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LIGO S2 Overview

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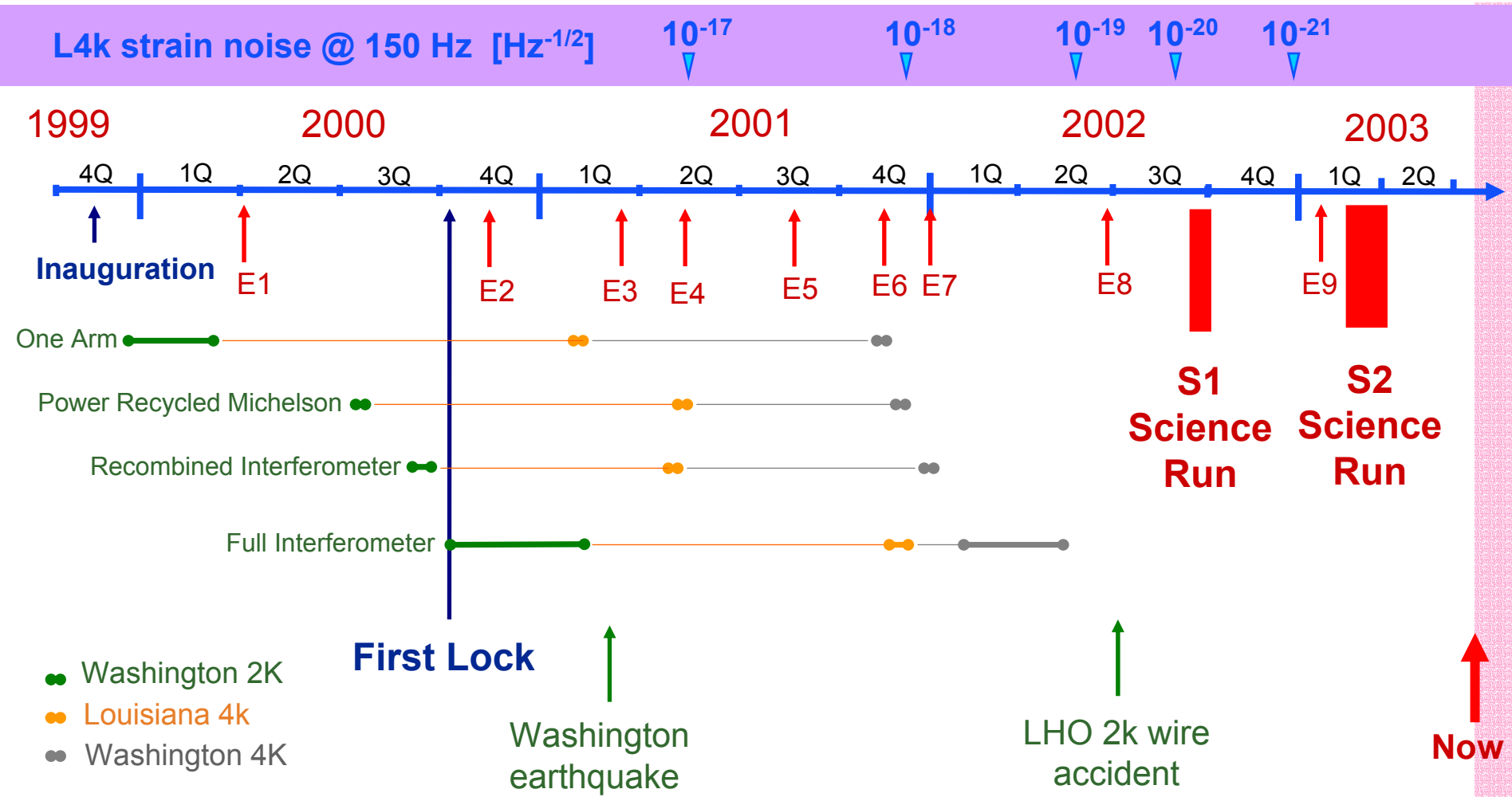
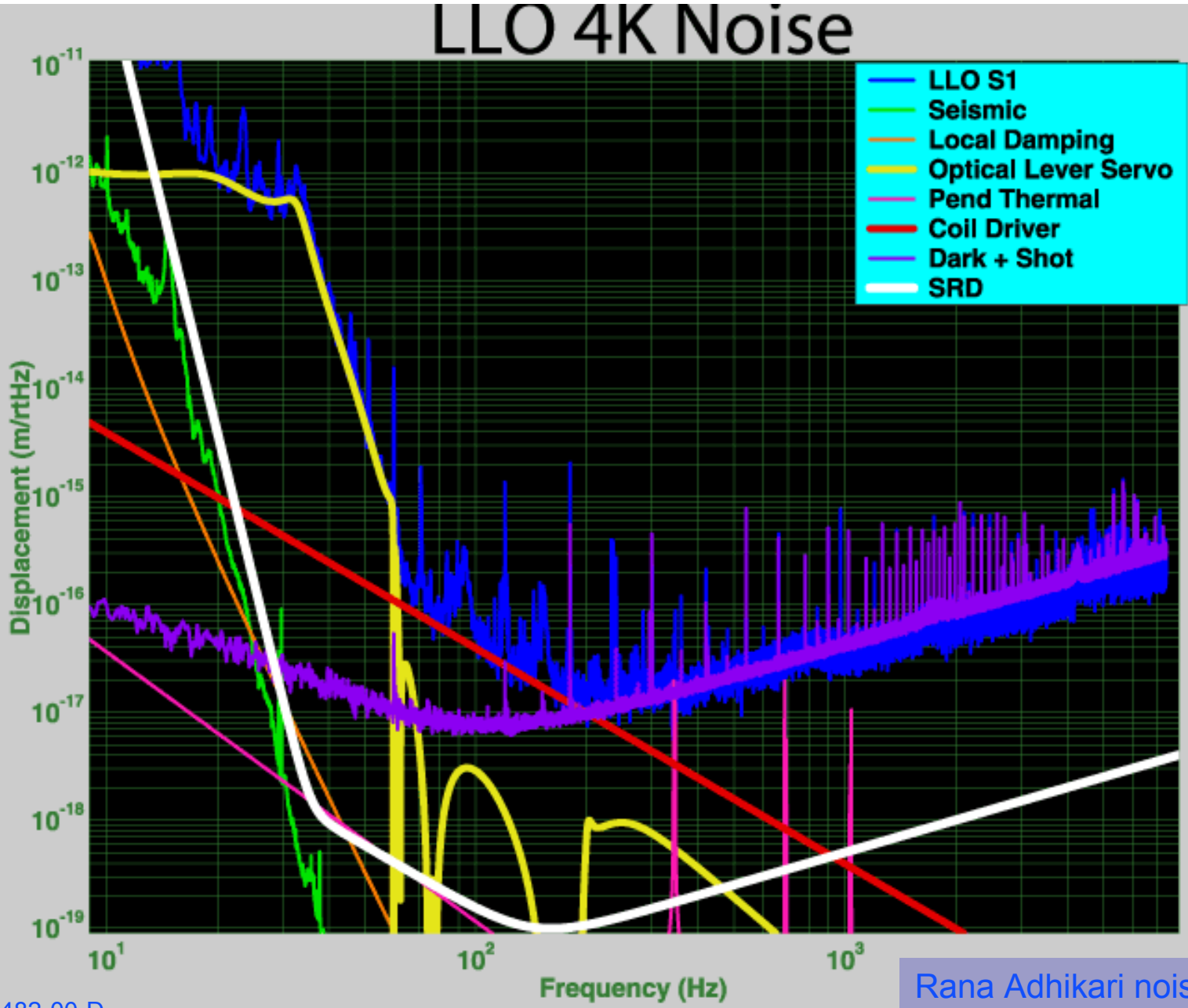
On behalf of the LIGO Scientific Collaboration

