executed

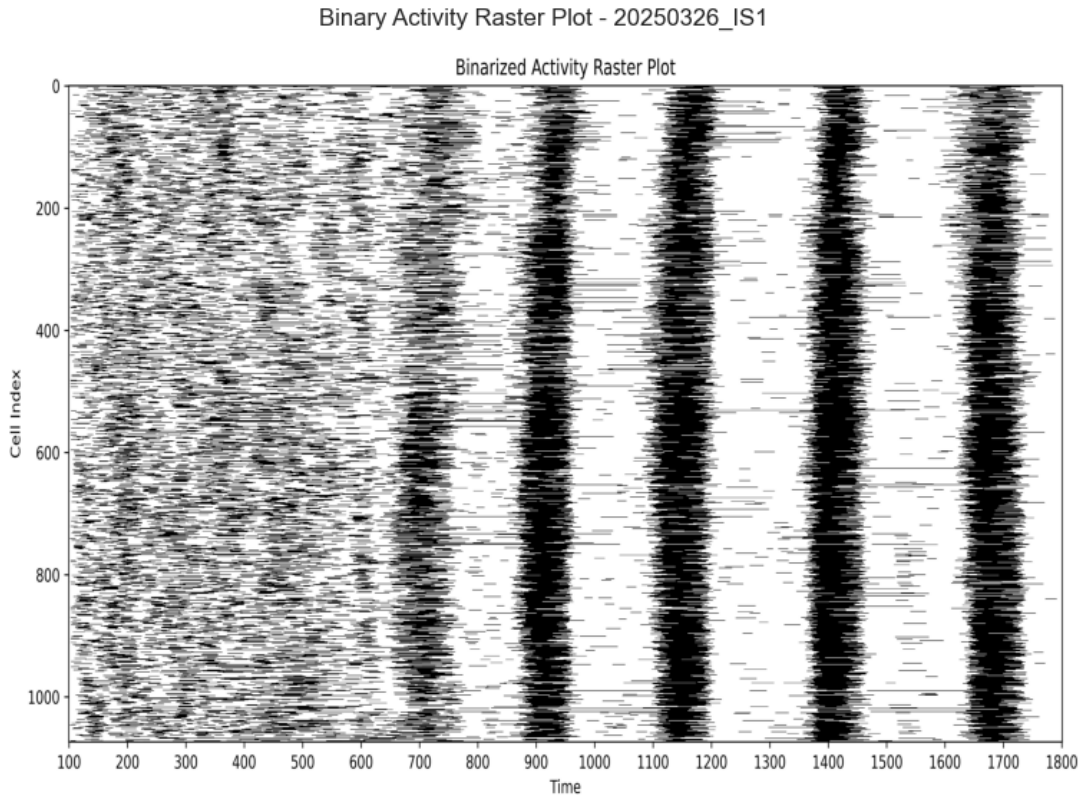
August 11, 2025

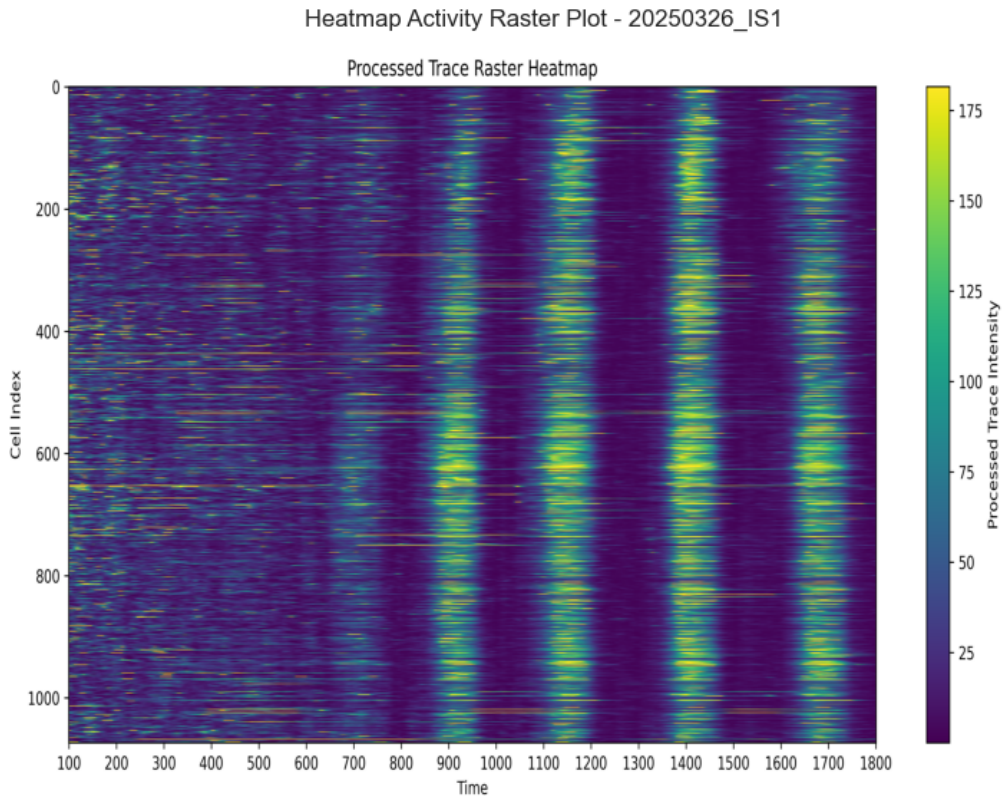
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



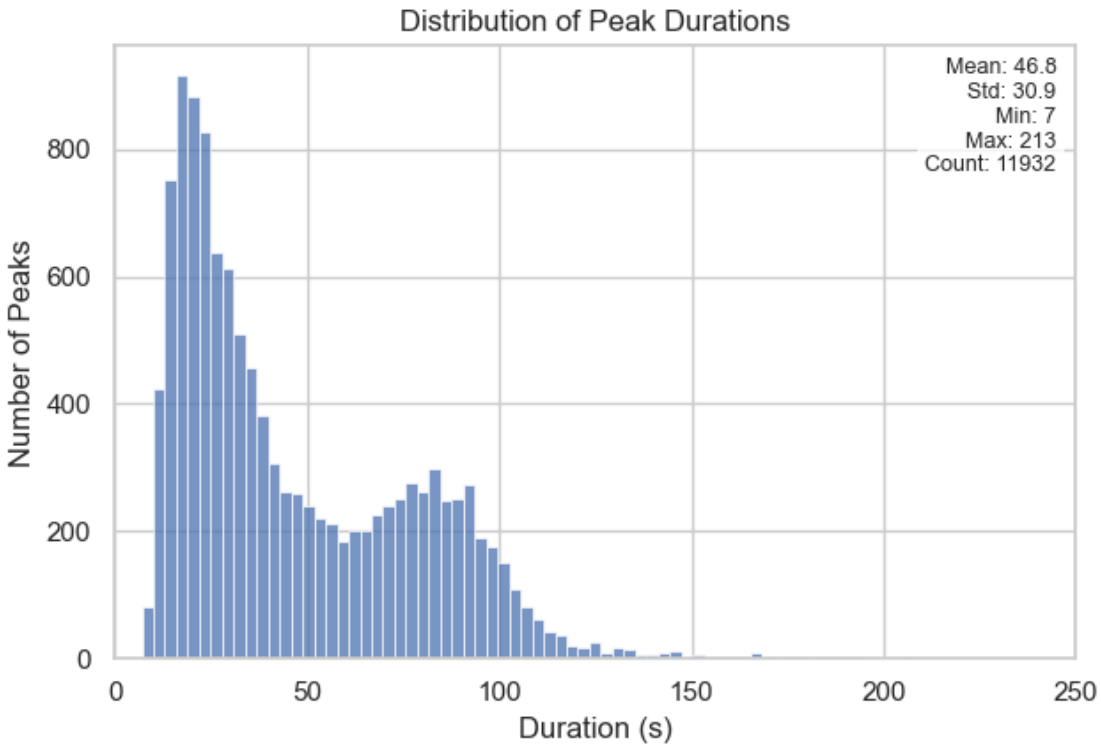


1.1.2 Peaks population

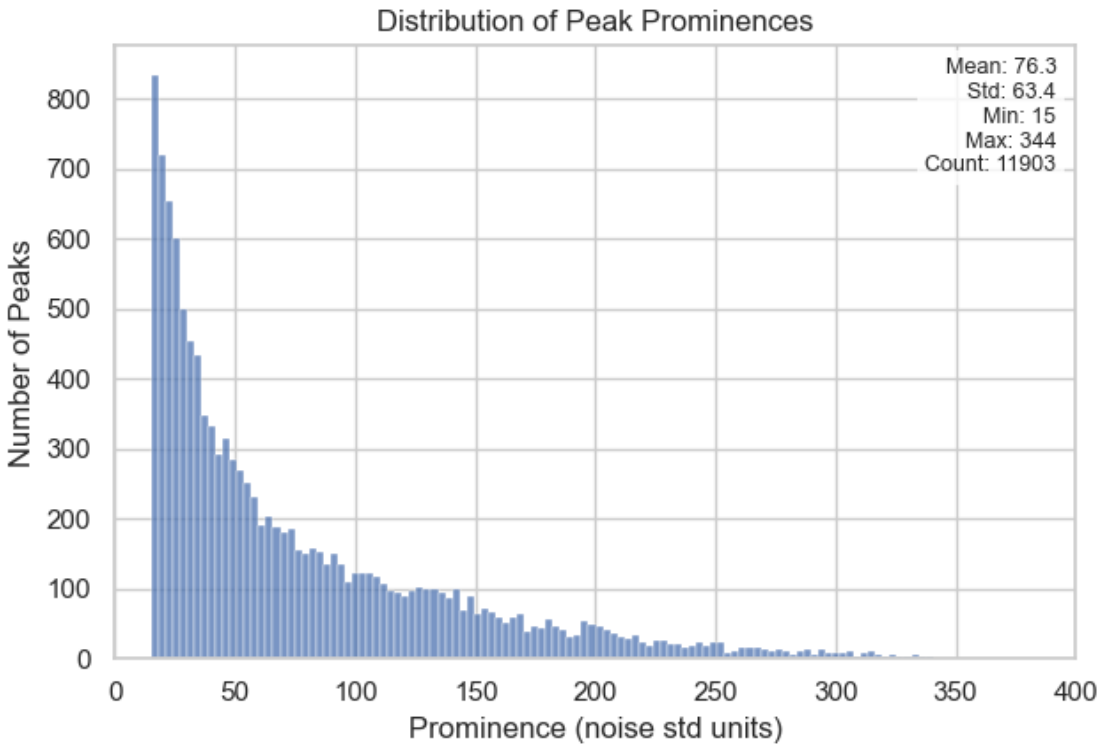
```
Total number of peaks: 11955
Total number of cells: 1074
```

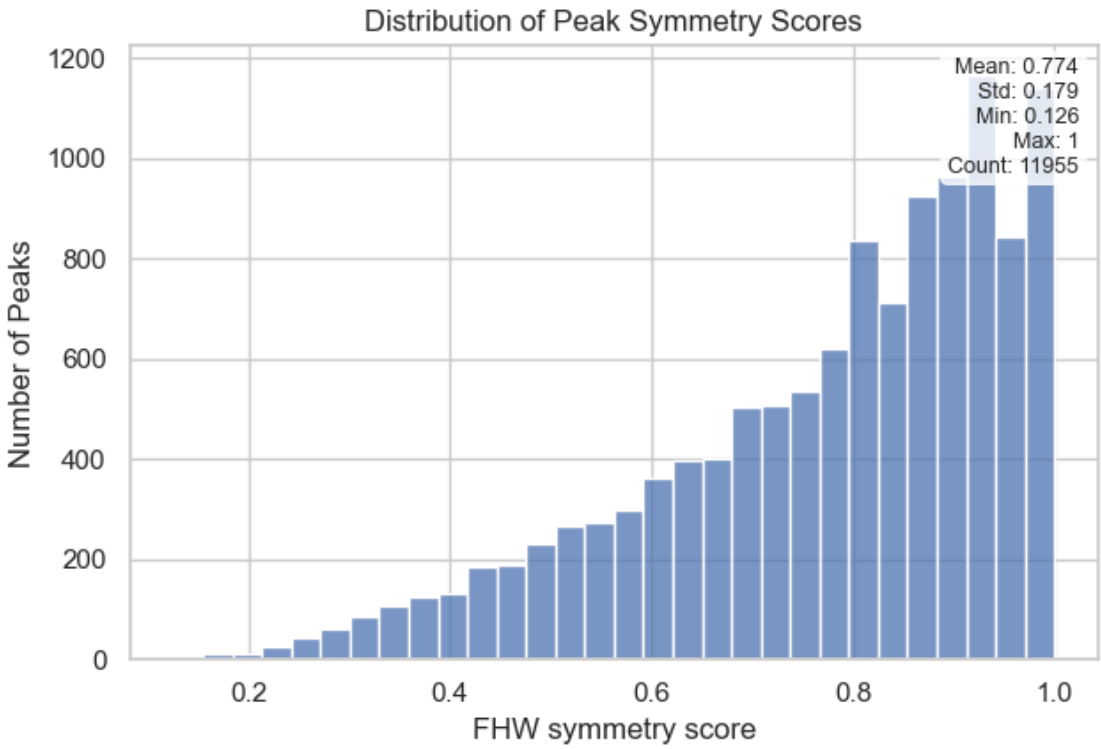
1.1.3 Peaks statistics

```
[2025-08-11 09:25:18] [INFO] calcium: plot_histogram: removed 23 outliers out of
11955 on 'Duration (s)' (lower=-132, upper=225)
```

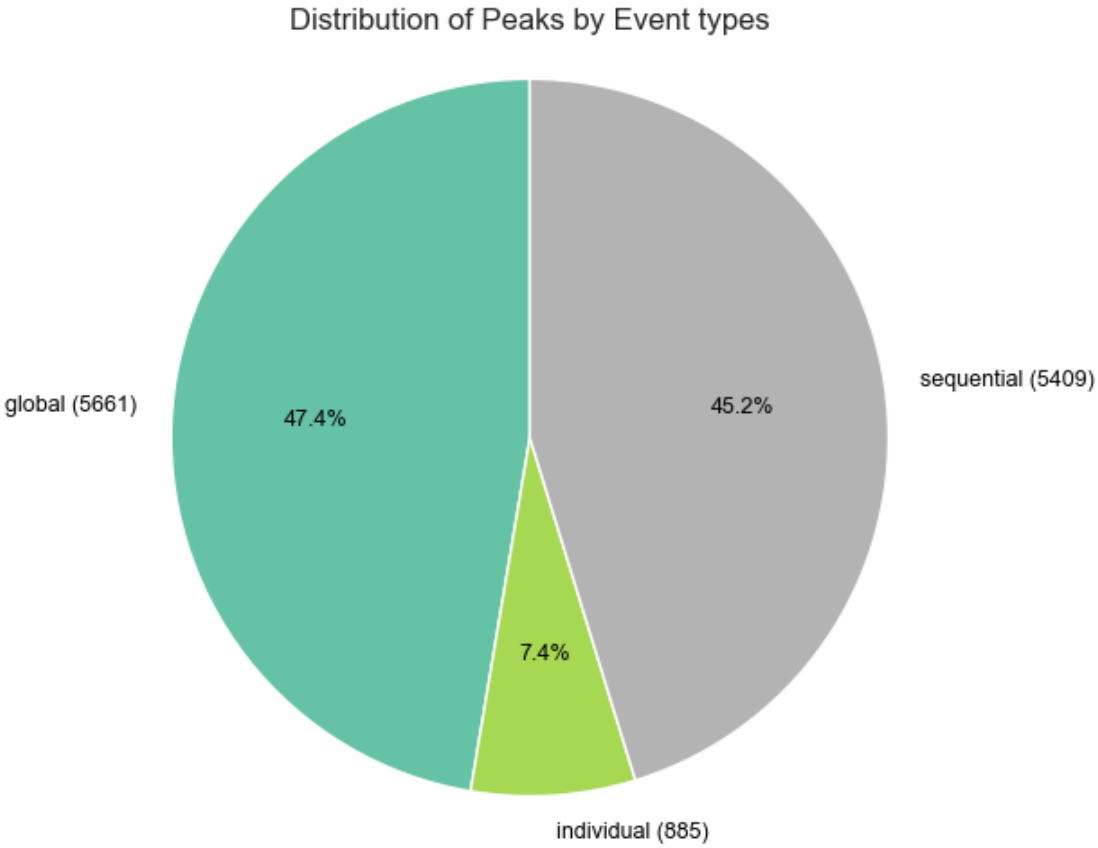



```
[2025-08-11 09:25:18] [INFO] calcium: plot_histogram: removed 52 outliers out of
11955 on 'Prominence (noise std units)' (lower=-210.35, upper=345.8)
```


Distribution of Peak Prominences
Mean: 76.3
Std: 63.4
Min: 15
Max: 344
Count: 11903
Number of Peaks
0
100
200
300
400
500
600
700
800
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

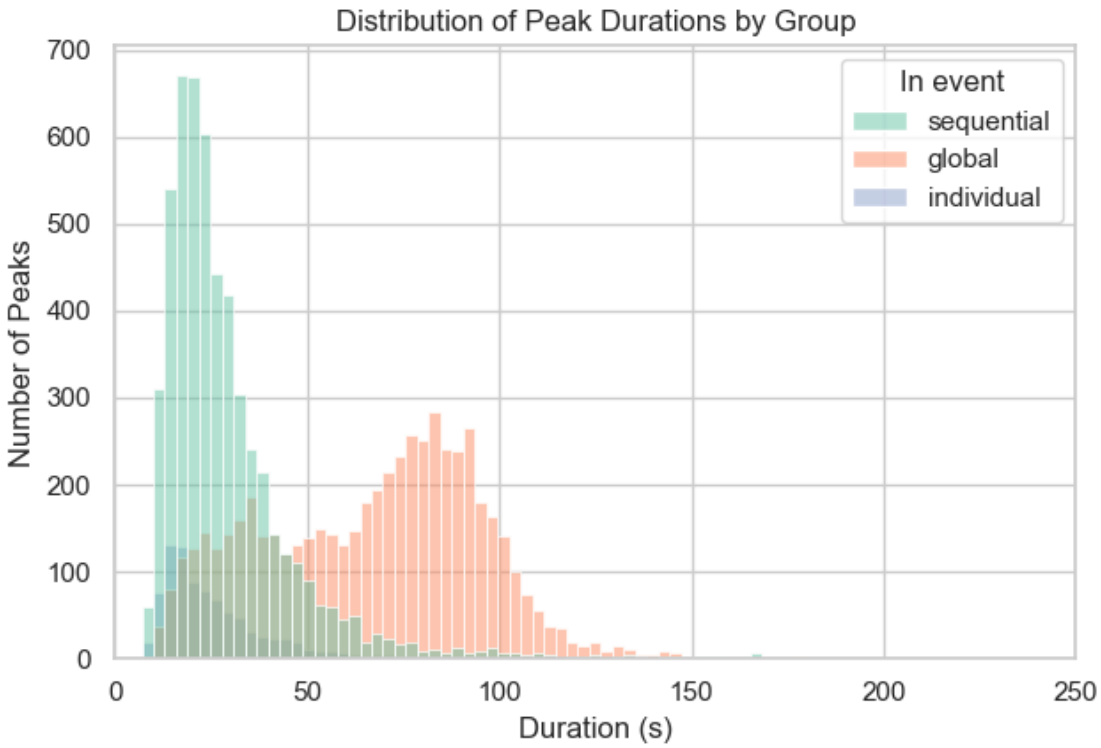

Distribution of Peak Symmetry Scores
Mean: 0.774
Std: 0.179
Min: 0.126
Max: 1
Count: 11955
Number of Peaks
0
200
400
600
800
1000
1200
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

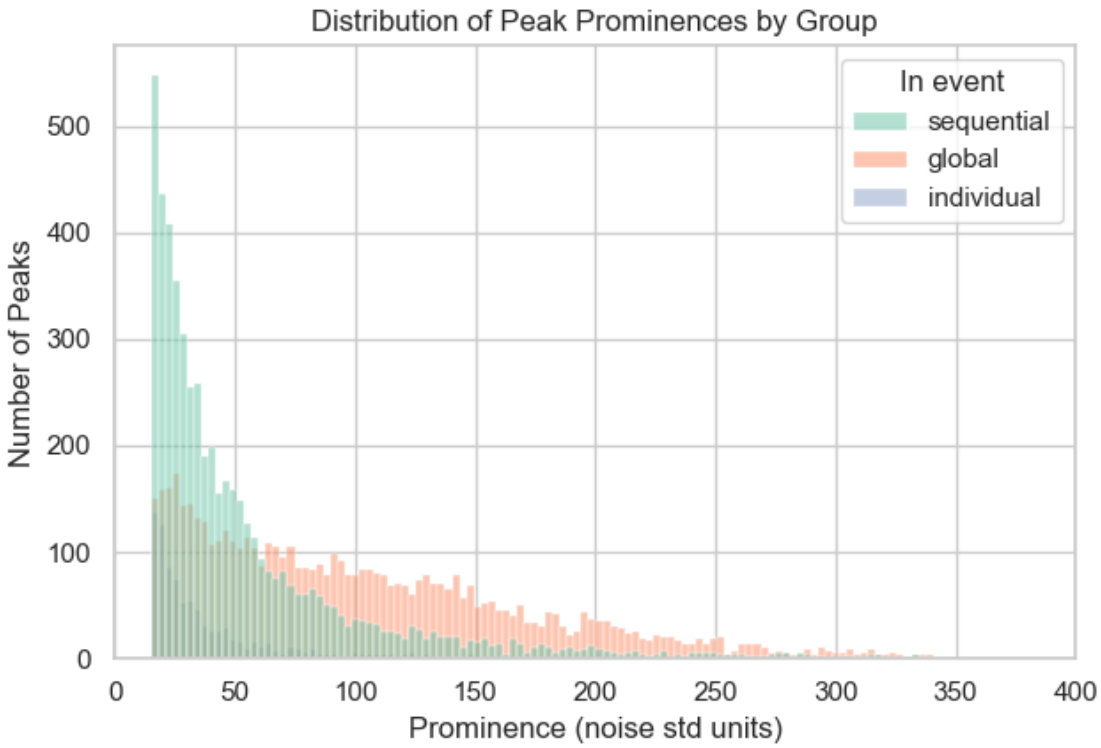


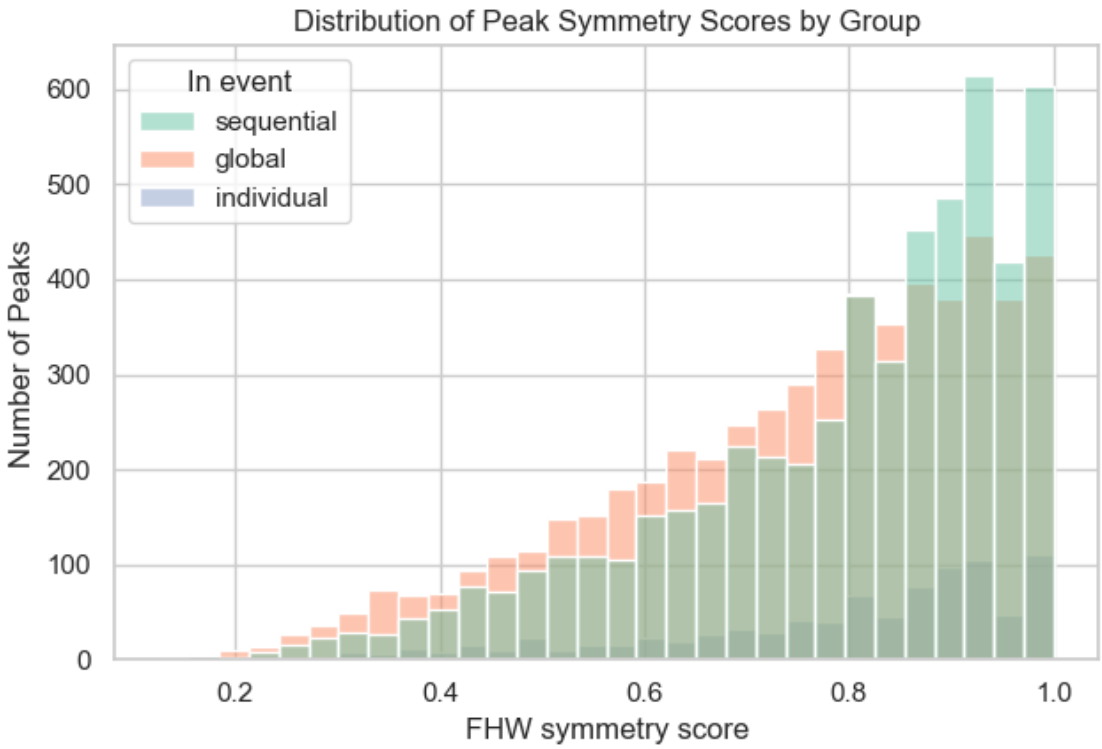
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:25:18] [INFO] calcium: plot_histogram_by_group: removed 23
outliers out of 11955 on 'Duration (s)' (lower=-132, upper=225)
```




```
[2025-08-11 09:25:18] [INFO] calcium: plot_histogram_by_group: removed 52
outliers out of 11955 on 'Prominence (noise std units)' (lower=-210.35,
upper=345.8)
```

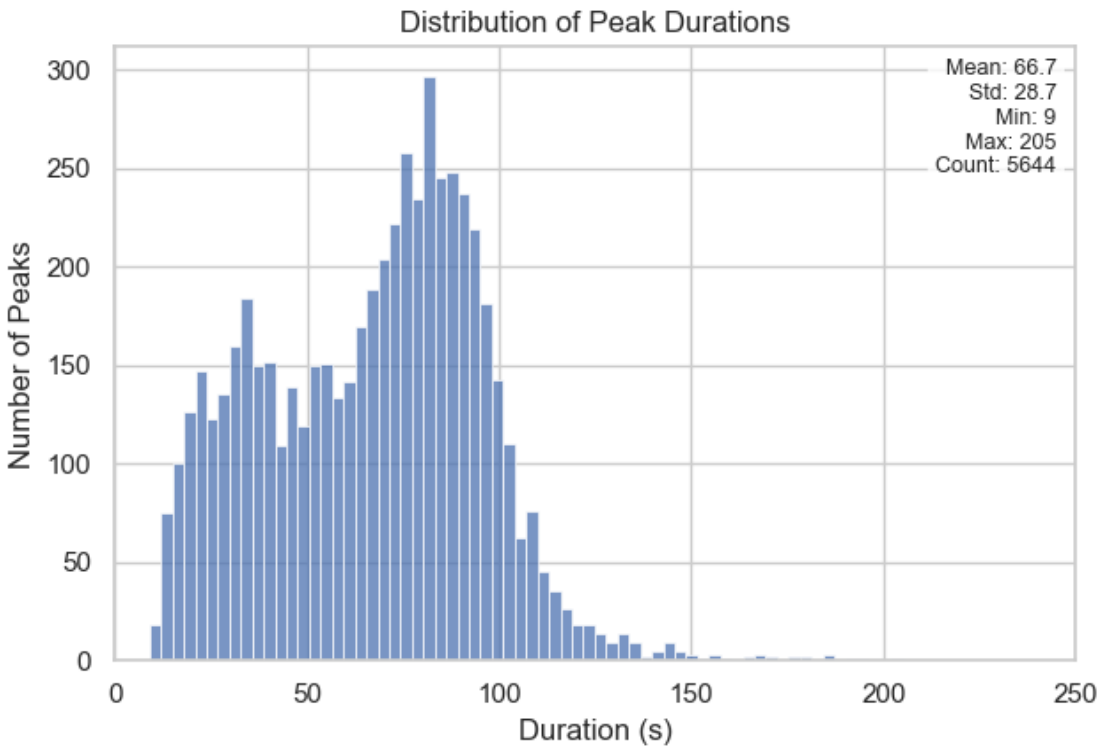

Distribution of Peak Prominences by Group
In event
sequential
global
individual
Number of Peaks
0
100
200
300
400
500
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
global
individual
Number of Peaks
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

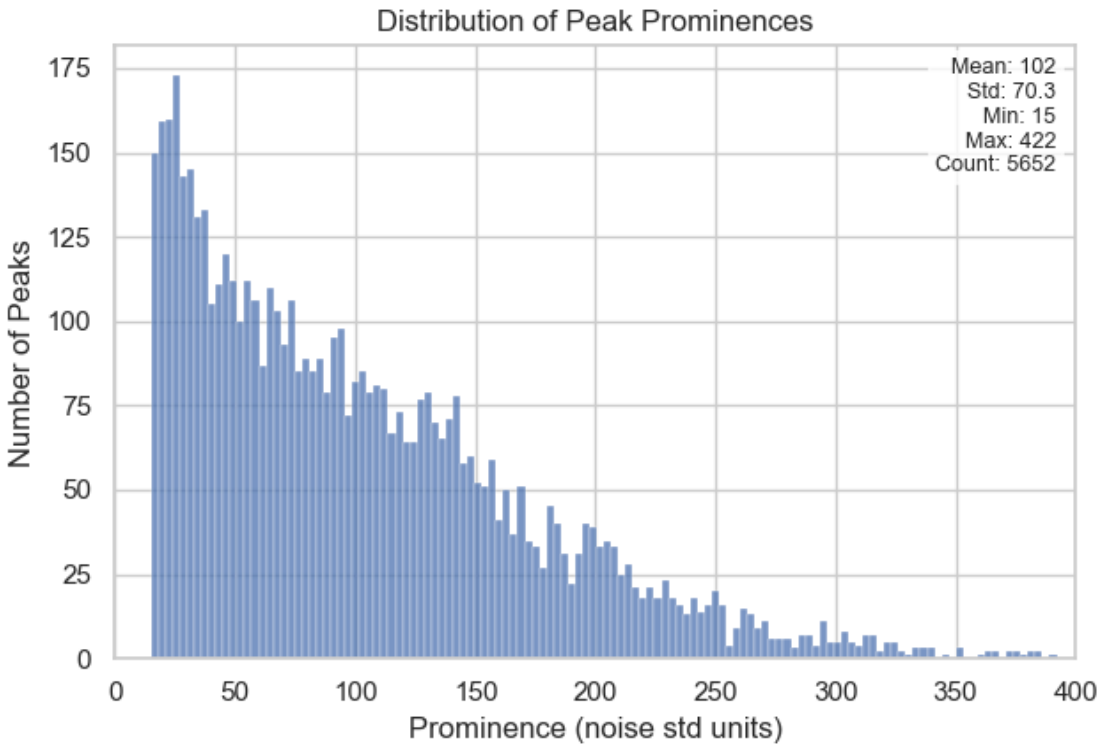
1.2 GLOBAL EVENTS

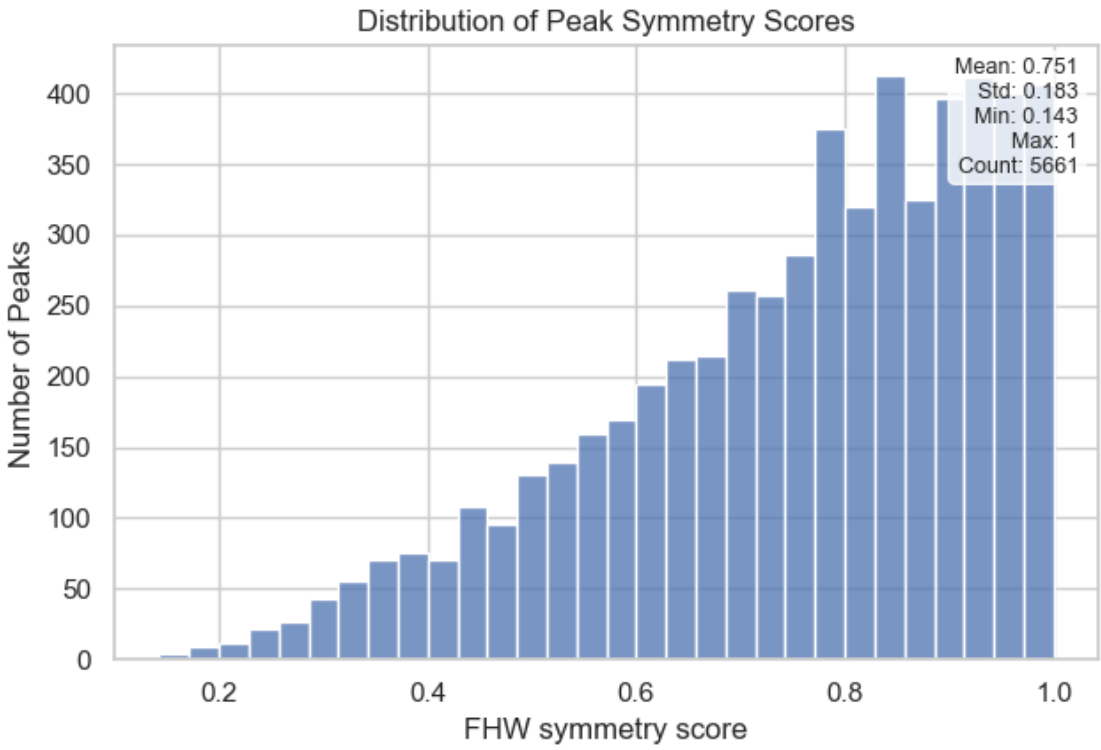
1.2.1 Peak statistics in global events

```
[2025-08-11 09:25:19] [INFO] calcium: plot_histogram: removed 17 outliers out of
5661 on 'Duration (s)' (lower=-92, upper=223)
```



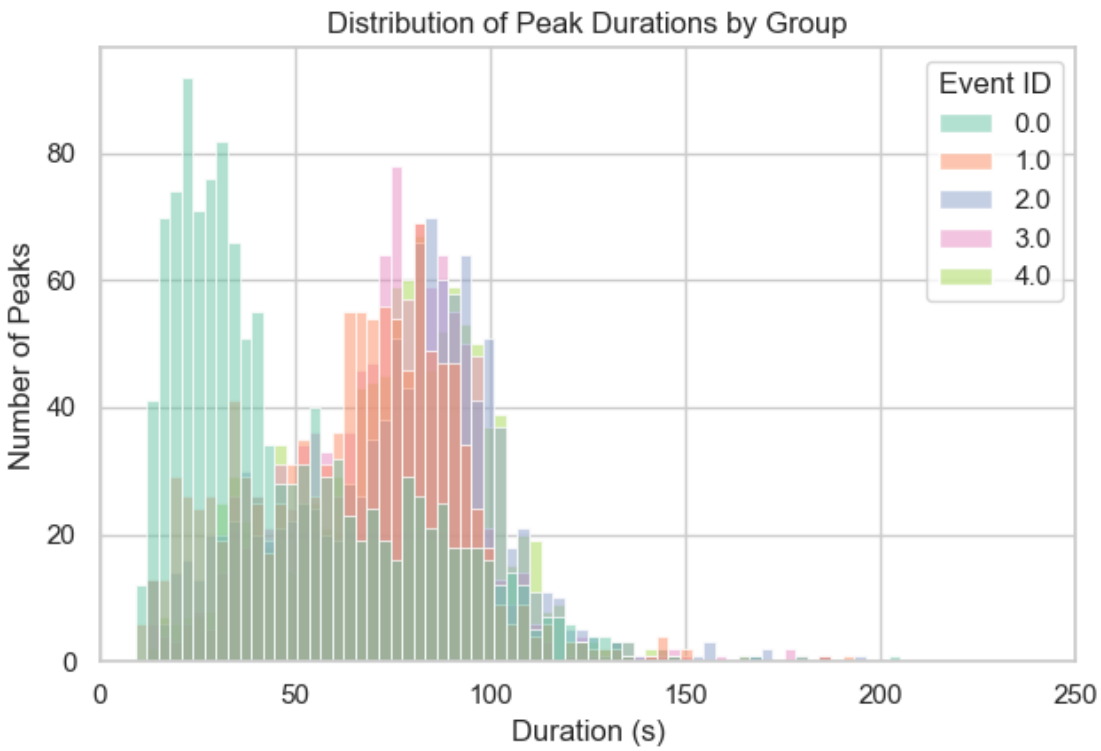

```
[2025-08-11 09:25:19] [INFO] calcium: plot_histogram: removed 9 outliers out of
5661 on 'Prominence (noise std units)' (lower=-248, upper=435.9)
```


Distribution of Peak Prominences
Mean: 102
Std: 70.3
Min: 15
Max: 422
Count: 5652
Number of Peaks
Prominence (noise std units)
0
25
50
75
100
125
150
175
0
50
100
150
200
250
300
350
400

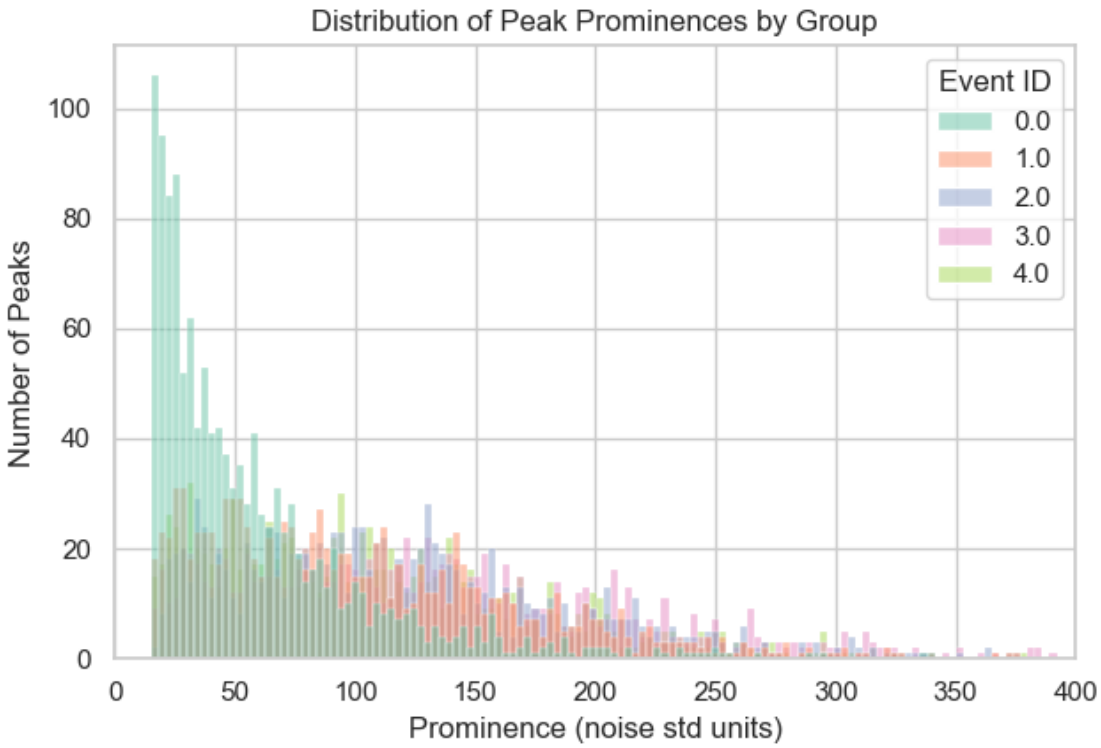

Distribution of Peak Symmetry Scores
Mean: 0.751
Std: 0.183
Min: 0.143
Max: 1
Count: 5661
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
300
350
400
0.2
0.4
0.6
0.8
1.0

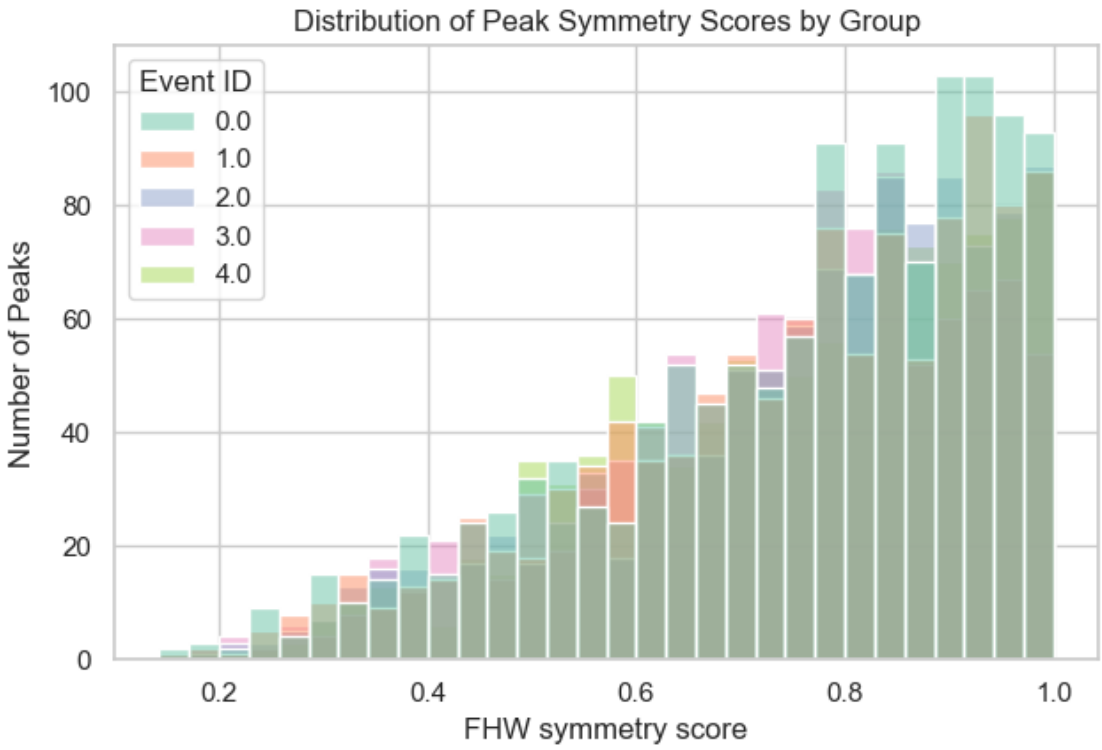
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:25:20] [INFO] calcium: plot_histogram_by_group: removed 17
outliers out of 5661 on 'Duration (s)' (lower=-92, upper=223)
```

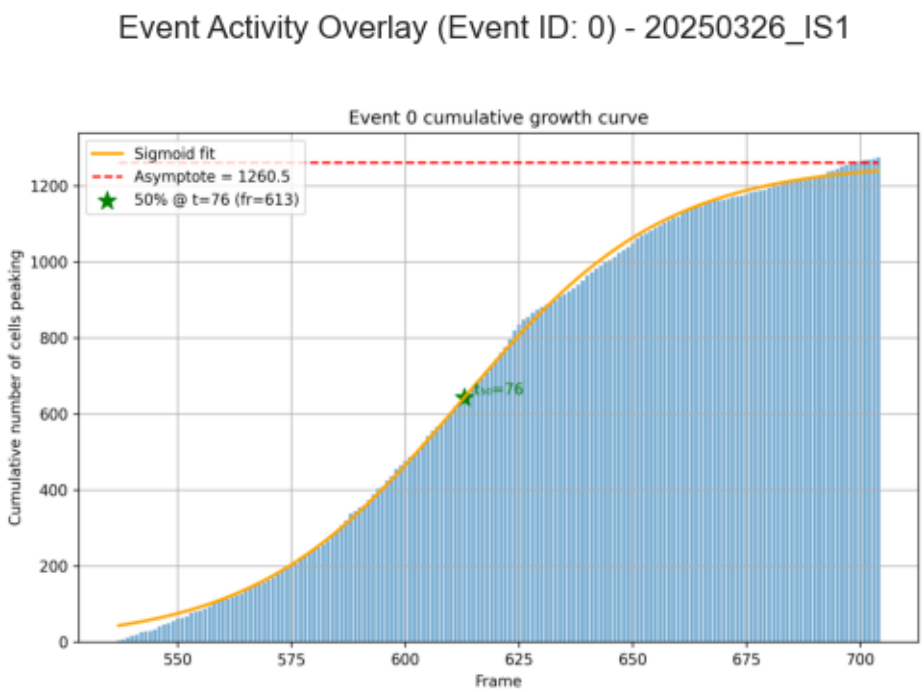


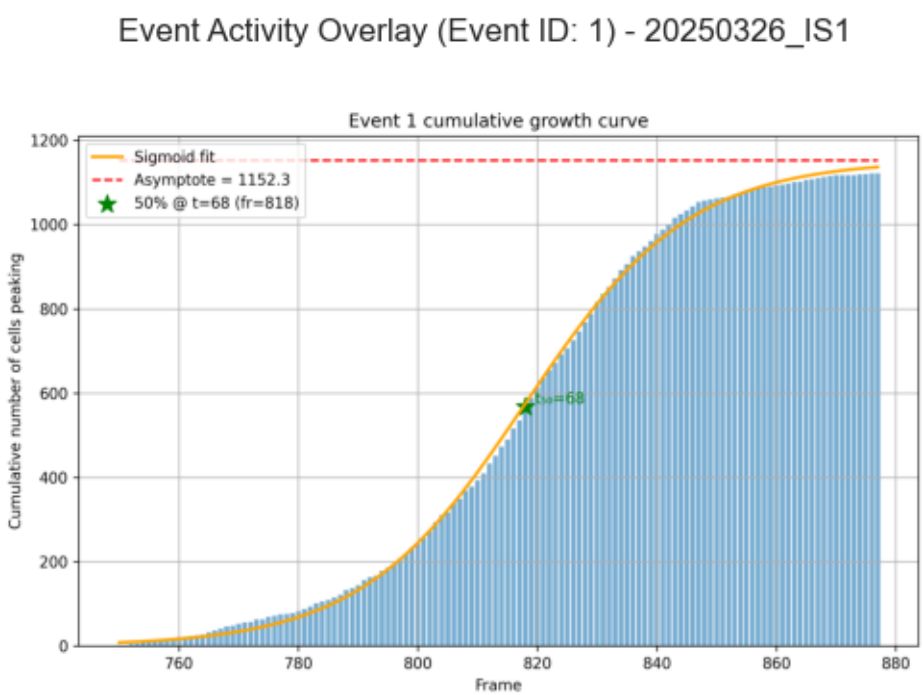

```
[2025-08-11 09:25:20] [INFO] calcium: plot_histogram_by_group: removed 9
outliers out of 5661 on 'Prominence (noise std units)' (lower=-248, upper=435.9)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

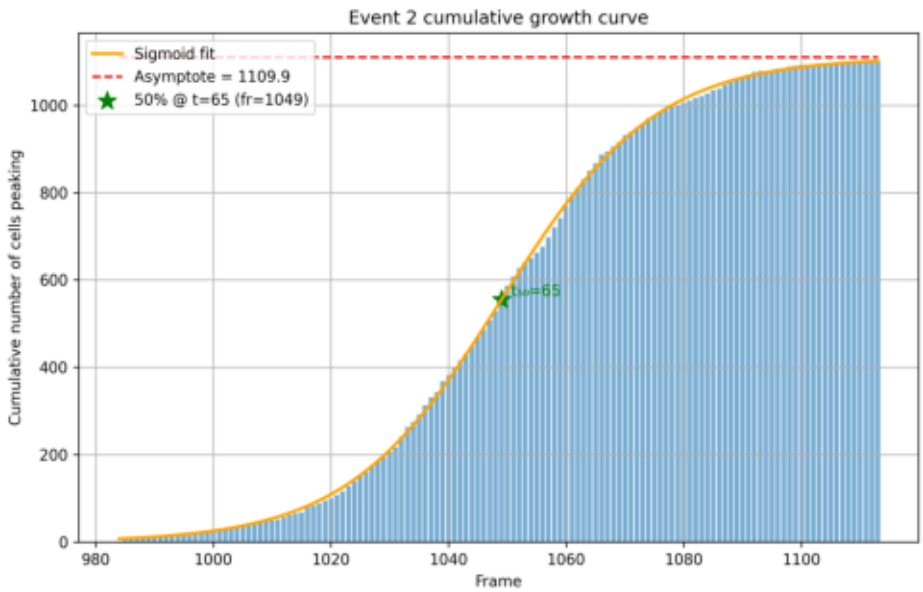

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2.3 Kinetics of global events

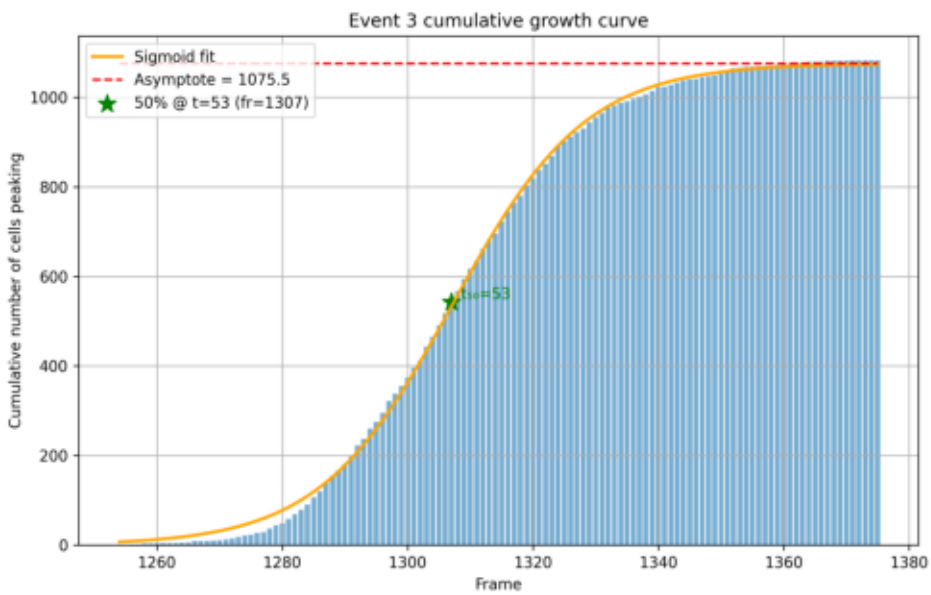


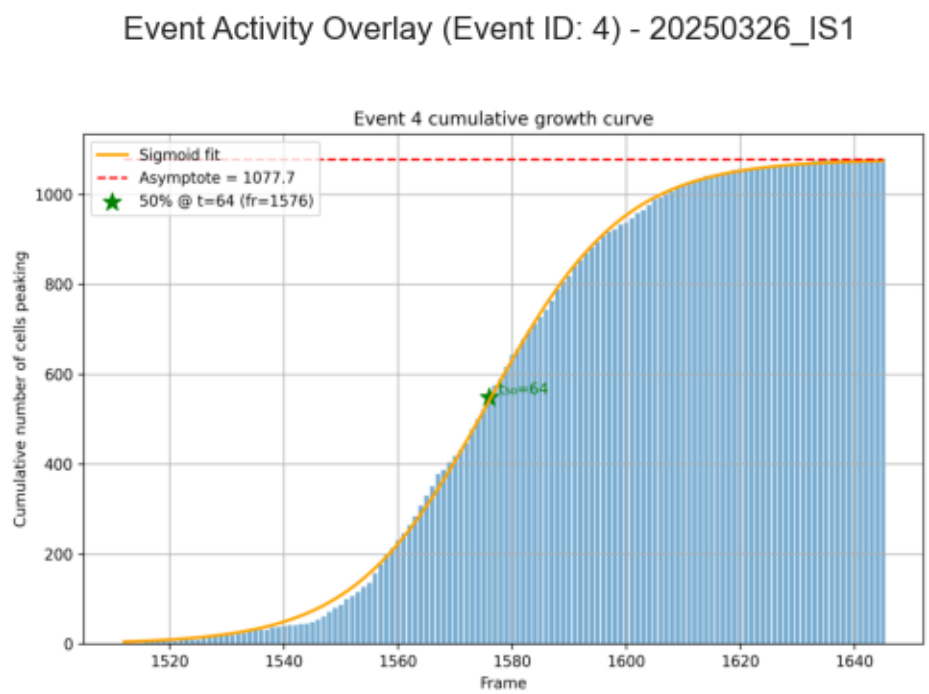


Event Activity Overlay (Event ID: 2) - 20250326_IS1

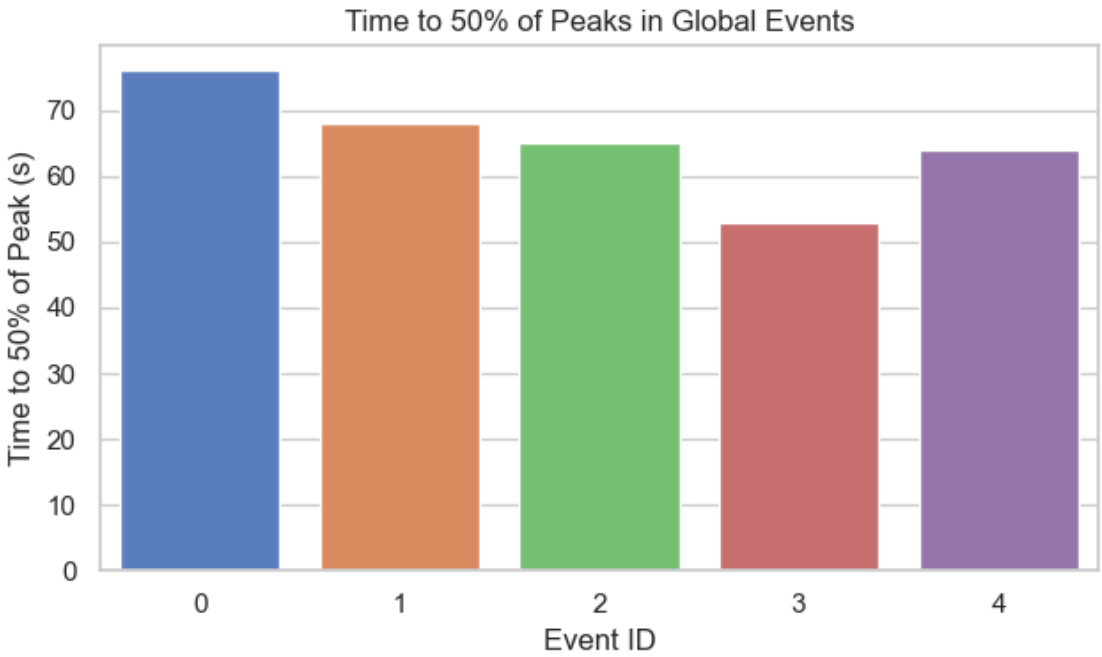


Event Activity Overlay (Event ID: 3) - 20250326_IS1

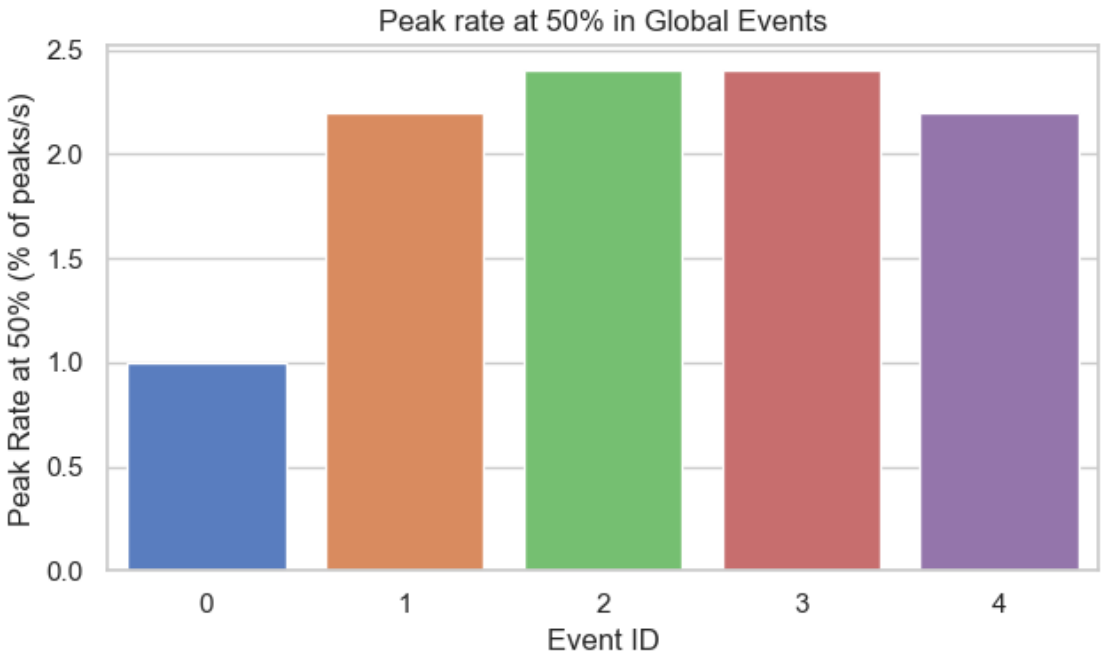




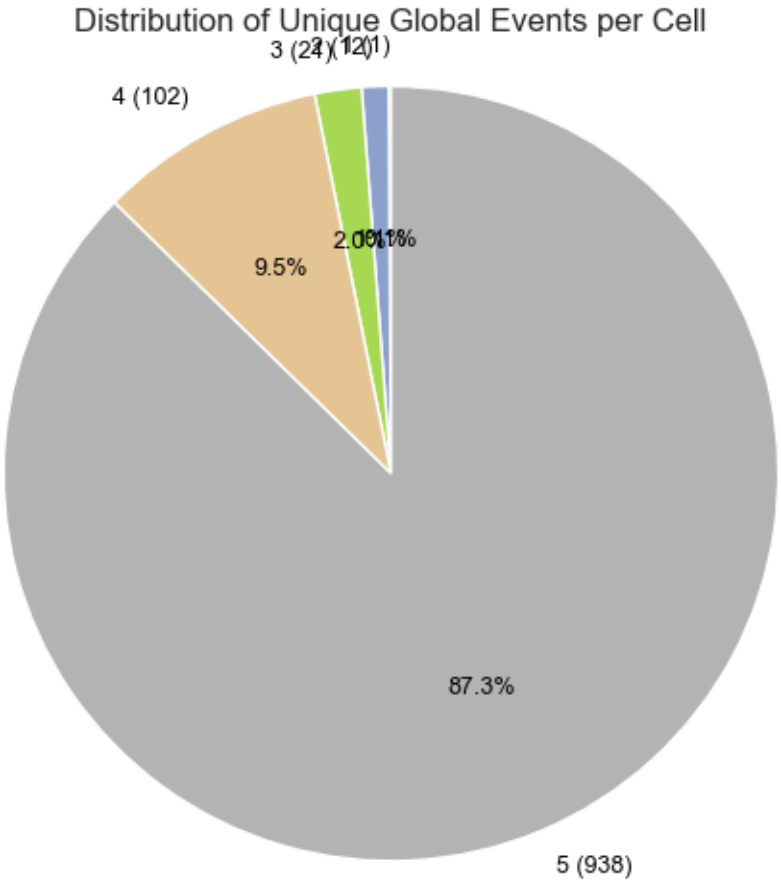

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



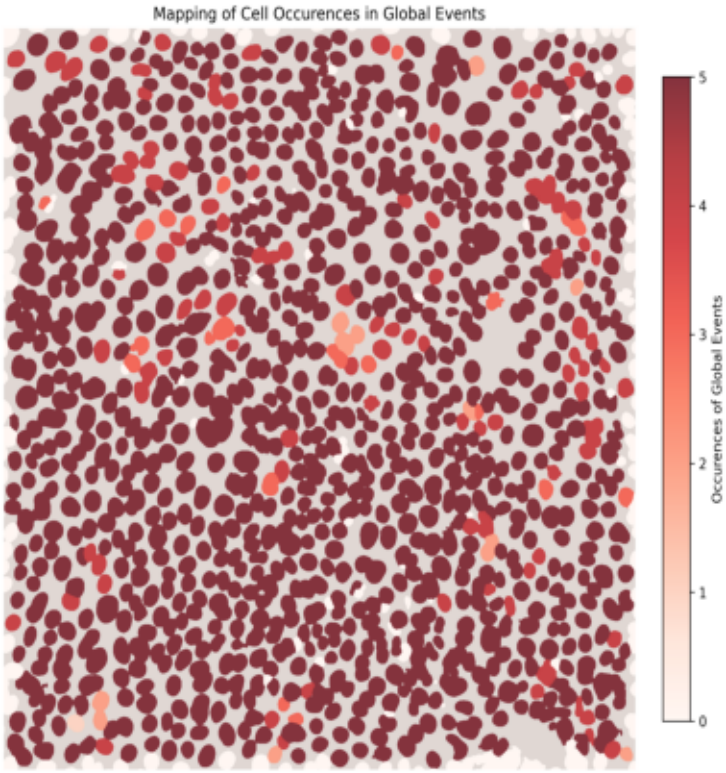

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
4
Event ID

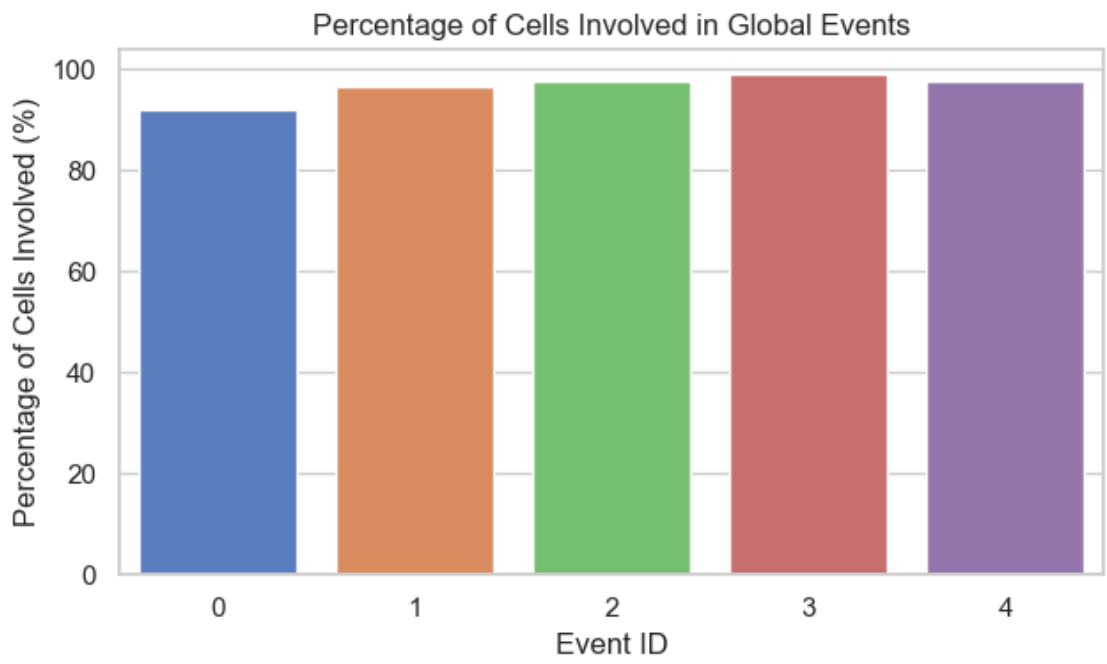
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250326_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

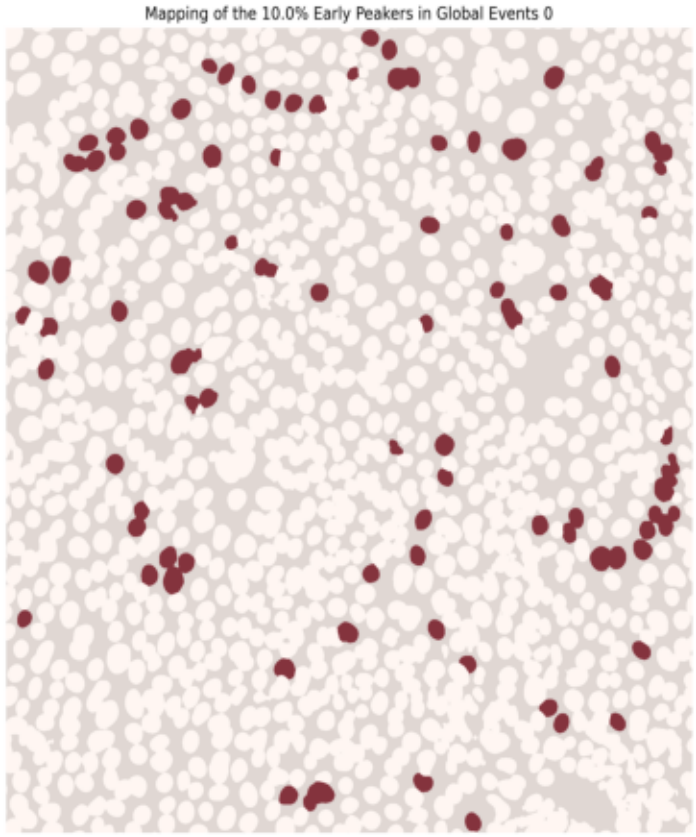


1.2.5 Inter-event interval analysis

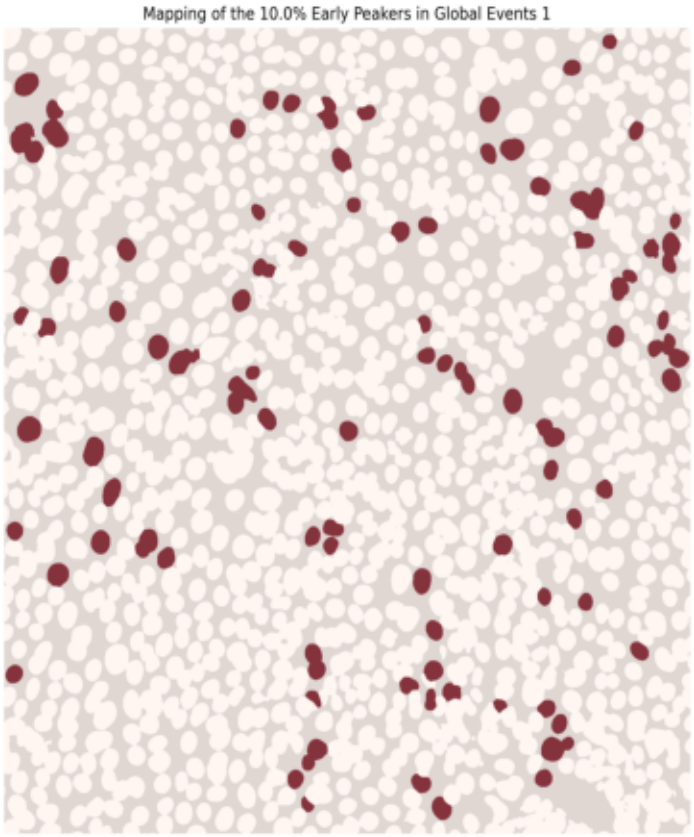
```
Intervals between global event peaks: [210.0, 227.0, 260.0, 267.0]
Estimated periodicity: 0.911
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.004 Hz
```

1.2.6 Early peakers in the events

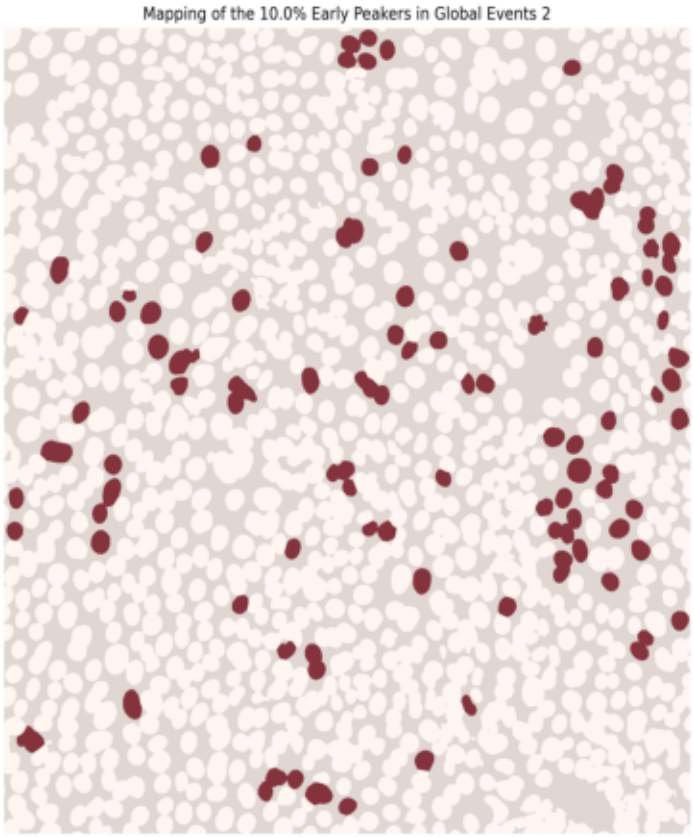
Cell Mapping with Early Peakers Overlay for event 0 - 20250326_IS1



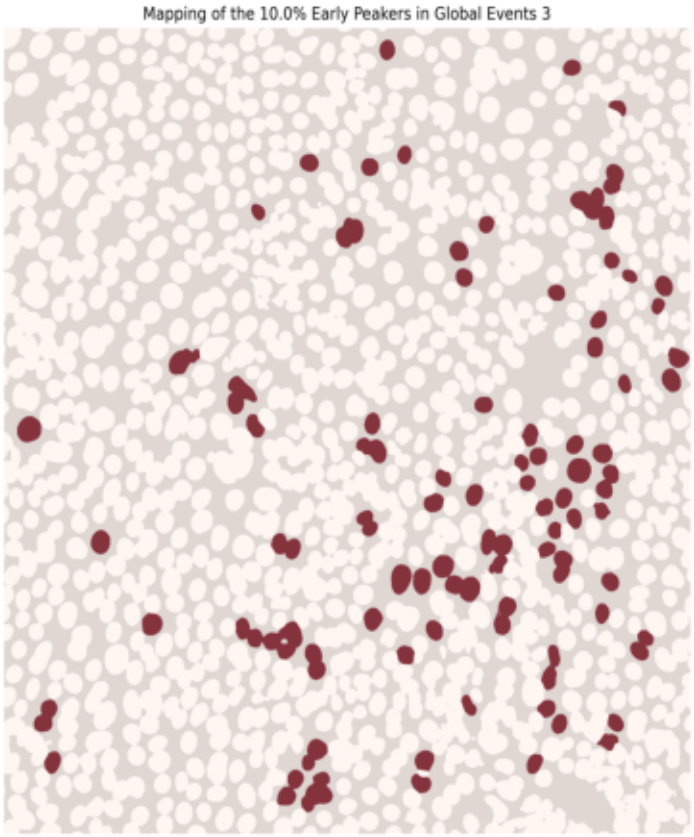
Cell Mapping with Early Peakers Overlay for event 1 - 20250326_IS1



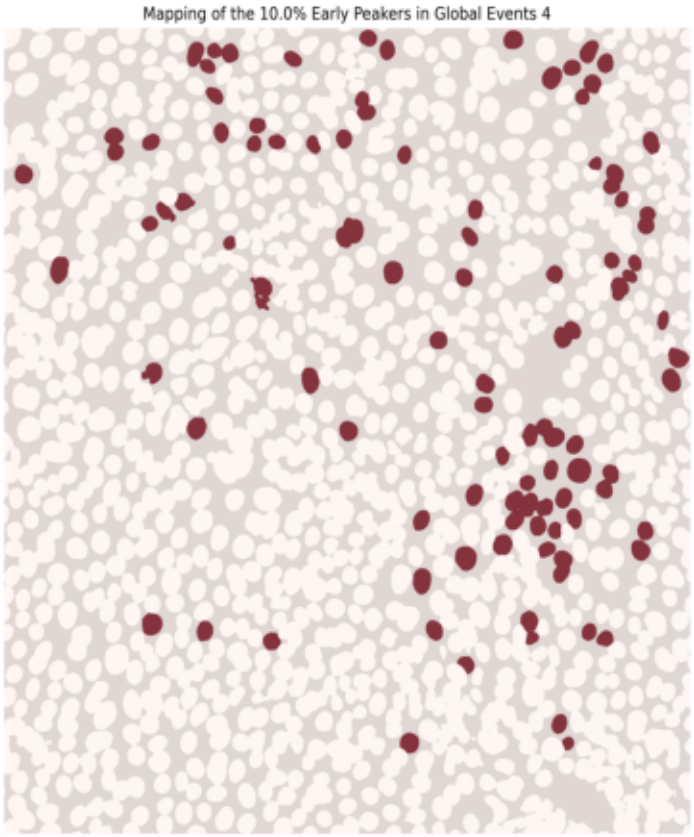
Cell Mapping with Early Peakers Overlay for event 2 - 20250326_IS1



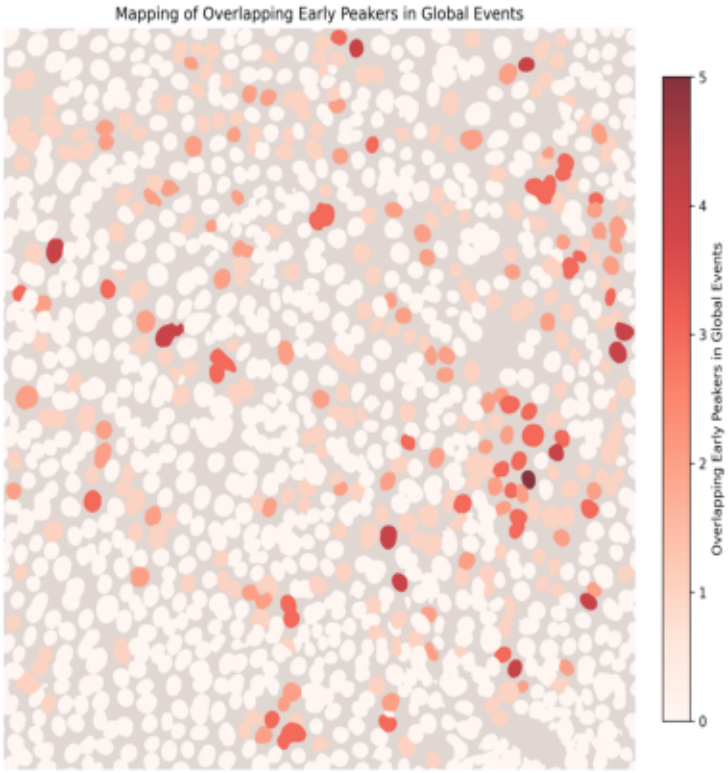
Cell Mapping with Early Peakers Overlay for event 3 - 20250326_IS1



Cell Mapping with Early Peakers Overlay for event 4 - 20250326_IS1

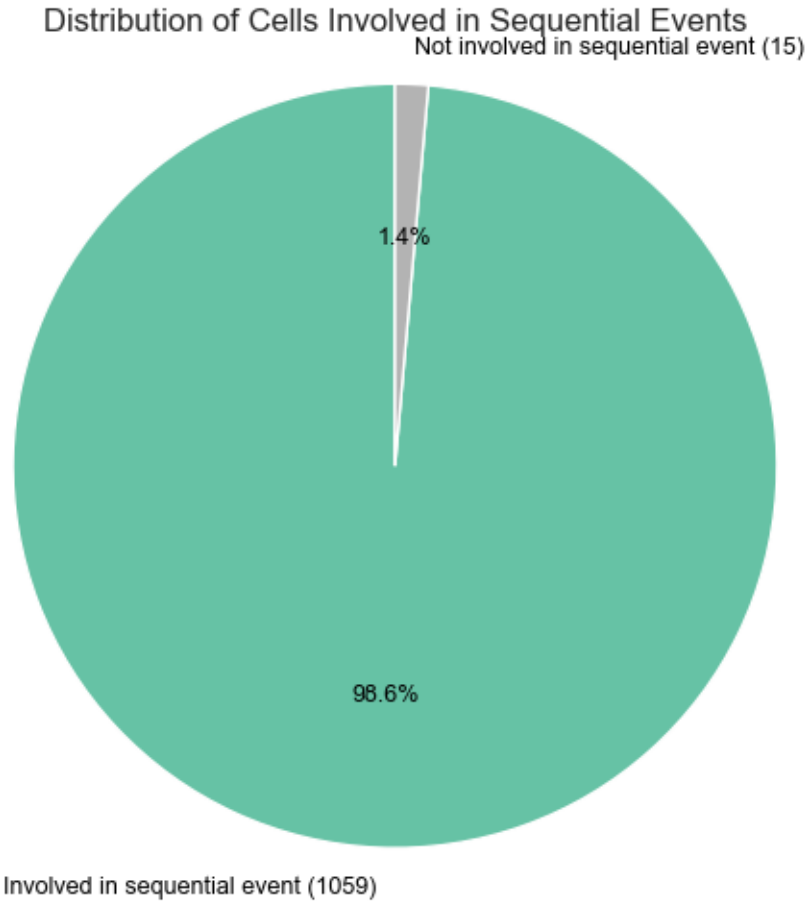


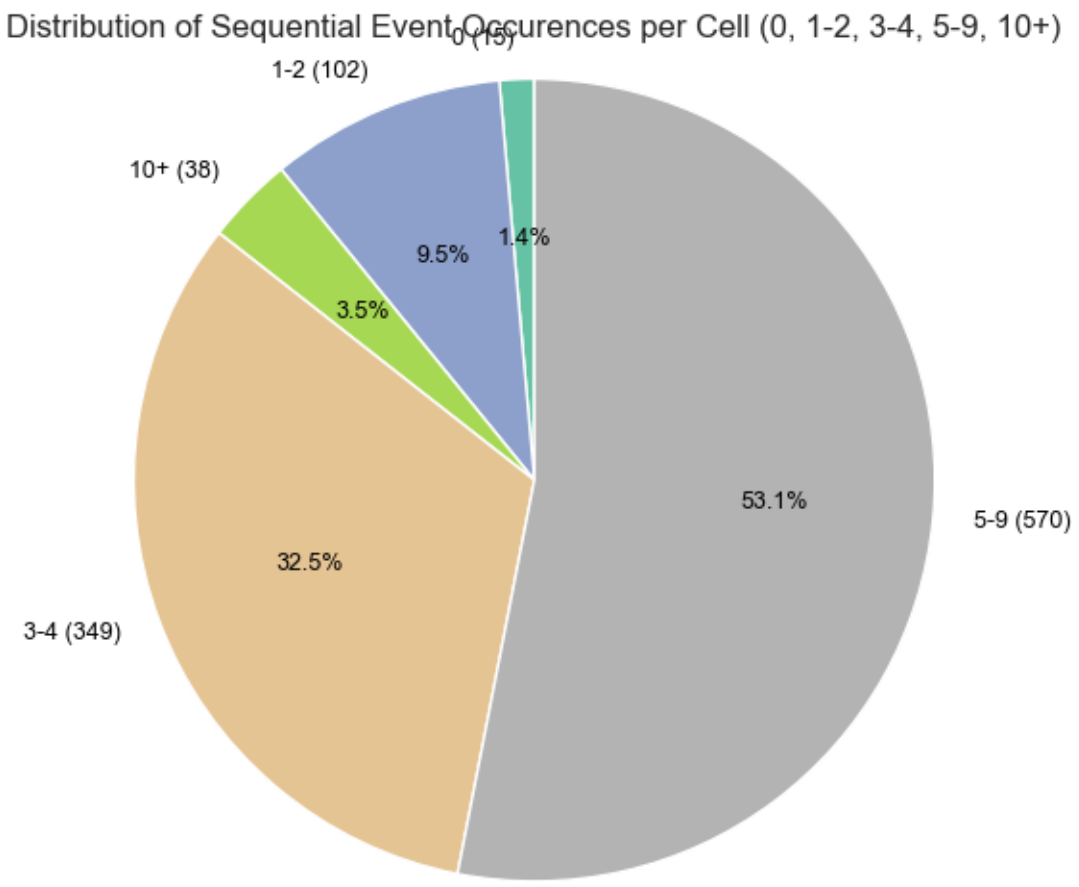
Cell Mapping with Occurences in Global Events Overlay - 20250326_IS1



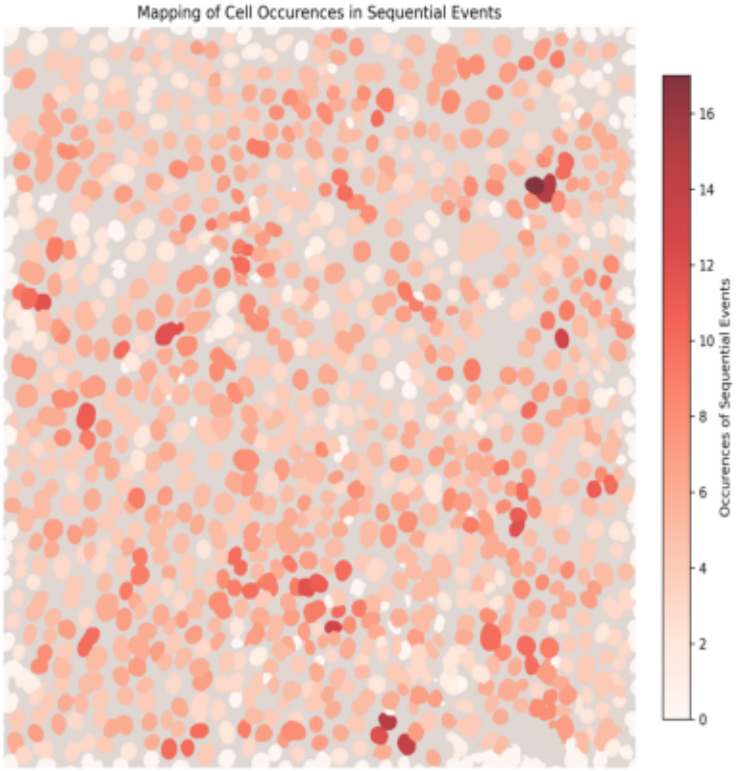
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

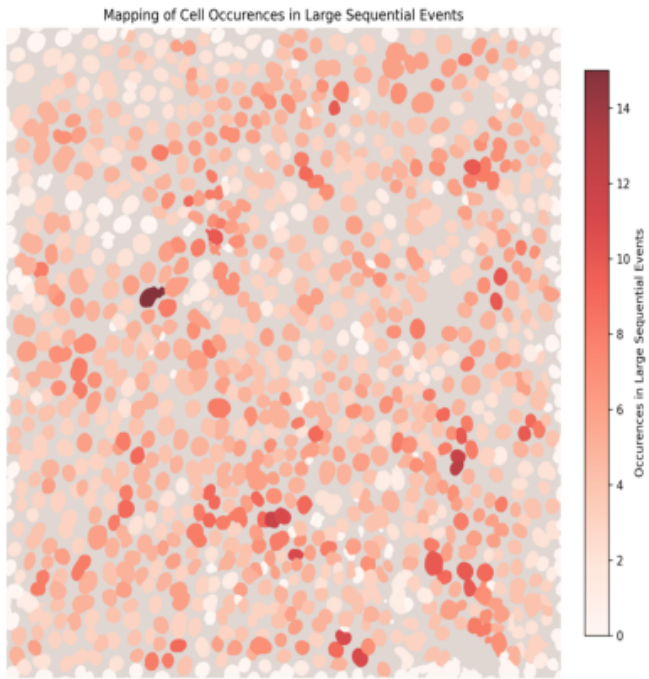



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (15)
1-2 (102)
10+ (38)
9.5%
1.4%
3.5%
53.1%
5-9 (570)
32.5%
3-4 (349)

Cell Mapping with Occurences in Sequential Events Overlay - 20250326_IS1

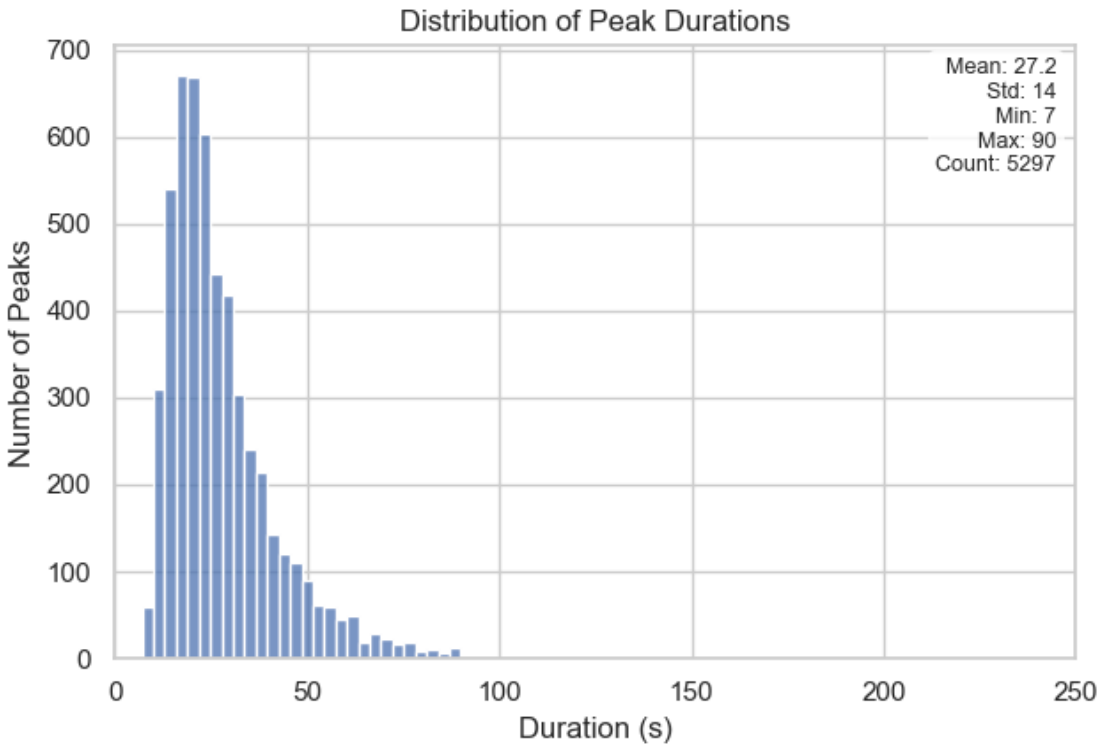


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250326_IS1

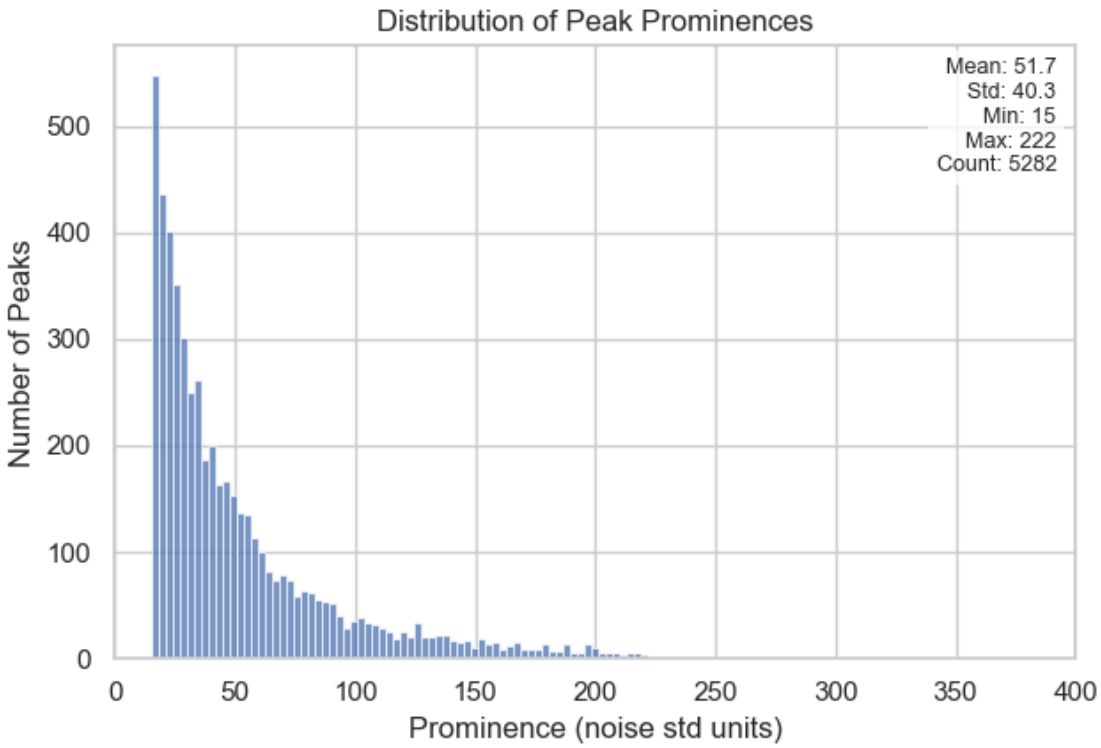


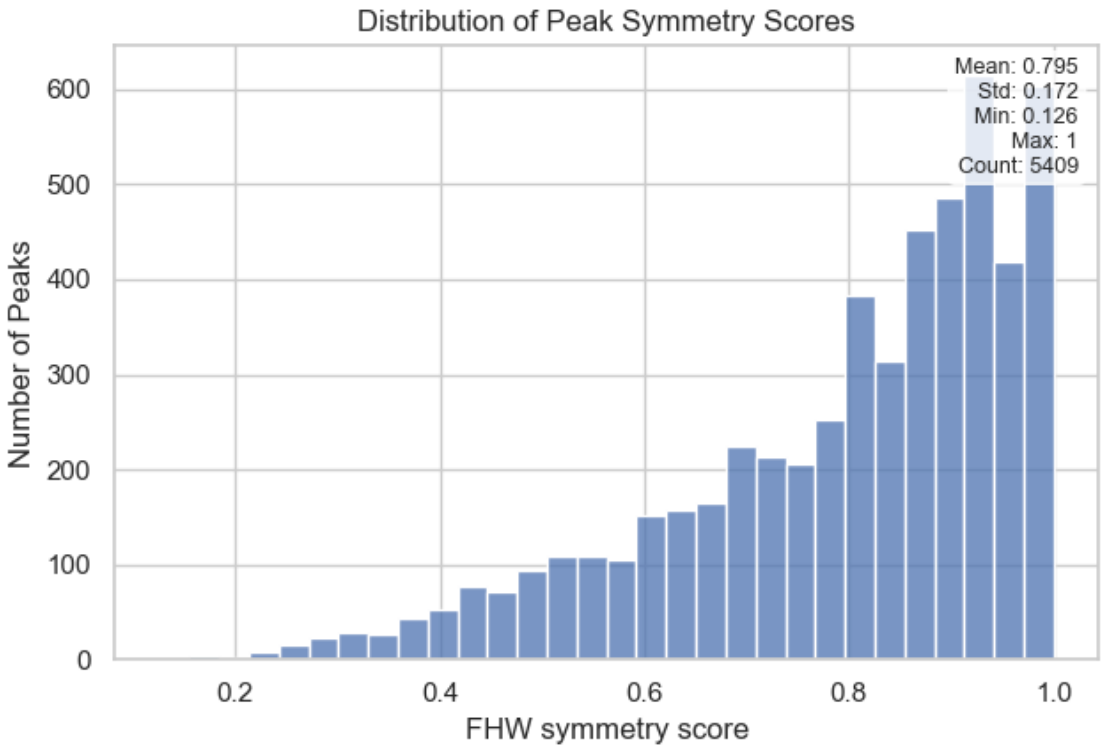
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:25:33] [INFO] calcium: plot_histogram: removed 112 outliers out
of 5409 on 'Duration (s)' (lower=-6, upper=90)
```



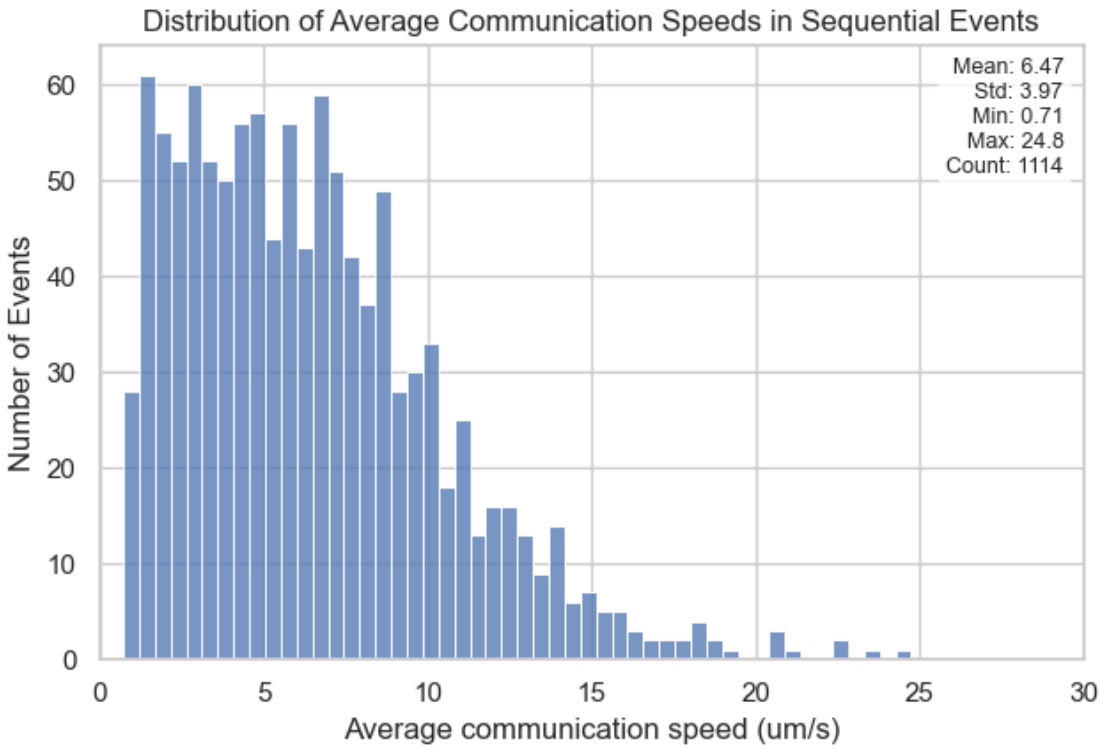

```
[2025-08-11 09:25:33] [INFO] calcium: plot_histogram: removed 127 outliers out
of 5409 on 'Prominence (noise std units)' (lower=-43.15, upper=223.85)
```


Distribution of Peak Prominences
Mean: 51.7
Std: 40.3
Min: 15
Max: 222
Count: 5282
Number of Peaks
0
100
200
300
400
500
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

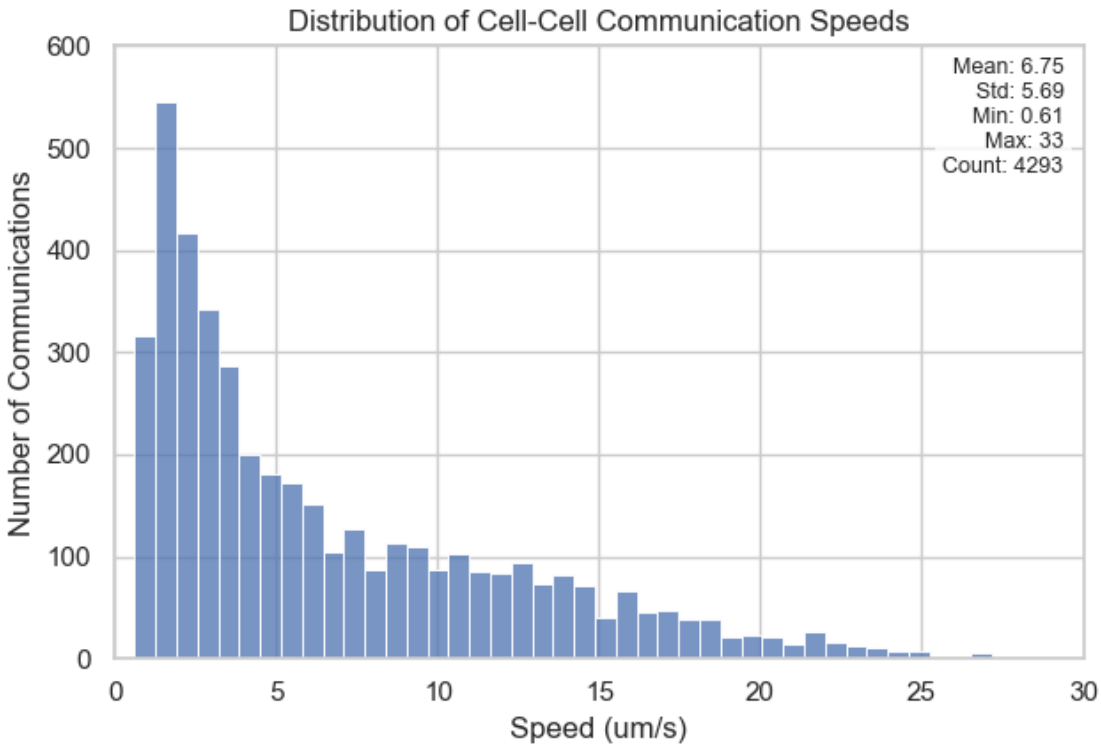

Distribution of Peak Symmetry Scores
Mean: 0.795
Std: 0.172
Min: 0.126
Max: 1
Count: 5409
Number of Peaks
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:25:34] [INFO] calcium: plot_histogram: removed 2 outliers out of
1116 on 'Average communication speed (um/s)' (lower=-12.71, upper=24.81)
```

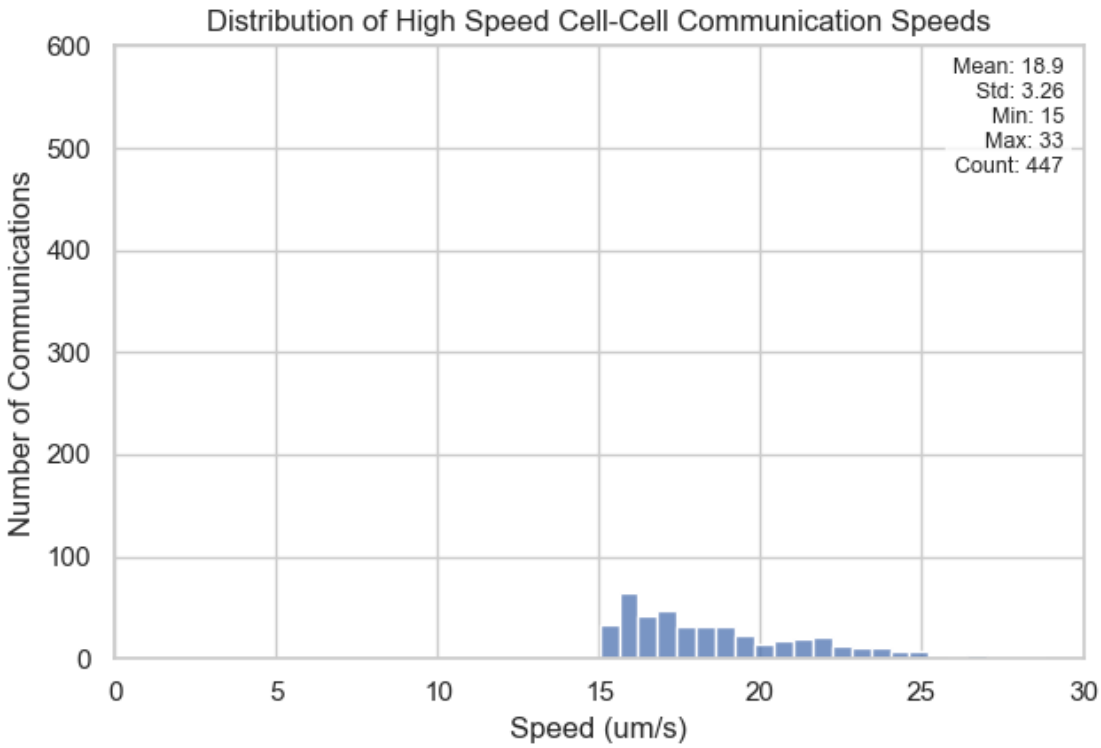



```
[2025-08-11 09:25:34] [INFO] calcium: plot_histogram: removed 0 outliers out of
4293 on 'Speed (um/s)' (lower=-21.66, upper=34.06)
```

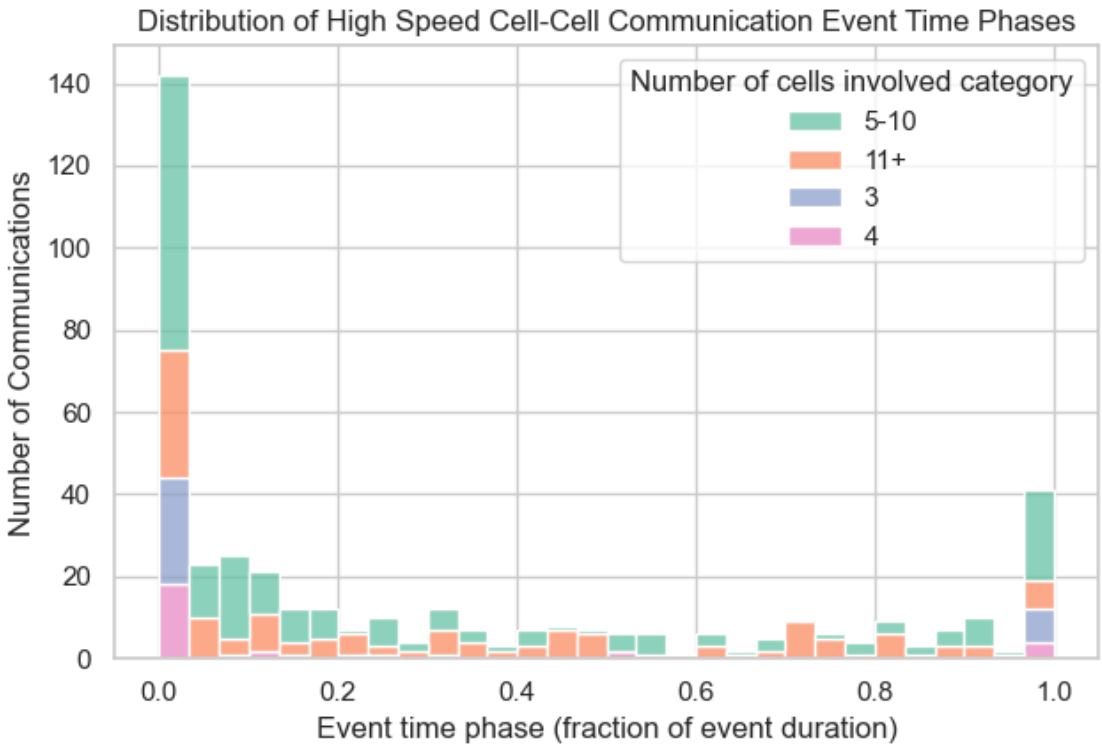


1.3.4 Double distribution in cell-cell communication speeds

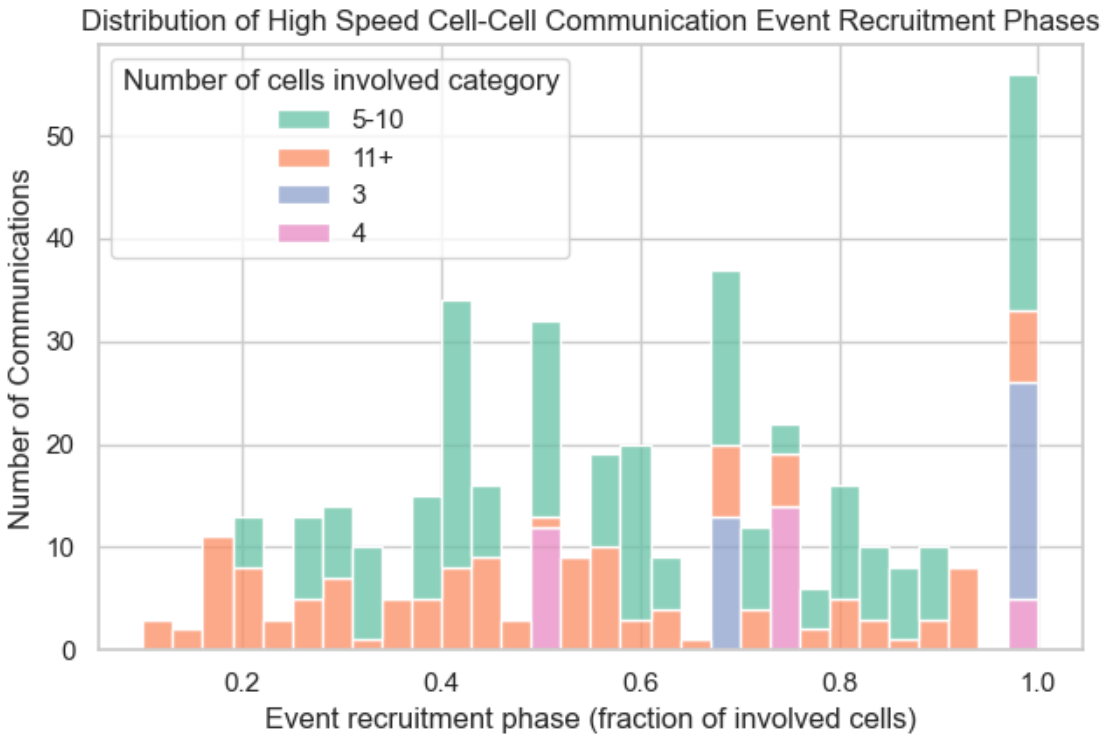
```
[2025-08-11 09:25:34] [INFO] calcium: plot_histogram: removed 0 outliers out of
447 on 'Speed (um/s)' (lower=2.985, upper=34.345)
```



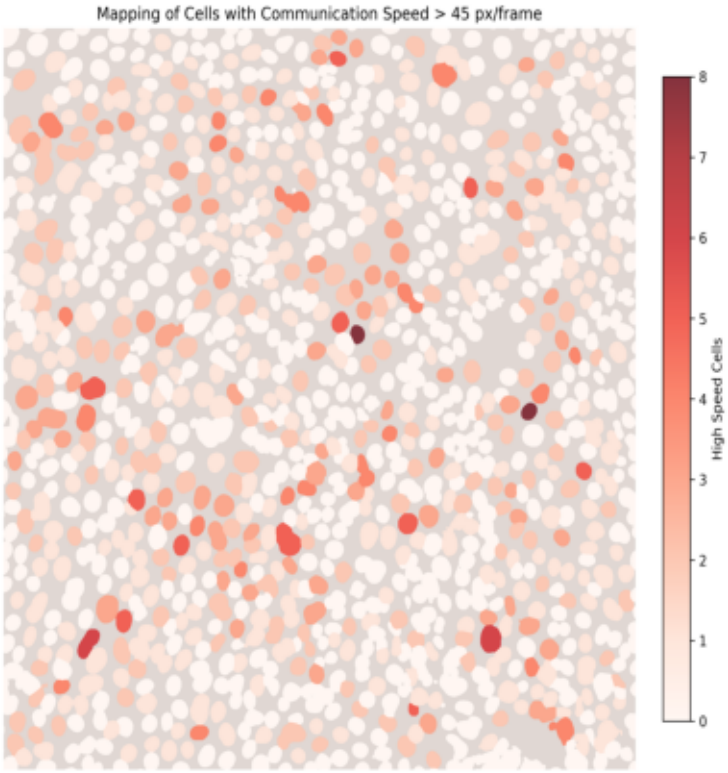

```
[2025-08-11 09:25:35] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 417 on 'Event time phase (fraction of event duration)'
(lower=-1.74, upper=2.32)
```



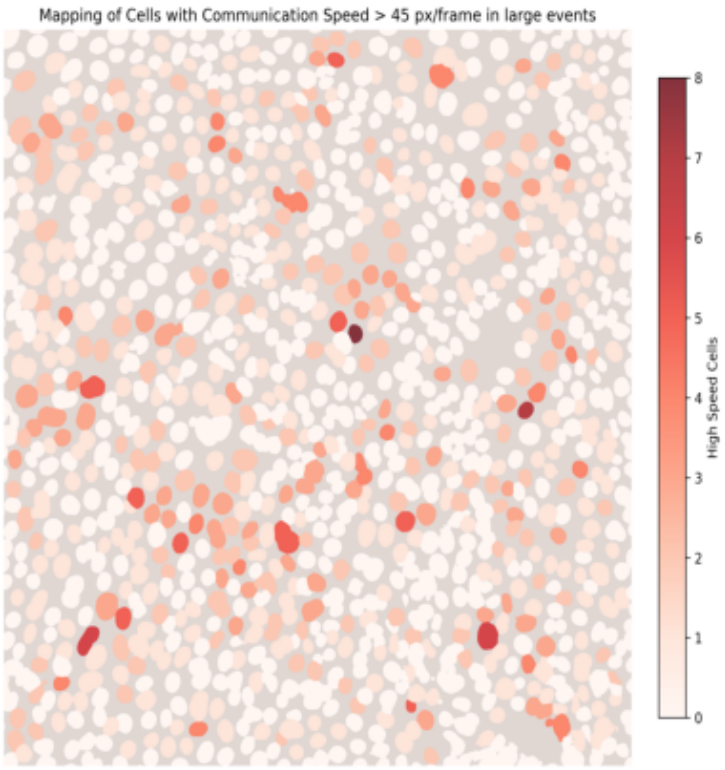

```
[2025-08-11 09:25:35] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 417 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.8, upper=2)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
3
4
Number of Communications
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

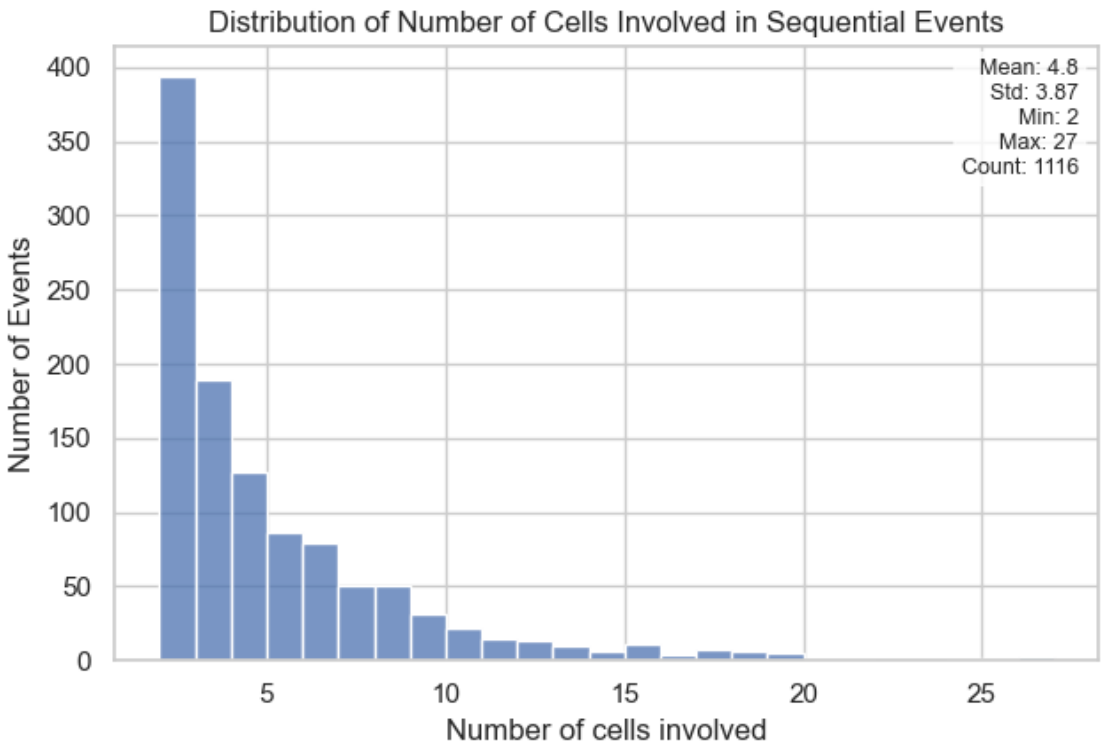
Cell Mapping with High Speed Cells Overlay - 20250326_IS1



Cell Mapping with High Speed Cells in Large Events Overlay - 20250326_IS1

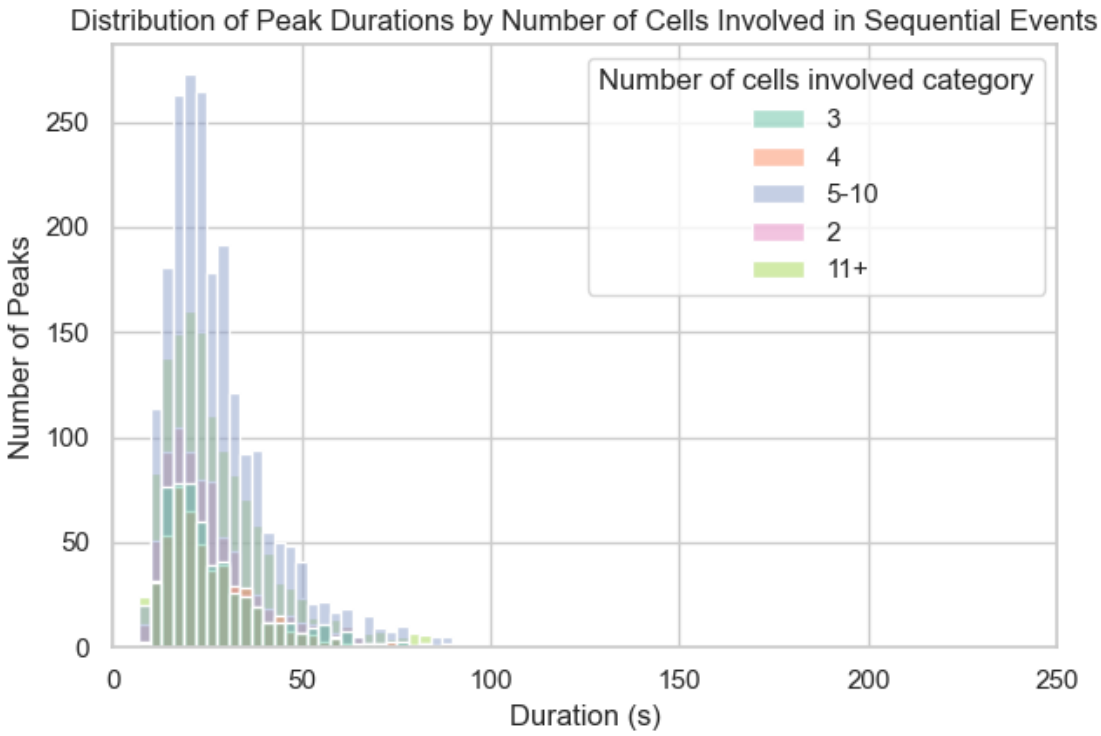


1.3.5 Number of cells involved per sequential events

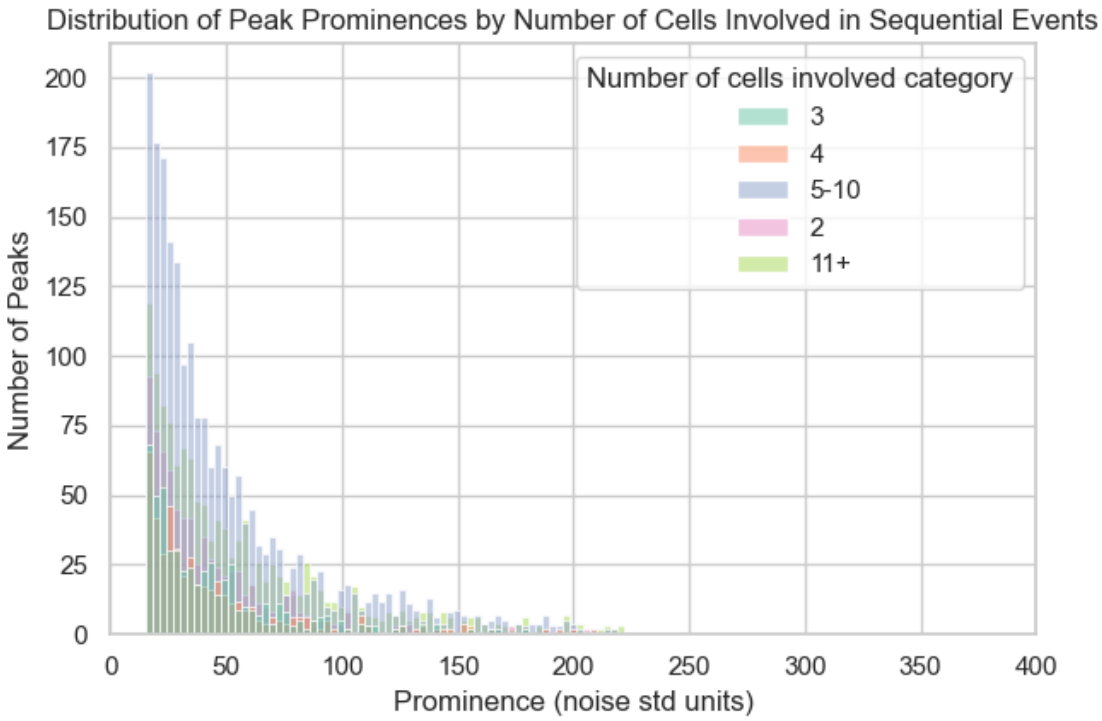


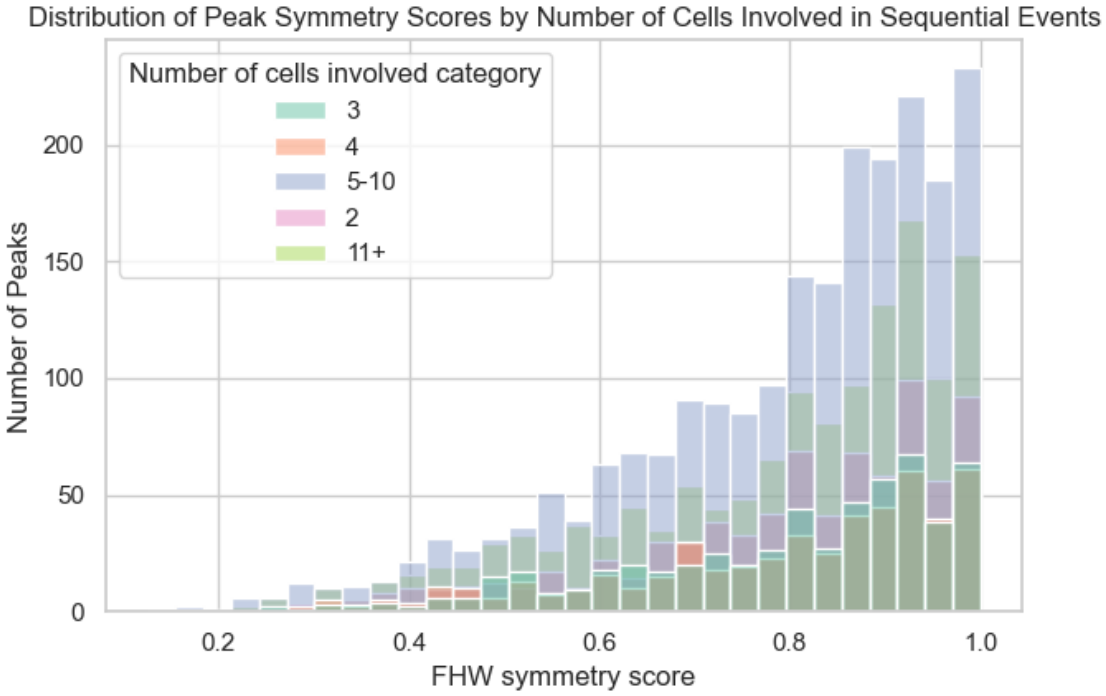
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:25:37] [INFO] calcium: plot_histogram_by_group: removed 112
outliers out of 5409 on 'Duration (s)' (lower=-6, upper=90)
```



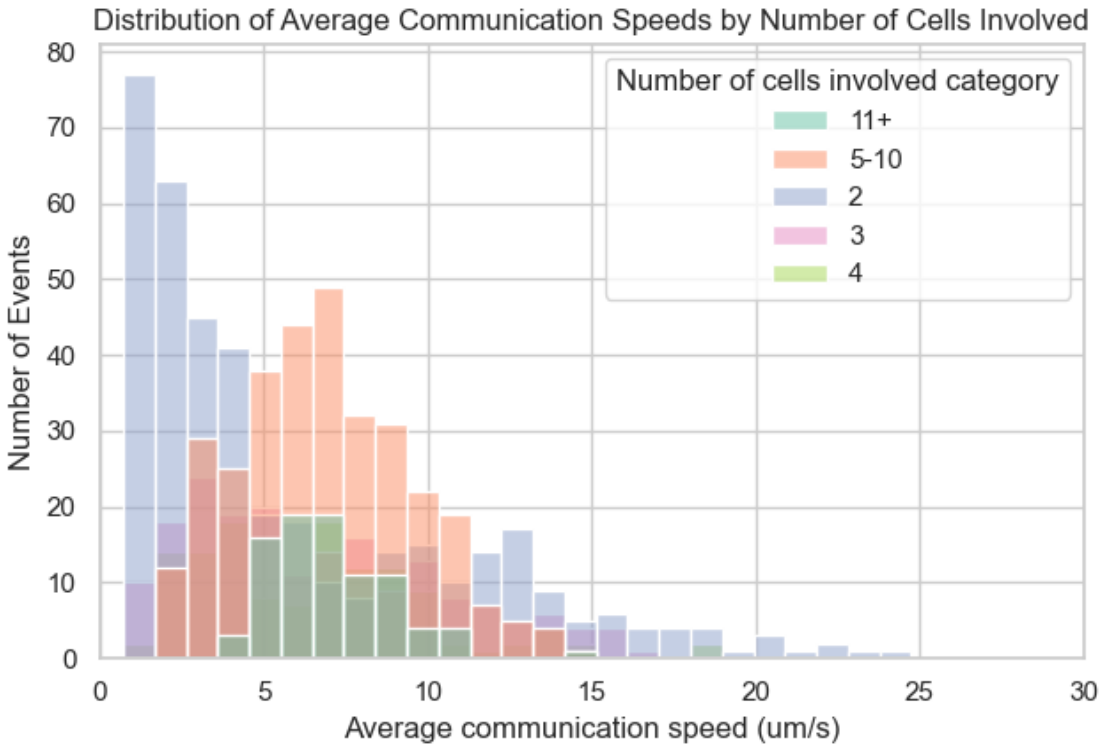

```
[2025-08-11 09:25:38] [INFO] calcium: plot_histogram_by_group: removed 127
outliers out of 5409 on 'Prominence (noise std units)' (lower=-43.15,
upper=223.85)
```



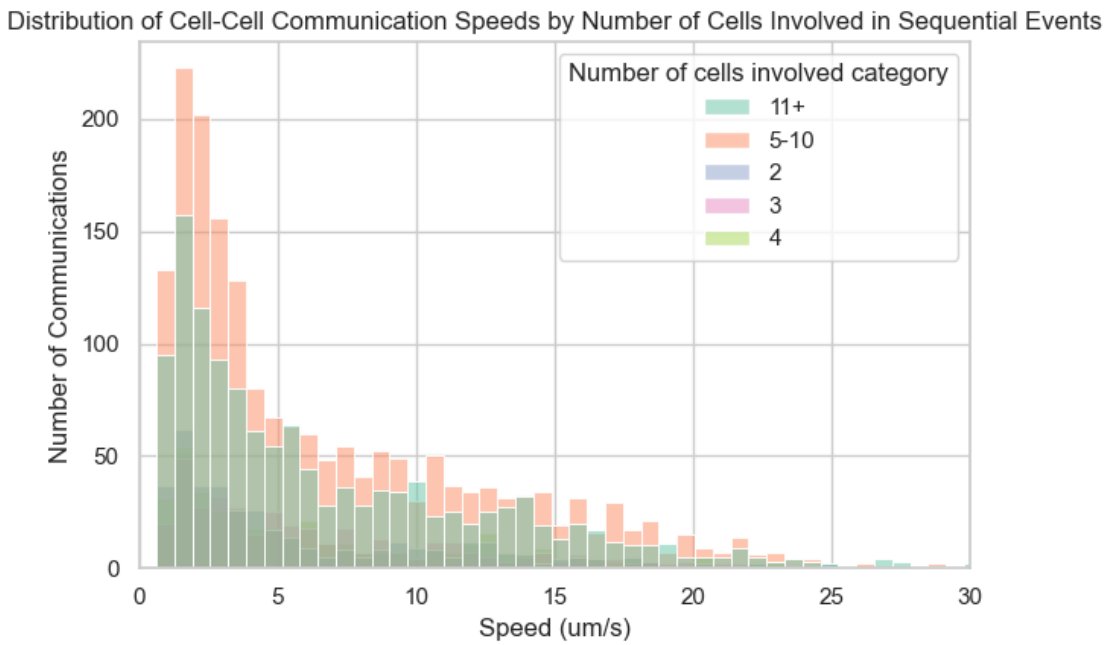



```
[2025-08-11 09:25:39] [INFO] calcium: plot_histogram_by_group: removed 2
```

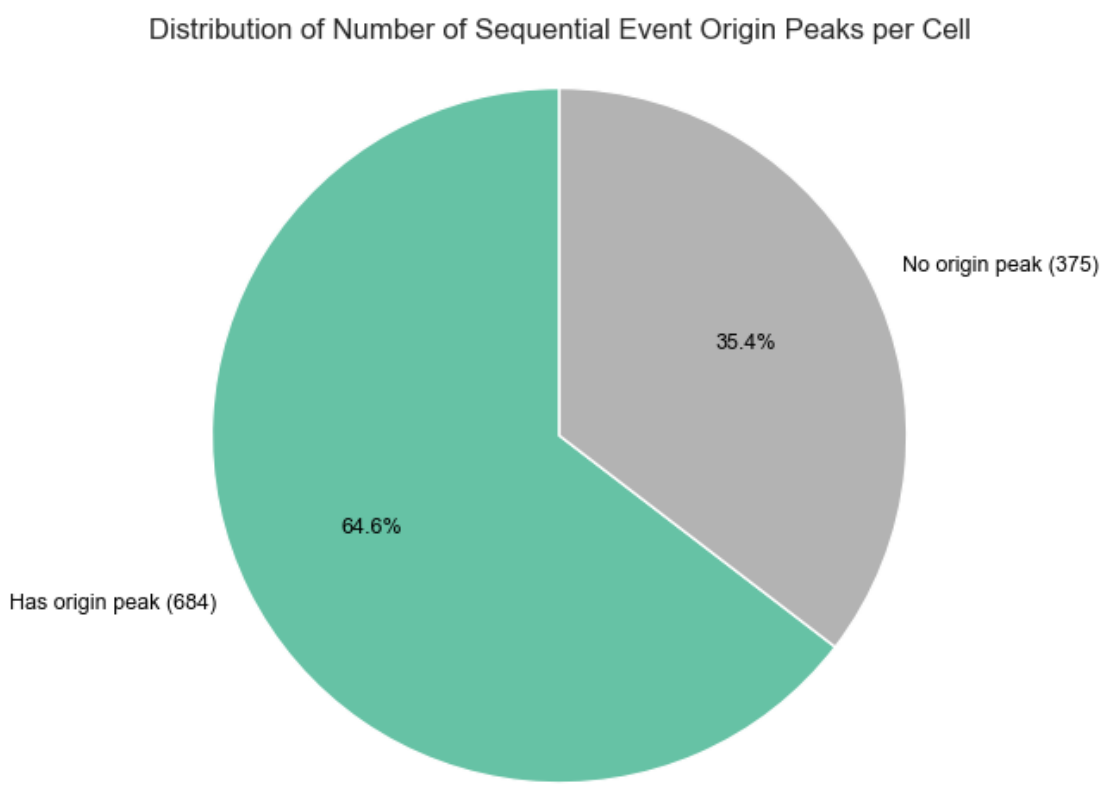
```
outliers out of 1116 on 'Average communication speed (um/s)' (lower=-12.71,
upper=24.81)
```

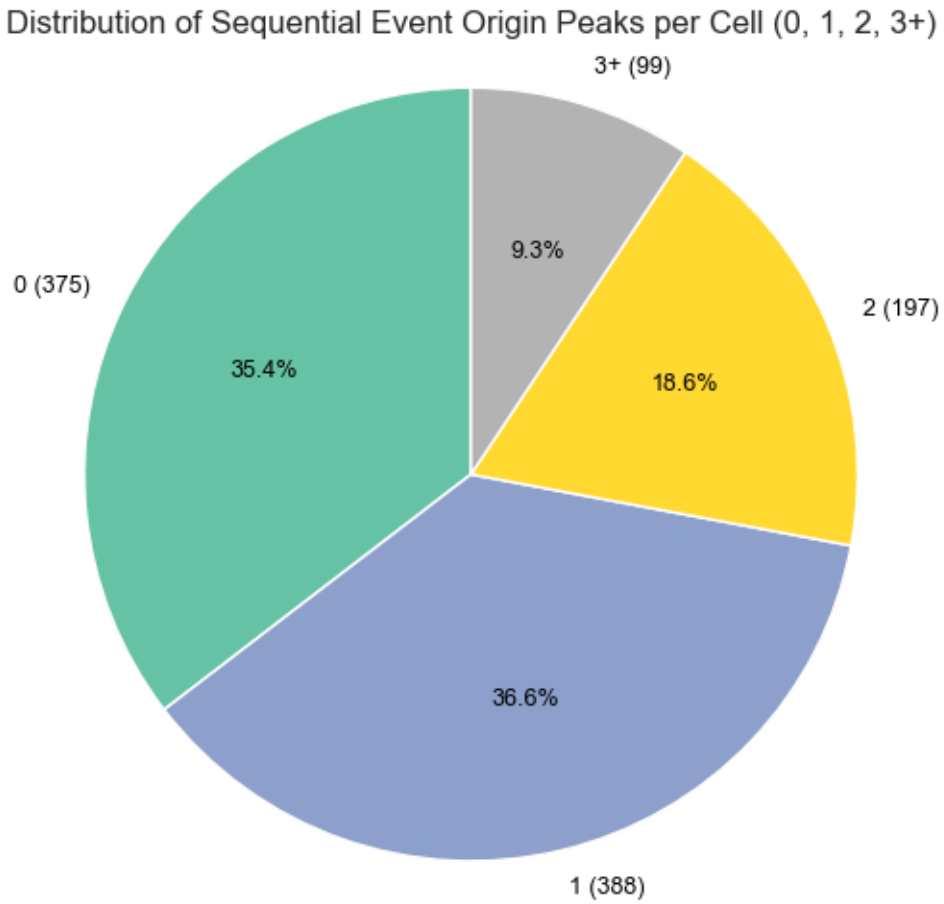



```
[2025-08-11 09:25:39] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 4293 on 'Speed (um/s)' (lower=-21.66, upper=34.06)
```

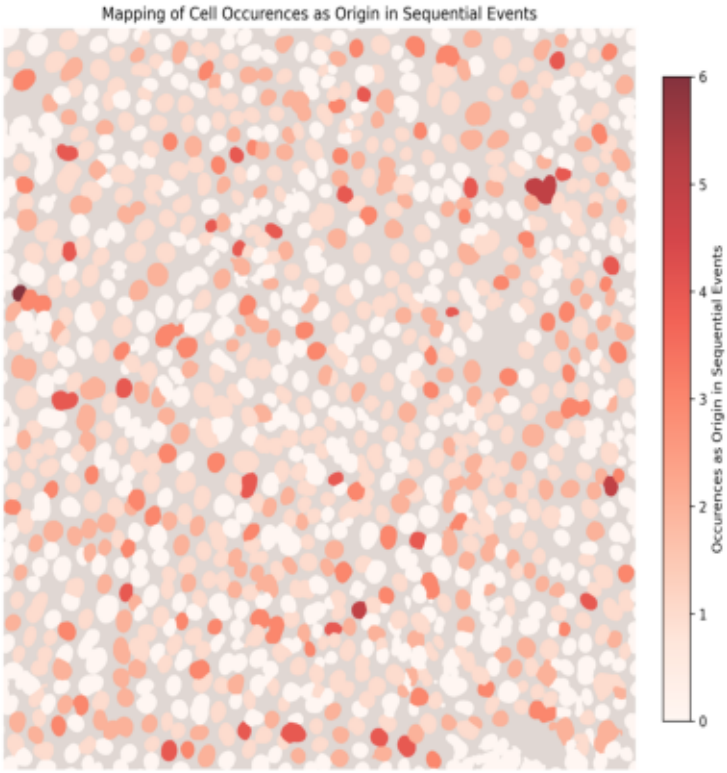


1.3.7 Cells occurences as origin in sequential events

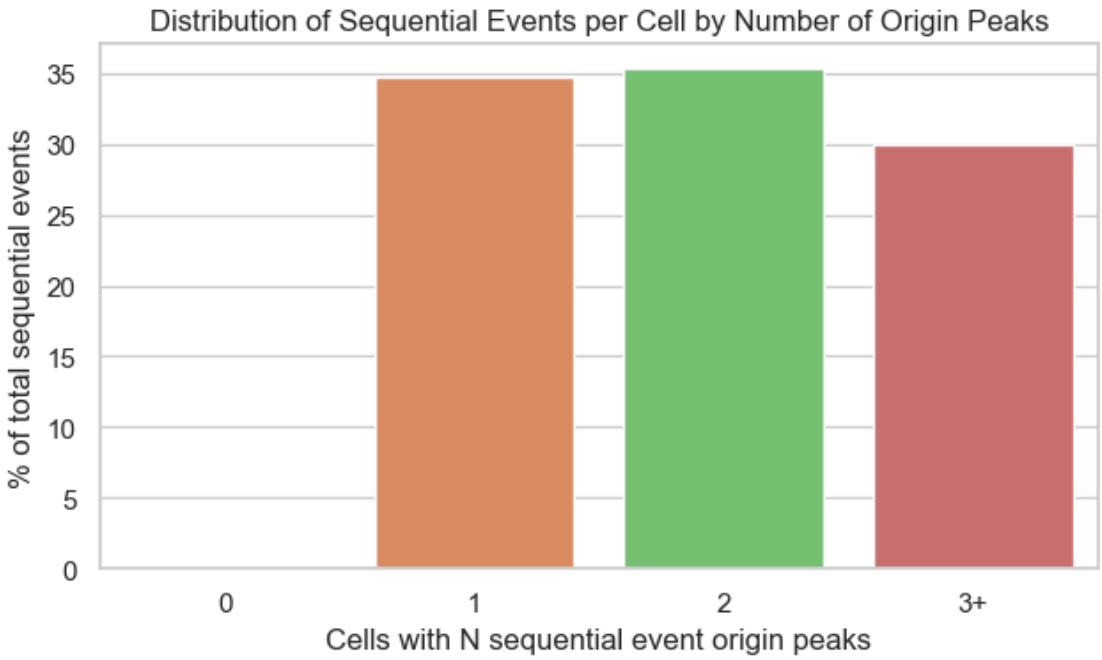



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (99)
9.3%
2 (197)
18.6%
1 (388)
36.6%
0 (375)
35.4%

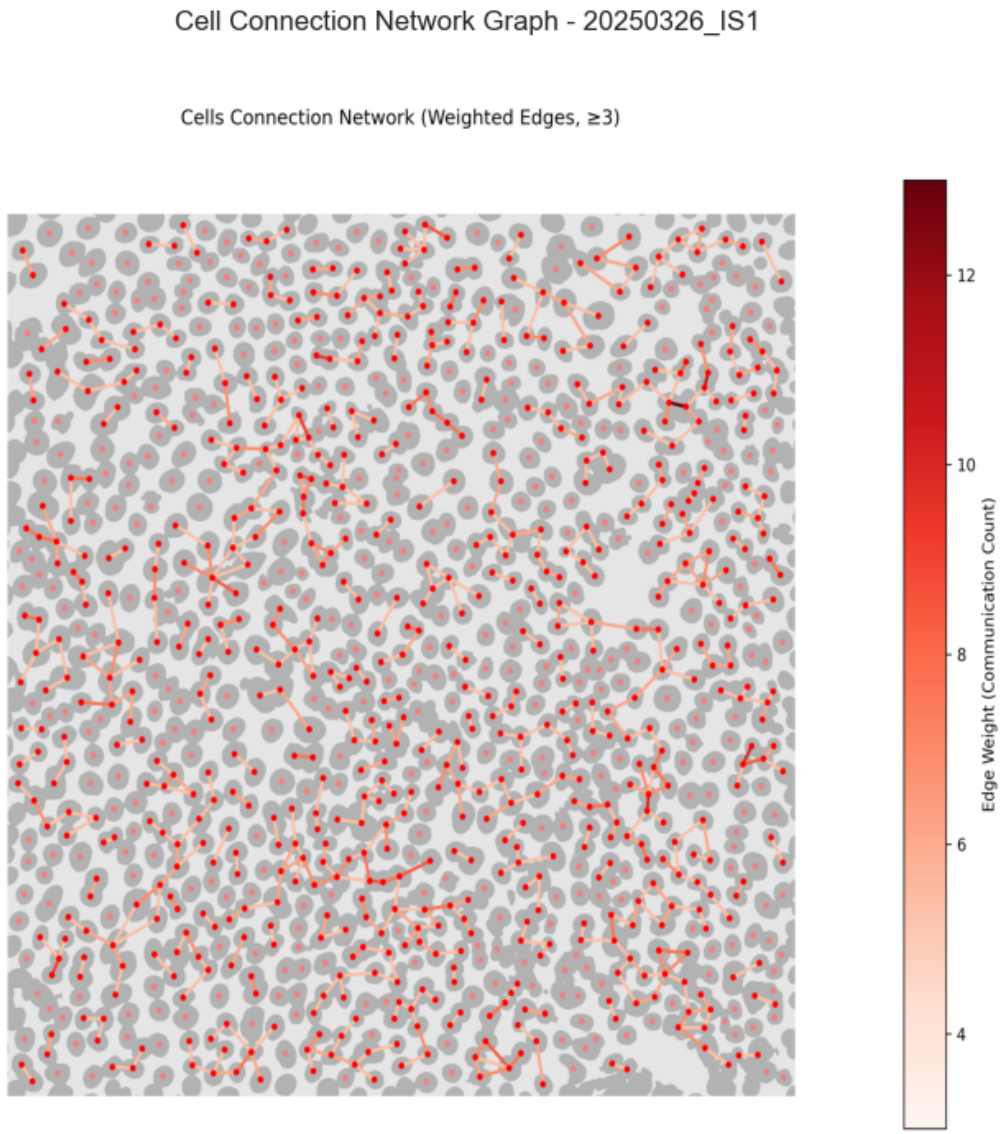
Cell Mapping with Origin Peaks Overlay - 20250326_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

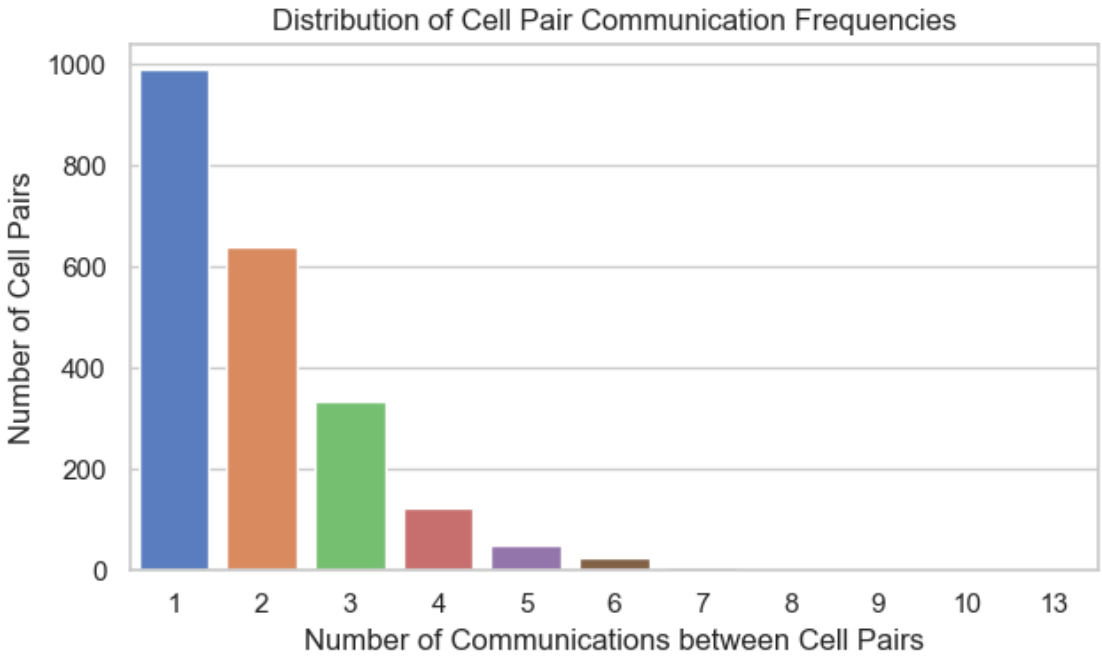

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



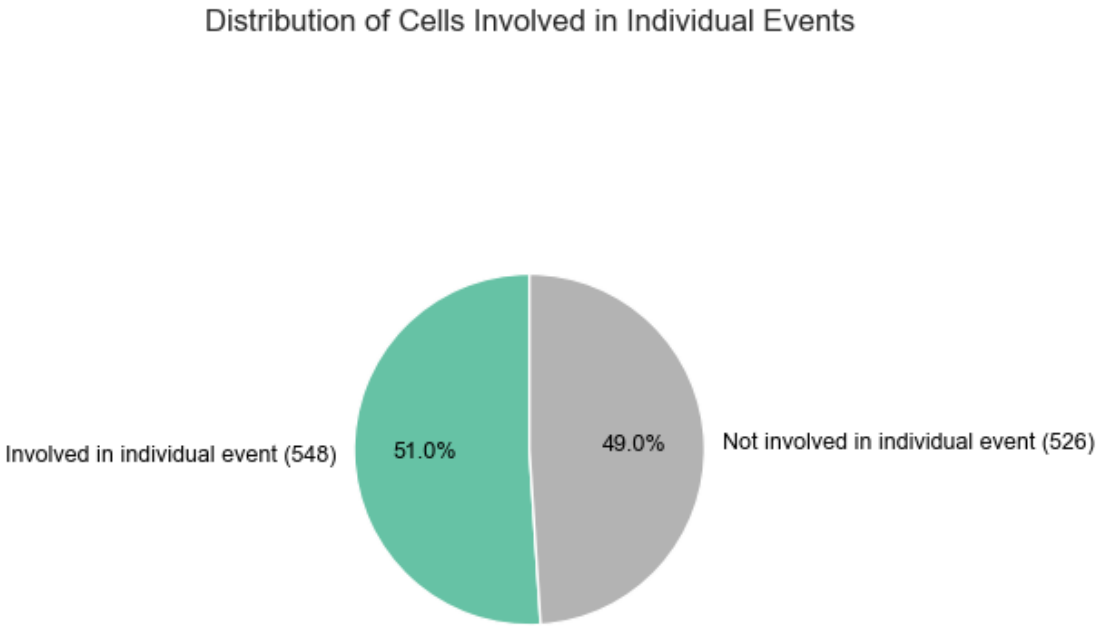

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

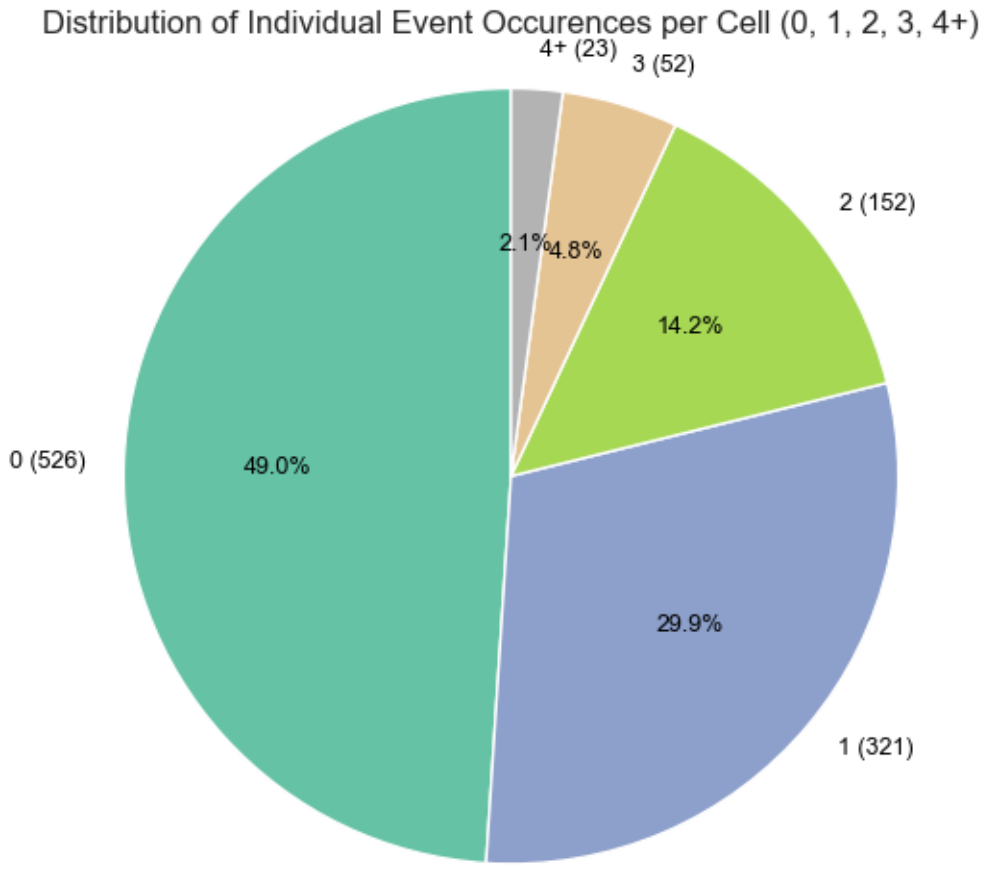
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
1000
800
600
400
200
0
1
2
3
4
5
6
7
8
9
10
13
Number of Communications between Cell Pairs

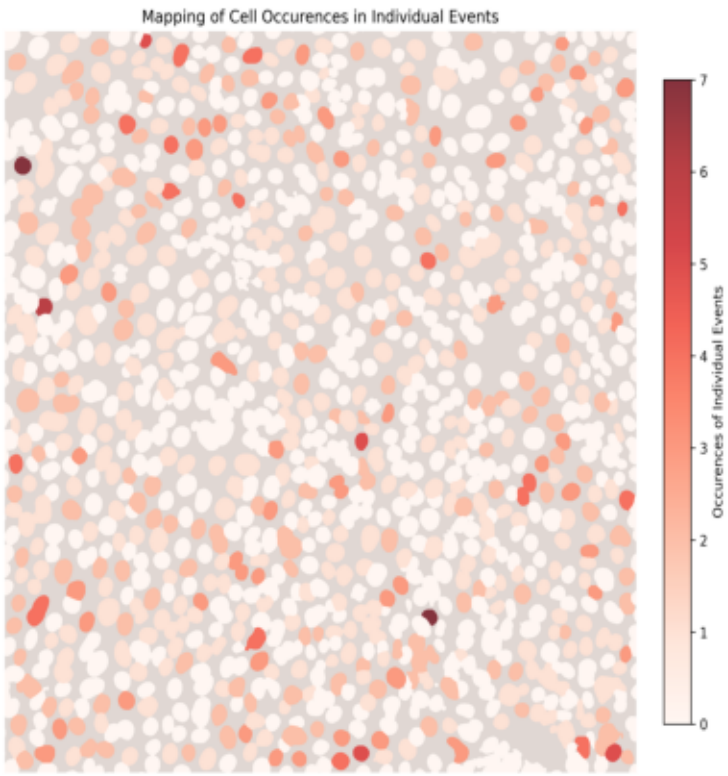
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



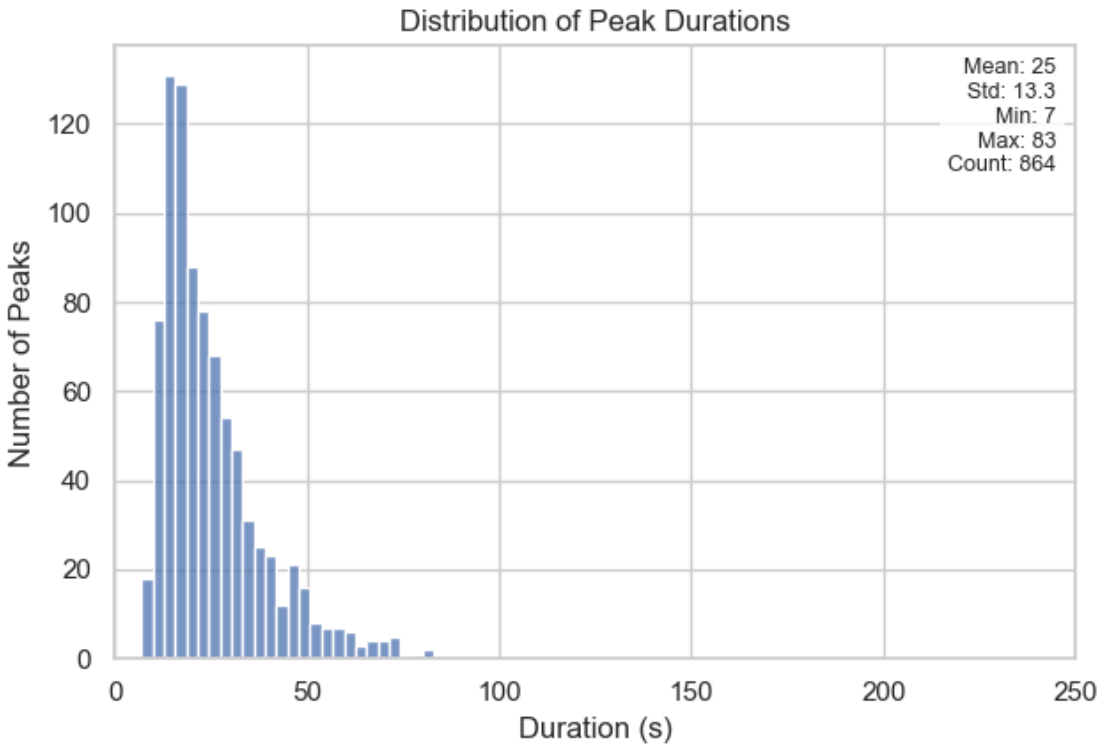

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (23)
3 (52)
2 (152)
2.1%
4.8%
14.2%
0 (526)
49.0%
29.9%
1 (321)

Cell Mapping with Occurences in Individual Events Overlay - 20250326_IS1

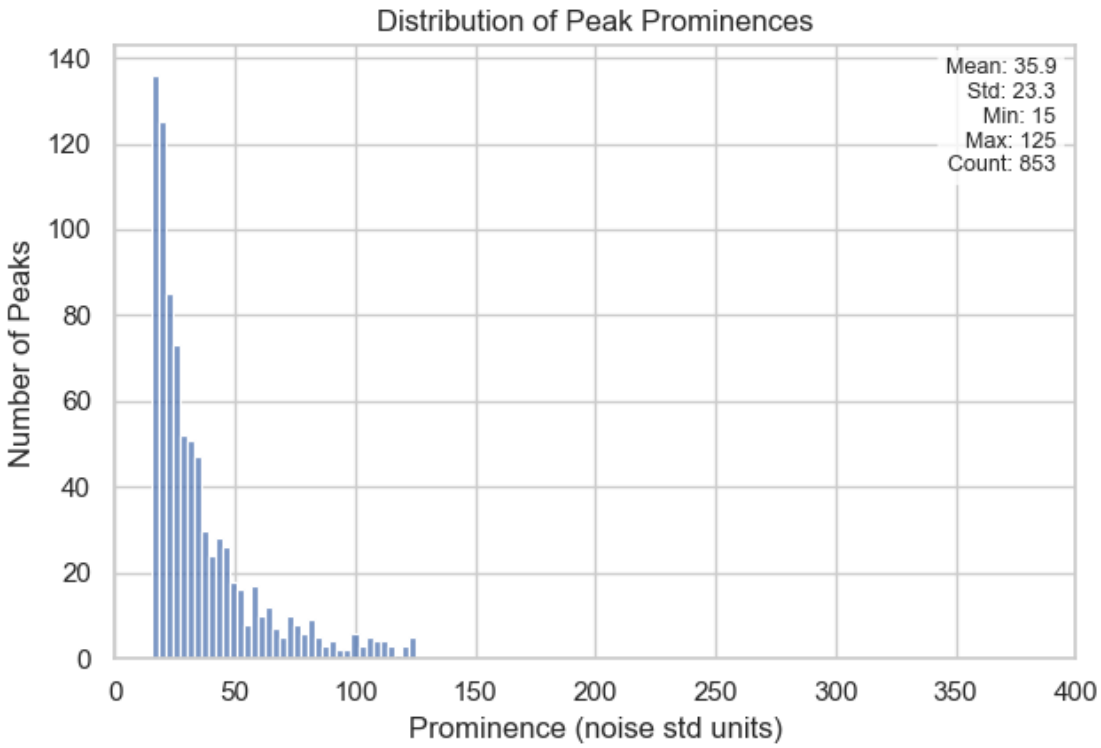


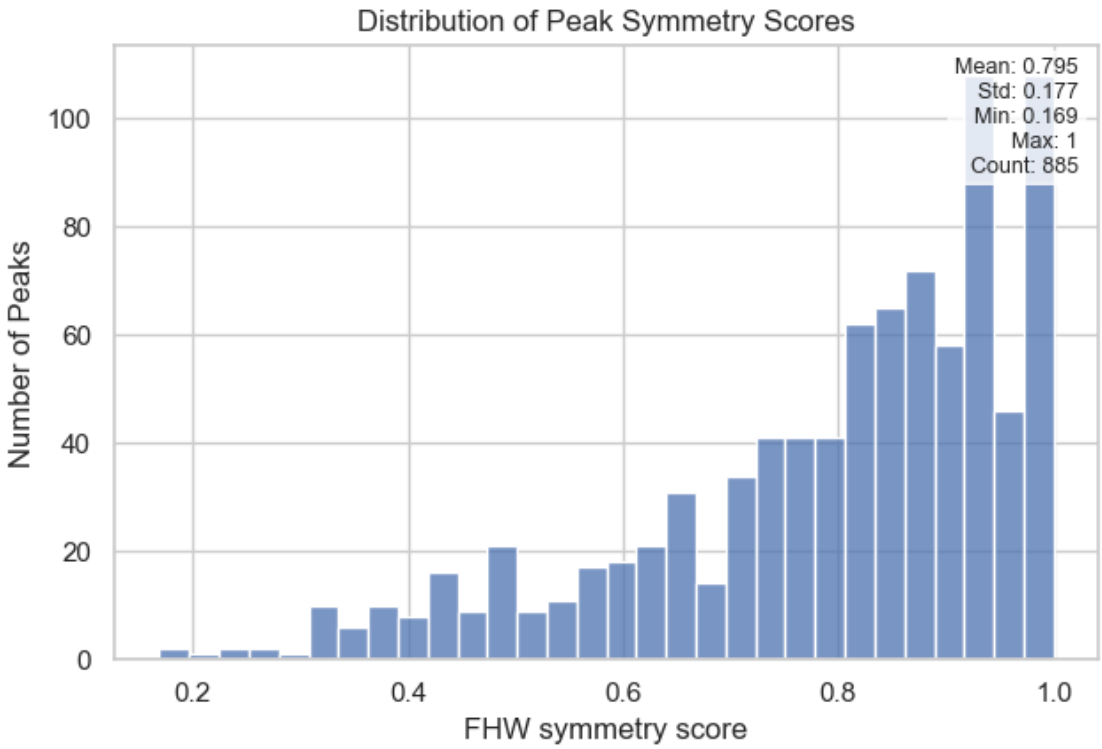
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:25:43] [INFO] calcium: plot_histogram: removed 21 outliers out of
885 on 'Duration (s)' (lower=-36, upper=83)
```

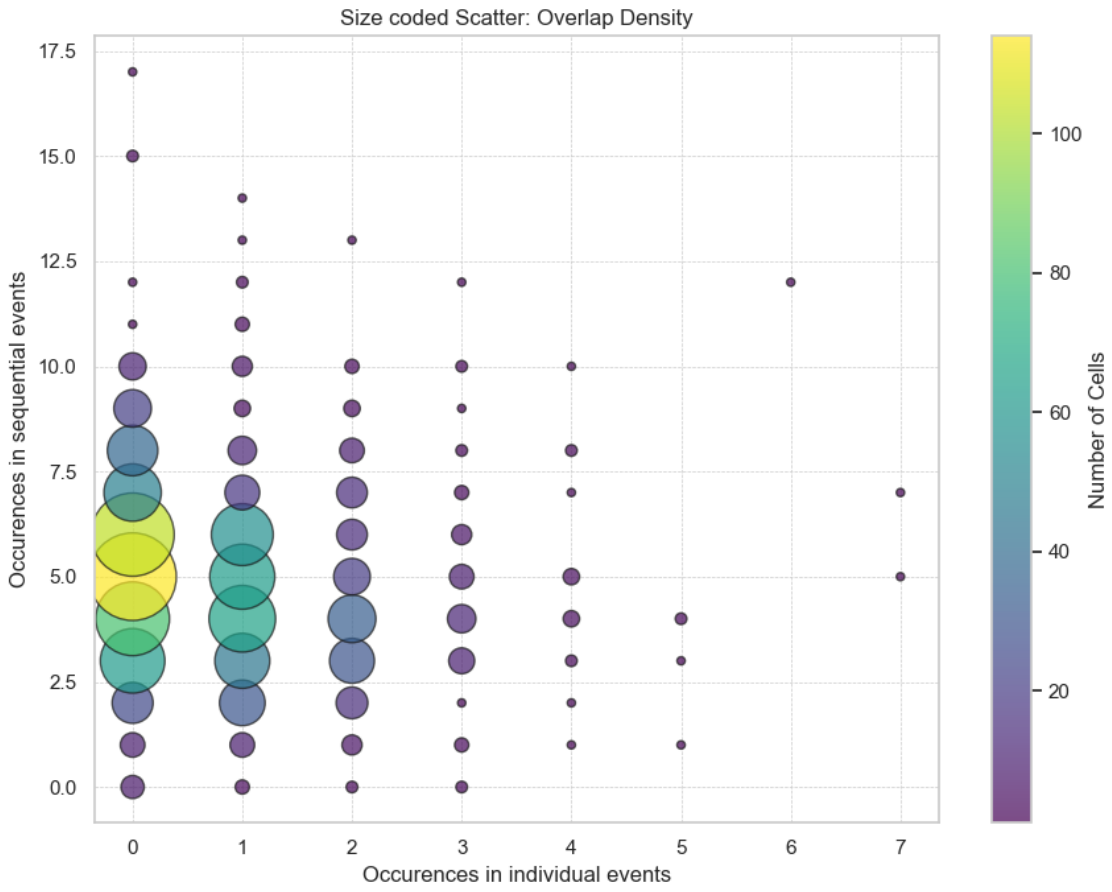



```
[2025-08-11 09:25:43] [INFO] calcium: plot_histogram: removed 32 outliers out of
885 on 'Prominence (noise std units)' (lower=-59, upper=125.1)
```

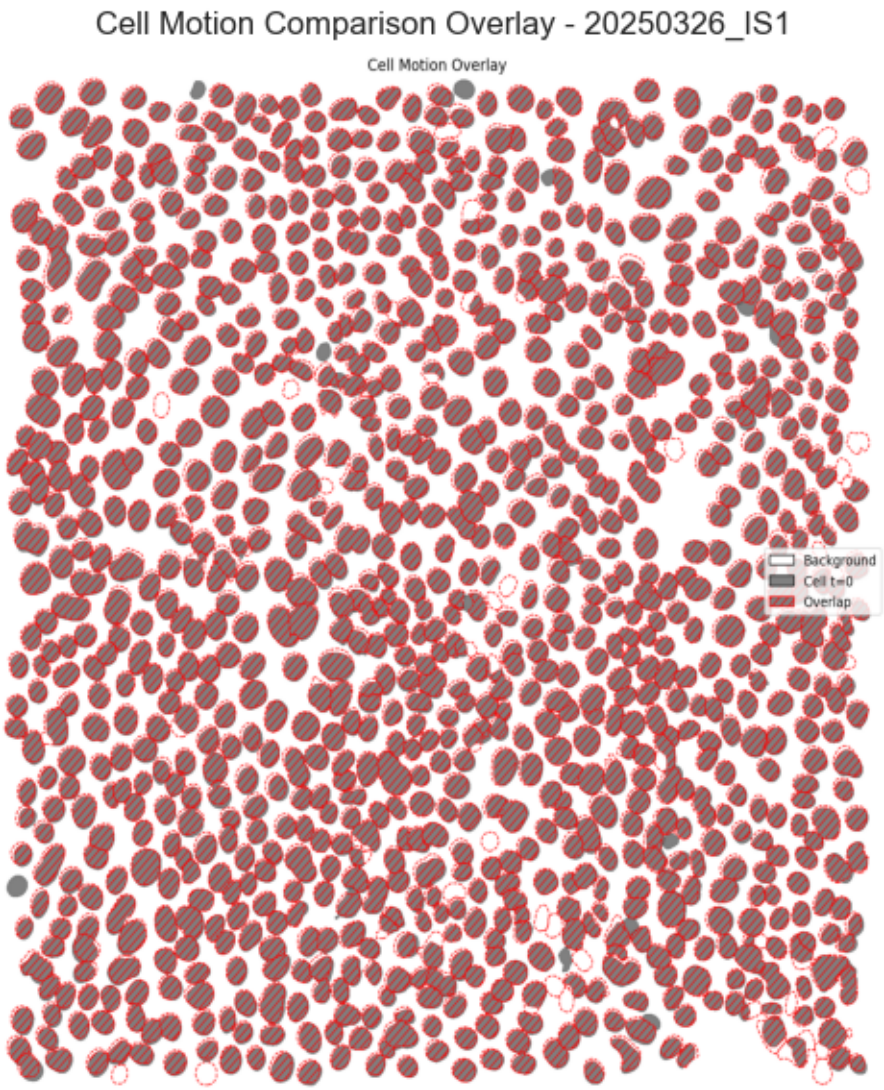

Distribution of Peak Prominences
Mean: 35.9
Std: 23.3
Min: 15
Max: 125
Count: 853
Number of Peaks
Prominence (noise std units)
0
20
40
60
80
100
120
140
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores
Mean: 0.795
Std: 0.177
Min: 0.169
Max: 1
Count: 885
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 1057
- Hoechst image taken at t=1801: 1054
- Number of cells difference: absolute 3, relative 0.28%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1118572
- Pixels segmented as cell at t=1801: 1144633
- Overlapping pixels between t=0 and t=1801: 985731(87.11% of total)
- Pixels exclusive to t=0: 132841 (11.88% of total)
- Pixels exclusive to t=1801: 158902 (13.88% of total)
```

executed

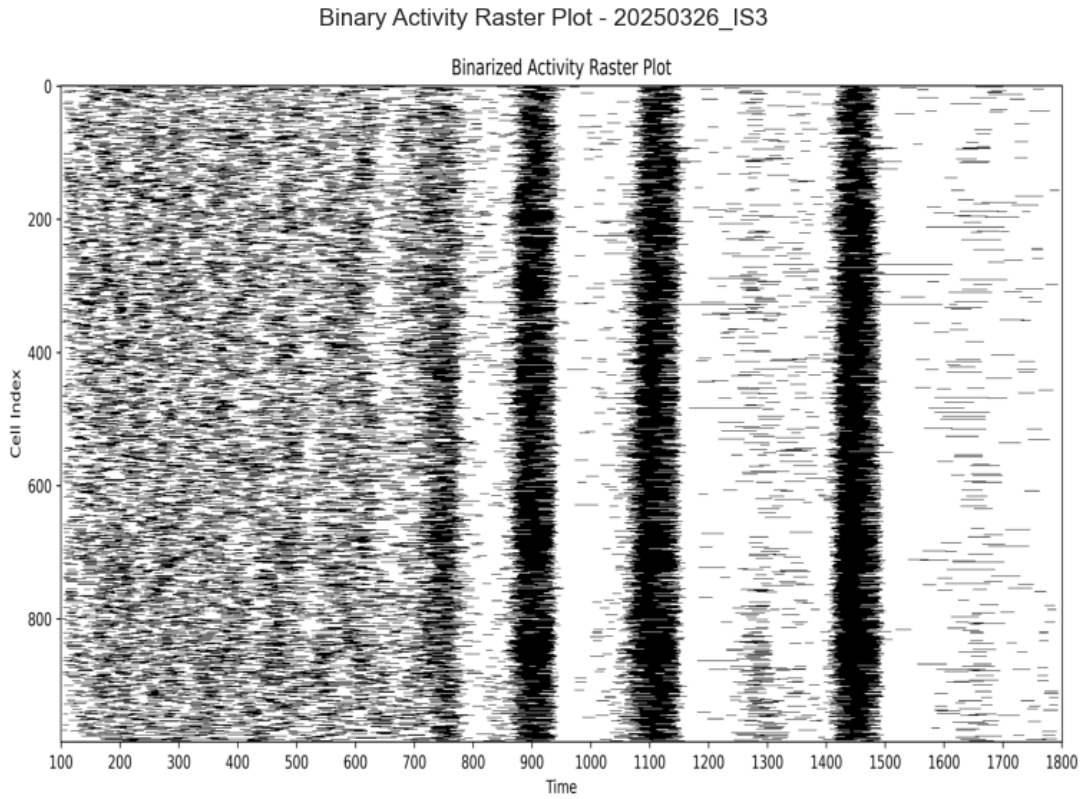
August 11, 2025

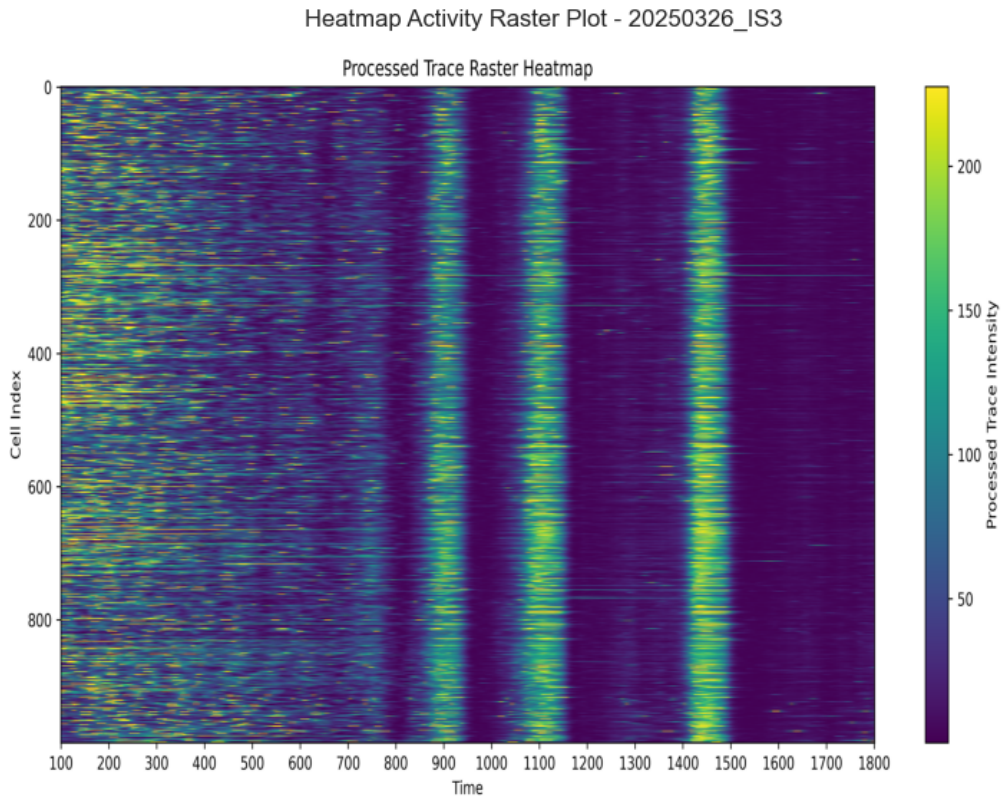
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



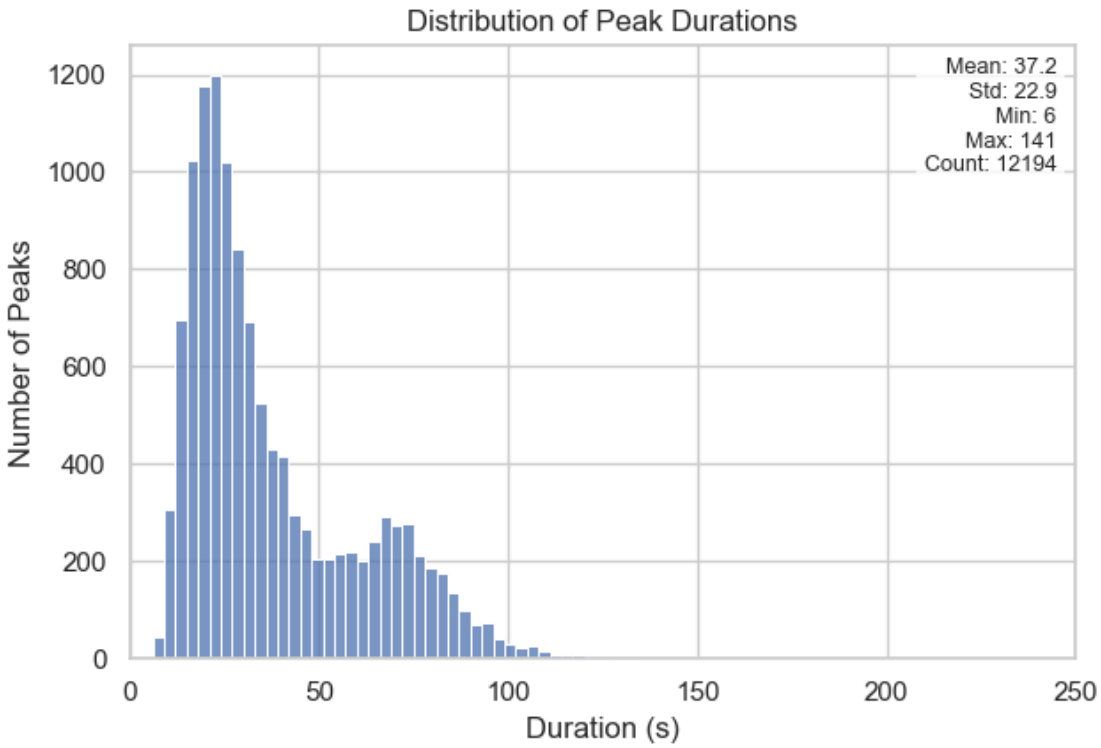


1.1.2 Peaks population

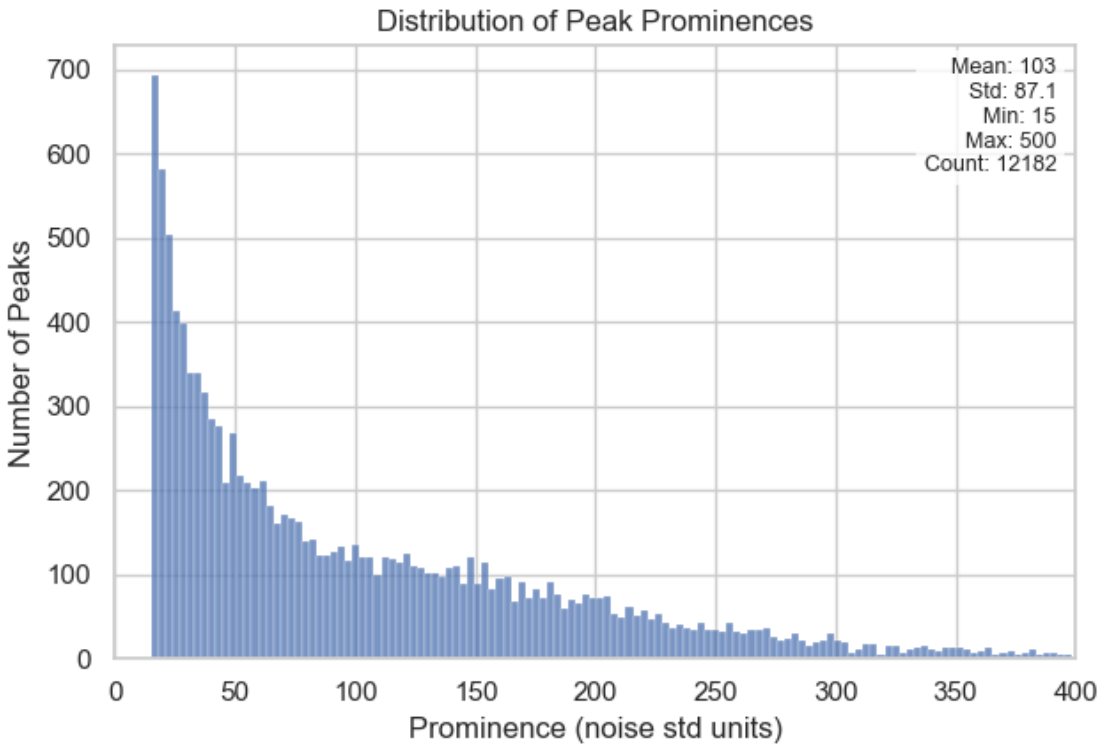
```
Total number of peaks: 12215
Total number of cells: 985
```

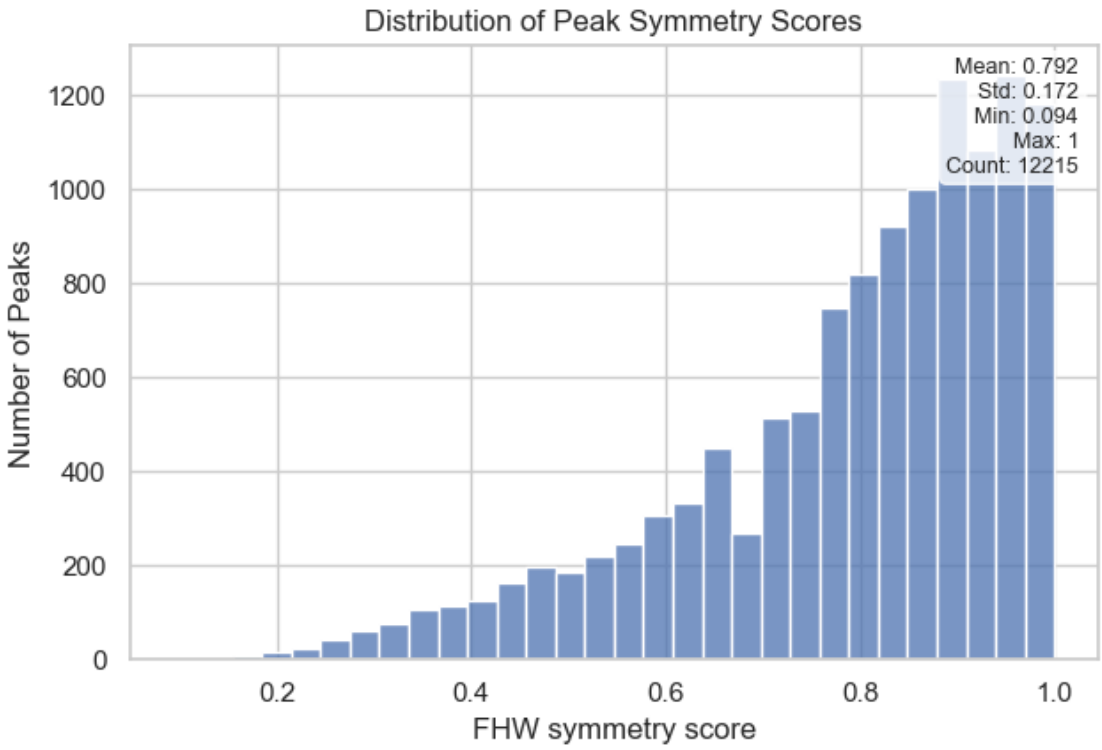
1.1.3 Peaks statistics

```
[2025-08-11 09:35:53] [INFO] calcium: plot_histogram: removed 21 outliers out of
12215 on 'Duration (s)' (lower=-73, upper=144)
```

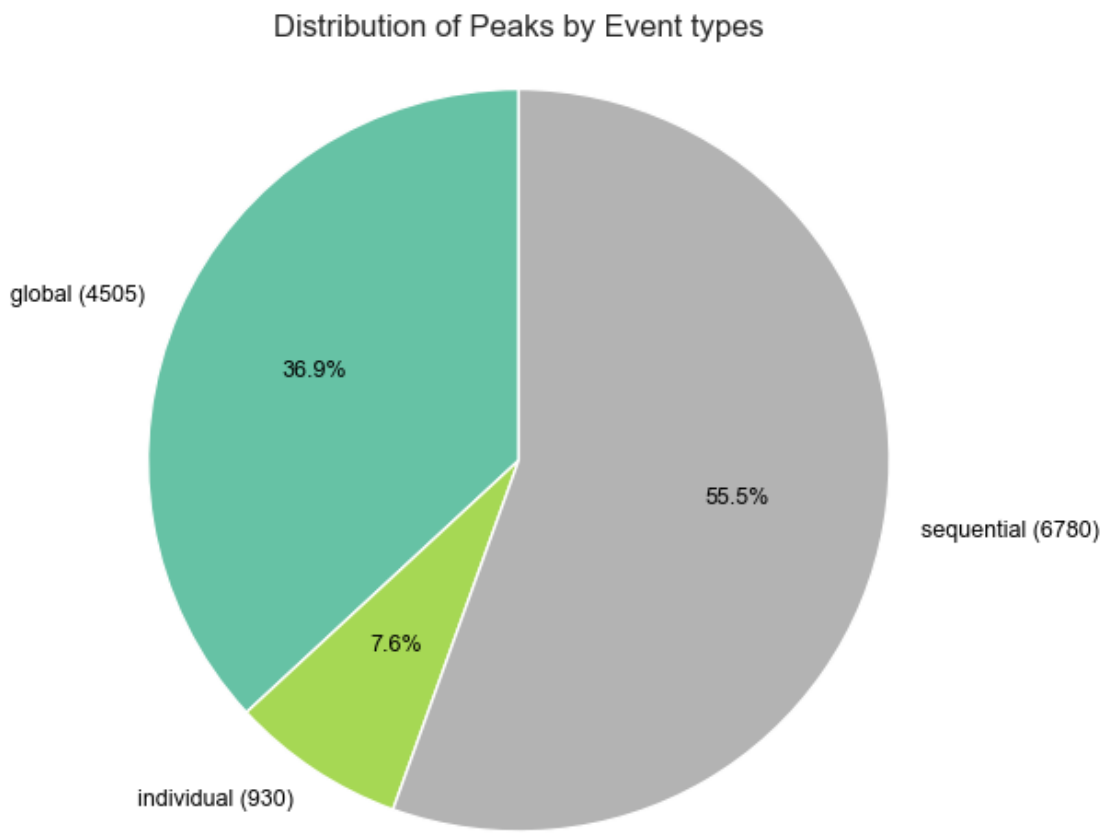



```
[2025-08-11 09:35:53] [INFO] calcium: plot_histogram: removed 33 outliers out of
12215 on 'Prominence (noise std units)' (lower=-318.8, upper=504.4)
```


Distribution of Peak Prominences
Mean: 103
Std: 87.1
Min: 15
Max: 500
Count: 12182
Number of Peaks
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

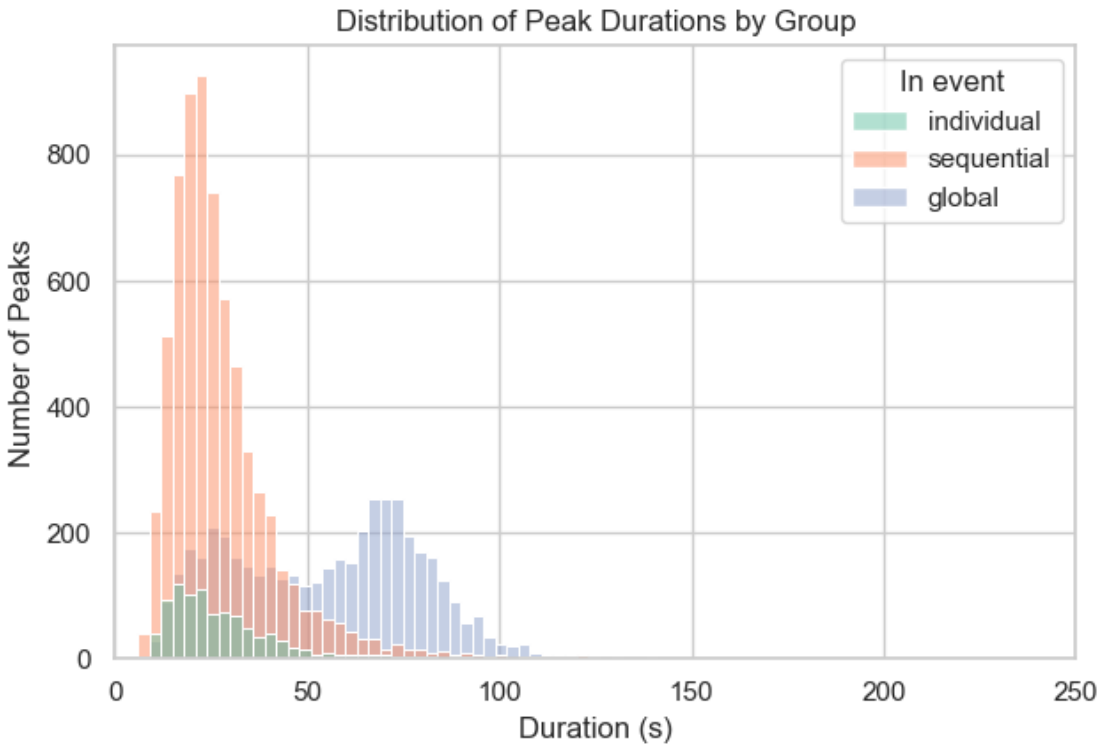

Distribution of Peak Symmetry Scores
Mean: 0.792
Std: 0.172
Min: 0.094
Max: 1
Count: 12215
Number of Peaks
0
200
400
600
800
1000
1200
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

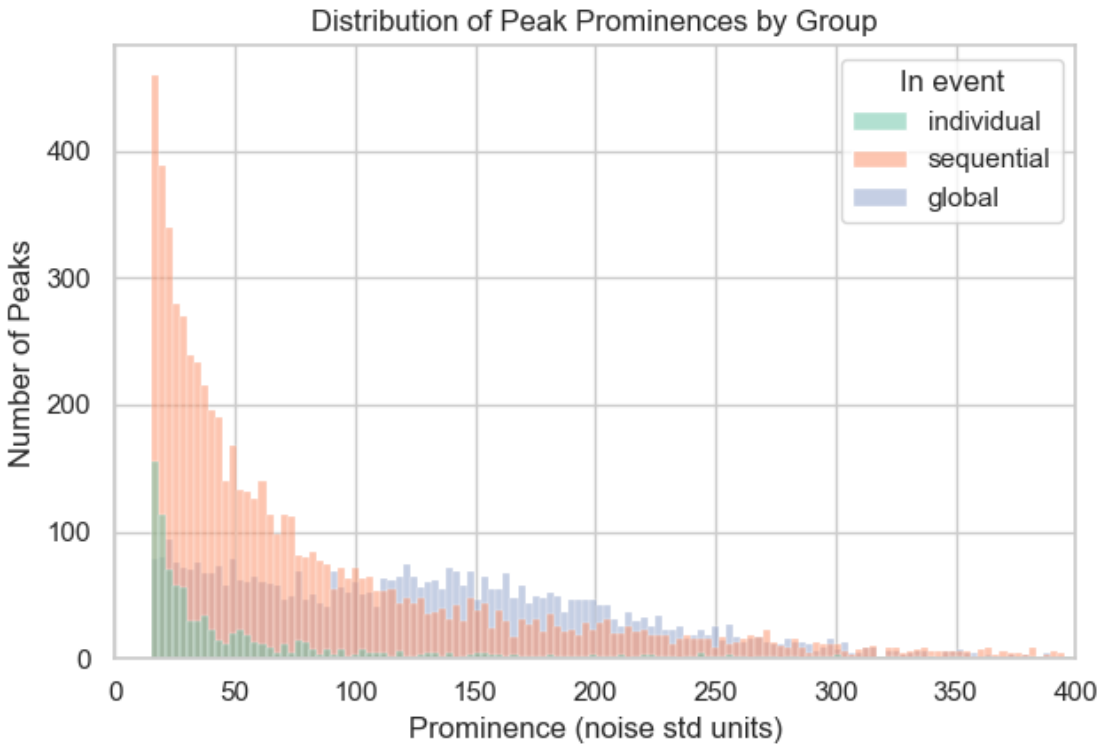


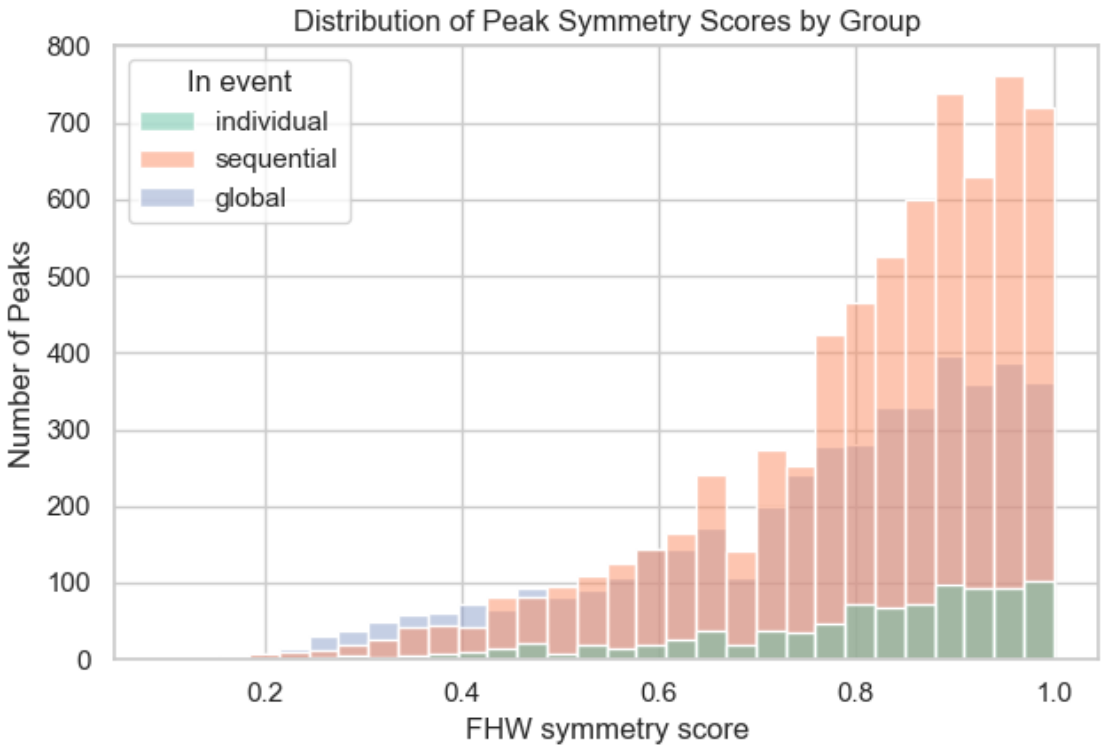
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:35:54] [INFO] calcium: plot_histogram_by_group: removed 21
outliers out of 12215 on 'Duration (s)' (lower=-73, upper=144)
```




```
[2025-08-11 09:35:54] [INFO] calcium: plot_histogram_by_group: removed 33
outliers out of 12215 on 'Prominence (noise std units)' (lower=-318.8,
upper=504.4)
```

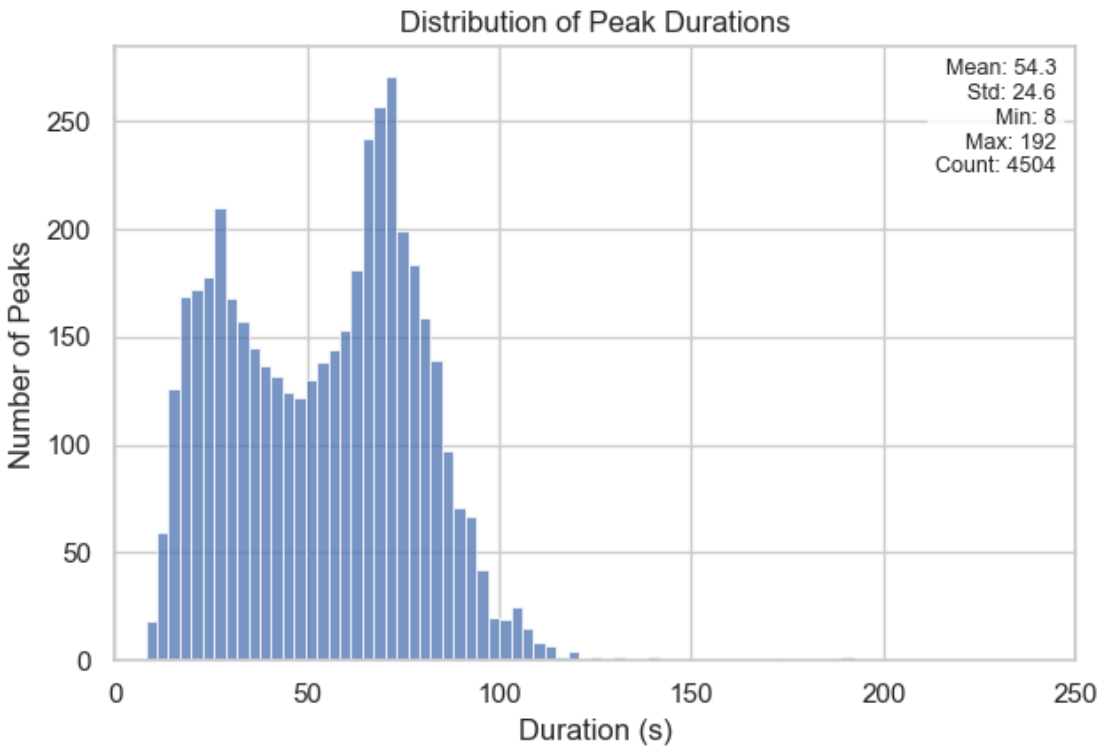

Distribution of Peak Prominences by Group
In event
individual
sequential
global
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
individual
sequential
global
Number of Peaks
0
100
200
300
400
500
600
700
800
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

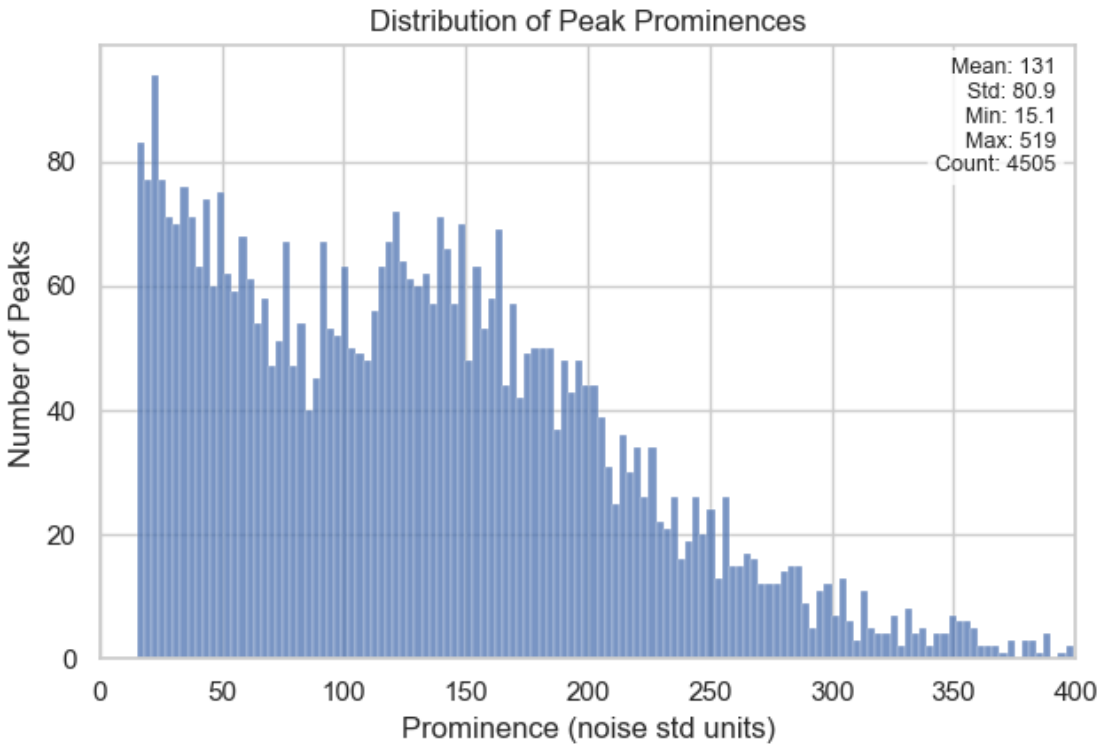
1.2 GLOBAL EVENTS

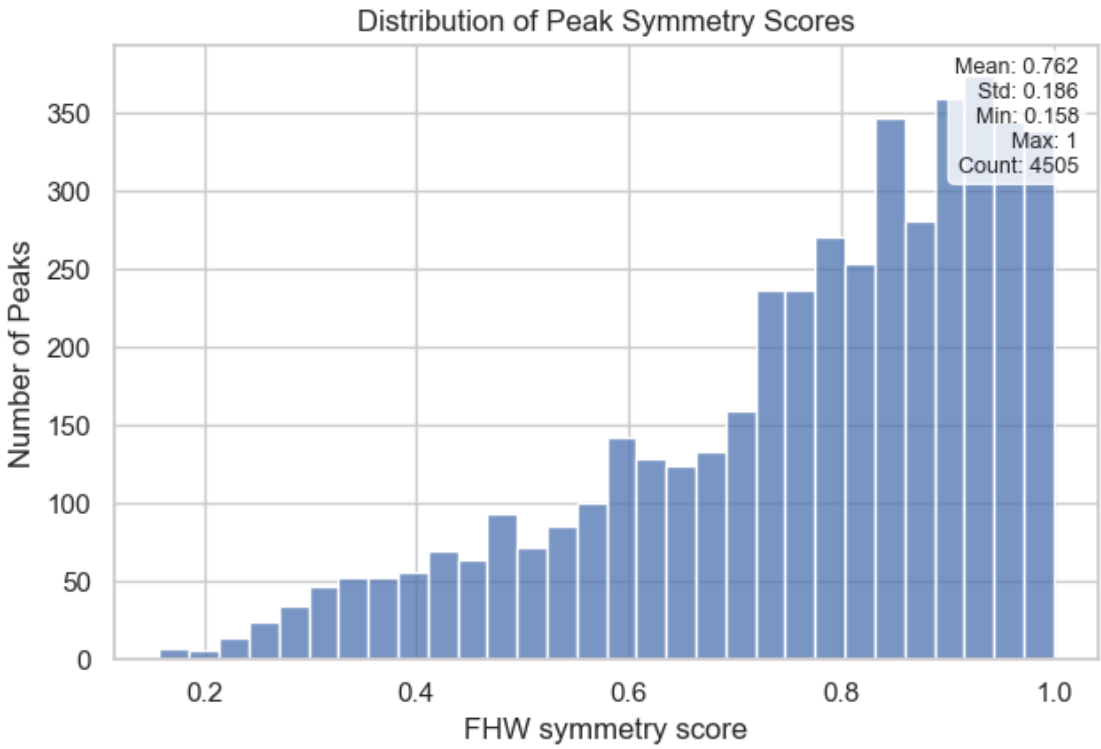
1.2.1 Peak statistics in global events

```
[2025-08-11 09:35:55] [INFO] calcium: plot_histogram: removed 1 outliers out of
4505 on 'Duration (s)' (lower=-91, upper=196)
```



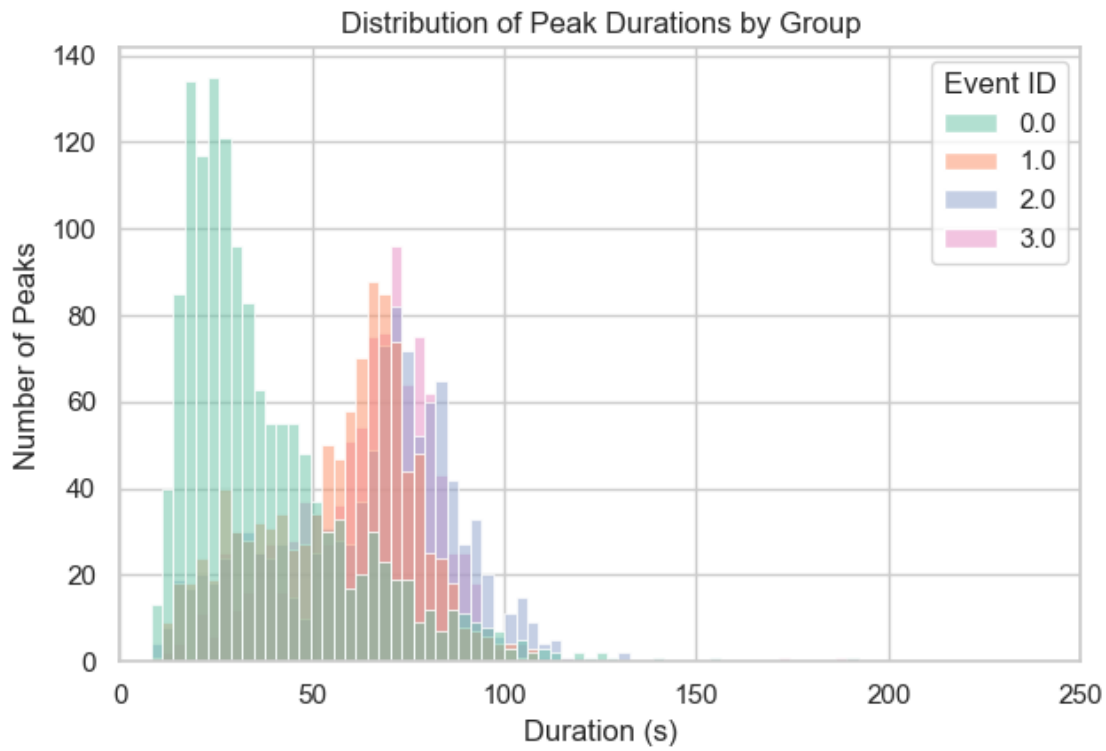

```
[2025-08-11 09:35:55] [INFO] calcium: plot_histogram: removed 0 outliers out of
4505 on 'Prominence (noise std units)' (lower=-297.8, upper=542.2)
```


Distribution of Peak Prominences
Mean: 131
Std: 80.9
Min: 15.1
Max: 519
Count: 4505
Number of Peaks
0
20
40
60
80
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

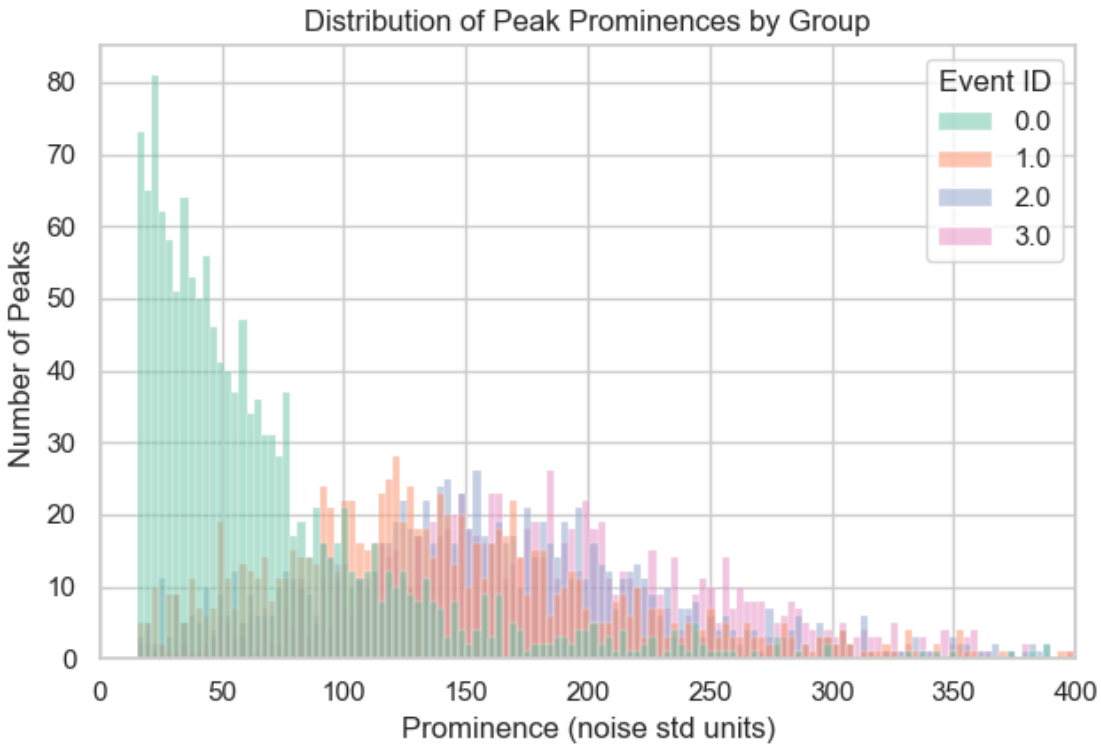

Distribution of Peak Symmetry Scores
Mean: 0.762
Std: 0.186
Min: 0.158
Max: 1
Count: 4505
Number of Peaks
0
50
100
150
200
250
300
350
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

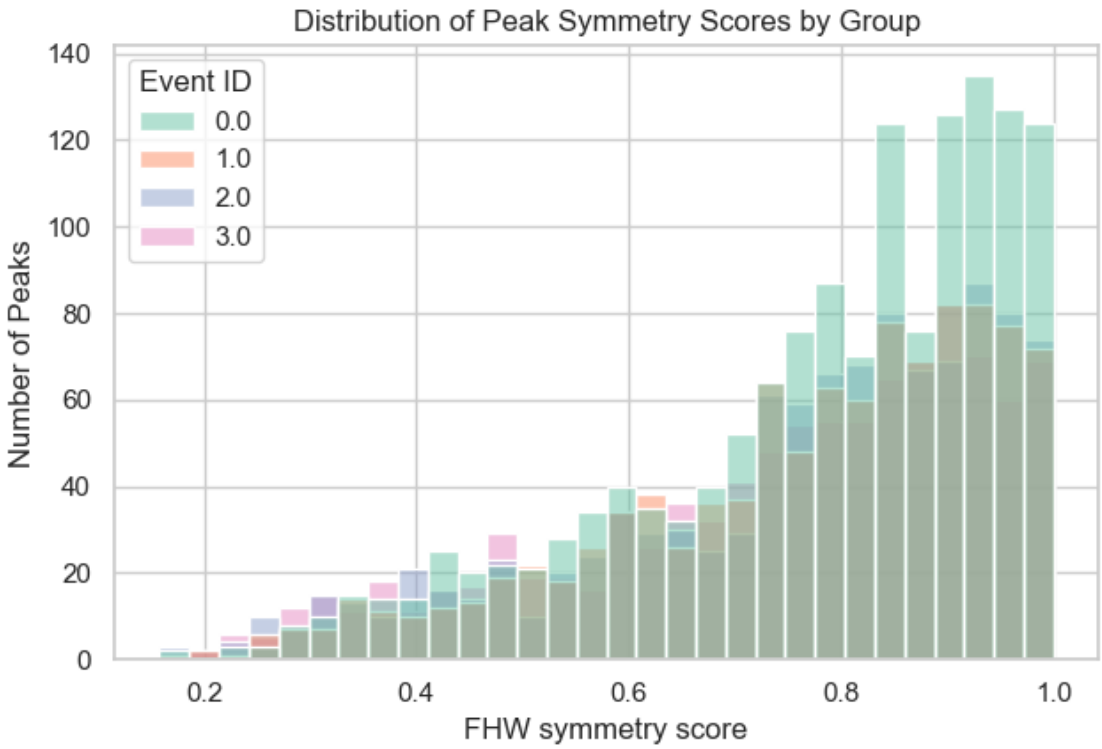
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:35:55] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 4505 on 'Duration (s)' (lower=-91, upper=196)
```

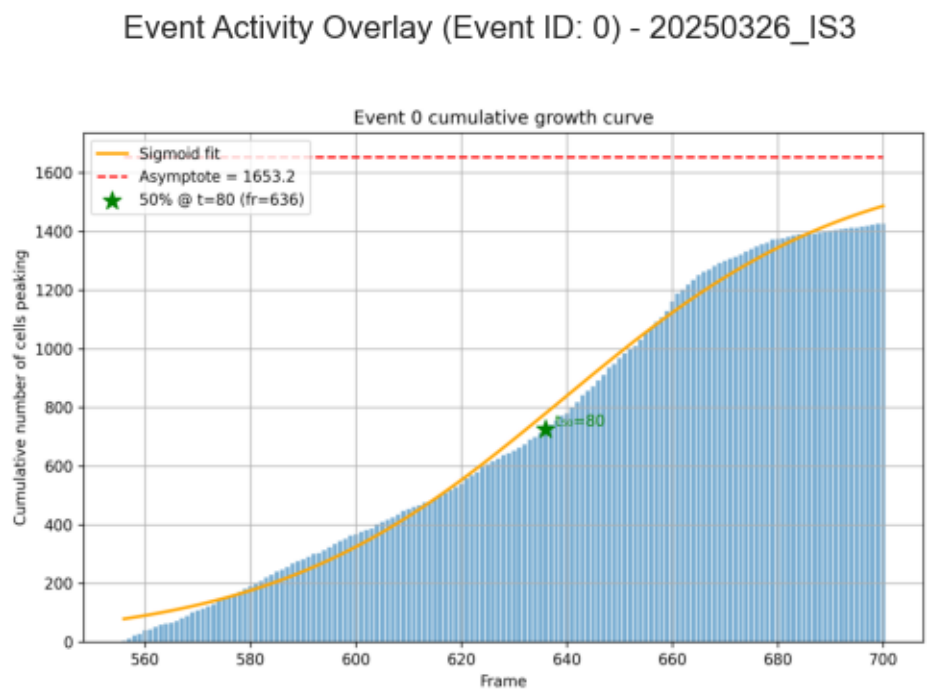


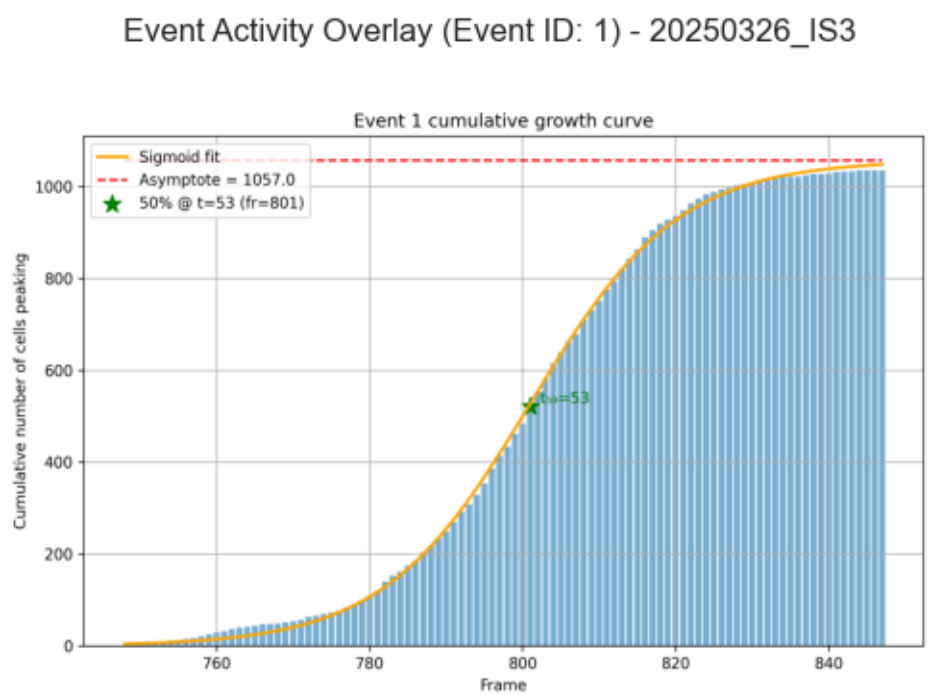

```
[2025-08-11 09:35:55] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 4505 on 'Prominence (noise std units)' (lower=-297.8,
upper=542.2)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

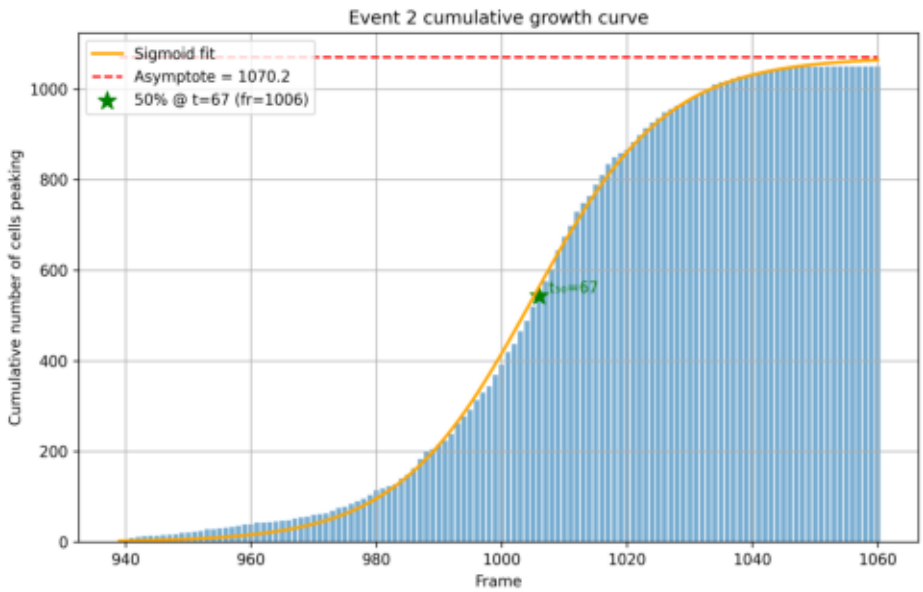

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
20
40
60
80
100
120
140
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2.3 Kinetics of global events

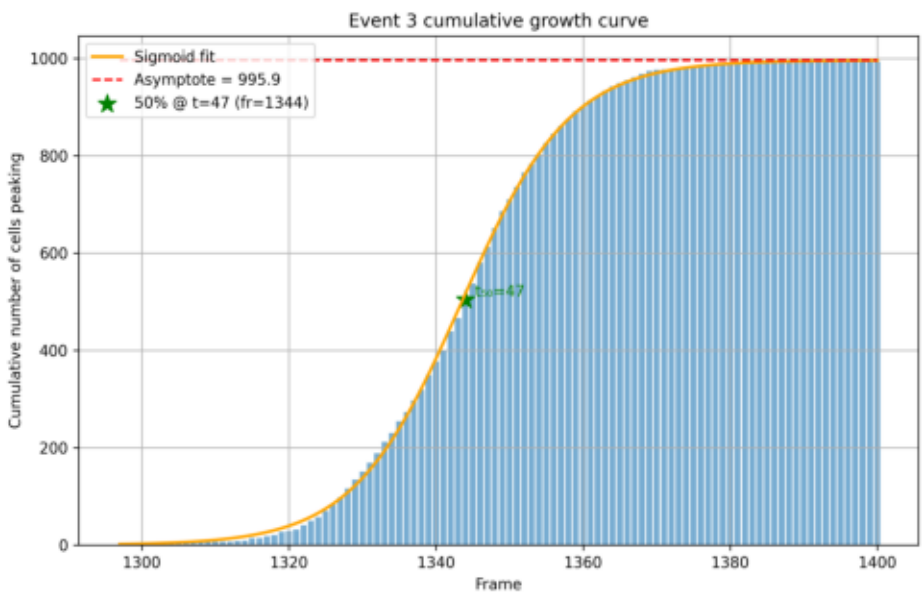




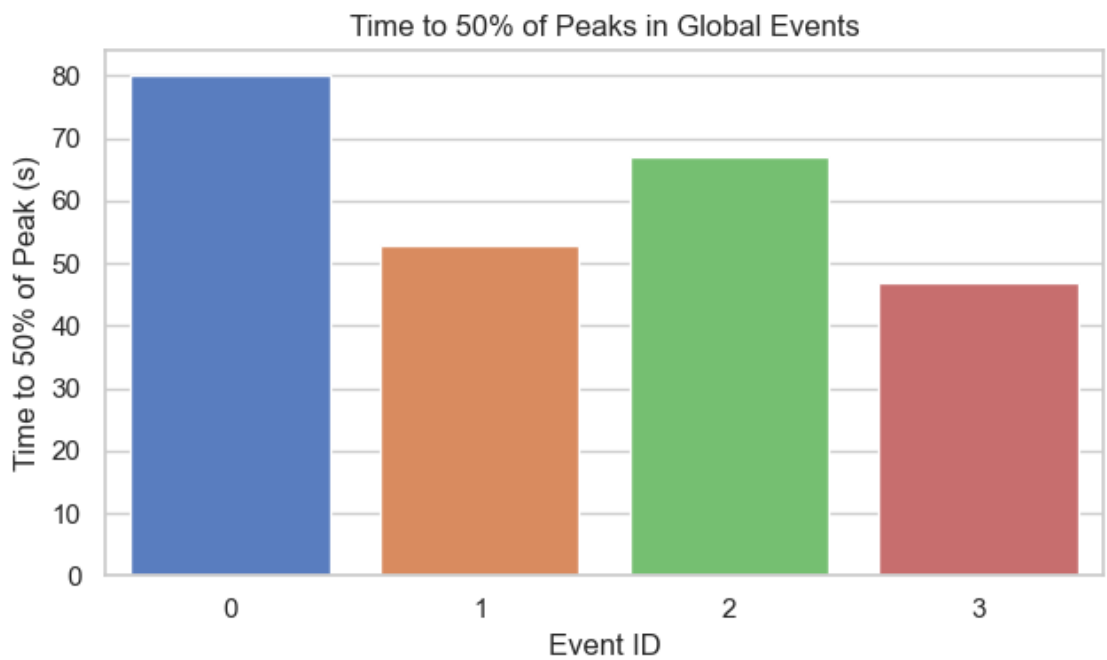
Event Activity Overlay (Event ID: 2) - 20250326_IS3



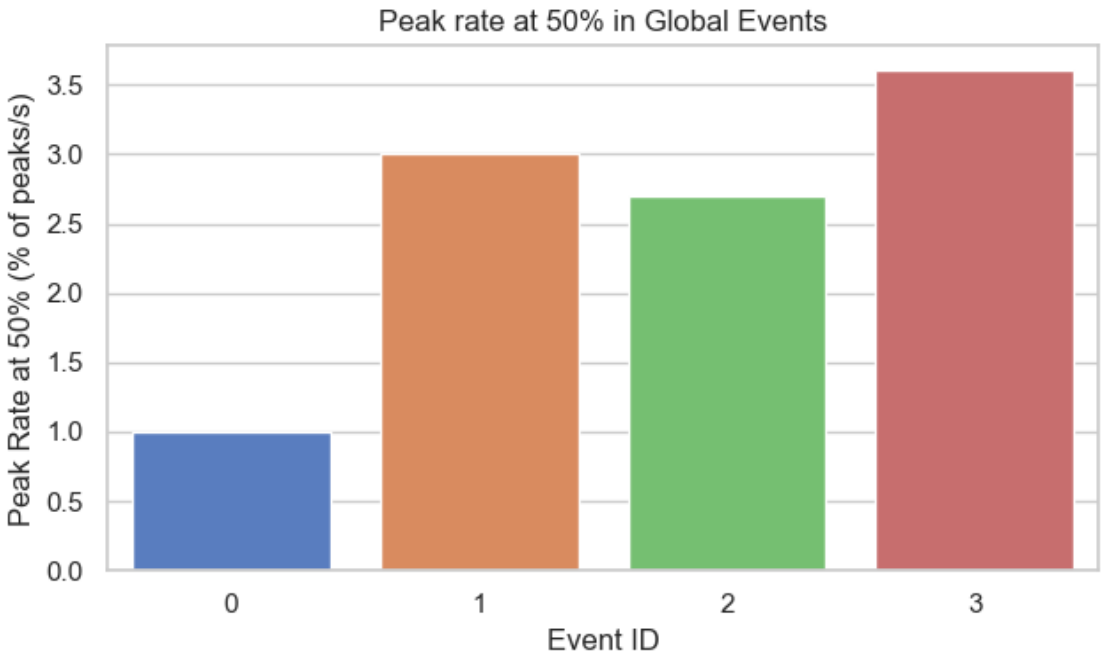
Event Activity Overlay (Event ID: 3) - 20250326_IS3



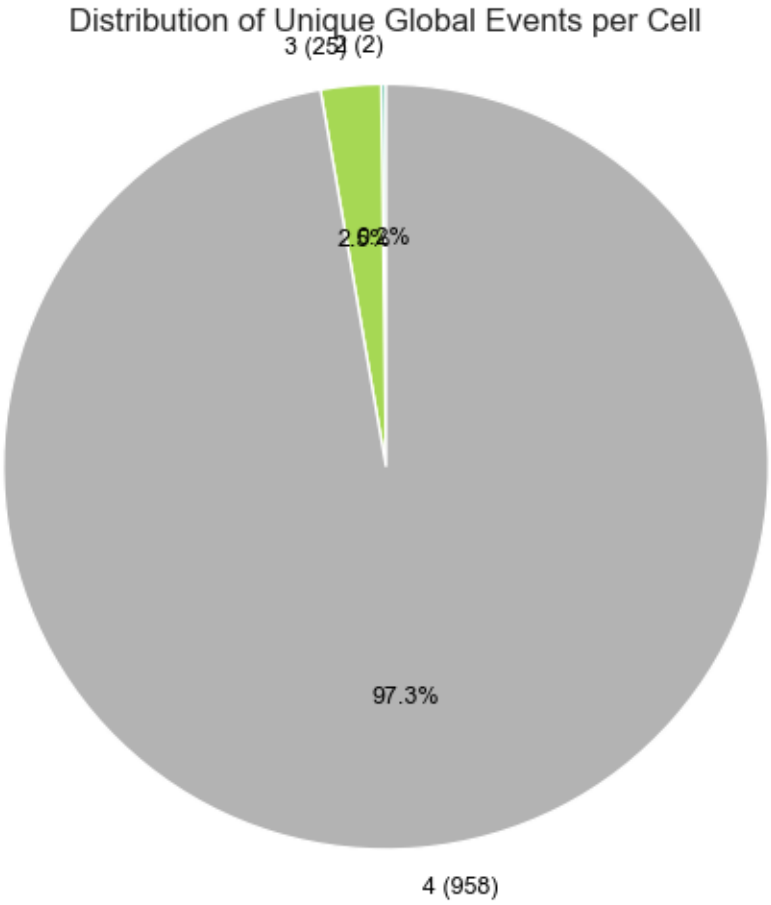
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



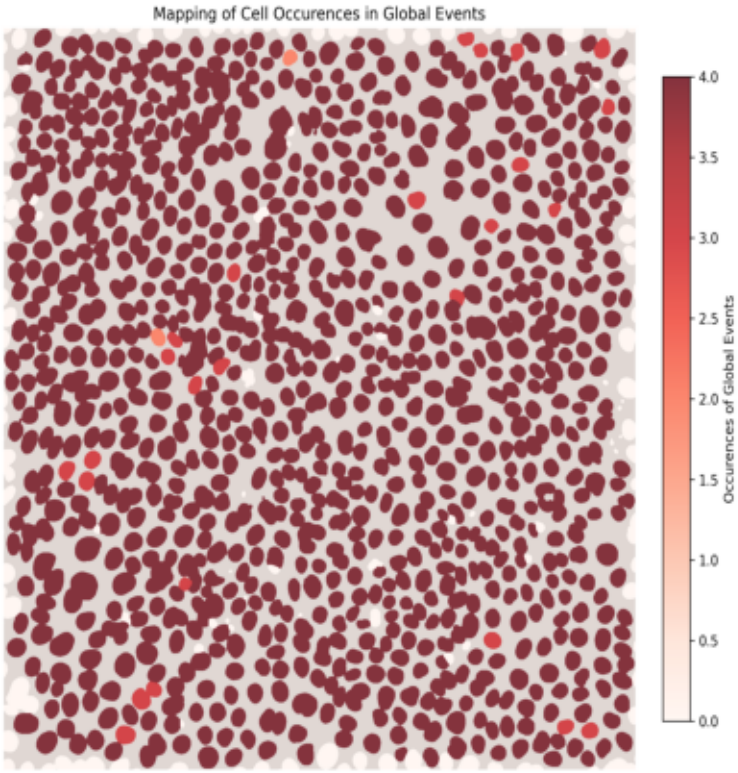

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
Event ID

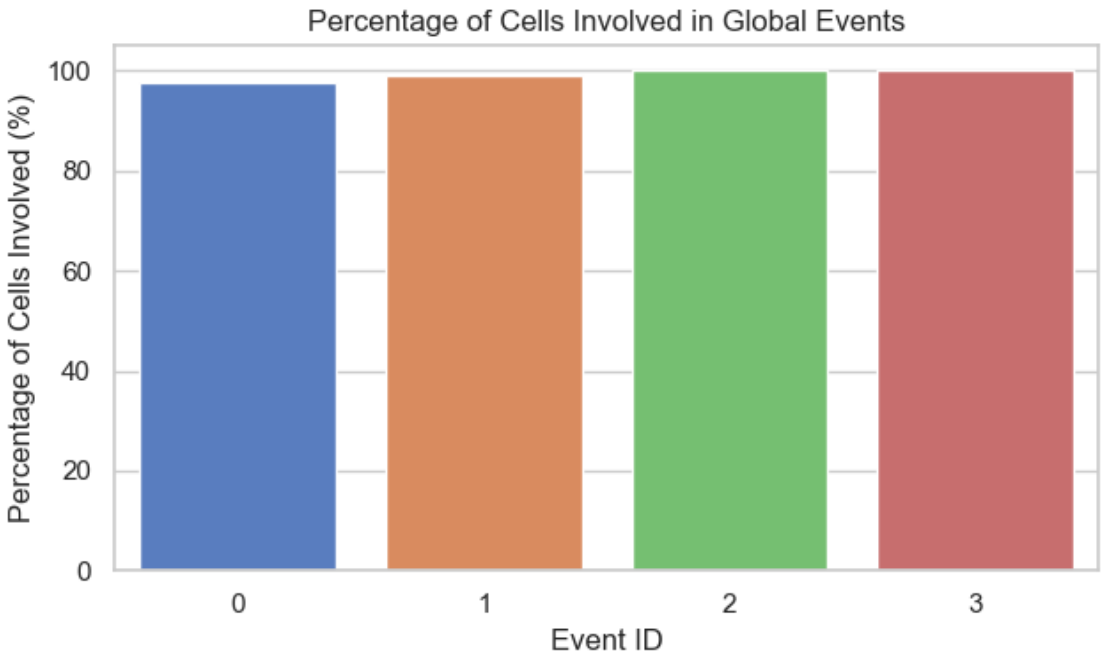
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250326_IS3




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

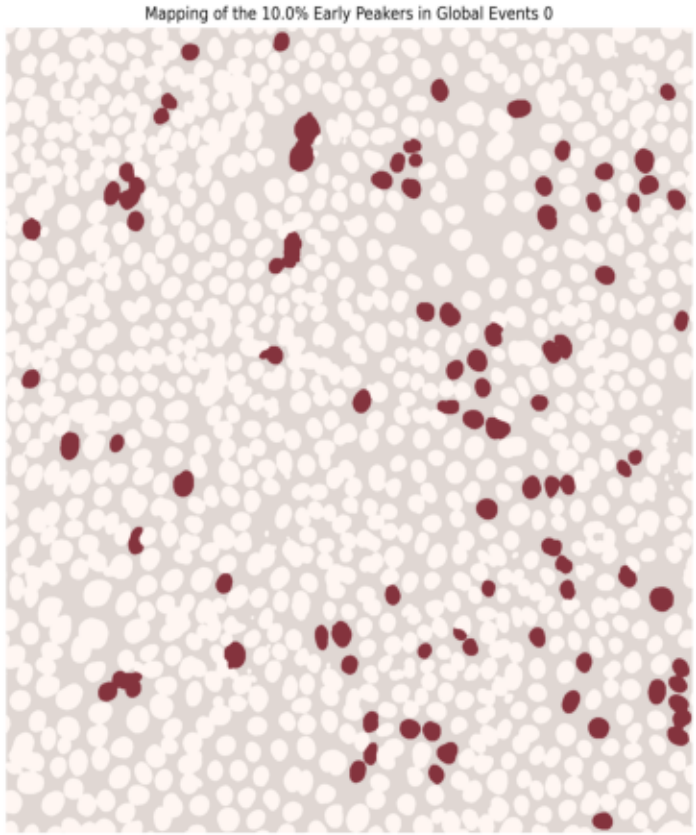


1.2.5 Inter-event interval analysis

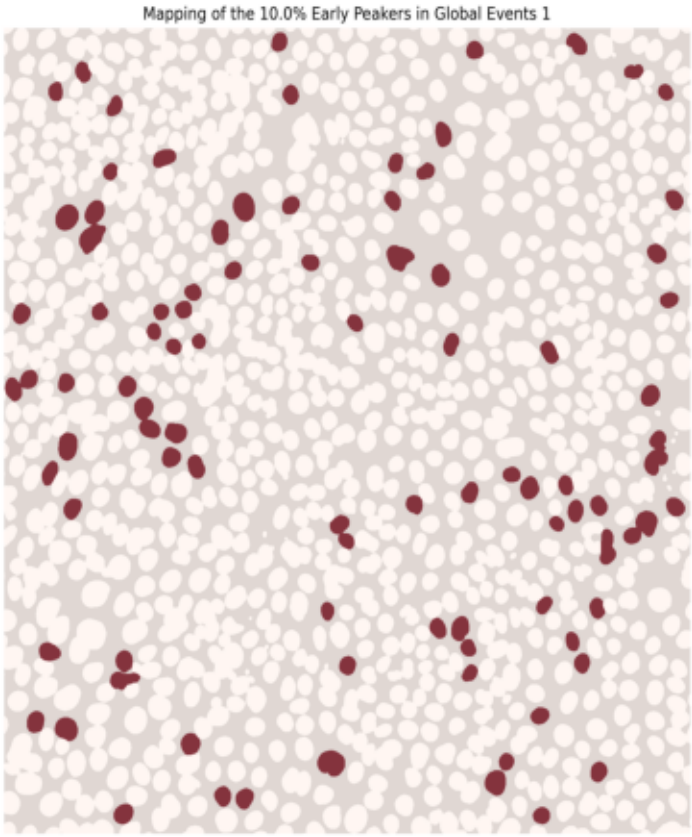
```
Intervals between global event peaks: [149.0, 205.0, 343.0]
Estimated periodicity: 0.740
```

1.2.6 Early peakers in the events

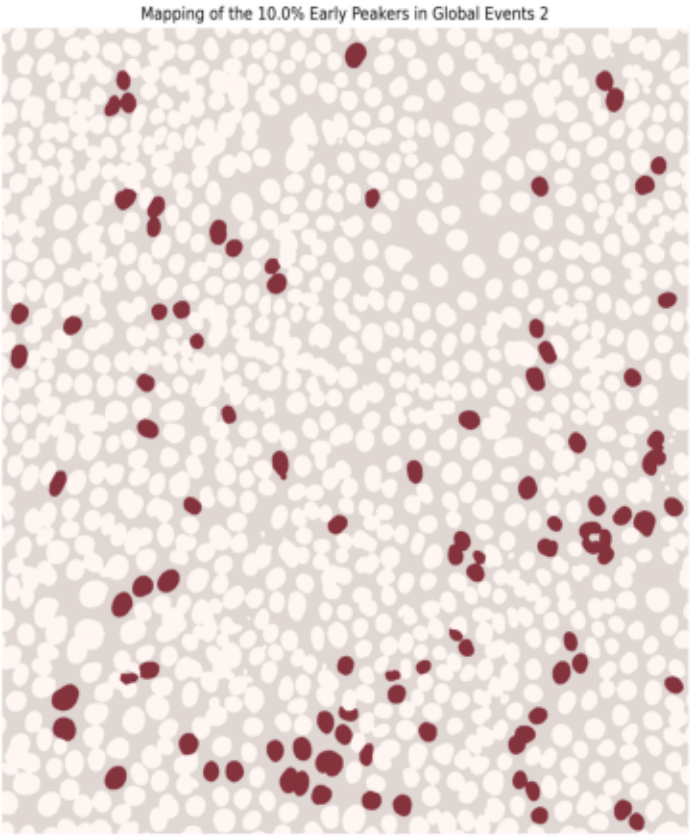
Cell Mapping with Early Peakers Overlay for event 0 - 20250326_IS3



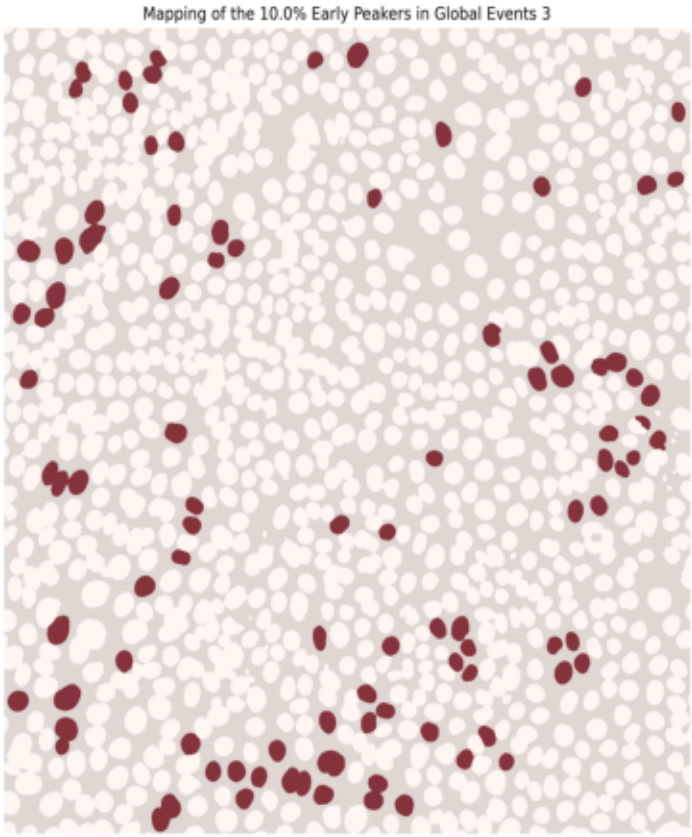
Cell Mapping with Early Peakers Overlay for event 1 - 20250326_IS3



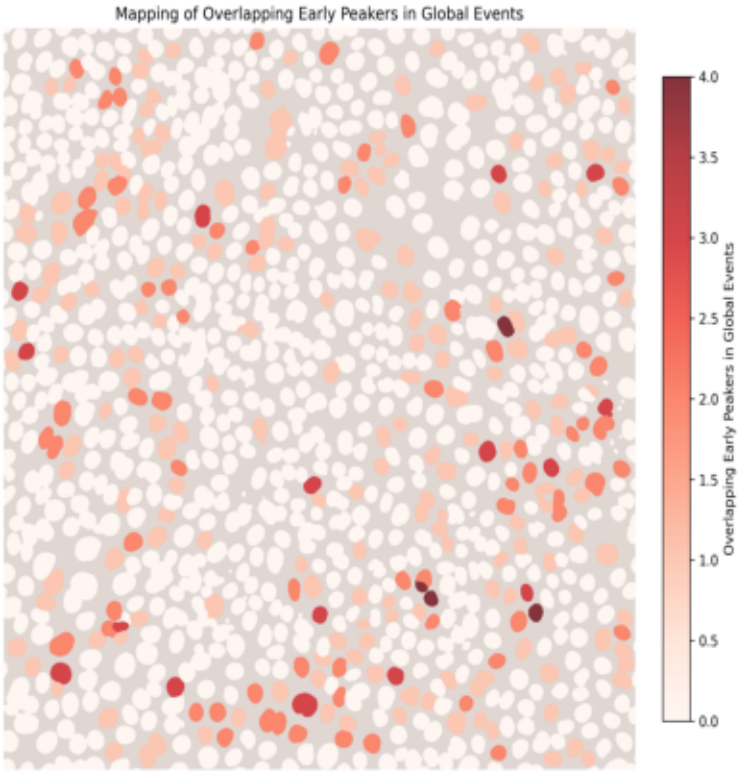
Cell Mapping with Early Peakers Overlay for event 2 - 20250326_IS3



Cell Mapping with Early Peakers Overlay for event 3 - 20250326_IS3

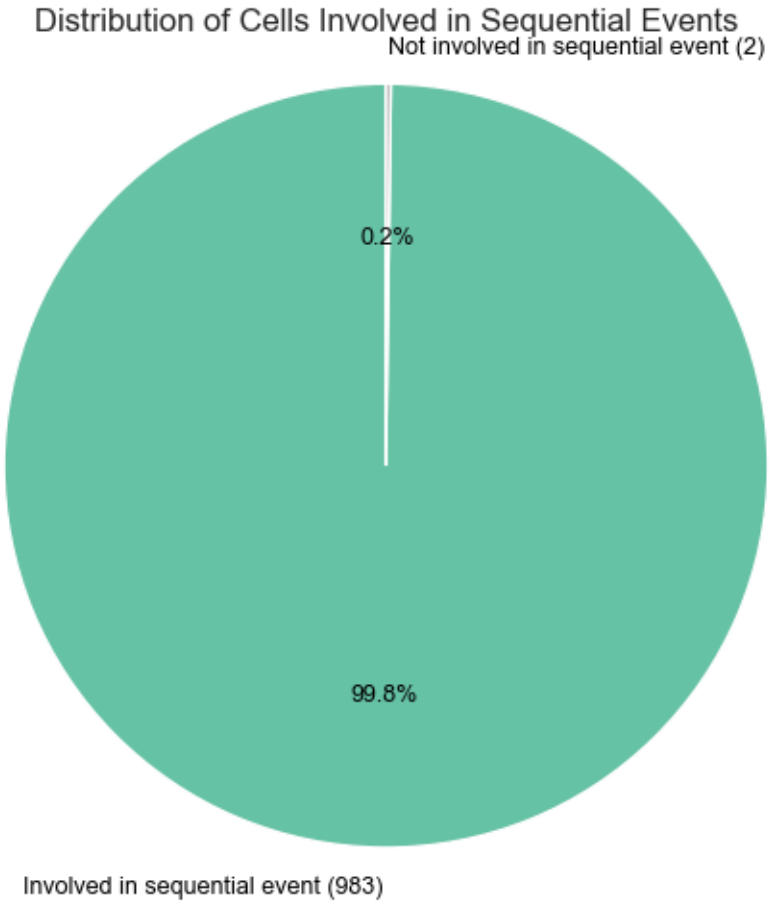


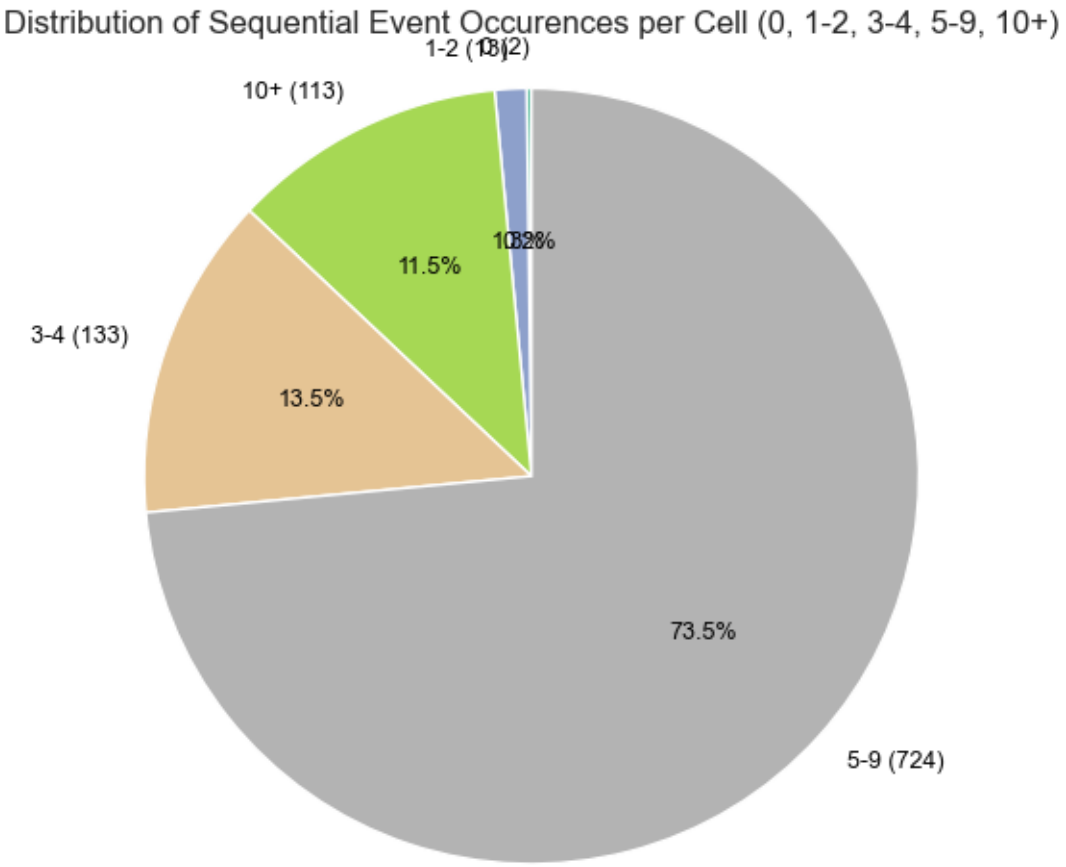
Cell Mapping with Occurences in Global Events Overlay - 20250326_IS3



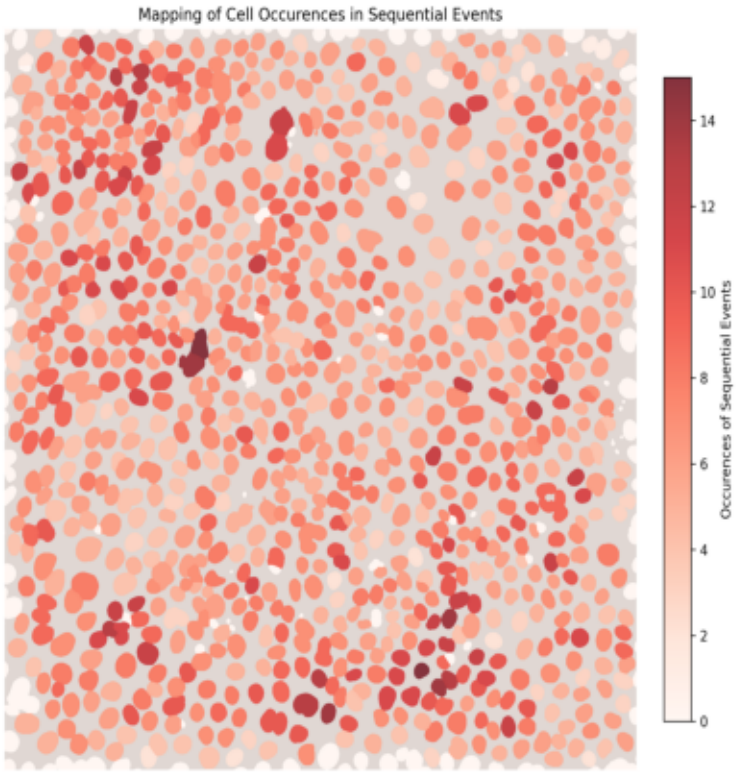
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

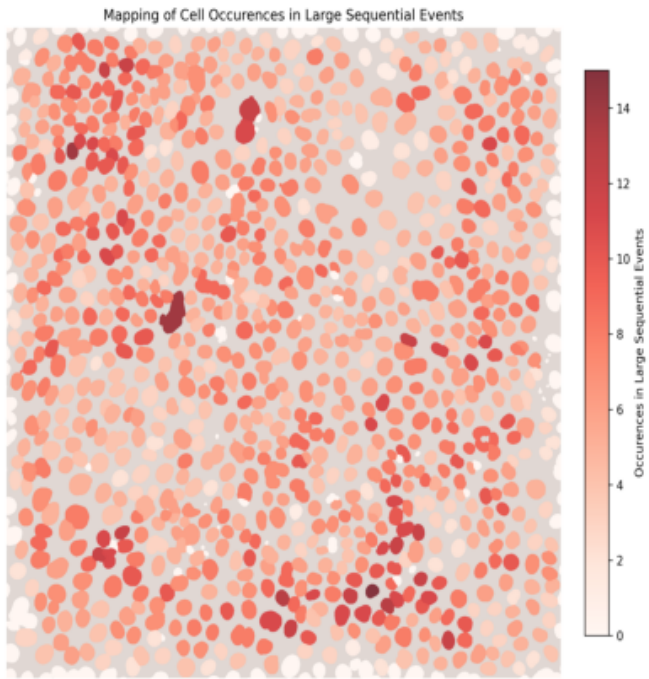



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
1-2 (18)
10+ (113)
11.5%
3-4 (133)
13.5%
73.5%
5-9 (724)

Cell Mapping with Occurences in Sequential Events Overlay - 20250326_IS3

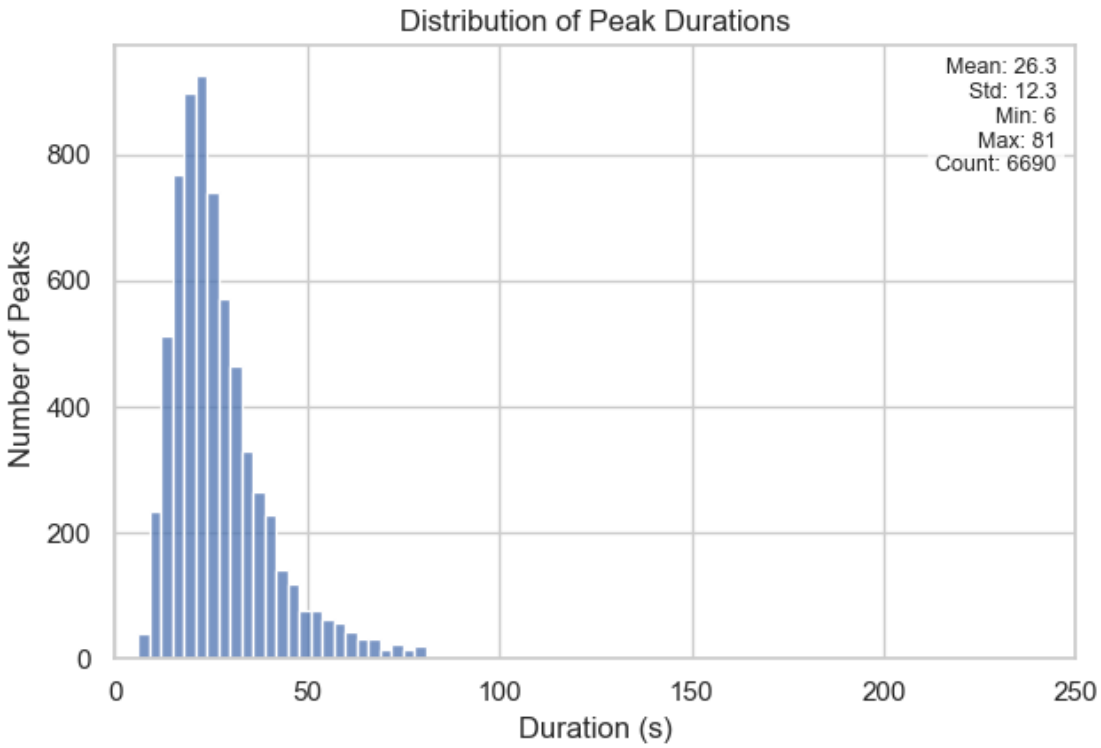


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250326_IS3

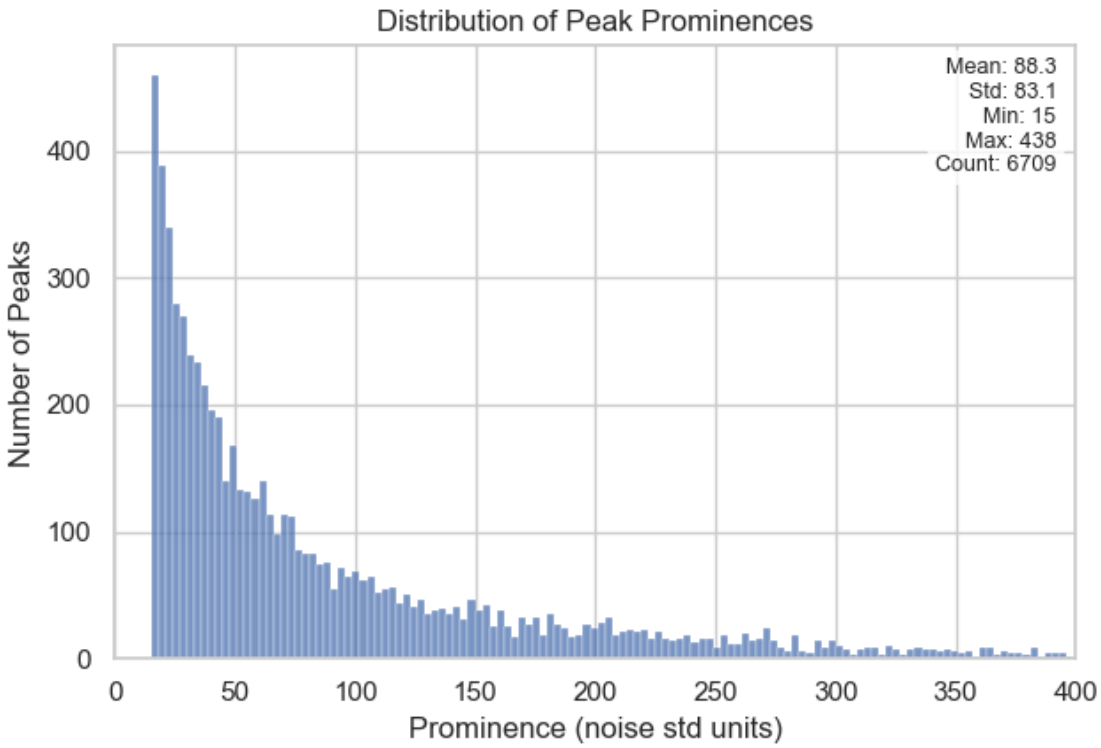


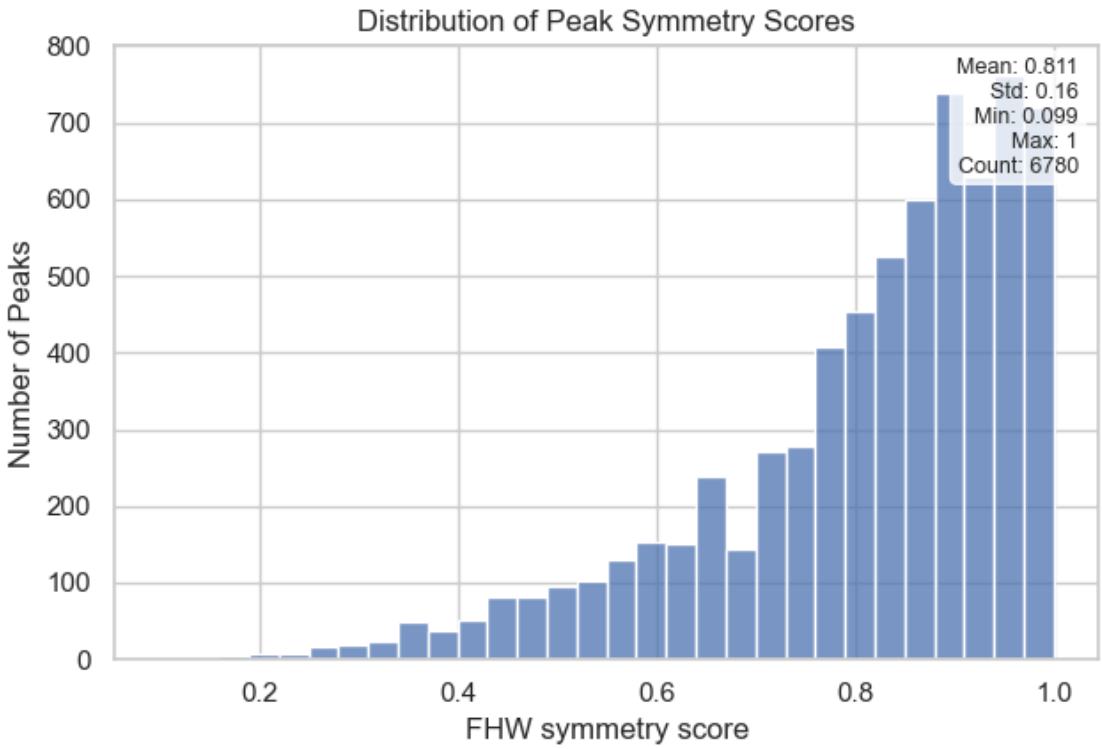
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:36:06] [INFO] calcium: plot_histogram: removed 90 outliers out of
6780 on 'Duration (s)' (lower=-3, upper=81)
```



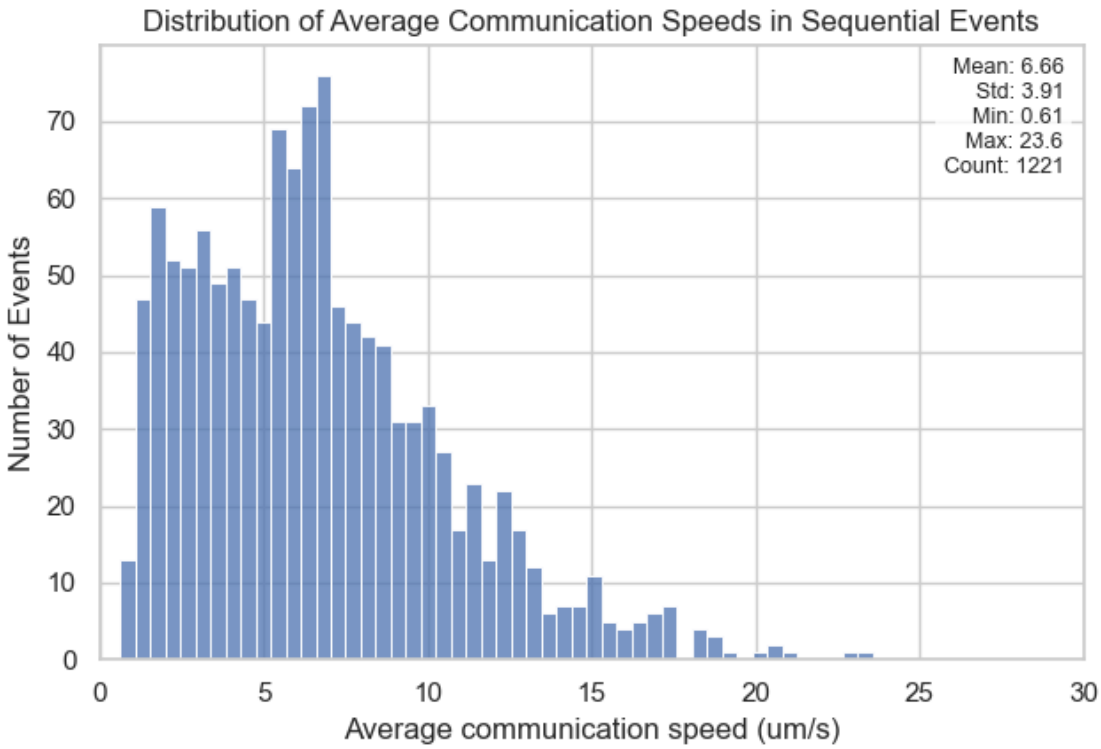

```
[2025-08-11 09:36:06] [INFO] calcium: plot_histogram: removed 71 outliers out of
6780 on 'Prominence (noise std units)' (lower=-106.91, upper=438.64)
```


Distribution of Peak Prominences
Mean: 88.3
Std: 83.1
Min: 15
Max: 438
Count: 6709
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

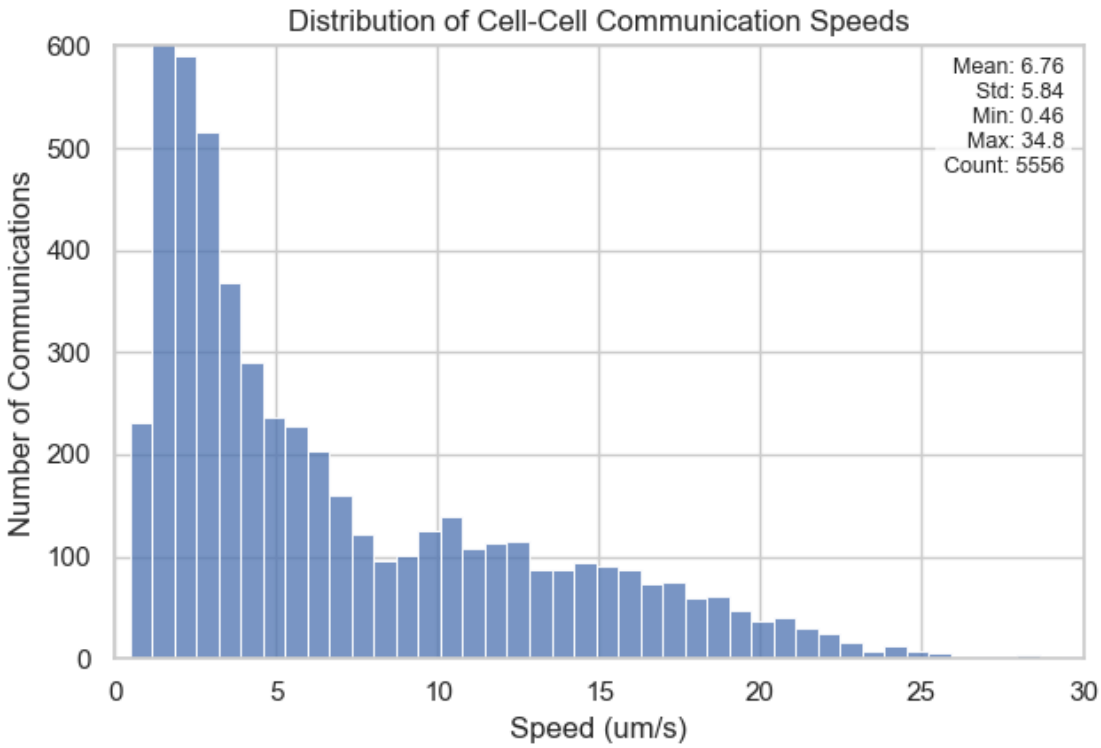

Distribution of Peak Symmetry Scores
Mean: 0.811
Std: 0.16
Min: 0.099
Max: 1
Count: 6780
Number of Peaks
0
100
200
300
400
500
600
700
800
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:36:07] [INFO] calcium: plot_histogram: removed 2 outliers out of
1223 on 'Average communication speed (um/s)' (lower=-11.95, upper=24.31)
```

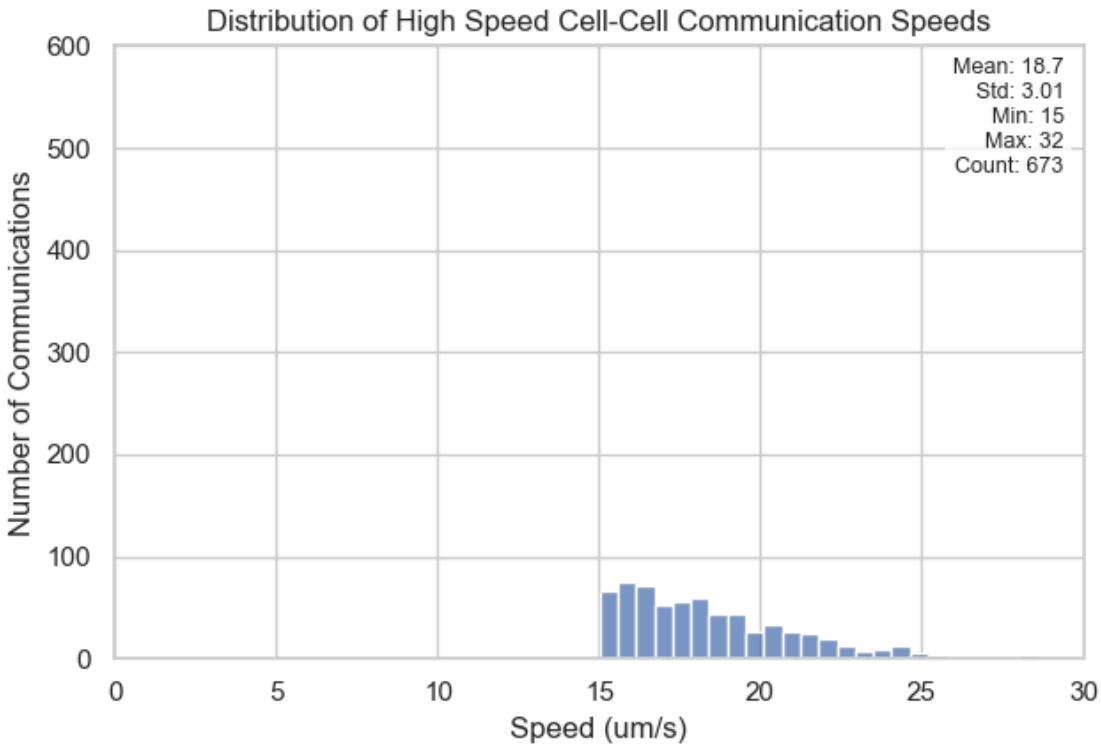



```
[2025-08-11 09:36:07] [INFO] calcium: plot_histogram: removed 1 outliers out of
5557 on 'Speed (um/s)' (lower=-22.35, upper=34.84)
```

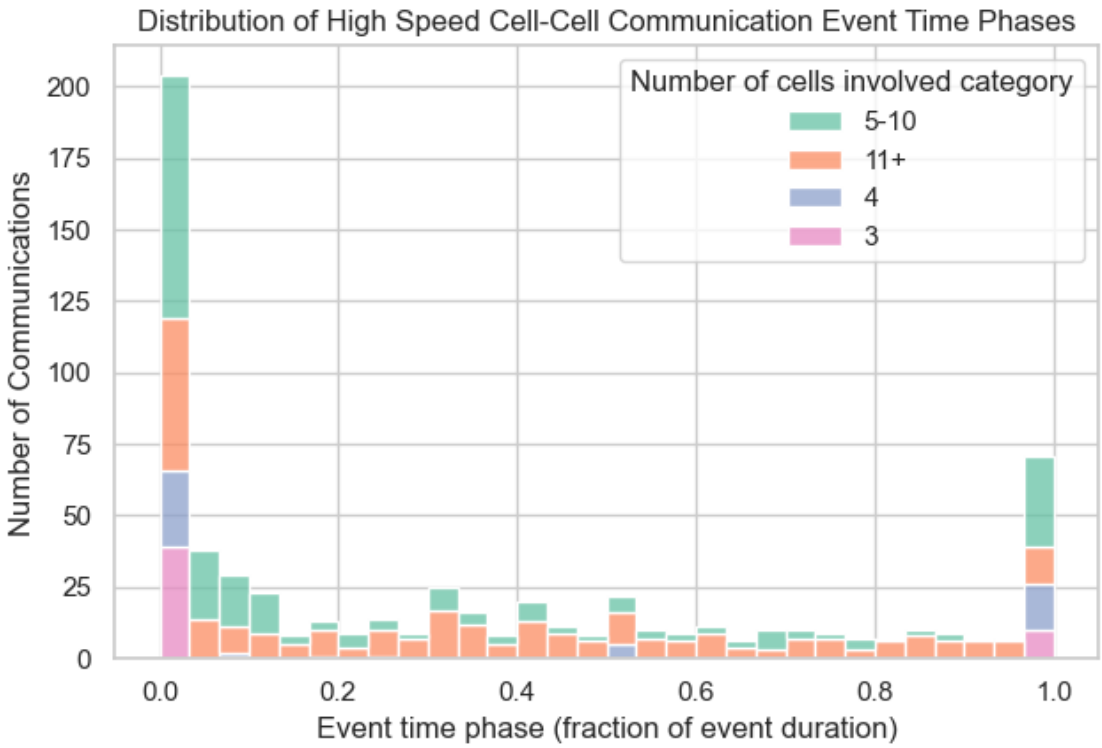


1.3.4 Double distribution in cell-cell communication speeds

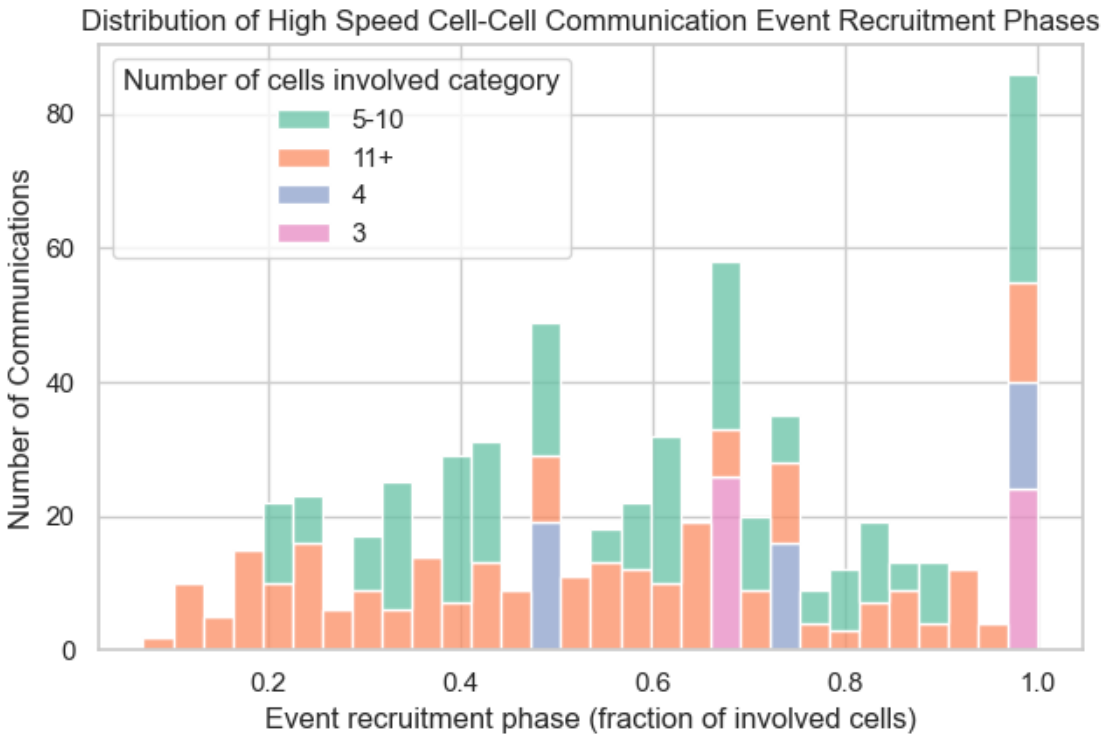
```
[2025-08-11 09:36:07] [INFO] calcium: plot_histogram: removed 3 outliers out of
676 on 'Speed (um/s)' (lower=4.34, upper=32.375)
```



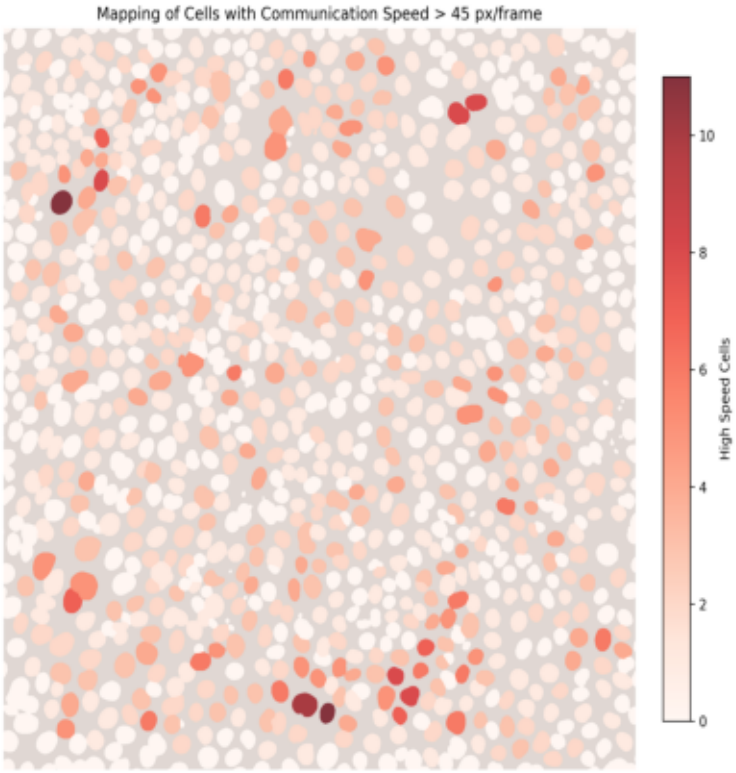

```
[2025-08-11 09:36:07] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 640 on 'Event time phase (fraction of event duration)'
(lower=-1.83, upper=2.44)
```



