EGO European Gravitational Observatory

Advanced Virgo ENV

ENV training
Part III
Data analysis techniques

Irene Fiori on behalf of the Commissioning team

VIR-0948A-19

Virgo training sessions

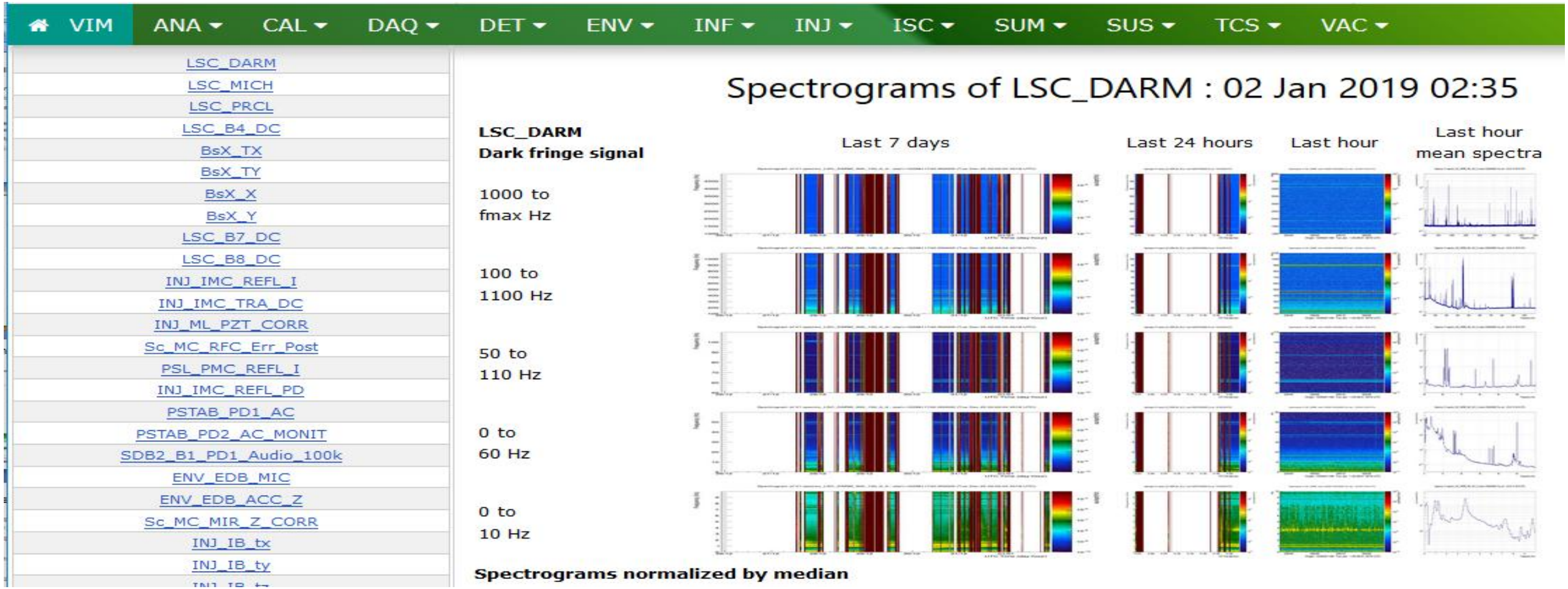
September 26 2019

Outline of Part III

- Inspection of Time-Frequency plots
- Correlations
  - On/off lines
  - Moving lines
  - Brute force approach
- Coherence (BruCo)
- Line DB and NoeMi Line finder
- Scattered light hunting
  - Spectral features (How to recognize you are dealing with S.L)
  - Investigation techniques

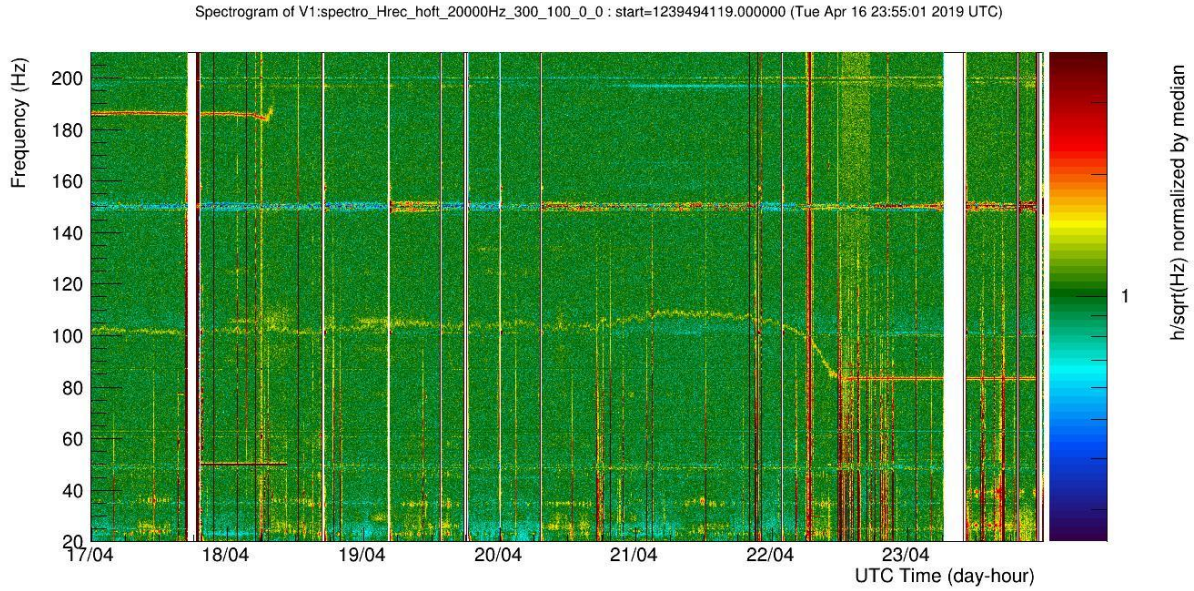
Inspection of Time-Frequency images

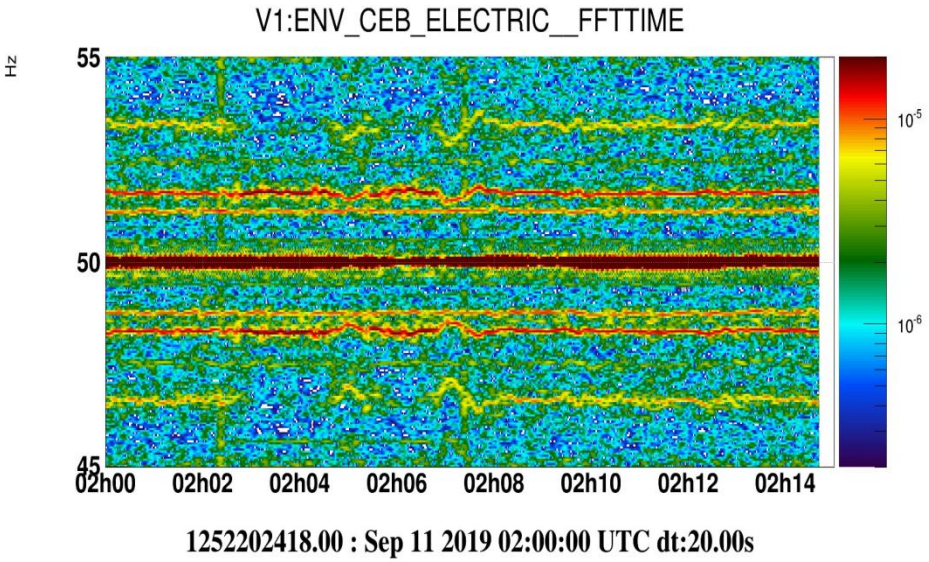
The VIM (see Nicolas Arnaud's talk)

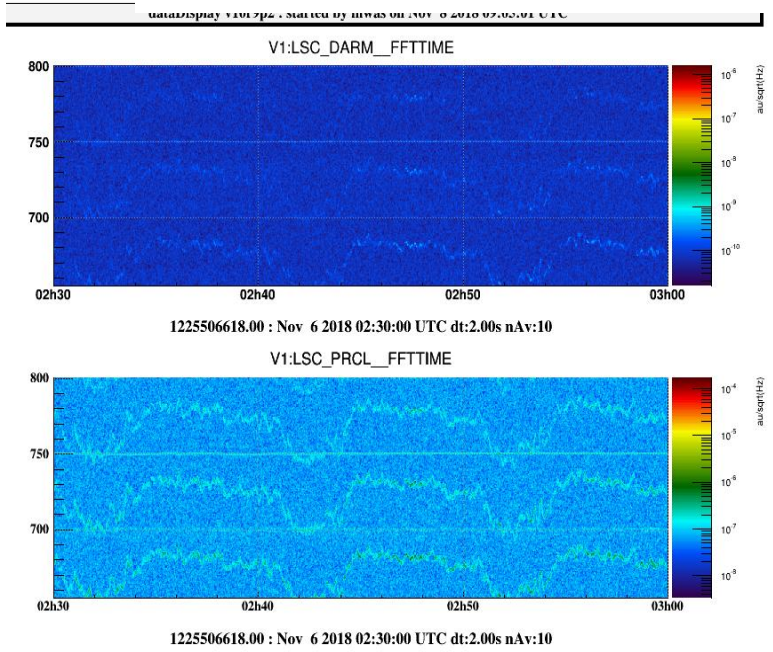


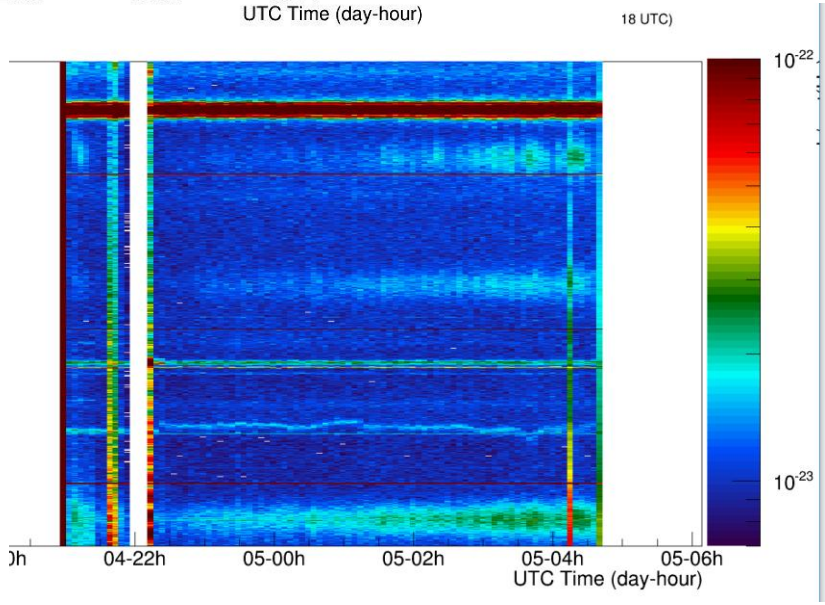
Inspection of Time-Frequency images

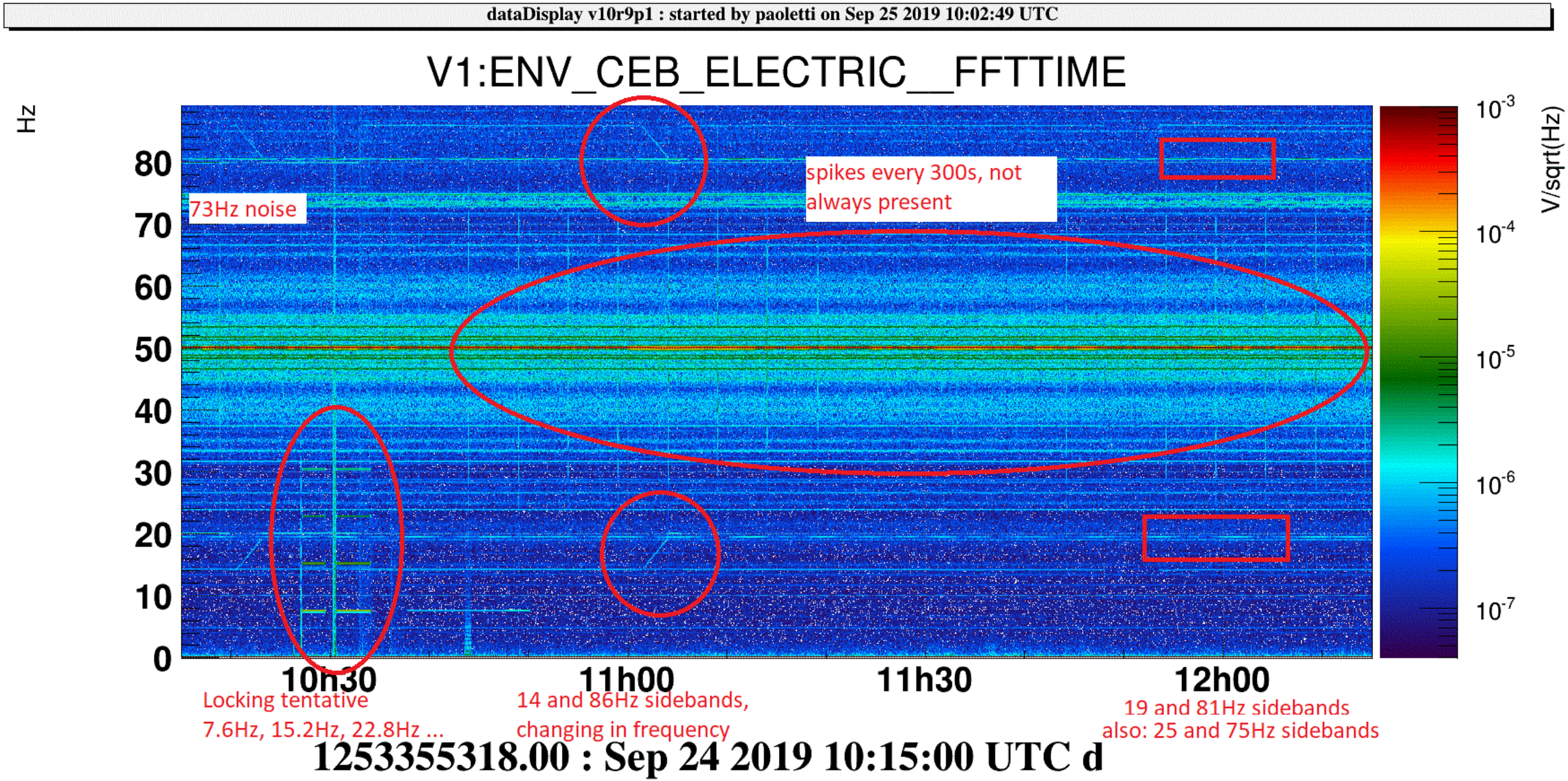
- Look for:
  - Lines or bumps that Start/stop/move
  - Periodic patterns
  - Combs (equally spaced lines)
  - Sidebands





