Advanced LIGO

the Laser Interferometer Gravitational-wave Observatory

Development and Status

Brian Lantz, Stanford University
for the LIGO Scientific Collaboration
(40+ institutions and hundreds of people...)

MG11, July 25 2006

black hole image courtesy of LISA,
http://lisa.jpl.nasa.gov

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The Advanced LIGO *proposal*

- Improve the sensitivity of existing observatories to dramatically enhance the astrophysics.
- Same facilities as Initial LIGO, but with new detectors.
- Development is very far along.
- Requested construction funding from NSF in FY2008.
- Project cost $186 M (US, 2006$)
    - NSF $172 M
    - AEI to supply the lasers.
      Already funded by Max Planck Gesellschaft for development and for $7.1M in 2006$ for fabrication.
    - UK/GEO for suspensions and core optics
      Already funded by PPARC for development and for $6.87M in 2006$ for fabrication.
    - ANU funding request submitted for ~$1.7M for output modecleaner.

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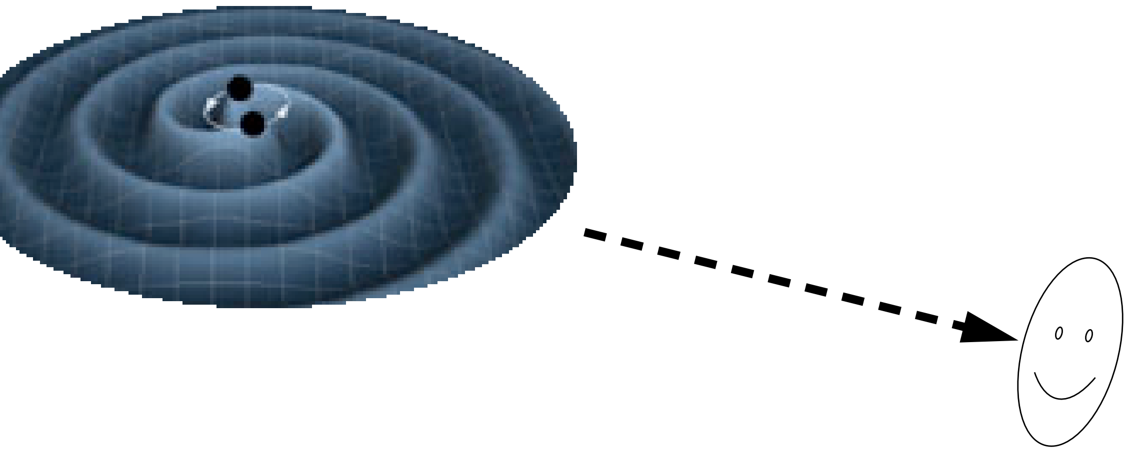
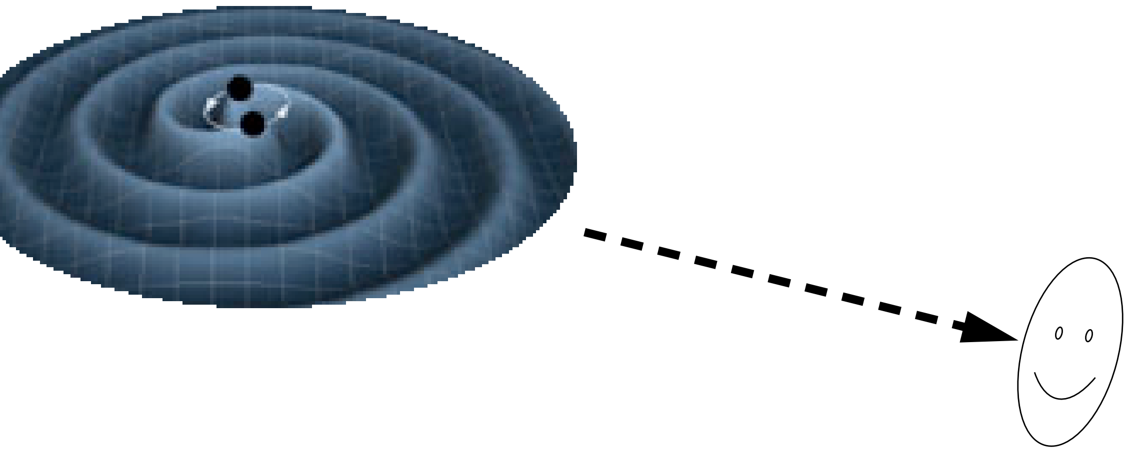
The Advanced LIGO *proposal*

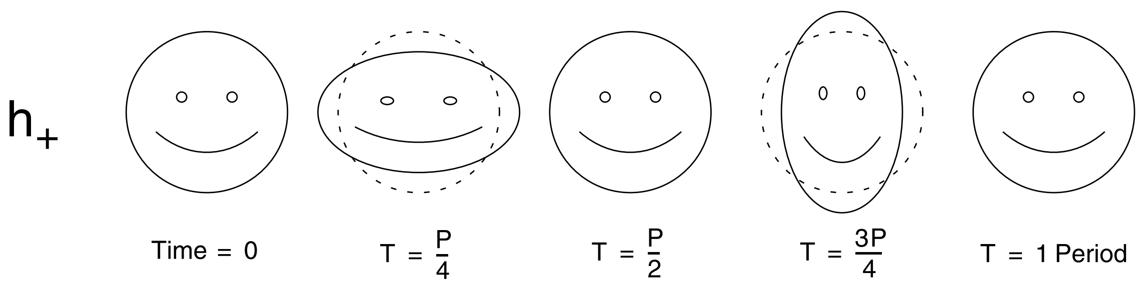
- Milestones:
  - Advanced LIGO funding at start of FY2008; fabrication, assembly, and stand-alone testing of detector components
  - Advanced LIGO starts decommissioning initial LIGO instruments in early 2011, installing new detector components from stockpile.
  - First Advanced LIGO interferometer accepted in early 2013, second and third in mid-2014. Project completes!
  - Commissioning of instruments, engineering runs starting in 2014.