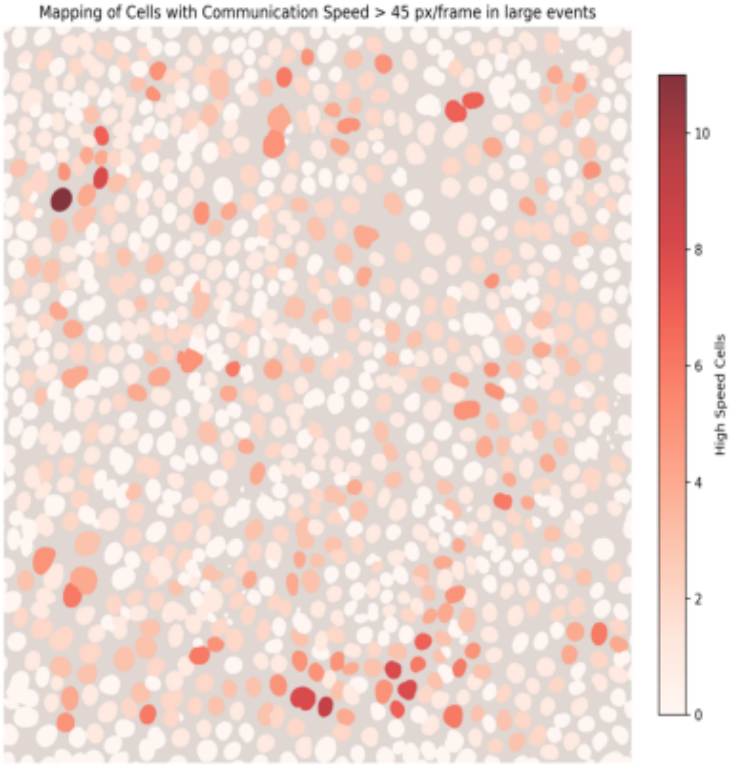

```
[2025-08-11 09:36:08] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 640 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.74, upper=1.92)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
4
3
Number of Communications
0
20
40
60
80
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

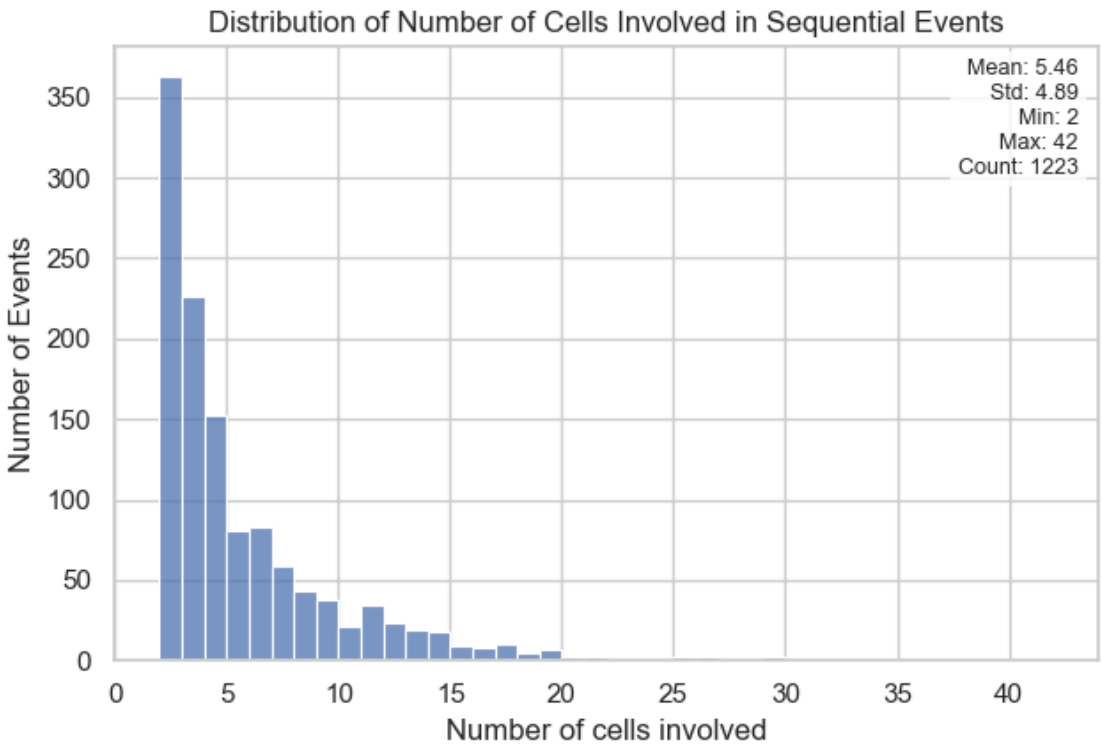
Cell Mapping with High Speed Cells Overlay - 20250326_IS3



Cell Mapping with High Speed Cells in Large Events Overlay - 20250326_IS3

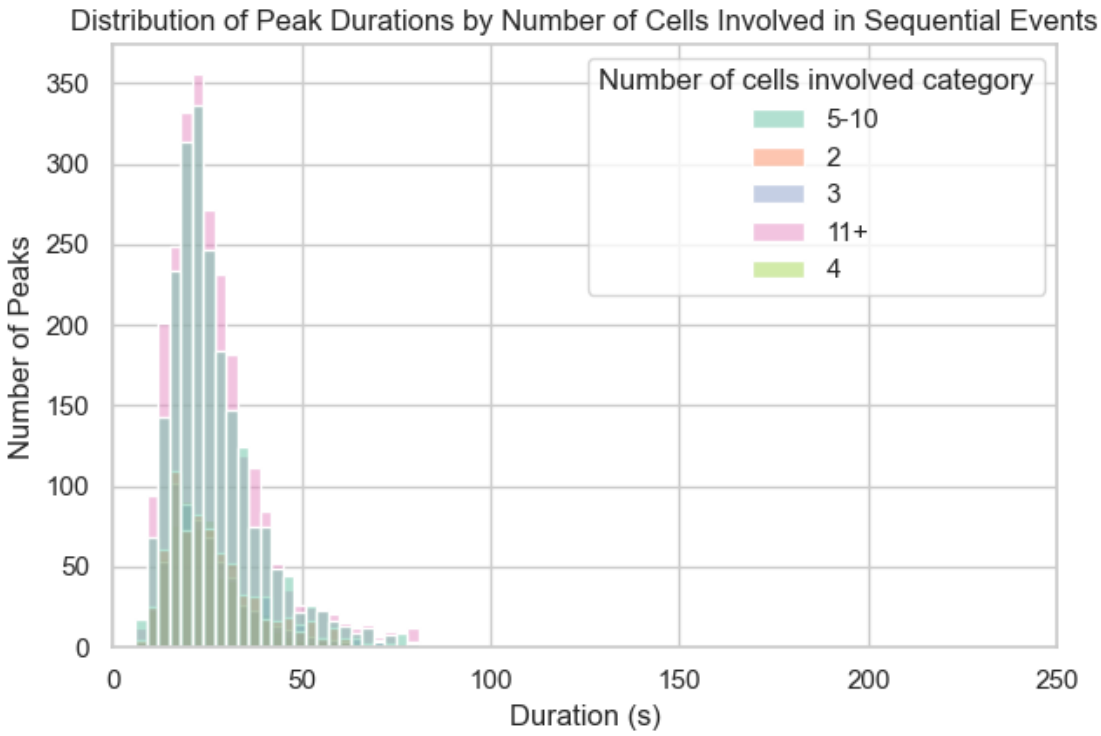


1.3.5 Number of cells involved per sequential events

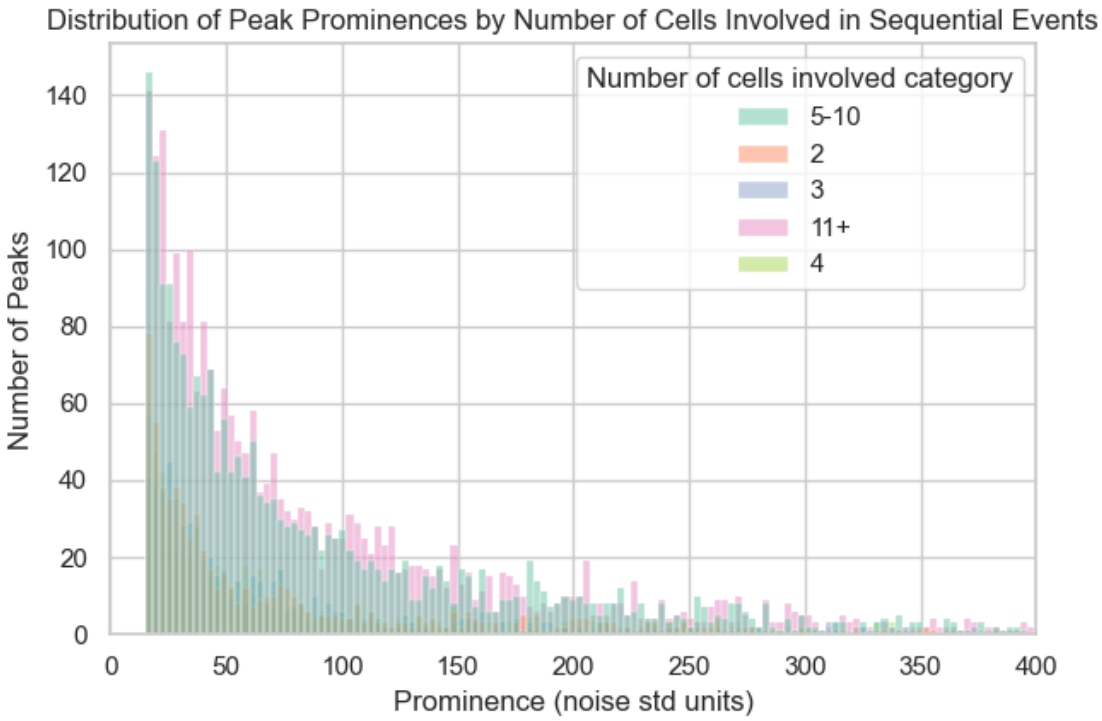


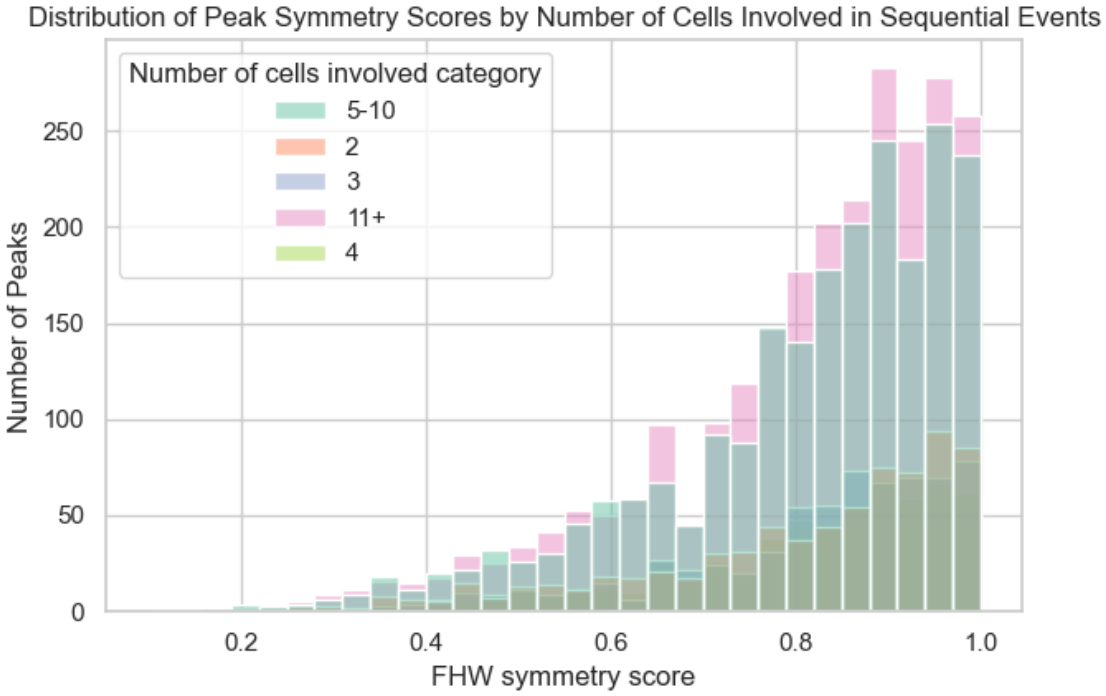
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:36:10] [INFO] calcium: plot_histogram_by_group: removed 90
outliers out of 6780 on 'Duration (s)' (lower=-3, upper=81)
```



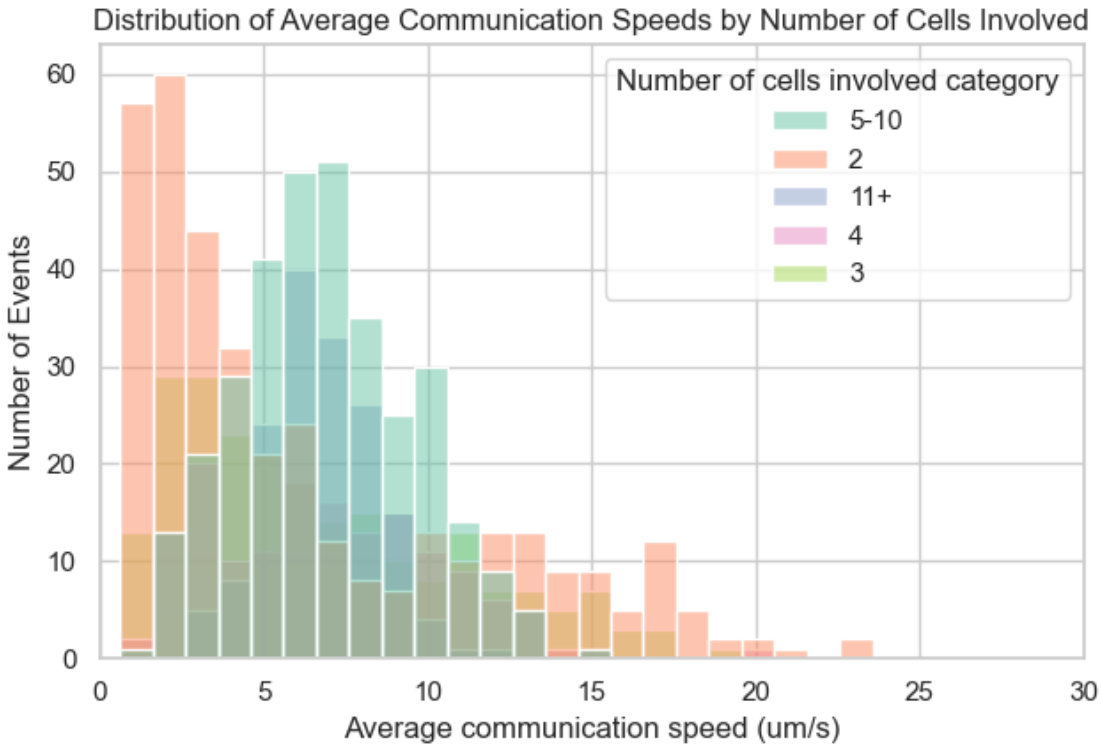

```
[2025-08-11 09:36:10] [INFO] calcium: plot_histogram_by_group: removed 71
outliers out of 6780 on 'Prominence (noise std units)' (lower=-106.91,
upper=438.64)
```



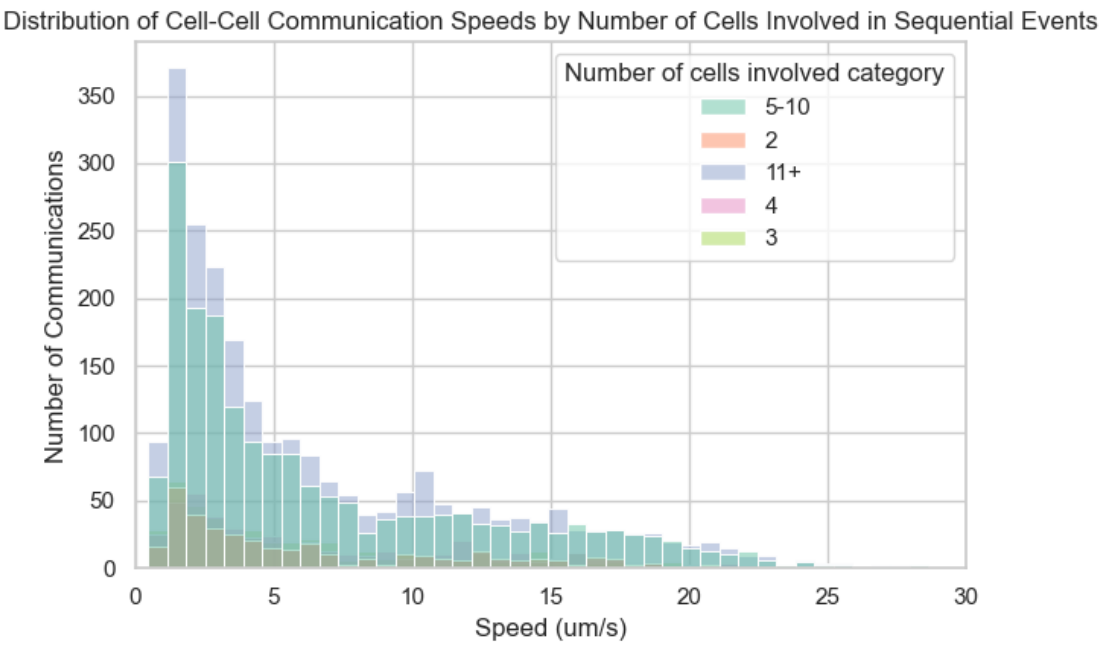



```
[2025-08-11 09:36:11] [INFO] calcium: plot_histogram_by_group: removed 2
```

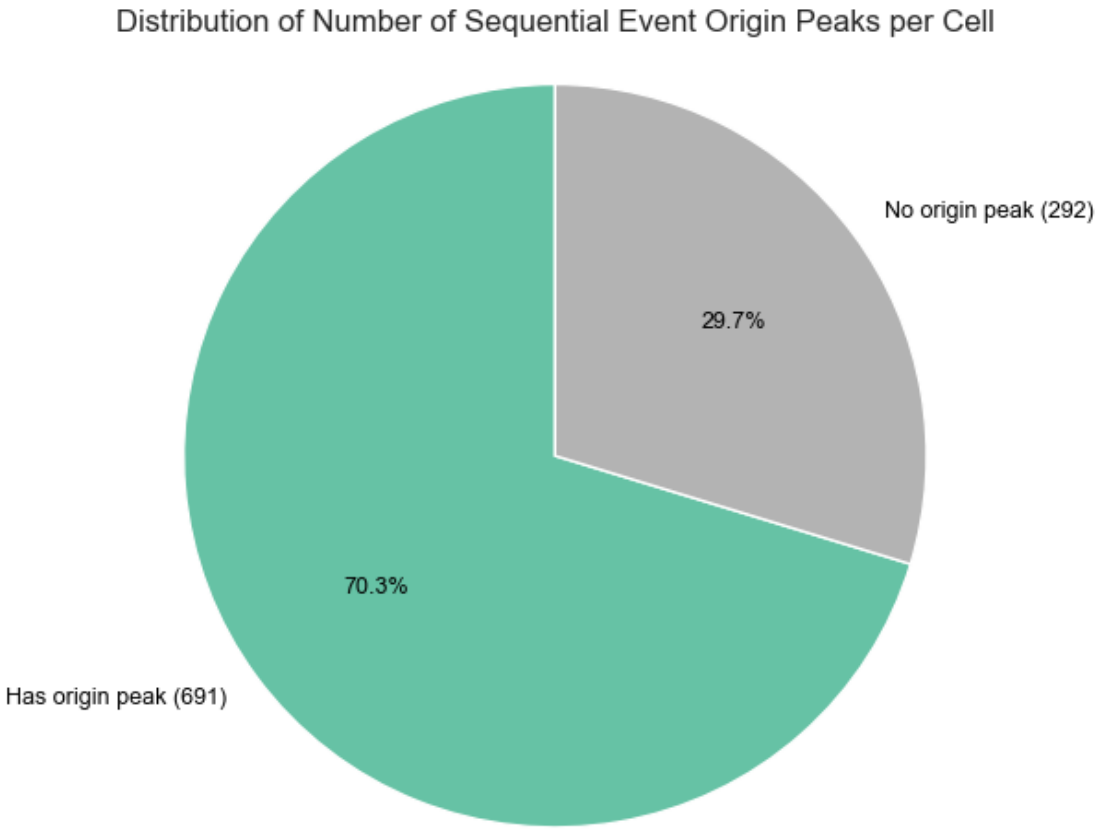
```
outliers out of 1223 on 'Average communication speed (um/s)' (lower=-11.95,
upper=24.31)
```

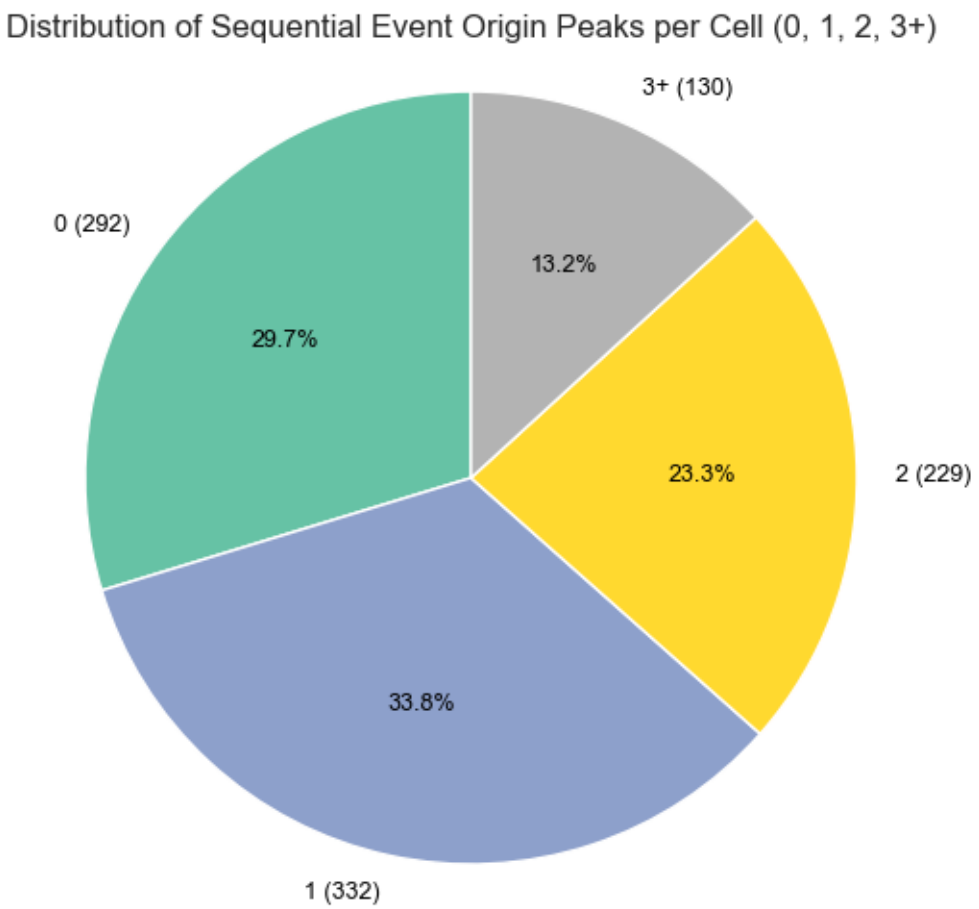



```
[2025-08-11 09:36:11] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 5557 on 'Speed (um/s)' (lower=-22.35, upper=34.84)
```

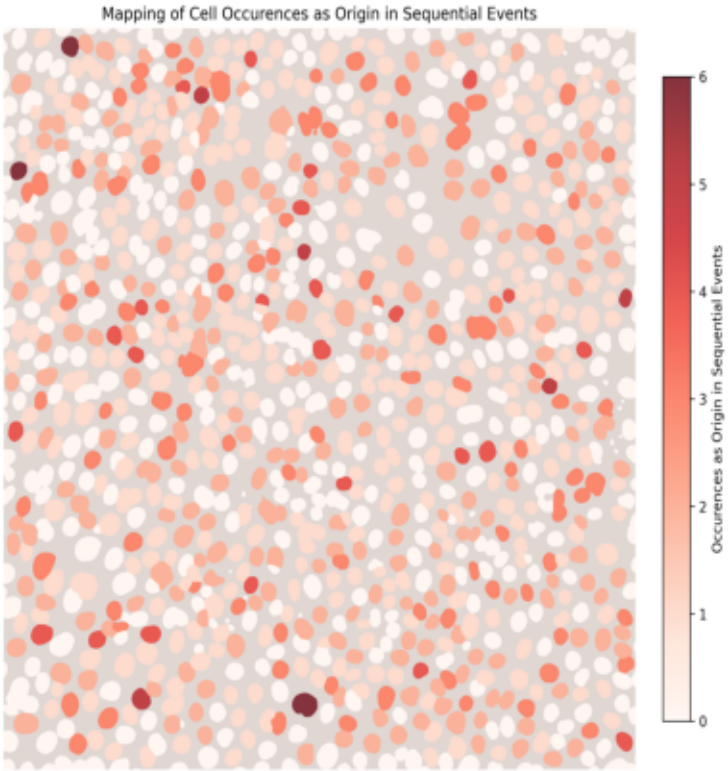

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
5-10
2
11+
4
3
Number of Communications
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
Speed (um/s)

1.3.7 Cells occurences as origin in sequential events

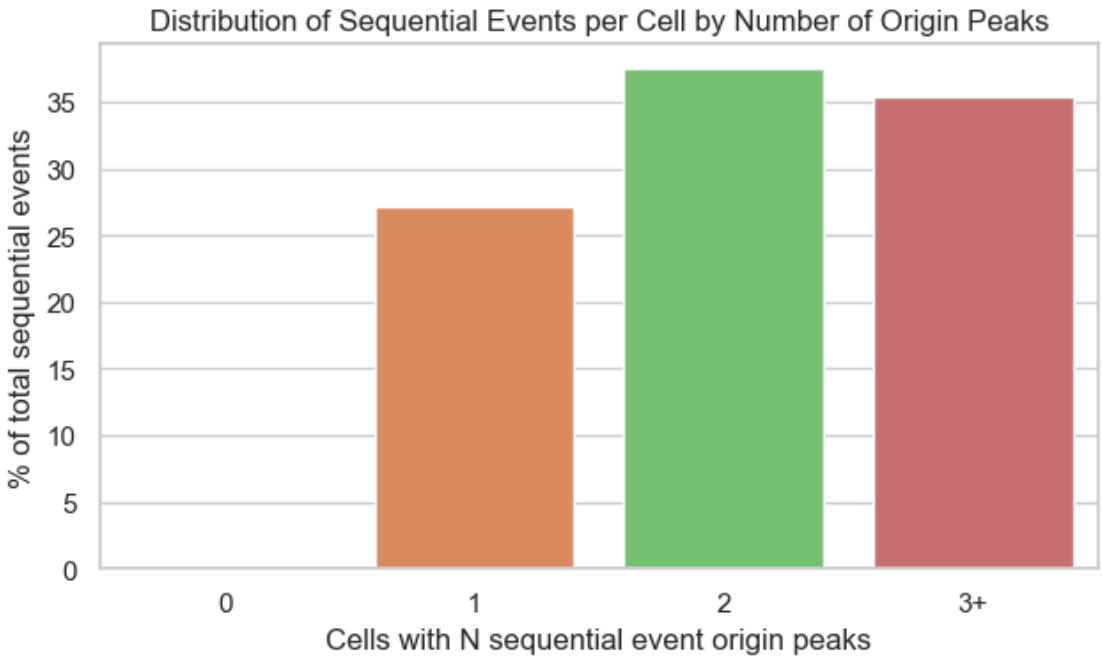



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (130)
13.2%
0 (292)
29.7%
23.3%
2 (229)
33.8%
1 (332)

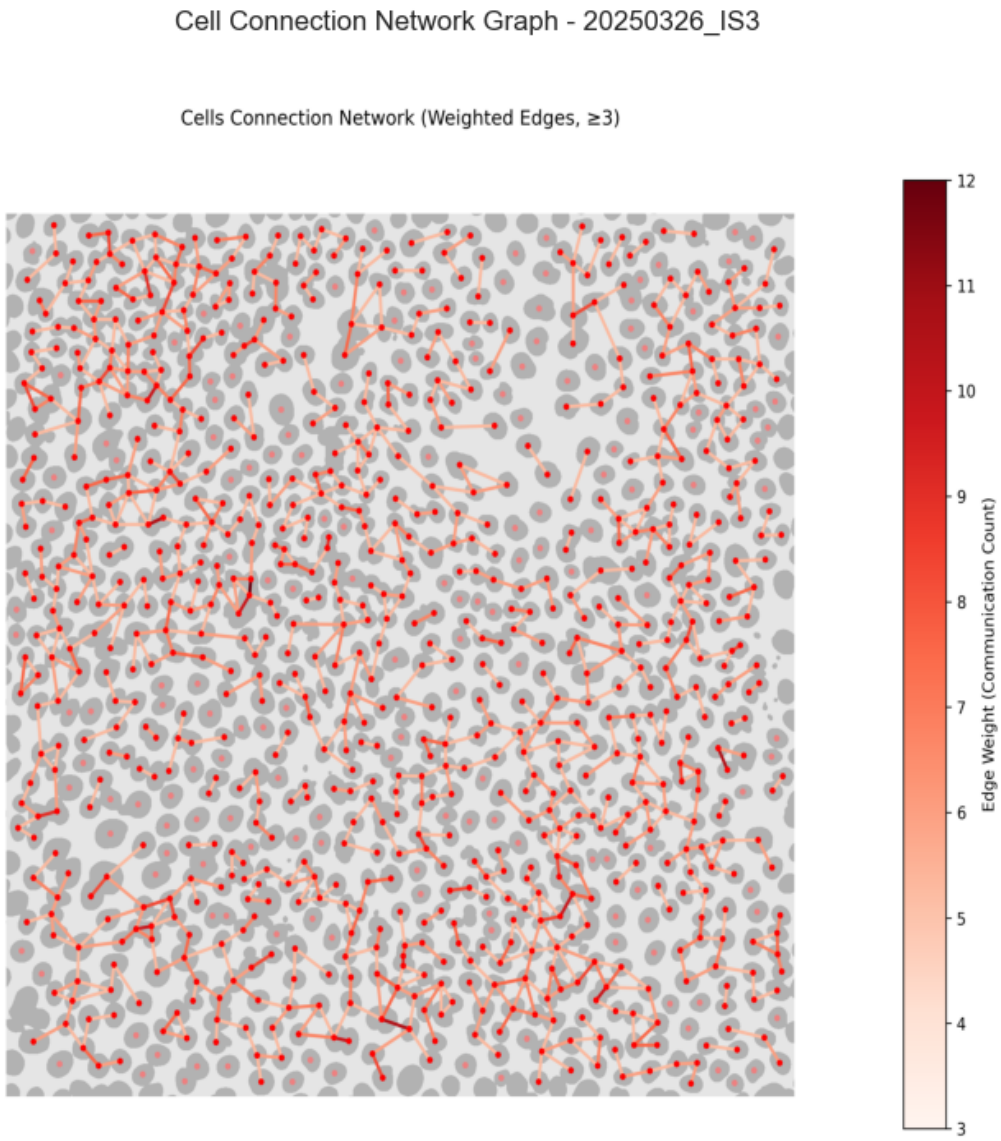
Cell Mapping with Origin Peaks Overlay - 20250326_IS3




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

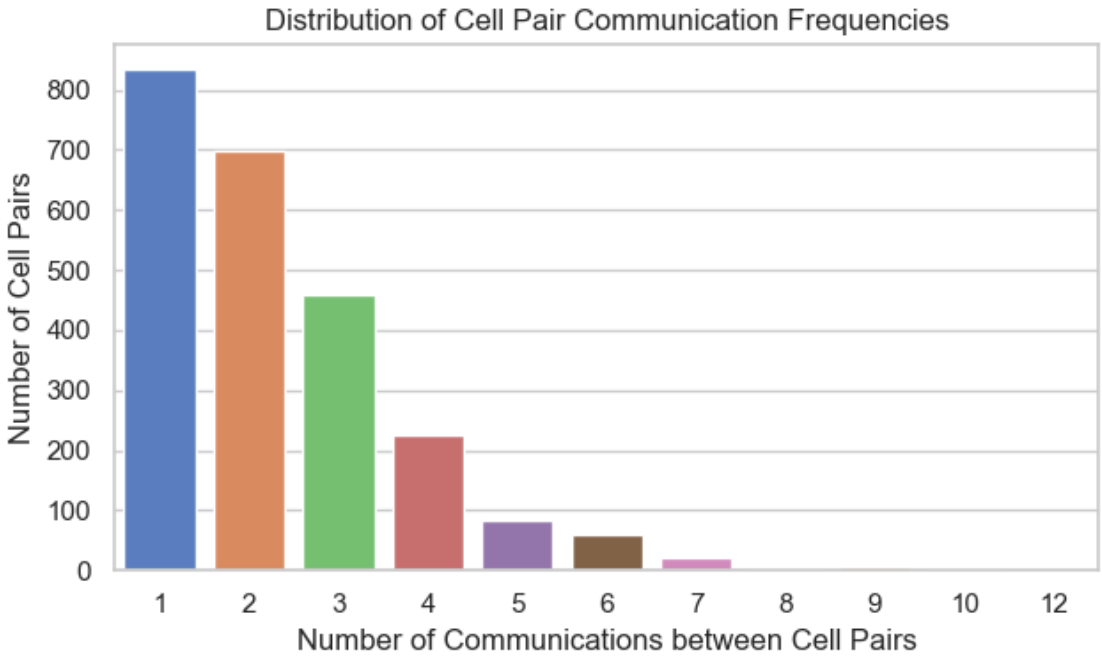

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



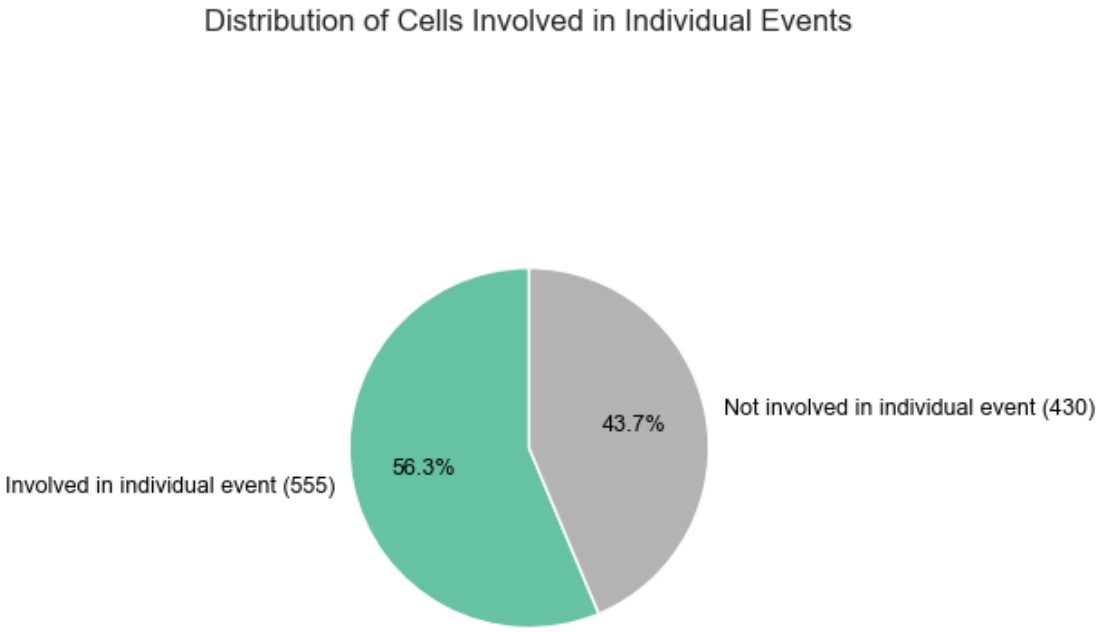

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

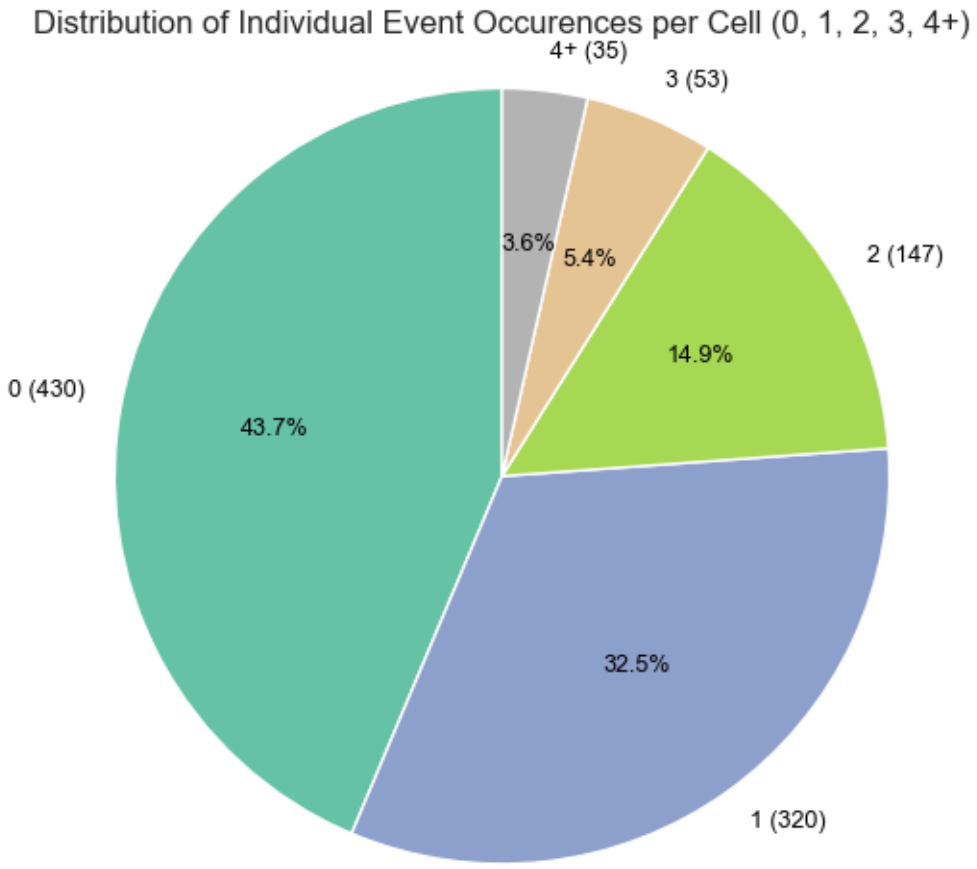
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
8
9
10
12
Number of Communications between Cell Pairs

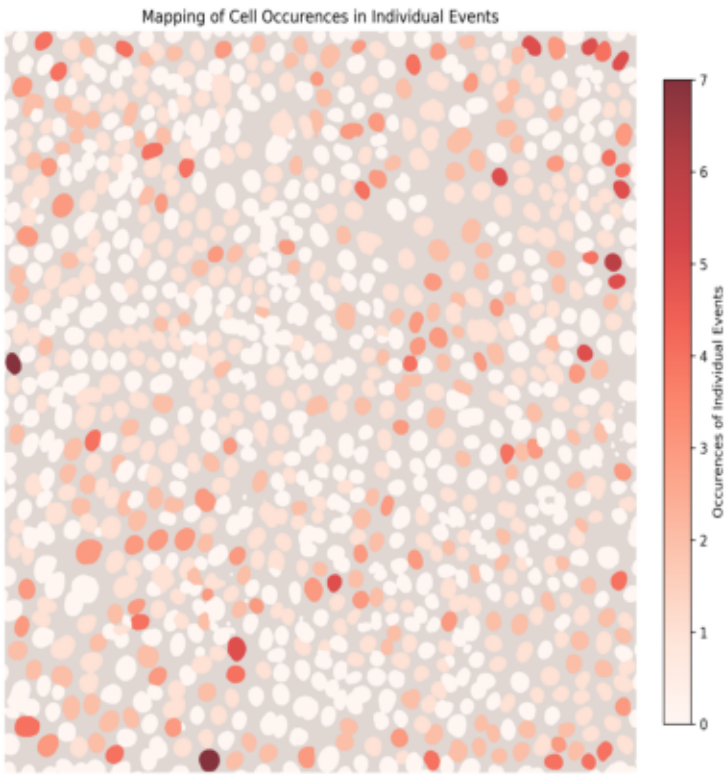
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



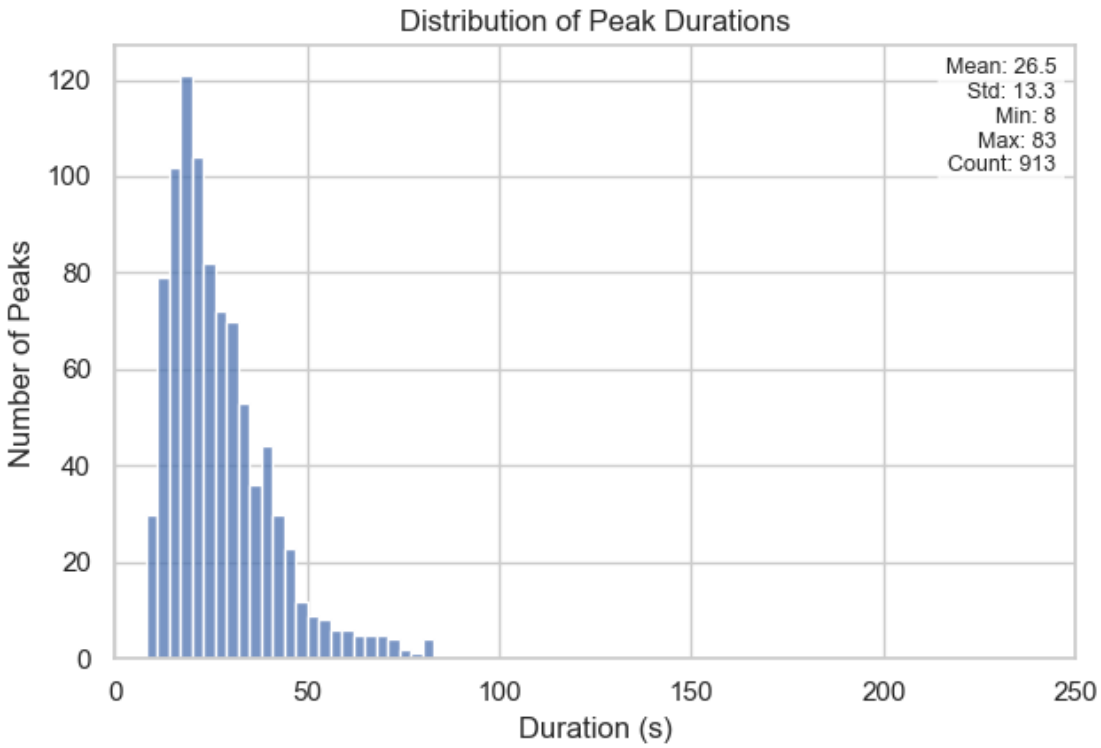

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (35)
3 (53)
2 (147)
1 (320)
0 (430)
3.6%
5.4%
14.9%
32.5%
43.7%

Cell Mapping with Occurences in Individual Events Overlay - 20250326_IS3

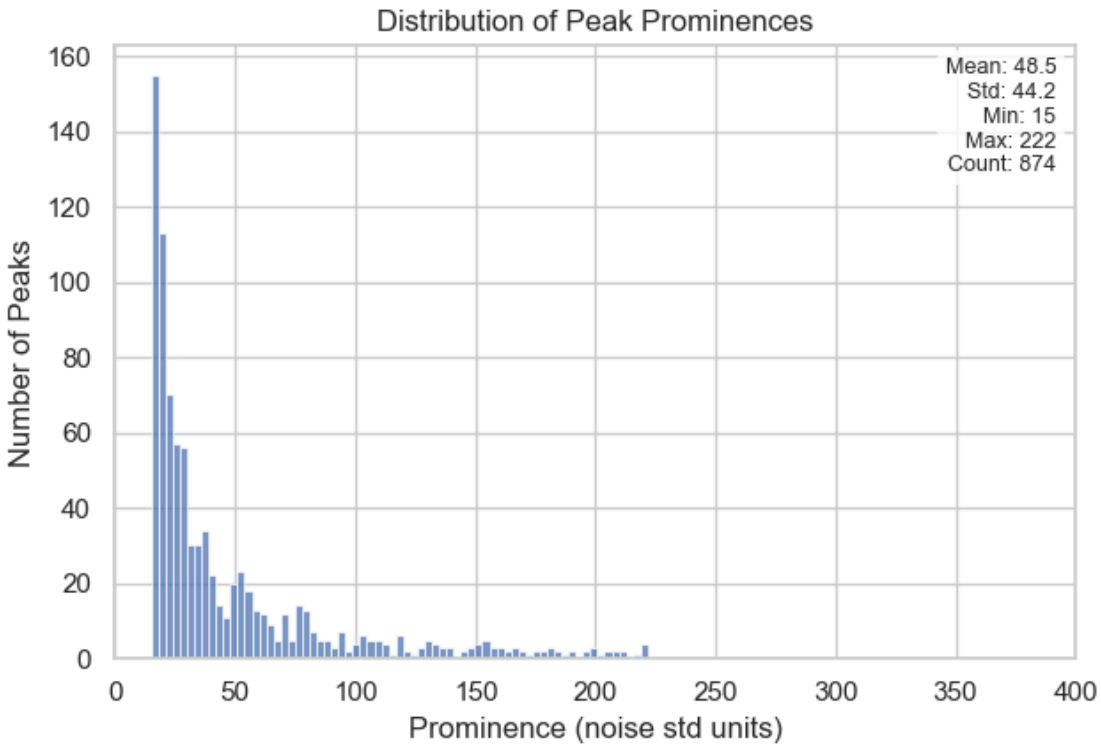


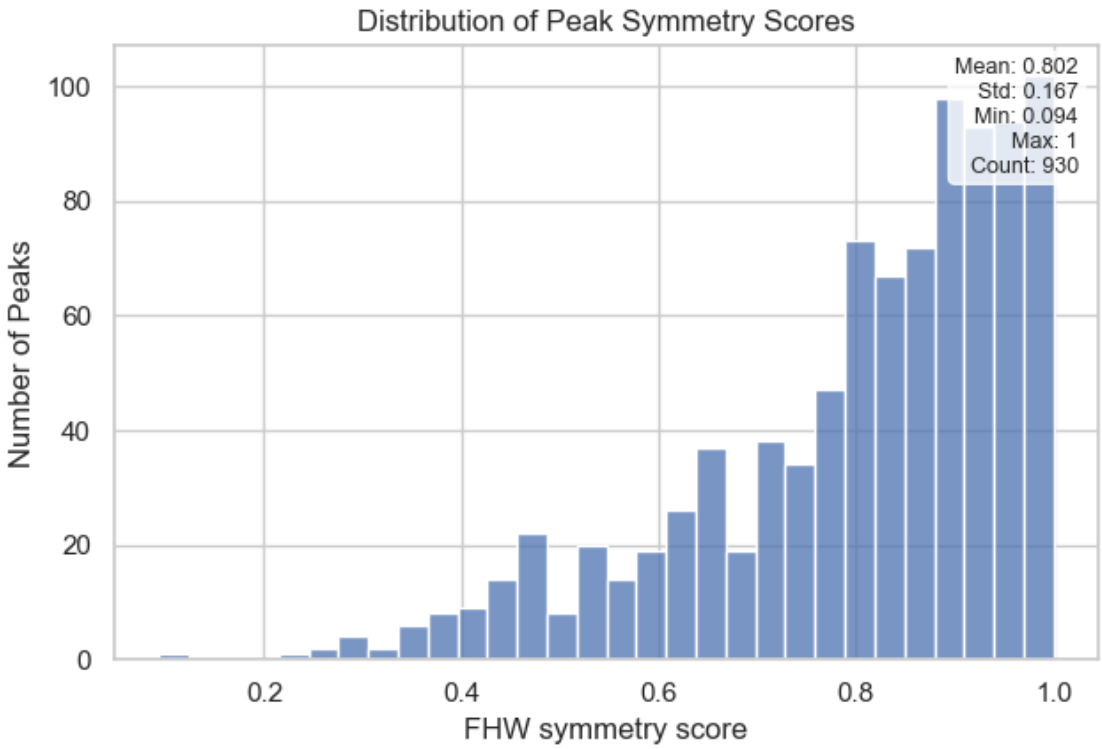
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:36:15] [INFO] calcium: plot_histogram: removed 17 outliers out of
930 on 'Duration (s)' (lower=-33.25, upper=84)
```

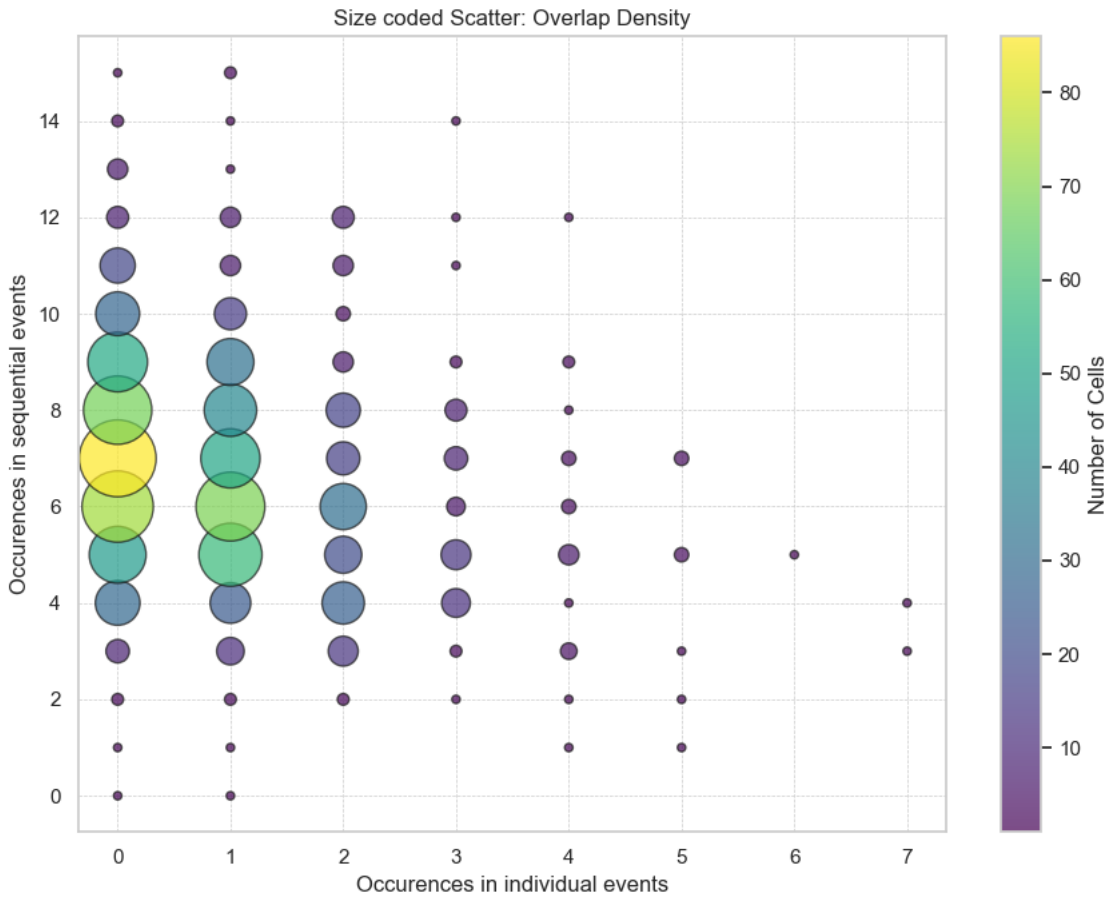



```
[2025-08-11 09:36:16] [INFO] calcium: plot_histogram: removed 56 outliers out of
930 on 'Prominence (noise std units)' (lower=-131.92, upper=222.62)
```

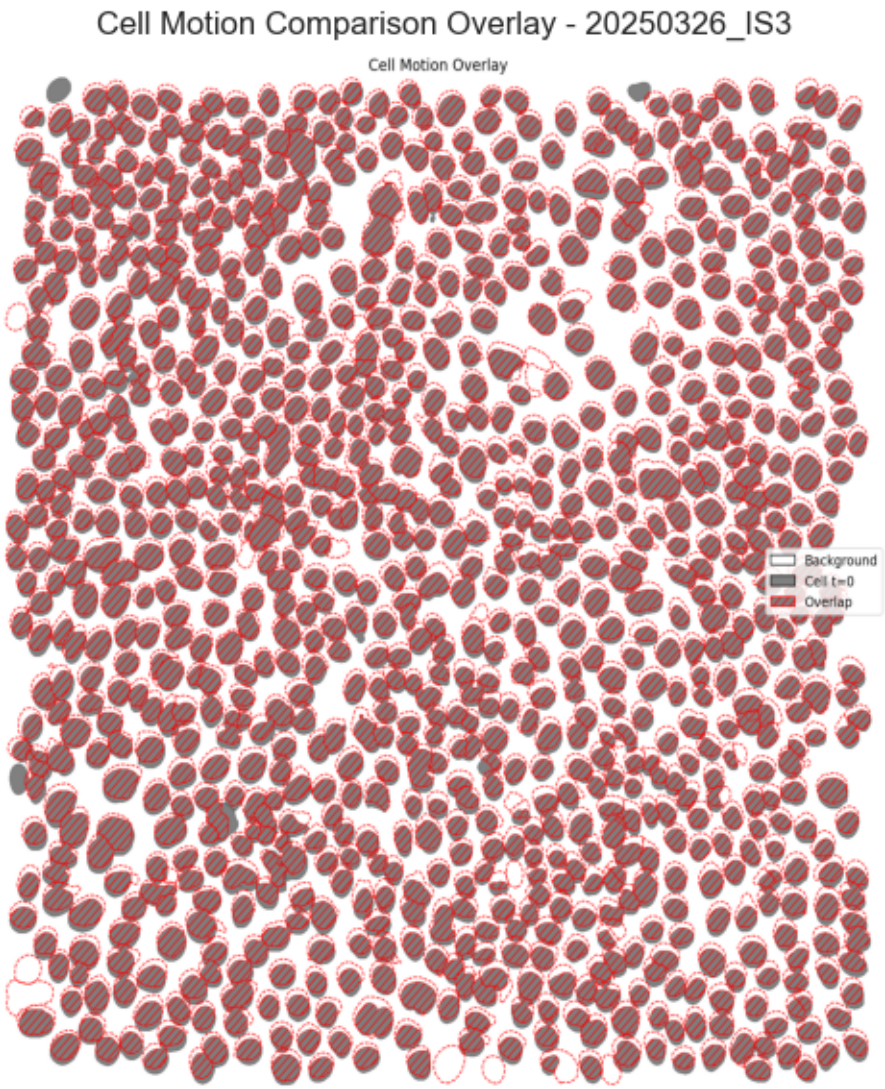

Distribution of Peak Prominences
Mean: 48.5
Std: 44.2
Min: 15
Max: 222
Count: 874
Number of Peaks
Prominence (noise std units)
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores
Mean: 0.802
Std: 0.167
Min: 0.094
Max: 1
Count: 930
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 985
- Hoechst image taken at t=1801: 999
- Number of cells difference: absolute 14, relative 1.41%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1166809
- Pixels segmented as cell at t=1801: 1288137
- Overlapping pixels between t=0 and t=1801: 937179(76.35% of total)
- Pixels exclusive to t=0: 229630 (19.68% of total)
- Pixels exclusive to t=1801: 350958 (27.25% of total)
```

executed

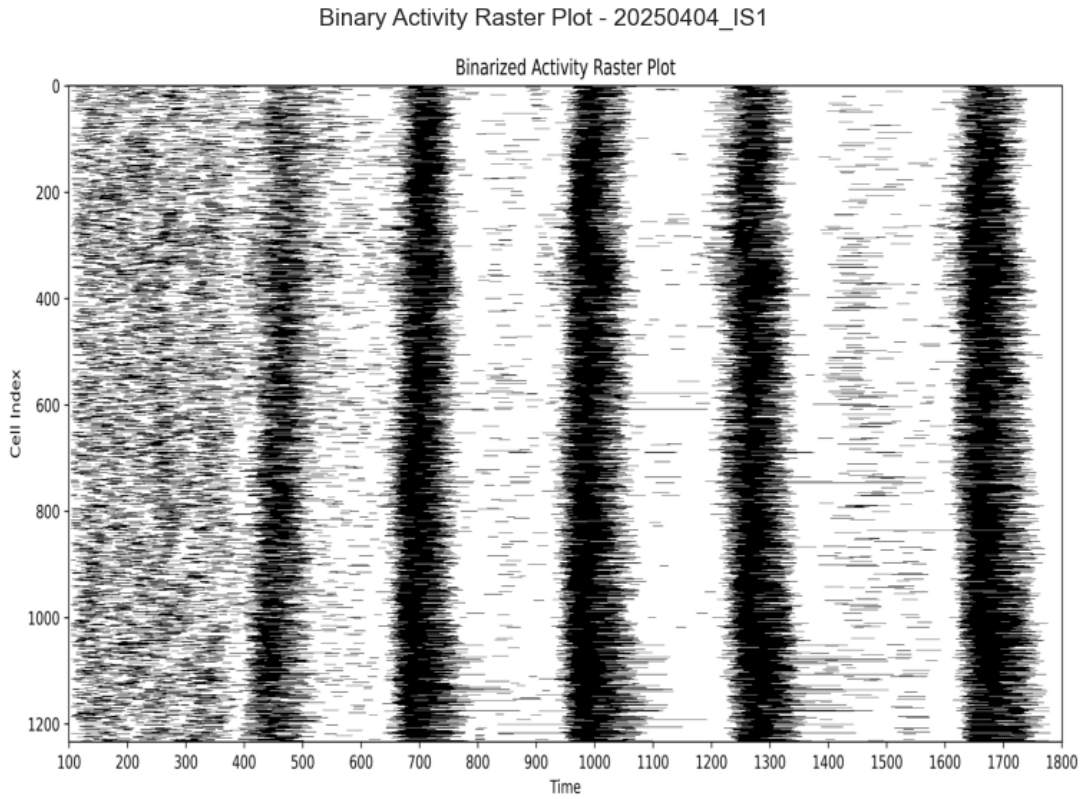
August 11, 2025

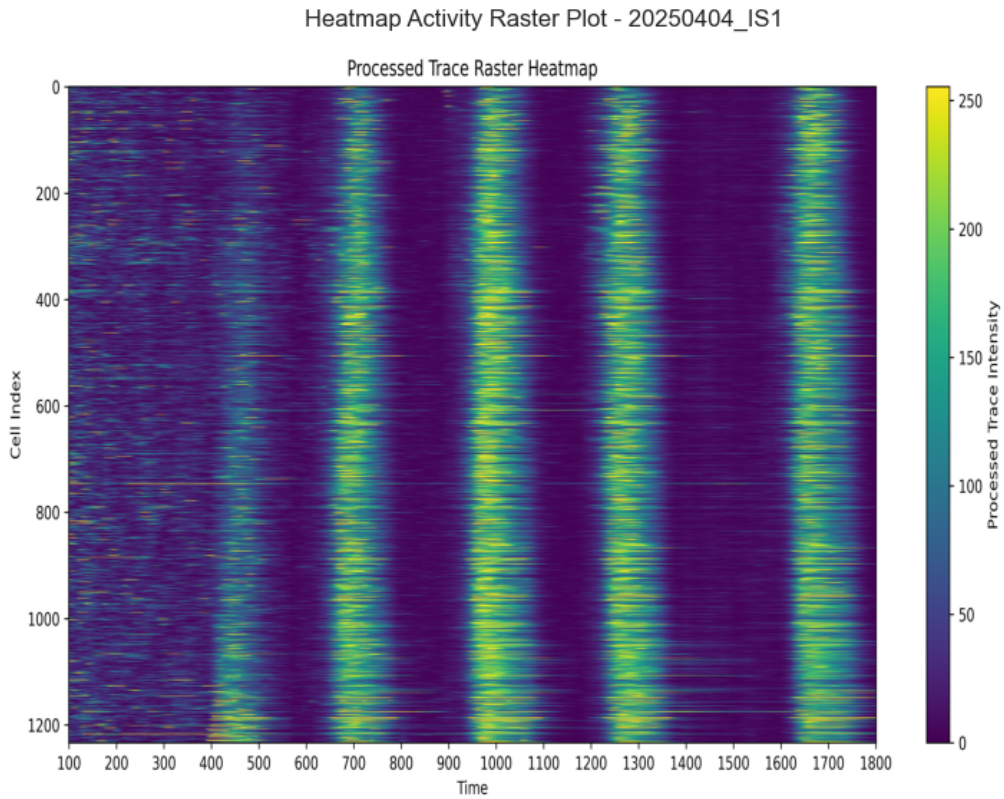
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



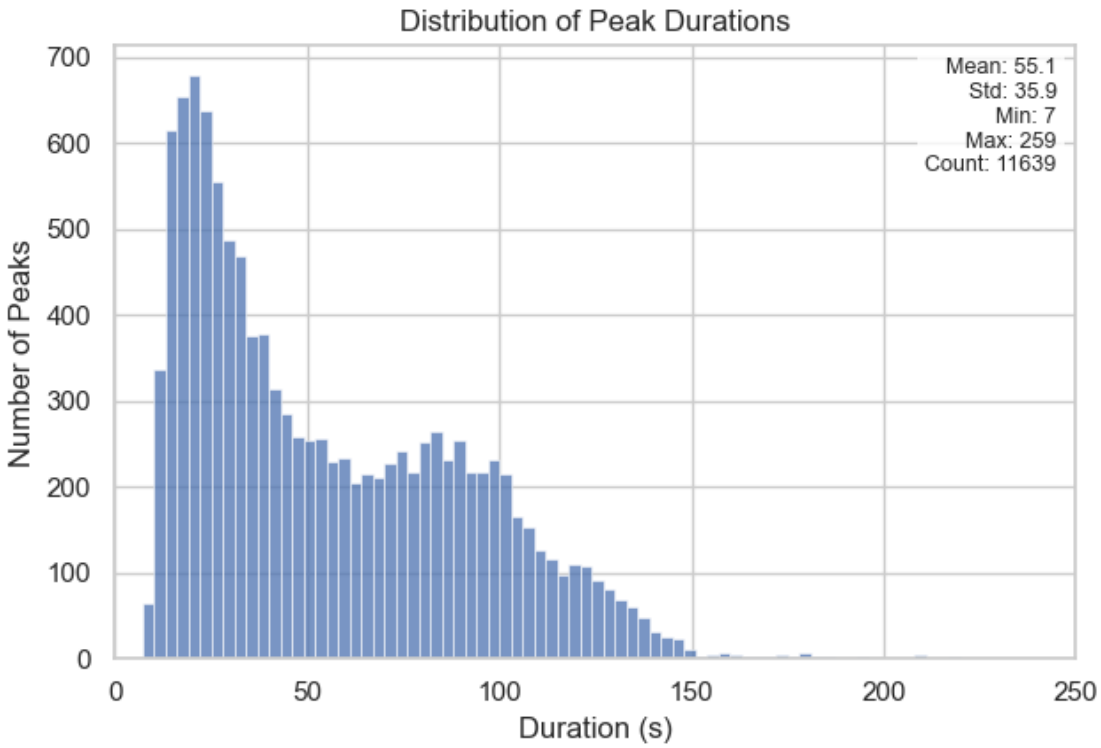


1.1.2 Peaks population

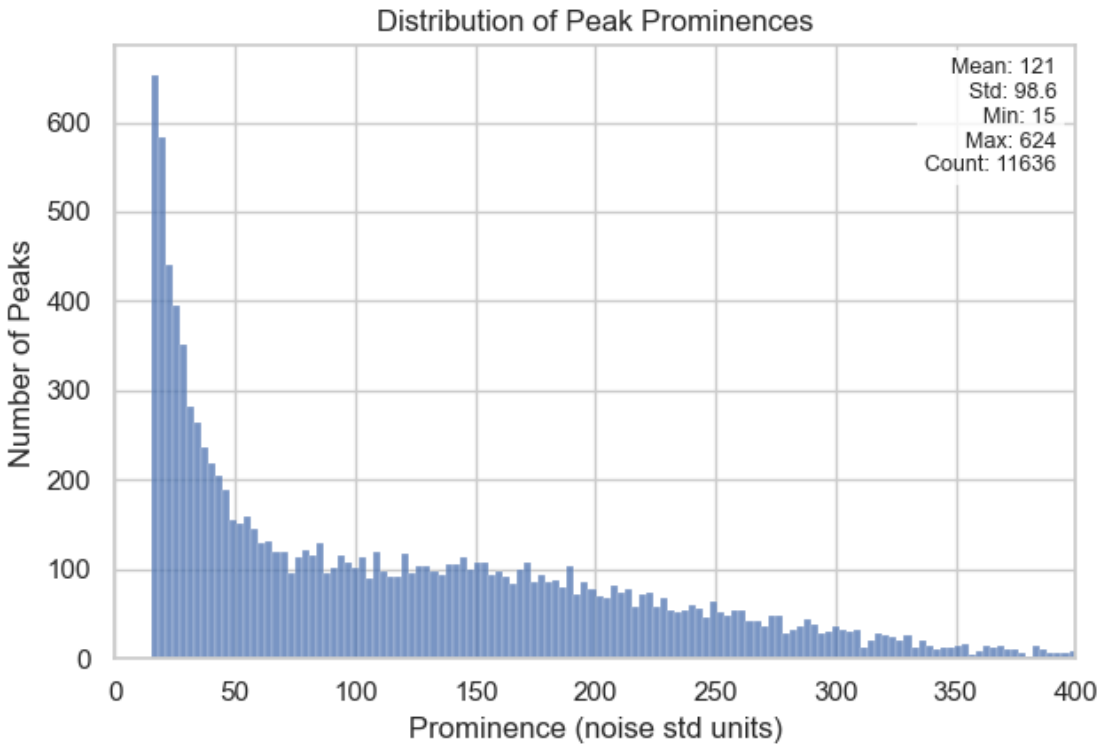
```
Total number of peaks: 11644
Total number of cells: 1234
```

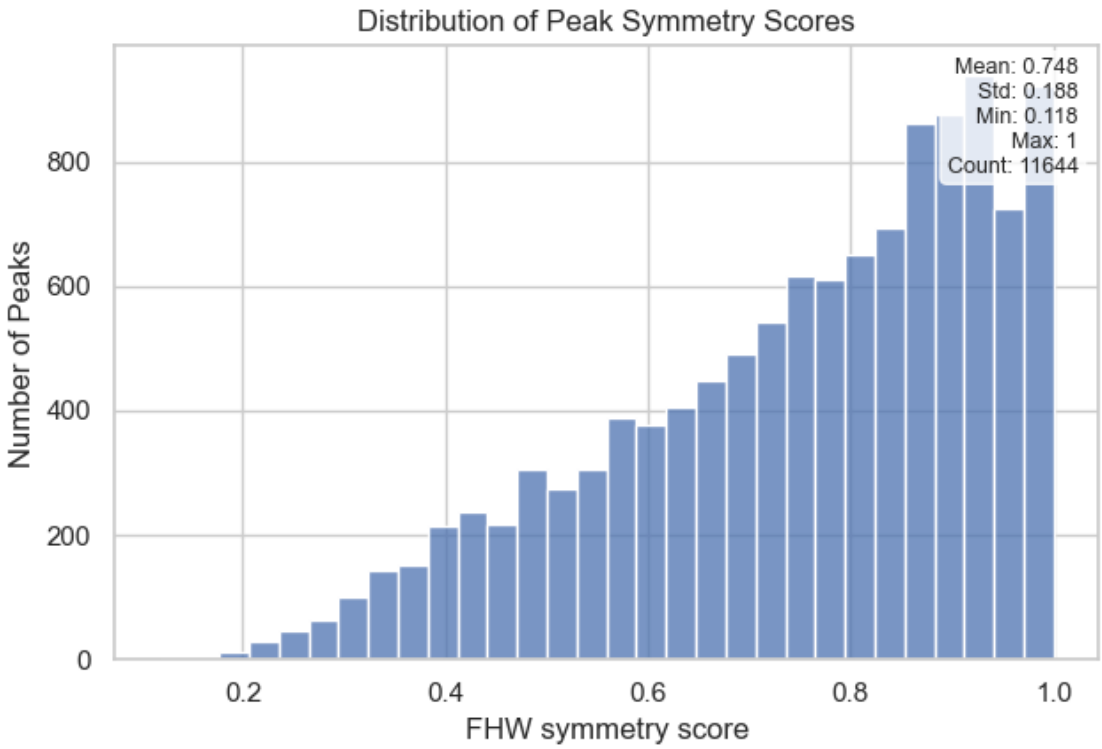
1.1.3 Peaks statistics

```
[2025-08-11 09:37:20] [INFO] calcium: plot_histogram: removed 5 outliers out of
11644 on 'Duration (s)' (lower=-153, upper=260)
```

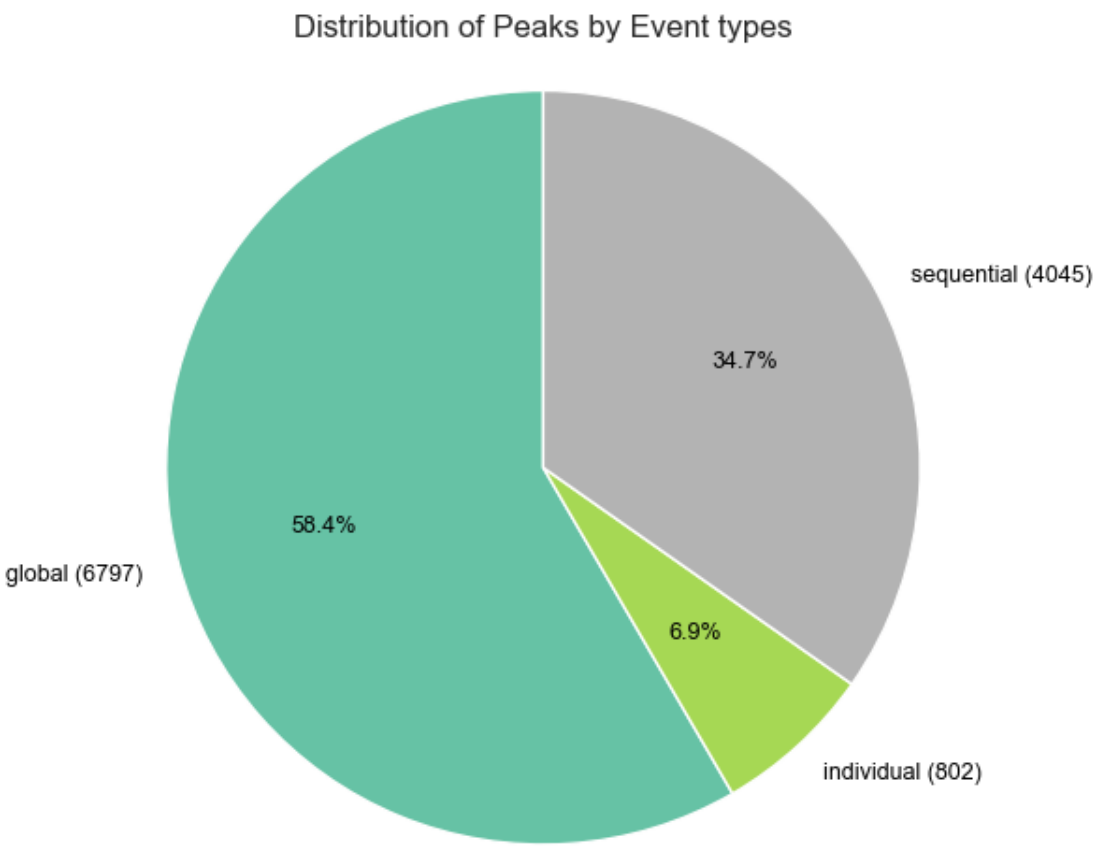



```
[2025-08-11 09:37:20] [INFO] calcium: plot_histogram: removed 8 outliers out of
11644 on 'Prominence (noise std units)' (lower=-407.2, upper=625.3)
```


Distribution of Peak Prominences
Mean: 121
Std: 98.6
Min: 15
Max: 624
Count: 11636
Number of Peaks
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

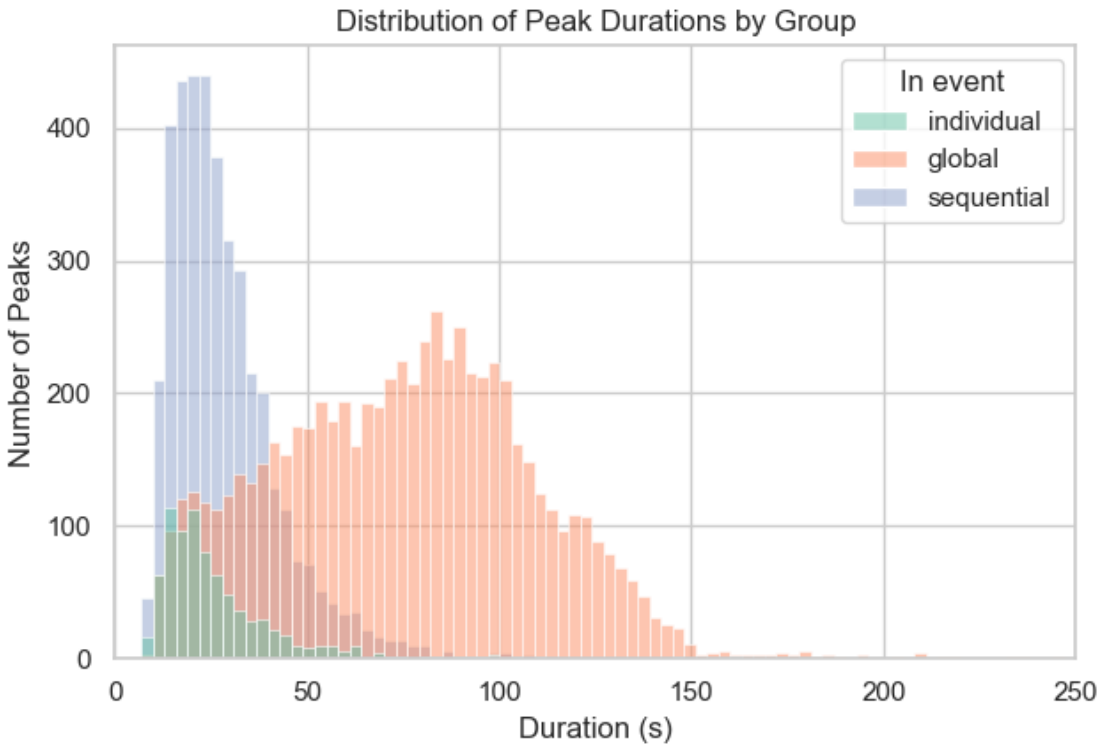

Distribution of Peak Symmetry Scores
Mean: 0.748
Std: 0.188
Min: 0.118
Max: 1
Count: 11644
Number of Peaks
0
200
400
600
800
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

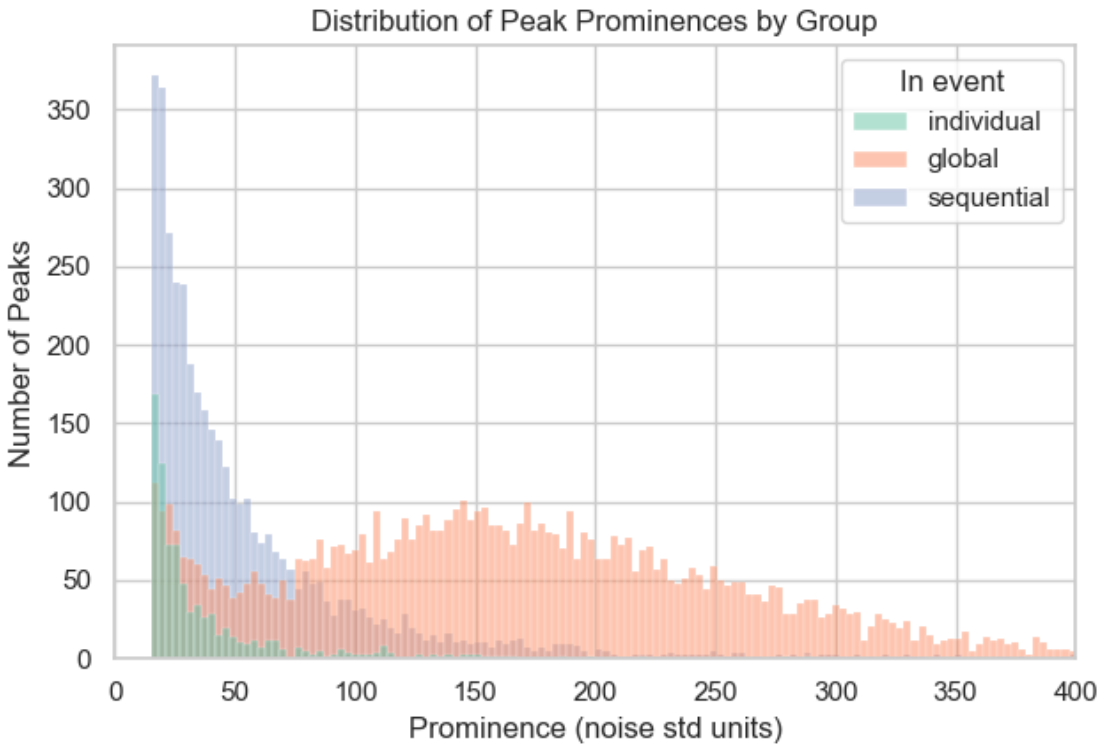


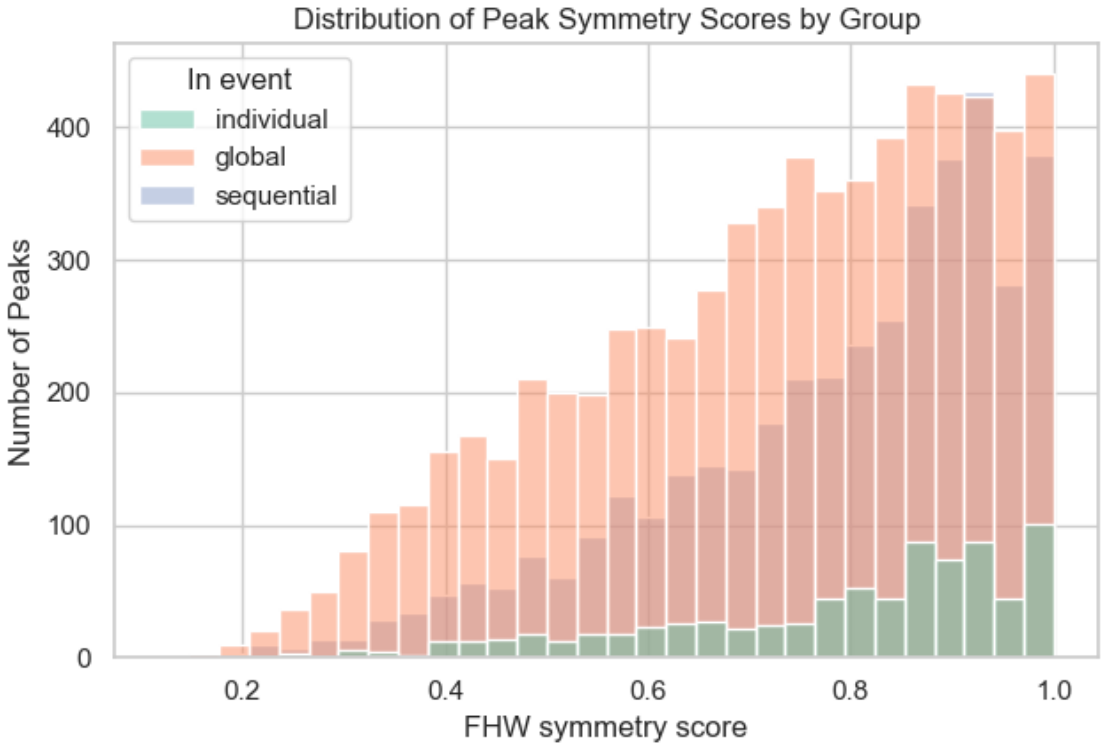
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:37:21] [INFO] calcium: plot_histogram_by_group: removed 5
outliers out of 11644 on 'Duration (s)' (lower=-153, upper=260)
```




```
[2025-08-11 09:37:21] [INFO] calcium: plot_histogram_by_group: removed 8
outliers out of 11644 on 'Prominence (noise std units)' (lower=-407.2,
upper=625.3)
```

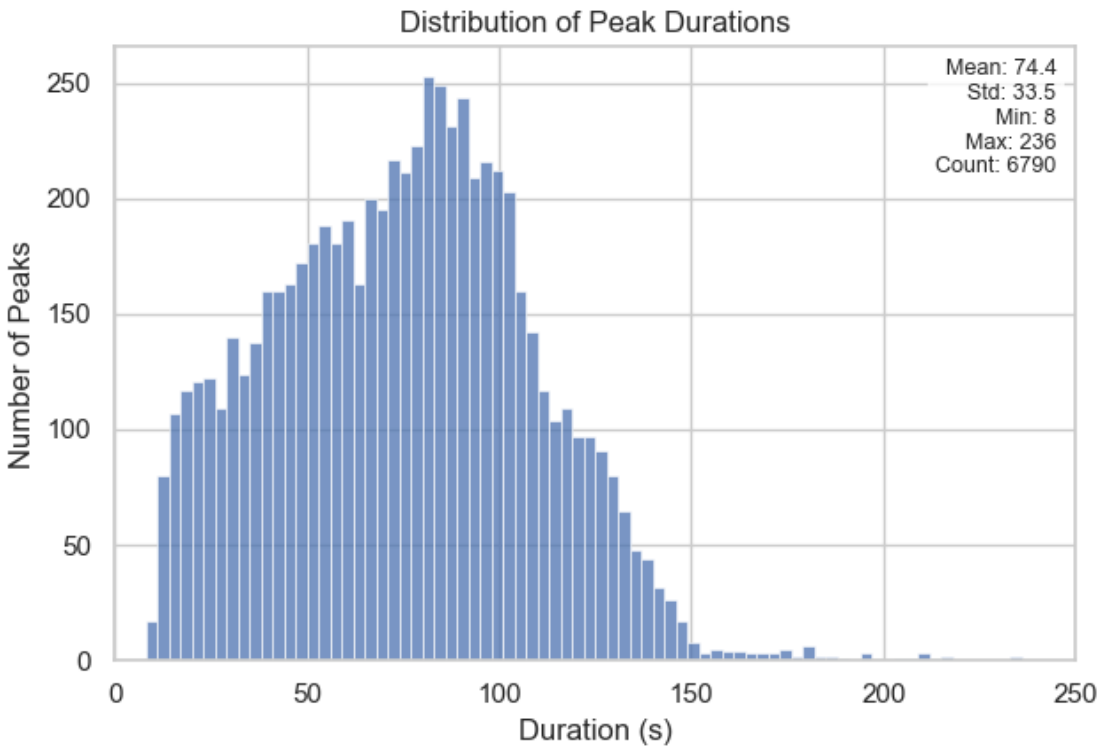

Distribution of Peak Prominences by Group
In event
individual
global
sequential
Number of Peaks
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
individual
global
sequential
Number of Peaks
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

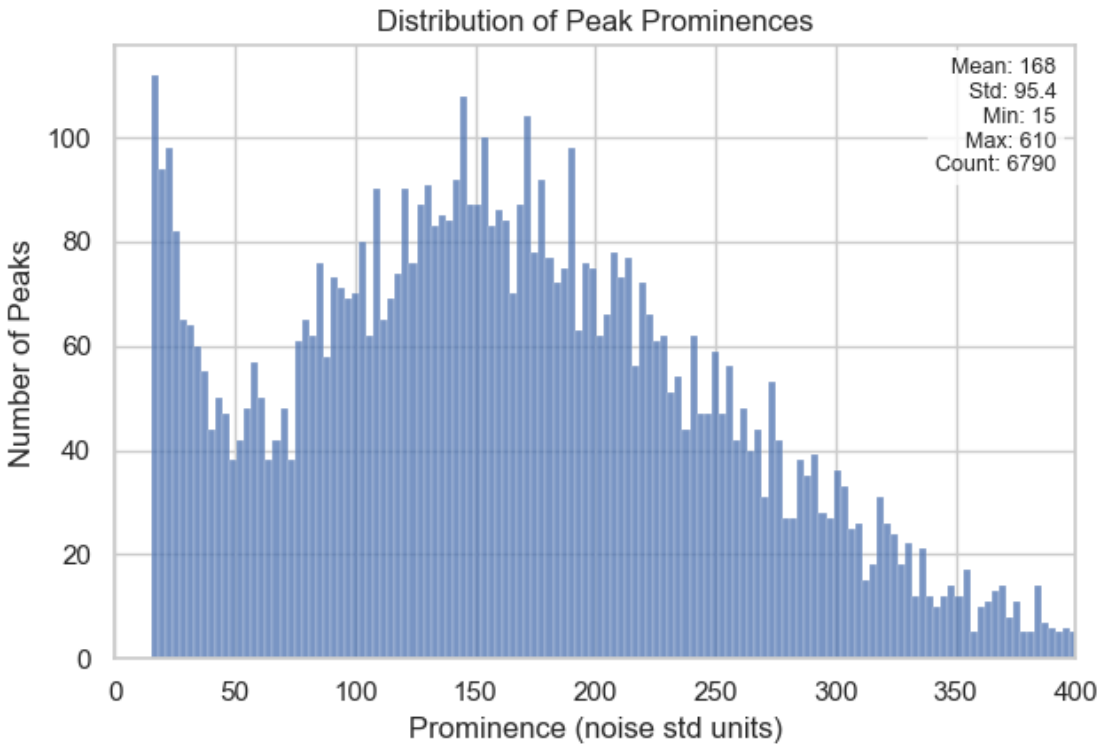
1.2 GLOBAL EVENTS

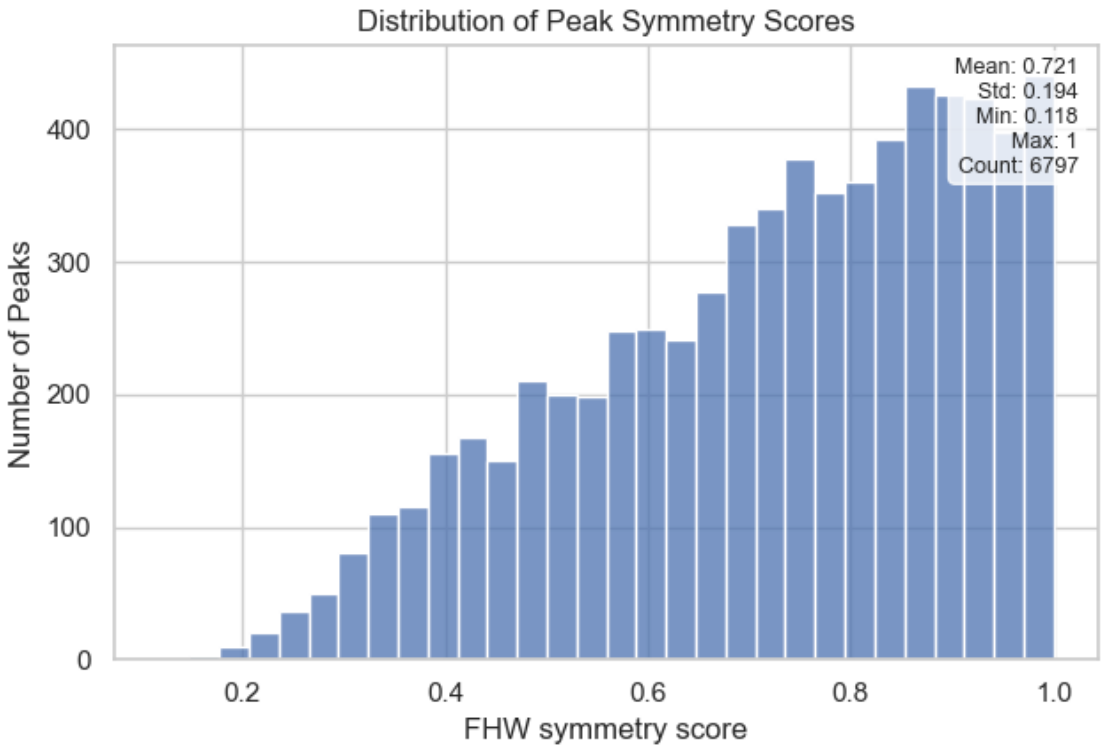
1.2.1 Peak statistics in global events

```
[2025-08-11 09:37:22] [INFO] calcium: plot_histogram: removed 7 outliers out of
6797 on 'Duration (s)' (lower=-98, upper=245)
```



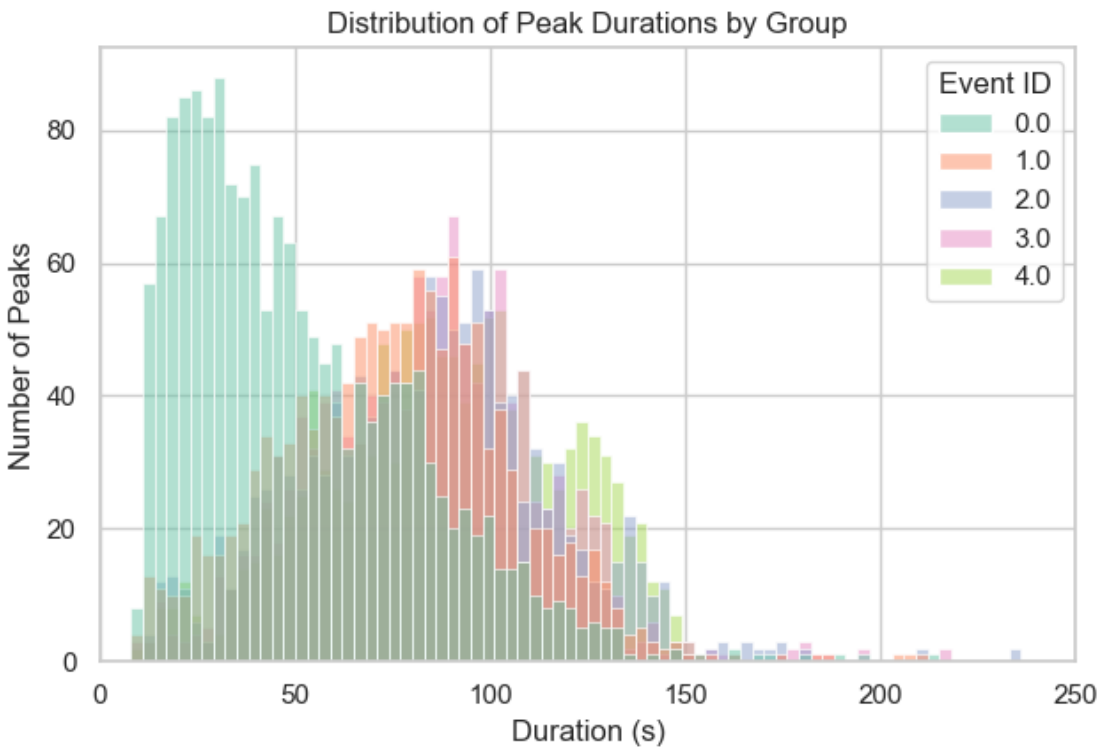

```
[2025-08-11 09:37:22] [INFO] calcium: plot_histogram: removed 7 outliers out of
6797 on 'Prominence (noise std units)' (lower=-286.2, upper=611.2)
```


Distribution of Peak Prominences
Mean: 168
Std: 95.4
Min: 15
Max: 610
Count: 6790
Number of Peaks
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

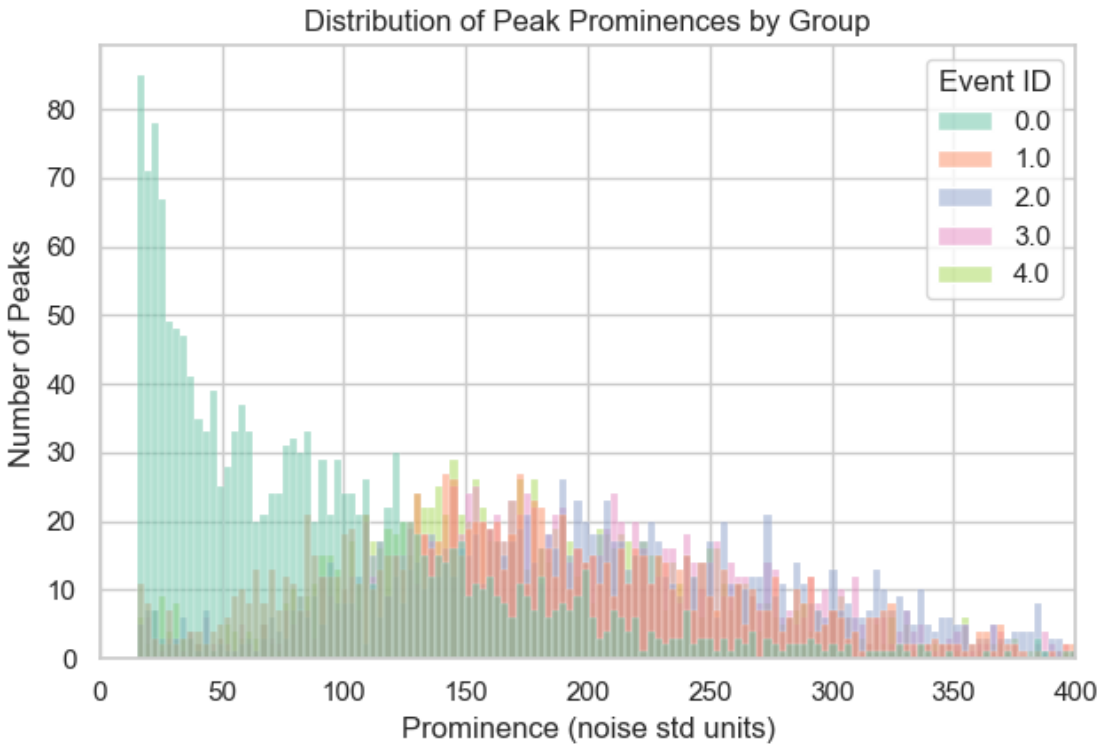

Distribution of Peak Symmetry Scores
Mean: 0.721
Std: 0.194
Min: 0.118
Max: 1
Count: 6797
Number of Peaks
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

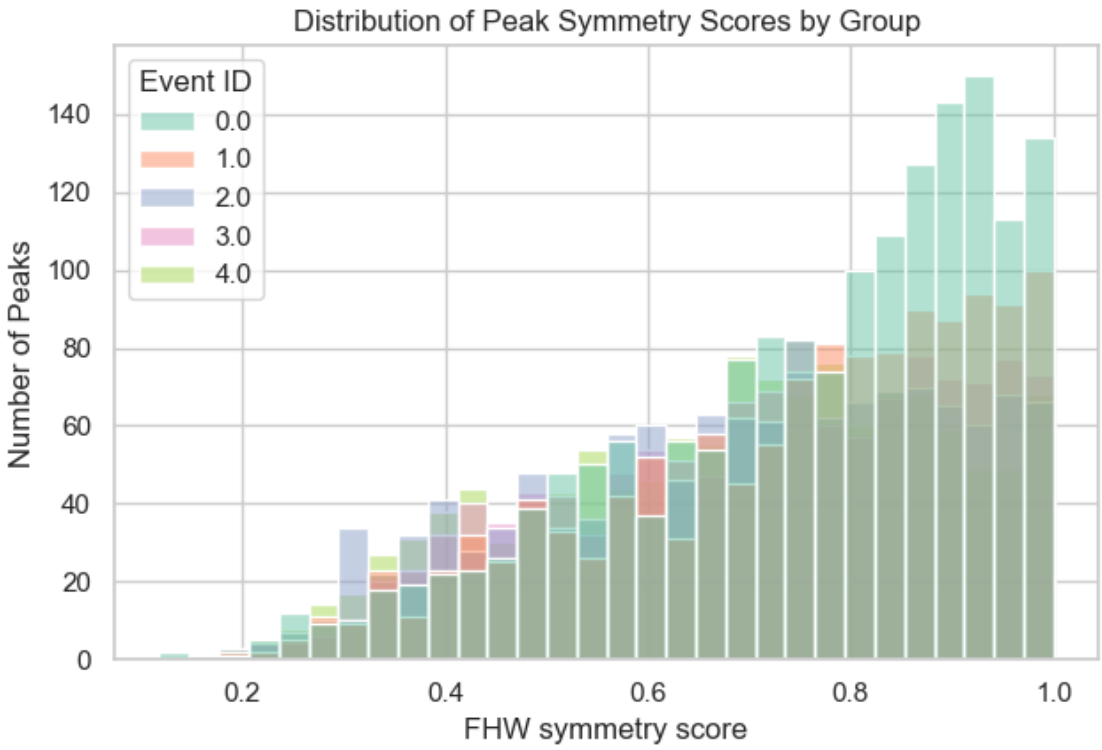
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:37:23] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 6797 on 'Duration (s)' (lower=-98, upper=245)
```

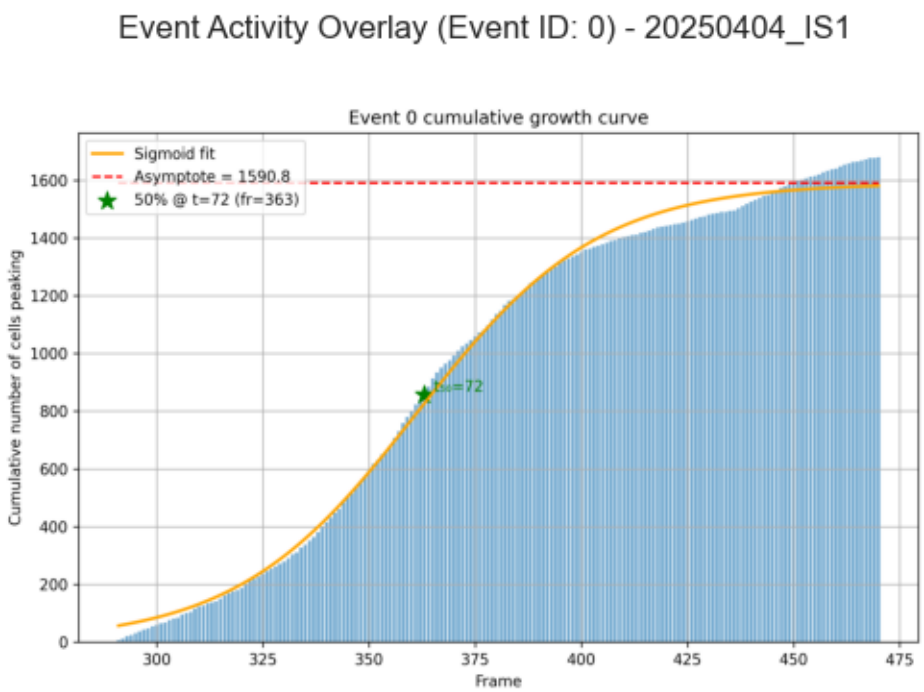


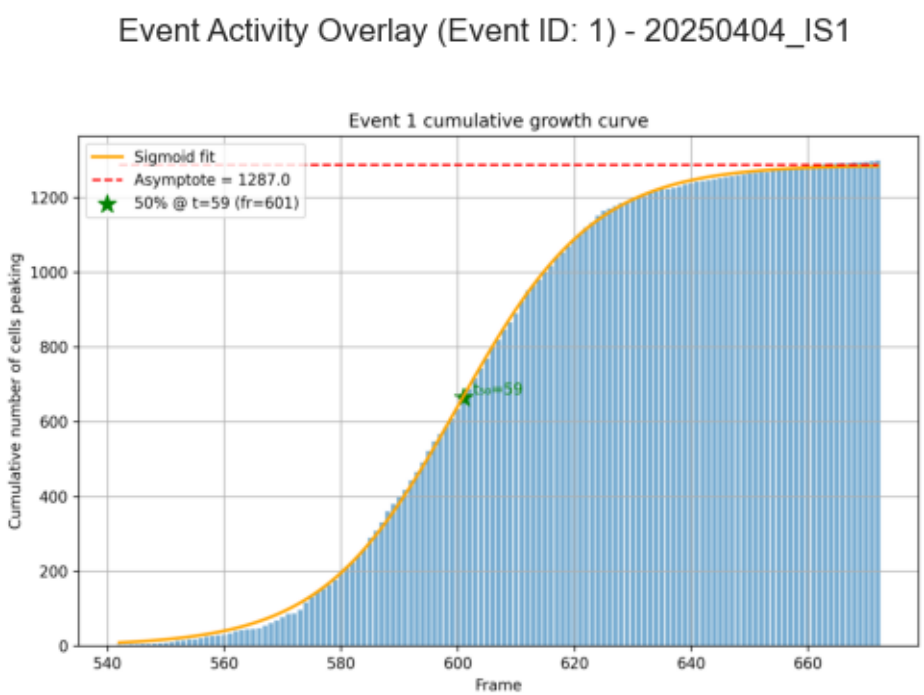

```
[2025-08-11 09:37:23] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 6797 on 'Prominence (noise std units)' (lower=-286.2,
upper=611.2)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

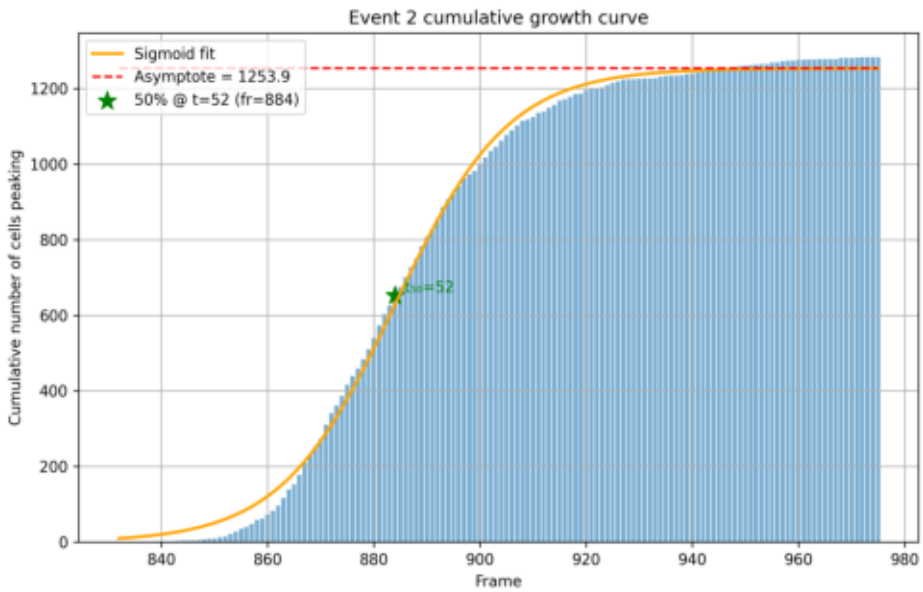

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
0
20
40
60
80
100
120
140
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2.3 Kinetics of global events

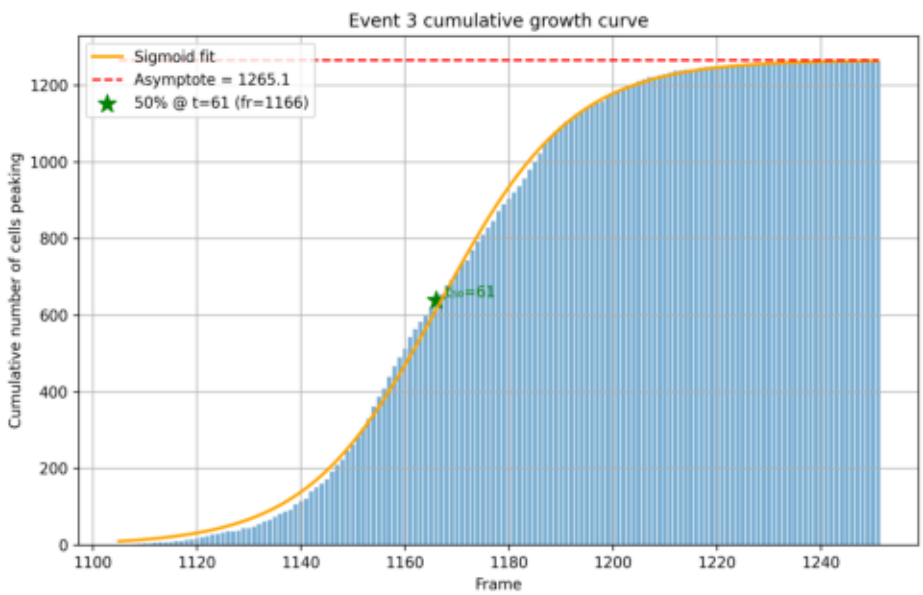


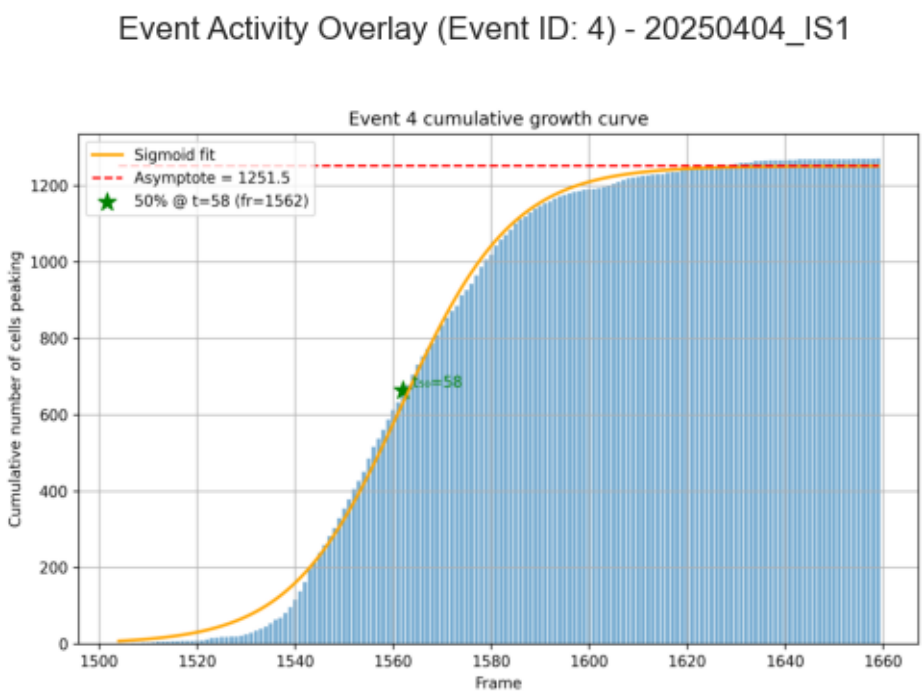


Event Activity Overlay (Event ID: 2) - 20250404_IS1

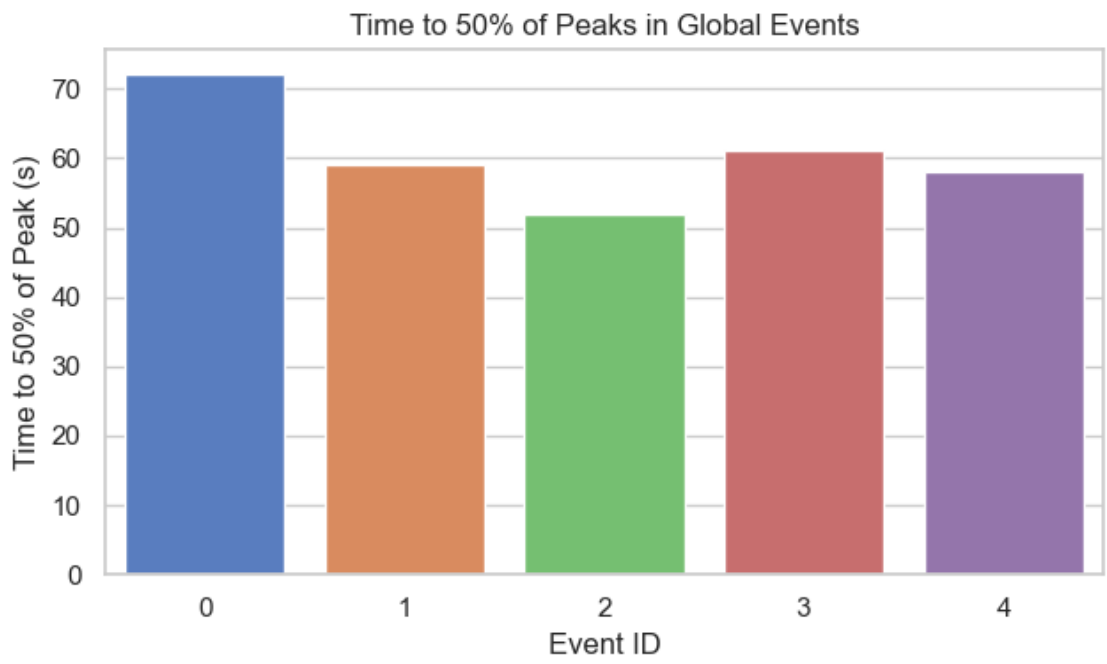


Event Activity Overlay (Event ID: 3) - 20250404_IS1

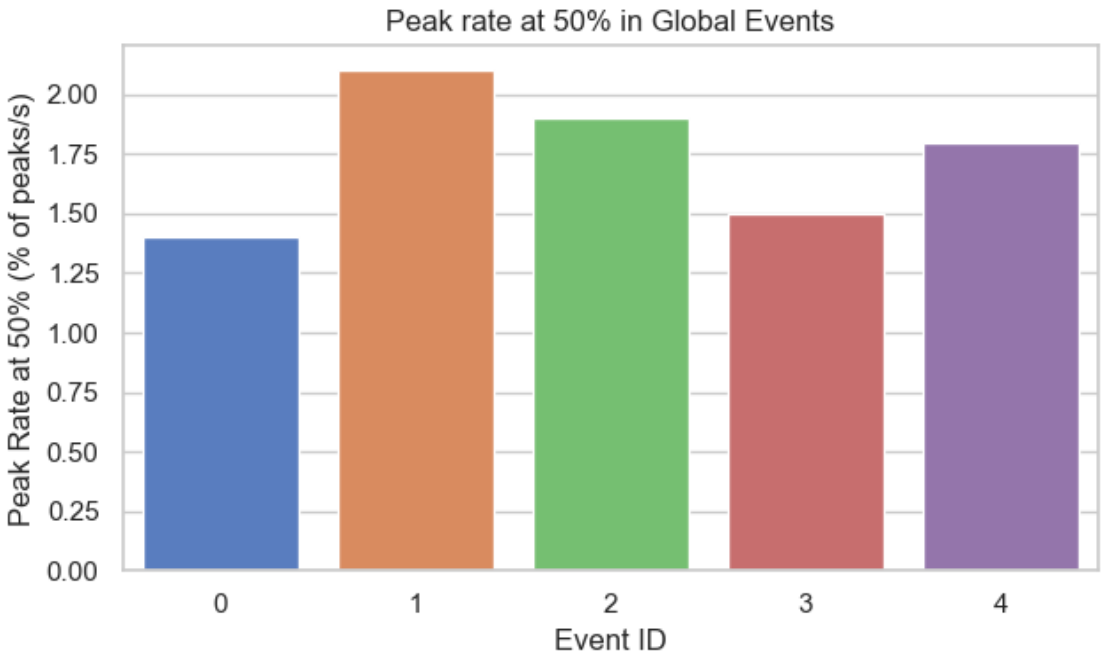




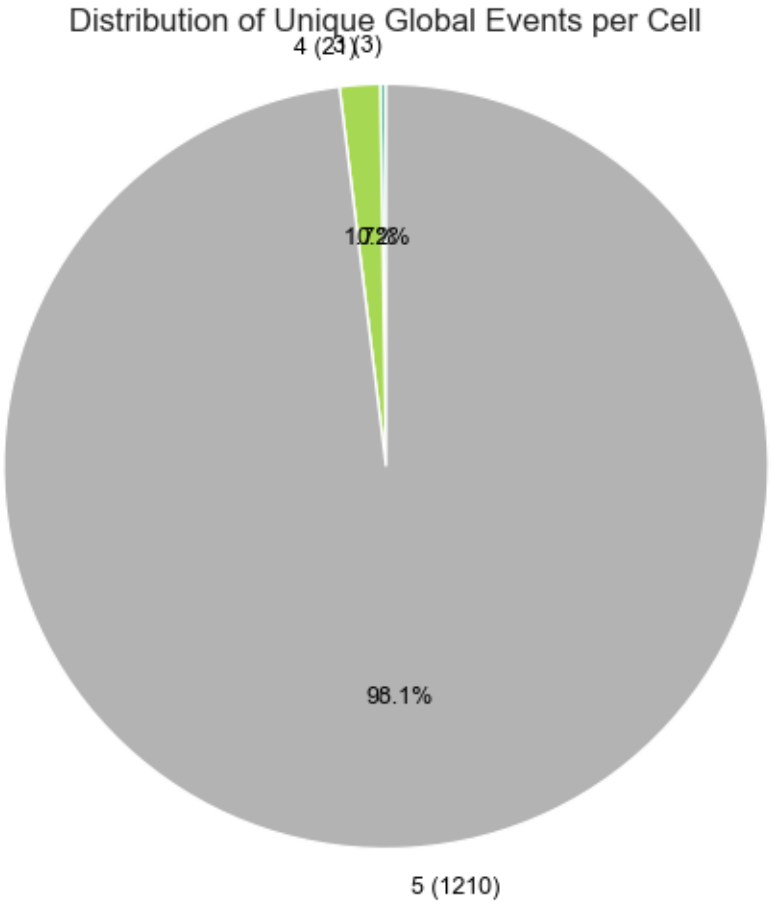

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



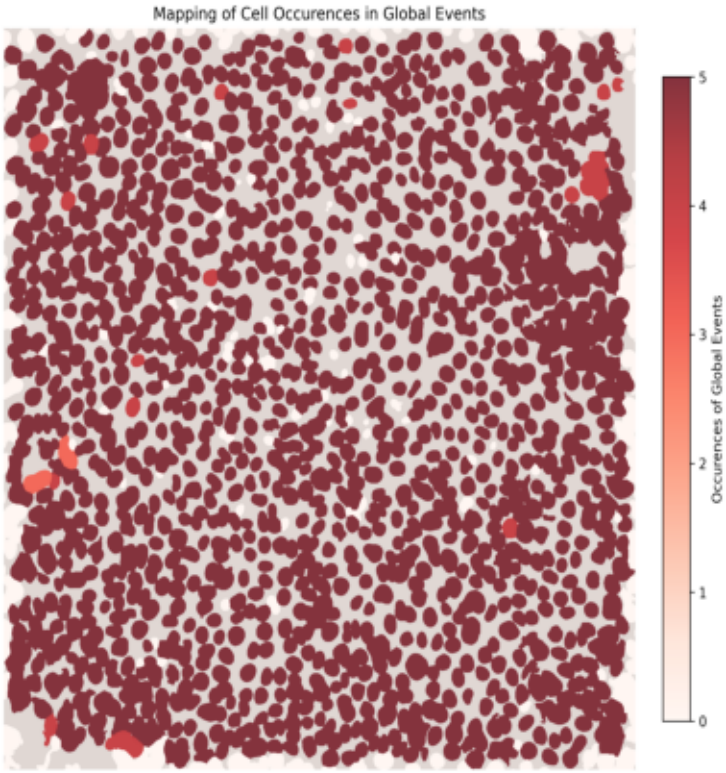

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
1
2
3
4
Event ID

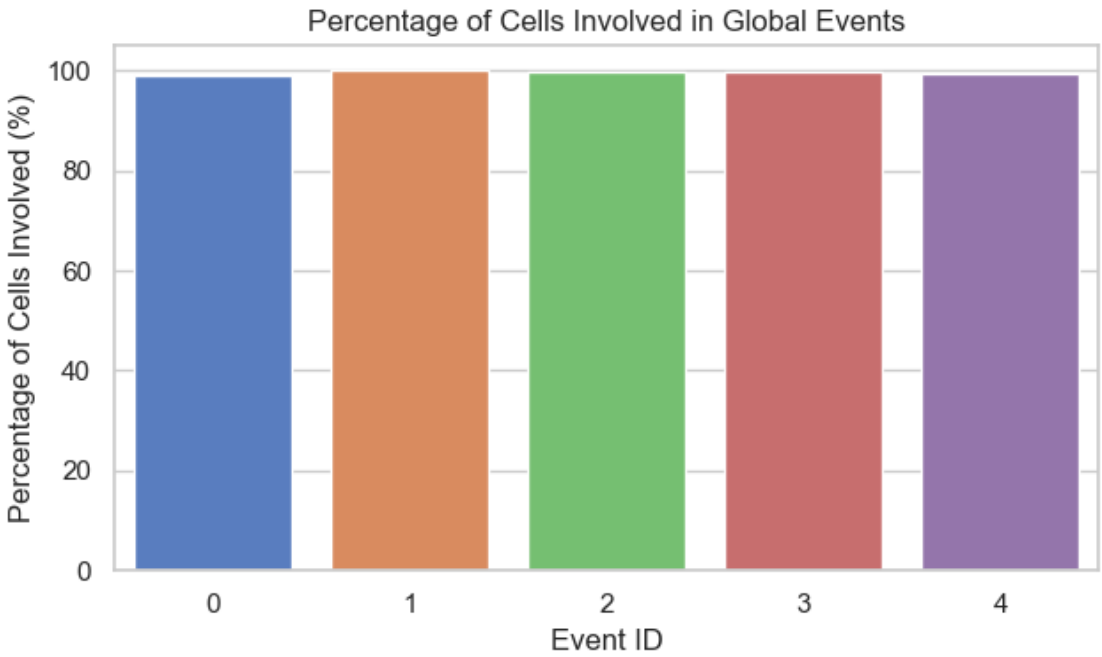
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250404_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

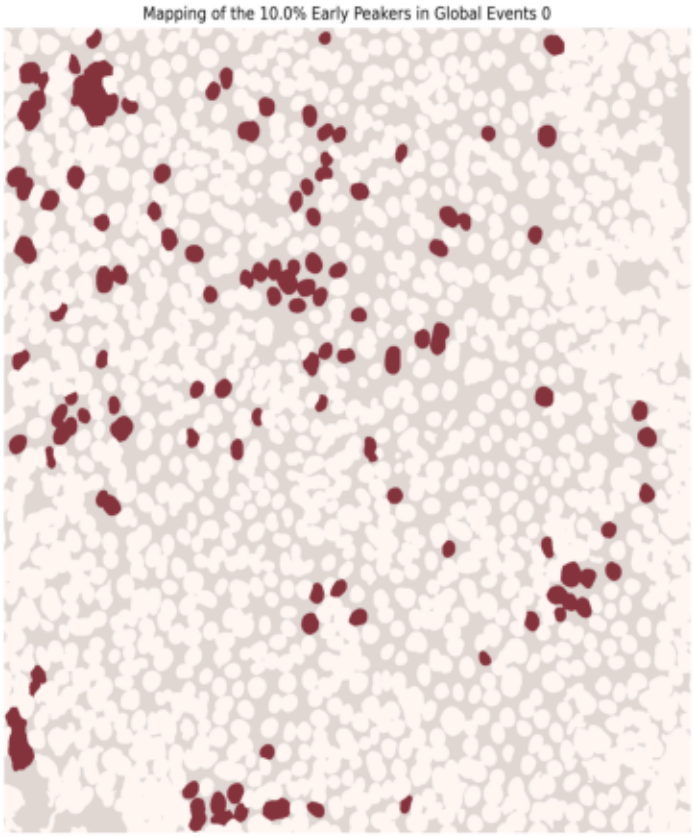


1.2.5 Inter-event interval analysis

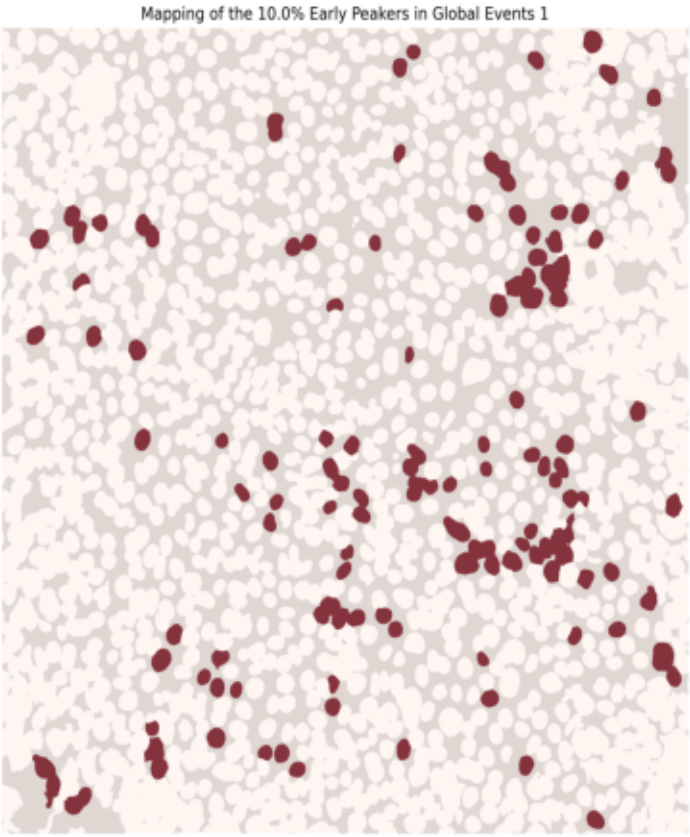
```
Intervals between global event peaks: [241.0, 286.0, 281.0, 396.0]
Estimated periodicity: 0.839
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.003 Hz
```

1.2.6 Early peakers in the events

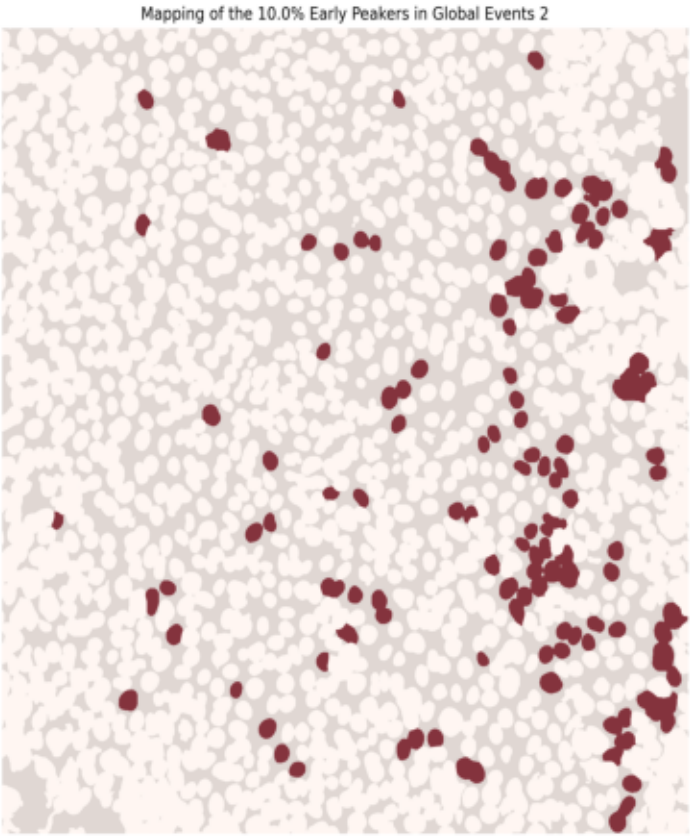
Cell Mapping with Early Peakers Overlay for event 0 - 20250404_IS1



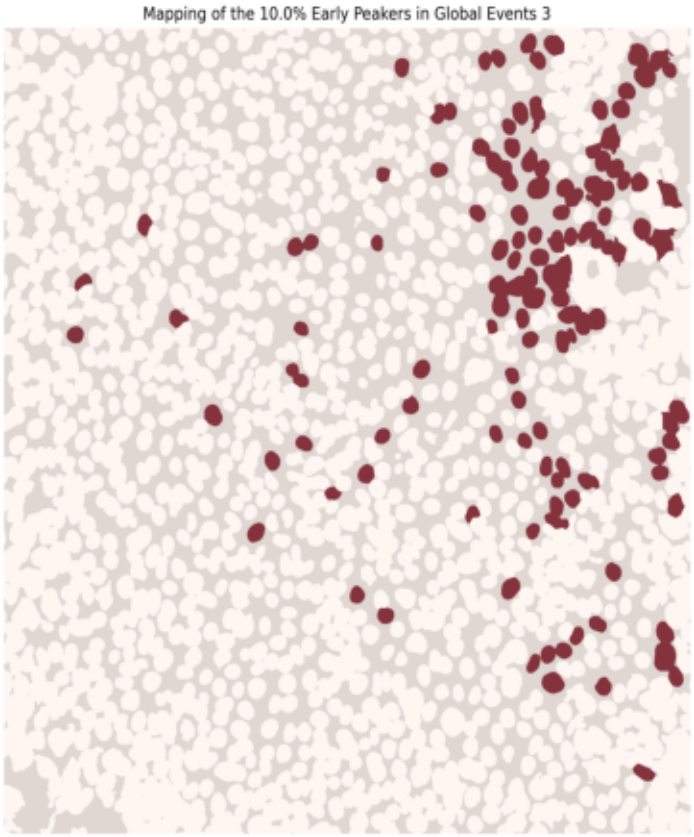
Cell Mapping with Early Peakers Overlay for event 1 - 20250404_IS1



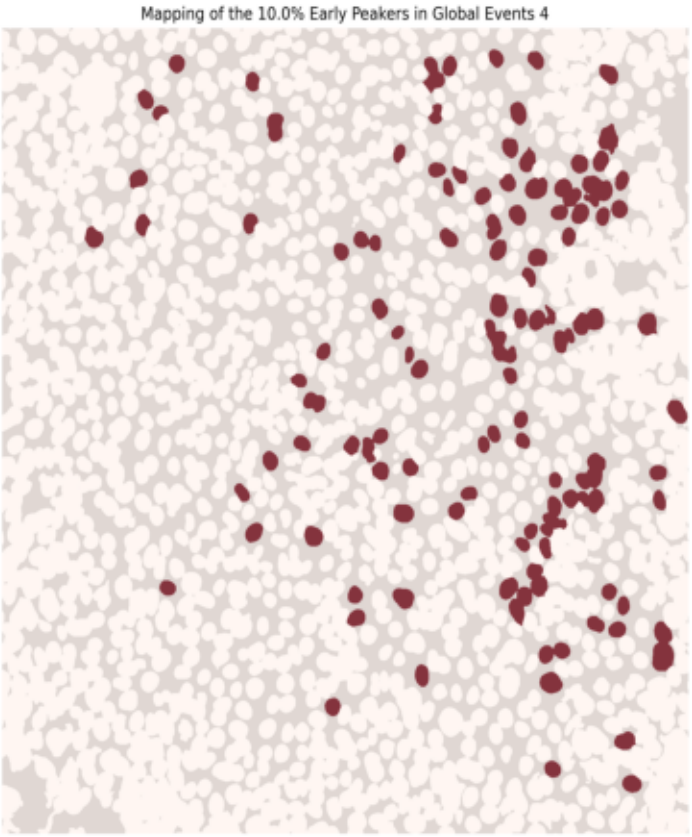
Cell Mapping with Early Peakers Overlay for event 2 - 20250404_IS1



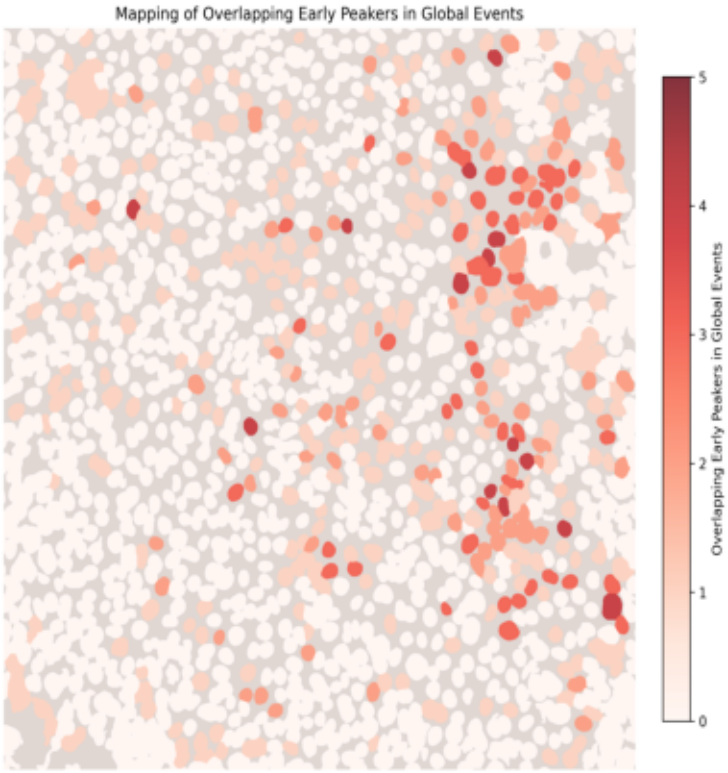
Cell Mapping with Early Peakers Overlay for event 3 - 20250404_IS1



Cell Mapping with Early Peakers Overlay for event 4 - 20250404_IS1

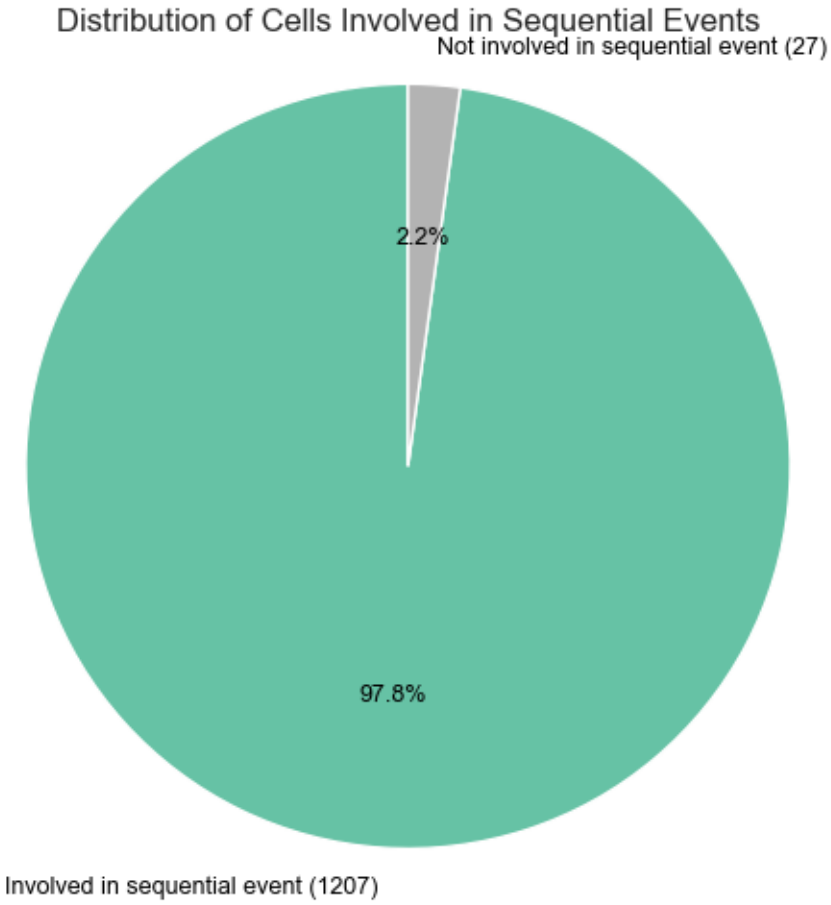


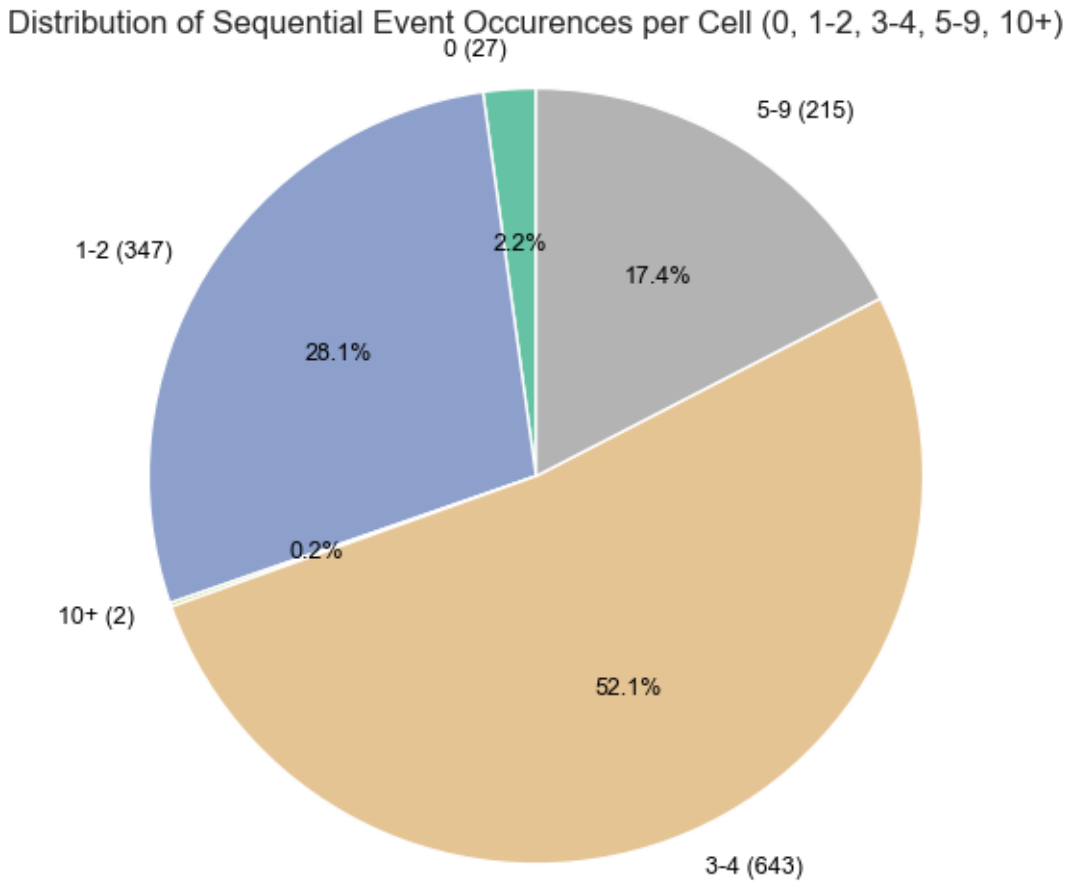
Cell Mapping with Occurences in Global Events Overlay - 20250404_IS1



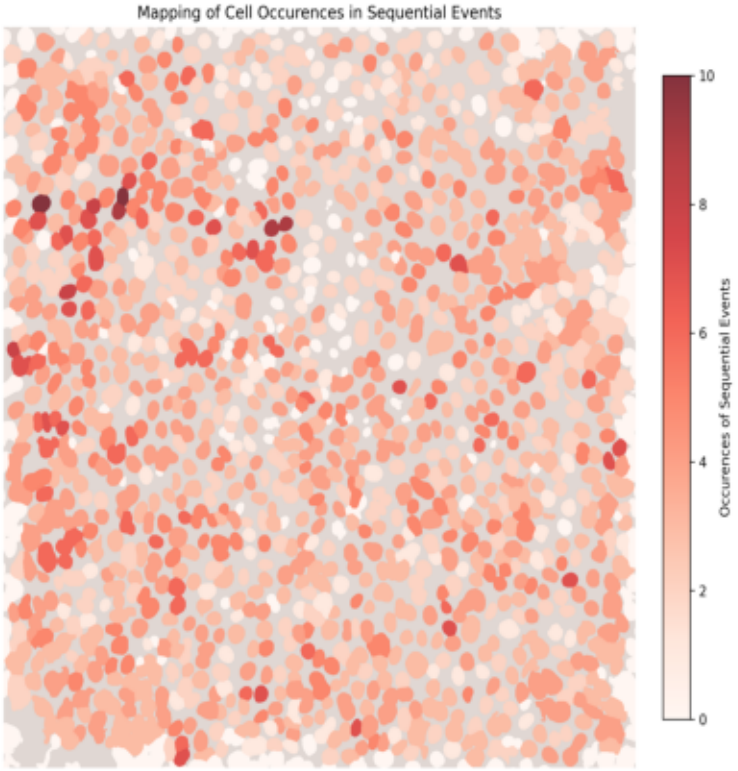
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

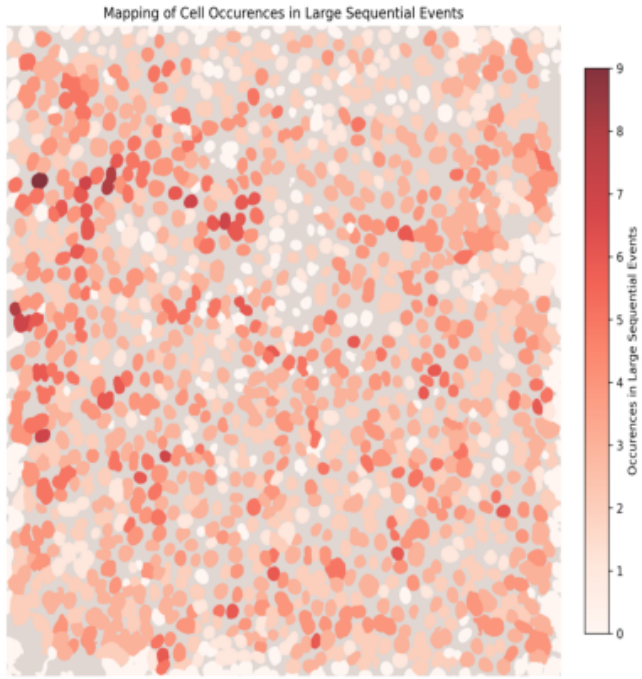



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (27)
5-9 (215)
1-2 (347)
2.2%
17.4%
28.1%
0.2%
10+ (2)
52.1%
3-4 (643)

Cell Mapping with Occurences in Sequential Events Overlay - 20250404_IS1

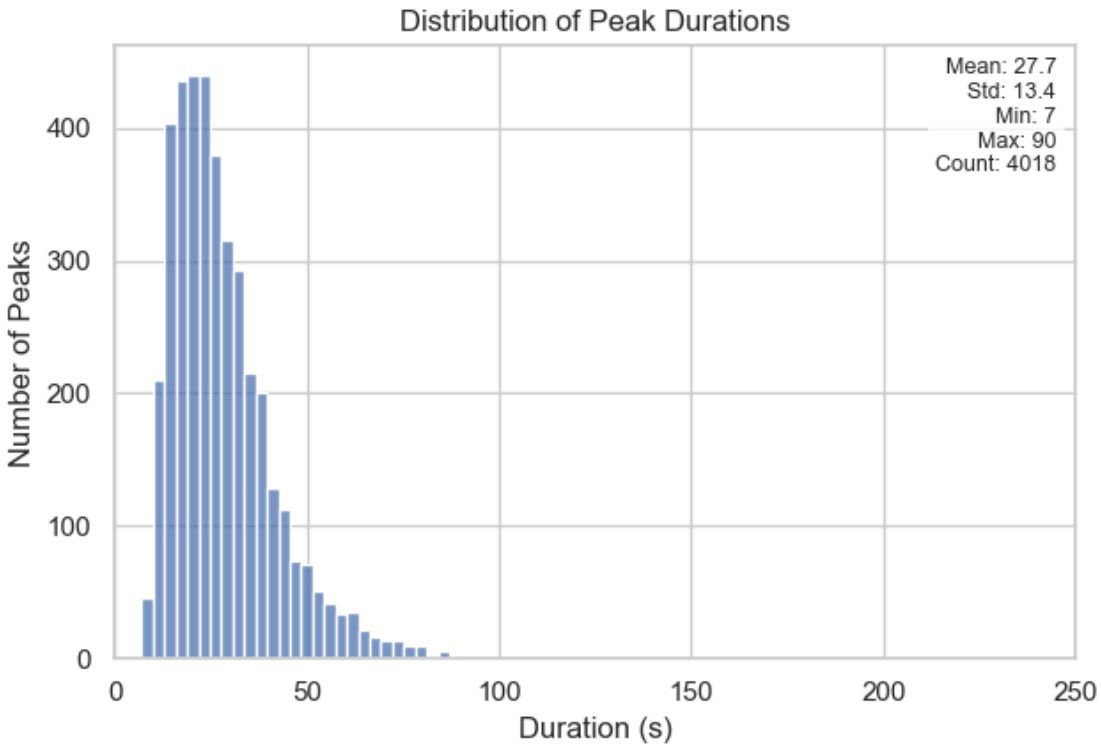


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250404_IS1

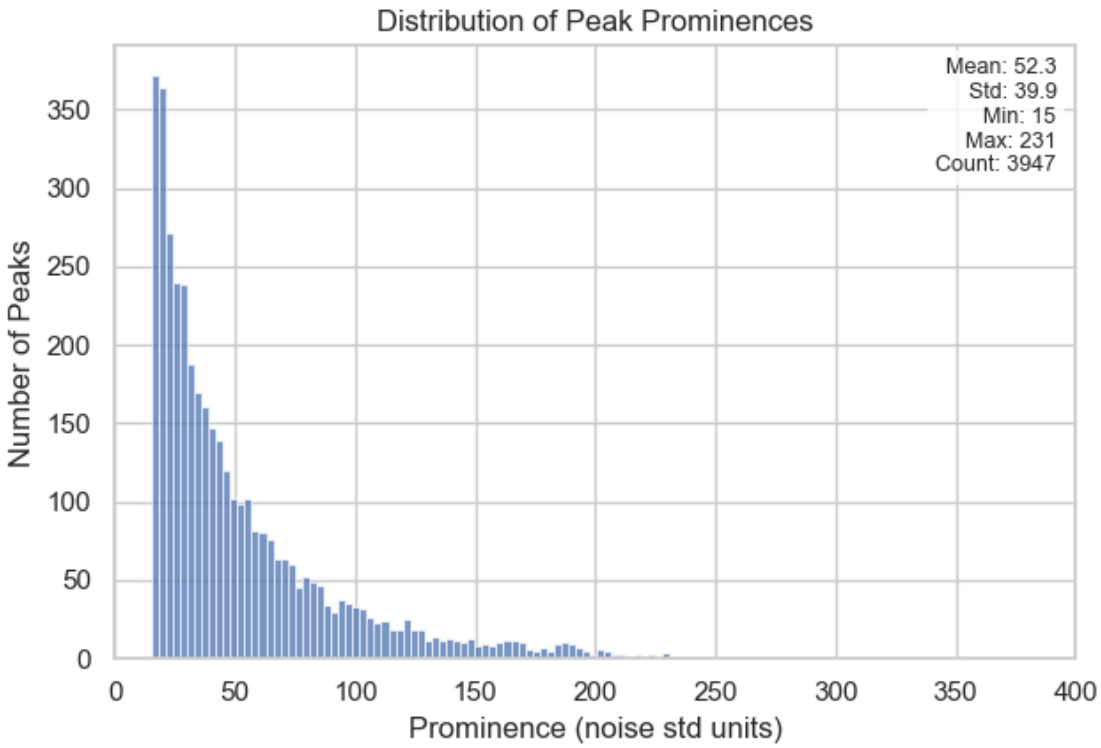


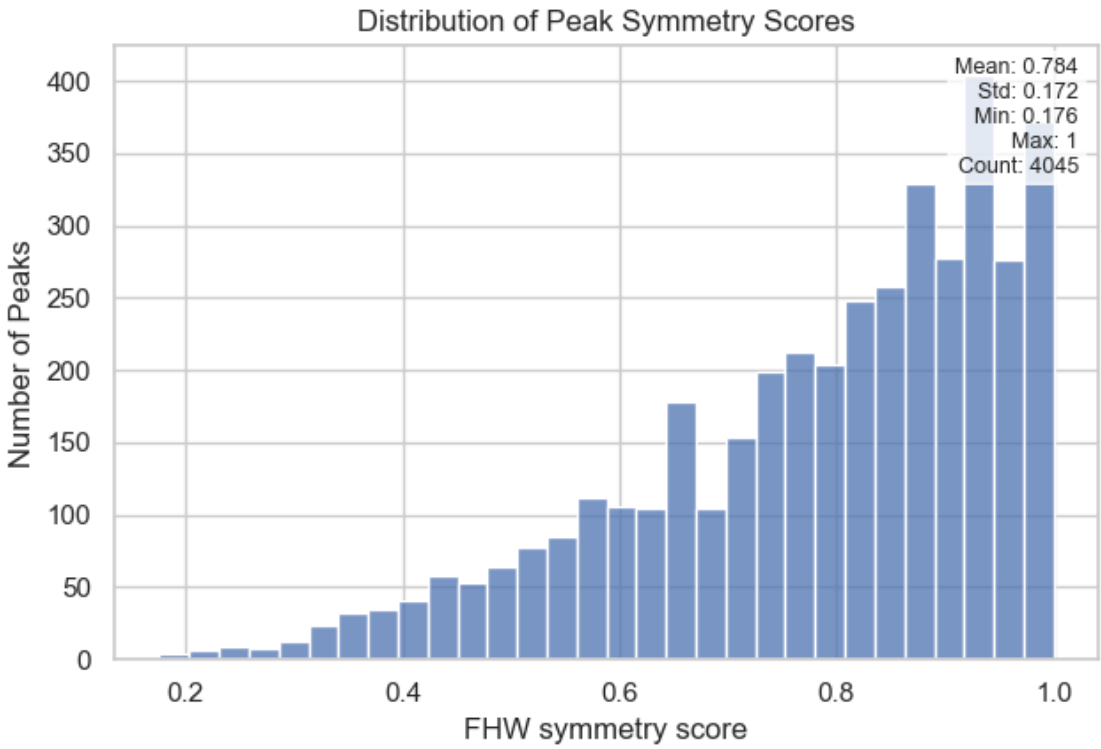
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:37:37] [INFO] calcium: plot_histogram: removed 27 outliers out of
4045 on 'Duration (s)' (lower=-6, upper=90)
```



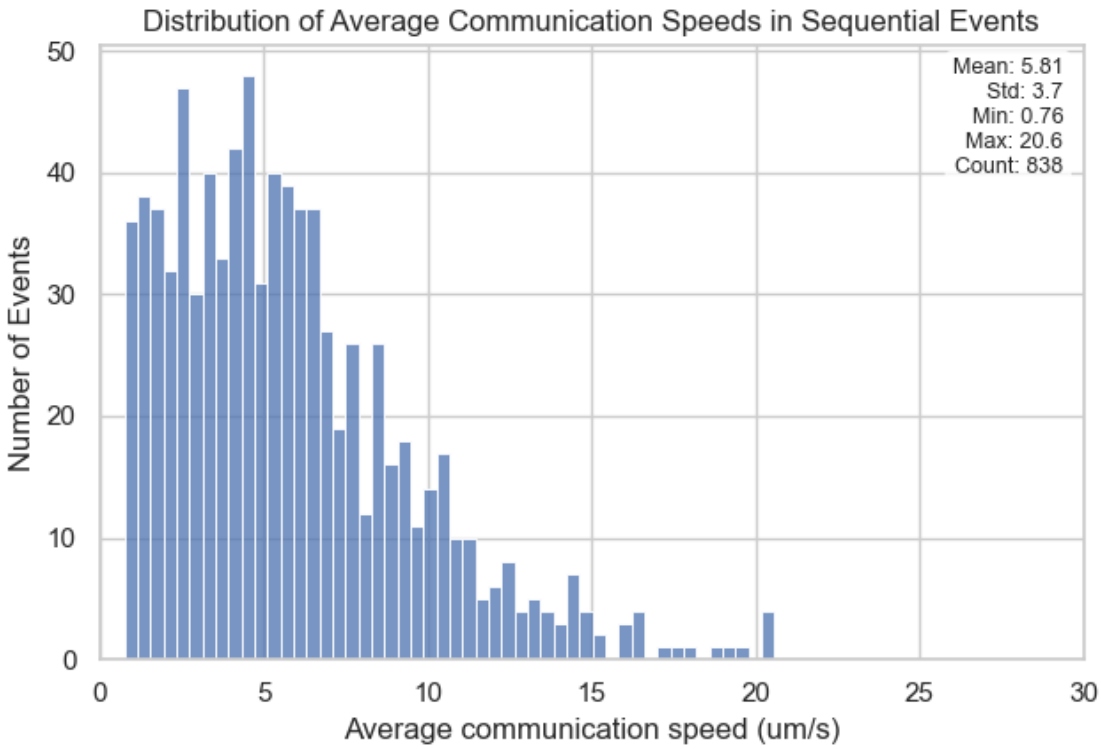

```
[2025-08-11 09:37:37] [INFO] calcium: plot_histogram: removed 98 outliers out of
4045 on 'Prominence (noise std units)' (lower=-45, upper=231)
```


Distribution of Peak Prominences
Mean: 52.3
Std: 39.9
Min: 15
Max: 231
Count: 3947
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400

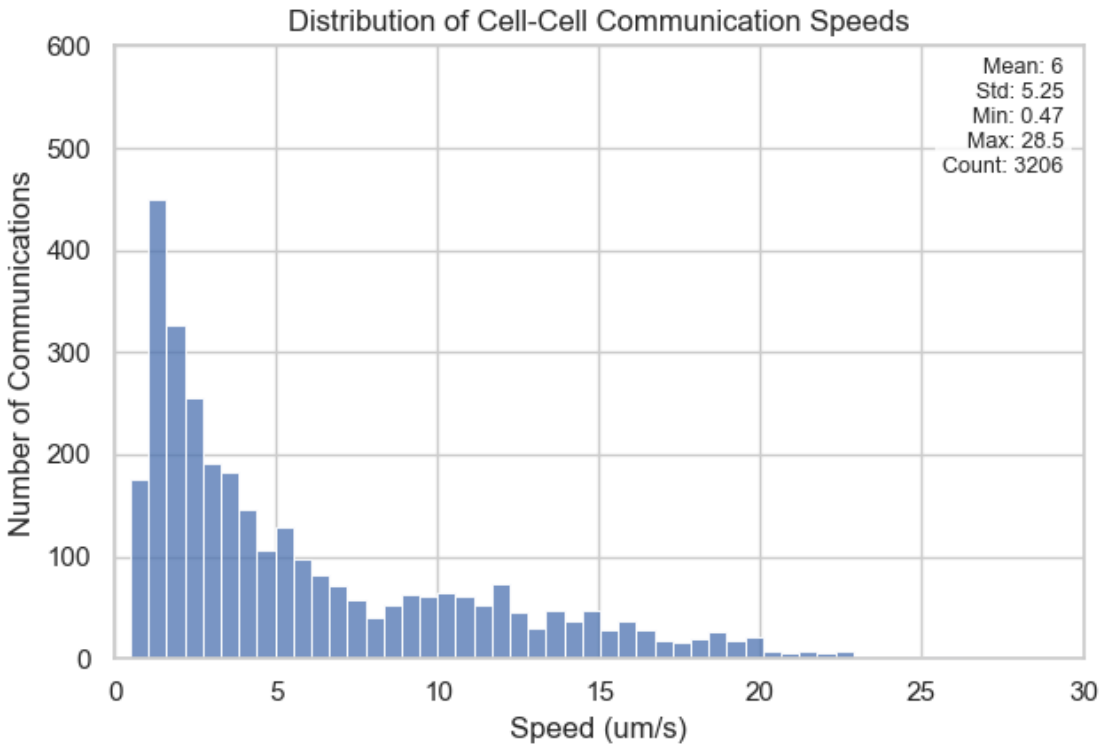

Distribution of Peak Symmetry Scores
Mean: 0.784
Std: 0.172
Min: 0.176
Max: 1
Count: 4045
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
300
350
400
0.2
0.4
0.6
0.8
1.0

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:37:37] [INFO] calcium: plot_histogram: removed 1 outliers out of
839 on 'Average communication speed (um/s)' (lower=-11.02, upper=21.845)
```

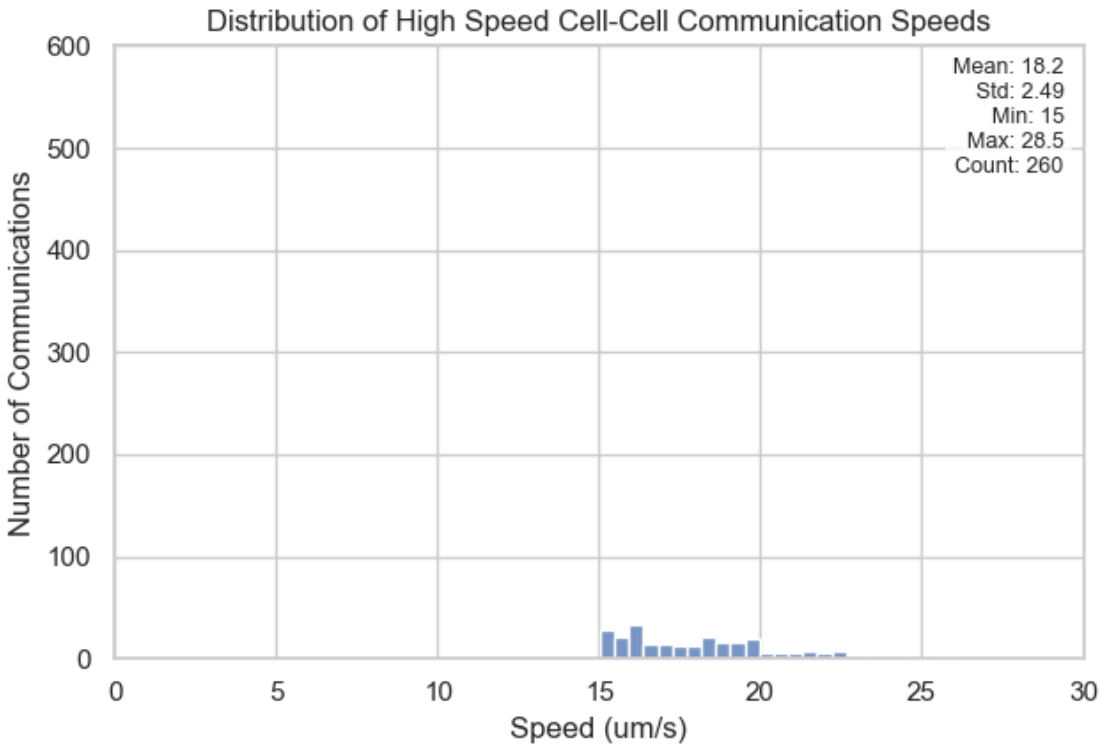



```
[2025-08-11 09:37:37] [INFO] calcium: plot_histogram: removed 0 outliers out of
3206 on 'Speed (um/s)' (lower=-20.387, upper=31.552)
```

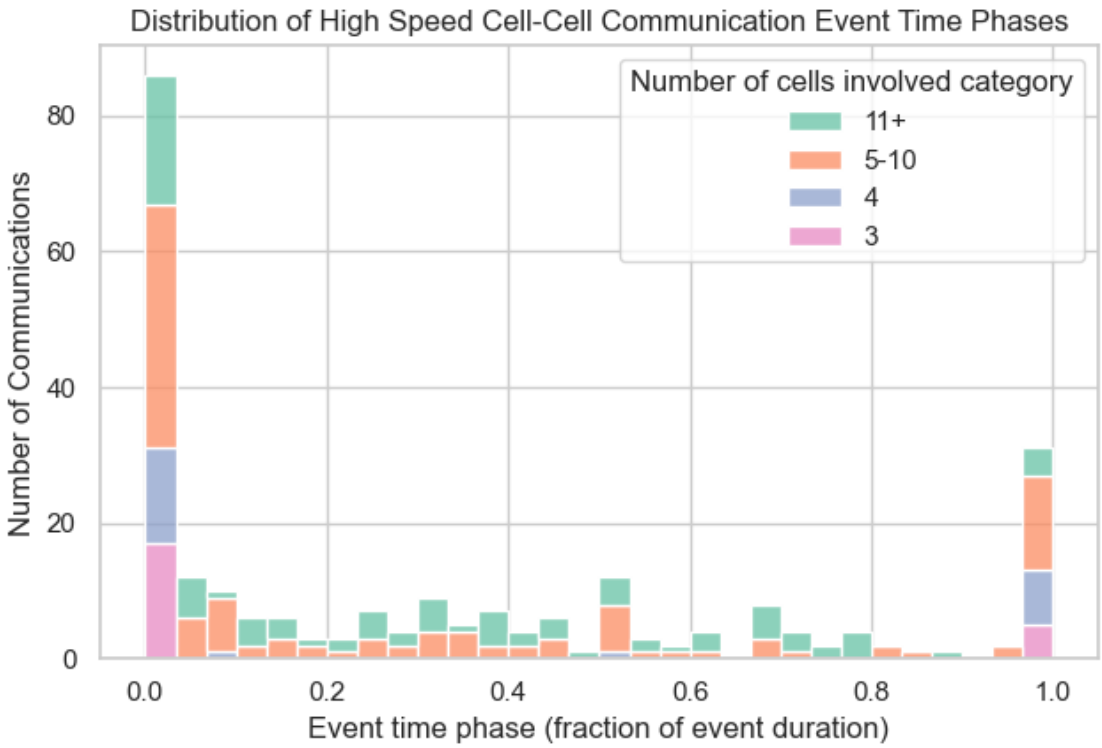


1.3.4 Double distribution in cell-cell communication speeds

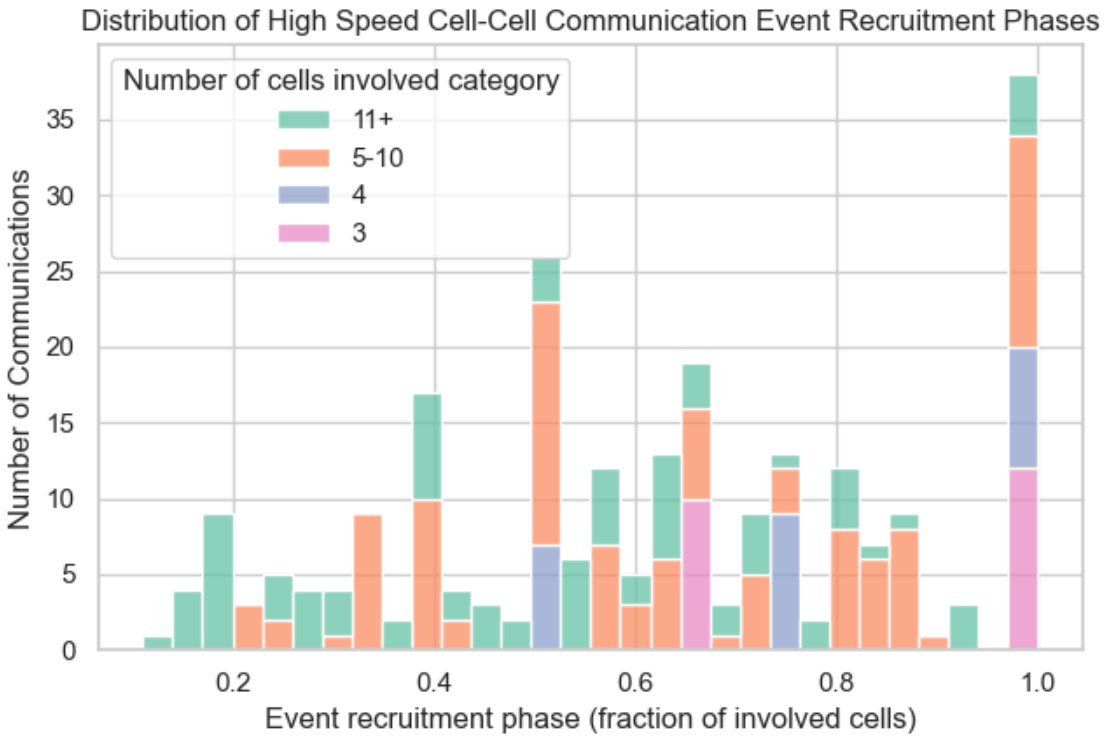
```
[2025-08-11 09:37:38] [INFO] calcium: plot_histogram: removed 0 outliers out of
260 on 'Speed (um/s)' (lower=5.835, upper=29.88)
```



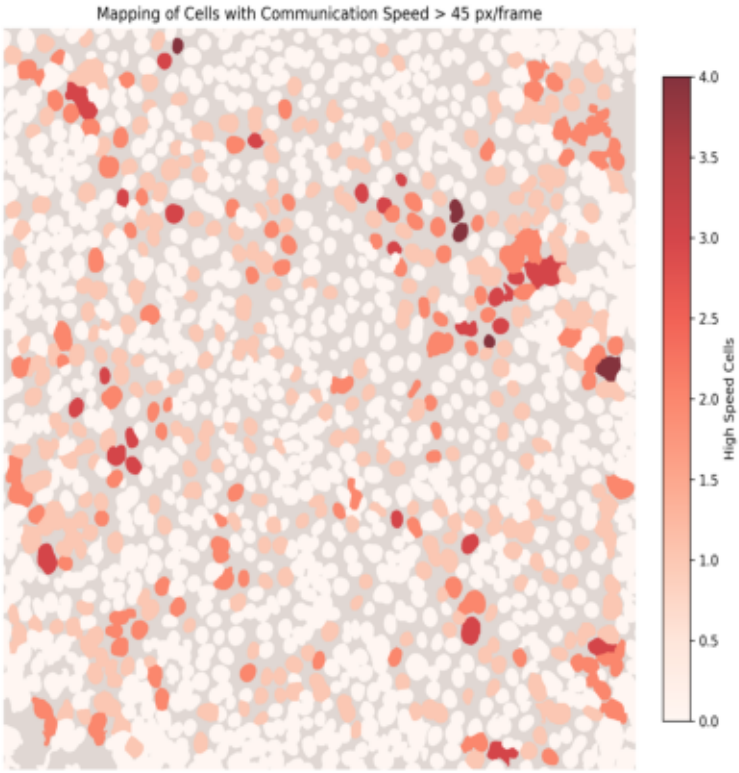

```
[2025-08-11 09:37:38] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 245 on 'Event time phase (fraction of event duration)'
(lower=-1.68, upper=2.24)
```



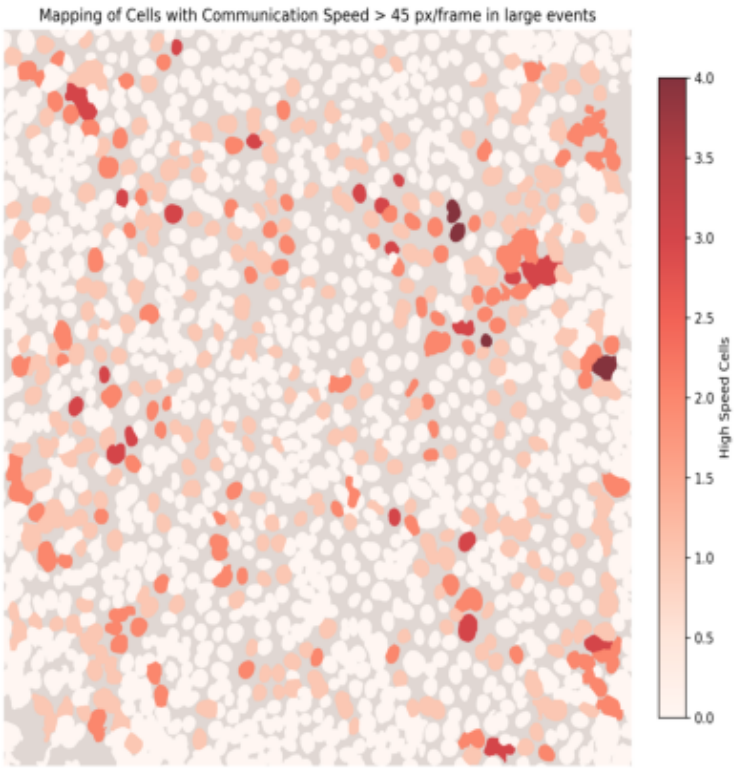

```
[2025-08-11 09:37:38] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 245 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.71, upper=1.95)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
11+
5-10
4
3
Number of Communications
0
5
10
15
20
25
30
35
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

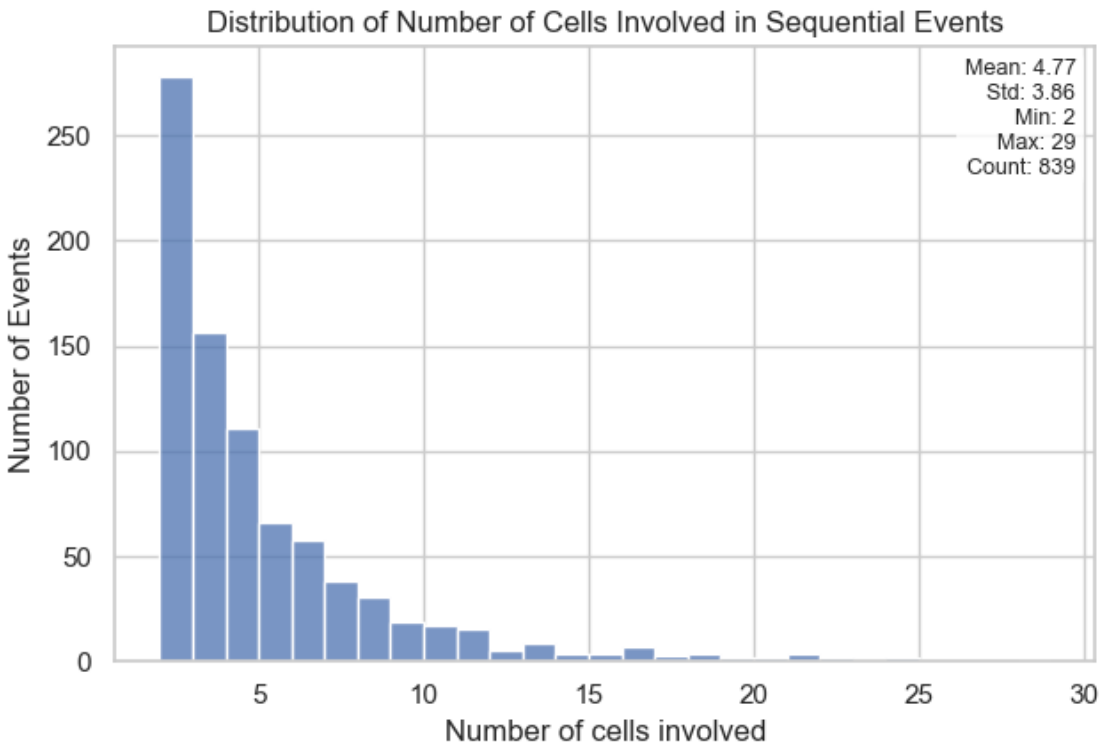
Cell Mapping with High Speed Cells Overlay - 20250404_IS1



Cell Mapping with High Speed Cells in Large Events Overlay - 20250404_IS1

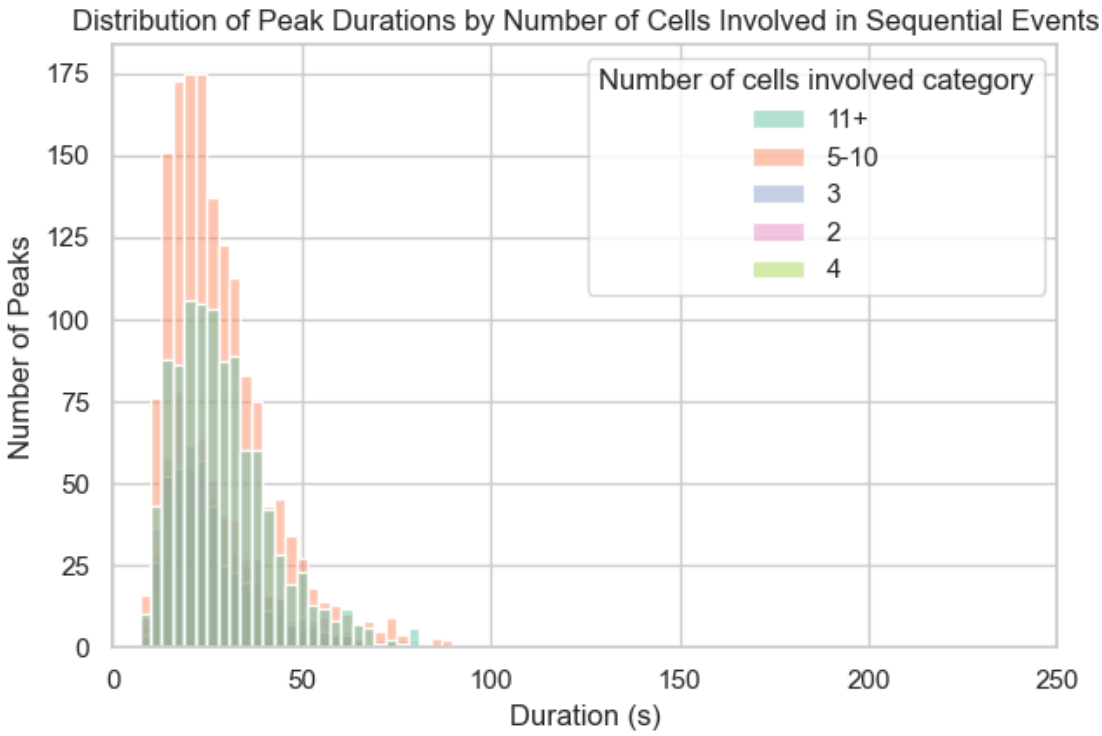


1.3.5 Number of cells involved per sequential events

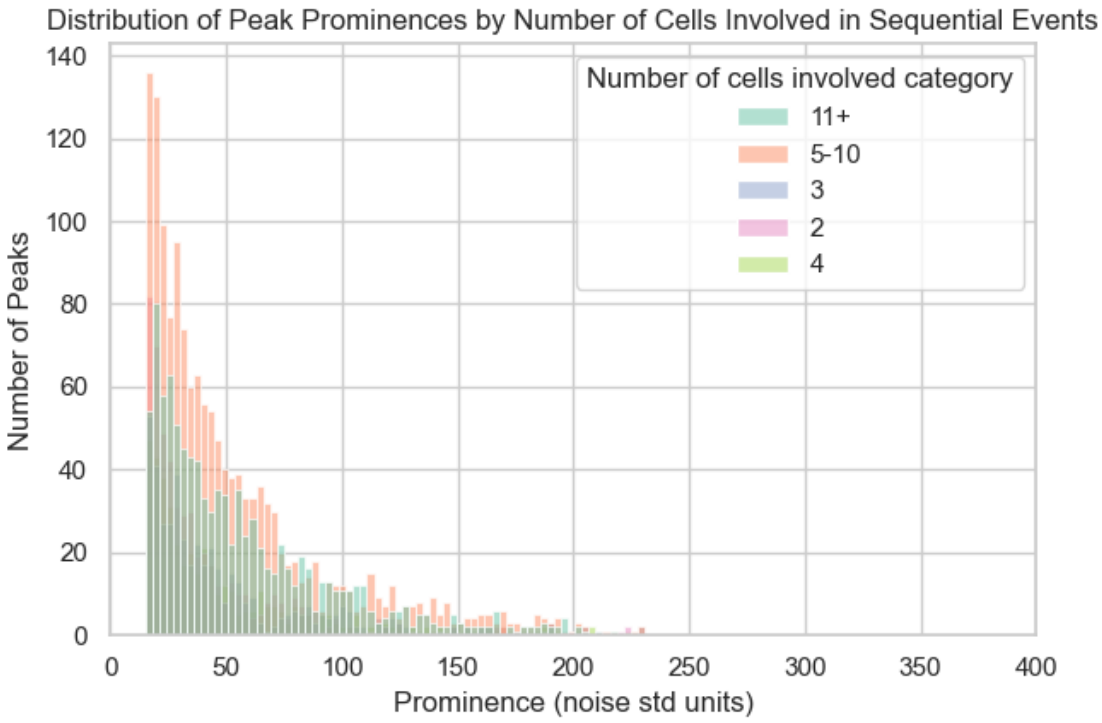


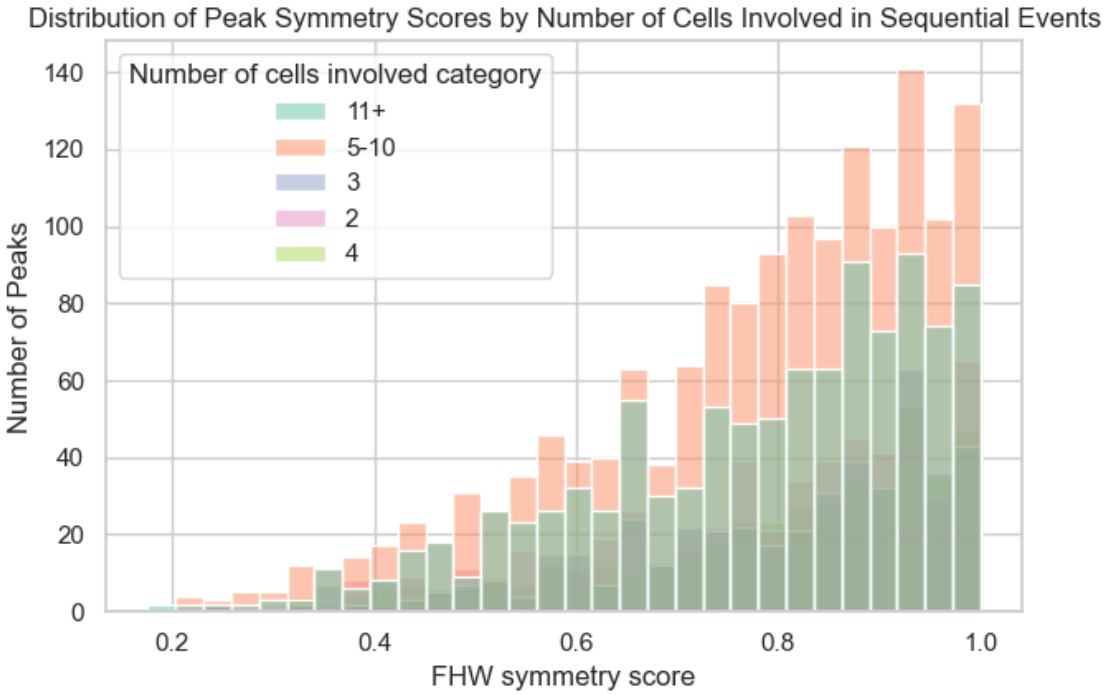
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:37:41] [INFO] calcium: plot_histogram_by_group: removed 27
outliers out of 4045 on 'Duration (s)' (lower=-6, upper=90)
```

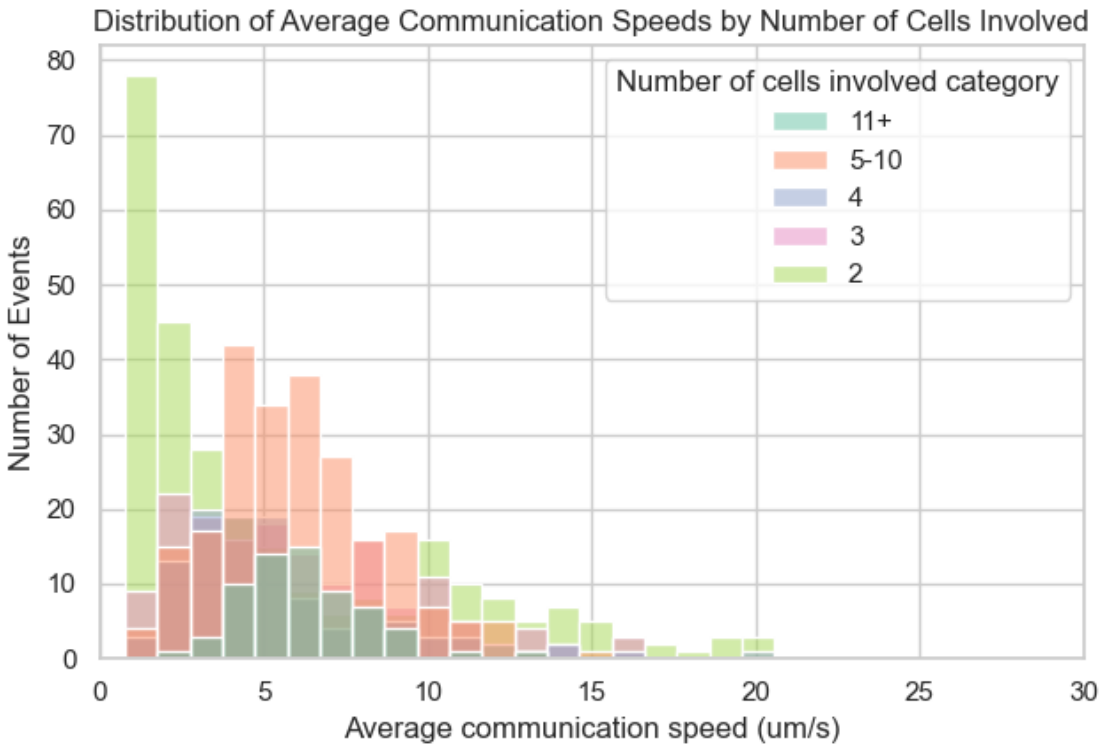



```
[2025-08-11 09:37:41] [INFO] calcium: plot_histogram_by_group: removed 98
outliers out of 4045 on 'Prominence (noise std units)' (lower=-45, upper=231)
```

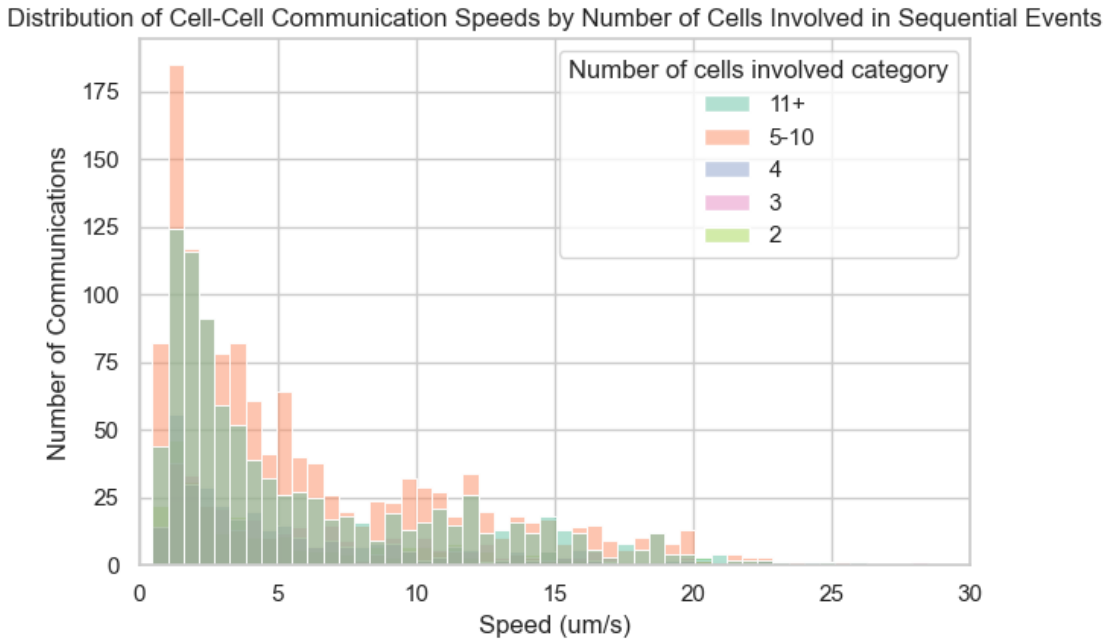




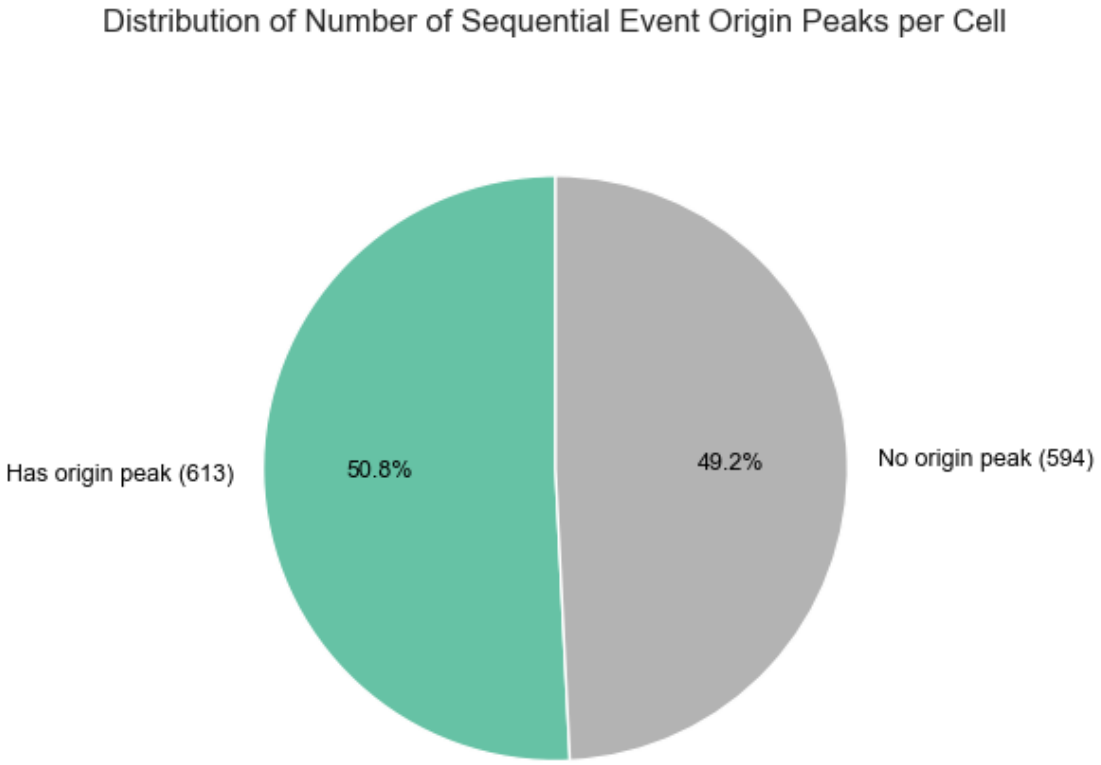

```
[2025-08-11 09:37:41] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 839 on 'Average communication speed (um/s)' (lower=-11.02,
upper=21.845)
```

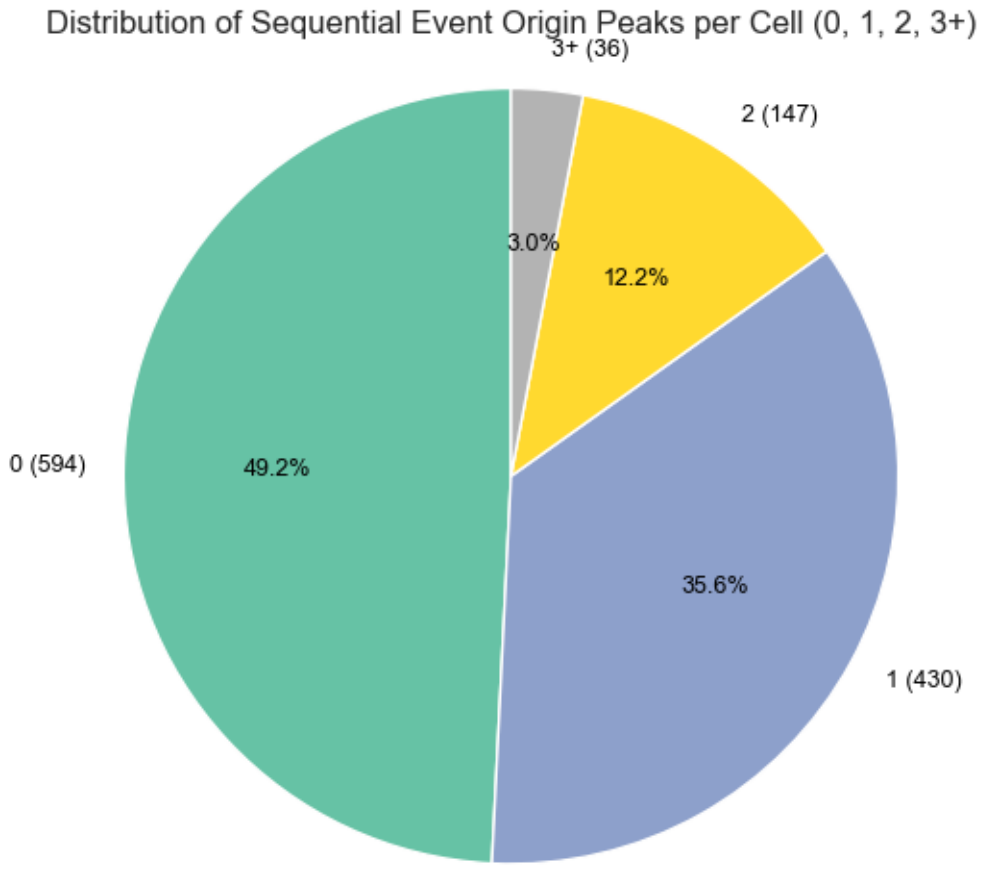



```
[2025-08-11 09:37:42] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 3206 on 'Speed (um/s)' (lower=-20.387, upper=31.552)
```

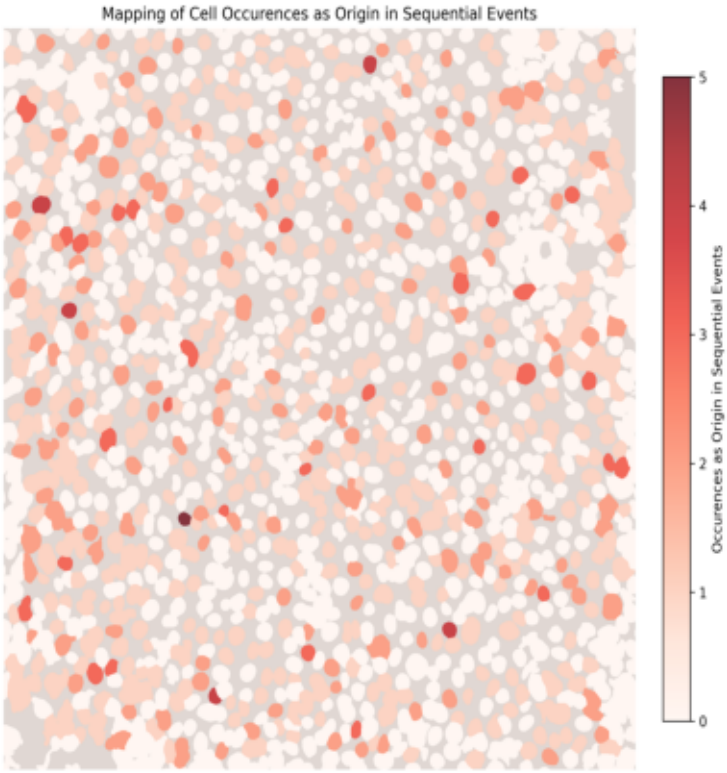


1.3.7 Cells occurences as origin in sequential events

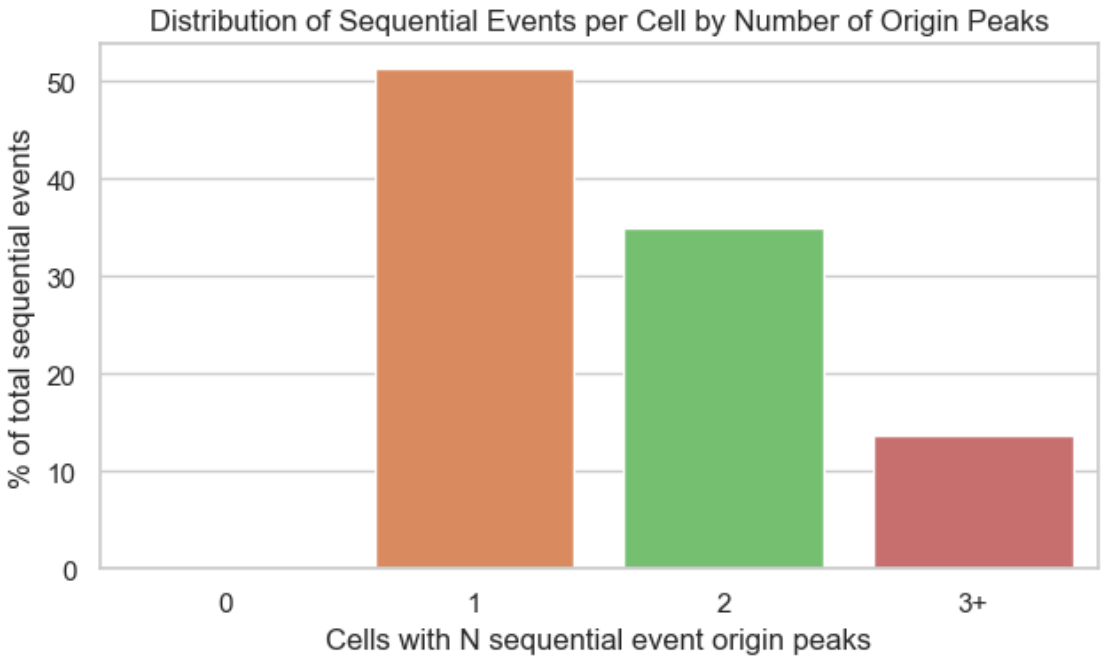



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (36)
2 (147)
3.0%
12.2%
0 (594)
49.2%
35.6%
1 (430)

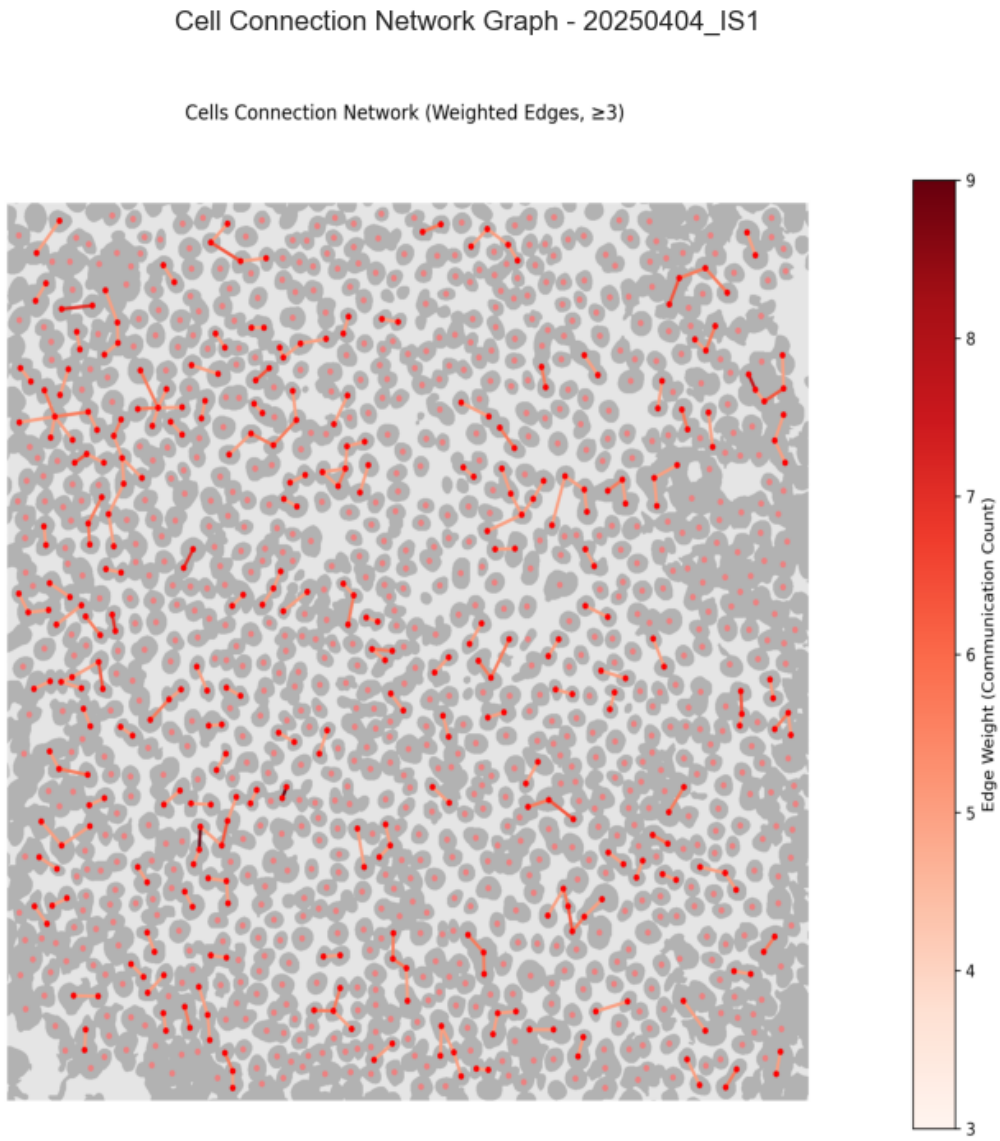
Cell Mapping with Origin Peaks Overlay - 20250404_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

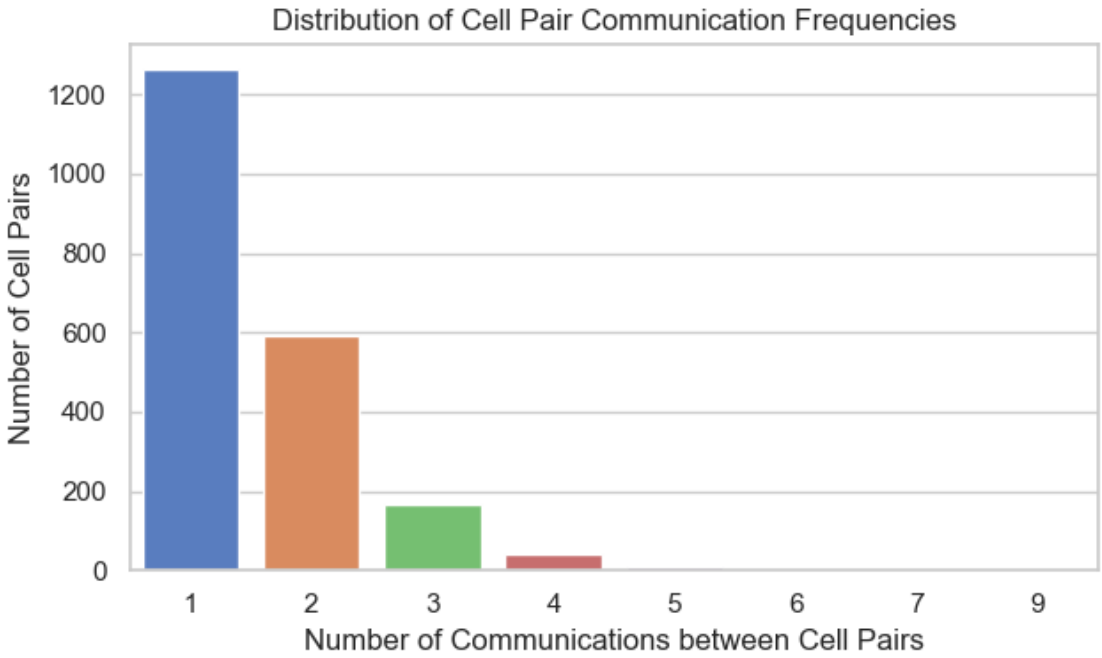

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
50
40
30
20
10
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



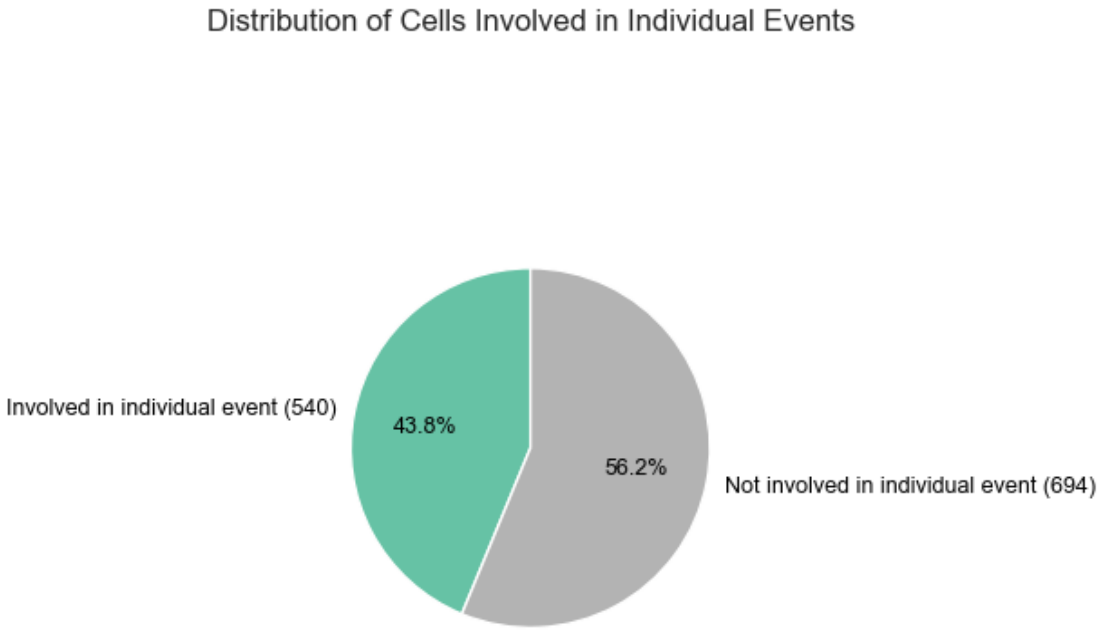

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

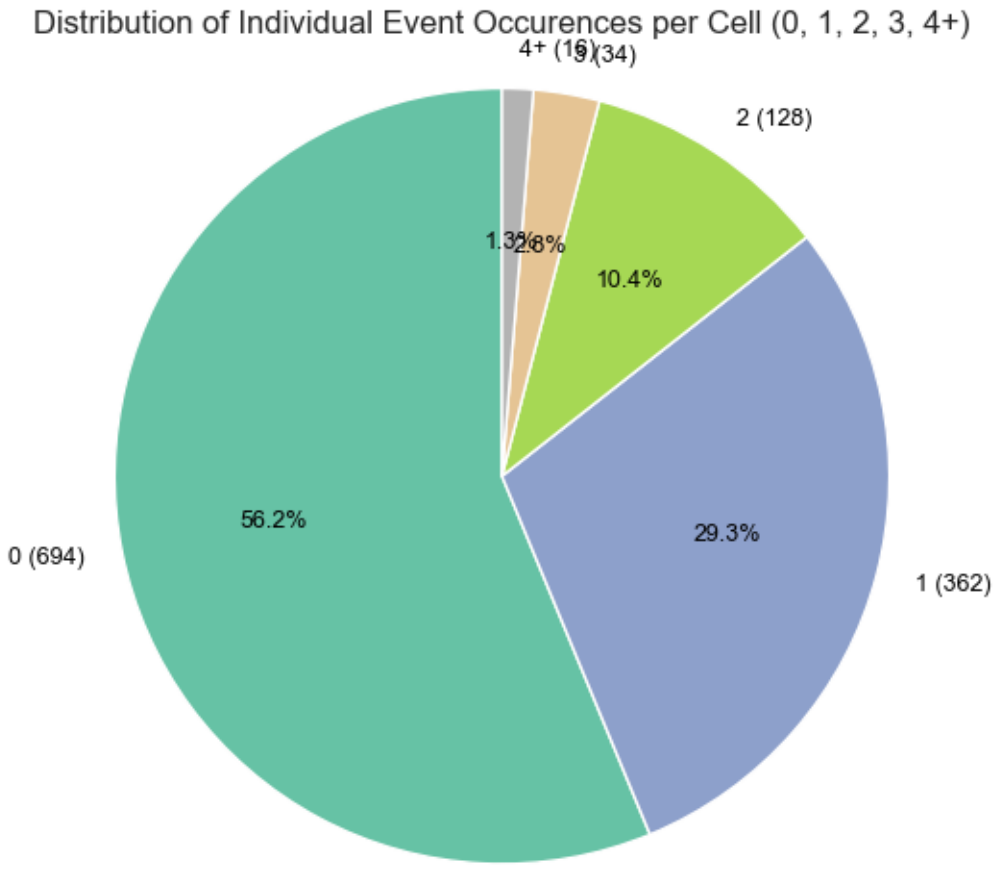
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
9
Number of Communications between Cell Pairs

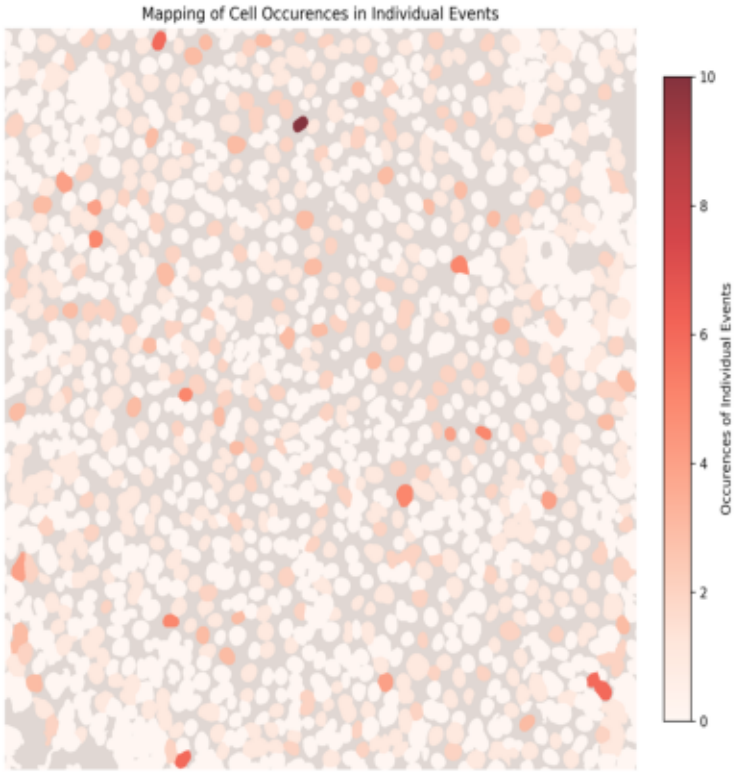
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



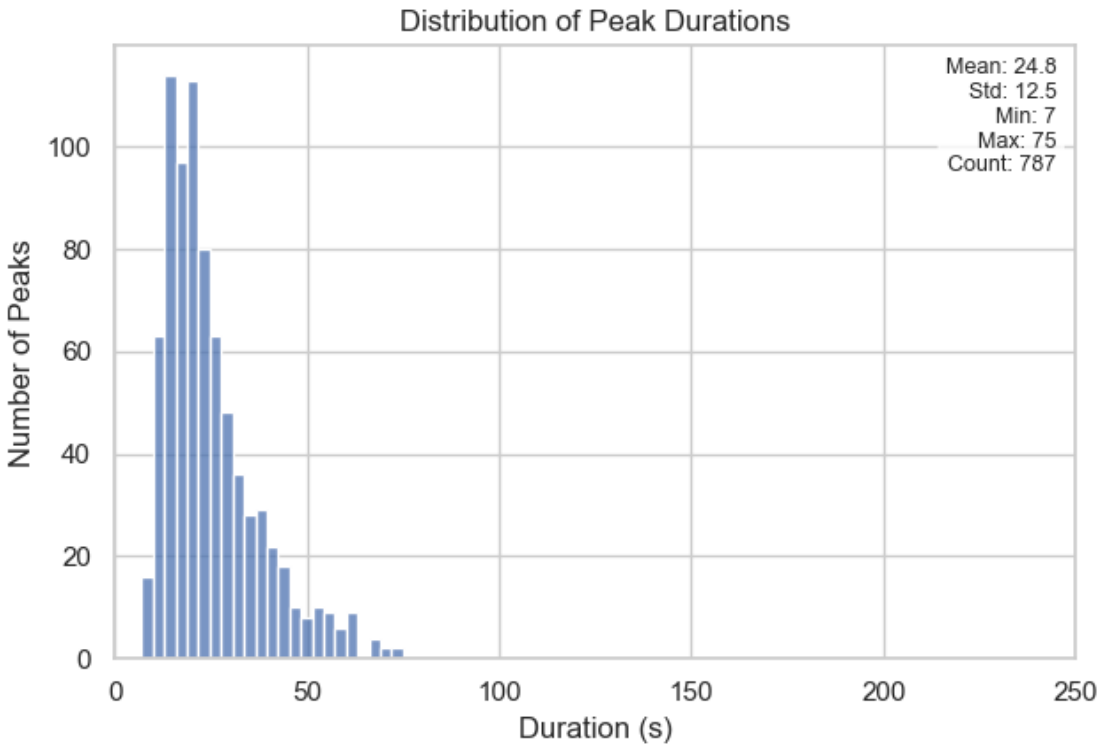

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (16)
3 (34)
2 (128)
1.3%
2.8%
10.4%
56.2%
29.3%
0 (694)
1 (362)

Cell Mapping with Occurences in Individual Events Overlay - 20250404_IS1

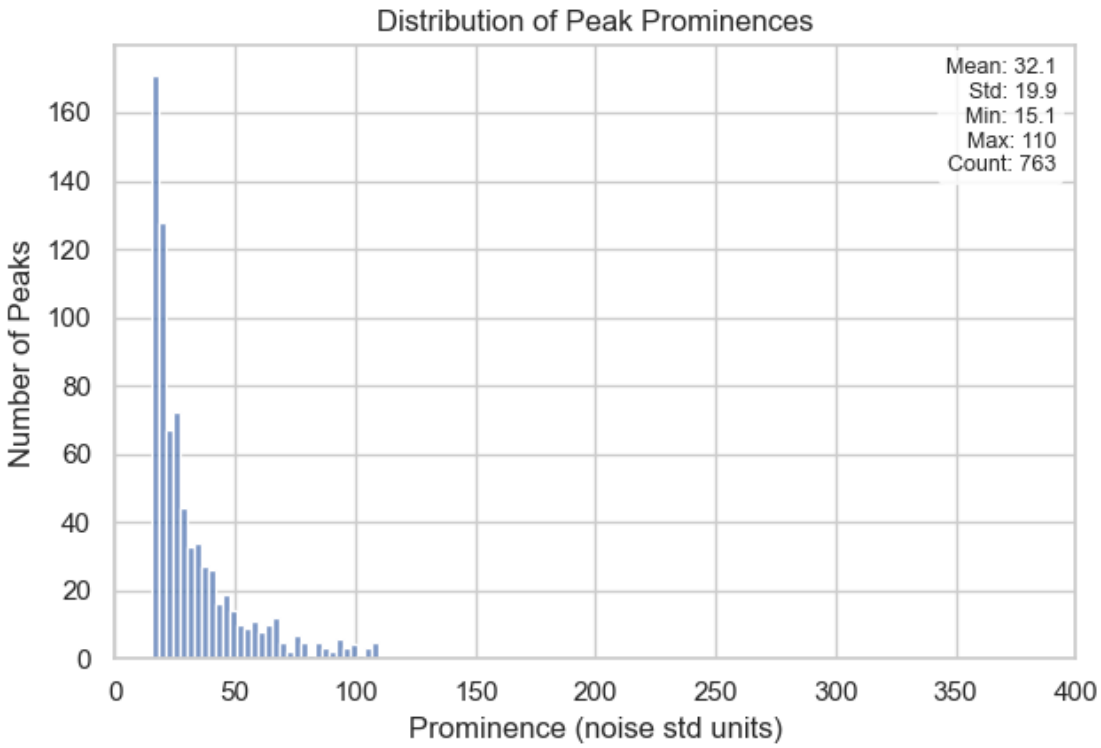


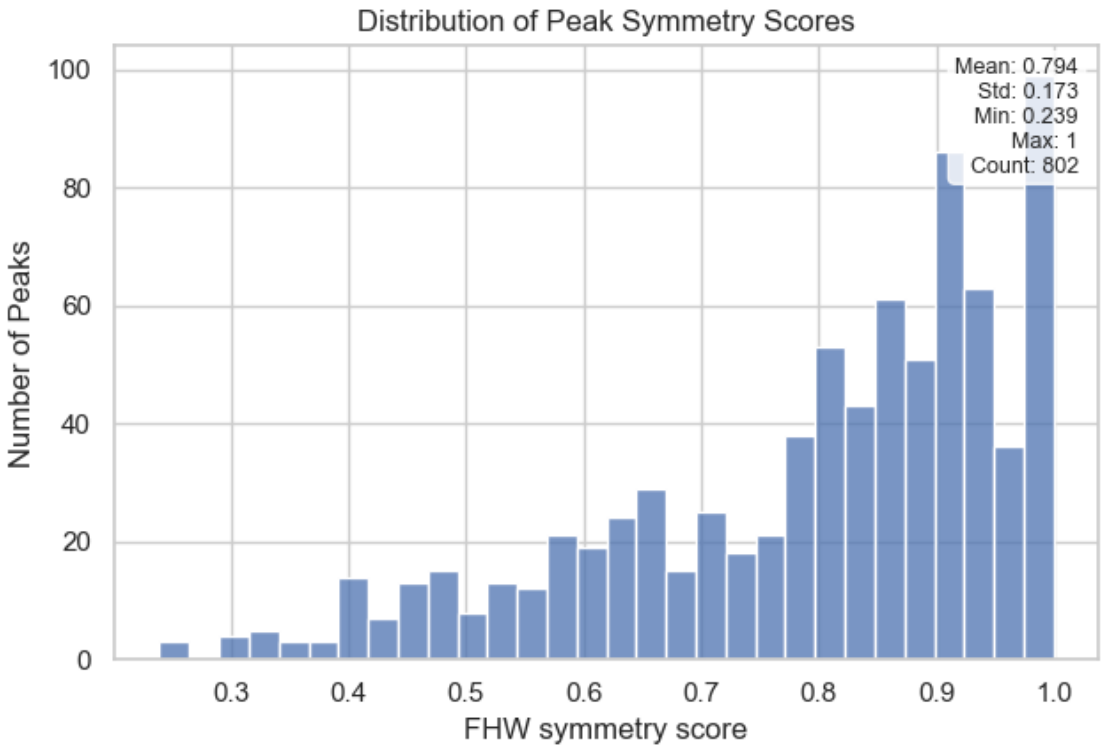
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:37:46] [INFO] calcium: plot_histogram: removed 15 outliers out of
802 on 'Duration (s)' (lower=-29, upper=76)
```

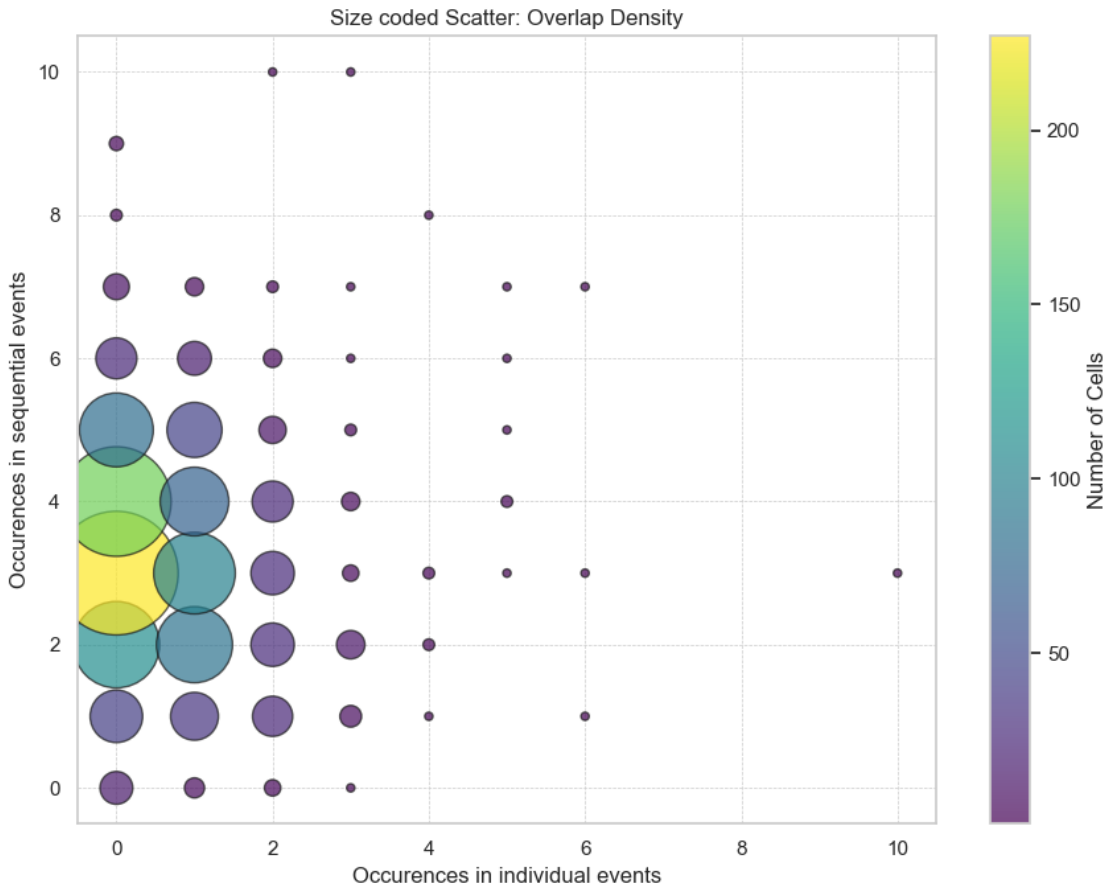



```
[2025-08-11 09:37:46] [INFO] calcium: plot_histogram: removed 39 outliers out of
802 on 'Prominence (noise std units)' (lower=-50, upper=110.3)
```

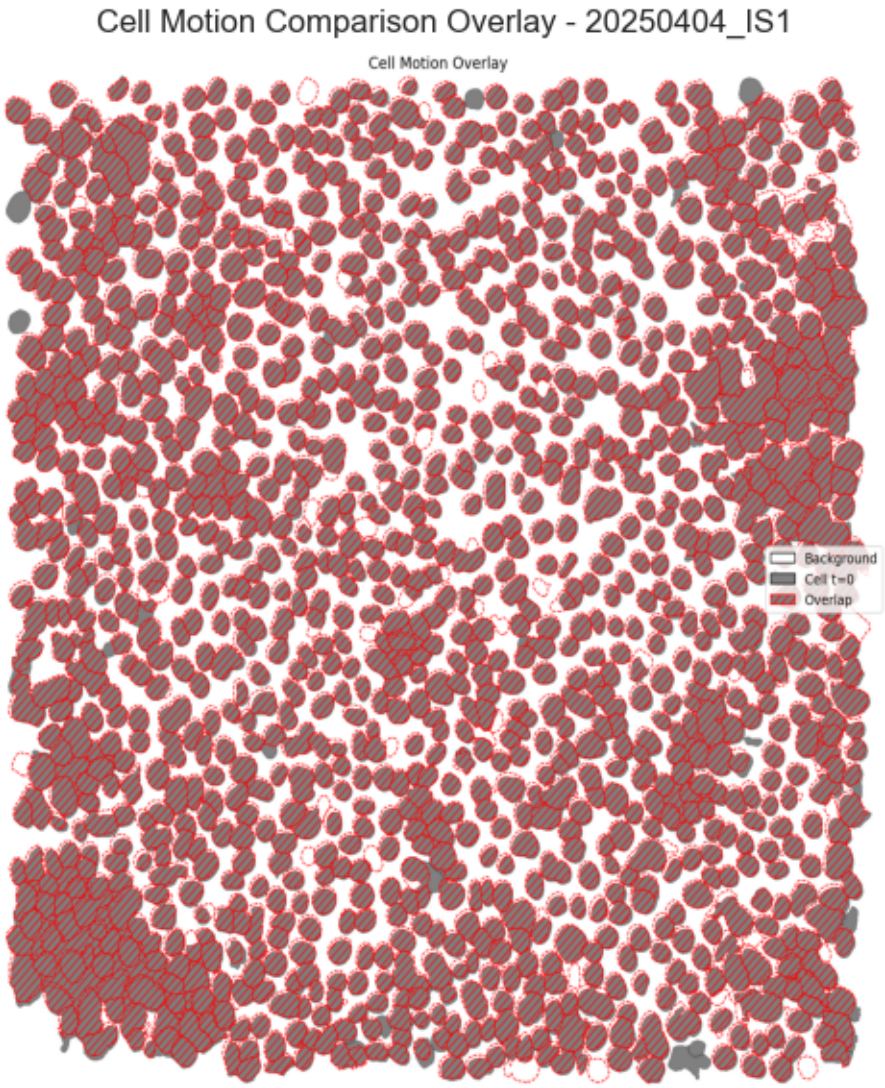

Distribution of Peak Prominences
Mean: 32.1
Std: 19.9
Min: 15.1
Max: 110
Count: 763
Number of Peaks
0
20
40
60
80
100
120
140
160
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.794
Std: 0.173
Min: 0.239
Max: 1
Count: 802
Number of Peaks
0
20
40
60
80
100
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 1234
- Hoechst image taken at t=1801: 1238
- Number of cells difference: absolute 4, relative 0.32%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1369674
- Pixels segmented as cell at t=1801: 1414102
- Overlapping pixels between t=0 and t=1801: 1219514(87.62% of total)
- Pixels exclusive to t=0: 150160 (10.96% of total)
- Pixels exclusive to t=1801: 194588 (13.76% of total)
```

executed

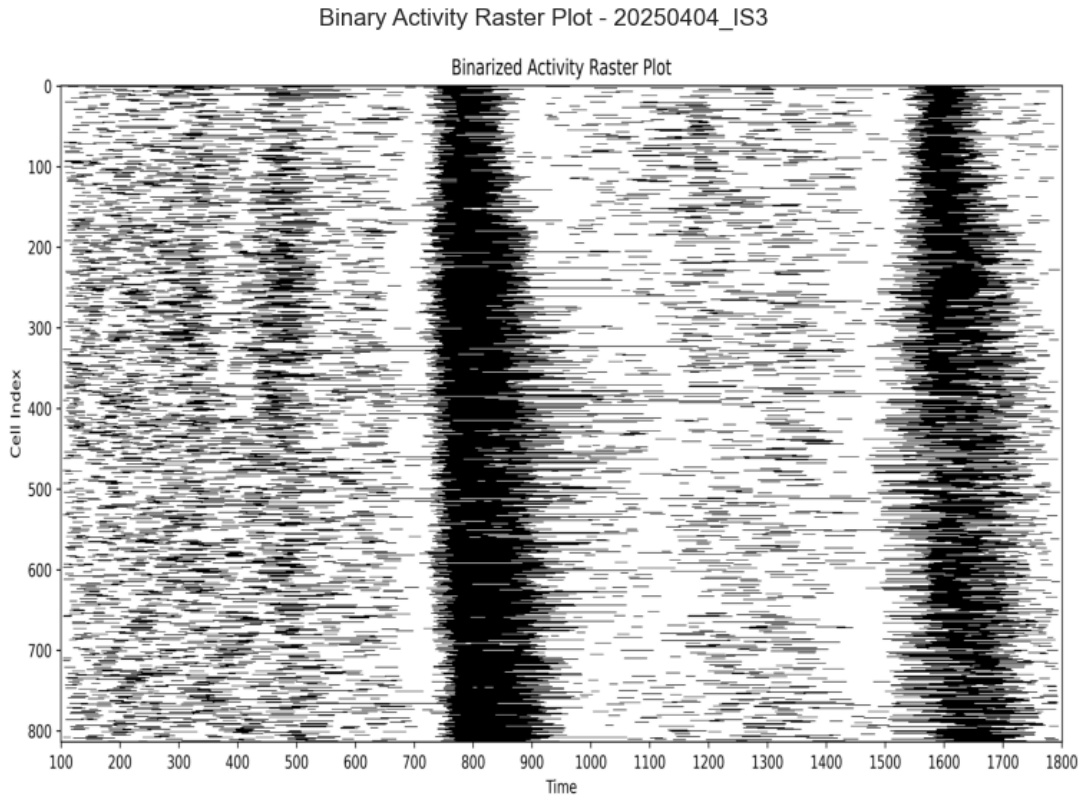
August 11, 2025

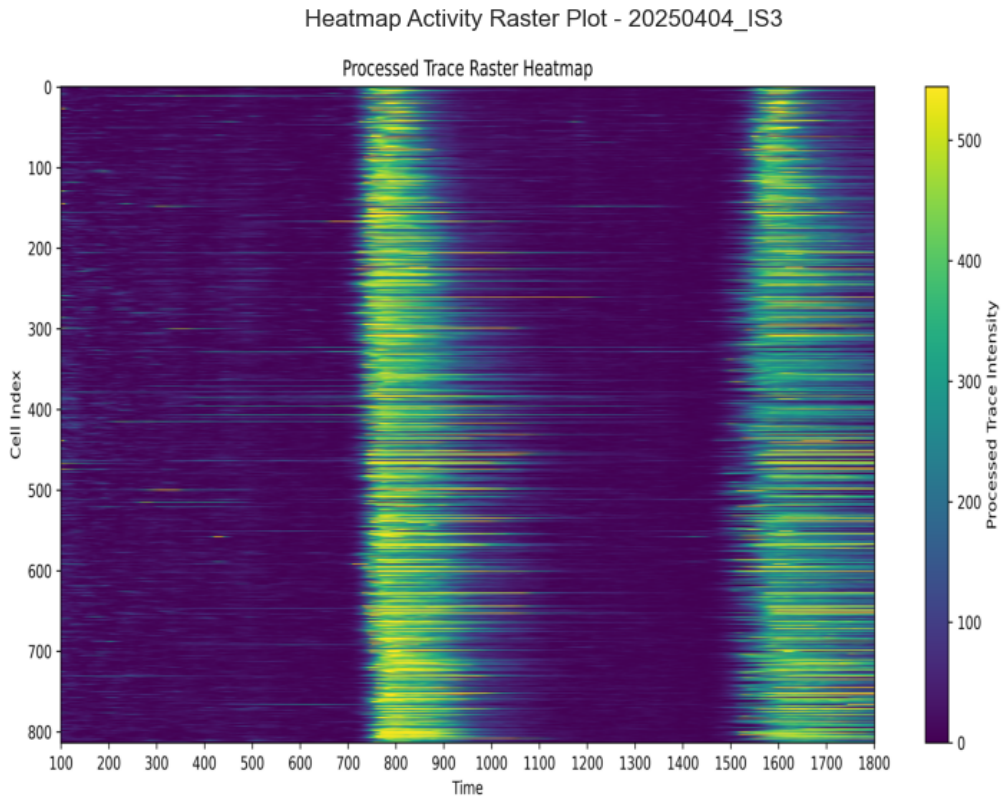
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



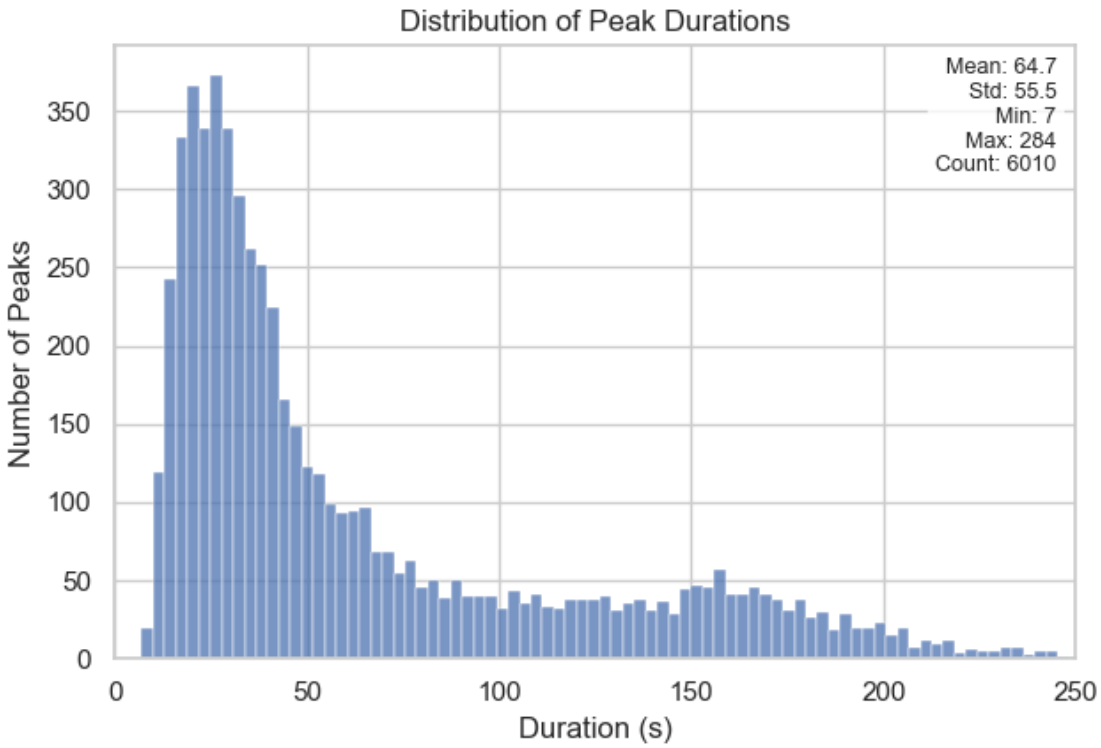


1.1.2 Peaks population

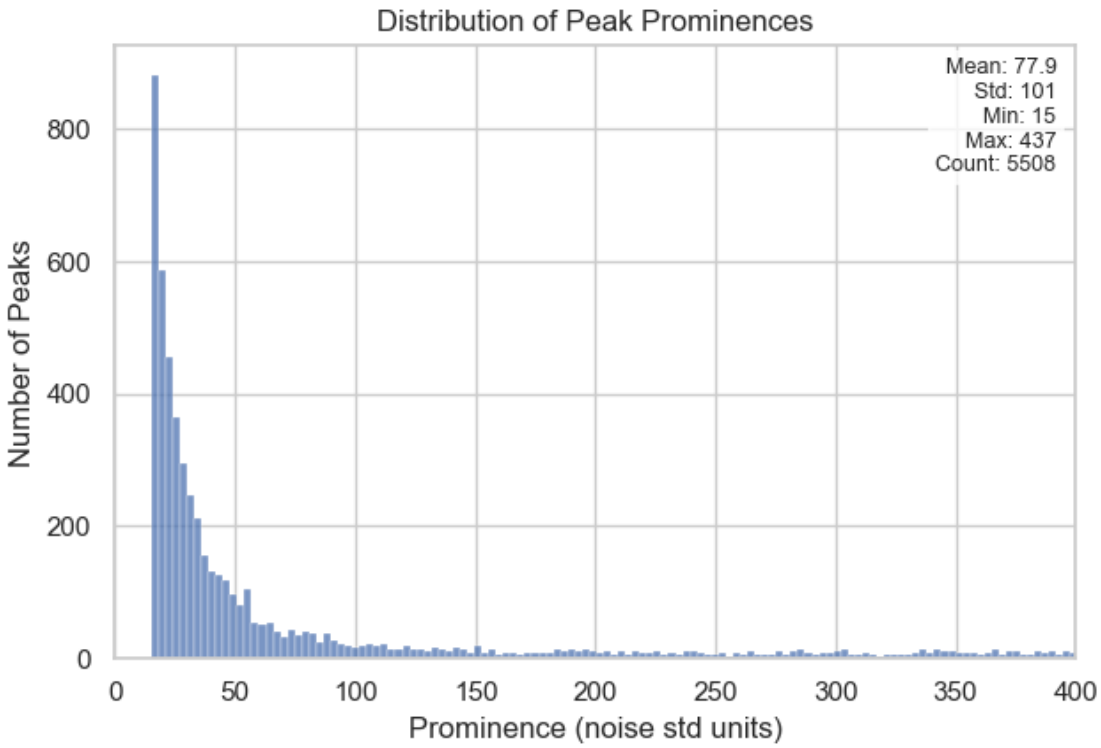
```
Total number of peaks: 6049
Total number of cells: 814
```

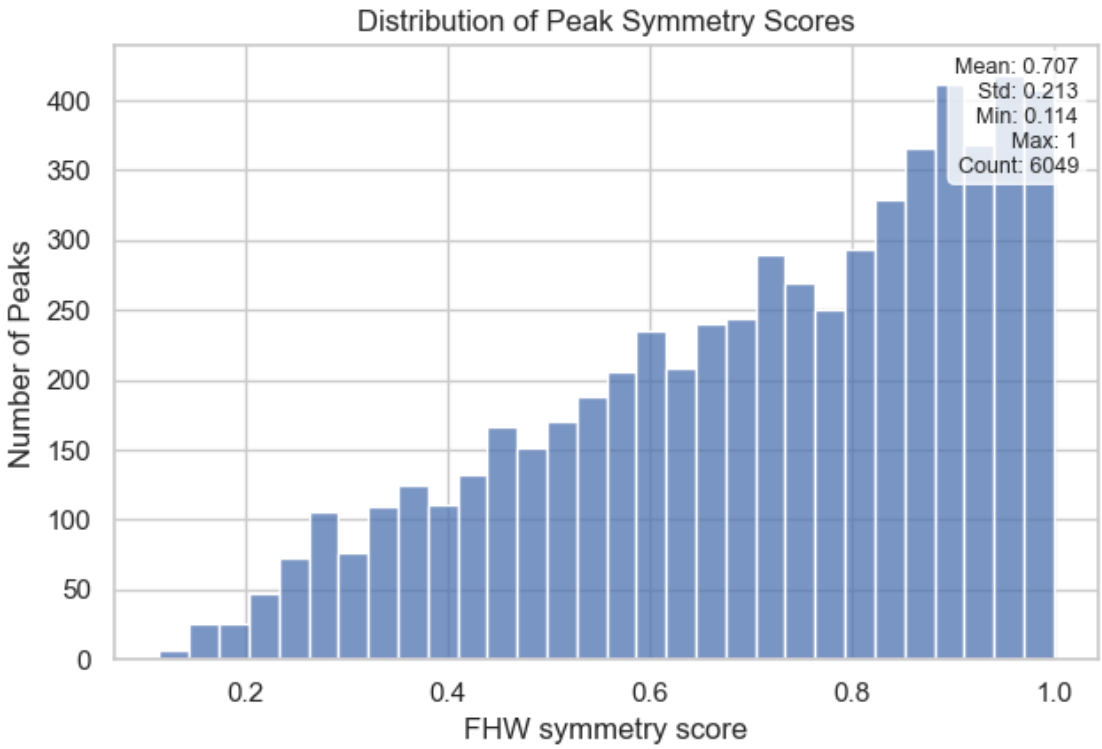
1.1.3 Peaks statistics

```
[2025-08-11 09:39:02] [INFO] calcium: plot_histogram: removed 39 outliers out of
6049 on 'Duration (s)' (lower=-170, upper=285)
```

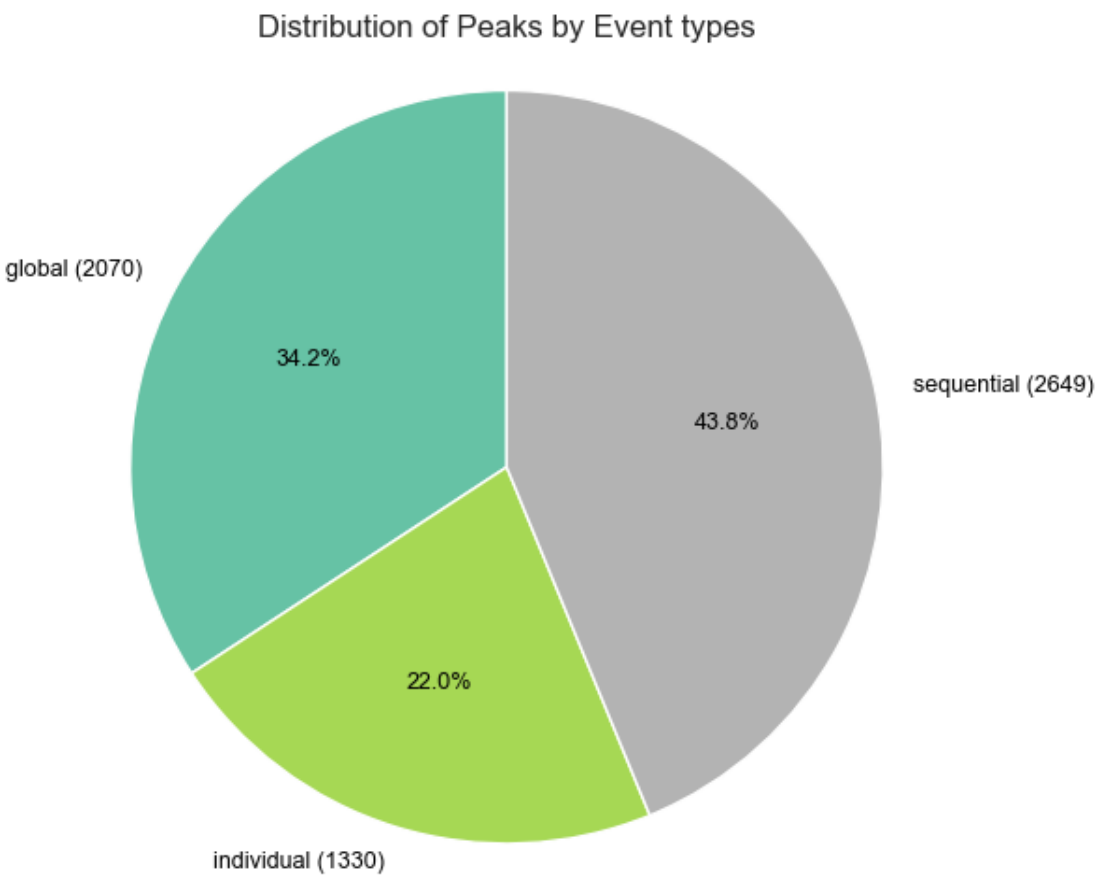



```
[2025-08-11 09:39:02] [INFO] calcium: plot_histogram: removed 541 outliers out
of 6049 on 'Prominence (noise std units)' (lower=-290.8, upper=437.2)
```


Distribution of Peak Prominences
Mean: 77.9
Std: 101
Min: 15
Max: 437
Count: 5508
Number of Peaks
0
200
400
600
800
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

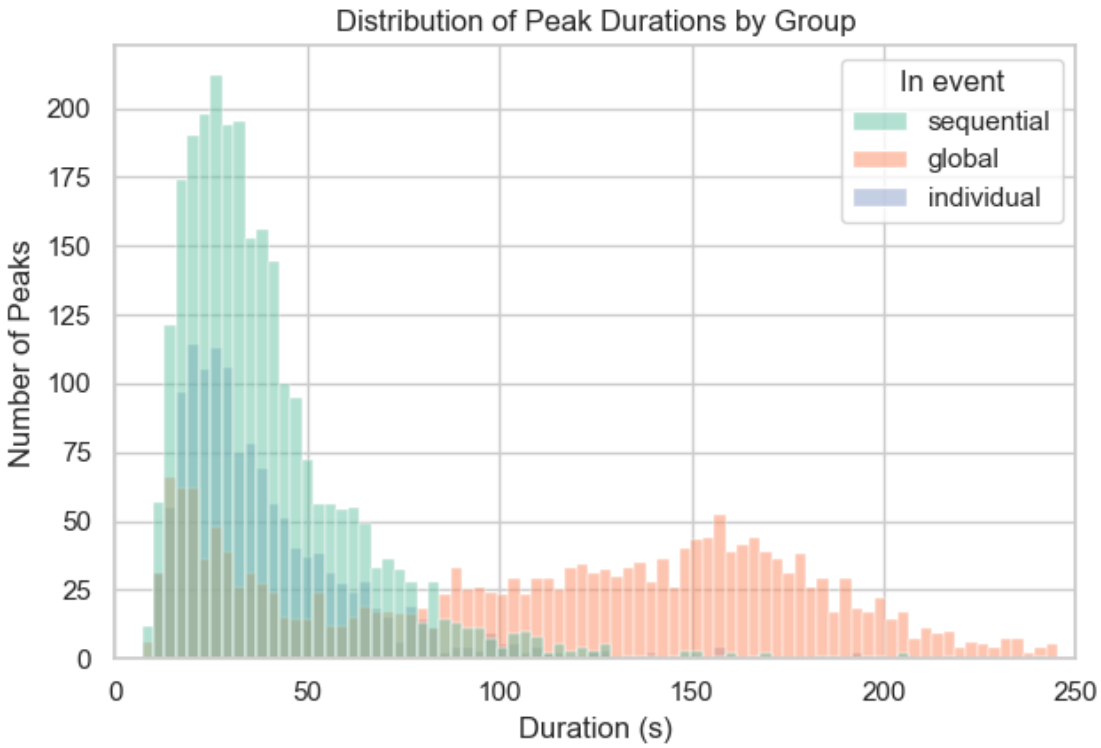

Distribution of Peak Symmetry Scores
Mean: 0.707
Std: 0.213
Min: 0.114
Max: 1
Count: 6049
Number of Peaks
0
50
100
150
200
250
300
350
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

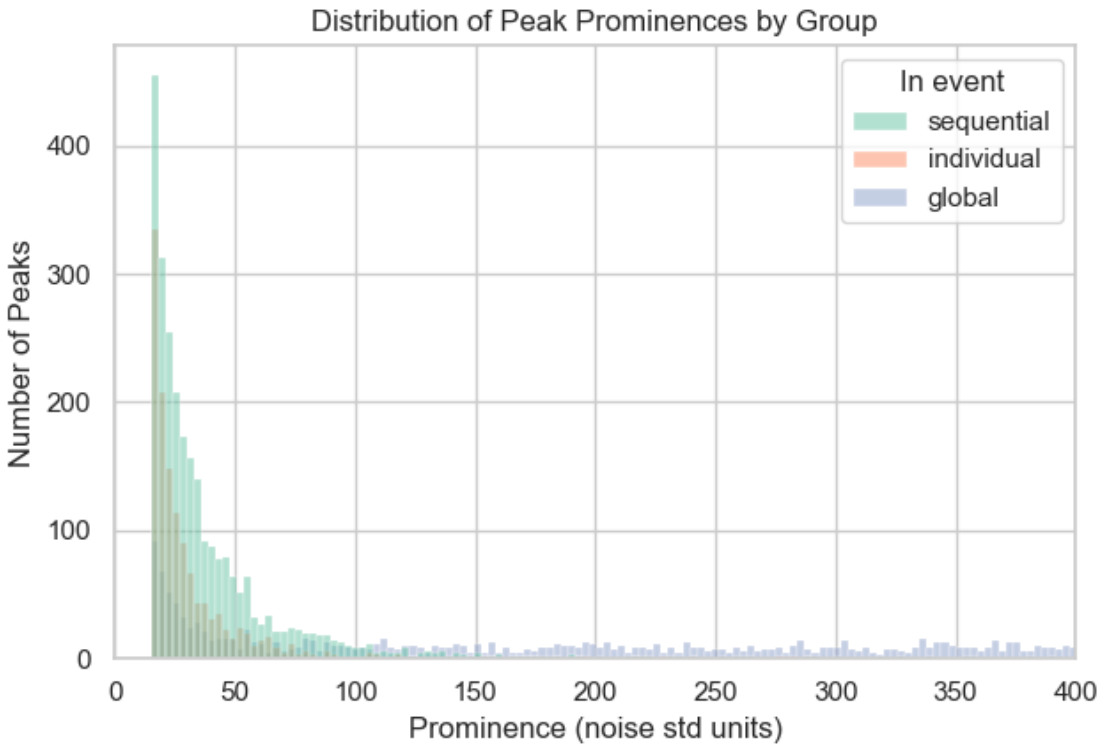


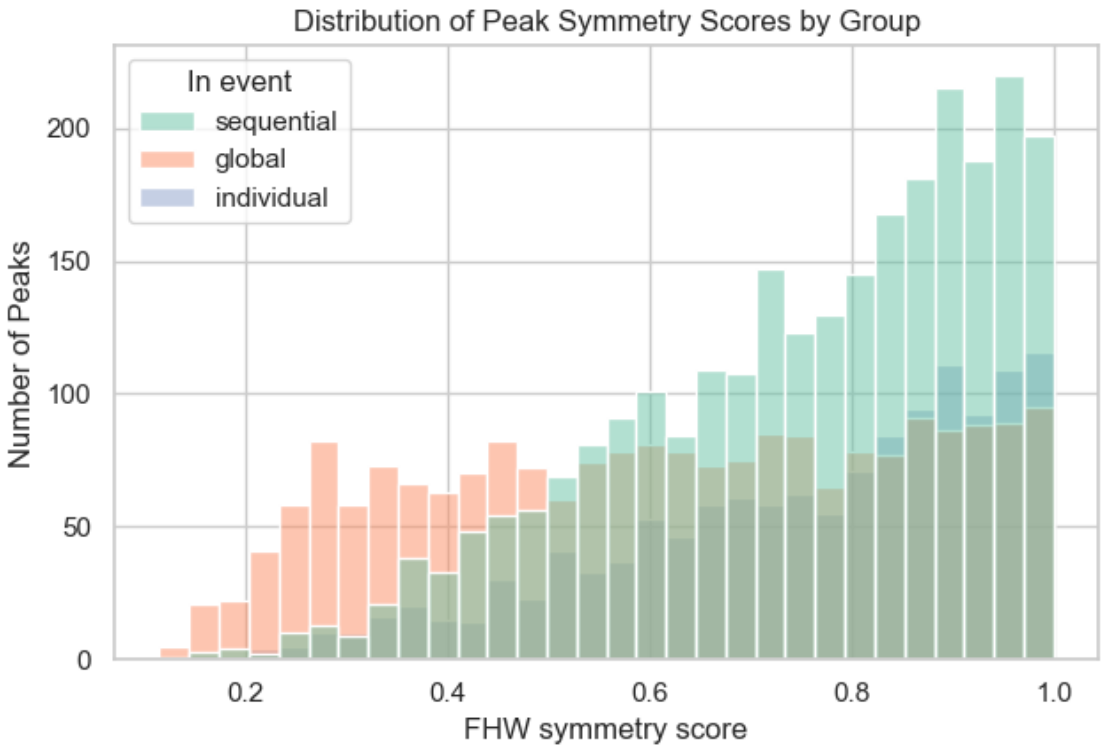
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:39:03] [INFO] calcium: plot_histogram_by_group: removed 39
outliers out of 6049 on 'Duration (s)' (lower=-170, upper=285)
```




```
[2025-08-11 09:39:03] [INFO] calcium: plot_histogram_by_group: removed 541
outliers out of 6049 on 'Prominence (noise std units)' (lower=-290.8,
upper=437.2)
```

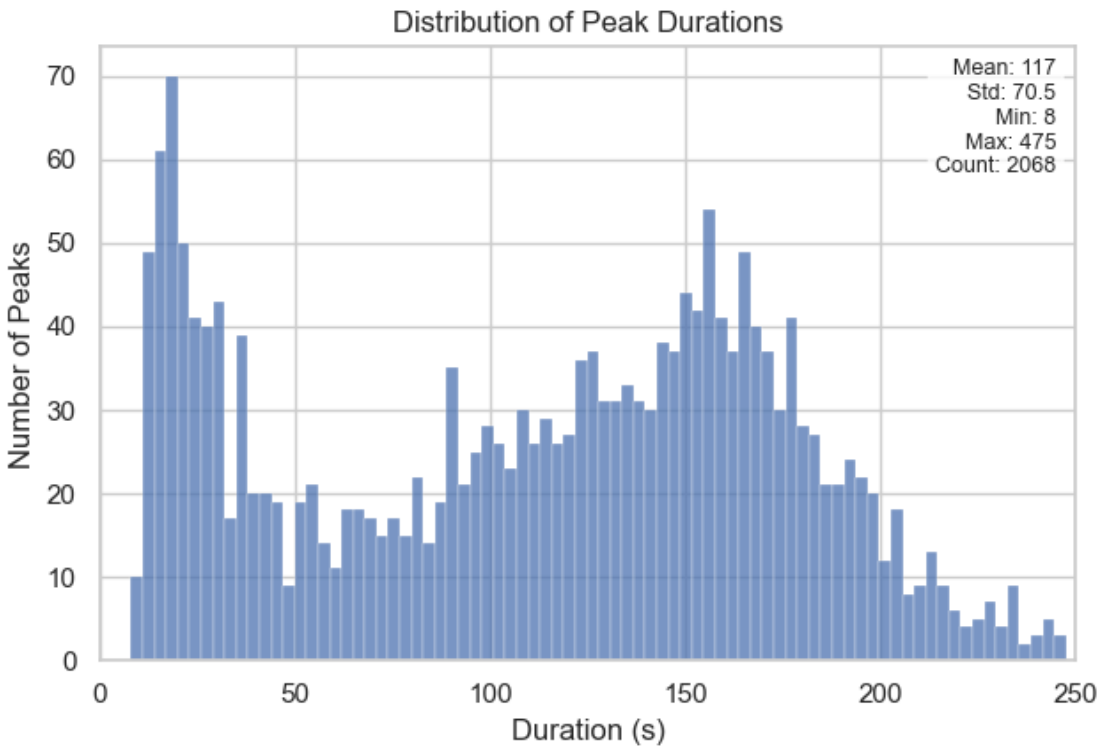

Distribution of Peak Prominences by Group
In event
sequential
individual
global
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
global
individual
Number of Peaks
0
50
100
150
200
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

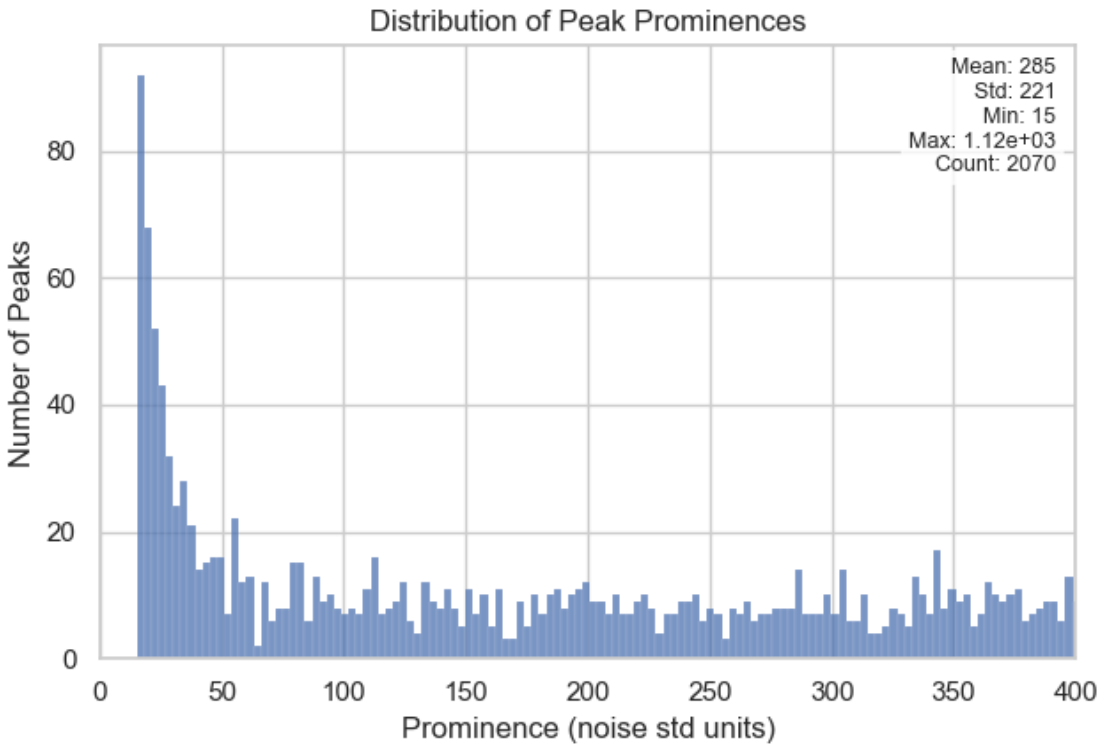
1.2 GLOBAL EVENTS

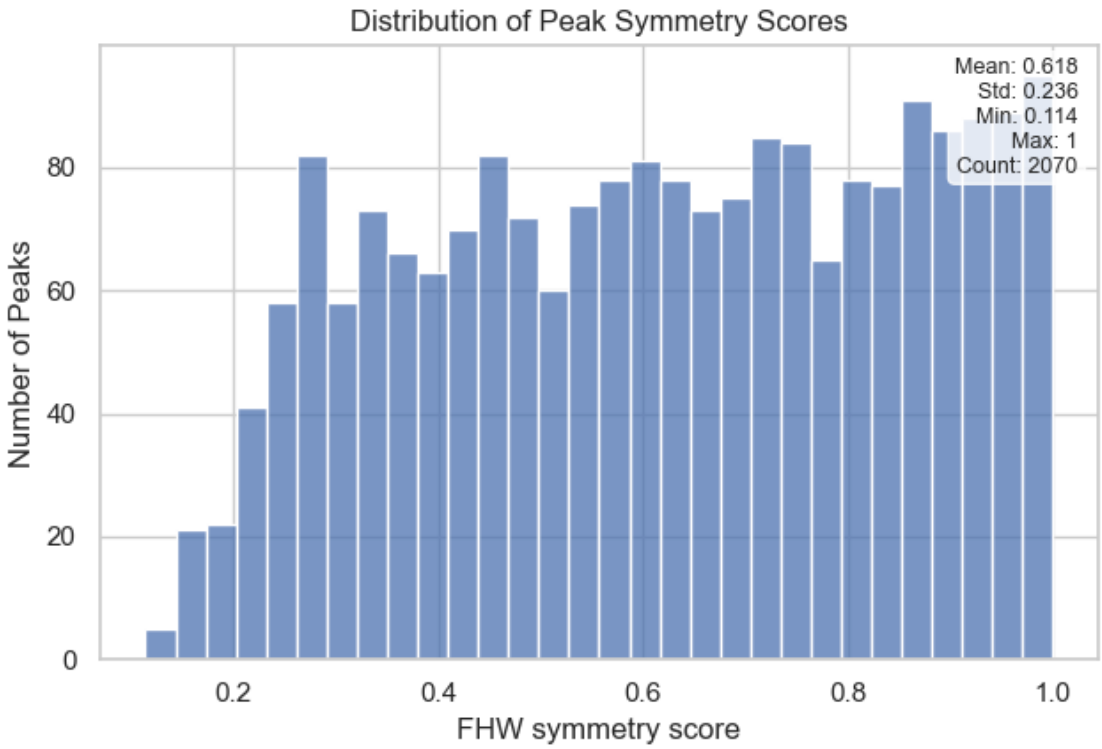
1.2.1 Peak statistics in global events

```
[2025-08-11 09:39:04] [INFO] calcium: plot_histogram: removed 2 outliers out of
2070 on 'Duration (s)' (lower=-279, upper=498)
```



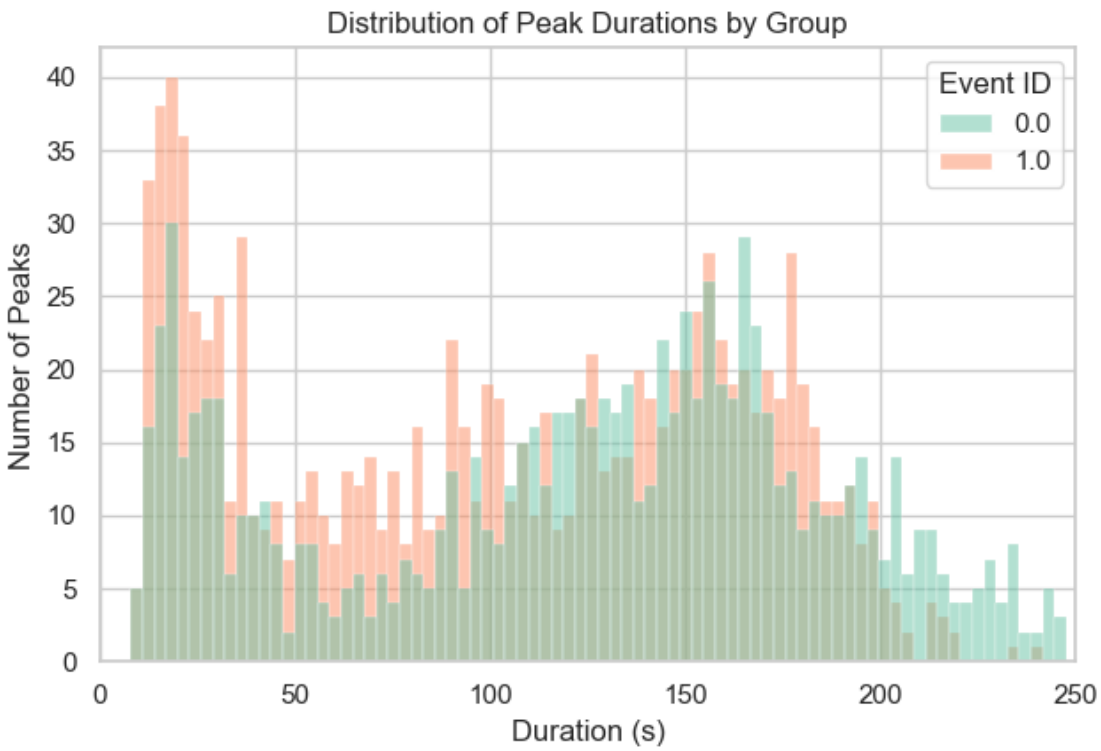

```
[2025-08-11 09:39:04] [INFO] calcium: plot_histogram: removed 0 outliers out of
2070 on 'Prominence (noise std units)' (lower=-1015.8, upper=1540.6)
```


Distribution of Peak Prominences
Mean: 285
Std: 221
Min: 15
Max: 1.12e+03
Count: 2070
Number of Peaks
0
20
40
60
80
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

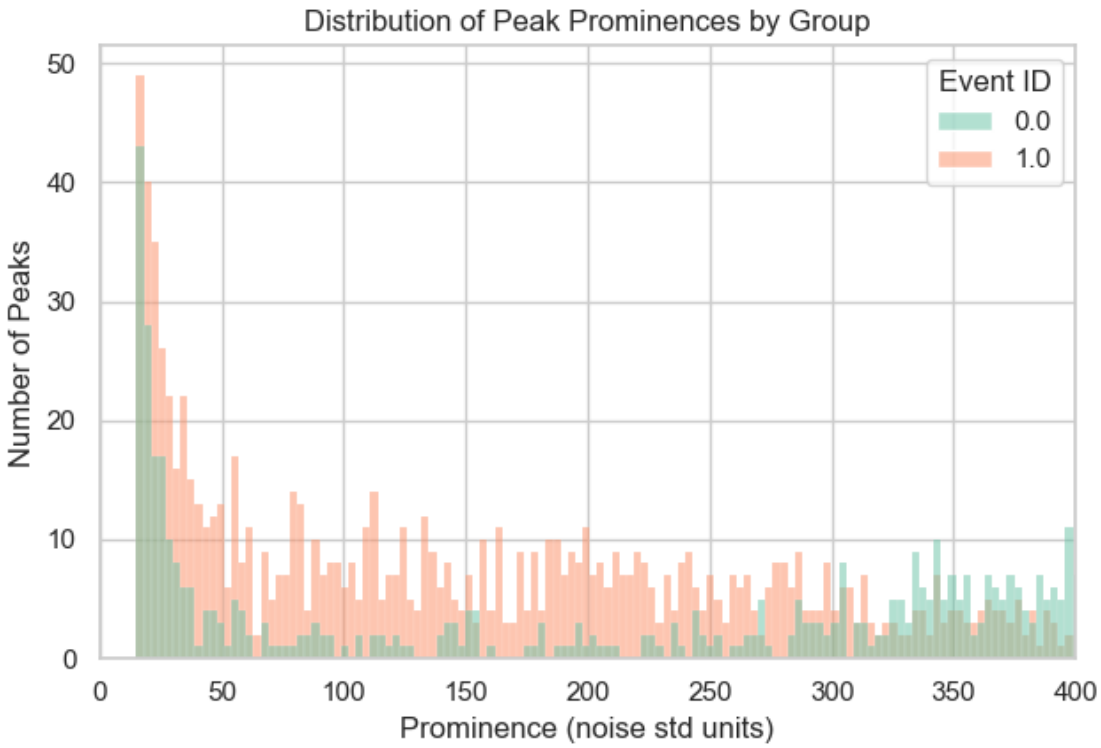

Distribution of Peak Symmetry Scores
Mean: 0.618
Std: 0.236
Min: 0.114
Max: 1
Count: 2070
Number of Peaks
0
20
40
60
80
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

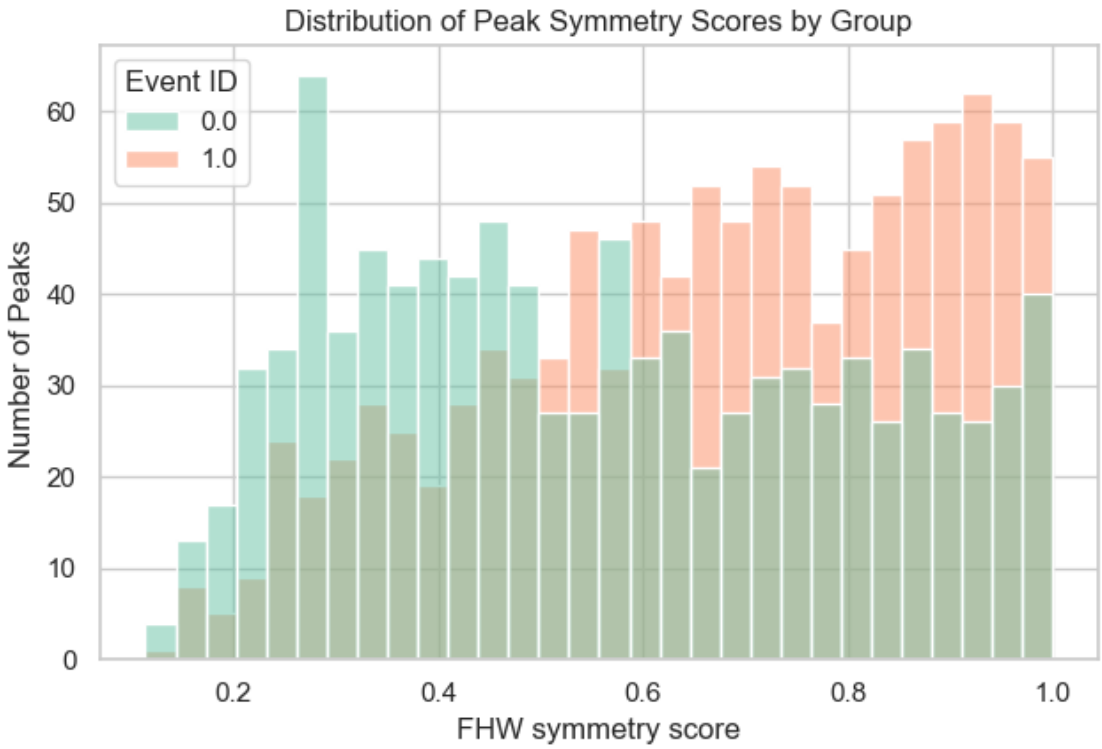
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:39:04] [INFO] calcium: plot_histogram_by_group: removed 2
outliers out of 2070 on 'Duration (s)' (lower=-279, upper=498)
```

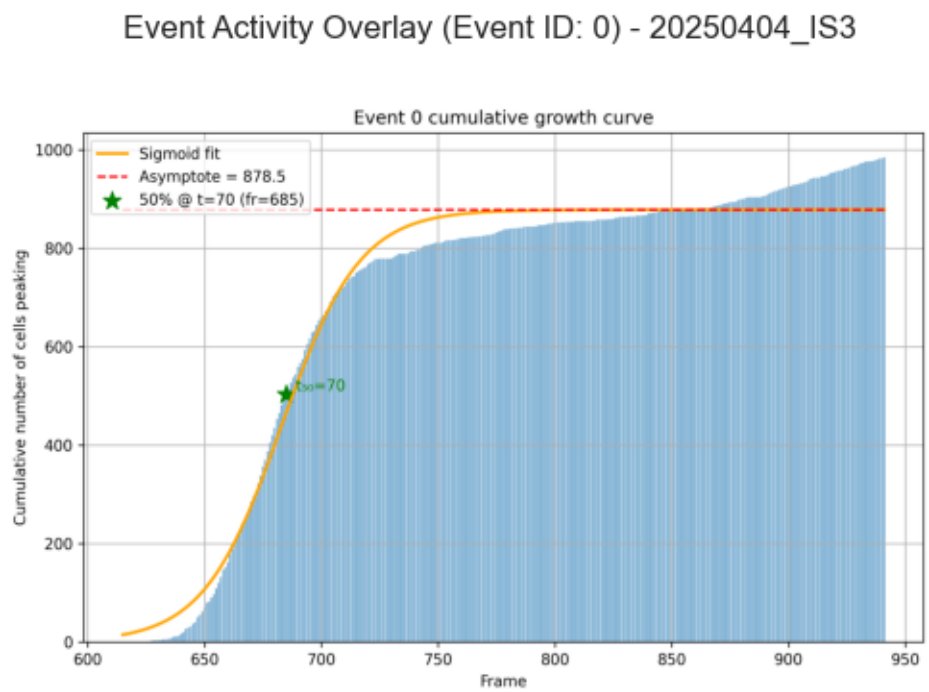


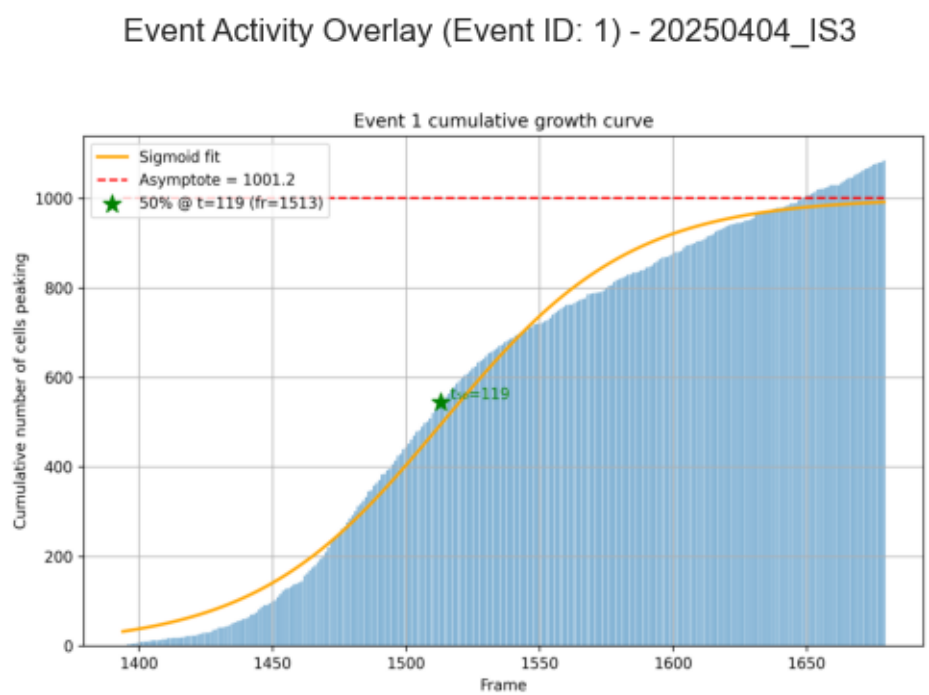

```
[2025-08-11 09:39:05] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 2070 on 'Prominence (noise std units)' (lower=-1015.8,
upper=1540.6)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
Number of Peaks
Prominence (noise std units)
0
10
20
30
40
50
0
50
100
150
200
250
300
350
400

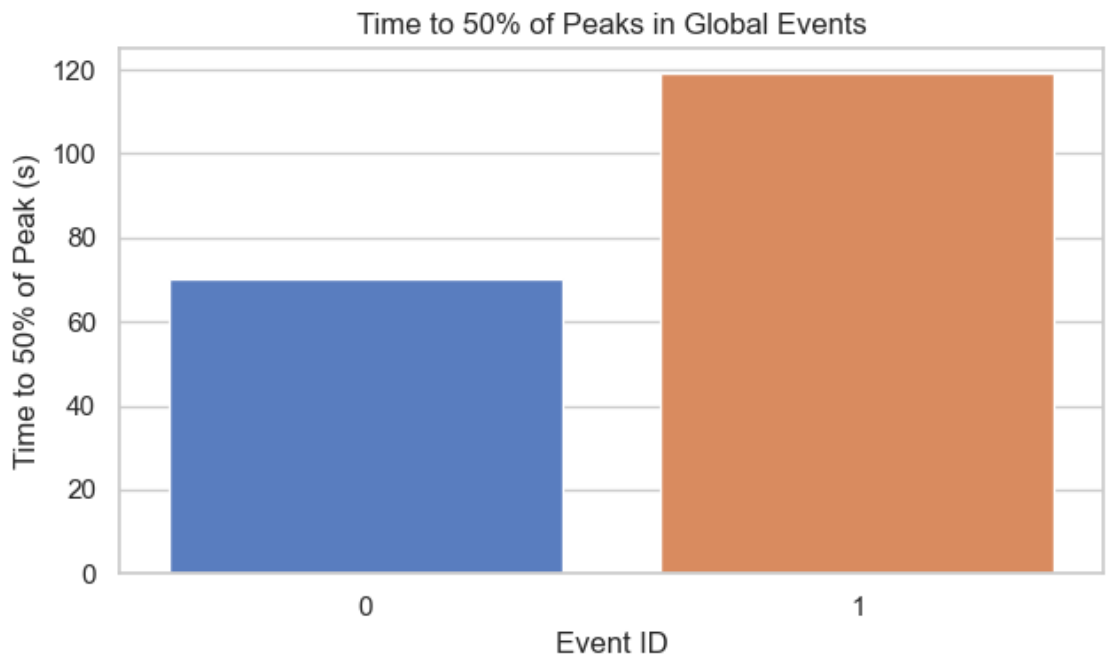

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
Number of Peaks
FHW symmetry score
0
10
20
30
40
50
60
0.2
0.4
0.6
0.8
1.0

1.2.3 Kinetics of global events

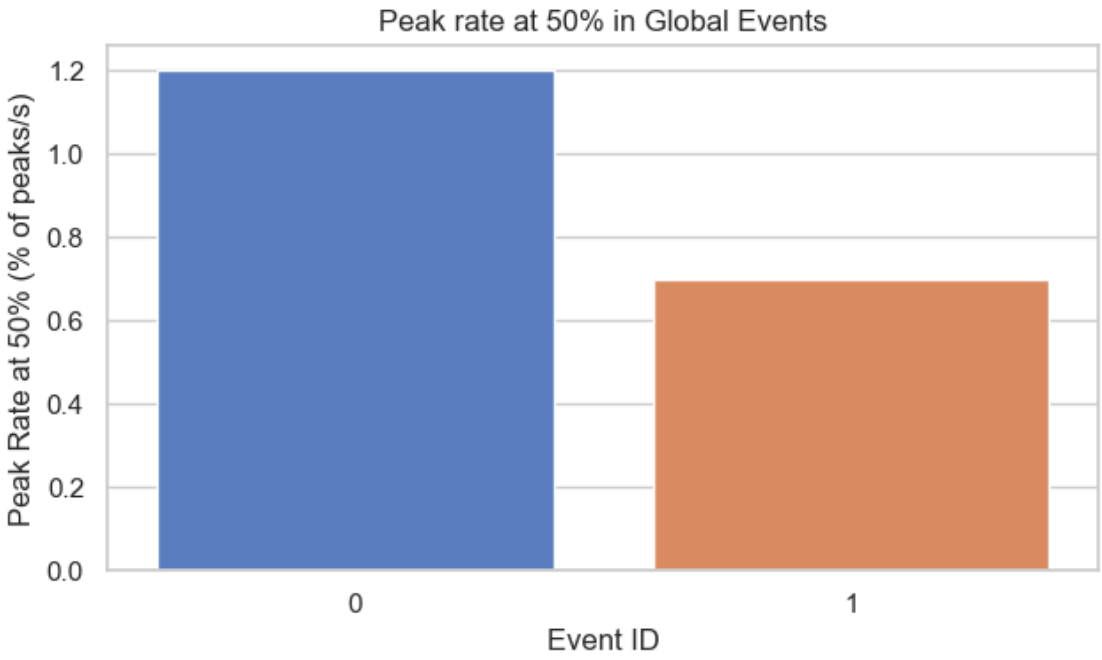




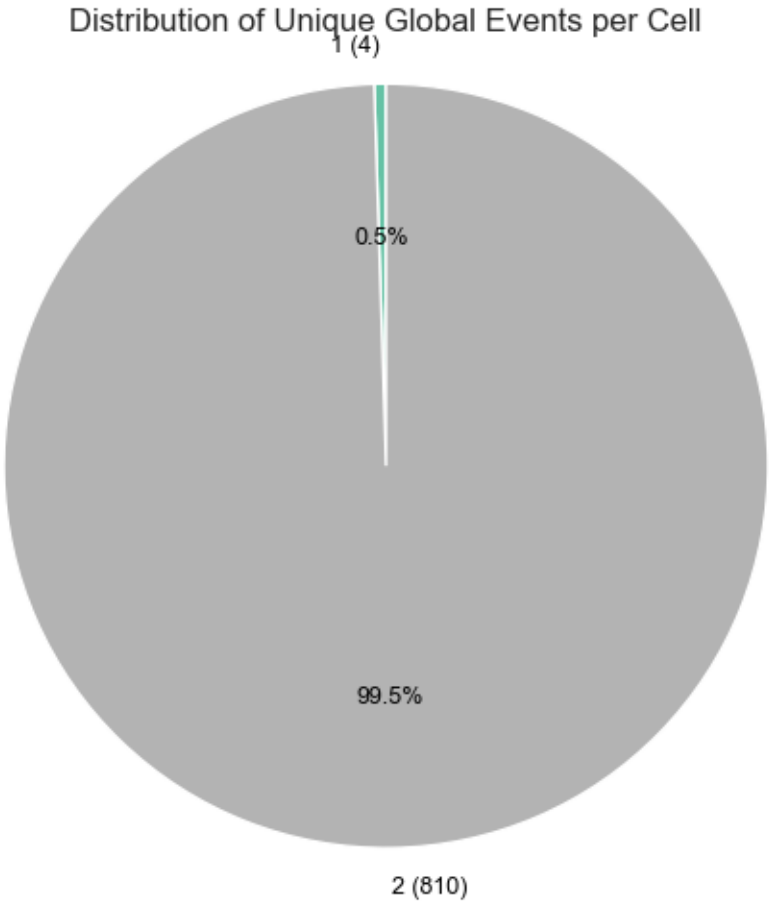
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



