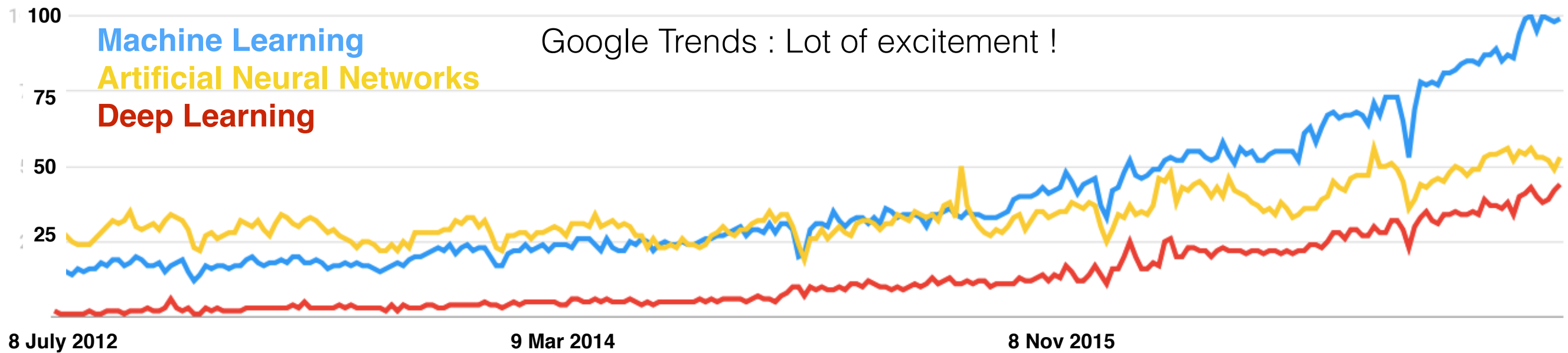


Machine Learning in
Characterization and Commissioning
@ GW Detectors

NIKHIL MUKUND MENON
IUCAA PUNE

GOLDEN AGE OF MACHINE LEARNING



@LIGO



System Identification

Transient Classification

Lockloss Monitoring

Intelligent Search Engine

Earthquake Lockloss Prediction

Control loop optimization

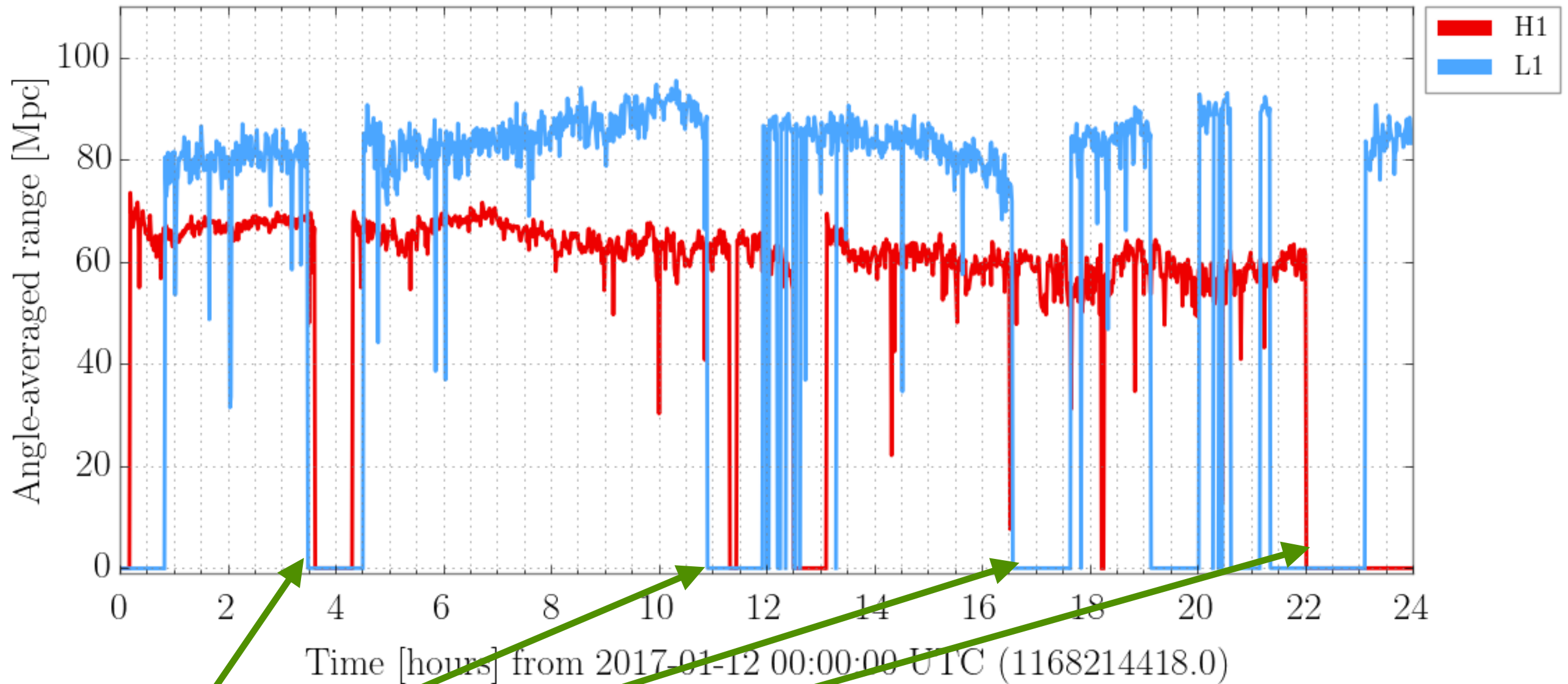
Noise Subtraction

Monitoring Lock-losses at Sites

LOCKLOSS MONITOR GOAL: MAXIMIZE IFO UPTIME

N. Mukund, A. Pele, J. Betzwieser, A. Mullavey, M. Kasprzack, S. Kandhasamy, S. Aston, J. Romie, B.O. Reilly, S. Mitra

LIGO binary neutron star inspiral range



Locklosses

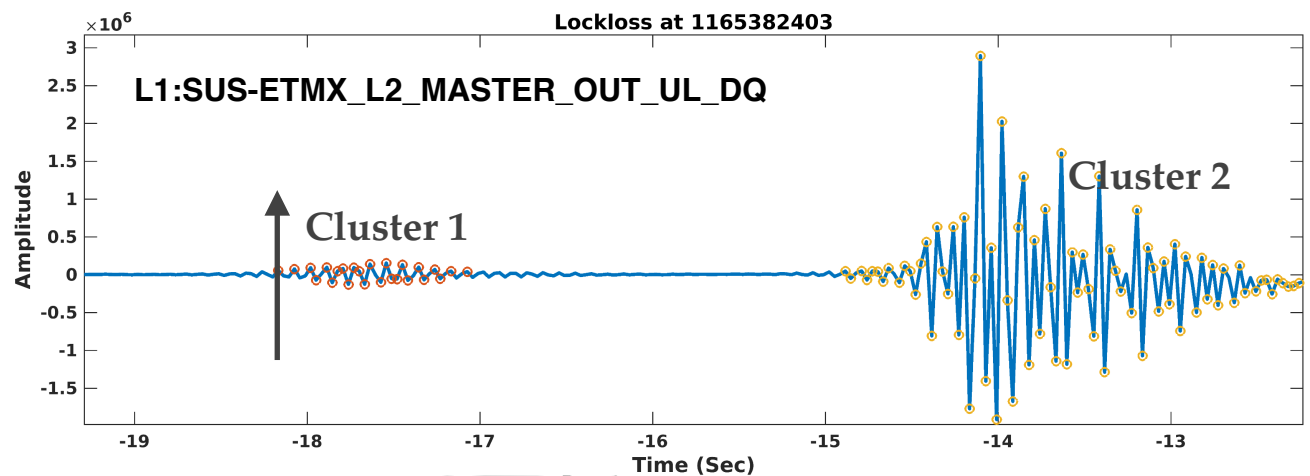
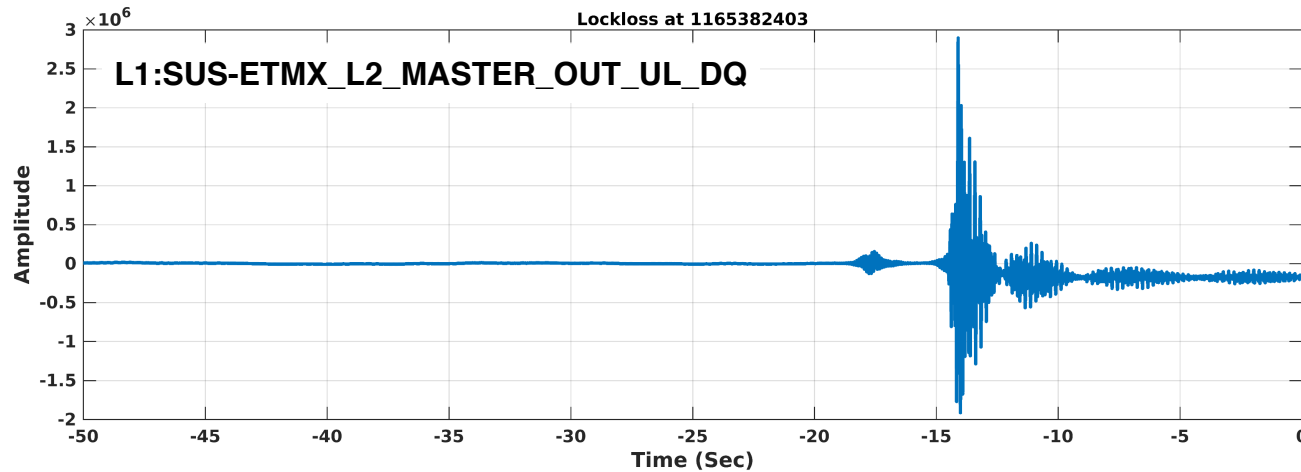
What triggered these lock-losses ?