Detecting Gravitational Waves

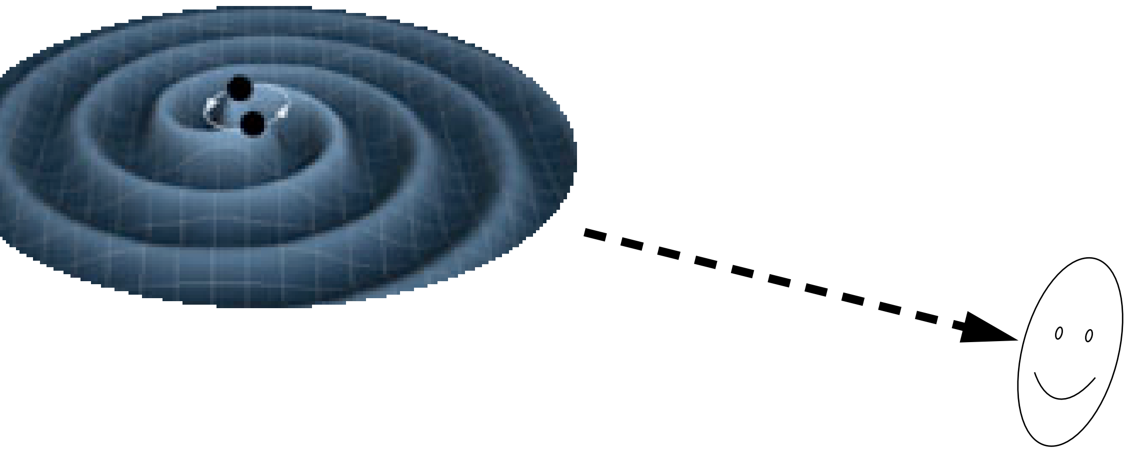


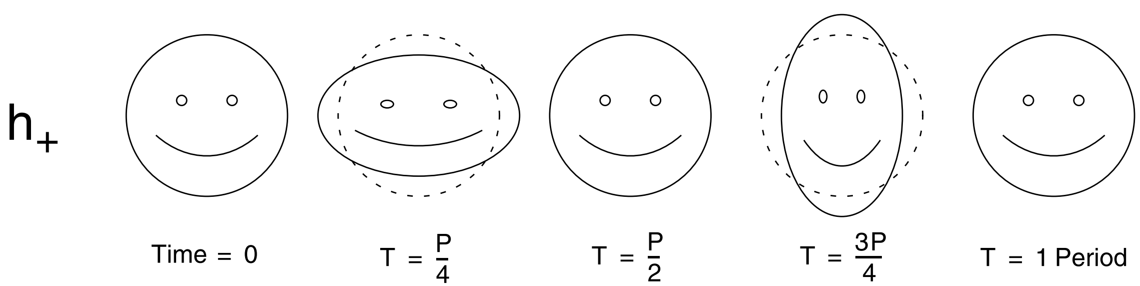
Detecting Gravitational Waves

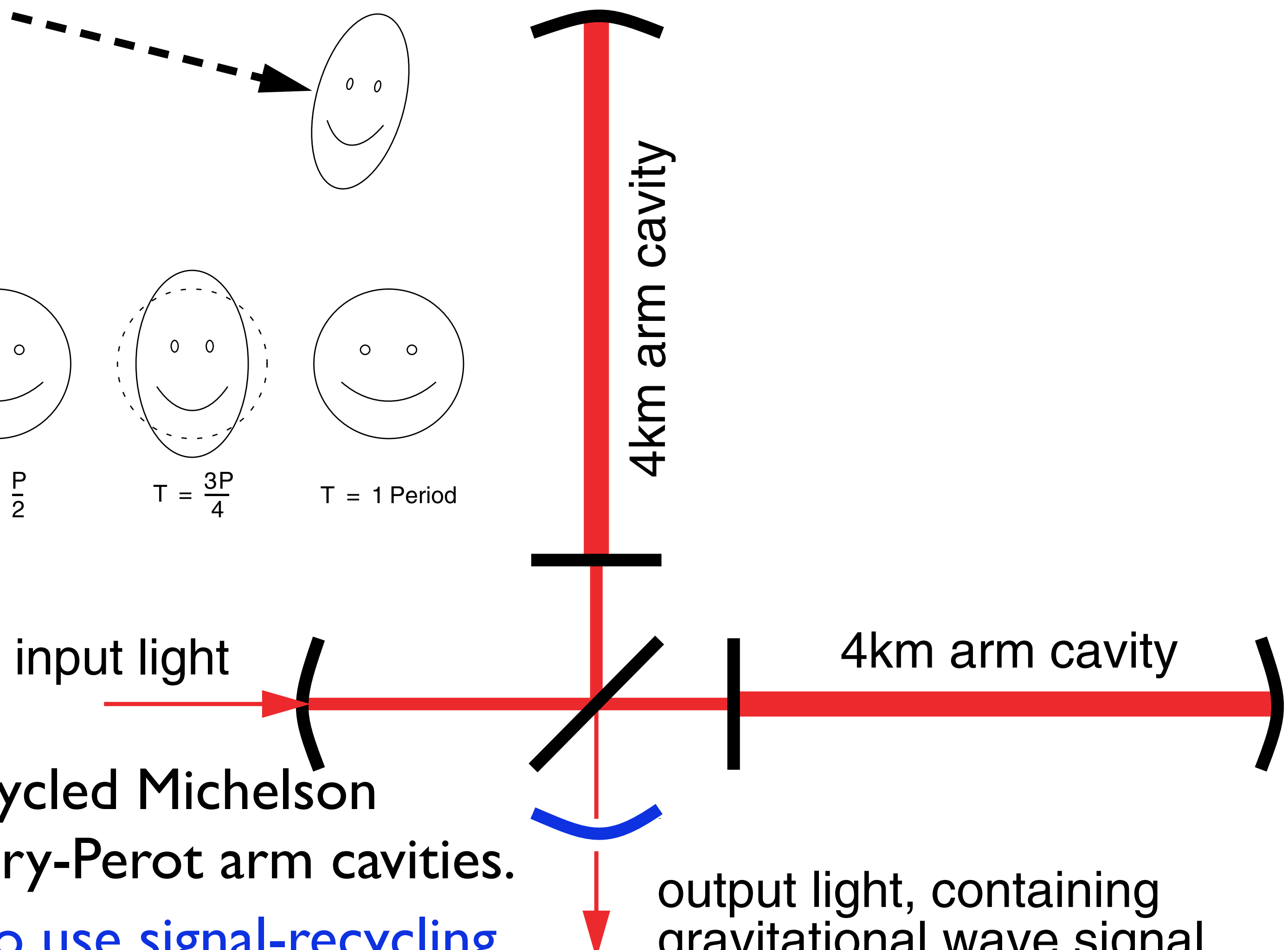




Detecting Gravitational Waves







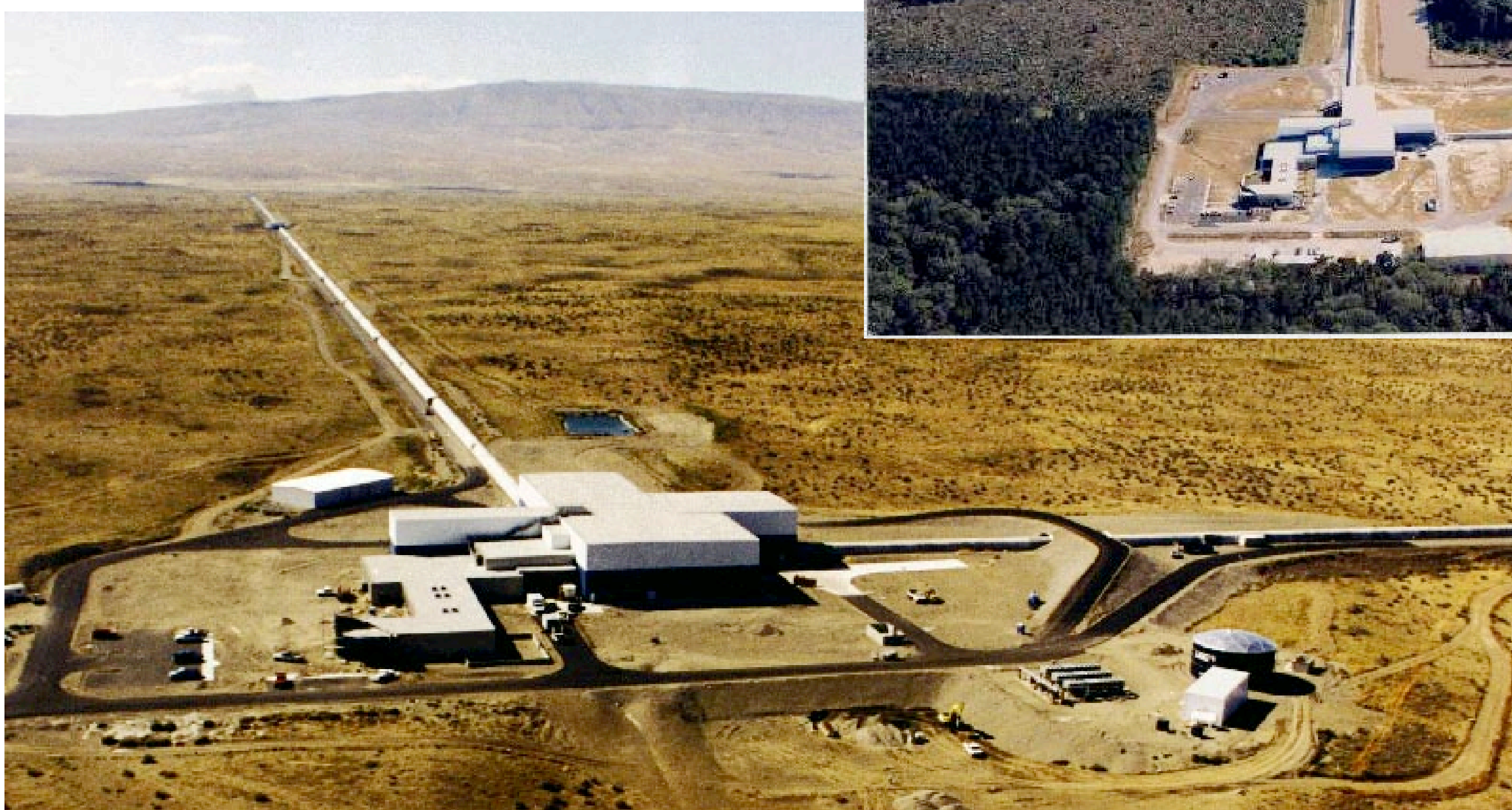
4km baseline power-recycled Michelson interferometer with Fabry-Perot arm cavities.

Advanced LIGO will also use signal-recycling

Initial LIGO

Observatories in Livingston LA and Hanford WA.

Science run 5 now underway at design sensitivity.



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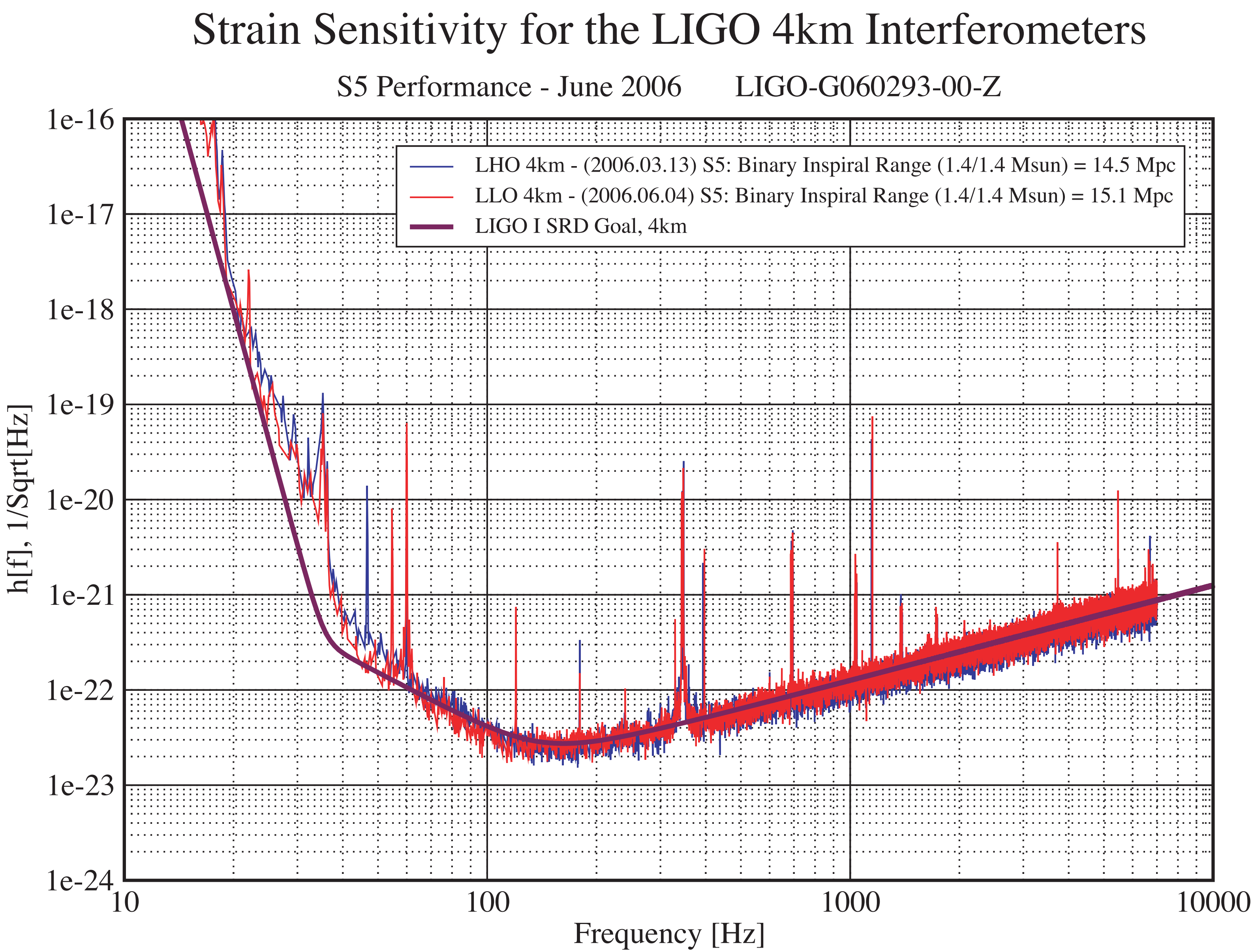
Initial LIGO Sensitivity



The Seeing

Initial LIGO NS/NS range ~15 MPc,
network range of ~22 MPc

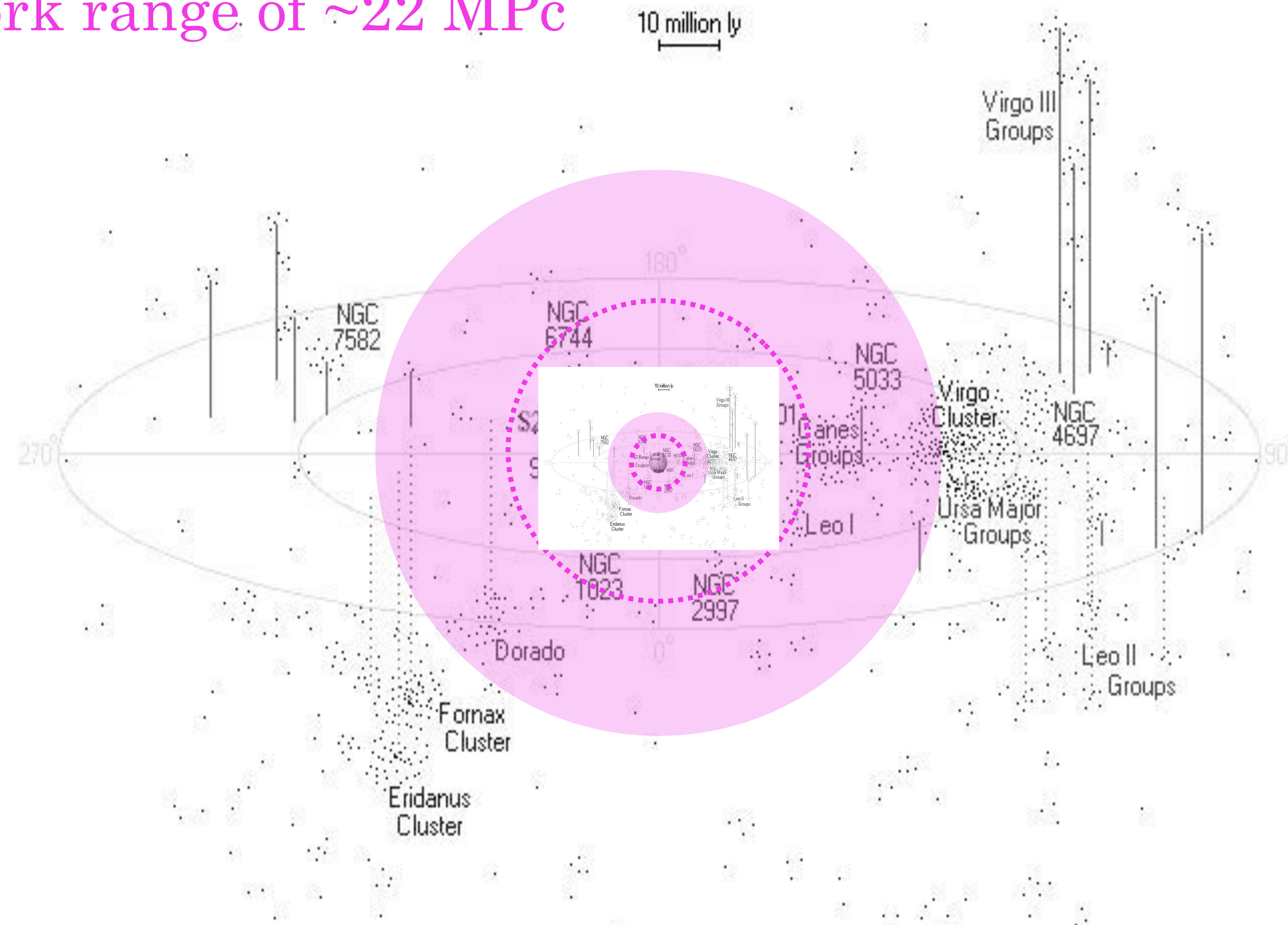
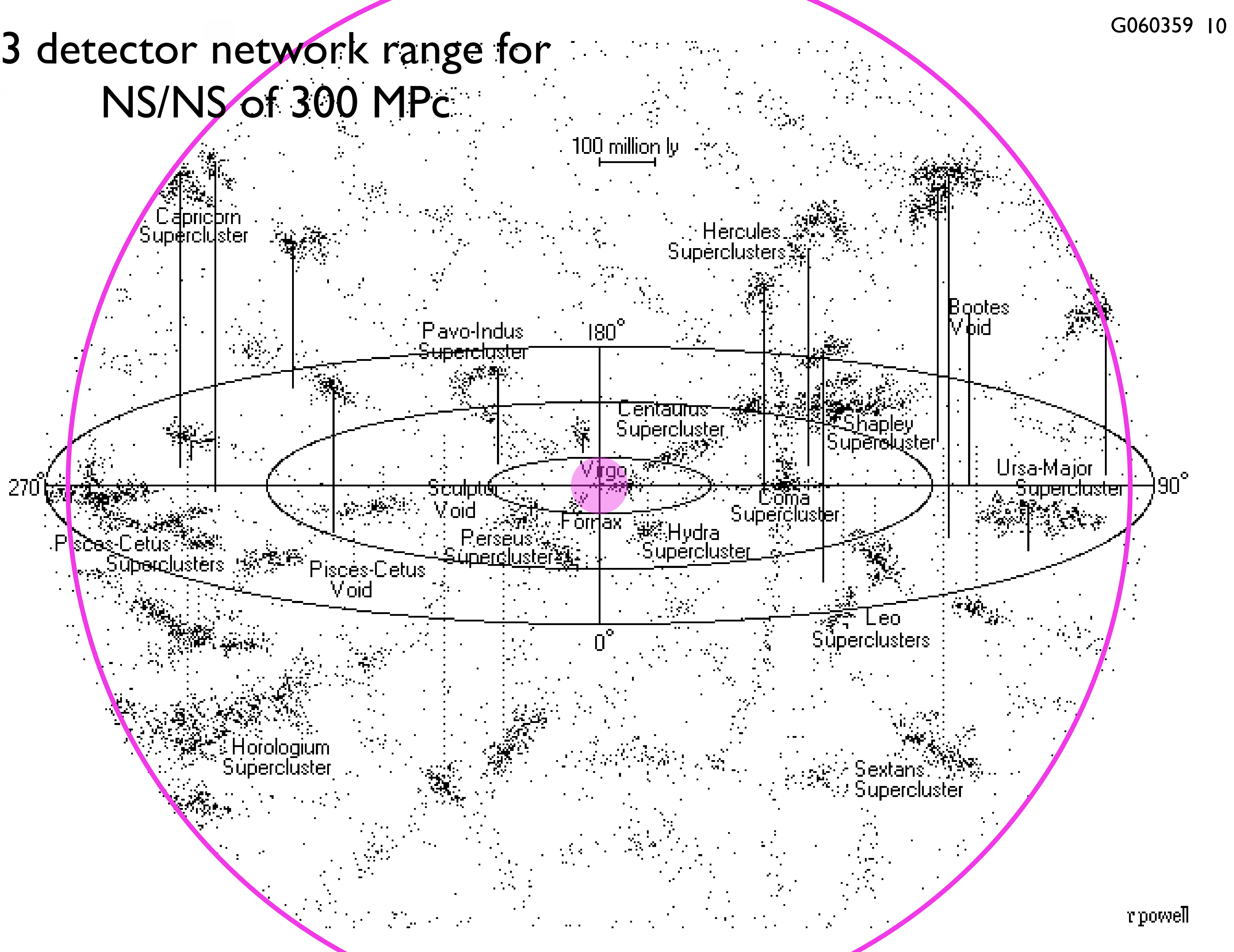


