LIGO
Commissioning Report

LSC Meeting, Hanover

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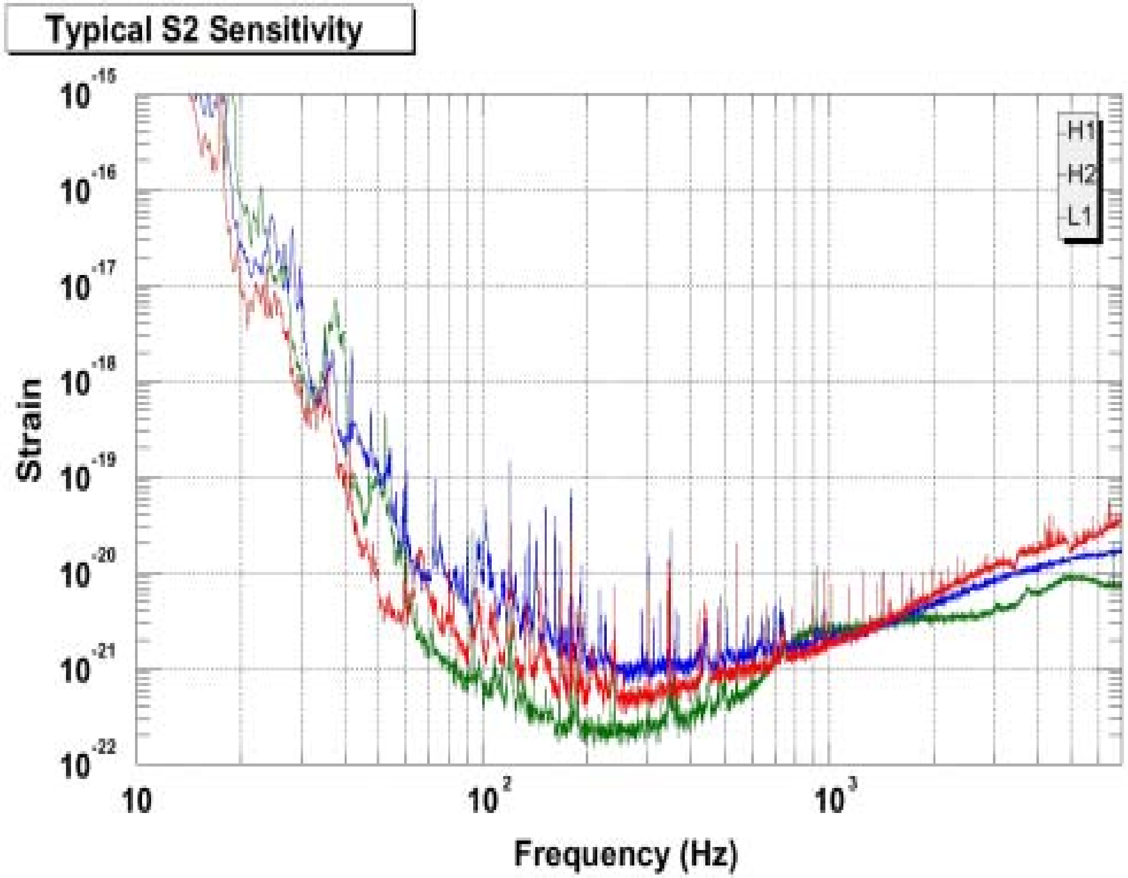
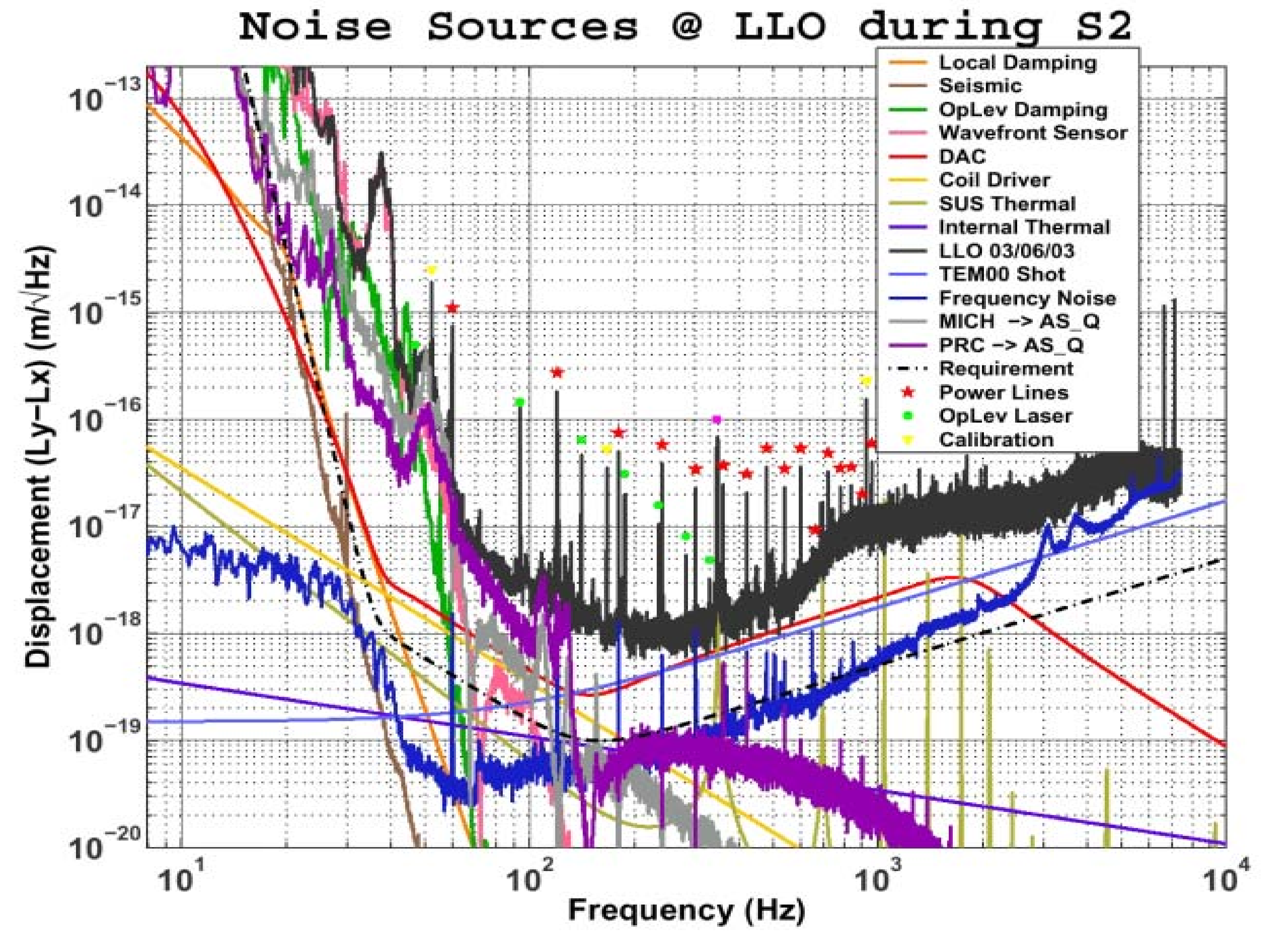
LIGO-G030433-00-Z