DENSITY BASED SPATIAL CLUSTERING

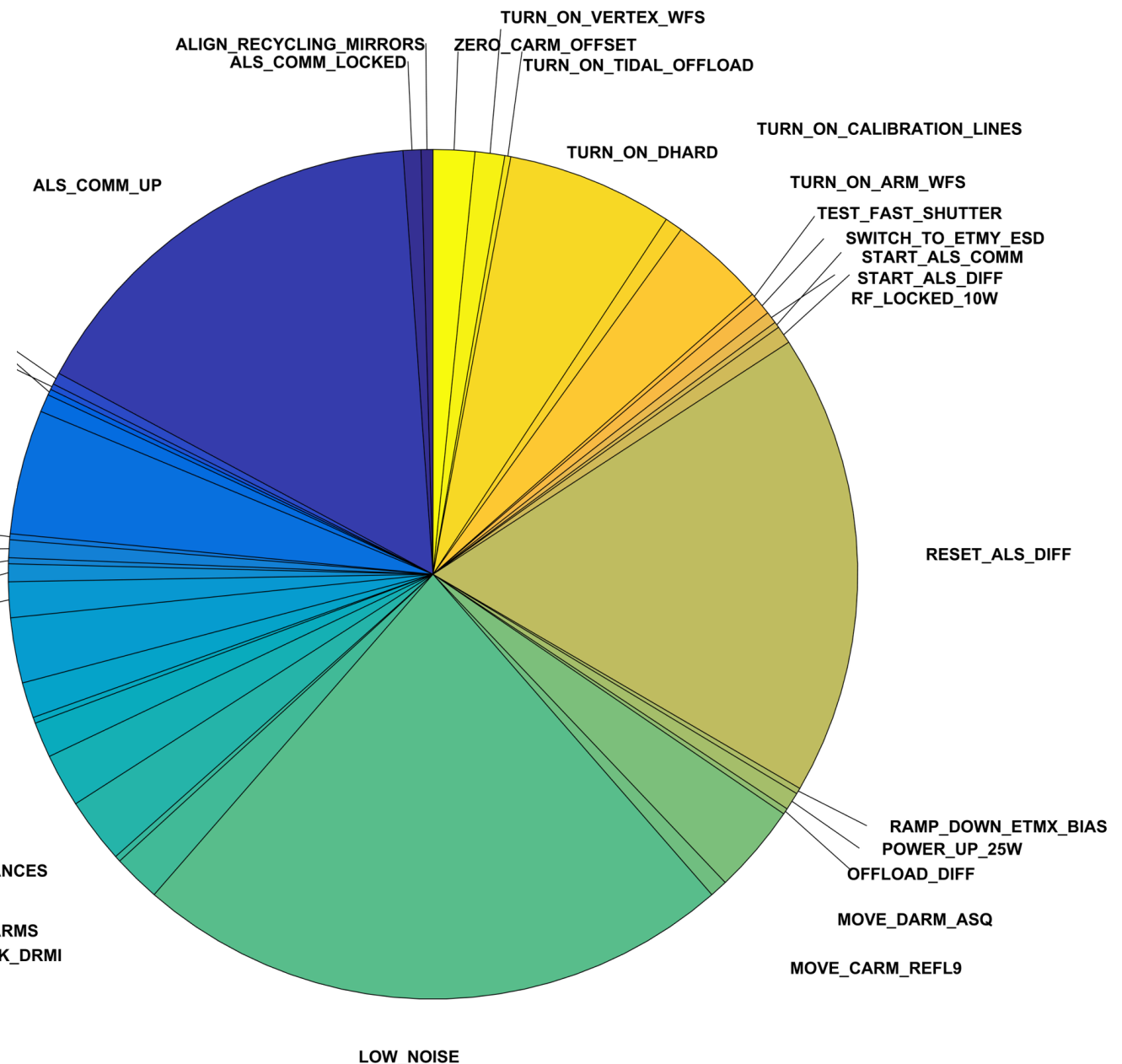
APPLICATIONS WITH NOISE

Identify the channels linked with the LOCKLOSS

<https://dcc.ligo.org/LIGO-G1602442>



LL0 O2A All Locklosses



Procedure

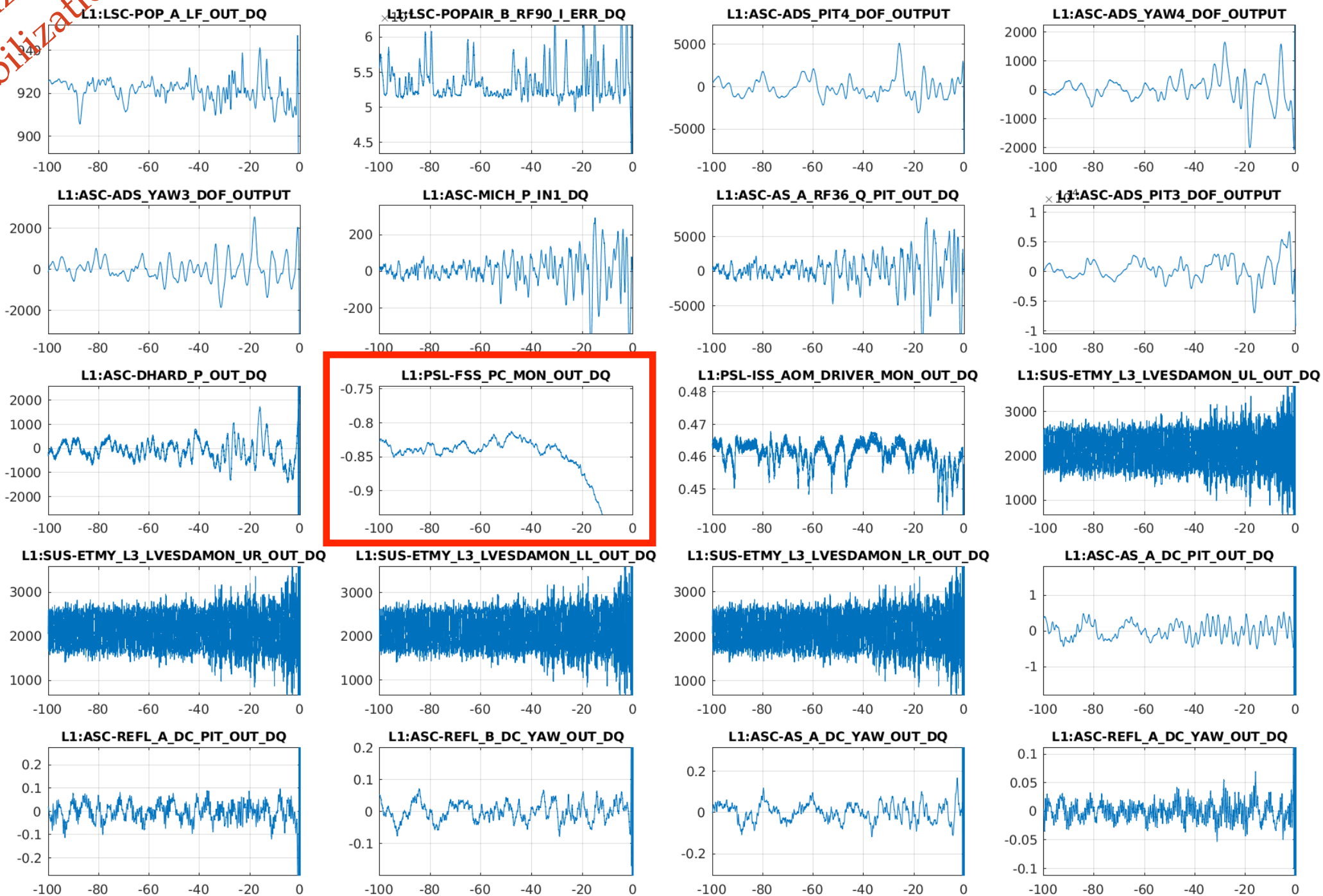
- Envelope Extraction
- Median based thresholding
- Trigger/Oscillation Identification
- Density based clustering
- Identifying Significant Clusters
- Select Cluster 1 start time
- Rank channels based on trigger time
- Generate Plot/Table → HTML file

Best Guess: Results

Identify the channel that lead to LOCKLOSS

“Pre Stabilized Laser
Frequency Stabilization Servo!!!”

LOCKLOSS MONITOR RESULTS
LOW_NOISE to LOCKLOSS at GPS 1167654616

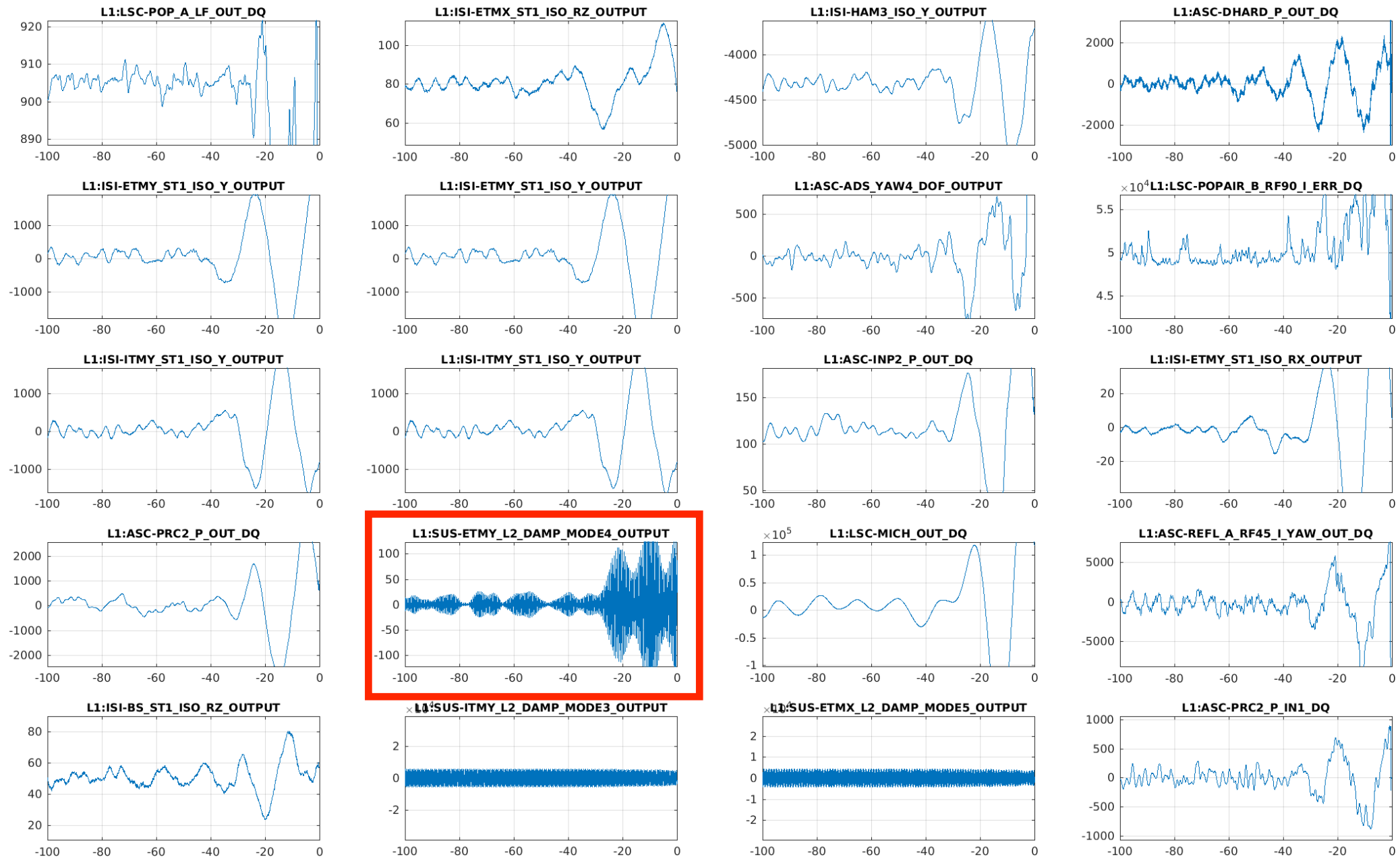


Best Guess: Results

Identify the channel that lead to LOCKLOSS

“Earthquake !!!”