image by R. Powell

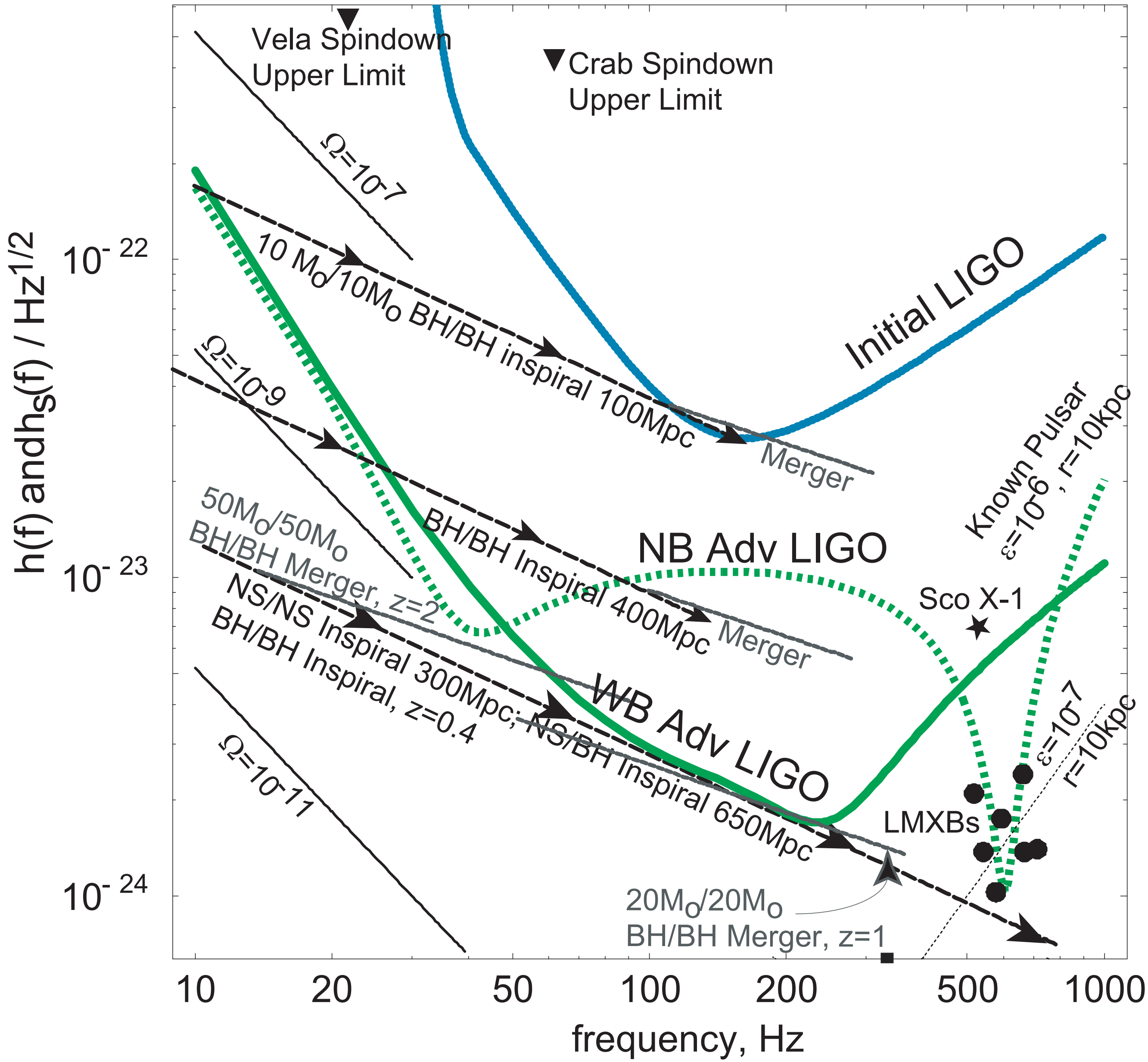
3 detector network range for NS/NS of 300 MPc



Advanced LIGO - Sources

Nelson Christensen, Stephen Fairhurst yesterday

- Neutron star and Black hole binaries
  - inspiral
  - merger
  - GRBs?
- Spinning NS's
  - LMXB
  - known pulsars
  - unknown?
- Birth of NS (supernovas)
  - tumbling
  - convection
- Stochastic Background
  - remnants of the big bang



