Gravitational Wave Astronomy

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on behalf of the **LIGO Scientific Collaboration** and the **Virgo Collaboration**

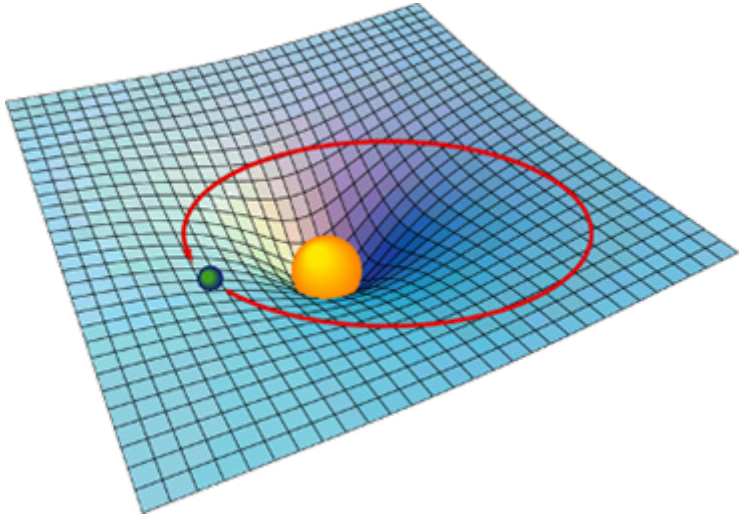
14th Lomonosov conference on Elementary Particle Physics
Moscow, 19th-25th August 2009

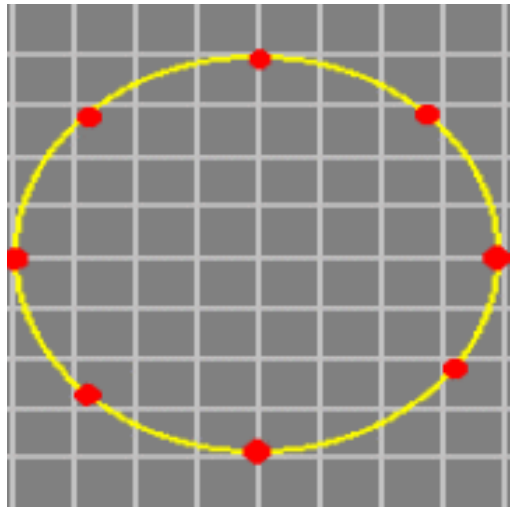
Overview of the presentation

- Introduction to Gravitational Waves
- A new probe of the Universe
- The worldwide interferometer network
- Noise sources in interferometers and current status
- Technology development underway for 2nd generation (Advanced) detectors
- Looking to the future

Introduction to Gravitational Waves

- The effects of gravitation are described by the geometry of space-time rather than a force (General Theory of Relativity)

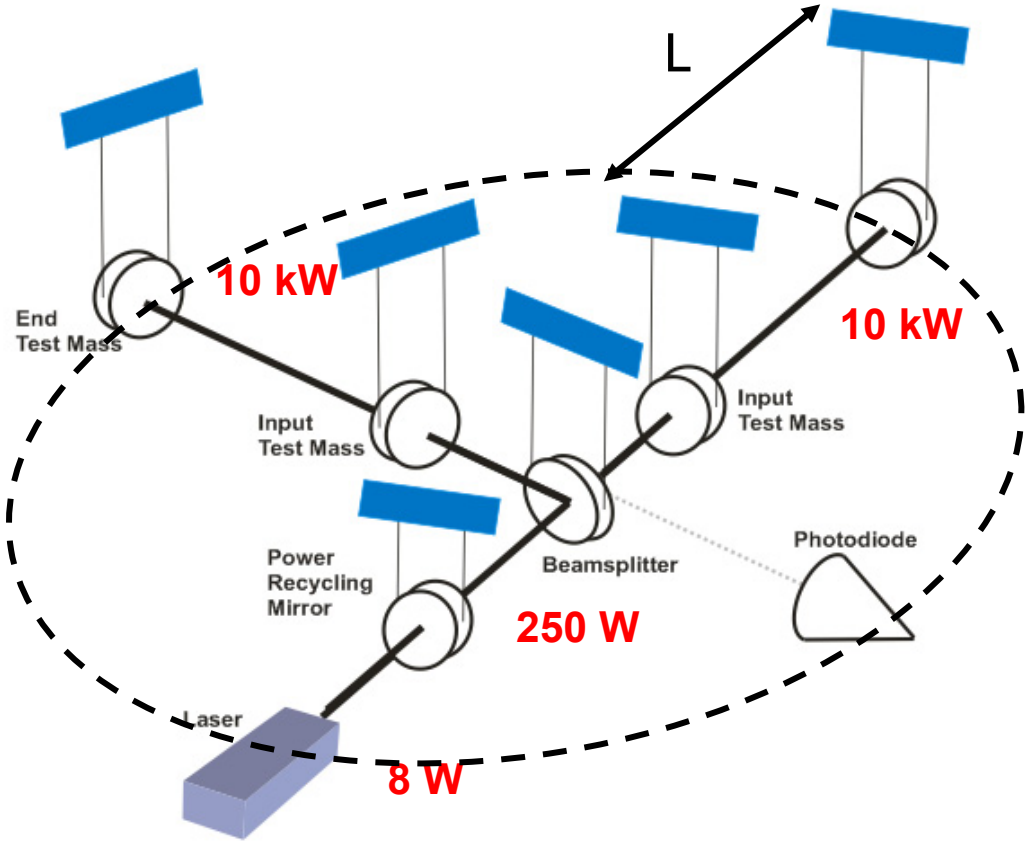




- Motion of matter creates ripples (distortions) in space-time which carry information about astrophysical sources at the speed of light => Gravitational Waves (GW's)

- GW's change the separation between the test masses (no effect on a single point in space-time

Introduction to Gravitational Waves



Typical Parameters

LIGO
λ=1.06 μm
L = 4000 m
$N_{roundtrip}$ = 40

- Gravitational wave interferometers offer broadband coverage from 10Hz-few kHz

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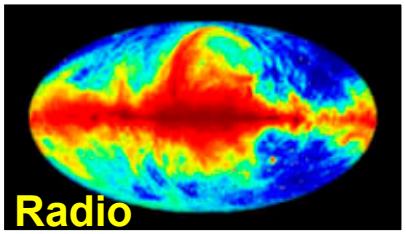
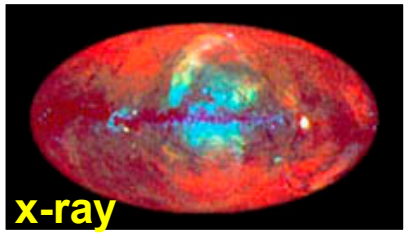
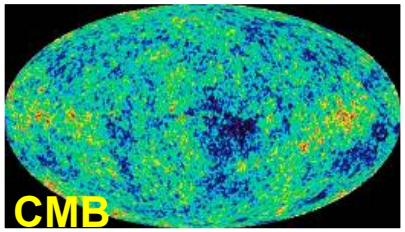
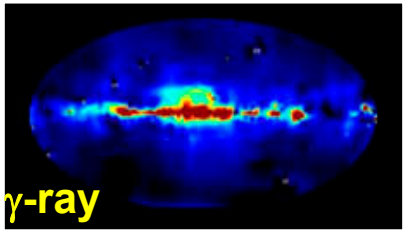
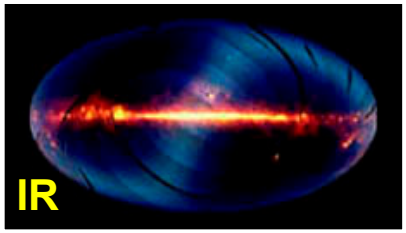
A New Probe of the Universe

