Prospects for the S5 Run

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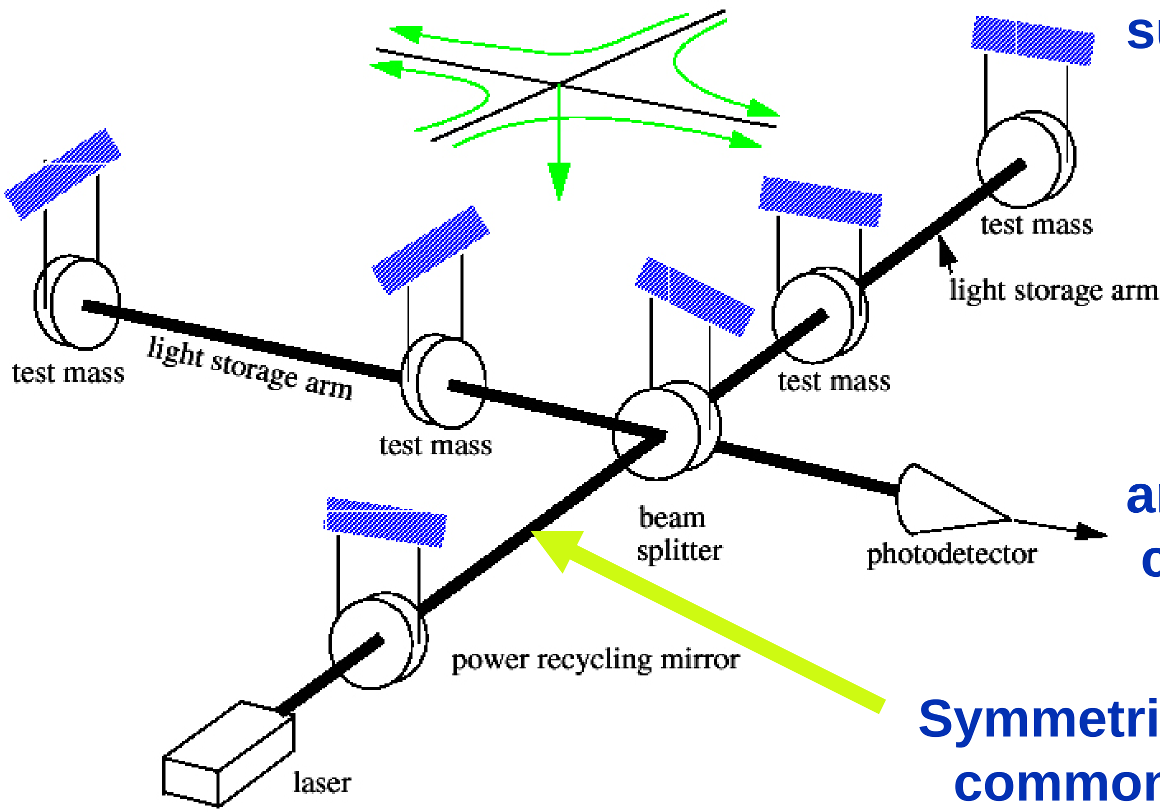
highlights

- Initial LIGO hardware
- What have we learned from running S1 $\Rightarrow$ S4
- Steps to S5; preparing for a long run
- Expectations
  - » Range/duty cycle goals
  - » Analysis goals
- Issues to study & resolve

Initial LIGO: Power-recycled Fabry-Perot-Michelson



suspended mirrors mark inertial frames

antisymmetric port carries GW signal

Symmetric port carries common-mode info

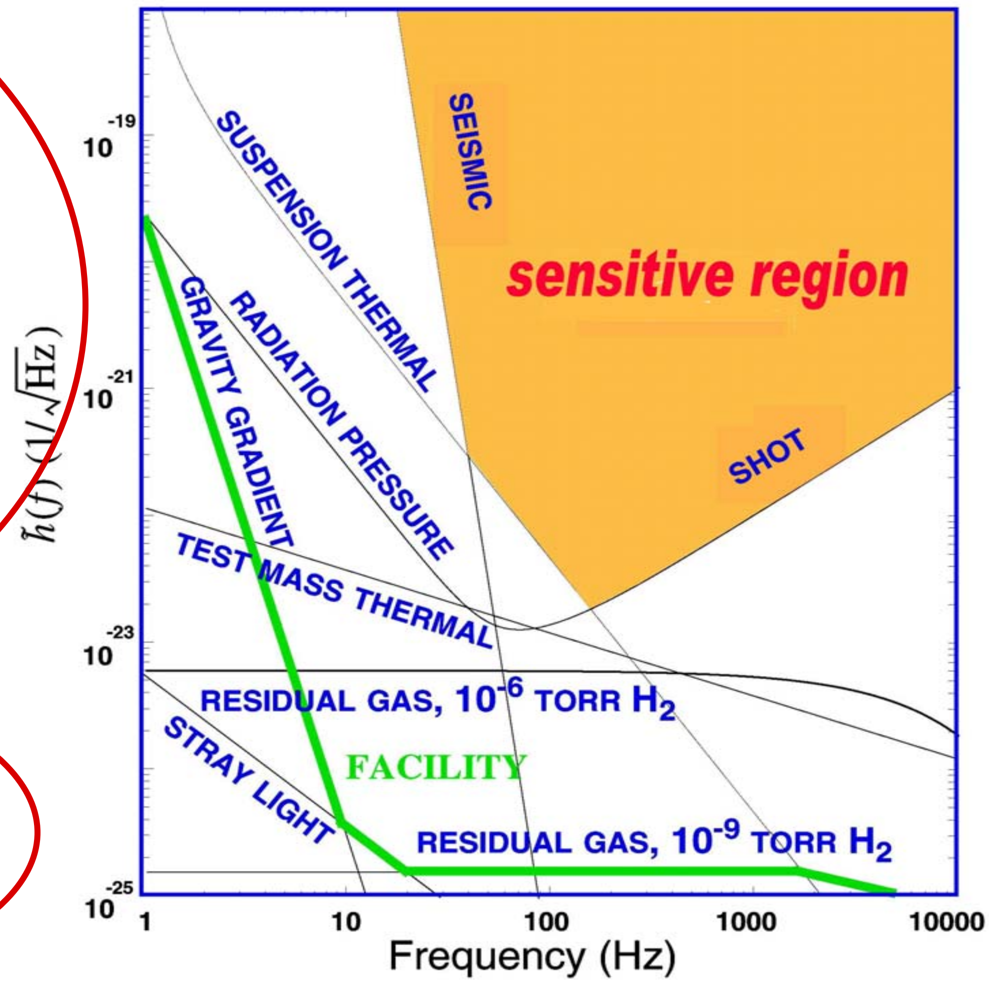
Intrinsically broad band and size-limited by speed of light.

What Limits Sensitivity of Interferometers?

