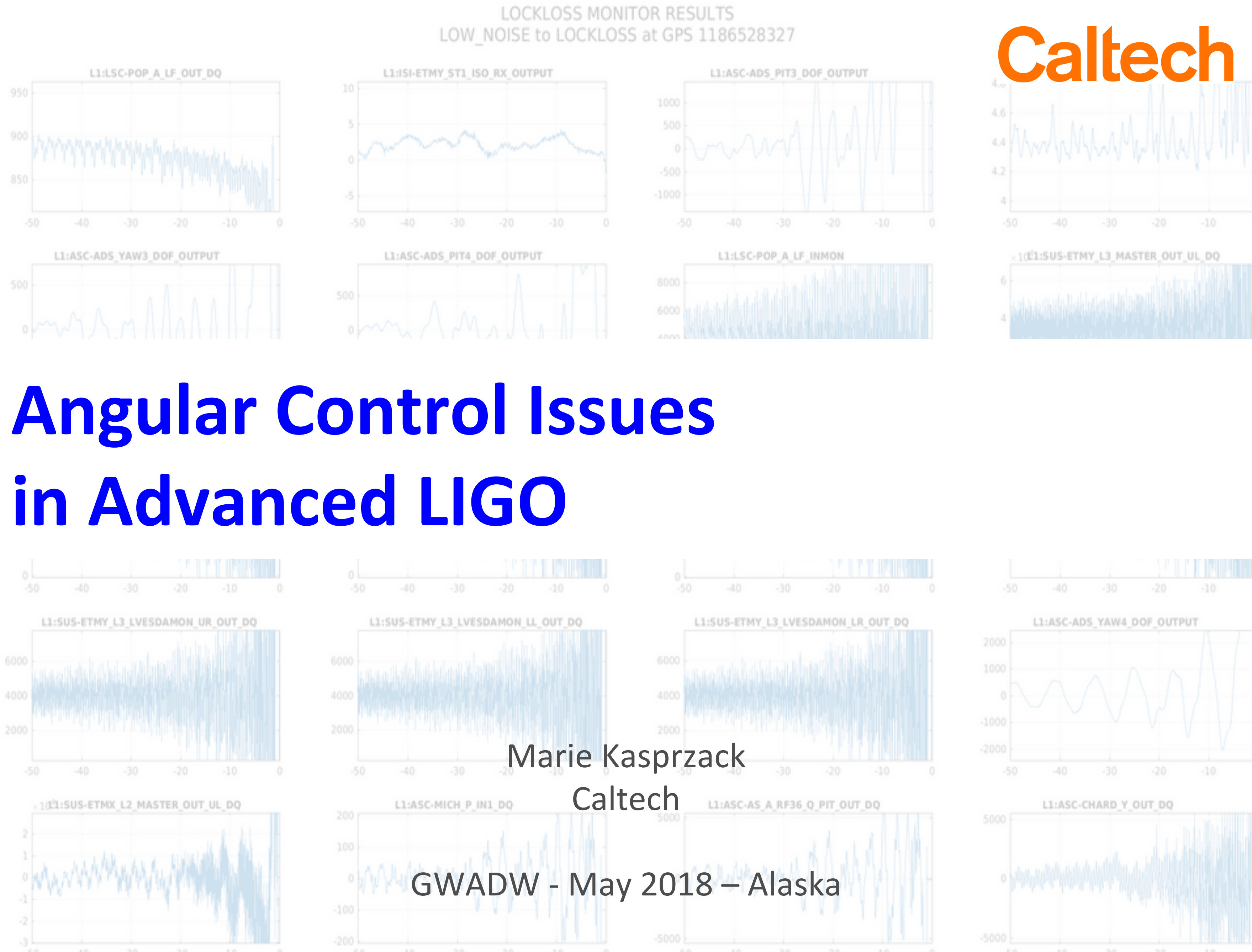


Caltech

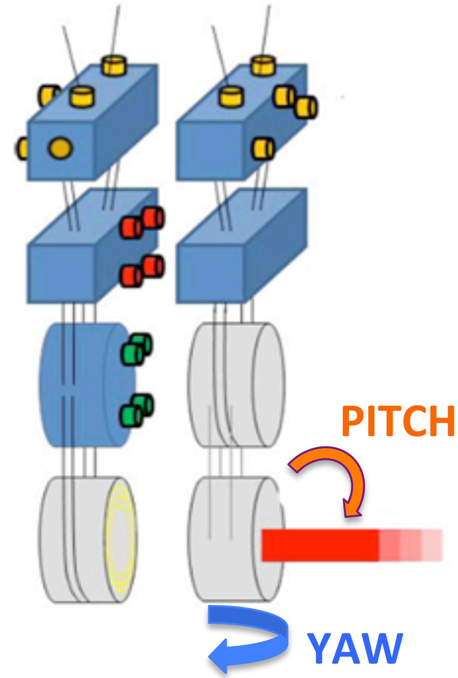
Angular Control Issues in Advanced LIGO

Marie Kasprzack
Caltech

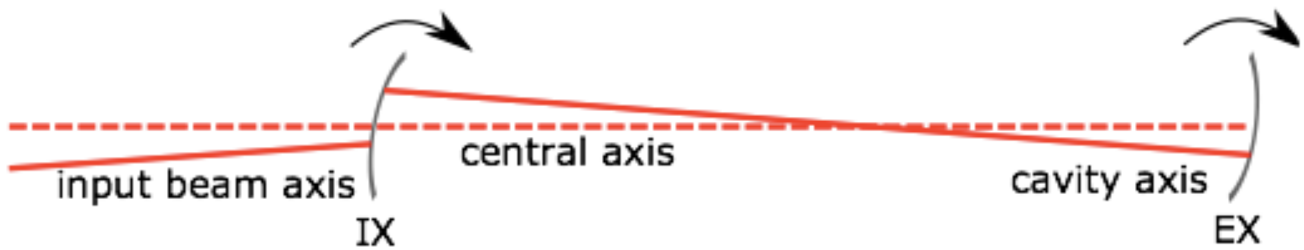
GWADW - May 2018 – Alaska

Angular Sensing and Control

- The main optics of the aLIGO detectors are suspended
  - 2 stages of seismic isolation + 4 stages pendulum
  - PITCH ≈ 3-5 YAW motion