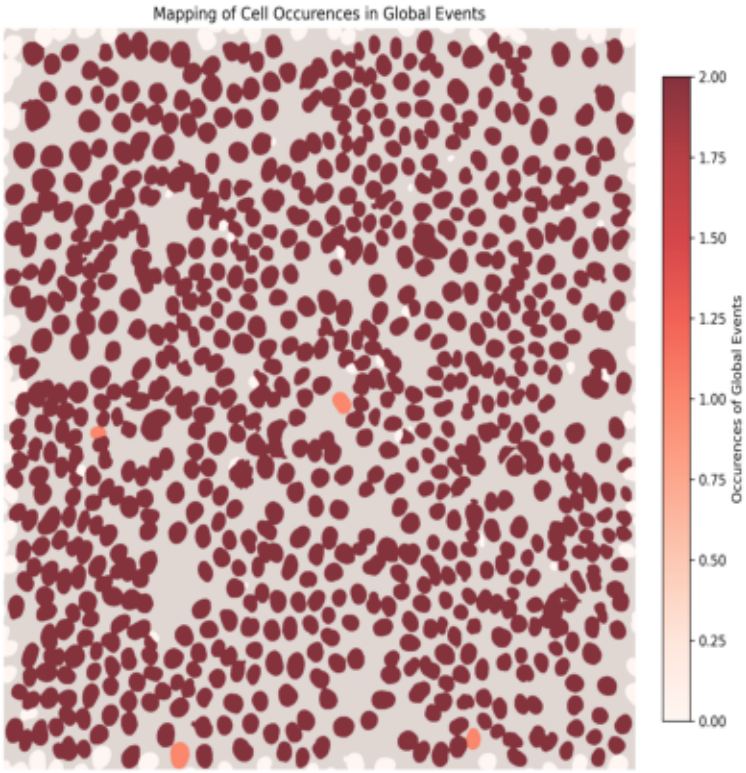

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
1
Event ID

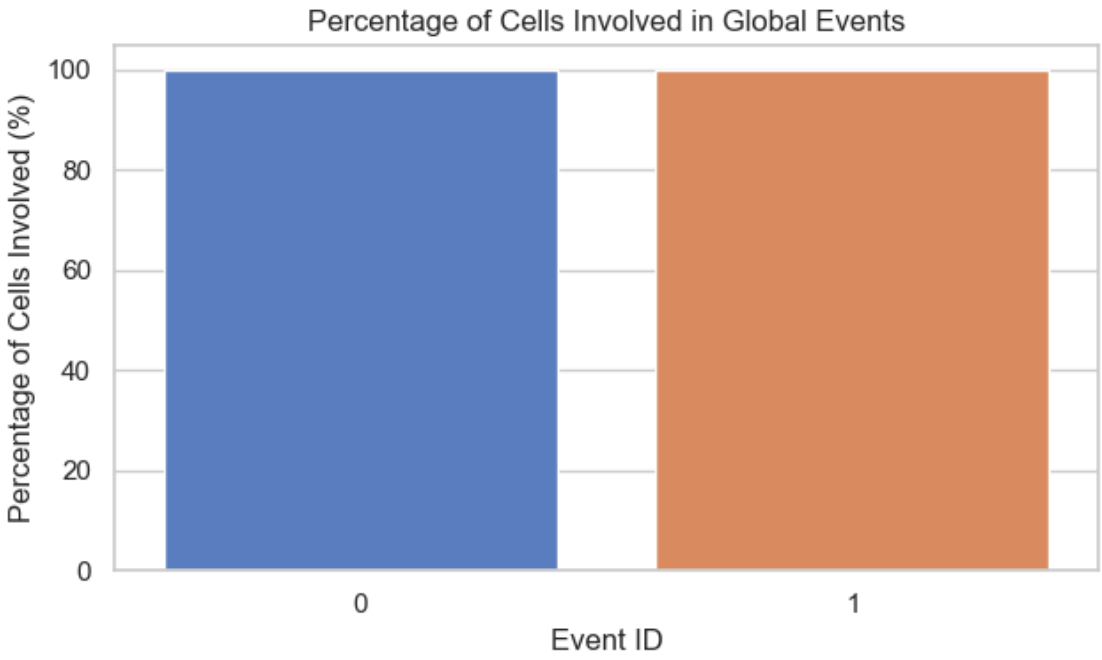
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250404_IS3




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

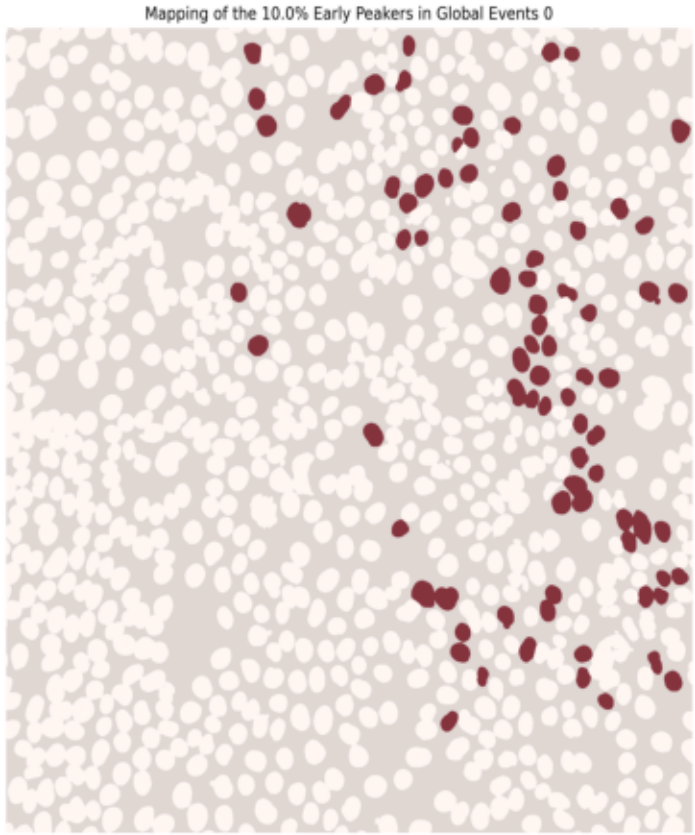


1.2.5 Inter-event interval analysis

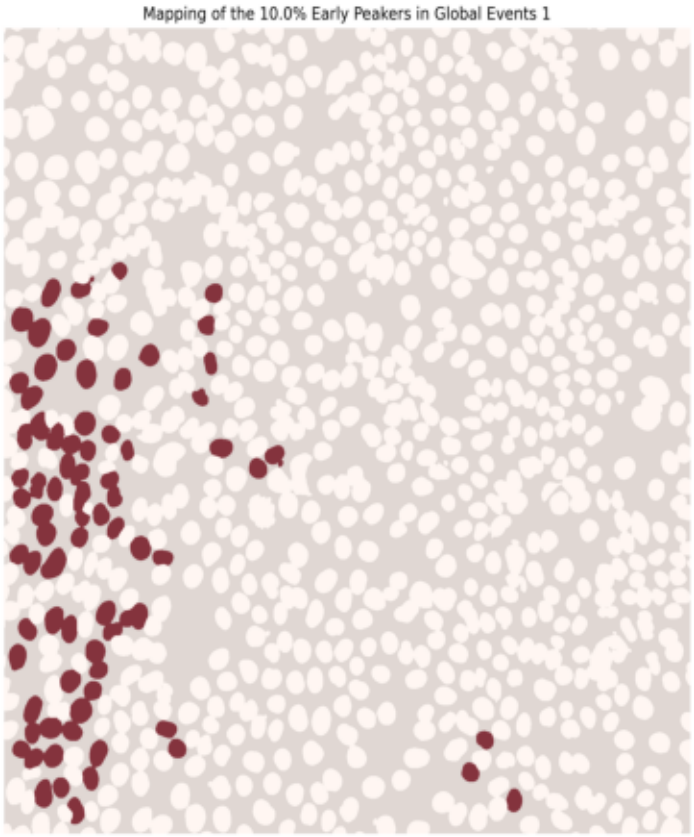
```
Intervals between global event peaks: [831.0]
```

1.2.6 Early peakers in the events

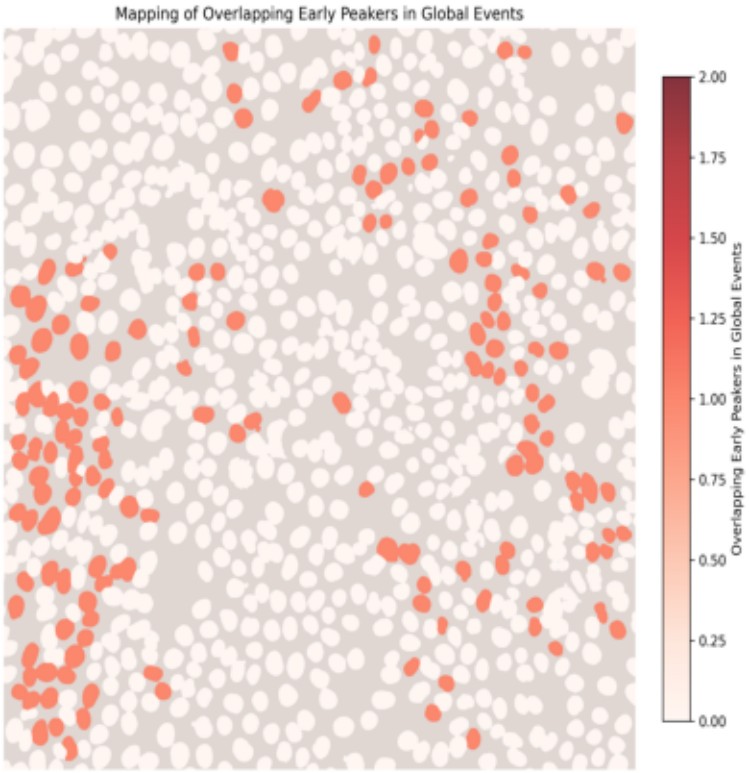
Cell Mapping with Early Peakers Overlay for event 0 - 20250404_IS3



Cell Mapping with Early Peakers Overlay for event 1 - 20250404_IS3

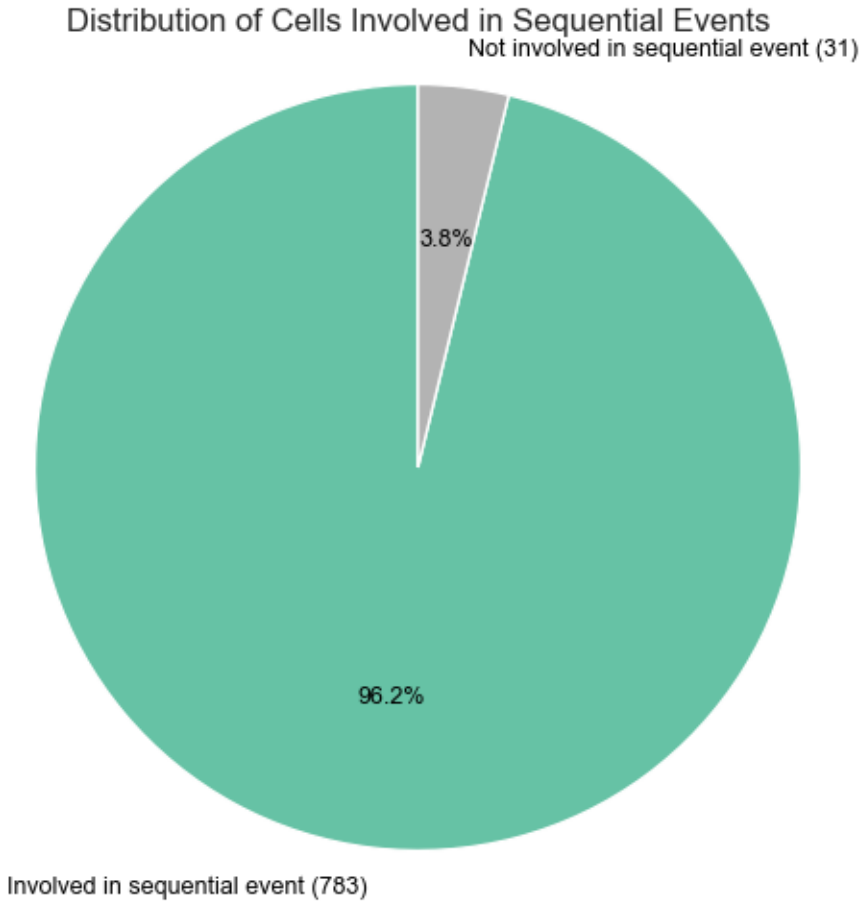


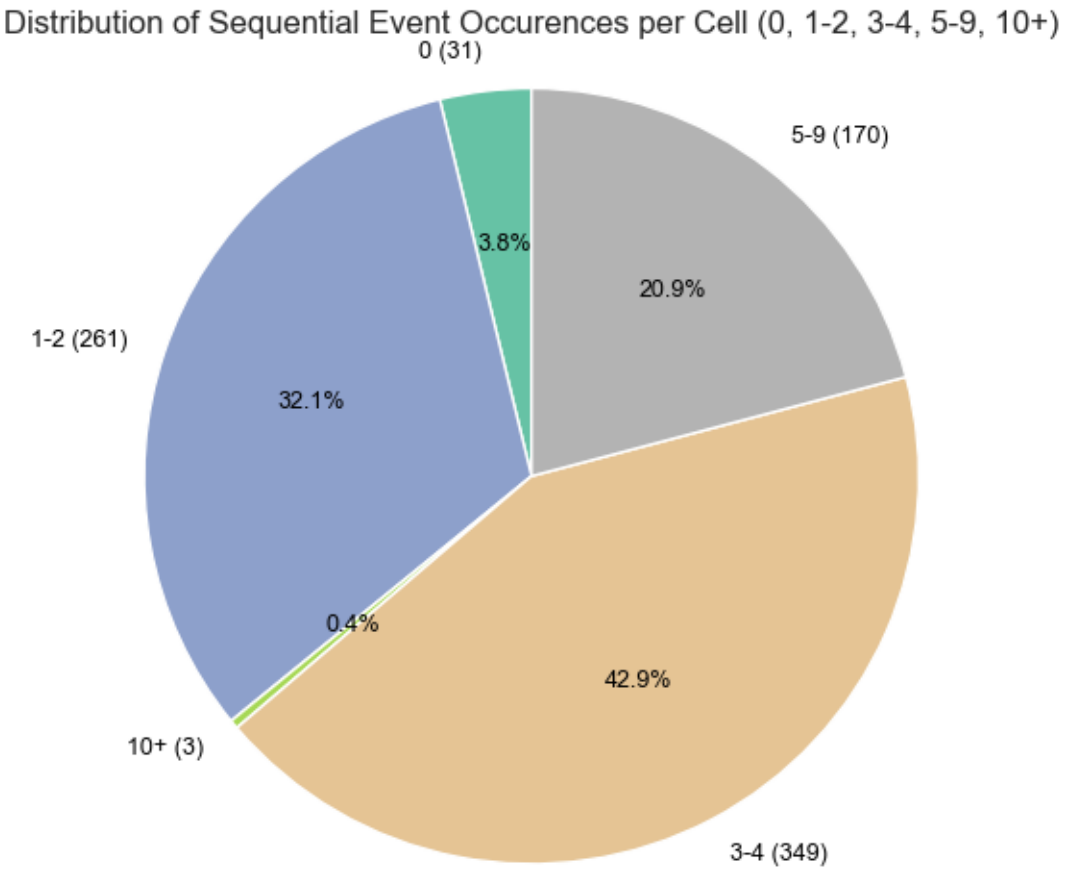
Cell Mapping with Occurences in Global Events Overlay - 20250404_IS3



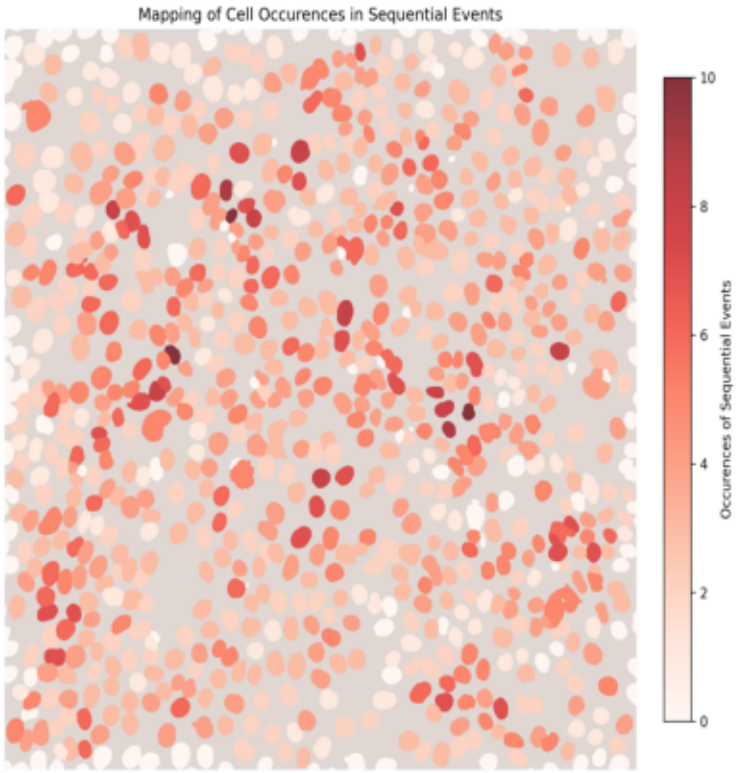
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

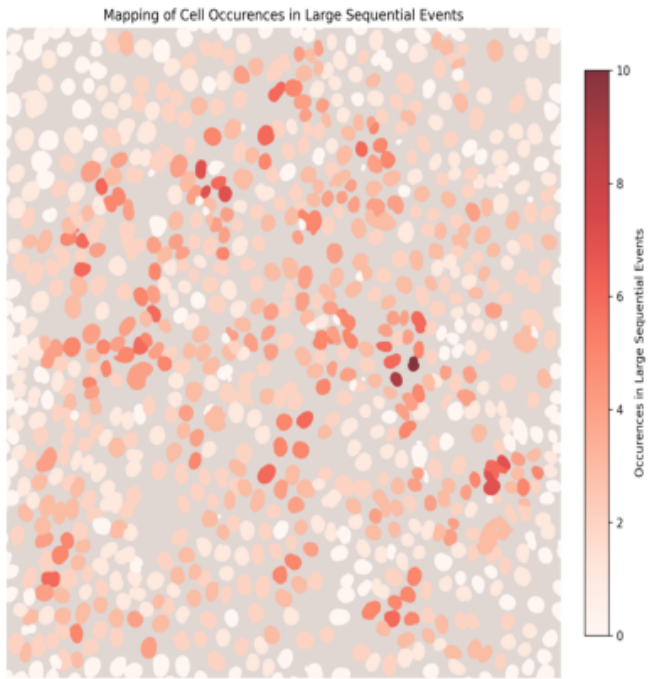



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (31)
5-9 (170)
3.8%
20.9%
1-2 (261)
32.1%
0.4%
42.9%
10+ (3)
3-4 (349)

Cell Mapping with Occurences in Sequential Events Overlay - 20250404_IS3

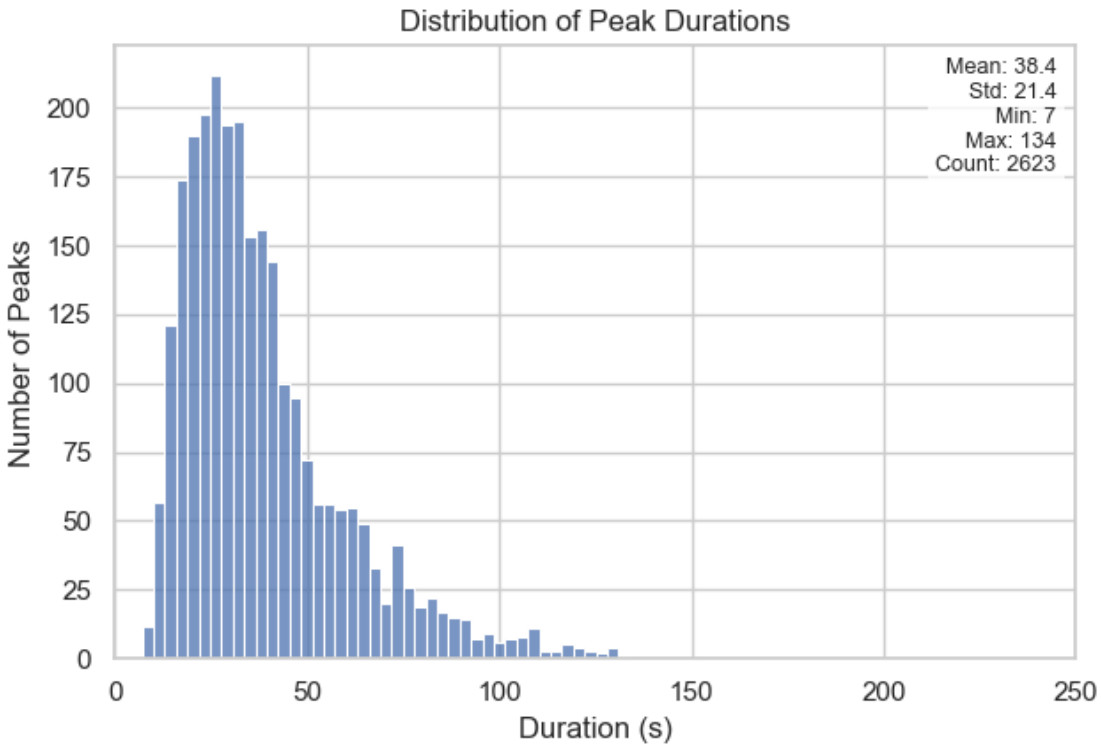


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250404_IS3

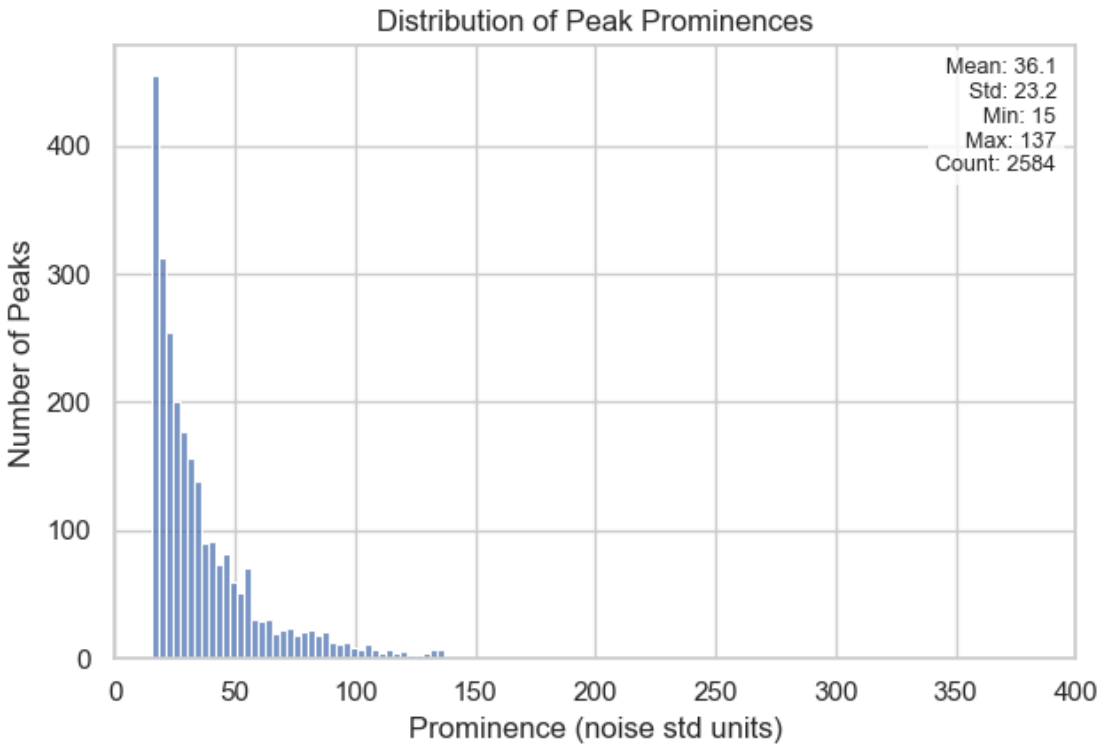


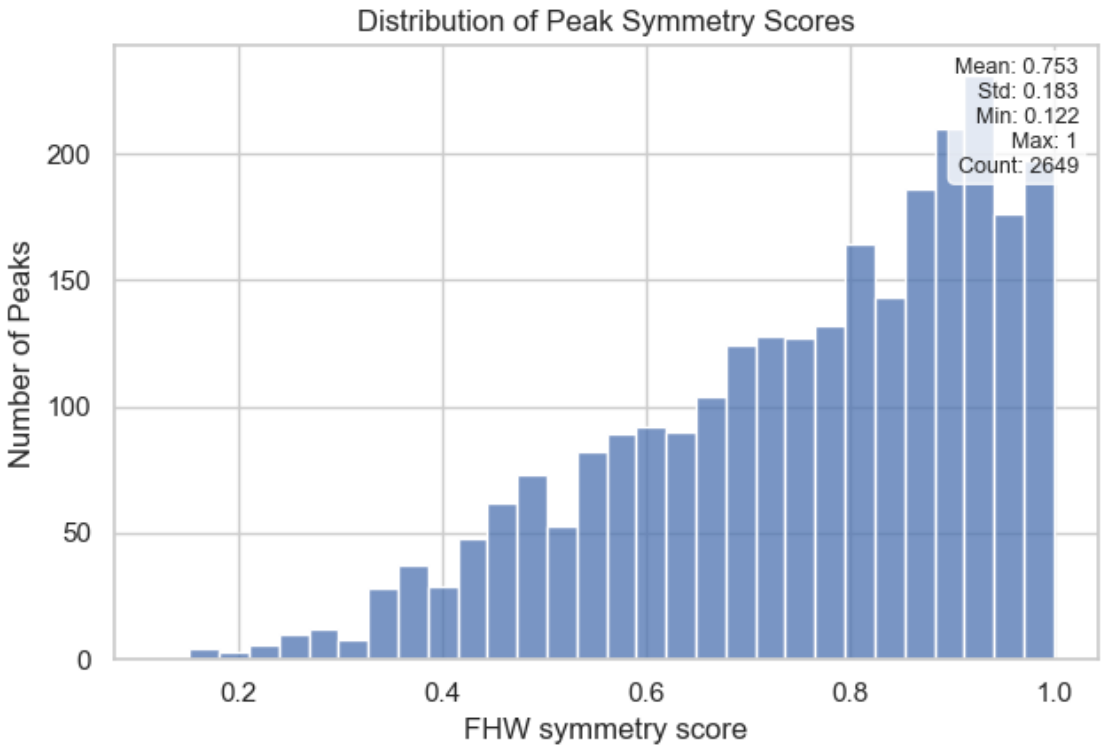
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:39:13] [INFO] calcium: plot_histogram: removed 26 outliers out of
2649 on 'Duration (s)' (lower=-14.5, upper=135.5)
```



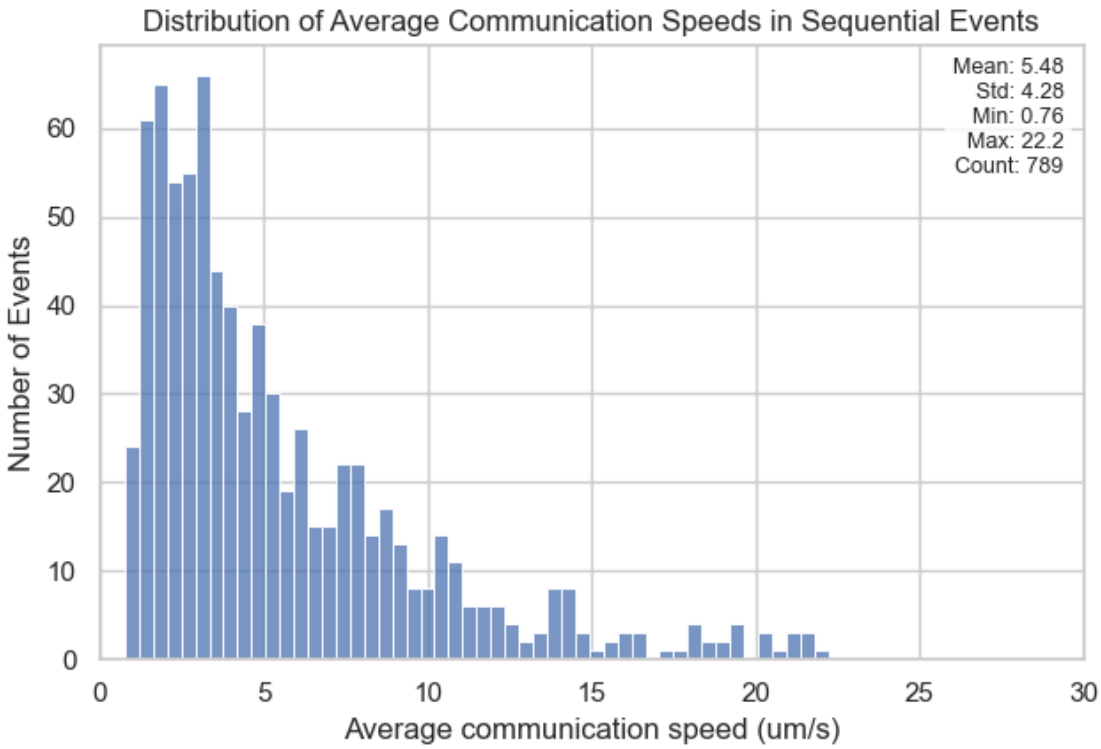

```
[2025-08-11 09:39:13] [INFO] calcium: plot_histogram: removed 65 outliers out of
2649 on 'Prominence (noise std units)' (lower=-19.25, upper=137.35)
```


Distribution of Peak Prominences
Mean: 36.1
Std: 23.2
Min: 15
Max: 137
Count: 2584
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

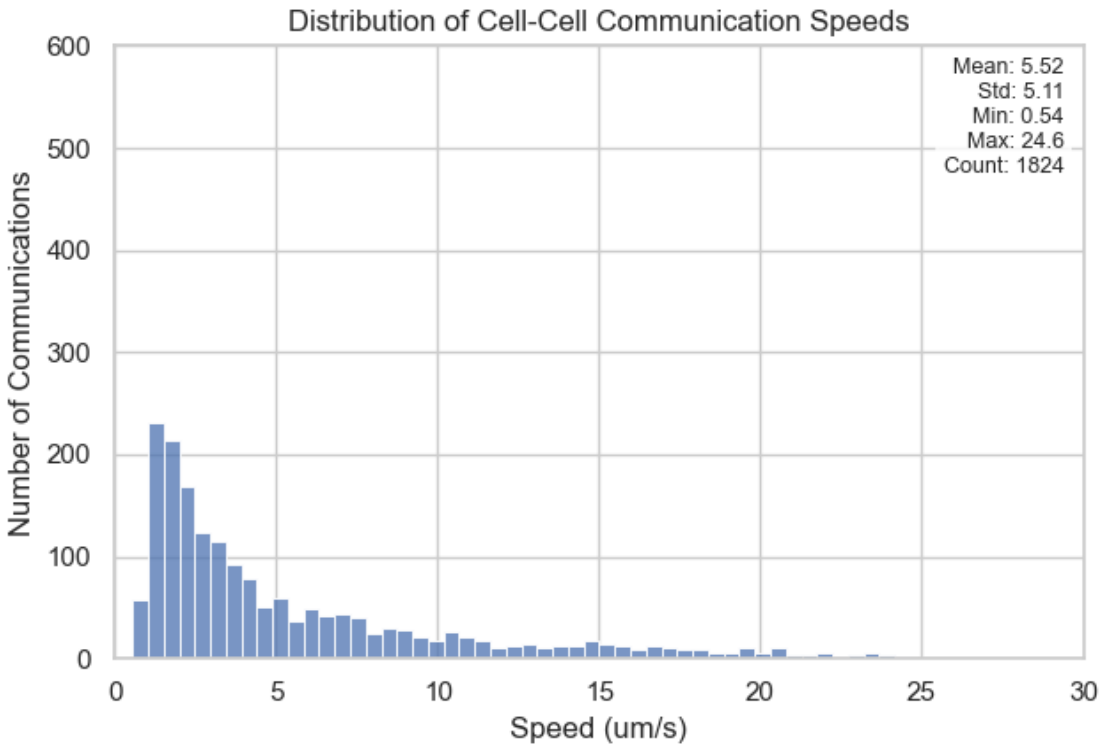

Distribution of Peak Symmetry Scores
Mean: 0.753
Std: 0.183
Min: 0.122
Max: 1
Count: 2649
Number of Peaks
0
50
100
150
200
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:39:14] [INFO] calcium: plot_histogram: removed 10 outliers out of
799 on 'Average communication speed (um/s)' (lower=-13.065, upper=23.09)
```

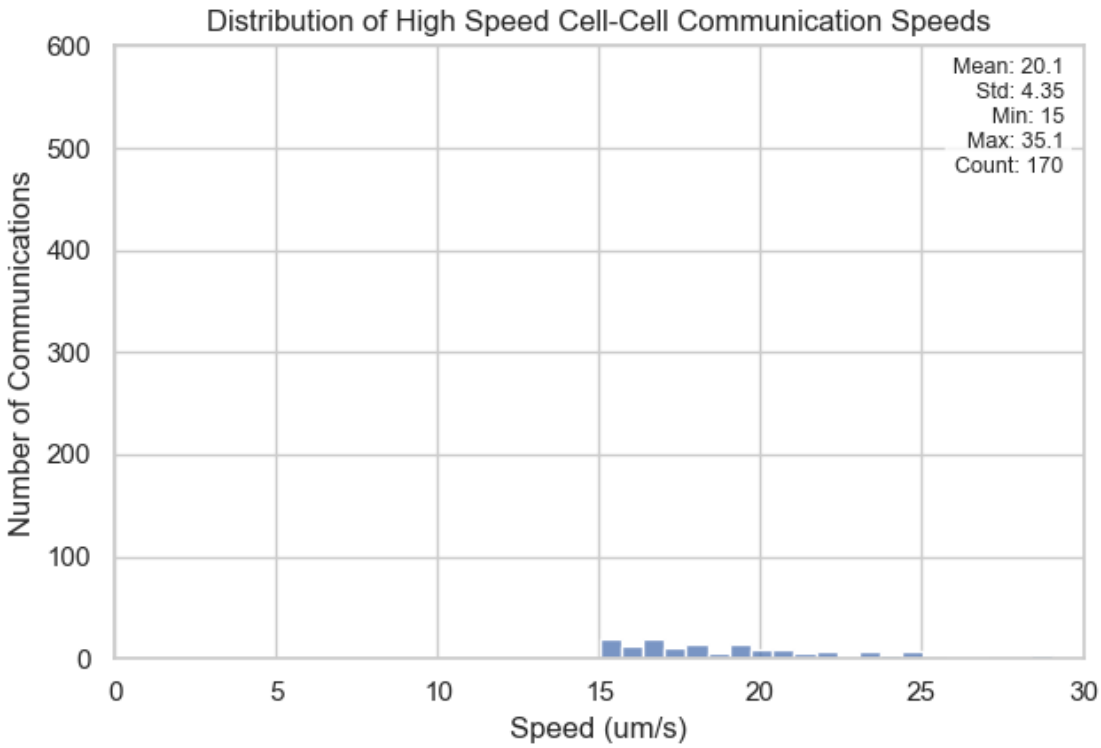



```
[2025-08-11 09:39:14] [INFO] calcium: plot_histogram: removed 26 outliers out of
1850 on 'Speed (um/s)' (lower=-15.27, upper=24.77)
```

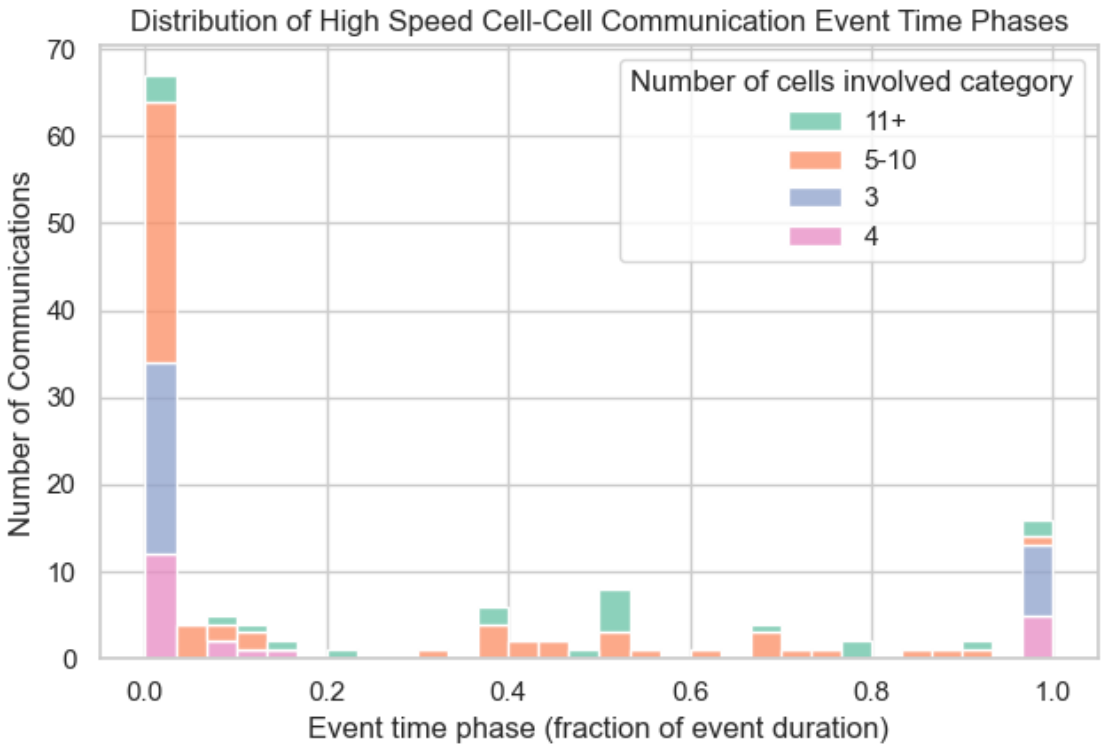


1.3.4 Double distribution in cell-cell communication speeds

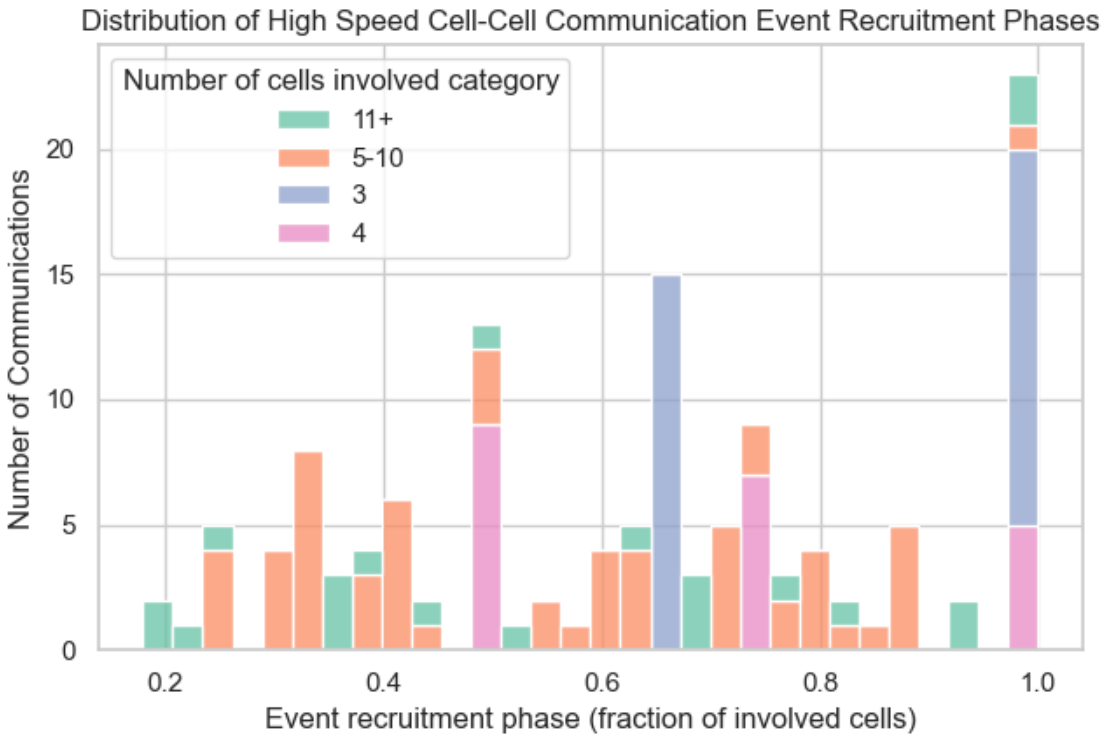
```
[2025-08-11 09:39:14] [INFO] calcium: plot_histogram: removed 0 outliers out of
170 on 'Speed (um/s)' (lower=-0.6375, upper=39.56)
```



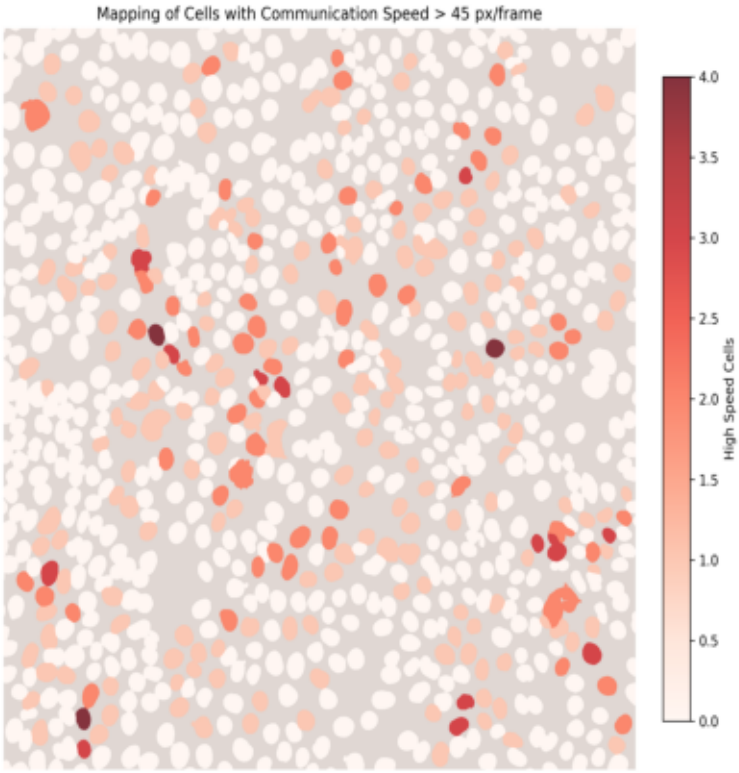

```
[2025-08-11 09:39:14] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 133 on 'Event time phase (fraction of event duration)'
(lower=-1.56, upper=2.08)
```



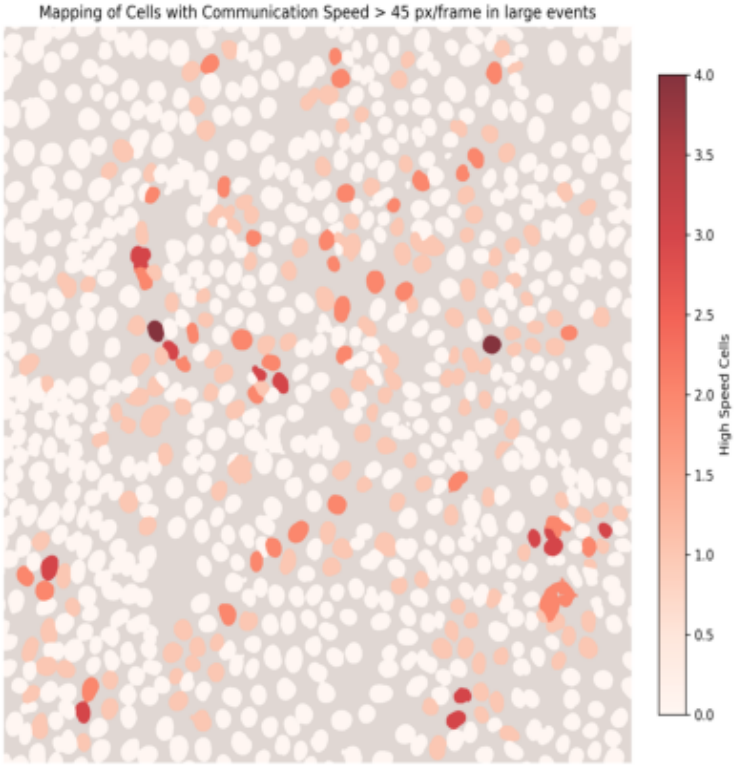

```
[2025-08-11 09:39:15] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 133 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.68, upper=1.91)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
11+
5-10
3
4
Number of Communications
0
5
10
15
20
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

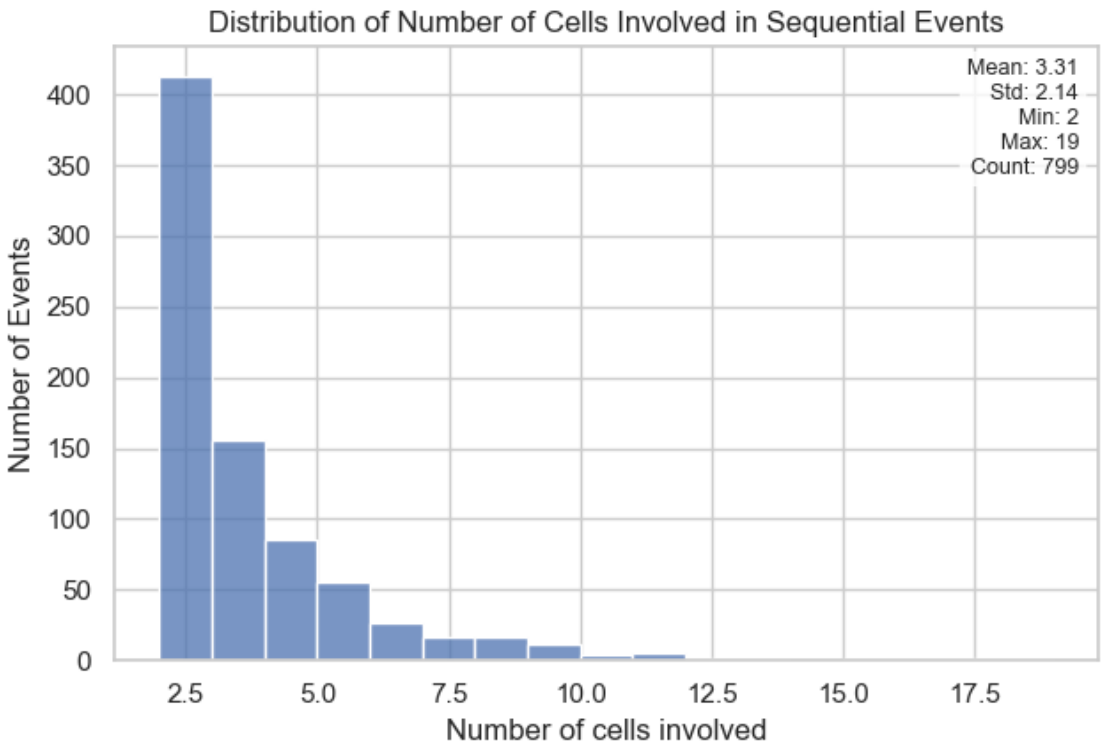
Cell Mapping with High Speed Cells Overlay - 20250404_IS3



Cell Mapping with High Speed Cells in Large Events Overlay - 20250404_IS3

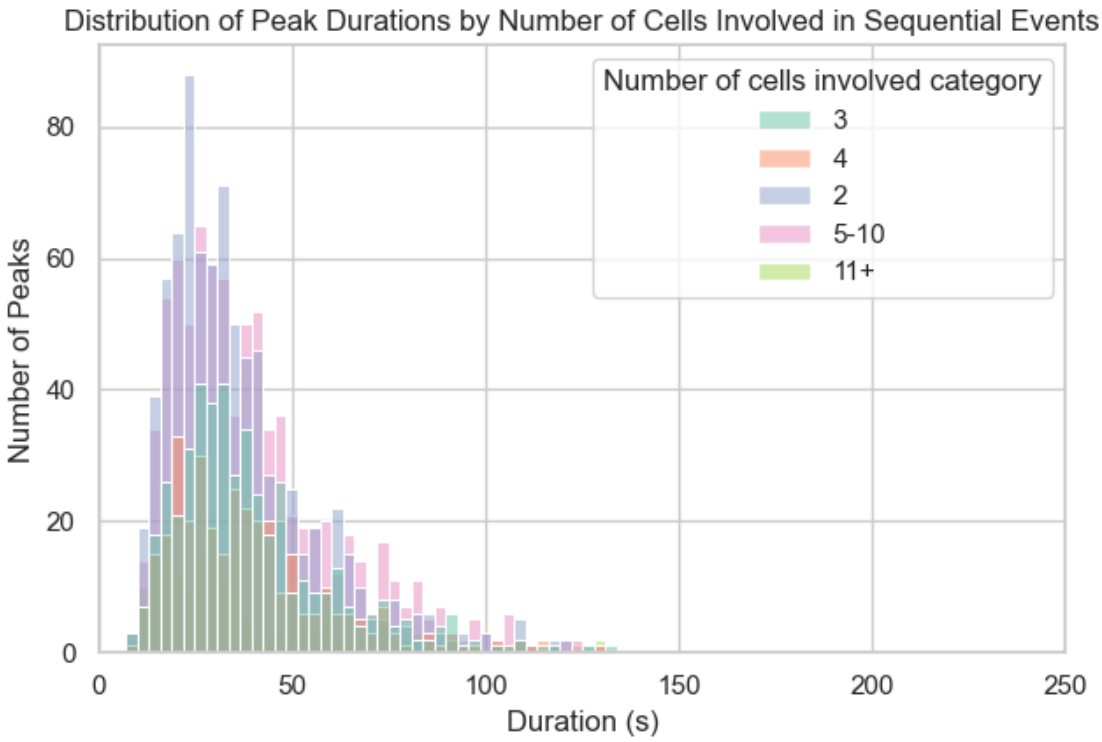


1.3.5 Number of cells involved per sequential events

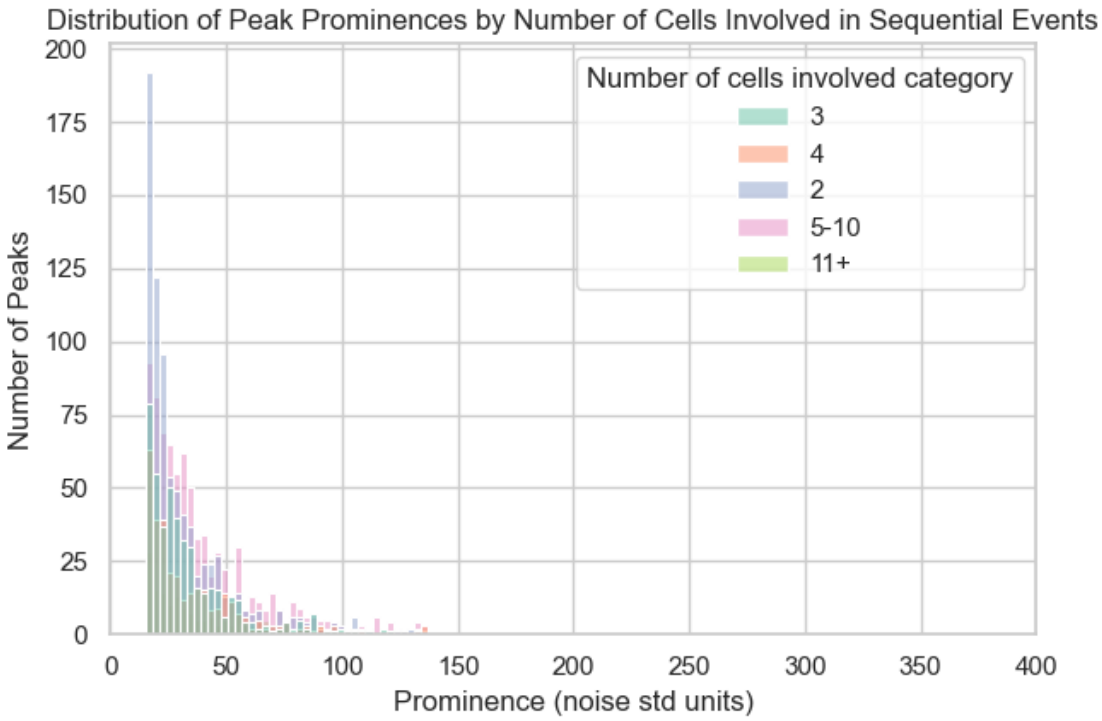


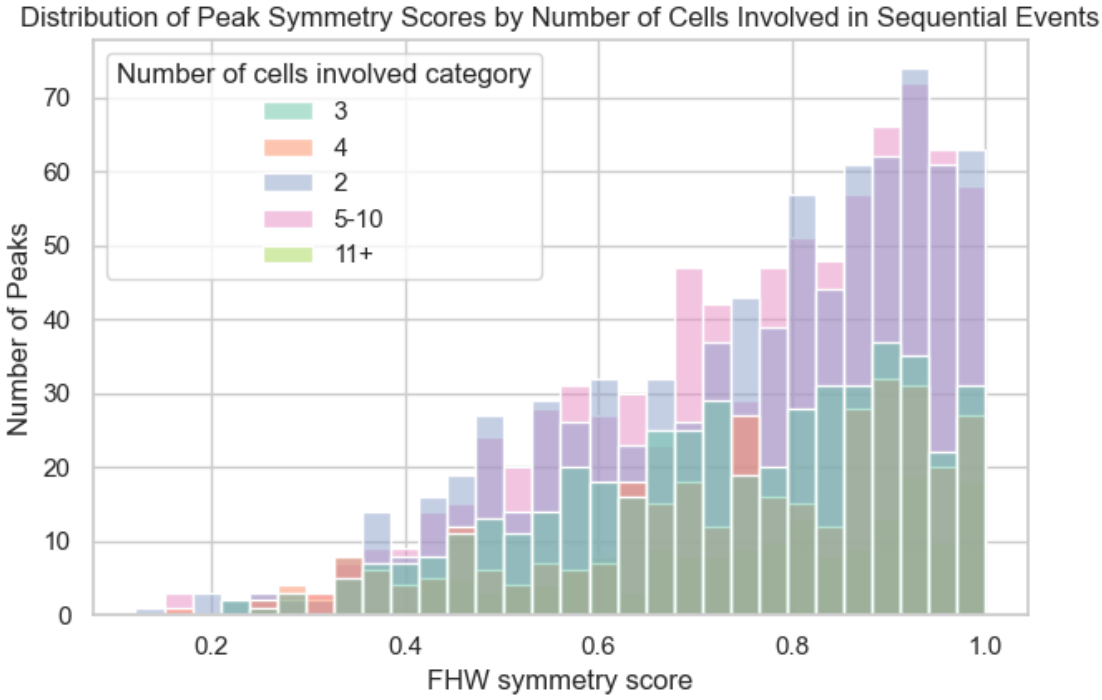
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:39:17] [INFO] calcium: plot_histogram_by_group: removed 26
outliers out of 2649 on 'Duration (s)' (lower=-14.5, upper=135.5)
```



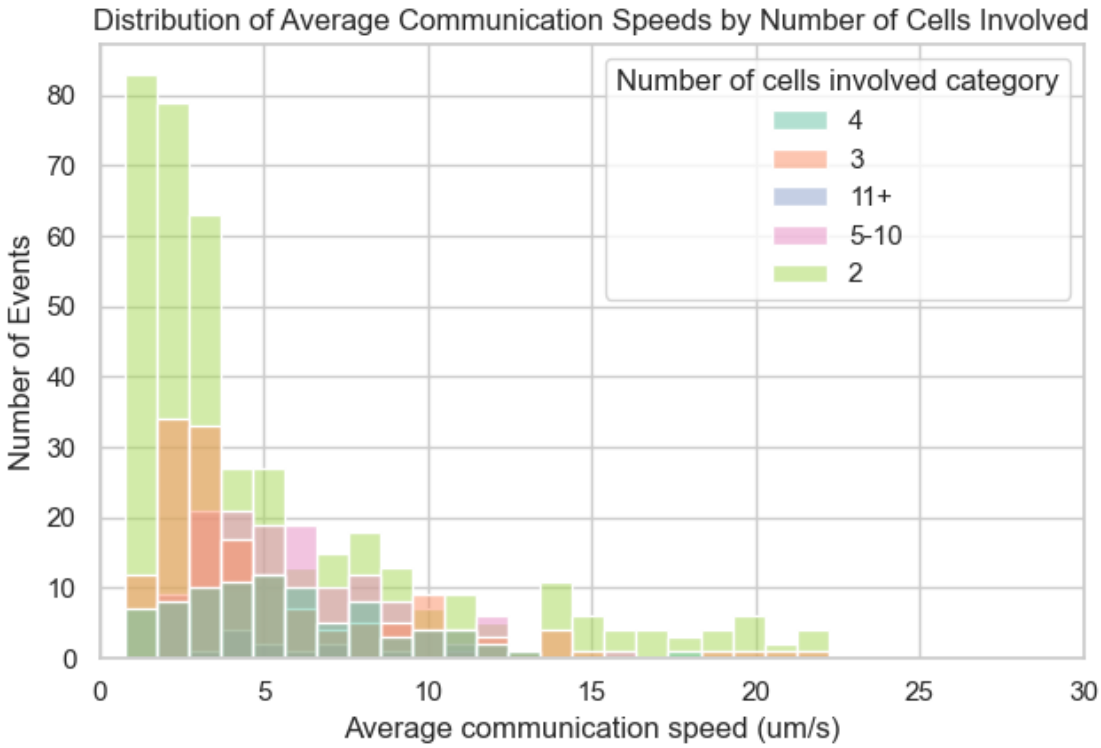

```
[2025-08-11 09:39:18] [INFO] calcium: plot_histogram_by_group: removed 65
outliers out of 2649 on 'Prominence (noise std units)' (lower=-19.25,
upper=137.35)
```



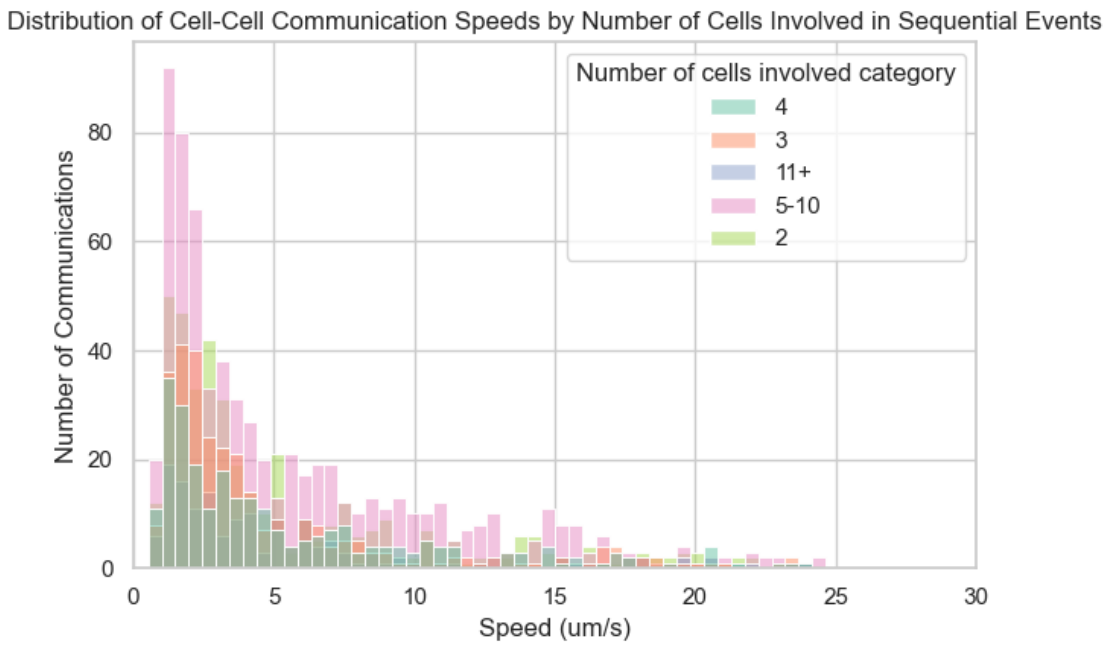



```
[2025-08-11 09:39:18] [INFO] calcium: plot_histogram_by_group: removed 10
```

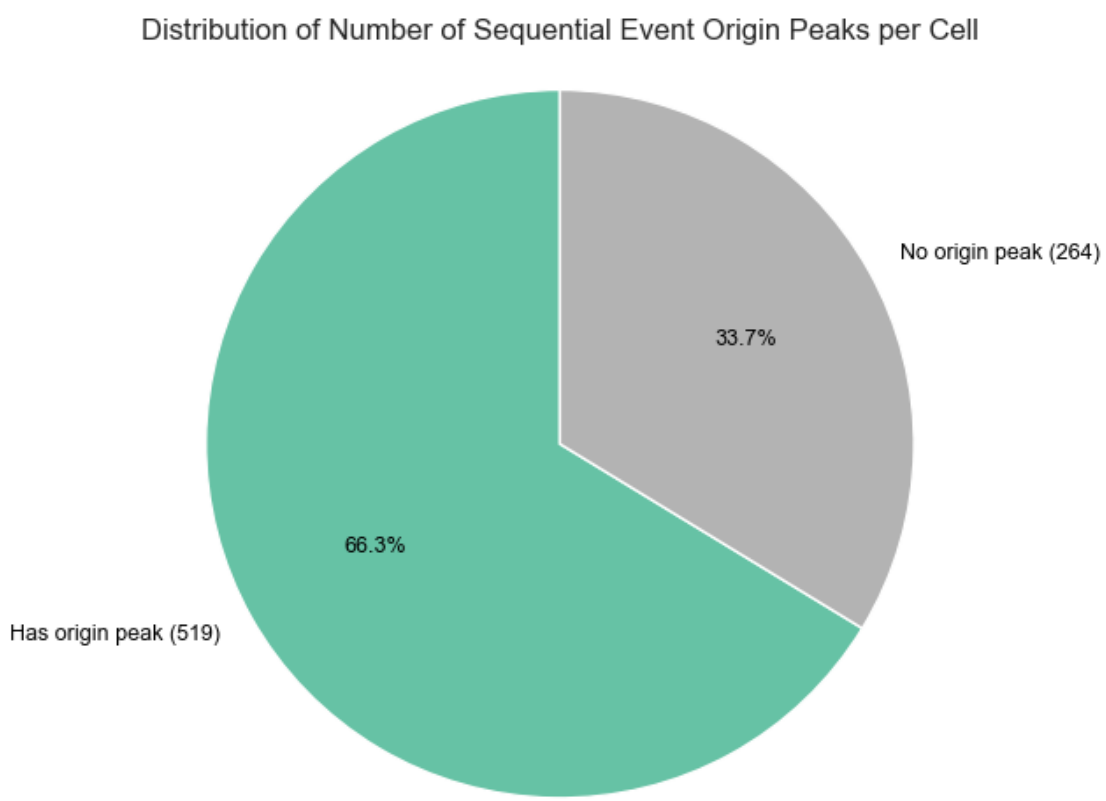
```
outliers out of 799 on 'Average communication speed (um/s)' (lower=-13.065,
upper=23.09)
```

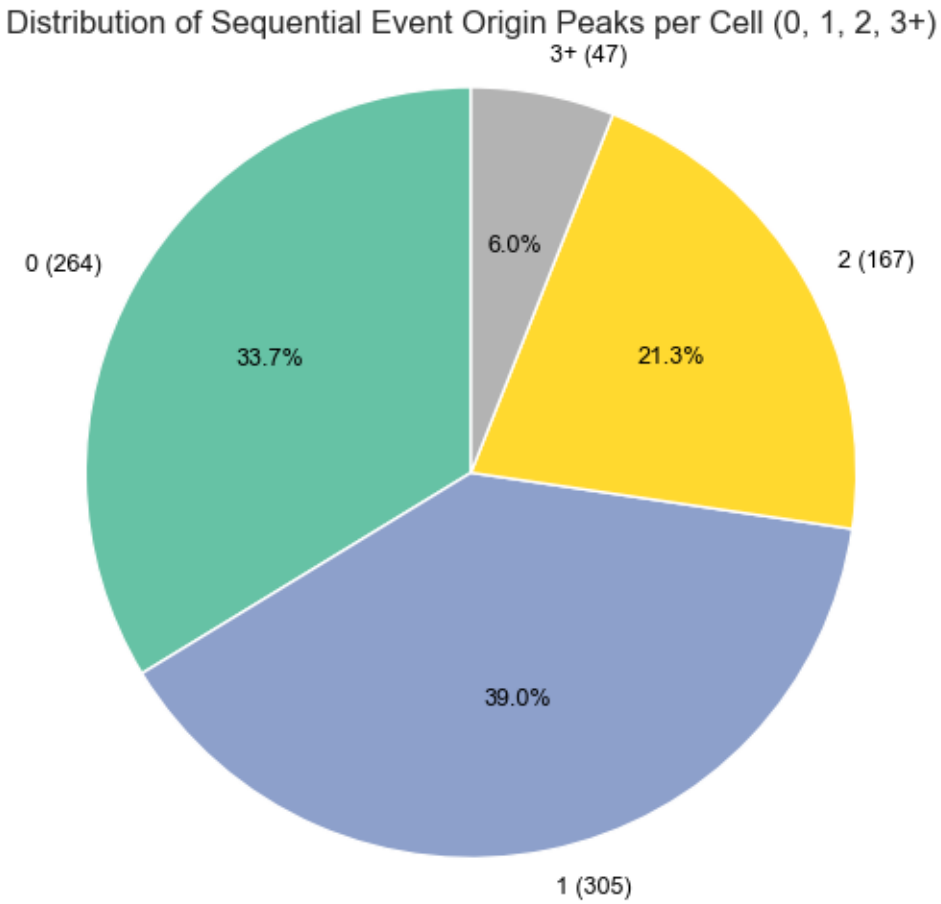



```
[2025-08-11 09:39:18] [INFO] calcium: plot_histogram_by_group: removed 26
outliers out of 1850 on 'Speed (um/s)' (lower=-15.27, upper=24.77)
```

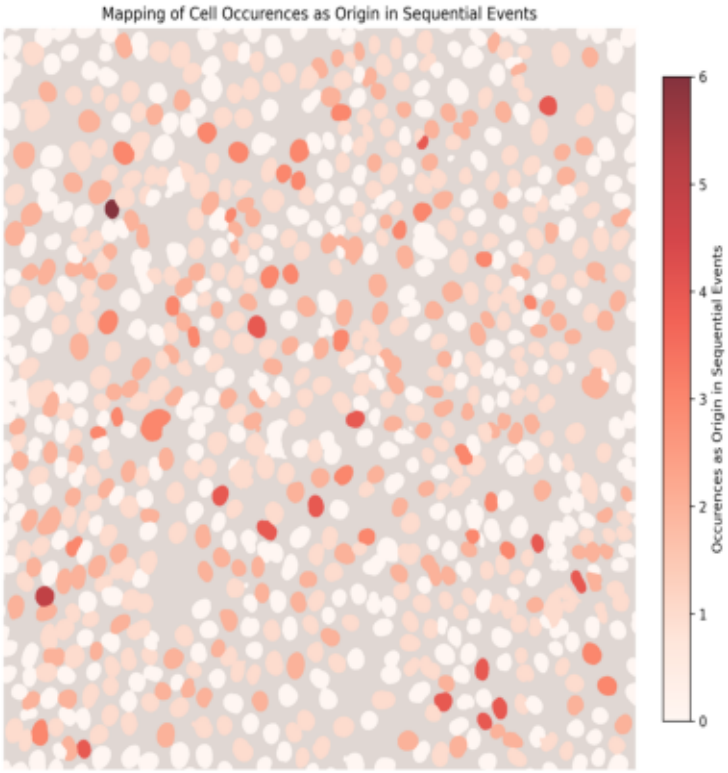


1.3.7 Cells occurences as origin in sequential events

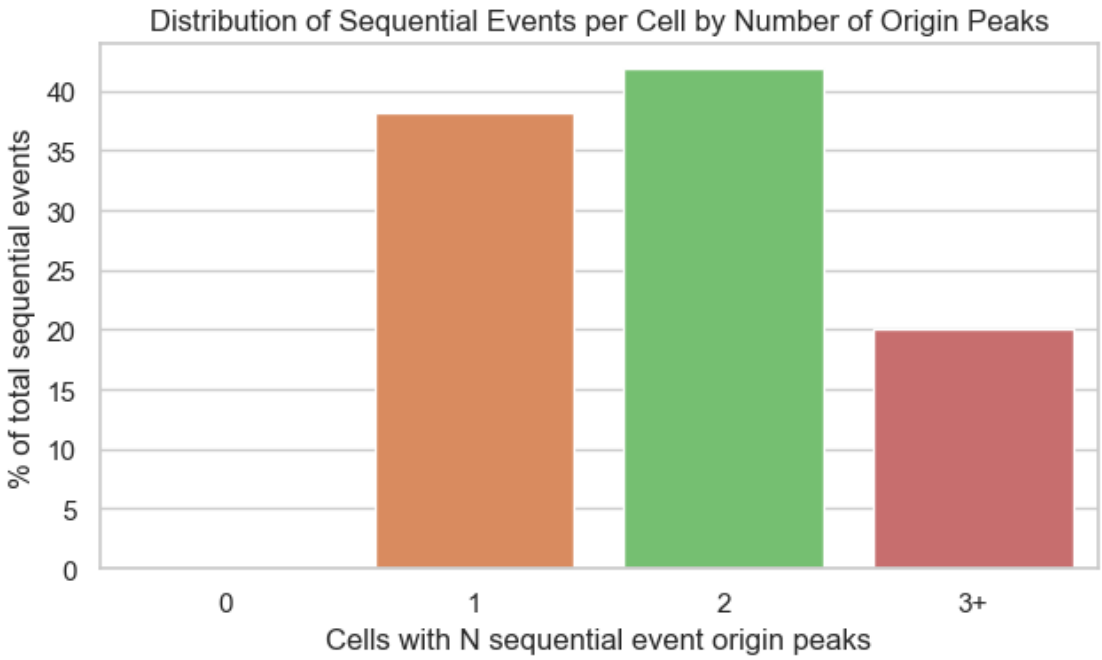



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (47)
6.0%
2 (167)
21.3%
0 (264)
33.7%
39.0%
1 (305)

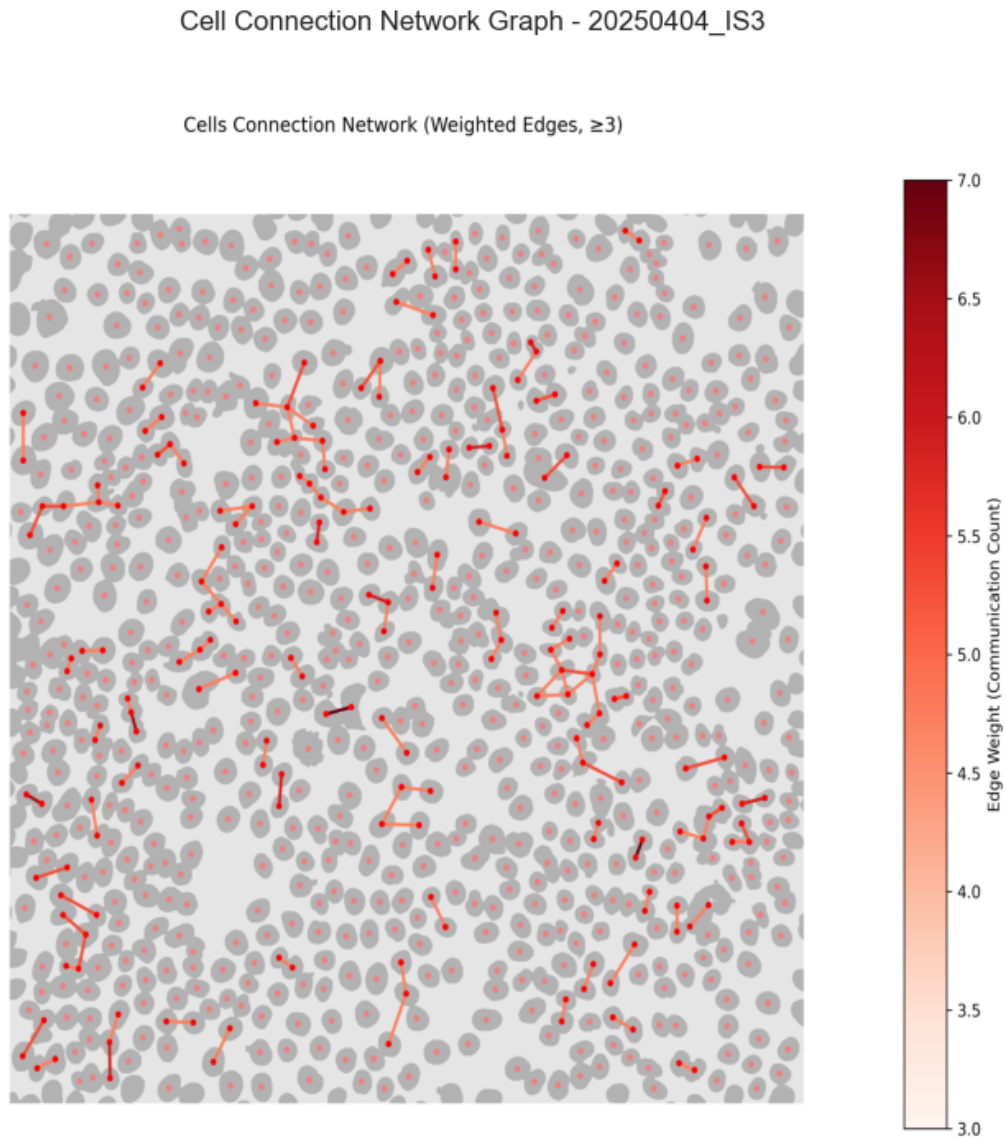
Cell Mapping with Origin Peaks Overlay - 20250404_IS3




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

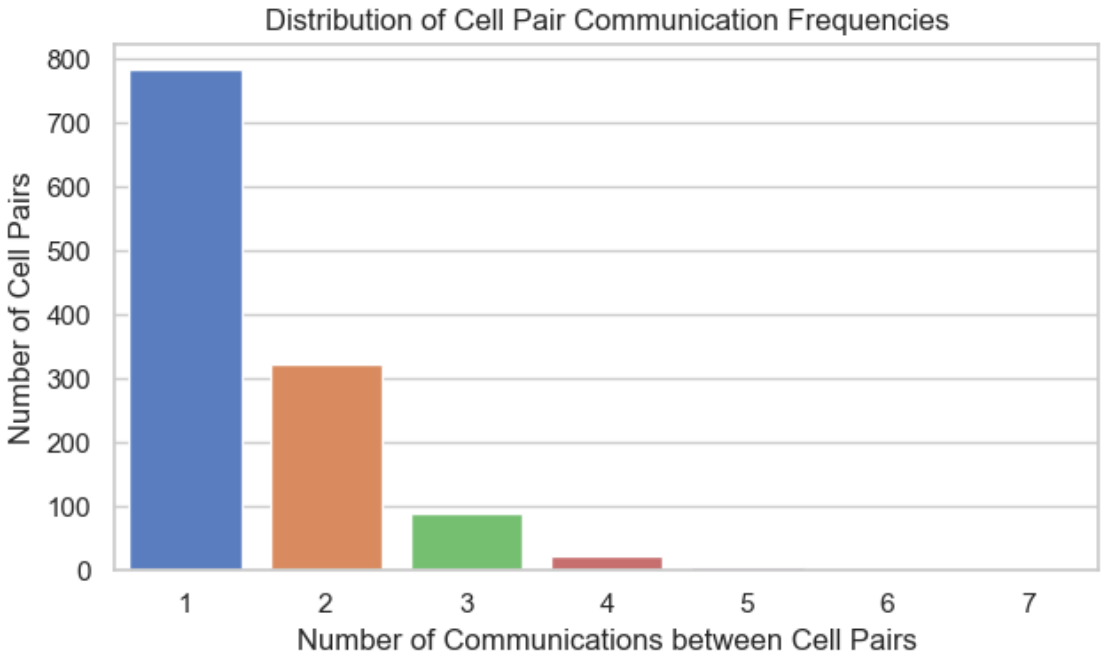

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
40
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



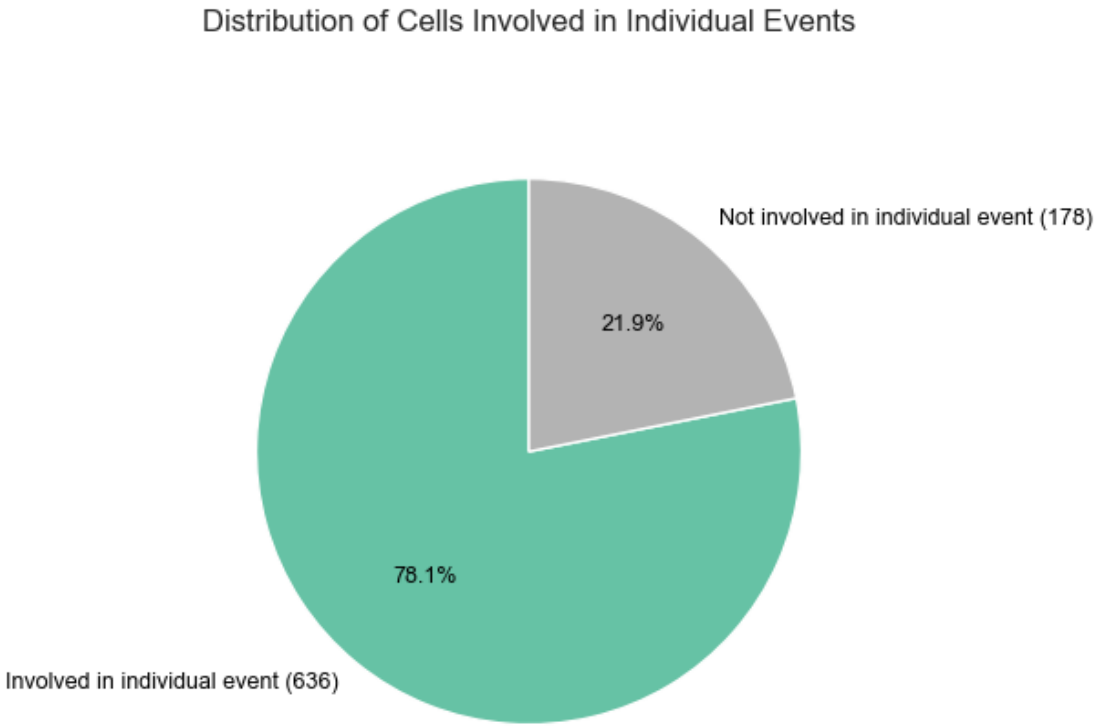

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

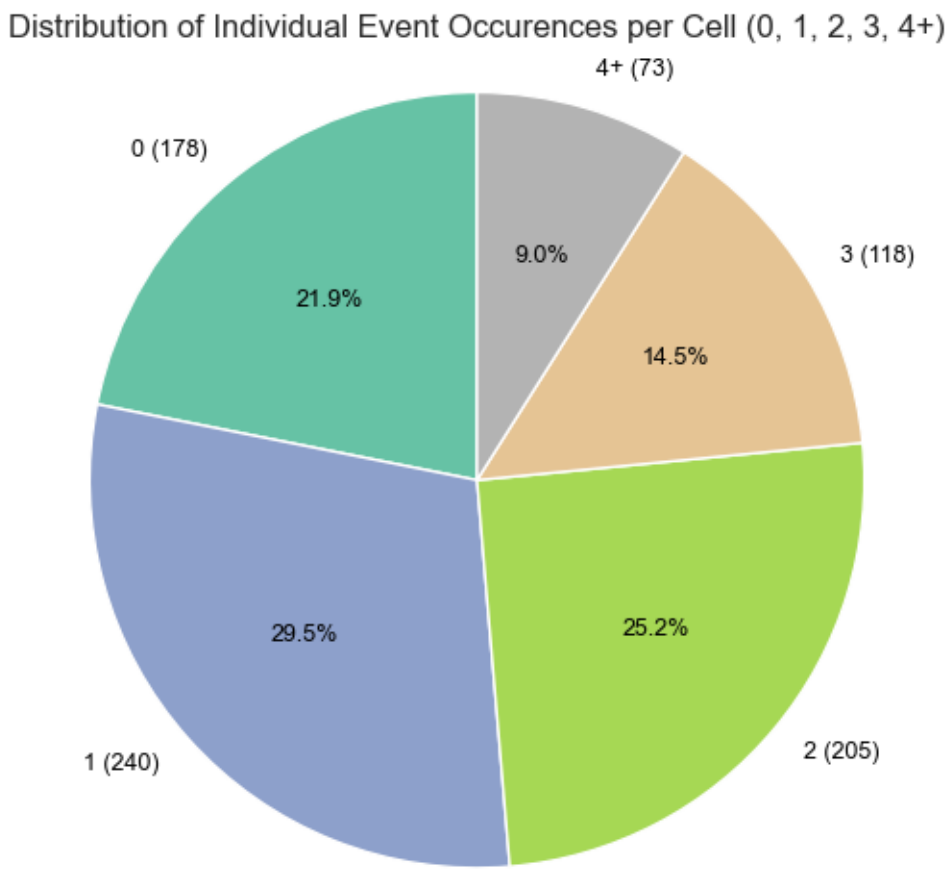
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
Number of Communications between Cell Pairs

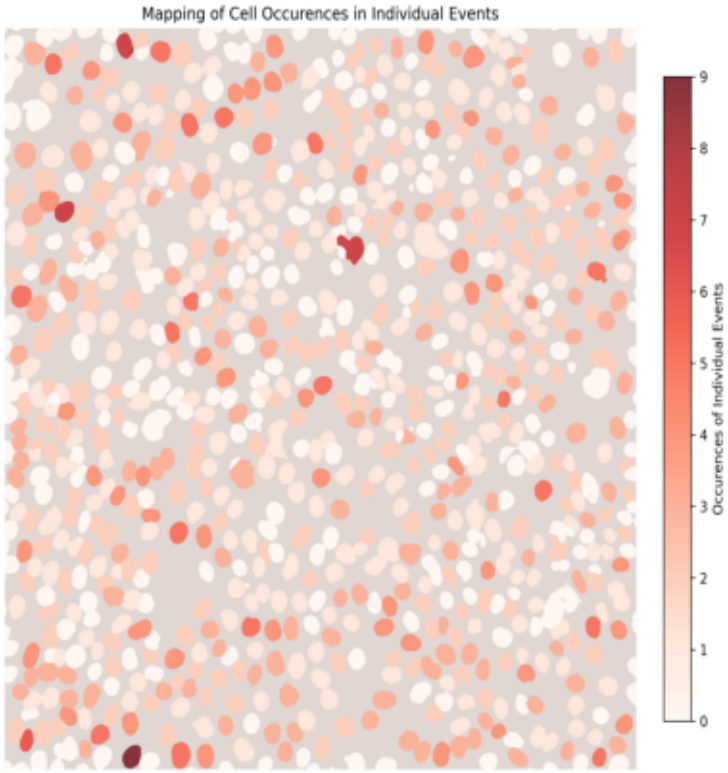
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



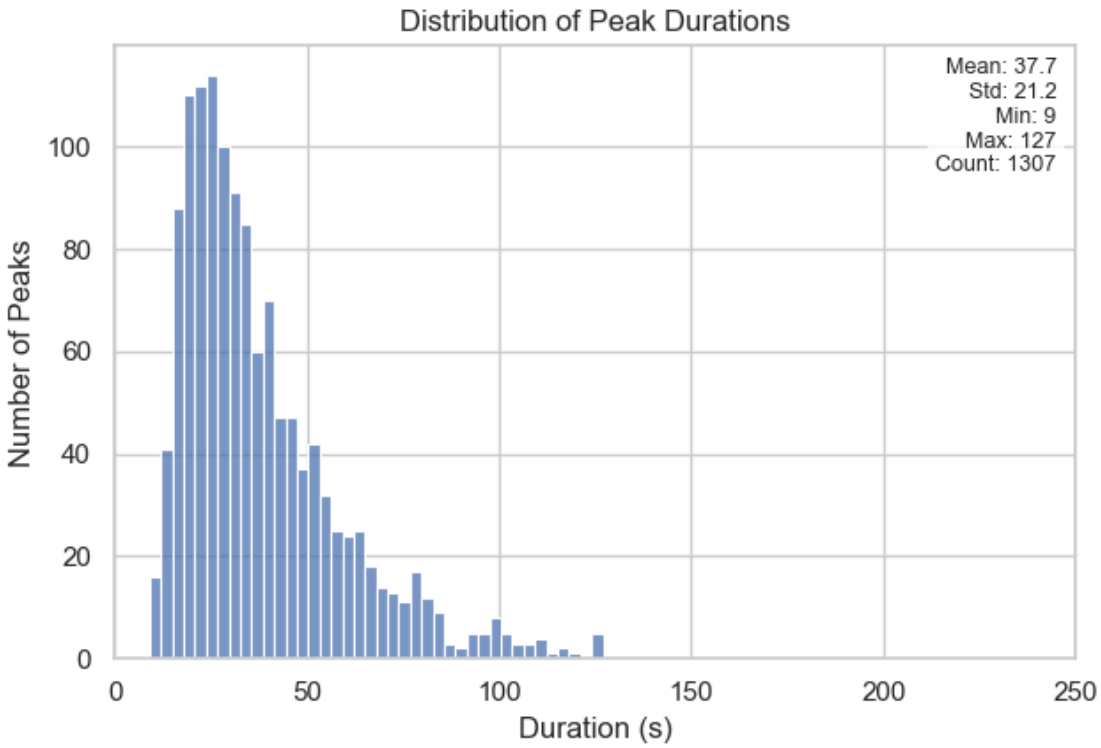

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (73)
9.0%
3 (118)
14.5%
2 (205)
25.2%
1 (240)
29.5%
0 (178)
21.9%

Cell Mapping with Occurences in Individual Events Overlay - 20250404_IS3

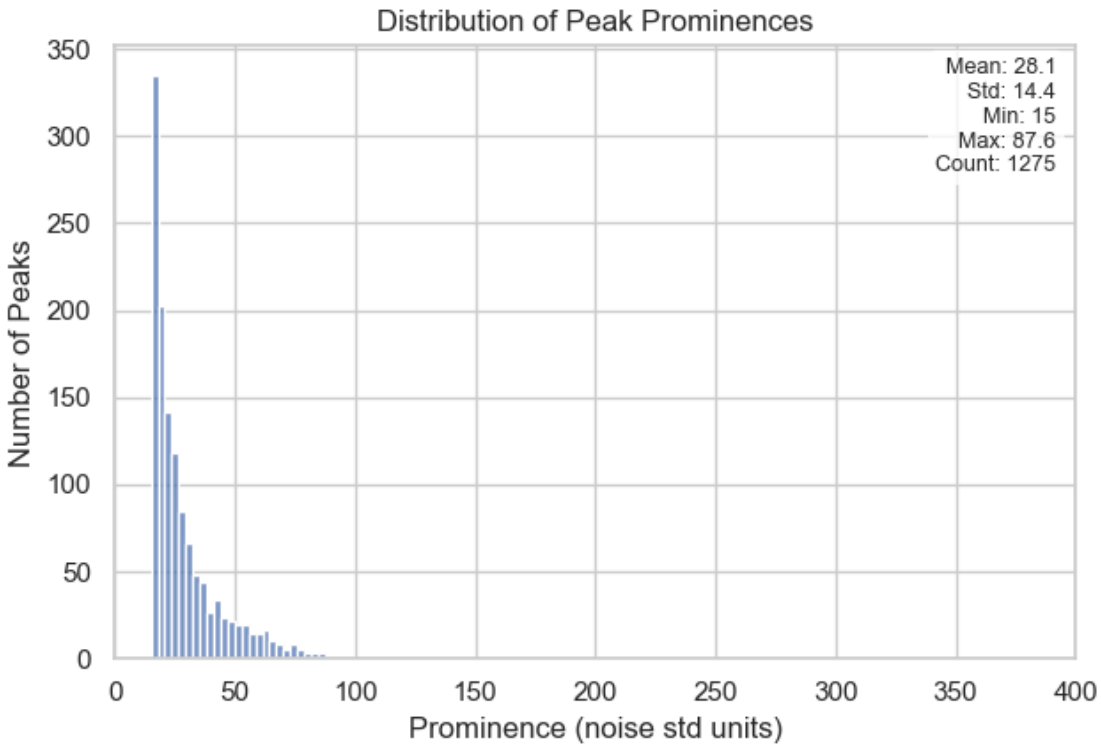


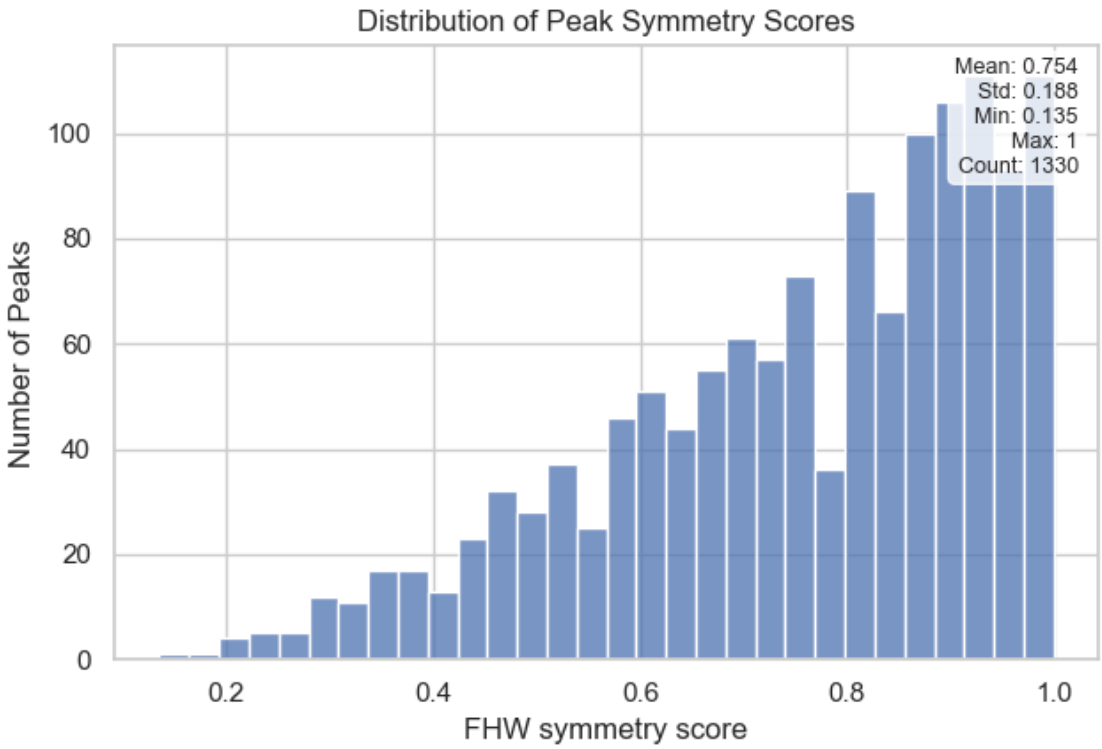
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:39:23] [INFO] calcium: plot_histogram: removed 23 outliers out of
1330 on 'Duration (s)' (lower=-55, upper=127)
```

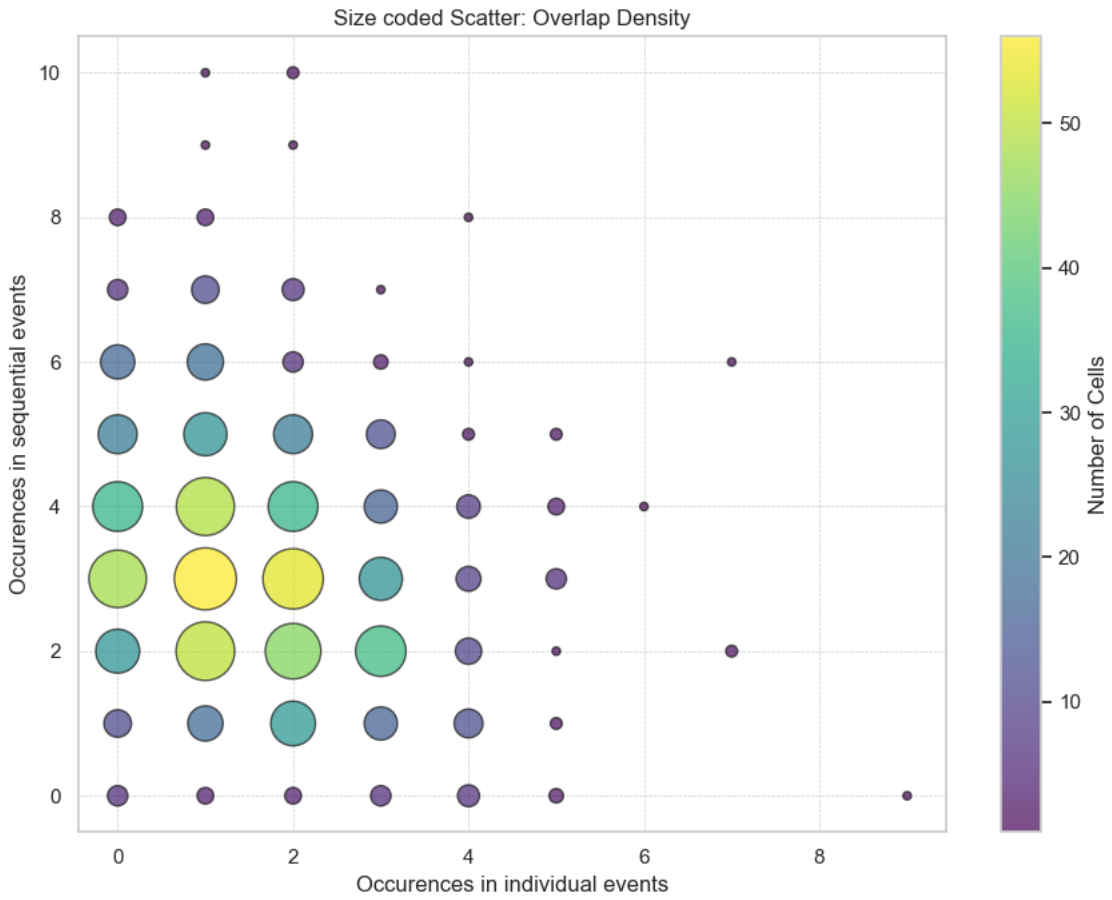



```
[2025-08-11 09:39:23] [INFO] calcium: plot_histogram: removed 55 outliers out of
1330 on 'Prominence (noise std units)' (lower=-34.525, upper=87.8)
```

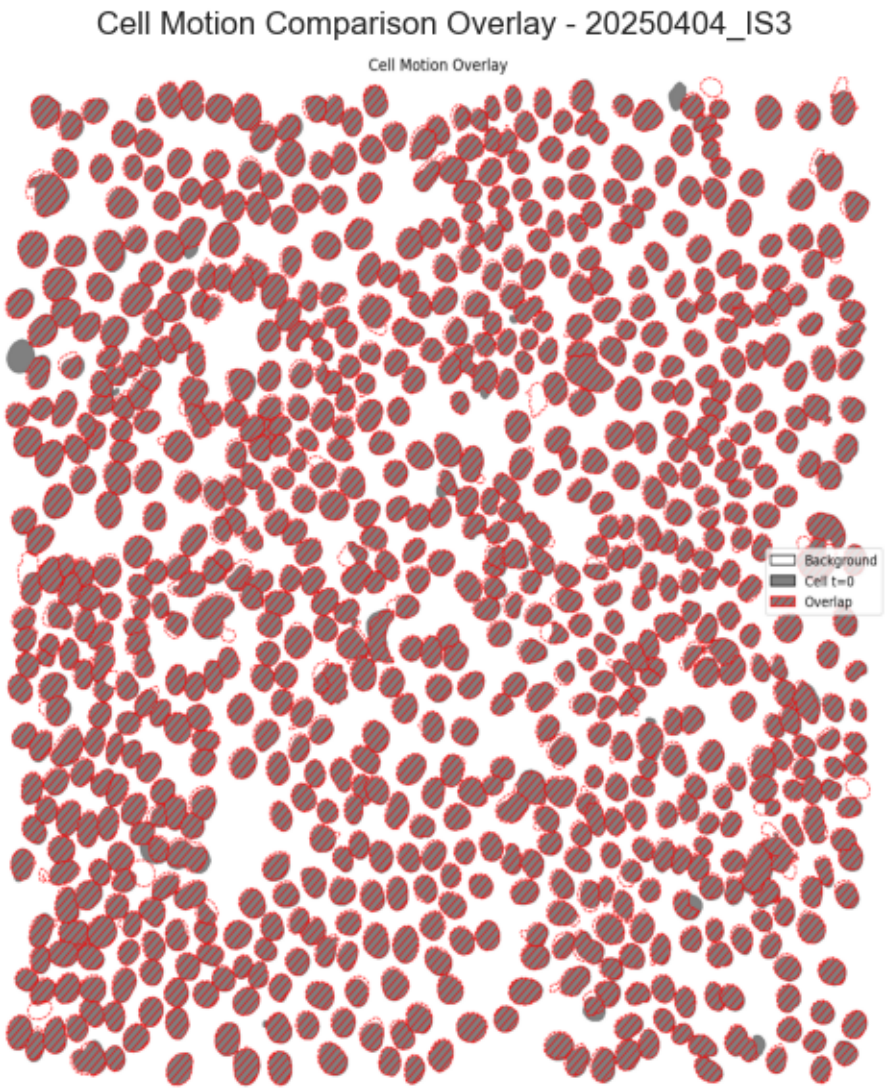

Distribution of Peak Prominences
Mean: 28.1
Std: 14.4
Min: 15
Max: 87.6
Count: 1275
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores
Mean: 0.754
Std: 0.188
Min: 0.135
Max: 1
Count: 1330
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 814
- Hoechst image taken at t=1801: 812
- Number of cells difference: absolute 2, relative 0.25%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1056876
- Pixels segmented as cell at t=1801: 1081782
- Overlapping pixels between t=0 and t=1801: 988607(92.45% of total)
- Pixels exclusive to t=0: 68269 (6.46% of total)
- Pixels exclusive to t=1801: 93175 (8.61% of total)
```

executed

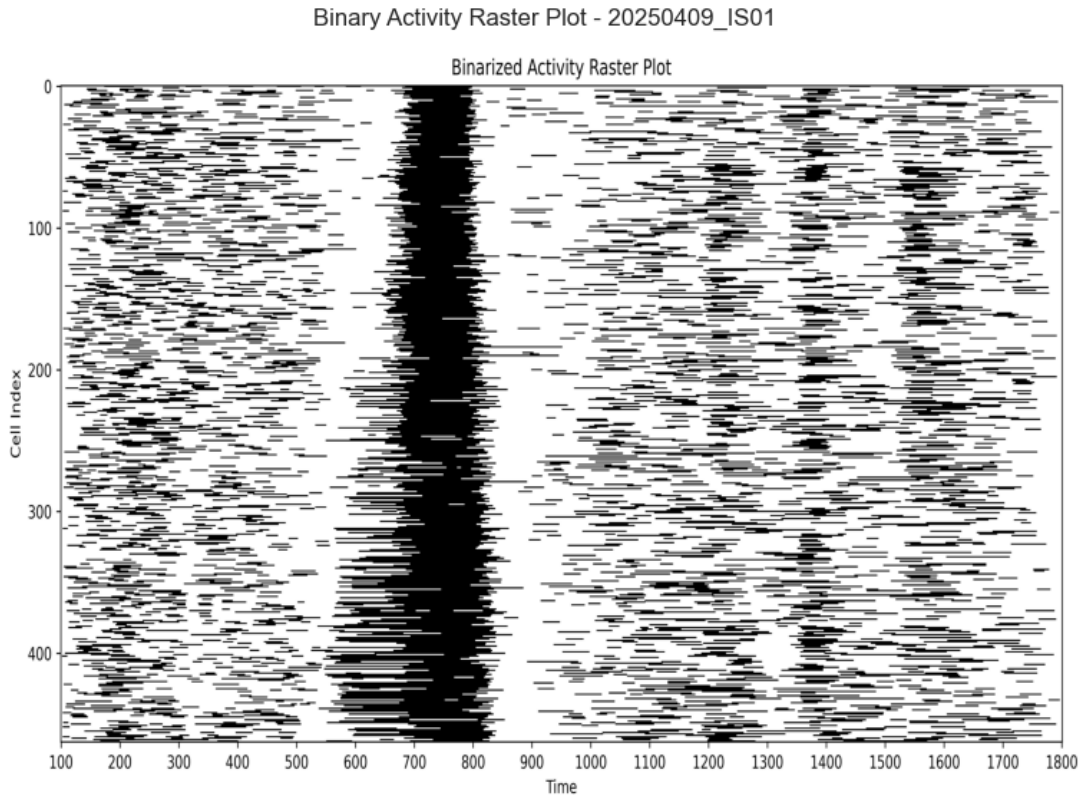
August 11, 2025

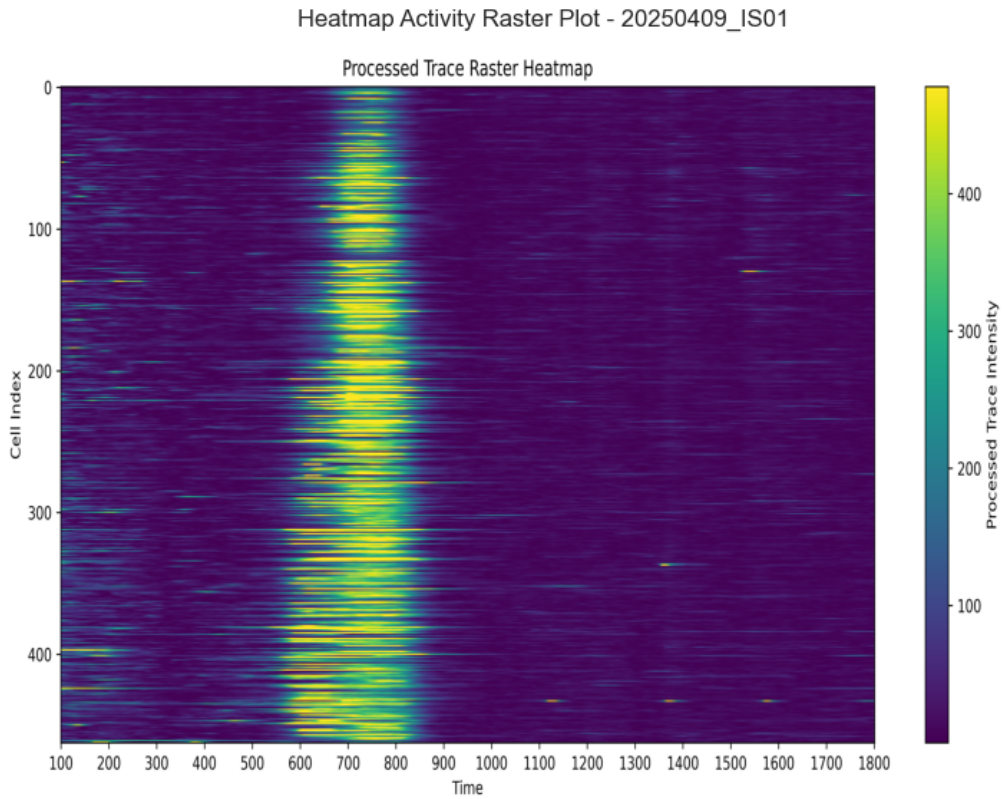
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



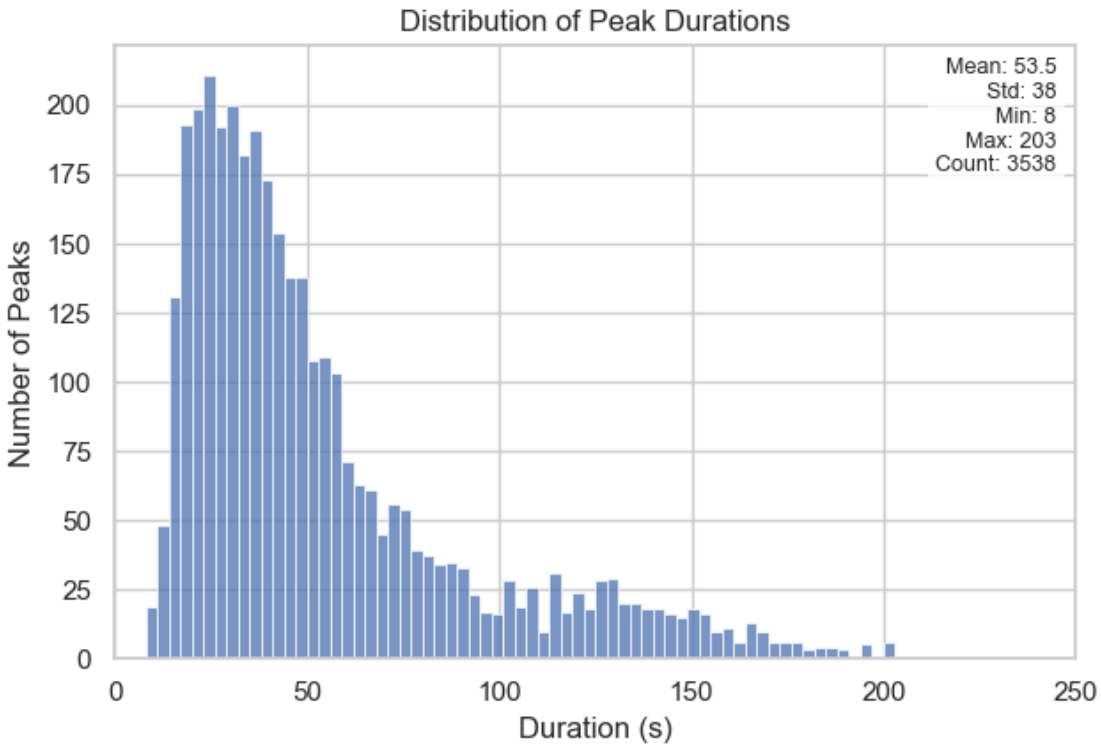


1.1.2 Peaks population

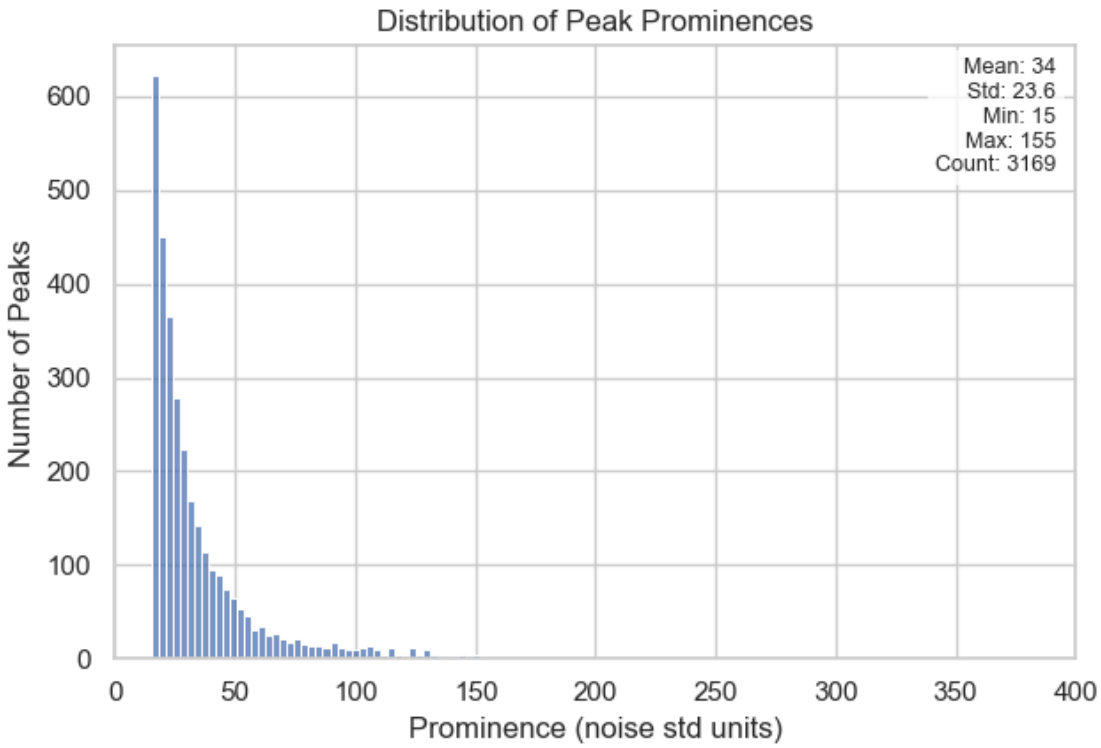
```
Total number of peaks: 3649
Total number of cells: 463
```

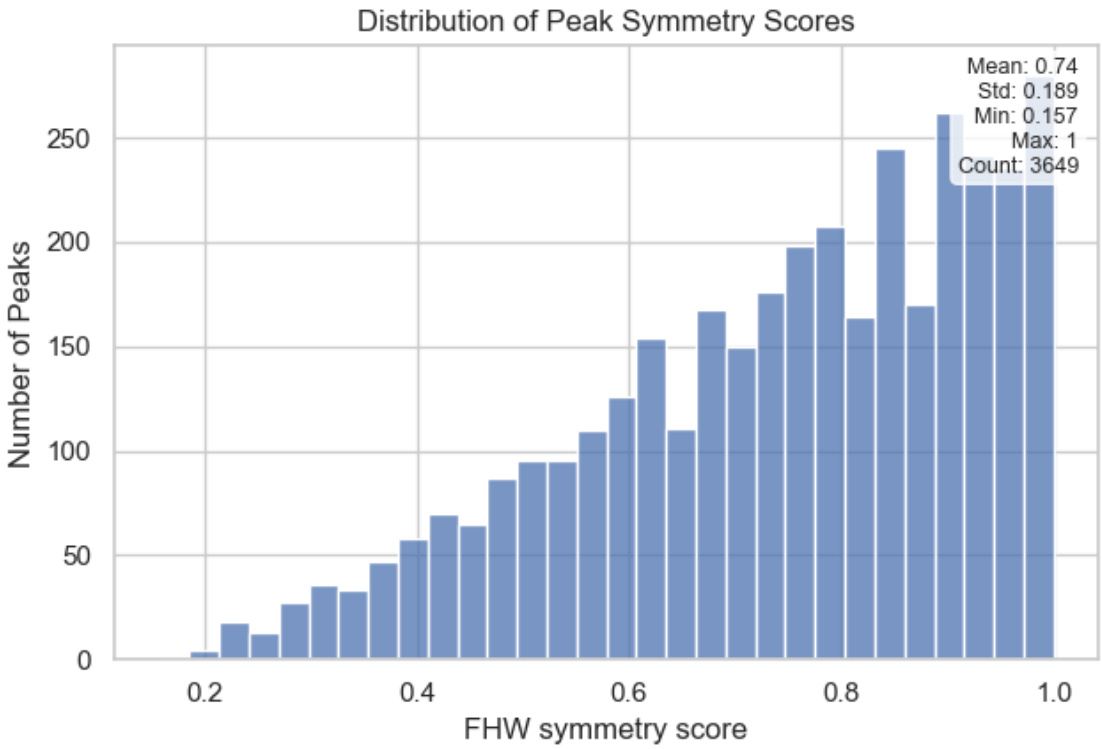
1.1.3 Peaks statistics

```
[2025-08-11 09:41:20] [INFO] calcium: plot_histogram: removed 111 outliers out
of 3649 on 'Duration (s)' (lower=-105, upper=203)
```

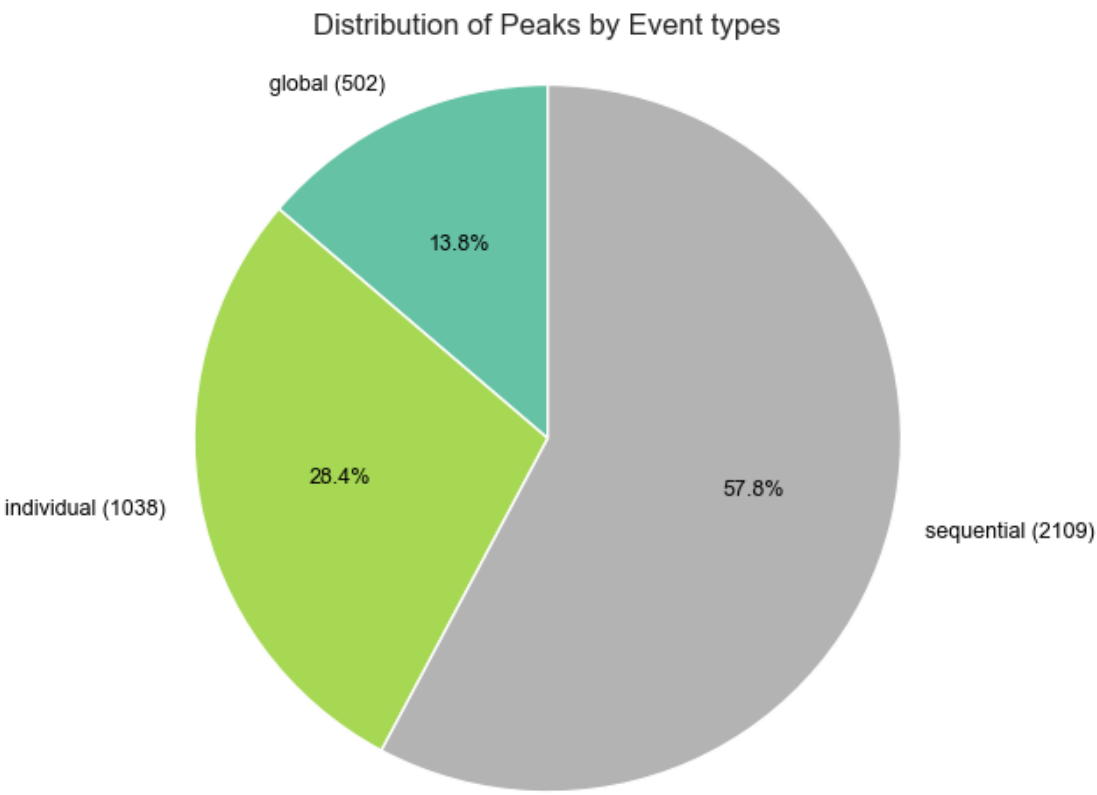



```
[2025-08-11 09:41:20] [INFO] calcium: plot_histogram: removed 480 outliers out
of 3649 on 'Prominence (noise std units)' (lower=-81.6, upper=155)
```


Distribution of Peak Prominences
Mean: 34
Std: 23.6
Min: 15
Max: 155
Count: 3169
Number of Peaks
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

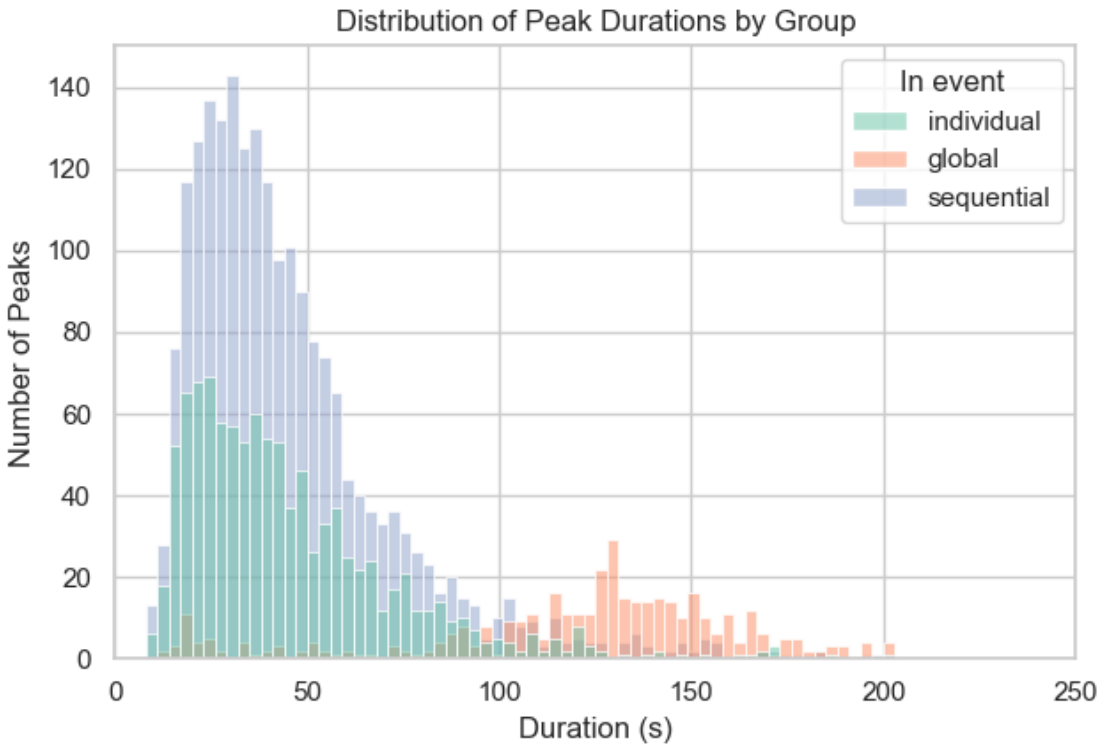

Distribution of Peak Symmetry Scores
Mean: 0.74
Std: 0.189
Min: 0.157
Max: 1
Count: 3649
Number of Peaks
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

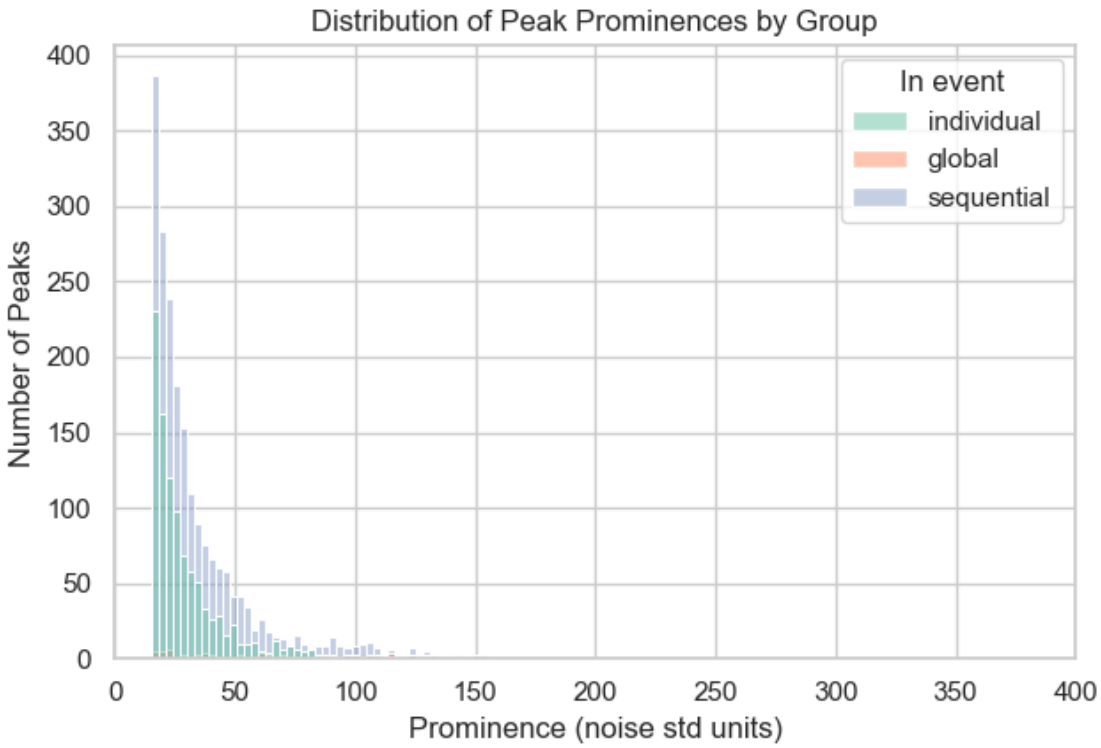


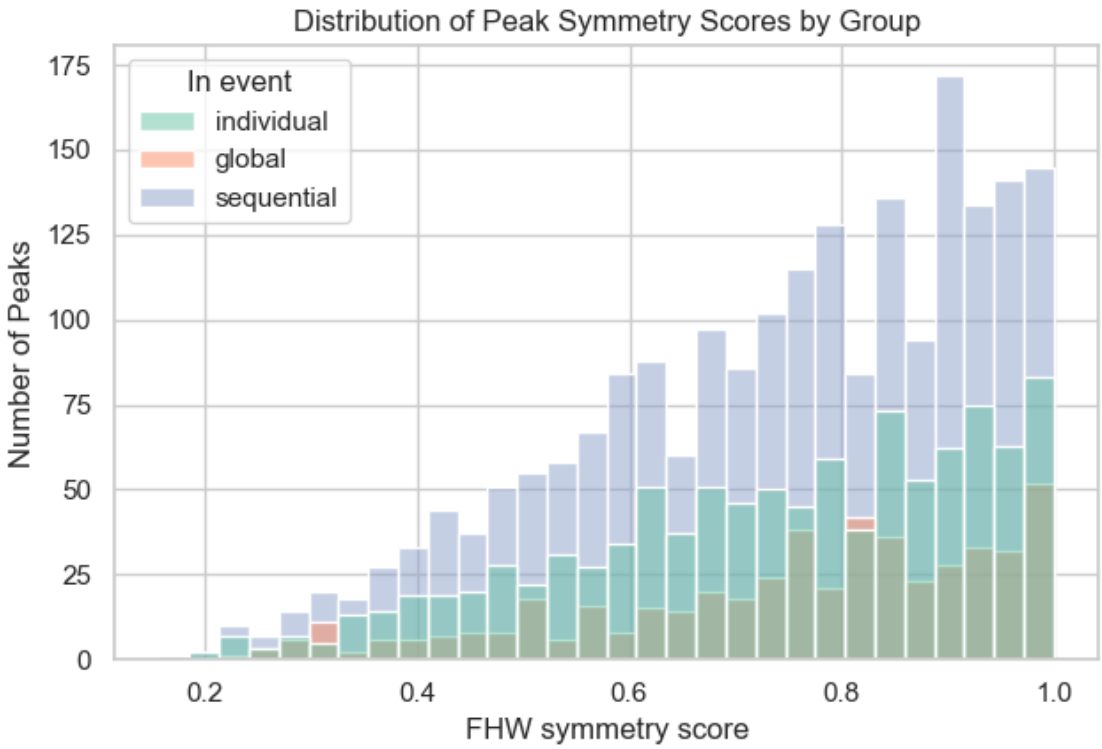
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:41:20] [INFO] calcium: plot_histogram_by_group: removed 111
outliers out of 3649 on 'Duration (s)' (lower=-105, upper=203)
```




```
[2025-08-11 09:41:20] [INFO] calcium: plot_histogram_by_group: removed 480
outliers out of 3649 on 'Prominence (noise std units)' (lower=-81.6, upper=155)
```

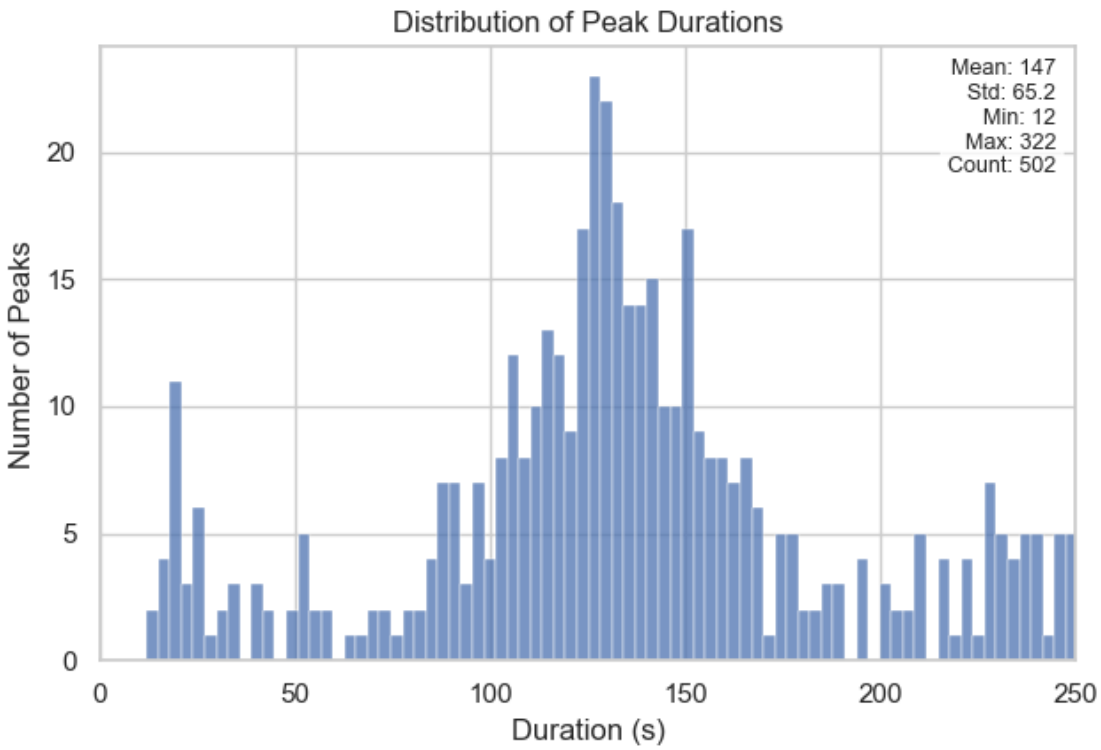

Distribution of Peak Prominences by Group
In event
individual
global
sequential
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores by Group
In event
individual
global
sequential
Number of Peaks
FHW symmetry score
0
25
50
75
100
125
150
175
0.2
0.4
0.6
0.8
1.0

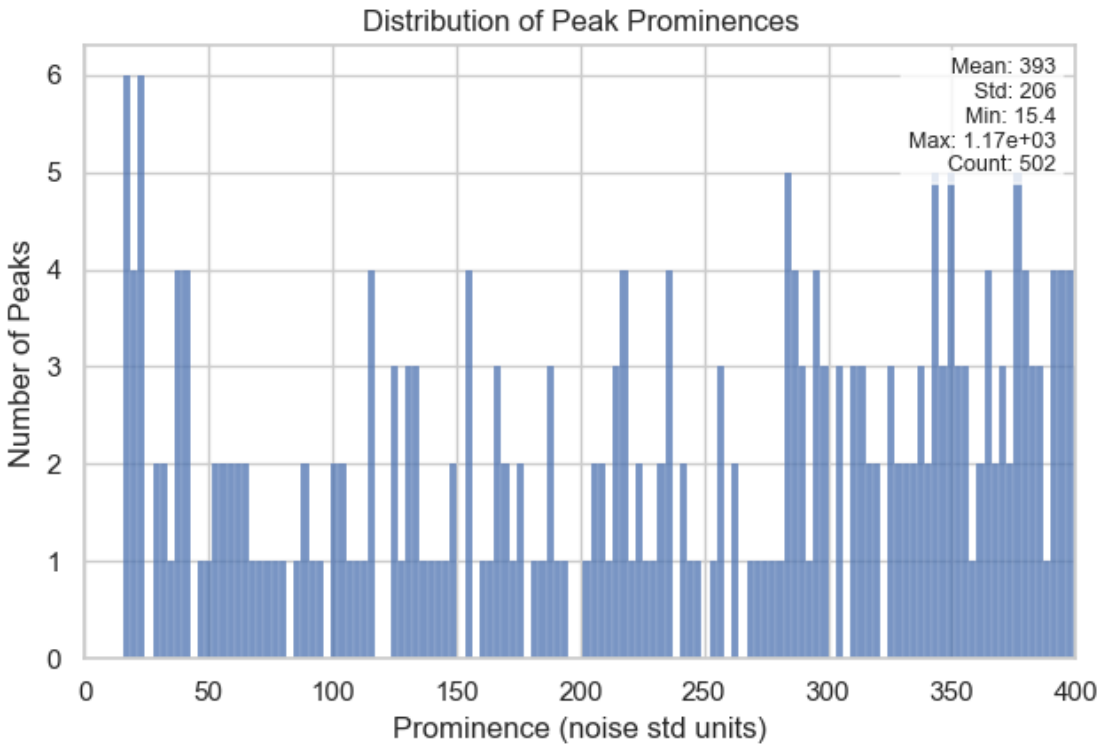
1.2 GLOBAL EVENTS

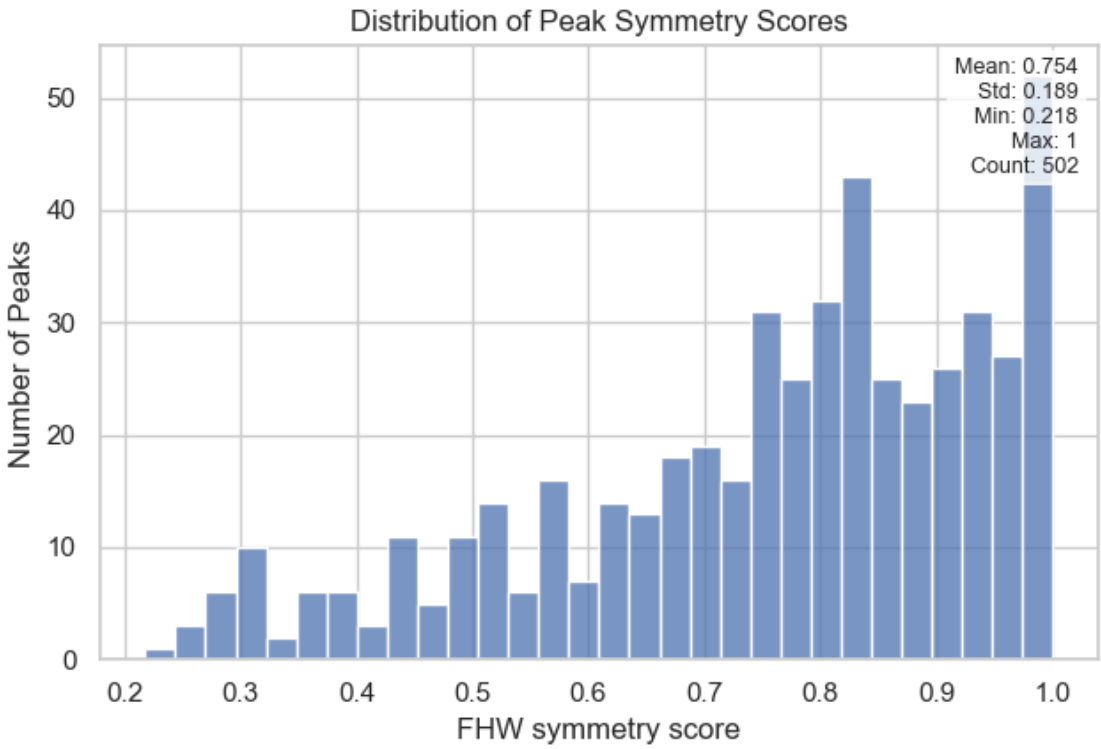
1.2.1 Peak statistics in global events

```
[2025-08-11 09:41:21] [INFO] calcium: plot_histogram: removed 0 outliers out of
502 on 'Duration (s)' (lower=-79, upper=369)
```



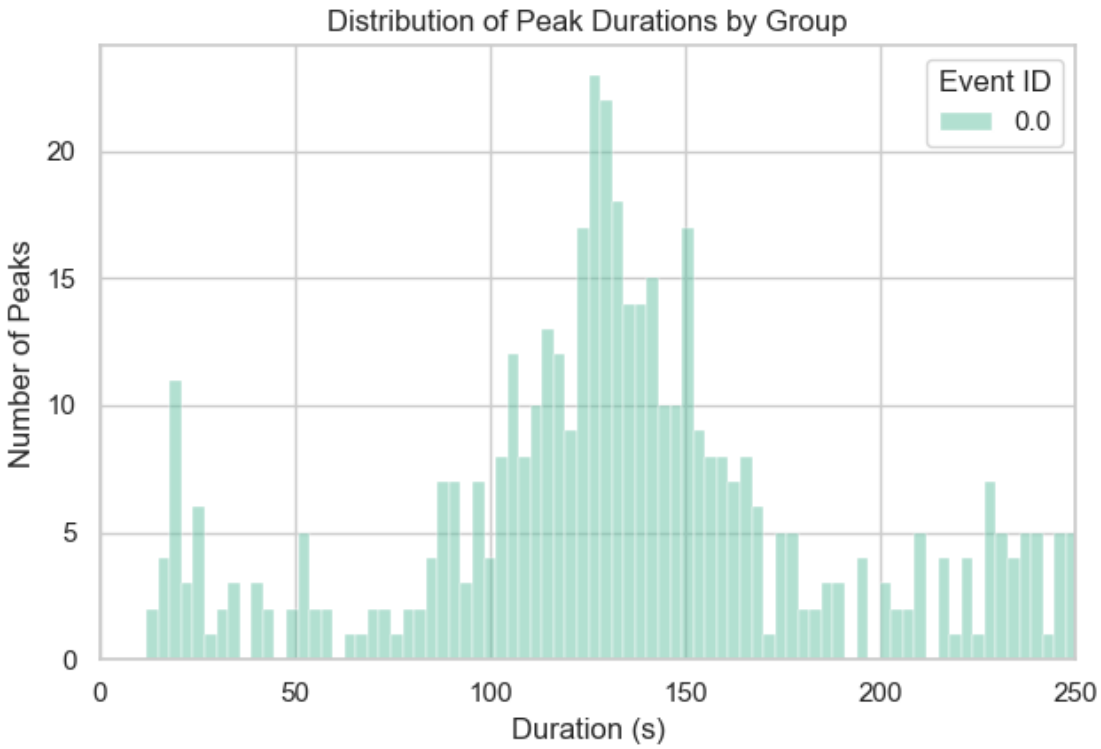

```
[2025-08-11 09:41:21] [INFO] calcium: plot_histogram: removed 0 outliers out of
502 on 'Prominence (noise std units)' (lower=-583.13, upper=1351)
```


Distribution of Peak Prominences
Mean: 393
Std: 206
Min: 15.4
Max: 1.17e+03
Count: 502
Number of Peaks
Prominence (noise std units)
0
1
2
3
4
5
6
0
50
100
150
200
250
300
350
400

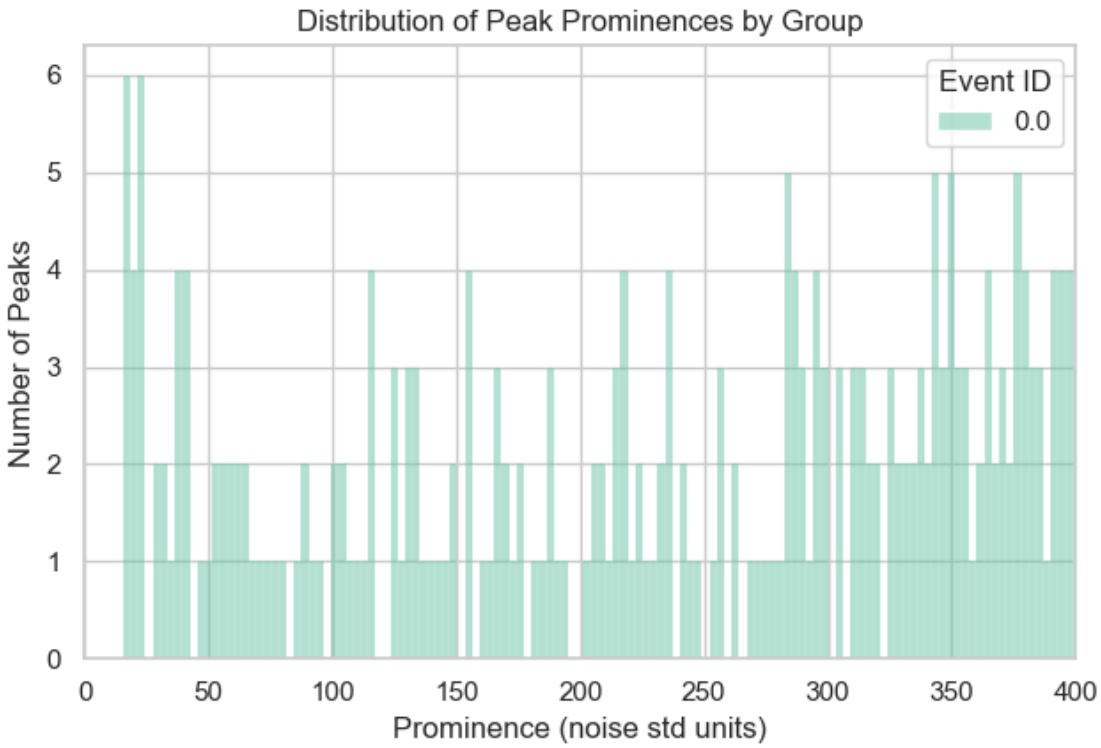

Distribution of Peak Symmetry Scores
Mean: 0.754
Std: 0.189
Min: 0.218
Max: 1
Count: 502
Number of Peaks
FHW symmetry score
0
10
20
30
40
50
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

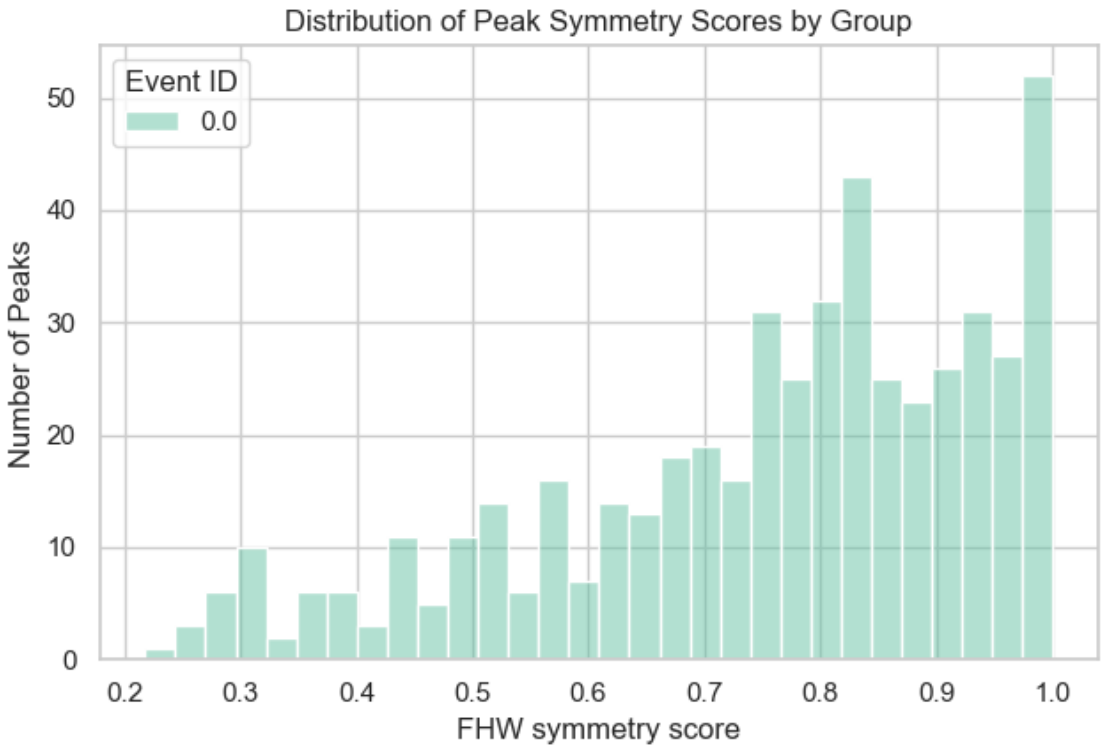
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:41:21] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 502 on 'Duration (s)' (lower=-79, upper=369)
```

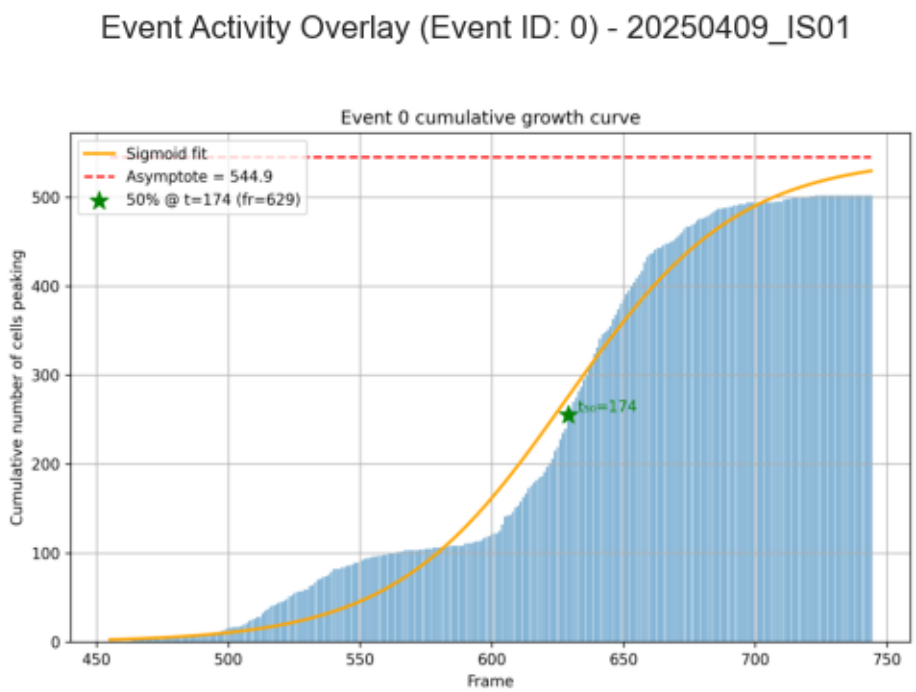



```
[2025-08-11 09:41:22] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 502 on 'Prominence (noise std units)' (lower=-583.13,
upper=1351)
```

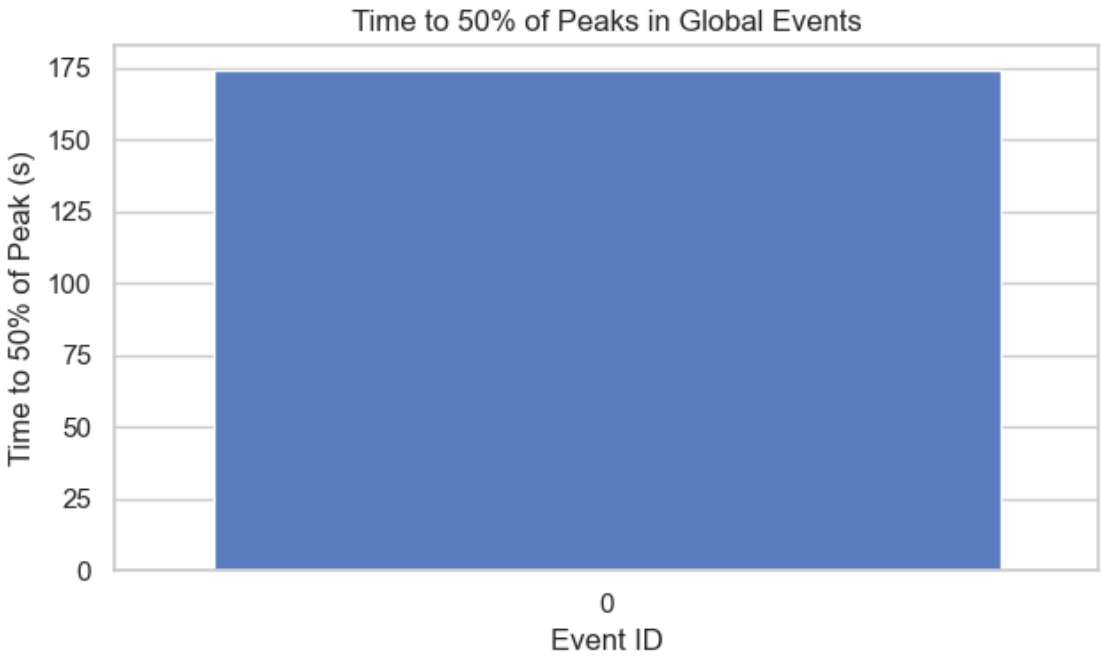

Distribution of Peak Prominences by Group
Event ID
0.0
Number of Peaks
0
1
2
3
4
5
6
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
Event ID
0.0
Number of Peaks
0
10
20
30
40
50
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

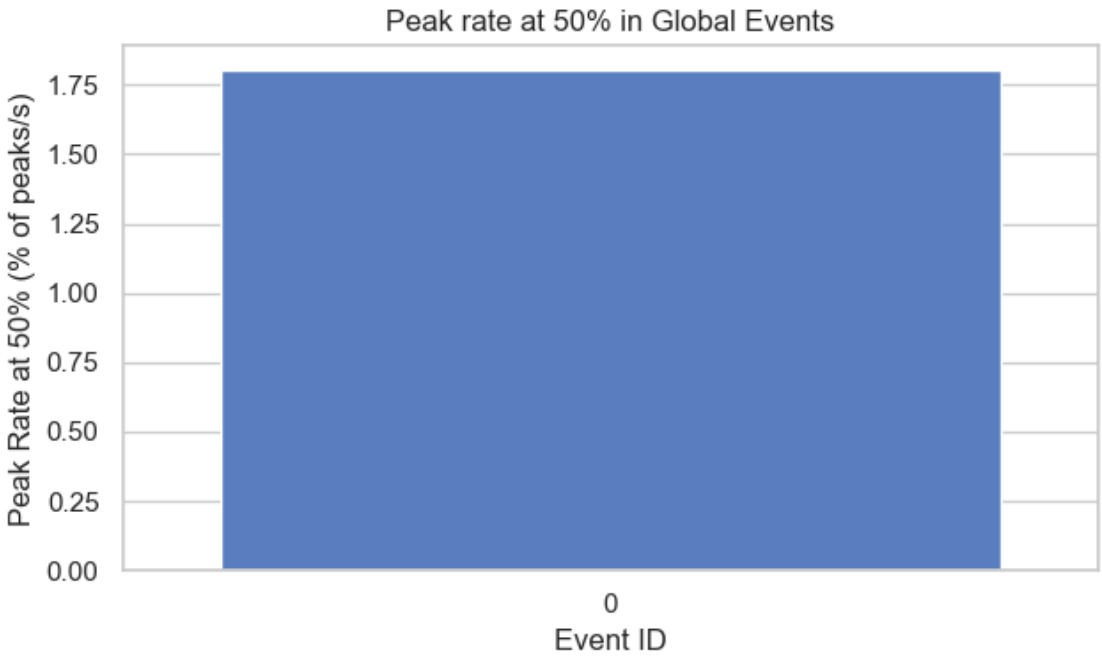
1.2.3 Kinetics of global events



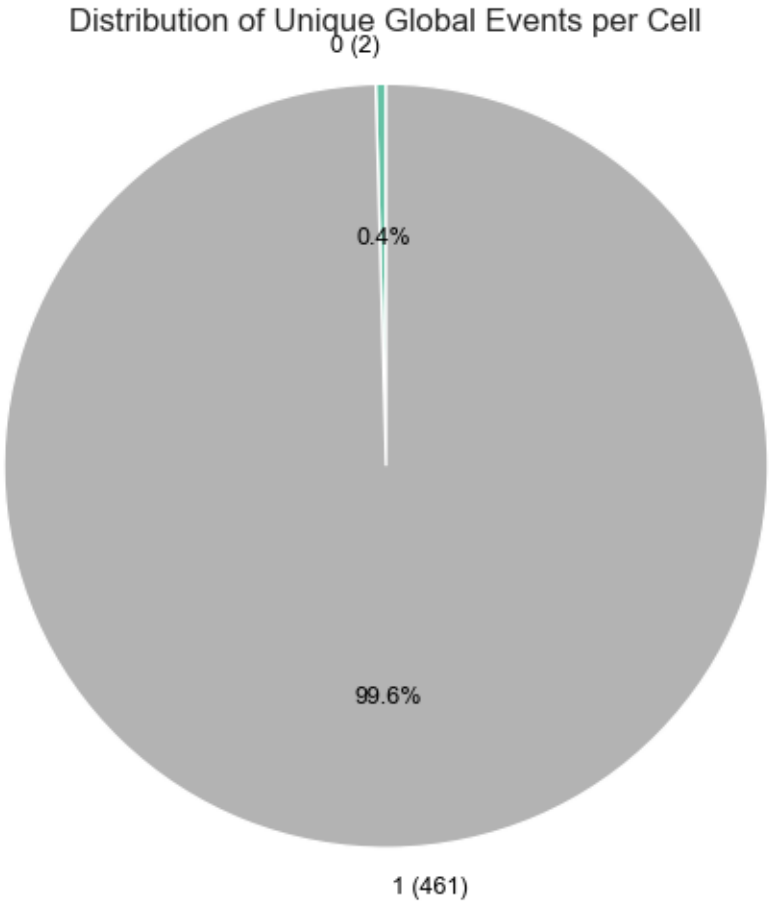

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



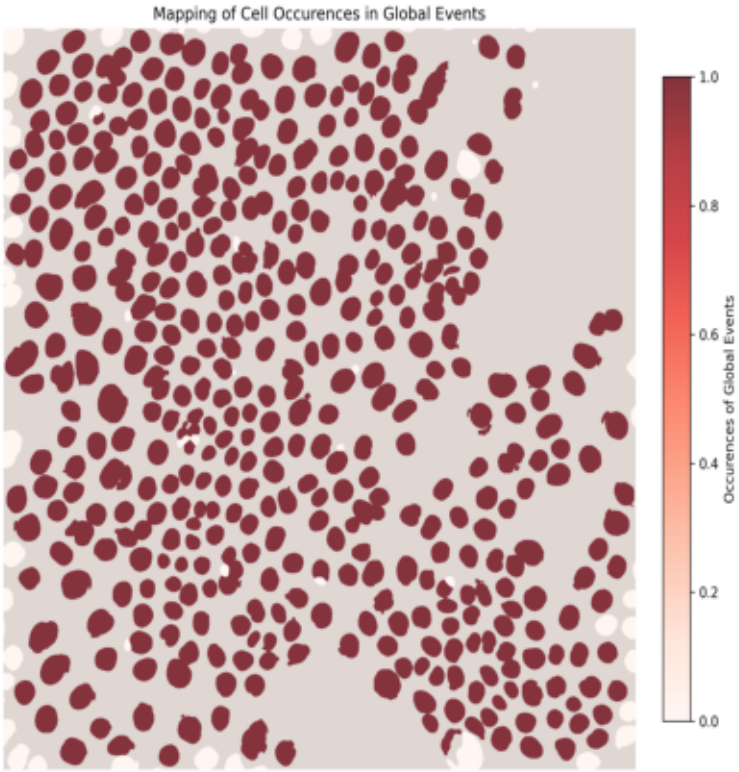

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
Event ID

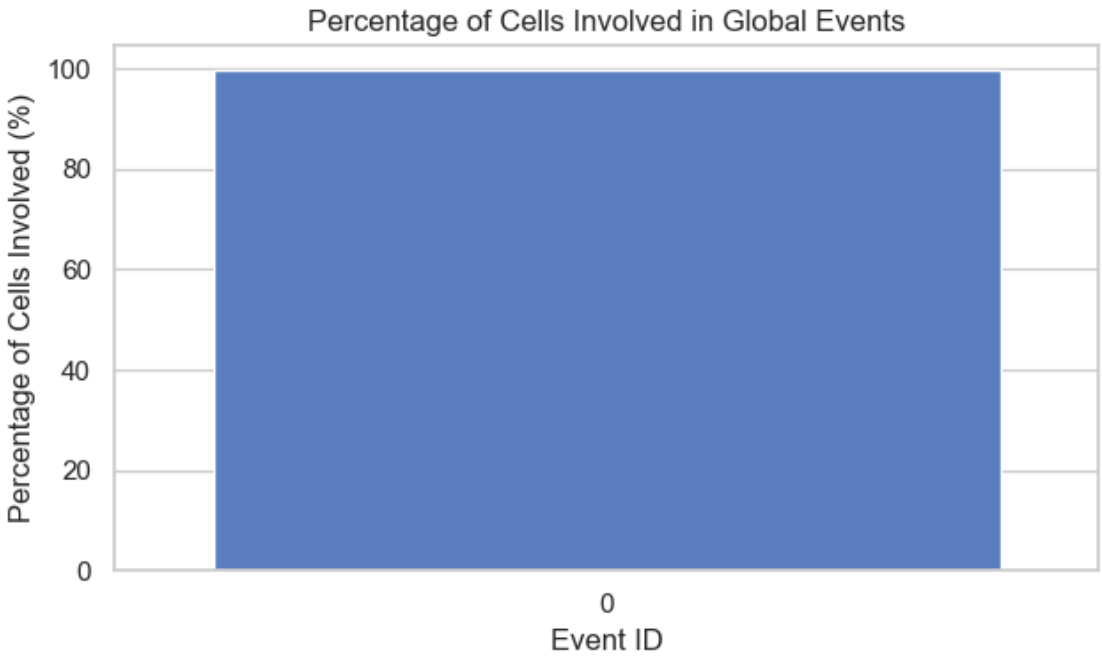
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS01




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

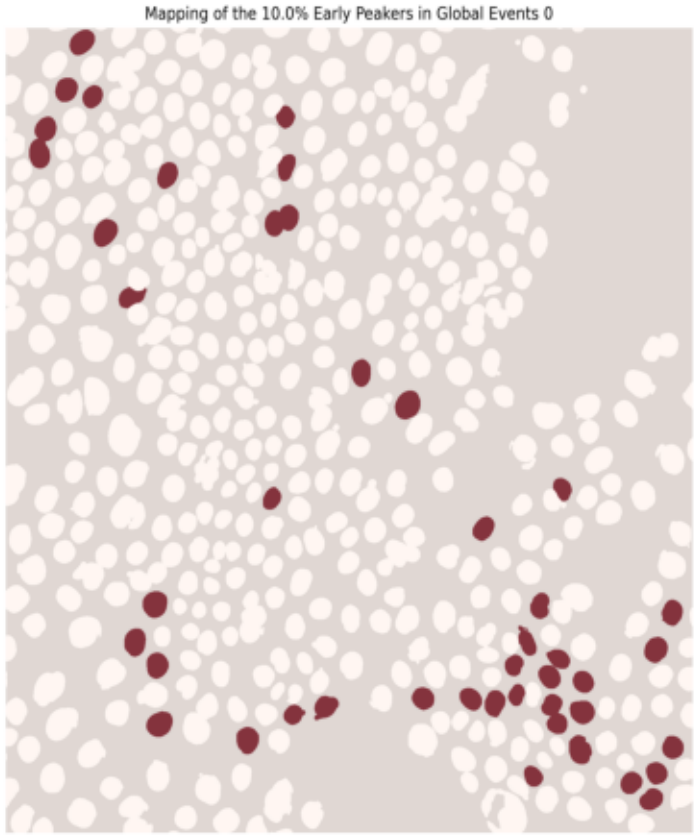


1.2.5 Inter-event interval analysis

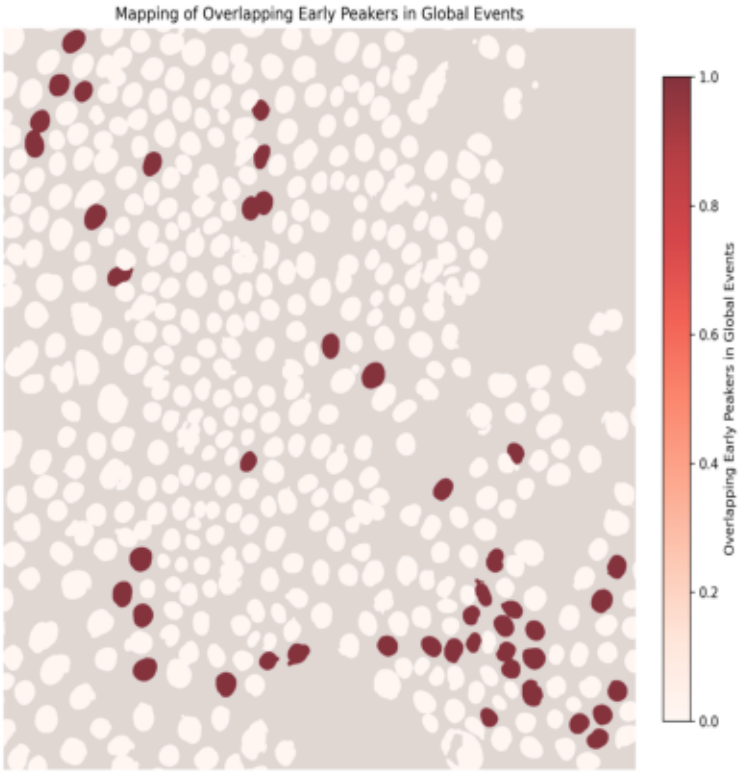
```
Intervals between global event peaks: []
```

1.2.6 Early peakers in the events

Cell Mapping with Early Peakers Overlay for event 0 - 20250409_IS01

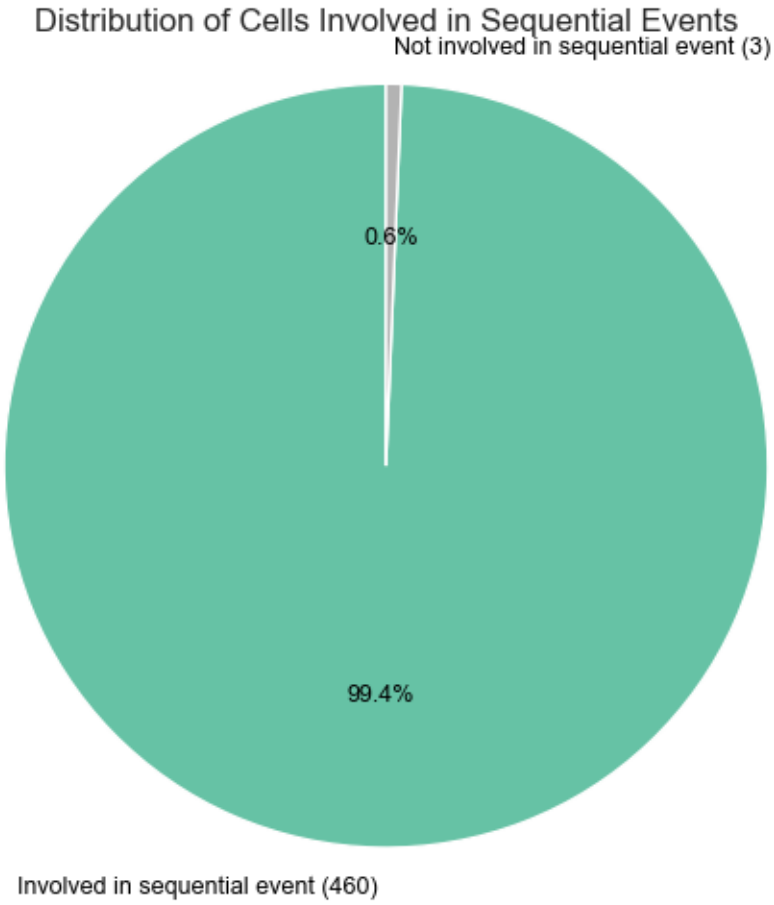


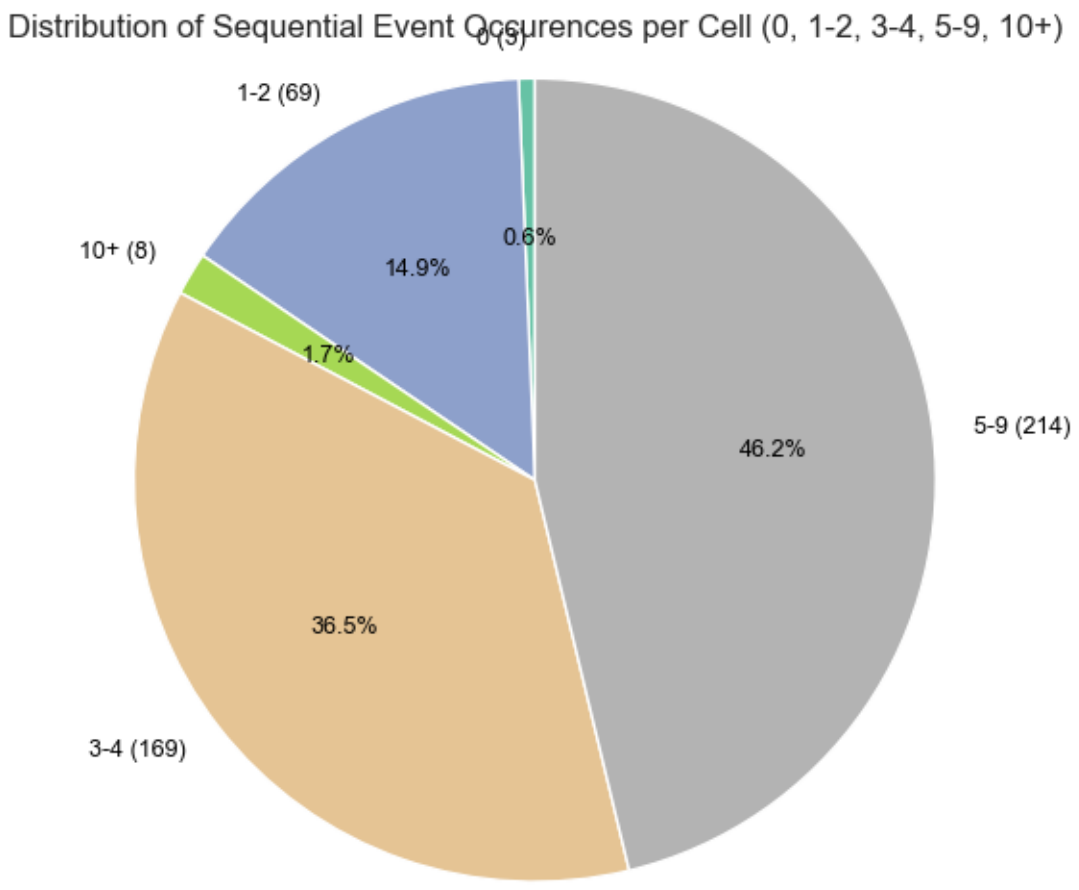
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS01



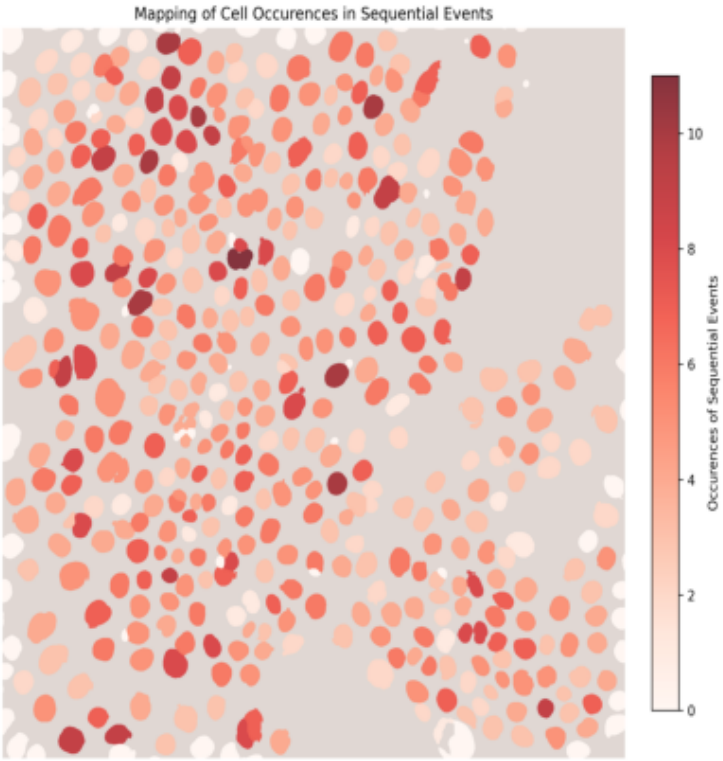
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

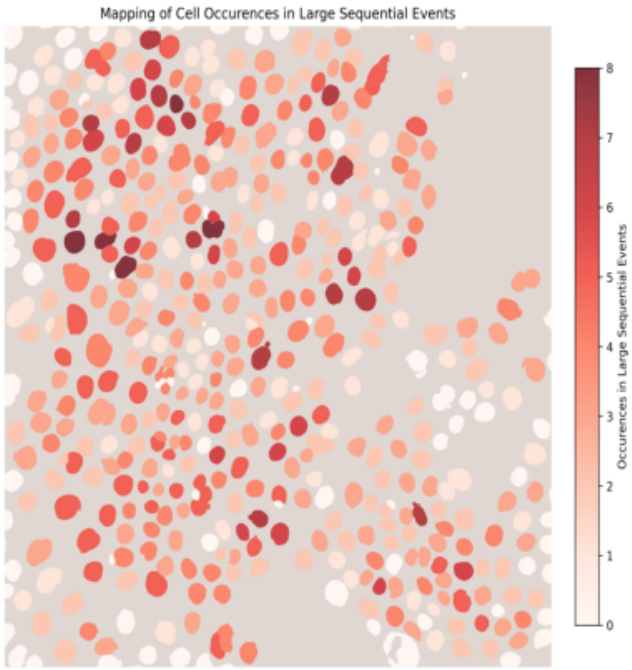



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (3)
1-2 (69)
10+ (8)
0.6%
14.9%
1.7%
46.2%
5-9 (214)
36.5%
3-4 (169)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS01

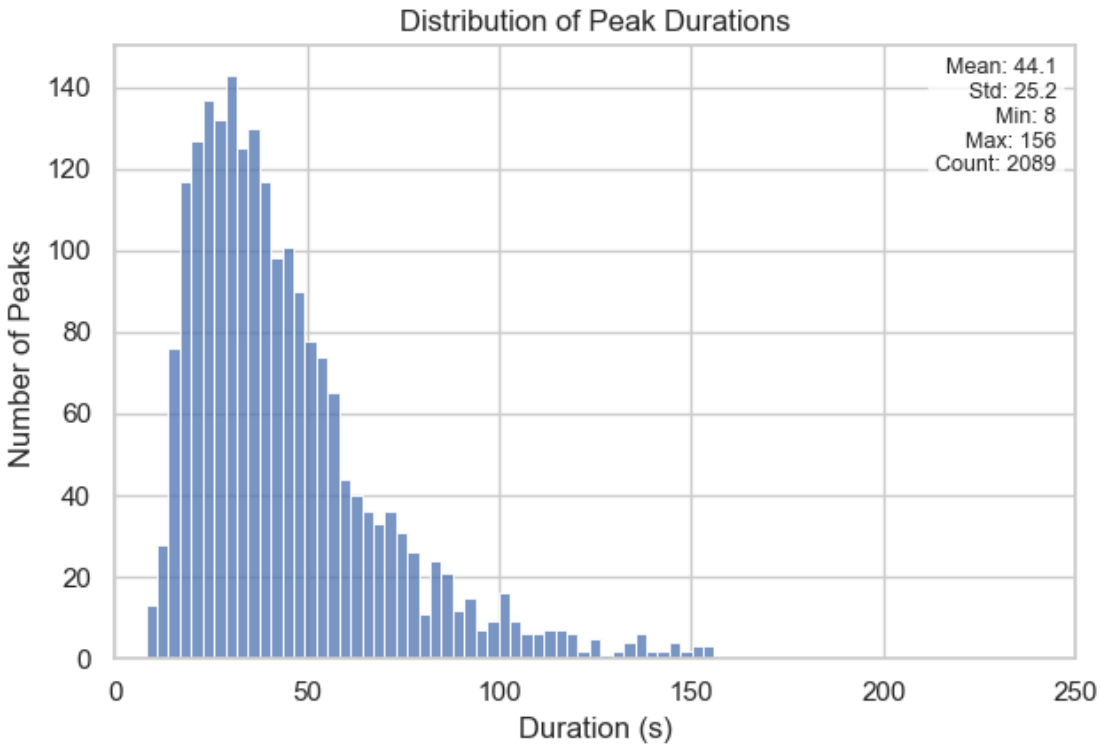


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS01

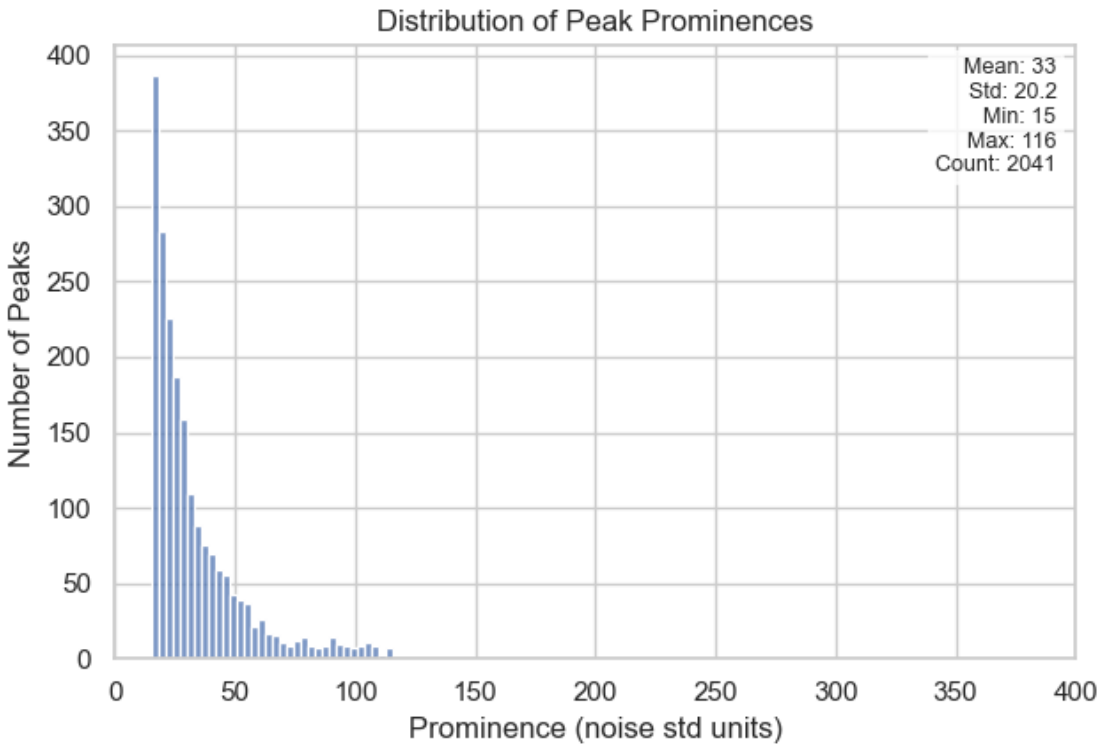


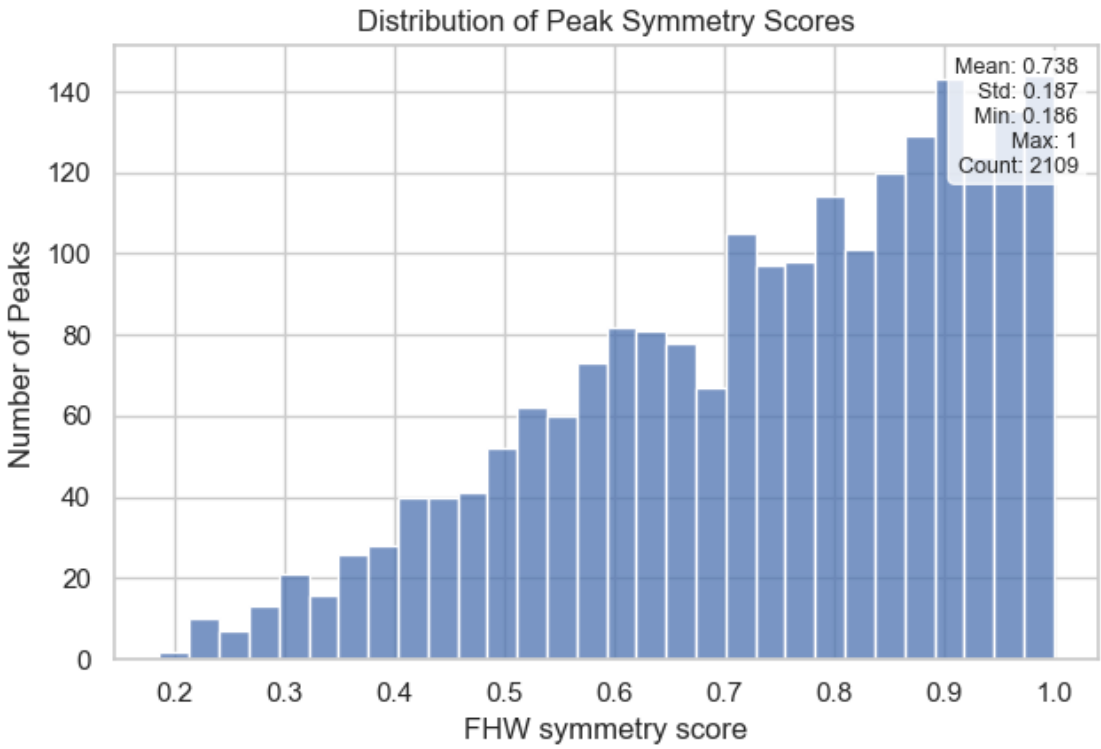
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:41:28] [INFO] calcium: plot_histogram: removed 20 outliers out of
2109 on 'Duration (s)' (lower=-17.5, upper=156.5)
```



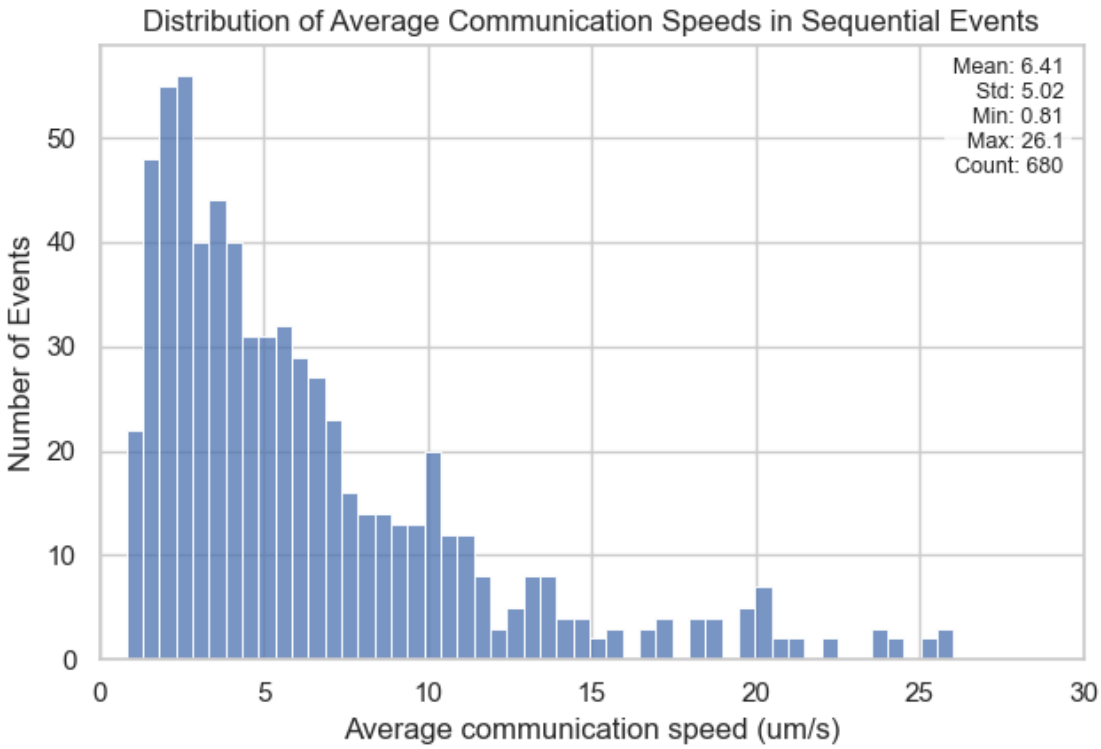

```
[2025-08-11 09:41:28] [INFO] calcium: plot_histogram: removed 68 outliers out of
2109 on 'Prominence (noise std units)' (lower=-13.75, upper=118.85)
```


Distribution of Peak Prominences
Mean: 33
Std: 20.2
Min: 15
Max: 116
Count: 2041
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400

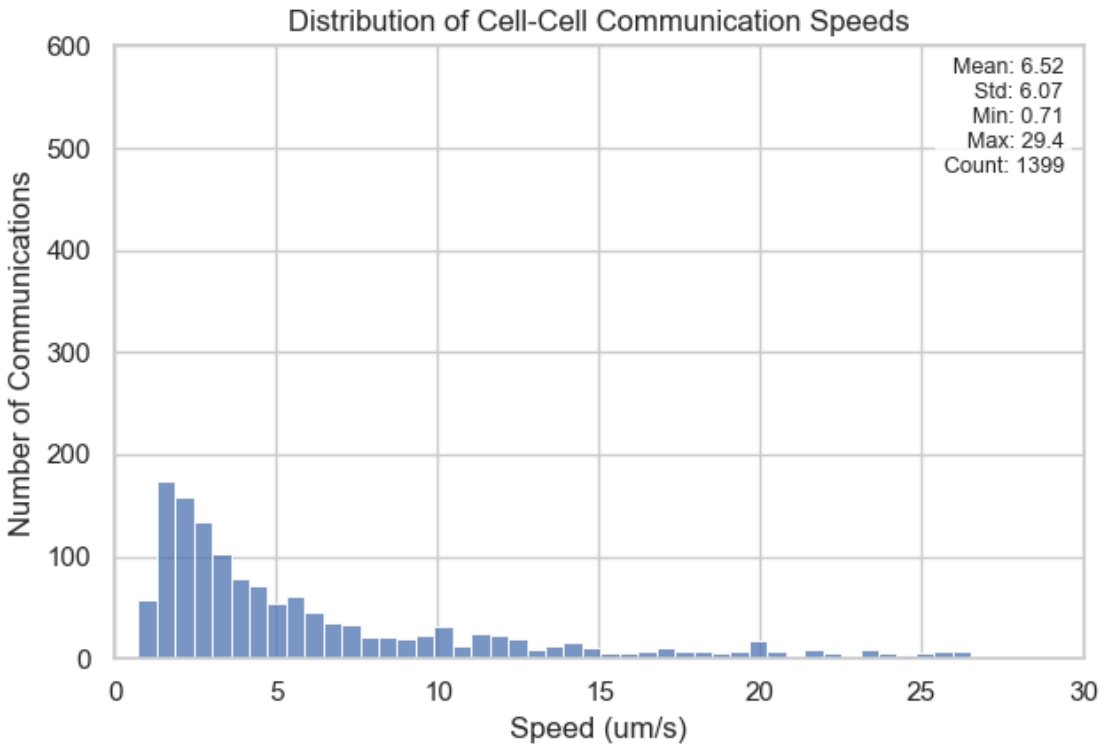

Distribution of Peak Symmetry Scores
Mean: 0.738
Std: 0.187
Min: 0.186
Max: 1
Count: 2109
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
120
140
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:41:28] [INFO] calcium: plot_histogram: removed 8 outliers out of
688 on 'Average communication speed (um/s)' (lower=-14.94, upper=26.43)
```

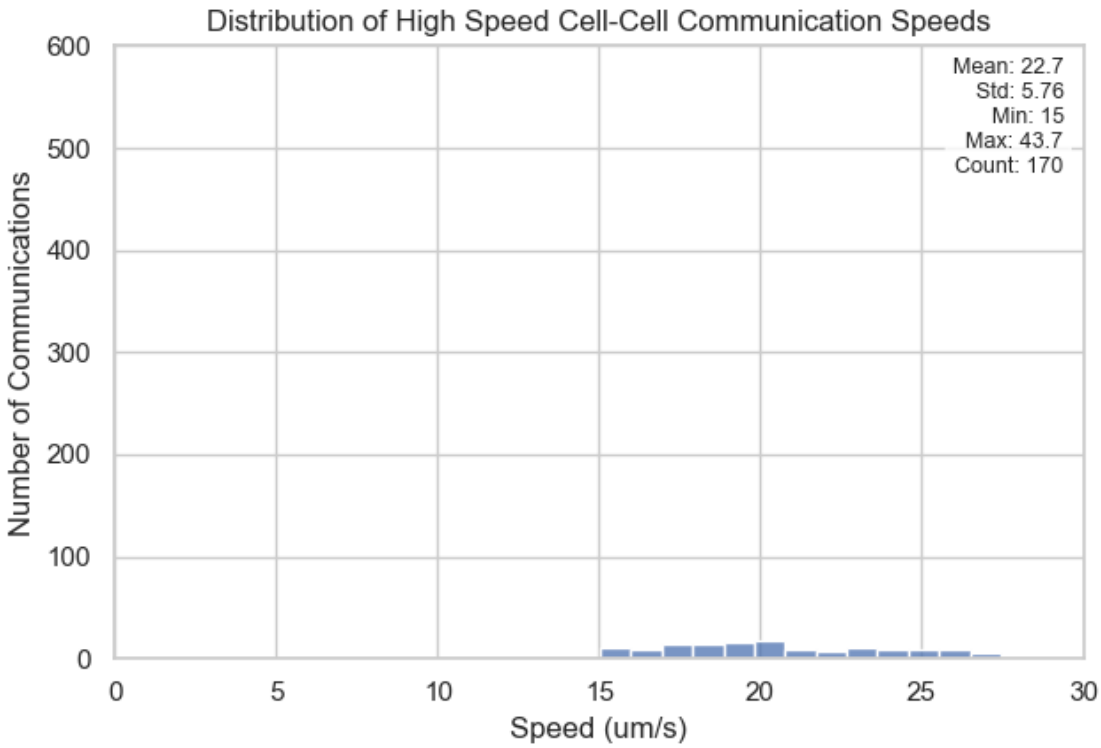



```
[2025-08-11 09:41:29] [INFO] calcium: plot_histogram: removed 22 outliers out of
1421 on 'Speed (um/s)' (lower=-18.19, upper=29.62)
```

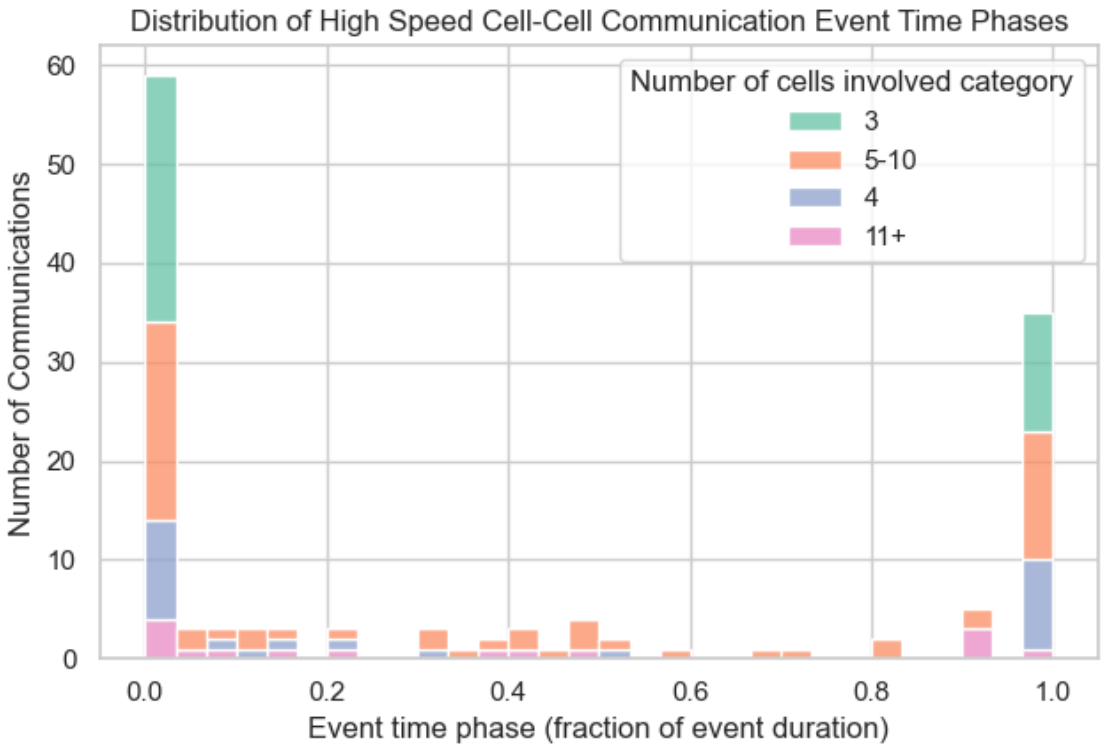


1.3.4 Double distribution in cell-cell communication speeds

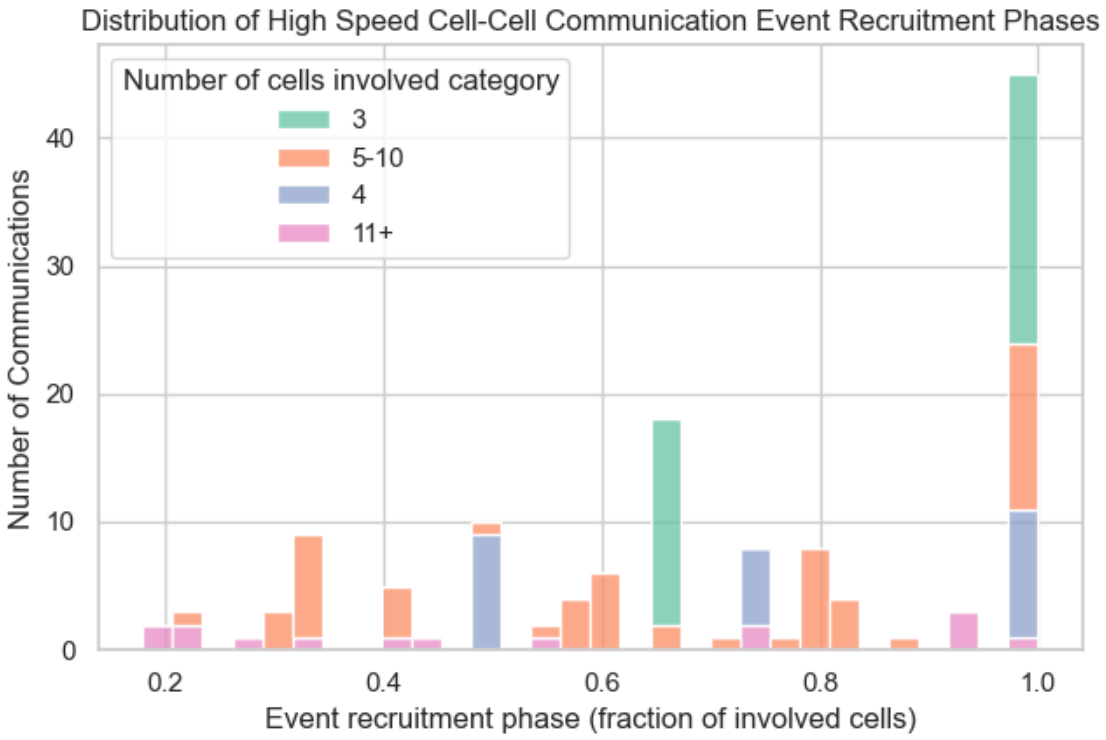
```
[2025-08-11 09:41:29] [INFO] calcium: plot_histogram: removed 0 outliers out of
170 on 'Speed (um/s)' (lower=-2.415, upper=46.34)
```



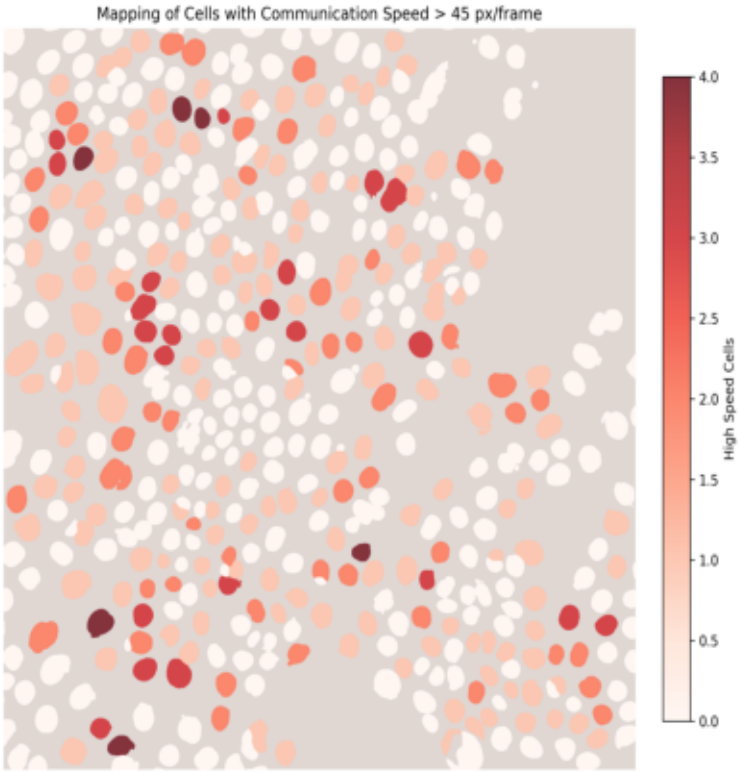

```
[2025-08-11 09:41:29] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 135 on 'Event time phase (fraction of event duration)'
(lower=-3, upper=4)
```



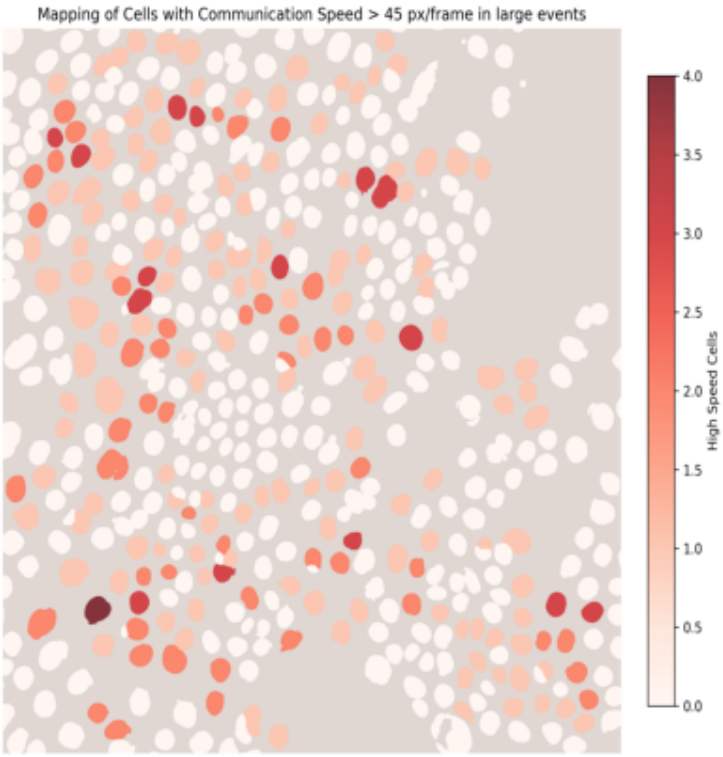

```
[2025-08-11 09:41:29] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 135 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.9, upper=2.425)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
3
5-10
4
11+
Number of Communications
0
10
20
30
40
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

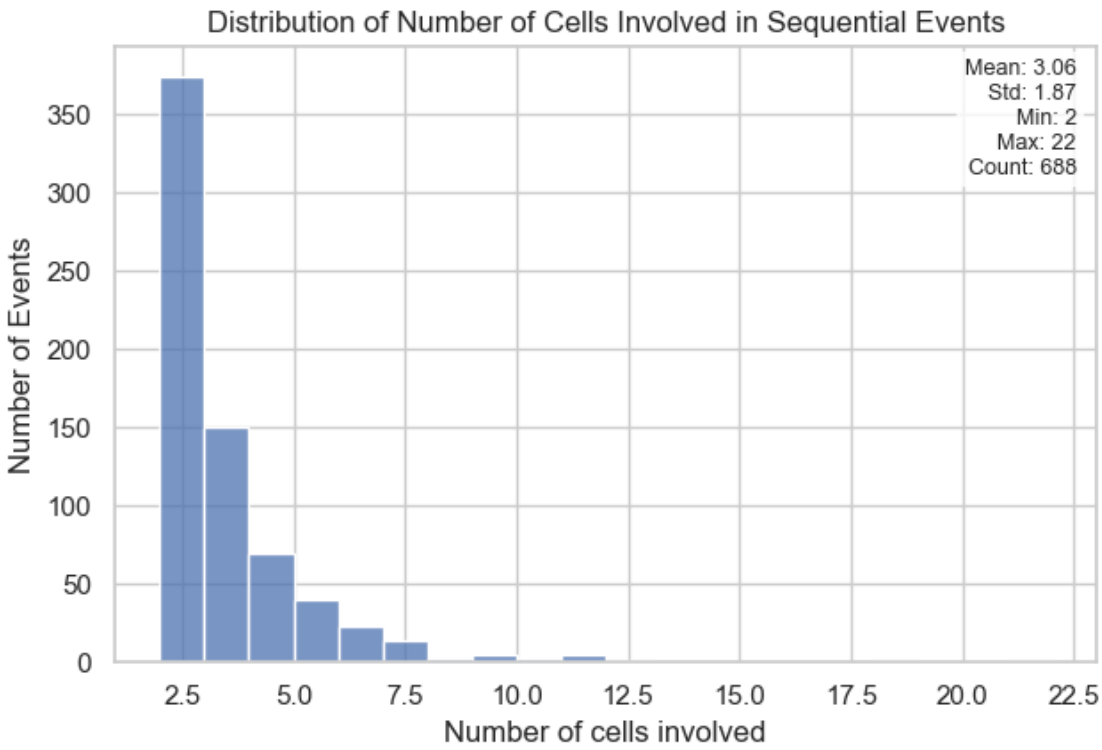
Cell Mapping with High Speed Cells Overlay - 20250409_IS01



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS01

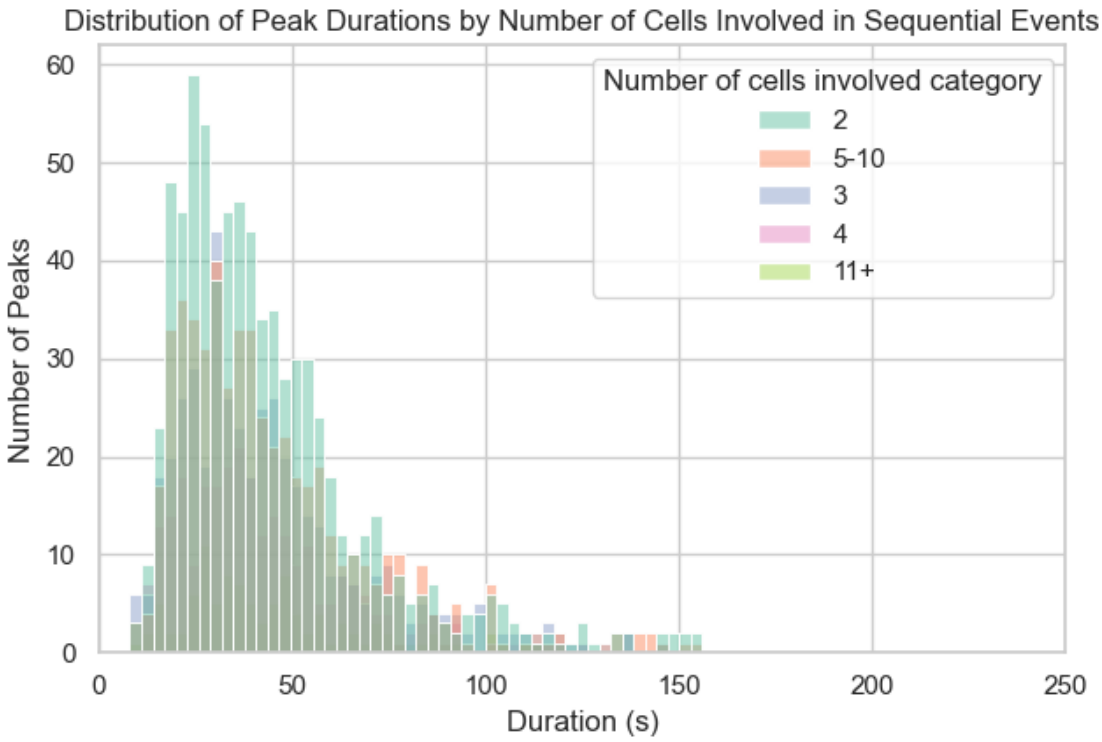


1.3.5 Number of cells involved per sequential events

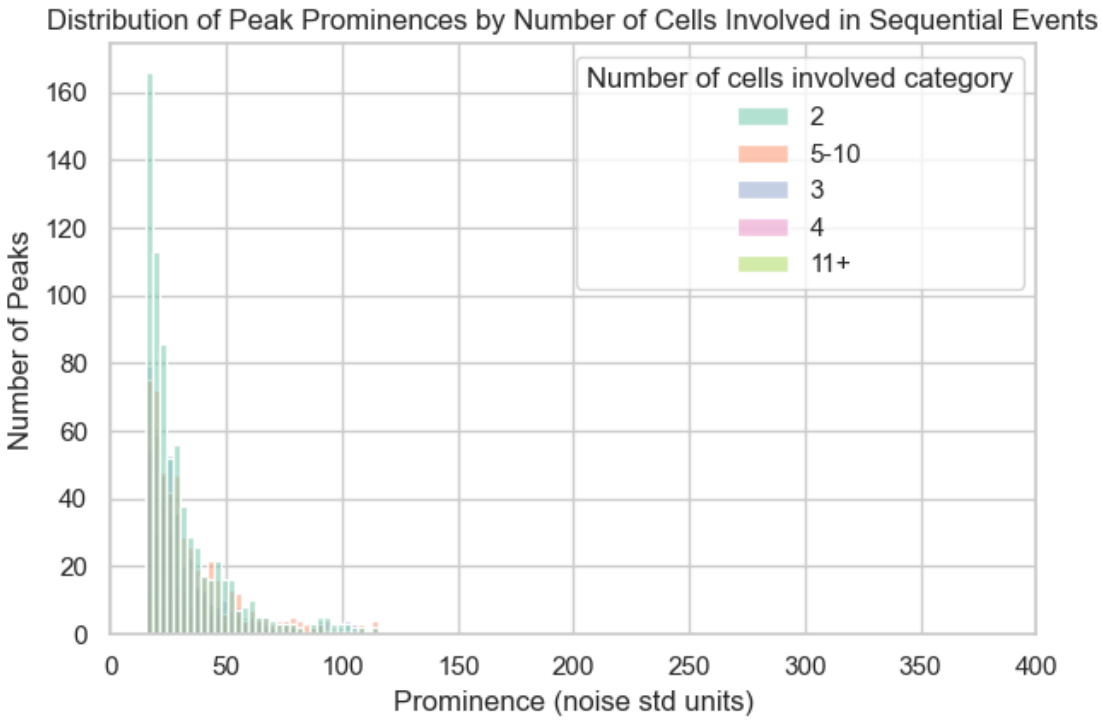


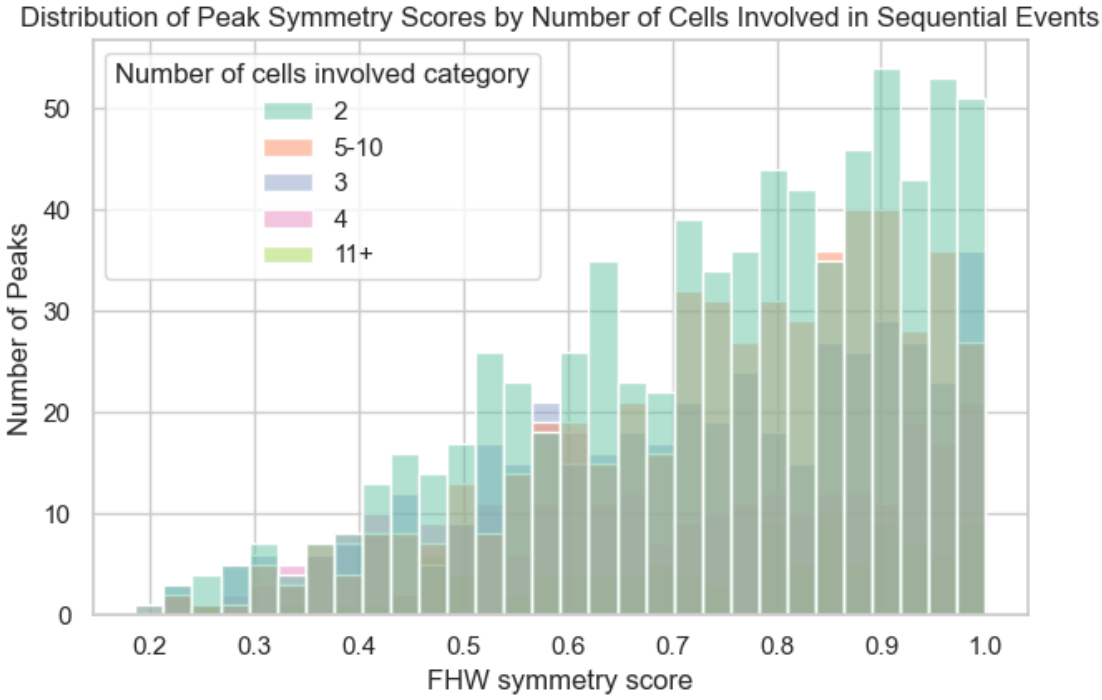
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:41:31] [INFO] calcium: plot_histogram_by_group: removed 20
outliers out of 2109 on 'Duration (s)' (lower=-17.5, upper=156.5)
```



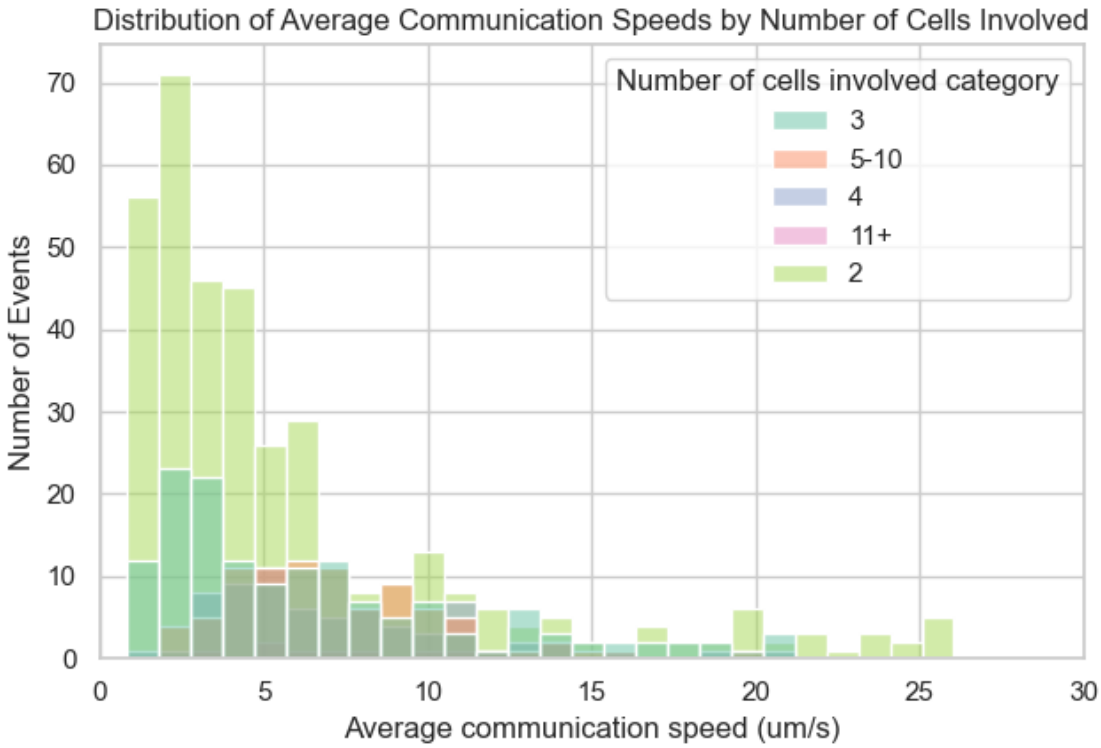

```
[2025-08-11 09:41:32] [INFO] calcium: plot_histogram_by_group: removed 68
outliers out of 2109 on 'Prominence (noise std units)' (lower=-13.75,
upper=118.85)
```



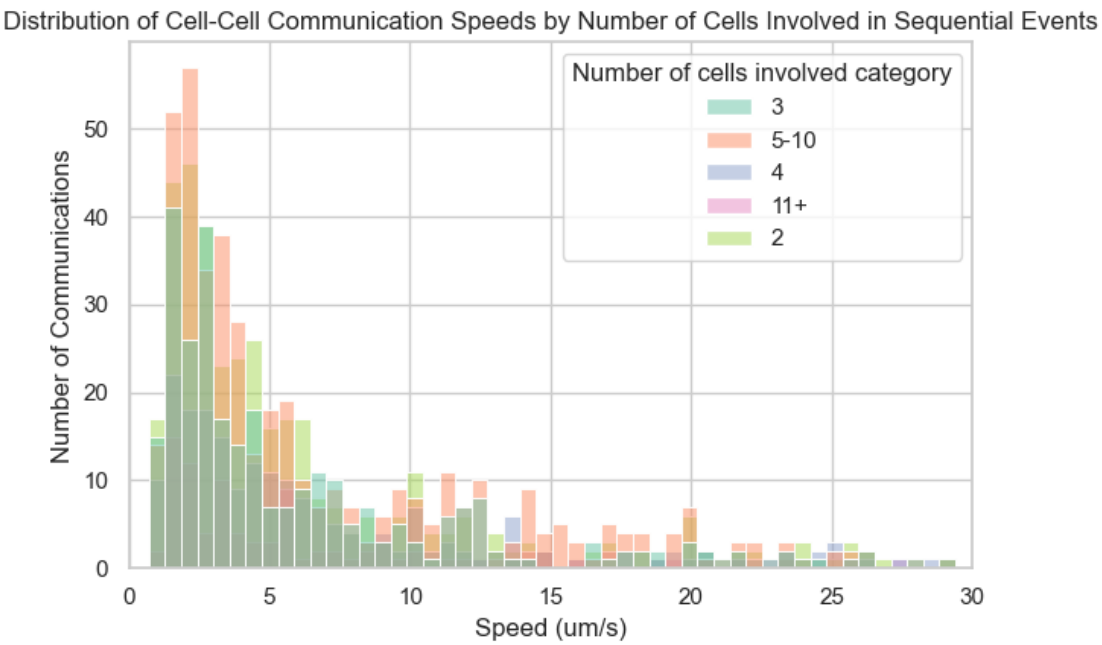



```
[2025-08-11 09:41:32] [INFO] calcium: plot_histogram_by_group: removed 8
```

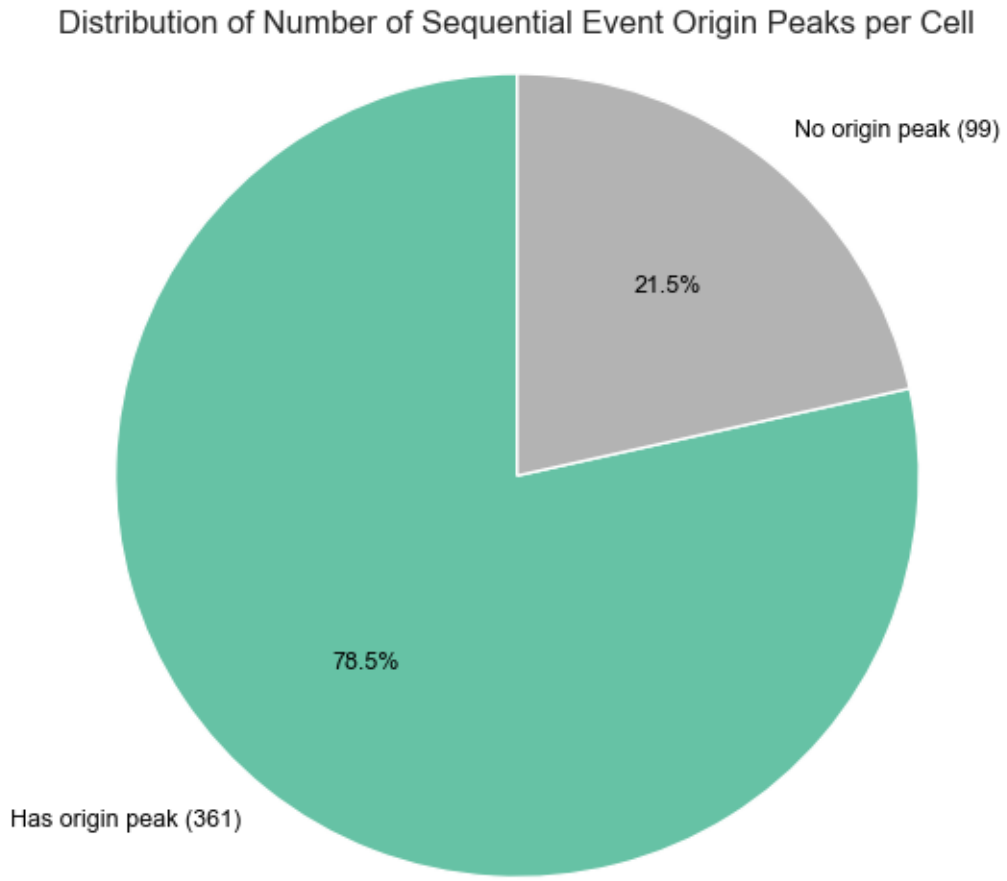
```
outliers out of 688 on 'Average communication speed (um/s)' (lower=-14.94,
upper=26.43)
```

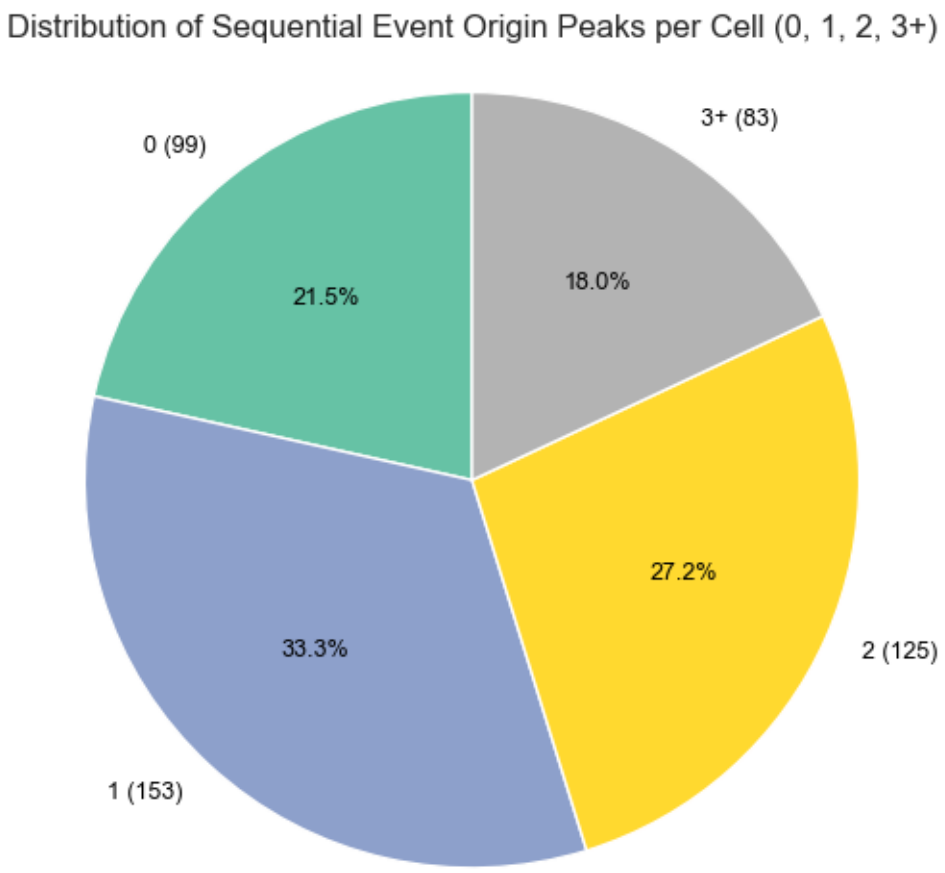



```
[2025-08-11 09:41:32] [INFO] calcium: plot_histogram_by_group: removed 22
outliers out of 1421 on 'Speed (um/s)' (lower=-18.19, upper=29.62)
```

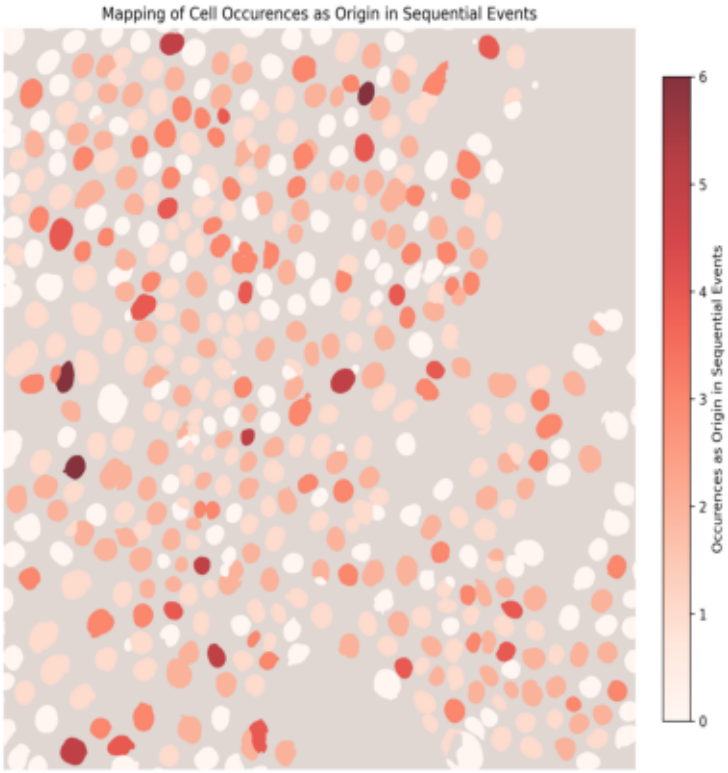

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
3
5-10
4
11+
2
Number of Communications
0
10
20
30
40
50
0
5
10
15
20
25
30
Speed (um/s)

1.3.7 Cells occurences as origin in sequential events

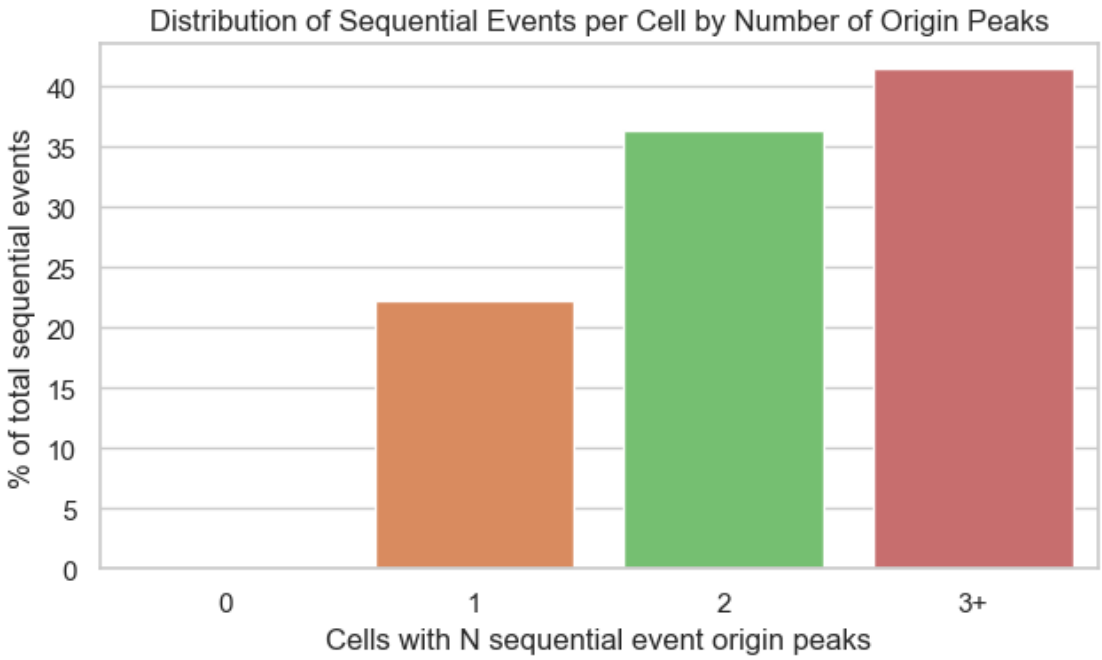



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
0 (99)
3+ (83)
21.5%
18.0%
27.2%
33.3%
2 (125)
1 (153)

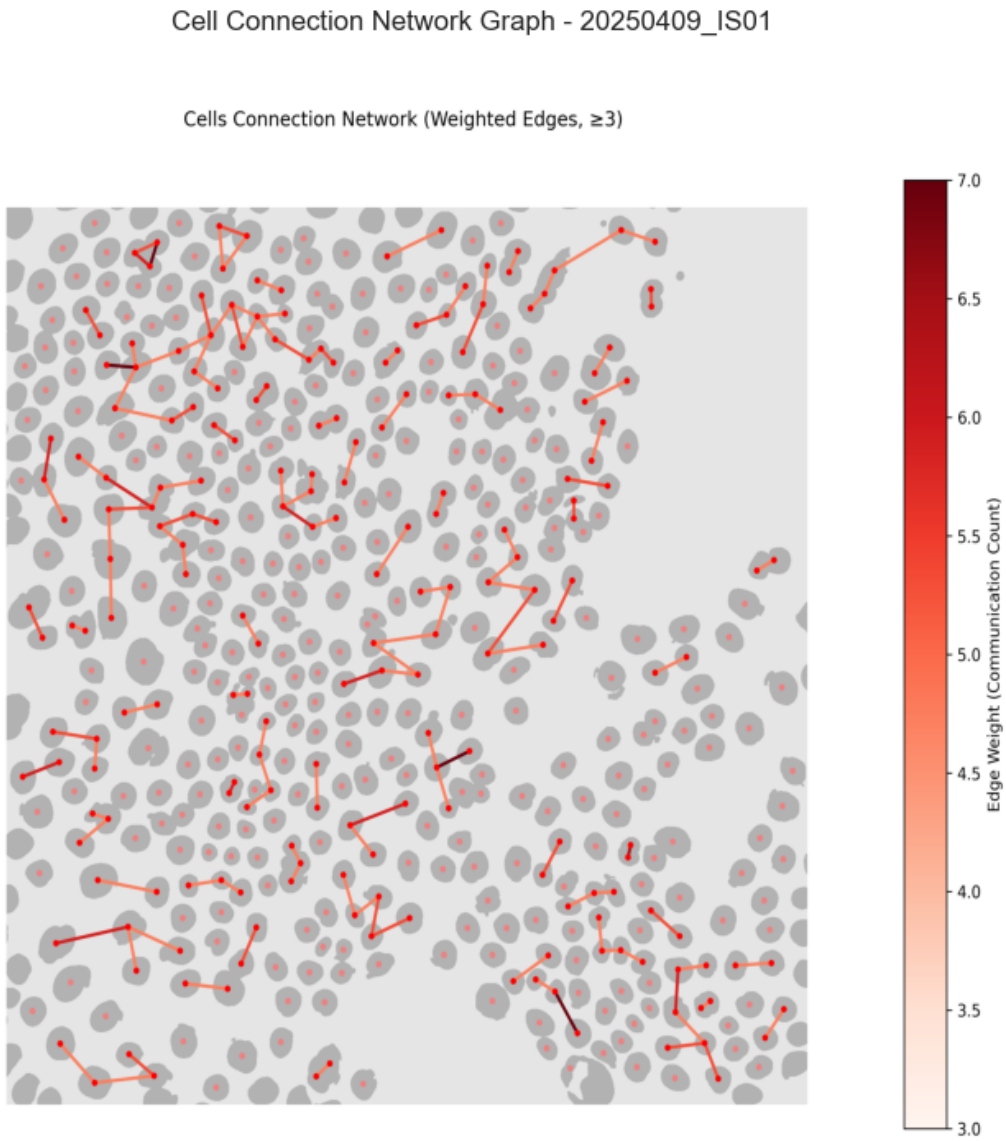
Cell Mapping with Origin Peaks Overlay - 20250409_IS01




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

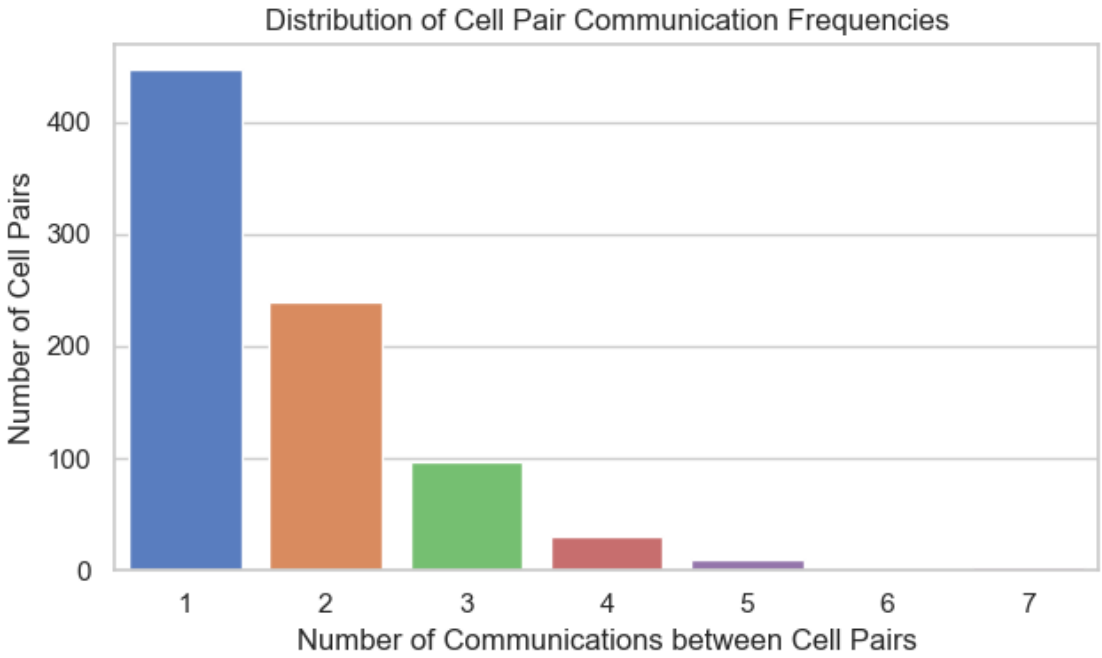

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
40
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



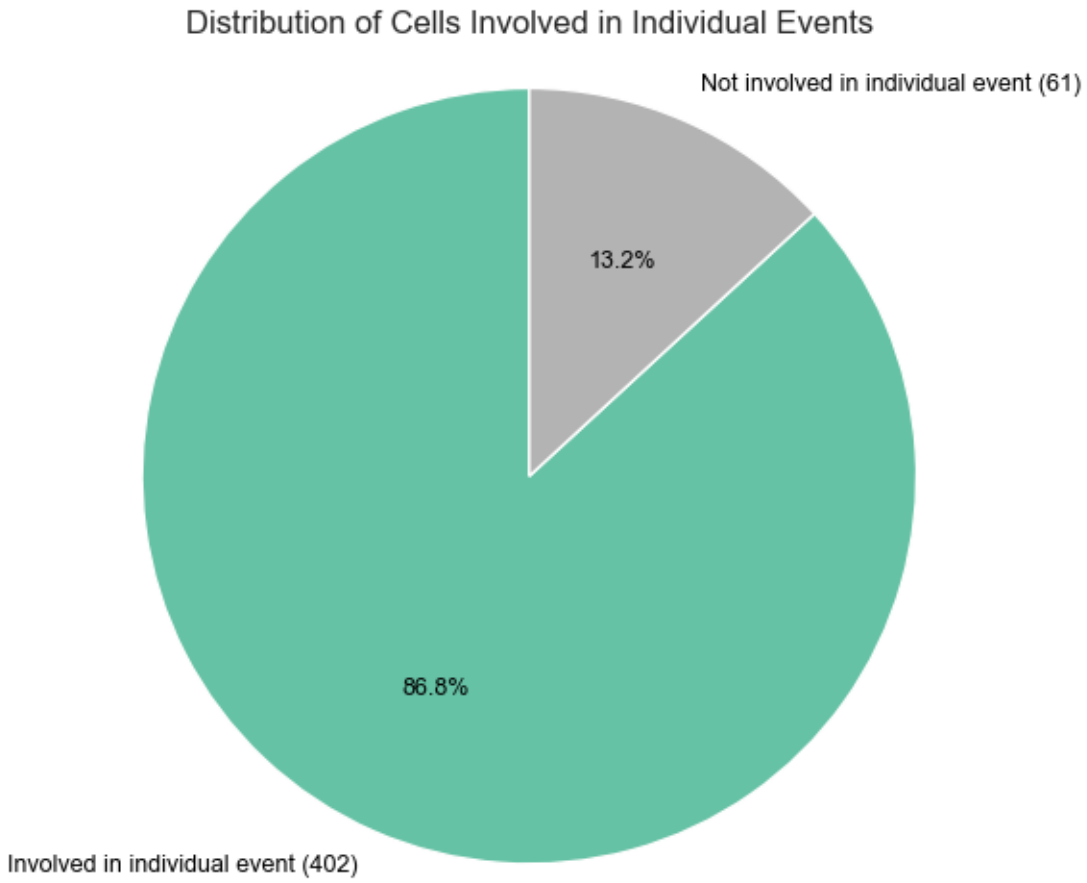

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

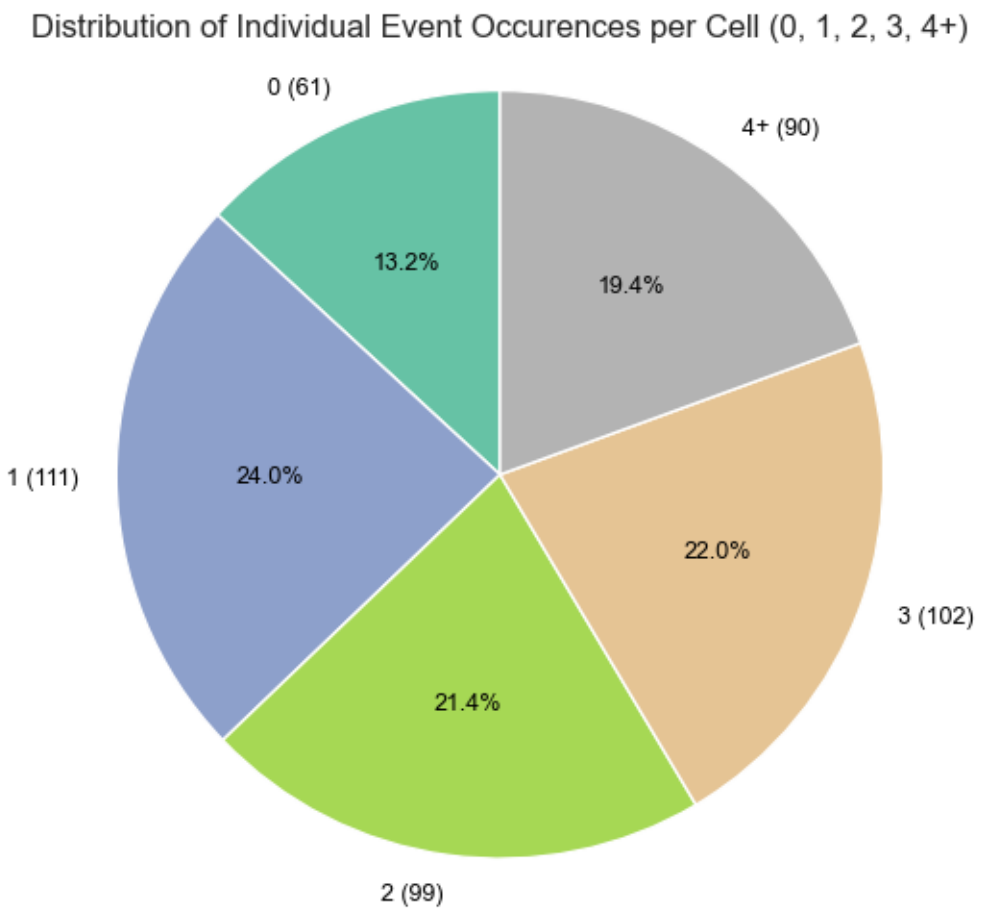
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
400
300
200
100
0
1
2
3
4
5
6
7
Number of Communications between Cell Pairs

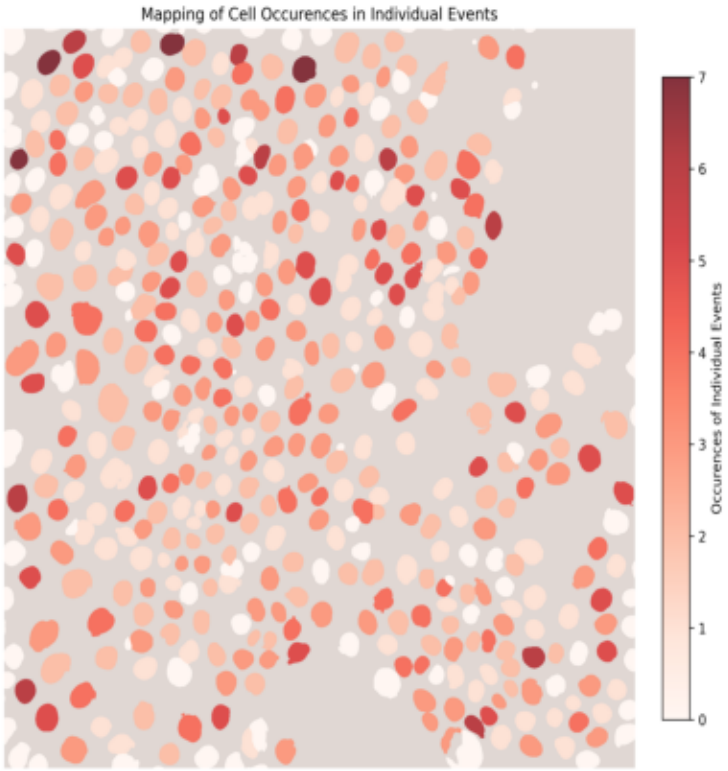
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



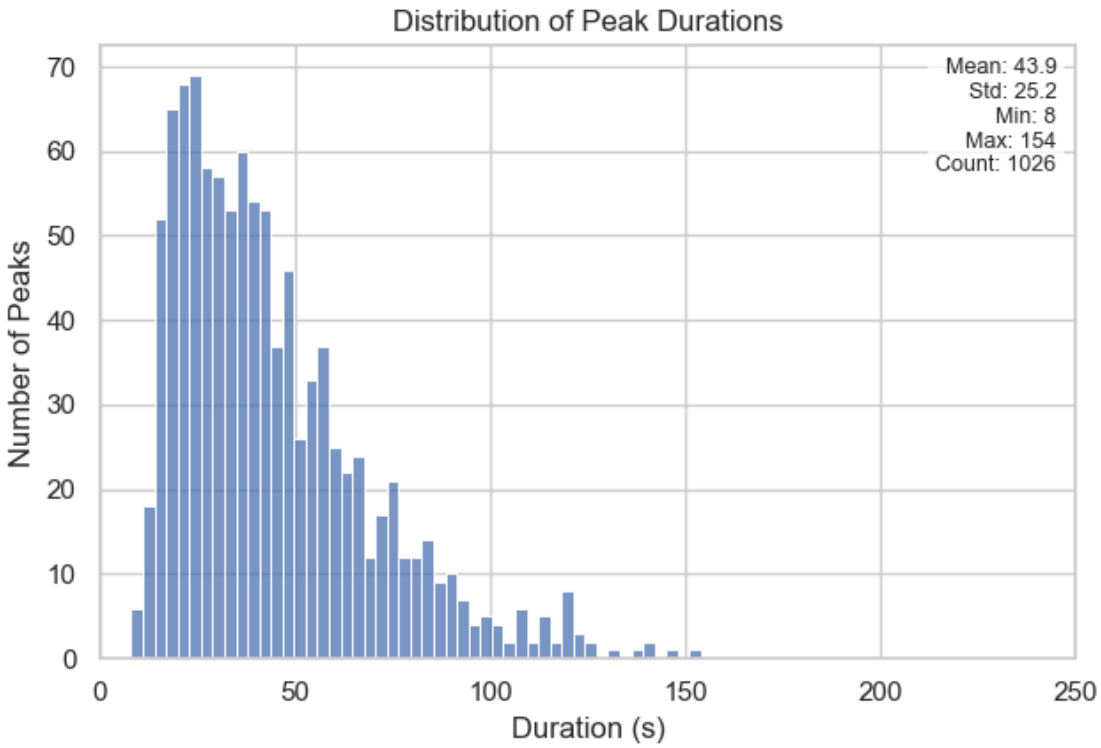

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
0 (61)
4+ (90)
13.2%
19.4%
1 (111)
24.0%
22.0%
3 (102)
21.4%
2 (99)

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS01

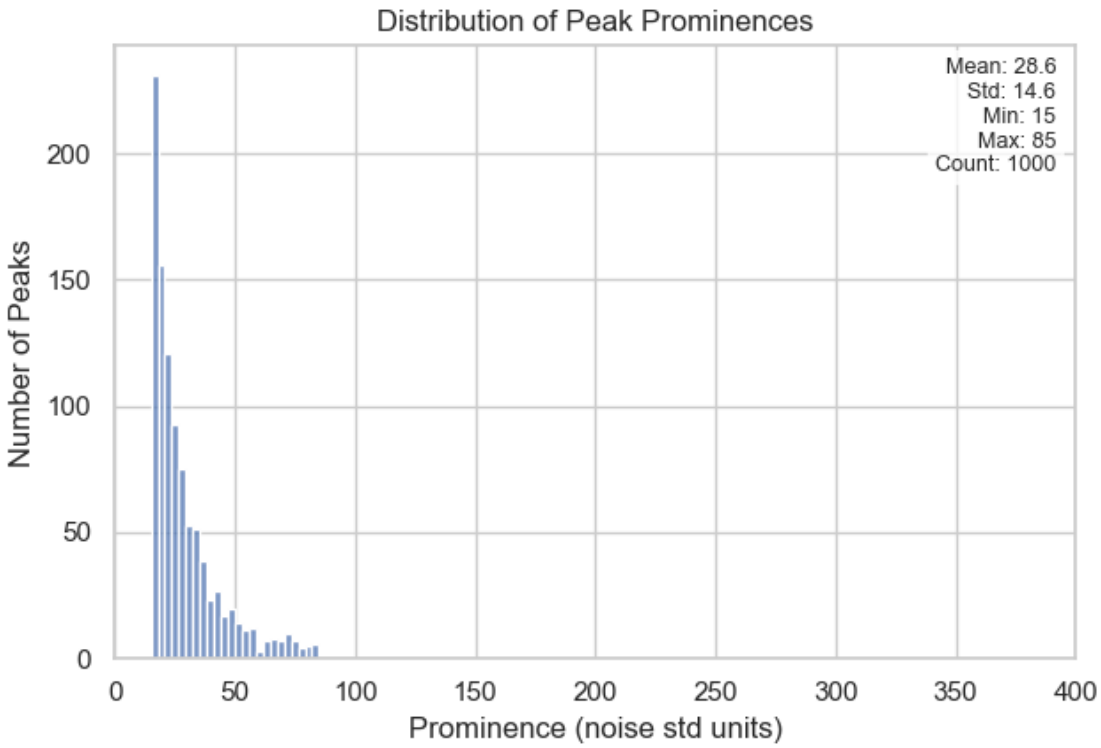


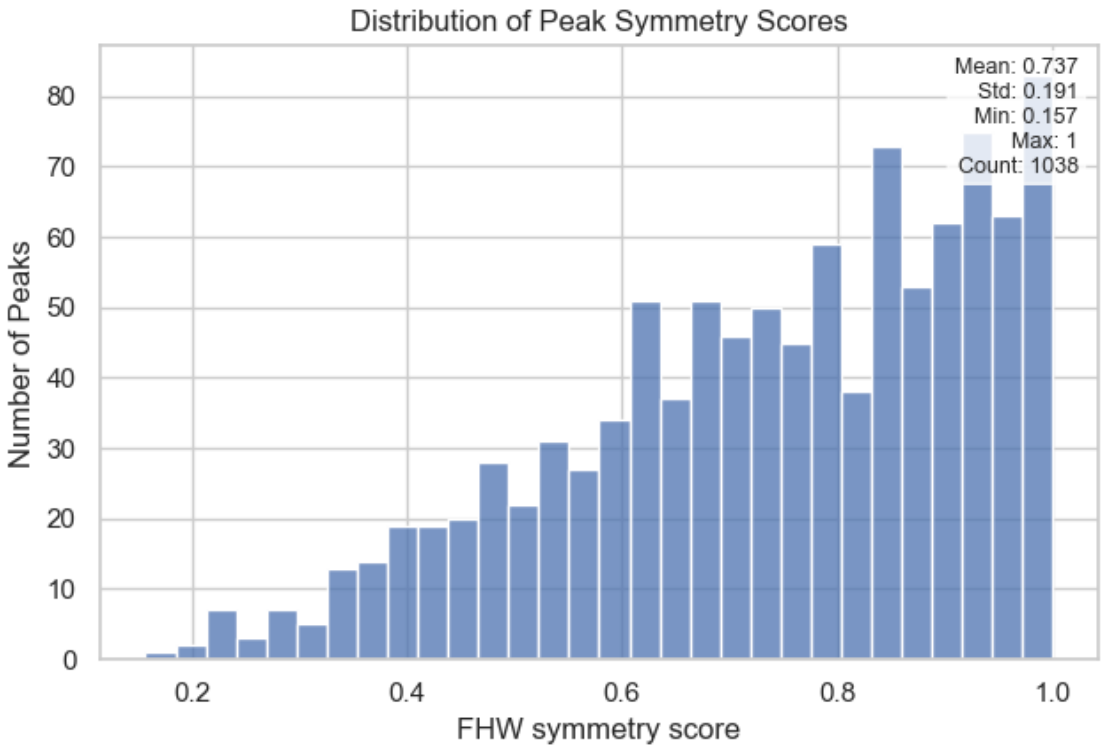
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:41:36] [INFO] calcium: plot_histogram: removed 12 outliers out of
1038 on 'Duration (s)' (lower=-73.25, upper=156)
```

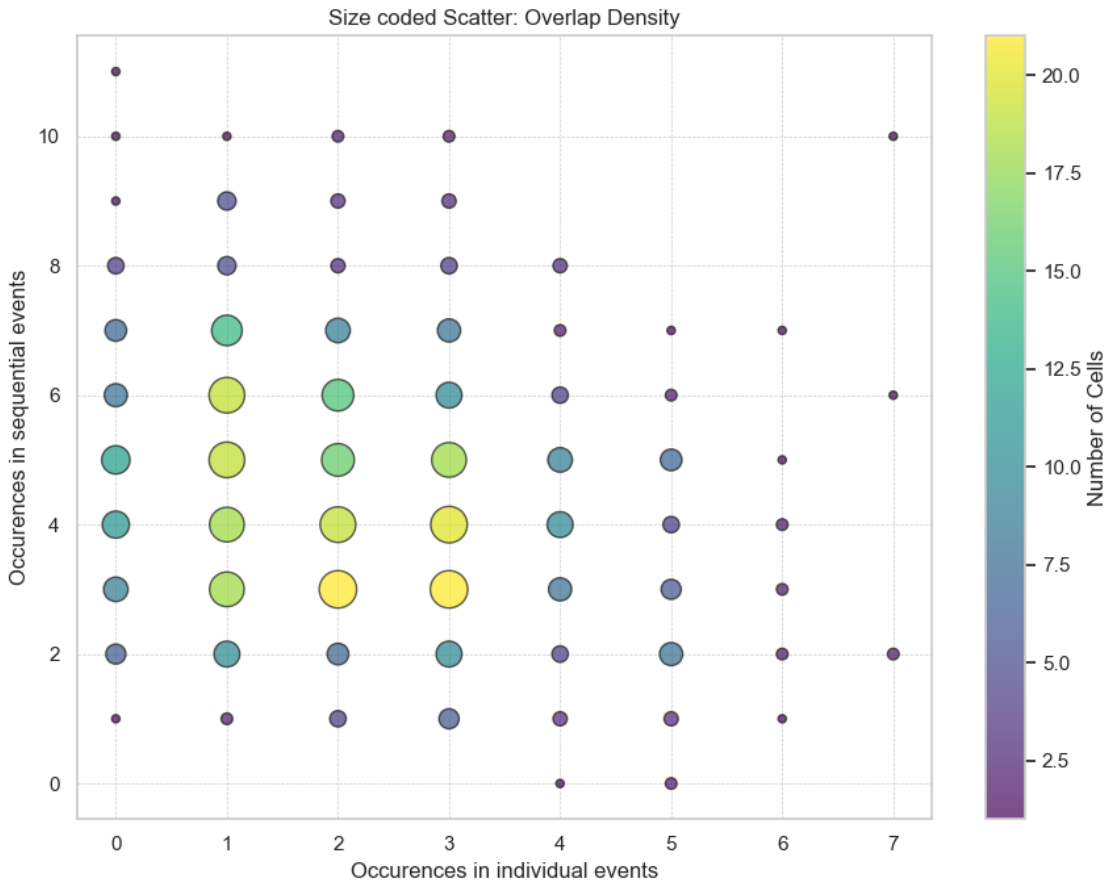



```
[2025-08-11 09:41:36] [INFO] calcium: plot_histogram: removed 38 outliers out of
1038 on 'Prominence (noise std units)' (lower=-32.625, upper=86.2)
```

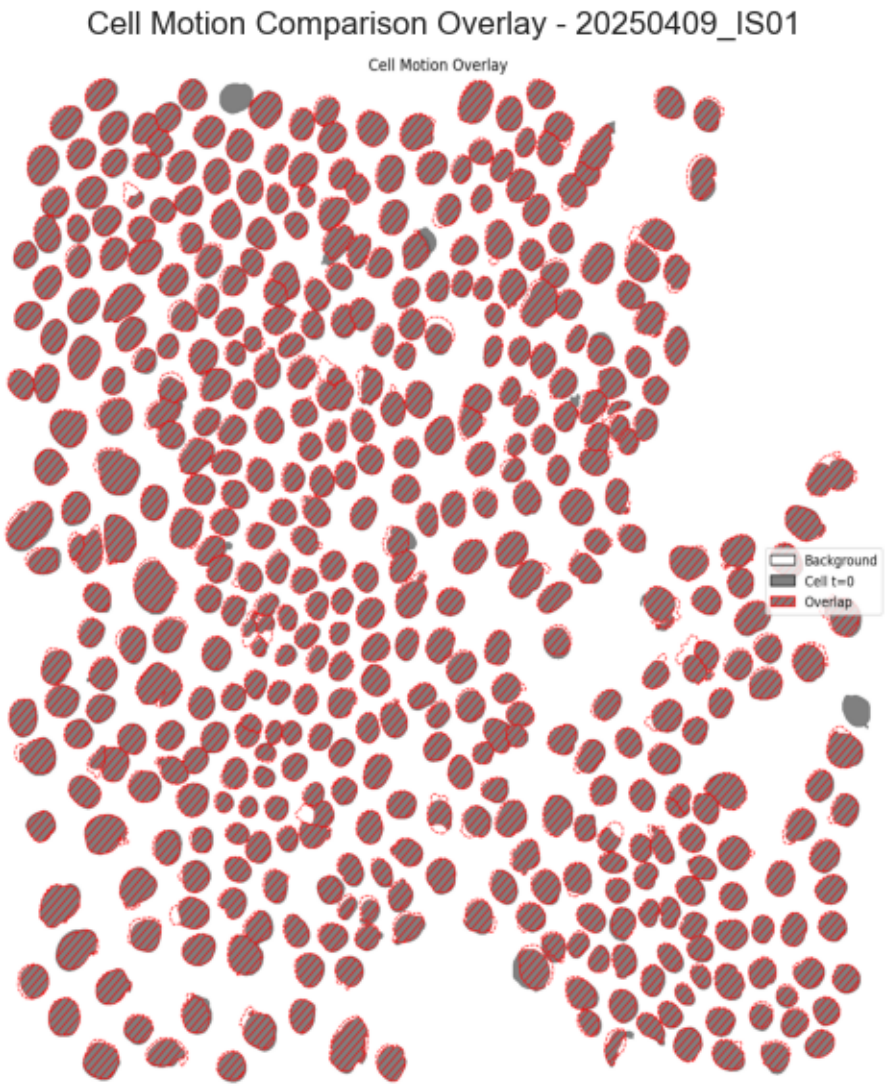

Distribution of Peak Prominences
Mean: 28.6
Std: 14.6
Min: 15
Max: 85
Count: 1000
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.737
Std: 0.191
Min: 0.157
Max: 1
Count: 1038
Number of Peaks
0
10
20
30
40
50
60
70
80
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 463
- Hoechst image taken at t=1801: 454
- Number of cells difference: absolute 9, relative 1.96%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 799186
- Pixels segmented as cell at t=1801: 781380
- Overlapping pixels between t=0 and t=1801: 723667(91.57% of total)
- Pixels exclusive to t=0: 75519 (9.45% of total)
- Pixels exclusive to t=1801: 57713 (7.39% of total)
```

executed

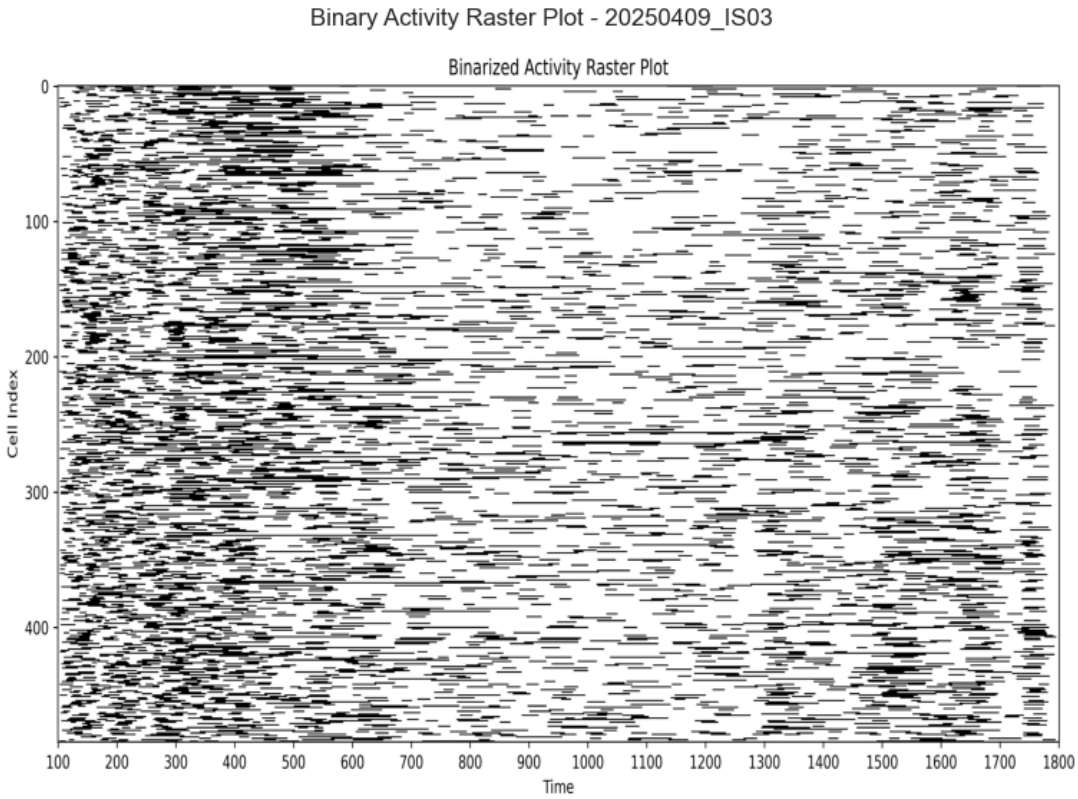
August 11, 2025

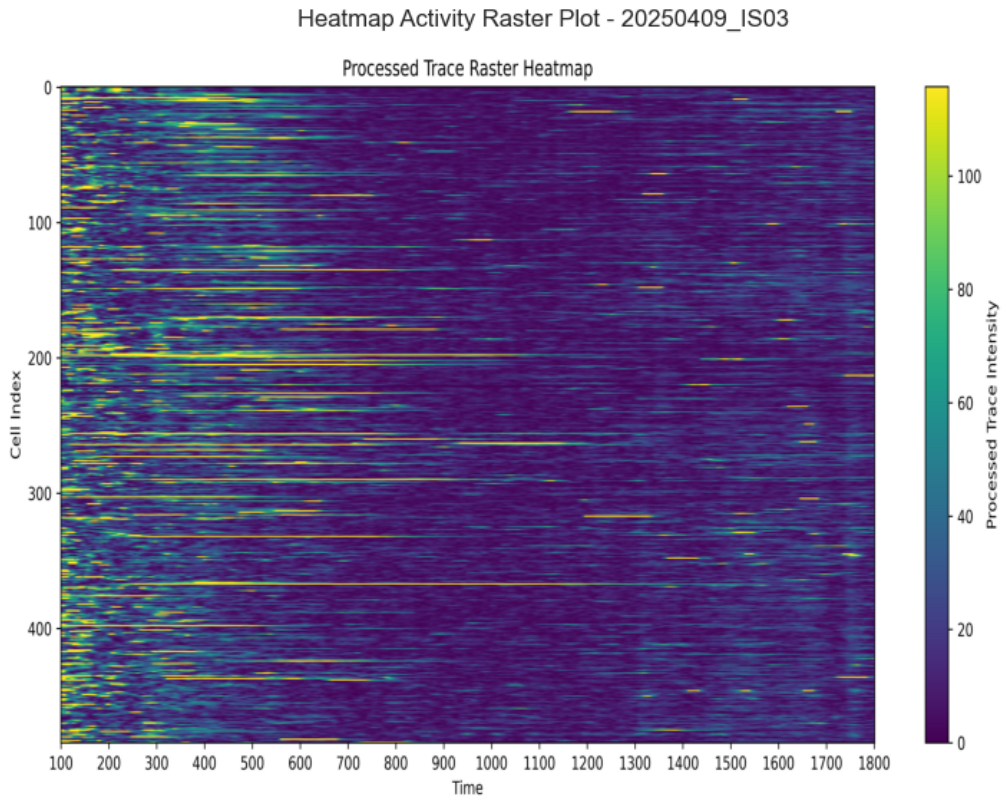
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



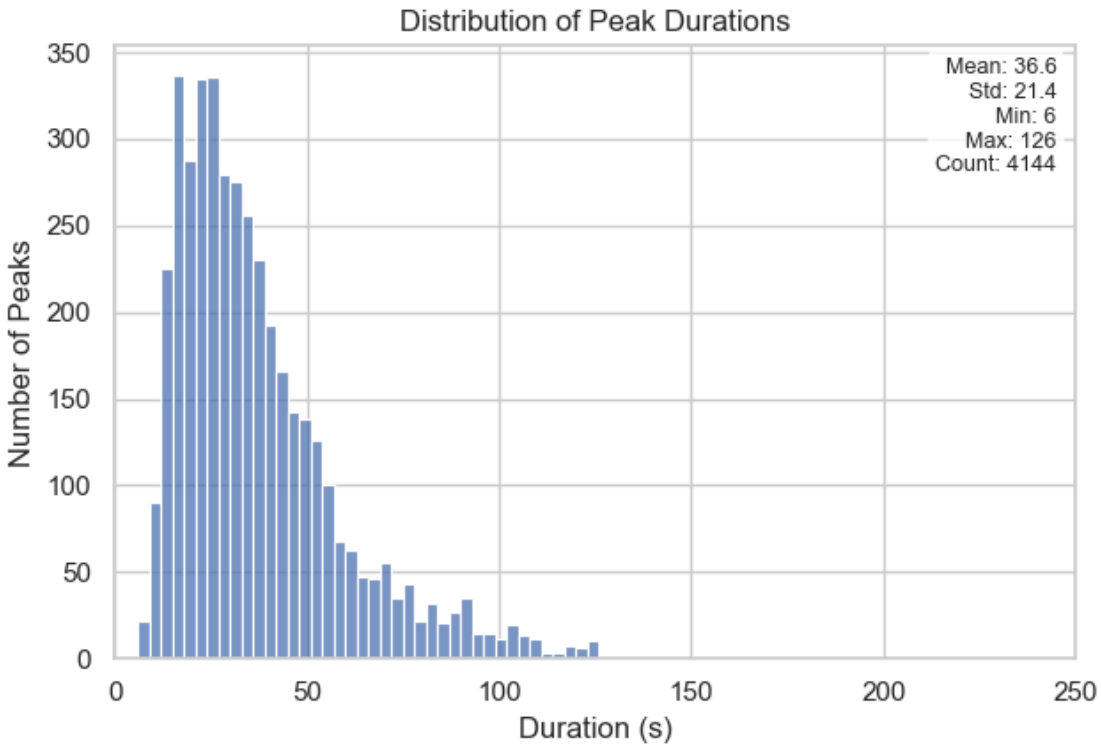


1.1.2 Peaks population

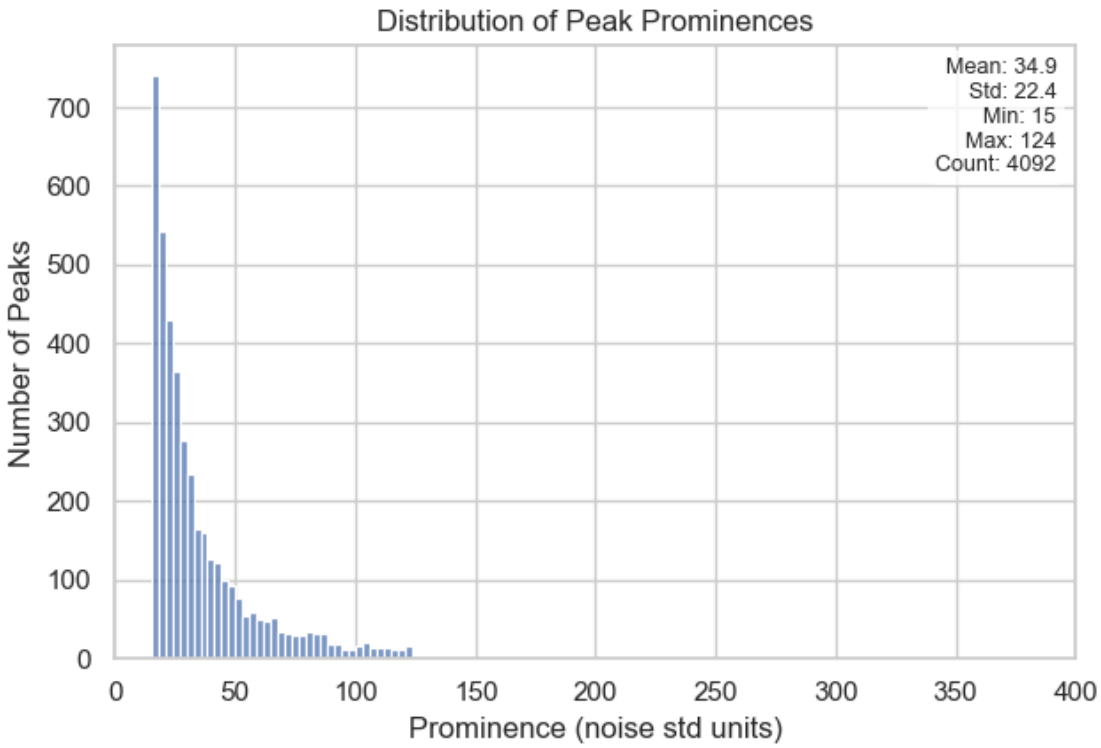
```
Total number of peaks: 4264
Total number of cells: 485
```

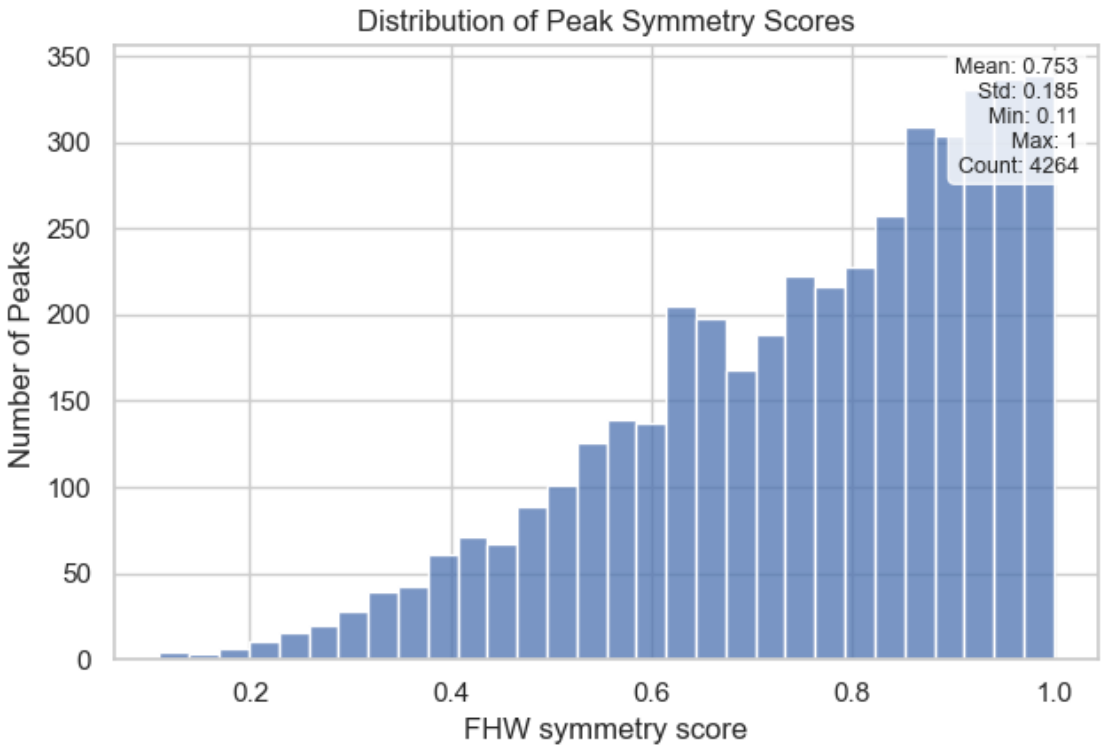
1.1.3 Peaks statistics

```
[2025-08-11 09:42:37] [INFO] calcium: plot_histogram: removed 120 outliers out
of 4264 on 'Duration (s)' (lower=-56, upper=126)
```

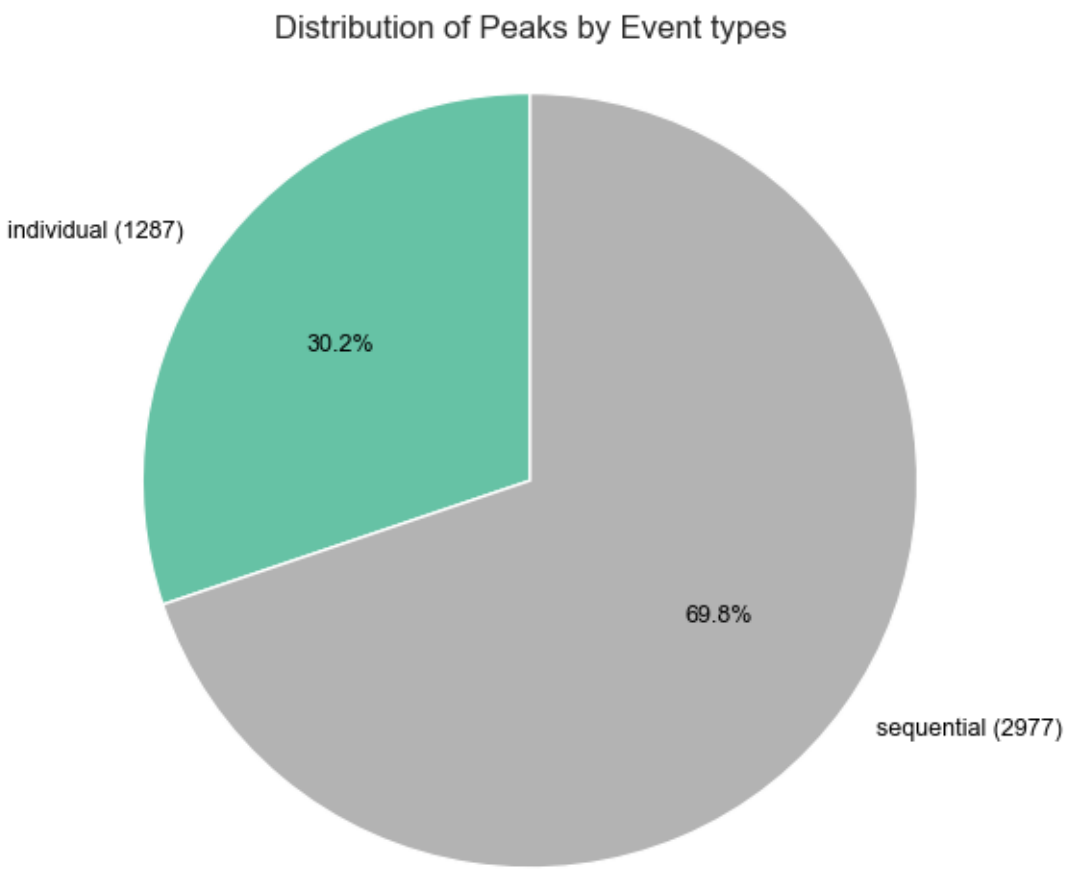



```
[2025-08-11 09:42:37] [INFO] calcium: plot_histogram: removed 172 outliers out
of 4264 on 'Prominence (noise std units)' (lower=-58.475, upper=123.7)
```


Distribution of Peak Prominences
Mean: 34.9
Std: 22.4
Min: 15
Max: 124
Count: 4092
Number of Peaks
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

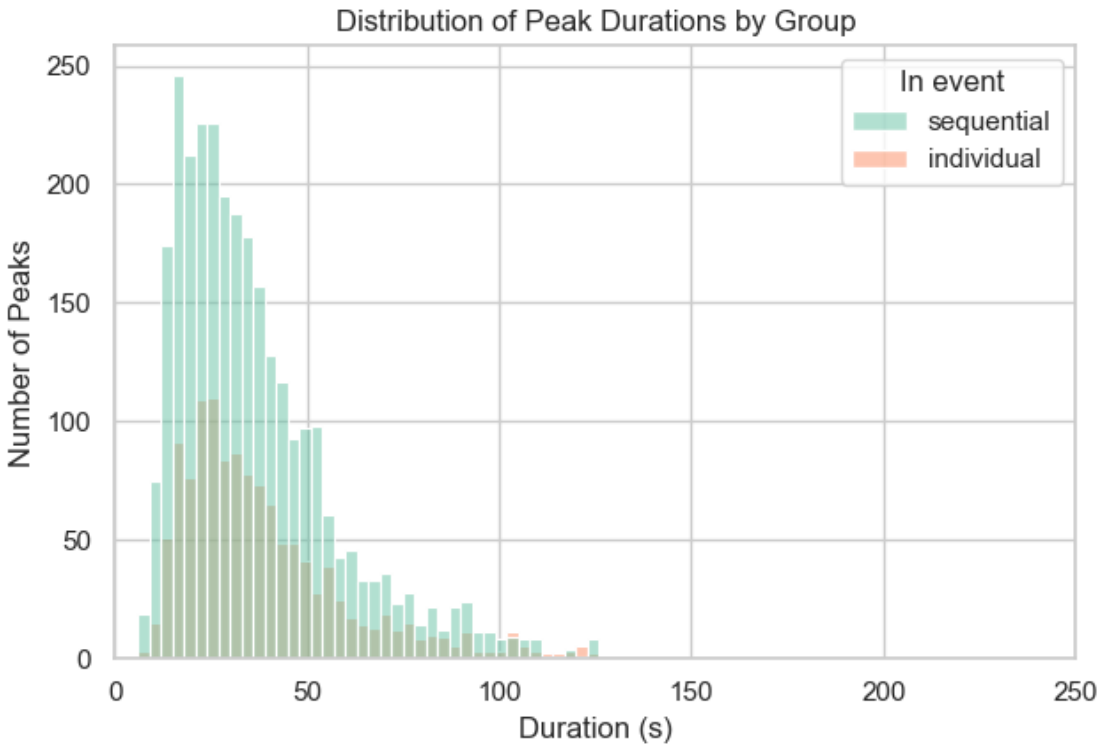

Distribution of Peak Symmetry Scores
Mean: 0.753
Std: 0.185
Min: 0.11
Max: 1
Count: 4264
Number of Peaks
0
50
100
150
200
250
300
350
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

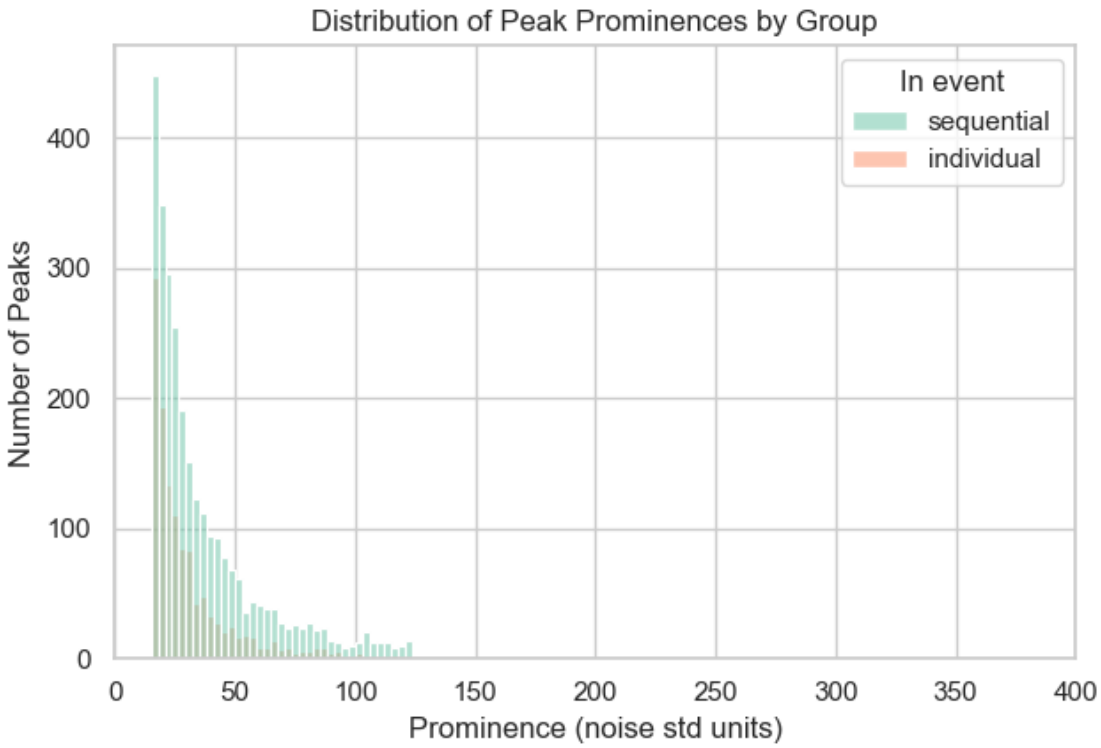


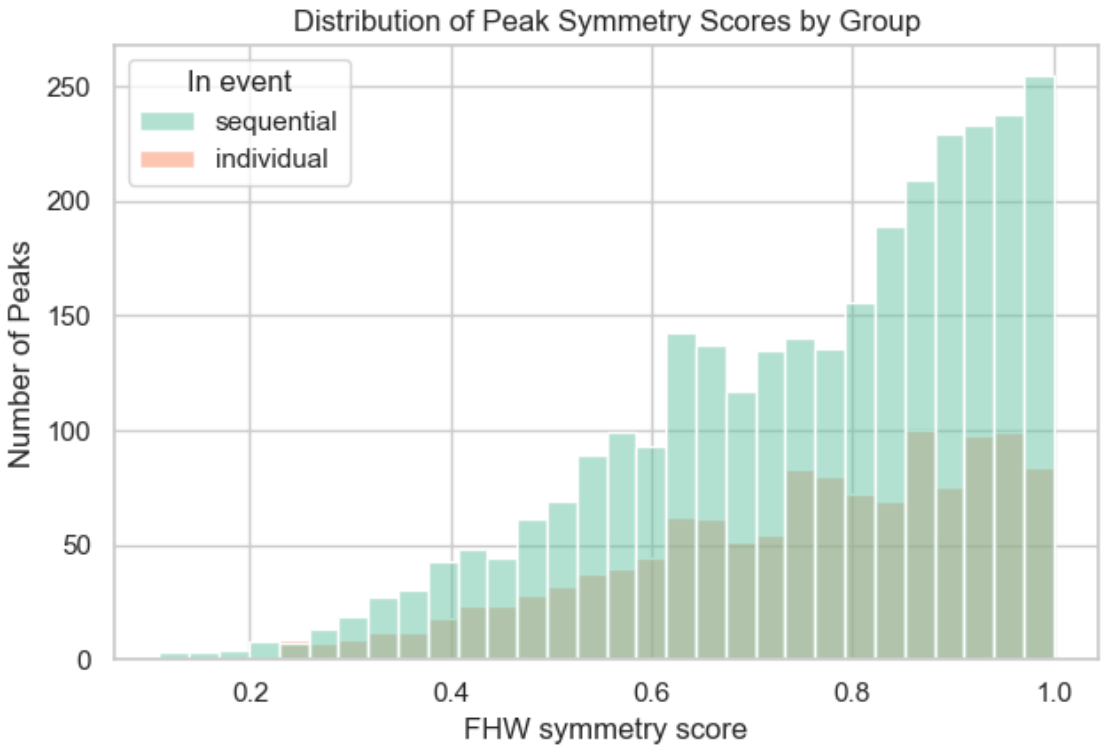
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:42:37] [INFO] calcium: plot_histogram_by_group: removed 120
outliers out of 4264 on 'Duration (s)' (lower=-56, upper=126)
```




