Status of LIGO

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for the LIGO Scientific Collaboration

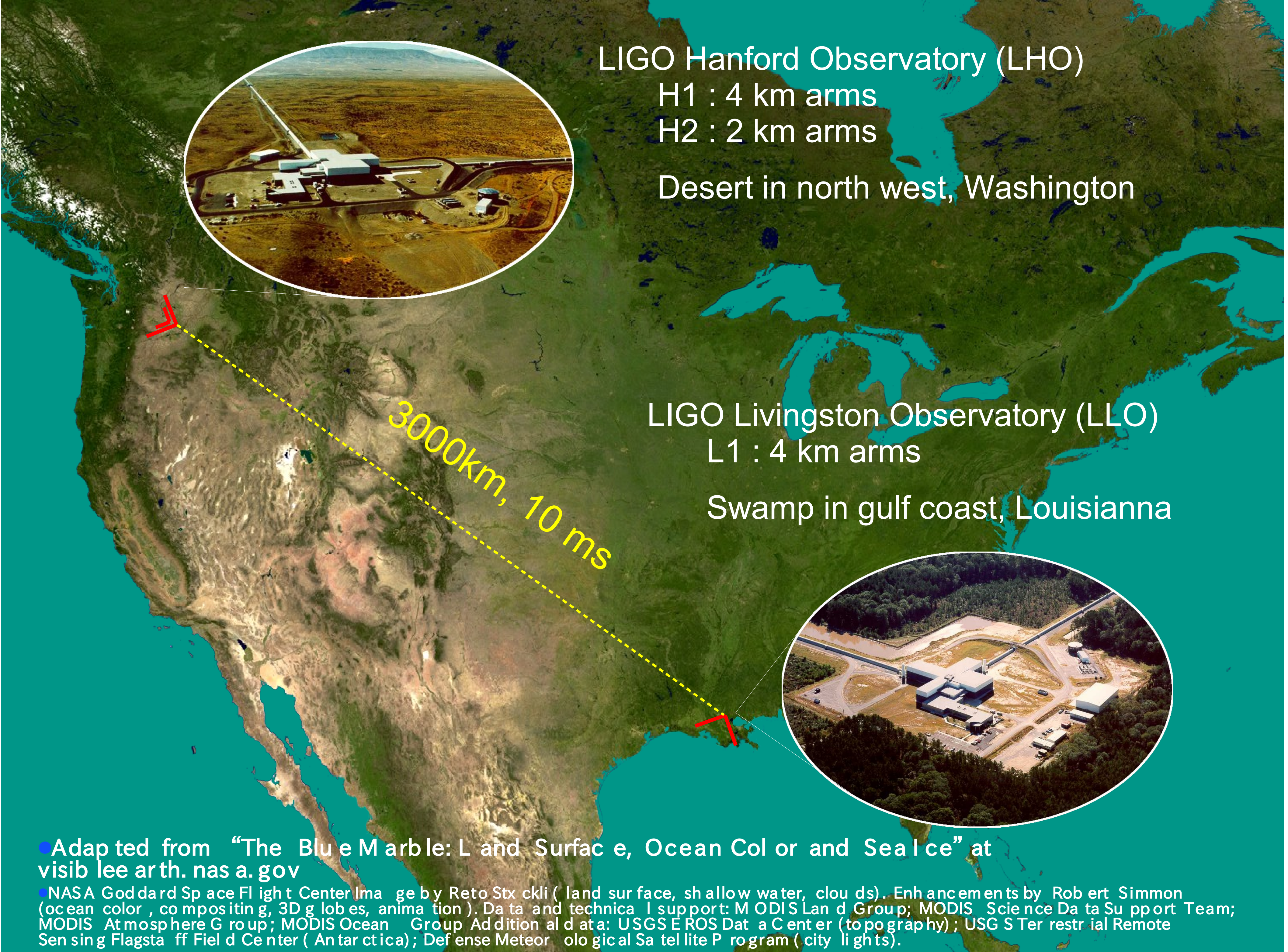
TOC

- Who we are
  - Introduction to LIGO and LSC
- Where we are at now
  - Status of Current Science Run (S5)
  - Detector Performance etc.
- Future

Who We Are

Who We Are

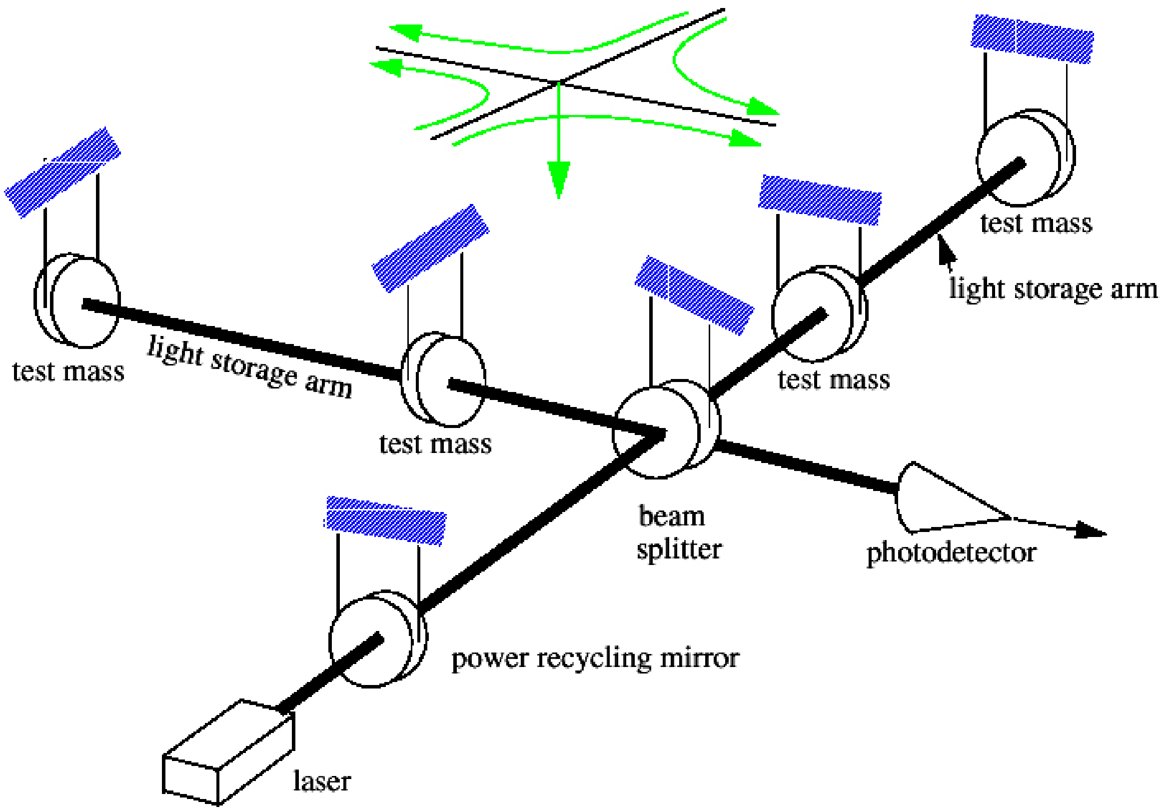
- Laser Interferometer Gravitational-Wave Observatory
- Funding: NSF
- Operation: Caltech-MIT
- 2 observatories, 3 detectors
  - Hanford (LHO), 4km & 2km, (30+ local staffs)
  - Livingston (LLO), 4km, (30+ local staffs)
- CIT/MIT staffs outside of site (more than 100)
- LIGO Scientific Collaboration (LSC), a body carrying out the scientific program of LIGO (about 570 as of now, all over the world)



- Adapted from "The Blue Marble: Land Surface, Ocean Color and Sea Ice" at visibleearth.nasa.gov
- NASA Goddard Space Flight Center Image by Reto Stöckli (land surface, shallow water, clouds). Enhancements by Robert Simmon (ocean color, compositing, 3D globes, animation). Data and technical support: MODIS Land Group; MODIS Science Data Support Team; MODIS Atmosphere Group; MODIS Ocean Group Additional data: USGS EROS Data Center (topography); USGS Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights).

Detection concept

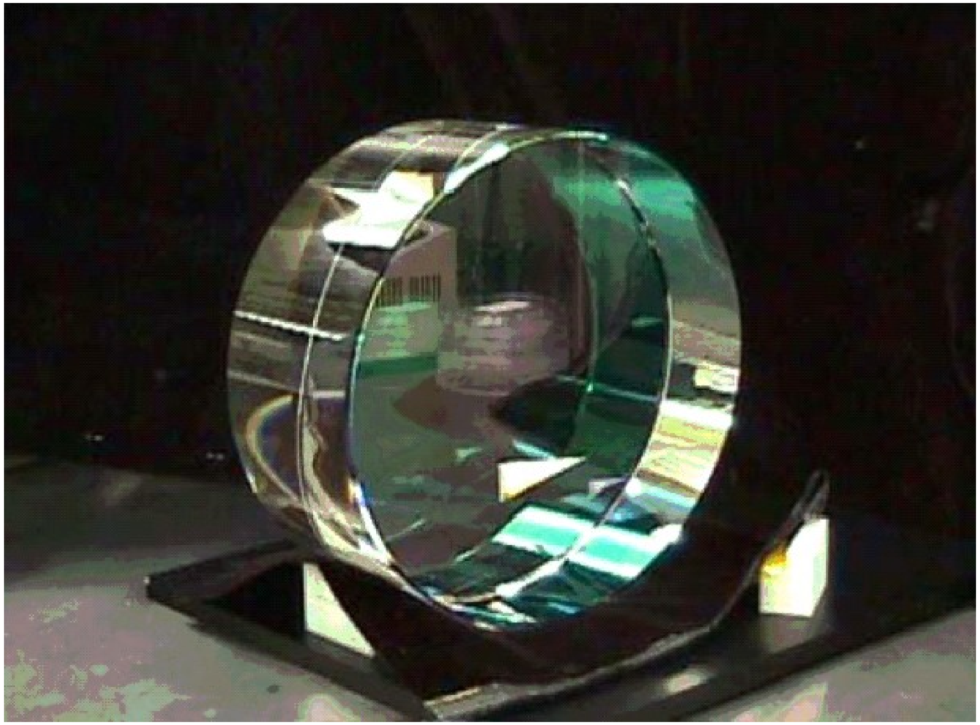
- Compare the travel time of photons in orthogonal directions using laser interferometer