- The cavities have to be **actively aligned**:
  - To maximize the power build-up in the cavities
  - To minimize the geometric losses



D. Martynov [1]

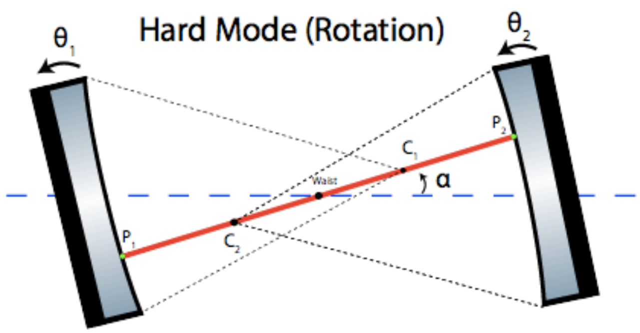
aLIGO arm geometry:

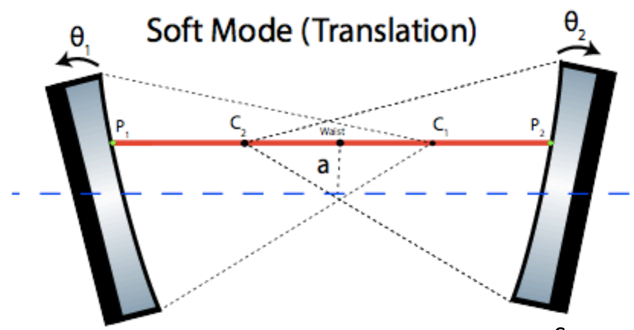
angular axis motion is x10 the angular motion of the test masses

Angular Sensing and Control

- Radiation pressure creates additional torque : $\tau = \hat{K}_{opt}(g_1, g_2, L, P)\begin{pmatrix} \theta_1 \\ \theta_2 \end{pmatrix}$

- Each arm cavity can therefore be treated as a unit with two orthogonal modes:





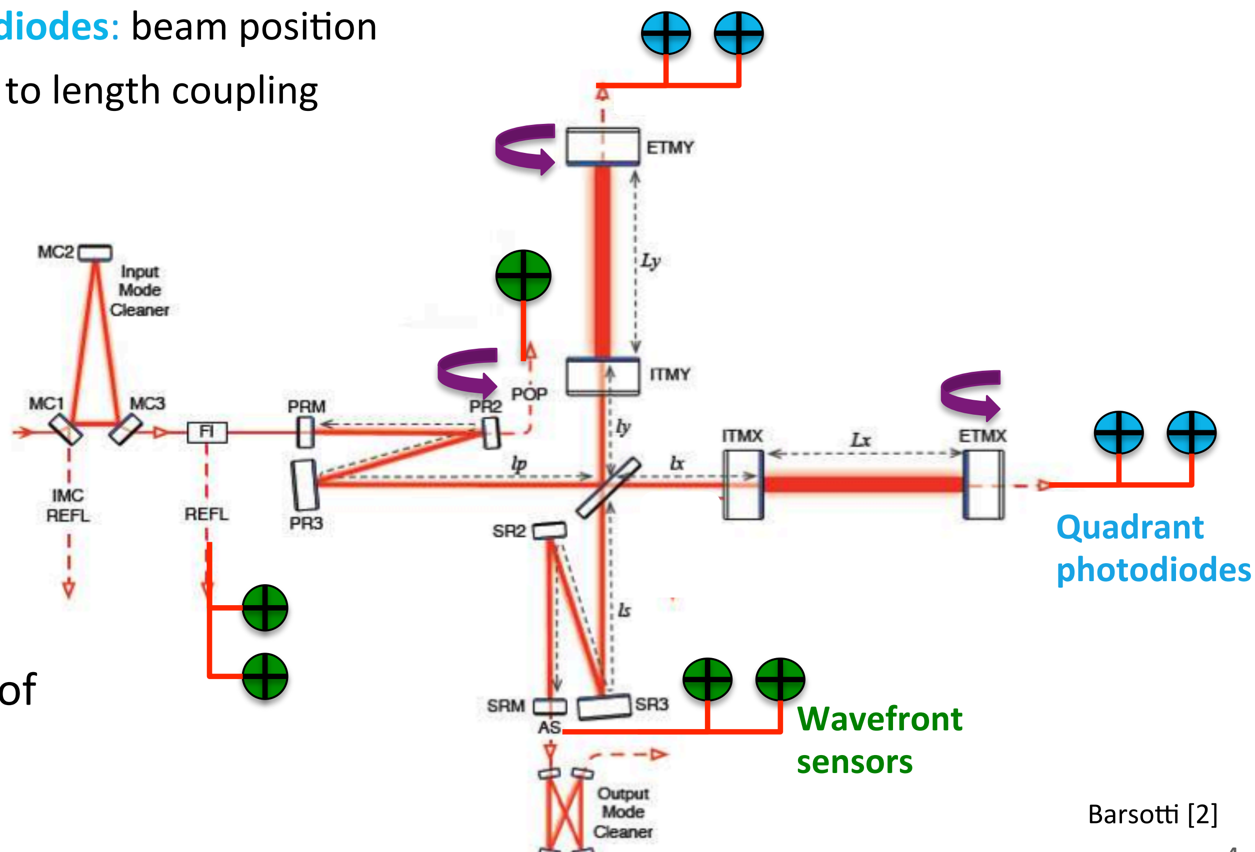
Seymour [3]

