Recent experiments in GEO600 regarding the holographic noise hypothesis

Stefan Hild for the GEO600 team

Holographic noise workshop, May 2009, Hannover

- Looking for holographic noise in GEO600 is quite a long story with lots of tricky details …
- … many people contributed to this effort (Hartmut, Jerome, Jonathan, Harald, Martin, Mirko, Ken, Graham etc)
- … I try to keep it short and give an ‘executive summary’.

Overview

- **The Problem:** Does GEO measure Holographic noise ?
  - Why is it so hard to tell?
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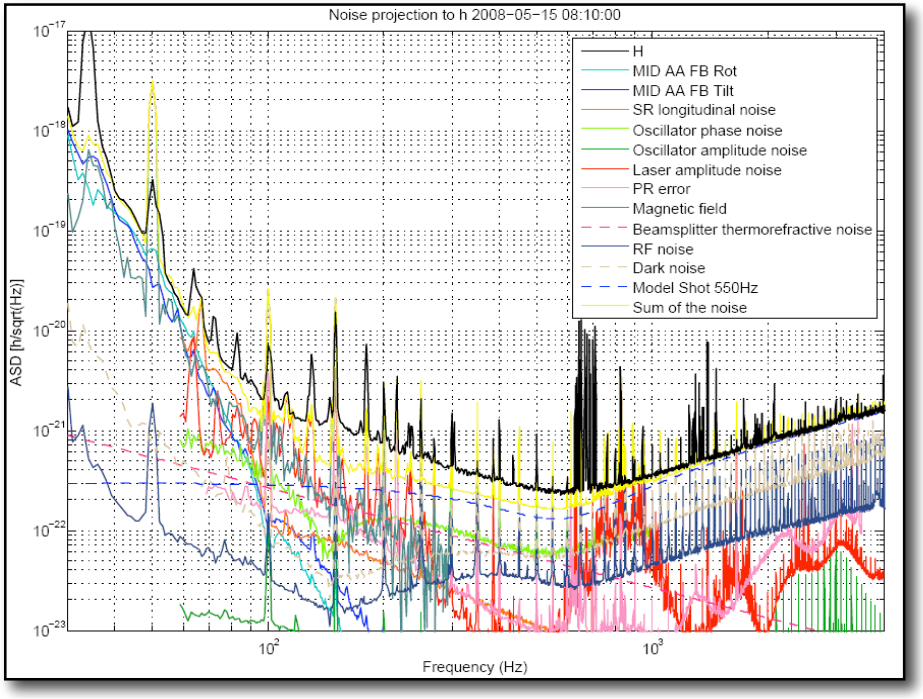
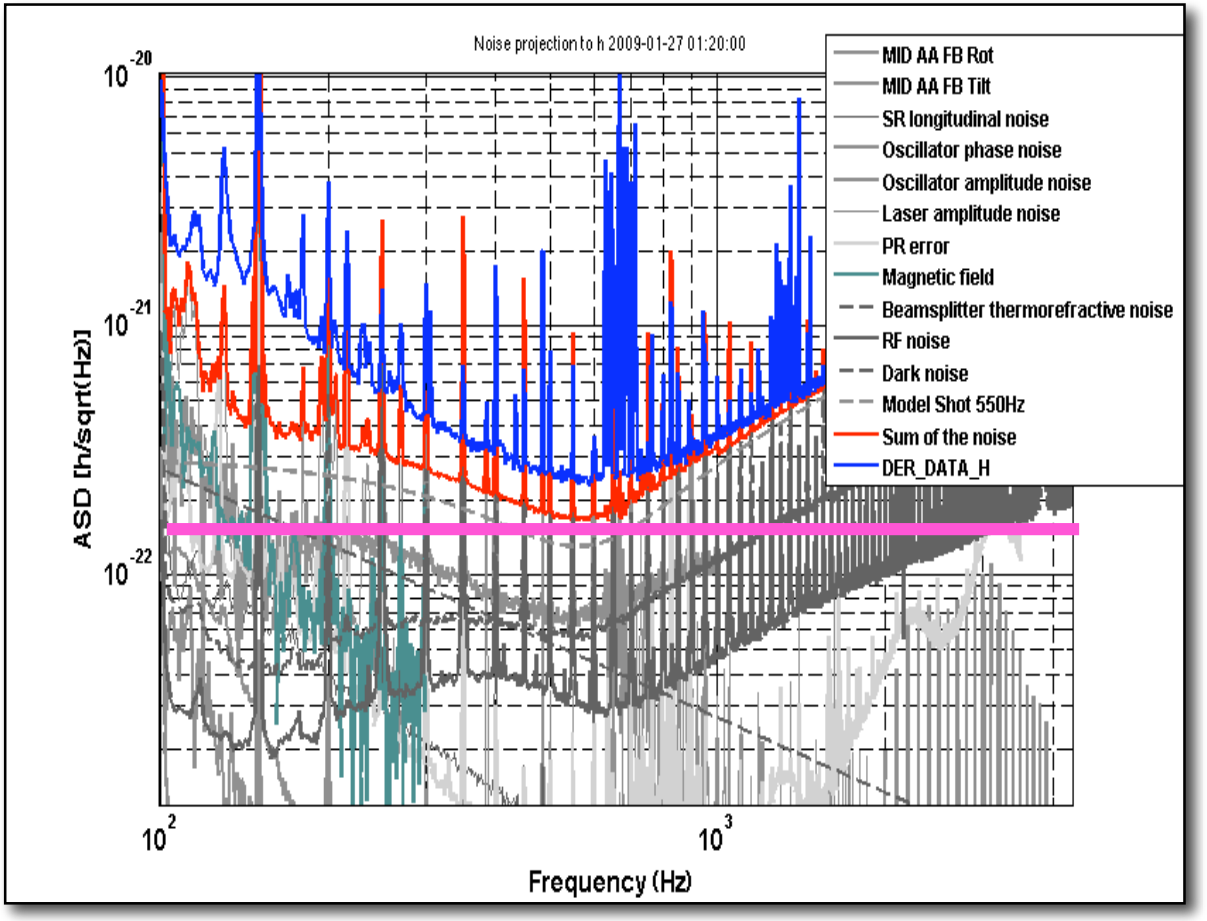
GEO's Mystery noise