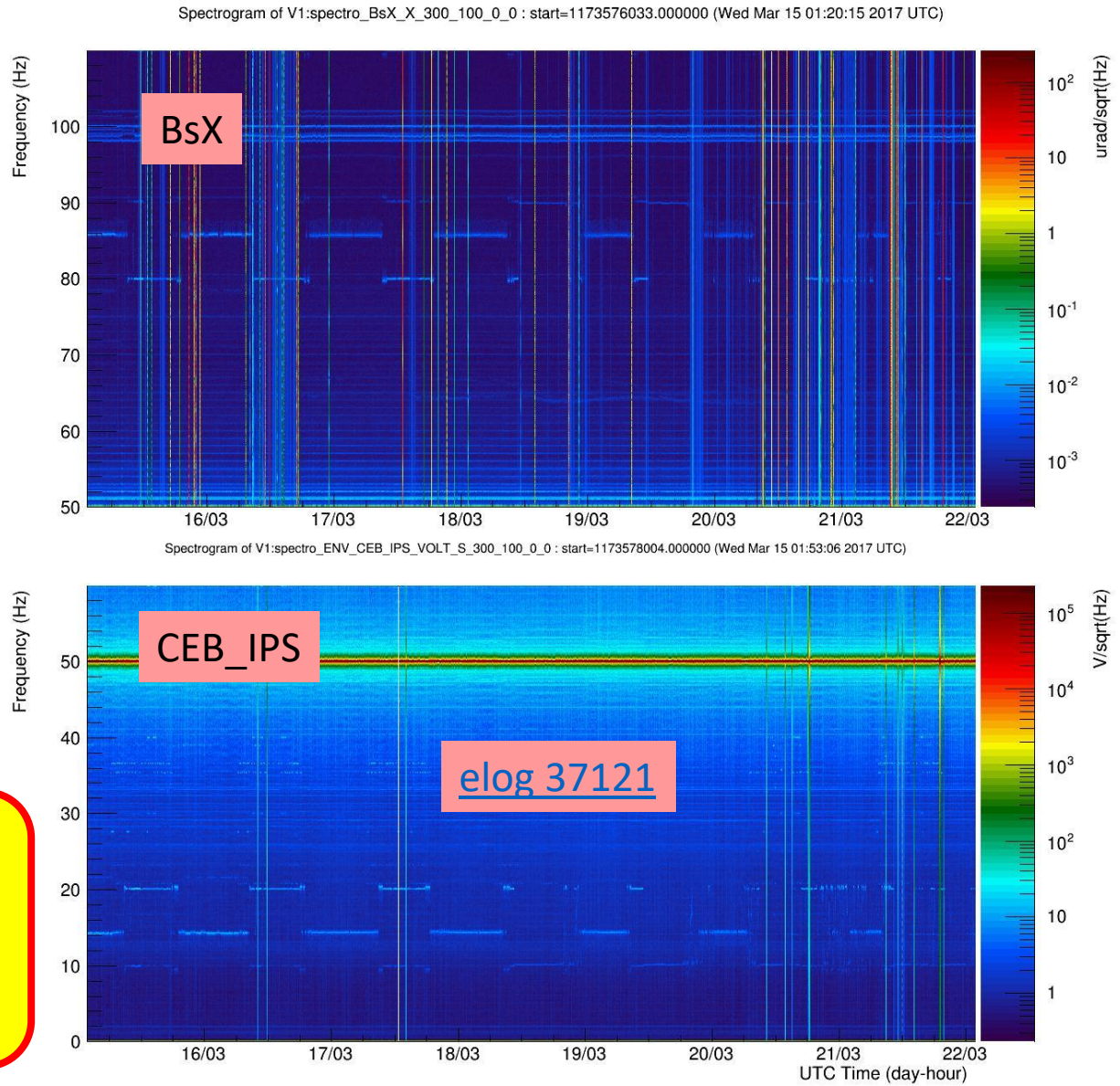





dataDisplay v10r9p1 : started by paoletti on Sep 25 2019 10:02:49 UTC
V1:ENV_CEB_ELECTRIC__FFTTIME
Hz
80
70
60
50
40
30
20
10
0
73Hz noise
spikes every 300s, not always present
10h30
11h00
11h30
12h00
Locking tentative
7.6Hz, 15.2Hz, 22.8Hz ...
14 and 86Hz sidebands, changing in frequency
19 and 81Hz sidebands
also: 25 and 75Hz sidebands
1253355318.00 : Sep 24 2019 10:15:00 UTC d
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
V/sqrt(Hz)

Inspection of Time-Frequency images

- Browse through VIM spectrogram and Look for correlated patterns
- Where:
  - Hrec and DARM
  - LSC_PRCL/MICH → orthogonal dofs
  - SNEB_B7/SWEB_B8/SPRB_B4 power of peak-off beams
  - SSFS_Err → frequency noise
  - BsX_* → input beam jitter
  - ENV_*SEIS, *MAG, *MIC, *UPS, *IPS → source is in the environment
  - …. all VIM channels are interesting, have been selected on purpose.



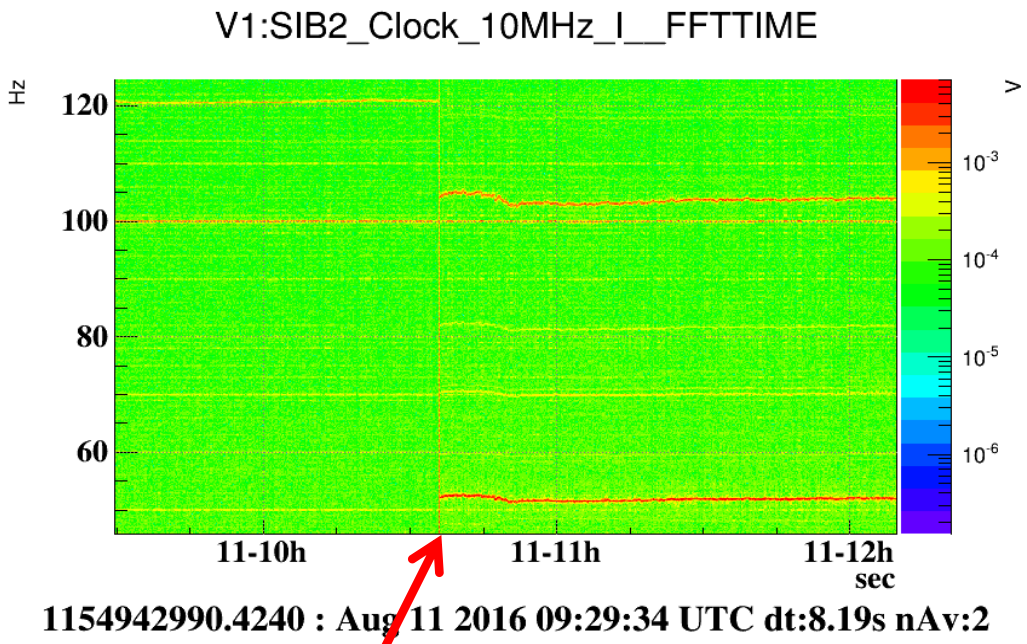
Did you know?

You can reproduce all VIM spectra and zoom/play as you like
https://logbook.virgo-gw.eu/virgo/?r=38996
USEFUL to inspect LONG time stretches

Correlate on/off lines

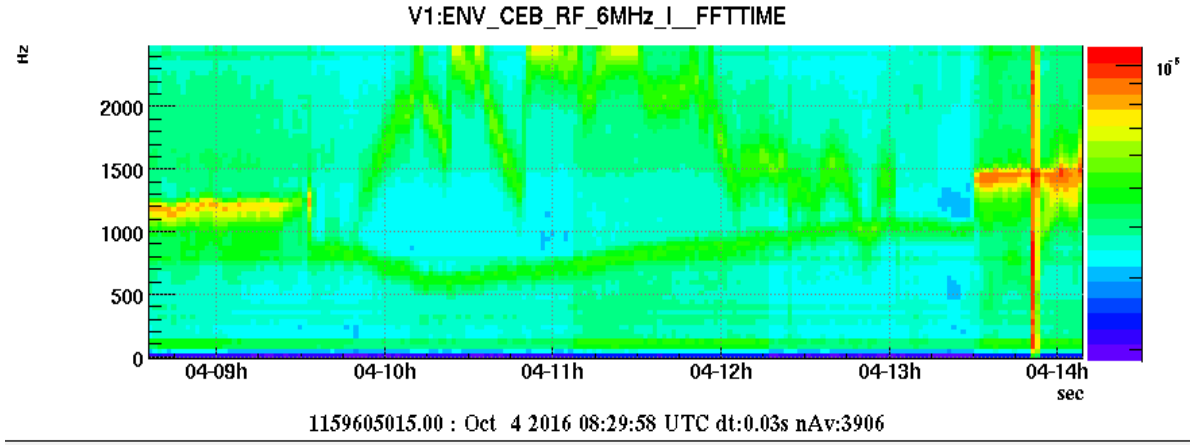
Often NEW NOISE appear during MAINTENANCES
Always suspect of “transparent activities” ☺☺☺

On/off lines usually means some device turned on/off …



Asked VACUUM guys if they did something…. “well… maybe we switched off one PLC driver”. YES!

RF noise at 1200Hz around 6MHz



Atomic GPS receiver board was swapped

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

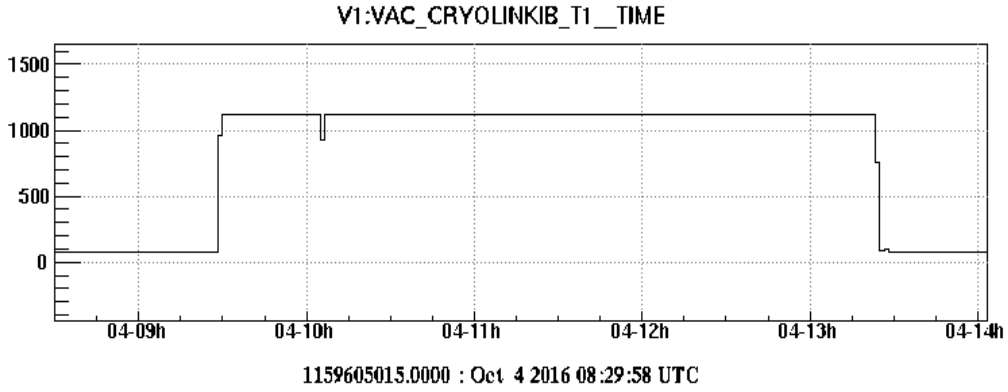
masserot, pacaud - 9:08 Thursday 11 August 2016 (34481)

Atomic GPS reciever

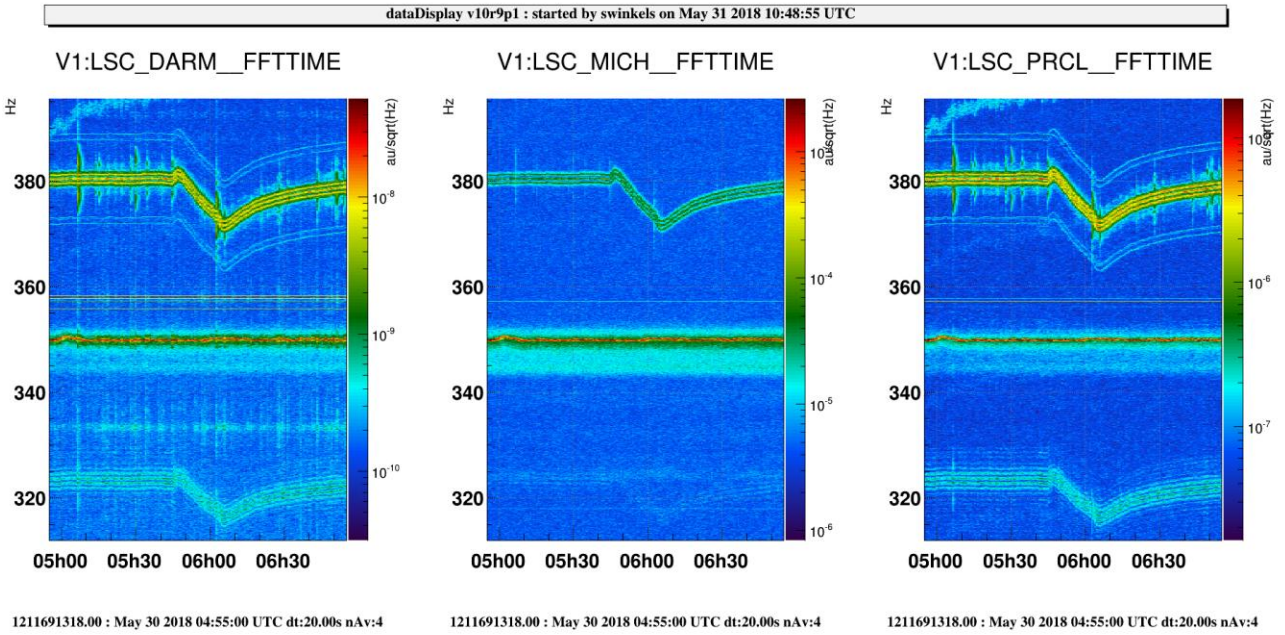
We observed that the GPS status propagated by the IRIGB is always at 2D state instead of fixed posistion (OC or PH) state

I bring from LAPP an atomic GPS receiver with its cable and antenna to perform some tests to check the antenna and the cables and to compare the IRIGB generated by an Atomic GPS receiver

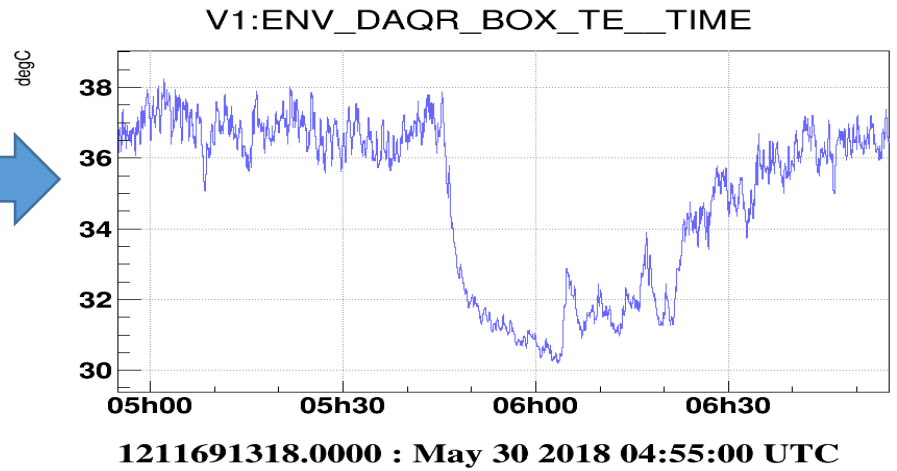
First I came to the DAQ room to check the display of the 2 Atomic GPS receivers. I found the two GPS receivers in OC state with 7 or 8 satellites (1st photo)



Elog 41624 “Forest of lines moving yesterday morning” (B.Swinkels)



Temperature of DAQ room



In case of Moving lines TEMPERATURE probes are the first to be looked at because:

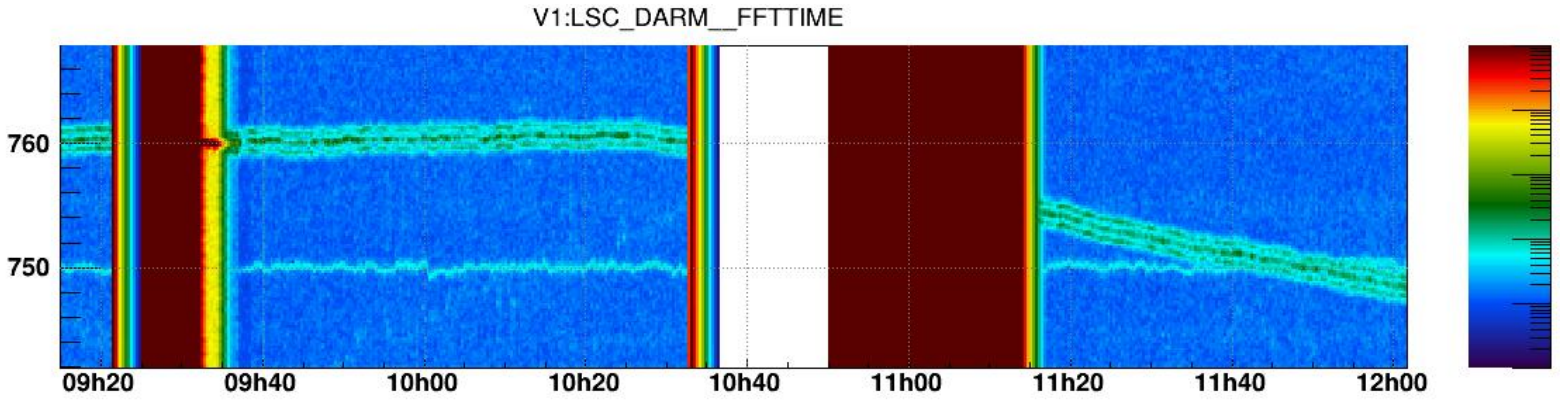
- Many noisy devices have temperature driven cycles (i.e. AirConditioners)
- Noise disturbances (EM) produced by electronic devices are typically very sensitive to temperature.