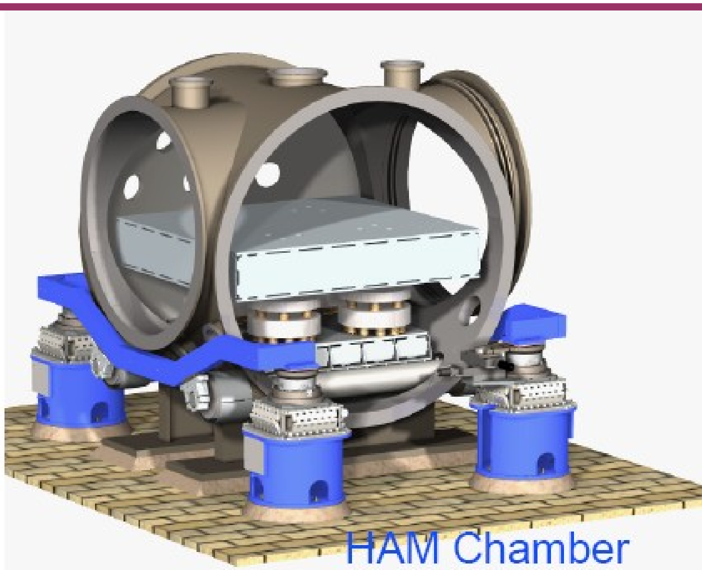
- Power-recycled,
- Michelson IFO,
- Fabry-Perot arms
  - 4km (or 2km)

Initial LIGO Core Optics

- Substrate: SiO_2
  - 25cm diam x 10cm thick
  - Homogeneity < 5×10^{-7}
  - Internal mode Q factor > 2×10^{6}
- Polishing
  - Surface uniformity < 1nm rms
  - Radius of curvature matched < 3%
- Coating
  - Scatter < 50ppm
  - Absorption < 2ppm
  - Uniformity < 10^{-3}



Core Optics Suspention and Vibration Isolation



Vibration-isolated chambers using stack

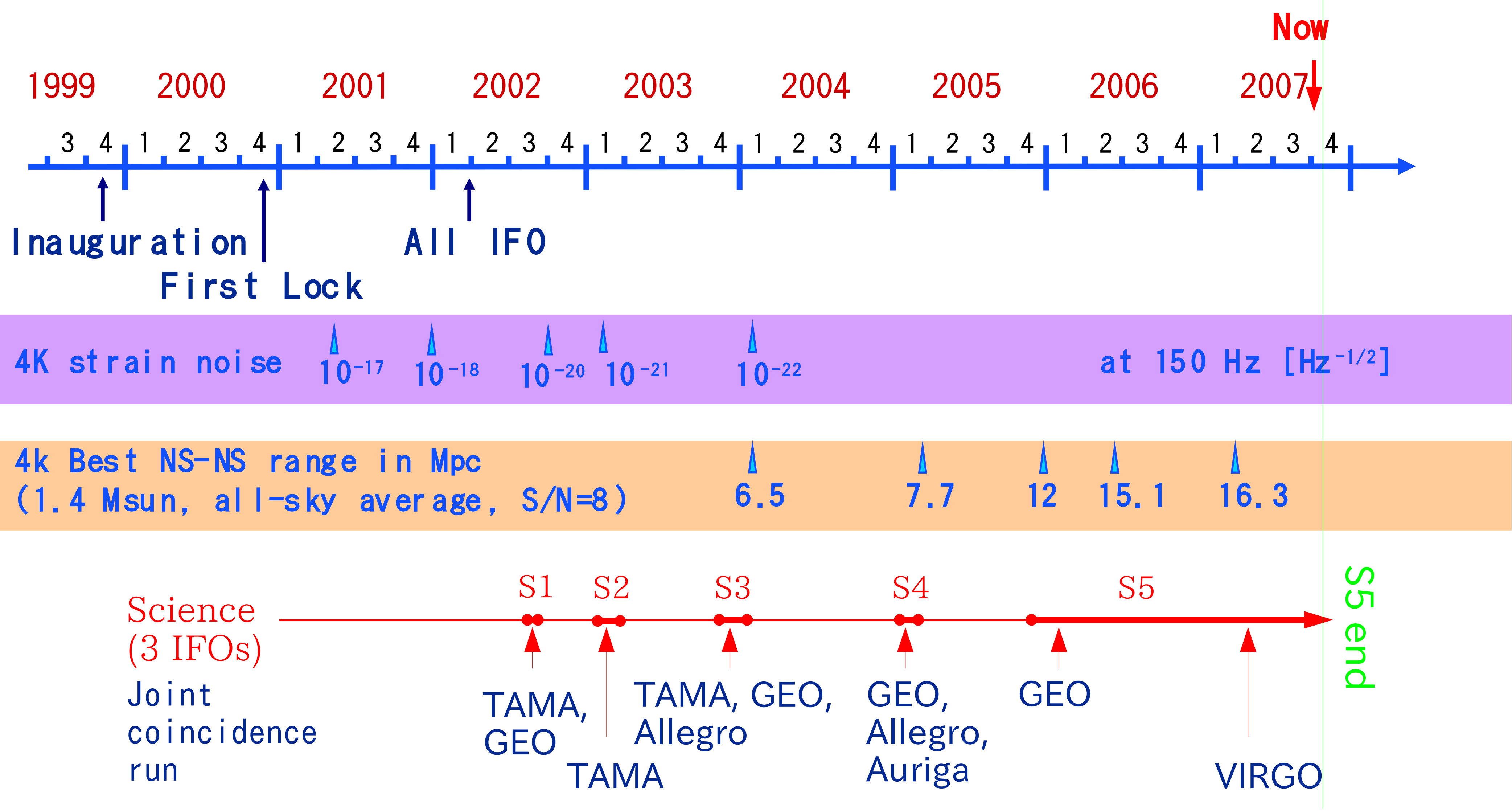
Core Optics Suspension

Where We Are At Now

Where We Are At Now

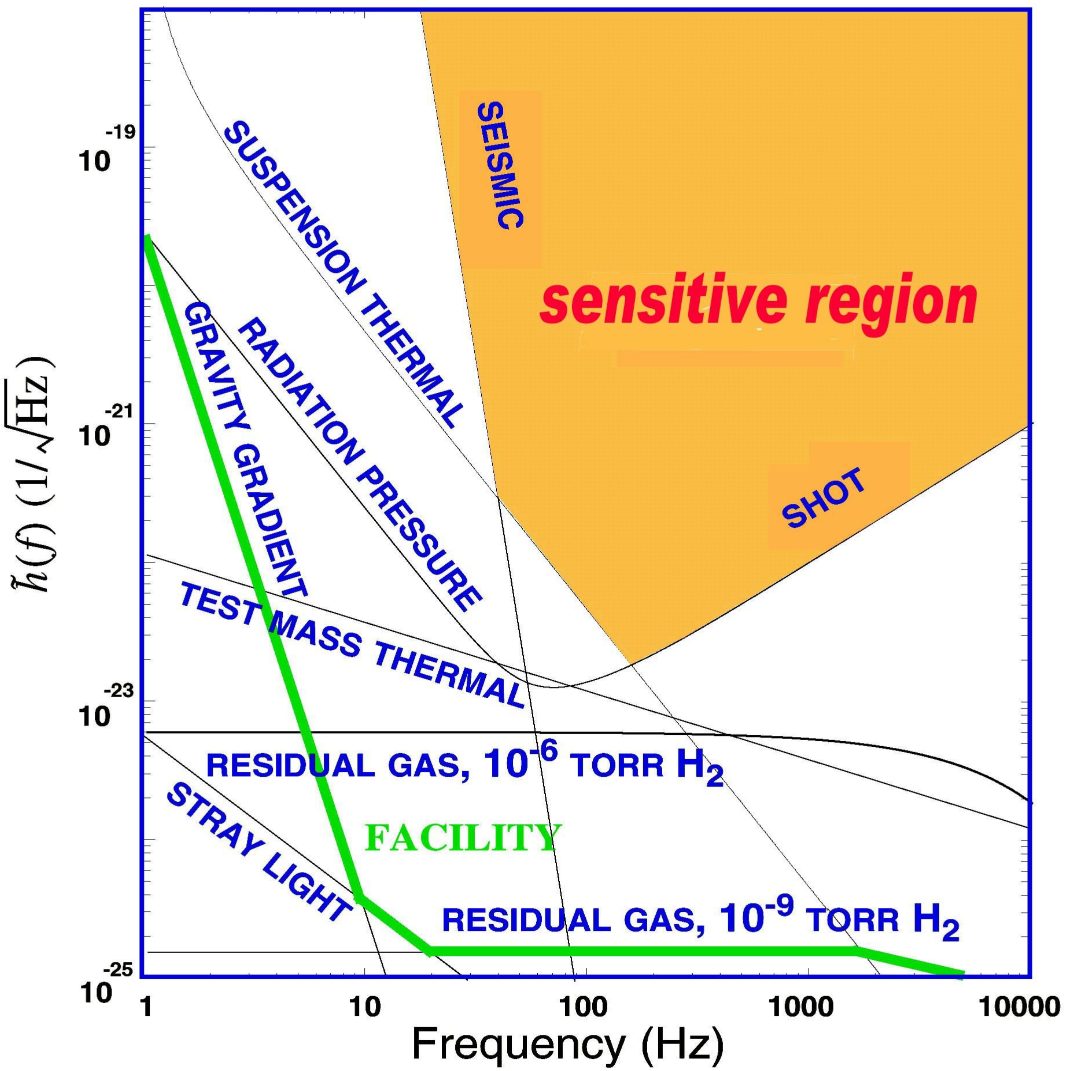
- 4 Science Runs (S1-S4) in the past
- S5, starting Nov/04/2005, is still ongoing
  - The last run with the current configuration
  - At design sensitivity (or better) for all 3 IFOs
  - Close to the end: 2007/Oct/01 00:00:00 UTC
    - Will accumulate one year's worth of 3-IFO coincidence by then
  - Coincident run with GEO and VIRGO
    - Sometimes 5-fold coincidence

