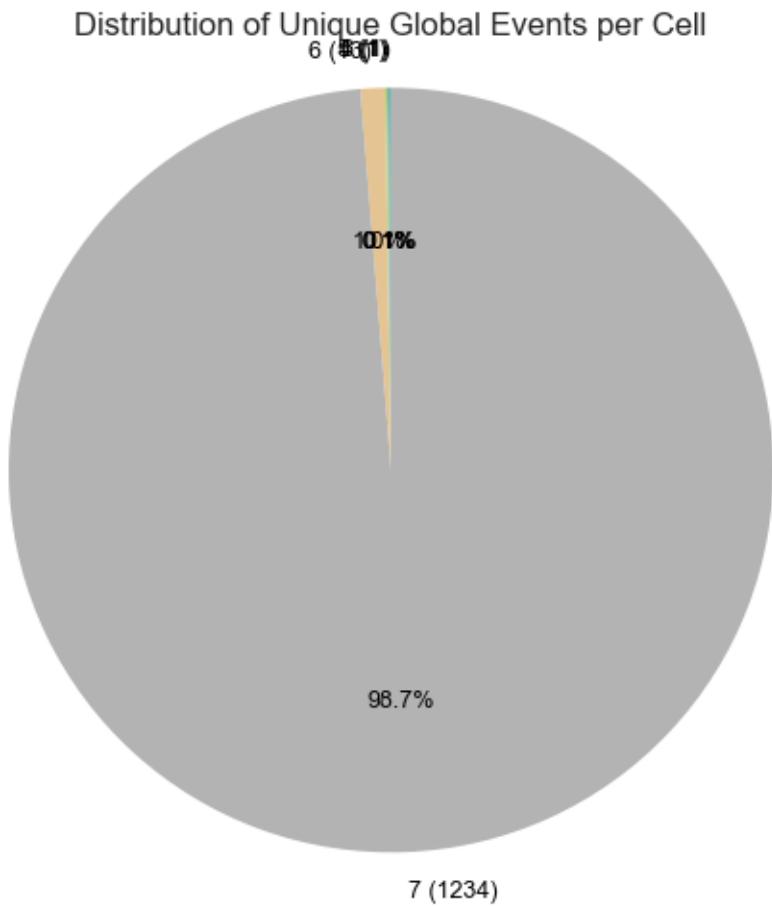
```



Peak rate at 50% in Global Events



#### 1.2.4 Cells Occurrences in global events

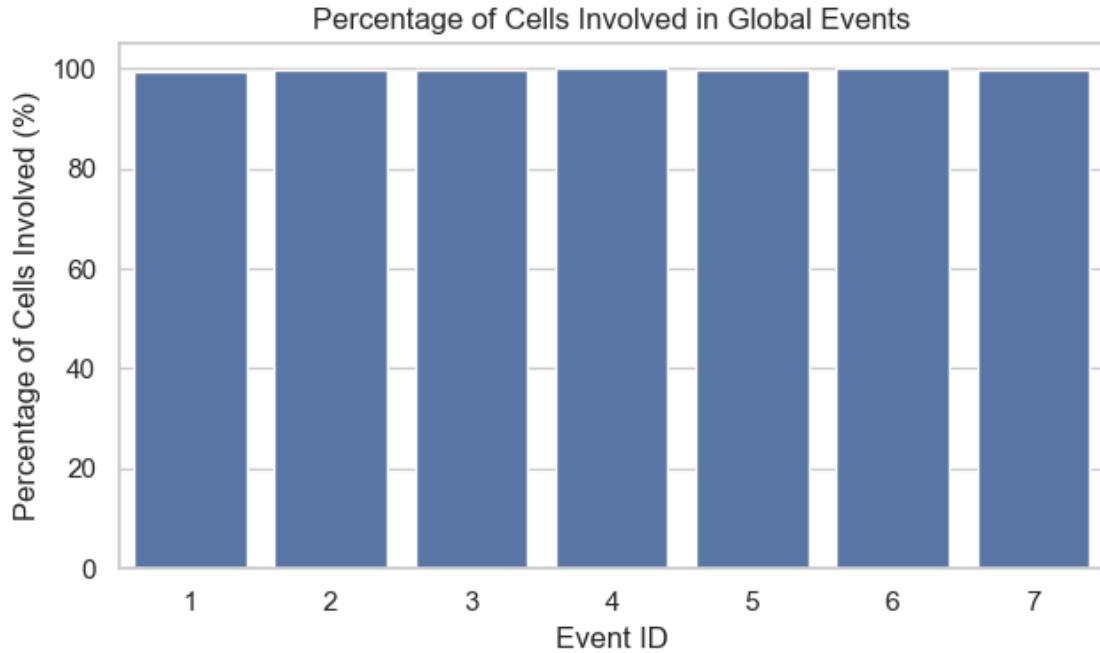


```
[2025-08-27 15:12:06] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\cell-
mapping\cell_Occurrences_in_global_events_overlay.png': [Errno 2] No such file
or directory: 'D:\\\\Mateo\\\\20250624\\\\Output\\\\IS10\\\\cell-
mapping\\\\cell_Occurrences_in_global_events_overlay.png'
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\IS10\cell-
mapping\cell_Occurrences_in_global_events_overlay.png'

```



### 1.2.5 Inter-event interval analysis

Intervals between global event peaks: [180.0, 226.0, 227.0, 238.0, 235.0, 255.0]  
Estimated periodicity: 0.908  
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 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\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 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\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 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\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 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\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

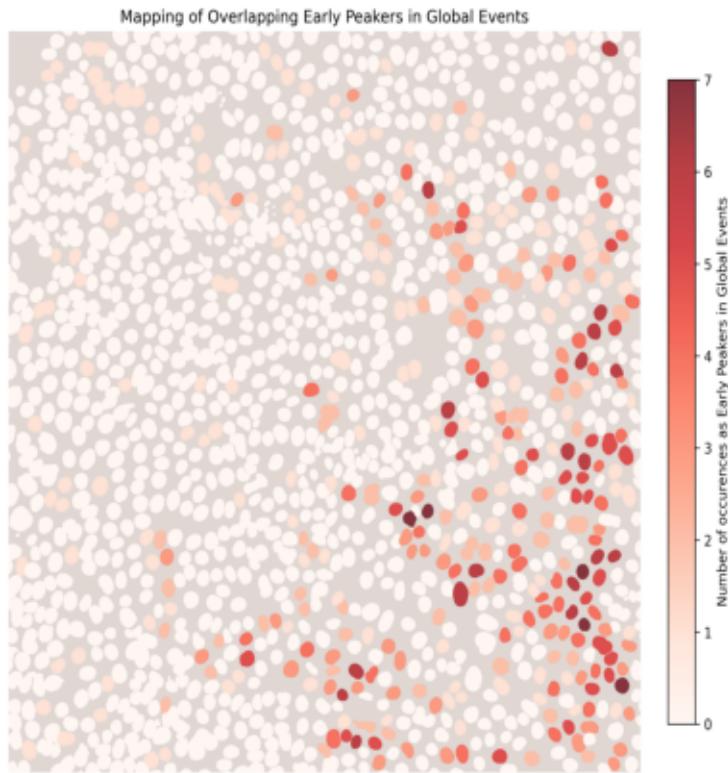
[2025-08-27 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\cell-
mapping\global_events\global_event_5_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\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

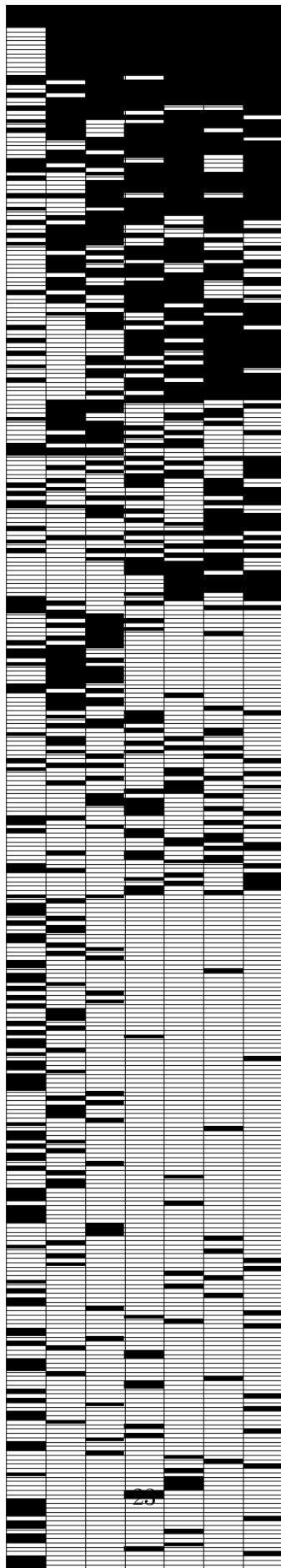
[2025-08-27 15:12:07] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\cell-
mapping\global_events\global_event_7_early_peakers_overlay.png': not a PNG file
Traceback (most recent call last):