LOCKLOSS MONITOR RESULTS
LOW_NOISE to LOCKLOSS at GPS 1165769597

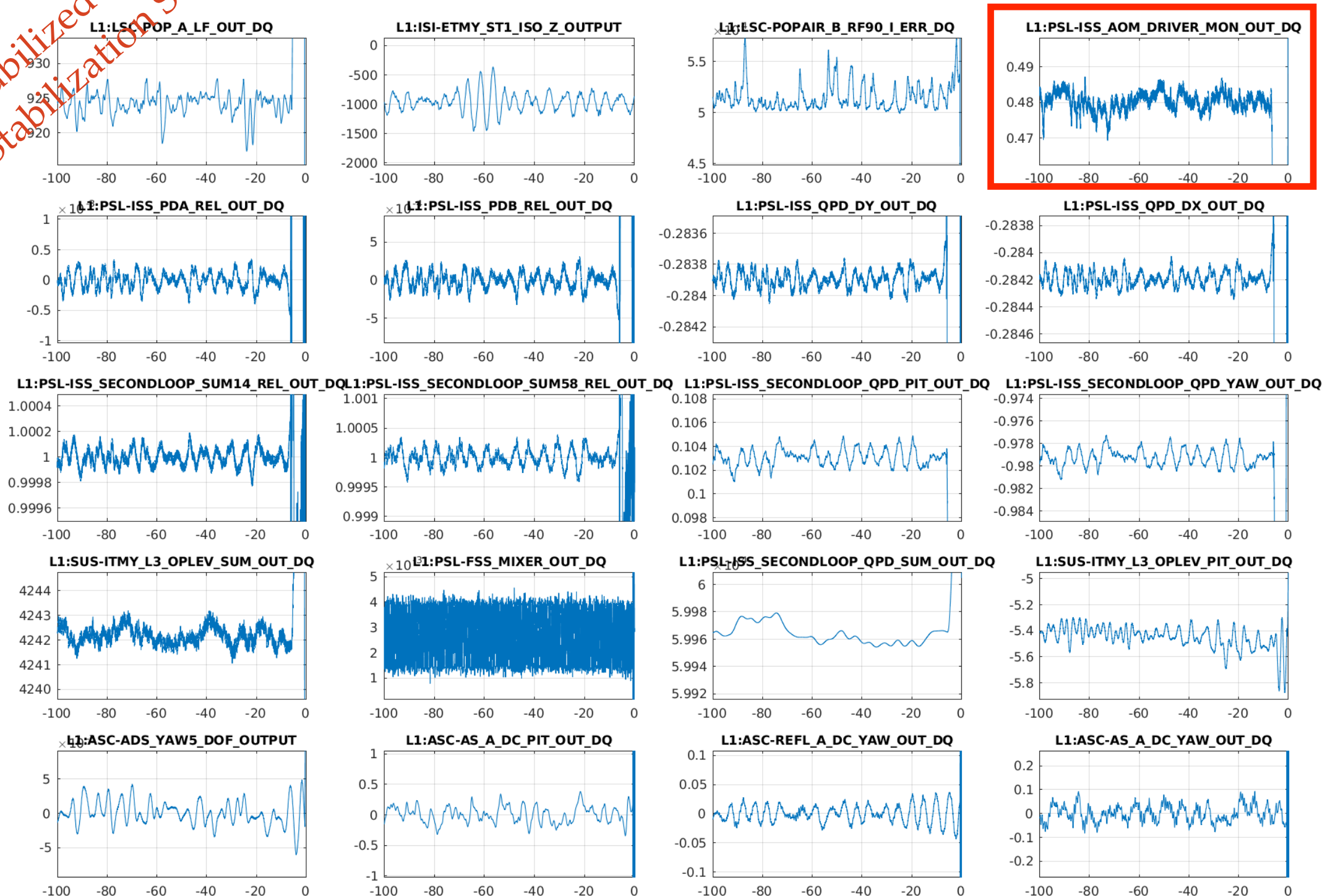


Best Guess: Results

*“Pre Stabilized Laser
Intensity Stabilization Servo!!!”*

Identify the channel that lead to LOCKLOSS

LOCKLOSS MONITOR RESULTS
LOW_NOISE to LOCKLOSS at GPS 1168445956



ML Based Recommendation System

MOTIVATION

Commissioning Perspective

- Issues within a detector are often seen to reappear
- LLO-LHO-Virgo-GEO : Can benefit from each others wisdom
- Current GW search engines are not smart enough
- Fast & accurate knowledge discovery saves time & resource

Detector Characterization Perspective

- Better understand the status of the instrument
- Identify the right person to contact
- Understand trends within or among the detectors
- Bridge the gap btw on-site work & off-site data analysis

Project "Hey LIGO"

heyligo.gw.iucaa.in

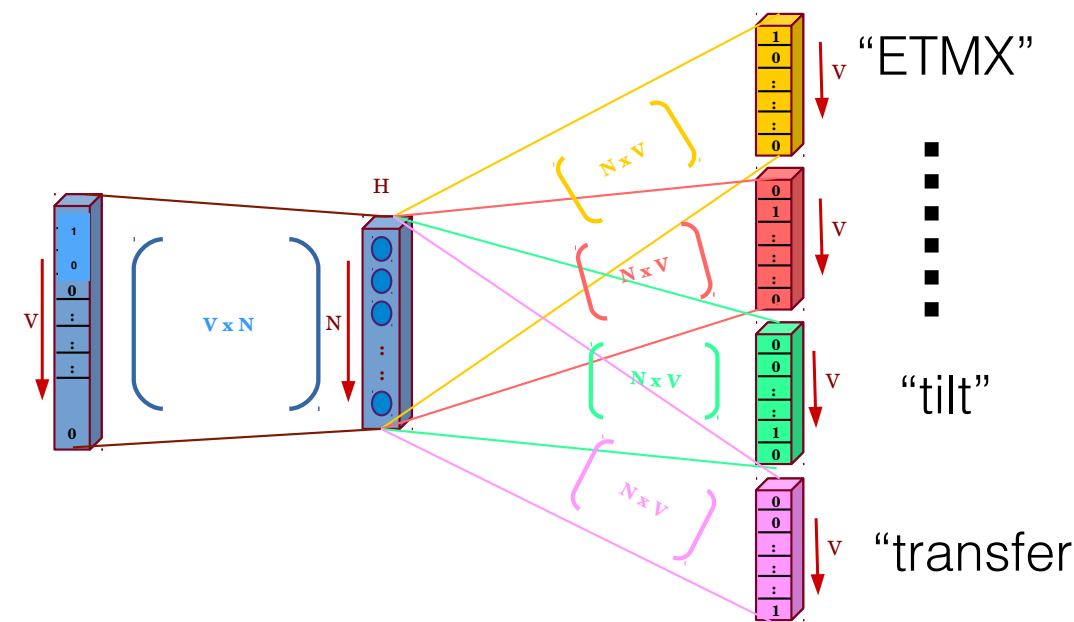


Answers queries about

- * DAC glitches
- * Bounce and roll mode damping
- * Operator reports on earthquakes
- * PSL ISS second loop instability
- * Jitter Coupling
- * Scattering noise
- * GRB Alerts
- *

"ML based Contextual Learning"

"BRS"



N Mukund et al, 2017

Key Idea : Uses a shallow neural network to perform semantic learning by converting LIGO logbook data to word vectors

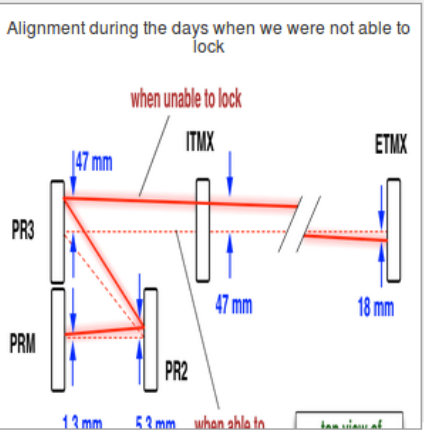
HEY LIGO ! WEB INTERFACE

heyligo.gw.iucaa.in

Most discussed issues for the day



Hosted at IUCAA Home LLO LHO Virgo All Alerts

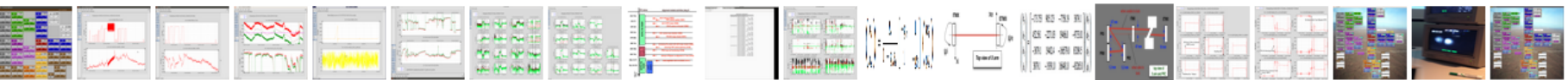


Hey Hanford!

Locking and alignment Search

Today's Trending

- NLN, RF noise
- Corrected H1 glitching with alignment of TMSX and TMSY
- Grass Fire Update
- OWL Operator Summary
- Ops Evening Shift Transition



Related Posts

- Arrived at NomLowNoise once, SRC align prevents staying there; other oscs killing further locks
jenne.driggers
Mon, 05 Jun 2017 22:09:00 GMT
- Difficulty with SRC_ALIGN in initial alignment process
edmond.merilh
Wed, 23 Nov 2016 09:34:00 GMT
- SUS Alignment Offsets during This Afternoon's Lock Stretch, in prep for tomorrow's RCG Upgrade Recovery
jeffrey.kissel
Mon, 17 Oct 2016 16:25:00 GMT
- IO IM2 shifting alignment with lock aquisition and lock loss
cheryl.vorvick
Wed, 06 Jul 2016 15:45:00 GMT
- looking into alignment as it might relate to locking issues

cheryl.vorvick

- Corrected H1 glitching with alignment of TMSX and TMSY
Mon, 03 Jul 2017 19:45:00 GMT
- Update on locking
Wed, 07 Jun 2017 04:57:00 GMT
- ISC_LOCK guardian doesn't set ALIGN_IFO to SET_SUS_FOR_ALS?
Sun, 30 Oct 2016 02:20:00 GMT
- locking issues - REFL centering not turning on when it needs to
Thu, 13 Oct 2016 11:34:00 GMT
- alignment recovery of input optics, SRs, and OMs - beam in HAM6 - OMC alignment continues
Tue, 09 Aug 2016 16:25:00 GMT
- Ops Day Summary: H1 locked at 40W and in Observe
Fri, 08 Jul 2016 15:53:00 GMT

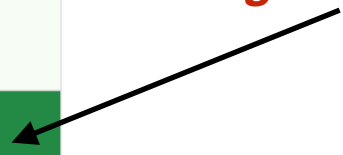
jenne.driggers

- Arrived at NomLowNoise once, SRC align prevents staying there; other oscs killing further locks
Mon, 05 Jun 2017 22:09:00 GMT
- IM4 pit and yaw inputs set to ON in initial alignment
Wed, 25 Jan 2017 14:29:00 GMT
- Chasing alignment offsets one more time
Thu, 13 Oct 2016 01:47:00 GMT
- BS alignment cleared more slowly after lockloss
Mon, 26 Sep 2016 23:01:00 GMT
- New guardian state for checking BS alignment during acquisition
Sun, 25 Sep 2016 20:10:00 GMT
- New IFO alignment - seems good so far
Fri, 02 Sep 2016 01:49:00 GMT
- Perhaps alignment progress?
Thu, 25 Aug 2016 01:00:00 GMT

alexan.staley

- Locking and Alignment Templates
Mon, 26 Jan 2015 10:47:00 GMT

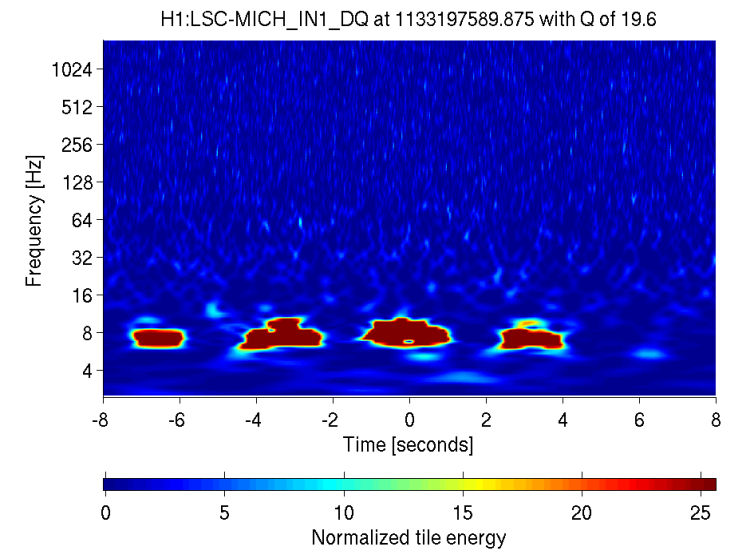
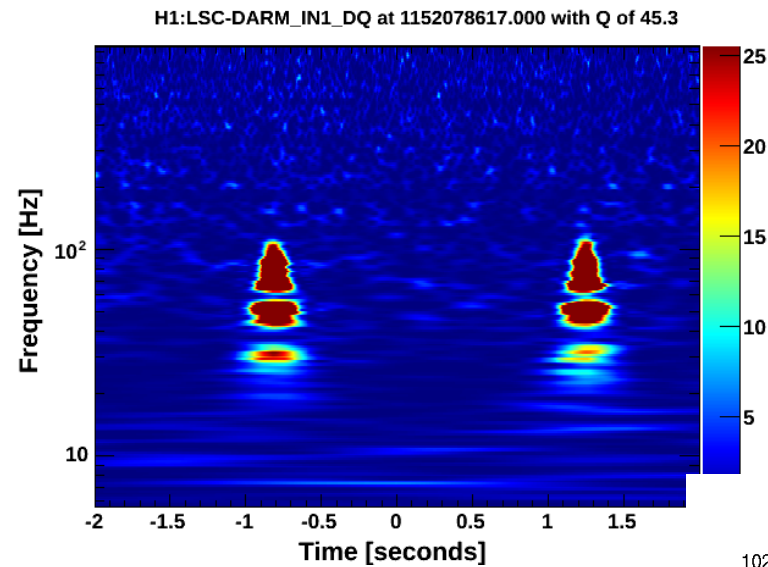
Strong Positive Sentiment



