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EGO

Mystery noise in GEO600

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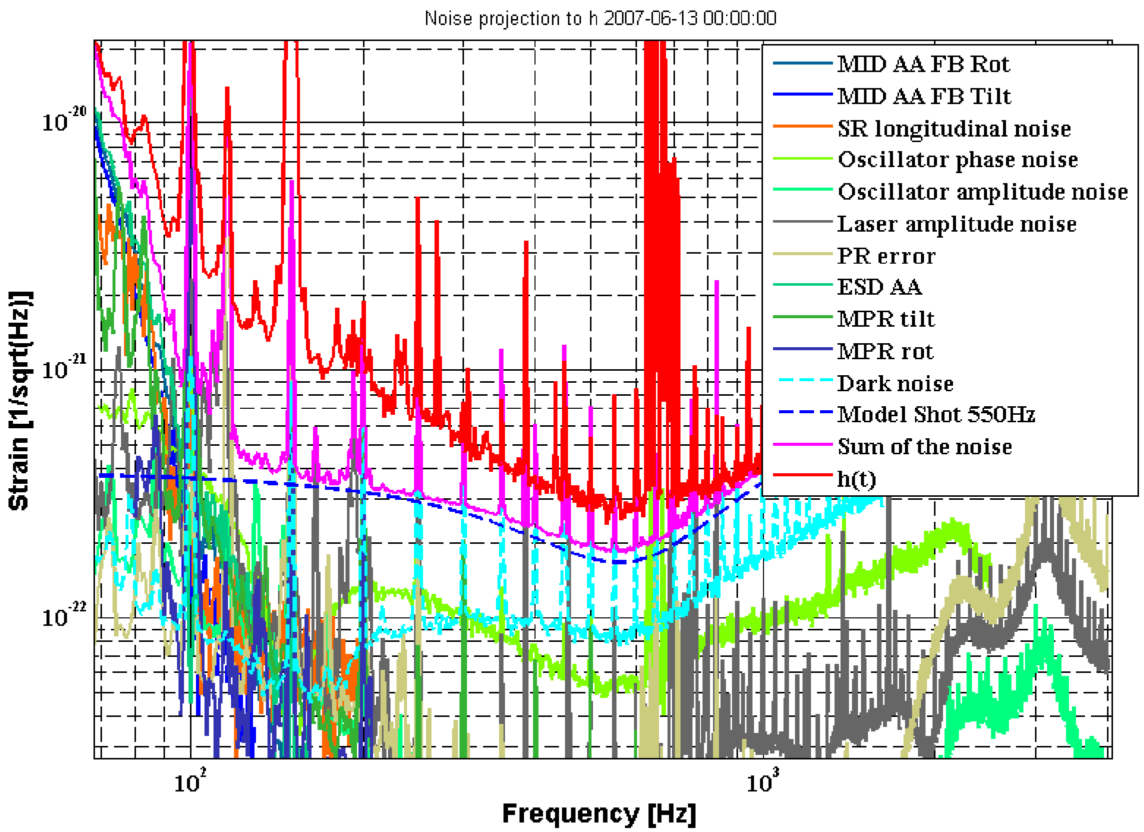
IGR

GEO 600

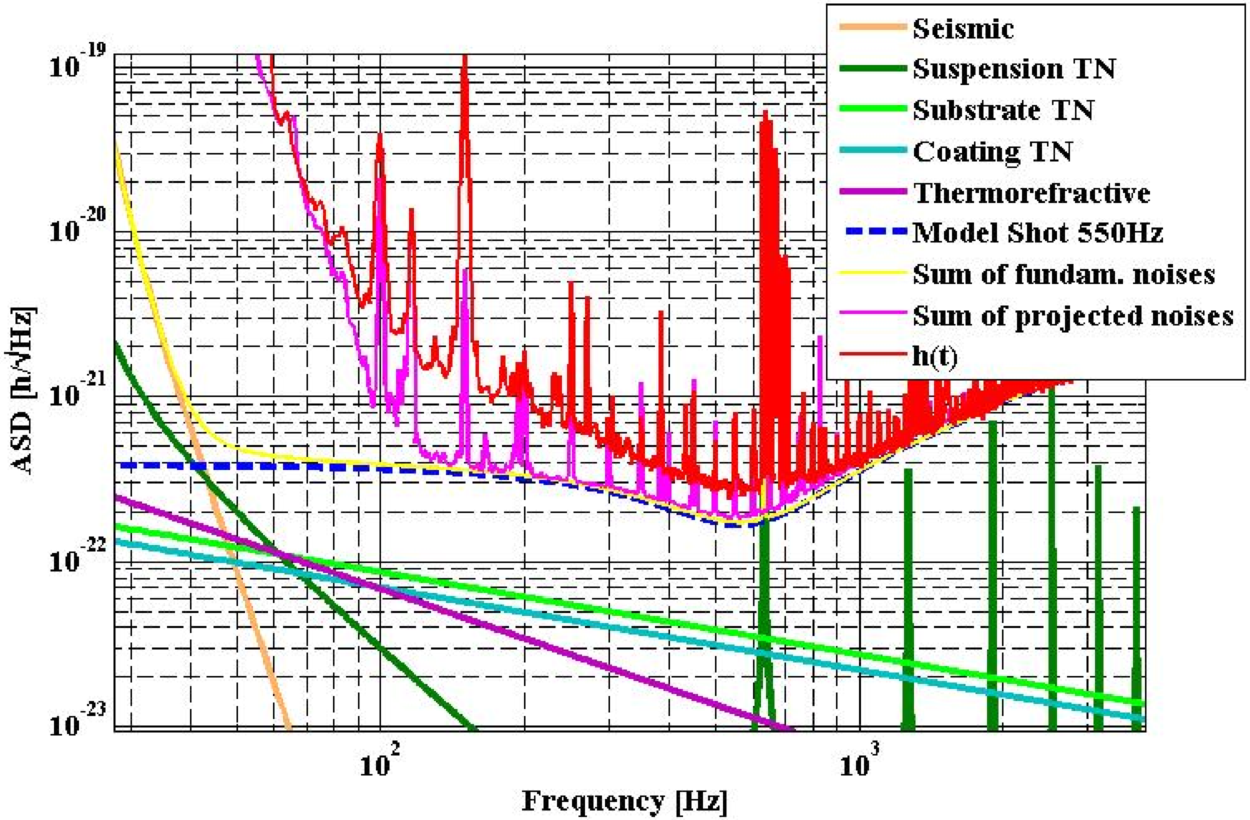
14th ILIAS WG1 meeting, October 2007, Hannover

Intro: What is „mystery noise“?



There is a big gap between the uncorrelated sum (pink) of all known noise contributions and the actually measured sensitivity (red).

Intro: What is „mystery noise"? (2)



Also the fundamental noise contributions, especially thermal noises are far below the current sensitivity.

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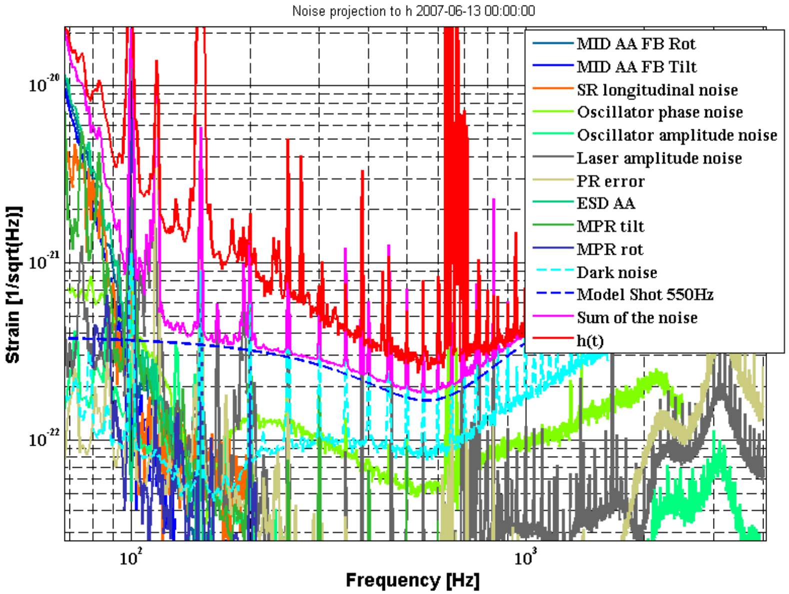
Mystery noise => High Priority

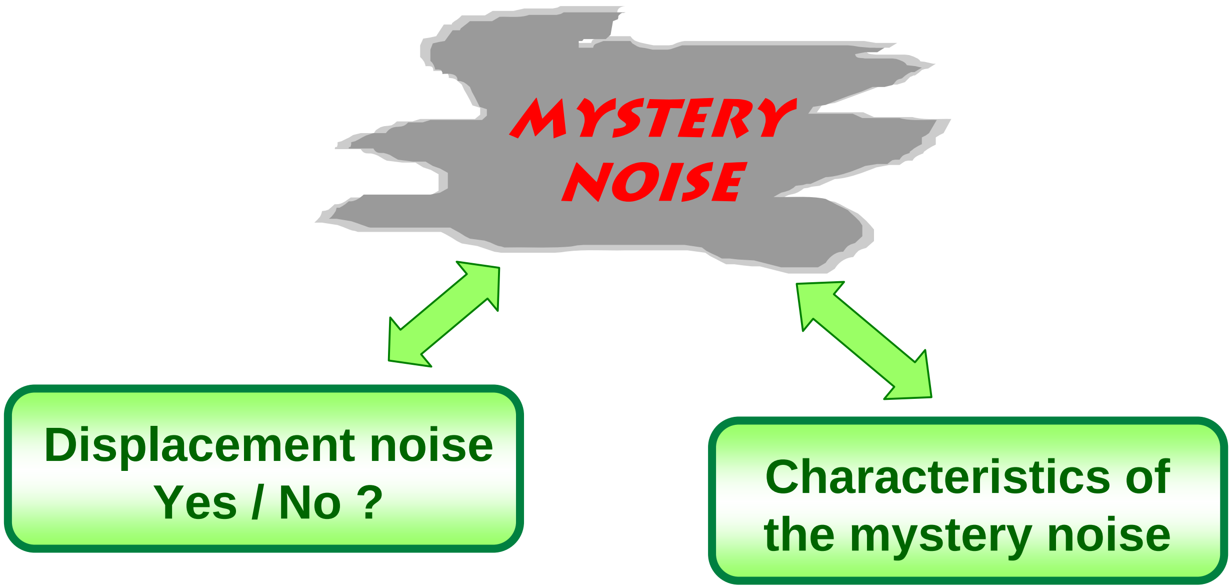
- Limits the GEO sensitivity between 100 and 800 Hz.
- Around 200 Hz without mystery noise the sensitivity would be 3 times better. The peak sensitivity (550 Hz) could be improved by about a factor sqrt(2).
- As long as mystery noise is present, i.e. GEO is not shot noise limited over the major part of the detection band, improvements like increased laser power, DC-readout, squeezing are partly worthless.



We need to find the mystery noise! (There is NO other option)

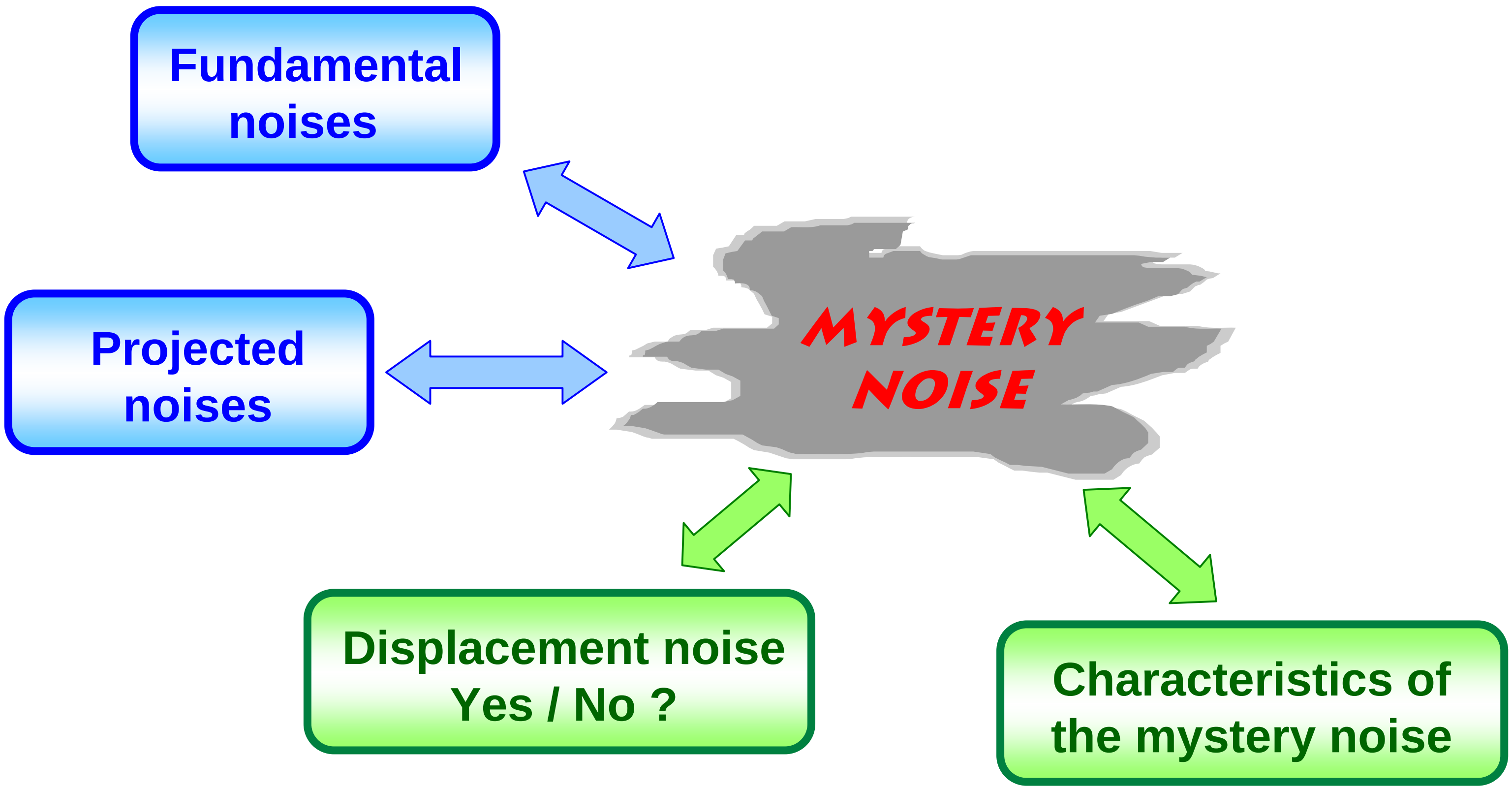
How to tackle the mystery noise ?

How to tackle the mystery noise ?



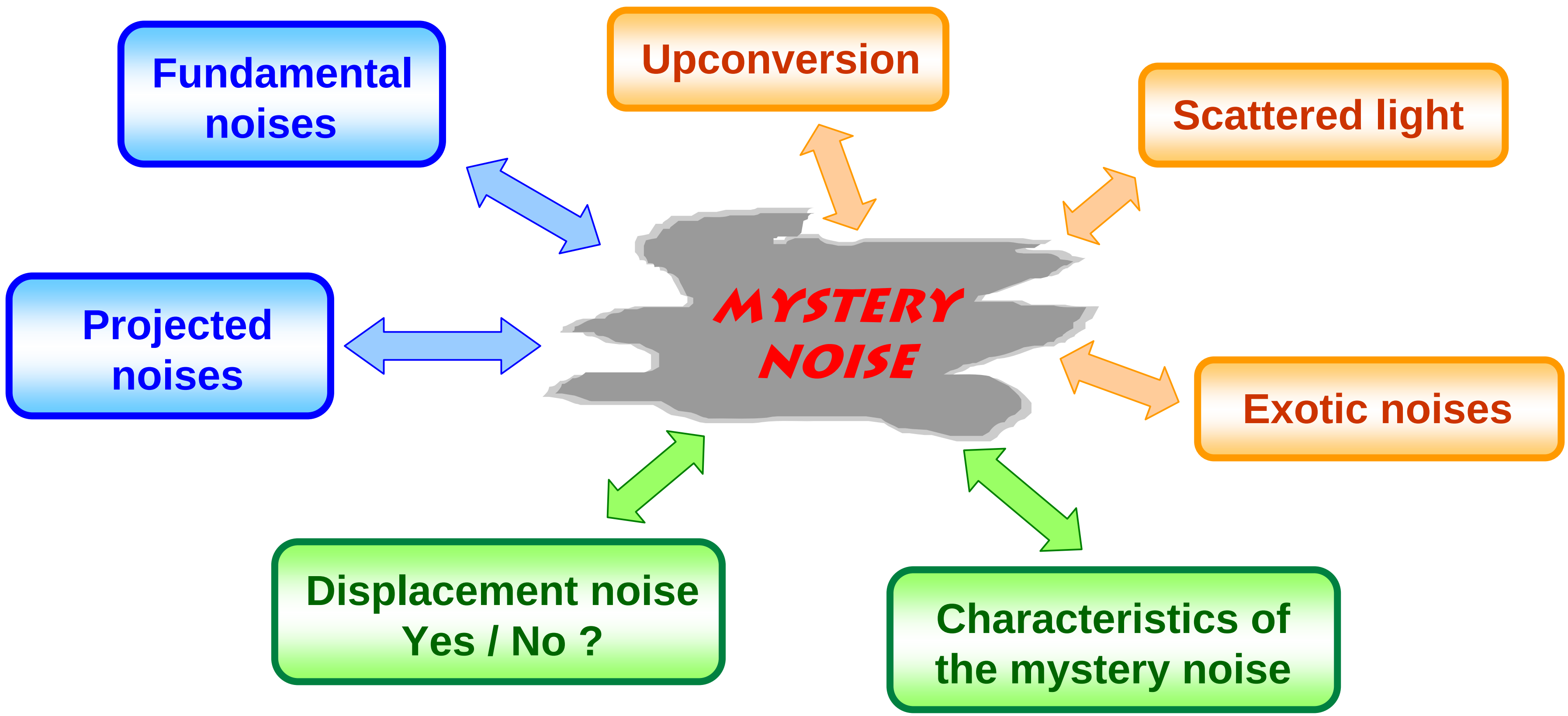
Any clues from the observation? Displacement-like or not? Stationary? Related to glitches? ....