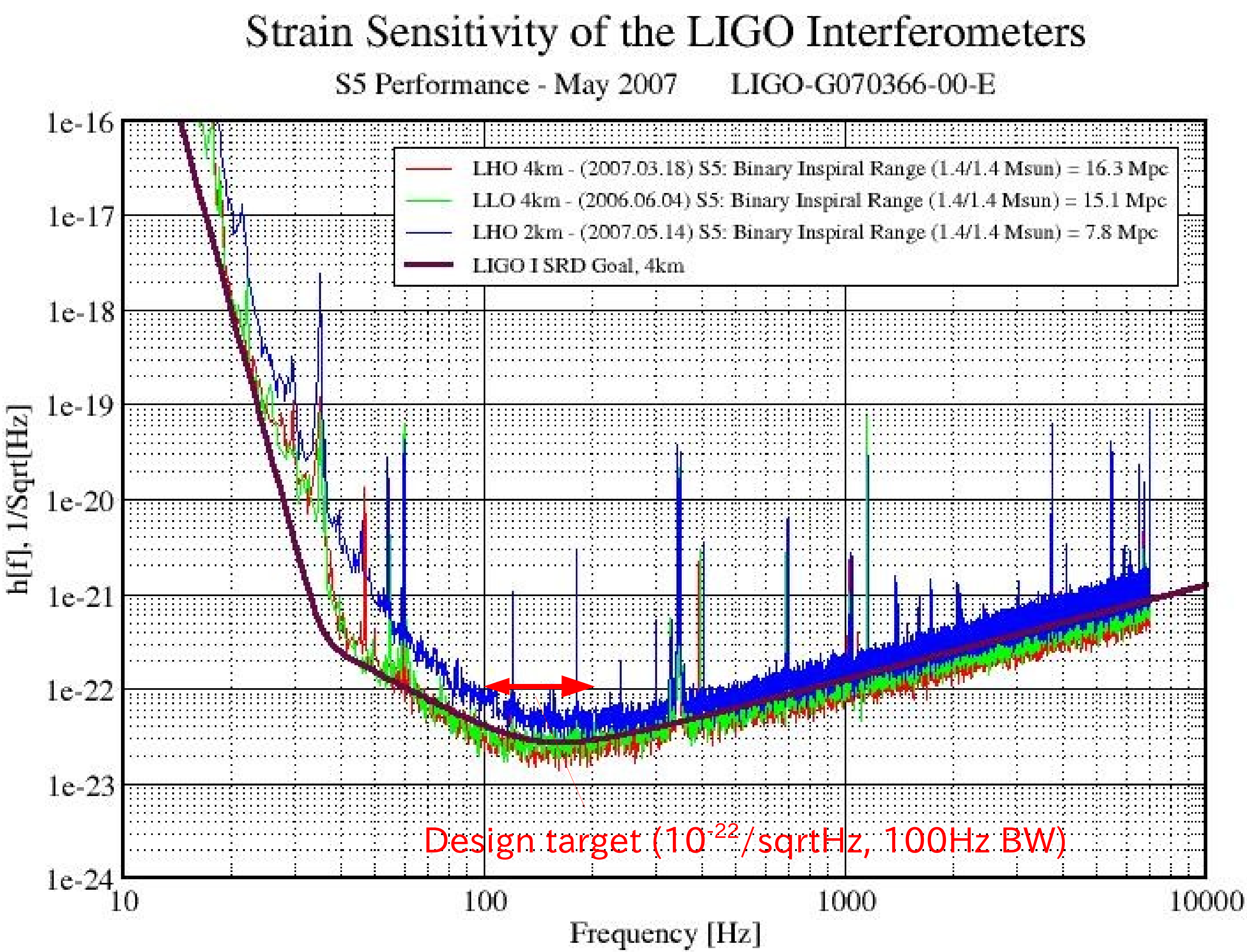
LIGO History



A Little about Detector Noise Limit

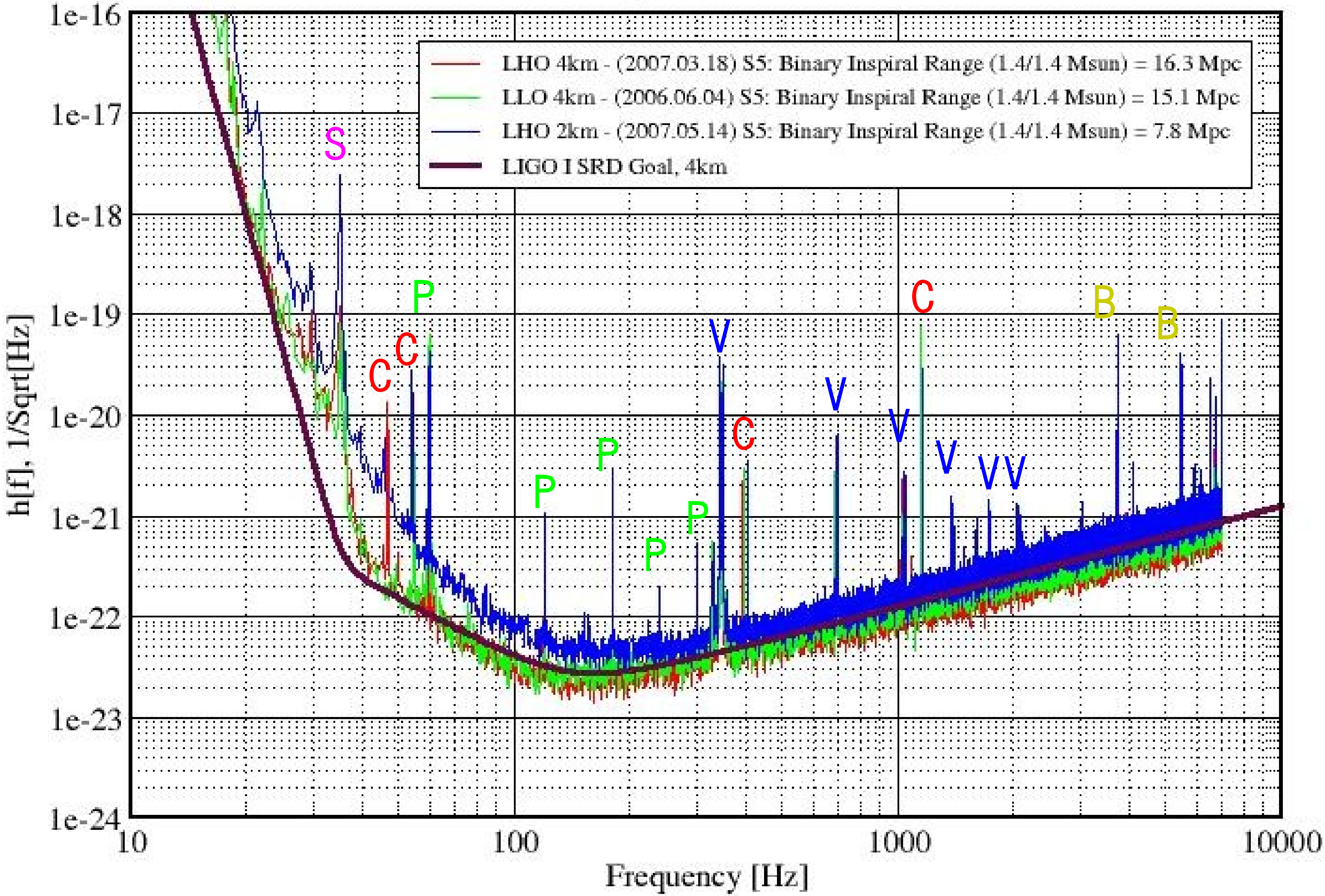
- Shot noise (and radiation pressure noise)
- Thermal motion of mirror and suspension
- Seismic motion
- Gravity gradient
- Residual gas
- Many, many technical noise not shown here
  - Electronics etc.



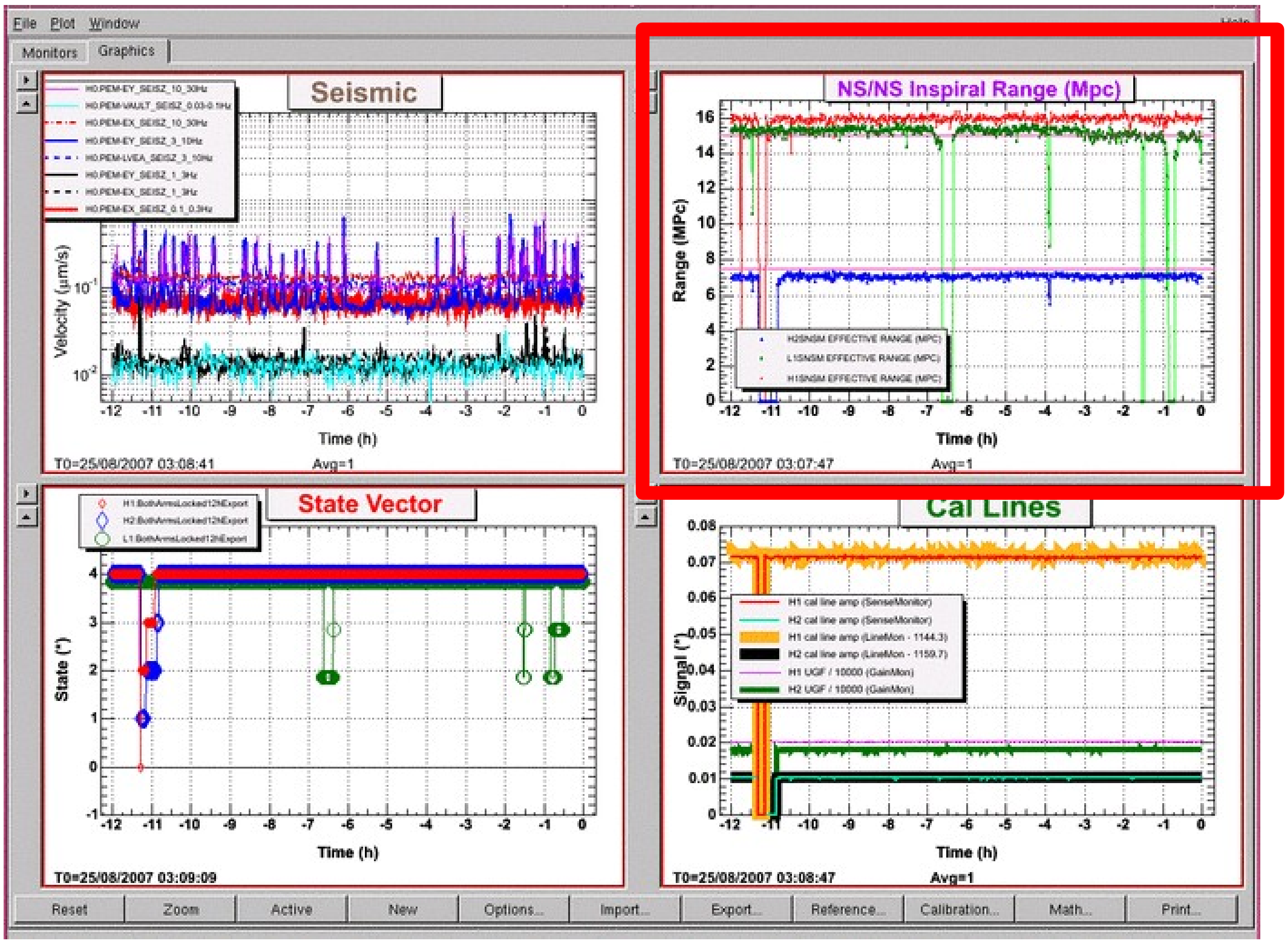

Strain Sensitivity of the LIGO Interferometers
S5 Performance - May 2007
LIGO-G070366-00-E
LHO 4km - (2007.03.18) S5: Binary Inspiral Range (1.4/1.4 Msun) = 16.3 Mpc
LLO 4km - (2006.06.04) S5: Binary Inspiral Range (1.4/1.4 Msun) = 15.1 Mpc
LHO 2km - (2007.05.14) S5: Binary Inspiral Range (1.4/1.4 Msun) = 7.8 Mpc
LIGO I SRD Goal, 4km
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]
Design target (10^{-22}/sqrtHz, 100Hz BW)

