Status of LIGO

Commissioning and detector improvements for S4

Aspen
January, 2005

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LIGO-G050045-00-D

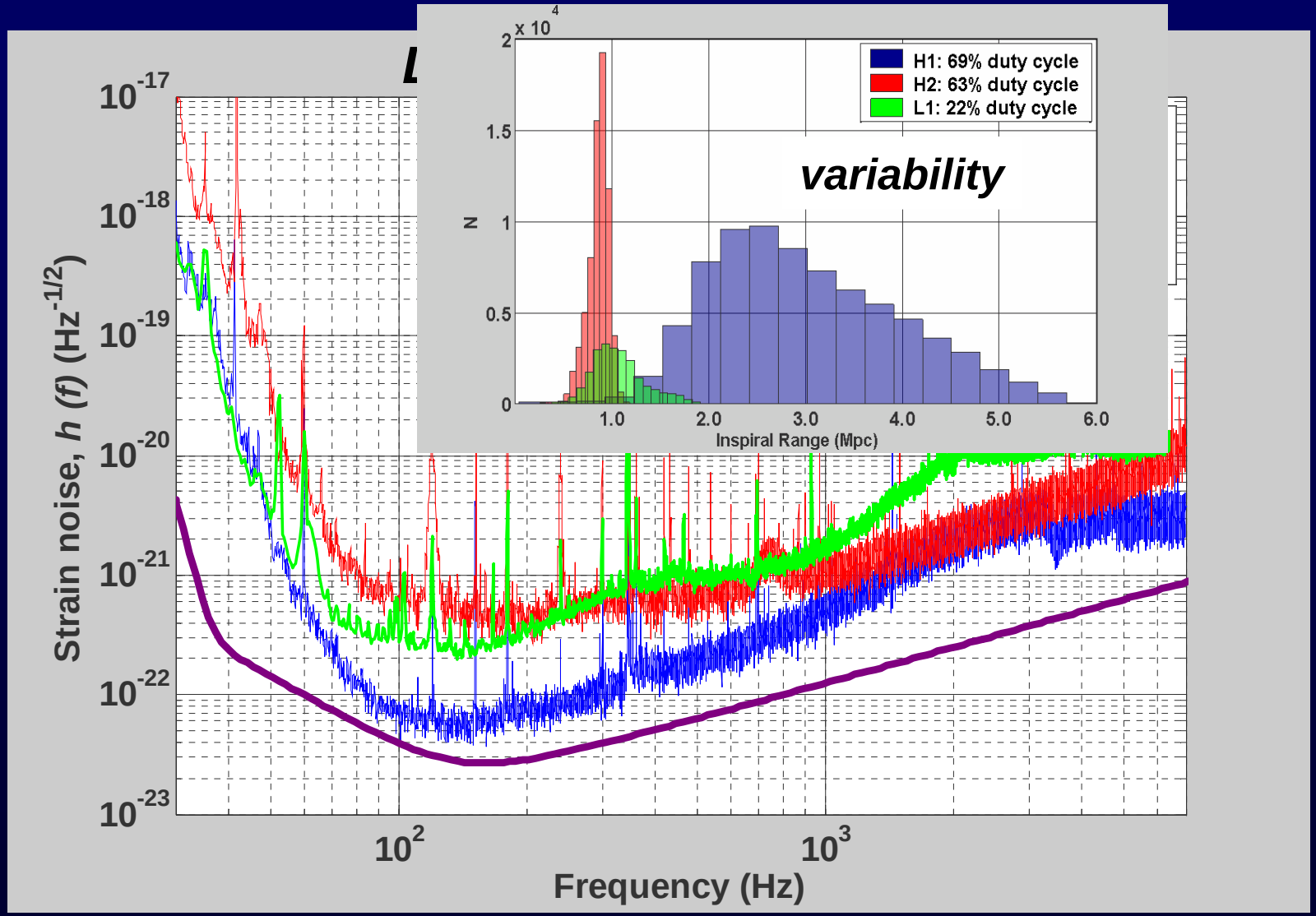
S4 Goals

- Sensitivity (in terms of inspiral reach)
  - H1 7.5 Mpc (7.5 Mpc)
  - H2 2 Mpc (1.5 Mpc)
  - L1 4 Mpc (2.5 Mpc)
- Stability and duty cycle
  - 70% individual
  - 40% triple coincidence
- Duration
  - 4 weeks
  - Starting February 22, 2005 (if E12 at LLO goes well)

Commissioning/Run plan

- E11 completed at LHO (Nov. 17 to 23)
  - Inspiral range: 6.5 to 7 Mpc
  - Duty cycle: 65% overall, 75% over last 4 days
  - Time for commissioning efforts to respond to problems found in the data (glitchiness, e.g.)
- E12 for LLO scheduled to start 1 Feb 2005 (1 wk)
- S5: one year of coincident data at the science goal sensitivity
  - Run should start early 2006

Reminder of S3 performance

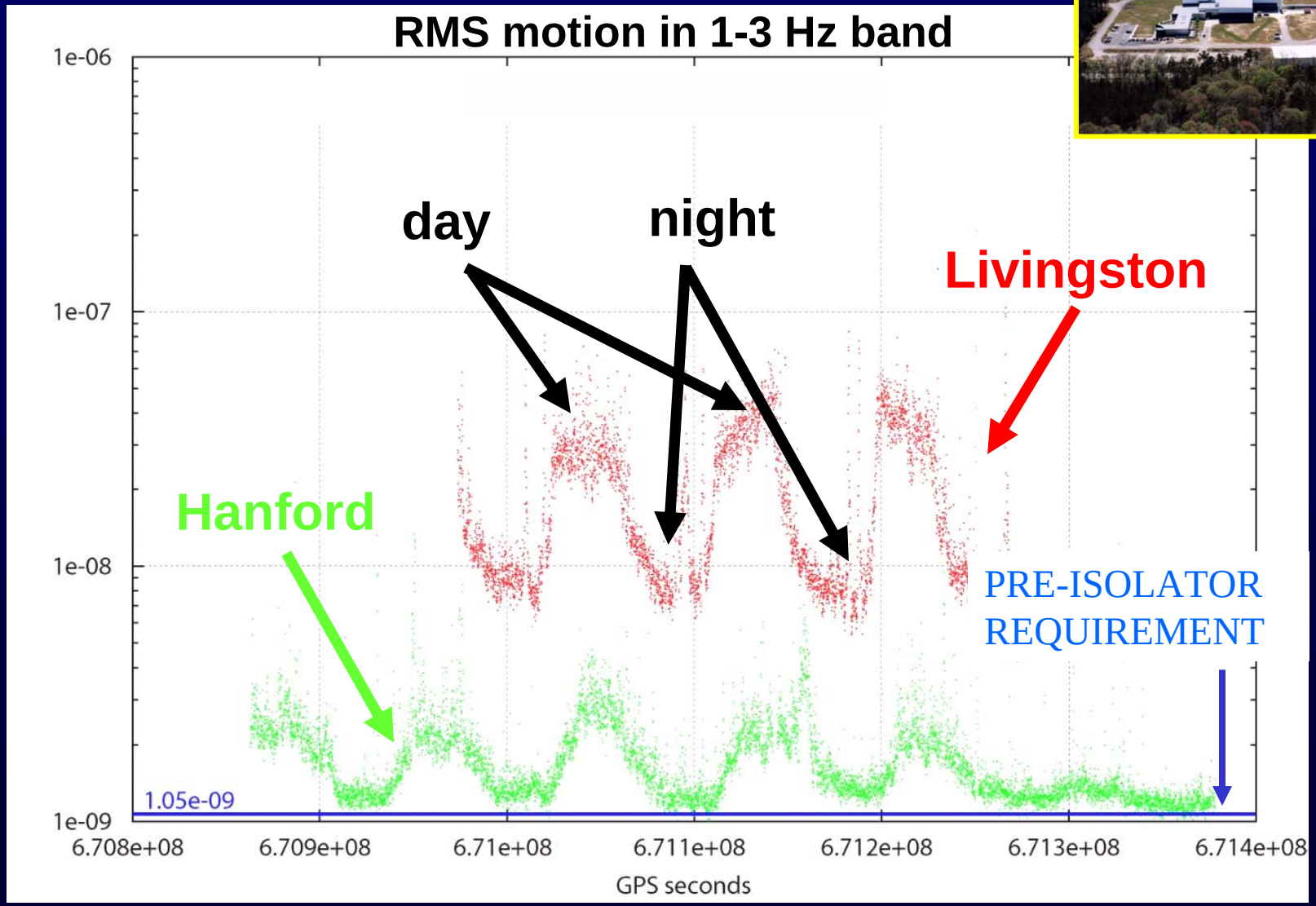


Post-S3 areas of focus

- **Sensitivity**
  - Increase laser power
  - Active thermal compensation
  - Phase noise of RF oscillator
  - Noise coupling from auxiliary degrees-of-freedom
  - Output mode cleaner tests
- **Reliability and stability**
  - Seismic retrofit at LLO
  - RFI retrofit at LLO
  - Improvements to auto-alignment system
  - Address causes of lock-loss