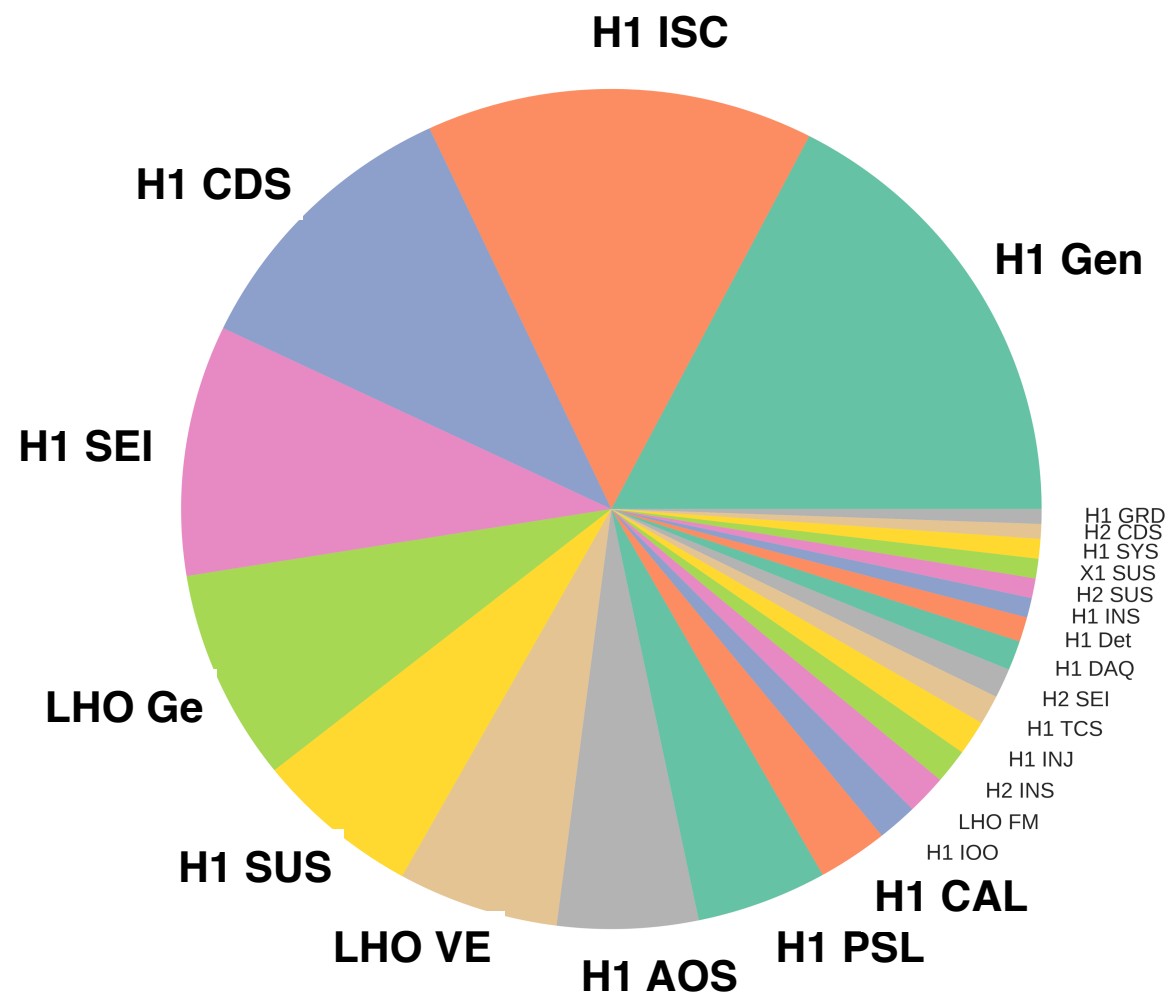
TRANSIENTS SEEN AT THE SITE

heylogo.gw.iucaa.in

- ISC : Interferometric Sensing & Control
- AOS : Auxiliary Optics Support
- CDS : Control & Data System
- SEI : Seismic External Isolation
- SUS : Suspension
- TCS : Thermal Compensating System
- PSL : Pre-Stabilized Laser
- PEM : Physical Environment Monitoring
- CAL : Calibration



Glitch distribution across different subsystems

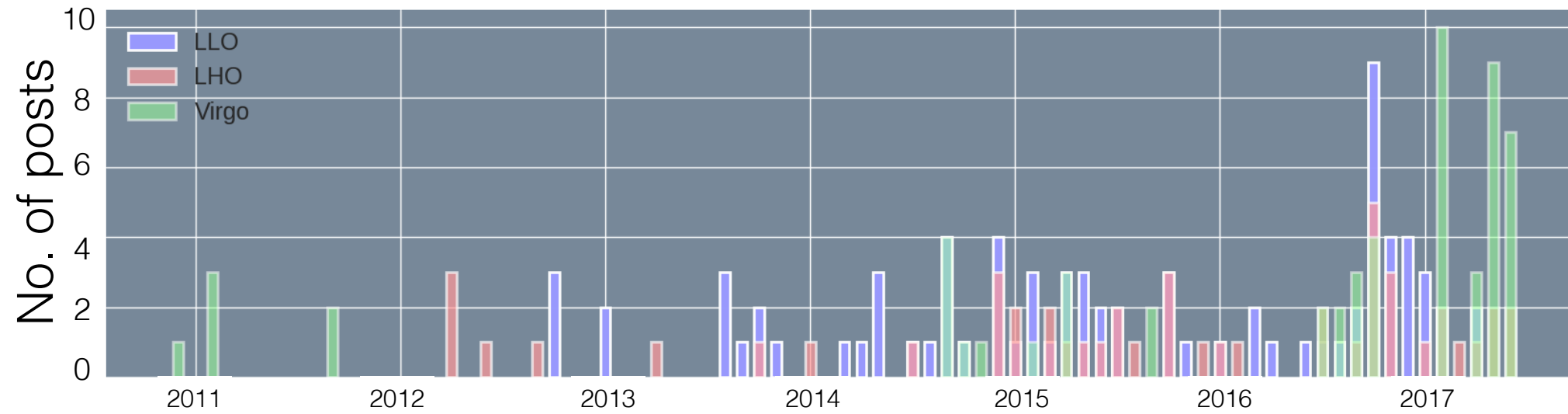


Related to DAC, timing systems, electronic pickup, control loops, optical levers, RF coupling, thunderstorms, overflows.....