DESIGN

- Seismic noise & vibration limit at low frequencies
- Atomic vibrations (Thermal Noise) inside components limit at mid frequencies
- Quantum nature of light (Shot Noise) limits at high frequencies
- Myriad details of the lasers, electronics, etc., can make problems above these levels

COMMISSIONING

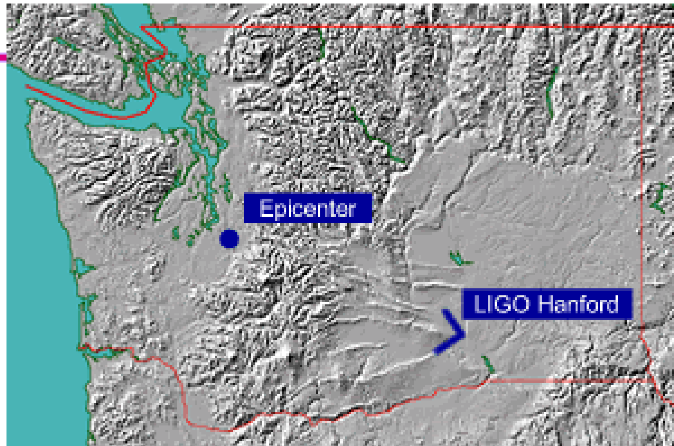


Some of the technical challenges for design and commissioning

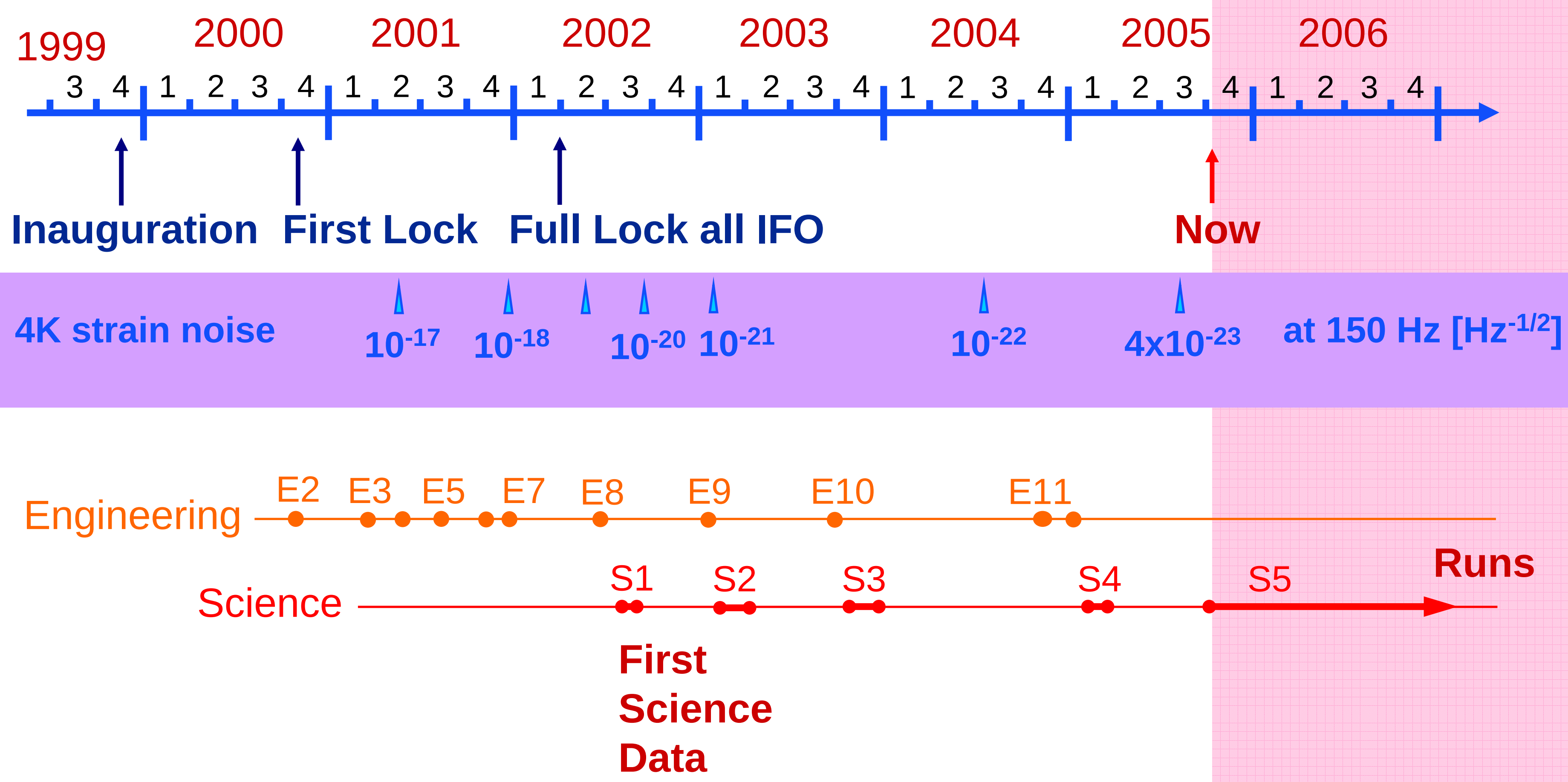
- ✓ Typical Strains < 10^{-21} at Earth ~ 1 hair's width at 4 light years
- ✓ Understand displacement fluctuations of 4-km arms at the millifermi level (1/1000th of a proton diameter)
- ✓ Control arm lengths to 10^{-13} meters RMS
- ✓ Detect optical phase changes of ~ 10^{-10} radians
- ✓ Hold mirror alignments to 10^{-8} radians
- ✓ Engineer structures to mitigate recoil from atomic vibrations in suspended mirrors
- Do all of the above 7x24x365

