EGO European Gravitational Observatory

Advanced Virgo ENV

Hunting environmental noise in Virgo

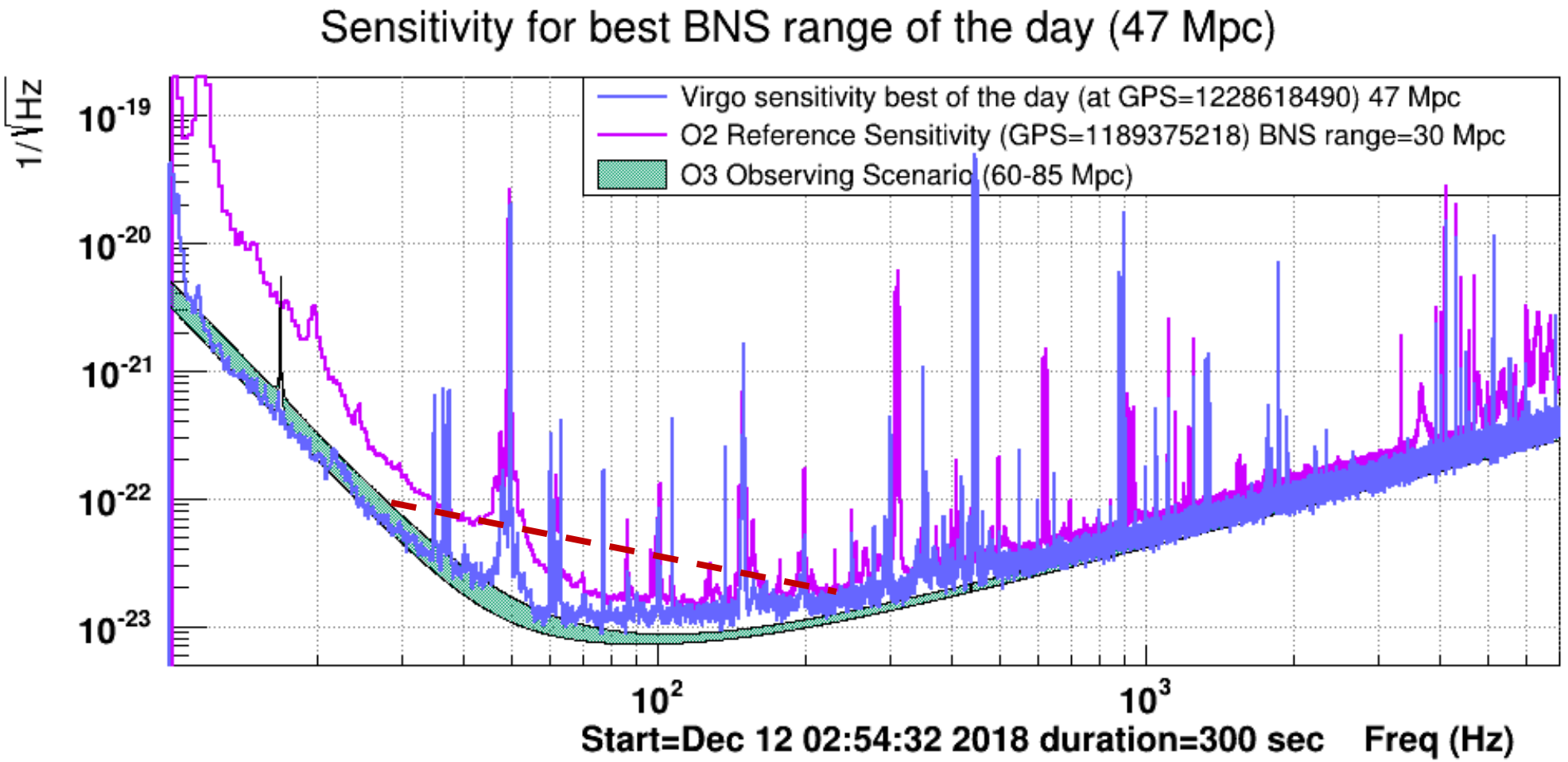
Irene Fiori – EGO

1st conference on ML for Gravitational Waves – EGO
Jan. 14th 2019

This talk

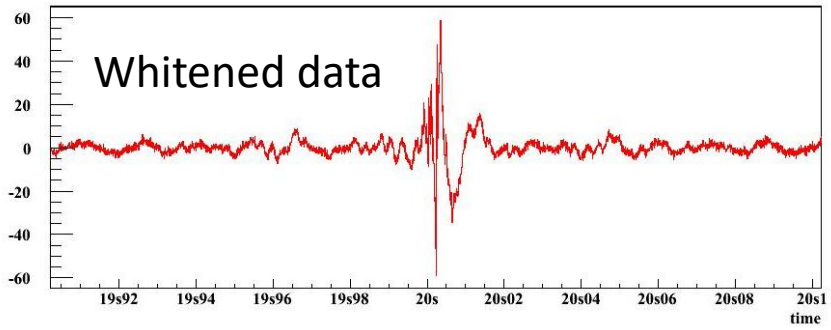
- Introduce *Noise* of a GW detector:
  - classes, monitoring, sources (environmental)
- Show working examples, focusing on:
  - Peculiar T-F patterns
  - Investigation methods
  - Investigation tools

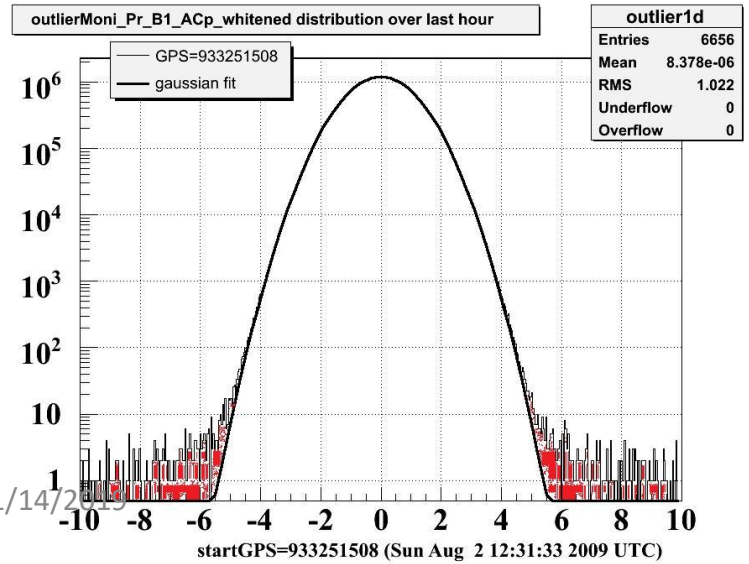
The Virgo noise curve

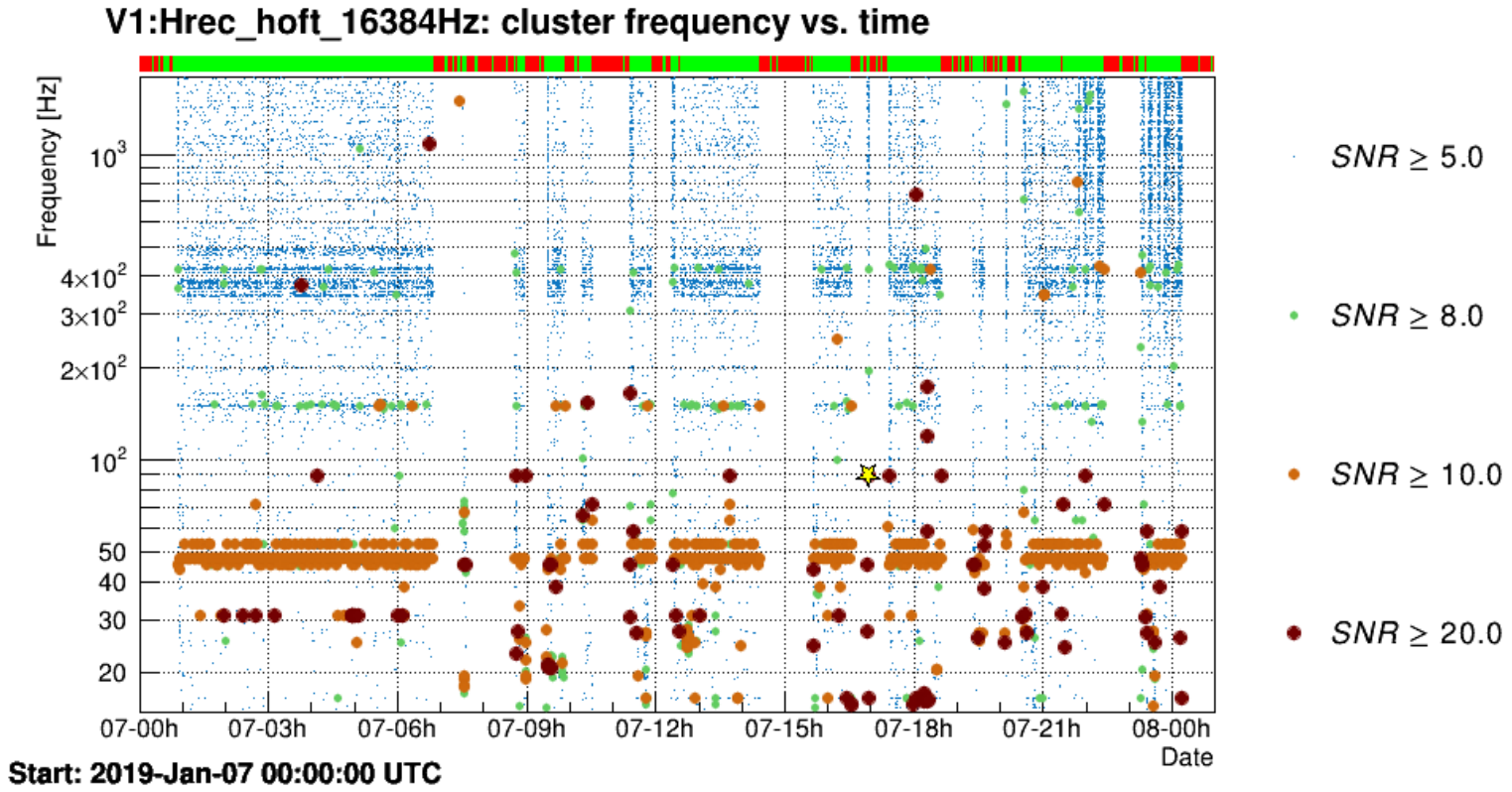


Transient noise

- Some (not all) of searched GW signals are short transients: coalescences, supernovae (few 100ms to few sec long). Quest for: stationary detector noise. Glitch-gram (transients are detected as energy clusters as specific time, frequency and S/N)