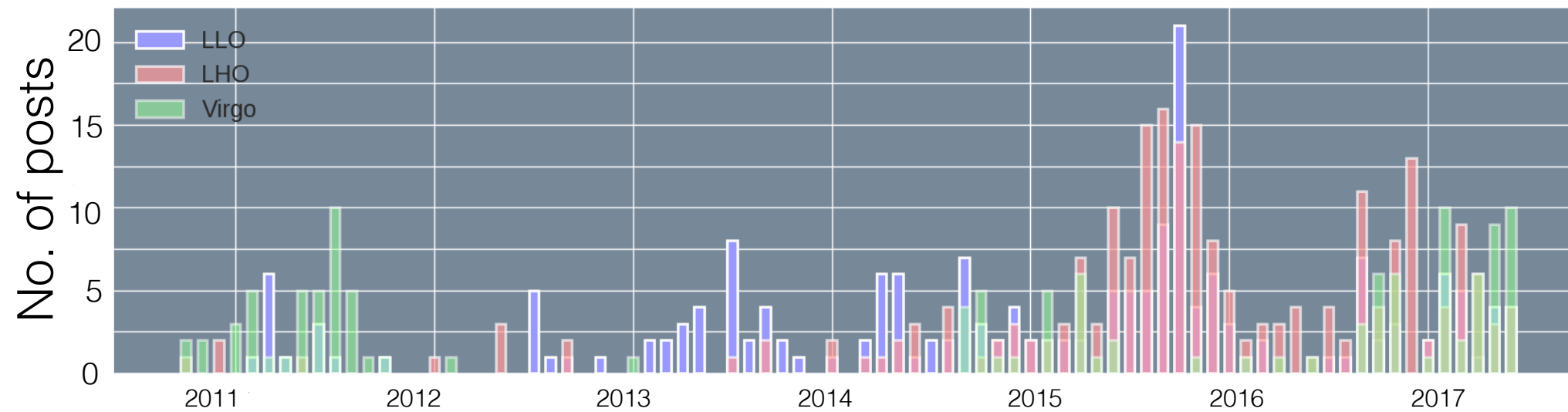
SAME ISSUE: MULTIPLE DETECTORS

heyligo.gw.iucaa.in

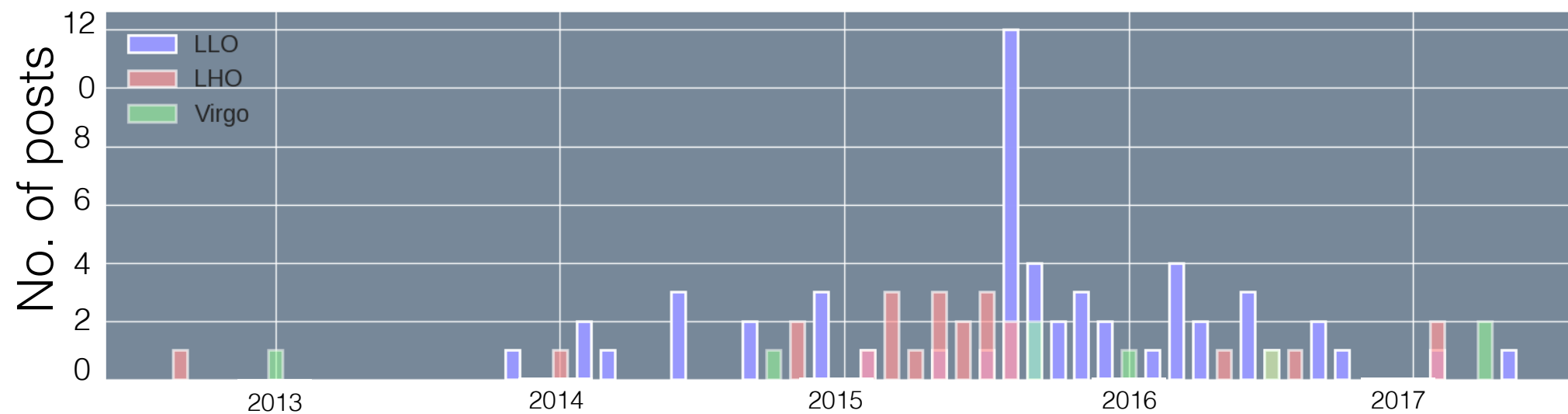
Rate of occurrence of Scatter



Rate of occurrence of Glitch



Rate of occurrence of bounce and roll



Classifying the non-astrophysical background

GLITCH STUDIES : MOTIVATION

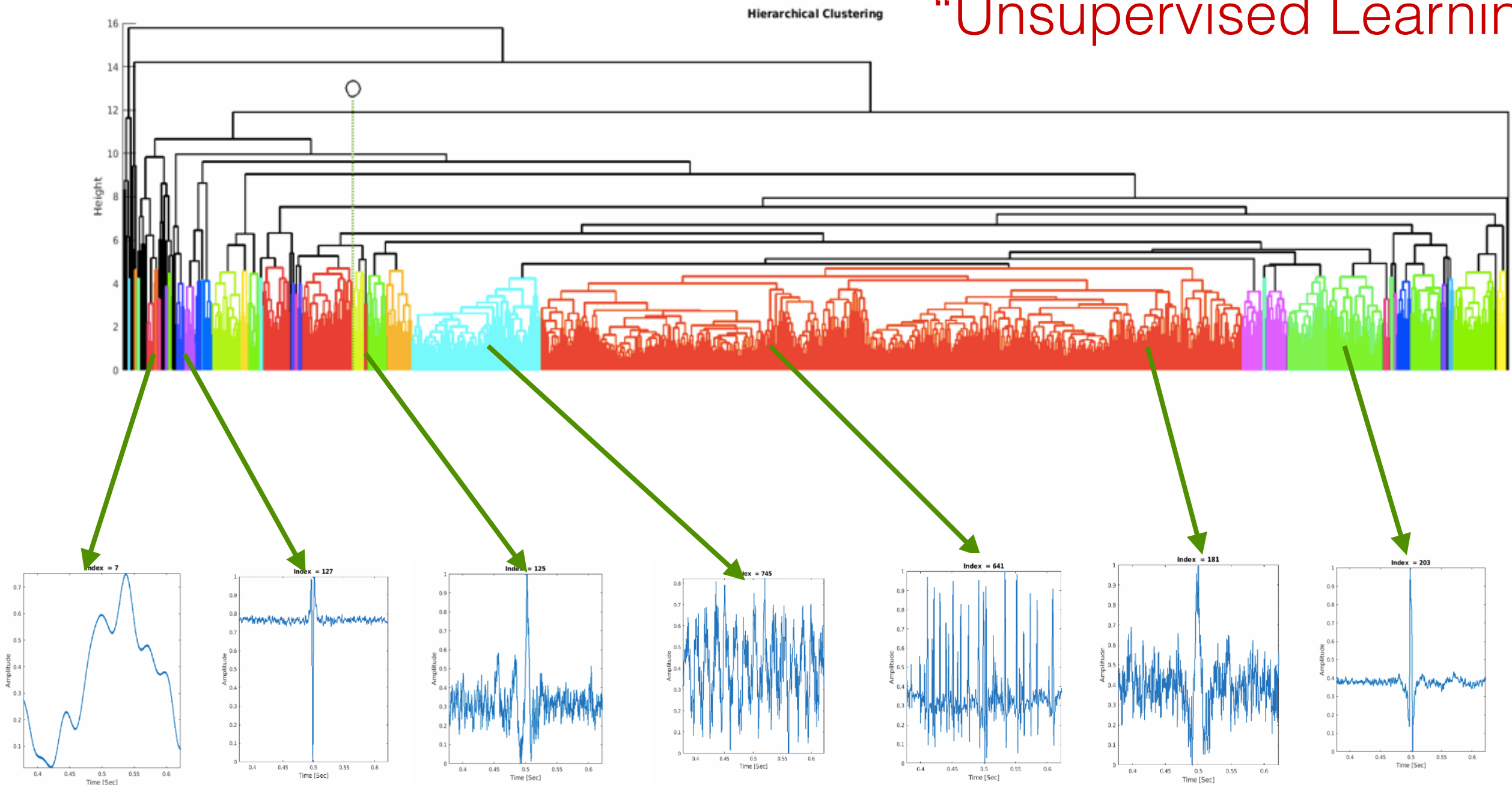
- Many of them have distinct time-frequency morphology
- Some of them share similarity with GW signals
- Leads to false triggers in various search pipelines
- Matched filtering and Burst pipelines mostly affected
- Often such triggers leave no signature in auxiliary channels
- Morphology based veto needs to be implemented
- Commissioning activities often hampered

HIERARCHICAL CLUSTERING OF TRANSIENTS

N. Mukund, S. Abraham, S. Kandhasamy, S. Mitra, and N. S. Philip
Phys. Rev. D 95, 104059

Morphology progressively changes

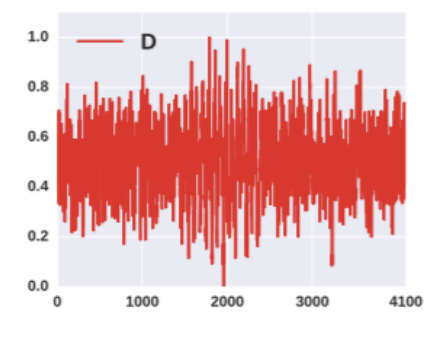
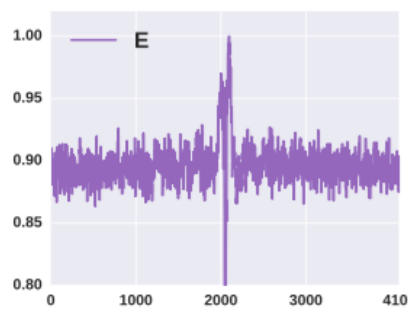
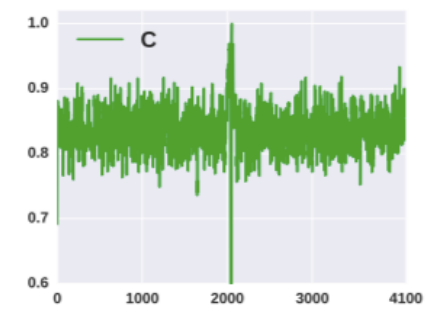
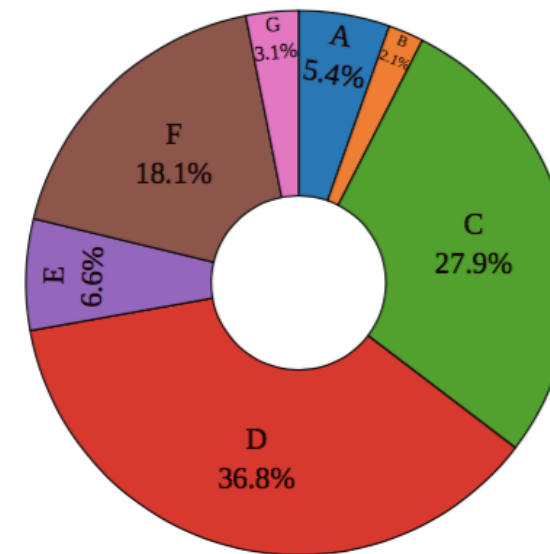
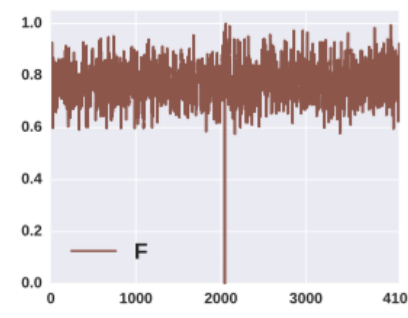
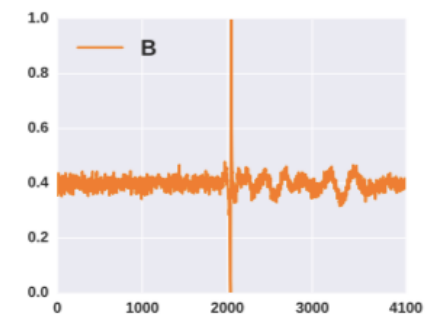
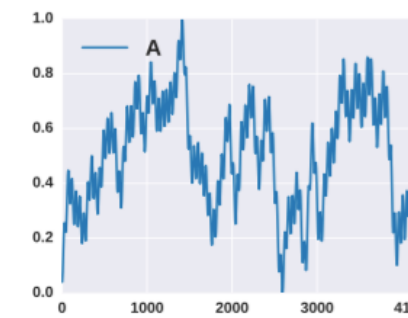
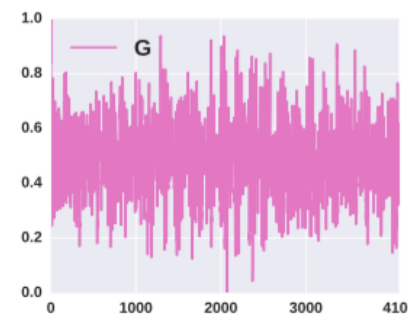
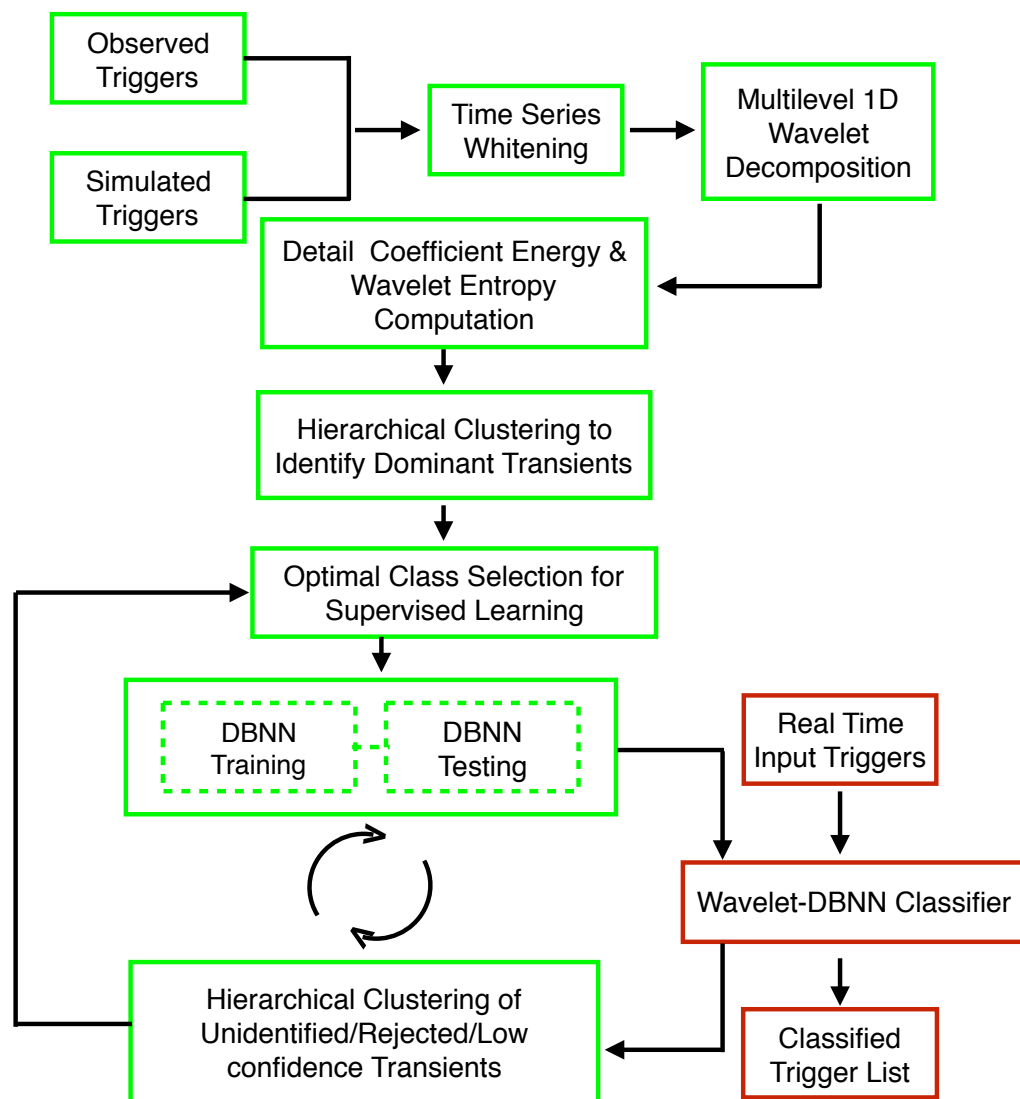
“Unsupervised Learning”