Starting point: 2nd Science Run

- **Inspiral Sensitivity**
  - L1: ~900 kpc
  - H1: ~350 kpc
  - H2: ~200 kpc
- **Duty cycle**
  - L1: 37%
  - H1: 74%
  - H2: 58%
  - Triple: 22%





Noise Sources @ LLO during S2
Local Damping
Seismic
OpLev Damping
Wavefront Sensor
DAC
Coil Driver
SUS Thermal
Internal Thermal
LLO 03/06/03
TEM00 Shot
Frequency Noise
MICH -> AS_Q
PRC -> AS_Q
Requirement
Power Lines
OpLev Laser
Calibration
Displacement (Ly−Lx) (m/√Hz)
Frequency (Hz)
10^{-13}
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}
10^{4}

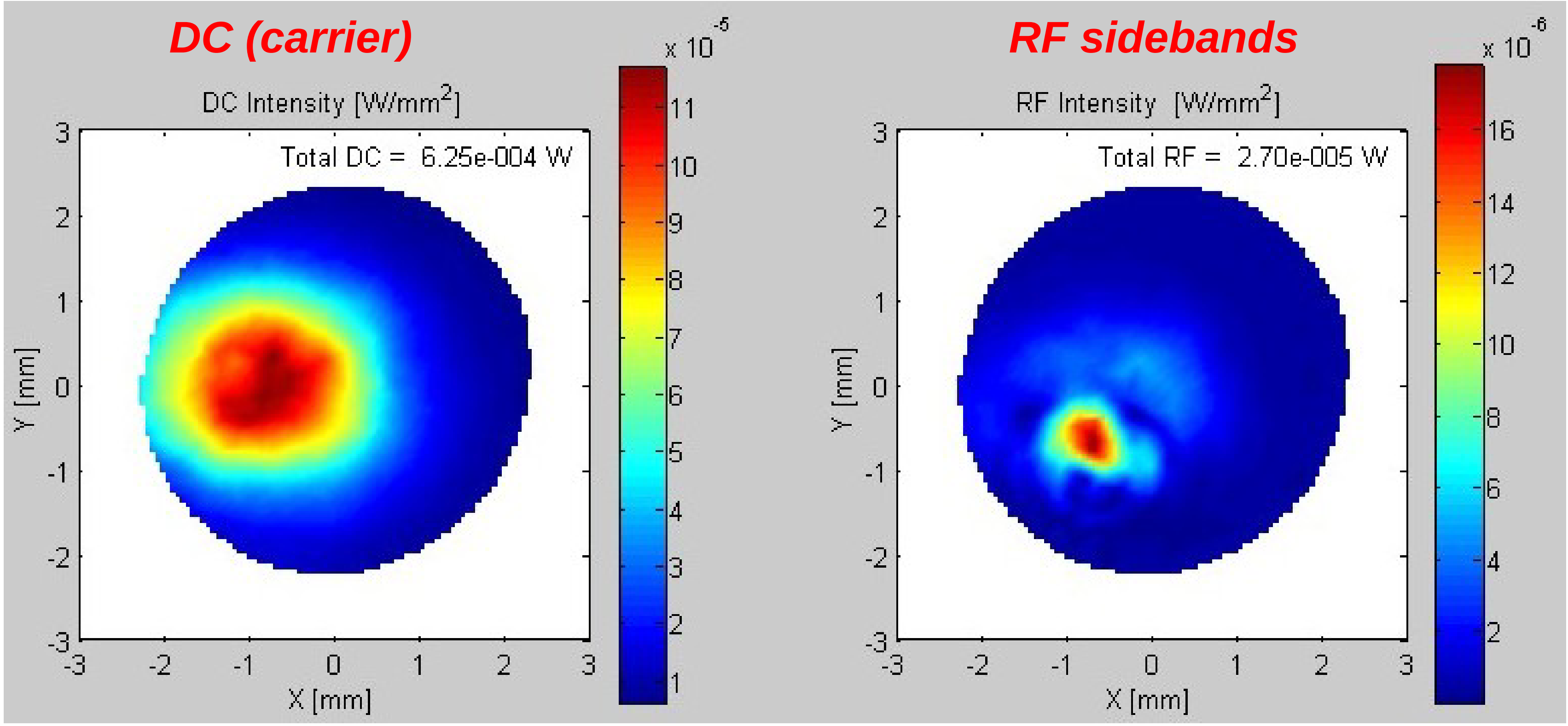
Major commissioning tasks for the S2:S3 interim

- Increase the effective laser power
  - S1-to-S2: increased AS port detector power approx. 30x – still not all
  - Increase input power – achieve thermally lensed, stable PRC
- Mitigate acoustic coupling at detection ports
  - Combination of improved acoustic isolation; reduction of acoustic noise sources; reduction of physical coupling mechanisms
- Continue implementation of wavefront sensor (WFS) alignment control
  - Achieve the control and stability H1 had during S2 for all three ifos – full implementation still post-S3
- Fix in-vacuum problems
  - Each ifo: takes approx. 4 weeks of full ifo time out of the 22 wks avail.