Strain Sensitivity of the LIGO Interferometers

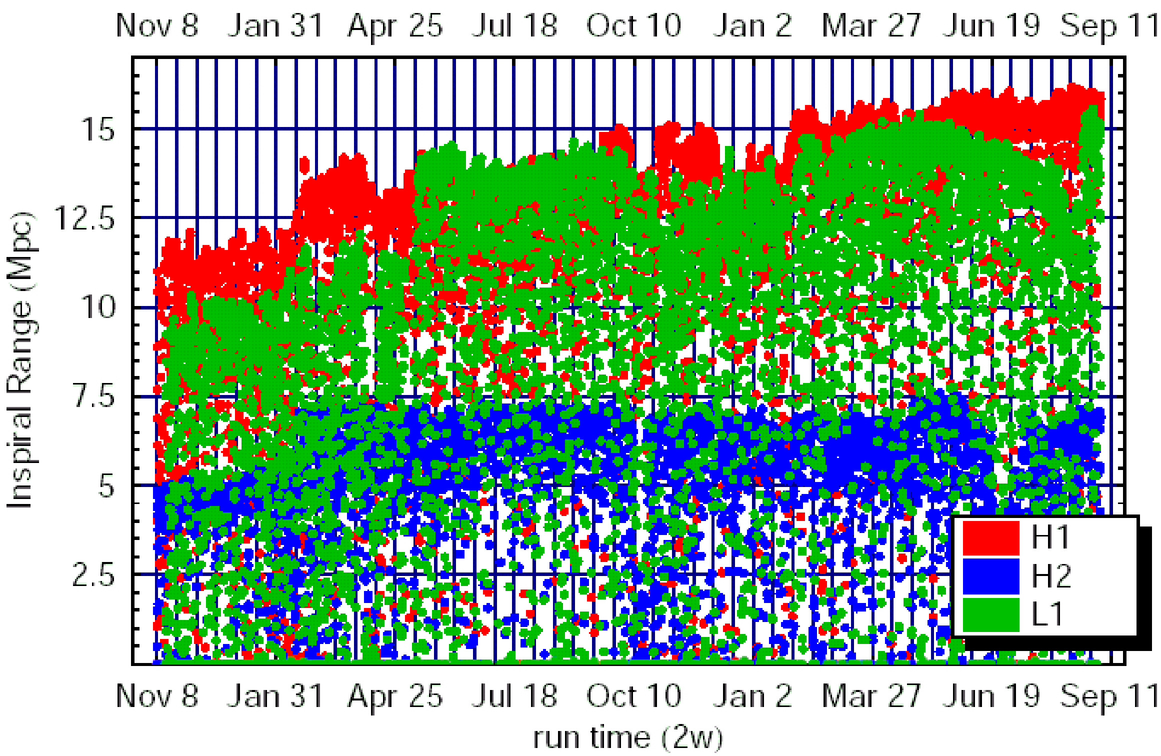
S5 Performance - May 2007 LIGO-G070366-00-E



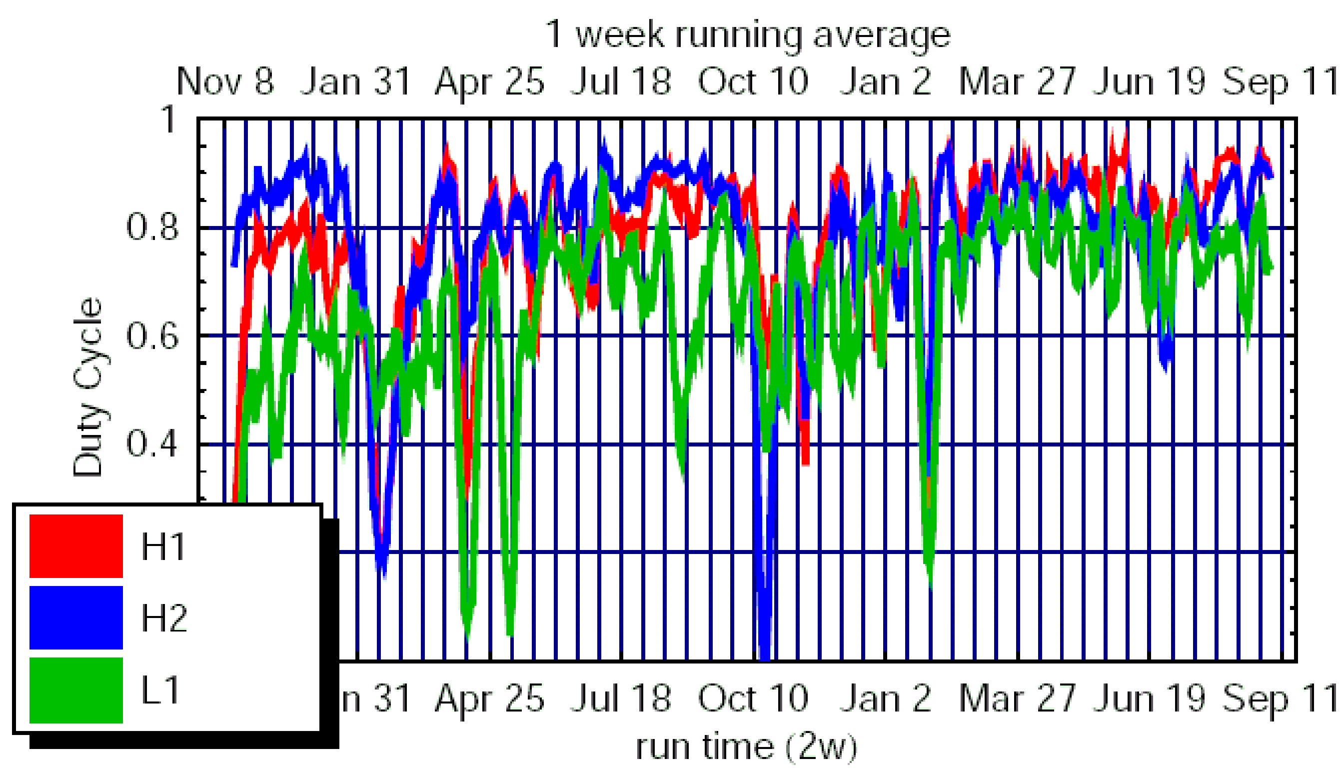
3 IFOs running well: Recent control room screen



- 12 hr trend of NS-NS inspiral range



NS-NS binary range from the start of S5

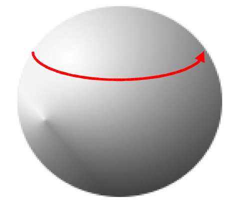


Duty factor from the start of S5

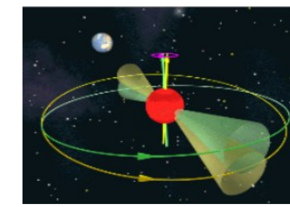
L

Anticipated Sources in LIGO's Band (And corresponding LSC Search Groups)

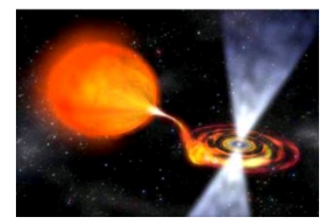
- Periodic sources
  - Binary pulsars, spinning NS, low mass X-ray binaries
  - Example of upper limits (targeted)
    - $h_0 < 4.8\times10^{-26}$ (PSR J1623-2631)
    - $\varepsilon < 1.1\times10^{-7}$ (PSR J2124-3358)
    - Crab pulsar: *observational GW emission upper limit is smaller than the spin-down derived limit*



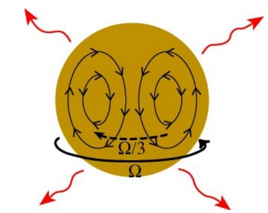
"Mountain" on neutron star



Wobbling neutron star

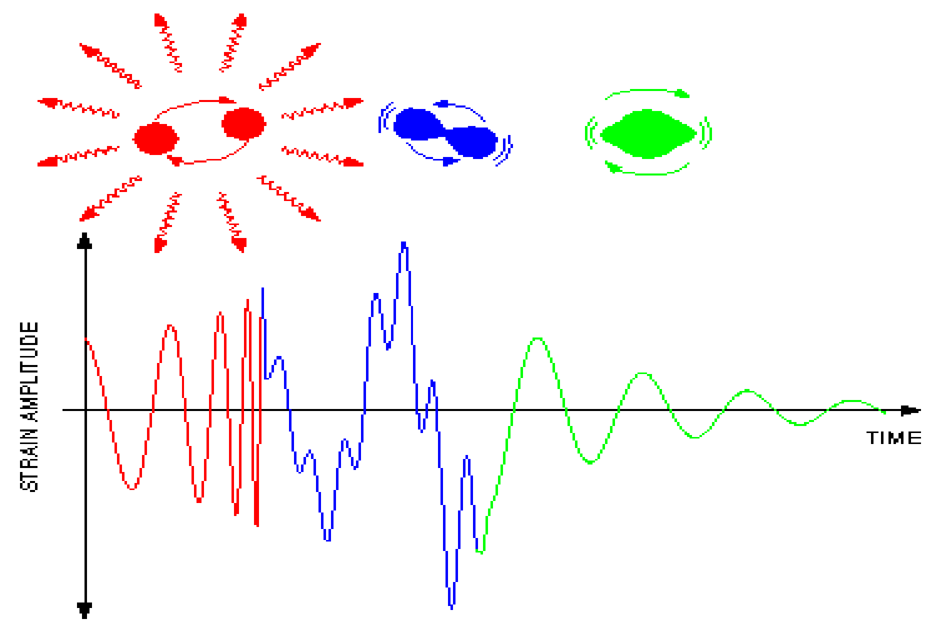


Accreting neutron star



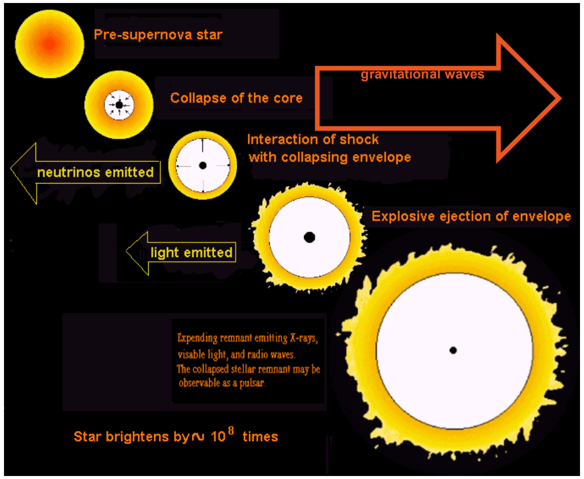
R-modes

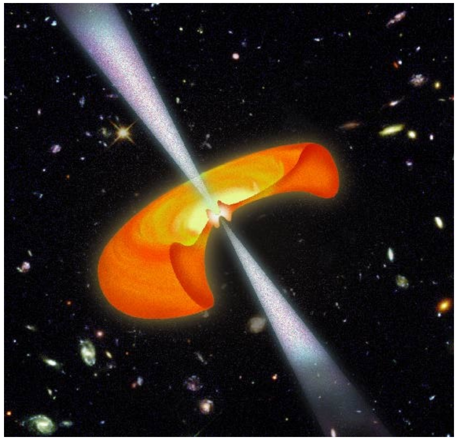
- Coalescing compact binaries
  - NS-NS, NS-BH, BH-BH
  - Physics regimes: Inspiral, merger, ringdown
  - Numerical relativity is essential to interpret GW waveform
  - ~16Mpc (1.4-1.4 $M_\odot$, all-sky, S/N=8)