10th Marcel Grossman Meeting
On General Relativity
Rio de Janeiro, Brazil
July 20-26, 2003

Commissioning History



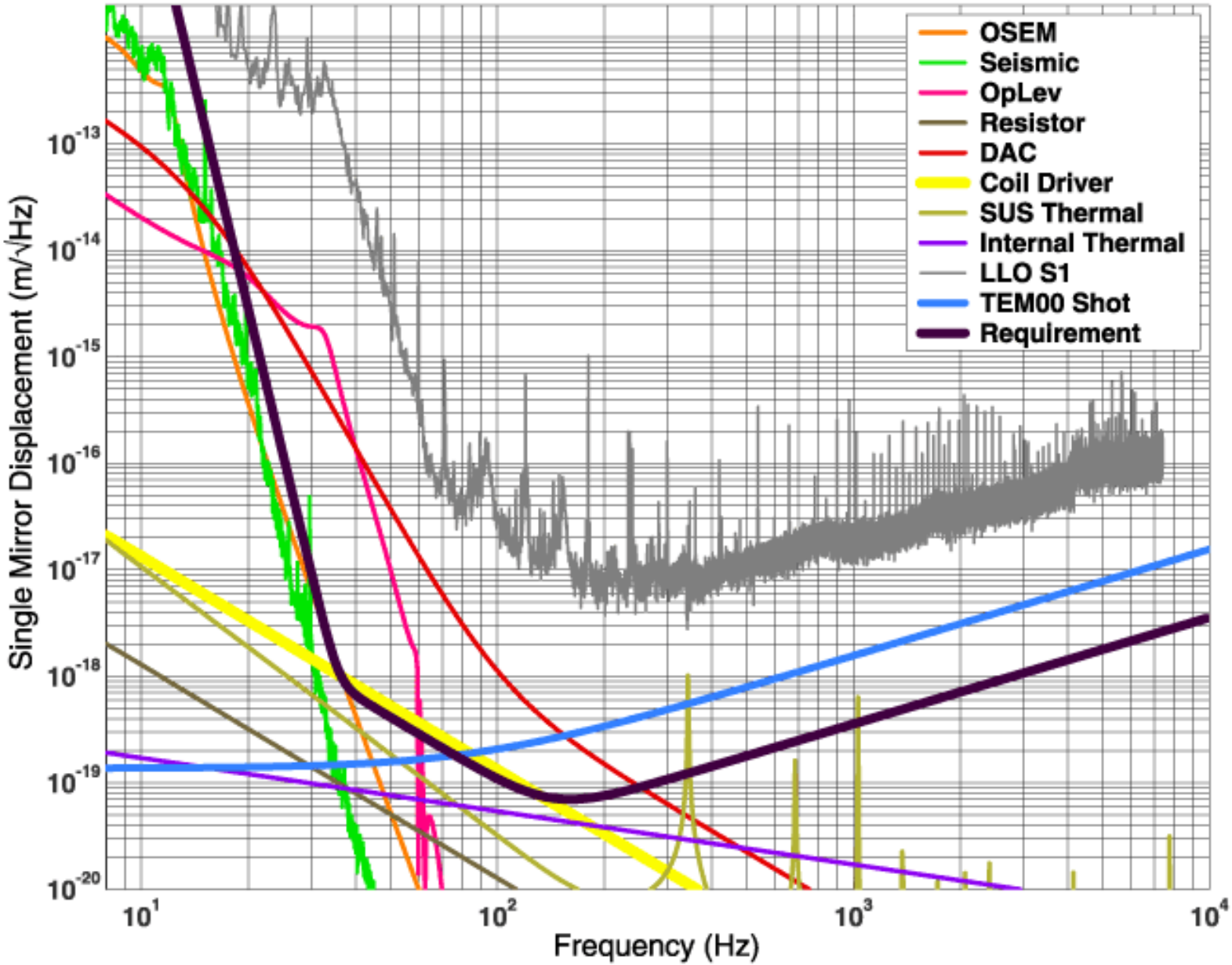
S1 Noise Component Analysis, LLO 4km

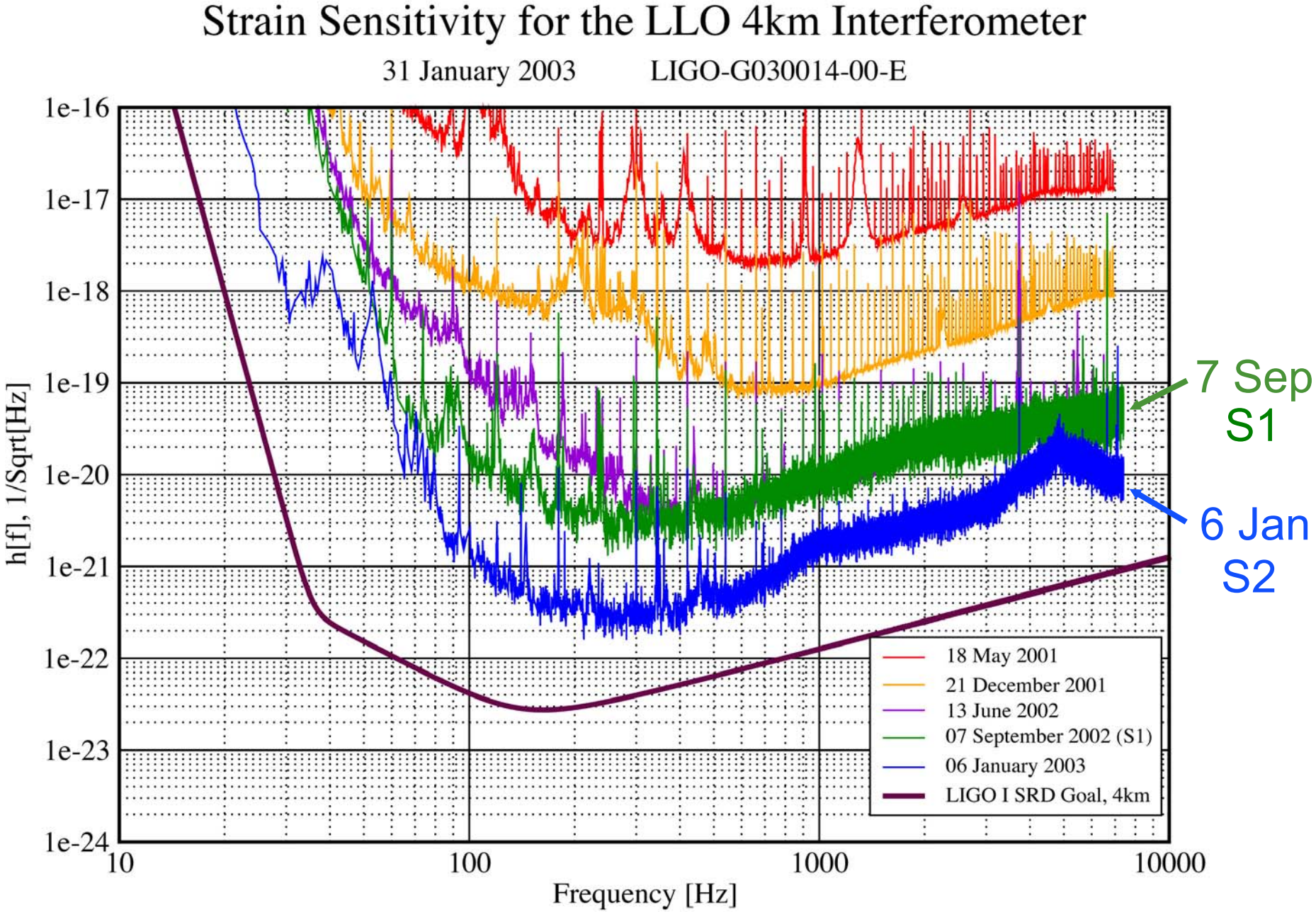


Rana Adhikari noise analysis

G020482-00-D

Estimated Noise Limits for S2




Strain Sensitivity for the LLO 4km Interferometer
31 January 2003
LIGO-G030014-00-E
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
18 May 2001
21 December 2001
13 June 2002
07 September 2002 (S1)
06 January 2003
LIGO I SRD Goal, 4km
7 Sep
S1
6 Jan
S2

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Changes Between S1 and S2

- Digital Suspensions installed on LHO-2K and LLO-4K
  - New coil drivers and real-time control code for suspensions
  - Lower noise, switchable dynamic range (200 mA acquisition, 5 mA running)
  - Separate DC biases for alignment
  - Better filtering, diagonalization and control/sequencing features
- Optical lever improvements
  - Structural stiffening (designed for thermal/kinematic stability, not low vibration)
  - Improved filtering to take advantage of reduced resonances
  - Pre-ADC "whitening" for improved dynamic reserve
- More Power
  - Enabled by better alignment stability
  - Also required control of "I-phase" photocurrent (overload)
  - Now ~1.5 W into mode cleaners, ~40 W at beamsplitter (R~40)
  - Only 10-20 mA average DC photocurrent at dark ports (optics very good)