How to tackle the mystery noise ?

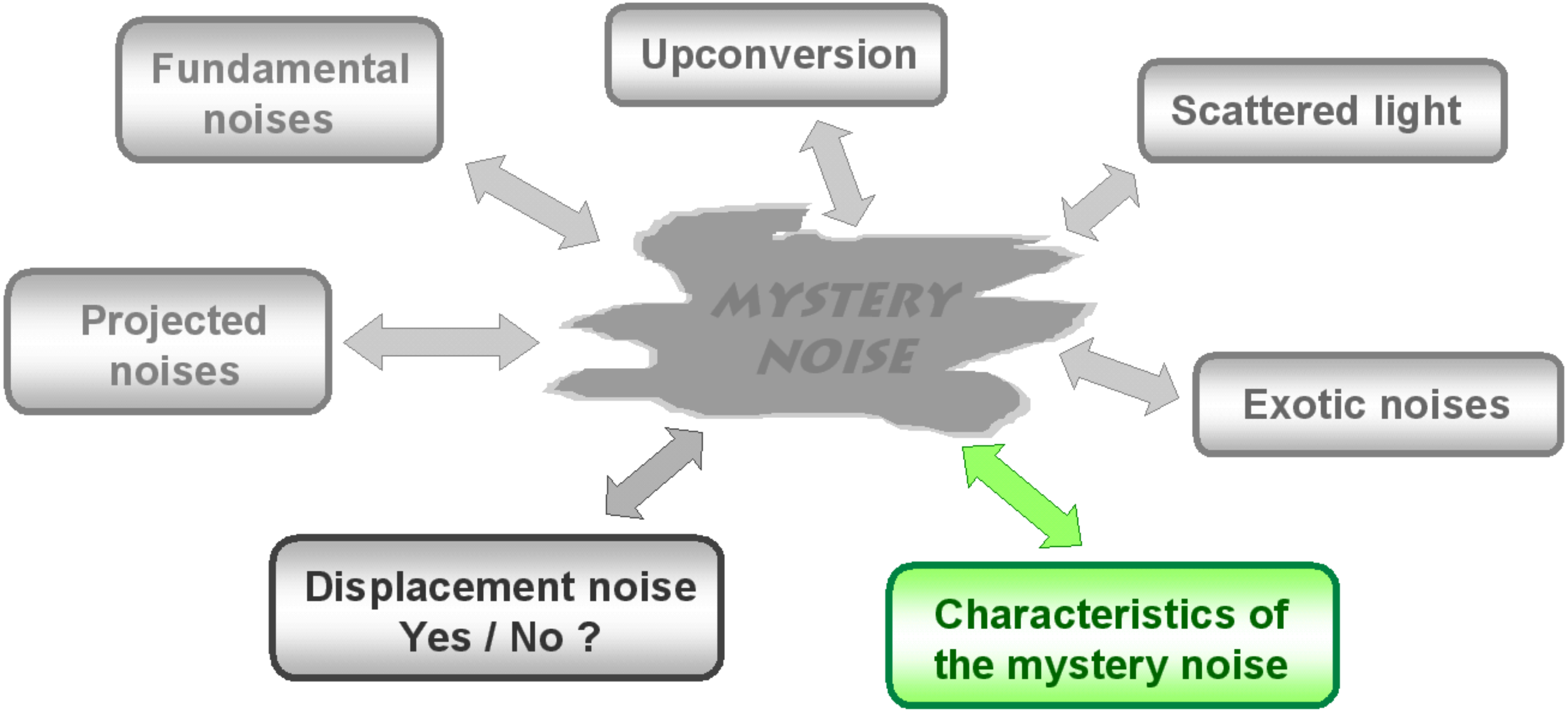


Is the gap real? All projections correct? Are all noises projected? Calculations of fundamental noises correct?

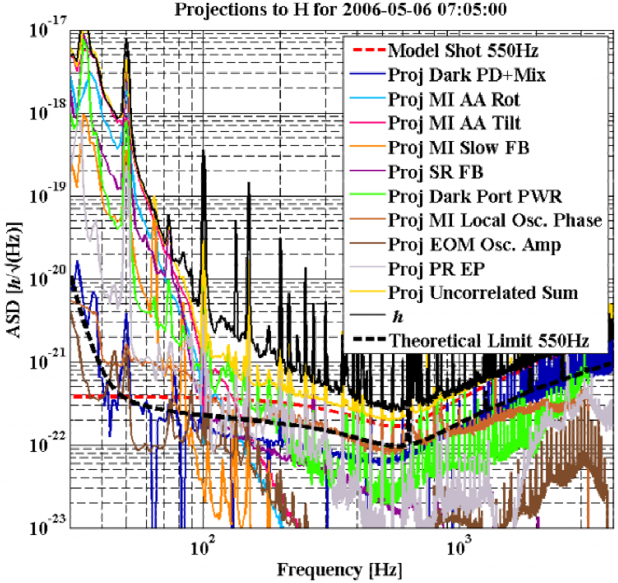
How to tackle the mystery noise ?

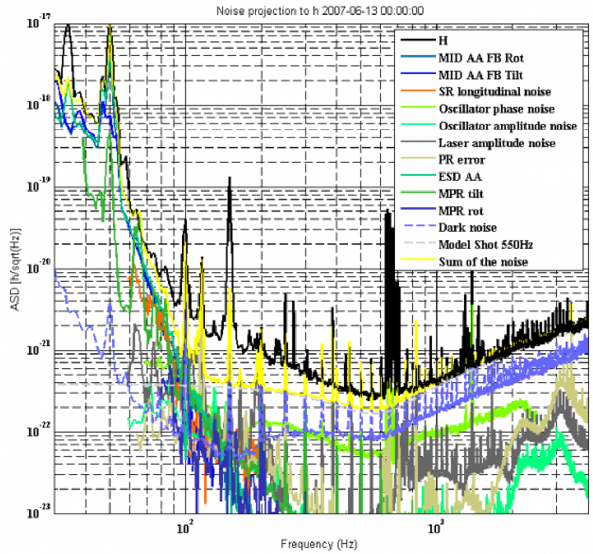


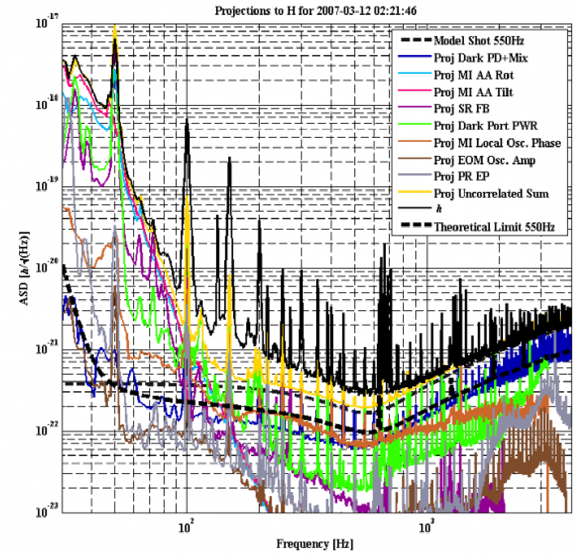
Can we rule out the usual candidates: non-linearly coupling noises?
How about exotic noises ? ....


Fundamental noises
Upconversion
Scattered light
Projected noises
MYSTERY NOISE
Exotic noises
Displacement noise Yes / No ?
Characteristics of the mystery noise

History of the mystery noise

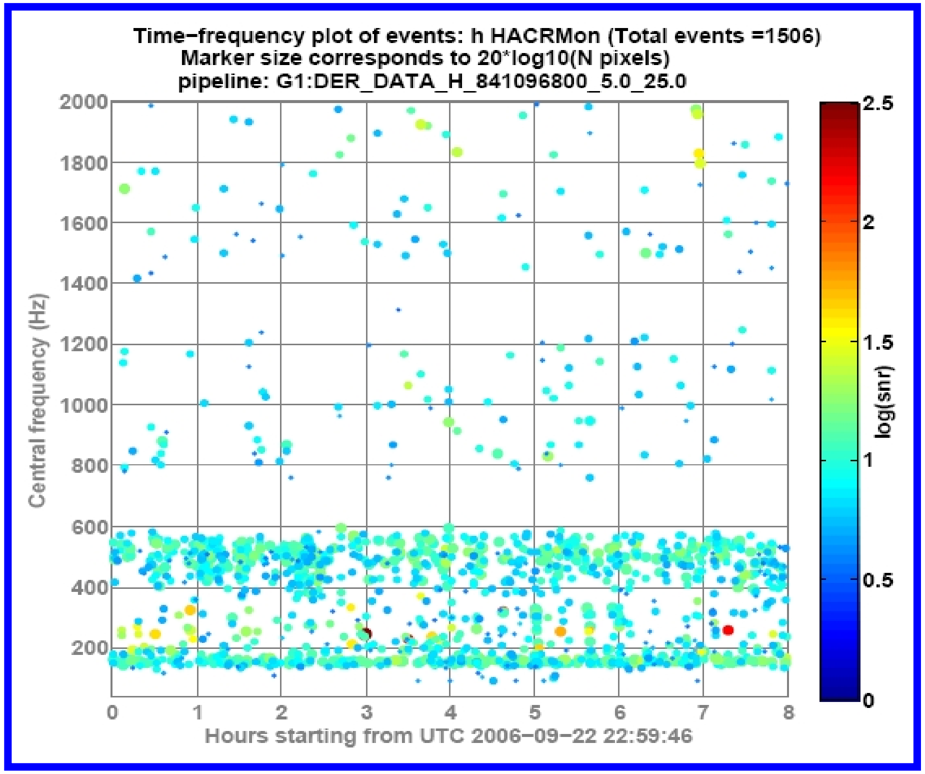


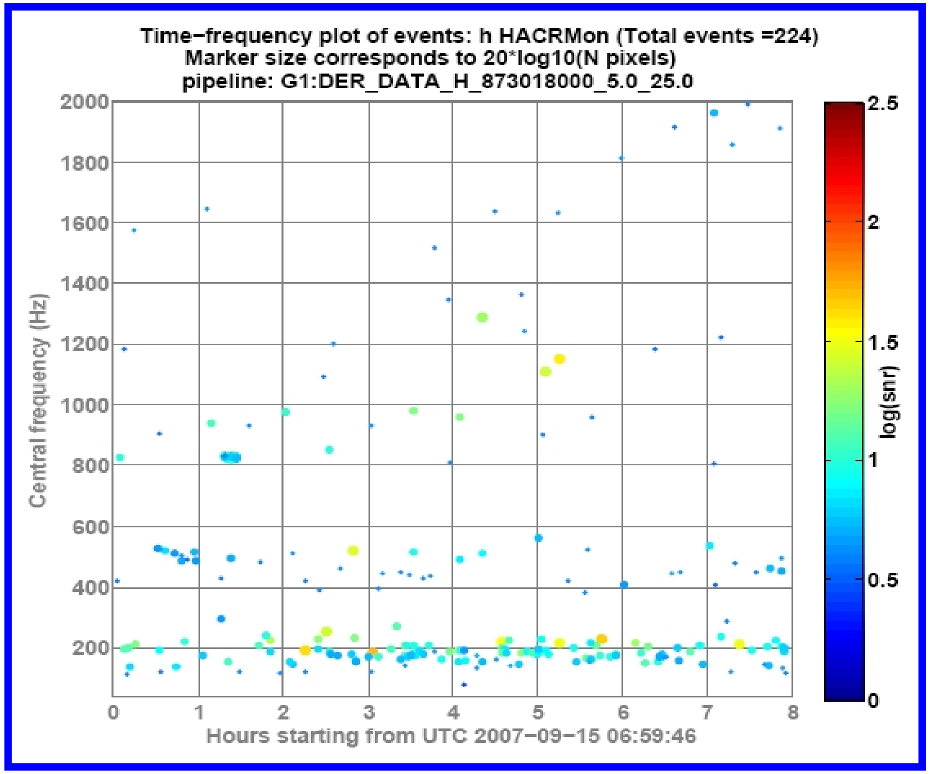




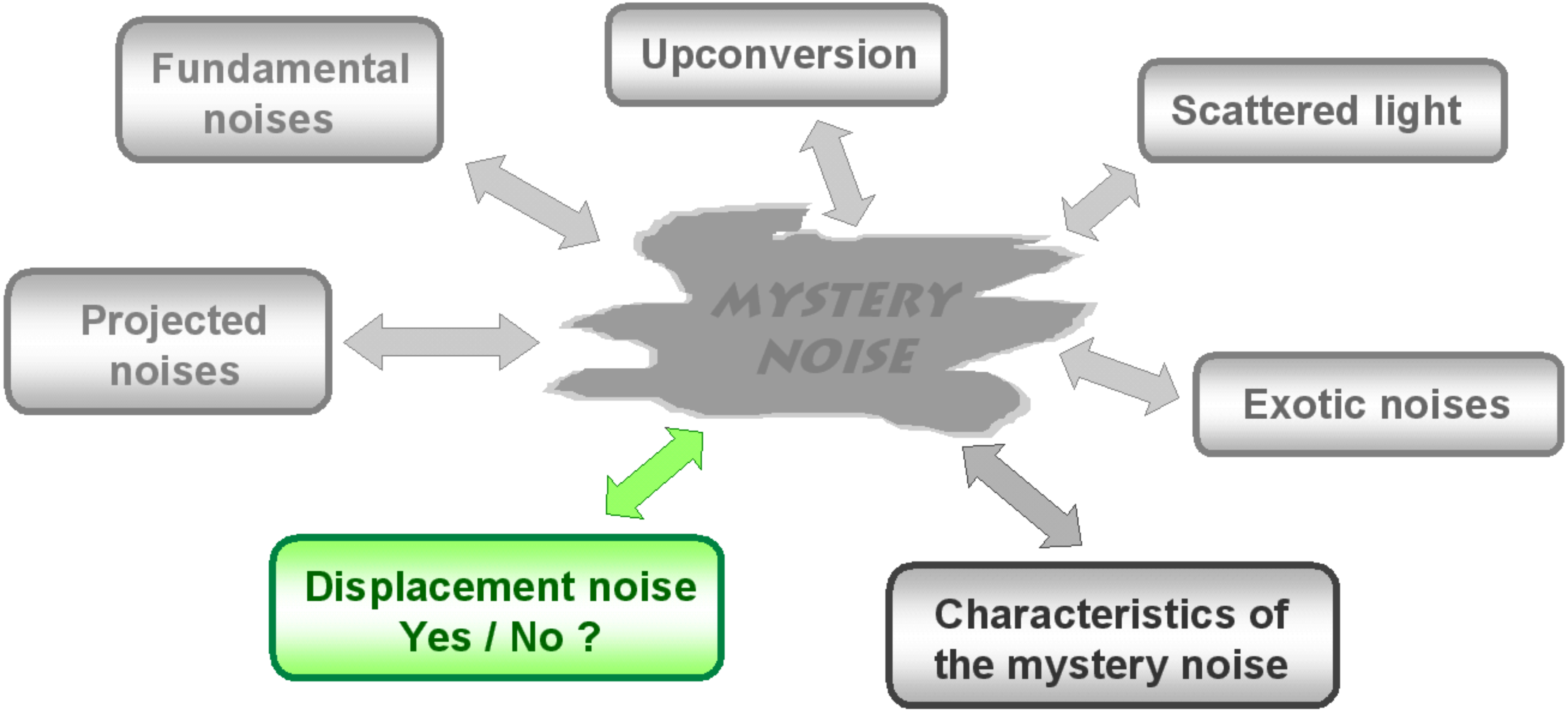
- Broadband noise (without significant structure /features)
- Mystery noise is found to be fairly stable over 15 months (within about 25%).
- Seems to be independent from environmental conditions.
- Spectrum (roughly): 1/f^2 below 200 Hz, 1/f above 200 Hz

Mystery noise is independent of the glirchrate





Eventhough we observe strong fluctuations in the glitchrate, the mystery noise stays always constant.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Does the mystery noise behave like displacement noise ??