  File "C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semest
er_2025\Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterizatio
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



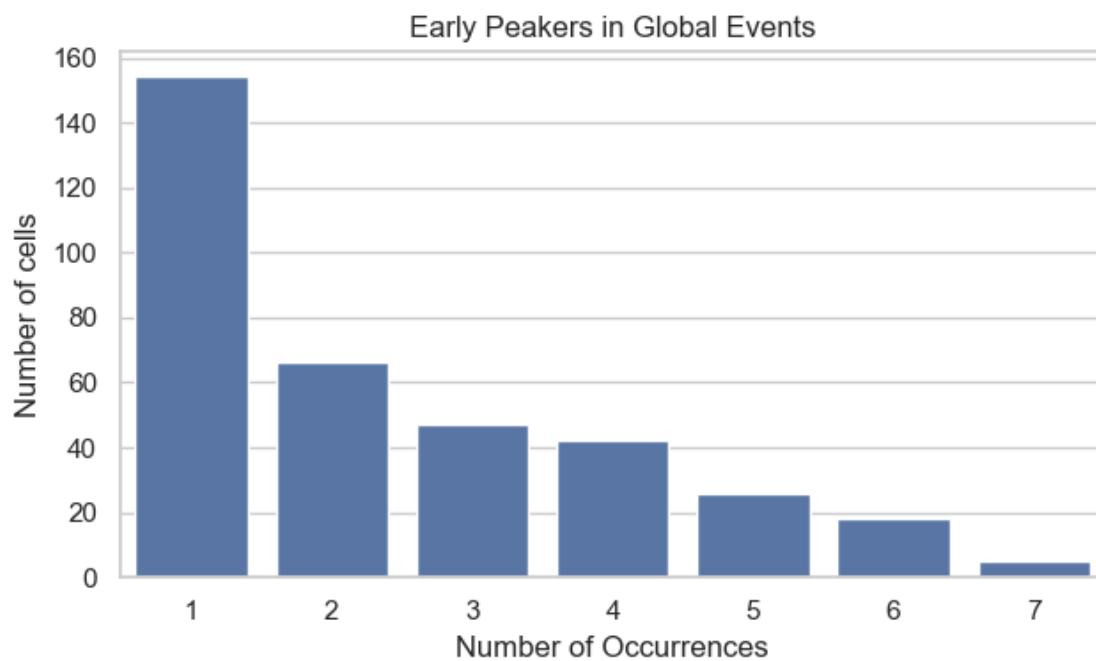
```
[2025-08-27 15:12:08] [WARNING] calcium: 'total_events' is deprecated and ignored. Using 7 unique event IDs.
```

```
[2025-08-27 15:12:08] [INFO] calcium: Early peakers event-matrix: 358 cells x 7 events; black squares: 868
```

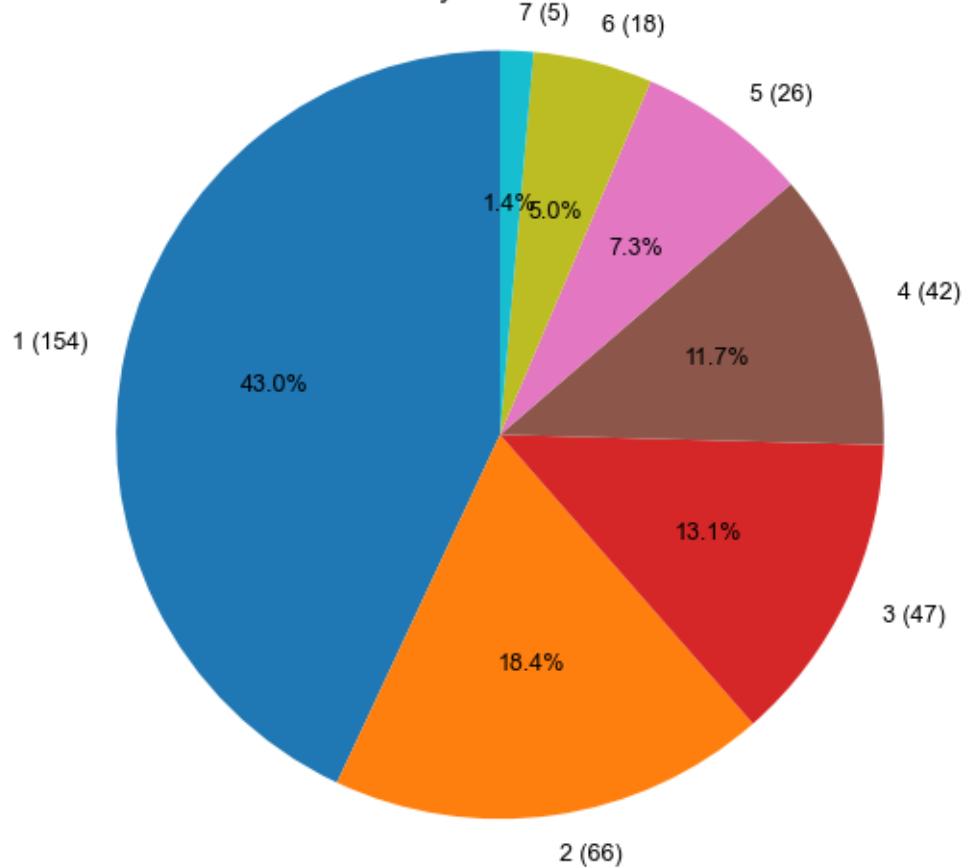


```
[2025-08-27 15:12:09] [INFO] calcium: Saved early peakers heatmap SVG to:  
early_peakers_heatmap.svg
```

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



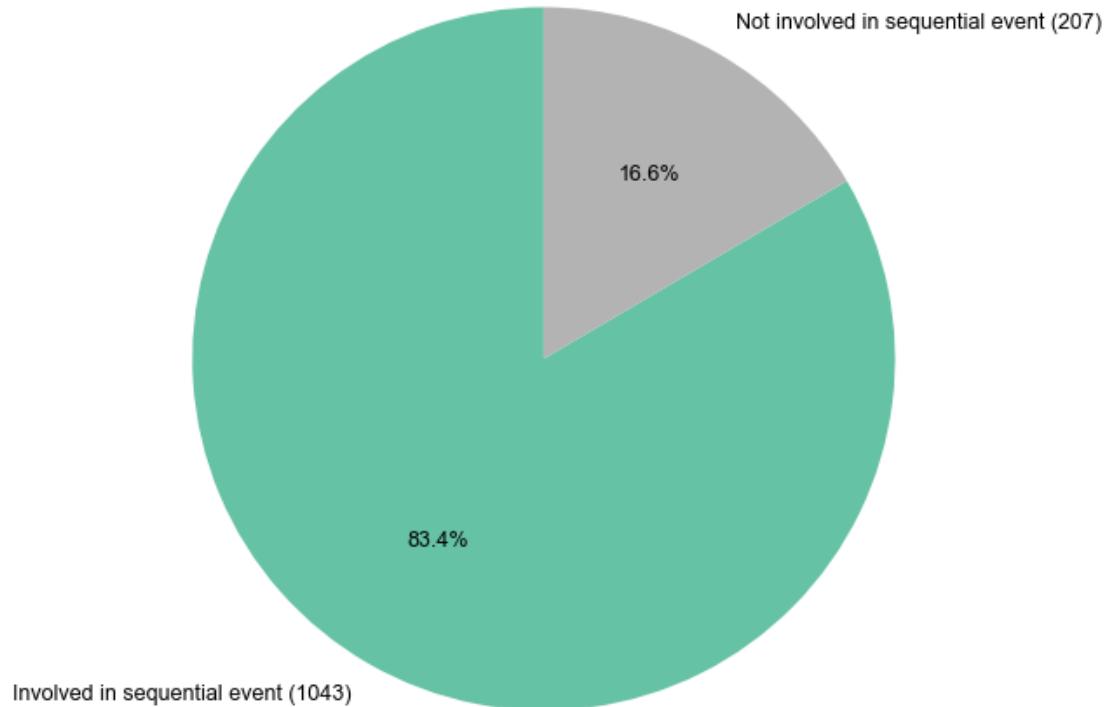
Distribution of Early Peakers in Global Events



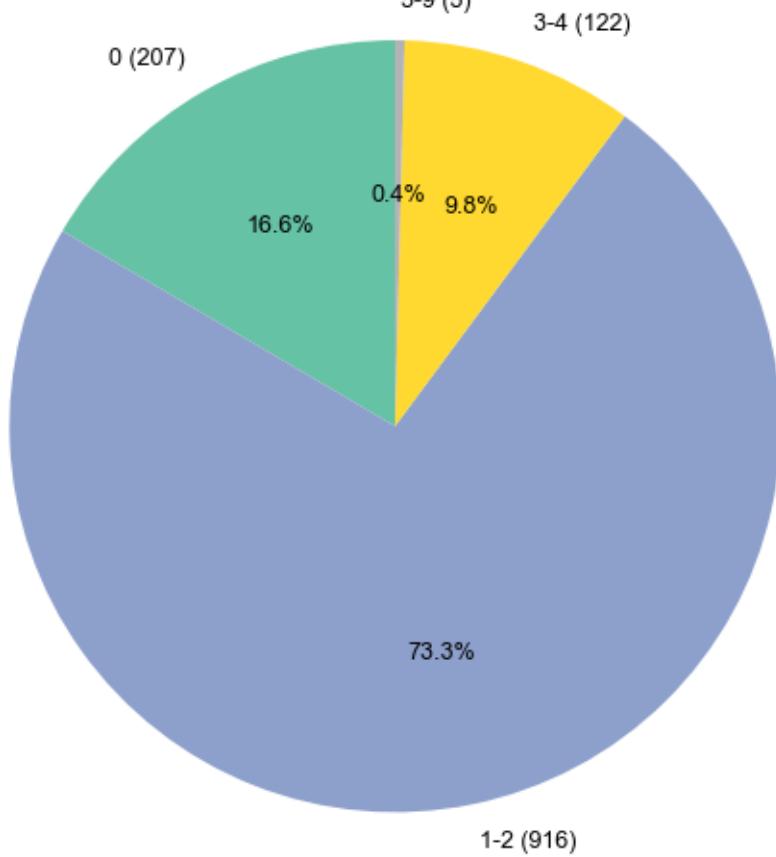
## 1.3 SEQUENTIAL EVENTS

### 1.3.1 Cells Occurrences in sequential events

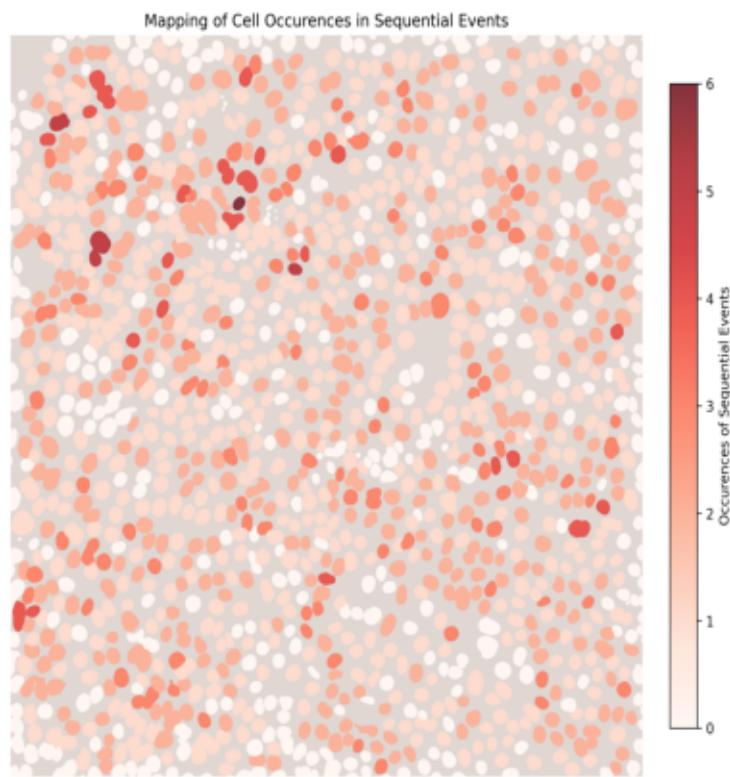
Distribution of Cells Involved in Sequential Events



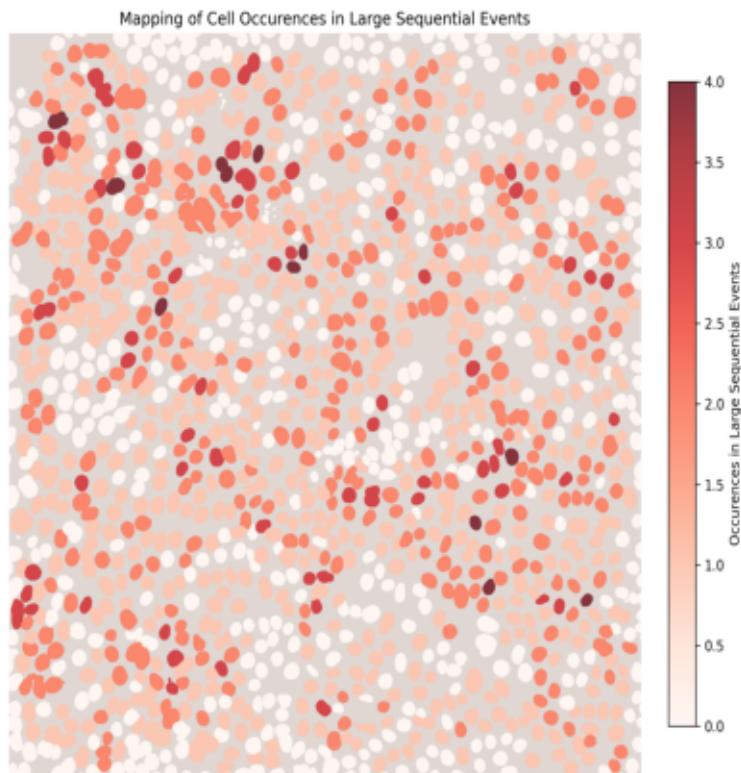
Distribution of Sequential Event Occurrences per Cell (0, 1-2, 3-4, 5-9, 10+)



## Cell Mapping with Occurrences in Sequential Events Overlay

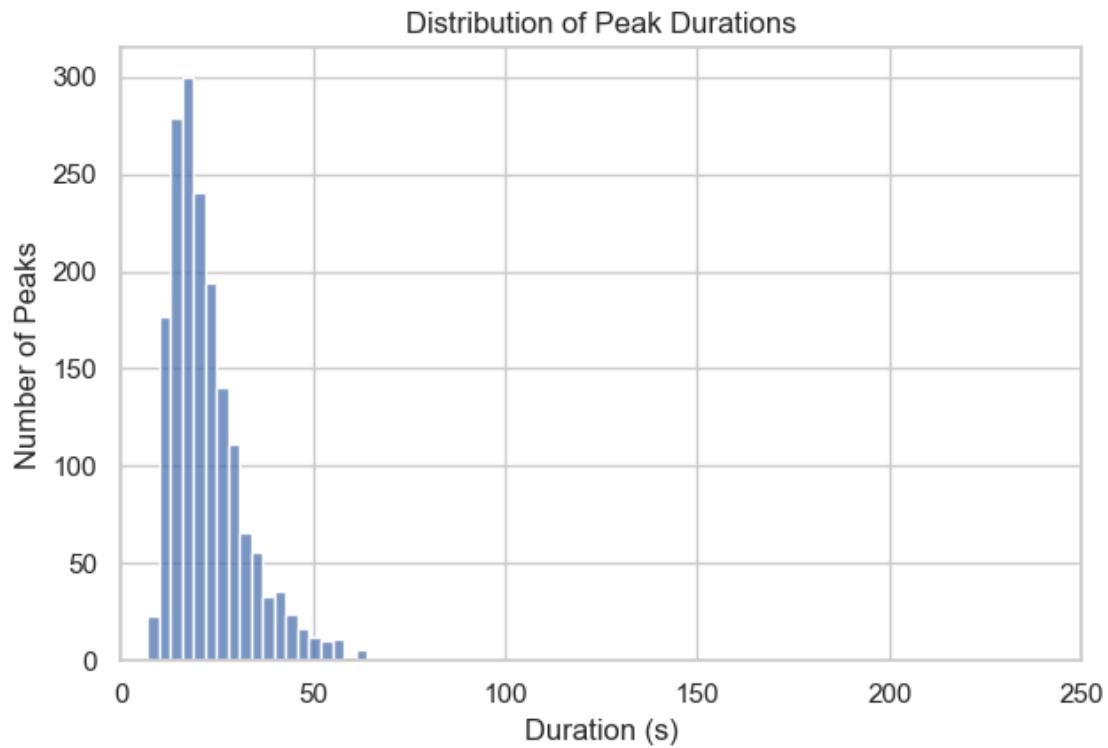


## Cell Mapping with Occurrences in Large Sequential Events Overlay (>2)

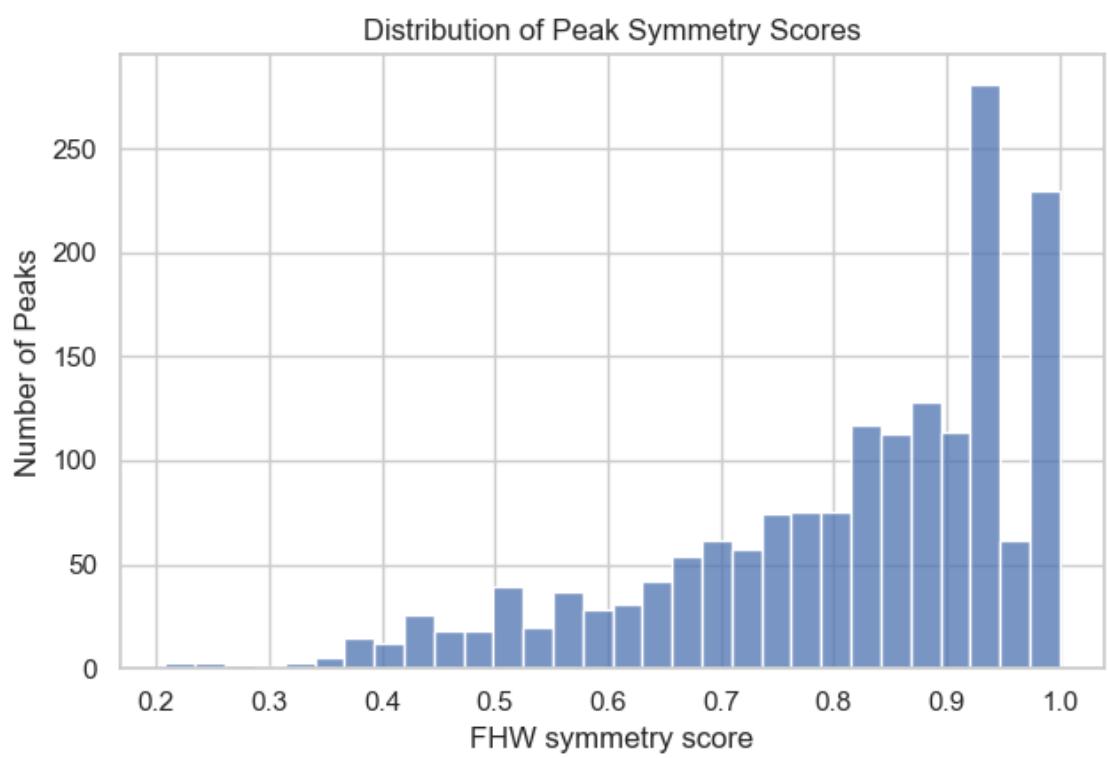
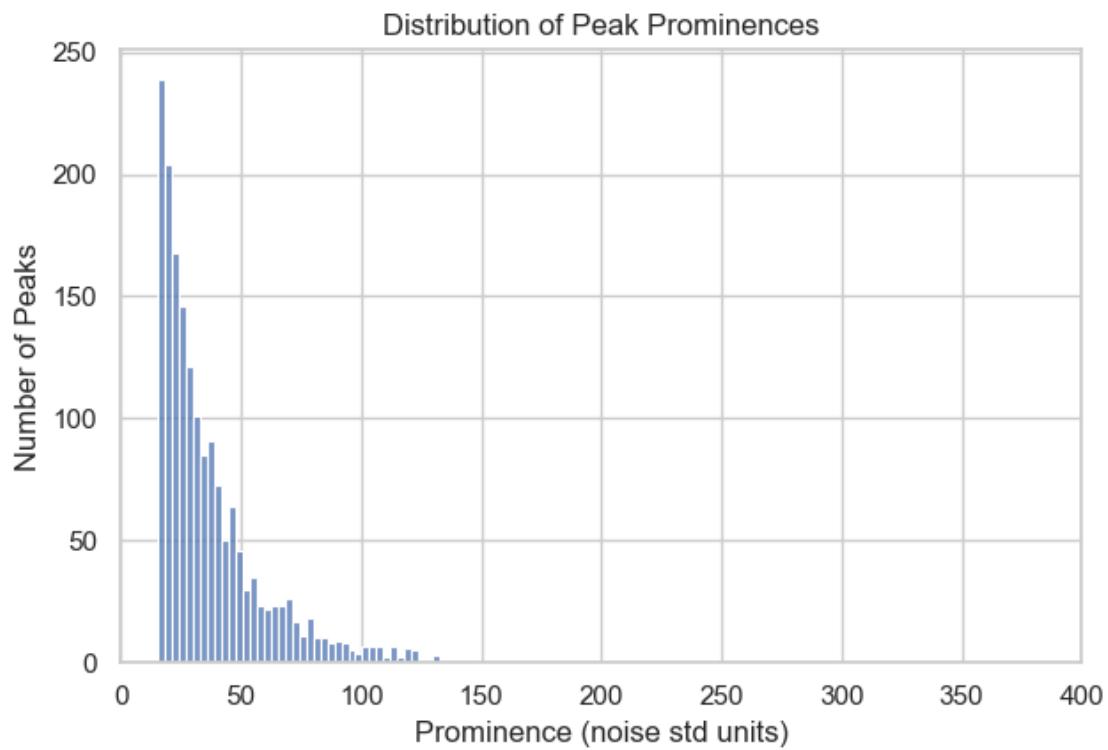


### 1.3.2 Peaks statistics in sequential events

```
[2025-08-27 15:12:15] [INFO] calcium: plot_histogram: removed 7 outliers out of 1745 on 'Duration (s)' (lower=-1.5, upper=64.5)
```

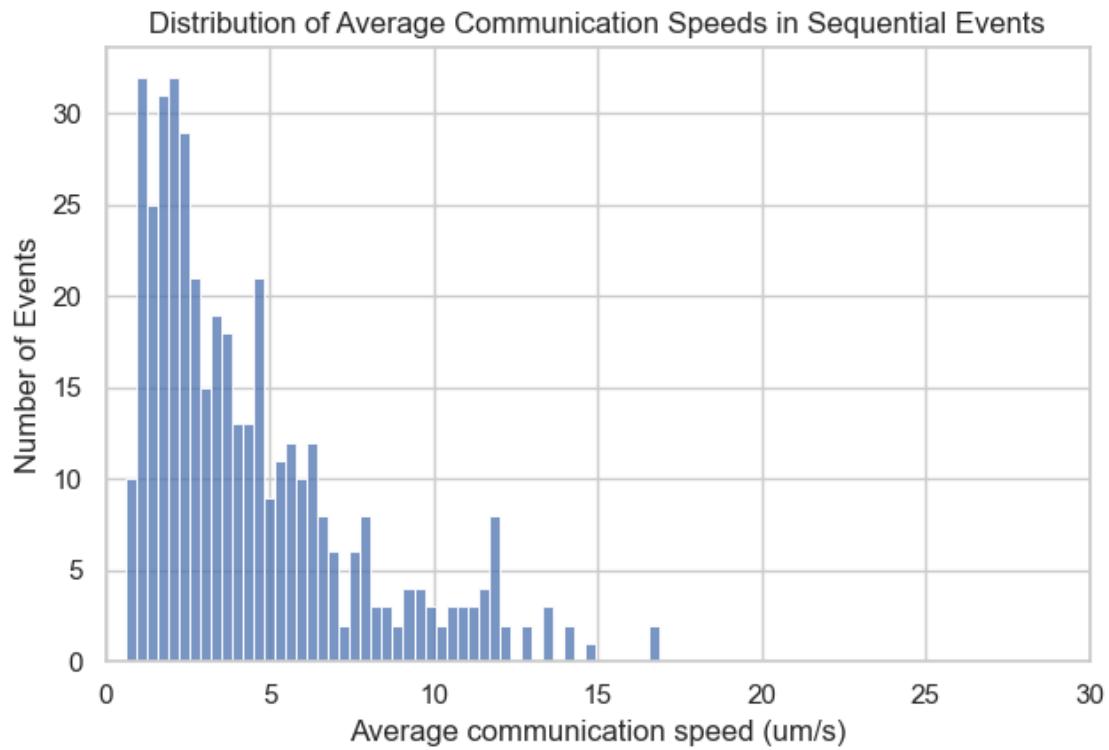


```
[2025-08-27 15:12:15] [INFO] calcium: plot_histogram: removed 28 outliers out of  
1745 on 'Prominence (noise std units)' (lower=-17.1, upper=134.1)
```



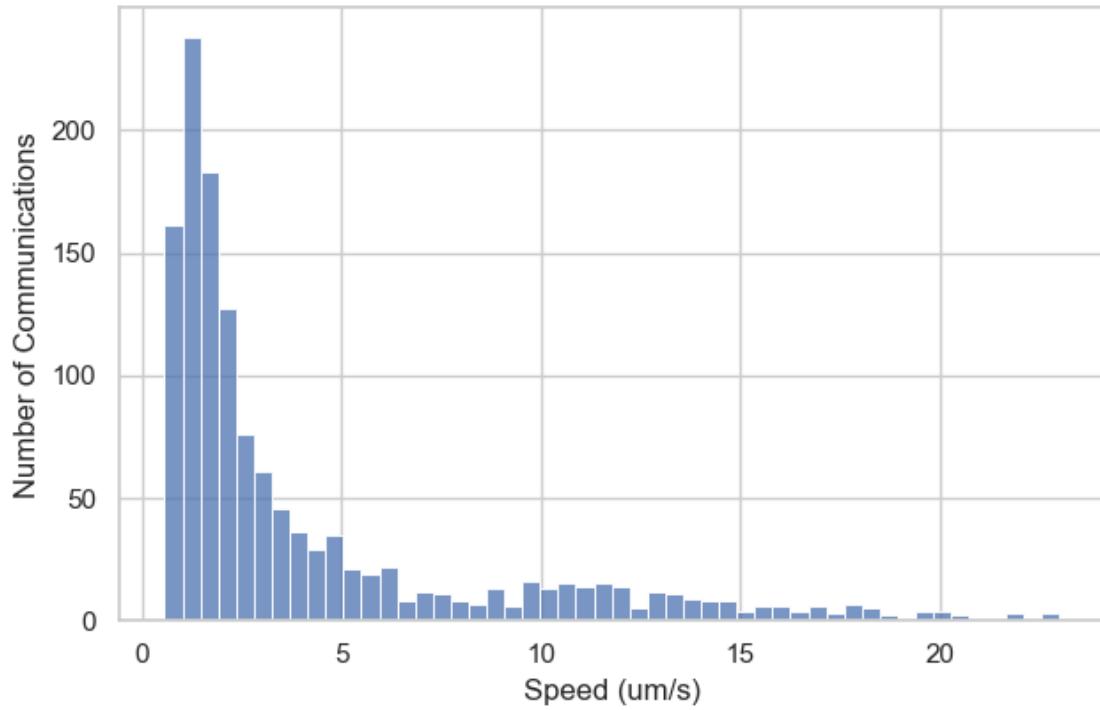