Seismic retrofit at LLO

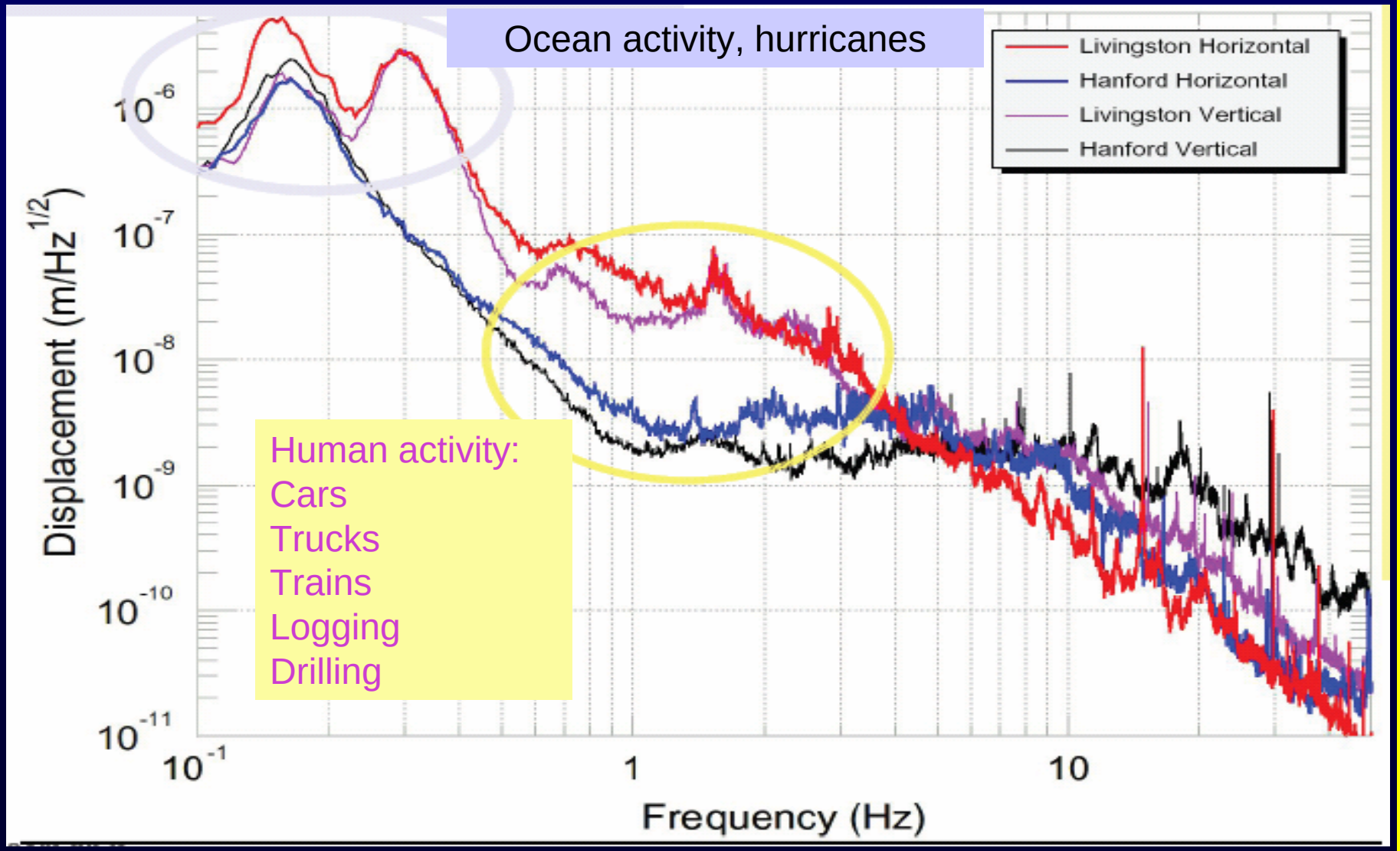
Daily Variability of Seismic Noise



Displacement (m)

Time (GPS seconds)