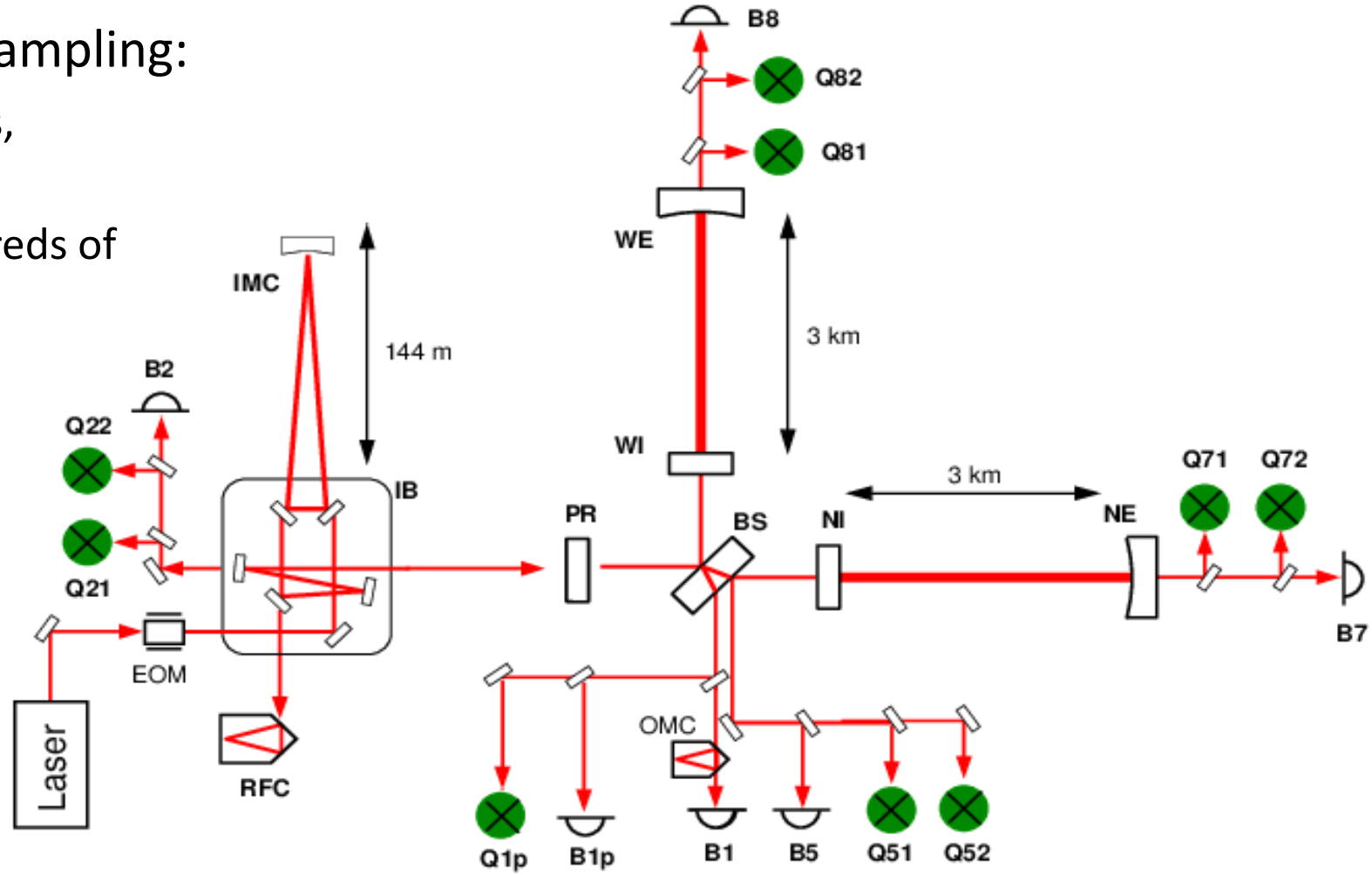






Interferometer Monitoring

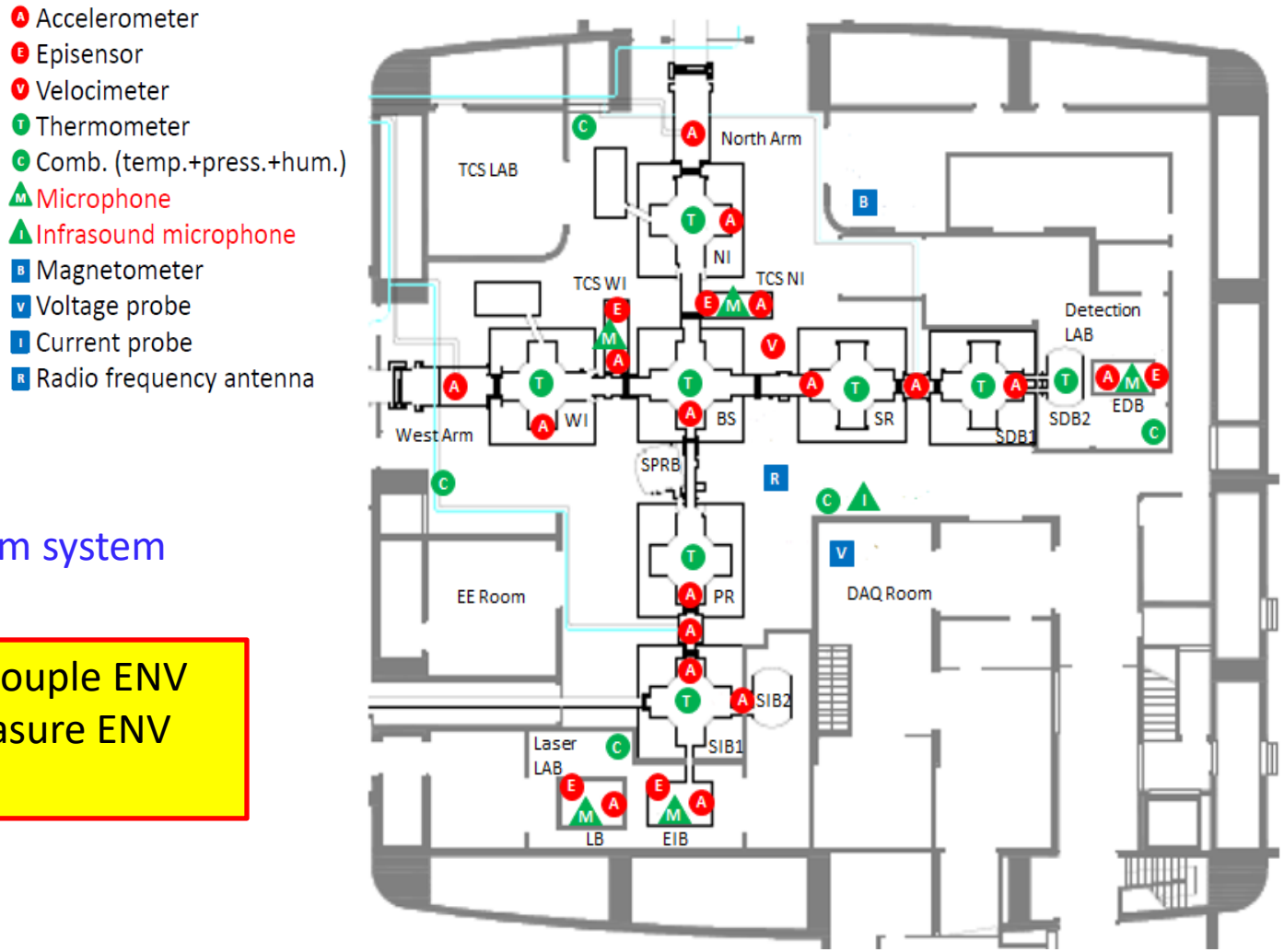
- ≈10,000 FAST probes, kHz sampling:
  - Beam monitors (photodiodes, quadrants, cameras)
  - Actuation & sensing of hundreds of feedback loops
  - Distributed clocks
  - Environment monitors
- Data flow is ≈50 MB/s



Environmental monitoring

- ≈200 <u>fast</u> probes (1 to 20kHz sampling)
  - seismometers, accelerometers
  - microphones
  - RF antennae
  - magnetic, voltage, current
- ≈12000 <u>slow</u> probes (1Hz sampling):
  - ENV temperatures, weather, lightings;
  - infrastructure machines, HVAC, UPS, vacuum system

Probes are close to ITF critical parts (prone to couple ENV noise). The idea is that they are capable to measure ENV disturbances with S/N much better than ITF



Sources of Environmental noise

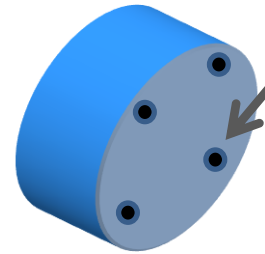
Virgo is very well isolated from the environment (suspended mirrors and optical benches seismic, in-vacuum beams) but the required low noise is Extremely(!) demanding

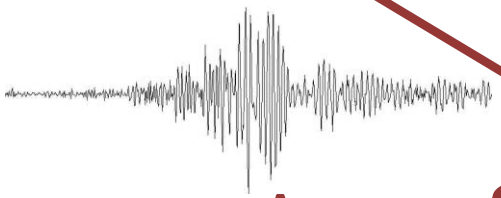
Radio waves (6MHz, 8MHz, 56MHz)

Photodiodes RF modulated used for angular and longitudinal controls (heterodyne)

Electro Magnetic fields

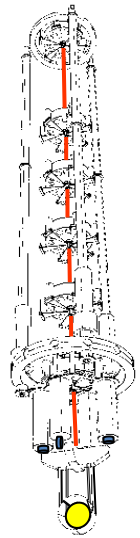
Act on mirror MAGNETS





Slow ground motion

Excite mechanical modes of mirrors and optical benches suspensions



Seism & Sounds

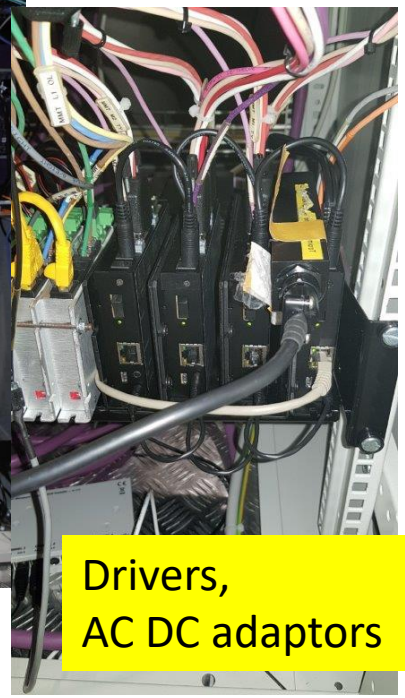
excite vibrations of vacuum pipes and tanks, optics on in-air benches

Imprint phase noise on spurious scattered light beams

Noise sources: interferometer infrastructure

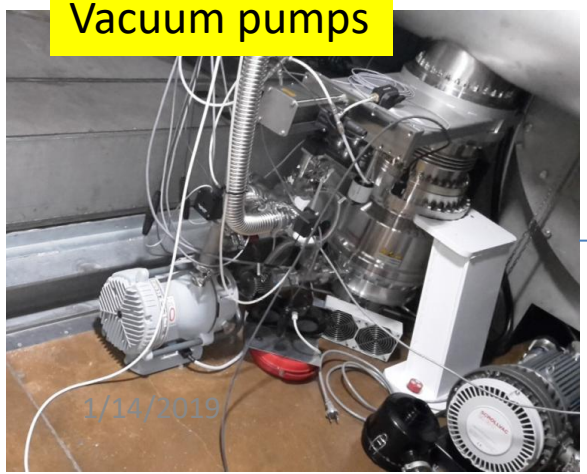

Chillers

Electronics, cooling fans

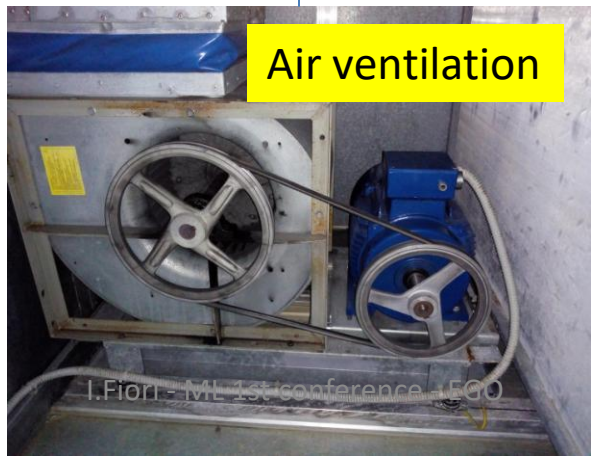


Drivers,
AC DC adaptors

Vacuum pumps



Air ventilation



External sources… distant but loud!

9

The Hunter work

(Reading from The *Hunter's Handbook …*)

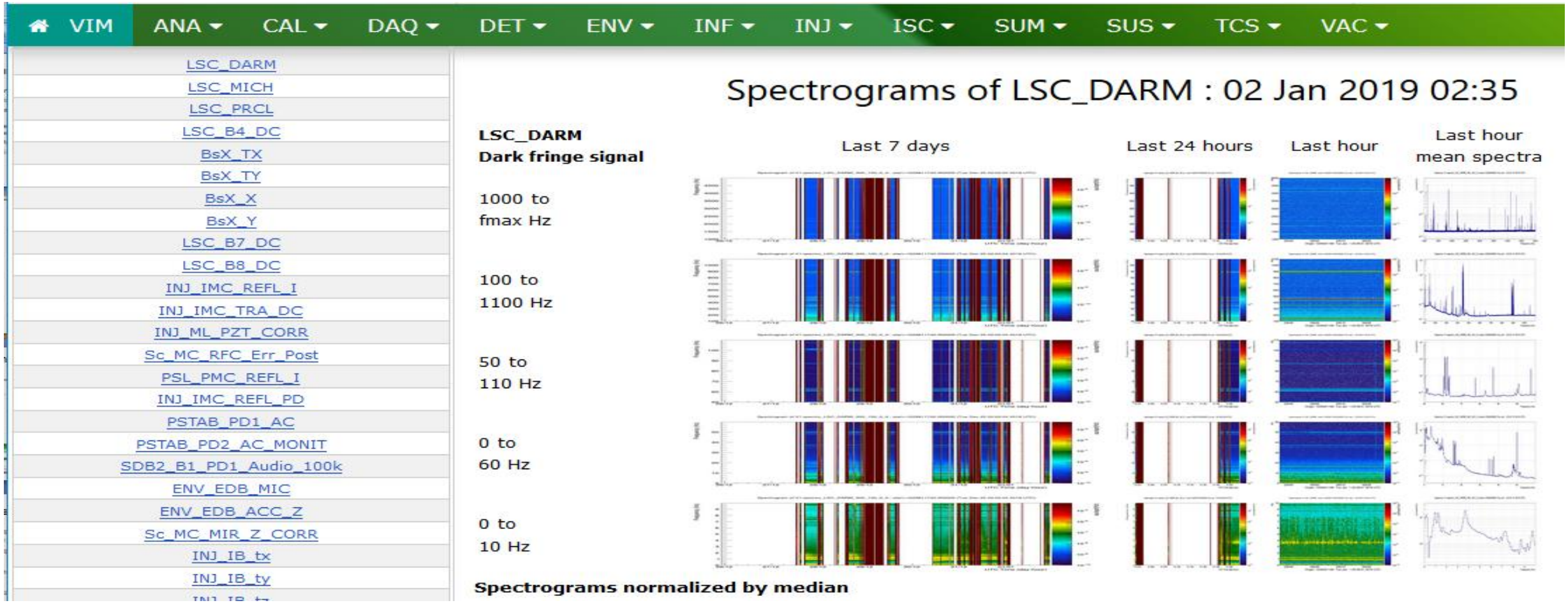
Phase 1 – identify noise source and path

- Visual inspection of signals and (mostly) of time-frequency images
- Correlation with other channels, or events (reading e-logbook activity reports)

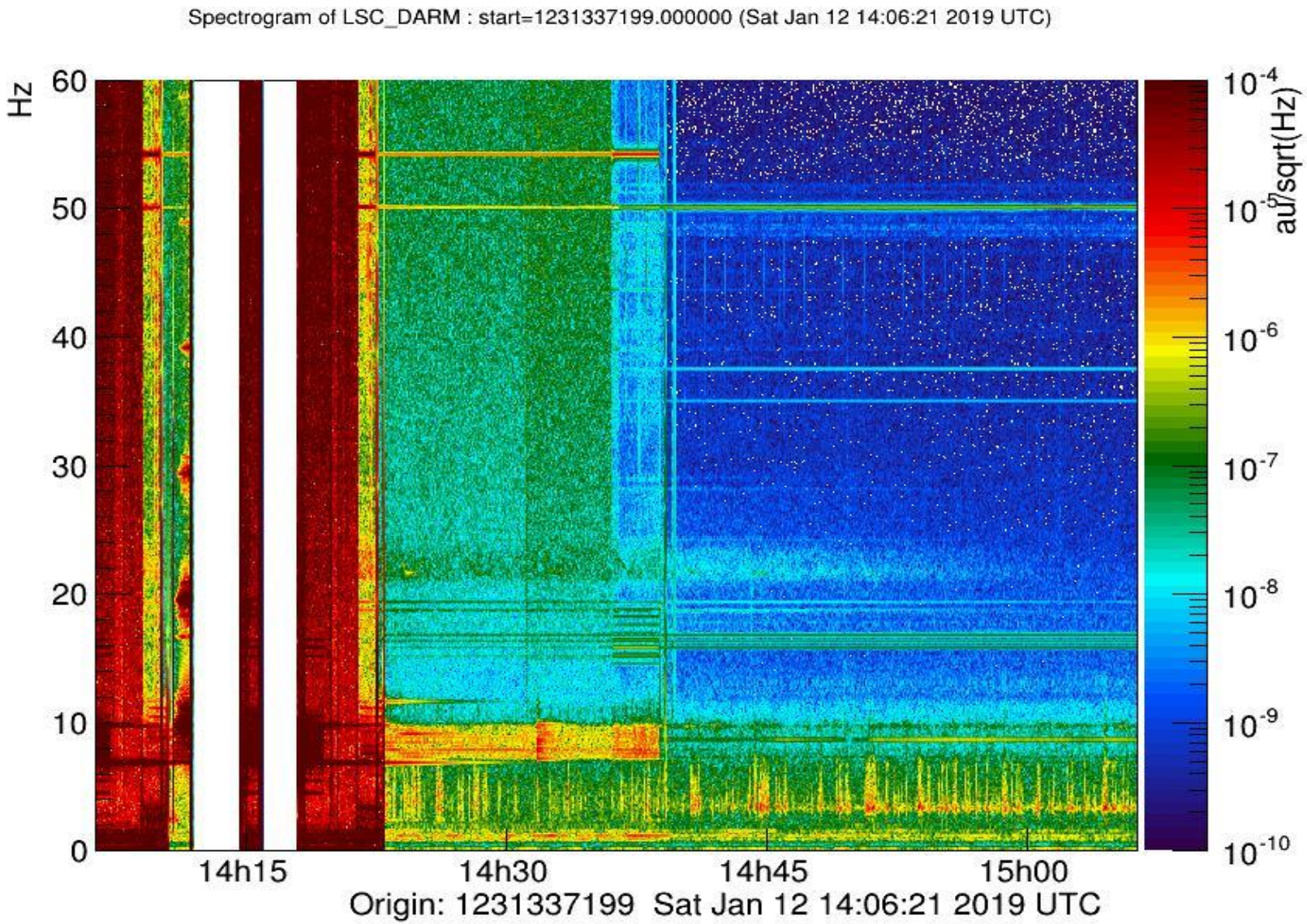
!! Tons of data (50 MB/s) → Need for automation !!