- For a long time we observe a unexplained noise component in GEO600.
- Shows up as a gap between the sum of all known noises (yellow) and the actual senstivity (black).
- Details available at:
  - Mystery-noise-Wiki http://www.sr.bham.ac.uk/dokuwiki/doku.php?id=geonoise:home
  - http://www.ego-gw.it/ILIAS-GW/WP1docs/hild_231007.ppt
  - http://www.ego-gw.it/ILIAS-GW/WP1docs/hild1_050308.ppt



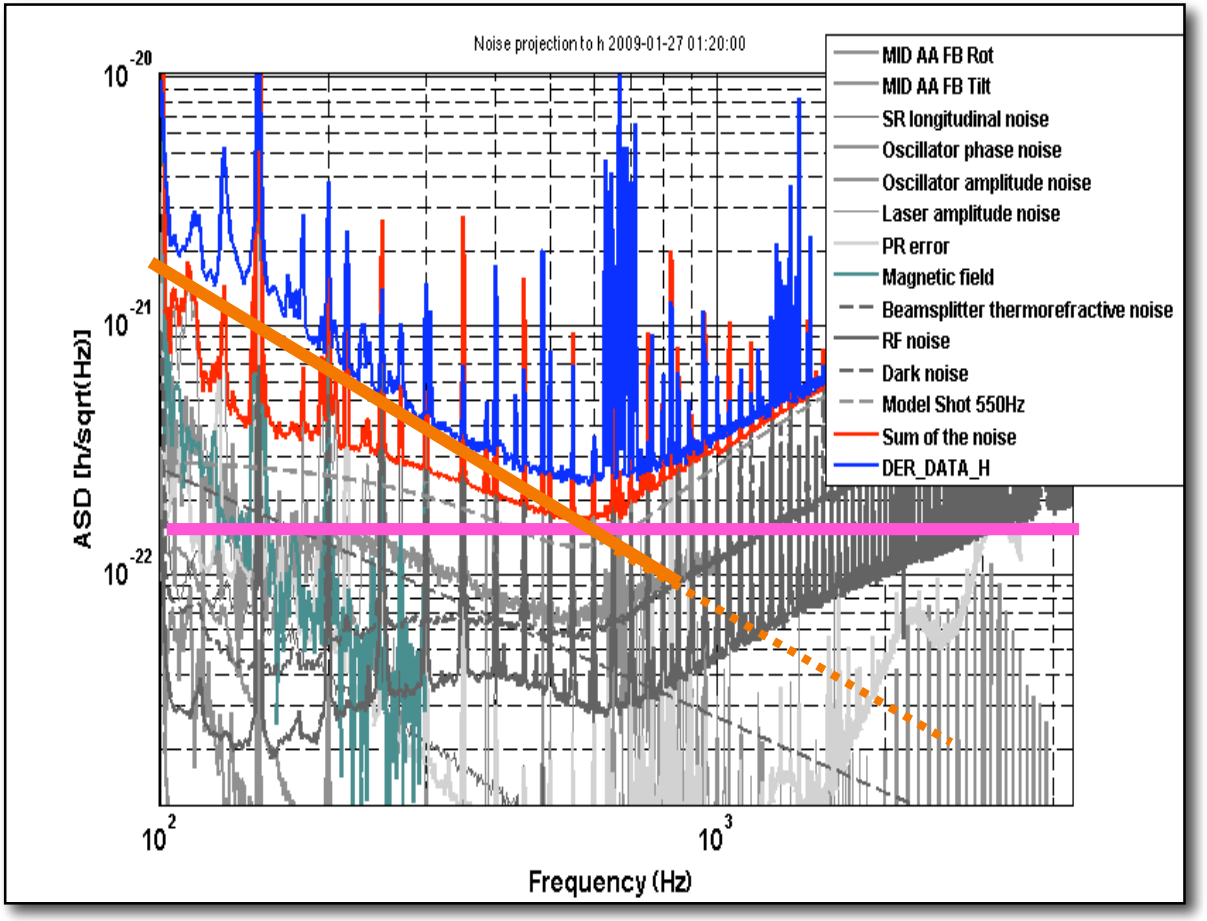
Why is it so hard to tell if GEO 'sees' holographic noise?

- Holographic noise prediction is about sqrt(2) below the current peak sensitivity. => very low SNR !! => **need to get each noise contribution to within a few % !**



Why is it so hard to tell if GEO 'sees' holographic noise?

- Holographic noise prediction is about sqrt(2) below the current peak sensitivity. => very low SNR !! => **need to get each noise contribution to within a few % !**
- There are other much stronger mystery noise components at lower frequencies.