Advanced LIGO - Technology

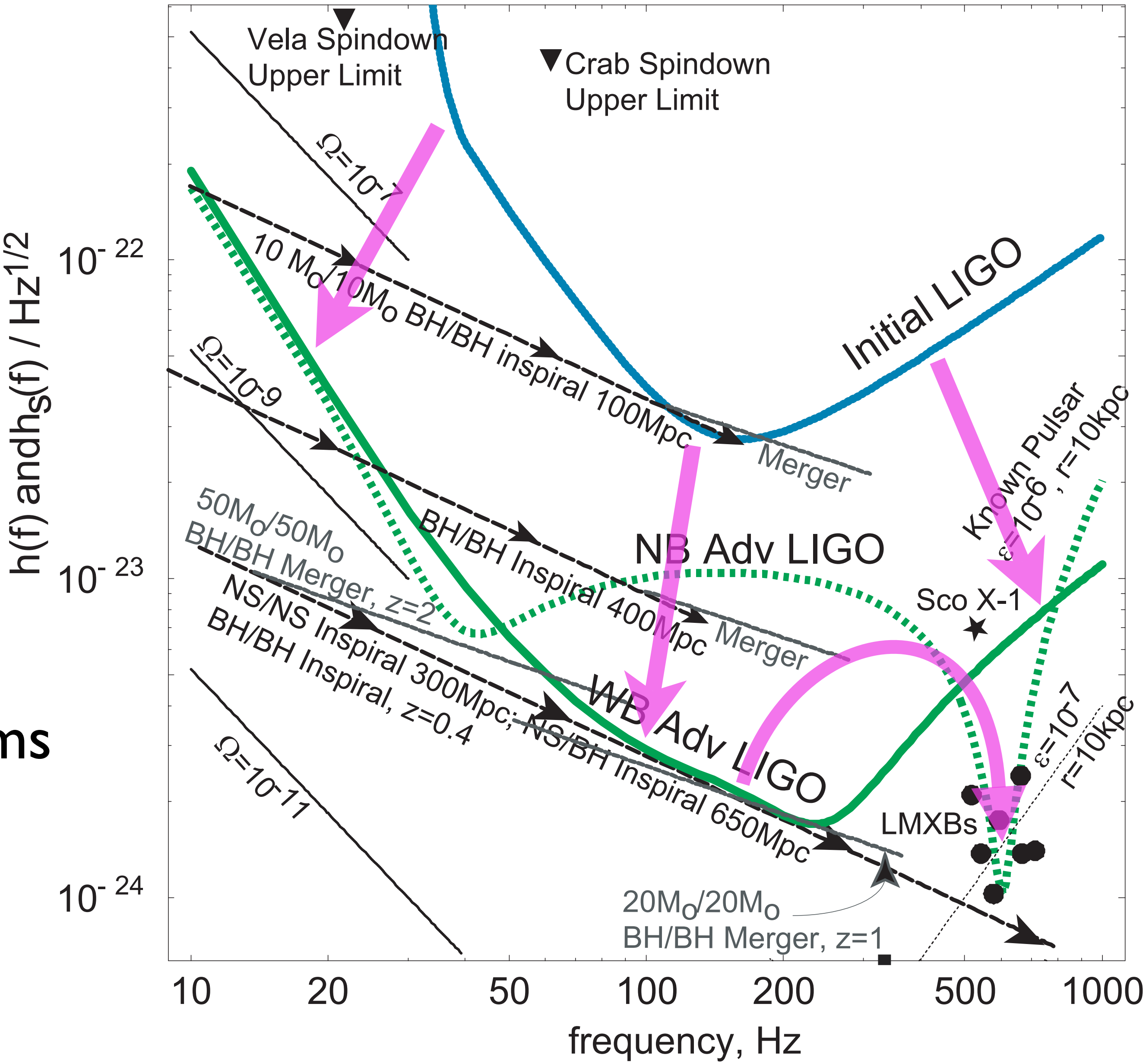
<u>Technical Improvements</u>

Environmental Isolation:
- platforms & pendulums

Thermal Noise control:
- suspensions & coatings

More Power
- new 180 W laser
- 830 kW circulating in arms

Signal recycling
- gives tunable response



Seismic Isolation & Alignment

Isolation of the test mass

10 Hz motion

test mass 1x10^{-19} m/√Hz

ground ~4x10^{-10} m/√Hz

rms length variation

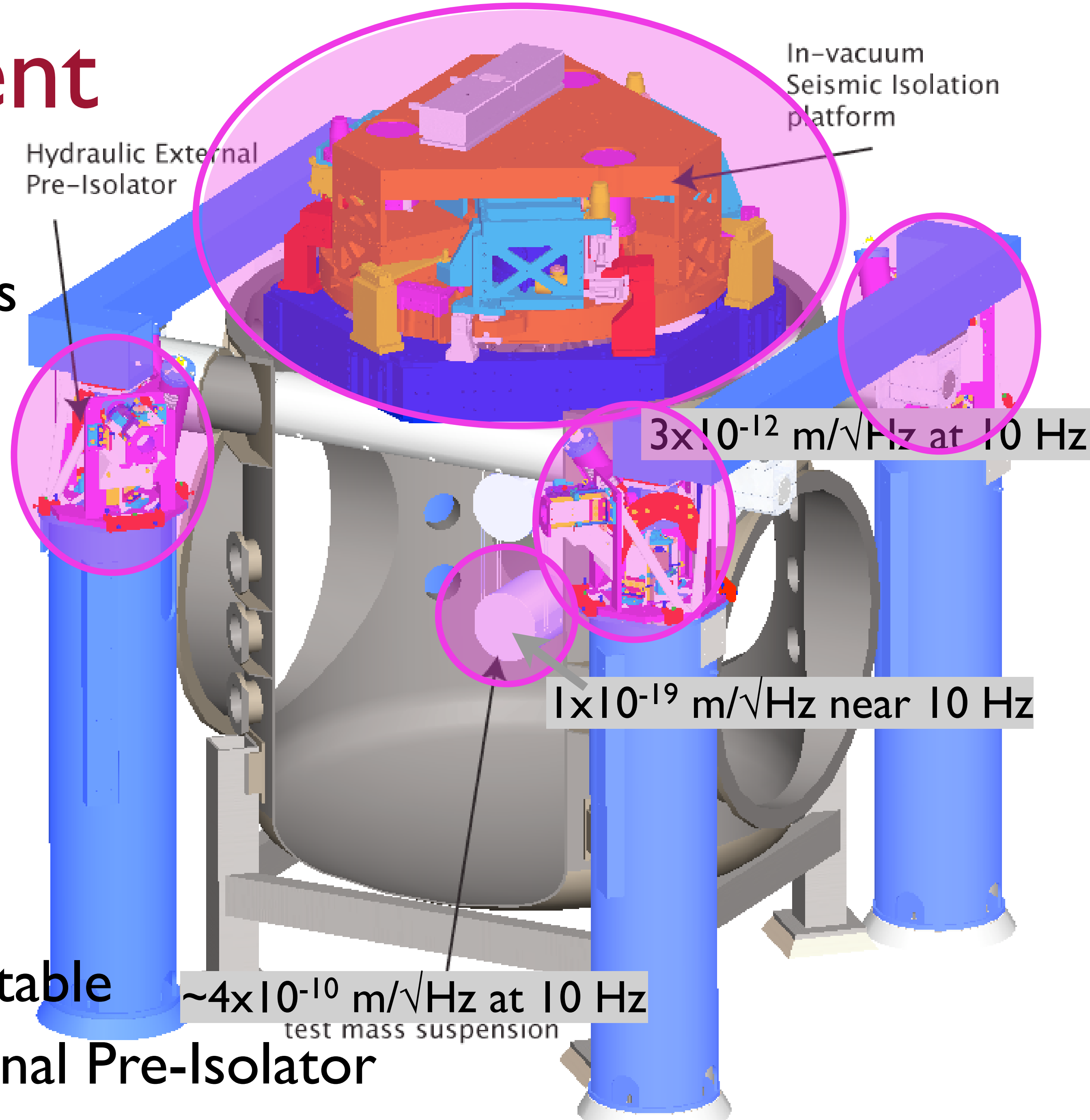
<1x10^{-14} m

<u>7 layers of isolation</u>

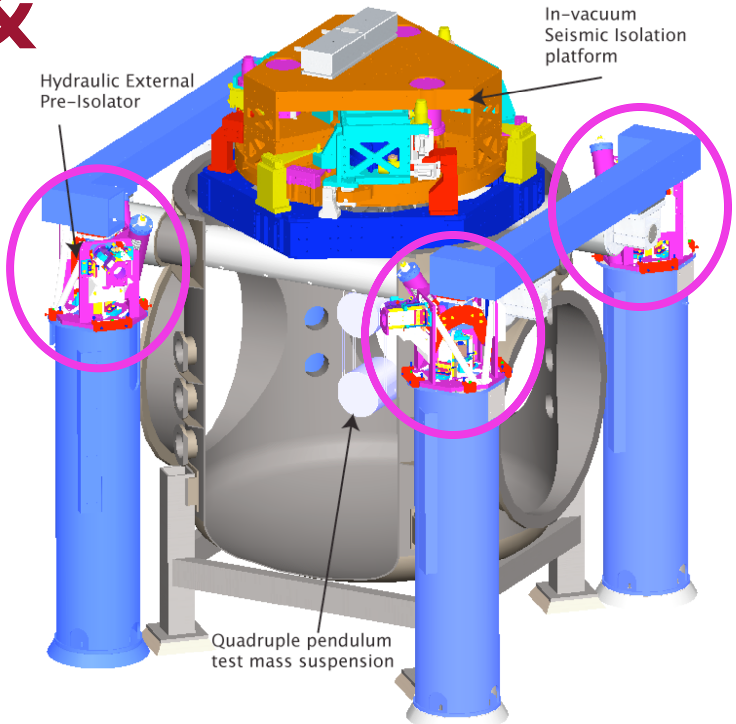
4 stage pendulum

2 stage active isolation table

1 stage Hydraulic External Pre-Isolator

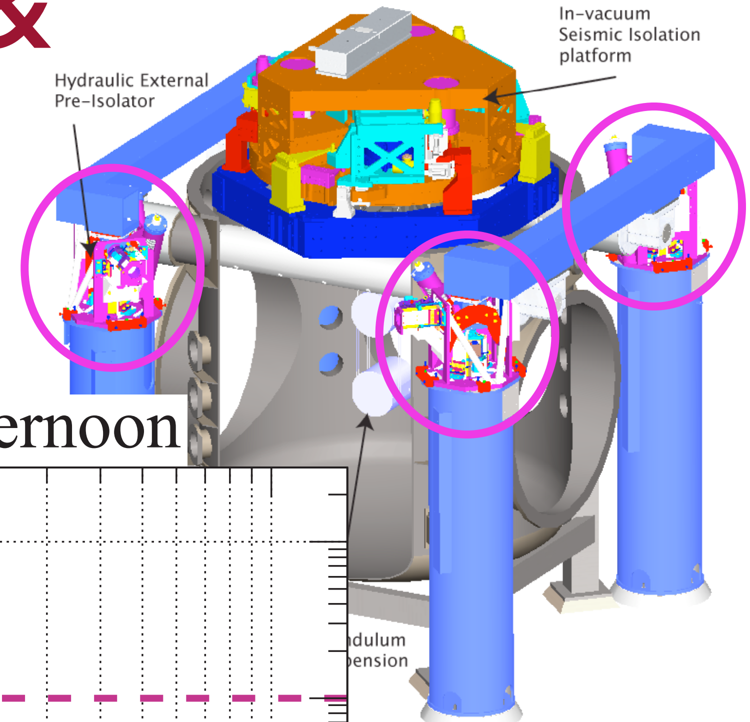


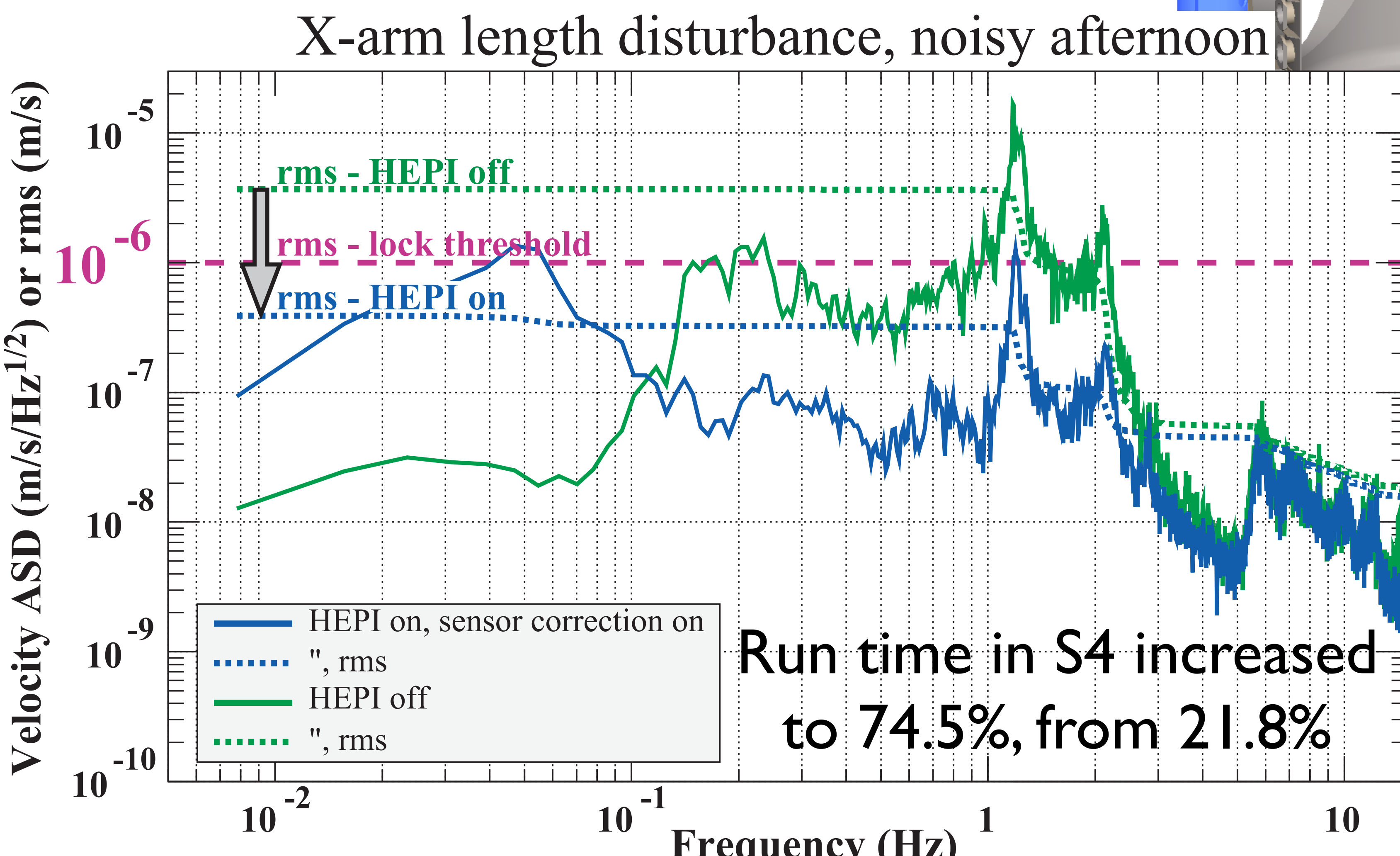
Seismic Isolation & Alignment - HEPI



- > Range of +/- 1 mm
- > Easily holds 1e3 N (400 lbs) static offset
- > Quiet (<1 nm/√Hz at 1 Hz)
- > 1 Vert, 1 Horz per pier for full 6DOF control
- > springs carry static load
- > Feed-forward ground sensors and feed-back local sensors for alignment and isolation.
- > Installed and running at LLO.

Seismic Isolation & Alignment - HEPI





Run time in S4 increased to 74.5%, from 21.8%

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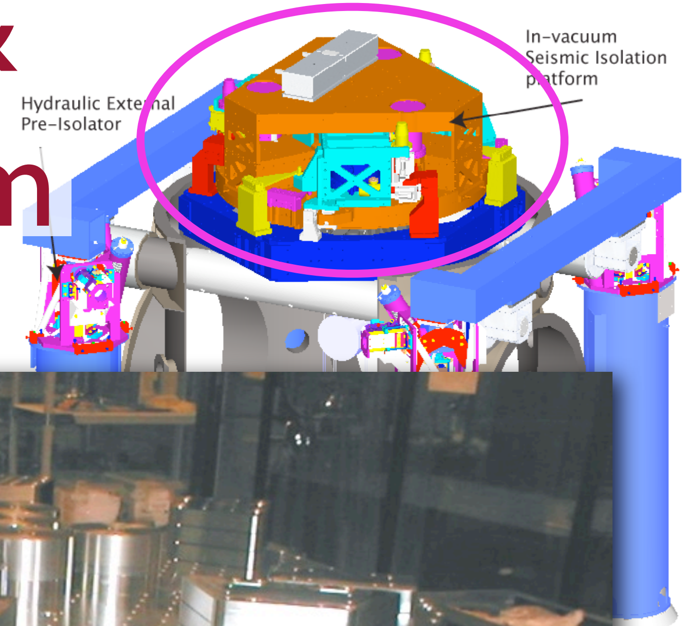
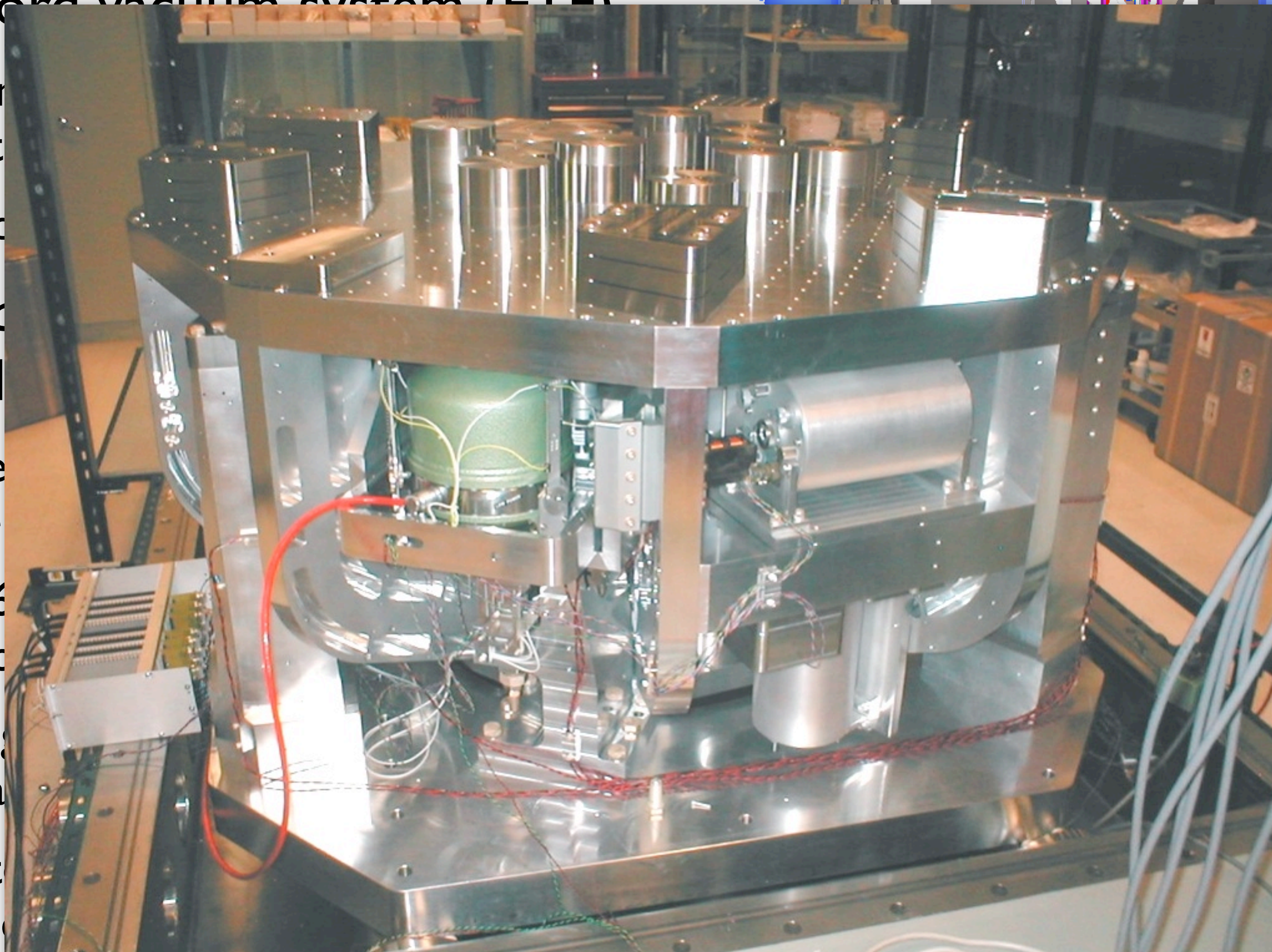
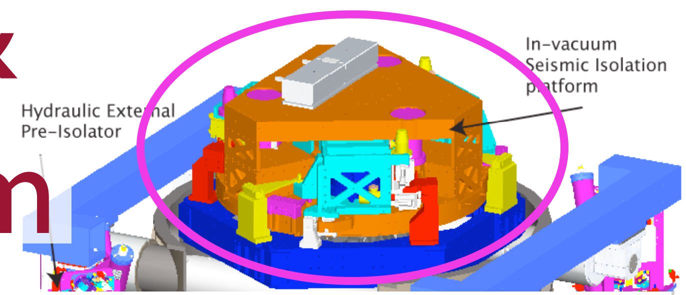
Seismic Isolation & Alignment - platform