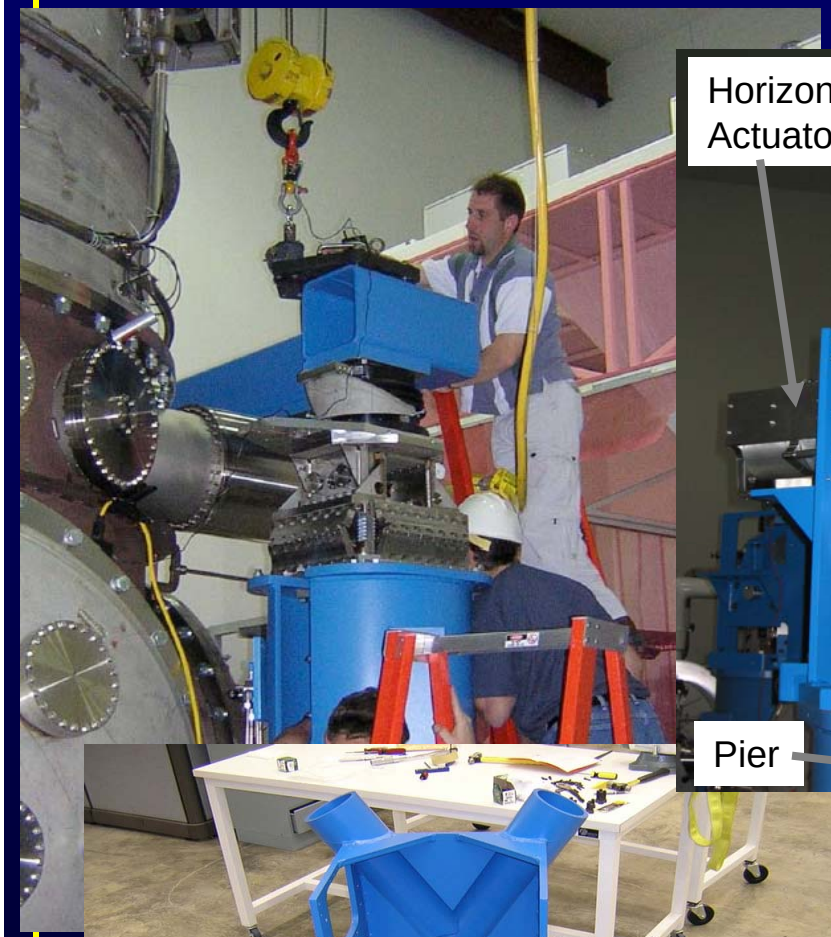
Seismic Noise: LLO vs LHO

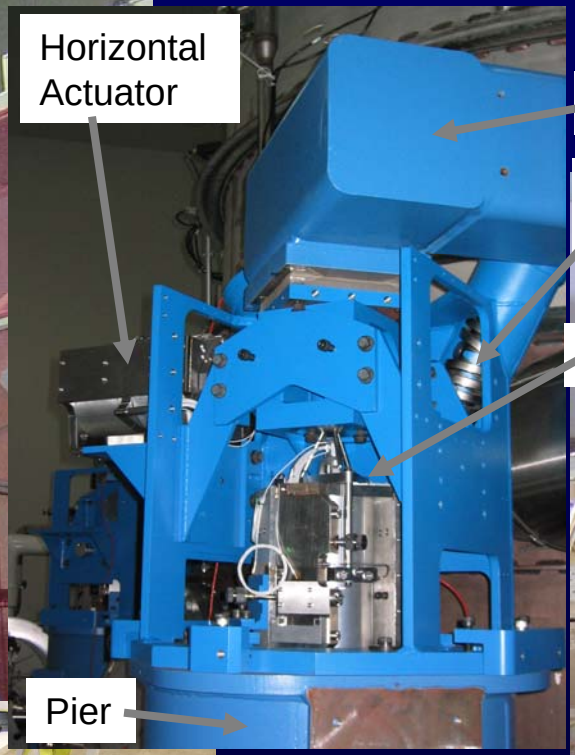


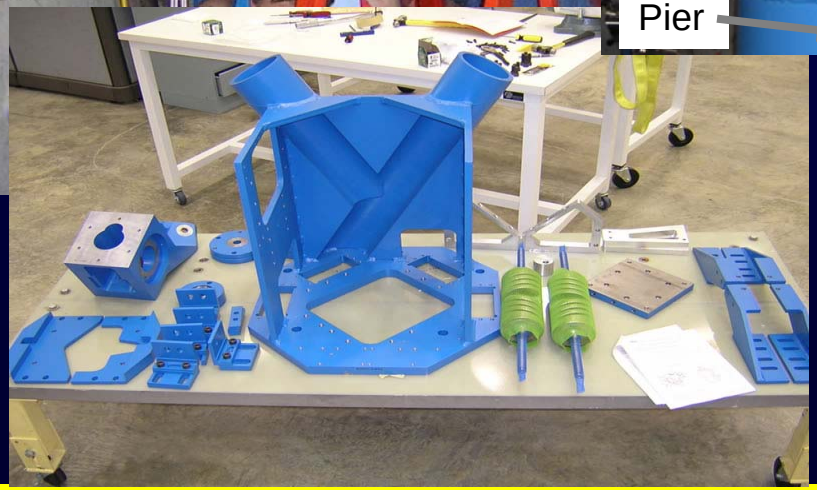
Hydraulic External Pre-Isolation HEPI at LLO

- Installation and commissioning of an active isolation stage between piers and external seismic support structure