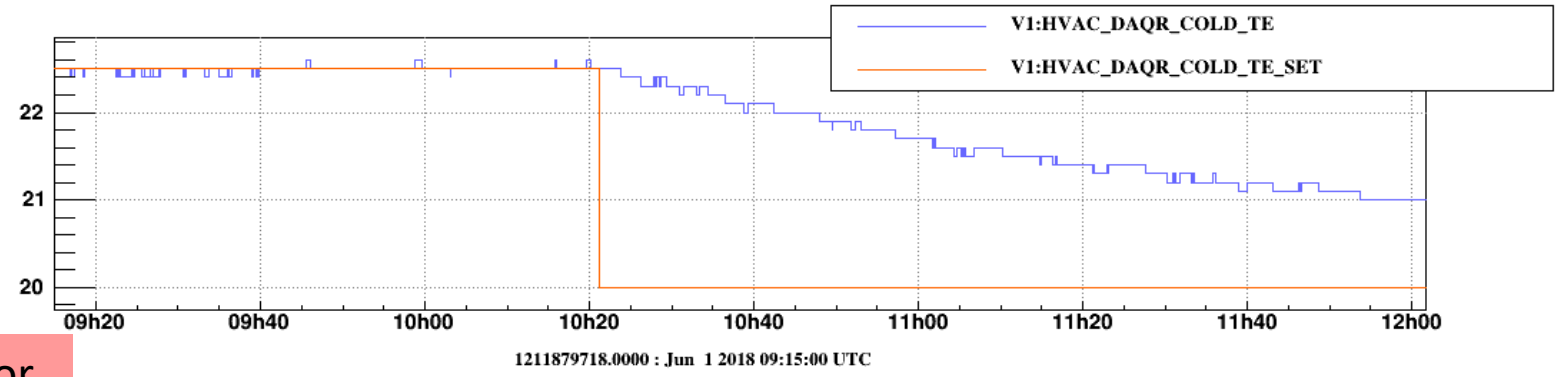
… follow up: source identified

- Changed on purpose DAQ room temperature by switching off air conditioner
- Magnetic sniffing and Tapping on Electronic boards

Tapping on only this chassis at ~4 Hz generates ~4 Hz sidebands on many of the frequencies that responded to the previous temperature test

GPS synchronized 10 MHz timing generator

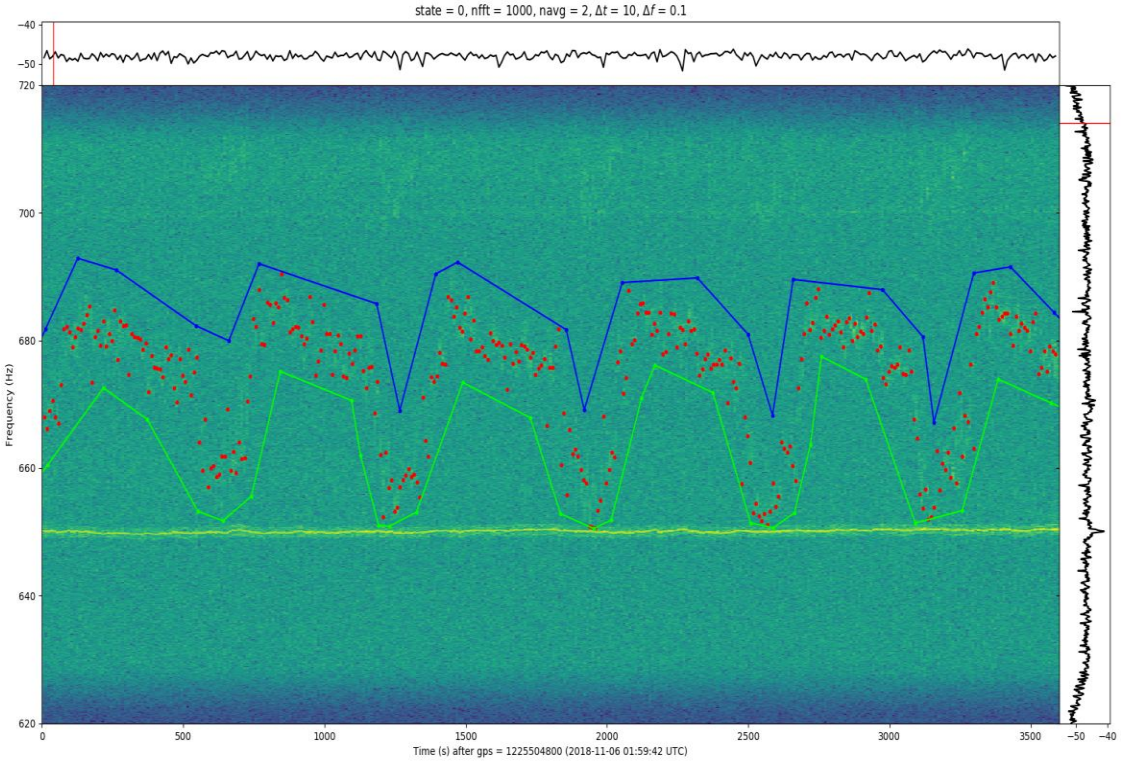


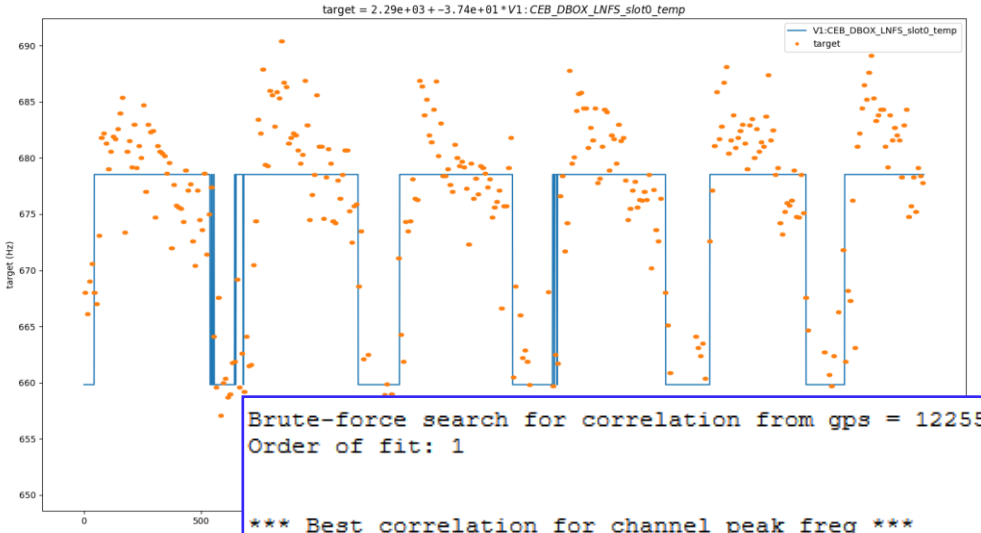


… but “brute force” works better

“brute force” approach = search noise correlation in **ALL slow channels** (i.e. O(10000 channels)!)

- **NonNA (Non-linear Noise Analysis)** by Francesco di Renzo, VIR-0406A-18
- ***BUFFALO - Brute-force Utilities For Finding Annoying Lines and Others*** by Bas Swinkels, VIR-0420A-18
- Example of Hrec line moving btw 650Hz and 700Hz. Correlated to Temperature of the electronics which demodulates photodiodes signals

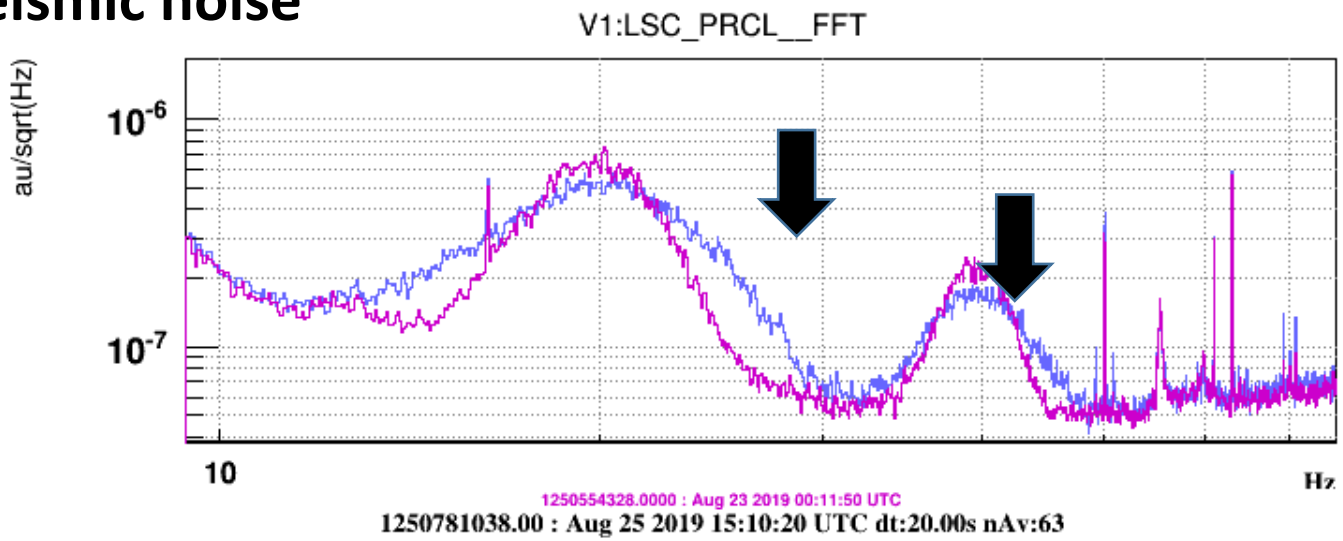


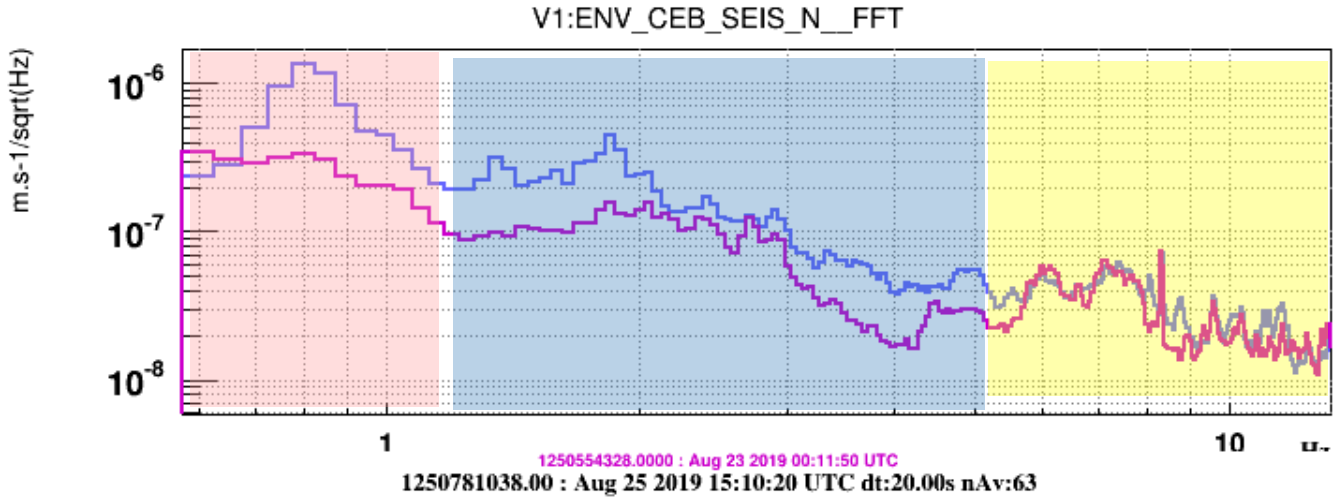



```
Brute-force search for correlation from gps = 1225504807
Order of fit: 1


*** 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
```

Do yourself…. correlations

- Maddalena's, 46852 "**PRCL noise between 5Hz to 50Hz correlates with low frequency seismic noise**"