BOOSTING THE DIFFERENCES USING NEURAL NETWORKS

N. Mukund, S. Abraham, S. Kandhasamy, S. Mitra, and N. S. Philip
Phys. Rev. D 95, 104059

Major Glitches seen in Adv LIGO 1st Observation Run



“Hybrid Learning”

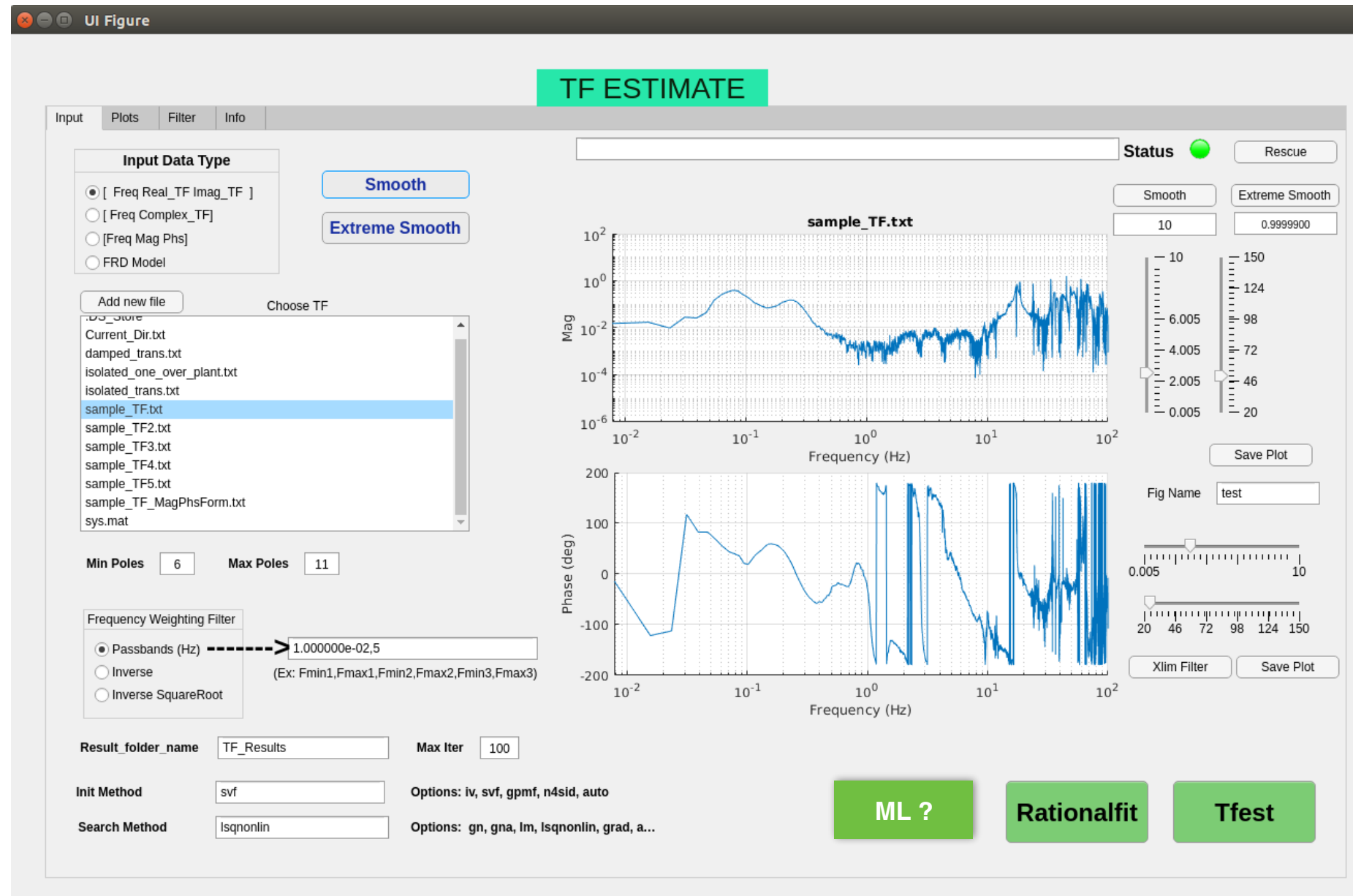
System Identification via Transfer Function Fitting

MODELLING SYSTEM DYNAMICS

- Often system dynamics are inaccessible to direct modelling
- Possible to built empirical models by fitting the measured frequency response data
- Use these surrogate models to predict behaviour
- Measurements are often noisy
- Fitting by hand takes few hours, not scalable
- Multi-parameter optimization/regression subject to stability constraints
- Some Applications : **Seismic feedforward**
Length to angle decoupling
Time domain Newtonian noise filters

MODELLING SYSTEM DYNAMICS

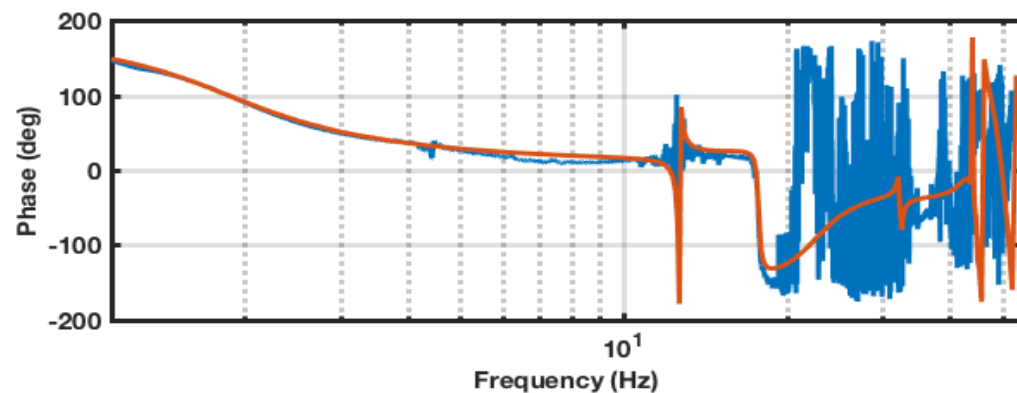
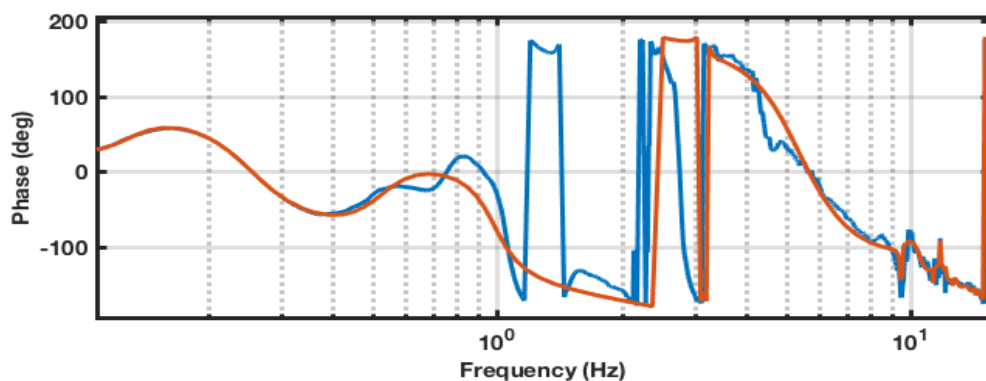
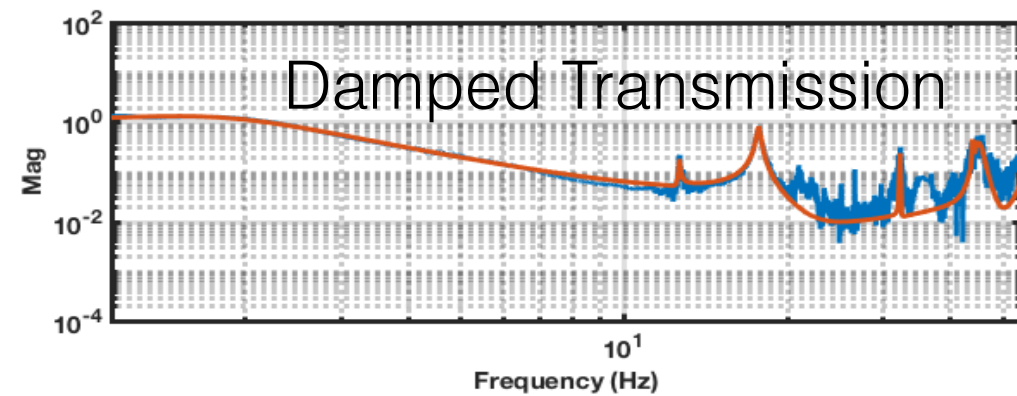
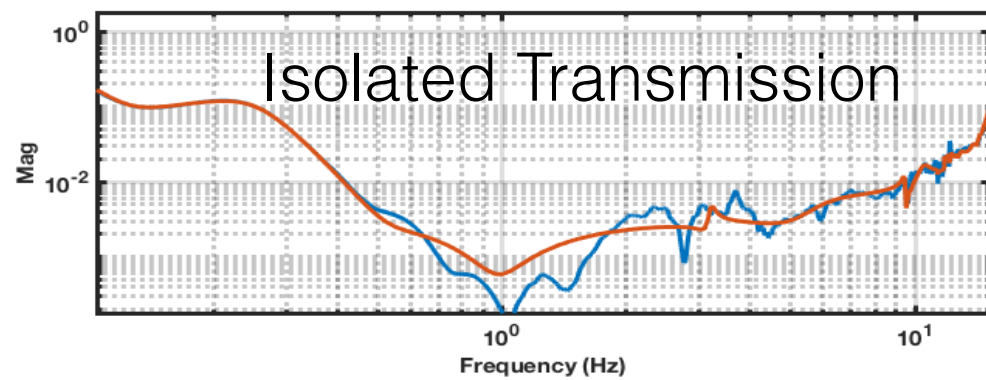
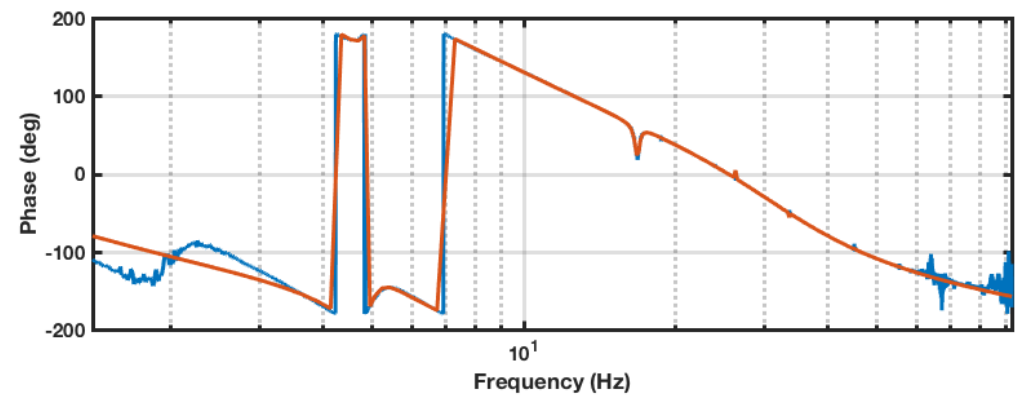
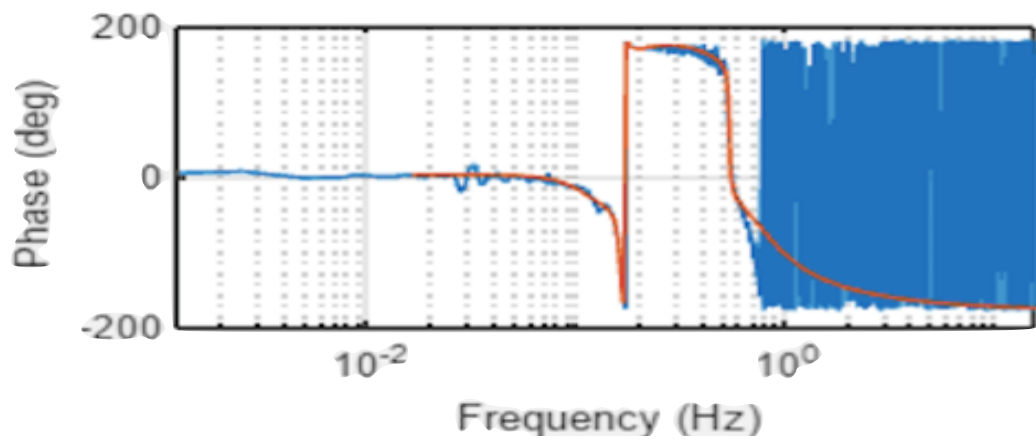
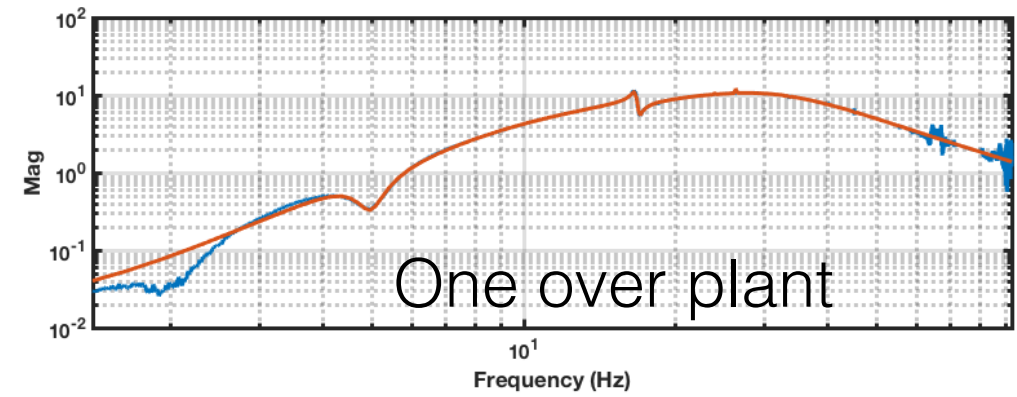
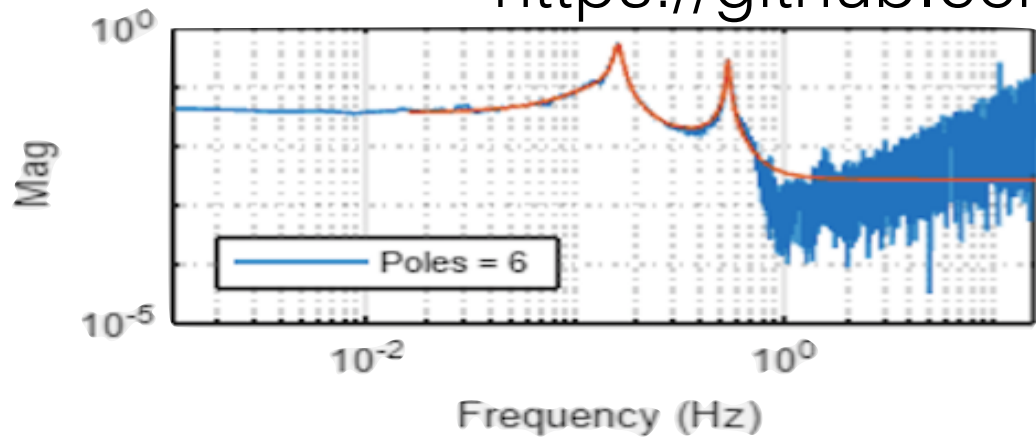
<https://github.com/Nikhil-Mukund/TFestimate>