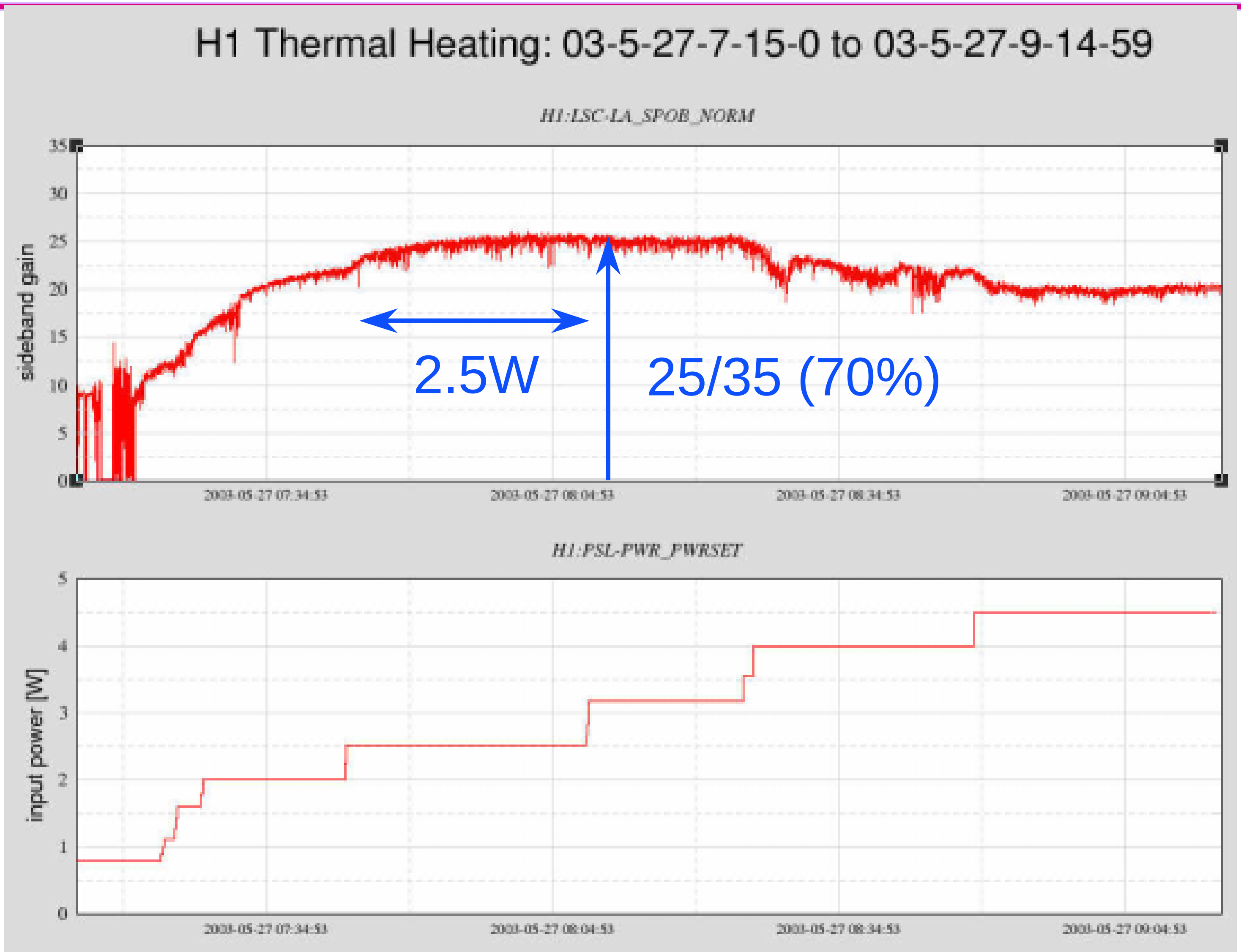
Motivation for increasing input power: recycling cavity degeneracy

- RF sideband efficiency is very low
  - H1 efficiency: ~6% (anti-symmetric port relative to input)
  - lack of ITM thermal lens makes $g_1 \cdot g_2 > 1$
    unstable resonator: low sideband power buildup

Bad mode overlap!



Thermal Lensing Investigations

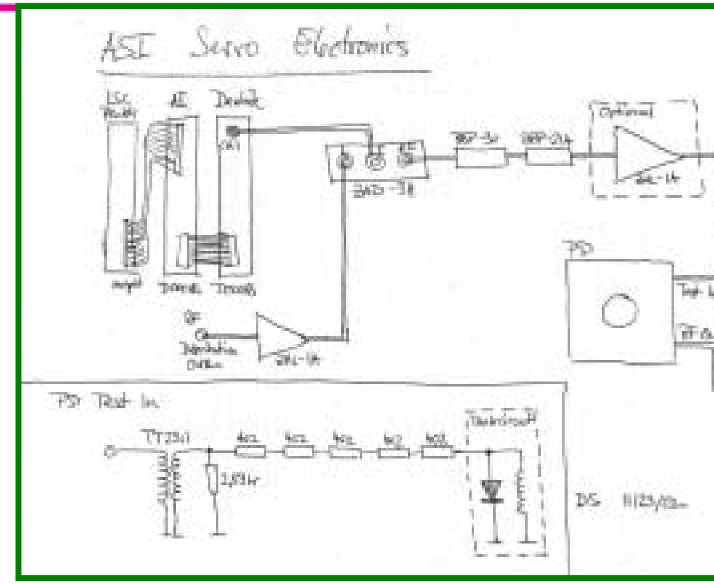


SB gain turns over before reaching the expected value of 35: asymmetrical thermal lensing?

For now (S3), H1 operates at 2.3 W input

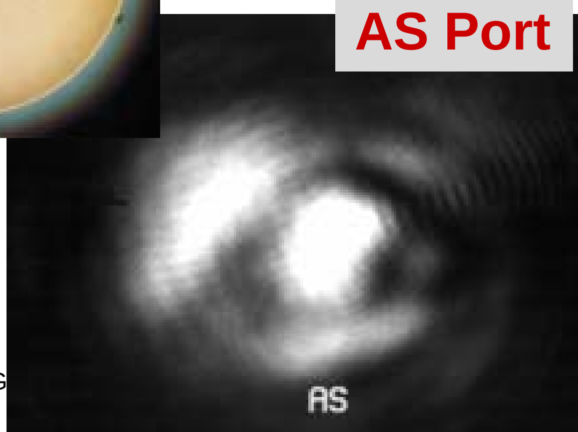
Getting to high power: *optical gain increase for LSC Photodiodes*

