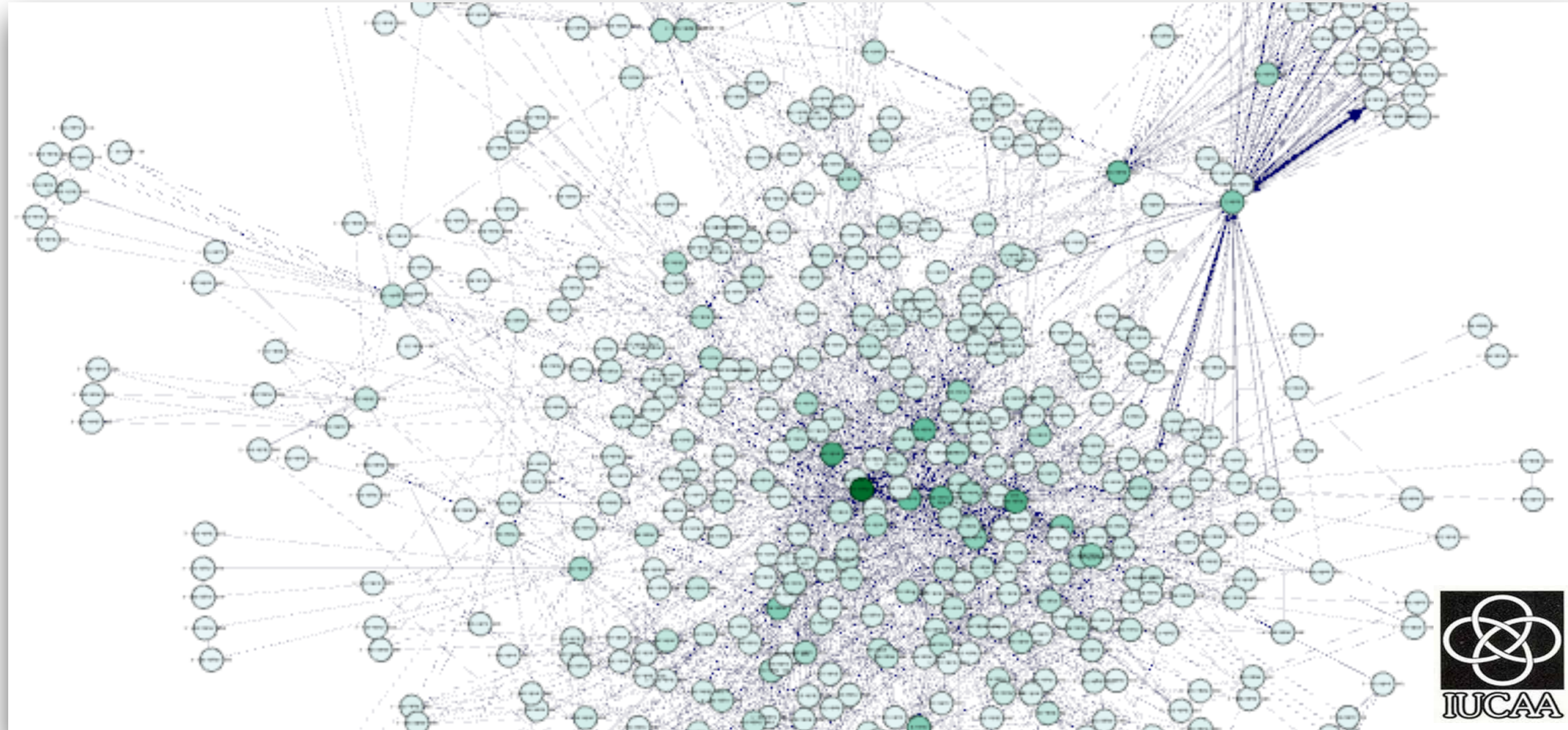
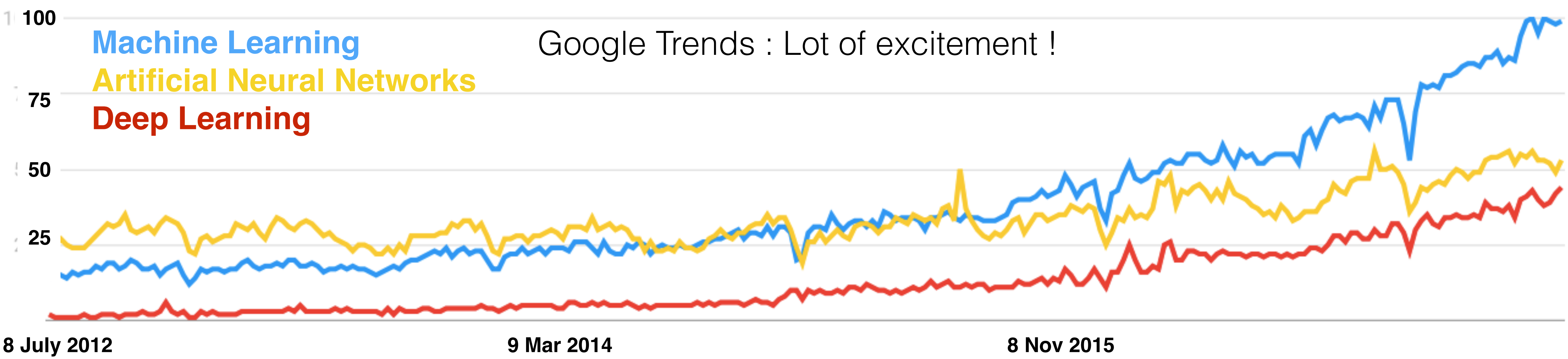