4 modes of angular motion: **CHARD, DHARD, CSOFT, DSOFT**

- During O2, the intra-cavity power was about 105-110 kW

Angular Sensing and Control

- Alignment signals, acquired with dedicated sensors, are filtered and fed-back to the mirror coil-magnet actuators to keep the mirrors aligned
- Three types of sensing:
  - **Wavefront sensors**: demodulated signals from RF sidebands (9, 36 and 45 MHz)
  - **Quadrant photodiodes**: beam position
  - **Dithering**: angle to length coupling
- 2x9 angular loops



Simplified overview of Advanced LIGO

Barsotti [2]

ASC performance

- ASC should maintain a residual angular motion of the arm cavity mirrors at ~ 1 nrad RMS in order to meet the aLIGO sensitivity target [2]

- **Control up to few Hz is challenging and directly impacts the interferometer**:

  - **Stability:** Duty cycle reduced by the lock losses
    - Impact from environmental conditions
    - Radiation Pressure instability

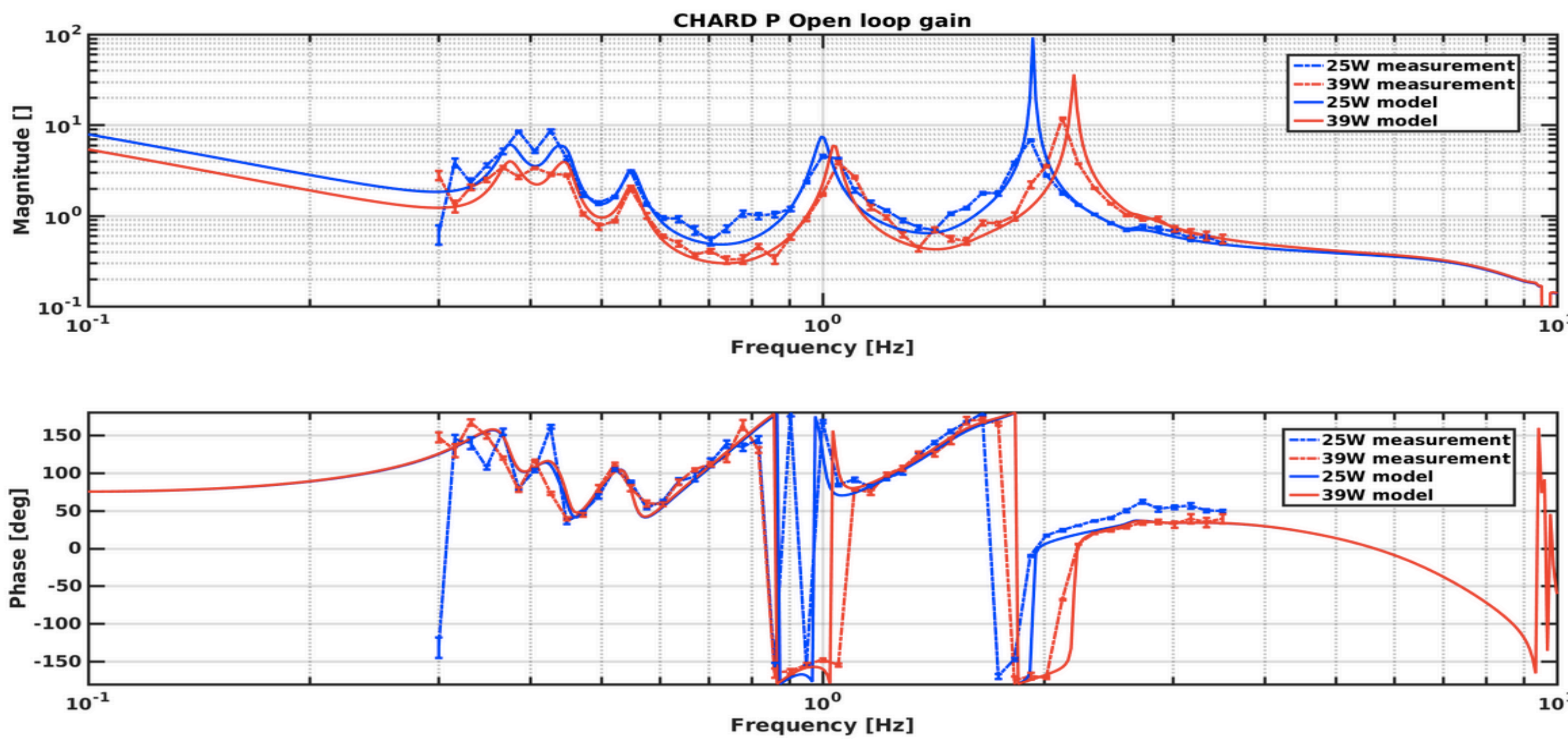
  - **Noise:** Sensitivity compromised by the coupling to DARM
    - ASC can couple linearly or bi-linearly to length
    - Limiting the low frequency of the observing band
    - Searches impacted by the glitches

Power increase in the arms

For the next runs of ALIGO, increase of the power in the arms:

But the plant changes with power:

- shift in the resonance frequency
- The overall gain is decreasing

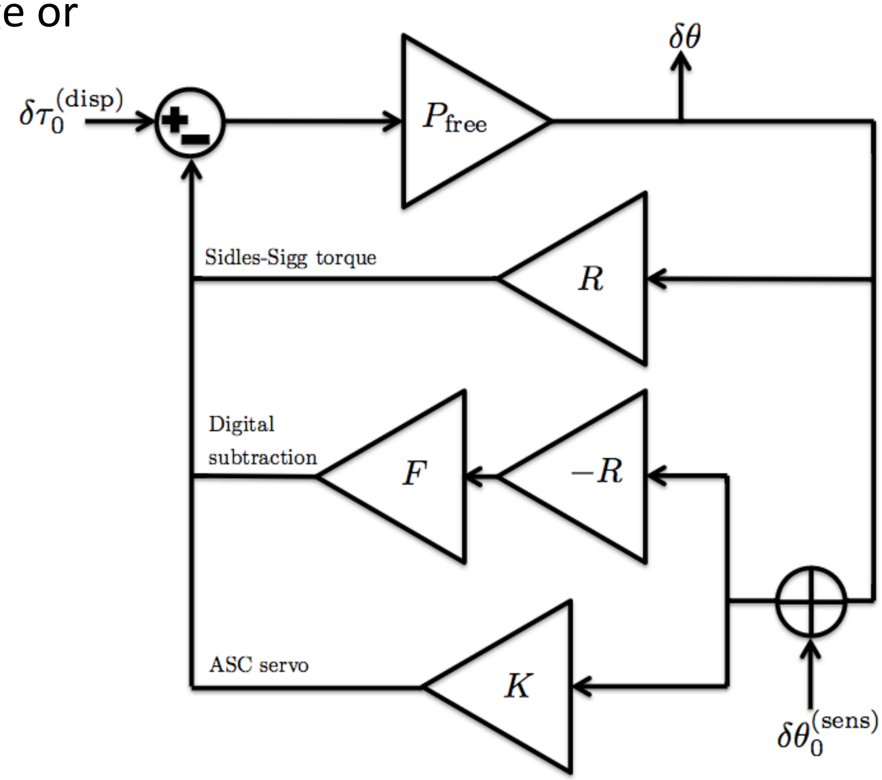


Good agreement between measurements and model → we know the plant

Power increase in the arms

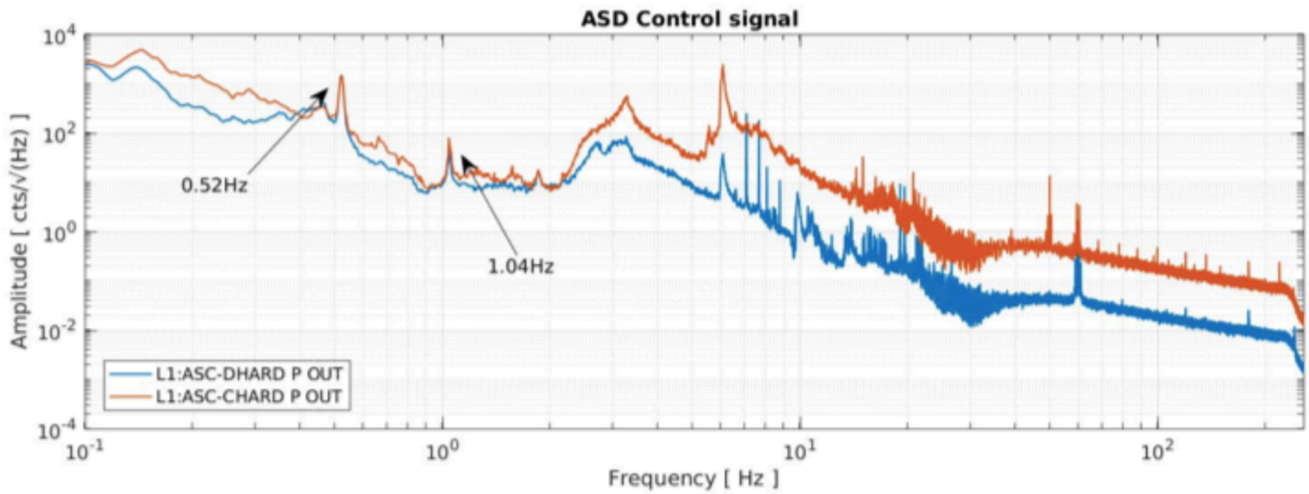
Stable at all frequencies but we have to:

- tune the filters for each power or
- Design filters stable for the power range or
- make the plant power independent :
  - digitally compensate for the power dependent plant
  - → See Hang talk

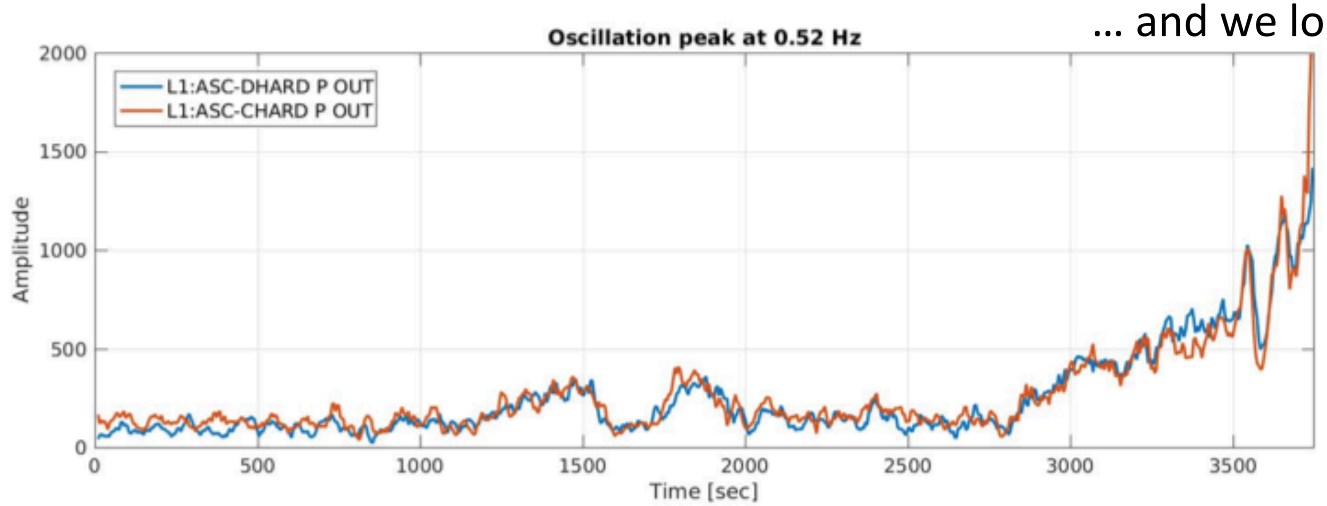


Power increase in the arms

However we see an unforeseen 0.5 Hz soft radiation pressure oscillation:



… and we loose lock!