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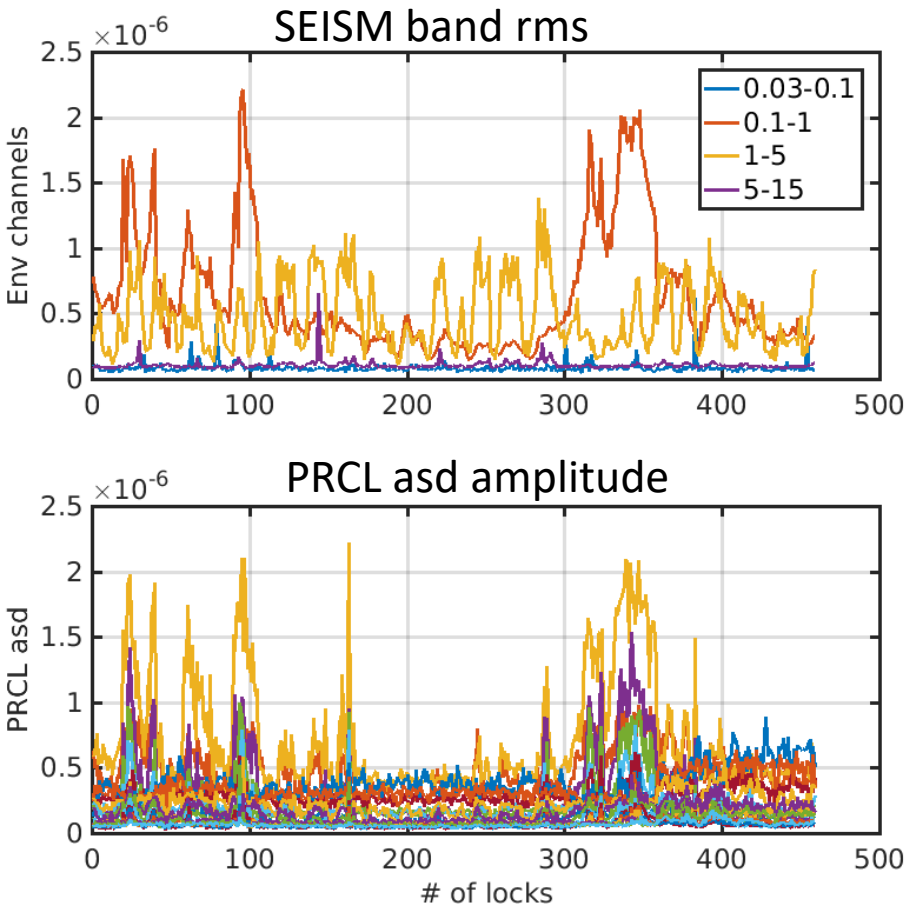
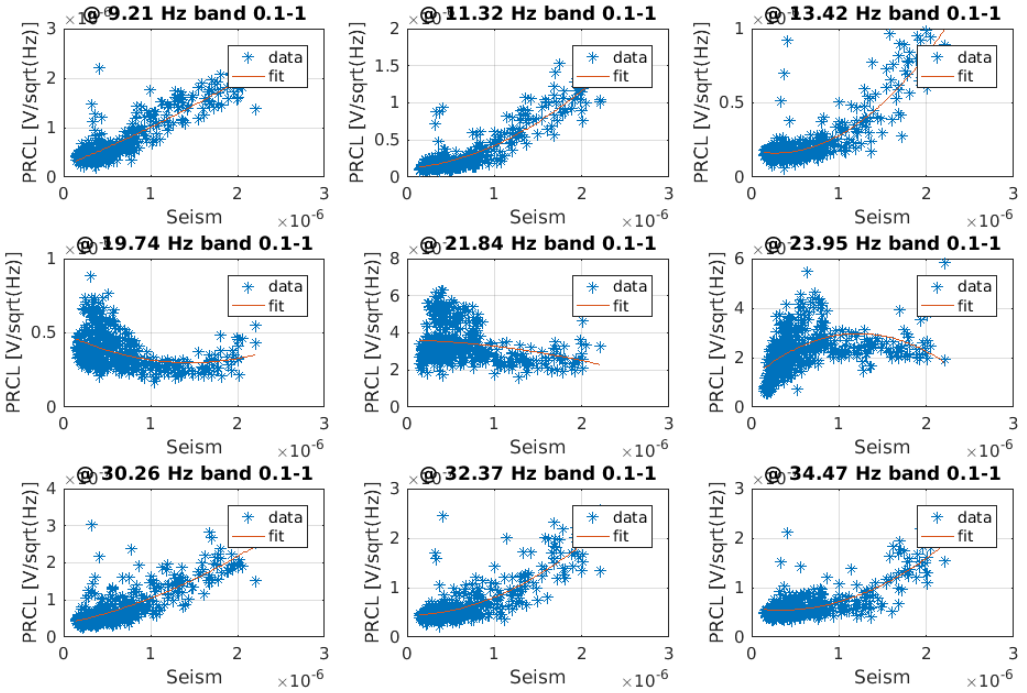




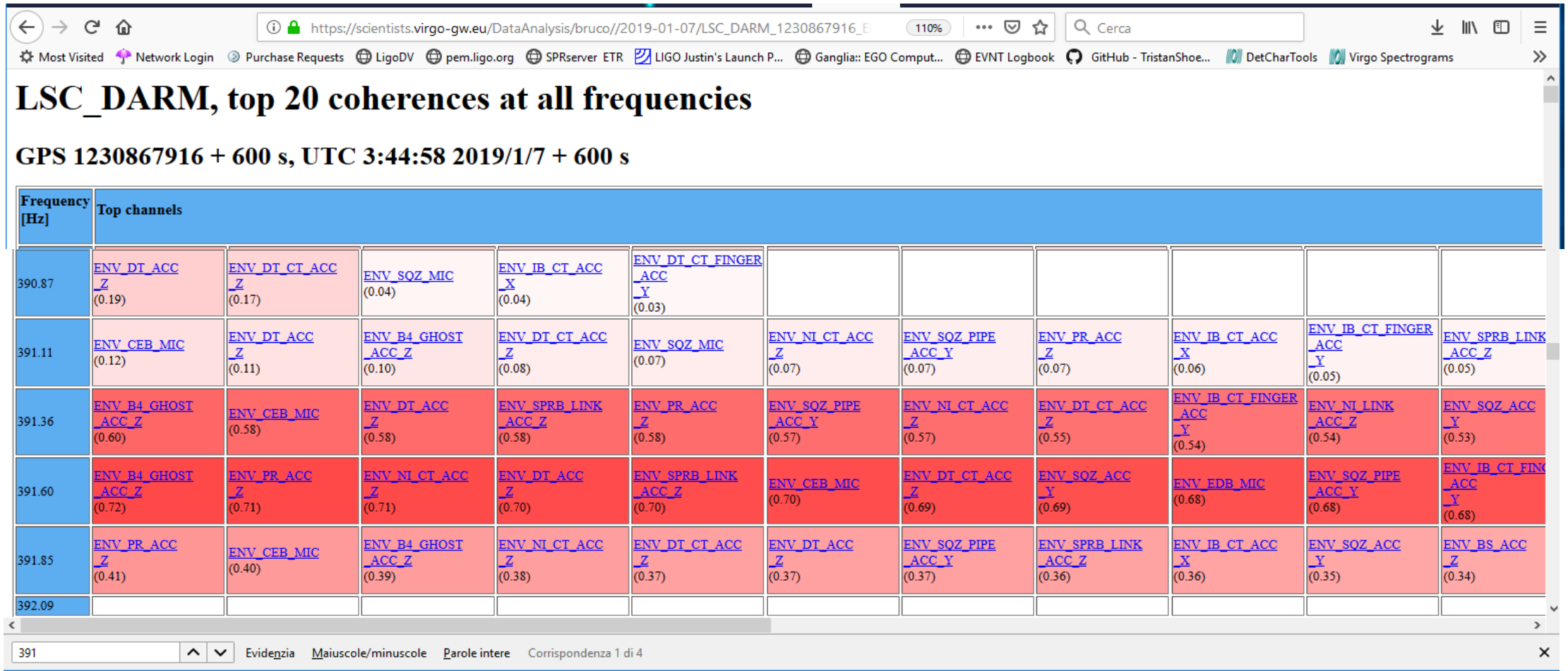
Several scripts exist, either in MATLAB or Python
…. ask commissioners ☺

BruCo: Brute force Coherence

- **BruCo** – *computes and ranks coherence* between Hrec and all AUXILIARY channels

(G.Vajente, https://dcc.ligo.org/LIGO-G1500230)

- BruCo VIM plots: daily and ARCHIVE https://vim-online.virgo-gw.eu/?config=28



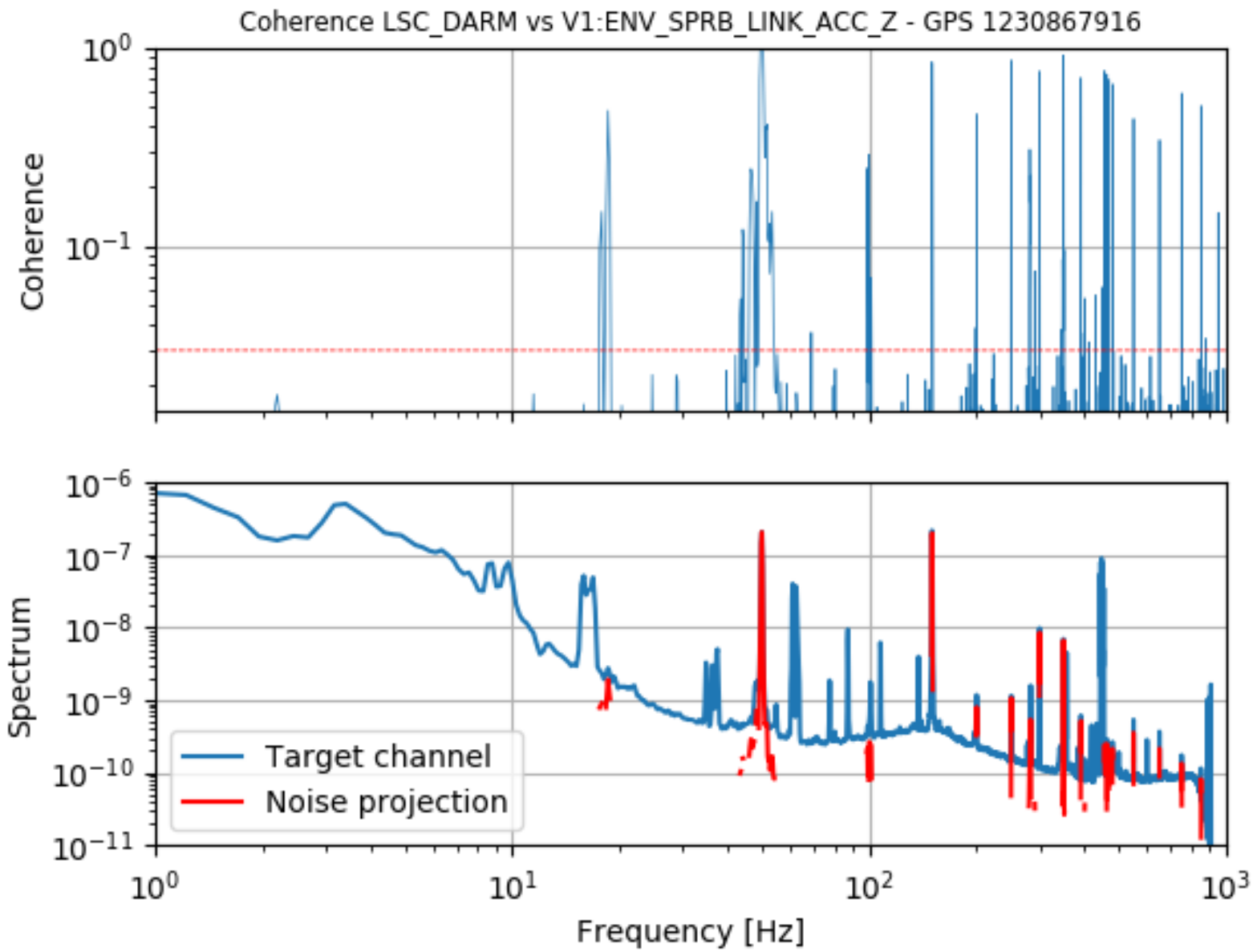
Frequency [Hz]	Top channels										
390.87	ENV_DT_ACC_Z (0.19)	ENV_DT_CT_ACC_Z (0.17)	ENV_SQZ_MIC (0.04)	ENV_IB_CT_ACC_X (0.04)	ENV_DT_CT_FINGER_ACC_Y (0.03)						
391.11	ENV_CEB_MIC (0.12)	ENV_DT_ACC_Z (0.11)	ENV_B4_GHOST_ACC_Z (0.10)	ENV_DT_CT_ACC_Z (0.08)	ENV_SQZ_MIC (0.07)	ENV_NI_CT_ACC_Z (0.07)	ENV_SQZ_PIPE_ACC_Y (0.07)	ENV_PR_ACC_Z (0.07)	ENV_IB_CT_ACC_X (0.06)	ENV_IB_CT_FINGER_ACC_Y (0.05)	ENV_SPRB_LINK_ACC_Z (0.05)
391.36	ENV_B4_GHOST_ACC_Z (0.60)	ENV_CEB_MIC (0.58)	ENV_DT_ACC_Z (0.58)	ENV_SPRB_LINK_ACC_Z (0.58)	ENV_PR_ACC_Z (0.58)	ENV_SQZ_PIPE_ACC_Y (0.57)	ENV_NI_CT_ACC_Z (0.57)	ENV_DT_CT_ACC_Z (0.55)	ENV_IB_CT_FINGER_ACC_Y (0.54)	ENV_NI_LINK_ACC_Z (0.54)	ENV_SQZ_ACC_Y (0.53)
391.60	ENV_B4_GHOST_ACC_Z (0.72)	ENV_PR_ACC_Z (0.71)	ENV_NI_CT_ACC_Z (0.71)	ENV_DT_ACC_Z (0.70)	ENV_SPRB_LINK_ACC_Z (0.70)	ENV_CEB_MIC (0.70)	ENV_DT_CT_ACC_Z (0.69)	ENV_SQZ_ACC_Y (0.69)	ENV_EDB_MIC (0.68)	ENV_SQZ_PIPE_ACC_Y (0.68)	ENV_IB_CT_FINC_ACC_Y (0.68)
391.85	ENV_PR_ACC_Z (0.41)	ENV_CEB_MIC (0.40)	ENV_B4_GHOST_ACC_Z (0.39)	ENV_NI_CT_ACC_Z (0.38)	ENV_DT_CT_ACC_Z (0.37)	ENV_DT_ACC_Z (0.37)	ENV_SQZ_PIPE_ACC_Y (0.37)	ENV_SPRB_LINK_ACC_Z (0.36)	ENV_IB_CT_ACC_X (0.36)	ENV_SQZ_ACC_Y (0.35)	ENV_BS_ACC_Z (0.34)
392.09											

• BruCo plot

COHERENCE

Dotted line:
Level of coherence
of pair of random signals

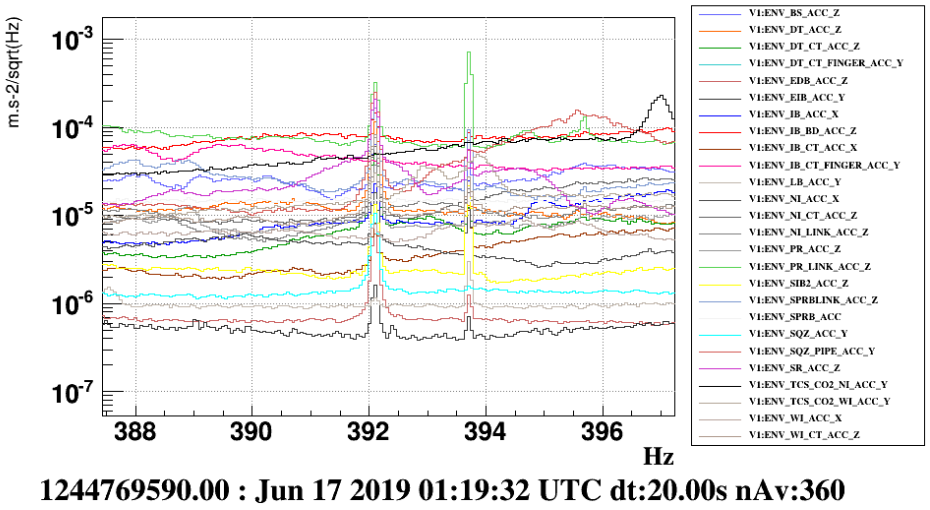
Blue: LSC_DARM
Red: Projected coherence
LSC_DARM*COHERENCE