# Machine Learning in Characterization and Commissioning @ GW Detectors

NIKHIL MUKUND MENON

IUCAA PUNE

# Golden Age of Machine Learning




@LIGO

System Identification

Transient Classification

Lockloss Monitoring

Intelligent Search Engine

Earthquake Lockloss Prediction

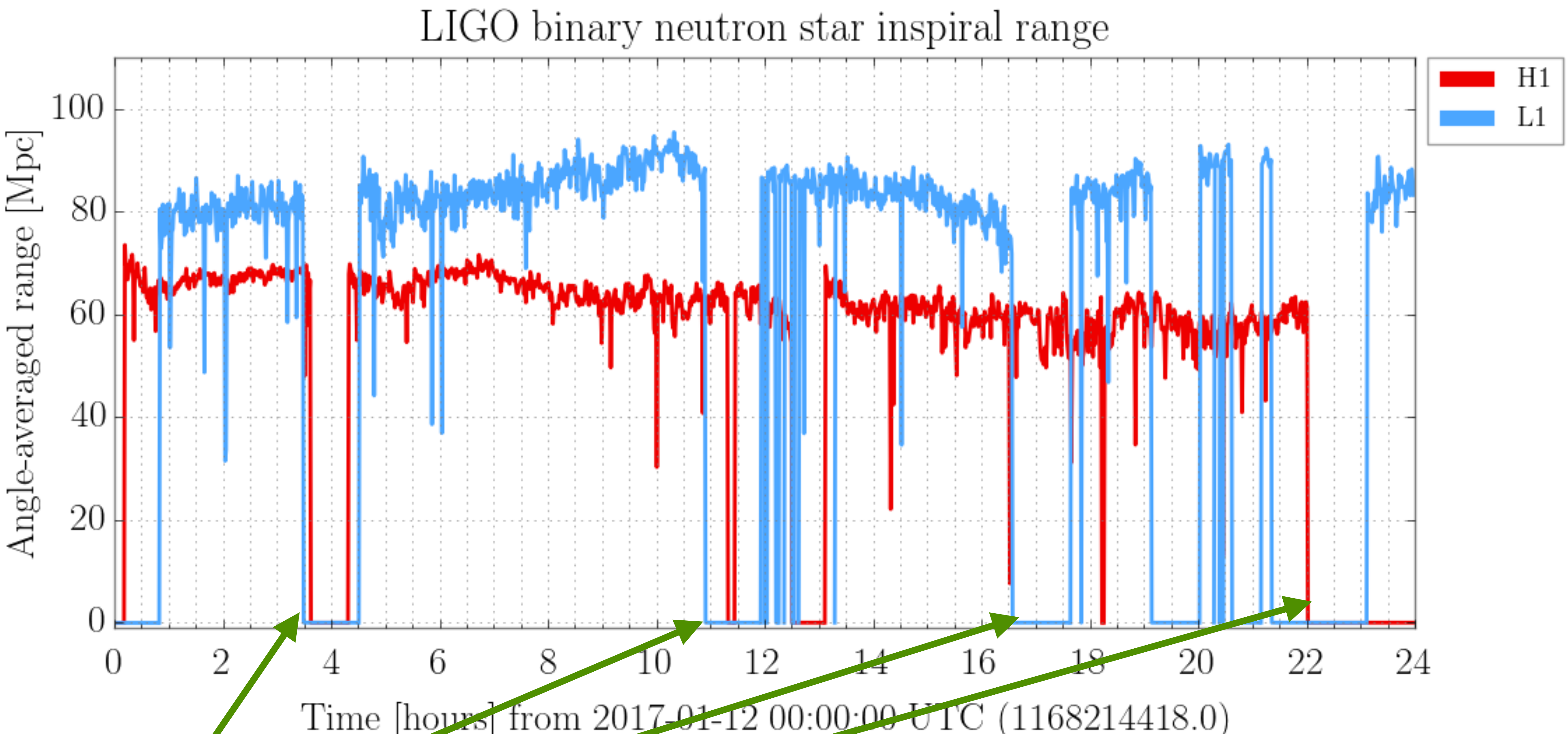
Control loop optimization

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

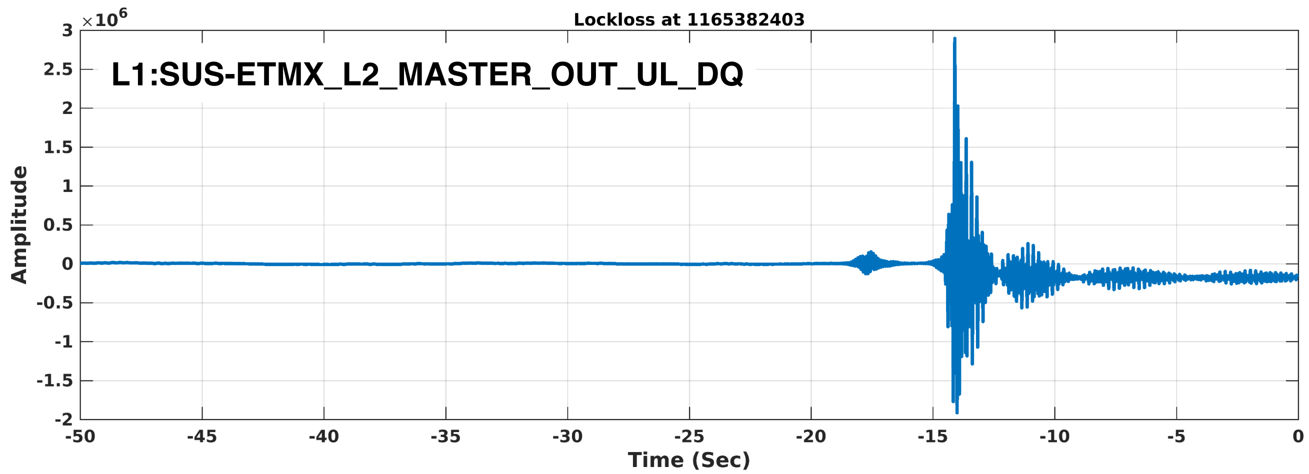


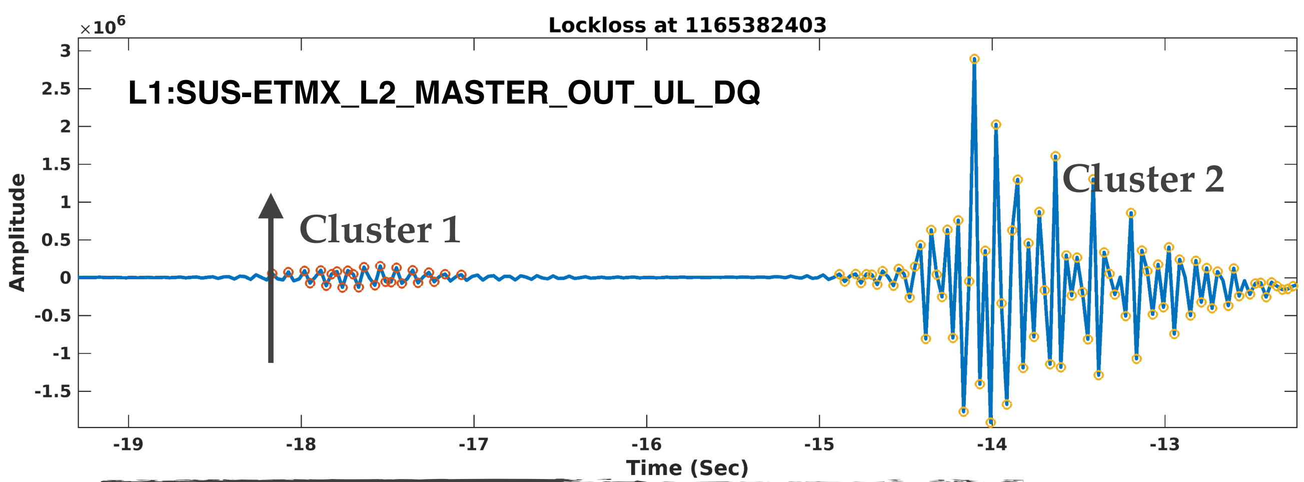

**Locklosses**

What triggered these lock-losses ?

