

REMOTE MEASUREMENTS OF VOLCANIC PLUME ELECTRIFICATION USING A SPARSE NETWORK TECHNIQUE

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EARTH NETWORKS TOTAL LIGHTNING NETWORK (ENTLN)

- ENTLN is a lightning detection network with over 1600 sensors globally

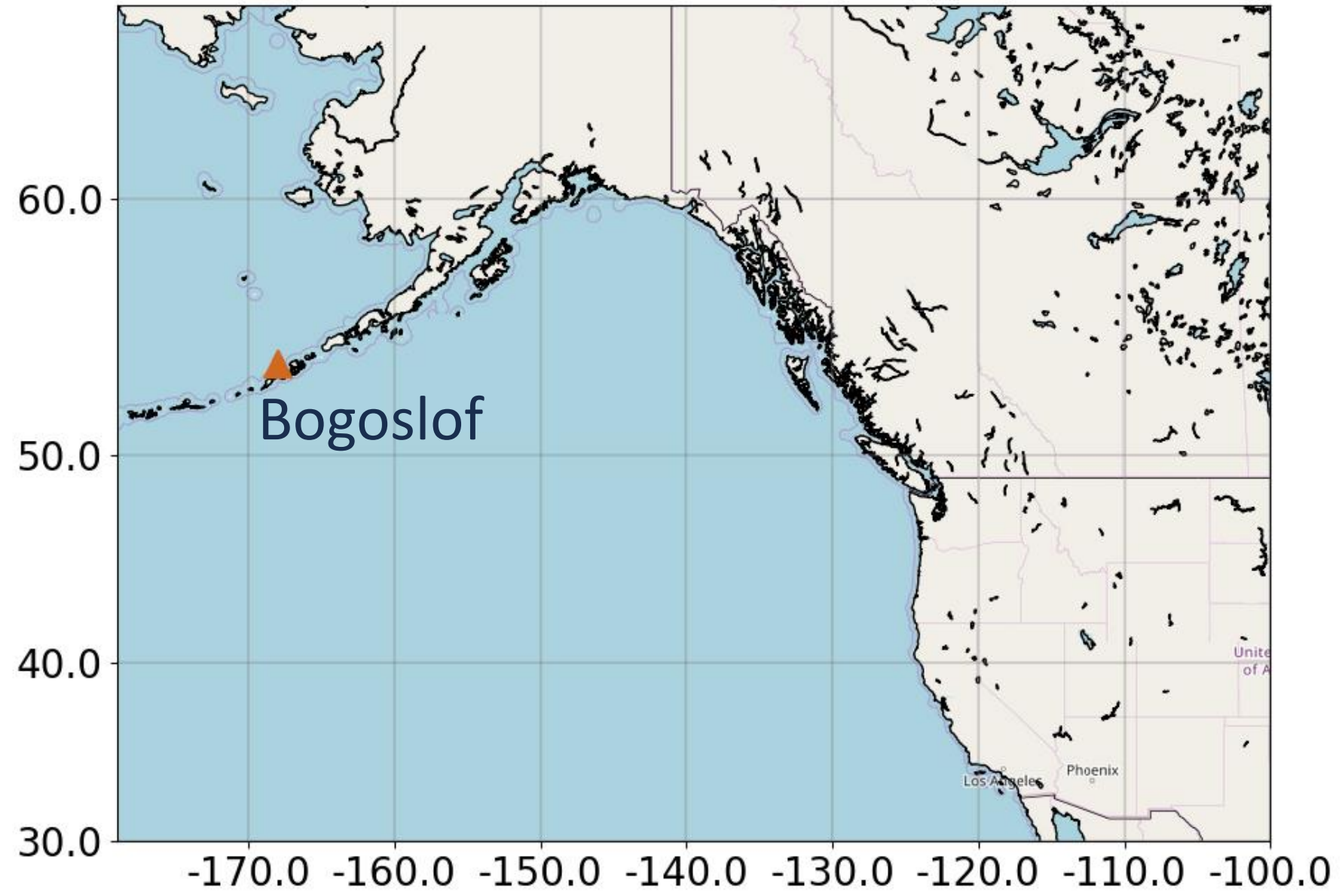


Detects radio waves from charge motion during lightning

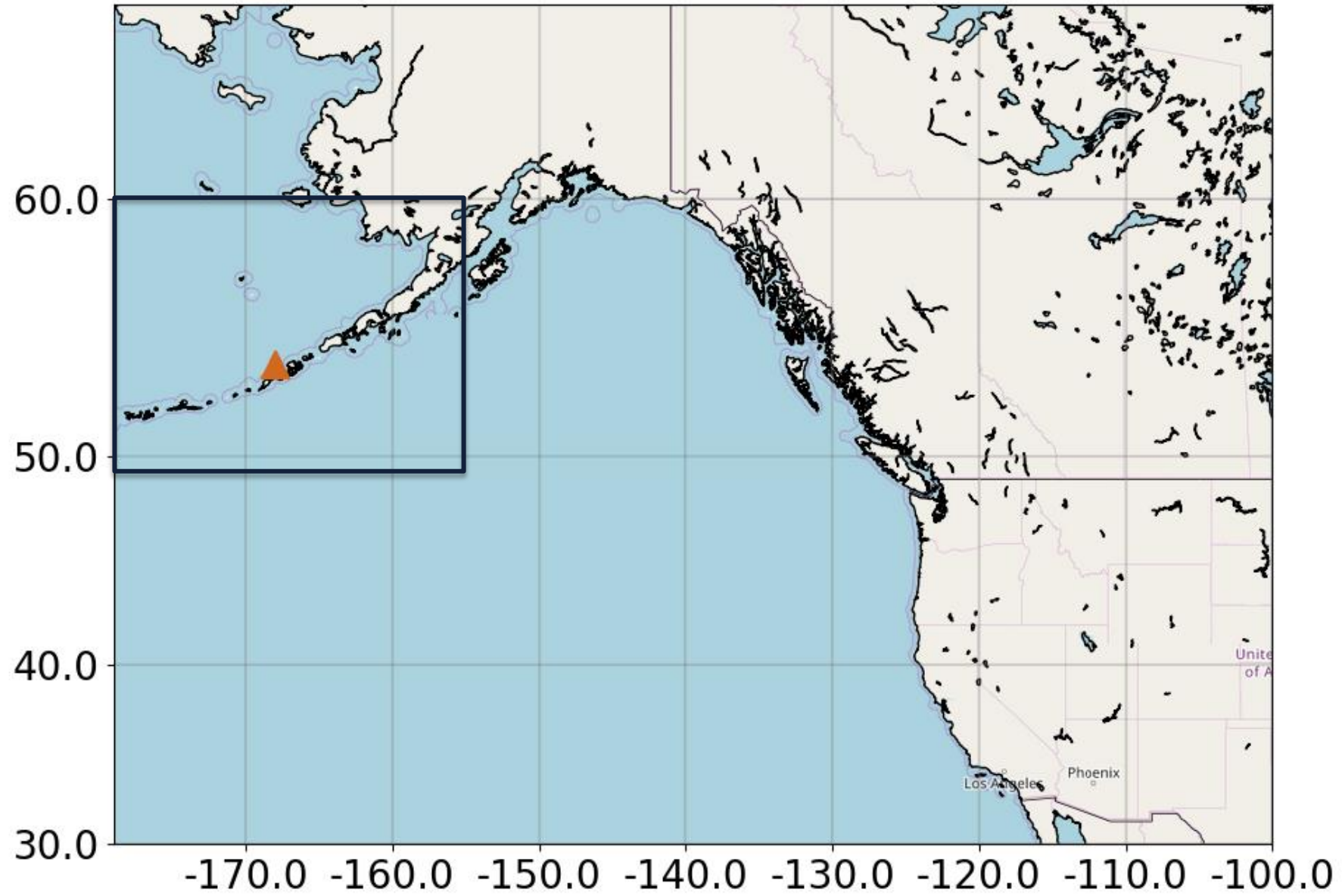
- Wideband E-field sensors (5 kHz – 10 MHz)
- Archive raw waveform data from each sensor.



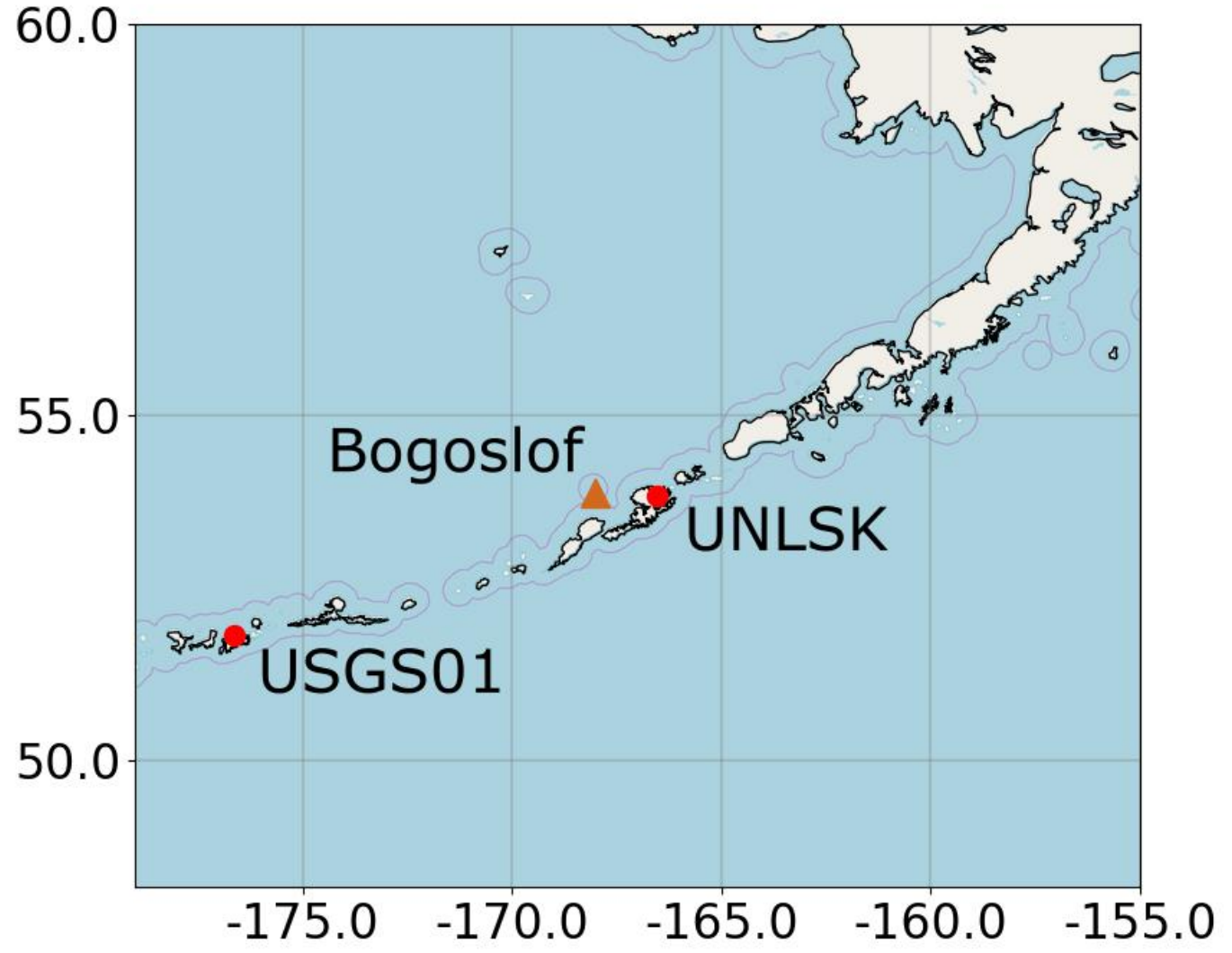
EARTH NETWORKS TOTAL LIGHTNING NETWORK (ENTLN)



