Attometer Astrophysics

LIGO Status in 2007

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on behalf of the LIGO Scientific Collaboration
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Outline

- Gravitational waves
  - GR & GW
  - Interferometric detectors
- LIGO fifth science run
  - Sensitivities
  - Performance
  - Limitations
- Future directions
  - Enhanced LIGO
  - Advanced LIGO

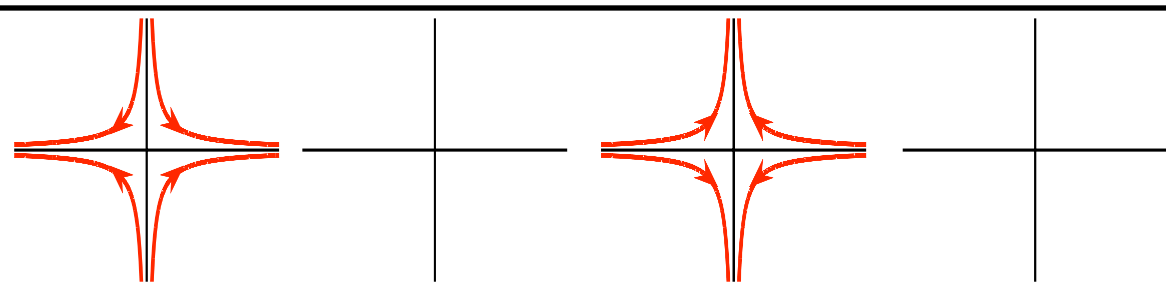
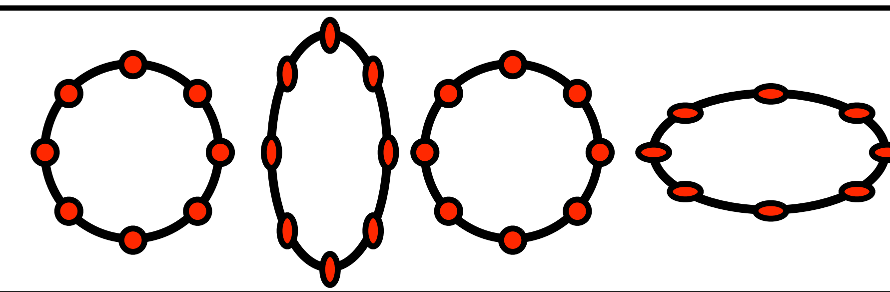
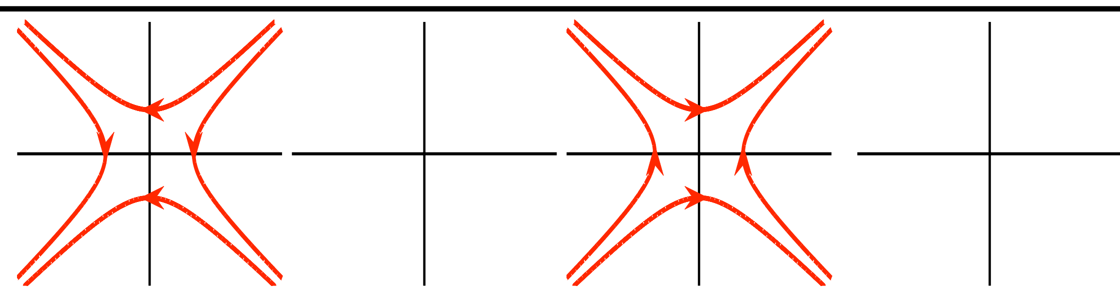
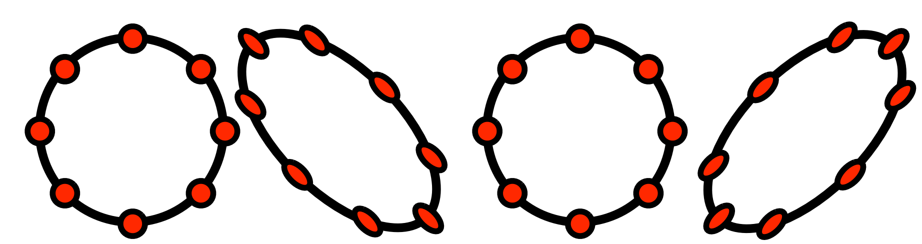
Linearized GR

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$$

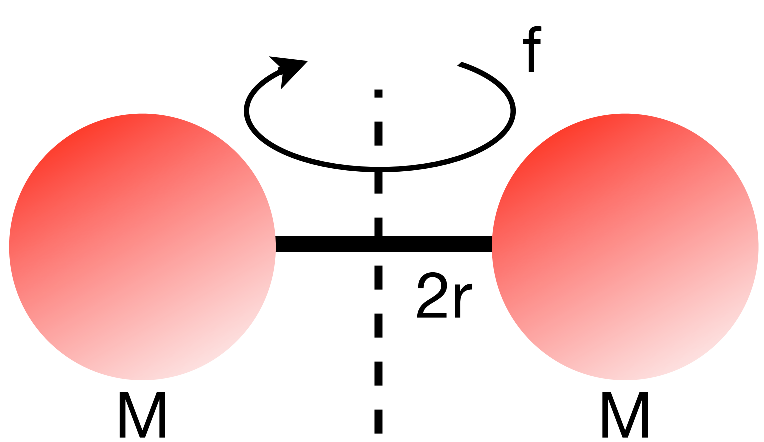
- Minkowski metric = flat spacetime
- $h_{\mu\nu}$ << 1 = perturbations
- plane waves propagate at *c* $h_{\mu\nu} = A_{\mu\nu} \exp(i k_\alpha x^\alpha)$
- Two dynamic DOFs: polarizations $A_+, \quad A_\times$

Strain and Gauge

	Locally Lorentz	Transverse Traceless
	Induced acceleration	**Induced strain**
	$\frac{d^2x}{dt^2} = \frac{1}{2}\left(\ddot{A}_+ x\,\hat{x} + \ddot{A}_\times y\,\hat{y}\right)$	$h = \frac{\delta l}{l}$
A_+ :		
$A_\times$:		

Generating GWs

- No monopoles: mass conservation
- No dipoles: momentum conservation
- Quadrupole moment: mass asymmetry