# Density Based Spatial Clustering Applications with Noise

Identify the channels linked with the LOCKLOSS



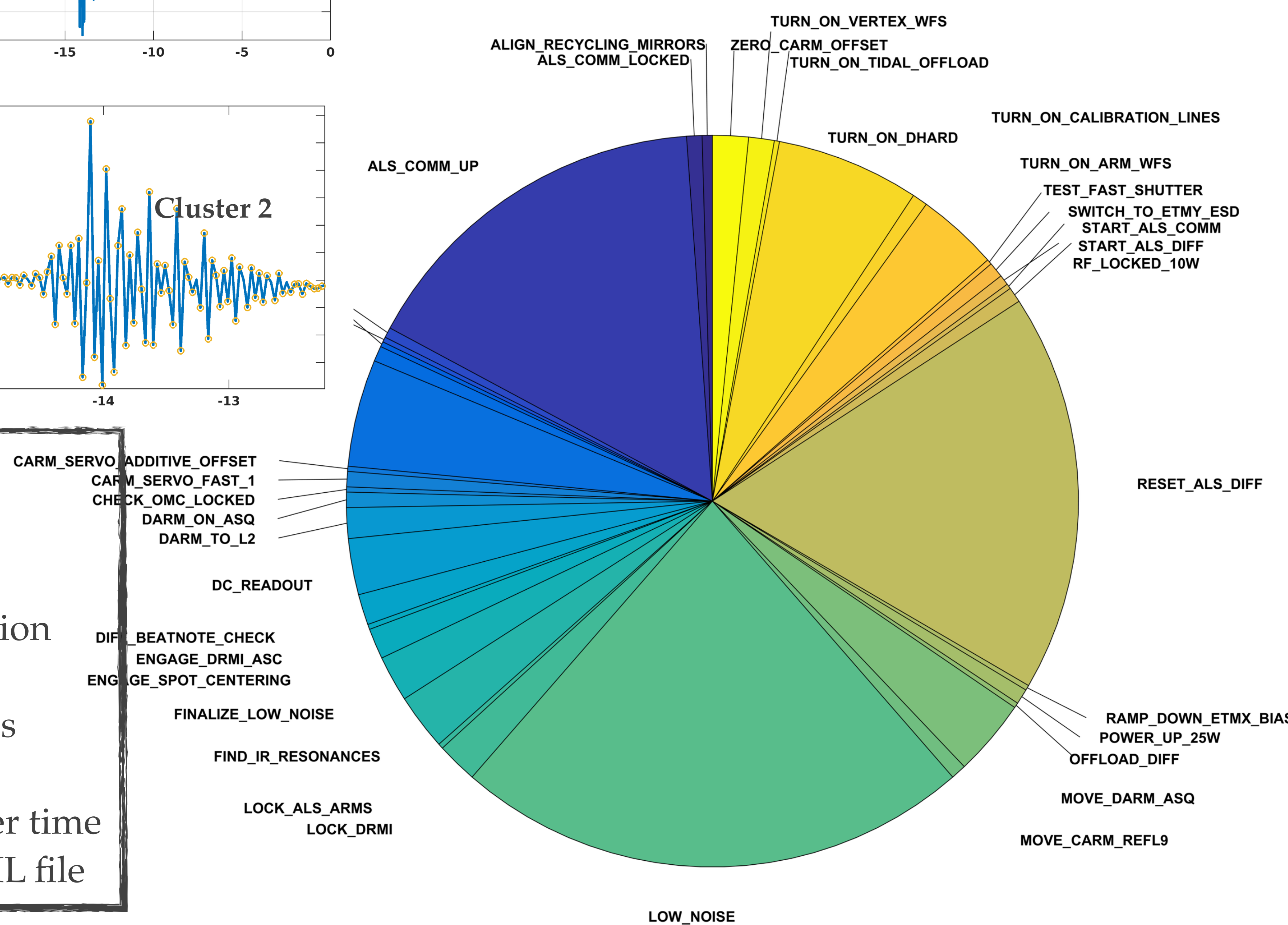




https://dcc.ligo.org/LIGO-G1602442

## 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

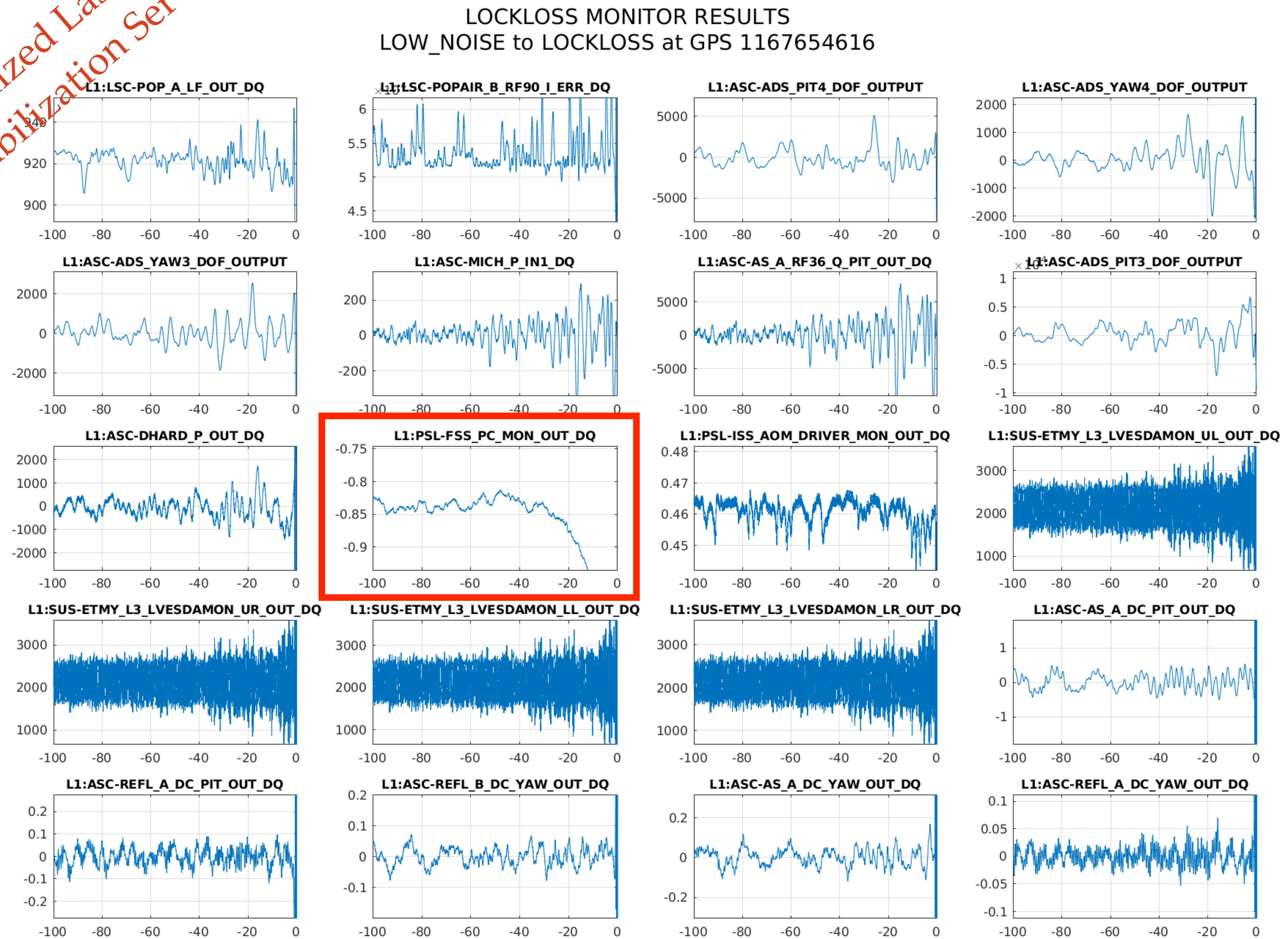
LLO O2A All Locklosses



# Best Guess: Results

Identify the channel that lead to LOCKLOSS

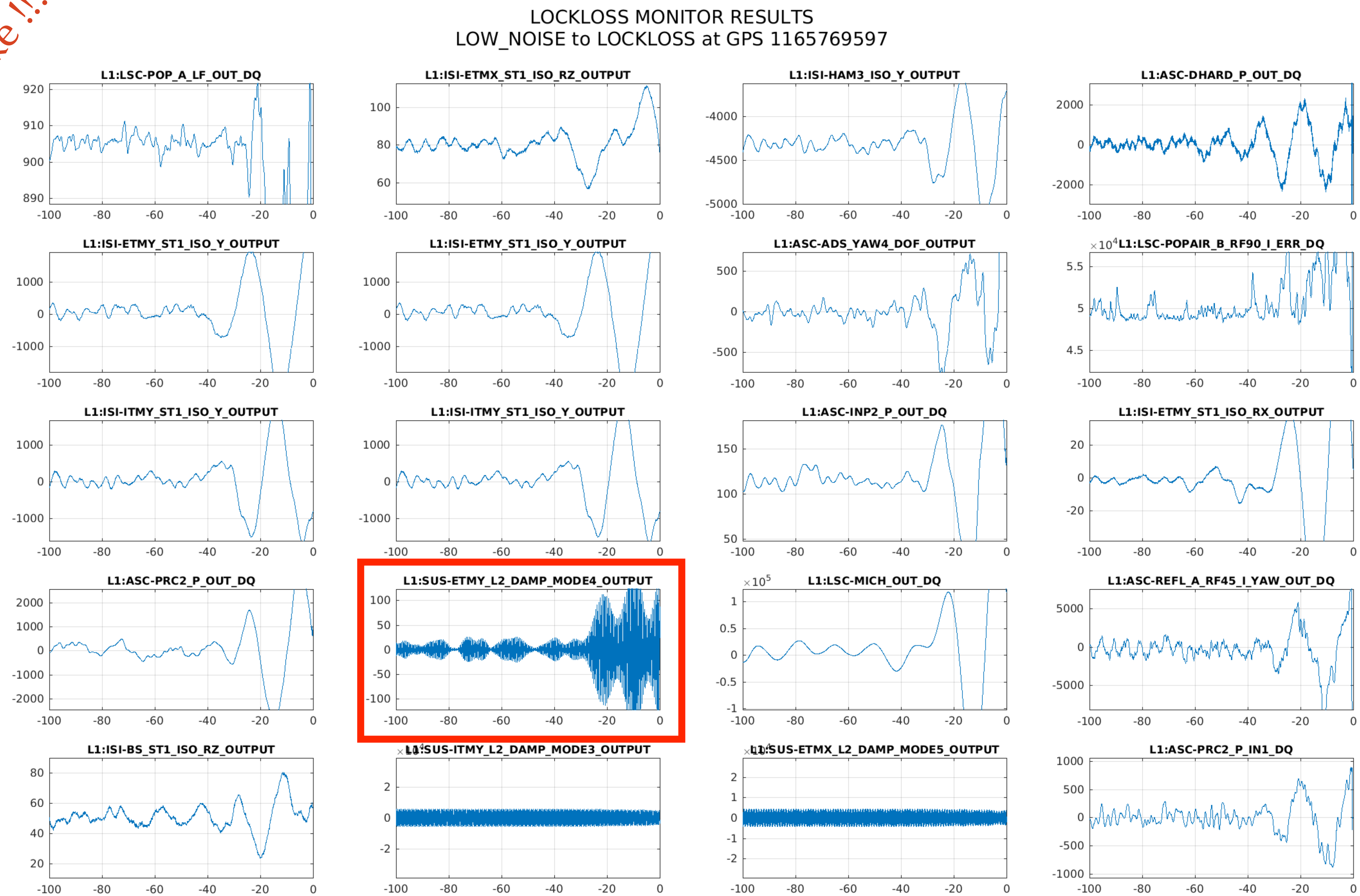
"Pre Stabilized Laser Frequency Stabilization Servo!!!"



# Best Guess: Results

## Identify the channel that lead to LOCKLOSS

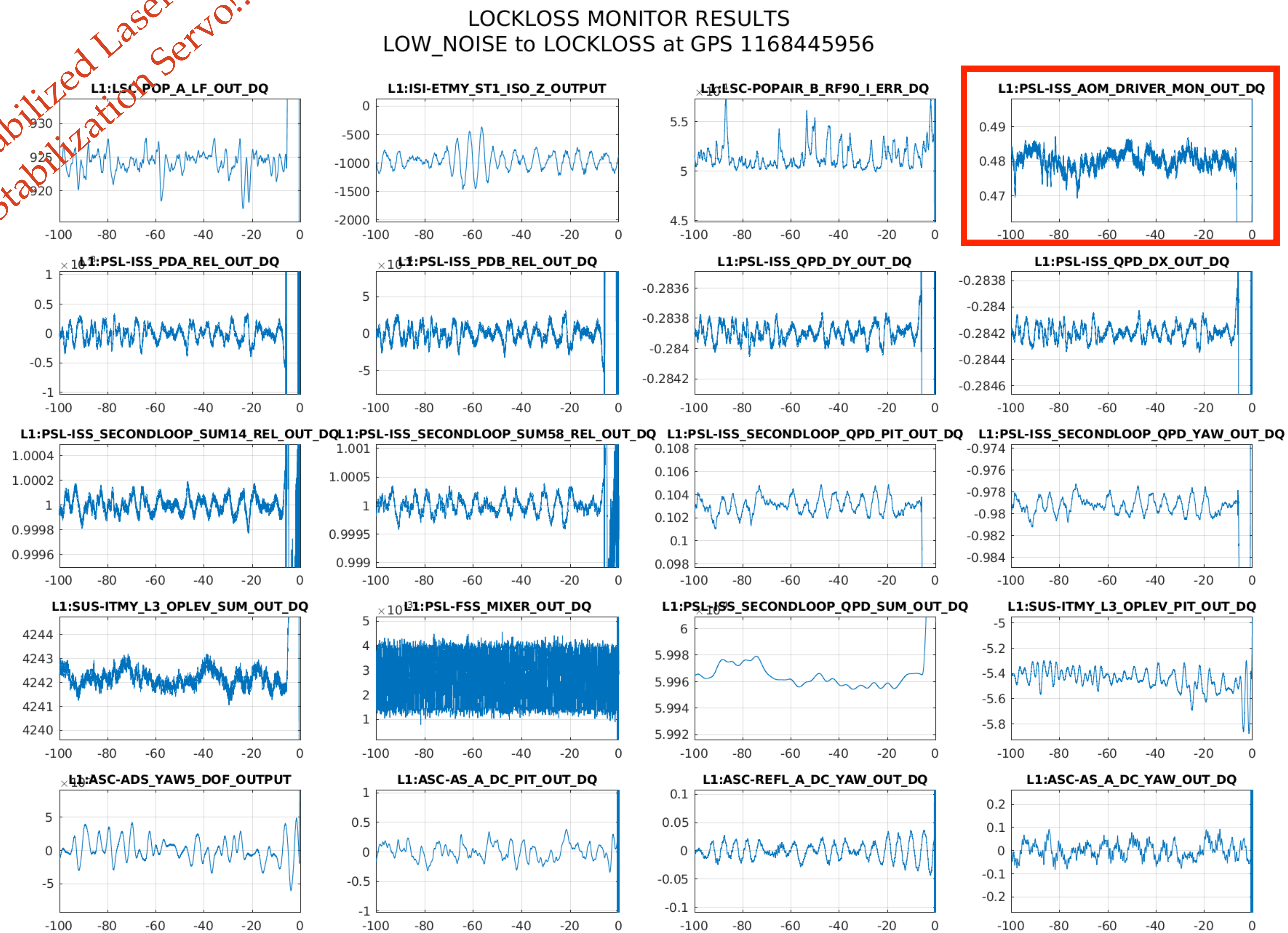
“Earthquake !!!”



# Best Guess: Results

Identify the channel that lead to LOCKLOSS

"Pre Stabilized Laser
Intensity Stabilization Servo!!!"