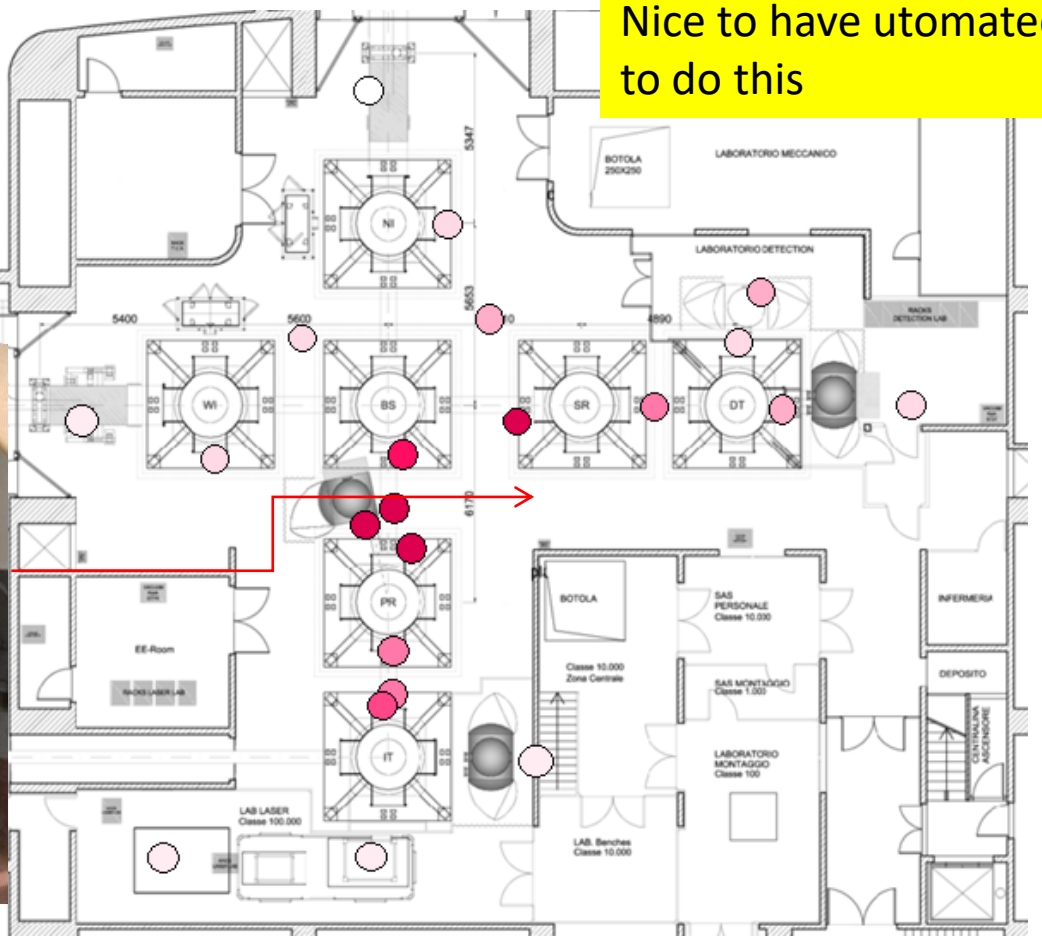


… follow up: locate the noise source

- Comparing the peak's amplitude in all ENV accelerometers in CEB (26) helps locating the source
- Example: 391Hz spectral line in all CEB accelerometers

… done by hand ☺
Nice to have utomated tool to do this





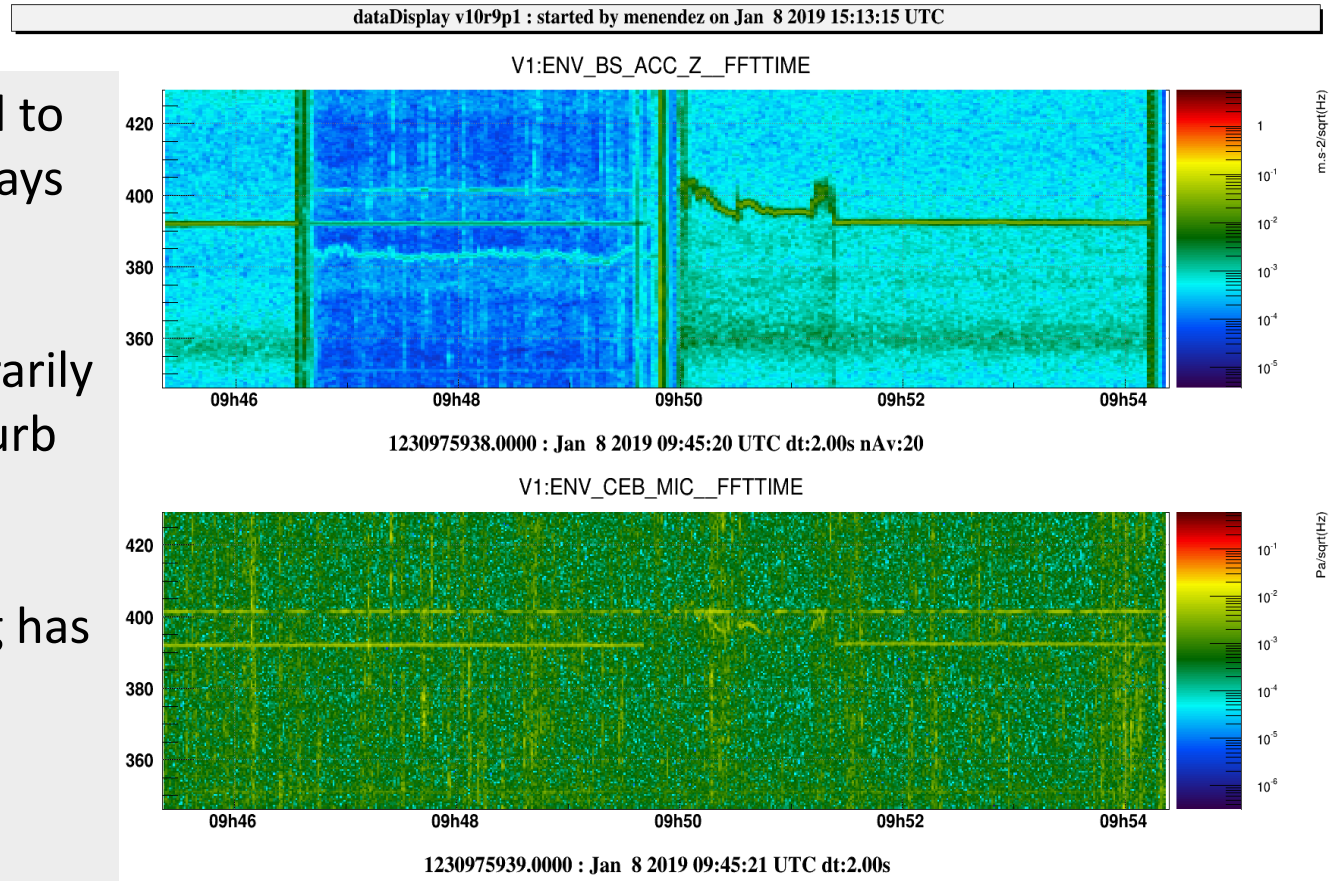
Sniffing ....

- Located the source of 391Hz line - **Noisy cooling fan of turbo pump driver**

➢Test accelerometer attached to chassis (double-side tape, always at hand ☺) → coherent line

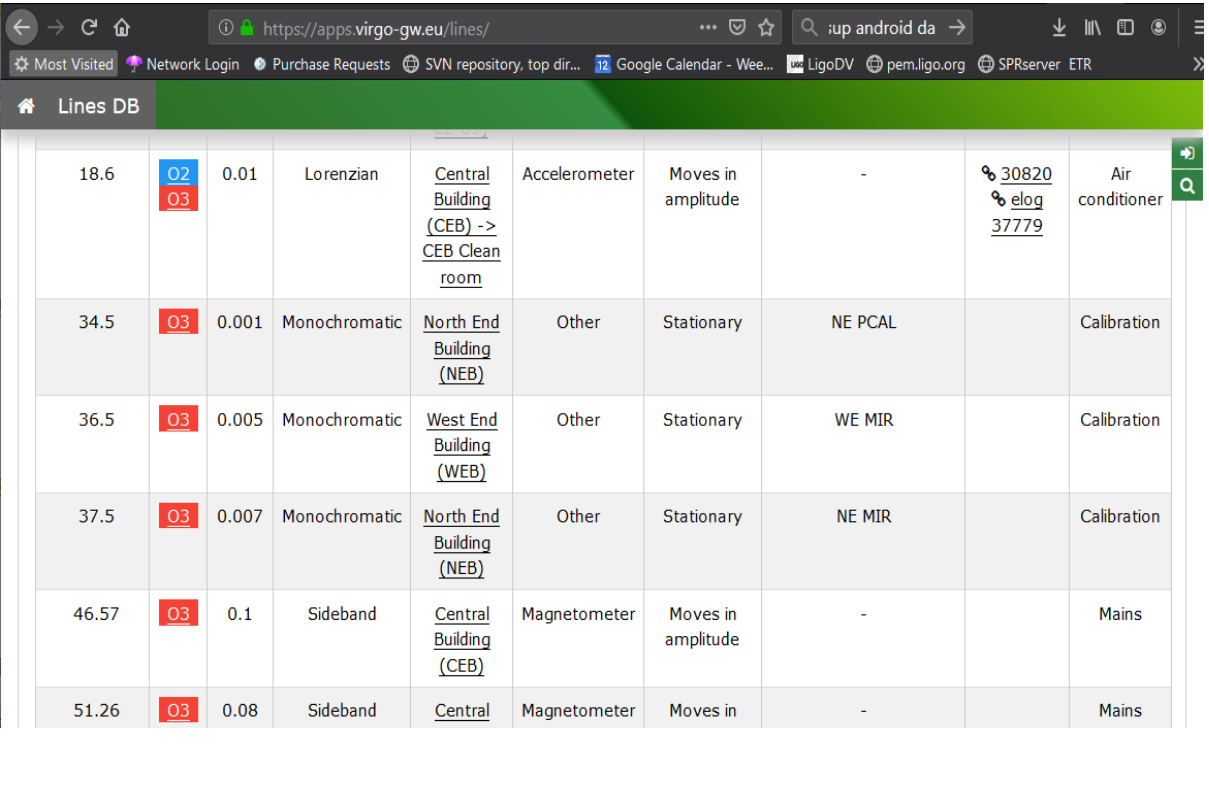
➢Used some paper to temporarily block the air outlet so to perturb the fan speed

➢ Noisy fan because of ageing has been replaced and added vibration dampers
(VACUUM team - O3)

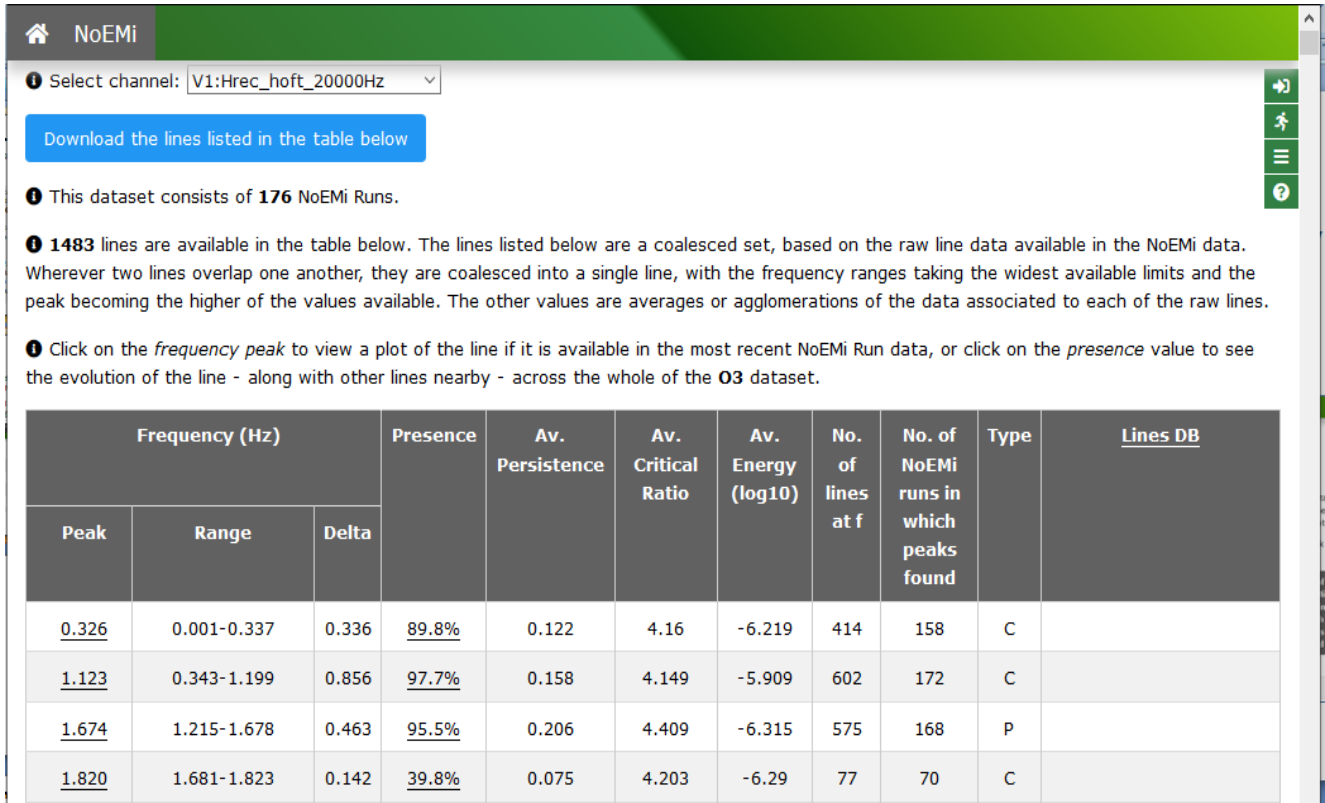


Lines

- **Lines DB :** archive of identified LINES https://apps.virgo-gw.eu/lines (by Gary Hemming). In charge: Neha Singh nsingh@astrouw.edu.pl
- **NoEMi V2.0** - LINES FINDER https://apps.virgo-gw.eu/noemi/?c=1. Ornella.Juliana.Piccinni@roma1.infn.it , gary.hemming@ego-gw.it



18.6	O2 O3	0.01	Lorenzian	Central Building (CEB) -> CEB Clean room	Accelerometer	Moves in amplitude	-	30820 elog 37779	Air conditioner
34.5	O3	0.001	Monochromatic	North End Building (NEB)	Other	Stationary	NE PCAL		Calibration
36.5	O3	0.005	Monochromatic	West End Building (WEB)	Other	Stationary	WE MIR		Calibration
37.5	O3	0.007	Monochromatic	North End Building (NEB)	Other	Stationary	NE MIR		Calibration
46.57	O3	0.1	Sideband	Central Building (CEB)	Magnetometer	Moves in amplitude	-		Mains
51.26	O3	0.08	Sideband	Central	Magnetometer	Moves in	-		Mains



Frequency (Hz)			Presence	Av. Persistence	Av. Critical Ratio	Av. Energy (log10)	No. of lines at f	No. of NoEMi runs in which peaks found	Type	Lines DB
Peak	Range	Delta								
0.326	0.001-0.337	0.336	89.8%	0.122	4.16	-6.219	414	158	C	
1.123	0.343-1.199	0.856	97.7%	0.158	4.149	-5.909	602	172	C	
1.674	1.215-1.678	0.463	95.5%	0.206	4.409	-6.315	575	168	P	
1.820	1.681-1.823	0.142	39.8%	0.075	4.203	-6.29	77	70	C	

Scattered light

A few slides tutorial:

- What is it
- How to recognize it … from spectral features (!)
- Investigation techniques to locate the scatterer

