Status of The Thermal Compensation System For Enhanced LIGO

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for the TCS TEAM:

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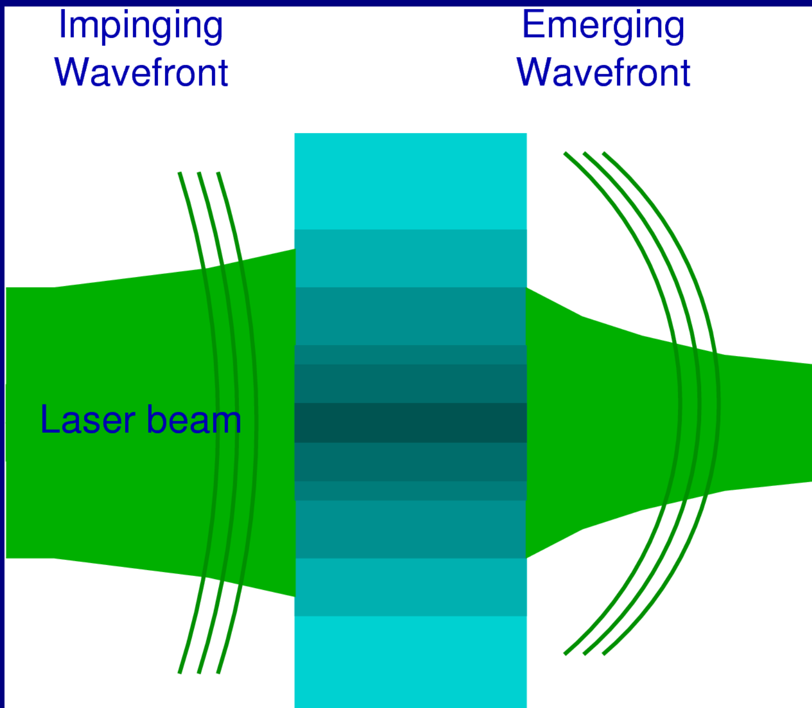
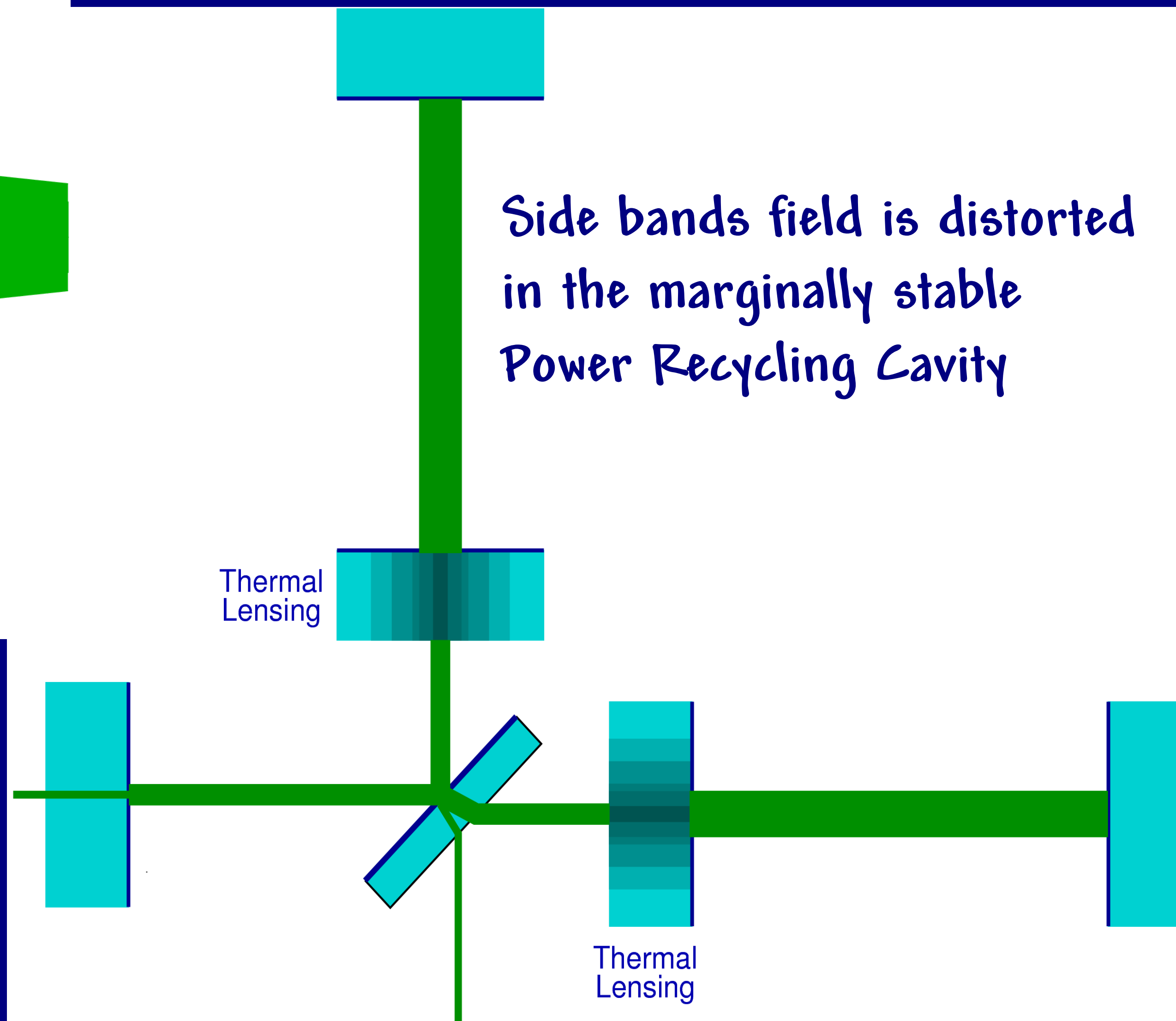
TCS: Talk Outline

- Brief Introduction to the Problem and to the Cure
- Thermal Compensation Requirements for Enhanced LIGO
- Upgrades Description for Enhanced LIGO
- Intensity Stabilization Results obtained with the TCS-ISS Prototype
- Installation & Commissioning Planning
- Possible improvements

TCS: Fundamental problem, Thermal Focusing



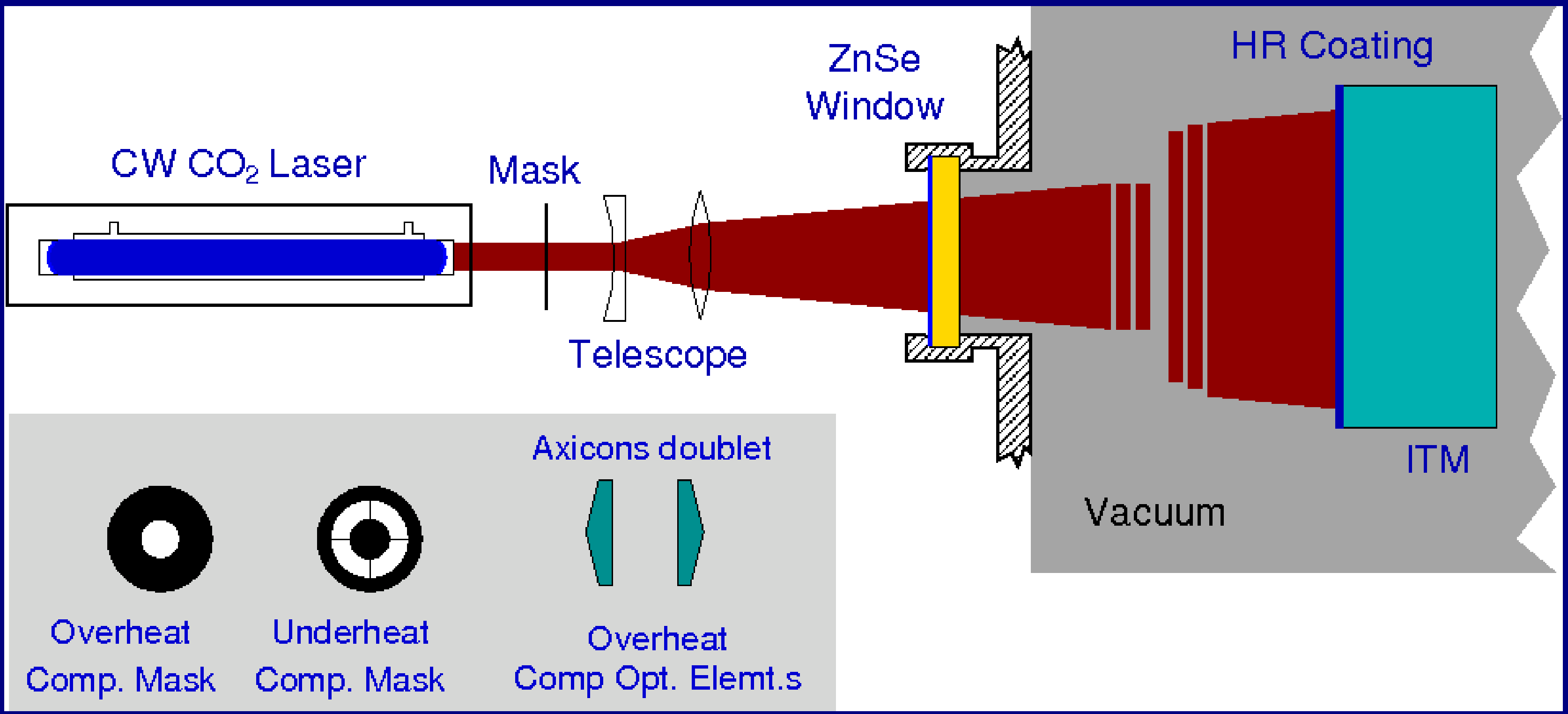
Gaussian Beam Heated Mirror
Builds up a Refractive Index Gradient