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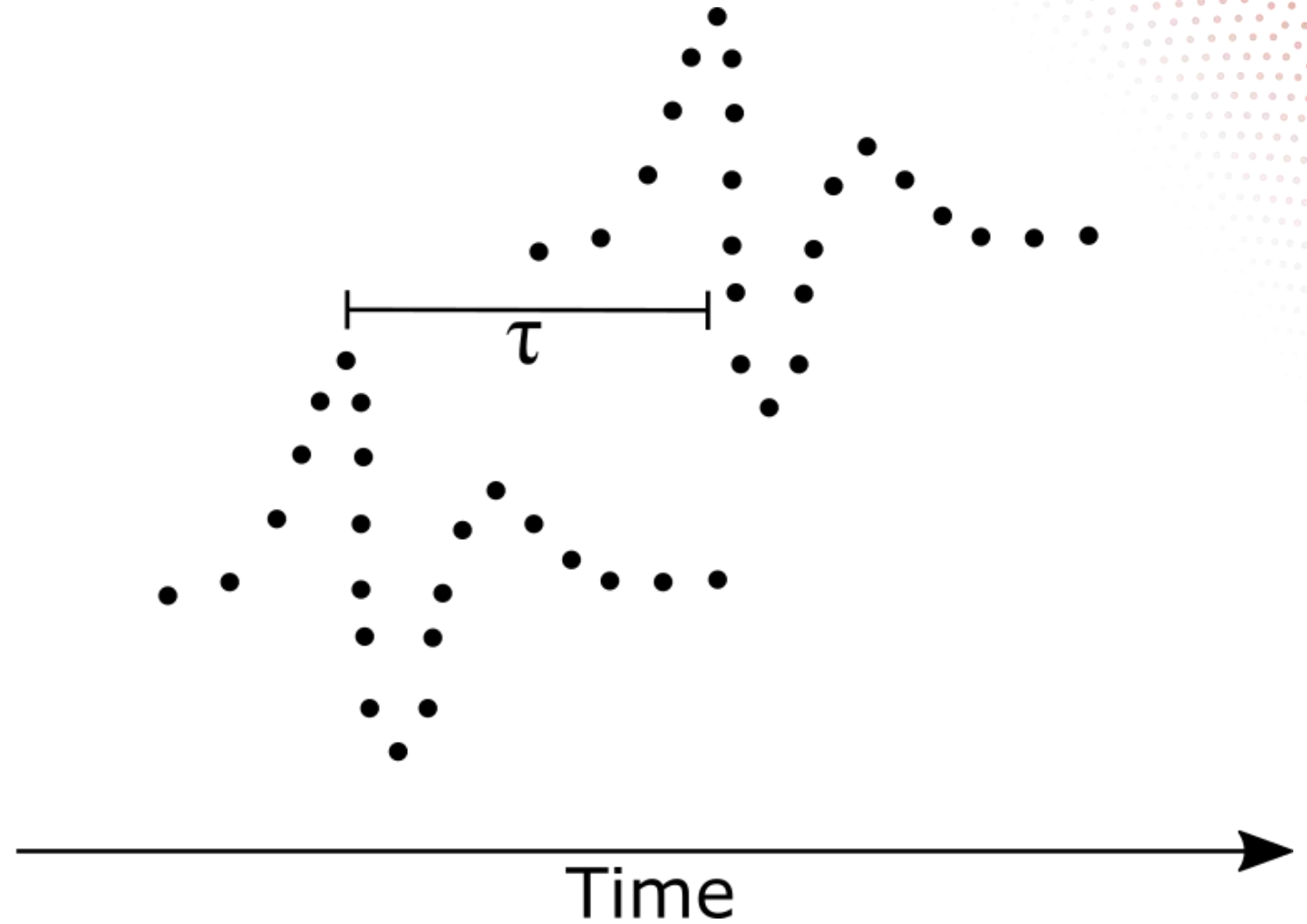


EARTH NETWORKS TOTAL LIGHTNING NETWORK (ENTLN)



CROSS-CORRELATION

$$X_c = \sum \frac{x(t) \times y(t - \tau)}{\sqrt{\sum x(t)^2} \sqrt{\sum y(t)^2}}$$



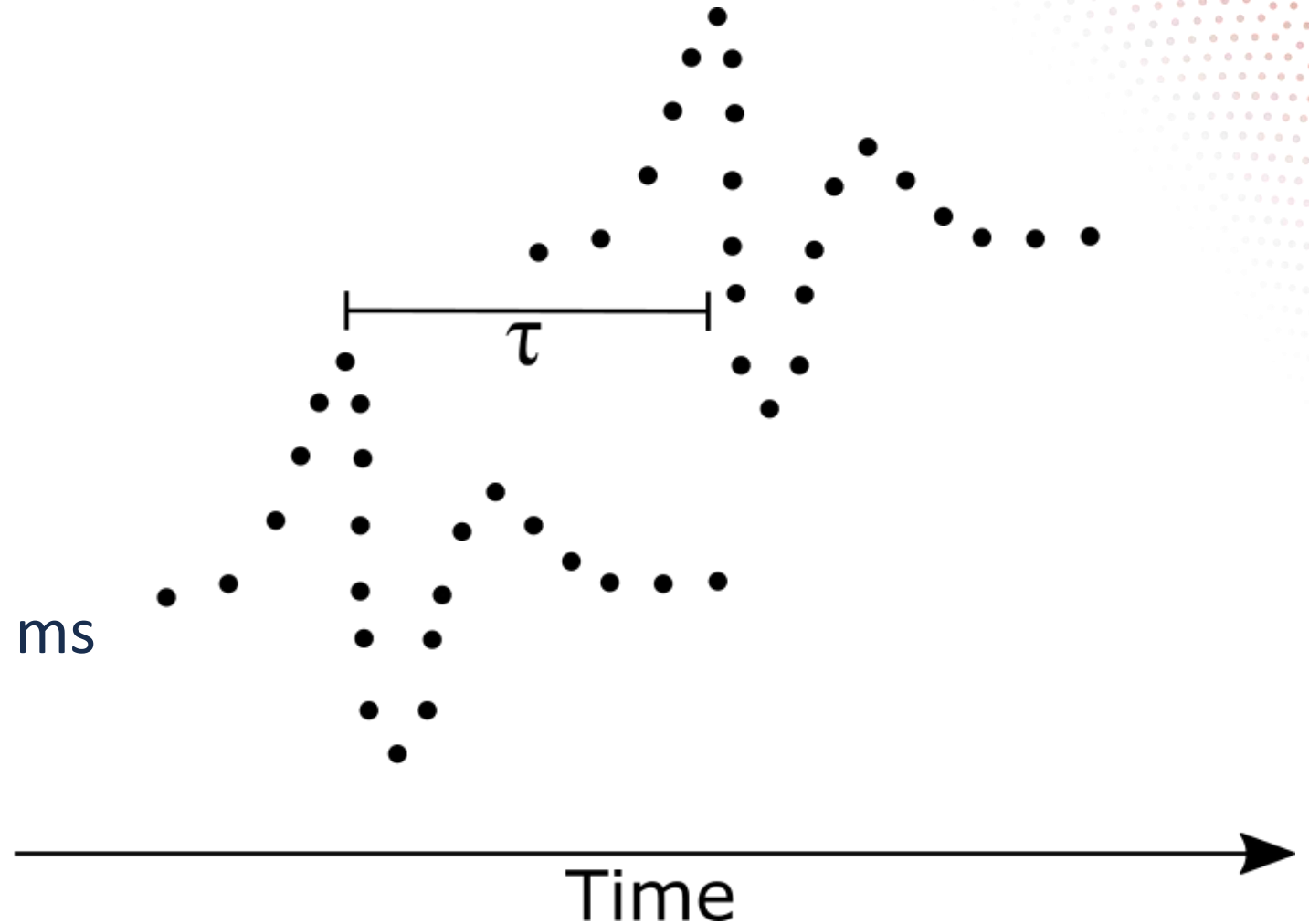
CROSS-CORRELATION

$$X_c = \sum \frac{x(t) \times y(t - \tau)}{\sqrt{\sum x(t)^2} \sqrt{\sum y(t)^2}}$$