If we could find out life would be much easier…

If the mystery noise doesn‘t look like displacement noise:

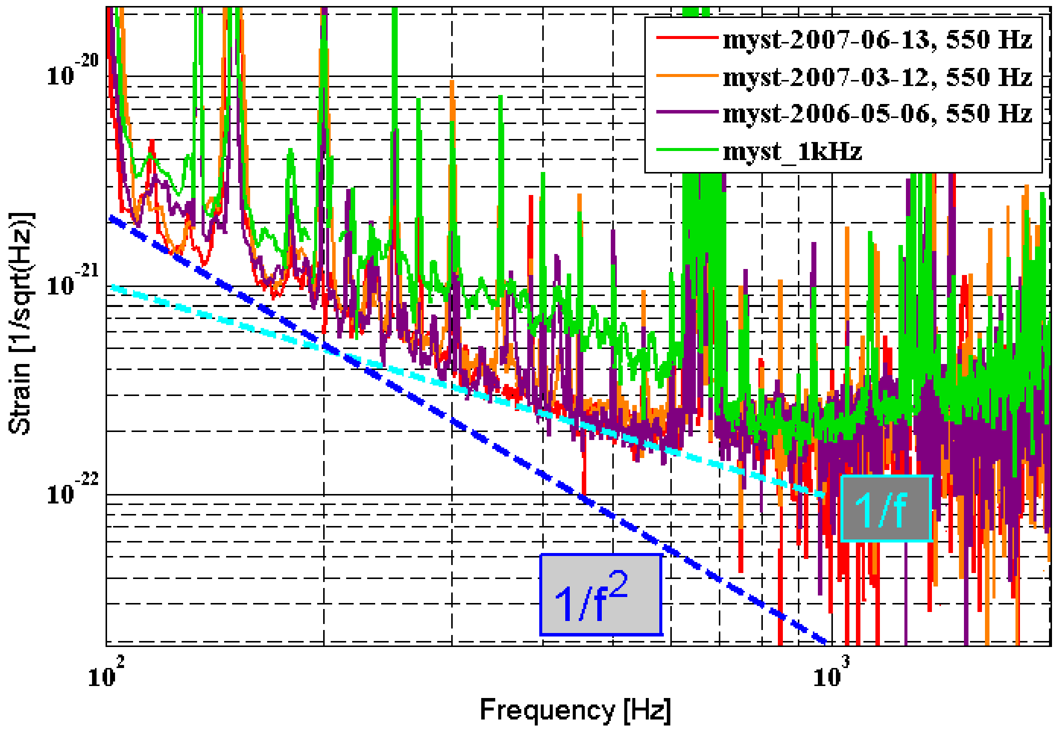
- Can rule out all thermal noises
- Can rule out any noise of the test masses
- ….

If the mystery noise looks like displacement noise:

- We can rule out many technical noises like oscillator phase noise, oscillator amplitude noise, frequency noise
- …..

Displacement noise
Yes / No ?

Checking the mystery noise for different Signal Recycling tunings (1)

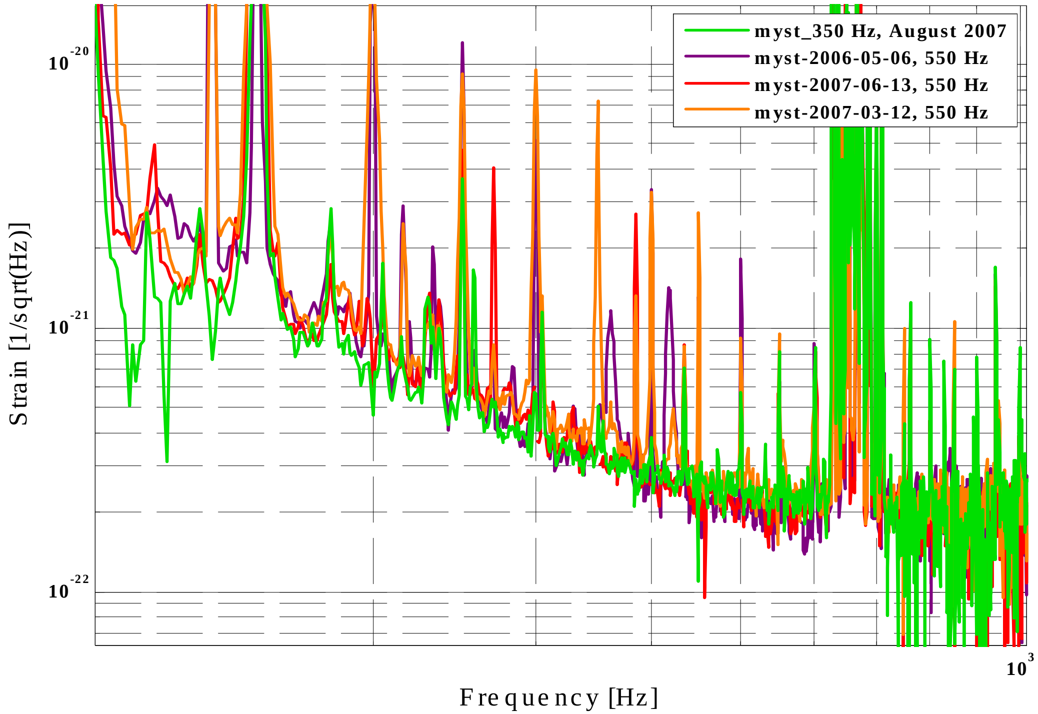


Mystery noise has different shape and level in **1kHz** and **550Hz** tuning.

=> Indication: does not look like displacement noise

Displacement noise Yes / No ?

Checking the mystery noise for different Signal Recycling tunings (2)



Mystery noise has same shape and level in **350Hz** and **550Hz** tuning.

=> Indication: does look like displacement noise

Displacement noise like: YES / NO ?

Observation 1:

Mystery noise has different shape and level in **1kHz** and **550Hz** tuning.

=> Indication: does not look like displacement noise.

Observation 2:

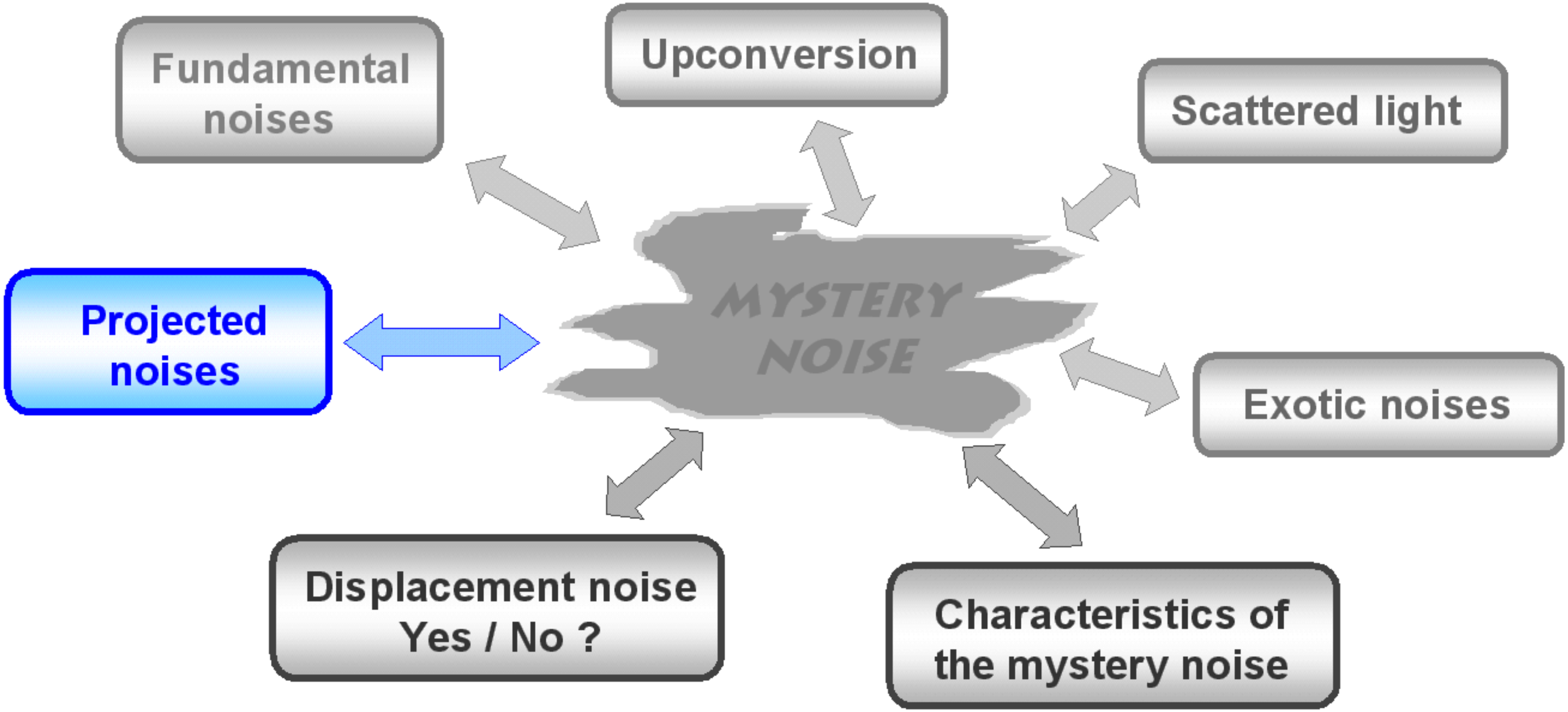
Mystery noise has same shape and level in **350Hz** and **550Hz** tuning.

=> Indication: does look like displacement noise.

Summary:

We cannot decide whether the mystery noise is displacment noise or not. (Perhaps it consists of two different components.)

=> We have to investigate both: displacement AND non-displacement noises.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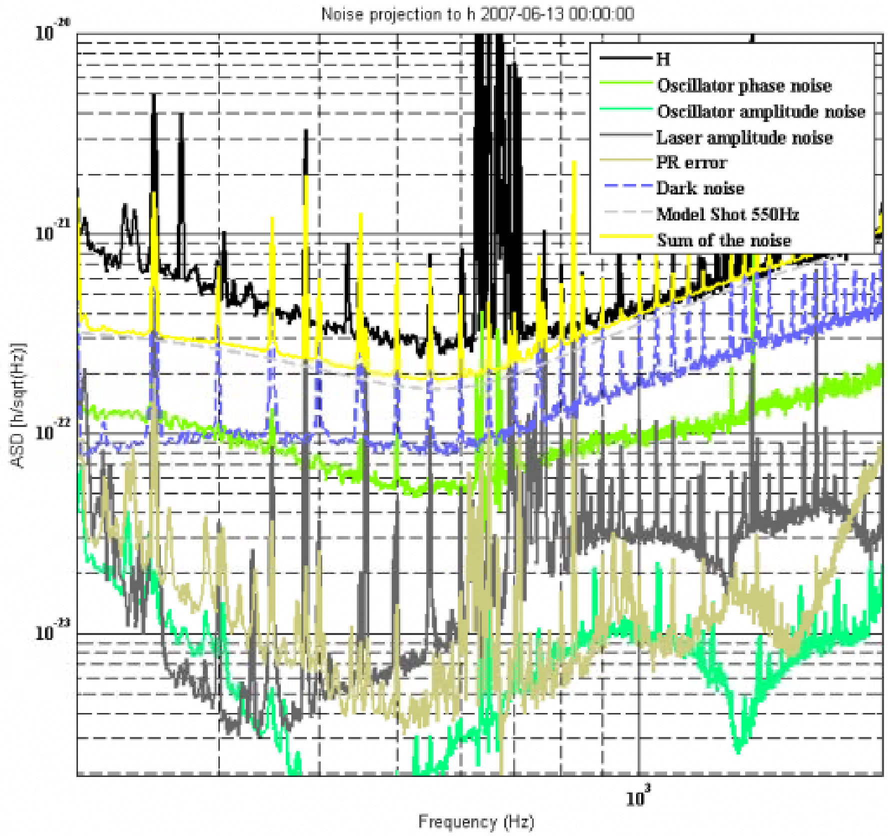
What do we have to check in terms of noise projections?

- Are the noise projections we do correct?
- Did we miss to project any relevant noise source?
- Are the transferfunctions used for the projections correct?

Which noise projections are relevant for the mystery noise frequency range ?

- Oscillator phase noise
- Oscillator amp noise
- Laser power noise
- Frequency noise
- Detection dark noise



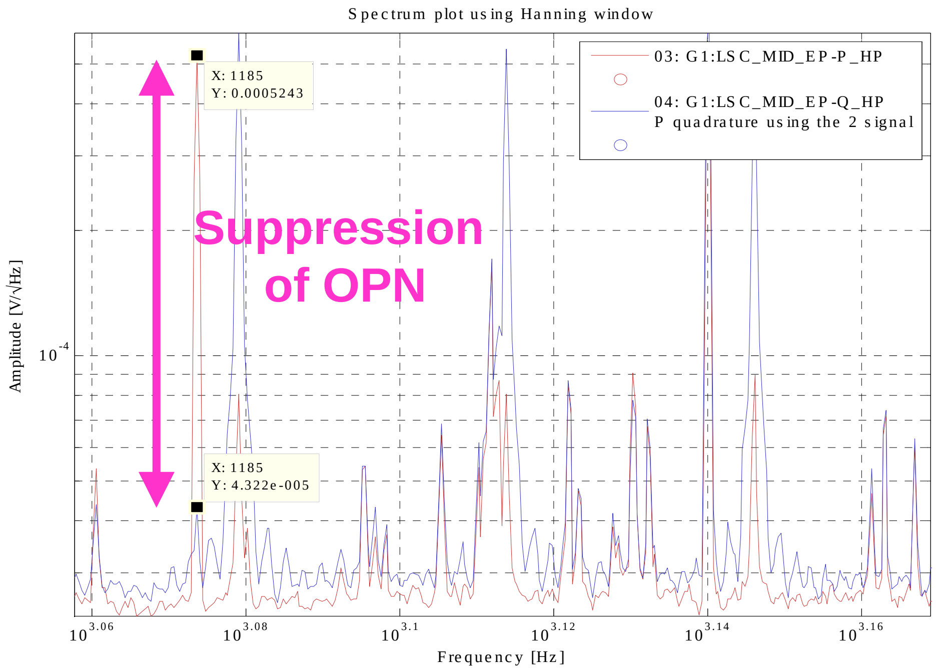
Two main suspects:

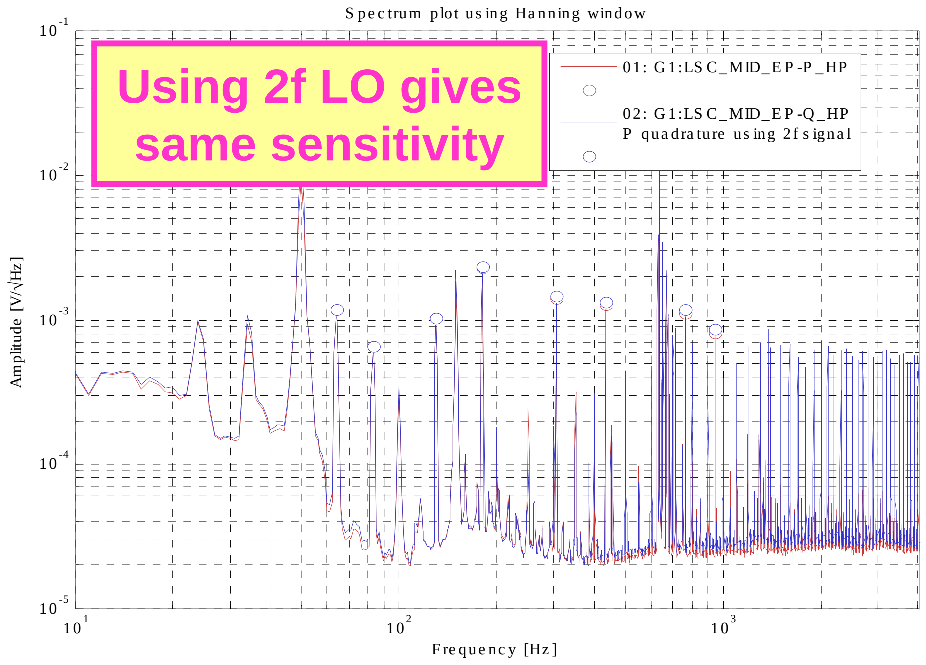
- OPN: shape would fit and is not too far from limiting.
- PR-noise: Was never really understood (In-loop, high gain)

Projected noises

OPN investigations 1: 2f local oscillator

- Nominal setup: Signal passes optical system, while LO is electrically.
- Using 2f signal from darkport (devided by 2) as LO => Signal and LO travel the same path.