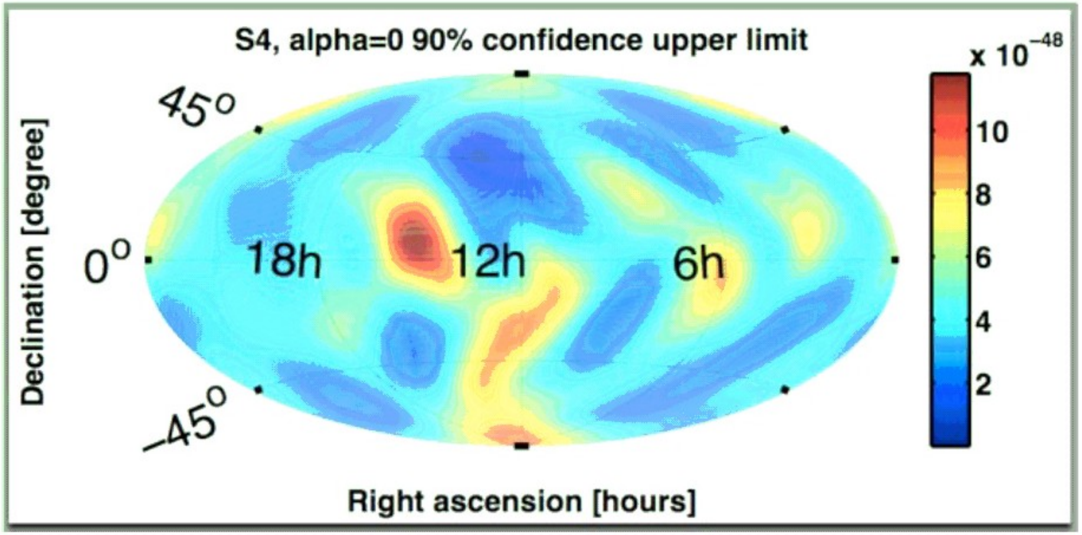
Anticipated Sources in LIGO's Band (Continued)

- Burst
  - e.g. Supernovae with asymmetric collapse
  - Abrupt, uncharacterized impulse.
  - Ex) Upper limit:
    - E_{GW} ~ 0.1 $M_\odot$ at 20 MpA (153 Hz case, untriggered)
    - E_{GW} ~ 10^{-7} to 10^{-8} $M_\odot$ (SGR1806-20 at 5-10 kpA)





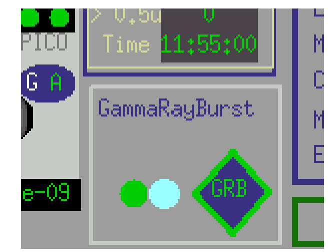
- Stochastic background
  - Primordial Big Bang (t = 10^{-22} sec)
  - Cross correlation of signals in pairs (LHO-LLO, LHO-LHO)
  - Ex.) First upper limit all-sky map of stochastic point source for S4

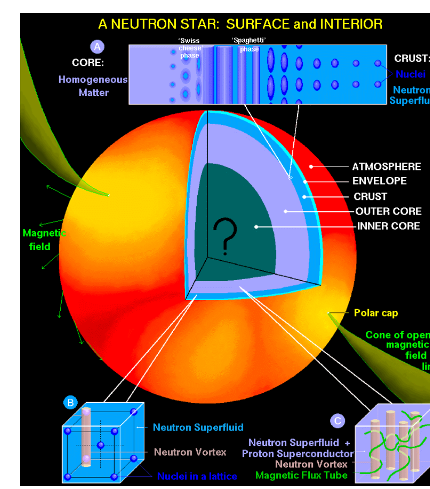


BTW, We Need Interaction With Non-GW Researchers

- Knowledge from any other means/channels
  - better GW source model etc.
  - trigger with location information (e.g. GRB/SWIFT) etc.
- GW detection might also impact underlying physics of observed objects
  - e.g. non axi-symmetry and NS equation of state
- NS specialists: please don't leave until the end of this talk (conference ad alert!).

Control room sAreen for GRB alert





www.astroscu.unam.mx/neutrones/NS-Picture/NStar/NStar_IS.gif

I'm afraid I don't have time to talk about these

- Many observational results for S4 and earlier were already published.
  - Please go to http://www.ligo.org
- Some analysis are going on for S4 and S5.
  - Some already appeared in conference talks.
    - Again http://www.ligo.org

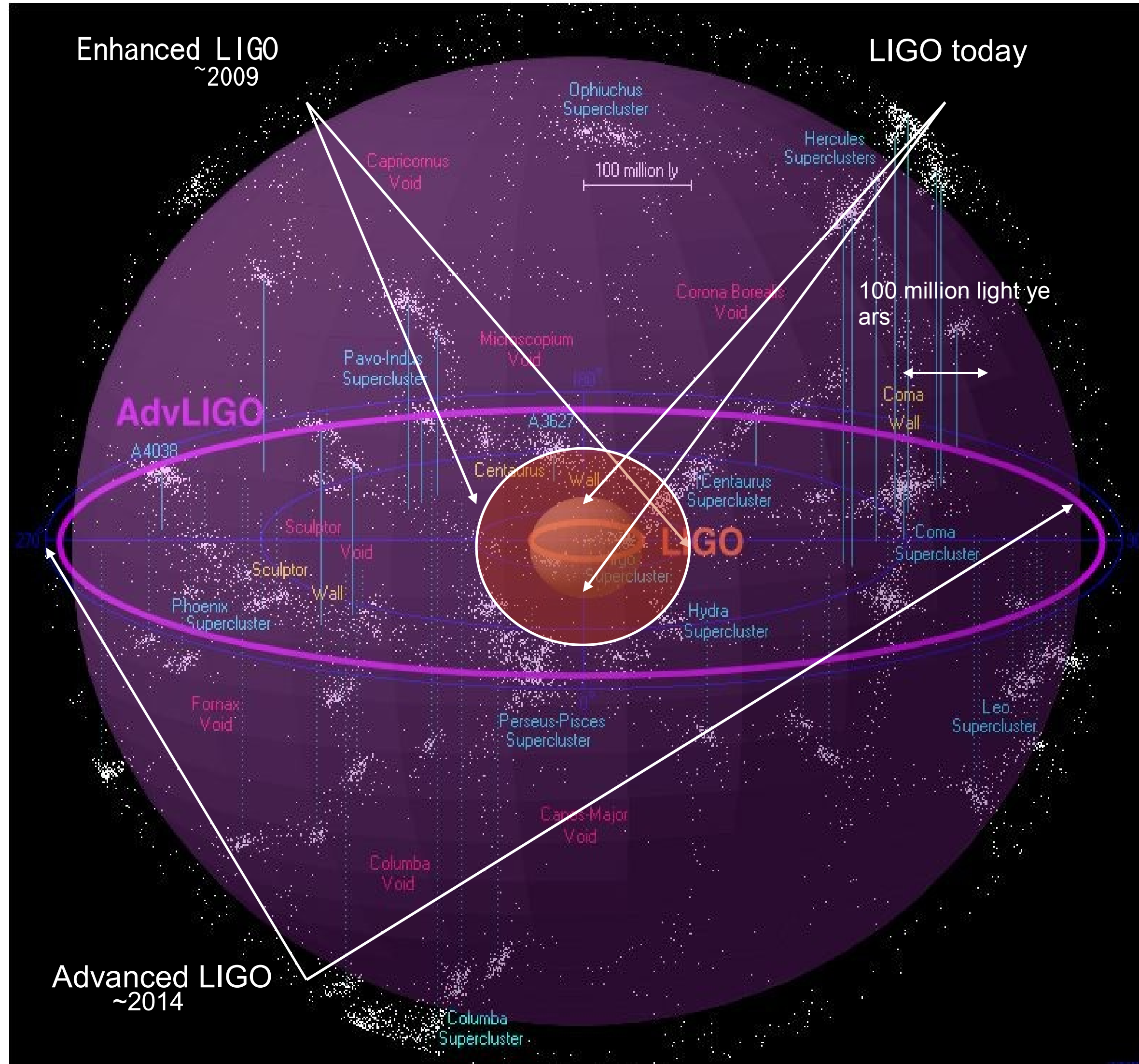
S5 summary

- Design sensitivity requirement met by all 3 IFOs.
- Good duty factors.
- As of Sep/10/2007, about 97.3 % of 1-year (~355 days) 3-coincidence data has been accumulated.
  - Already more than 1-year 2-site coincidence (accomplished July 2007)
- End of S5 date set: 2007/Oct/01 00:00:00 UTC
  - We'll very likely accumulate more than 1year worth of 3-coincidence data.
- We'll be ready for the next step very soon!