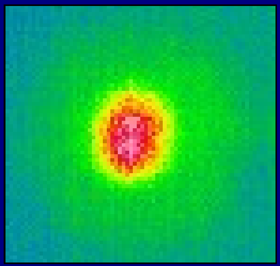


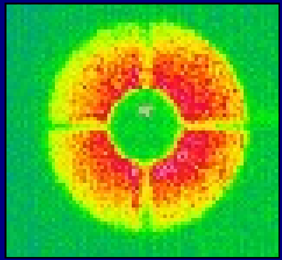
Side bands field is distorted in the marginally stable Power Recycling Cavity

- Side bands are the ones most affected:
  - poor side bands build up
  - poor carrier side bands overlap because of the carrier spot size

TCS: Projector, Basic Idea for Thermal Compensation

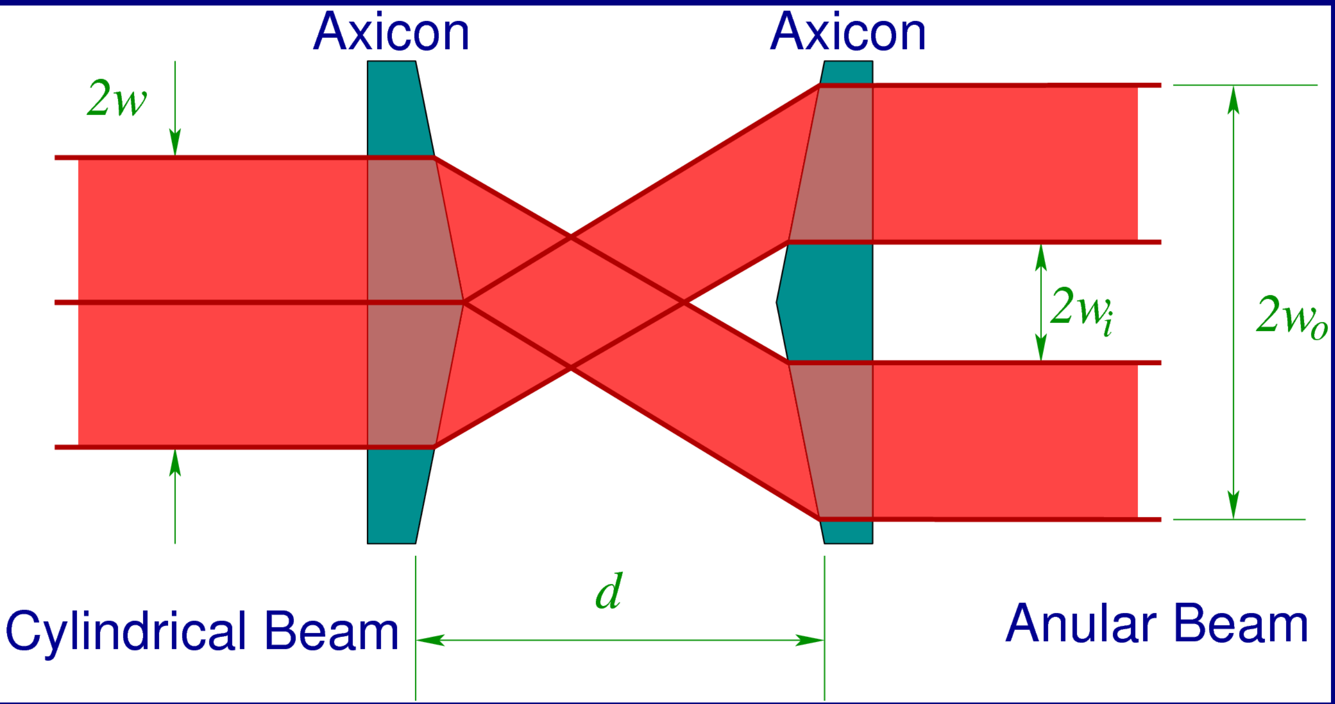


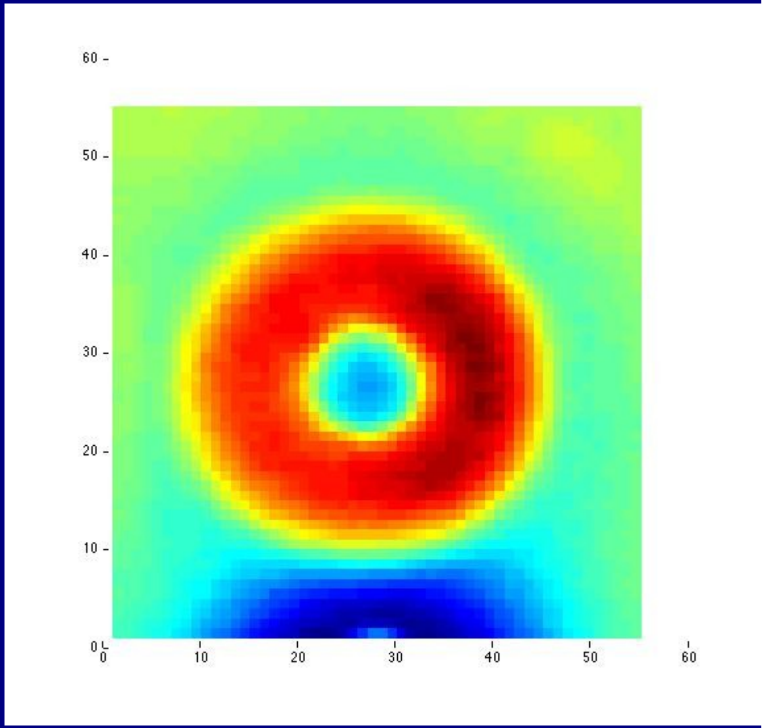




- Hole mask heat the central part of the ITM to keep The IFO in "warm state" when unlocked.
- Annular mask replaced by the axicons doublet heats an annular surface of the ITMs to optimize the side band coupling in the power recycling cavity.
- Available wavelenght for efficient absorption ~10um

TCS: Co2 Projector, Axicons doubletG070470-00-R





Intensity Profile using a Thermal Imaging Camera

- Inner output beam diameter $2w_i$ controlled by changing axicons distance d
- Outer output beam diameter $2w_o$ controlled by changing input beam diameter 2w
- Measured Efficiency: 89%

TCS-ISS: Projector Power Requirements

- Mirror Absorptions measured at end of S5:
  - H1 ITMX: 6.8 ppm
  - H1 ITMY: 5.4 ppm
  - L1 ITMX: 2.3 ppm
  - L1 ITMY: 3.4 ppm

- ITMs have been drag-wiped and should absorb less now, but Enhanced LIGO TCS design is not assuming this.