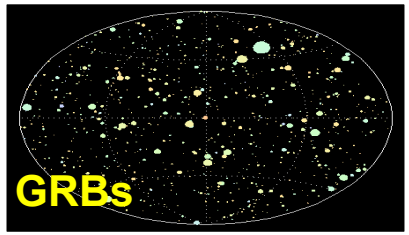












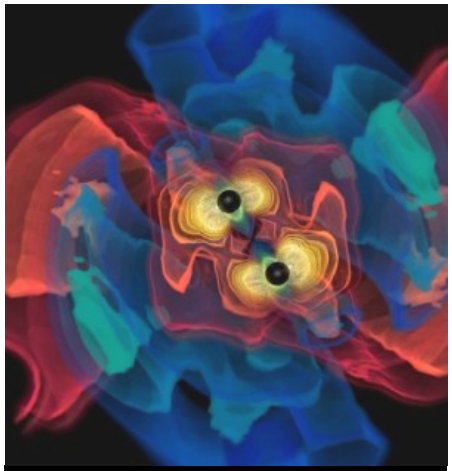
Gravitational Waves will give us a different, non electromagnetic, view of the universe and open a new spectrum for observation.

This will be complementary information, as different from what we know as *hearing* is from *seeing*.

EXPECT THE UNEXPECTED!!

SUPA IGR advancedligo VIRGO LSC

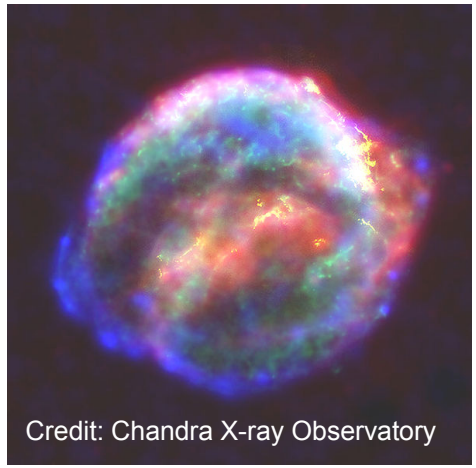
Astrophysical Sources



Credit: AEI, CCT, LSU

Coalescing Binary Systems

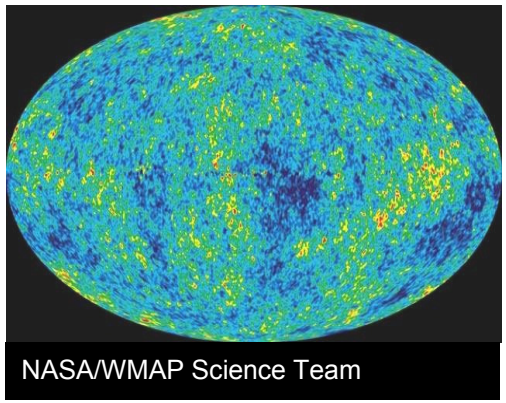
- Neutron stars, low mass black holes, and NS/BS systems



Credit: Chandra X-ray Observatory

Bursts

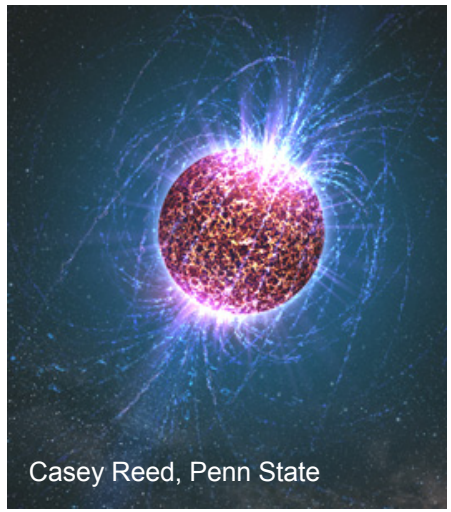
- galactic asymmetric core collapse supernovae
- ???



NASA/WMAP Science Team

Cosmic GW background

- stochastic, incoherent background



Casey Reed, Penn State

Continuous Sources

- Spinning neutron stars
- probe crustal deformations

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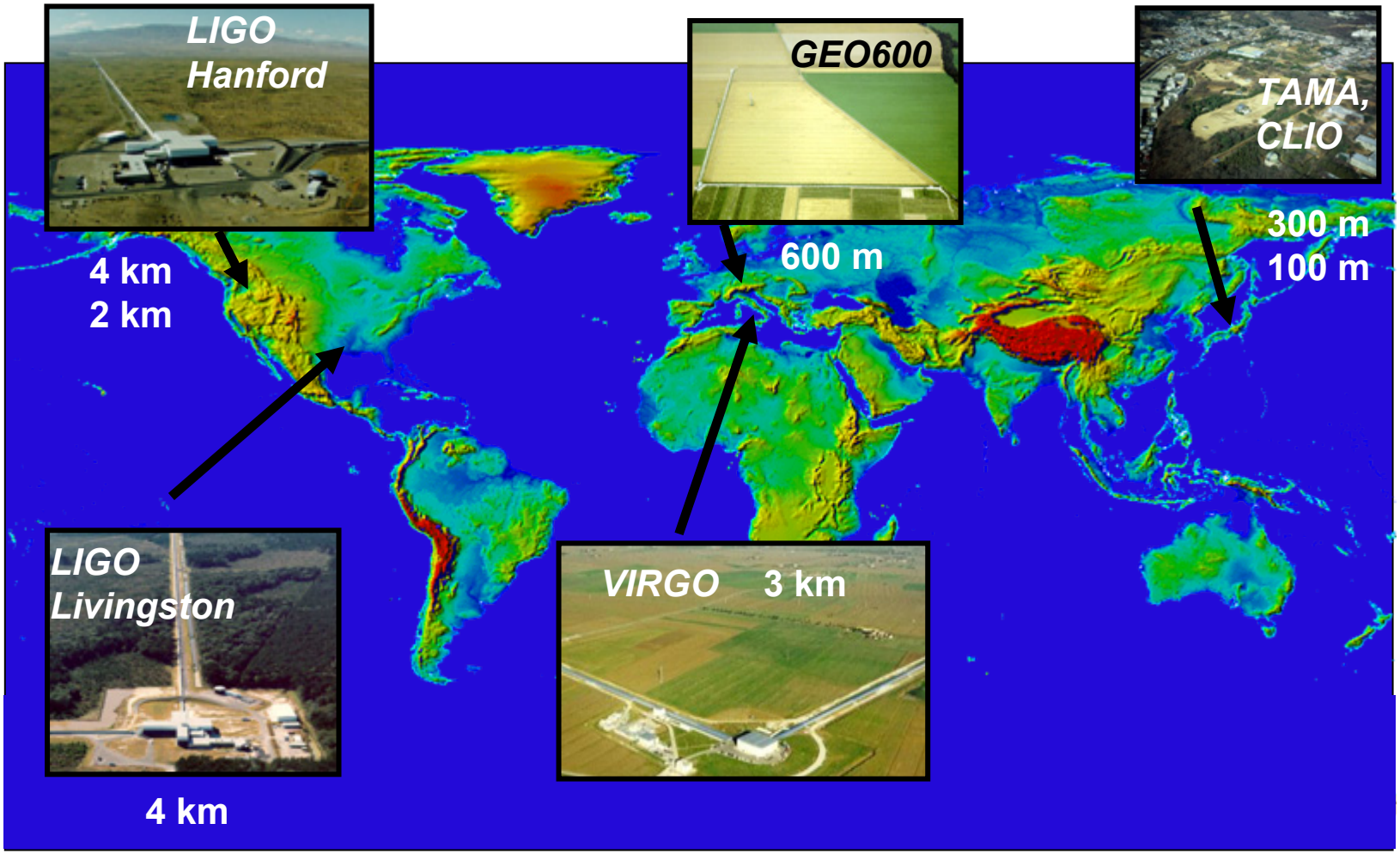
Worldwide Network of Interferometers