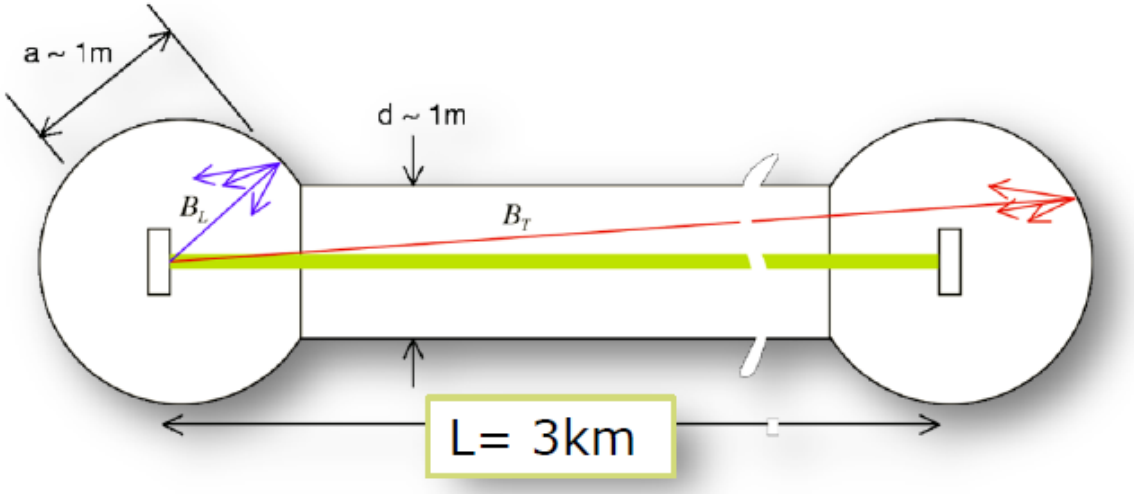
An Old Enemy

Credits: Antonino Chiummo
VIR-0013A-19

EGO - VIRGO

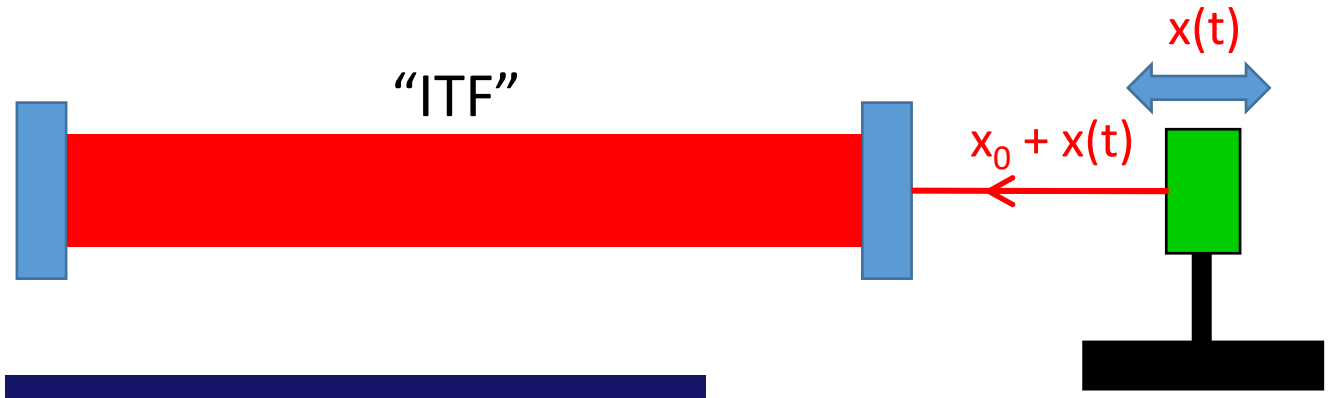
- Stray light gave countless problems during past generation (as long expected)

- A tiny amount of stray light coupling with the fundamental mode after "probing" the vibrations of infrastructures will bury any gravitational signal.



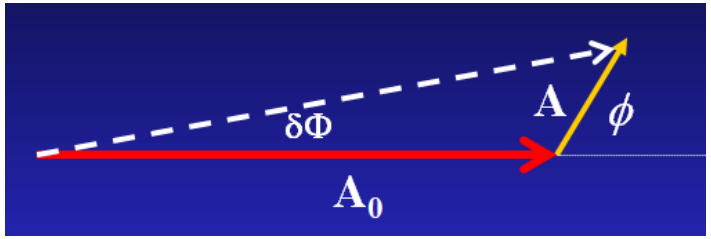
Scattered light, some formulas

From: S.Braccini – VIR-0277A-09
Reference: Vinet J-Y, Brisson V and Braccini S 1996 Scattered light noise in gravitational wave interferometric detectors: Coherent effects, PRD 54,2 1276



Scatterer = some surface ground connected in view of ITF beam (typical: optics on not suspended bench, vacuum chamber…)

Seismically excited: displacement x(t)



"G"

$$\delta\Phi(t) = \frac{Im\,\vec{A}}{|\vec{A}_0|} = \frac{|\vec{A}| \cdot \sin\phi}{|\vec{A}_0|} = T \cdot \sqrt{\frac{2F}{\pi}}\sqrt{\varepsilon}\,\sin(\phi_0 + \phi(t)) = K \cdot \sqrt{\varepsilon}\,\sin(\frac{2\pi}{\lambda}2(x_0 + x(t)))$$

1. A change of x(t) of λ/2 means a change of optical path length of λ and a full rotation of the stray light vector

$x : \lambda/2 = \varphi : 2\pi$ ⇒ $\varphi = 4\pi x / \lambda$

2. Frequency of noise = rate of rotation: $\frac{d\varphi/dt}{2\pi} = 2\,(dx/dt)/\lambda$

Frequency of the induced noise is proportional to the absolute value of scatterer velocity

$$f_{fringe}(t) = \left|2\frac{v_{sc}(t)}{\lambda}\right|$$

NON LINEAR !
Expect non linear effects (up-conversions) if

$$\delta x(t) \quad >> \quad \frac{\lambda}{4\pi} \simeq 10^{-7}\mathrm{m}$$

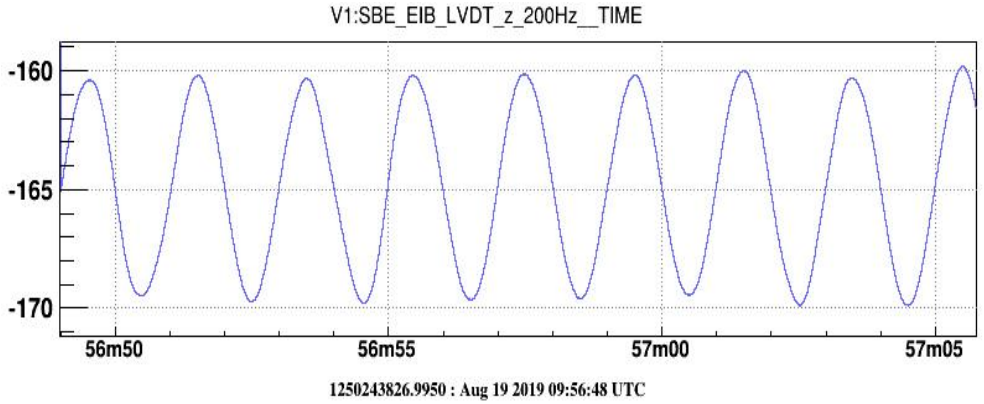
Scattered light – ARCHES

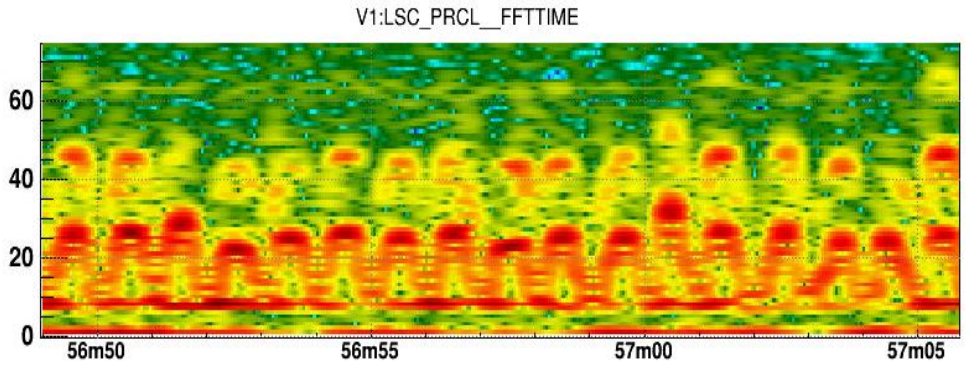
Derivative of bench displacement

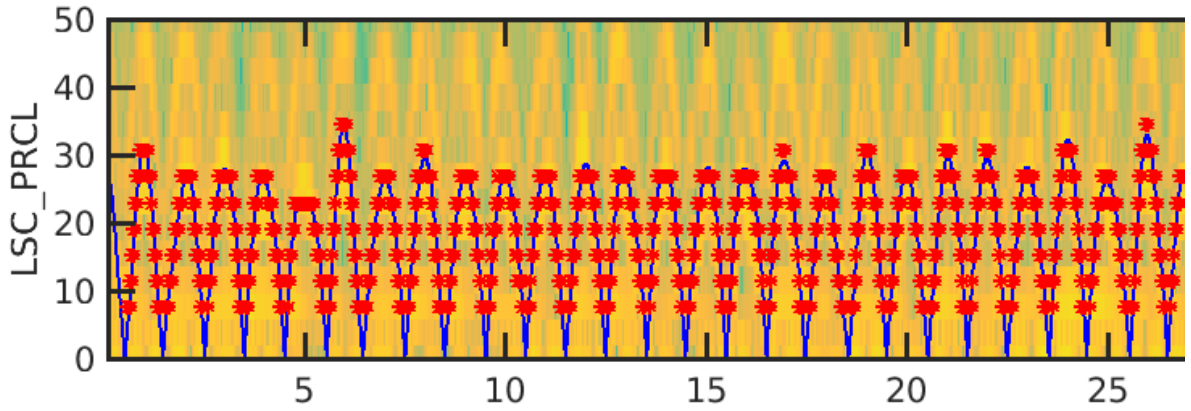
Example: shaking EIB with 0.5Hz sinus (46720)

Blue line is $f_{fringe}(t) = \left| 2\frac{v_{sc}(t)}{\lambda} \right|$

Bench displacement in microns:





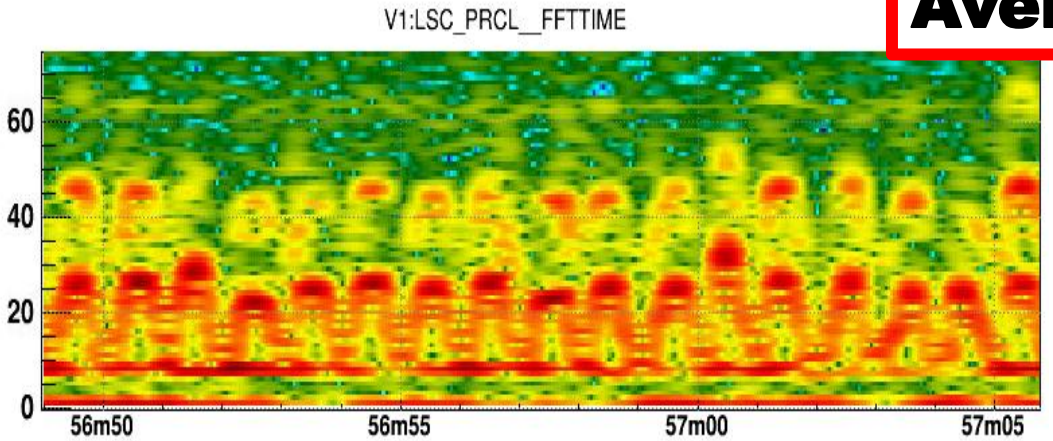


NOTE that:

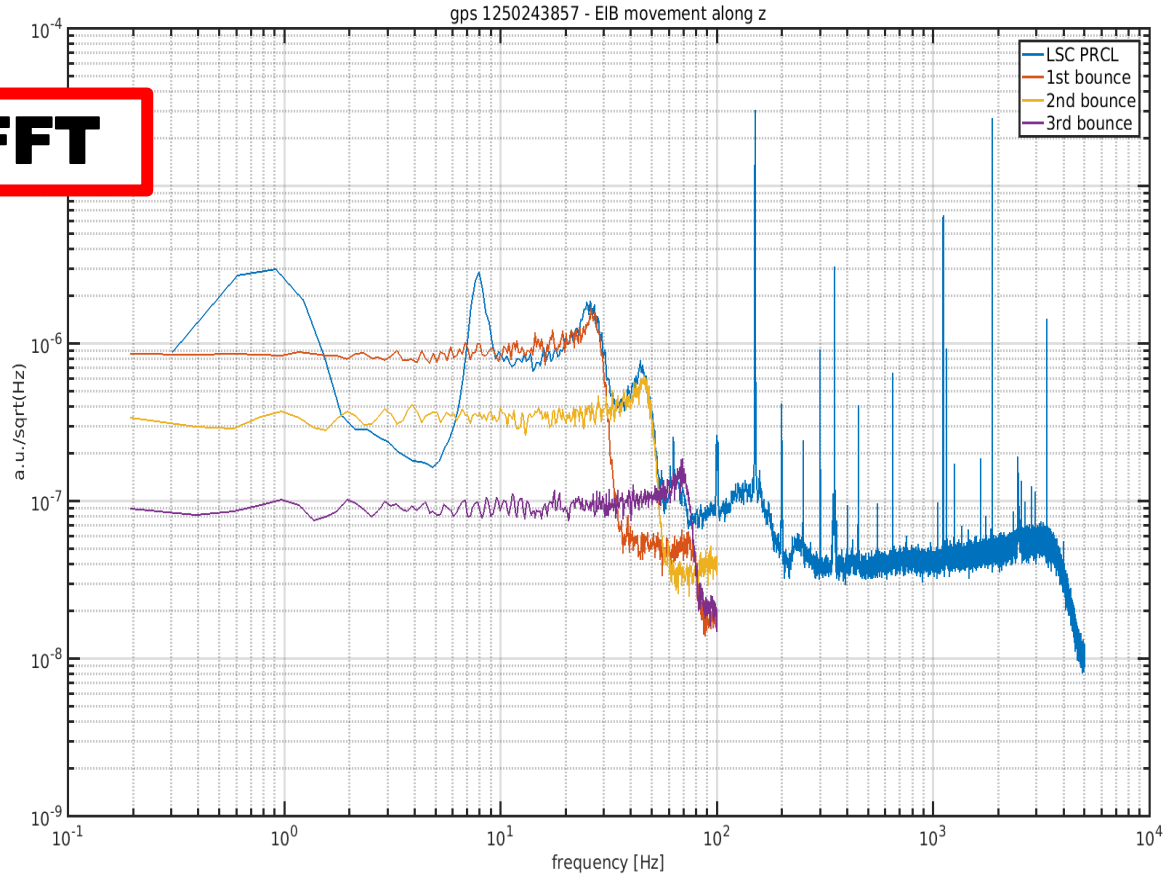
- Height of arches is proportional to scatterer velocity (i.e. if f_{max} = 20Hz → V_{max}= 20*λ/2 = 10 λ = 10µm, a LOT!!)
- Spacing of arches = half of scatterer period or 1/(2*$f_{scatterer}$)
- Second order of arches: scattered beam does double bounce

Scattered light – SHOULDERS

Is just another way to look at the arches….