HEPI in pictures

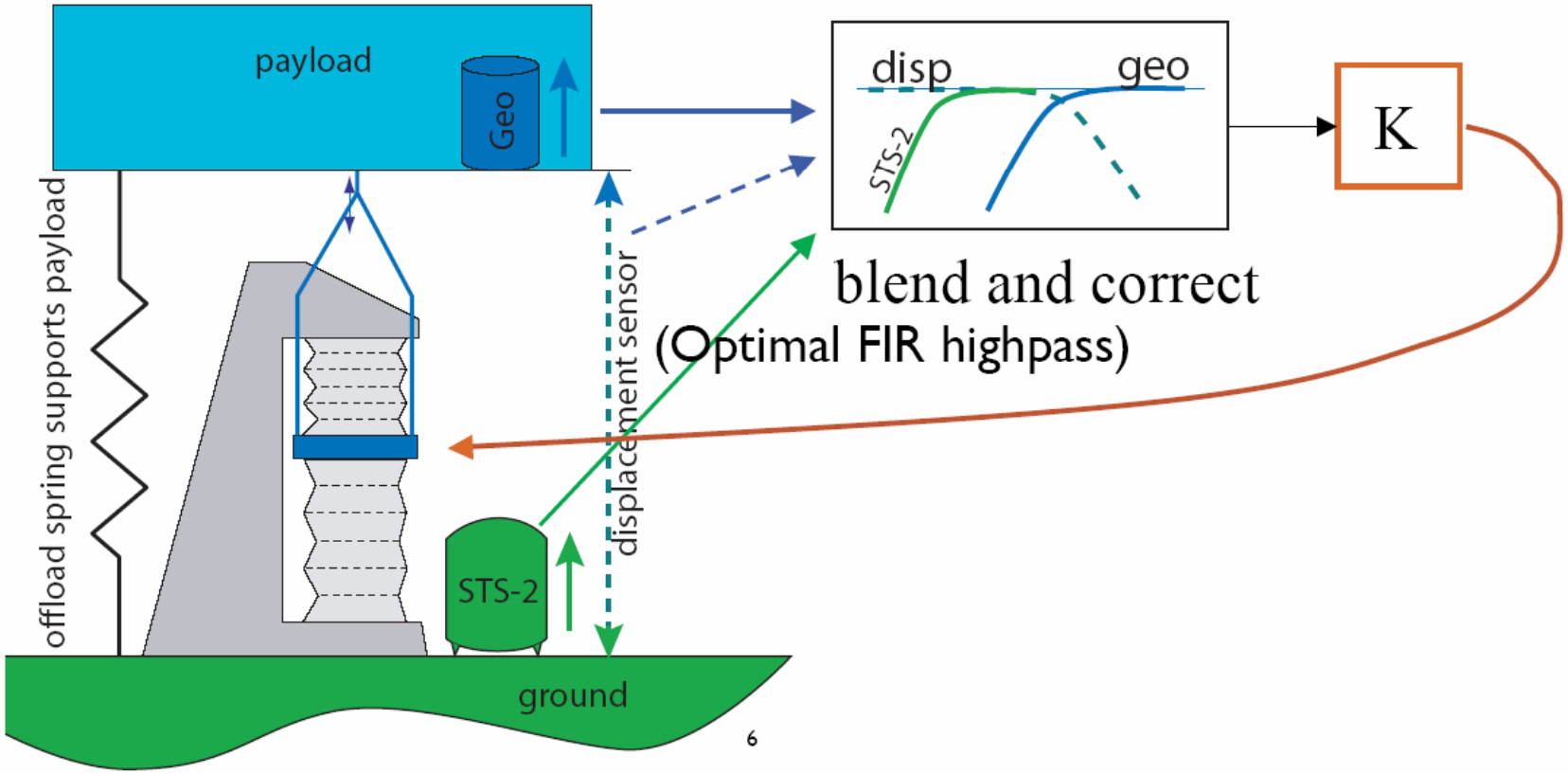




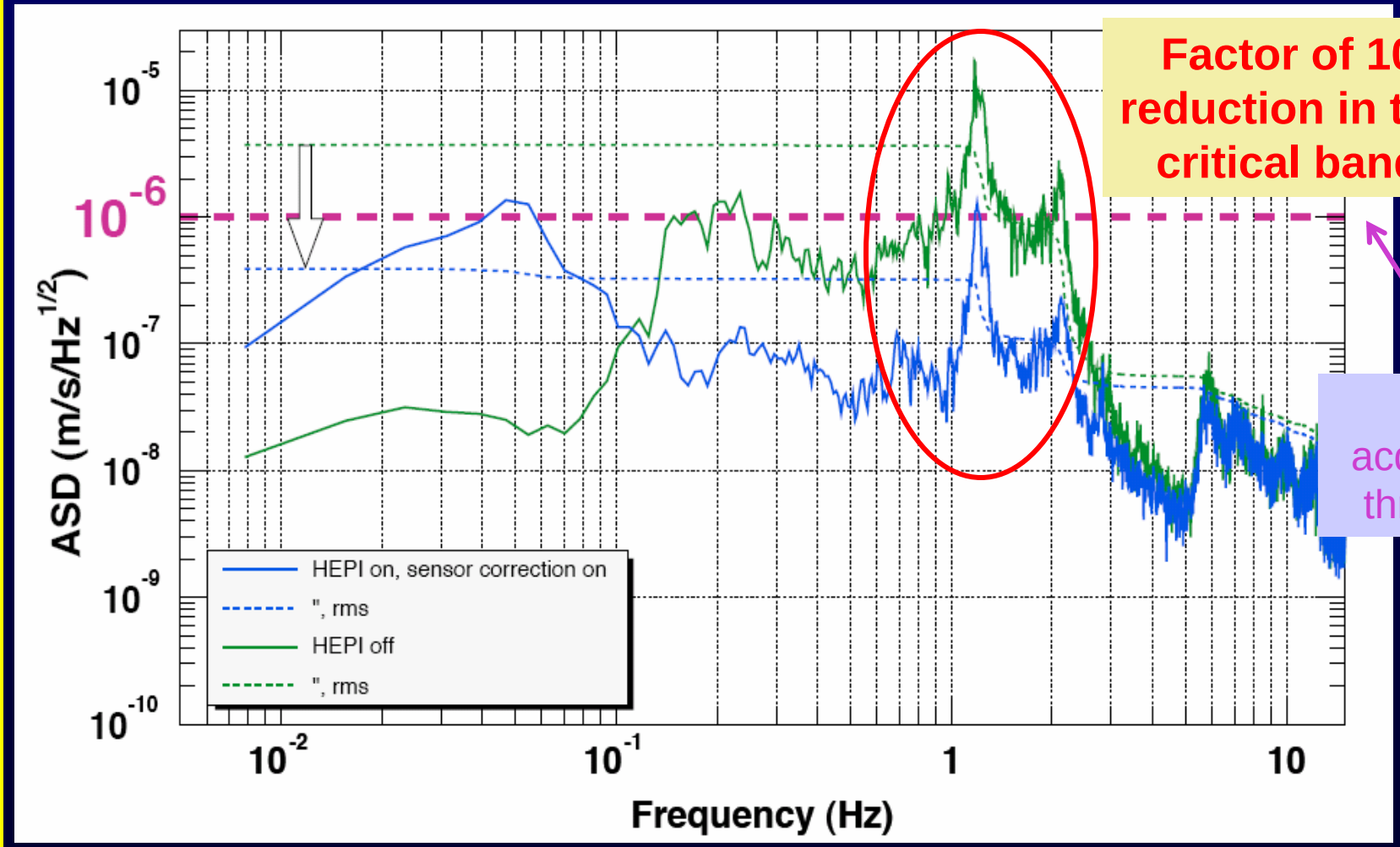


Low-frequency pre-isolation

- At each tank corner pier, there is a sensor/actuator set, vertical and horizontal.
- Each DOF controlled with respect to HEPI displacement sensors and geophones.
- Displacement sensor corrected for floor motion as measured by Streckeisen STS-2., in x, y, z DOF's.



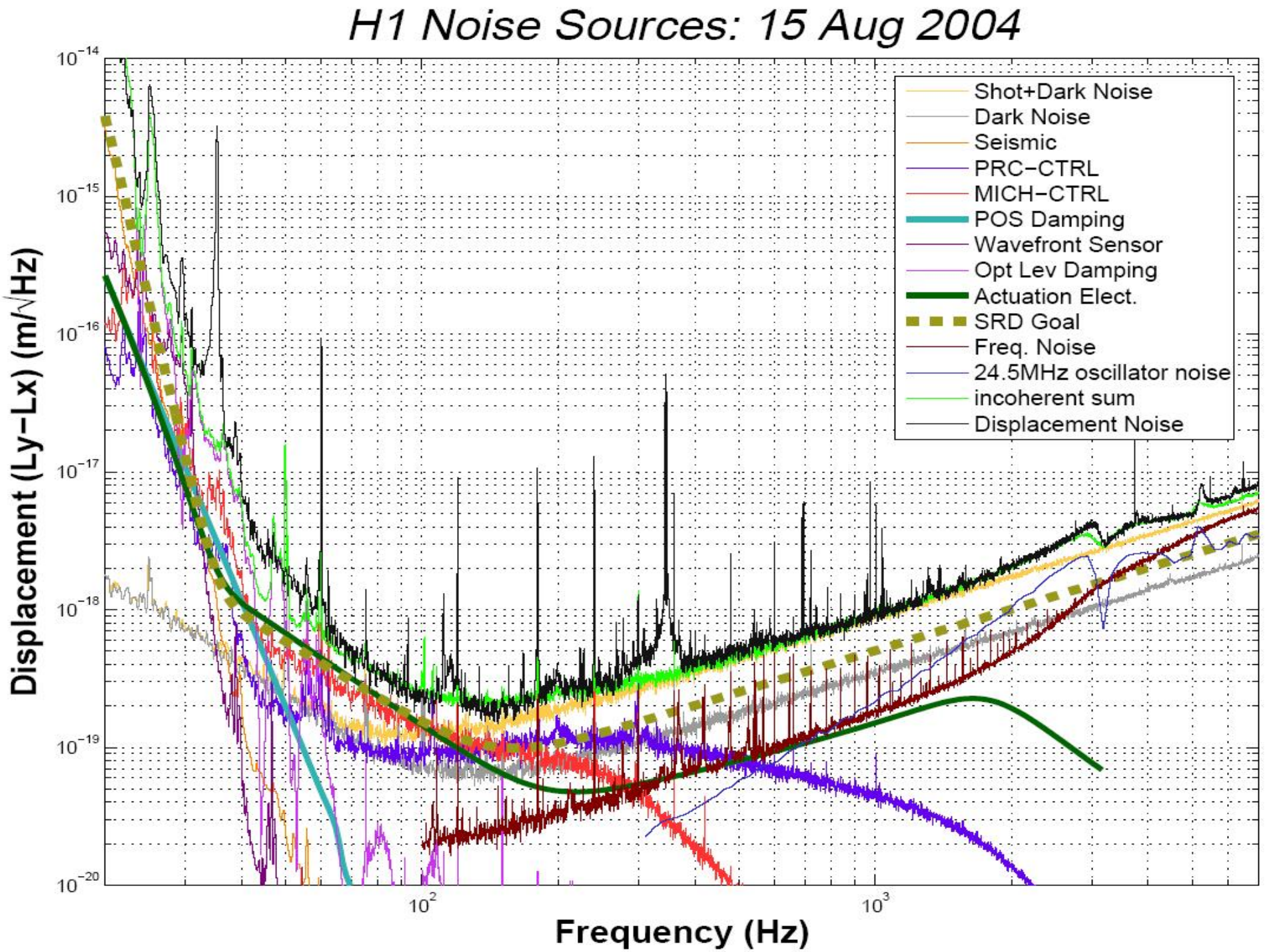
HEPI performance on a noisy afternoon relative velocity between ITMX & ETMX