UNLSK = 98 km
USGS01 = 622 km

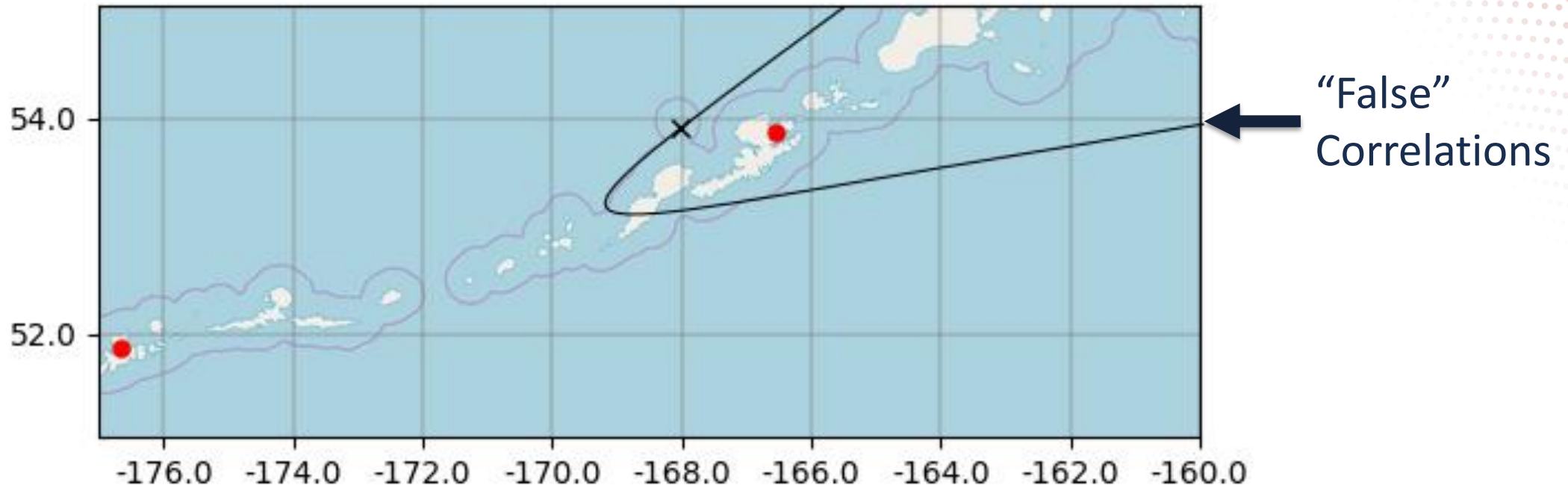


$\tau = 1.7$ ms



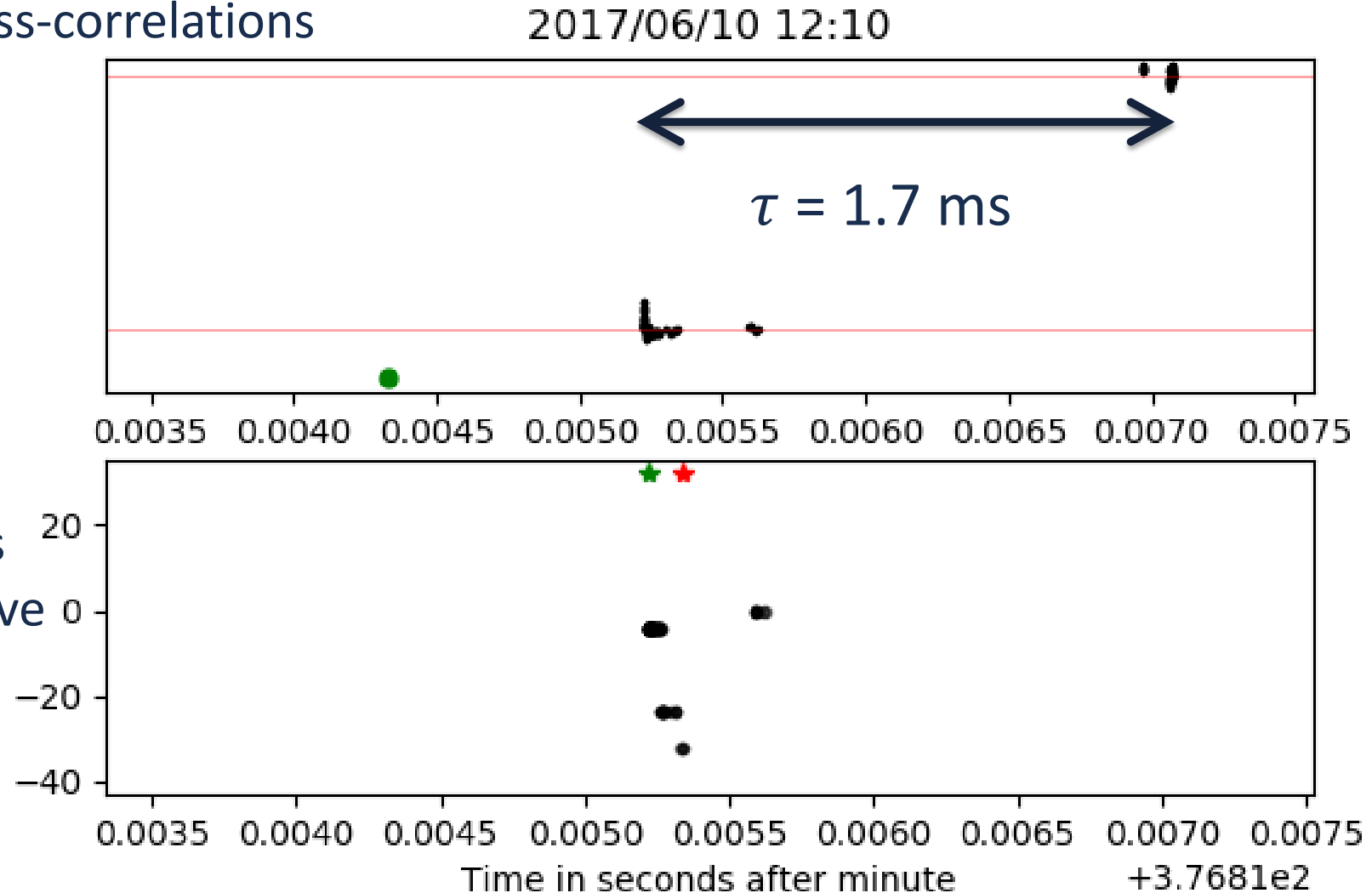
CROSS-CORRELATION: FALSE DETECTIONS

2 station TOA equation = Hyperbola

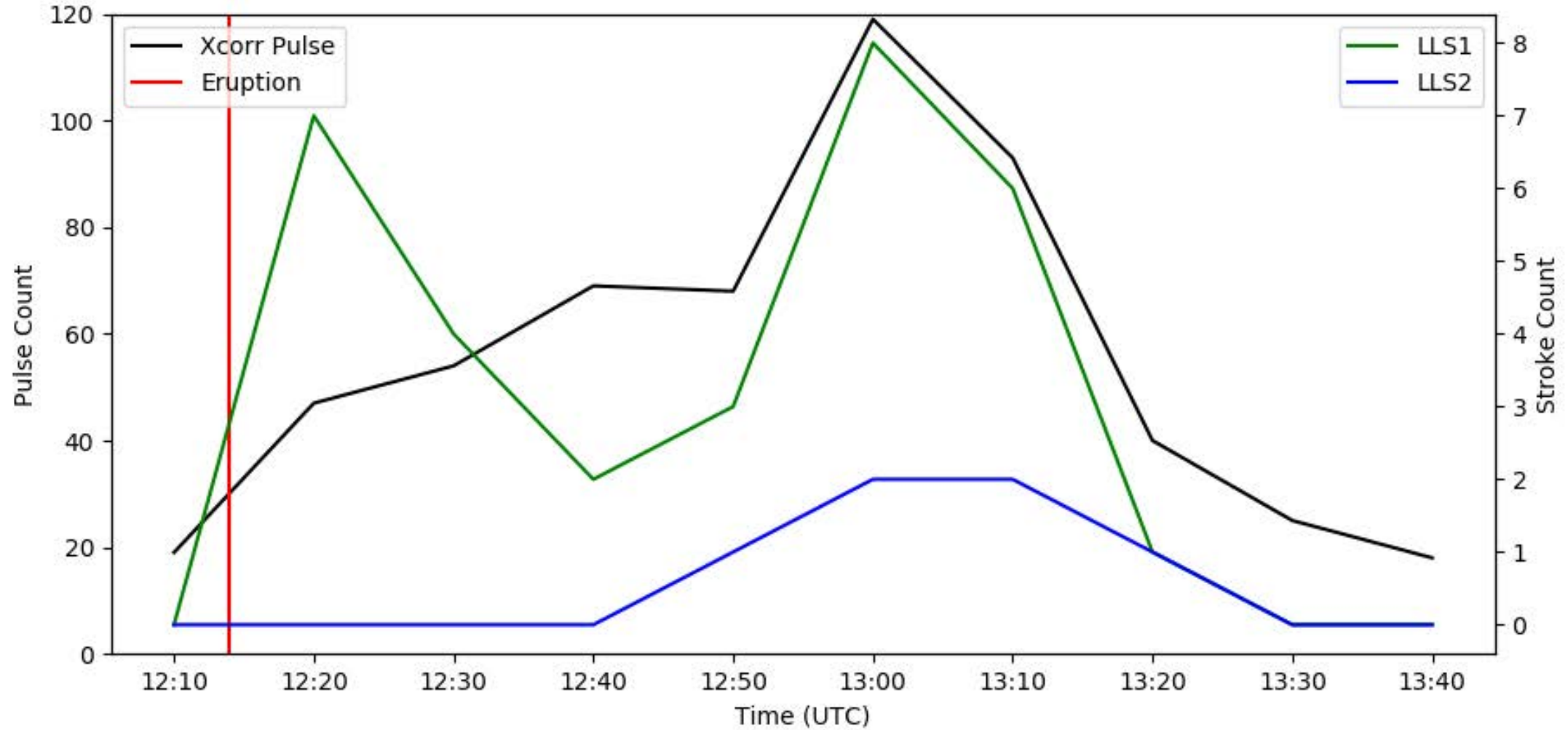


CROSS-CORRELATION: CLUSTERING

- “Pulse” \equiv cluster of high cross-correlations
- Threshold: $\sigma/2$
- At least 10 points and $66 \mu\text{s}$
- Less than 1 ms separation
- Duration of pulse: as long as the cross-correlation stays above the threshold