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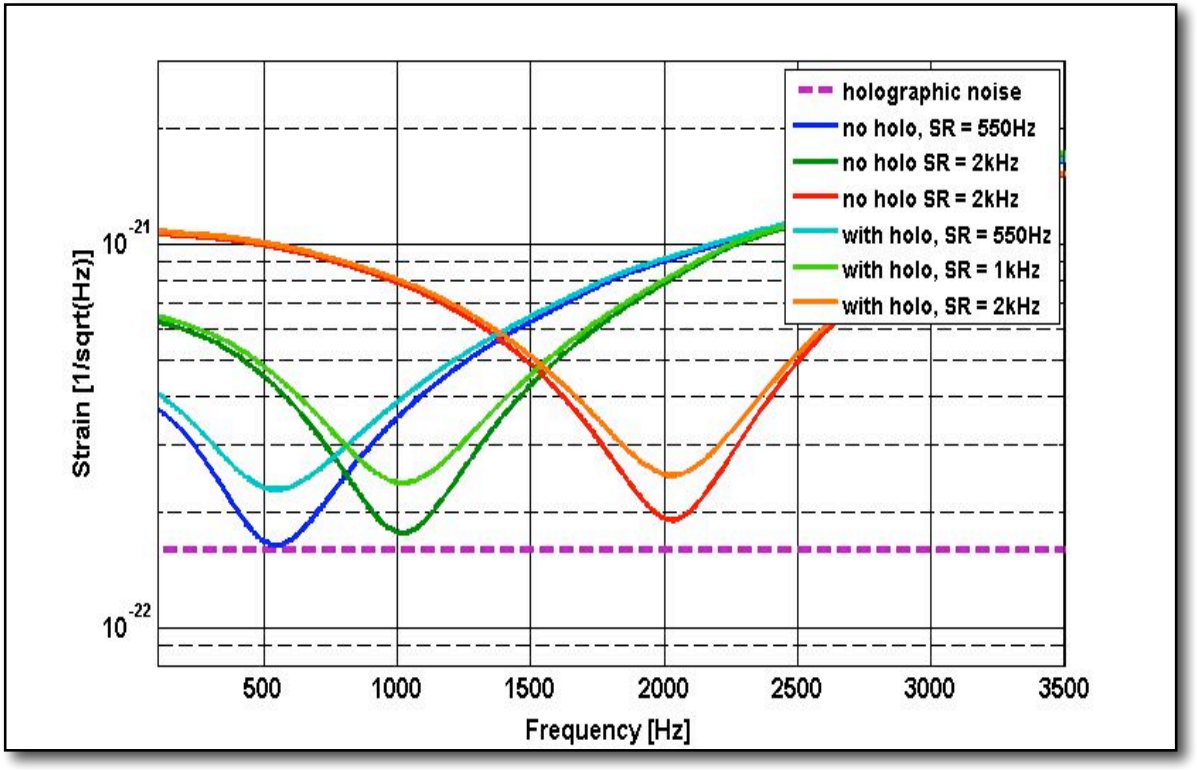
Mapping the mystery noise with different SR-detunings

- Assuming:
  - Current GEO600 sensitivity
  - Calibration accuracy of 10%
- Possibility to characterize any flat noise component at different frequencies.
- Expected difference w/o holo graphic noise: 30-50%



This plot only considers shot noise and holo noise…
Reality a bit more complicated …

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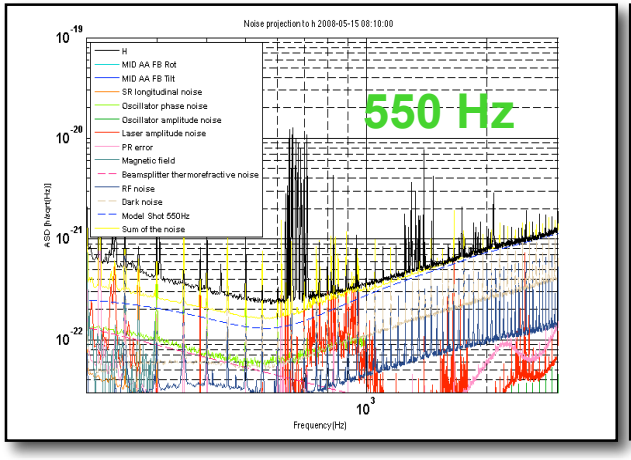
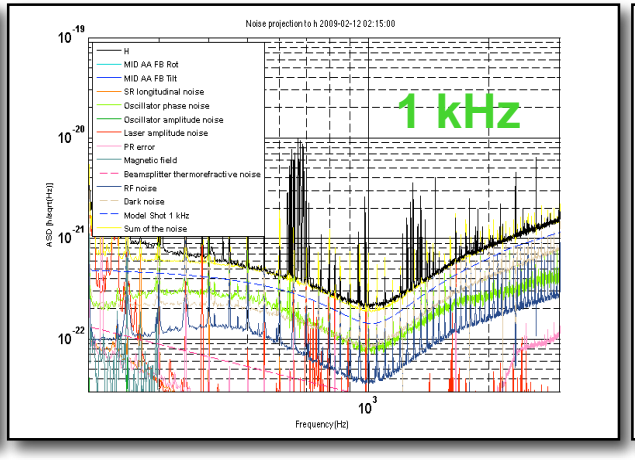
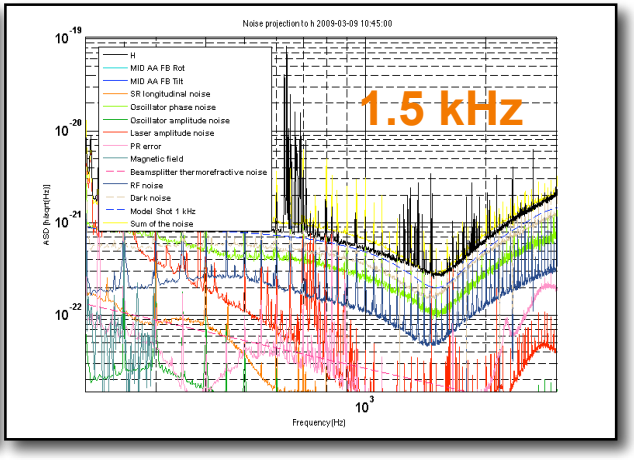
Measurements performed so far

- Explored different high frequency detunings:
  - 1kHz: stable operation, reliable calibration
  - 1.5kHz: stable operation, some calibration non-stationarity
  - 2kHz: no stable operation

- We have noise projections for 550 Hz and 1kHz available (and could probably make 1.5kHz work if necessary).