# 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

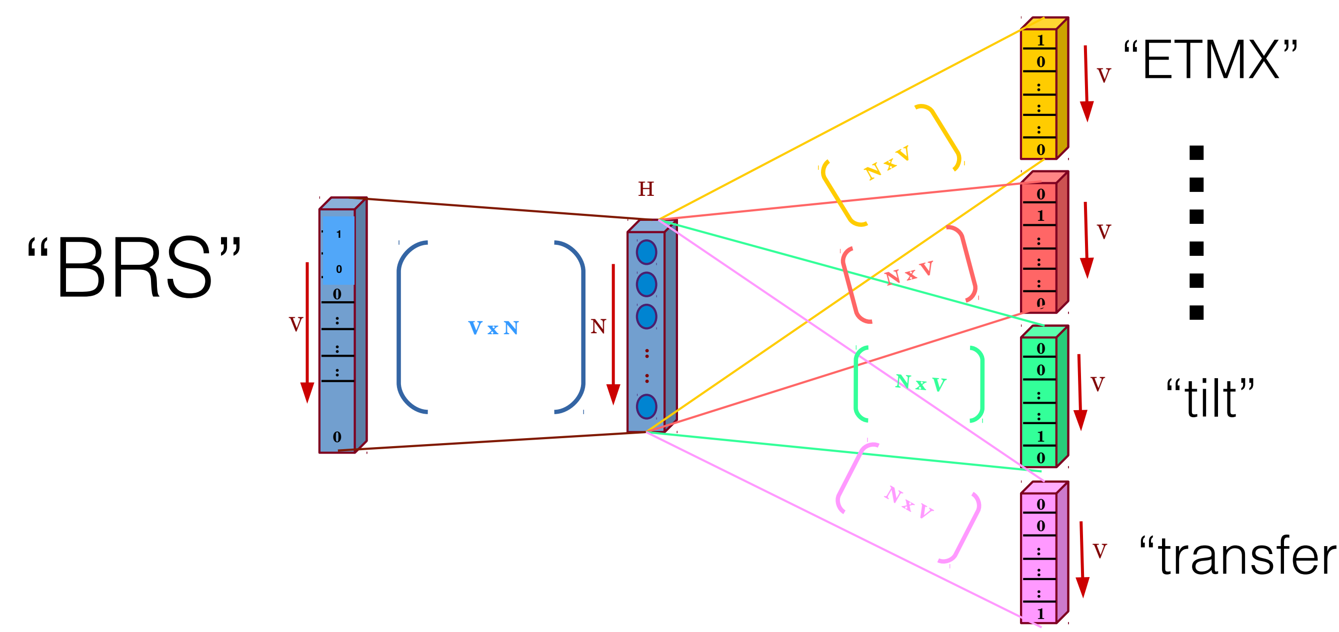
# *Project "Hey LIGO"*

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"*




N Mukund et al, 2017

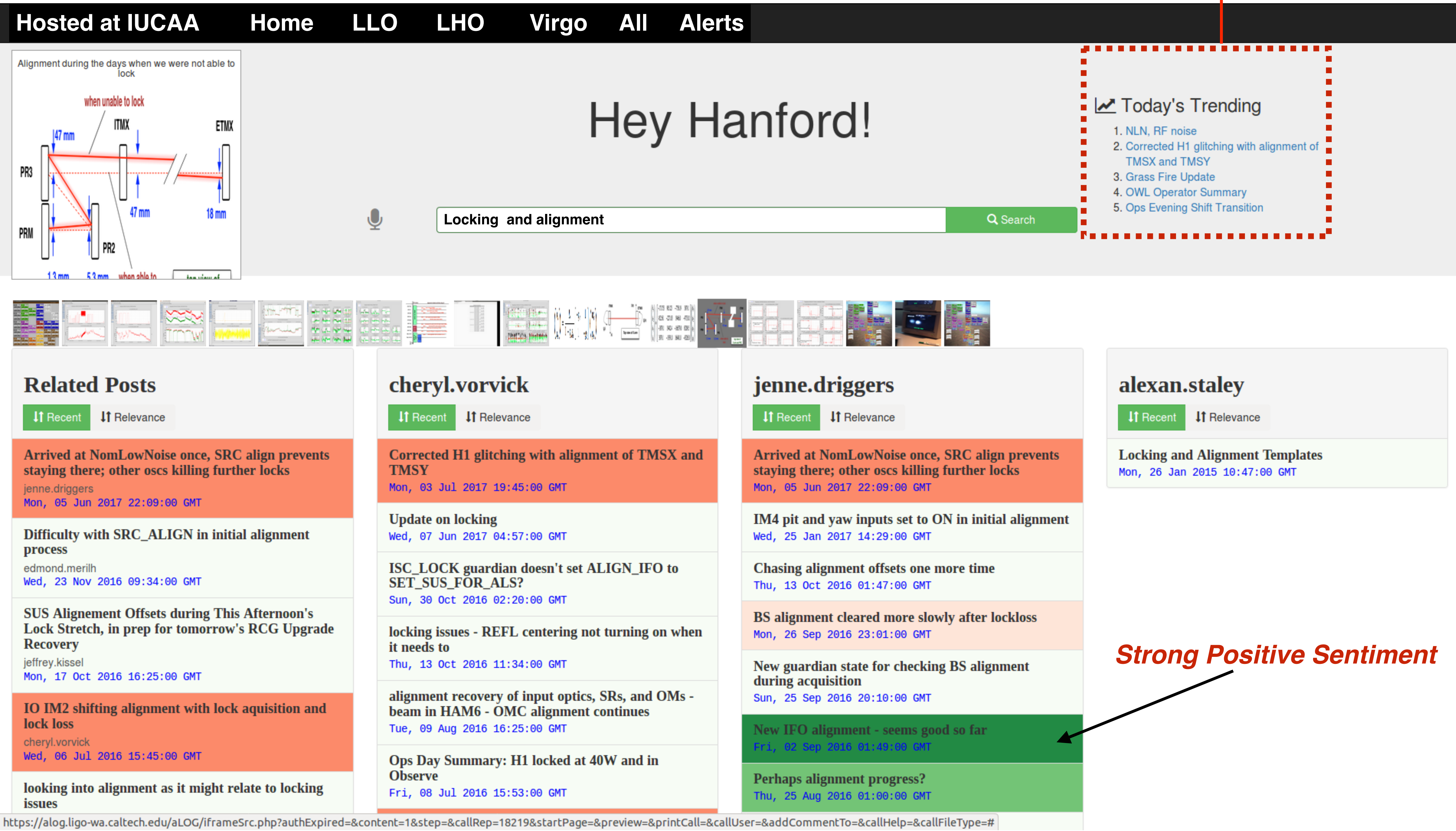
Key Idea : Uses a shallow neural network to perform semantic learning by converting LIGO logbook data to word vectors

https://dcc.ligo.org/LIGO-G1701131

# Hey LIGO ! Web Interface

heyligo.gw.iucaa.in

*Most discussed issues for the day*

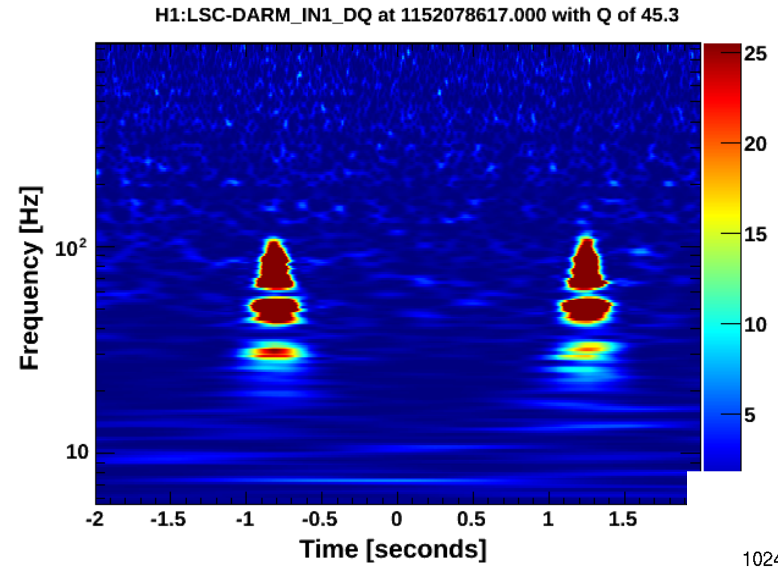


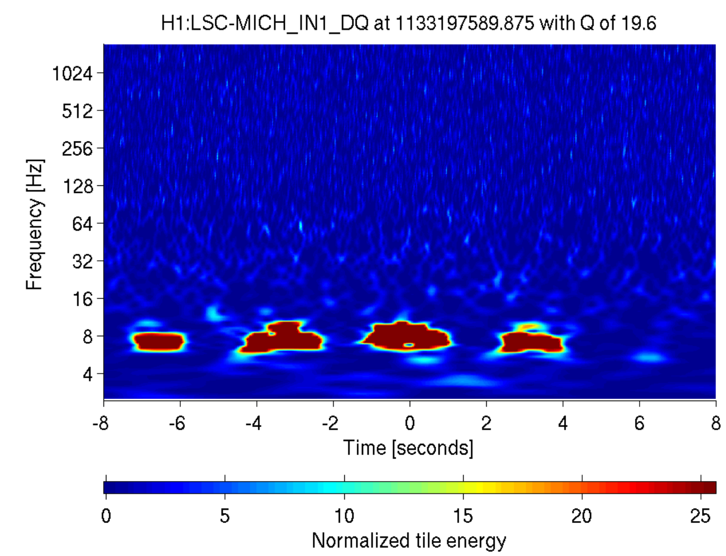

***Strong Positive Sentiment***

# Transients seen at the site

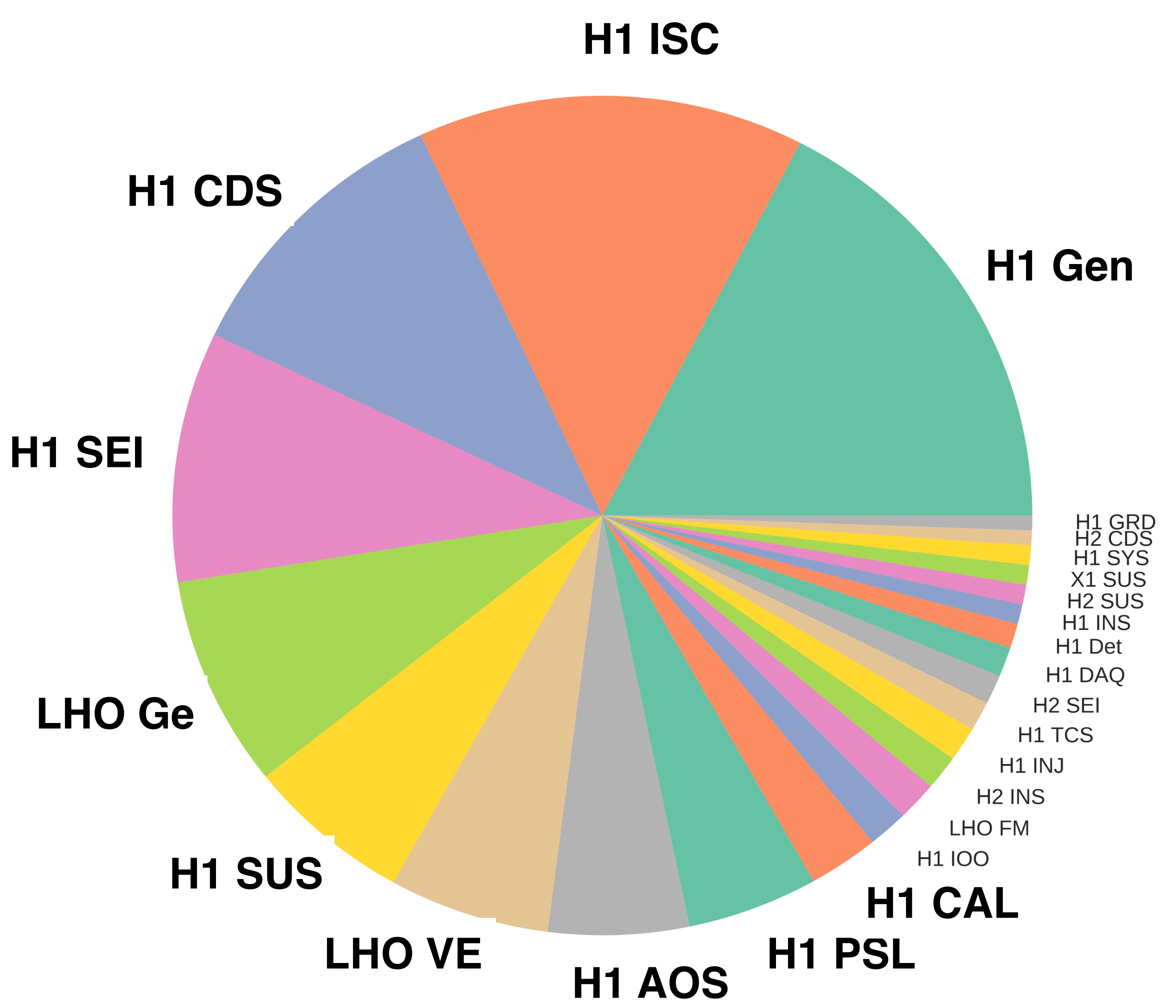
[heyligo.gw.iucaa.in](heyligo.gw.iucaa.in)