Power increase in the arms

0.5 Hz soft radiation pressure oscillation:

- First seen at LIGO Hanford in 2015, then at LLO
- From a spurious dependence of circulating power on the beam spot position

Mechanism:

Radiation pressure torque
from miscentered beams:

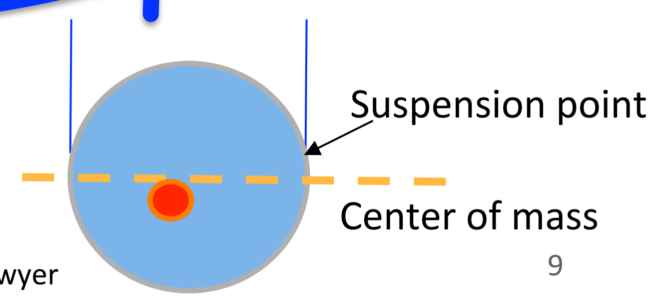
beam spot motion from HARD/SOFT modes
$= -4.8 \times 10^4$ [m/rad] for CHARD;
$= 2.1 \times 10^3$ [m/rad] for SOFT.

DC miscentering

Power fluctuations: $dP/d\theta$

→ changes radiation pressure
→ moves length

Longitudinal force cross couples to pitch because suspension fibers attach above center