- Assuming 75 KW arm power, and 10x more annular power than absorbed power, Enhanced LIGO will need:
  - H1 ITMX: 5.1 W
  - H1 ITMY: 4.1 W
  - L1 ITMX: 1.7 W
  - L1 ITMY: 2.6 W

TCS-ISS: Major Noise Coupling Mechanisms

TCS noise couples into the IFO through :

- the laser beam optical path fluctuation
- photon pressure (not dominant)

TCS optical path fluctuation arises because of:

- Thermo-optic (Thermal Lensing) Noise: fluctuation of the substrate refractive index due to temperature change.
- Thermo-elastic Noise: fluctuation of the elastic expansion of the substrate due to heating.
- Elasto-Optic Noise: fluctuation of the substrate refractive index due to the elastic deformations.
- Flexure noise, bulk flexure of the whole mirror due to differential thermal expansion (dominant for annular compensation)

TCS-ISS Prototype: Free Running Laser (SYNRAD)

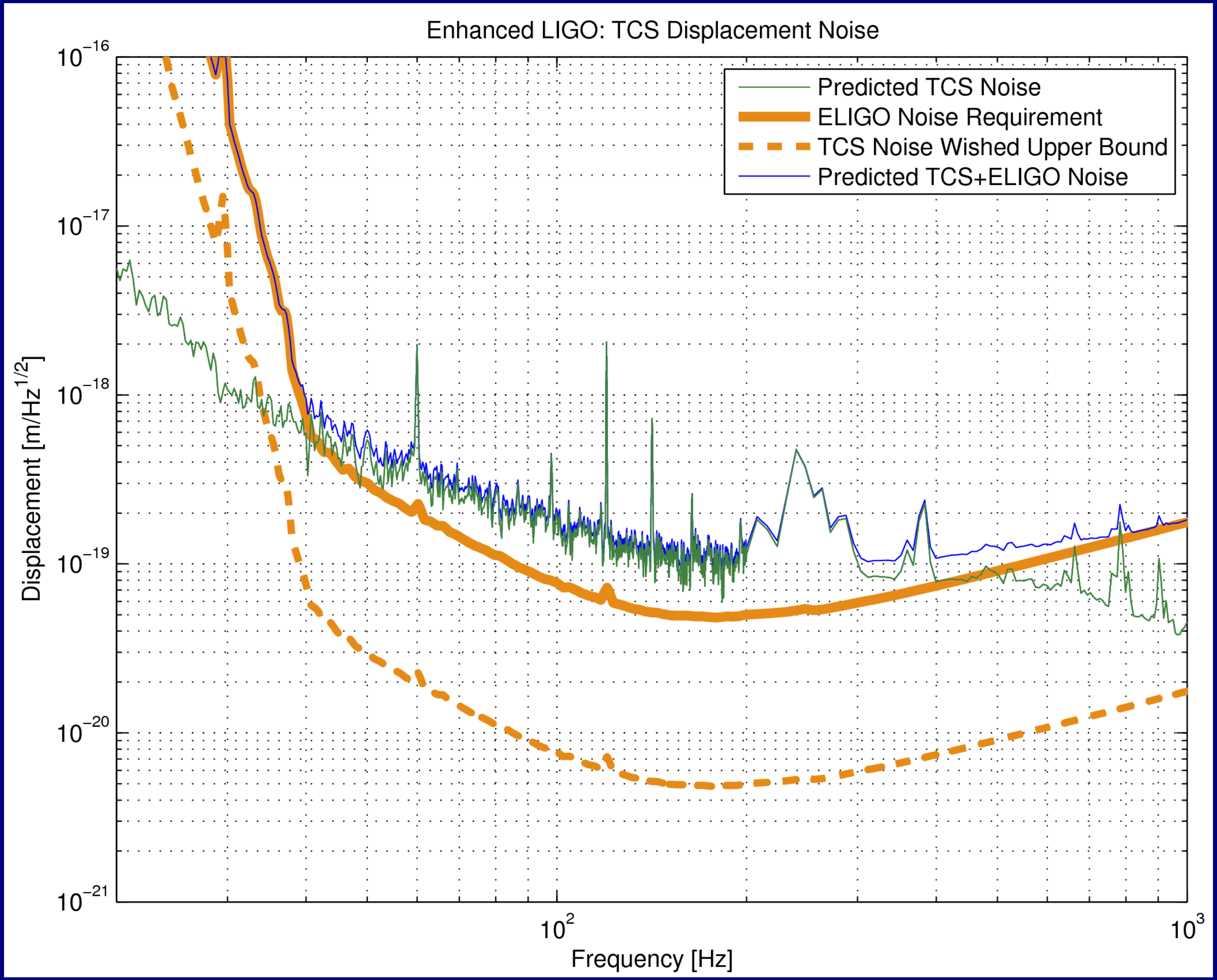
Free Running laser noise is too high to meet the Enhanced LIGO requirements

$\partial x(f) = a \langle P \rangle \; RIN / f$ (*)

(annular heating)
$a = 2.1 \times 10^{-12}$ Hz/W
(central heating)
$a = 1.5 \times 10^{-11}$ Hz/W

=> an intensity (Power) stabilization system is clearly needed from
30 Hz to ~ 1 kHz

with a desirable suppression factor of about 20-50



(*)Stefan Ballmer Ph.D. Thesis

TCS: Enhanced LIGO Upgrades

- Higher Laser Power, from 8W to 35W

- Laser Power Stabilization using an Acousto-Optic-Modulator

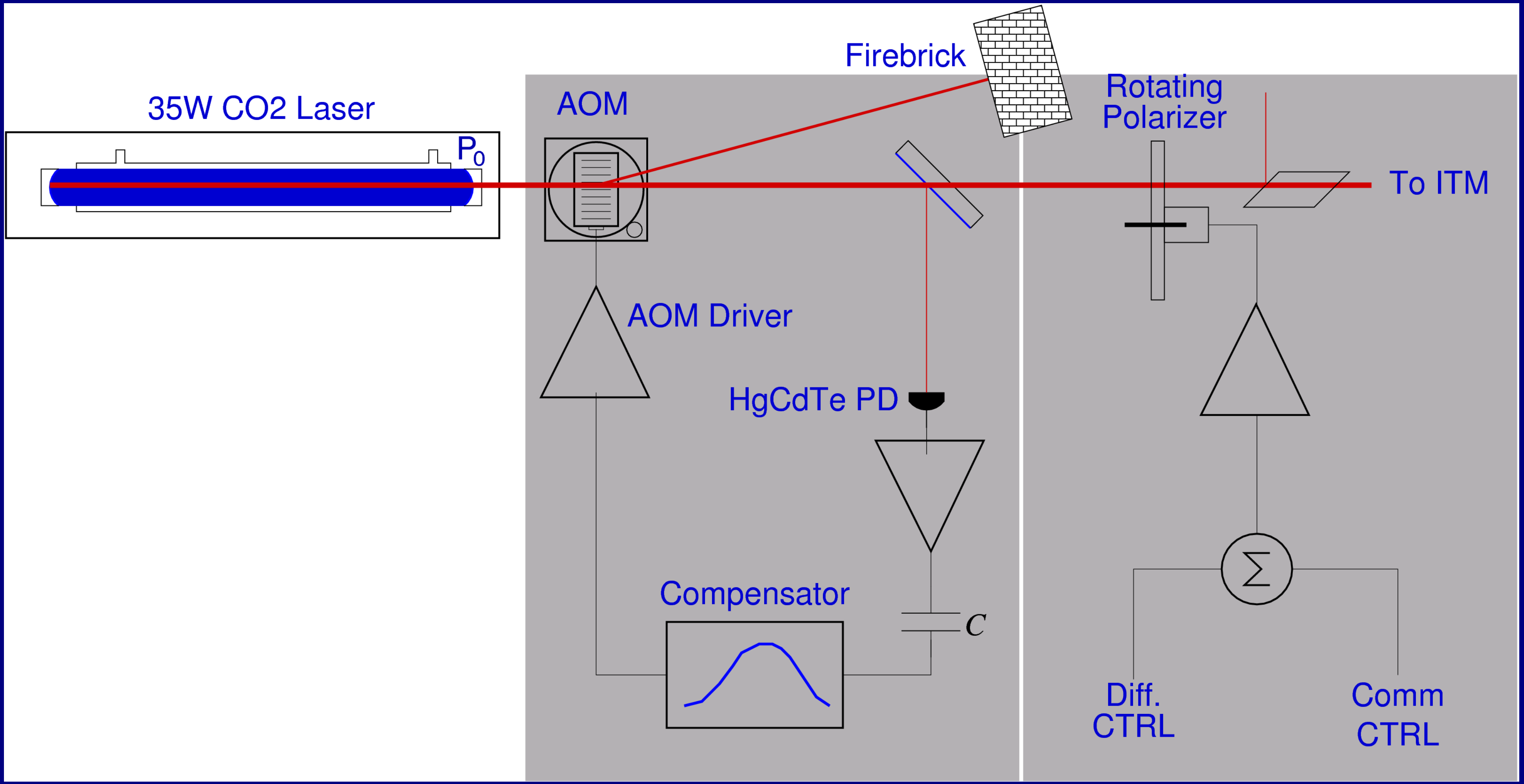
- DC Power level setting using a rotating polarizer

- Acoustically and EMI quieter CO2 laser chiller and acoustically isolated into an enclosure