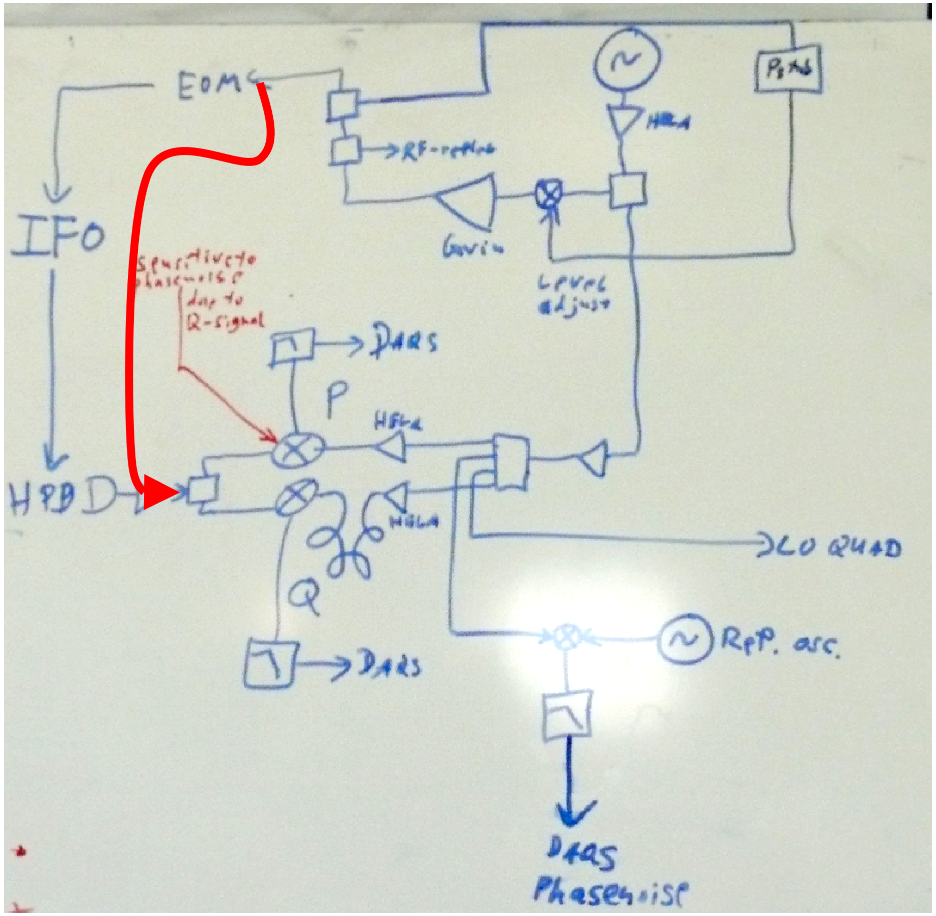




- Indication: mystery noise is not related to OPN

OPN investigations 2: wire instead of MI

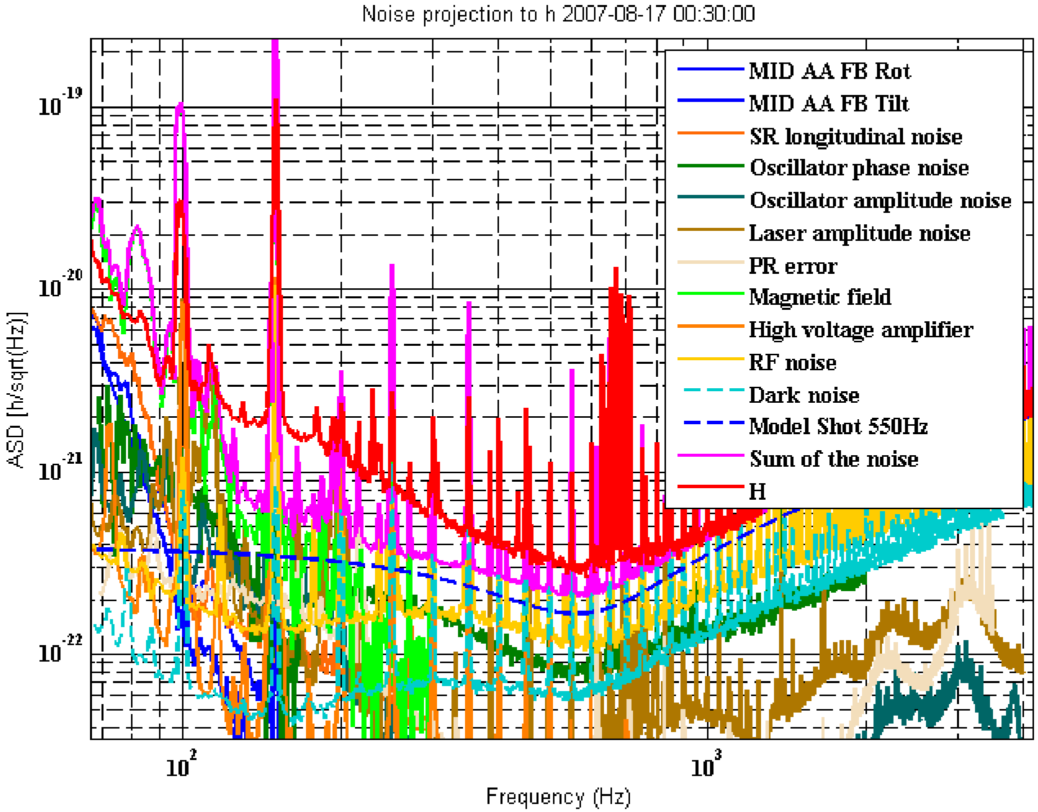
Idea: Replacing the IFO by a wire should give lower limit of OPN.



Replacing:
- **EOM,**
- **IFO and**
- **photodiode**

by a ‘good‘ wire

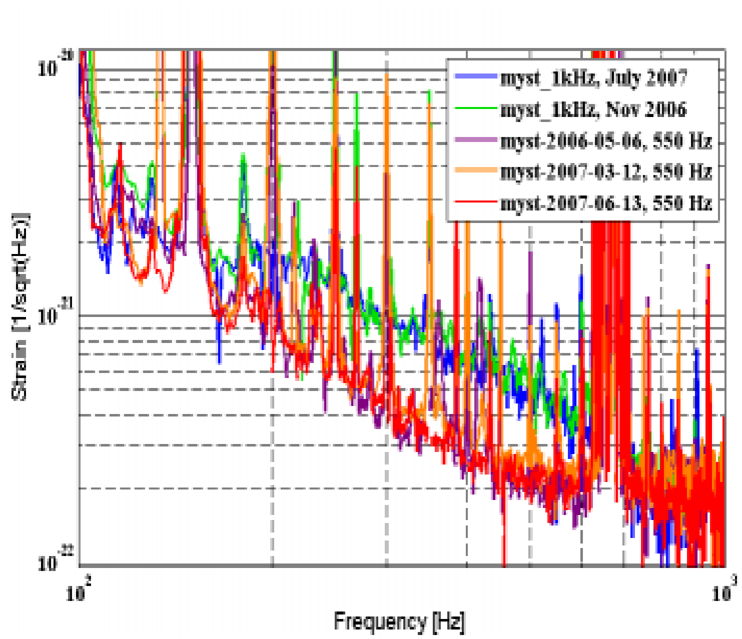
OPN investigations 2: wire instead of MI

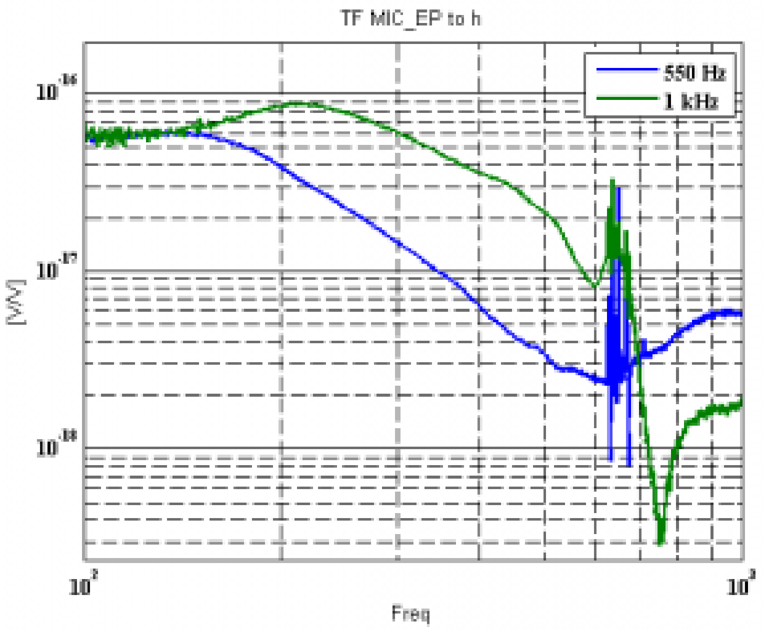


‚Wire projection‘ gives a noise (yellow trace) close to shot noise.

=> Mystery noise gap gets smaller.

Frequency noise projection: A smoking gun ?



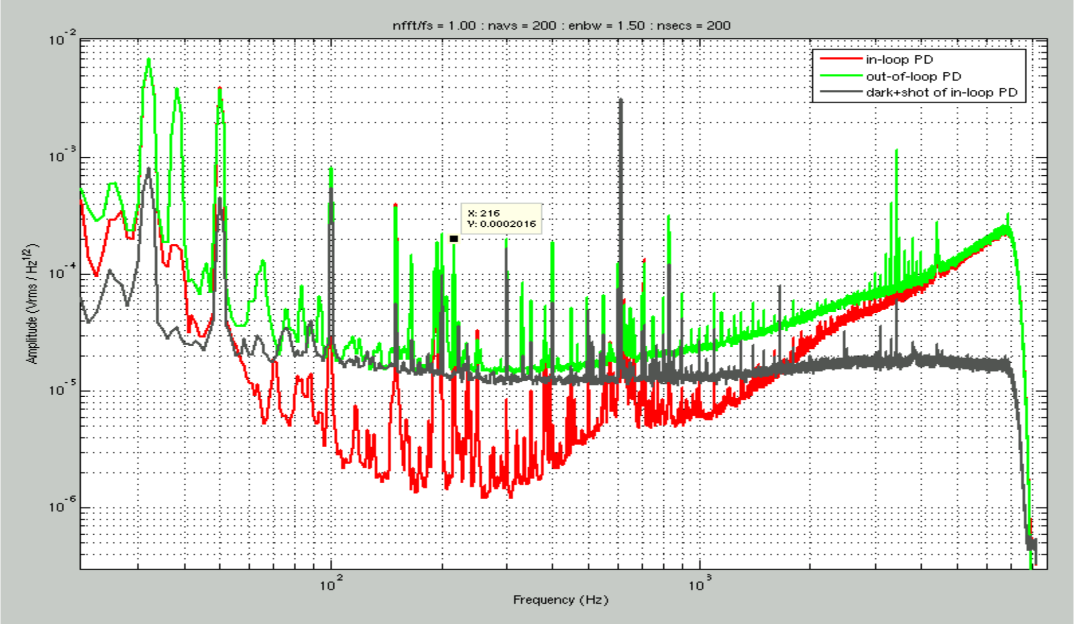


The change of the mystery noise from 550Hz to 1kHz tuning looks suspiciously similar to the change of the frequency noise transfer function.

Frequency noise projection (2)

Main problem of this loop: In-loop measurement with high gain.

One important experiment is to set up an out-of-loop photodiode.



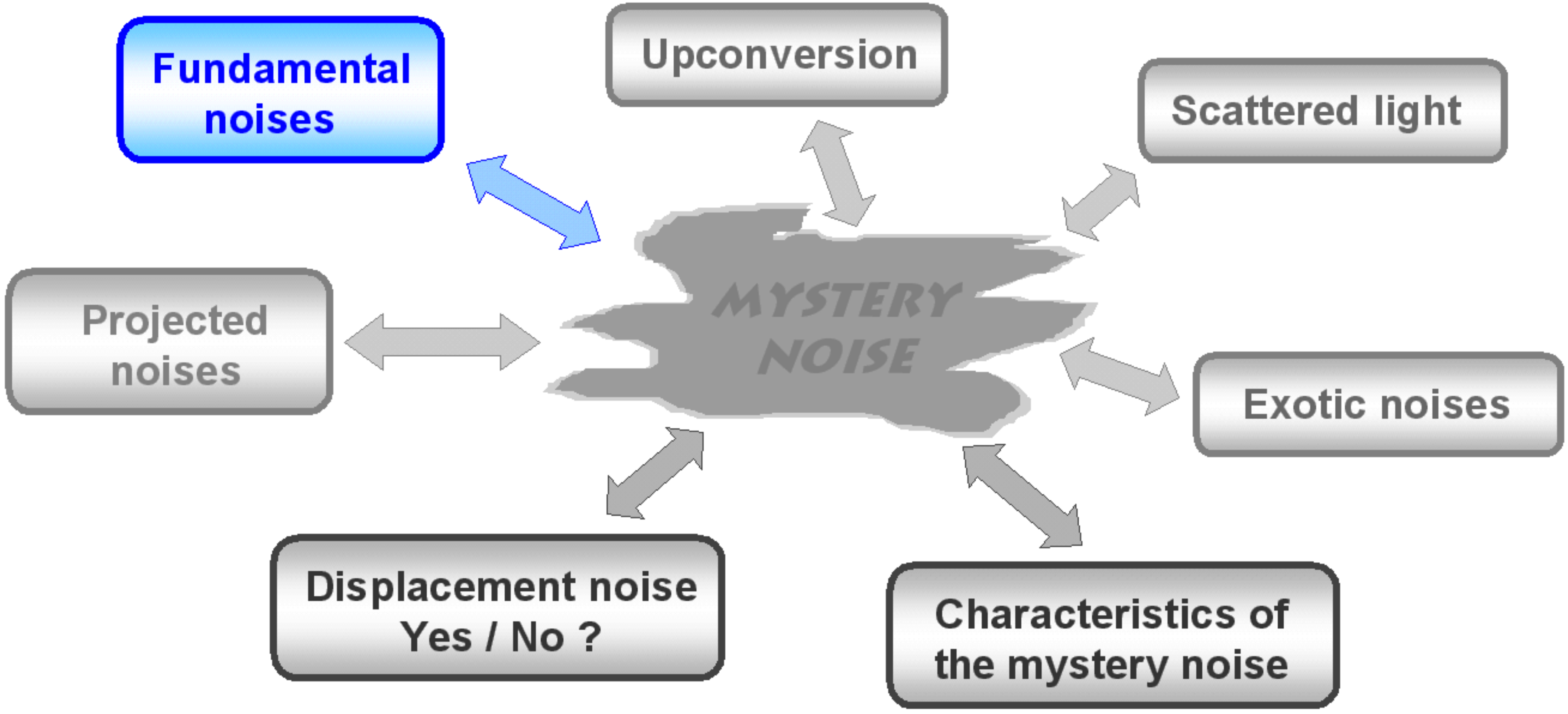
Can rule out any sensing noise of the PR-loop.

Left over: Any frequency noise on the light (4 above detection noise) could be the mystery noise.

Noise projections summary

- improved existing projections
- added a few missing projections
- checked for any non-linearities in the transferfunctions (compared swept sine and random noise measurements)
- the gap got smaller, but is still there....