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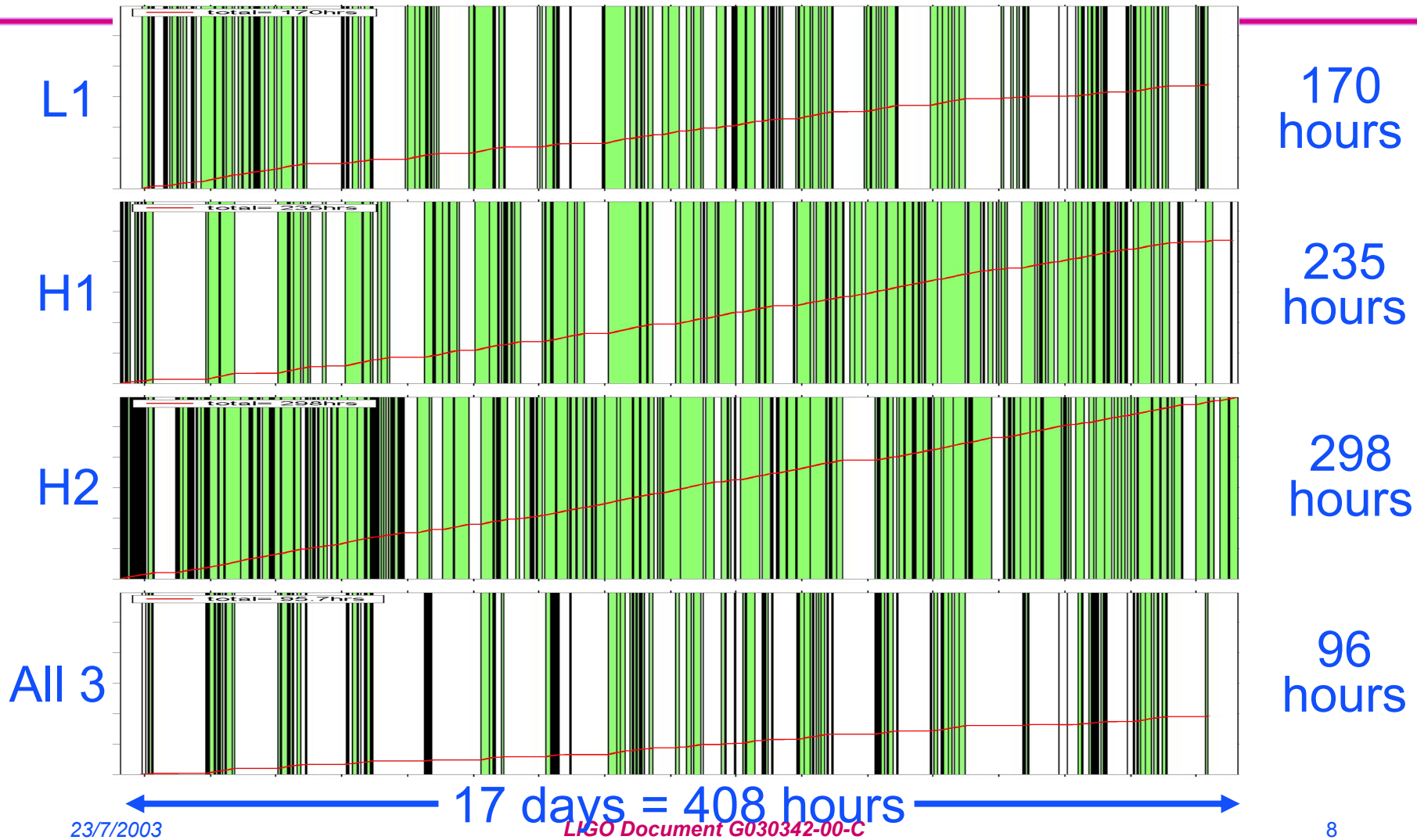
Second Science Run (S2)

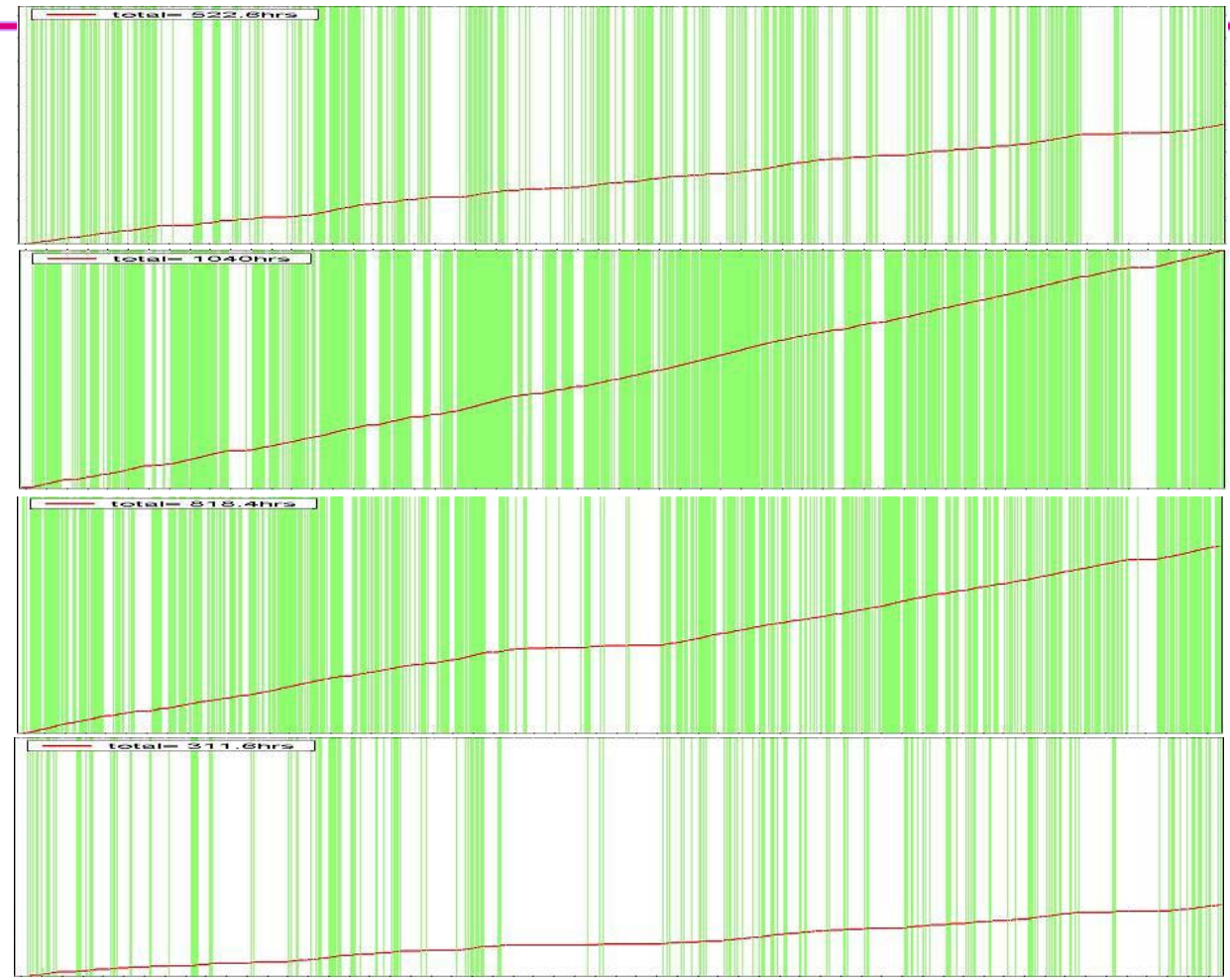
- February 14 – April 14, 2002 (~1400 hours)
- Three LIGO interferometers and TAMA (Japan)
- Steady improvement in sensitivity continues
  - Approximately 10x improvement over S1
- Duty cycle similar to S1
  - Increased sensitivity did not degrade operation
  - Longest locked stretch ~66 hours (LHO-4K)