Phase 2 – devise and implement mitigation actions

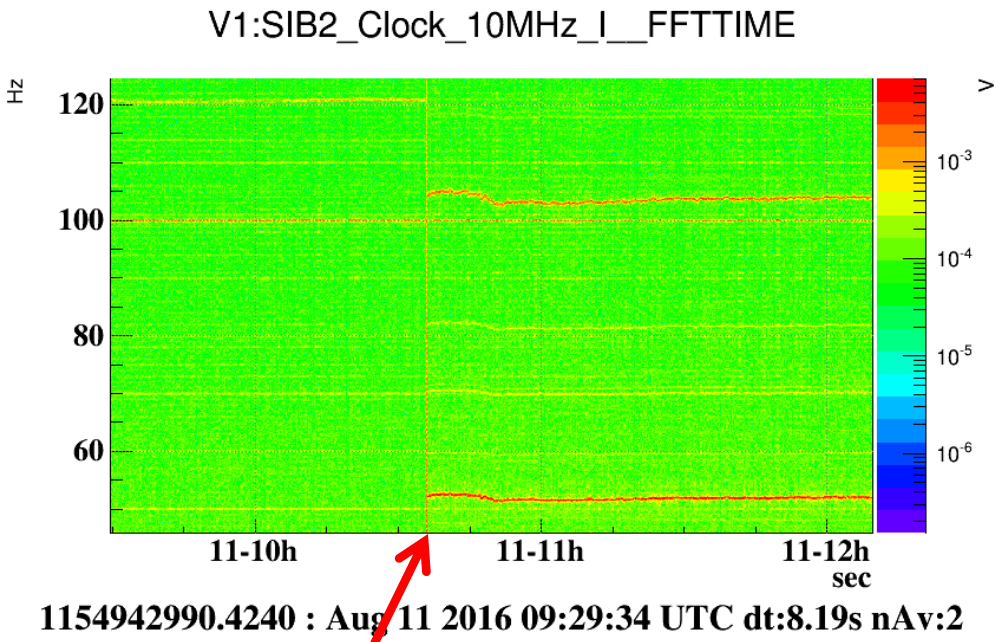
Inspection of T-F images

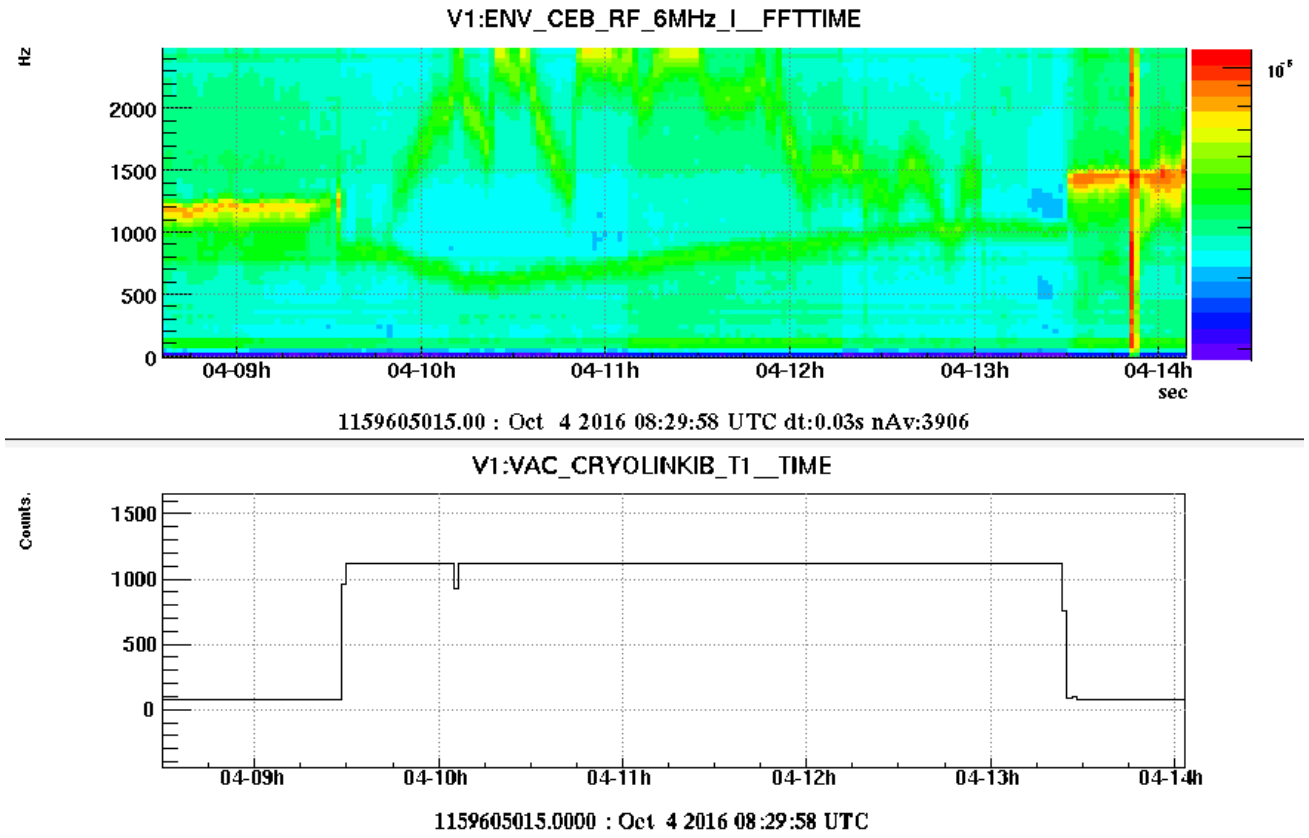


Inspection of Time-Frequency images



Correlate on/off lines





AdV-COM (AdV commissioning (1st part))

masserot,pacaud - 09:08, Thursday 11 August 2016 (34481)

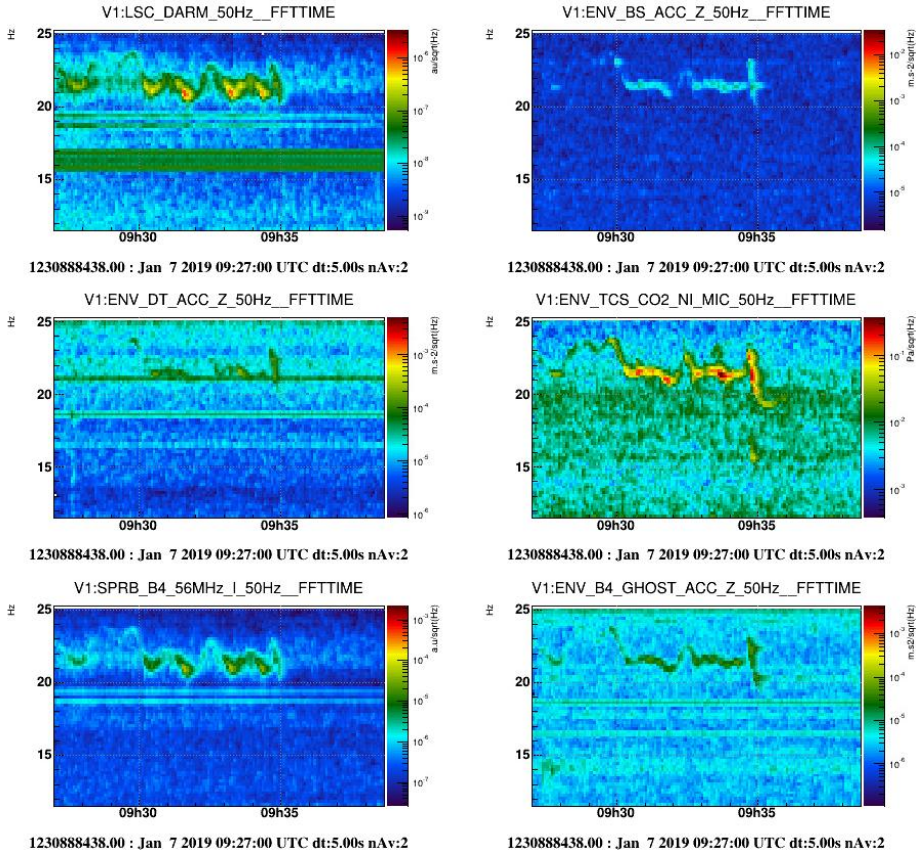
Atomic GPS reciever

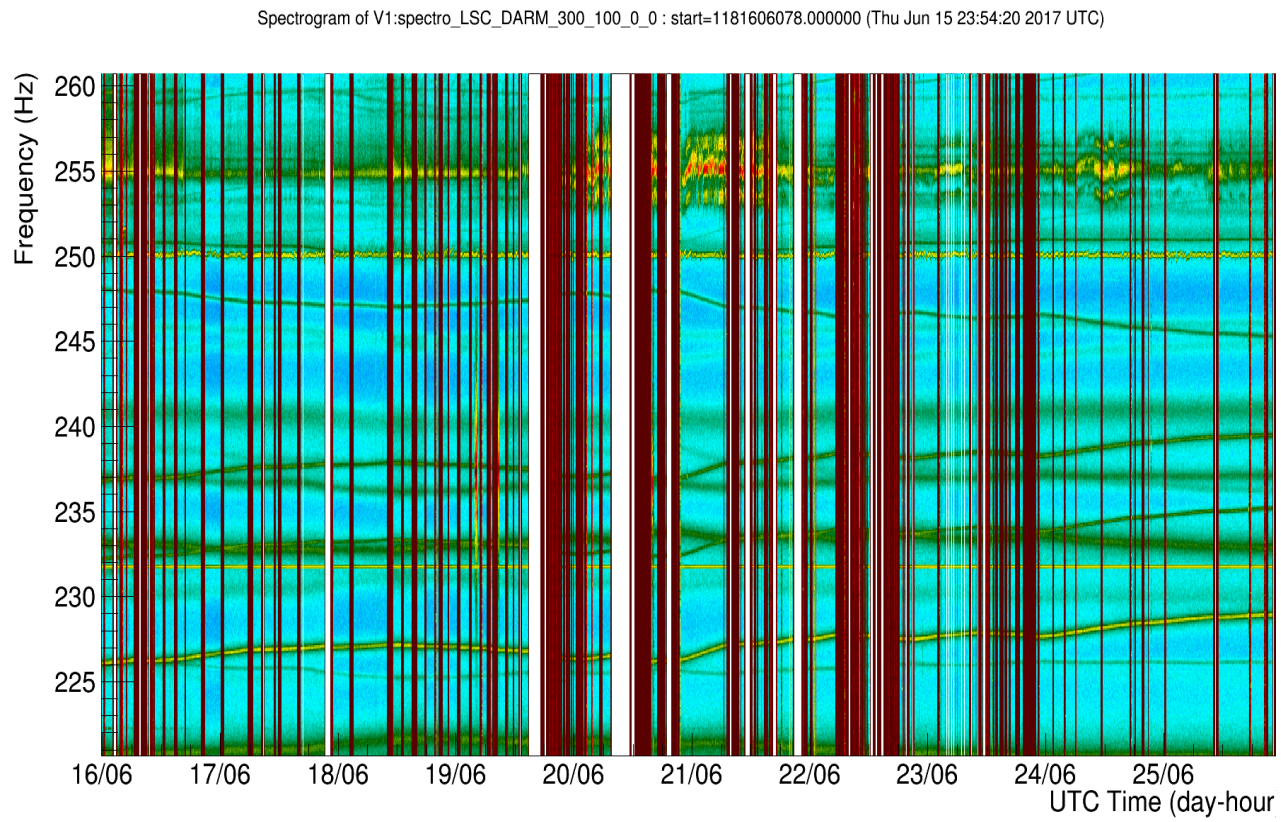
We observed that the GPS status propagated by the IRIGB is al