Starting soon at an observatory near you…

Also: keep tragedy away ✓



Commissioning and Running Time Line



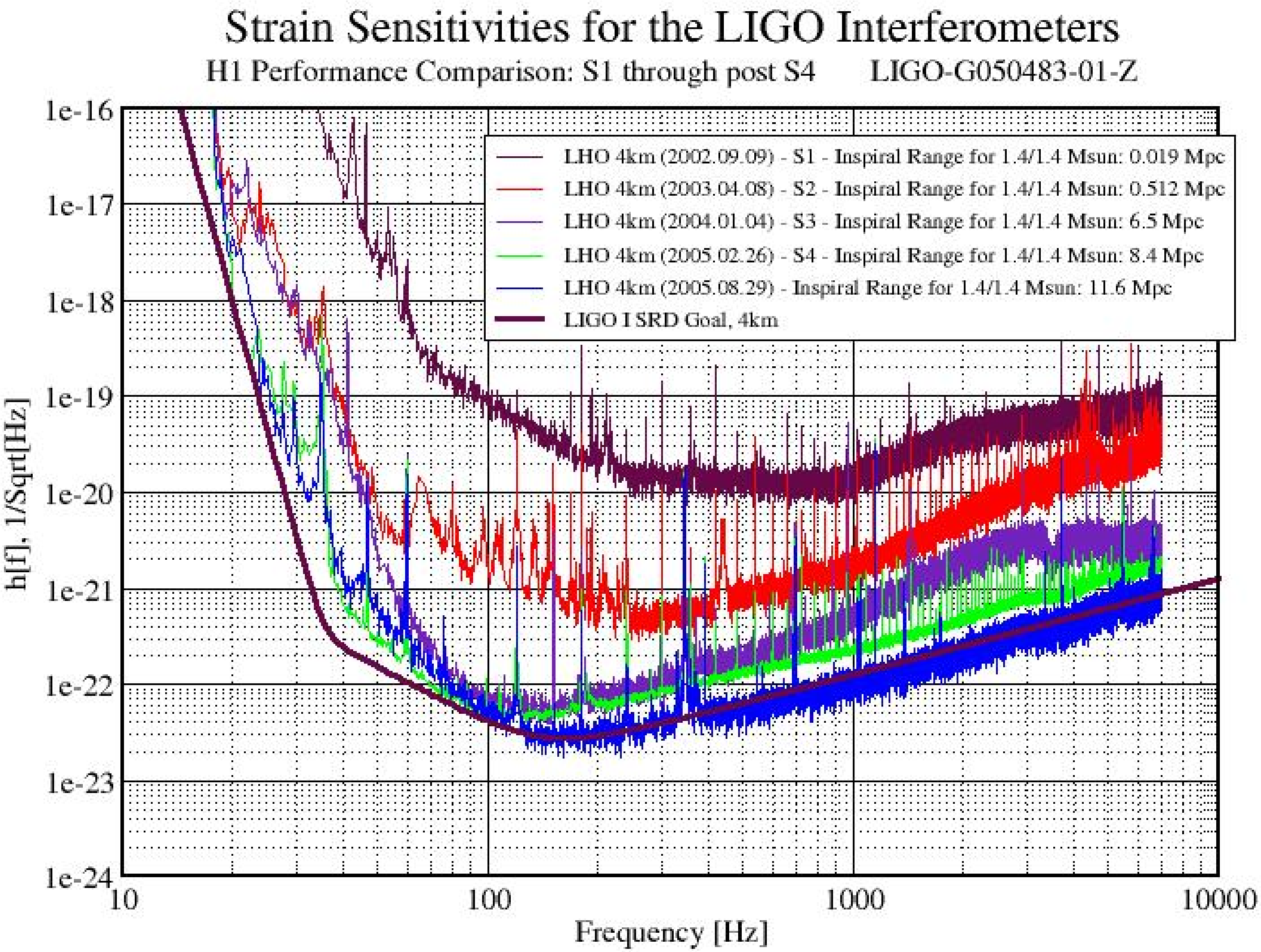
Feedback & Control for Mirrors and Light

- Damp suspended mirrors to vibration-isolated tables
  - » 14 mirrors × (pos, pit, yaw, side) = 56 loops
- Damp mirror angles to lab floor using optical levers
  - » 7 mirrors × (pit, yaw) = 14 loops
- Pre-stabilized laser
  - » (frequency, intensity, pre-mode-cleaner) = 3 loops
- Cavity length control
  - » (mode-cleaner, common-mode frequency, common-arm, differential arm, michelson, power-recycling) = 6 loops
- Wave-front sensing/control
  - » 7 mirrors × (pit, yaw) = 14 loops
- Beam-centering control
  - » 3 points × (pit, yaw) = 6 loops

LIGO Science Runs and what we learned from them…

- S1: 17 days in Aug-Sep 2002
  - » 3 LIGO interferometers in coincidence with GEO600 and ~2 days with TAMA300
- S2: Feb 14 – Apr 14, 2003
  - » 3 LIGO interferometers in coincidence with TAMA300
- S3: Oct 31, 2003 – Jan 9, 2004
  - » 3 LIGO interferometers in coincidence with periods of operation of TAMA300, GEO600 and Allegro
- S4: Feb 22 – Mar 23, 2005
  - » 3 LIGO interferometers in coincidence with GEO600, Allegro, Auriga

After a lot of effort, it works!



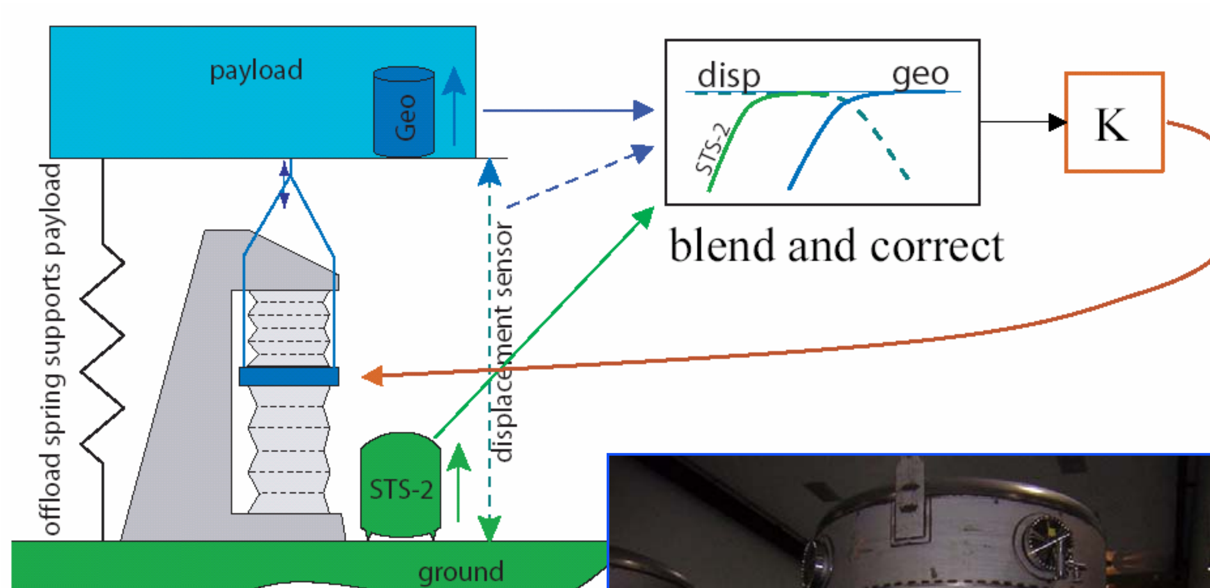
S3 showed we could meet our RMS goal, but…