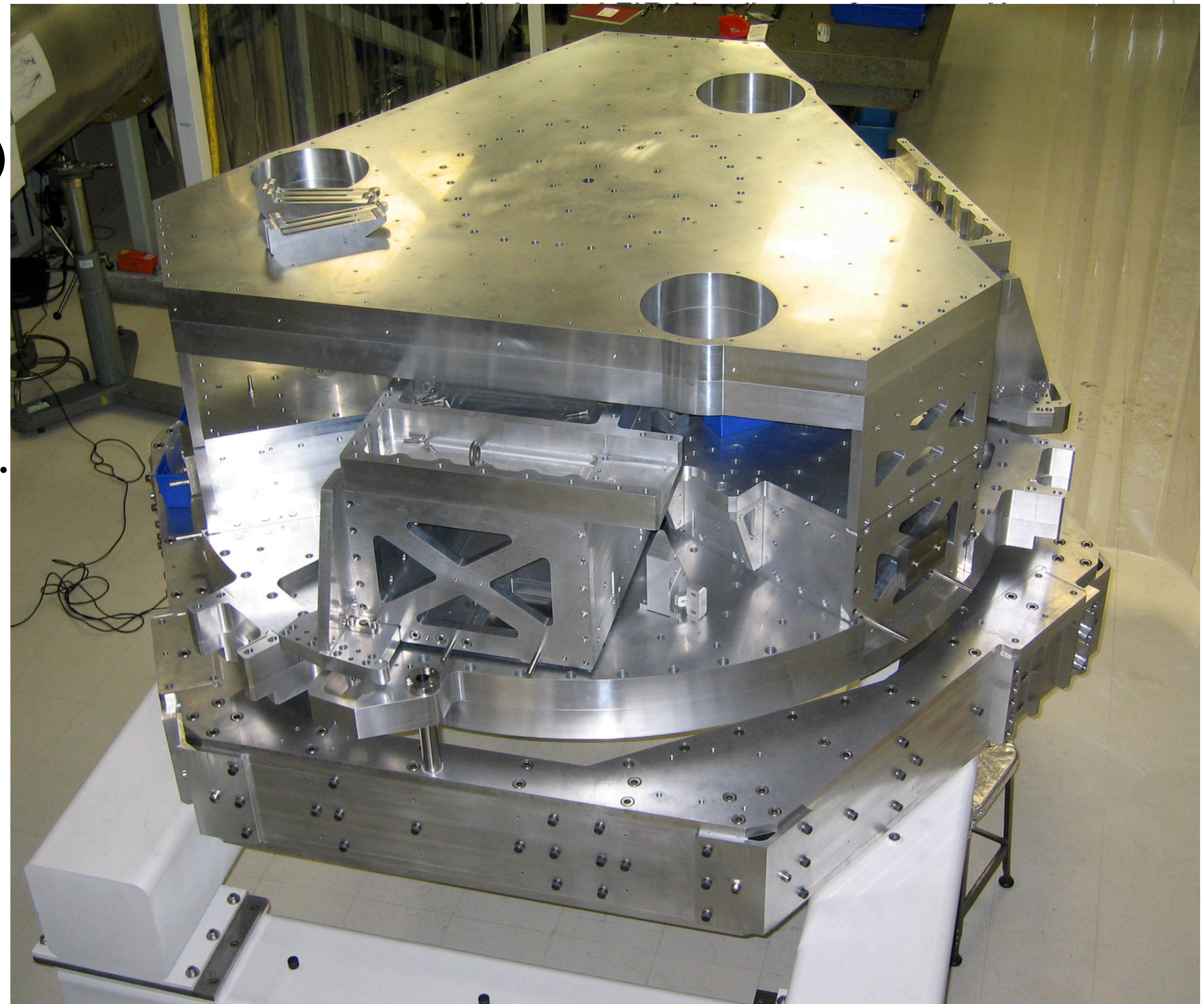
- Technology demonstrator designed and installed in Stanford vacuum system (ETF)
  - mechanical syster
  size platform, wit
  - most sensors and
- True prototype b
for full scale, UH
  - modal frequencie
  to accommodate
  - modeling of 6 x 6
  We design horizo
  - new design for ri
  motion during ea
  - can accommodat
  tolerate mechani



Seismic Isolation & Alignment - platform



- Isolation requirement:
  100 at 1 Hz (met!)
  3000 at 10 Hz (design mod)
- We modified the LASTI prototype to increase vertical passive isolation at 10 Hz, based on these tests.
- LASTI prototype now being assembled at MIT. Testing to commence forthwith.



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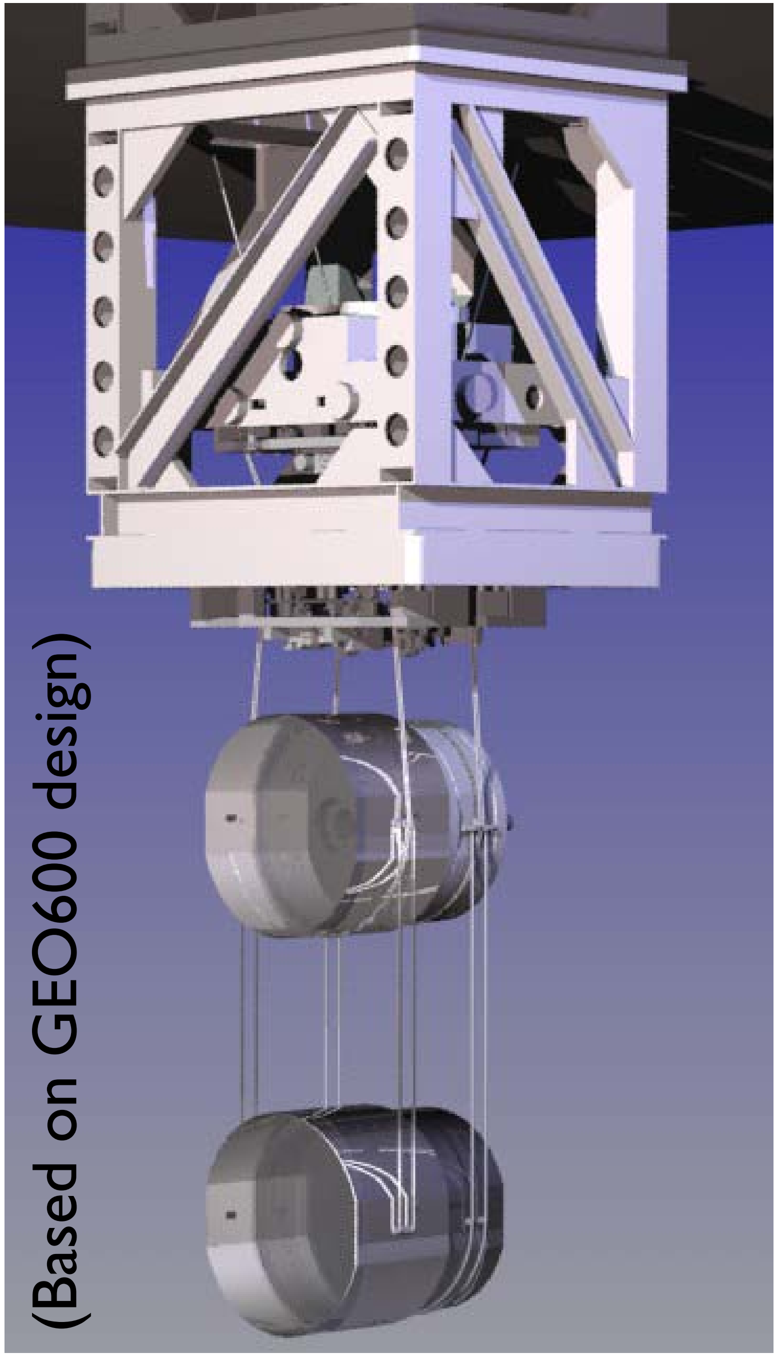
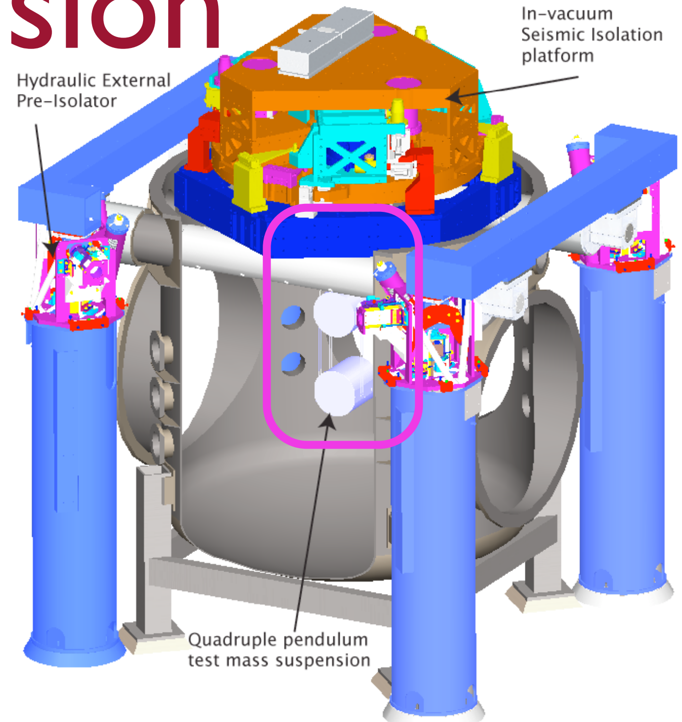
Pendulum Suspension



Drawings courtesy of Calum Torrie and GEO600

(see upcoming talk by Alastair Heptonstall)



Multiple-pendulums for control flexibility & seismic attenuation

Test masses:
Synthetic fused silica, 40 kg, 34 cm dia.

» Q ≥ 1e7
» low optical absorption

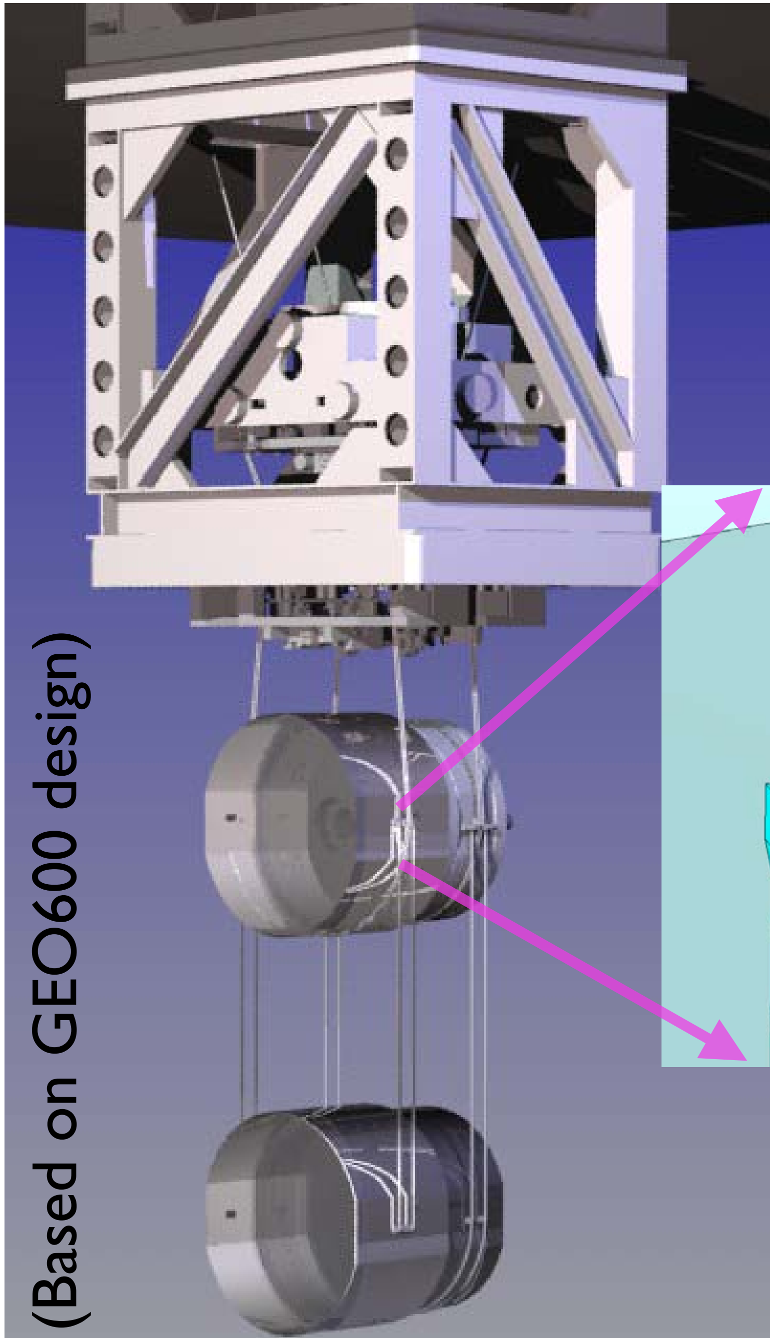
Final suspensions are fused silica, joined to form monolithic final stages.