- 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



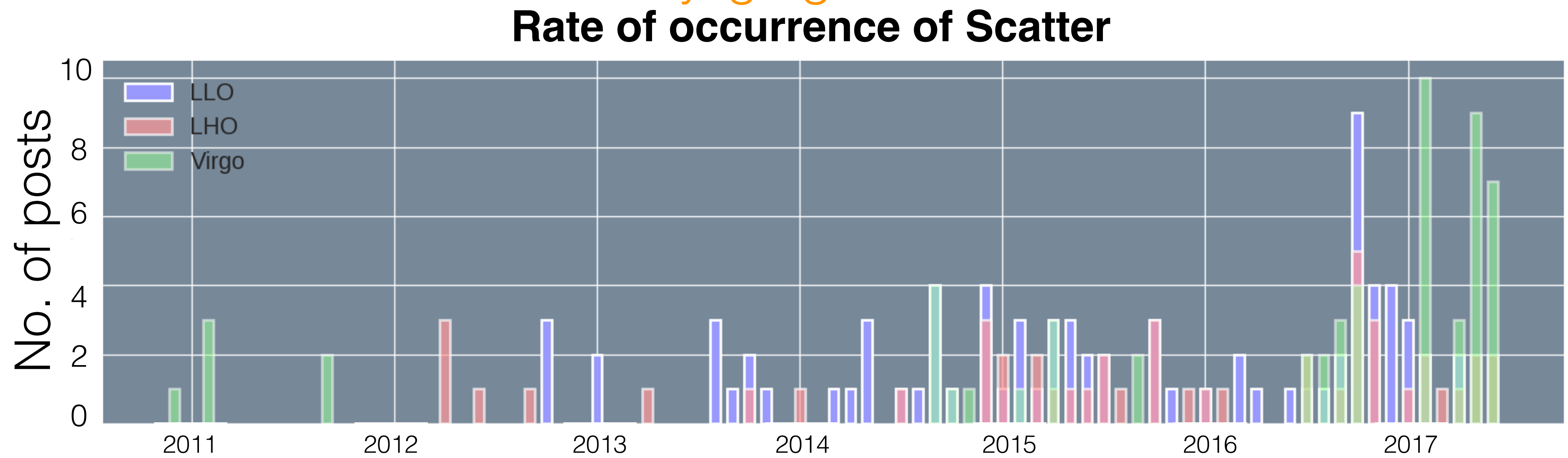

Glitch distribution across different subsystems

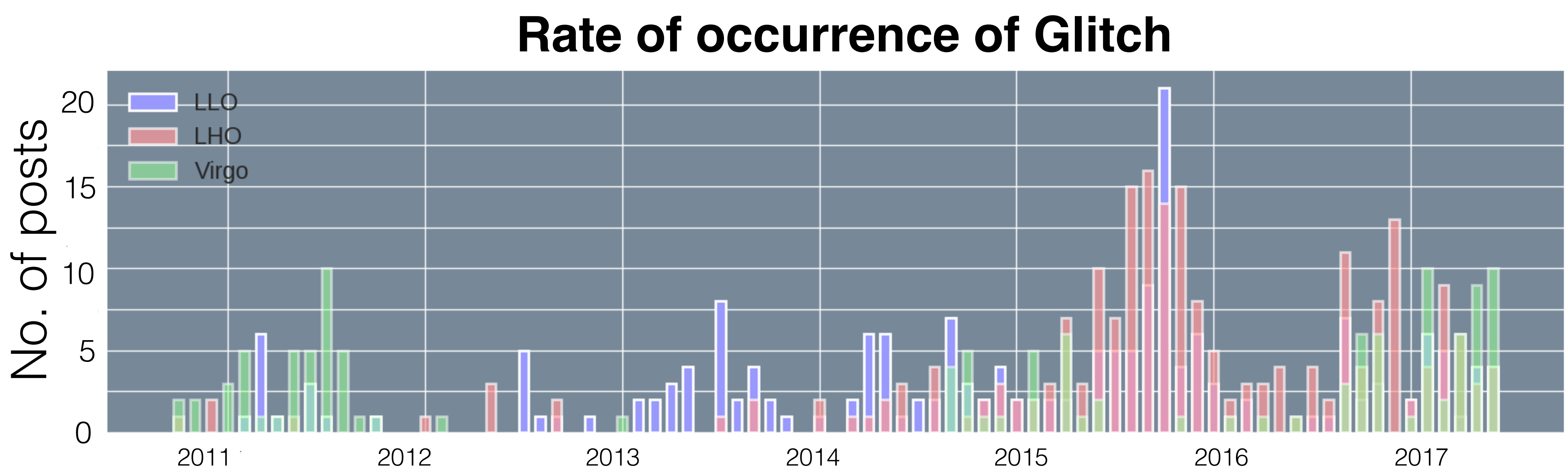


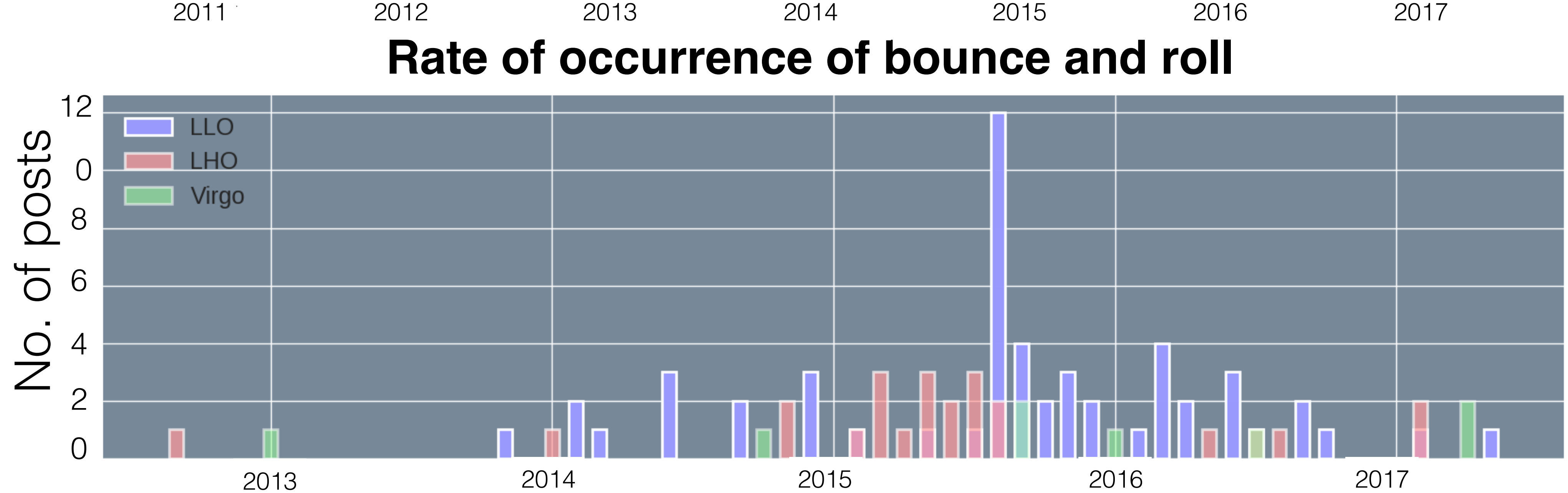

Related to DAC, timing systems, electronic pickup, control loops, optical levers, RF coupling, thunderstorms, overflows.....

# Same Issue: Multiple Detectors

heyligo.gw.iucaa.in



# Classifying the non-astrophysical background

# Glitch Studies : Motivation

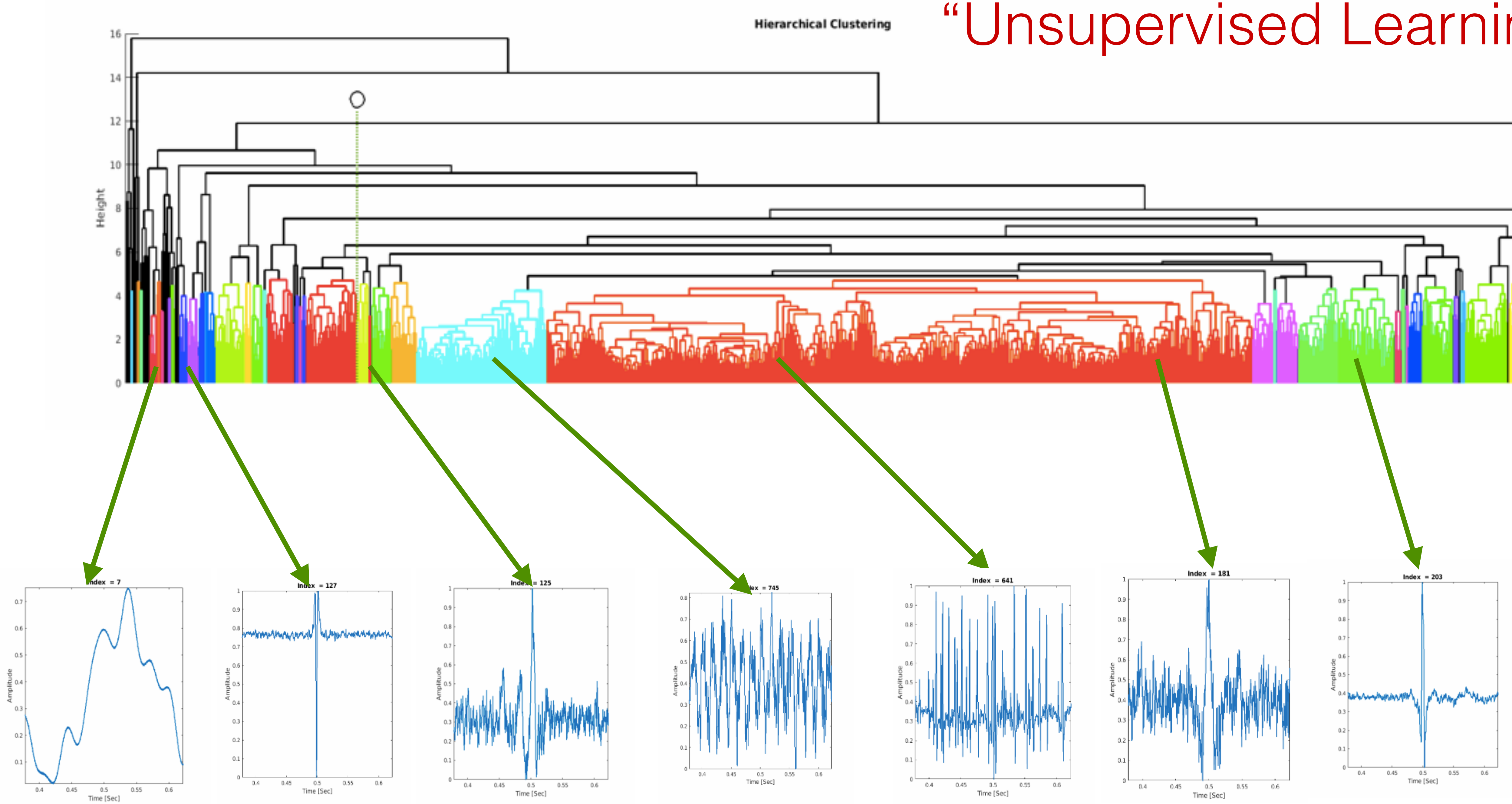
- Many of them have distinct time-frequency morphology
- Some of them share similarity with GW signals
- Leads to false triggers in various search pipelines
- Matched filtering and Burst pipelines mostly affected
- Often such triggers leave no signature in auxiliary channels
- Morphology based veto needs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

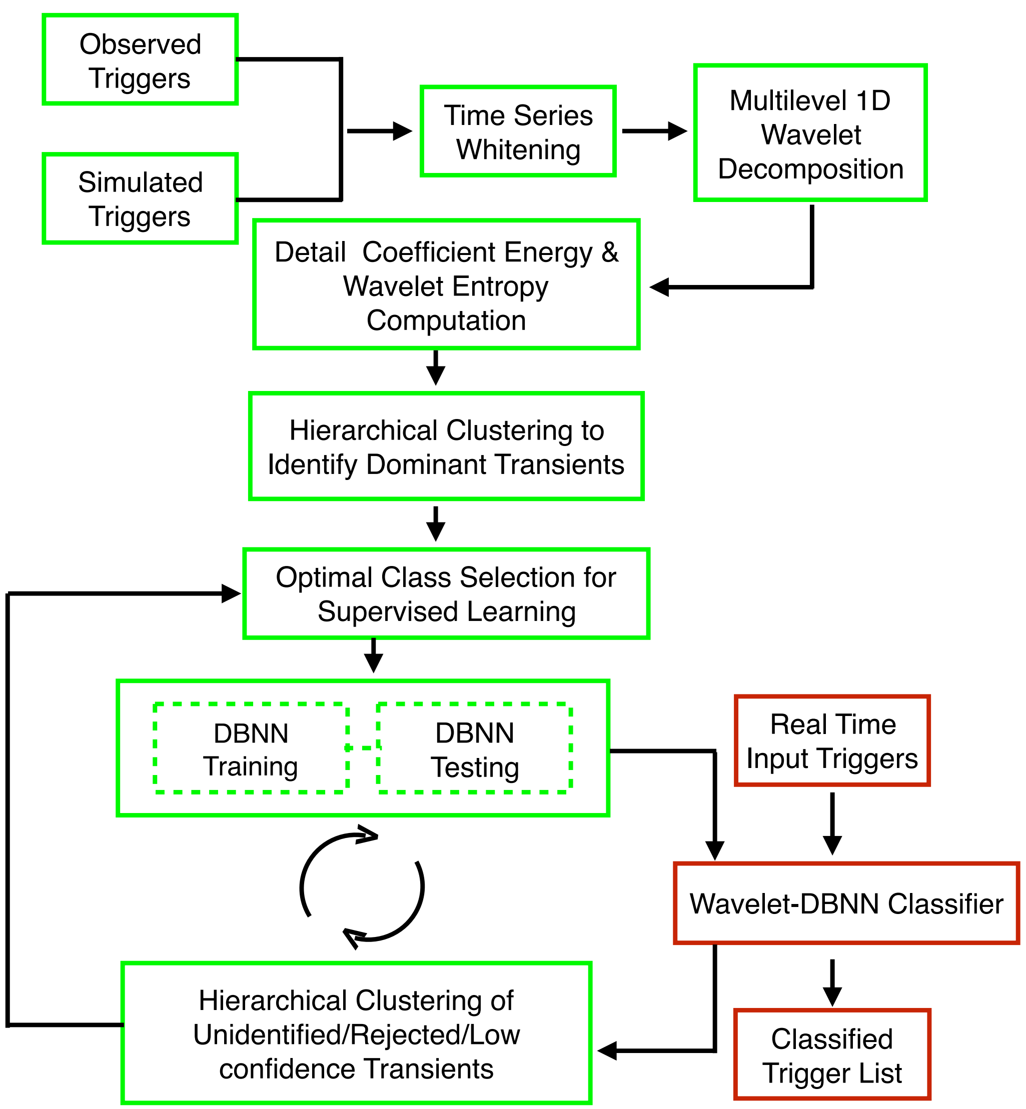
Morphology progressively changes

"Unsupervised Learning"