- We believe that OPN is not causing the mystery noise.
- We believe that the mystery is not related to magnetic fields.
- We believe that frequency noise is still a good candidate.
  - Can rule out the electronics (?)
  - Can rule out the detection
  - Frequency noise on the light could explain the mystery noise.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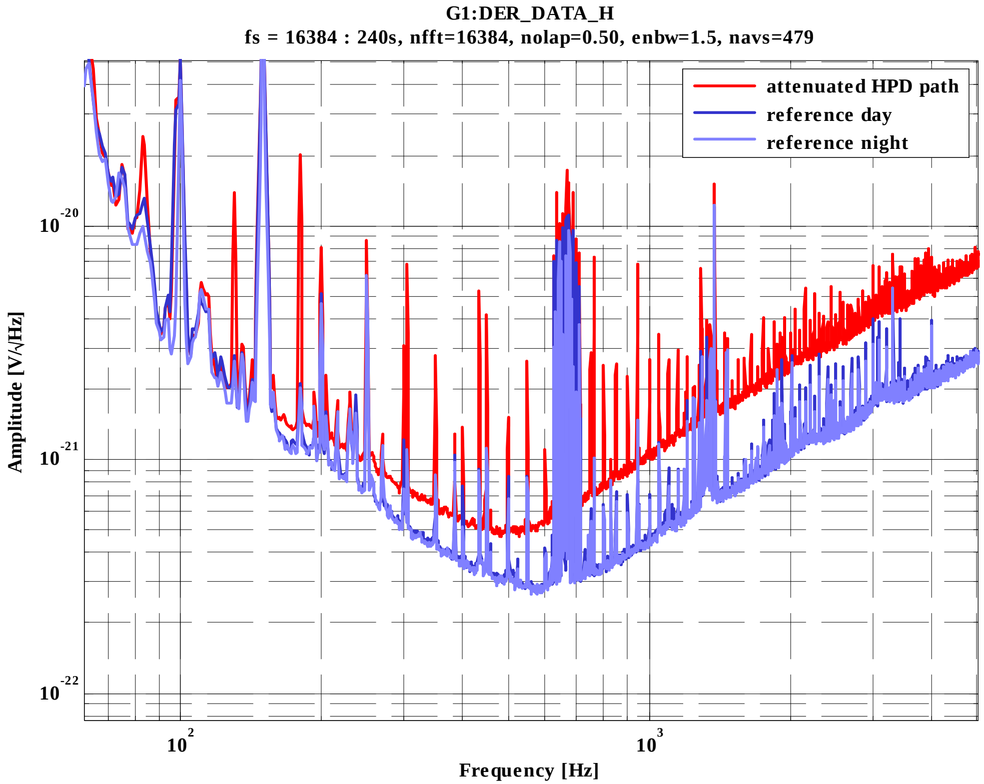
Checking correctness of shot noise (1)

Attenuation experiment:



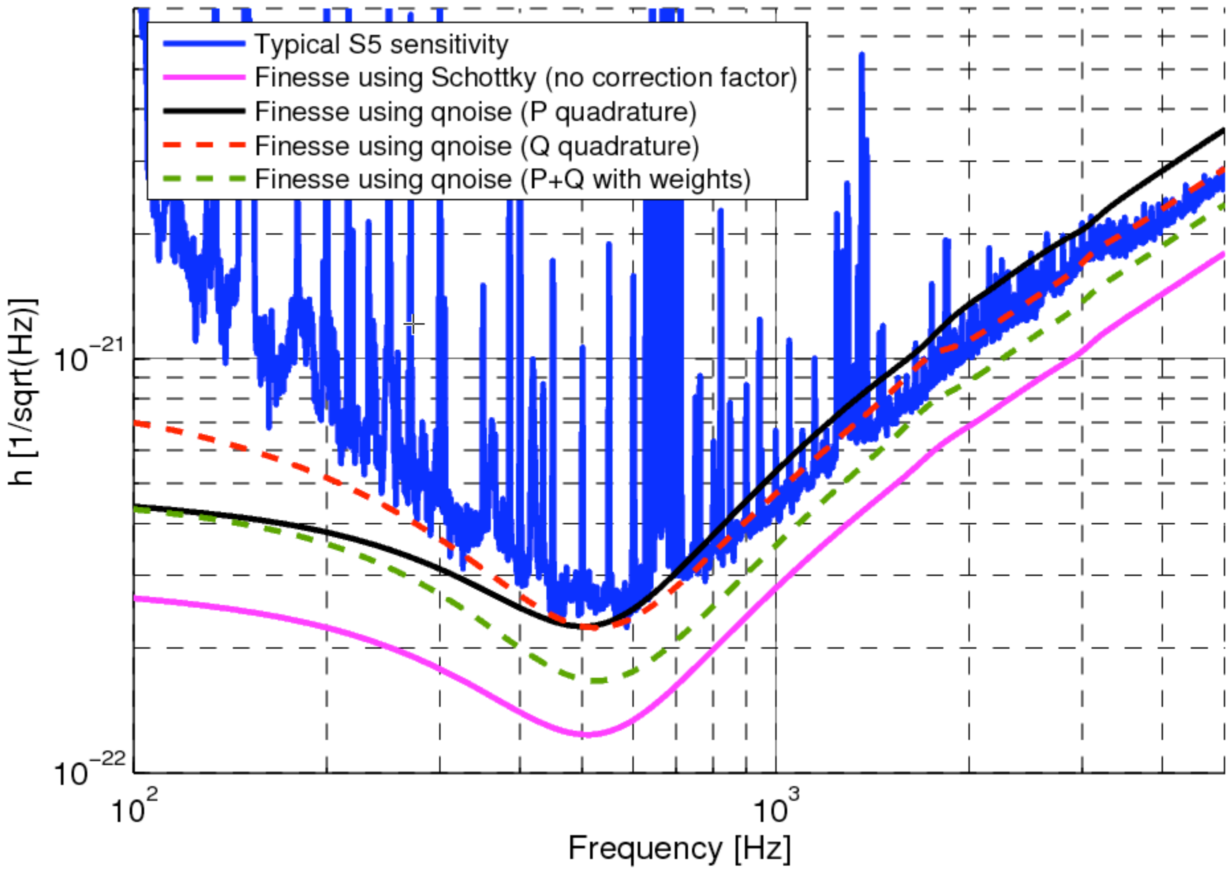
Expected sensitivity decrease found (all frequencies)

Nominal light power

Attenuated the detected light at main photodetector. The sensitivity measured matches the shot noise calculations.

Checking correctness of shot noise (2)

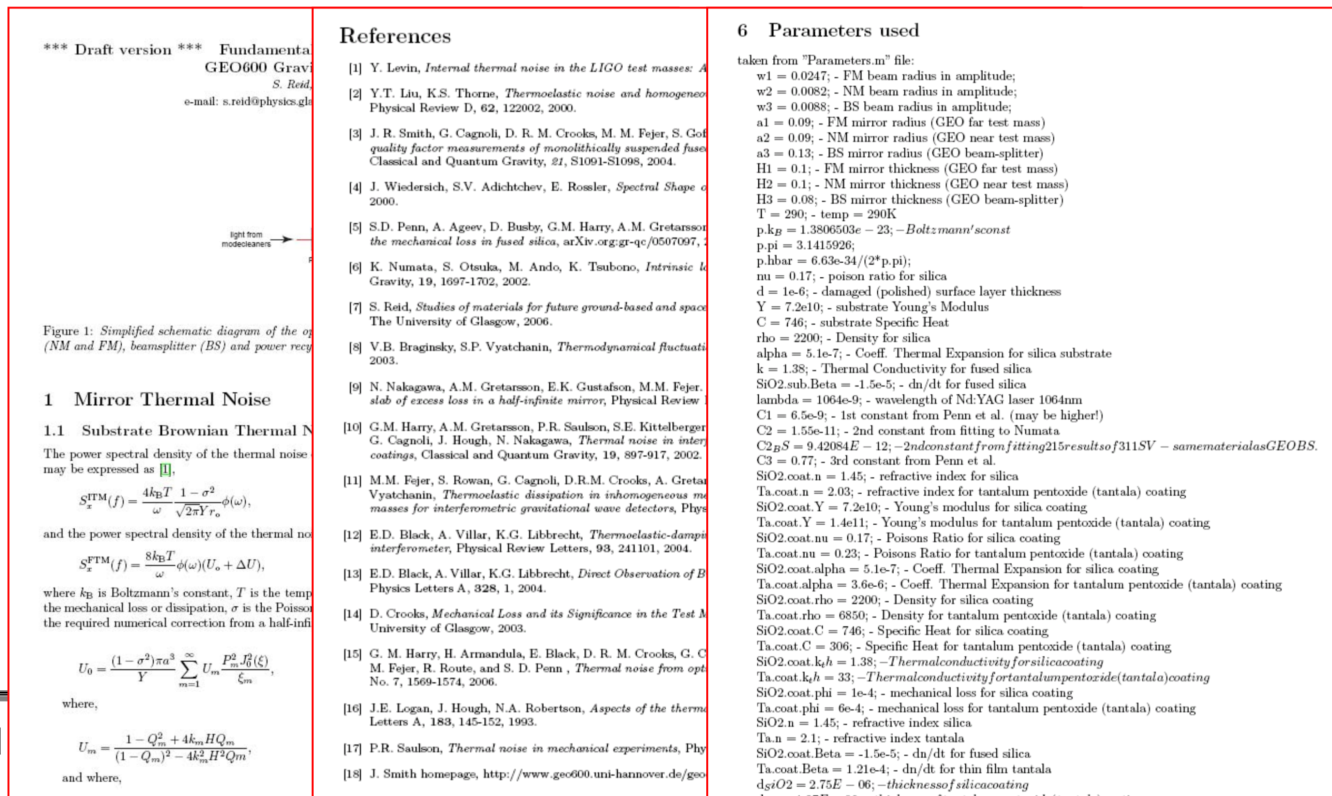
Shot noise simulations using FINESSE:



Revisiting the thermal noise calculations

<u>The Glasgow group (Reid, Rowan, Hough) revisited all thermal noise calculations:</u>

- Draft version of a nice and detailed document is available now (includes all equations, references and used parameters).



*** Draft version *** Fundamenta
GEO600 Gravi
S. Reid,
e-mail: s.reid@physics.gla

Figure 1: Simplified schematic diagram of the o
(NM and FM), beamsplitter (BS) and power recy

1 Mirror Thermal Noise

1.1 Substrate Brownian Thermal N

The power spectral density of the thermal noise
may be expressed as [1],

$$S_x^{\mathrm{ITM}}(f) = \frac{4k_BT}{\omega}\frac{1-\sigma^2}{\sqrt{2\pi}Yr_o}\phi(\omega),$$

and the power spectral density of the thermal no

$$S_x^{\mathrm{FTM}}(f) = \frac{8k_BT}{\omega}\phi(\omega)(U_o + \Delta U),$$

where k_B is Boltzmann's constant, T is the temp
the mechanical loss or dissipation, σ is the Poisso
the required numerical correction from a half-infi

$$U_0 = \frac{(1-\sigma^2)\pi a^3}{Y}\sum_{m=1}^{\infty} U_m \frac{P_m^2 J_0^2(\xi)}{\xi_m},$$

where,

$$U_m = \frac{1-Q_m^2 + 4k_m H Q_m}{(1-Q_m)^2 - 4k_m^2 H^2 Q_m},$$

and where,

References

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[16] J.E. Logan, J. Hough, N.A. Robertson, *Aspects of the therm* Letters A, 183, 145-152, 1993.
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6 Parameters used

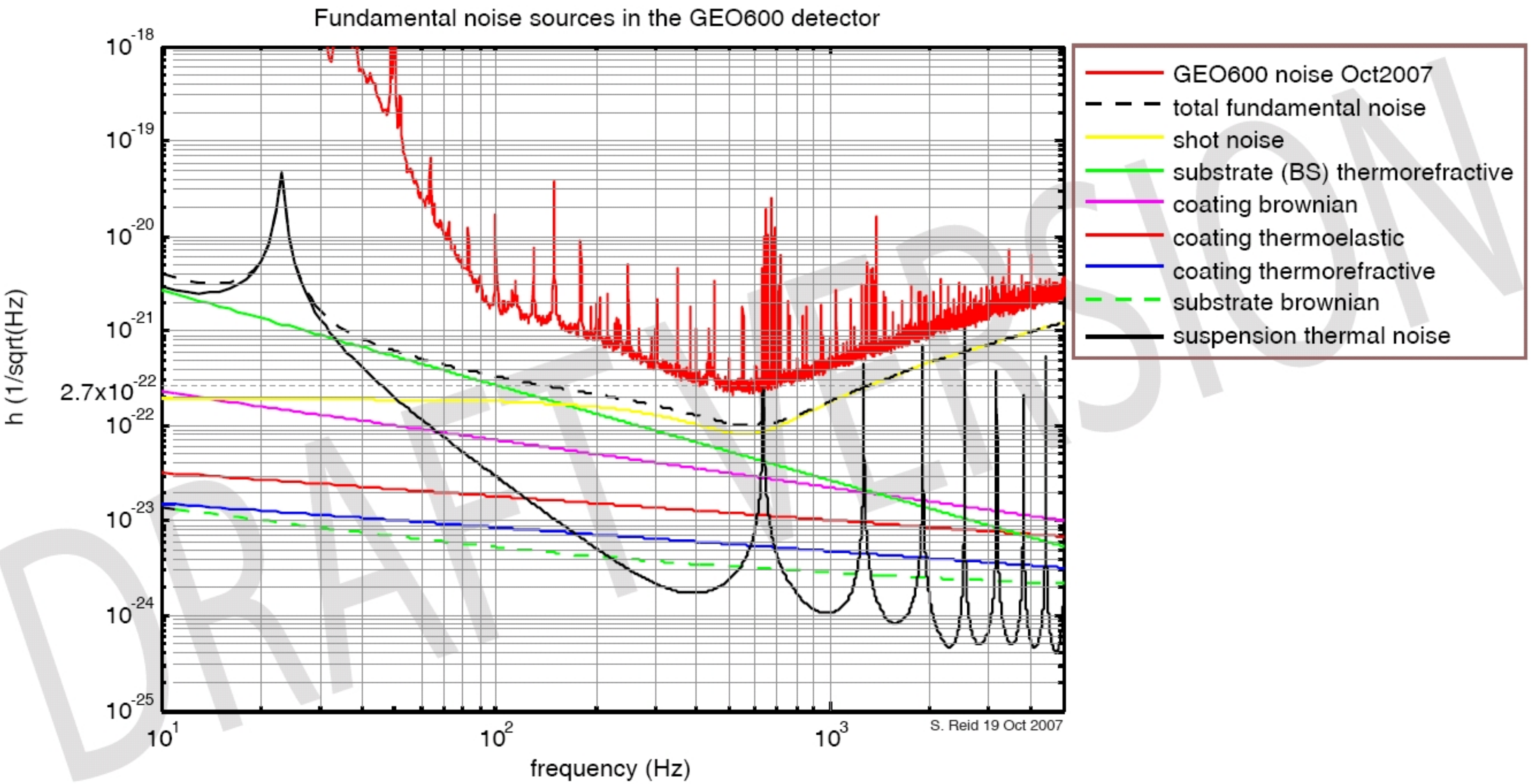
taken from "Parameters.m" file:
w1 = 0.0247; - FM beam radius in amplitude;
w2 = 0.0082; - NM beam radius in amplitude;
w3 = 0.0088; - BS beam radius in amplitude;
a1 = 0.09; - FM mirror radius (GEO far test mass)
a2 = 0.09; - NM mirror radius (GEO near test mass)
a3 = 0.13; - BS mirror radius (GEO beam-splitter)
H1 = 0.1; - FM mirror thickness (GEO far test mass)
H2 = 0.1; - NM mirror thickness (GEO near test mass)
H3 = 0.08; - BS mirror thickness (GEO beam-splitter)
T = 290; - temp = 290K
p.k$_B$ = 1.3806503e − 23; −Boltzmann'sconst
p.pi = 3.1415926;
p.hbar = 6.63e-34/(2*p.pi);
nu = 0.17; - poison ratio for silica
d = 1e-6; - damaged (polished) surface layer thickness
Y = 7.2e10; - substrate Young's Modulus
C = 746; - substrate Specific Heat
rho = 2200; - Density for silica
alpha = 5.1e-7; - Coeff. Thermal Expansion for silica substrate
k = 1.38; - Thermal Conductivity for fused silica
SiO2.sub.Beta = -1.5e-5; - dn/dt for fused silica
lambda = 1064e-9; - wavelength of Nd:YAG laser 1064nm
C1 = 6.5e-9; - 1st constant from Penn et al. (may be higher!)
C2 = 1.55e-11; - 2nd constant from fitting to Numata
C2$_B$S = 9.42084E − 12; −2ndconstantfromfitting215resultsof311SV − samematerialasGEOBS.
C3 = 0.77; - 3rd constant from Penn et al.
SiO2.coat.n = 1.45; - refractive index for silica
Ta.coat.n = 2.03; - refractive index for tantalum pentoxide (tantala) coating
SiO2.coat.Y = 7.2e10; - Young's modulus for silica coating
Ta.coat.Y = 1.4e11; - Young's modulus for tantalum pentoxide (tantala) coating
SiO2.coat.nu = 0.17; - Poisons Ratio for silica coating
Ta.coat.nu = 0.23; - Poisons Ratio for tantalum pentoxide (tantala) coating
SiO2.coat.alpha = 5.1e-7; - Coeff. Thermal Expansion for silica coating
Ta.coat.alpha = 3.6e-6; - Coeff. Thermal Expansion for tantalum pentoxide (tantala) coating
SiO2.coat.rho = 2200; - Density for silica coating
Ta.coat.rho = 6850; - Density for tantalum pentoxide (tantala) coating
SiO2.coat.C = 746; - Specific Heat for silica coating
Ta.coat.C = 306; - Specific Heat for tantalum pentoxide (tantala) coating
SiO2.coat.k$_t$h = 1.38; −Thermalconductivityforsilicacoating
Ta.coat.k$_t$h = 33; −Thermalconductivityfortantalumpentoxide(tantala)coating
SiO2.coat.phi = 1e-4; - mechanical loss for silica coating
Ta.coat.phi = 6e-4; - mechanical loss for tantalum pentoxide (tantala) coating
SiO2.n = 1.45; - refractive index silica
Ta.n = 2.1; - refractive index tantala
SiO2.coat.Beta = -1.5e-5; - dn/dt for fused silica
Ta.coat.Beta = 1.21e-4; - dn/dt for thin film tantala
d$_S$iO2 = 2.75E − 06; −thicknessofsilicacoating
d$_T$a = 1.97E − 06; −thicknessoftantalumpentoxide(tantala)coating

Revisiting the thermal noise calculations

The Glasgow group (Reid, Rowan, Hough) revisited all thermal noise calculations:

- Draft version of a nice and detailed document is available now (includes all equations, references and used parameters).
- Coating TN now distingished in thermorefractive, thermoelastic and brownian. Brownian is the dominant contribution. *Didn't change.*
- Substrate Brownian noise. Changed slope and level. Now lower, but less steep.
- BS thermorefractive noise. Now 3.5 times higher. => Dominating TN for frequencies up to 1.5kHz.