I bring from LAPP an atomic GPS receiver with its cable and ant

and to compare the IRIGB generated by an Atomic GPS receiver

Repeated T-F patters

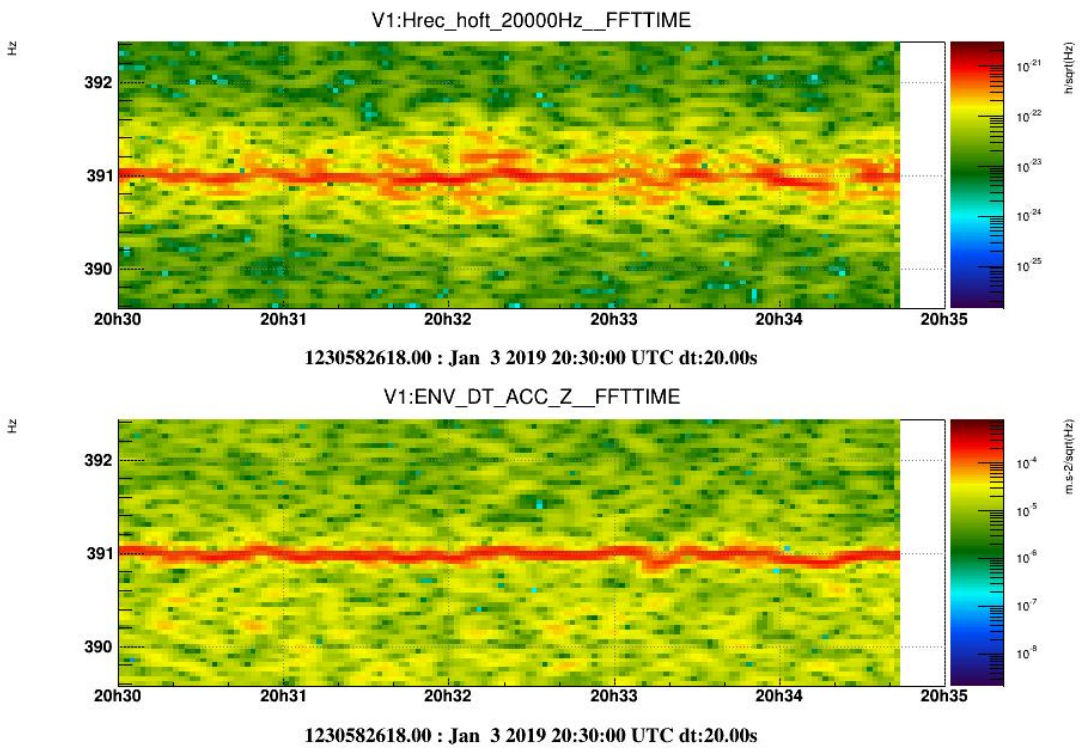


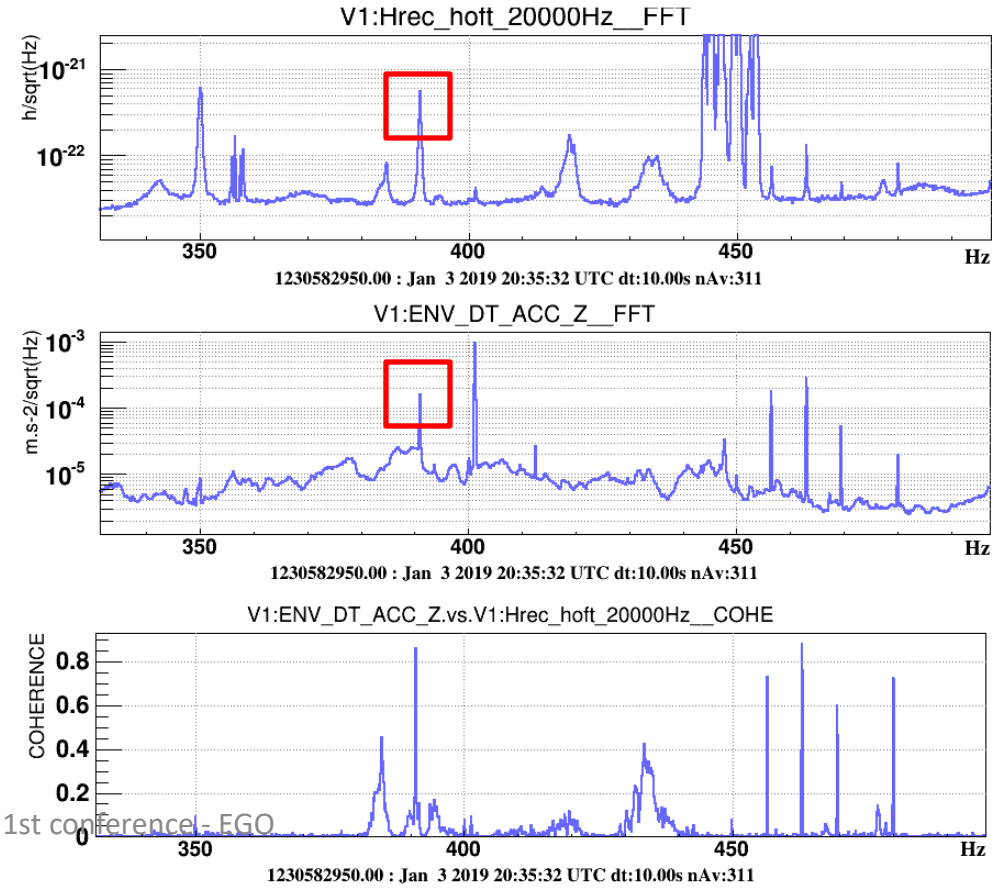


Case of seismic source, cooling fan

- Noise linearly coupling to ITF:
  expect significant coherence with the witness channels

$$C_{xy}(\omega) = \frac{|P_{xy}(\omega)|^2}{P_{xx}(\omega)P_{yy}(\omega)}$$

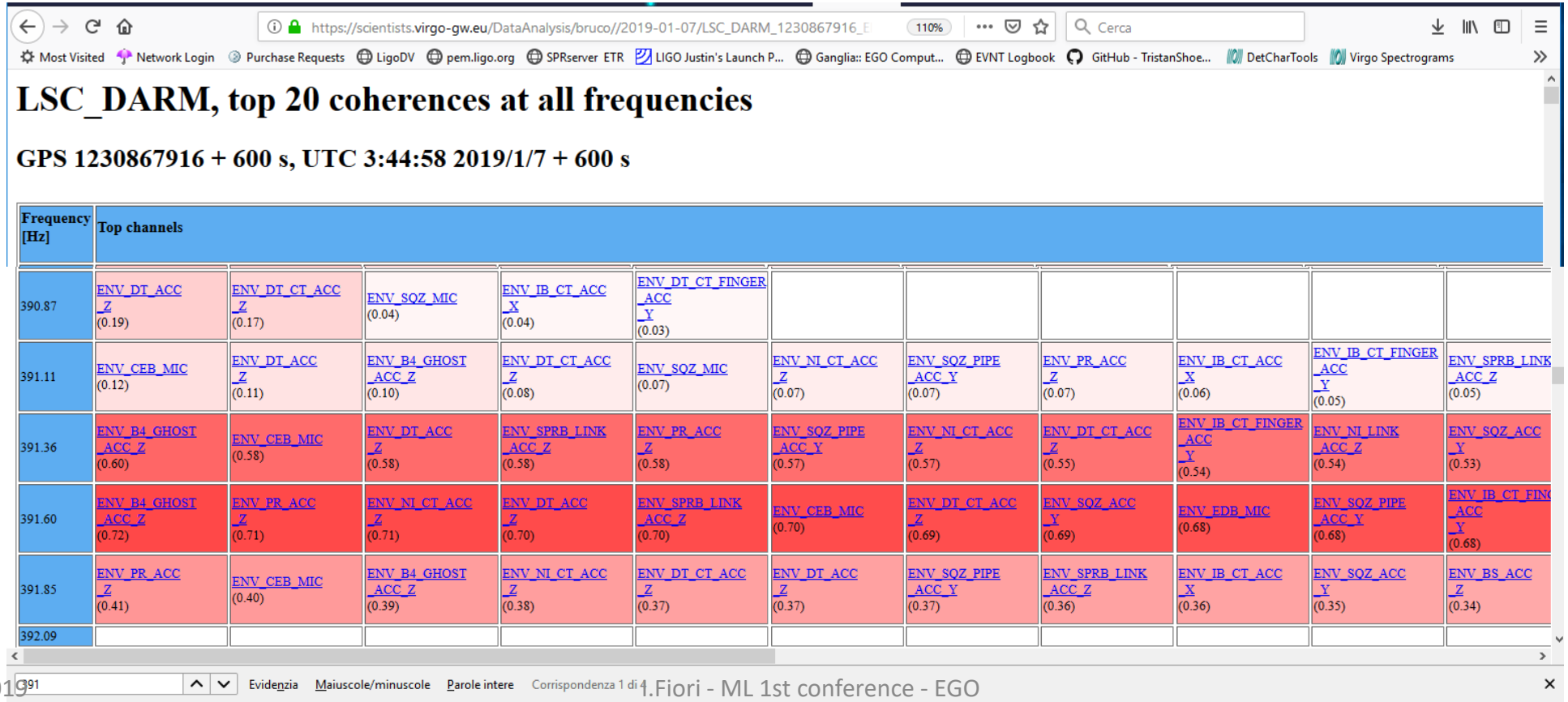




“Brute force” Coherence tool

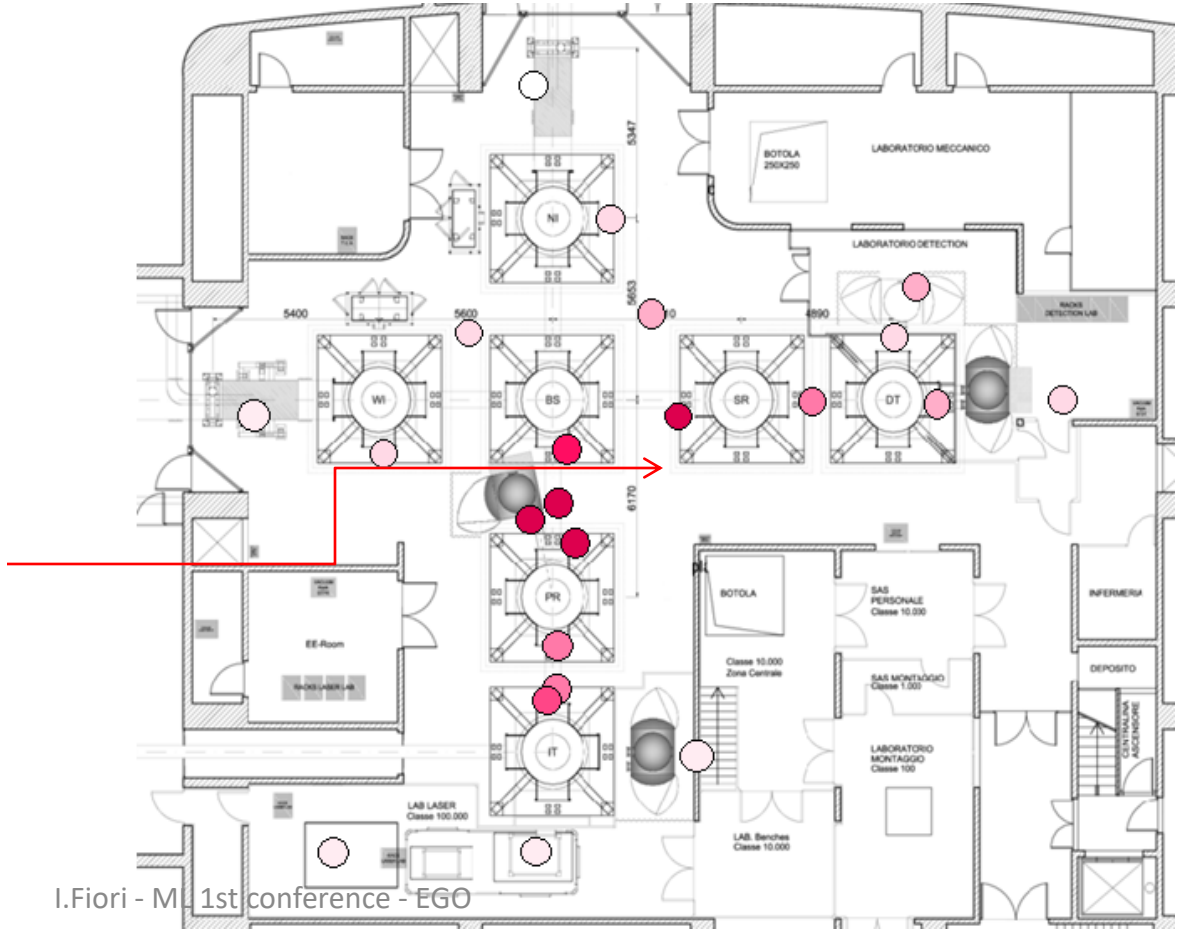
- BruCo – *computes and ranks Coherence* between Hrec and all AUXILIARY channels (G.Vajente, https://dcc.ligo.org/LIGO-G1500230)

“brute force” approach = search noise correlation in ALL (not obvious) channels (i.e. O(10000 channels)!)



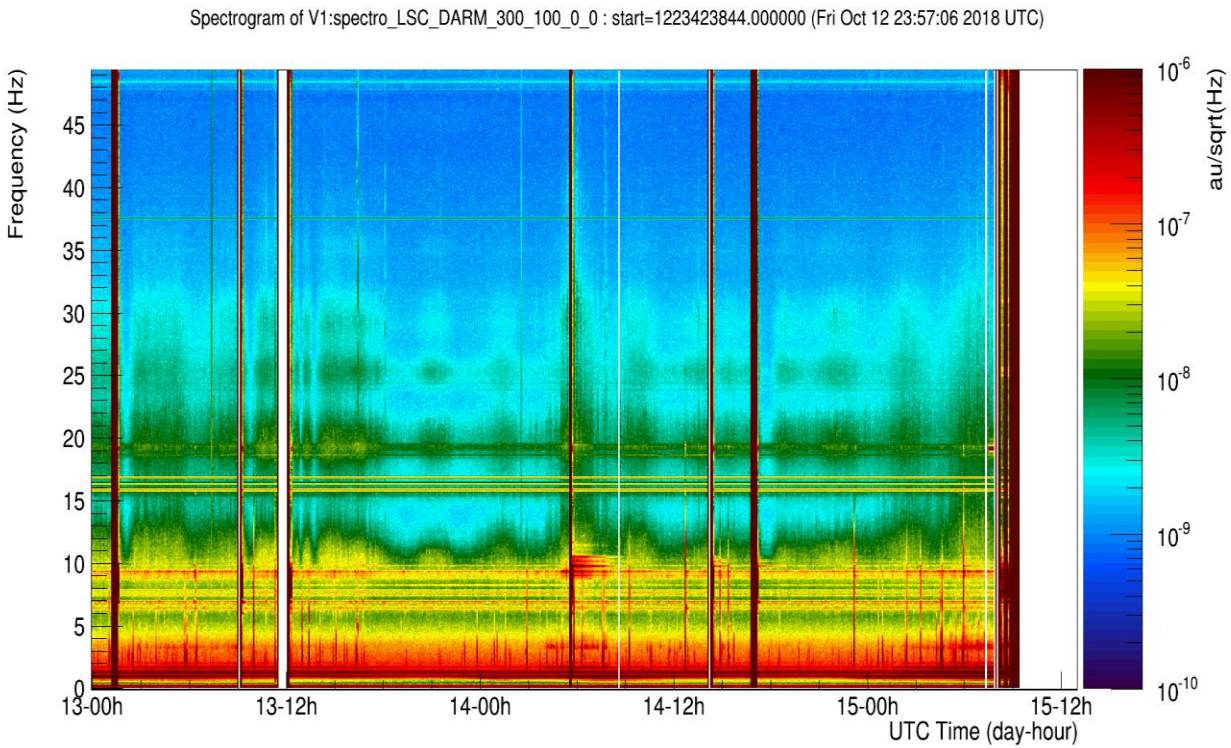
Locate the noise source

- Comparing the peak amplitude in all ENV sensors helps locating the source
- Example: 391Hz spectral line in all CEB accelerometers