### 1.3.3 Cell-cell communication speed

[2025-08-27 15:12:16] [INFO] calcium: plot\_histogram: removed 4 outliers out of 421 on 'Average communication speed (um/s)' (lower=-10.03, upper=17.97)

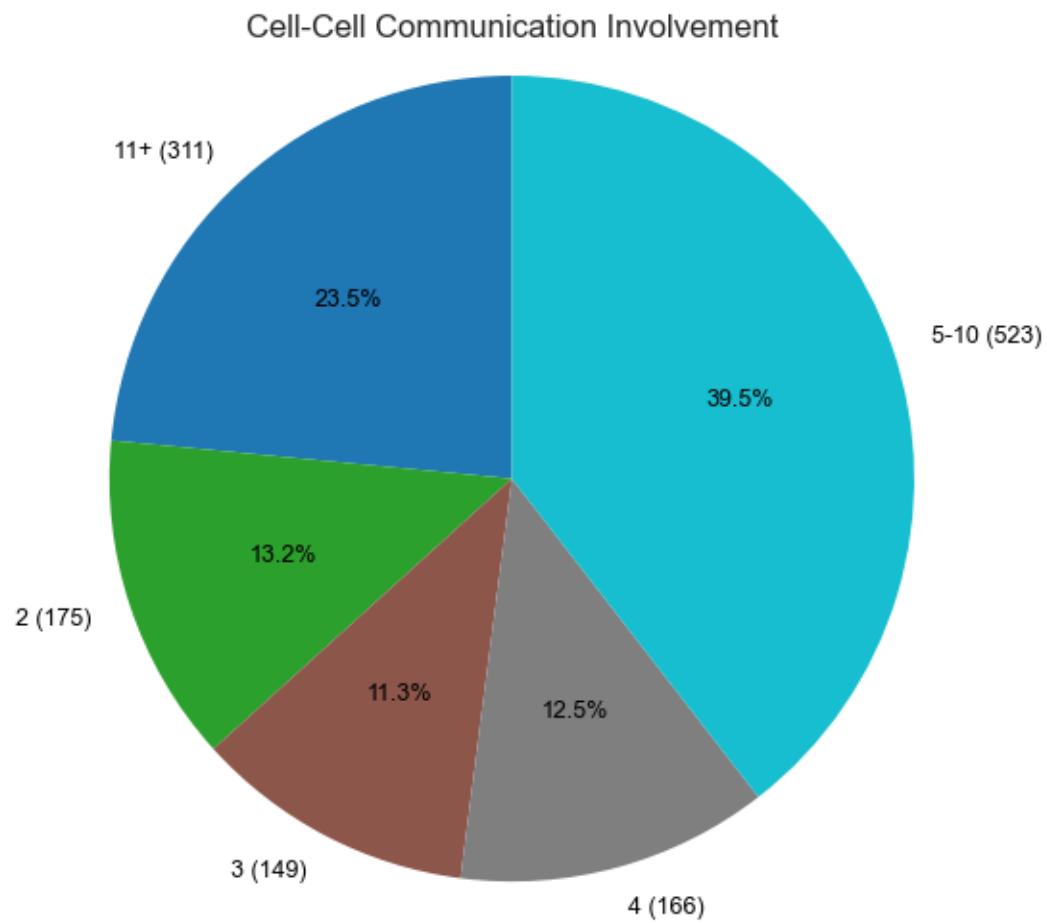


[2025-08-27 15:12:16] [INFO] calcium: plot\_histogram: removed 4 outliers out of 1324 on 'Speed (um/s)' (lower=-9.9075, upper=23.775)

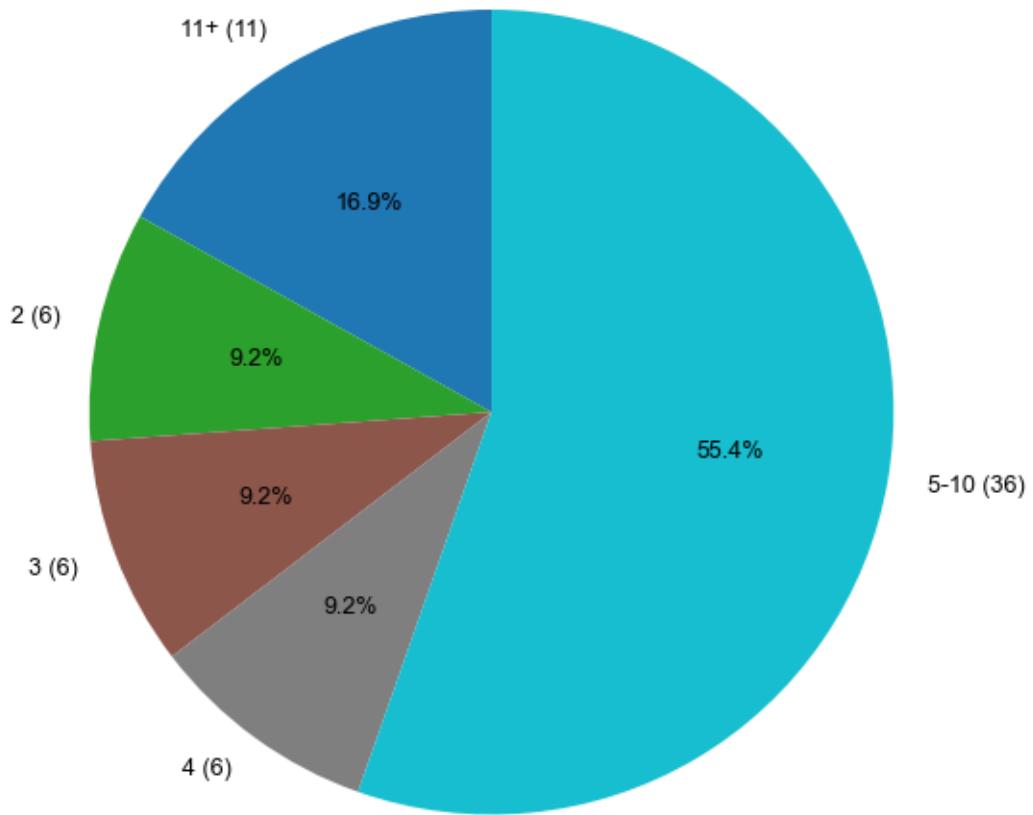
Distribution of Cell-Cell Communication Speeds



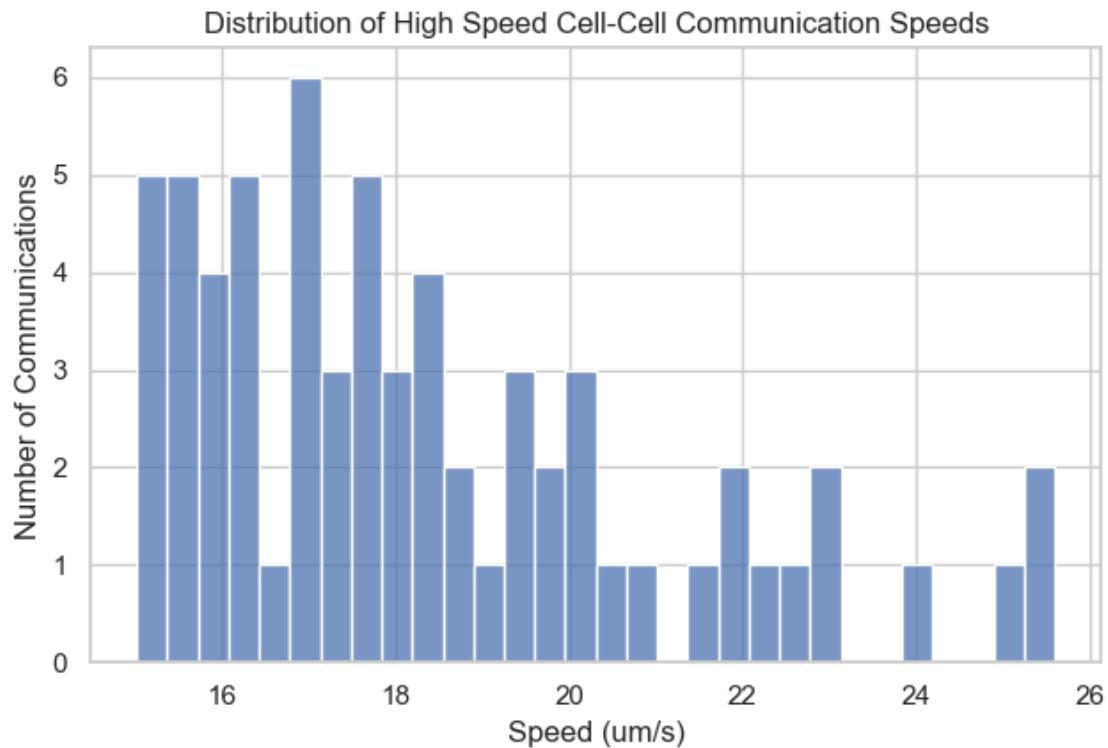
#### 1.3.4 Double distribution in cell-cell communication speeds



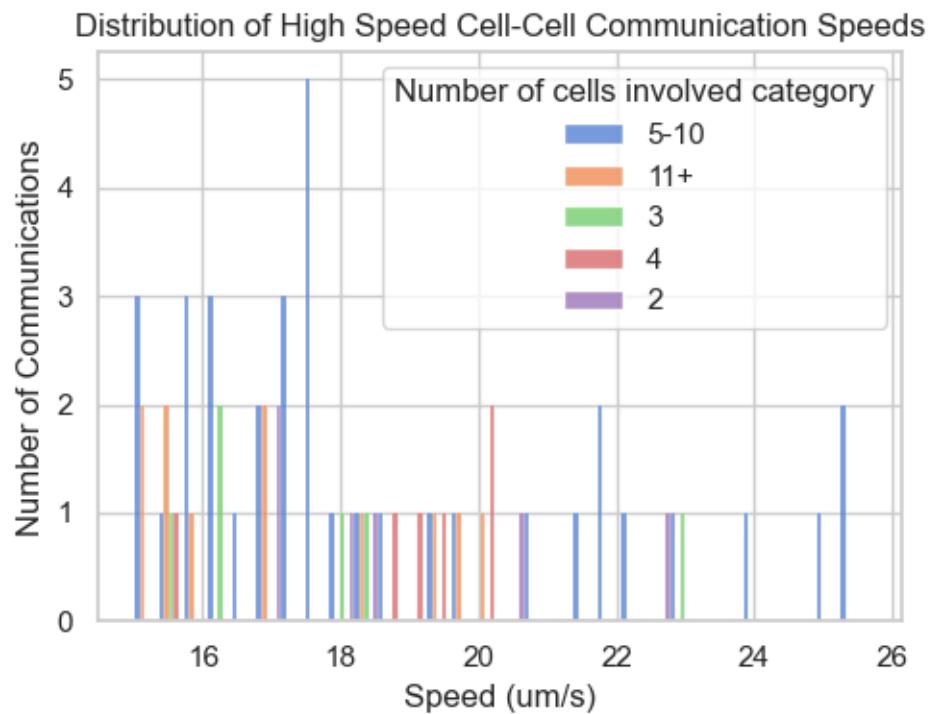
### High Speed Cell-Cell Communication Involvement



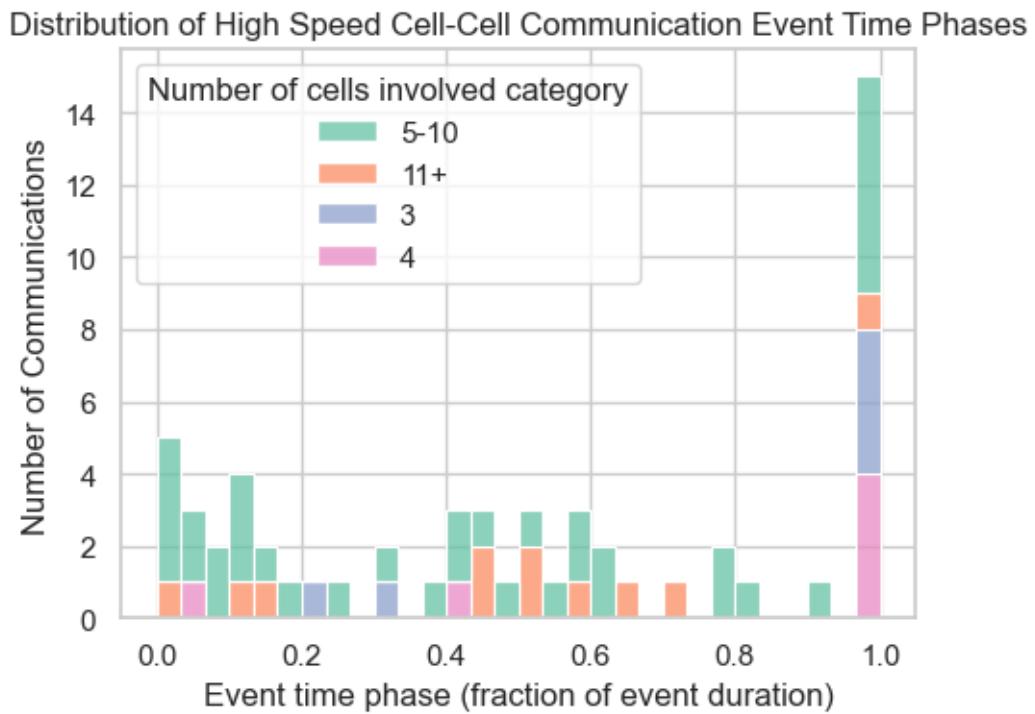
[2025-08-27 15:12:17] [INFO] calcium: plot\_histogram: removed 0 outliers out of 65 on 'Speed (um/s)' (lower=5.4, upper=30.81)



```
[2025-08-27 15:12:18] [INFO] calcium: plot_histogram_by_group: removed 0 outliers out of 65 on 'Speed (um/s)' (lower=5.4, upper=30.81)
```

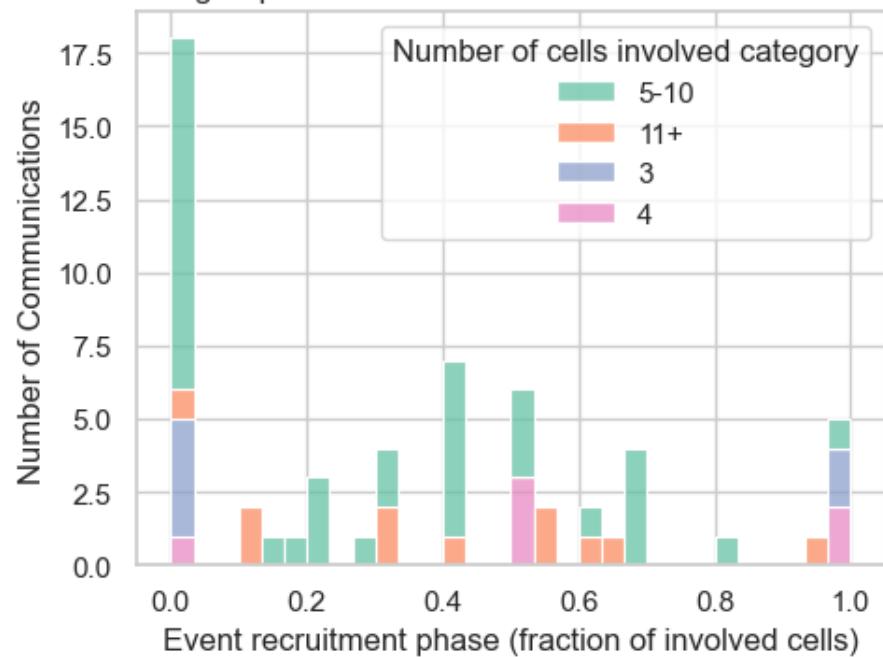


[2025-08-27 15:12:19] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 59 on 'Event time phase (fraction of event duration)' (lower=-2.27, upper=3.365)

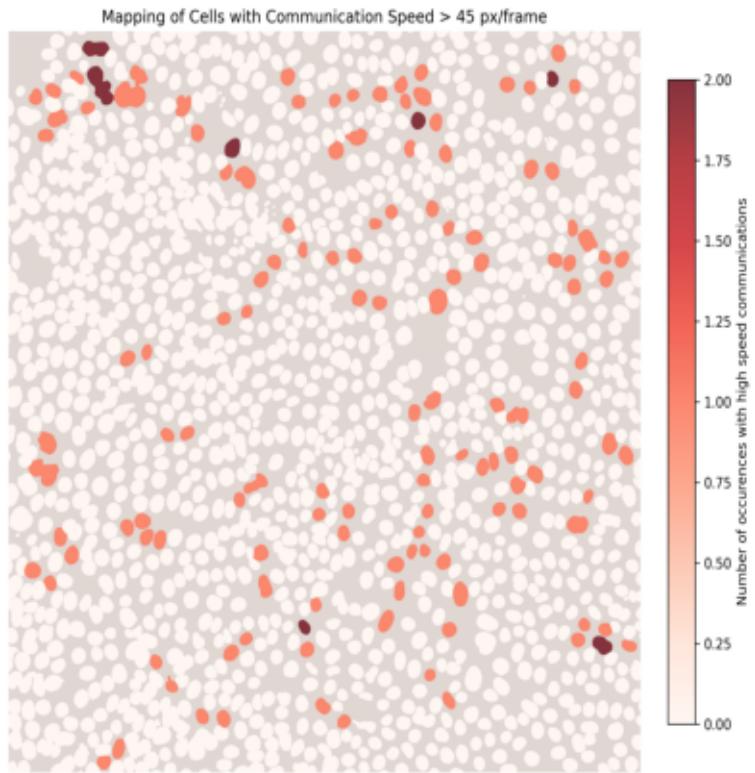


[2025-08-27 15:12:21] [INFO] calcium: plot\_histogram\_by\_group: removed 0 outliers out of 59 on 'Event recruitment phase (fraction of involved cells)' (lower=-1.62, upper=2.16)

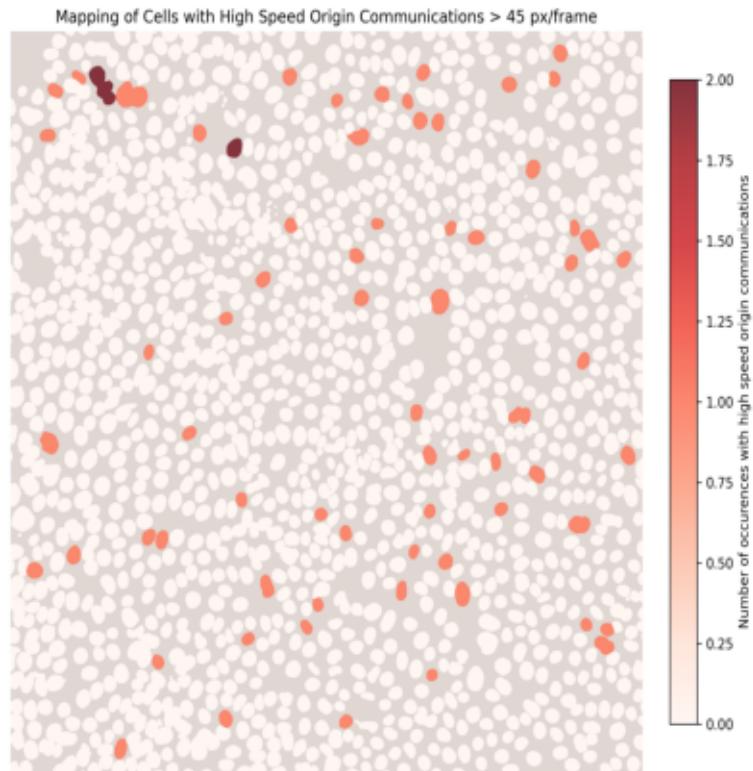
Distribution of High Speed Cell-Cell Communication Event Recruitment Phases



## 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	\
37	2018625832320	10	1374	0
44	2018625846192	11	1808	1
50	2018625845520	12	1402	0
62	2018624808096	12	1431	1
96	2018625845856	17	323	1
...	...	...	...	...