New thermal noise calculations



Revisited thermal noises cannot explain the mystery noise.

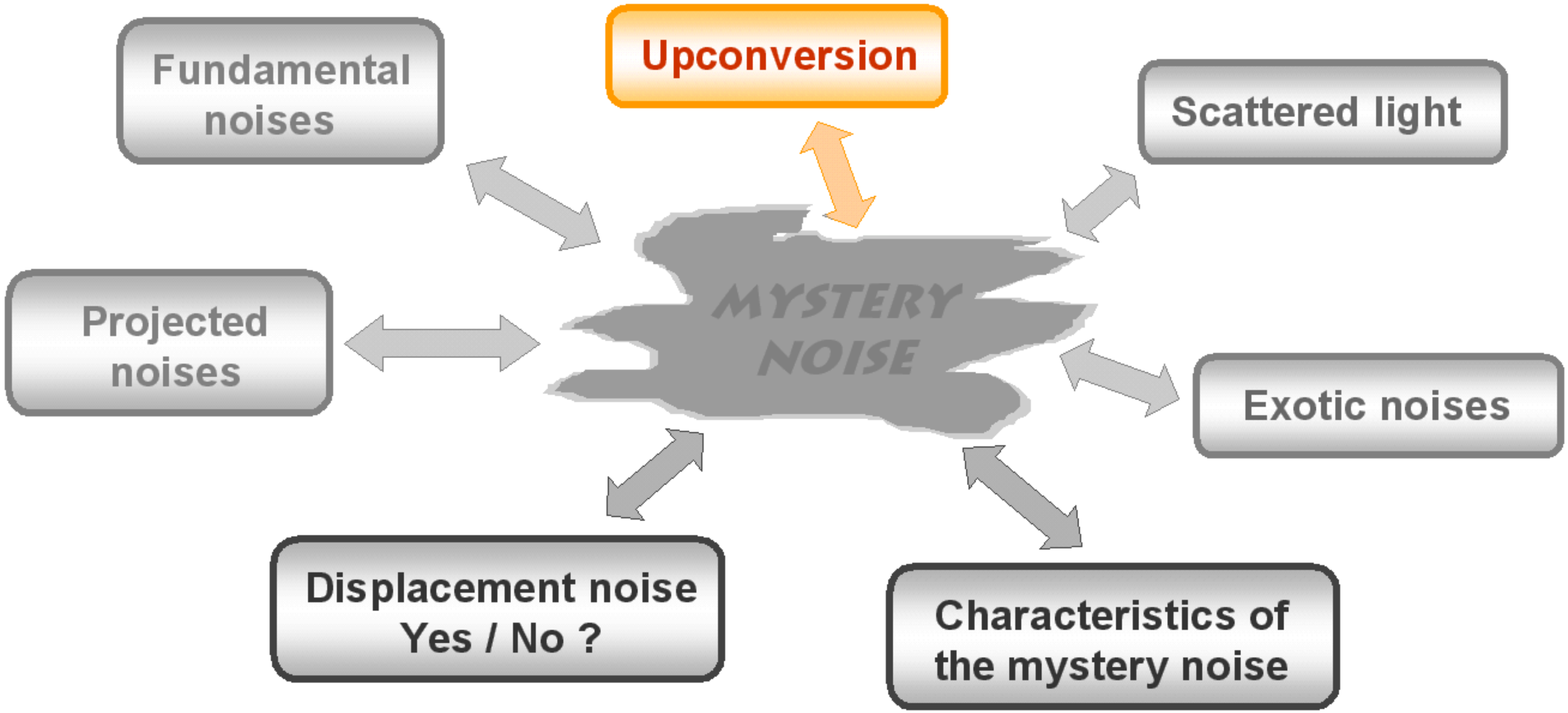
Increased thermal noise due to excess damping ?

IDEA:

- Testmass is close to touching its catcher
- There might be conditions where additional damping is caused
- Could such damping reduce the Q of the modes and therfore increase the thermal noise ???

- (Famous Livingston Earthquake stops???)

- We tried to take photographs of the testmasses. Due to the restricted view angles for 4 of the 5 main optics we cannot say how far they are from their catchers.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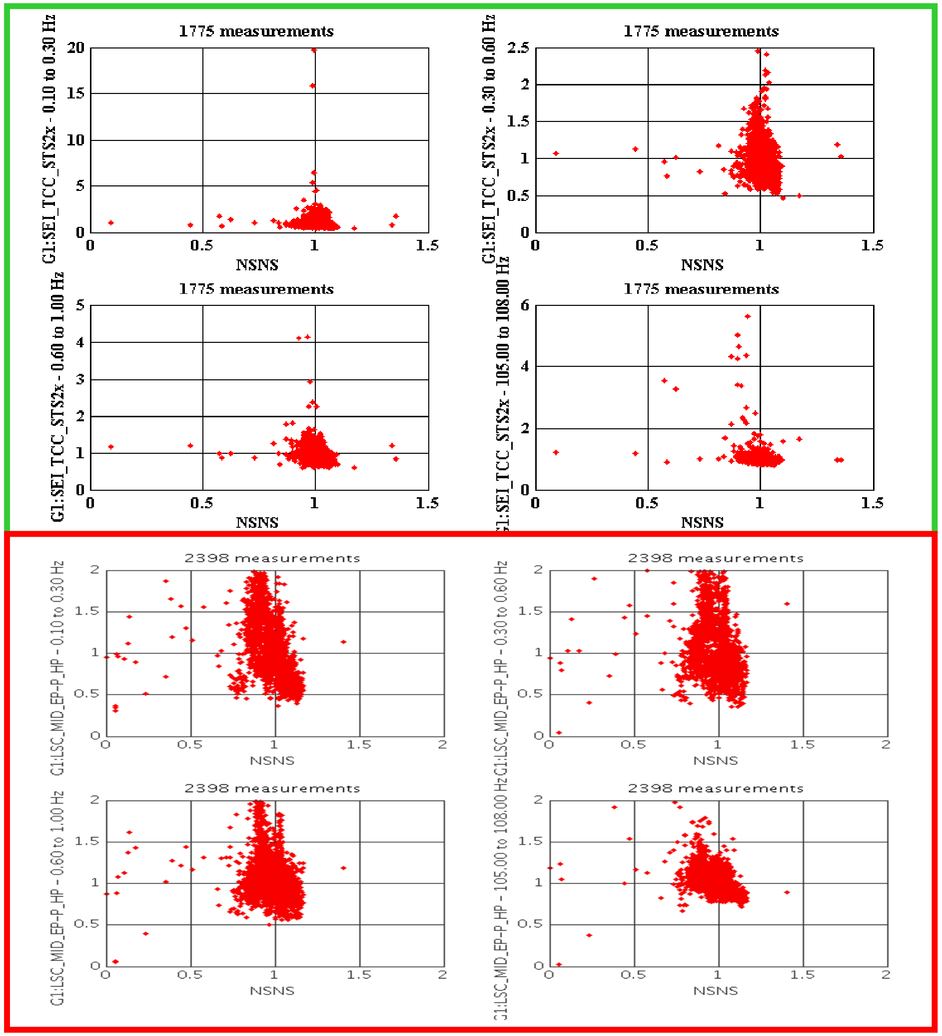
Upconversion

Is there any indication for upconversion?

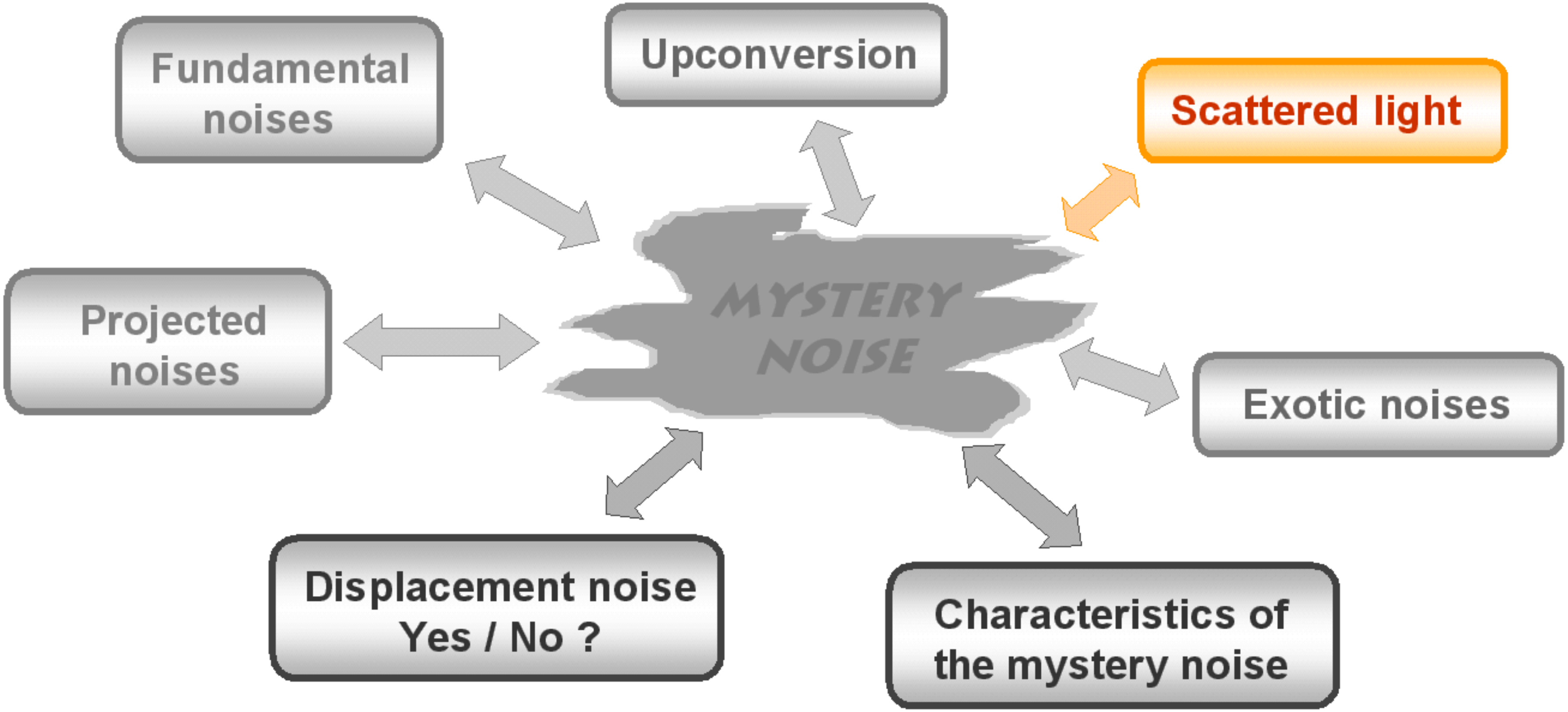


Scatter plots:

- low freq signal *vs* sensitivity
- Used low-freq channels: Seismic, MI differential lenght, MI differential auto-alignment

Usually no indication of significant upconversion

So far only a single data set showed indication for upconversion (0.1 –0.3 Hz) from MID long and MID AA.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Scattering Overview

External Scattering (outside the vacuum)

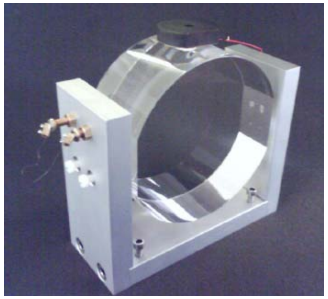
- All interferometer ports
- Detection bench

- **In-vacuum-Scattering**
- Scattered light from catchers
- Scattering inside the central cluster
- Small angle scattering in the folded arms
- ‚Grating'-scattering from coating defects

External Scattering

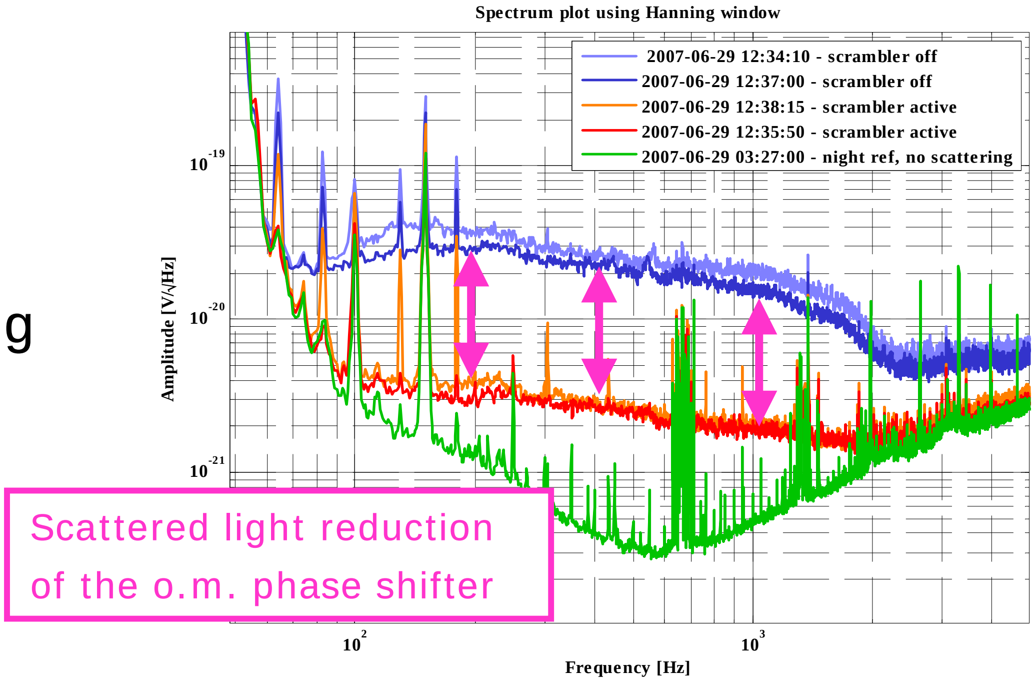
- **All interferometer ports**

  We did 2 complete rounds of filter / blocking experiments for all ports outside the vacuum.
  => No limiting scattering observed

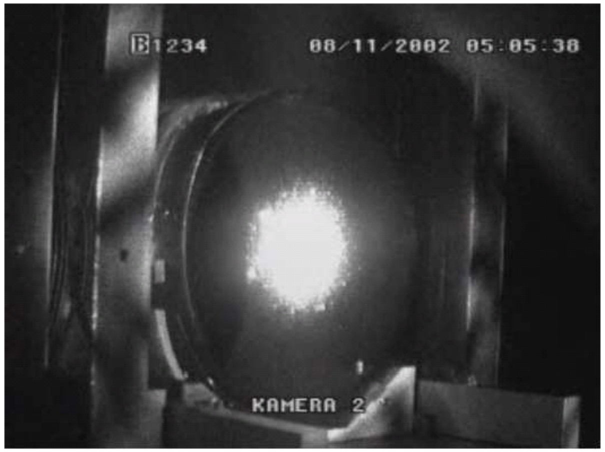


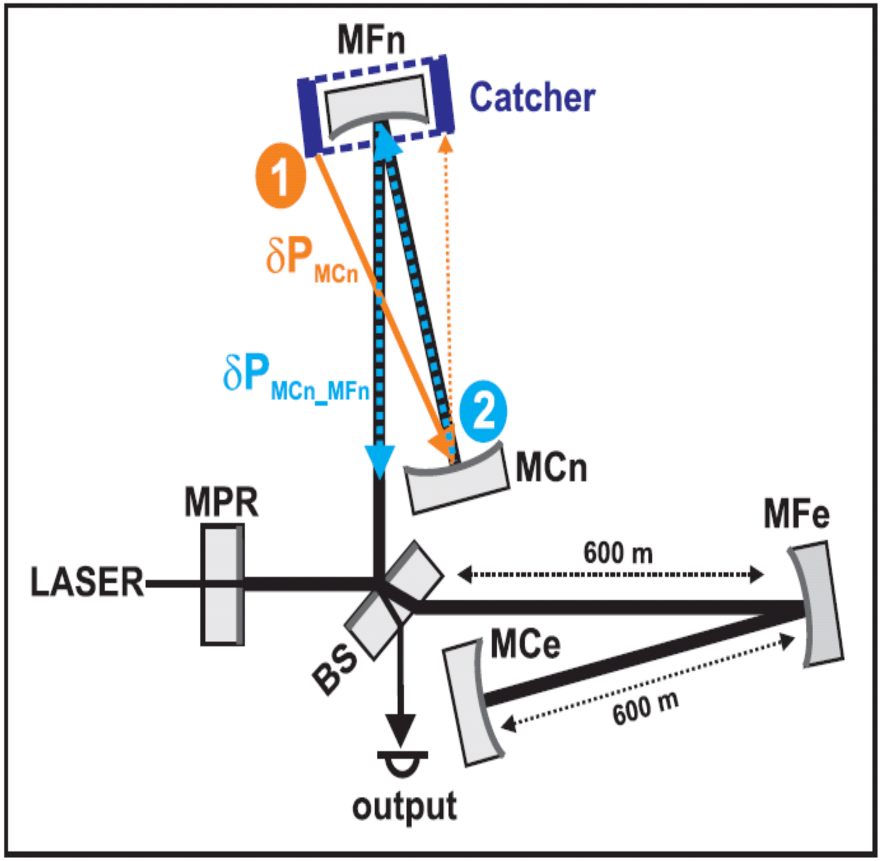
- **Detection bench**

  Ruled out scattering from HPD-path and quadrant path by using an opto-mechanical phase shifter.