ML will be used to determine the optimal algorithm and optimal input parameters. This will require collection of user feedback and more input data.

TFESTIMATE : FITS OBTAINED

<https://github.com/Nikhil-Mukund/TFestimate>

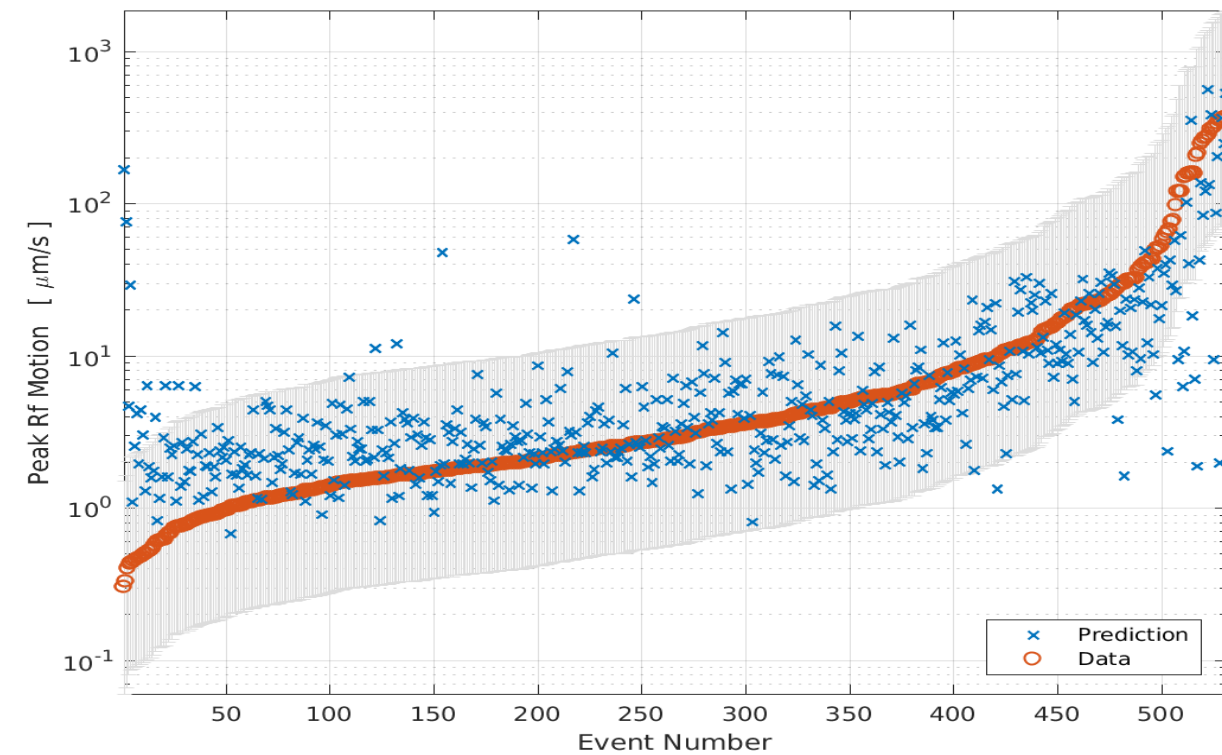
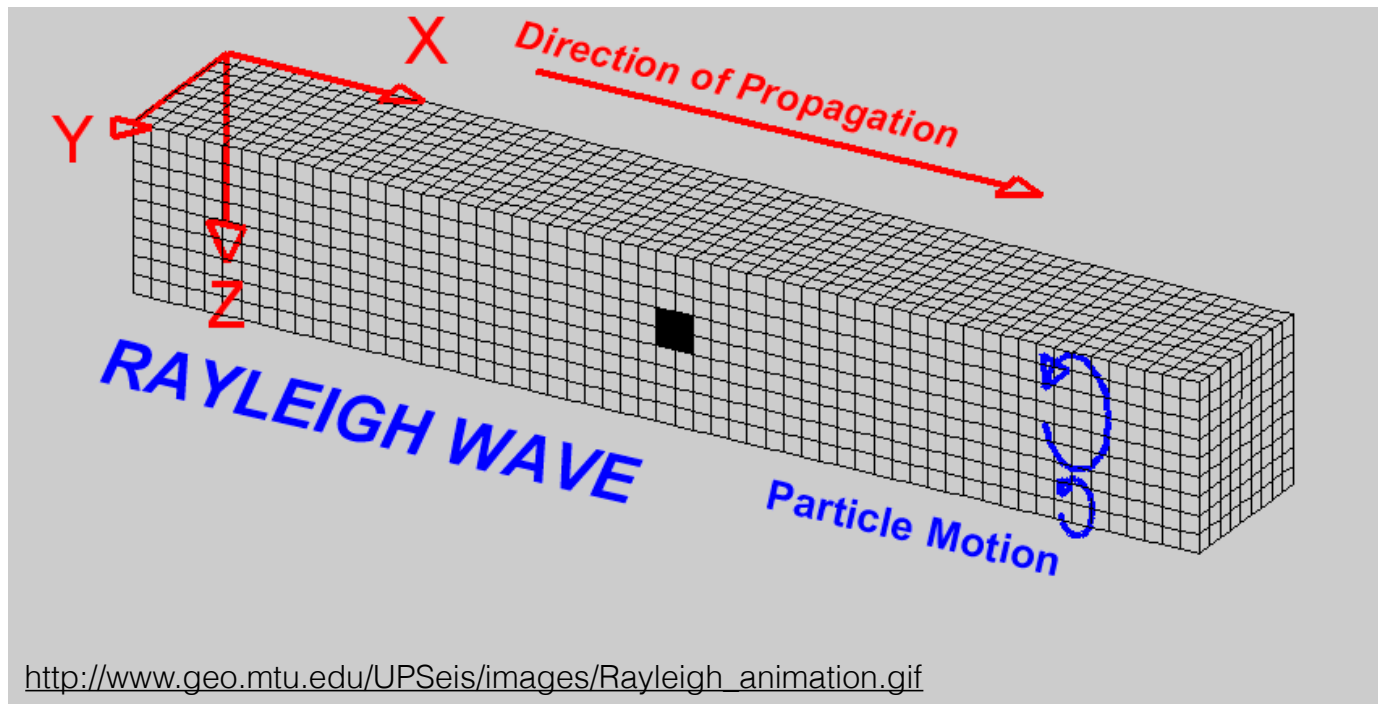


Regression / Multiparameter Optimization

PREDICTING EARTHQUAKE IMPACT AT SITES

M. Coughlin, P. Earle, J. Harms, S. Biscans, C. Buchanan, E. Coughlin, F. Donovan, J. Fee, H. Gabbard, M. Guy, N. Mukund, and M. Perry

[Classical and Quantum Gravity, Volume 34, Number 4]



Model that predicts ground motion from earthquakes. It is currently used to issue early warning at GW Observatories.