	LLO-4K	LHO-4K	LHO-2K	Triple Coinc
Duty cycle (cf. S1)	37% (42%)	74% (58%)	58% (73%)	22% (24%)

S1 Lock Statistics



S2 Lock Statistics



L1 — 523 hours

H1 — 1040 hours

H2 — 818 hours

All 3 — 312 hours

59 days = 1415 hours

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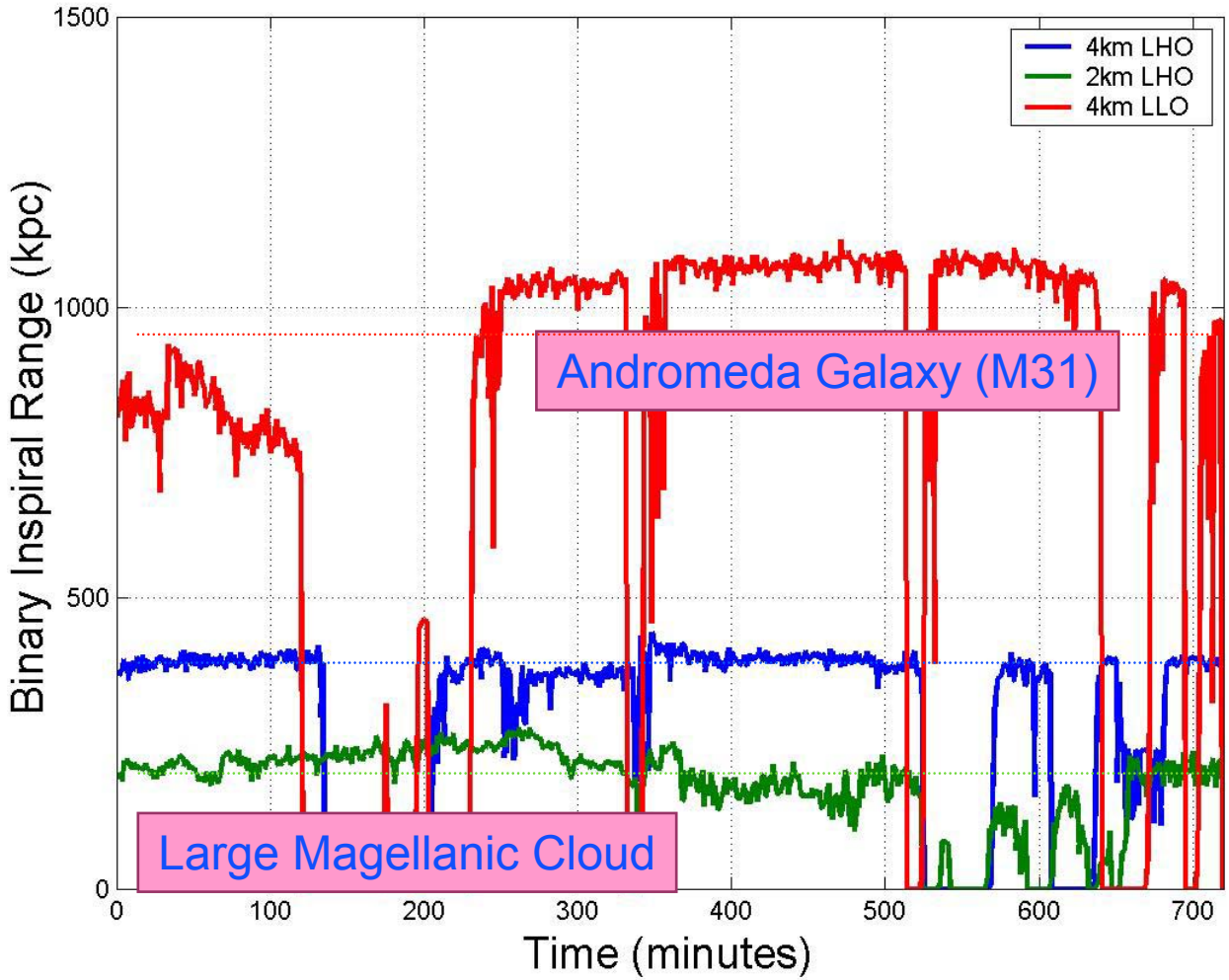
Stability improvements for S2