- Use of an Axicon Doublet to produce the ITMs anular heating

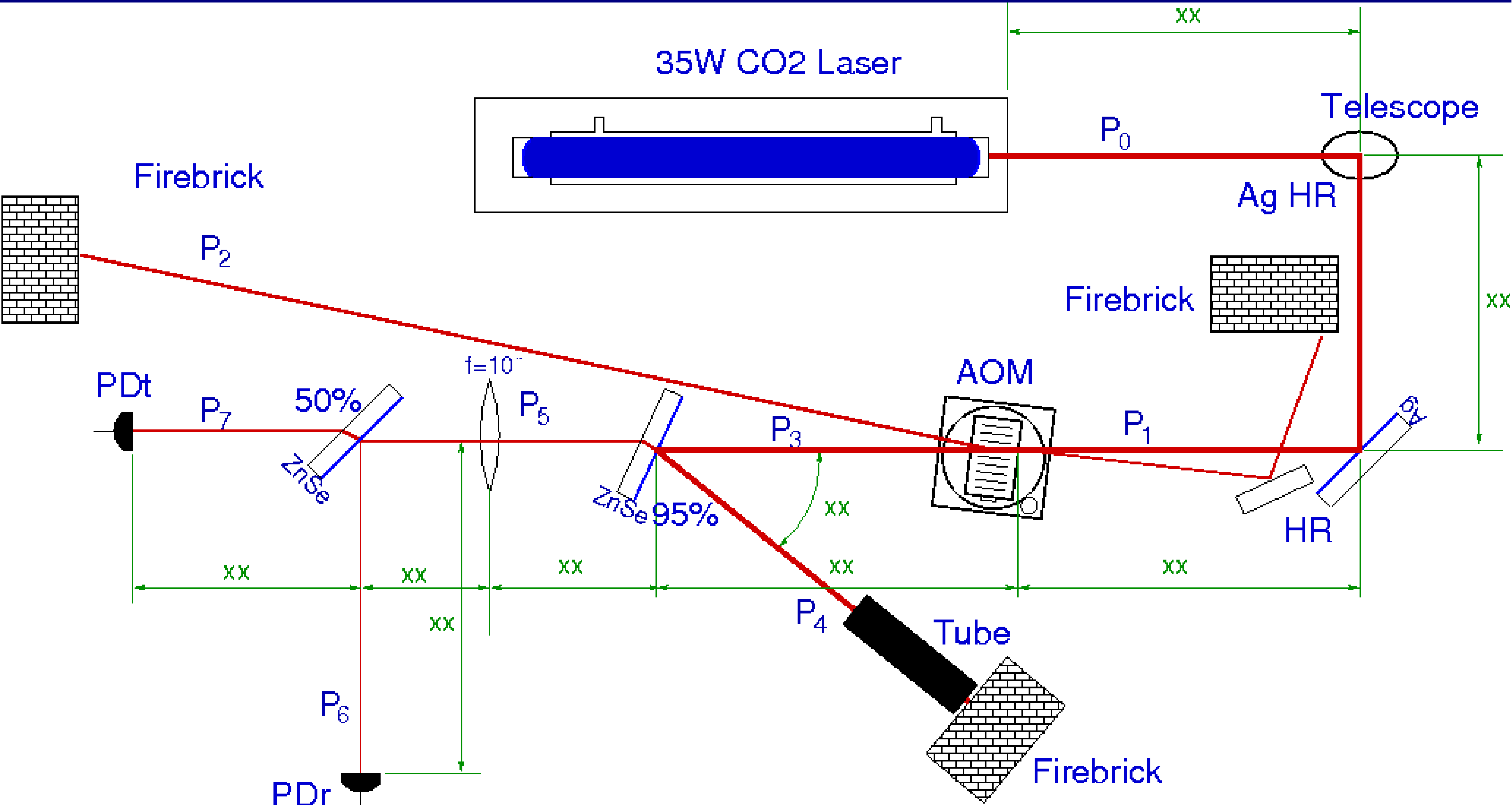
- Possible changes in the TCS low frequency control scheme due to the Output Mode Cleaner and DC readout. (change in the differential mode error signal input, common mode the same)

TCS-ISS: Servo Topology



- Differential and common control signals drive the rotating polarizer at very low frequency to optimize the sidebands build up, oscillator phase noise, AS_I, … .
- Local intensity stabilization of the CO2 Laser keeps the injected noise due to the optical path fluctuation below the IFO resolution.

TCS: ISS Prototype, Optical Layout



- Caltech, Downs Building Room 18 , a quite noisy environment.

TCS-ISS Prototype: Photo-detectors, Characteristics

•Photodetector Type:

HgCdTe doped junction

•Source:

Vigo (Polish manufacturer)

•Configuration:

Photo-voltaic Mode

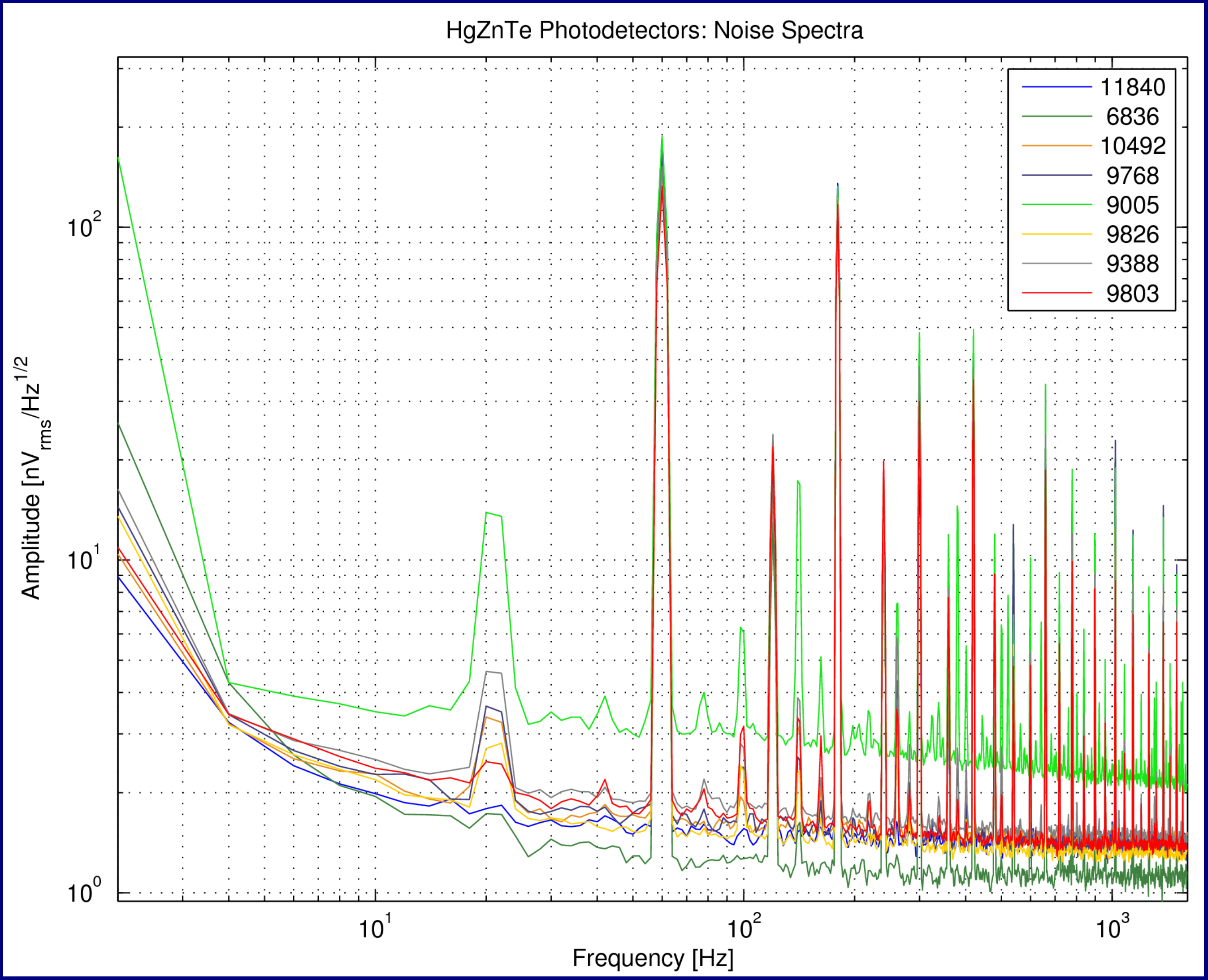
Dark Noise (in Volts)

$\partial V \approx 1.5\text{-}4\ nV_{rms}/\sqrt{Hz}$

•Preamplifier noise floor:

$\partial V \approx 1\ nV_{rms}/\sqrt{Hz}$ @ 100Hz

Some detectors noisier than others.