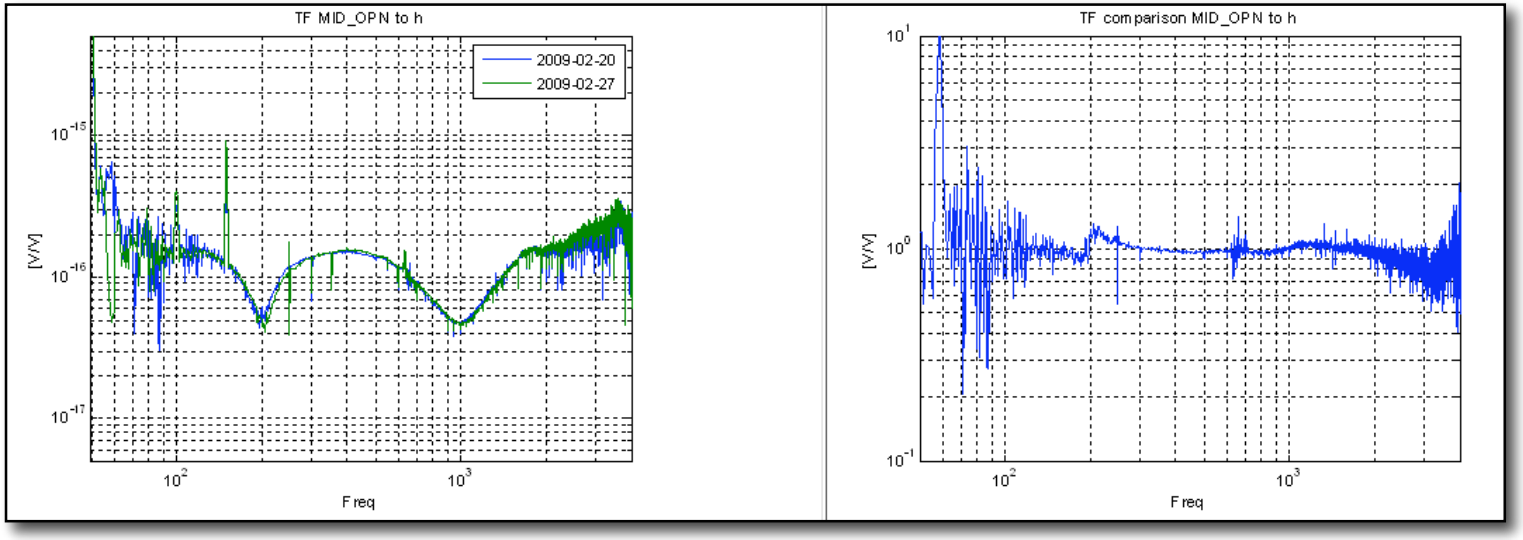






Stationarity of noise transfer functions

- Performed analyses on stationarity and reproducibility of all relevant noise coupling transfer functions. Labbook 5354



- Even though the level of the coupling TFs is found to vary by up to 10%, the overall change in the sum of all explained noises is still in sub-percent range. Labbook 5357