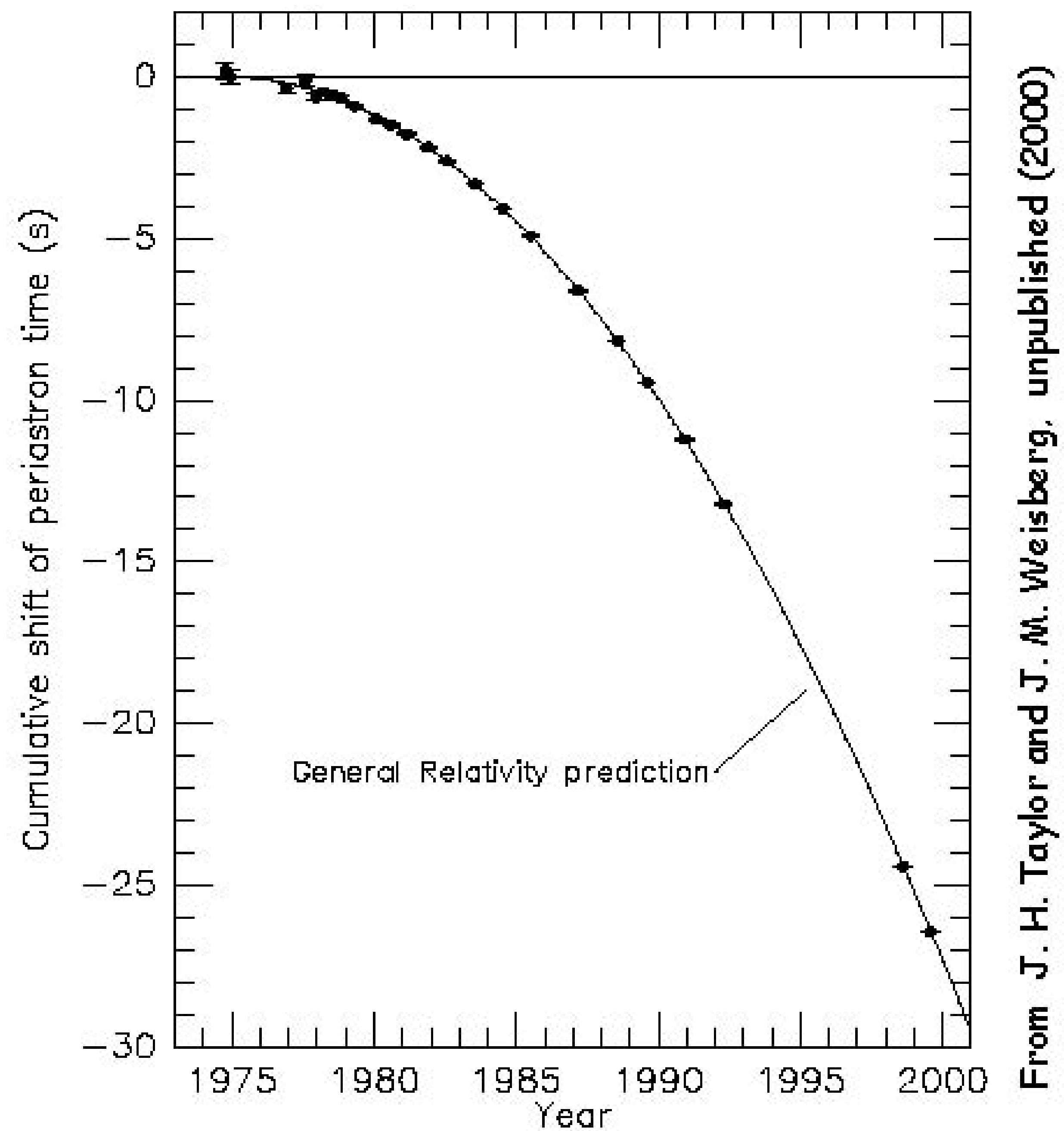
$$I_{xx} \approx 2Mr^2 \cos^2 2\pi f t$$