1193	2018625813280	362	1595	1
1204	2018624810928	365	1504	1
1210	2018624806656	371	1635	0
1238	2018625801280	383	1698	0
1269	2018625811216	396	1800	1

	Cause cell ID	Cause cell peak ID	Start time (s)	End time (s)	\
37	1326	0	33.0	34.0	
44	1770	2	109.0	109.0	
50	1439	1	109.0	109.0	
62	1398	1	93.0	94.0	
96	360	1	77.0	77.0	
...	...	...	...	...	
1193	1636	1	79.0	80.0	
1204	1570	1	104.0	105.0	
1210	1623	0	17.0	18.0	
1238	1755	0	69.0	70.0	
1269	1798	1	135.0	136.0	
	Duration (s)	Distance (um)	Speed (um/s)	\	
37	1.0	18.87	18.87		
44	0.0	19.40	19.40		
50	0.0	15.42	15.42		
62	1.0	17.01	17.01		
96	0.0	16.19	16.19		
...	...	...	...	...	
1193	1.0	21.69	21.69		
1204	1.0	22.68	22.68		
1210	1.0	19.51	19.51		
1238	1.0	22.81	22.81		
1269	1.0	16.95	16.95		
	Event time phase (fraction of event duration)	\			
37		0.46			
44		0.77			
50		0.44			
62		0.03			
96		0.00			
...		...			
1193		0.60			
1204		NaN			
1210		0.40			
1238		0.48			
1269		0.62			
	Event recruitment phase (fraction of involved cells)		dataset	\	
37		0.40	20250624_IS10		
44		0.20	20250624_IS10		
50		0.31	20250624_IS10		
62		0.00	20250624_IS10		
96		0.00	20250624_IS10		
...		...	...		
1193		0.40	20250624_IS10		
1204		NaN	20250624_IS10		

1210		0.50	20250624_IS10
1238		0.67	20250624_IS10
1269		0.67	20250624_IS10

	Number of cells involved	category	Speed category
37		5-10	High speed
44		5-10	High speed
50		11+	High speed
62		11+	High speed
96		5-10	High speed
...		...	...
1193		5-10	High speed
1204		2	High speed
1210		4	High speed
1238		5-10	High speed
1269		5-10	High speed

[65 rows x 16 columns]

Origin cell ID	Speed category	High speed	Low speed
220		0	1
221		0	1
224		0	1
230		0	1
233		0	1
...	...	...	...
1891		0	3
1892		0	1
1894		0	2
1899		0	2
1902		0	2

[693 rows x 2 columns]

Cell ID	Centroid X coordinate (um)	Centroid Y coordinate (um)	\
7 220	443.62		10.72
8 221	375.38		11.05
11 224	68.25		11.38
16 230	51.35		13.65
19 233	421.20		13.97
...	...	...	...
1237 1891	457.60		488.15
1238 1892	57.20		487.50
1240 1894	207.68		489.78
1244 1899	292.18		492.05
1247 1902	478.07		493.03

Number of peaks Is active Occurrences in global events \

7	9	True	7
8	8	True	7
11	10	True	7
16	9	True	7
19	9	True	7
...	...	...	...
1237	8	True	7
1238	9	True	7
1240	10	True	7
1244	12	True	7
1247	12	True	7

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