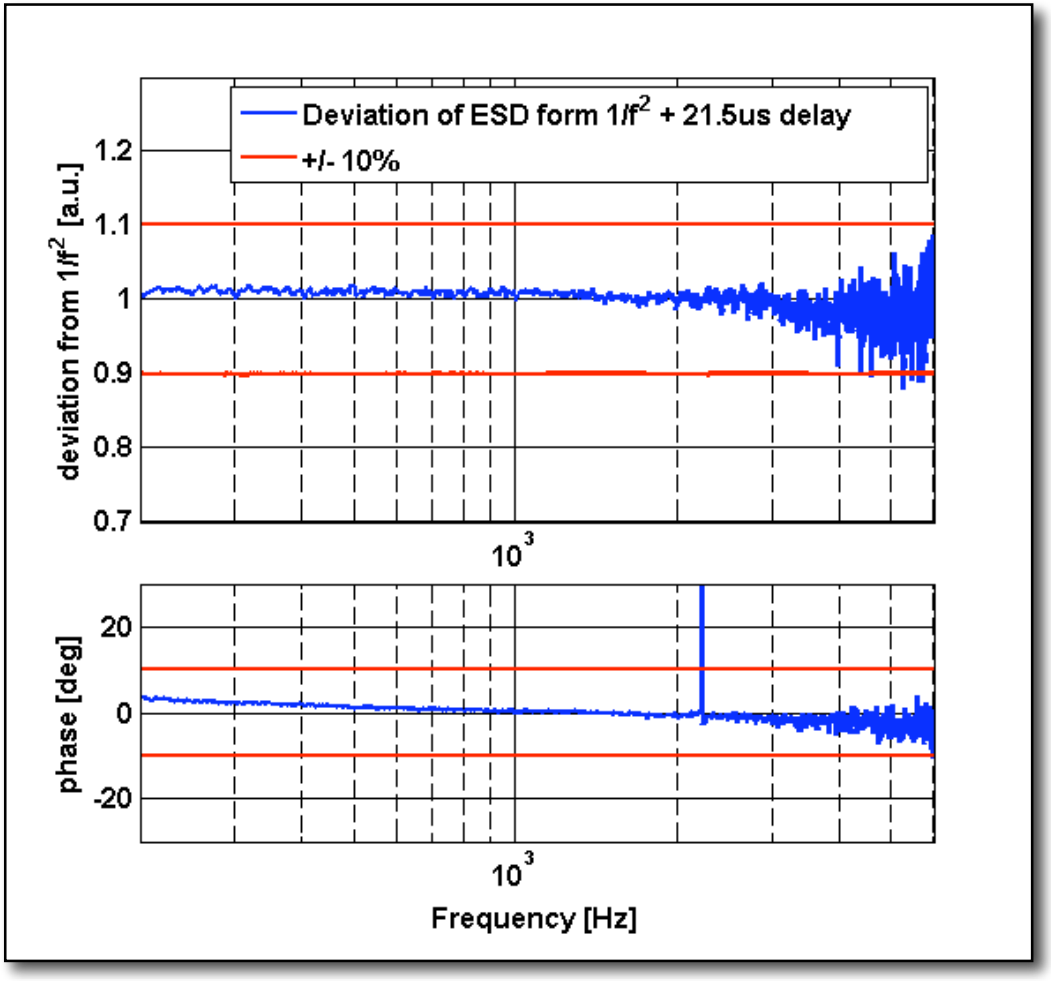
Work on Absolute Calibration

- Main subject: absolute response of the electro-static actuators (displacement per Volts)
- Revisited and improved the standard calibration method: (ESD => common mode arm length => MMC2b feedback => Laser PZT => absolute length of MC1)
- Established a new calibration method: Free swinging Michelson (unlocked Michelson driven with 72 Hz).
  - We always longed for an alternative calibration. Now we have it.
- **Both methods agree well:**
  - ESD to MC1 = 106nm/V @ 1Hz
  - Free swinging MI = 98nm/V @ 1Hz

Most relevant labbook pages: 5434, 5439, 5444

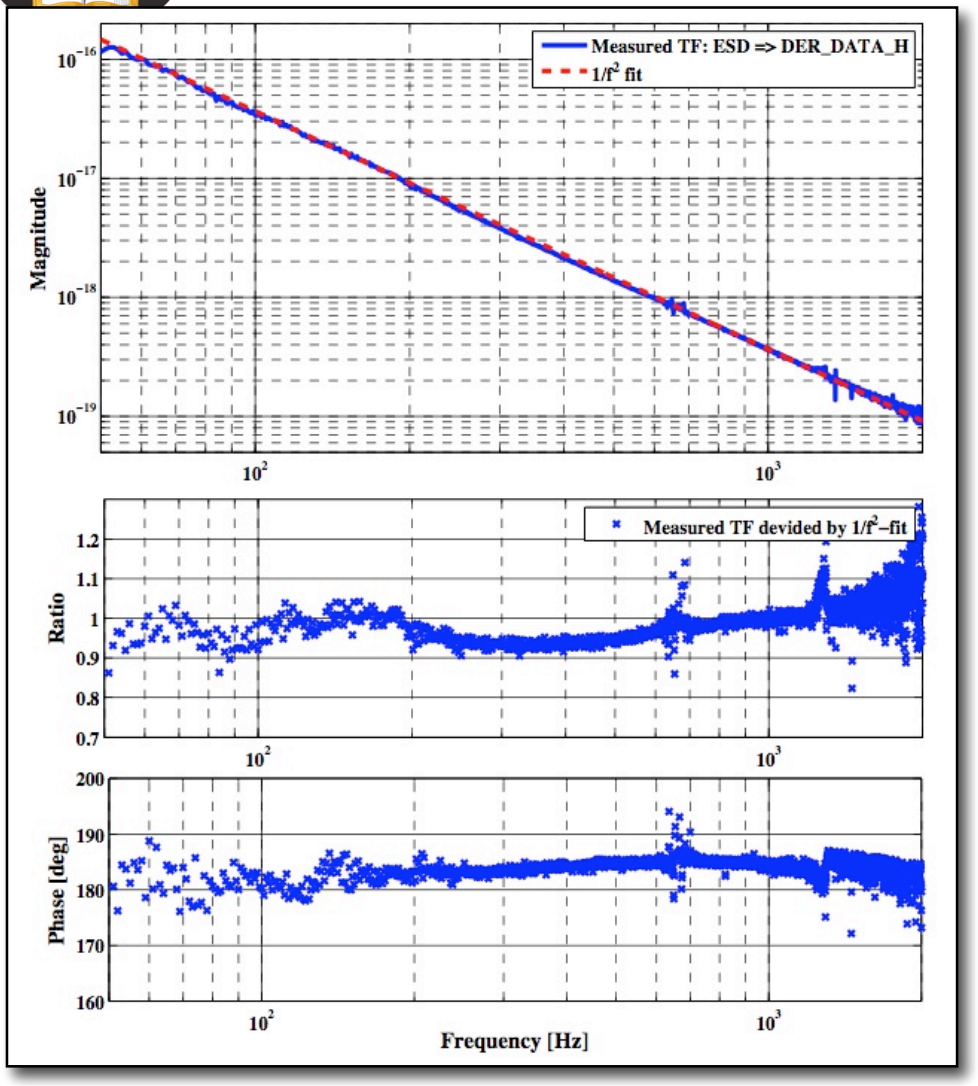
Calibration work (relative)

- One thing we haven't checked carefully for years is the frequency response of the ESDs.
- Performed measurements in PRMI (without SR).
- ESD response is exactly what we expect!