To perform the measurement it's necessary to go through two amplifying stages which create a quite serious ground loop problem!

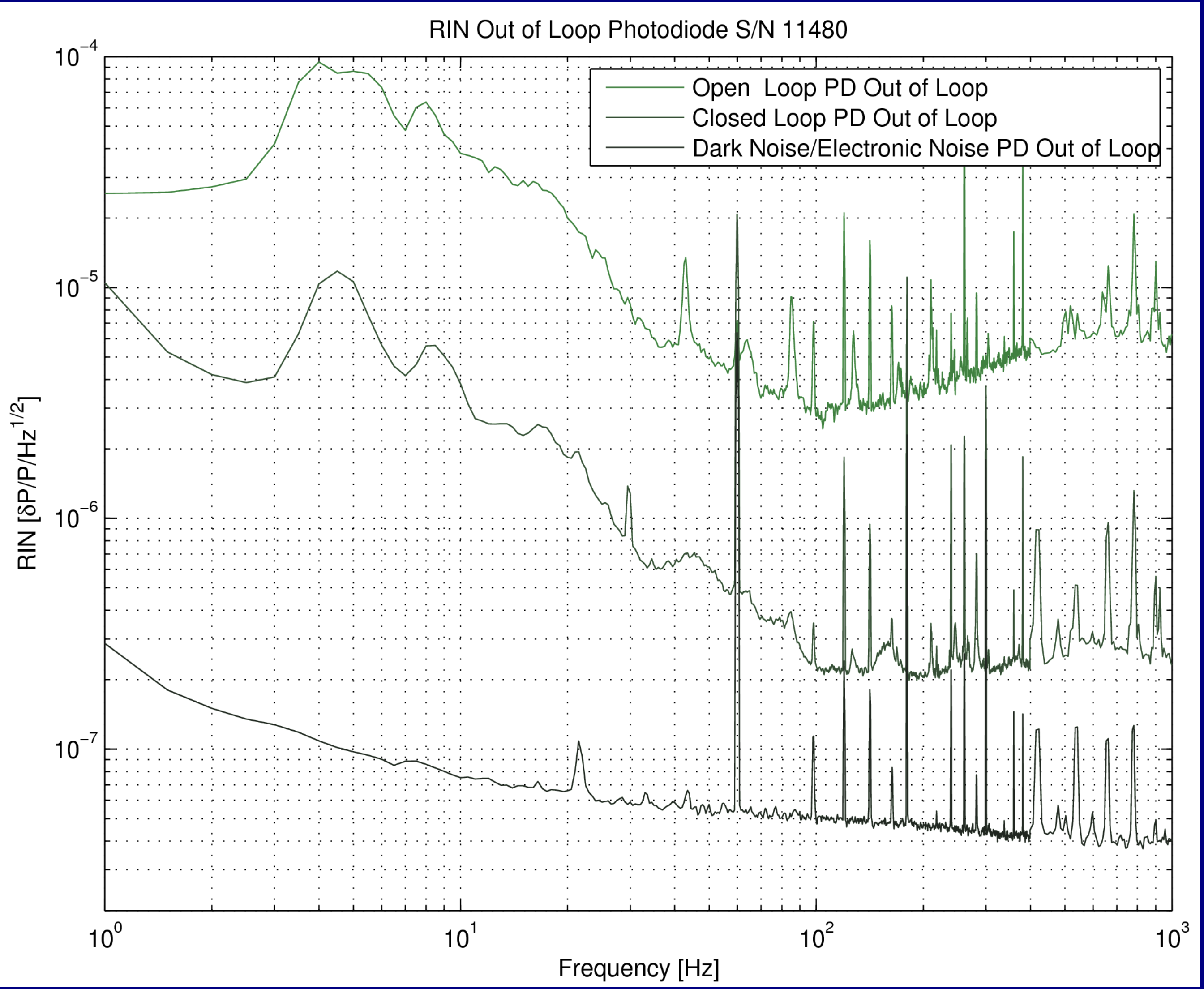
TCS-ISS Prototype: RIN Open & Closed Loop

- Out of the loop photodetector shows that apparently there is still room for improvement

- In loop gain is larger than the out of loop gain reduction

- Coherence between in loop and out of loop detectors is practically zero

=> Common noise seen by the two detectors have been already taken out the beam



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TCS-ISS Prototype: Noise Sources

Major Source of Noise

- Electronics, i.e. Sensor noise , amplifier noise, ..
  - not limited by the electronic noise
- laser jittering coupling of the acoustic a mechanical noise through the clipping or PD non uniform response,
- temperature fluctuations of the laser tube which can change the beam intensity or cause longitudinal mode hopping,
  - Power drift of DP/<P> ~ 5% for 12 hour period, more investigation needed to ensure the laser doesn't produce excessive noise.
- What else ?

TCS-ISS Prototype: Noise Sources Hunting

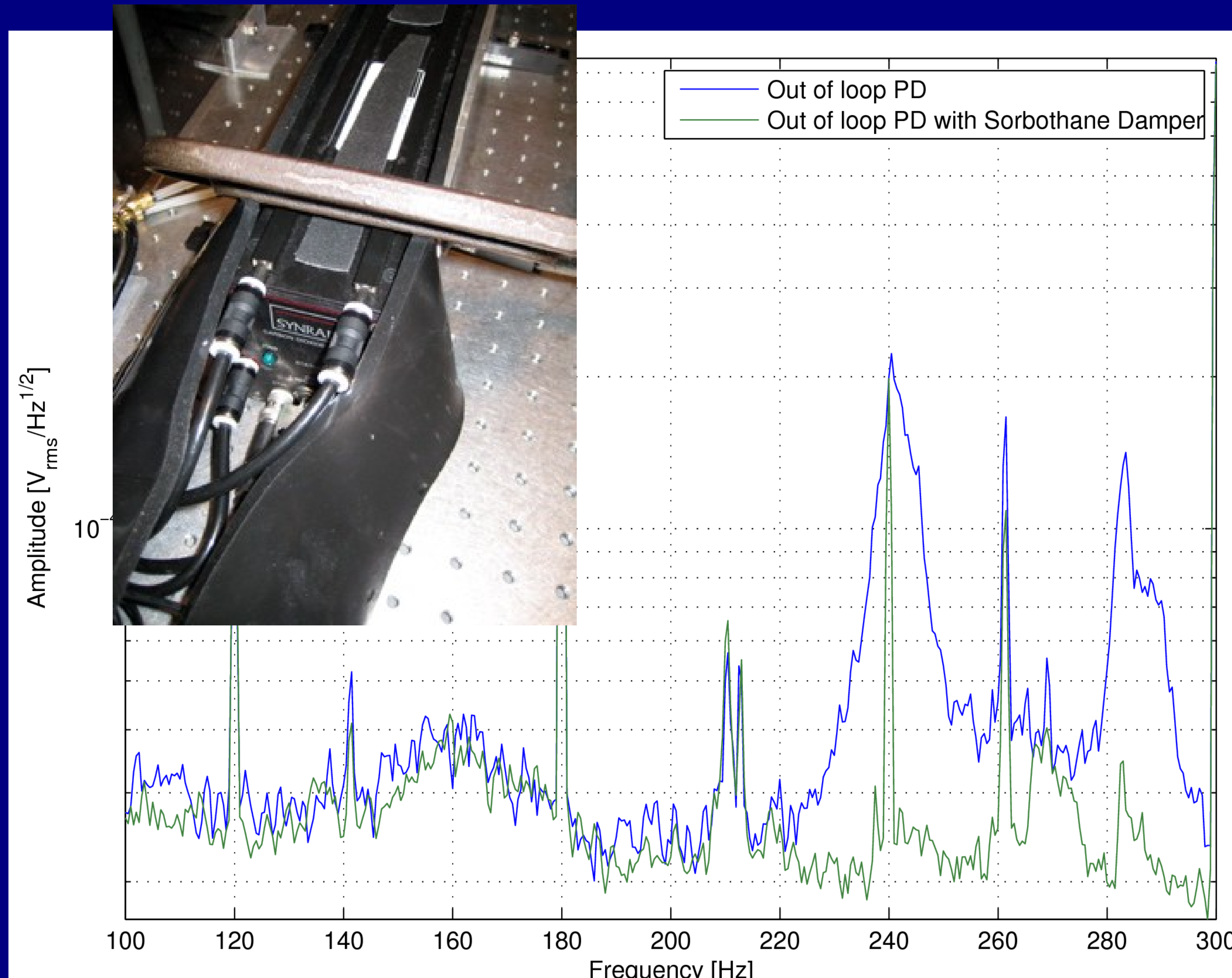
- Noise hunting philosophy: find and fix any 'show-stoppers' but leave detailed noise hunting for during installation.