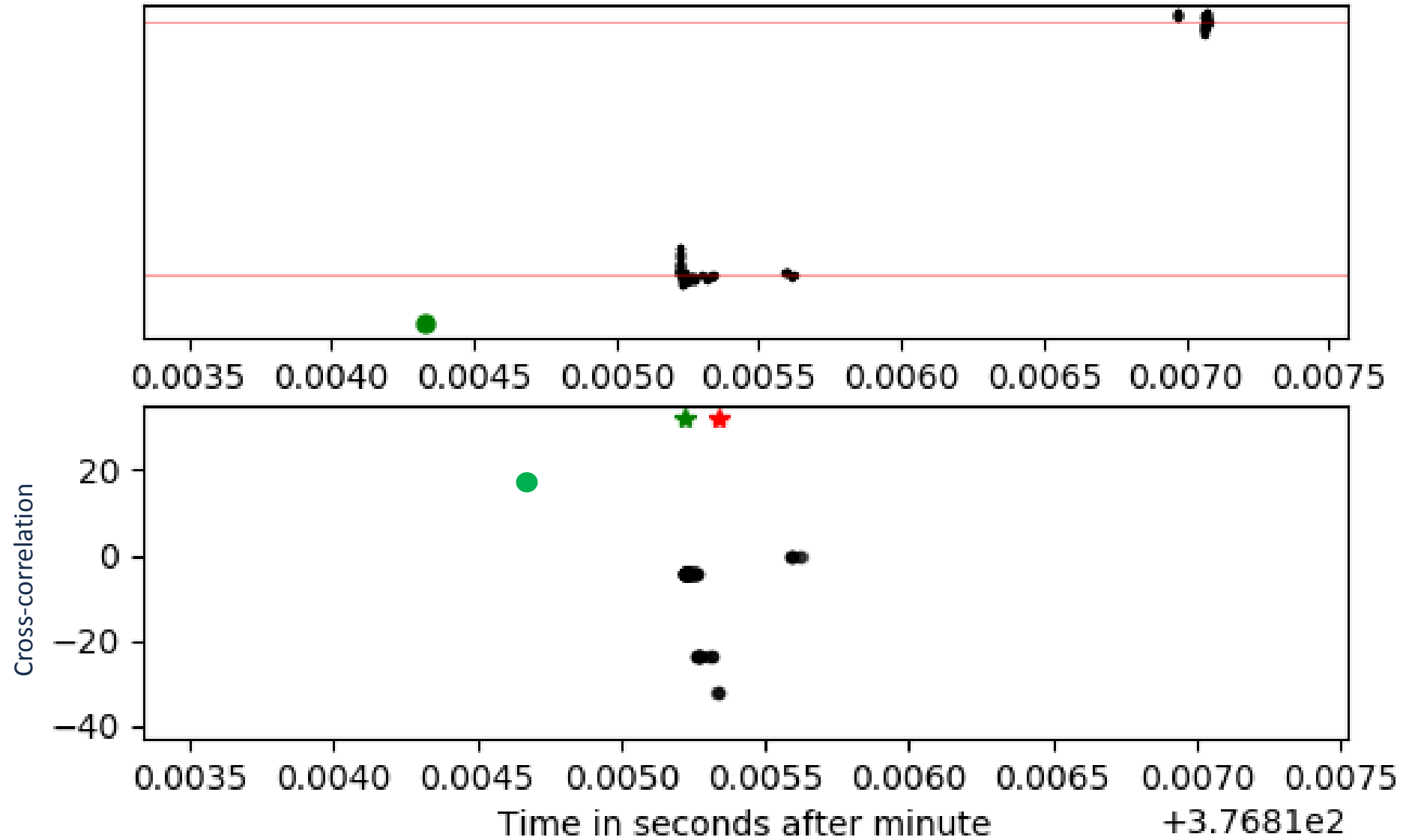


RESULTS: SUMMARY



MATCHING PULSES TO LLS STROKES

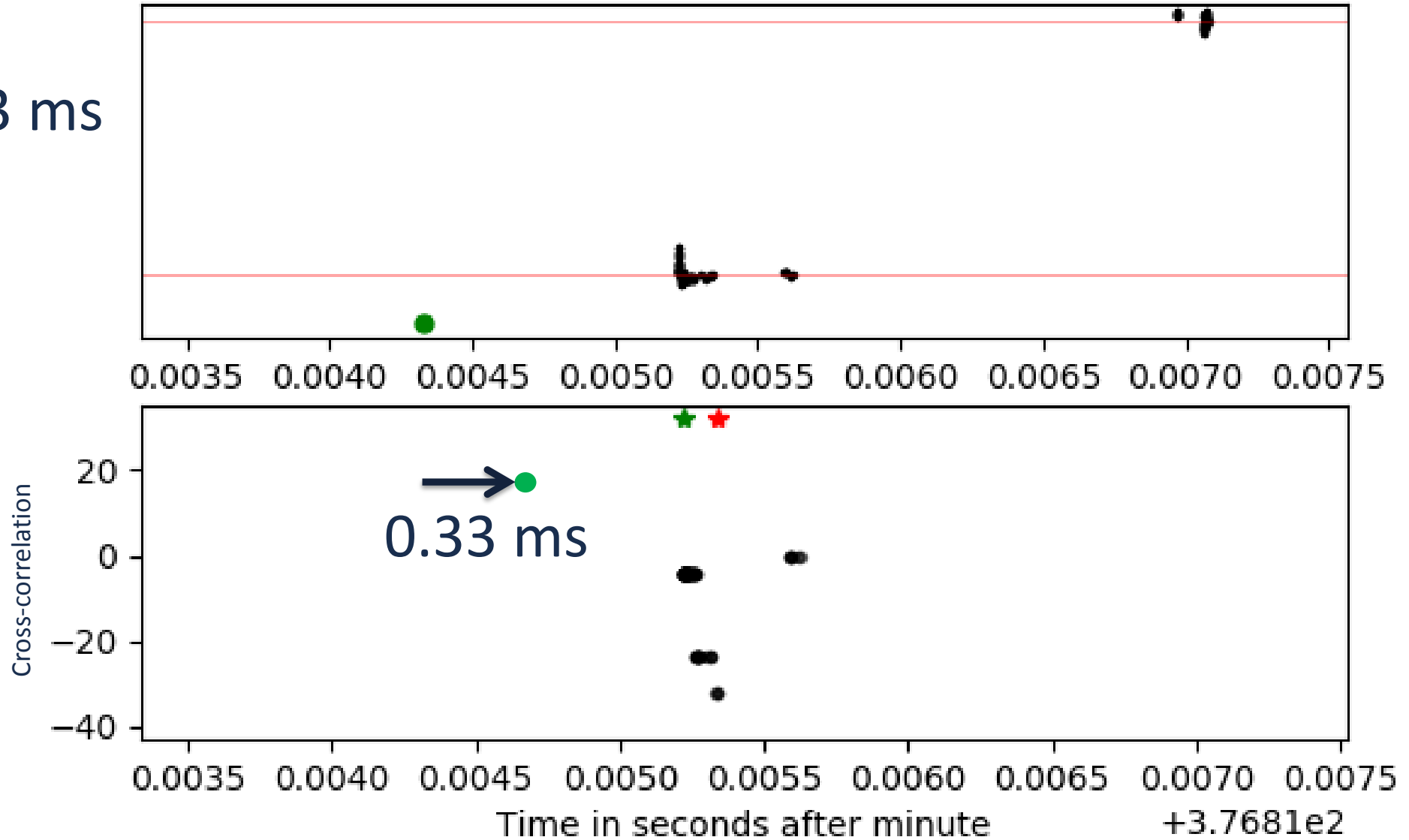
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MATCHING PULSES TO LLS STROKES