7	1	[2]
8	0	[]
11	1	[1]
16	0	[]
19	0	[]
...	...	...
1237	2	[4, 6]
1238	0	[]
1240	0	[]
1244	3	[1, 2, 4]
1247	3	[1, 6, 7]

Occurrences in sequential events \

7	1
8	1
11	2
16	2
19	1
...	...
1237	1
1238	1
1240	2
1244	3
1247	2

Occurrences in sequential events as origin \

7	1
8	1
11	0
16	0
19	0
...	...
1237	0
1238	1
1240	1

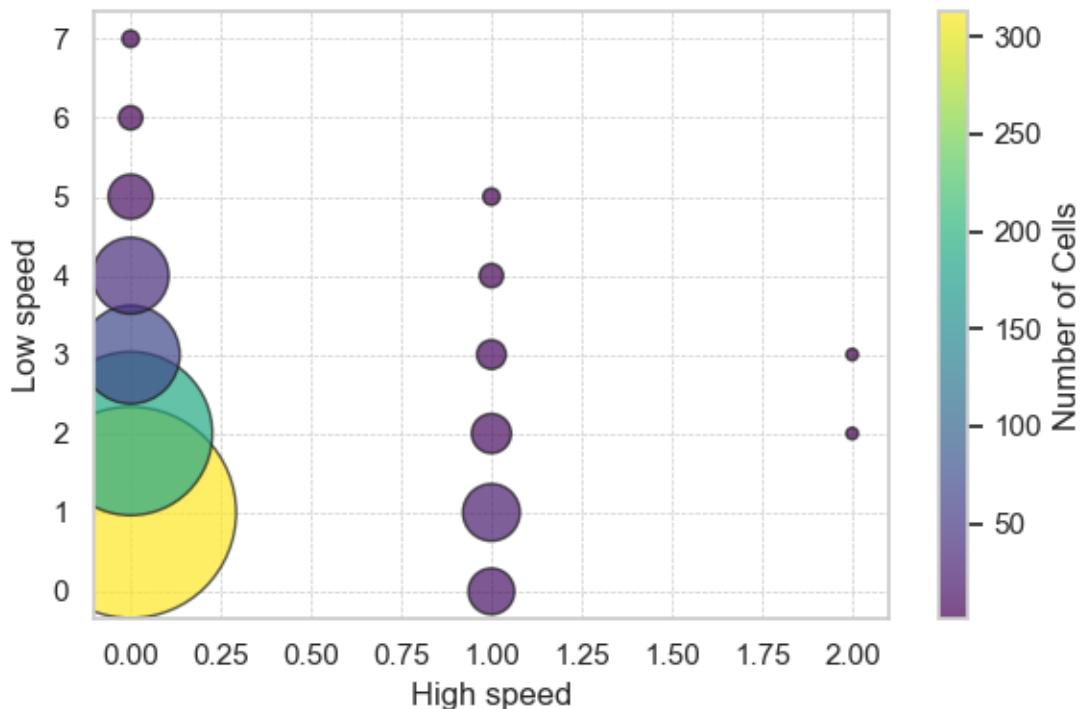
1244		2	
1247		1	
Occurrences in individual events Peak frequency (Hz) \			
7	0	0.0053	
8	0	0.0047	
11	0	0.0059	
16	0	0.0053	
19	1	0.0053	
...	...	...	
1237	0	0.0047	
1238	1	0.0053	
1240	0	0.0059	
1244	1	0.0071	
1247	2	0.0071	
Periodicity score Neighbor count Neighbors (labels) dataset \			
7	0.72	4	[227, 235, 280, 298] 20250624_IS10
8	0.79	3	[225, 249, 252] 20250624_IS10
11	0.69	4	[230, 245, 273, 281] 20250624_IS10
16	0.74	4	[209, 224, 263, 281] 20250624_IS10
19	0.74	4	[235, 239, 284, 287] 20250624_IS10
...	...	...	...
1237	0.87	4	[1850, 1859, 1902, 1909] 20250624_IS10
1238	0.75	4	[1846, 1851, 1874, 1898] 20250624_IS10
1240	0.67	4	[1853, 1863, 1867, 1889] 20250624_IS10
1244	0.61	2	[1858, 1882] 20250624_IS10
1247	0.60	3	[1850, 1873, 1891] 20250624_IS10
Involved in sequential event Occurrences in sequential events category \			
7	Involved in sequential event		1-2
8	Involved in sequential event		1-2
11	Involved in sequential event		1-2
16	Involved in sequential event		1-2
19	Involved in sequential event		1-2
...	...	...	...
1237	Involved in sequential event		1-2
1238	Involved in sequential event		1-2
1240	Involved in sequential event		1-2
1244	Involved in sequential event		3-4
1247	Involved in sequential event		1-2
High speed Low speed			
7	0.0	1.0	
8	0.0	1.0	
11	0.0	1.0	
16	0.0	1.0	
19	0.0	1.0	

```

...
1237      0.0      3.0
1238      0.0      1.0
1240      0.0      2.0
1244      0.0      2.0
1247      0.0      2.0

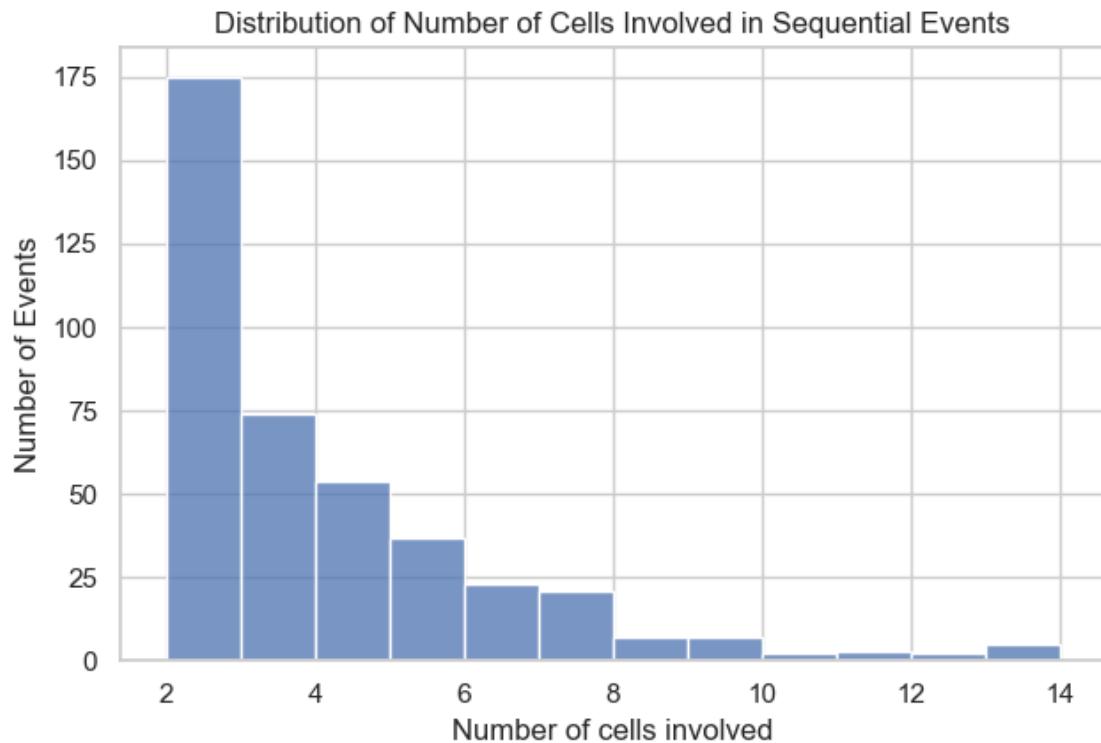
```

[693 rows x 20 columns]



### 1.3.5 Number of cells involved per sequential events

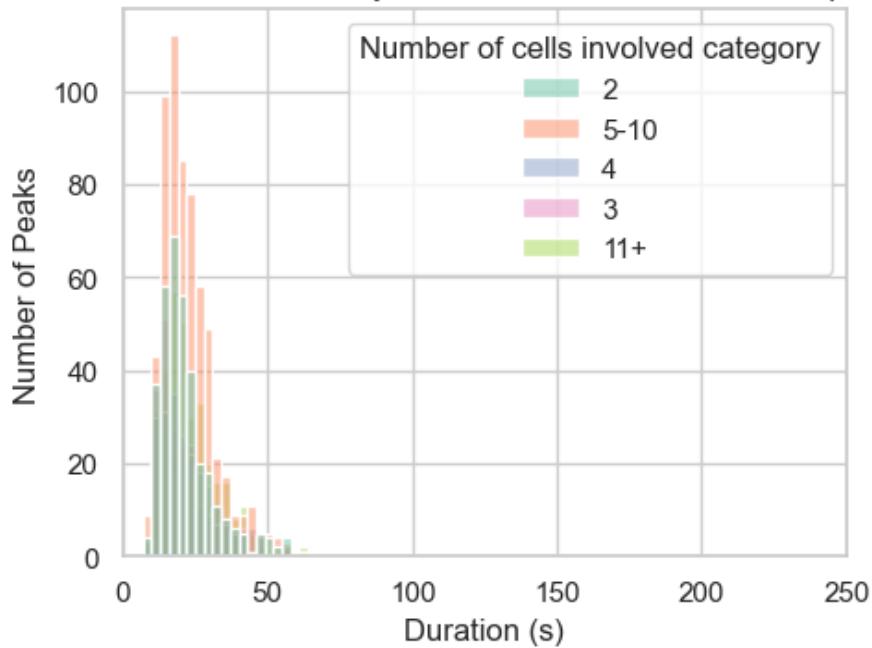
[2025-08-27 15:12:32] [INFO] calcium: plot\_histogram: removed 11 outliers out of 421 on 'Number of cells involved' (lower=-7, upper=14)



### 1.3.6 Influence of cell count per event on statistics

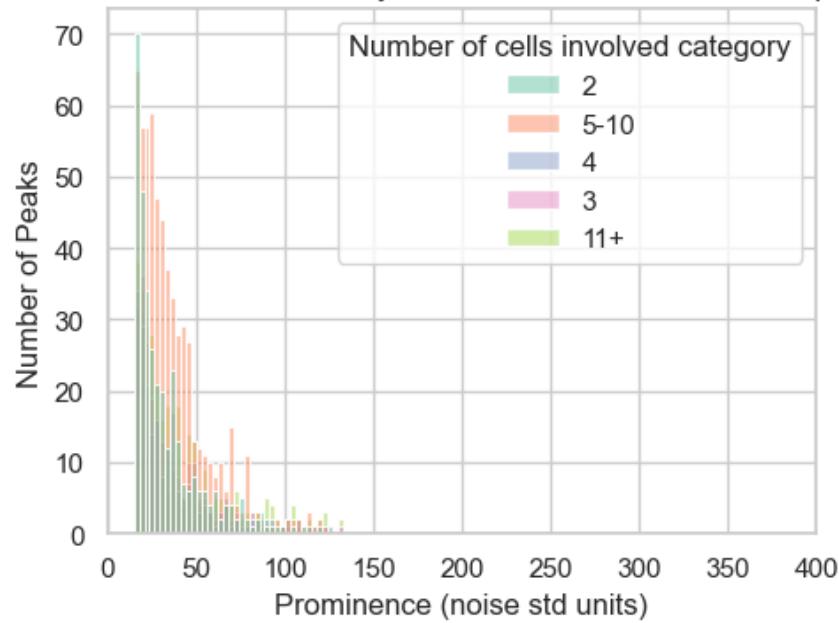
```
[2025-08-27 15:12:33] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 1745 on 'Duration (s)' (lower=-1.5, upper=64.5)