- Some of the successful noise source hunting and reduction:
  - Beam clipping minimized, (1" optics sufficient) more investigation on the PD clipping is required,
  - Floating table reduced 10-80 Hz noise in shaky room (quieter LVEA floor should not need this).
  - Laser sandwiched with an elastomer (sorbothane),
  - Chiller moved moved to the room next to the optical table room
  - AOM driver also moved
  - Optical Table enclosed into a Plexiglas box

TCS-ISS Prototype: Sorbothane Effect

- Elastomer very effective to turn mechanical energy into heat due to its strong hysteresis.
- Claimed to be better than neoprene , rubber

- Kludged a jacket around the Laser using a couple of aluminum plates and three carpenter clamps.



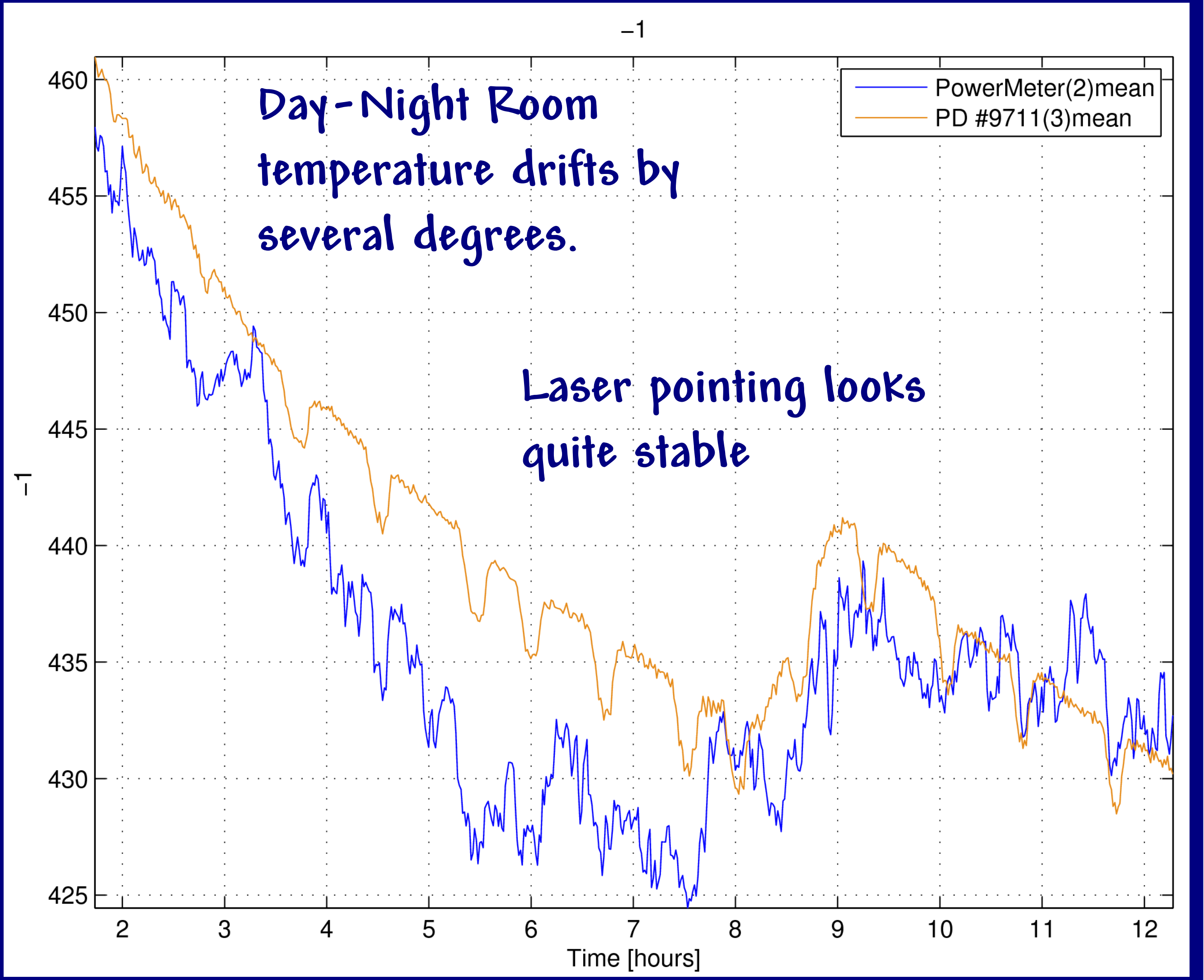
- Broad peaks about 240Hz and 287Hz are quite effectively damped (maybe modes were constrained more than damped)

TCS-ISS Prototype: Power Drift Free Running Laser

- Measurement done using a calorimeter and a HgCdZnTe photodetector.
  - $P_{out} \approx 35W$
  - $P_{DP} \approx 470mW$
  - $P_{cal} \approx 470mW$
  - $t_0 = 8{:}45PM$

- Some dips about every hour (not very well equi-spaced) of about 3mW (0.7% fluctuation)

- ~ 7% fluctuation of the power during night time



Possible explanation: chiller doesn't properly compensate temp. changes in the room Chiller has hiccups sometimes => source of the dips?

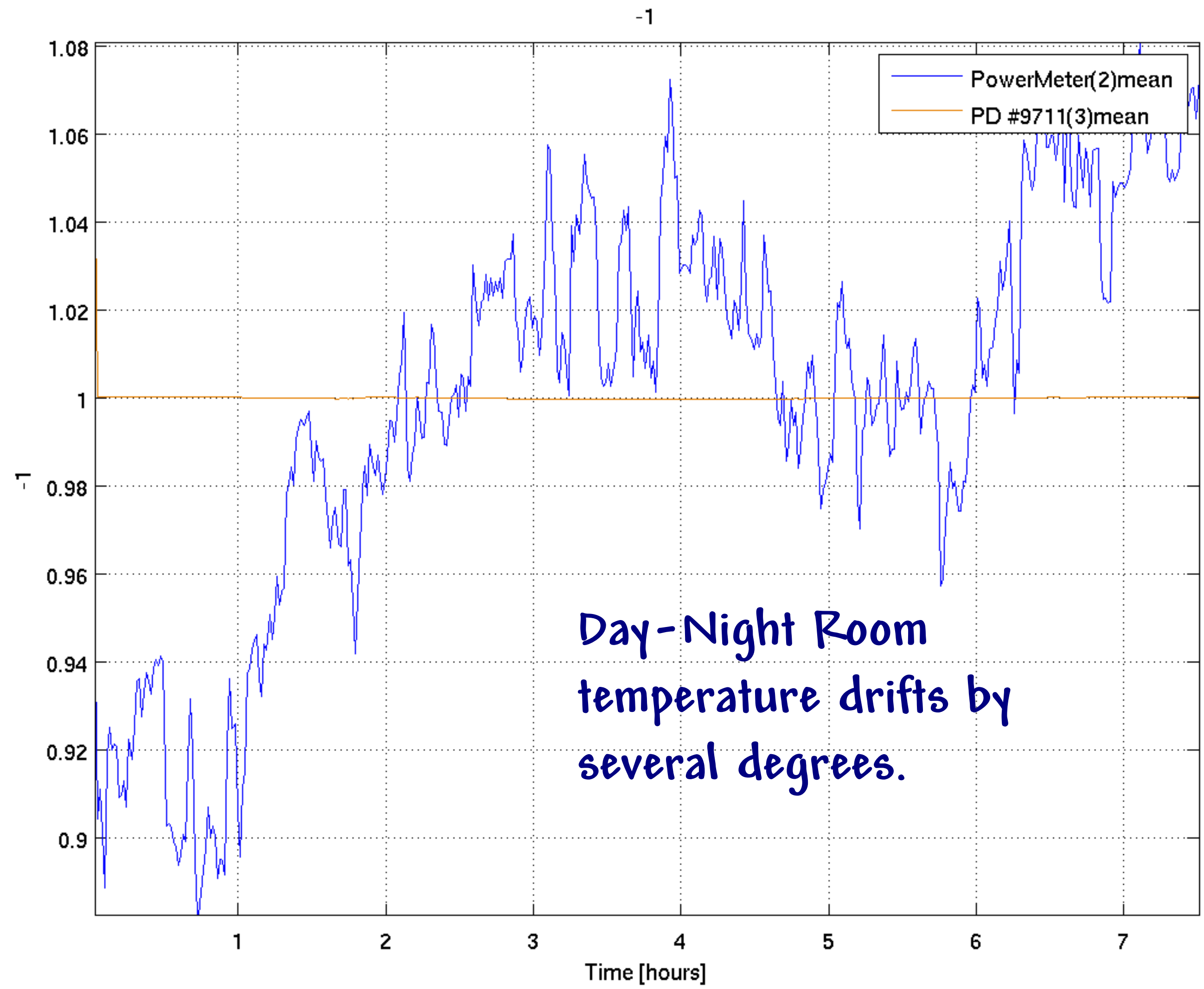
TCS-ISS Prototype: Power Drift Free Running Laser