$$h_{\mu\nu} = \frac{2G}{Rc^4} \ddot{I}_{\mu\nu}$$

$$h_{xx} = \frac{32\pi^2 G}{Rc^4} M r^2 f^2 \cos 4\pi f t$$

$$h = 2.6 \times 10^{-42} \frac{1}{[kg][m][Hz^2]}$$

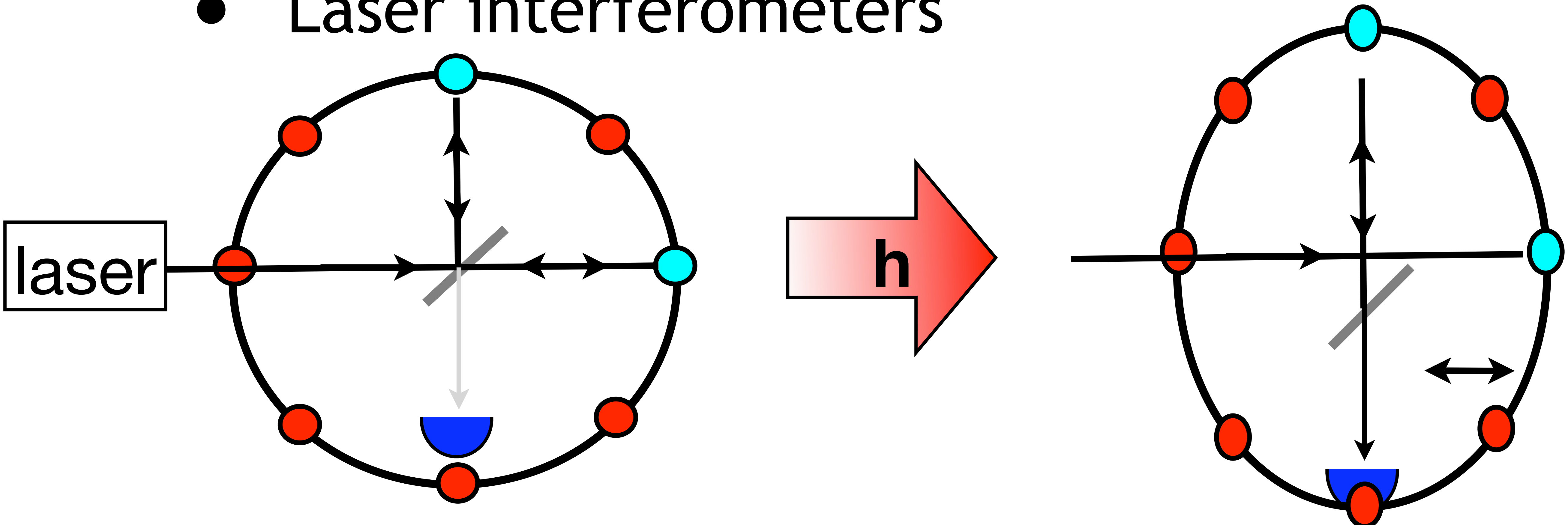
Indirect GWs



- Hulse & Taylor
- Binary NS system
  - $r = 1.6 \times 10^9$ m
  - $m_1 \sim m_2 \sim 1.4\ M_\odot$
  - 8 hr orbit
  - 7.5 kpc
- GR predicts 3mm/orbit
- $h = 7.2 \times 10^{-23}$

Detecting GWs

- Two technologies:
  - Resonant bar detectors
  - Laser interferometers



Michelson interferometer:

Null measurement
Matched antenna pattern
Cancels technical noise

$$P \propto \sin^2 \frac{\Delta x}{\lambda}$$

IFO statistics

- ~10 W, 1.064 μm Nd:YAG lasers
- ~1 km Michelson interferometers
- ~20 kW stored power
- 10 - 1,000 Hz bandwidth
- $\Delta x \sim 10^{-19}$ m/rHz length sensitivity
- h ~ 10^{-23} /rHz strain sensitivity

Hurry up and wait

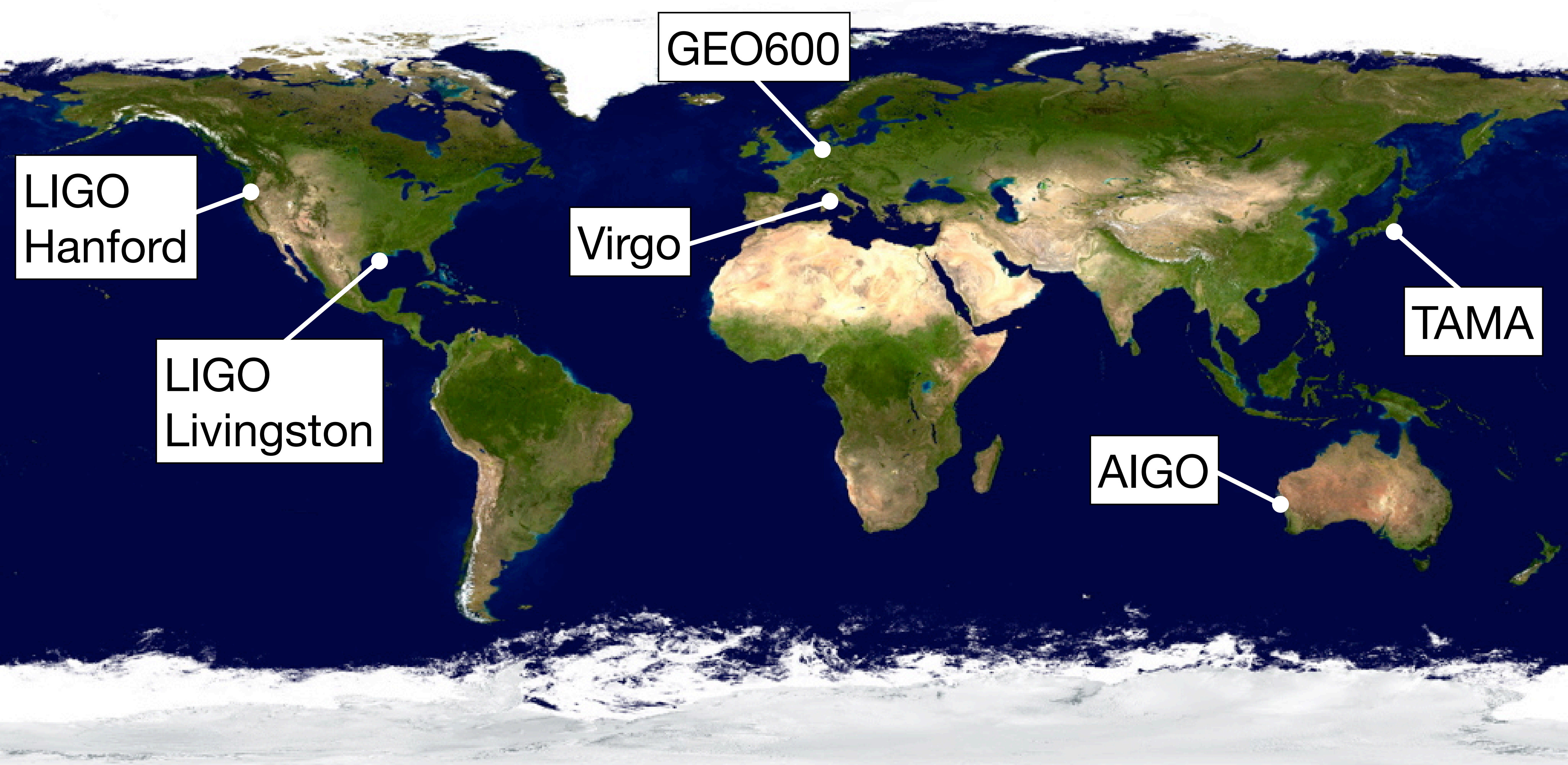
- Detectors are sensitive to GW *field amplitude*
- 1.4/1.4 $M_\odot$ Binary Neutron Star inspiral is a standard candle
- Horizon Range:

$$R_0 \propto \left[\frac{M_{chirp}}{SNR} \int_{f_{min}}^{f_{max}} df\ H(f)^{-2} f^{-7/3} \right]^{1/2}$$