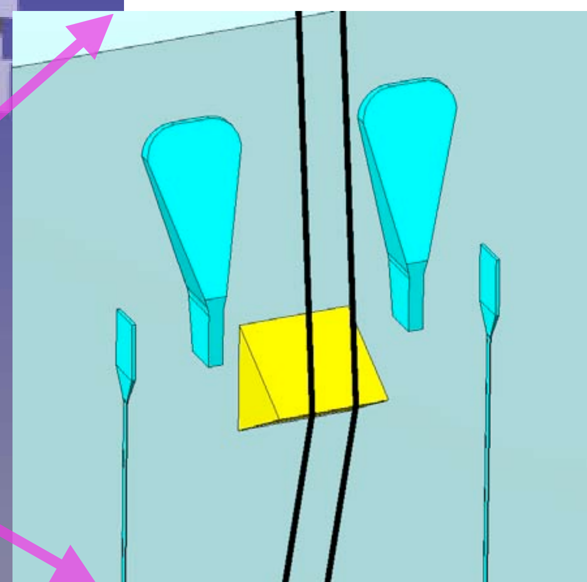
Thermal vibrations at the optical surface set the performance limit of the suspension.

Pendulum Suspension

(see upcoming talk by
Alastair Heptonstall)

Multiple-pendulums for control flexibility & seismic attenuation





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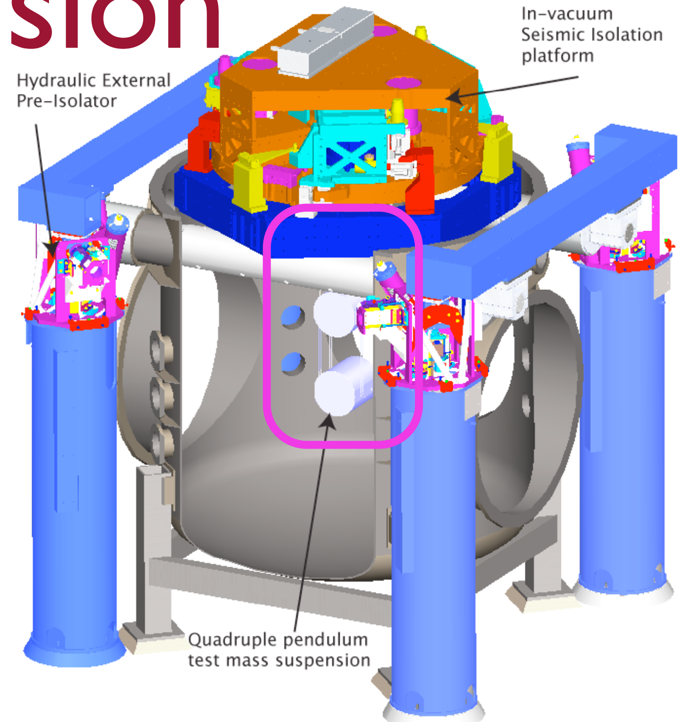

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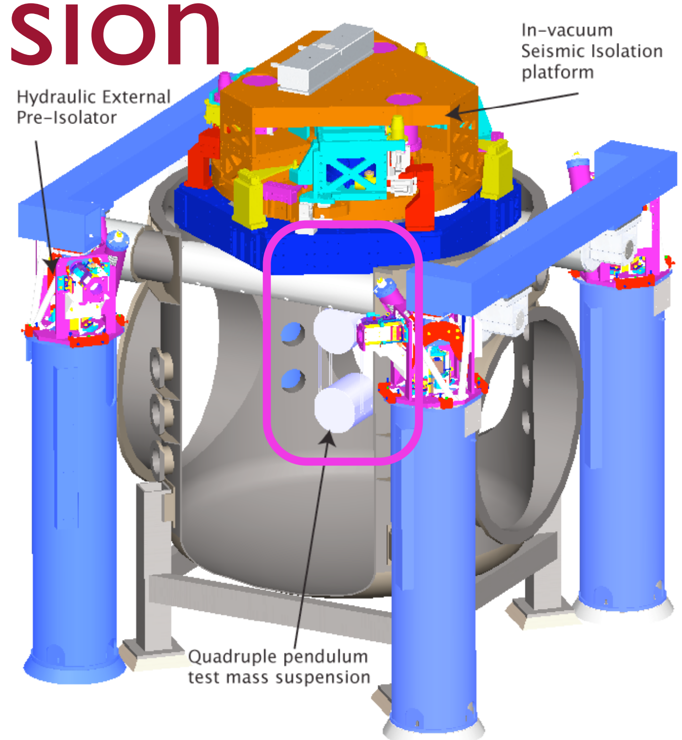
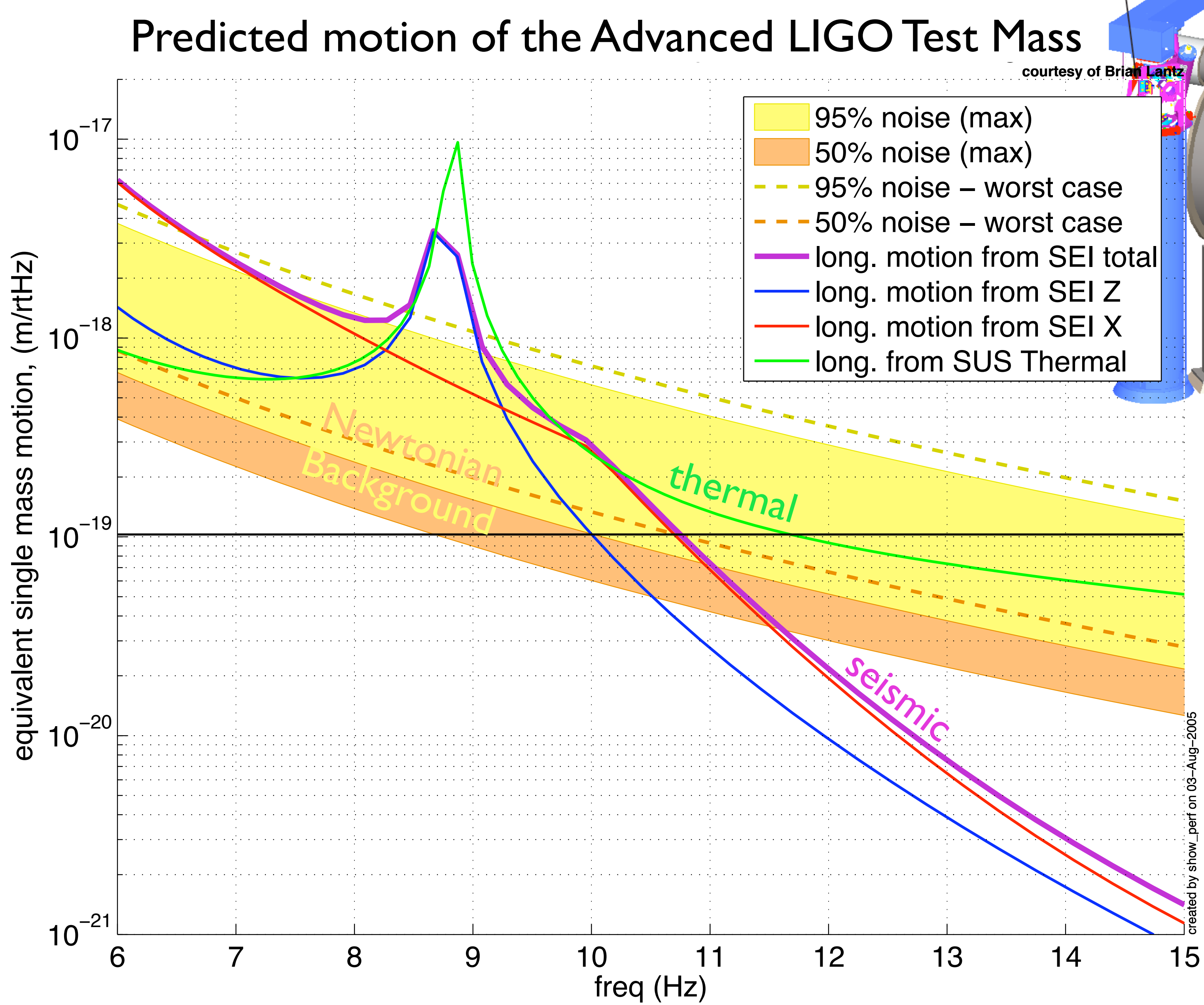
Pendulum Suspension

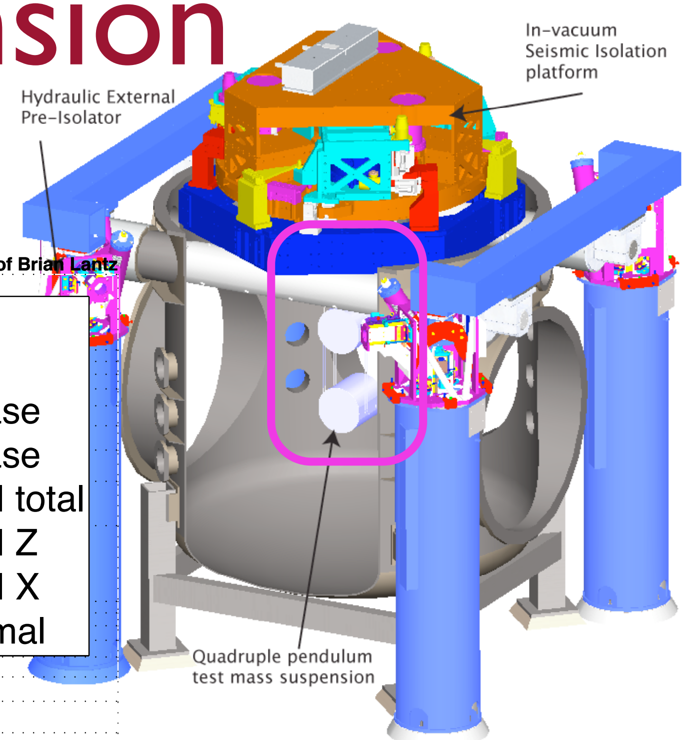


Installing 'controls prototype' at MIT
(metal masses, metal wires)

'Noise prototype' due in early 2007
(glass optics, silica ribbon suspensions)