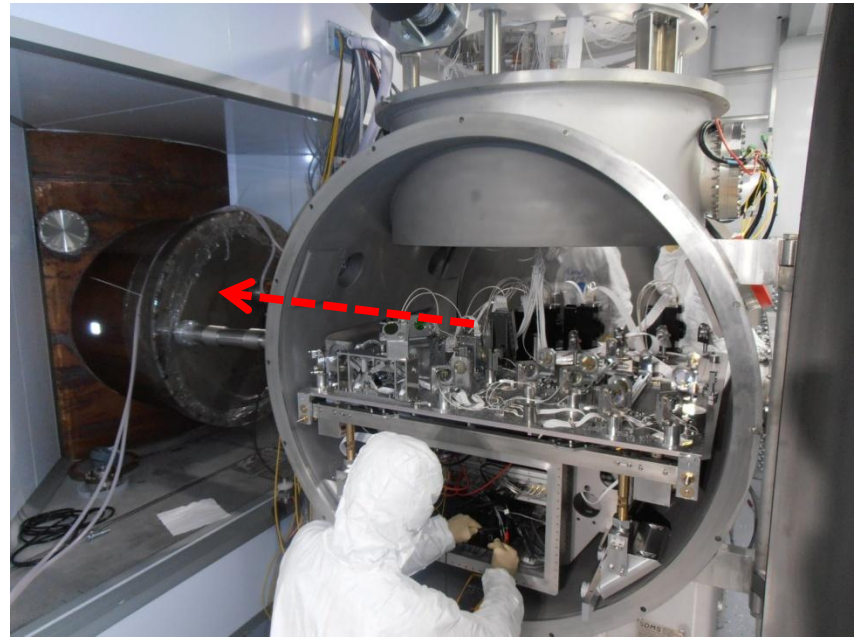


Case of amplitude modulated patterns

- During C11 the SDB2 optical bench was sitting on ground (not suspended) so slowly moving following room temperature. The optics were moving with respect to the rest of ITF and back scattering some amount of light
- The coupling is not linear, so we do not expect coherence (BruCo does not help…)

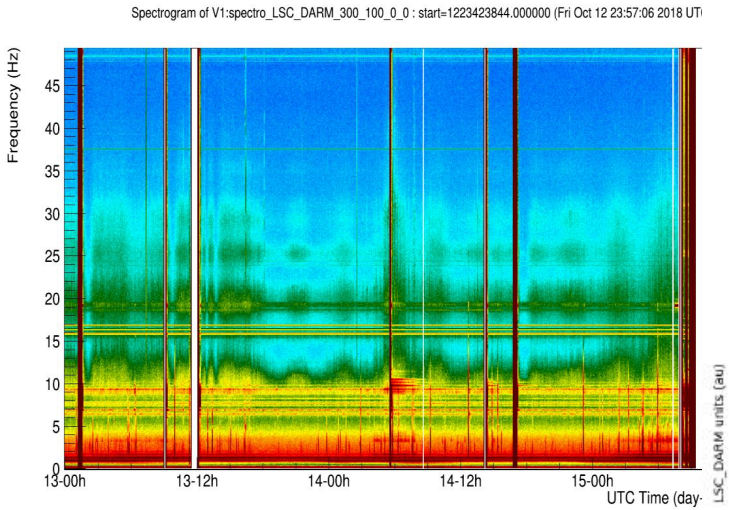


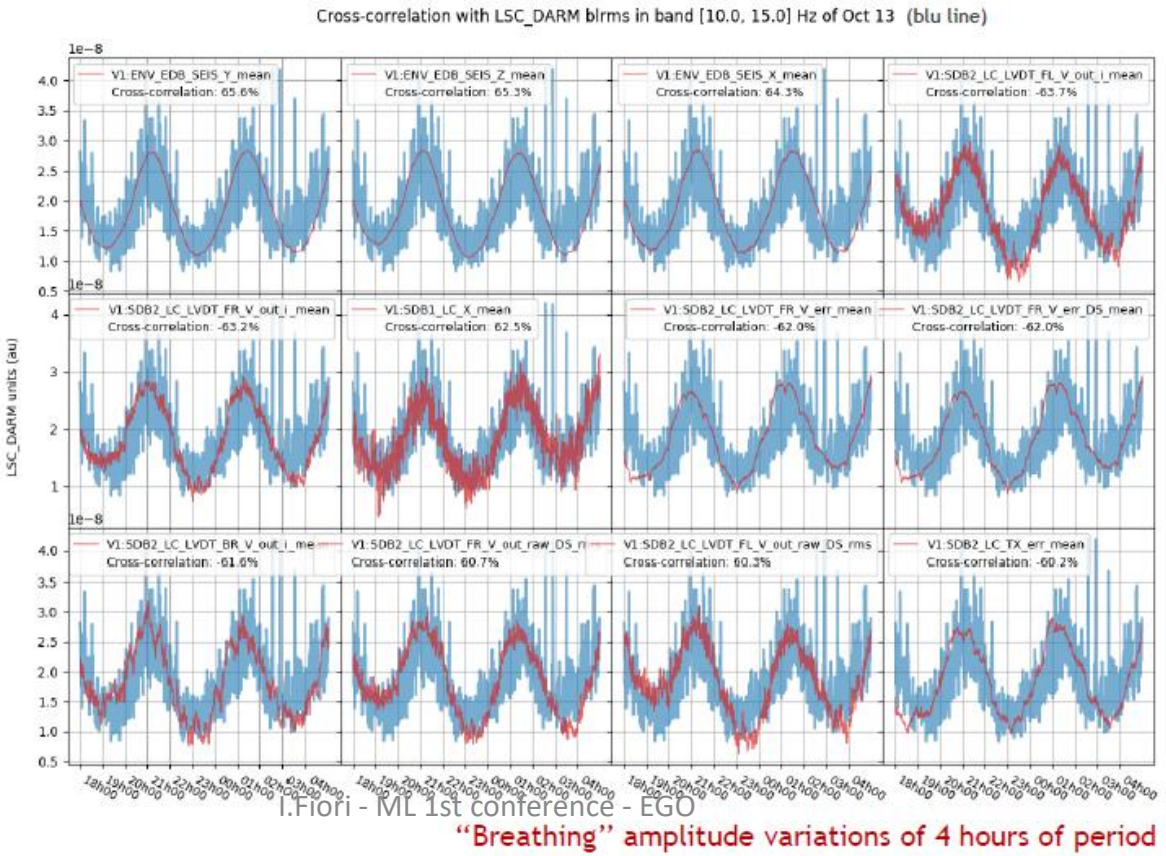
$$h(t) = G\ (\sin\ (\frac{4\pi}{\lambda}(x(t) - x_0)))$$



“Brute force” correlation

- NonNA tool, F.Di Renzo, [VIR-0406A-18]
- Hrec RMS noise in the [10,30]Hz band is correlated with few thousands of SLOW auxiliary channels. Most correlated channels were slow monitors of bench motion and temperature





NonNA corre example

Total duration of the script: 0 hours, 7 minutes, and 47.3 seconds.

Parameters:

target:	LSC_DARM
gps:	1223488818.0
duration:	39600.0
outfs:	0.02
frequency band(s):	[10.0, 15.0]
order:	1
nameSpec_list:	['ENV_*', 'SDB2_*', 'standard']

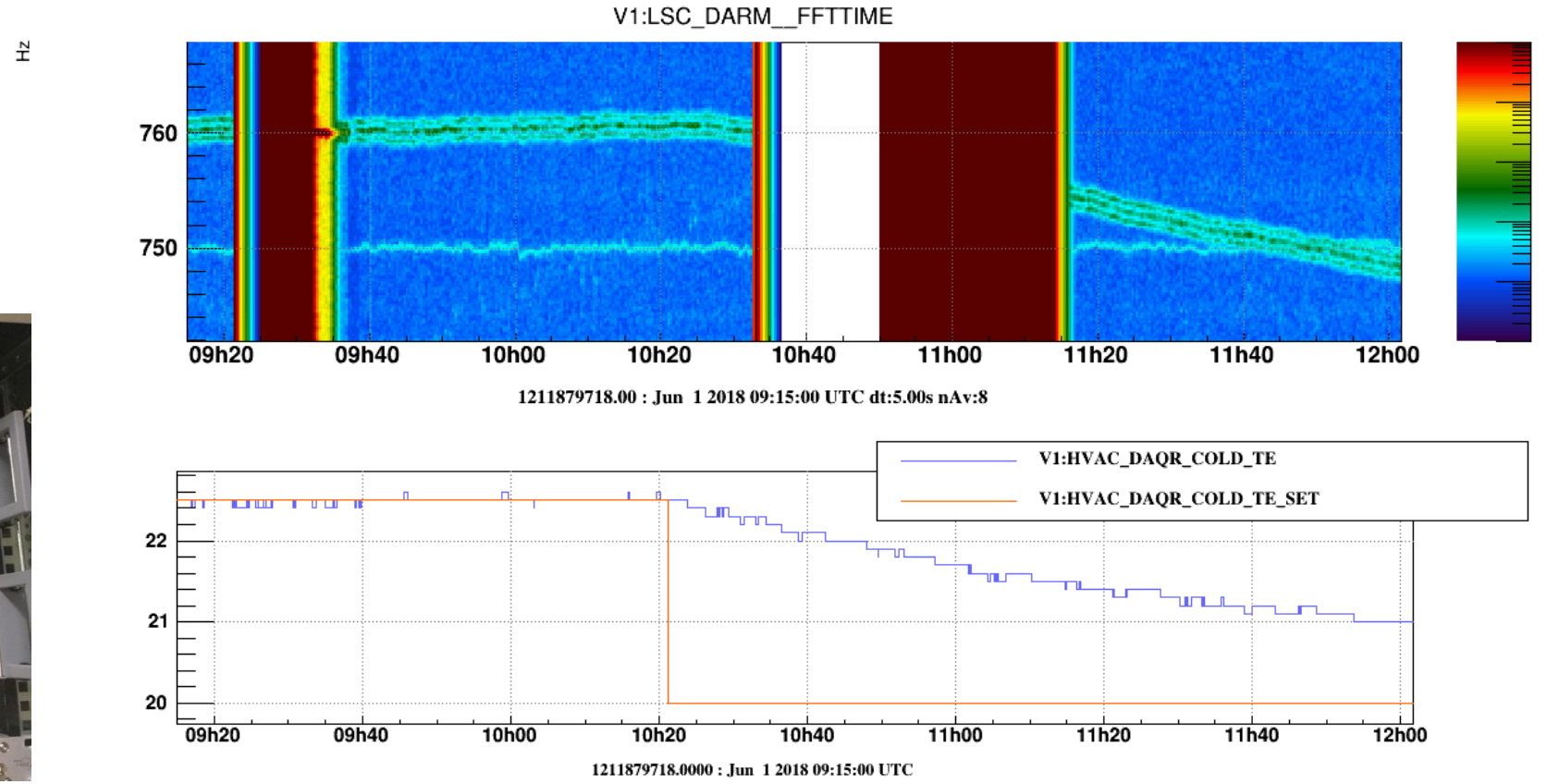
The 40 most correlated channels are:

Channel name	correlation coeff. [%]
V1:ENV_EDB_SEIS_Y_mean	**65.576**
V1:ENV_EDB_SEIS_Z_mean	**65.272**
V1:ENV_EDB_SEIS_X_mean	**64.311**
V1:SDB2_LC_LVDT_FL_V_out_i_mean	-63.709
V1:SDB2_LC_LVDT_FR_V_out_i_mean	-63.177
V1:SDB1_LC_X_mean	62.479
V1:SDB2_LC_LVDT_FR_V_err_mean	-61.986
V1:SDB2_LC_LVDT_FR_V_err_DS_mean	-61.981
V1:SDB2_LC_LVDT_BR_V_out_i_mean	-61.624
V1:SDB2_LC_LVDT_FR_V_out_raw_DS_rms	60.651
V1:SDB2_LC_LVDT_FL_V_out_raw_DS_rms	60.295
V1:SDB2_LC_TX_err_mean	-60.240
V1:SDB2_LC_TX_mean	60.210
V1:SDB2_LC_TX_err_DS_mean	-60.0

...