- Exposure:

$$N_{det} \propto T\, R_0^3$$

Interferometer Network



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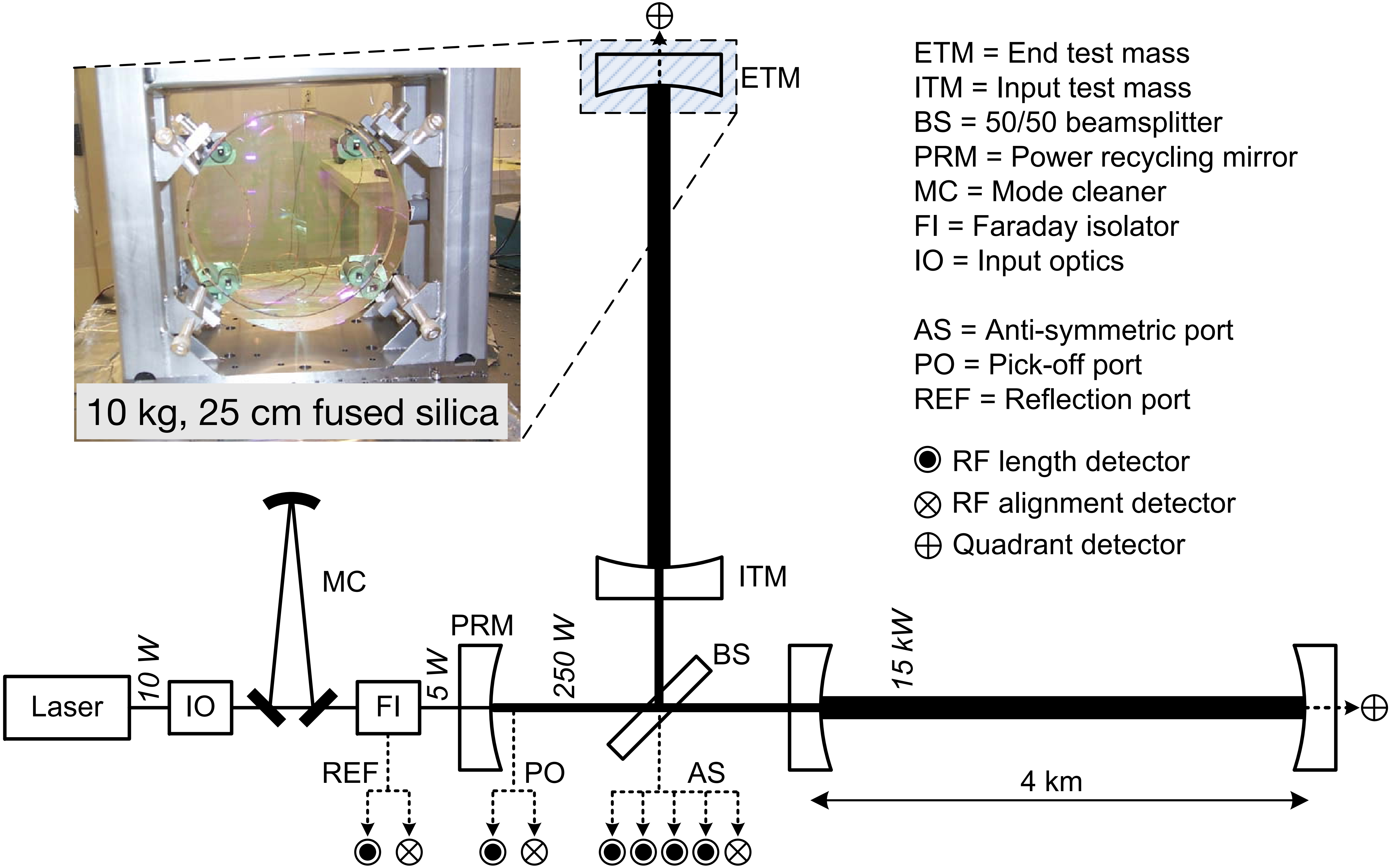
LIGO detectors