Relevant labbook pages: 5327, 5351, 5356

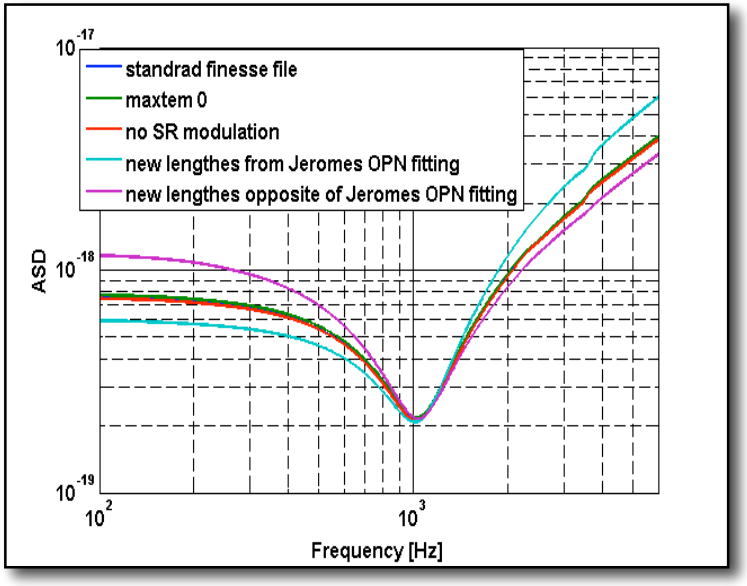
Check of full calibration chain (relative)



- Knowing the ESD response…
- Injecting broadband noise into ESDs …
- We can check the calibration accuracy at each frequency bin !

Main Problem so far: Estimating Shot Noise

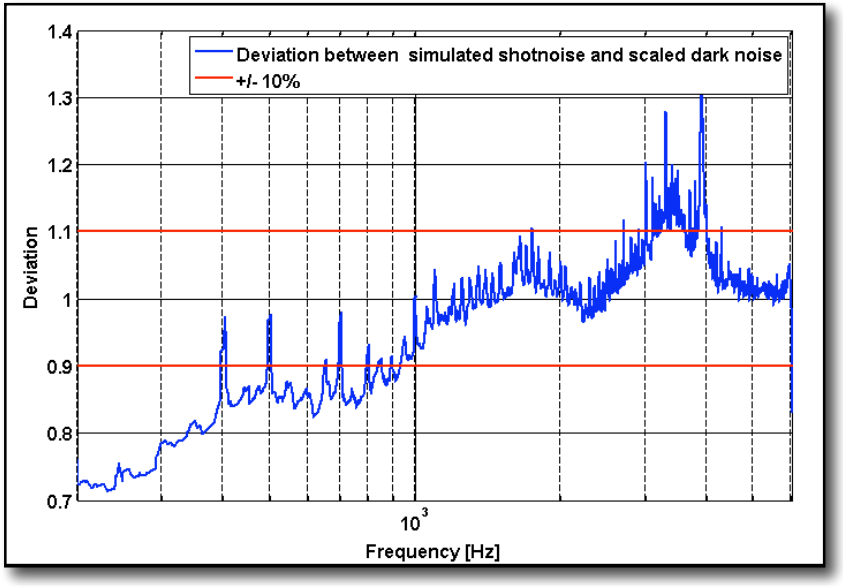
- In the standard noise projections shot noise is the only trace (close) to be limiting the GEO sensitivity which is not derived from a measurement, but a numerical simulation.
- The optical simulation of GEO600 is quite complex (imperfect/dirty optics, heterodyne readout, a myriad of hidden parameters etc)
- Therefore, we want to experimentally check shape and level of the shot noise contribution



Illustrating example of how the simulated shot noise changes with slightly modified parameter sets. (labbook 5413)

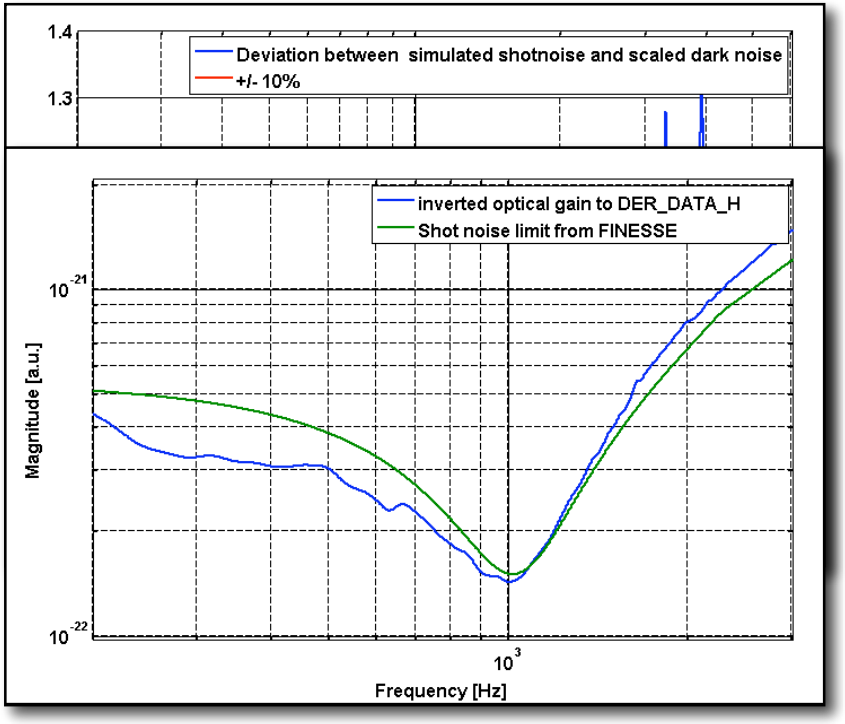
Attempts of pinning down the shape of the shot noise

- Compare to the shape of projected dark noise (photodiode + electronics + demodulation)