P. Shawhan, LIGO-G0900080-v1

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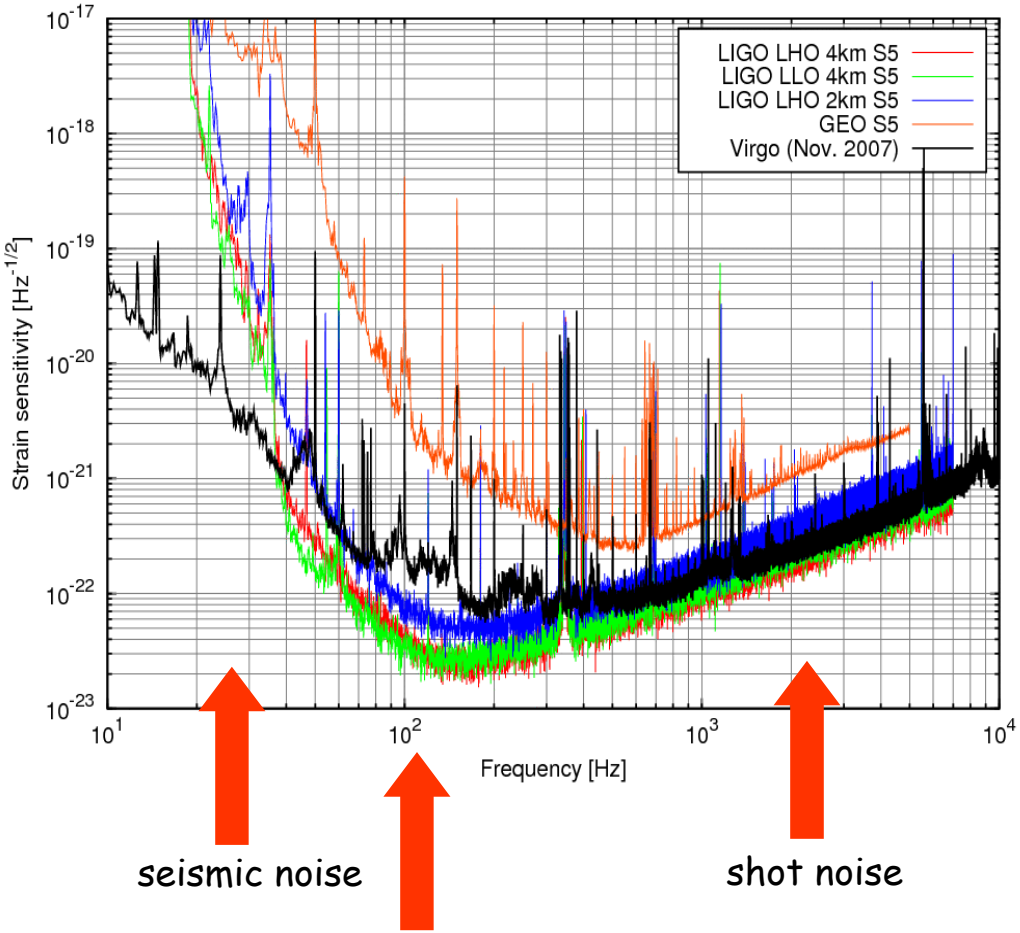
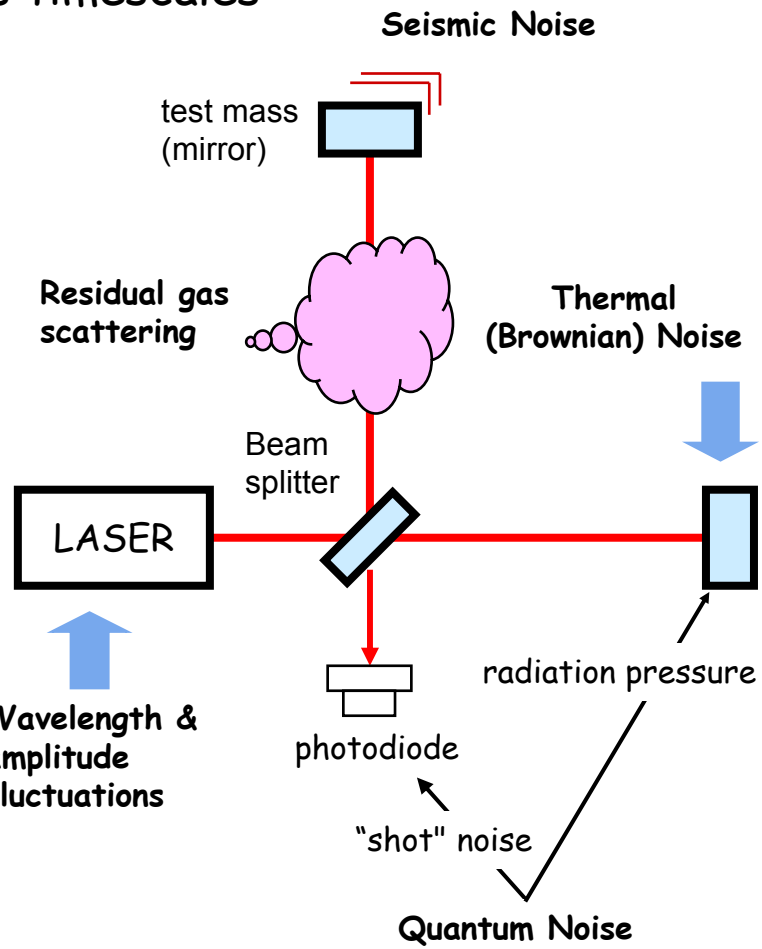
Noise Sources in Interferometers