- Wavefront sensing (WFS) for alignment control
  - Uses the main laser beam to sense the proper alignment for the suspended optics
  - Complex - 10 coupled degrees of freedom
    - Sensing degrees-of-freedom different from control degrees-of-freedom
- S1
  - All interferometers had 2 degrees-of-freedom controlled by WFS
- S2
  - LHO-4K: 8 of 10 alignment degrees-of-freedom under feedback control
- Now
  - LHO-4k and LLO: All 10 degrees of freedom controlled by WFS

S2 Sensitivity and Stability



Major Ongoing Commissioning Activities

- Seismic retrofit at LLO
- Finish wavefront sensing alignment system
- RFI cleanup, linear power supplies
- Shot noise sensitivity
  - Thermal lensing
  - Increase of number of photodiodes
- Reduce acoustic coupling
- Numerous smaller tasks

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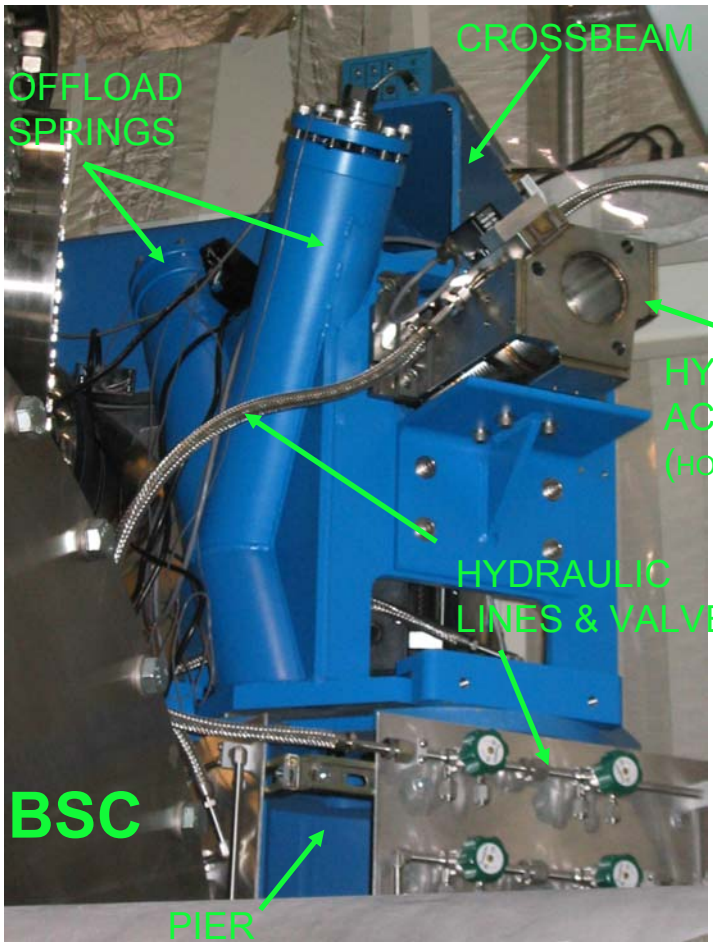
Seismic Isolation Upgrade

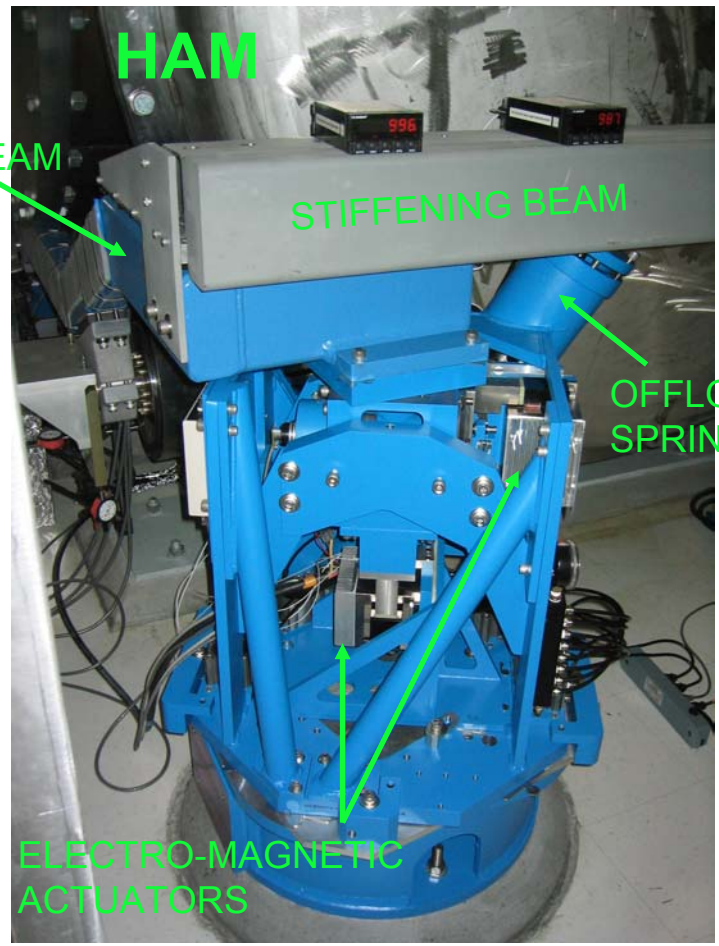
- Upgrade of Seismic Isolation System at LLO
  - Seismic noise environment much worse below 10 Hz than originally planned (logging largest factor, but also train, other anthropogenic noise)
  - Plan is to add an active, external pre-isolation (EPI) stage without disturbing the alignment of the installed optics
- Current Plan:
  - Continue prototype testing at MIT
  - Order components, fabricate and assemble; fabrication/assembly phase lasts ~5.5 months
  - Installation starts ~Jan '04 and should complete ~Apr '04

Seismic Isolation Testing at MIT

Hydraulic External Pre-Isolator (HEPI)