```
[2025-08-11 09:42:37] [INFO] calcium: plot_histogram_by_group: removed 172
outliers out of 4264 on 'Prominence (noise std units)' (lower=-58.475,
upper=123.7)
```


Distribution of Peak Prominences by Group
In event
sequential
individual
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
individual
Number of Peaks
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2 GLOBAL EVENTS

1.2.1 Peak statistics in global events

```
[2025-08-11 09:42:38] [WARNING] calcium: No data to plot for column 'Duration
(s)' - DataFrame is empty.
```

```
[2025-08-11 09:42:38] [WARNING] calcium: No data to plot for column 'Prominence
(noise std units)' - DataFrame is empty.
```

```
[2025-08-11 09:42:38] [WARNING] calcium: No data to plot for column 'FHW
symmetry score' - DataFrame is empty.
```

1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:42:38] [WARNING] calcium: plot_histogram_by_group: empty
DataFrame
```

```
[2025-08-11 09:42:38] [WARNING] calcium: plot_histogram_by_group: empty
DataFrame
```

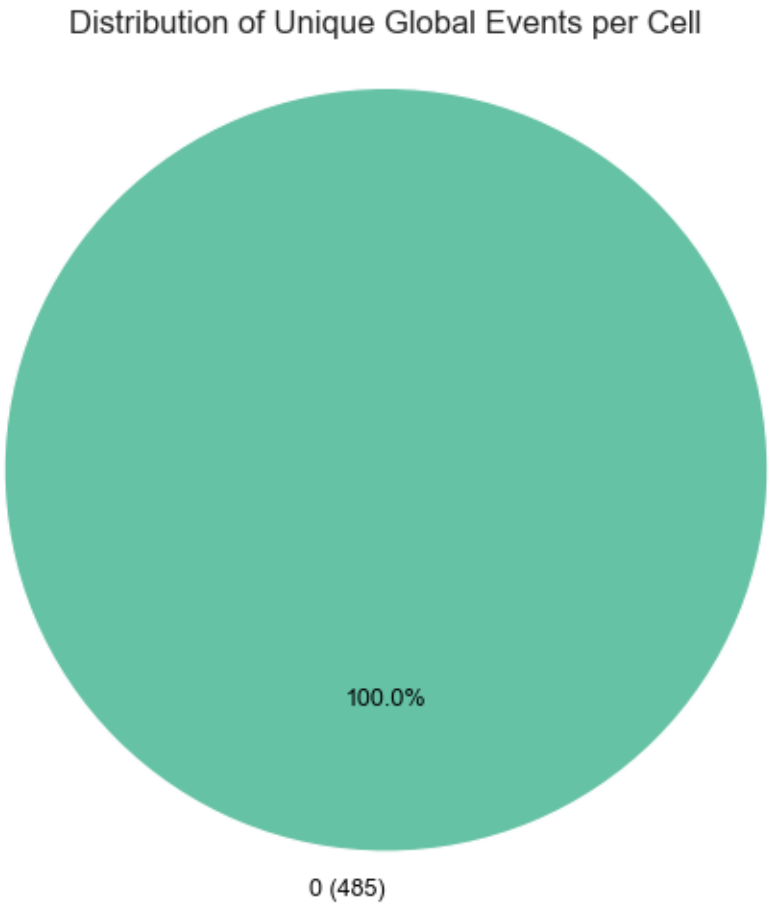
```
[2025-08-11 09:42:38] [WARNING] calcium: plot_histogram_by_group: empty
DataFrame
```

1.2.3 Kinetics of global events

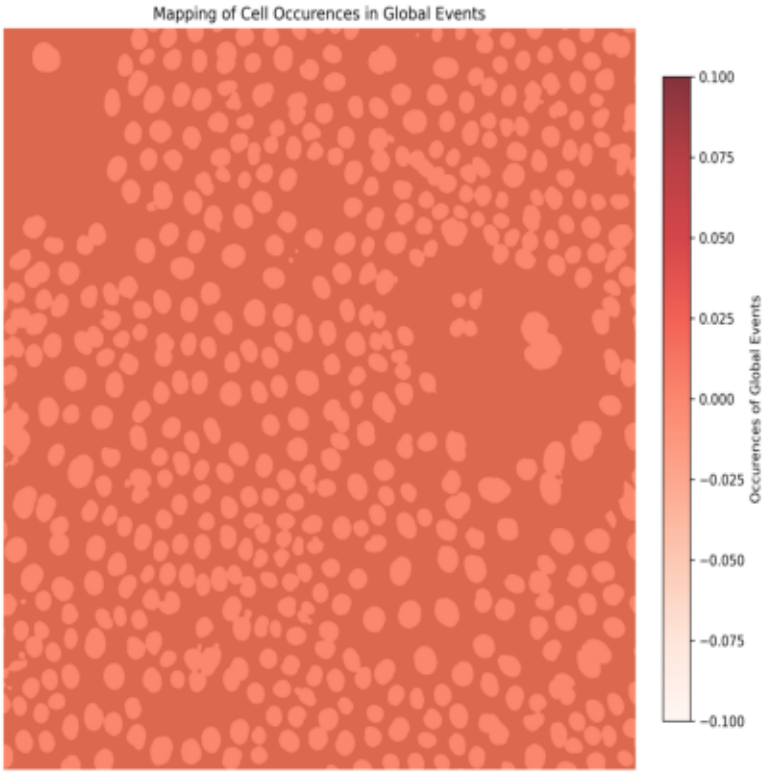
```
[2025-08-11 09:42:38] [WARNING] calcium: plot_bar: received empty DataFrame
```

```
[2025-08-11 09:42:38] [WARNING] calcium: plot_bar: received empty DataFrame
```

1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS03



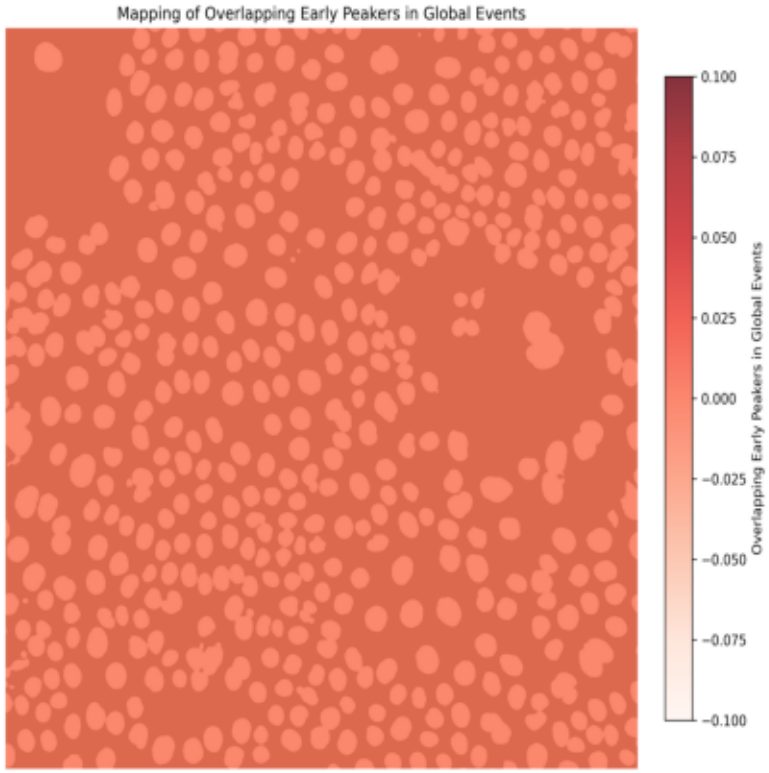

```
[2025-08-11 09:42:39] [WARNING] calcium: plot_bar: received empty DataFrame
```

1.2.5 Inter-event interval analysis

```
Intervals between global event peaks: []
```

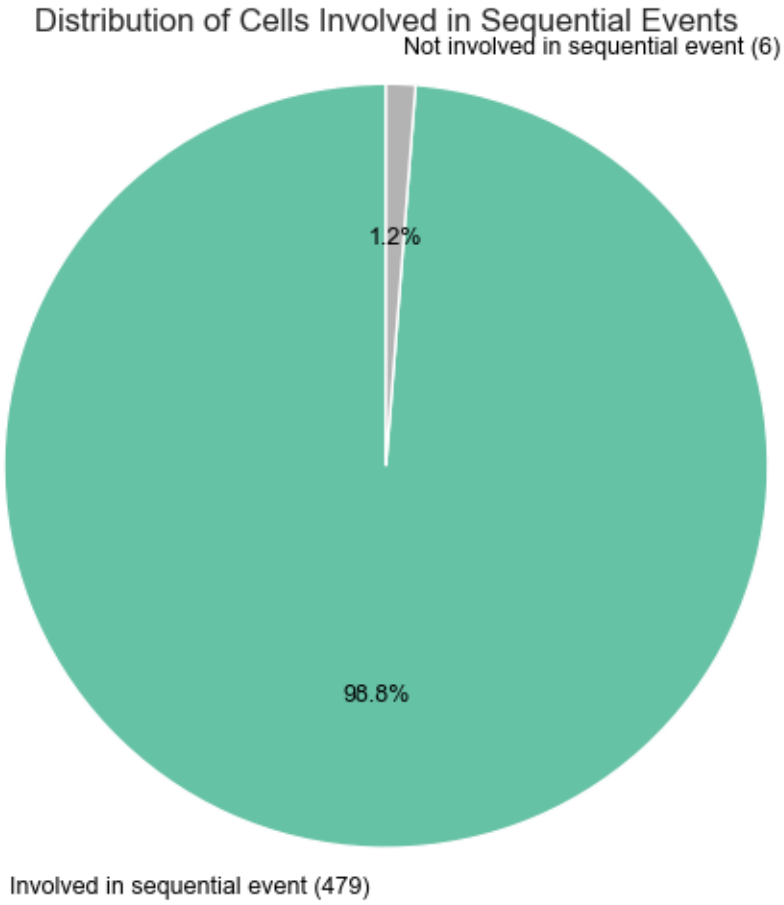
1.2.6 Early peakers in the events

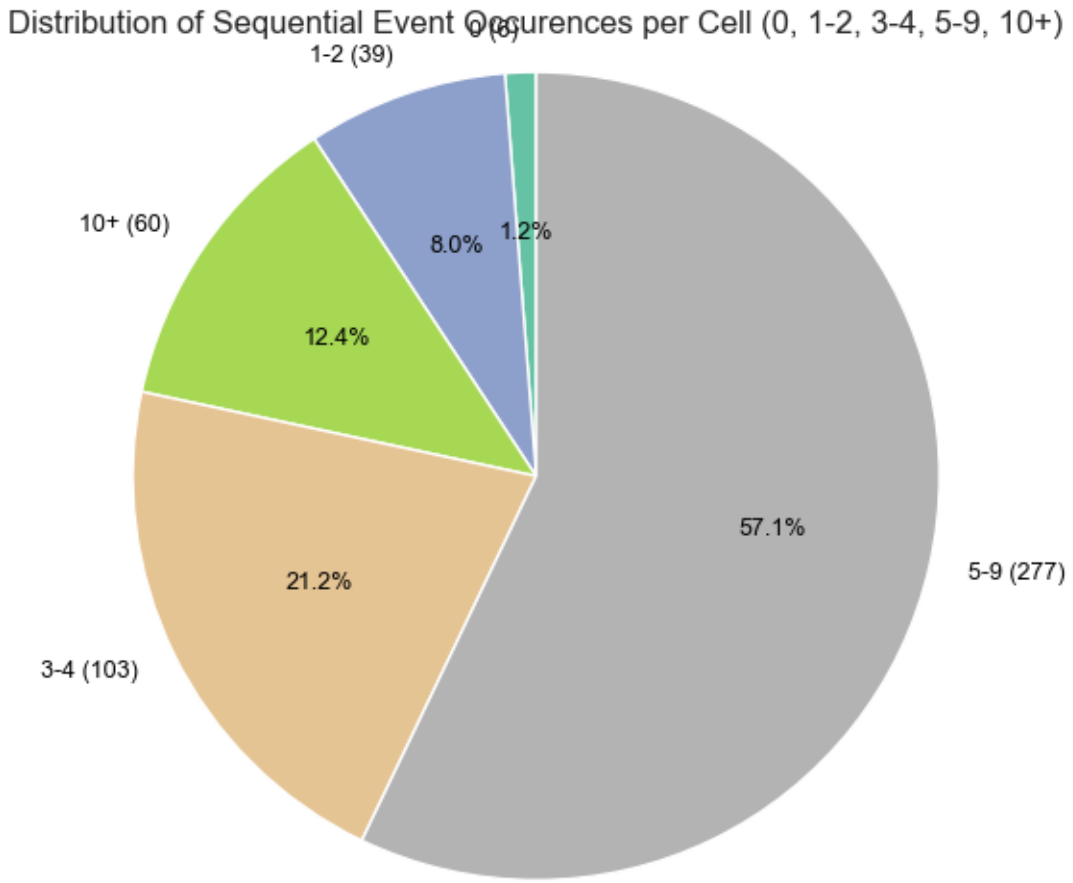
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS03



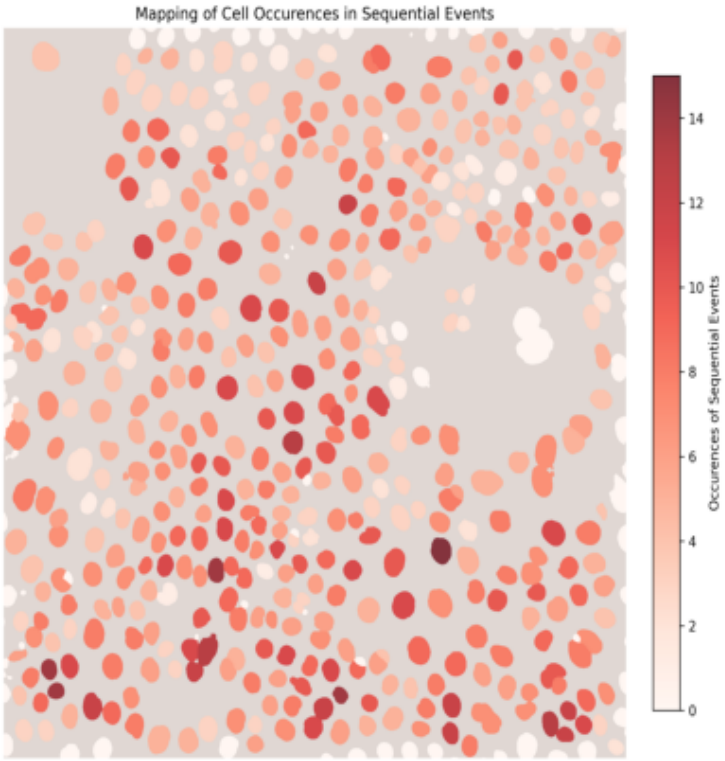
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

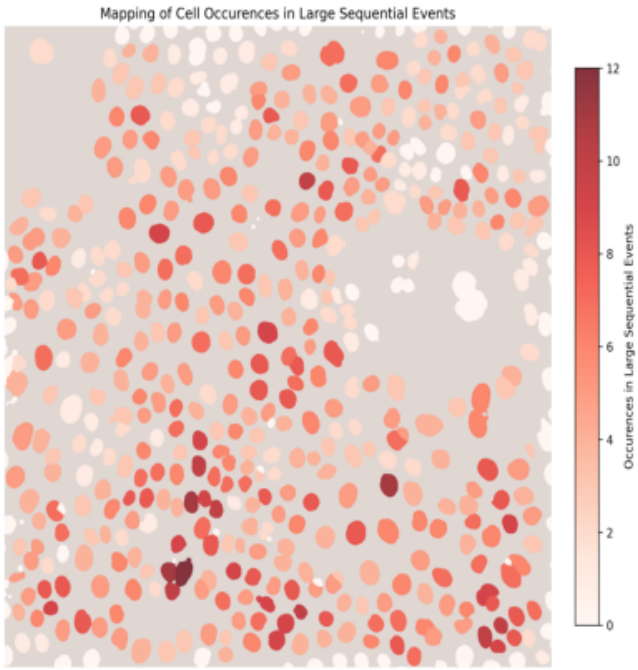



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (6)
1-2 (39)
10+ (60)
8.0%
1.2%
12.4%
57.1%
21.2%
5-9 (277)
3-4 (103)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS03

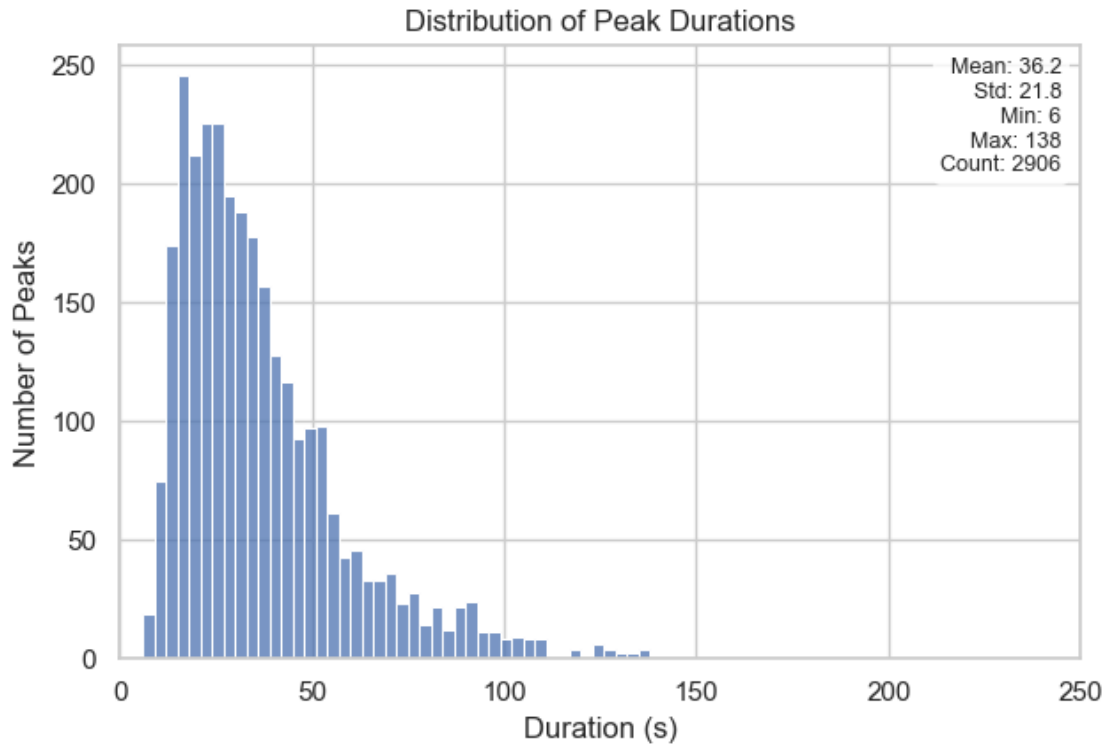


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS03

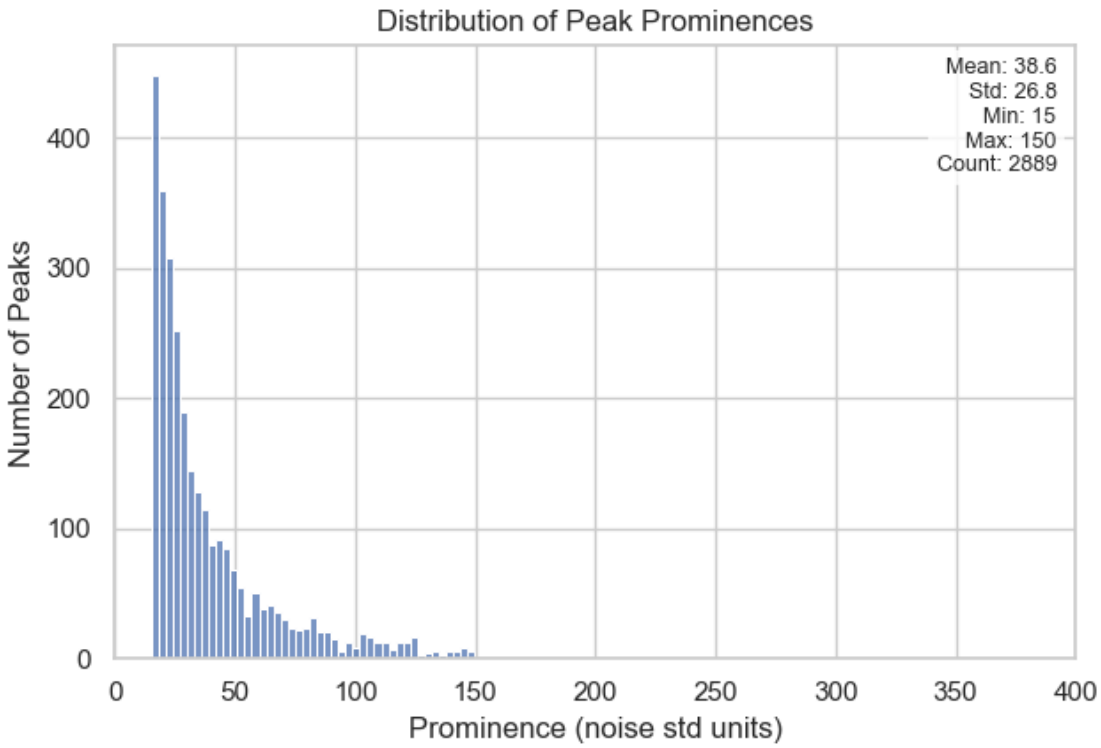


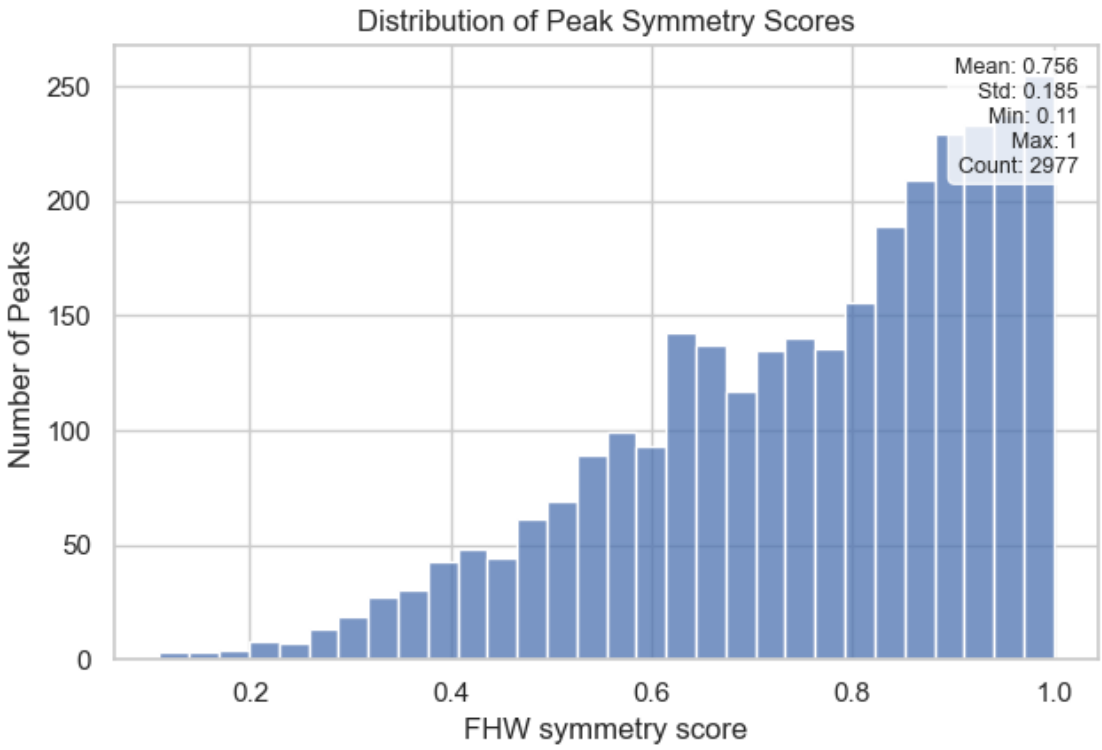
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:42:42] [INFO] calcium: plot_histogram: removed 71 outliers out of
2977 on 'Duration (s)' (lower=-18, upper=138)
```



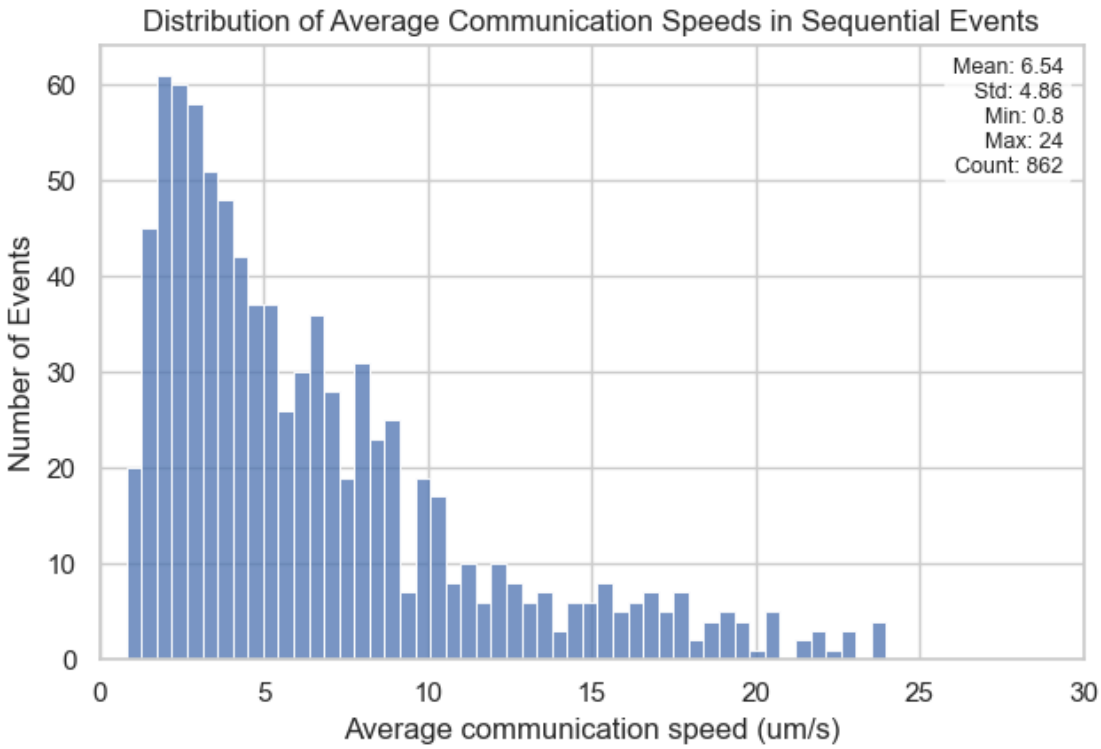

```
[2025-08-11 09:42:43] [INFO] calcium: plot_histogram: removed 88 outliers out of
2977 on 'Prominence (noise std units)' (lower=-22.8, upper=150)
```


Distribution of Peak Prominences
Mean: 38.6
Std: 26.8
Min: 15
Max: 150
Count: 2889
Number of Peaks
0
100
200
300
400
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

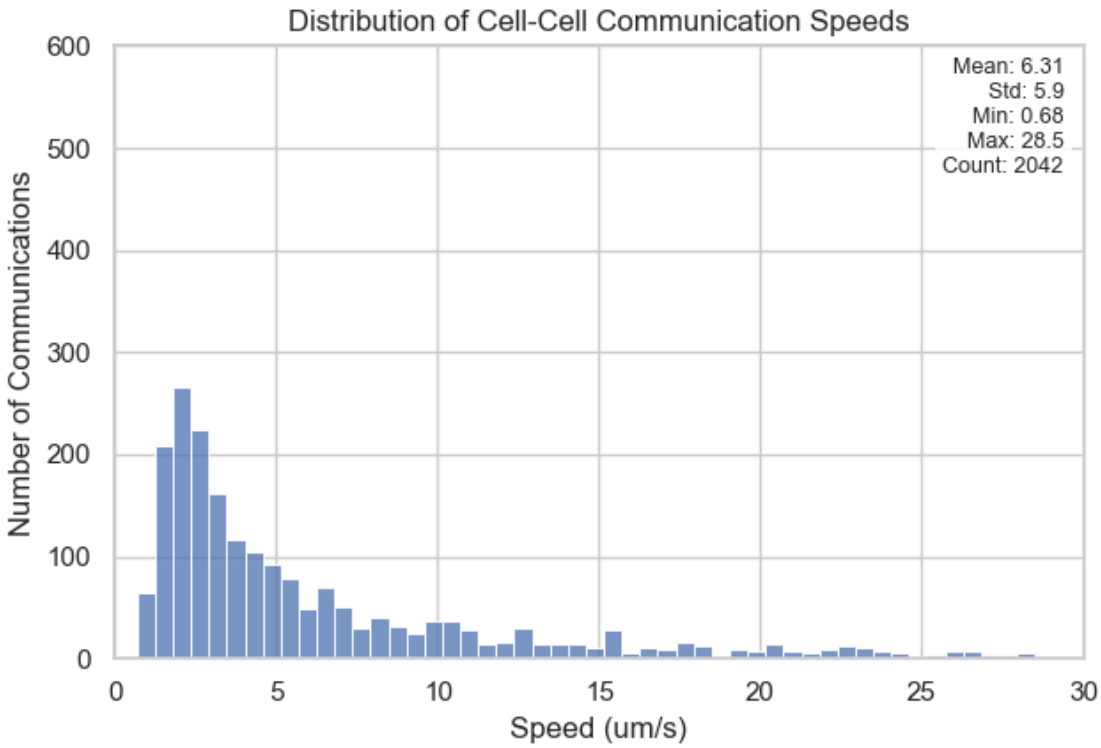

Distribution of Peak Symmetry Scores
Mean: 0.756
Std: 0.185
Min: 0.11
Max: 1
Count: 2977
Number of Peaks
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:42:43] [INFO] calcium: plot_histogram: removed 13 outliers out of
875 on 'Average communication speed (um/s)' (lower=-14.61, upper=26.305)
```

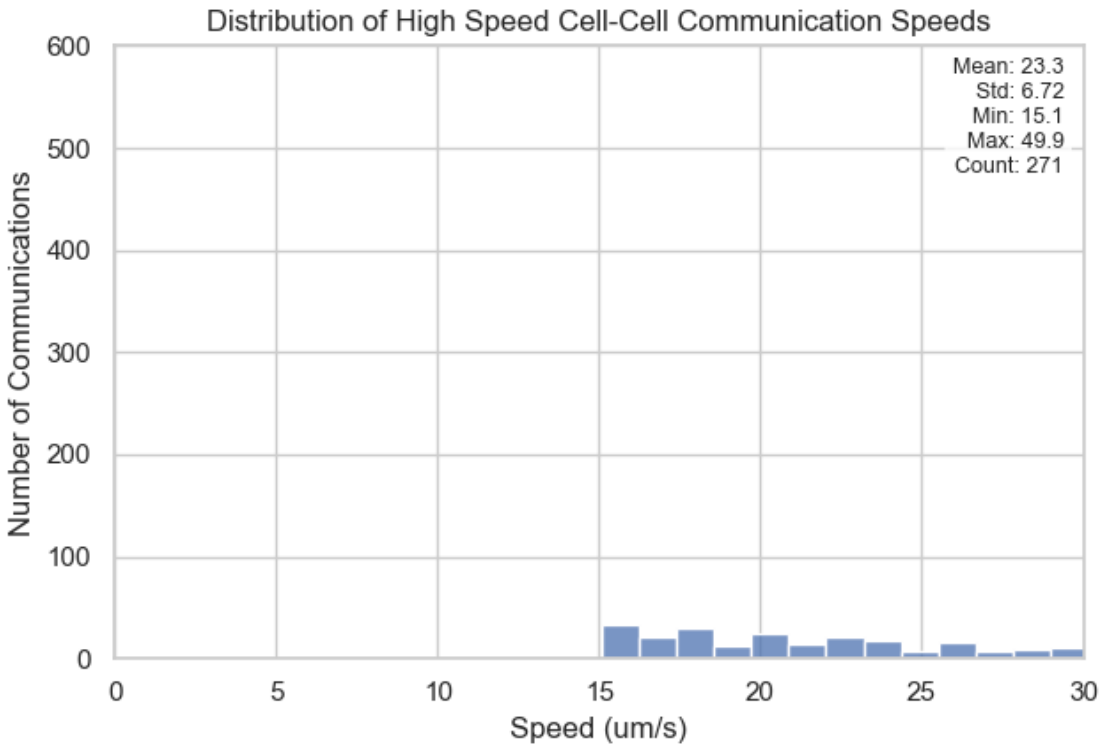



```
[2025-08-11 09:42:43] [INFO] calcium: plot_histogram: removed 60 outliers out of
2102 on 'Speed (um/s)' (lower=-17.36, upper=28.542)
```

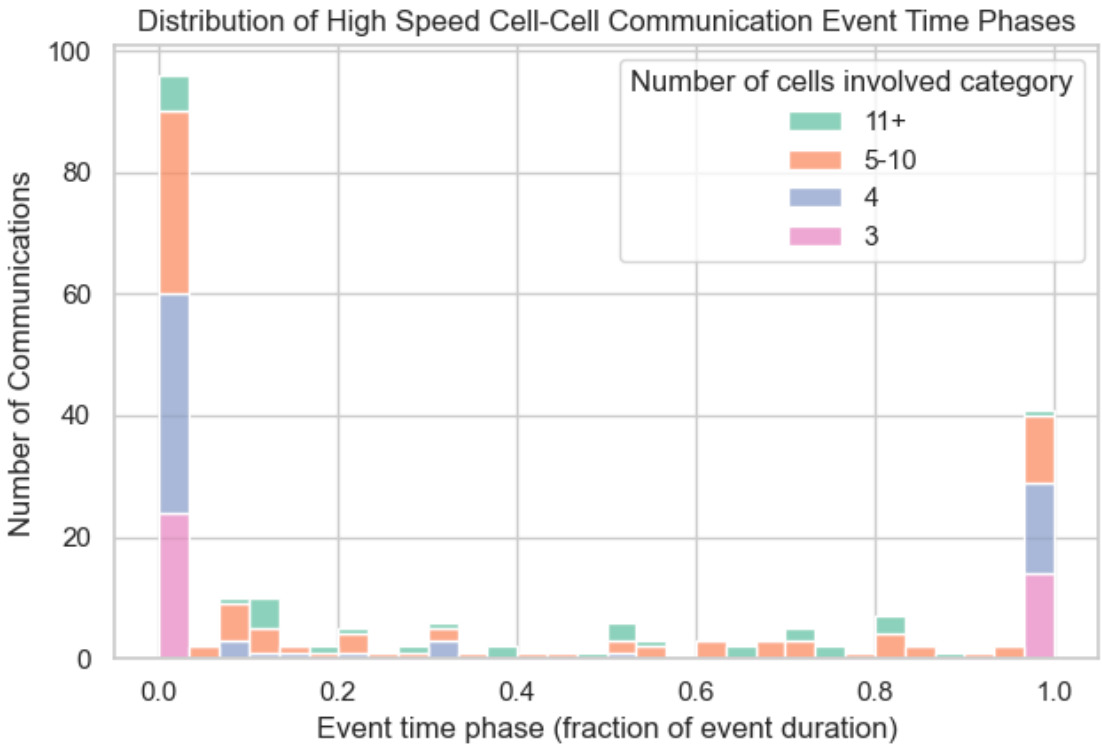


1.3.4 Double distribution in cell-cell communication speeds

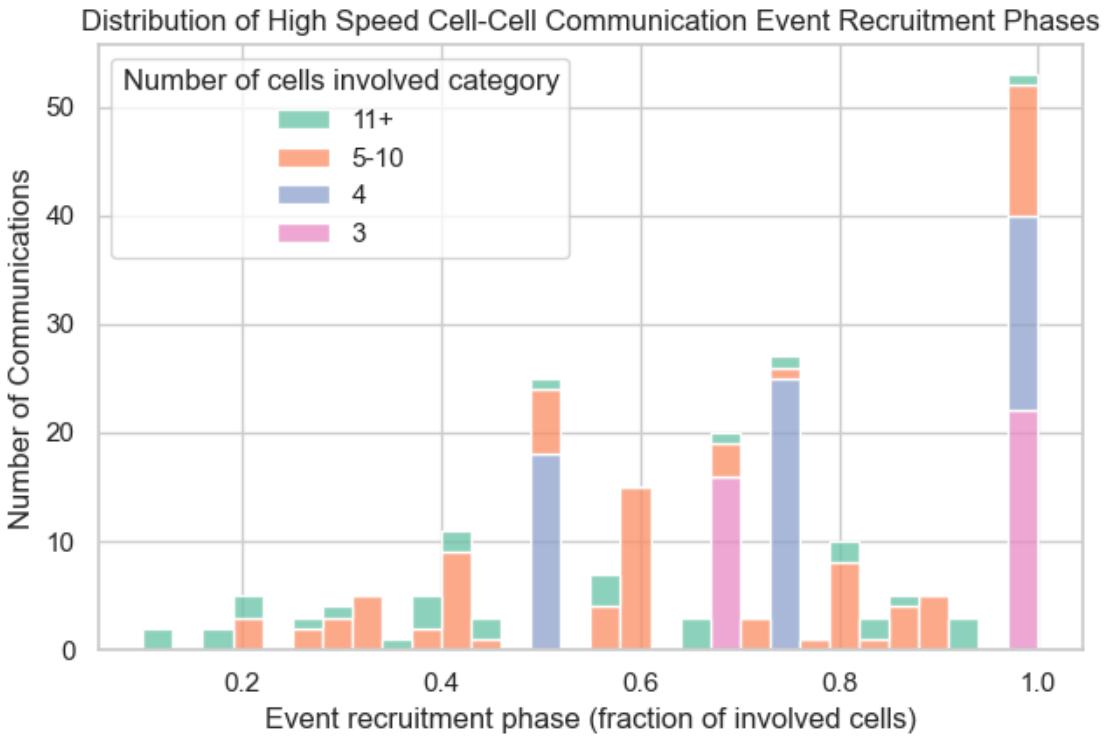
```
[2025-08-11 09:42:43] [INFO] calcium: plot_histogram: removed 2 outliers out of
273 on 'Speed (um/s)' (lower=-12.21, upper=57.58)
```



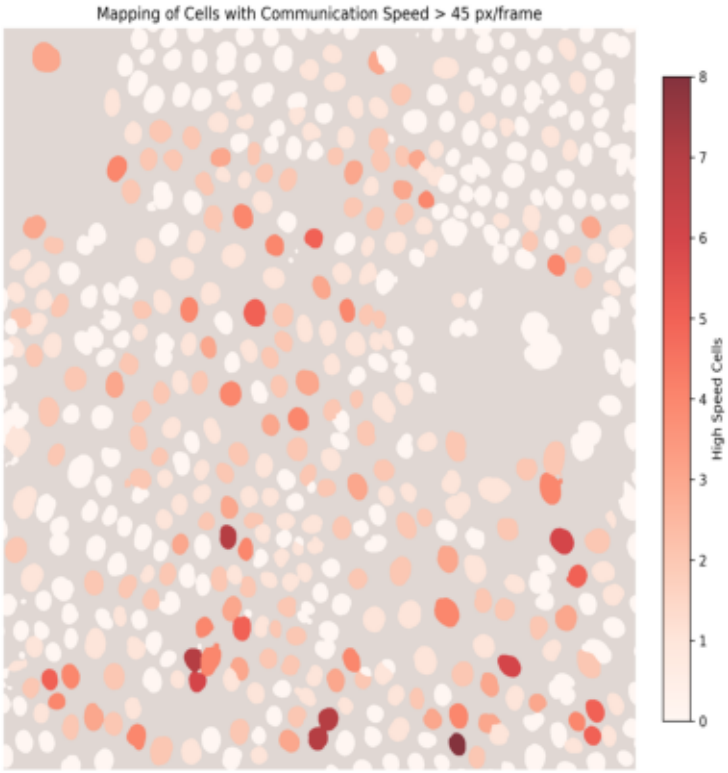

```
[2025-08-11 09:42:44] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 221 on 'Event time phase (fraction of event duration)'
(lower=-2.28, upper=3.04)
```



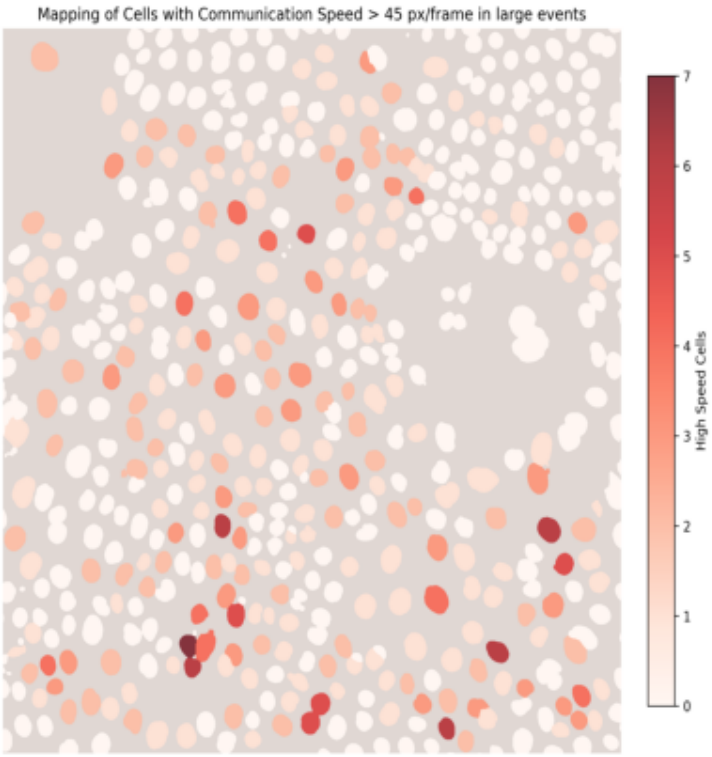

```
[2025-08-11 09:42:44] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 221 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.73, upper=2.14)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
11+
5-10
4
3
Number of Communications
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

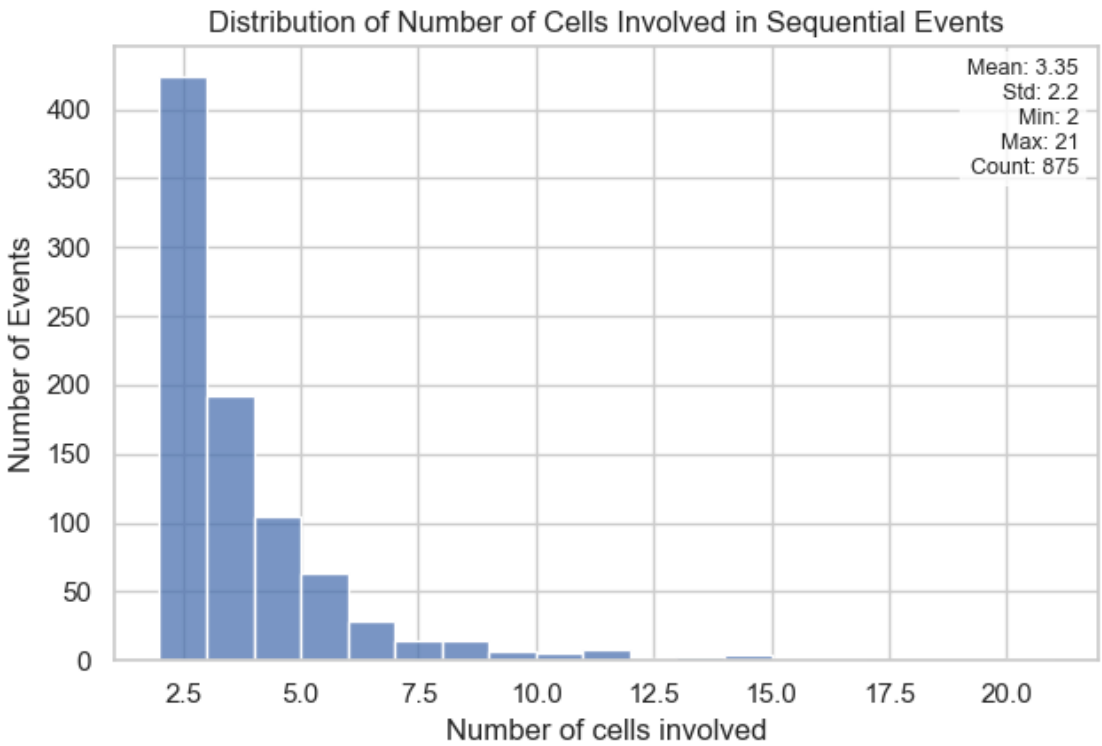
Cell Mapping with High Speed Cells Overlay - 20250409_IS03



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS03

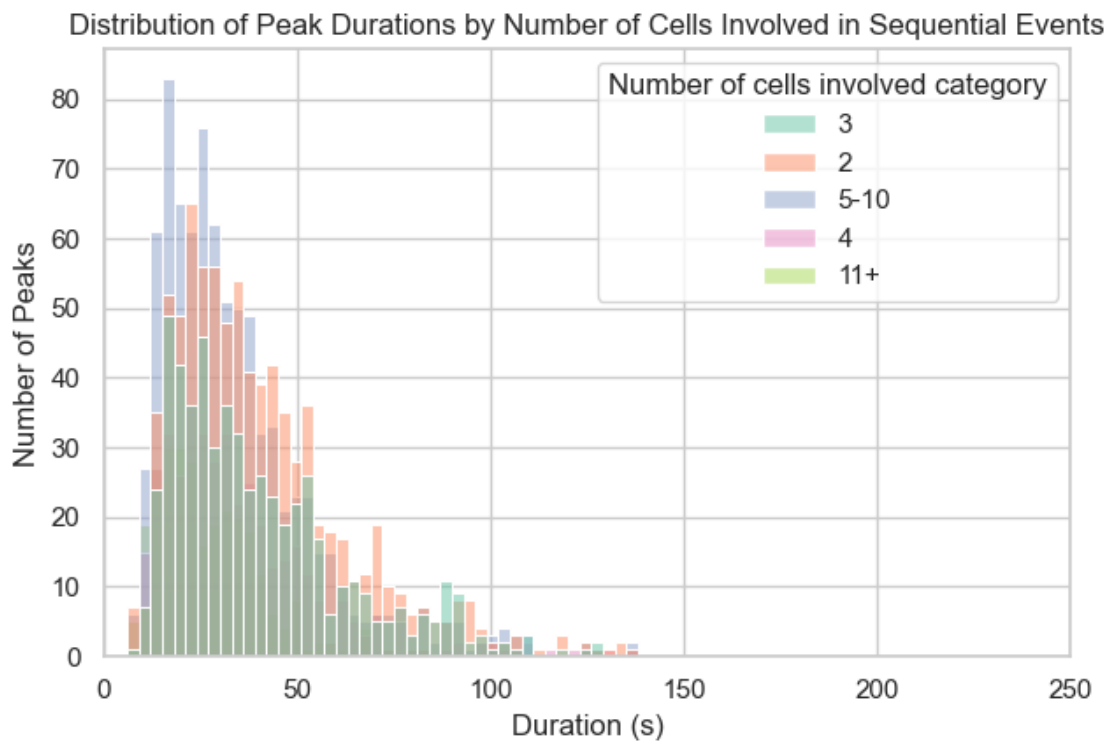


1.3.5 Number of cells involved per sequential events

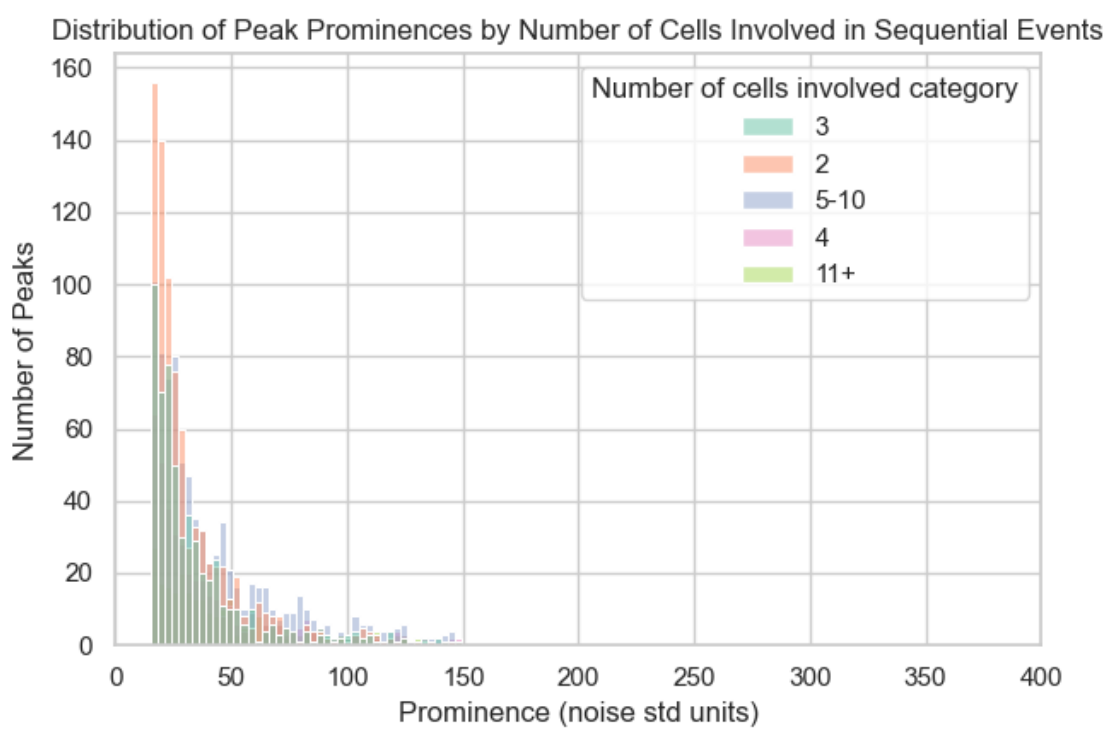


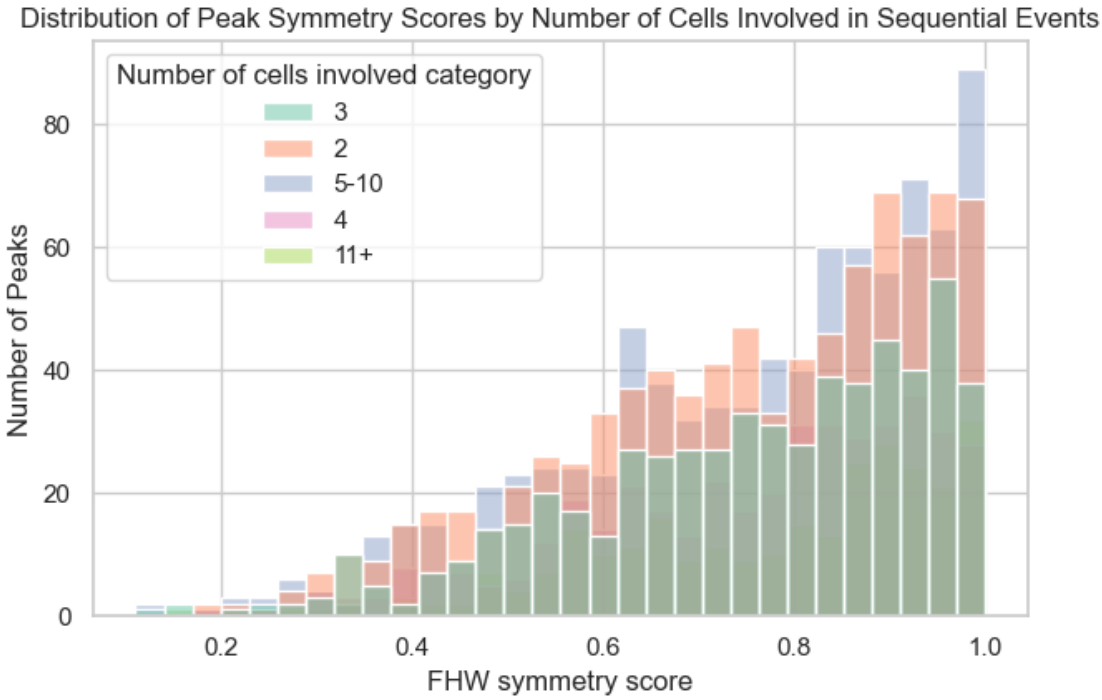
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:42:46] [INFO] calcium: plot_histogram_by_group: removed 71
outliers out of 2977 on 'Duration (s)' (lower=-18, upper=138)
```

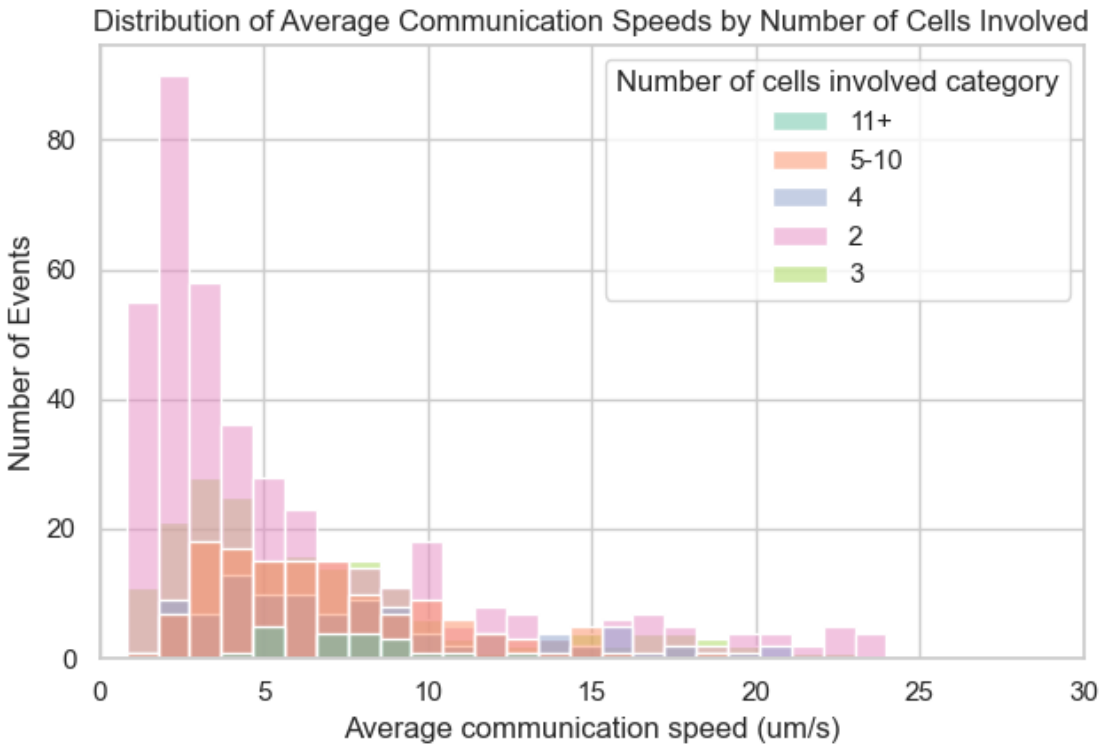



```
[2025-08-11 09:42:46] [INFO] calcium: plot_histogram_by_group: removed 88
outliers out of 2977 on 'Prominence (noise std units)' (lower=-22.8, upper=150)
```

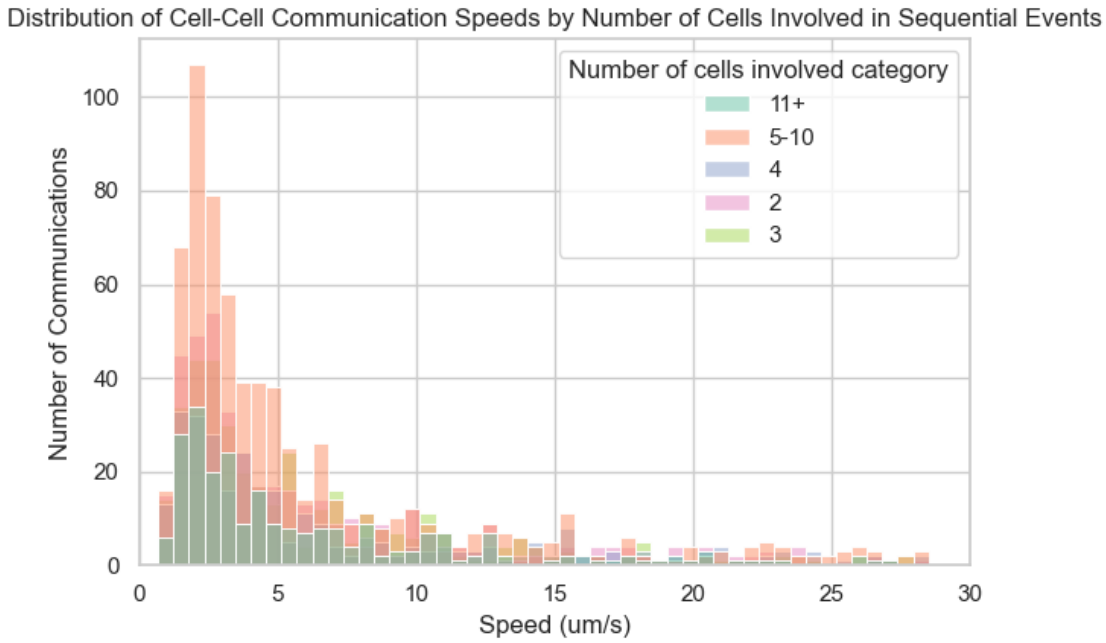




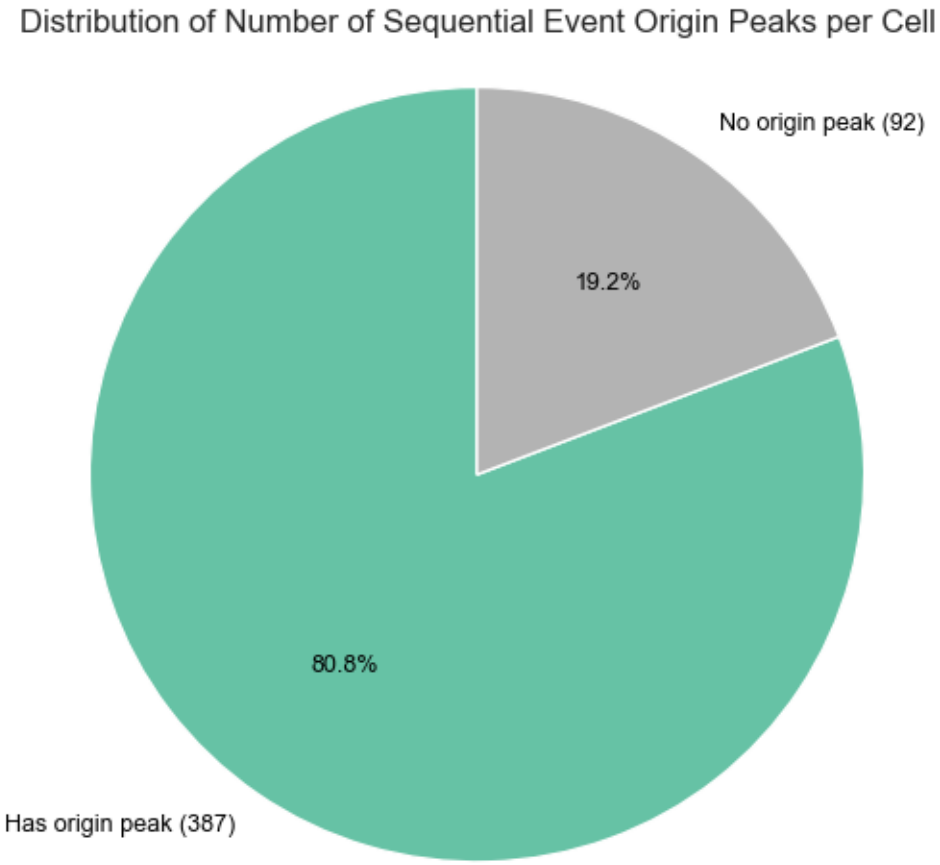

```
[2025-08-11 09:42:47] [INFO] calcium: plot_histogram_by_group: removed 13
outliers out of 875 on 'Average communication speed (um/s)' (lower=-14.61,
upper=26.305)
```

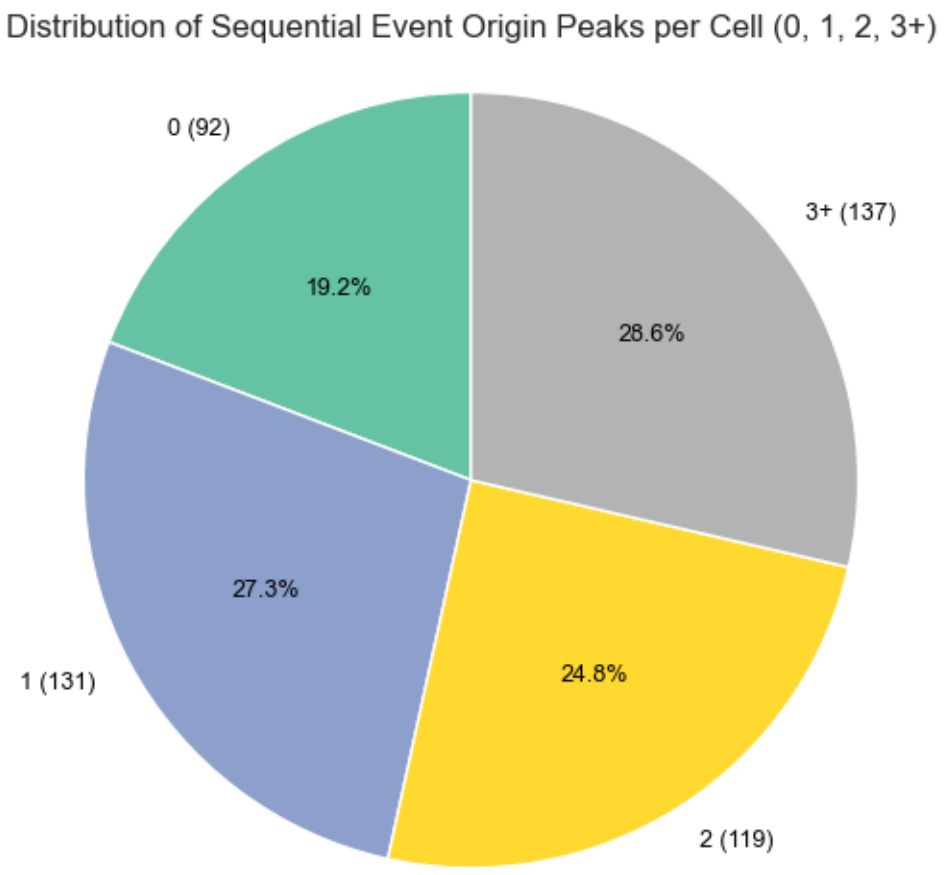



```
[2025-08-11 09:42:47] [INFO] calcium: plot_histogram_by_group: removed 60
outliers out of 2102 on 'Speed (um/s)' (lower=-17.36, upper=28.542)
```

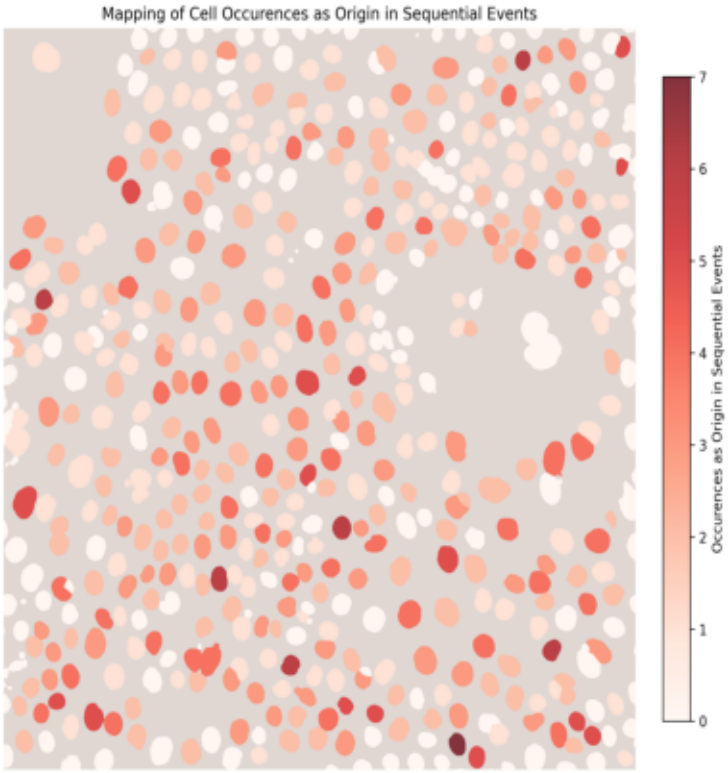


1.3.7 Cells occurences as origin in sequential events

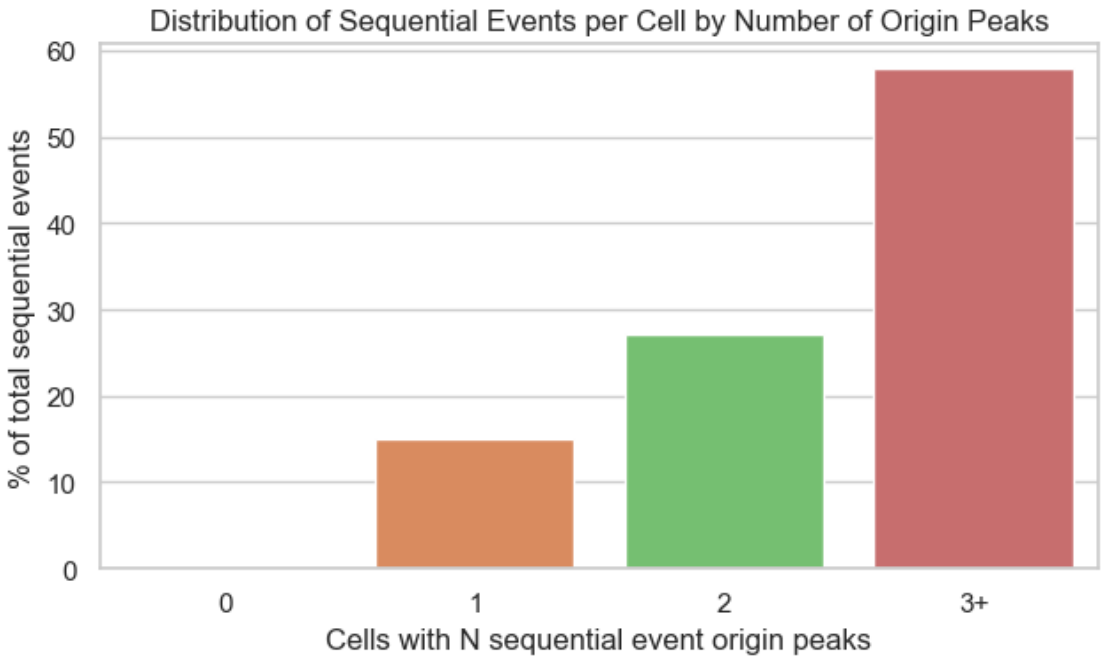



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
0 (92)
19.2%
3+ (137)
28.6%
27.3%
1 (131)
24.8%
2 (119)

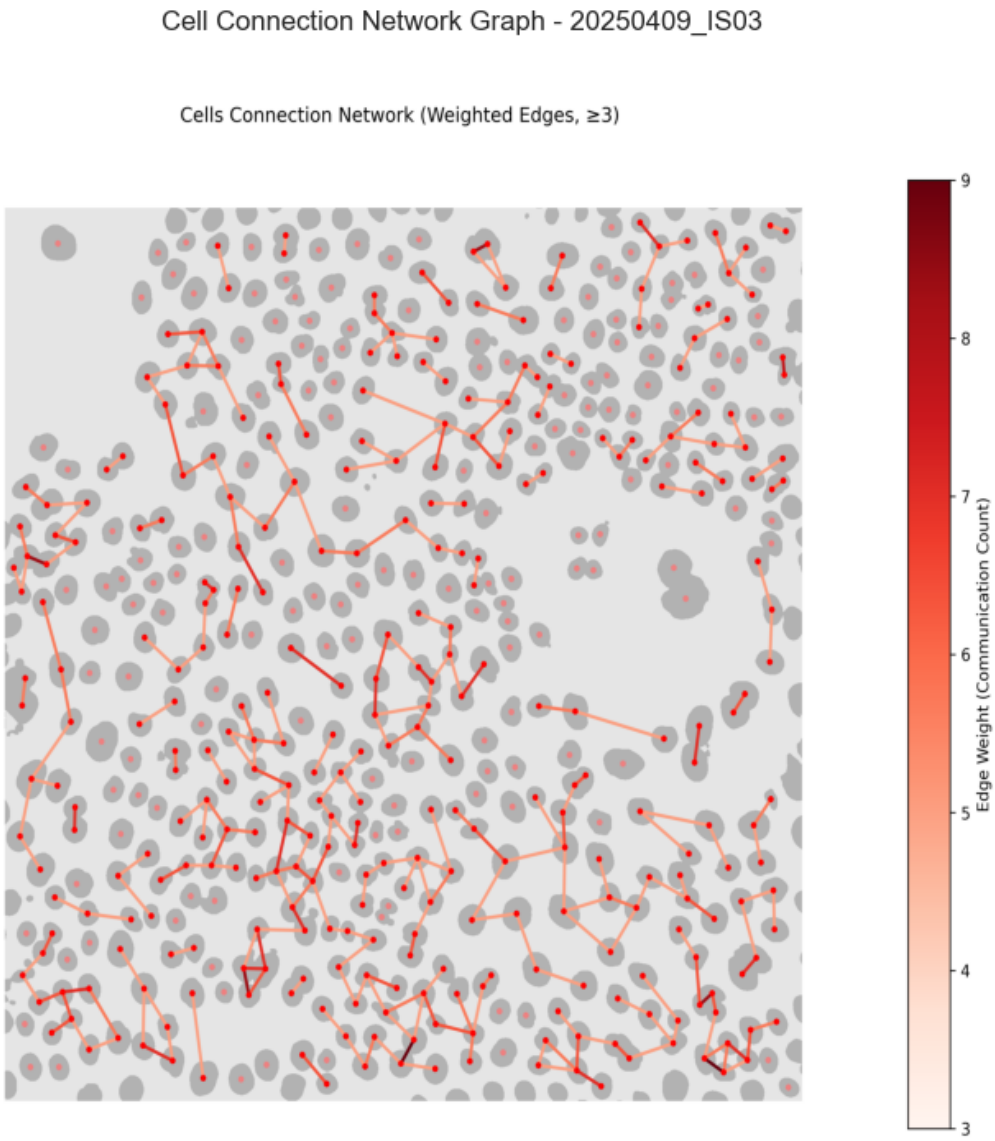
Cell Mapping with Origin Peaks Overlay - 20250409_IS03




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

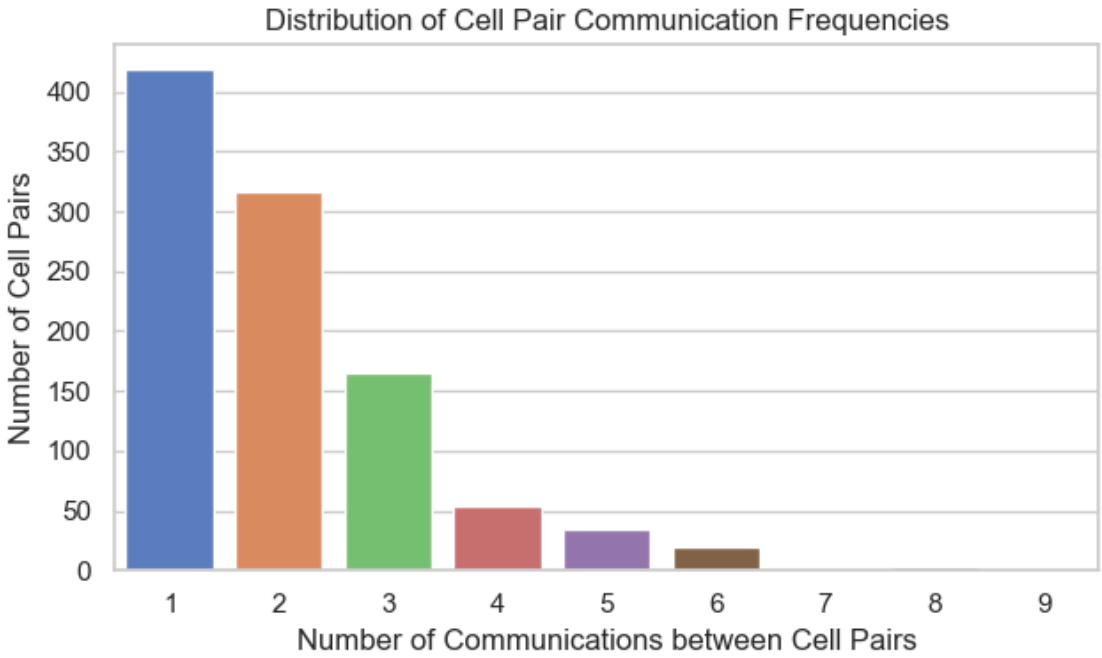

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
60
50
40
30
20
10
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



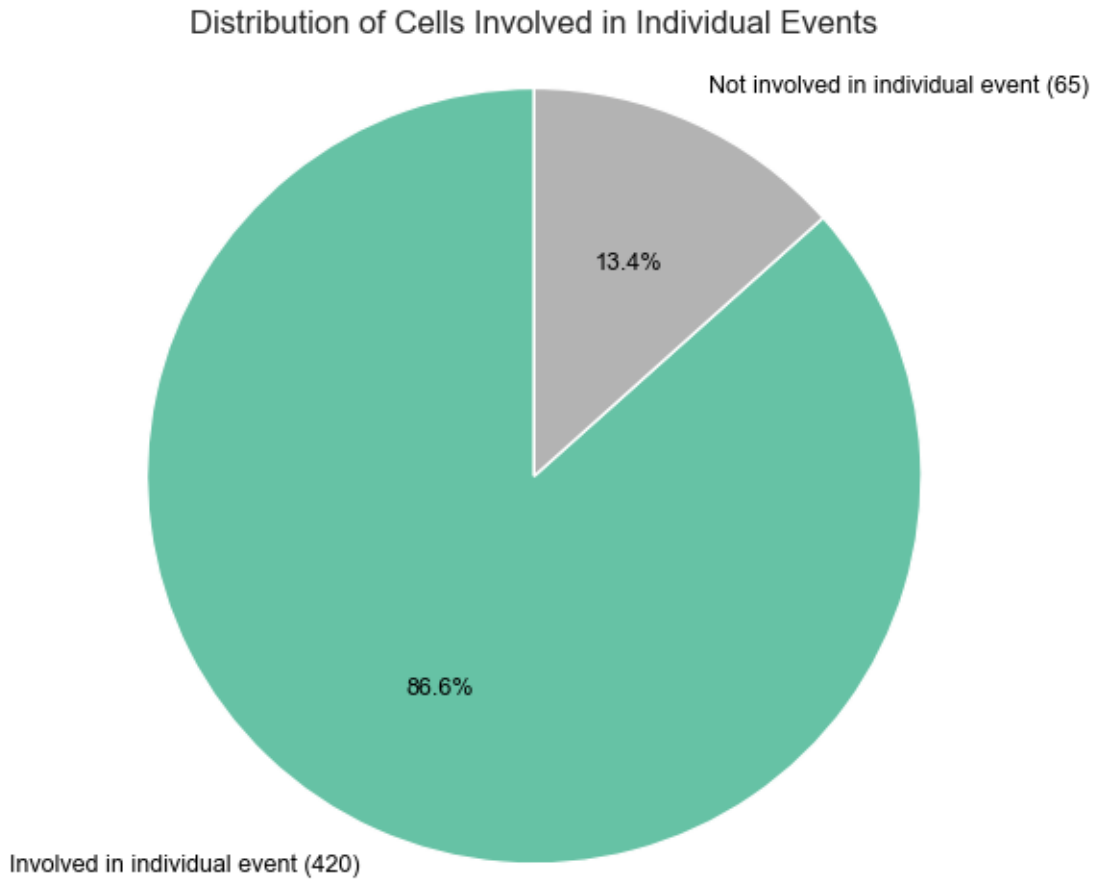

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

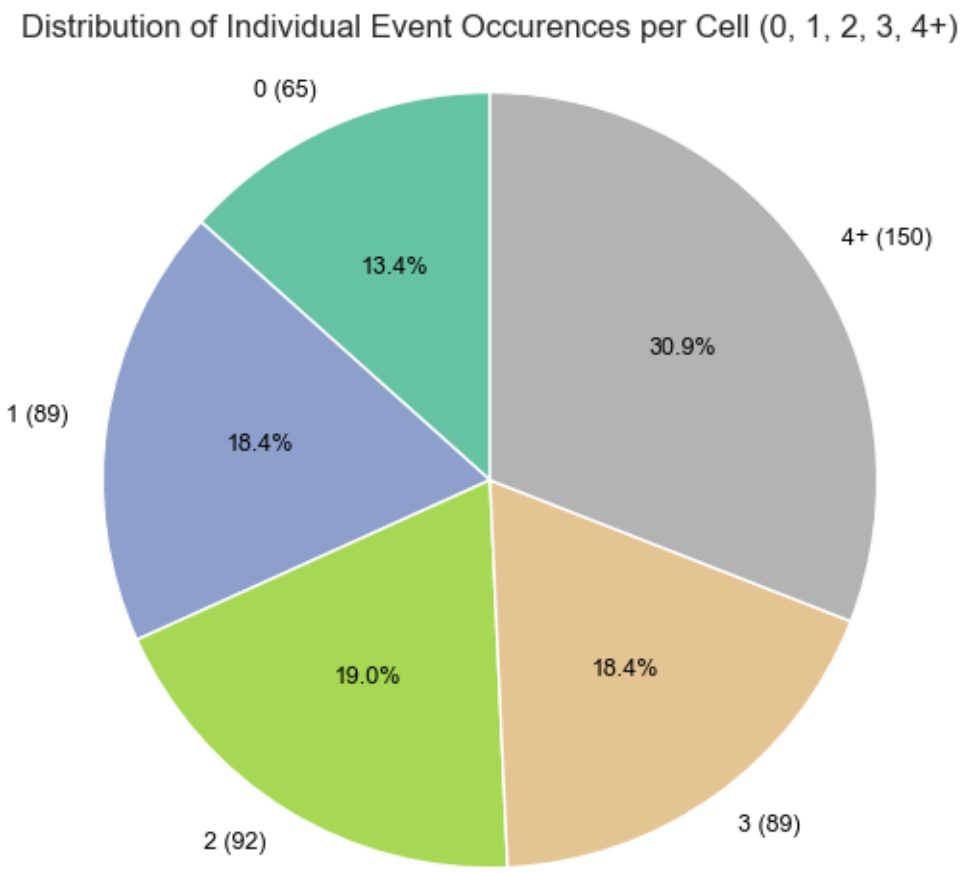
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Number of Communications between Cell Pairs

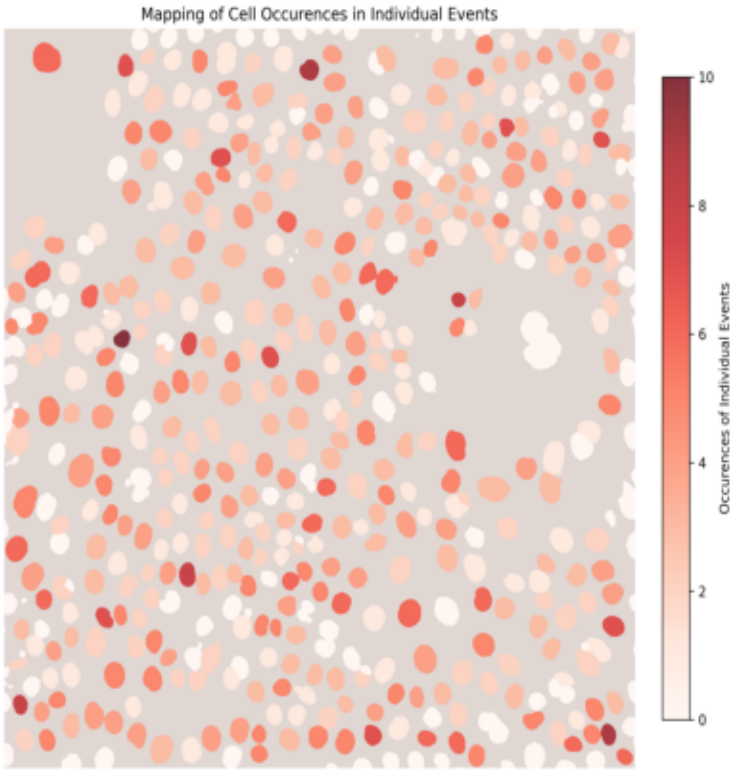
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



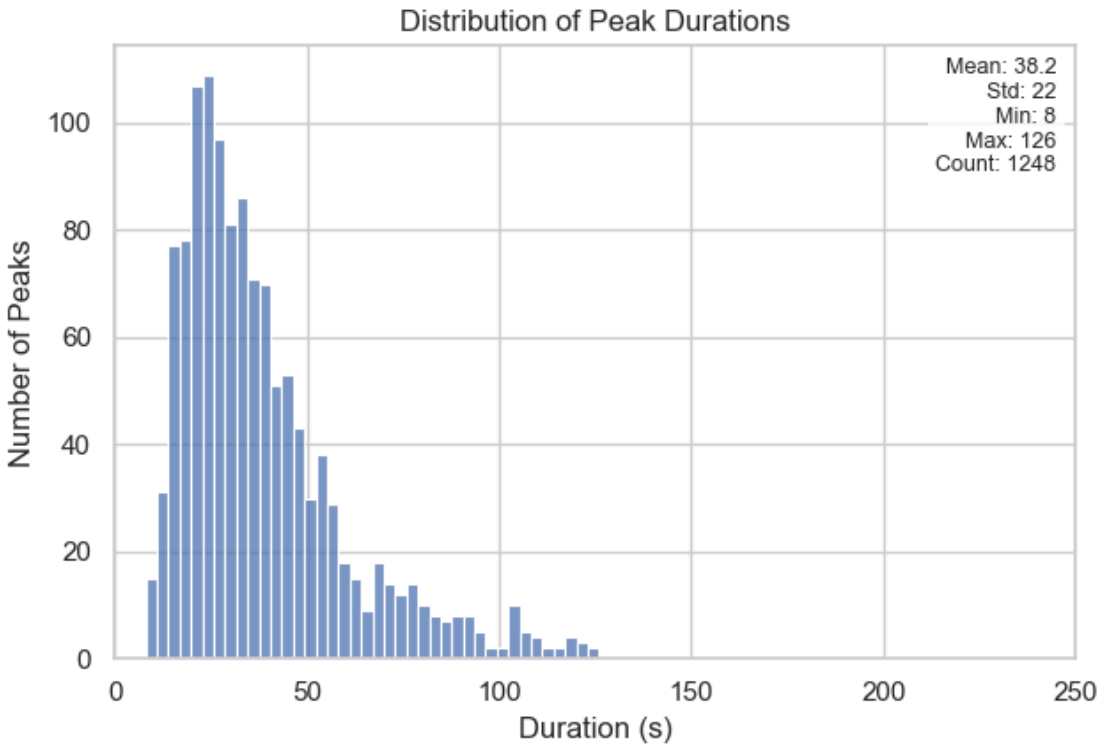

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
0 (65)
13.4%
4+ (150)
30.9%
1 (89)
18.4%
19.0%
18.4%
2 (92)
3 (89)

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS03

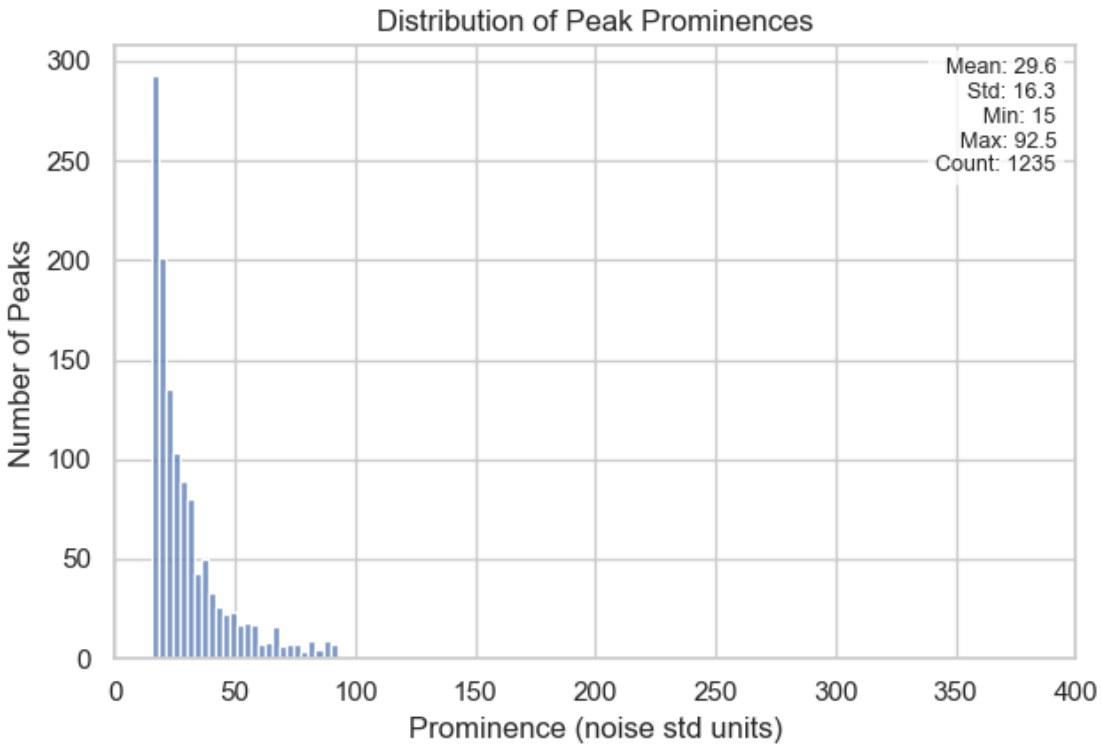


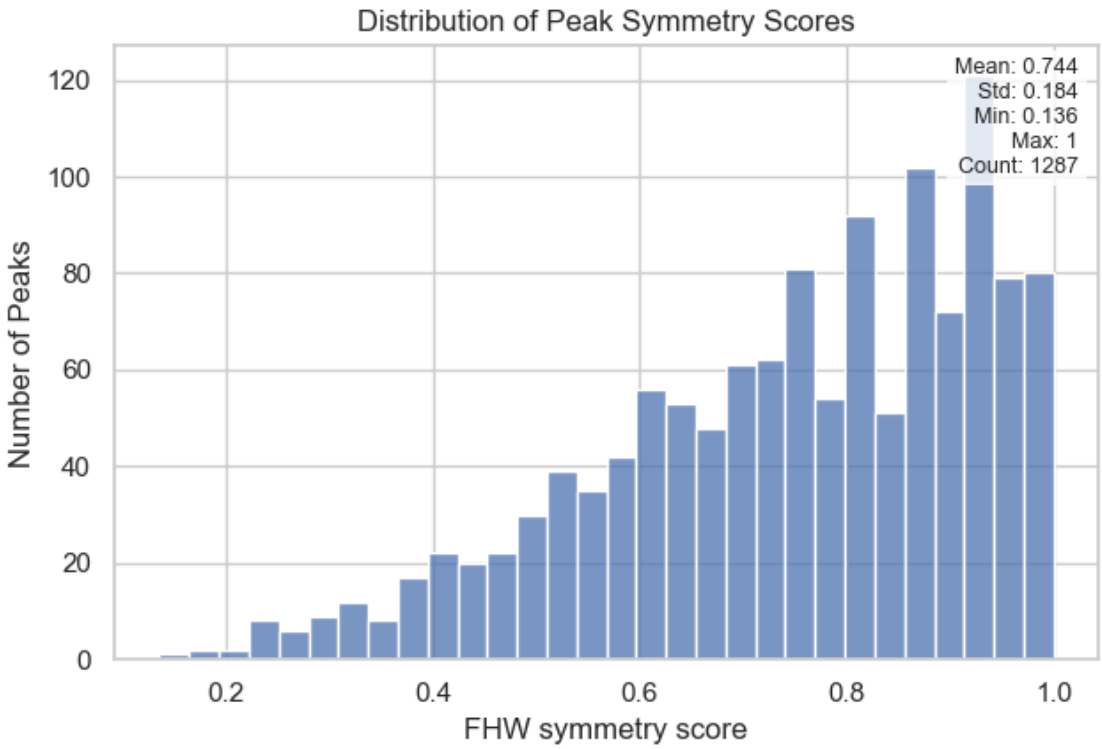
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:42:52] [INFO] calcium: plot_histogram: removed 39 outliers out of
1287 on 'Duration (s)' (lower=-55, upper=127)
```

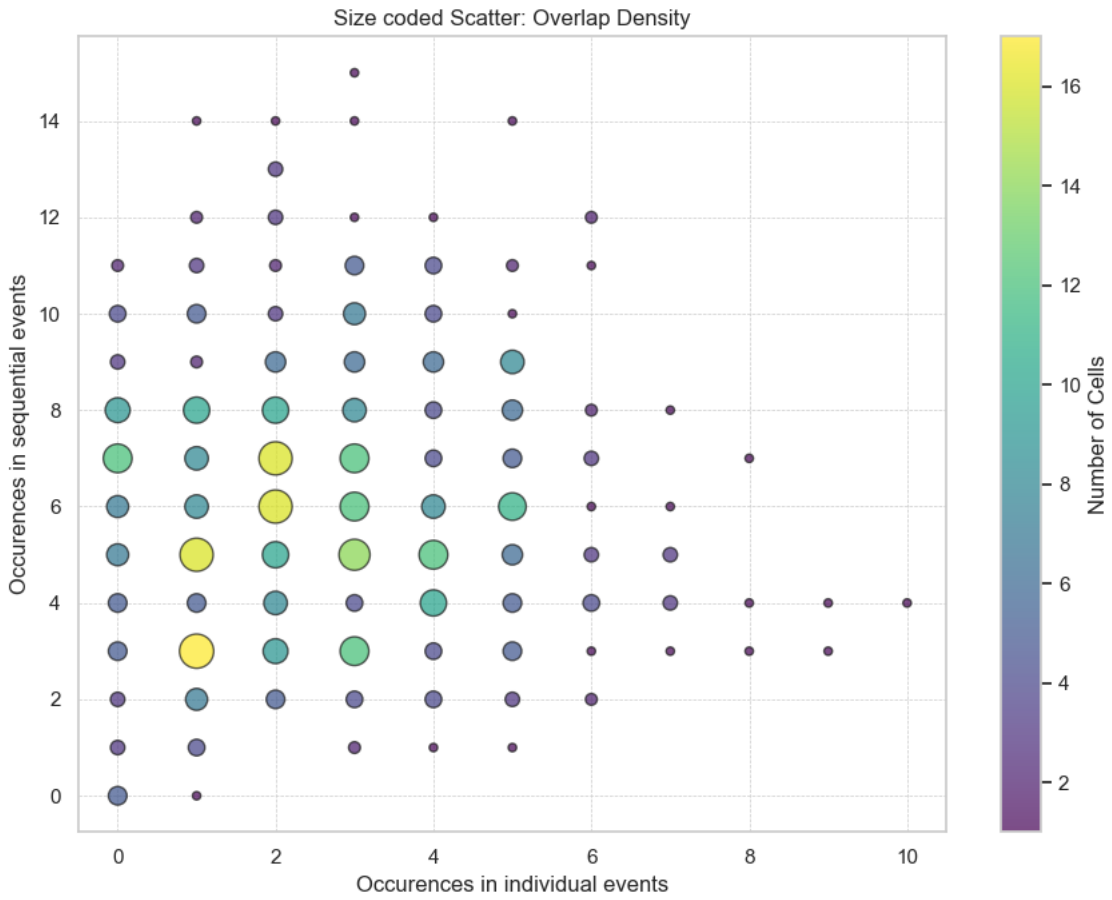



```
[2025-08-11 09:42:52] [INFO] calcium: plot_histogram: removed 52 outliers out of
1287 on 'Prominence (noise std units)' (lower=-37.55, upper=93)
```

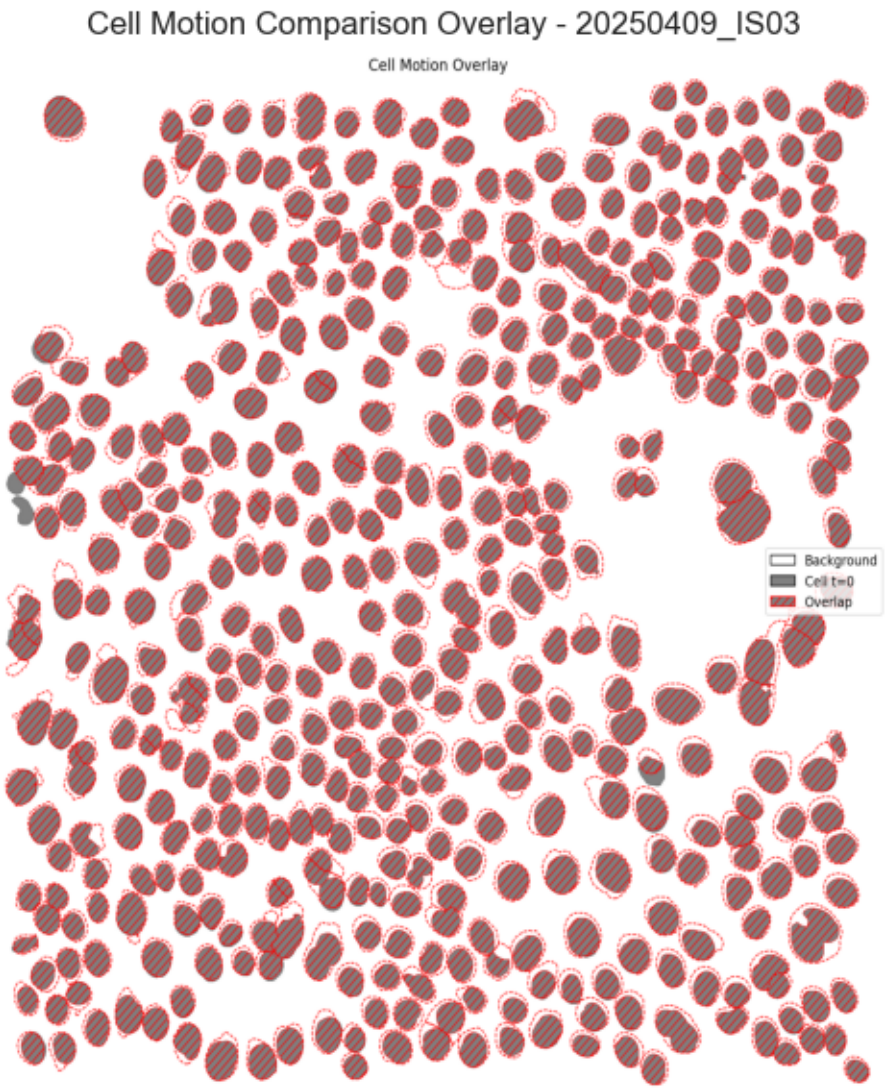

Distribution of Peak Prominences
Mean: 29.6
Std: 16.3
Min: 15
Max: 92.5
Count: 1235
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores
Mean: 0.744
Std: 0.184
Min: 0.136
Max: 1
Count: 1287
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 485
- Hoechst image taken at t=1801: 479
- Number of cells difference: absolute 6, relative 1.24%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 753273
- Pixels segmented as cell at t=1801: 957052
- Overlapping pixels between t=0 and t=1801: 734853(85.93% of total)
- Pixels exclusive to t=0: 18420 (2.44% of total)
- Pixels exclusive to t=1801: 222199 (23.22% of total)
```

executed

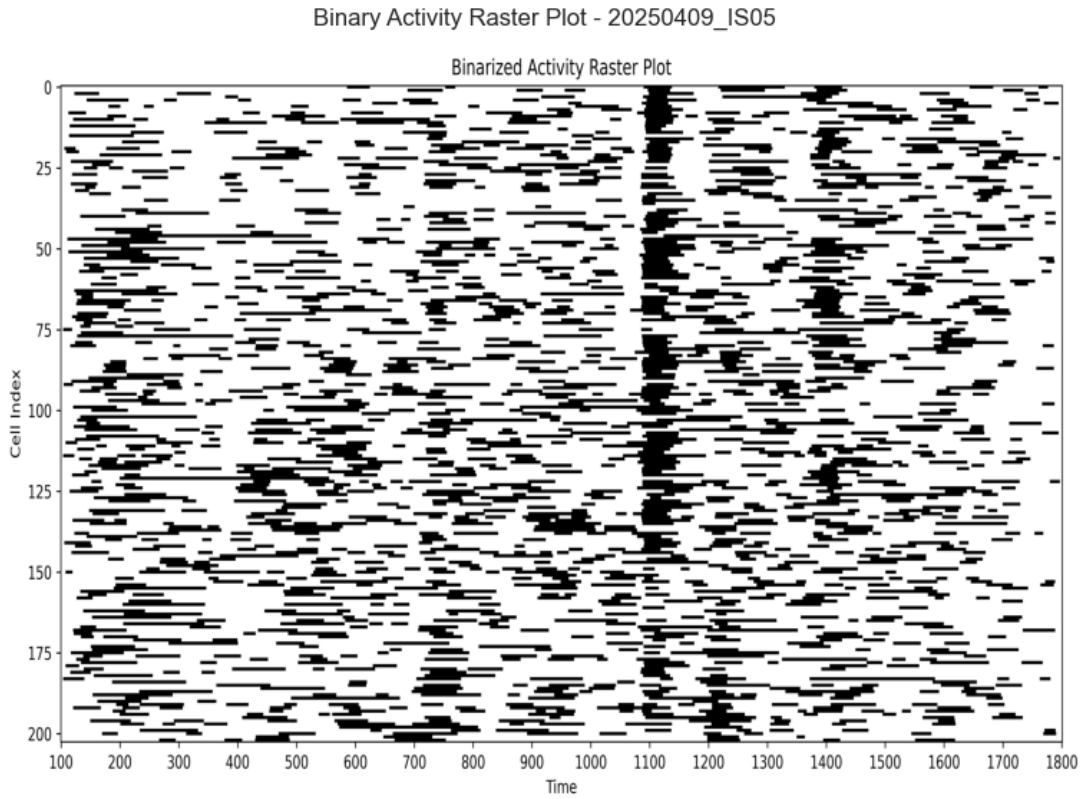
August 11, 2025

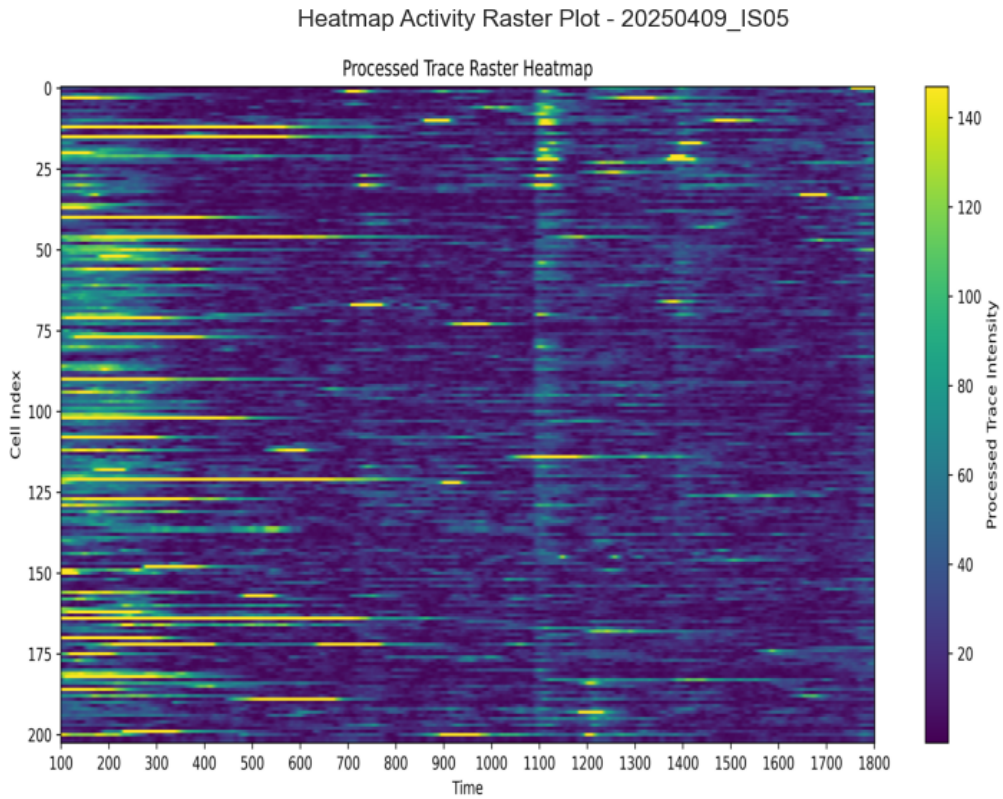
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



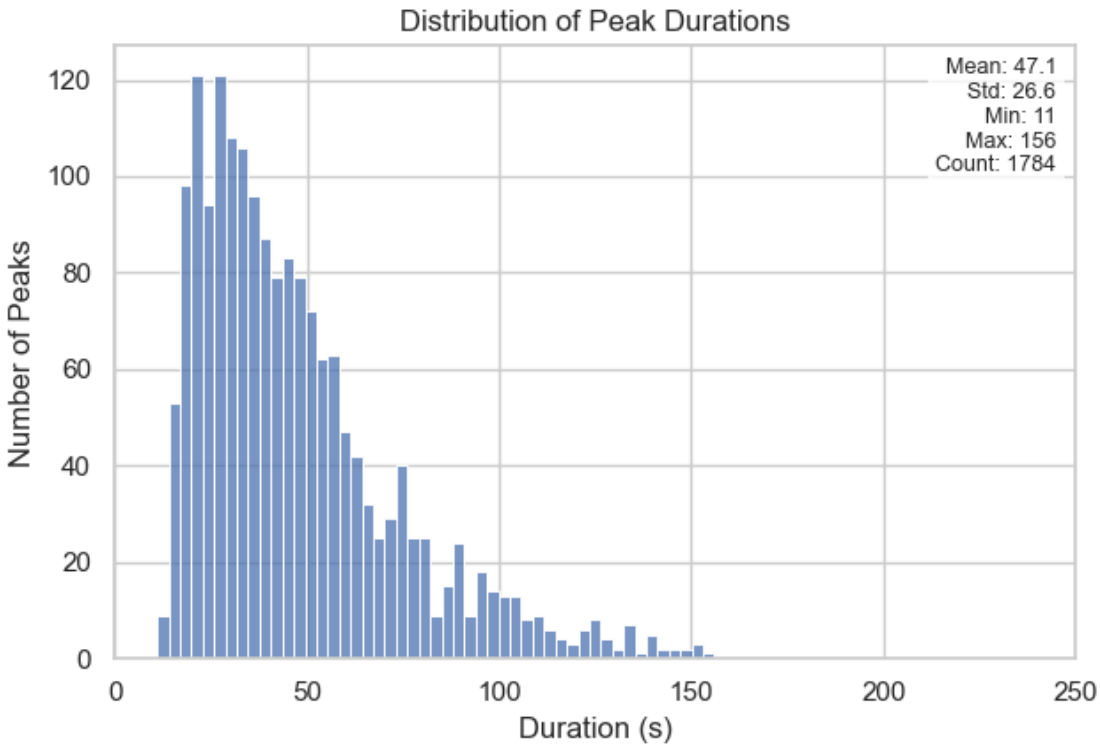


1.1.2 Peaks population

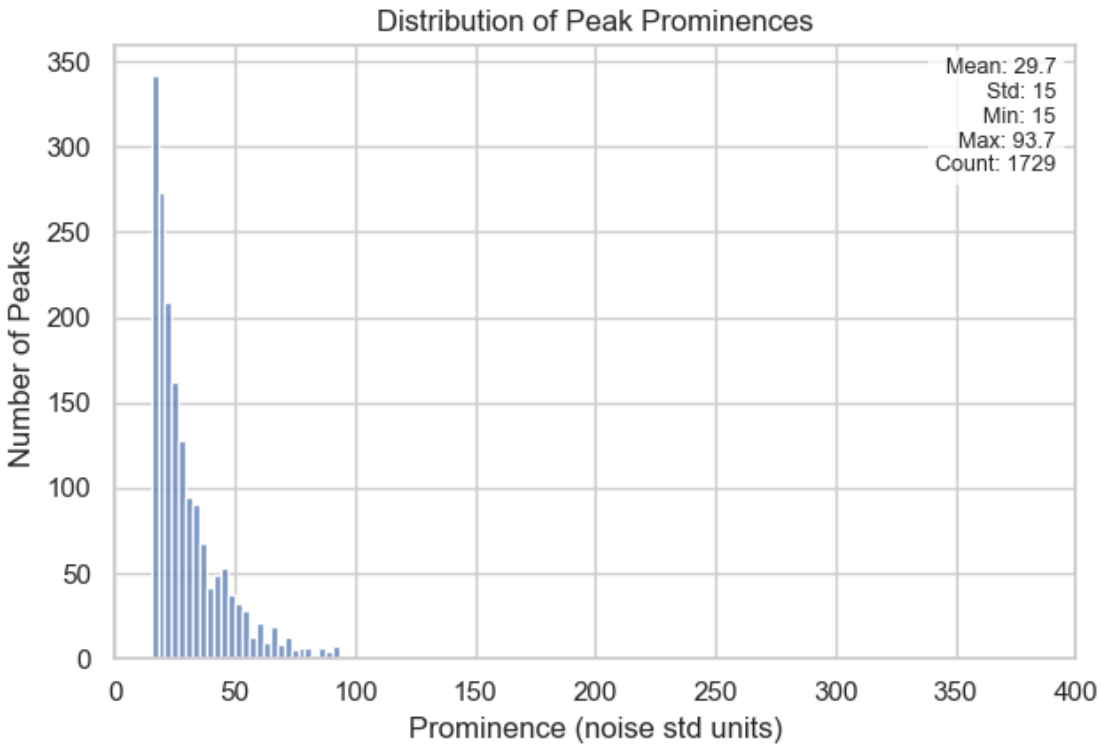
```
Total number of peaks: 1806
Total number of cells: 203
```

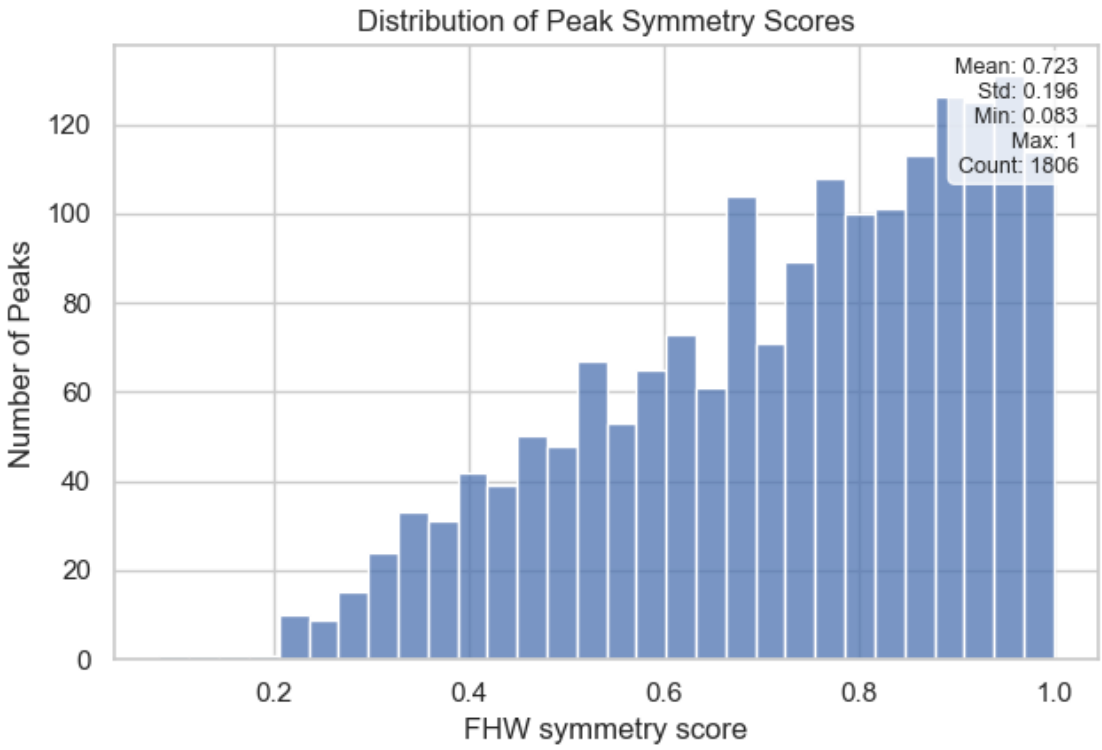
1.1.3 Peaks statistics

```
[2025-08-11 09:43:54] [INFO] calcium: plot_histogram: removed 22 outliers out of
1806 on 'Duration (s)' (lower=-68, upper=156)
```

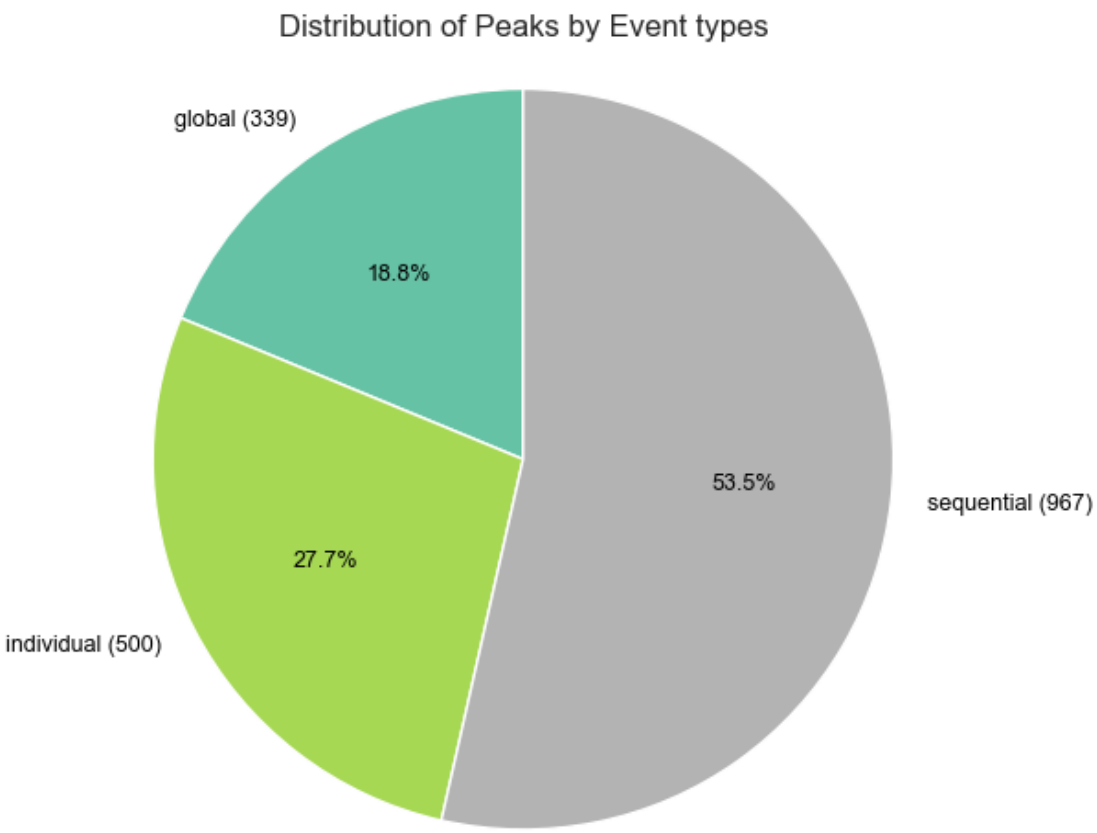



```
[2025-08-11 09:43:54] [INFO] calcium: plot_histogram: removed 77 outliers out of
1806 on 'Prominence (noise std units)' (lower=-37.4, upper=94.2)
```


Distribution of Peak Prominences
Mean: 29.7
Std: 15
Min: 15
Max: 93.7
Count: 1729
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400

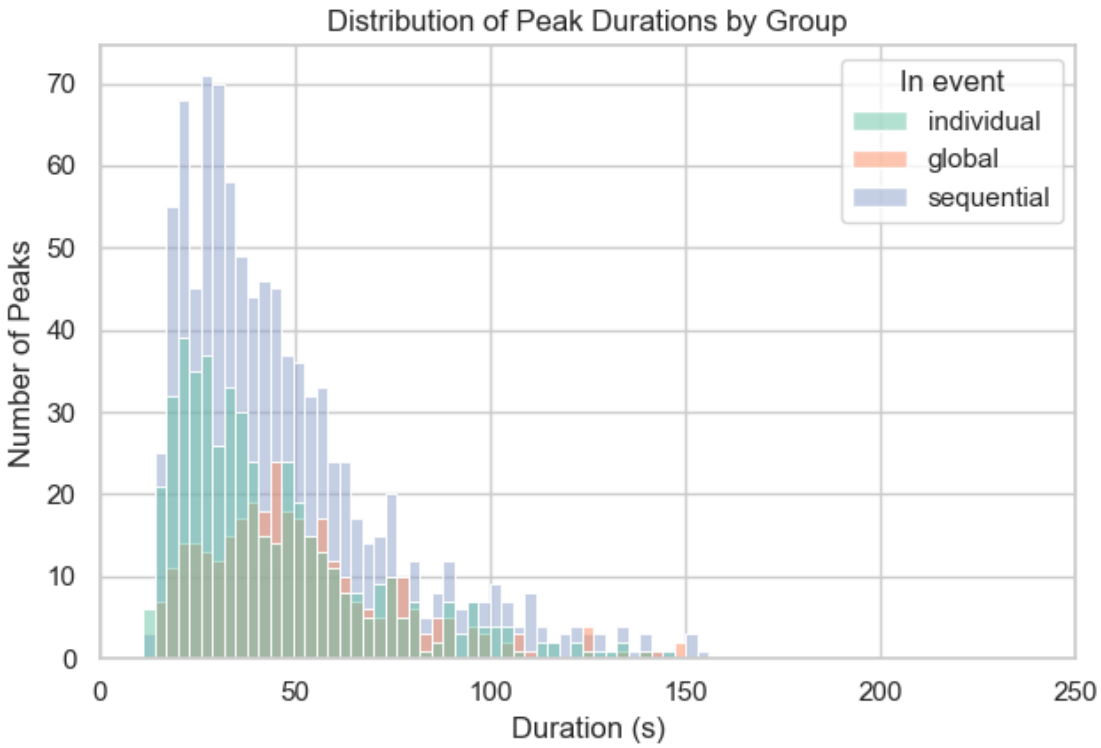

Distribution of Peak Symmetry Scores
Mean: 0.723
Std: 0.196
Min: 0.083
Max: 1
Count: 1806
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0

1.1.4 Distribution of peaks per event types

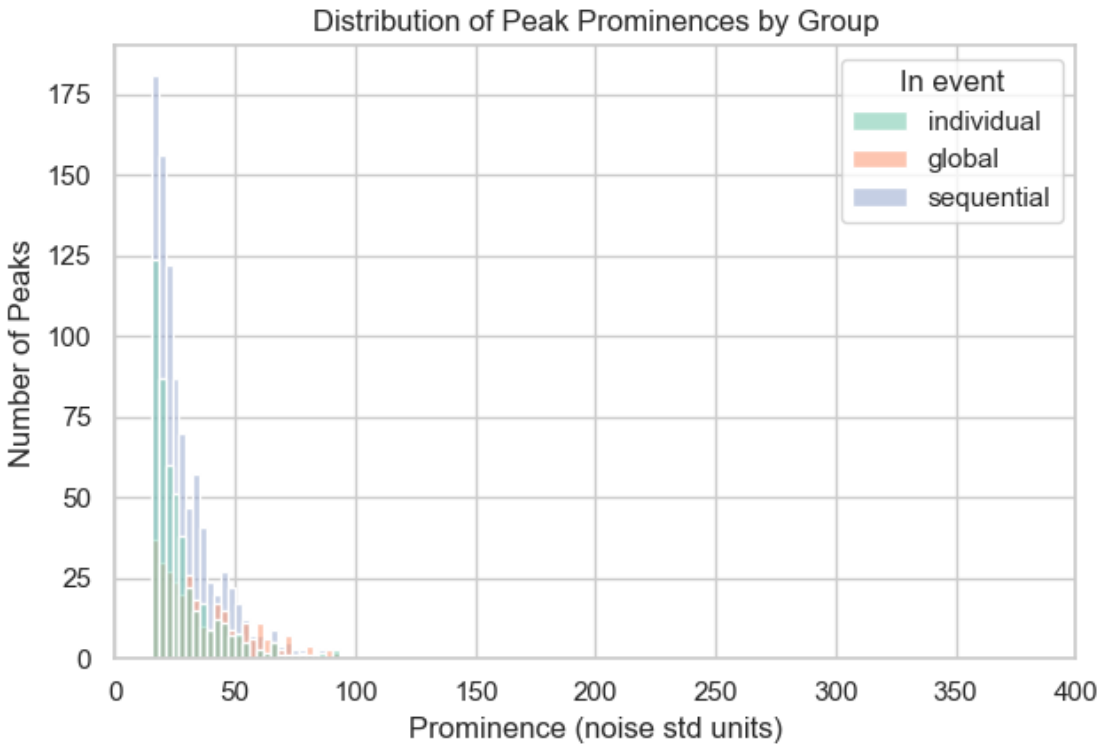


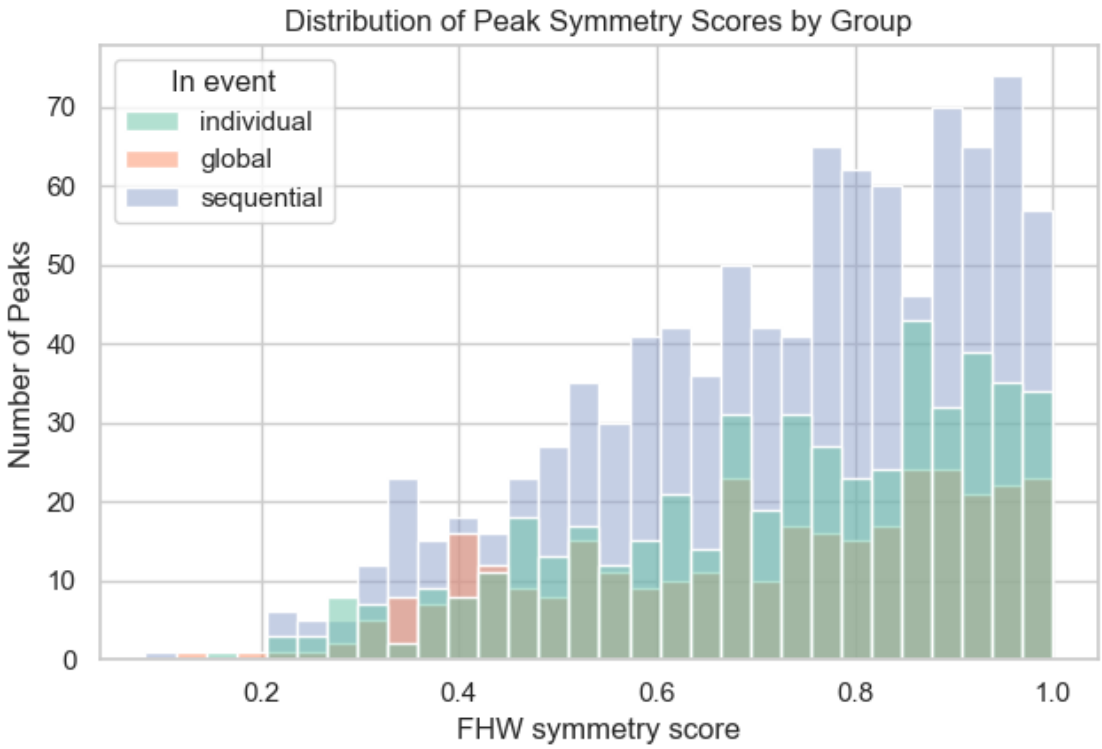
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:43:55] [INFO] calcium: plot_histogram_by_group: removed 22
outliers out of 1806 on 'Duration (s)' (lower=-68, upper=156)
```




```
[2025-08-11 09:43:55] [INFO] calcium: plot_histogram_by_group: removed 77
outliers out of 1806 on 'Prominence (noise std units)' (lower=-37.4, upper=94.2)
```

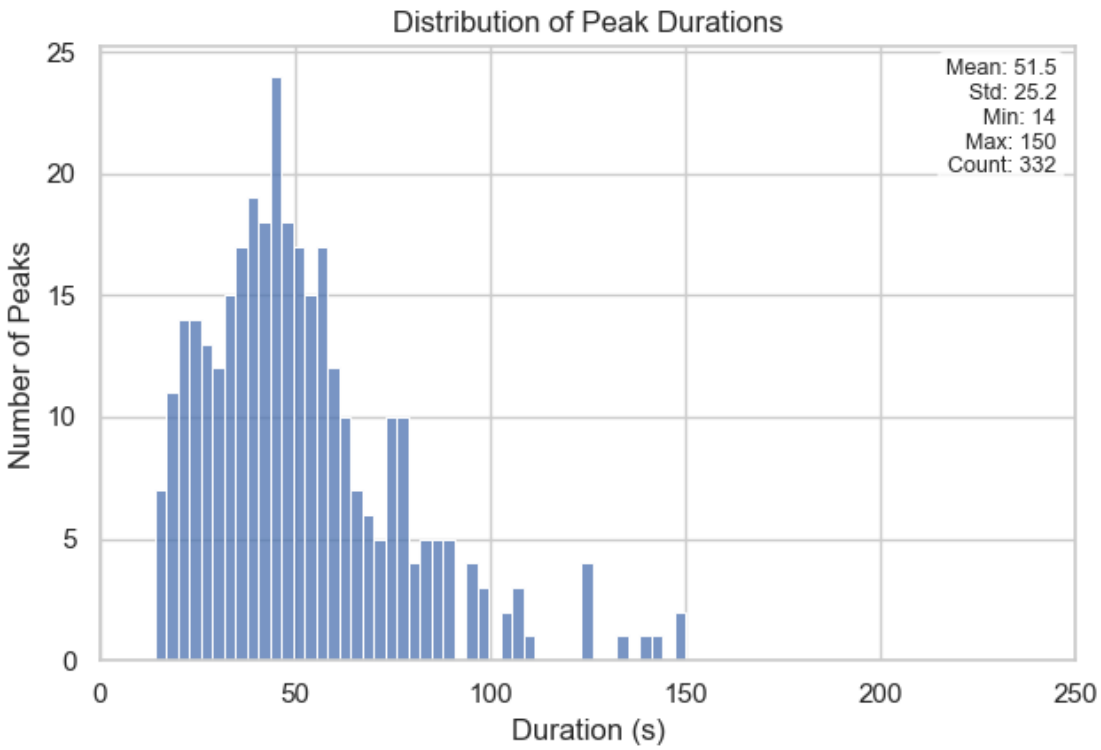

Distribution of Peak Prominences by Group
In event
individual
global
sequential
Number of Peaks
0
25
50
75
100
125
150
175
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
individual
global
sequential
Number of Peaks
0
10
20
30
40
50
60
70
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

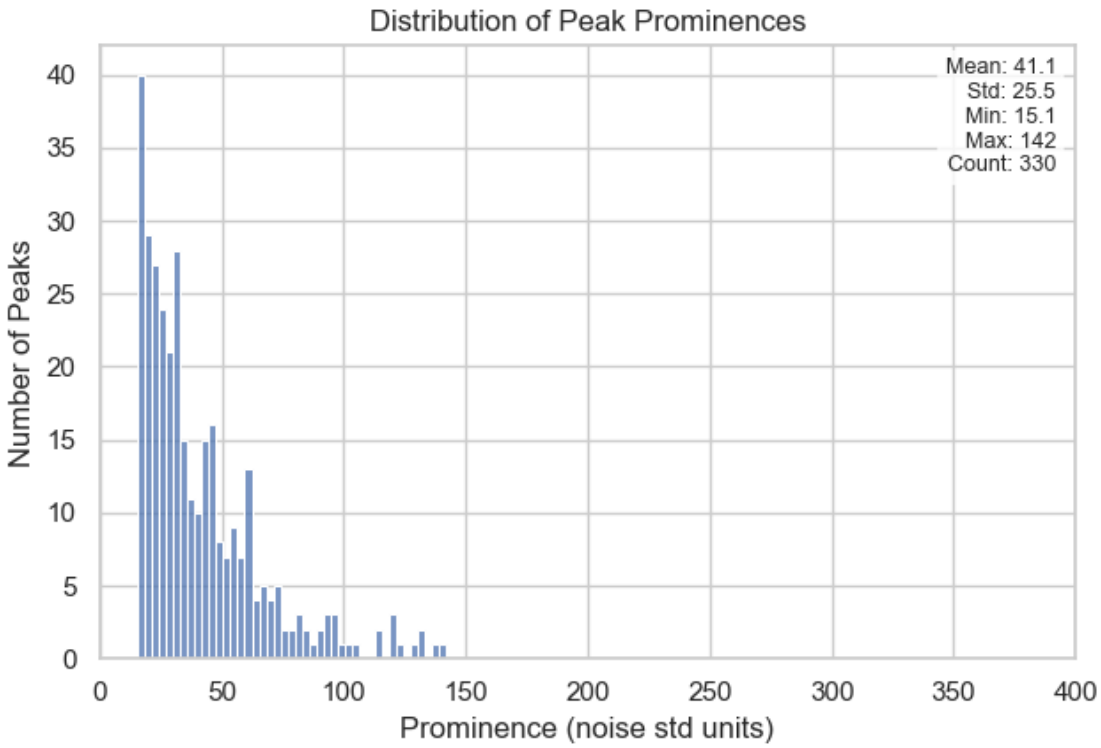
1.2 GLOBAL EVENTS

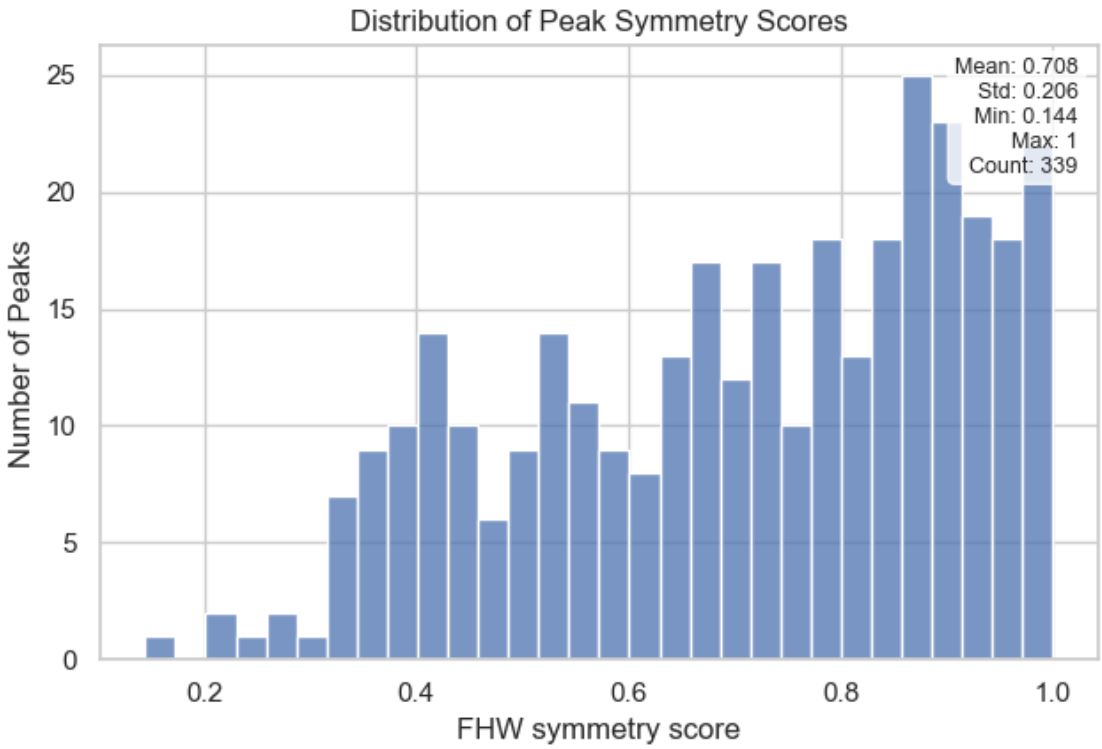
1.2.1 Peak statistics in global events

```
[2025-08-11 09:43:55] [INFO] calcium: plot_histogram: removed 7 outliers out of
339 on 'Duration (s)' (lower=-59, upper=158)
```



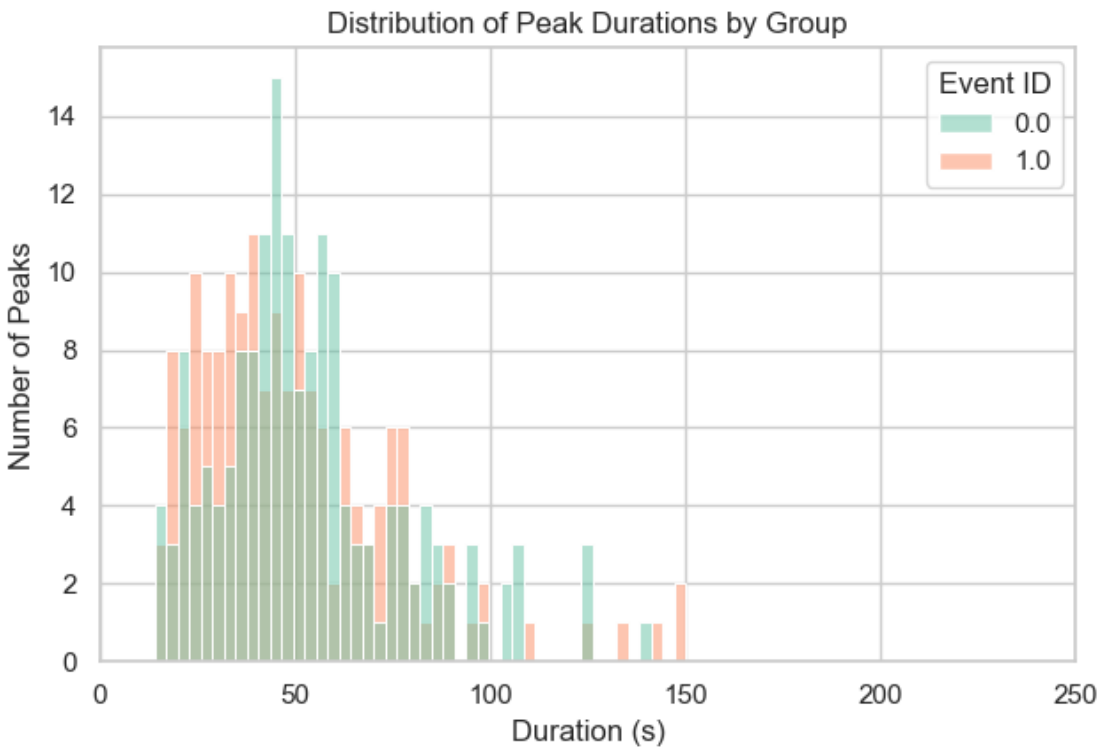

```
[2025-08-11 09:43:56] [INFO] calcium: plot_histogram: removed 9 outliers out of
339 on 'Prominence (noise std units)' (lower=-73.4, upper=150.25)
```


Distribution of Peak Prominences
Mean: 41.1
Std: 25.5
Min: 15.1
Max: 142
Count: 330
Number of Peaks
Prominence (noise std units)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

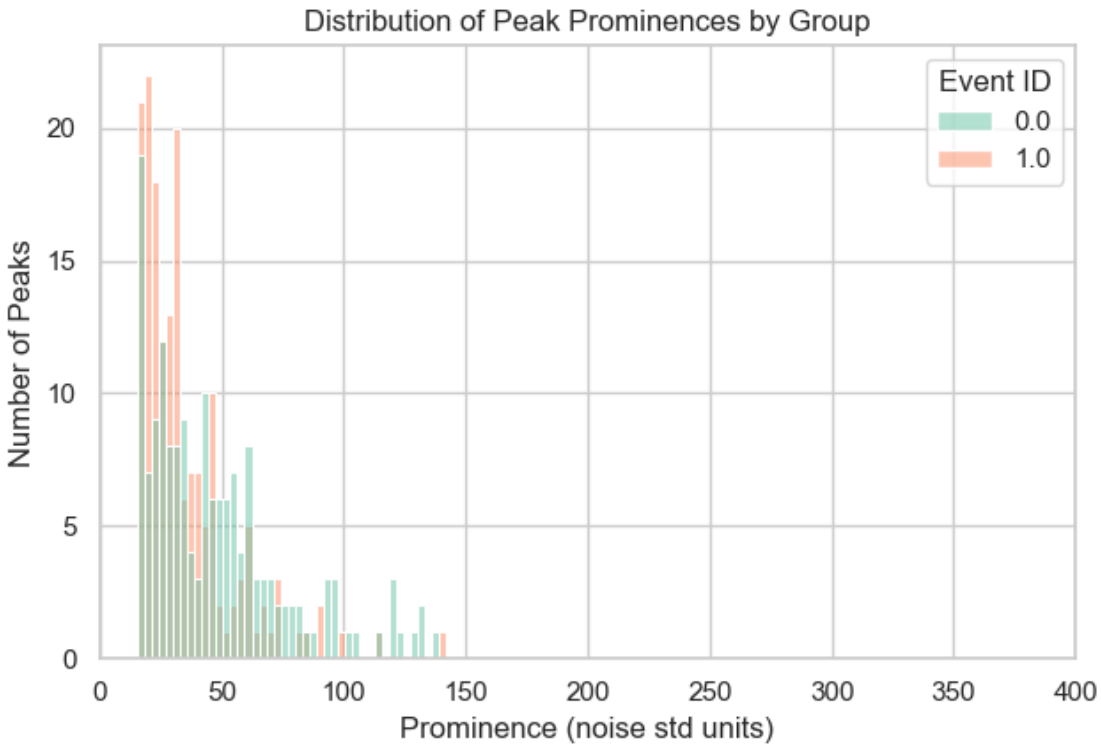

Distribution of Peak Symmetry Scores
Mean: 0.708
Std: 0.206
Min: 0.144
Max: 1
Count: 339
Number of Peaks
FHW symmetry score
0
5
10
15
20
25
0.2
0.4
0.6
0.8
1.0

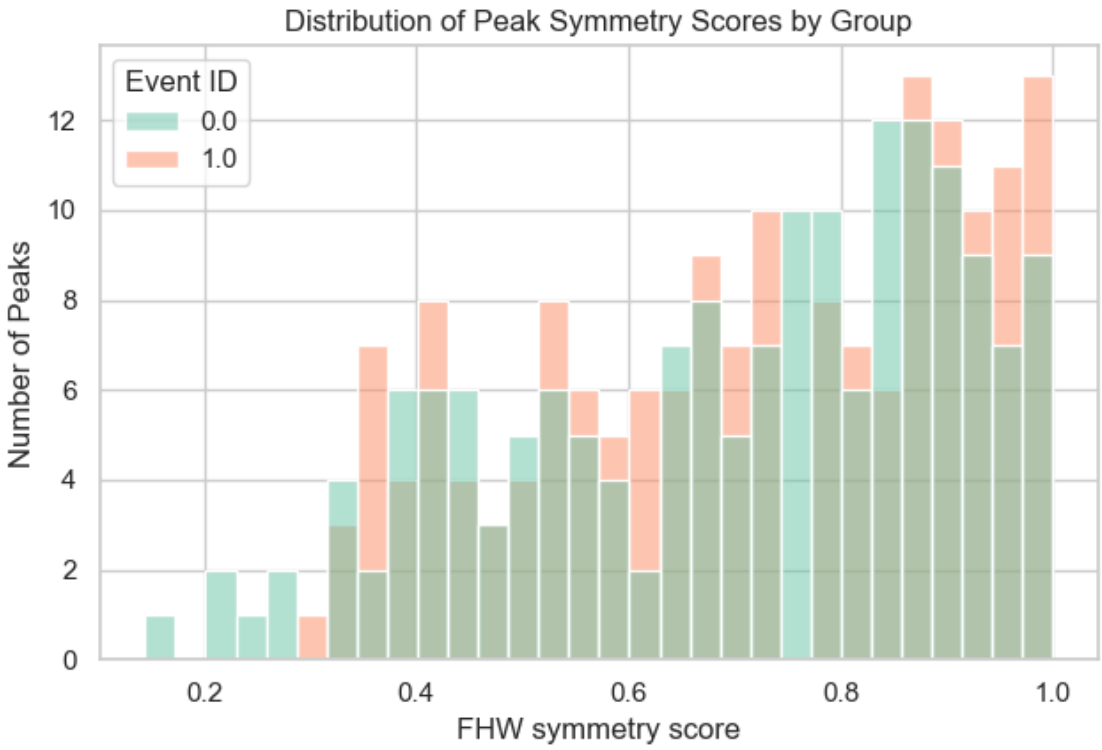
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:43:56] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 339 on 'Duration (s)' (lower=-59, upper=158)
```

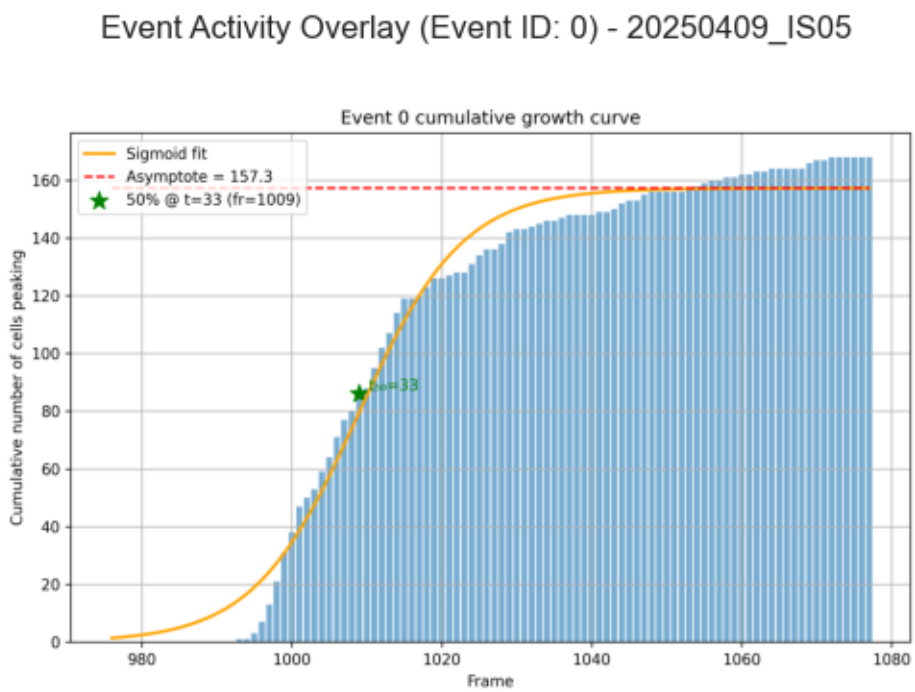


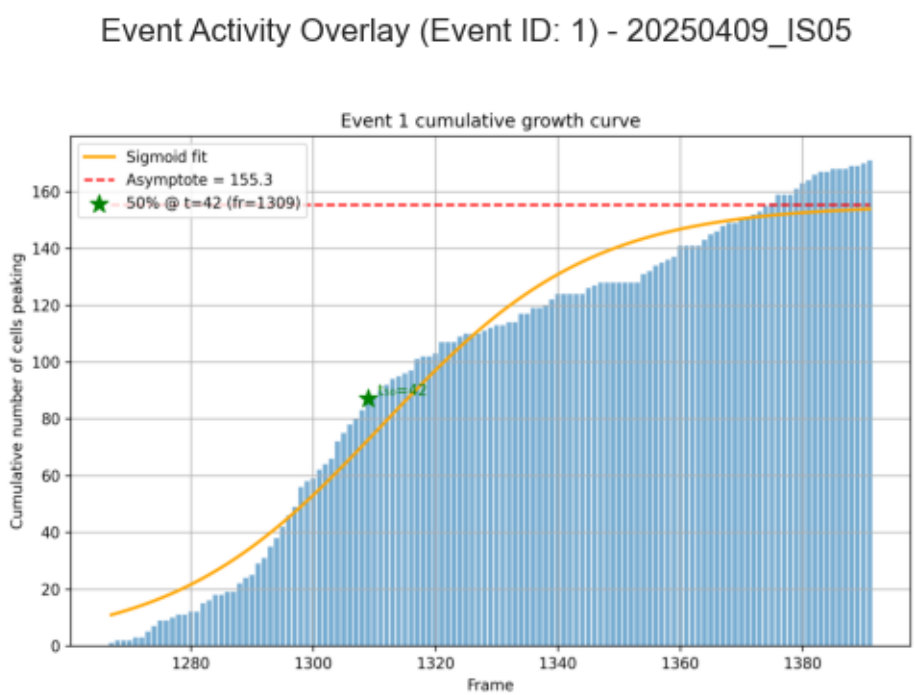

```
[2025-08-11 09:43:56] [INFO] calcium: plot_histogram_by_group: removed 9
outliers out of 339 on 'Prominence (noise std units)' (lower=-73.4,
upper=150.25)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
Number of Peaks
0
5
10
15
20
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

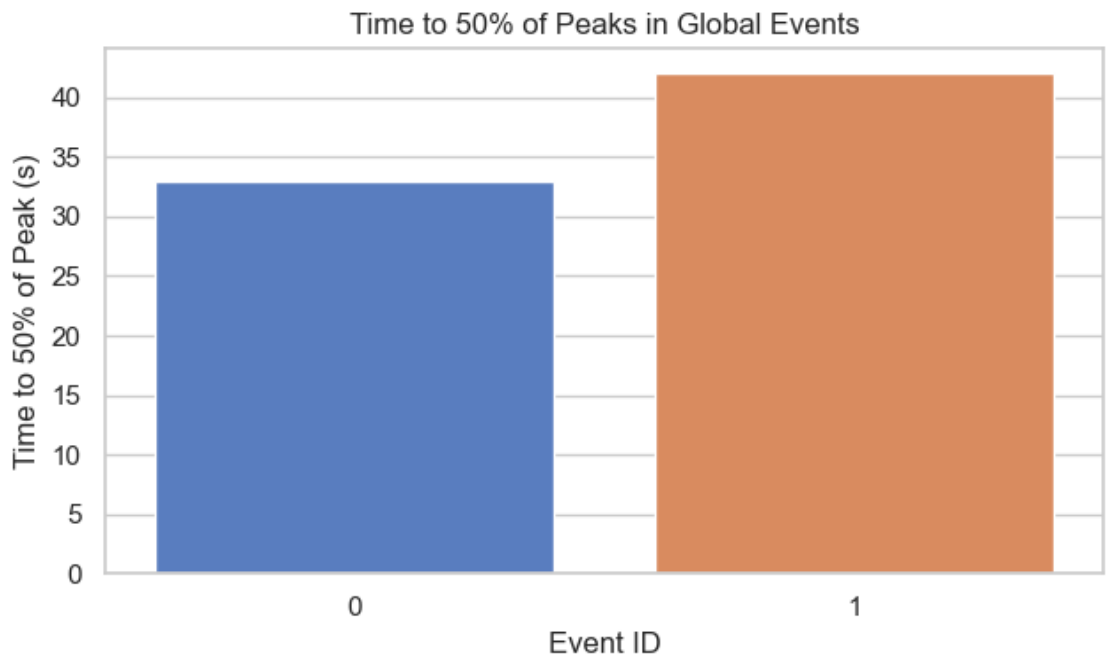

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
Number of Peaks
0
2
4
6
8
10
12
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2.3 Kinetics of global events

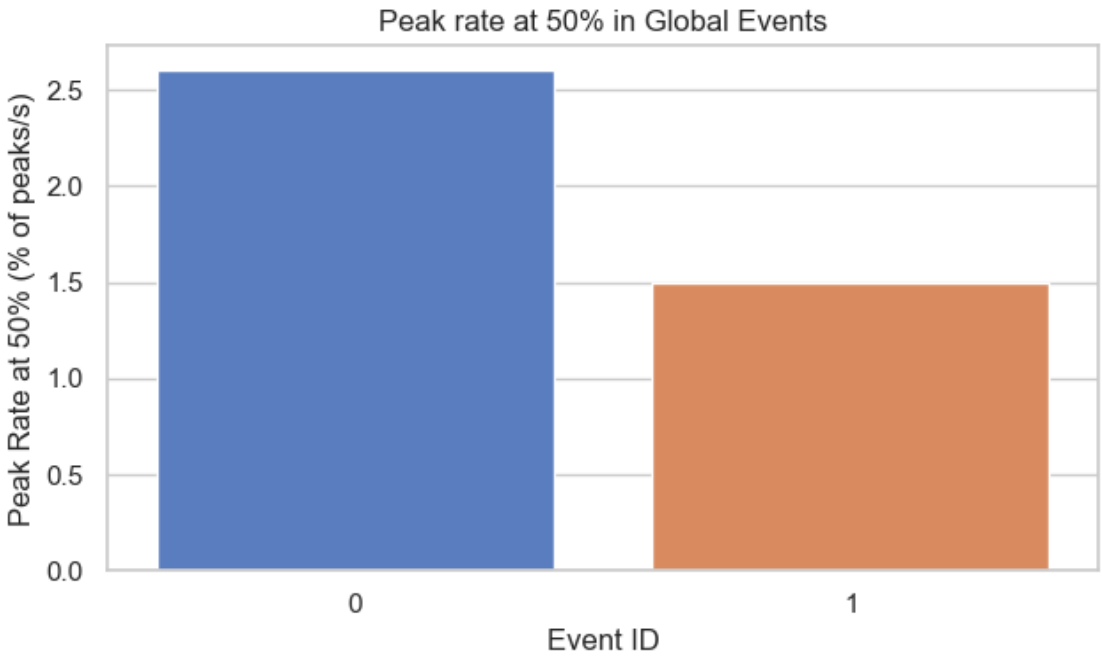




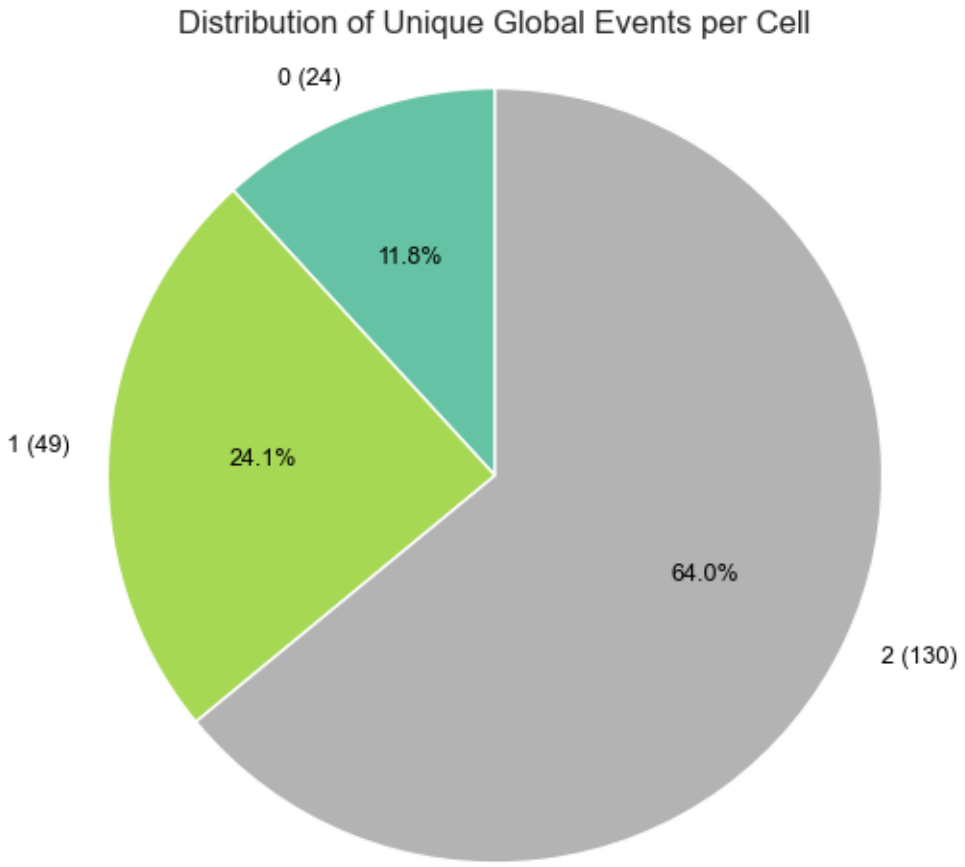
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



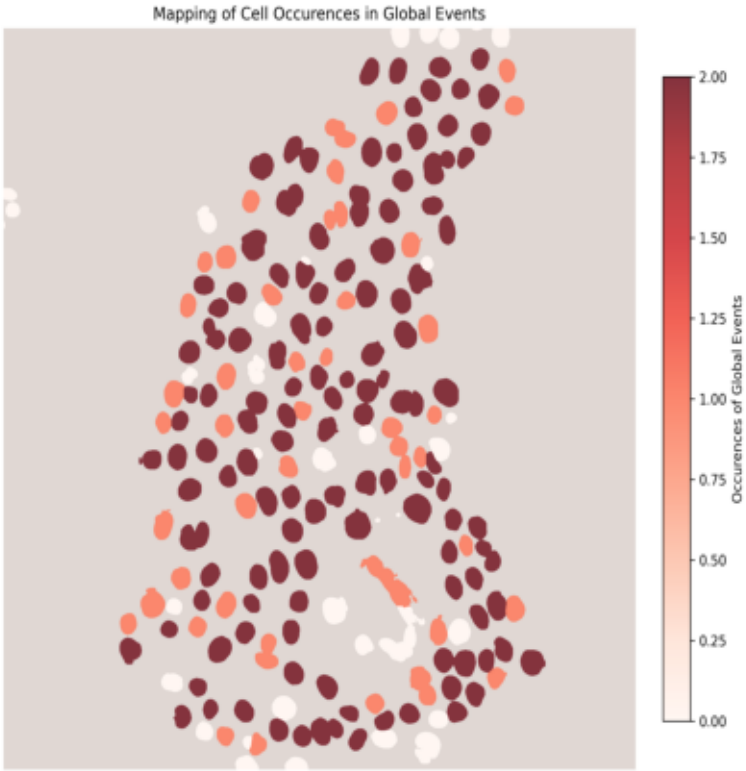

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.5
2.0
1.5
1.0
0.5
0.0
0
1
Event ID

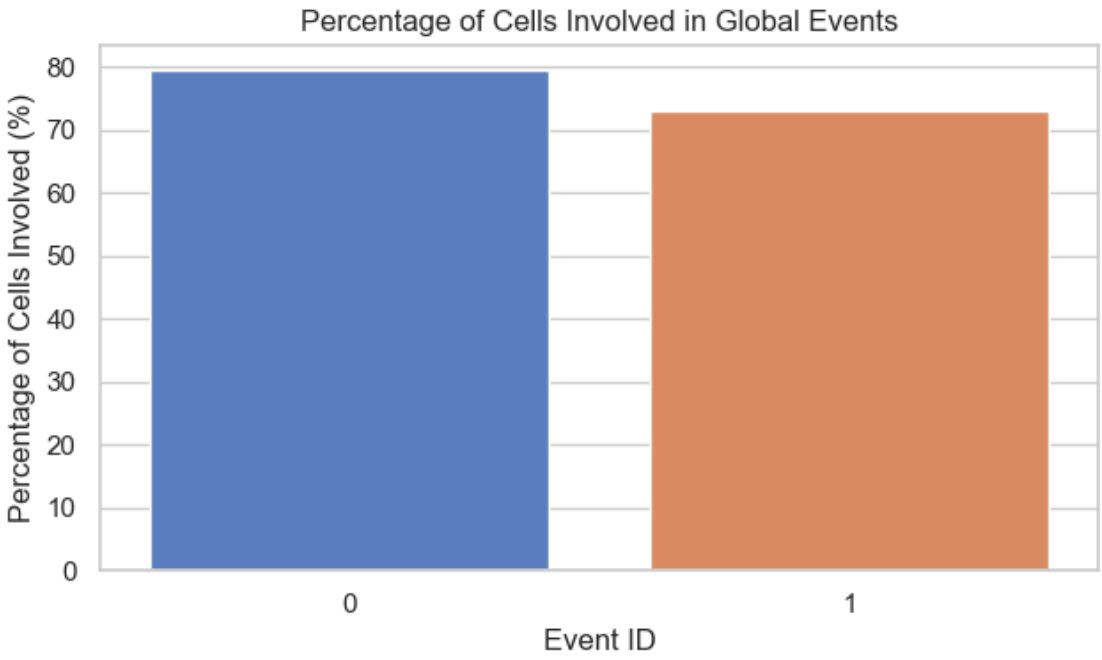
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS05




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



1.2.5 Inter-event interval analysis

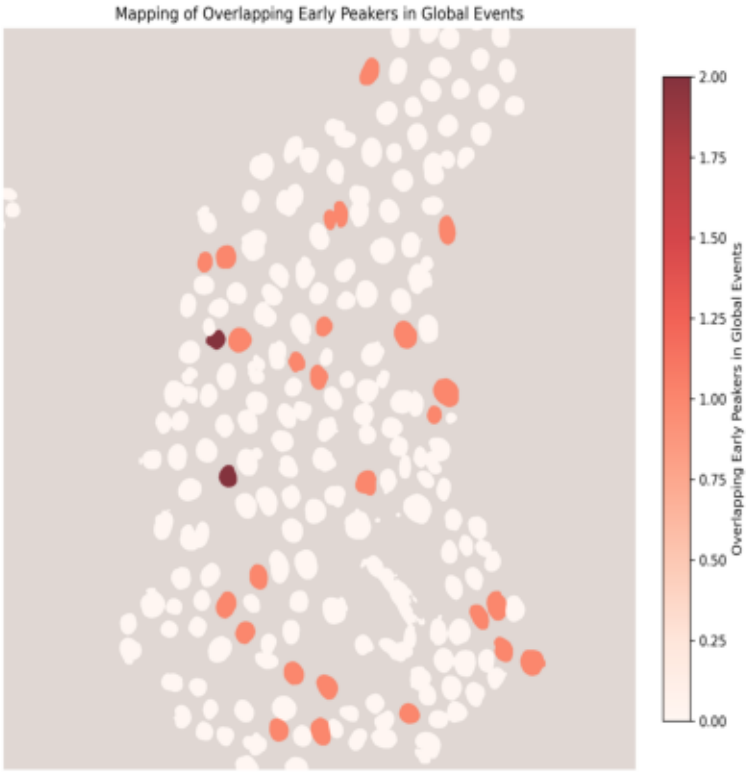
```
Intervals between global event peaks: [292.0]
```

1.2.6 Early peakers in the events

Cell Mapping with Early Peakers Overlay for event 0 - 20250409_IS05

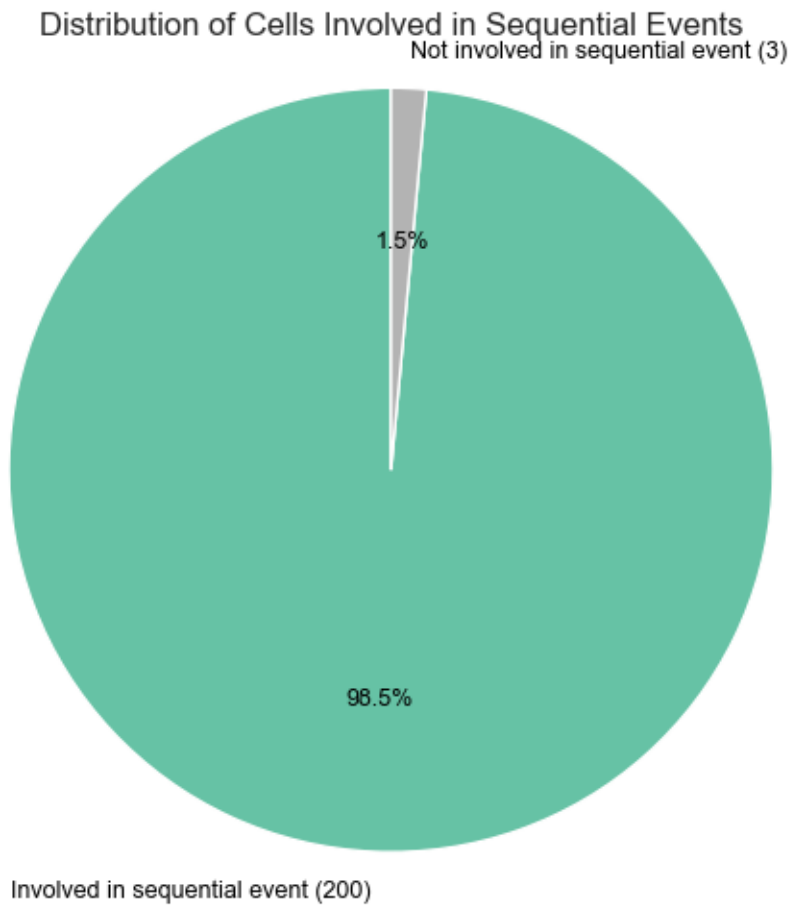
Cell Mapping with Early Peakers Overlay for event 1 - 20250409_IS05

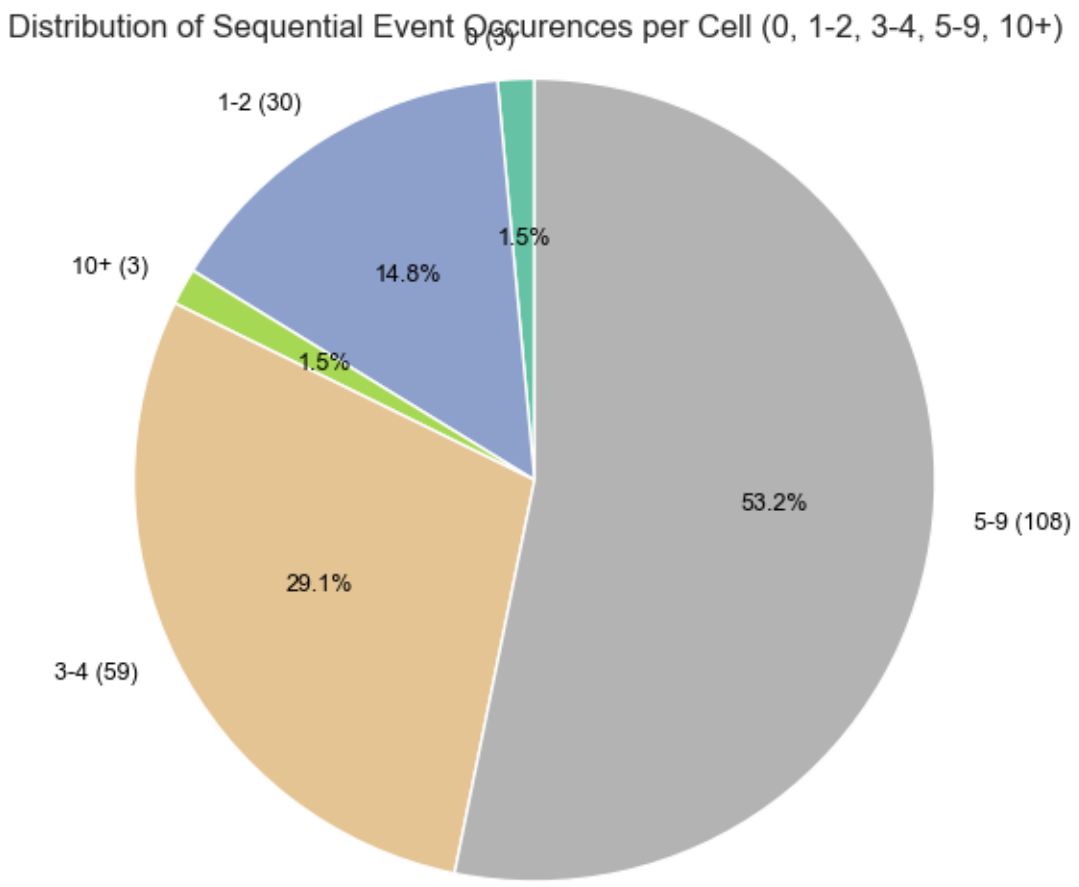
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS05



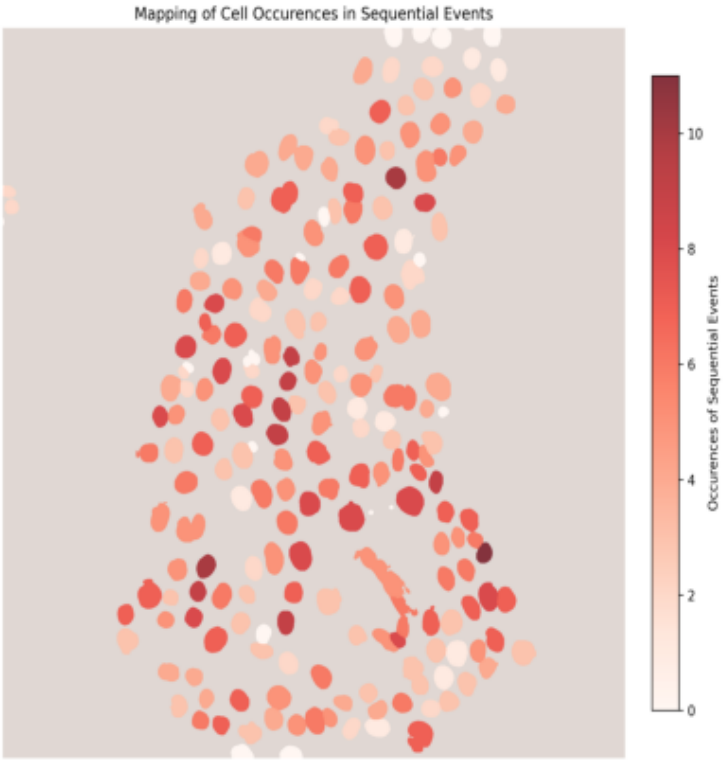
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

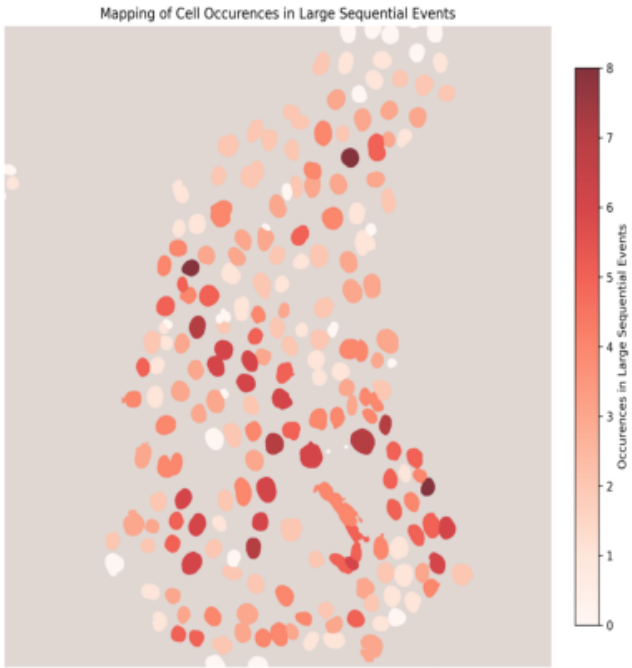



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (3)
1-2 (30)
10+ (3)
1.5%
14.8%
1.5%
53.2%
5-9 (108)
29.1%
3-4 (59)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS05

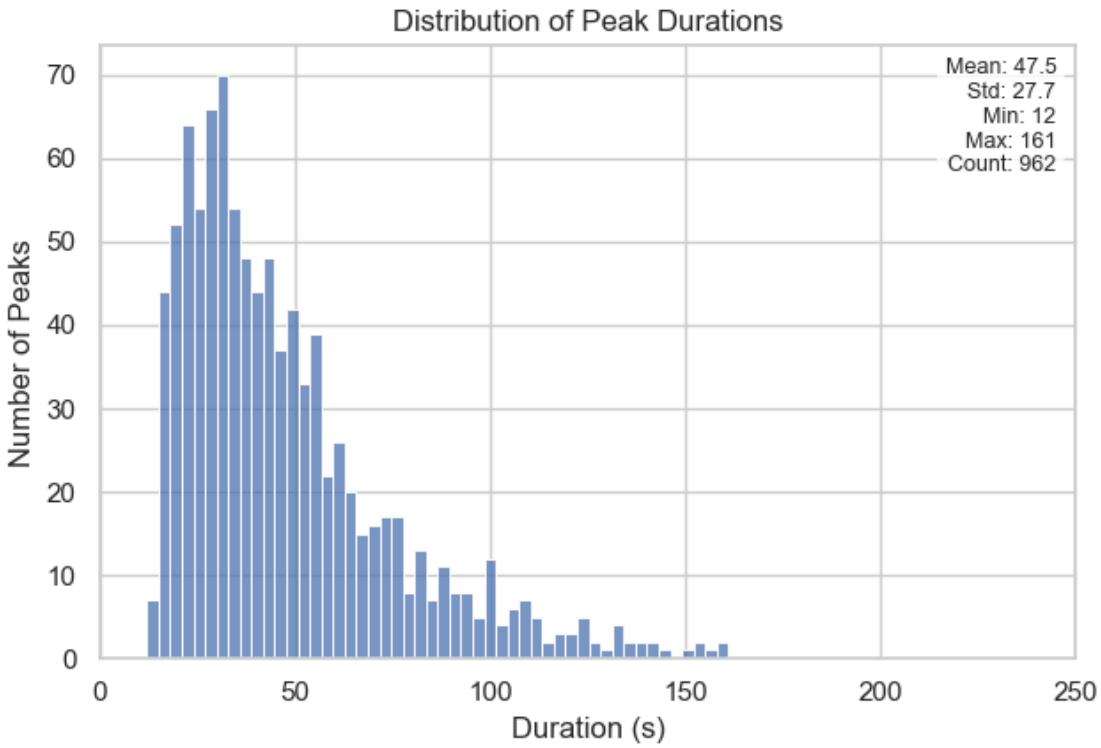


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS05

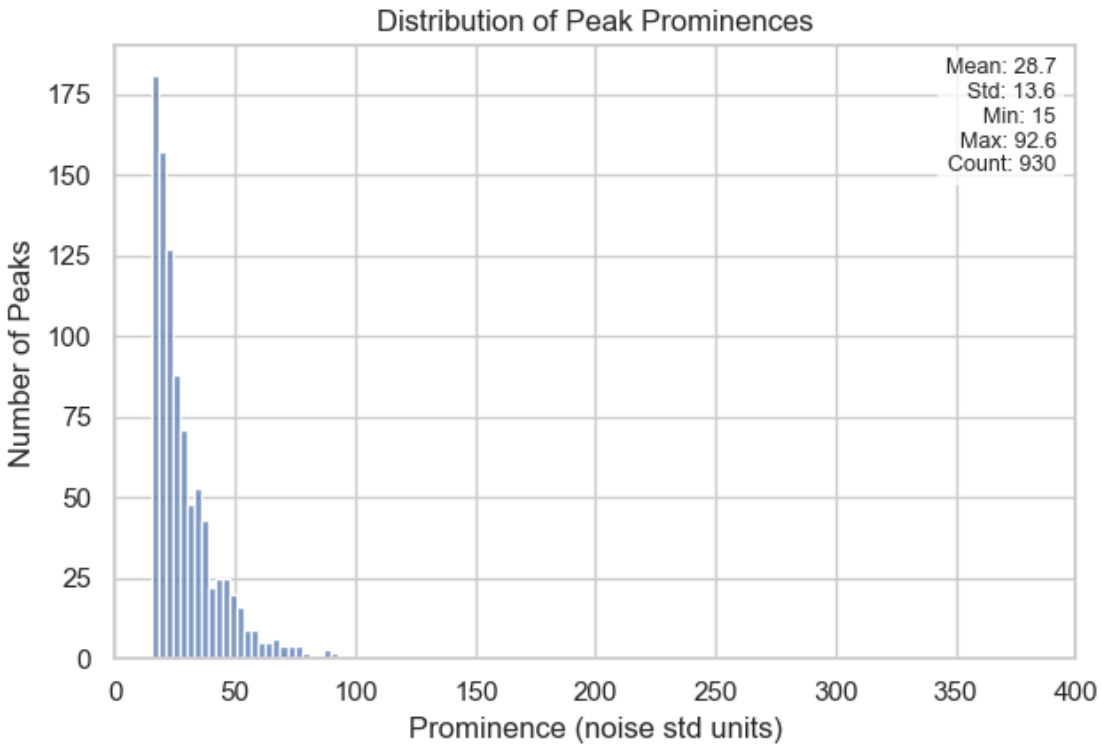


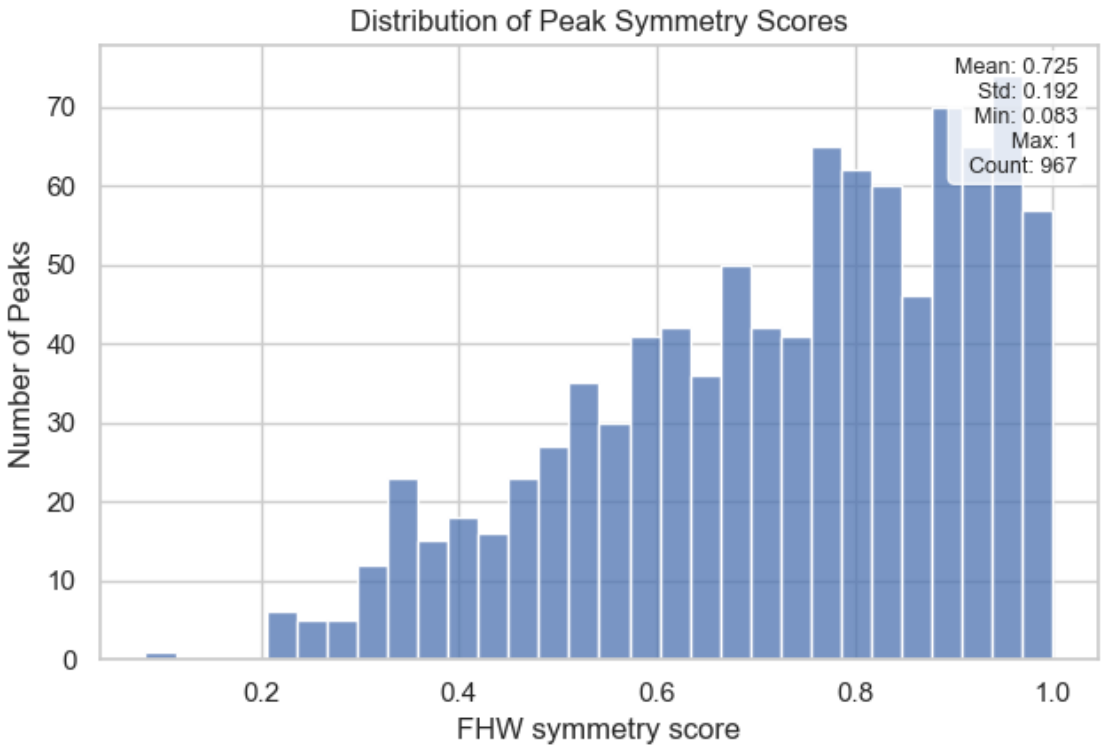
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:44:04] [INFO] calcium: plot_histogram: removed 5 outliers out of
967 on 'Duration (s)' (lower=-20, upper=172)
```



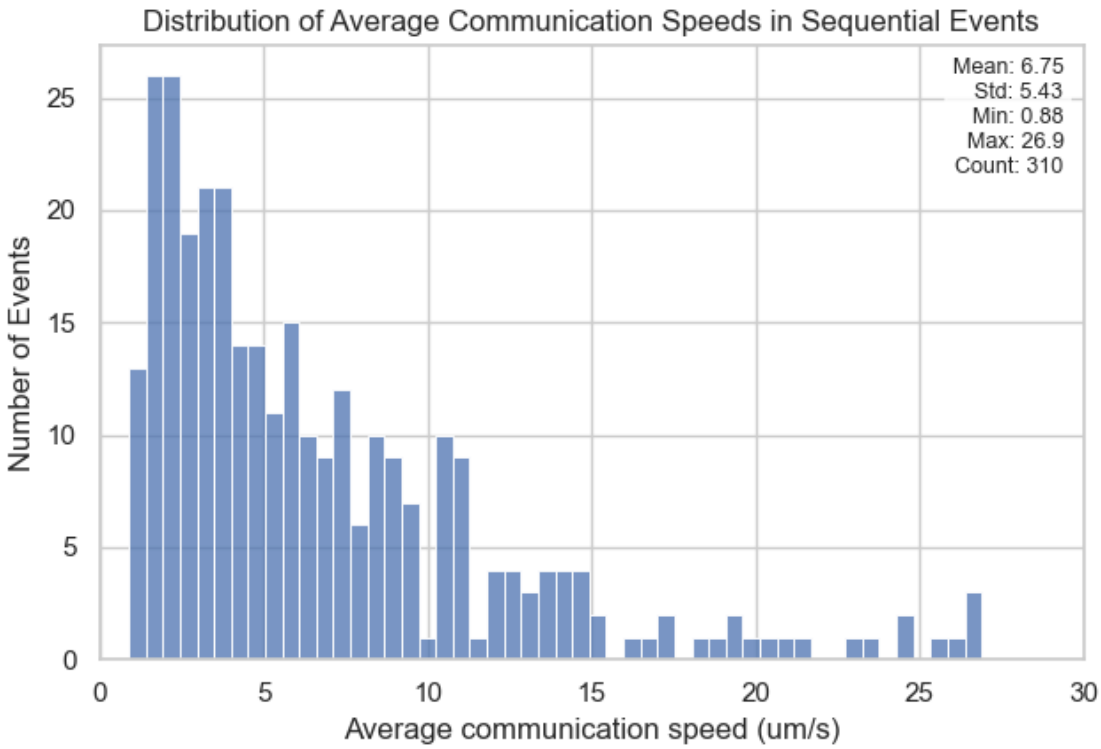

```
[2025-08-11 09:44:04] [INFO] calcium: plot_histogram: removed 37 outliers out of
967 on 'Prominence (noise std units)' (lower=-6.025, upper=94.475)
```


Distribution of Peak Prominences
Mean: 28.7
Std: 13.6
Min: 15
Max: 92.6
Count: 930
Number of Peaks
0
25
50
75
100
125
150
175
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

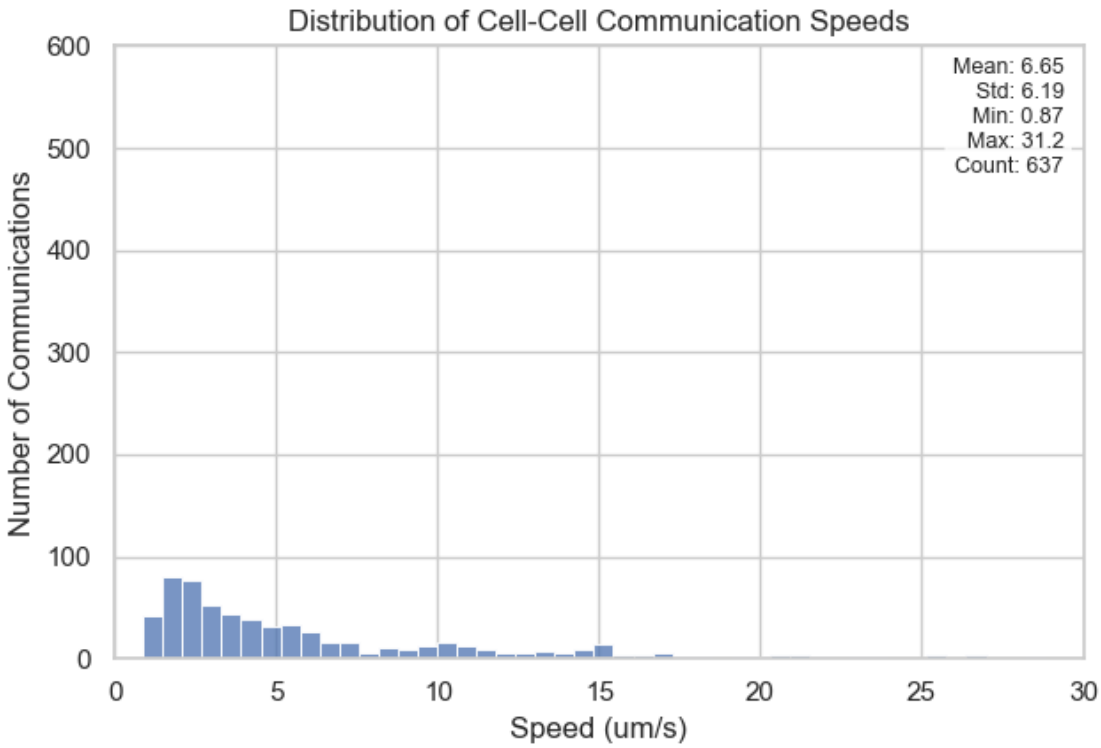

Distribution of Peak Symmetry Scores
Mean: 0.725
Std: 0.192
Min: 0.083
Max: 1
Count: 967
Number of Peaks
0
10
20
30
40
50
60
70
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:44:05] [INFO] calcium: plot_histogram: removed 7 outliers out of
317 on 'Average communication speed (um/s)' (lower=-16.12, upper=28.26)
```

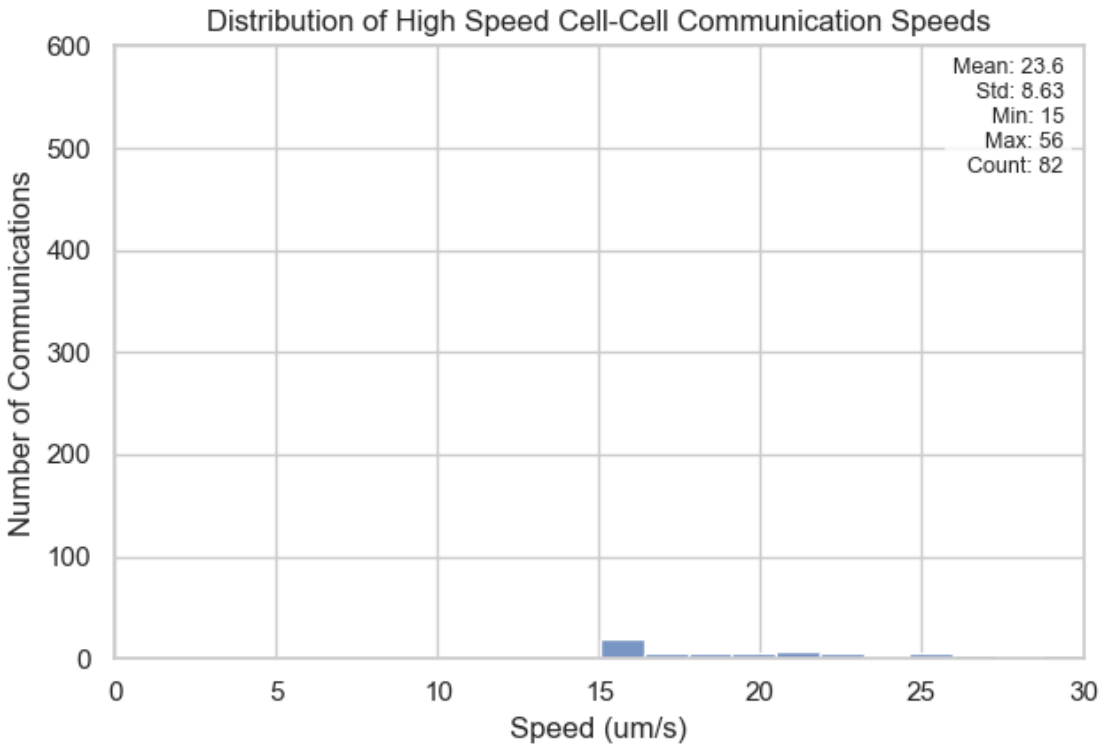



```
[2025-08-11 09:44:05] [INFO] calcium: plot_histogram: removed 13 outliers out of
650 on 'Speed (um/s)' (lower=-19.35, upper=31.312)
```

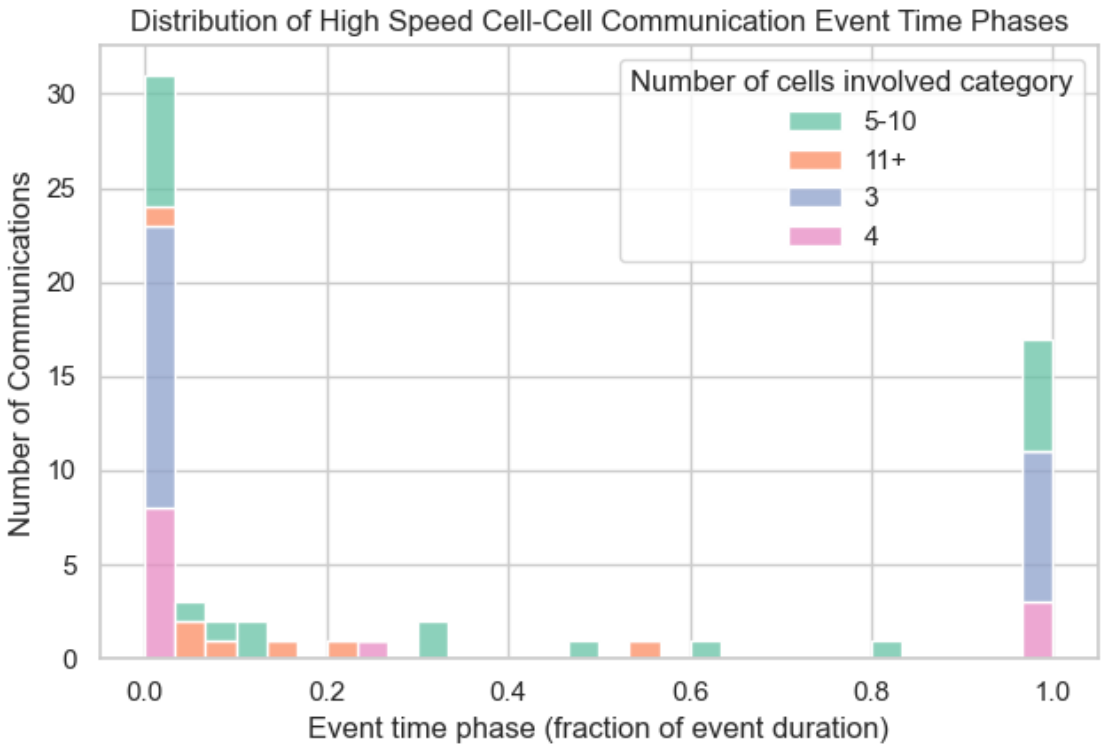


1.3.4 Double distribution in cell-cell communication speeds

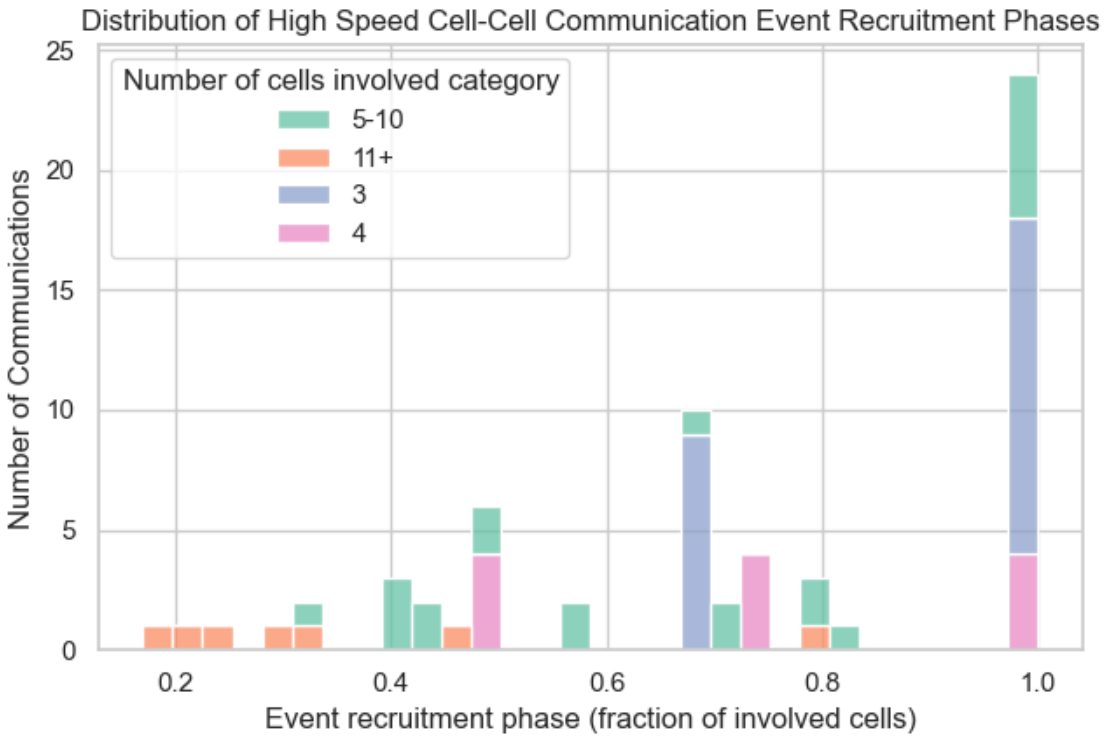
```
[2025-08-11 09:44:05] [INFO] calcium: plot_histogram: removed 1 outliers out of
83 on 'Speed (um/s)' (lower=-18.255, upper=63.61)
```



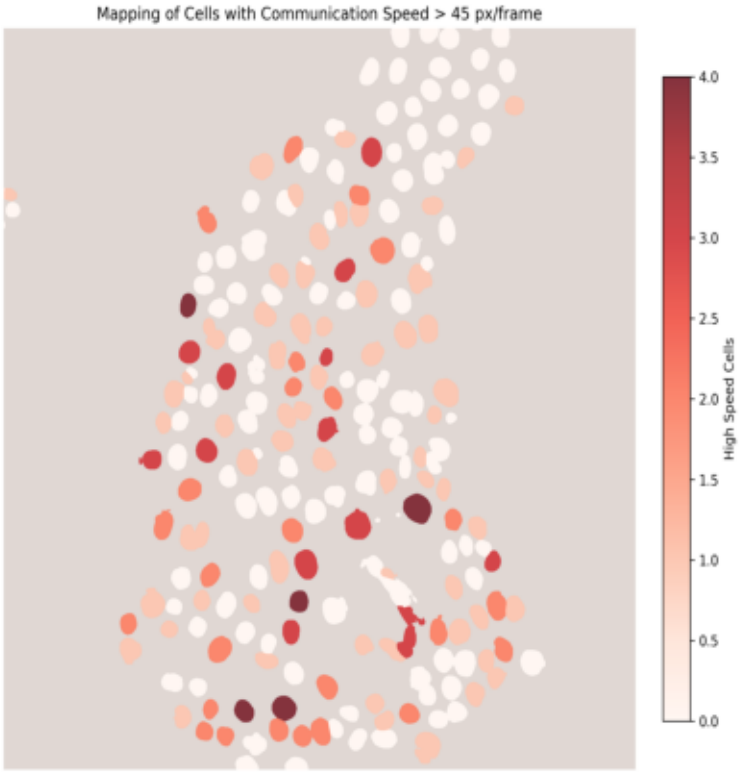

```
[2025-08-11 09:44:05] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 64 on 'Event time phase (fraction of event duration)' (lower=-3,
upper=4)
```



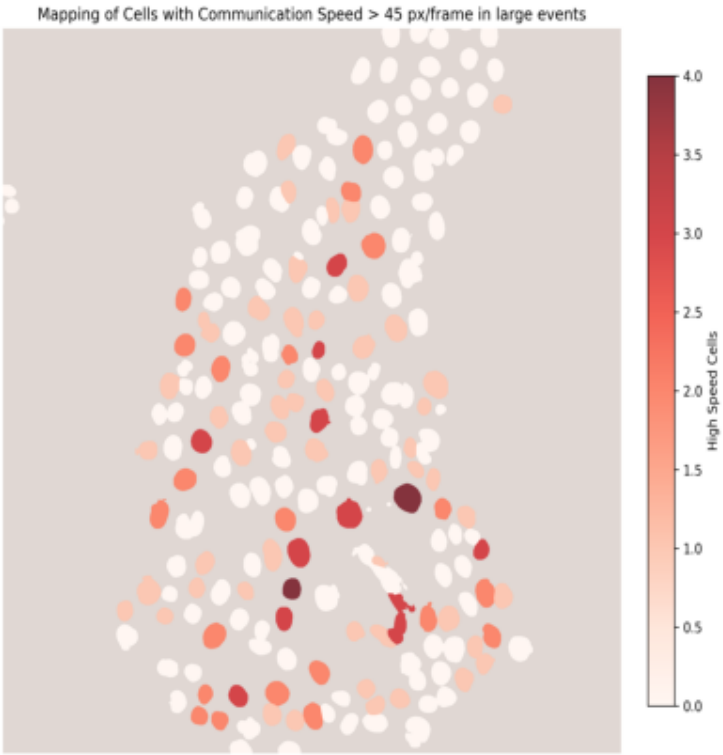

```
[2025-08-11 09:44:05] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 64 on 'Event recruitment phase (fraction of involved cells)'
(lower=-1, upper=2.5)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
3
4
Number of Communications
0
5
10
15
20
25
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

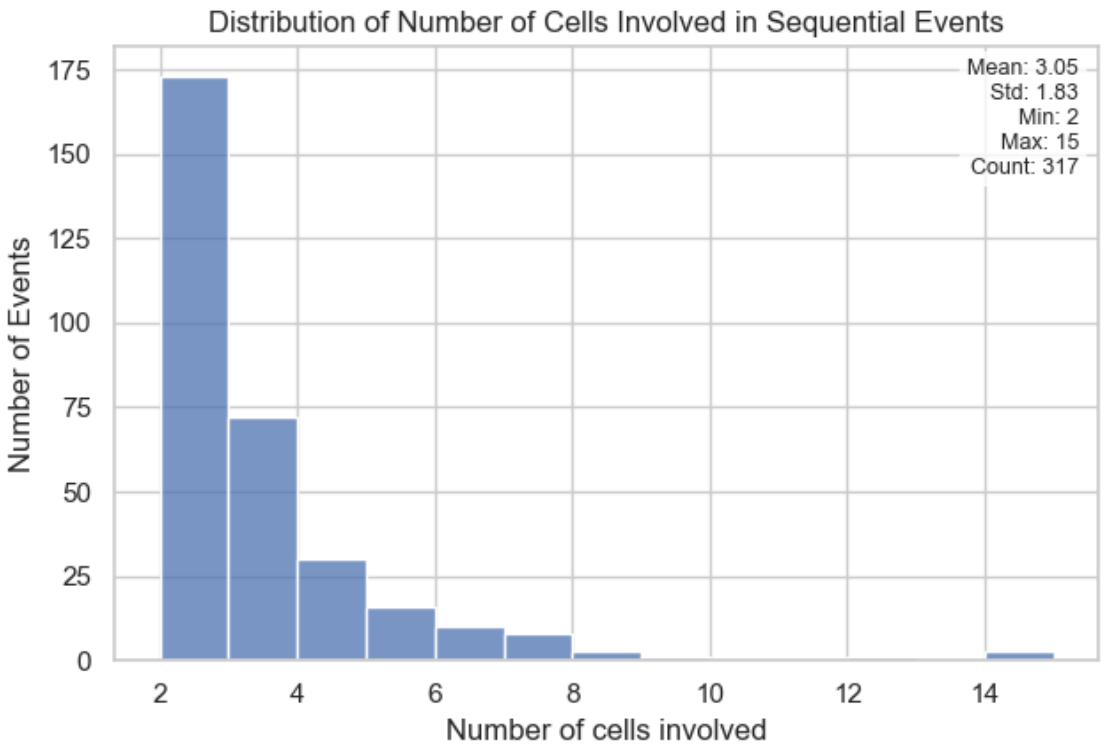
Cell Mapping with High Speed Cells Overlay - 20250409_IS05



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS05

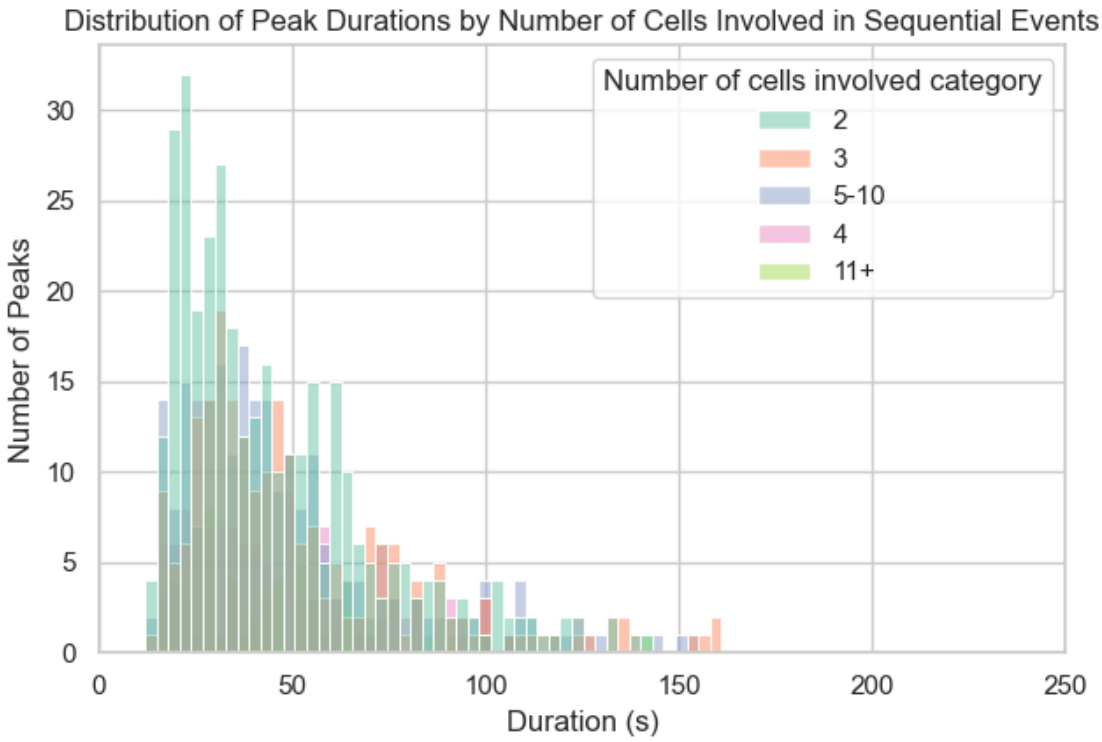


1.3.5 Number of cells involved per sequential events

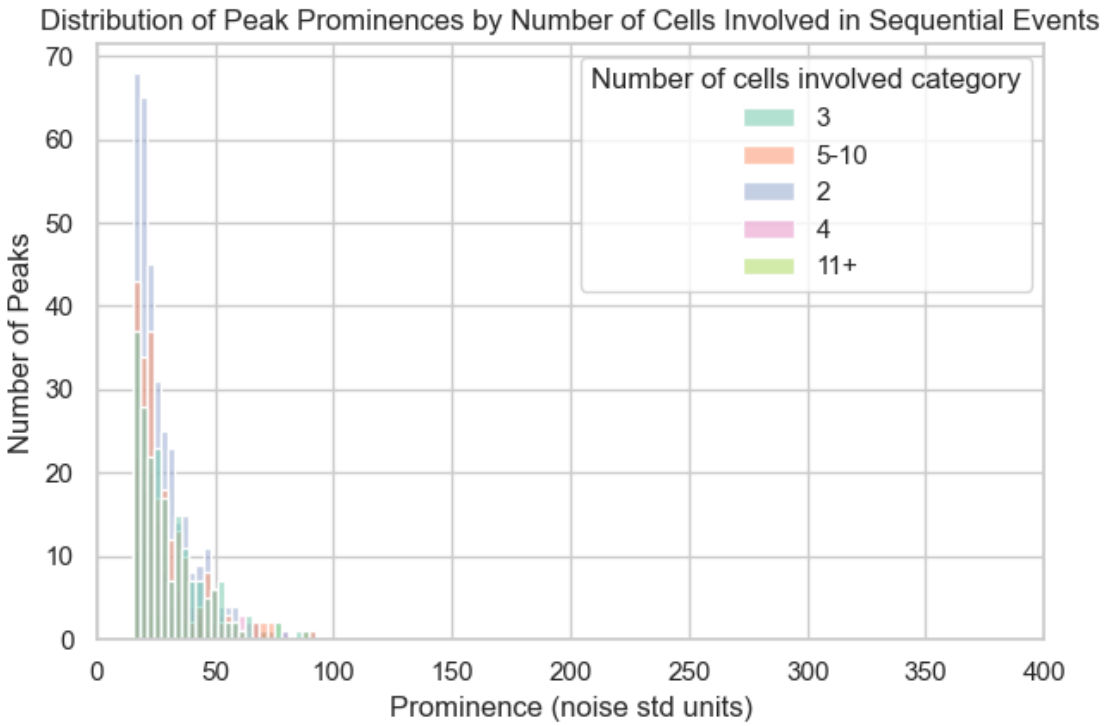


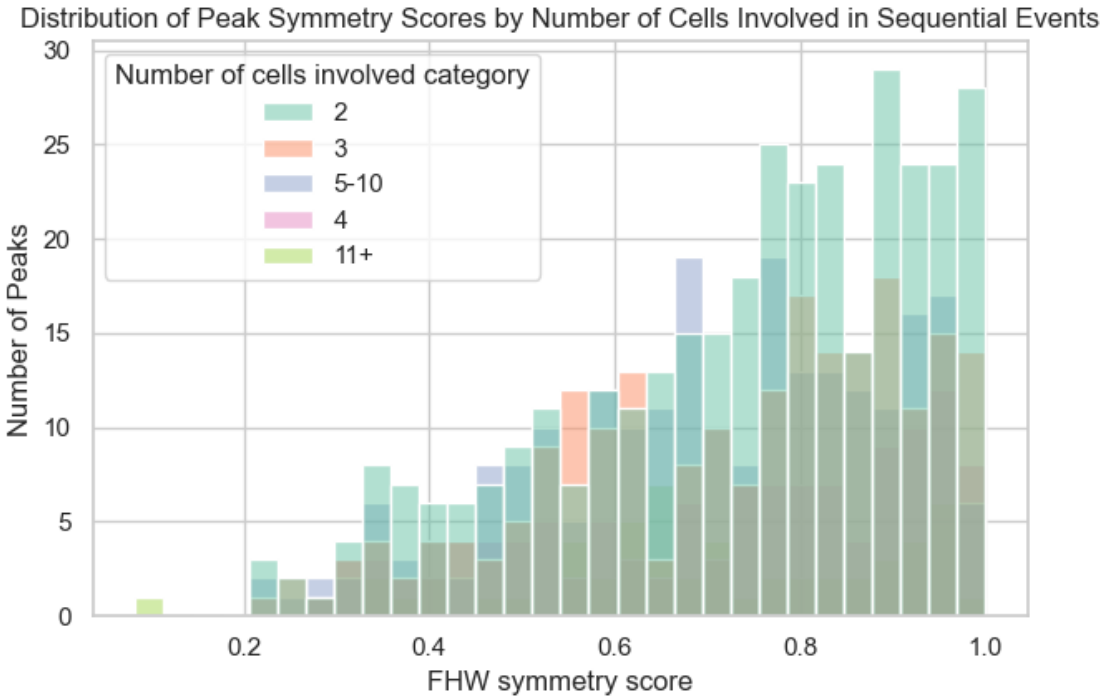
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:44:08] [INFO] calcium: plot_histogram_by_group: removed 5
outliers out of 967 on 'Duration (s)' (lower=-20, upper=172)
```



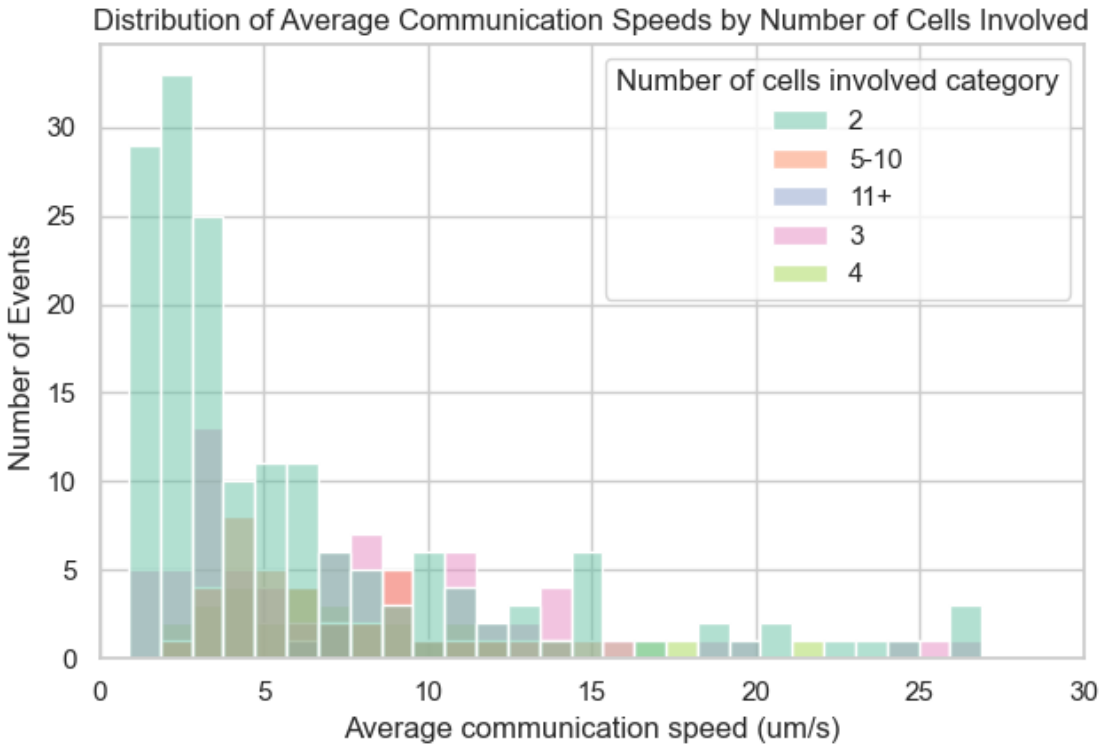

```
[2025-08-11 09:44:08] [INFO] calcium: plot_histogram_by_group: removed 37
outliers out of 967 on 'Prominence (noise std units)' (lower=-6.025,
upper=94.475)
```



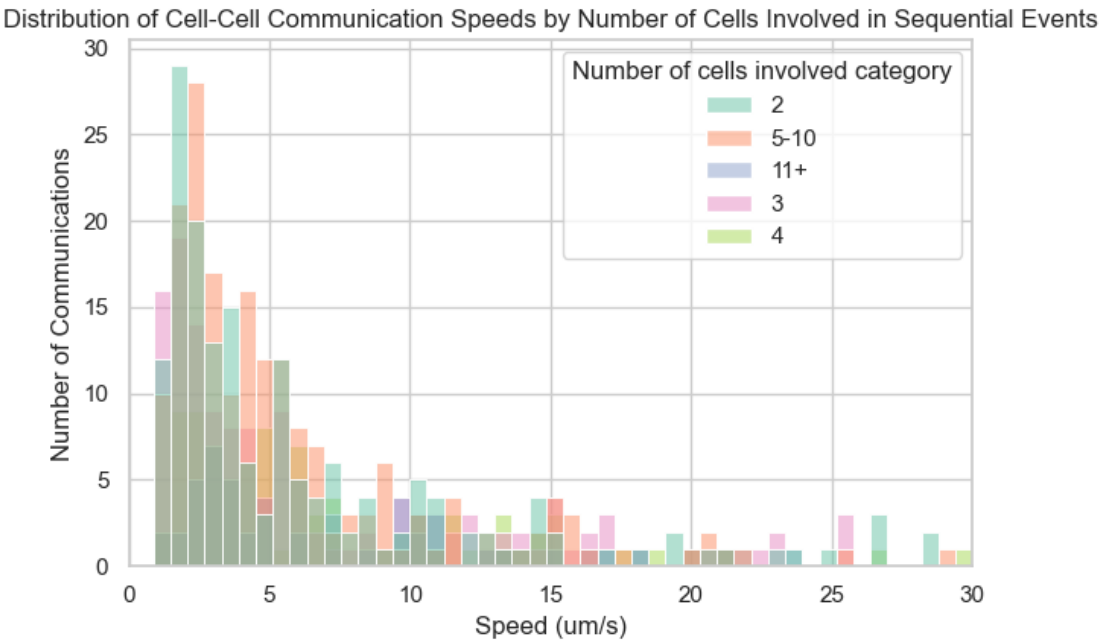



```
[2025-08-11 09:44:08] [INFO] calcium: plot_histogram_by_group: removed 7
```

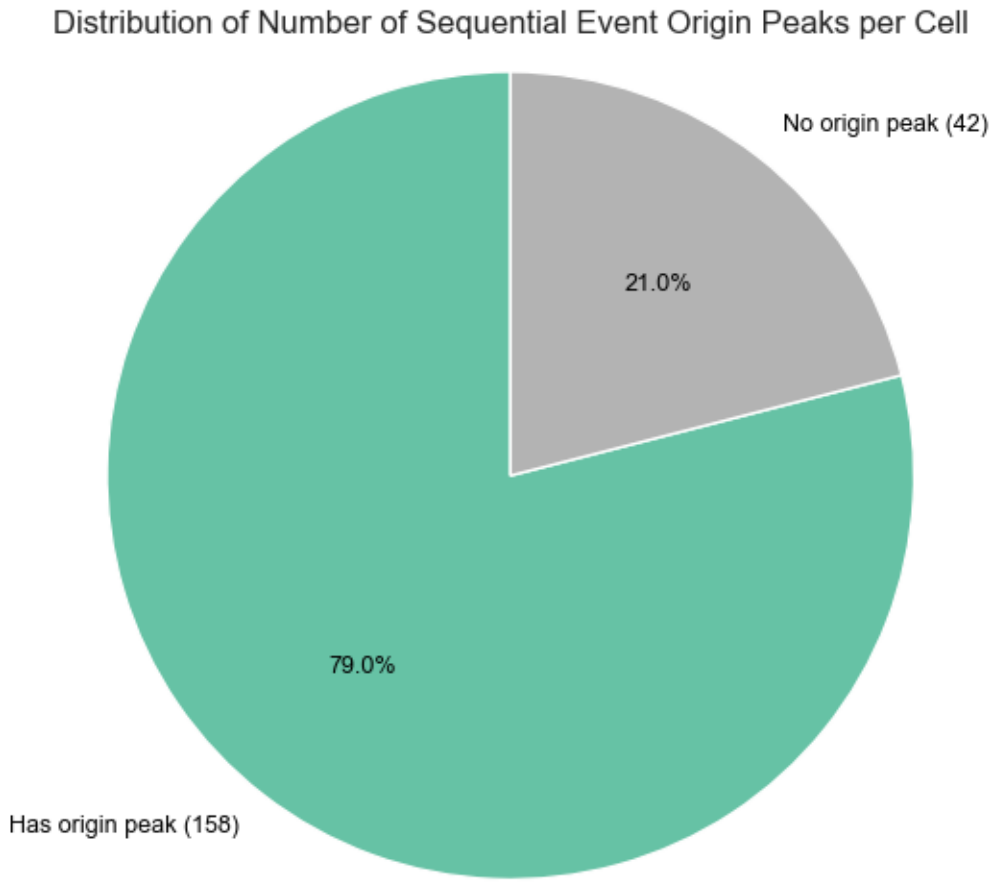
```
outliers out of 317 on 'Average communication speed (um/s)' (lower=-16.12,
upper=28.26)
```

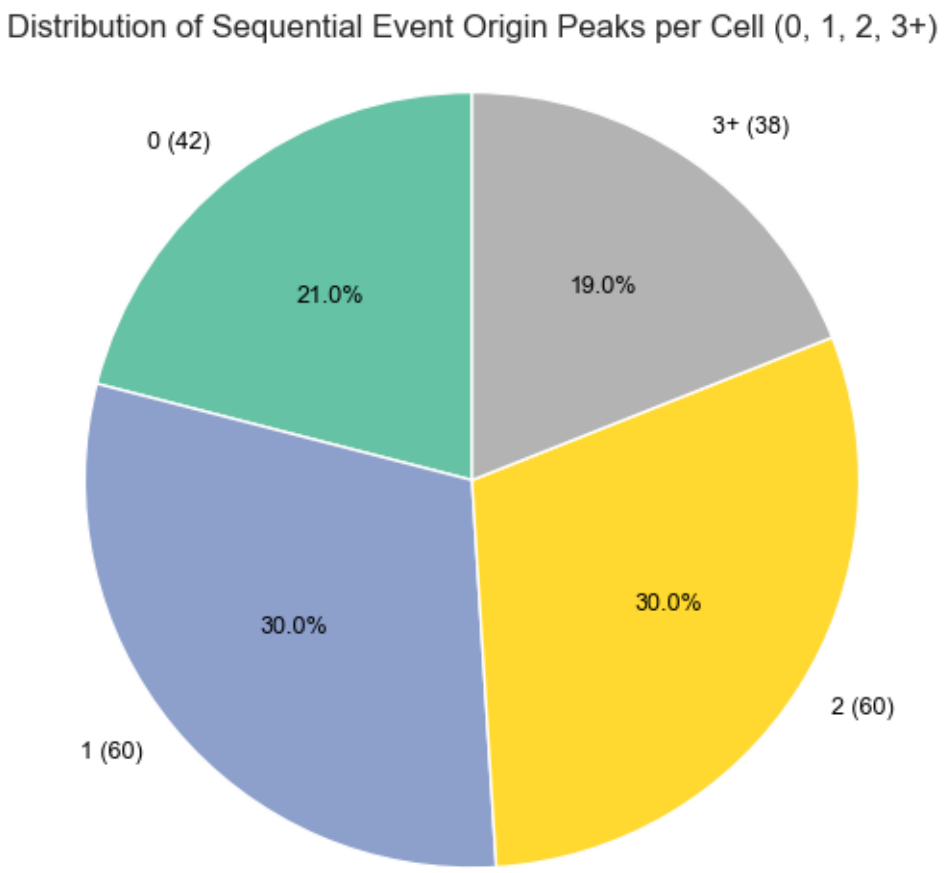



```
[2025-08-11 09:44:08] [INFO] calcium: plot_histogram_by_group: removed 13
outliers out of 650 on 'Speed (um/s)' (lower=-19.35, upper=31.312)
```

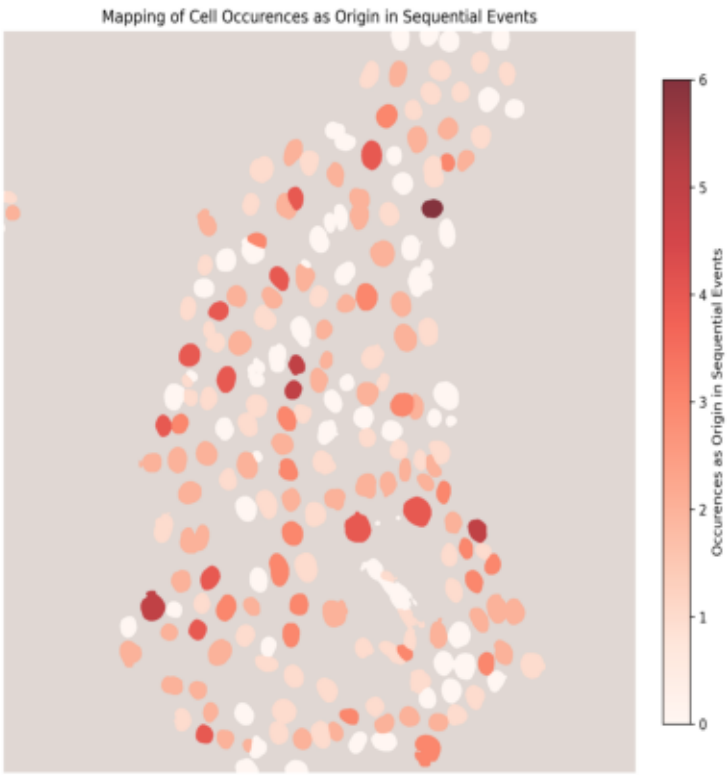

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of Communications
Speed (um/s)
Number of cells involved category
2
5-10
11+
3
4
0
5
10
15
20
25
30

1.3.7 Cells occurences as origin in sequential events

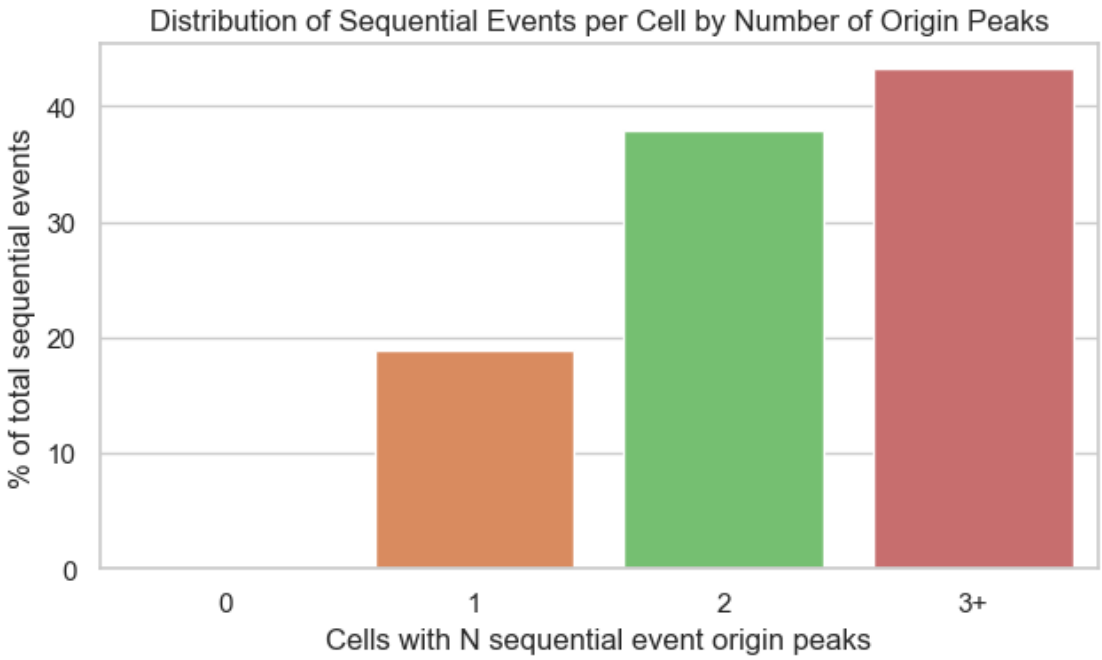



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
0 (42)
3+ (38)
21.0%
19.0%
30.0%
30.0%
2 (60)
1 (60)

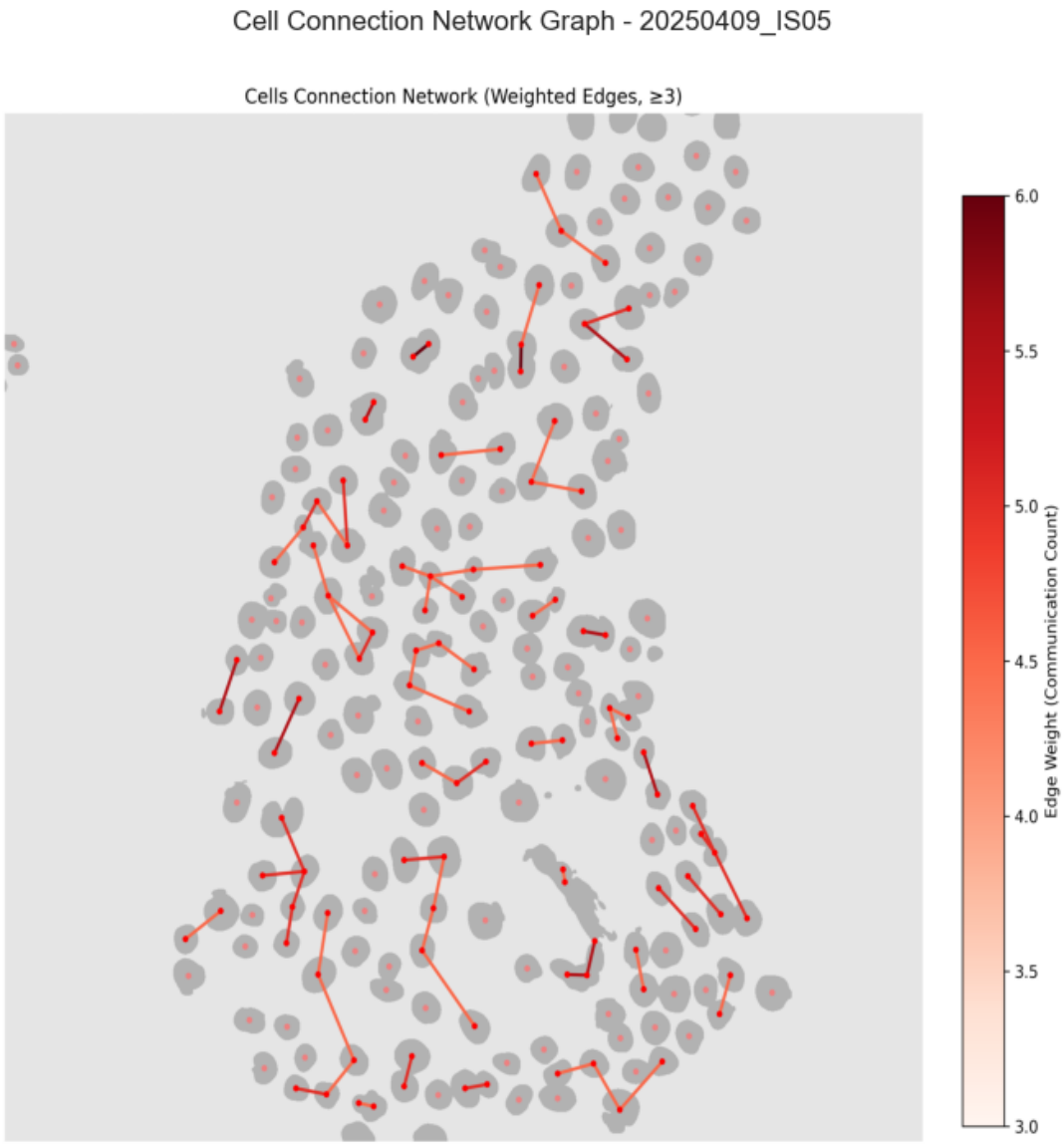
Cell Mapping with Origin Peaks Overlay - 20250409_IS05




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

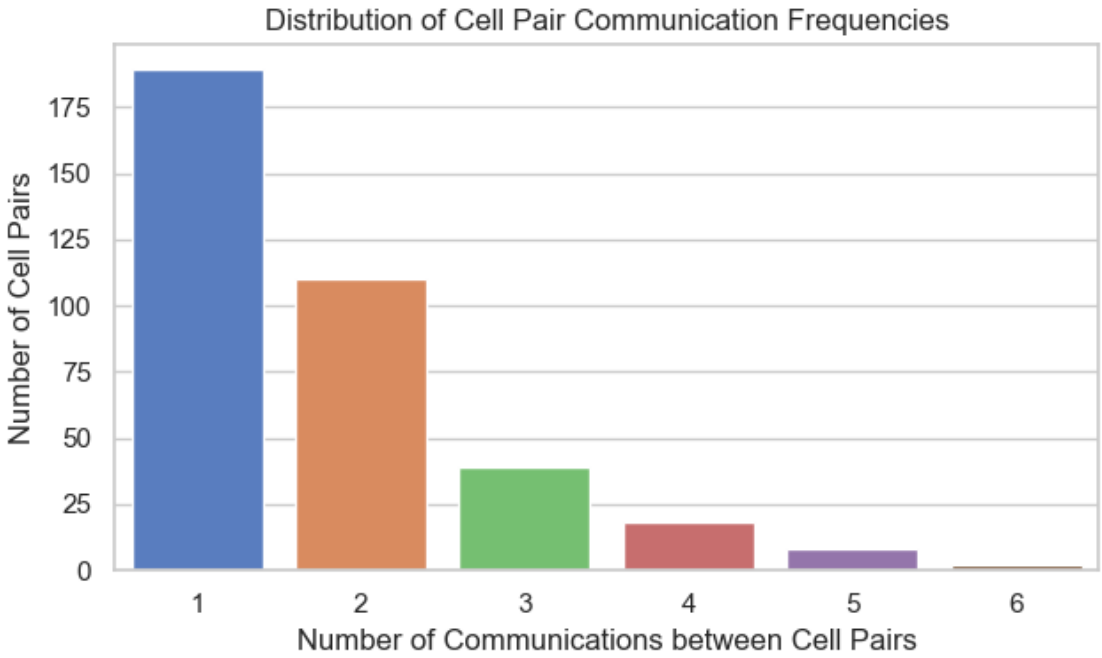

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
0
10
20
30
40
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



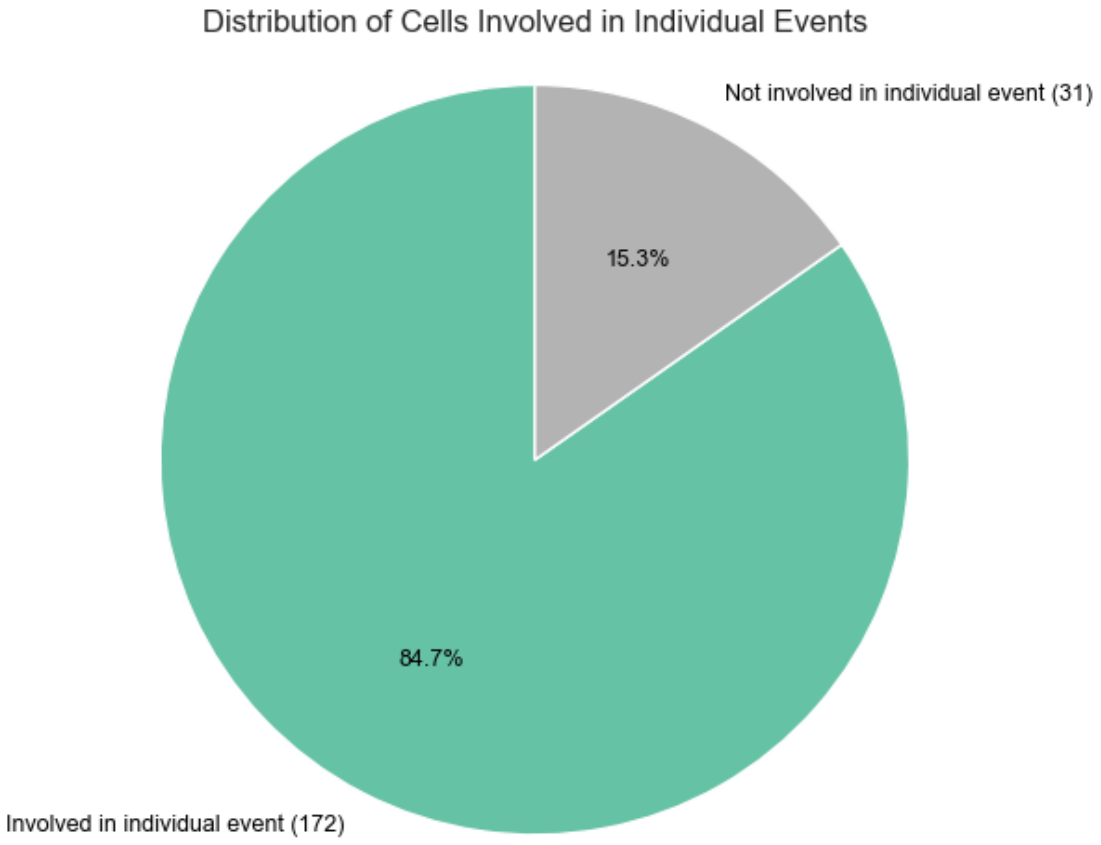

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

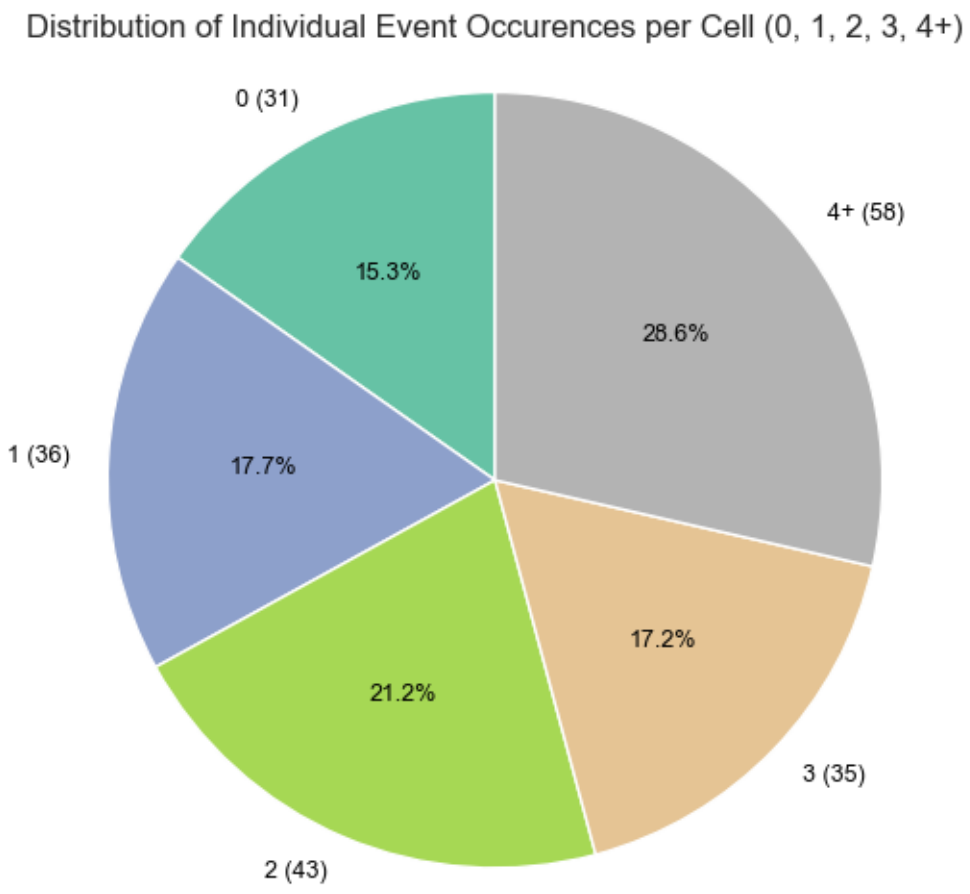
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
175
150
125
100
75
50
25
0
1
2
3
4
5
6
Number of Communications between Cell Pairs

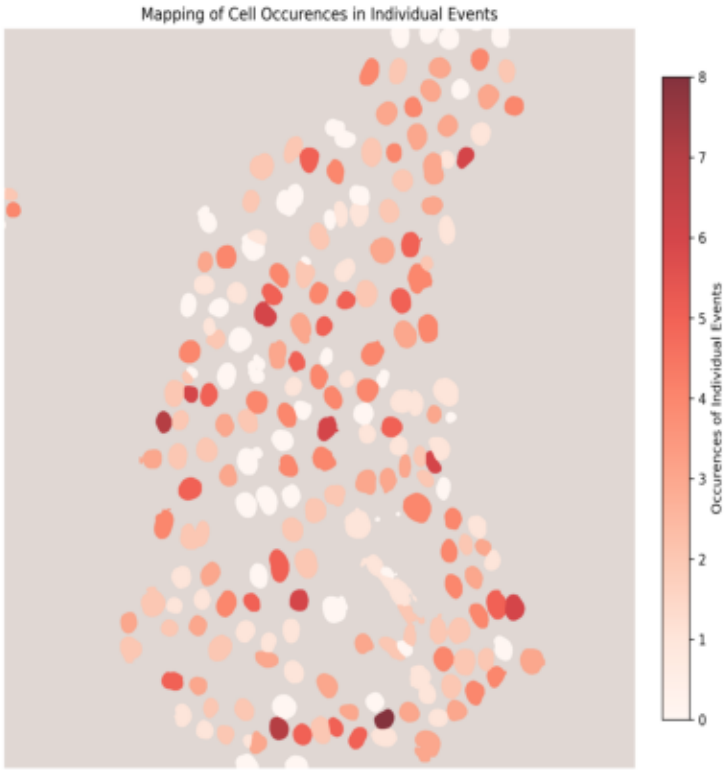
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



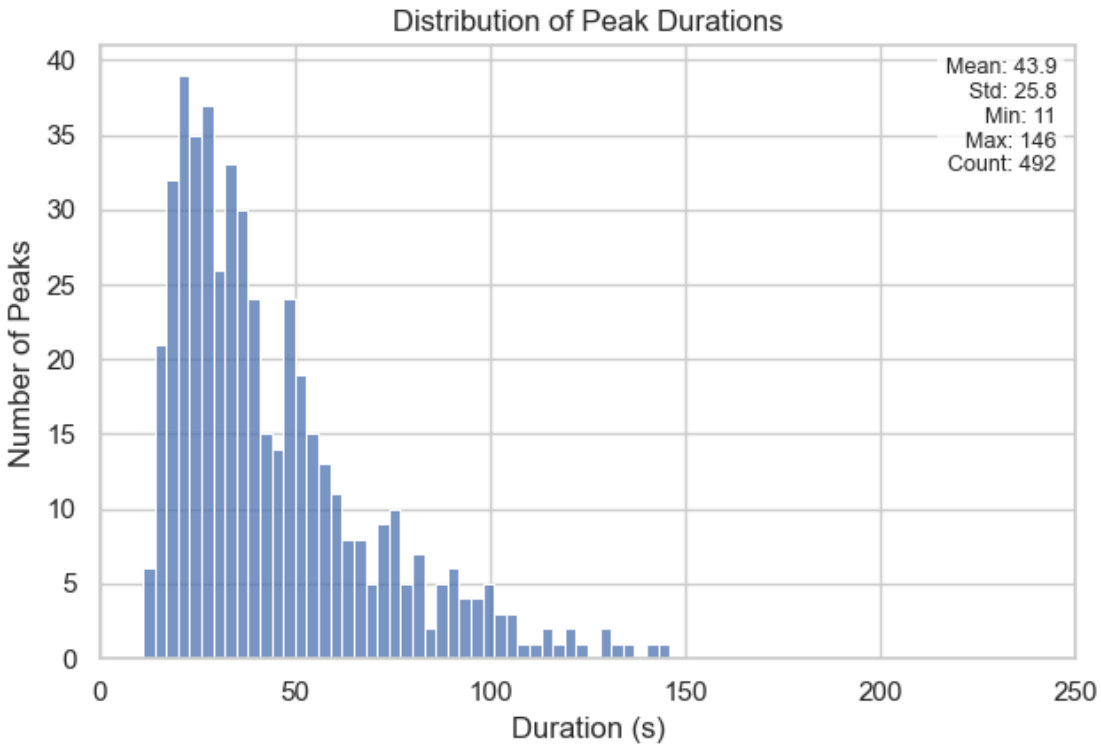

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
0 (31)
15.3%
4+ (58)
28.6%
1 (36)
17.7%
17.2%
21.2%
3 (35)
2 (43)

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS05

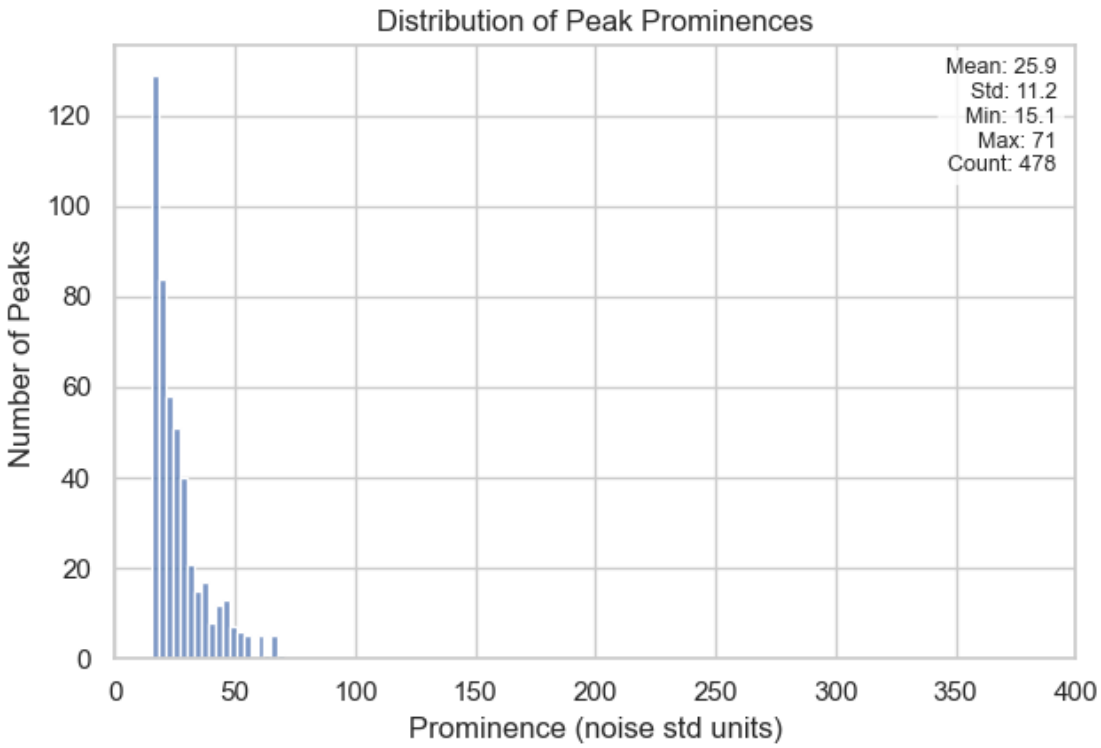


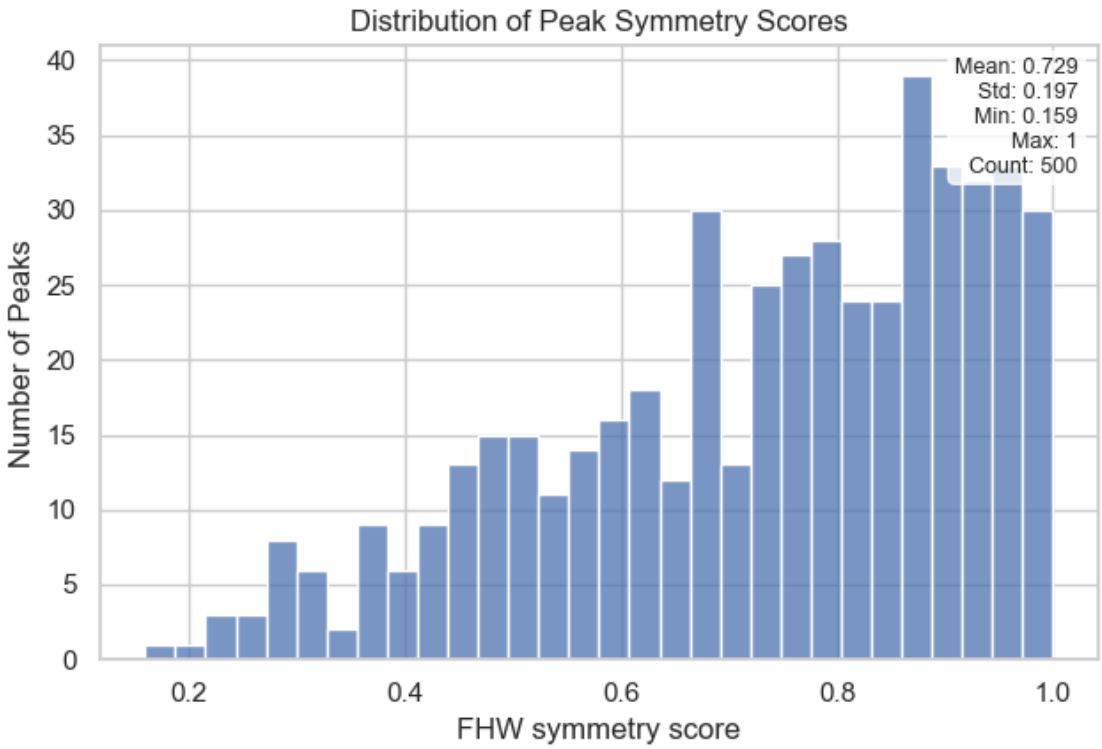
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:44:13] [INFO] calcium: plot_histogram: removed 8 outliers out of
500 on 'Duration (s)' (lower=-75, upper=156)
```

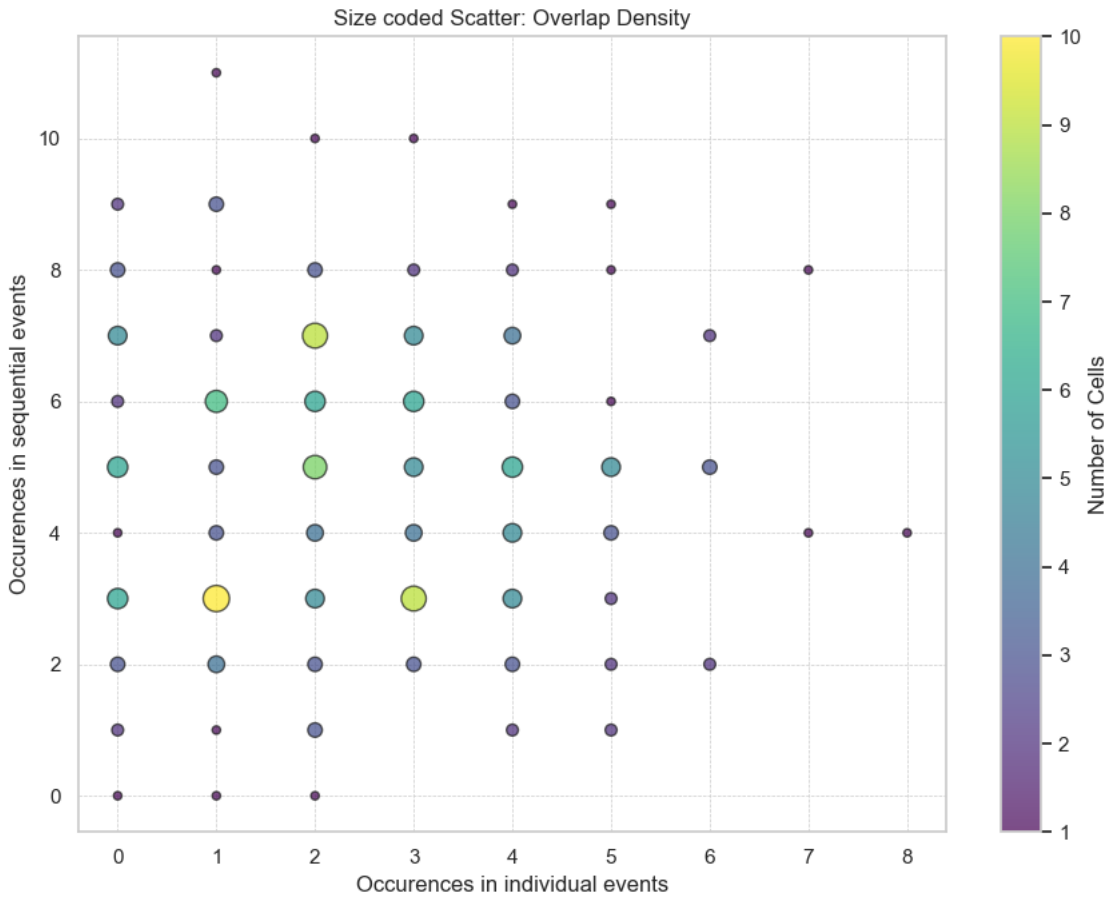



```
[2025-08-11 09:44:13] [INFO] calcium: plot_histogram: removed 22 outliers out of
500 on 'Prominence (noise std units)' (lower=-23.775, upper=73.7)
```


Distribution of Peak Prominences
Mean: 25.9
Std: 11.2
Min: 15.1
Max: 71
Count: 478
Number of Peaks
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.729
Std: 0.197
Min: 0.159
Max: 1
Count: 500
Number of Peaks
0
5
10
15
20
25
30
35
40
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION

```
Number of cells:
- Hoechst image taken at t=0: 203
- Hoechst image taken at t=1801: 204
- Number of cells difference: absolute 1, relative 0.49%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 359358
- Pixels segmented as cell at t=1801: 377004
- Overlapping pixels between t=0 and t=1801: 345439(93.82% of total)
- Pixels exclusive to t=0: 13919 (3.87% of total)
- Pixels exclusive to t=1801: 31565 (8.37% of total)
```

executed

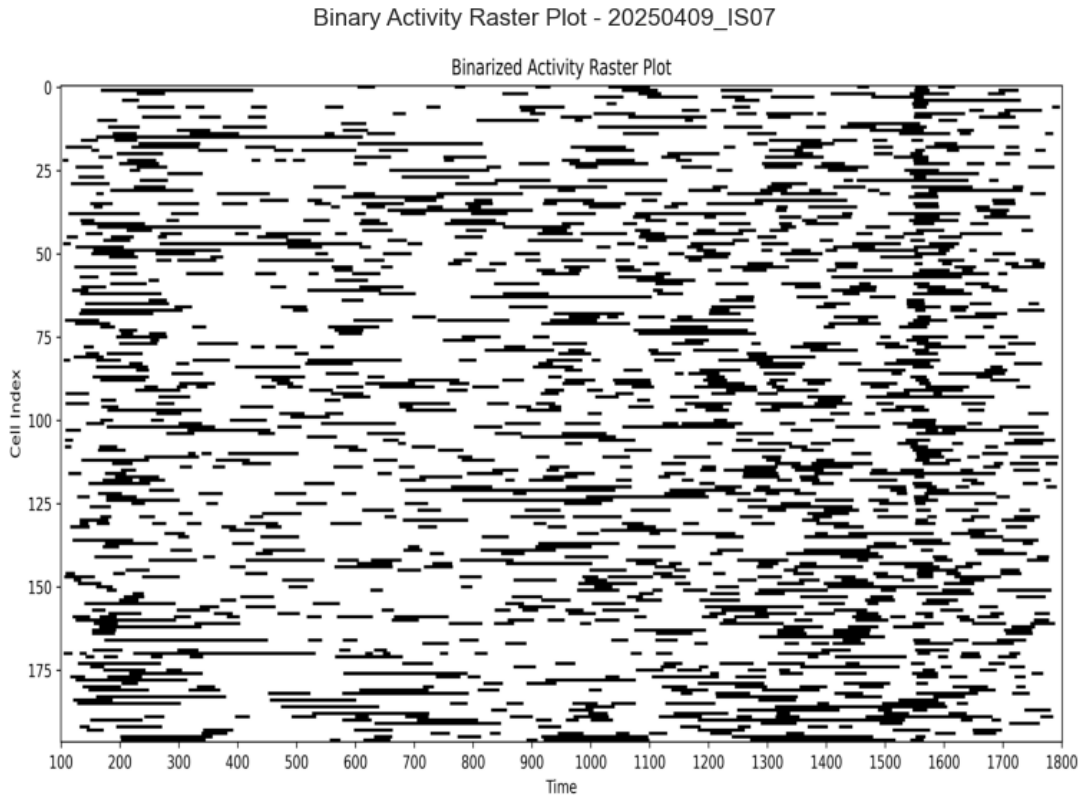
August 11, 2025

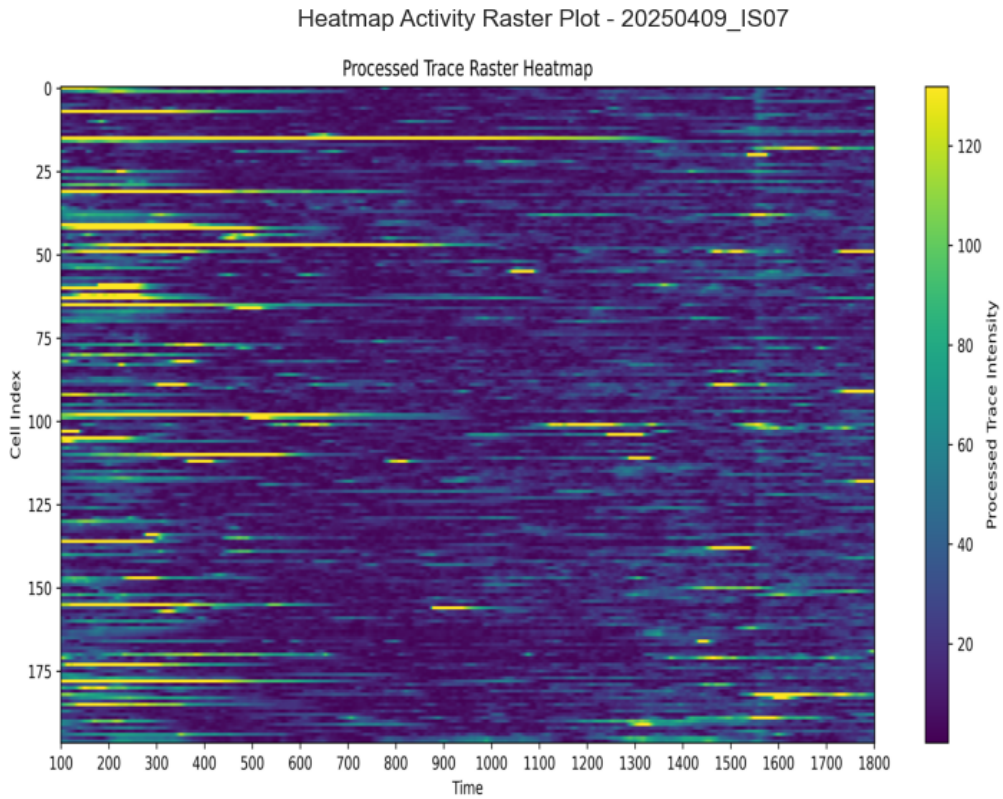
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



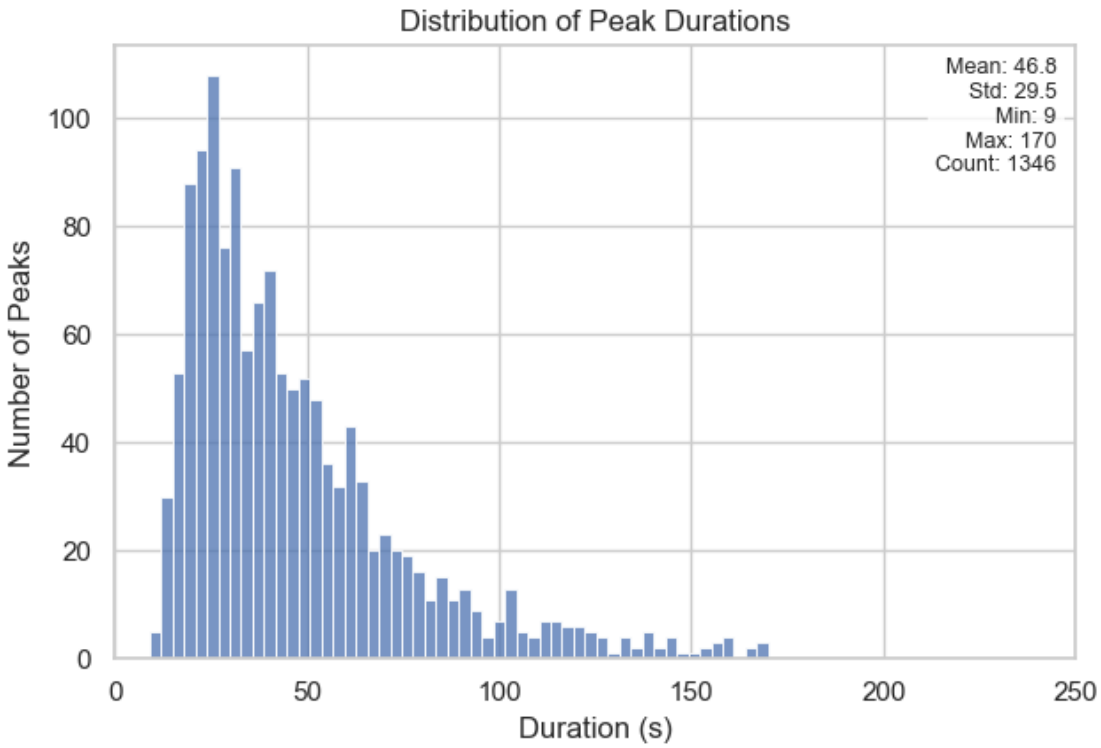


1.1.2 Peaks population

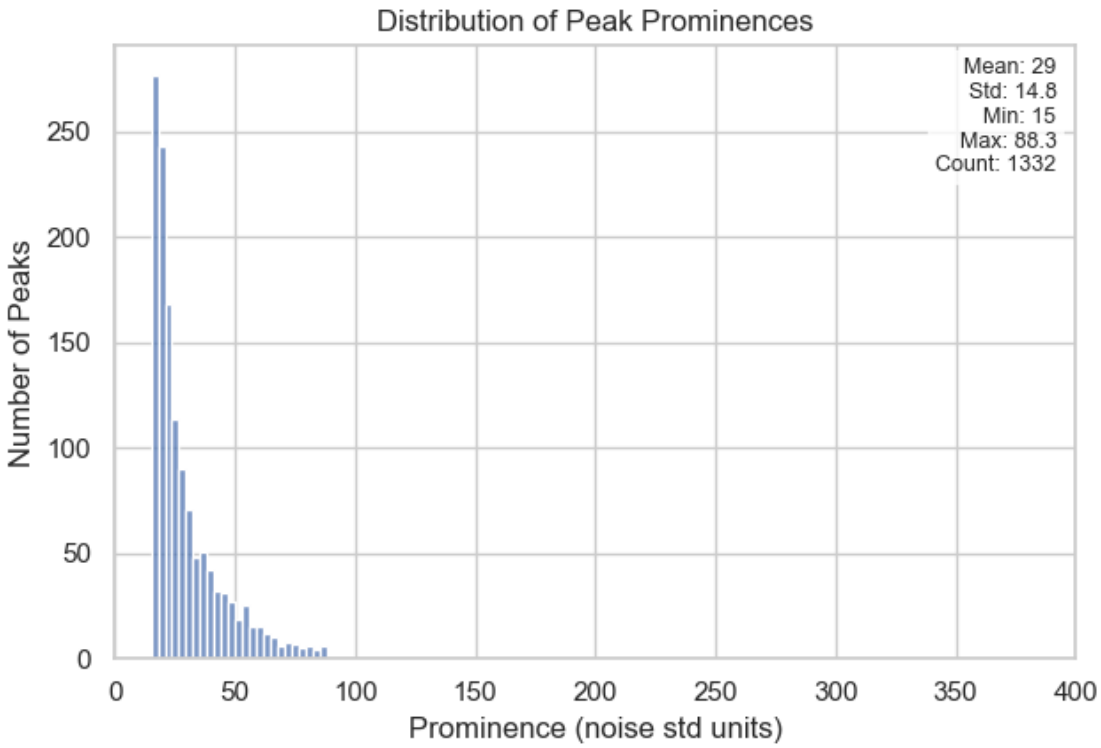
```
Total number of peaks: 1391
Total number of cells: 197
```

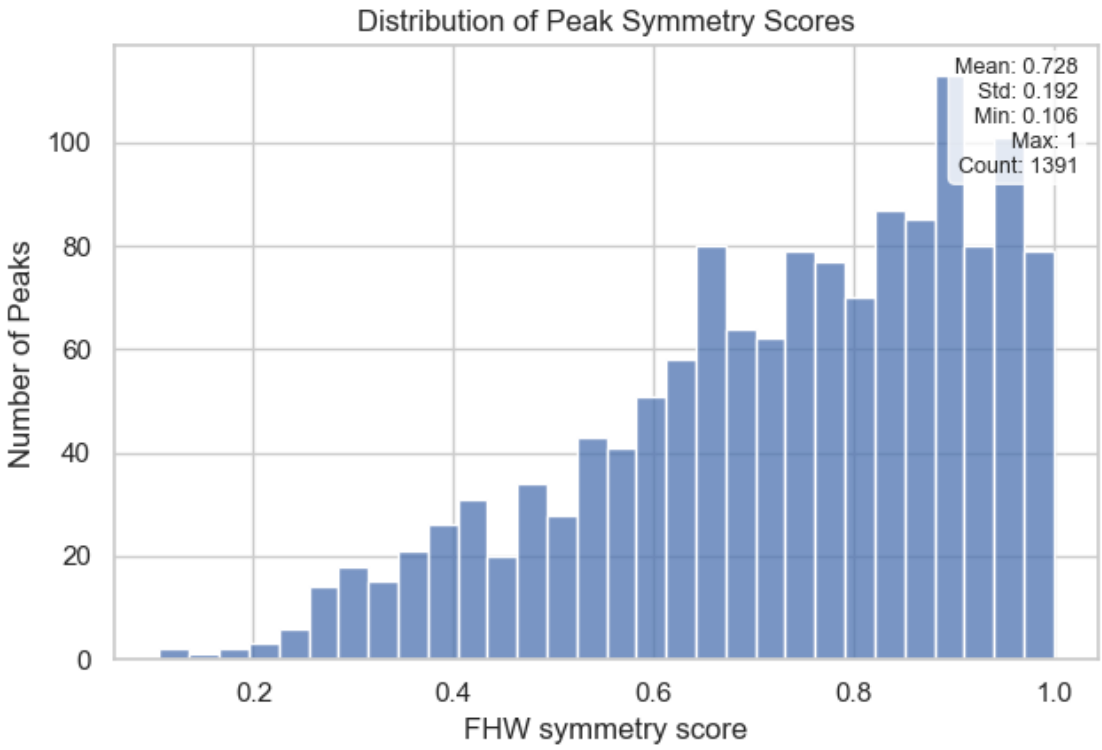
1.1.3 Peaks statistics

```
[2025-08-11 09:45:10] [INFO] calcium: plot_histogram: removed 45 outliers out of
1391 on 'Duration (s)' (lower=-82, upper=170)
```

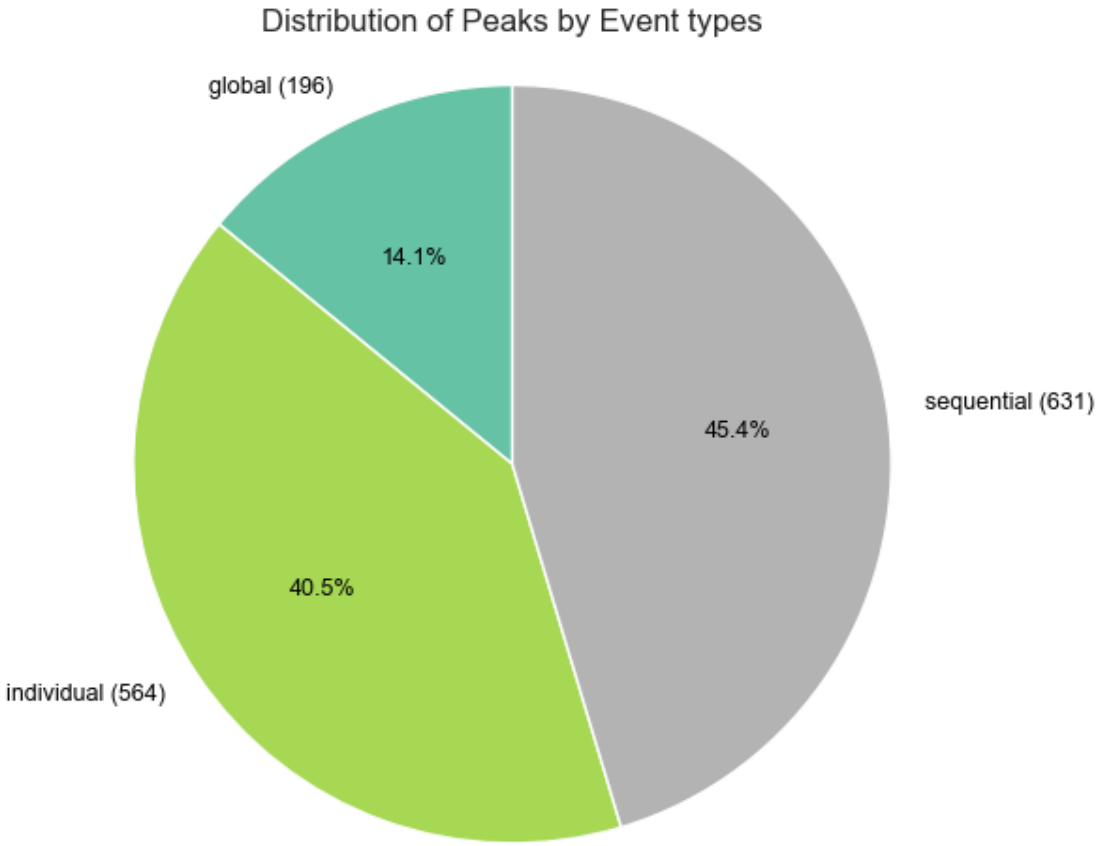



```
[2025-08-11 09:45:10] [INFO] calcium: plot_histogram: removed 59 outliers out of
1391 on 'Prominence (noise std units)' (lower=-36.05, upper=91.7)
```


Distribution of Peak Prominences
Mean: 29
Std: 14.8
Min: 15
Max: 88.3
Count: 1332
Number of Peaks
0
50
100
150
200
250
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

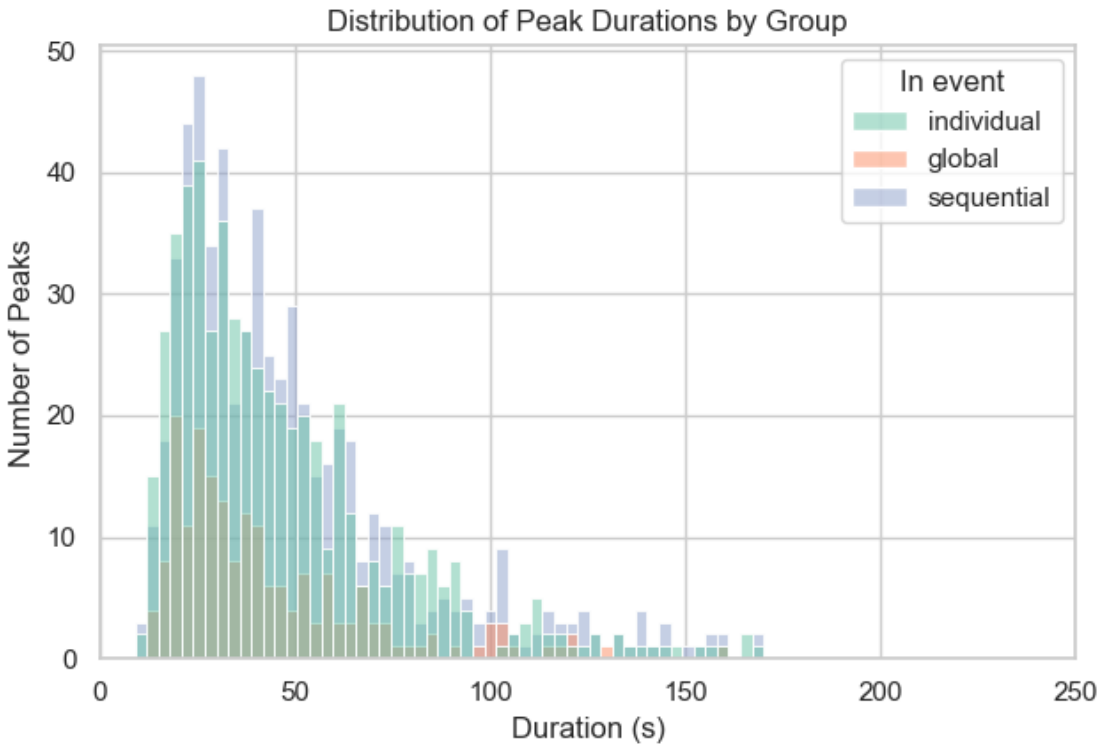

Distribution of Peak Symmetry Scores
Mean: 0.728
Std: 0.192
Min: 0.106
Max: 1
Count: 1391
Number of Peaks
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

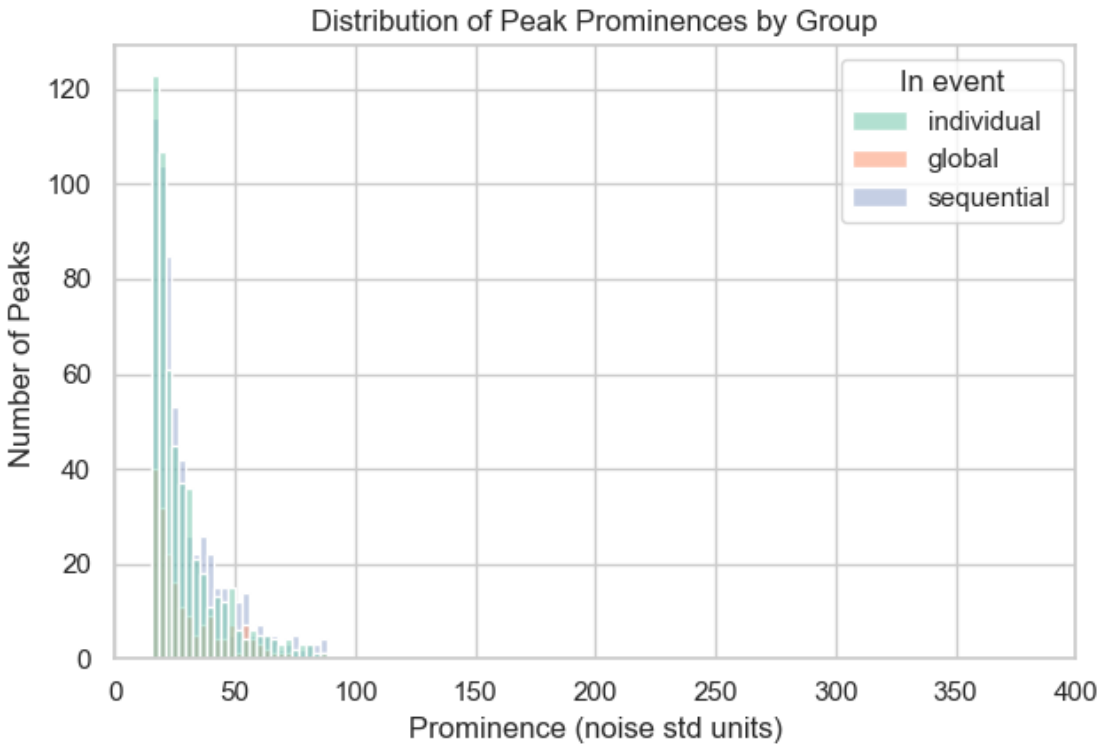


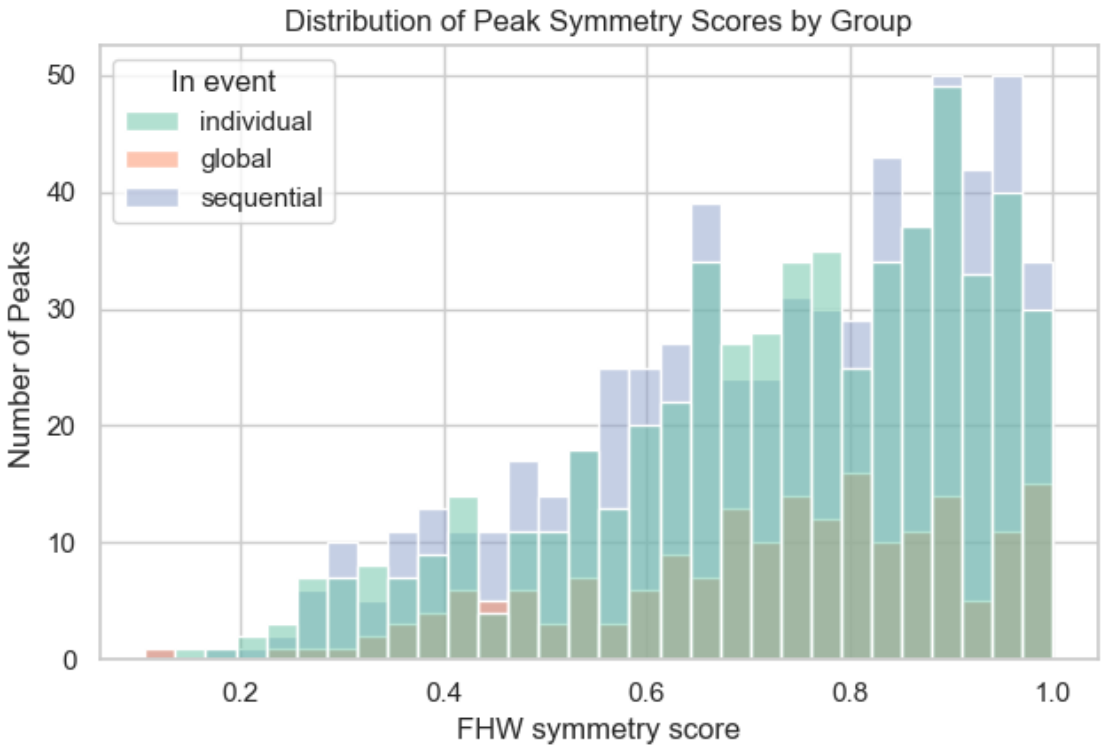
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:45:10] [INFO] calcium: plot_histogram_by_group: removed 45
outliers out of 1391 on 'Duration (s)' (lower=-82, upper=170)
```