LIGO Future

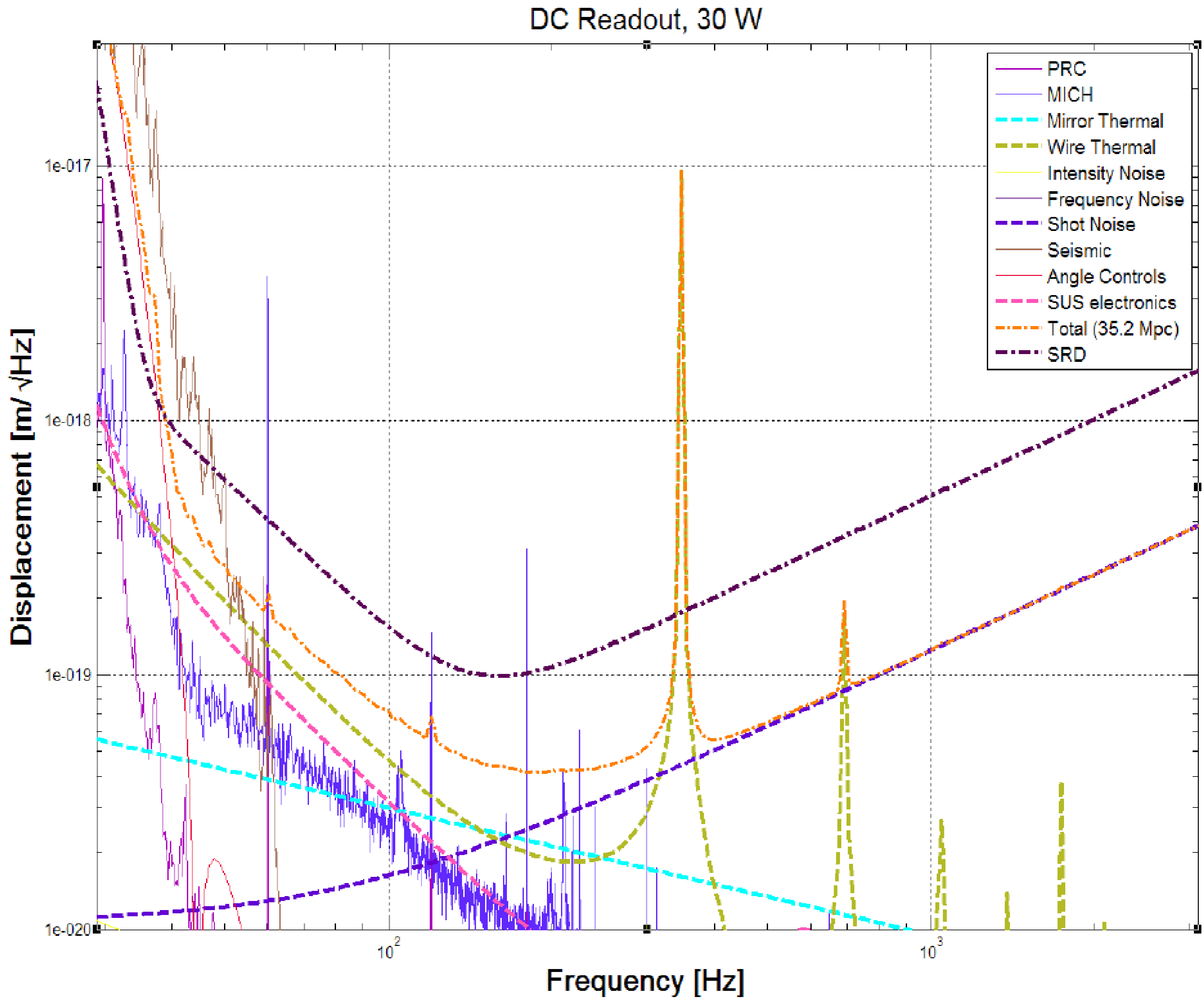
LIGO Future

- S5, 1yr data, with design sensitivity
  - Hundreds of galaxies in range, detection possible
- Enhanced LIGO
  - Operation in 2009
  - 8 times more galaxies in range, 8 times more detection probability
- Advanced LIGO project (~200M$)
  - Construction start expected in FY08
  - 1000X more galaxies in range
  - Expect ~1 signal/day- 1/week in ~2014



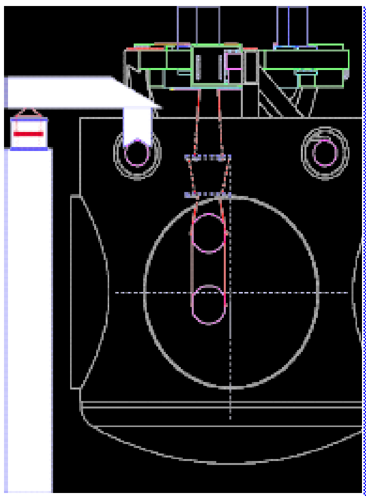
Mid-term Enhancement Plan

- Realistic, modest upgrade of initial LIGO detectors
- Early commissioning of advanced LIGO technologies
  - One high power laser module, allowing us to inject 30+ W (instead of 7-8 W)
  - DC readout with output mode cleaner
  - Better thermal compensation
- Another ~1-year run, S6, before AdLIGO

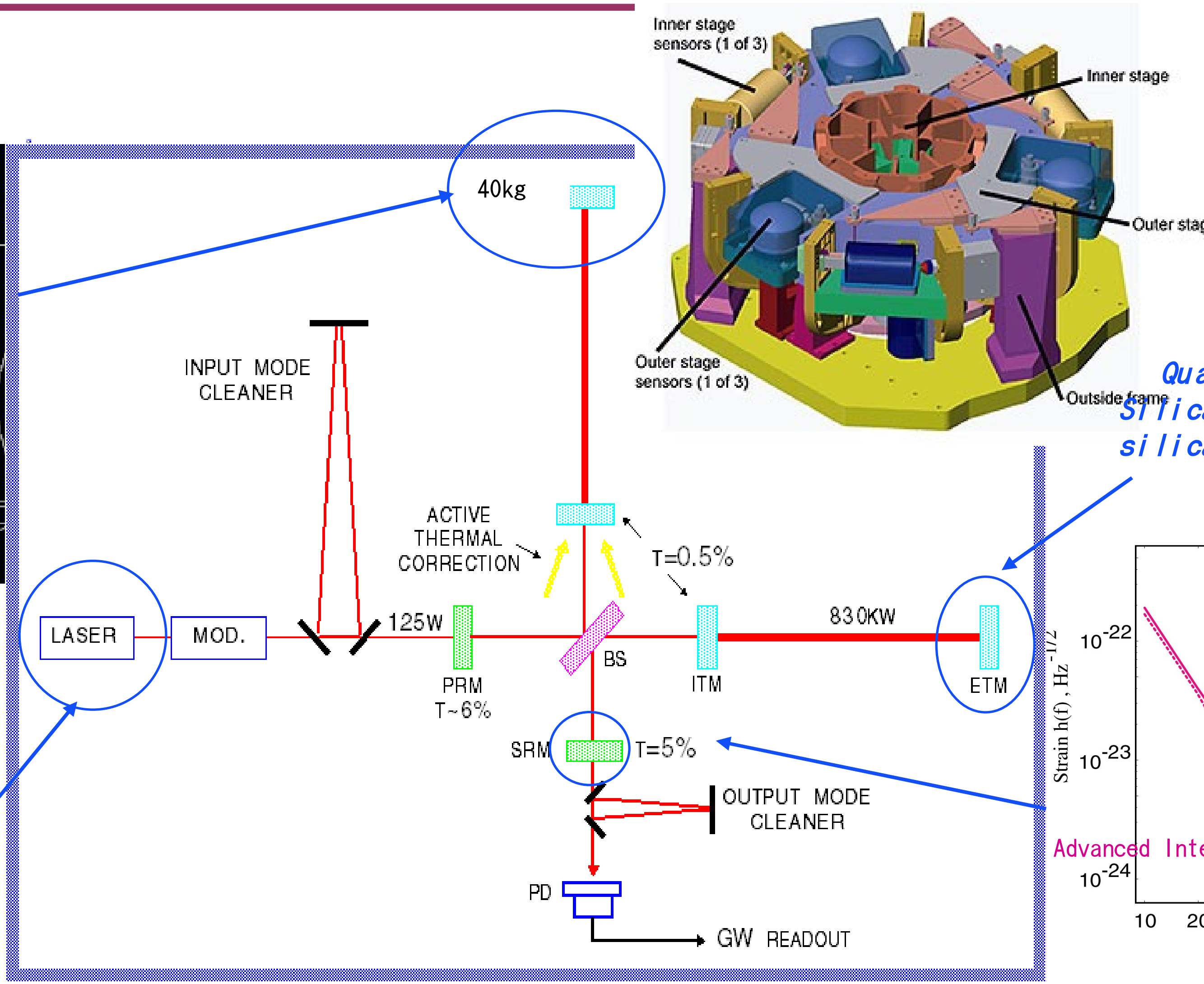

DC Readout, 30 W
PRC
MICH
Mirror Thermal
Wire Thermal
Intensity Noise
Frequency Noise
Shot Noise
Seismic
Angle Controls
SUS electronics
Total (35.2 Mpc)
SRD
1e-017
1e-018
1e-019
1e-020
Displacement [m/ √Hz]
10^2
10^3
Frequency [Hz]

LIGO

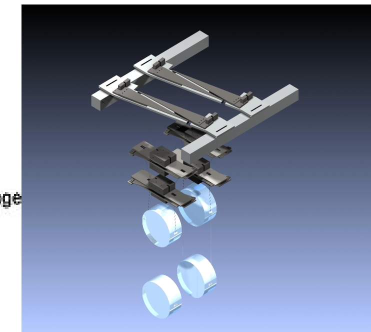
Advanced LIGO



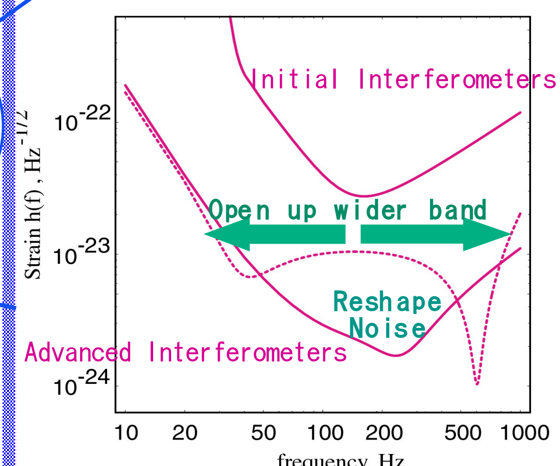
Active vibration isolation systems



High power laser (180W)