- sensitivity better than ~1 attometre on 10ms timescales





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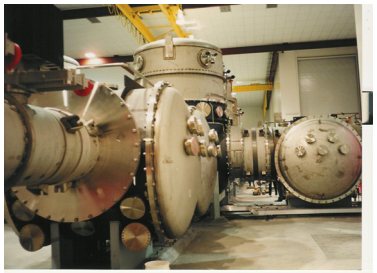
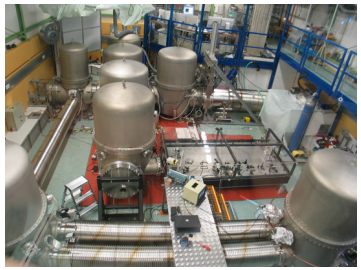
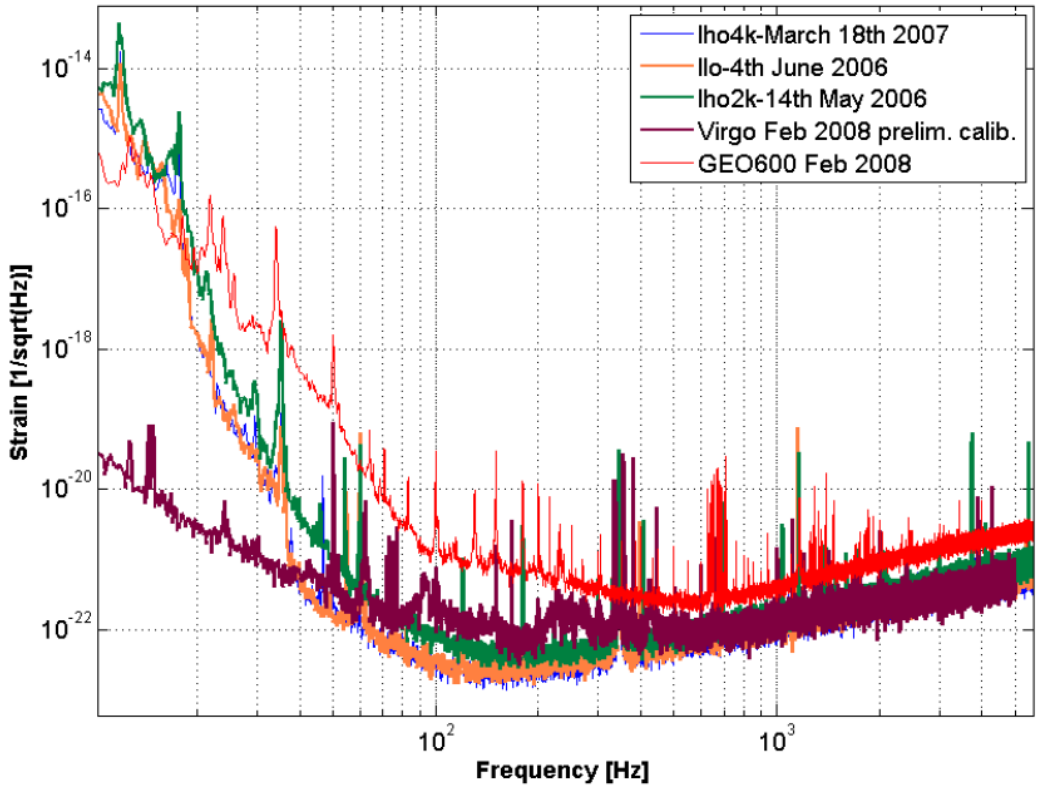
Current Status







- LIGO detectors are operating at design sensitivity and have completed a successful s5 science run together with GEO 600 and VIRGO
- Detectors are now starting to produce interesting results

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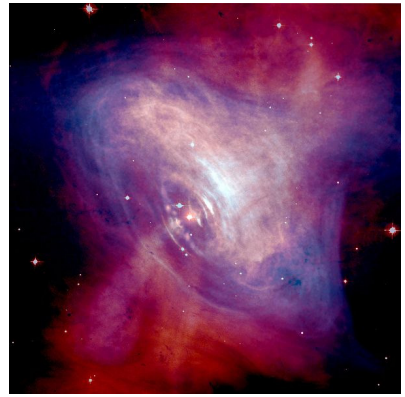
Current Status

- observed luminosity of the Crab nebula accounts for < 1/2 spin down power
- spin down due to:
  - electromagnetic braking
  - particle acceleration
  - GW emission?
- early S5 result=> < 6% of radiated energy is in GW's



Crab pulsar

(Abbott, et al., Ap. J. Lett. **683**, L45-L49, 2008.)

- During s5, GRB 07201 was observed with a sky position coincident with M31
- A binary merger ($1M_\odot<m_1<3M_\odot$ and $1M_\odot<m_2<40M_\odot$) in M31 is excluded at >99% level

M31 Gamma Ray Burst (GRB)

(Abbott, et al., Ap. J. Lett. **683**, L45-L49, 2008.)

Advanced Detectors

- During the next 5 years the worldwide network of detectors will be enhanced and upgraded (to open up the Gravitational Wave window on the Universe)

GEO-HF: squeezed light (2009, x2 increase)

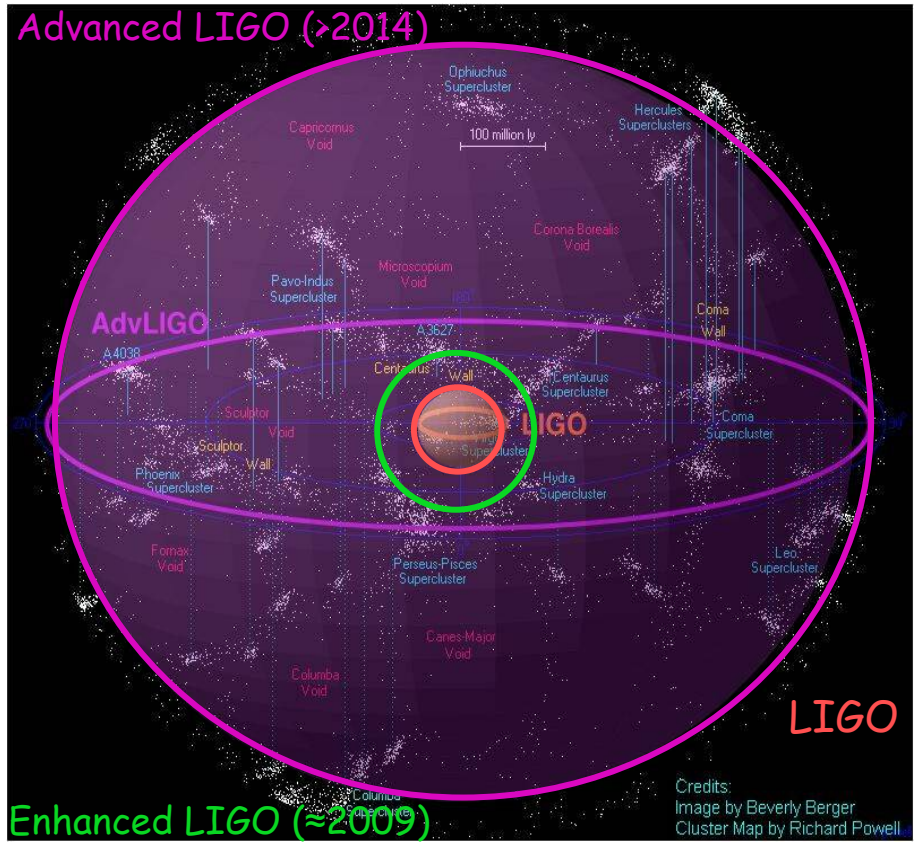
Enhanced LIGO: higher laser power and modified readout scheme (2009, x2 increase)

VIRGO+: modified suspensions and thermal compensation (2009, x2 increase)

Advanced LIGO: higher laser power, new suspensions and optics (2014, x10 increase)

Advanced VIRGO: higher laser power, new suspensions and optics (2014, x10 increase)