2017/06/10 12:10

98 km / c = 0.33 ms



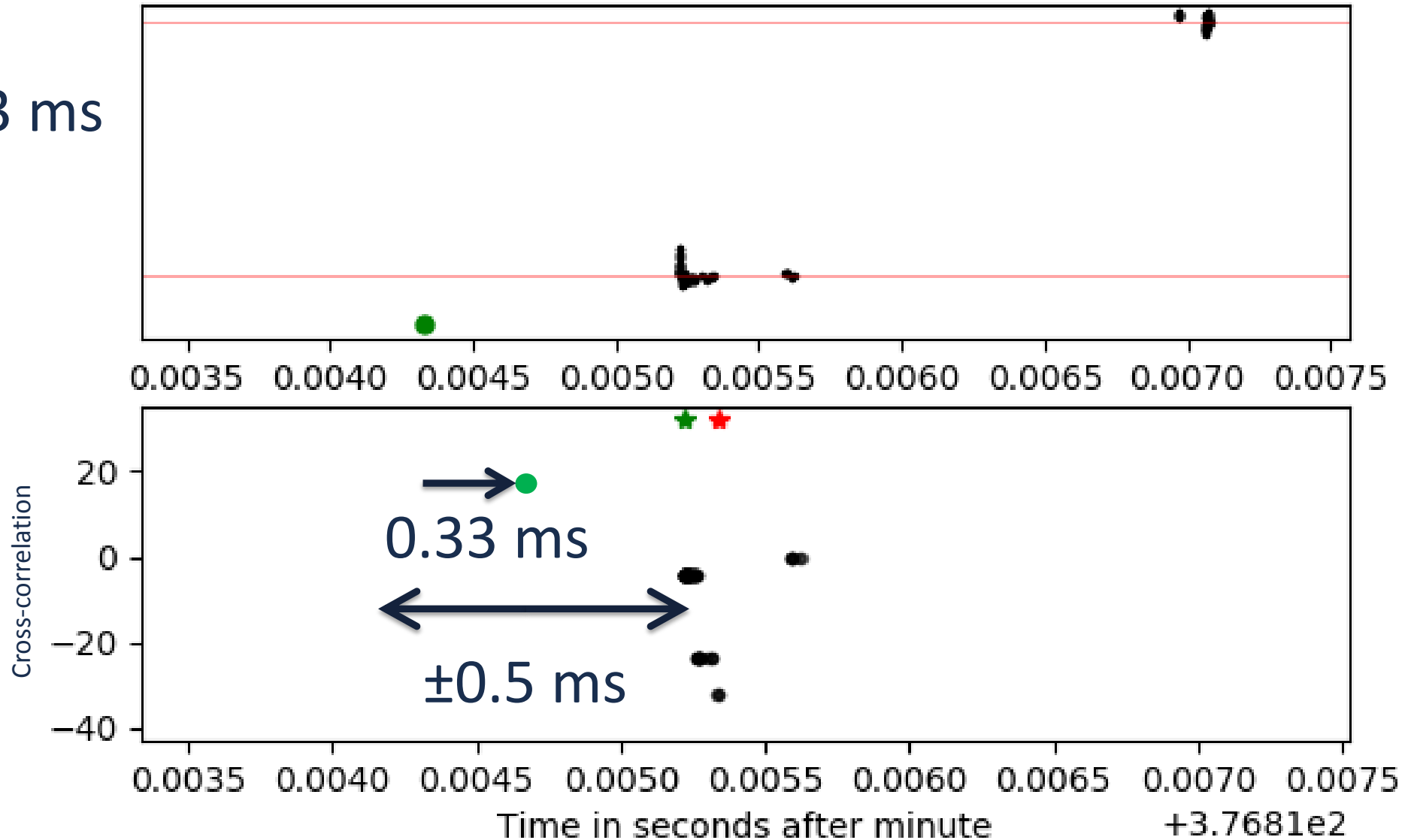
MATCHING PULSES TO LLS STROKES

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98 km / c = 0.33 ms

LLS1 = ± 0.5 ms

LLS2 = ± 0.5 s



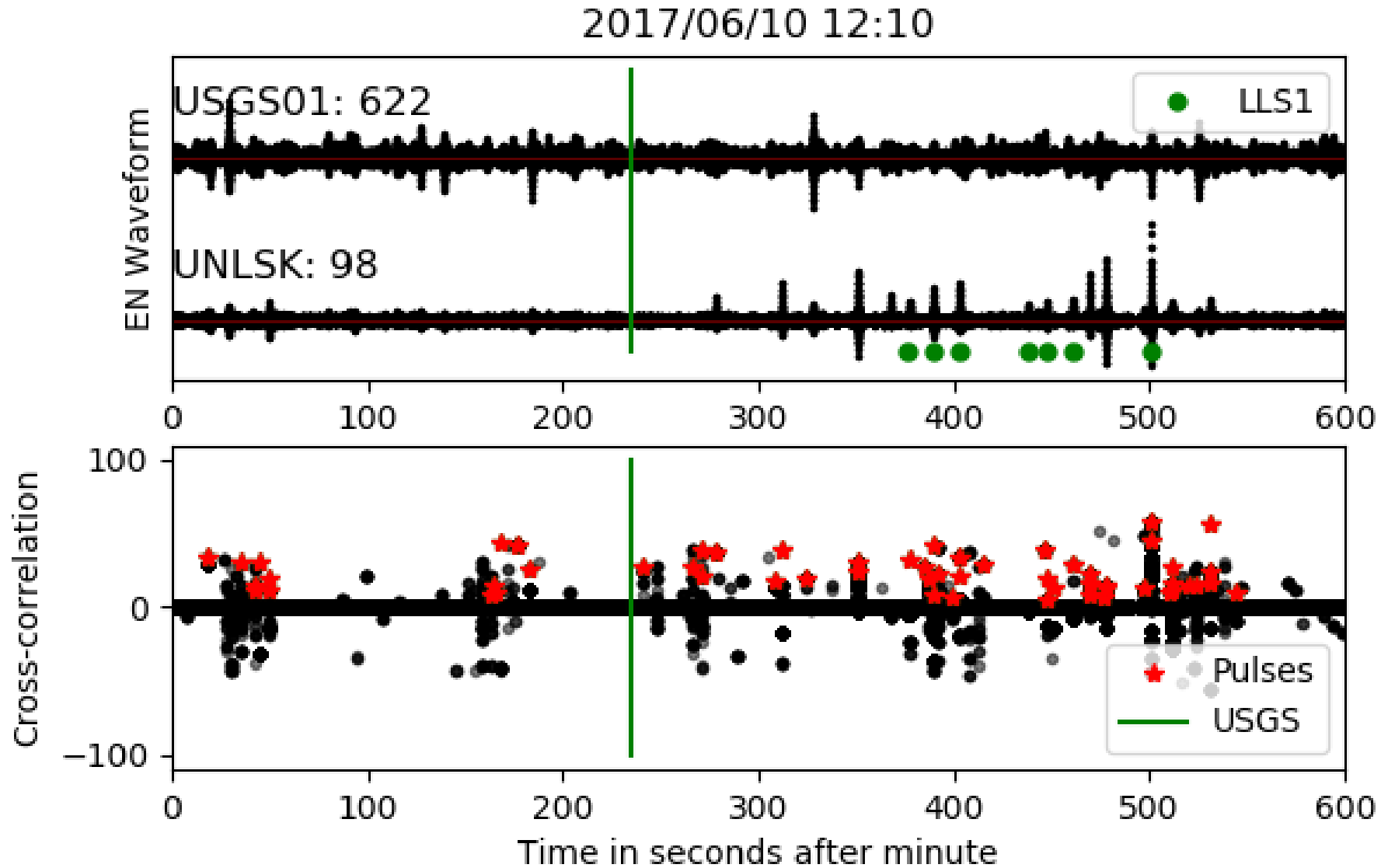
RESULTS: SUMMARY

Time (UTC)	LLS1 Stroke	LLS1 Match	LLS2 Stroke	LLS2 Match	Pulses (this method)
12:10	0	0	0	0	19
12:20	7	6	0	0	47
12:30	4	3	0	0	54
12:40	2	2	0	0	69
12:50	3	3	1	1	68
13:00	8	6	2	2	119
13:10	6	5	2	2	93
13:20	1	1	1	1	40
13:30	0	0	0	0	25
13:40	0	0	0	0	18
Total	31	26	6	6	552

84% DE

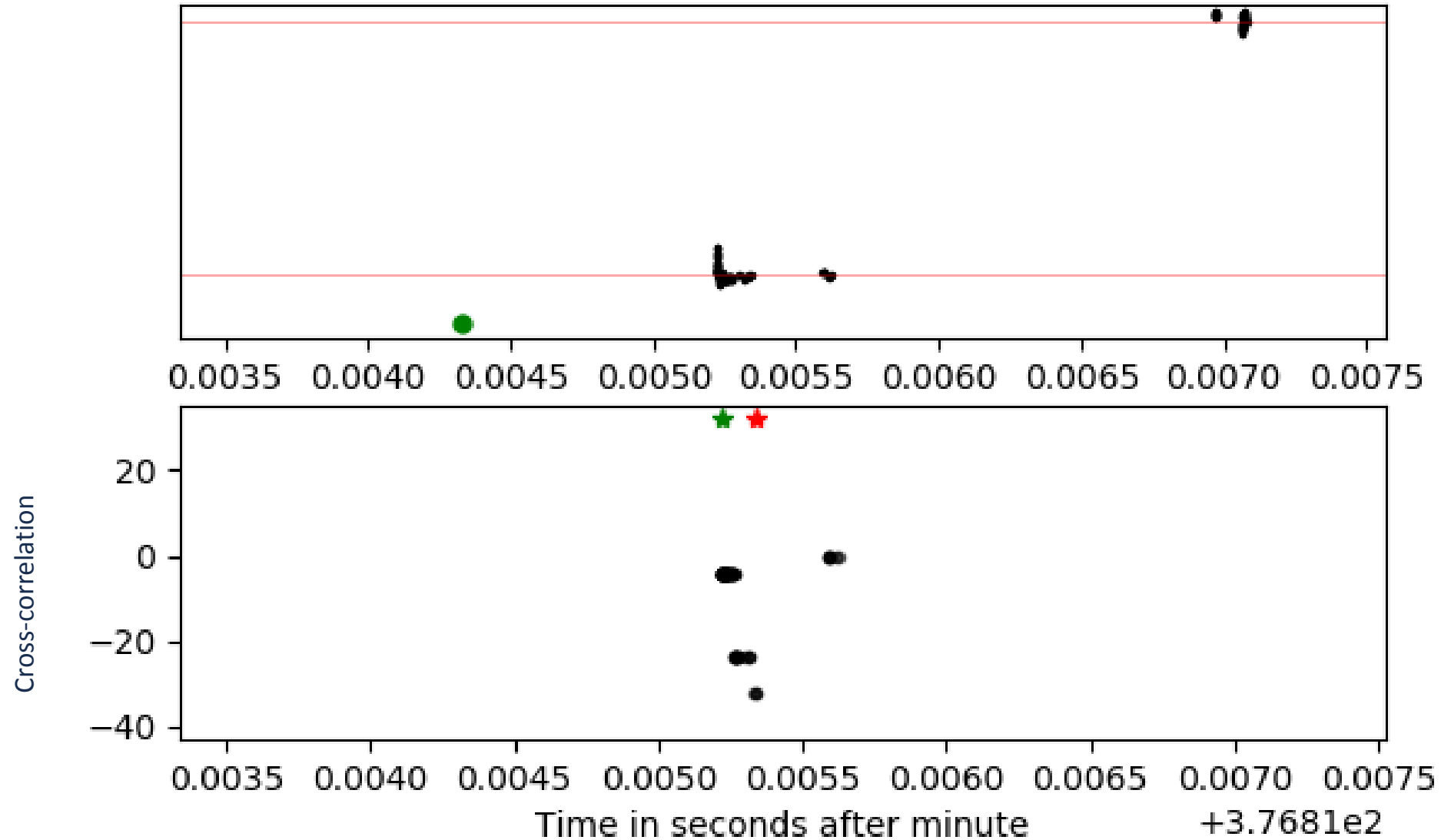
100% DE

RESULTS: SUMMARY

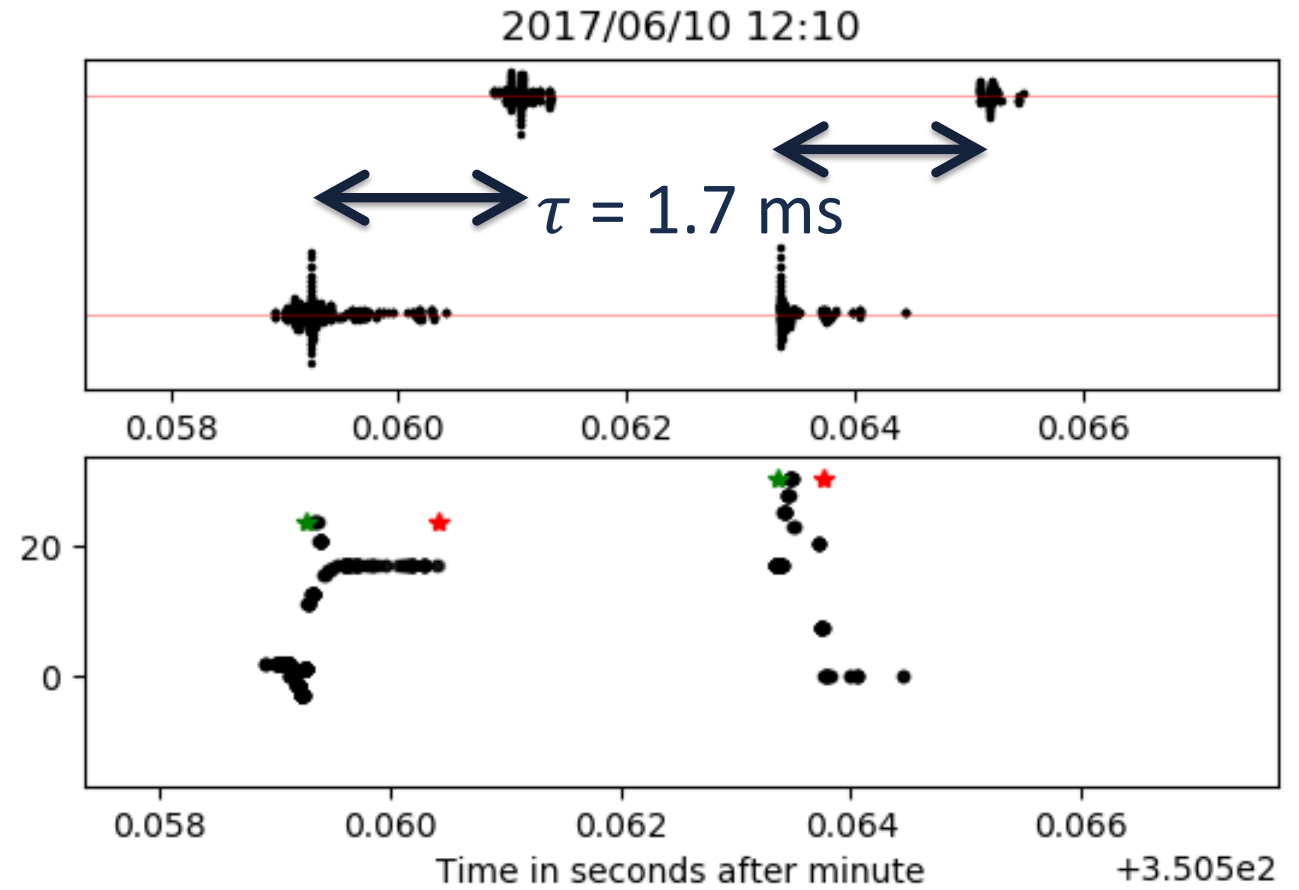
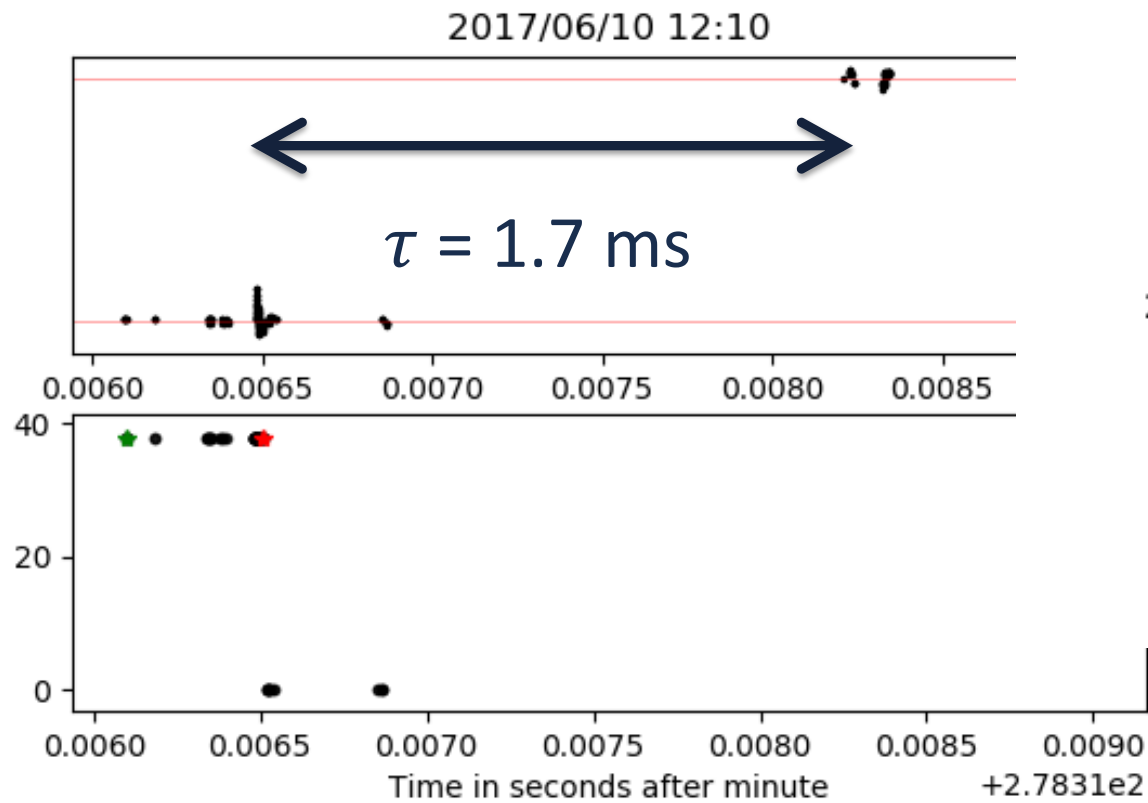