Scattered light from the catchers (1)





- Light on the catchers from small angle scattering.
- Catchers are not seismically isolated
- Light scattered back into IFO mode can harm sensitivity

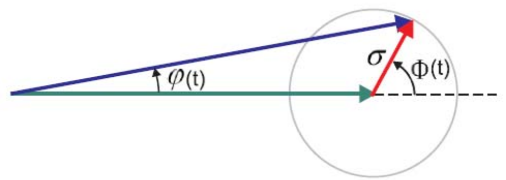
Scattered light from the catchers (2)

$$\delta P_{\mathrm{MCn}} = P_{\mathrm{cat}} \cdot f_{\mathrm{cat}}(\theta) \cdot \delta\Omega_1,$$

$$\delta P_{\mathrm{MCn}} = 4.07 \cdot 10^{-8}\ \mathrm{W}$$

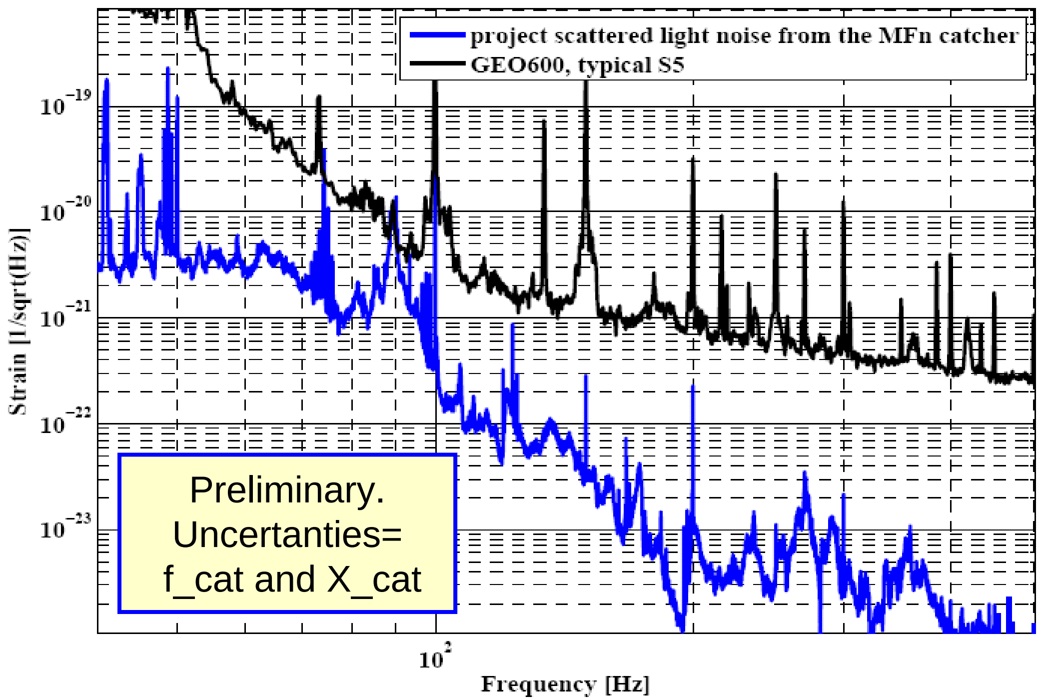
$$\delta P_{\mathrm{MCn\_MFn}} = P_{\mathrm{MCn}} \cdot f_{\mathrm{MCn}}(\theta) \cdot \delta\Omega_2,$$

$$\delta P_{\mathrm{MCn\_MFn}} = 7.4 \cdot 10^{-12}\ \mathrm{W}.$$



$$\sigma^2 = \frac{\delta P_{\mathrm{MFn}}}{P_{\mathrm{cav}}} = \frac{7.4 \cdot 10^{-12}\ \mathrm{W}}{1300\ \mathrm{W}},$$

$$\sigma = 7.5 \cdot 10^{-8}$$



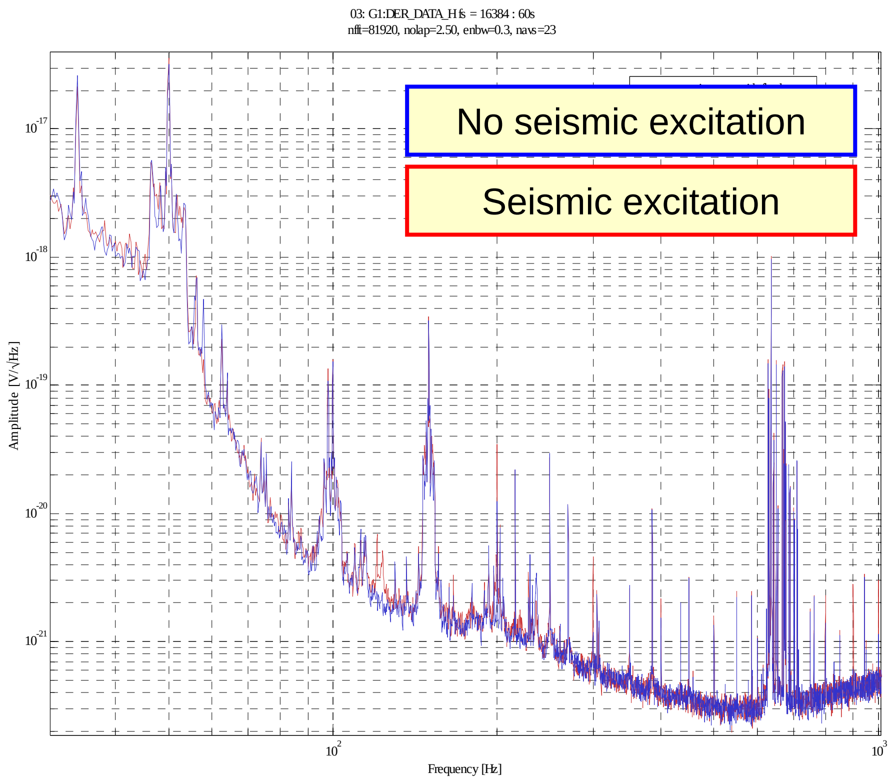
Displacement noise from scattering

Displacement of catcher

$$\hat{N}_{\mathrm{scat}} = \hat{X}_{\mathrm{cat}} \cdot \sigma,$$

Scattered light from the catchers (3)

- Seismic excitation of catchers => no change in h(t) **=> ruled out scattering from catchers**
- However, probably not far from limiting => preparing baffles



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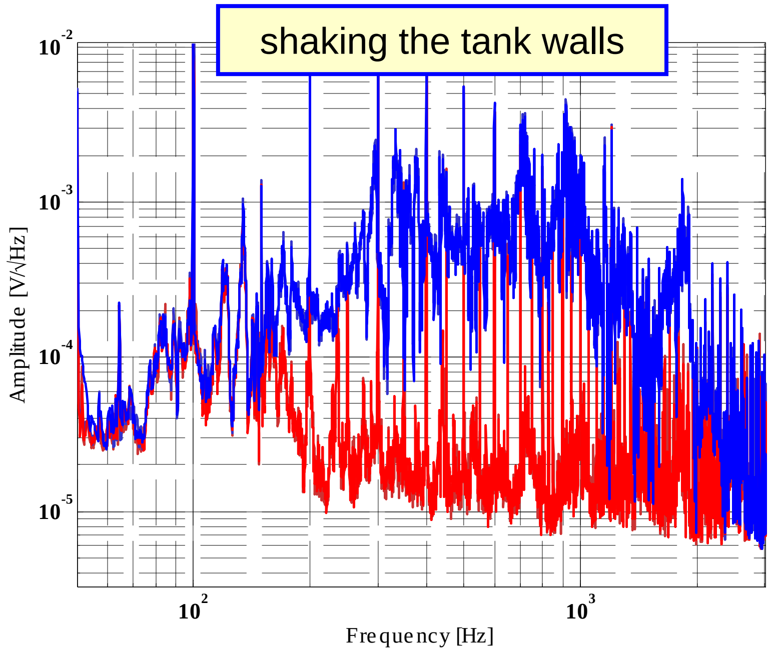
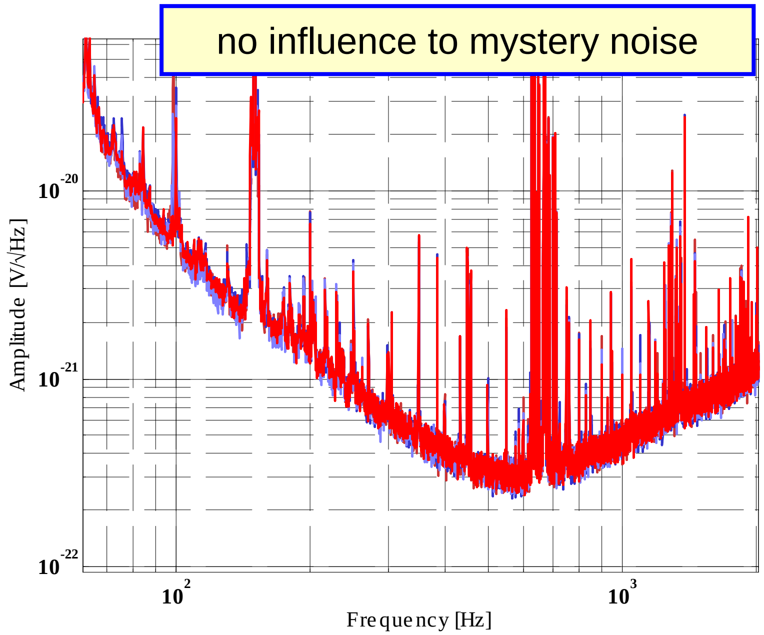
Scattered light

Scattering inside the central cluster (involving tank walls)

Idea:

- We observe a lot of scattered light inside the central cluster.
- Some of the stray light from the tank wall might mind find the way to the detection port
- **Ruled out by external shaking of the tank walls:**

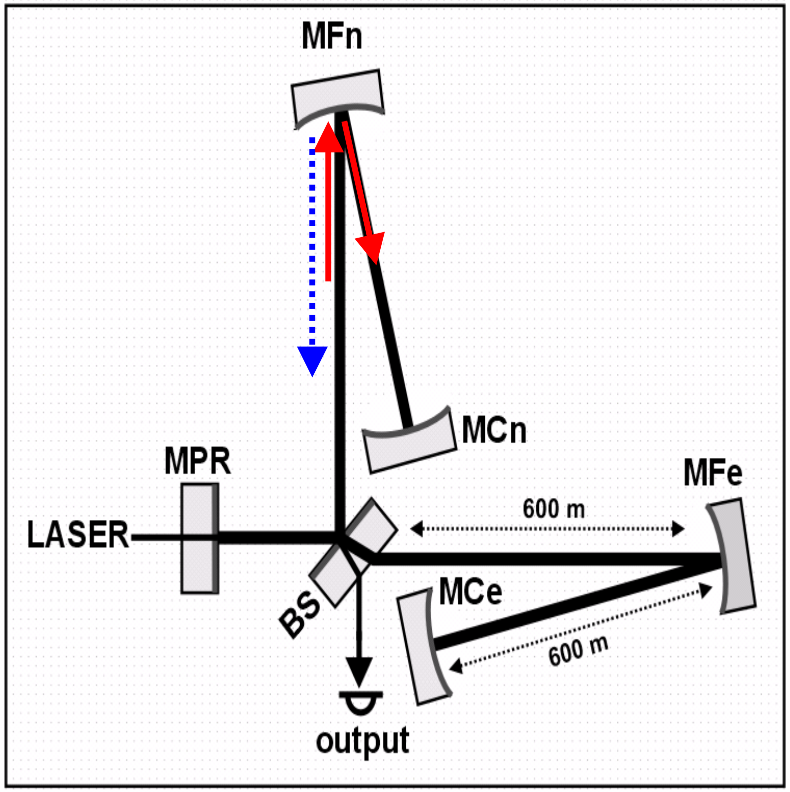




Small angle scattering in the folded arms

IDEA:

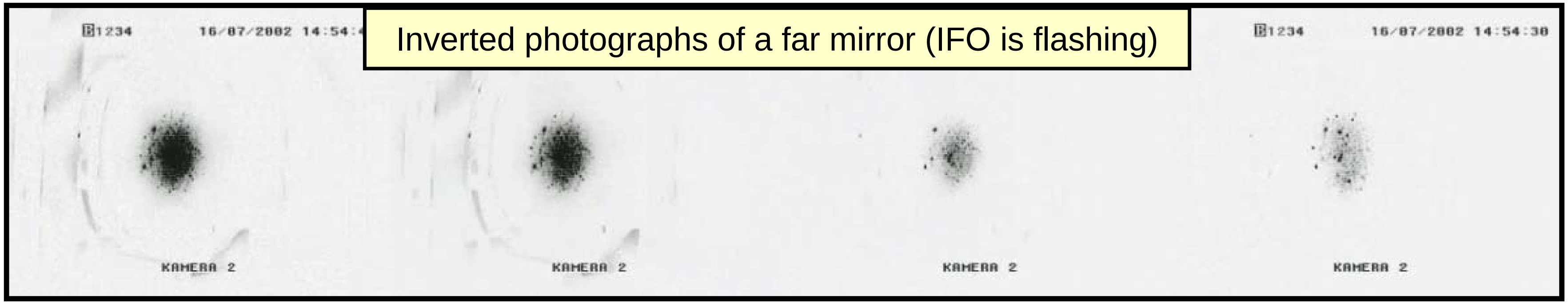
Some light hitting the far mirrors is directly scattered back.



Can be ruled out as mystery noise:

- Far mirrors only move a few microns (rms)
- Mirrors are isolated by triple pendulum

‚Grating'-scattering from coating defects

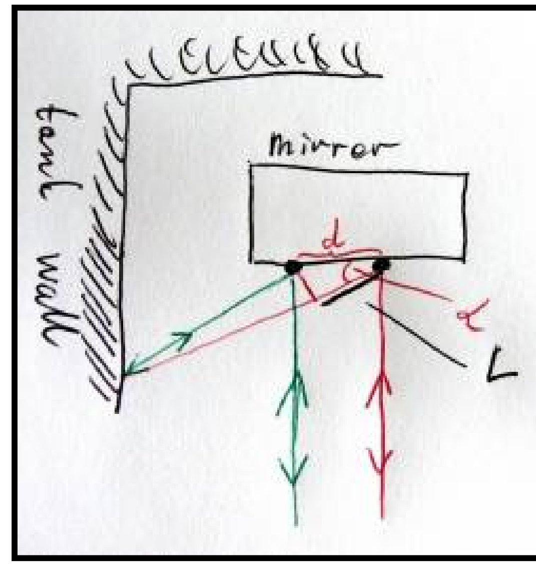


Inverted photographs of a far mirror (IFO is flashing)

IDEA:

- Coating defects can be described as grating.
- Scattering path: Coating defect => tank wall => Coating defect
- Beam jitter would cause phase noise analogous to a grating.