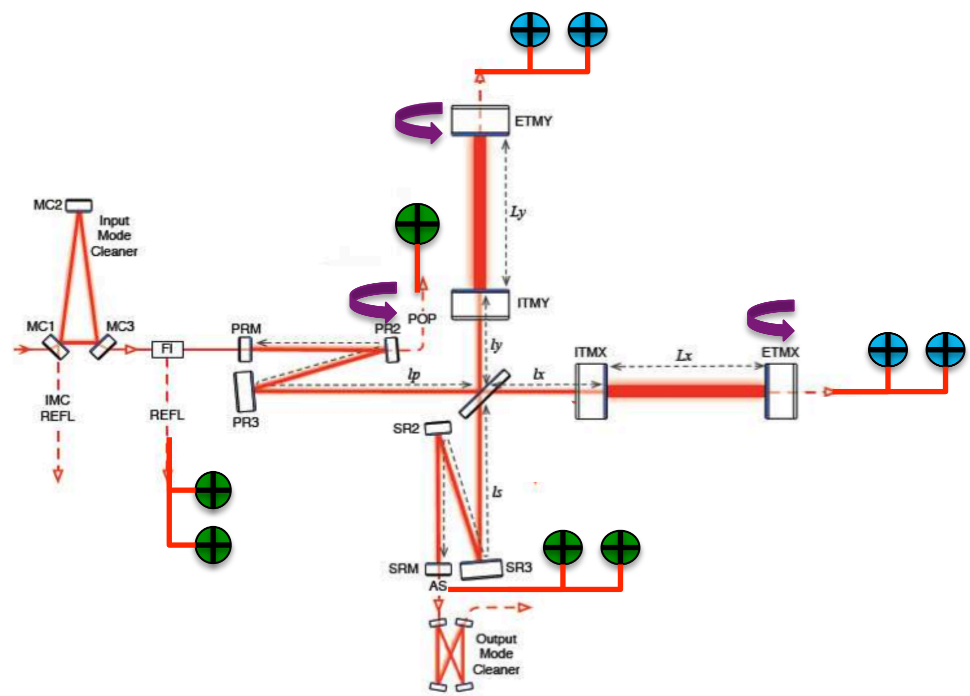


Dwyer

Power increase in the arms

0.5 Hz soft radiation pressure oscillation can be suppressed or reduced:

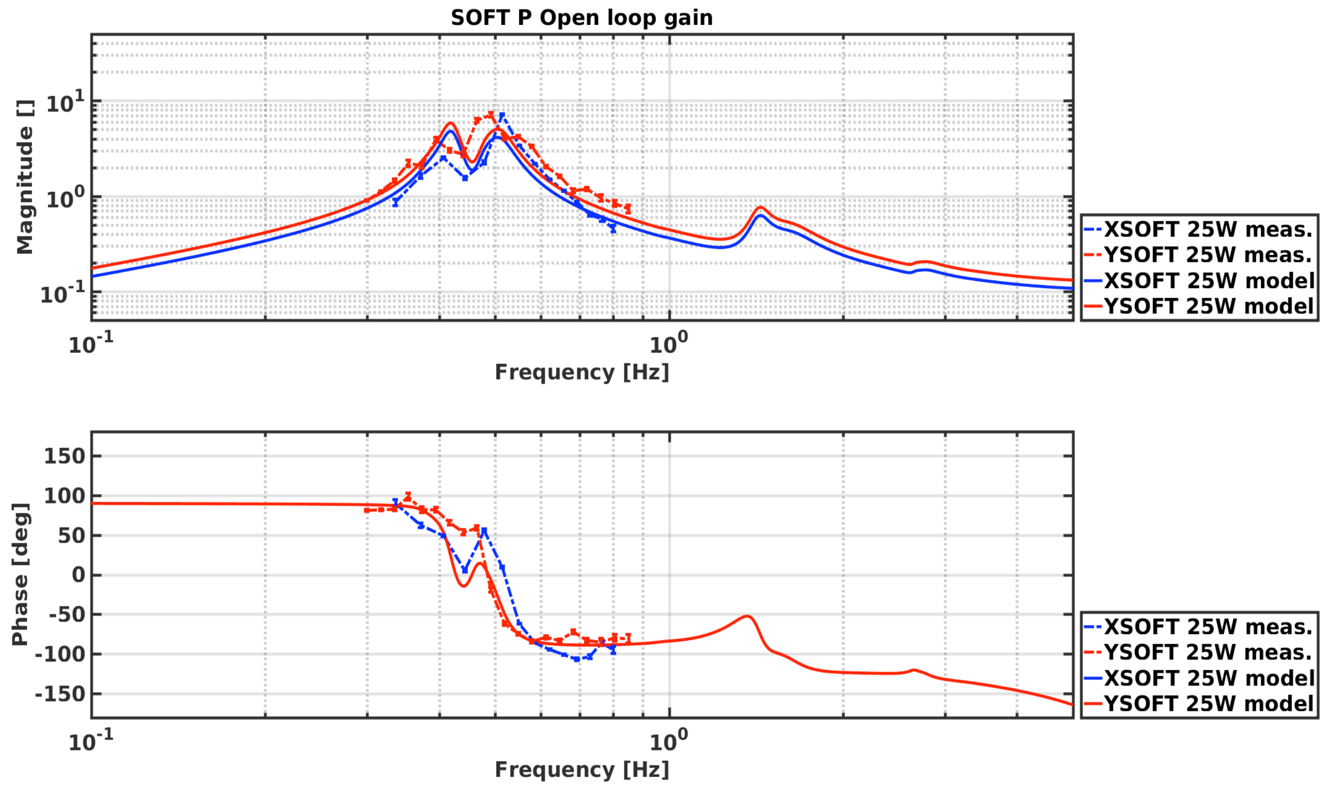
- Controlling CSOFT pit using the transmission of the arms
- Optical lever damping
- Changing coupling from spot position to circulating power
- Feedback to laser intensity to stabilize arm powers



Power increase in the arms

- Tested solution at LLO:

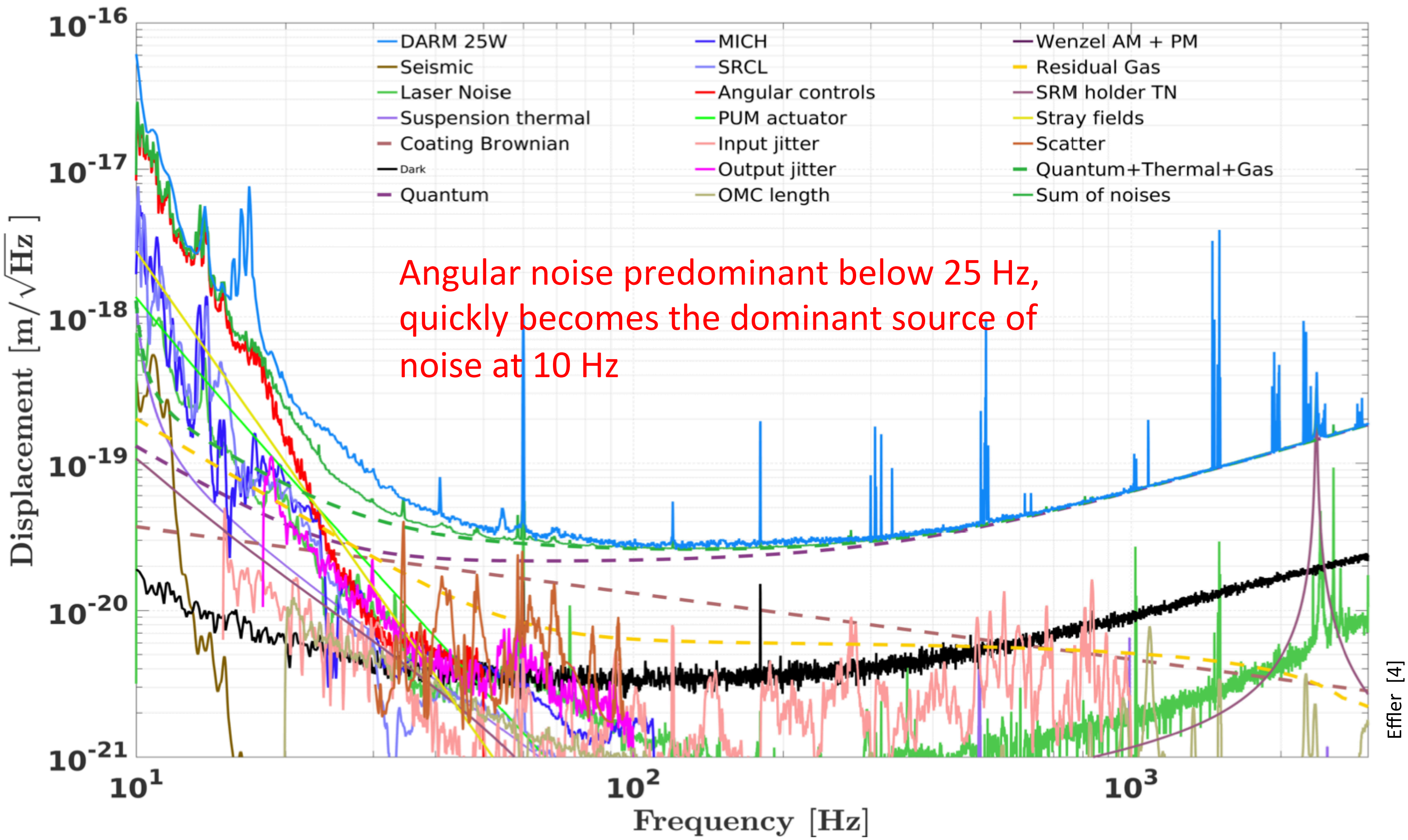
Extra damping with the arm transmission QPDs