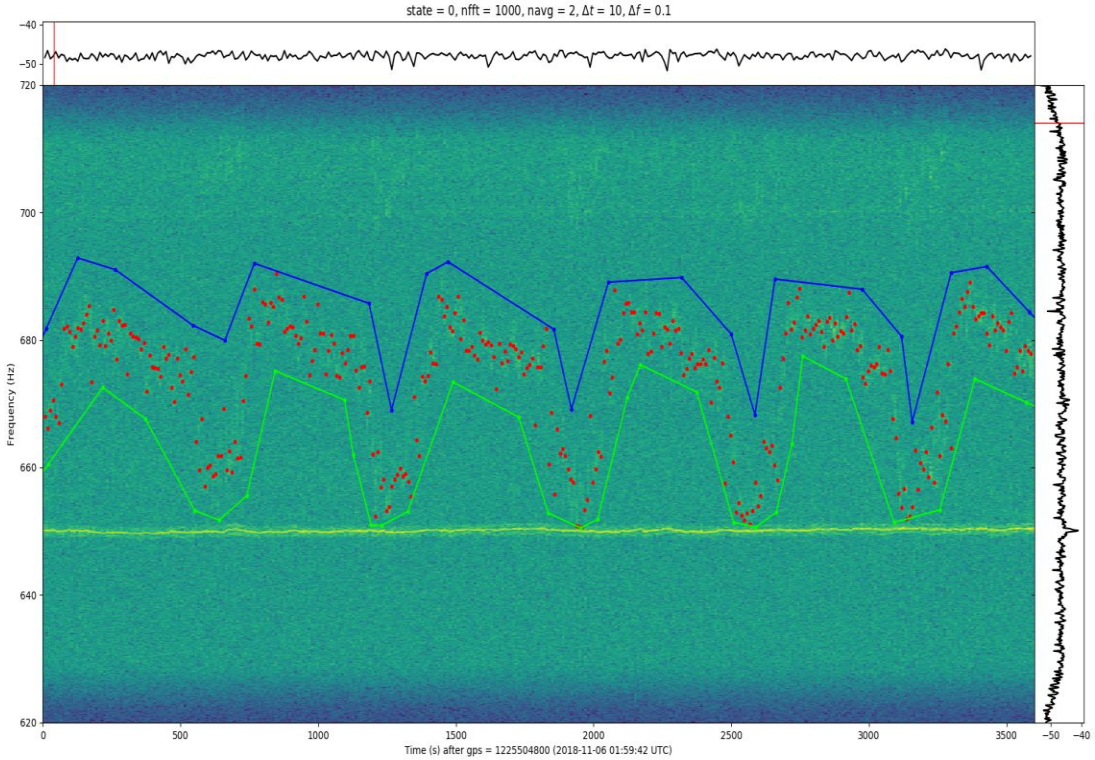
Case of moving frequency lines

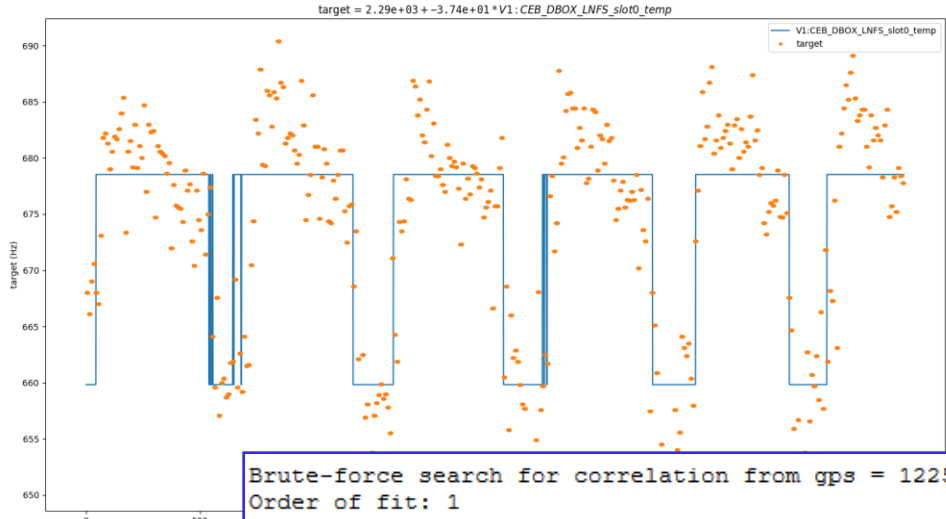
- Noise disturbances (EM) produced by electronic devices are typically very sensitive to temperature. Example of Test experiment of changing on purpose Room temperature by switching off air conditioner.



Case of moving frequency lines

- Tool line tracker VIR-0420A-18 (*BUFFALO - Brute-force Utilities For Finding Annoying Lines and Others*, B.Swinkels) . Example of Hrec line moving btw 650Hz and 700Hz. Correlated to Temperature of the electronics which demodulates photodiodes signals at Laser …MHz modulation frequencies.

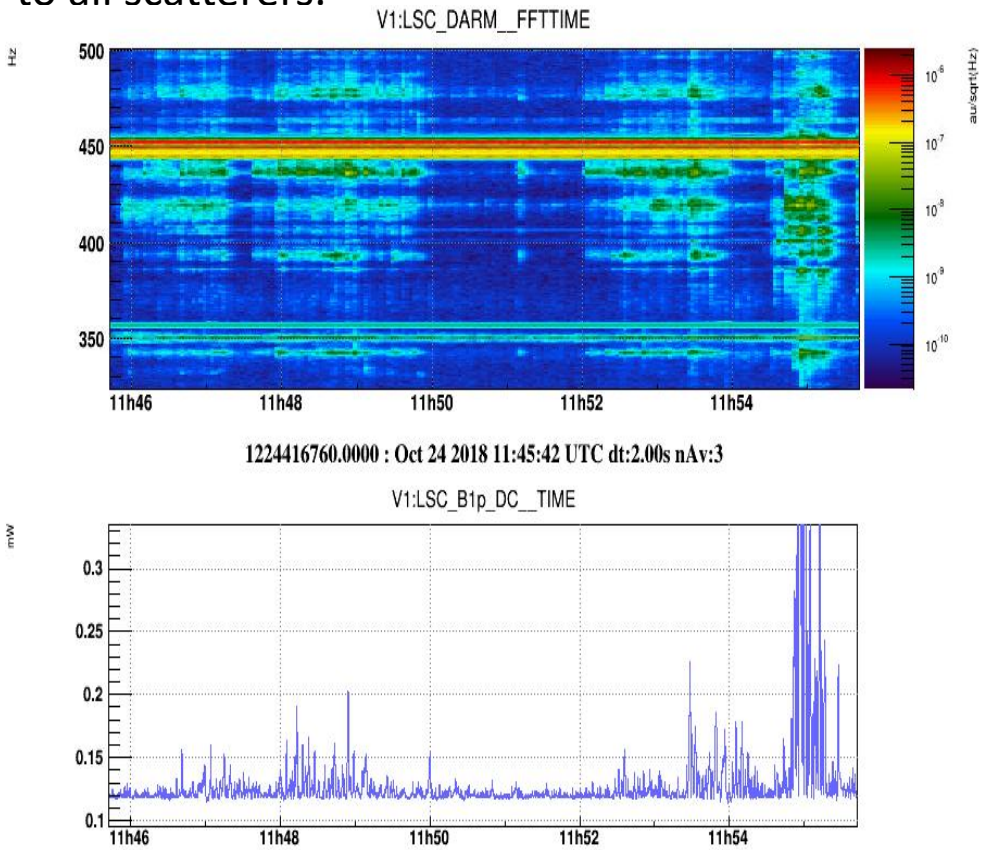




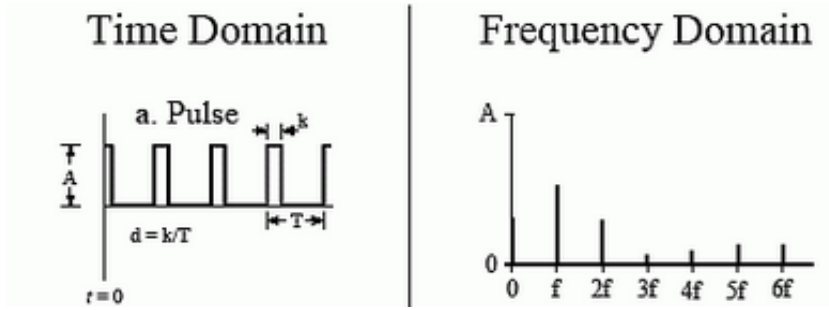

```
Brute-force search for correlation from gps = 1225504807
Order of fit: 1


*** Best correlation for channel peak_freq ***

rank  residual   channel
   1  1.20e+05  V1:CEB_DBOX_LNFS_slot0_temp
   2  1.46e+05  V1:DAQ_LNFS_56MHz_raw_dFreq_rms
   3  1.46e+05  V1:DAQ_EOM_56MHz_raw_dFreq_rms
   4  1.60e+05  V1:DAQ_LNFS_8MHz_raw_dFreq_rms
   5  1.64e+05  V1:DAQ_EOM_8MHz_raw_dFreq_rms
   6  1.73e+05  V1:DAQ_TDBv2_return_100MHz_ACq_mean
   7  1.81e+05  V1:HVAC_INJ_LLR_FLUX_IN_CORR
```

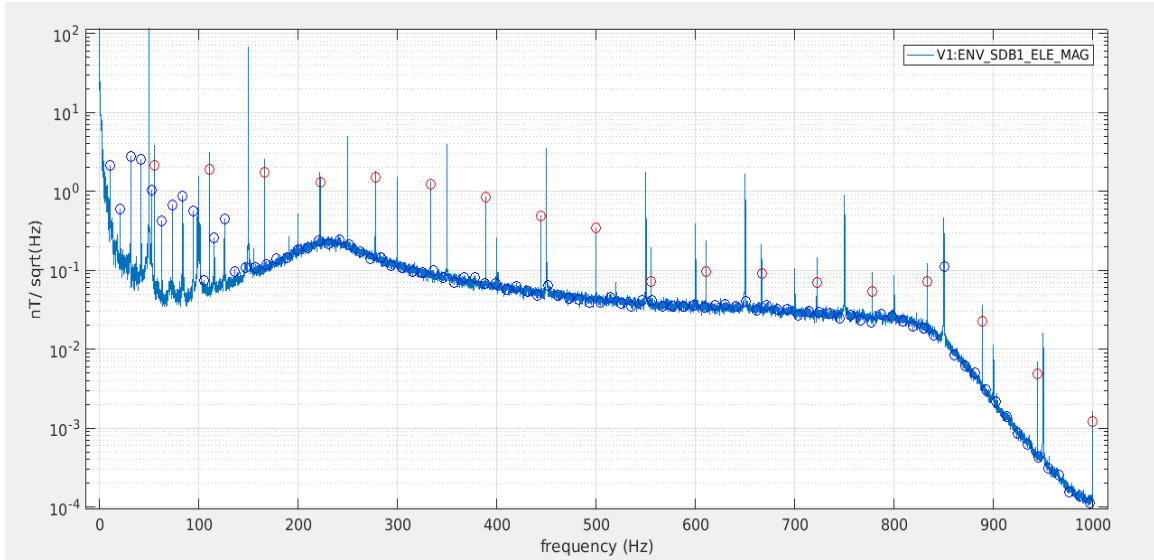
Repeated T-F patters inside Hrec

LEFT example - Lines with similar amplitude modulation. This case: each line associates to a scatterer object (i.e. optical mounts) on SDB1 suspended bench. Bench misalignments cause a change of amount of back-scattering, common to all scatterers.



RIGHT example - Equally spaced lines ("comb"): i.e. from clocks

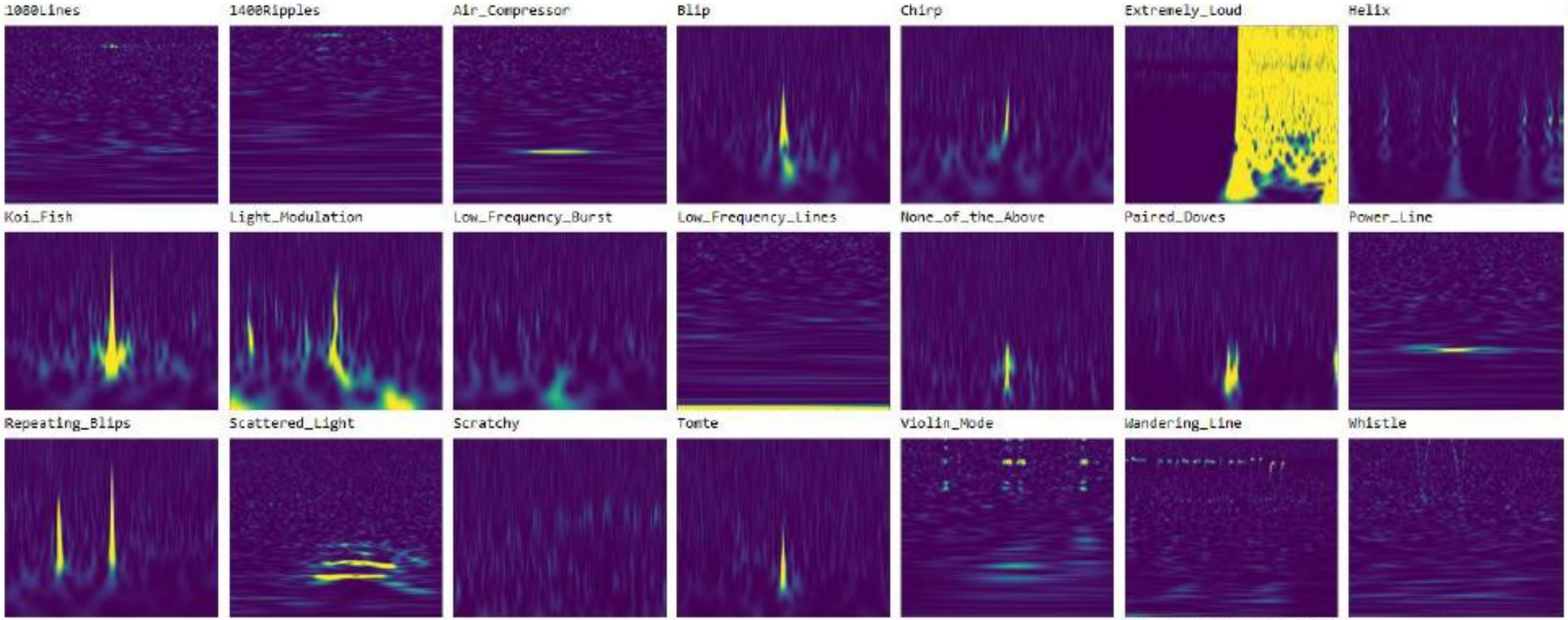




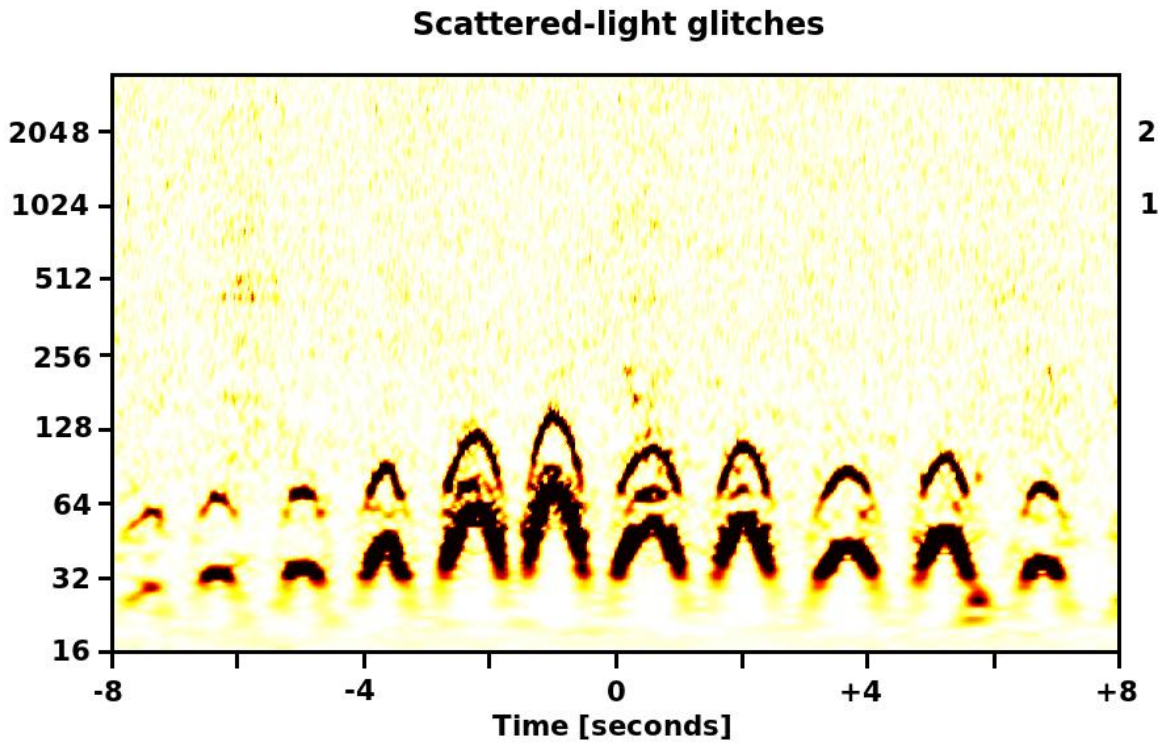
https://www.zooniverse.org/projects/zooniverse/gravity-spy