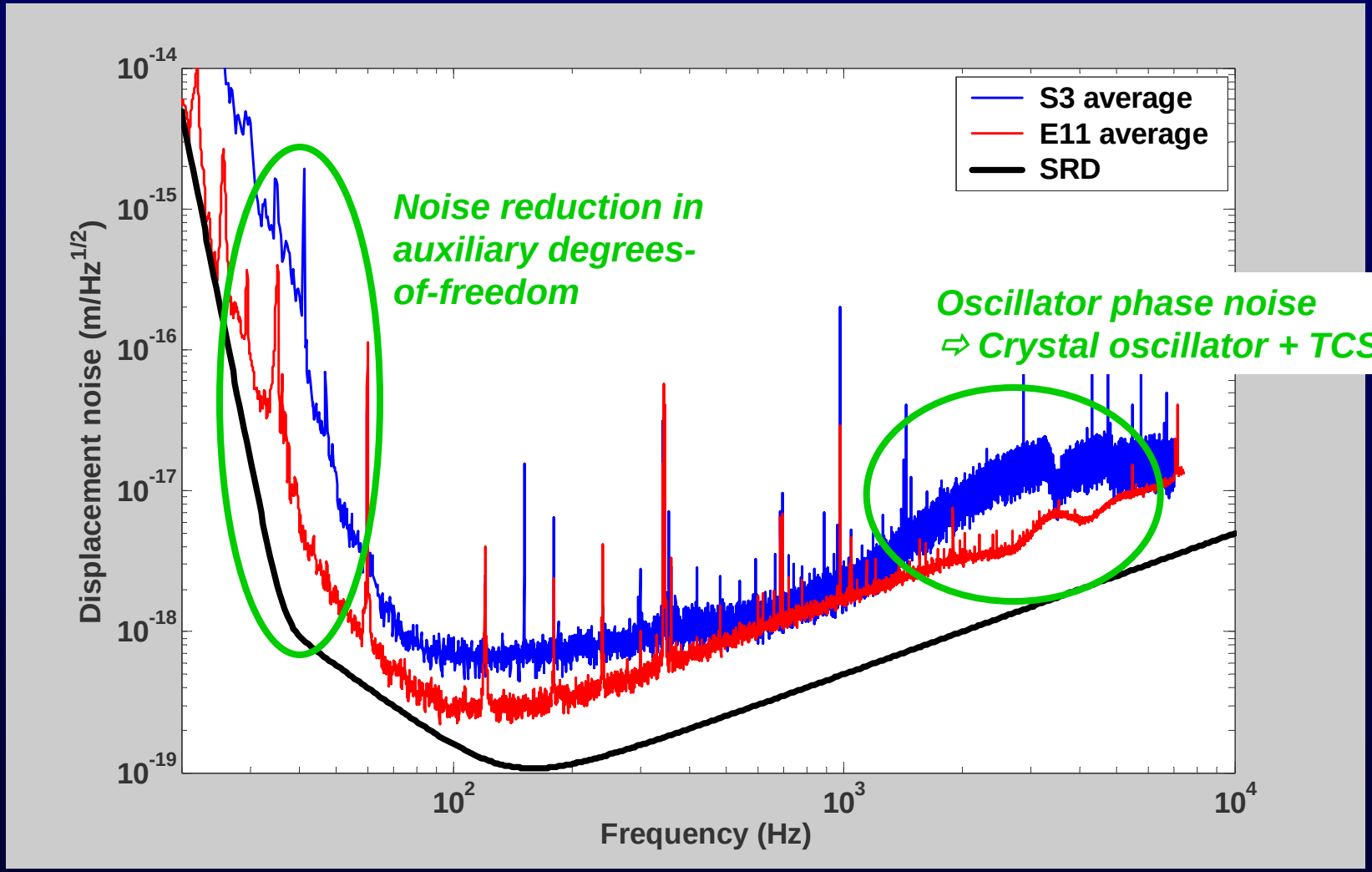
HEPI status

- **Installation complete, March to July 2004**
  - Keeping on eye on some hardware reliability issues
    - Had problems with actuator valve failure, sensor failure, corruption of sensor ADC data
  - Seems more reliable recently
- **Controls implementation**
  - All 5 BSC chambers (TMs and BS) have full isolation in all DOF (still room for tweaking the servo filters/gains)
  - Isolation control for HAM chambers being developed
- **Impact**
  - For the first time at LLO, allows locking and commissioning of the full interferometer during the day!
  - Pre-Isolator is first Advanced LIGO subsystem shown to work at required specification in an Observatory setting

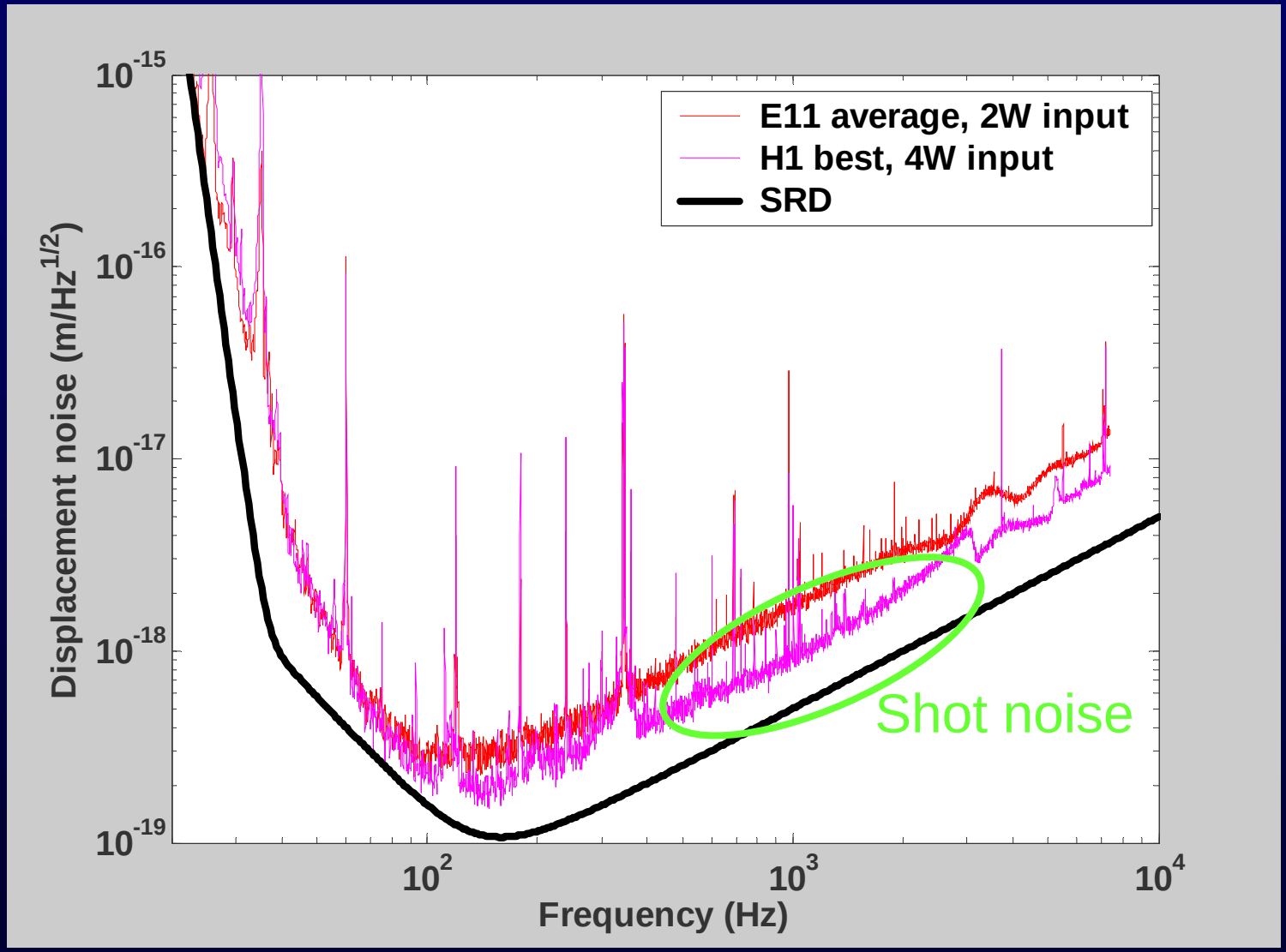
Noise Improvements


H1 Noise Sources: 15 Aug 2004
Displacement (Ly−Lx) (m/√Hz)
Frequency (Hz)
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{2}
10^{3}
Shot+Dark Noise
Dark Noise
Seismic
PRC−CTRL
MICH−CTRL
POS Damping
Wavefront Sensor
Opt Lev Damping
Actuation Elect.
SRD Goal
Freq. Noise
24.5MHz oscillator noise
incoherent sum
Displacement Noise