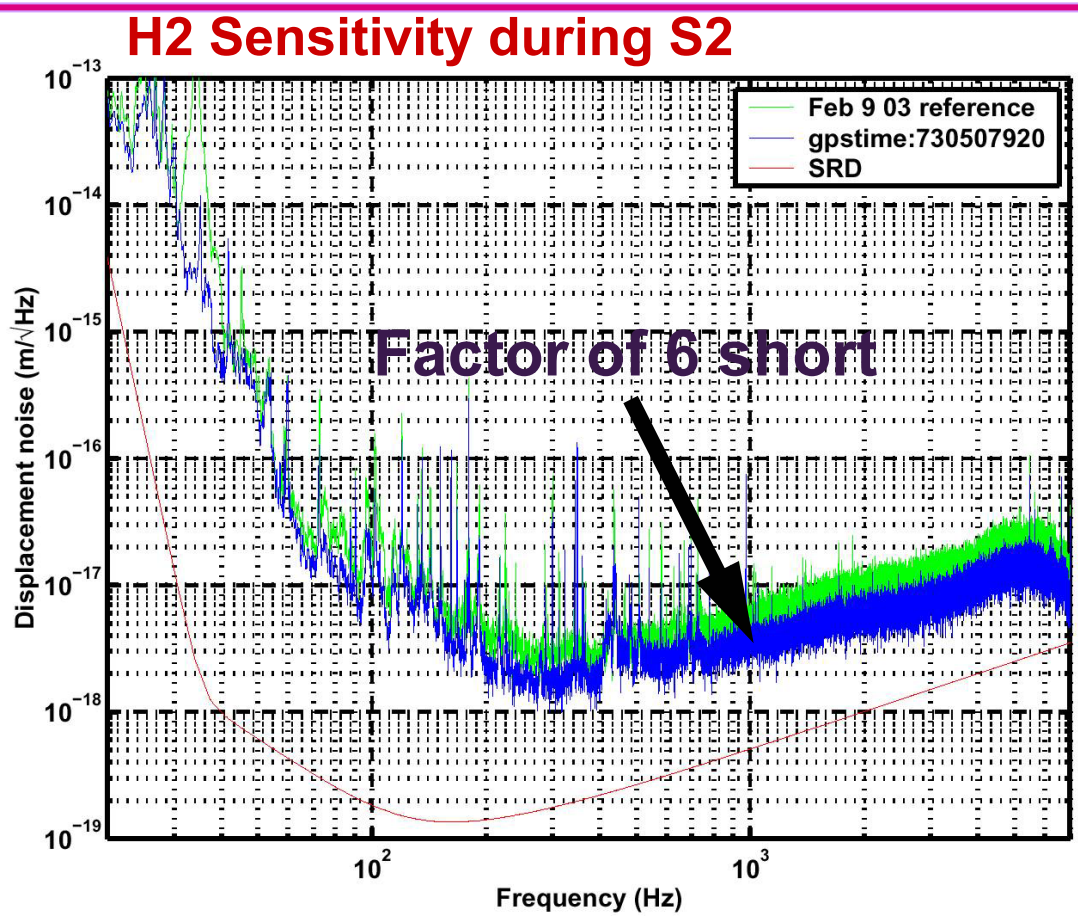


Electro-Magnetic External Pre-Isolator (MEPI)



Shot Noise Sensitivity

- Simplistic power calculations suggests factor of ~2 shortfall
  - 10x increase in laser power would give factor ~3 improvement
- Does not take improved sideband efficiency into account



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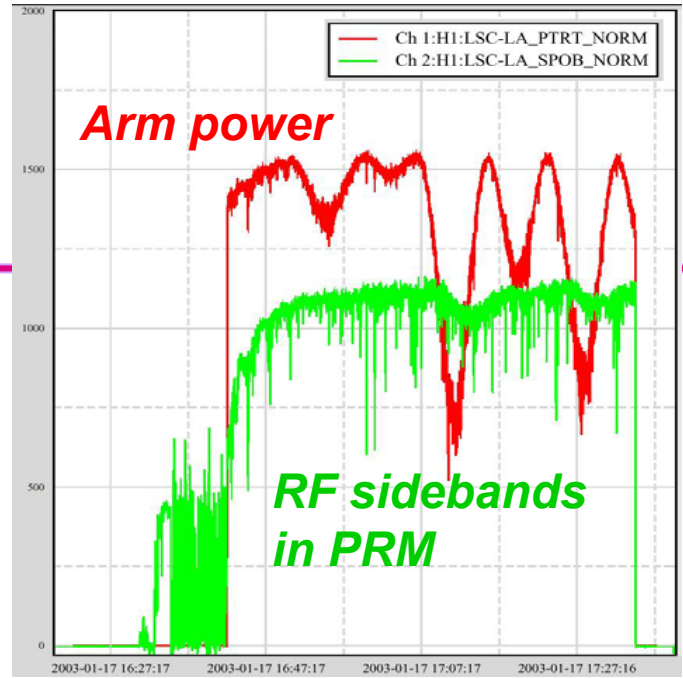
Optical characterization

- Good news: optics quality is (almost all) good
  - Recycling gain meets or exceeds goals (design was >30)
    - LLO-4K : Gain of nearly 50 seen, more usually about 45
    - LHO-4K : Gain of 40-45
  - Contrast defect meets or exceeds goals (design was < 10^{-3})
    - LLO-4K : $P_{as}/ P_{bs} = 3 \times 10^{-5}$
    - LHO-4K : $P_{as}/ P_{bs} = 6 \times 10^{-4}$
  - LHO-2K: Cause of low recycling gain (20) discovered
    - Bad AR coating on ITMX, has been replaced
- Low RF sideband gain/efficiency
  - LHO-4K : Sideband power efficiency to AS port: ~6%
  - Cause: thermal lensing in the ITMs isn't at the design level
  - Achieving shot noise goal requires that this be fixed