Time: Tue Apr 04 22:08:38 UTC 2017

Location: 69km SSE of Adak, Alaska; LAT: 51.0, LON: -176.4

Magnitude: 5.7

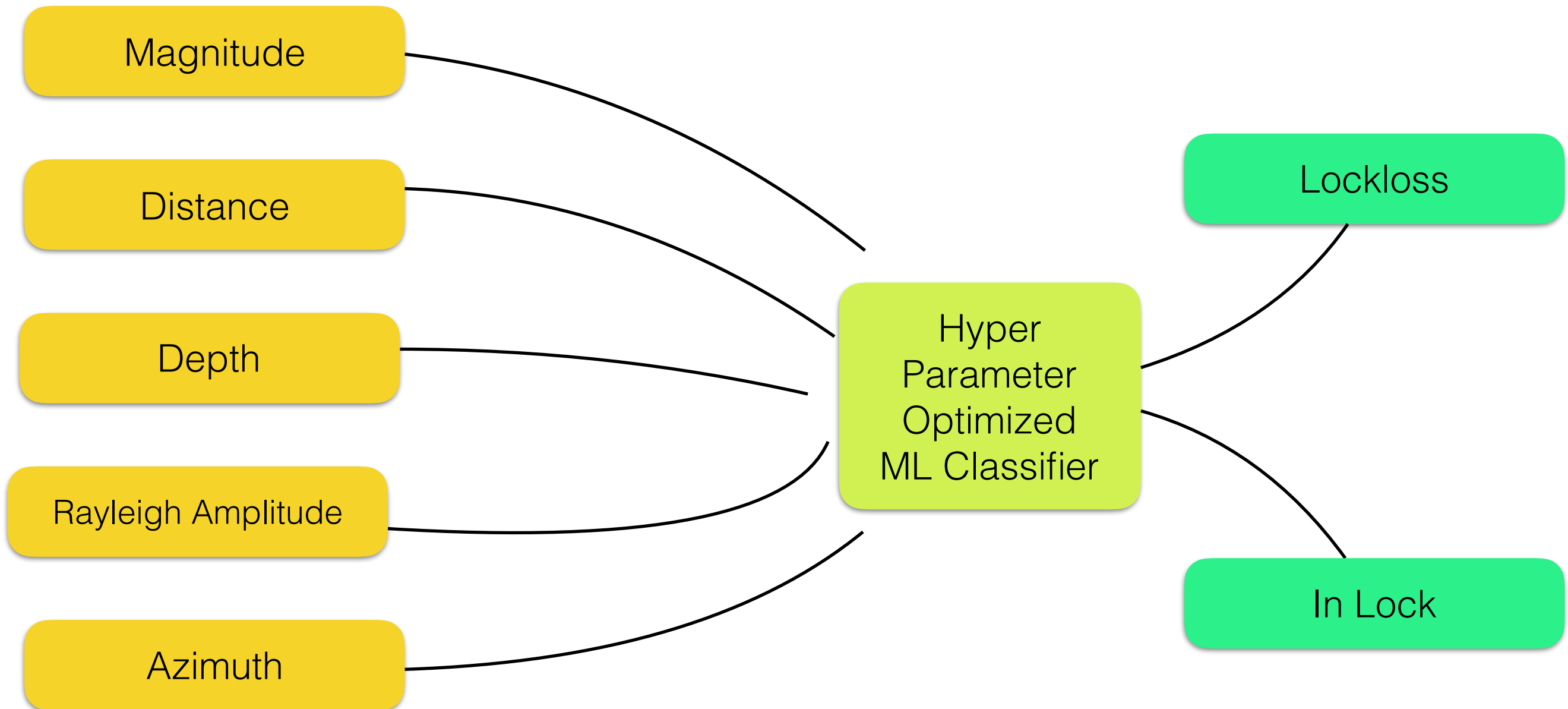
[USGS event link](#)

ifo	P-phase Arrival Time	S-phase Arrival Time	R-wave Arrival Time	R-Wave Velocity (micro m/s)	EQ Distance (km)	GPS P-phase Arrival Time	GPS S-phase Arrival Time	GPS R-wave Arrival Time
H1	15:15:47 PST	15:15:48 PST	15:28:07 PST	4.81367	4091.405	1175379365.1	1175379366.0	1175380105.0
L1	17:19:14 CST	17:19:15 CST	17:42:40 CST	3.6175	7148.653	1175379572.8	1175379573.8	1175380978.5
G1	00:20:31 CET	00:20:32 CET	00:49:19 CET	1.74679	8543.346	1175379649.4	1175379650.4	1175381377.0
V1	00:21:16 CET	00:21:17 CET	00:53:50 CET	2.39336	9495.016	1175379694.9	1175379695.9	1175381648.9

PREDICTING EQ LOCKLOSS AT SITES

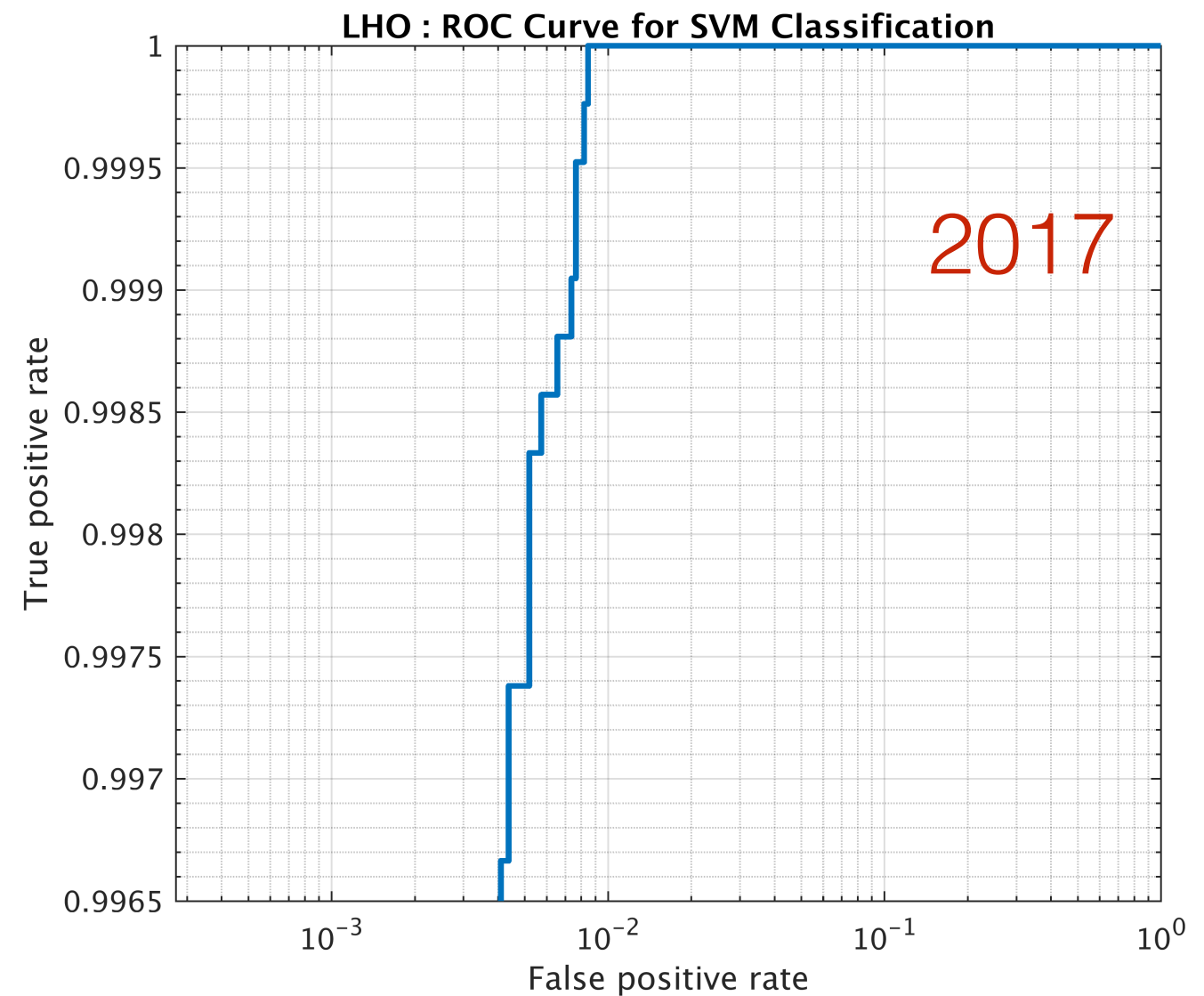
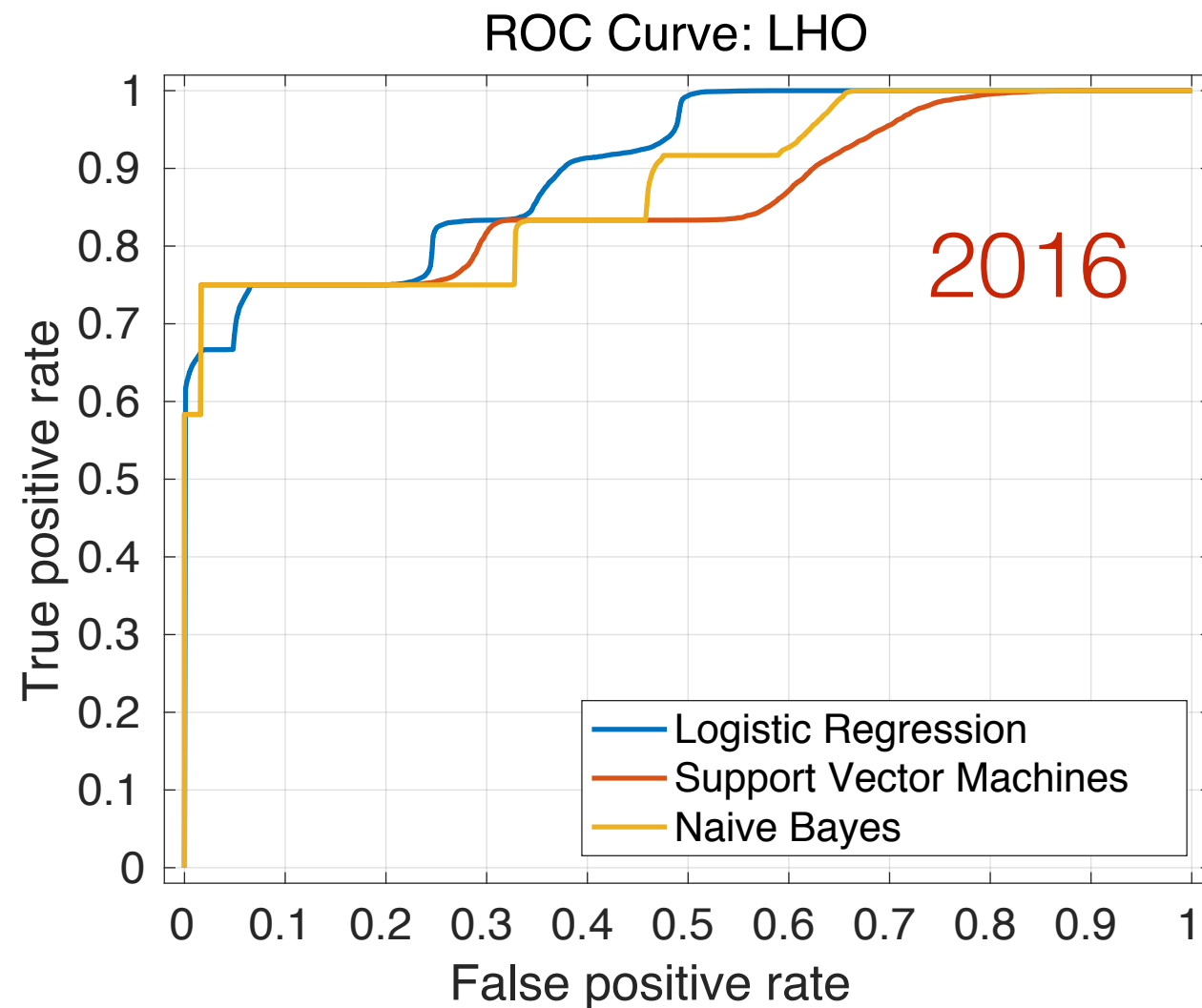
Will this earthquake cause a lockloss ?

Earthquake Parameters



PREDICTING EARTHQUAKE IMPACT AT SITES

Model Improvements:



Models need be updated regularly to reflect configuration changes made at the detectors

- ✱ More Data (O1+ O2)
- ✱ More Input Parameters
- ✱ Hyper Parameter Tuned Classifier

CONCLUSION

- ML : Growing field, lot of opportunities
- Not a single technique but an agglomeration
 - Clustering, Classification, Regression, Dimensionality Reduction, Contextual Learning, Reinforcement learning, Deep Learning...
- Extensive code development happening worldwide
- Well-suited for big data problems
- Will aid automated and adaptive control

Thank You...