LIGO IFOs

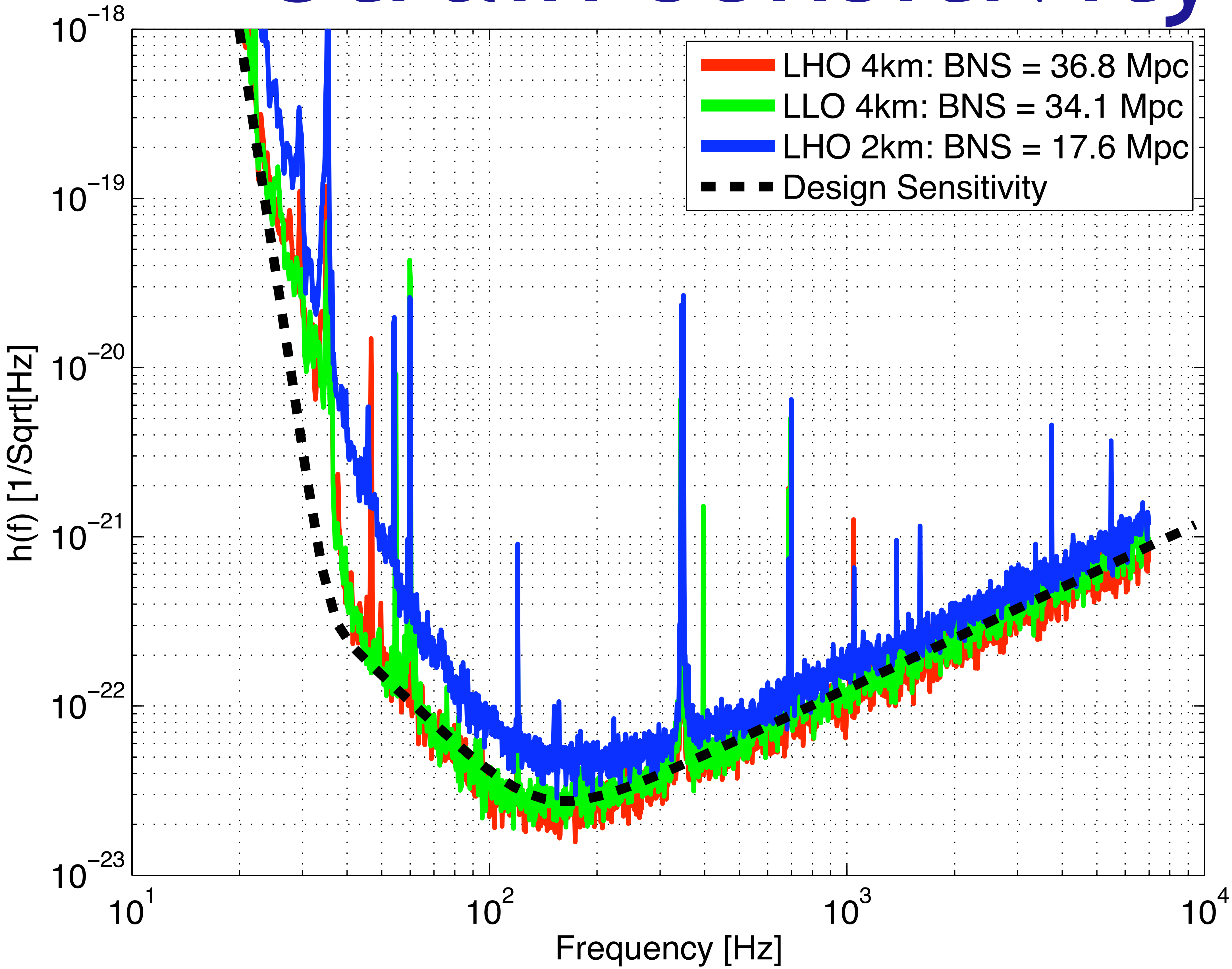


ETM = End test mass
ITM = Input test mass
BS = 50/50 beamsplitter
PRM = Power recycling mirror
MC = Mode cleaner
FI = Faraday isolator
IO = Input optics

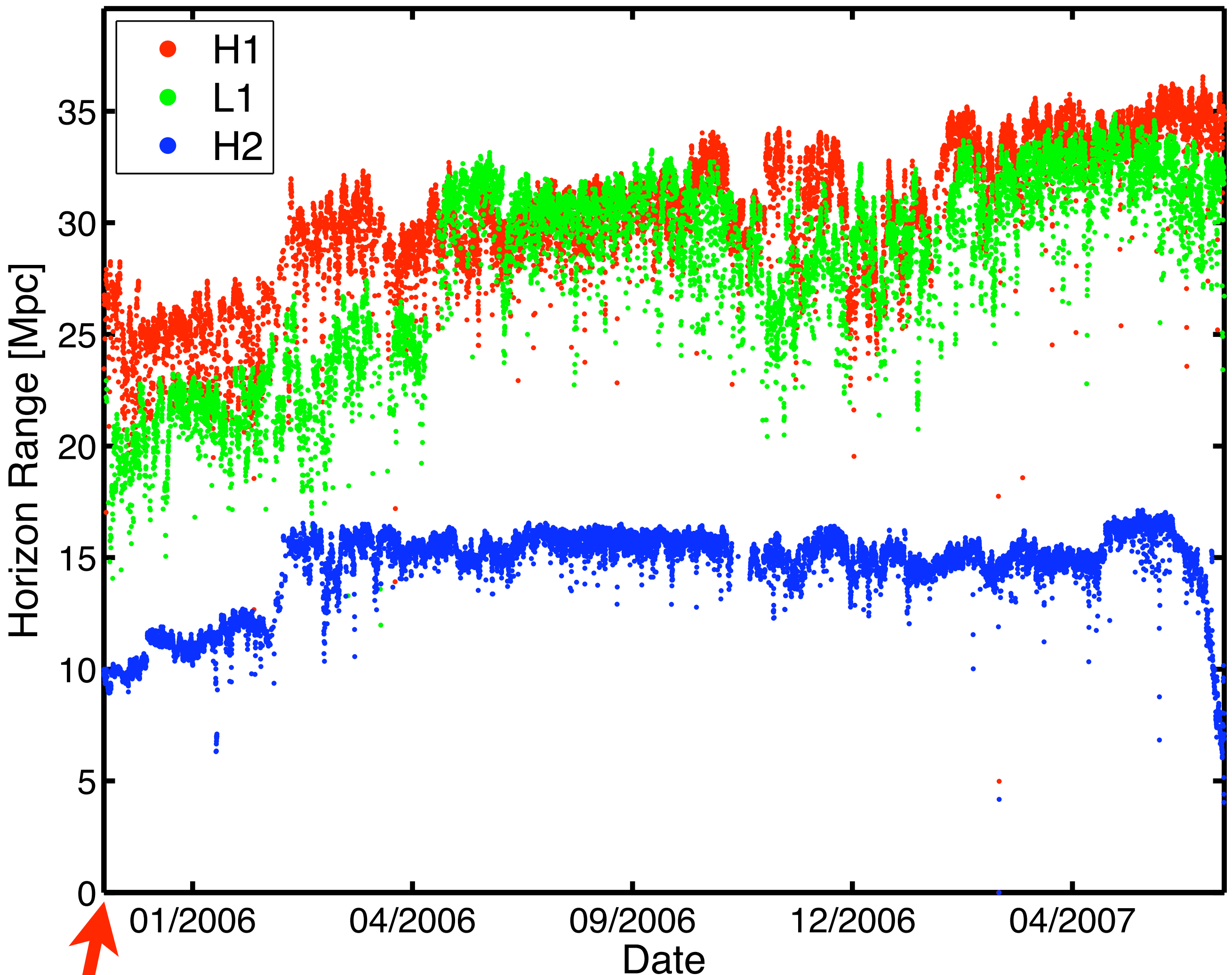
AS = Anti-symmetric port
PO = Pick-off port
REF = Reflection port