```
[2025-08-11 09:45:11] [INFO] calcium: plot_histogram_by_group: removed 59
outliers out of 1391 on 'Prominence (noise std units)' (lower=-36.05,
upper=91.7)
```

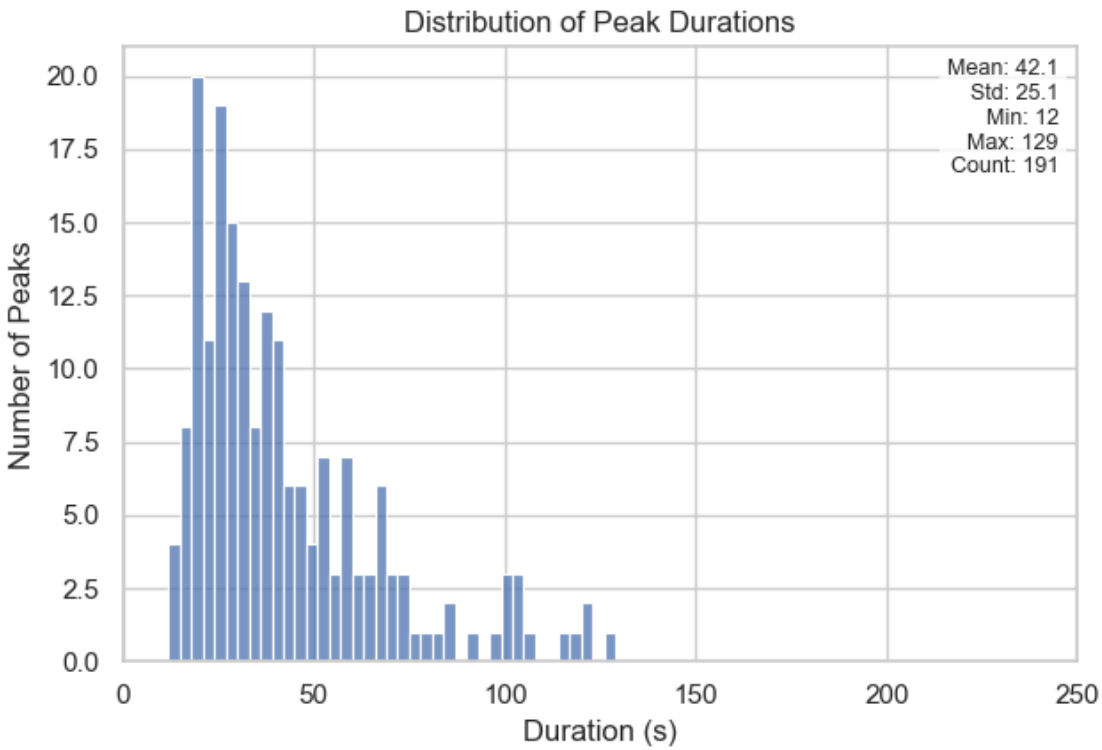

Distribution of Peak Prominences by Group
In event
individual
global
sequential
Number of Peaks
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
individual
global
sequential
Number of Peaks
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

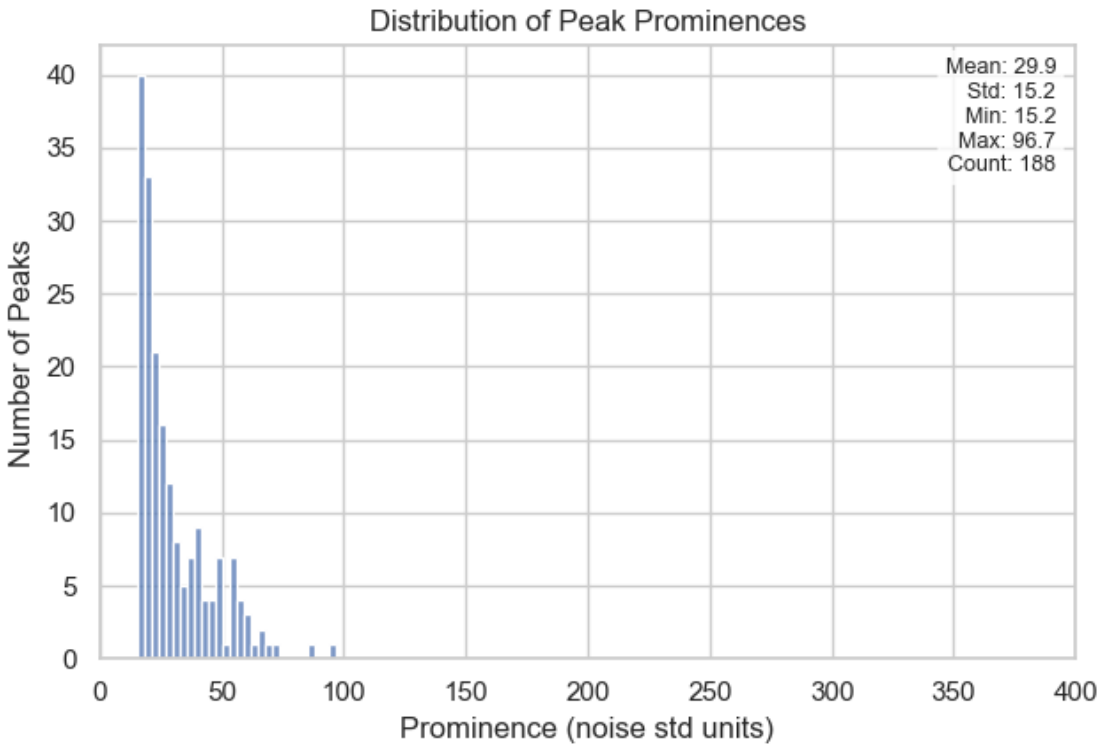
1.2 GLOBAL EVENTS

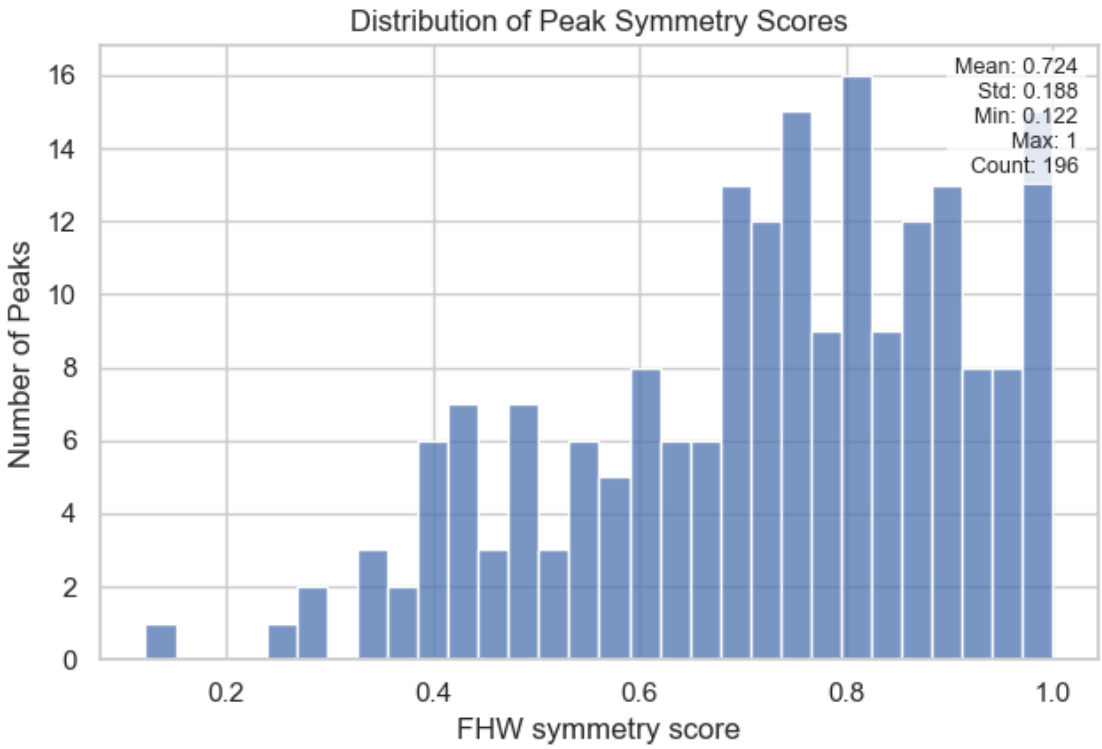
1.2.1 Peak statistics in global events

```
[2025-08-11 09:45:11] [INFO] calcium: plot_histogram: removed 5 outliers out of
196 on 'Duration (s)' (lower=-72.75, upper=153)
```



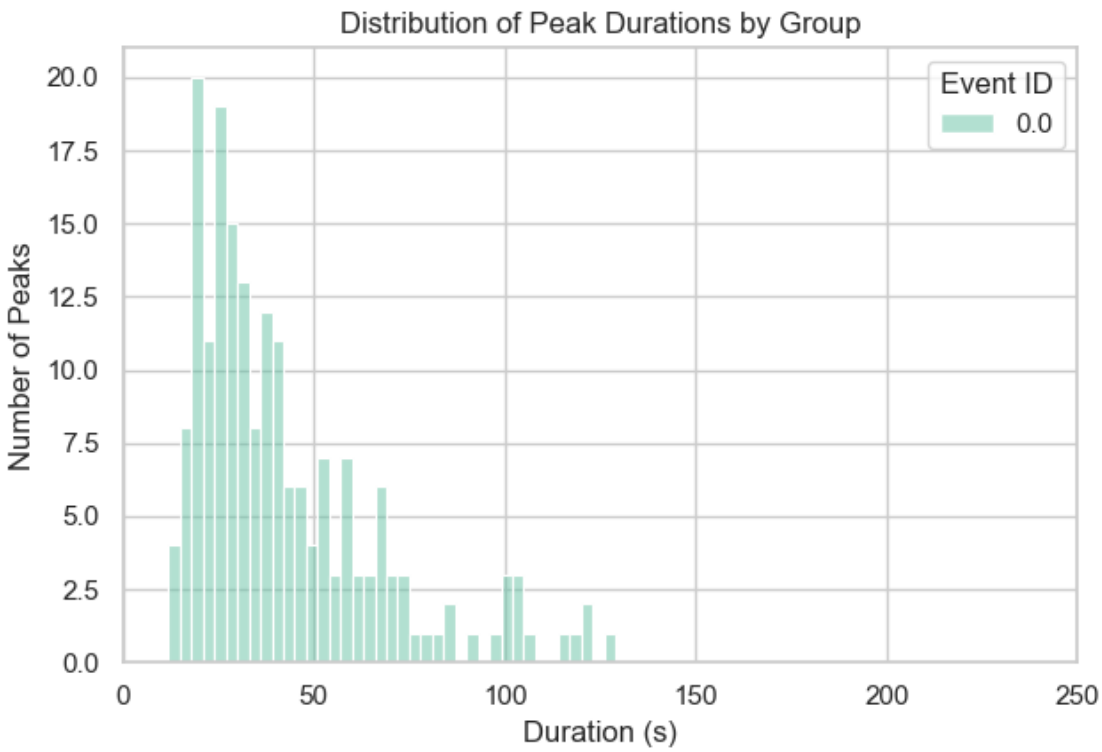

```
[2025-08-11 09:45:11] [INFO] calcium: plot_histogram: removed 8 outliers out of
196 on 'Prominence (noise std units)' (lower=-44.275, upper=102.9)
```


Distribution of Peak Prominences
Mean: 29.9
Std: 15.2
Min: 15.2
Max: 96.7
Count: 188
Number of Peaks
Prominence (noise std units)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

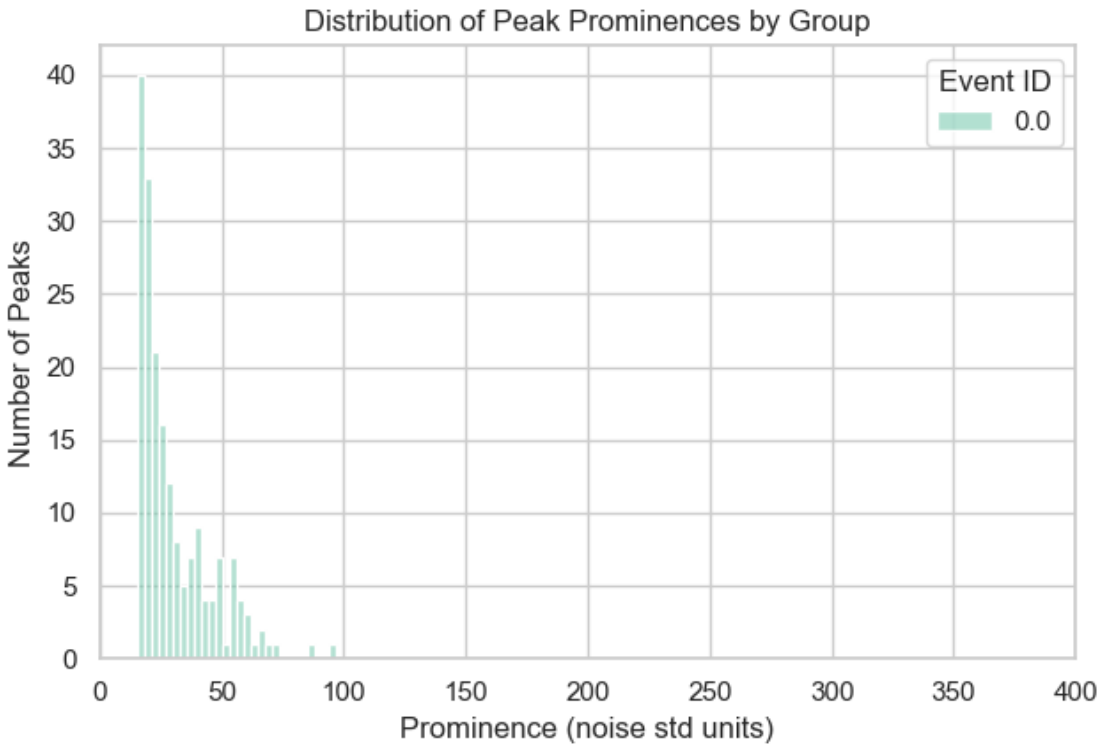

Distribution of Peak Symmetry Scores
Mean: 0.724
Std: 0.188
Min: 0.122
Max: 1
Count: 196
Number of Peaks
FHW symmetry score
0
2
4
6
8
10
12
14
16
0.2
0.4
0.6
0.8
1.0

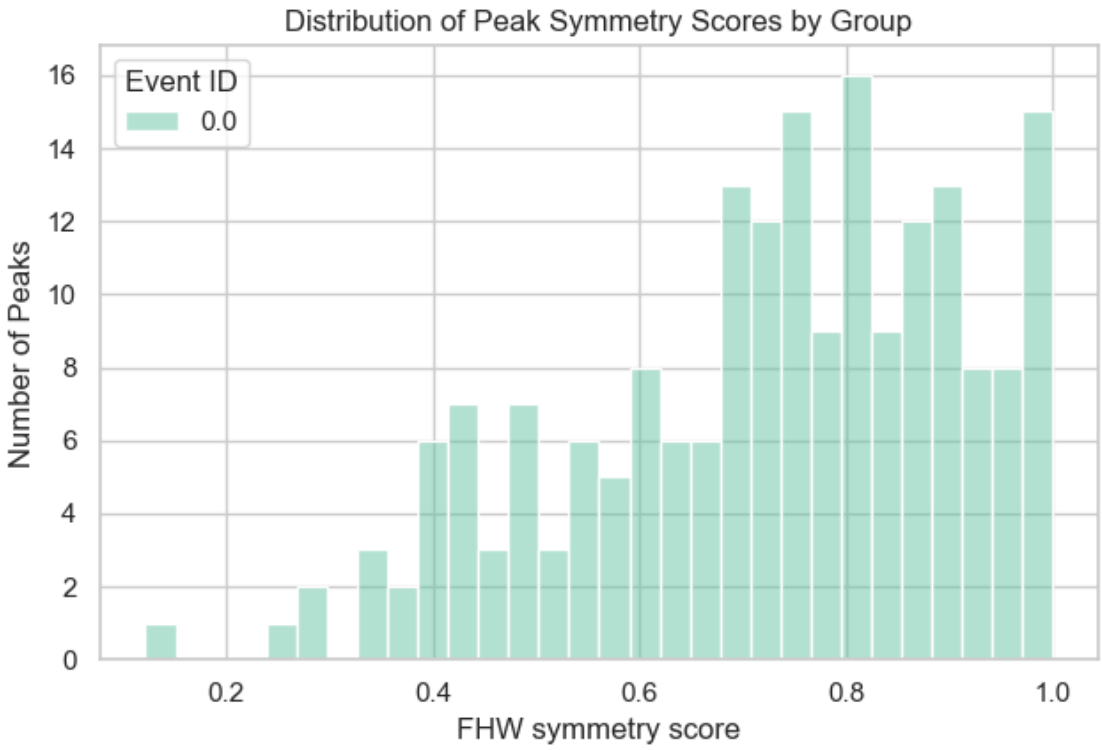
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:45:11] [INFO] calcium: plot_histogram_by_group: removed 5
outliers out of 196 on 'Duration (s)' (lower=-72.75, upper=153)
```

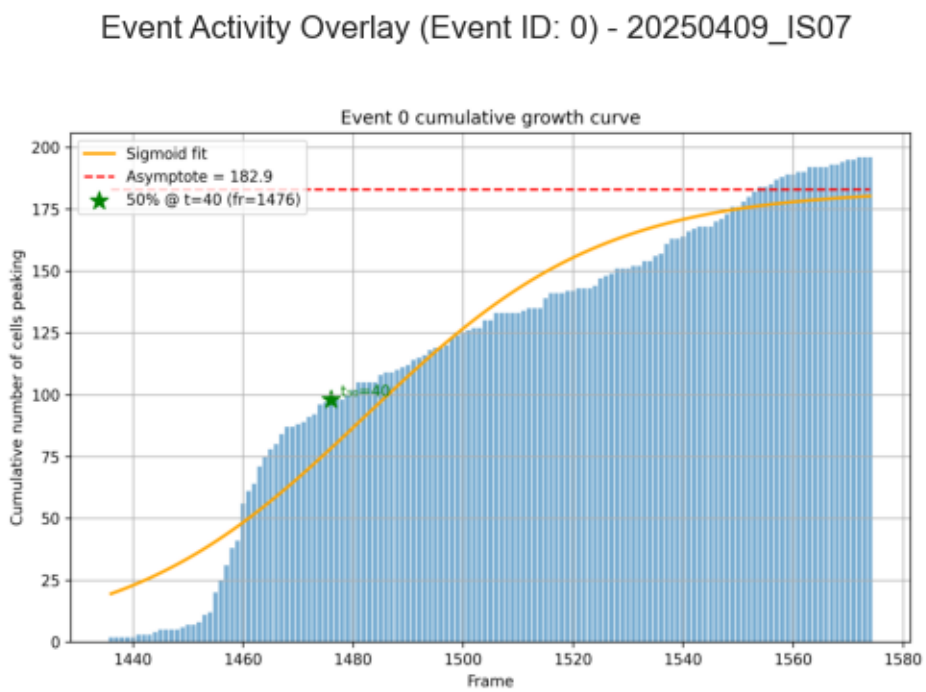



```
[2025-08-11 09:45:11] [INFO] calcium: plot_histogram_by_group: removed 8
outliers out of 196 on 'Prominence (noise std units)' (lower=-44.275,
upper=102.9)
```

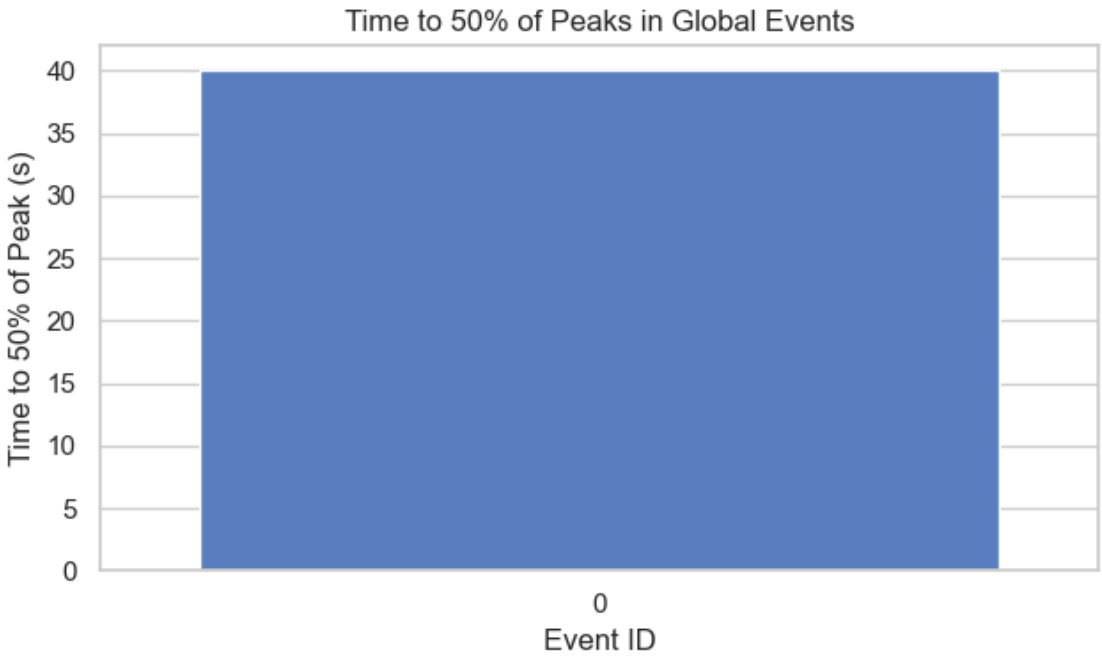

Distribution of Peak Prominences by Group
Event ID
0.0
Number of Peaks
Prominence (noise std units)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores by Group
Event ID
0.0
Number of Peaks
FHW symmetry score
0
2
4
6
8
10
12
14
16
0.2
0.4
0.6
0.8
1.0

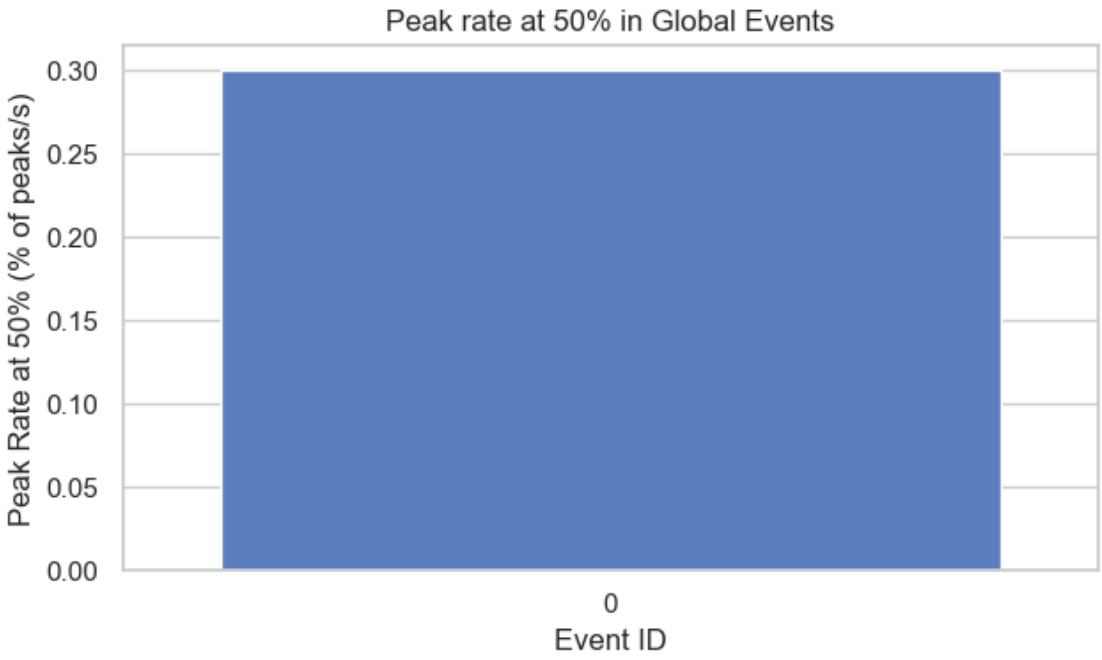
1.2.3 Kinetics of global events



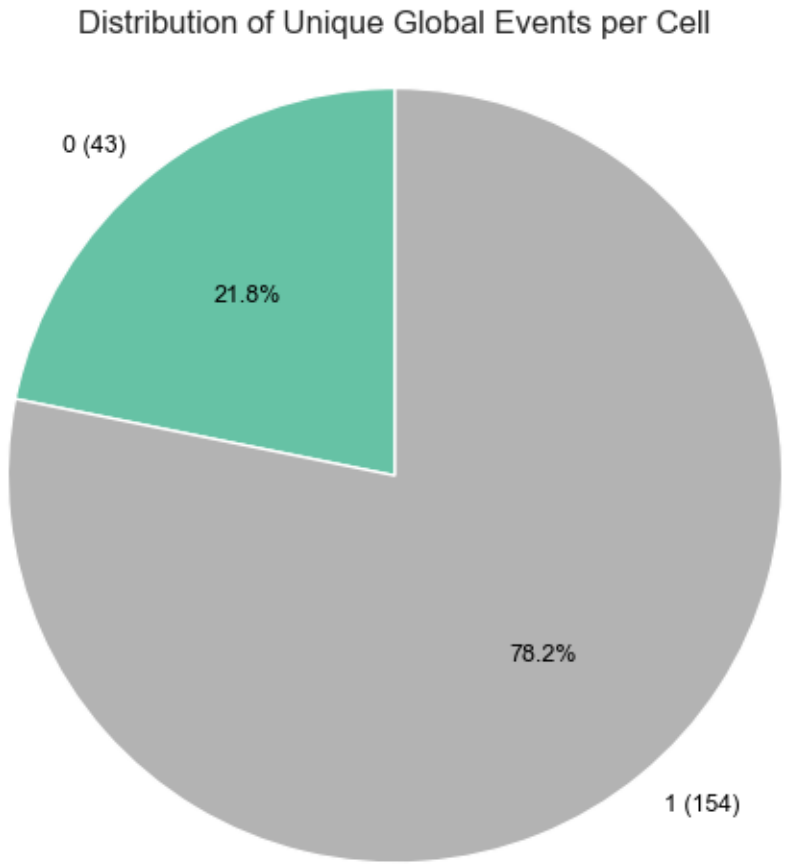

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



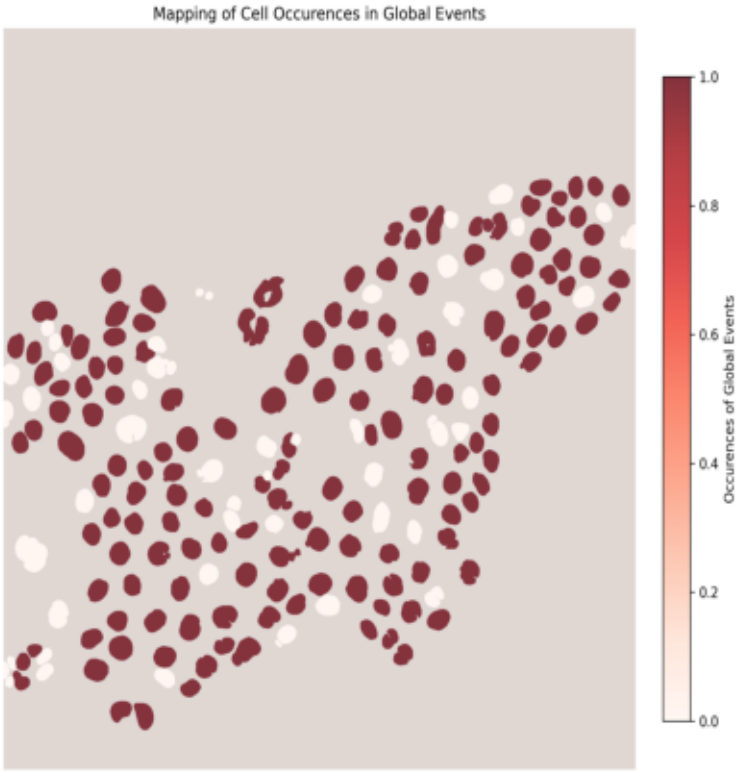

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
Event ID

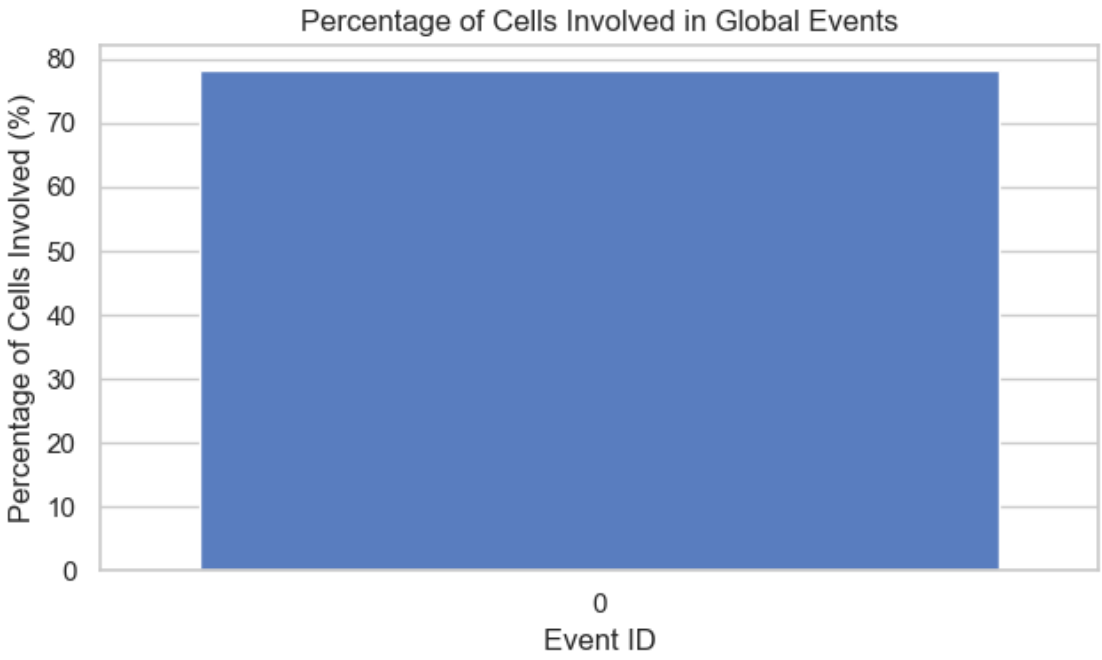
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS07




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

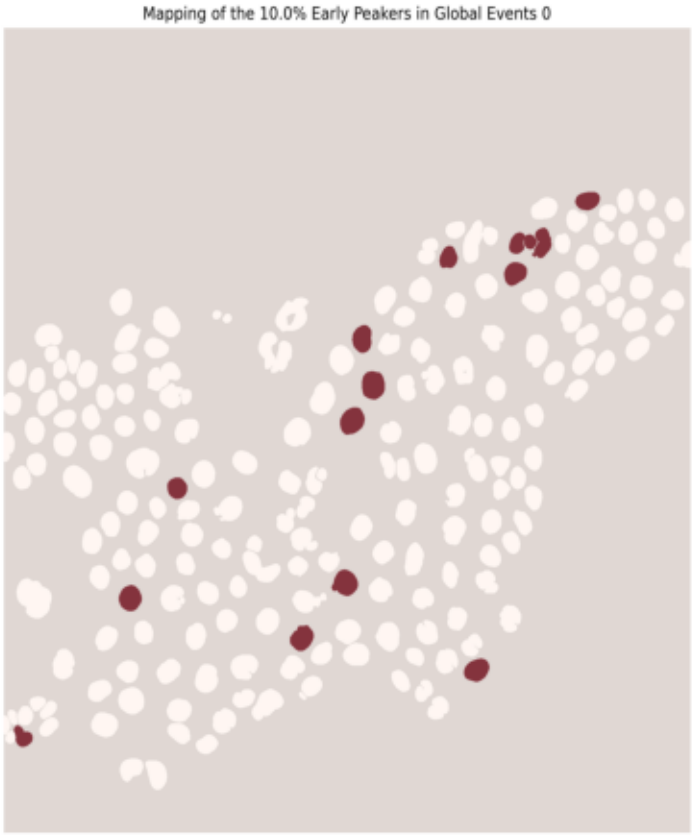


1.2.5 Inter-event interval analysis

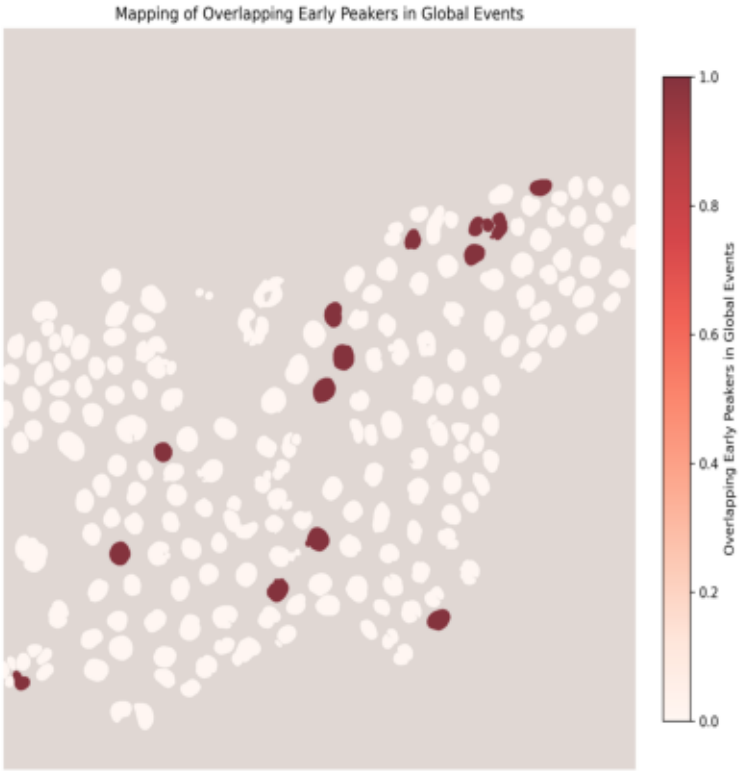
```
Intervals between global event peaks: []
```

1.2.6 Early peakers in the events

Cell Mapping with Early Peakers Overlay for event 0 - 20250409_IS07

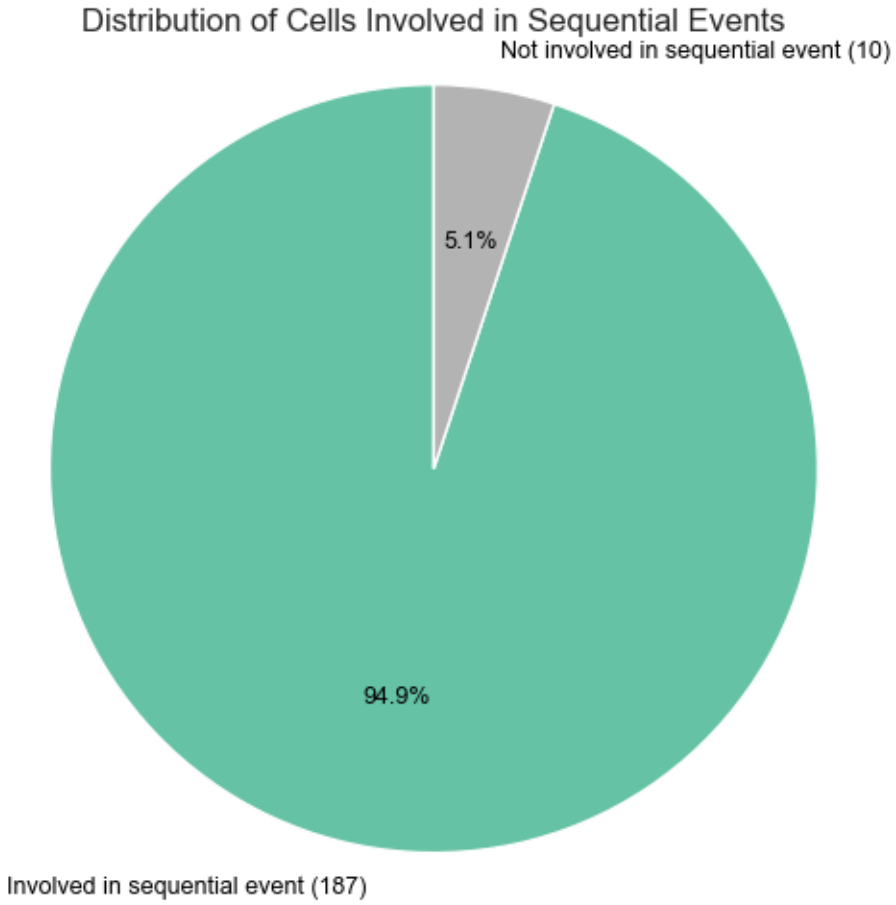


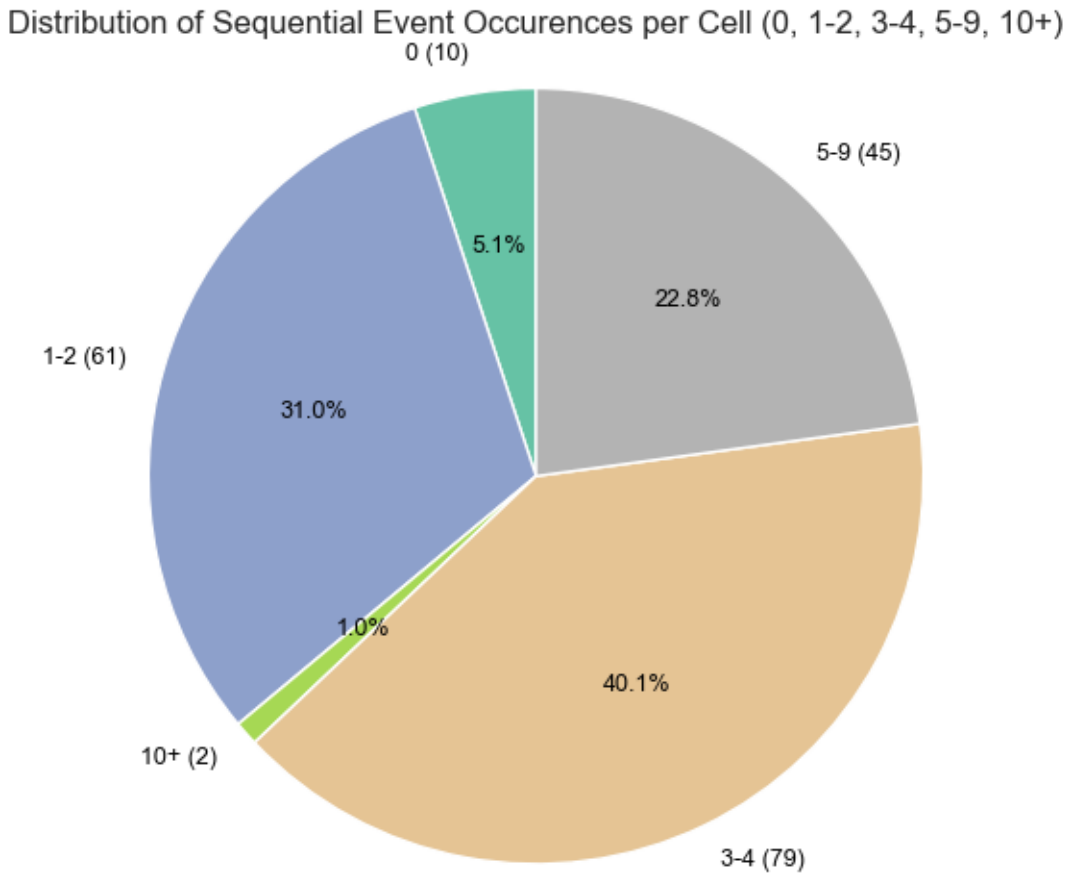
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS07



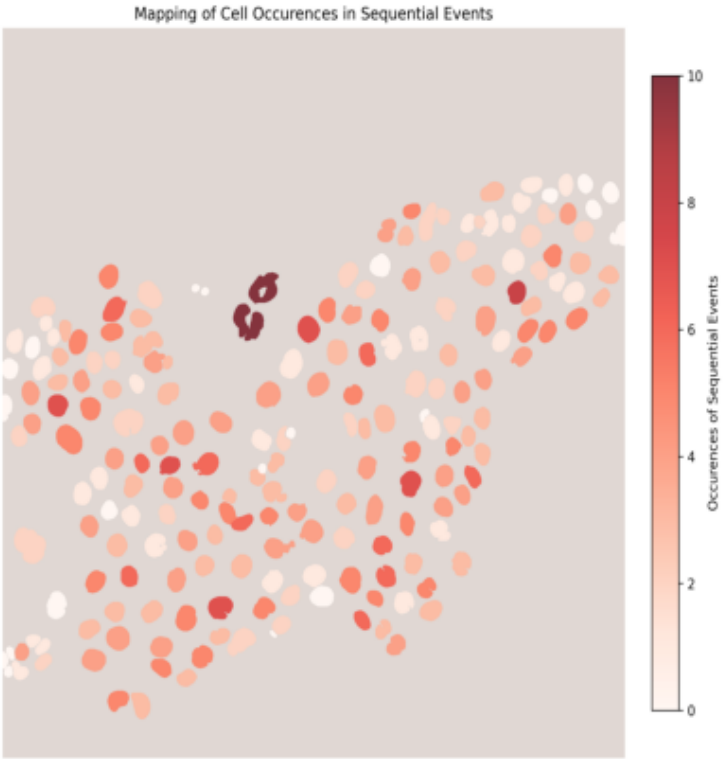
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

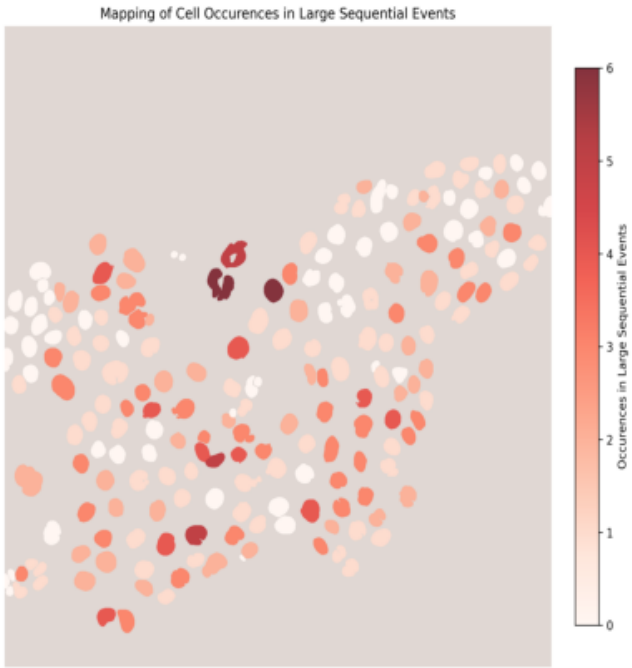



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (10)
5-9 (45)
5.1%
22.8%
1-2 (61)
31.0%
1.0%
40.1%
10+ (2)
3-4 (79)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS07

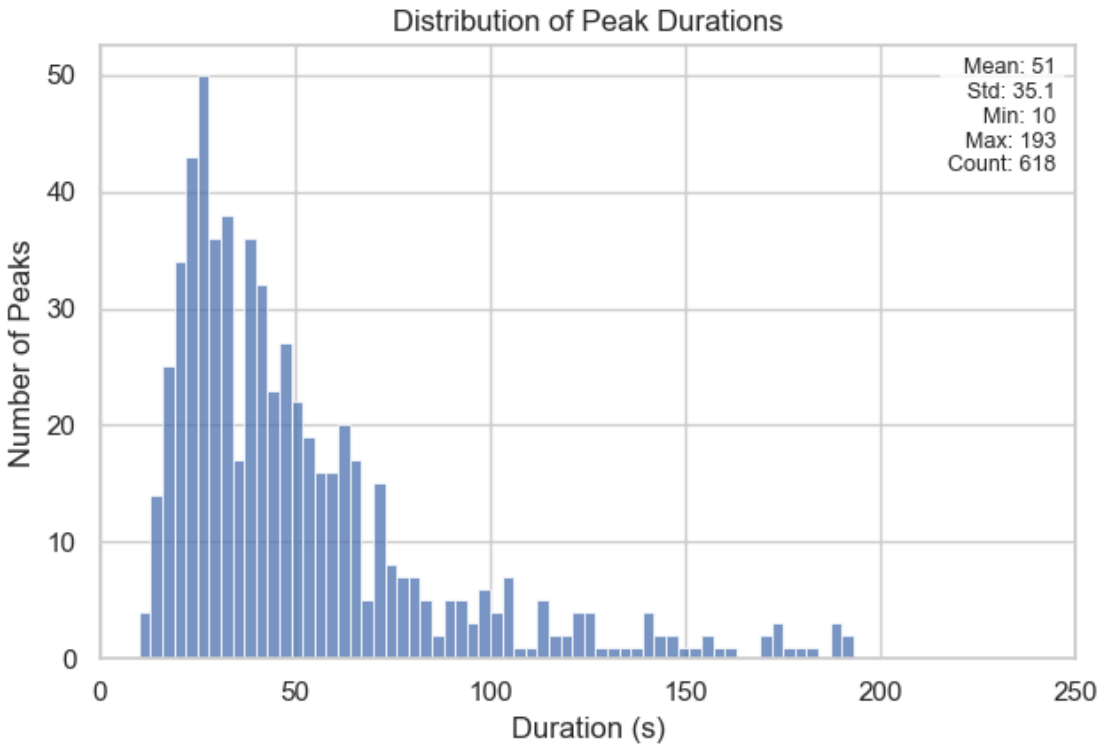


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS07

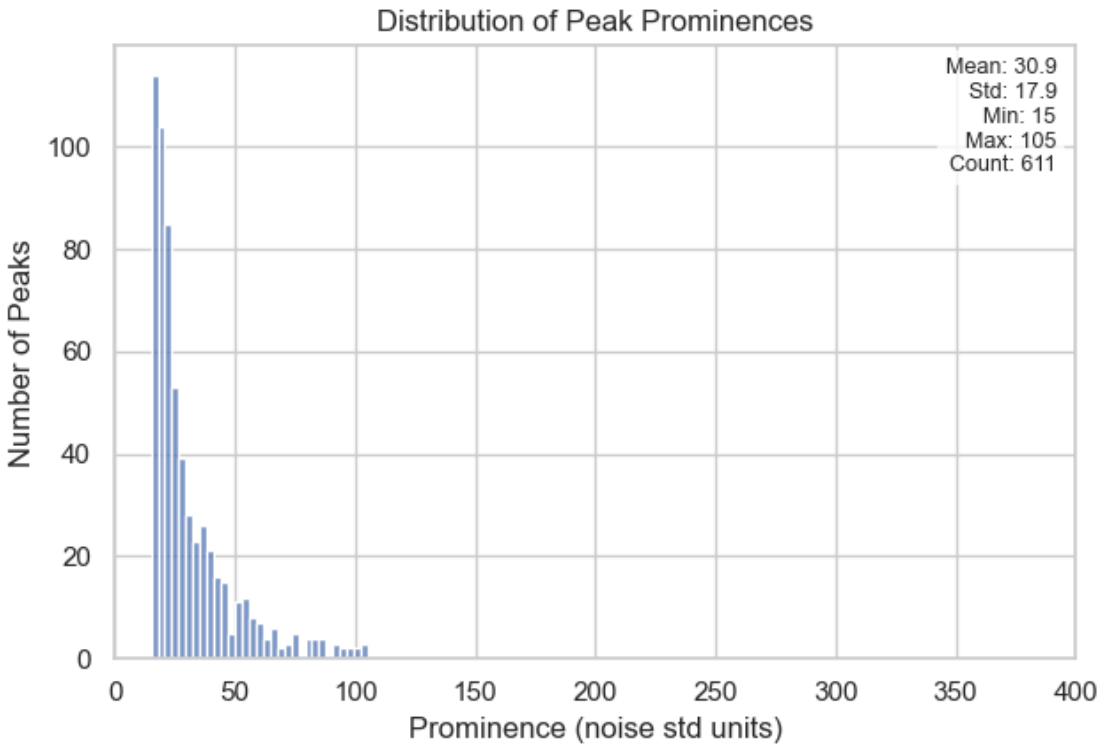


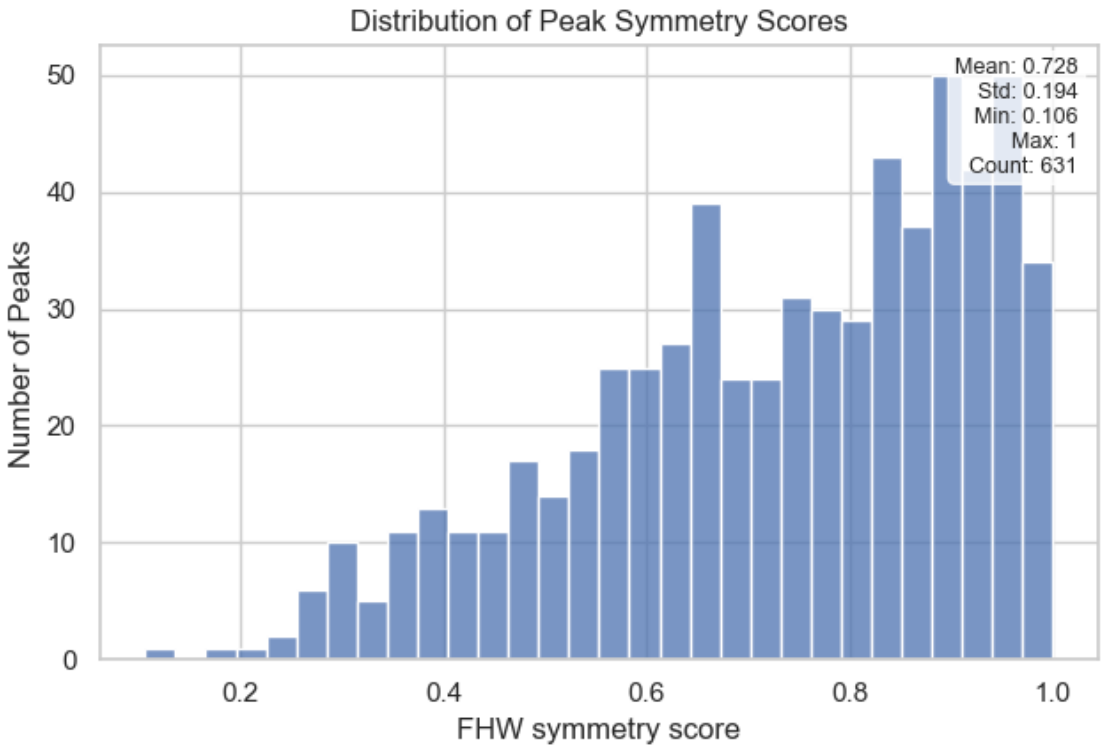
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:45:17] [INFO] calcium: plot_histogram: removed 13 outliers out of
631 on 'Duration (s)' (lower=-28.5, upper=193.5)
```



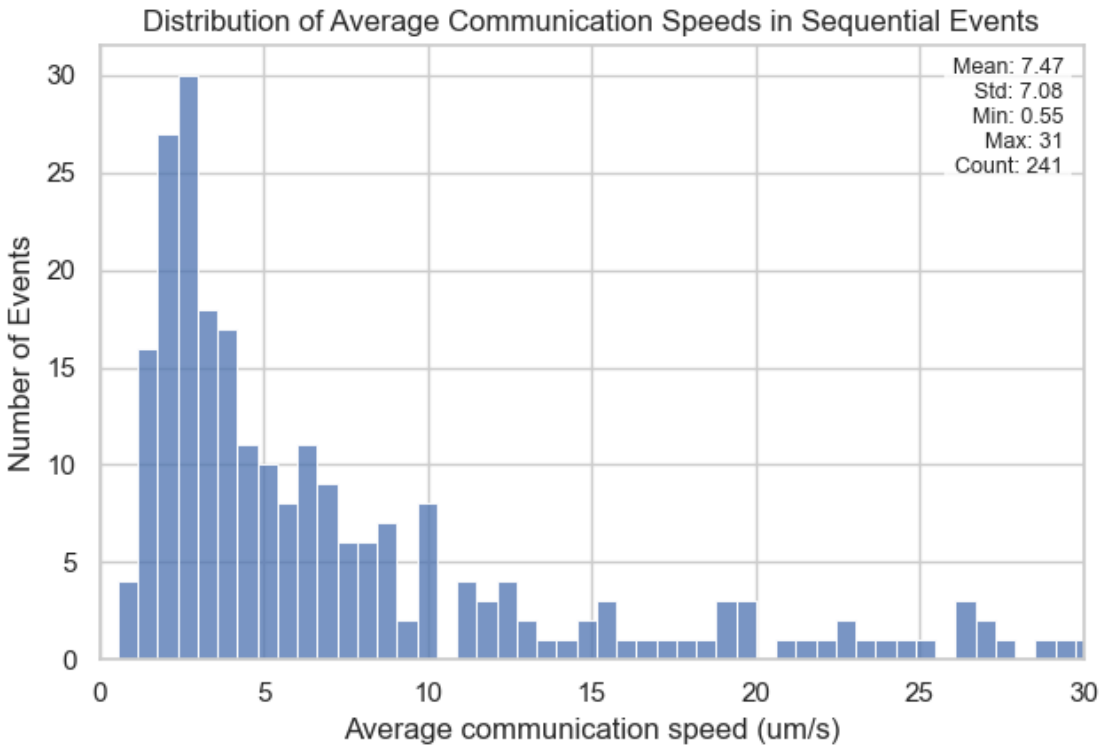

```
[2025-08-11 09:45:17] [INFO] calcium: plot_histogram: removed 20 outliers out of
631 on 'Prominence (noise std units)' (lower=-10.275, upper=107.03)
```


Distribution of Peak Prominences
Mean: 30.9
Std: 17.9
Min: 15
Max: 105
Count: 611
Number of Peaks
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

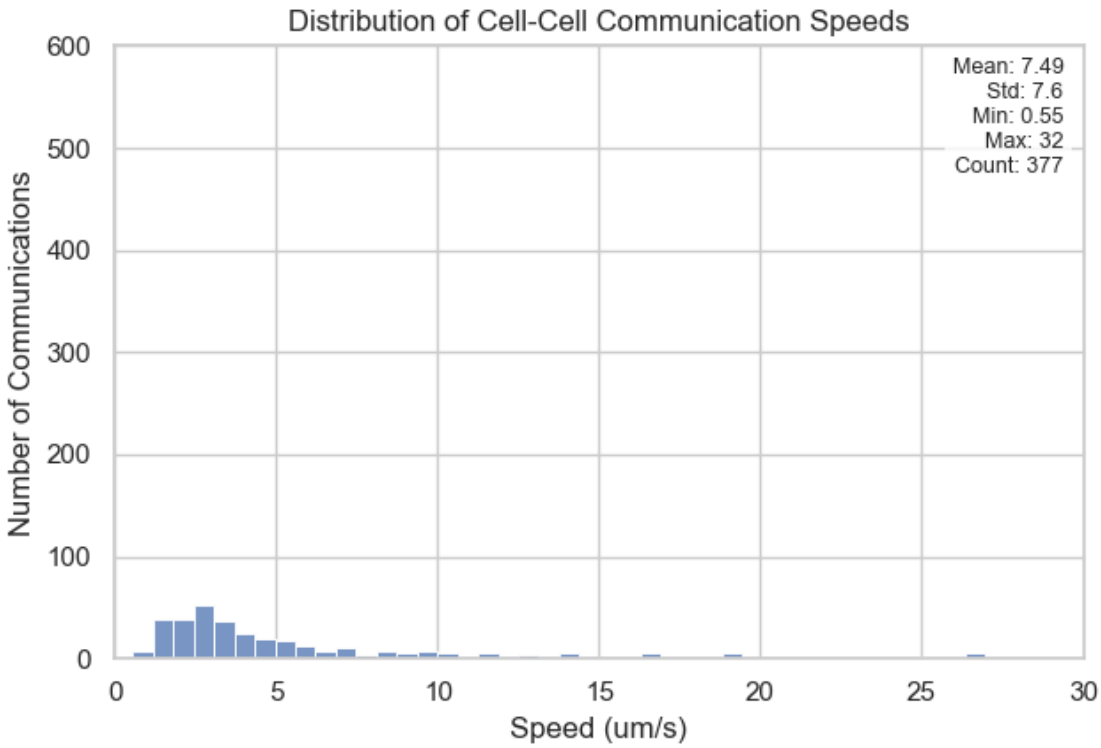

Distribution of Peak Symmetry Scores
Mean: 0.728
Std: 0.194
Min: 0.106
Max: 1
Count: 631
Number of Peaks
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:45:18] [INFO] calcium: plot_histogram: removed 6 outliers out of
247 on 'Average communication speed (um/s)' (lower=-19.16, upper=31.66)
```

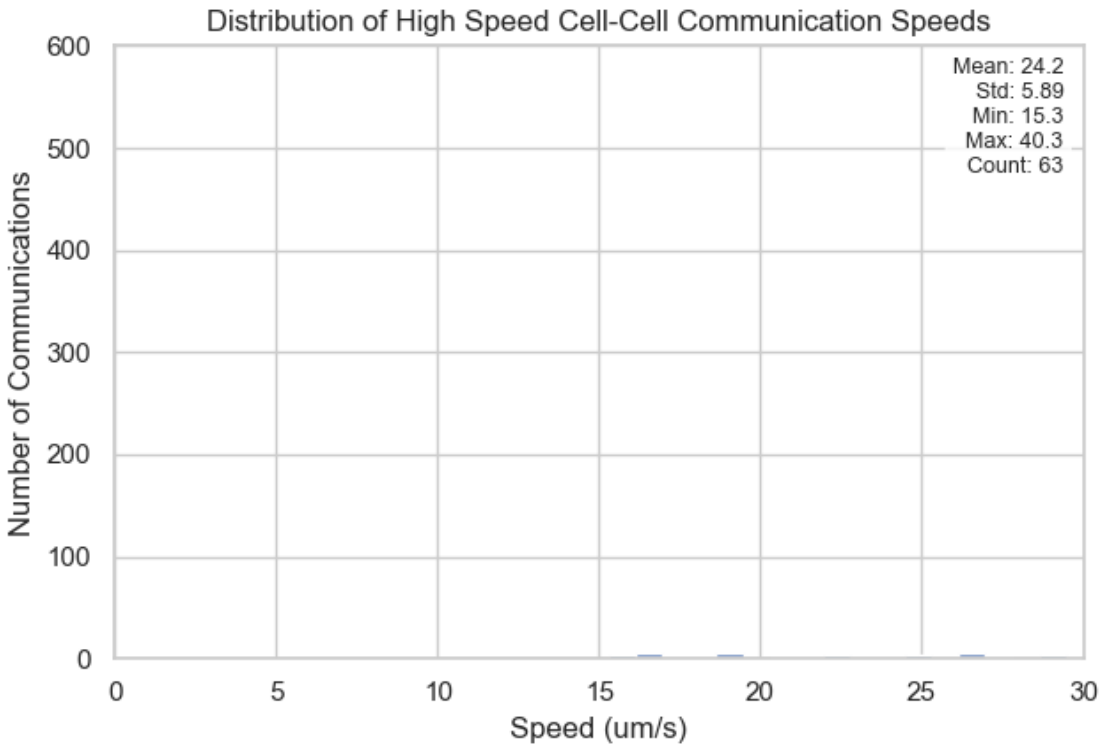



```
[2025-08-11 09:45:18] [INFO] calcium: plot_histogram: removed 7 outliers out of
384 on 'Speed (um/s)' (lower=-19.875, upper=32.398)
```

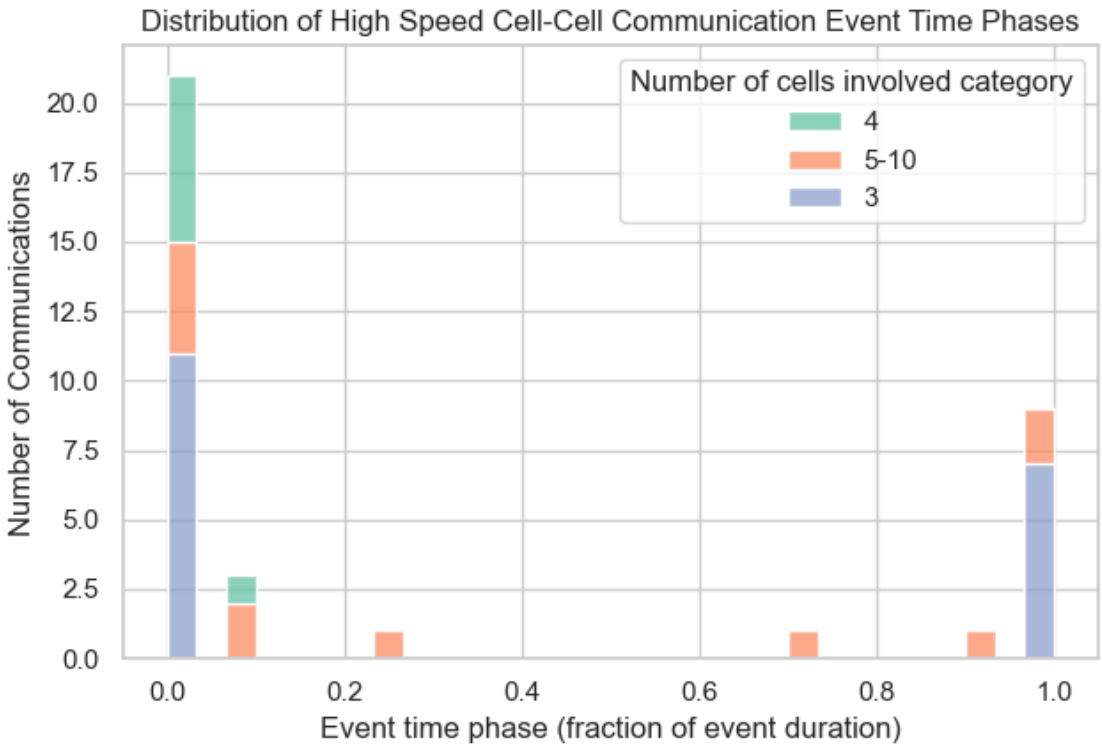


1.3.4 Double distribution in cell-cell communication speeds

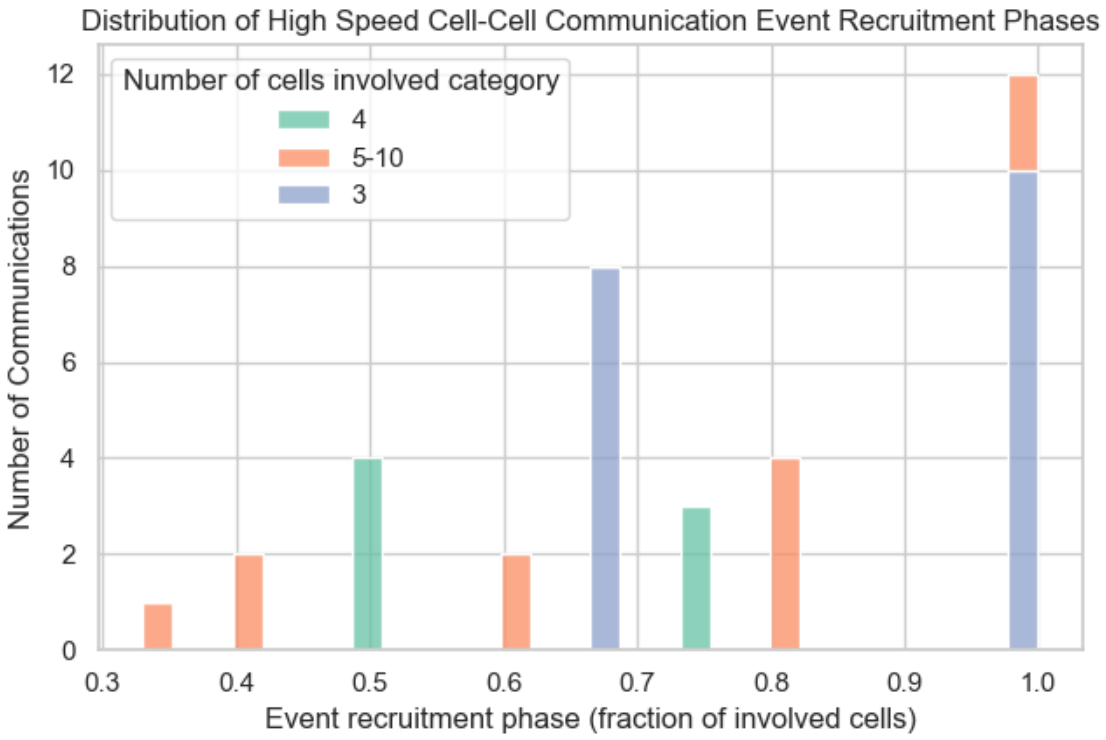
```
[2025-08-11 09:45:18] [INFO] calcium: plot_histogram: removed 2 outliers out of
65 on 'Speed (um/s)' (lower=-10.17, upper=58.29)
```



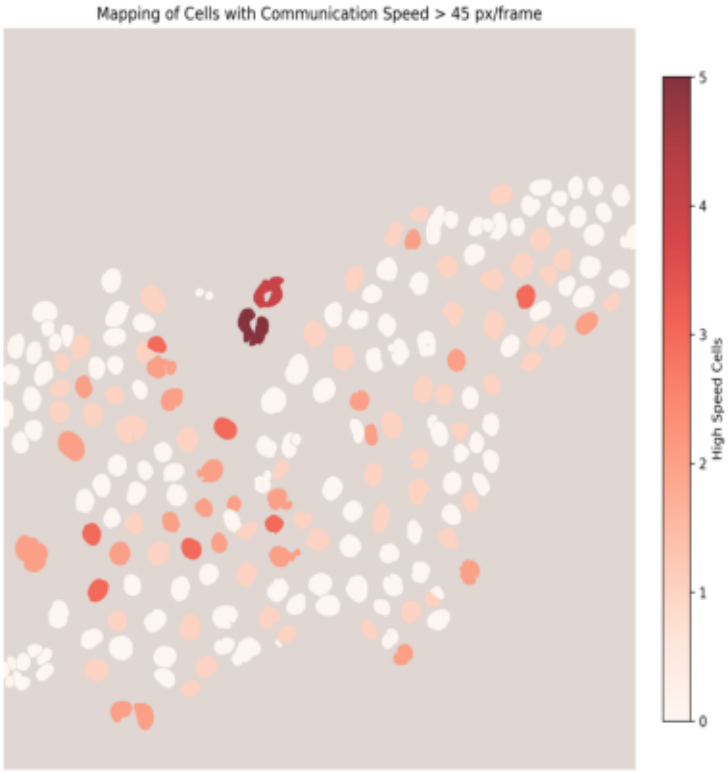

```
[2025-08-11 09:45:18] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 36 on 'Event time phase (fraction of event duration)'
(lower=-2.8425, upper=3.79)
```



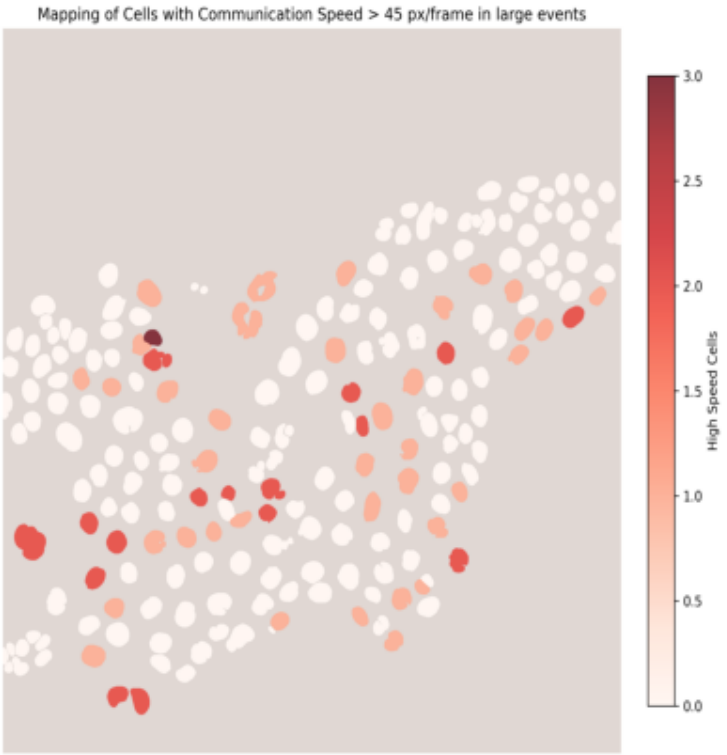

```
[2025-08-11 09:45:18] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 36 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.37, upper=2.0275)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
4
5-10
3
Number of Communications
0
2
4
6
8
10
12
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Event recruitment phase (fraction of involved cells)

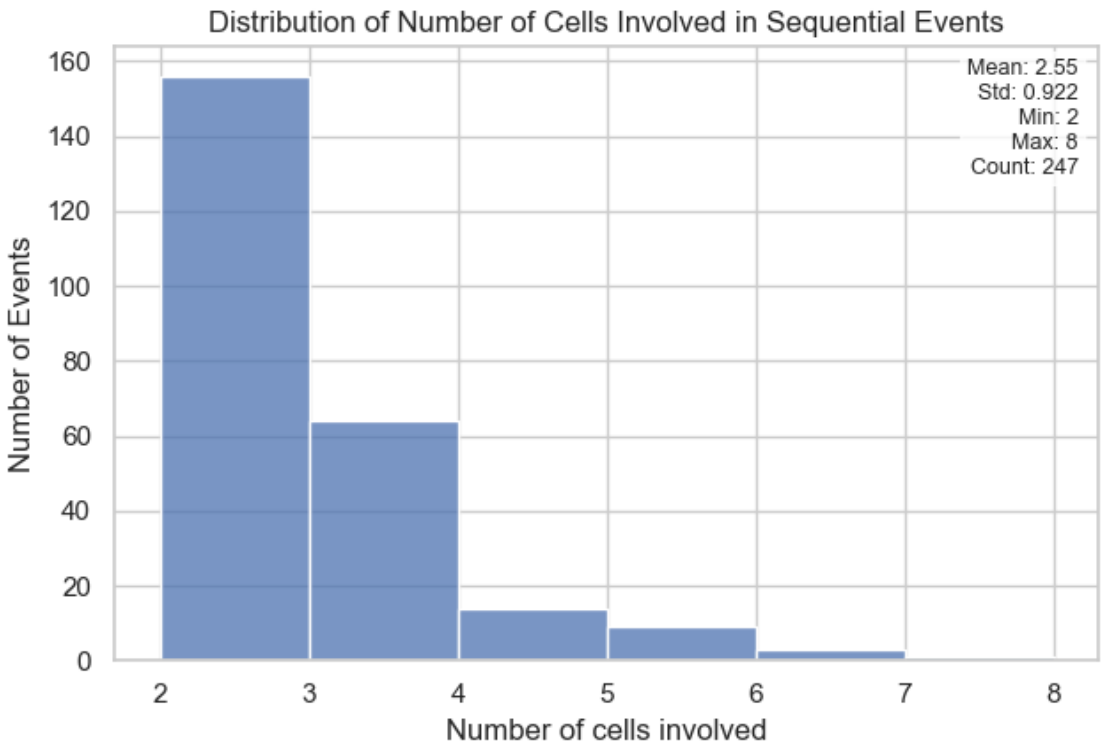
Cell Mapping with High Speed Cells Overlay - 20250409_IS07



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS07

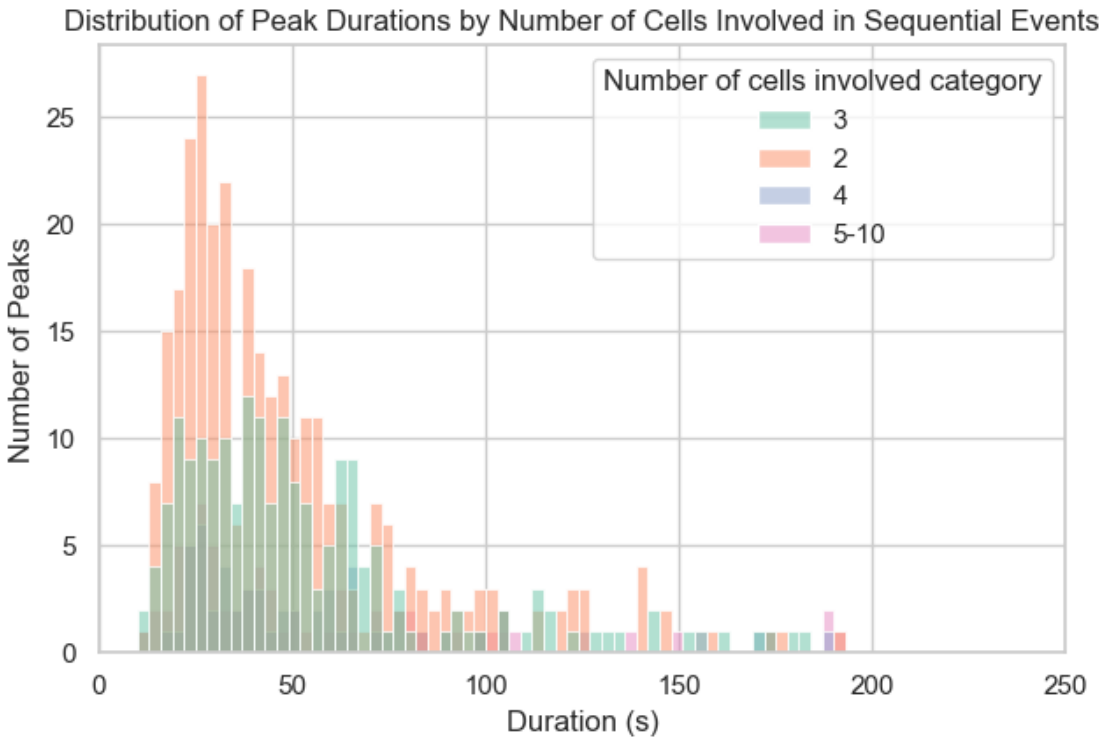


1.3.5 Number of cells involved per sequential events

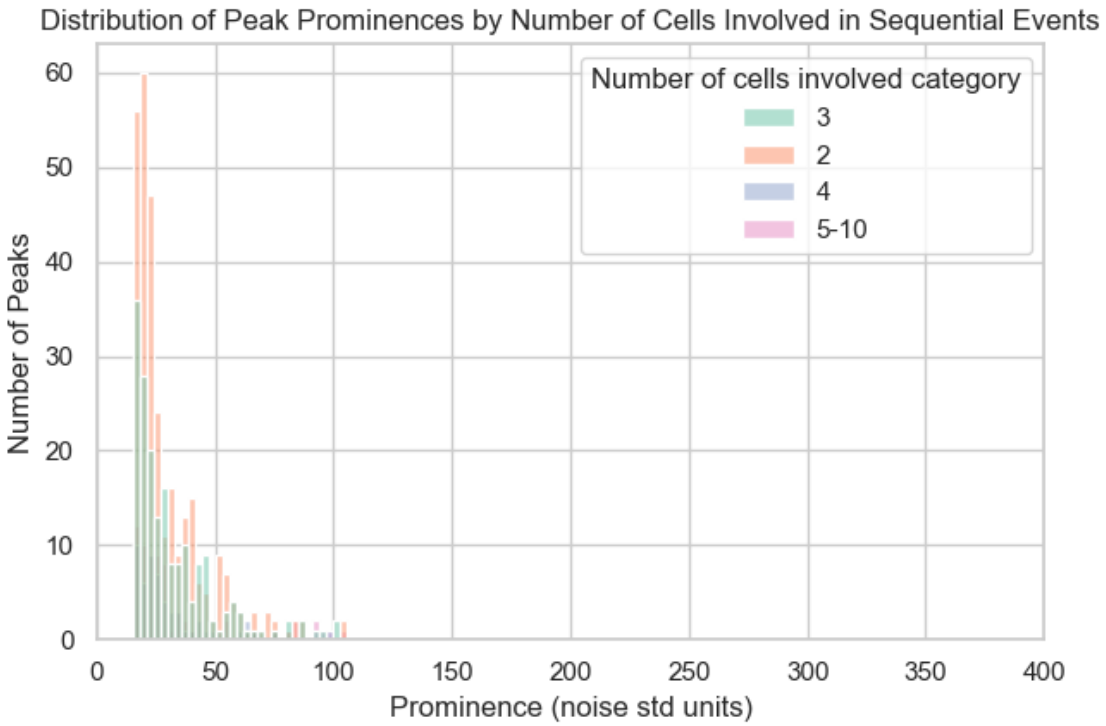


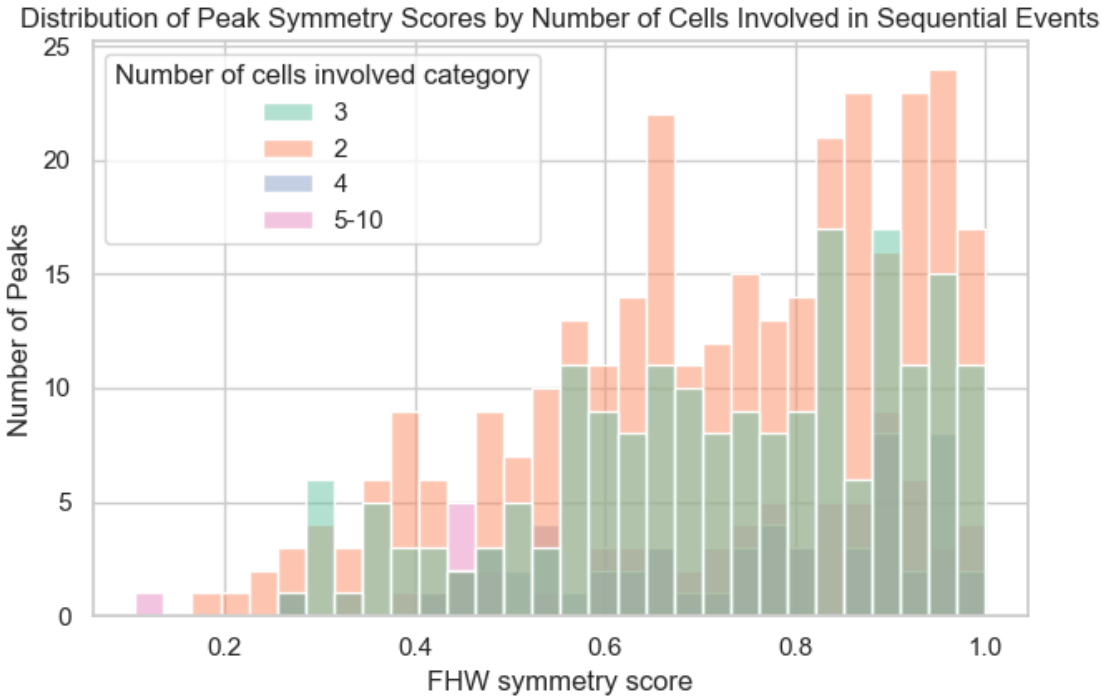
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:45:21] [INFO] calcium: plot_histogram_by_group: removed 13
outliers out of 631 on 'Duration (s)' (lower=-28.5, upper=193.5)
```



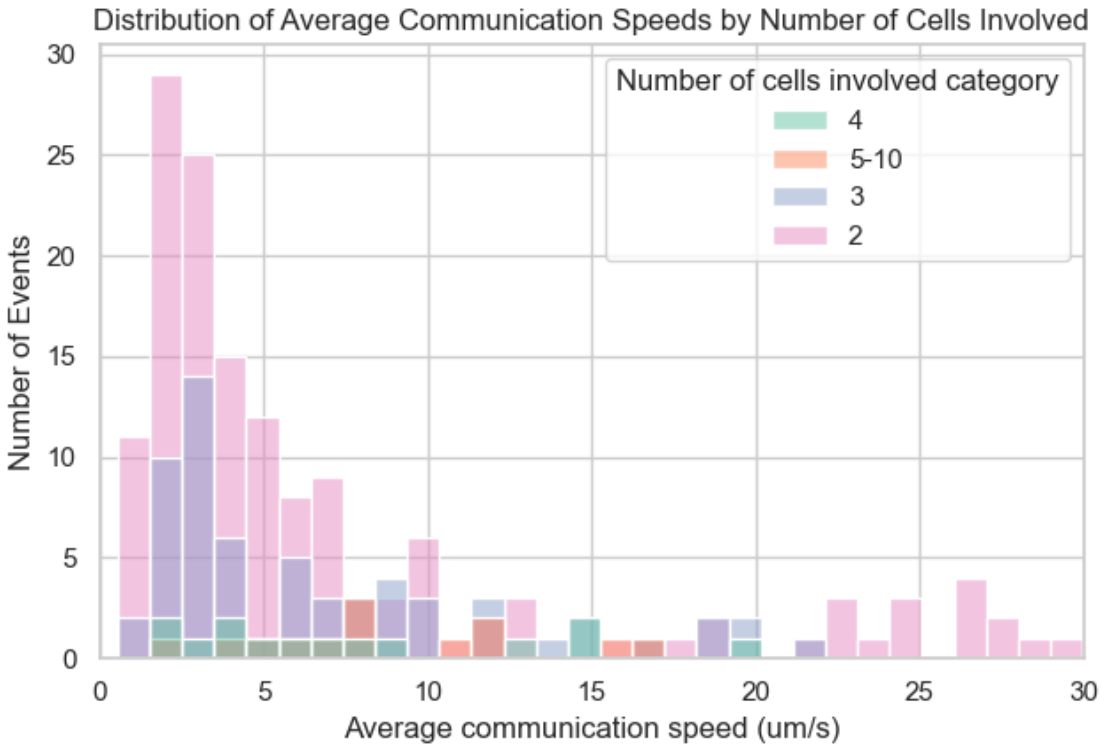

```
[2025-08-11 09:45:21] [INFO] calcium: plot_histogram_by_group: removed 20
outliers out of 631 on 'Prominence (noise std units)' (lower=-10.275,
upper=107.03)
```



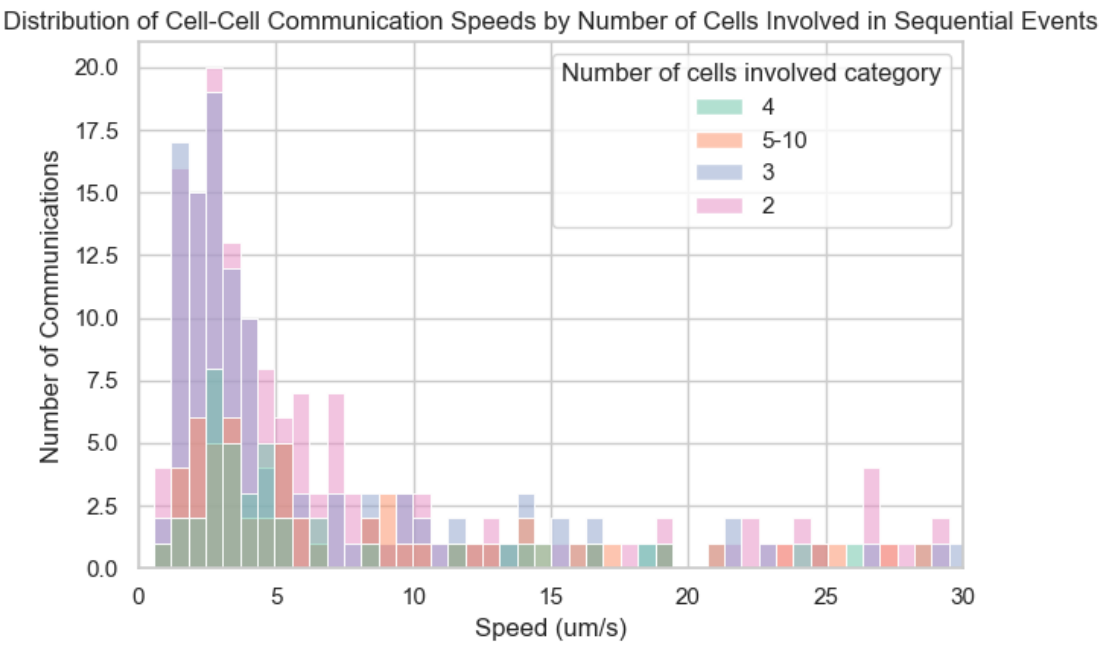



```
[2025-08-11 09:45:21] [INFO] calcium: plot_histogram_by_group: removed 6
```

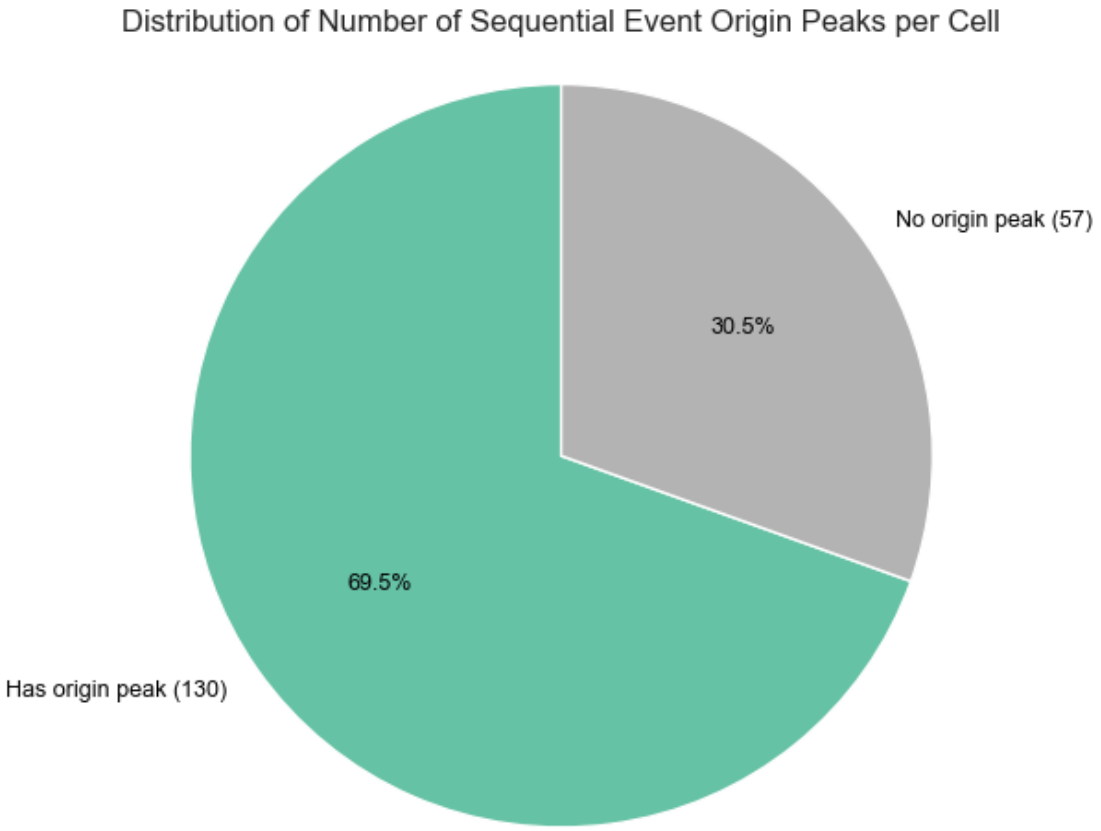
```
outliers out of 247 on 'Average communication speed (um/s)' (lower=-19.16,
upper=31.66)
```

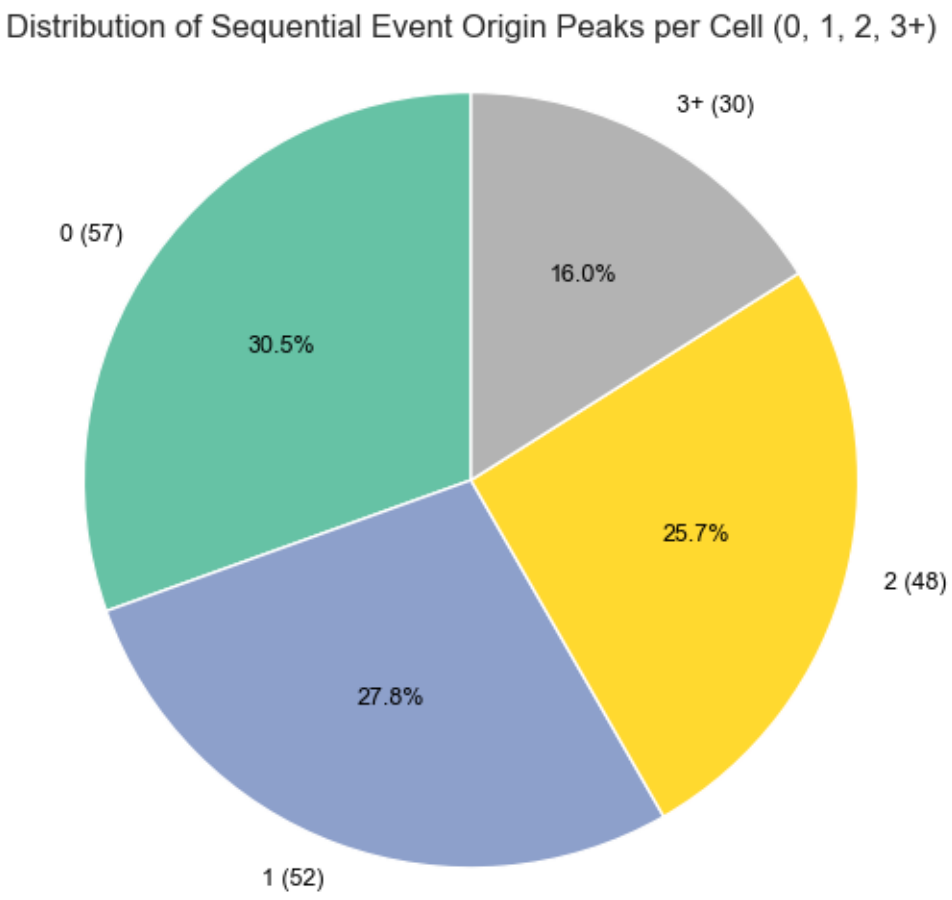



```
[2025-08-11 09:45:21] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 384 on 'Speed (um/s)' (lower=-19.875, upper=32.398)
```

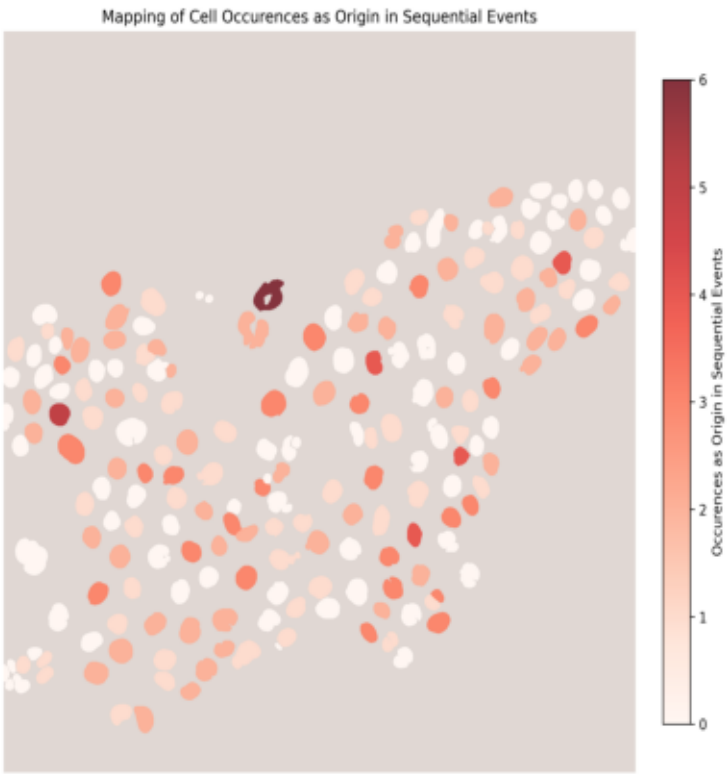

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
4
5-10
3
2
Number of Communications
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0
5
10
15
20
25
30
Speed (um/s)

1.3.7 Cells occurences as origin in sequential events

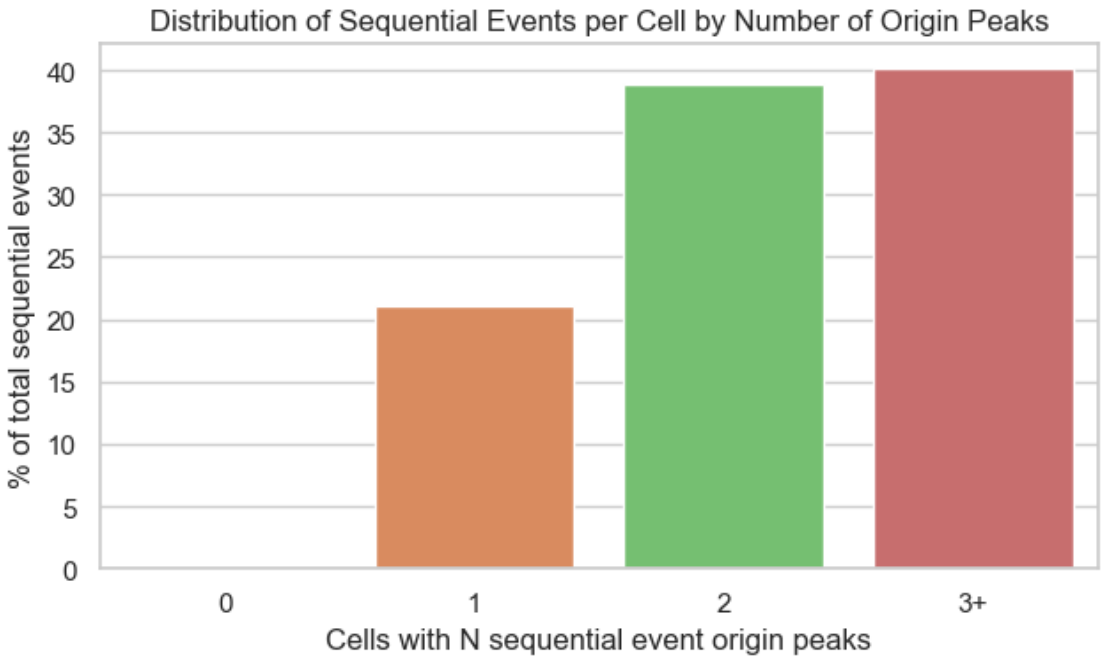



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (30)
16.0%
0 (57)
30.5%
25.7%
2 (48)
27.8%
1 (52)

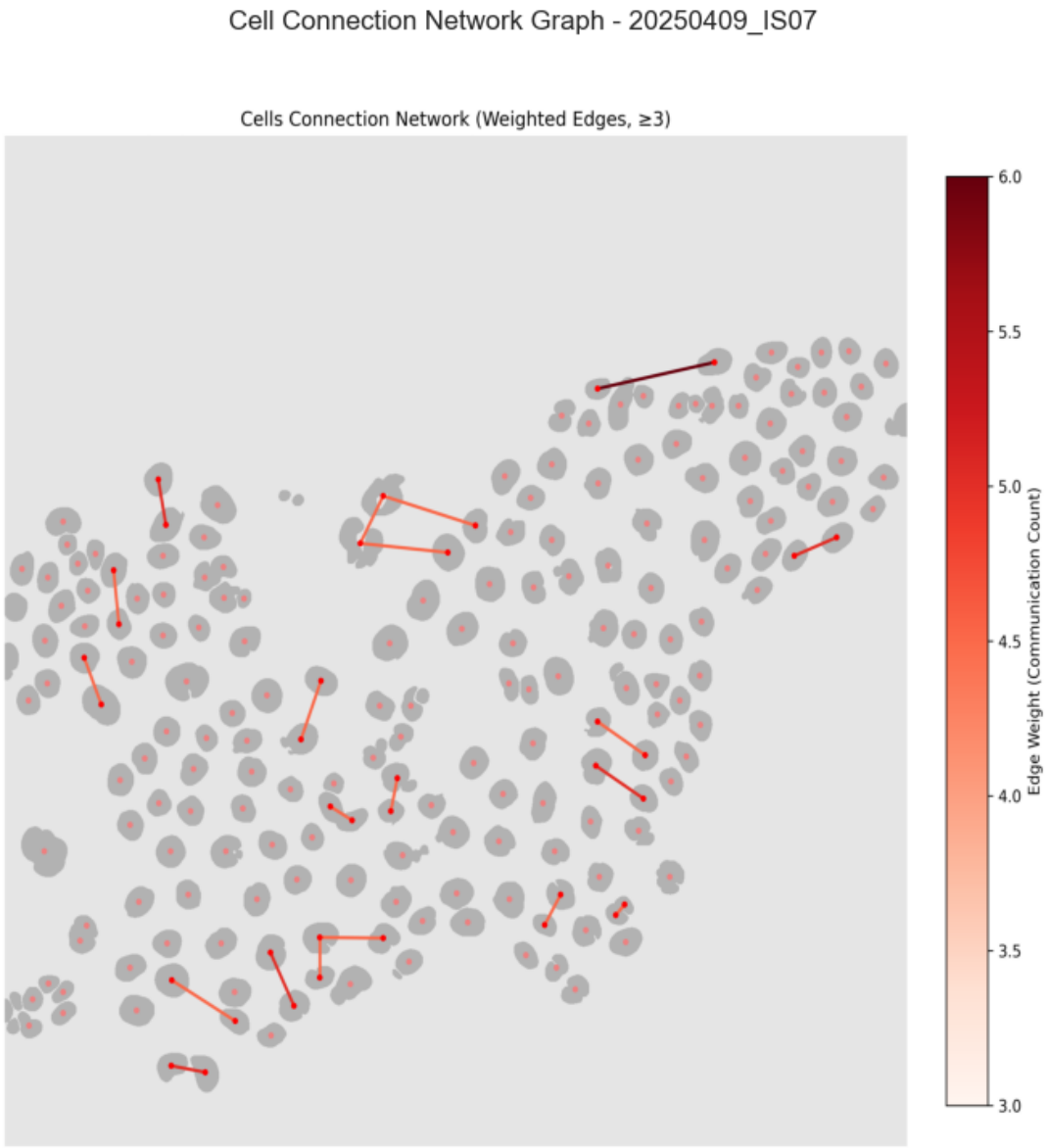
Cell Mapping with Origin Peaks Overlay - 20250409_IS07




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

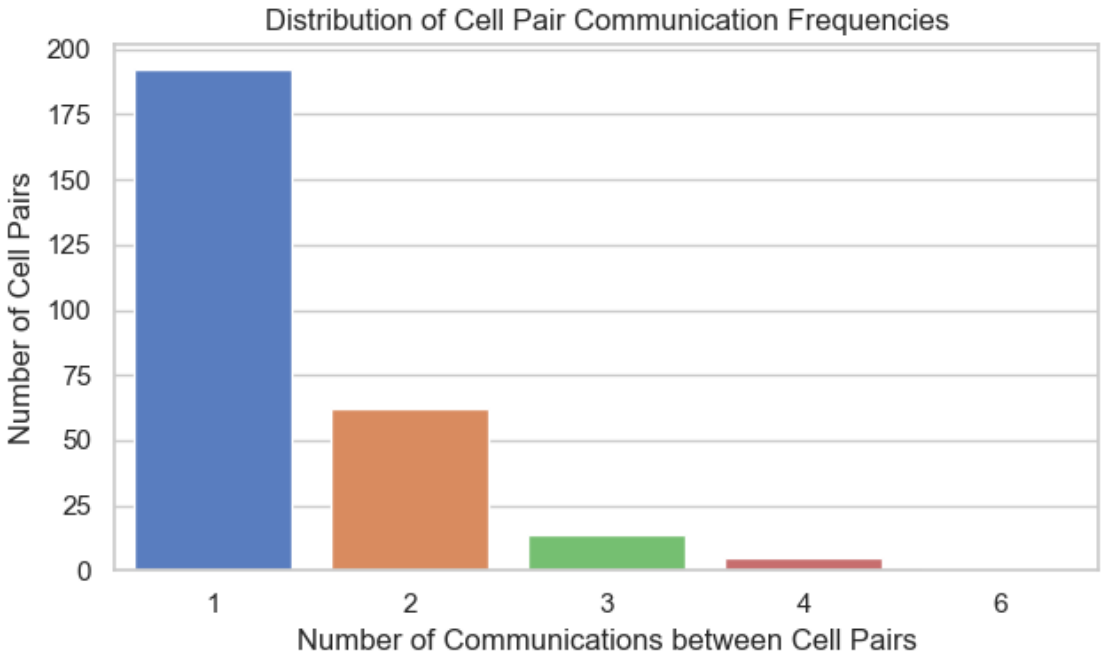

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
40
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



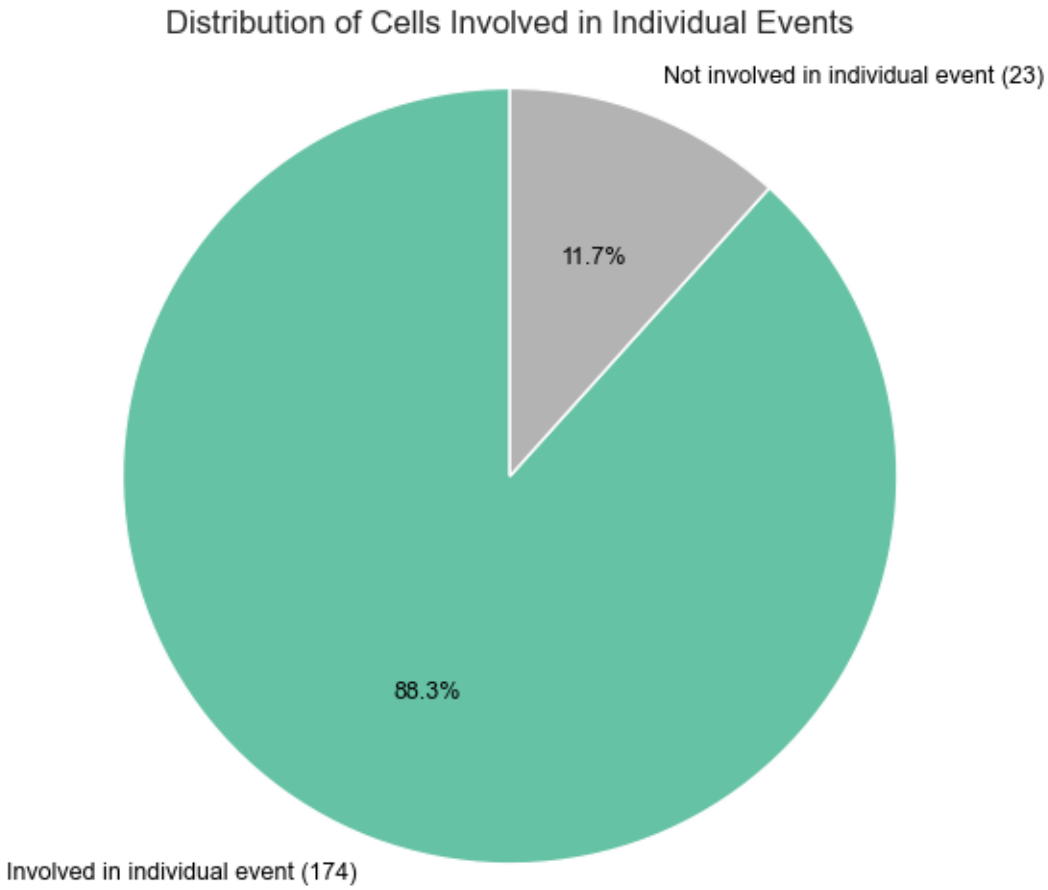

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

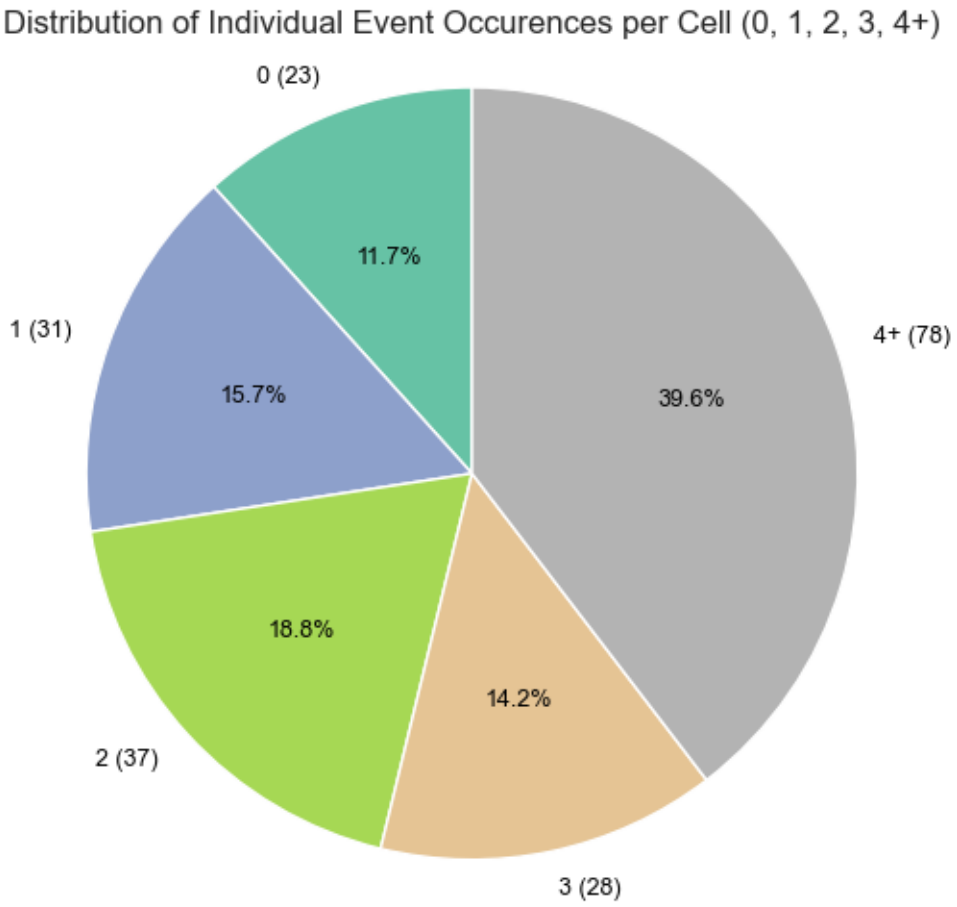
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
200
175
150
125
100
75
50
25
0
1
2
3
4
6
Number of Communications between Cell Pairs

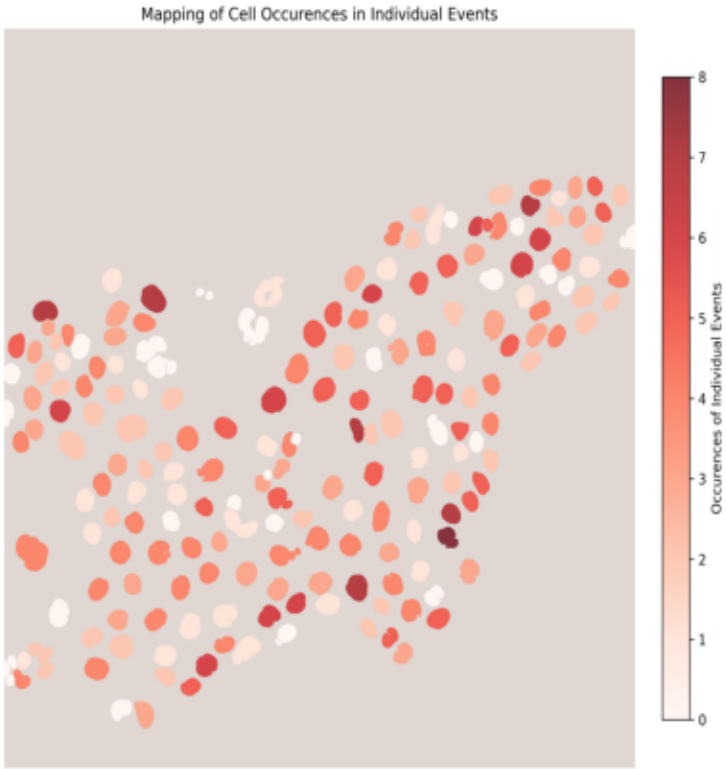
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



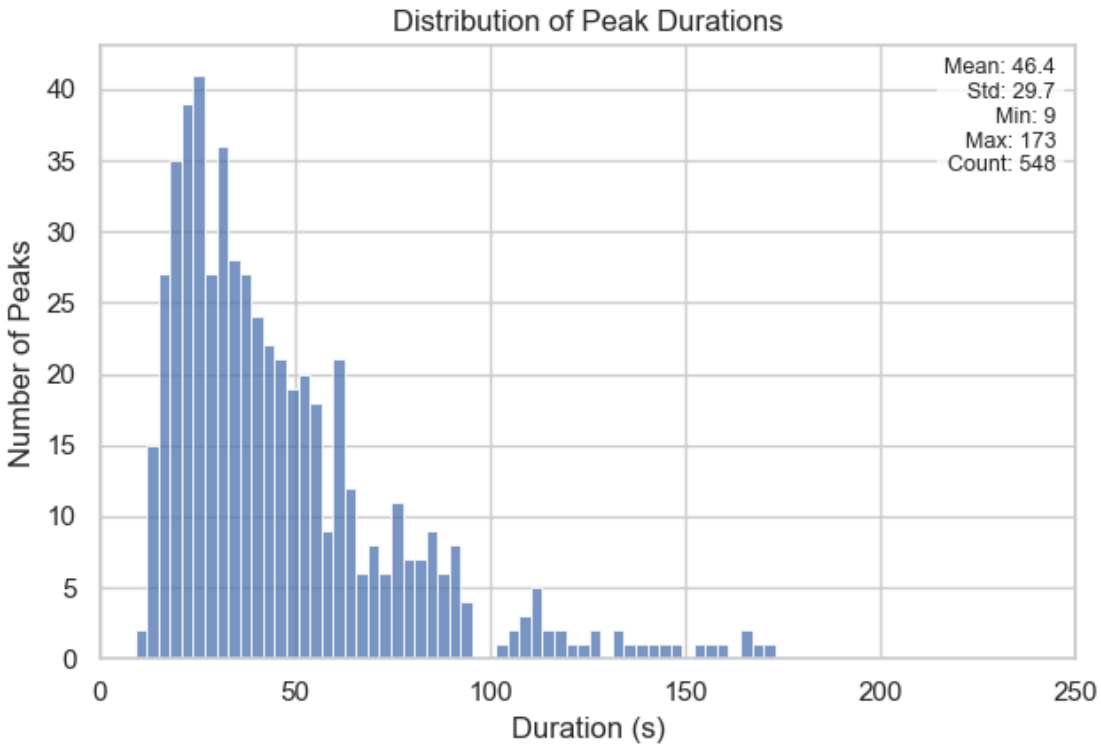

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
0 (23)
11.7%
1 (31)
15.7%
4+ (78)
39.6%
18.8%
14.2%
2 (37)
3 (28)

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS07

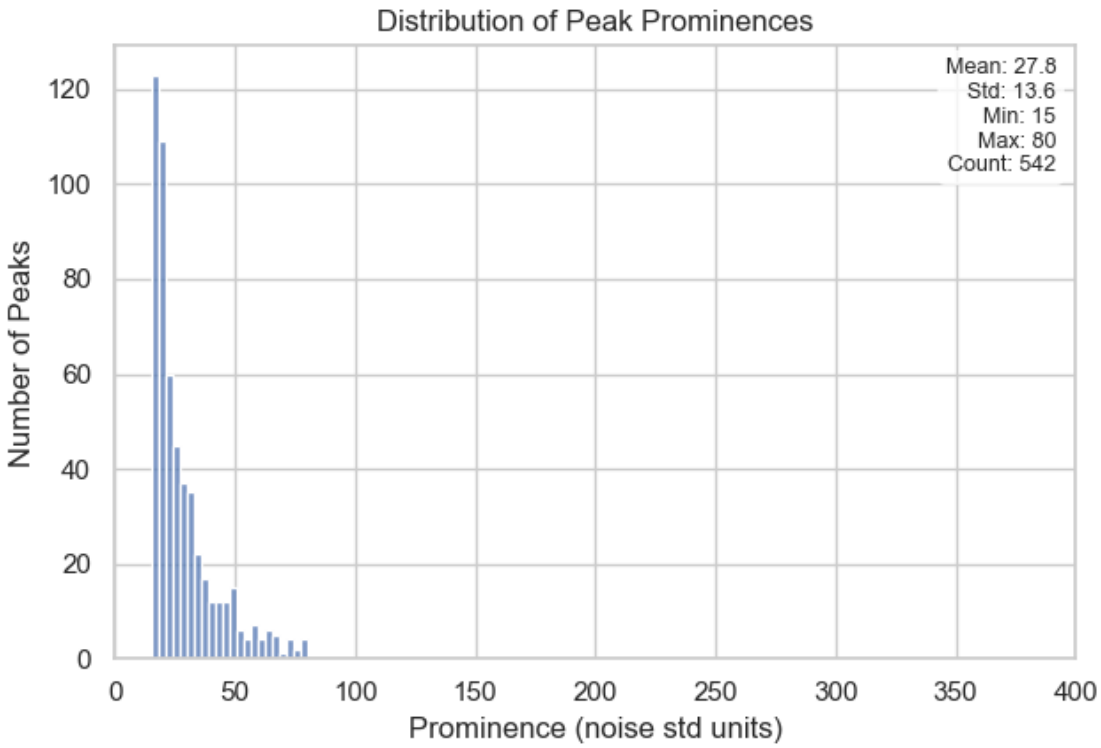


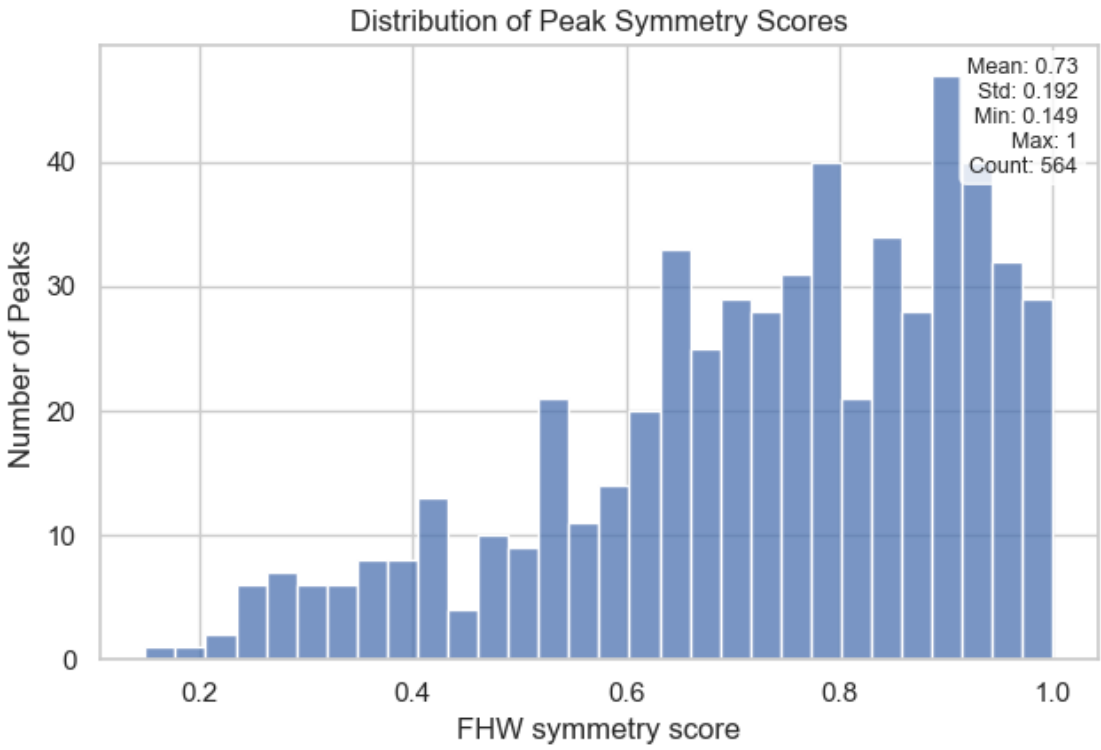
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:45:25] [INFO] calcium: plot_histogram: removed 16 outliers out of
564 on 'Duration (s)' (lower=-86, upper=173)
```

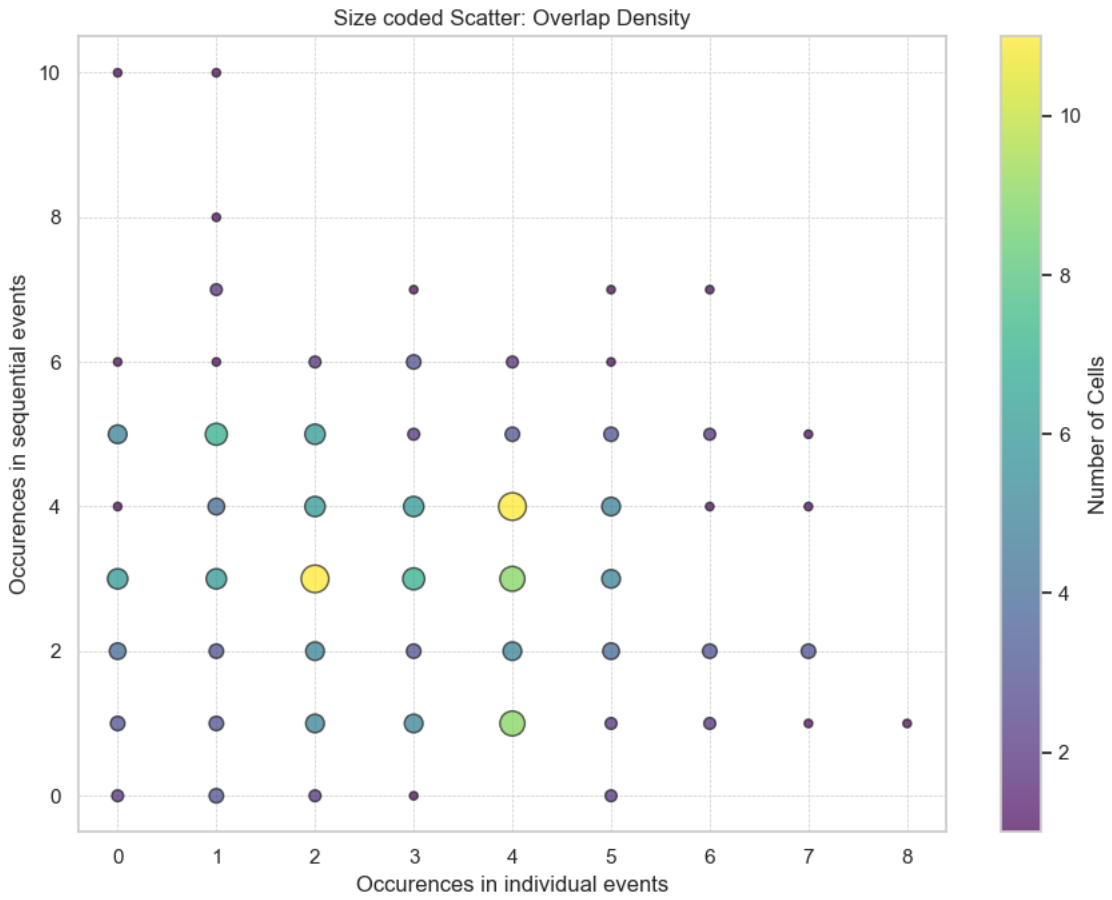



```
[2025-08-11 09:45:26] [INFO] calcium: plot_histogram: removed 22 outliers out of
564 on 'Prominence (noise std units)' (lower=-28.4, upper=80.8)
```

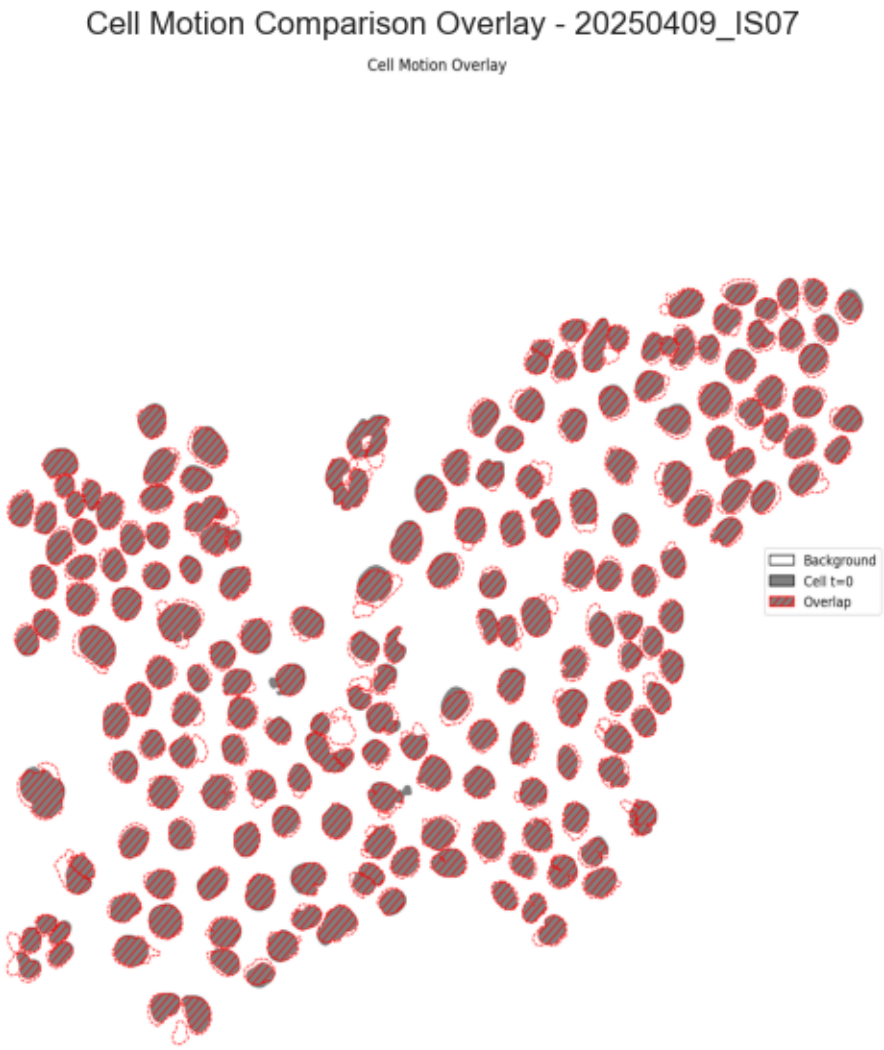

Distribution of Peak Prominences
Mean: 27.8
Std: 13.6
Min: 15
Max: 80
Count: 542
Number of Peaks
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.73
Std: 0.192
Min: 0.149
Max: 1
Count: 564
Number of Peaks
0
10
20
30
40
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 197
- Hoechst image taken at t=1801: 200
- Number of cells difference: absolute 3, relative 1.51%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 333101
- Pixels segmented as cell at t=1801: 378795
- Overlapping pixels between t=0 and t=1801: 317727(89.26% of total)
- Pixels exclusive to t=0: 15374 (4.61% of total)
- Pixels exclusive to t=1801: 61068 (16.12% of total)
```

executed

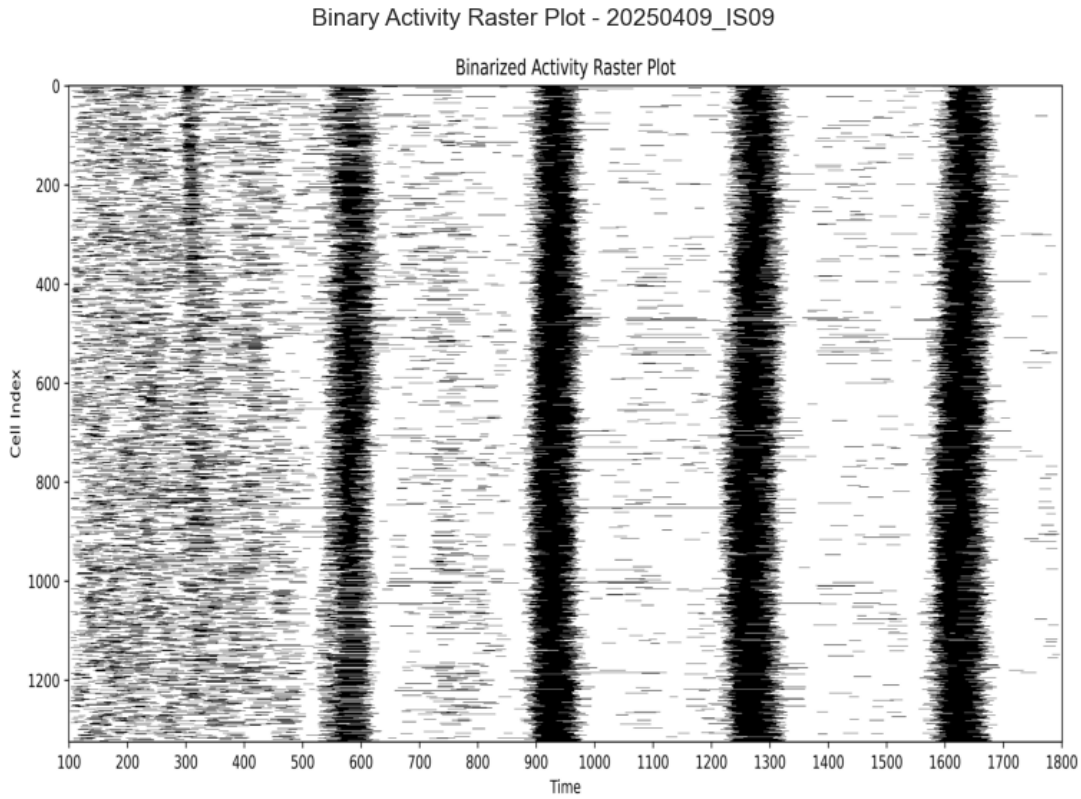
August 11, 2025

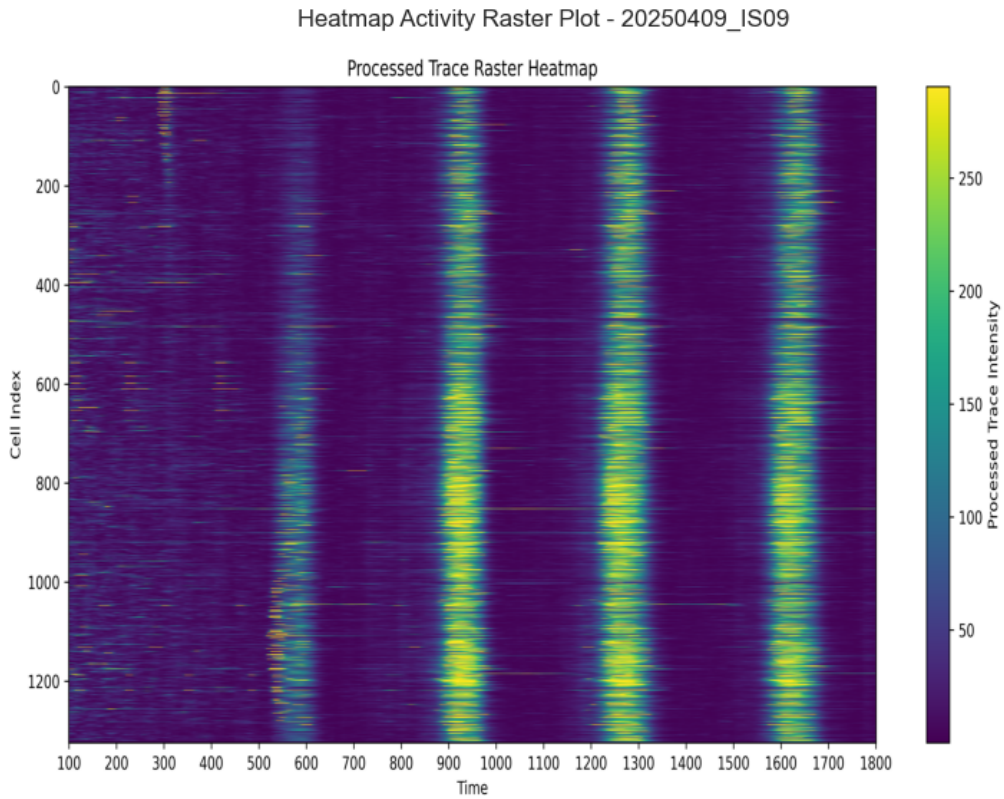
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



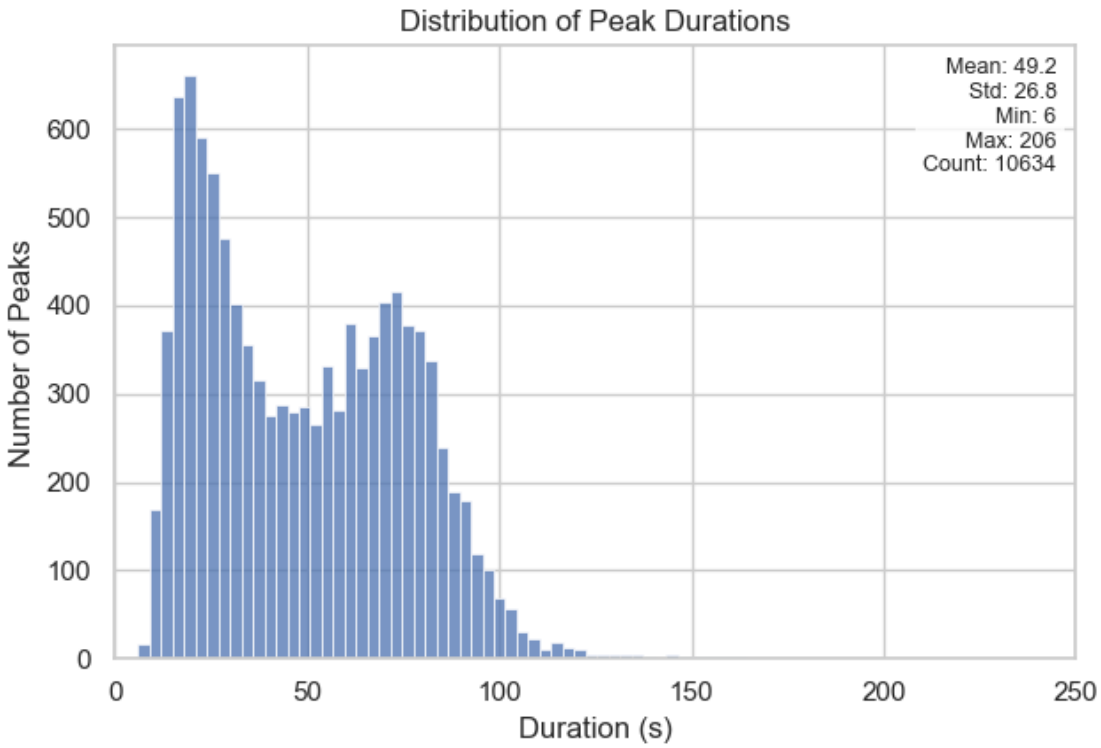


1.1.2 Peaks population

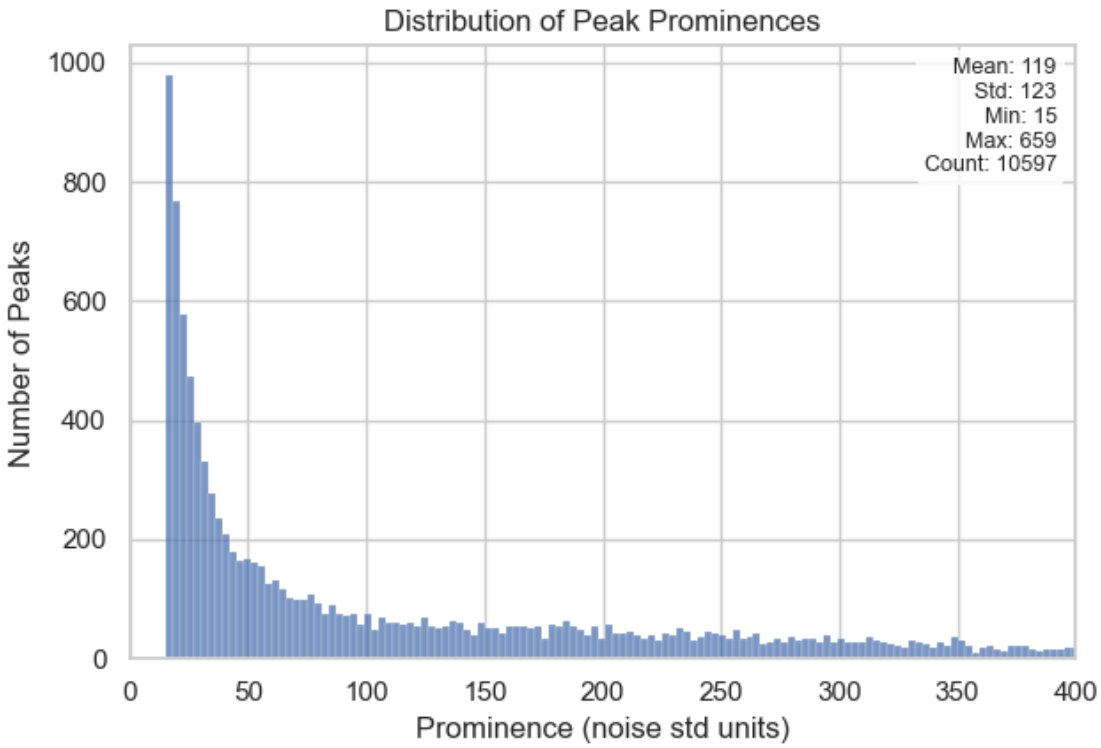
```
Total number of peaks: 10638
Total number of cells: 1325
```

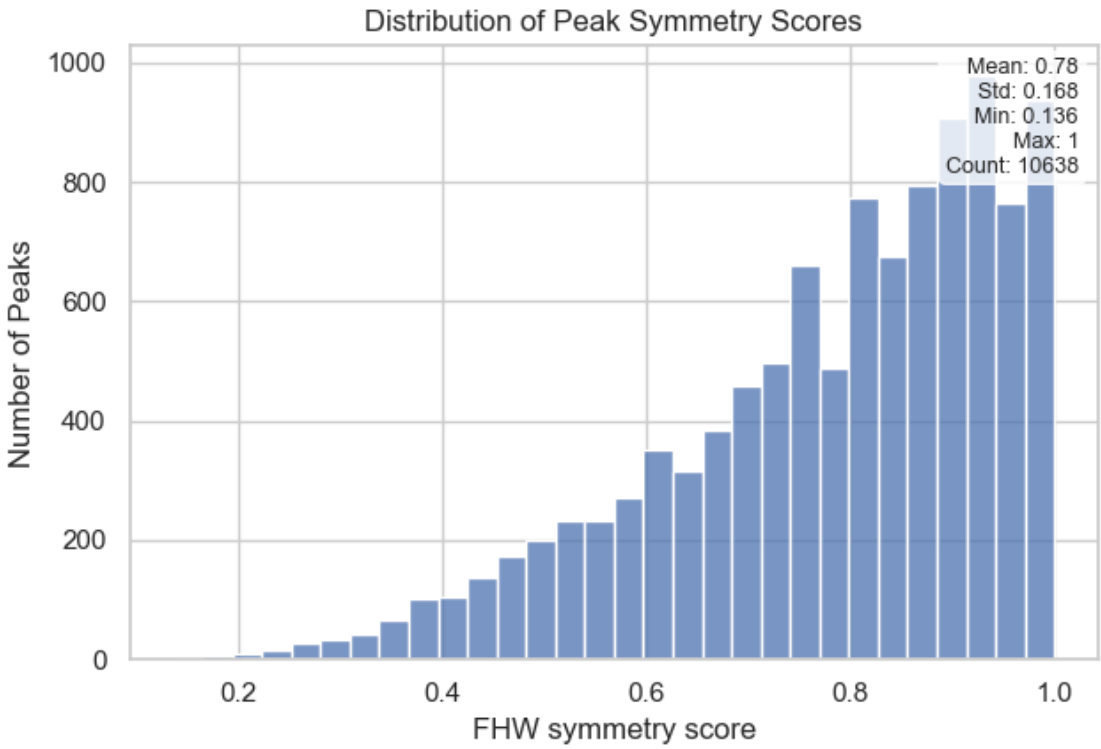
1.1.3 Peaks statistics

```
[2025-08-11 09:46:21] [INFO] calcium: plot_histogram: removed 4 outliers out of
10638 on 'Duration (s)' (lower=-113, upper=209)
```

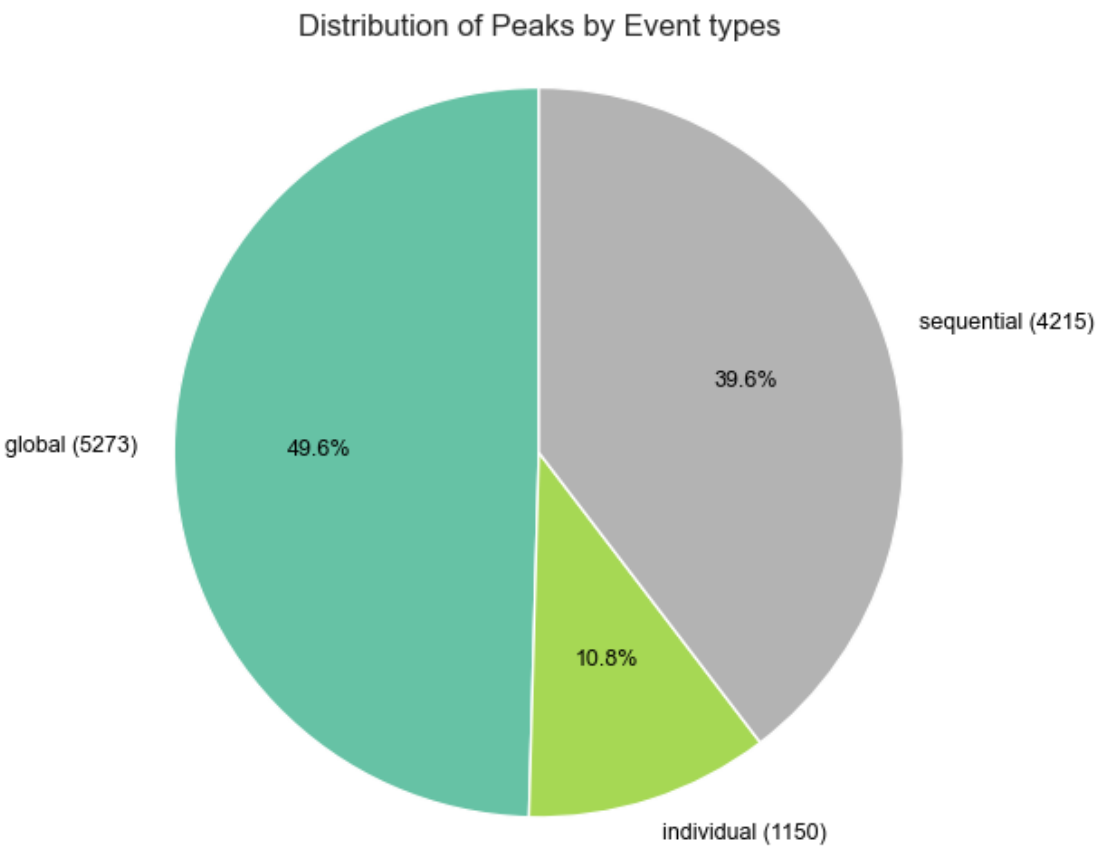



```
[2025-08-11 09:46:21] [INFO] calcium: plot_histogram: removed 41 outliers out of
10638 on 'Prominence (noise std units)' (lower=-449.93, upper=660.8)
```


Distribution of Peak Prominences
Mean: 119
Std: 123
Min: 15
Max: 659
Count: 10597
Number of Peaks
Prominence (noise std units)
0
200
400
600
800
1000
0
50
100
150
200
250
300
350
400

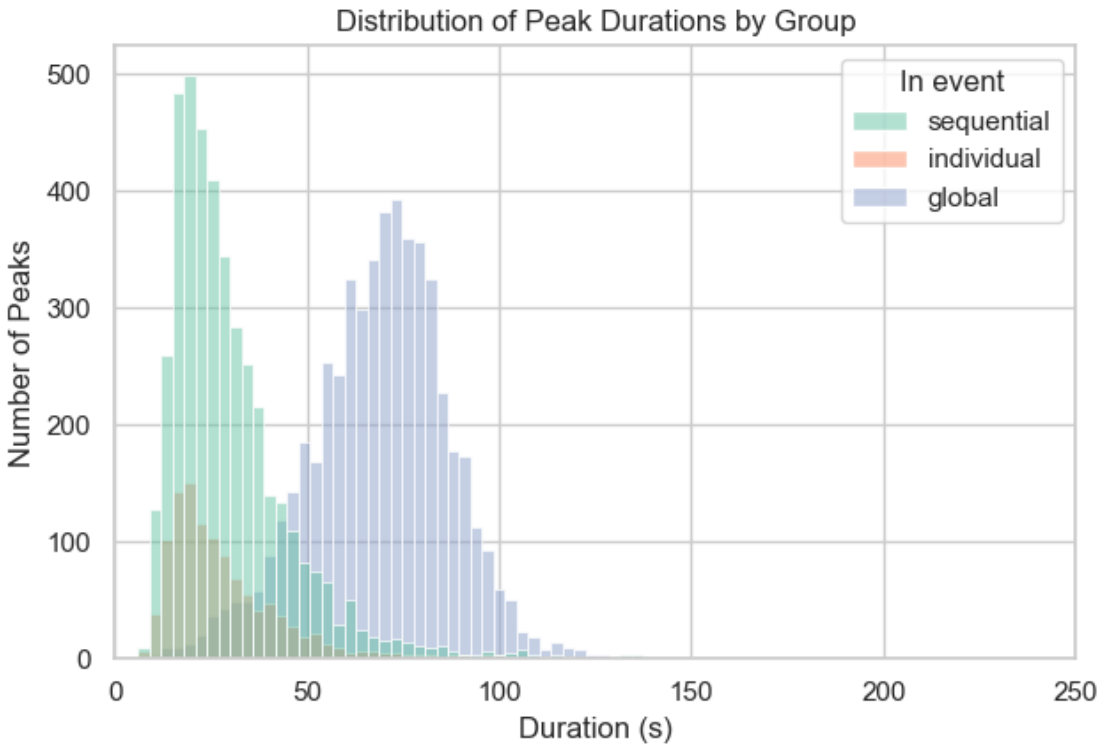

Distribution of Peak Symmetry Scores
Mean: 0.78
Std: 0.168
Min: 0.136
Max: 1
Count: 10638
Number of Peaks
FHW symmetry score
0
200
400
600
800
1000
0.2
0.4
0.6
0.8
1.0

1.1.4 Distribution of peaks per event types

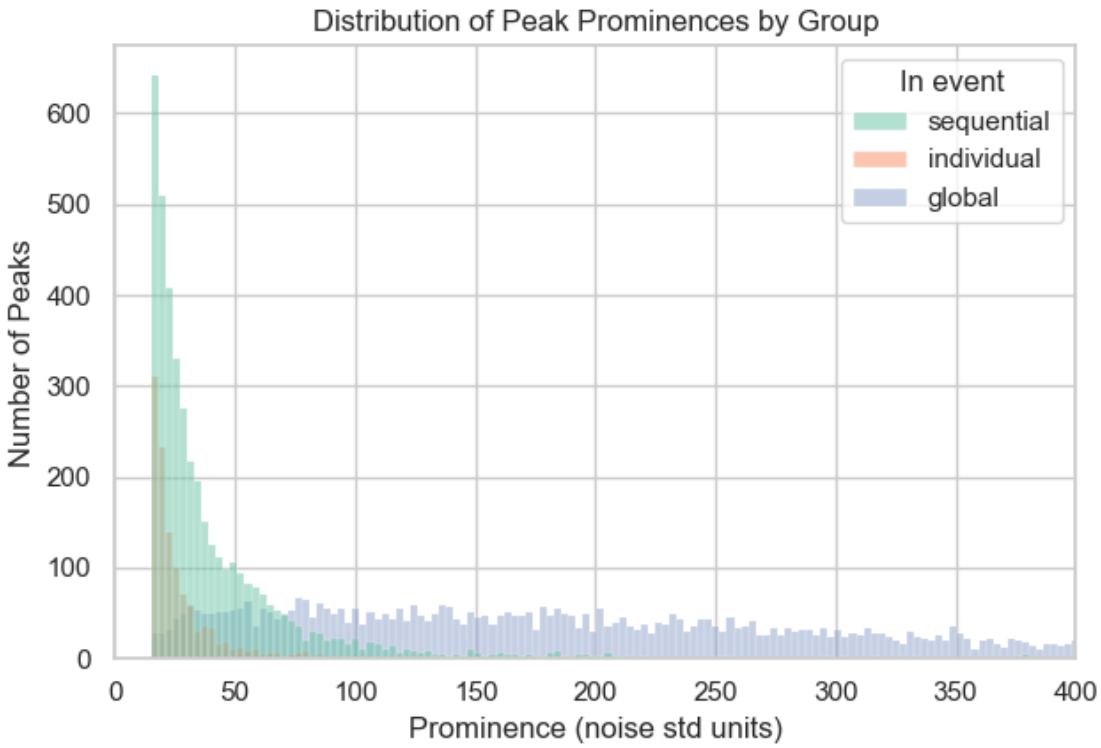


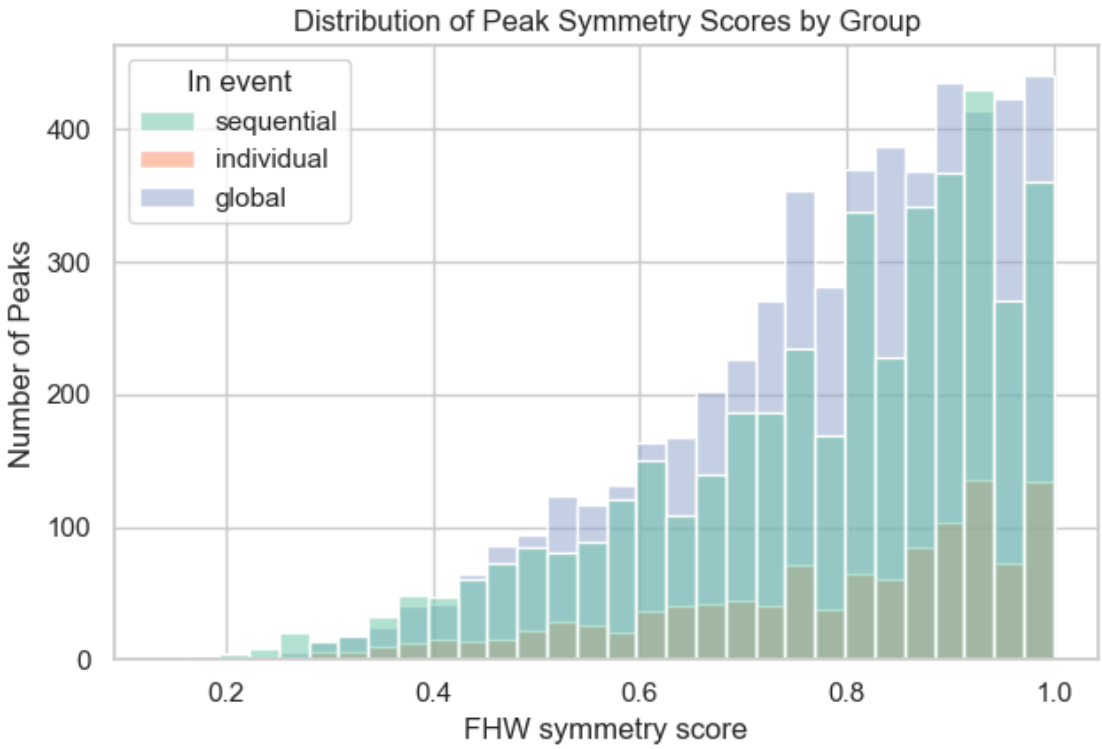
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:46:22] [INFO] calcium: plot_histogram_by_group: removed 4
outliers out of 10638 on 'Duration (s)' (lower=-113, upper=209)
```




```
[2025-08-11 09:46:22] [INFO] calcium: plot_histogram_by_group: removed 41
outliers out of 10638 on 'Prominence (noise std units)' (lower=-449.93,
upper=660.8)
```

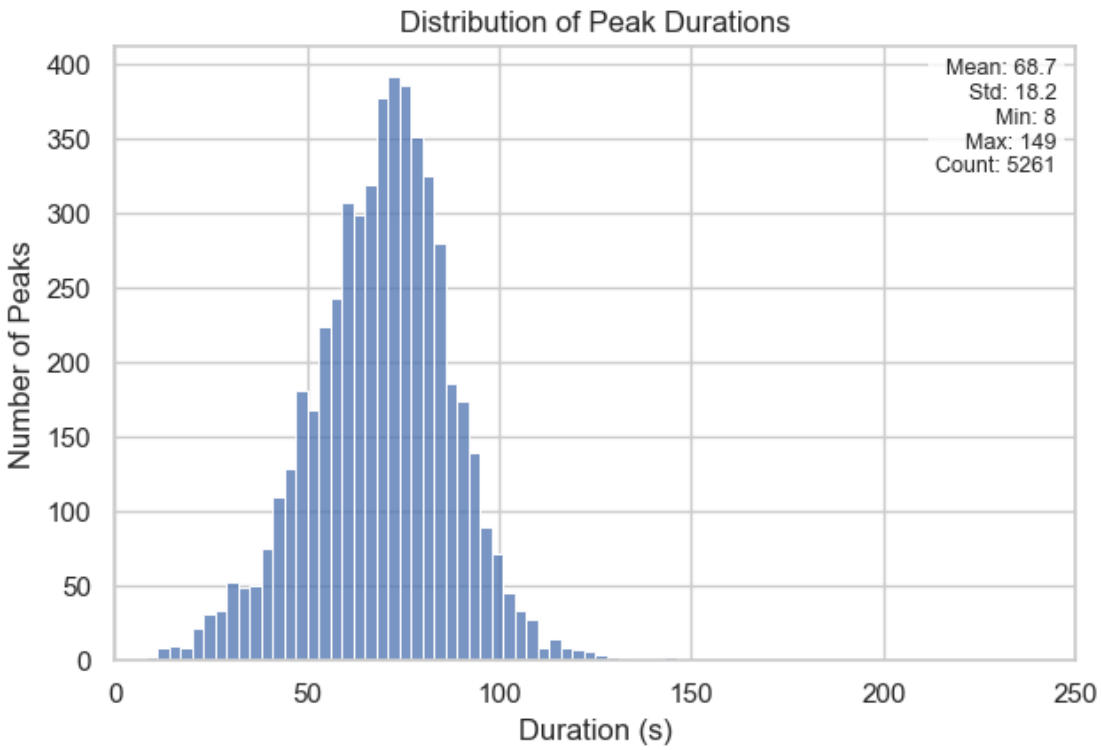

Distribution of Peak Prominences by Group
In event
sequential
individual
global
Number of Peaks
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
individual
global
Number of Peaks
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

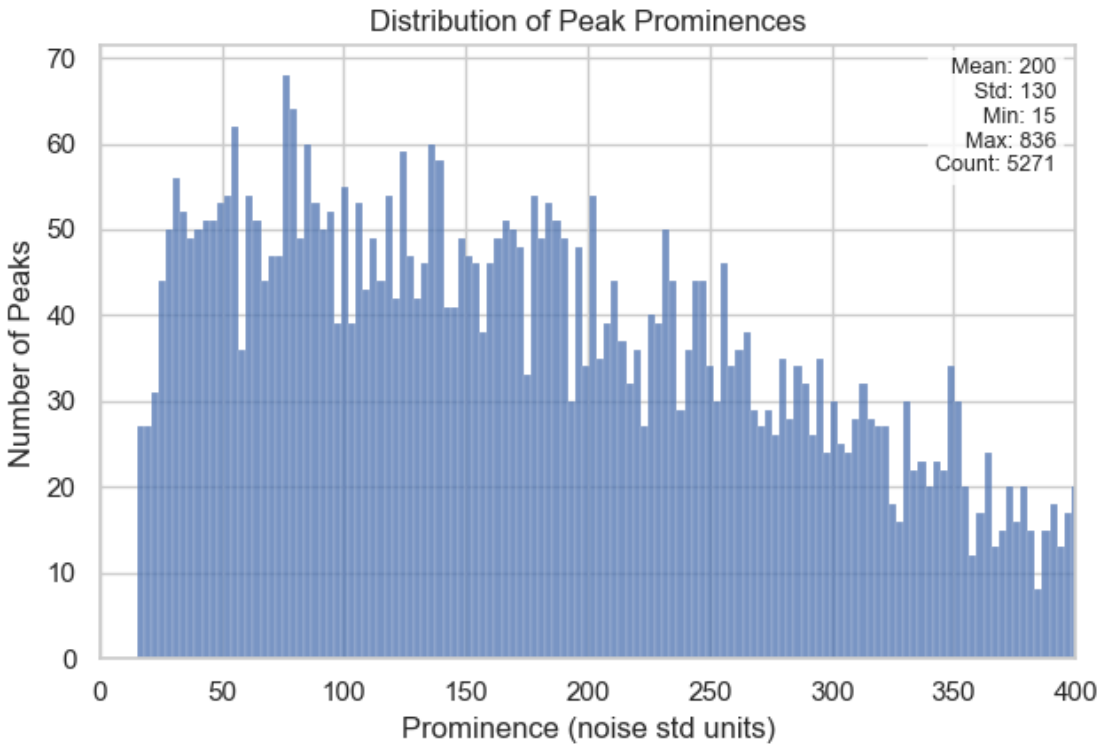
1.2 GLOBAL EVENTS

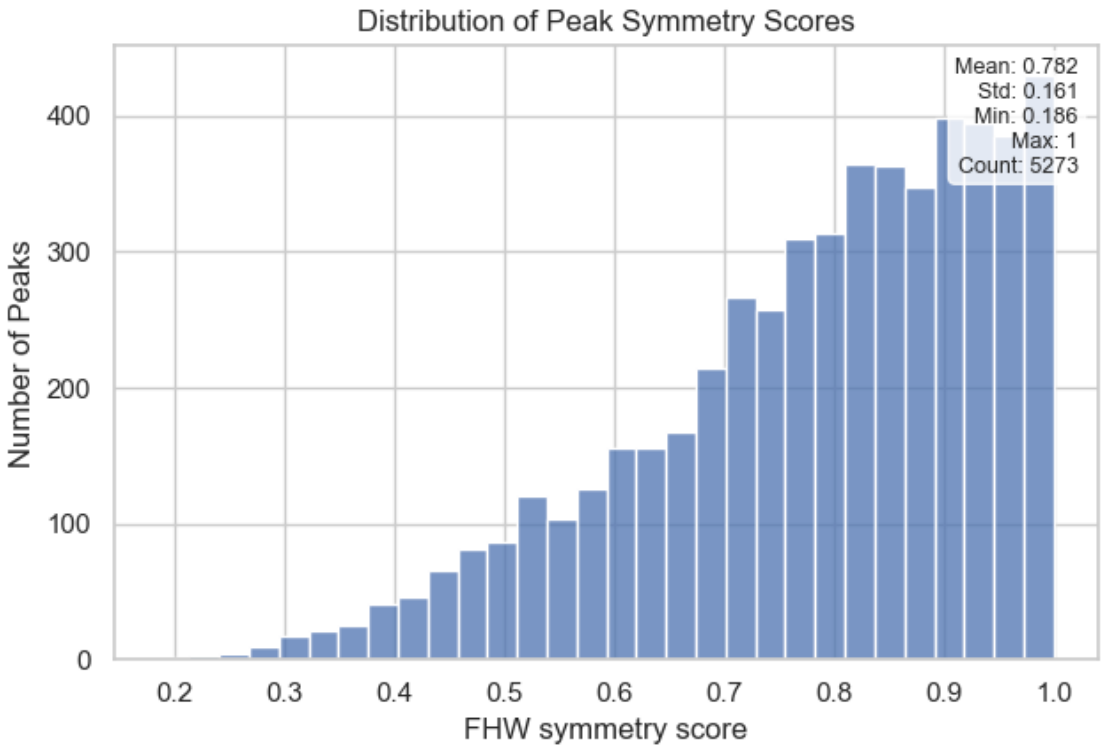
1.2.1 Peak statistics in global events

```
[2025-08-11 09:46:23] [INFO] calcium: plot_histogram: removed 12 outliers out of
5273 on 'Duration (s)' (lower=-11, upper=150)
```



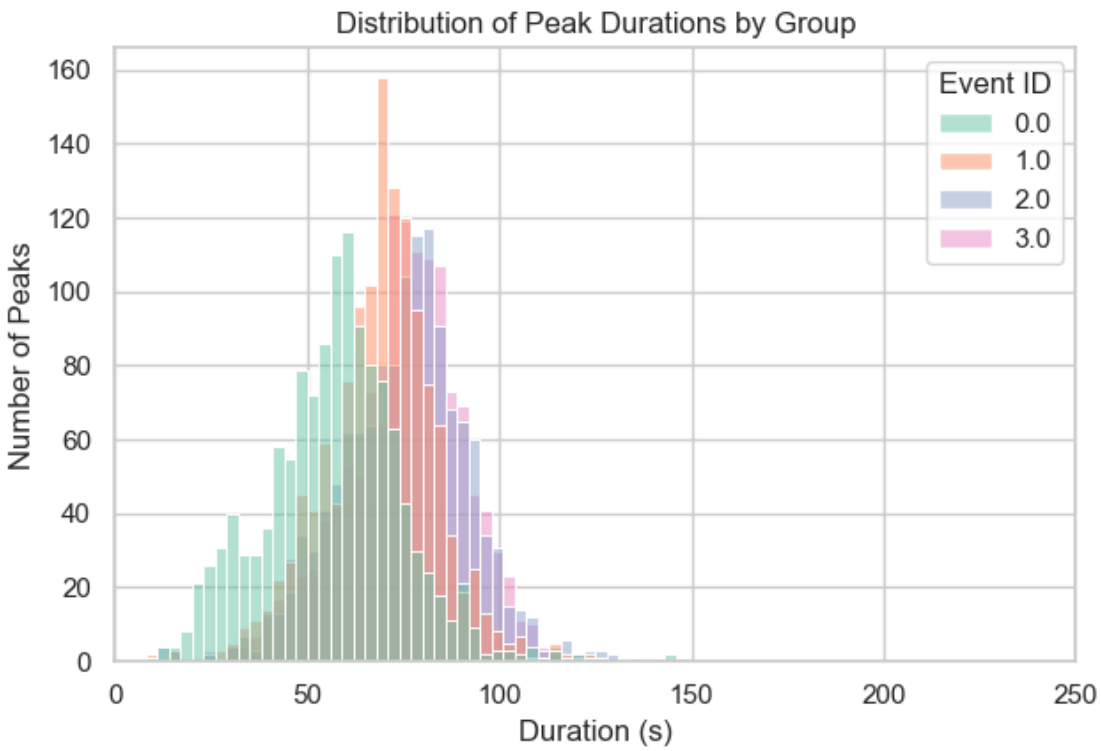

```
[2025-08-11 09:46:23] [INFO] calcium: plot_histogram: removed 2 outliers out of
5273 on 'Prominence (noise std units)' (lower=-461.2, upper=837.3)
```


Distribution of Peak Prominences
Mean: 200
Std: 130
Min: 15
Max: 836
Count: 5271
Number of Peaks
Prominence (noise std units)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400

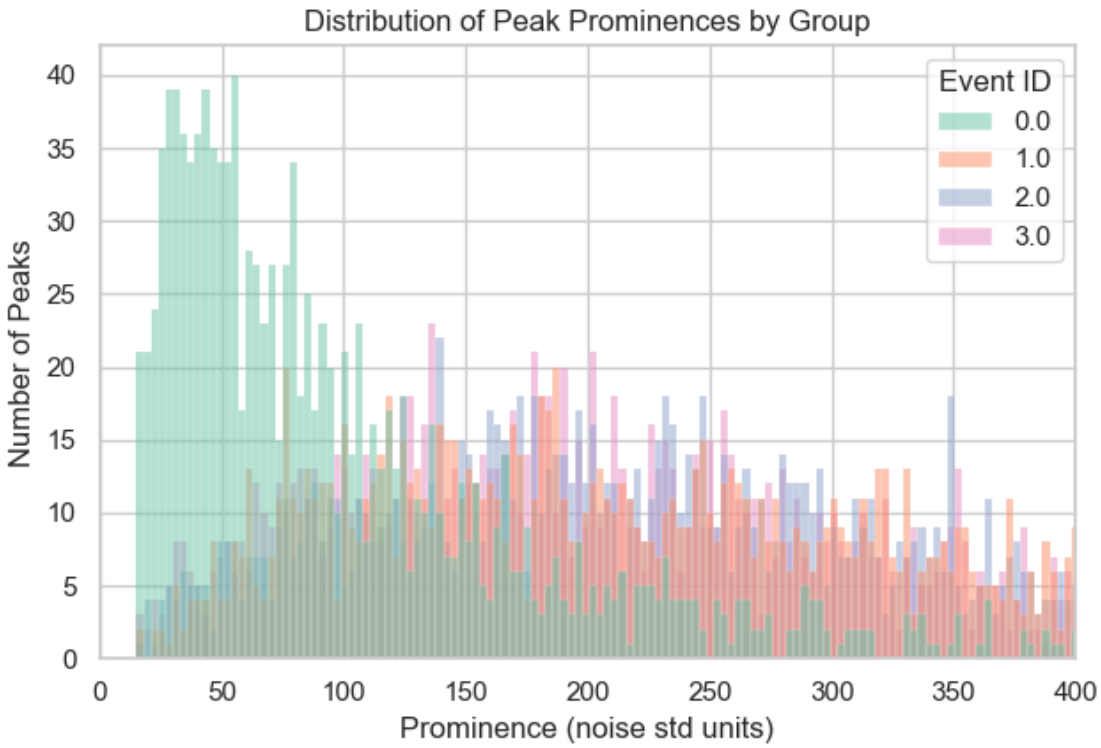

Distribution of Peak Symmetry Scores
Mean: 0.782
Std: 0.161
Min: 0.186
Max: 1
Count: 5273
Number of Peaks
FHW symmetry score
0
100
200
300
400
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

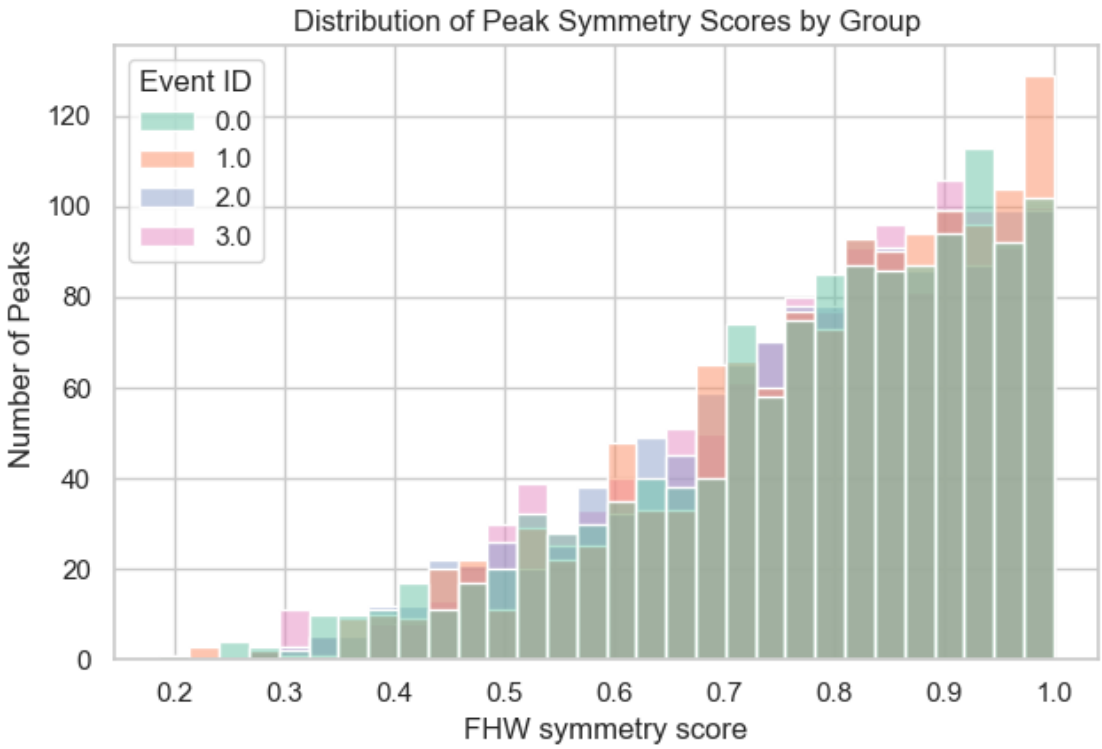
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:46:23] [INFO] calcium: plot_histogram_by_group: removed 12
outliers out of 5273 on 'Duration (s)' (lower=-11, upper=150)
```

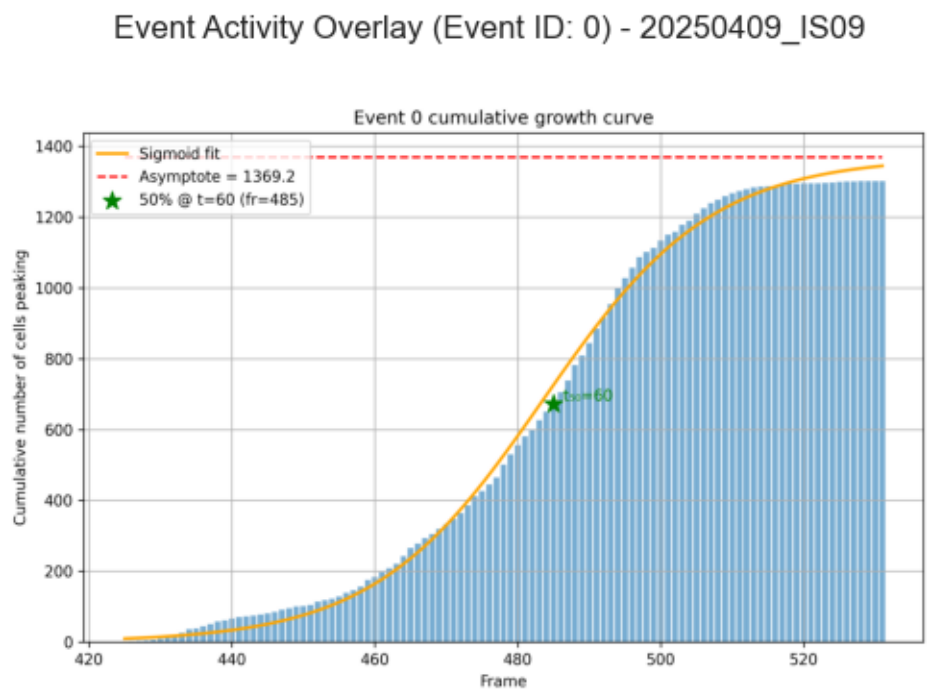


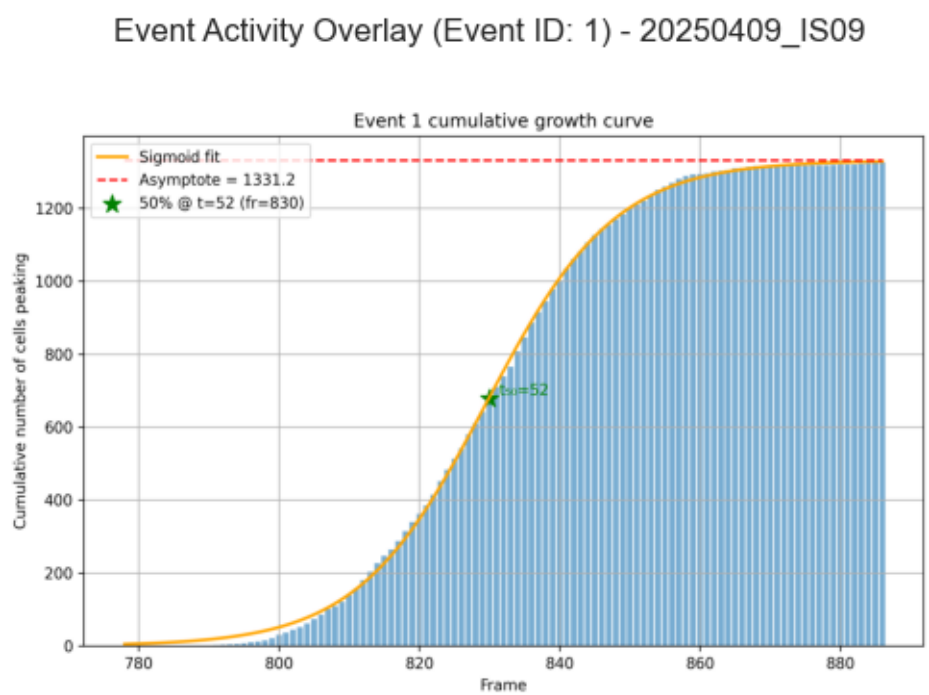

```
[2025-08-11 09:46:23] [INFO] calcium: plot_histogram_by_group: removed 2
outliers out of 5273 on 'Prominence (noise std units)' (lower=-461.2,
upper=837.3)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
Prominence (noise std units)
0
5
10
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400

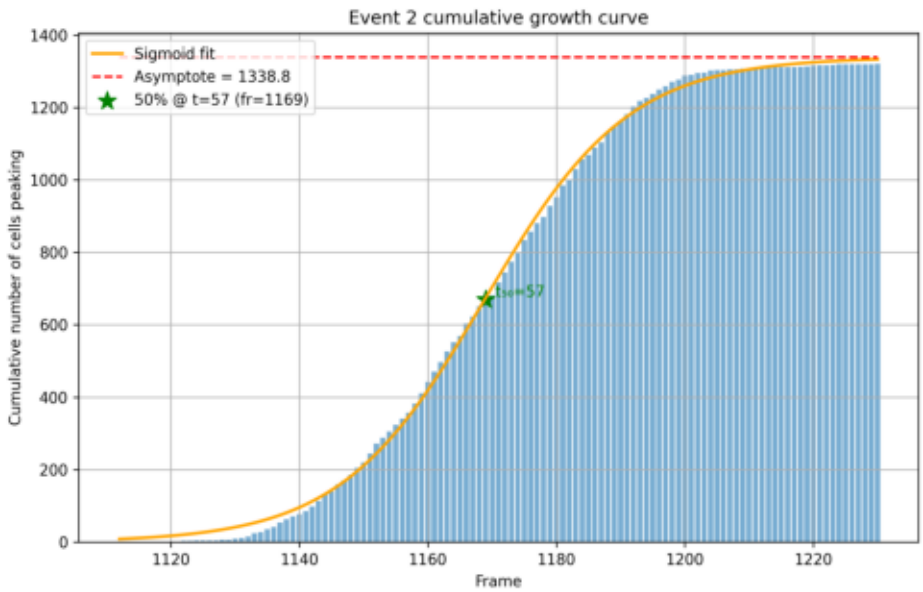

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
120
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

1.2.3 Kinetics of global events

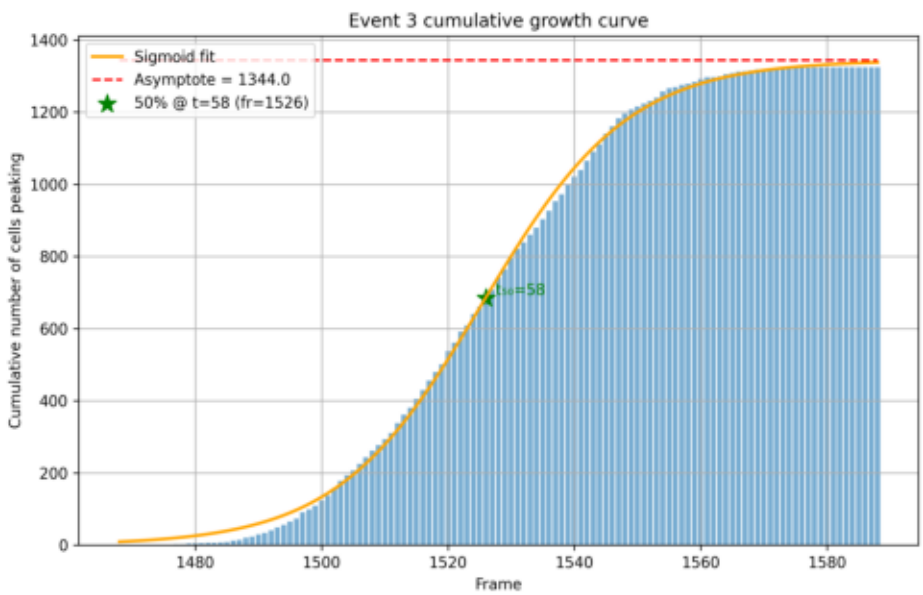




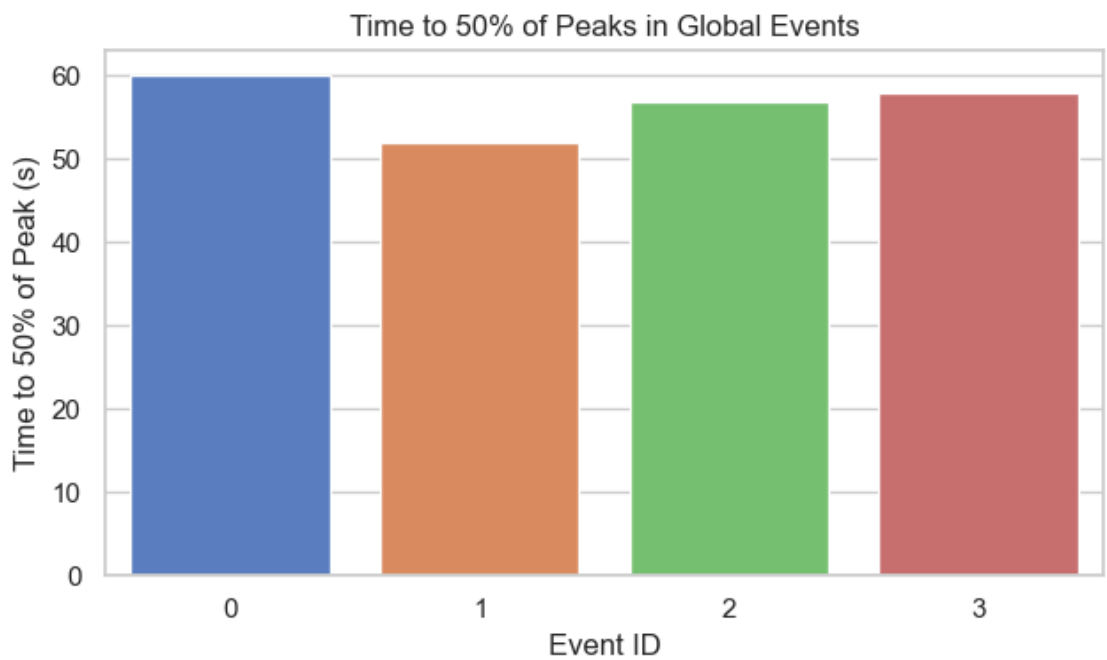
Event Activity Overlay (Event ID: 2) - 20250409_IS09



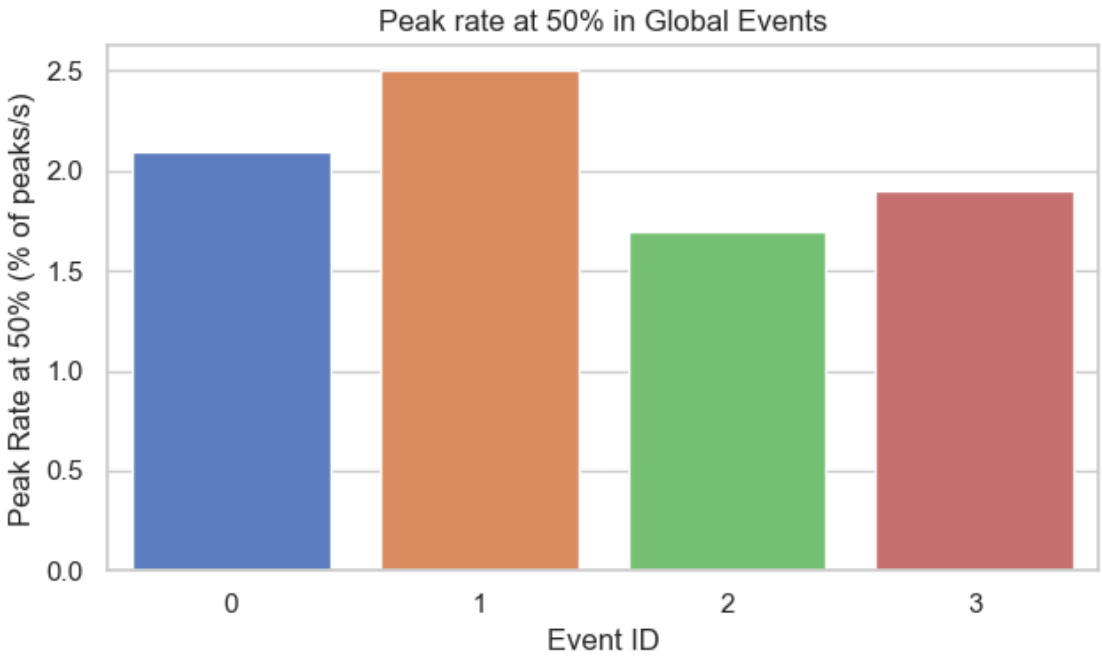
Event Activity Overlay (Event ID: 3) - 20250409_IS09



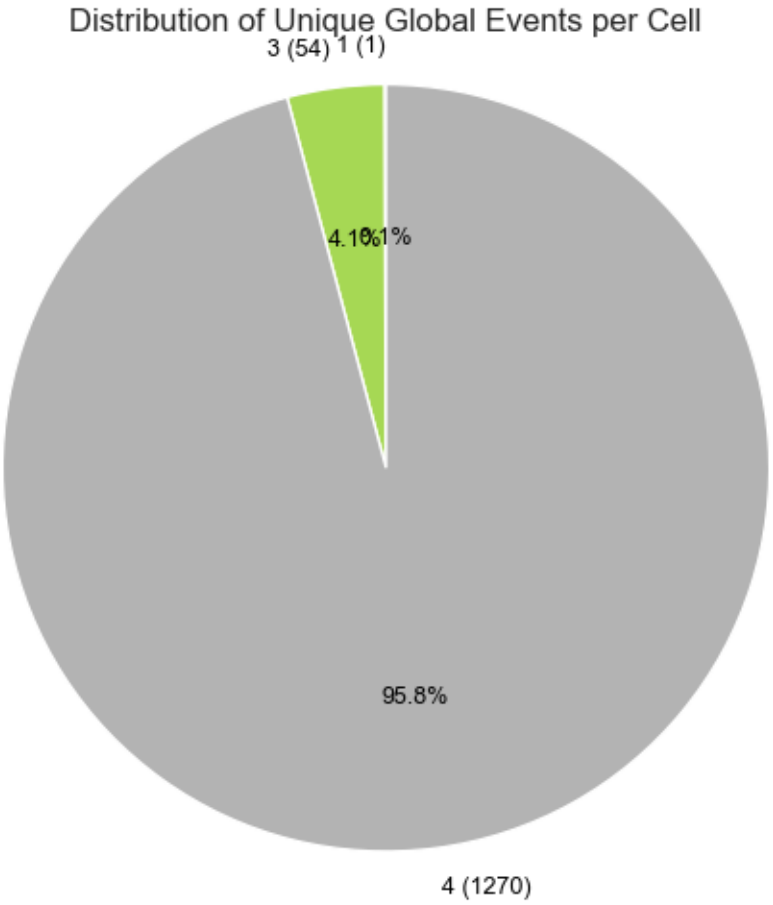
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



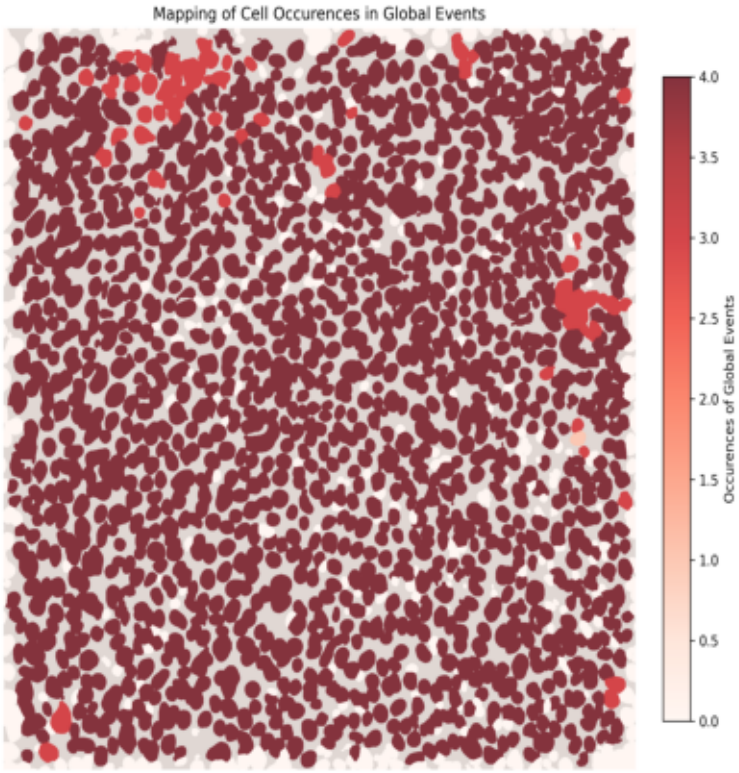

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
Event ID

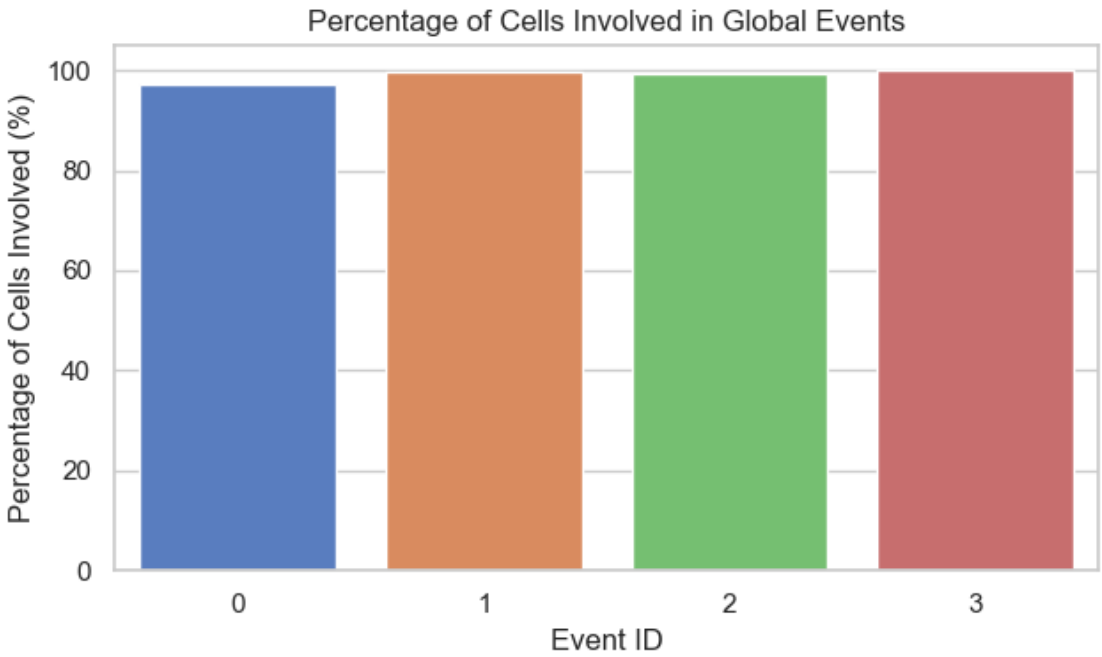
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS09




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

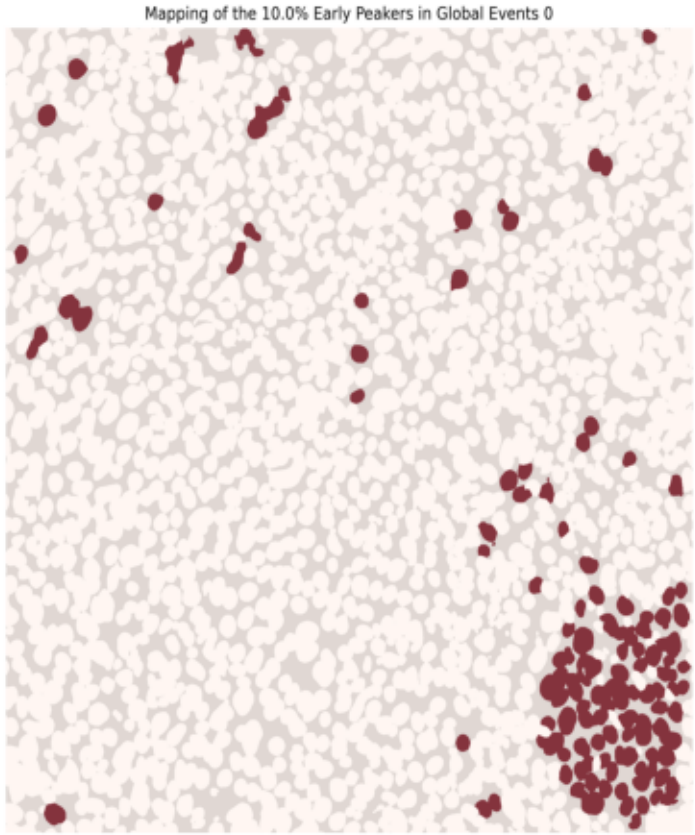


1.2.5 Inter-event interval analysis

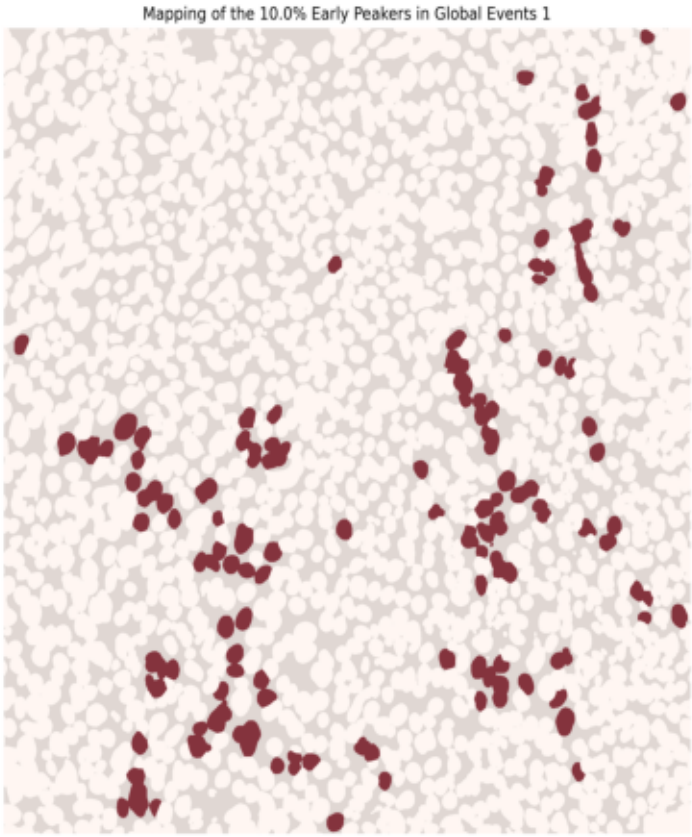
```
Intervals between global event peaks: [348.0, 342.0, 357.0]
Estimated periodicity: 0.983
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.003 Hz
```

1.2.6 Early peakers in the events

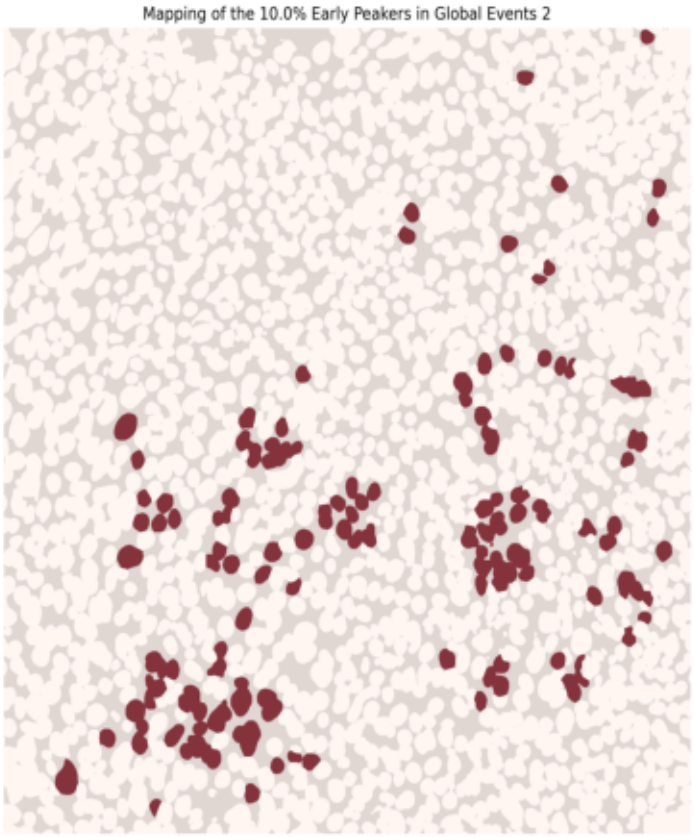
Cell Mapping with Early Peakers Overlay for event 0 - 20250409_IS09



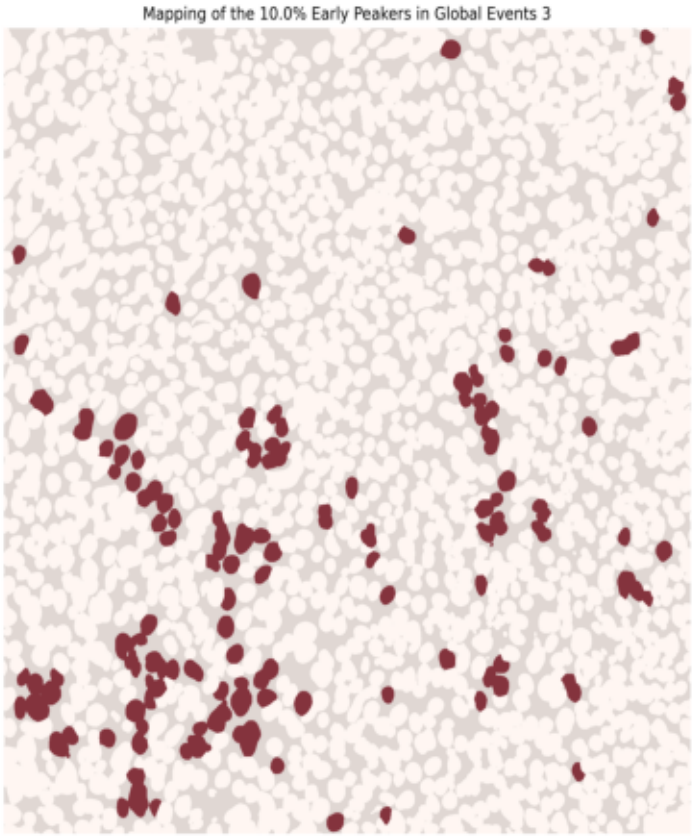
Cell Mapping with Early Peakers Overlay for event 1 - 20250409_IS09



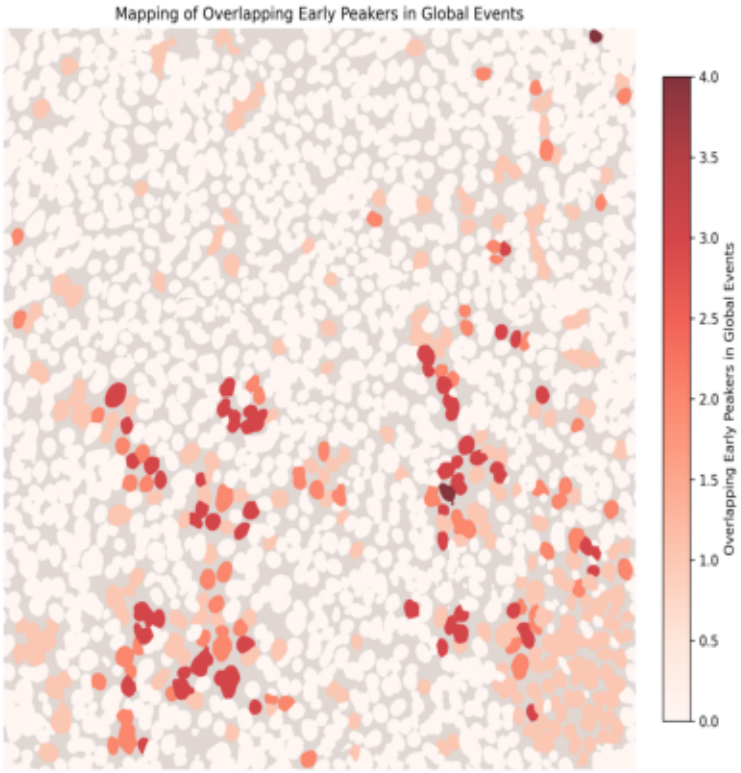
Cell Mapping with Early Peakers Overlay for event 2 - 20250409_IS09



Cell Mapping with Early Peakers Overlay for event 3 - 20250409_IS09

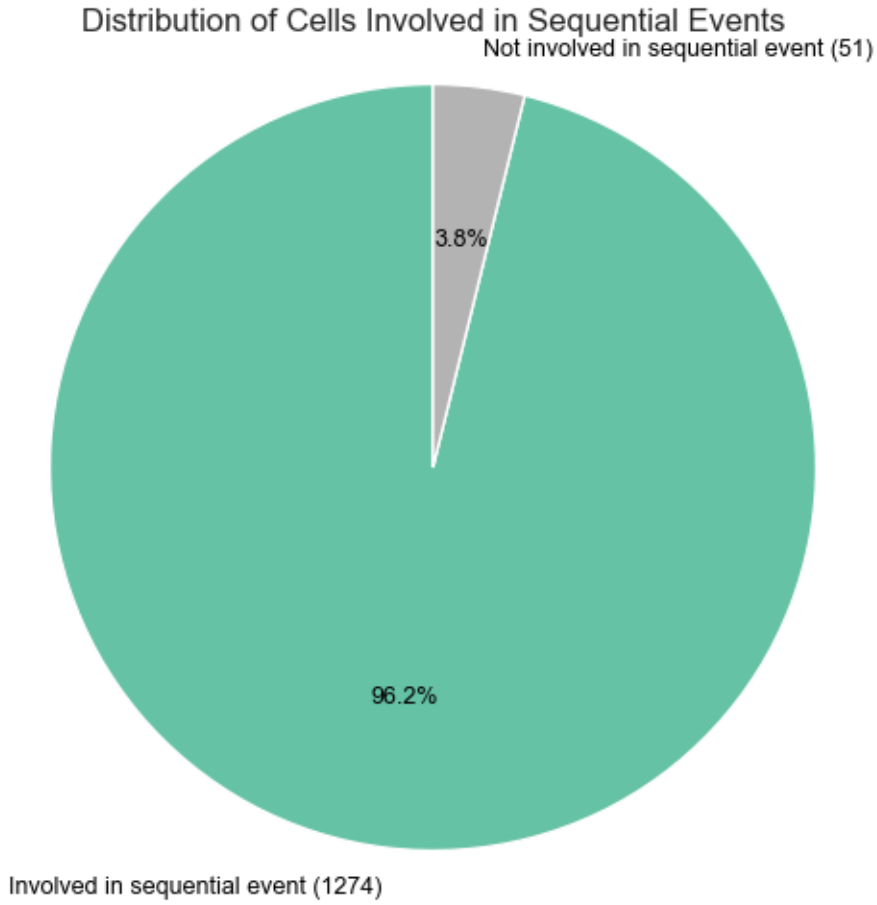


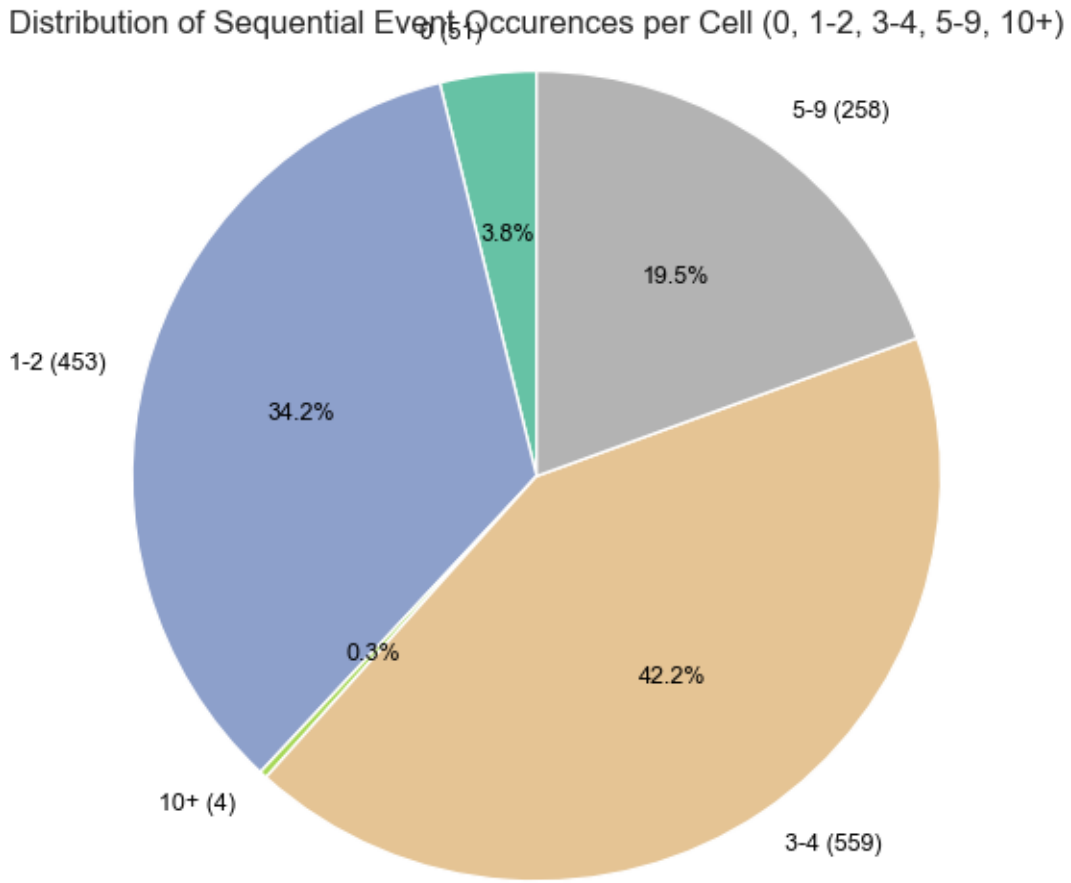
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS09



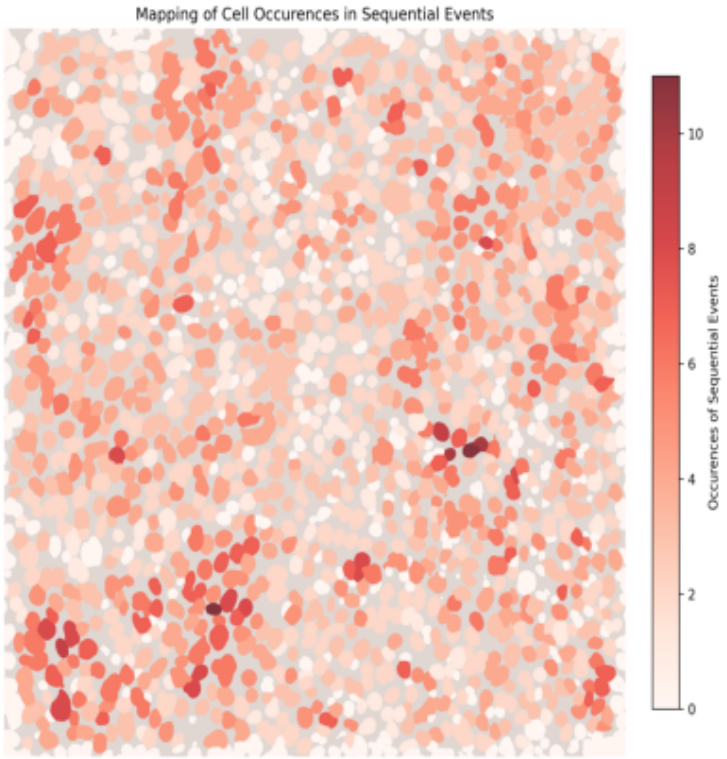
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

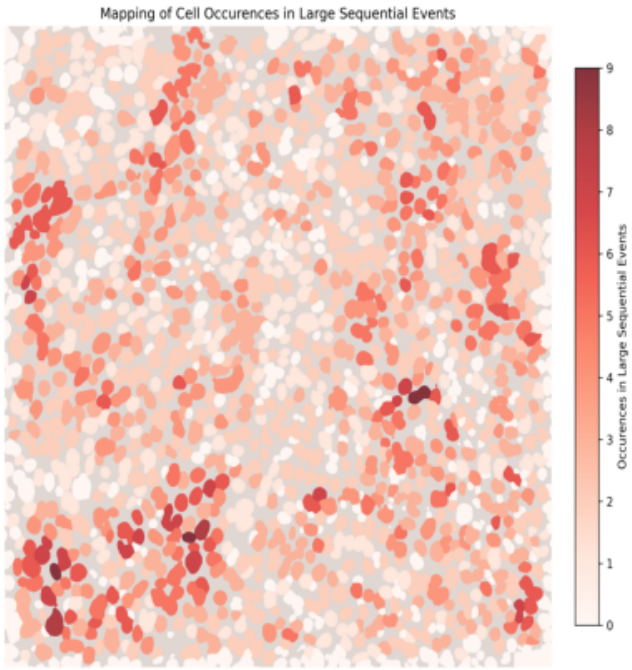



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (51)
5-9 (258)
3.8%
19.5%
1-2 (453)
34.2%
0.3%
42.2%
10+ (4)
3-4 (559)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS09

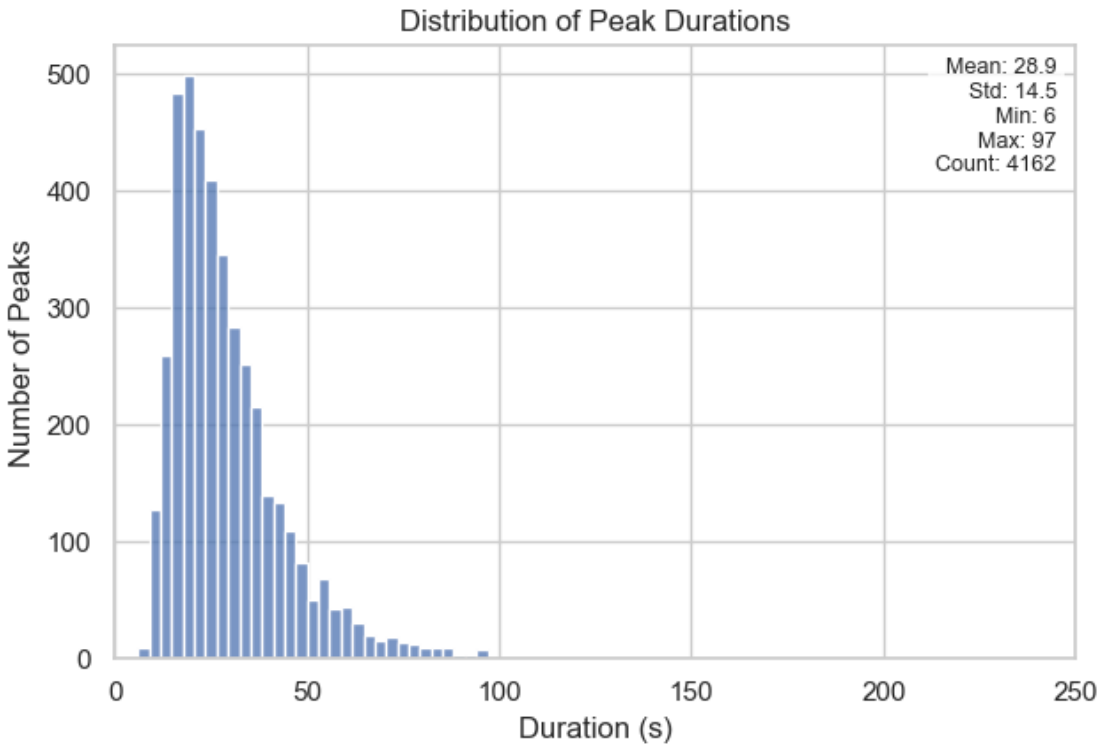


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS09

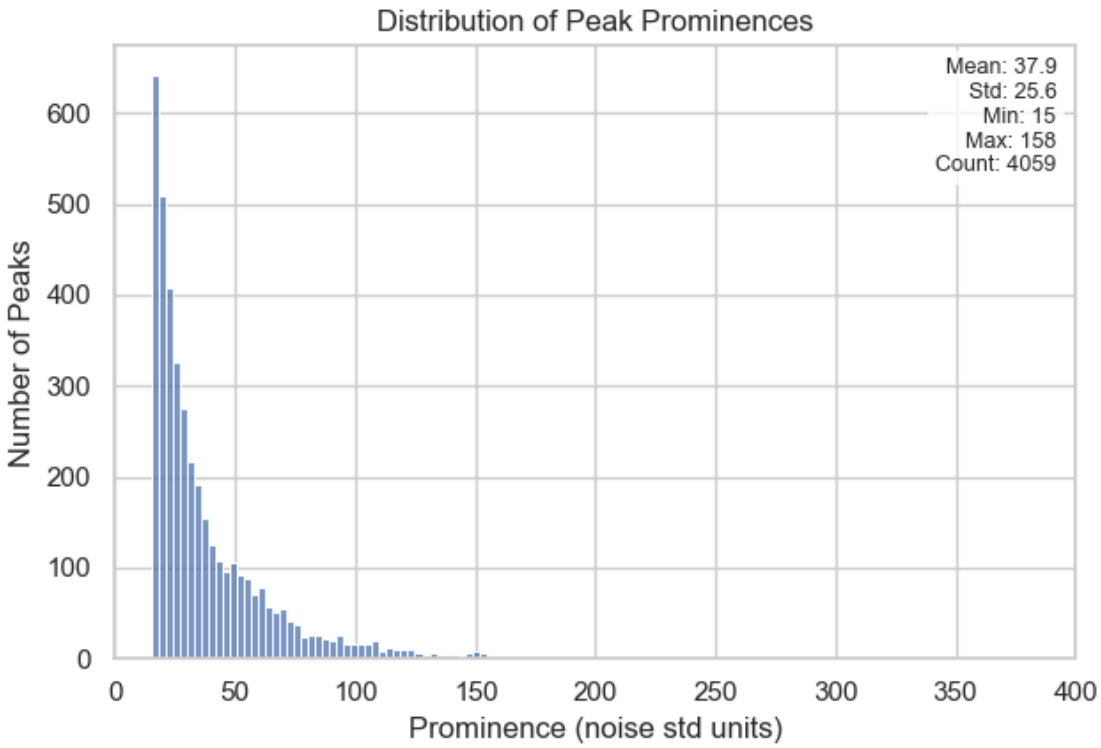


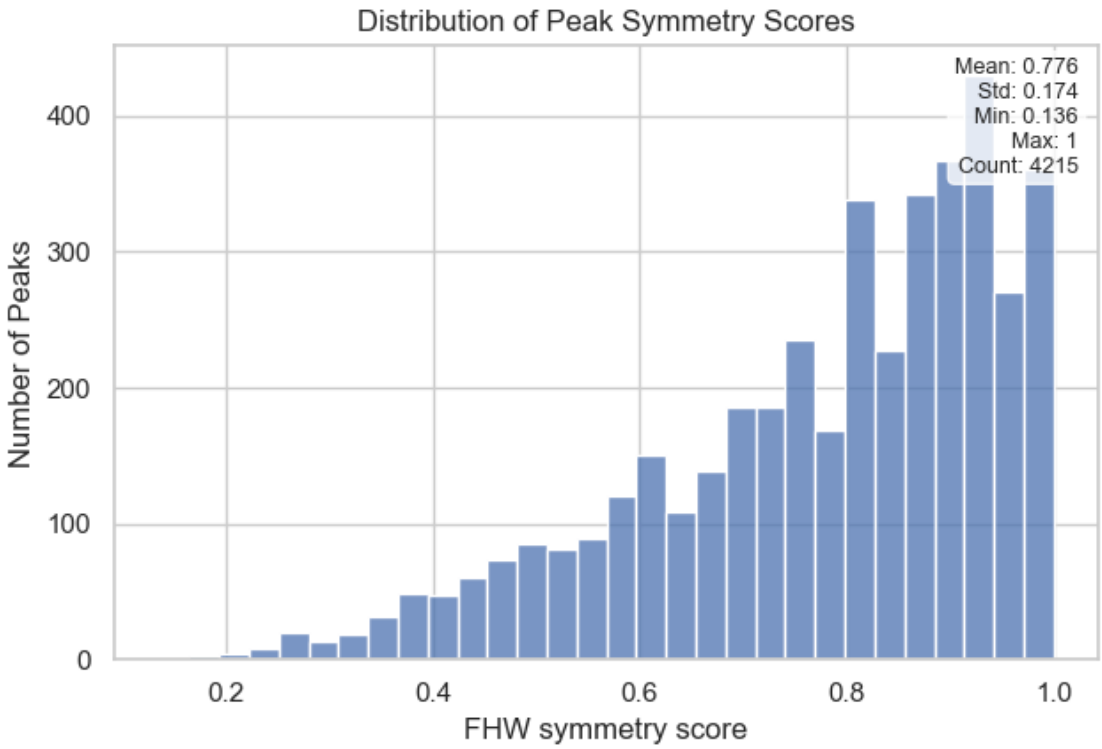
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:46:34] [INFO] calcium: plot_histogram: removed 53 outliers out of
4215 on 'Duration (s)' (lower=-9, upper=99)
```



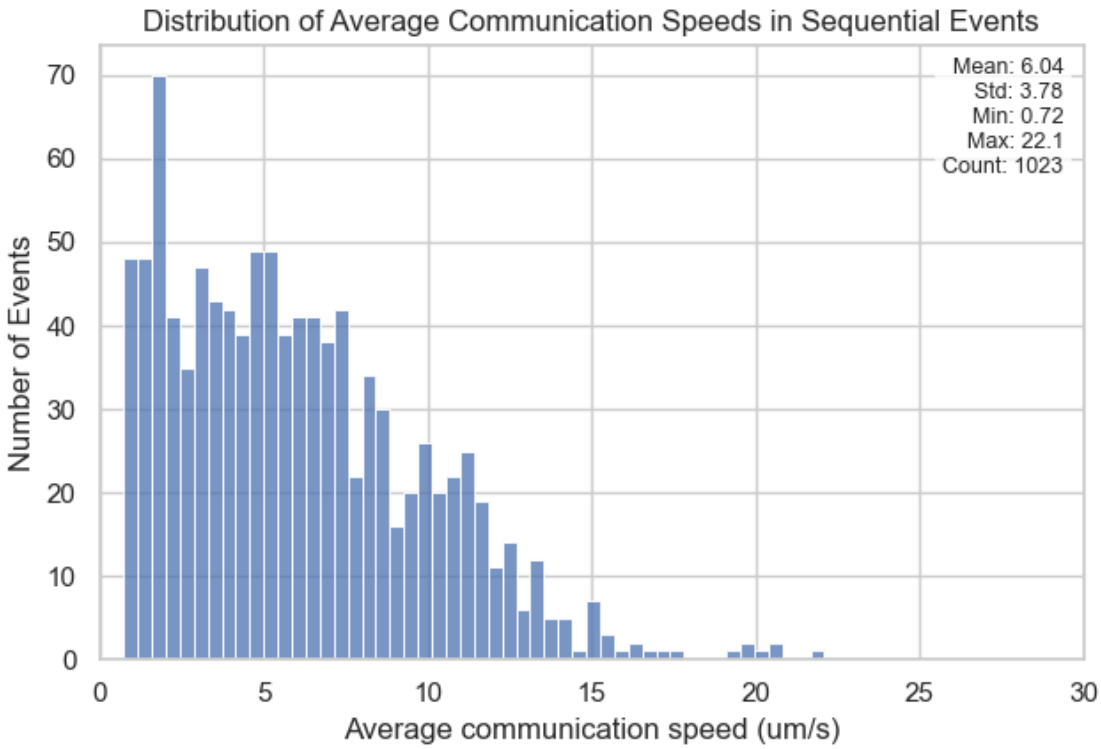

```
[2025-08-11 09:46:34] [INFO] calcium: plot_histogram: removed 156 outliers out
of 4215 on 'Prominence (noise std units)' (lower=-25.45, upper=157.55)
```


Distribution of Peak Prominences
Mean: 37.9
Std: 25.6
Min: 15
Max: 158
Count: 4059
Number of Peaks
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

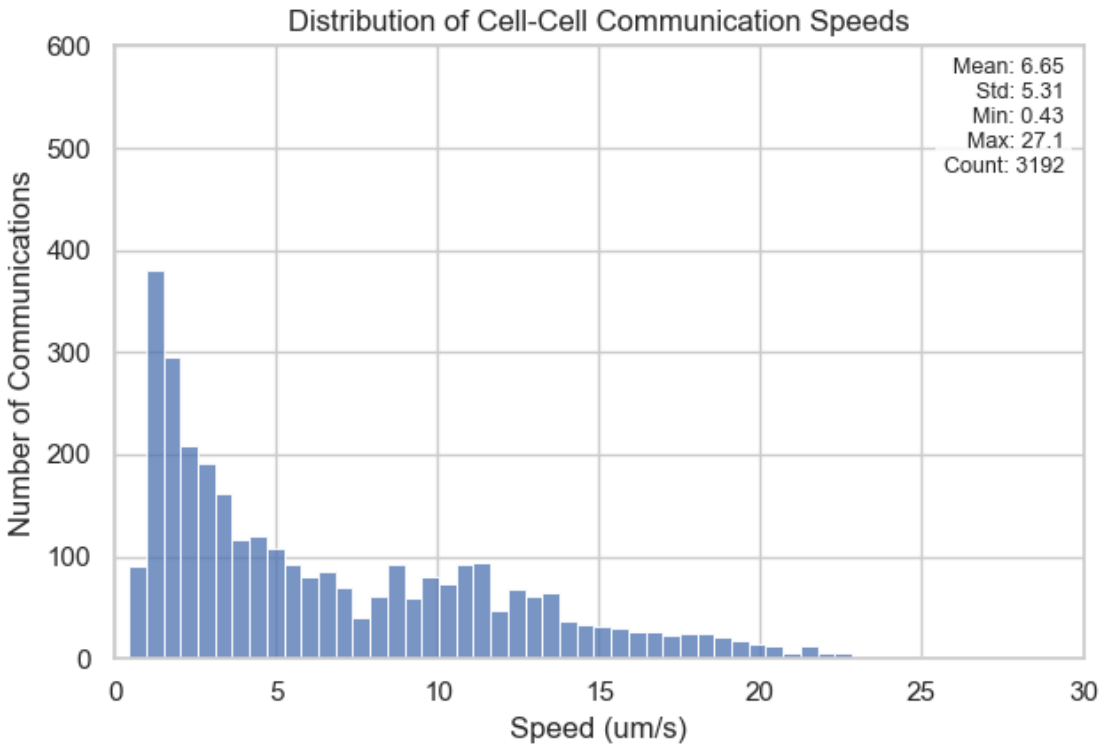

Distribution of Peak Symmetry Scores
Mean: 0.776
Std: 0.174
Min: 0.136
Max: 1
Count: 4215
Number of Peaks
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:46:35] [INFO] calcium: plot_histogram: removed 0 outliers out of
1023 on 'Average communication speed (um/s)' (lower=-13.275, upper=24.63)
```

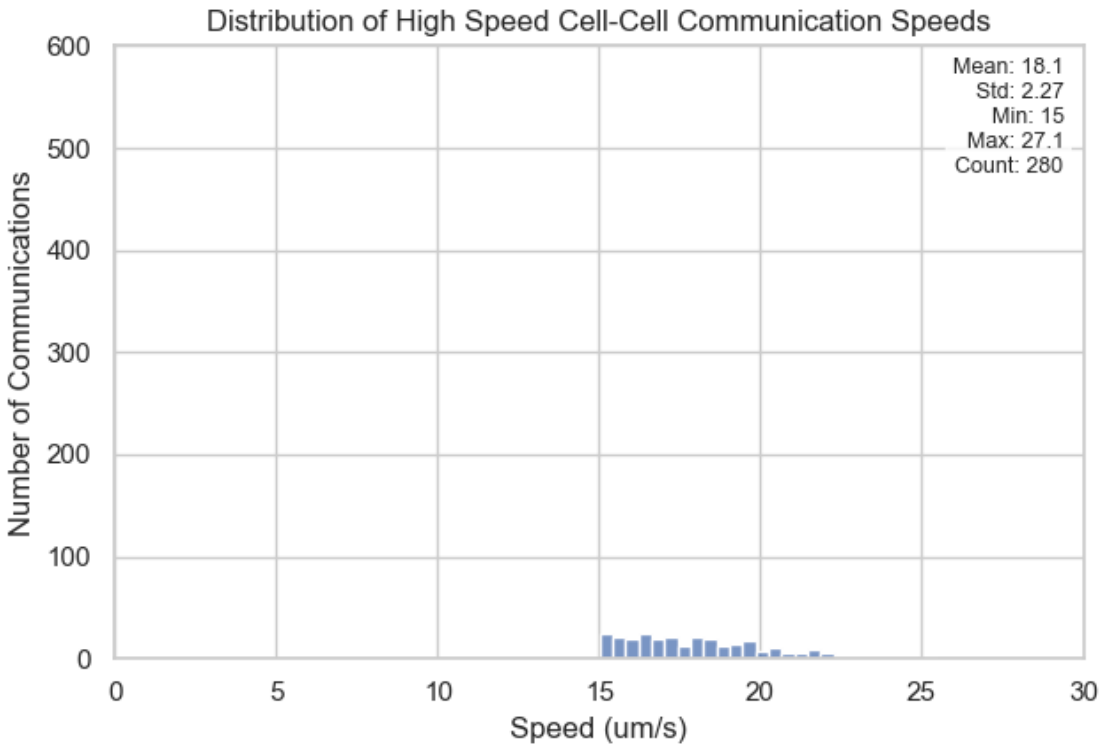



```
[2025-08-11 09:46:35] [INFO] calcium: plot_histogram: removed 0 outliers out of
3192 on 'Speed (um/s)' (lower=-23.047, upper=35.63)
```

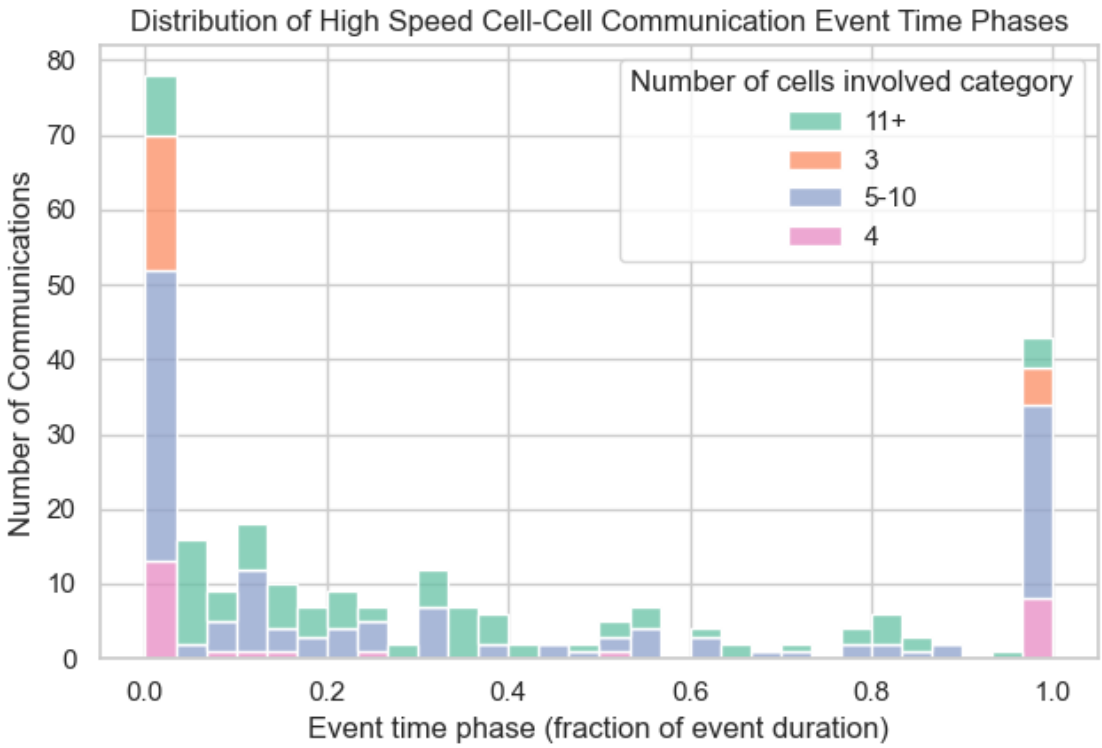


1.3.4 Double distribution in cell-cell communication speeds

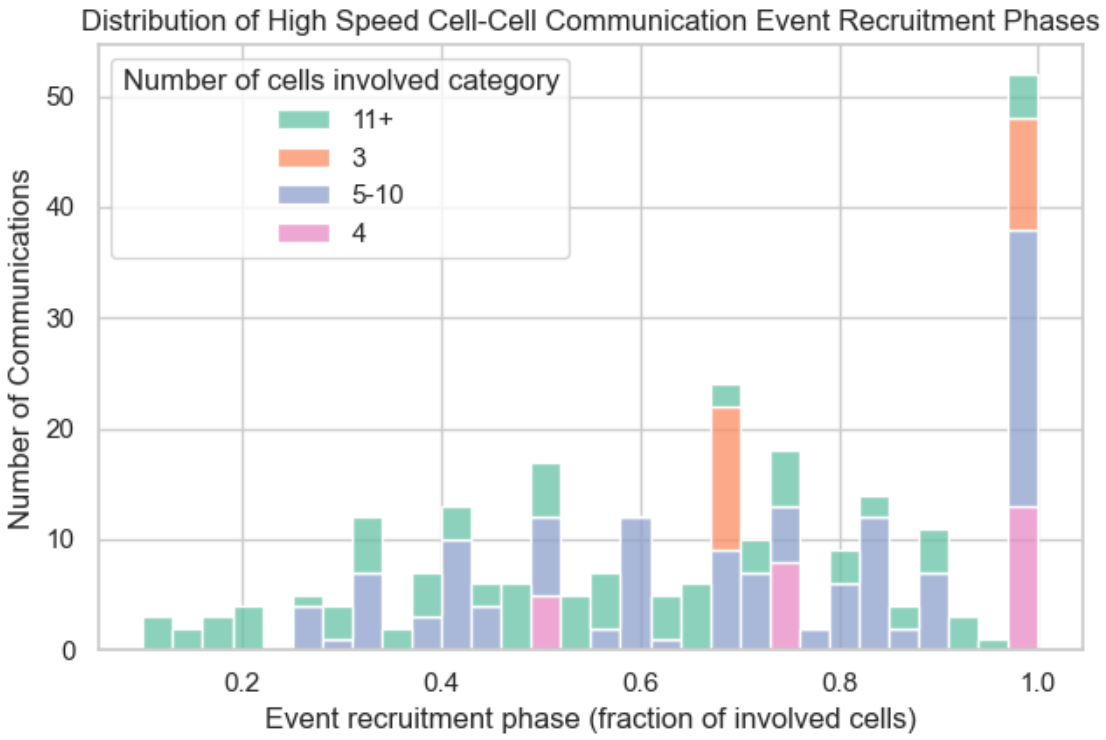
```
[2025-08-11 09:46:35] [INFO] calcium: plot_histogram: removed 0 outliers out of
280 on 'Speed (um/s)' (lower=6.72, upper=29.032)
```



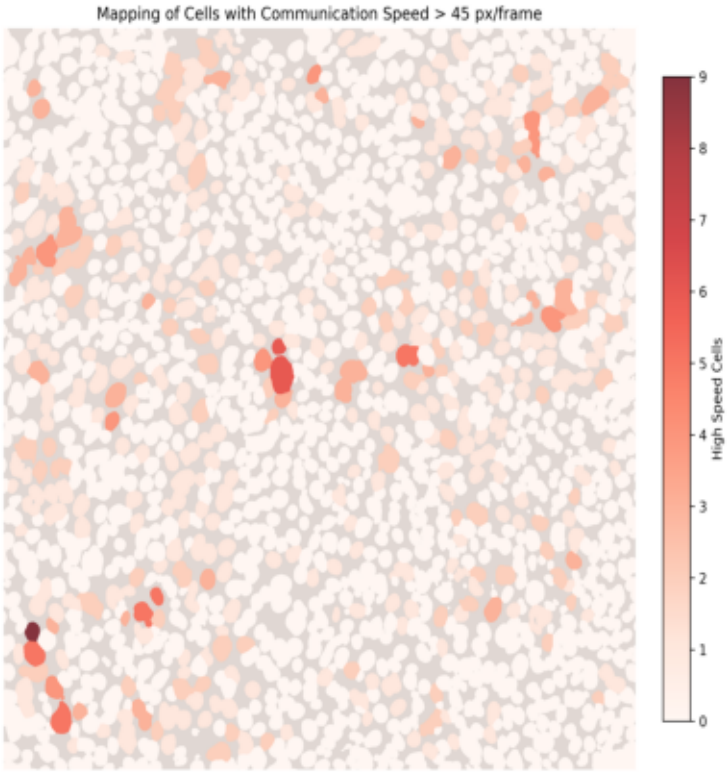

```
[2025-08-11 09:46:35] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 267 on 'Event time phase (fraction of event duration)'
(lower=-1.8, upper=2.4)
```



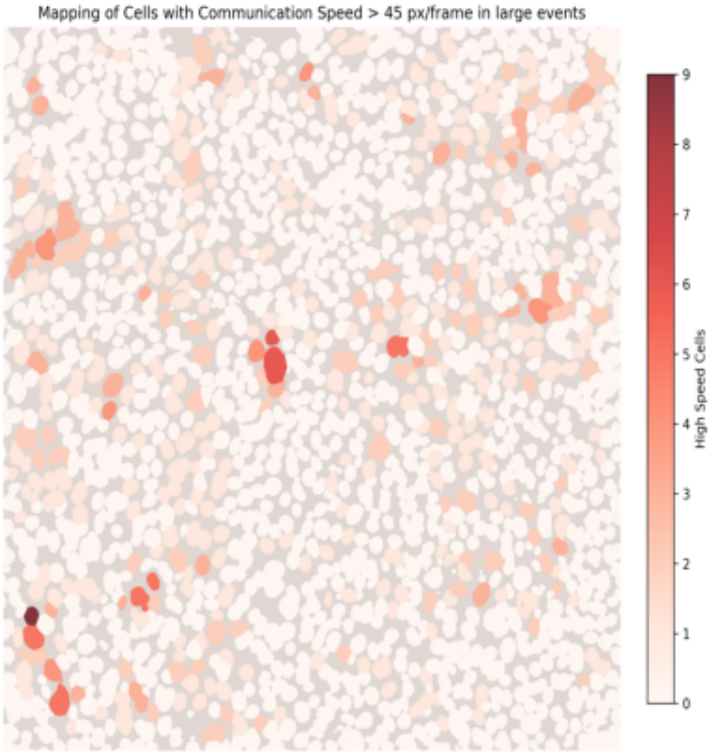

```
[2025-08-11 09:46:35] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 267 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.65, upper=2.01)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
11+
3
5-10
4
Number of Communications
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

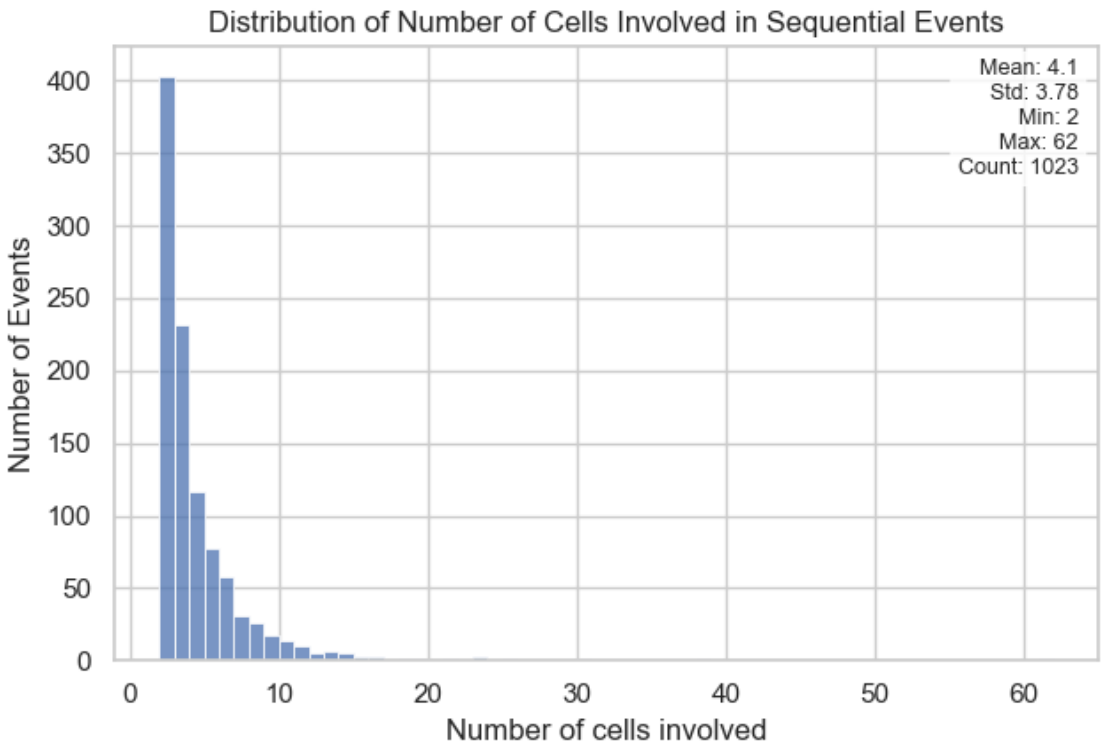
Cell Mapping with High Speed Cells Overlay - 20250409_IS09



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS09

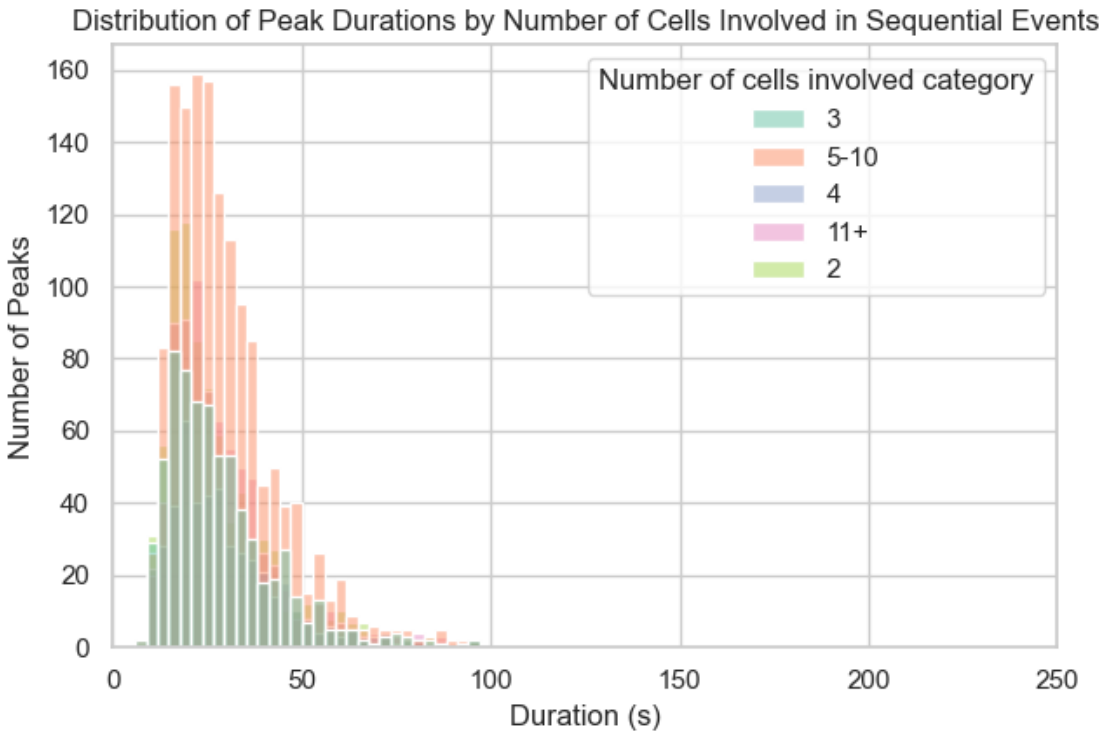


1.3.5 Number of cells involved per sequential events

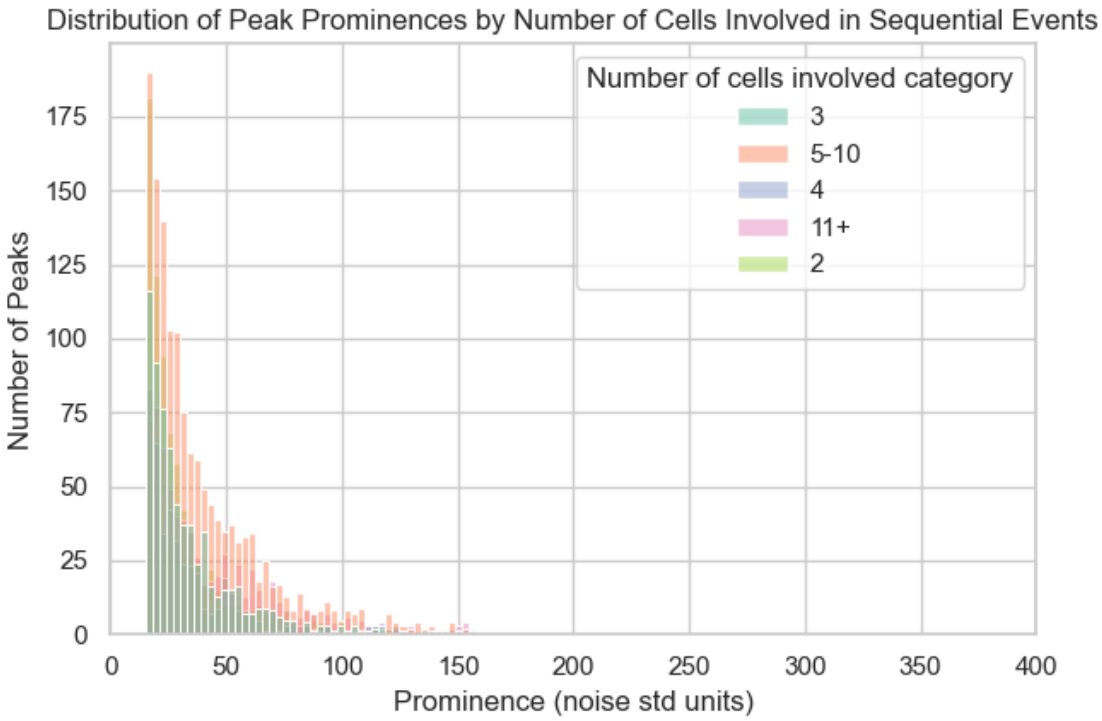


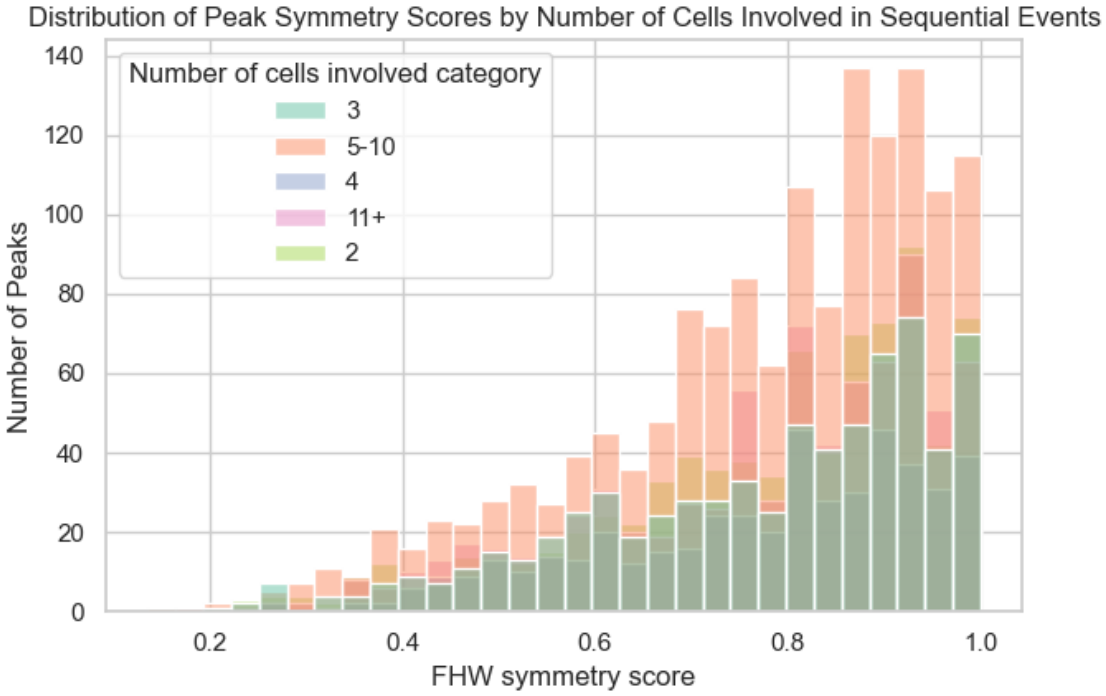
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:46:38] [INFO] calcium: plot_histogram_by_group: removed 53
outliers out of 4215 on 'Duration (s)' (lower=-9, upper=99)
```



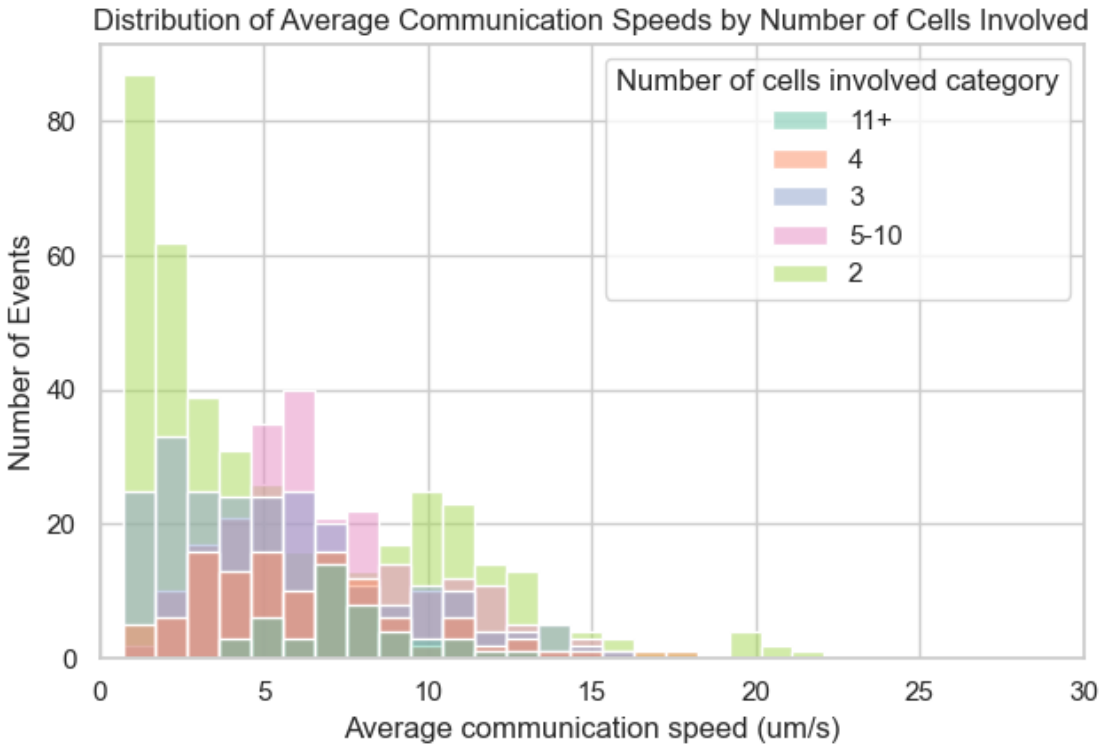

```
[2025-08-11 09:46:38] [INFO] calcium: plot_histogram_by_group: removed 156
outliers out of 4215 on 'Prominence (noise std units)' (lower=-25.45,
upper=157.55)
```



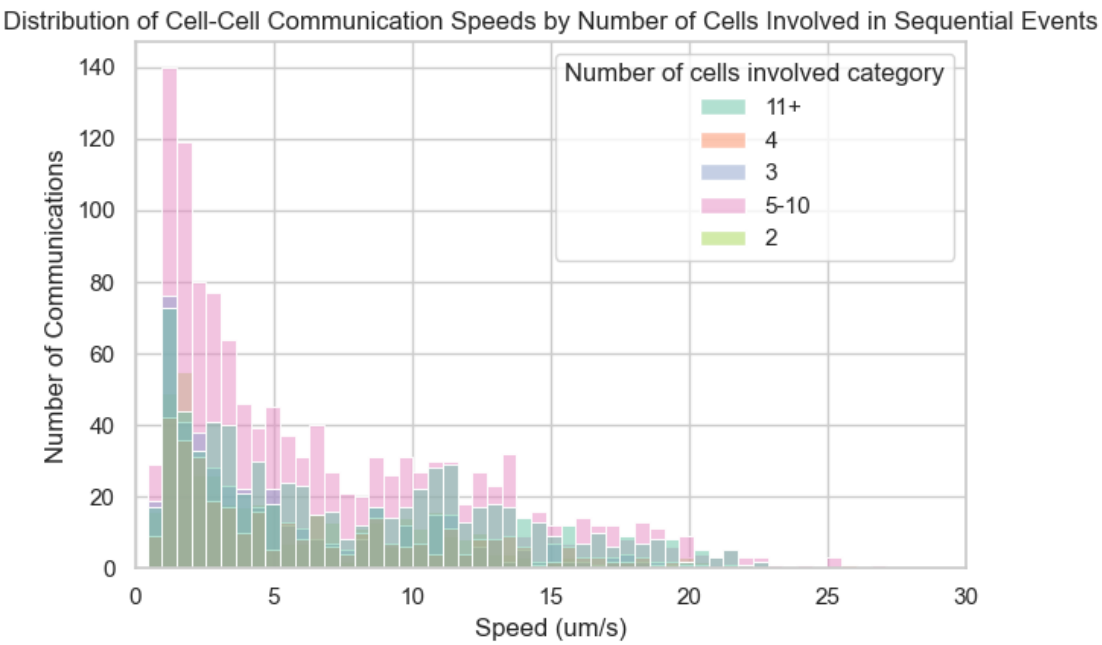



```
[2025-08-11 09:46:39] [INFO] calcium: plot_histogram_by_group: removed 0
```

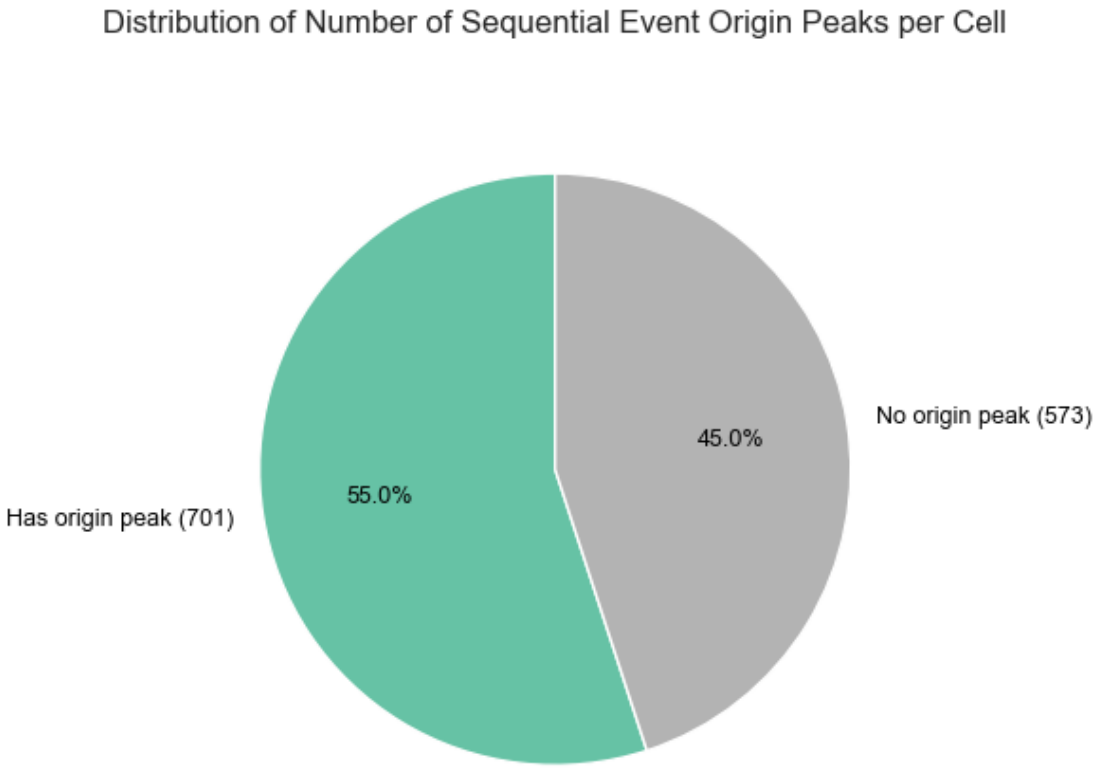
```
outliers out of 1023 on 'Average communication speed (um/s)' (lower=-13.275,
upper=24.63)
```

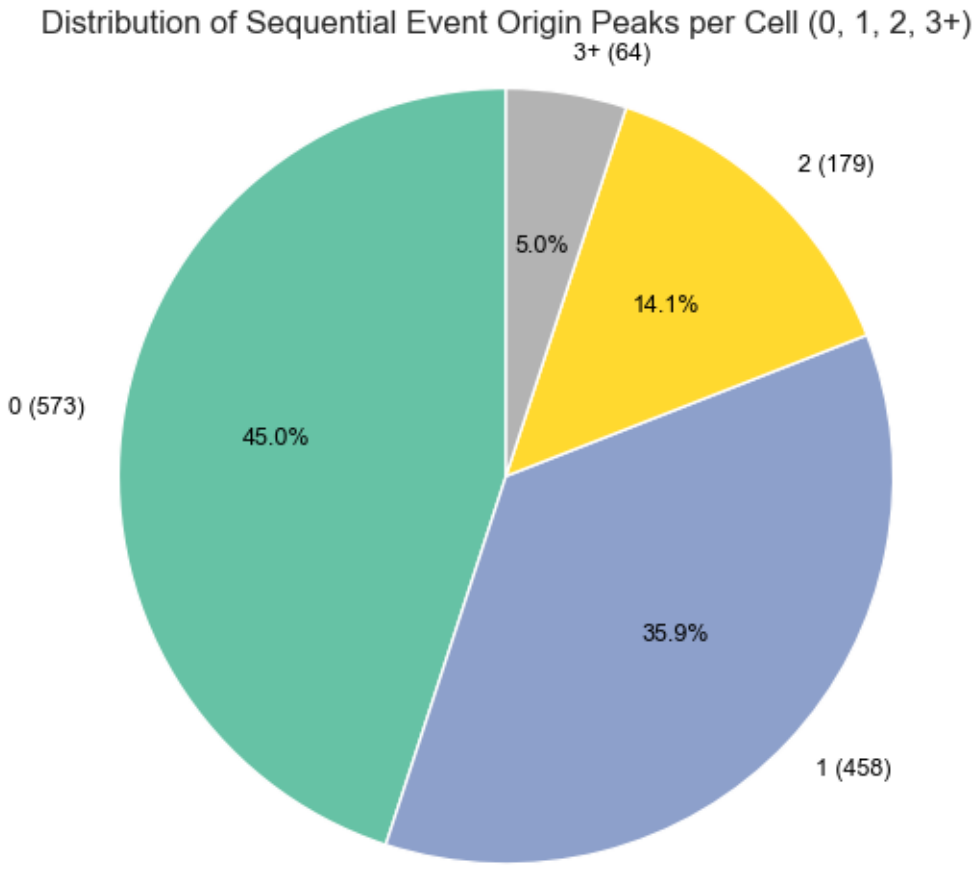



```
[2025-08-11 09:46:39] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 3192 on 'Speed (um/s)' (lower=-23.047, upper=35.63)
```

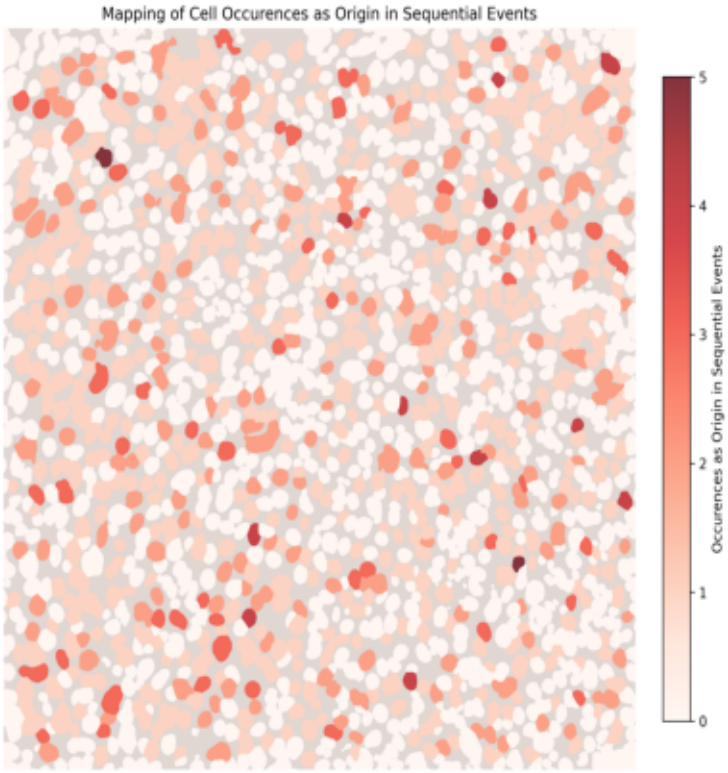

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
11+
4
3
5-10
2
Number of Communications
Speed (um/s)
0
20
40
60
80
100
120
140
0
5
10
15
20
25
30

1.3.7 Cells occurences as origin in sequential events

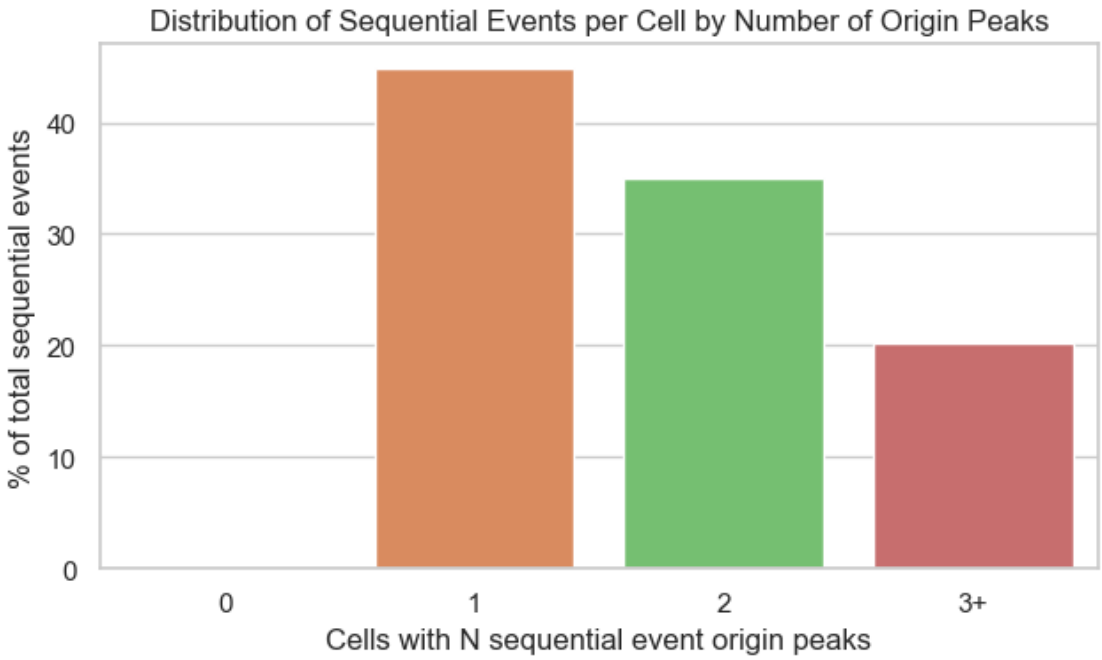



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (64)
2 (179)
5.0%
14.1%
0 (573)
45.0%
35.9%
1 (458)

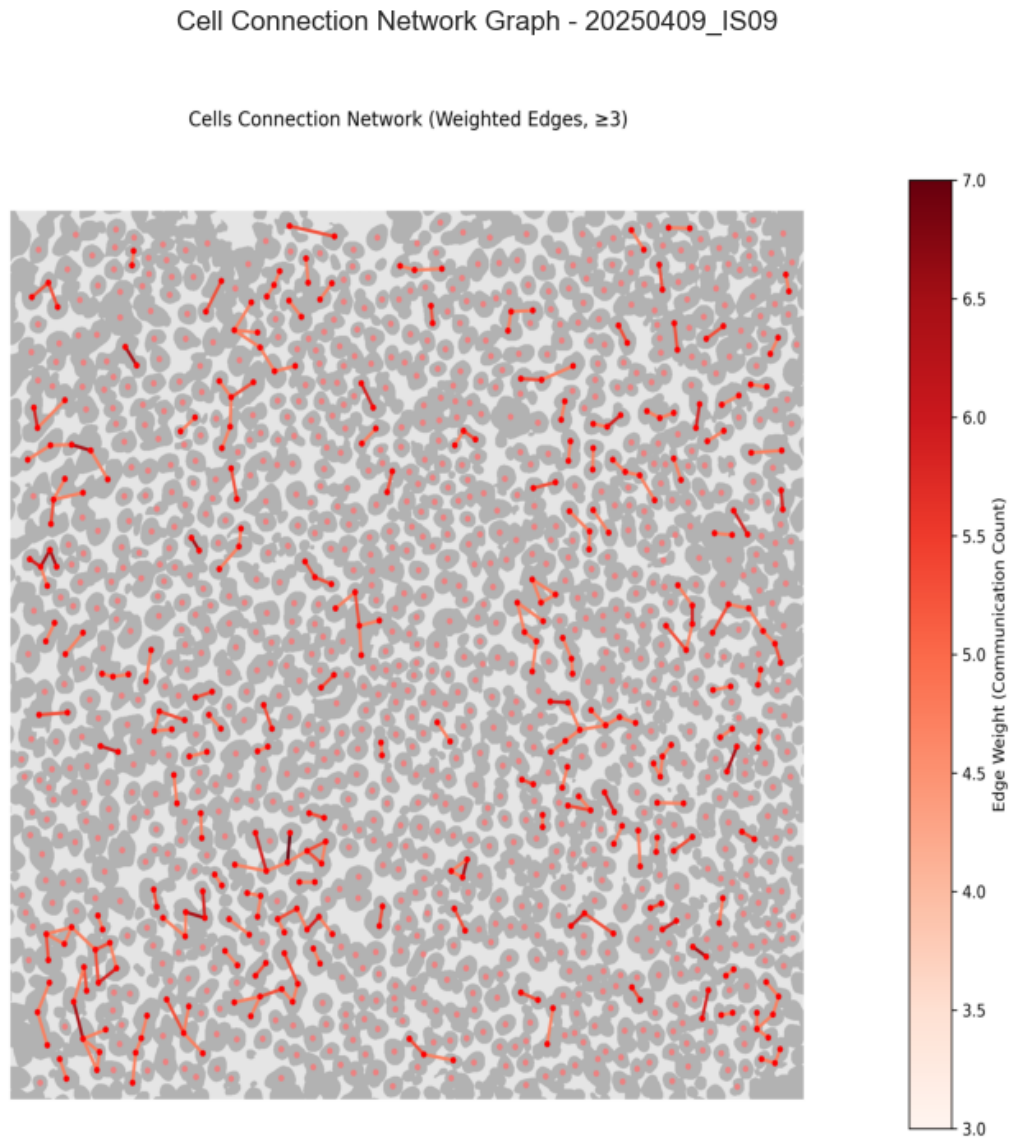
Cell Mapping with Origin Peaks Overlay - 20250409_IS09




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

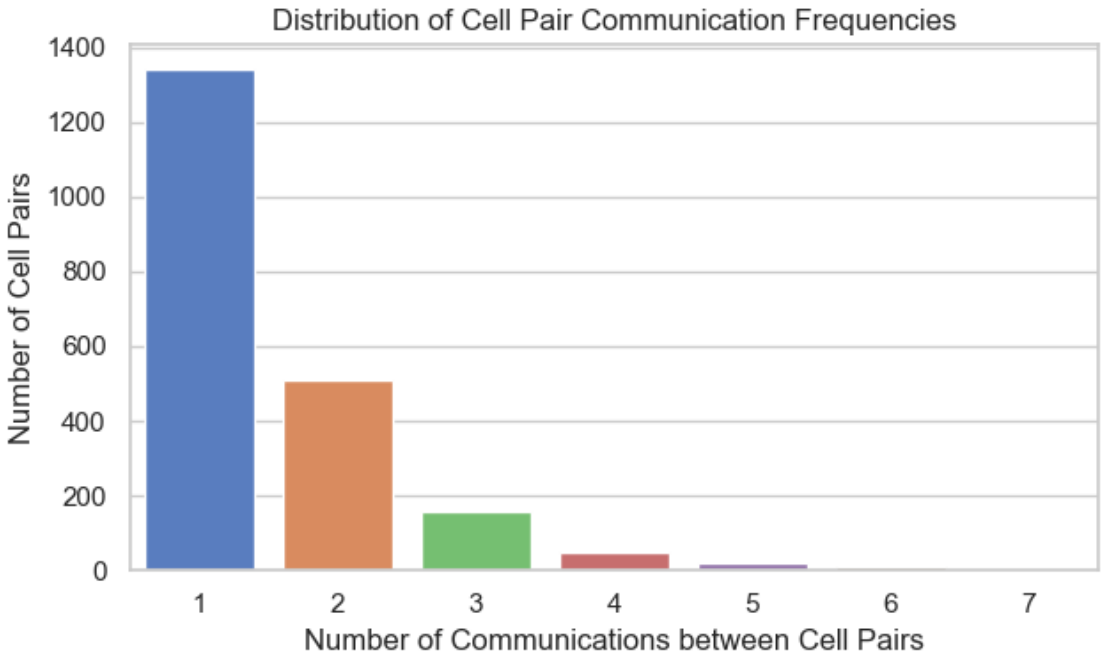

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
0
10
20
30
40
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



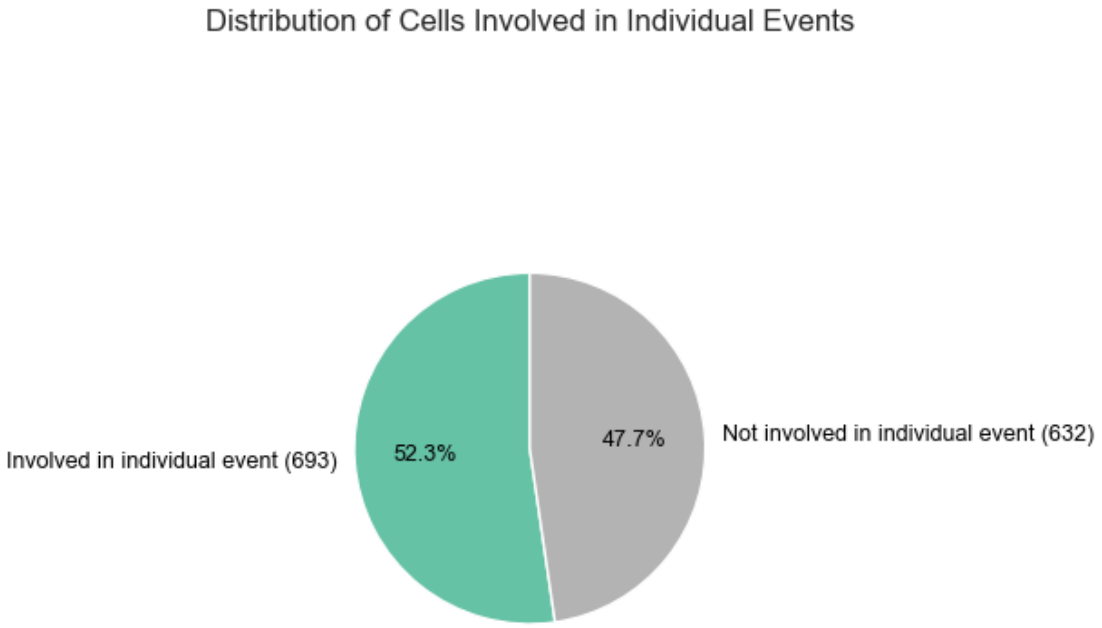

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

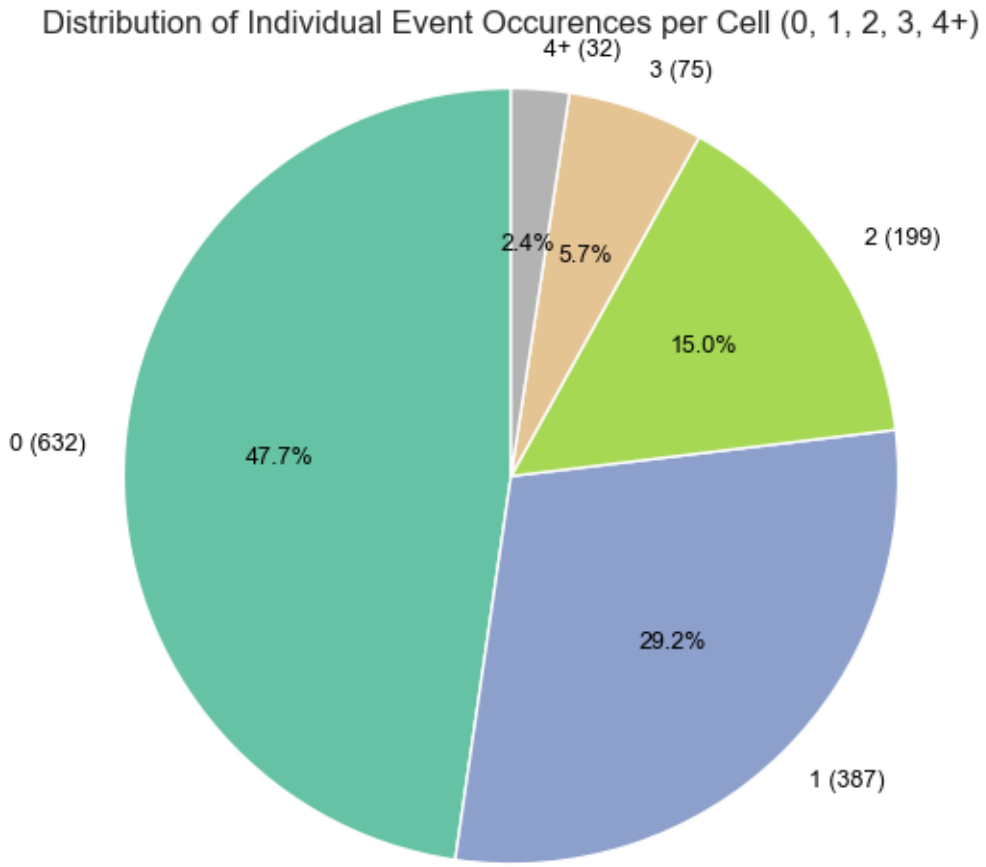
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
1400
1200
1000
800
600
400
200
0
1
2
3
4
5
6
7
Number of Communications between Cell Pairs

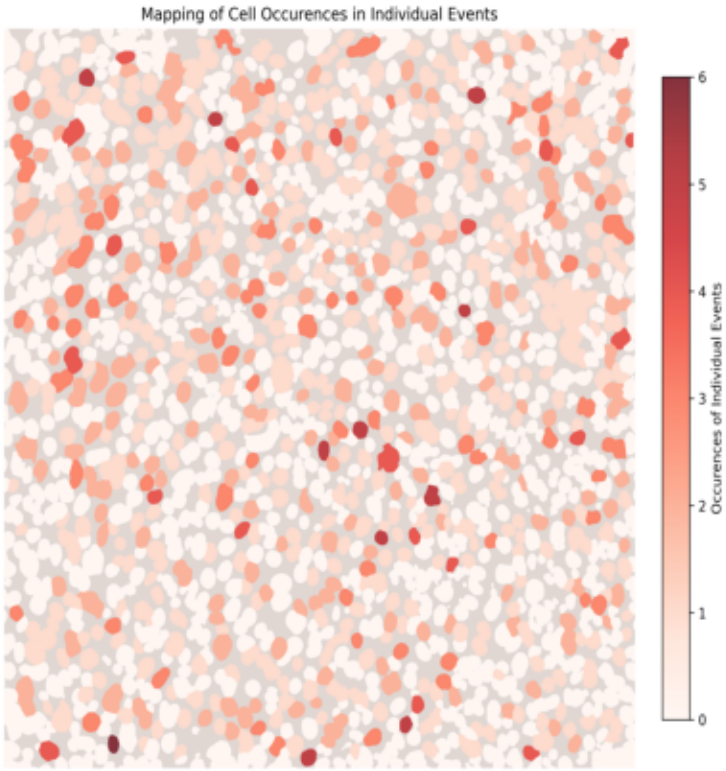
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



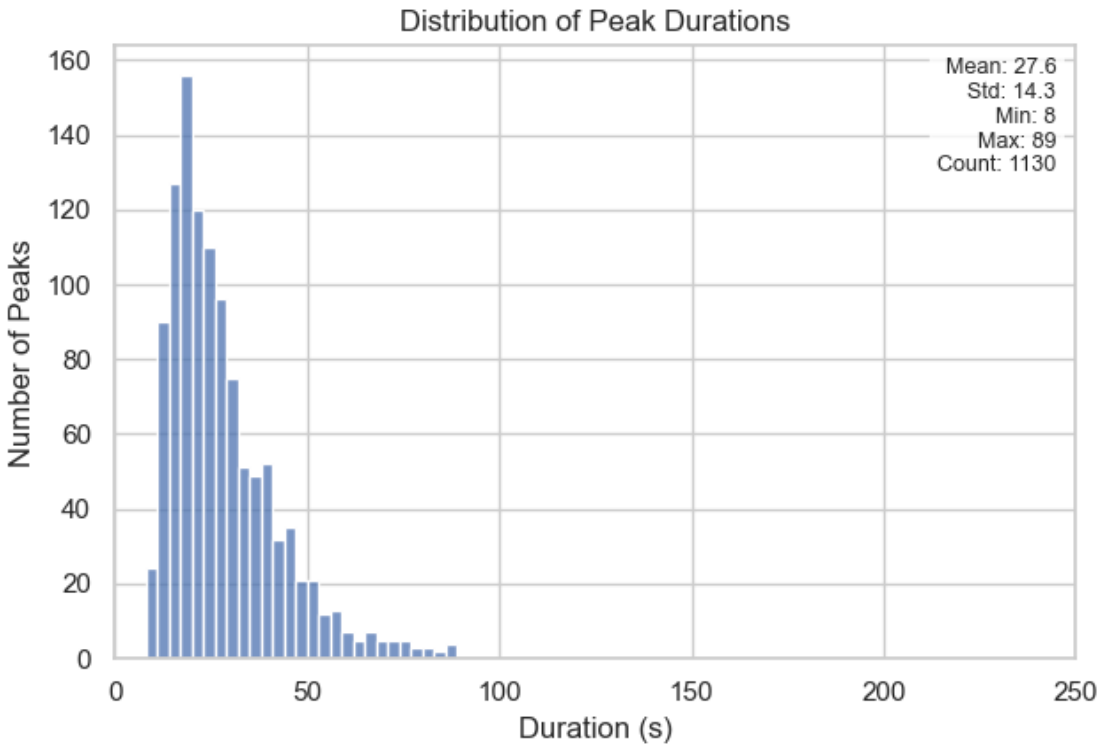

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (32)
3 (75)
2 (199)
0 (632)
1 (387)
2.4%
5.7%
15.0%
47.7%
29.2%

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS09

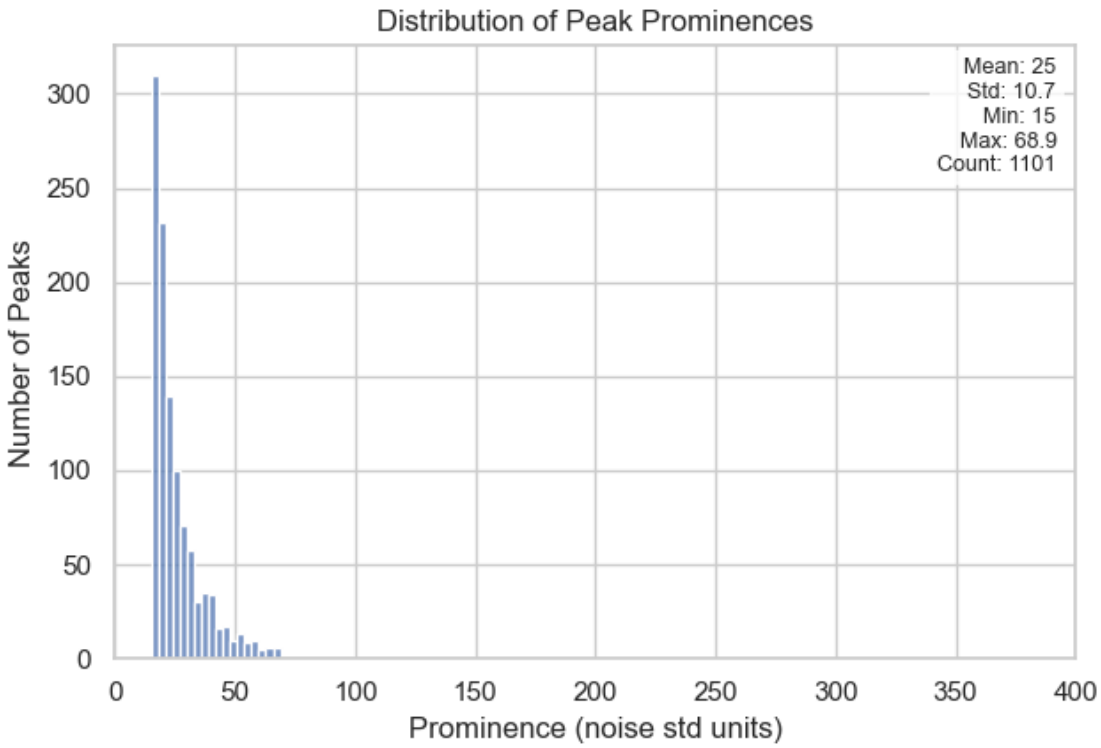


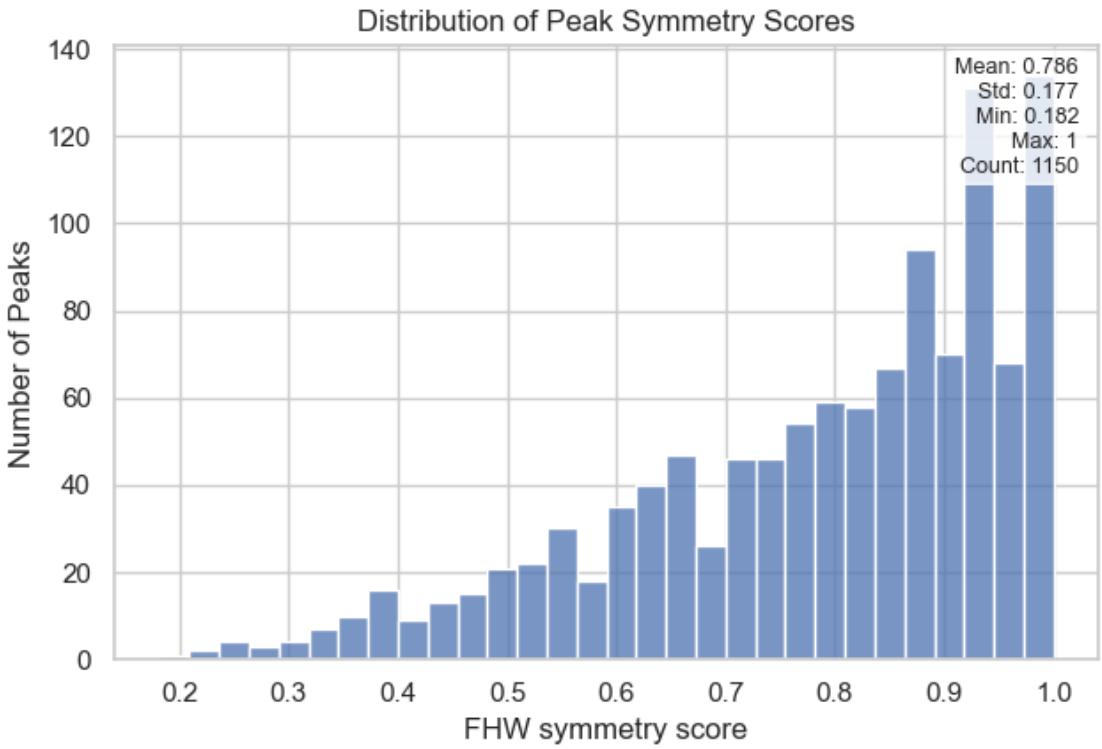
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:46:43] [INFO] calcium: plot_histogram: removed 20 outliers out of
1150 on 'Duration (s)' (lower=-37, upper=89)
```