Noise improvements on H1



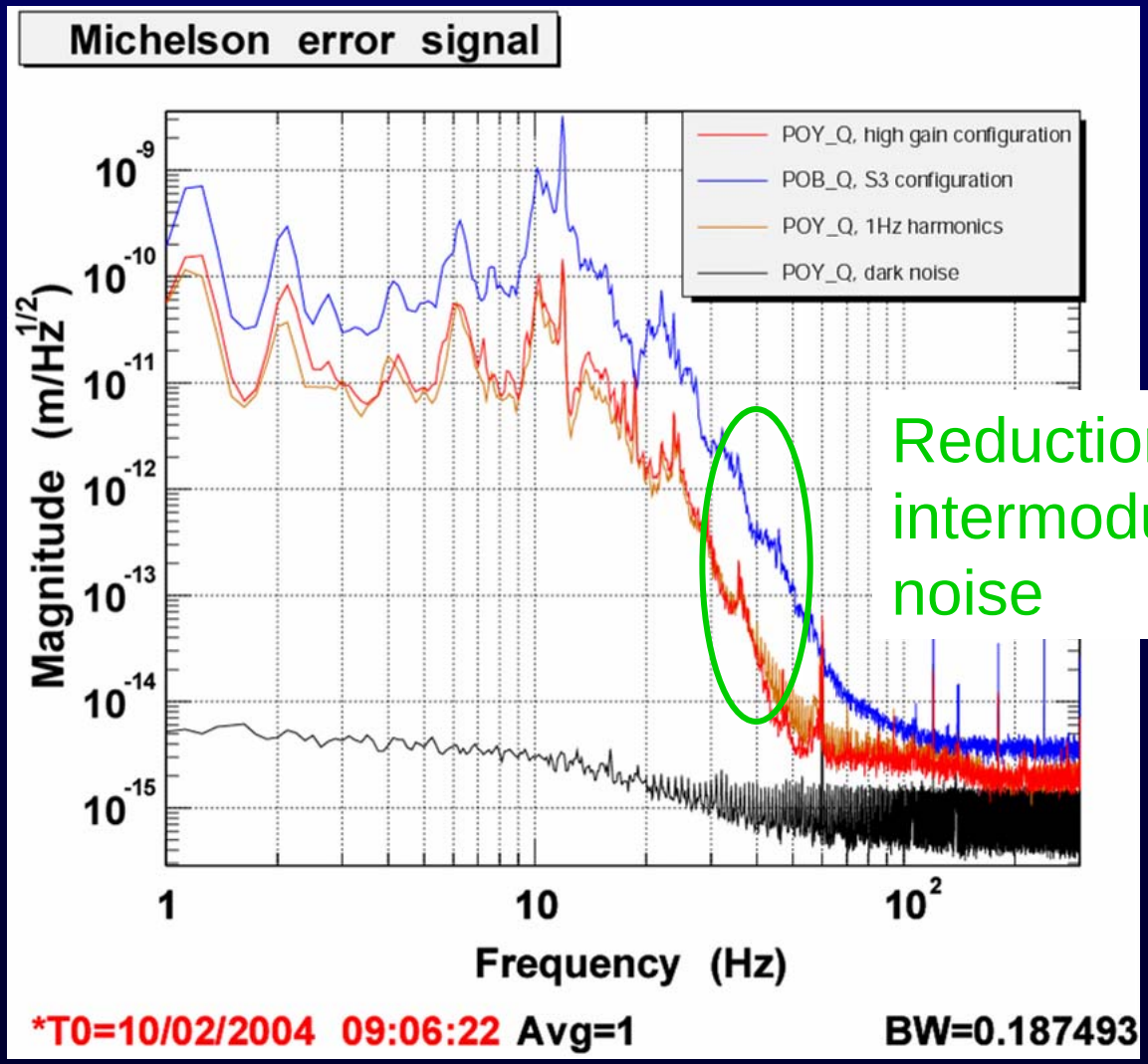
H1 goal for next science run



Auxiliary degrees-of-freedom
Small but noisy coupling to GW channel

- Change of control strategy for PRM degrees of freedom
- Problem (S3, e.g.)
  - Low bandwidth servos with sharp low-pass filtering in the GW band
  - DOF too loosely controlled ➔ suffered from intermodulation noise production
- Solution
  - Higher-bandwidth servos with real-time subtraction of noise from GW channel
- Benefits
  - 10x or more reduction of PRC noise below ~100 Hz
  - Allows detection of higher power (10x) for these DOF, reducing shot noise region, above ~100 Hz

Auxiliary degrees-of-freedom
Small but noisy coupling to GW channel



Reduction of intermodulation noise

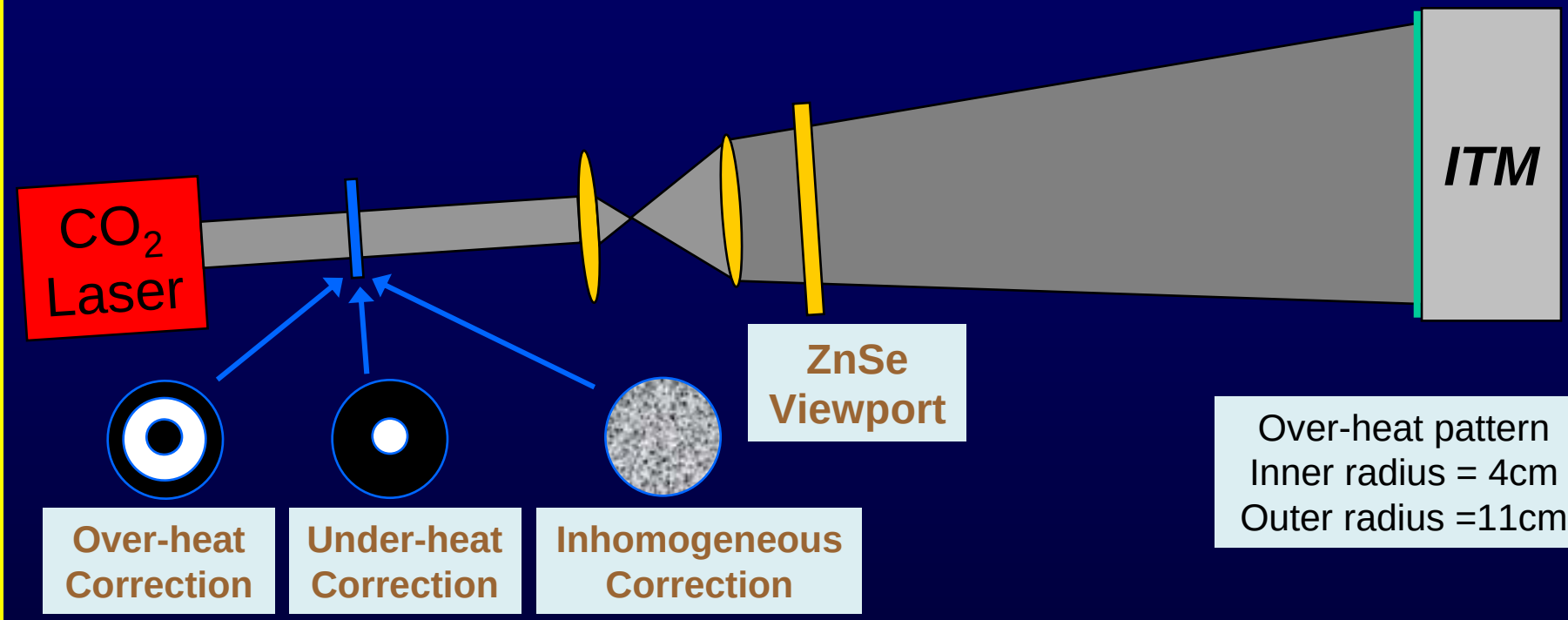
What to do at high frequencies?

- Increase laser power
  - Lasers refurbishing, now running at ~8W
    - Approximately 4 W incident on interferometers
  - Input optics-train modified and aligned for better throughput
  - Additional photodiodes added to antisymmetric port
- Additional power produces “thermal lensing” in interferometer optics
    - Need Thermal Compensation System (TCS)
- Reduce other high-frequency noise sources
  - Oscillator phase noise → crystal oscillator
  - Higher-order transverse modes of laser field → Output mode cleaner (OMC)

Thermal Compensation System (TCS)