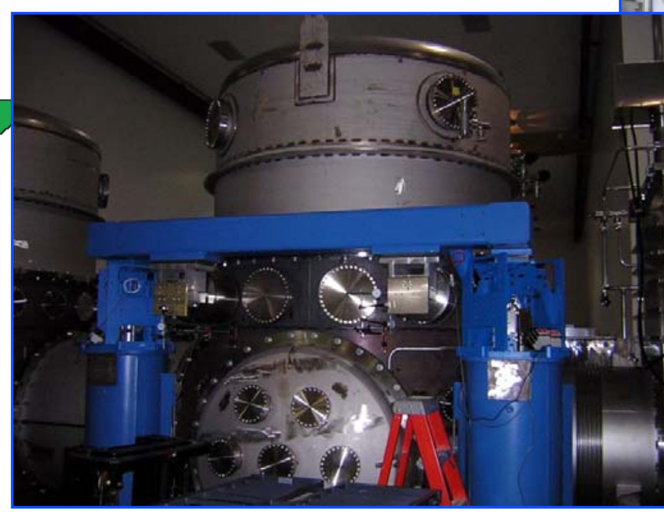
Needed to fix the duty cycle

Run	*S3*
L1	21.8%
H1	69.3%
H2	63.4%
Triple	15.8%

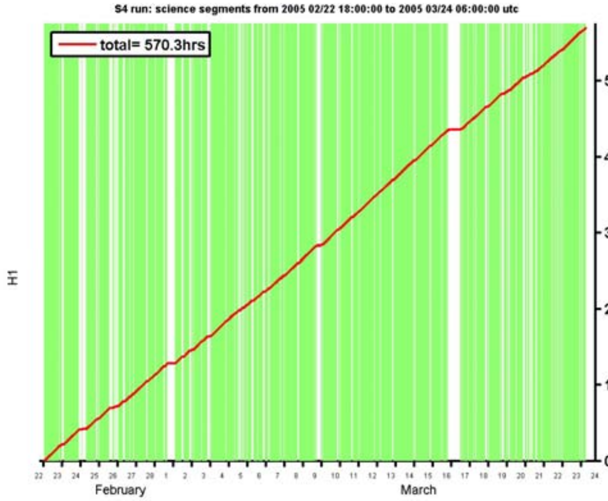
Also wanted to improve high-frequency operation