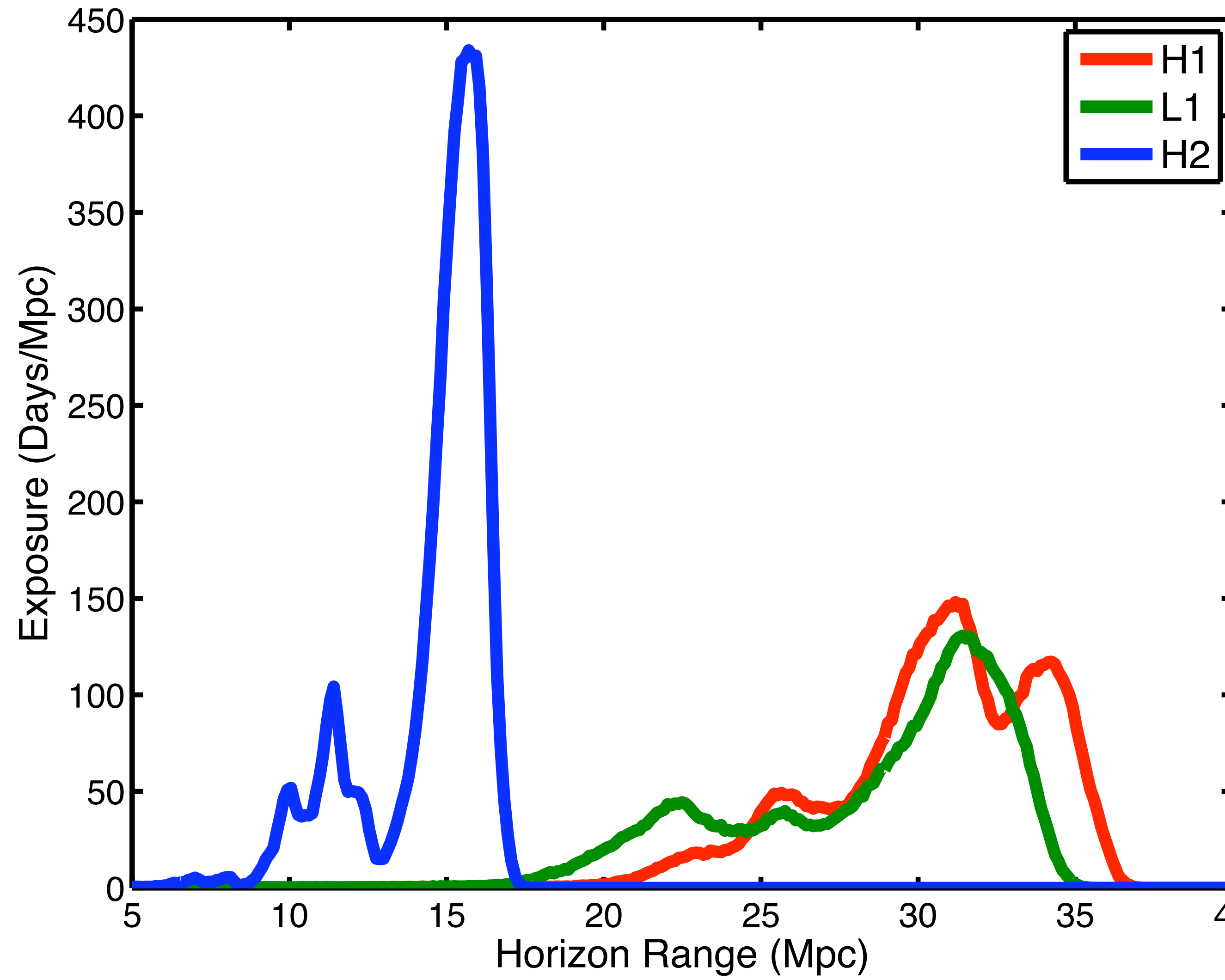
◉ RF length detector
⊗ RF alignment detector
⊕ Quadrant detector