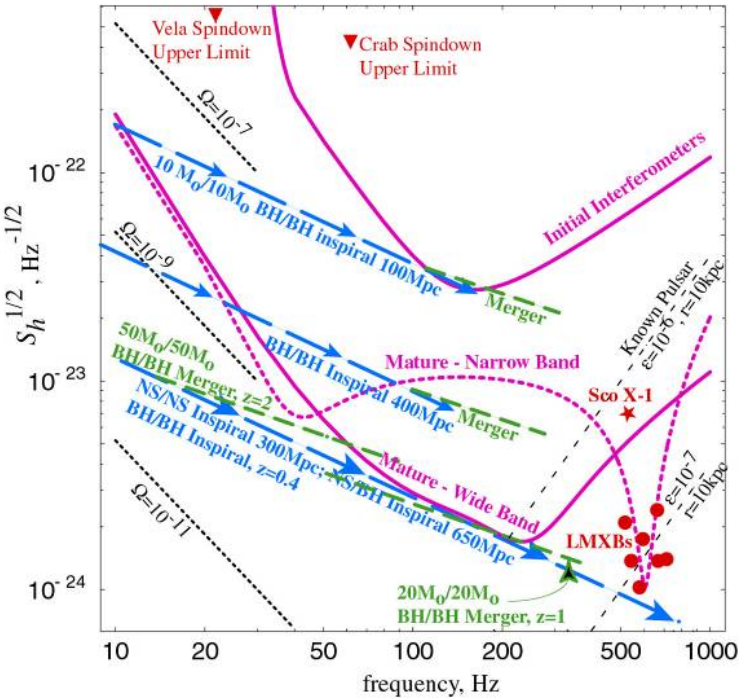
AIGO: large scale detector in southern hemisphere (2017, Australia)

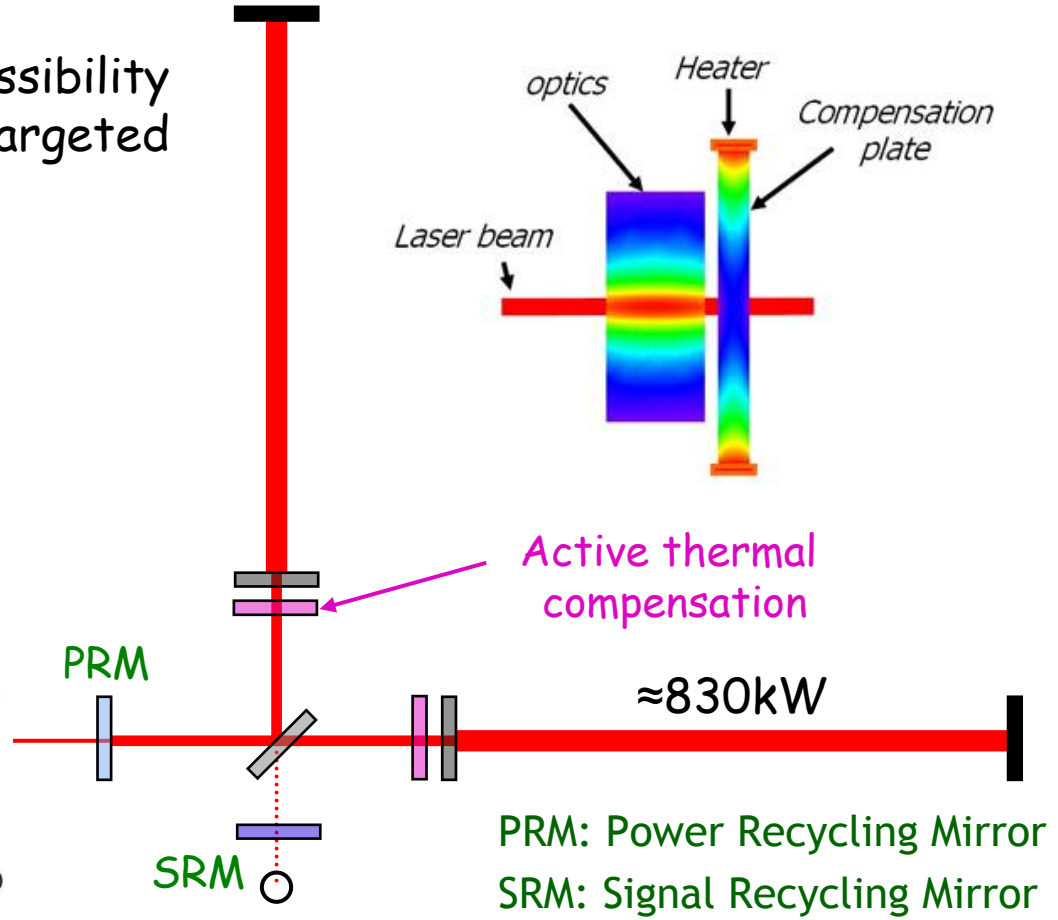


X10 increase in strain sensitivity => **x1000** increase in number of potential sources

Advanced Detector Topology

- Completely new interferometers at the same observatory sites
- New optical layout with signal recycling and thermal compensation
- Signal recycling allows the possibility of tuning the detector for targeted searches

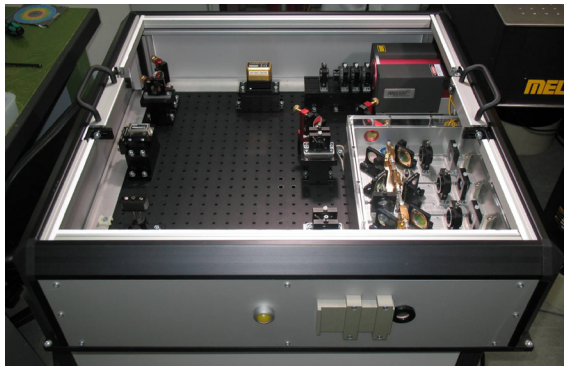




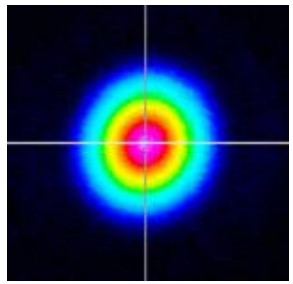
High Power Laser

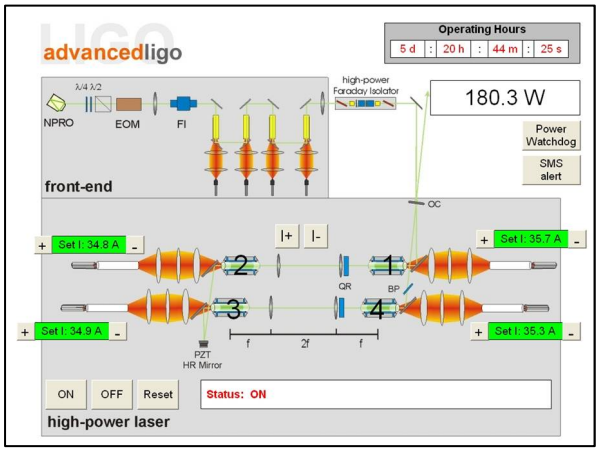
- The 180W Advanced LIGO laser comprises a medium power (35W) front end (will be used in Enhanced LIGO) and a high power output stage