George, Shen, Huerta – Glitch Classification and Clustering for Ligo with Deep Transfer Learning
https://arxiv.org/pdf/1711.07468

Example of Glitch signals



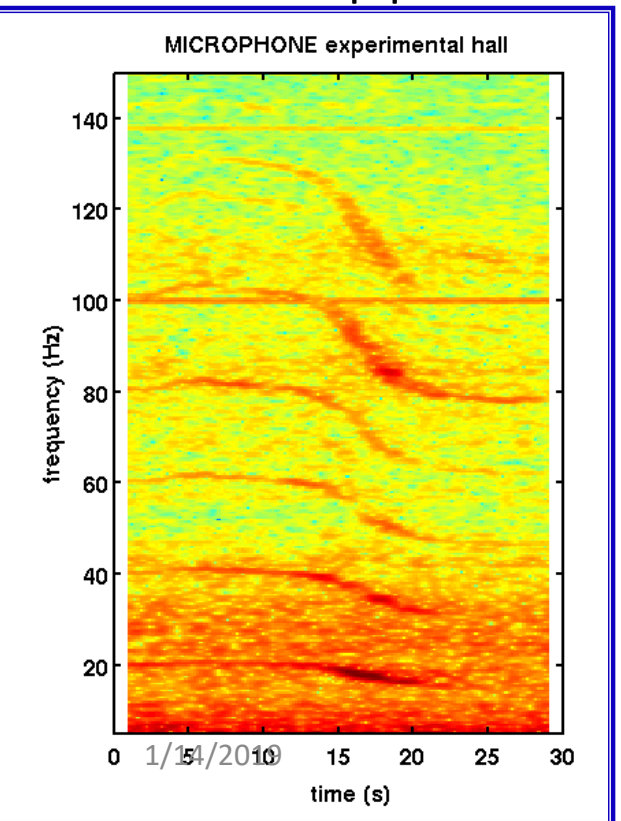
Scattered light glitches



See Antonino Chiummo's talk

Transient noise

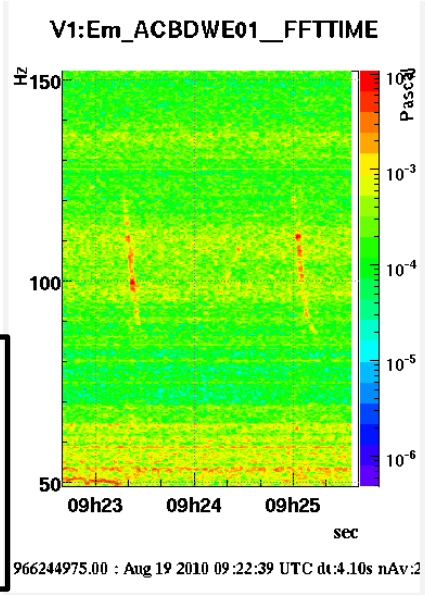
- Flying objects: cause sound and ground vibrations. Typical frequencies 15-150Hz. Amplify mechanical modes of in-air or grounded Optical benches and Vacuum tanks . Now less of a problem than for Virgo+. Current approach: use excess RMS monitor to FLAG the even and VETO in the GW pipelines.

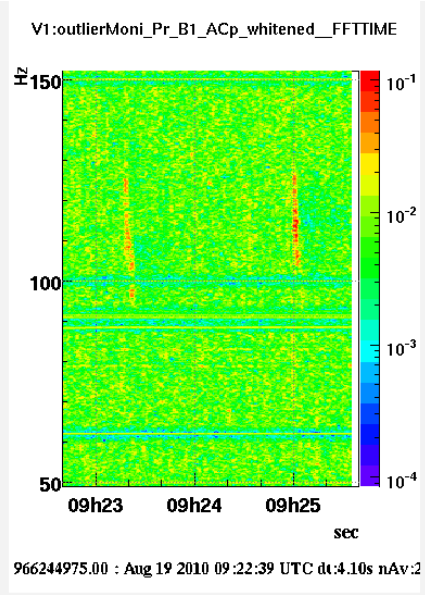


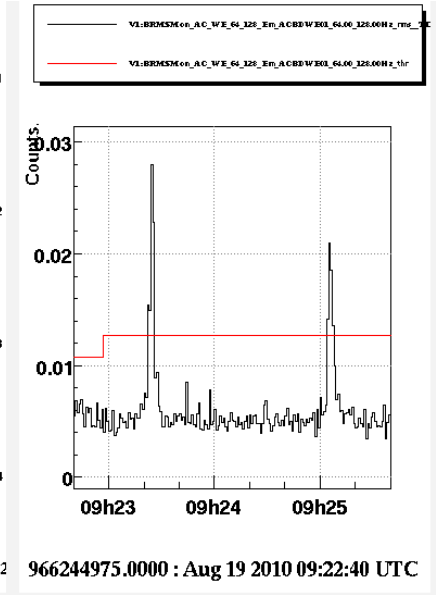
Doppler shift

$$f'(t) = f \frac{c}{c - v\cos(\theta(t))}$$

Typical frequencies (f):
Copter rotor ≈ 20Hz
and harmonics
C130 blades ≈ 100Hz

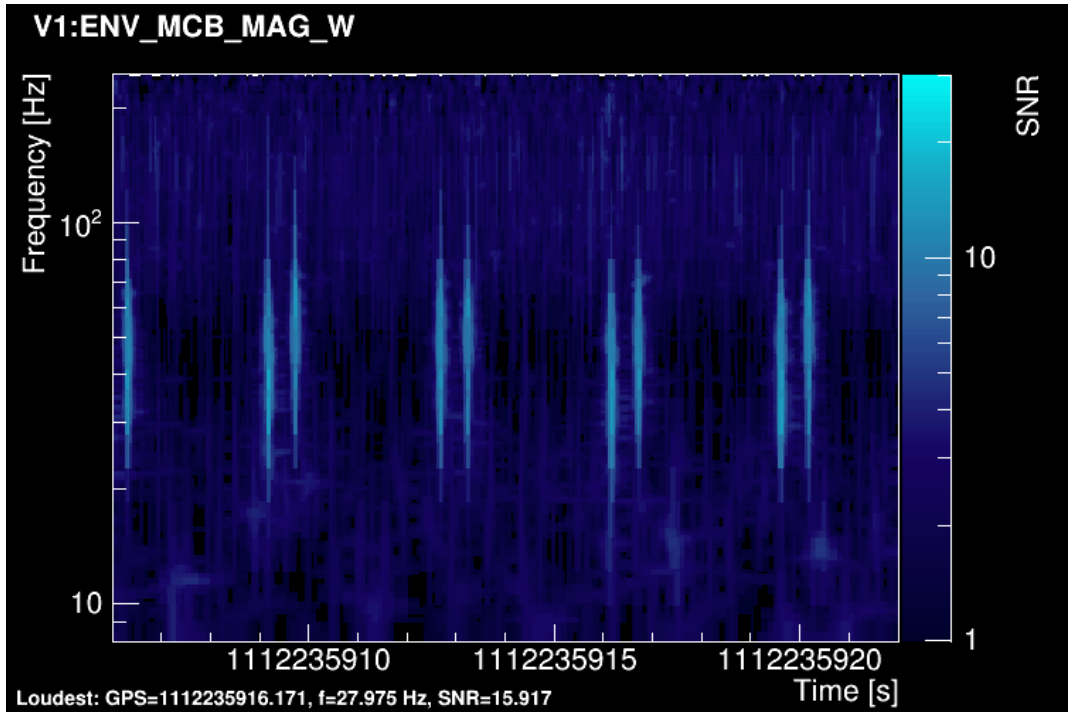




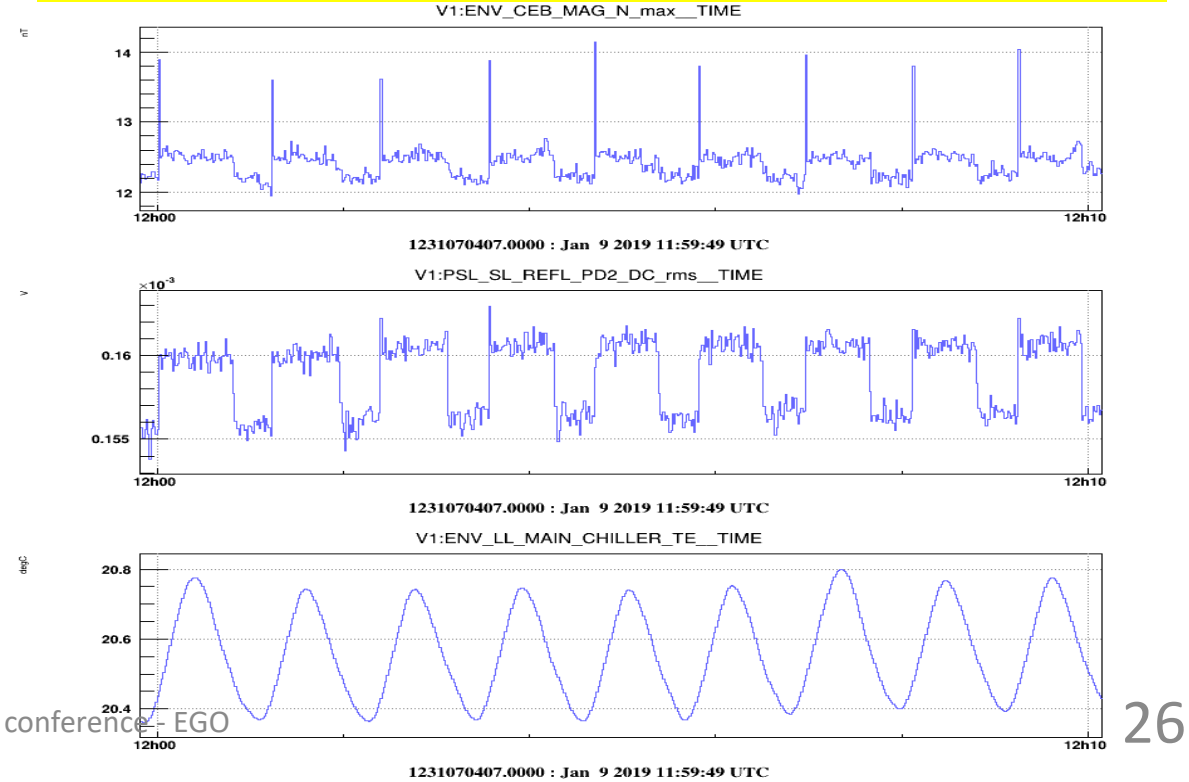


EM glitches

- Engines that do on-off cycles (water chillers, air compressors, boilers) produce large inrush current spikes, propagated in the electric power network and eventually give radiated EM fields and electric ground noise.
- Look for similar periodicity in INFrastructure monitors, power and magnetic sensors, temperatures …