- ❑ Dynamic range problem: 1000x
  - ➢ Locking ~100 µA / running ~100 mA
  - ➢ Separate PDs for locking (low power) and running (high power)
  - ➢ Remote dial for laser power



ASI Servo

Diodes can be damaged by high power pulses



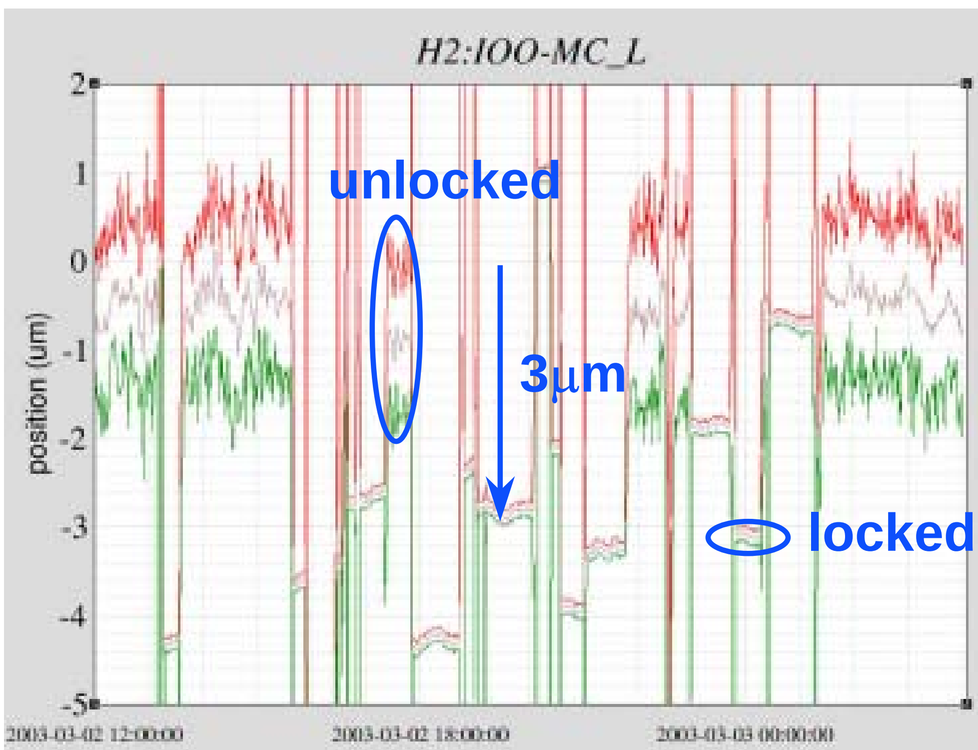
AS Port

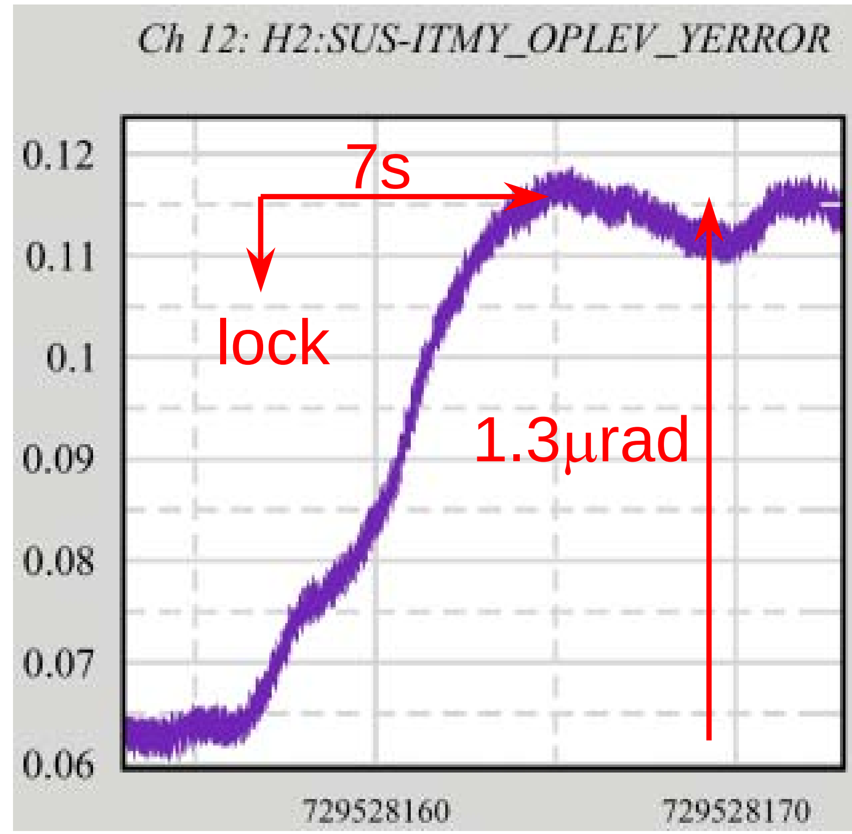
- ❑ **AS quadrature signal dominant!**
- ❑ Multiple AS port detectors
  - ➢ H1: P_{AS} = 500-600 mW ⇒ 4 detectors
  - ➢ L1: P_{AS} = ~20-30 mW ⇒ 1 detector

Getting to high power: *radiation pressure*

- Not a small effect!

Mode cleaner length shift (2kW)