Medium power front end



97% TEM_{00} @ 37W



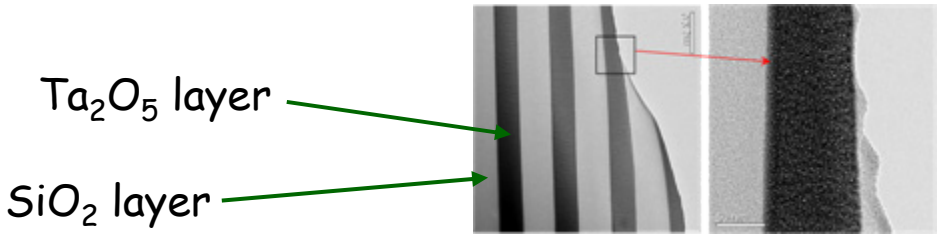


Diode box

- Under development/testing at Laser Zentrum, Hannover, Germany

Mirror Coatings and Charging

- Coating noise will limit sensitivity of Advanced LIGO around 40-200Hz
- Ta_2O_5 is the dominant source of dissipation in current SiO_2/Ta_2O_5 coatings
- Doping the Ta_2O_5 with TiO_2 can reduce the mechanical dissipation by ~40%

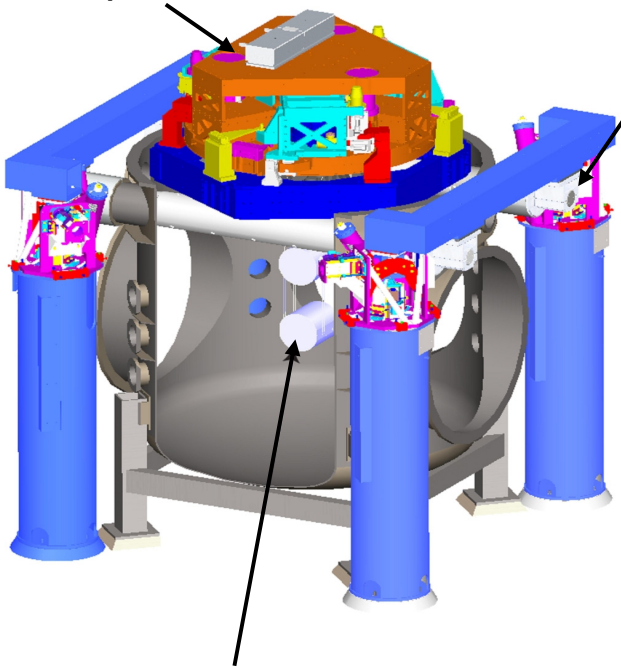


- The charging group is currently looking at the charging mechanisms of silica optics (MSU: V. Mitrofanov, V. Braginsky)
- Charging could occur during pumpdown, when the test mass contacts an earthquake stop, via cosmic rays or when a protective polymer film is removed from the test mass.
- Measurements show that the time constant for charge motion on clean silica is quite long (several months). Work is underway to look at discharge using UV light.