Averaged FFT



NOTE that:

- Height of shoulder is proportional to "G",
  i.e. amount of scattered light which is coupling to ITF

- Fitting the shoulders → measure G

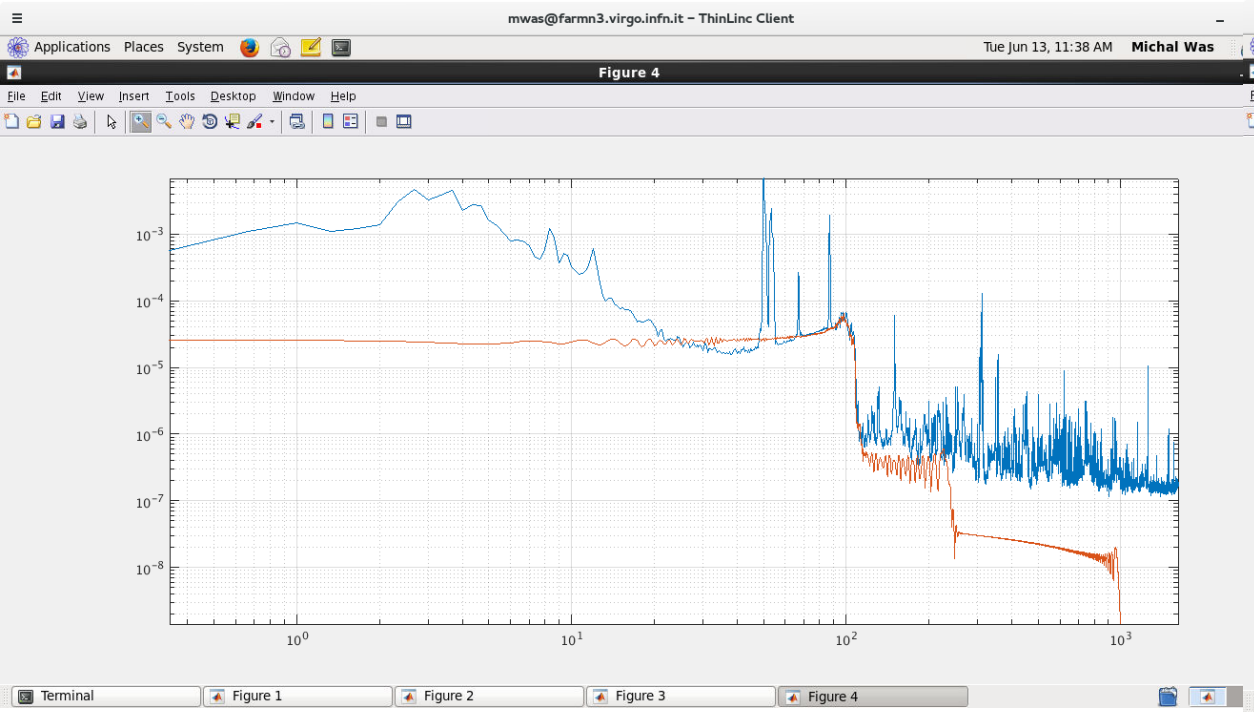
Measure and project

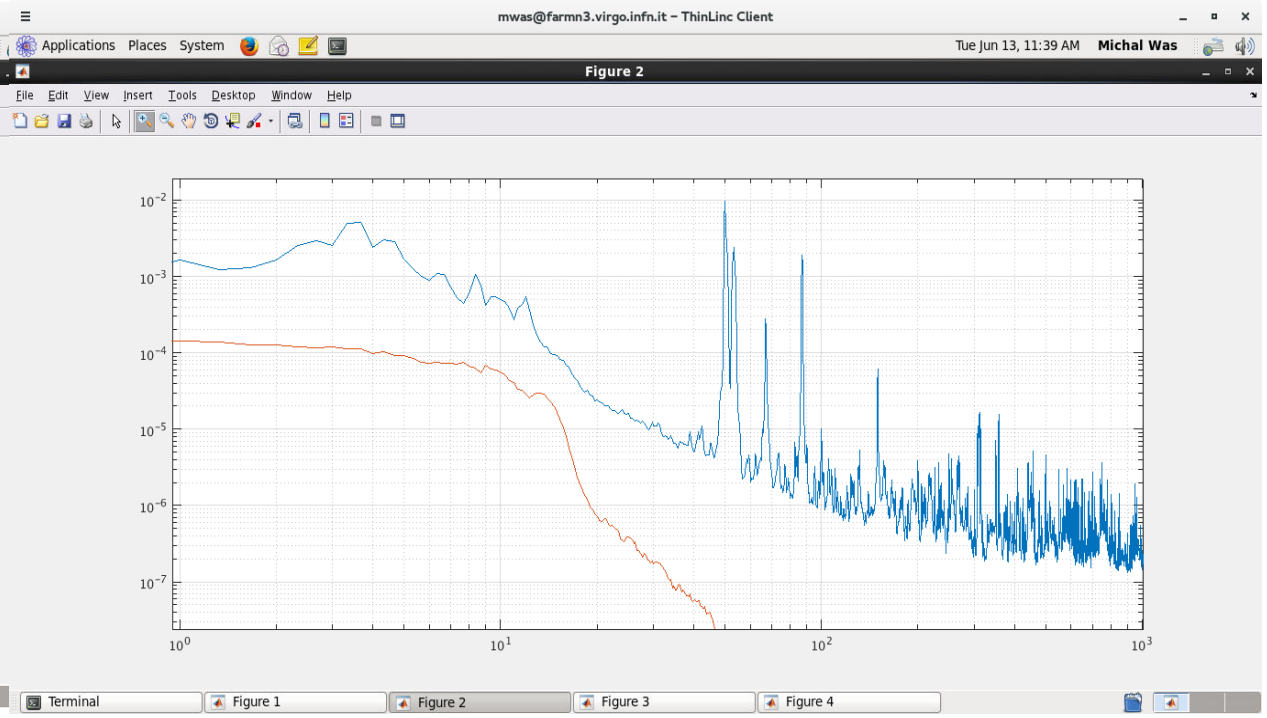
This technique is used to measure and monitor the
Amount of scattered light from benches
See Michal Was's Noise Budget training session

$$h_{sc}(t) = G \cdot \sin\left(\frac{4\pi}{\lambda}(x_0 + \delta x_{sc}(t))\right)$$

1. Apply a known (some microm) motion x(t) to the bench (use voice coil actuators)
Do fit of the shoulder to extract "G"

2. Use this G and x(t) in quiet condition to evaluate the "expected contribution"
Of scattered light from that bench

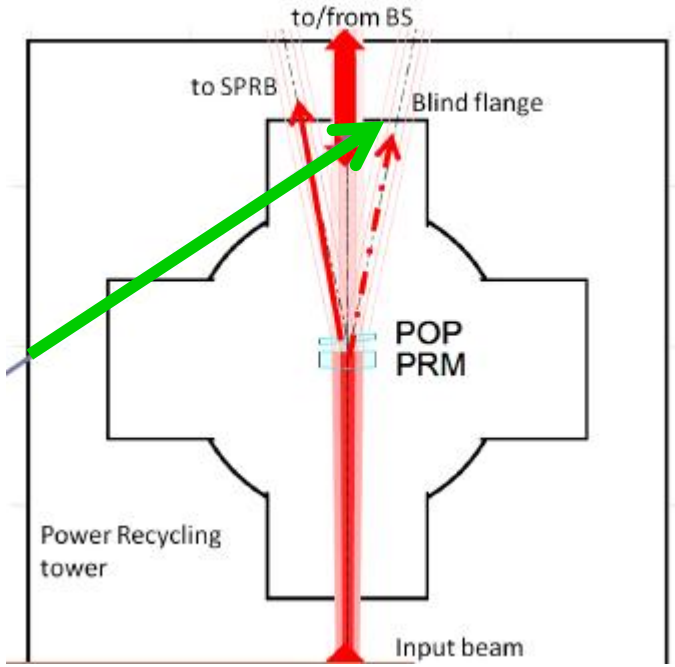




Scattered light - BUMPS

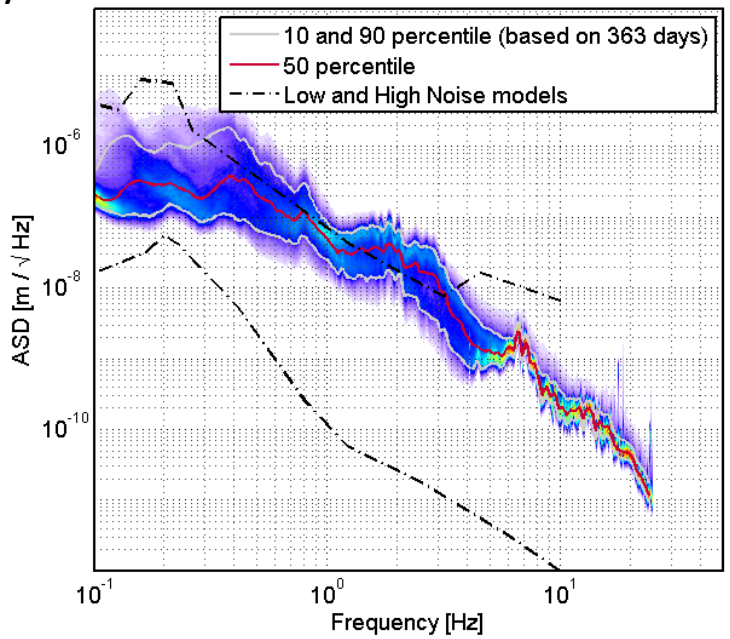
Mono-chromatic vibration due to a fan or resonant mode of a mount or bench (typically in the 10Hz to 100Hz range) is seen as a BUMP in Hrec (!)

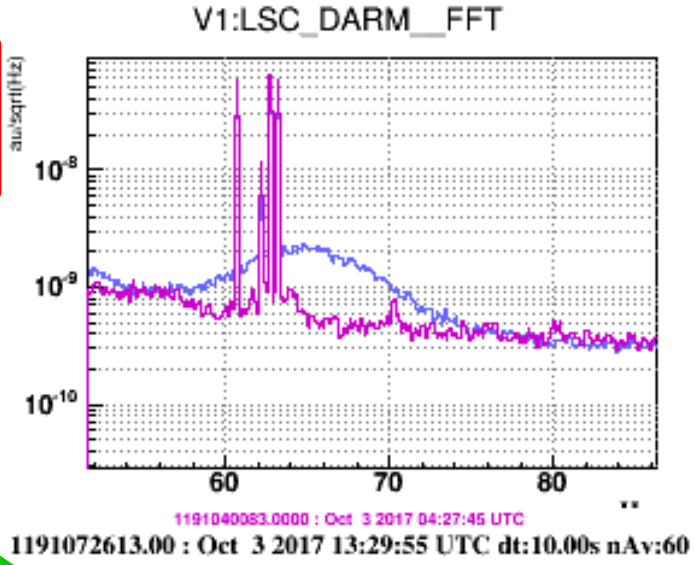
- **Case of light scattered from PR chamber blind flange:**

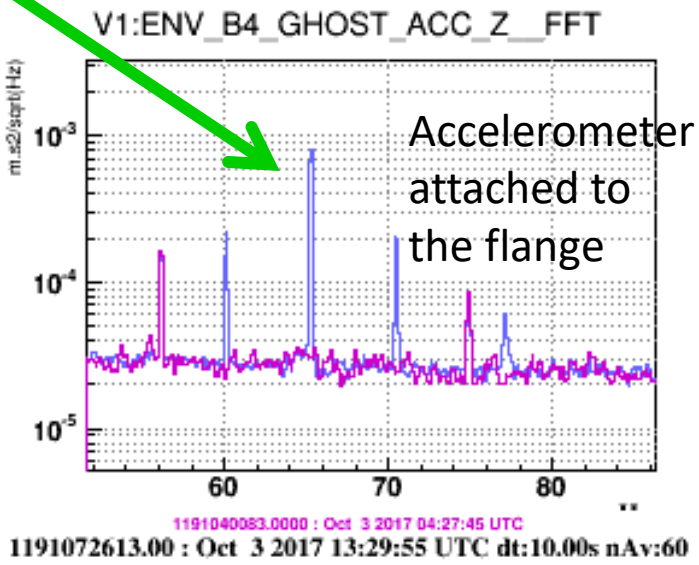


See Antonino Chiummo
VIR-0013A-19

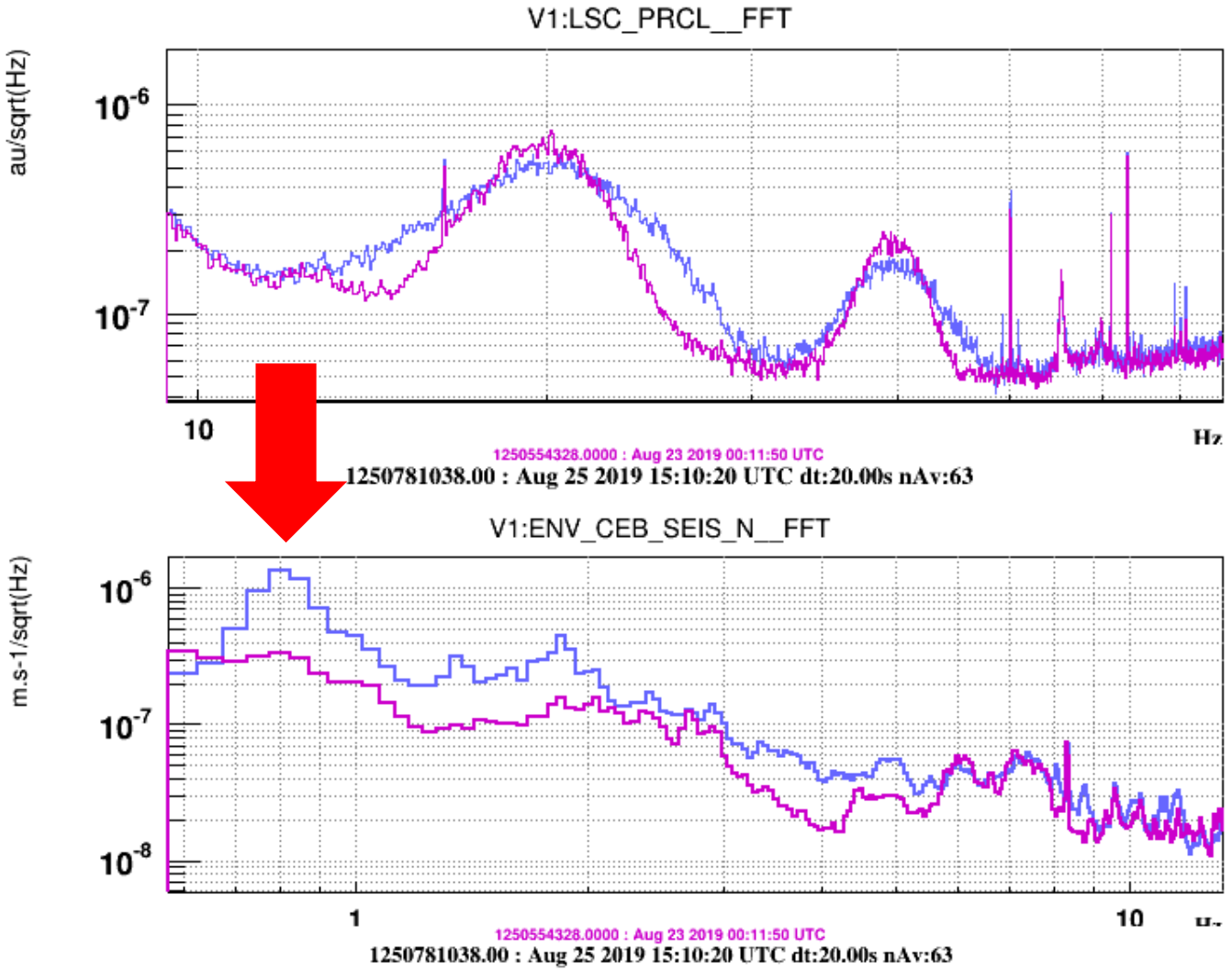
Flange had vibration at 65Hz of ≈ 10^-9m
Small… BUT flange overall displacement was actually of O(microns) because of low frequency **microseism**