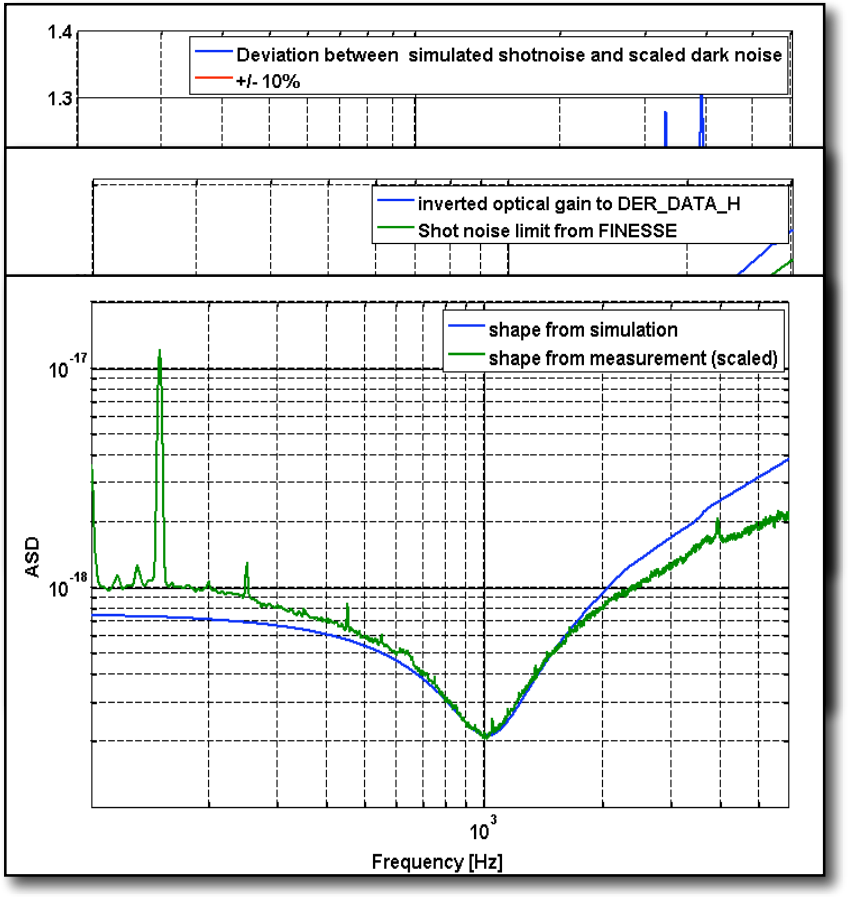
Attempts of pinning down the shape of the shot noise

- Compare to the shape of projected dark noise (photodiode + electronics + demodulation)
- Deriving the optical gain of DER_DATA_H from the 8 calibration parameters.



Attempts of pinning down the shape of the shot noise

- Compare to the shape of projected dark noise (photodiode + electronics + demodulation)
- Deriving the optical gain of DER_DATA_H from the 8 calibration parameters.
- Injection of white RF noise into the main 14.9 MHz mixers and propagating this through the calibration and combining routines.
- So far not really satisfying … :(
  … though perhaps already good enough for the holographic measurements



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What needs to be done to pin down the shot noise contribution ?

- For sure we are able to derive the correct shot noise contribution … so far we did not take this task serious enough.
- Possible solution 1: Attenuation experiments
  - Reduce light power on my photo detector => dominate sensitivity by shot noise.
  - Problem: run into dark noise => might require building a photo detector especially adjusted for the reduced light level (optimise dark noise)
- Possible solution 2: Using the calibration parameters
  - Derive optical gains for HP and HQ from calibration parameters.
  - Creating optical of DER_DATA_H using the combining filter in time domain…

How to analyse the data ?

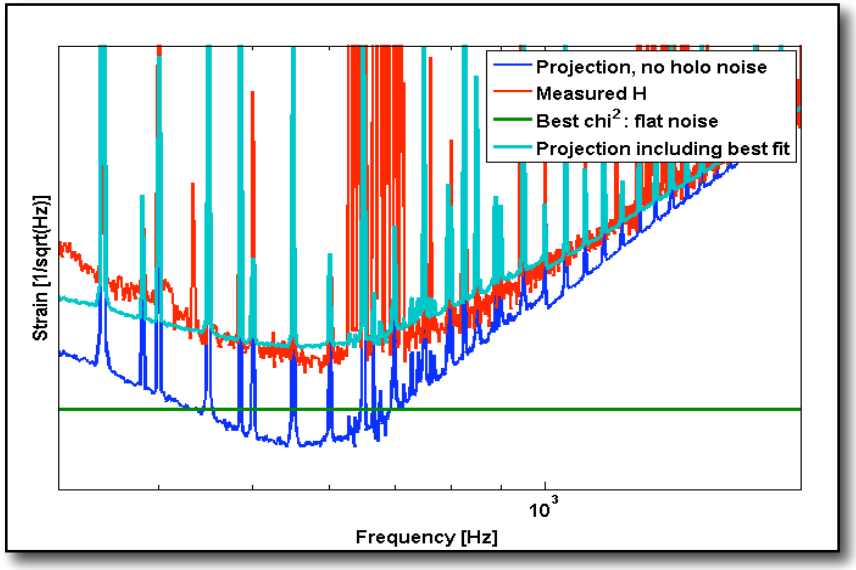
- 1st idea was to use a Chi^2 analysis.