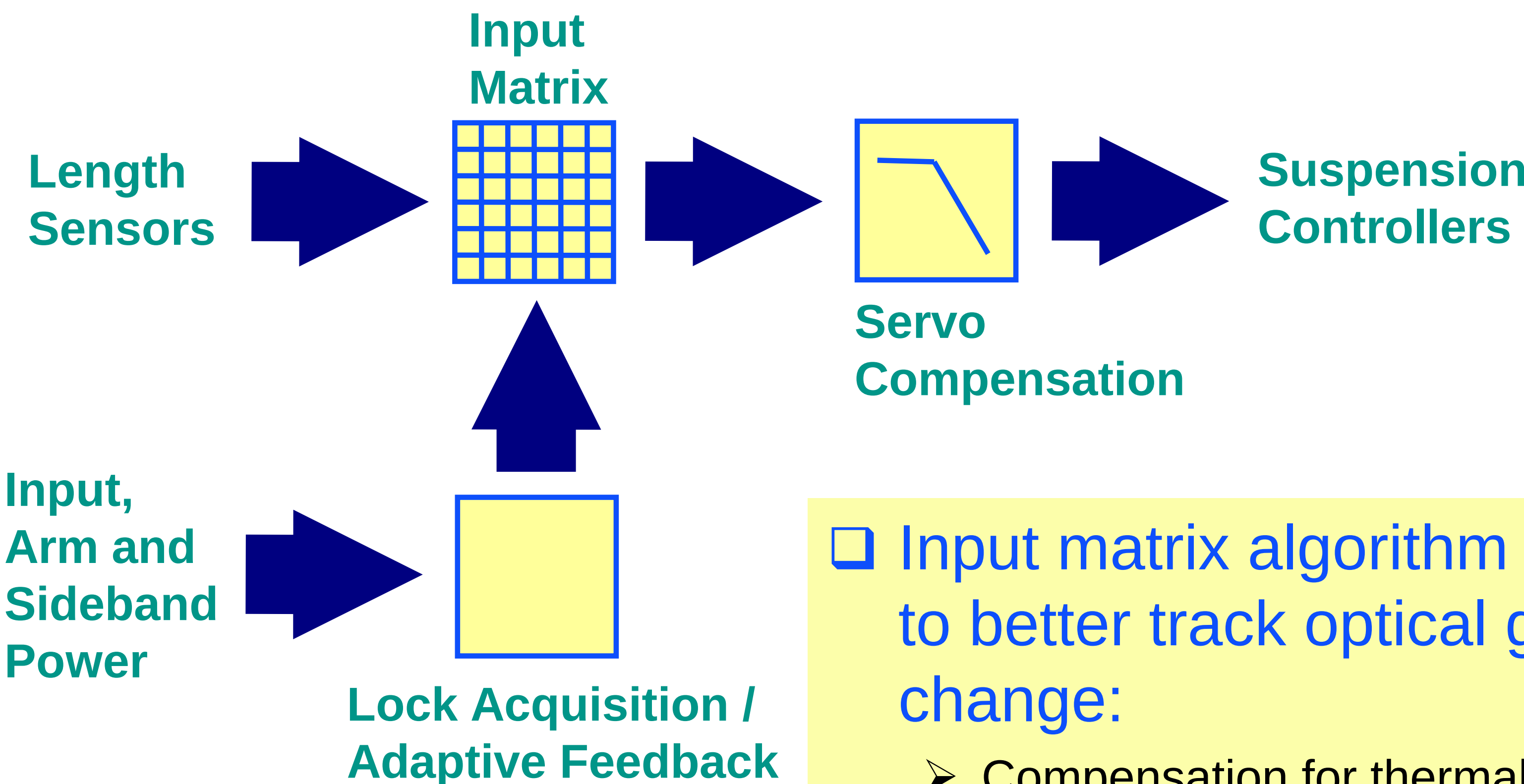
Arm cavity angular shift

2cm de-centering at 5kW

Getting to high power: *sequence*

- Acquire lock at low power, ~1 Watt
  - Separate, low-power 'acquisition photodetectors' used to acquire
- Engage common mode servo (laser frequency feedback) & transition to detection mode
  - Reduces residual demodulation signal levels
- Ramp up input power, wait for thermal lens to form (~15 min)
  - Radiation pressure angle shifts corrected with wavefront sensor feedback, ultimately
  - So far, have used WFS for ETMs & dc optical lever feedback for ITMs
- Implemented on H1: up to 2.3 W into MC, close to 5kW in each arm

Adaptive Feedback Control for Power Increase



- Input matrix algorithm updated to better track optical gain change:
  - Compensation for thermal heating
  - Spatial overlap coefficients

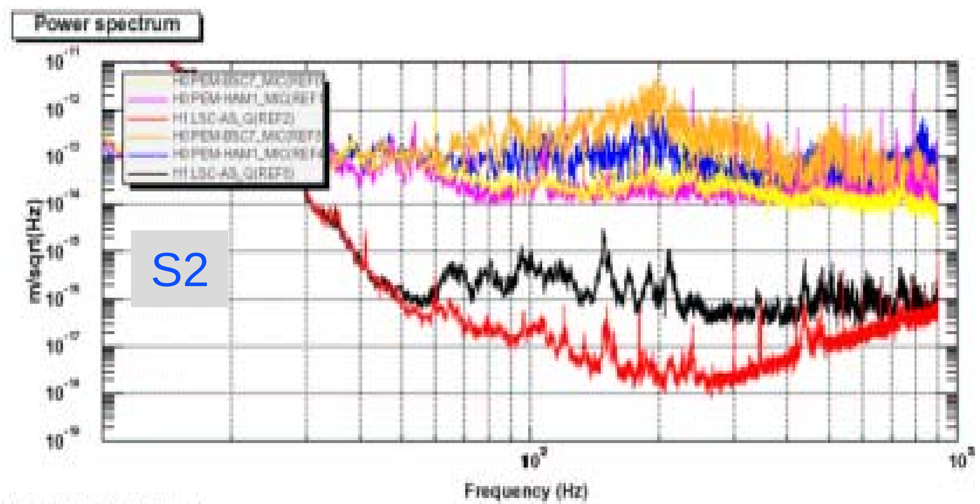
Acoustic Noise Coupling

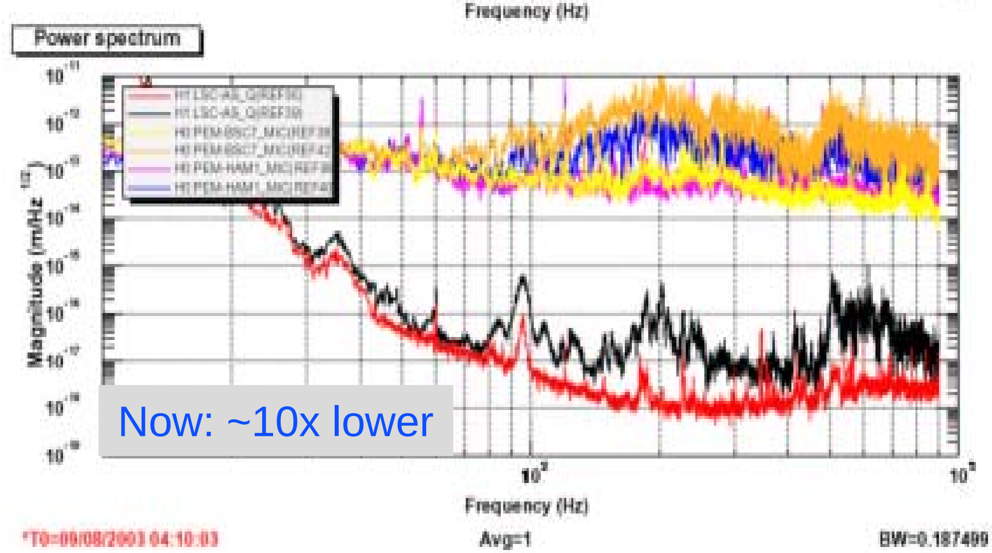
- Peaks occur in 50-1000 Hz band, at a level 10-100x the design sensitivity
  - Major source for H1/H2 broad-band correlations
  - Source for H1/H2 coincident bursts (?)
- So far, dominant mechanism appears to be beam clipping, rather than backscattering
  - Appear directly on AS_Q, through the AS port detection chain
  - Also via the PRC (& MICH) loops, throug the pick-off detection chain, and the PRC (MICH) coupling to AS_Q