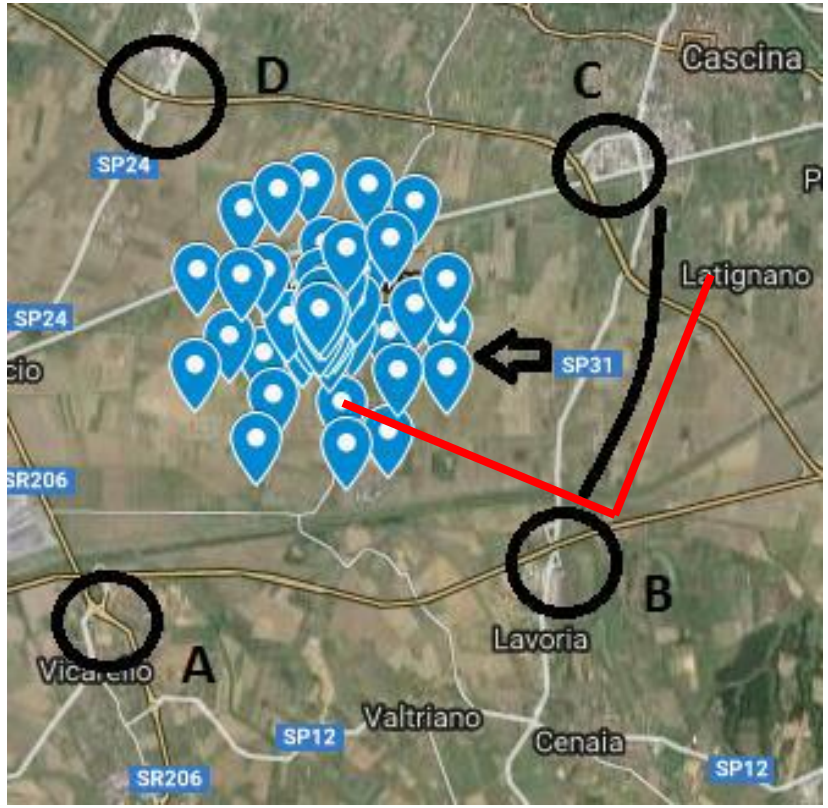


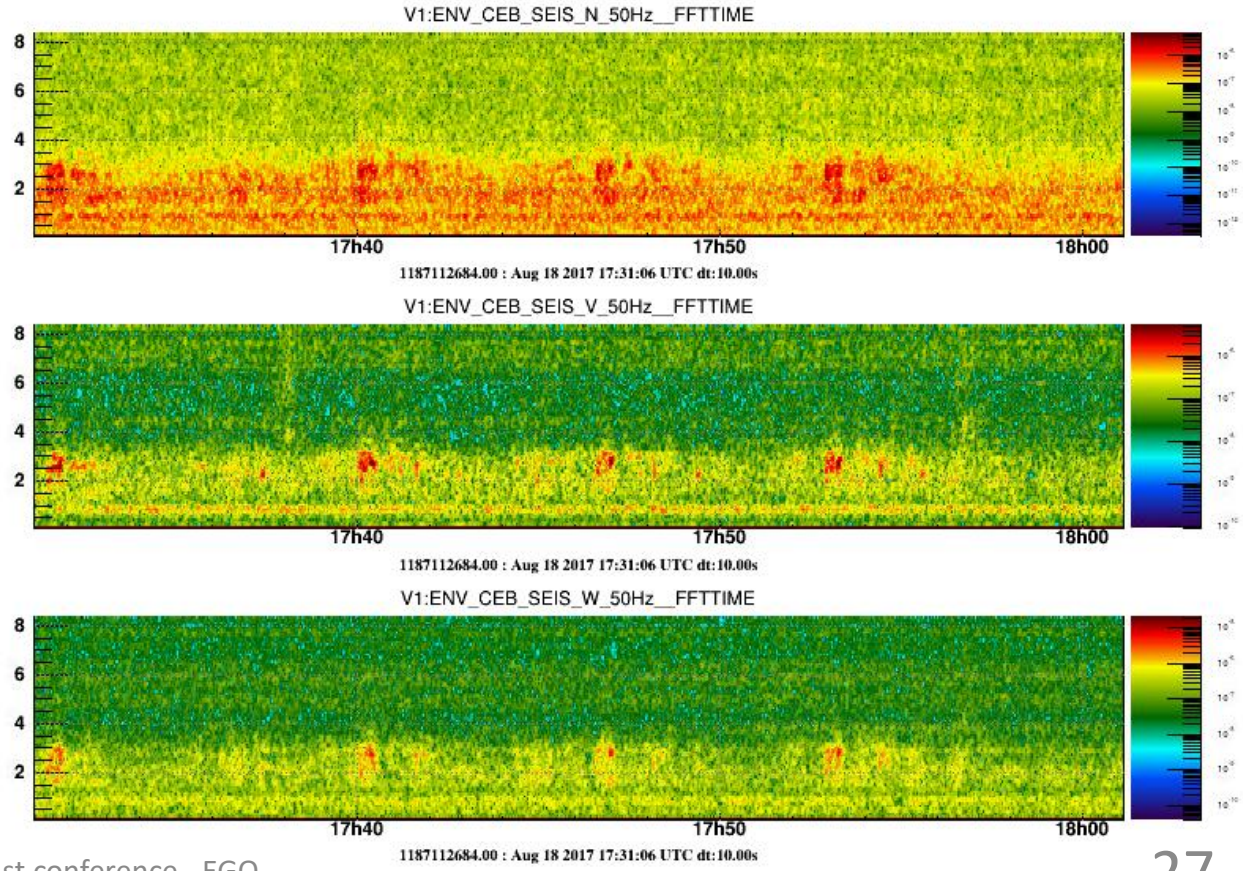
Fresh from last week: glitches in Hrec from laser chiller



Trucks glitches

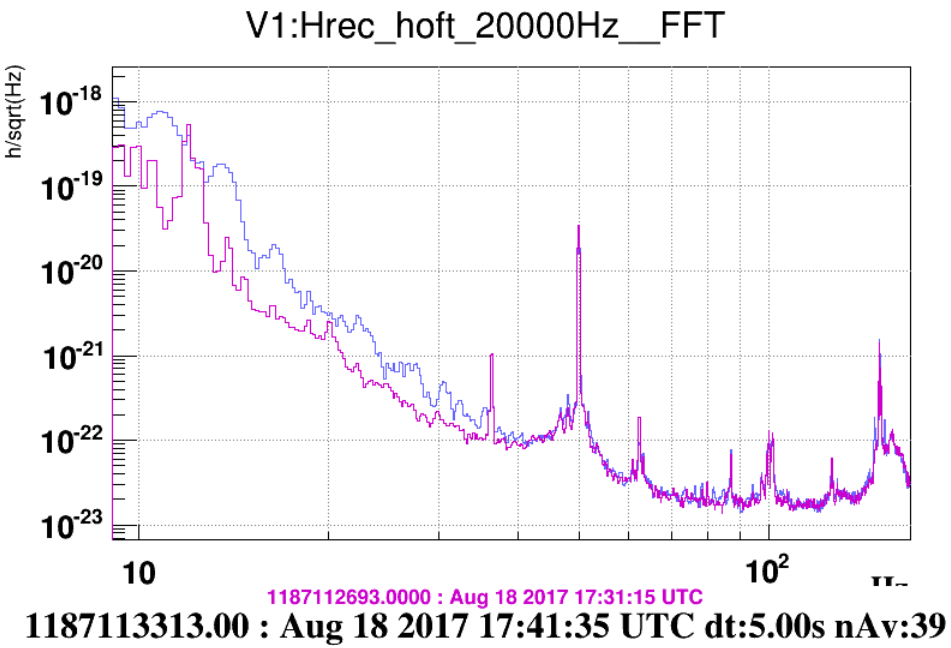
- Heavy traffic on viaduct East of Virgo produce 2-3Hz peaked pulsed wave field (see results of circular array studies, Soumen Koley *https://doi.org/10.1190/segam2017-17681951.1*)

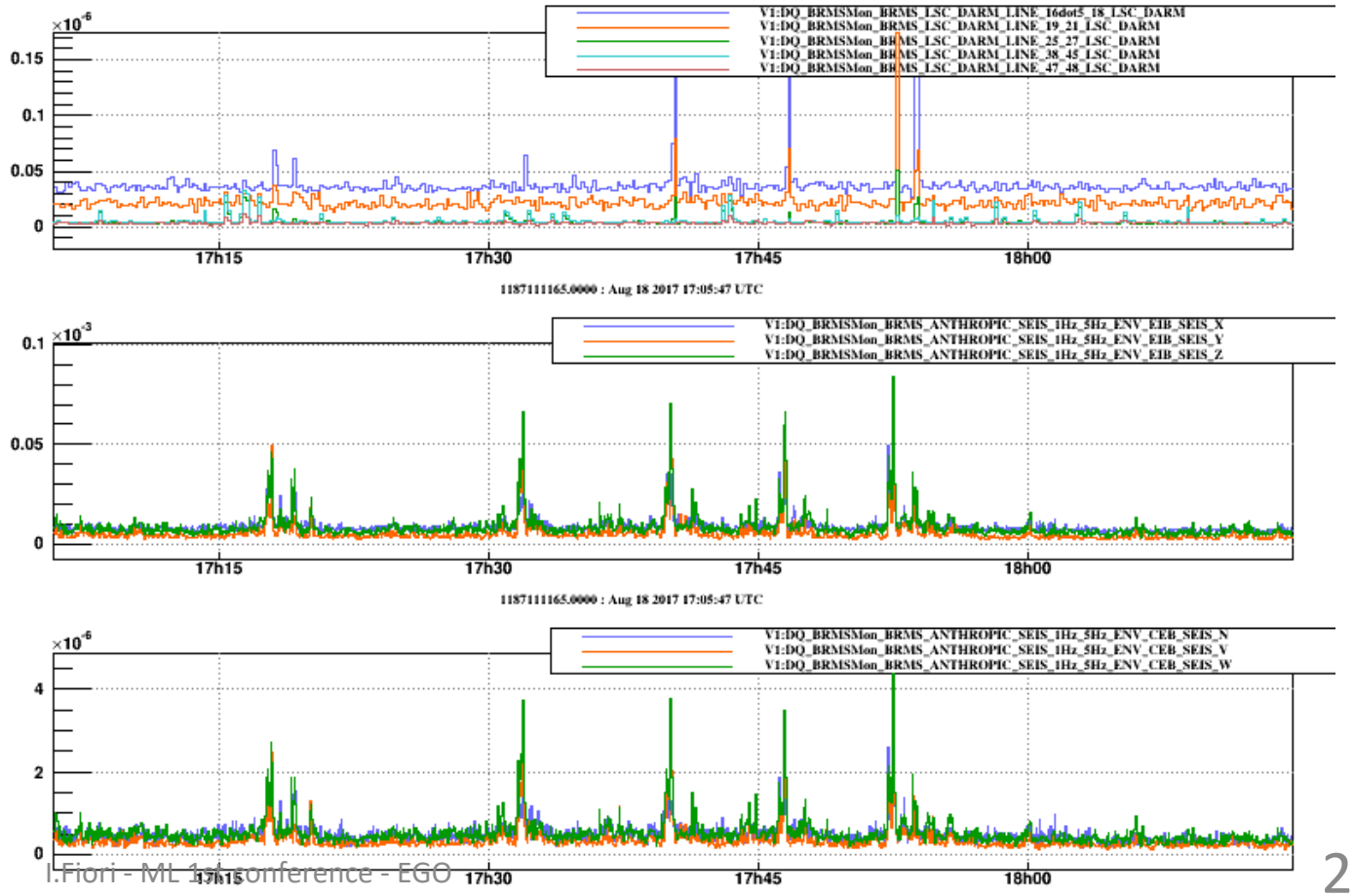




Trucks glitches

- During O2 (August 2017) these seismic glitches were correlated with transient excess noise in Hrec the 10-30Hz frequency.

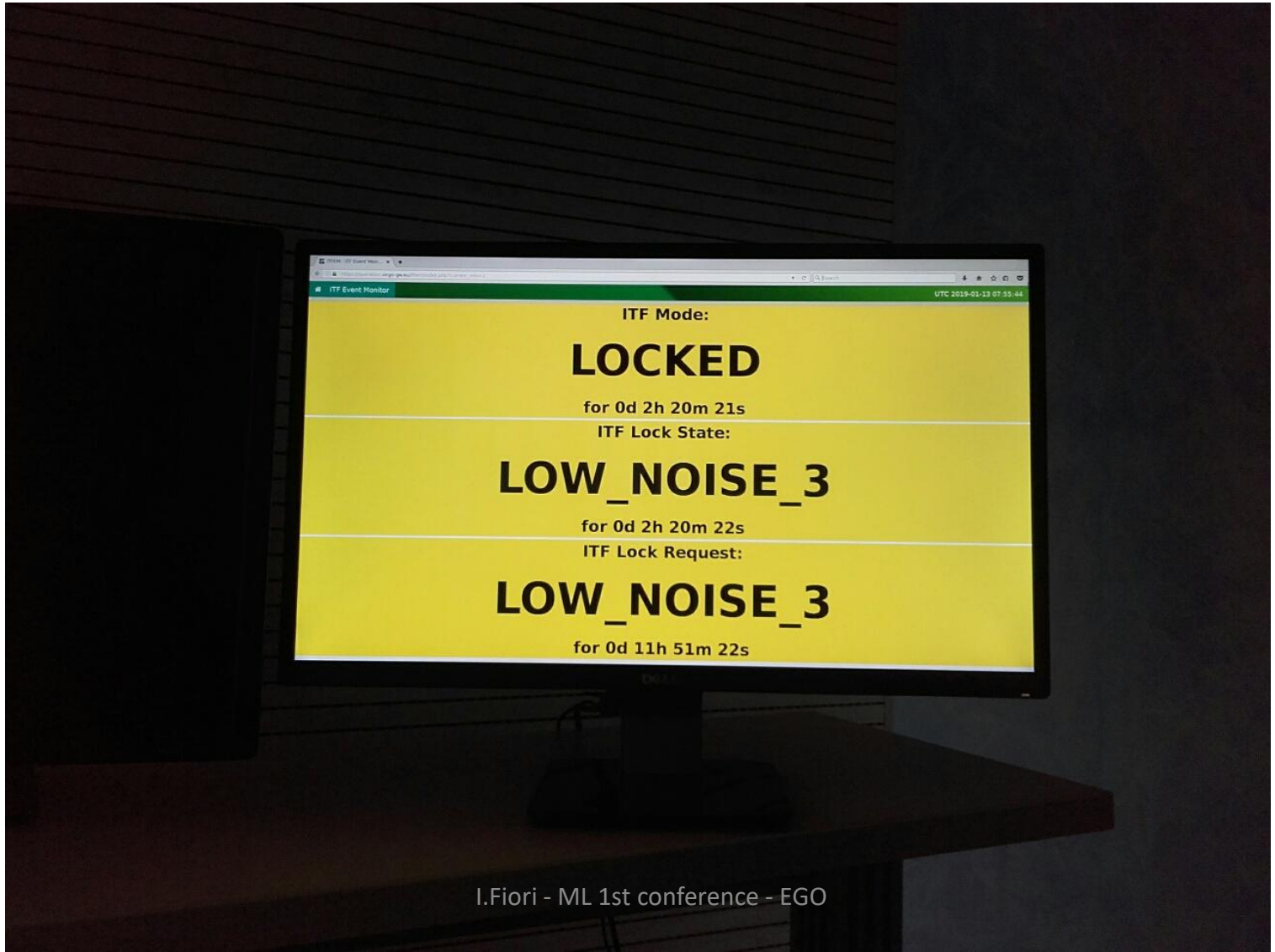




Conclusions

- Environmental sources generate continuous T-F patters that change in amplitude or frequency, and also transient repeated patters.
- Noise hunting in Virgo/Ligo means inspecting and digesting Huge amount of data (50MB/s) looking for patters and Correlate those with information contained in thousand of auxiliary channels.
- Clearly too much for Humans!
- Semi-automated tools have developed, but more needs to be done.
- ML can help?!

End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ITF Lock State:
LOW_NOISE_3
for 0d 2h 20m 22s
ITF Lock Request:
LOW_NOISE_3
for 0d 11h 51m 22s