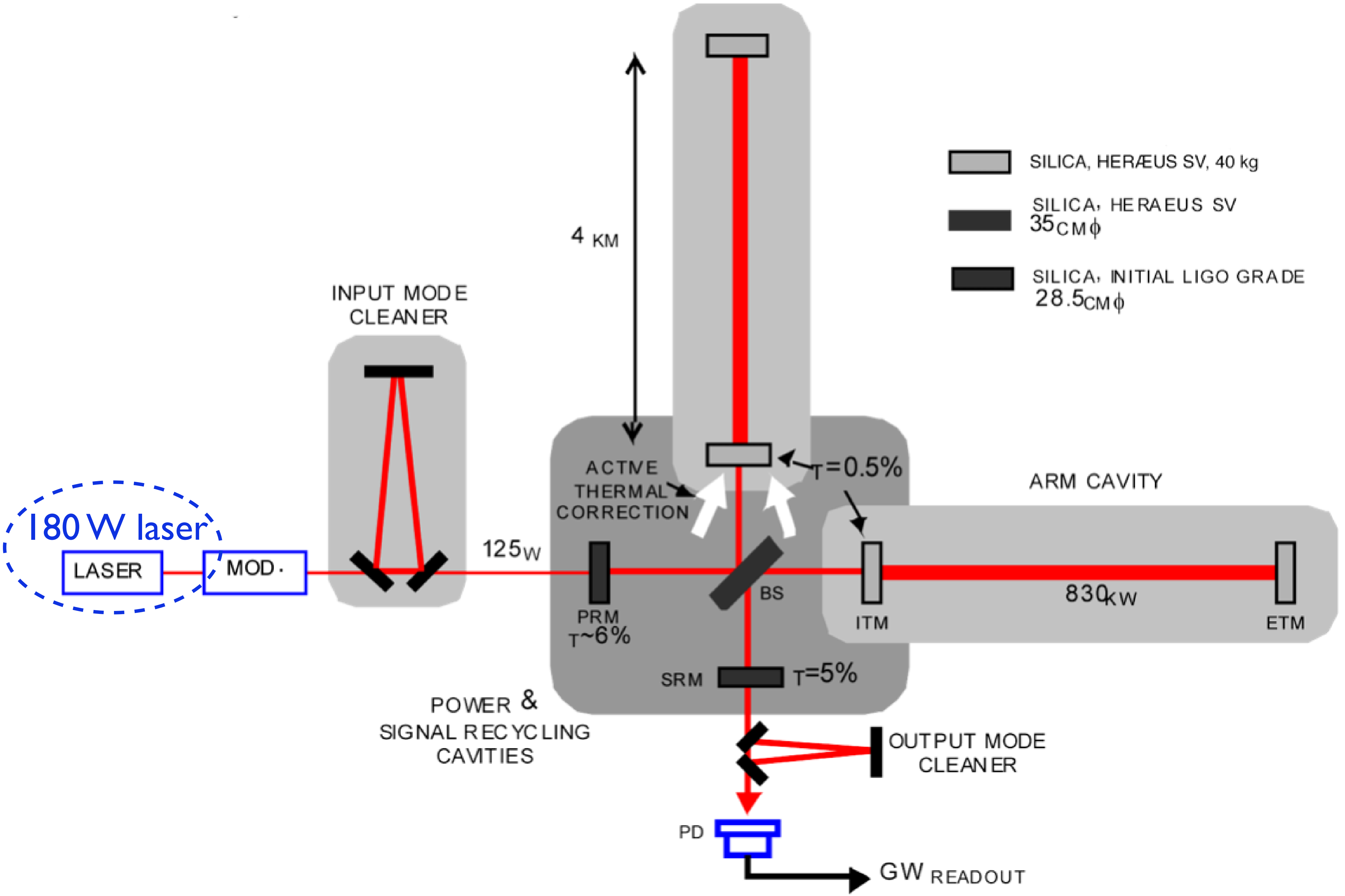
Pendulum Suspension





1e-19 m/√Hz

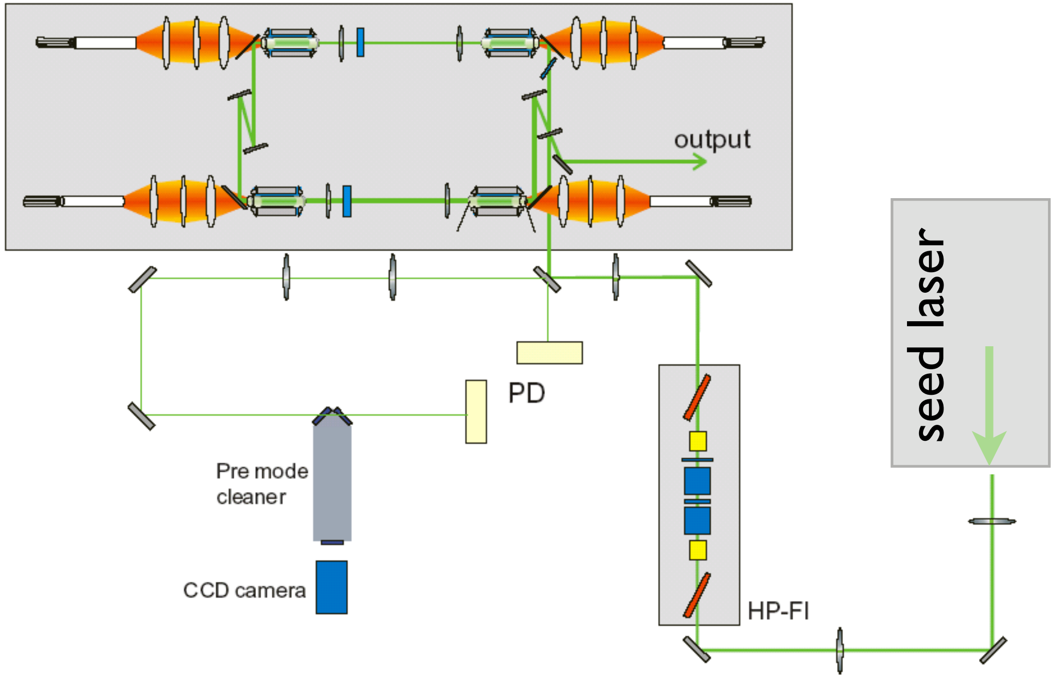
Power, Optics, and Interferometers

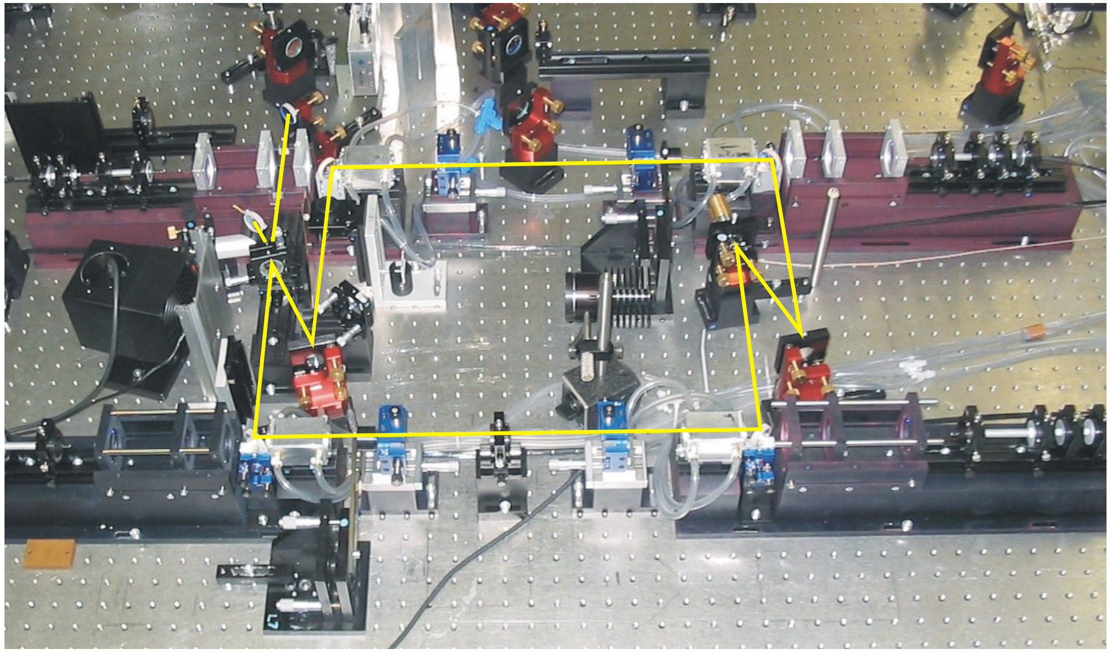


High Power Laser

- 180 W with good beam shape
- 1064 nm (YAG)
- very low intensity and frequency noise
- Developed by
  Max-Planck Institute, Hanover &
  Laser Zentrum Hanover
- stable front end
  determines laser frequency and frequency fluctuations.
- high power stage,
  Injection seeded ring oscillator
  determines power,
  power fluctuations, and
  beam shape.

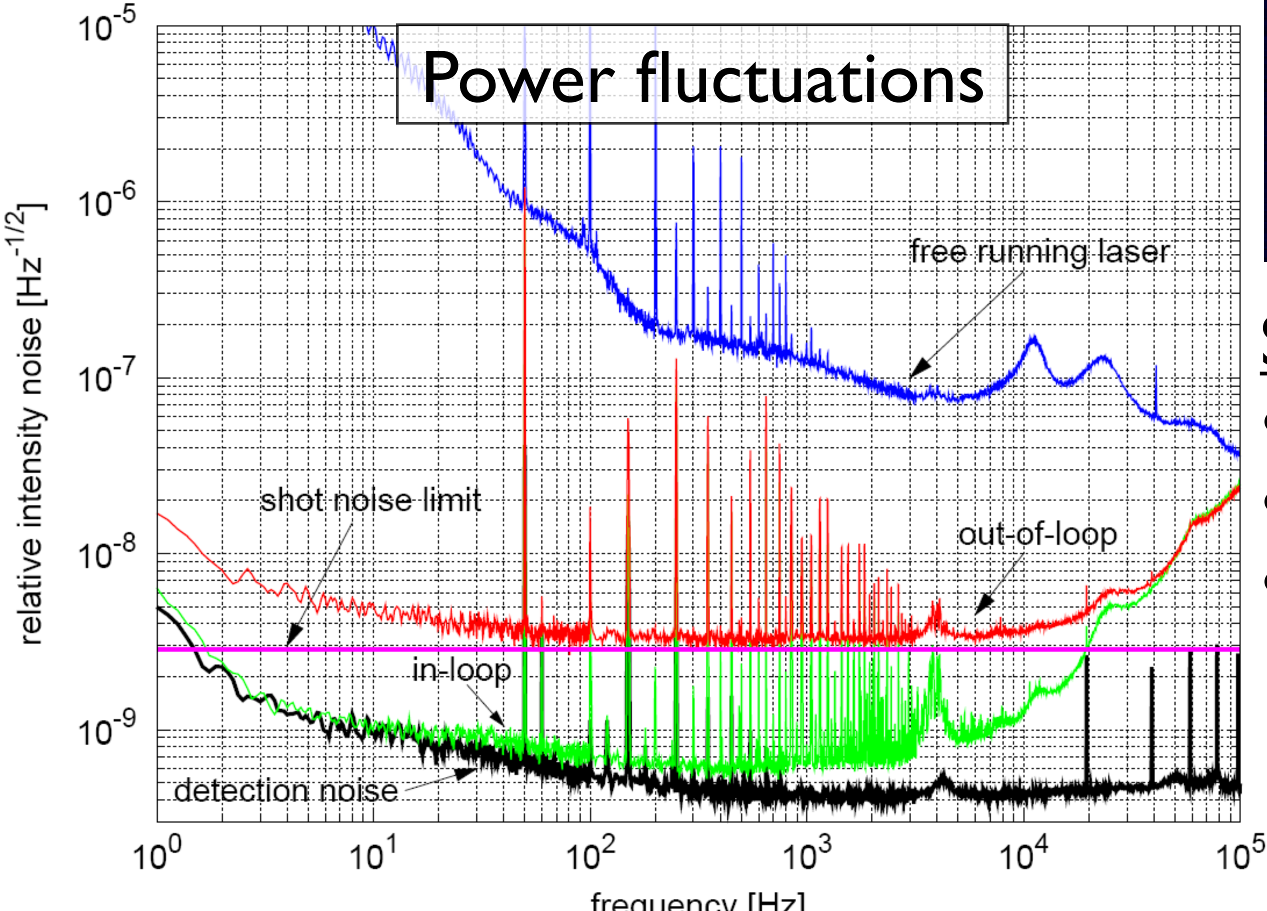
high-power injection-locked oscillator

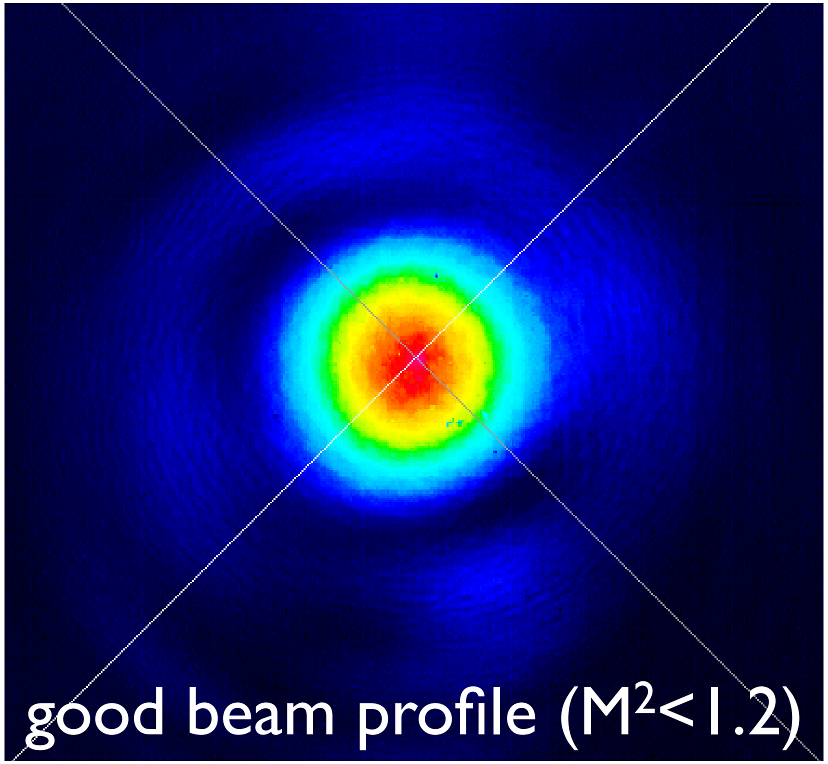




High Power Laser

<u>Achieved:</u>
- 180 W output power
- good spatial profile
- power fluctuations close to requirement.