Holo noise hypothesis

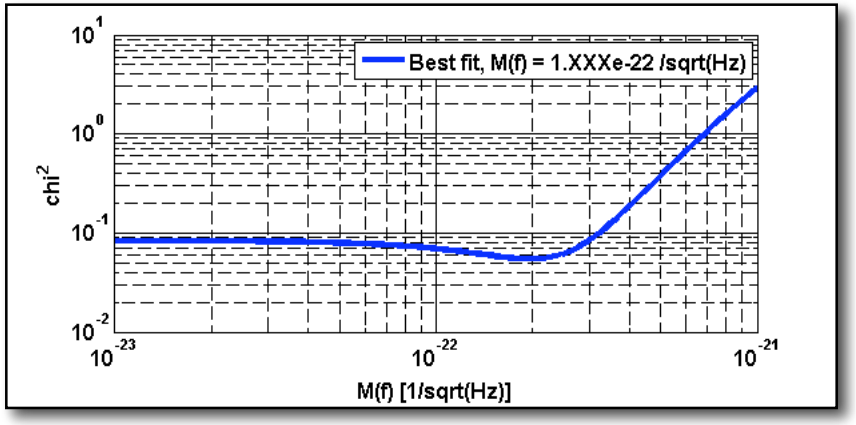
Explained noise

$$\chi_i^2 = \sum_f \frac{(\sqrt{P(f)^2 + M_i(f)^2} - H(f))^2}{H(f)^2}$$

Measured h(t)

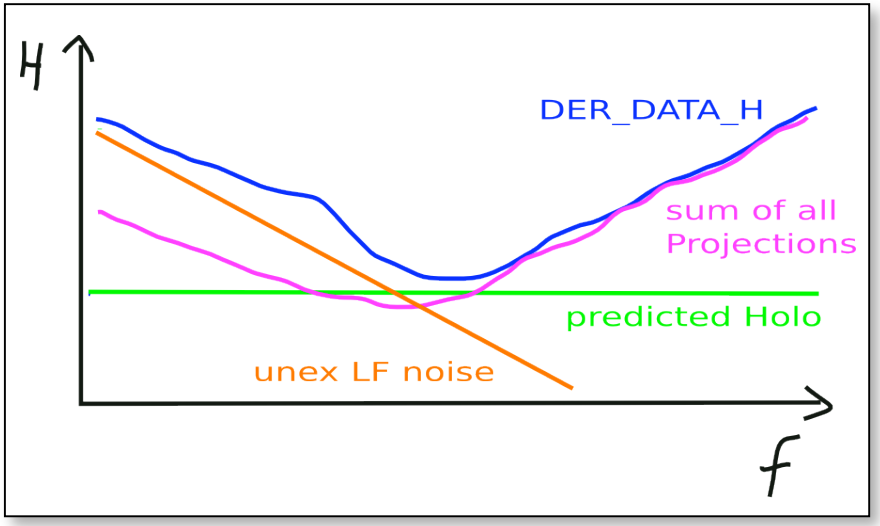


- Problems of Chi^2 analysis:
  - Frequency cut
  - Mystery noise at low frequencies
  - How to interpret the result?



Bayesian Approach (G. Woan)

- Graham proposed to use a Bayesian Approach.
- This would allow to 'properly' take into account:
  - unexplained noise at low frequencies
  - all other uncertainities
- Can combine data from different SR detunings
- Get an understandable number out:



$$R = \frac{\text{likelihood that the data came from standard noise + holographic noise}}{\text{likelihood that the data came from the standard noise model}}$$

holo/trunk/other_documents/holo_bayesian_Graham.pdf

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The Goal for the near-term future

- Finish measurements, analysis and writing up an article containing a likelihood statement by mid of June.
- There is a dedicated svn repository (documentation and version control) for the holo-noise measurements at GEO:
  - analysis codes
  - relevant data
  - tex-files etc

Likelihood of the presence of holographic noise in the GEO 600 interferometer

The GEO600-team[1,2,3] and The LSC[4]

[1]*School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK*
[2]*SUPA, Physics & Astronomy, University of Glasgow, Glasgow G12 8QQ, Great Britain*
[3]*Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Leibniz Universität Hannover, Callinstr. 38, D–30167 Hannover, Germany.*
[4]*This Universe and the next one.*
(Dated: May 19, 2009)

Holographic noise was claimed to be a limiting noise source of the GEO 600 gravitational wave observatory. ... we did some measurments ... Holographic noise was claimed to be a limiting noise source of the GEO 600 gravitational wave observatory. ... we did some measurments ... Holographic noise was claimed to be a limiting noise source of the GEO 600 gravitational wave observatory. ... we did some measurments ... Holographic noise was claimed to be a limiting noise source of the GEO 600 gravitational wave observatory. ... we did some measurments ...

PACS numbers: 04.80.Nn, 07.60.Ly, 95.75.Kk, 95.55.Ym

I. INTRODUCTION

Recently the concept of indeterminacy of holographic quantum geometry has been proposed [1, 2]. Here should go a 5 sentence description of the concept.
In [1, 2] it is claimed that the sensitivity of the GEO 600 gravitational wave detector [3] might be limited by holographic noise, which is equivalent to a lateral movement of the GEO 600 beam splitter. In this article we present a detailed analysis of the unexplained noise contributions observed with GEO 600 and conclude by evaluating a value for the probability that GEO 600 actually measures holographic noise.

II. THEORETICALLY EXPECTED EFFECTS ON THE GEO 600 SENSITIVITY IN CASE HOLOGRAPHIC NOISE IS PRESENT

Introducing the conept of different detunings to scan for the holographic noise. Talking a bit about the general problem to identific a noise source with snr slightly smaller one. Probably also putting in the very simplified plot from the GEO logbook page 5297.

beam splitter thermo-refractive noise.

B. Noise Projections for GEO 600

Show and explain the noise projections: This includes a very brief description of the procedure plus a refernce to Josh's paper. Also we should show the final noise projections for any detuning we use for our analysis. Also we should give a statement on the reproducibility and stability of the noise projections.

C. Relative and Absolute Calibration

We should talk about our confidence on the absolute and relative calibration accurarcy. This section needs to be carefully written in order to avoid upsetting people and politicians.

IV. EVALUATING THE PROBABLITY OF GEO 600 BEING LIMITED BY HOLOGRAPHIC NOISE

E N D