Acoustic Mitigation: 3 prong attack

- Acoustic enclosures around output tables
  - Outfitted with low-frequency damping panels
  - Factor of 15 reduction in acoustic noise
  - *AS port enclosures in place for S3*
- Reduce couplings
  - *Simplify beam path: eliminate E-O shutters, larger optics (S3)*
  - *New stiffer periscope (S3)*
  - Investigation of table supports: float tables?
- Reduce source
  - Muffle fan noise at electronics crates
  - *Racks on isolation legs (S3)*
  - Move racks out of VEA
  - *Reduce HVAC noise (S3)*
  - Insulate mechanical room

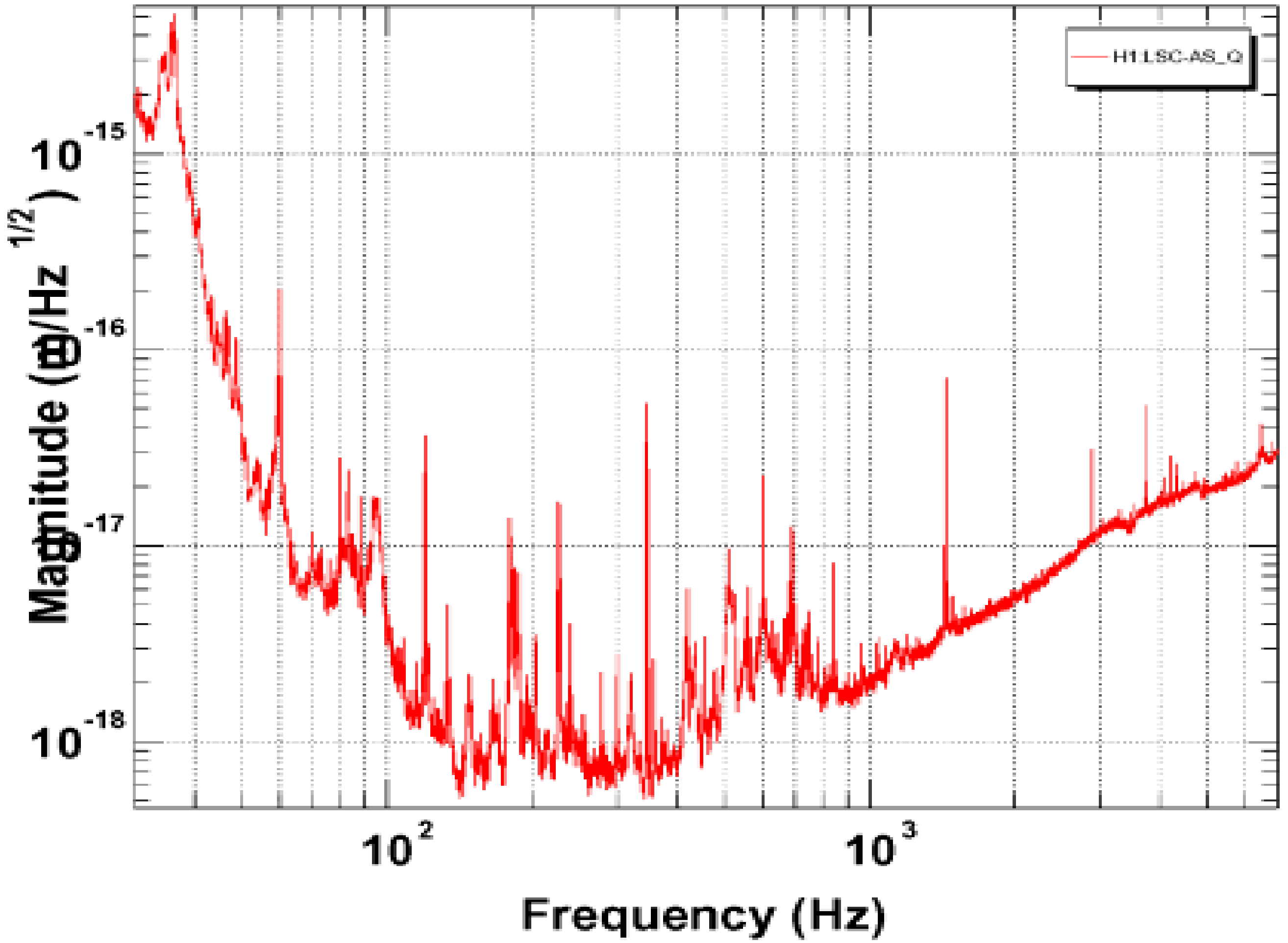
Sensitivity tested by adding acoustic noise:





Latest H1 spectrum: high power & acoustic improvements

InspiralRange = 1506kpc



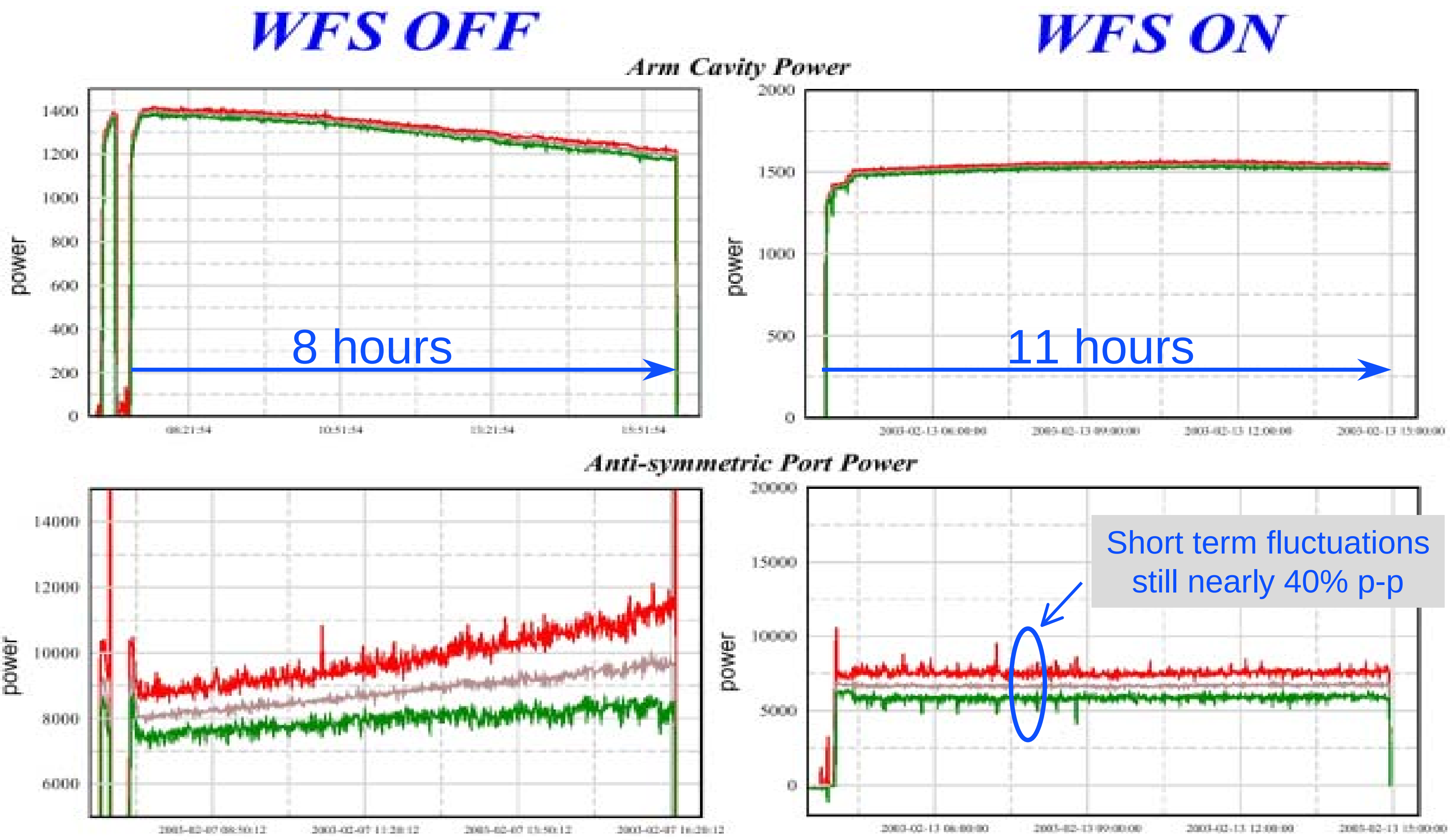
T0=11/08/2003 03:03:00 Avg=20/Bin=5L BW=0.187493

- 2 AS port photodetectors, 20 ma avg. DC current each
- Acoustic peak improvements due to simplified AS port detection chain

Status of WFS alignment control

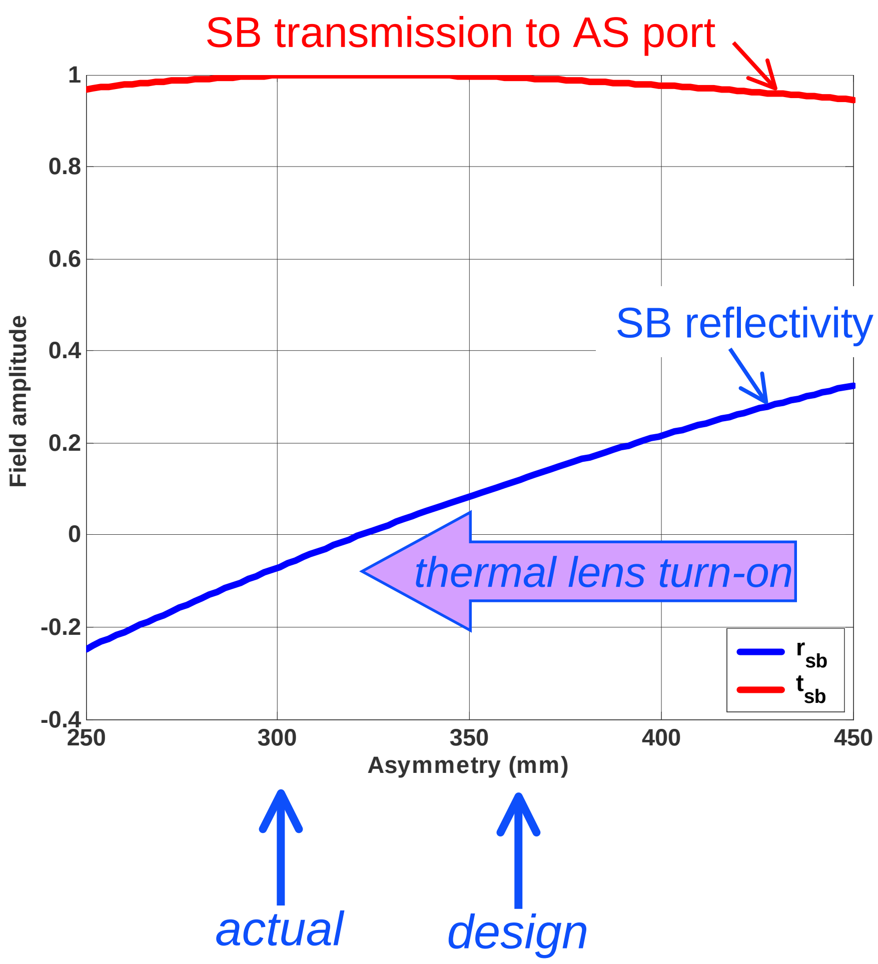
- S2: H1 had 4 of 5 (low-bandwidth) feedback loops; L1 & H2 only 1
- Now, H1 & L1 have:
  - Closed all 5 feedback loops
    - 1-few Hz bandwidth for AS port WFS to ETMs
    - Less than 0.1 Hz bandwidth for others sensors; system becomes unstable for higher gain
  - Included a low-bandwidth feedback using the ETM transmission quad detectors, to counter spot position drift
- Still needs work to make reliable & routine
  - S3: goal is long-term power stability at least as good as H1 during S2
- Post S3
  - Increased control bandwidth to reduce short-term power fluctuations, & allow (noisy) optical lever damping to be turned off
  - Simulation (SimLIGO) is being used to develop a high-bandwidth, multiple degree-of-freedom feedback solution