RESULTS: STROKE AND PULSE

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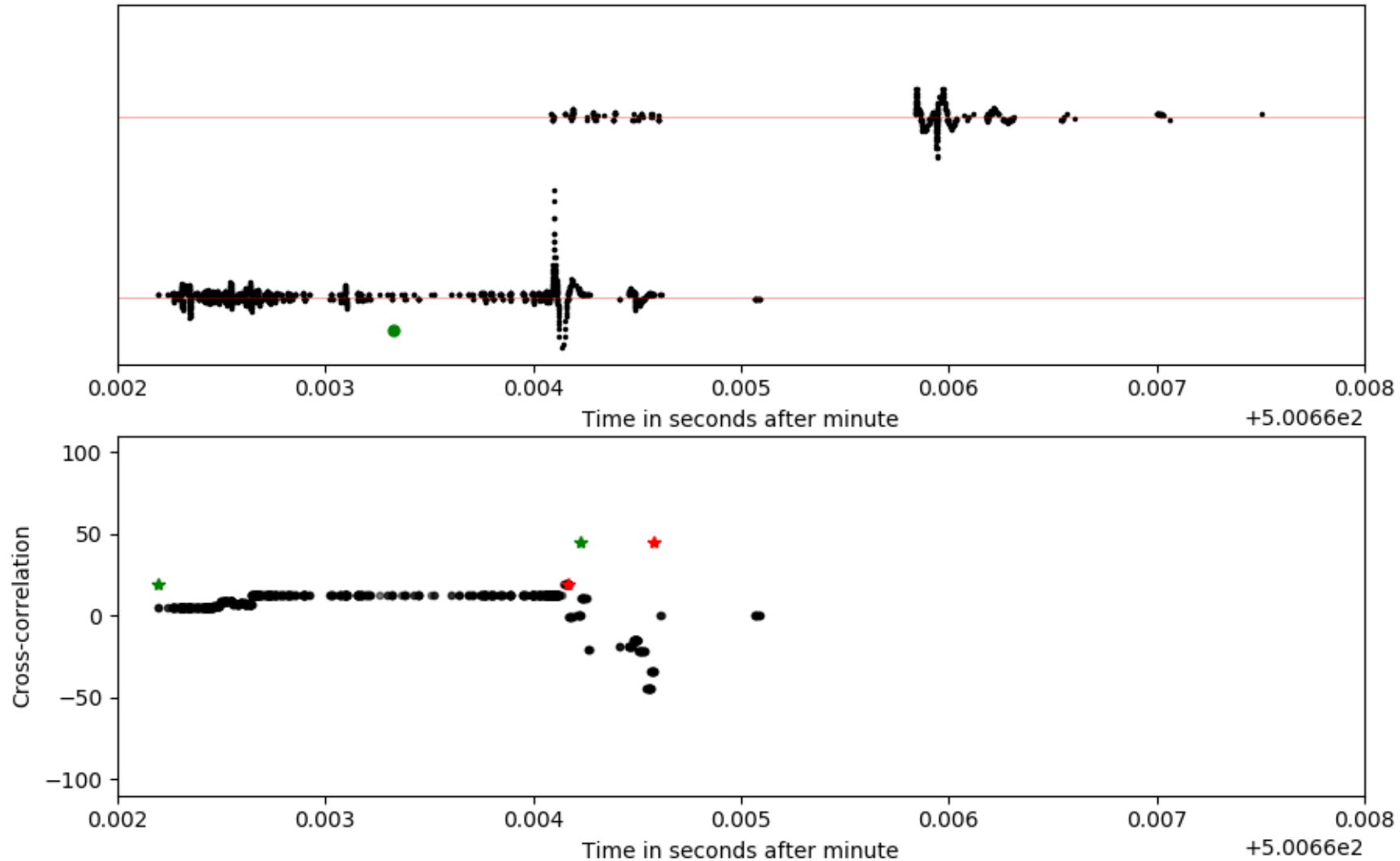


RESULTS: PULSE, BUT NO STROKE



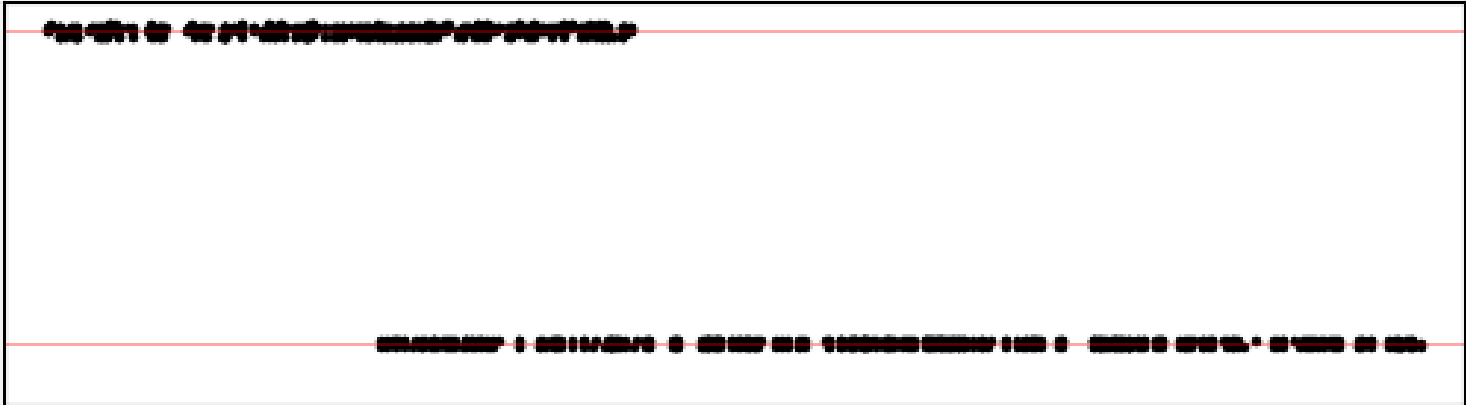
RESULTS: DOUBLE COUNTING

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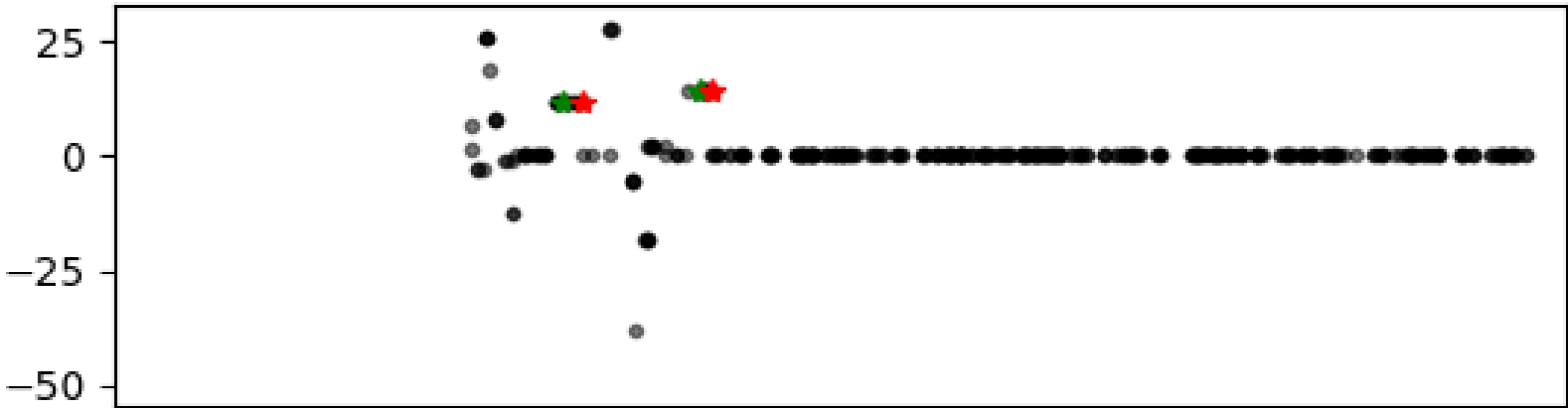