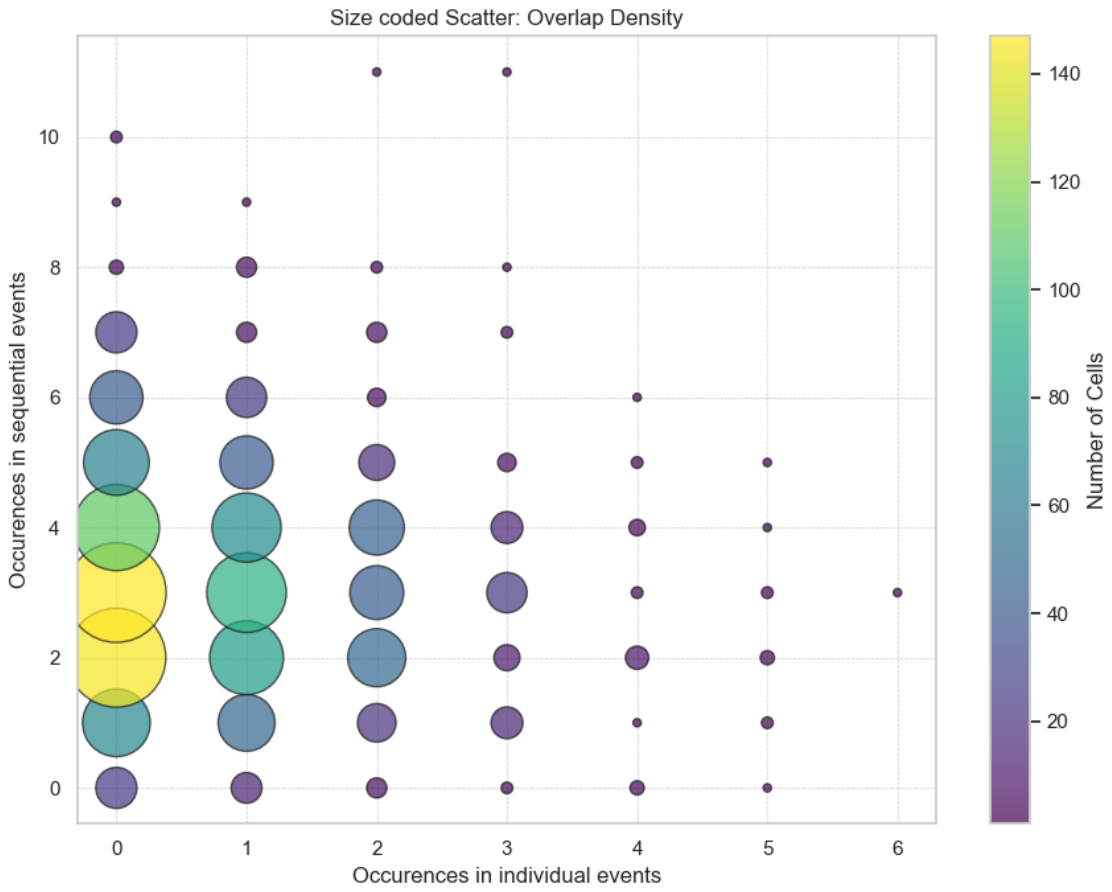



```
[2025-08-11 09:46:43] [INFO] calcium: plot_histogram: removed 49 outliers out of
1150 on 'Prominence (noise std units)' (lower=-20.7, upper=68.9)
```

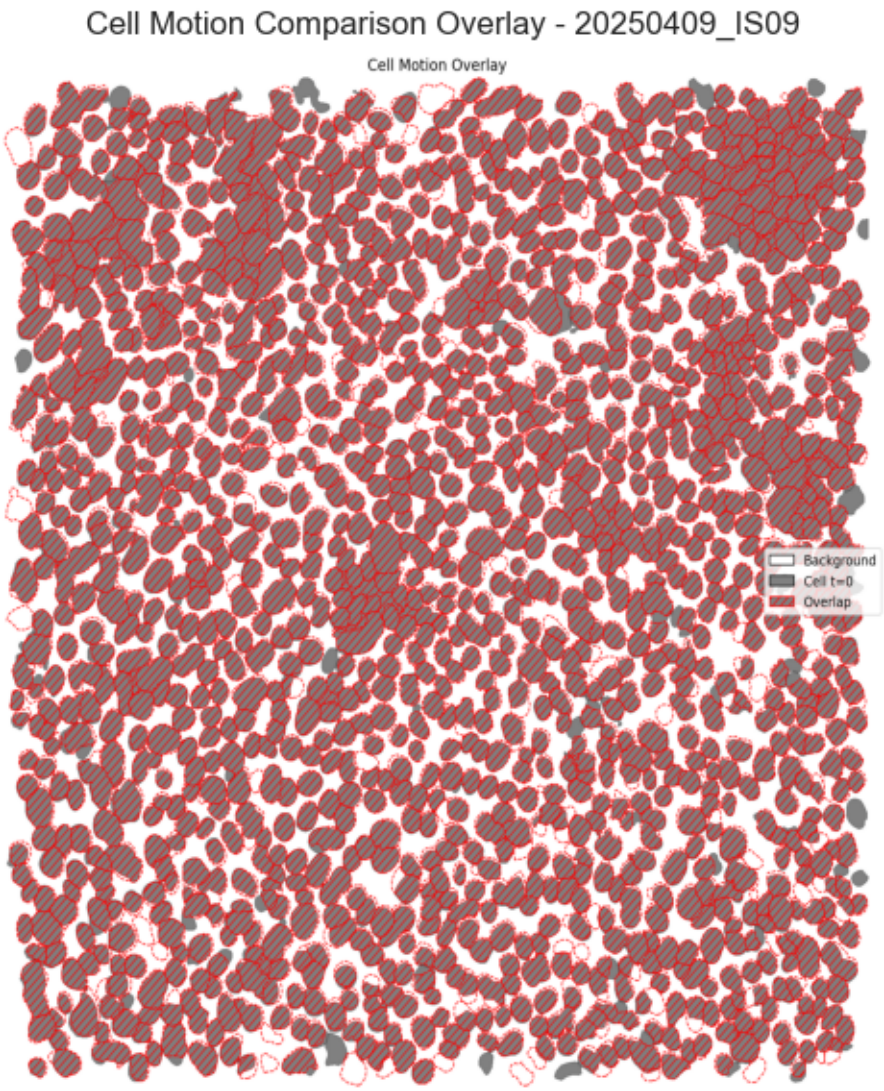

Distribution of Peak Prominences
Mean: 25
Std: 10.7
Min: 15
Max: 68.9
Count: 1101
Number of Peaks
0
50
100
150
200
250
300
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.786
Std: 0.177
Min: 0.182
Max: 1
Count: 1150
Number of Peaks
0
20
40
60
80
100
120
140
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 1325
- Hoechst image taken at t=1801: 1321
- Number of cells difference: absolute 4, relative 0.30%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1444822
- Pixels segmented as cell at t=1801: 1510000
- Overlapping pixels between t=0 and t=1801: 1328466(89.92% of total)
- Pixels exclusive to t=0: 116356 (8.05% of total)
- Pixels exclusive to t=1801: 181534 (12.02% of total)
```

executed

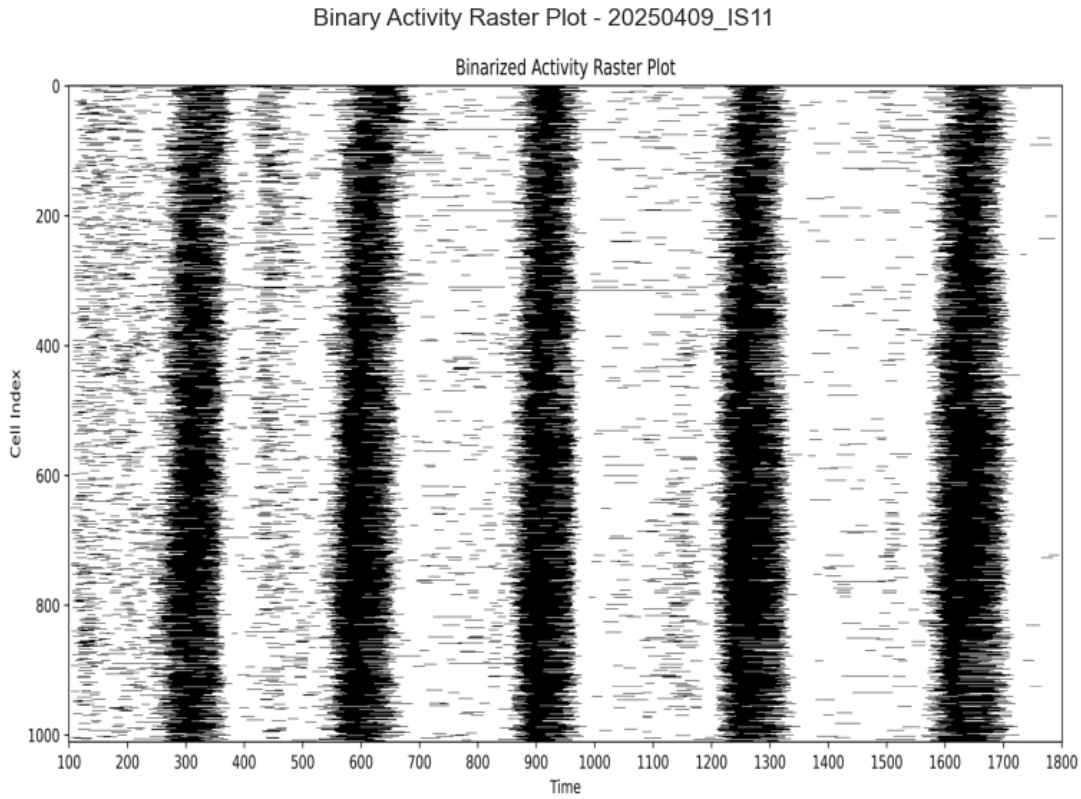
August 11, 2025

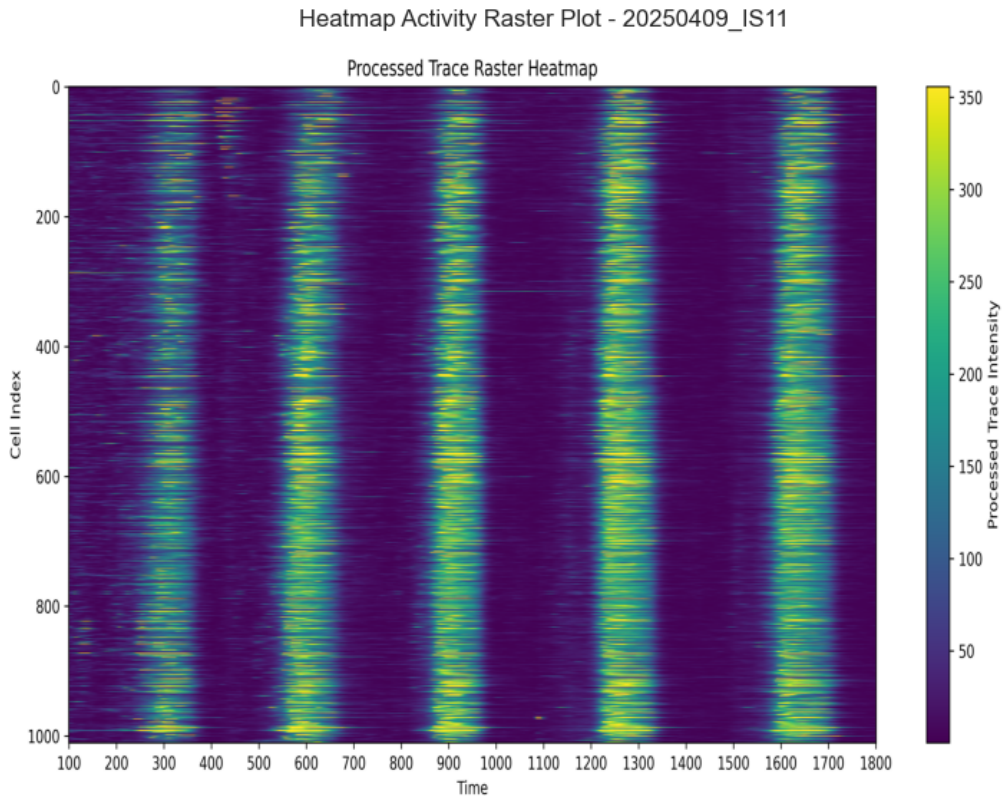
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



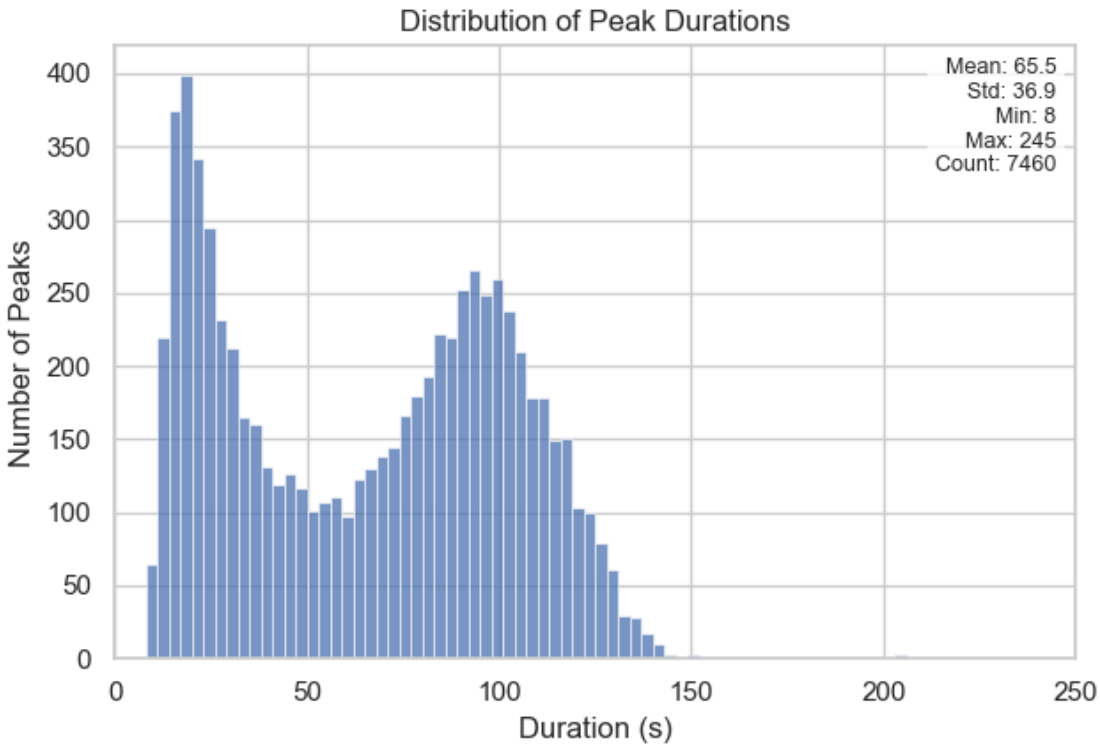


1.1.2 Peaks population

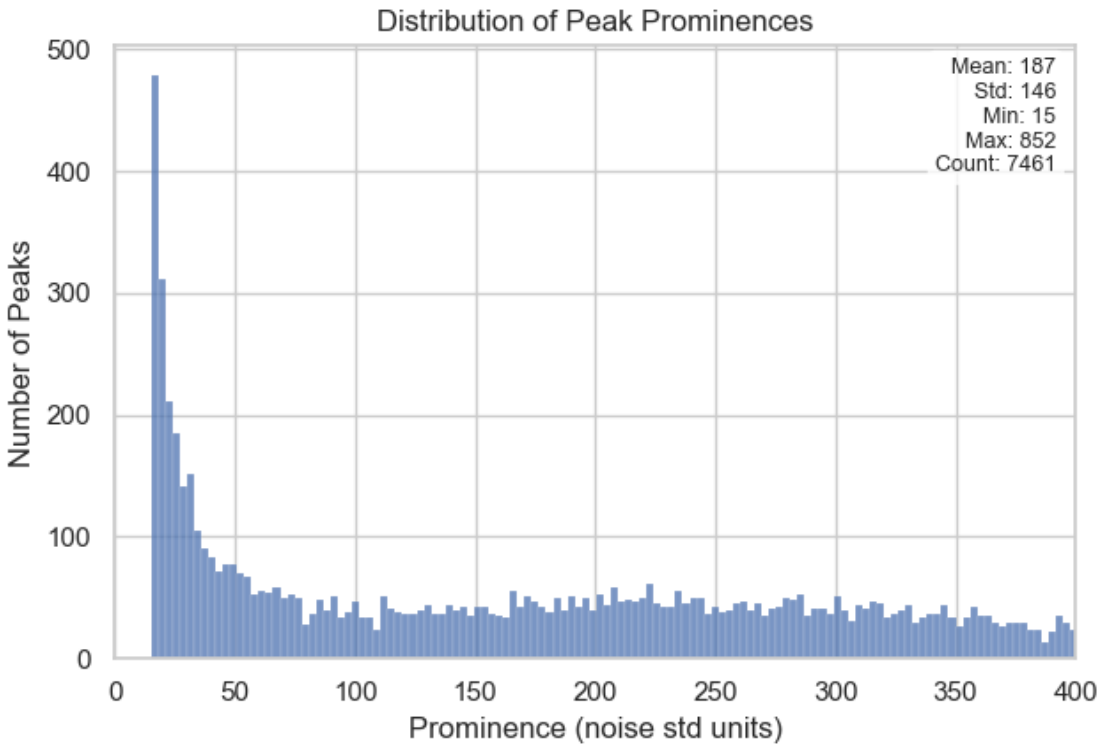
```
Total number of peaks: 7461
Total number of cells: 1011
```

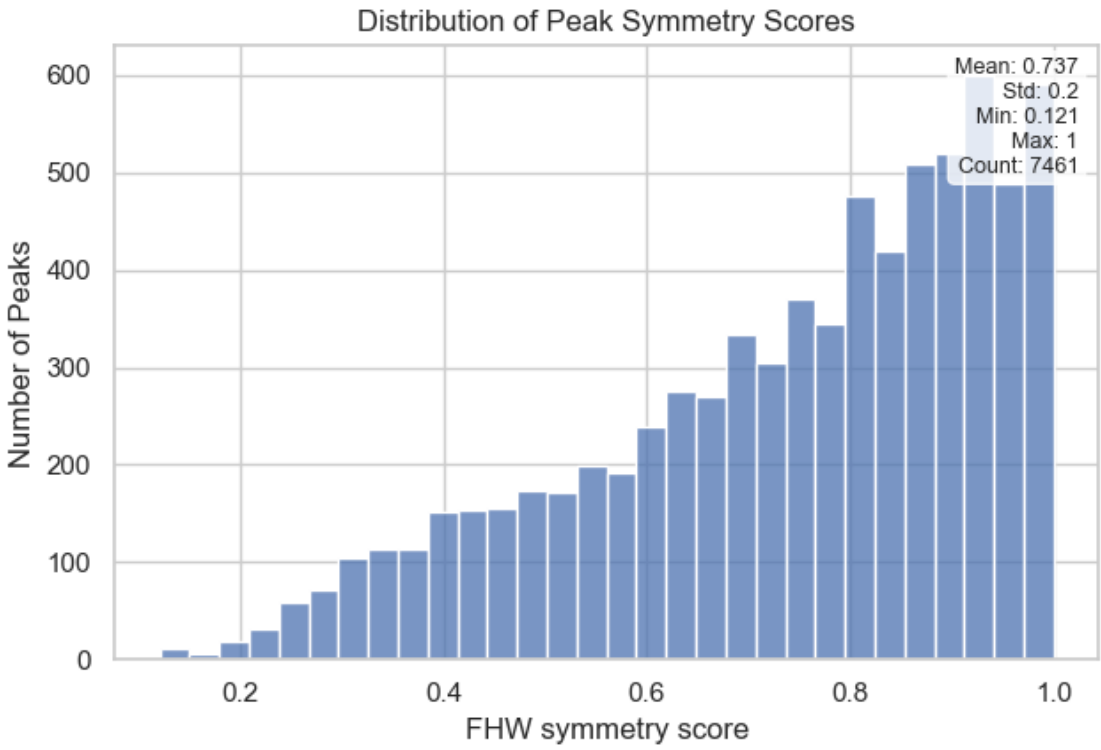
1.1.3 Peaks statistics

```
[2025-08-11 09:47:45] [INFO] calcium: plot_histogram: removed 1 outliers out of
7461 on 'Duration (s)' (lower=-179, upper=304)
```

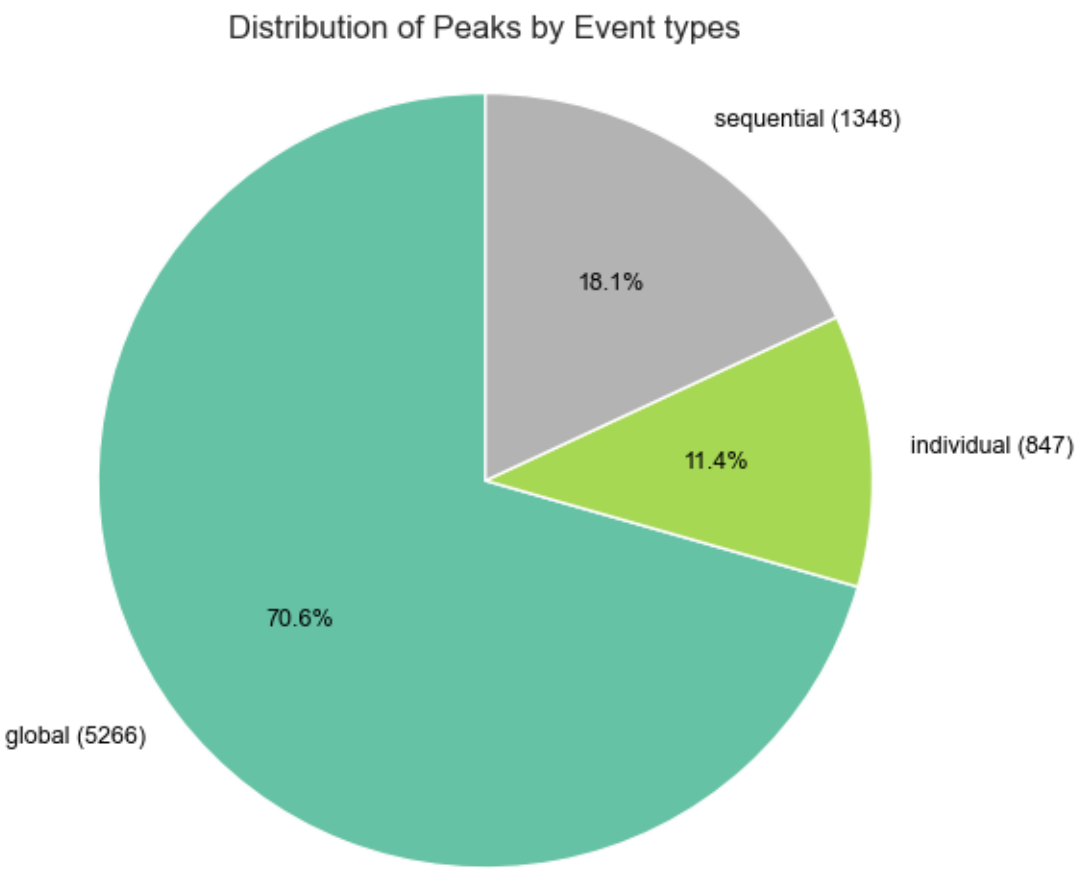



```
[2025-08-11 09:47:45] [INFO] calcium: plot_histogram: removed 0 outliers out of
7461 on 'Prominence (noise std units)' (lower=-698, upper=1038.7)
```


Distribution of Peak Prominences
Mean: 187
Std: 146
Min: 15
Max: 852
Count: 7461
Number of Peaks
Prominence (noise std units)
0
100
200
300
400
500
0
50
100
150
200
250
300
350
400

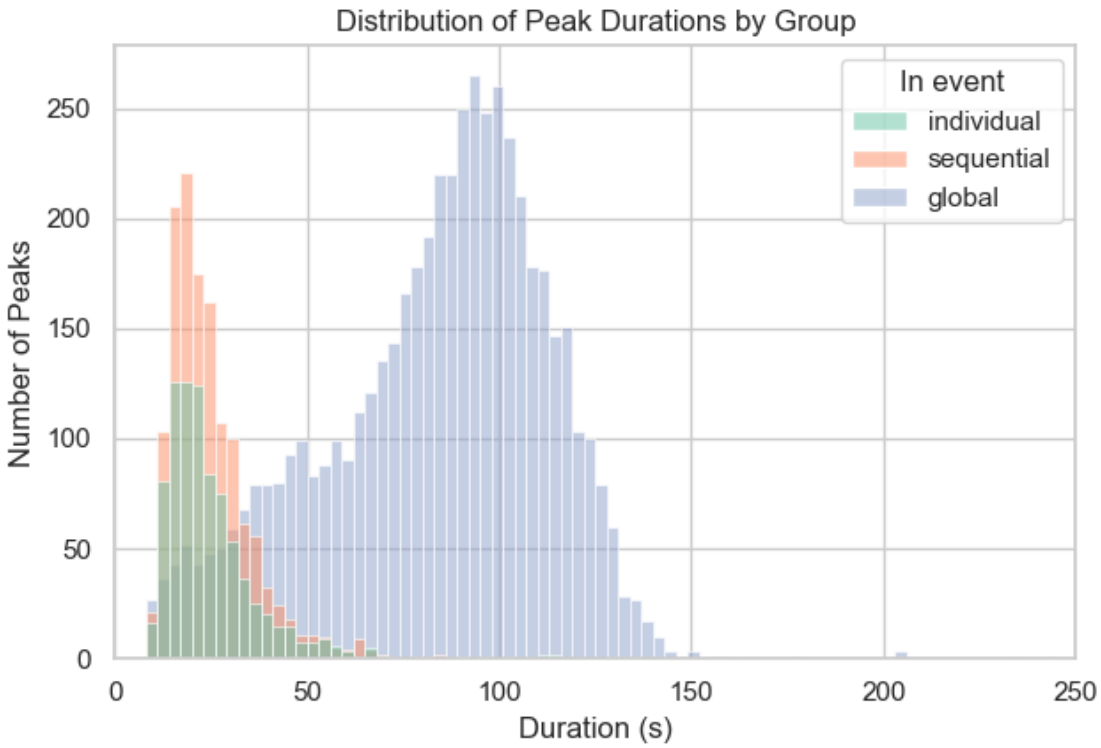

Distribution of Peak Symmetry Scores
Mean: 0.737
Std: 0.2
Min: 0.121
Max: 1
Count: 7461
Number of Peaks
FHW symmetry score
0
100
200
300
400
500
600
0.2
0.4
0.6
0.8
1.0

1.1.4 Distribution of peaks per event types

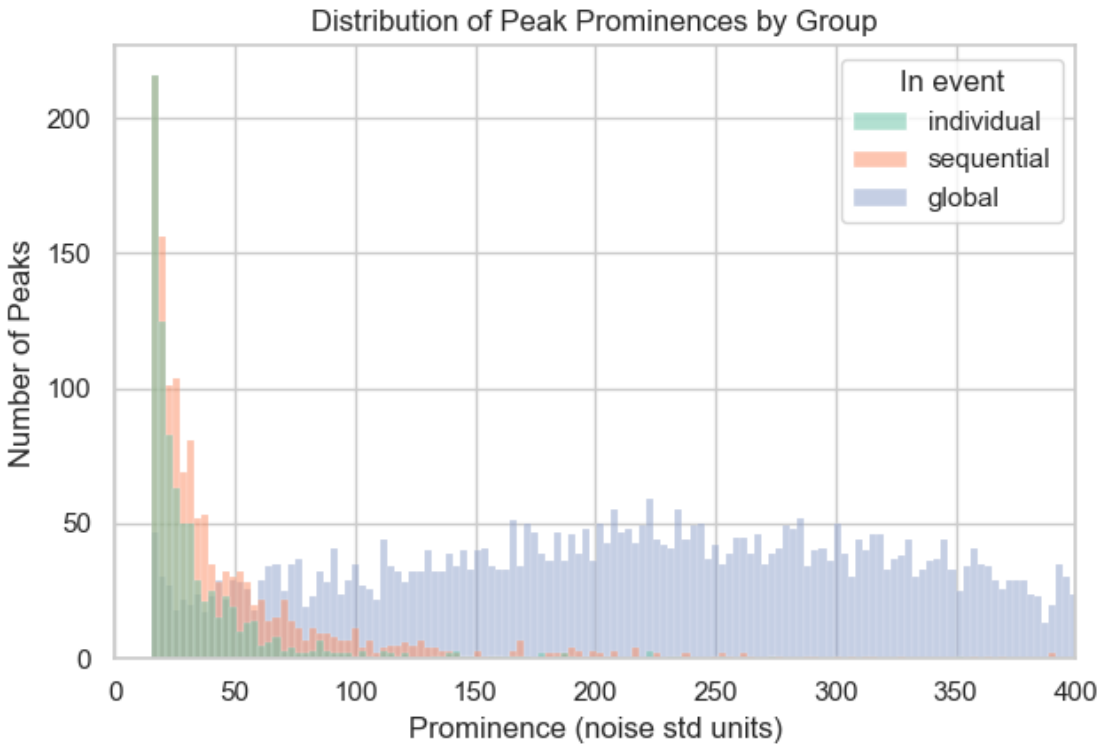


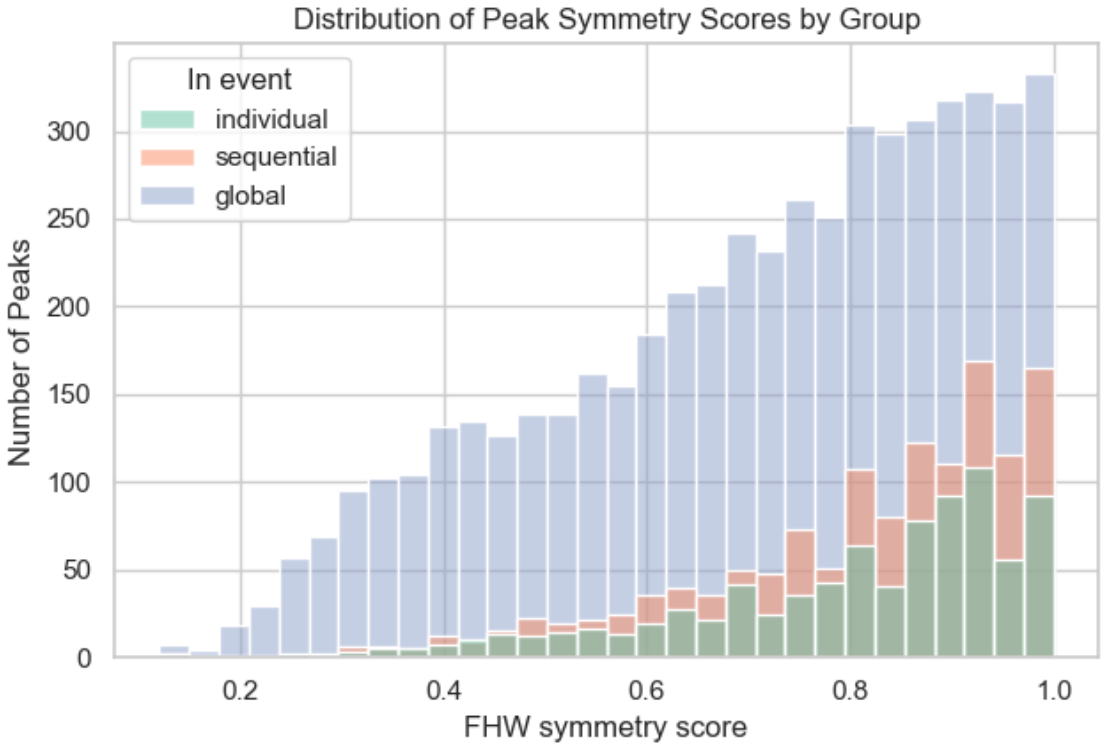
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:47:45] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 7461 on 'Duration (s)' (lower=-179, upper=304)
```




```
[2025-08-11 09:47:46] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 7461 on 'Prominence (noise std units)' (lower=-698,
upper=1038.7)
```

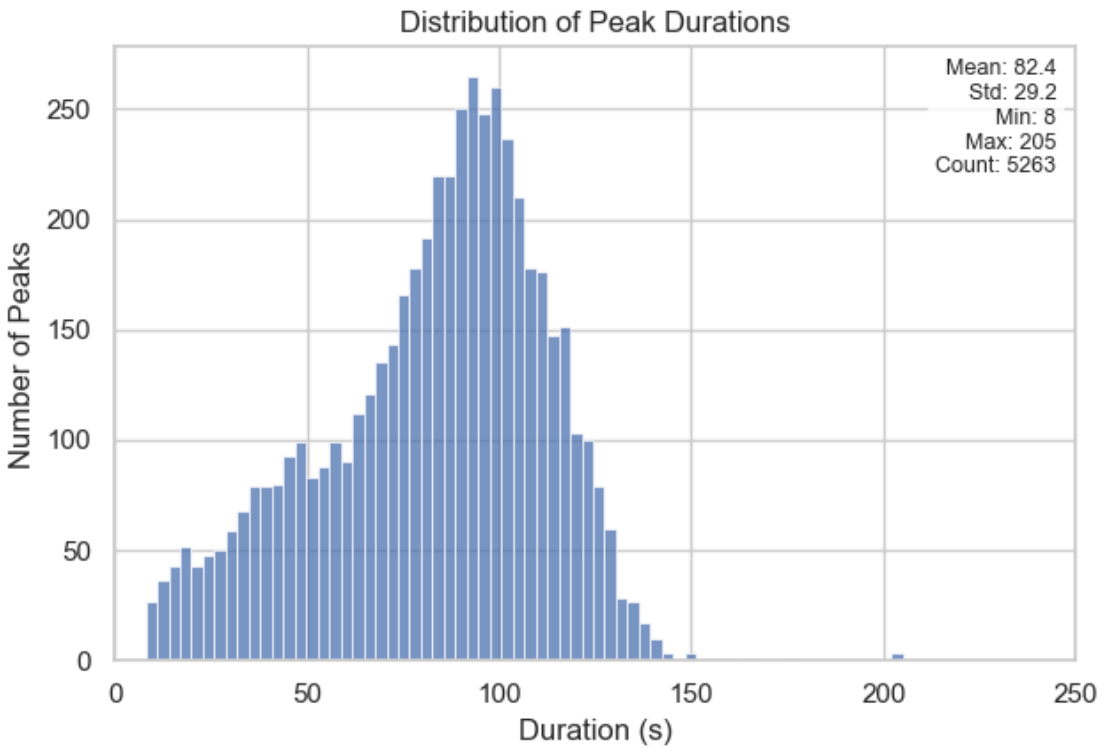

Distribution of Peak Prominences by Group
In event
individual
sequential
global
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
individual
sequential
global
Number of Peaks
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

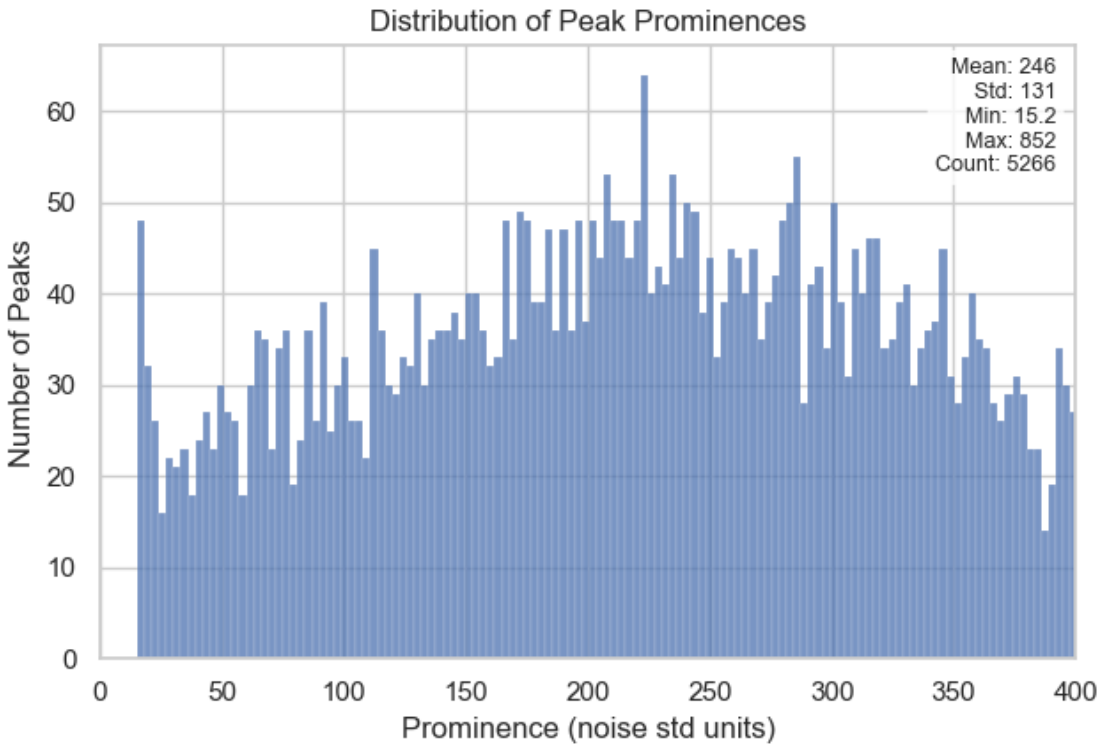
1.2 GLOBAL EVENTS

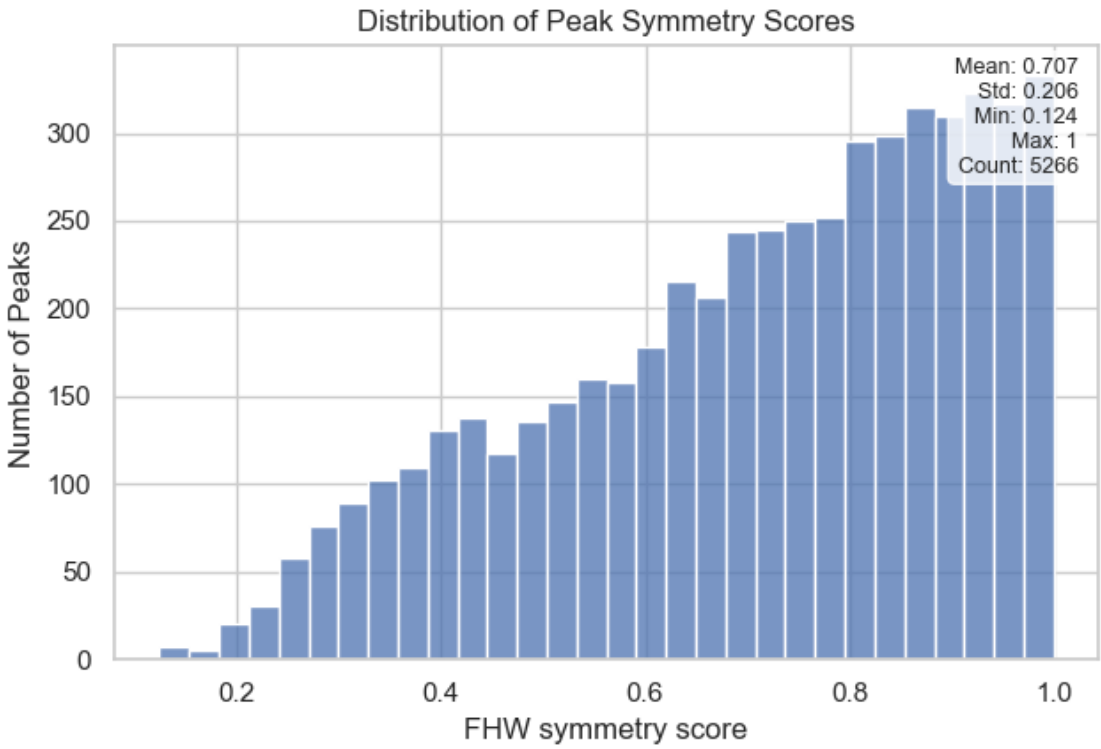
1.2.1 Peak statistics in global events

```
[2025-08-11 09:47:46] [INFO] calcium: plot_histogram: removed 3 outliers out of
5266 on 'Duration (s)' (lower=-53, upper=220)
```



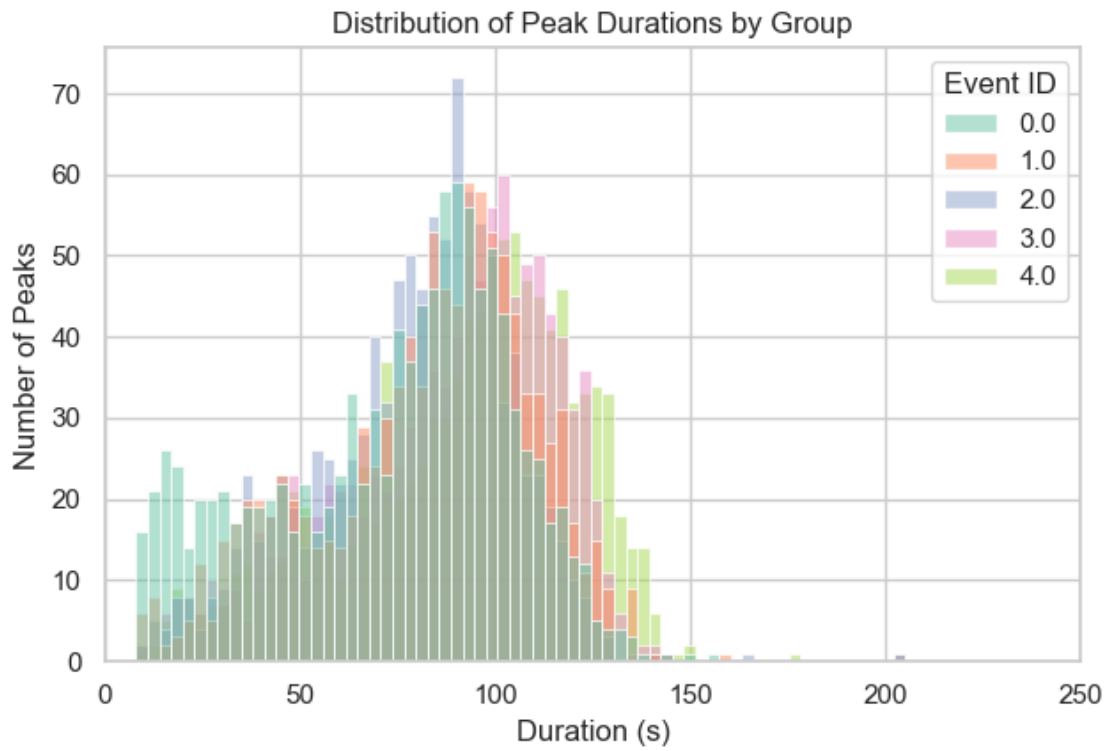

```
[2025-08-11 09:47:46] [INFO] calcium: plot_histogram: removed 0 outliers out of
5266 on 'Prominence (noise std units)' (lower=-410, upper=891.82)
```


Distribution of Peak Prominences
Mean: 246
Std: 131
Min: 15.2
Max: 852
Count: 5266
Number of Peaks
Prominence (noise std units)
0
10
20
30
40
50
60
0
50
100
150
200
250
300
350
400

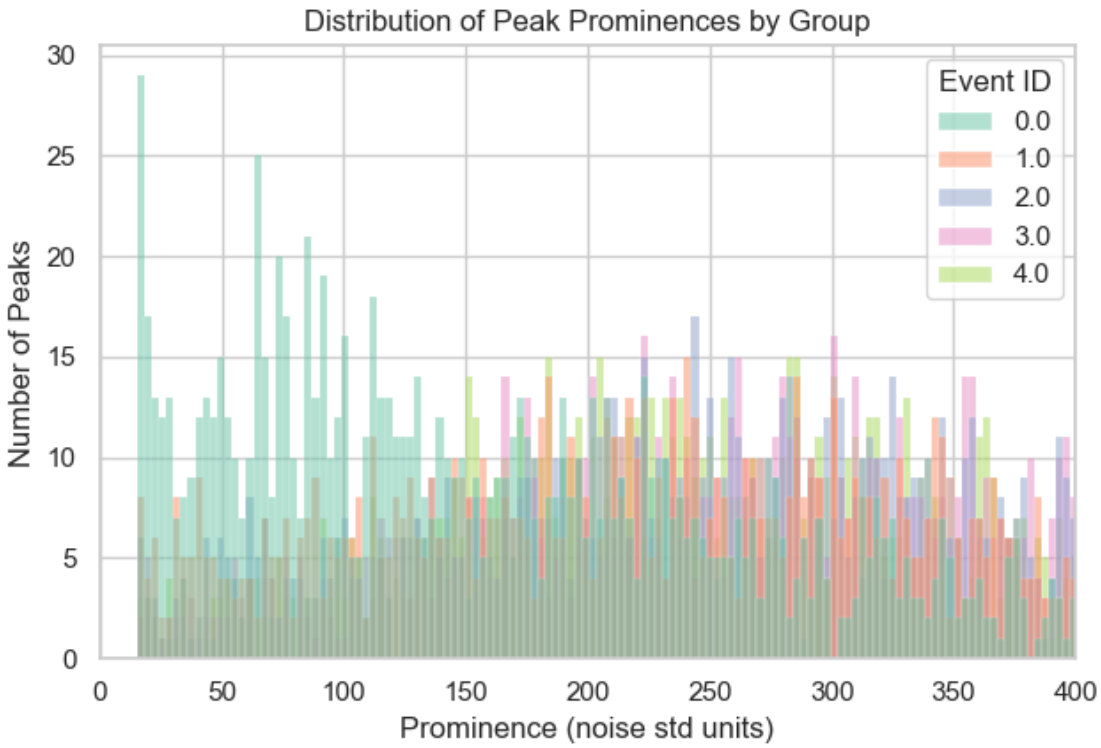

Distribution of Peak Symmetry Scores
Mean: 0.707
Std: 0.206
Min: 0.124
Max: 1
Count: 5266
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0

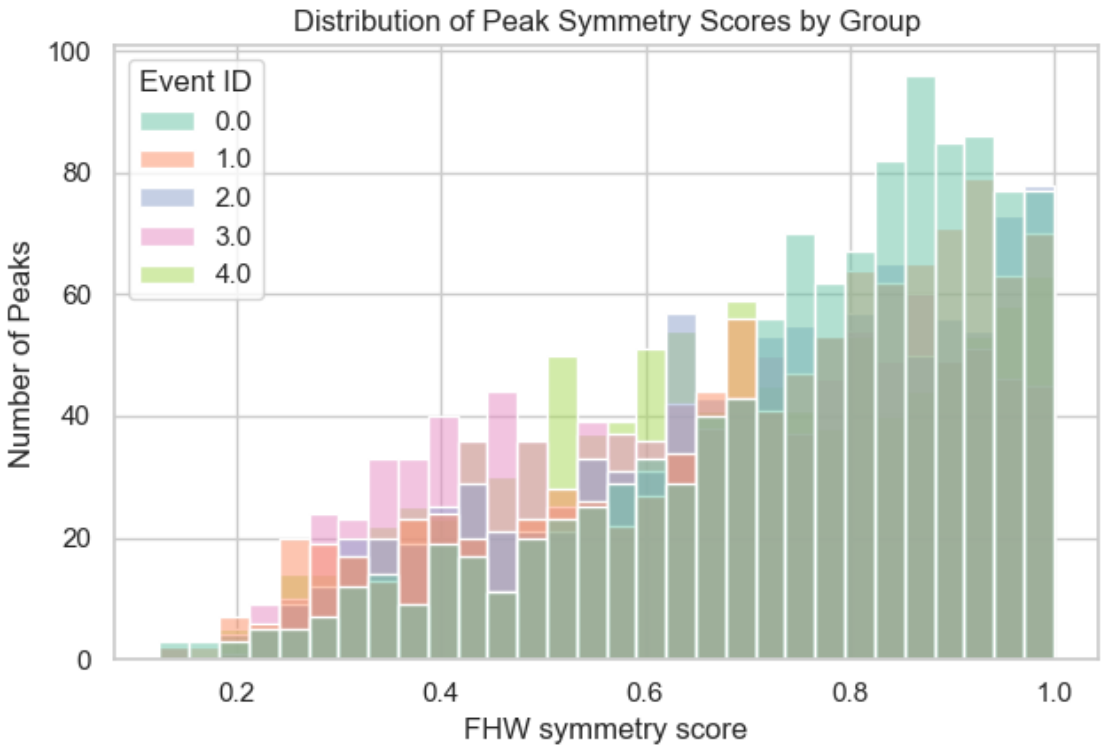
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:47:47] [INFO] calcium: plot_histogram_by_group: removed 3
outliers out of 5266 on 'Duration (s)' (lower=-53, upper=220)
```

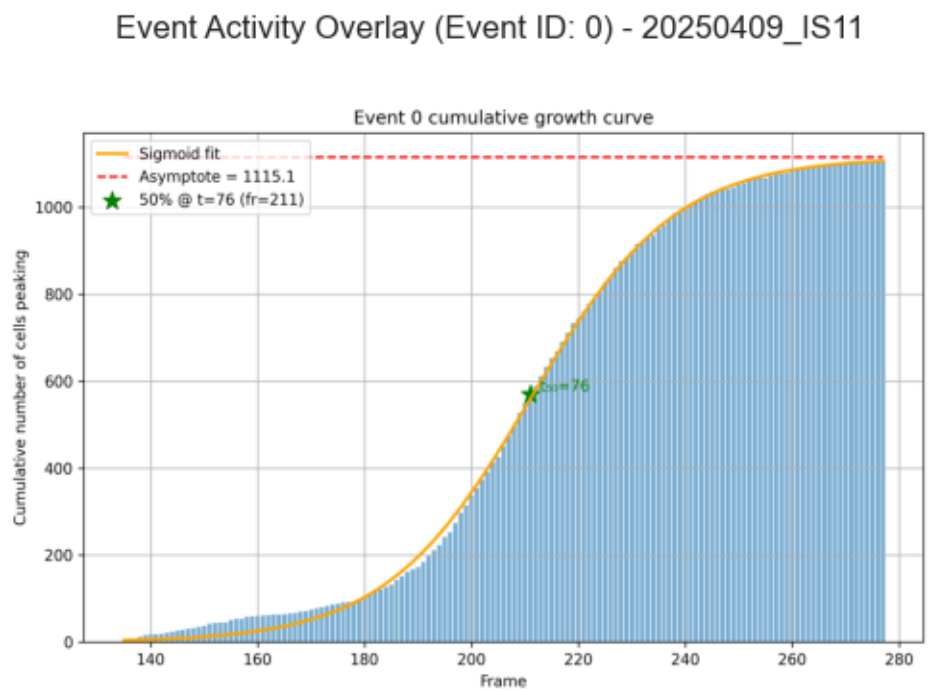


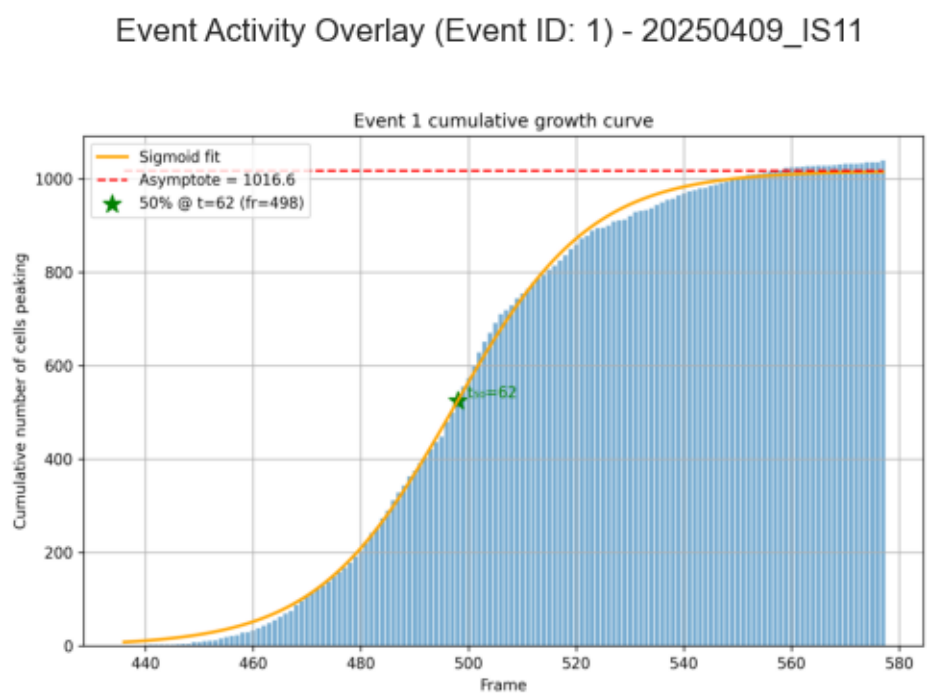

```
[2025-08-11 09:47:47] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 5266 on 'Prominence (noise std units)' (lower=-410,
upper=891.82)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
Prominence (noise std units)
0
5
10
15
20
25
30
0
50
100
150
200
250
300
350
400

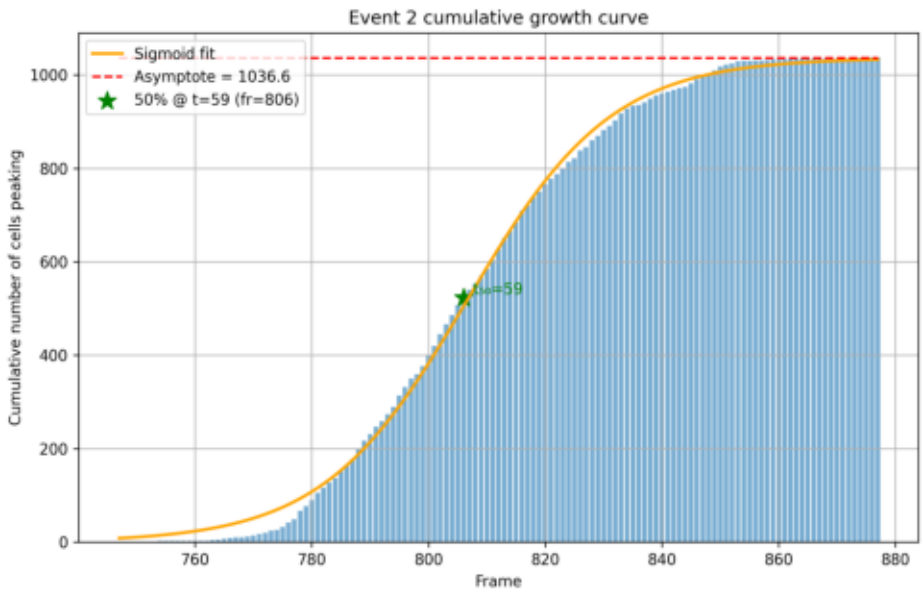

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
4.0
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0

1.2.3 Kinetics of global events

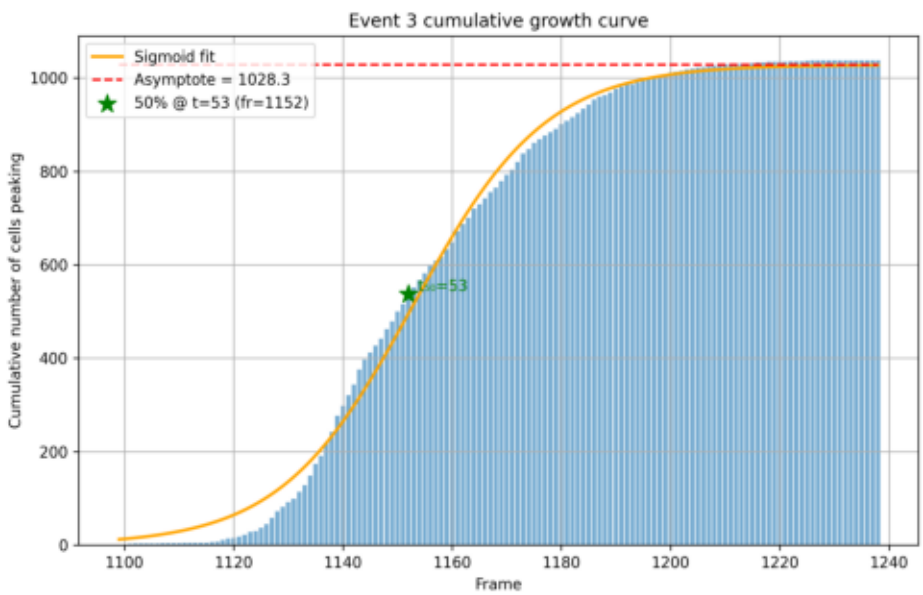


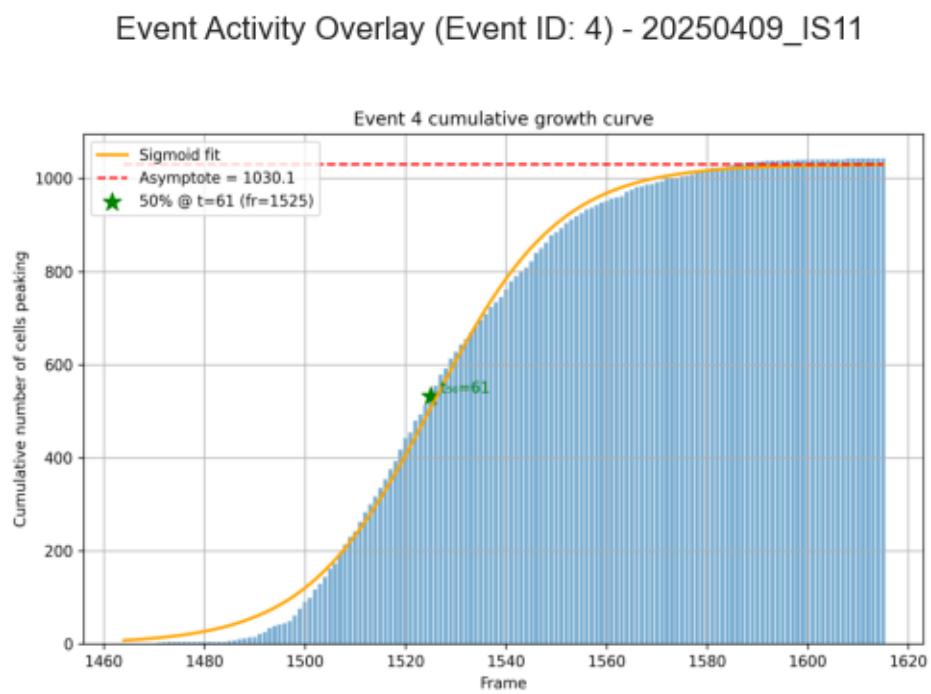


Event Activity Overlay (Event ID: 2) - 20250409_IS11

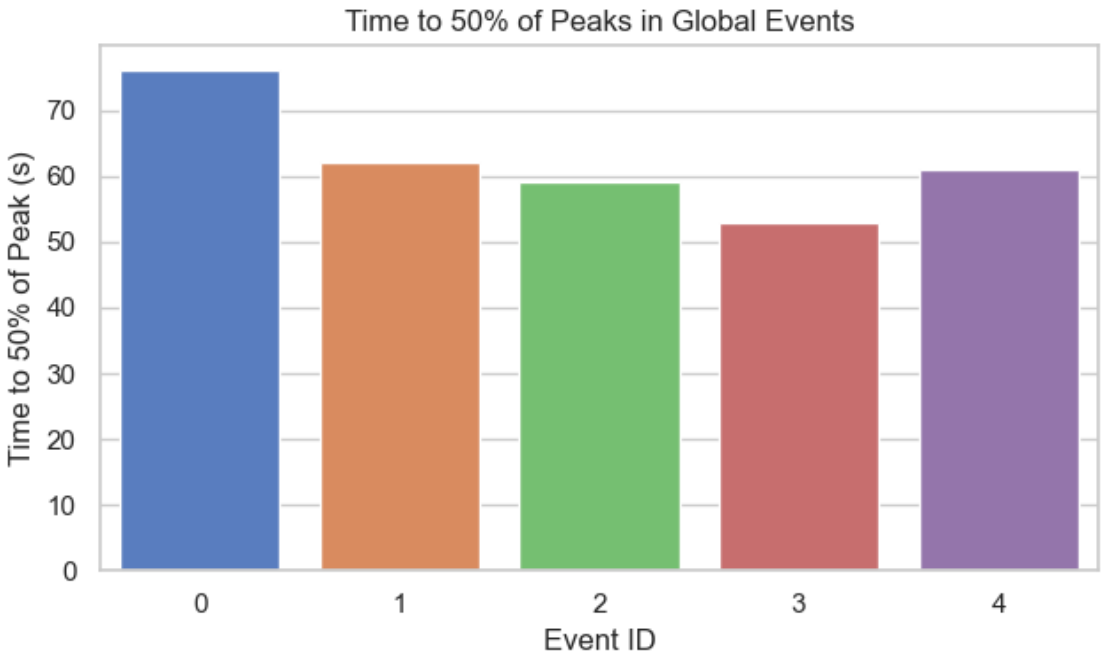


Event Activity Overlay (Event ID: 3) - 20250409_IS11

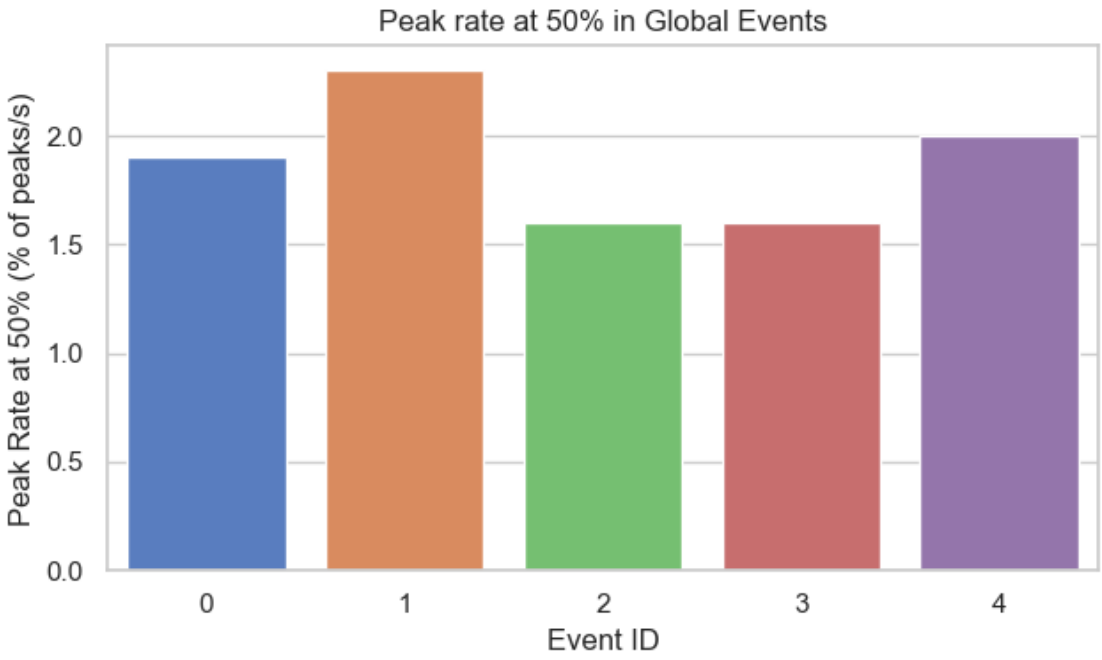




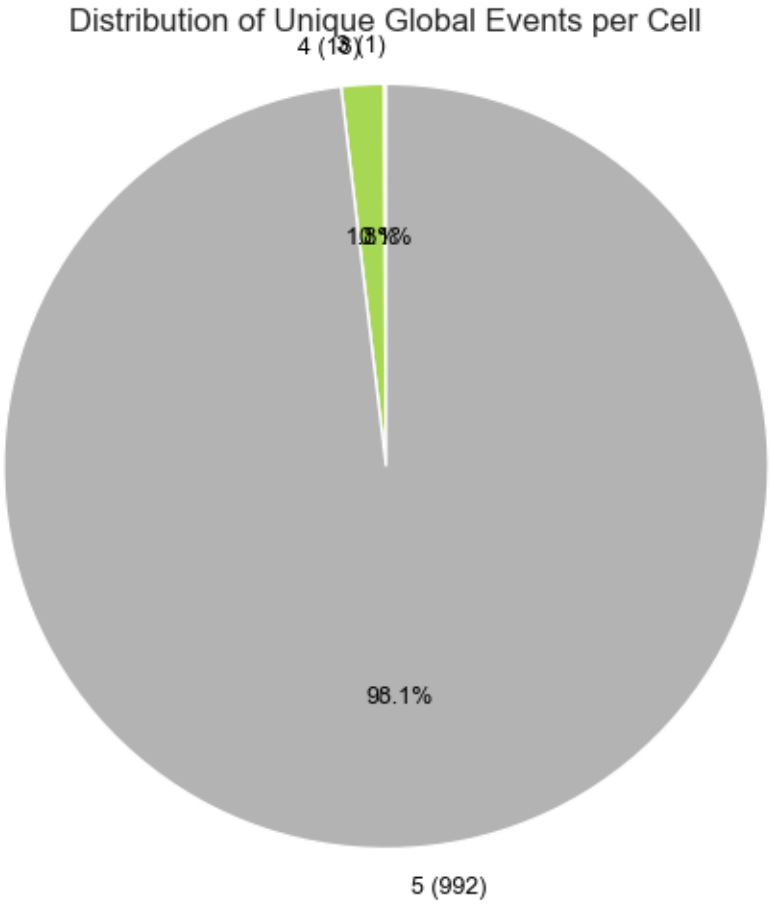

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



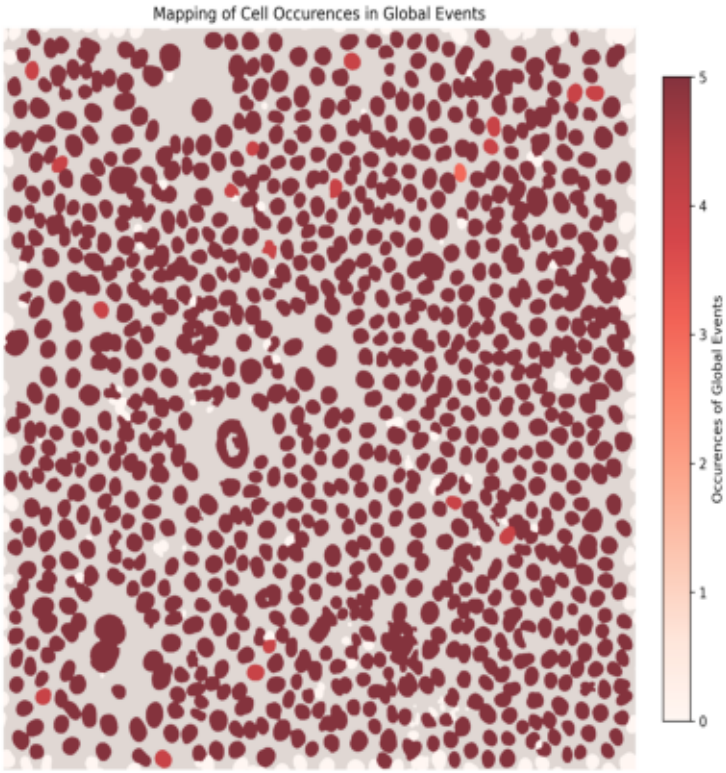

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
Event ID

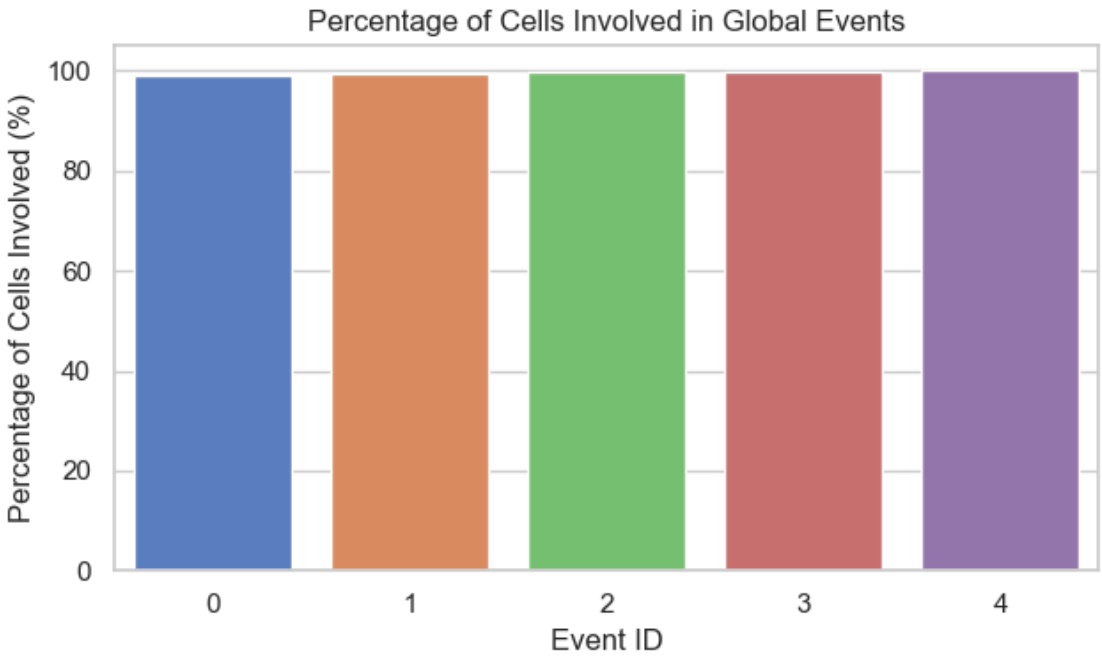
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250409_IS11




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

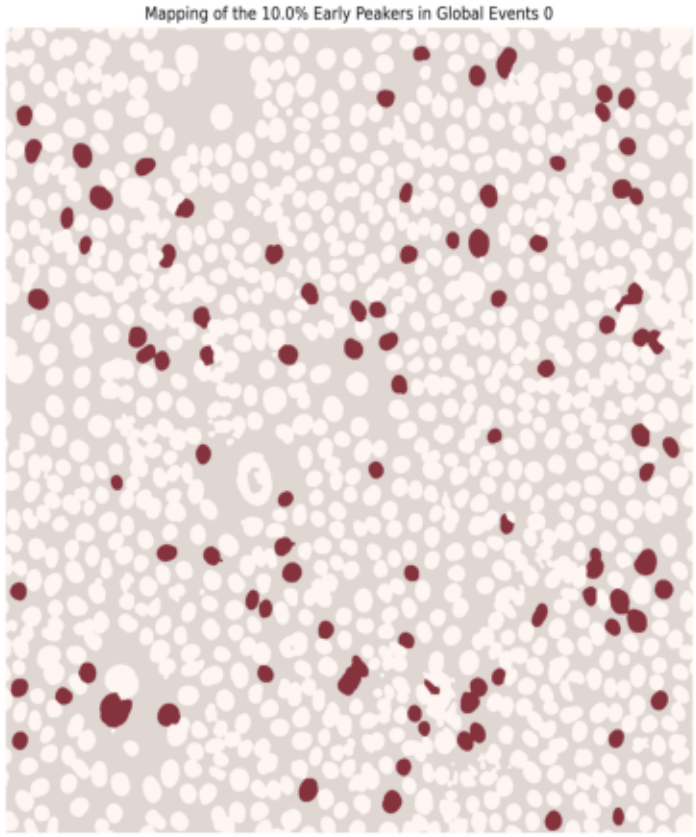


1.2.5 Inter-event interval analysis

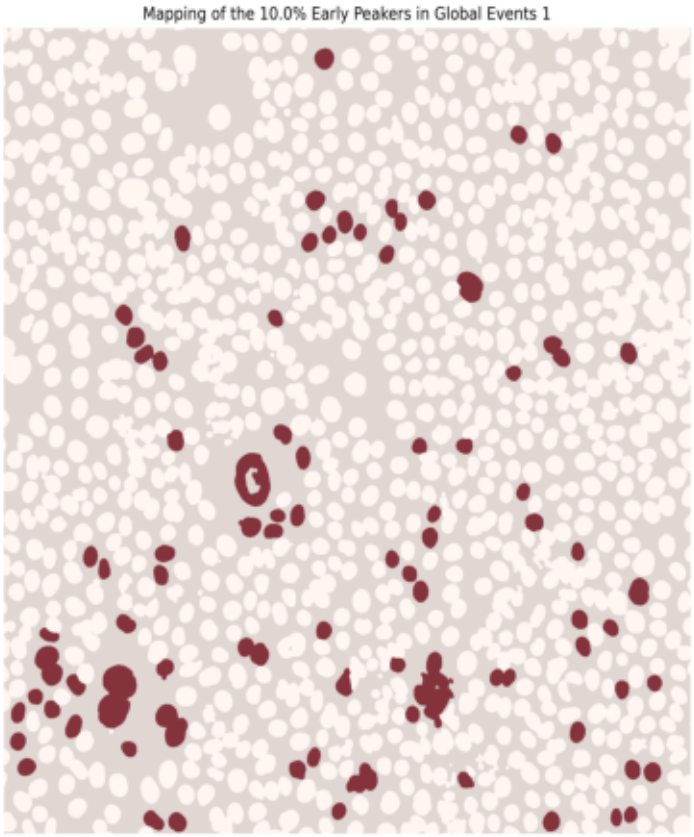
```
Intervals between global event peaks: [288.0, 309.0, 350.0, 377.0]
Estimated periodicity: 0.905
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.003 Hz
```

1.2.6 Early peakers in the events

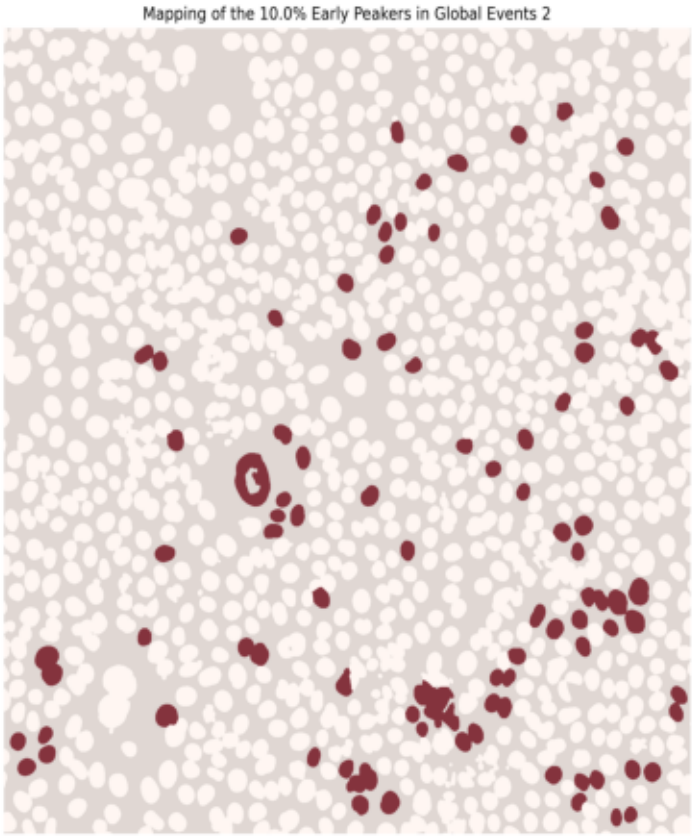
Cell Mapping with Early Peakers Overlay for event 0 - 20250409_IS11



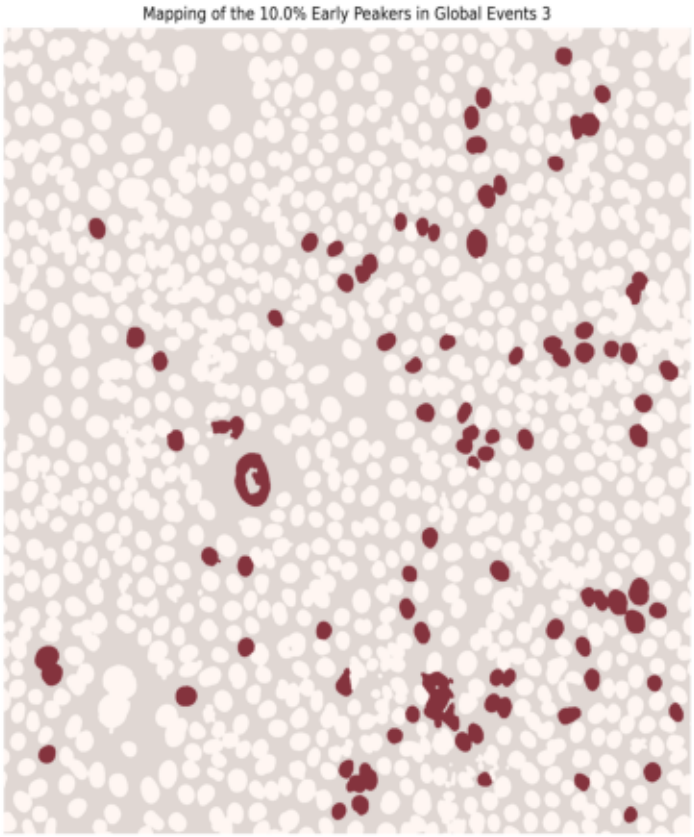
Cell Mapping with Early Peakers Overlay for event 1 - 20250409_IS11



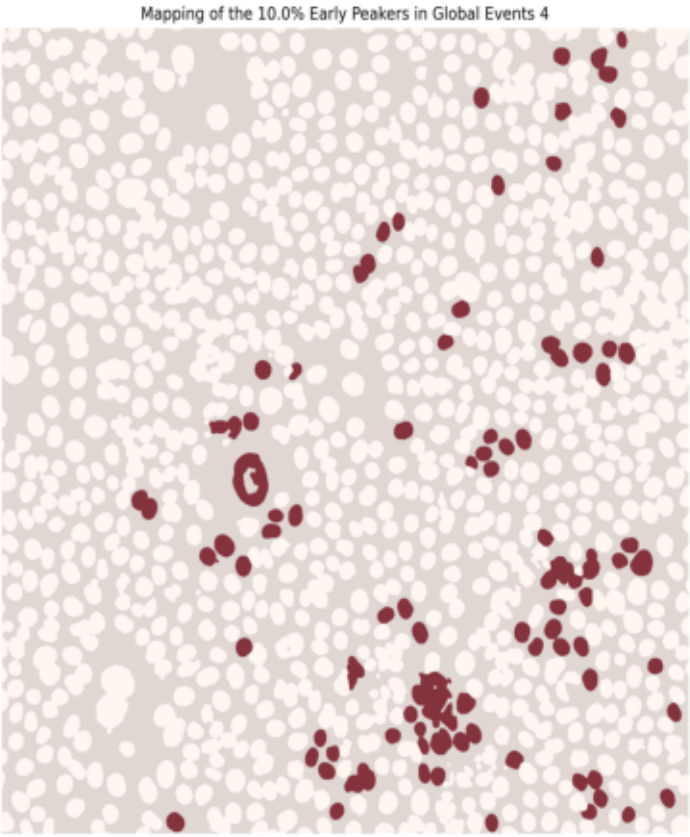
Cell Mapping with Early Peakers Overlay for event 2 - 20250409_IS11



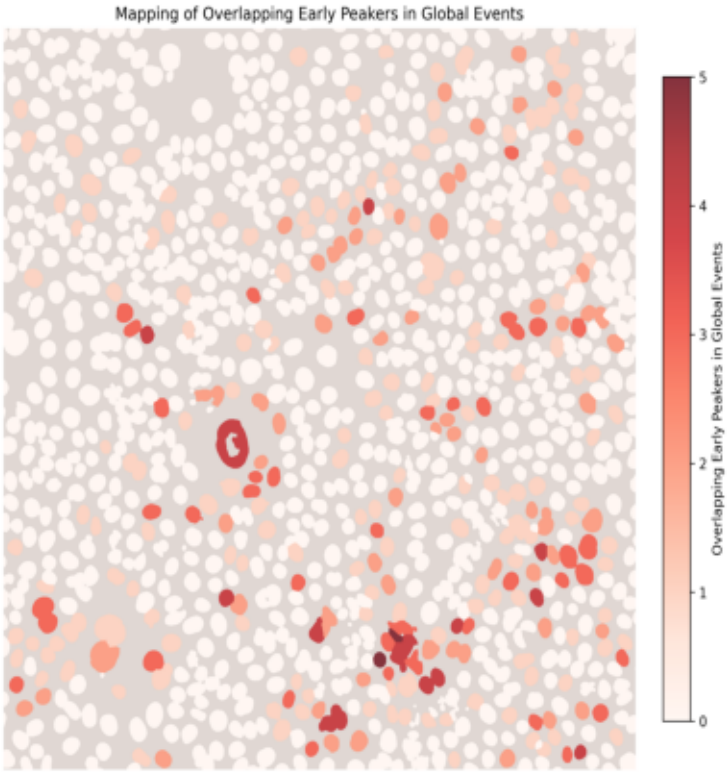
Cell Mapping with Early Peakers Overlay for event 3 - 20250409_IS11



Cell Mapping with Early Peakers Overlay for event 4 - 20250409_IS11

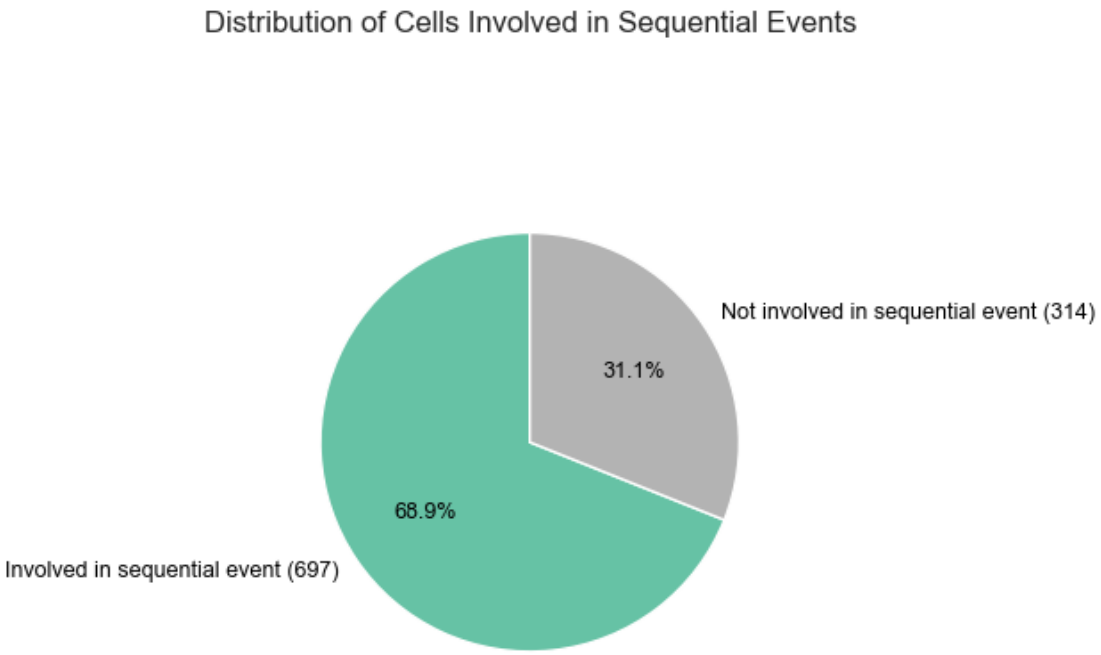


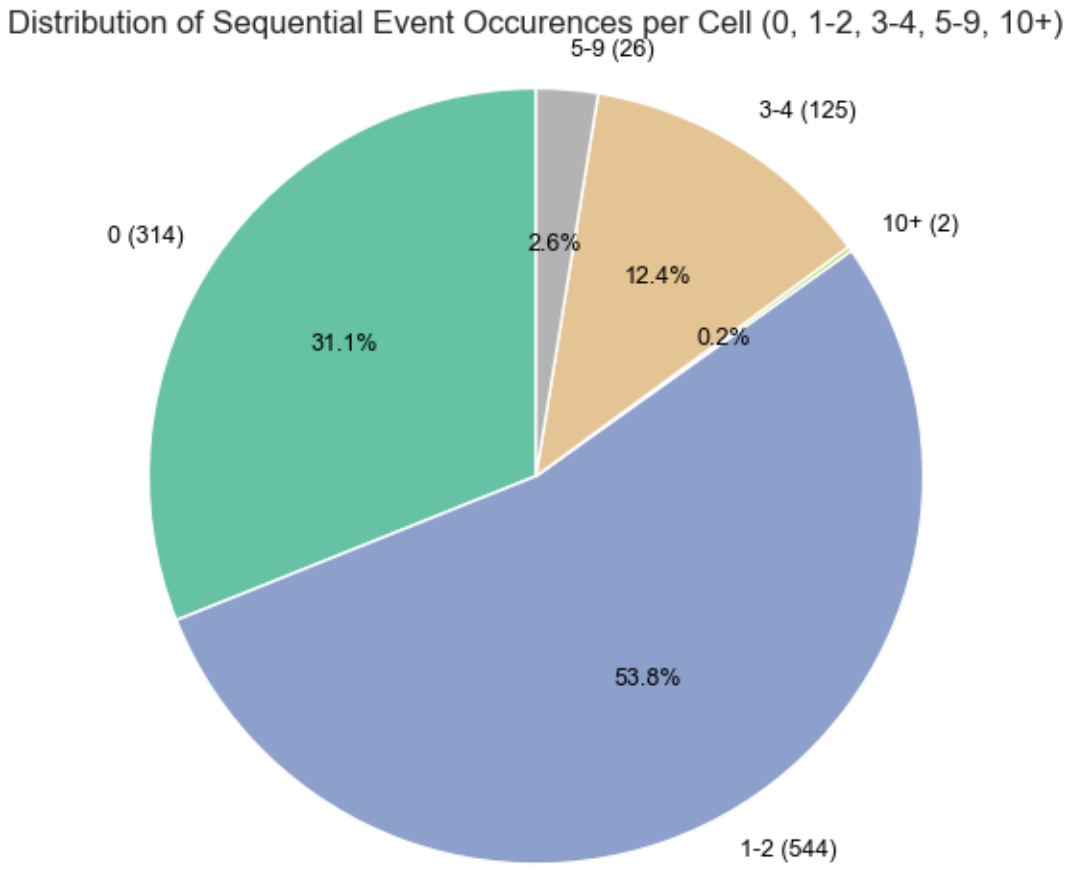
Cell Mapping with Occurences in Global Events Overlay - 20250409_IS11



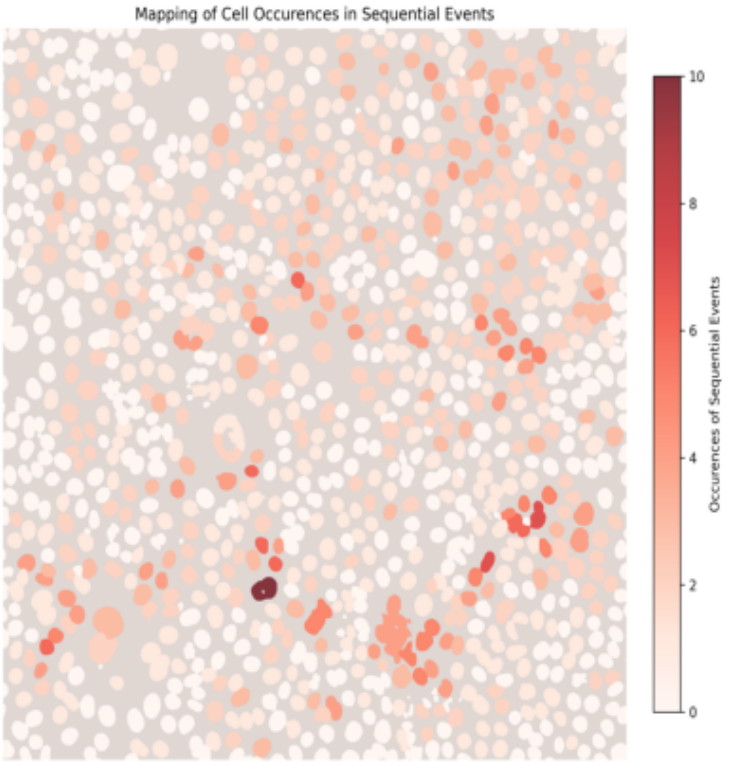
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

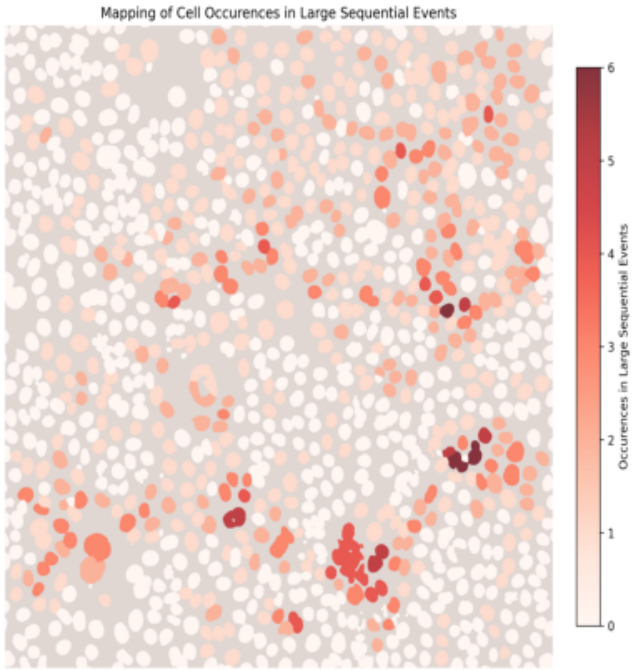



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (26)
3-4 (125)
10+ (2)
0 (314)
2.6%
12.4%
0.2%
31.1%
53.8%
1-2 (544)

Cell Mapping with Occurences in Sequential Events Overlay - 20250409_IS11

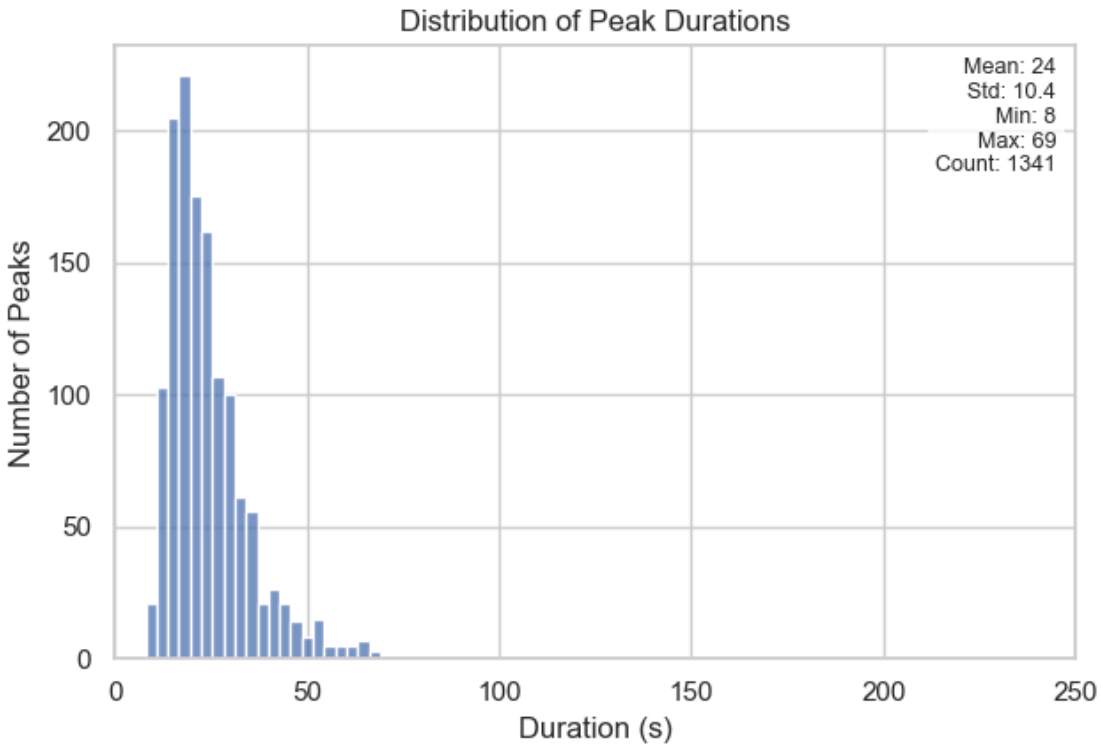


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250409_IS11

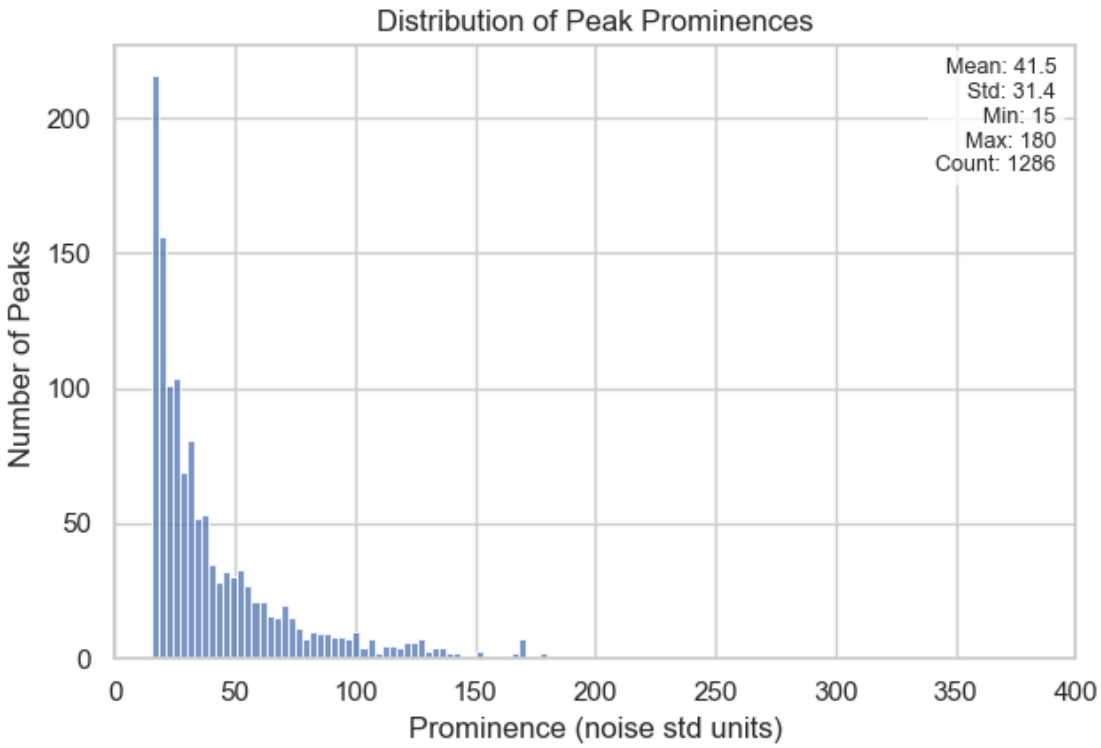


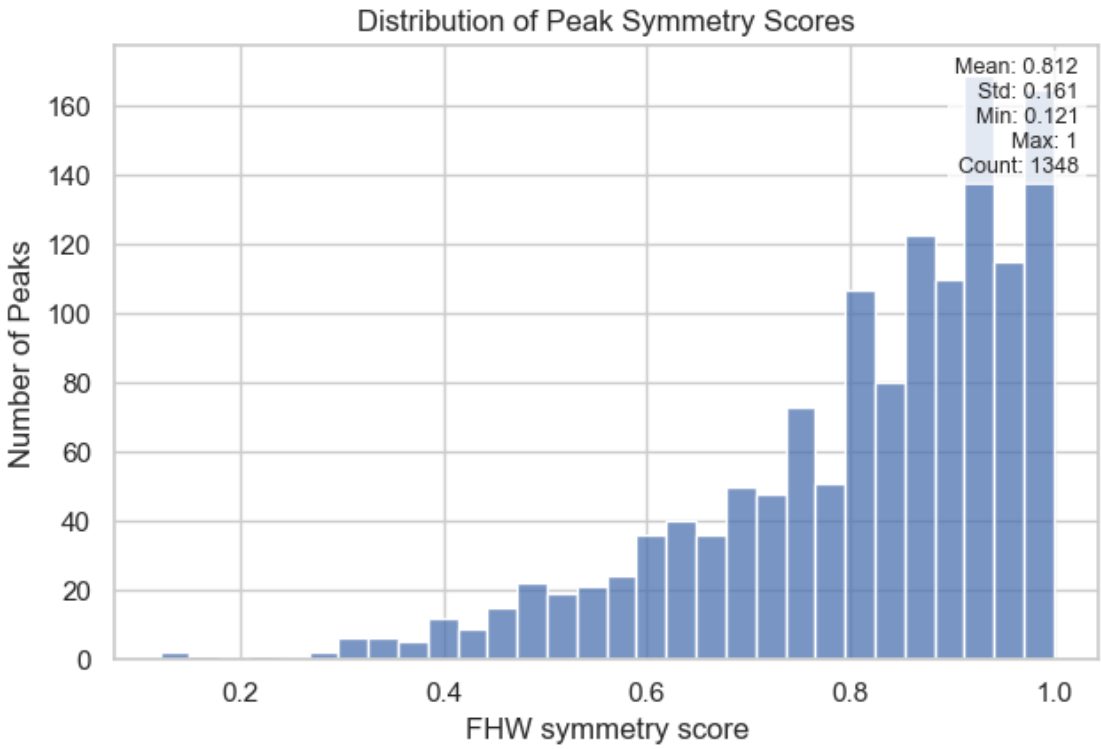
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:47:59] [INFO] calcium: plot_histogram: removed 7 outliers out of
1348 on 'Duration (s)' (lower=-1, upper=71)
```



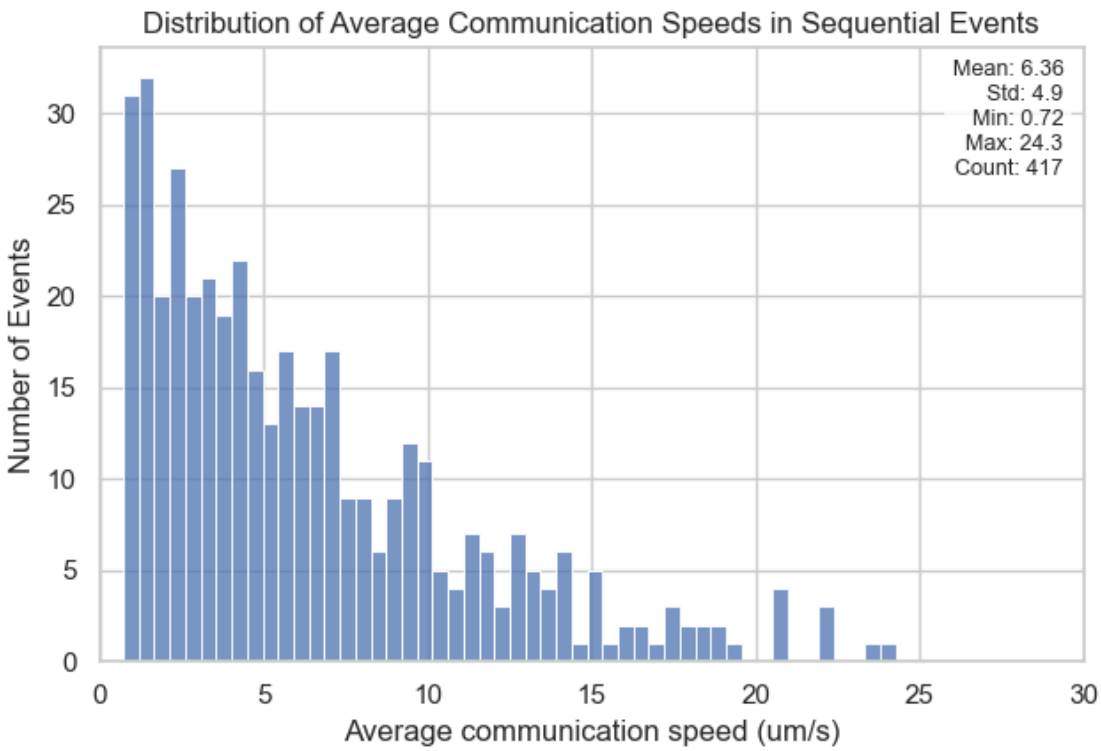

```
[2025-08-11 09:48:00] [INFO] calcium: plot_histogram: removed 62 outliers out of
1348 on 'Prominence (noise std units)' (lower=-33.688, upper=181.86)
```


Distribution of Peak Prominences
Mean: 41.5
Std: 31.4
Min: 15
Max: 180
Count: 1286
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

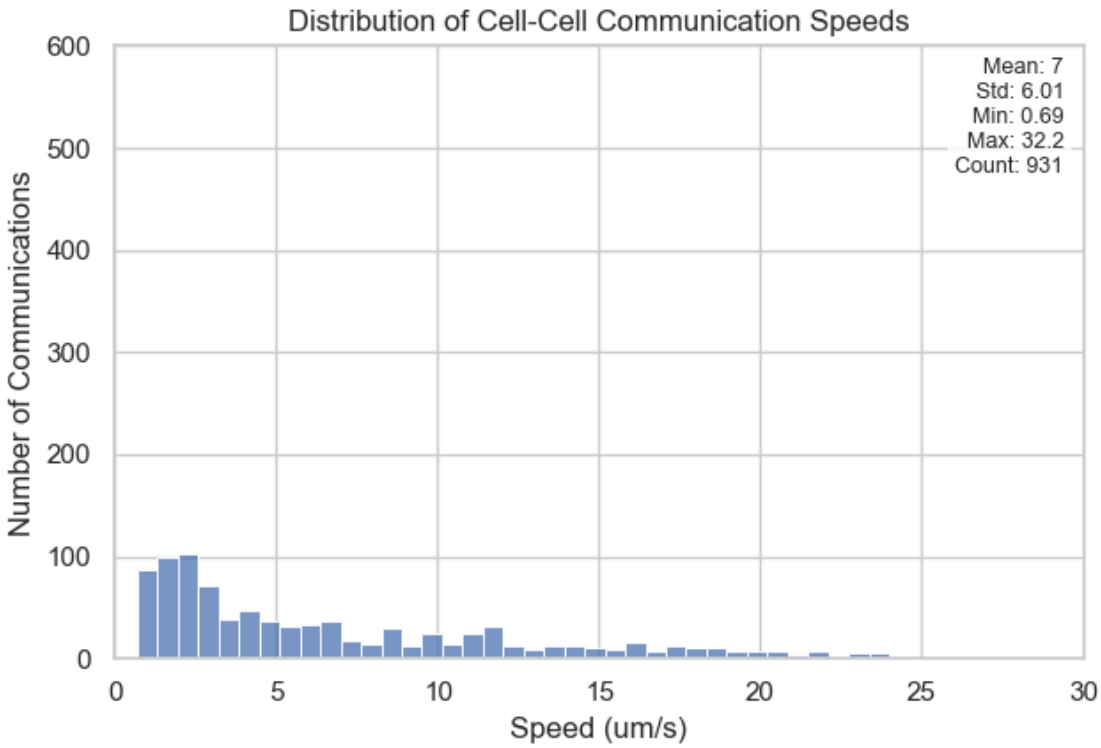

Distribution of Peak Symmetry Scores
Mean: 0.812
Std: 0.161
Min: 0.121
Max: 1
Count: 1348
Number of Peaks
0
20
40
60
80
100
120
140
160
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:48:00] [INFO] calcium: plot_histogram: removed 0 outliers out of
417 on 'Average communication speed (um/s)' (lower=-17.09, upper=28.69)
```

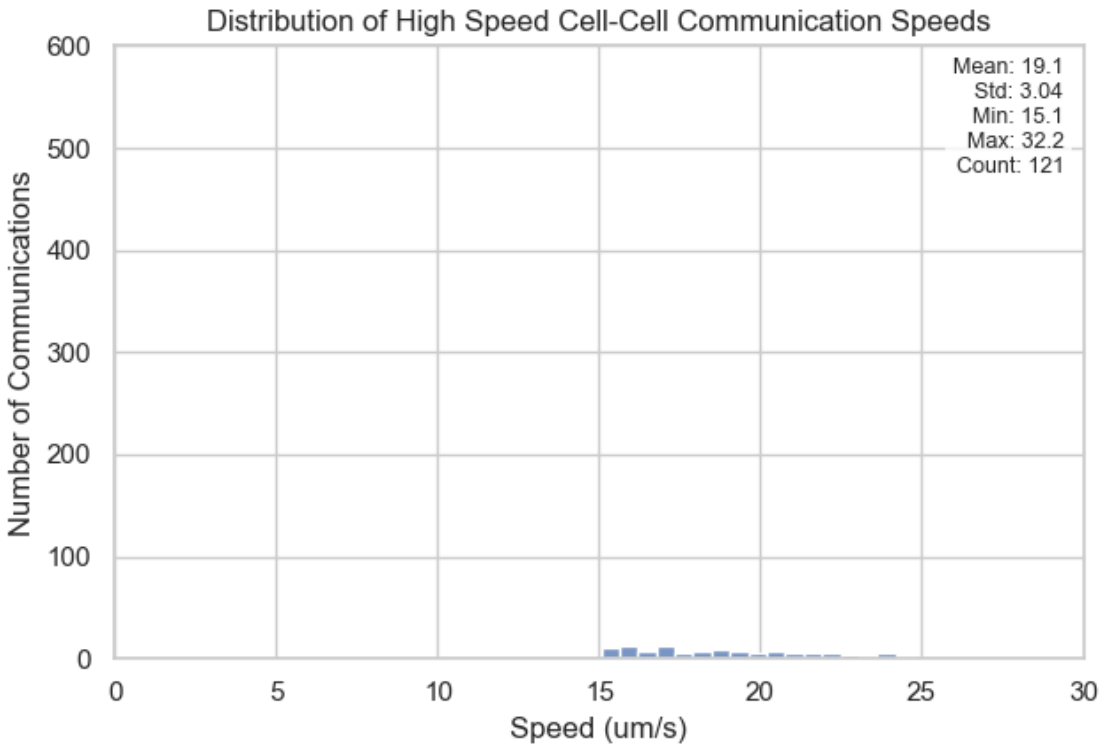



```
[2025-08-11 09:48:00] [INFO] calcium: plot_histogram: removed 0 outliers out of
931 on 'Speed (um/s)' (lower=-23.375, upper=36.3)
```

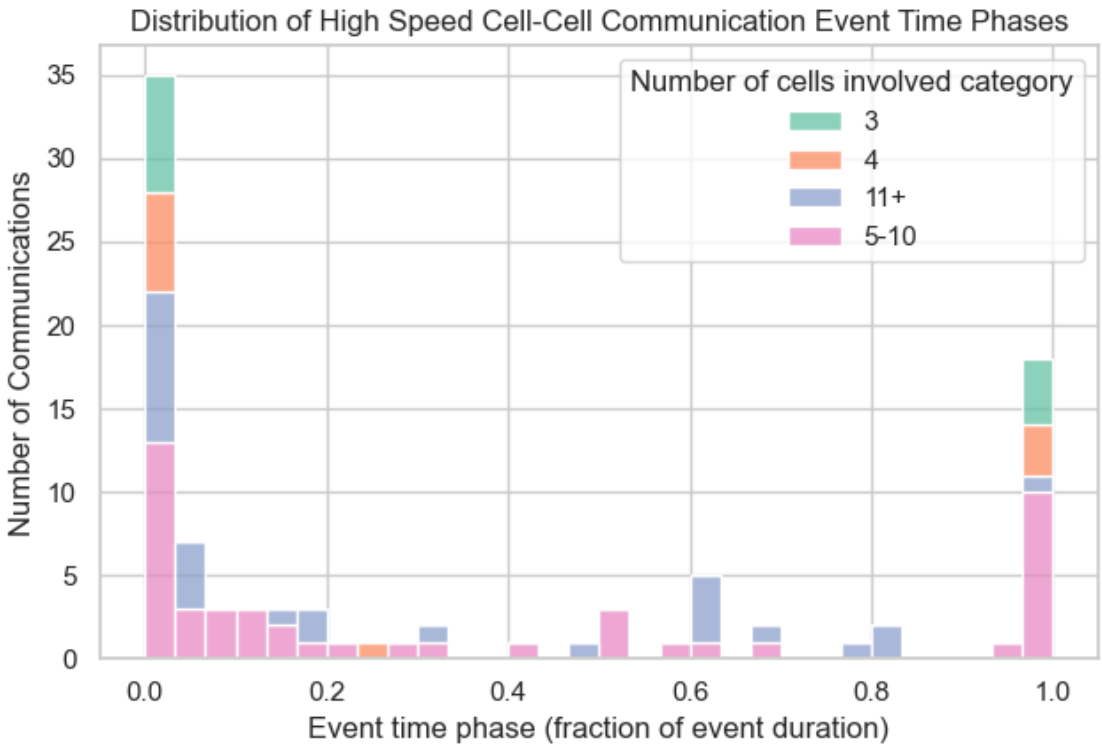


1.3.4 Double distribution in cell-cell communication speeds

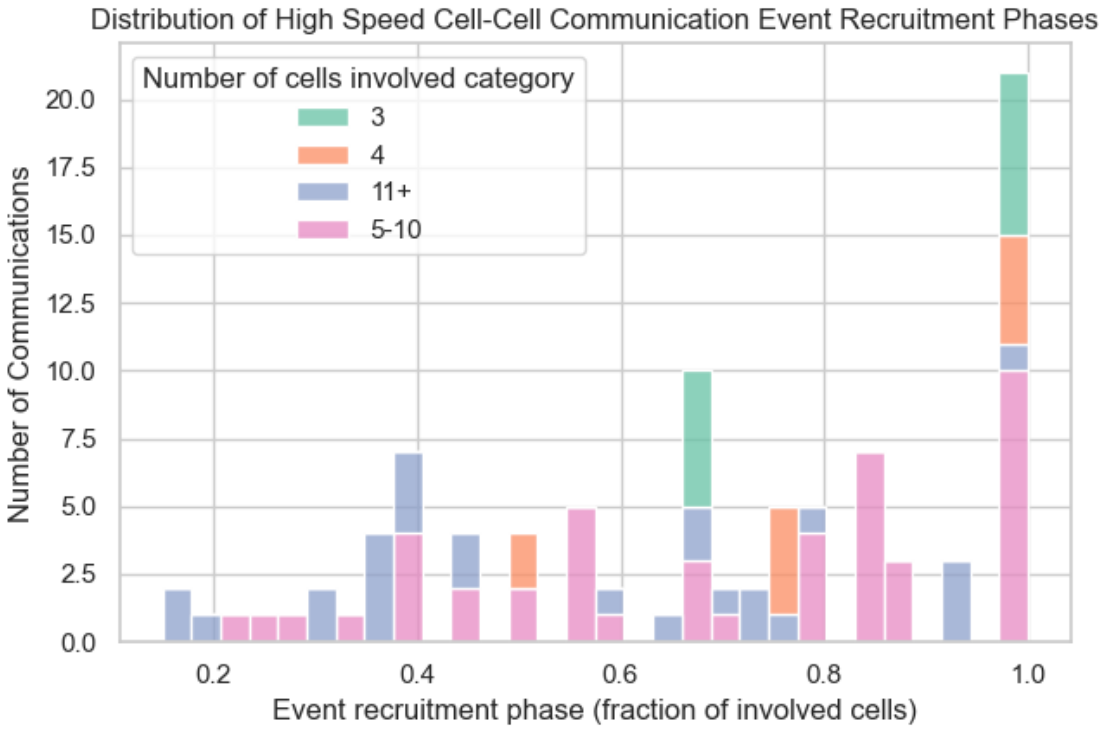
```
[2025-08-11 09:48:00] [INFO] calcium: plot_histogram: removed 0 outliers out of
121 on 'Speed (um/s)' (lower=3.67, upper=33.84)
```



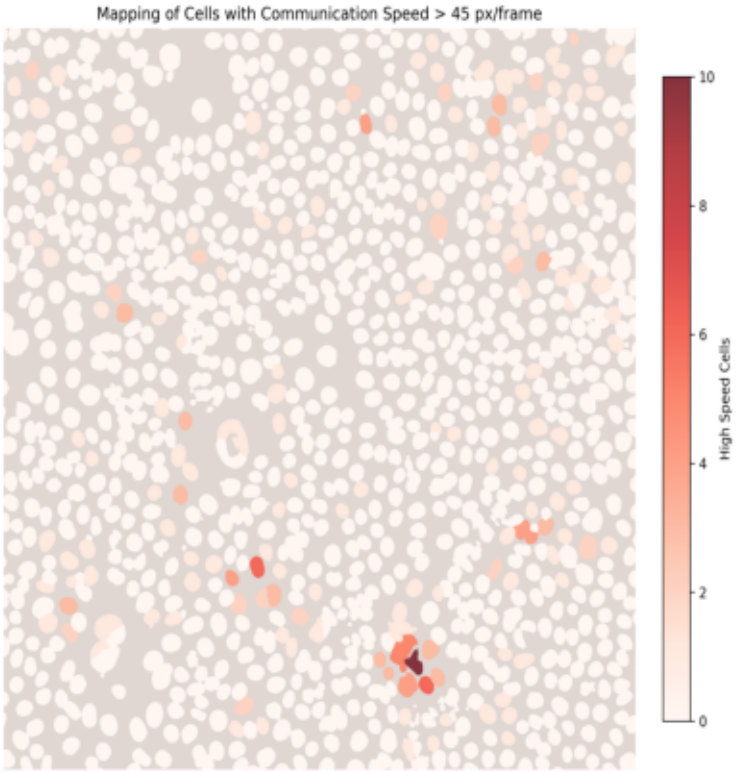

```
[2025-08-11 09:48:01] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 94 on 'Event time phase (fraction of event duration)'
(lower=-1.9725, upper=2.63)
```



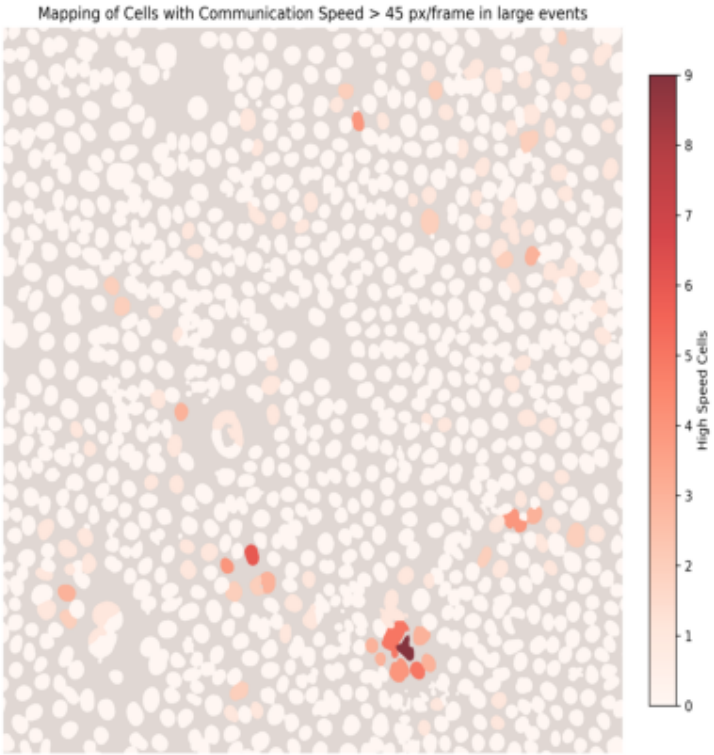

```
[2025-08-11 09:48:01] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 94 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.865, upper=2.2325)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
3
4
11+
5-10
Number of Communications
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
0.0
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

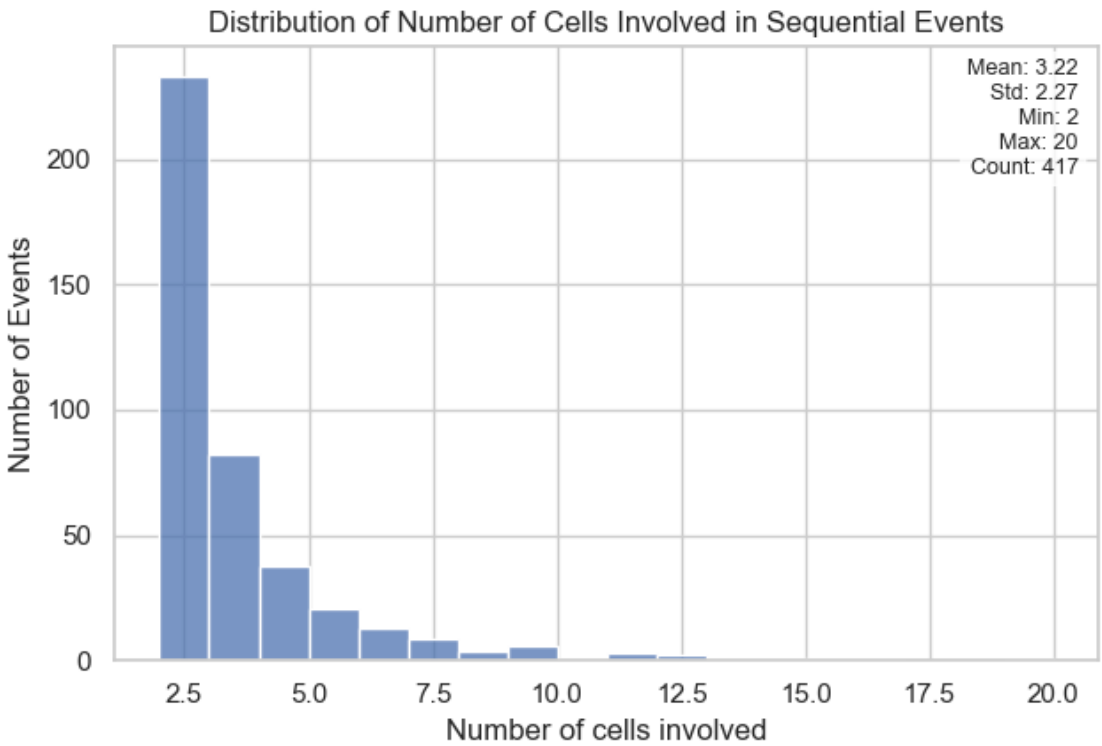
Cell Mapping with High Speed Cells Overlay - 20250409_IS11



Cell Mapping with High Speed Cells in Large Events Overlay - 20250409_IS11

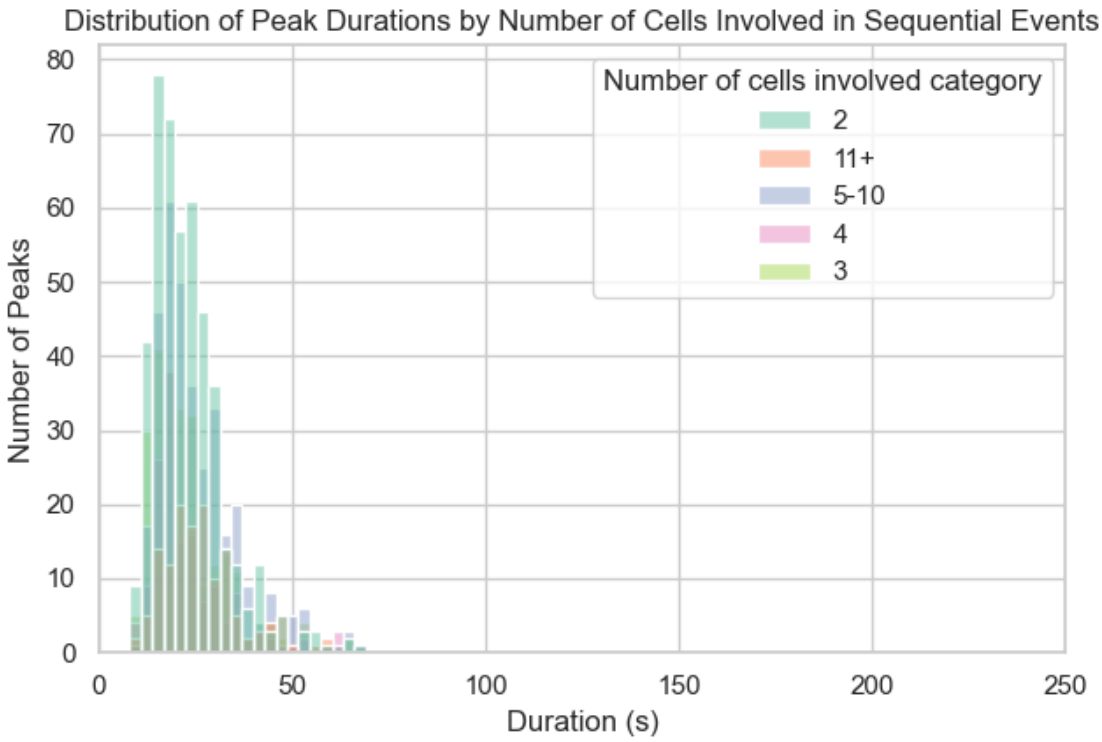


1.3.5 Number of cells involved per sequential events

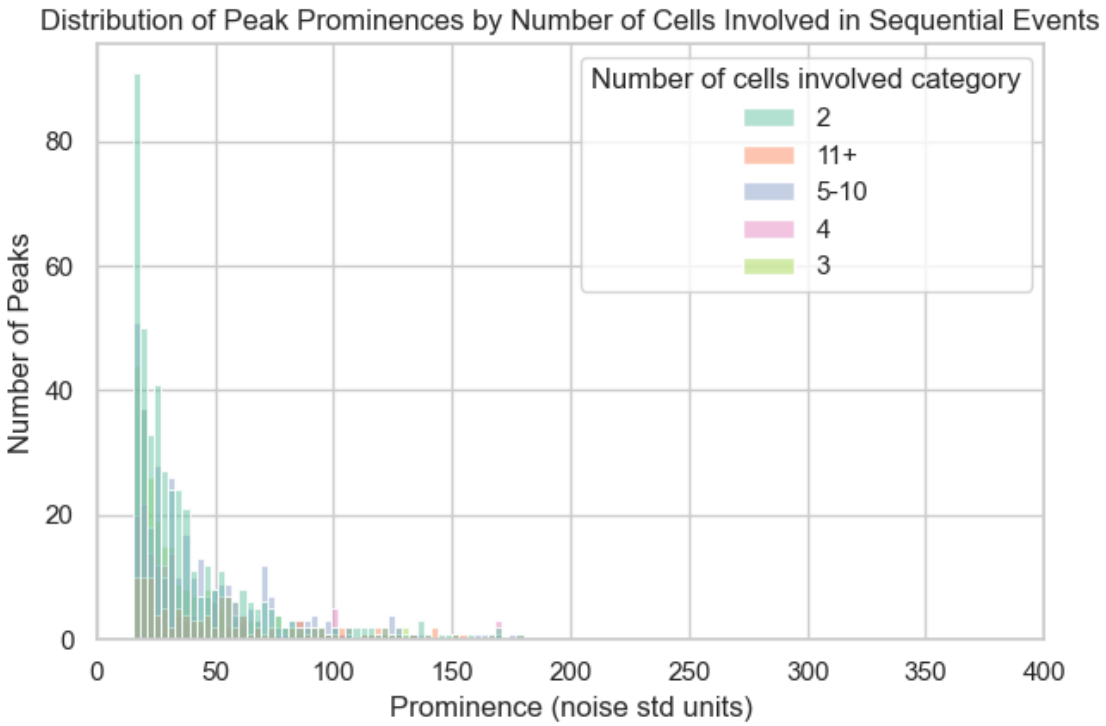


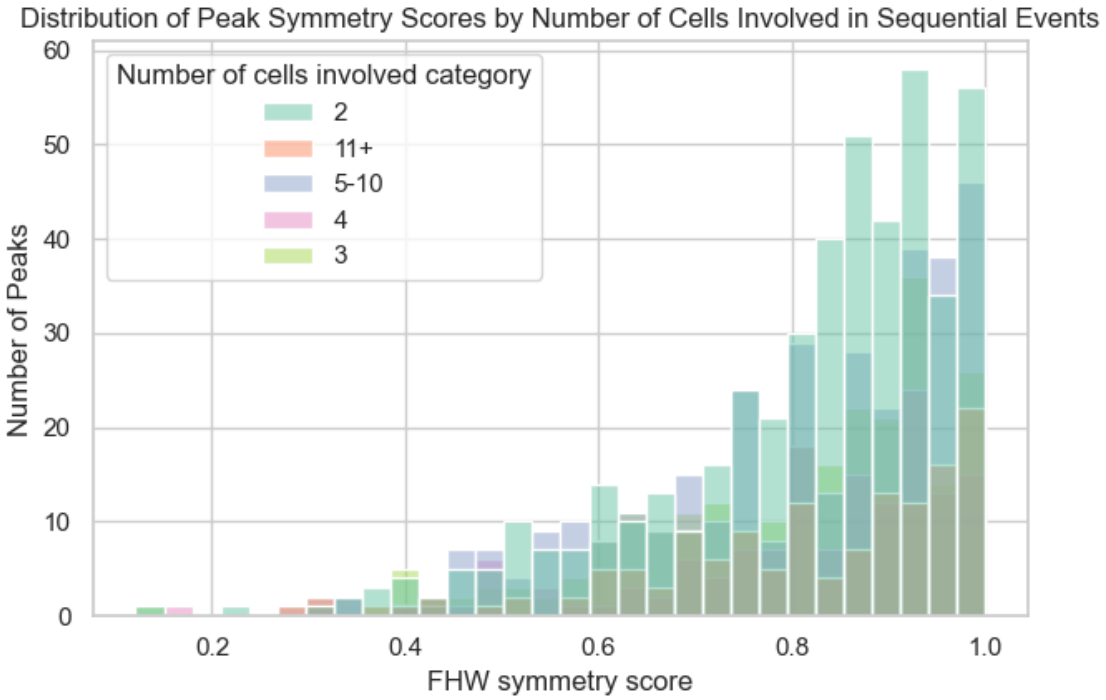
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:48:03] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 1348 on 'Duration (s)' (lower=-1, upper=71)
```



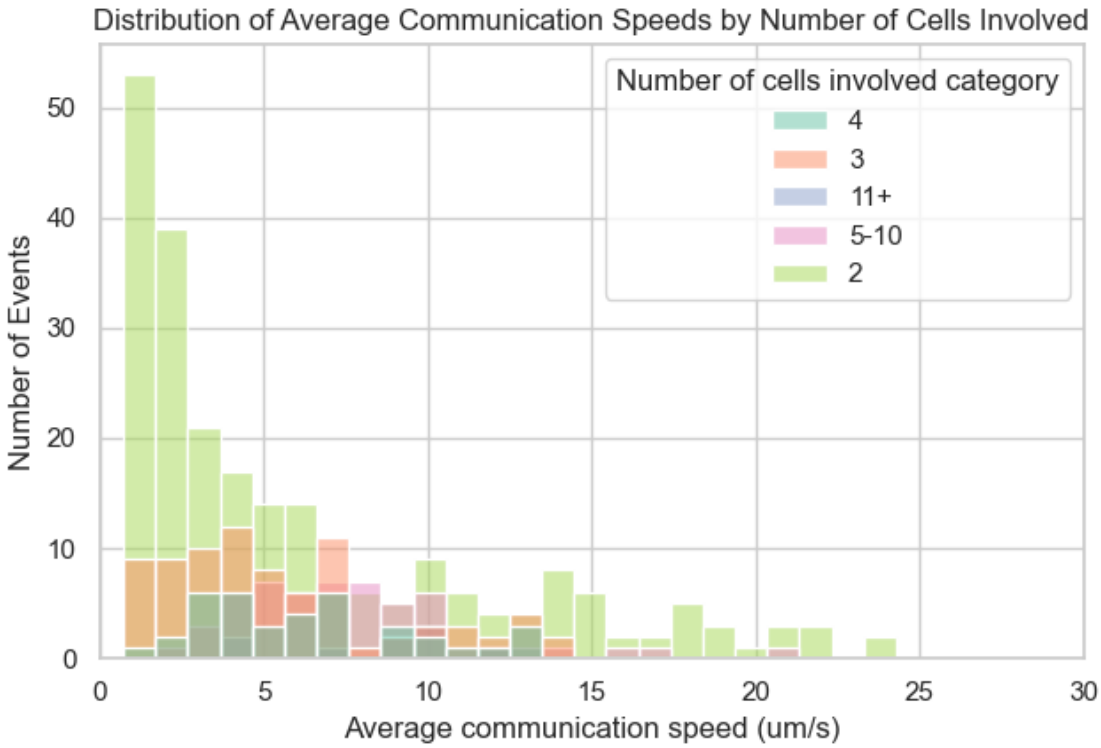

```
[2025-08-11 09:48:03] [INFO] calcium: plot_histogram_by_group: removed 62
outliers out of 1348 on 'Prominence (noise std units)' (lower=-33.688,
upper=181.86)
```



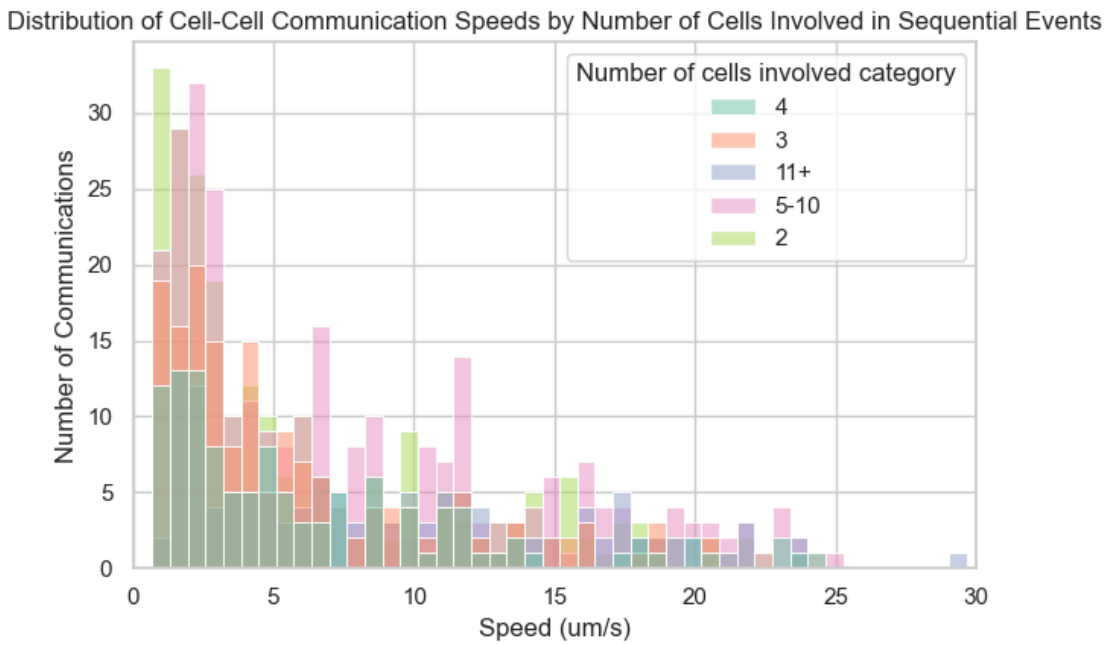



```
[2025-08-11 09:48:04] [INFO] calcium: plot_histogram_by_group: removed 0
```

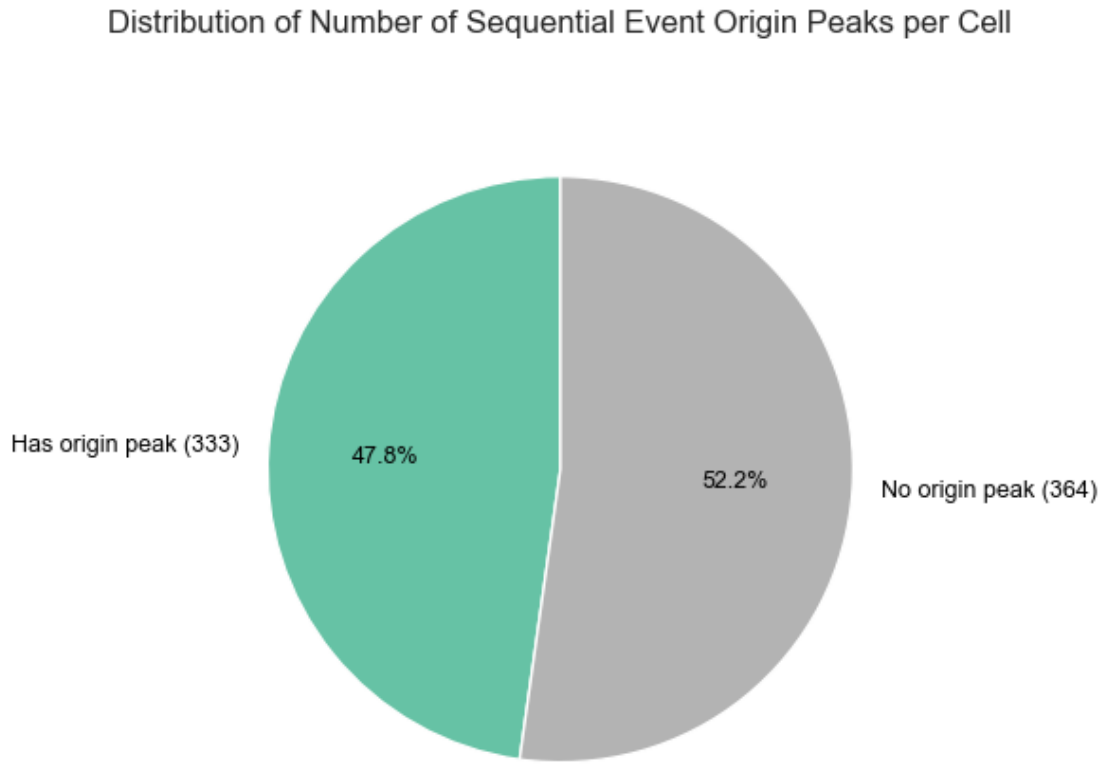
```
outliers out of 417 on 'Average communication speed (um/s)' (lower=-17.09,
upper=28.69)
```

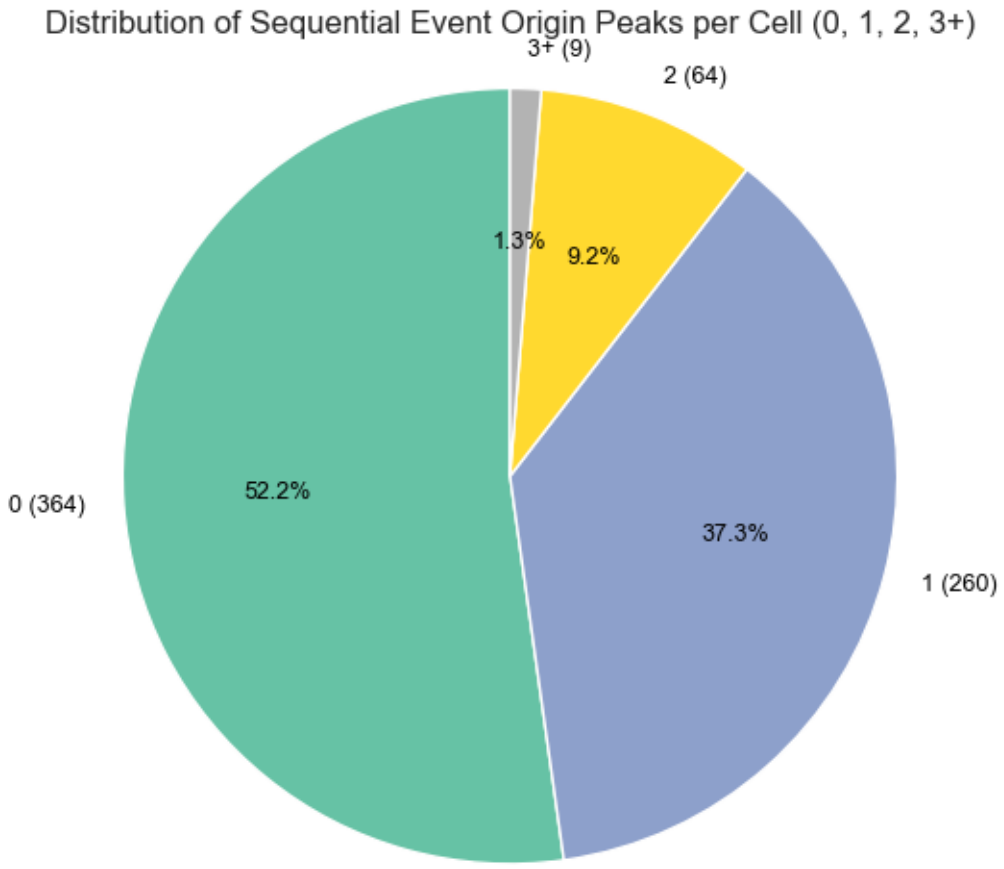



```
[2025-08-11 09:48:04] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 931 on 'Speed (um/s)' (lower=-23.375, upper=36.3)
```

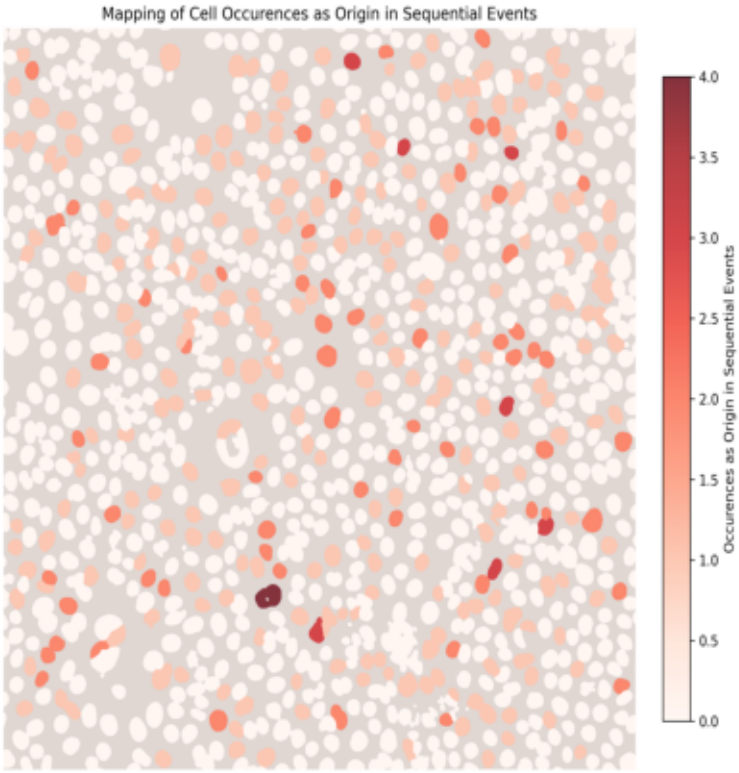

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
4
3
11+
5-10
2
Number of Communications
Speed (um/s)
0
5
10
15
20
25
30

1.3.7 Cells occurences as origin in sequential events

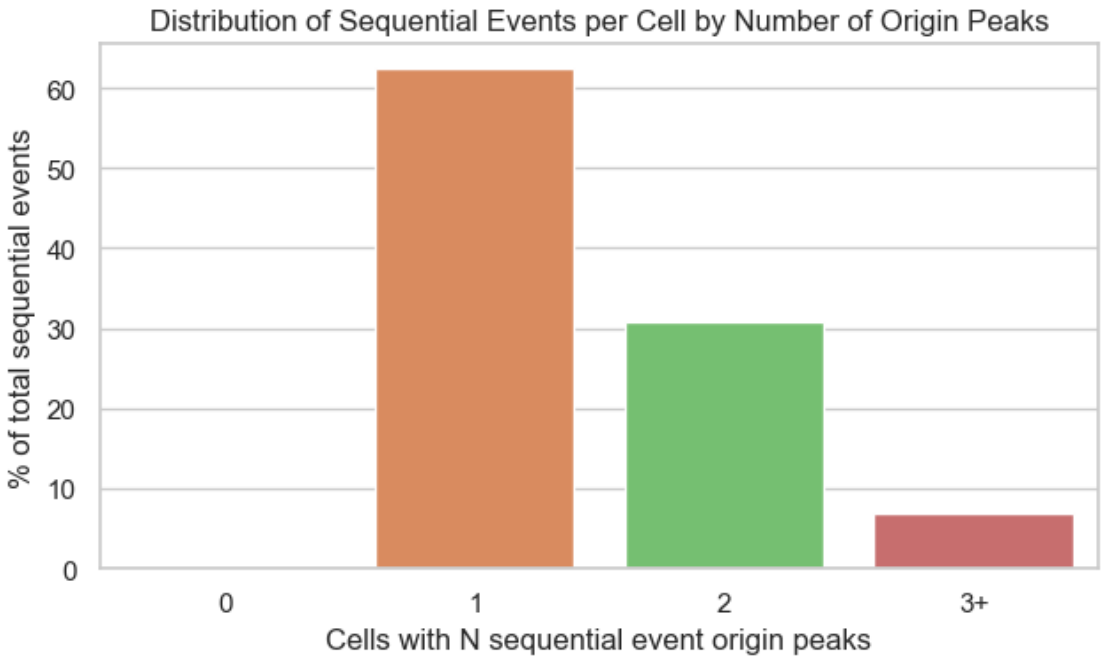



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (9)
2 (64)
1.3%
9.2%
0 (364)
52.2%
37.3%
1 (260)

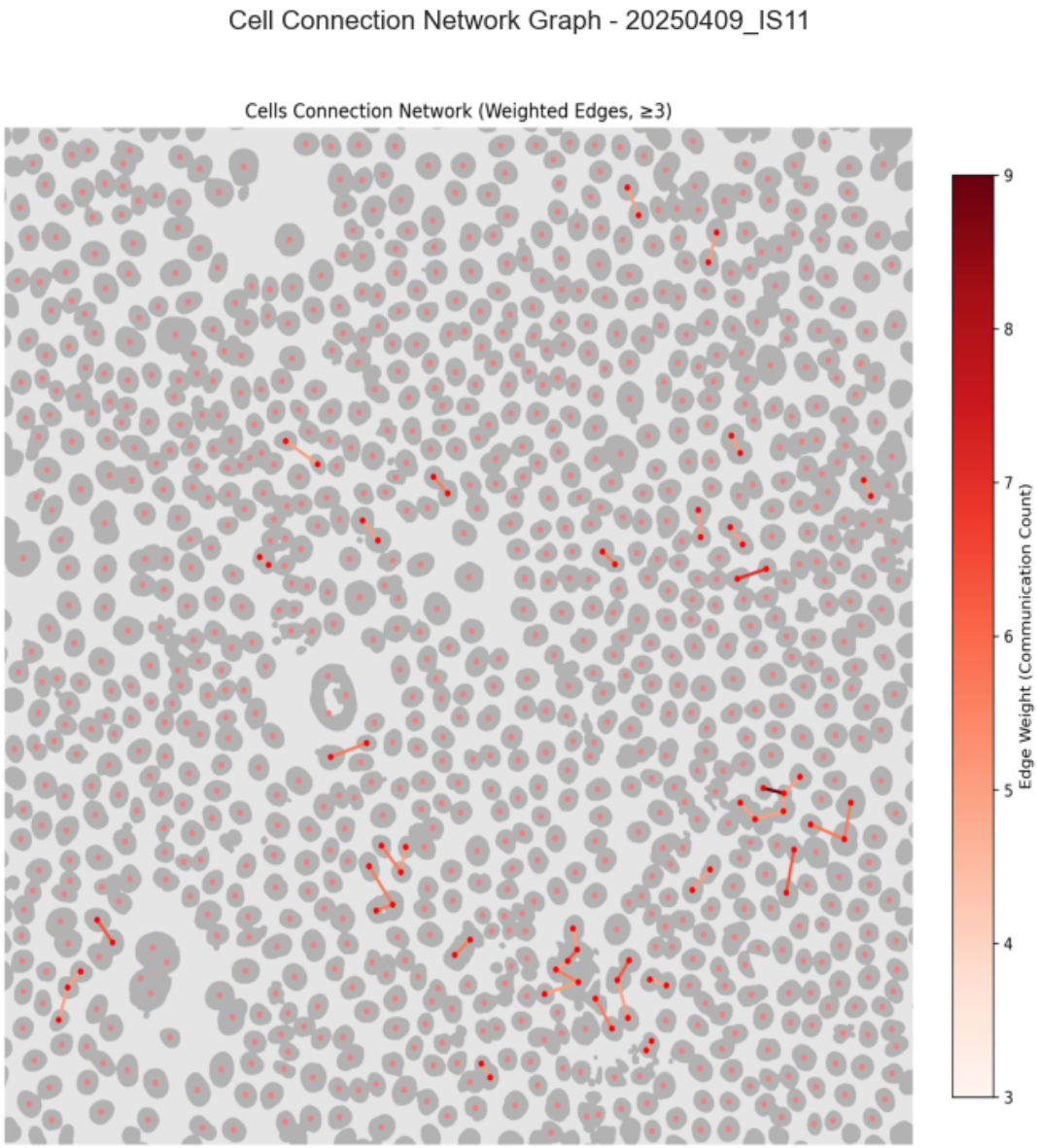
Cell Mapping with Origin Peaks Overlay - 20250409_IS11




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

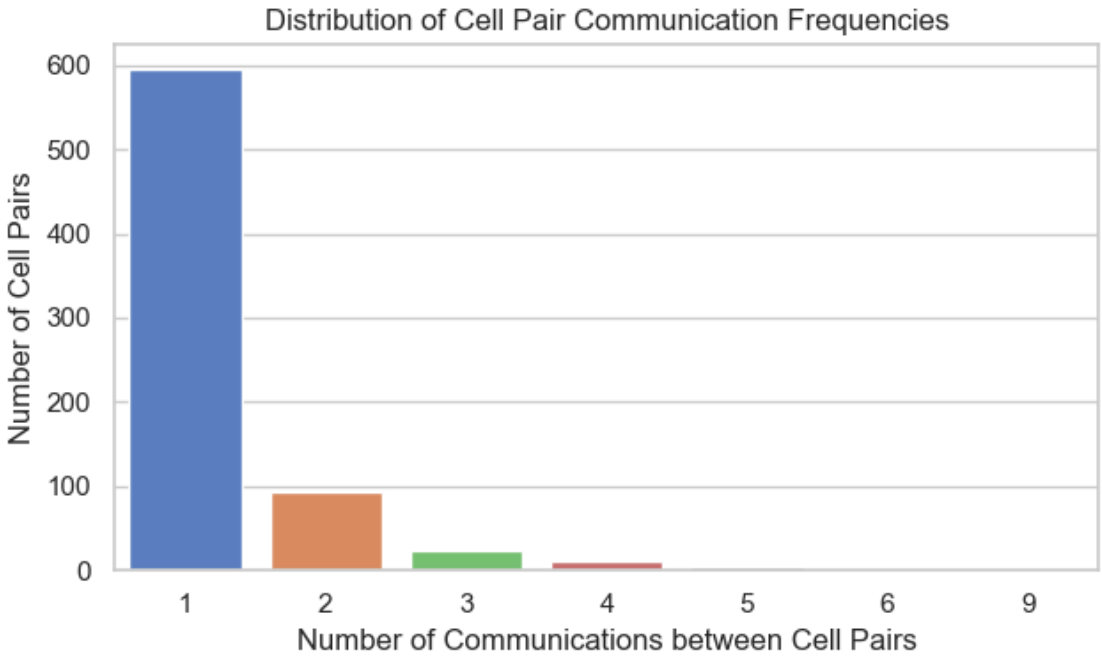

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
60
50
40
30
20
10
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



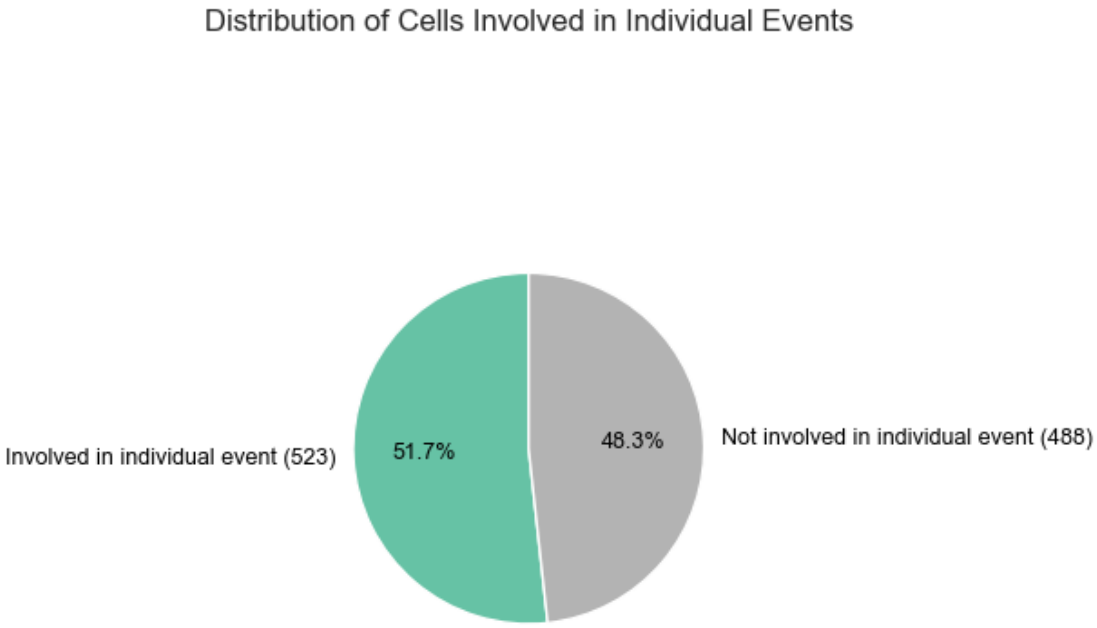

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

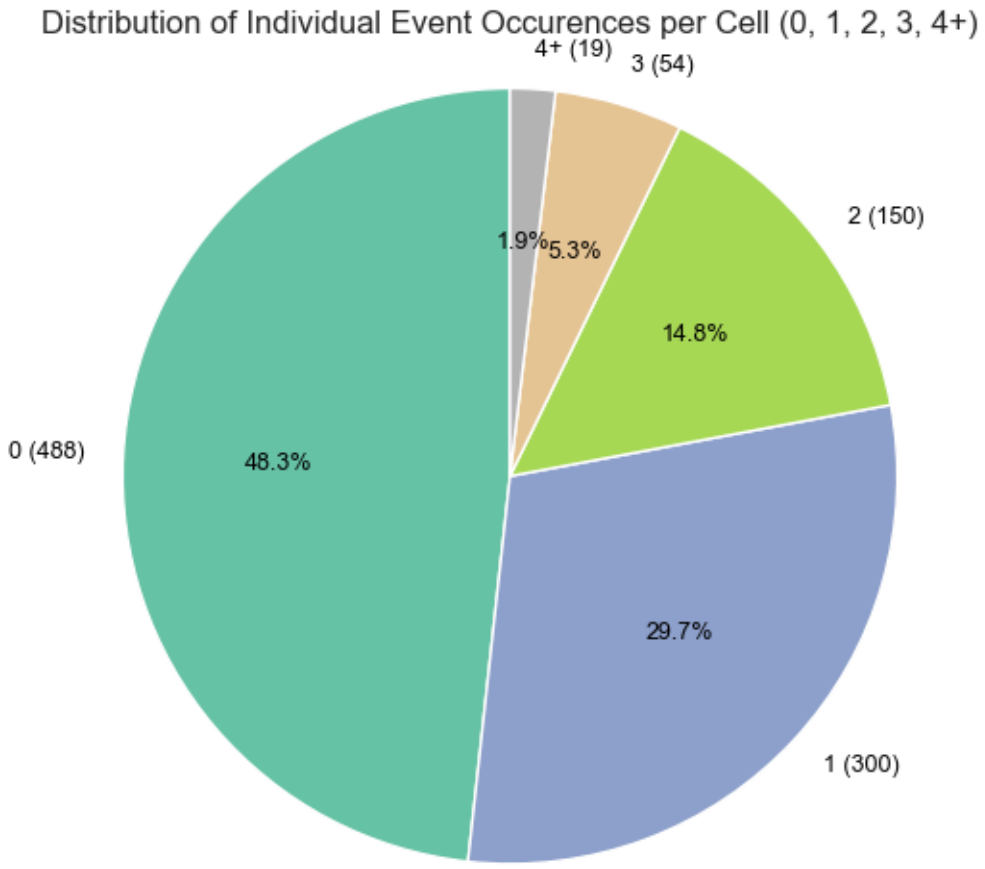
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
600
500
400
300
200
100
0
1
2
3
4
5
6
9
Number of Communications between Cell Pairs

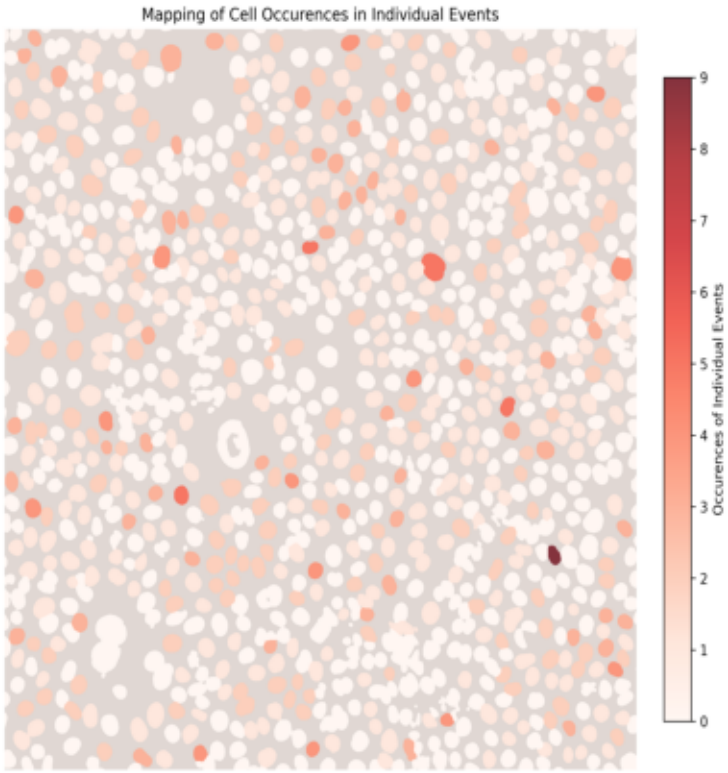
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



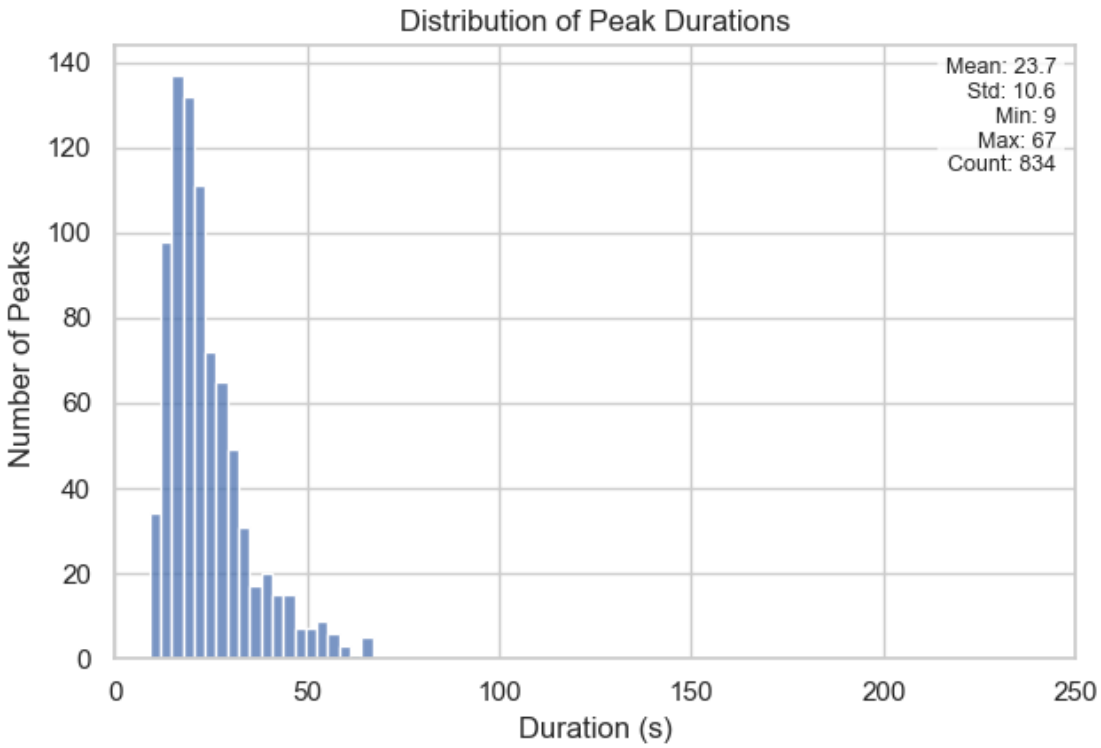

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (19)
3 (54)
2 (150)
1.9%
5.3%
14.8%
0 (488)
48.3%
29.7%
1 (300)

Cell Mapping with Occurences in Individual Events Overlay - 20250409_IS11

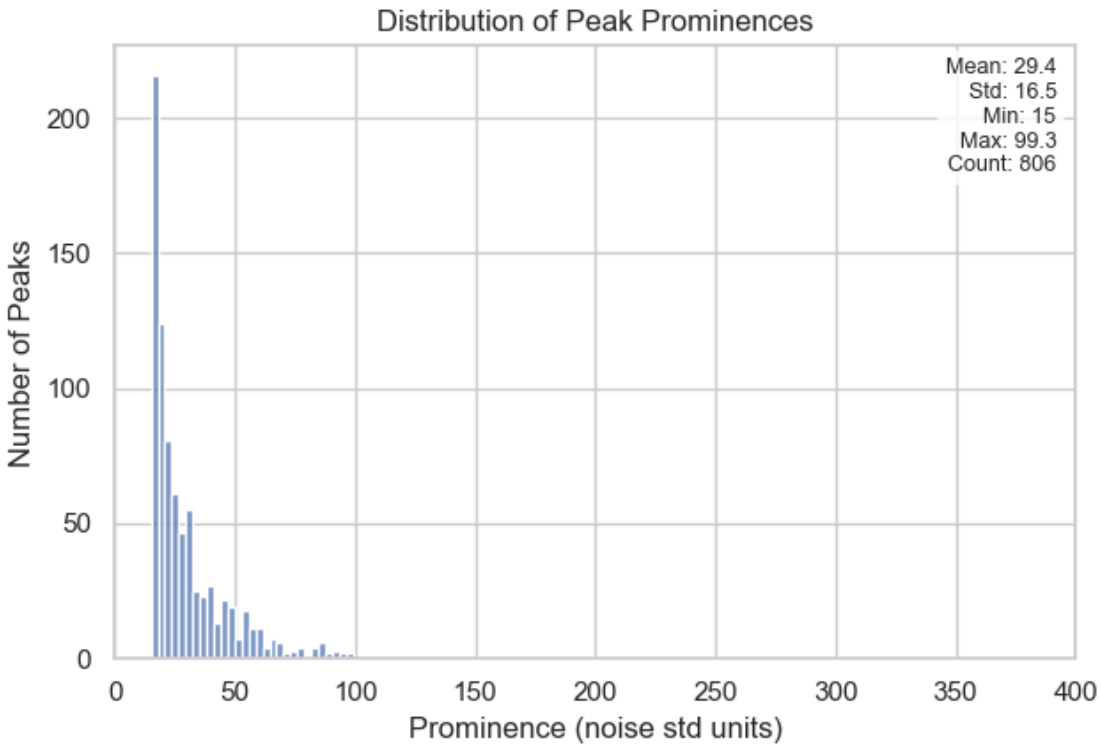


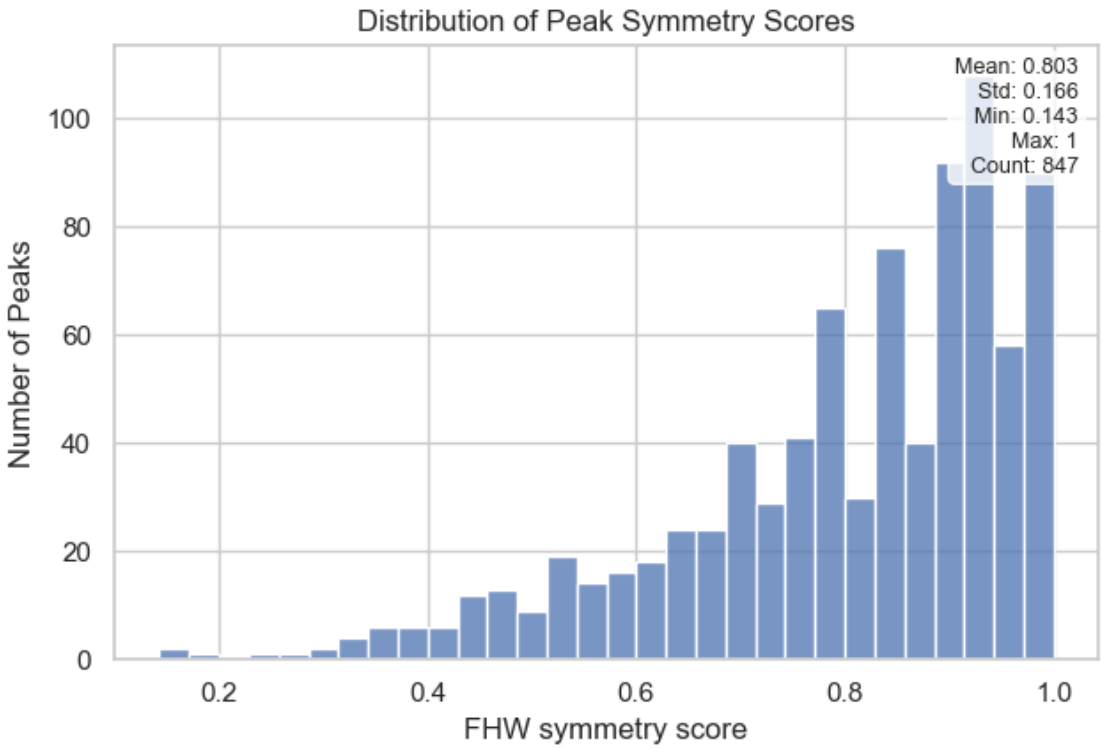
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:48:08] [INFO] calcium: plot_histogram: removed 13 outliers out of
847 on 'Duration (s)' (lower=-23, upper=68)
```

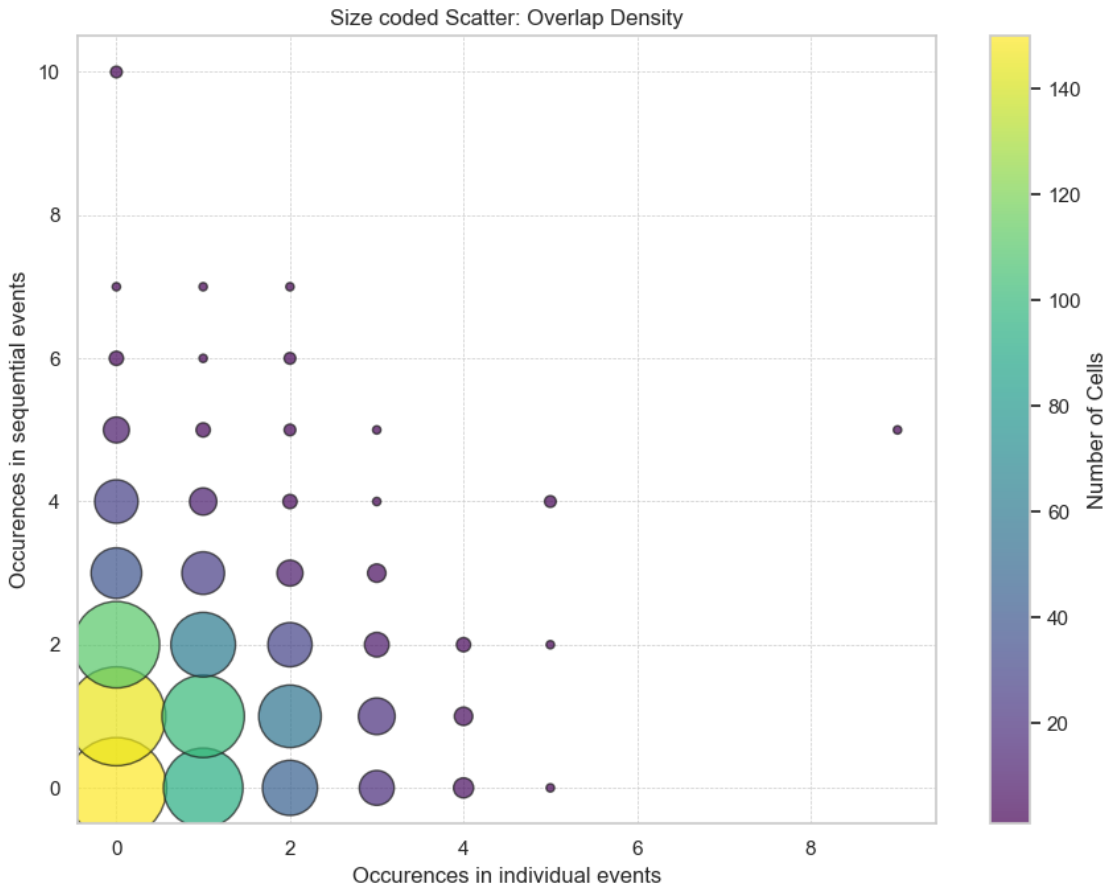



```
[2025-08-11 09:48:08] [INFO] calcium: plot_histogram: removed 41 outliers out of
847 on 'Prominence (noise std units)' (lower=-43.75, upper=100.1)
```

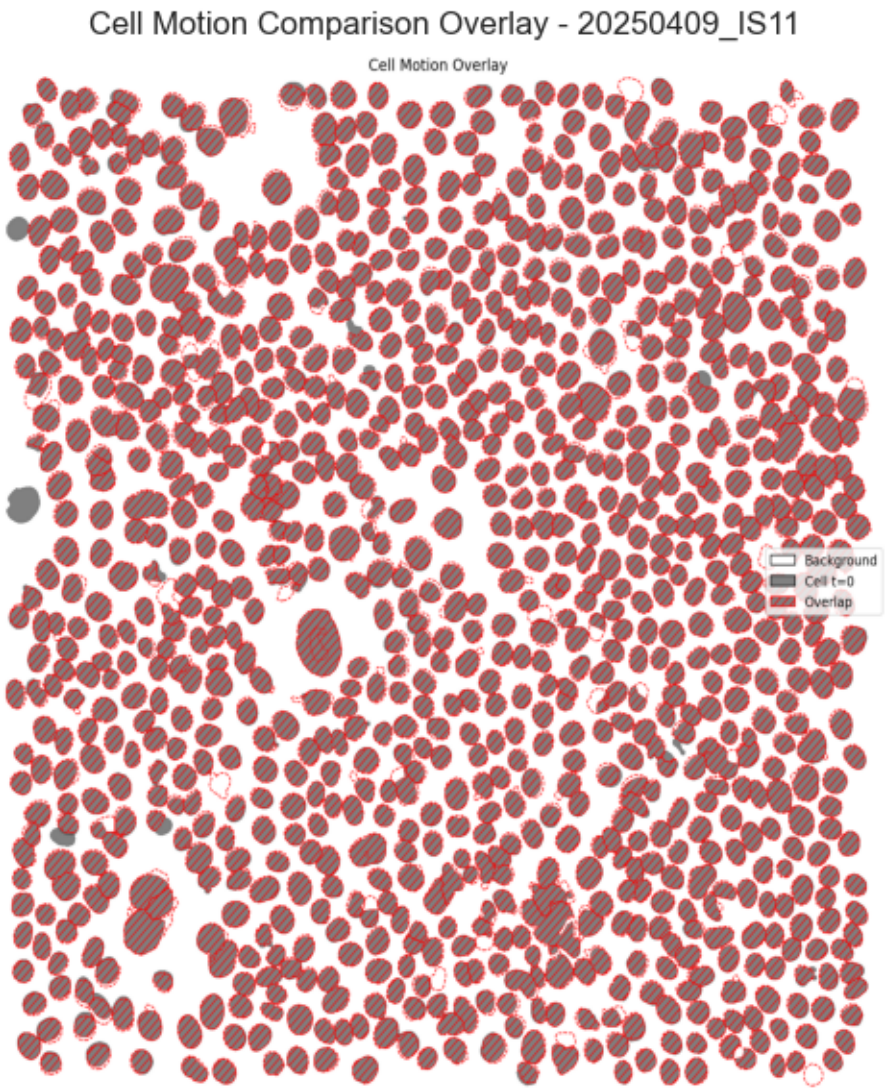

Distribution of Peak Prominences
Mean: 29.4
Std: 16.5
Min: 15
Max: 99.3
Count: 806
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.803
Std: 0.166
Min: 0.143
Max: 1
Count: 847
Number of Peaks
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 1011
- Hoechst image taken at t=1801: 1007
- Number of cells difference: absolute 4, relative 0.40%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1078456
- Pixels segmented as cell at t=1801: 1126020
- Overlapping pixels between t=0 and t=1801: 1020007(92.54% of total)
- Pixels exclusive to t=0: 58449 (5.42% of total)
- Pixels exclusive to t=1801: 106013 (9.41% of total)
```

executed

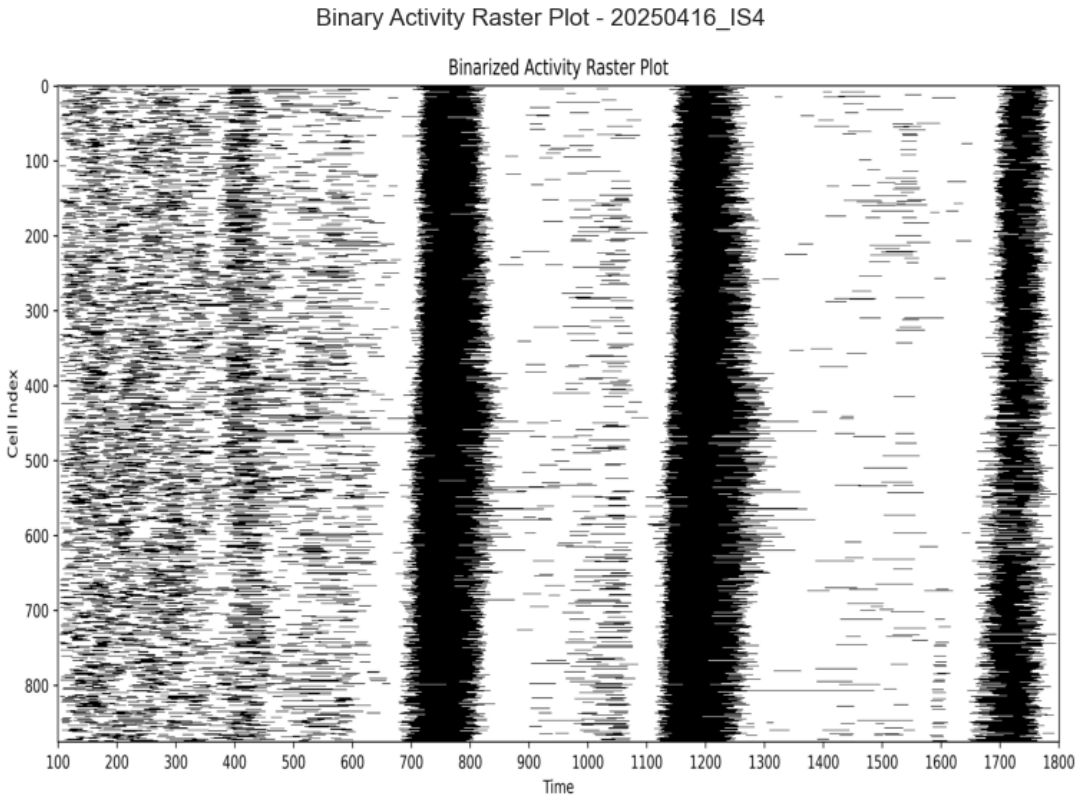
August 11, 2025

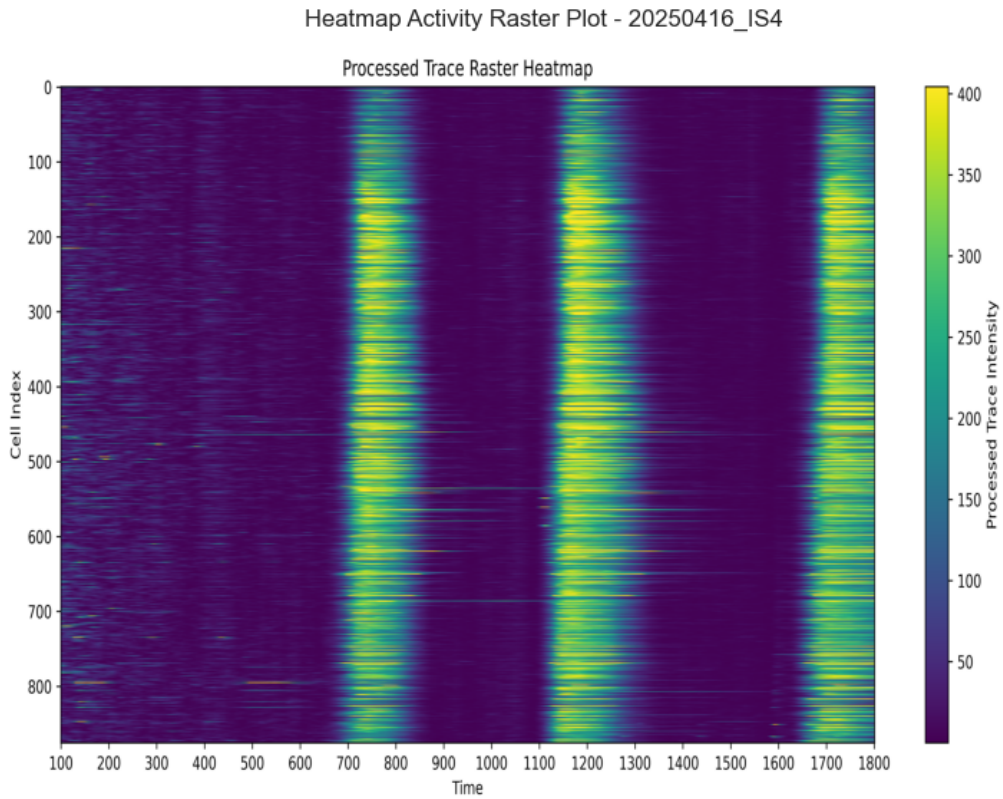
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



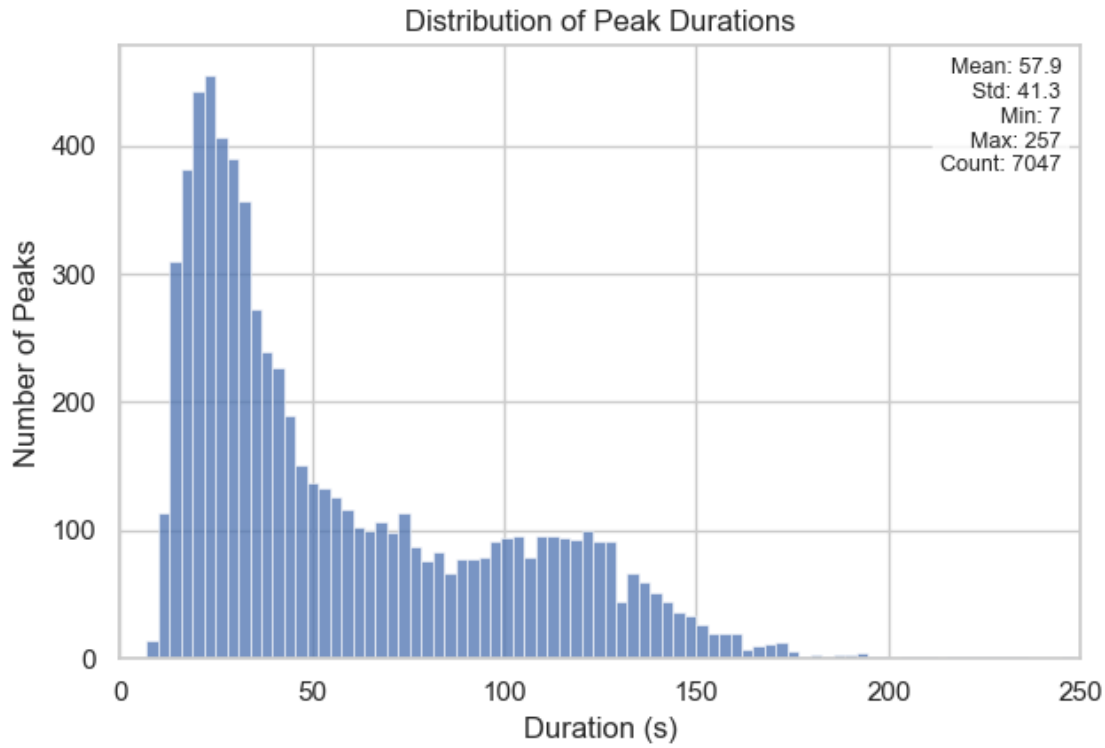


1.1.2 Peaks population

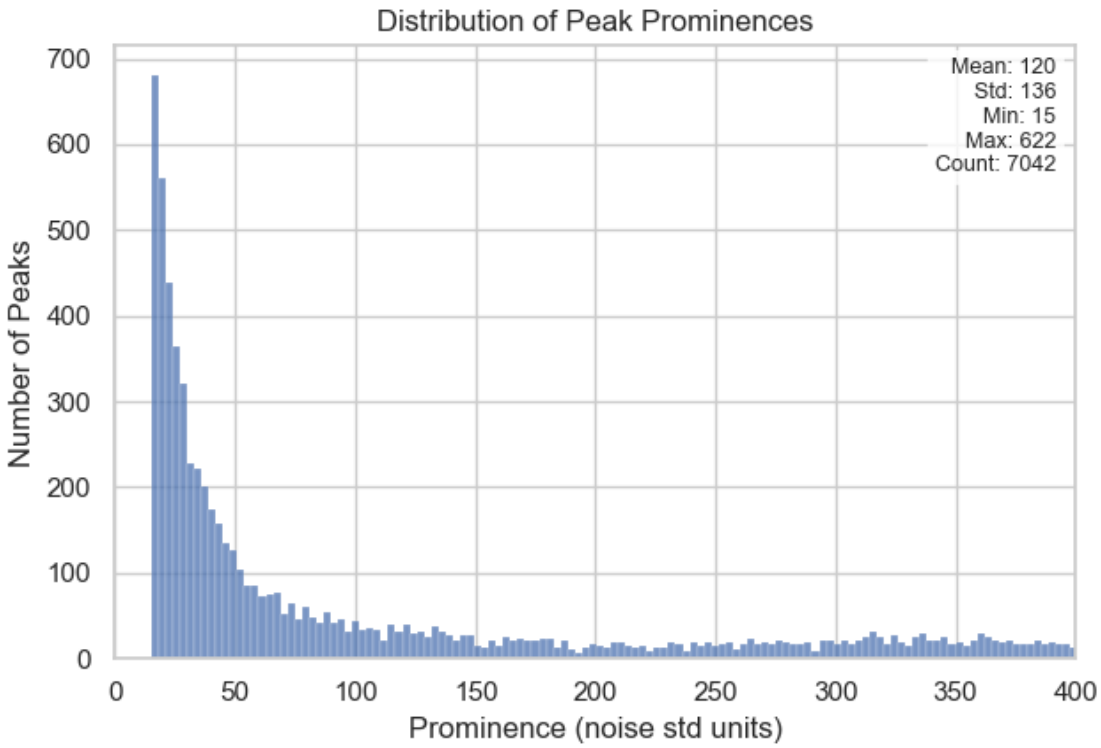
```
Total number of peaks: 7049
Total number of cells: 876
```

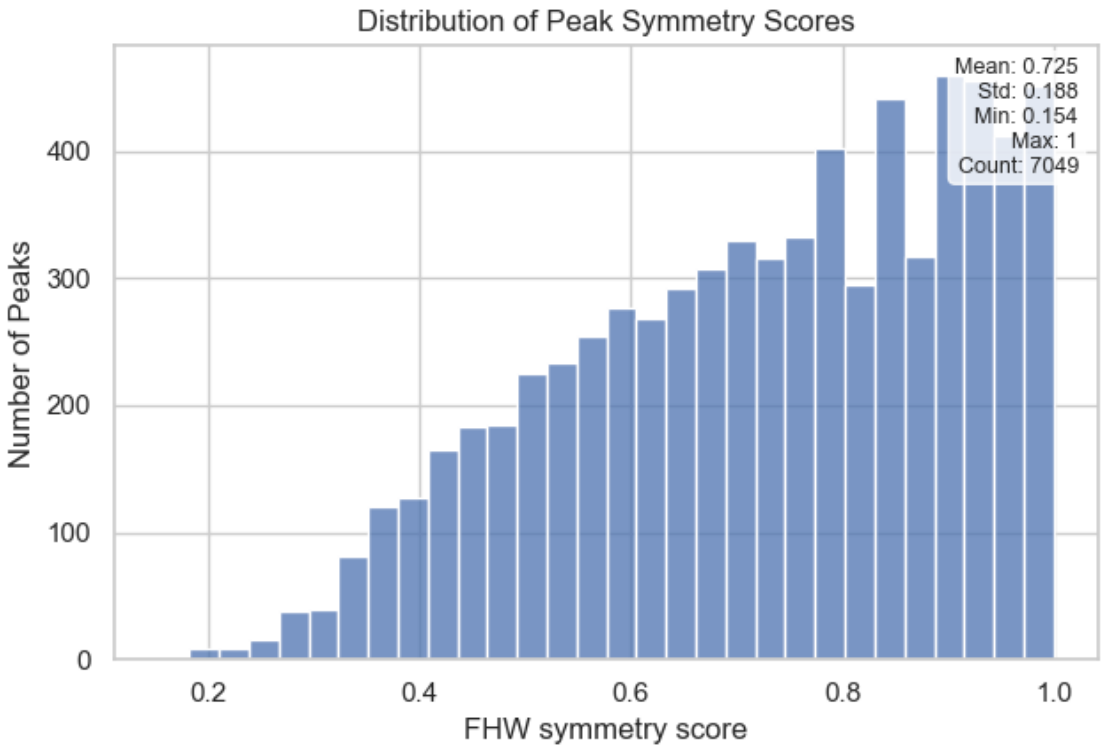
1.1.3 Peaks statistics

```
[2025-08-11 09:51:38] [INFO] calcium: plot_histogram: removed 2 outliers out of
7049 on 'Duration (s)' (lower=-161, upper=273)
```

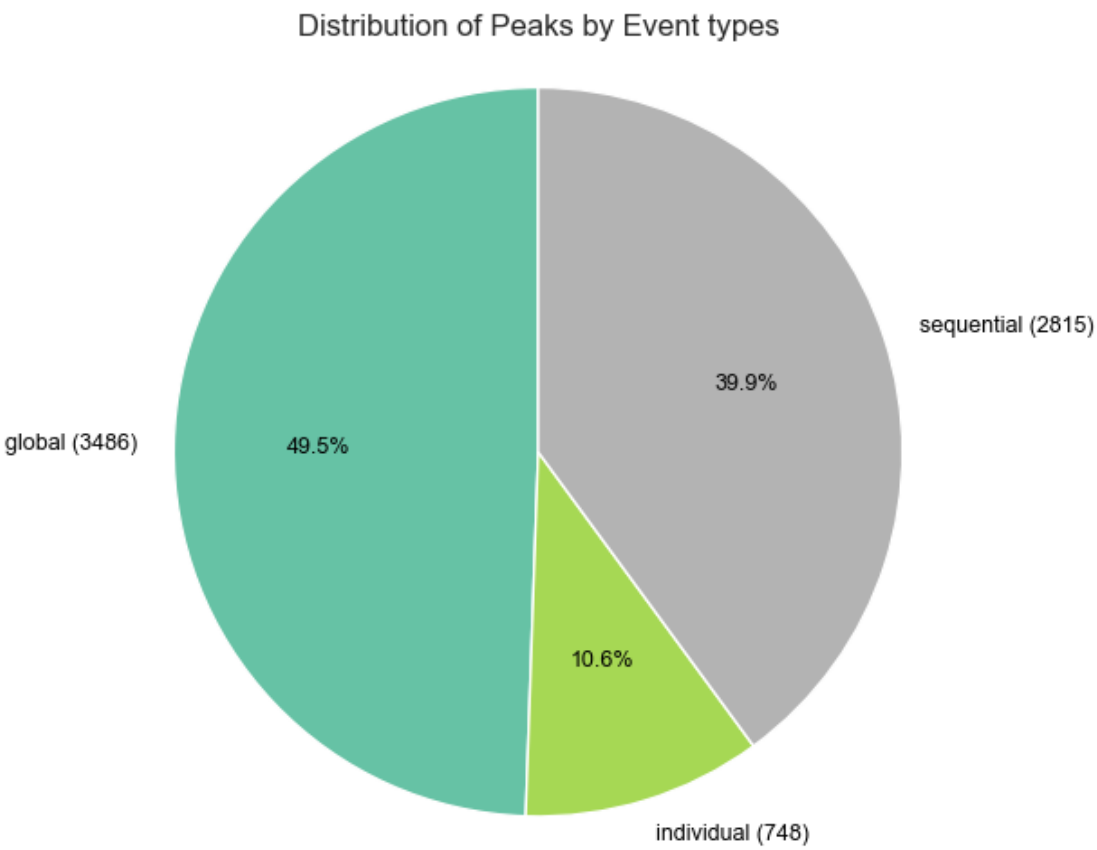



```
[2025-08-11 09:51:38] [INFO] calcium: plot_histogram: removed 7 outliers out of
7049 on 'Prominence (noise std units)' (lower=-427.2, upper=627)
```


Distribution of Peak Prominences
Mean: 120
Std: 136
Min: 15
Max: 622
Count: 7042
Number of Peaks
Prominence (noise std units)
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400

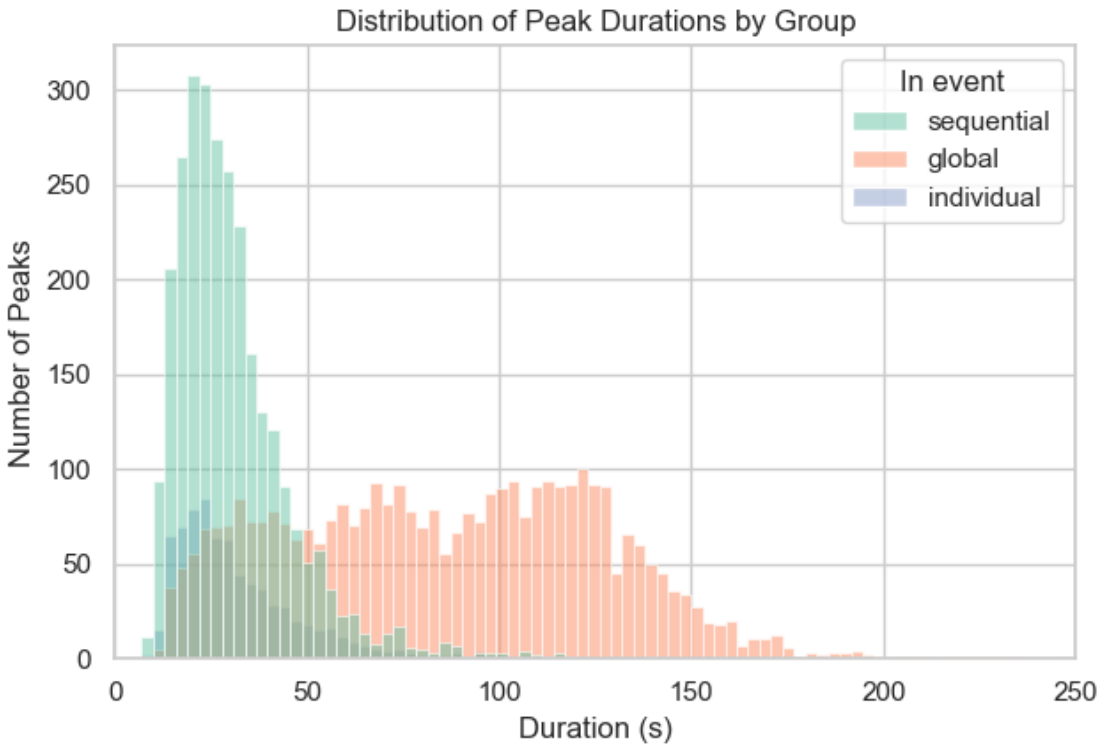

Distribution of Peak Symmetry Scores
Mean: 0.725
Std: 0.188
Min: 0.154
Max: 1
Count: 7049
Number of Peaks
FHW symmetry score
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0

1.1.4 Distribution of peaks per event types

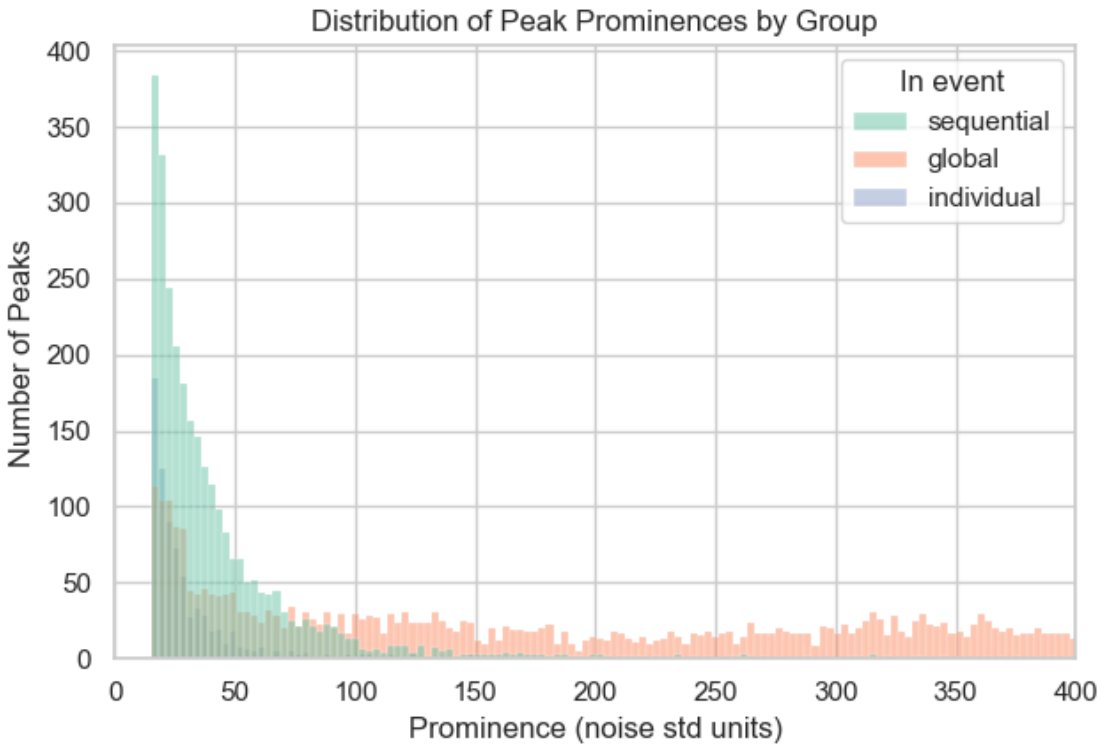


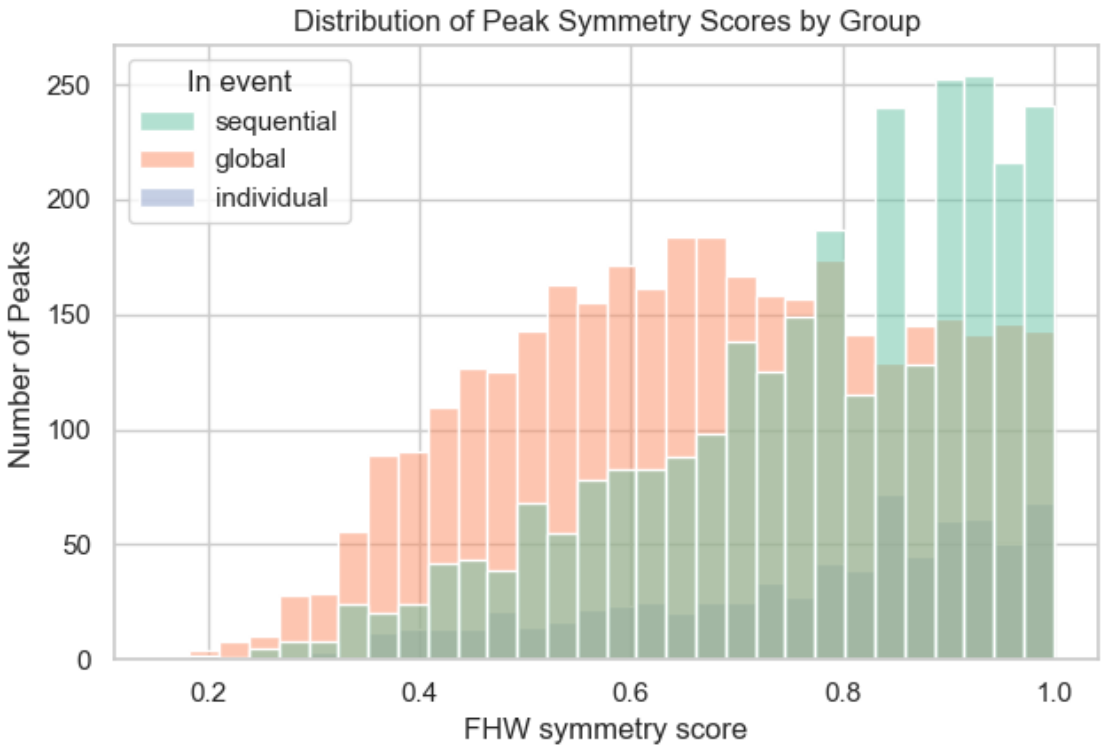
1.1.5 Peaks statistics per event types

```
[2025-08-11 09:51:39] [INFO] calcium: plot_histogram_by_group: removed 2
outliers out of 7049 on 'Duration (s)' (lower=-161, upper=273)
```




```
[2025-08-11 09:51:39] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 7049 on 'Prominence (noise std units)' (lower=-427.2, upper=627)
```

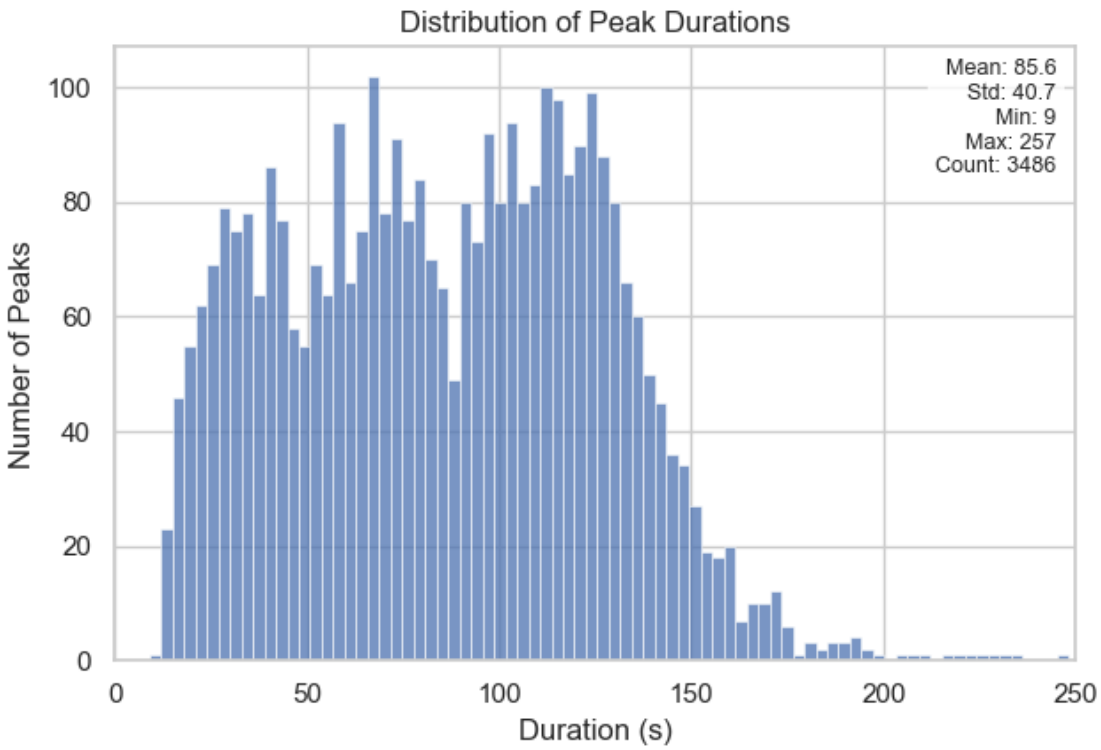

Distribution of Peak Prominences by Group
In event
sequential
global
individual
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400


Distribution of Peak Symmetry Scores by Group
In event
sequential
global
individual
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0

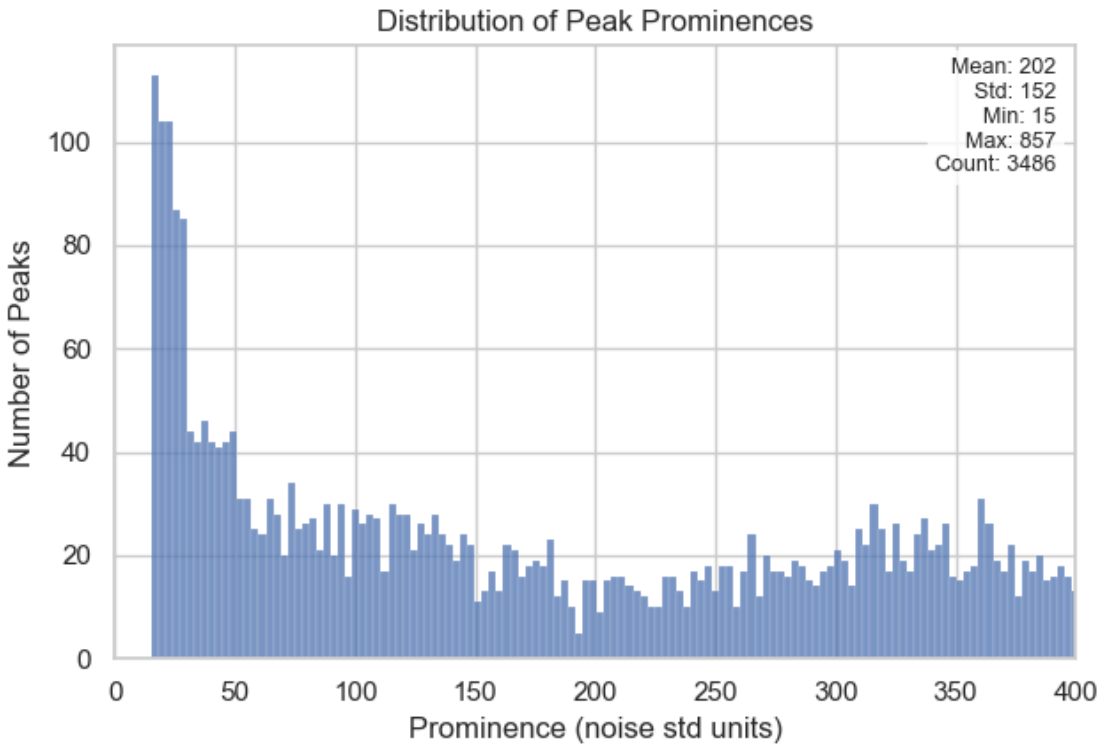
1.2 GLOBAL EVENTS

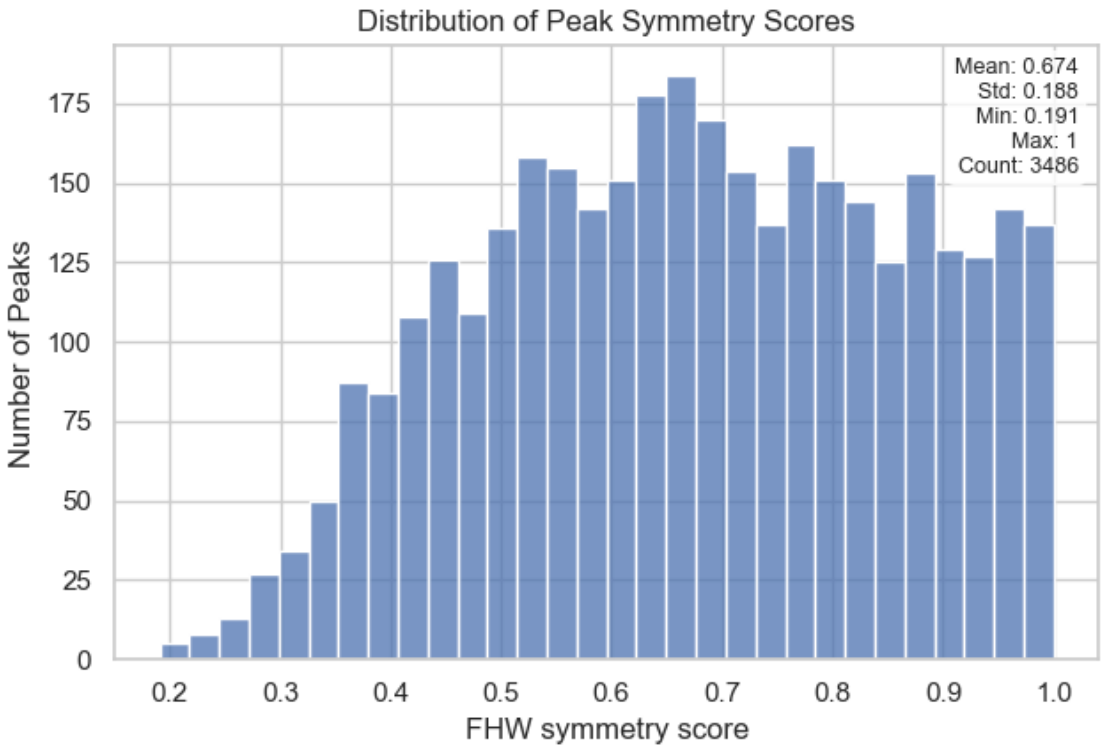
1.2.1 Peak statistics in global events

```
[2025-08-11 09:51:40] [INFO] calcium: plot_histogram: removed 0 outliers out of
3486 on 'Duration (s)' (lower=-145.25, upper=315)
```



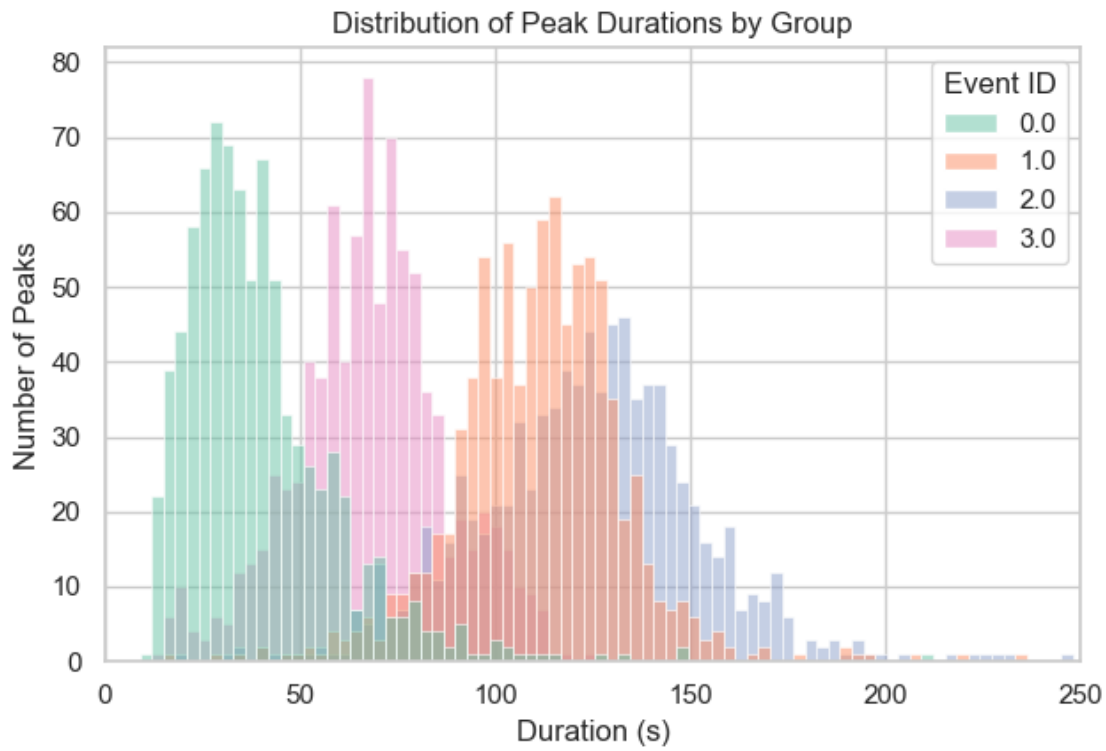

```
[2025-08-11 09:51:40] [INFO] calcium: plot_histogram: removed 0 outliers out of
3486 on 'Prominence (noise std units)' (lower=-751.12, upper=1138)
```


Distribution of Peak Prominences
Mean: 202
Std: 152
Min: 15
Max: 857
Count: 3486
Number of Peaks
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

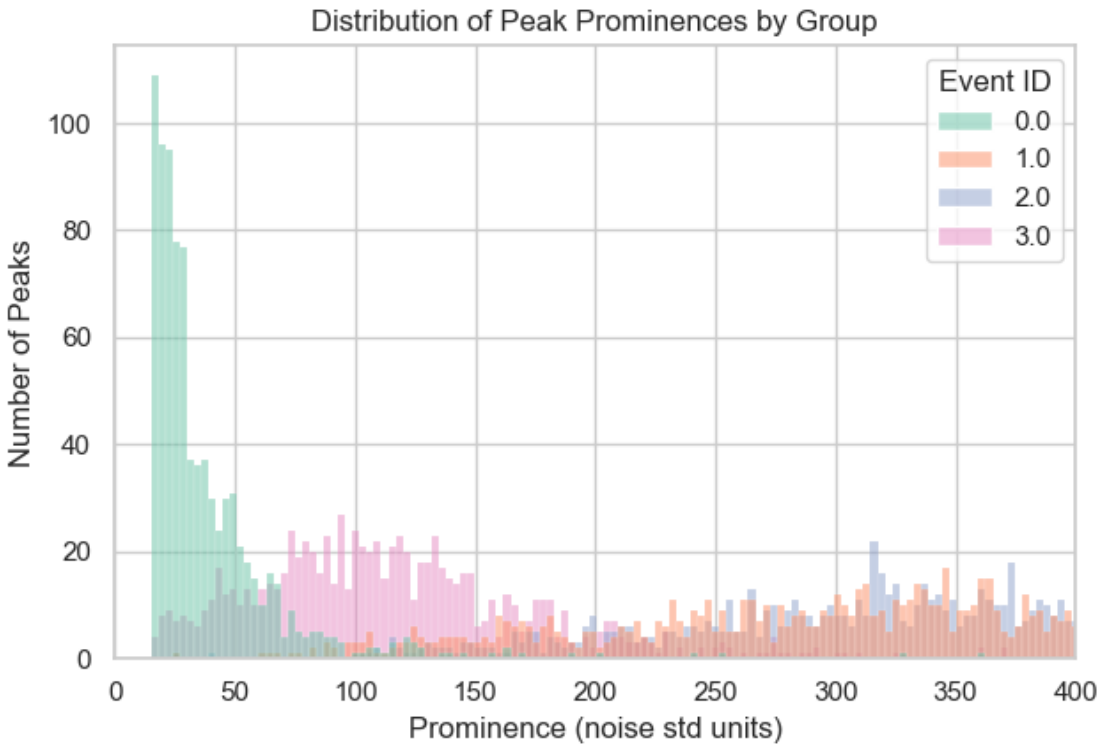

Distribution of Peak Symmetry Scores
Mean: 0.674
Std: 0.188
Min: 0.191
Max: 1
Count: 3486
Number of Peaks
0
25
50
75
100
125
150
175
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

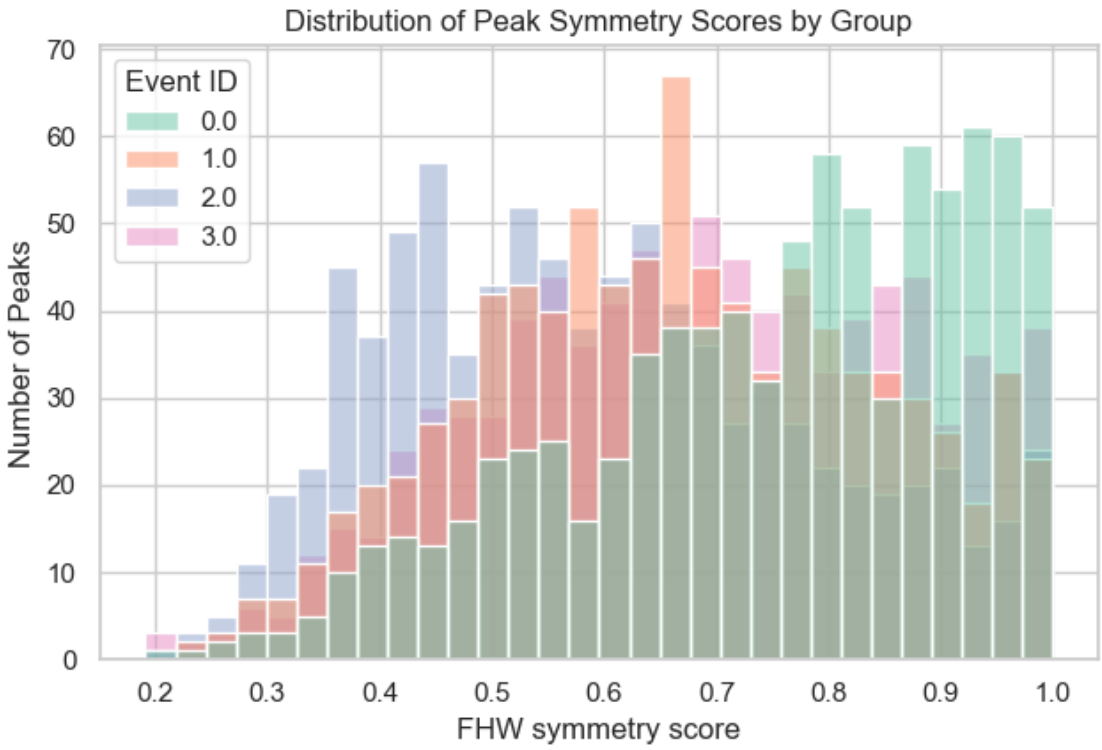
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 09:51:40] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 3486 on 'Duration (s)' (lower=-145.25, upper=315)
```

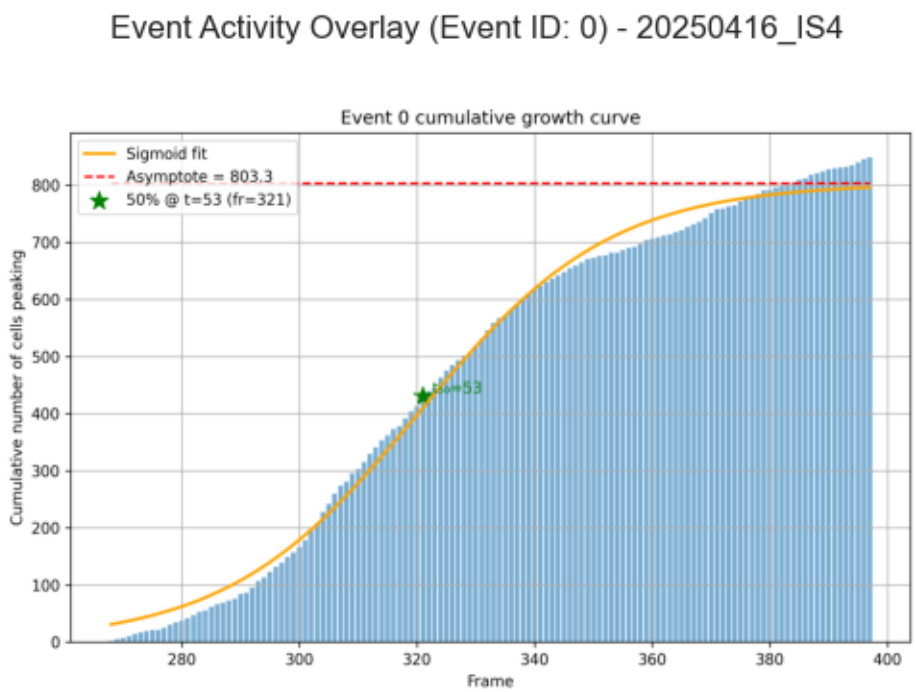


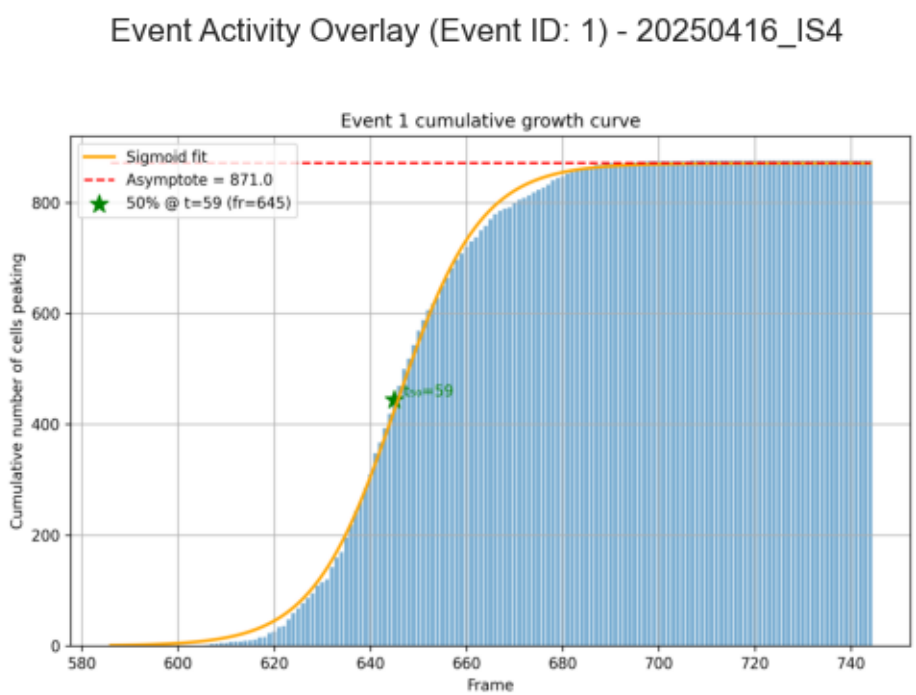

```
[2025-08-11 09:51:40] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 3486 on 'Prominence (noise std units)' (lower=-751.12,
upper=1138)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
20
40
60
80
100
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

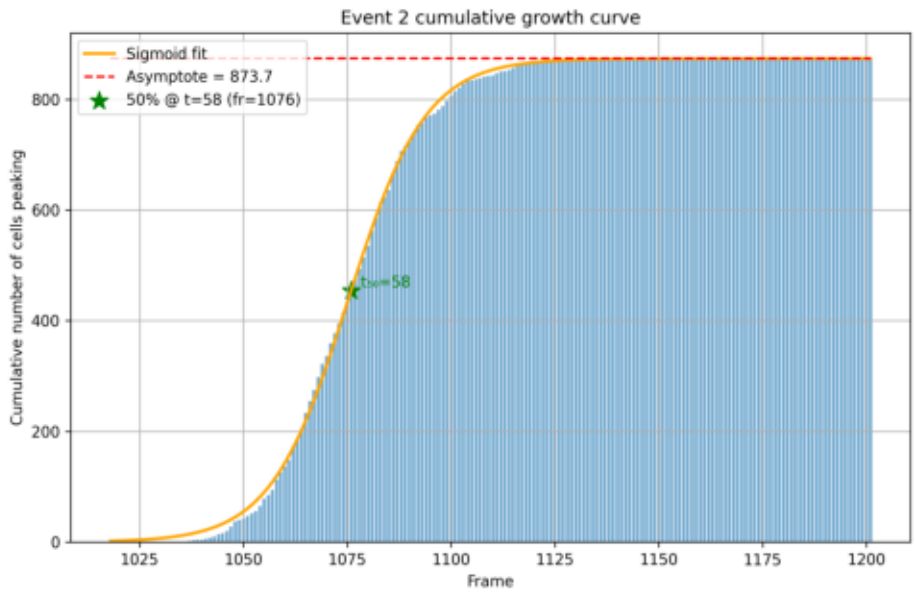

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
10
20
30
40
50
60
70
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.2.3 Kinetics of global events

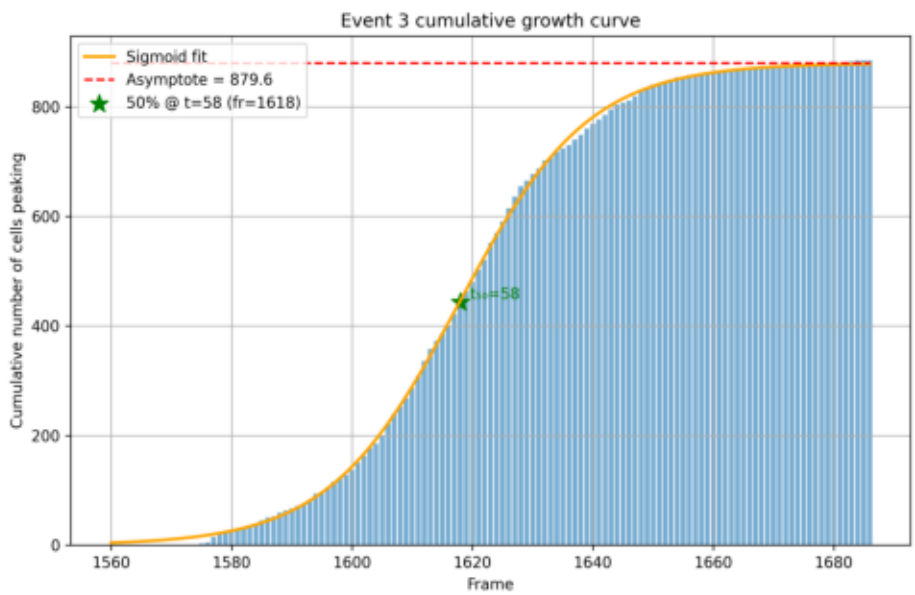




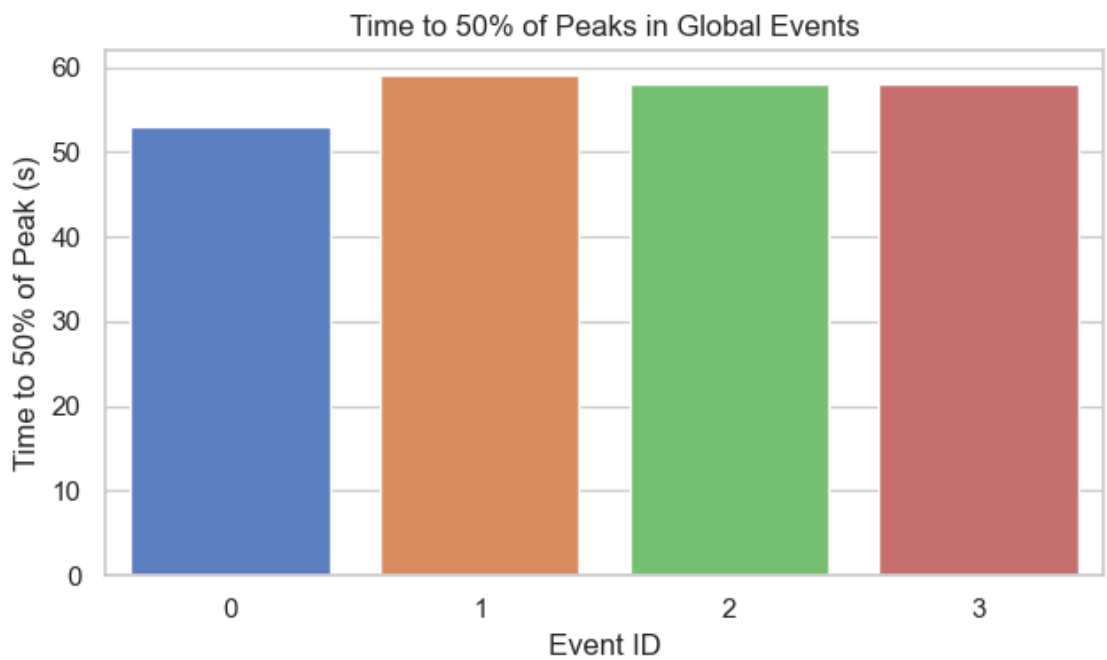
Event Activity Overlay (Event ID: 2) - 20250416_IS4



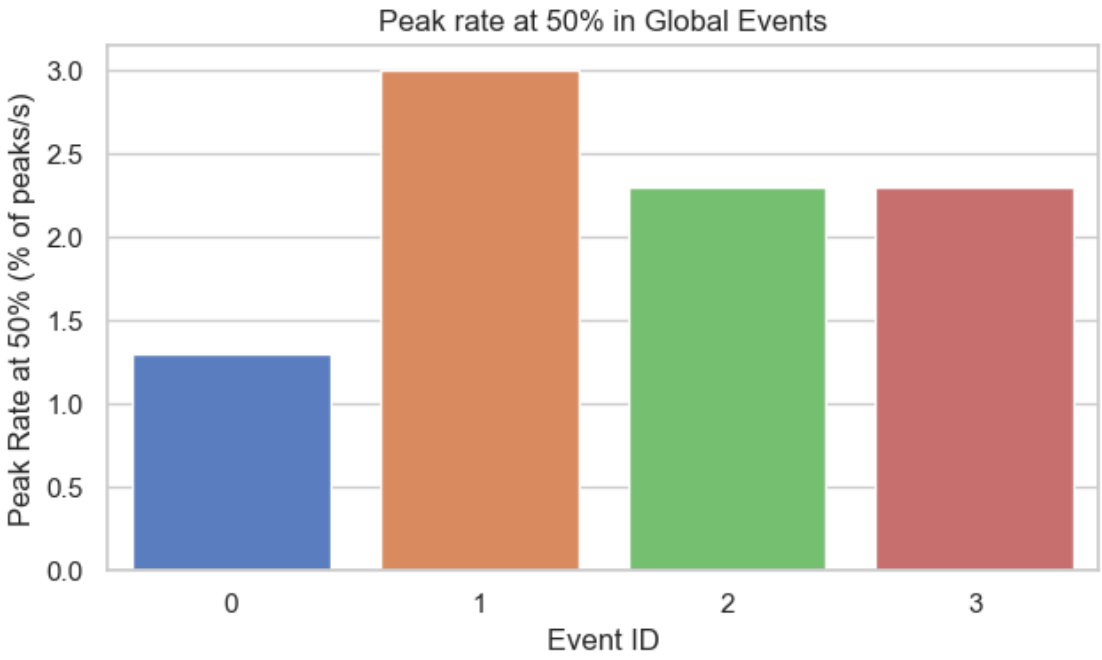
Event Activity Overlay (Event ID: 3) - 20250416_IS4



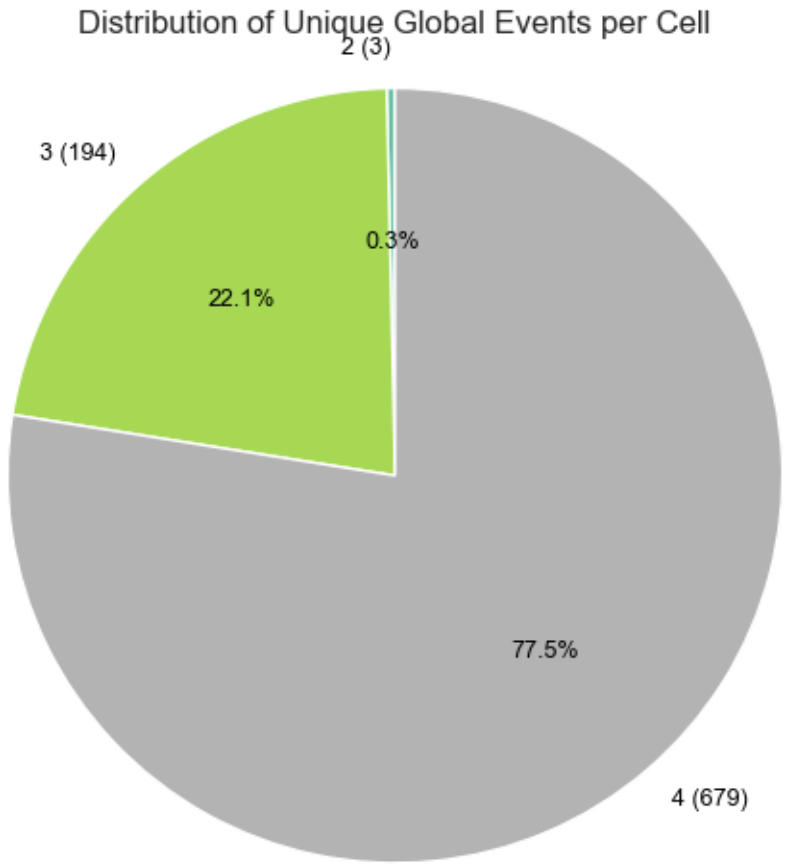
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



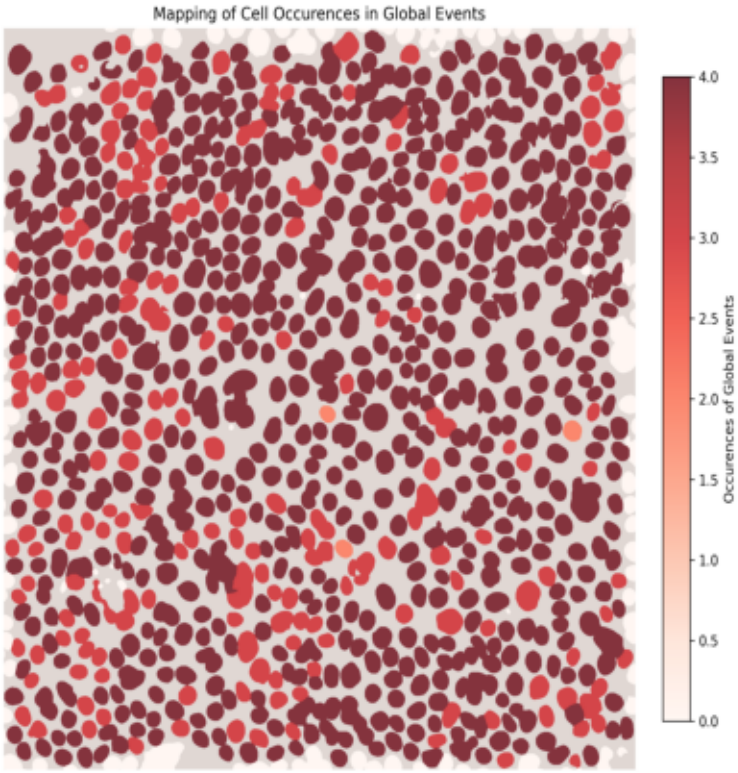

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
Event ID

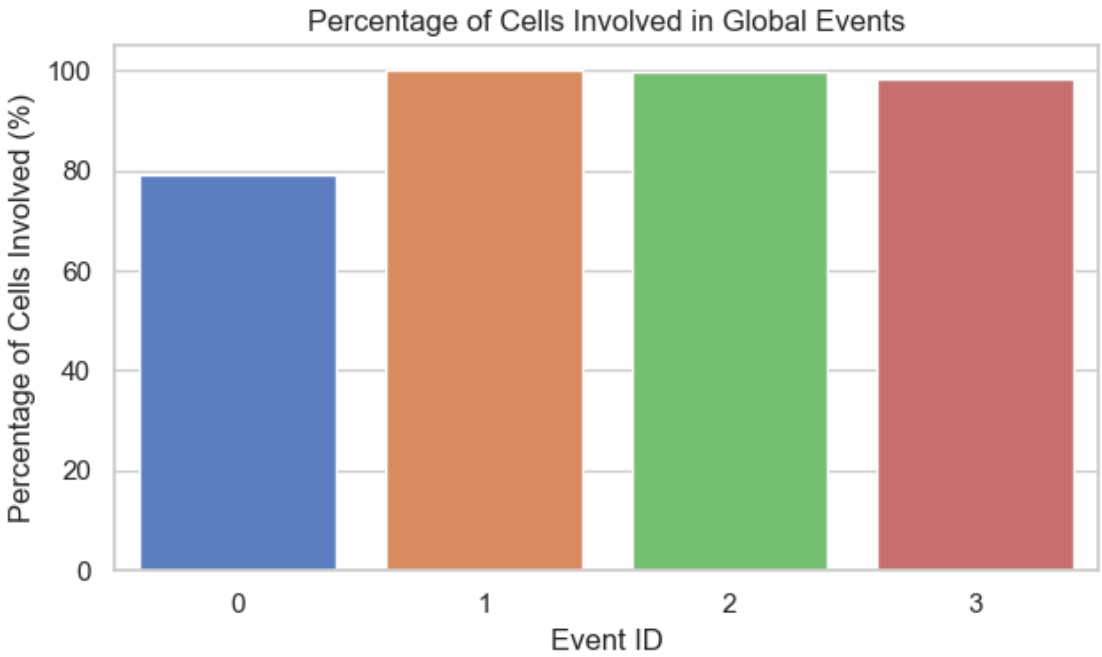
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250416_IS4




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

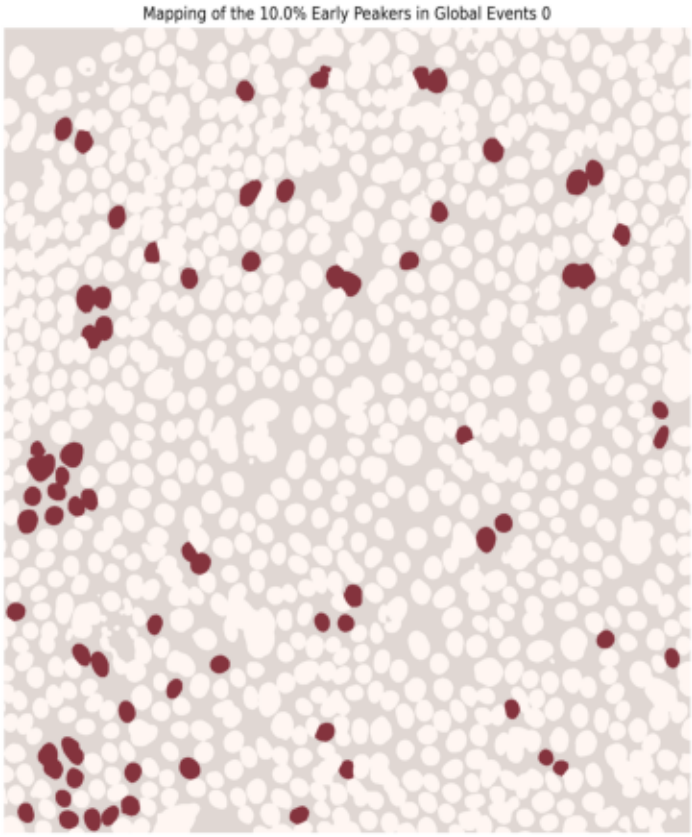


1.2.5 Inter-event interval analysis

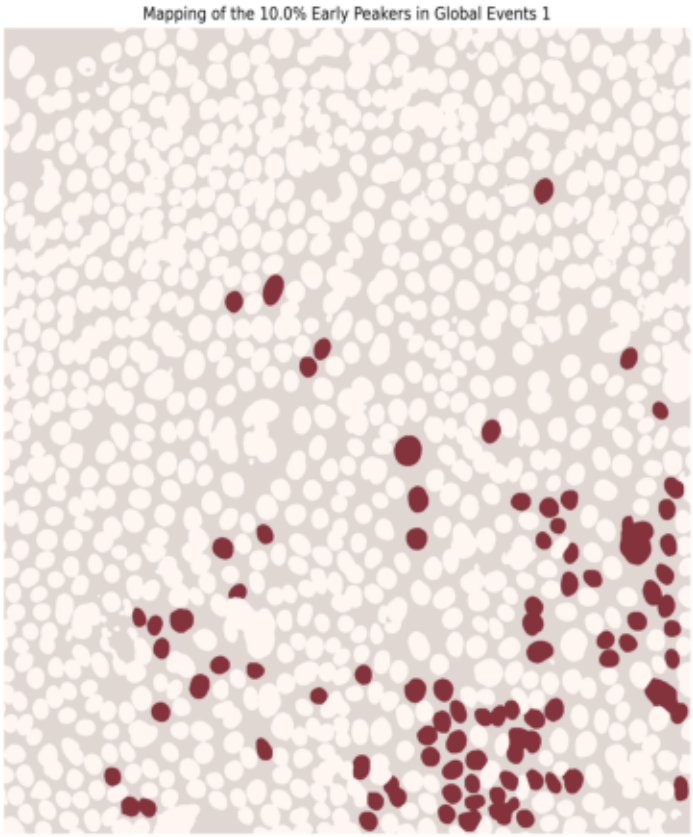
```
Intervals between global event peaks: [343.0, 428.0, 540.0]
Estimated periodicity: 0.844
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.002 Hz
```

1.2.6 Early peakers in the events

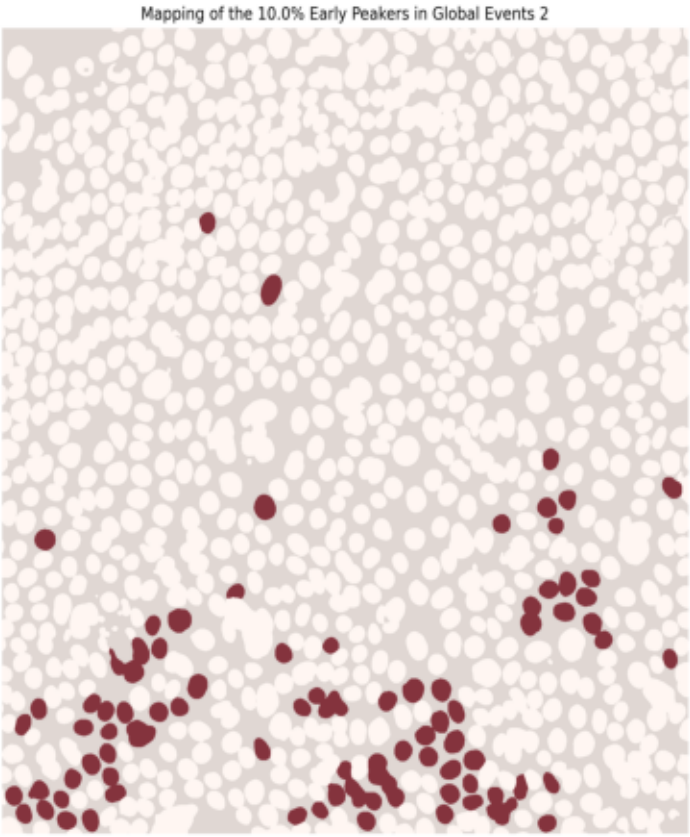
Cell Mapping with Early Peakers Overlay for event 0 - 20250416_IS4



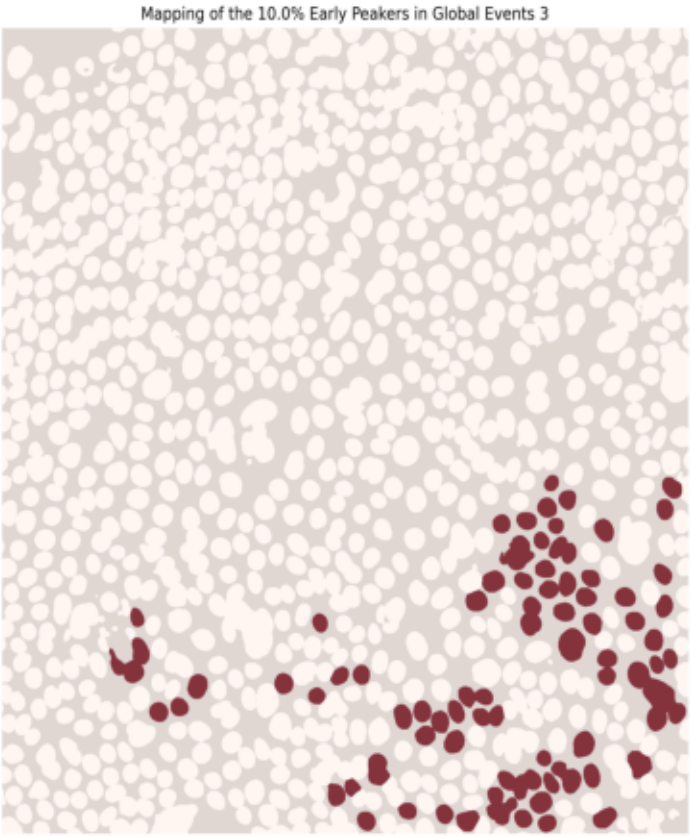
Cell Mapping with Early Peakers Overlay for event 1 - 20250416_IS4



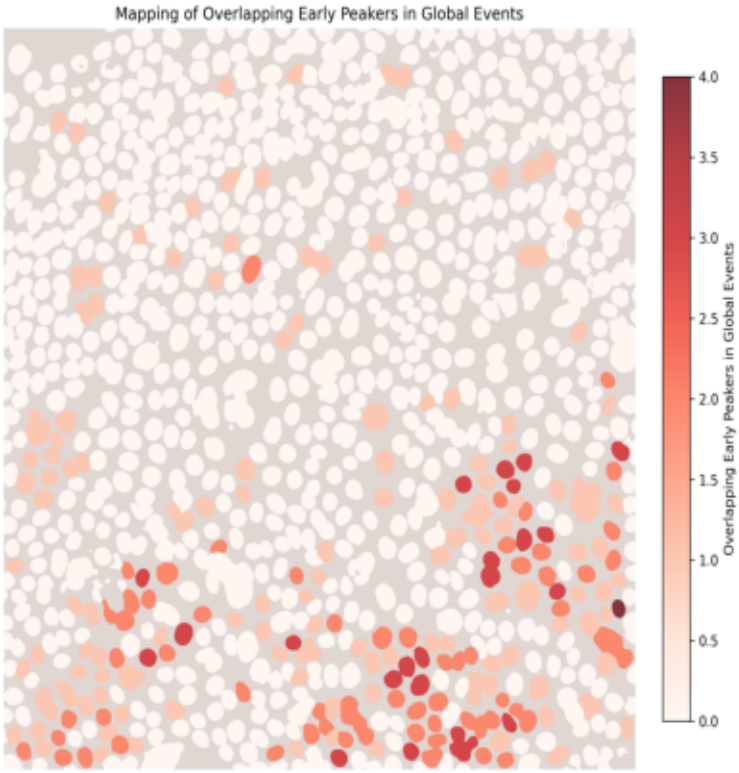
Cell Mapping with Early Peakers Overlay for event 2 - 20250416_IS4



Cell Mapping with Early Peakers Overlay for event 3 - 20250416_IS4

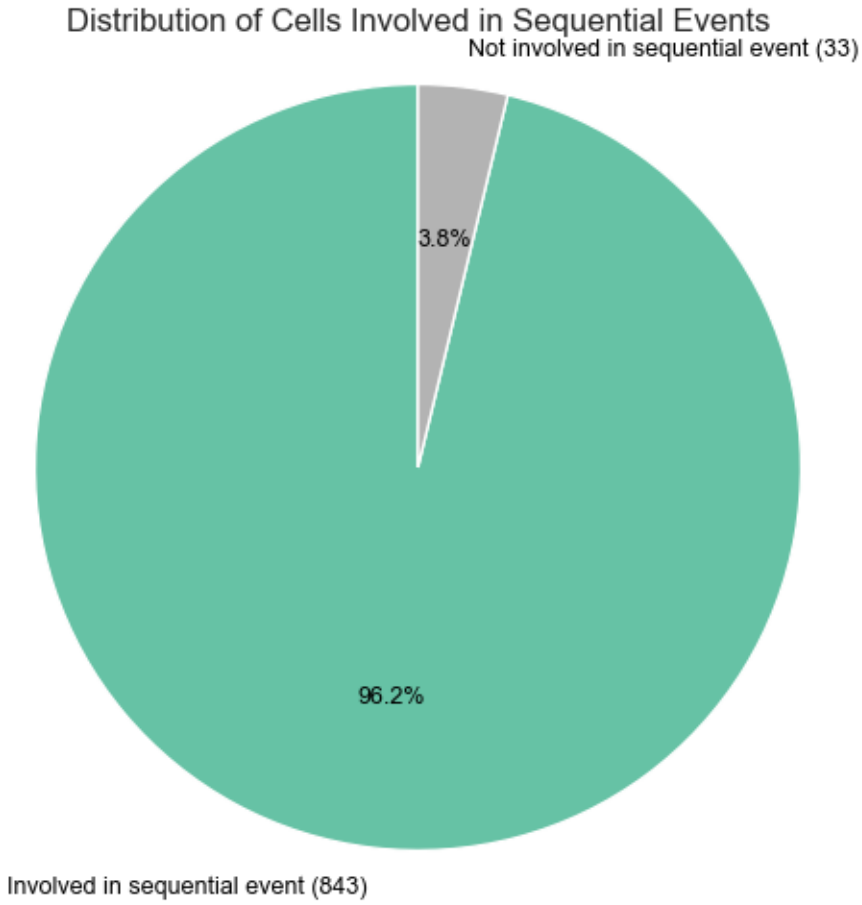


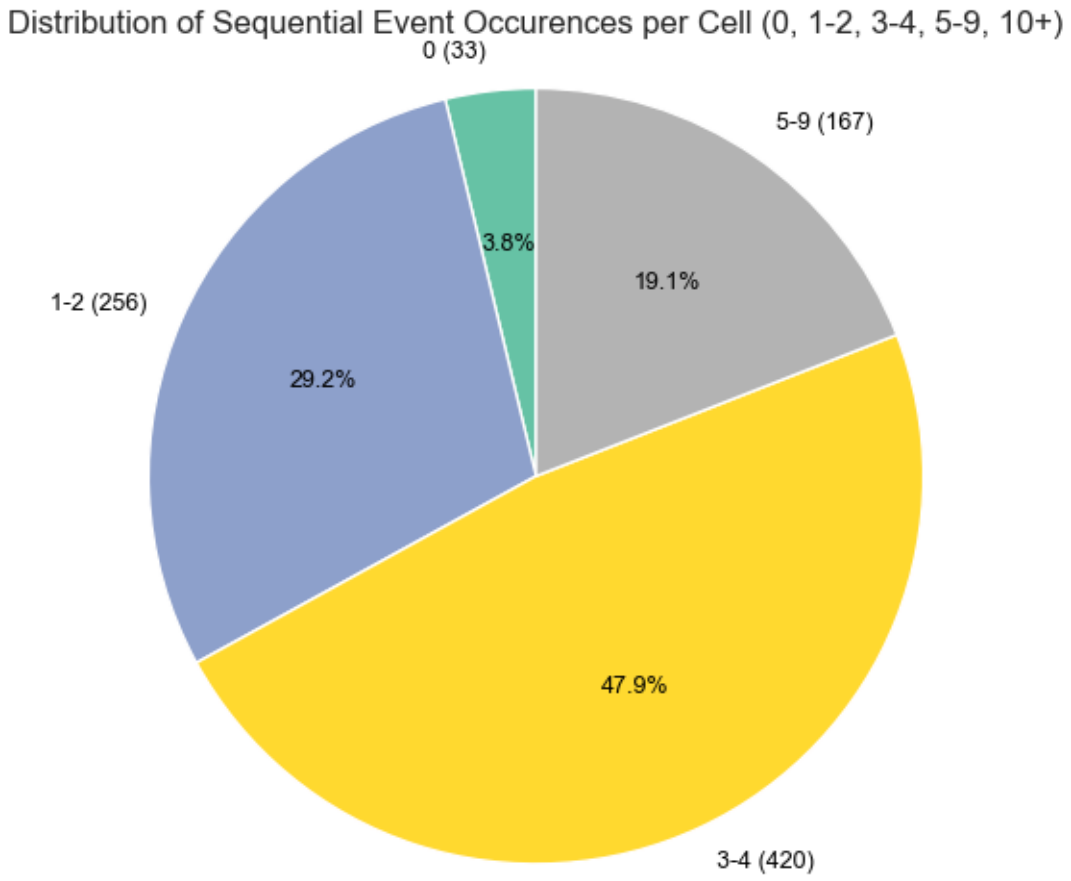
Cell Mapping with Occurences in Global Events Overlay - 20250416_IS4



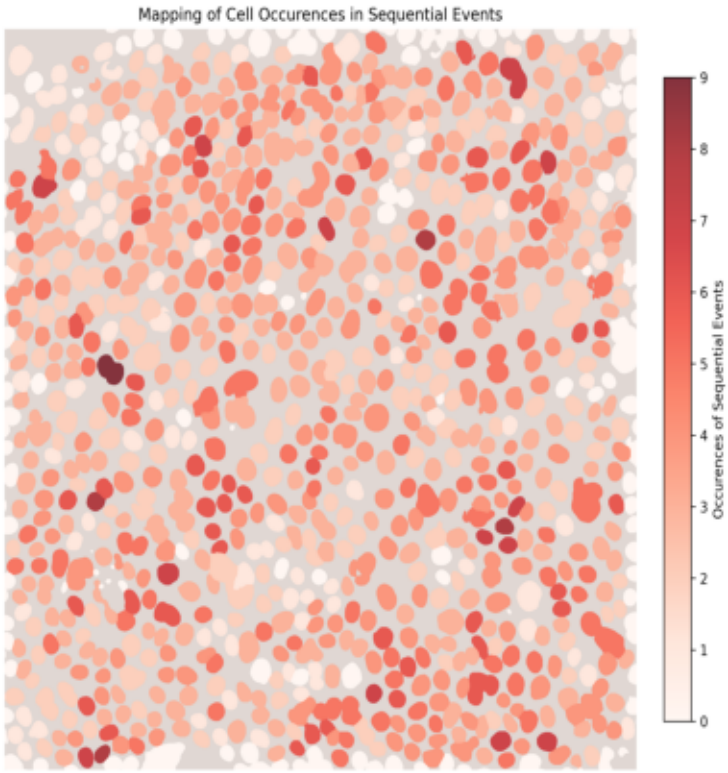
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

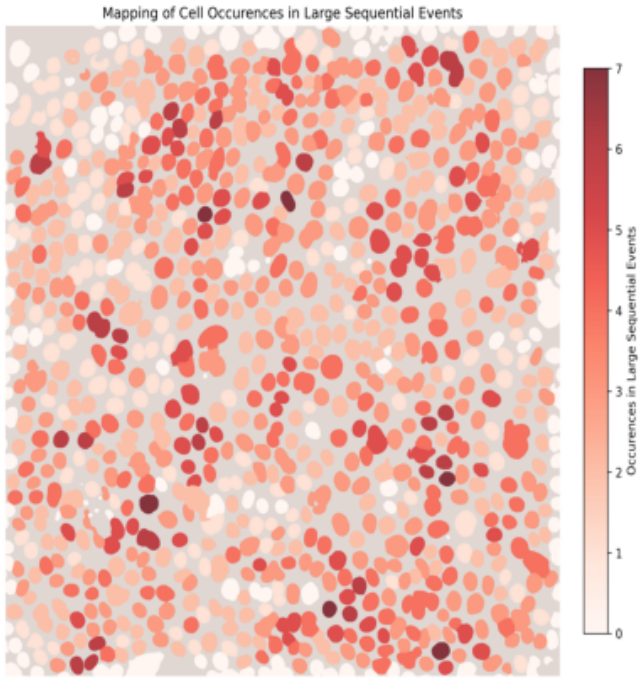



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (33)
5-9 (167)
3.8%
19.1%
1-2 (256)
29.2%
47.9%
3-4 (420)

Cell Mapping with Occurences in Sequential Events Overlay - 20250416_IS4

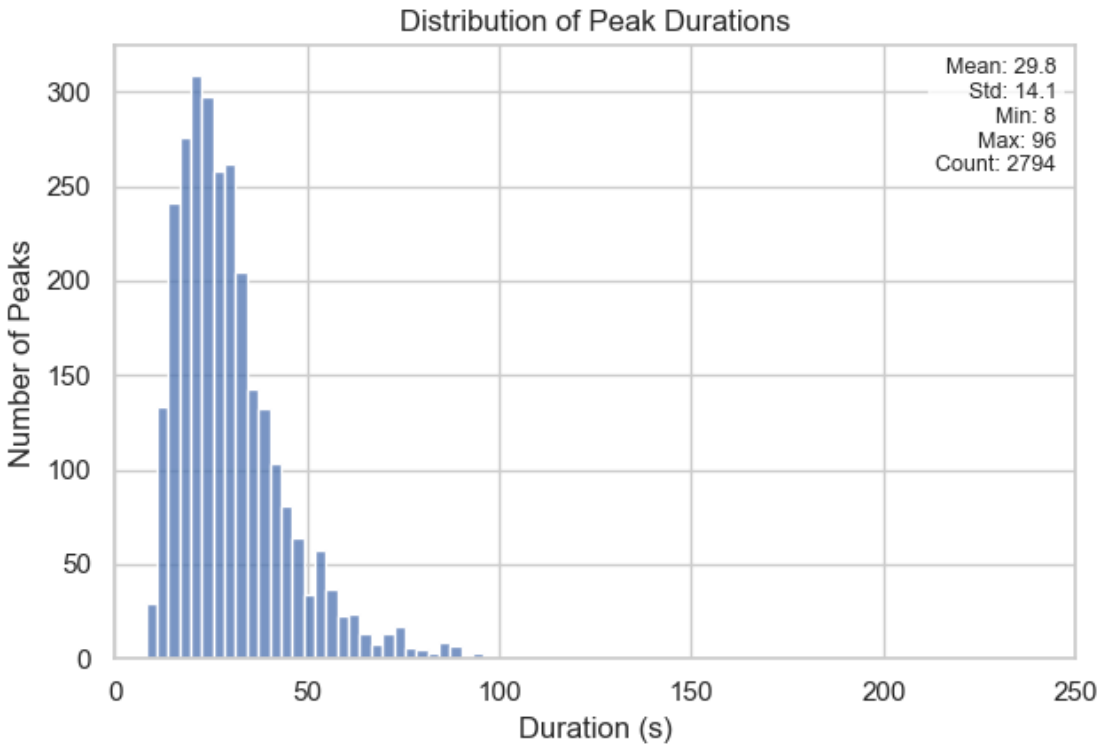


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250416_IS4

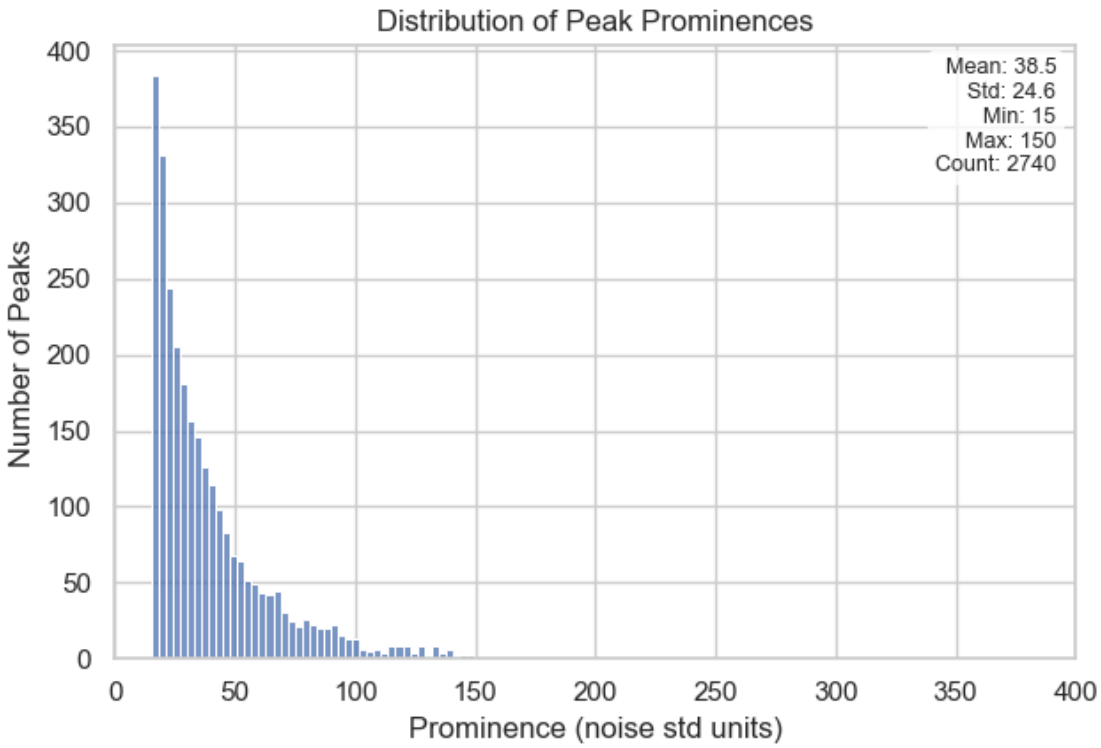


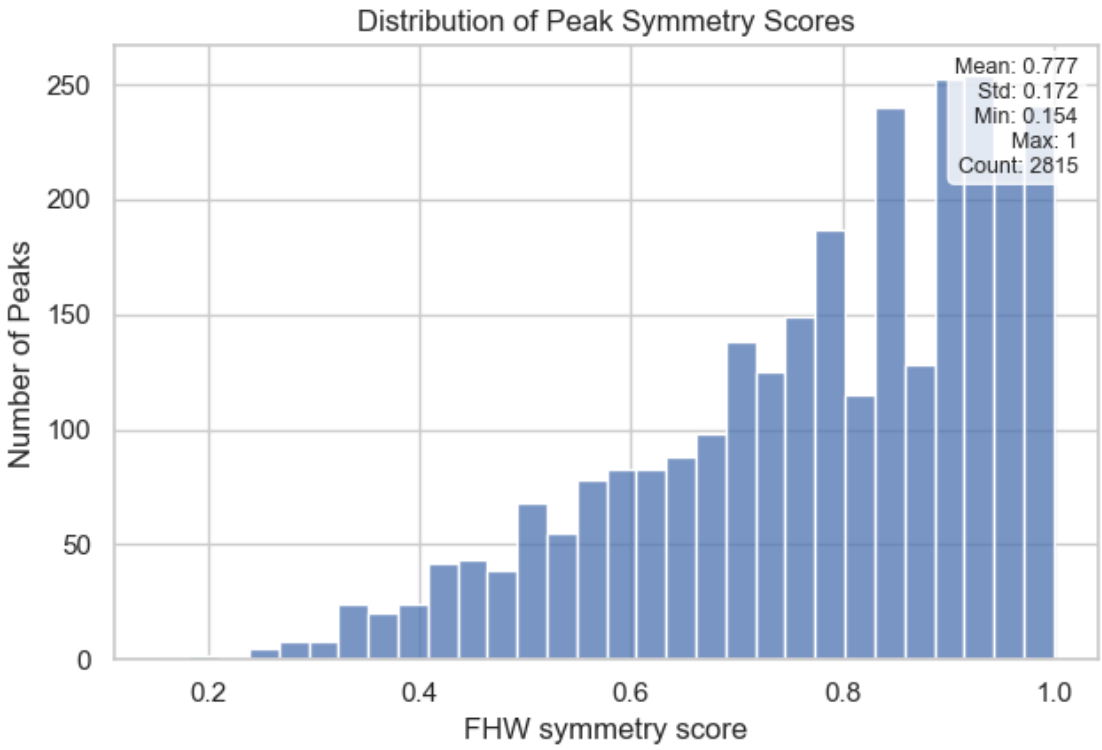
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 09:51:51] [INFO] calcium: plot_histogram: removed 21 outliers out of
2815 on 'Duration (s)' (lower=-5.5, upper=96.5)
```



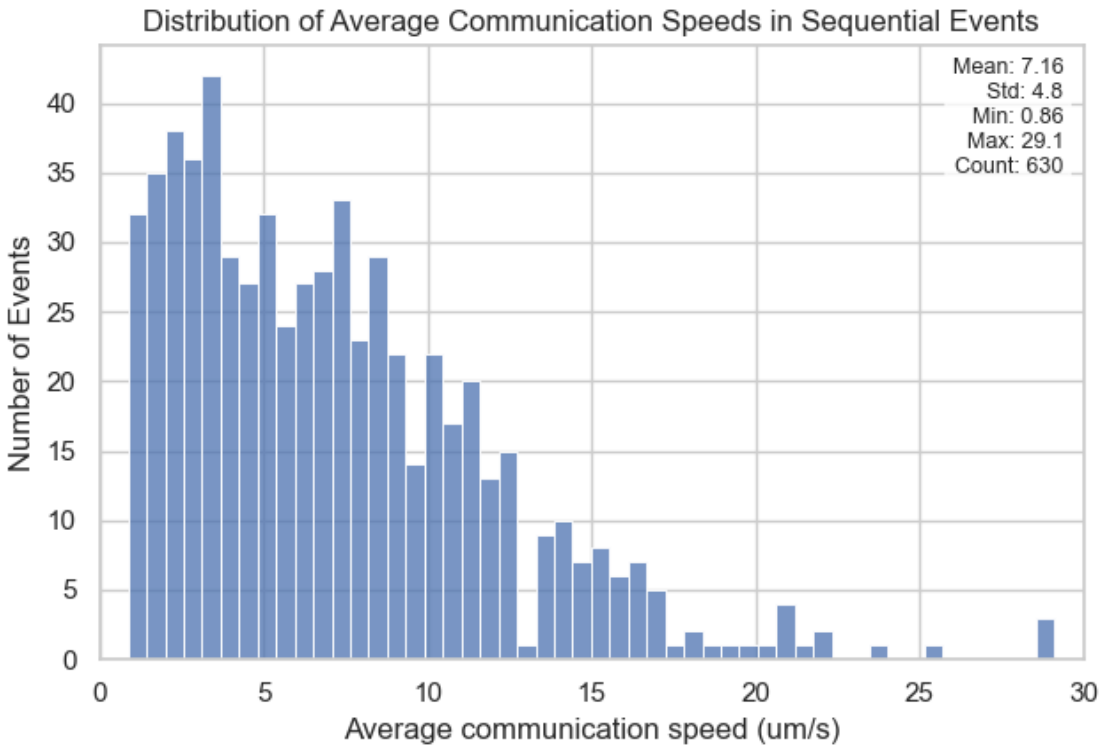

```
[2025-08-11 09:51:51] [INFO] calcium: plot_histogram: removed 75 outliers out of
2815 on 'Prominence (noise std units)' (lower=-22.075, upper=149.82)
```


Distribution of Peak Prominences
Mean: 38.5
Std: 24.6
Min: 15
Max: 150
Count: 2740
Number of Peaks
Prominence (noise std units)
0
50
100
150
200
250
300
350
400

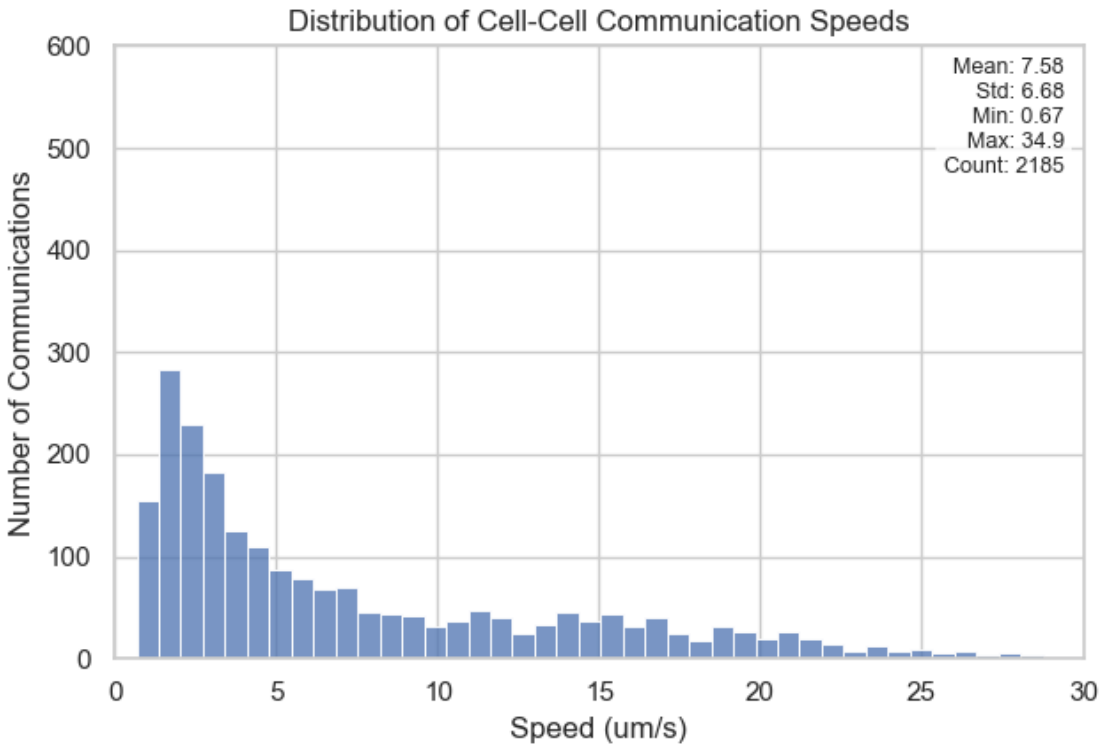

Distribution of Peak Symmetry Scores
Mean: 0.777
Std: 0.172
Min: 0.154
Max: 1
Count: 2815
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0

1.3.3 Cell-cell communication speed