Quadruple pendulum: Silica optics, welded to silica suspension fibers



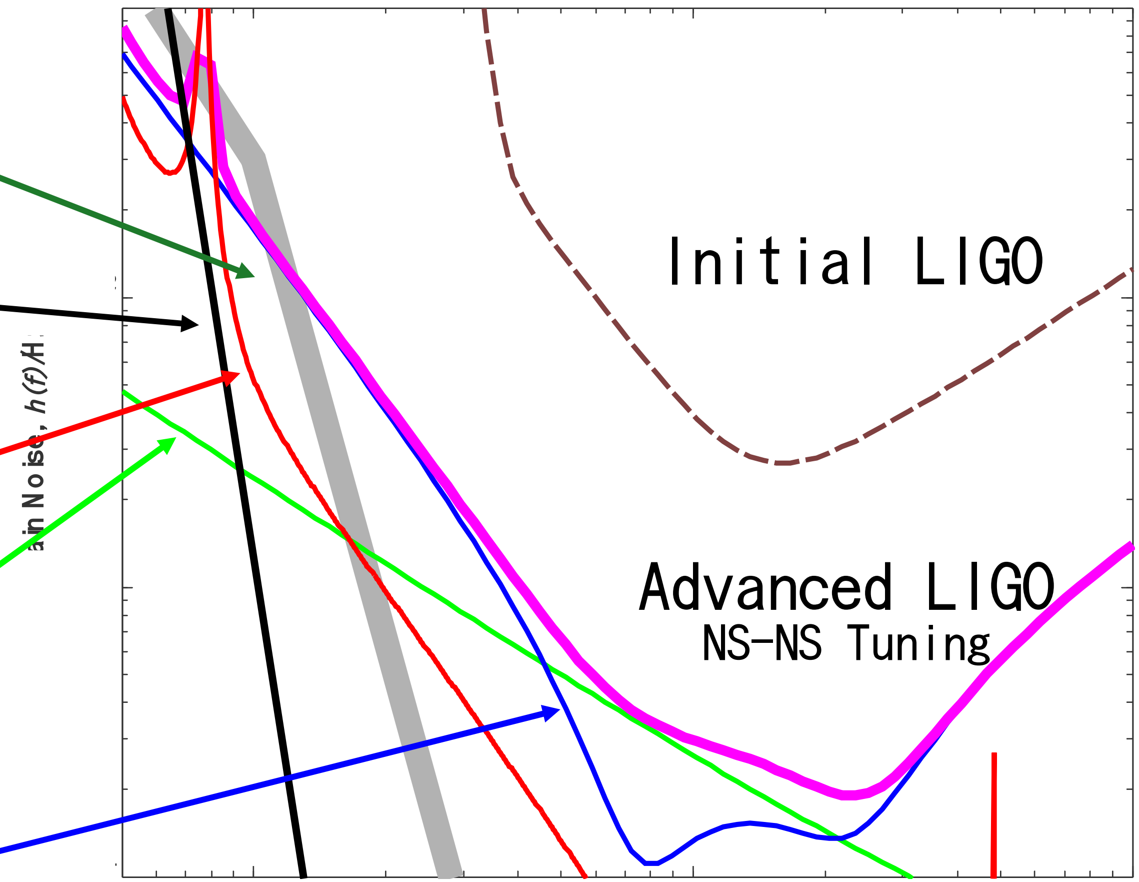
Advanced interferometry
Signal recycling

AdLIGO Suspension Prototype

LIGO

Example of AdLIGO Noise

- Newtonian background, estimate for LIGO sites
- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Test mass thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning



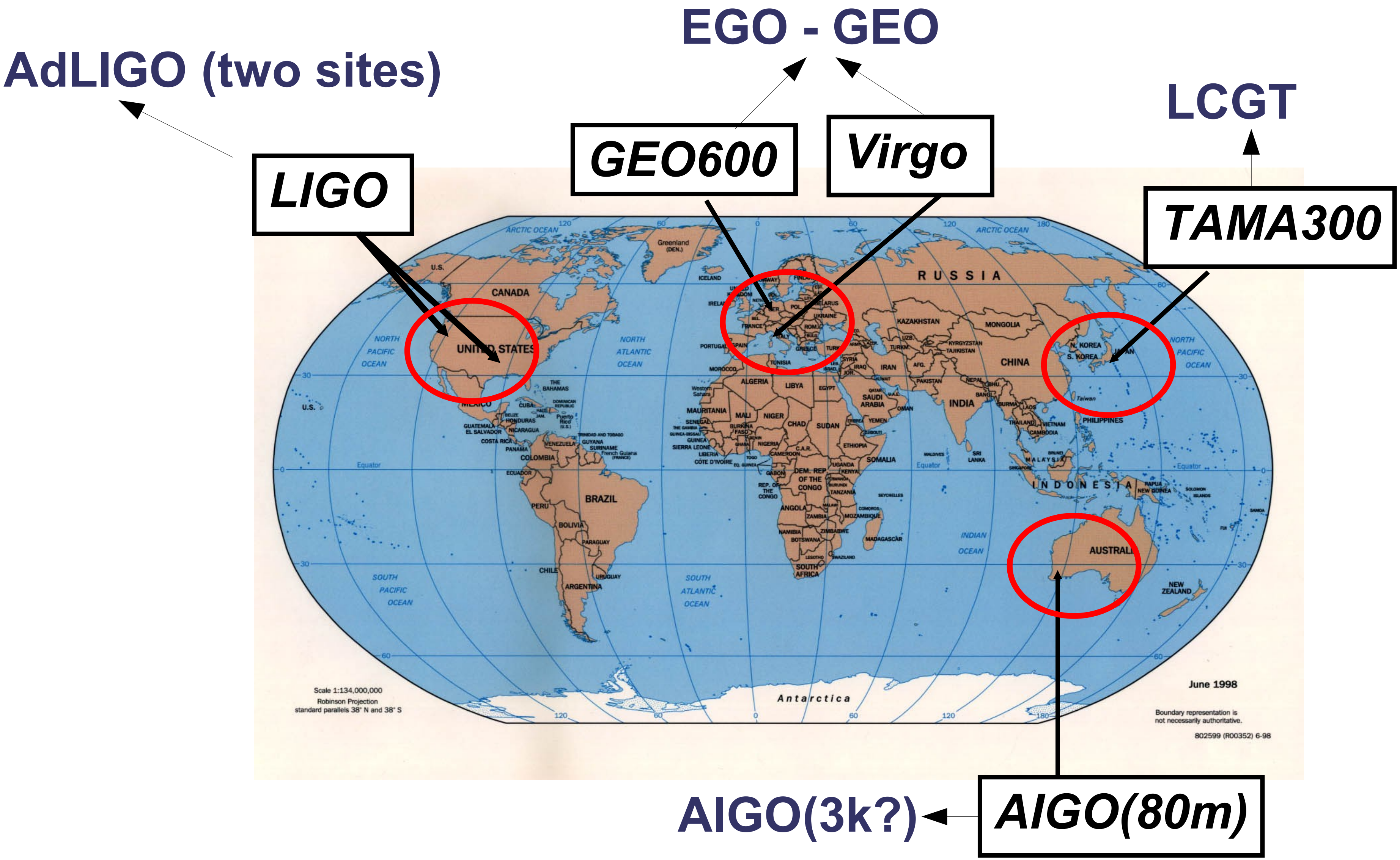
LIGO Conclusion

- LIGO is close to an end of S5 run with excellent performance
- Data analyses ongoing
- Ready for the next step
  - LIGO enhancement (operation 2009)
  - Advanced LIGO expected to detect GW on a regular basis (in 2014)

Global Network of GW Detectors in the Future

- GW detection for astronomy
  - Higher detection confidence
  - Better localization of sources
  - Better polarization decomposition of the wave
- All of these necessitates multiple detectors around the world!

Global Network of GW Detectors in the Future



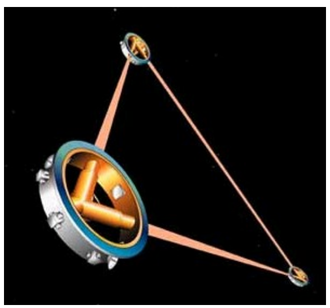
Network of Terrestrial and Space GW Detectors in the Future

AdLIGO (two sites)

EGO - GEO

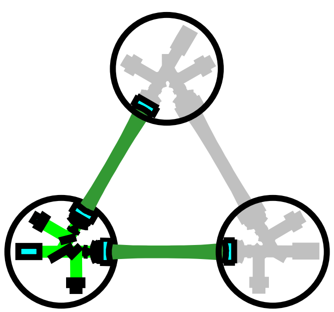
LCGT

LISA



http://lisa.nasa.gov
Courtesy NASA/JPL-Caltech

DECIGO



Courtesy S.Kawamura

LIGO

GEO600

Virgo

TAMA300

AIGO(3k?) ← AIGO(80m)

Advertisement 1: 2nd Annual NS/LSC Meeting

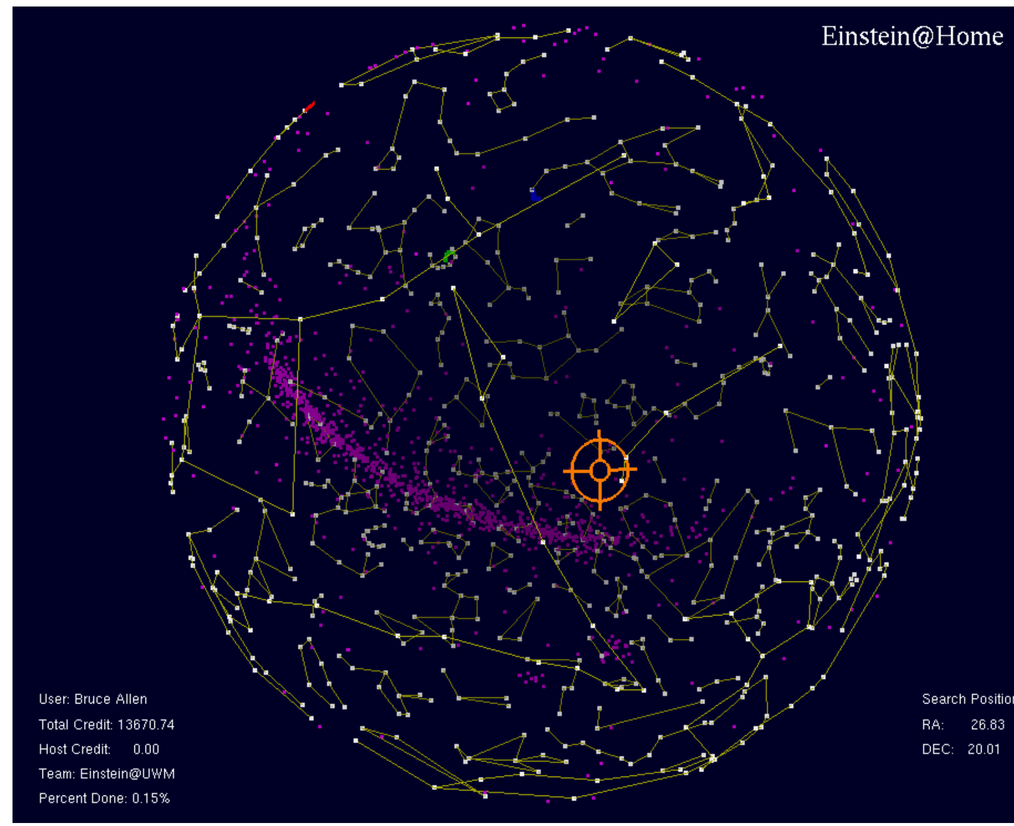
http://www.ligo-wa.caltech.edu/~mlandry/NSMeet/Oct07/

- Oct/20/2007, Albert Einstein Institute in Hannover, Germany.
- A meeting between neutron star experts and gravitational wave researchers searching for continuous wave.
- "spin evolution, braking indices, crusts, magnetic fields, population studies, new surveys, and anything else that could affect detectability of gravitational waves."

Advertisement 2: Pulsar analysis using your PC!