Installation of HEPI at Livingston has improved the stability of L1

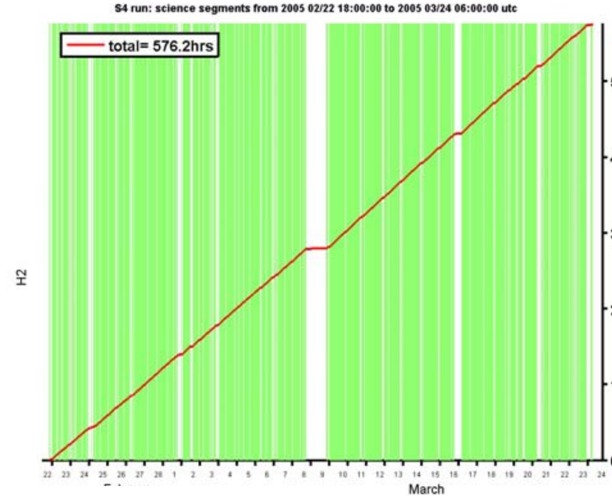




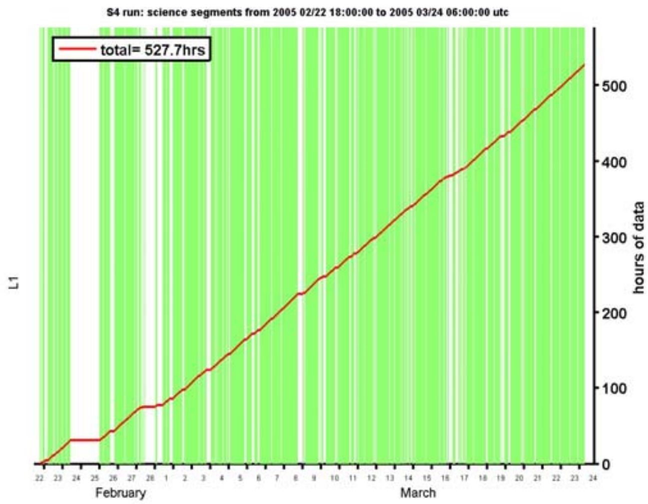
S4 Science Duty Cycle



H1: 80.5%



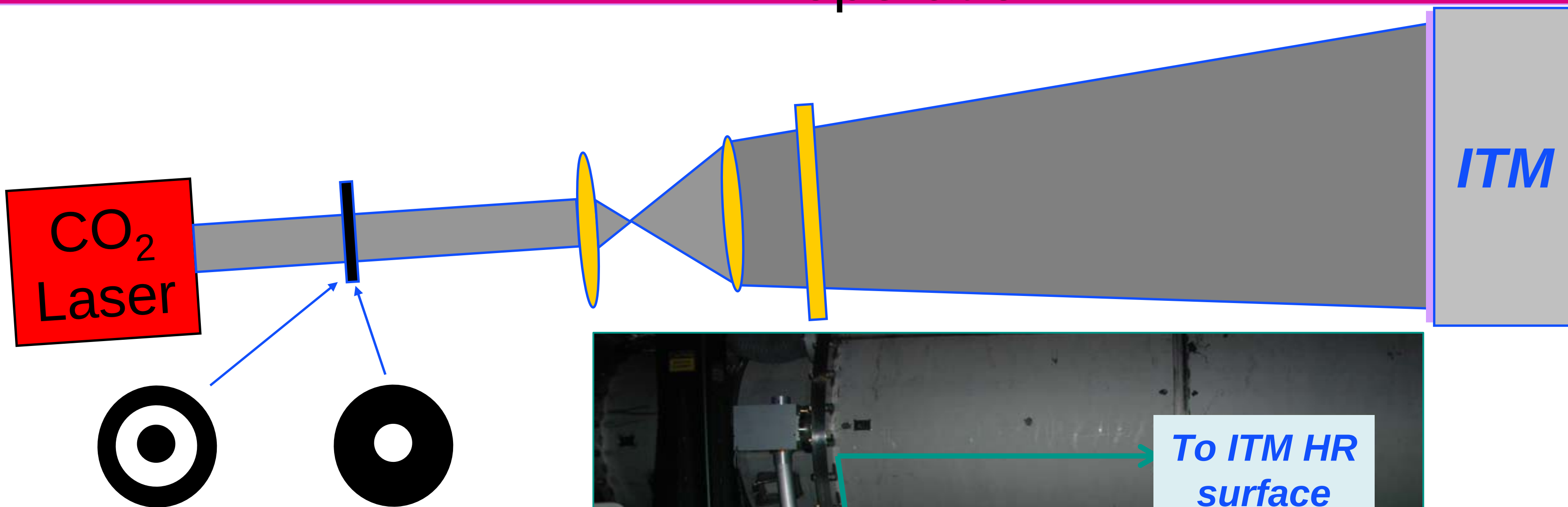
H2: 81.4%

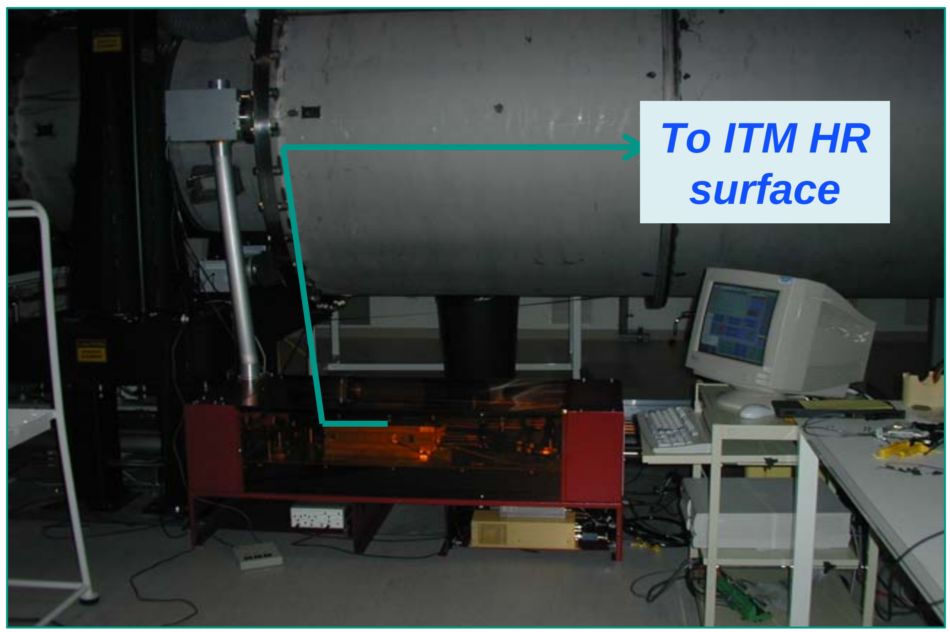


HEPI delivers!

L1: 74.5%

TCS system improves recycling cavity stability, facilitates the use of higher laser power in the interferometers, better high-frequency operation





Improvements since S4

- More laser power
- Improved oscillator phase noise
- Reduced acoustic coupling
- Reduction of dust-induced glitches
- Reduction of “dewar glitches”
- Improved alignment stability
- Reduced 60-Hz family of lines in L1
- Replaced absorbing H1:ITMX
- Improved REFL beam stability
- Microseism feedback on H1

We now think Initial LIGO detector is ready for a long run

Sensitivity targets*:

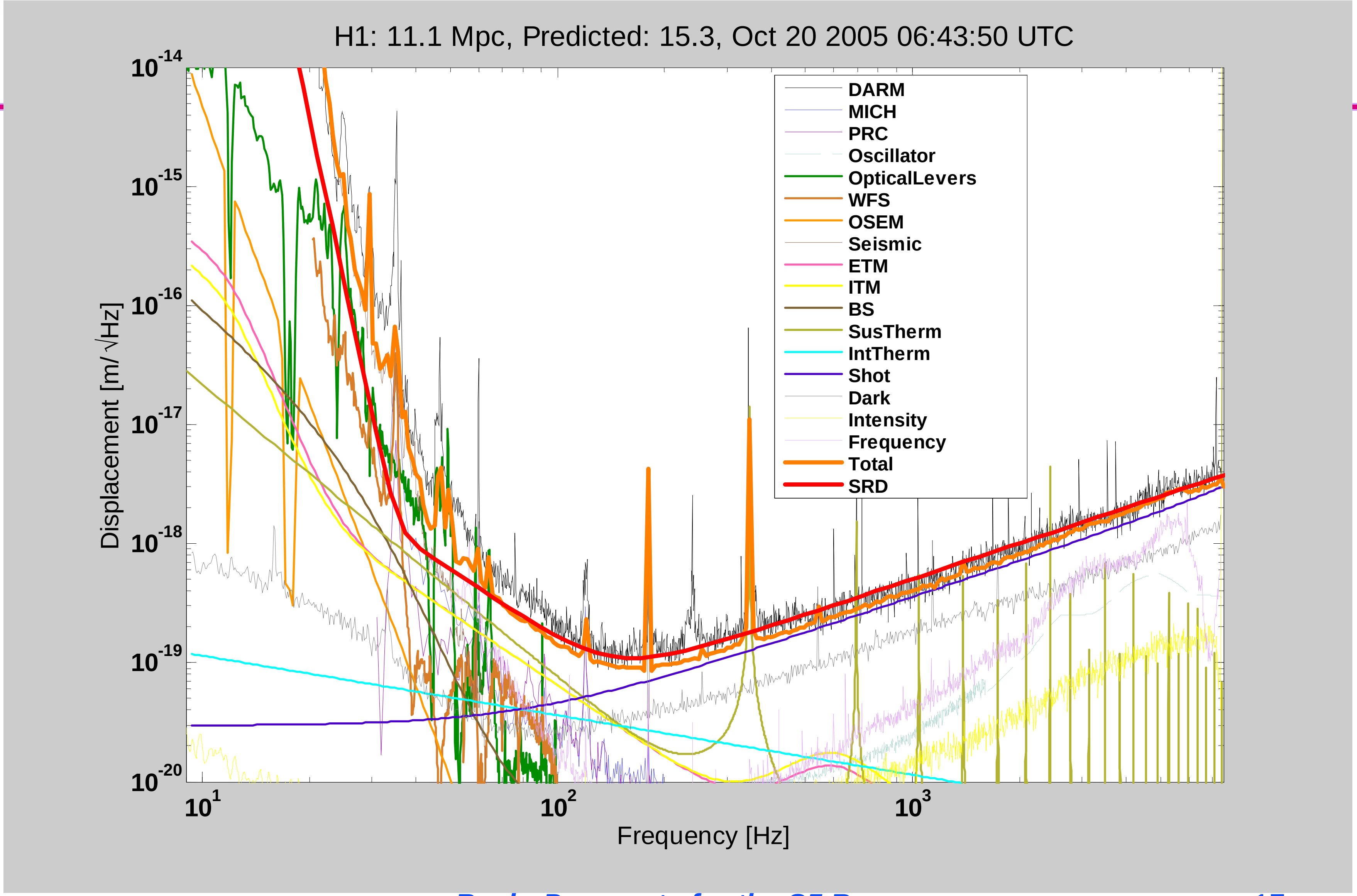
- H1 inspiral range ~ 10 Mpc
- L1 inspiral range ~ 10 Mpc
- H2 inspiral range ~ 5 Mpc

Duty Cycle targets:

Run	*S4*	*S5 Target*	*SRD goal*
L1	75%	85%	90%
H1	81%	85%	90%
H2	81%	85%	90%
3-way	57%	70%	75%