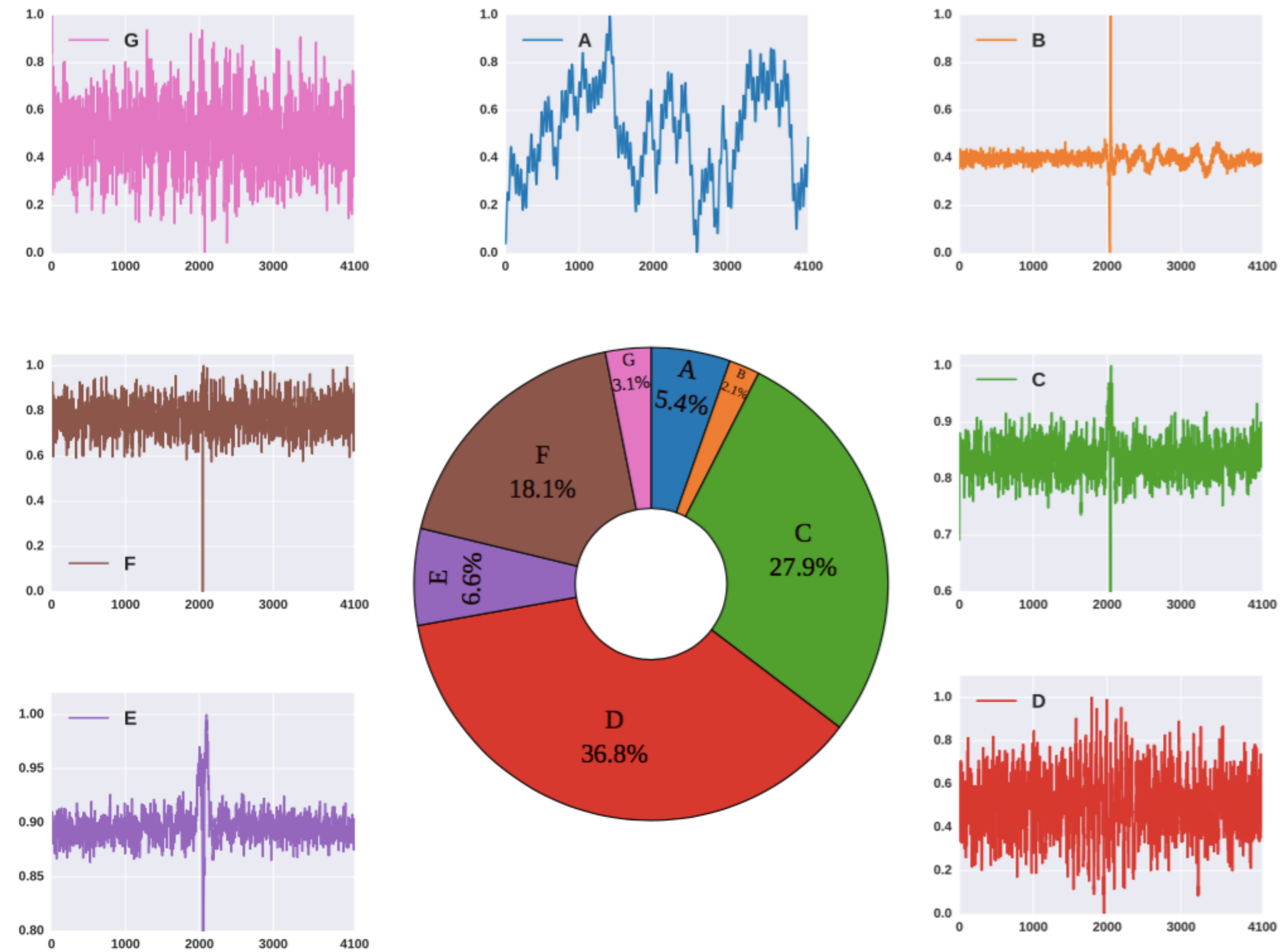


# Boosting the Differences using Neural Networks

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

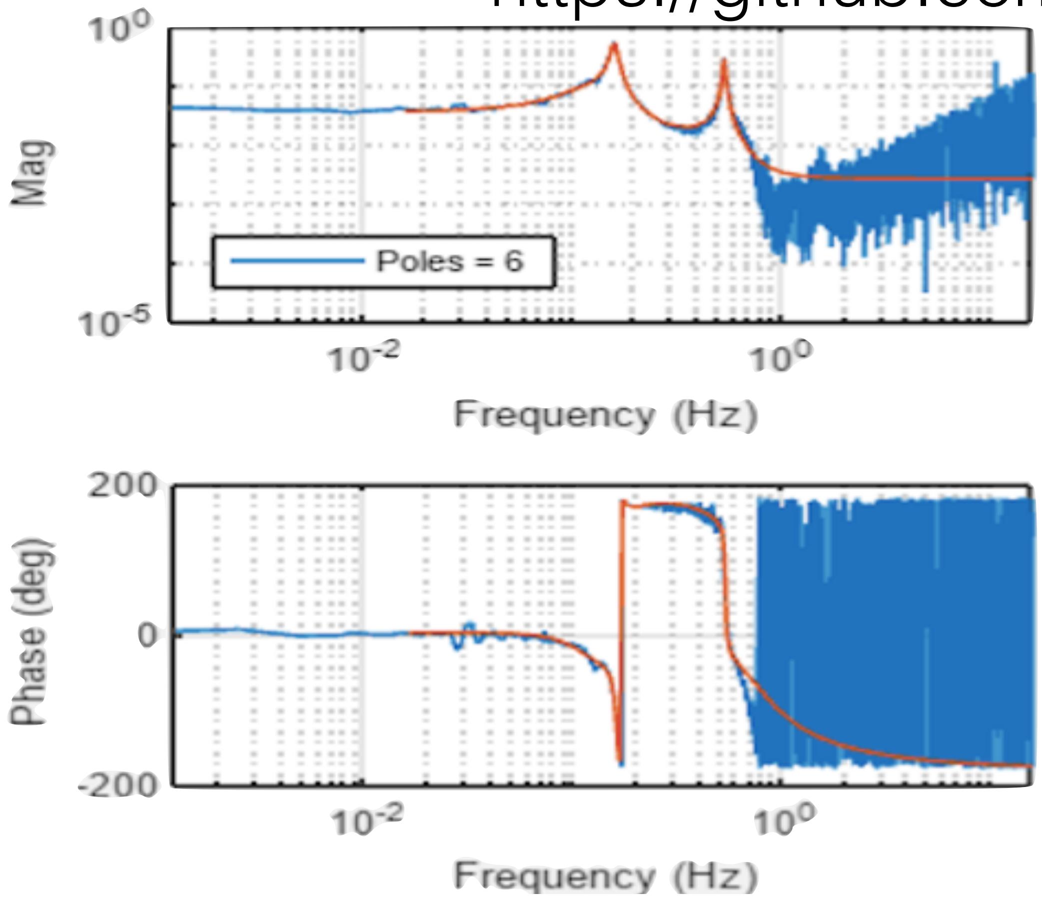

ML will be used to determine the optimal algorithm and optimal input parameters. This will require collection of user feedback and more input data.