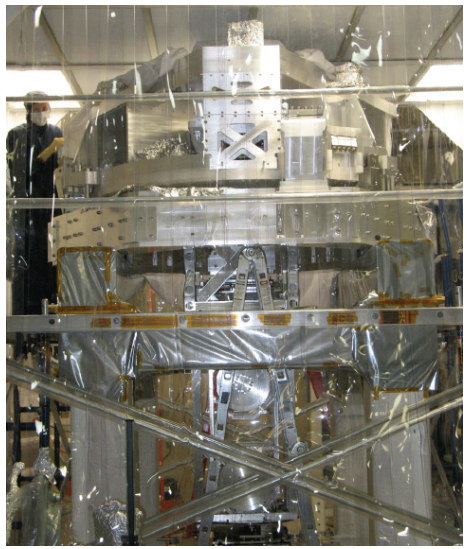
Seismic Isolation and Suspensions

In-vacuum seismic isolation platform

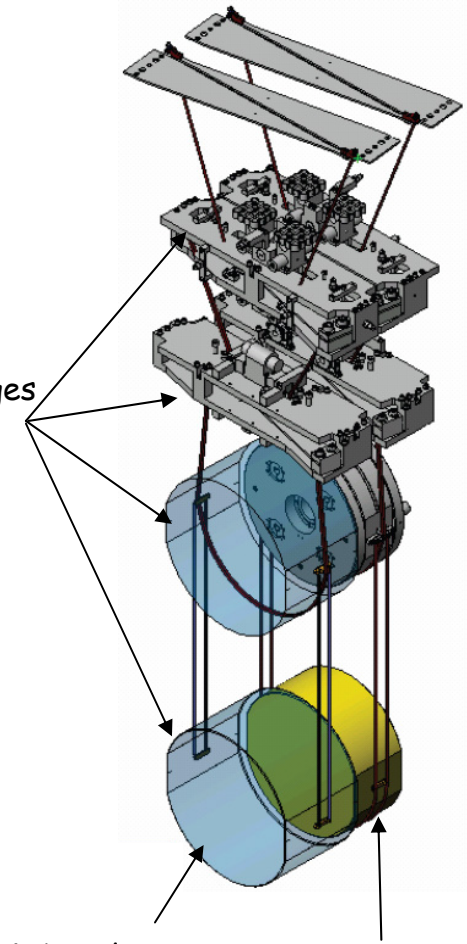
Hydraulic pre-isolator



Quadruple pendulum



four stages

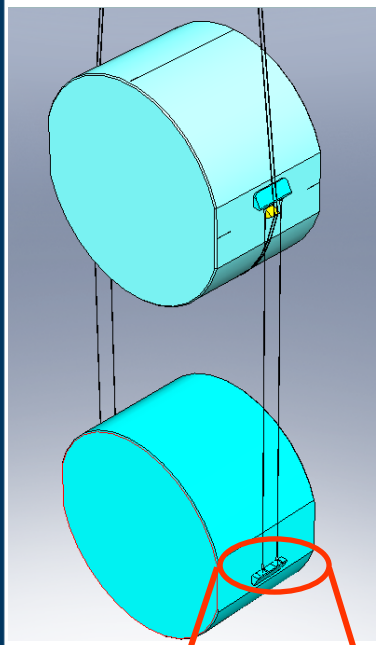


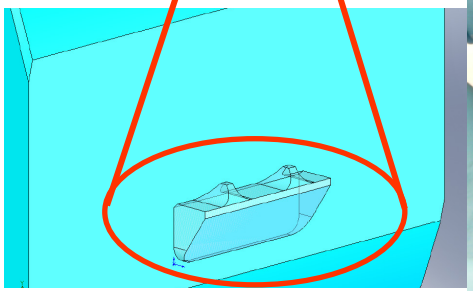
40kg silica test mass

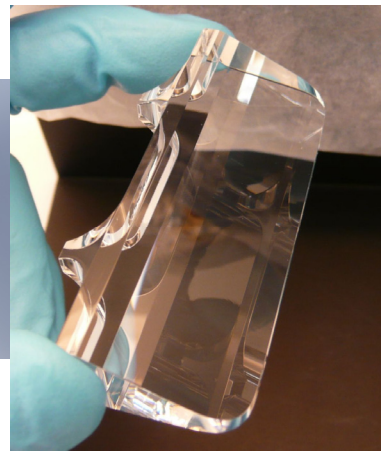
parallel reaction chain for control

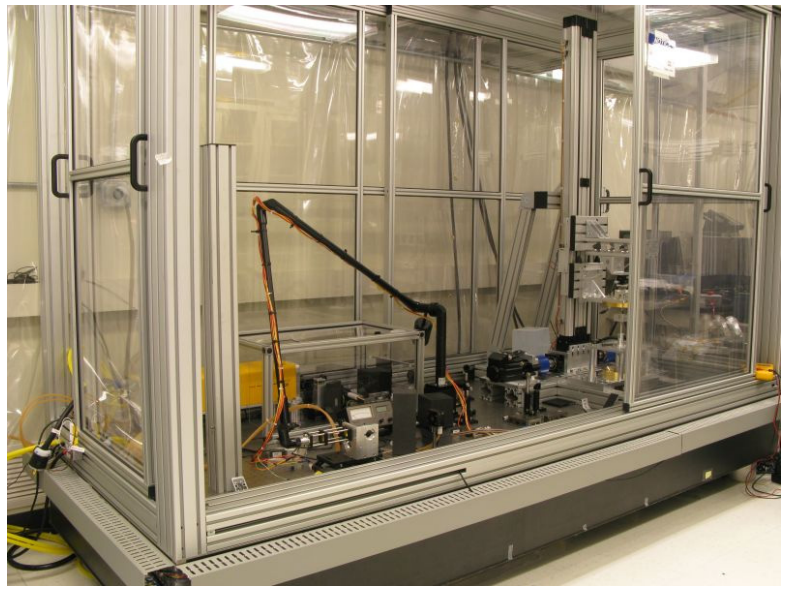
Monolithic Suspensions

- University of Glasgow is providing the monolithic suspension for Advanced LIGO
- 40kg test mass suspended by 4 silica fibres
- Fibres are butt welded onto silica ears bonded to the test mass
- Decision to go for an upsizing of the proven GEO ears









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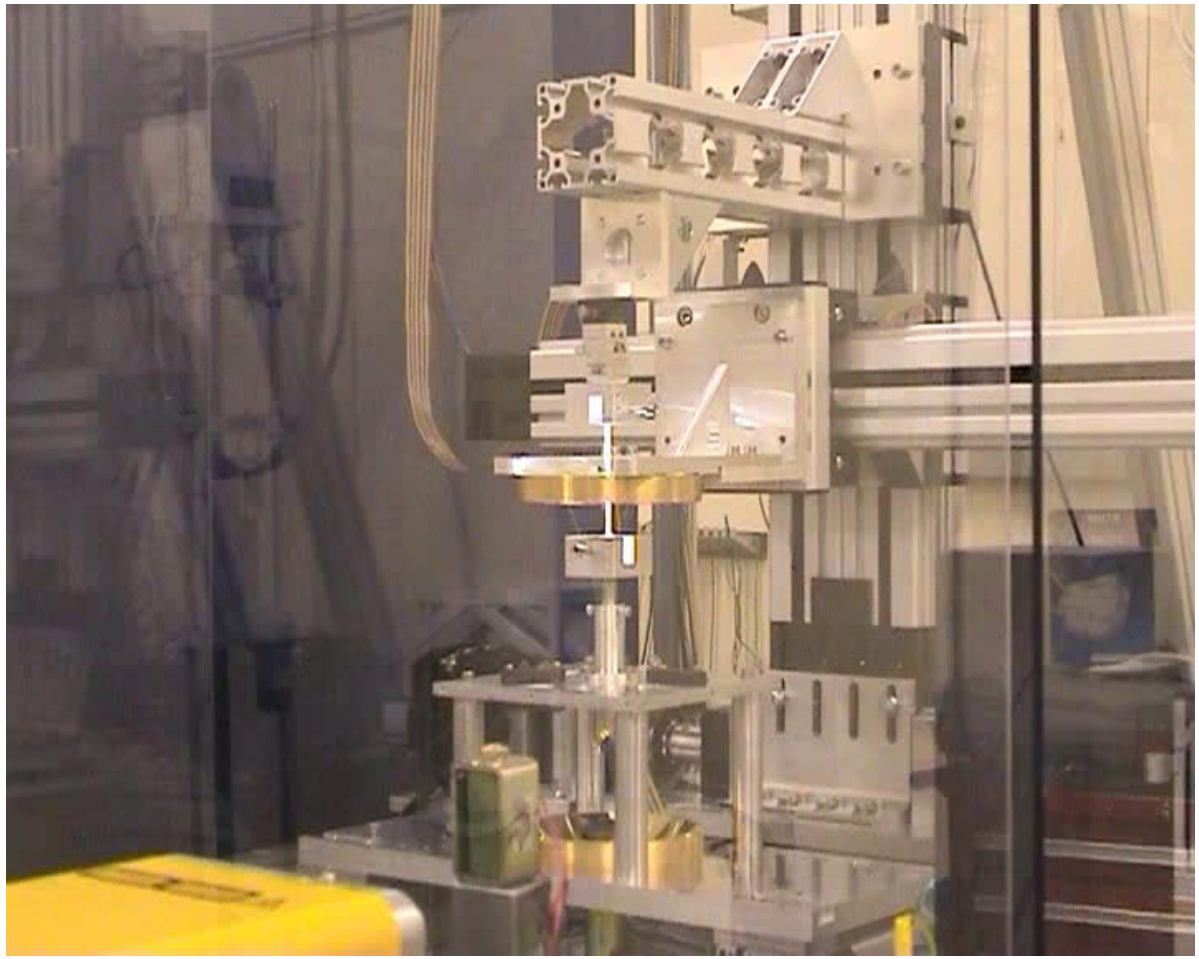
Laser Pulled Fibres



Laser pulling machine

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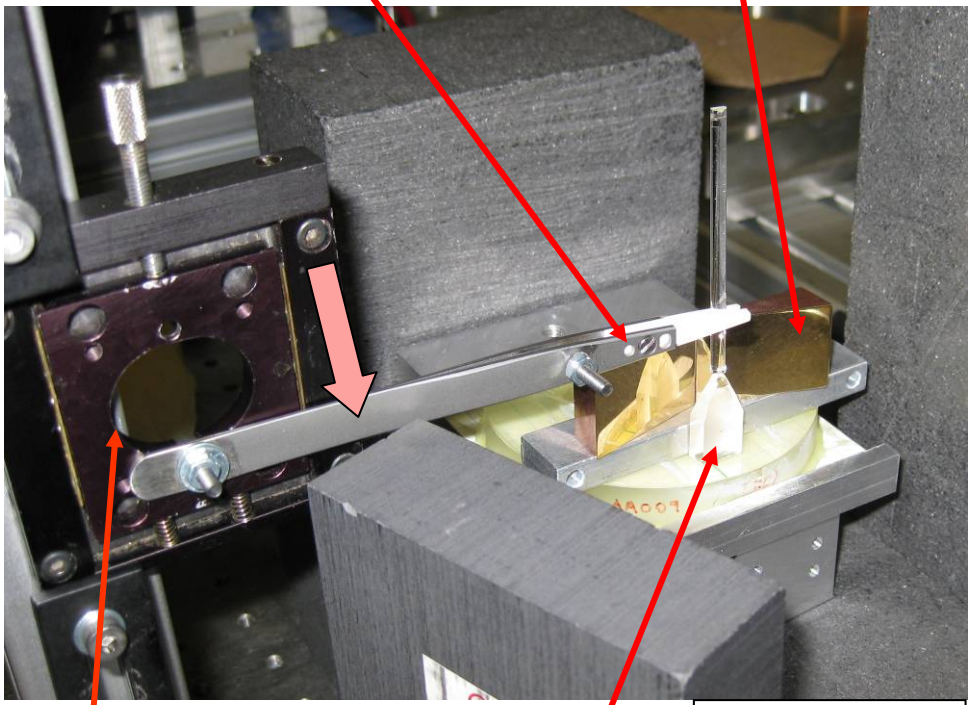
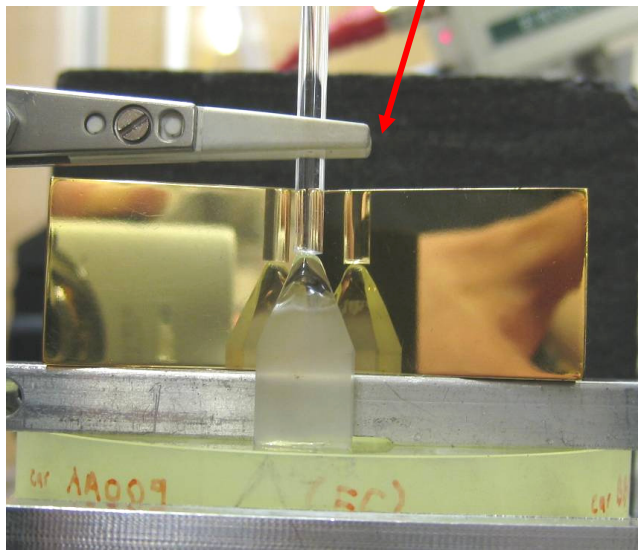
Laser Welding