Up to date: 14 hours of lock at LLO with ~ 170 kW in the arms

We need to reach stability at 50 W input → seems achievable

Impact of the angular performance in O2



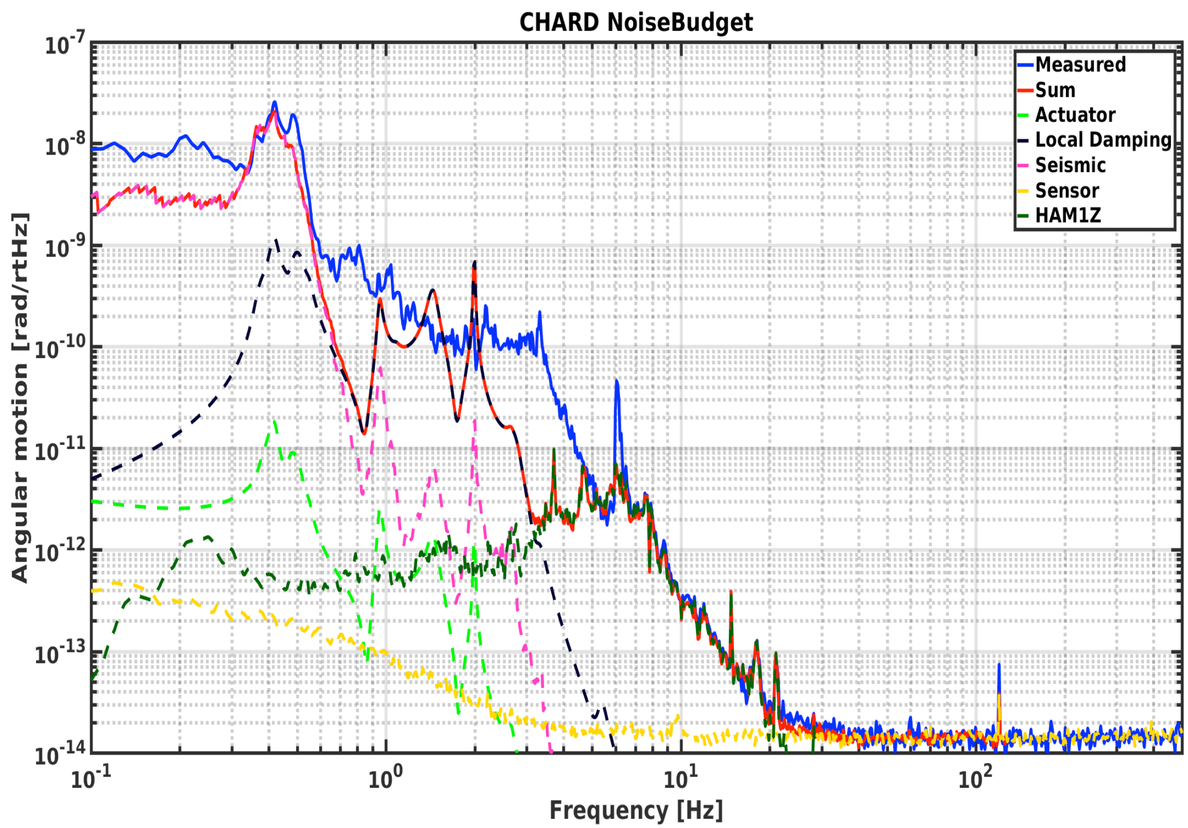
Design expectations: factor 10 below DARM [3]

Noise

- Challenge for the control:
  - control of the arms up to few Hz
  - Then aggressive cut-off to minimize the impact on DARM

- Noise sources :
  - seismic motion
  - longitudinal control
  - thermal drifts
  - sensor noises
  - radiation pressure

- Excess Noise in CHARD P



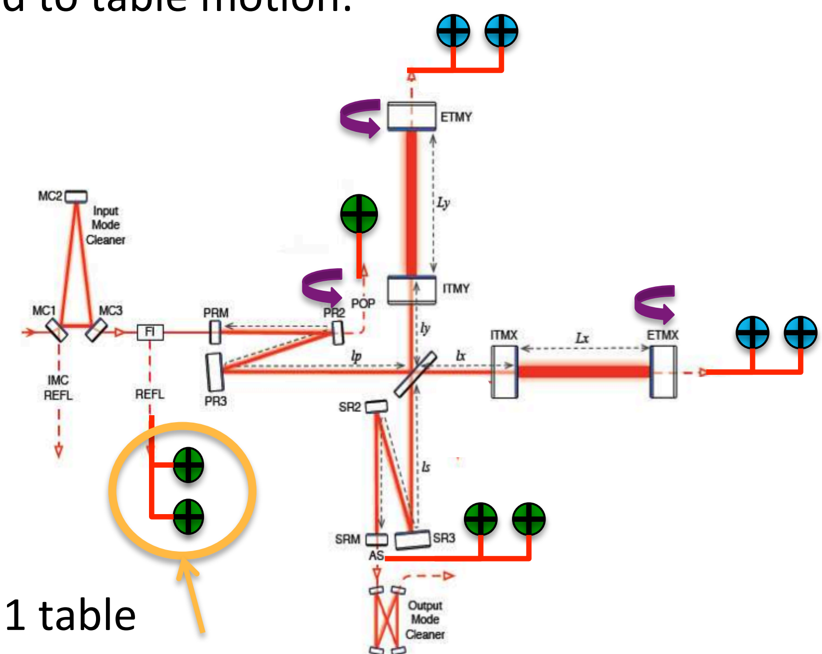
Excess noise

- Excess noise in the CHARD sensors correlated to table motion:
  - Experienced at both sites