* As measured by SenseMon

Automated Noise Budget



Binary Inspiral Search: LIGO Ranges

binary neutron star range

binary black hole range

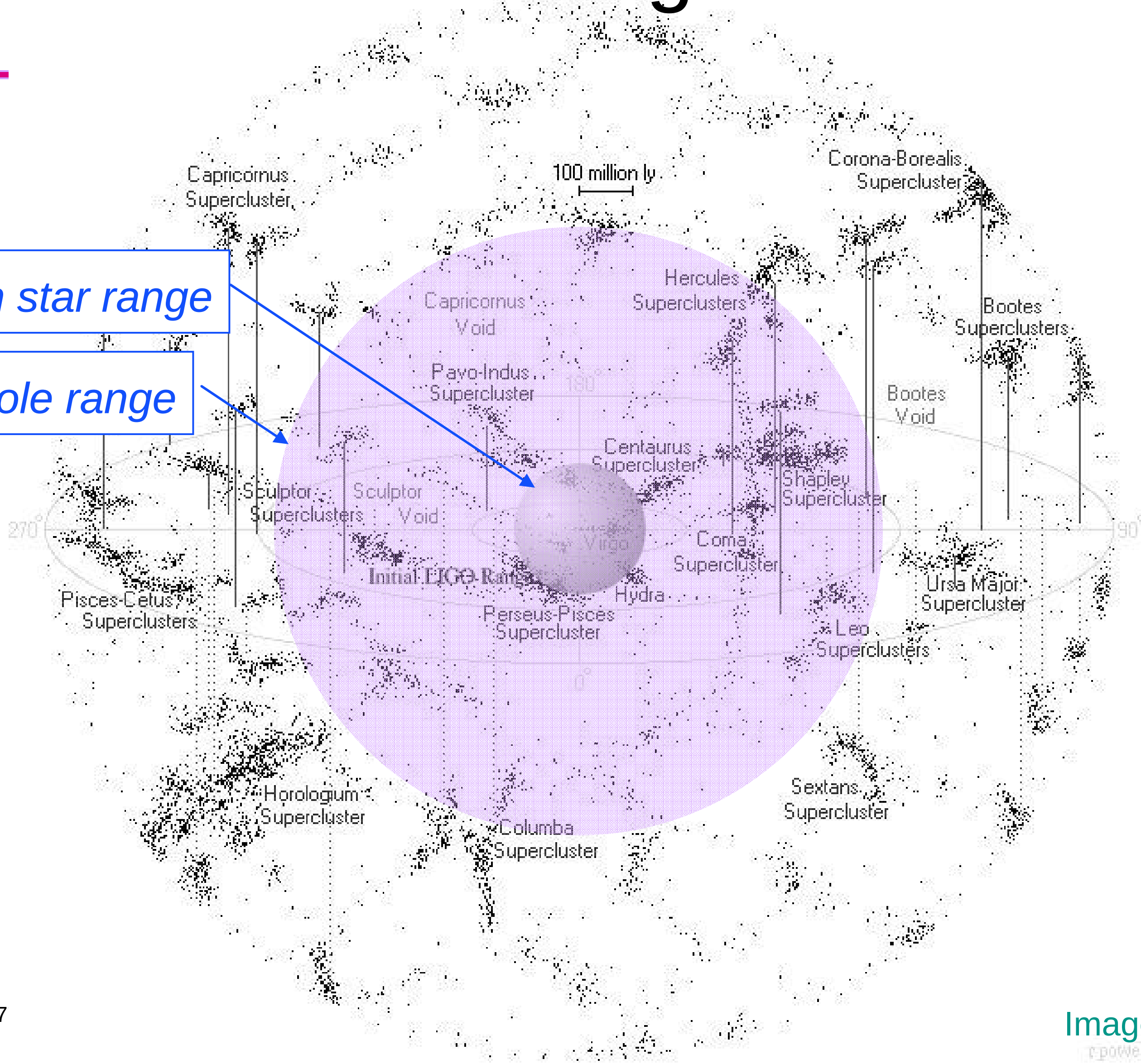
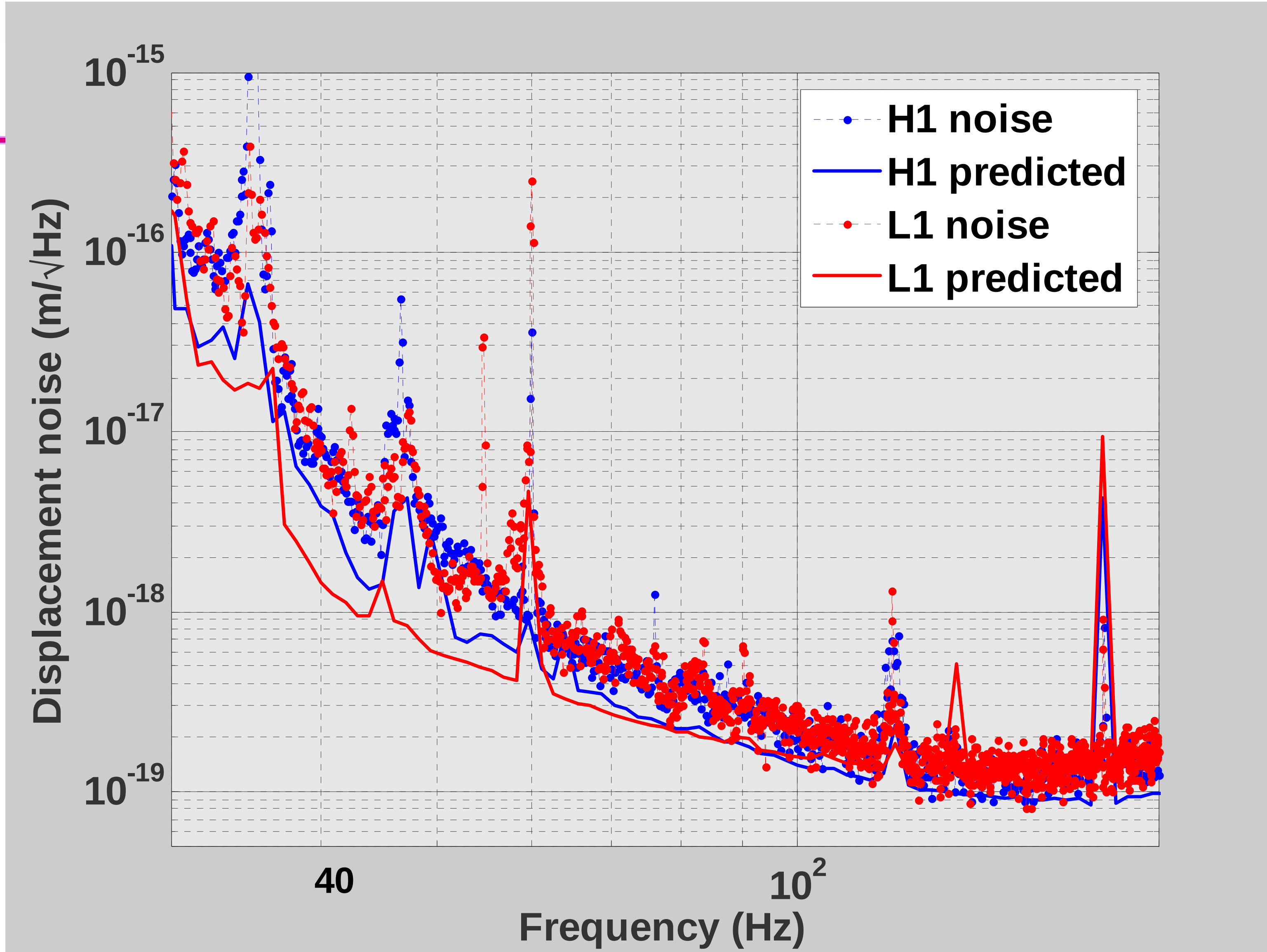