Strain sensitivity



Fifth Science Run



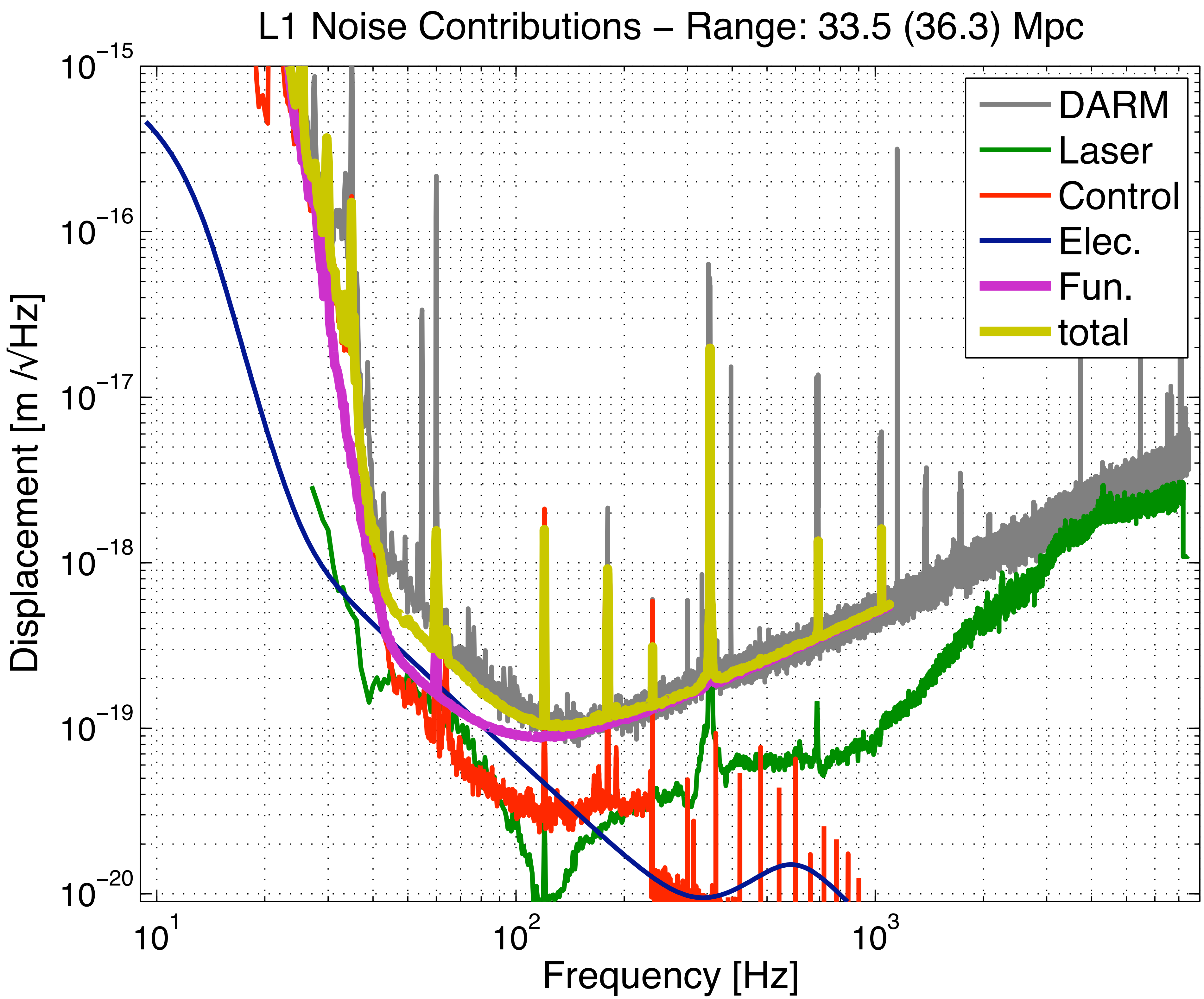


Nov. 14 2005

- 356 days dual site, 308 days triple coincidence*
- 64% to 77% science mode duty factor
- S5 scheduled end Fall 2007

** since June 26*

Noise Budget



- **LASER** intensity, frequency & oscillator
- **CONTROL** MICH, PRC, WFS, OSEM, etc.
- **ELECtronic** ETM, ITM & BS bias & coil driver
- **FUN**damental: shot, seismic, & thermal

GW detections

LIGO collaborates with GEO and Virgo on joint searches for GWs

- Coalescence of binary compact objects
  - *See P.Sutton's talk, next*
- Search for GW bursts (eg. supernovae)
  - *See P.Sutton's talk, next*
- GWs from (un)known pulsars
  - *See P.Sutton's talk, next*
- Stochastic background of GWs
  - *See P.Sutton's talk, next*

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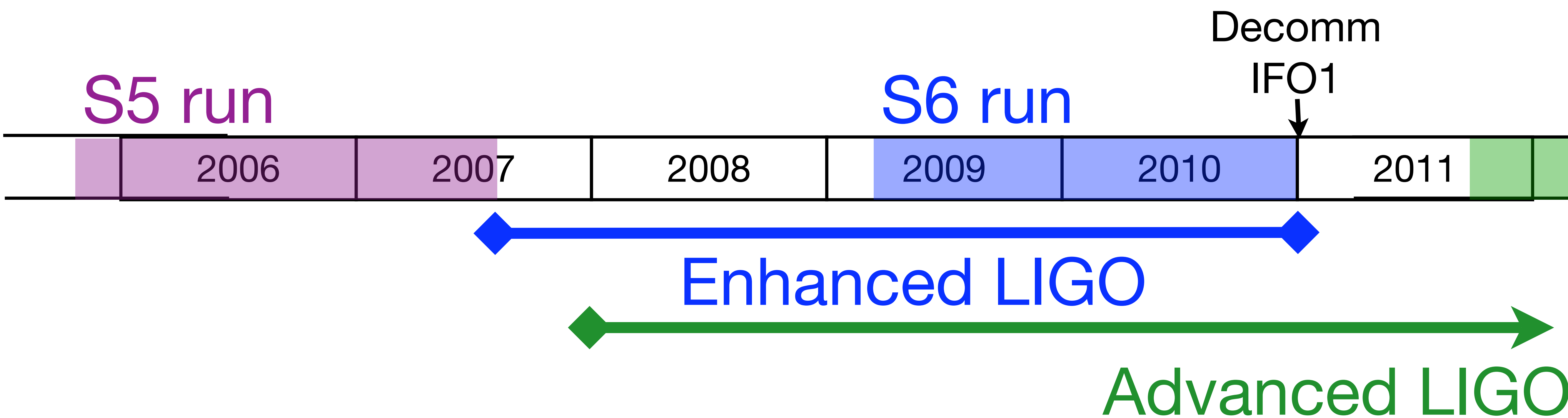
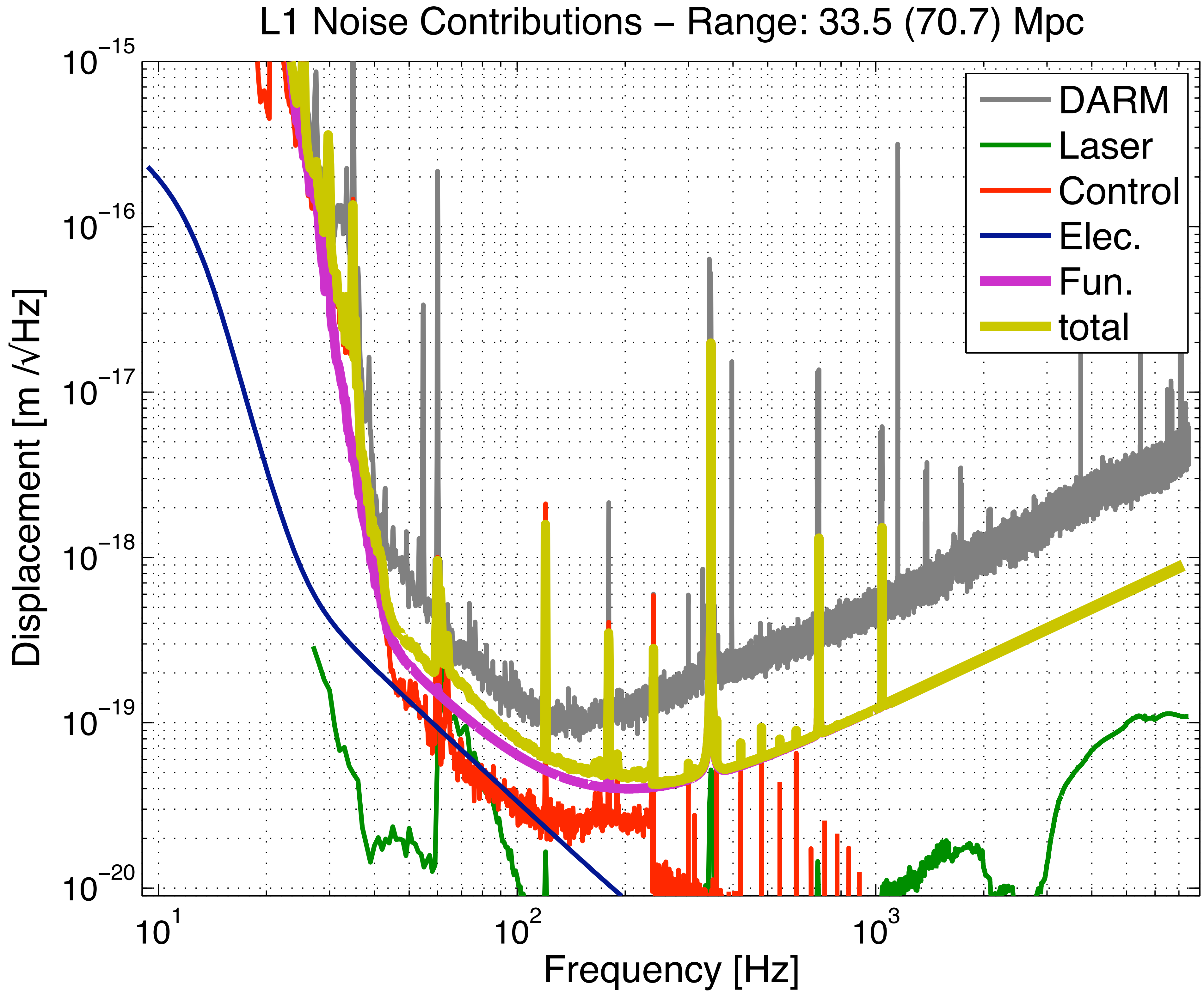
2007 thru ...