```

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

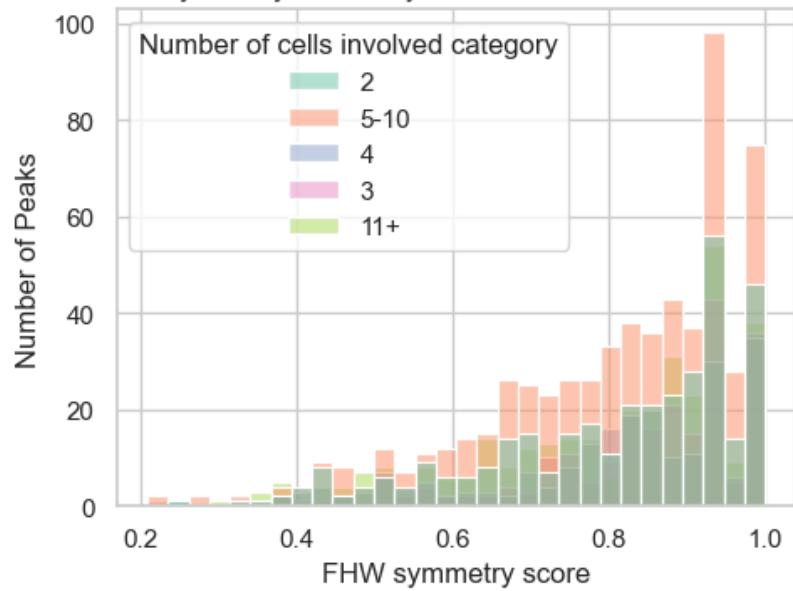


```
[2025-08-27 15:12:35] [INFO] calcium: plot_histogram_by_group: removed 28 outliers out of 1745 on 'Prominence (noise std units)' (lower=-17.1, upper=134.1)
```

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

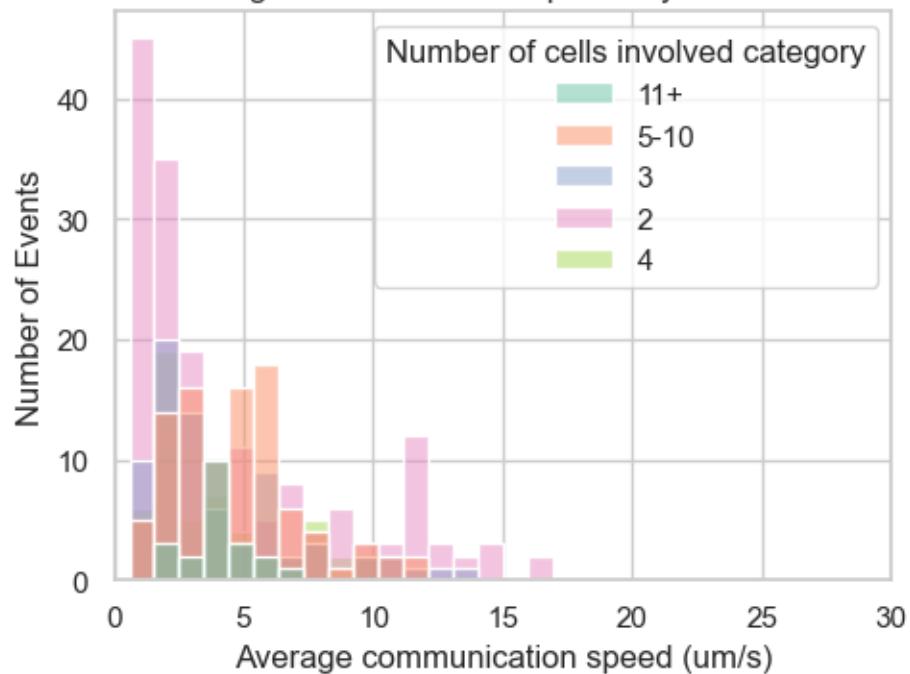


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



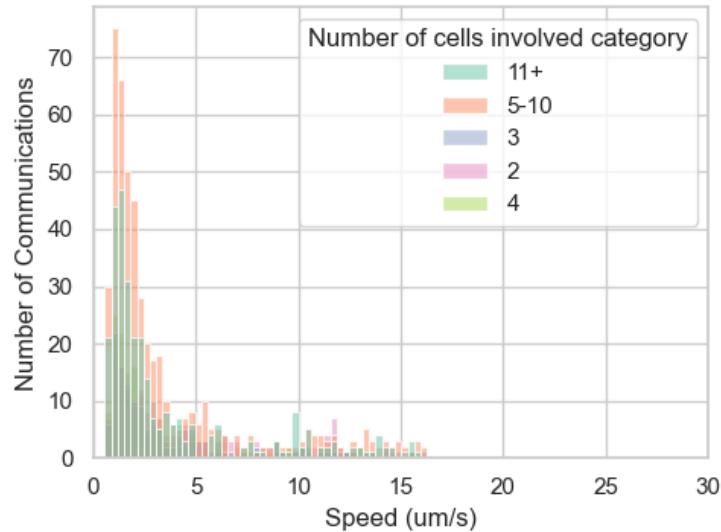
```
[2025-08-27 15:12:39] [INFO] calcium: plot_histogram_by_group: removed 4 outliers out of 421 on 'Average communication speed (um/s)' (lower=-10.03, upper=17.97)
```

Distribution of Average Communication Speeds by Number of Cells Involved



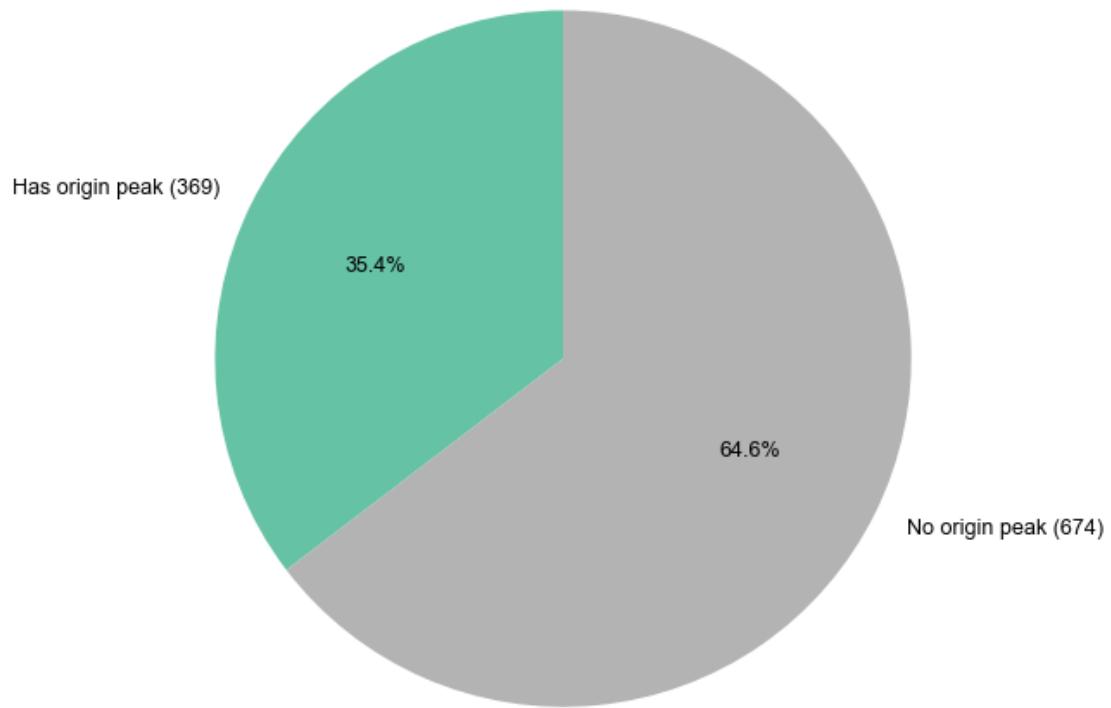
[2025-08-27 15:12:40] [INFO] calcium: plot\_histogram\_by\_group: removed 48 outliers out of 1324 on 'Speed (um/s)' (lower=-9.9075, upper=16.29)

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

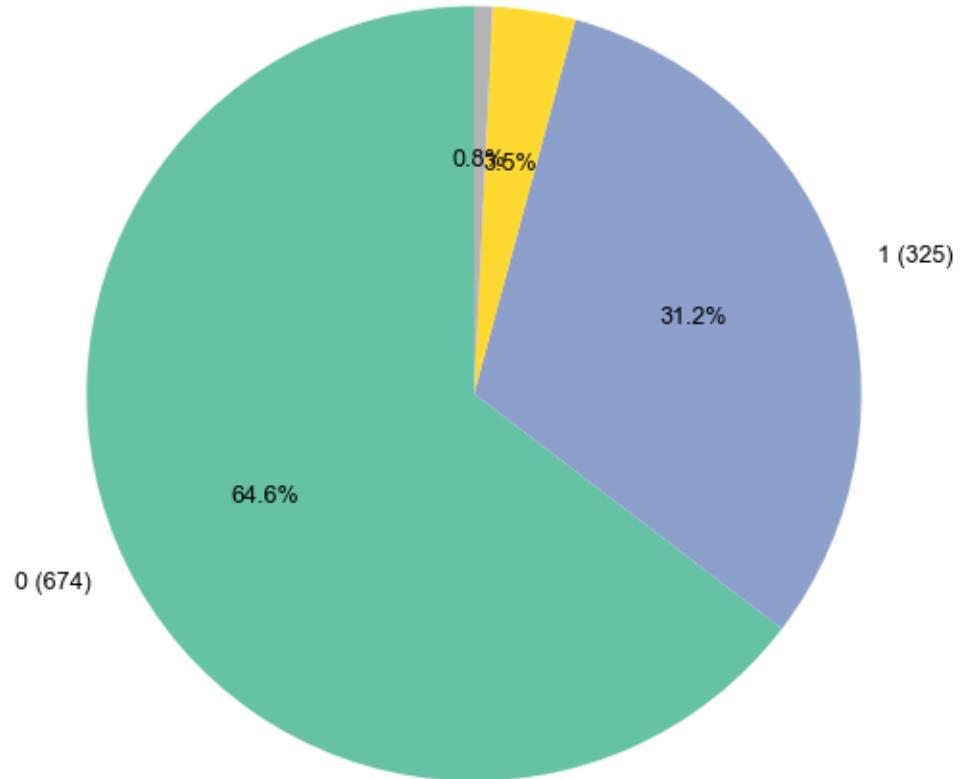


### 1.3.7 Cells Occurrences as origin in sequential events

Distribution of Number of Sequential Event Origin Peaks per Cell

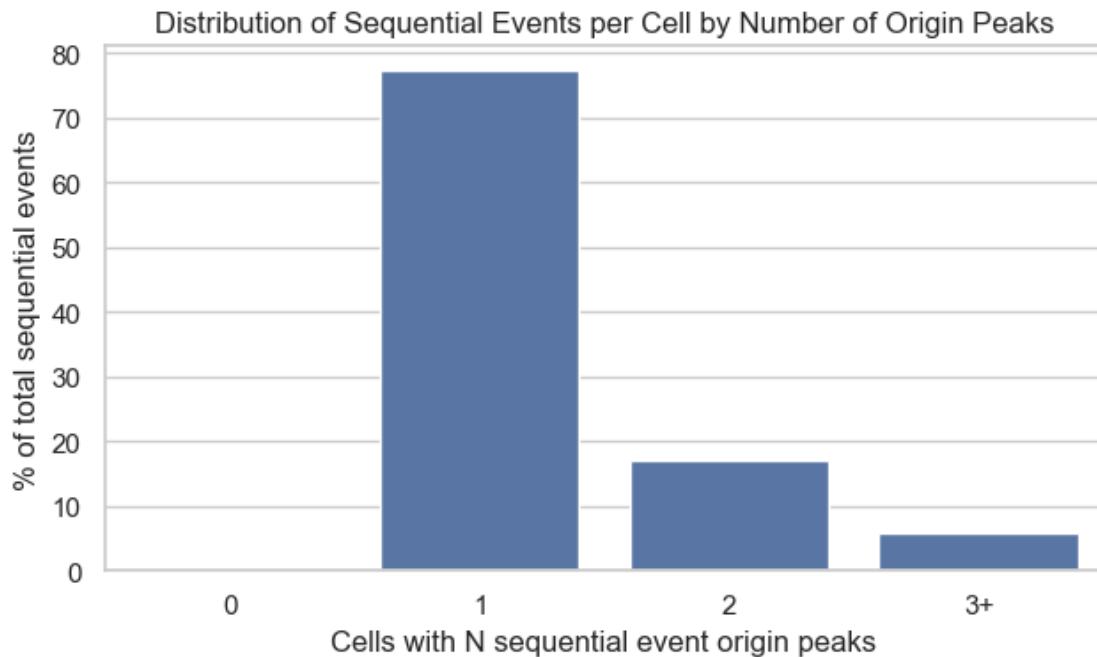


Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)



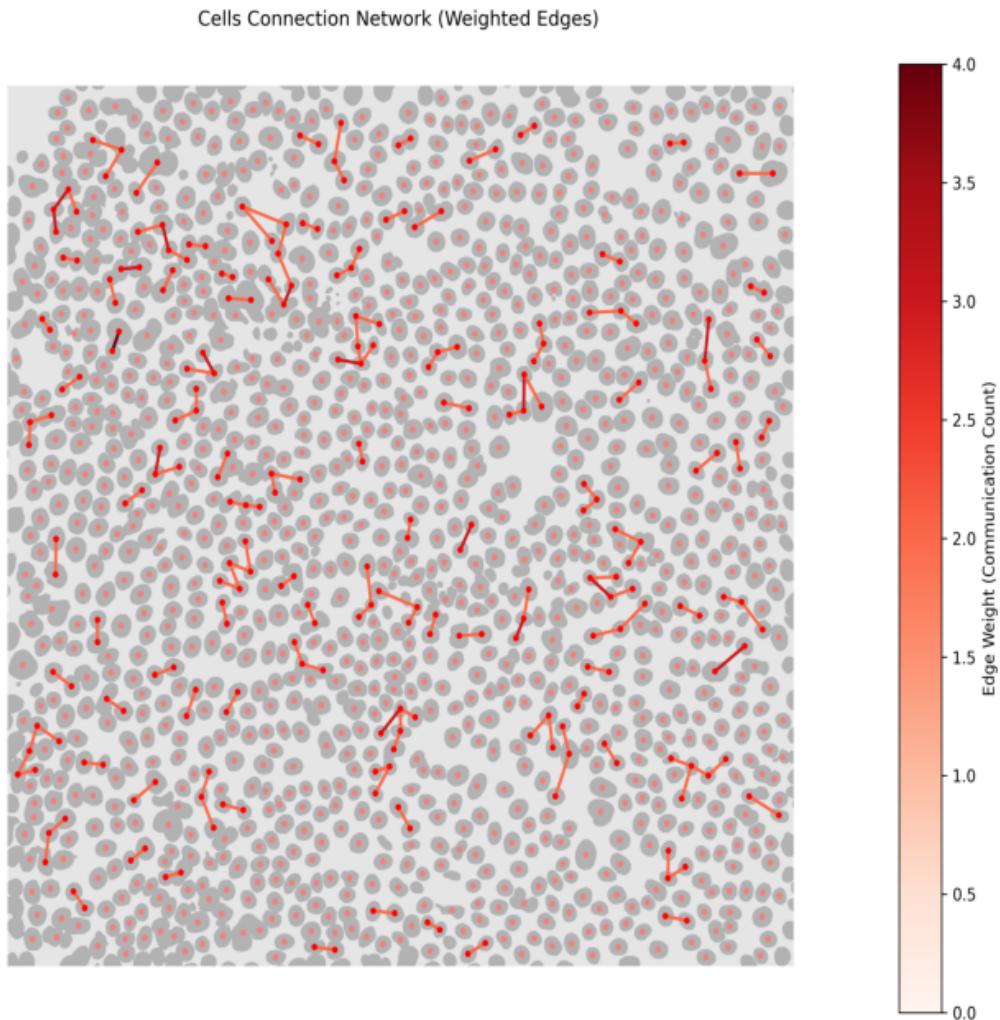
```
[2025-08-27 15:12:44] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\cell-
mapping\cell_Occurrences_in_origin_seq_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS10\\cell-
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
Traceback (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\\IS10\\cell-  
mapping\\cell_Occurrences_in_origin_seq_events_overlay.png'
```



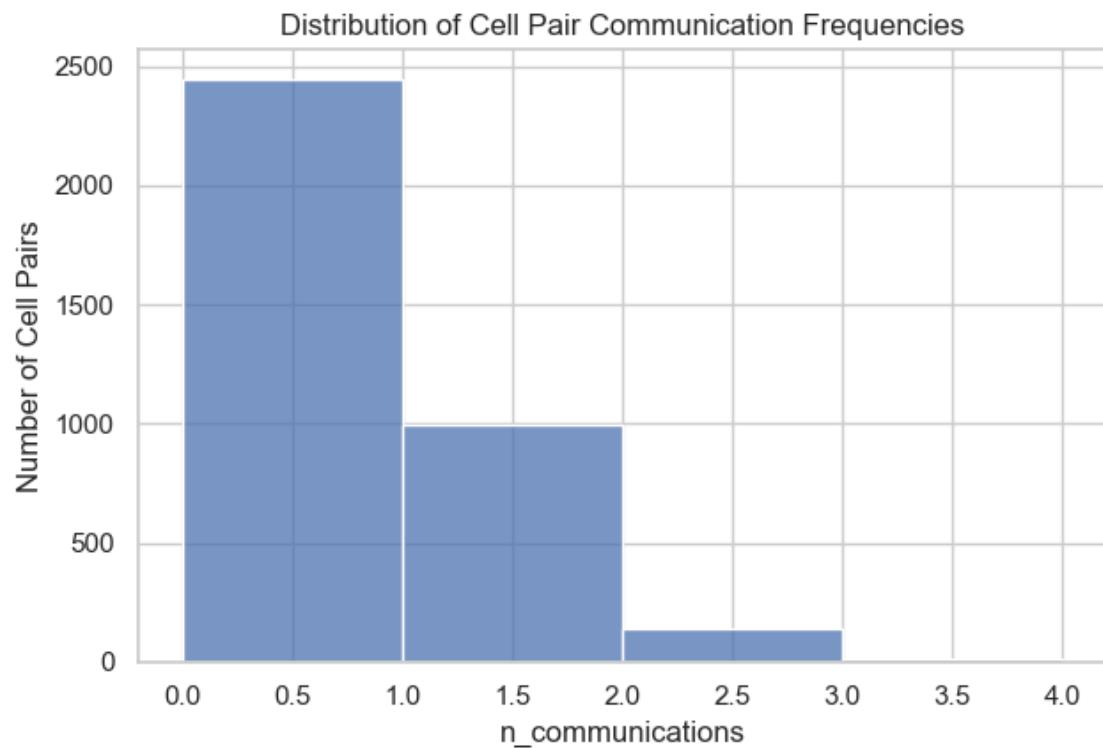
### 1.3.8 Connection network between cells

Cell Connection Network Graph



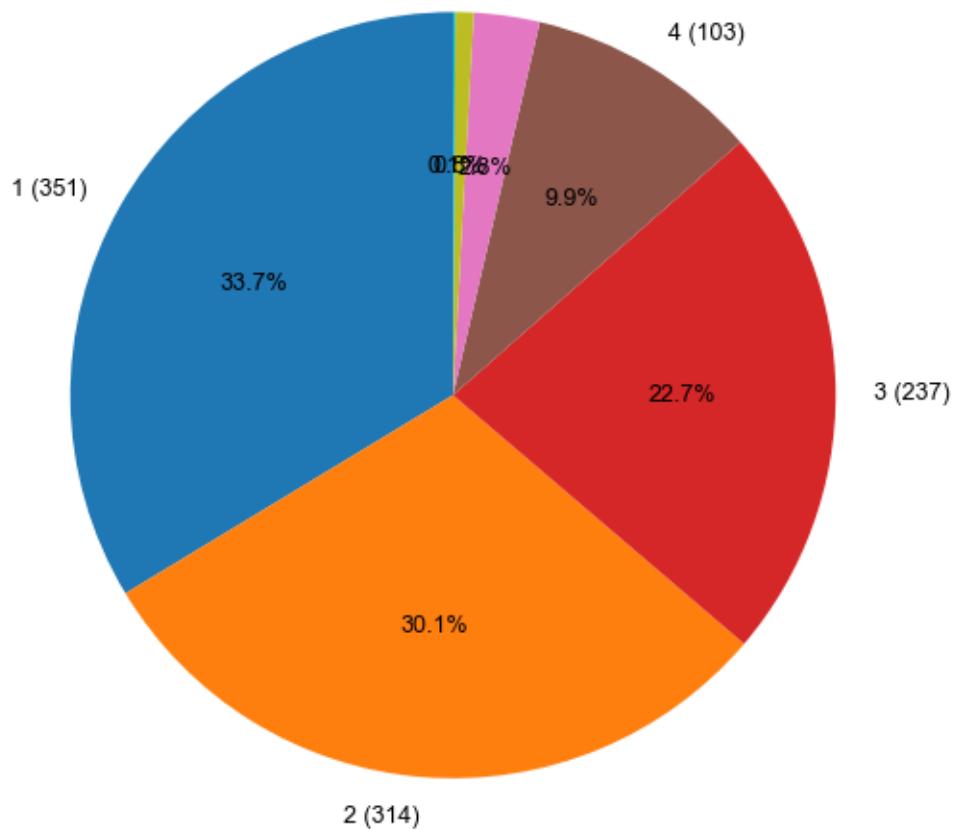
### 1.3.9 Pair/Trios with high communication networks

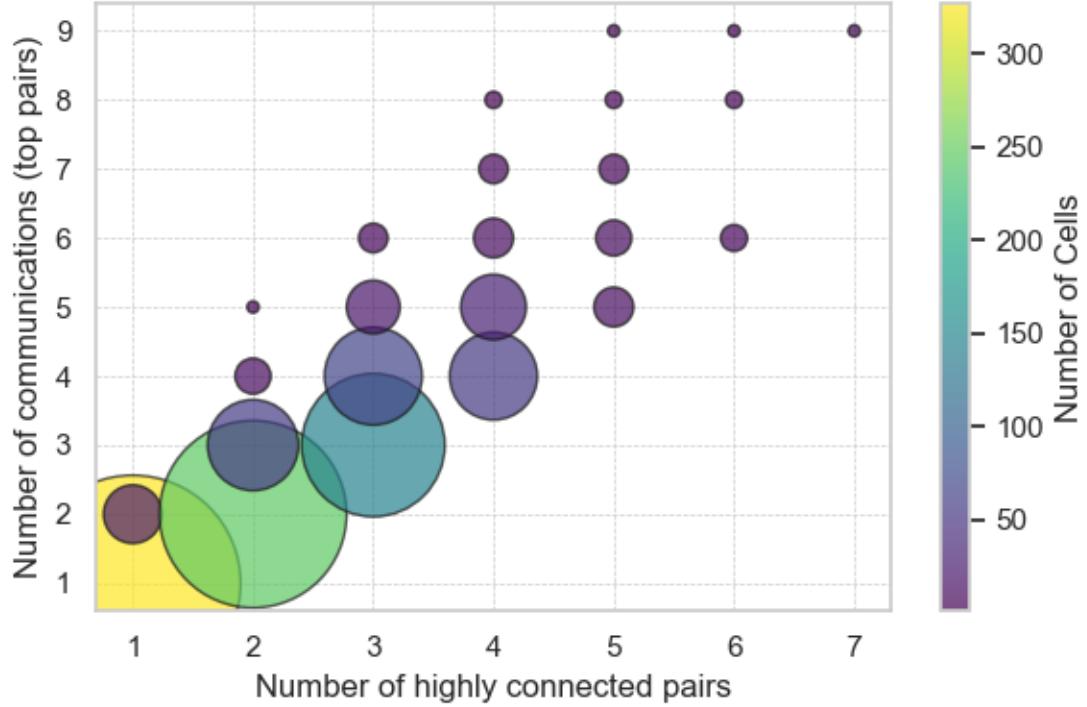
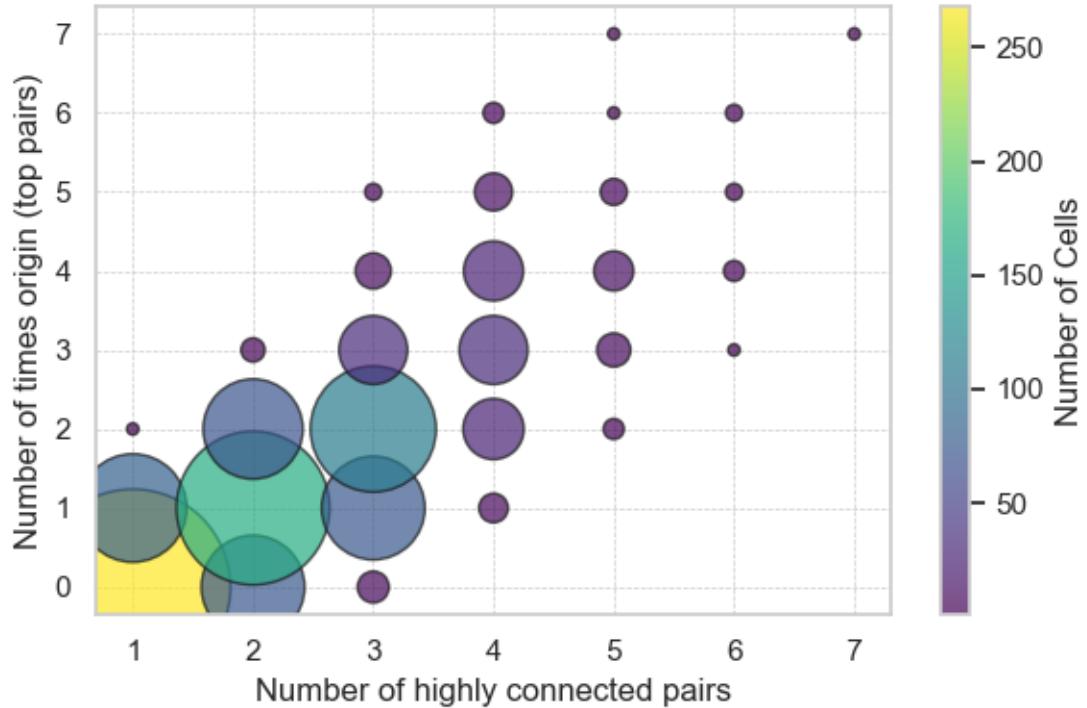
```
[2025-08-27 15:12:49] [INFO] calcium: build_neighbor_pair_stats: built 3597 pairs across 1 datasets (mean distance=15.39 um)
```

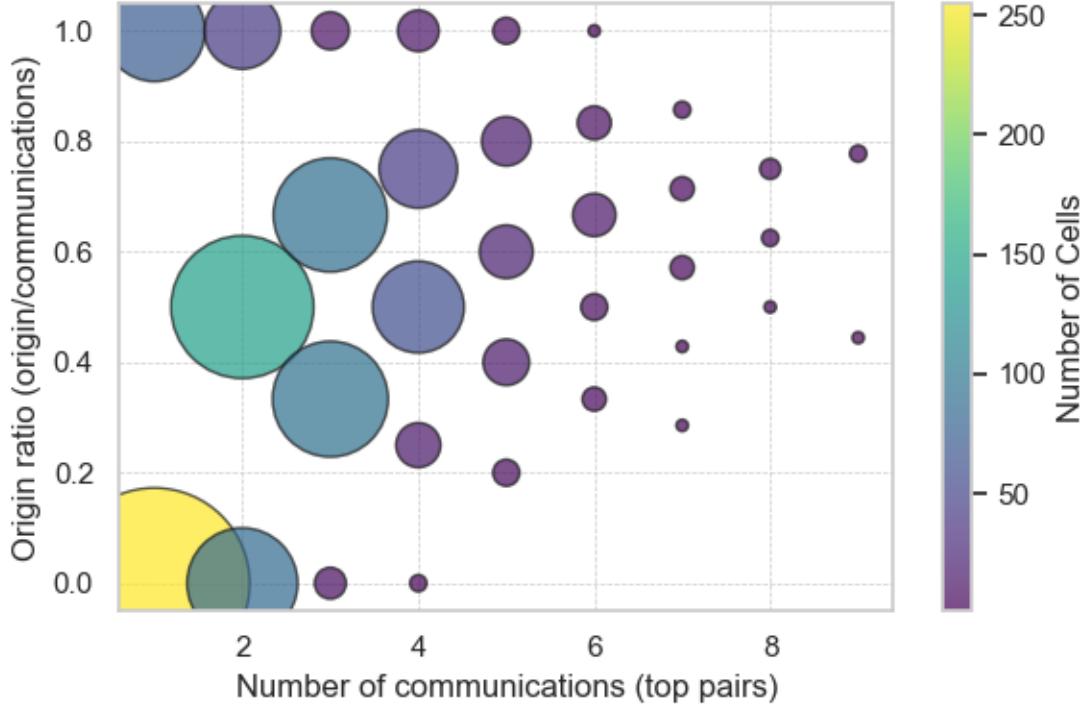
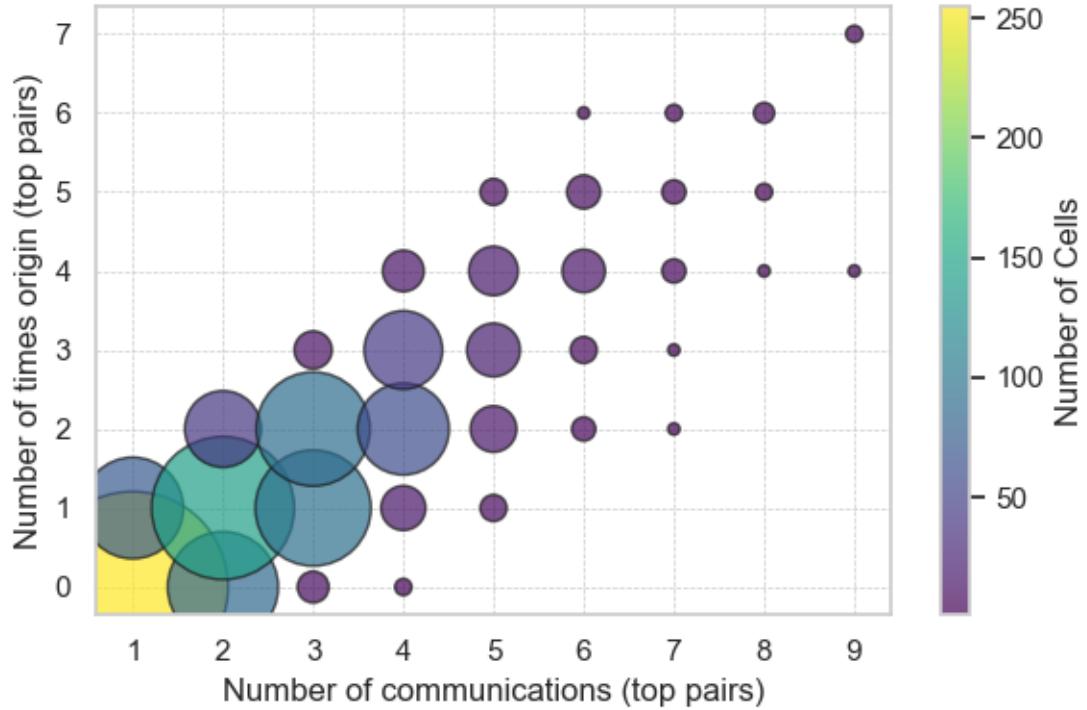


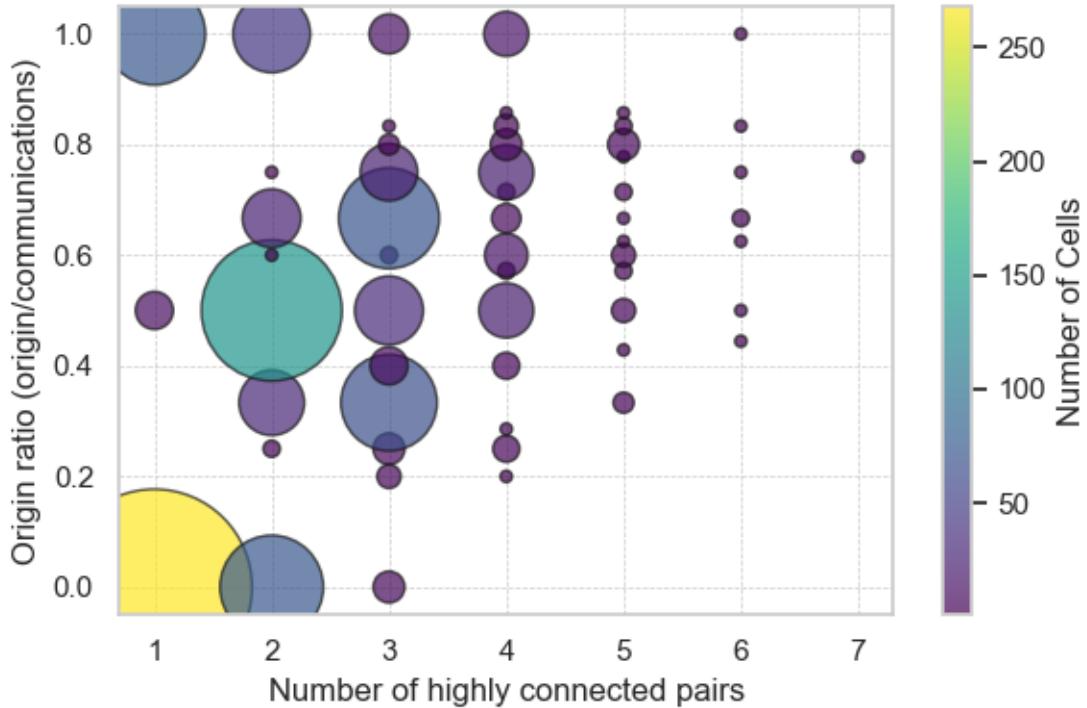
95th percentile threshold: 1.0

Cells involved in multiple pairs highly connected