Low-bandwidth Auto-Alignment System



In-vacuum fixes

- Schnupp asymmetry on 4 km IFOs
  - Common mode error signal: uses reflected RF sidebands (SB) as local oscillator field
    - Design intent: choose asymmetry to have a SB field reflectivity of 10%
    - Reality: asymmetry was made the same as the 2 km: too small
  - ITMs moved along optic axis by approx. 3 cm
- Suspension wire protection
  - 2 wire cutting incidents on H2
  - Baffles installed to protect wires

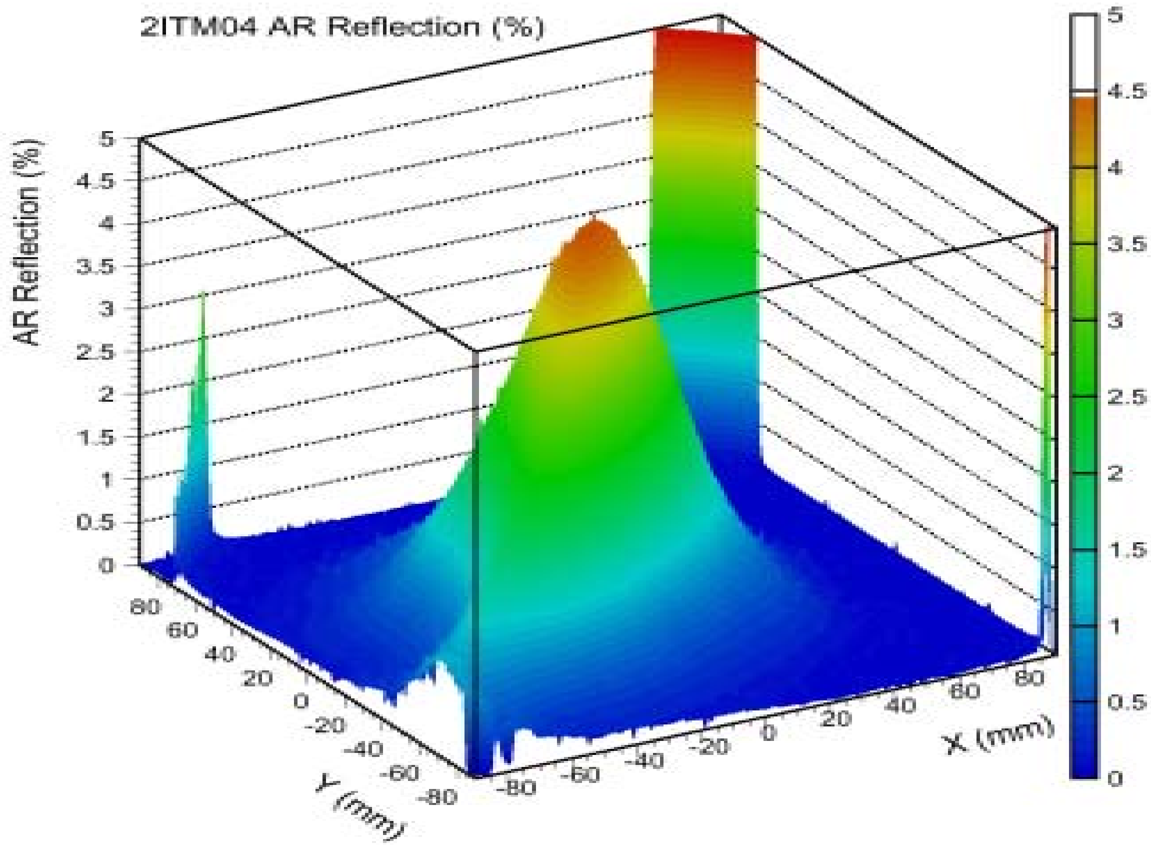


In-vacuum fixes, cont'd

- L1 recycling cavity length
  - Lack of RF sideband power buildup suggested the recycling cavity length was off by a couple of cm
  - Error verified by locking the recycling cavity, and performing an AM sweep across a higher-order resonance
  - One ITM moved to simultaneously correct recycling cavity length and Schnupp asymmetry
- Impact
  - More SB power for AS_Q, MICH and PRC error signals: better shot noise sensitivity
  - Allows thermal lensing to be characterized

In-vacuum fixes: new H2 ITMX

- H2 recycling gain always low, up to ~20
- ITMX AR surface reflectivity measured in-situ at ~3%
  - Reflectivity scan after removal
  - Transmission map also shows spatial variation
- New ITMX installed in June
  - Recycling gain up to **55** seen so far



Additional Tasks

- High power necessities
  - PSL/IO maintenance: tune/replace lasers, lossy pre-mode cleaners & EOMs
  - Remote power adjustment installed
- Lower noise coil drivers
  - H1: output electronics noise now below SRD level at all frequencies
- Automated initial alignment
  - H1: using additional WFS at AS port to auto-align both arm cavities
- Digital mode cleaner alignment system
  - L1: MC WFS feedback to MC mirrors, to stabilize residual fluctuations
- RFI cleanup: linear power supplies
  - H1 & H2 now complete, benefit seen
- Photon calibrator
  - One installed on an H1 ETM
- Install atomic clocks for timing diagnostics
  - Verify GPS timing, synchronize photon calibrator; S3 readiness not certain

Summary for S3

Currently ongoing efforts:

- High power operations
- Acoustic mitigation
- Improved alignment control

Significant improvement in H1 sensitivity in hand

One week Engineering run starting 17 October, allows one week before S3 to fix problems