One last feature:
when microseism increases bumps get shorter and fatter



Try yourself:

all these features can be easily reproduced with a simple simulation, feeding one realistic x(t) in the formula

$$h_{sc}(t) = G \cdot \sin\left(\frac{4\pi}{\lambda}(x_0 + \delta x_{sc}(t))\right)$$

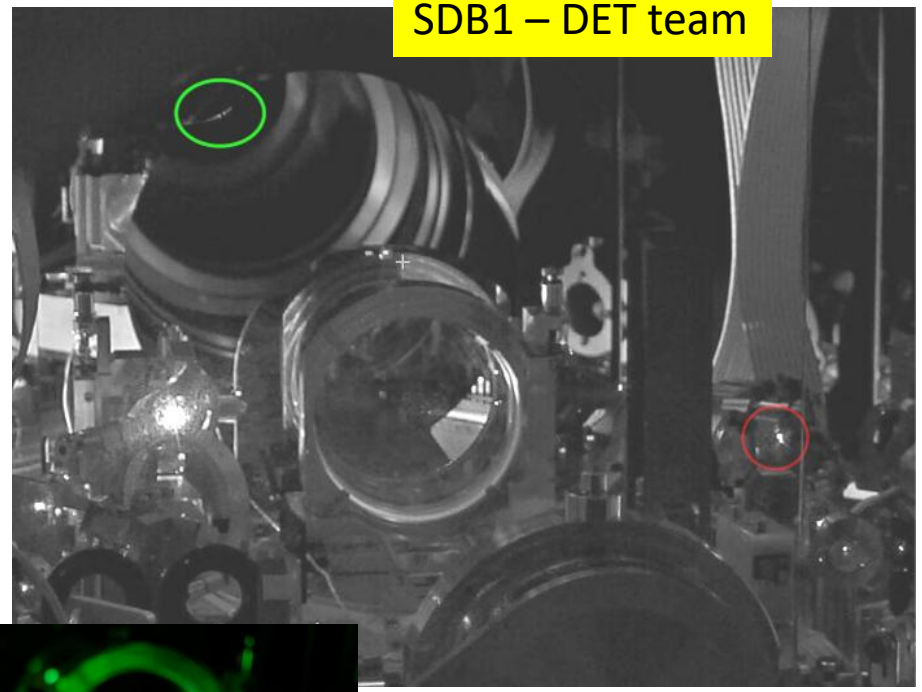
Scattered light hunting techniques

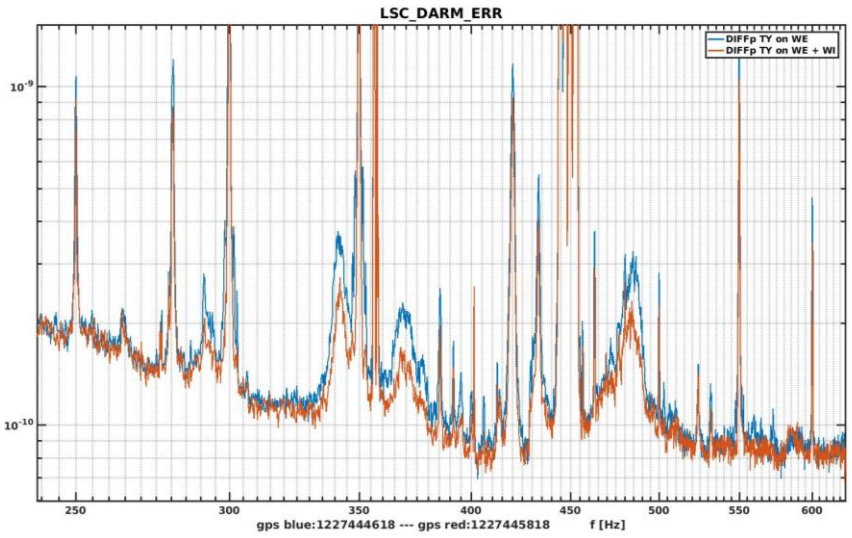
1. Inspect optical bench with infrared camera or IR cards to locate stray light beams
2. Tap the optics → DARM noise “explodes” when touching the critical one

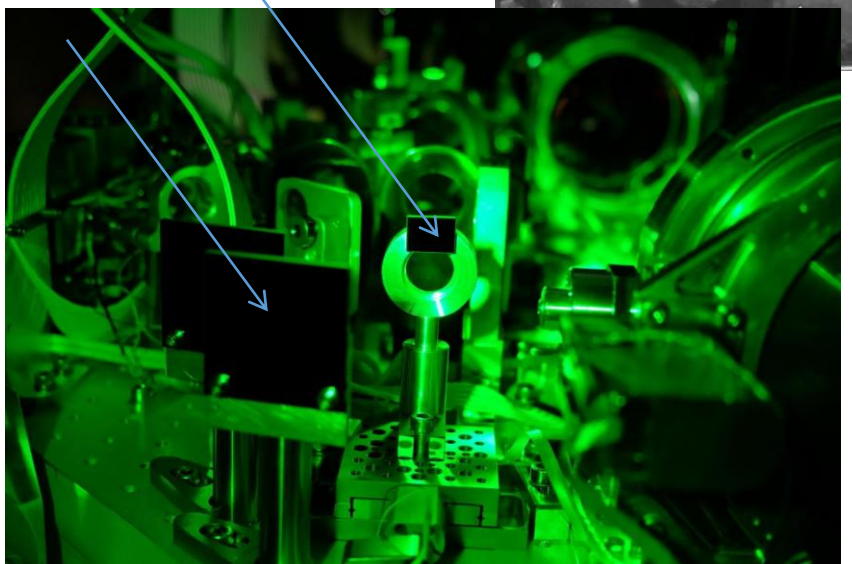
MITIGATIONS:

→ add beam dumps/black glass to absorb scattered beams

→ Better align the beam on the bench, improve ITF global alignment:

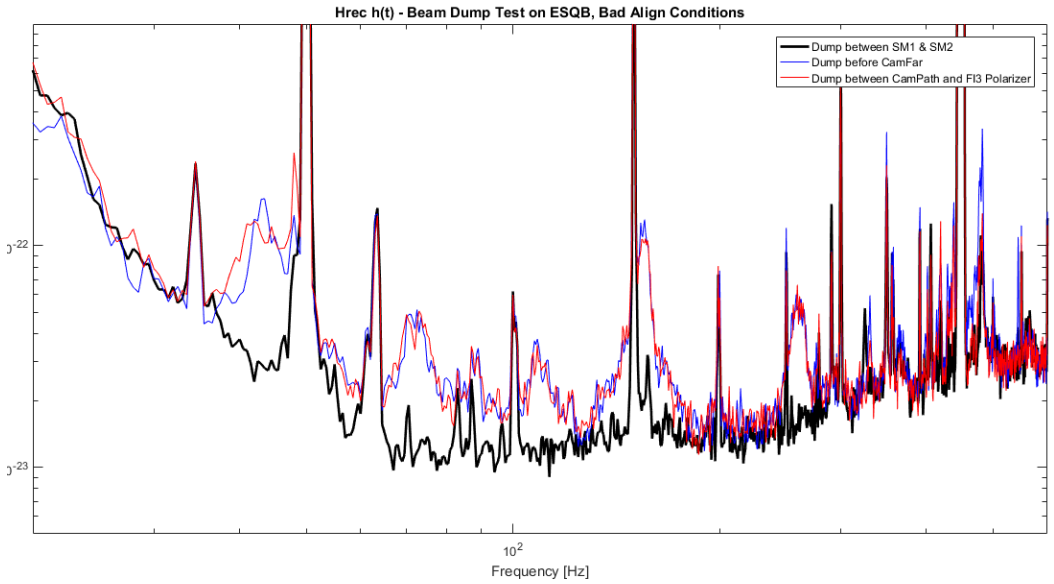






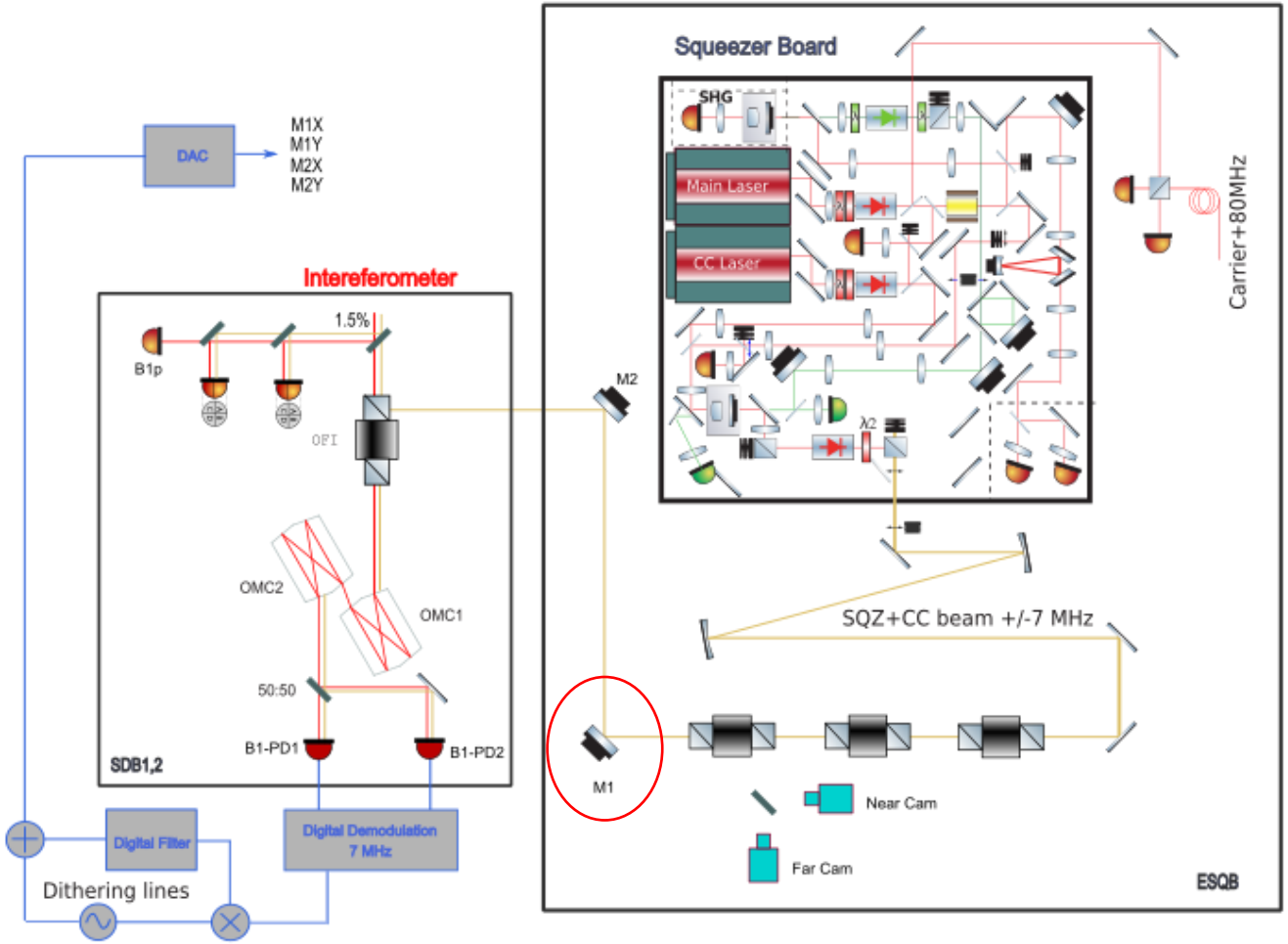
Scattered light hunting techniques

3. Block the beam on bench following backwards the beam path and see when noise disappears



Critical scattering mitigated: improved alignment of SQZ injection, reduced OFI reflected power

Elog 45006: ESQZB - Beam Dump Test and IR Viewer/Card Inspection (S.Chua et al)



Scattered light hunting techniques

SDB1 chamber

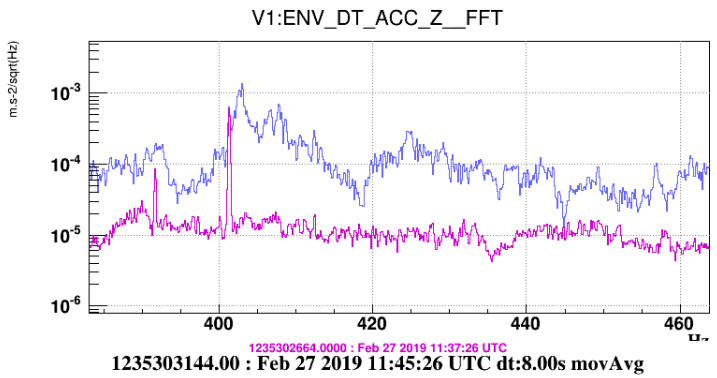
4. Shake or TAP (gently!) and see if some existing structures in Hrec grow….
(see Federico's talk – ENV training Part 2)

White noise injected with shaker on SDB1 chamber wall

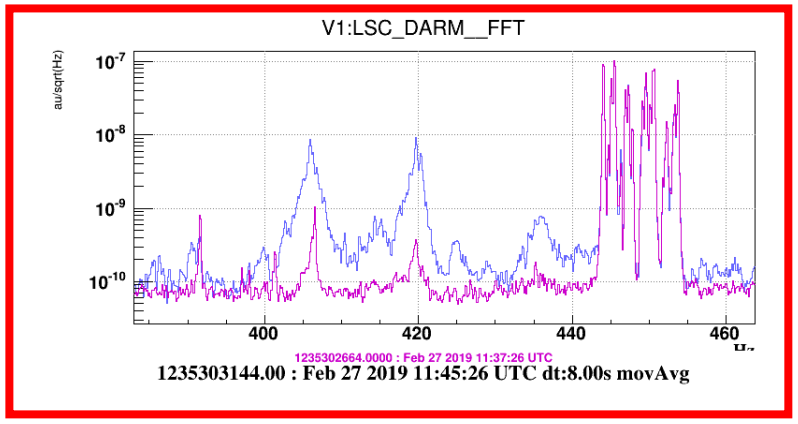
Cause is: **light scattered off SDB1 onto chamber walls**

- Disadvantage: **shaker injection is not localized**, sometimes we prefer using instrumented hammer or "tapping"

ACCELEROMETER



Hrec



Concluding …

- Noise Hunter skills:
  - Curiosity
  - Perseverance
  - Dedication
  - …
  - Curiosity!

END

Thank you for your kind attention!