[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=351 for Number of highly connected pairs=1

[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=314 for Number of highly connected pairs=2

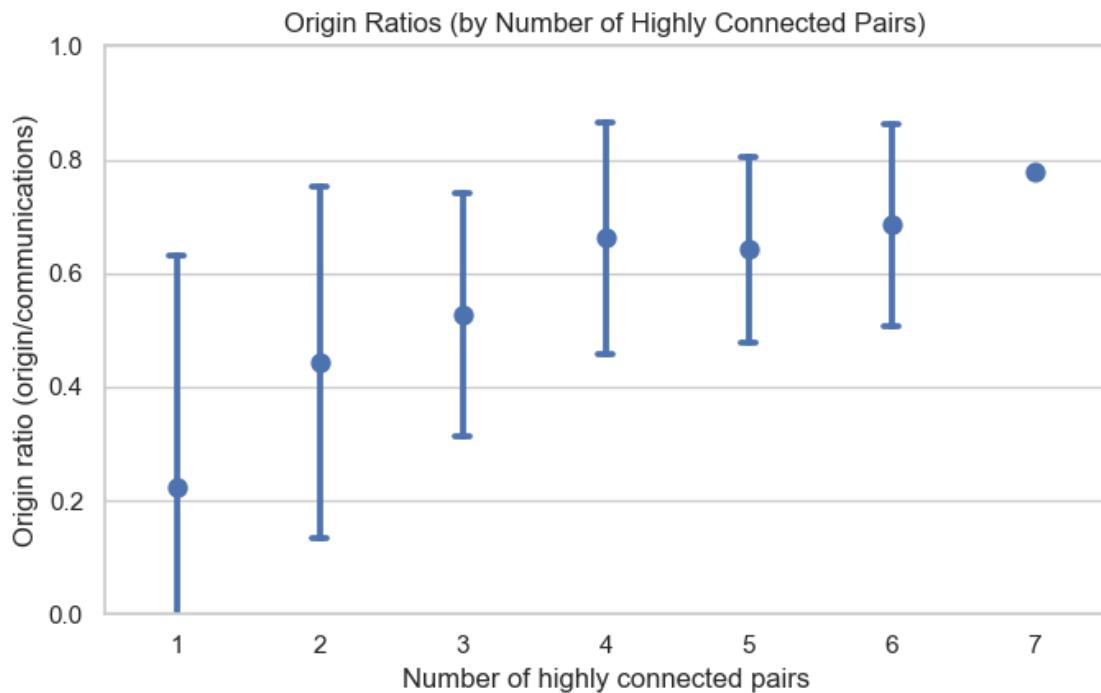
[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=237 for Number of highly connected pairs=3

[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=103 for Number of highly connected pairs=4

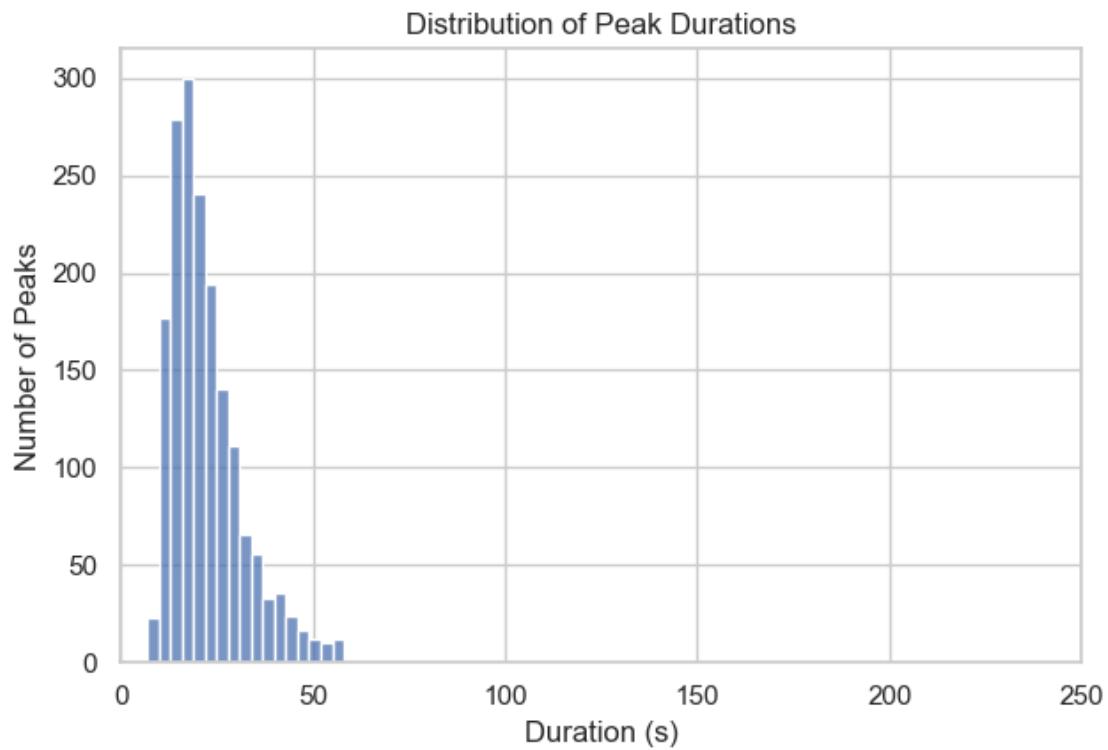
[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=29 for Number of highly connected pairs=5

[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=8 for Number of highly connected pairs=6

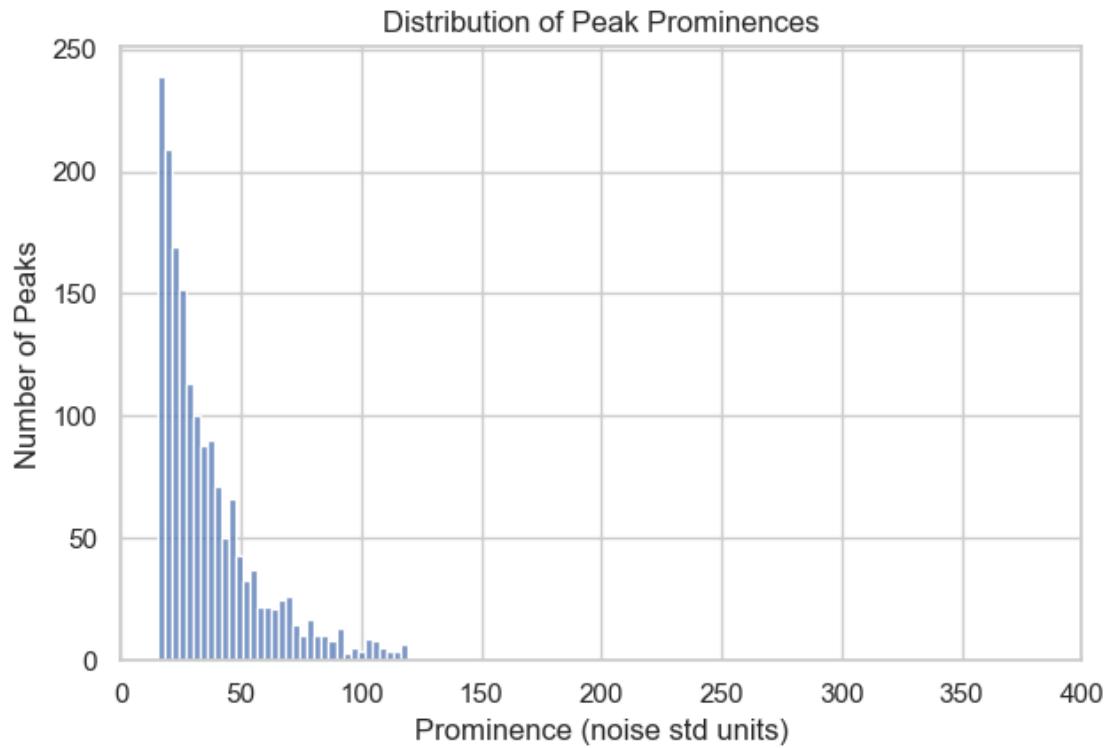
[2025-08-27 15:12:52] [INFO] calcium: plot\_points\_mean\_std: N=1 for Number of highly connected pairs=7

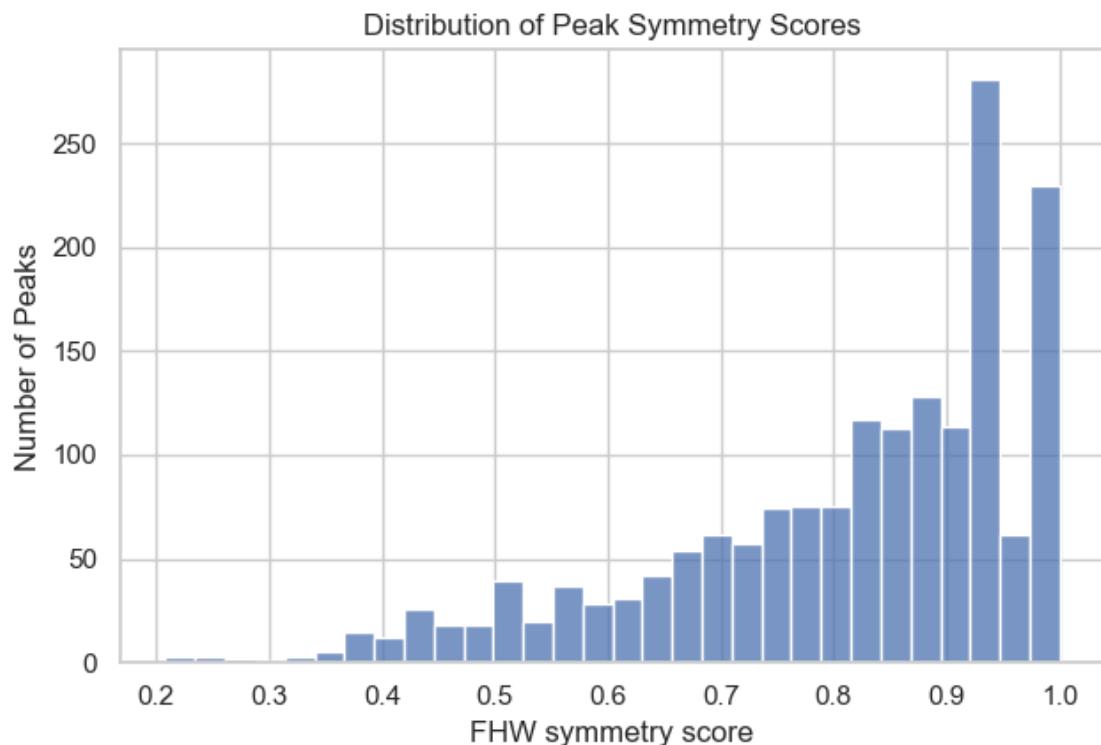


[2025-08-27 15:12:53] [INFO] calcium: plot\_histogram: removed 14 outliers out of 1745 on 'Duration (s)' (lower=-18, upper=59)

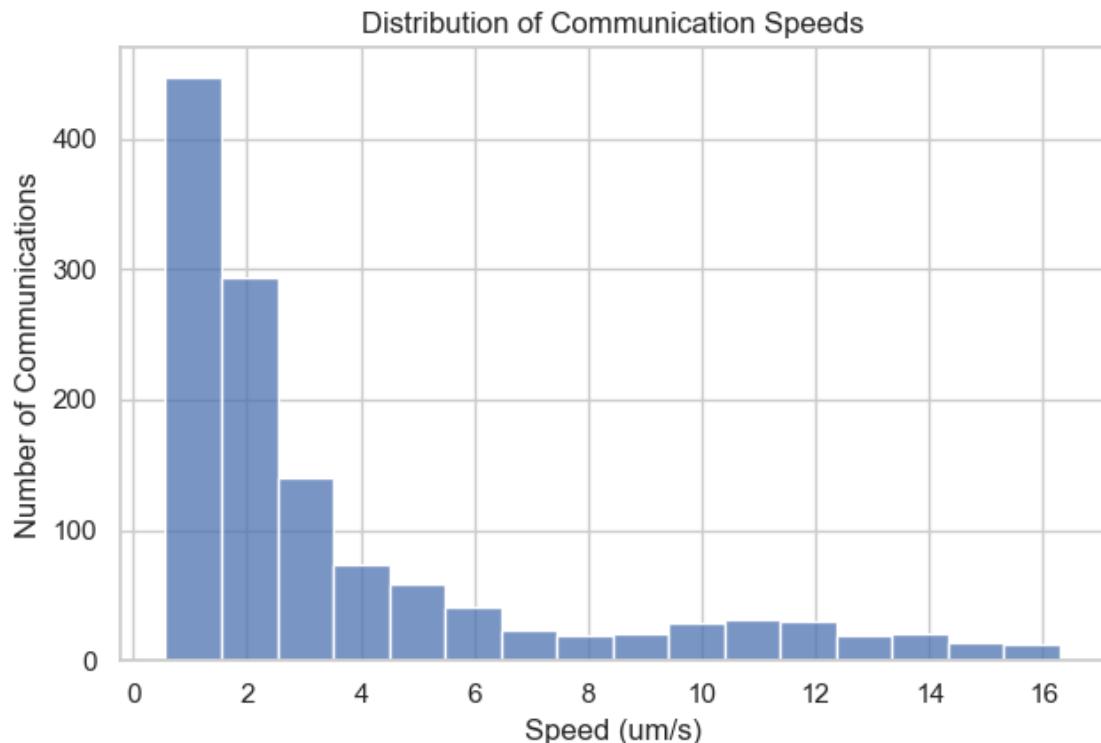


[2025-08-27 15:12:53] [INFO] calcium: plot\_histogram: removed 37 outliers out of 1745 on 'Prominence (noise std units)' (lower=-54.9, upper=121.5)

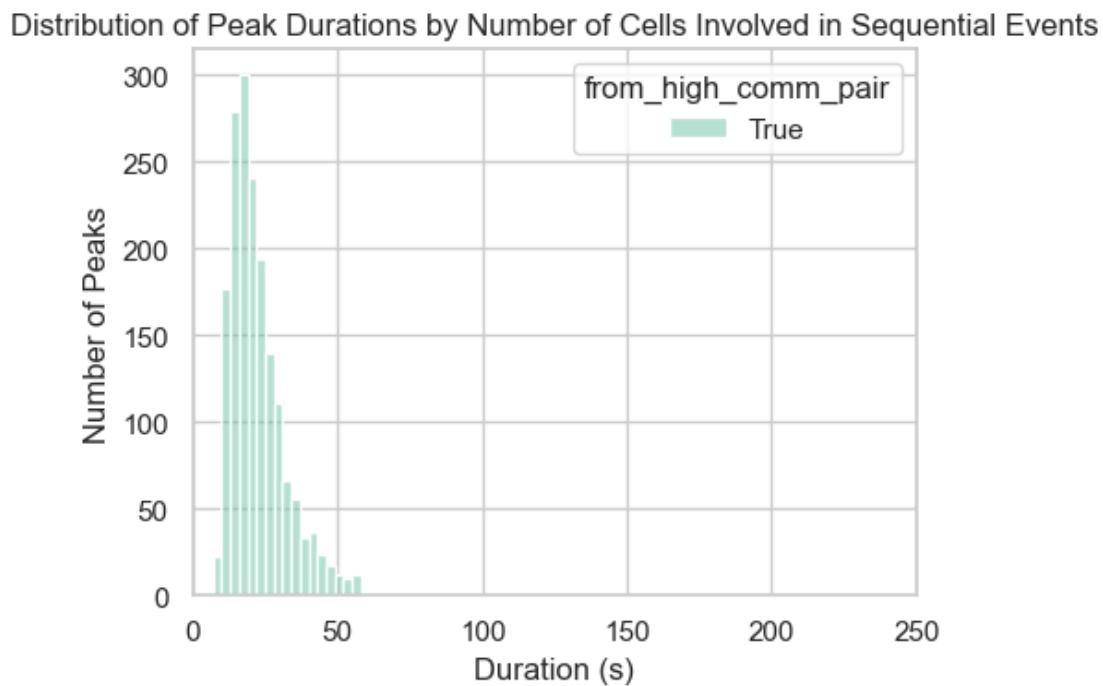




```
[2025-08-27 15:12:54] [INFO] calcium: plot_histogram: removed 48 outliers out of  
1324 on 'Speed (um/s)' (lower=-9.9075, upper=16.29)
```

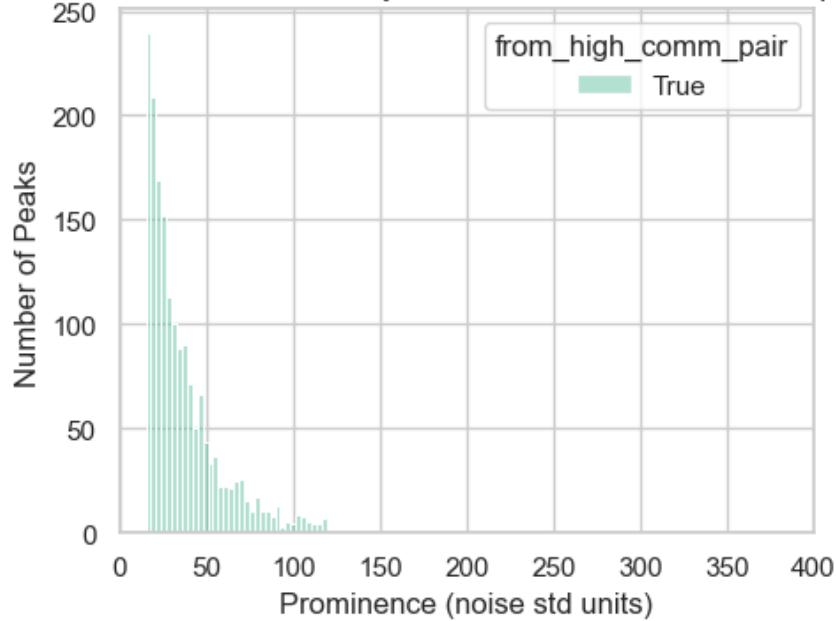


```
[2025-08-27 15:12:55] [INFO] calcium: plot_histogram_by_group: removed 14 outliers out of 1745 on 'Duration (s)' (lower=-18, upper=59)
```

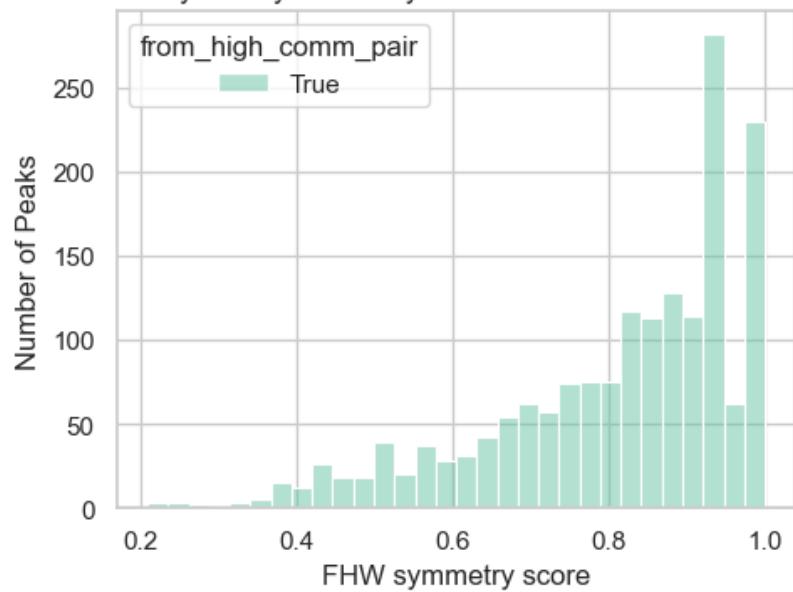


[2025-08-27 15:12:55] [INFO] calcium: plot\_histogram\_by\_group: removed 37 outliers out of 1745 on 'Prominence (noise std units)' (lower=-54.9, upper=121.5)

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

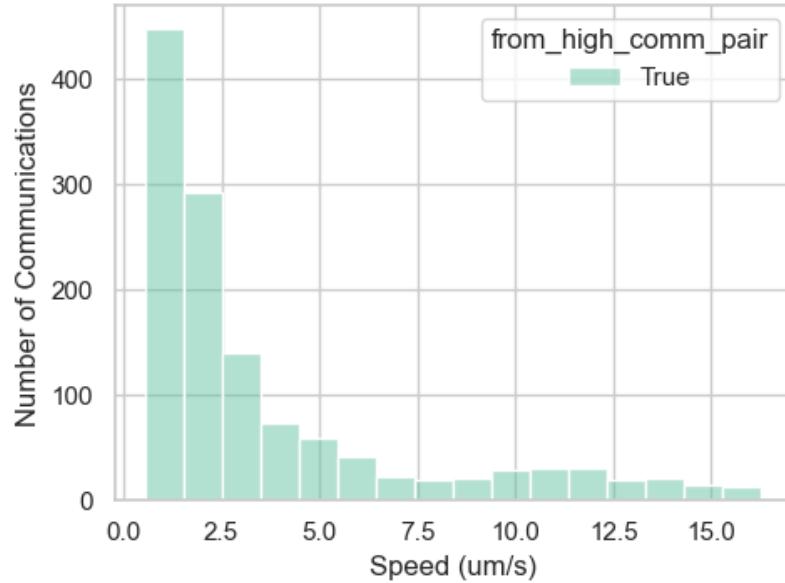


Distribution of Peak Symmetry Scores by Number of Cells Involved in Sequential Events



[2025-08-27 15:12:56] [INFO] calcium: plot\_histogram\_by\_group: removed 48 outliers out of 1324 on 'Speed (um/s)' (lower=-9.9075, upper=16.29)

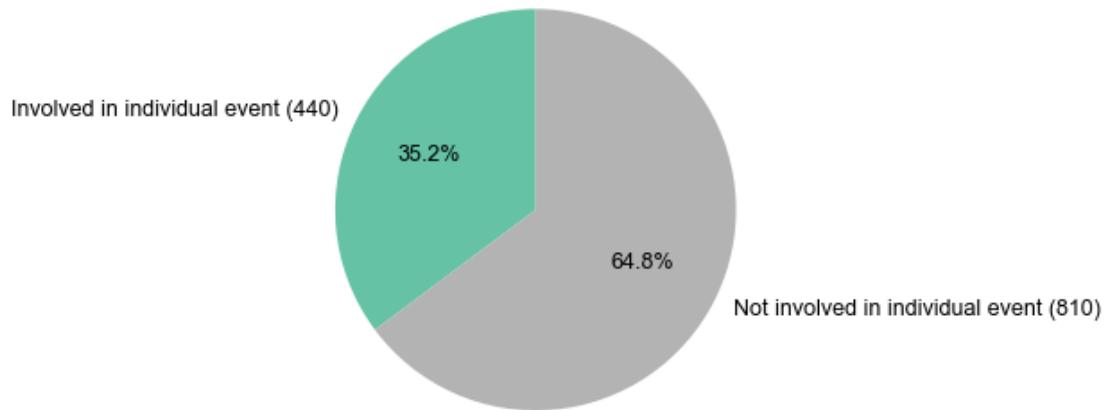
Distribution of Communication Speeds by Number of Cells Involved in Sequential Events



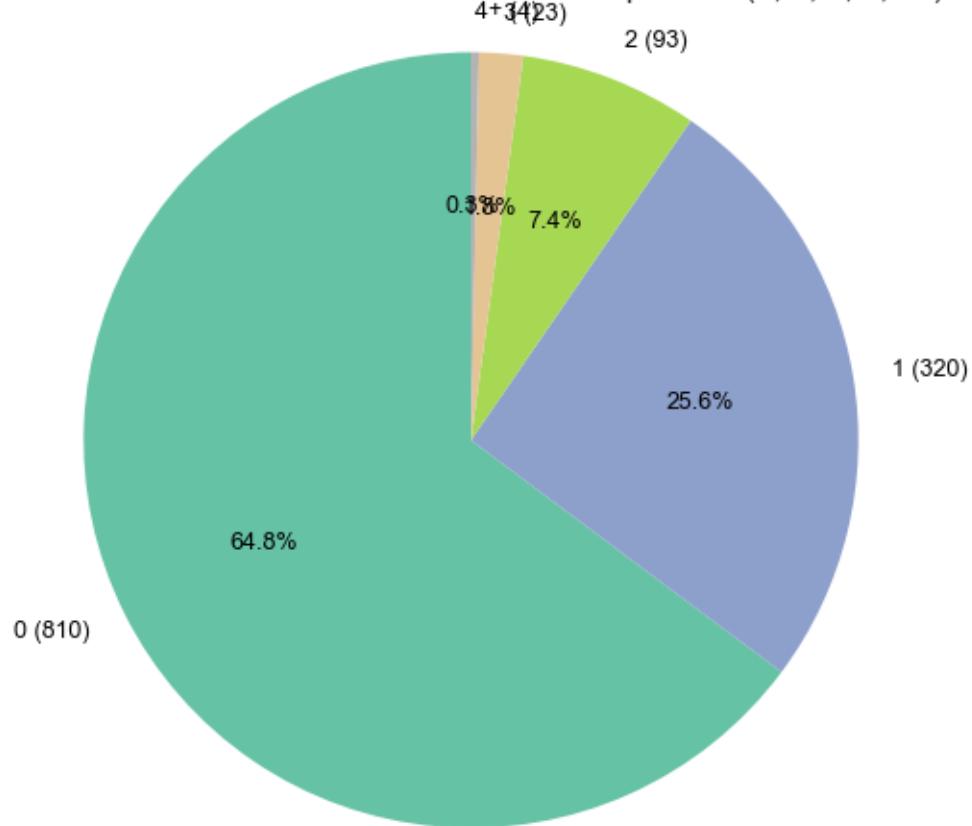