```
[2025-08-11 09:51:51] [INFO] calcium: plot_histogram: removed 0 outliers out of
630 on 'Average communication speed (um/s)' (lower=-16.478, upper=29.793)
```

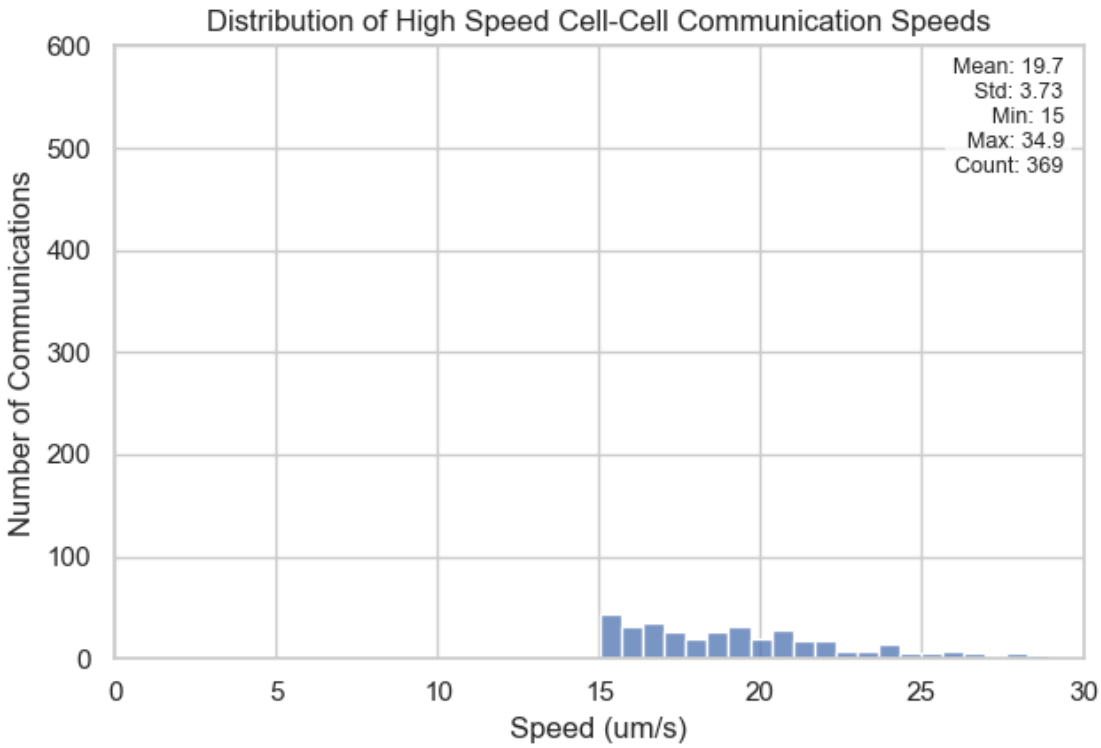



```
[2025-08-11 09:51:52] [INFO] calcium: plot_histogram: removed 0 outliers out of
2185 on 'Speed (um/s)' (lower=-25.68, upper=39.63)
```

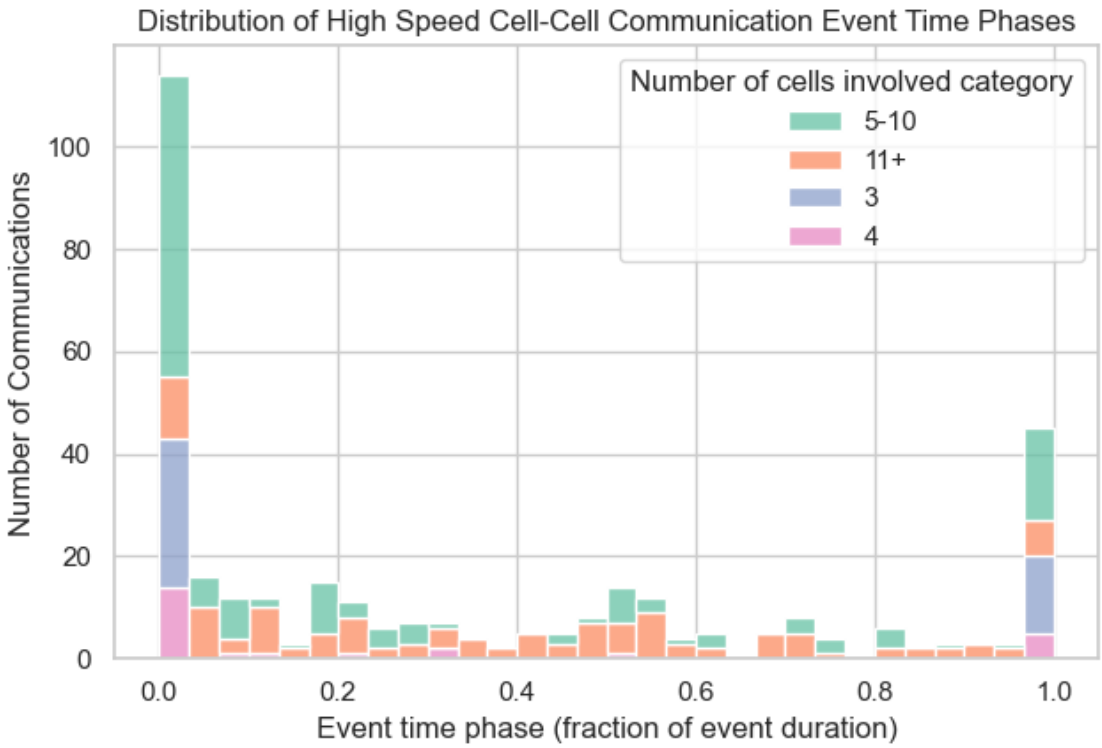


1.3.4 Double distribution in cell-cell communication speeds

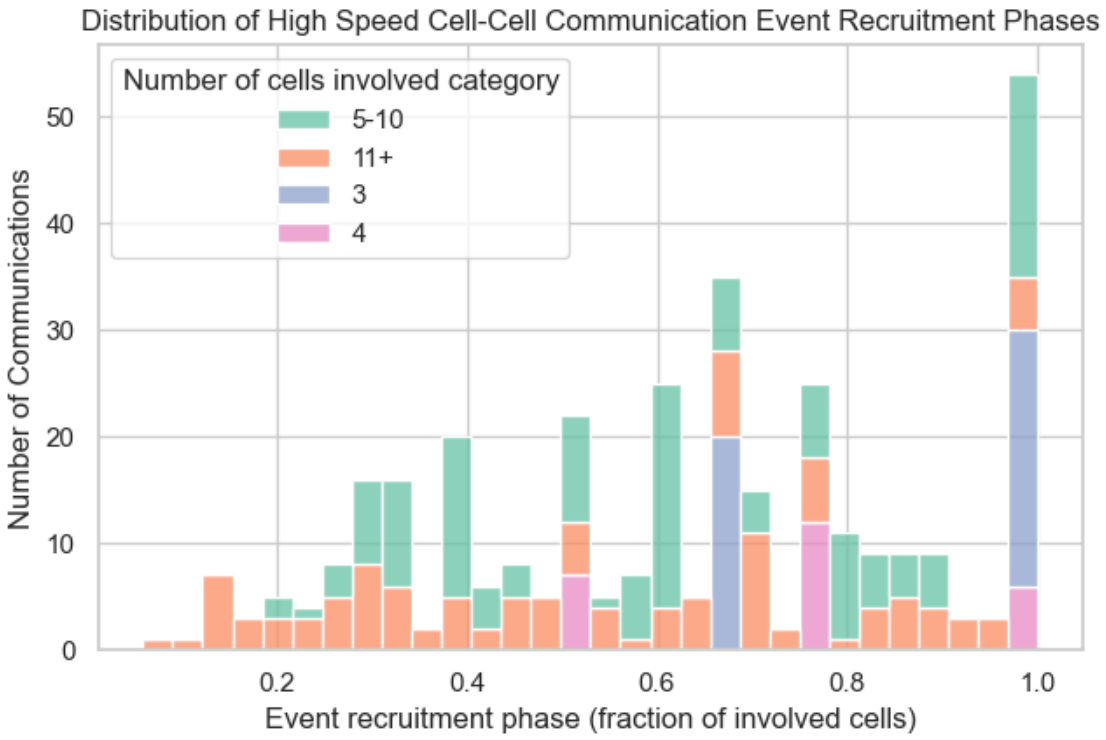
```
[2025-08-11 09:51:52] [INFO] calcium: plot_histogram: removed 0 outliers out of
369 on 'Speed (um/s)' (lower=1.81, upper=36.46)
```



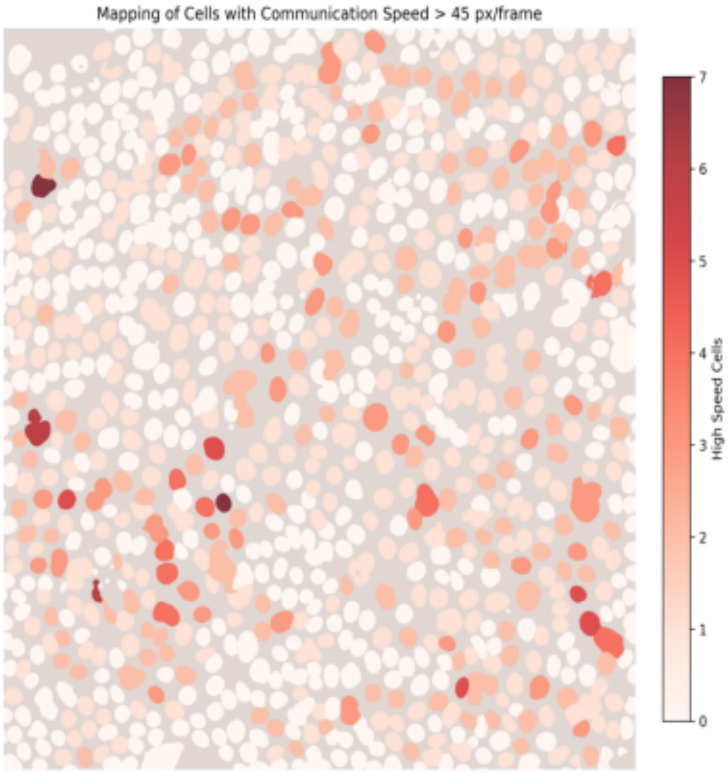

```
[2025-08-11 09:51:52] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 341 on 'Event time phase (fraction of event duration)'
(lower=-1.71, upper=2.28)
```



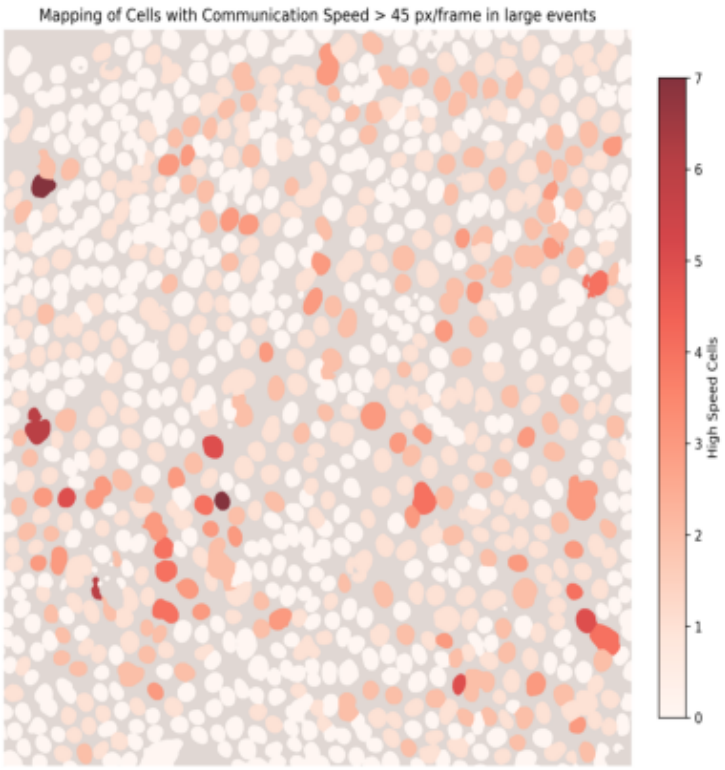

```
[2025-08-11 09:51:52] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 341 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.74, upper=1.99)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
3
4
Number of Communications
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

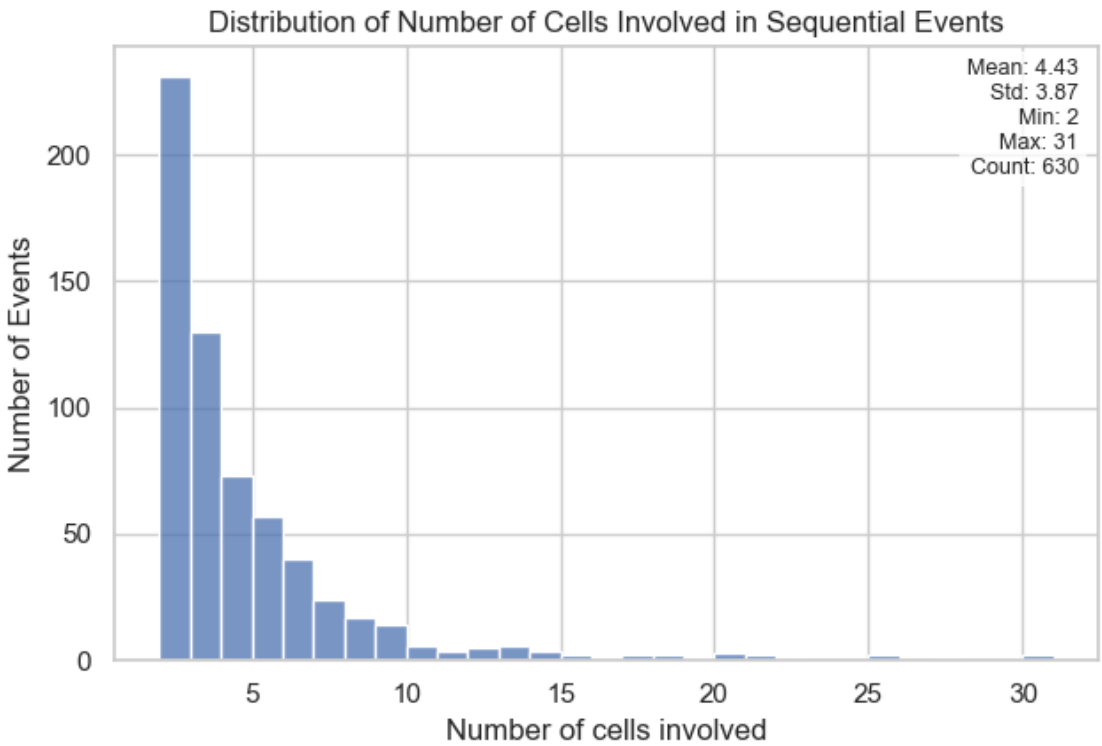
Cell Mapping with High Speed Cells Overlay - 20250416_IS4



Cell Mapping with High Speed Cells in Large Events Overlay - 20250416_IS4

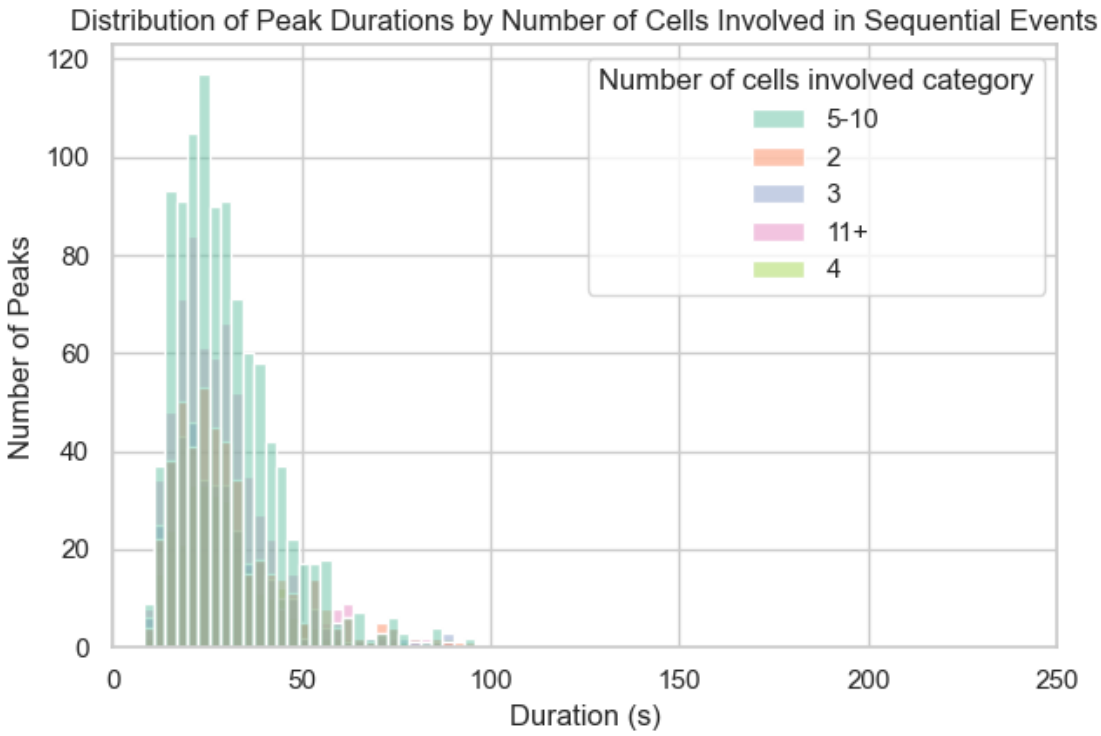


1.3.5 Number of cells involved per sequential events

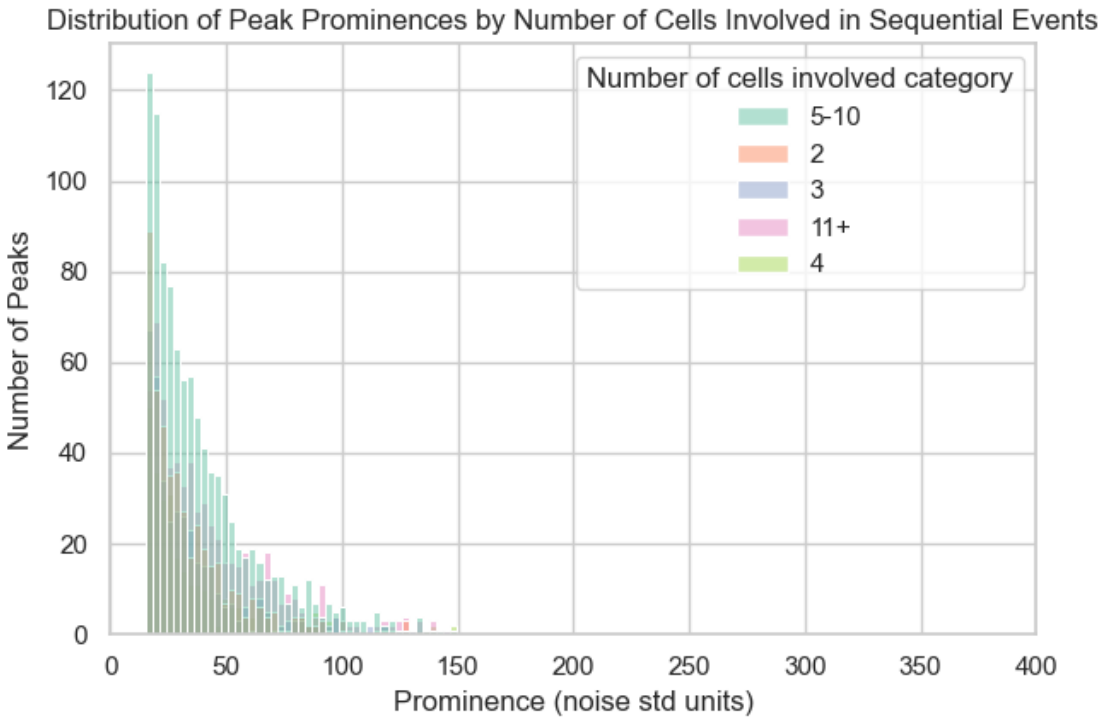


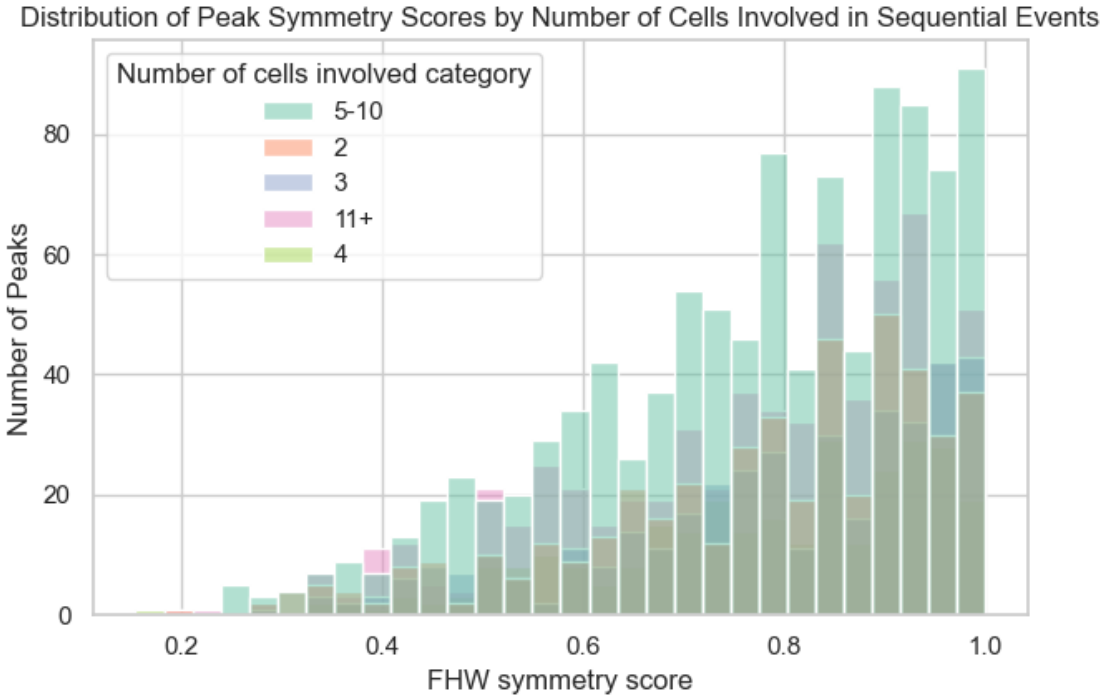
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 09:51:55] [INFO] calcium: plot_histogram_by_group: removed 21
outliers out of 2815 on 'Duration (s)' (lower=-5.5, upper=96.5)
```



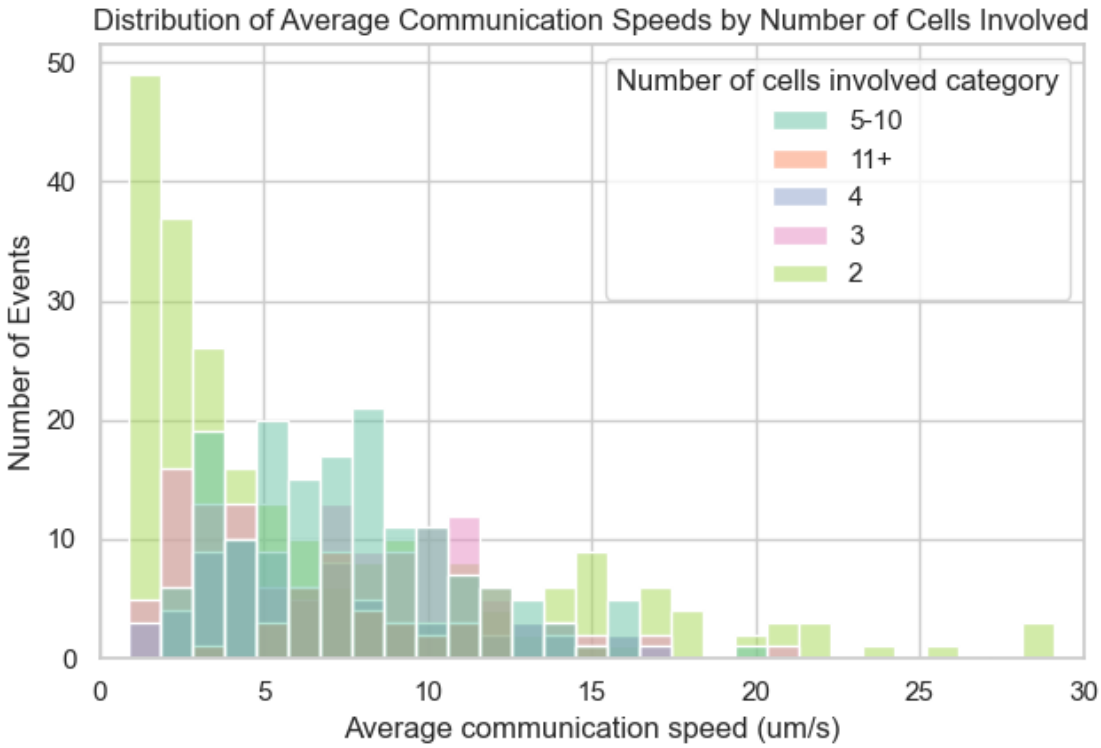

```
[2025-08-11 09:51:55] [INFO] calcium: plot_histogram_by_group: removed 75
outliers out of 2815 on 'Prominence (noise std units)' (lower=-22.075,
upper=149.82)
```



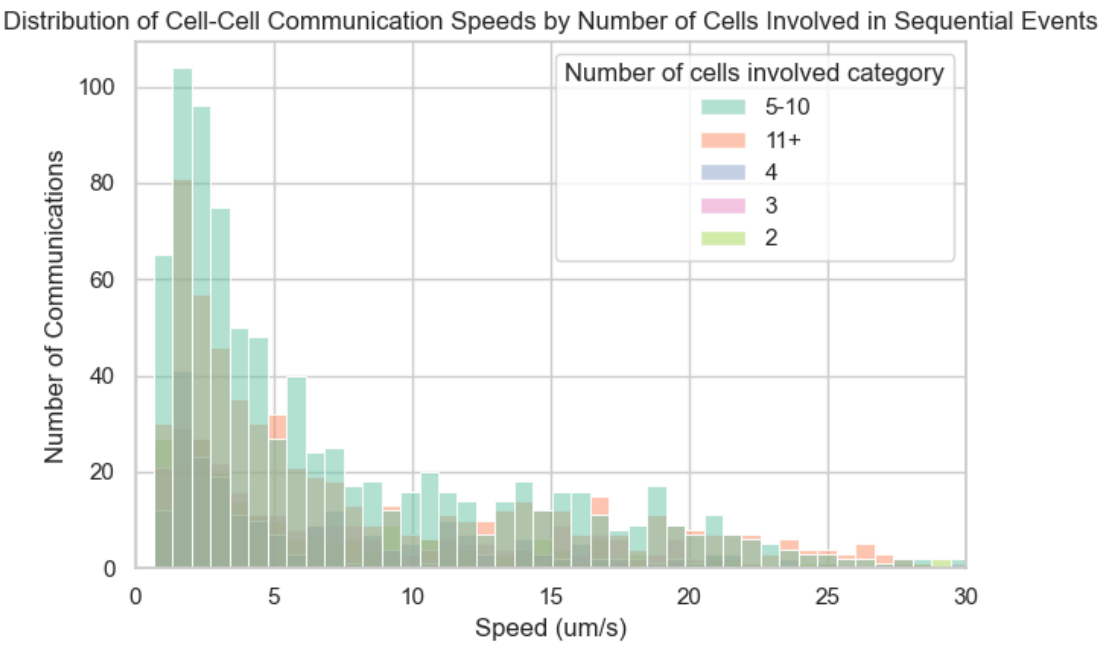



```
[2025-08-11 09:51:55] [INFO] calcium: plot_histogram_by_group: removed 0
```

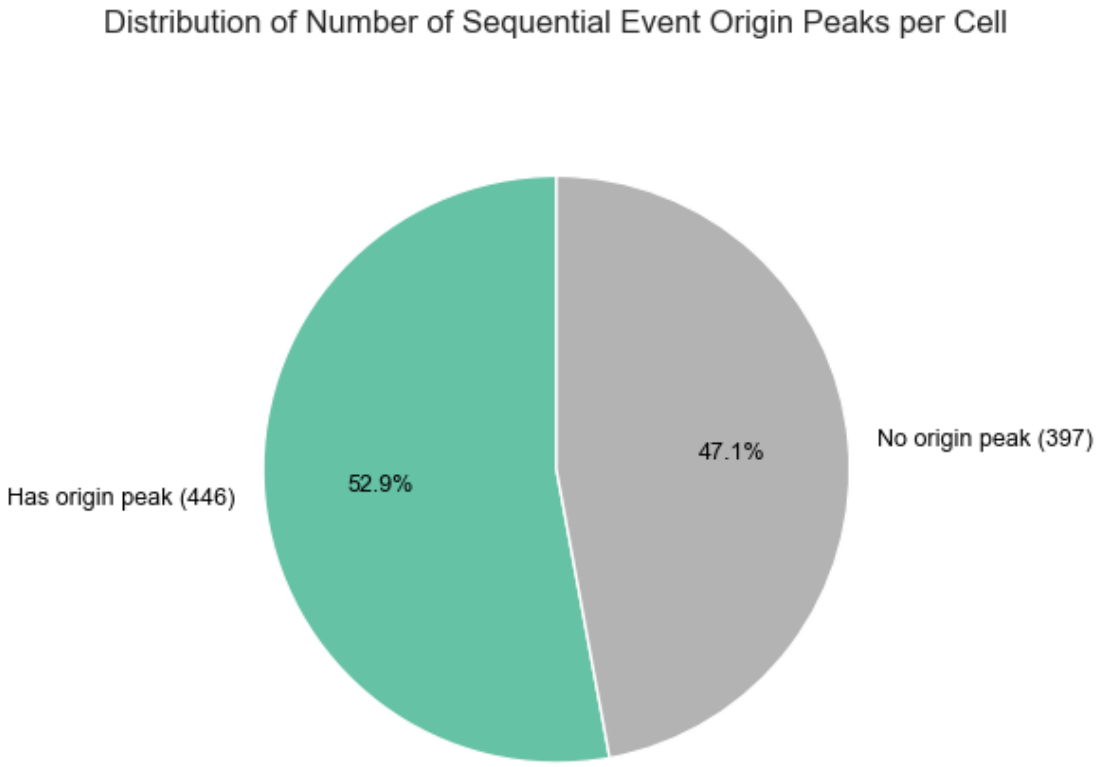
```
outliers out of 630 on 'Average communication speed (um/s)' (lower=-16.478,
upper=29.793)
```

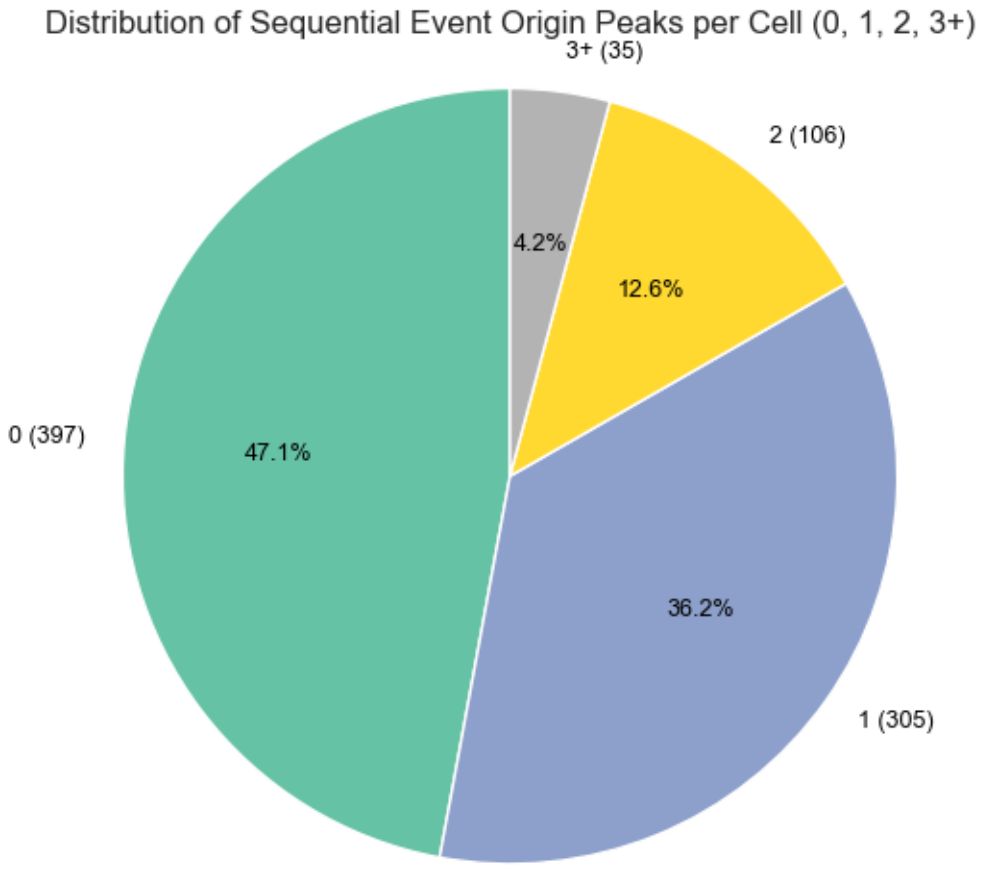



```
[2025-08-11 09:51:55] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 2185 on 'Speed (um/s)' (lower=-25.68, upper=39.63)
```

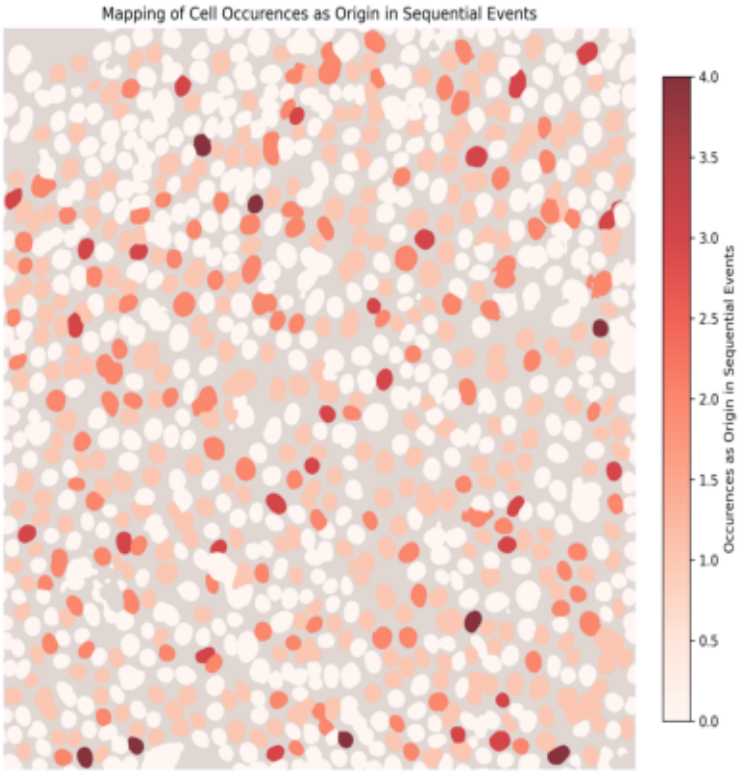

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
5-10
11+
4
3
2
Number of Communications
0
20
40
60
80
100
0
5
10
15
20
25
30
Speed (um/s)

1.3.7 Cells occurences as origin in sequential events

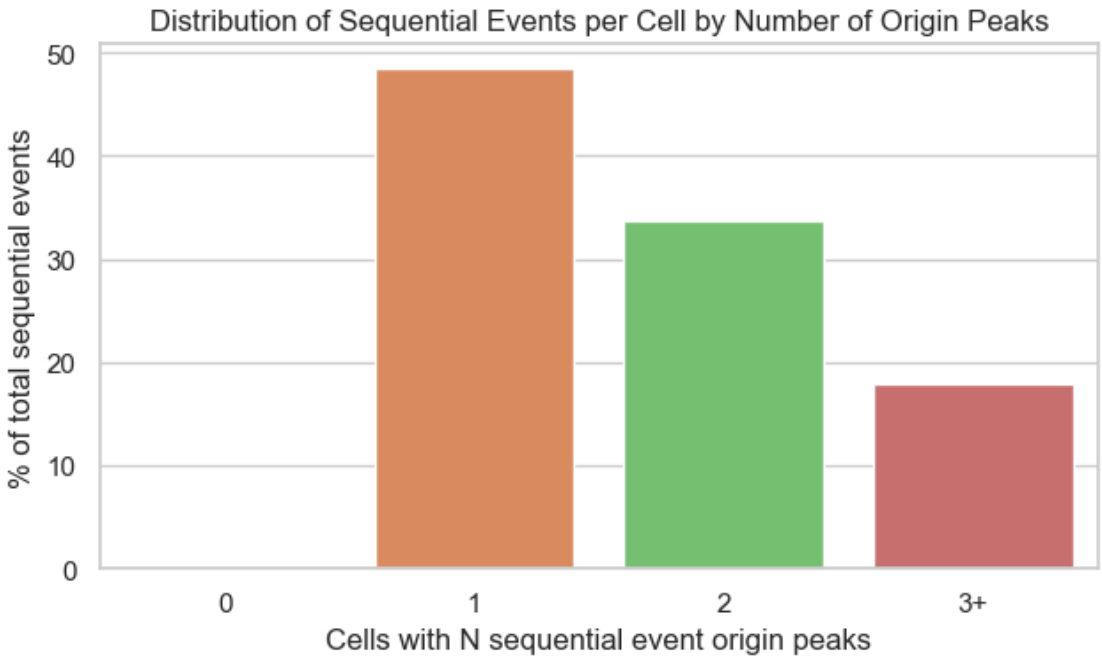



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (35)
2 (106)
4.2%
12.6%
0 (397)
47.1%
36.2%
1 (305)

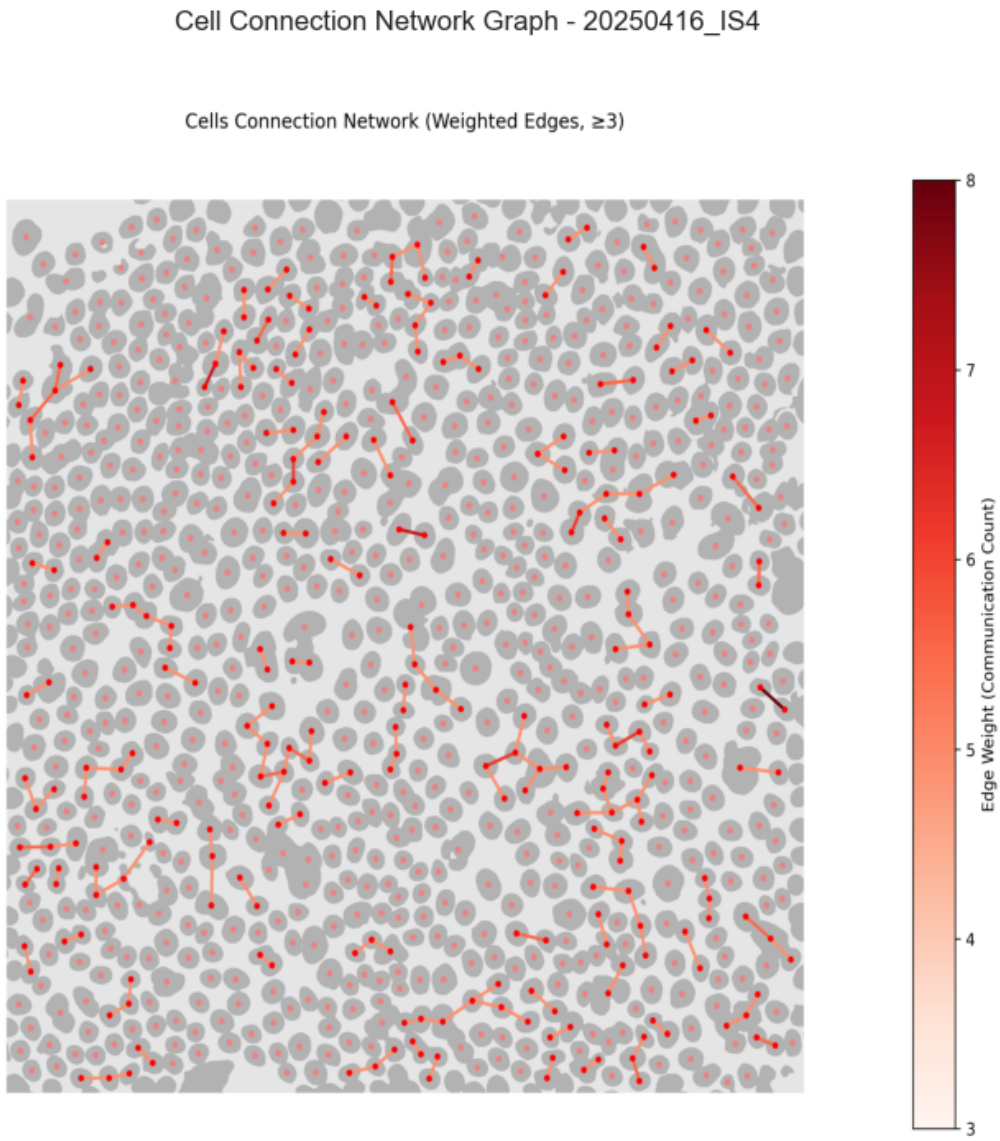
Cell Mapping with Origin Peaks Overlay - 20250416_IS4




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

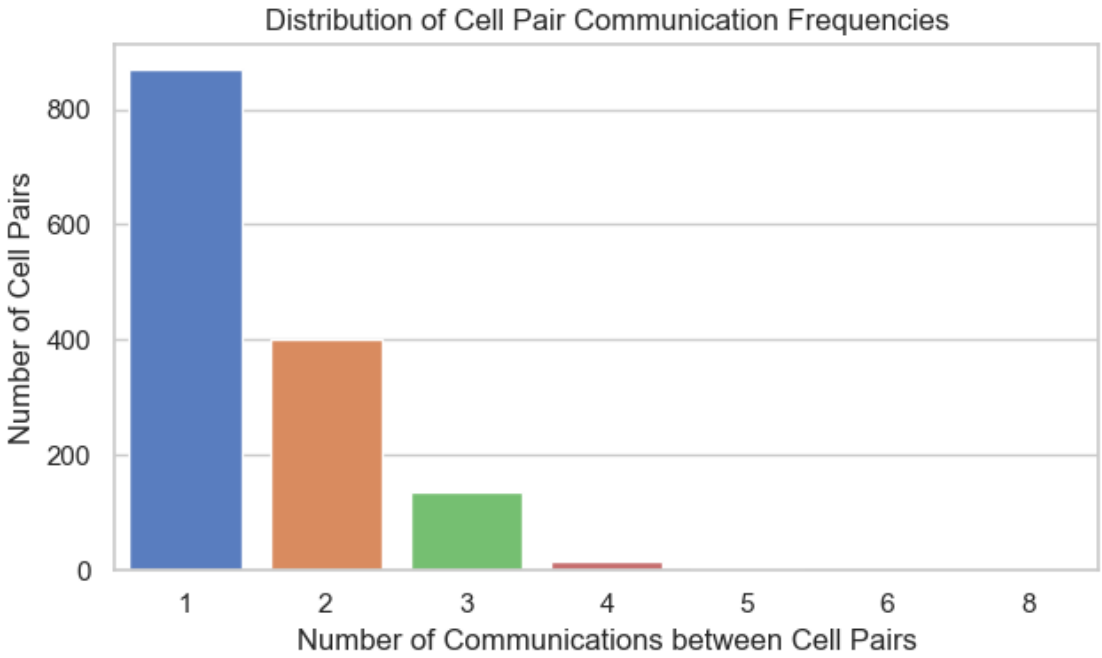

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
50
40
30
20
10
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



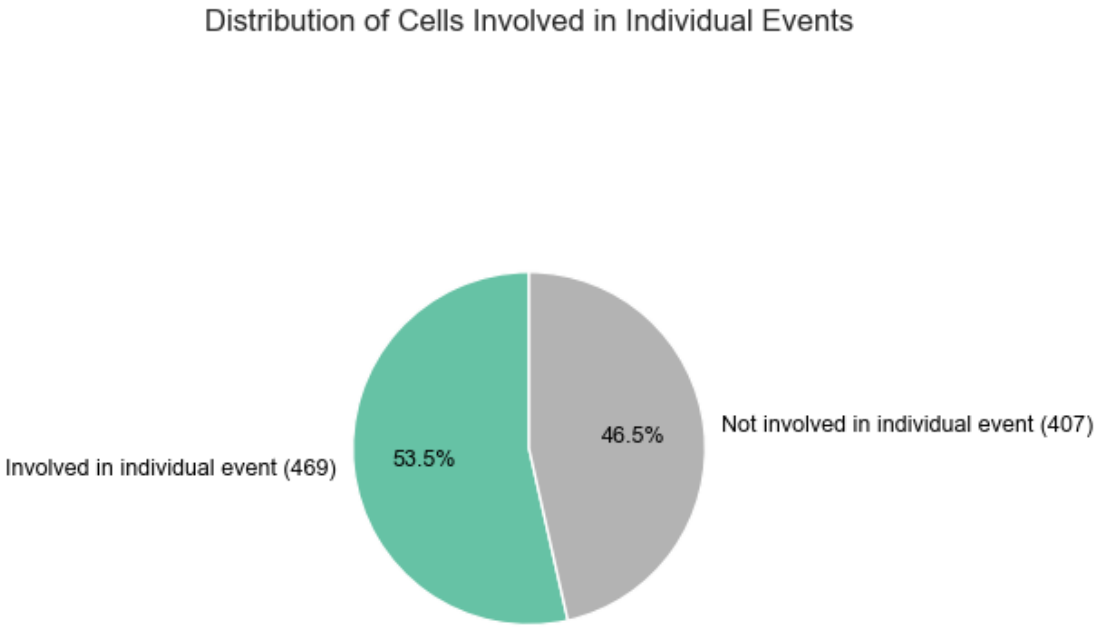

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

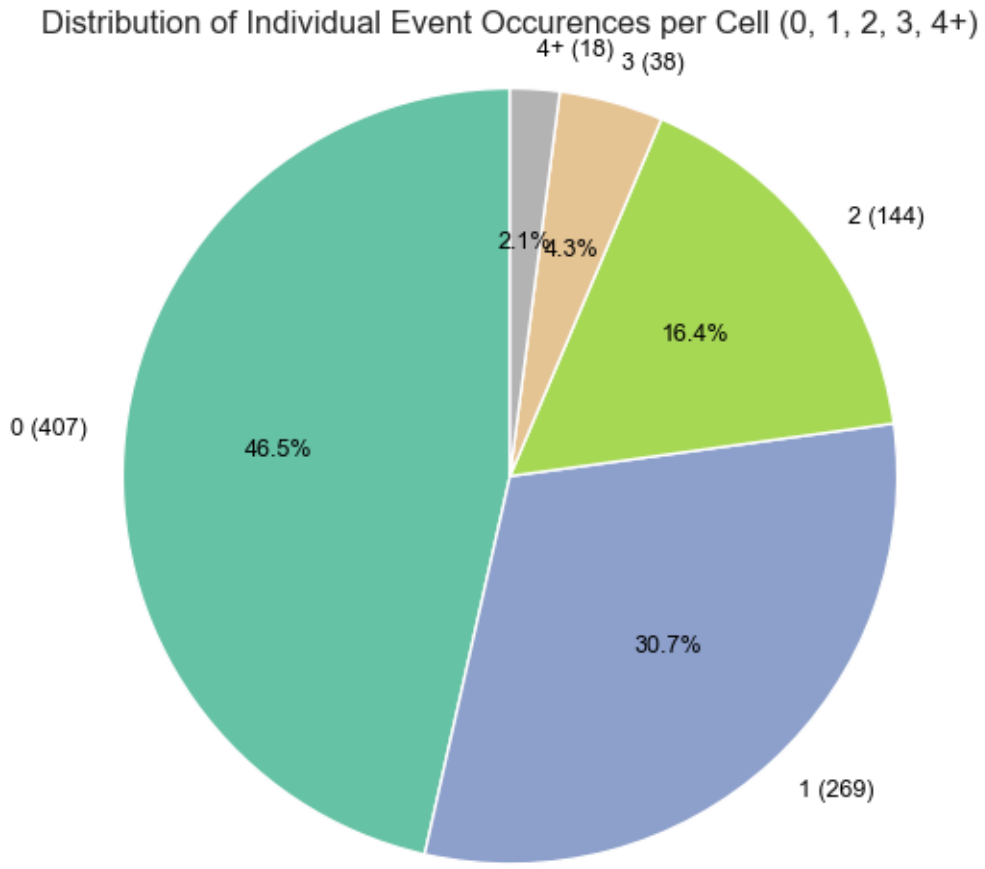
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
800
600
400
200
0
1
2
3
4
5
6
8
Number of Communications between Cell Pairs

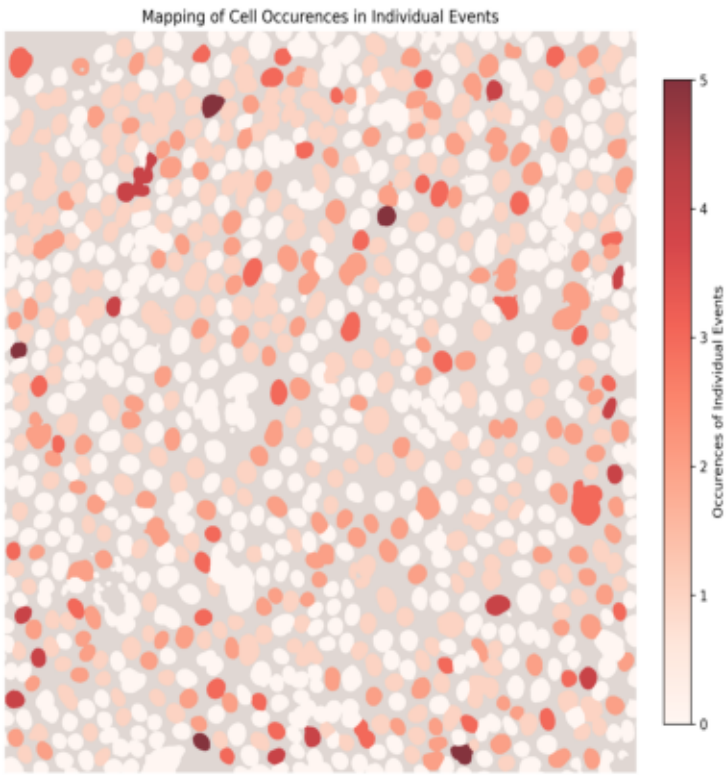
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



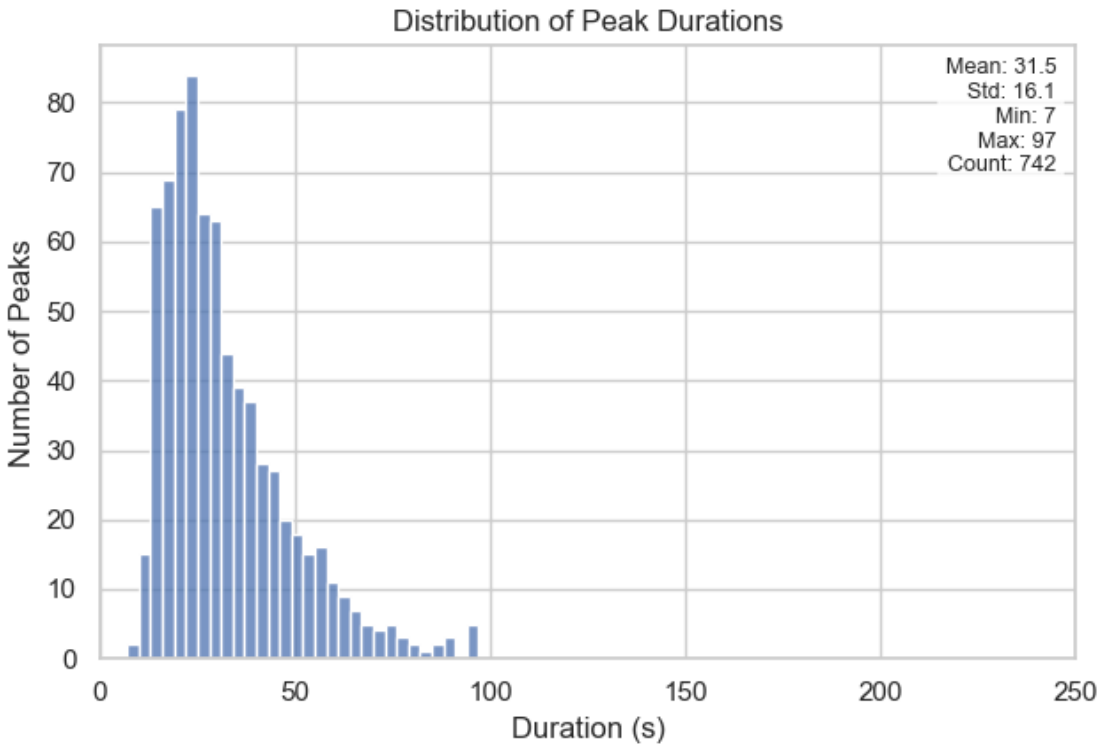

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (18)
3 (38)
2 (144)
2.1%
4.3%
16.4%
0 (407)
46.5%
30.7%
1 (269)

Cell Mapping with Occurences in Individual Events Overlay - 20250416_IS4

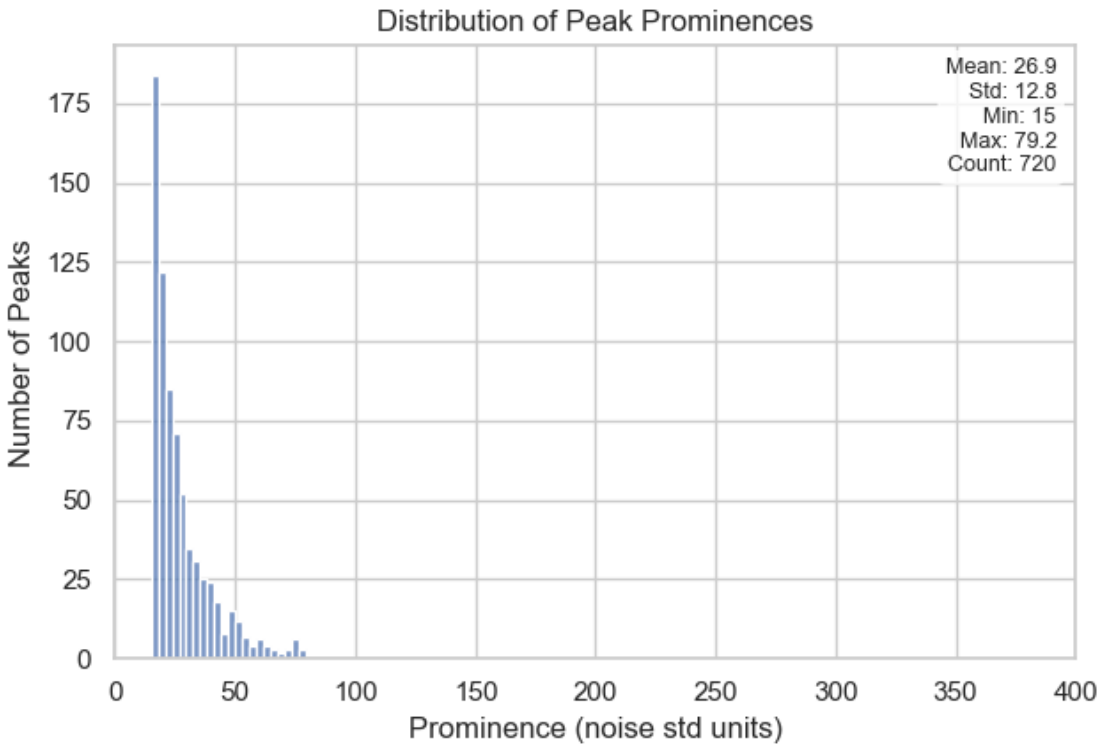


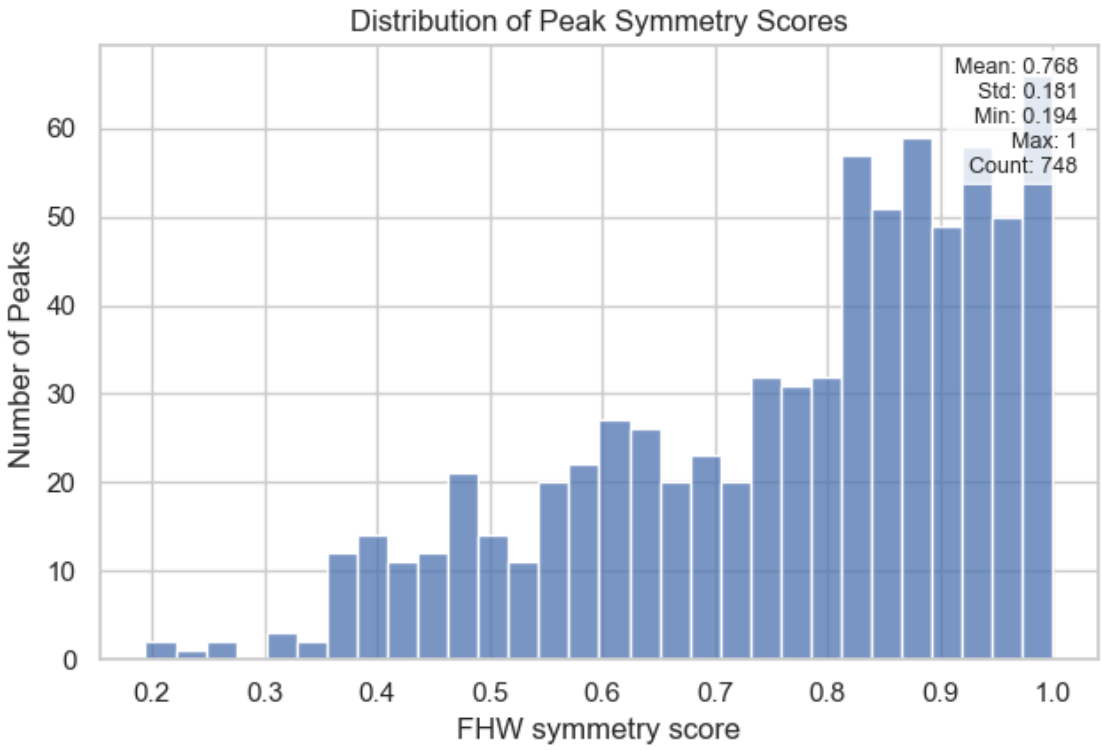
1.4.2 Peaks statistics in individual events

```
[2025-08-11 09:51:59] [INFO] calcium: plot_histogram: removed 6 outliers out of
748 on 'Duration (s)' (lower=-37.75, upper=97)
```

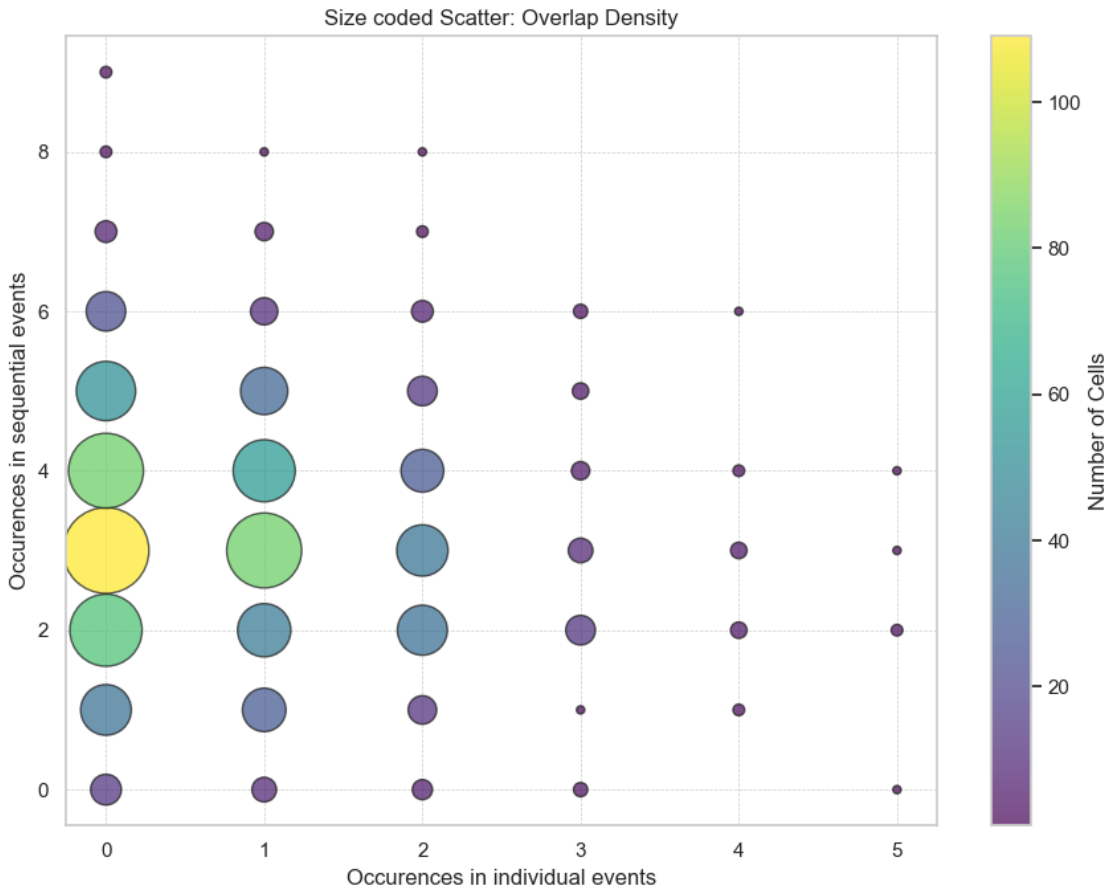



```
[2025-08-11 09:52:00] [INFO] calcium: plot_histogram: removed 28 outliers out of
748 on 'Prominence (noise std units)' (lower=-28.05, upper=79.575)
```

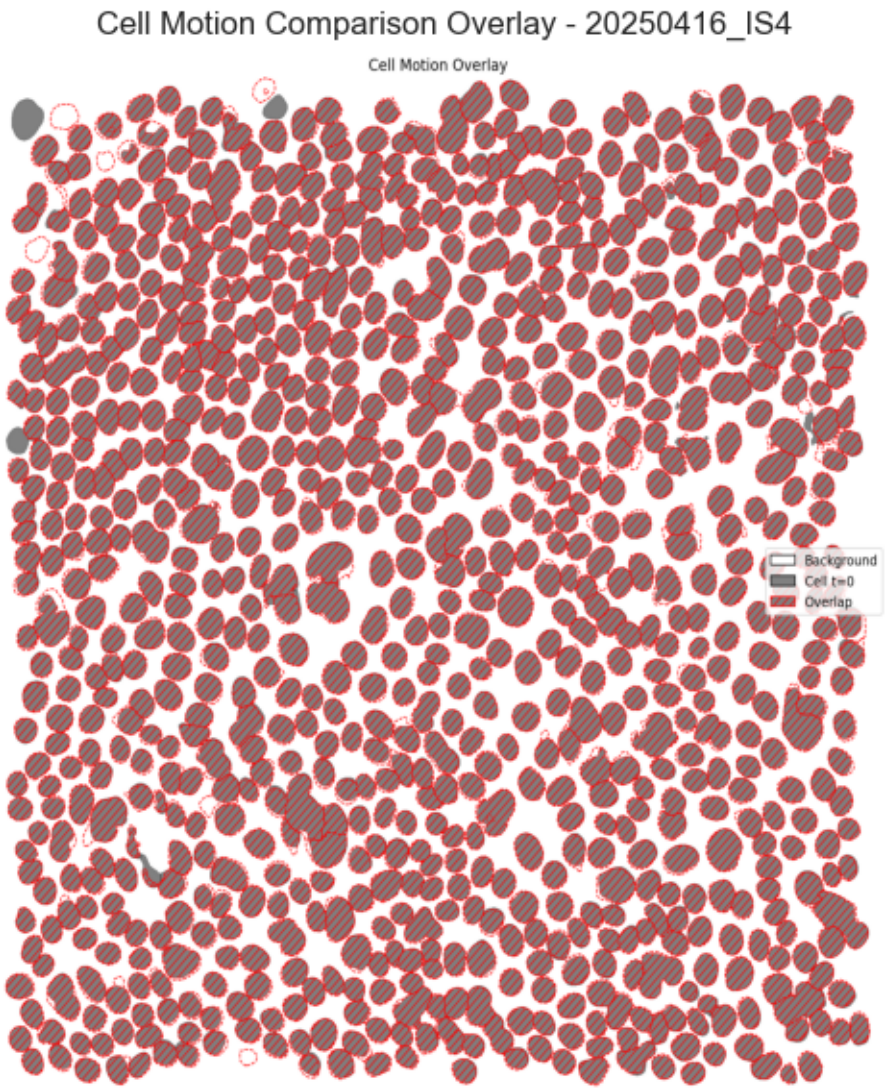

Distribution of Peak Prominences
Mean: 26.9
Std: 12.8
Min: 15
Max: 79.2
Count: 720
Number of Peaks
0
25
50
75
100
125
150
175
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.768
Std: 0.181
Min: 0.194
Max: 1
Count: 748
Number of Peaks
0
10
20
30
40
50
60
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 876
- Hoechst image taken at t=1801: 868
- Number of cells difference: absolute 8, relative 0.92%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 1254566
- Pixels segmented as cell at t=1801: 1290238
- Overlapping pixels between t=0 and t=1801: 1201518(94.43% of total)
- Pixels exclusive to t=0: 53048 (4.23% of total)
- Pixels exclusive to t=1801: 88720 (6.88% of total)
```

executed

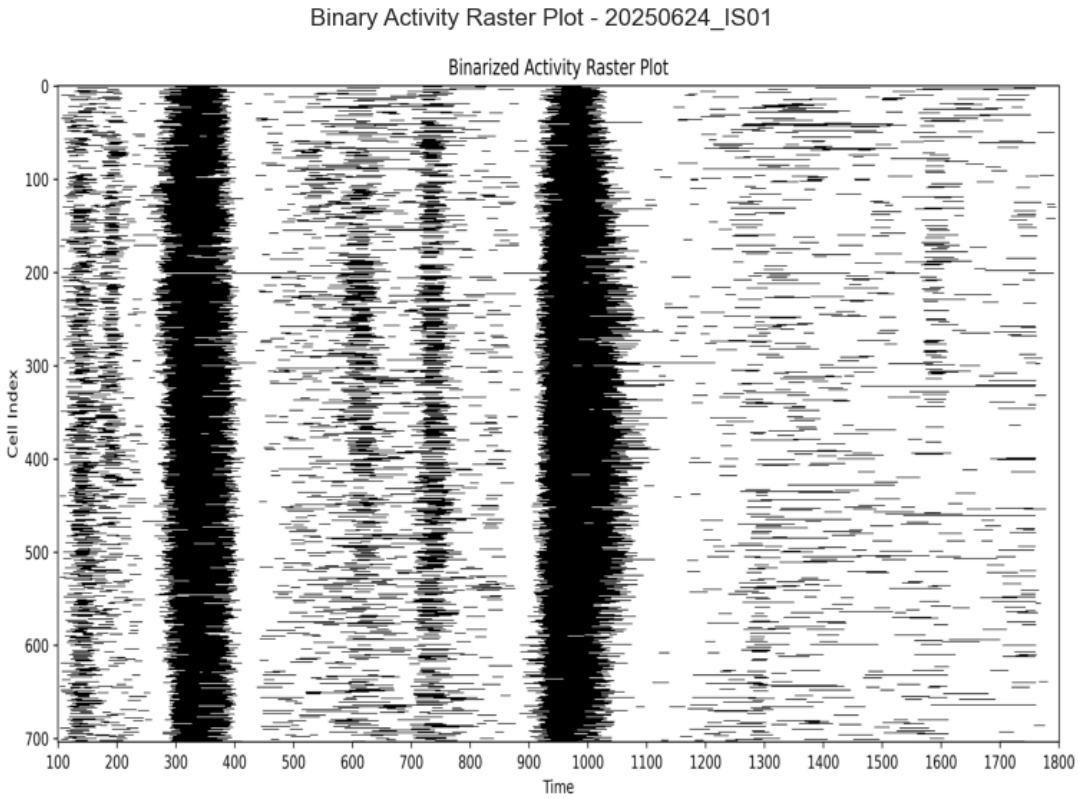
August 11, 2025

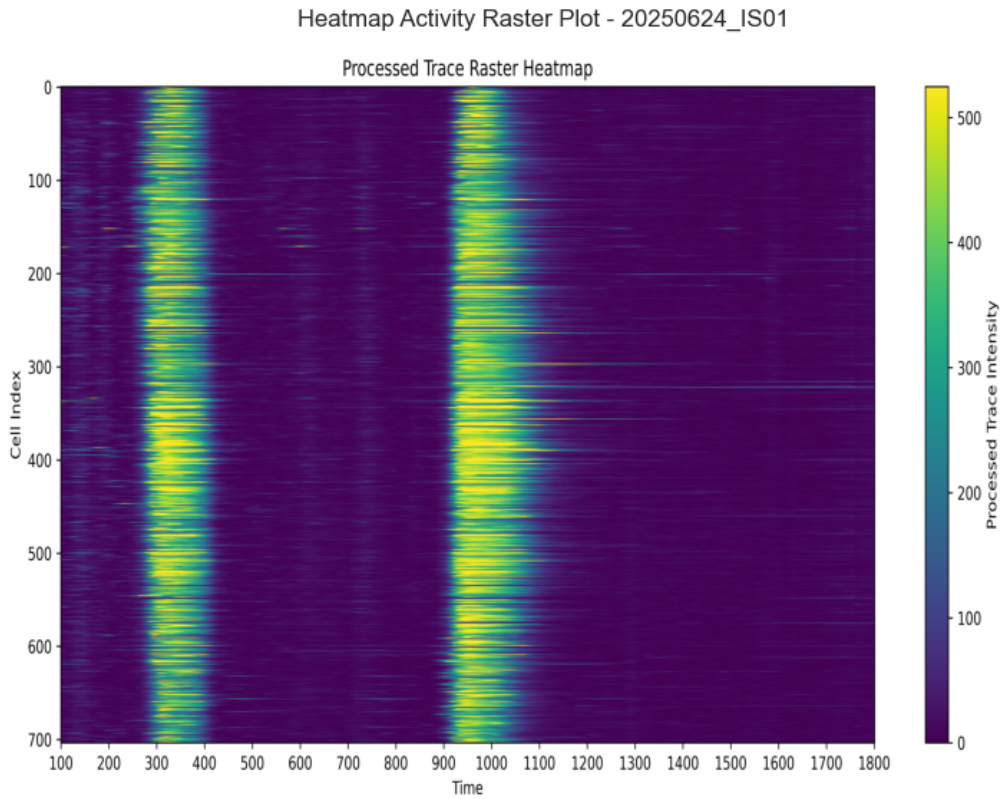
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



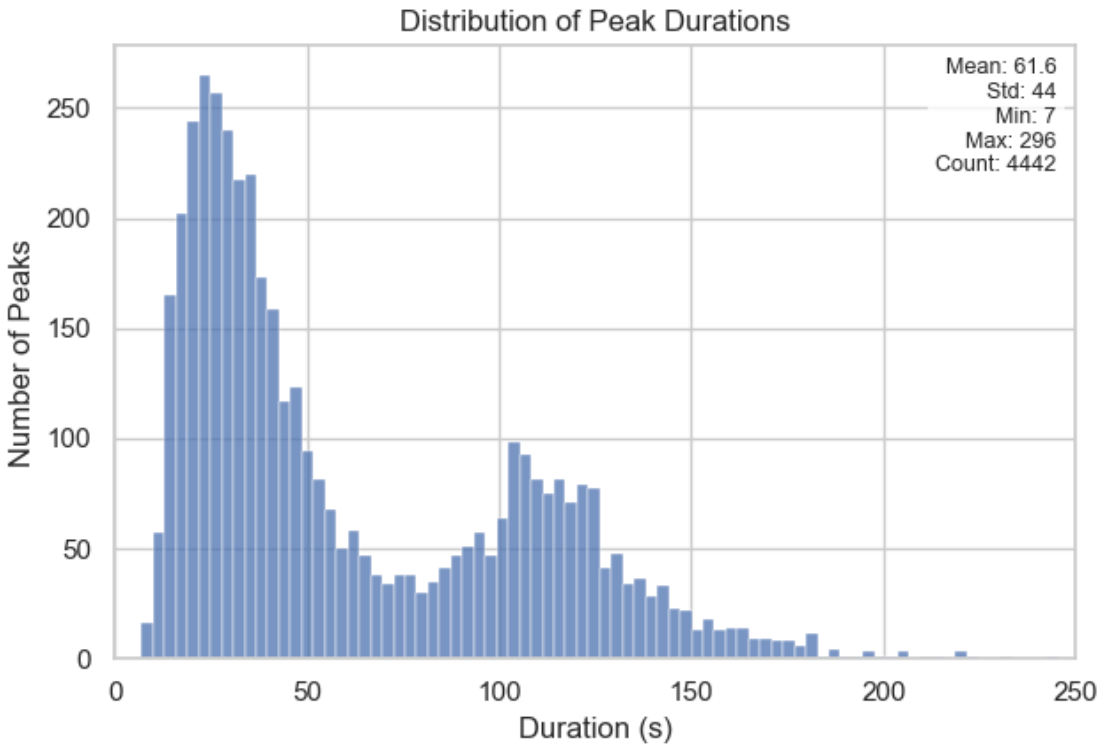


1.1.2 Peaks population

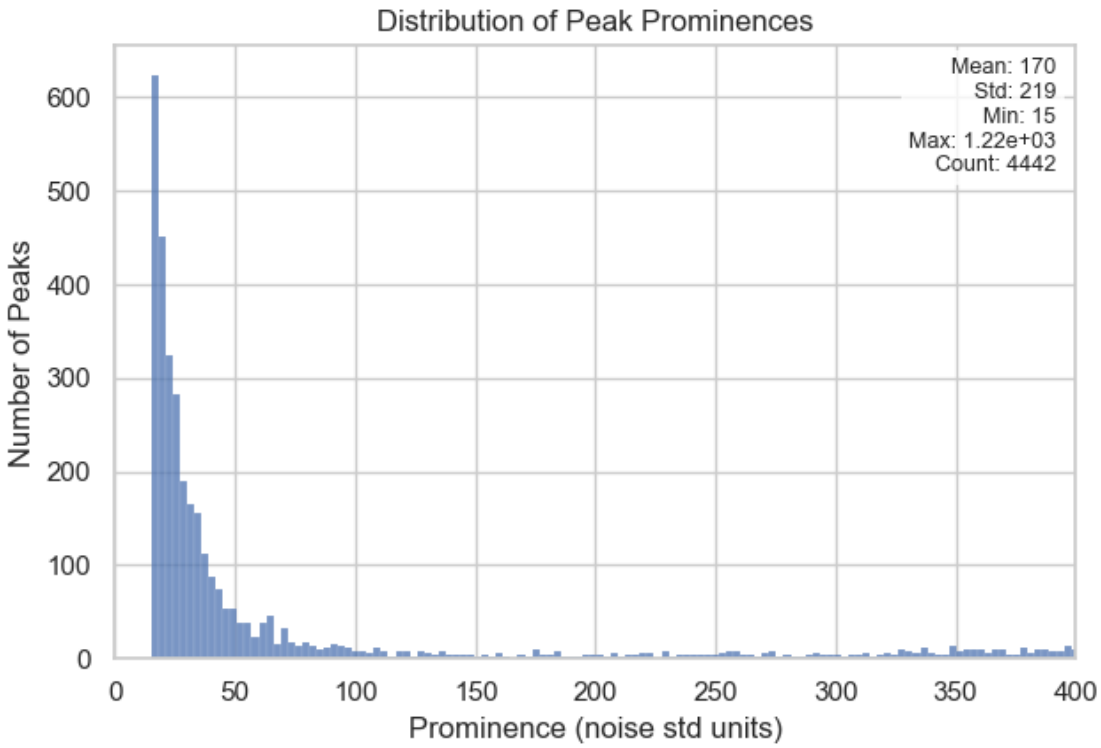
```
Total number of peaks: 4443
Total number of cells: 704
```

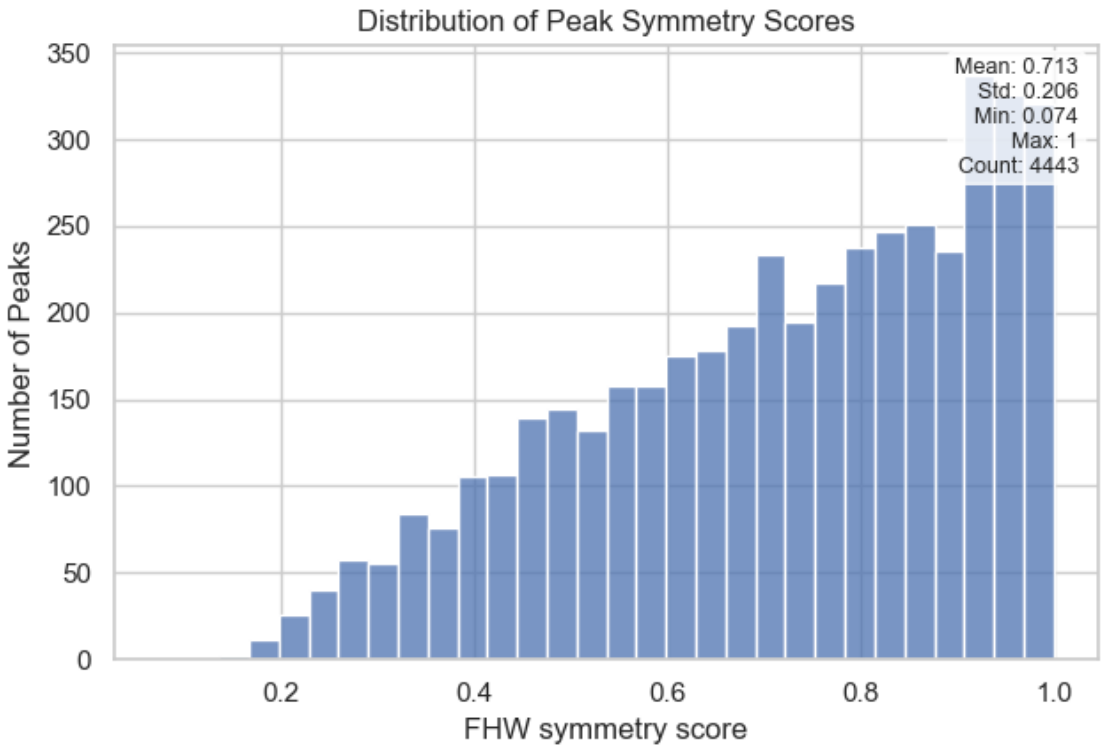
1.1.3 Peaks statistics

```
[2025-08-11 10:13:48] [INFO] calcium: plot_histogram: removed 1 outliers out of
4443 on 'Duration (s)' (lower=-199, upper=326)
```

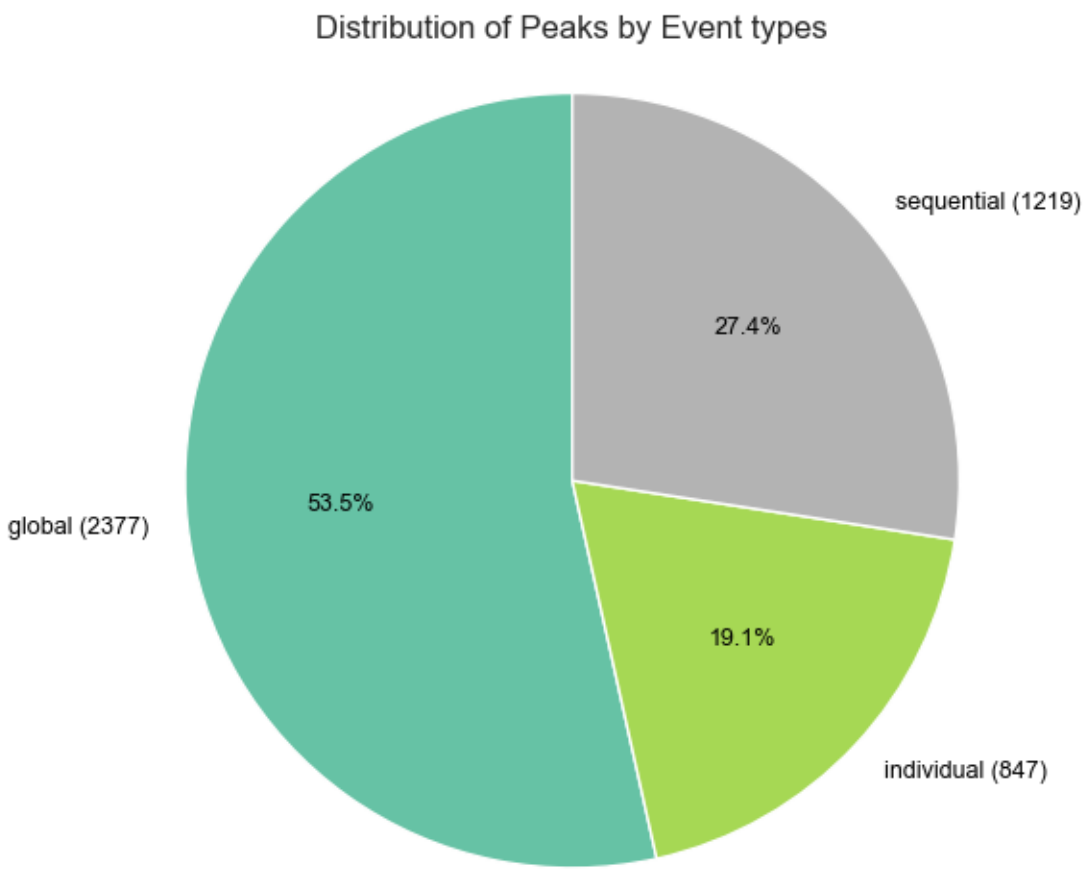



```
[2025-08-11 10:13:48] [INFO] calcium: plot_histogram: removed 1 outliers out of
4443 on 'Prominence (noise std units)' (lower=-929.05, upper=1288.2)
```


Distribution of Peak Prominences
Mean: 170
Std: 219
Min: 15
Max: 1.22e+03
Count: 4442
Number of Peaks
0
100
200
300
400
500
600
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

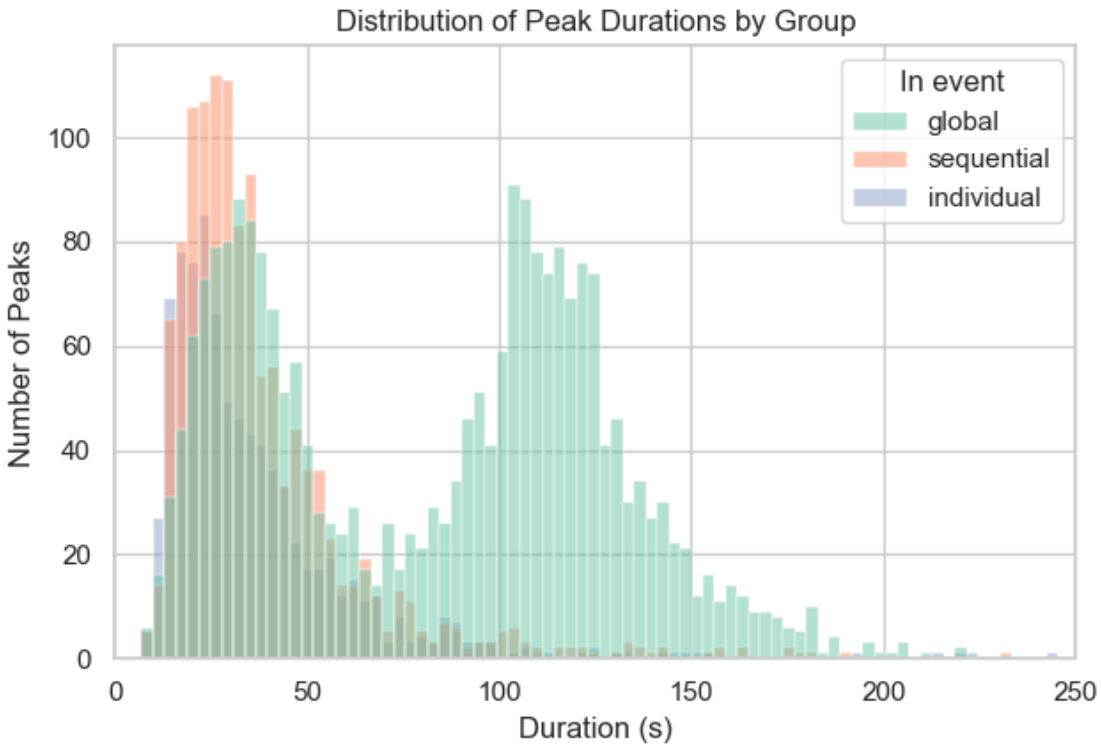

Distribution of Peak Symmetry Scores
Mean: 0.713
Std: 0.206
Min: 0.074
Max: 1
Count: 4443
Number of Peaks
0
50
100
150
200
250
300
350
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

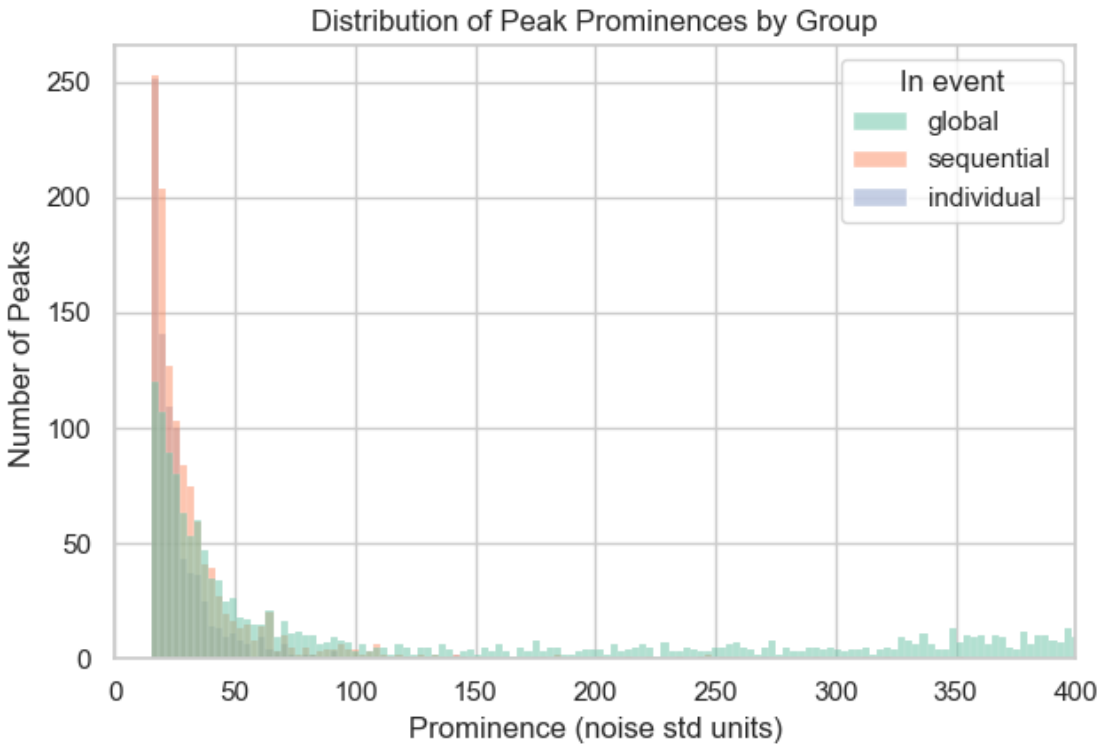


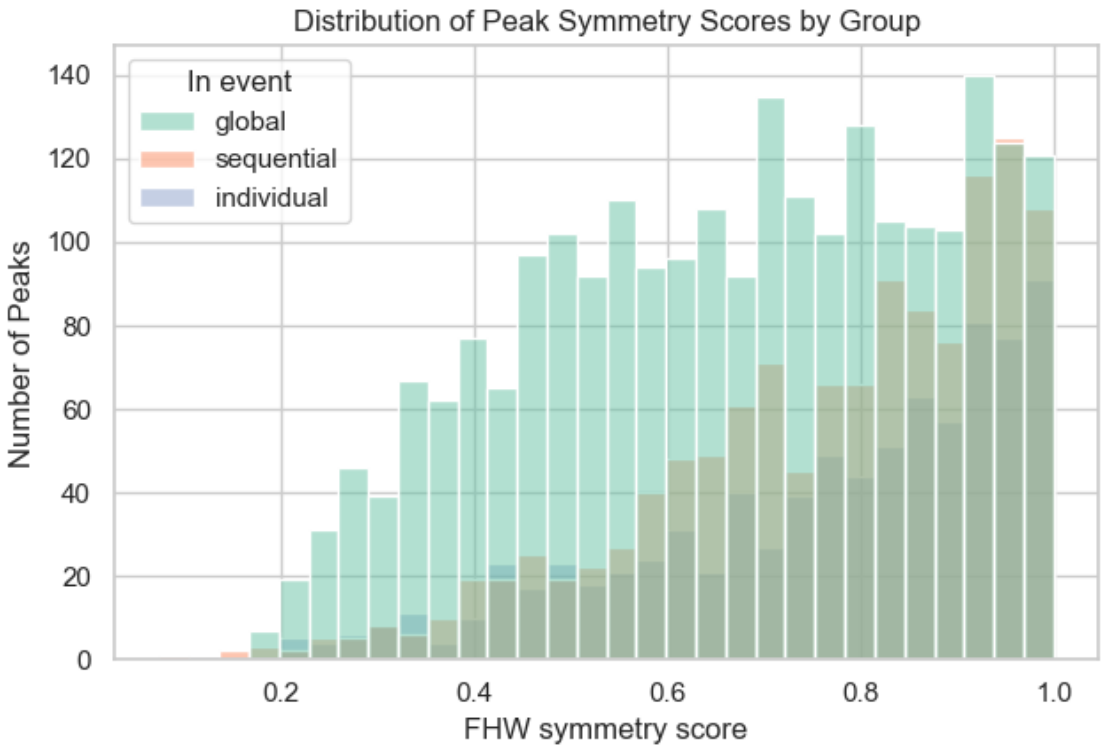
1.1.5 Peaks statistics per event types

```
[2025-08-11 10:13:49] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 4443 on 'Duration (s)' (lower=-199, upper=326)
```




```
[2025-08-11 10:13:49] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 4443 on 'Prominence (noise std units)' (lower=-929.05,
upper=1288.2)
```

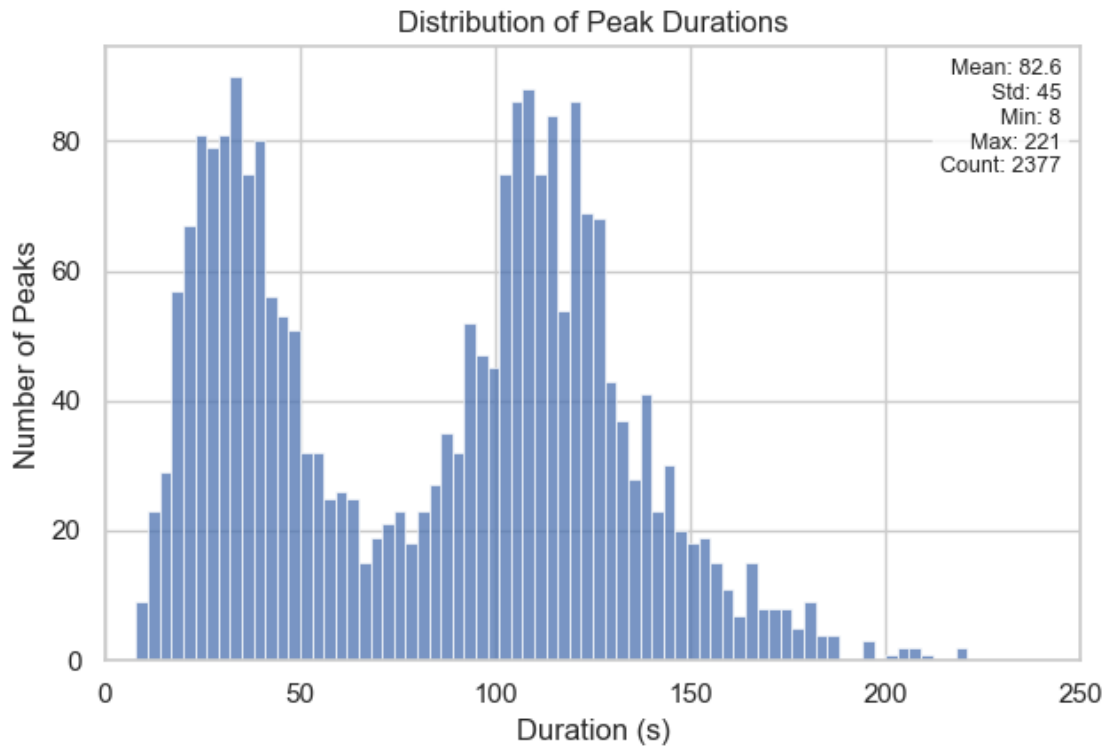

Distribution of Peak Prominences by Group
In event
global
sequential
individual
Number of Peaks
0
50
100
150
200
250
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
global
sequential
individual
Number of Peaks
0
20
40
60
80
100
120
140
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

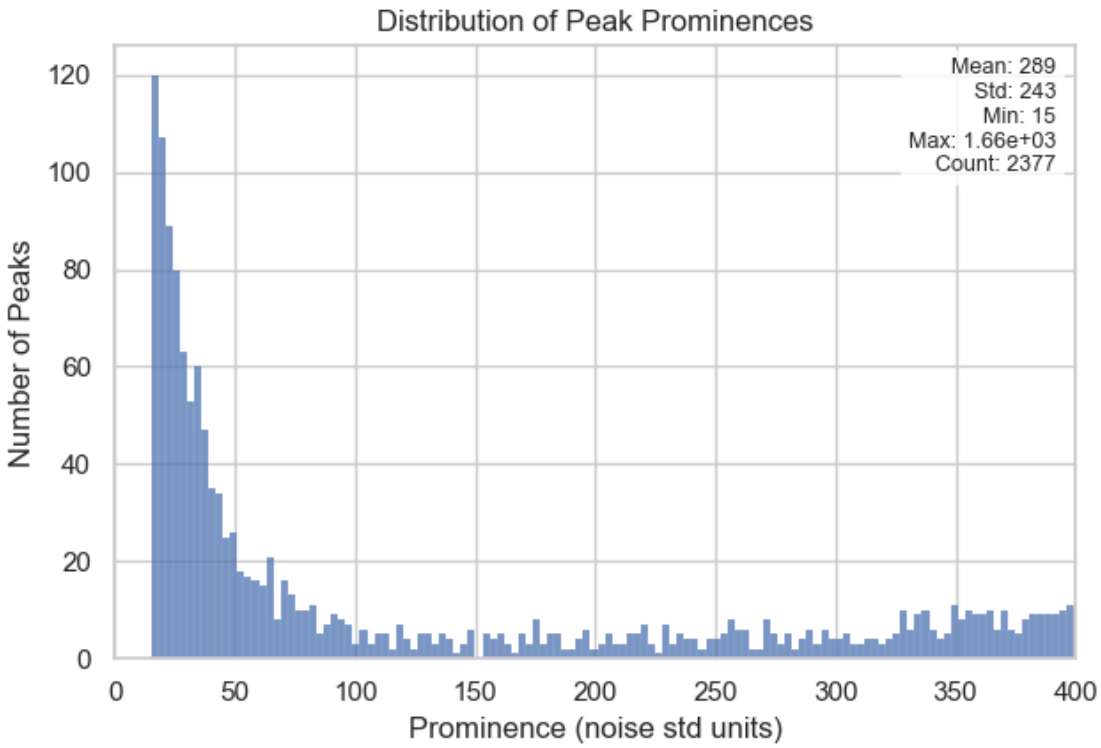
1.2 GLOBAL EVENTS

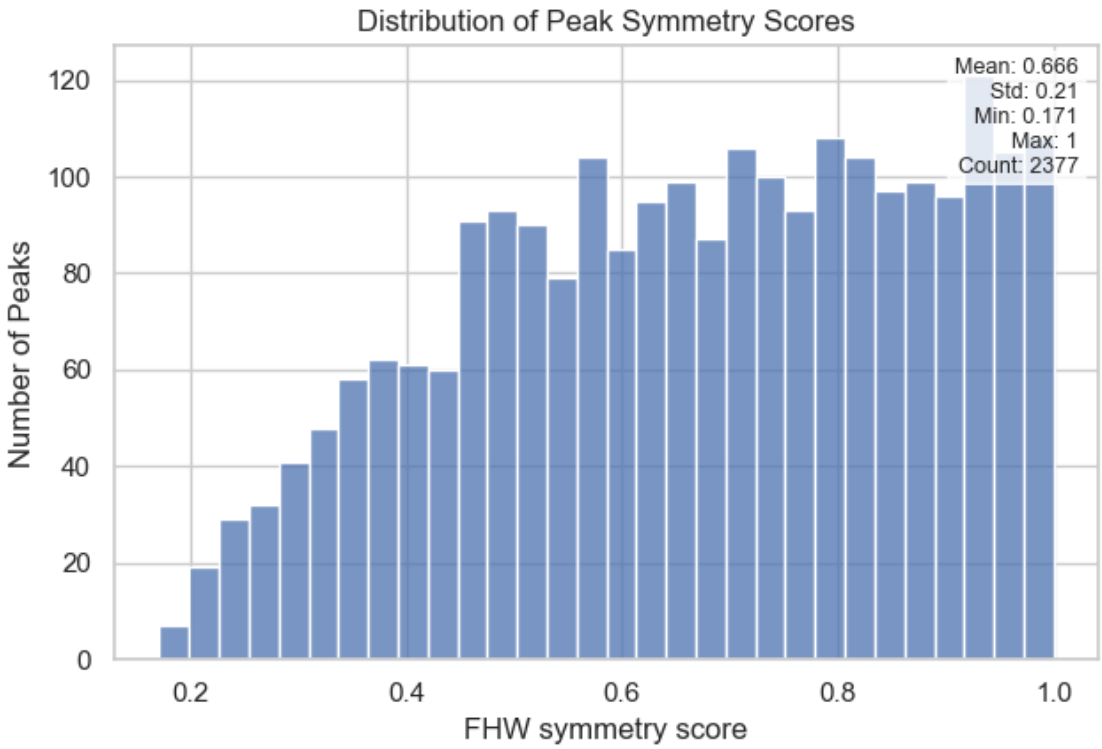
1.2.1 Peak statistics in global events

```
[2025-08-11 10:13:50] [INFO] calcium: plot_histogram: removed 0 outliers out of
2377 on 'Duration (s)' (lower=-202, upper=358)
```



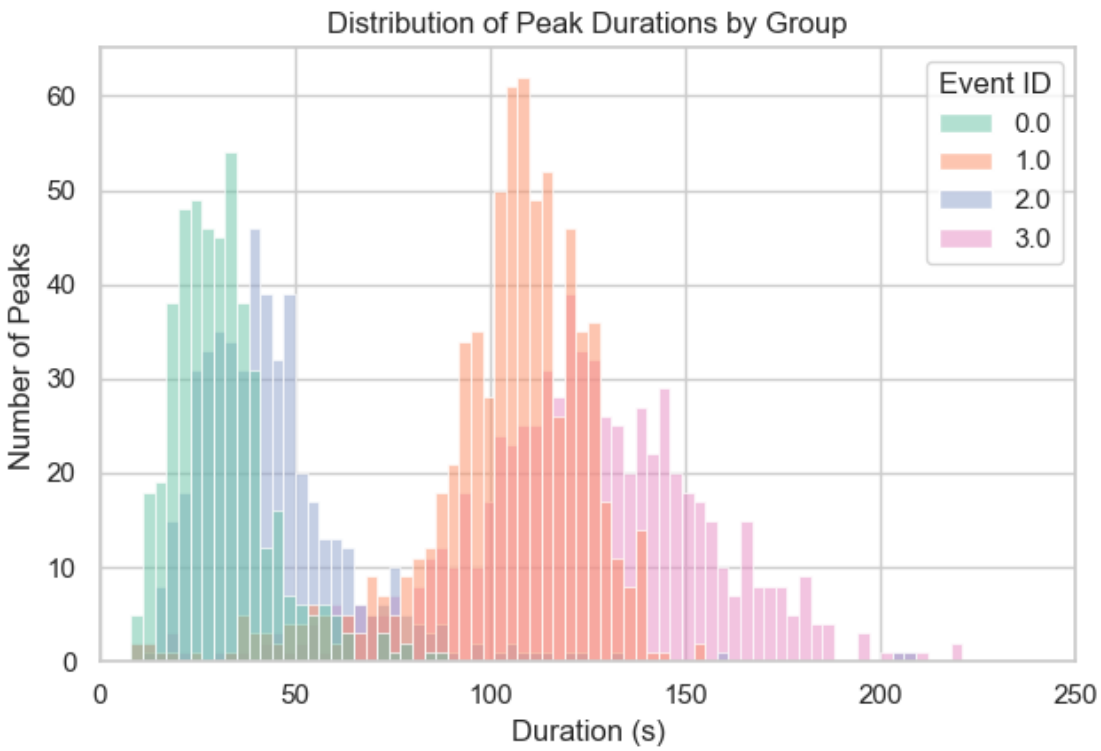

```
[2025-08-11 10:13:50] [INFO] calcium: plot_histogram: removed 0 outliers out of
2377 on 'Prominence (noise std units)' (lower=-1329.4, upper=1859.8)
```


Distribution of Peak Prominences
Mean: 289
Std: 243
Min: 15
Max: 1.66e+03
Count: 2377
Number of Peaks
Prominence (noise std units)
0
20
40
60
80
100
120
0
50
100
150
200
250
300
350
400

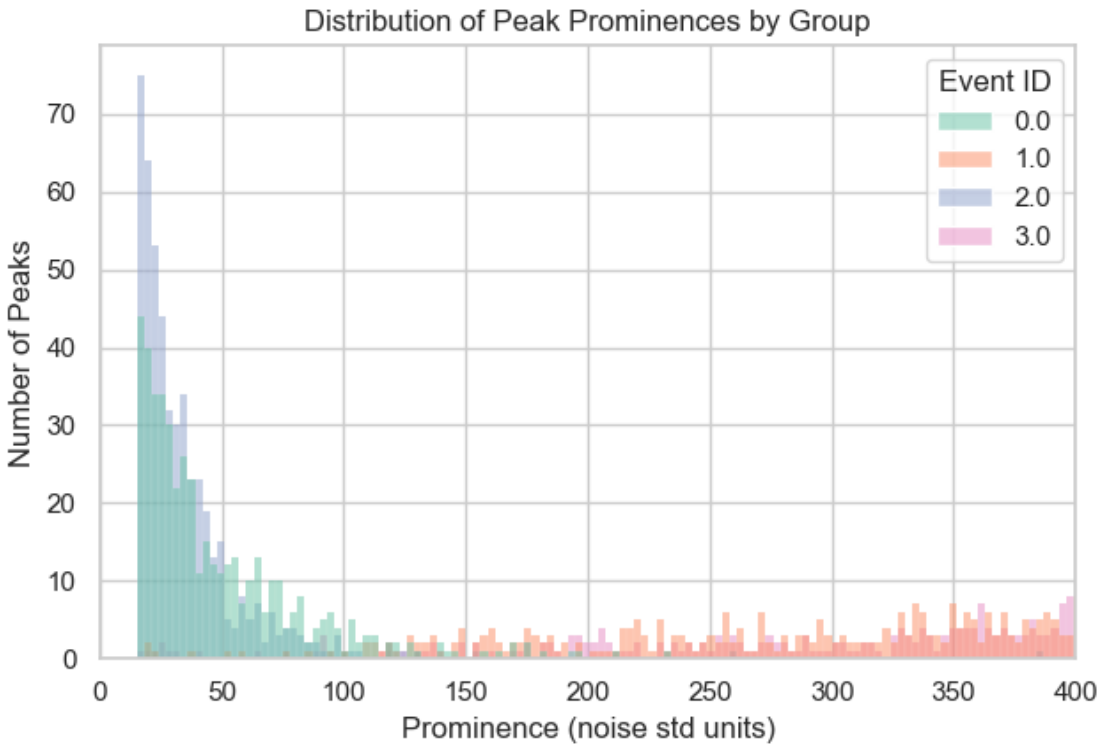

Distribution of Peak Symmetry Scores
Mean: 0.666
Std: 0.21
Min: 0.171
Max: 1
Count: 2377
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0

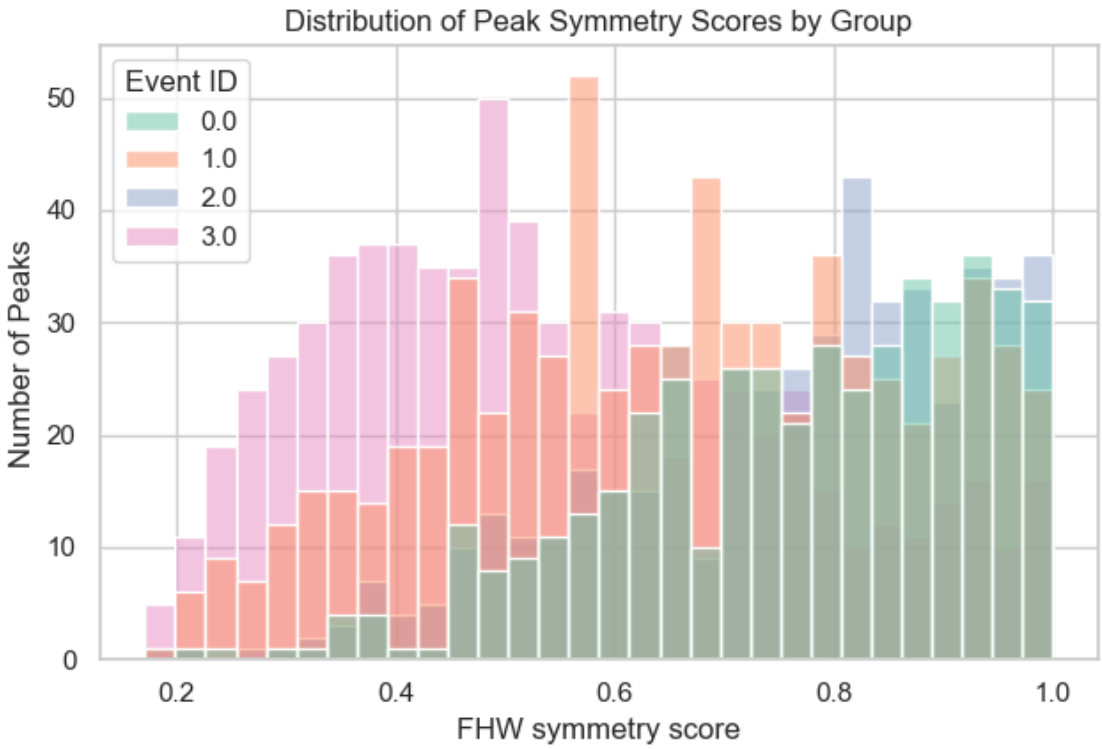
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 10:13:51] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 2377 on 'Duration (s)' (lower=-202, upper=358)
```

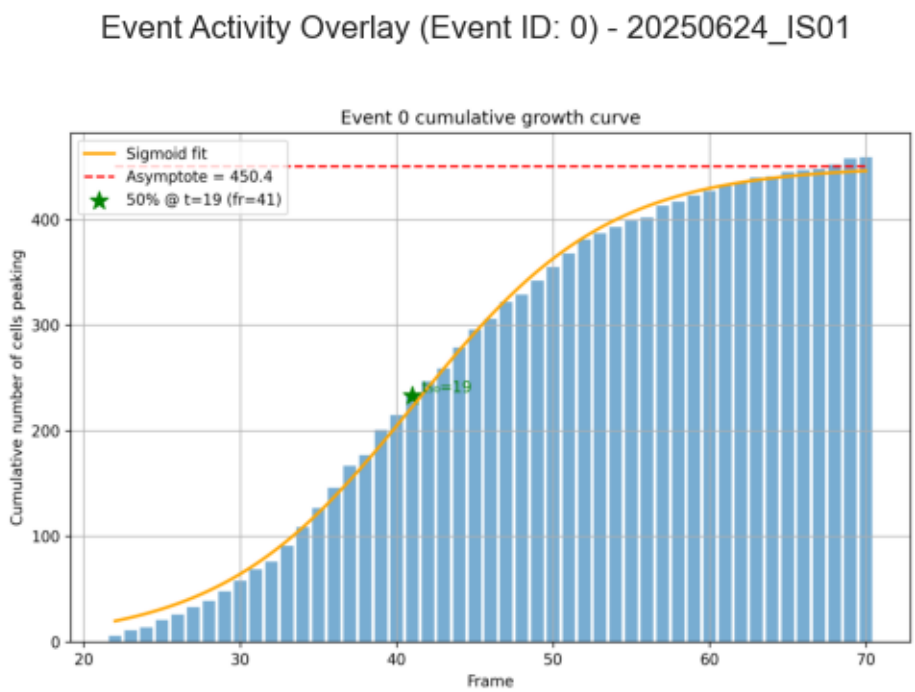


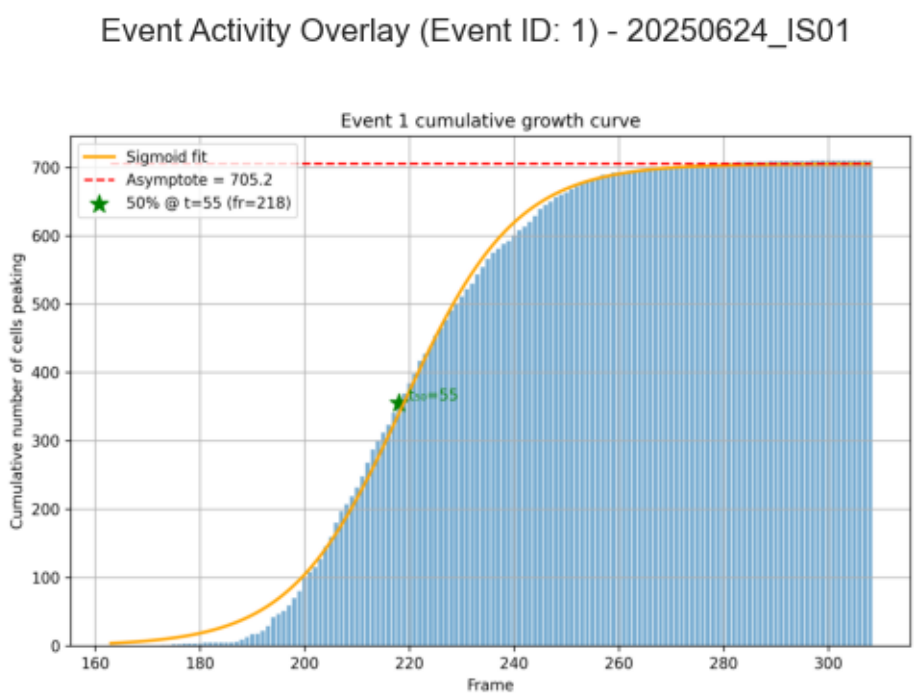

```
[2025-08-11 10:13:52] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 2377 on 'Prominence (noise std units)' (lower=-1329.4,
upper=1859.8)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

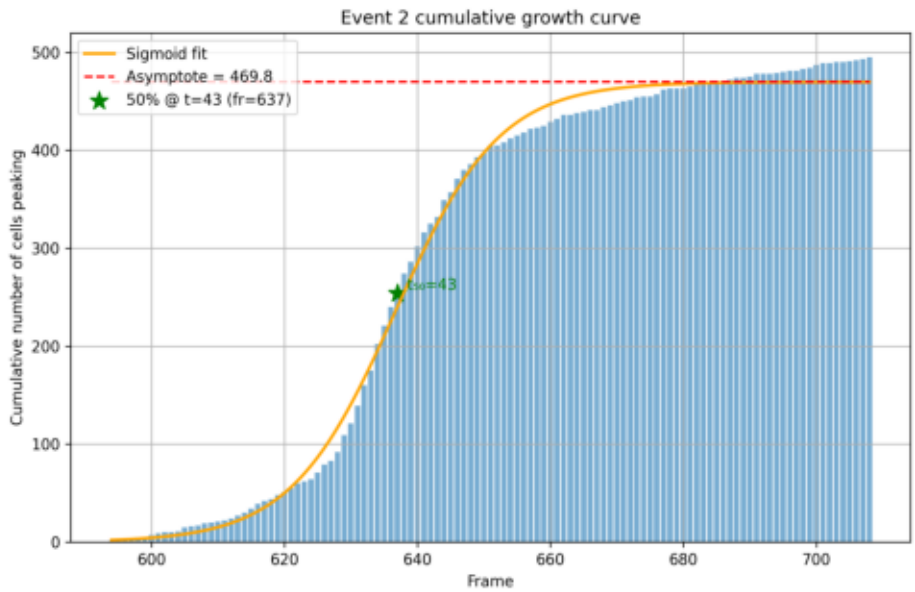

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
3.0
Number of Peaks
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.2.3 Kinetics of global events

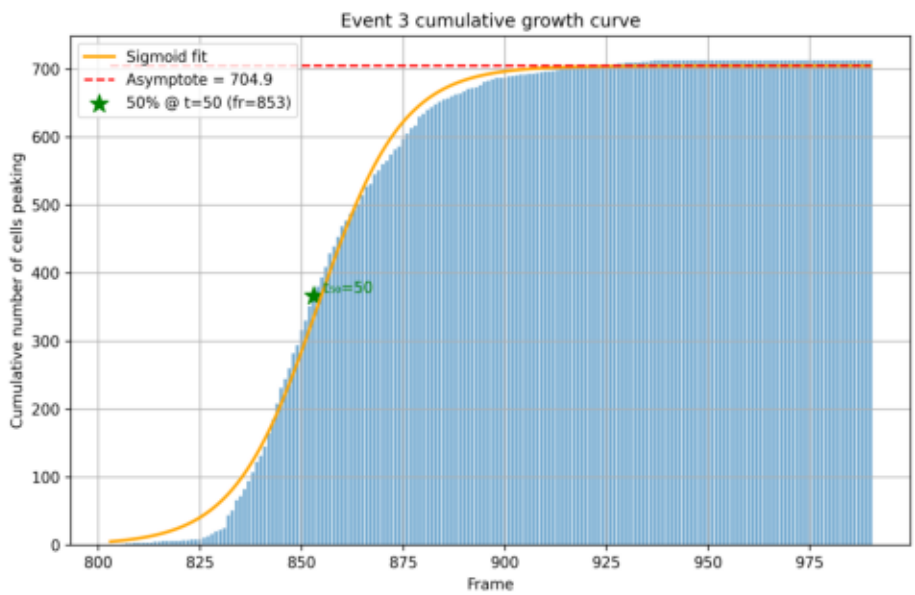




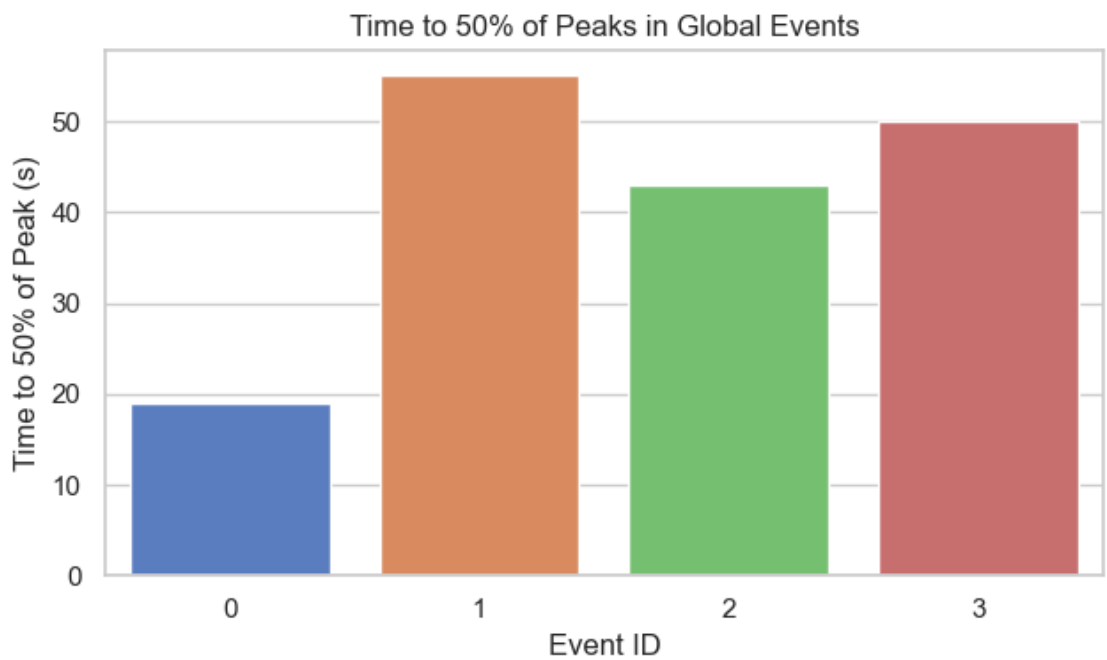
Event Activity Overlay (Event ID: 2) - 20250624_IS01



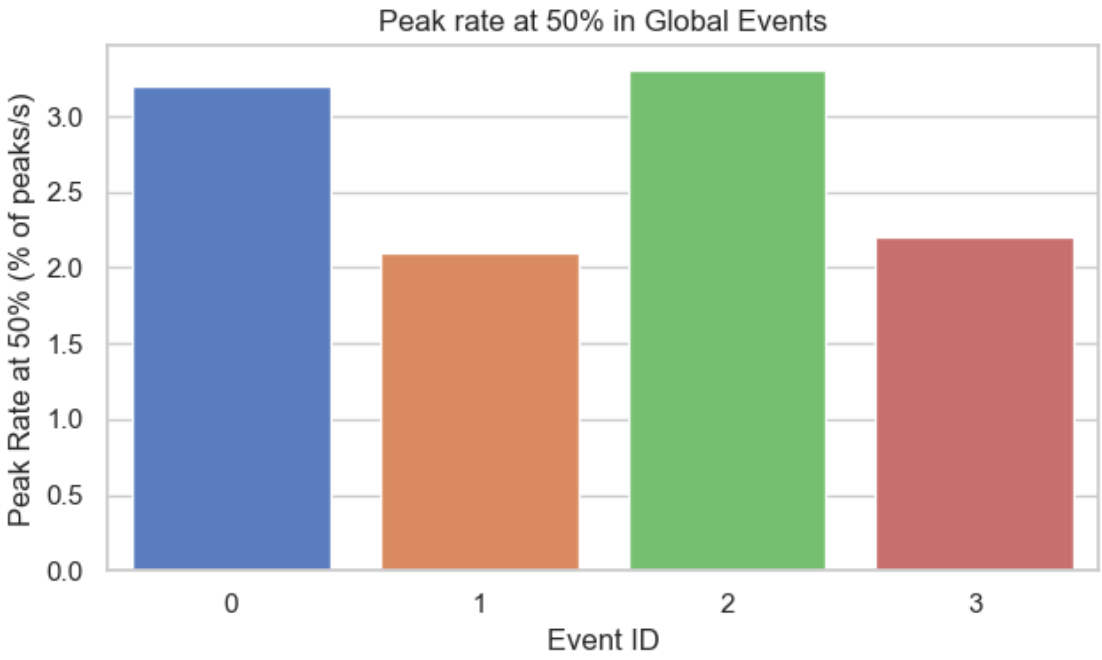
Event Activity Overlay (Event ID: 3) - 20250624_IS01



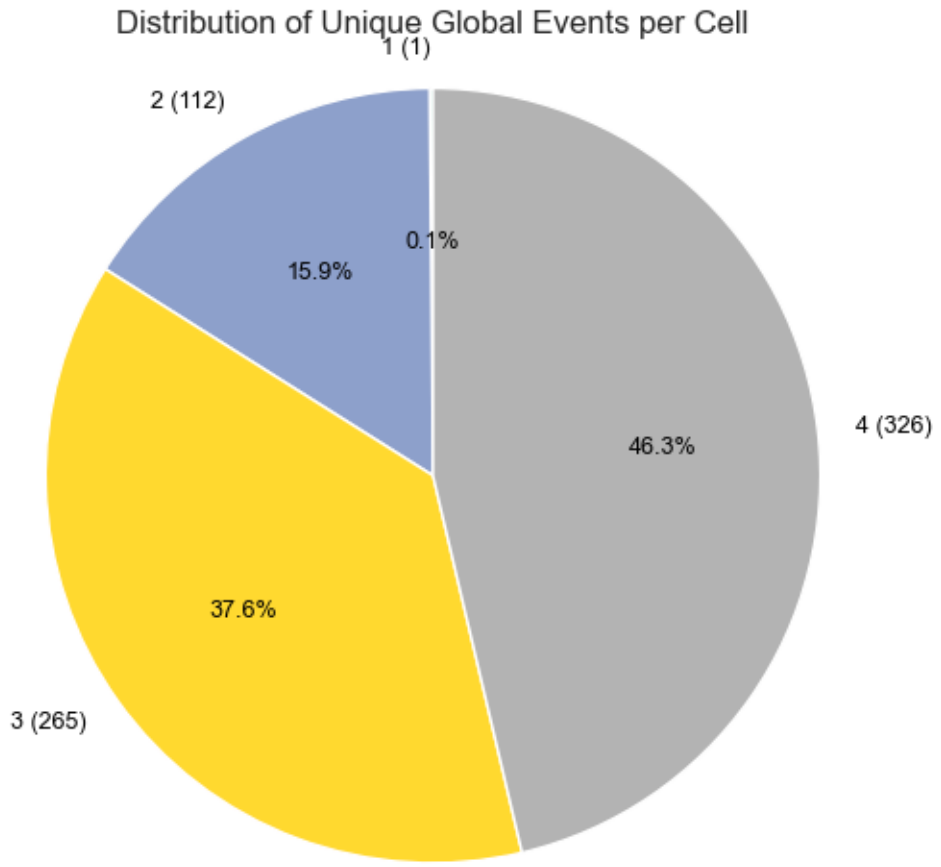
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



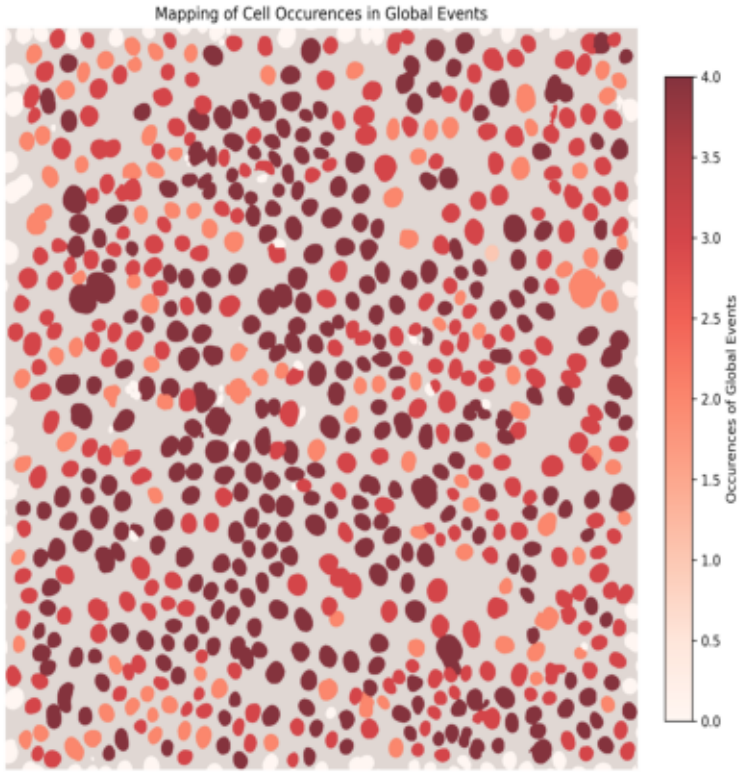

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
1
2
3
Event ID

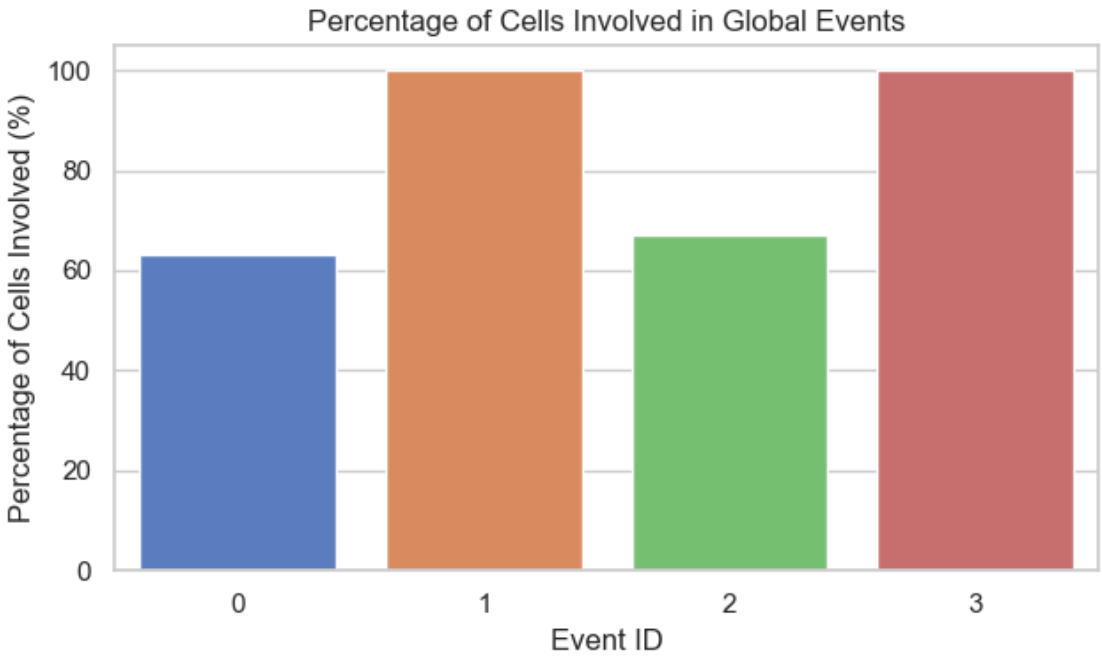
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250624_IS01




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

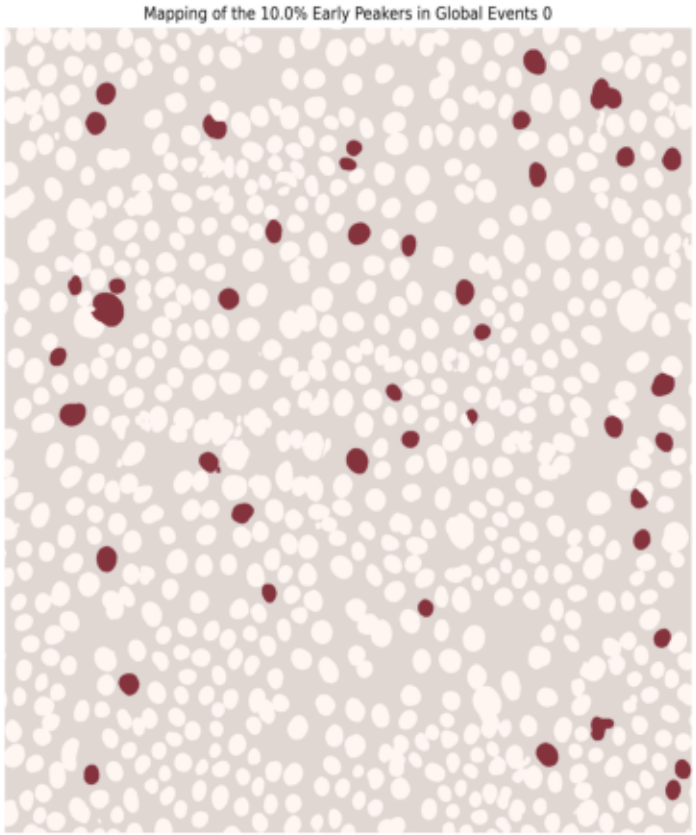


1.2.5 Inter-event interval analysis

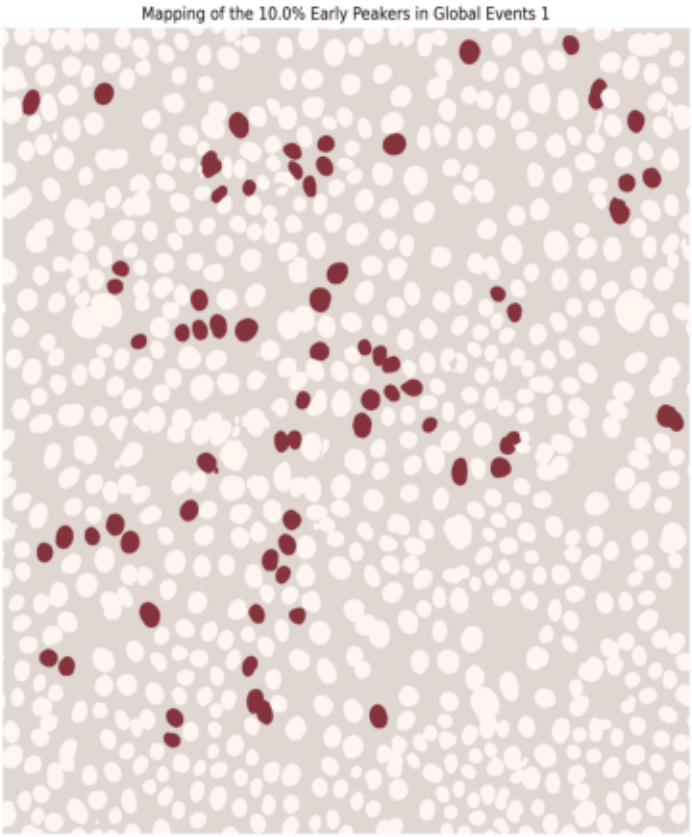
```
Intervals between global event peaks: [188.0, 407.0, 232.0]
Estimated periodicity: 0.745
```

1.2.6 Early peakers in the events

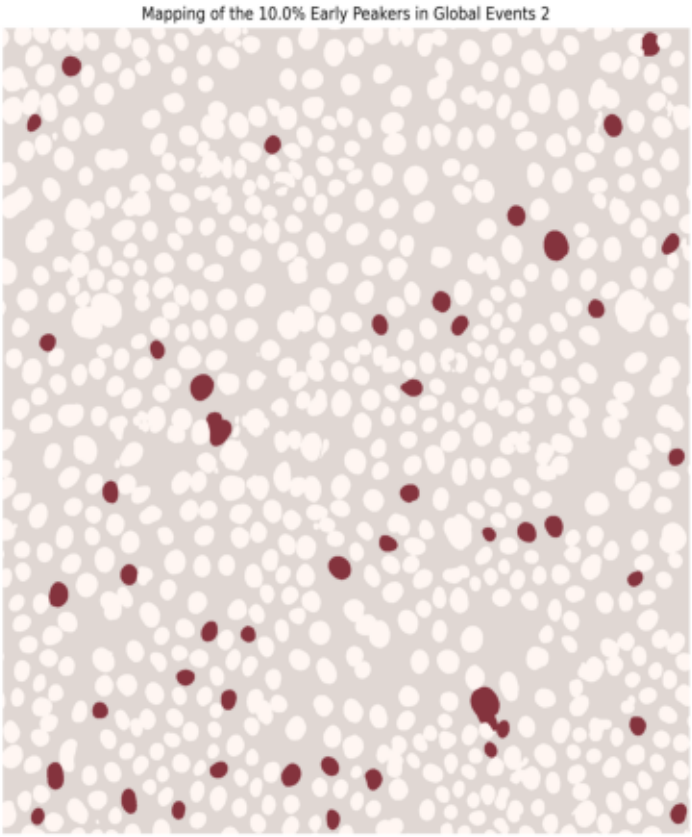
Cell Mapping with Early Peakers Overlay for event 0 - 20250624_IS01



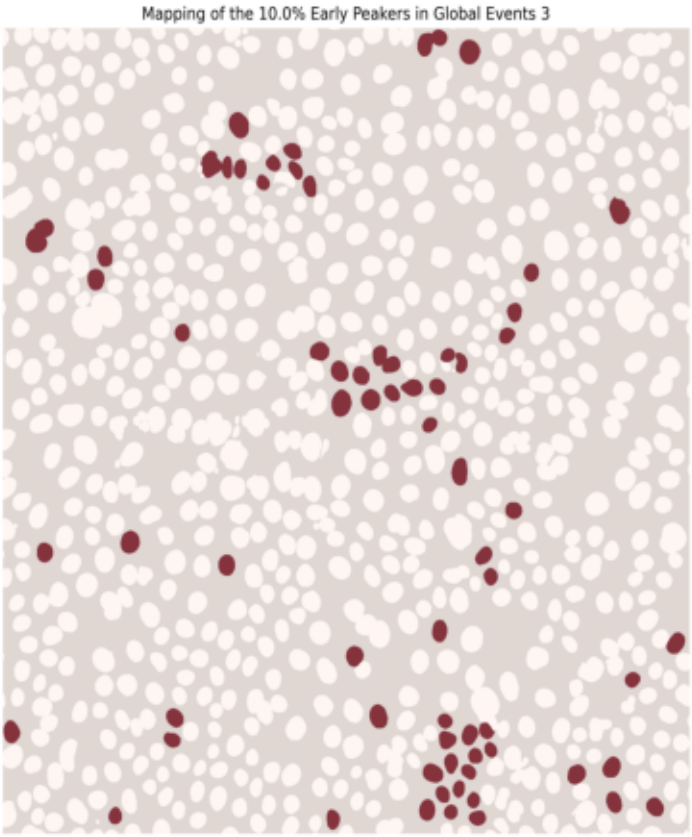
Cell Mapping with Early Peakers Overlay for event 1 - 20250624_IS01



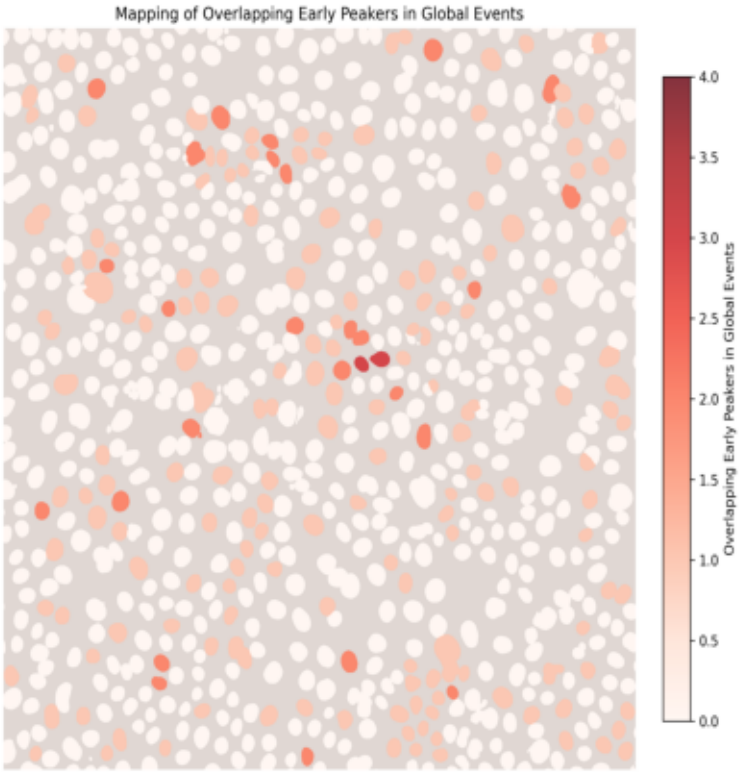
Cell Mapping with Early Peakers Overlay for event 2 - 20250624_IS01



Cell Mapping with Early Peakers Overlay for event 3 - 20250624_IS01

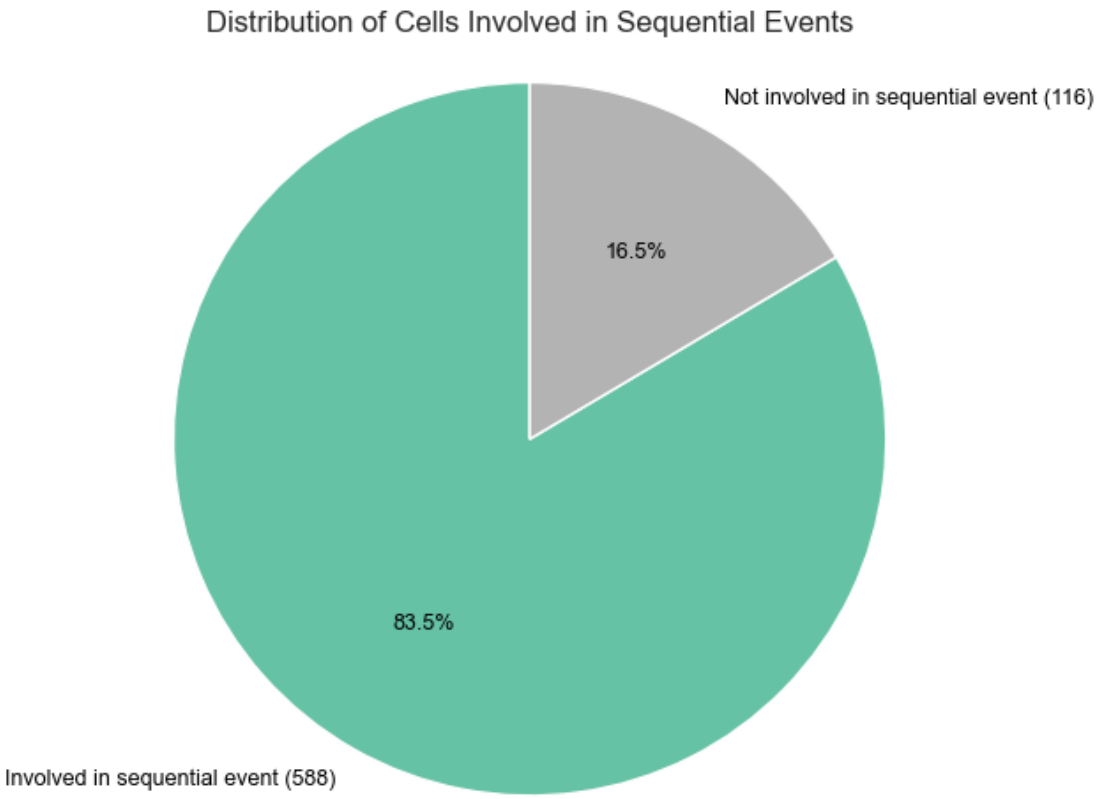


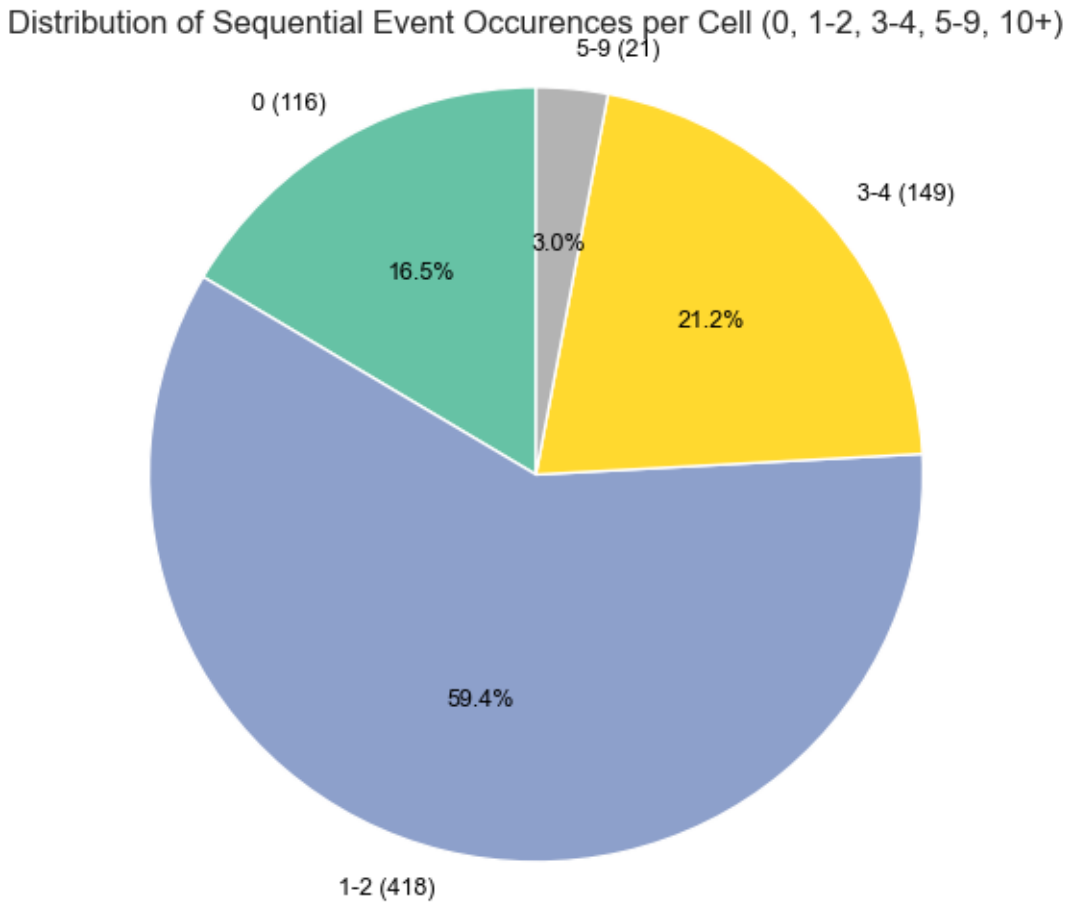
Cell Mapping with Occurences in Global Events Overlay - 20250624_IS01



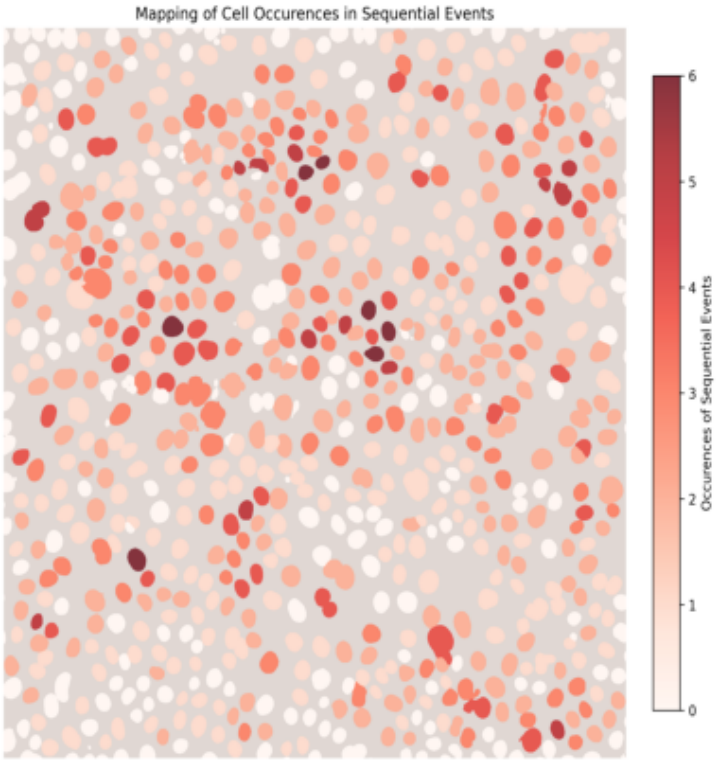
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

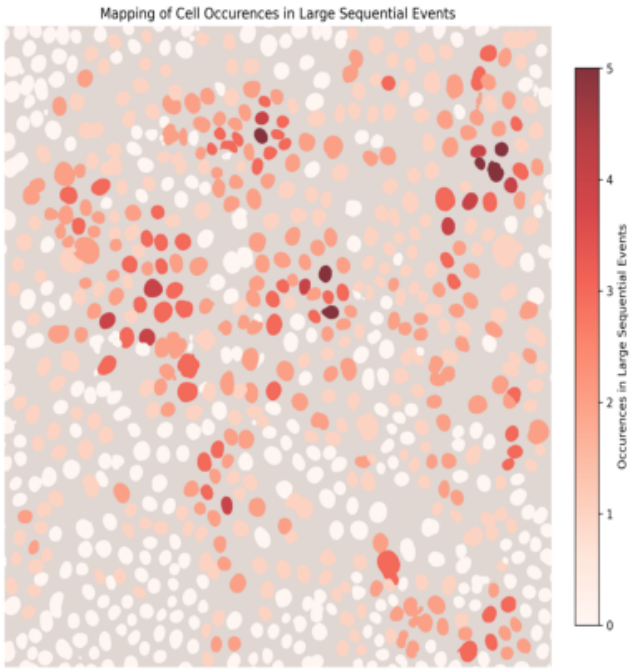



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
5-9 (21)
0 (116)
3-4 (149)
3.0%
16.5%
21.2%
59.4%
1-2 (418)

Cell Mapping with Occurences in Sequential Events Overlay - 20250624_IS01

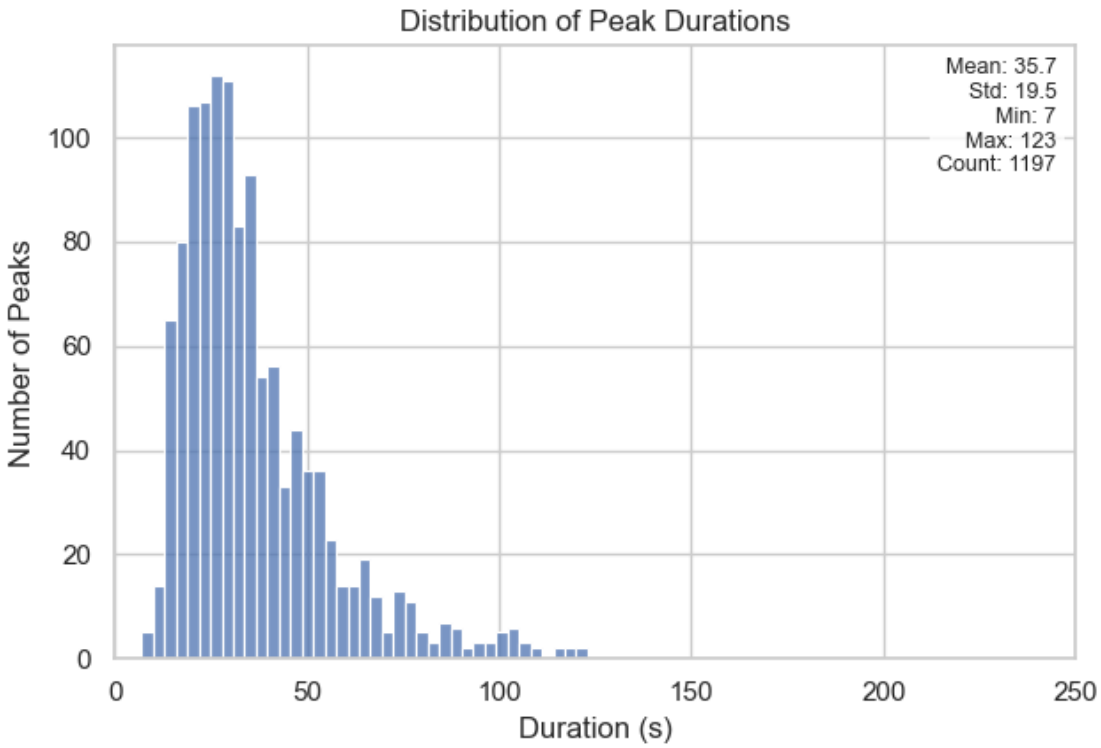


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250624_IS01

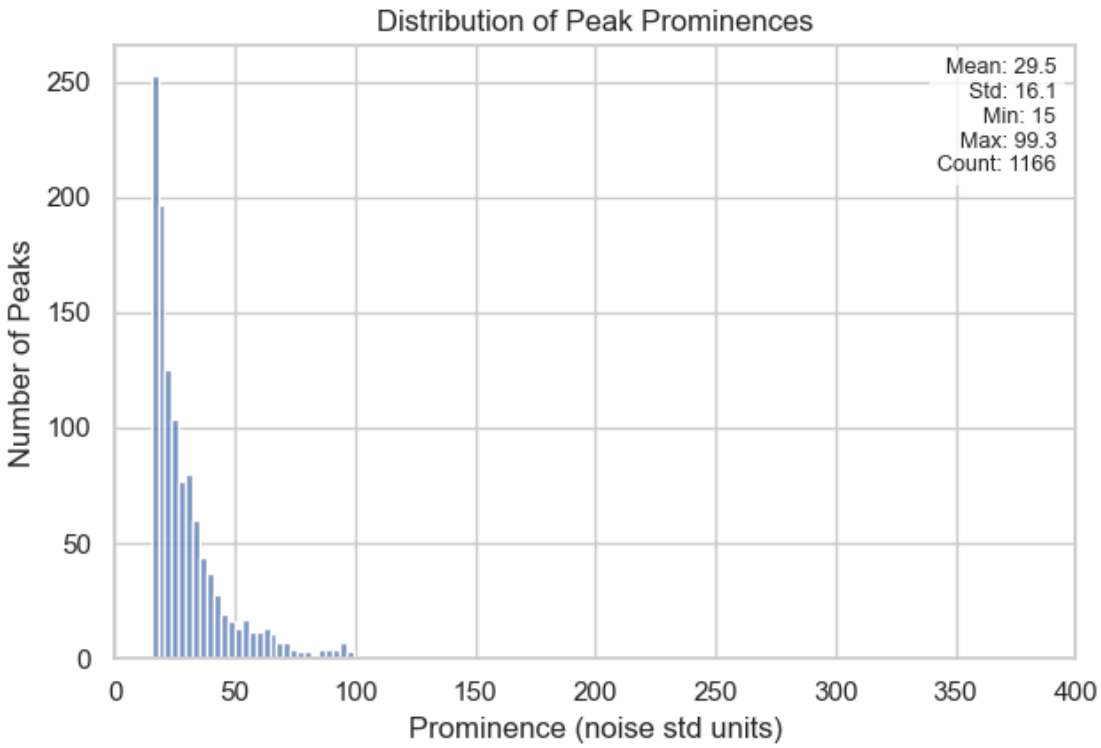


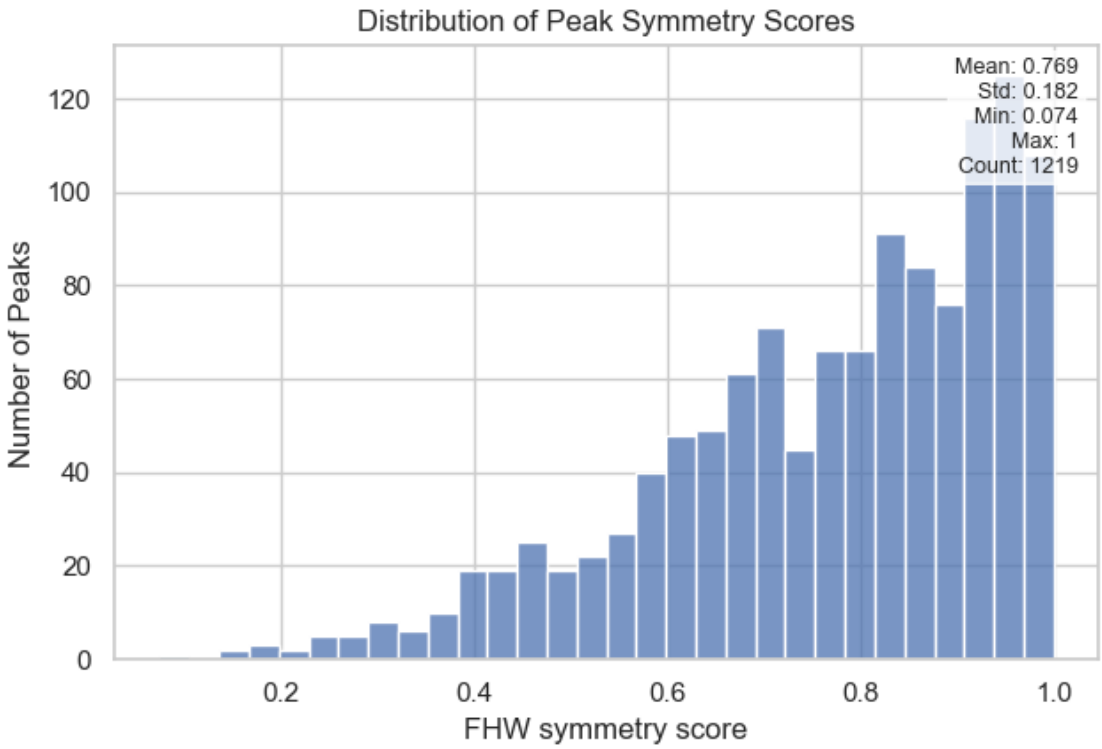
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 10:14:05] [INFO] calcium: plot_histogram: removed 22 outliers out of
1219 on 'Duration (s)' (lower=-12.5, upper=125.5)
```



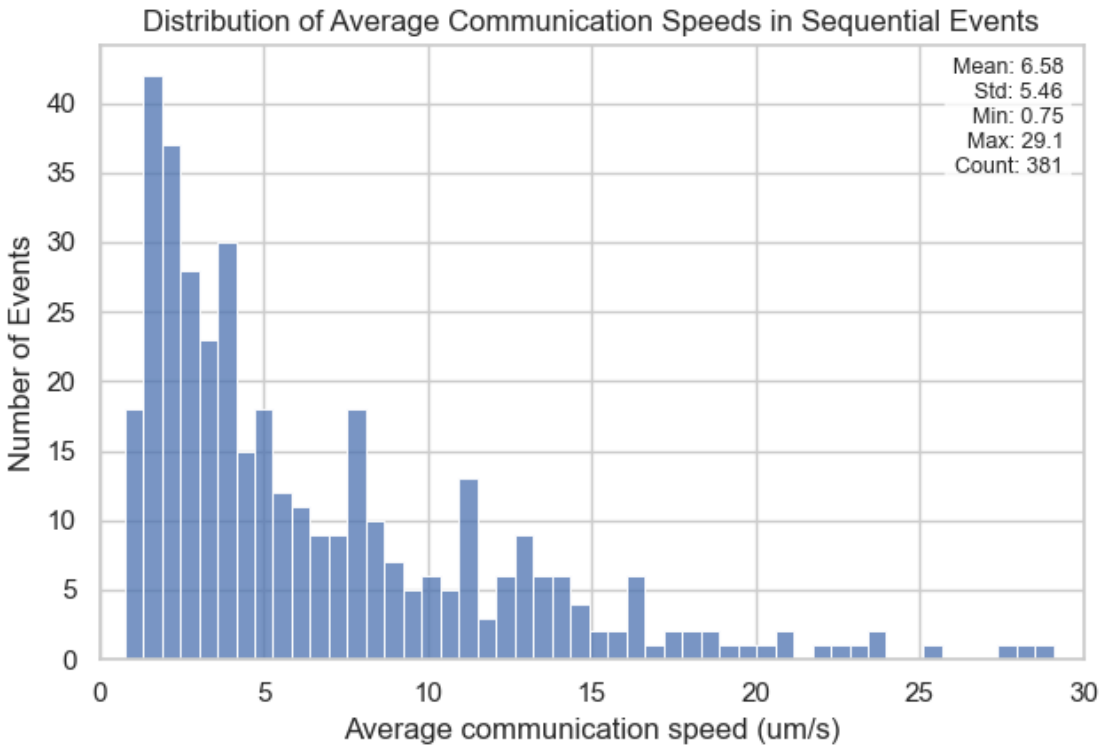

```
[2025-08-11 10:14:05] [INFO] calcium: plot_histogram: removed 53 outliers out of
1219 on 'Prominence (noise std units)' (lower=-8.325, upper=99.375)
```


Distribution of Peak Prominences
Mean: 29.5
Std: 16.1
Min: 15
Max: 99.3
Count: 1166
Number of Peaks
0
50
100
150
200
250
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

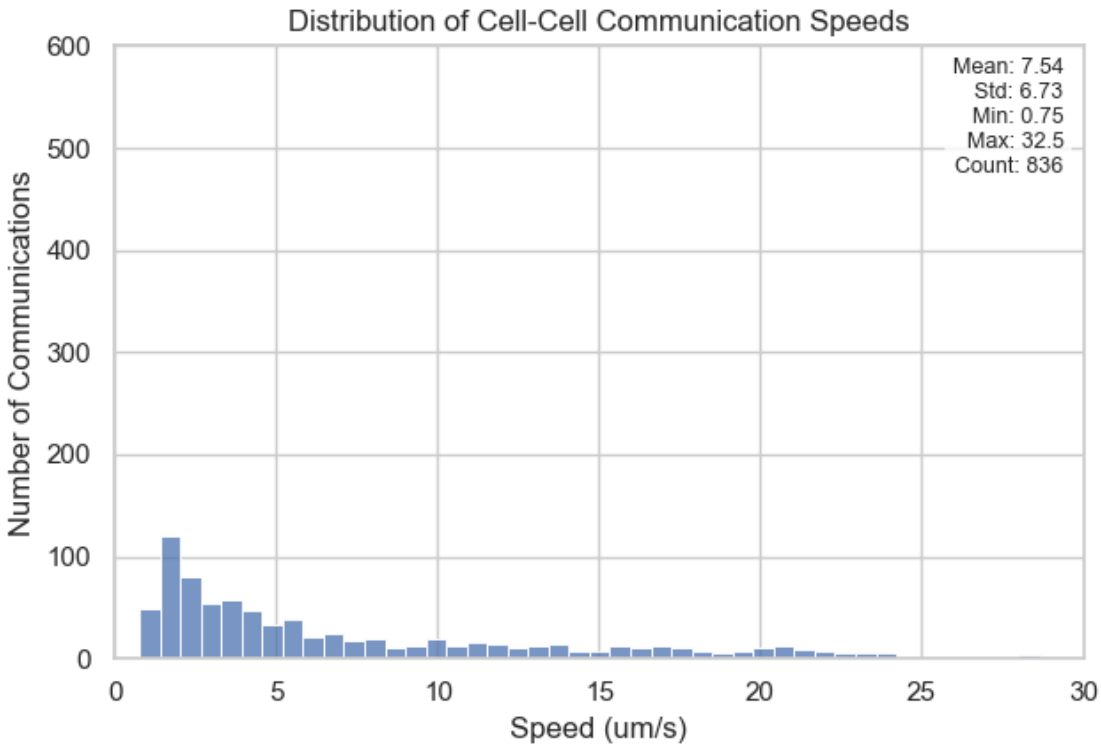

Distribution of Peak Symmetry Scores
Mean: 0.769
Std: 0.182
Min: 0.074
Max: 1
Count: 1219
Number of Peaks
0
20
40
60
80
100
120
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 10:14:05] [INFO] calcium: plot_histogram: removed 1 outliers out of
382 on 'Average communication speed (um/s)' (lower=-18.01, upper=29.643)
```

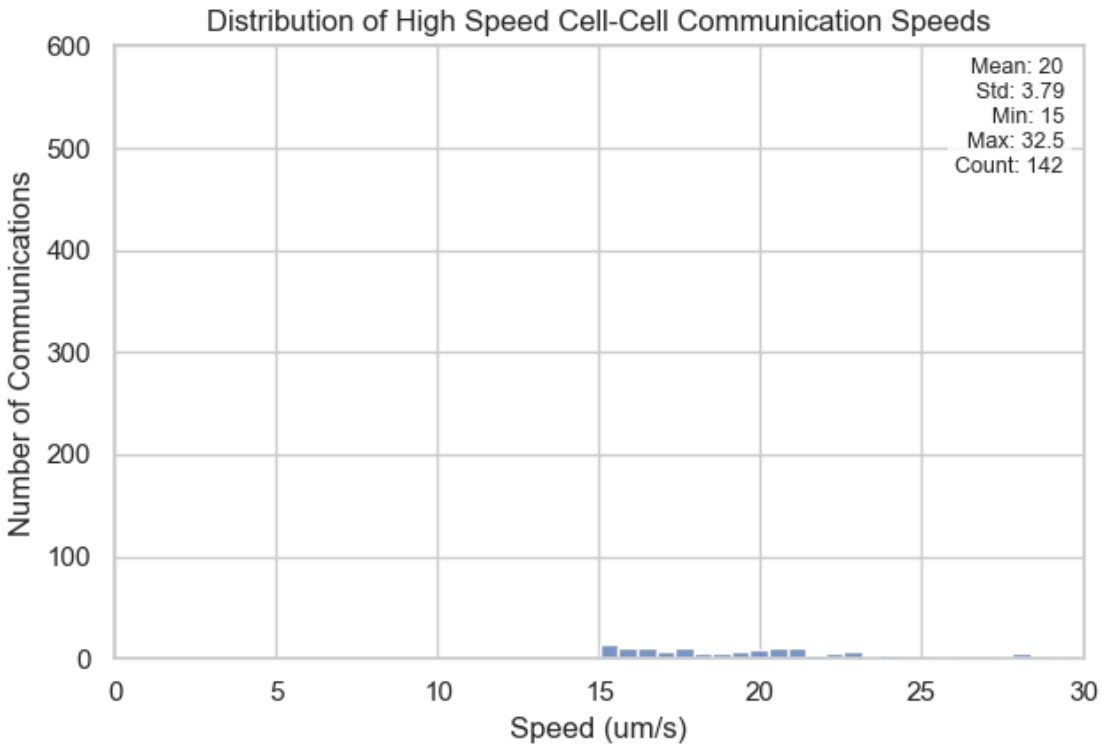



```
[2025-08-11 10:14:05] [INFO] calcium: plot_histogram: removed 1 outliers out of
837 on 'Speed (um/s)' (lower=-24.32, upper=37.7)
```

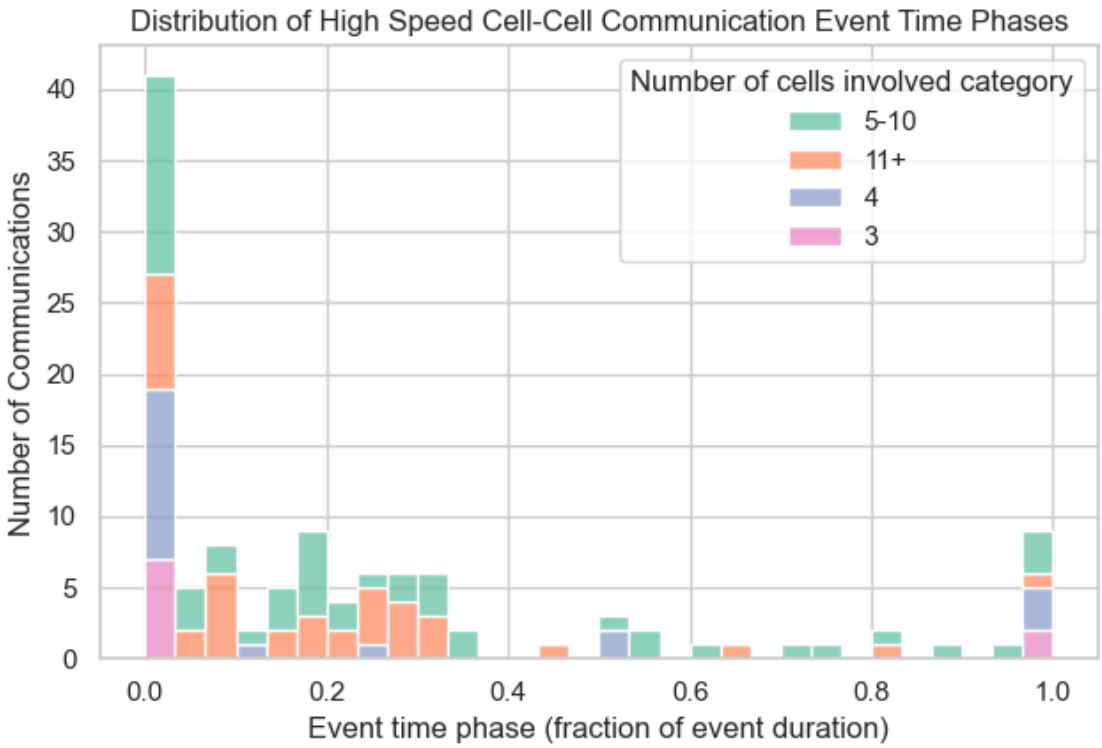


1.3.4 Double distribution in cell-cell communication speeds

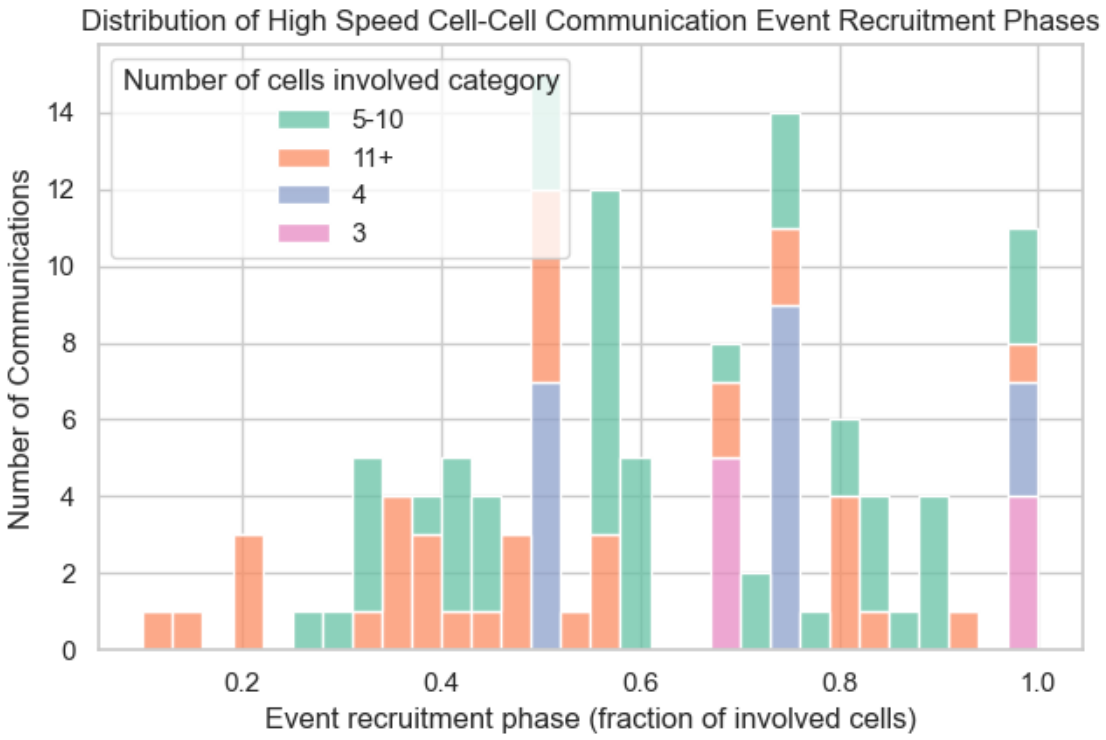
```
[2025-08-11 10:14:06] [INFO] calcium: plot_histogram: removed 1 outliers out of
143 on 'Speed (um/s)' (lower=1.095, upper=37.845)
```



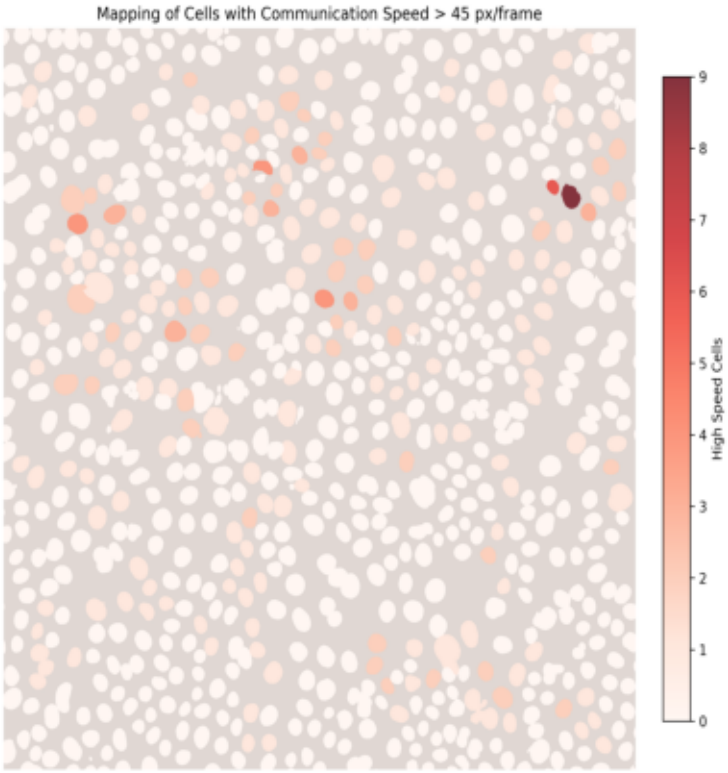

```
[2025-08-11 10:14:06] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 117 on 'Event time phase (fraction of event duration)'
(lower=-0.93, upper=1.24)
```



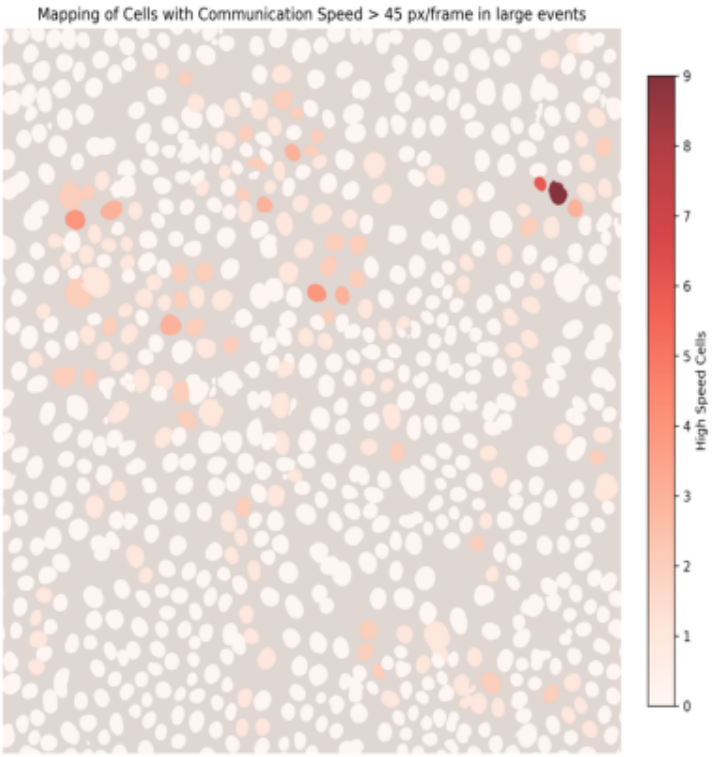

```
[2025-08-11 10:14:06] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 117 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.37, upper=1.59)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
4
3
Number of Communications
0
2
4
6
8
10
12
14
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

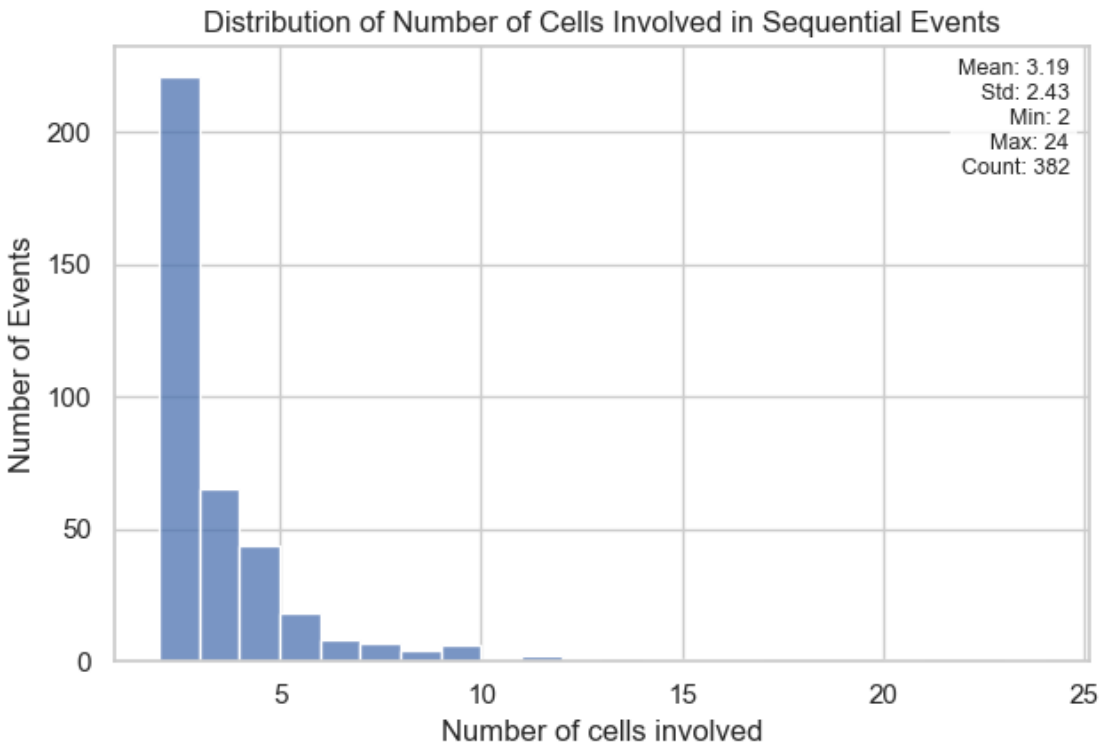
Cell Mapping with High Speed Cells Overlay - 20250624_IS01



Cell Mapping with High Speed Cells in Large Events Overlay - 20250624_IS01

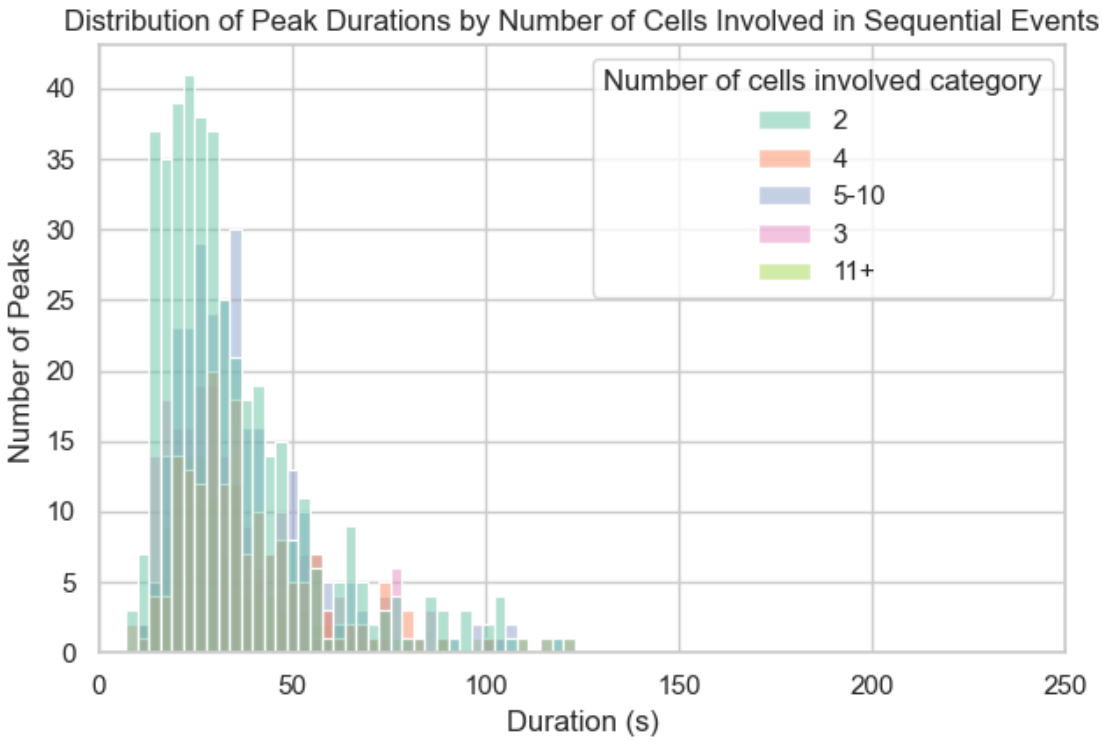


1.3.5 Number of cells involved per sequential events

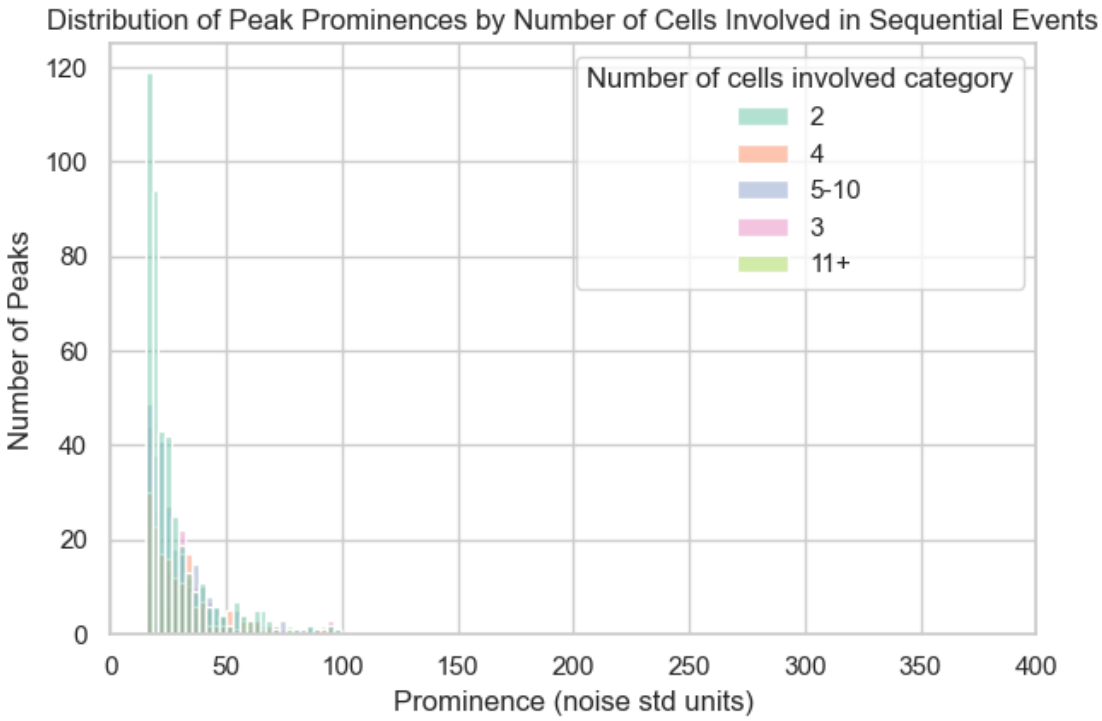


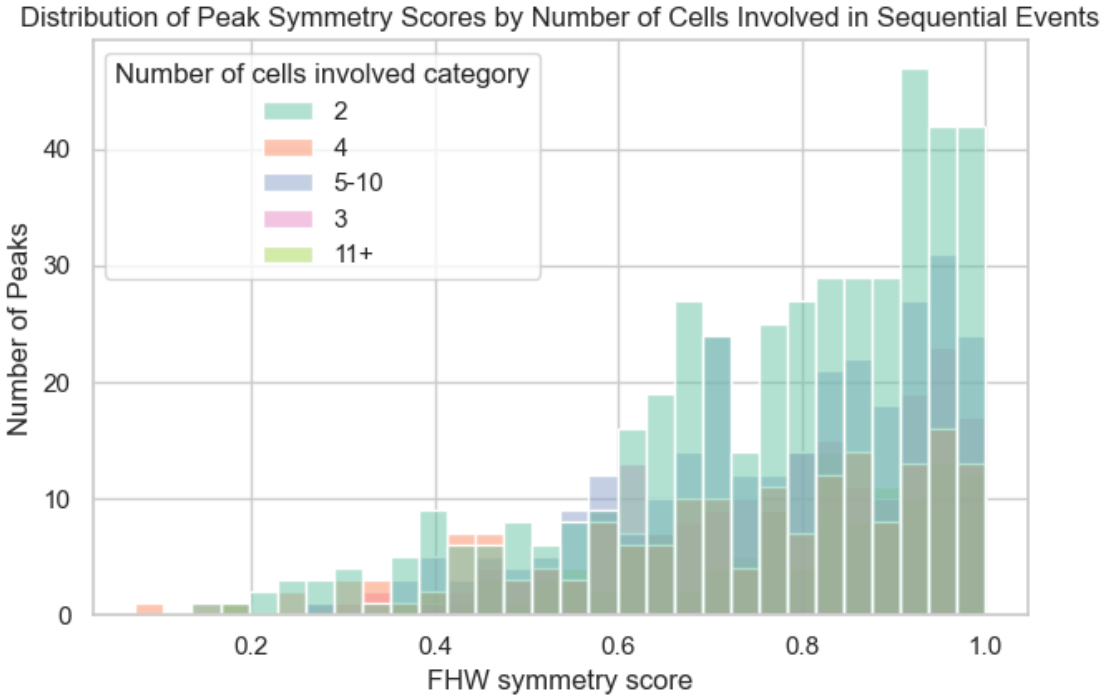
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 10:14:09] [INFO] calcium: plot_histogram_by_group: removed 22
outliers out of 1219 on 'Duration (s)' (lower=-12.5, upper=125.5)
```



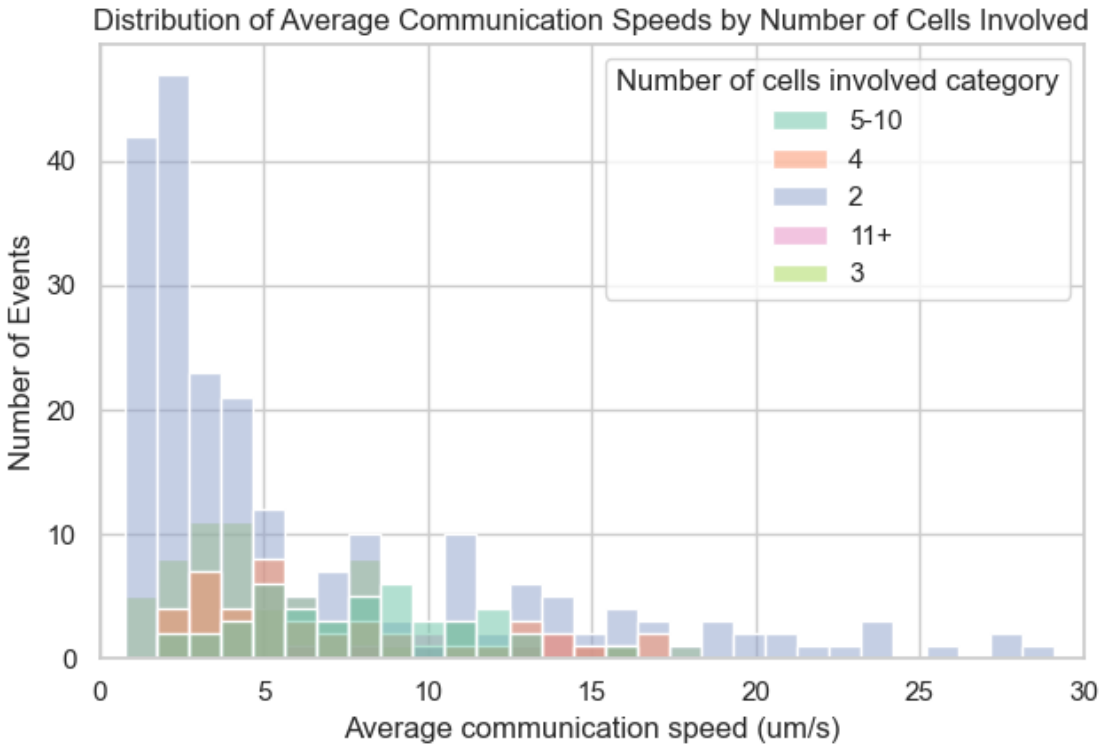

```
[2025-08-11 10:14:09] [INFO] calcium: plot_histogram_by_group: removed 53
outliers out of 1219 on 'Prominence (noise std units)' (lower=-8.325,
upper=99.375)
```



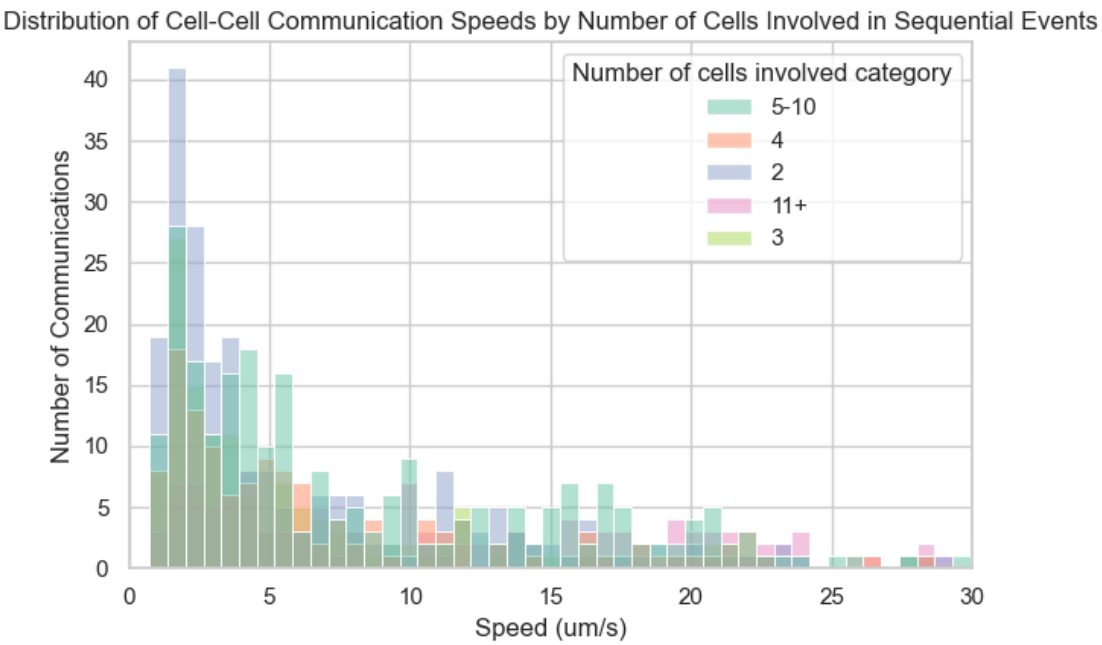



```
[2025-08-11 10:14:09] [INFO] calcium: plot_histogram_by_group: removed 1
```

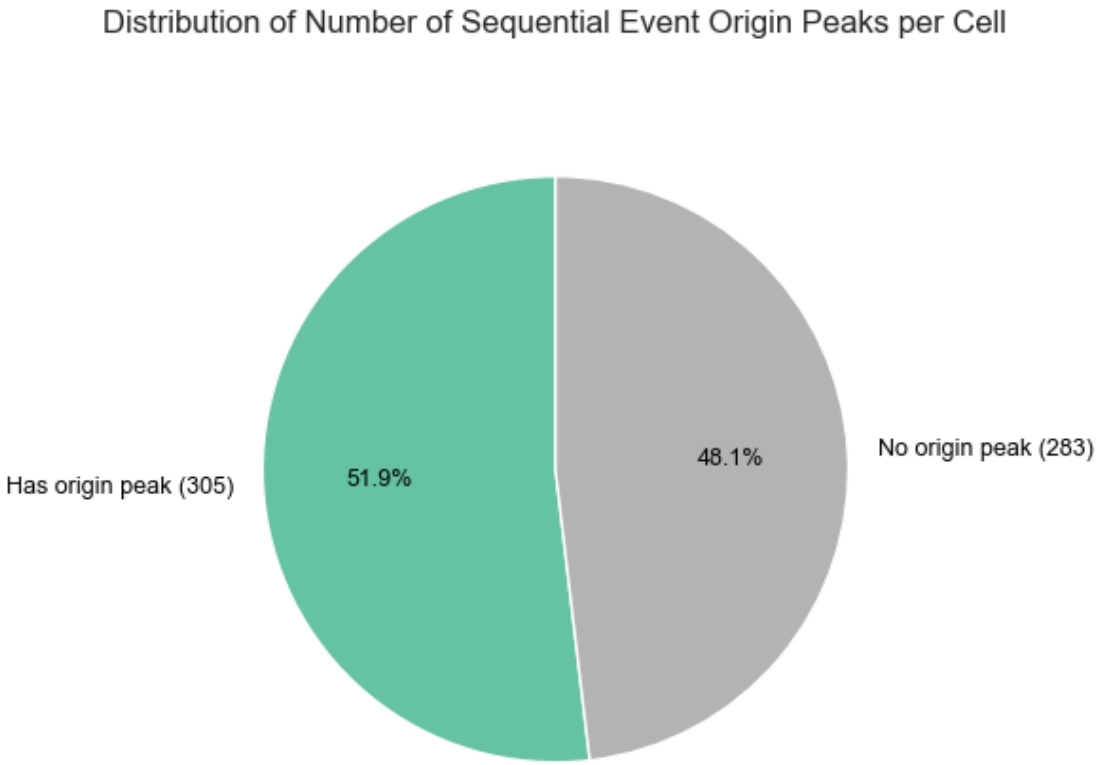
```
outliers out of 382 on 'Average communication speed (um/s)' (lower=-18.01,
upper=29.643)
```

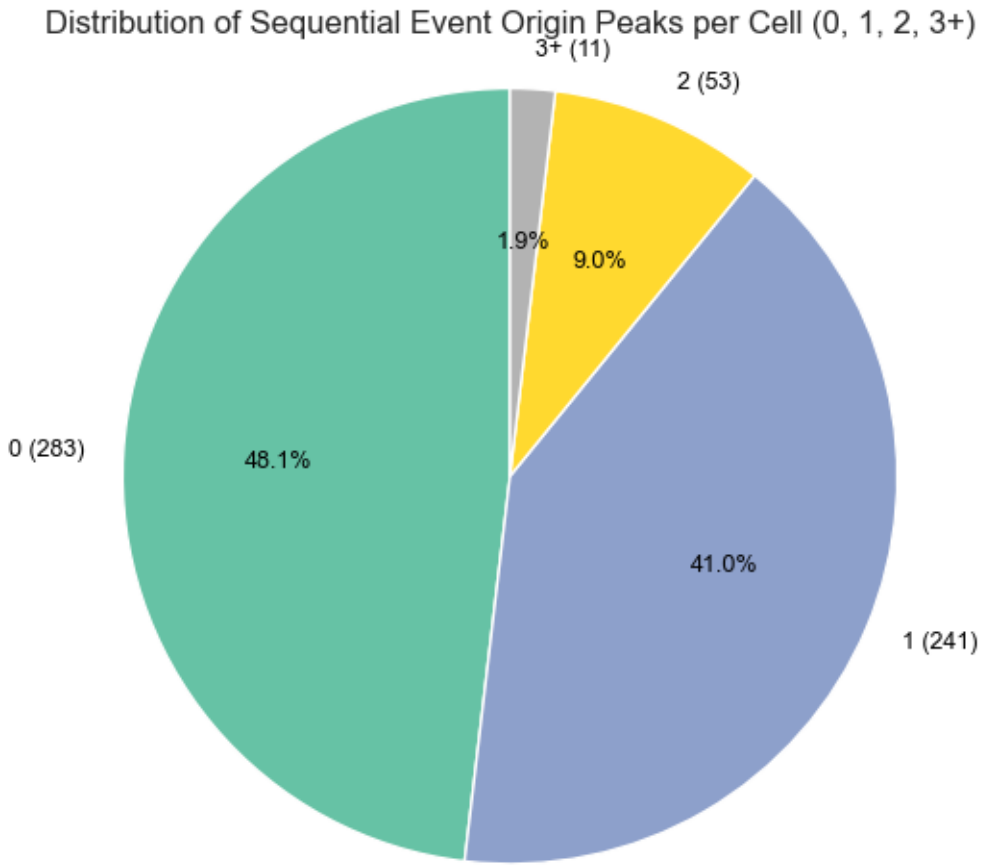



```
[2025-08-11 10:14:10] [INFO] calcium: plot_histogram_by_group: removed 1
outliers out of 837 on 'Speed (um/s)' (lower=-24.32, upper=37.7)
```

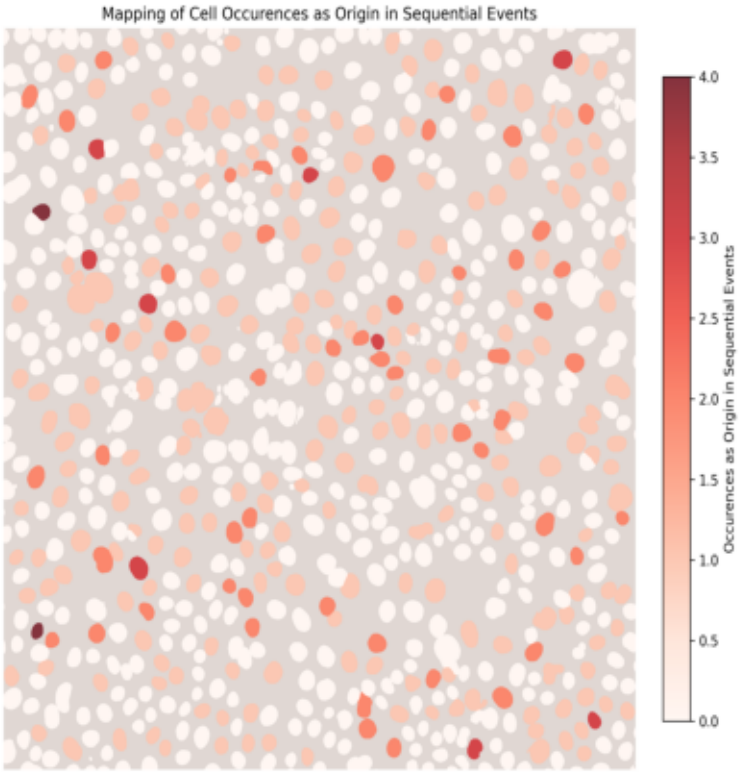

Distribution of Cell-Cell Communication Speeds by Number of Cells Involved in Sequential Events
Number of cells involved category
5-10
4
2
11+
3
Number of Communications
Speed (um/s)
0
5
10
15
20
25
30
35
40

1.3.7 Cells occurences as origin in sequential events

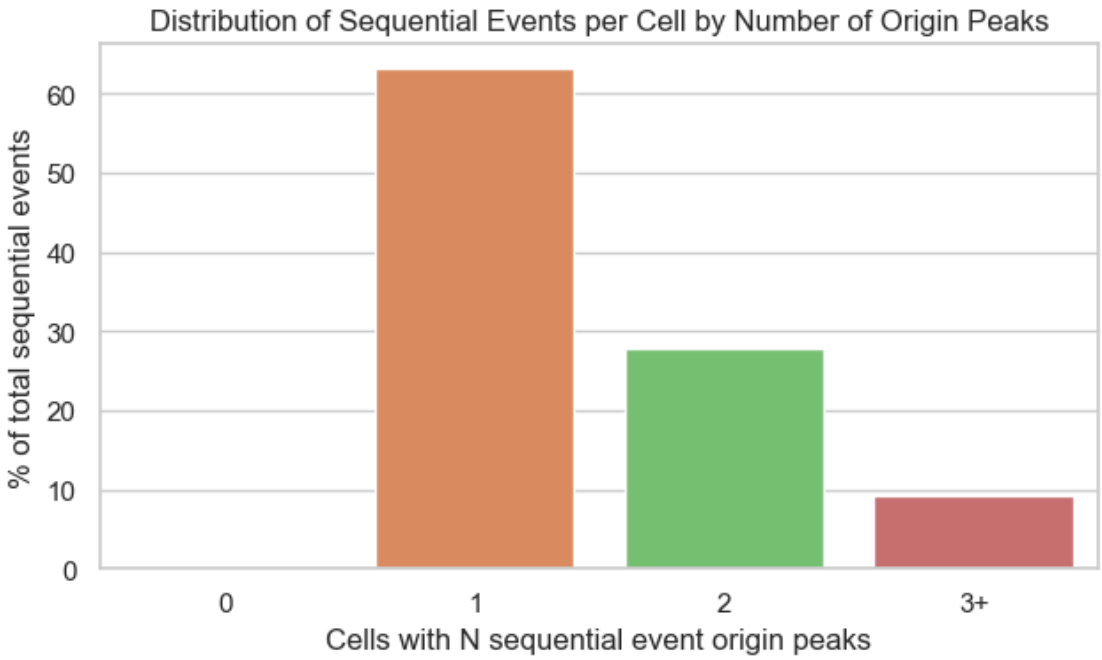



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (11)
2 (53)
1.9%
9.0%
0 (283)
48.1%
41.0%
1 (241)

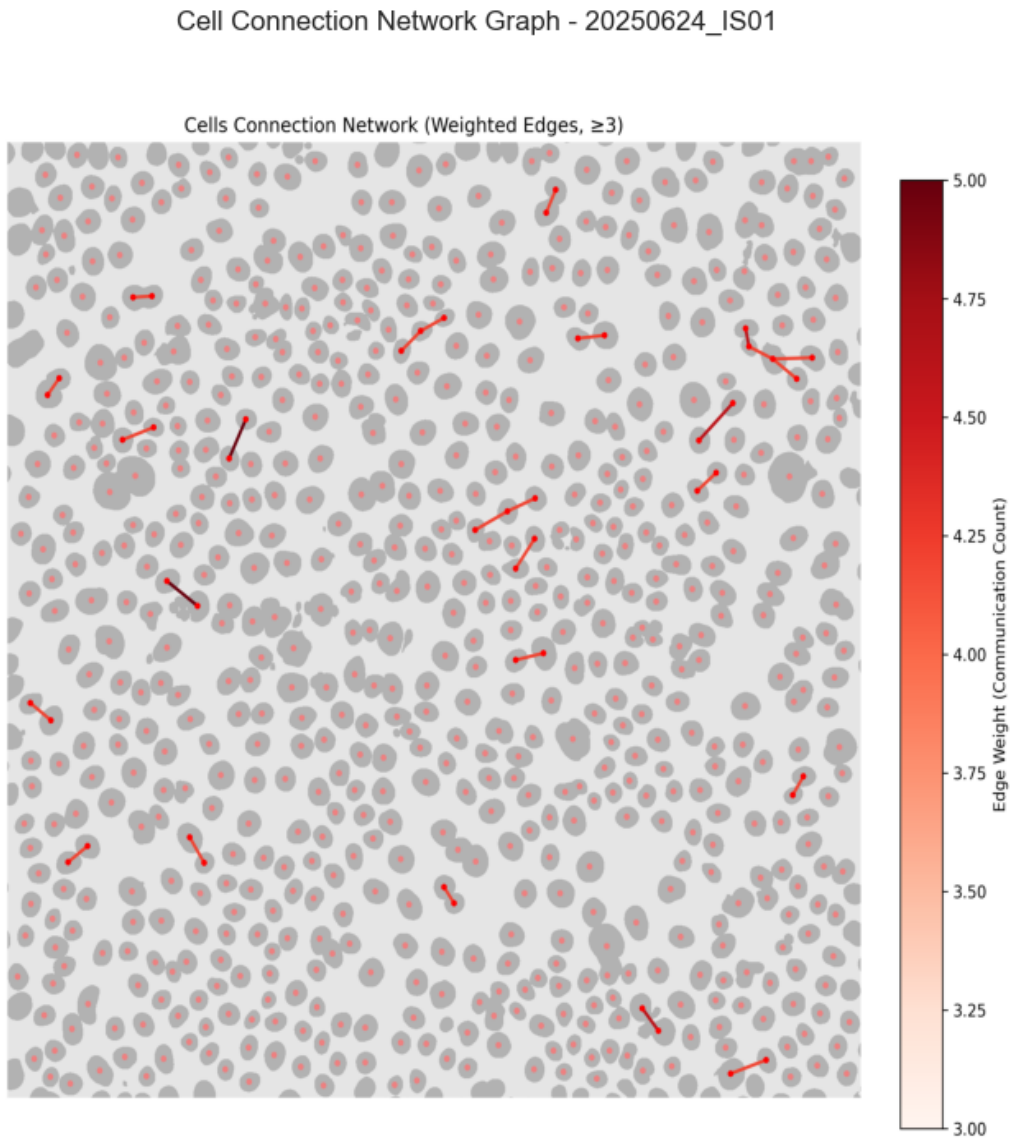
Cell Mapping with Origin Peaks Overlay - 20250624_IS01




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

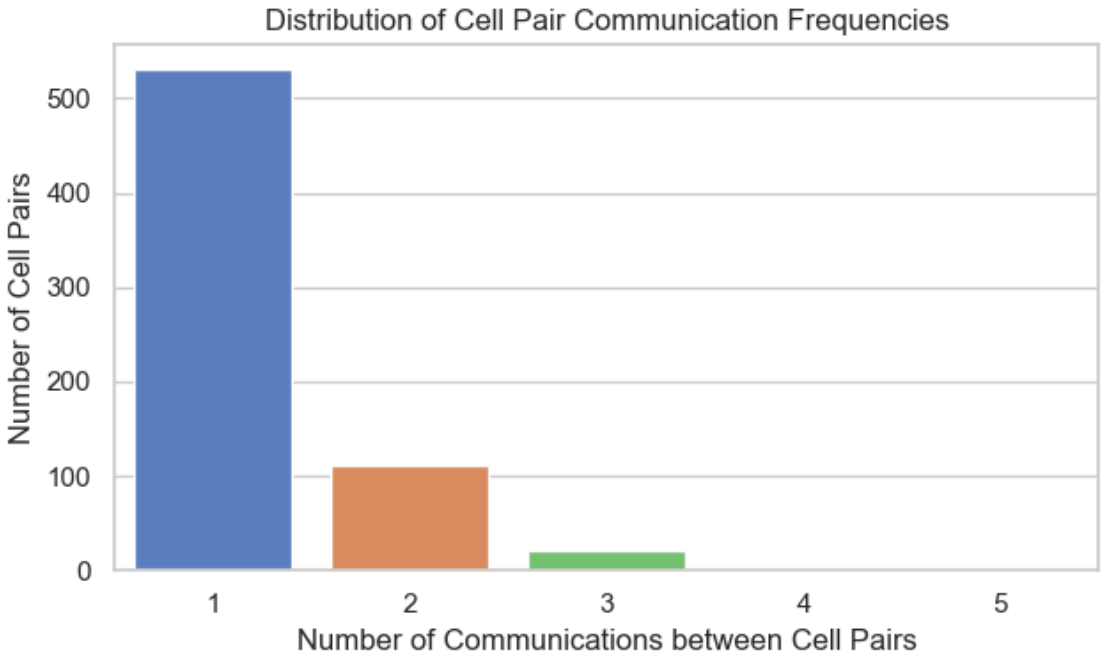

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
0
10
20
30
40
50
60
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



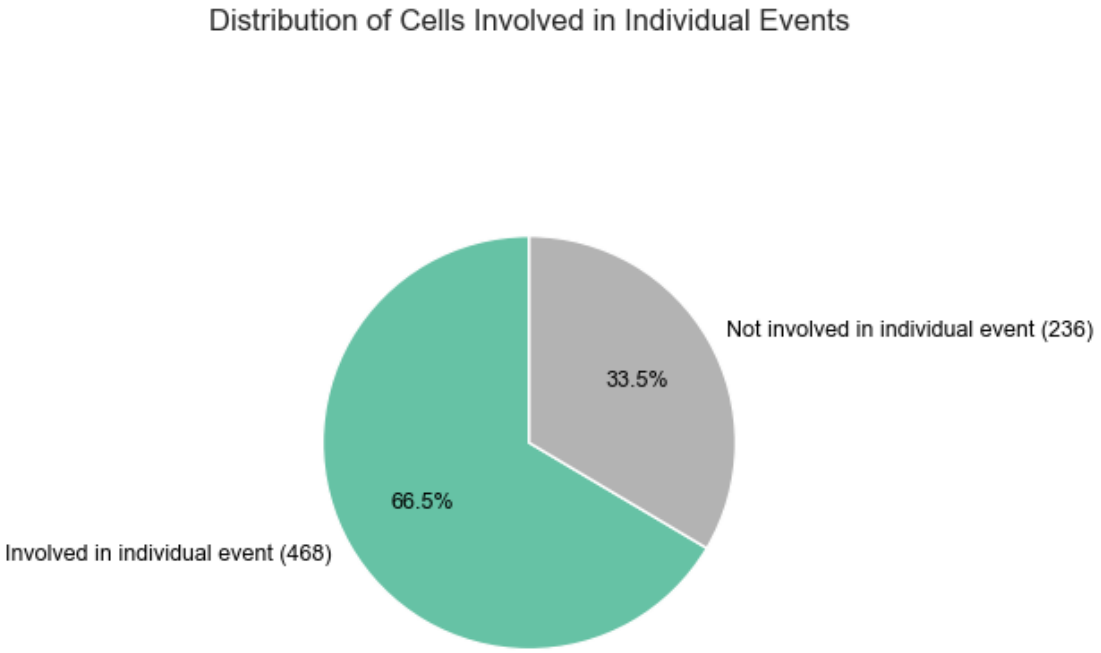

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

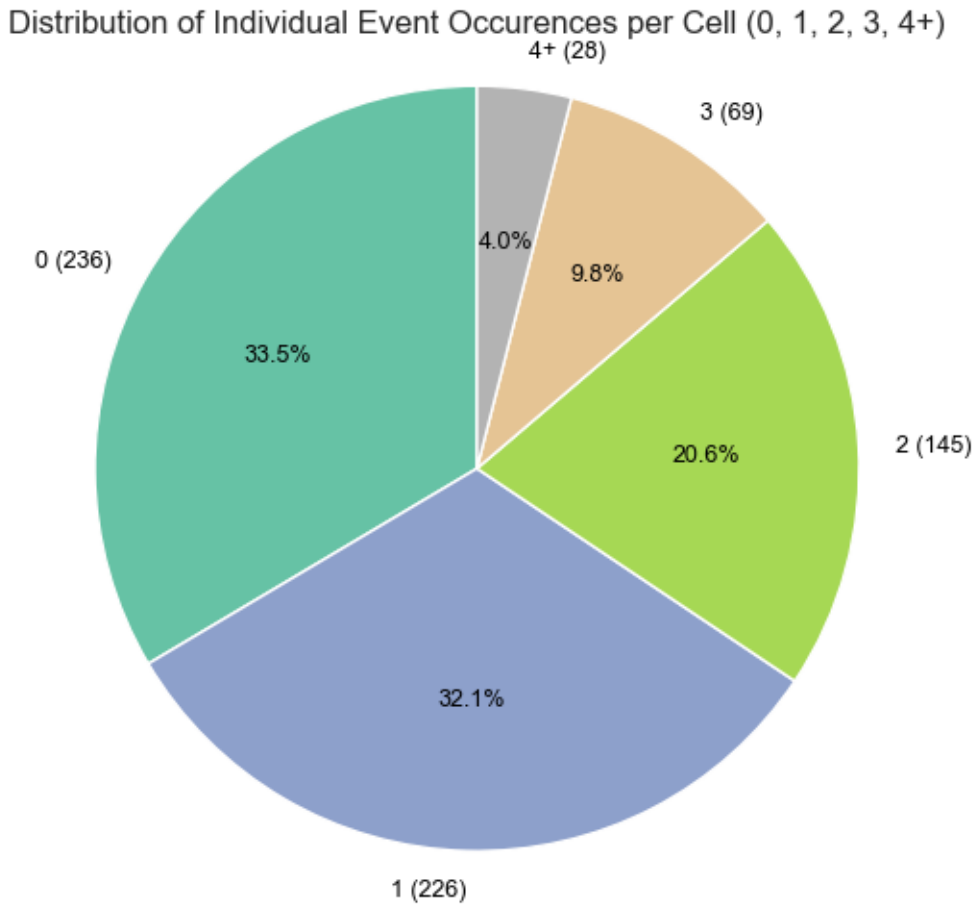
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
500
400
300
200
100
0
1
2
3
4
5
Number of Communications between Cell Pairs

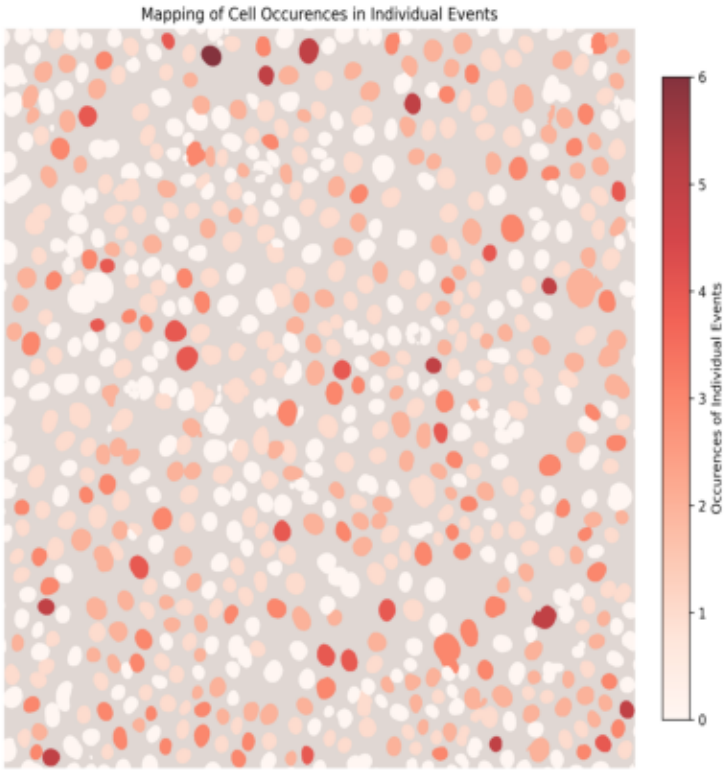
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



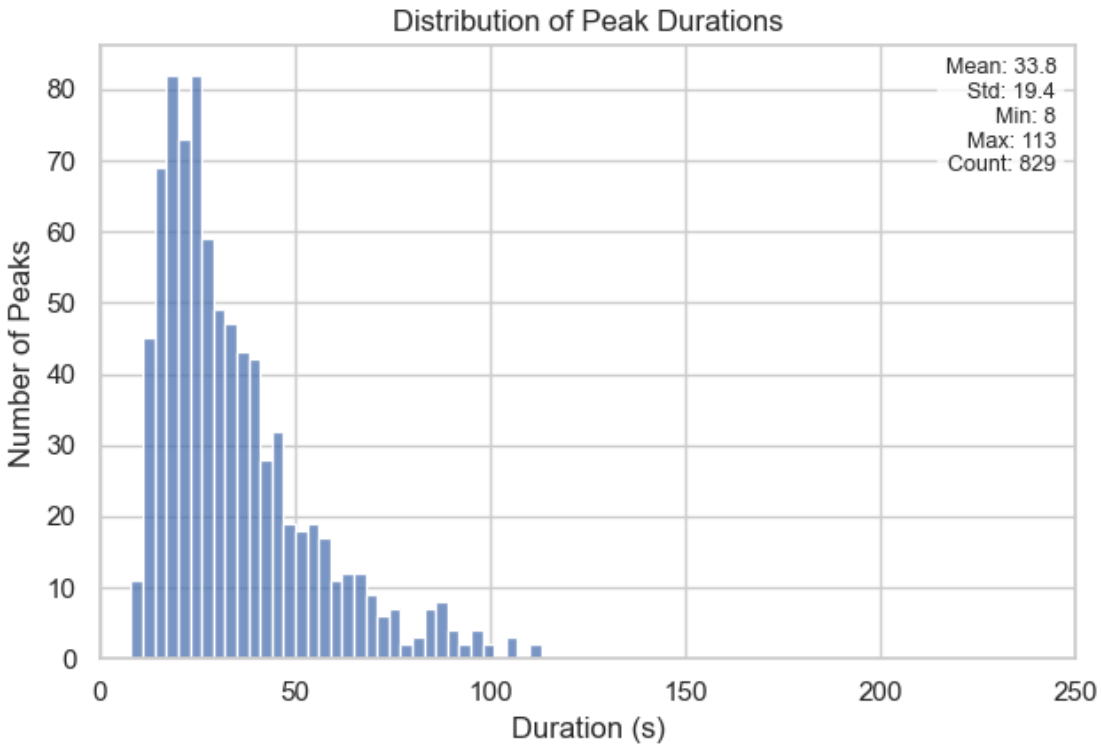

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (28)
3 (69)
2 (145)
1 (226)
0 (236)
4.0%
9.8%
20.6%
32.1%
33.5%

Cell Mapping with Occurences in Individual Events Overlay - 20250624_IS01

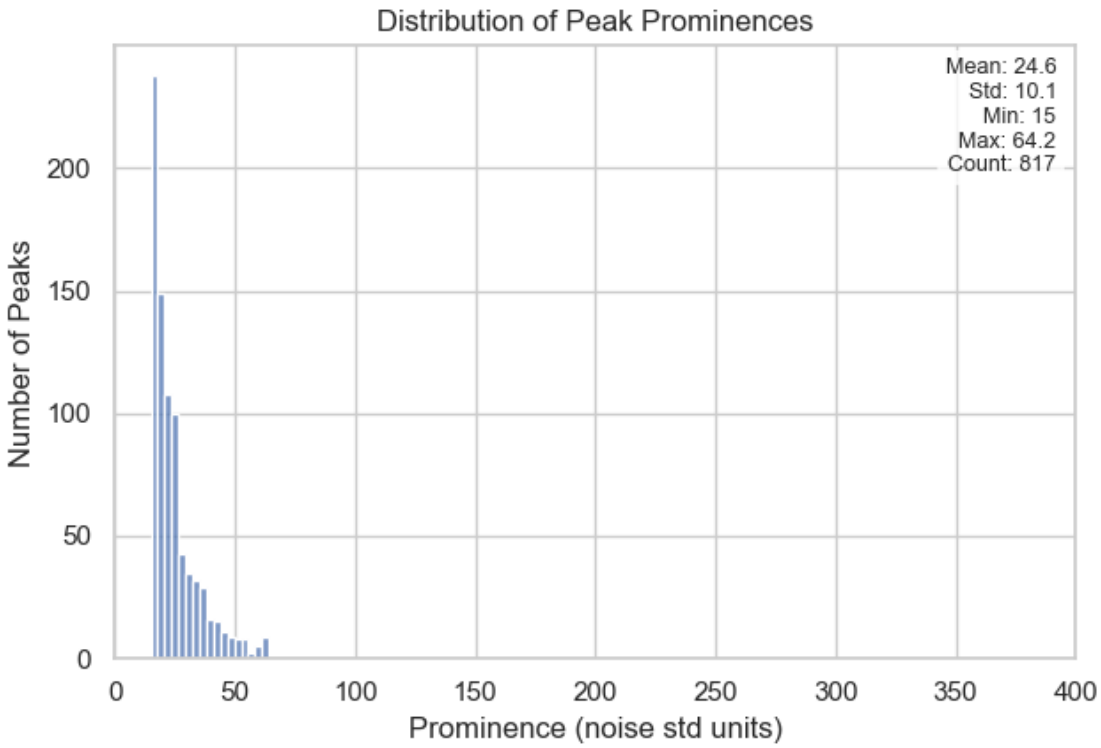


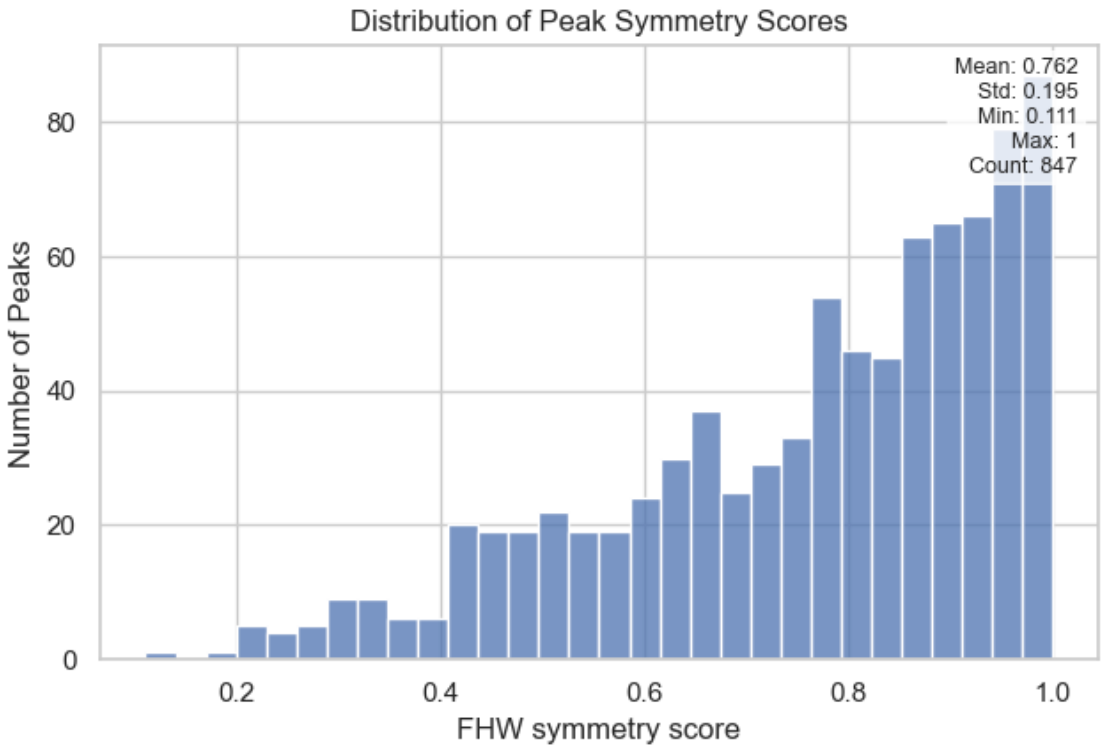
1.4.2 Peaks statistics in individual events

```
[2025-08-11 10:14:14] [INFO] calcium: plot_histogram: removed 18 outliers out of
847 on 'Duration (s)' (lower=-52, upper=116)
```

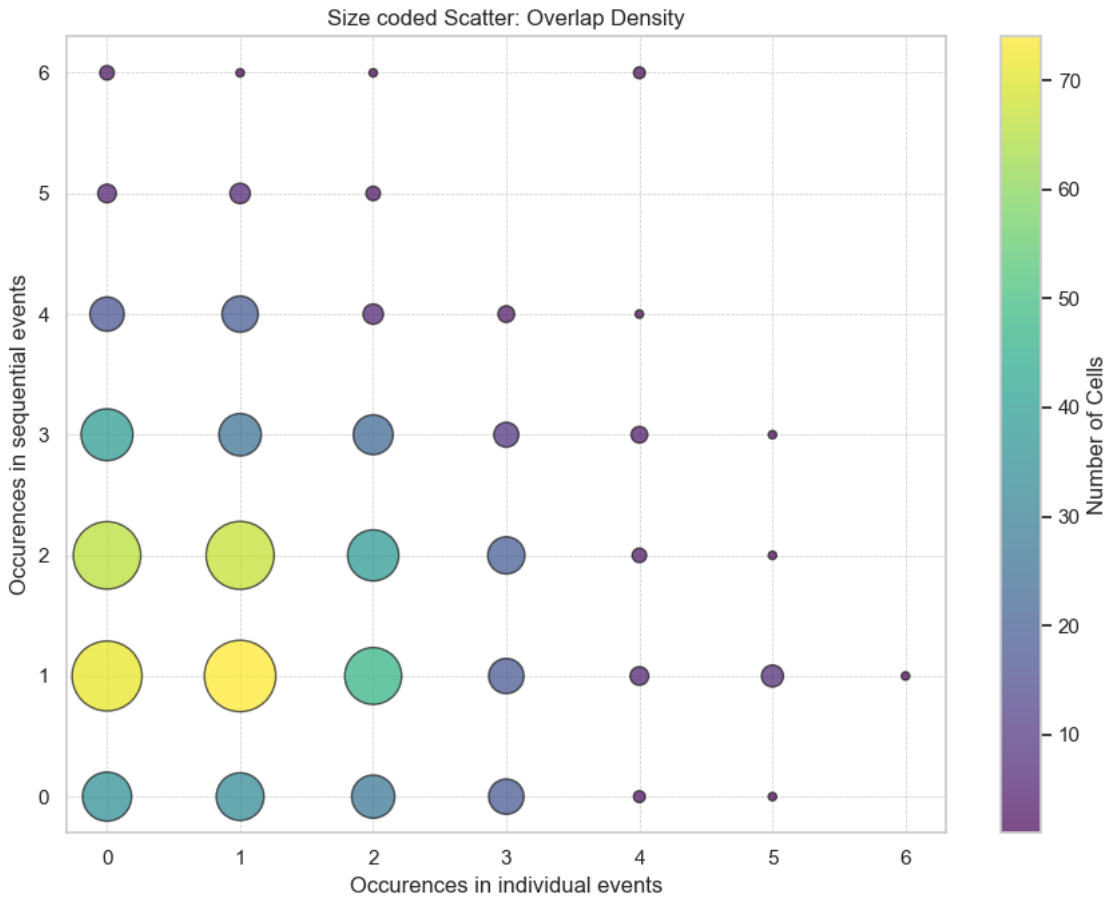



```
[2025-08-11 10:14:14] [INFO] calcium: plot_histogram: removed 30 outliers out of
847 on 'Prominence (noise std units)' (lower=-17.6, upper=64.3)
```

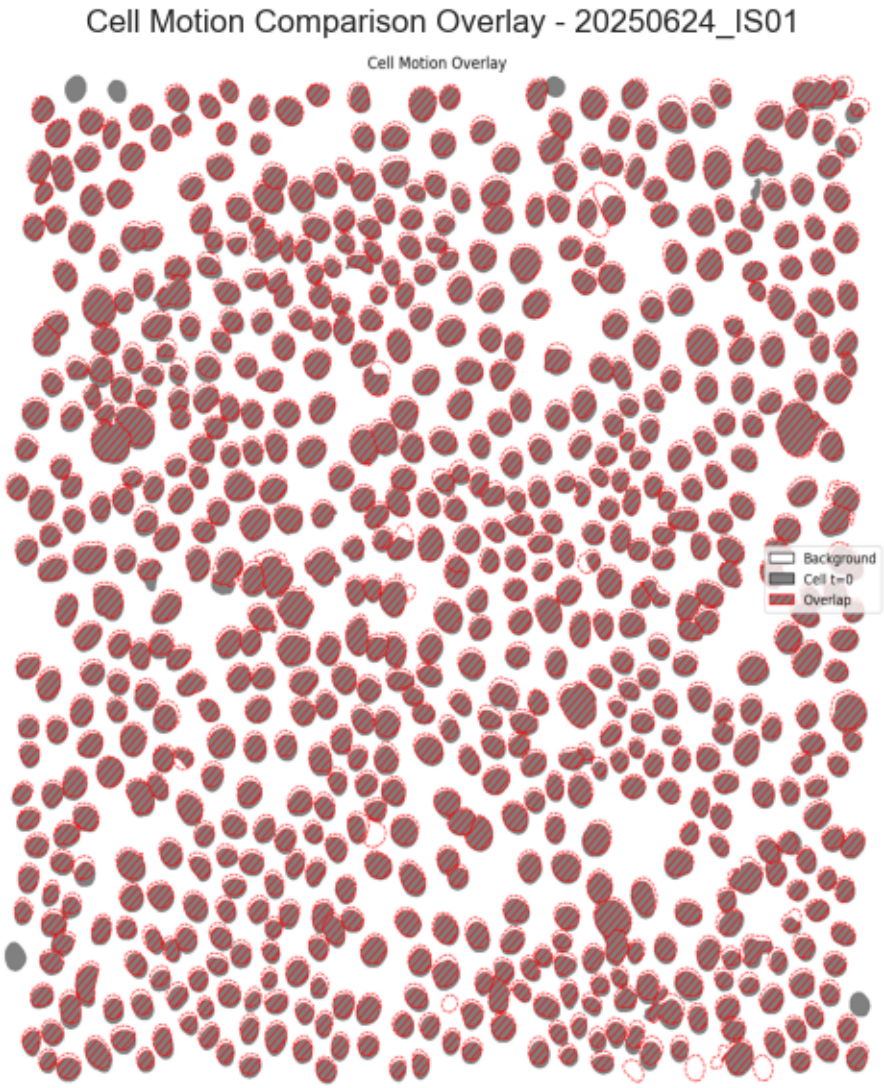

Distribution of Peak Prominences
Mean: 24.6
Std: 10.1
Min: 15
Max: 64.2
Count: 817
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.762
Std: 0.195
Min: 0.111
Max: 1
Count: 847
Number of Peaks
0
20
40
60
80
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 704
- Hoechst image taken at t=1801: 700
- Number of cells difference: absolute 4, relative 0.57%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 864200
- Pixels segmented as cell at t=1801: 858437
- Overlapping pixels between t=0 and t=1801: 706604(82.04% of total)
- Pixels exclusive to t=0: 157596 (18.24% of total)
- Pixels exclusive to t=1801: 151833 (17.69% of total)
```

executed

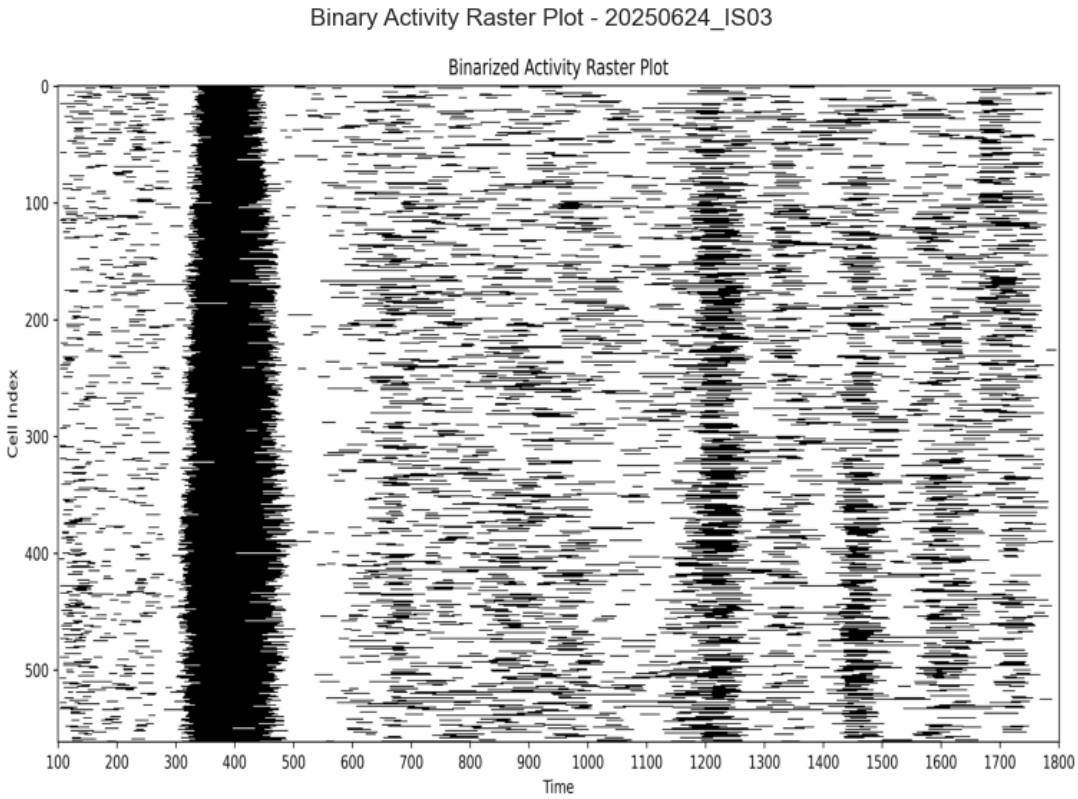
August 11, 2025

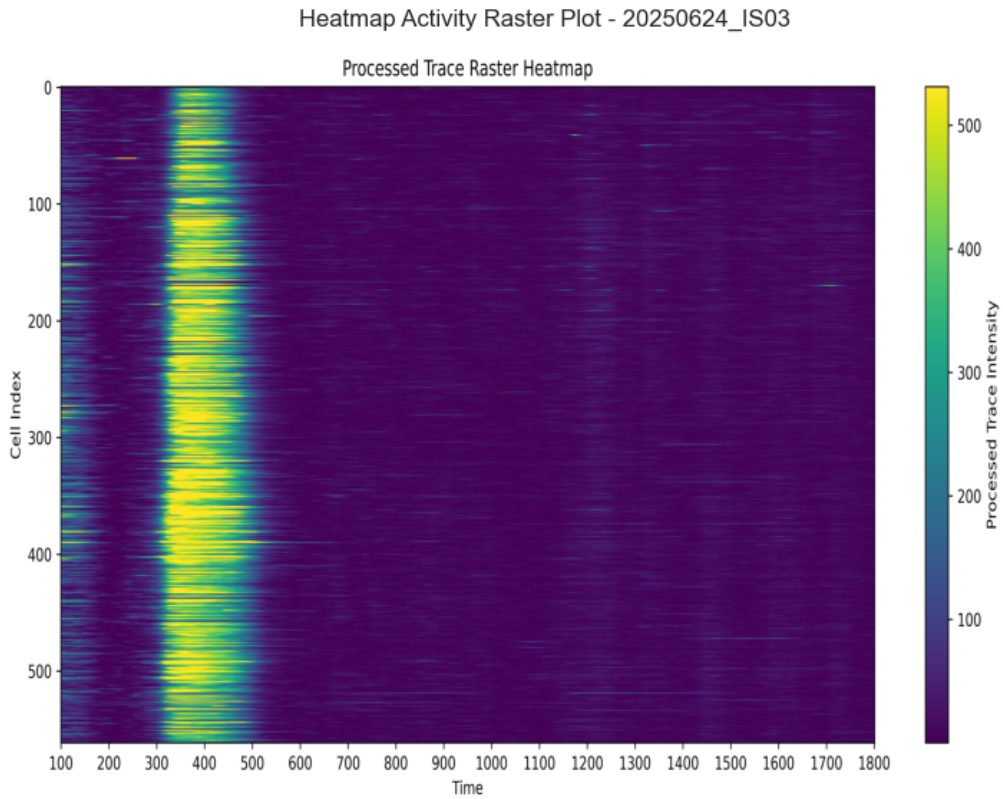
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



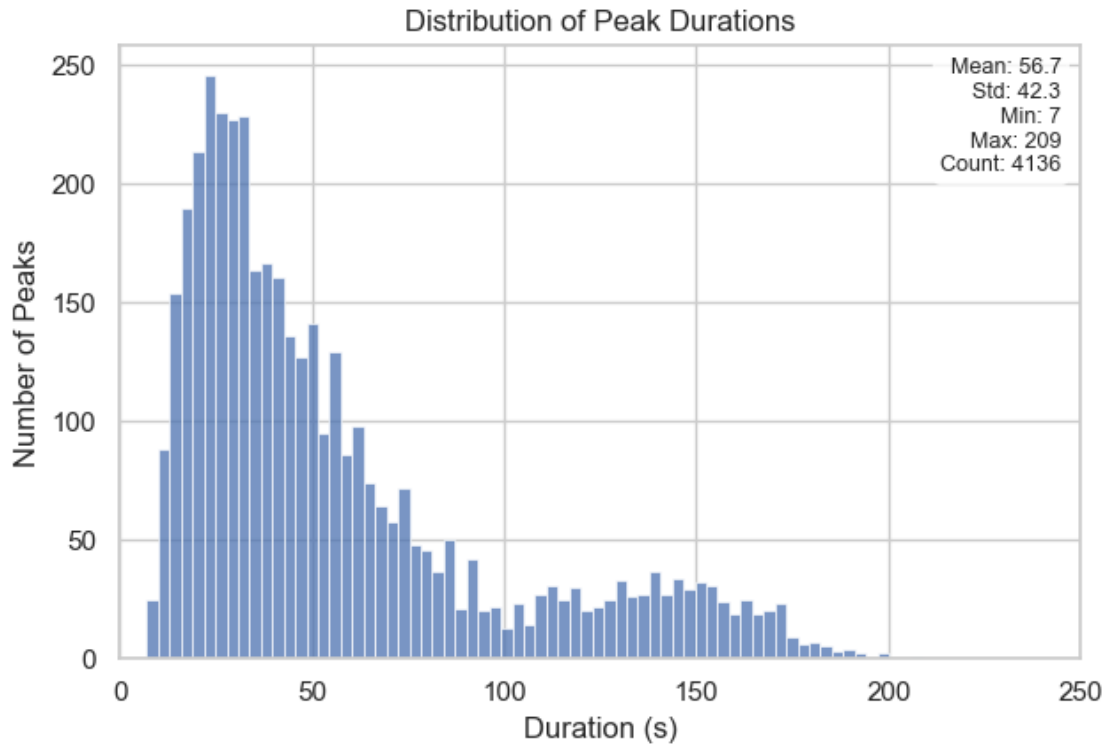


1.1.2 Peaks population

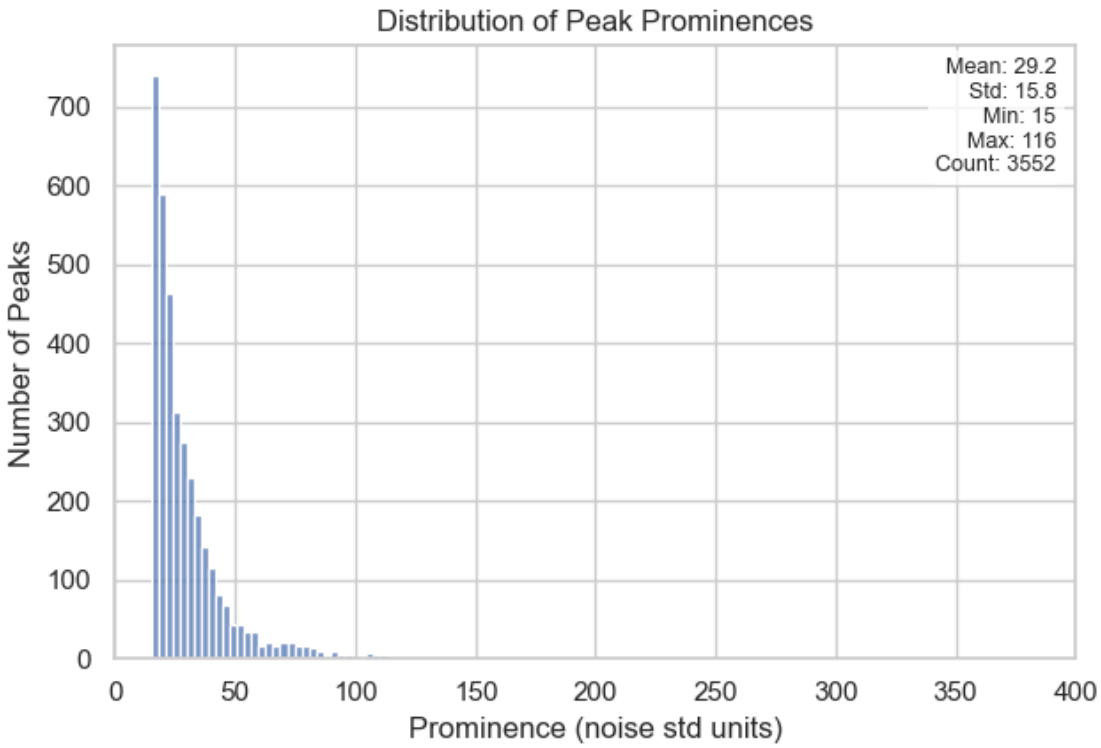
```
Total number of peaks: 4143
Total number of cells: 562
```

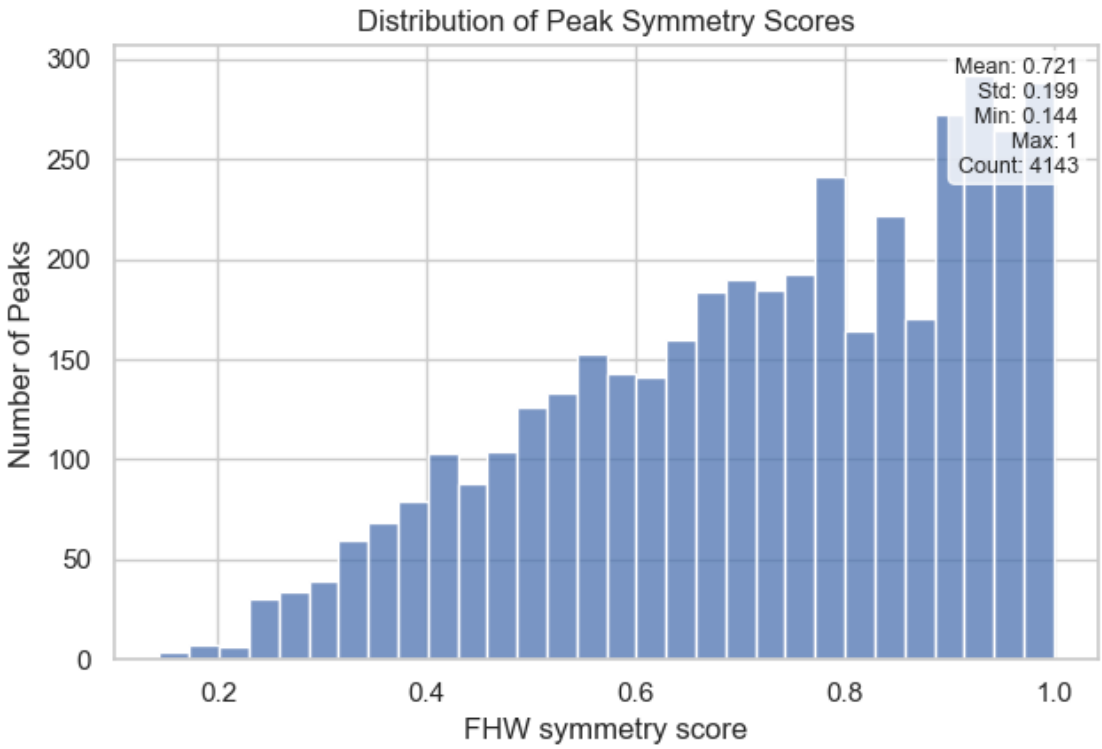
1.1.3 Peaks statistics

```
[2025-08-11 10:15:18] [INFO] calcium: plot_histogram: removed 7 outliers out of
4143 on 'Duration (s)' (lower=-115, upper=214)
```

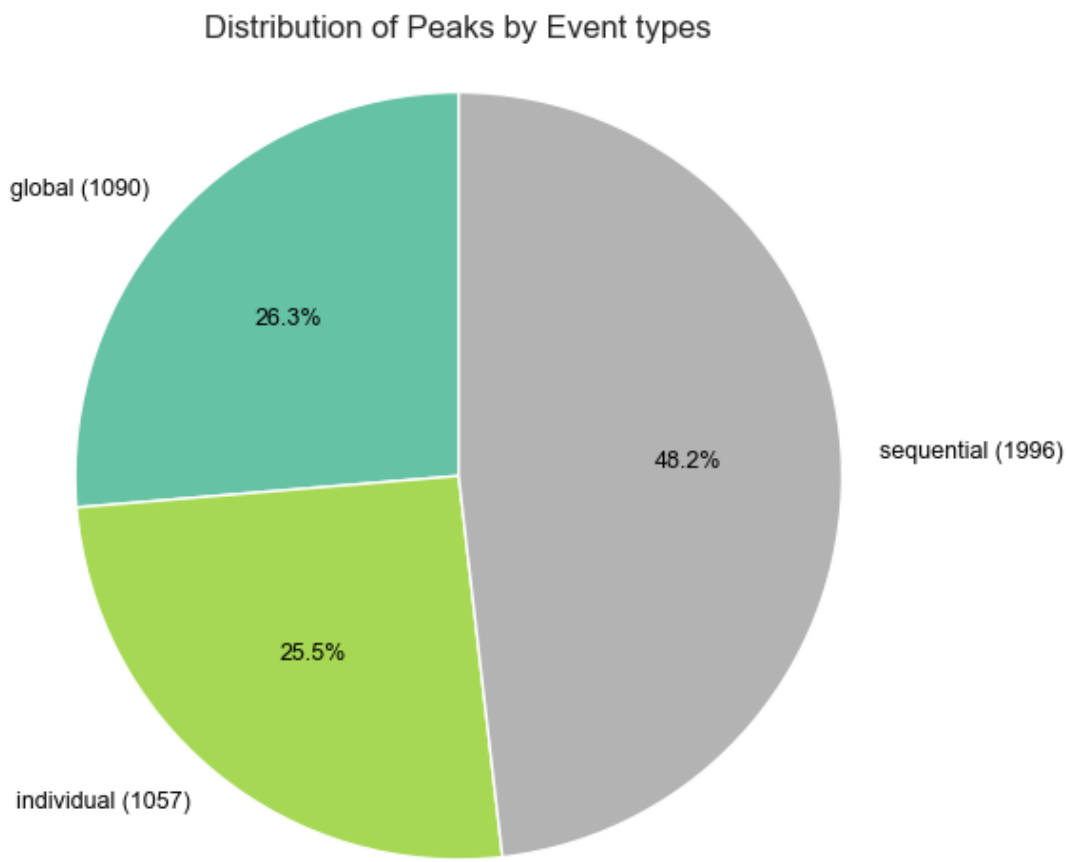



```
[2025-08-11 10:15:18] [INFO] calcium: plot_histogram: removed 591 outliers out
of 4143 on 'Prominence (noise std units)' (lower=-54.35, upper=117.5)
```


Distribution of Peak Prominences
Mean: 29.2
Std: 15.8
Min: 15
Max: 116
Count: 3552
Number of Peaks
0
100
200
300
400
500
600
700
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

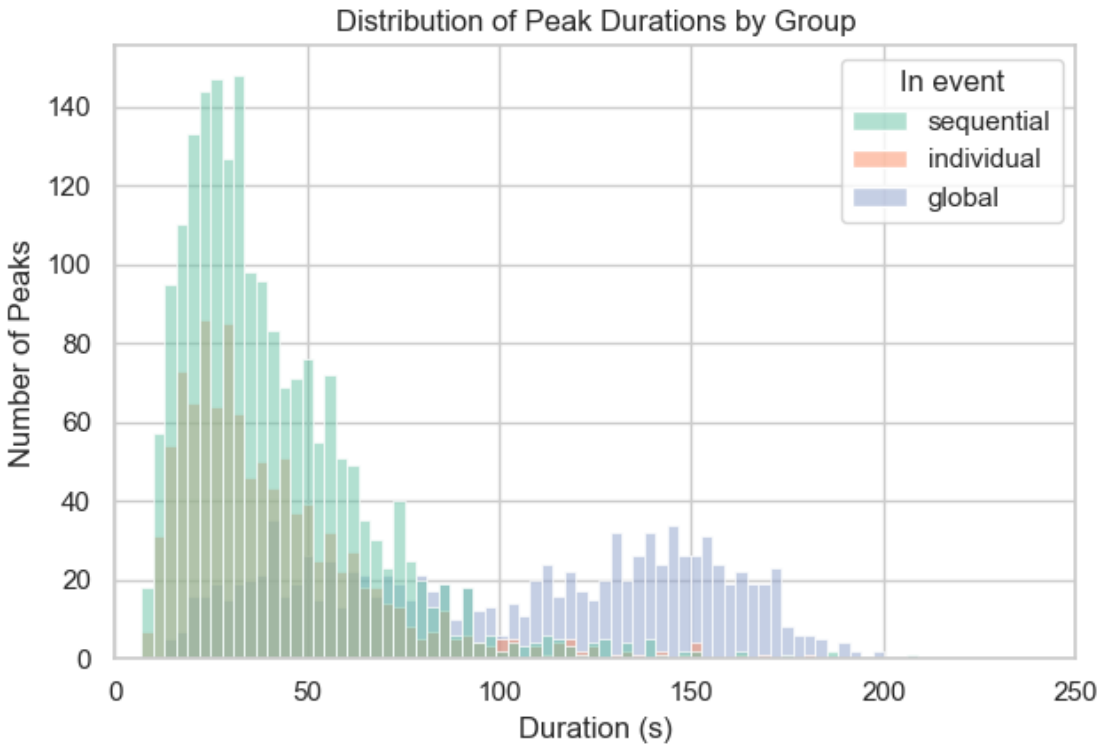

Distribution of Peak Symmetry Scores
Mean: 0.721
Std: 0.199
Min: 0.144
Max: 1
Count: 4143
Number of Peaks
0
50
100
150
200
250
300
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

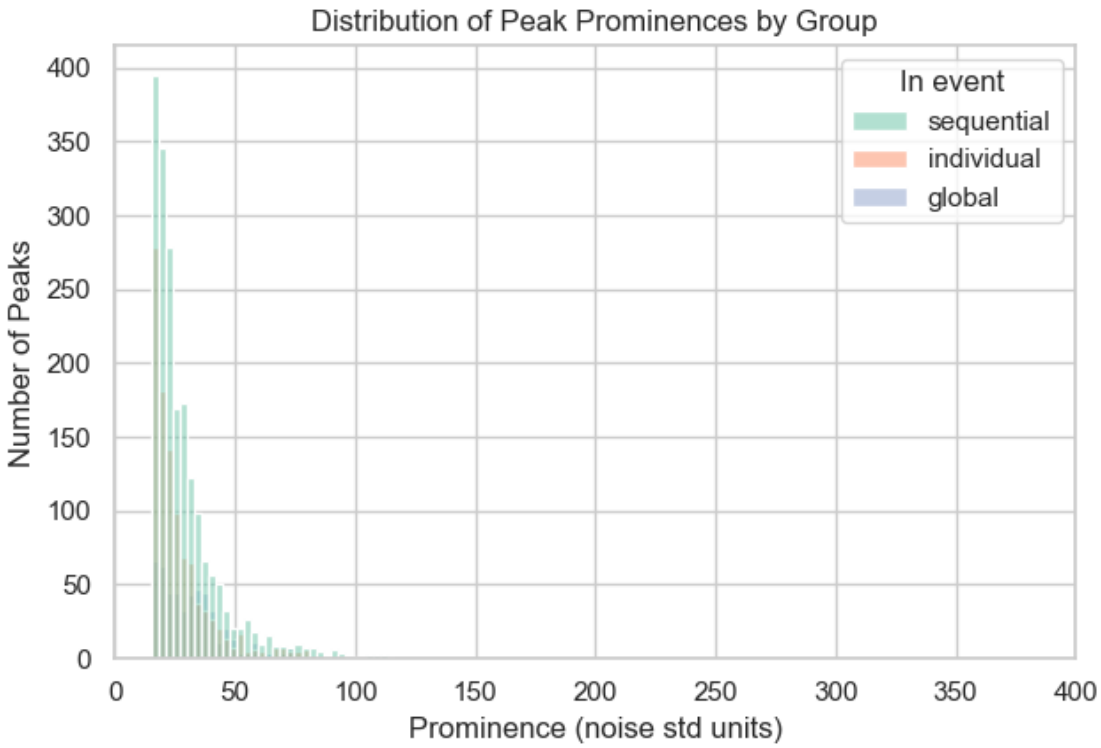


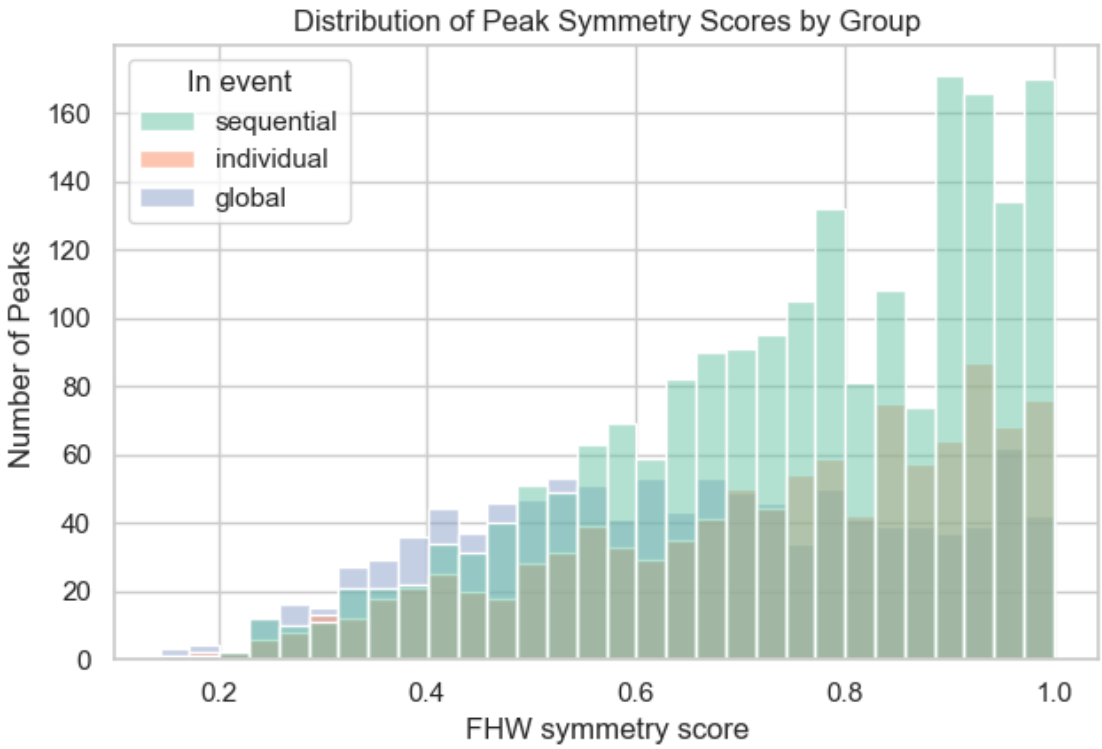
1.1.5 Peaks statistics per event types

```
[2025-08-11 10:15:18] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 4143 on 'Duration (s)' (lower=-115, upper=214)
```




```
[2025-08-11 10:15:18] [INFO] calcium: plot_histogram_by_group: removed 591
outliers out of 4143 on 'Prominence (noise std units)' (lower=-54.35,
upper=117.5)
```

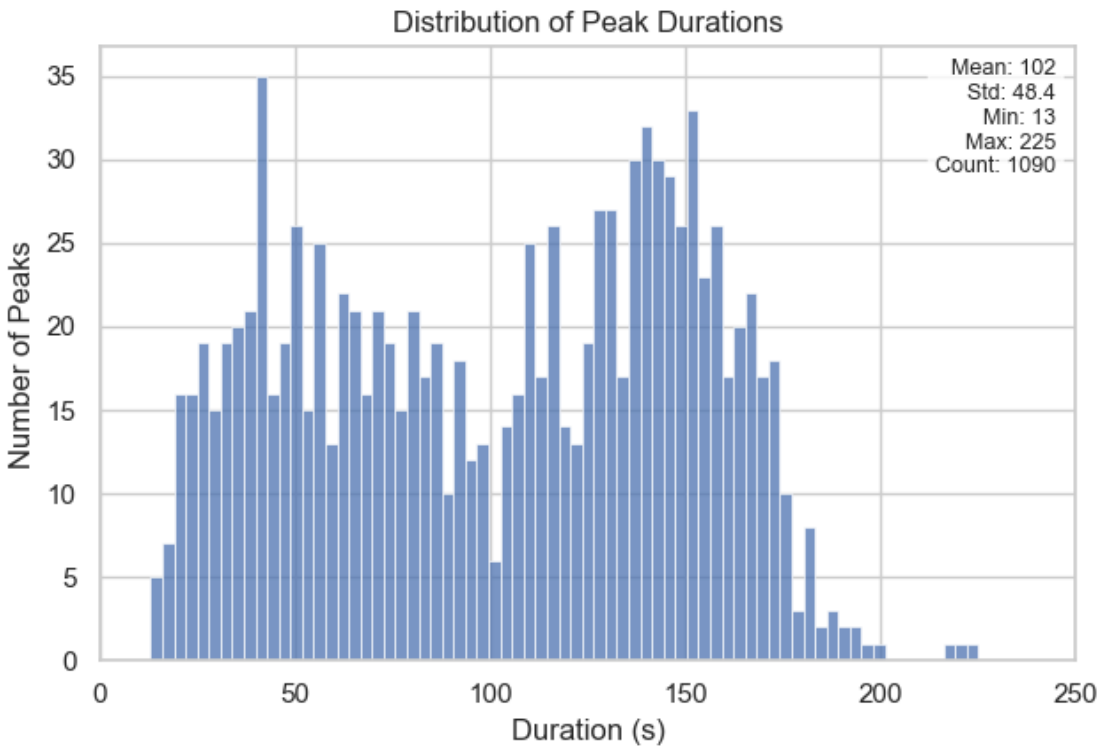

Distribution of Peak Prominences by Group
In event
sequential
individual
global
Number of Peaks
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
individual
global
Number of Peaks
0
20
40
60
80
100
120
140
160
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

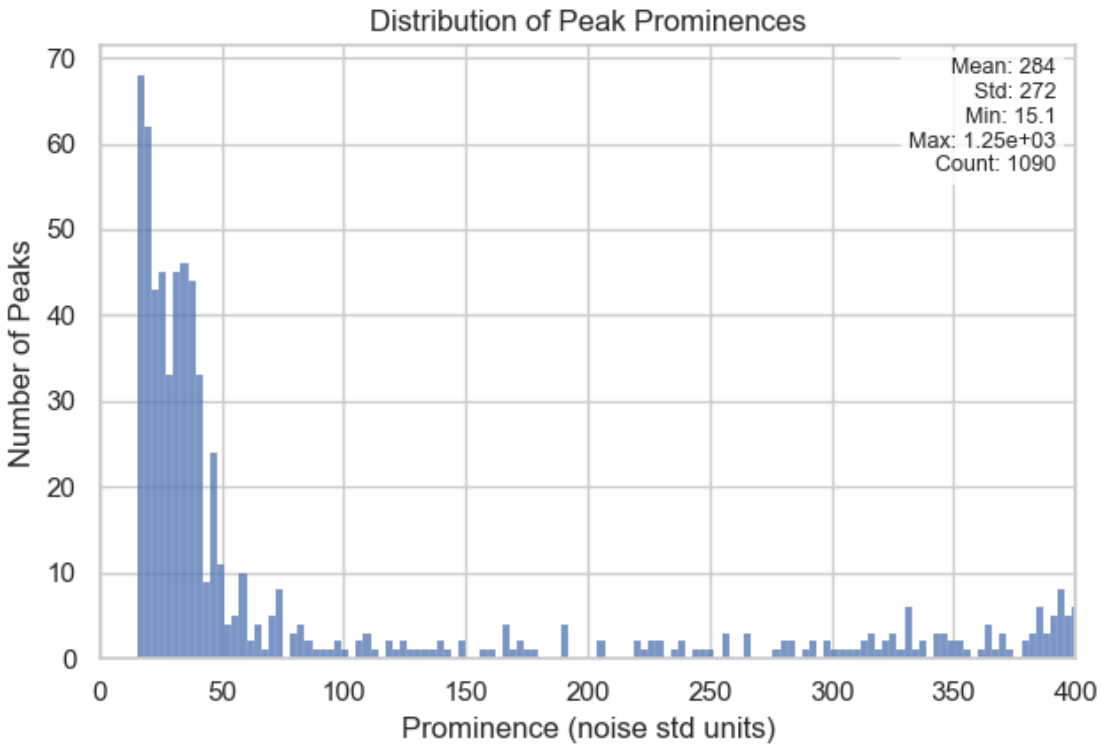
1.2 GLOBAL EVENTS

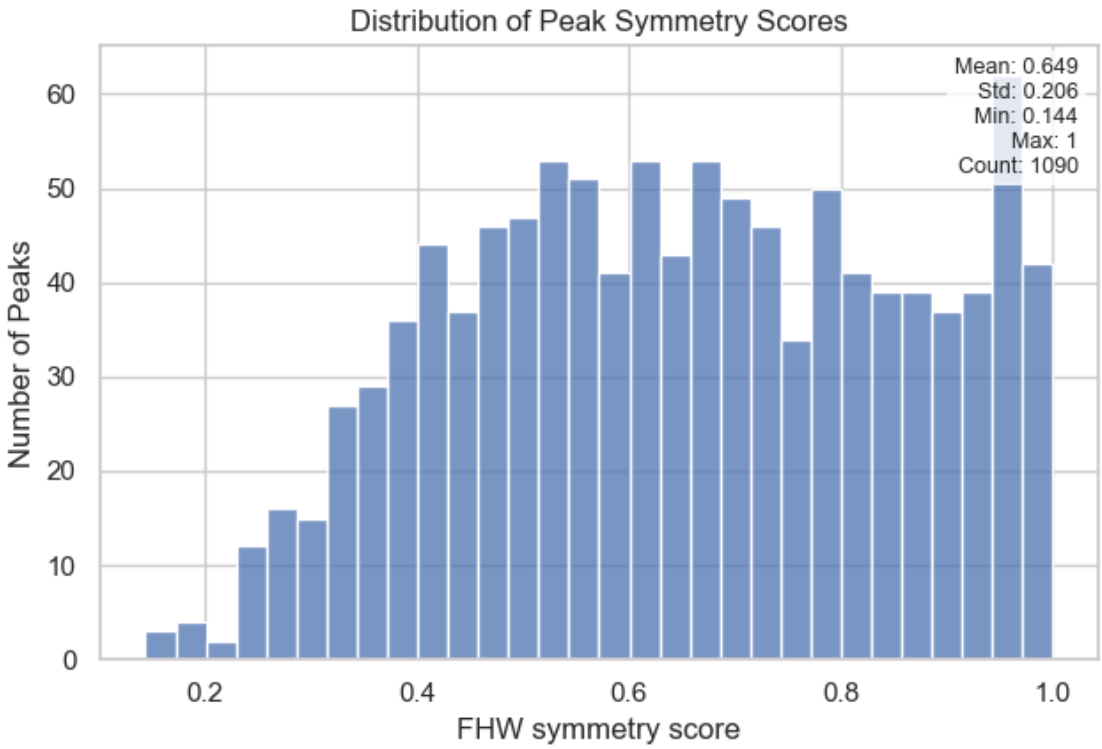
1.2.1 Peak statistics in global events

```
[2025-08-11 10:15:19] [INFO] calcium: plot_histogram: removed 0 outliers out of
1090 on 'Duration (s)' (lower=-204, upper=405)
```



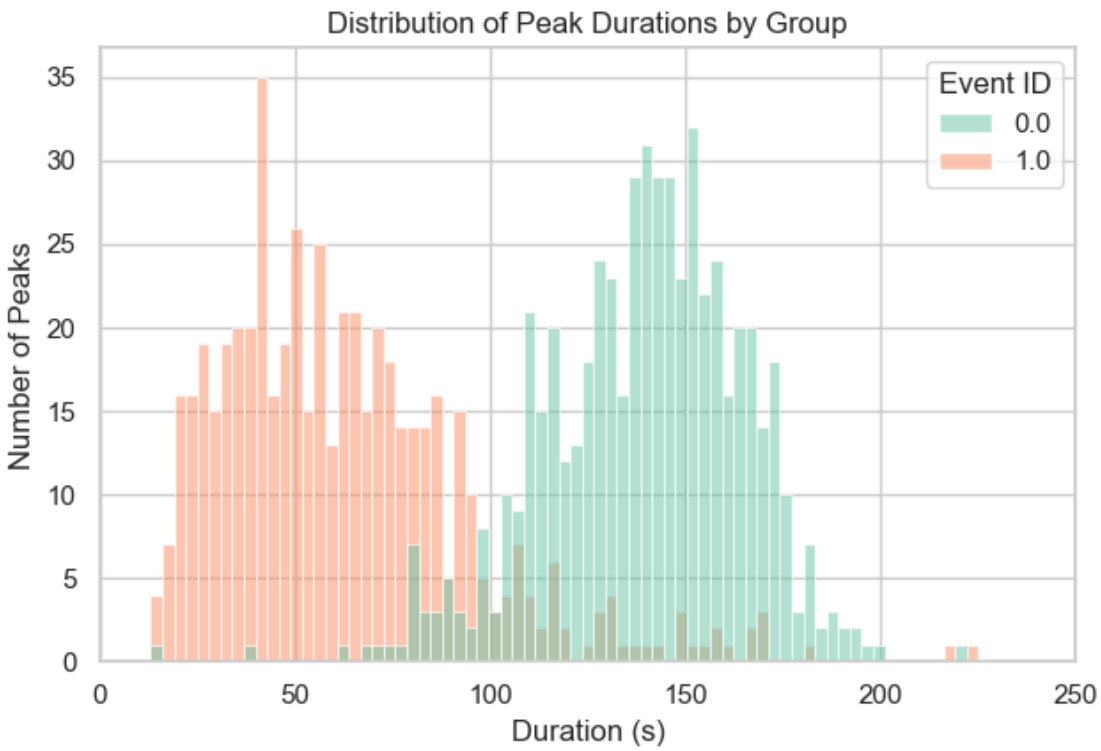

```
[2025-08-11 10:15:19] [INFO] calcium: plot_histogram: removed 0 outliers out of
1090 on 'Prominence (noise std units)' (lower=-1448.5, upper=2003.7)
```


Distribution of Peak Prominences
Mean: 284
Std: 272
Min: 15.1
Max: 1.25e+03
Count: 1090
Number of Peaks
Prominence (noise std units)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400

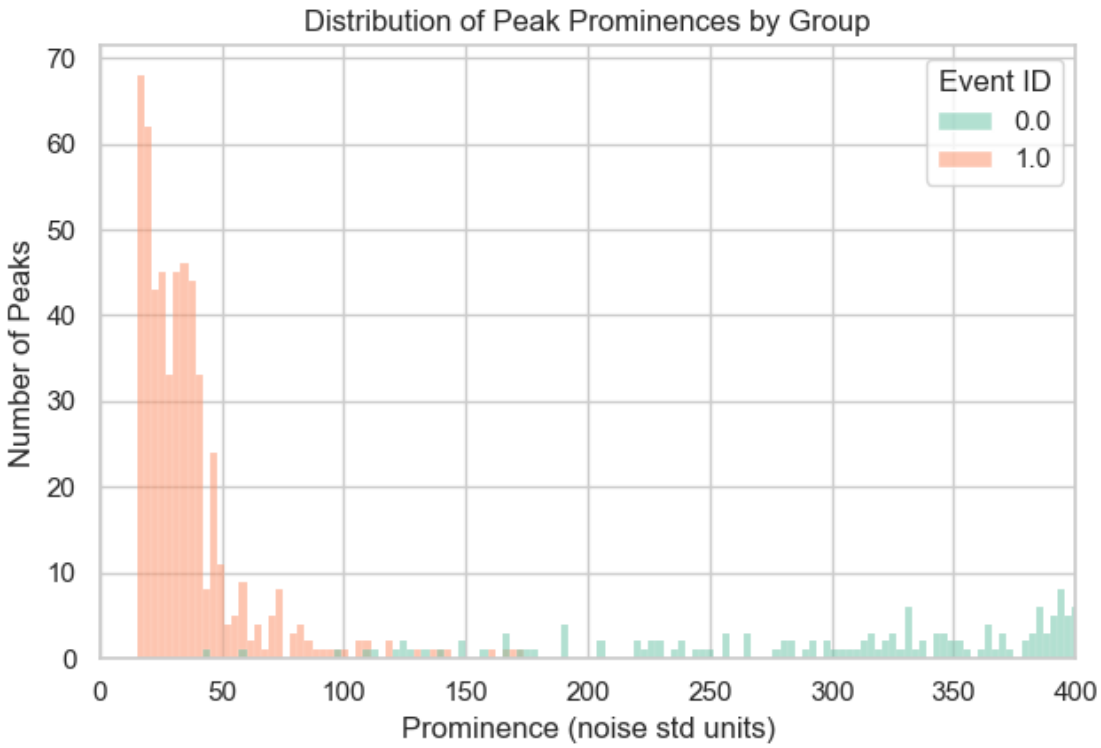

Distribution of Peak Symmetry Scores
Mean: 0.649
Std: 0.206
Min: 0.144
Max: 1
Count: 1090
Number of Peaks
FHW symmetry score
0
10
20
30
40
50
60
0.2
0.4
0.6
0.8
1.0

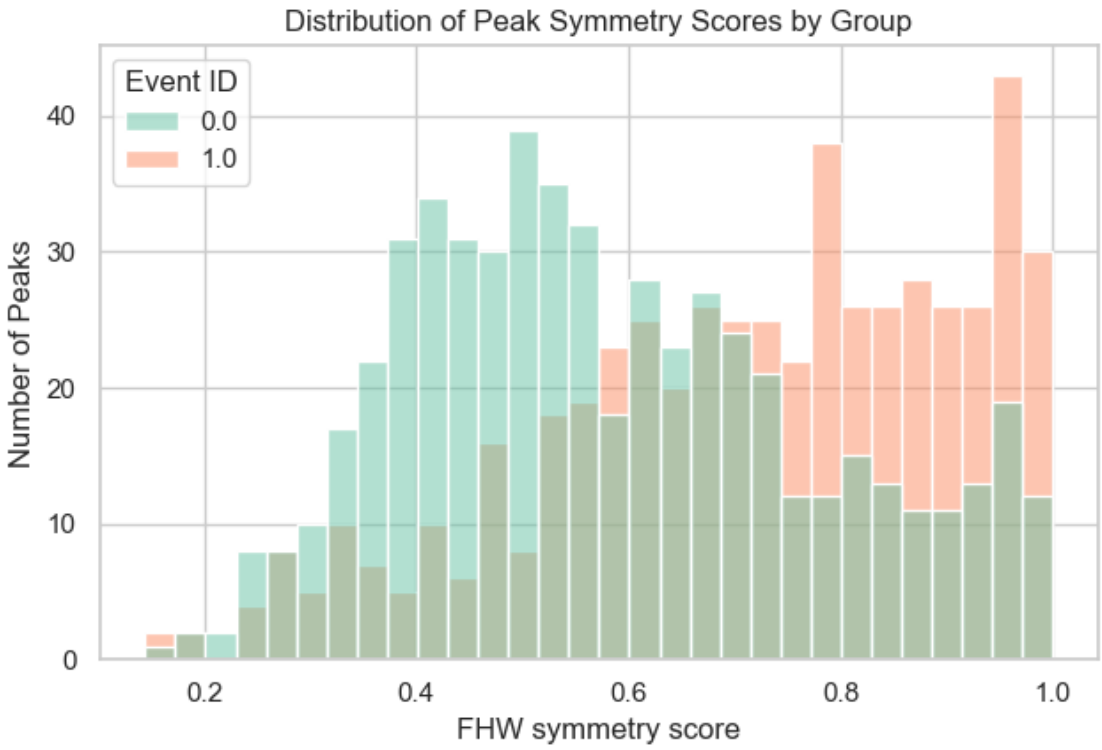
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 10:15:19] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 1090 on 'Duration (s)' (lower=-204, upper=405)
```