Mitigation strategies:

- Reduce the noise

- Reduce the coupling
  - feeding forward the motion of the HAM1 table
  - Blending



Sensors for CHARD on HAM1 table

- LLO worked on reducing the noise and then the coupling via FF
- LHO has the same problem but also a solution to reduce the coupling

→ to be tested soon at LLO

Pele [6]

SRM control

- Loop does not reliably work:
  - Very slow loop
  - we can sometimes close it, sometimes not

- Sensing issue:
  - Sensing matrix measurements indicate that the coupling should be better with the new SRM but it is not the case
  - Pollution by high order modes
  - Sensor sensitive to beam spot position

- New scheme:
  - Use an additional sensor at LLO? → but needs DC centering work
  - New frequency (72 MHz) to be tested at both observatories soon.

Issues to solve and Conclusion

- We have several issues ahead to solve:
  - Oscillation shifting down with higher circulating power
  - Sensing noise
  - Cross coupling
  - Loop control for SRM
- Angular coupling is still one of the main limits at low frequencies for the detectors
- Investigations are on-going to reduce the noise/coupling
- New challenges ahead for the future runs:

  How do we plan for them : Better/More sensors? Optimal control ? …

  We need more work force in this topic

References

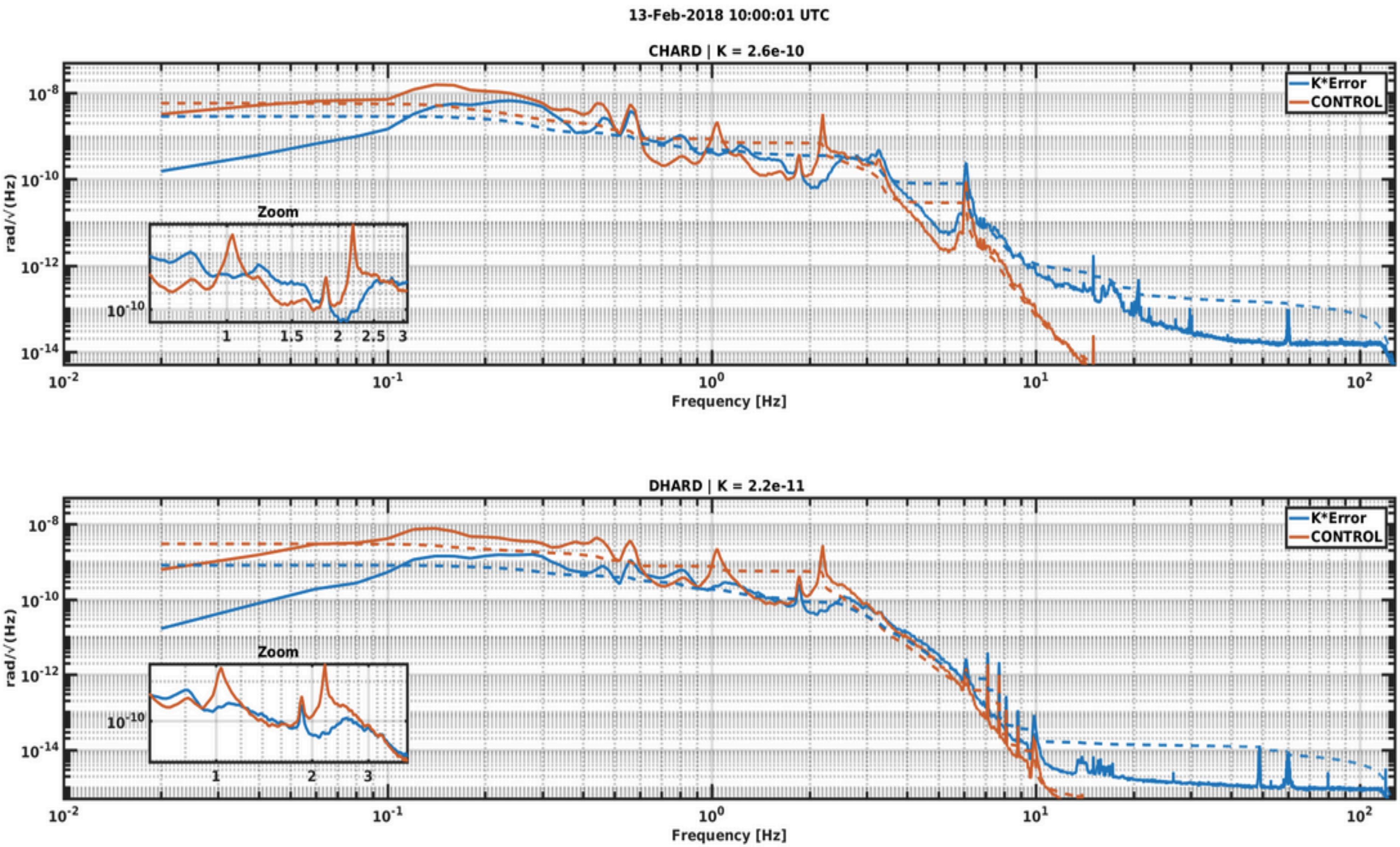
1 D. Martynov, *"Lock Acquisition and Sensitivity Analysis of Advanced LIGO Interferometers "*

2 L. Barsotti, *"Modeling of Alignment Sensing and Control for Advanced LIGO"*

3 B. Seymour, *"Non-Linear Angular Noise Coupling into Differential Arm Length"*

4 https://alog.ligo-la.caltech.edu/aLOG/index.php?callRep=33552

Lock at 40 W – Angular motion suppression



REFL WFS noise

A coupling similar to L1 is observed at H1 for REFL WFS