## 1.4 INDIVIDUAL EVENTS

### 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+)

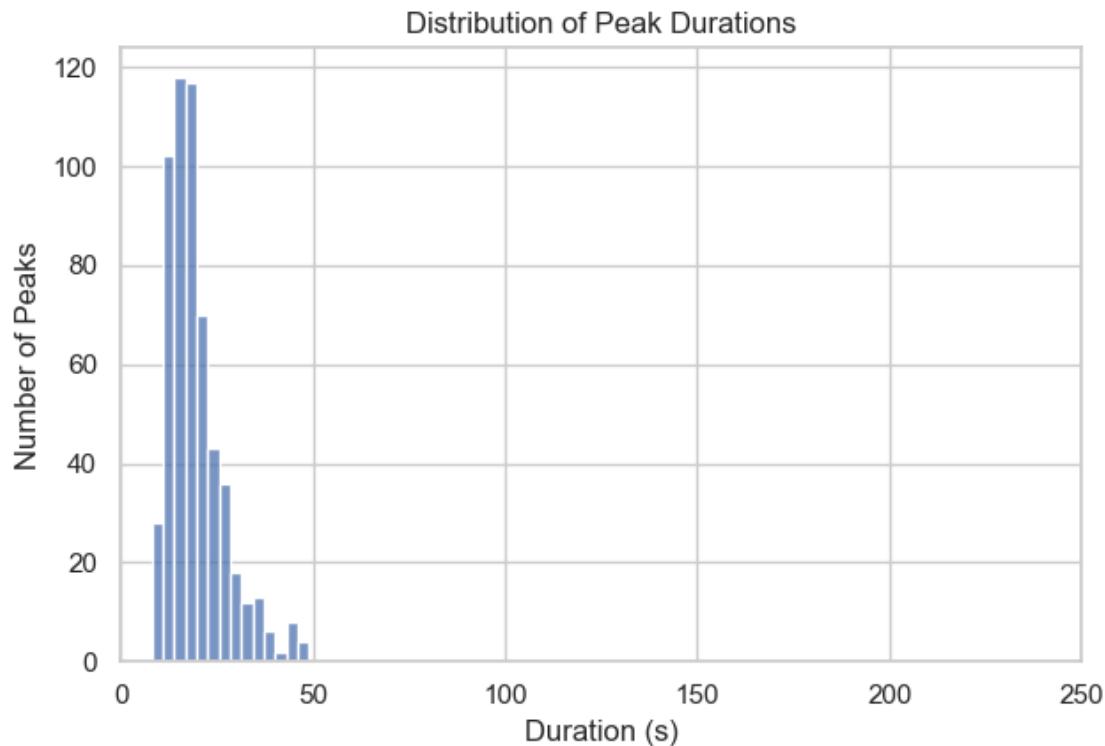


```
[2025-08-27 15:12:57] [ERROR] calcium: Failed to read image
'D:\Mateo\20250624\Output\IS10\cell-
mapping\cell_occurrences_in_individual_events_overlay.png': [Errno 2] No such
file or directory: 'D:\\Mateo\\20250624\\Output\\IS10\\cell-
mapping\\cell_occurrences_in_individual_events_overlay.png'
Traceback (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:
```

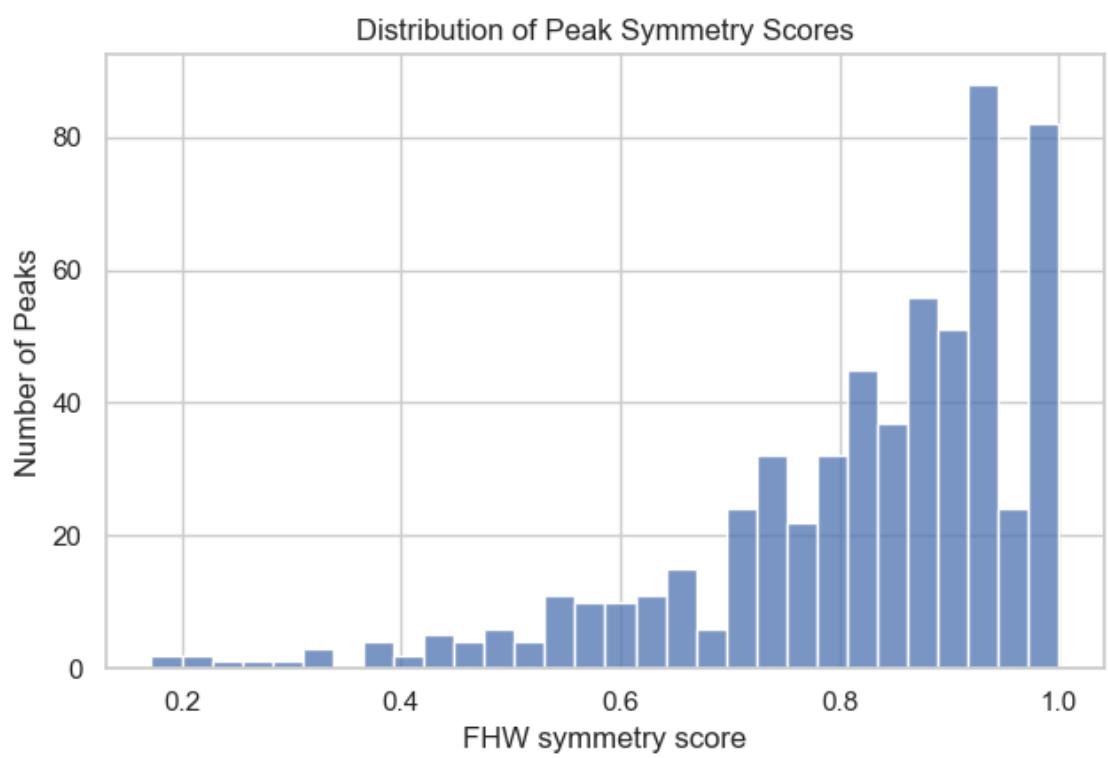
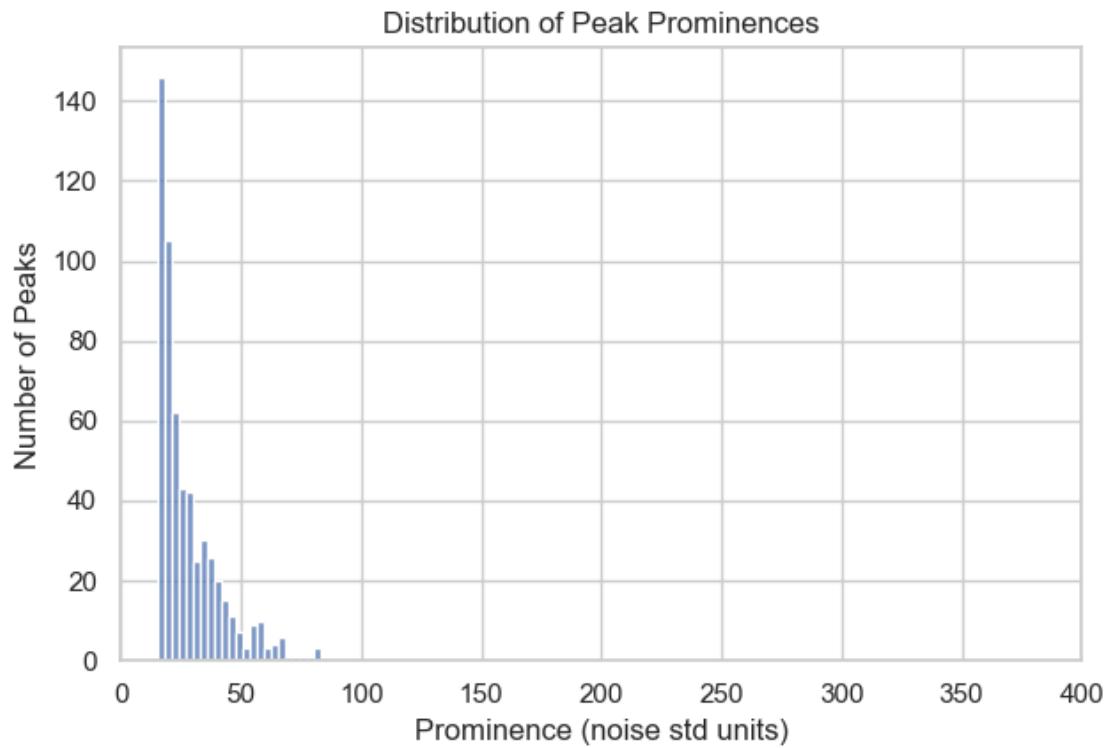
'D:\\Mateo\\20250624\\Output\\IS10\\cell-mapping\\cell\_occurrences\_in\_individual\_events\_overlay.png'

#### 1.4.2 Peaks statistics in individual events

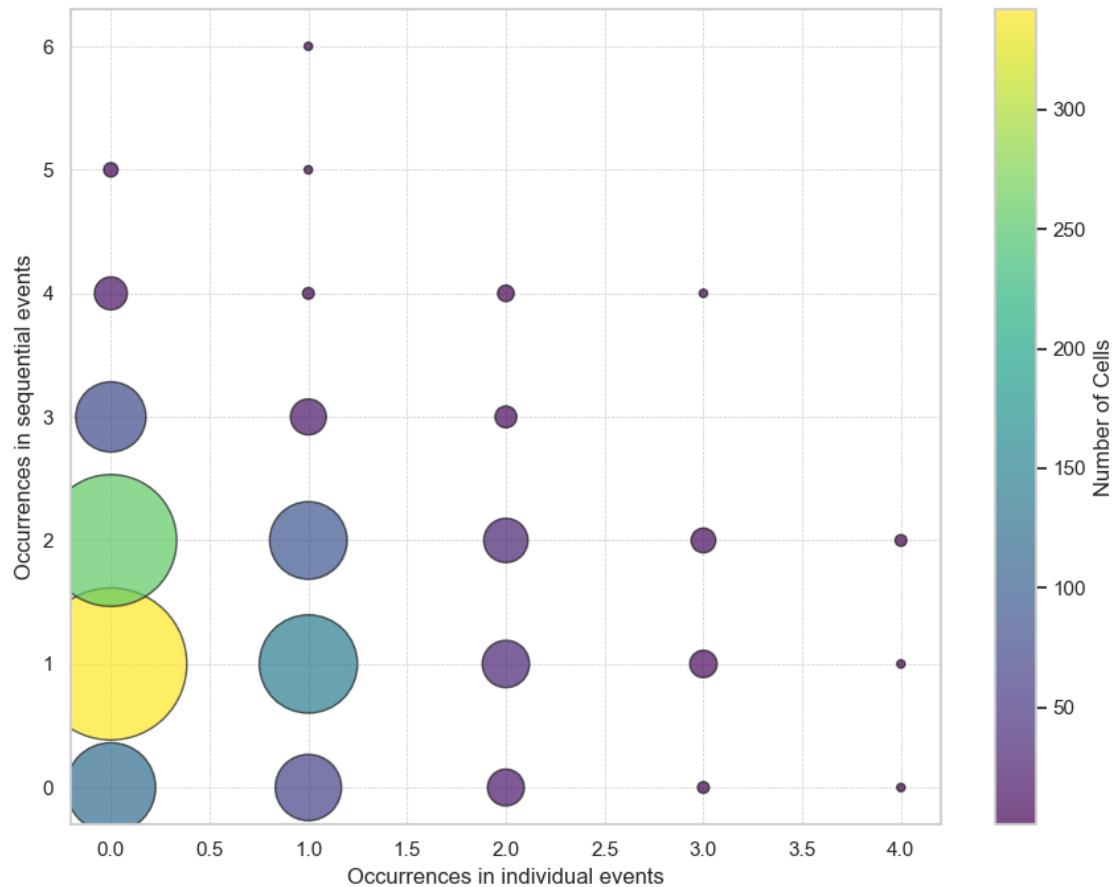
[2025-08-27 15:12:58] [INFO] calcium: plot\_histogram: removed 14 outliers out of 591 on 'Duration (s)' (lower=-13, upper=50)



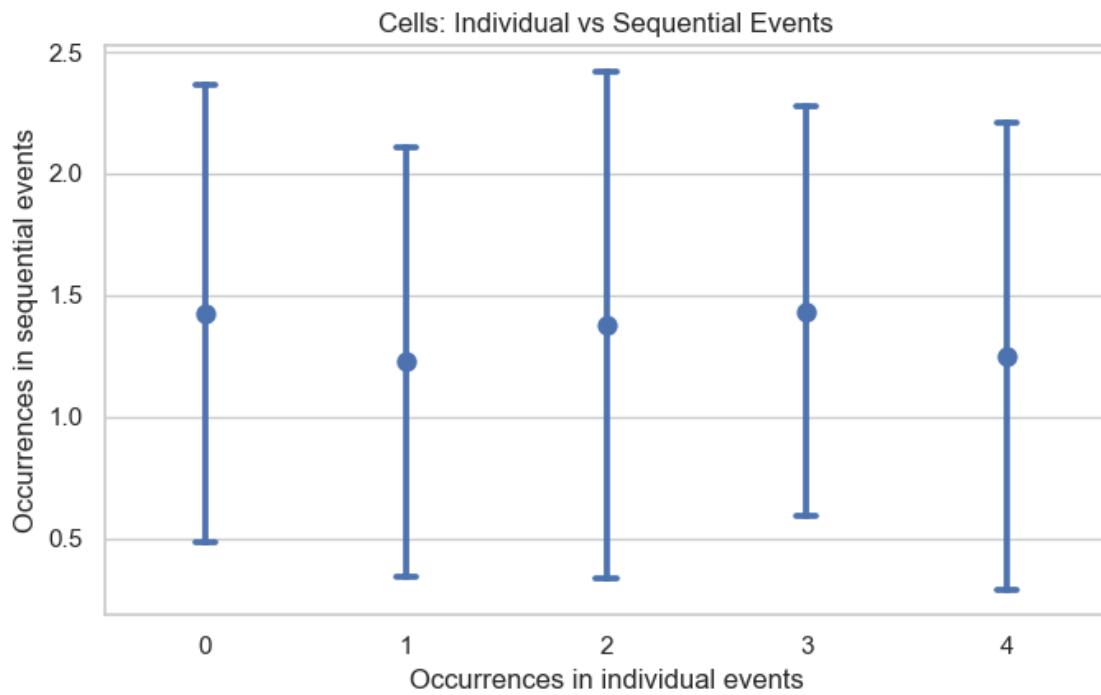
[2025-08-27 15:12:58] [INFO] calcium: plot\_histogram: removed 17 outliers out of 591 on 'Prominence (noise std units)' (lower=-32.7, upper=85.6)



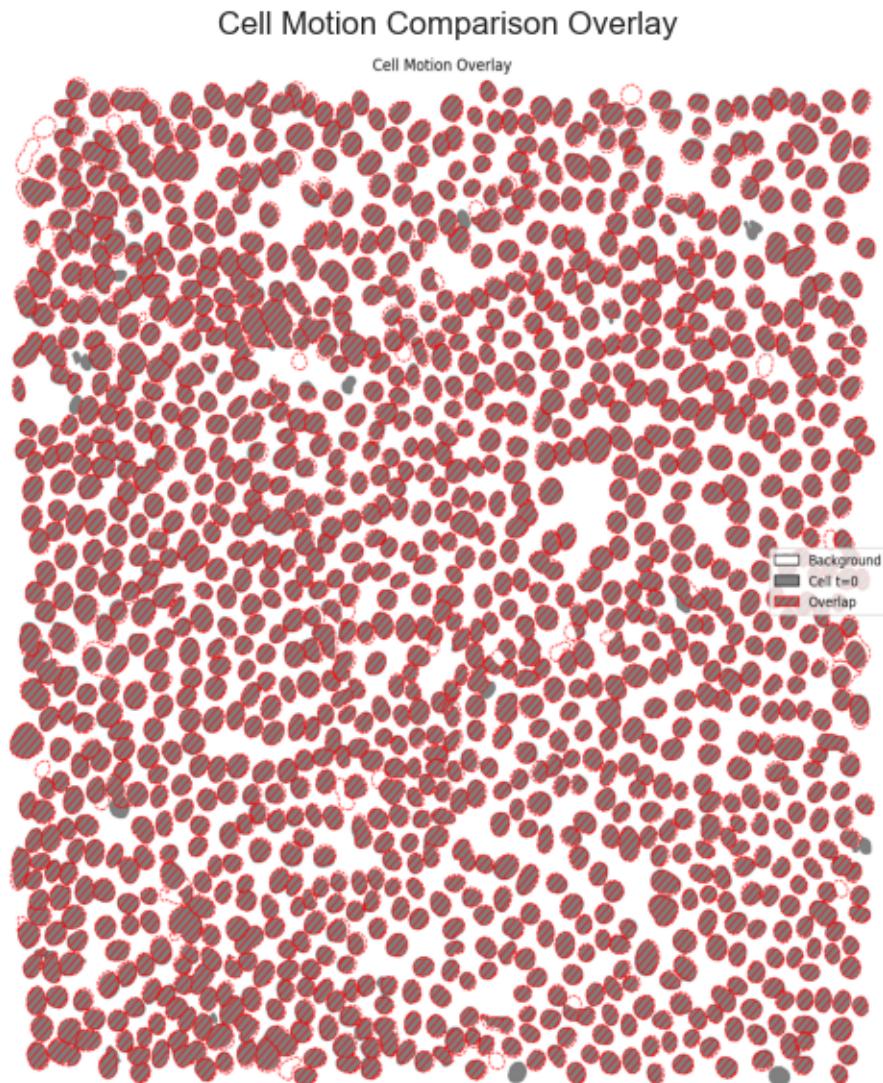
### 1.4.3 Correlation between event activity level & individual activity level



```
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: removed 1/1250 outliers on 'Occurrences in sequential events' (lower=-2, upper=5)
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: N=810 for Occurrences in individual events=0
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: N=319 for Occurrences in individual events=1
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: N=93 for Occurrences in individual events=2
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: N=23 for Occurrences in individual events=3
[2025-08-27 15:13:00] [INFO] calcium: plot_points_mean_std: N=4 for Occurrences in individual events=4
```



## 1.5 CELLS MOTION



Number of cells:

- Hoechst image taken at t=0: 1250
- Hoechst image taken at t=1801: 1251
- Number of cells difference: absolute 1, relative 0.08%

Pixel-level cell segmentation:

- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1119467
- Pixels segmented as cell at t=1801: 1118864
- Overlapping pixels between t=0 and t=1801: 1021606 (91.28% of total)
- Pixels exclusive to t=0: 97861 (8.74% of total)
- Pixels exclusive to t=1801: 97258 (8.69% of total)