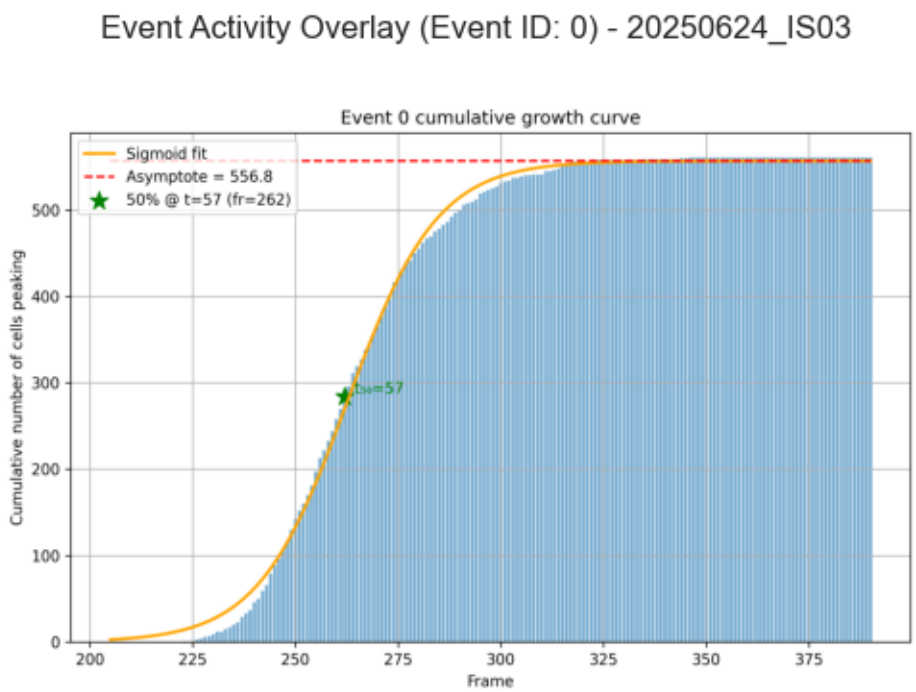


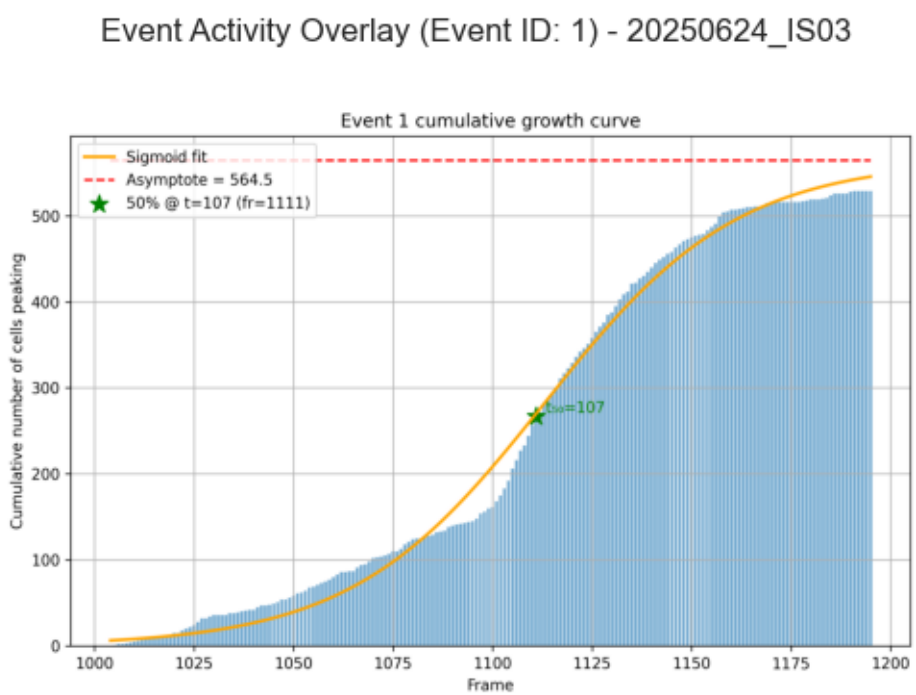

```
[2025-08-11 10:15:20] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 1090 on 'Prominence (noise std units)' (lower=-1448.5,
upper=2003.7)
```


Distribution of Peak Prominences by Group
Event ID
0.0
1.0
Number of Peaks
Prominence (noise std units)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400

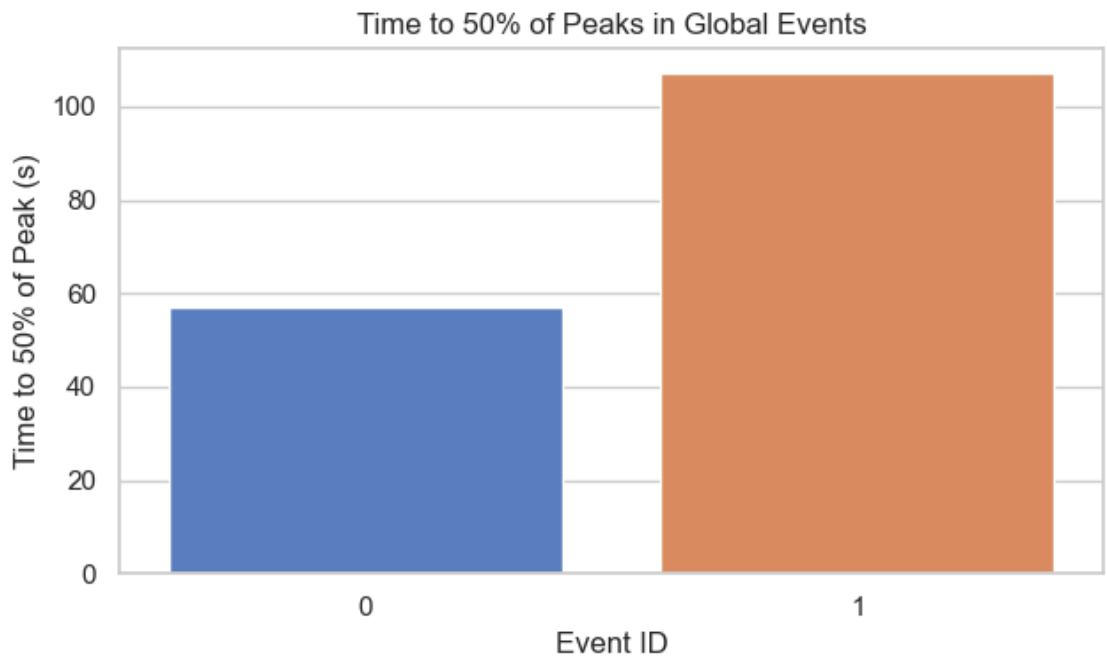

Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
Number of Peaks
FHW symmetry score
0
10
20
30
40
0.2
0.4
0.6
0.8
1.0

1.2.3 Kinetics of global events

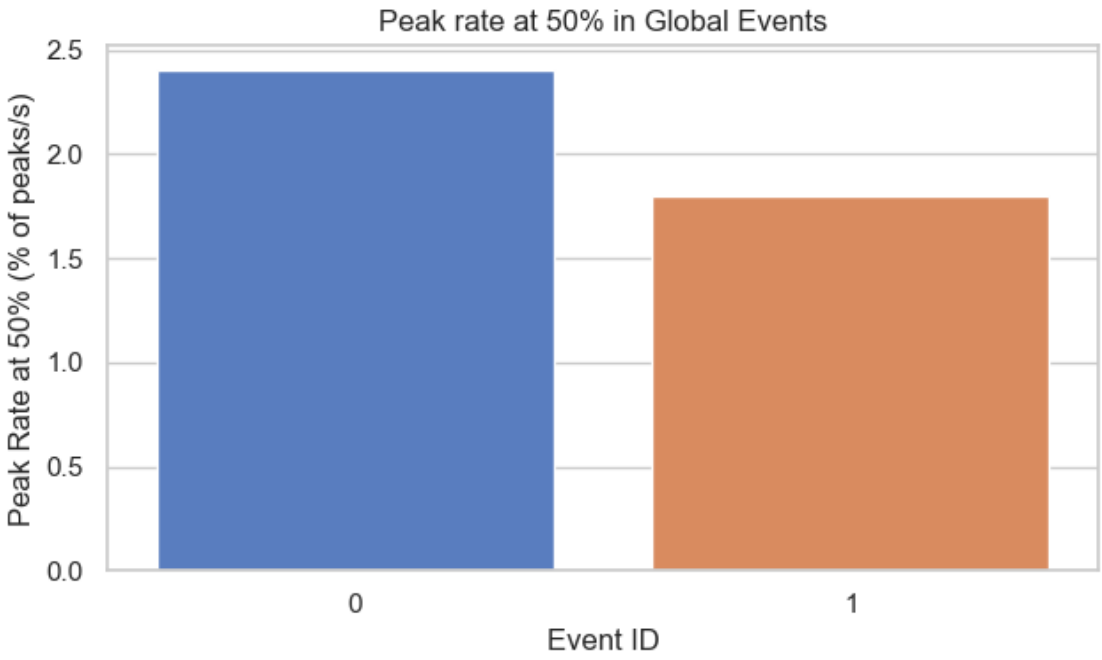




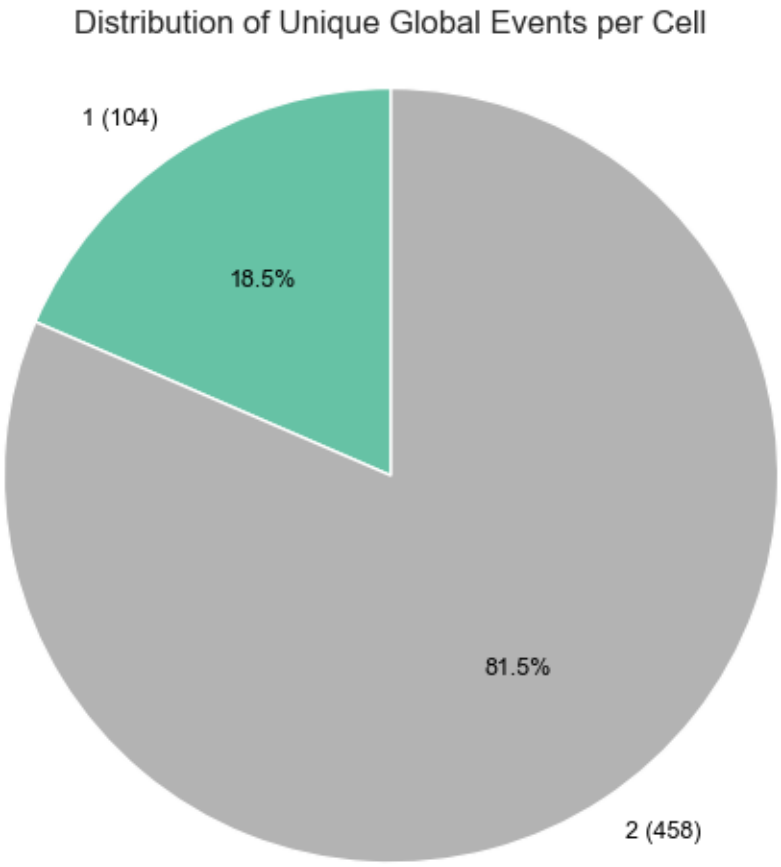
```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



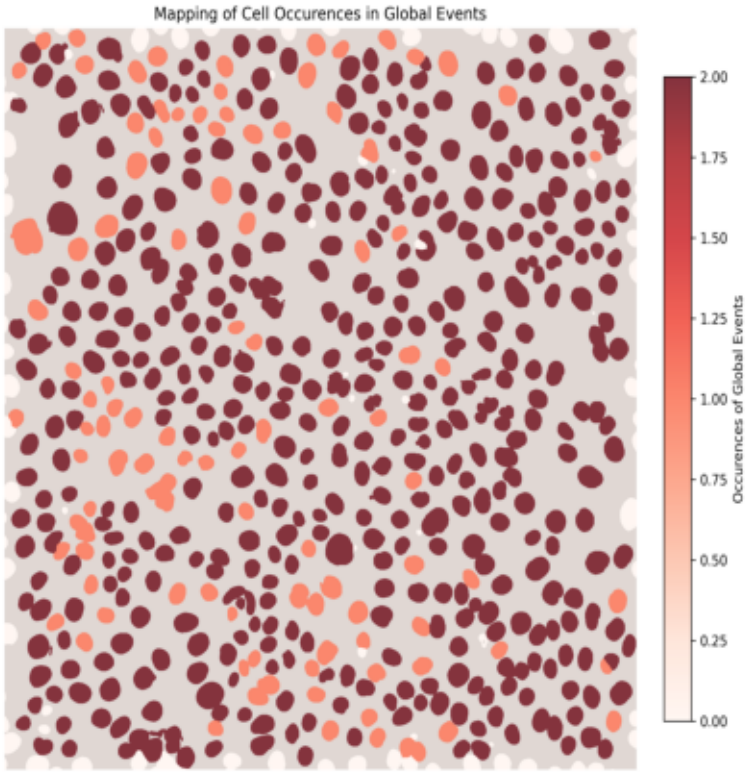

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.5
2.0
1.5
1.0
0.5
0.0
0
1
Event ID

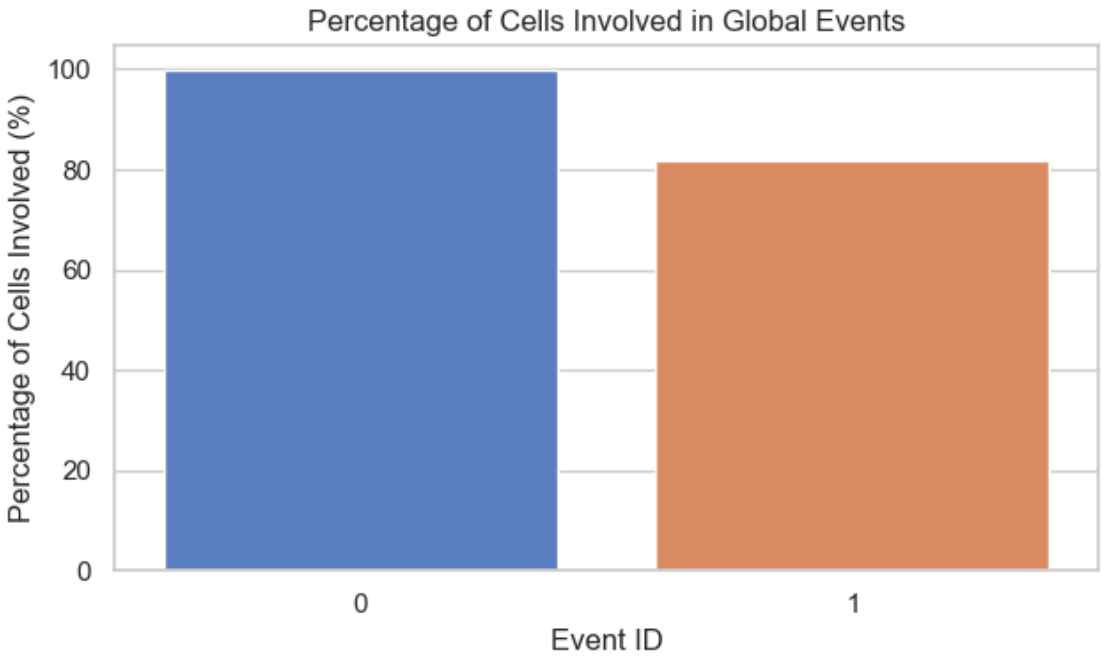
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250624_IS03




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

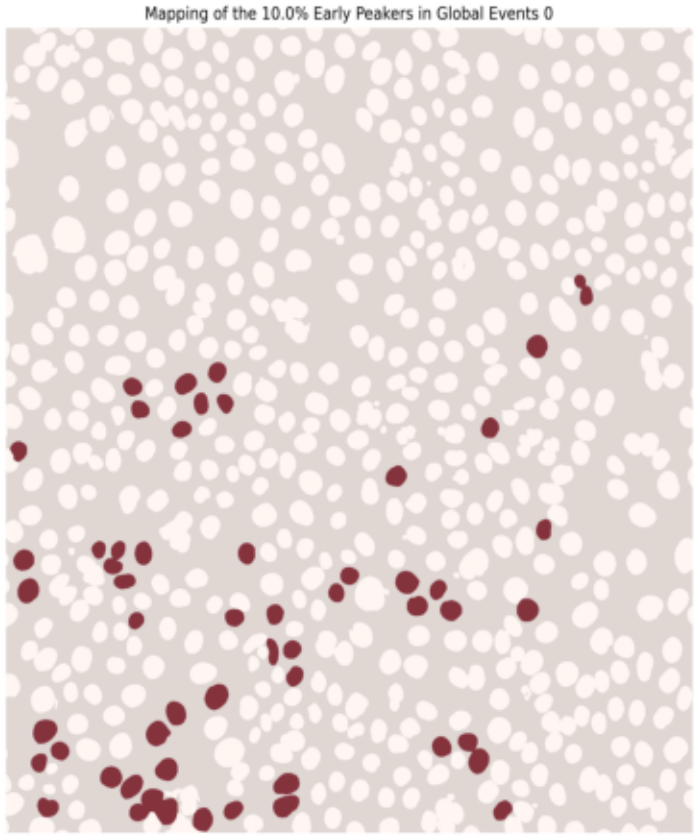


1.2.5 Inter-event interval analysis

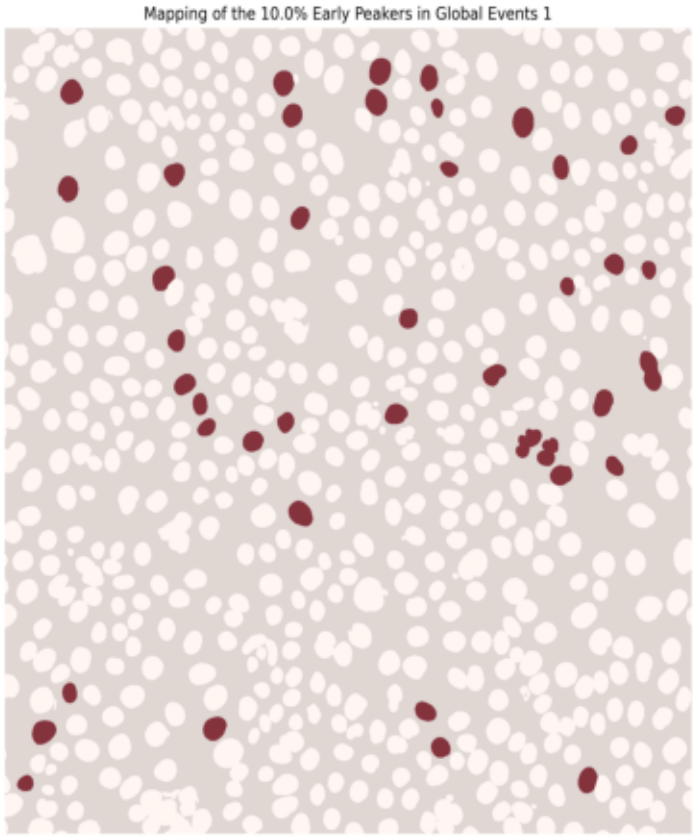
```
Intervals between global event peaks: [832.0]
```

1.2.6 Early peakers in the events

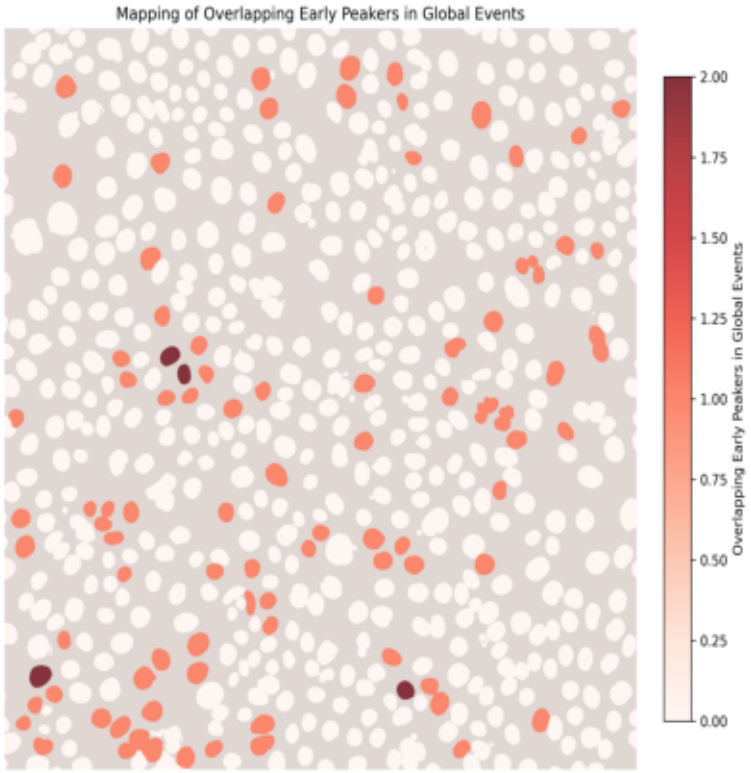
Cell Mapping with Early Peakers Overlay for event 0 - 20250624_IS03



Cell Mapping with Early Peakers Overlay for event 1 - 20250624_IS03

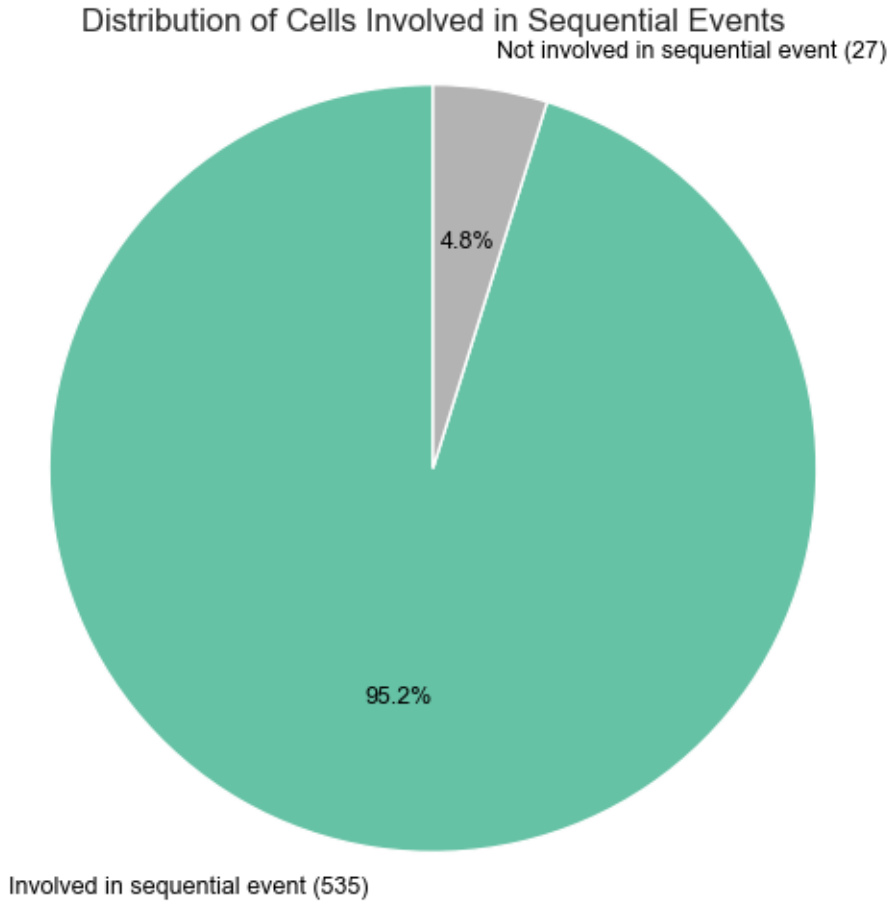


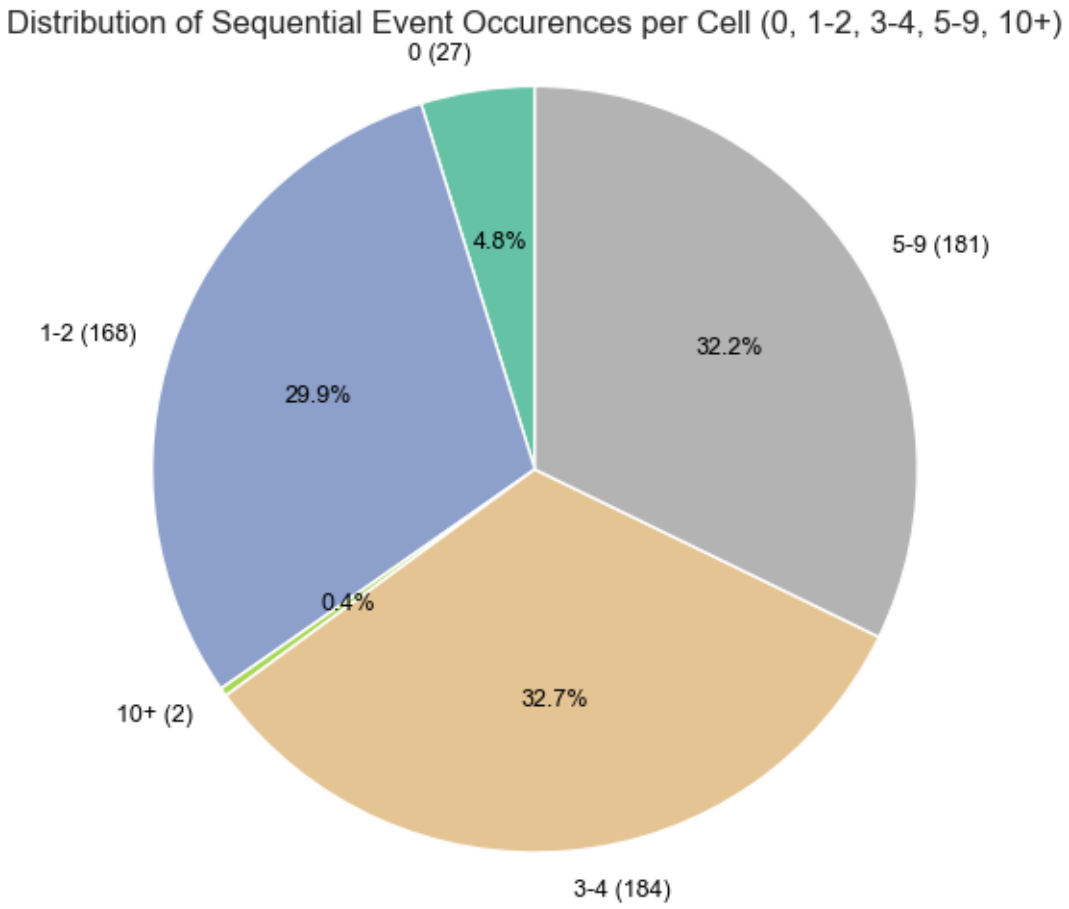
Cell Mapping with Occurences in Global Events Overlay - 20250624_IS03



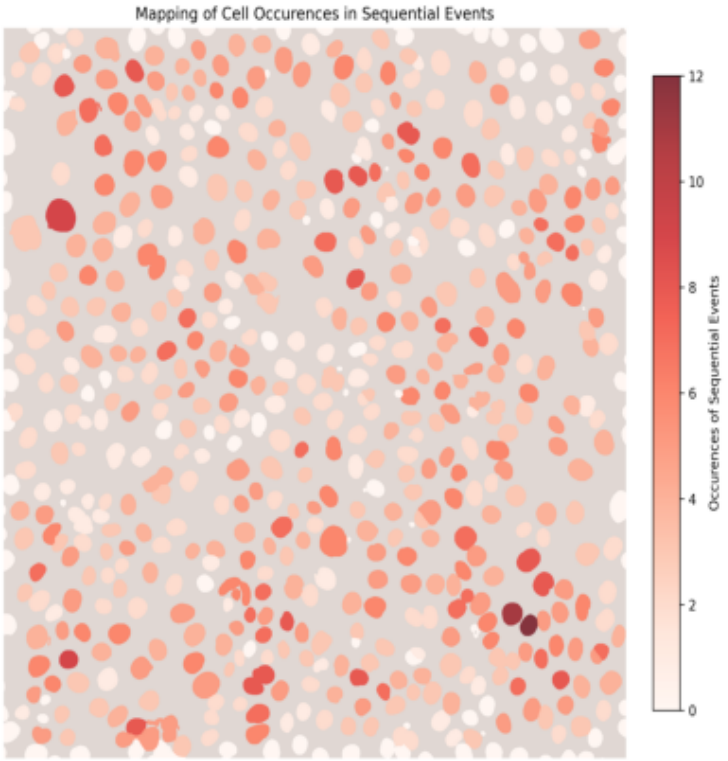
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

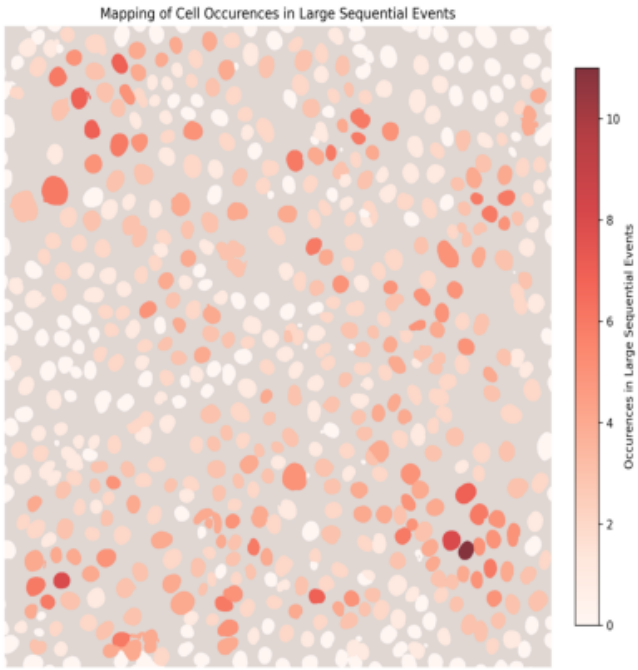



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (27)
4.8%
5-9 (181)
32.2%
1-2 (168)
29.9%
0.4%
10+ (2)
32.7%
3-4 (184)

Cell Mapping with Occurences in Sequential Events Overlay - 20250624_IS03

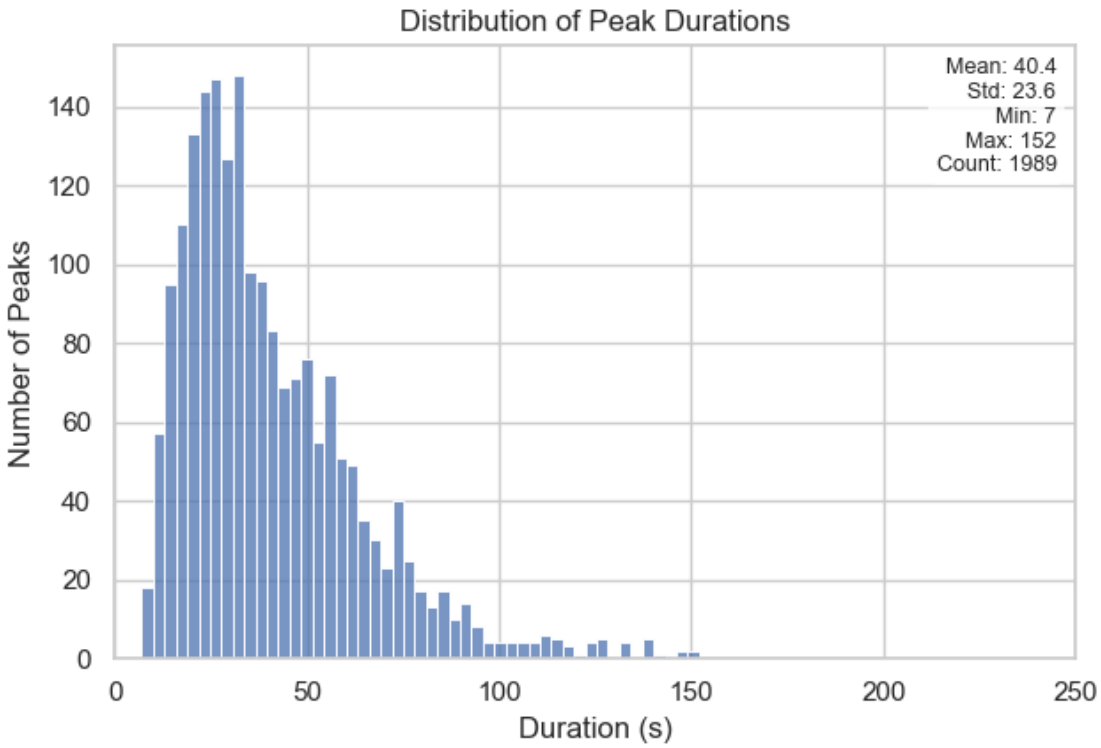


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250624_IS03

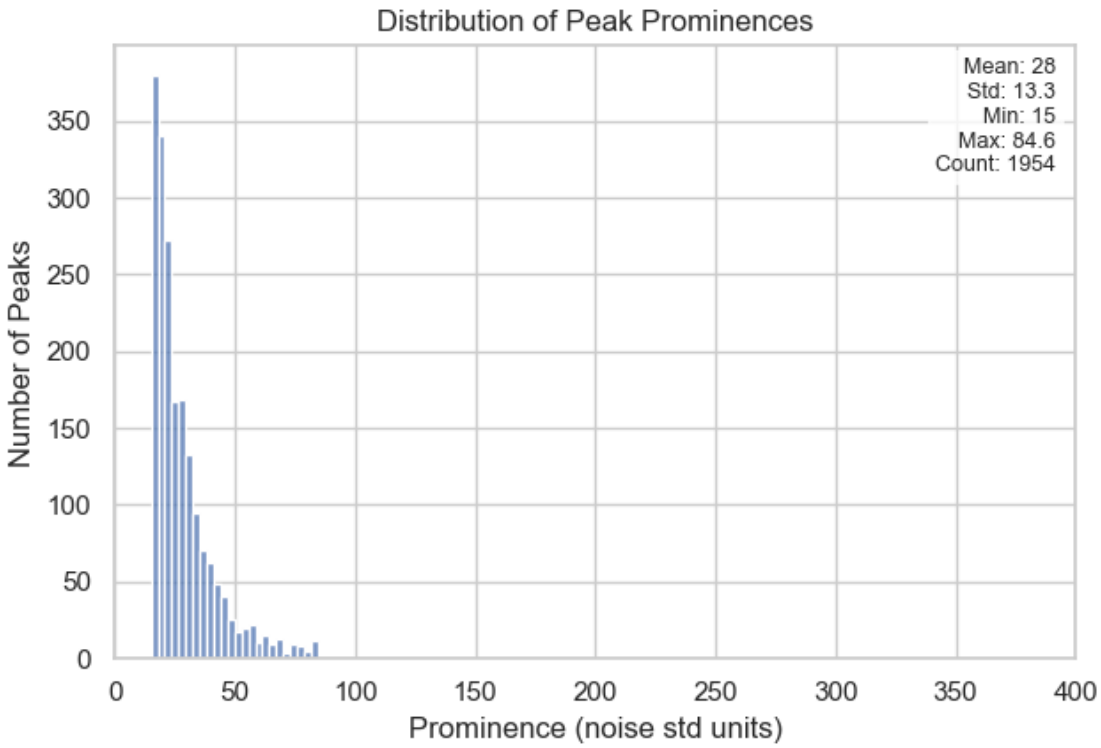


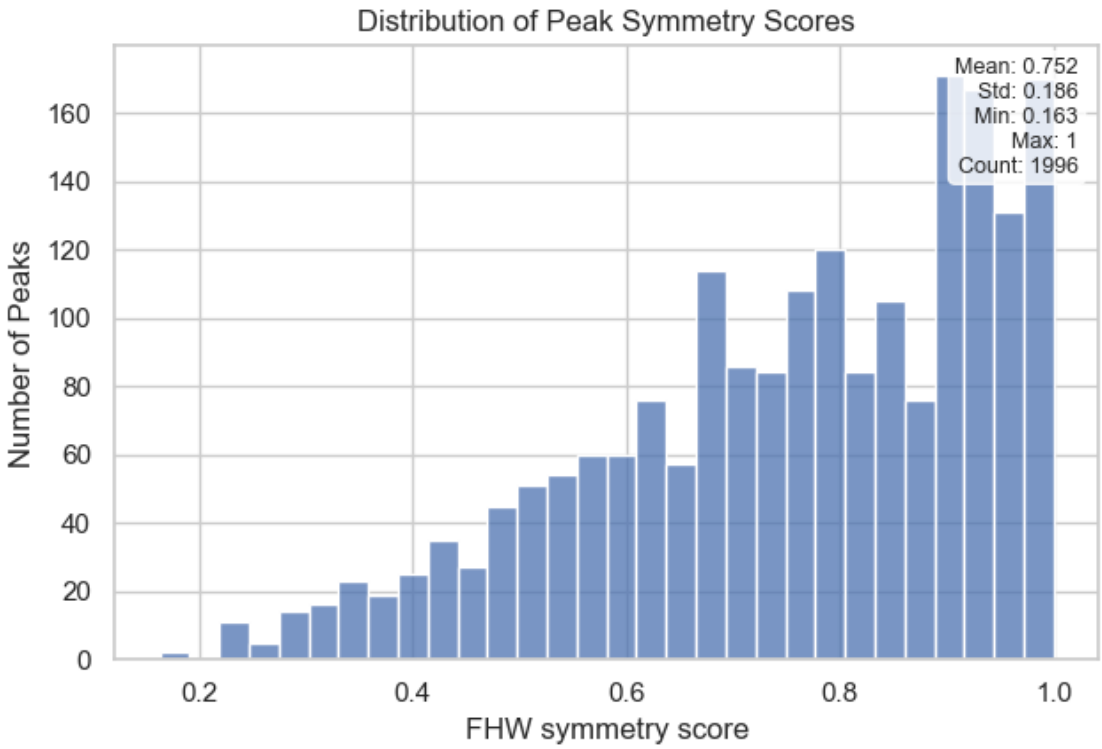
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 10:15:28] [INFO] calcium: plot_histogram: removed 7 outliers out of
1996 on 'Duration (s)' (lower=-22, upper=158)
```



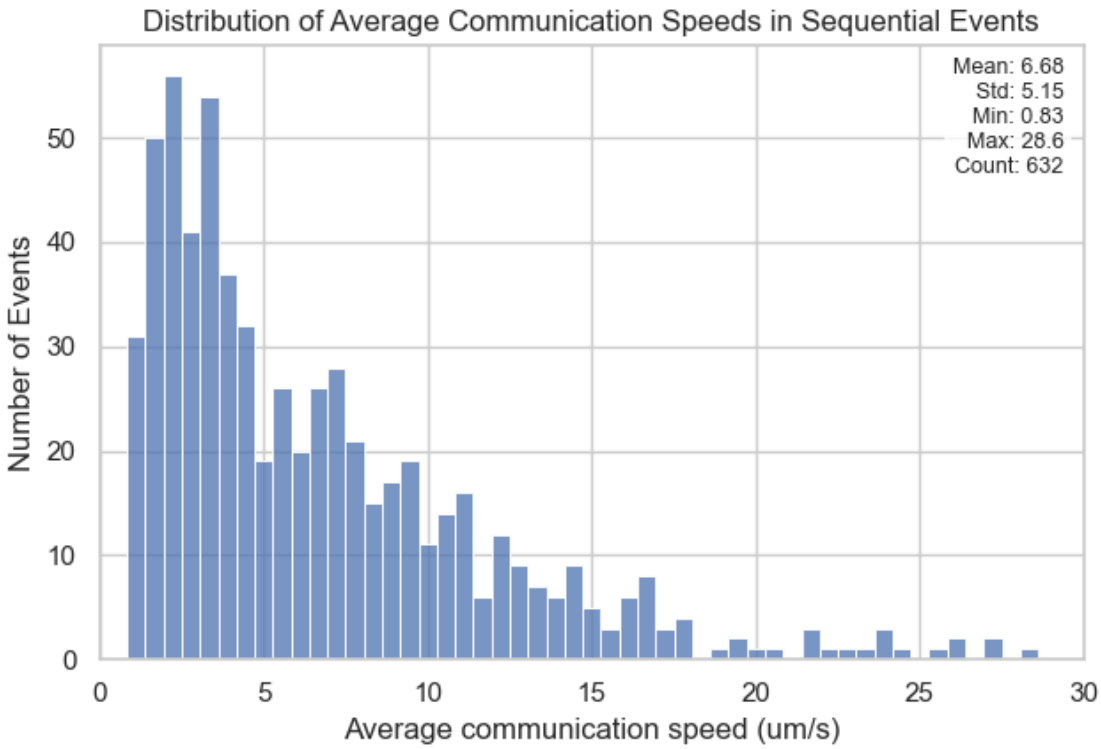

```
[2025-08-11 10:15:28] [INFO] calcium: plot_histogram: removed 42 outliers out of
1996 on 'Prominence (noise std units)' (lower=-3.1375, upper=84.612)
```


Distribution of Peak Prominences
Mean: 28
Std: 13.3
Min: 15
Max: 84.6
Count: 1954
Number of Peaks
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

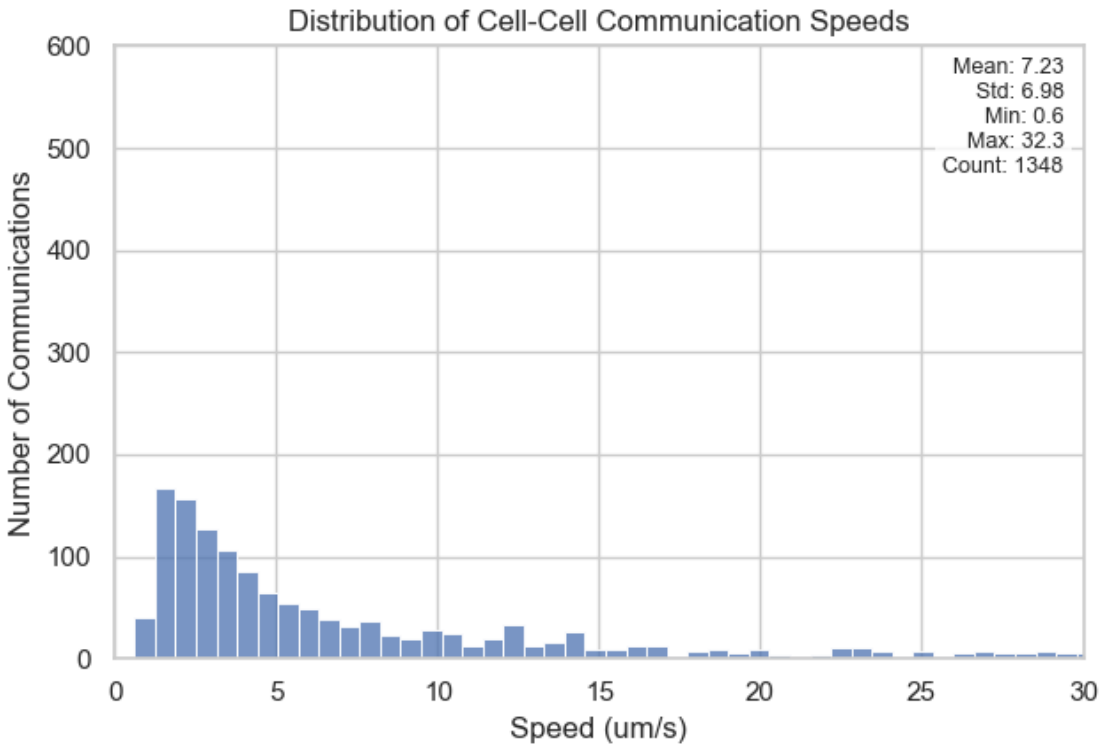

Distribution of Peak Symmetry Scores
Mean: 0.752
Std: 0.186
Min: 0.163
Max: 1
Count: 1996
Number of Peaks
0
20
40
60
80
100
120
140
160
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.3.3 Cell-cell communication speed

```
[2025-08-11 10:15:28] [INFO] calcium: plot_histogram: removed 6 outliers out of
638 on 'Average communication speed (um/s)' (lower=-16.73, upper=28.788)
```

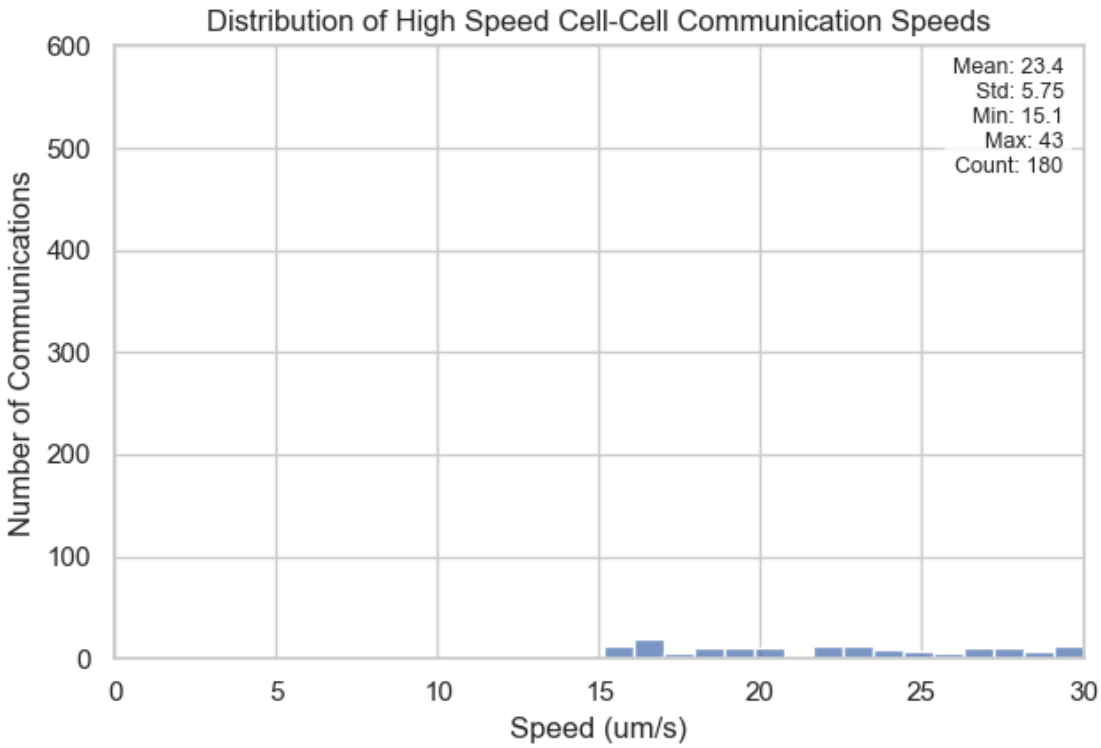



```
[2025-08-11 10:15:28] [INFO] calcium: plot_histogram: removed 10 outliers out of
1358 on 'Speed (um/s)' (lower=-20.297, upper=32.64)
```

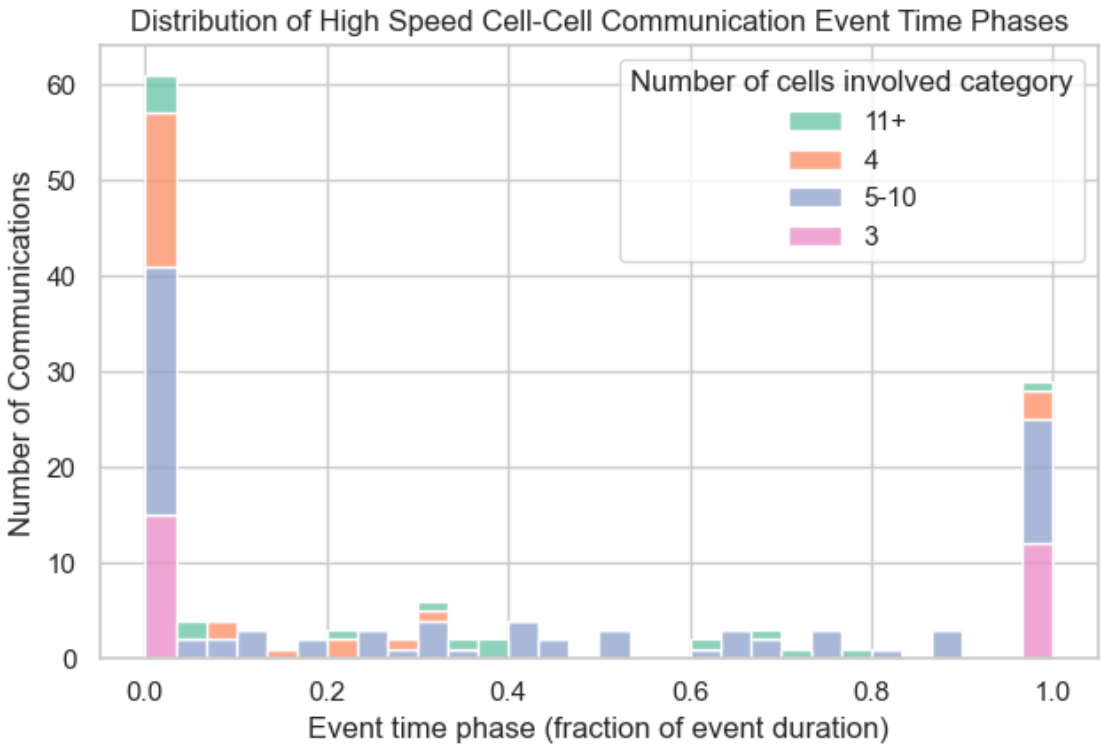


1.3.4 Double distribution in cell-cell communication speeds

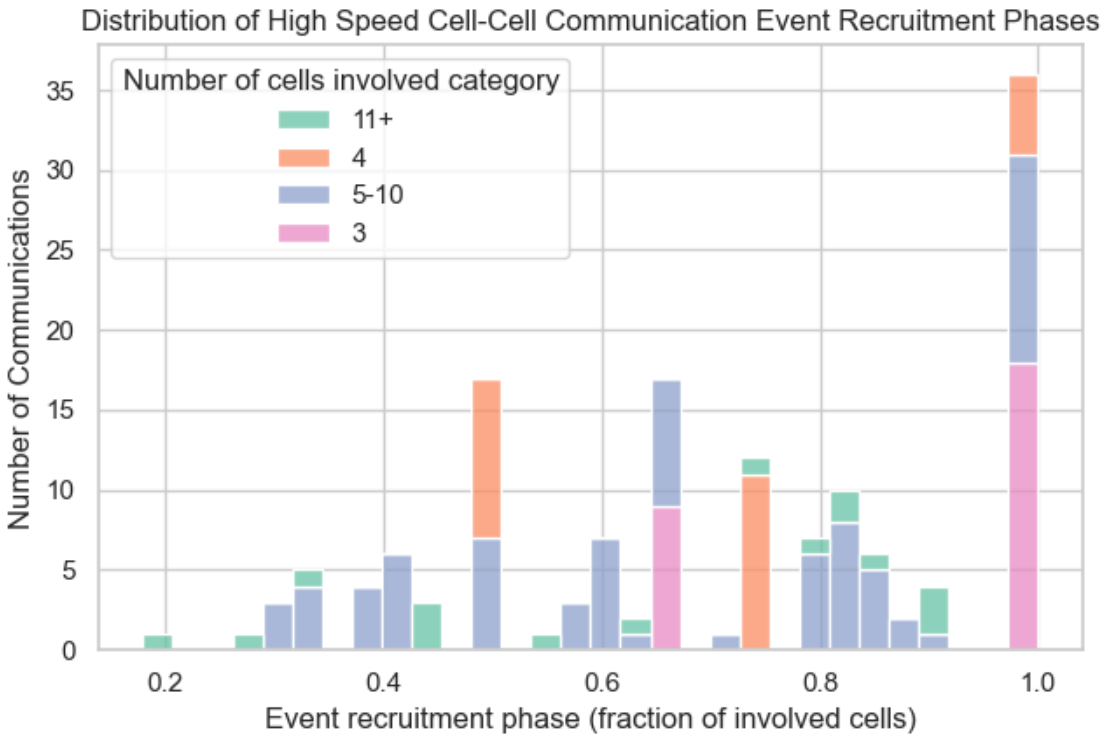
```
[2025-08-11 10:15:28] [INFO] calcium: plot_histogram: removed 0 outliers out of
180 on 'Speed (um/s)' (lower=-8.745, upper=54.815)
```



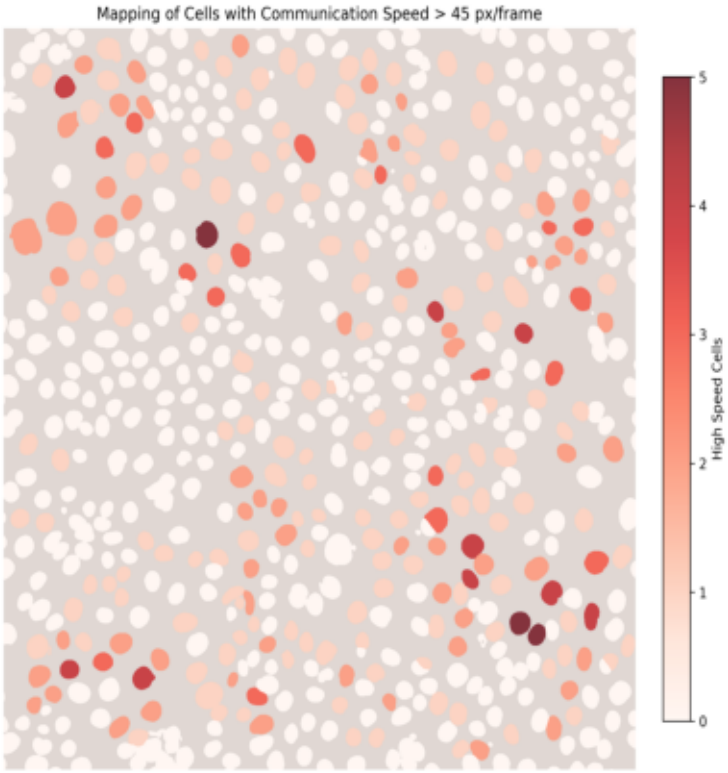

```
[2025-08-11 10:15:29] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 148 on 'Event time phase (fraction of event duration)'
(lower=-2.1375, upper=2.85)
```



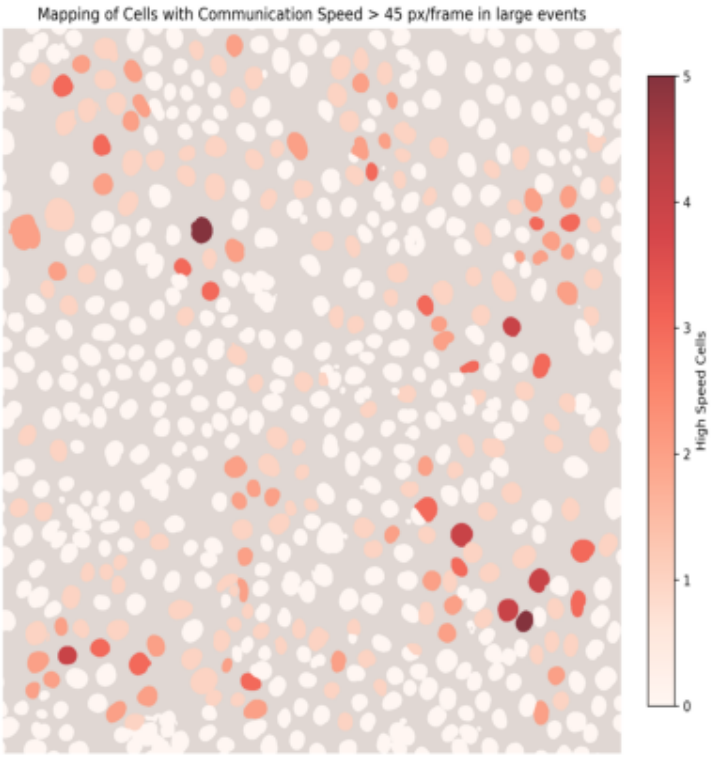

```
[2025-08-11 10:15:29] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 148 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.73, upper=2.14)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
11+
4
5-10
3
Number of Communications
0
5
10
15
20
25
30
35
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

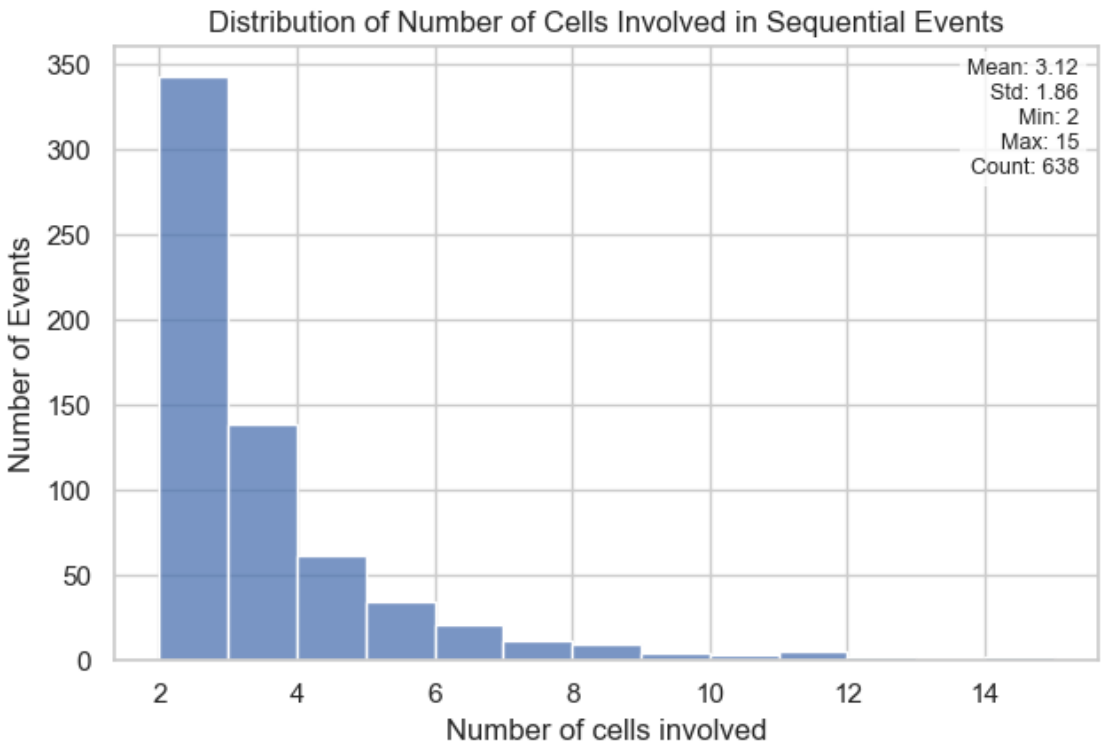
Cell Mapping with High Speed Cells Overlay - 20250624_IS03



Cell Mapping with High Speed Cells in Large Events Overlay - 20250624_IS03

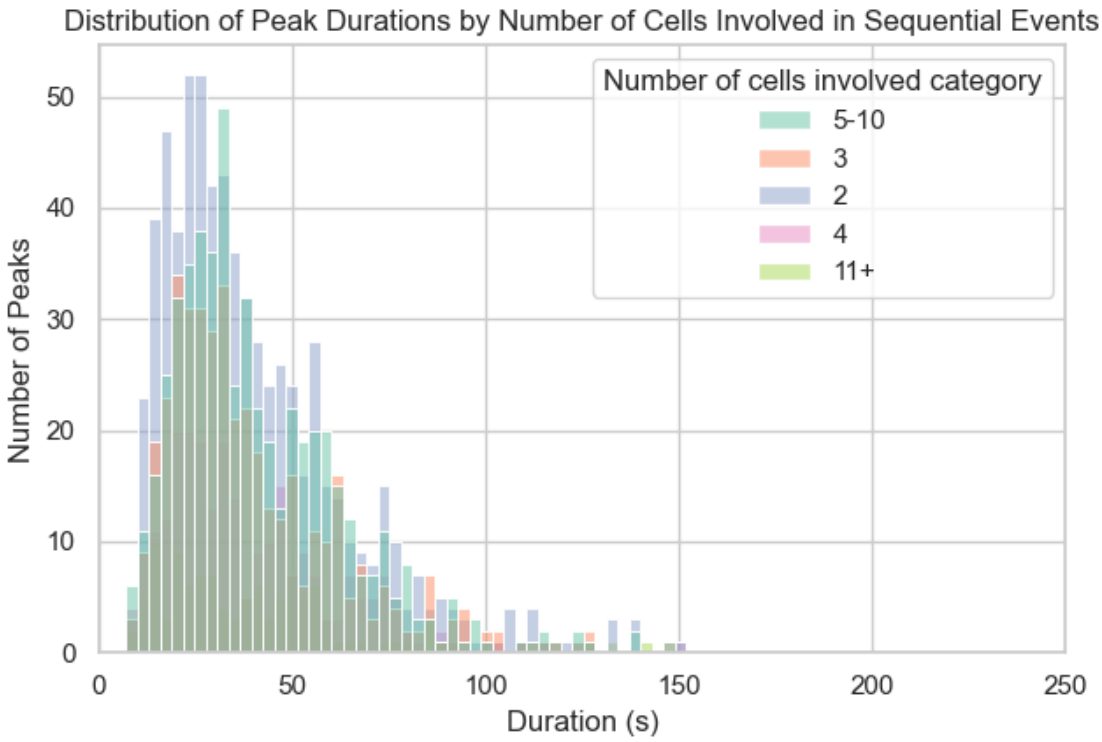


1.3.5 Number of cells involved per sequential events

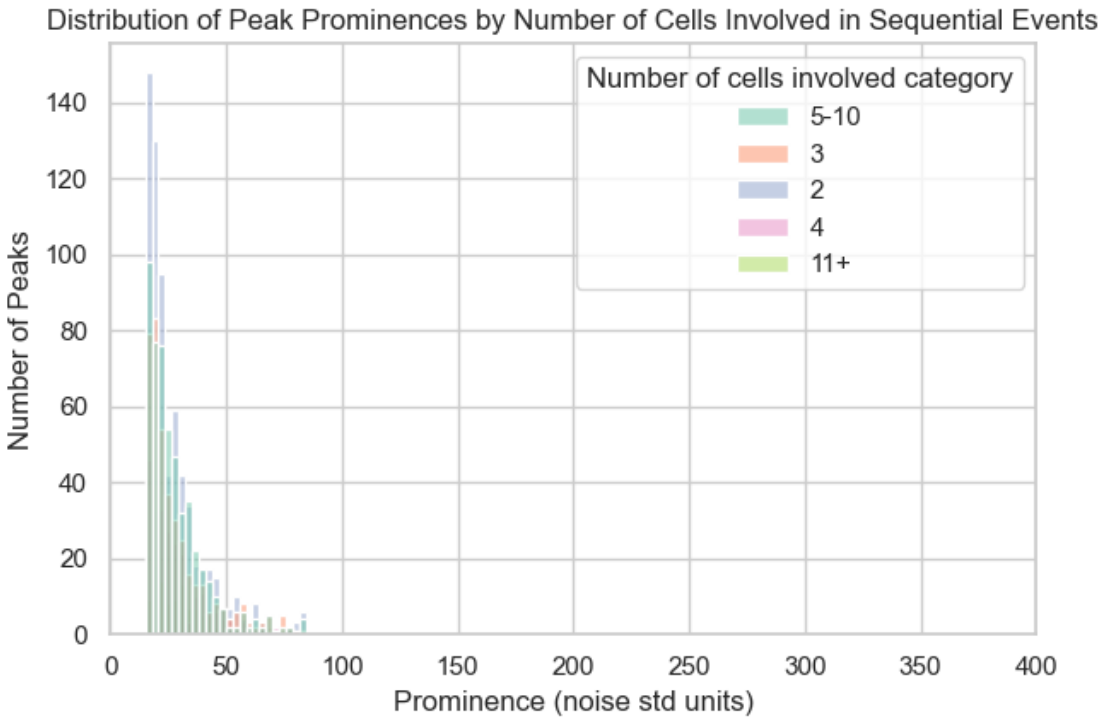


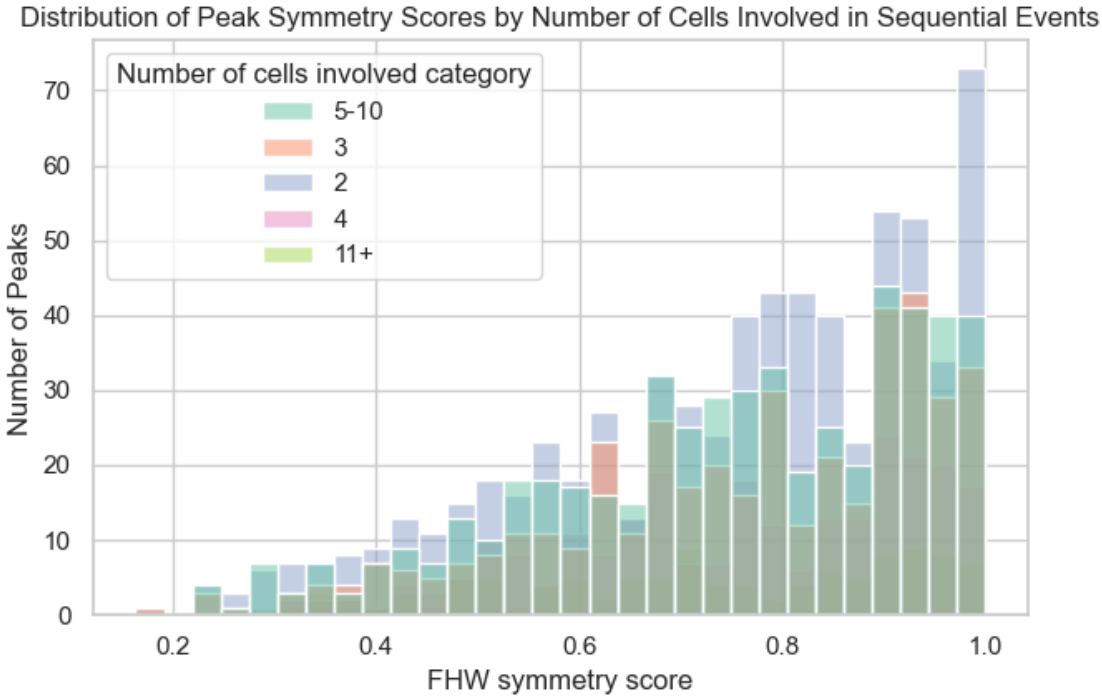
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 10:15:31] [INFO] calcium: plot_histogram_by_group: removed 7
outliers out of 1996 on 'Duration (s)' (lower=-22, upper=158)
```



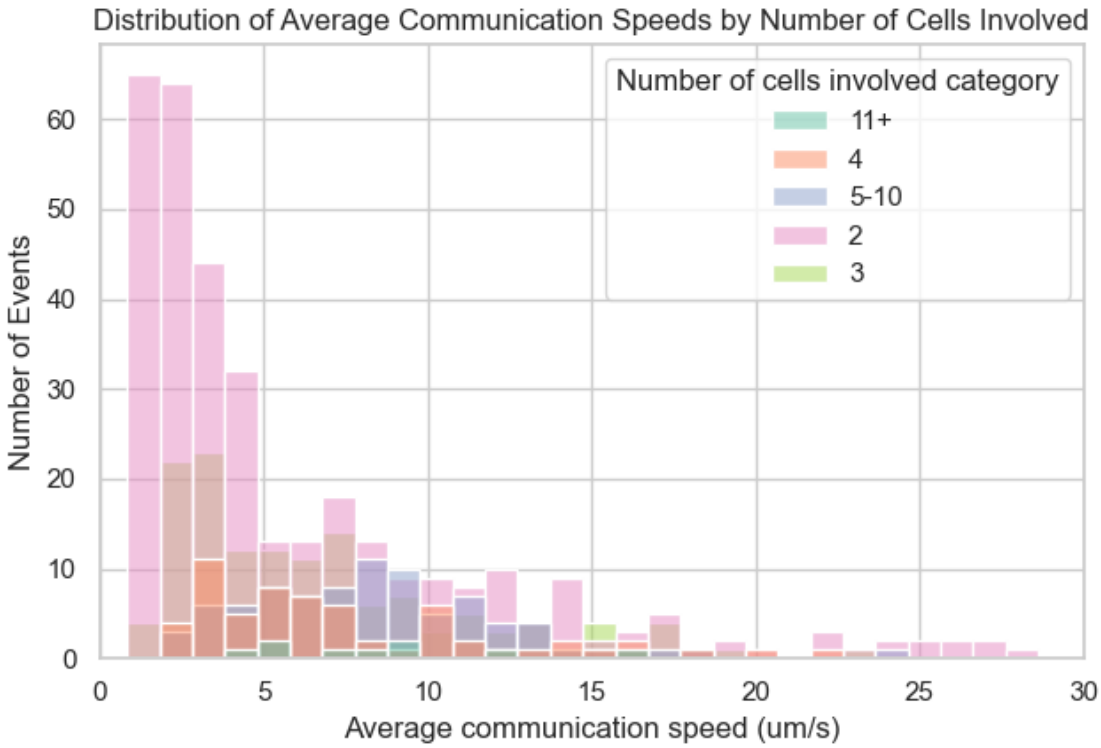

```
[2025-08-11 10:15:32] [INFO] calcium: plot_histogram_by_group: removed 42
outliers out of 1996 on 'Prominence (noise std units)' (lower=-3.1375,
upper=84.612)
```



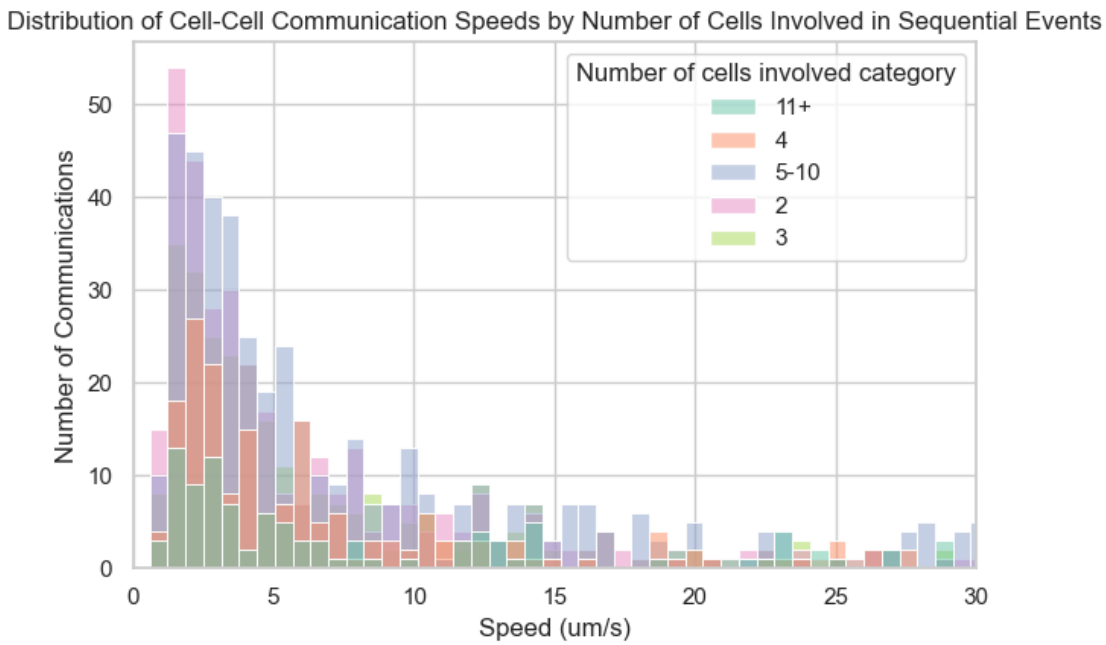



```
[2025-08-11 10:15:32] [INFO] calcium: plot_histogram_by_group: removed 6
```

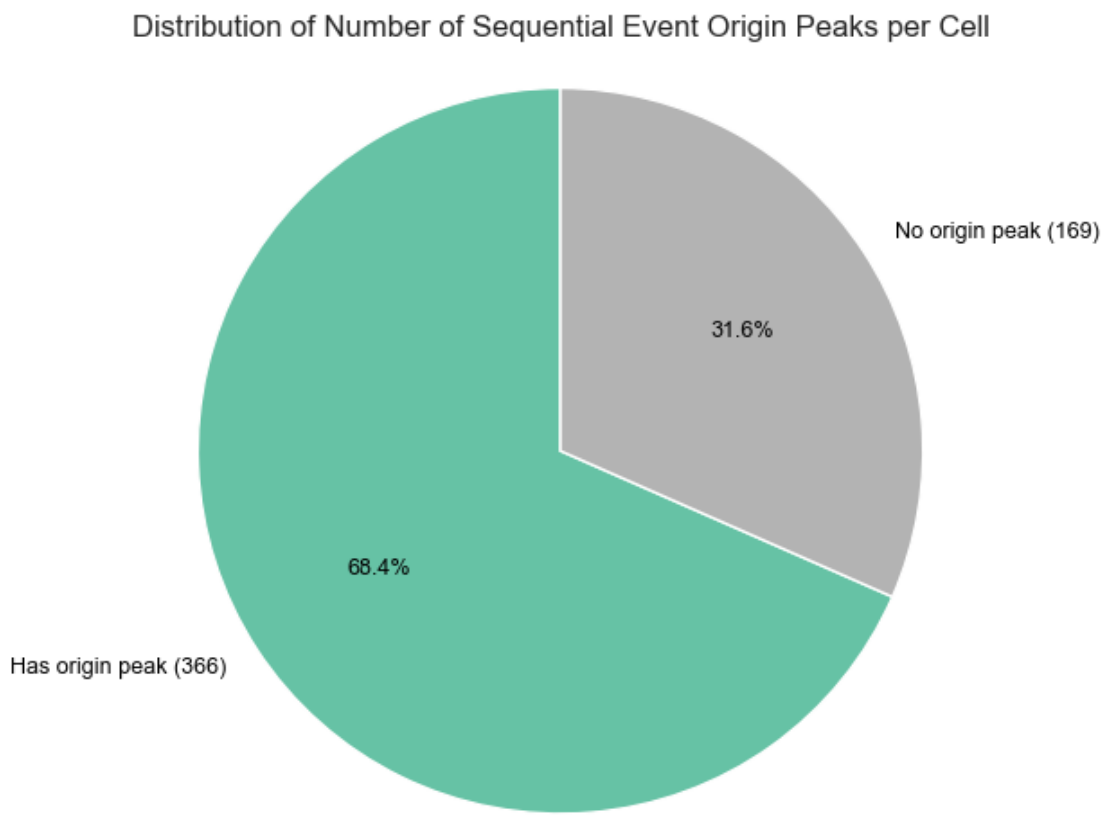
```
outliers out of 638 on 'Average communication speed (um/s)' (lower=-16.73,
upper=28.788)
```

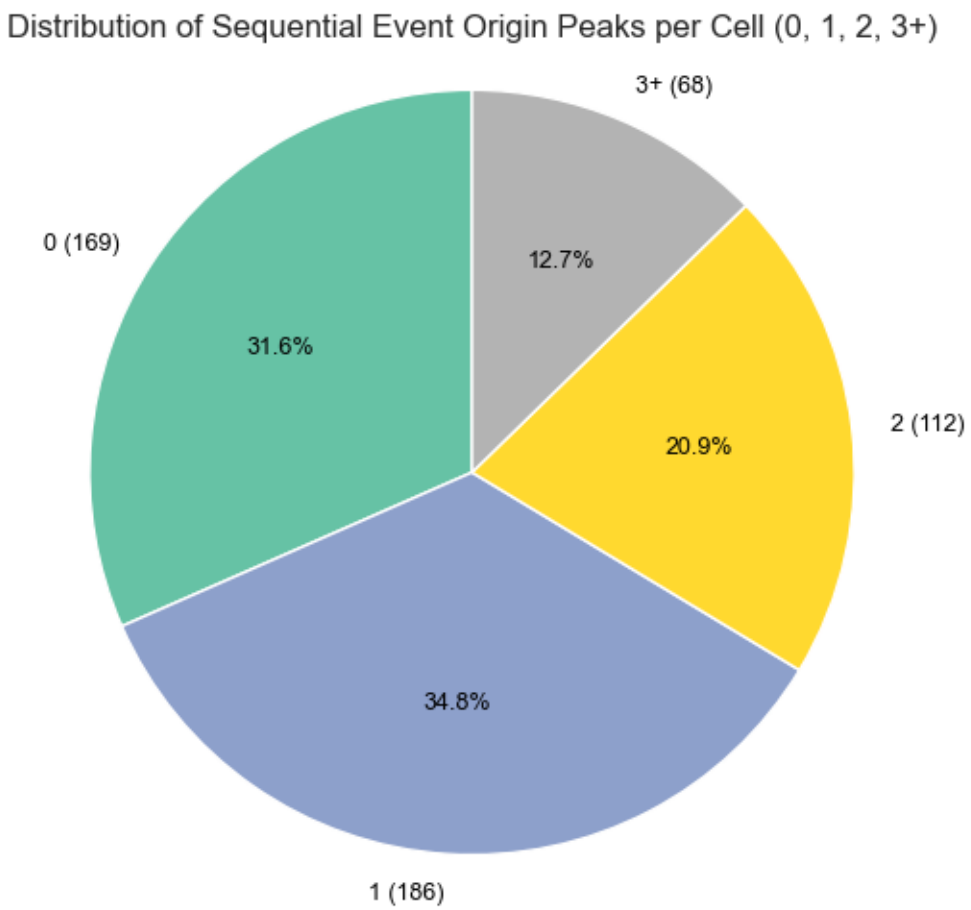



```
[2025-08-11 10:15:32] [INFO] calcium: plot_histogram_by_group: removed 10
outliers out of 1358 on 'Speed (um/s)' (lower=-20.297, upper=32.64)
```

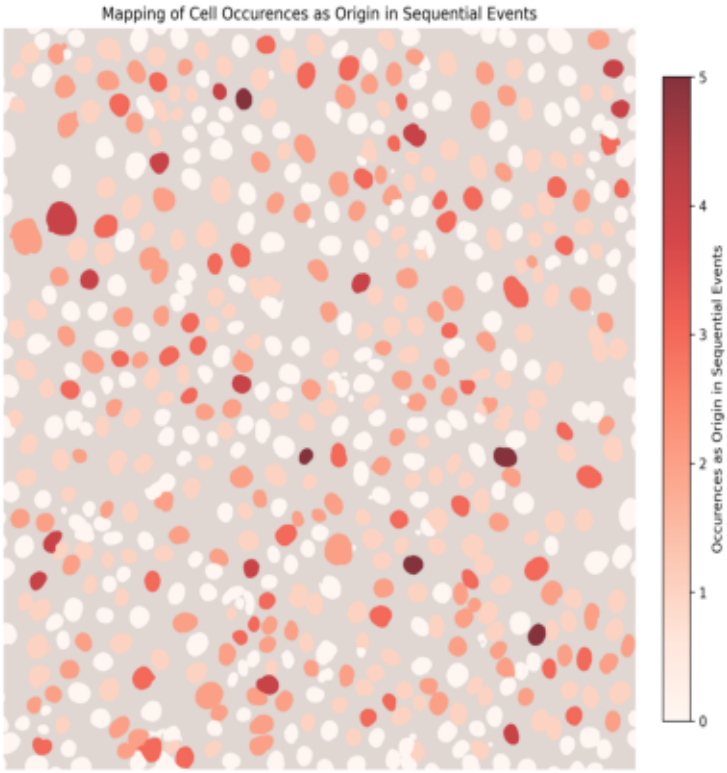


1.3.7 Cells occurences as origin in sequential events

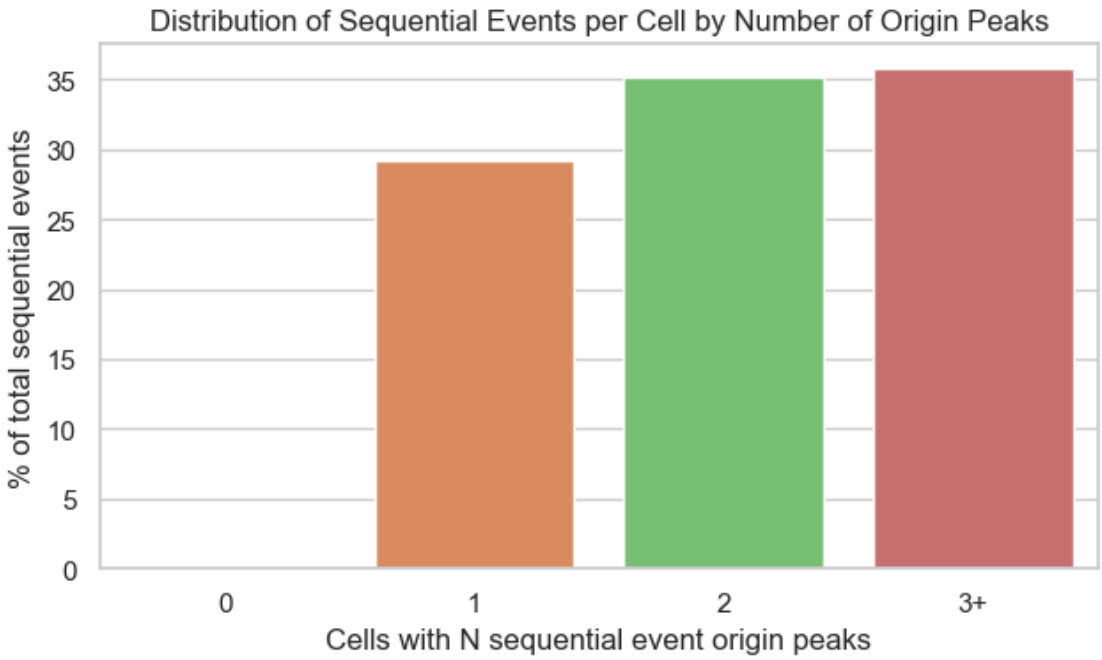



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (68)
12.7%
0 (169)
31.6%
2 (112)
20.9%
34.8%
1 (186)

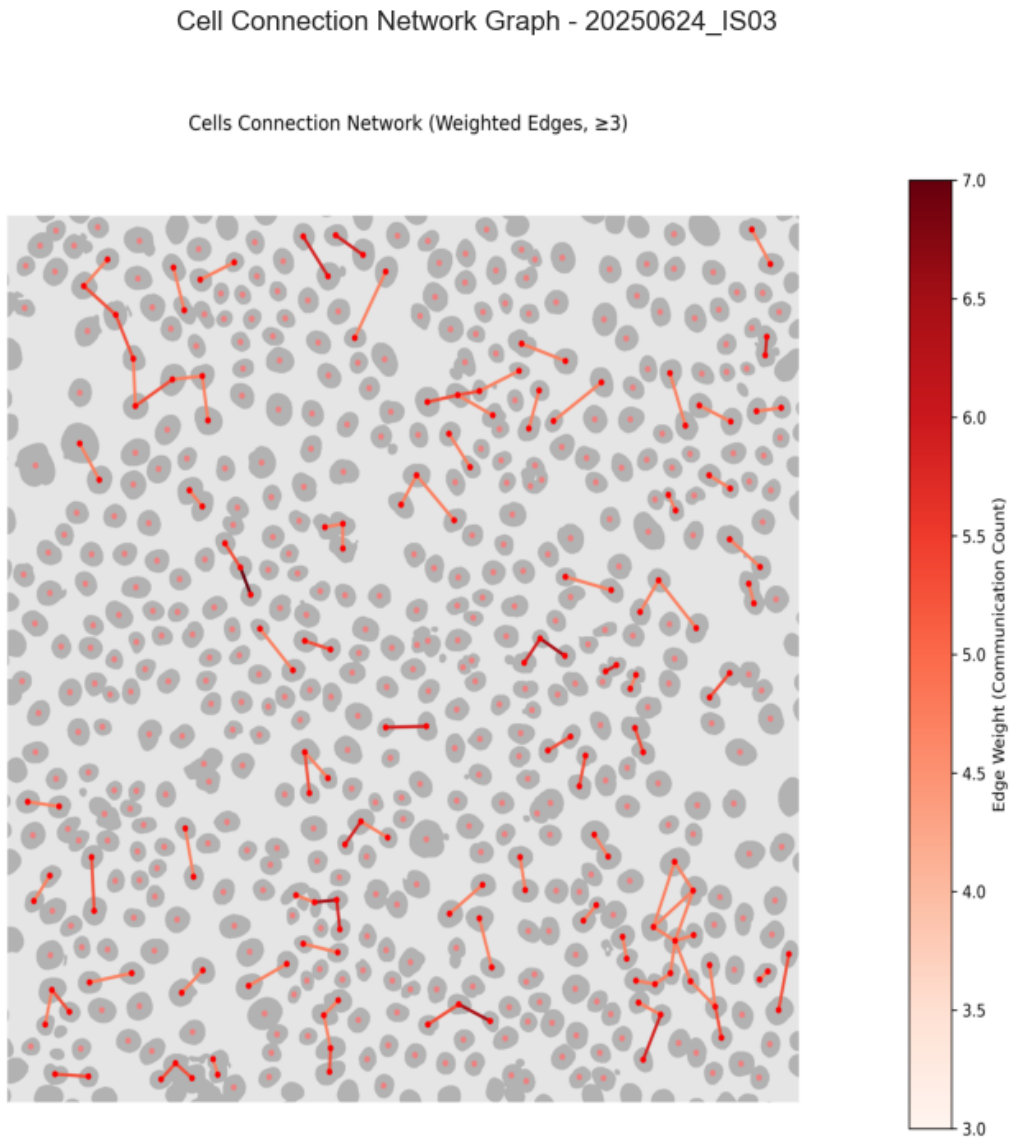
Cell Mapping with Origin Peaks Overlay - 20250624_IS03




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

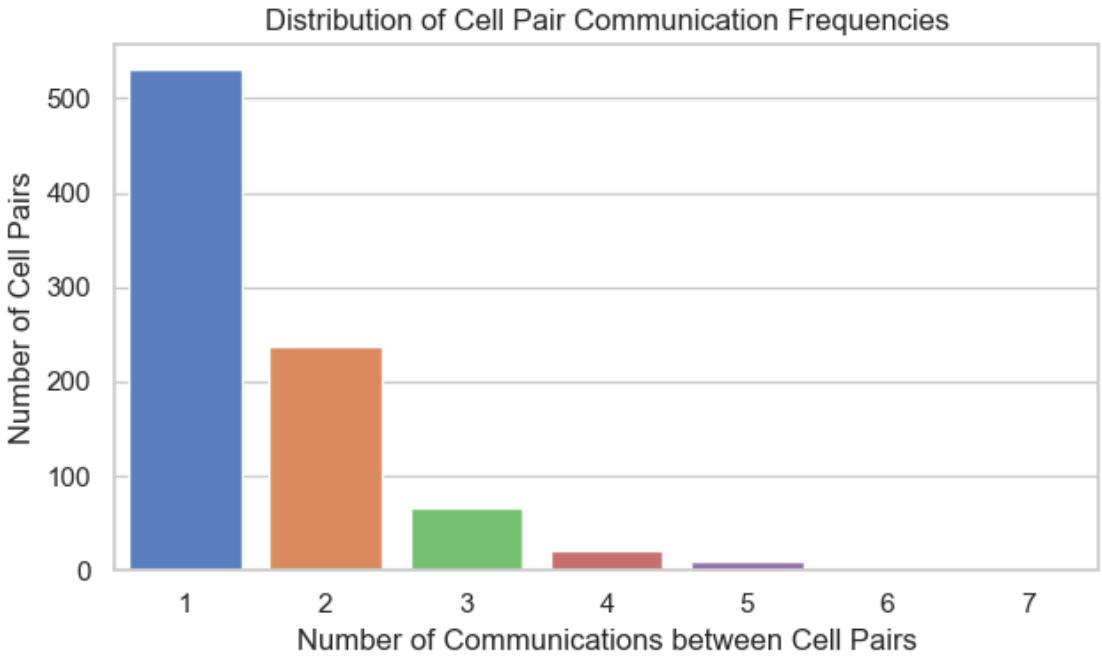

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



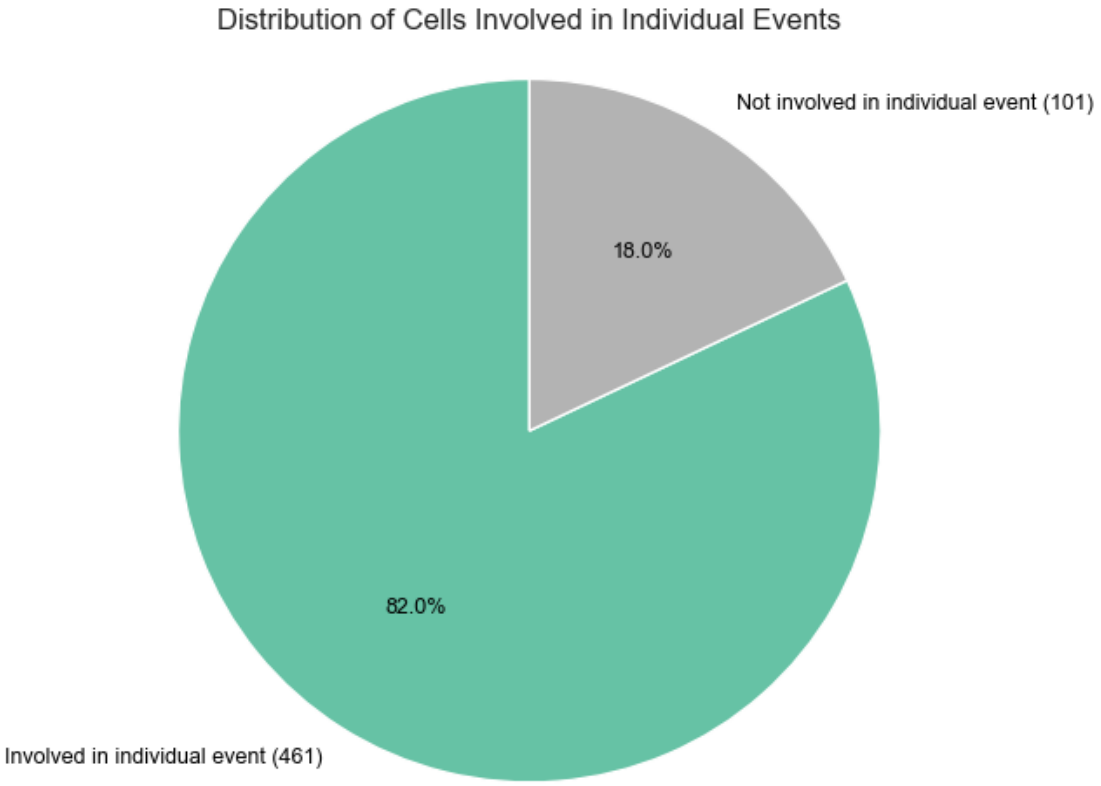

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

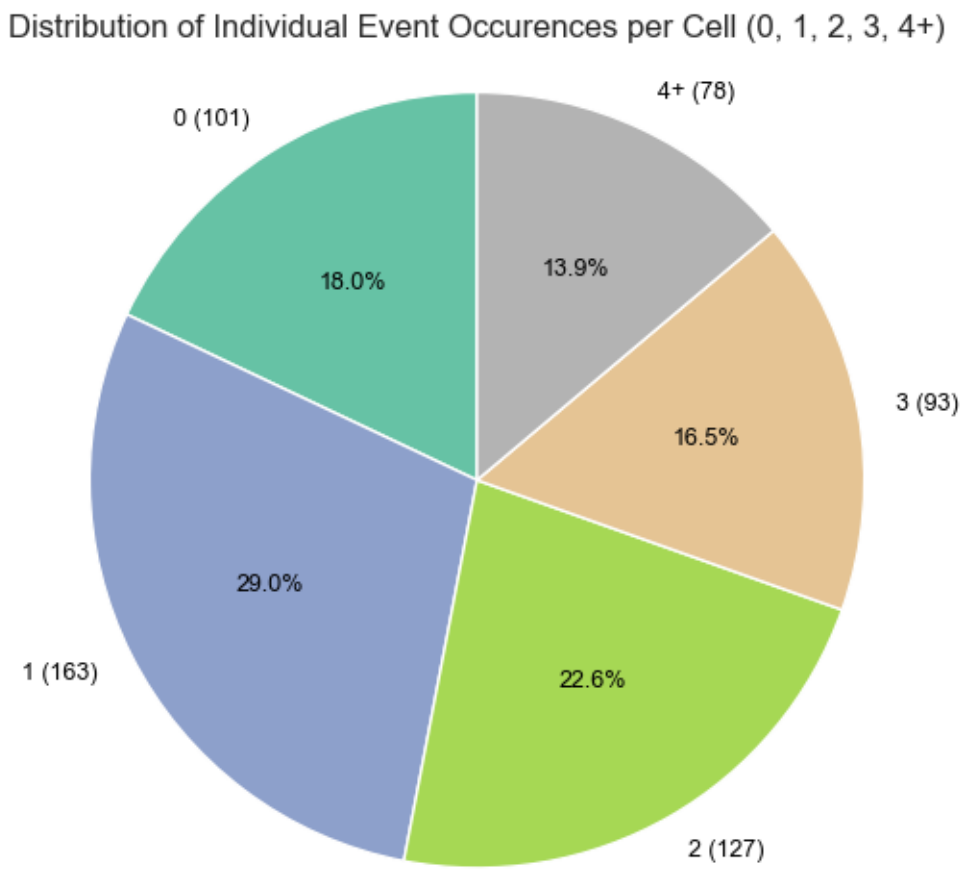
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
500
400
300
200
100
0
1
2
3
4
5
6
7
Number of Communications between Cell Pairs

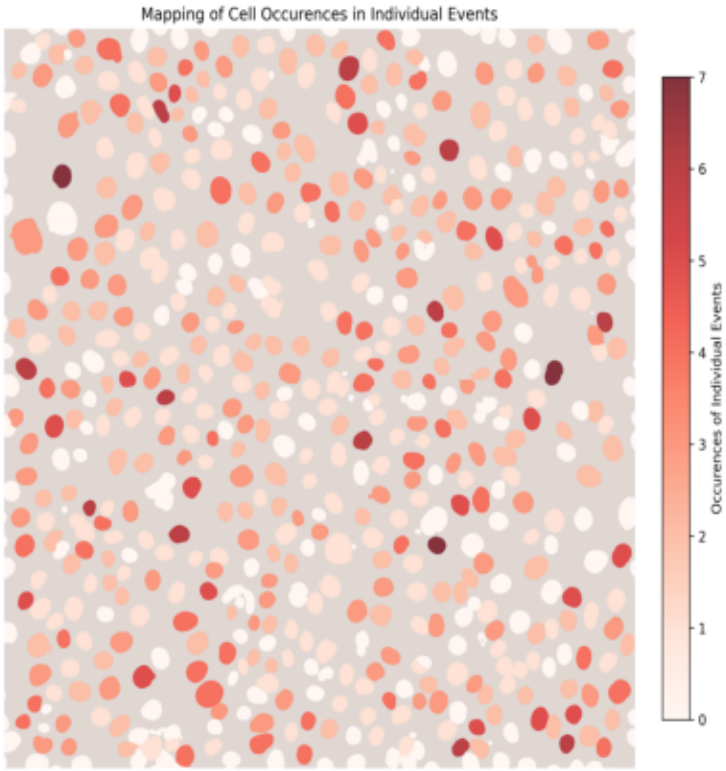
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



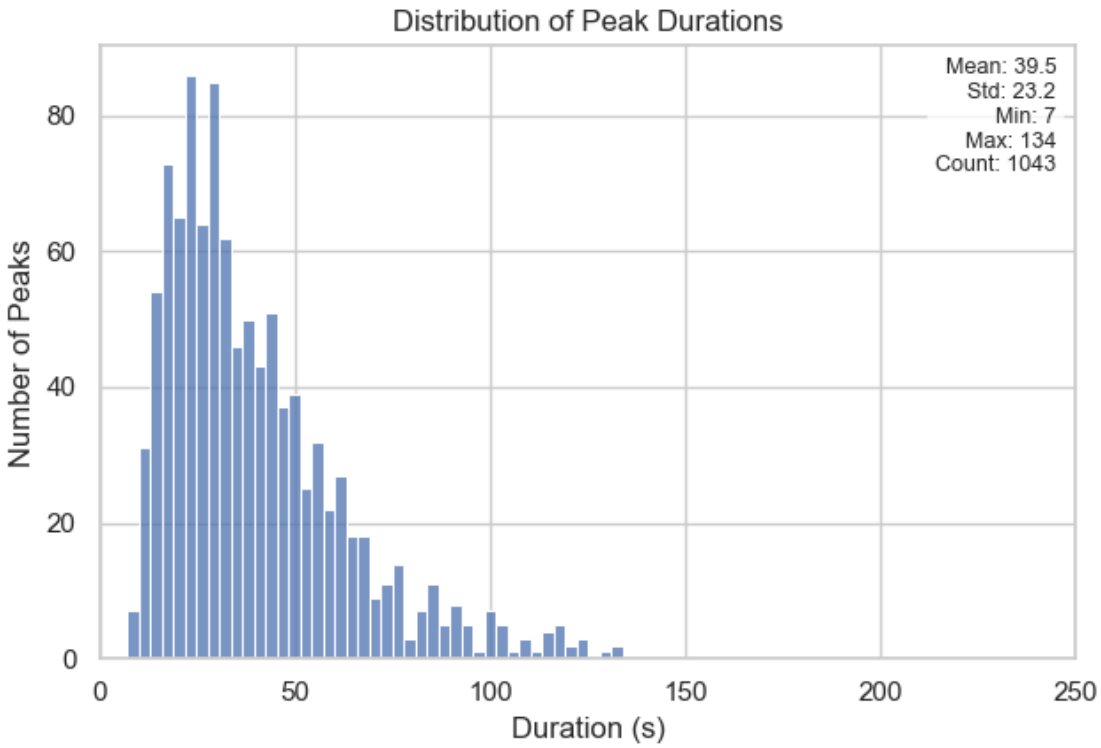

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (78)
13.9%
3 (93)
16.5%
2 (127)
22.6%
1 (163)
29.0%
0 (101)
18.0%

Cell Mapping with Occurences in Individual Events Overlay - 20250624_IS03

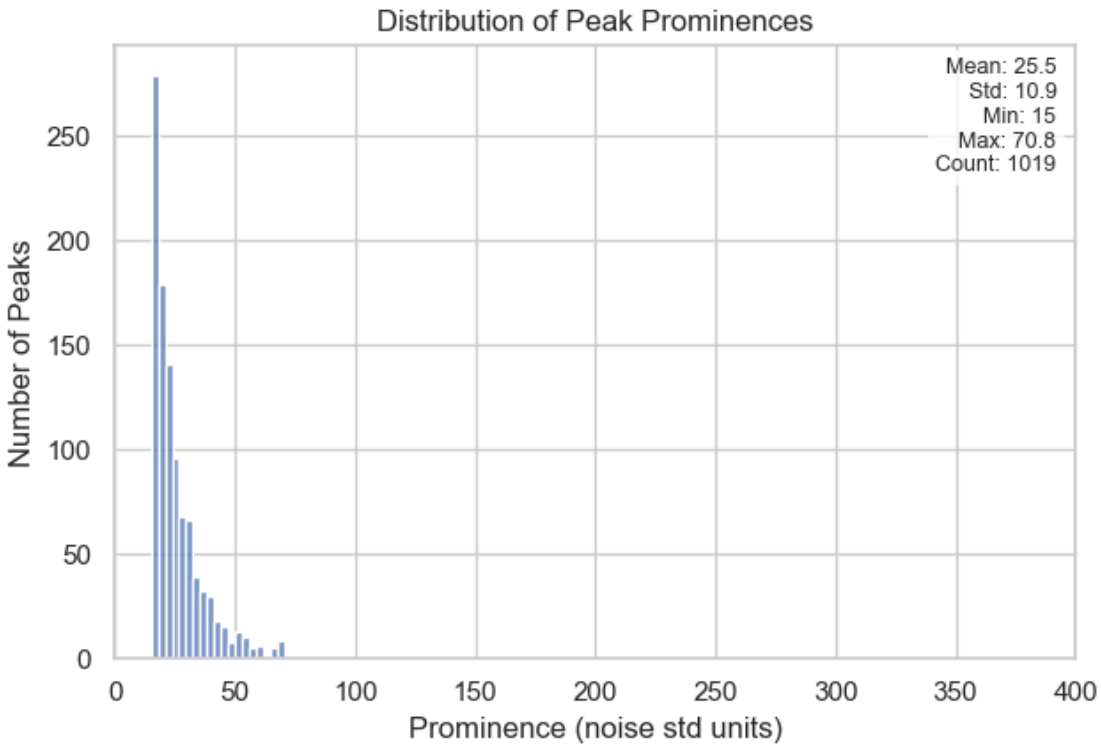


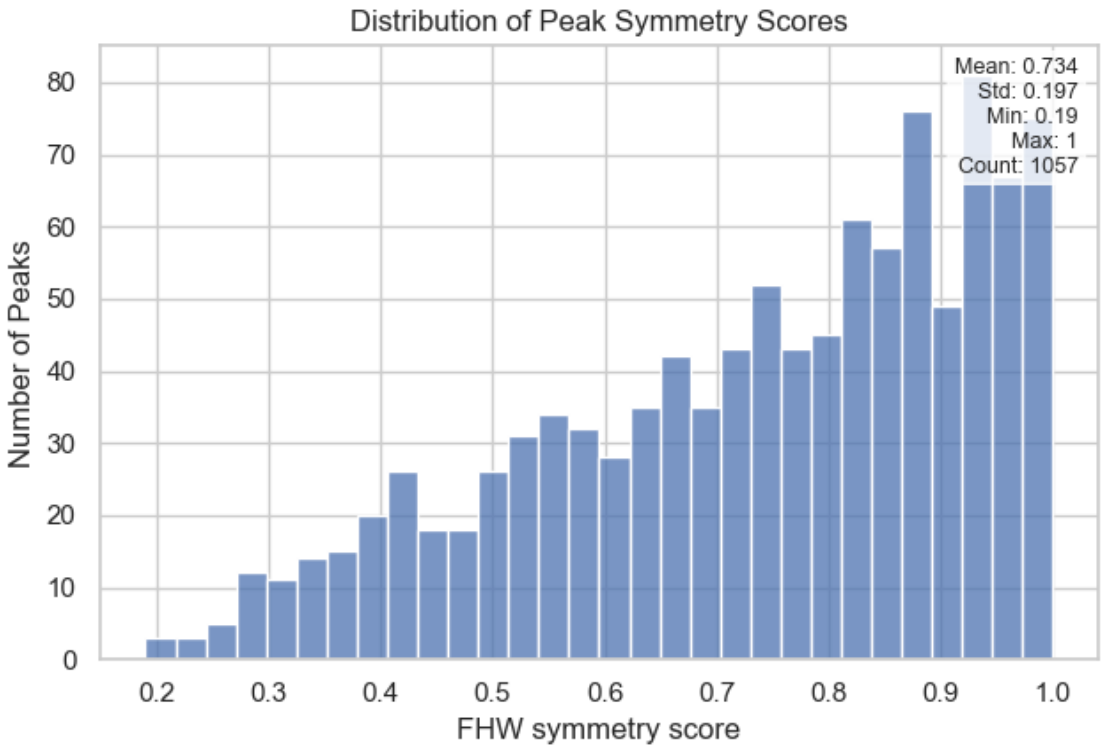
1.4.2 Peaks statistics in individual events

```
[2025-08-11 10:15:36] [INFO] calcium: plot_histogram: removed 14 outliers out of
1057 on 'Duration (s)' (lower=-61, upper=135)
```

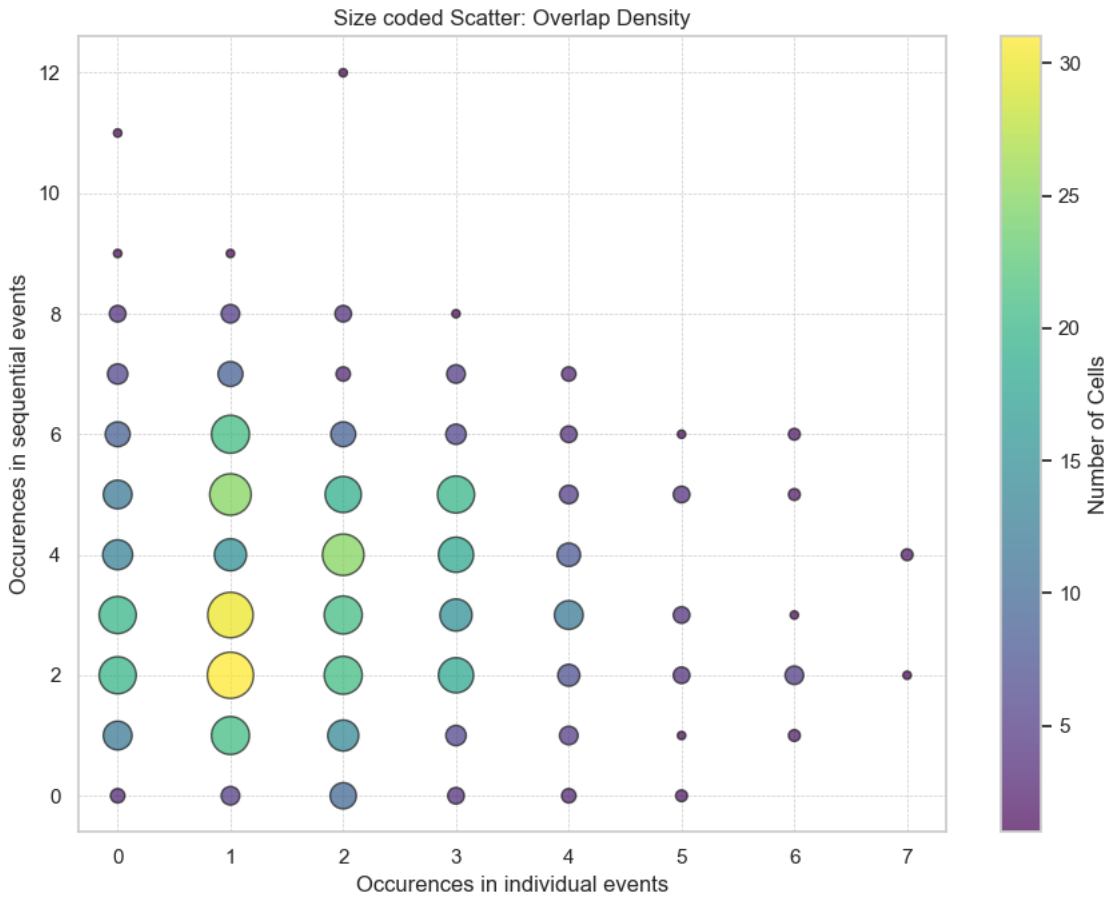



```
[2025-08-11 10:15:36] [INFO] calcium: plot_histogram: removed 38 outliers out of
1057 on 'Prominence (noise std units)' (lower=-22.4, upper=71.4)
```

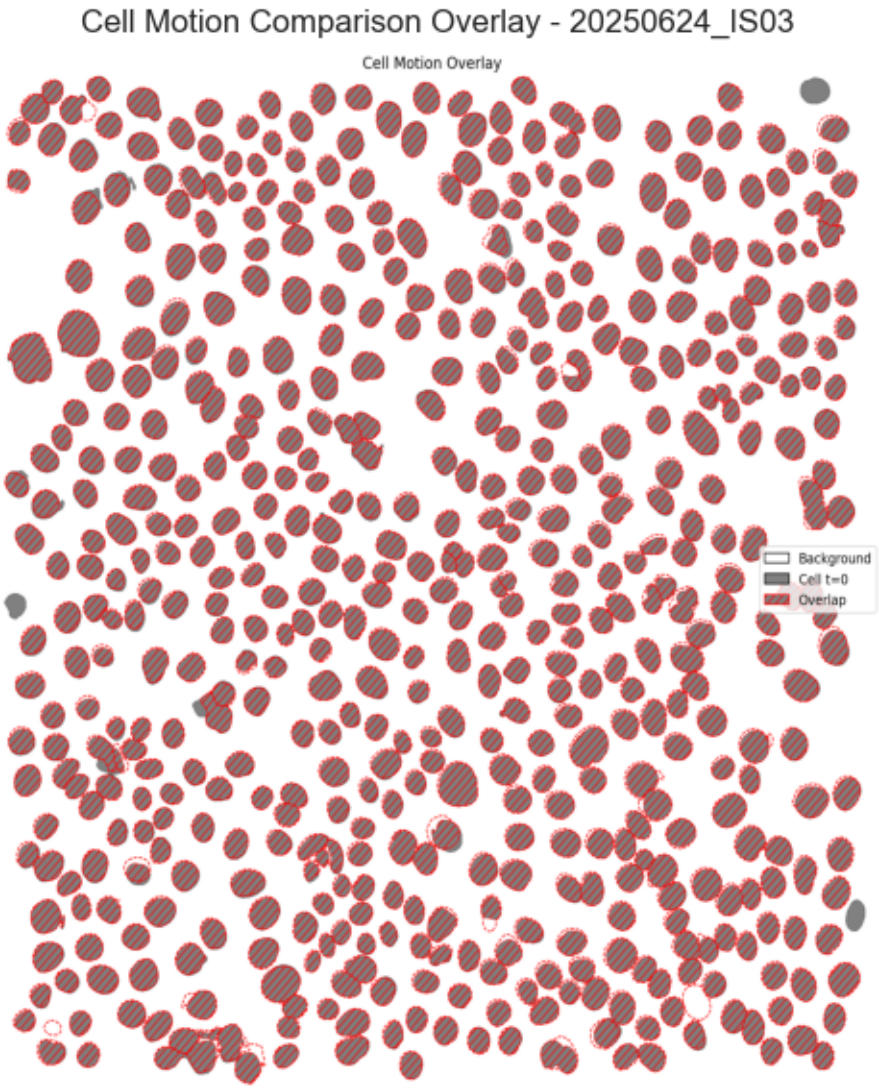

Distribution of Peak Prominences
Mean: 25.5
Std: 10.9
Min: 15
Max: 70.8
Count: 1019
Number of Peaks
0
50
100
150
200
250
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.734
Std: 0.197
Min: 0.19
Max: 1
Count: 1057
Number of Peaks
0
10
20
30
40
50
60
70
80
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 562
- Hoechst image taken at t=1801: 552
- Number of cells difference: absolute 10, relative 1.80%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 780011
- Pixels segmented as cell at t=1801: 787021
- Overlapping pixels between t=0 and t=1801: 725792(92.63% of total)
- Pixels exclusive to t=0: 54219 (6.95% of total)
- Pixels exclusive to t=1801: 61229 (7.78% of total)
```

executed

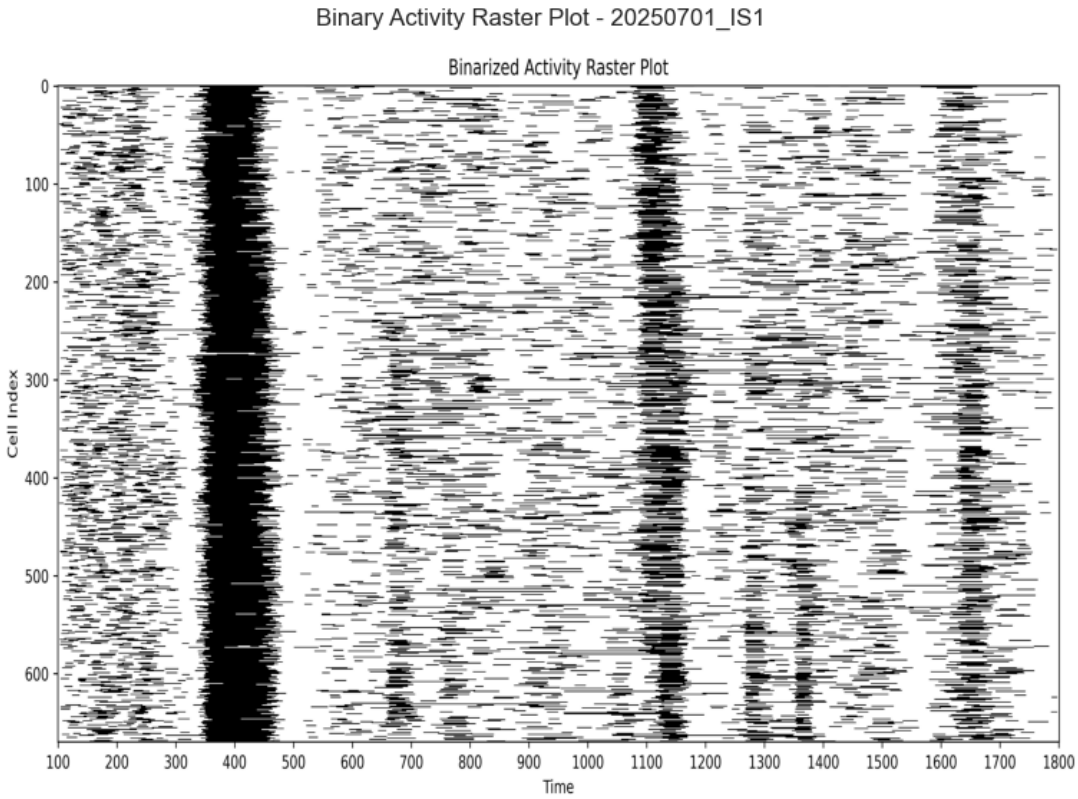
August 11, 2025

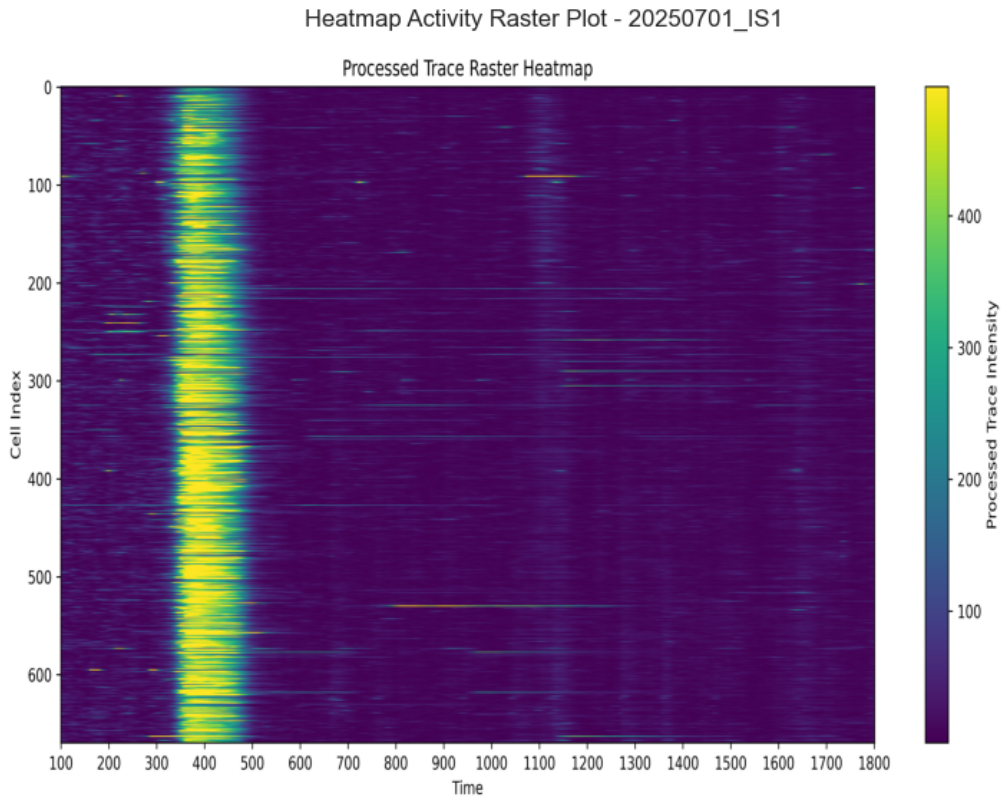
1 ANALYSIS OF AN IMAGE SEQUENCE AFTER DATA GENERATION USING THE CALCIUM CHARACTERIZATION PIPELINE

1.0.1 Initialization

1.1 POPULATION

1.1.1 Binary & Heatmap Raster Plot



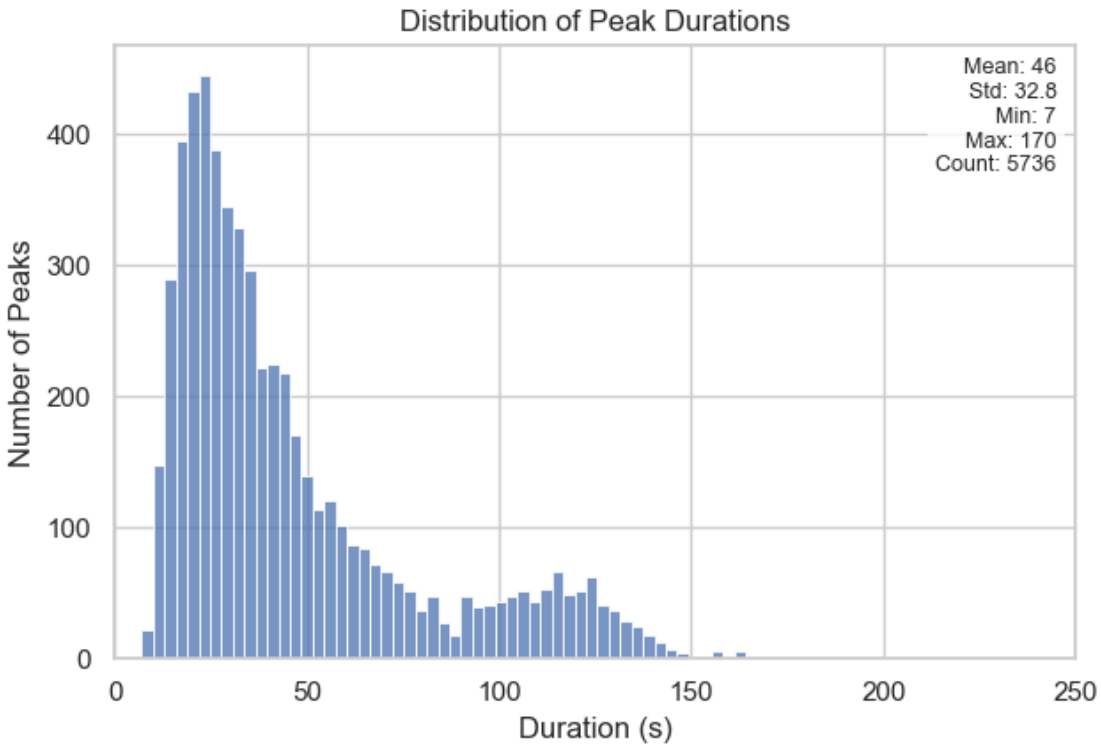


1.1.2 Peaks population

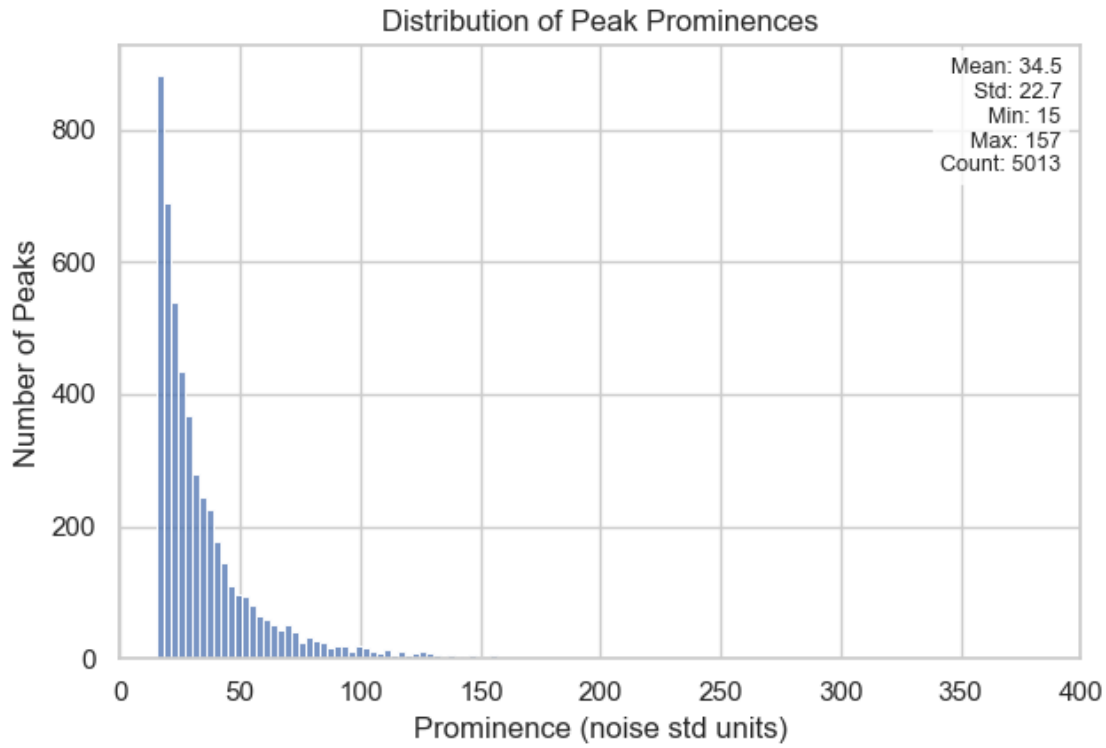
```
Total number of peaks: 5765
Total number of cells: 670
```

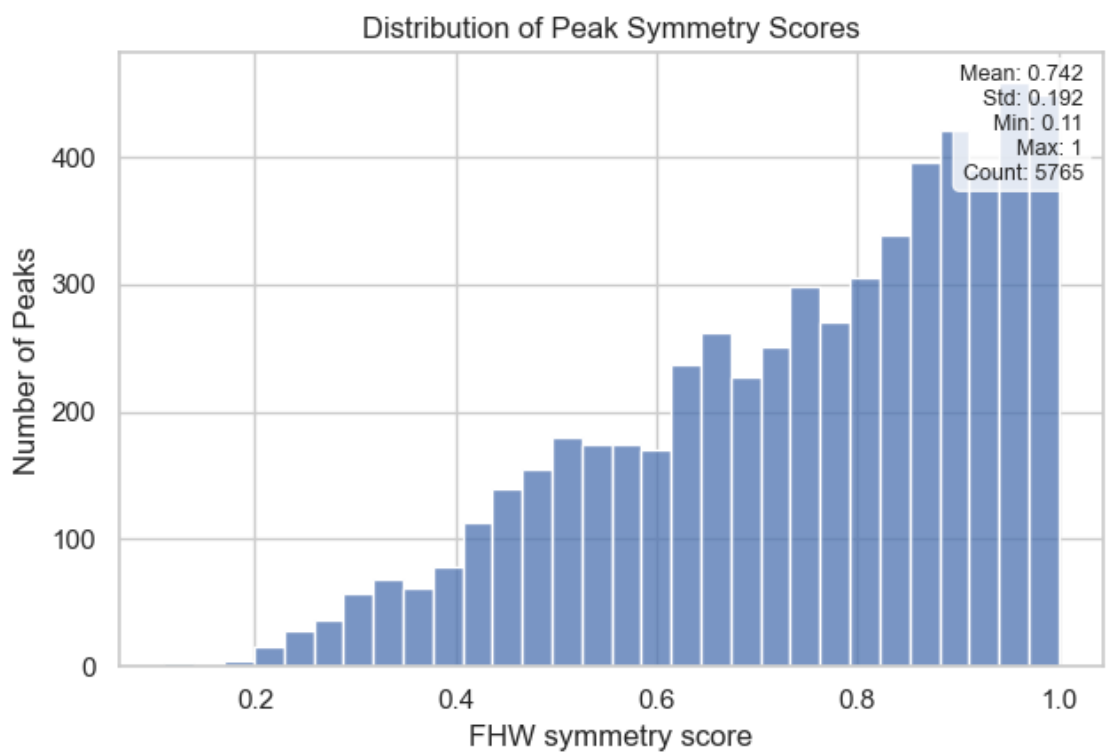
1.1.3 Peaks statistics

```
[2025-08-11 10:22:28] [INFO] calcium: plot_histogram: removed 29 outliers out of
5765 on 'Duration (s)' (lower=-89, upper=170)
```

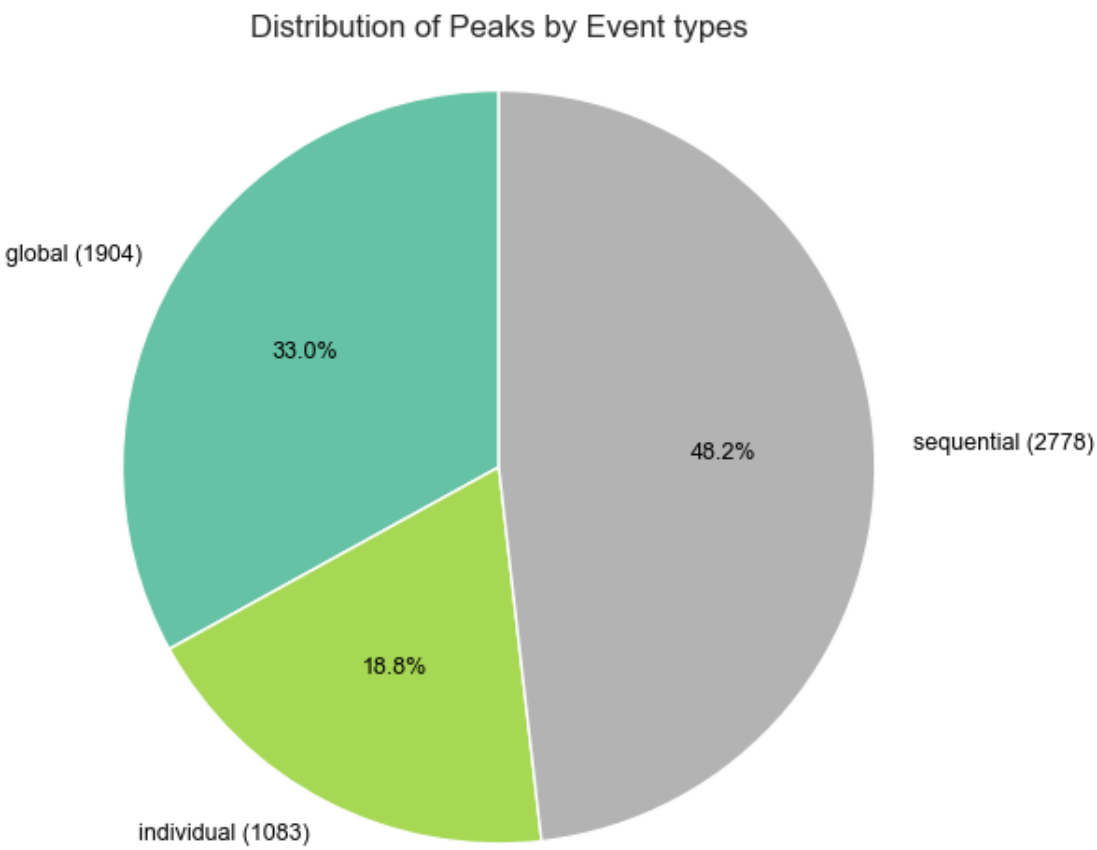



```
[2025-08-11 10:22:29] [INFO] calcium: plot_histogram: removed 752 outliers out
of 5765 on 'Prominence (noise std units)' (lower=-83.2, upper=158.3)
```


Distribution of Peak Prominences
Mean: 34.5
Std: 22.7
Min: 15
Max: 157
Count: 5013
Number of Peaks
0
200
400
600
800
0
50
100
150
200
250
300
350
400
Prominence (noise std units)

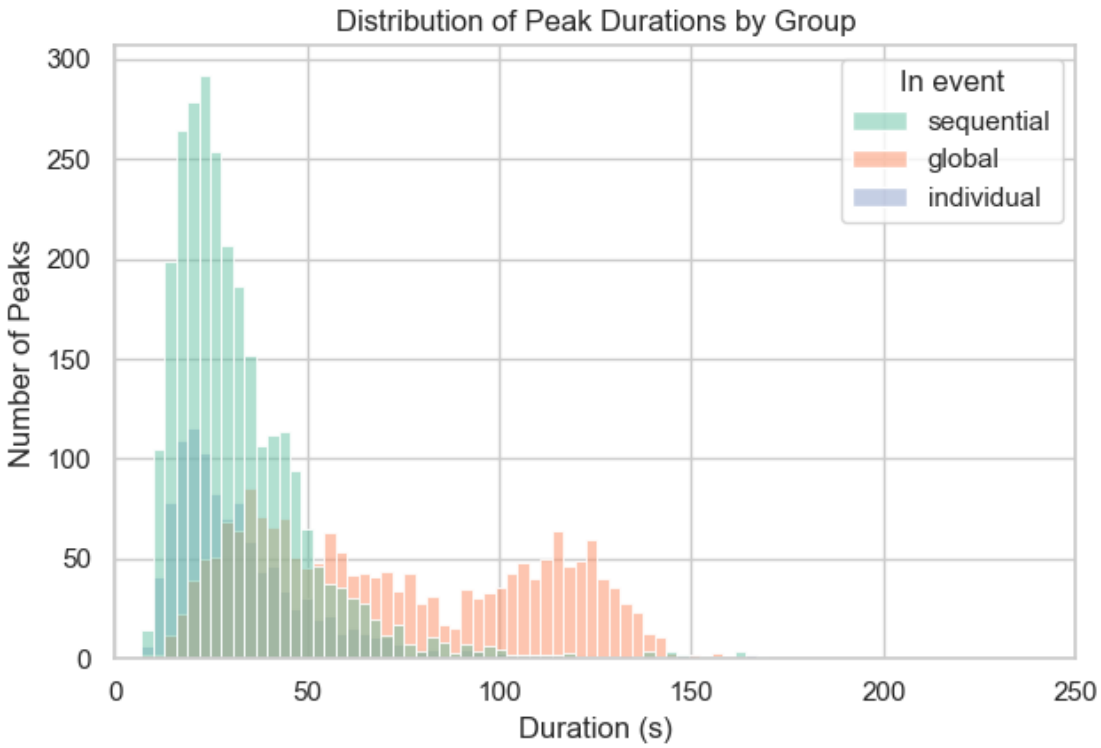

Distribution of Peak Symmetry Scores
Mean: 0.742
Std: 0.192
Min: 0.11
Max: 1
Count: 5765
Number of Peaks
0
100
200
300
400
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

1.1.4 Distribution of peaks per event types

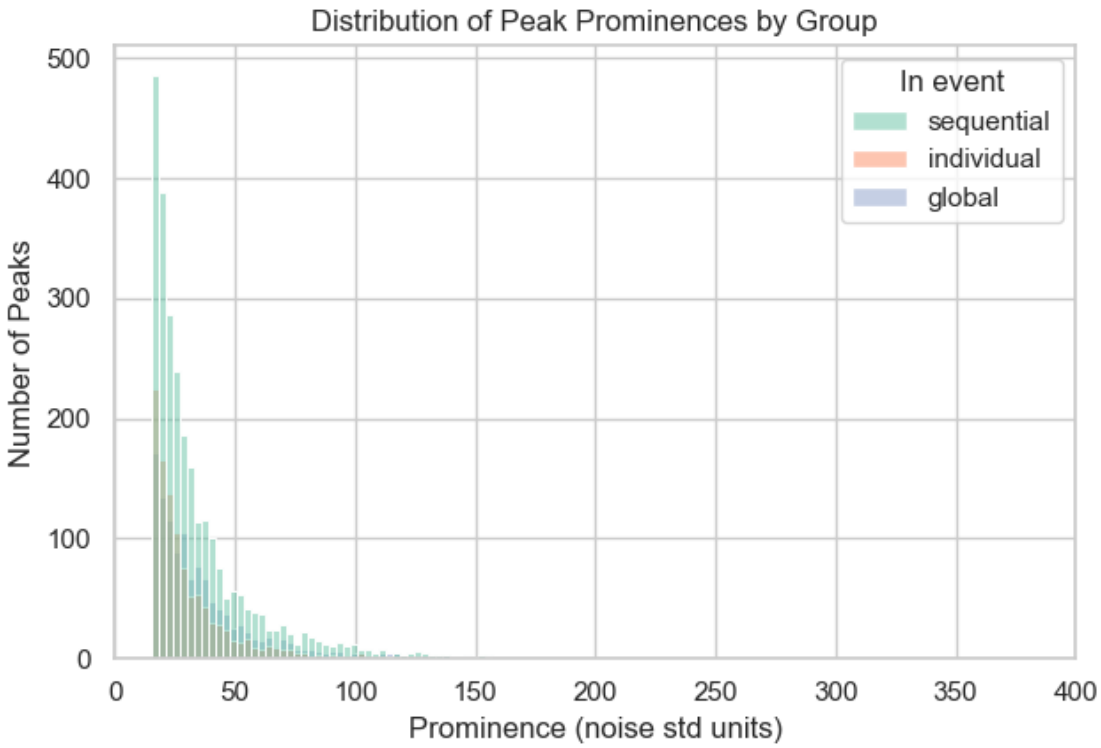


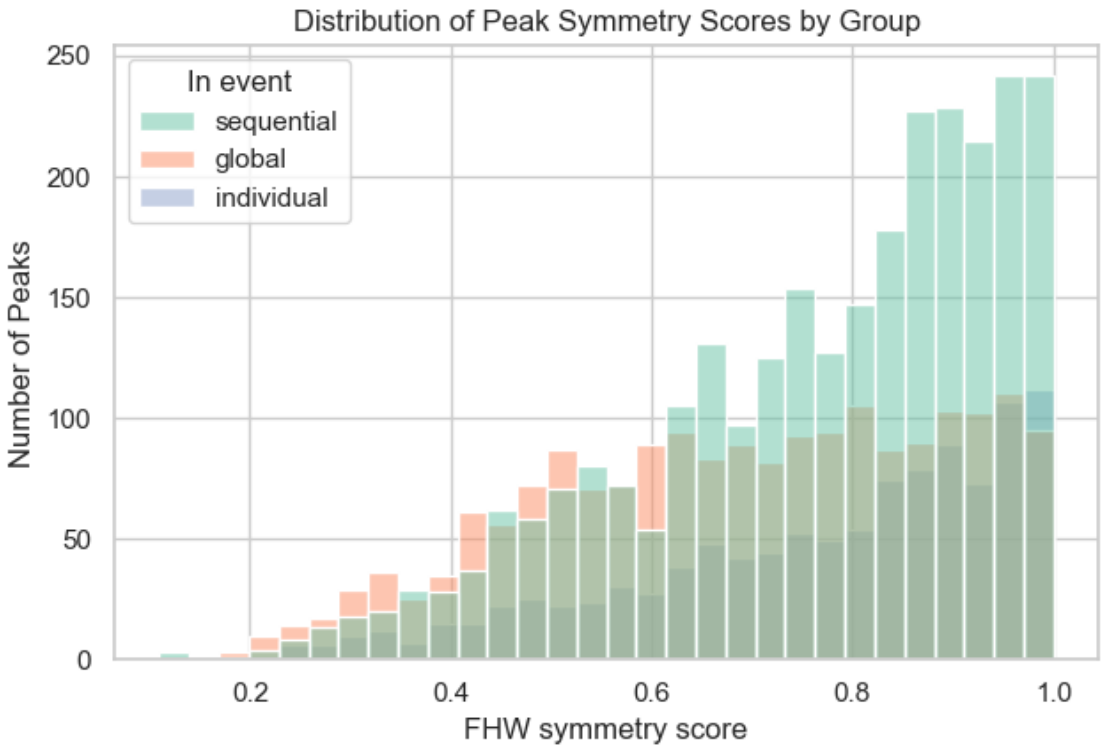
1.1.5 Peaks statistics per event types

```
[2025-08-11 10:22:29] [INFO] calcium: plot_histogram_by_group: removed 29
outliers out of 5765 on 'Duration (s)' (lower=-89, upper=170)
```




```
[2025-08-11 10:22:29] [INFO] calcium: plot_histogram_by_group: removed 752
outliers out of 5765 on 'Prominence (noise std units)' (lower=-83.2,
upper=158.3)
```

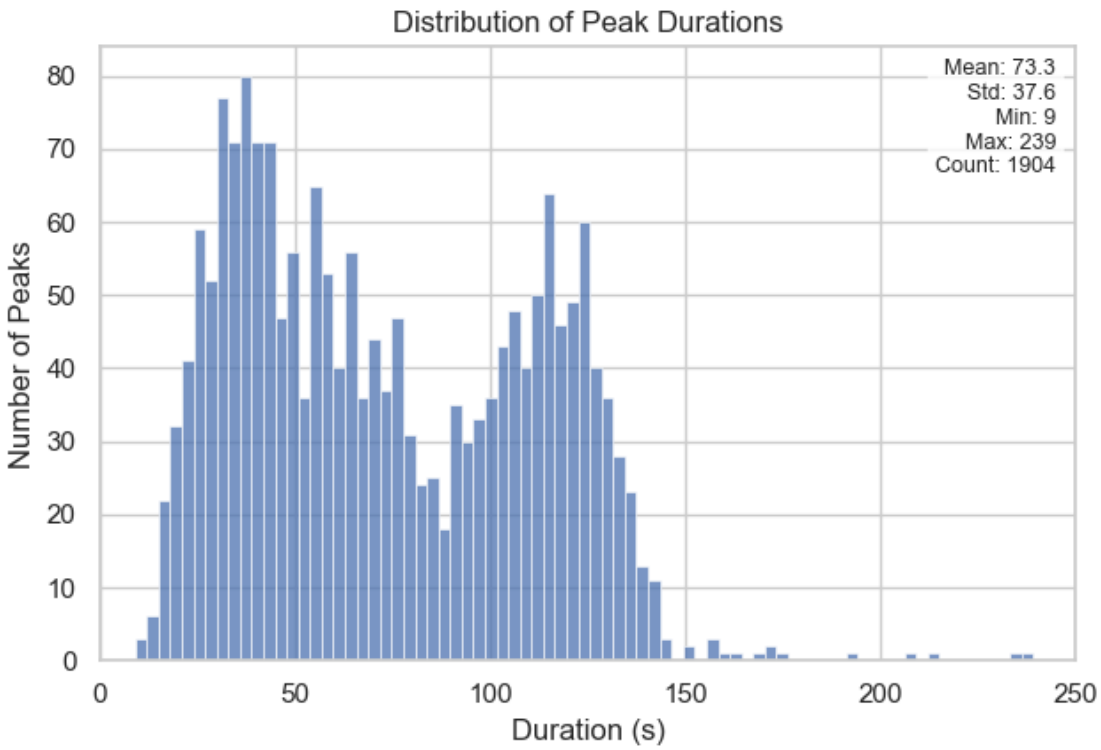

Distribution of Peak Prominences by Group
In event
sequential
individual
global
Number of Peaks
0
100
200
300
400
500
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
In event
sequential
global
individual
Number of Peaks
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

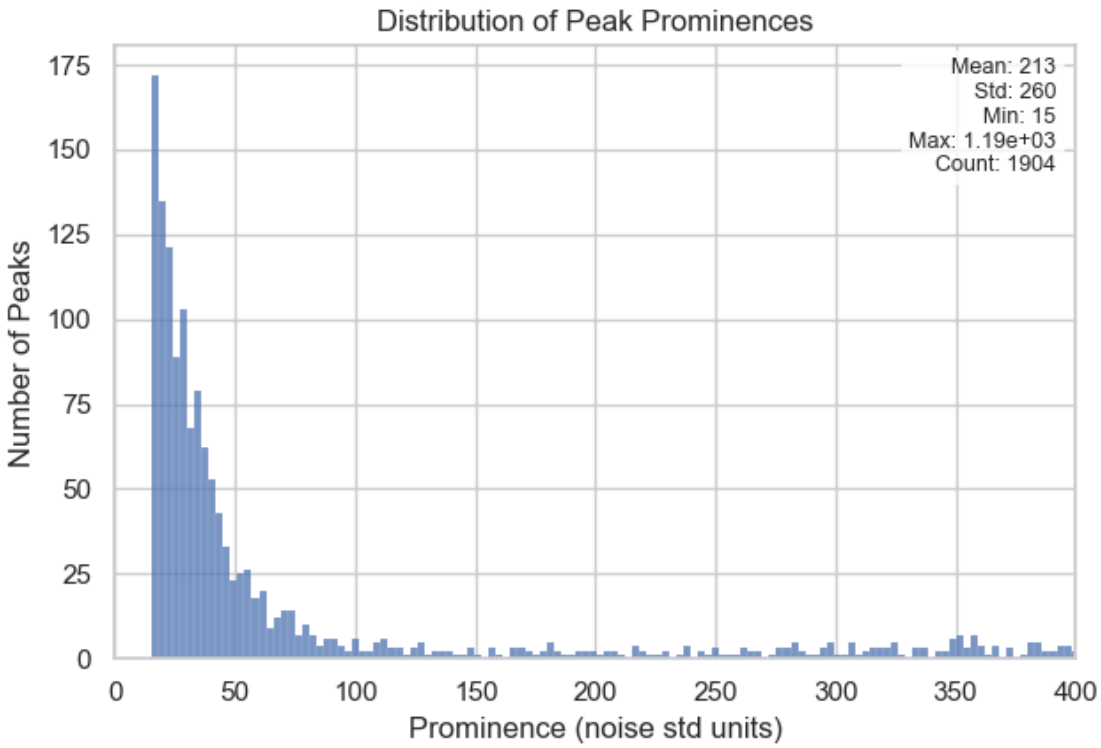
1.2 GLOBAL EVENTS

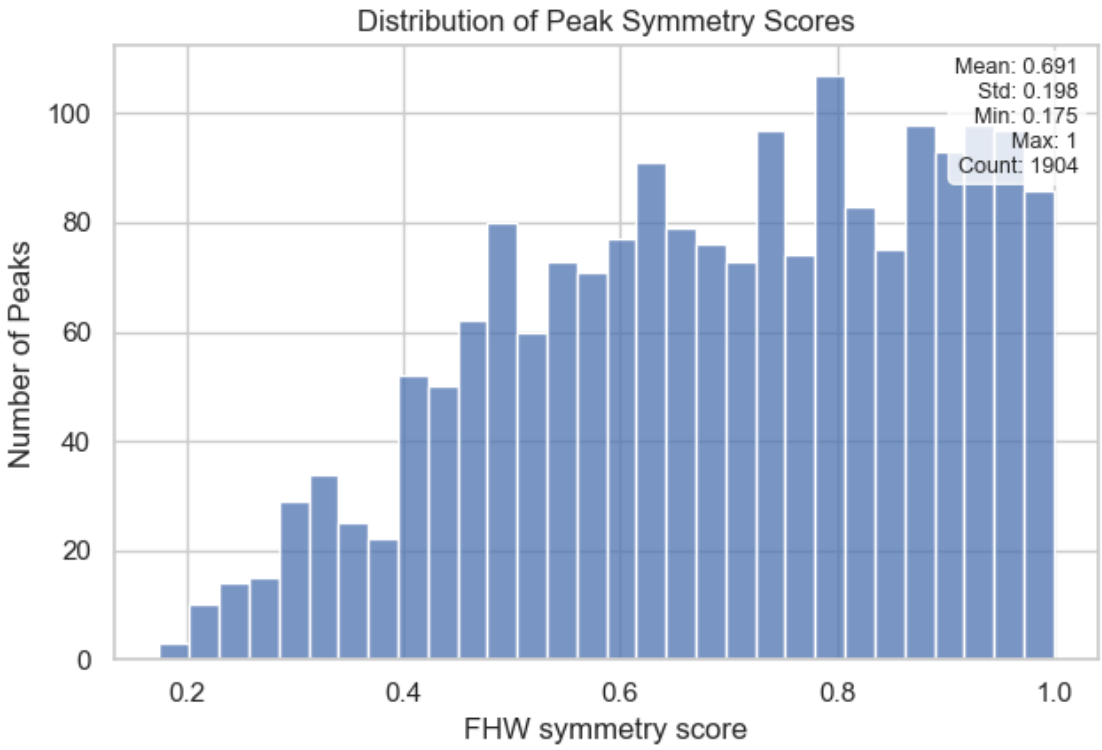
1.2.1 Peak statistics in global events

```
[2025-08-11 10:22:30] [INFO] calcium: plot_histogram: removed 0 outliers out of
1904 on 'Duration (s)' (lower=-164, upper=312)
```



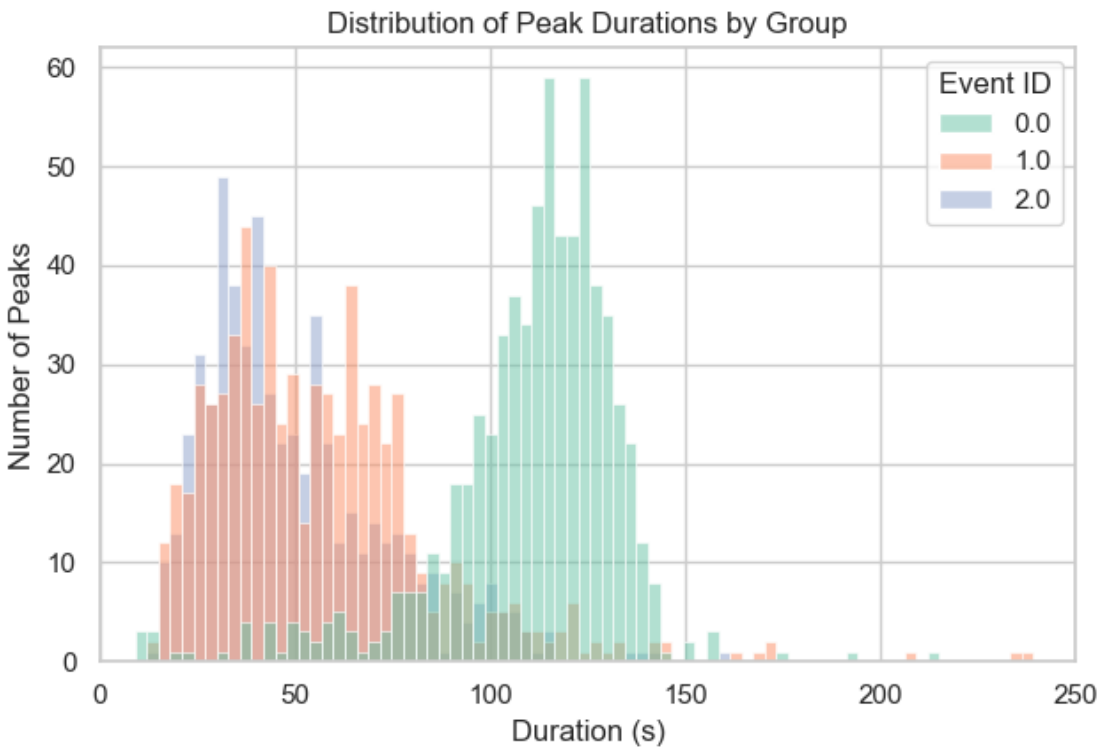

```
[2025-08-11 10:22:30] [INFO] calcium: plot_histogram: removed 0 outliers out of
1904 on 'Prominence (noise std units)' (lower=-1164.4, upper=1611.3)
```


Distribution of Peak Prominences
Mean: 213
Std: 260
Min: 15
Max: 1.19e+03
Count: 1904
Number of Peaks
Prominence (noise std units)
0
25
50
75
100
125
150
175
0
50
100
150
200
250
300
350
400

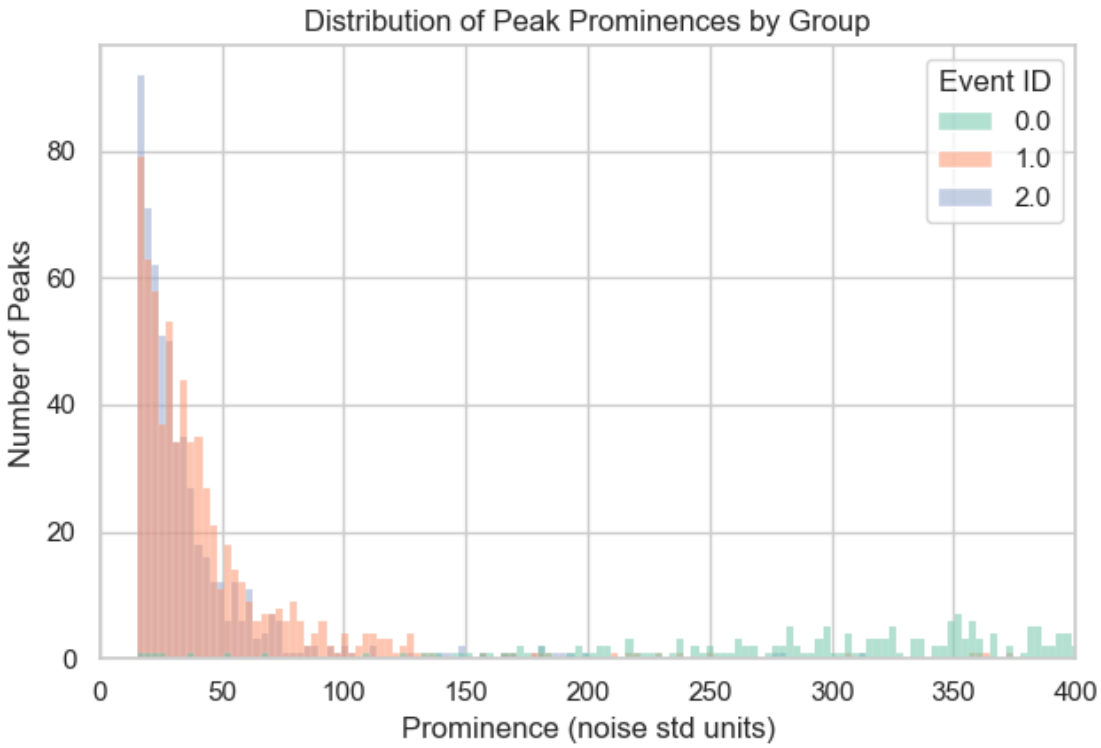

Distribution of Peak Symmetry Scores
Mean: 0.691
Std: 0.198
Min: 0.175
Max: 1
Count: 1904
Number of Peaks
FHW symmetry score
0
20
40
60
80
100
0.2
0.4
0.6
0.8
1.0

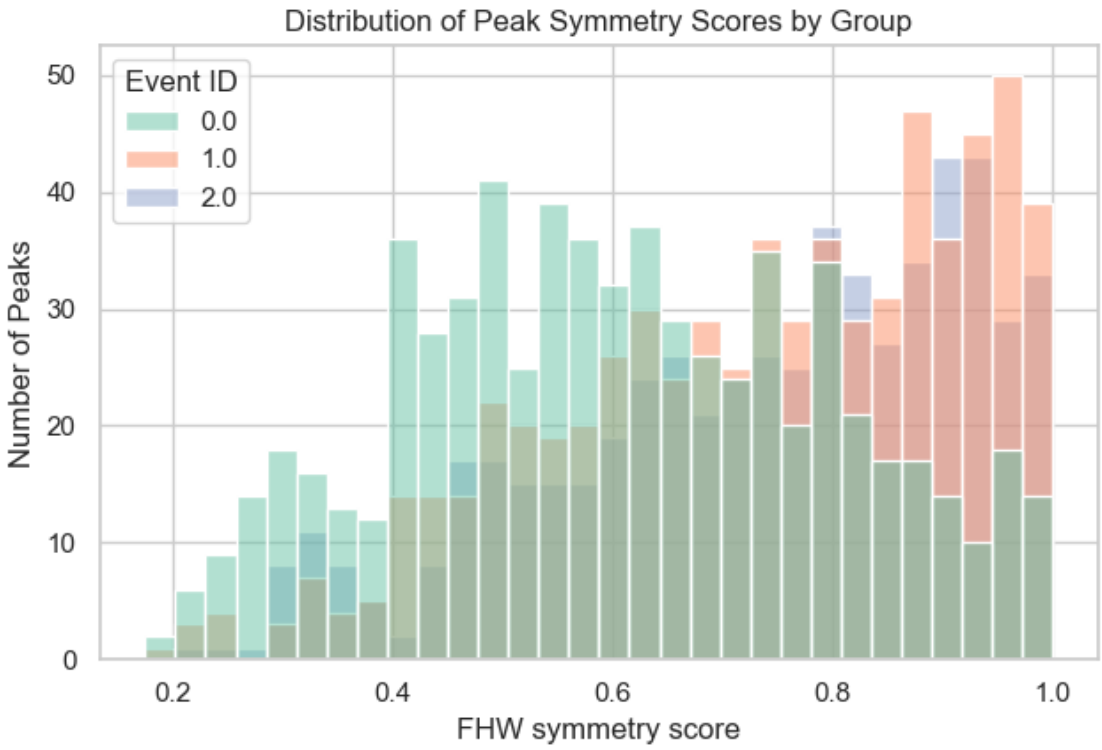
1.2.2 Peak statistics in global event per event ID

```
[2025-08-11 10:22:30] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 1904 on 'Duration (s)' (lower=-164, upper=312)
```

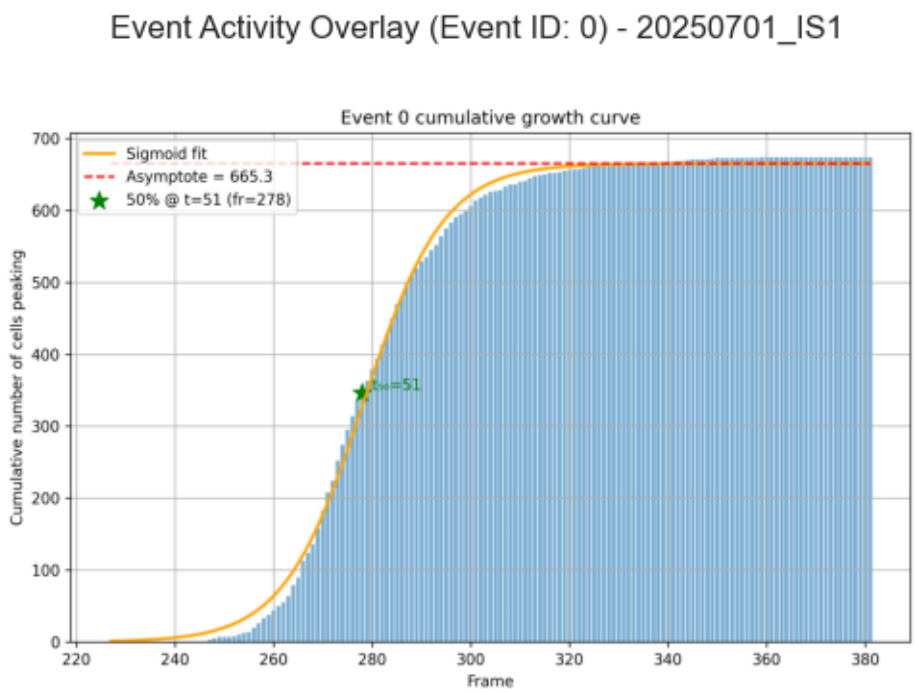


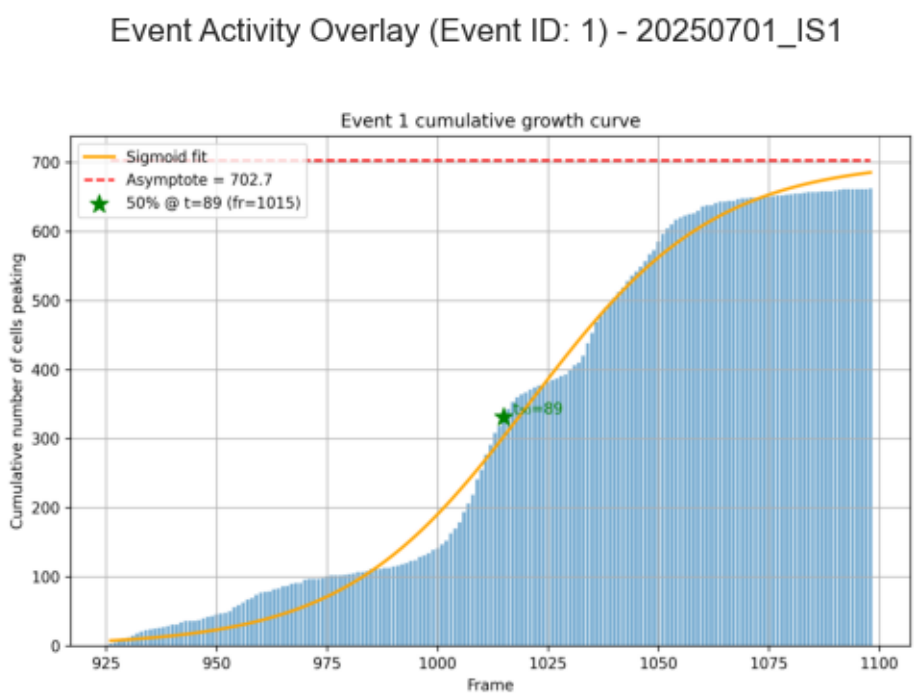

```
[2025-08-11 10:22:30] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 1904 on 'Prominence (noise std units)' (lower=-1164.4,
upper=1611.3)
```

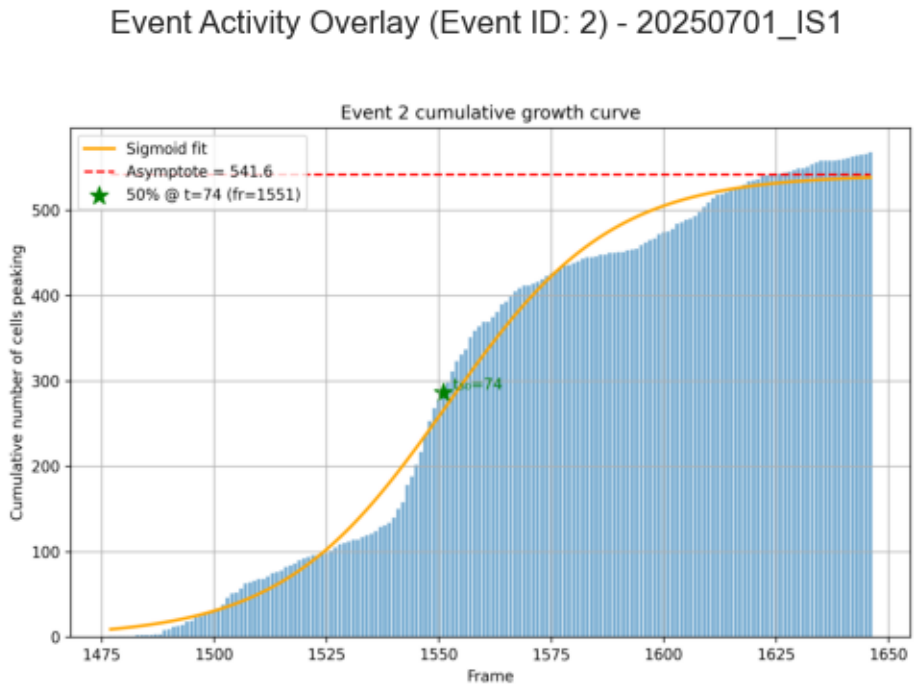

Distribution of Peak Prominences by Group
Event ID
0.0
1.0
2.0
Number of Peaks
0
20
40
60
80
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores by Group
Event ID
0.0
1.0
2.0
Number of Peaks
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
FHW symmetry score

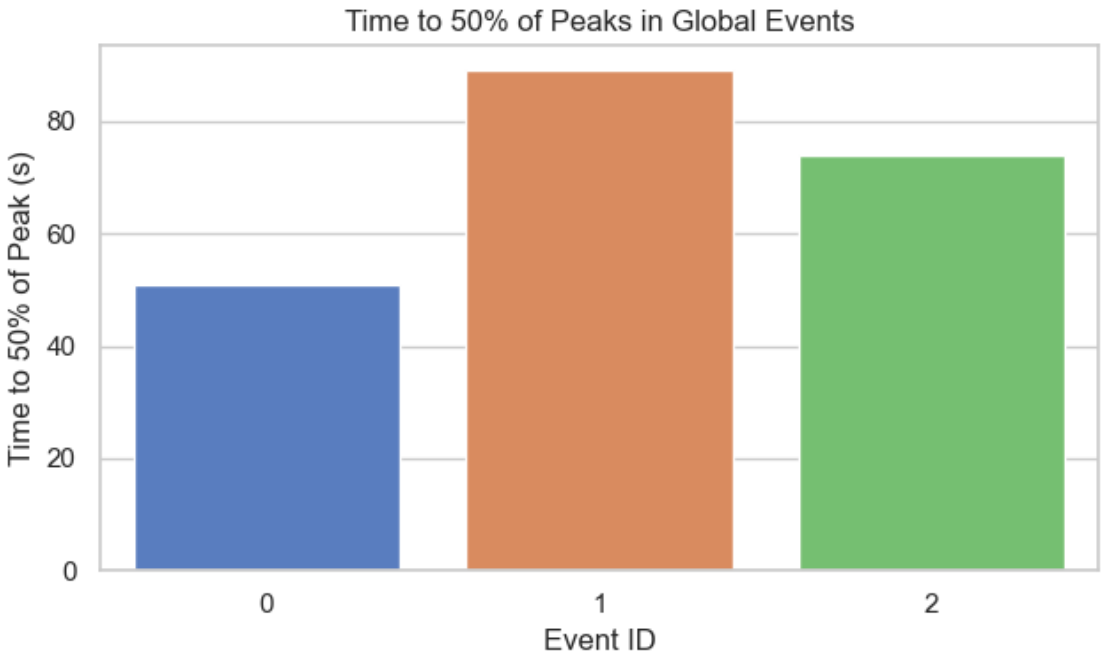
1.2.3 Kinetics of global events



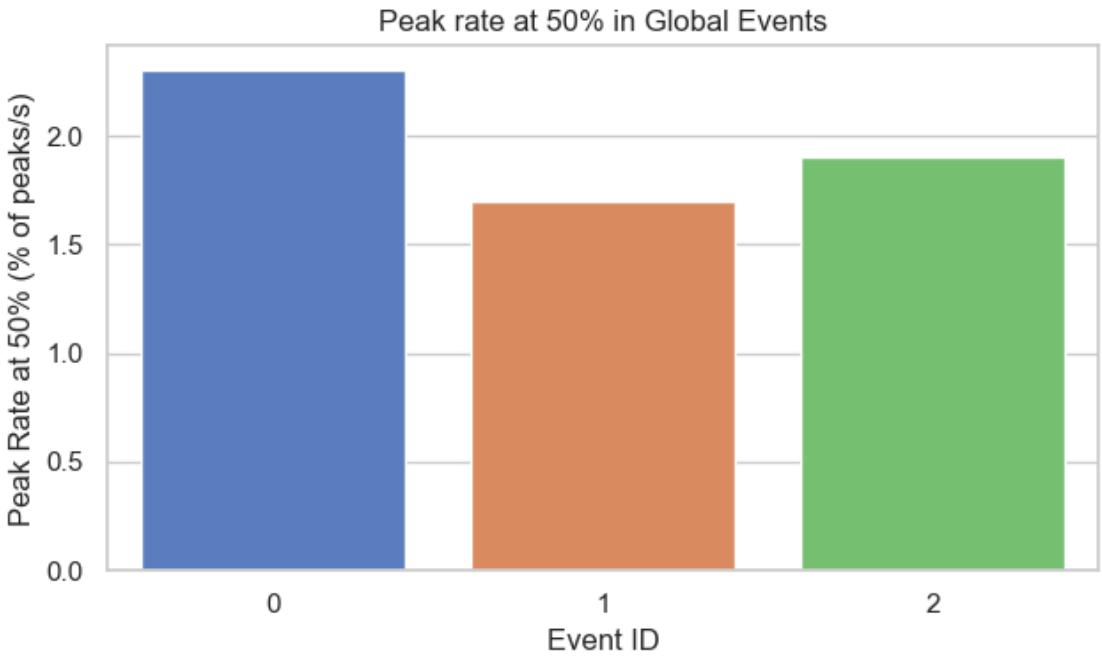




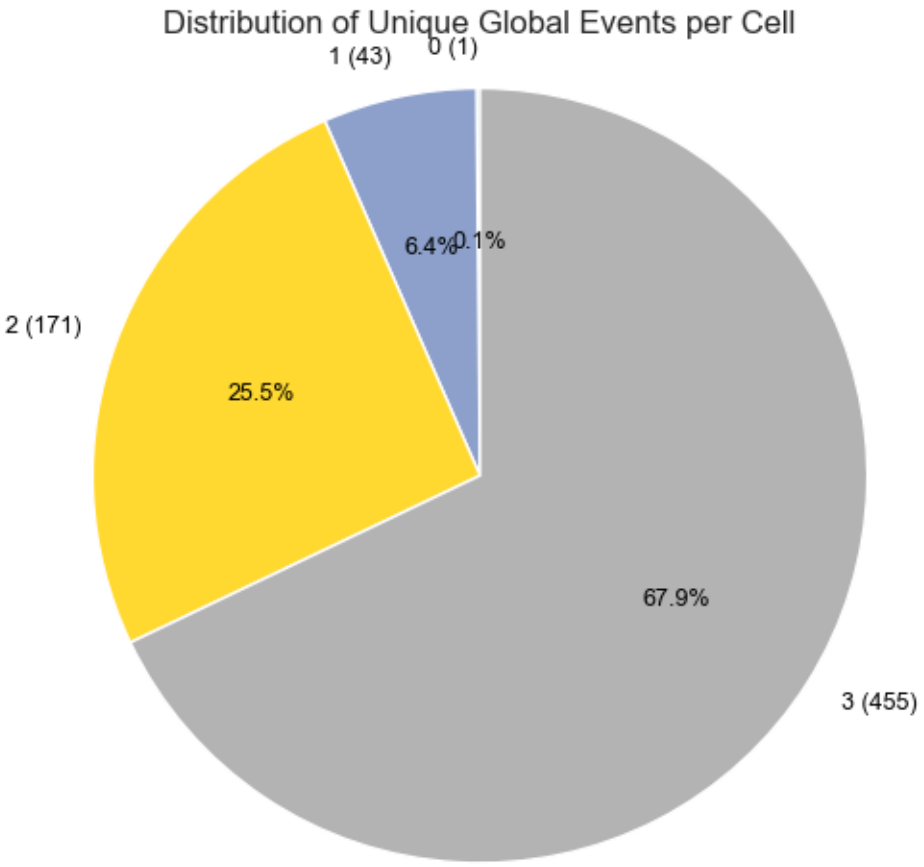

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```



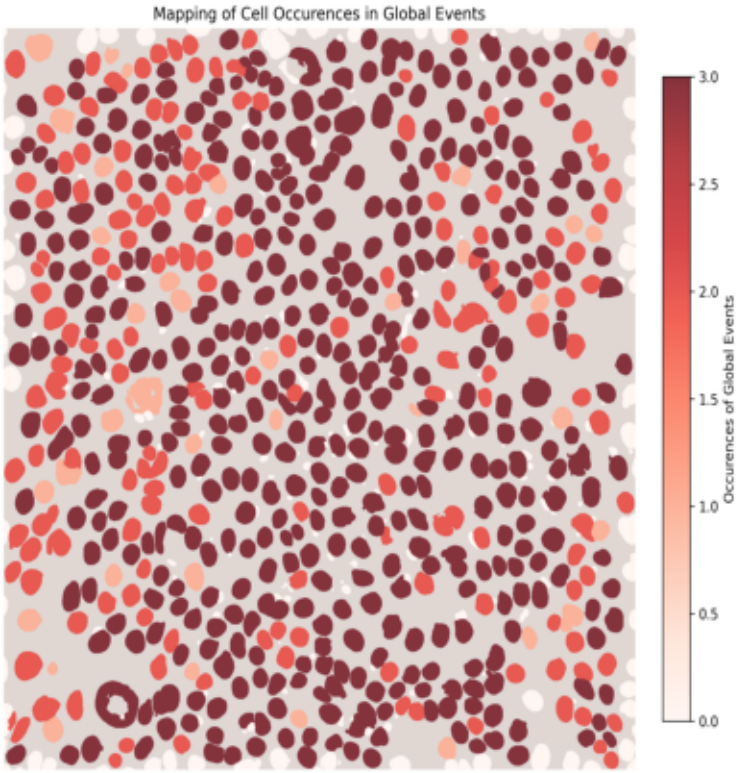

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```


Peak rate at 50% in Global Events
Peak Rate at 50% (% of peaks/s)
2.0
1.5
1.0
0.5
0.0
0
1
2
Event ID

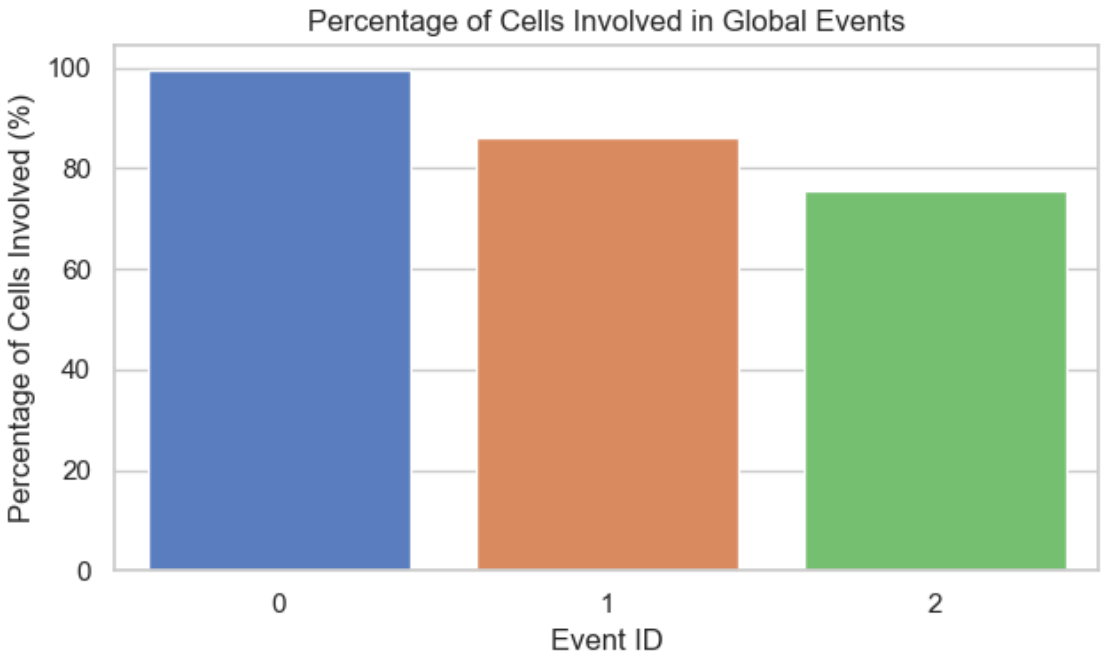
1.2.4 Cells occurences in global events



Cell Mapping with Occurences in Global Events Overlay - 20250701_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

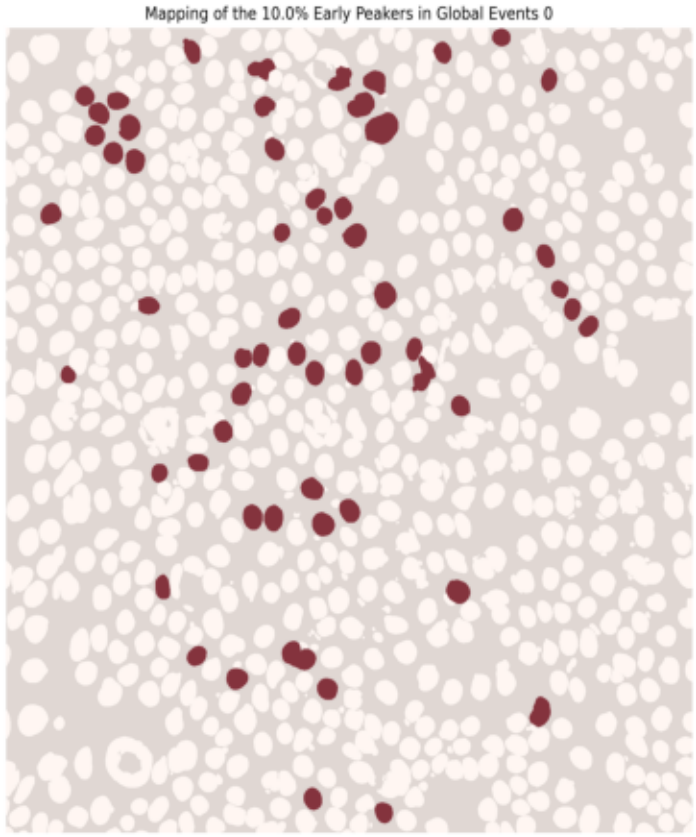


1.2.5 Inter-event interval analysis

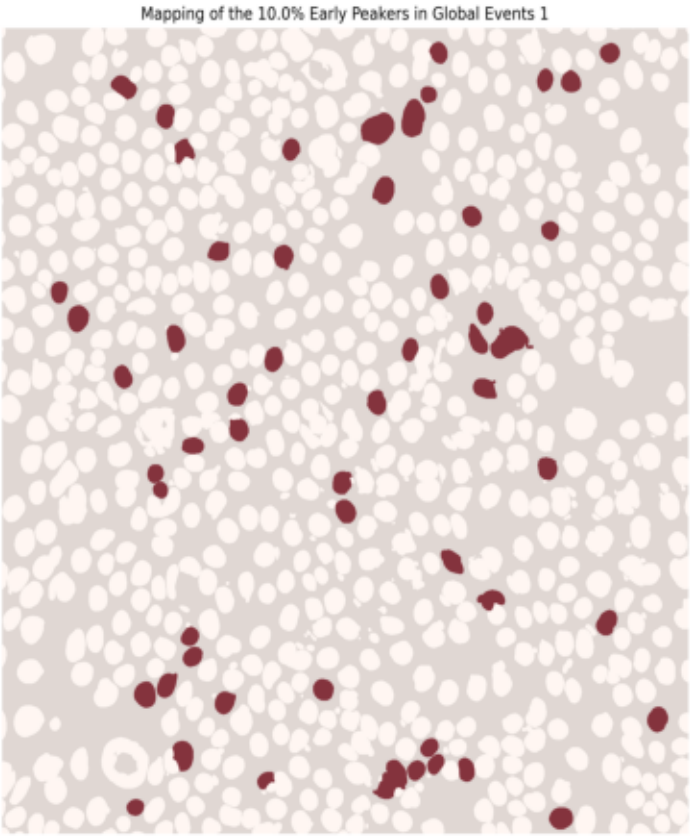
```
Intervals between global event peaks: [744.0, 523.0]
Estimated periodicity: 0.851
The global events exhibit a regular periodic pattern.
Estimated frequency (1/mean interval): 0.002 Hz
```

1.2.6 Early peakers in the events

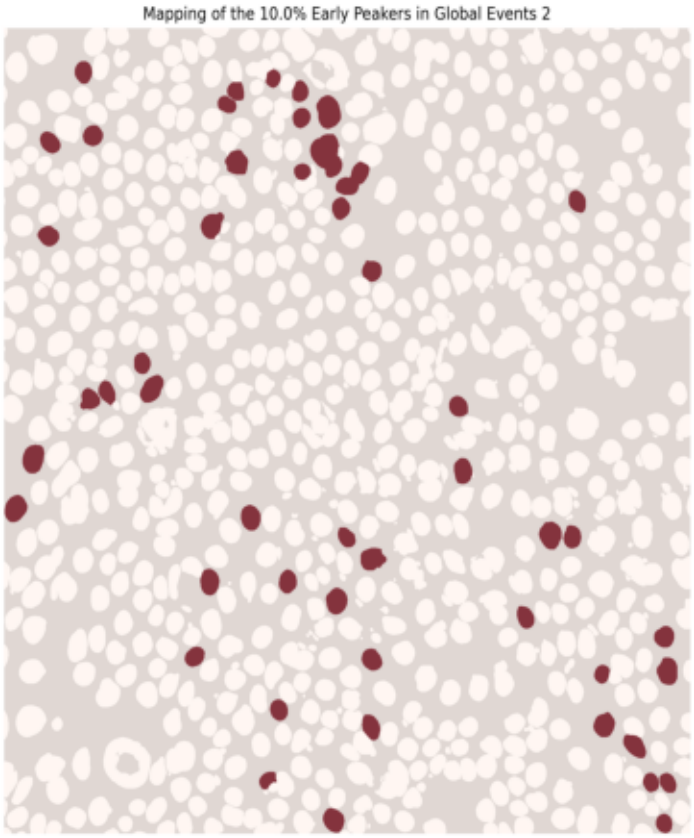
Cell Mapping with Early Peakers Overlay for event 0 - 20250701_IS1



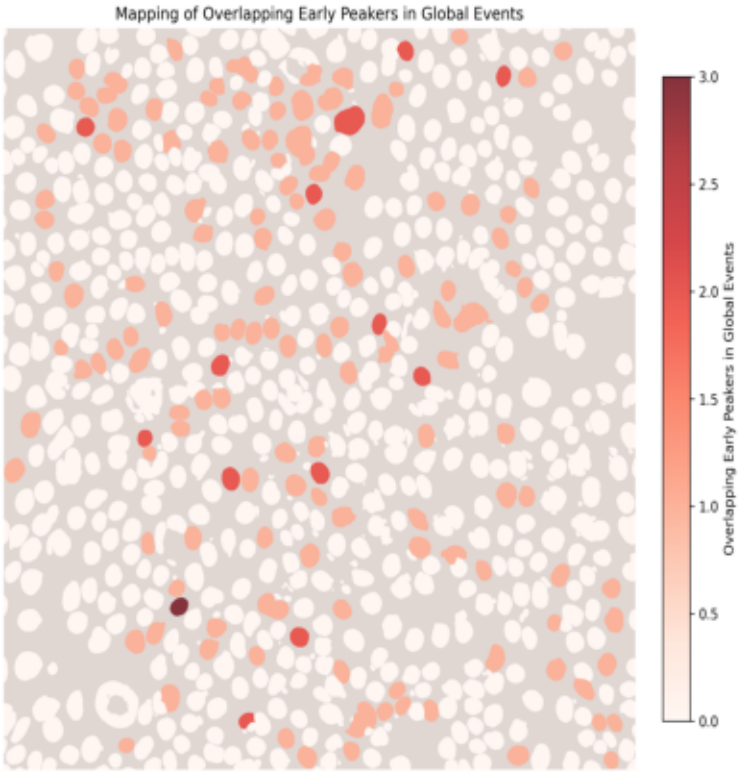
Cell Mapping with Early Peakers Overlay for event 1 - 20250701_IS1



Cell Mapping with Early Peakers Overlay for event 2 - 20250701_IS1

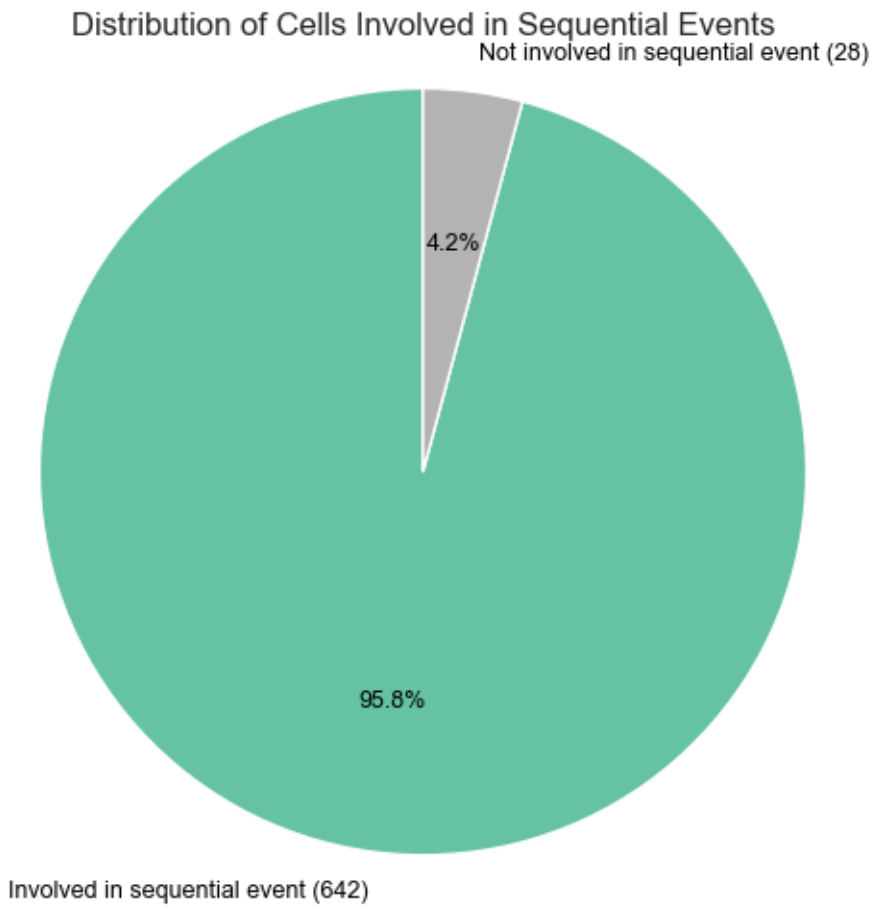


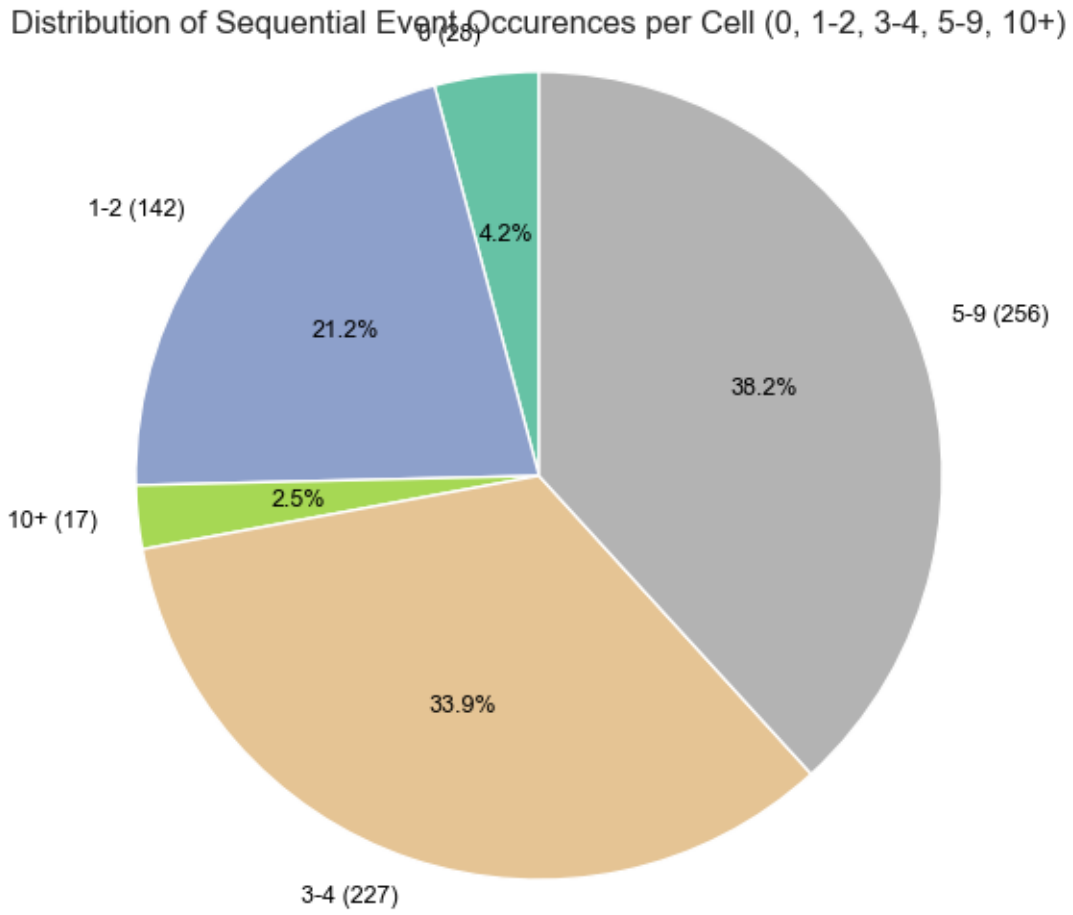
Cell Mapping with Occurences in Global Events Overlay - 20250701_IS1



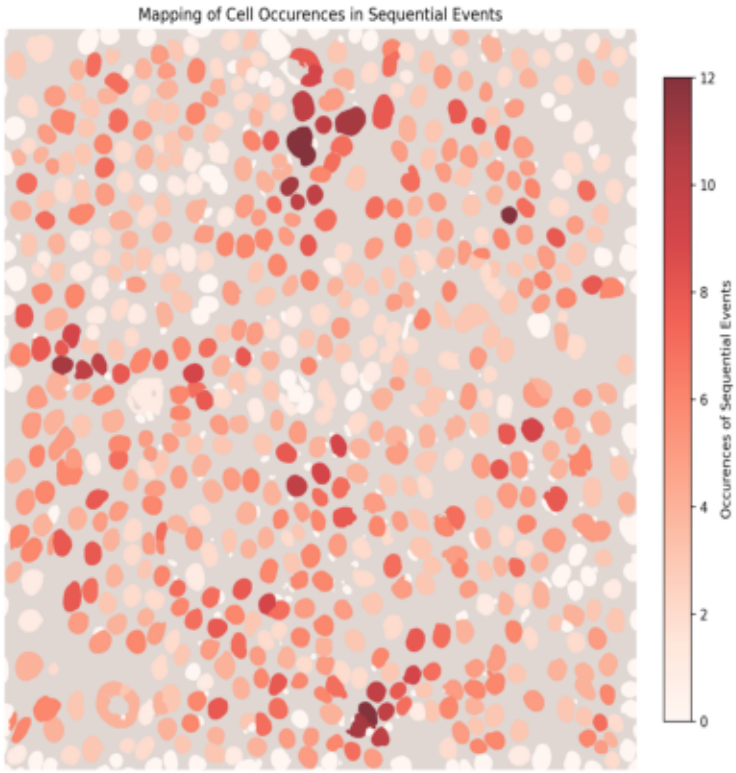
1.3 SEQUENTIAL EVENTS

1.3.1 Cells occurences in sequencial events

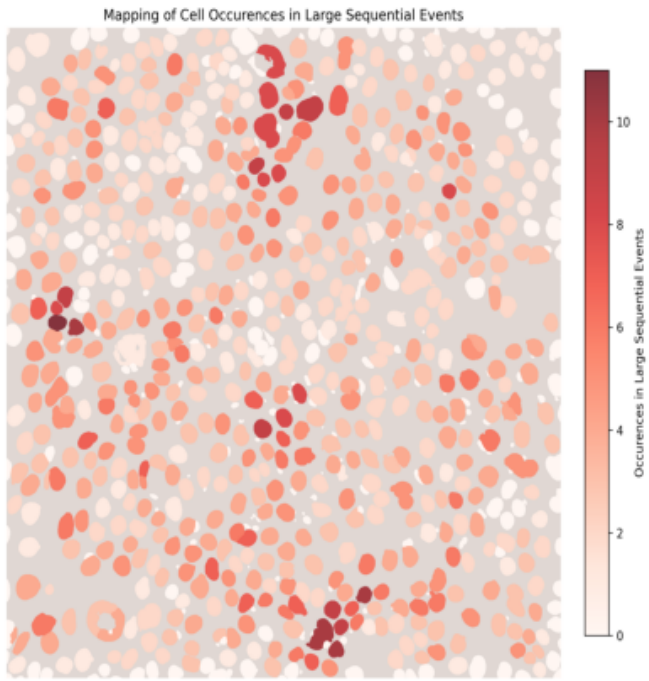



Distribution of Sequential Event Occurences per Cell (0, 1-2, 3-4, 5-9, 10+)
0 (28)
4.2%
1-2 (142)
21.2%
5-9 (256)
38.2%
10+ (17)
2.5%
33.9%
3-4 (227)

Cell Mapping with Occurences in Sequential Events Overlay - 20250701_IS1

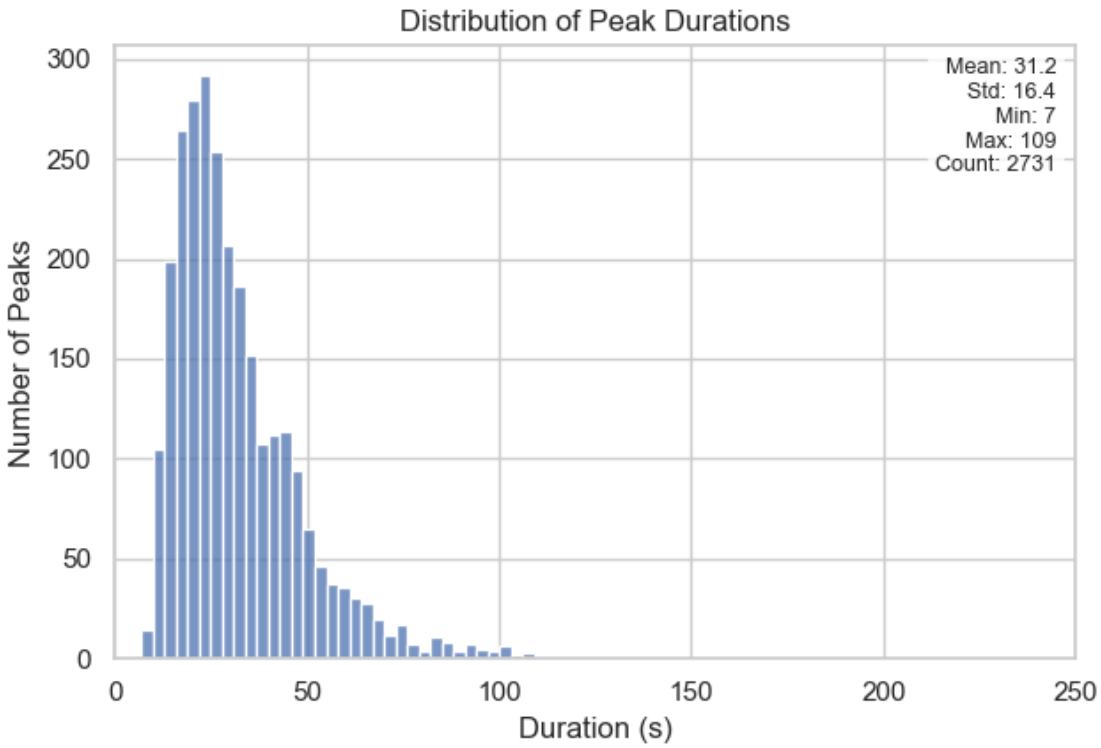


Cell Mapping with Occurences in Large Sequential Events Overlay (>2) - 20250701_IS1

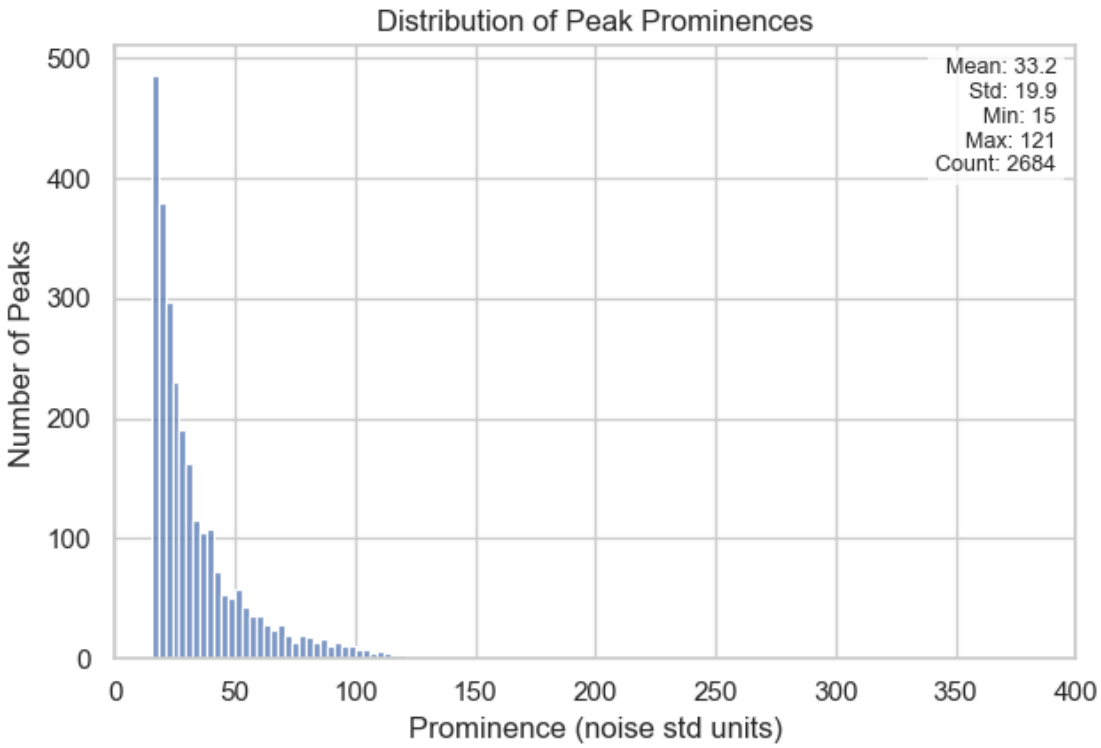


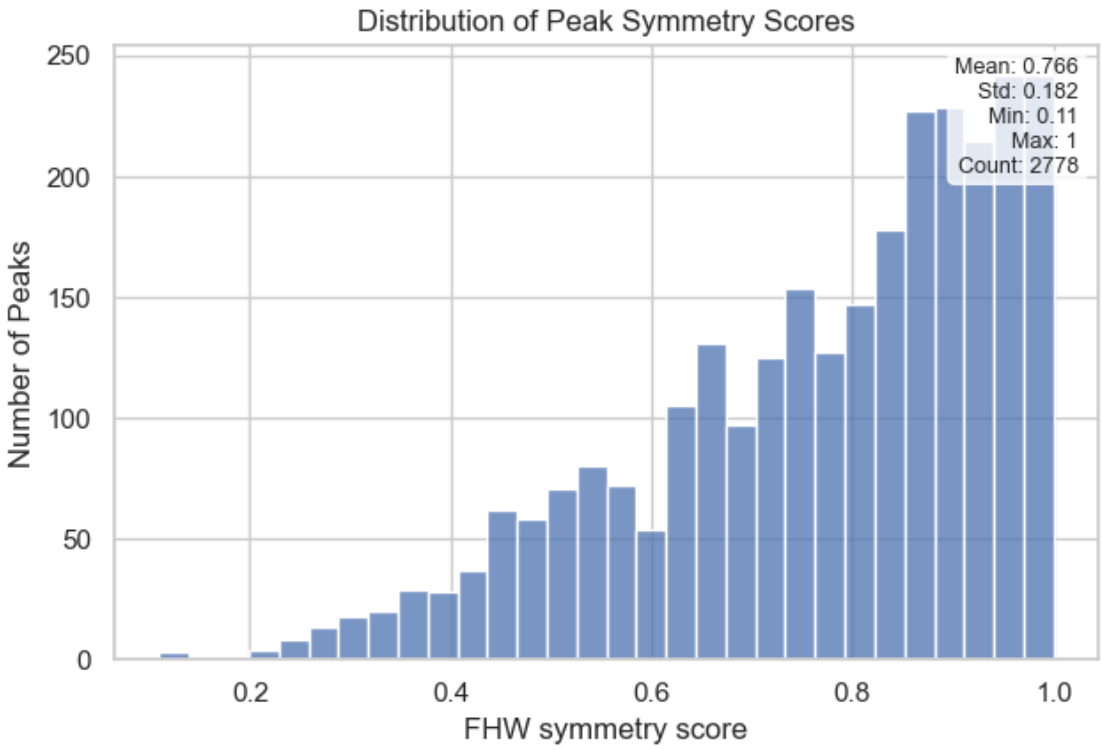
1.3.2 Peaks statistics in sequential events

```
[2025-08-11 10:22:40] [INFO] calcium: plot_histogram: removed 47 outliers out of
2778 on 'Duration (s)' (lower=-10, upper=110)
```



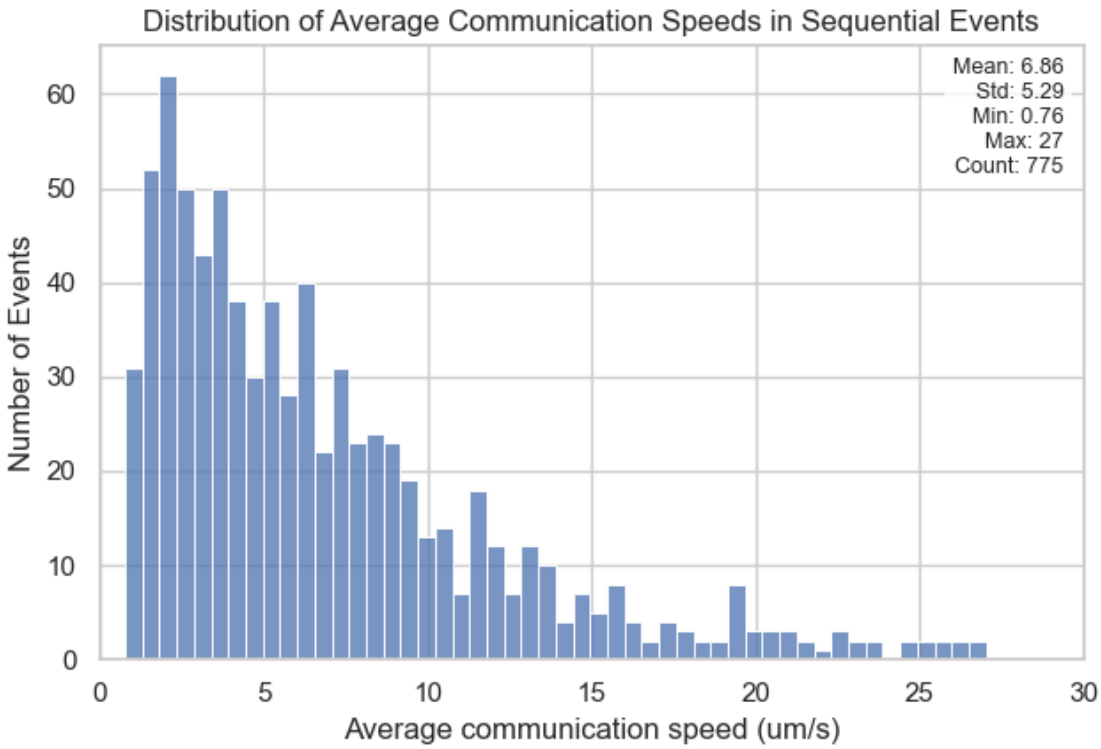

```
[2025-08-11 10:22:40] [INFO] calcium: plot_histogram: removed 94 outliers out of
2778 on 'Prominence (noise std units)' (lower=-14.6, upper=121)
```


Distribution of Peak Prominences
Mean: 33.2
Std: 19.9
Min: 15
Max: 121
Count: 2684
Number of Peaks
Prominence (noise std units)
0
100
200
300
400
500
0
50
100
150
200
250
300
350
400

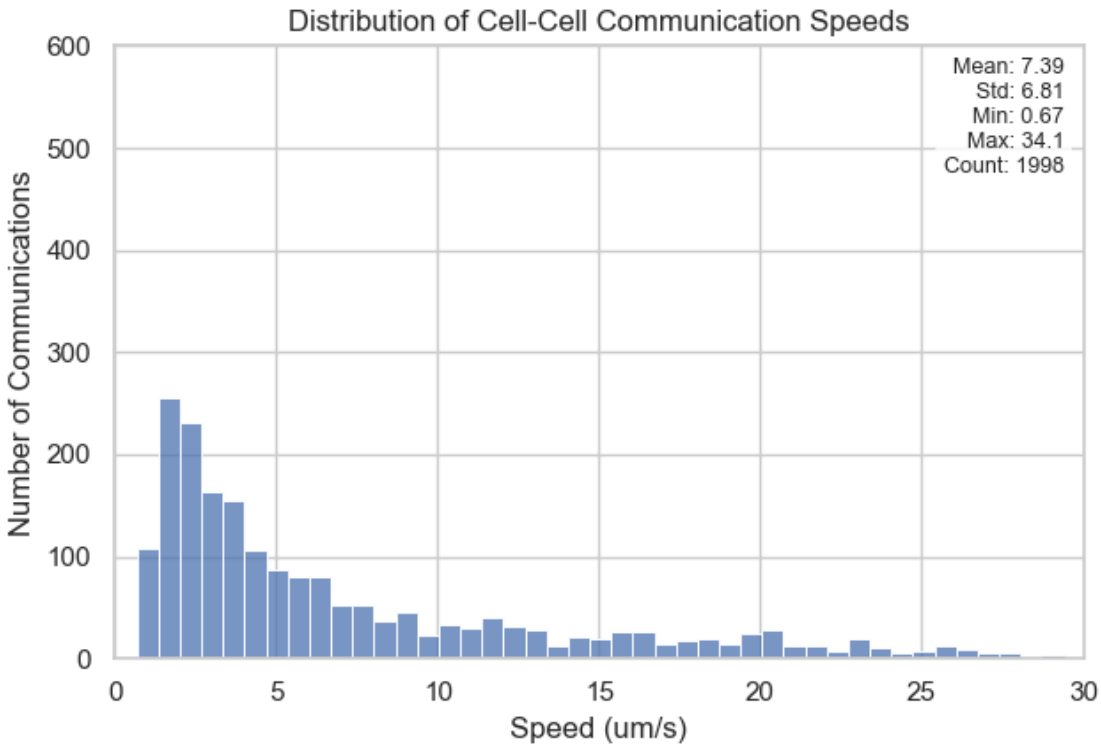

Distribution of Peak Symmetry Scores
Mean: 0.766
Std: 0.182
Min: 0.11
Max: 1
Count: 2778
Number of Peaks
FHW symmetry score
0
50
100
150
200
250
0.2
0.4
0.6
0.8
1.0

1.3.3 Cell-cell communication speed

```
[2025-08-11 10:22:41] [INFO] calcium: plot_histogram: removed 0 outliers out of
775 on 'Average communication speed (um/s)' (lower=-15.805, upper=27.735)
```

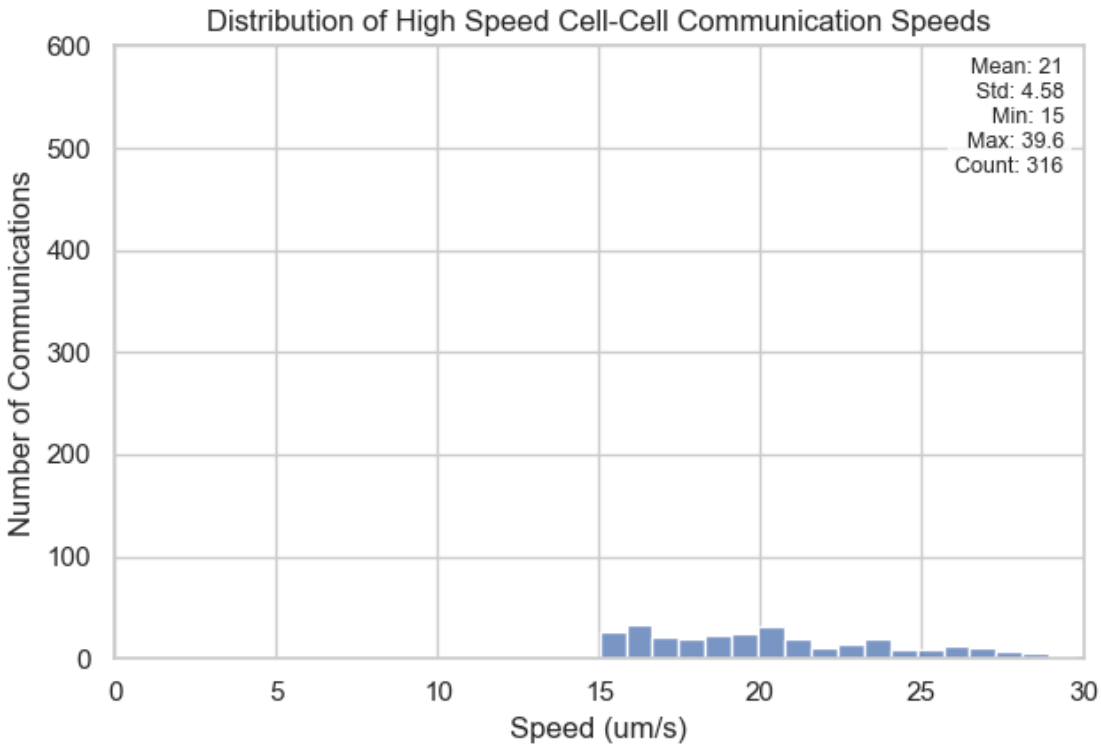



```
[2025-08-11 10:22:41] [INFO] calcium: plot_histogram: removed 5 outliers out of
2003 on 'Speed (um/s)' (lower=-22.205, upper=35.16)
```

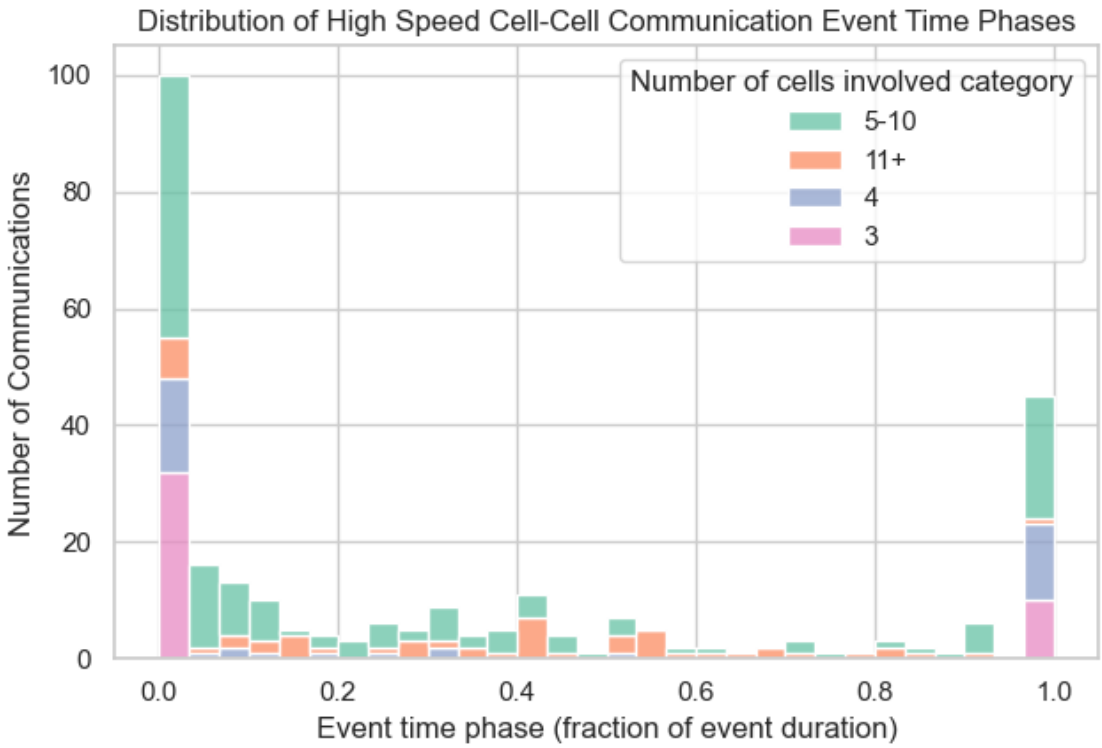


1.3.4 Double distribution in cell-cell communication speeds

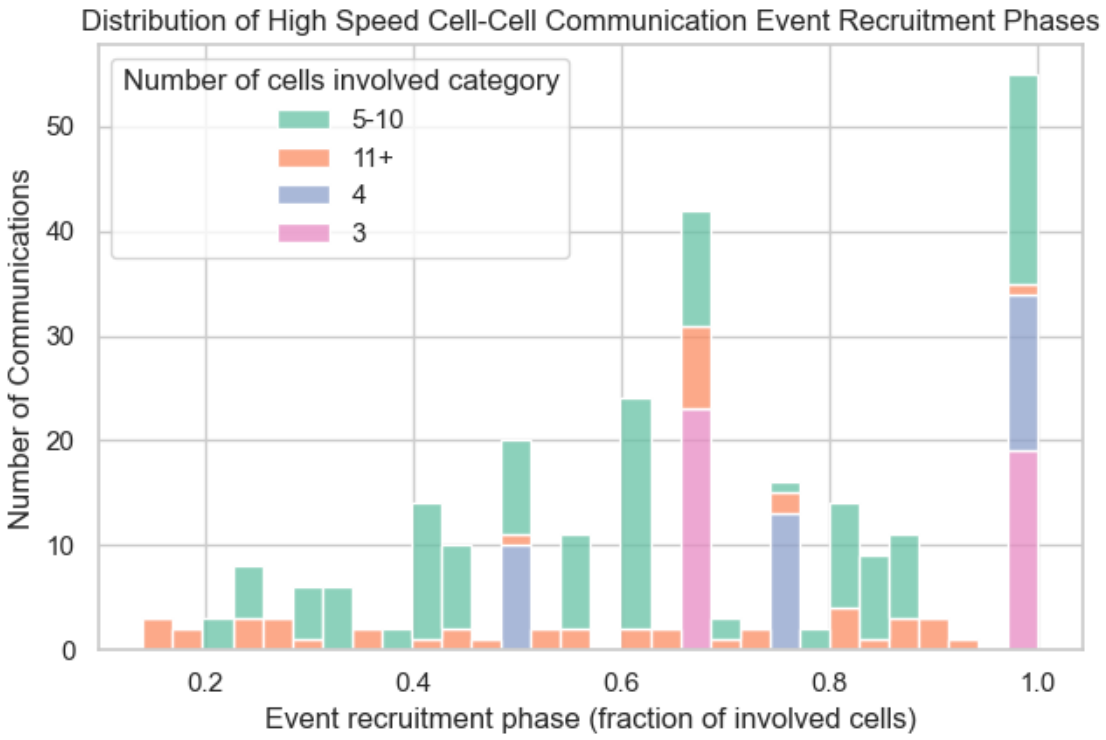
```
[2025-08-11 10:22:41] [INFO] calcium: plot_histogram: removed 1 outliers out of
317 on 'Speed (um/s)' (lower=-0.64, upper=41.5)
```



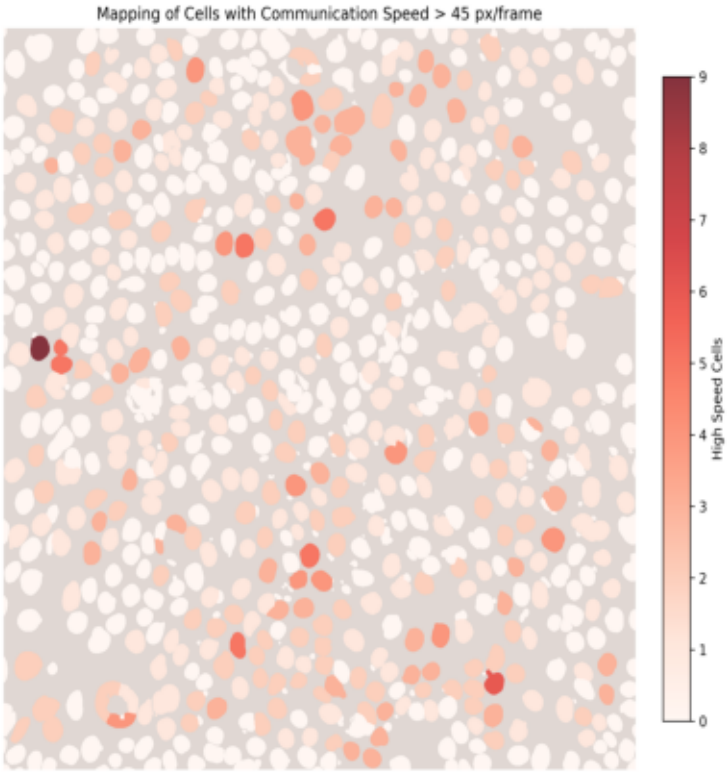

```
[2025-08-11 10:22:41] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 277 on 'Event time phase (fraction of event duration)'
(lower=-1.68, upper=2.24)
```



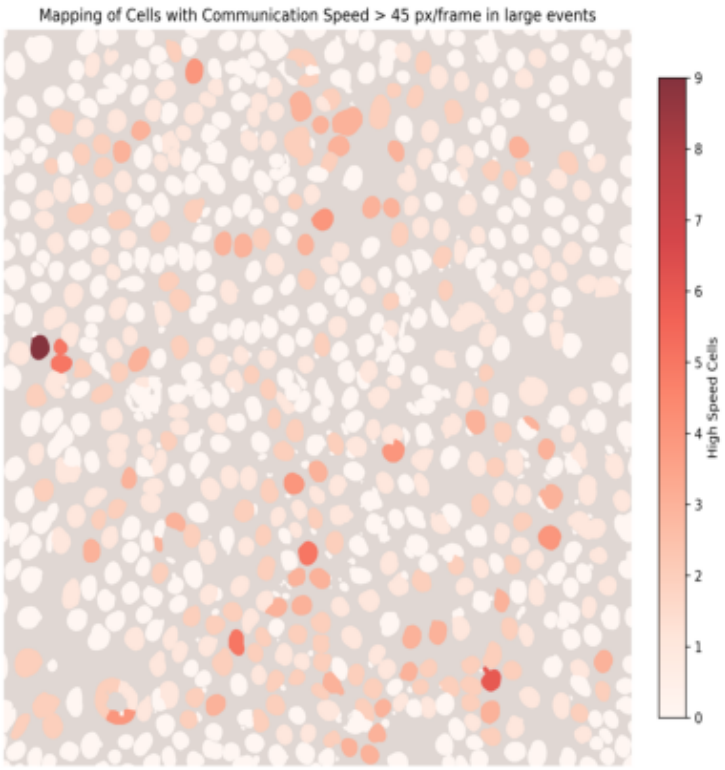

```
[2025-08-11 10:22:41] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 277 on 'Event recruitment phase (fraction of involved cells)'
(lower=-0.58, upper=1.94)
```


Distribution of High Speed Cell-Cell Communication Event Recruitment Phases
Number of cells involved category
5-10
11+
4
3
Number of Communications
0
10
20
30
40
50
0.2
0.4
0.6
0.8
1.0
Event recruitment phase (fraction of involved cells)

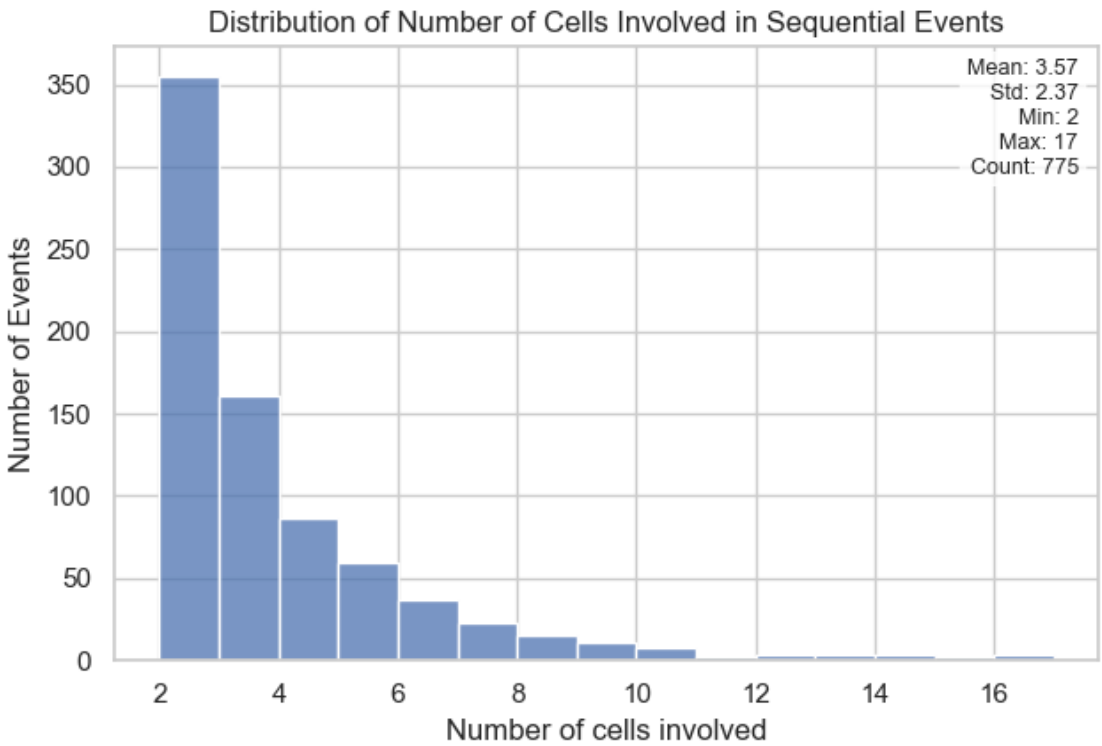
Cell Mapping with High Speed Cells Overlay - 20250701_IS1



Cell Mapping with High Speed Cells in Large Events Overlay - 20250701_IS1

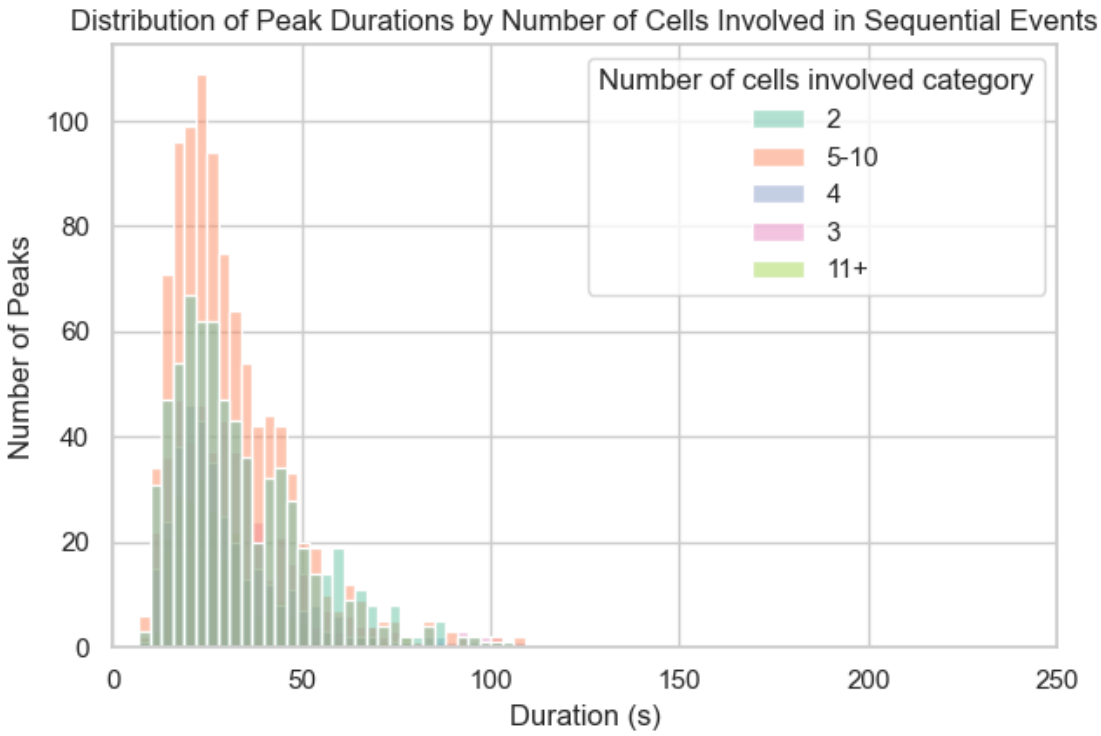


1.3.5 Number of cells involved per sequential events

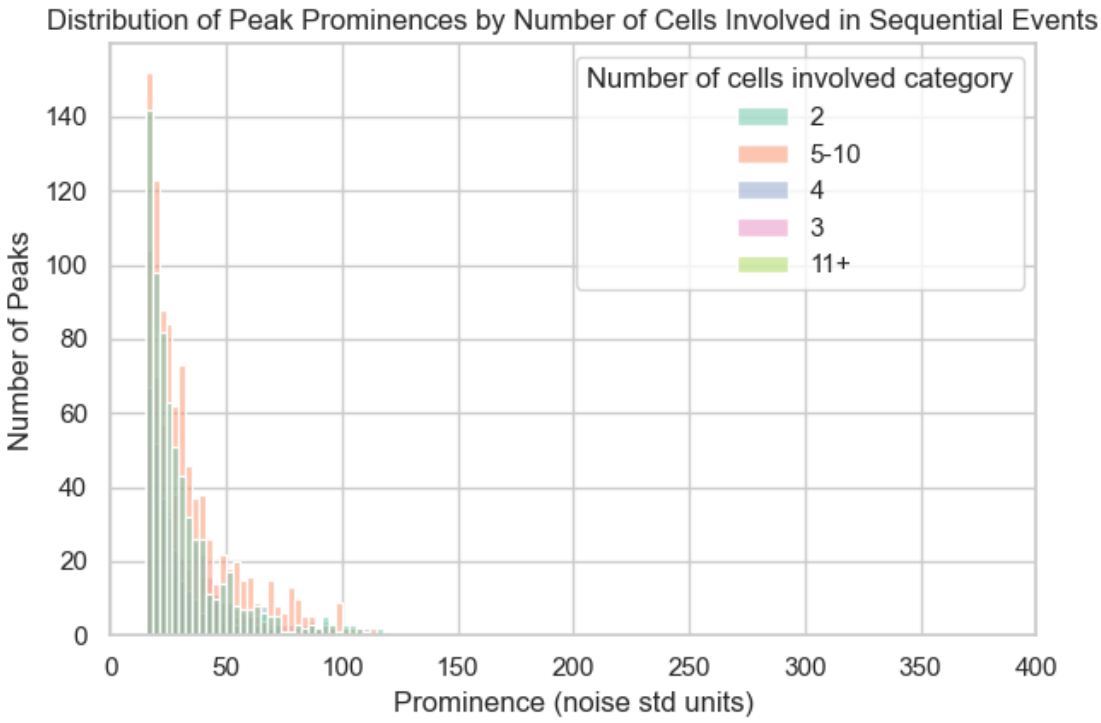


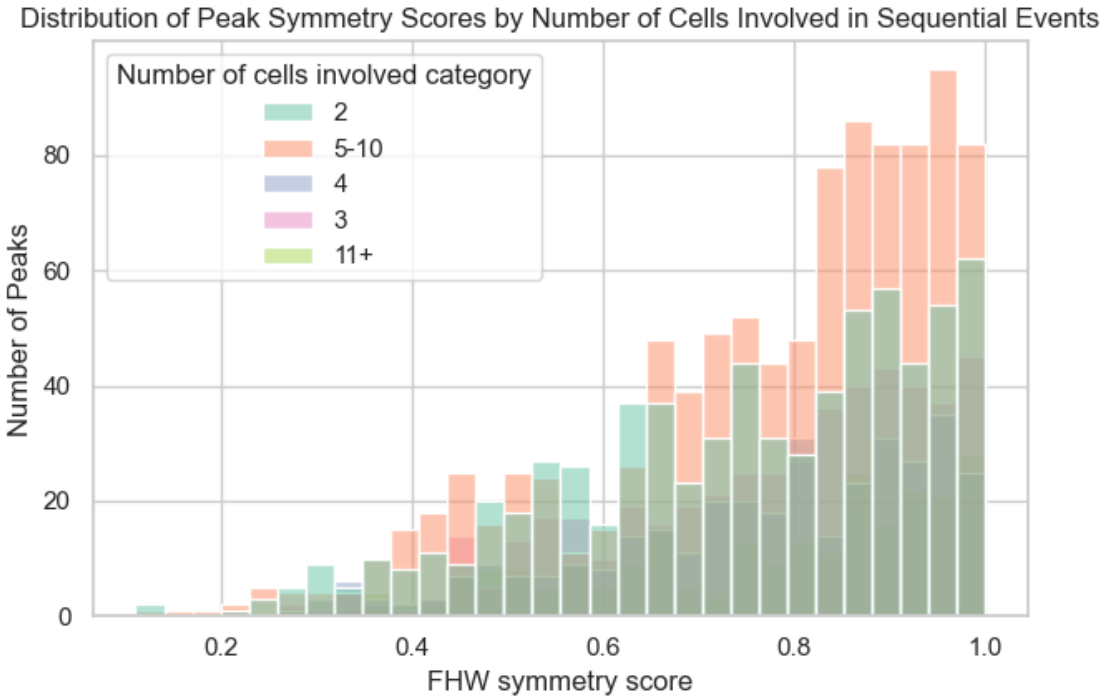
1.3.6 Influence of cell count per event on statistics

```
[2025-08-11 10:22:44] [INFO] calcium: plot_histogram_by_group: removed 47
outliers out of 2778 on 'Duration (s)' (lower=-10, upper=110)
```

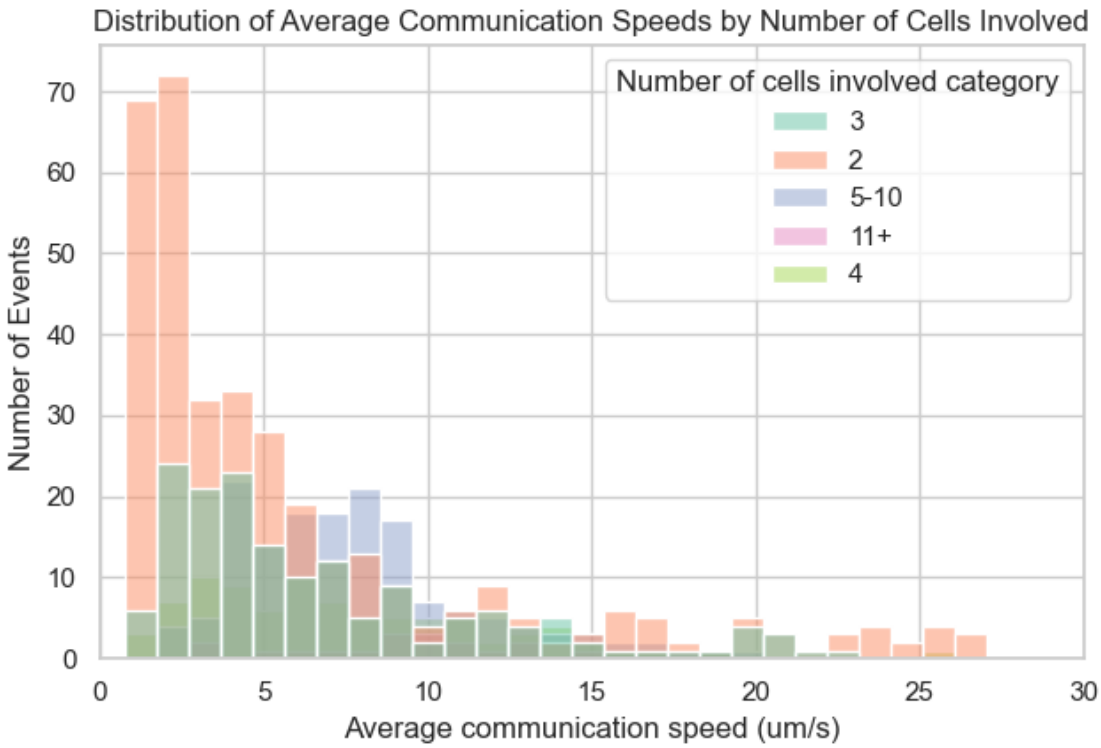



```
[2025-08-11 10:22:44] [INFO] calcium: plot_histogram_by_group: removed 94
outliers out of 2778 on 'Prominence (noise std units)' (lower=-14.6, upper=121)
```

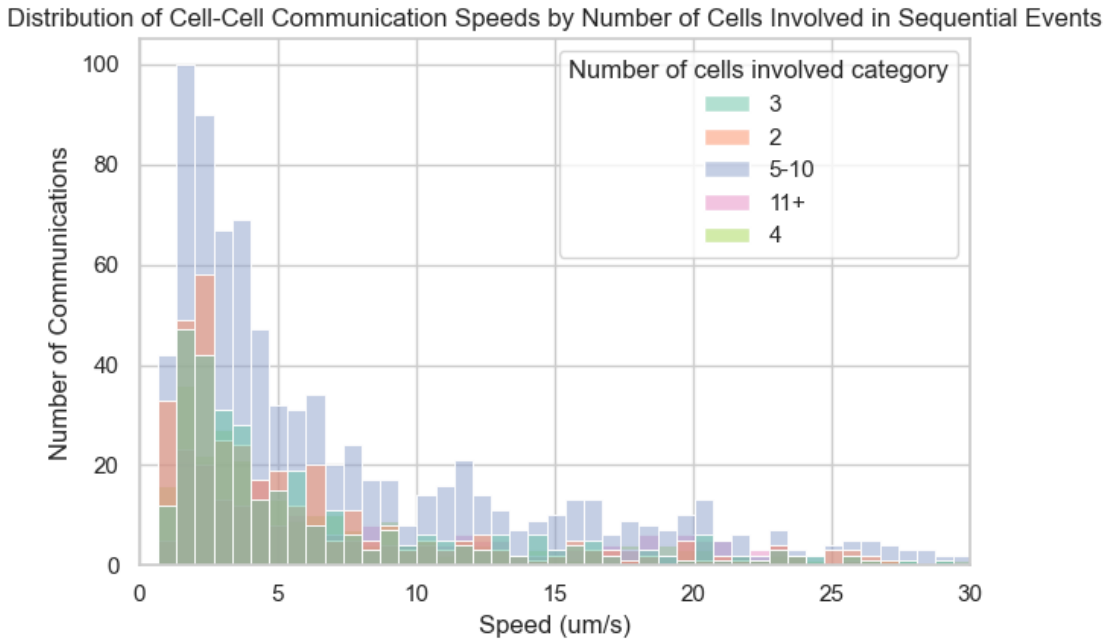




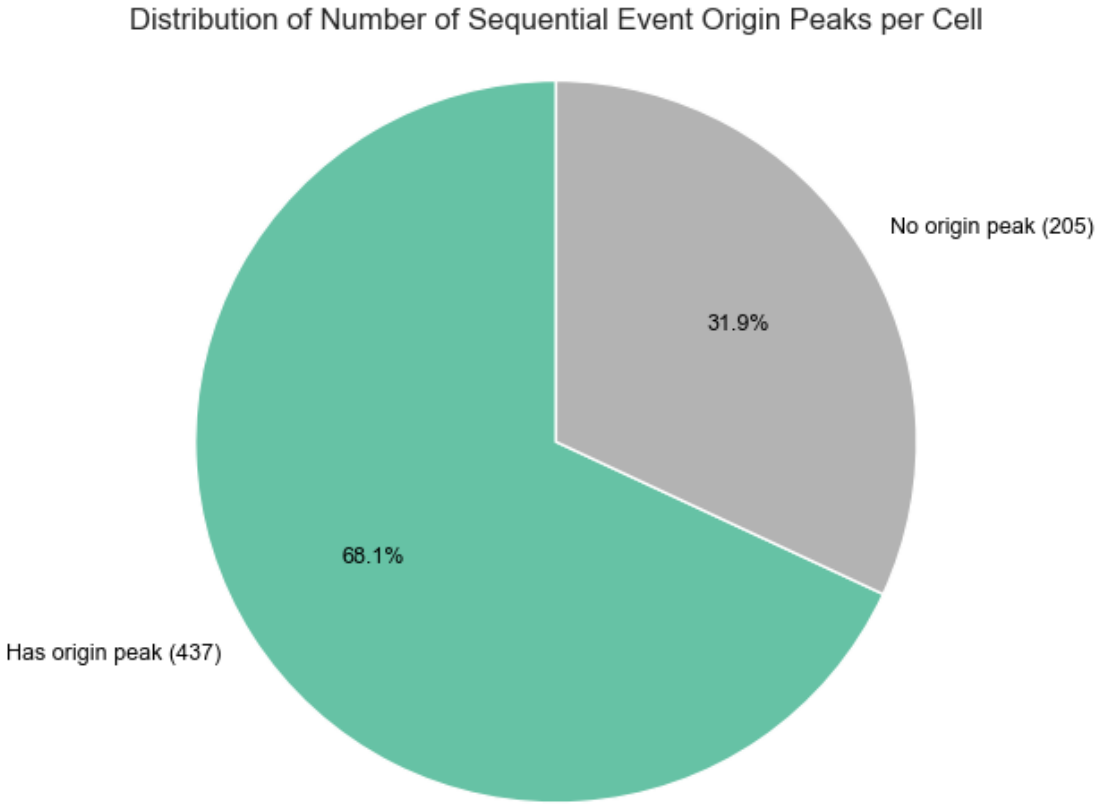

```
[2025-08-11 10:22:44] [INFO] calcium: plot_histogram_by_group: removed 0
outliers out of 775 on 'Average communication speed (um/s)' (lower=-15.805,
upper=27.735)
```

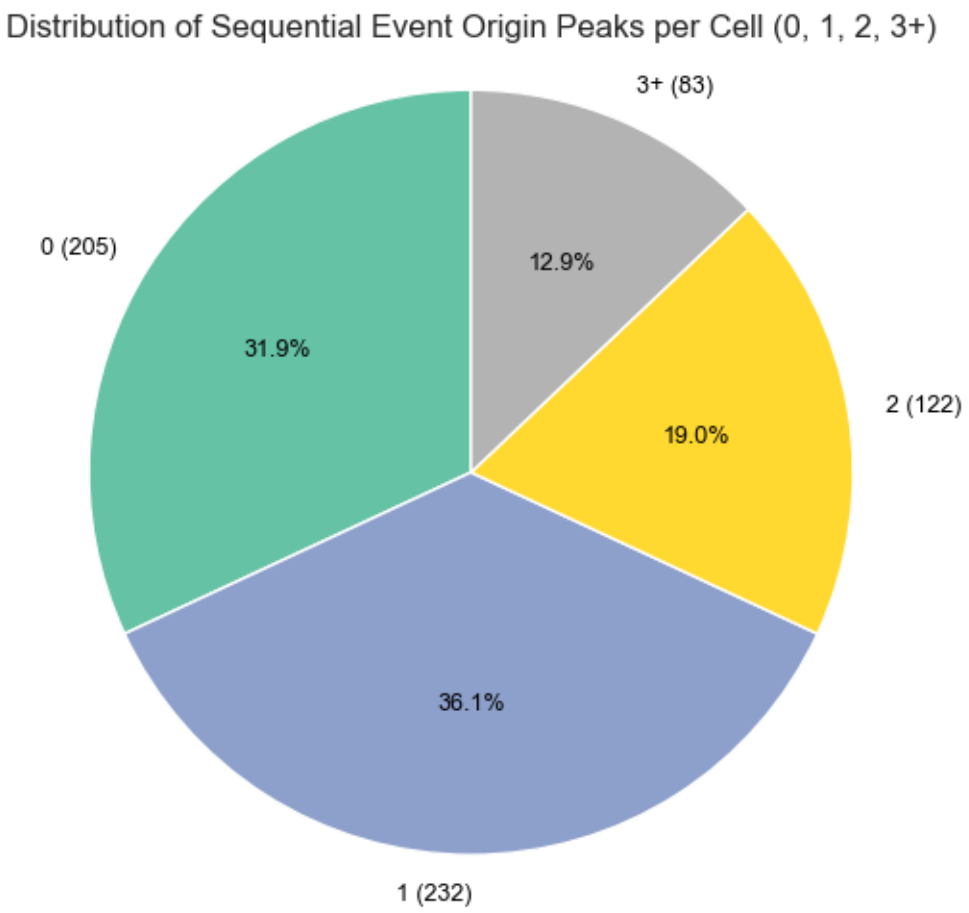



```
[2025-08-11 10:22:45] [INFO] calcium: plot_histogram_by_group: removed 5
outliers out of 2003 on 'Speed (um/s)' (lower=-22.205, upper=35.16)
```

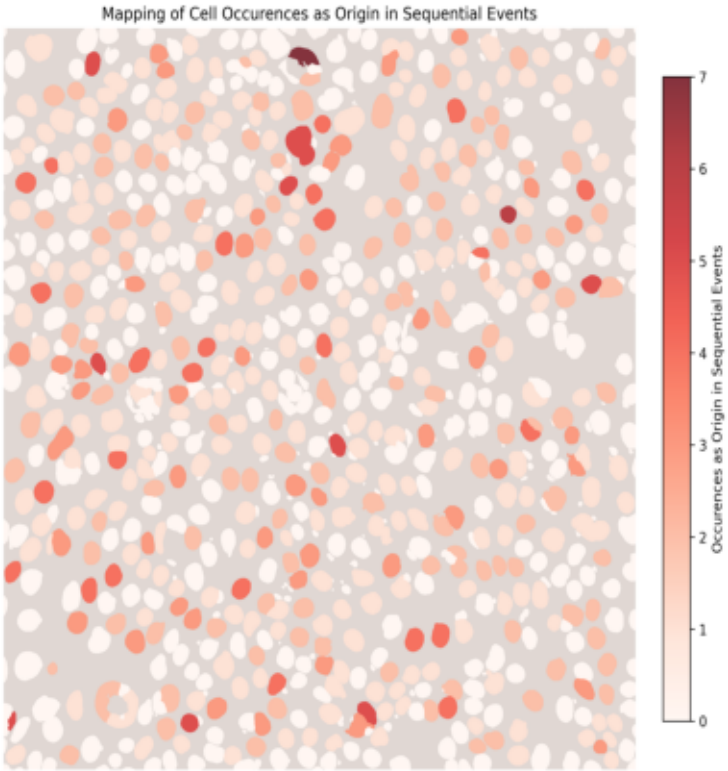


1.3.7 Cells occurences as origin in sequential events

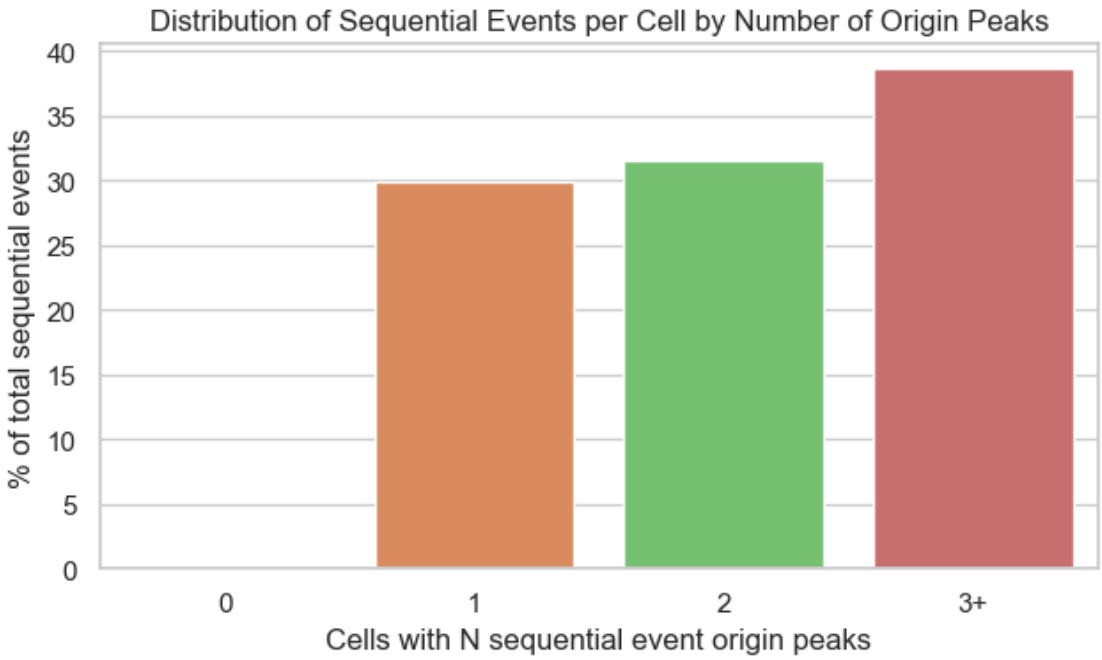



Distribution of Sequential Event Origin Peaks per Cell (0, 1, 2, 3+)
3+ (83)
12.9%
0 (205)
31.9%
2 (122)
19.0%
36.1%
1 (232)

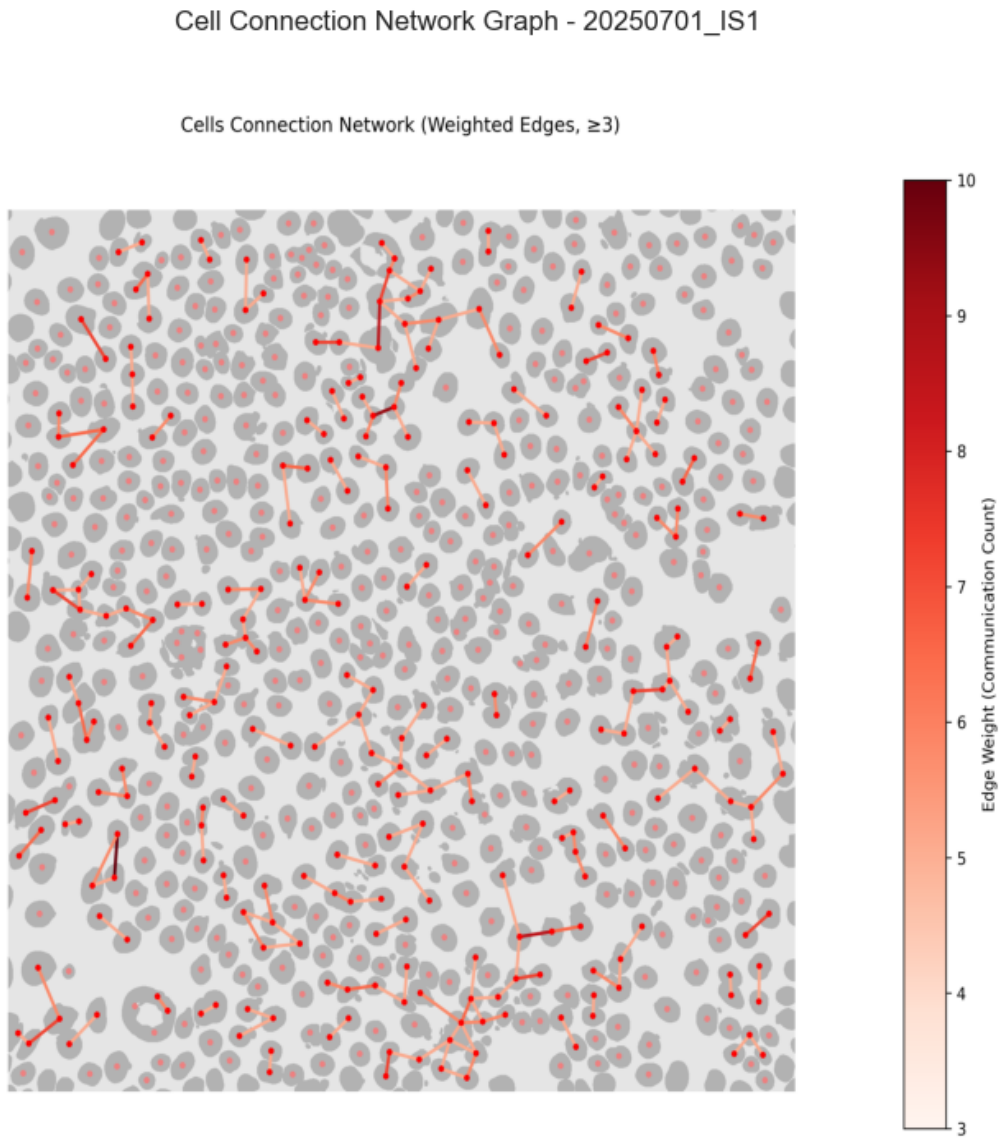
Cell Mapping with Origin Peaks Overlay - 20250701_IS1




```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.

  sns.barplot(
```

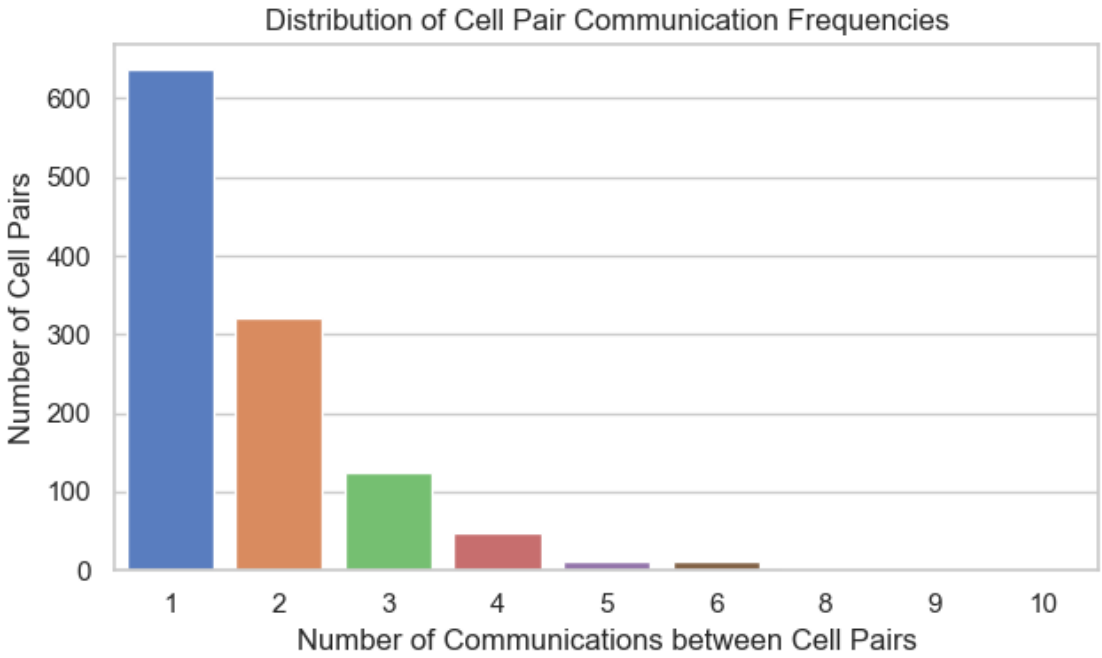

Distribution of Sequential Events per Cell by Number of Origin Peaks
% of total sequential events
40
35
30
25
20
15
10
5
0
0
1
2
3+
Cells with N sequential event origin peaks

1.3.8 Connection network between cells



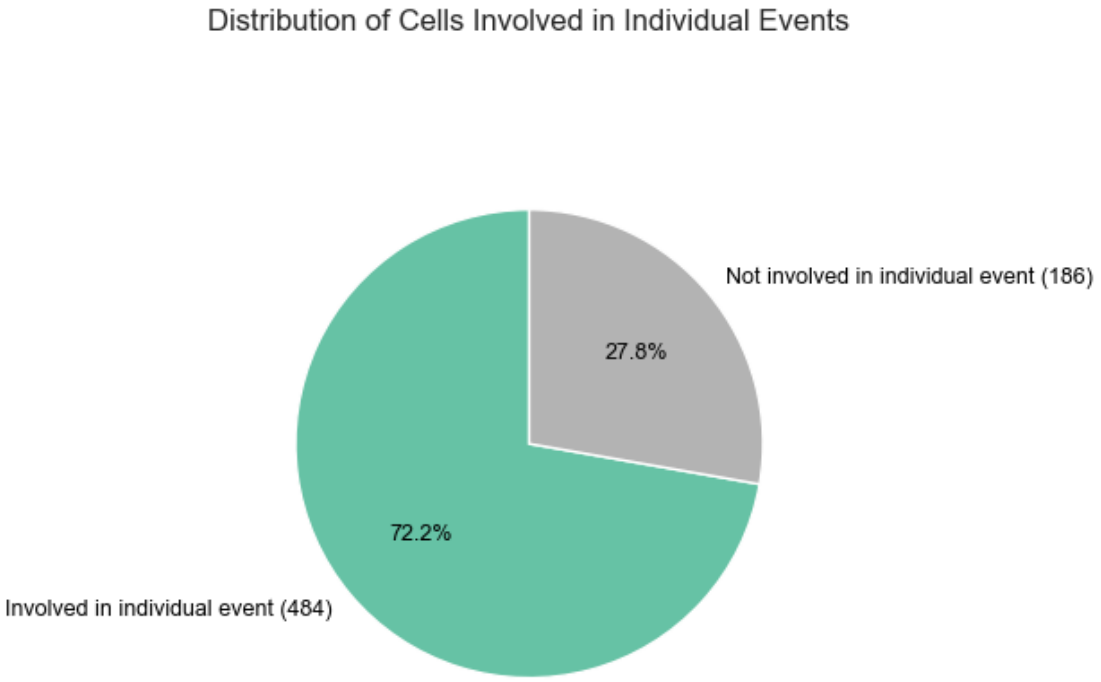

```
C:\Users\poseidon\OneDrive\Documents\01_ETHZ\Master_Degree\Spring_Semester_2025\
Master_Thesis\Coding\Image_analysis\src\calcium_activity_characterization\analys
is\visualizers.py:399: FutureWarning:

Passing `palette` without assigning `hue` is deprecated and will be removed in
v0.14.0. Assign the `x` variable to `hue` and set `legend=False` for the same
effect.
```

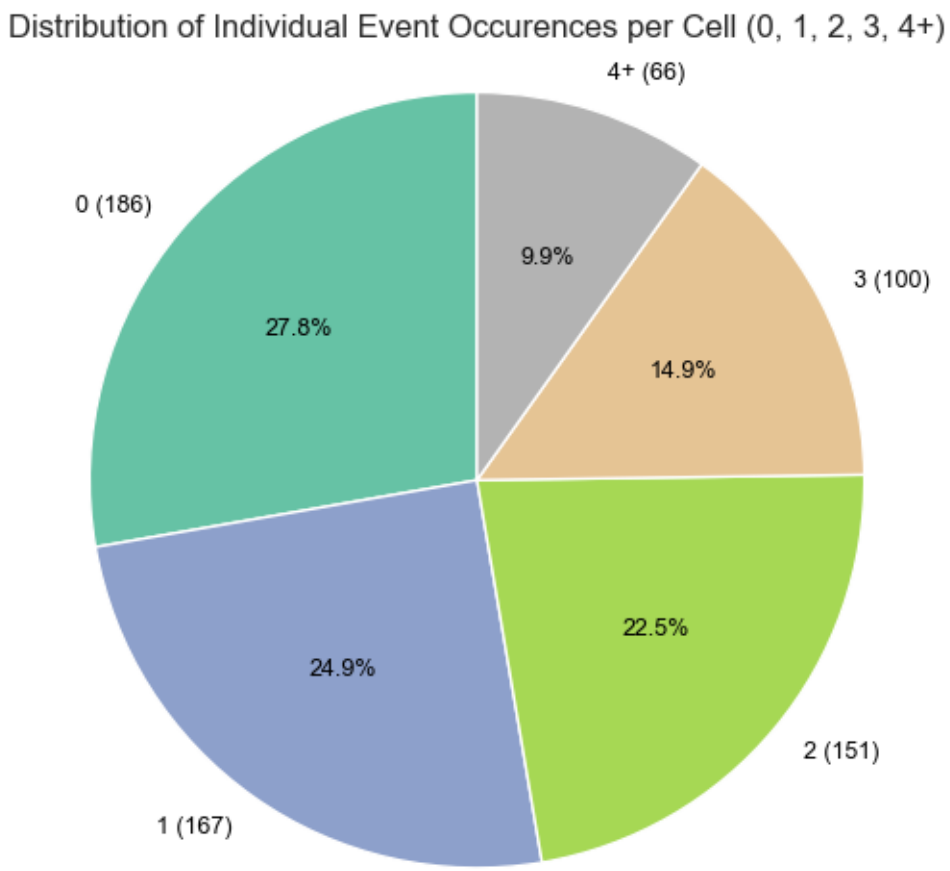
```
sns.barplot(
```


Distribution of Cell Pair Communication Frequencies
Number of Cell Pairs
600
500
400
300
200
100
0
1
2
3
4
5
6
8
9
10
Number of Communications between Cell Pairs

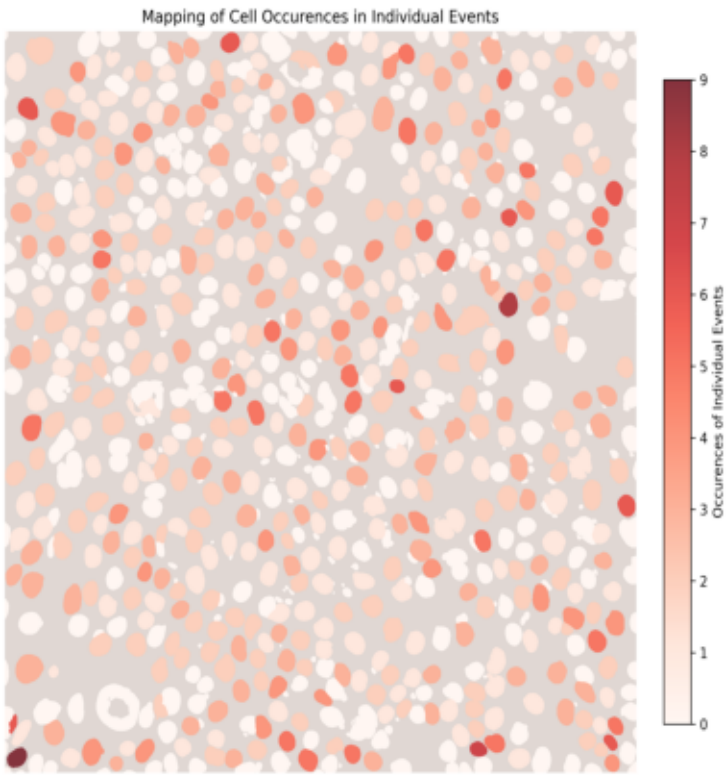
1.4 INDIVIDUAL EVENTS

1.4.1 Cells occurences in individual events



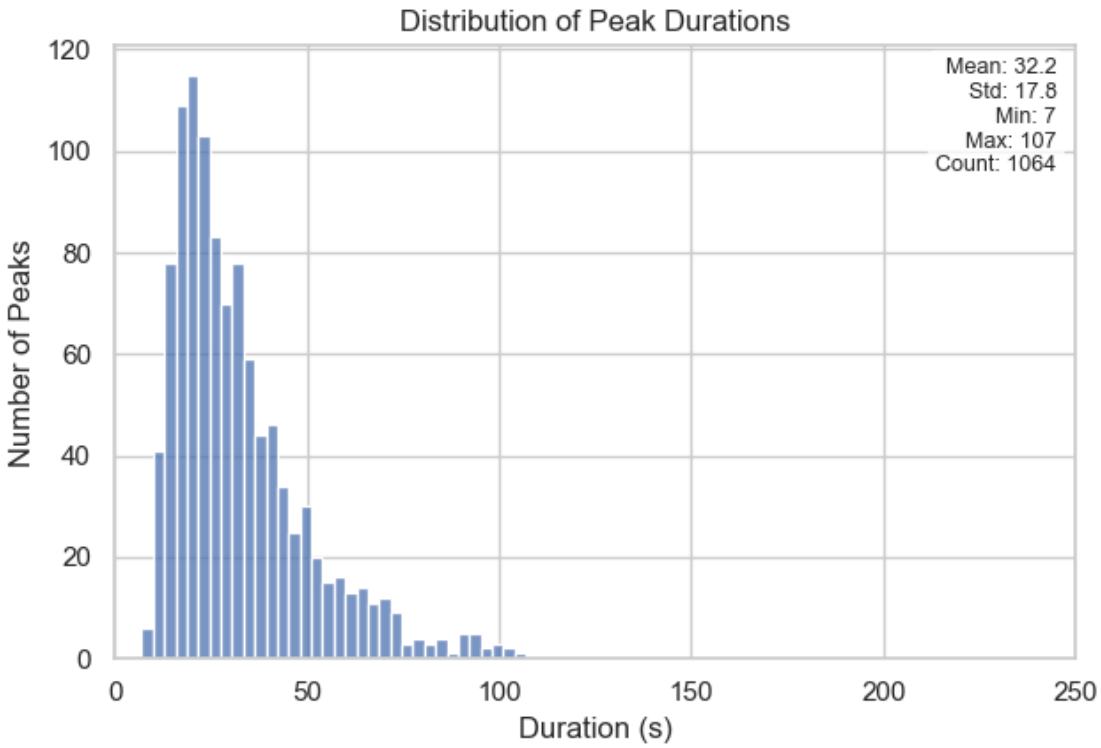

Distribution of Individual Event Occurences per Cell (0, 1, 2, 3, 4+)
4+ (66)
9.9%
3 (100)
14.9%
2 (151)
22.5%
1 (167)
24.9%
0 (186)
27.8%

Cell Mapping with Occurences in Individual Events Overlay - 20250701_IS1

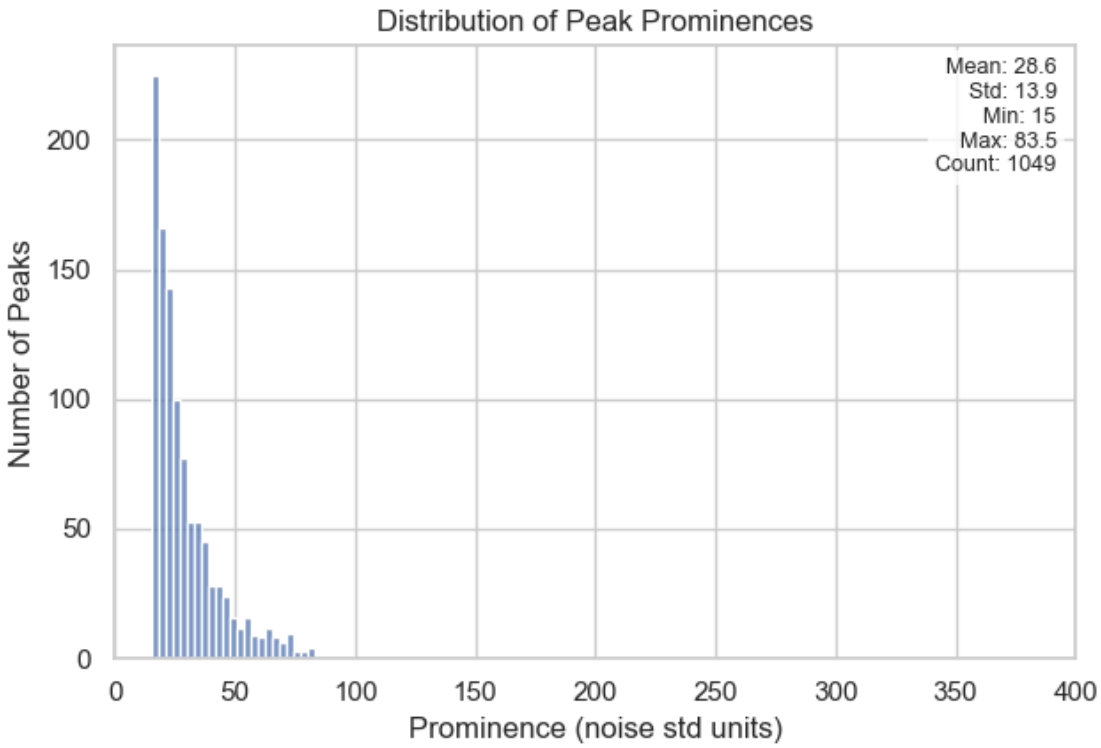


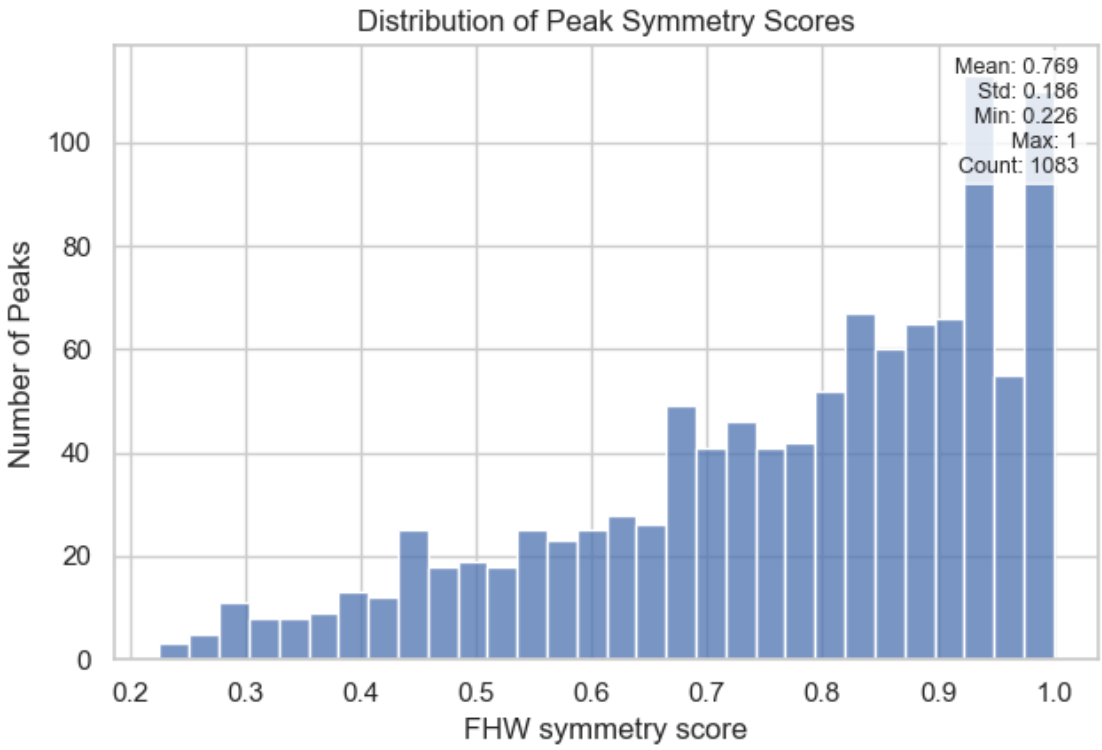
1.4.2 Peaks statistics in individual events

```
[2025-08-11 10:22:49] [INFO] calcium: plot_histogram: removed 19 outliers out of
1083 on 'Duration (s)' (lower=-47, upper=107)
```

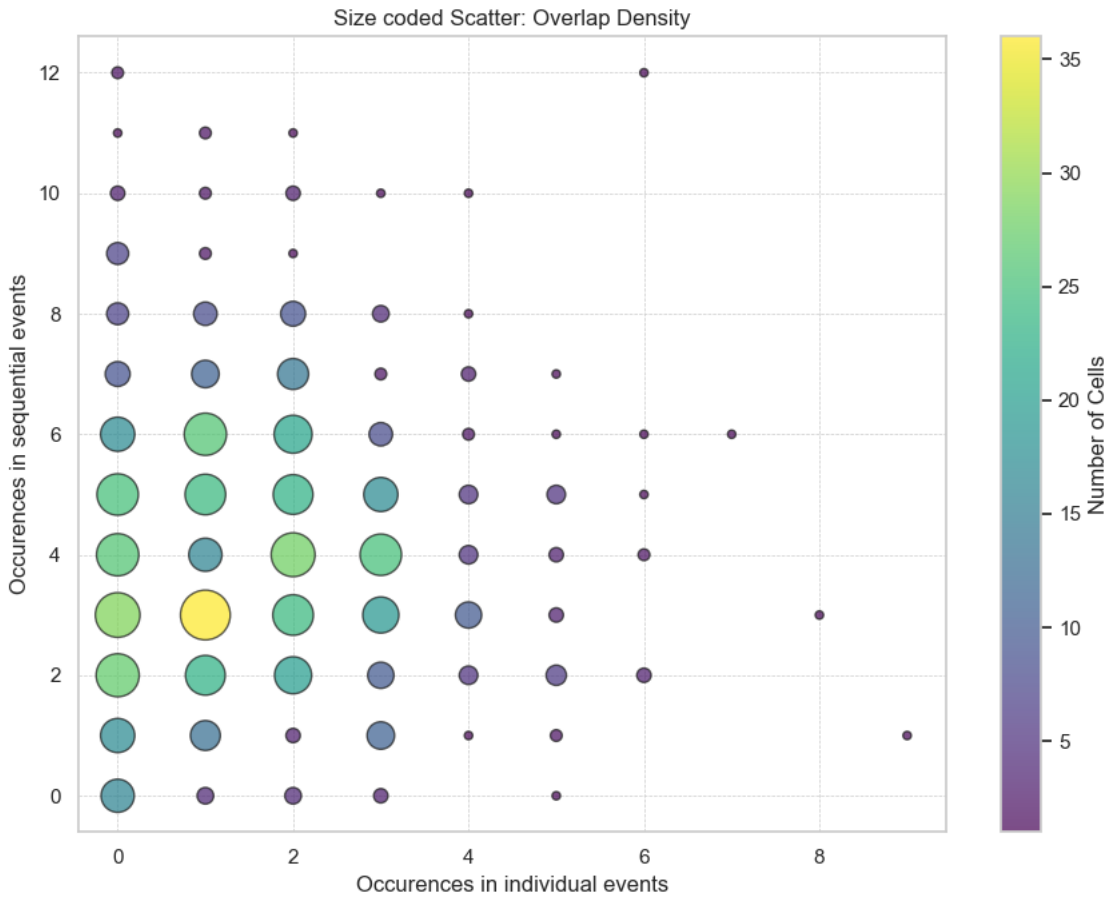



```
[2025-08-11 10:22:49] [INFO] calcium: plot_histogram: removed 34 outliers out of
1083 on 'Prominence (noise std units)' (lower=-32.5, upper=86.5)
```

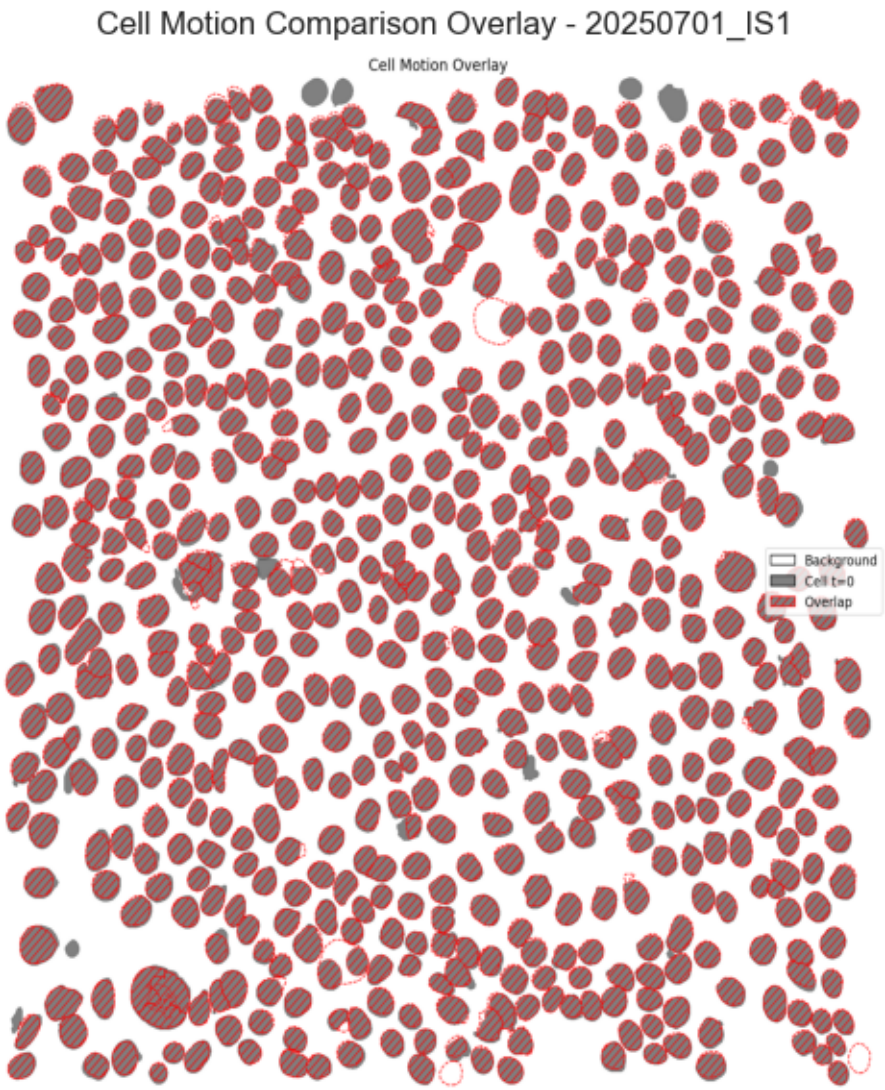

Distribution of Peak Prominences
Mean: 28.6
Std: 13.9
Min: 15
Max: 83.5
Count: 1049
Number of Peaks
0
50
100
150
200
0
50
100
150
200
250
300
350
400
Prominence (noise std units)


Distribution of Peak Symmetry Scores
Mean: 0.769
Std: 0.186
Min: 0.226
Max: 1
Count: 1083
Number of Peaks
0
20
40
60
80
100
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
FHW symmetry score

1.4.3 Correlation between event activity level & individual activity level



1.5 CELLS MOTION




```
Number of cells:
- Hoechst image taken at t=0: 670
- Hoechst image taken at t=1801: 649
- Number of cells difference: absolute 21, relative 3.18%
Pixel-level cell segmentation:
- Total number of pixels in image: 4194304
- Pixels segmented as cell at t=0: 989219
- Pixels segmented as cell at t=1801: 878100
- Overlapping pixels between t=0 and t=1801: 841293(90.11% of total)
- Pixels exclusive to t=0: 147926 (14.95% of total)
- Pixels exclusive to t=1801: 36807 (4.19% of total)
```