- Measurement done using a Calorimeter and a HgCdZnTe Photodetector.
- No light impinging on the Calorimeter and the Photodetector

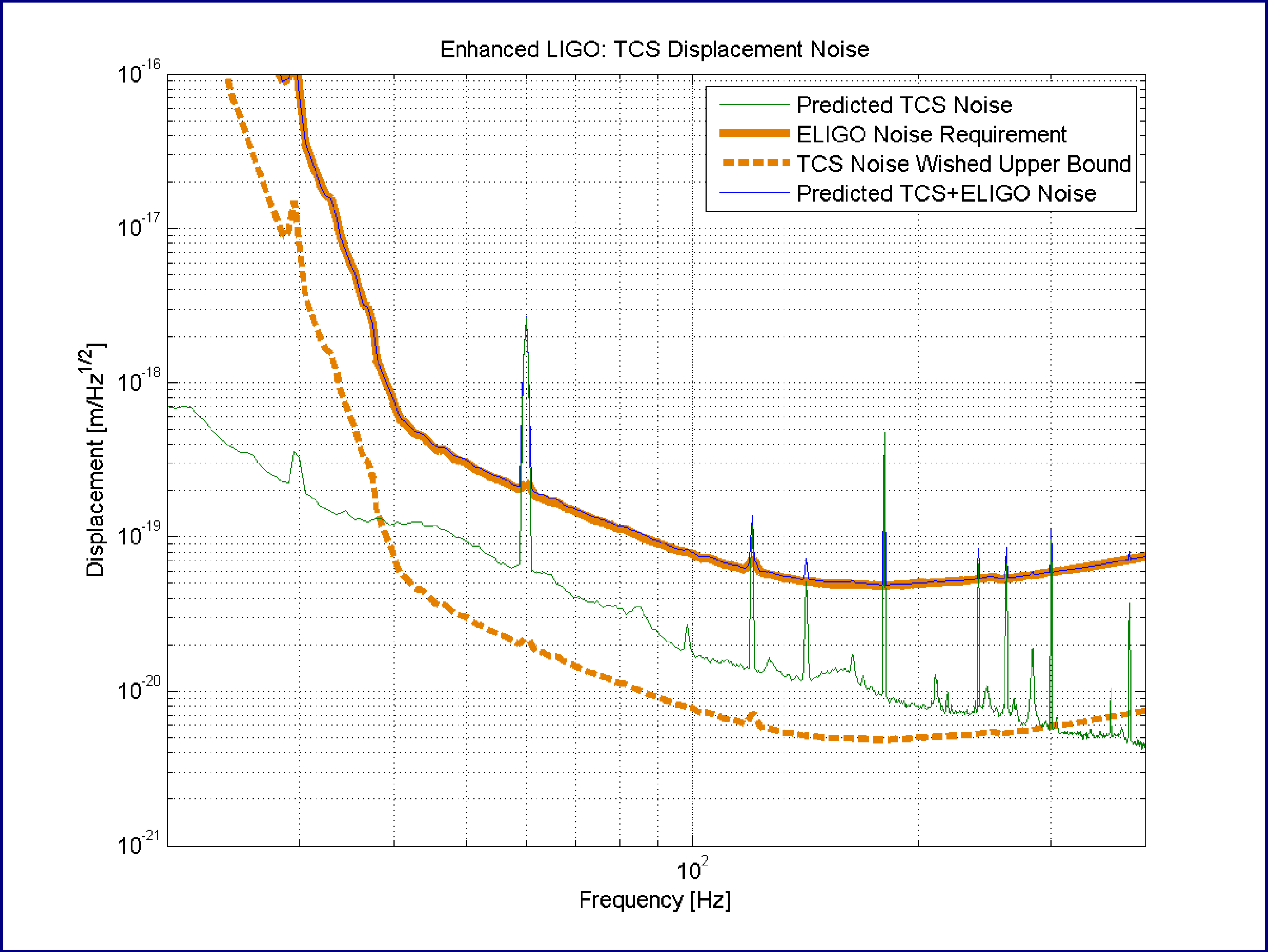
RESULTS

As expected, the calorimeter is more sensitive to temperature fluctuations than the Photodetector.

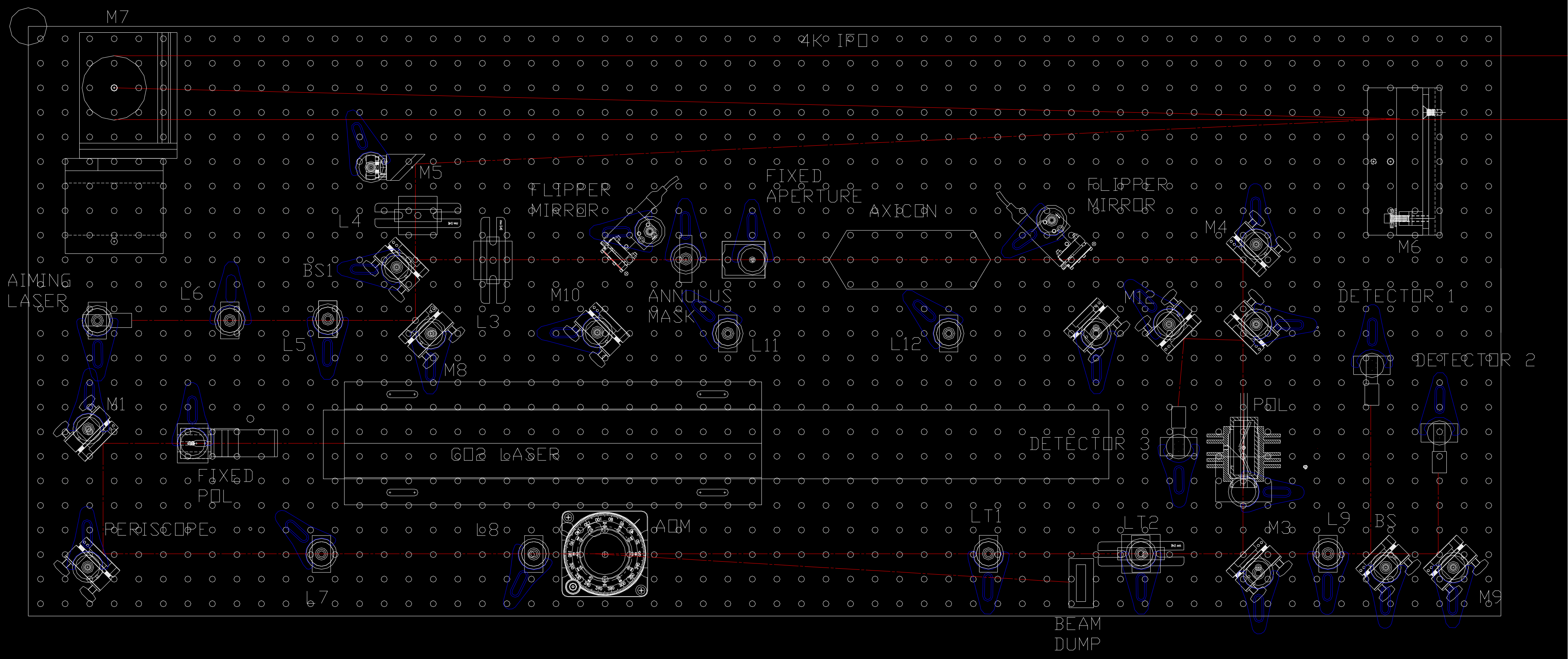
=> This should explain the power drift discrepancies in the previous plot.



TCS-ISS Prototype: TCS-IFO Noise Budget



TCS: Optical Layout for Enhanced LIGO



- Design recycles most of the TCS LIGO hardware,
- optical table dimensions: ~1500mm x 610 mm,
- enclosure to contain the beam will be probably made using bathroom tiles (we promise to use austere decorations and not flowery ornaments),
- no plans to suspend the optical table.