<u>Still to Verify:</u>
- RIN at modulation freq.
- higher order mode content
- pointing fluctuations

see talks by Benno Willke & Nary Man

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Test Mass Requirements

see upcoming talk by Peter Murray

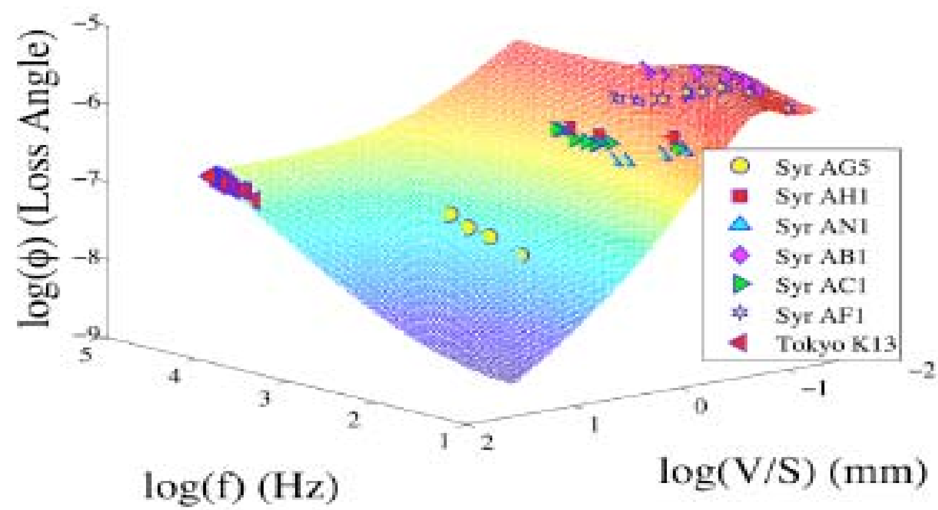
Mass	40 kg
Dimensions	340 mm x 200 mm
Surface figure	< 1 nm rms
Micro-roughness	< 0.1 nm rms
Double-pass optical homogeneity	< 20 nm rms,
Bulk absorption	< 3 ppm/cm
Bulk mechanical loss	$< 3\times10^{-9}$
Optical coating absorption	< 0.5 ppm(required) < 0.2 ppm(goal)
Optical coating scatter	< 2 ppm(required) < 1 ppm(goal)
Optical coating mechanical loss	$< 2\times10^{-4}$ (required) $< 3\times10^{-5}$ (goal)
Arm cavity optical loss / round trip	< 75 ppm

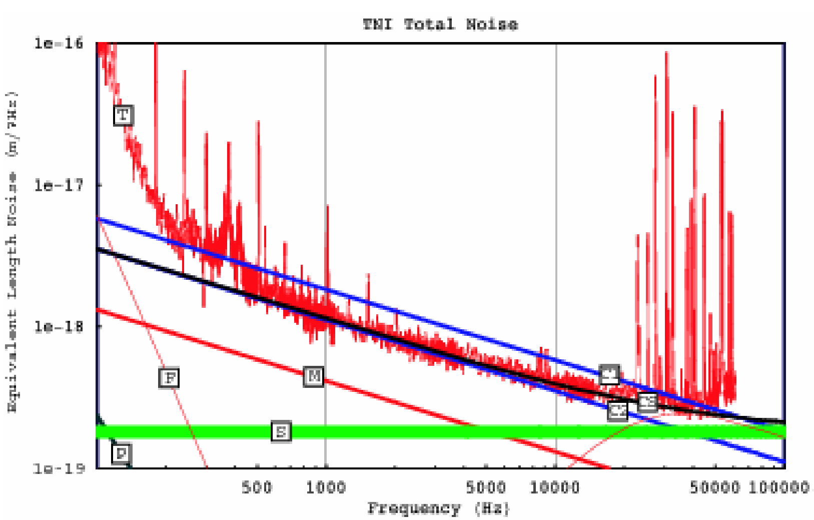
courtesy of Gregory Harry

Core Optics - Development Status

Silica

- Mechanical loss modeled from Q data
- Polishing will use initial LIGO technique
- Metrology close to adequate to guide polishing
- Substrate optical absorption less than coating and acceptable with planned thermal compensation
- Silicate bonding acceptable for connecting "ears" with suspensions





Coating

- Low mechanical loss silica/titania-doped tantala demonstrated on small test samples
- Direct observation of thermal noise from silica/titania-doped tantala coatings confirms thermal noise reduction
- Optical absorption near required level
- Silica/silica-doped titania also shows improved mechanical loss
- Scatter requires improvement over initial LIGO levels

slide courtesy of Gregory Harry

and more...

- End-to-end model
- Sensing and control for all length and angle DOFs
- Big computing pipeline for both instrument control and for data analysis.
- output mode cleaner (CIT 40 meter lab)
- high power input optics (Univ. Florida)
- 40 m lab & Thermal noise interferometer at Caltech, LASTI at MIT, high-power test facility at Gingin, 10 meter lab at Univ. Glasgow, ETF at Stanford, the LIGO and GEO observatories...

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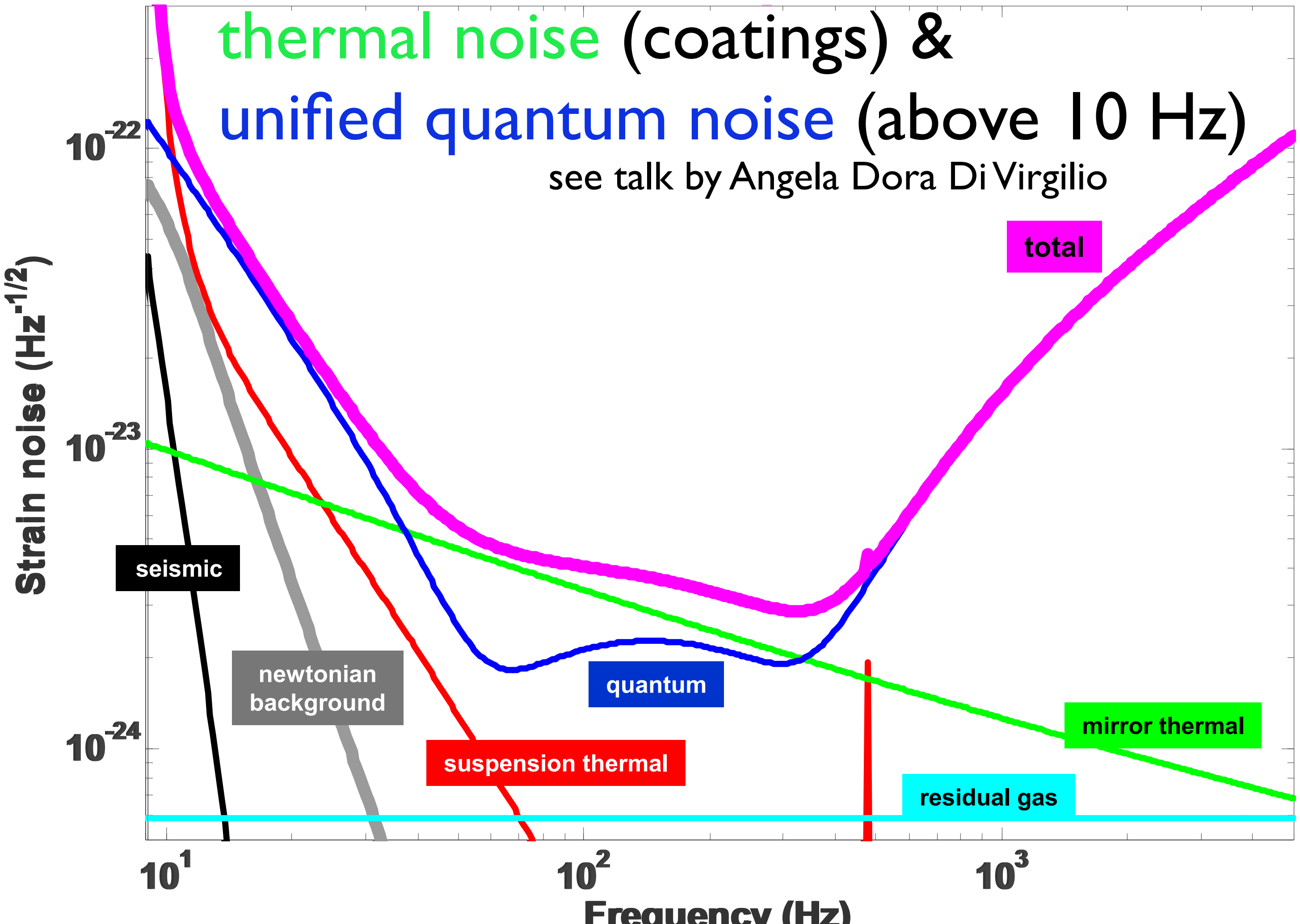
Tuning

Instrument noise floor set by
thermal noise (coatings) &
unified quantum noise (above 10 Hz)
see talk by Angela Dora Di Virgilio



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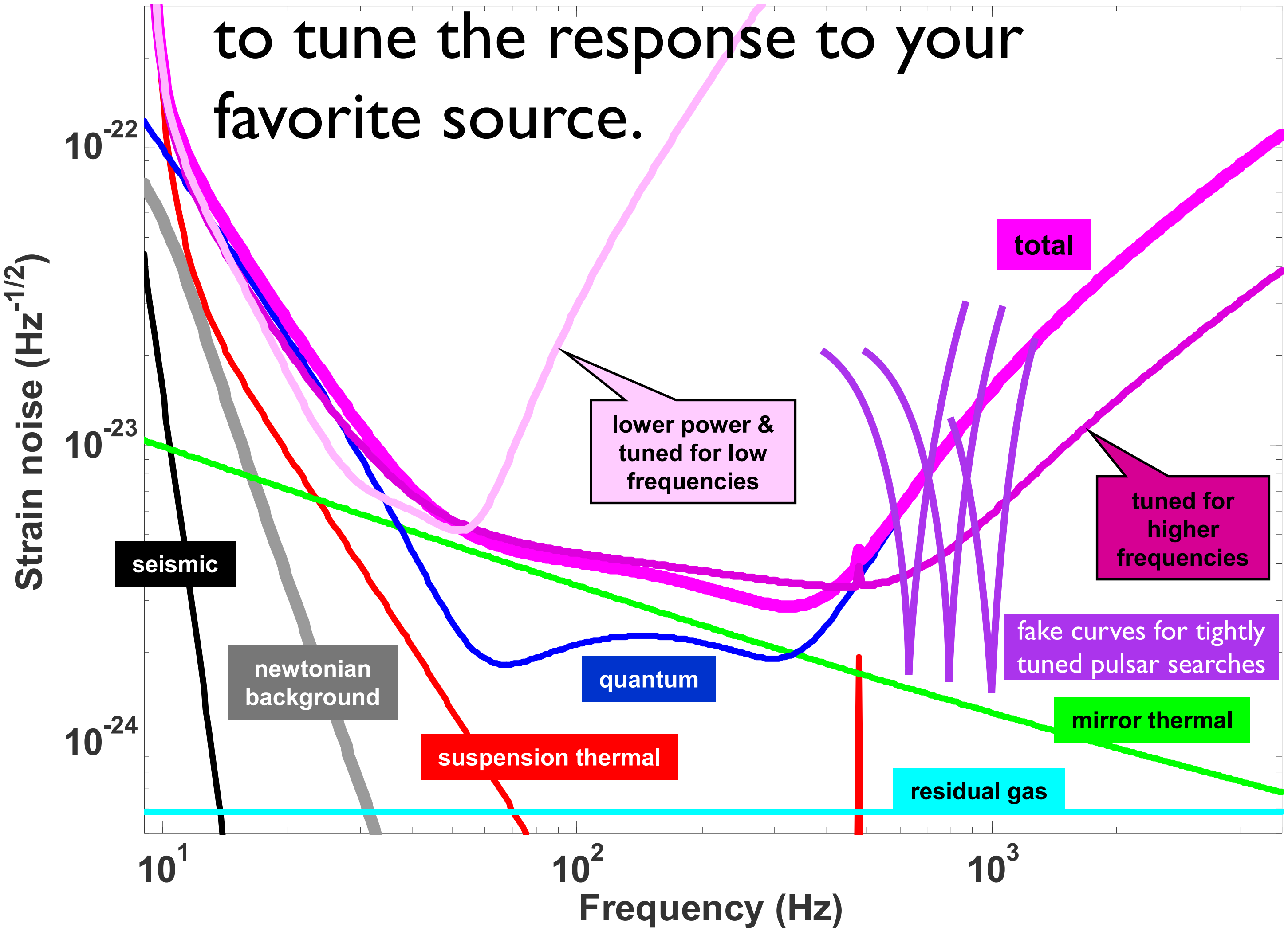
Tuning

Signal recycling mirror makes it possible to tune the response to your favorite source.



When we start measuring gravitational waves, this flexible instrument can be directed towards many different astrophysical goals.

in Conclusion...

- LIGO science collaboration is large and active,
- We've developed a tremendous amount of new technology,
- We now have the technology in hand to make a fantastic new instrument, and
- We'll be ready to start construction next fall.

The astrophysics will be great!