- Advanced LIGO planned start in 2008
- First IFO decommissioned in 2010
- Use Enhanced LIGO to
  - Increase exposure 10x
  - Minimize advLIGO risk

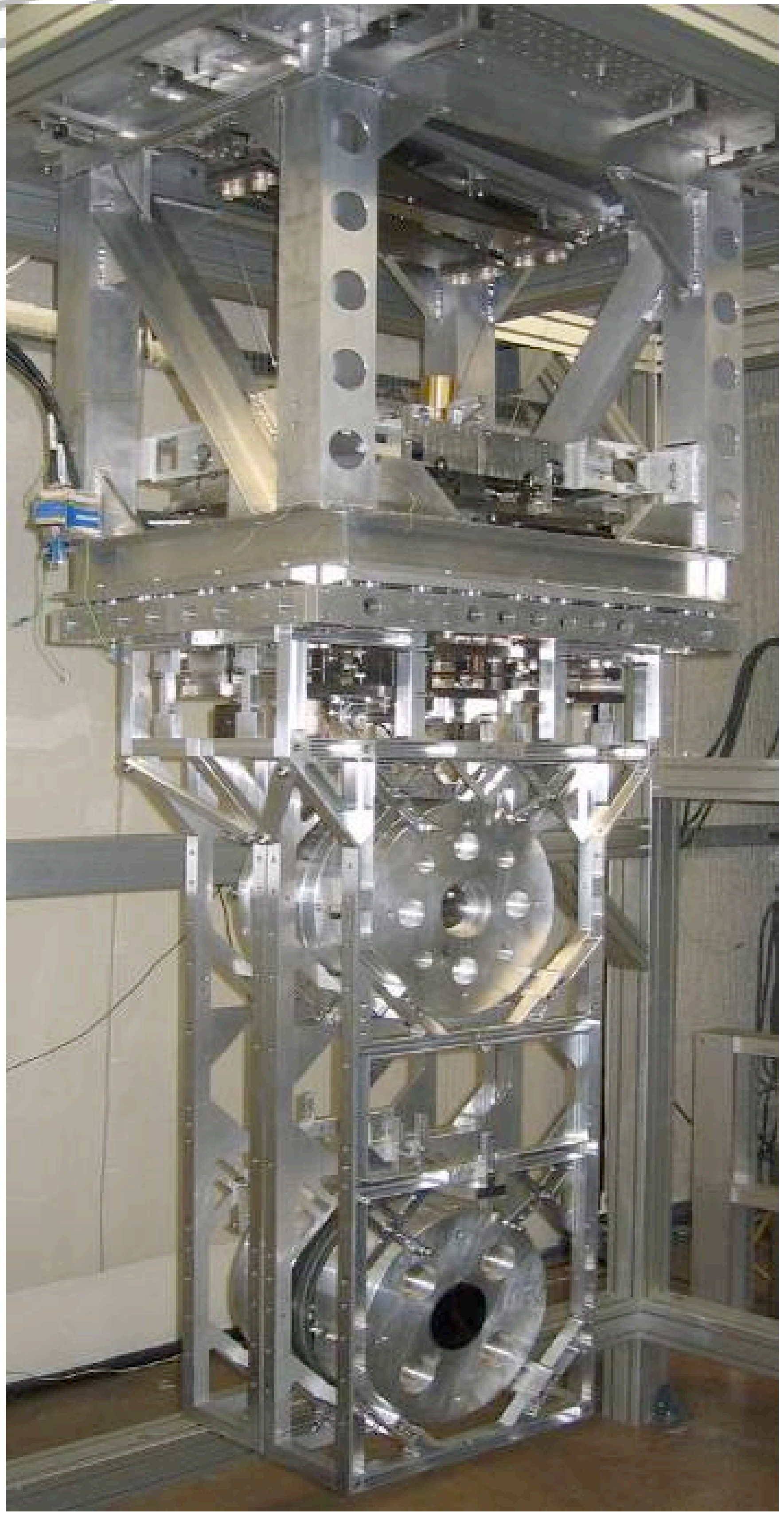


Enhanced LIGO

- P_{Laser} to 35 W (~2x, >100Hz)
- RF to DC (~2x, 100Hz)
- Many "fixes"



Advanced LIGO



- Quadrupole pendulum, monolithic fused silica suspension
- Active seismic isolation
- Signal recycling
- P_{Laser} to 125 W, P_{arm} to 750 kW
- Extremely low loss coatings

Conclusion

- S5 run ends this fall
- eLIGO will increase sensitivity 2x for S6
- advLIGO with 20x sensitivity in 2010