Not completely understood so far. **However, could be ruled out by shaking experiments.**



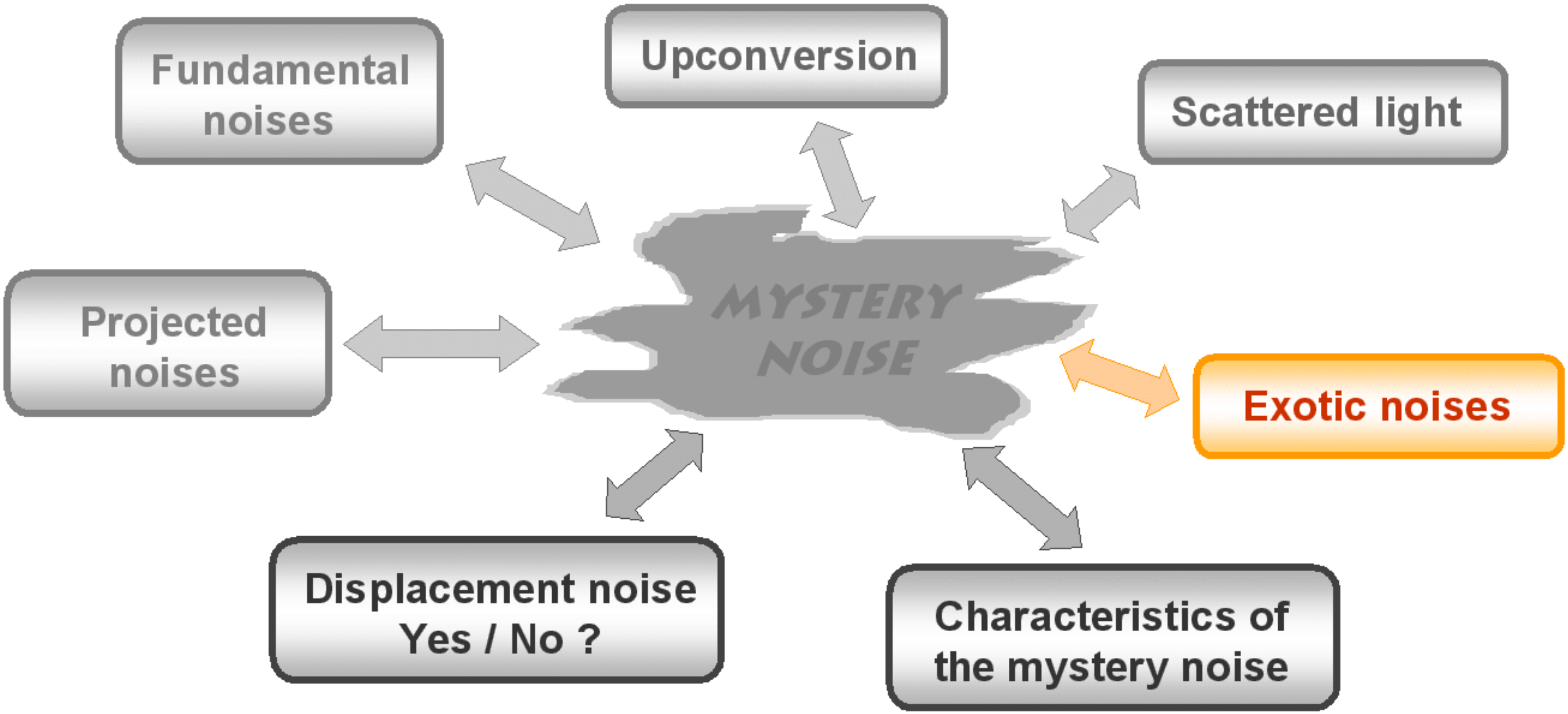
Scattering Overview

External Scattering (outside the vacuum)

- All interferometer ports
- Detection bench

- **In-vacuum-Scatteri**
- Scattered light fr atchers
- Scattering i the central cluster
- Small scattering in the folded arms
- g'-scattering from coating defects

We think we ruled out NEARLY ALL scattered processes we can think of.

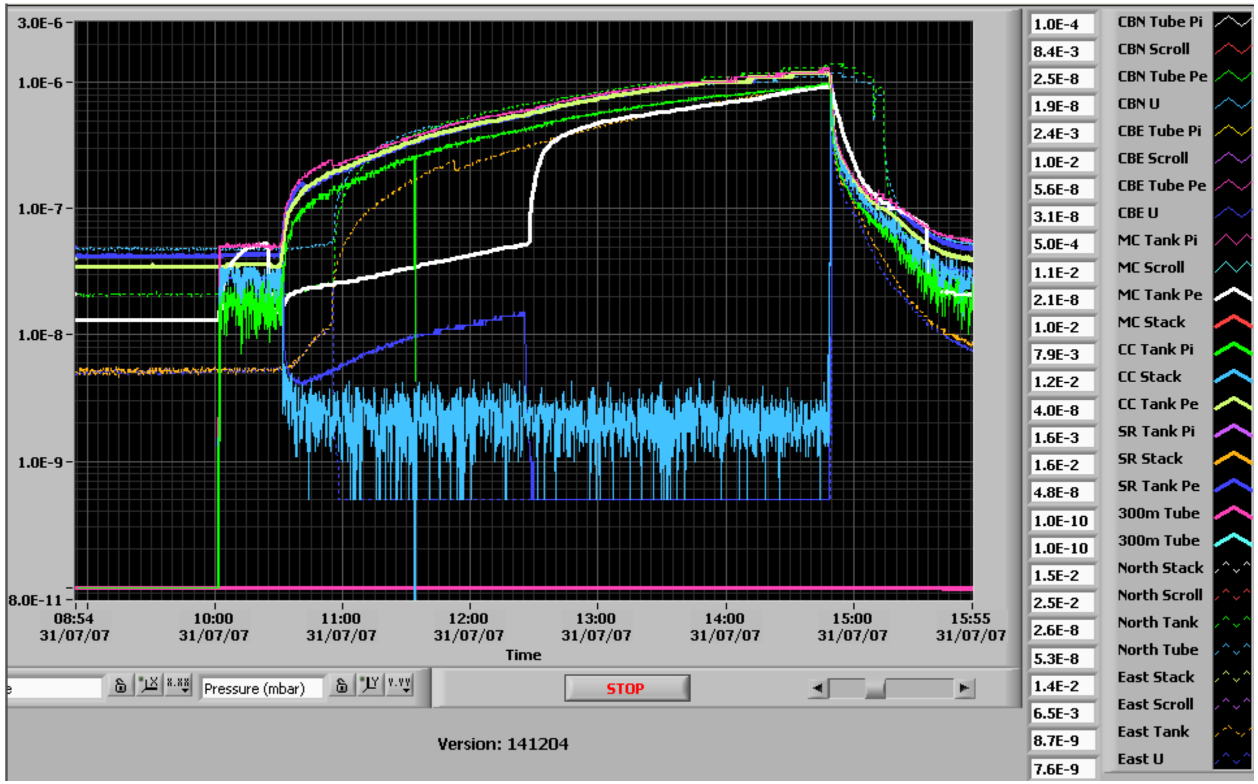

Fundamental noises
Upconversion
Scattered light
Projected noises
MYSTERY NOISE
Exotic noises
Displacement noise Yes / No ?
Characteristics of the mystery noise

Controlled increase of pressure inside the vacuum system (1)

Is the mystery noise caused by residual gas pressure?

Experiment: Closed all valves to turbo pumps.

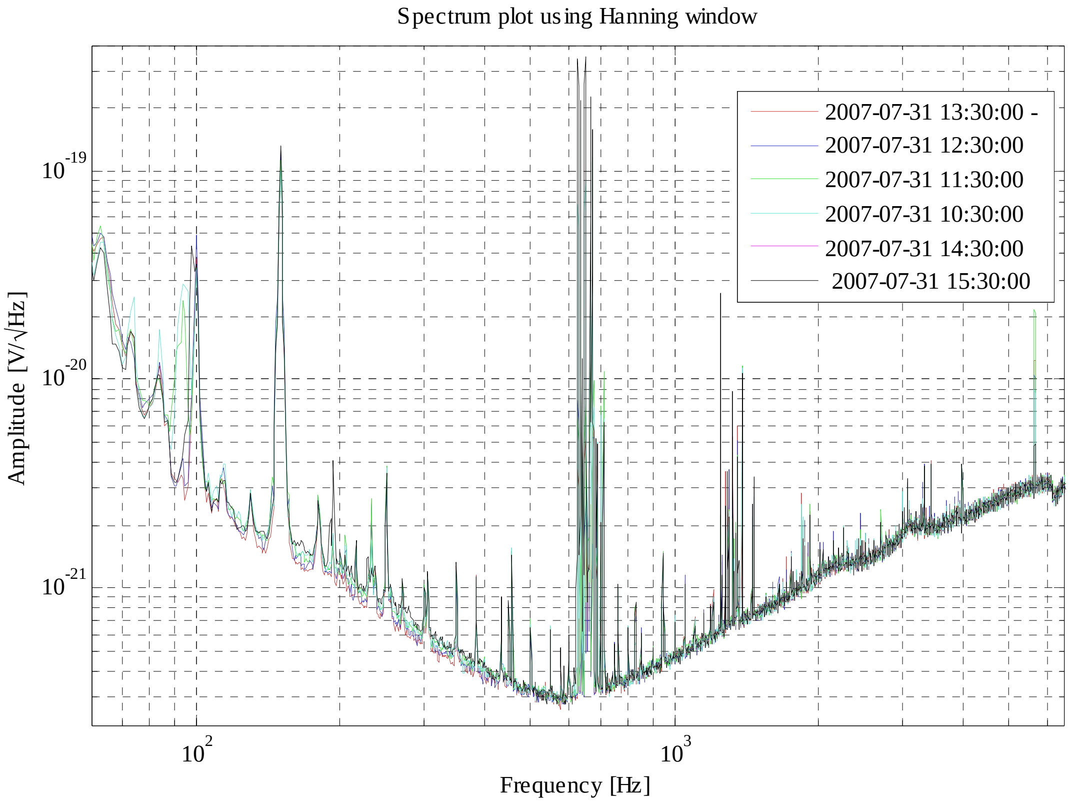
Pressure at all sensors increased by about a factor 30.



Controlled increase of pressure inside the vacuum system (2)

No effect seen in sensitivity.

Can ruled out residual pressure as cause of the mystery noise.

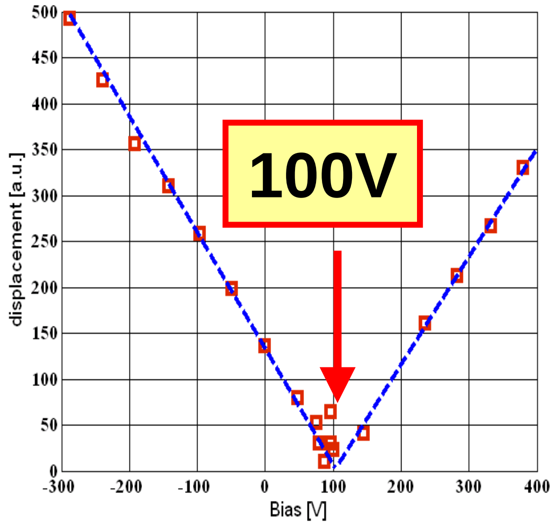


Effects from test mass charging?

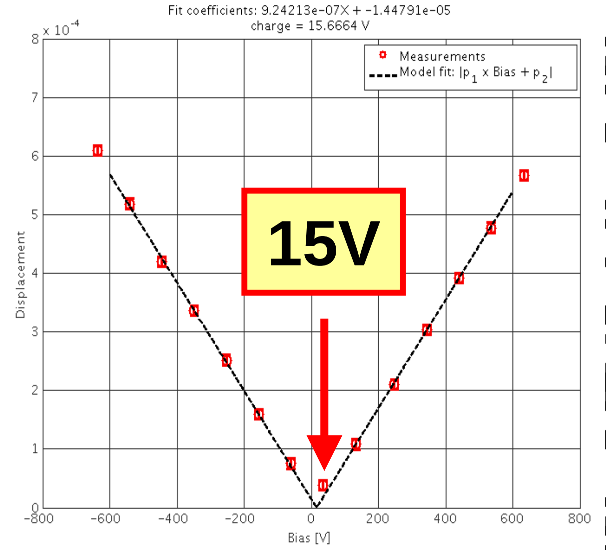
<u>Charges on test masses</u>

- **Measured positive charging of testmasses**
- **Discharged by using a UV-lamp (electrons are freed from ESD electrodes)**

BEFORE



AFTER



<u>Problem:</u> charges on test masses effect out calibration.

However, we believe the charges did not harm the sensitivity.

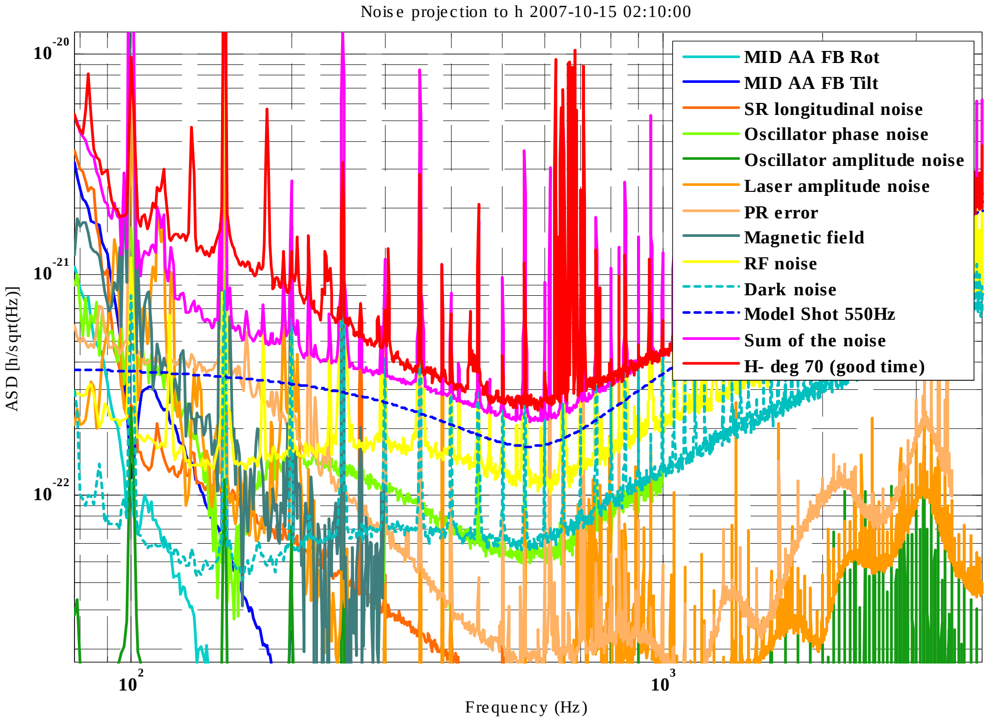
What else is left over ??

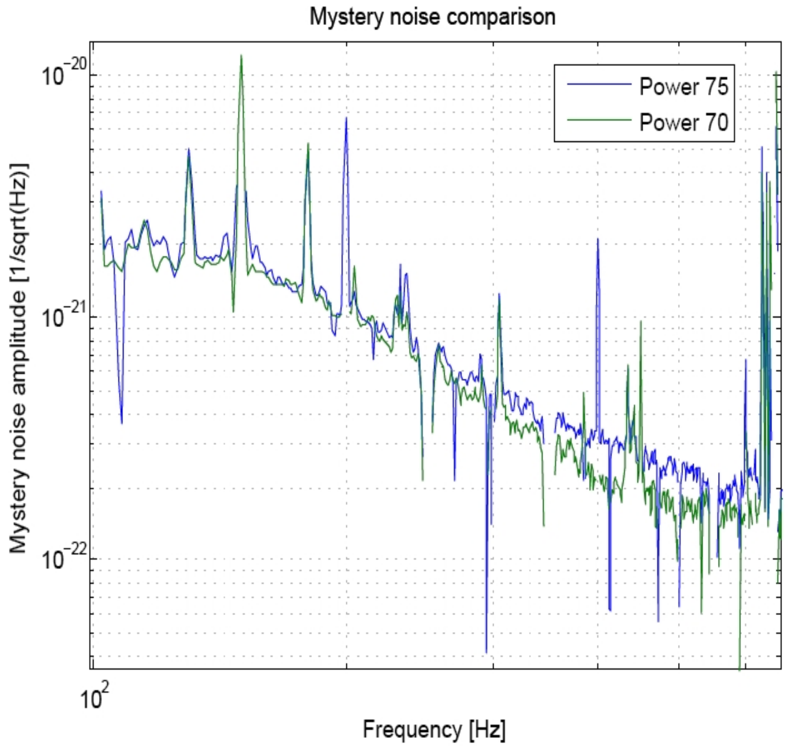
- Barkhausen noise
  - Unlikely: Only MSR and MPR have magnets directly at the mirror

<u>Maybe the mystery noise is a new type of noise (GEO specific):</u>

- ESDs ?
- Signal-Recycling ?
- Monolithic suspensions ?
- Folded arms ? High power in BS substrate ?
- High PR gain ?

Does the mystery noise depend on the optical power ??





- Using only 66% of nominal optical power reduces the ‚gap‘.
- Above 300 Hz the mystery noise is smaller with low power, while below 300 Hz it stays constant.
- Another indication that we are looking for more than one mystery noises.

Additional Slides