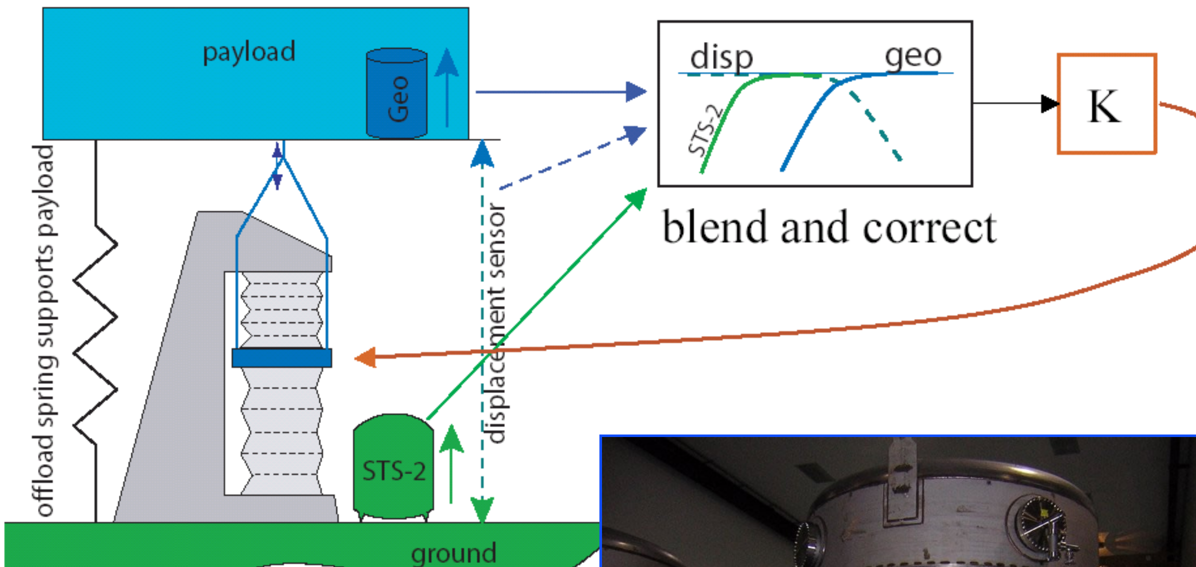
- All-sky pulsar GW search
  - computer intensive, bound by CPU power.
- You can help by taking part in Einstein@Home!
- Distributed computing with SETI@Home technology.
- Really easy with Windows, Linux and OSX.
- 55000 active users, 70+ TFLOPS
- http://einstein.phys.uwm.edu/

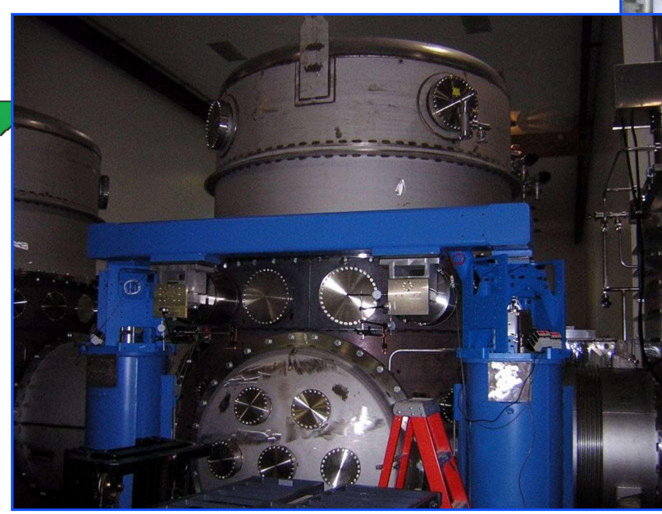
Pretty screensaver!



END

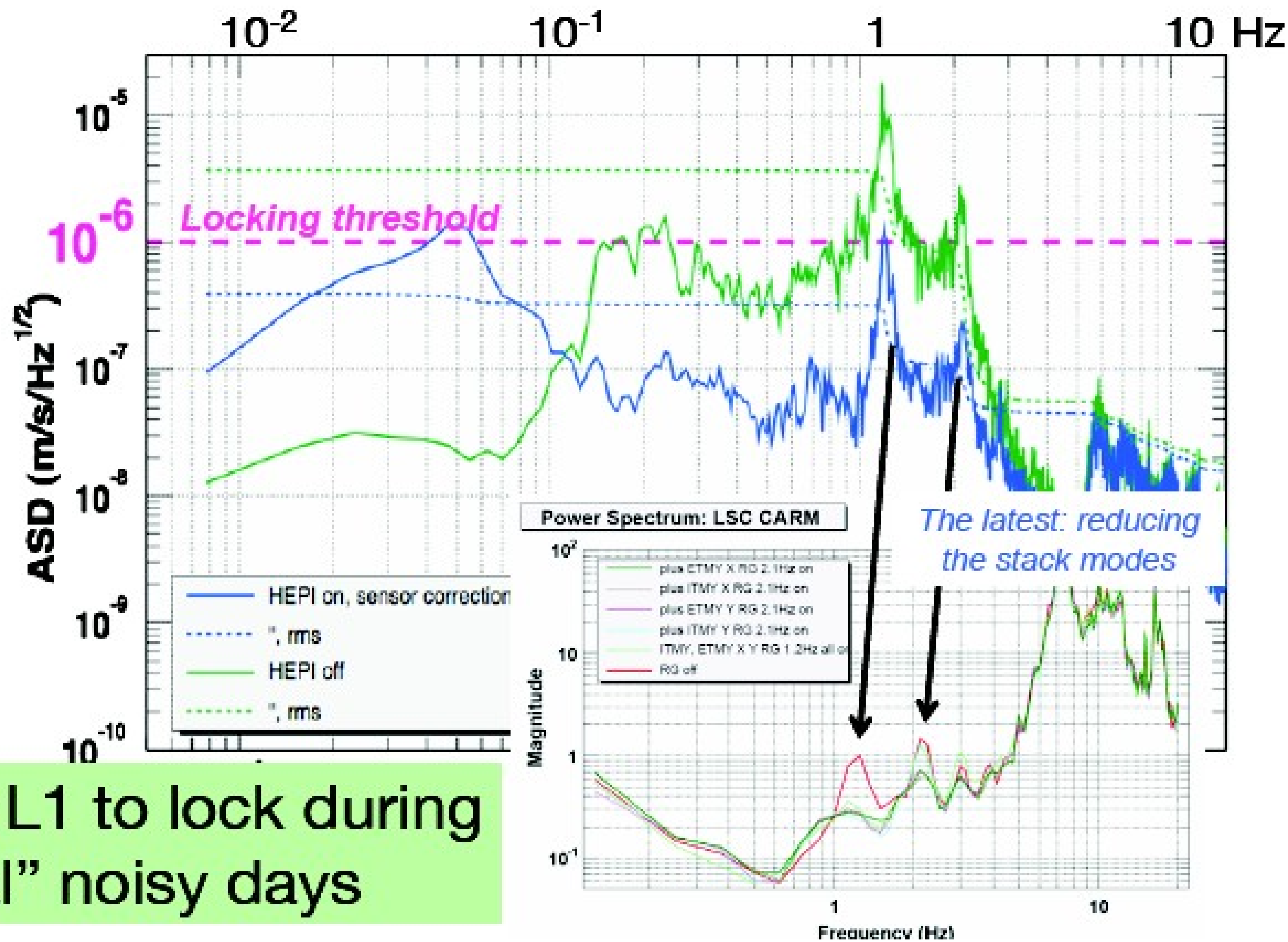
HEPI:
Hydraulic External Pre-Isolator





Early implementation of AdLIGO technique

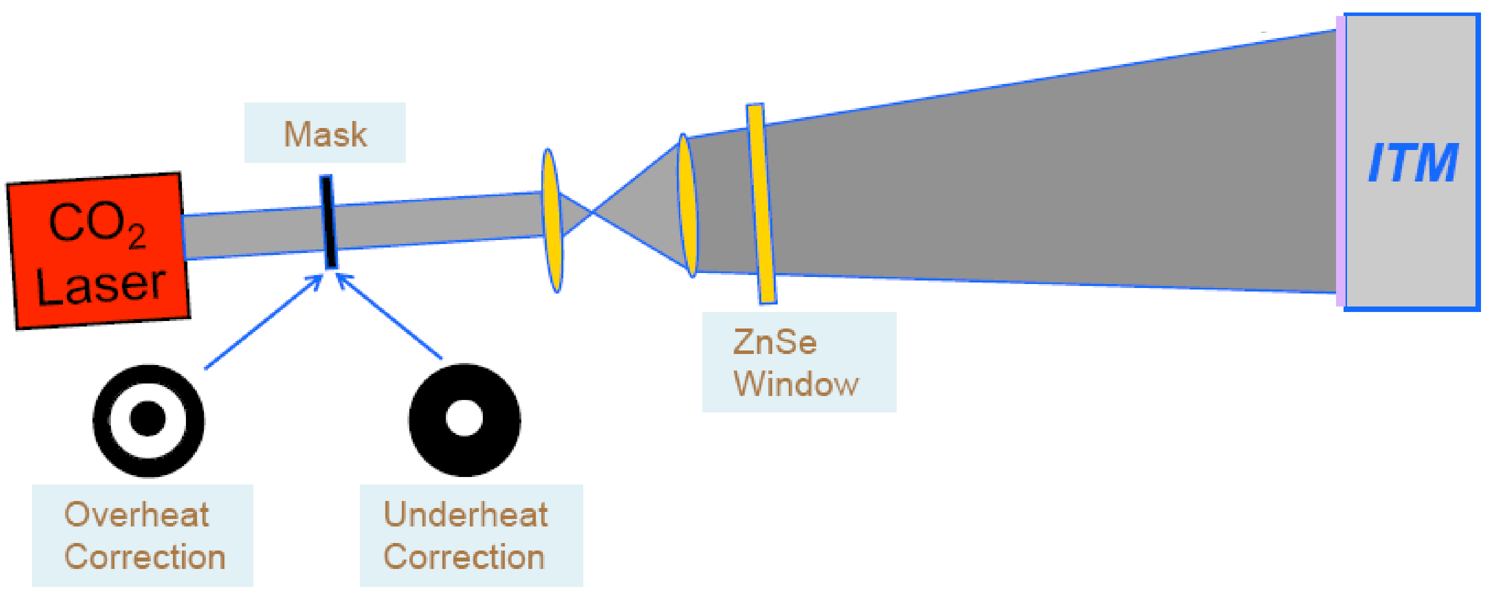
HEPI performance



Allows L1 to lock during “typical” noisy days

TCS: Thermal Compensation System

- Heat optics using CO2 laser
  - to counter the wave front distortion caused by the absorption of interferometer beam in the substrate



Early implementation of AdLIGO technique

Thermal lens effect and TCS