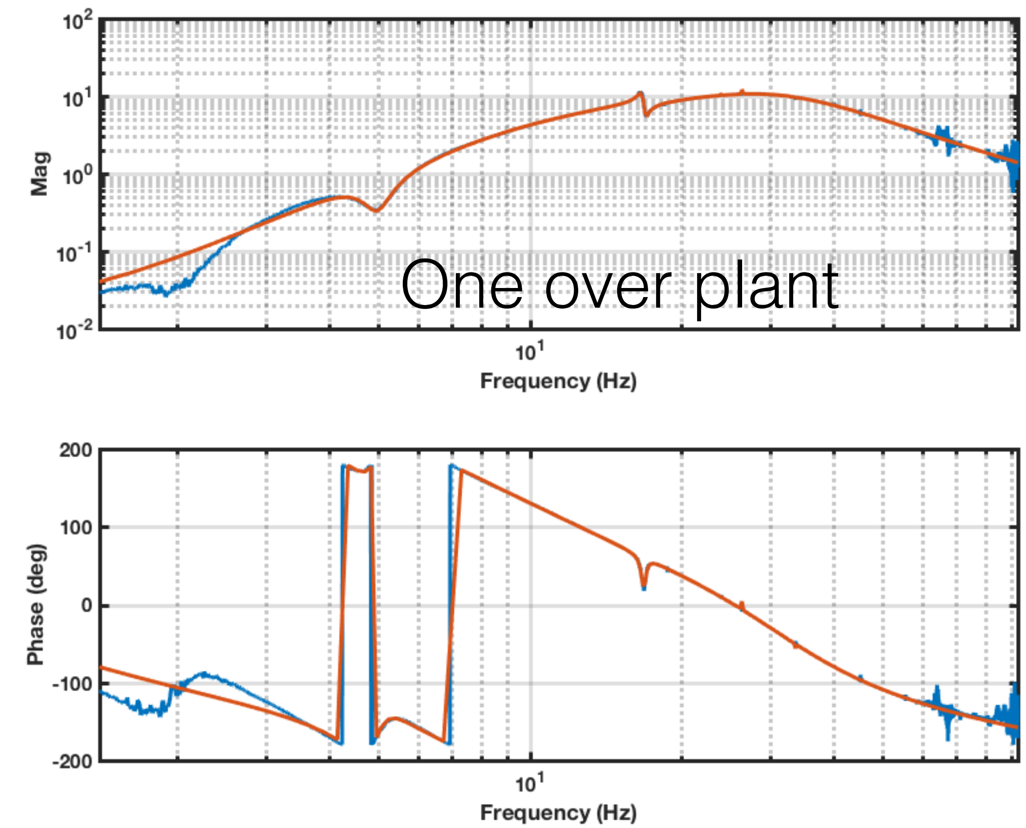


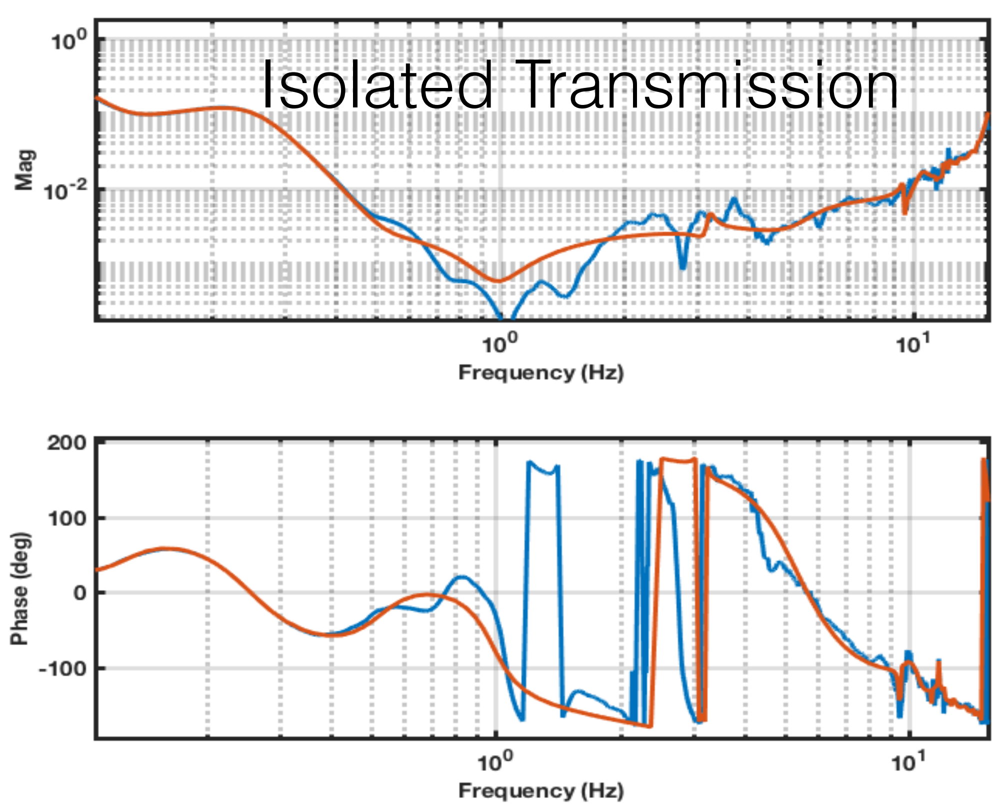
https://dcc.ligo.org/LIGO-G1700625

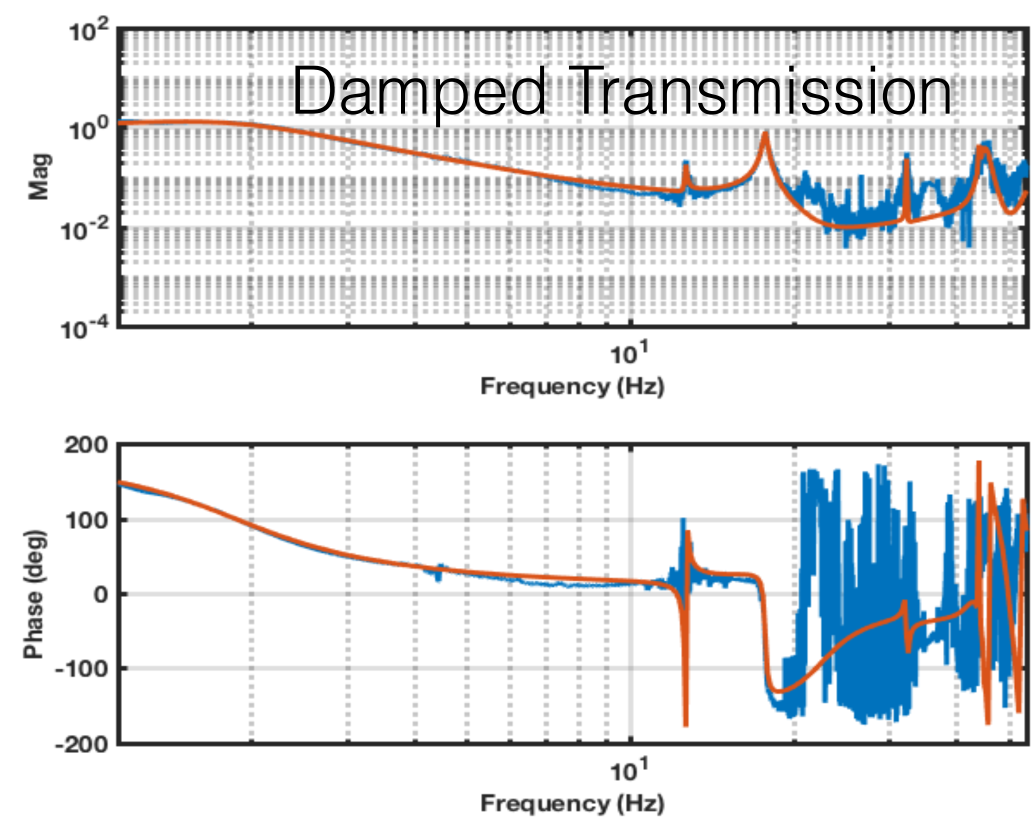
# TFestimate : Fits obtained

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



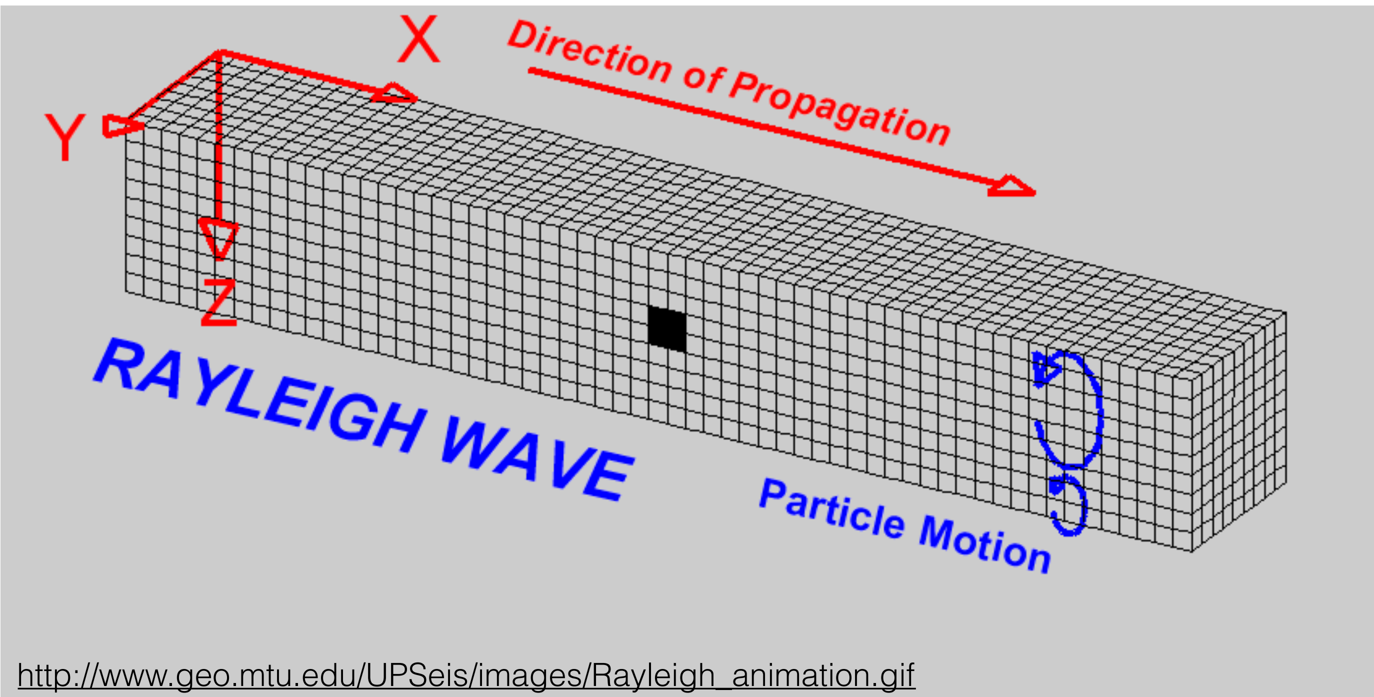



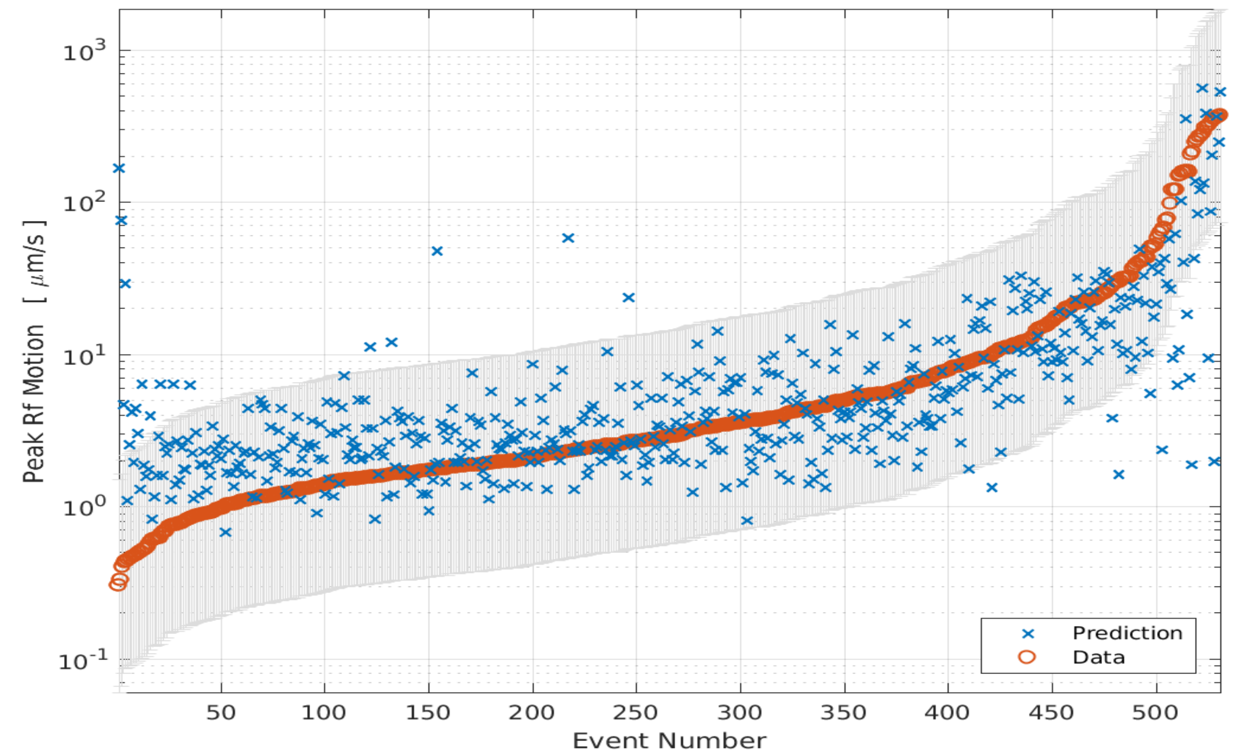
# Regression / Multiparameter Optimization