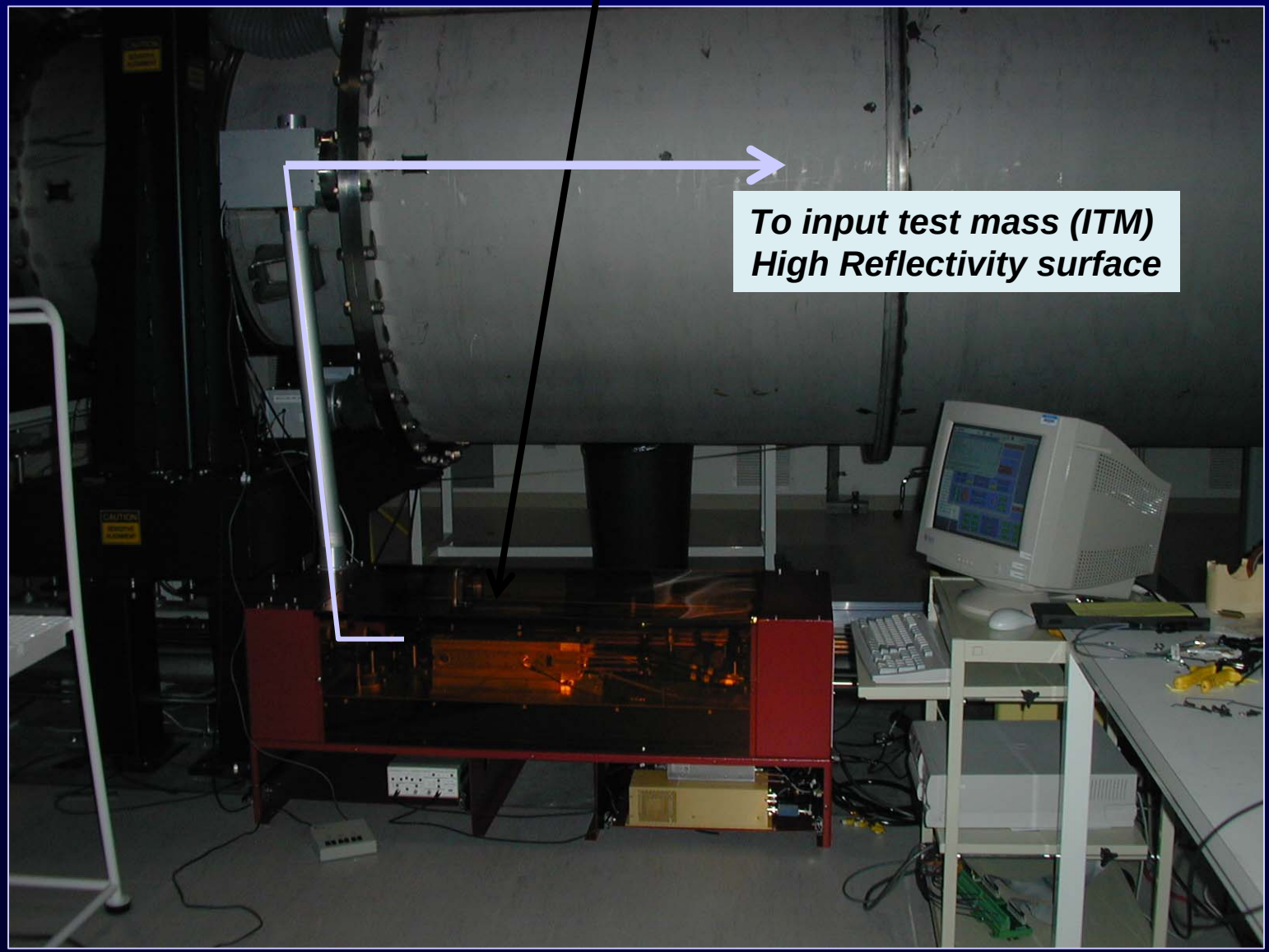
- Mirrors of the interferometer absorb laser light and heat up ➔ thermal lensing
  - Mirror profile (shape) distorted according to the laser beam and absorption profiles
  - Cold power recycling cavity is unstable
    - Poor buildup and mode shape for the RF sidebands
- Use external laser beam shaped to match the input beam to the mode supported in the arm cavities
  - ITM thermal lens power of ~0.00003 diopters needed to achieve a stable, mode-matched cavity
    - Intended to be produced by ~30 mW absorbed from 10 µm beam

Thermal Compensation System (TCS)



Over-heat pattern
Inner radius = 4cm
Outer radius =11cm

Two CO_2 lasers installed on H1

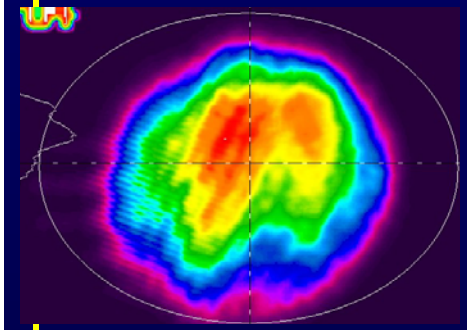


TCS on H1

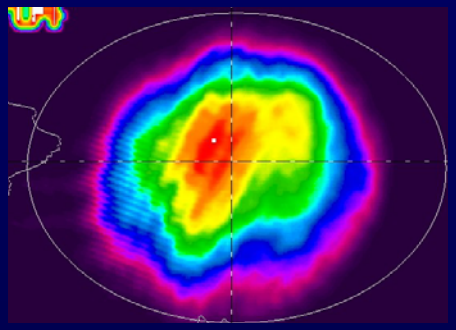
- At 4 W into the mode cleaner, H1 requires annulus mask (‘external cooling’) to maintain optimal lensing
  - Evidence that ITMX (X-arm of Michelson) is over-absorbing
- Common control of TCS (both ITMs)
  - Set to point of maximum sideband buildup (maximum optical gain)
- Differential control of TCS (diff. between ITMs)
  - Reduces the coupling of RF phase noise, by equalizing the amplitudes of the RF sidebands
  - Error signal: I-phase signal at AS port (GW signal is in the Q-phase)