TCS: Installation & Commissioning

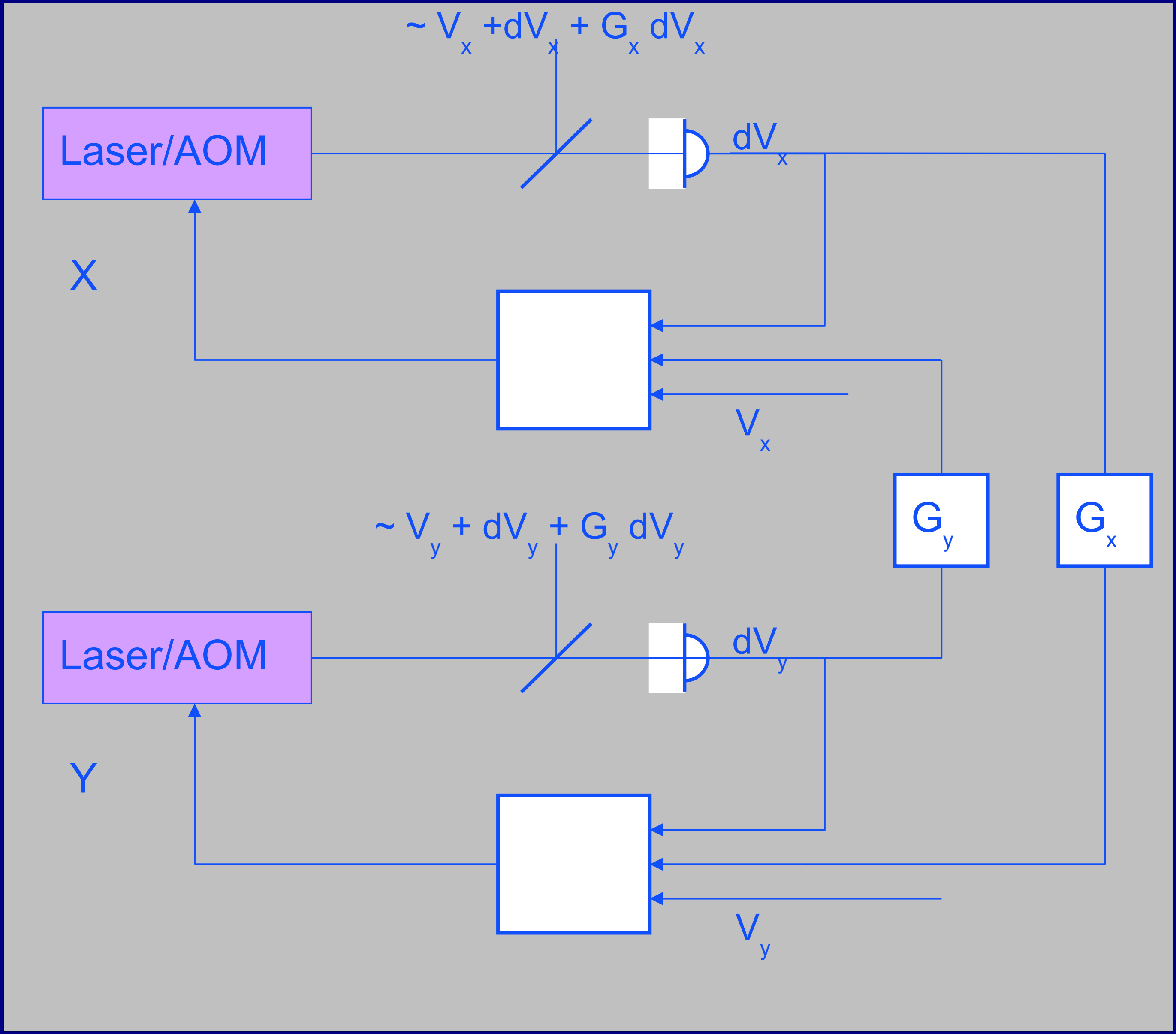
- Livingston
  - Installation: starting on March 24th (lasting ~2-3 weeks, starting on starting about a week from now).
  - Commissioning: nominally from April 4th to May 17th

- Hanford
  - Installation: nominally starting from April 18th to May 2nd (lasting ~2 weeks).
  - Commissioning: nominally from April 4th to May 17th

TCS: Possible Improvement, Intensity Noise CMR

- Basic idea: if TCS power noise is detector-limited, then let's use the CMR of the IFO by injecting the residual error signals into the IFO.

- Acting on the gains Gx and Gy, one should be able to cancel out to some extent the residual intensity noise.

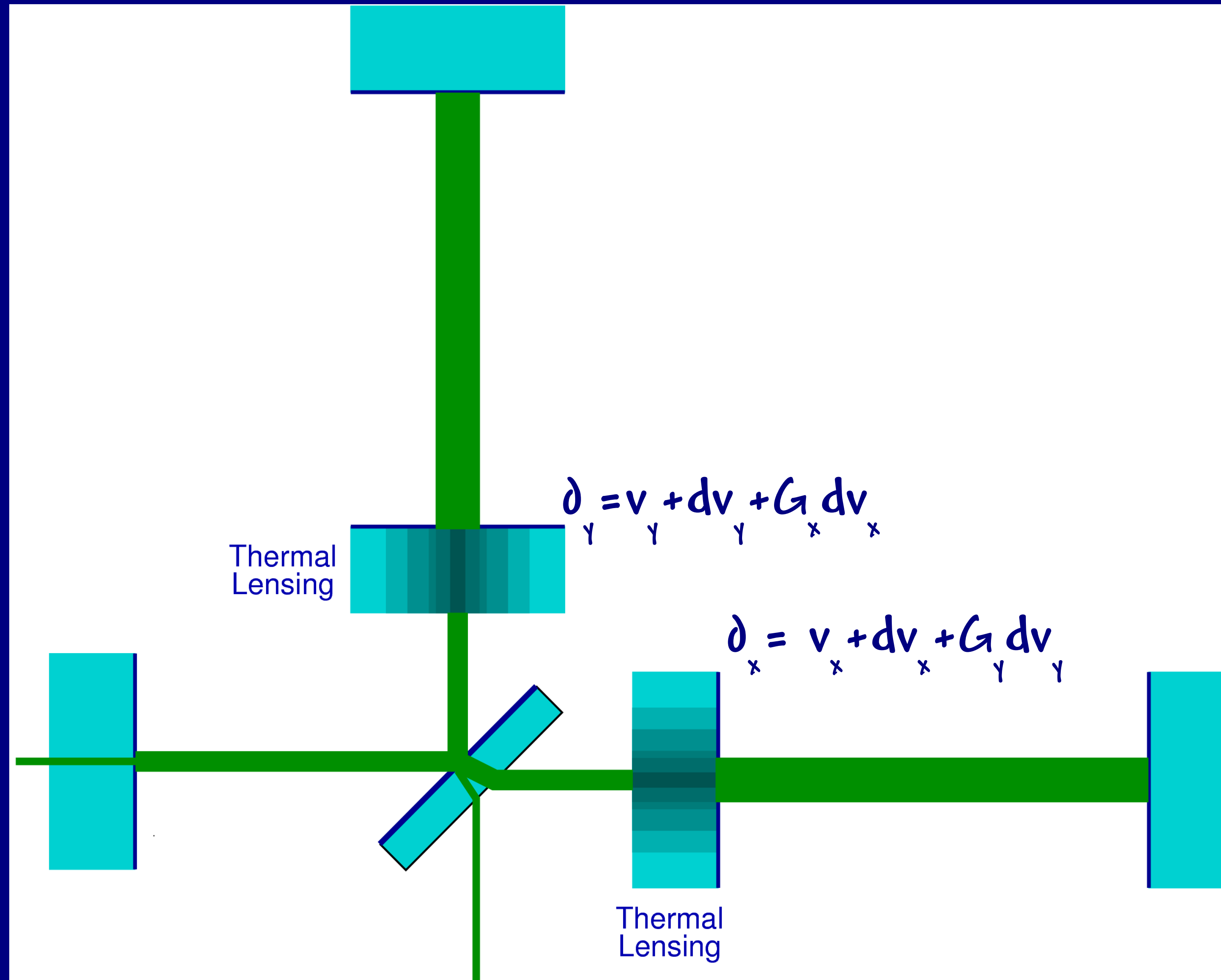


LIGO

TCS: Possible Improvement, Intensity Noise CMR

- Technique that requires only electronic feedback between the two TCS tables (no new optics) and can be held in reserve if we need better noise performance.

- (Certainly worth trying even if not necessary...)



$$dr = a_y v_y + dr_y + a_x v_x + dr_x - a_y G_x dv_x - a_x G_y dv_y$$