# 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**

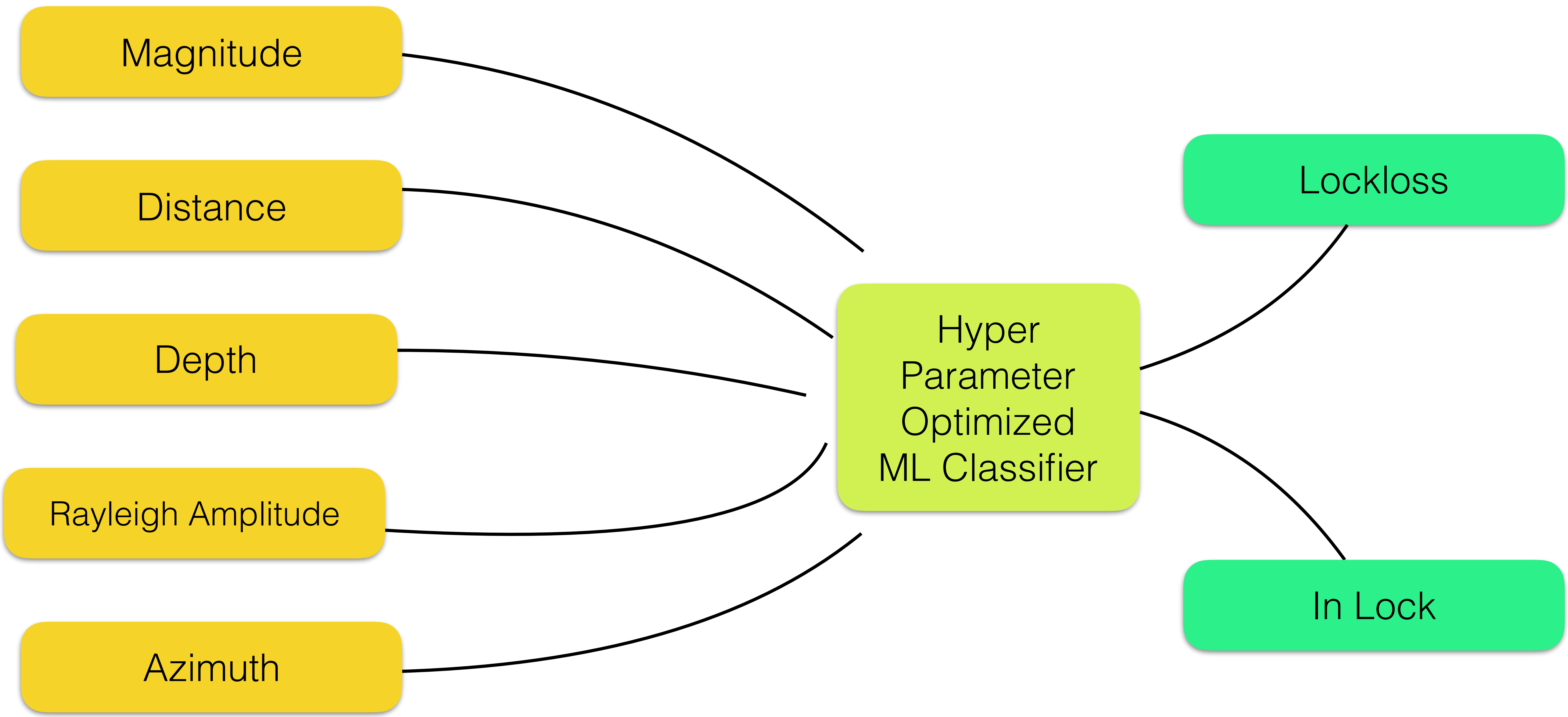
USGS event link

| 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 ?

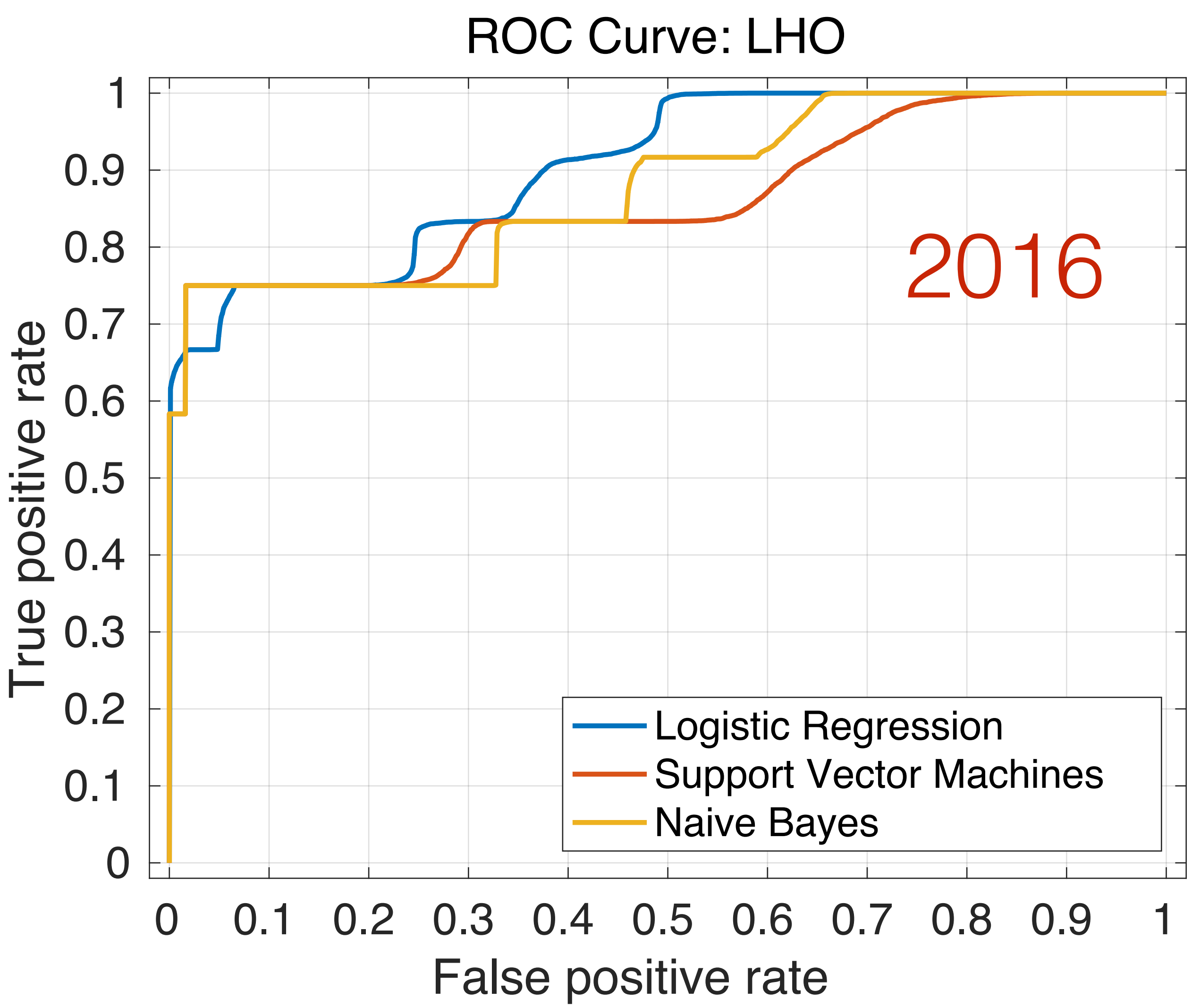
Earthquake Parameters

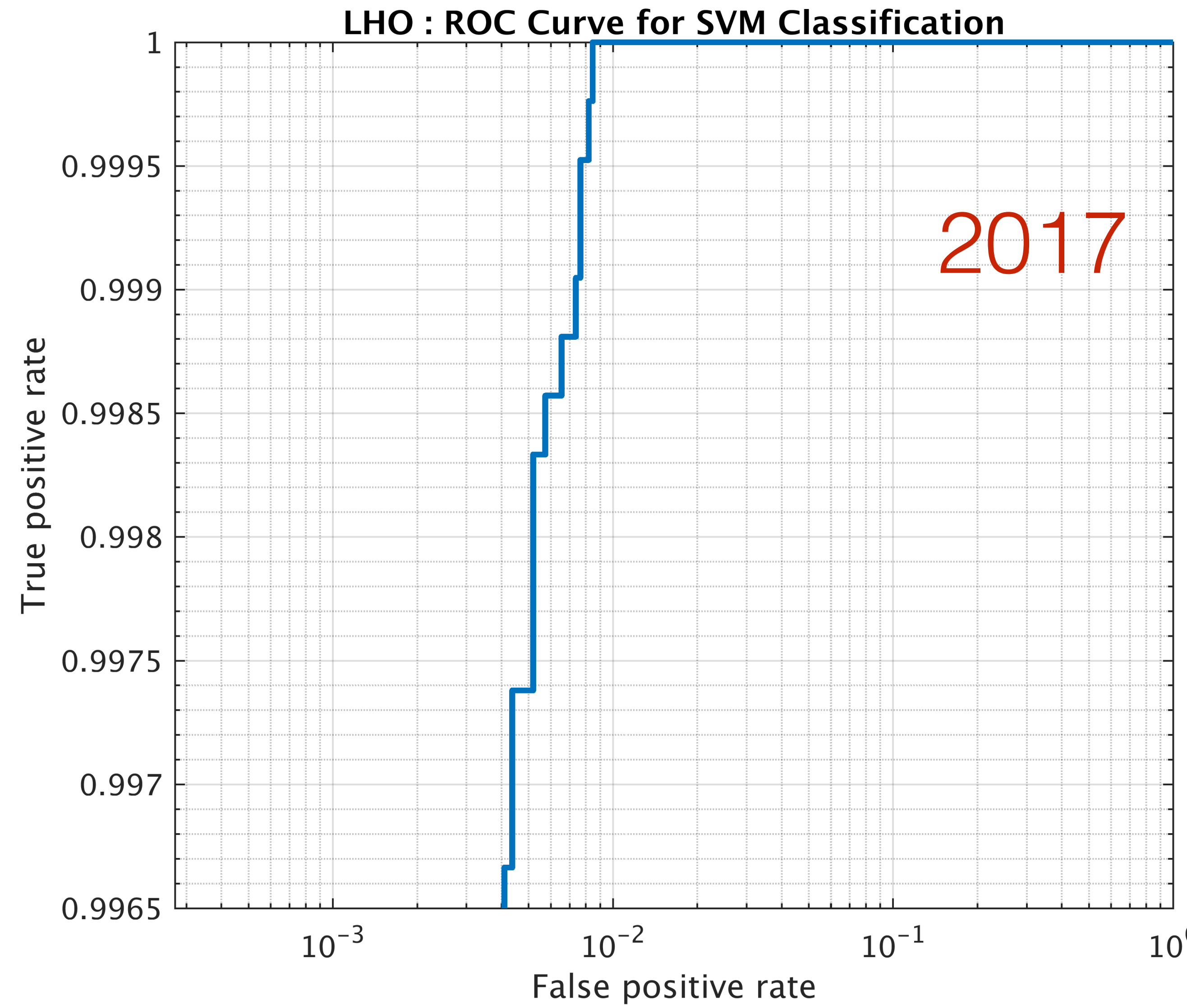



https://dcc.ligo.org/LIGO-G1602420

# 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…*