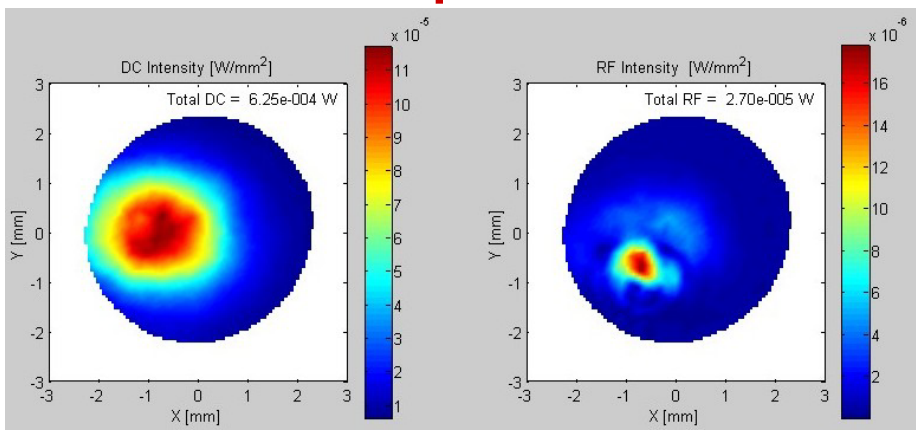
Thermal Lensing



ITM Heating

- RF sideband efficiency is low
  - Power recycling cavity slightly unstable: lack of Input Test Mass (ITM) thermal lens makes $g_1 \cdot g_2 > 1$
  - Recycling Mirror (RM) curvature relies on point design for thermal lensing
  - Heating differs from design value
- Possible solutions
  - Change RM (w/ new radius of curvature); 6 month lead time
  - Add the missing heat to ITMs with another source (AdvLIGO or GEO technique)
  - Pursued in parallel with other commissioning activities

Bad mode overlap



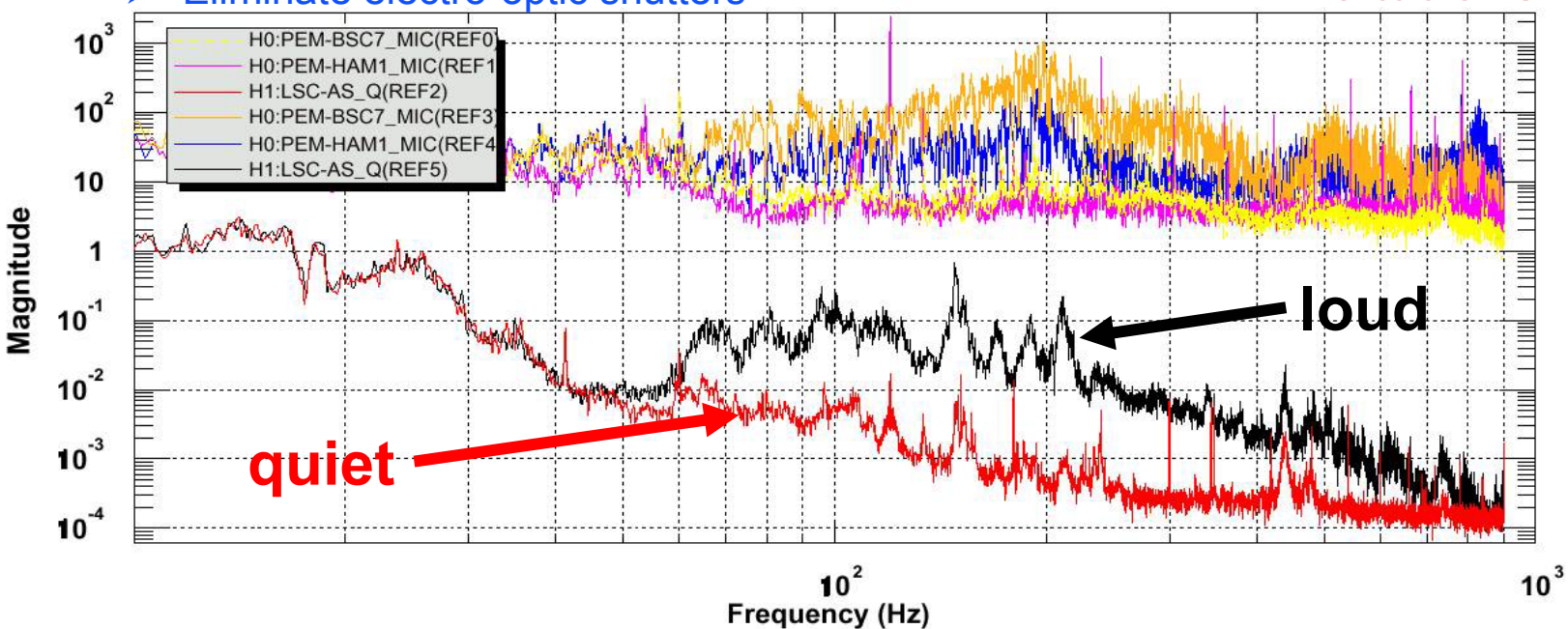
DC (carrier)

RF sidebands

Acoustic Peaks

- Peaks occur in 80-1000 Hz band, at 10-100x required level
- Source for LHO correlated noise (stochastic search)
- Investigating:
  - Acoustic isolation improvements
  - Modify output periscopes/mirror mounts: stiffer, damped
  - Active beam direction stabilization
  - Eliminate electro-optic shutters

Acoustic Excitations



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Summary

- Commissioning of detectors progressing well
  - Steady progression on all fronts: sensitivity, duty cycle, stability
  - Next Science Run: S3, Nov 2003 – Jan 2004
- First science analyses underway
  - S1 results demonstrate analysis techniques, S2 data (and beyond) offer a real possibility to detect gravitational waves
  - Developing synergy between detector commissioning and data analysis efforts
  - Four analysis papers (and one instrumental) in final stages of preparation
- Design performance (both sensitivity and duty cycle) should be achieved next year