RESULTS: FALSE ALARM FROM NOISE

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42.20 42.25 42.30 42.35 42.40 42.45

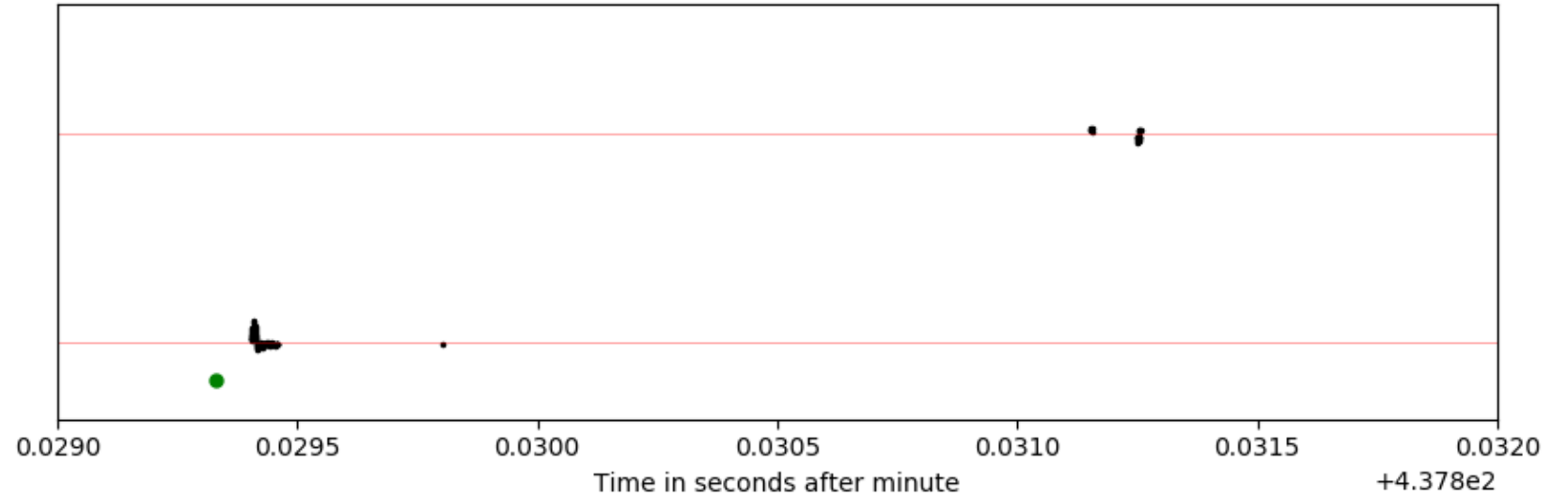


42.20 42.25 42.30 42.35 42.40 42.45

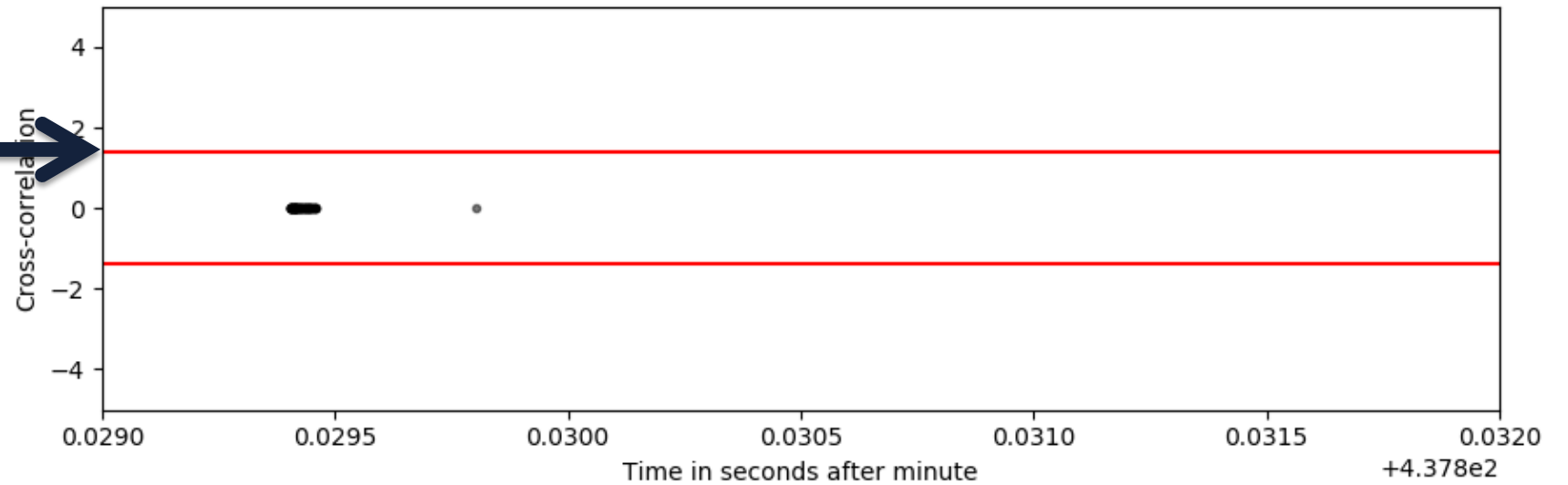
Time in seconds after minute

RESULTS: STROKE, BUT NO PULSE

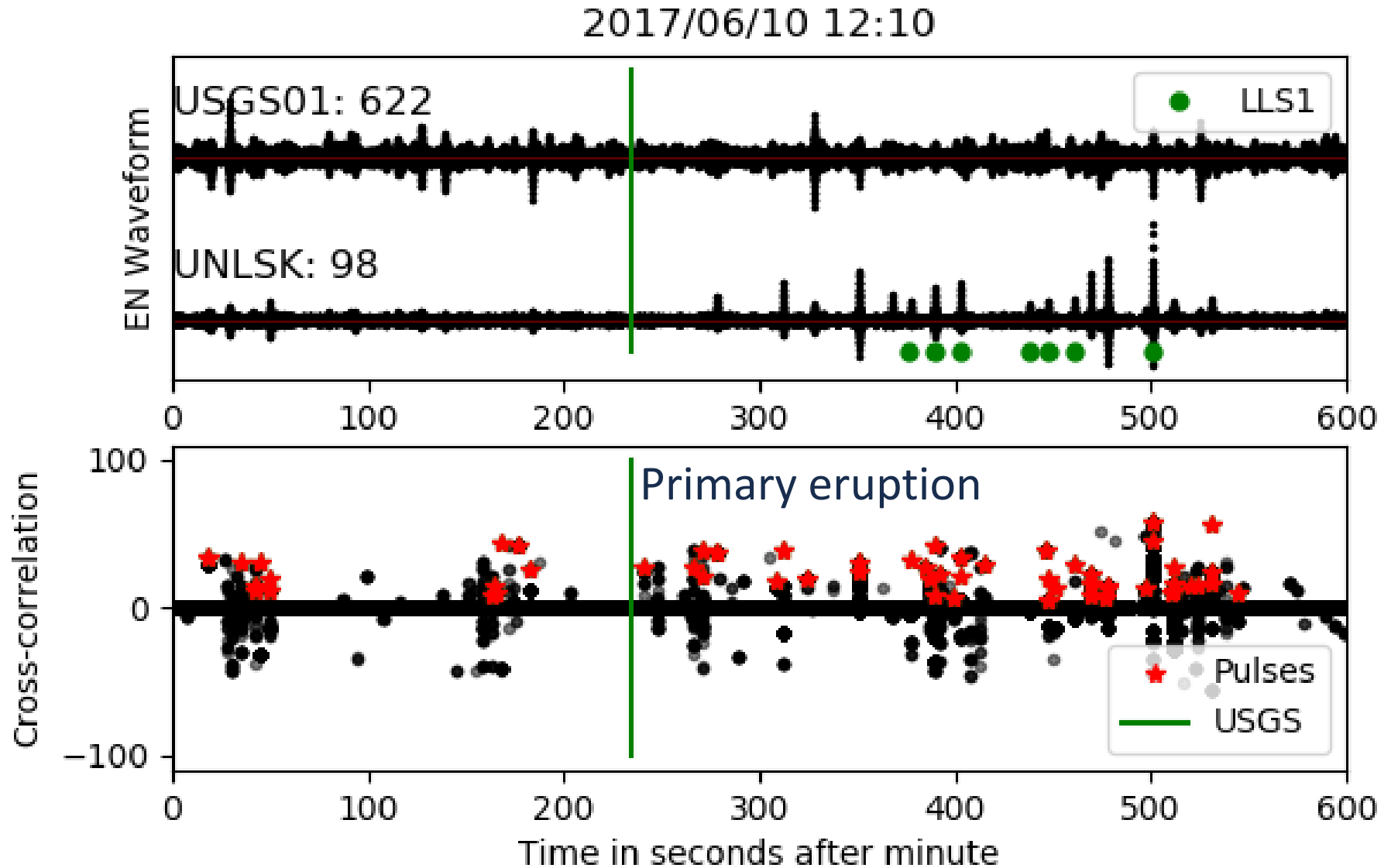
2017/06/10 12:10



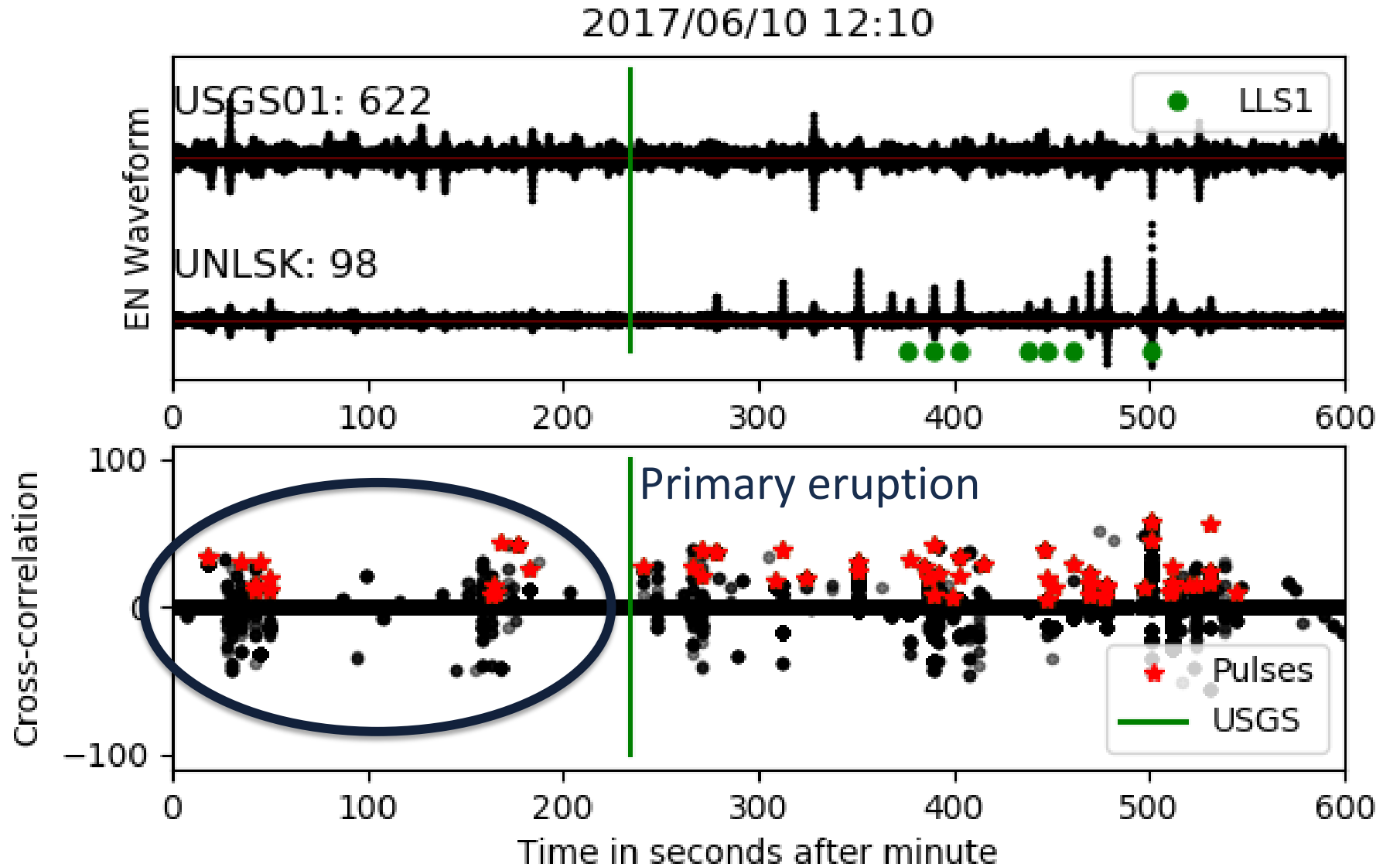
Threshold = 1.4



RESULTS: PULSES BEFORE THE ONSET OF SEISMIC ACTIVITY



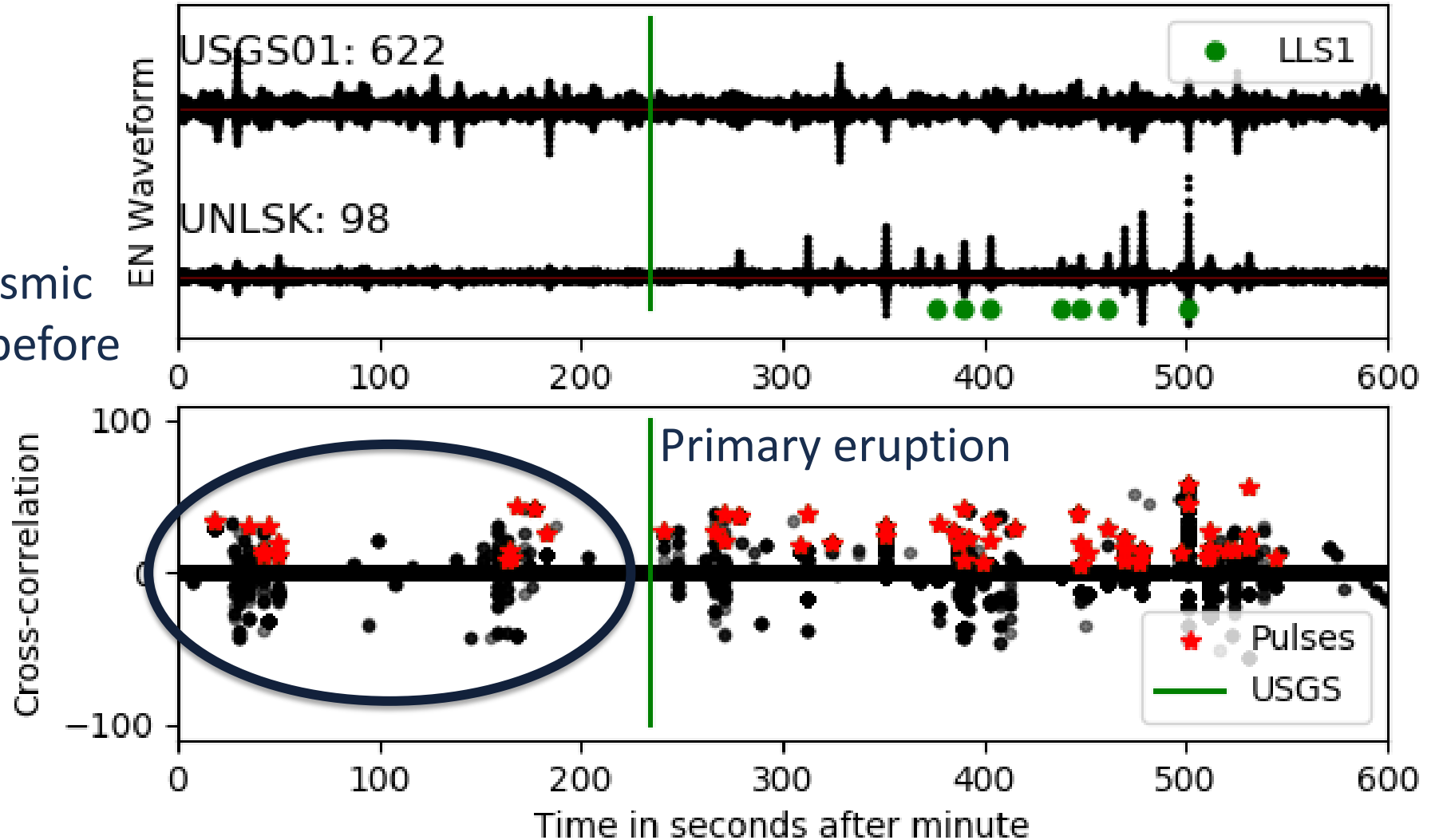
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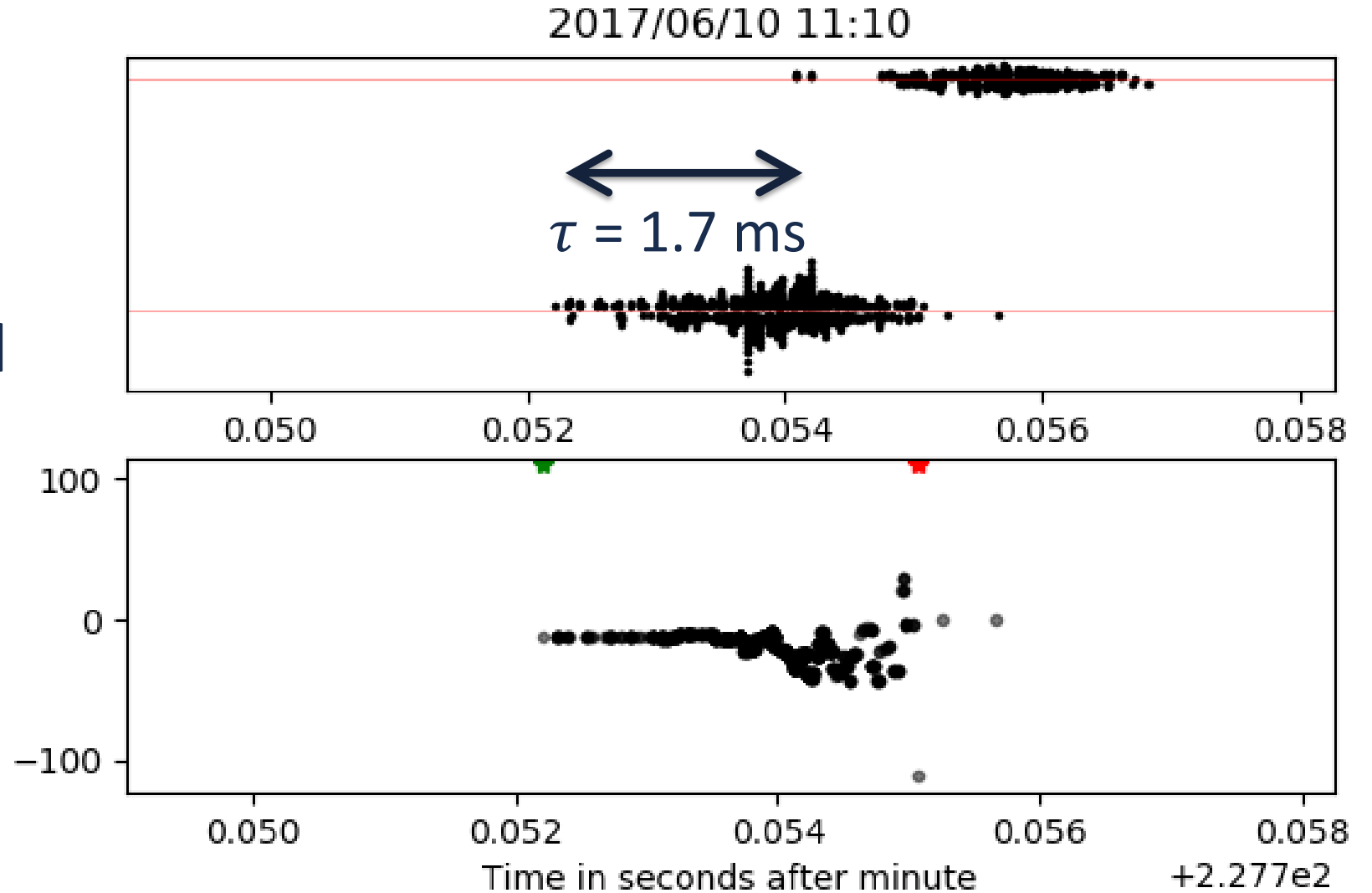
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Evidence of unusual seismic occurring for ~2 hours before the primary eruption



RESULTS: PULSES BEFORE THE ONSET OF SEISMIC ACTIVITY

> 1 hour before the primary eruption and any LLS detections!



SUMMARY

- Developed a new lightning detection technique using only two sensors
- Leverages the ENTLN waveforms to apply a cross-correlation for a known location
- Detection Efficiency (compared to LLS strokes) > 80%
- Detects many events that are missed by LLS, even > 1 hour before the first LLS detection!
- Need to work on reducing false alarms.



THANK YOU

QUESTIONS AND COMMENTS?