TCS on the power recycled Michelson
Beam images at antisymmetric port

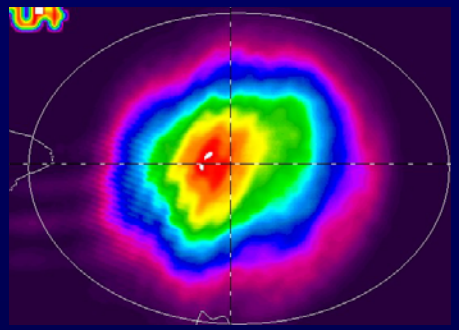
No Heating



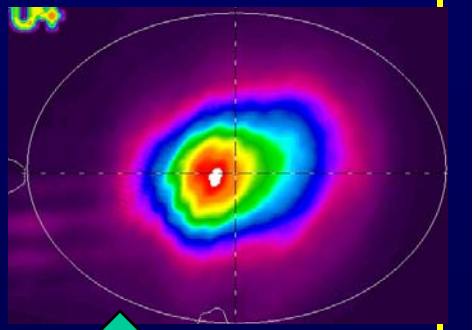
30 mW



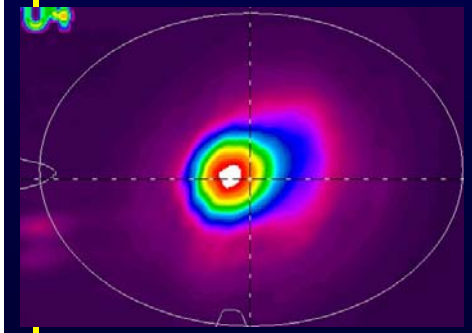
60 mW



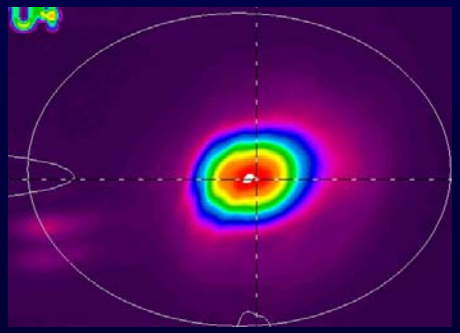
90 mW



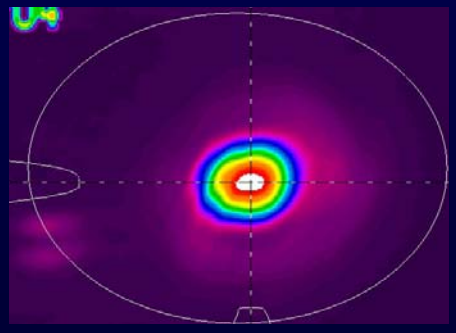
Best match



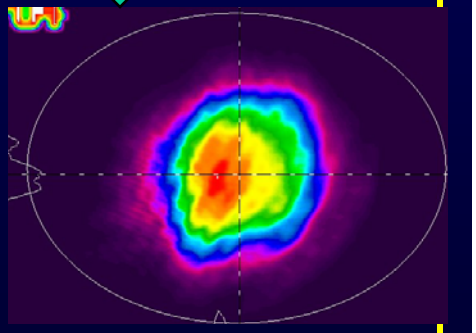
120 mW



150 mW



180 mW



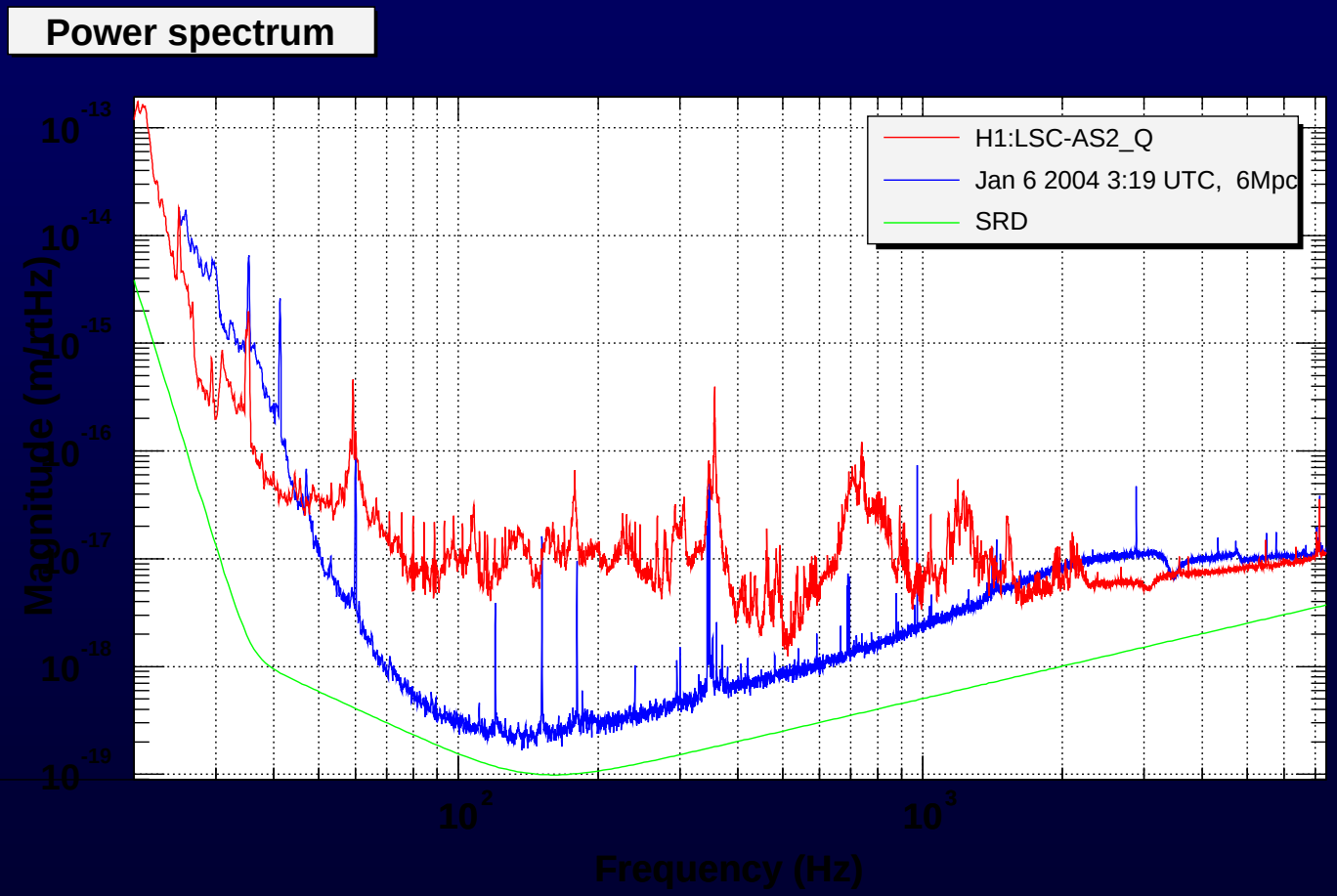
Input beam

Output Mode Cleaner -- The Good

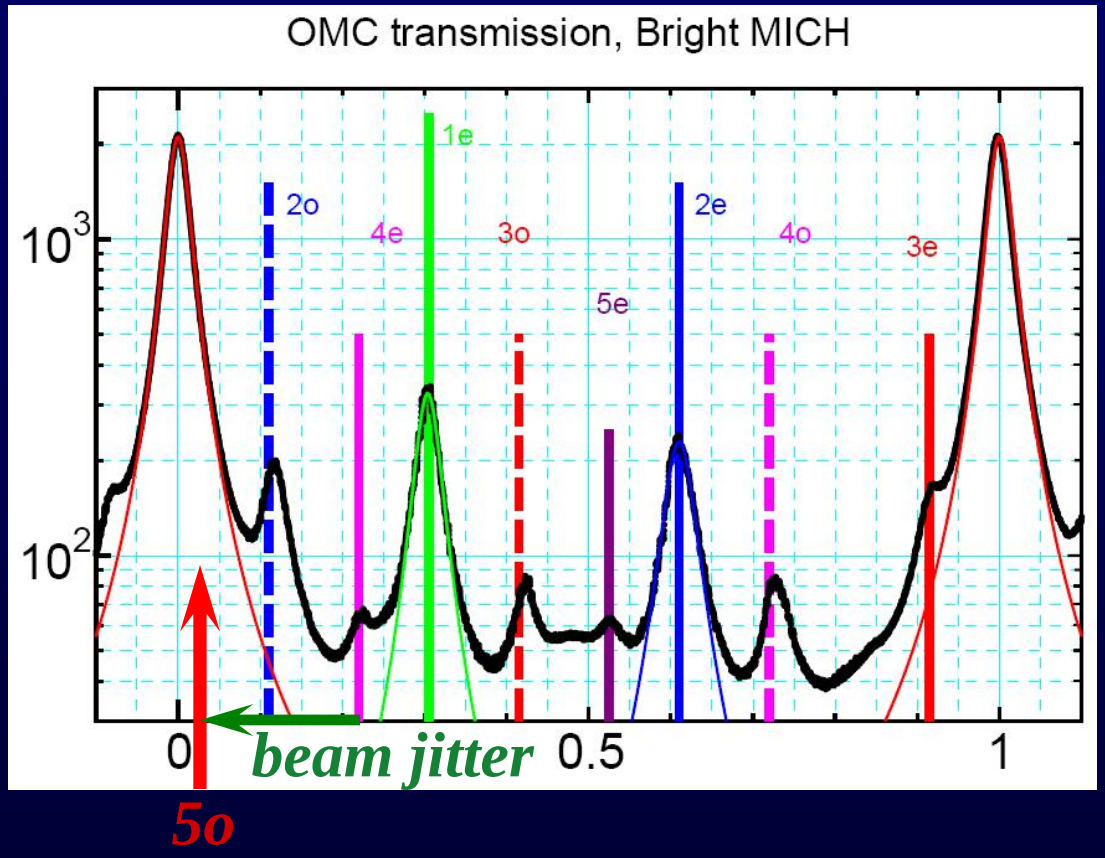
- Filters higher-order spatial modes before light exiting antisymmetric port is detected
- Carrier contrast defect improves by factor of 20
  - With OMC → carrier 2% of total power at AS port
  - Makes it possible to reduce modulation index
- Removes offset corresponding to 10^{-12} m
  - Reduced AM noise coupling by factor of 60 at 3 kHz
  - Reduced oscillator phase noise coupling by factor of 2 at 3 kHz
- Orthogonal quadrature (ASI) signal decreased by 7x
  - "ASI locking" symmetrizes RF sidebands

Would be able to operate with a single PD at AS port!

Output Mode Cleaner -- The Bad



Output Mode Cleaner -- The Ugly



- Higher order modes and beam jitter generate a PDH-like signal
- Elliptical beam is a problem
- Triangular cavity geometry is a problem

- A new 4-mirror OMC has been tested – beam jitter still a problem
- Designs for an in-vacuum implementation are being considered

Miscellaneous improvements

- New low-noise D-A converters from Freq. Devices Inc.
  - 30-40 dB lower noise
- New Faraday isolator for H2
  - Larger aperture to reduce clipping
  - Lower absorption for higher power operation
- Photon calibrators
  - In place on H1
- Reduce glitches due to dust falling through AS beam
  - better layout with bigger beams + dust covers for beam path
- New laser power stabilization servo
  - Lower intensity noise above 1 kHz
- Upgraded DAQ reflective memory network
  - higher capacity & CRC checksums
- Micro-seismic feedback system to fine actuators at LHO
- 100 kHz DAQ channels, w/ heterodyning
  - new GW channel at the arm cavity first free-spectral-range (37kHz)