Image: R. Powell

Issues to resolve

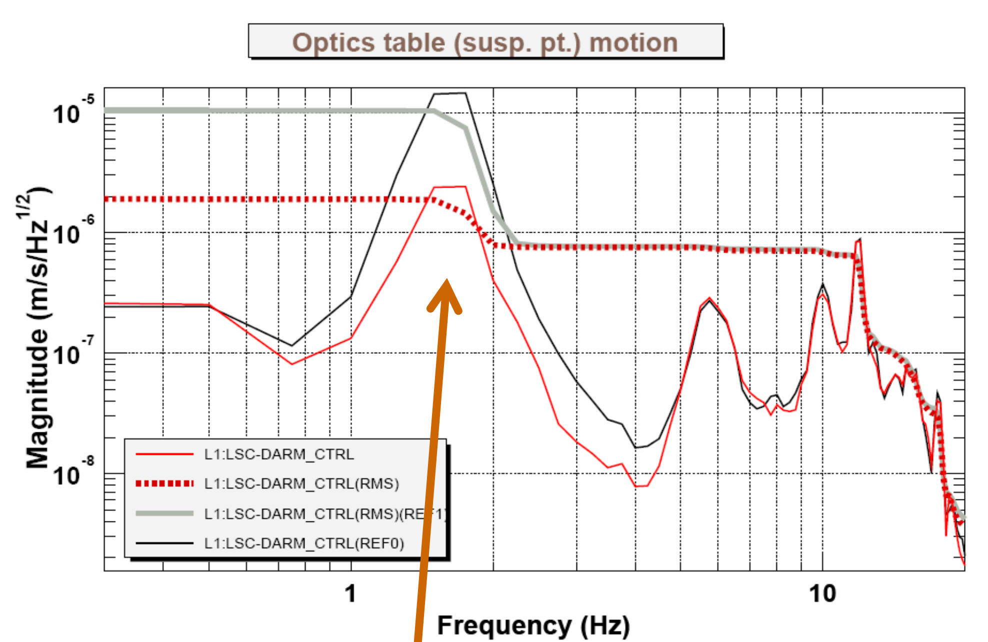
- At current sensitivity and duty cycle, it would be a shame not to start a long run, but some issues remain to be resolved during the run
- Use monitors to identify sources of instrumental transients
- Identify low-frequency noise to extend range
- Upconversion is known to be important
  - » Need better vetoes
  - » Identify and mitigate sources
- Near “the wall” on high power operation
  - » Protective shutters to handle loss of lock have a tough time
  - » Steady state AS-port light is stressing photodiodes to limit
  - » Need to design and implement an output mode cleaner to enable higher power operation (probably post-S5)

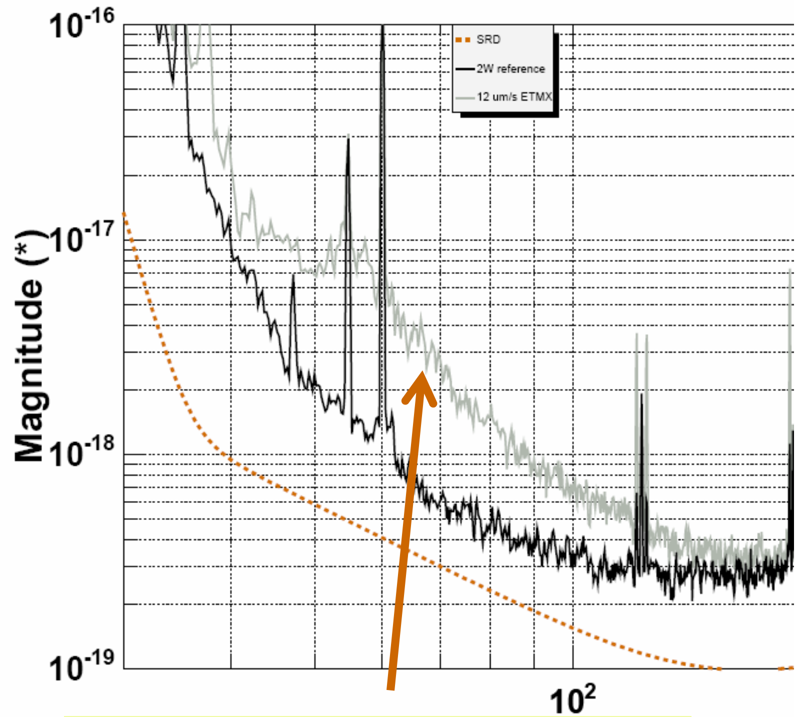
Low frequency noise not explained



Possible source: upconversion from stack motion

Effect measured both at LHO & at LLO:



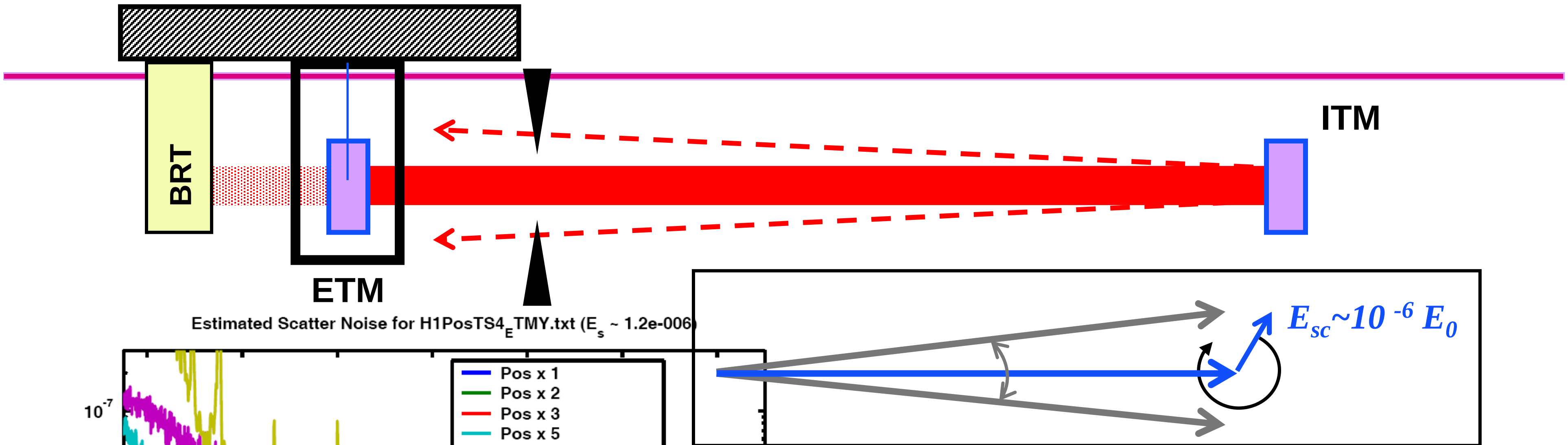


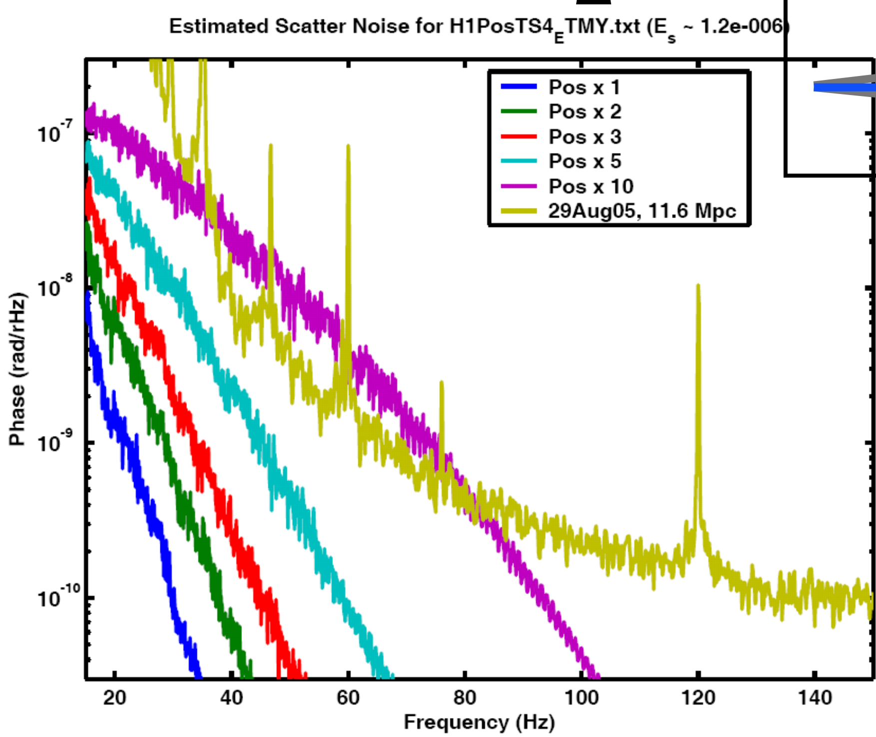
Using HEPI, increase the suspension point motion at 1.5 Hz by a factor of 5

DARM noise increases significantly over a wide band

H1 exhibits a day-to-night variation in low frequency noise, with a ~10% reduction in inspiral range during the day

Scattered light fringe wrapping?

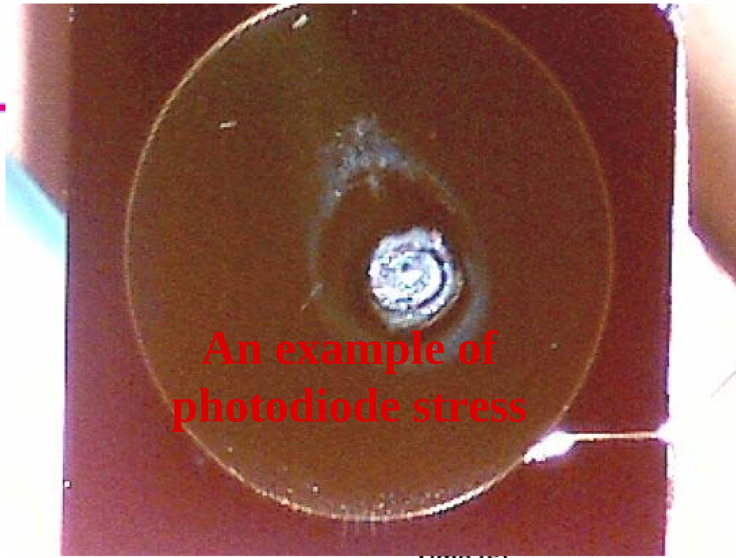




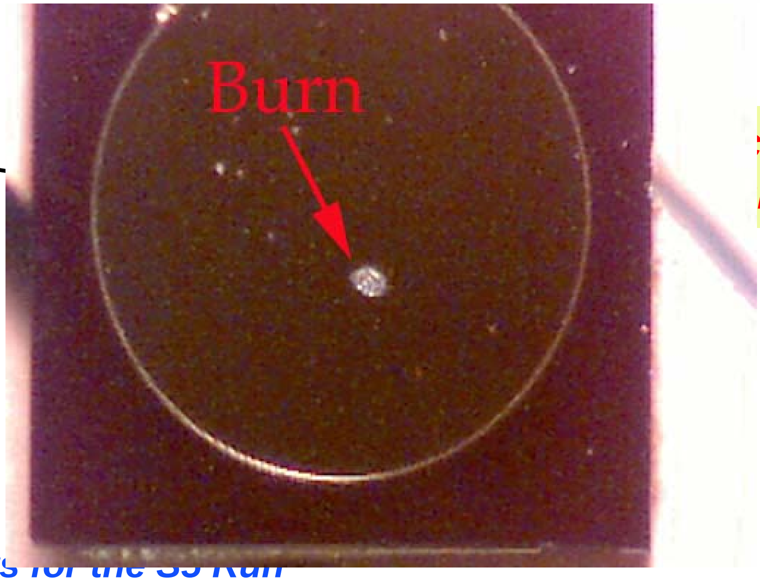
For 1% reflection from beam reducing optics & excitation of ETMX only

Stress at the antisymmetric port:

- Loss-of-lock: full beamsplitter power can be dumped out the AS port, in a ~10 msec width pulse
- PD damage due to
  - » Too high trigger level
  - » Shutter failure
  - » Shutter too slow
- Damaged PDs can be noisy and position-dependent
- Working on shutter improvements
- Steady-state stress (principally due to AS_I saturation) needs relief



100 W



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What to expect from S5 analyses

- Sensitivity to bursts ~10^{-21} RMS
- Sensitivity to neutron-star inspirals at Virgo cluster
- Pulsars
  - » expect best limits on known neutron star ellipticities at few x10^{-7}
  - » expect to beat spindown limit on Crab pulsar
  - » Hierarchical all-sky/all-frequency search
- Cosmic GW background limits expected to be near Ω_{GW}~10^{-5}
- Perhaps a discovery?

These are exciting times!

Cosmic Mystery Solved

FEATURE

Swift Spacecraft Solves Mystery of Short Gamma-Ray Bursts **10.05.05**

Scientists have solved a 35-year-old mystery of the origin of powerful, split-second flashes of light called short gamma-ray bursts. These flashes, brighter than a billion suns yet lasting only a few milliseconds, have been simply too fast to catch... until now.

If you guessed that a black hole is involved, you are at least half right. Short gamma-ray bursts arise from collisions between a black hole and a neutron star or between two neutron stars. In the first scenario, the black hole gulps down the neutron star and grows bigger. In the second scenario, the two neutron stars create a black hole.

Click on images for high resolution

Pinning down origins of short GRBs will result in more solid estimates of NS-NS and NS-BH mergers

Groups led by Burrows and Wheeler now have supernova models that explode! Expect to see action in re-computing GWB waveforms.

On the more speculative front…

Graphic from KITP newsletter, heralding an observable string theory prediction: GWs from cosmological strings may be verified by LIGO in its first long science run.

Closing remarks…

- Progressive detector improvements have achieved design goals
- Early implementation of Advanced LIGO techniques helped achieve goals
  - » HEPI for duty-cycle boost
  - » Thermal compensation of mirrors for high-power operation
- Some commissioning breaks expected during S5 to improve performance and/or reliability
- Believe still room for post-S5 improvements

The Beginning