ceramic tipped tweezers

gold coated mirror

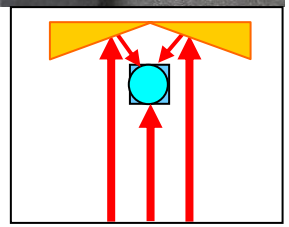
back side accessible via mirror reflection

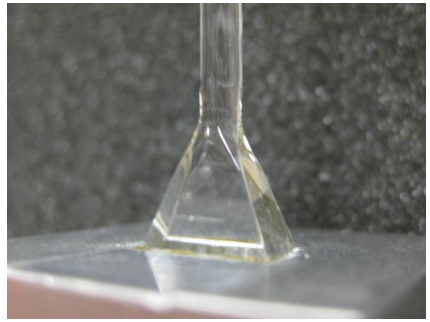


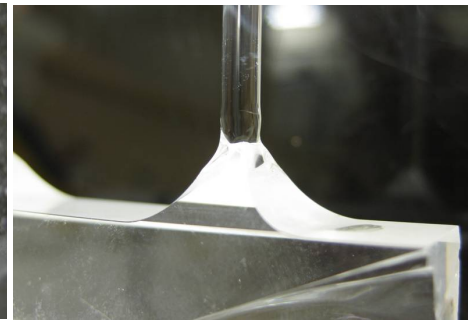


translation stage to move stock down

test ear

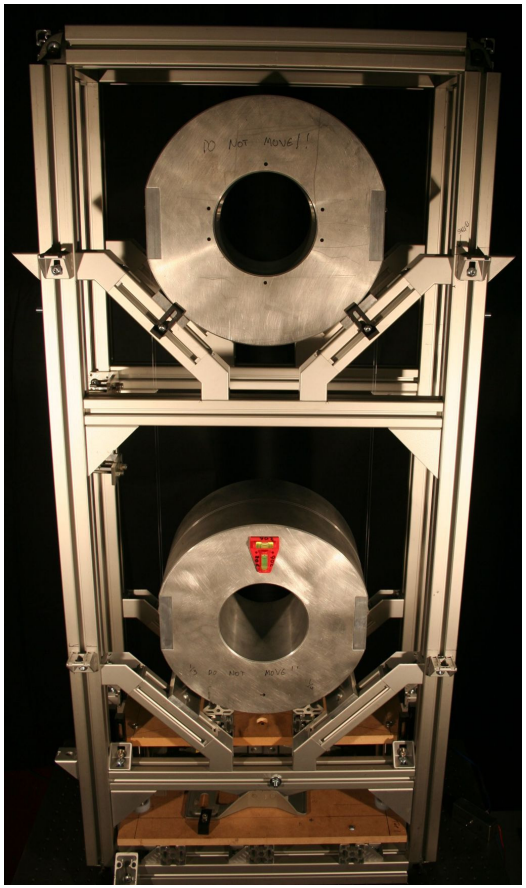


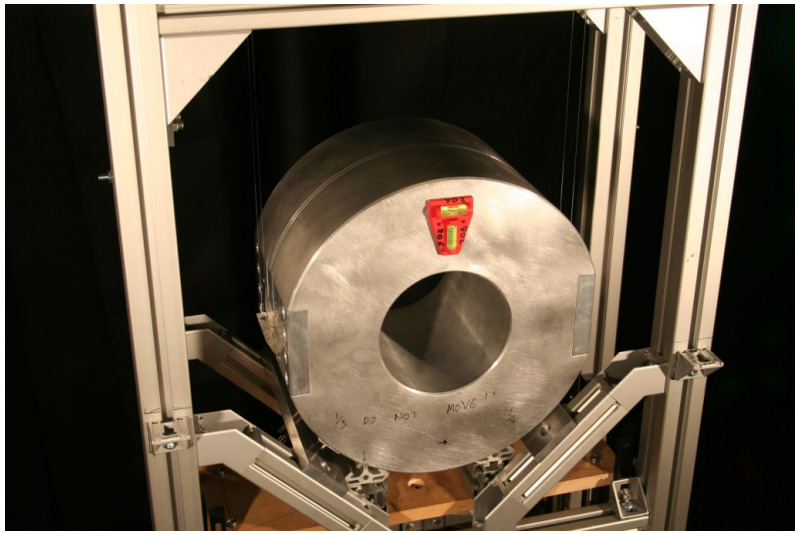


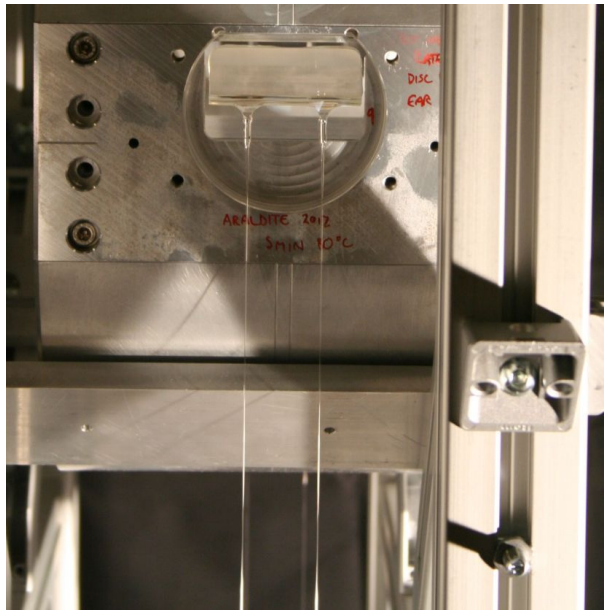


(K. Tokmakov, former MSU graduate)

40kg Test Suspension







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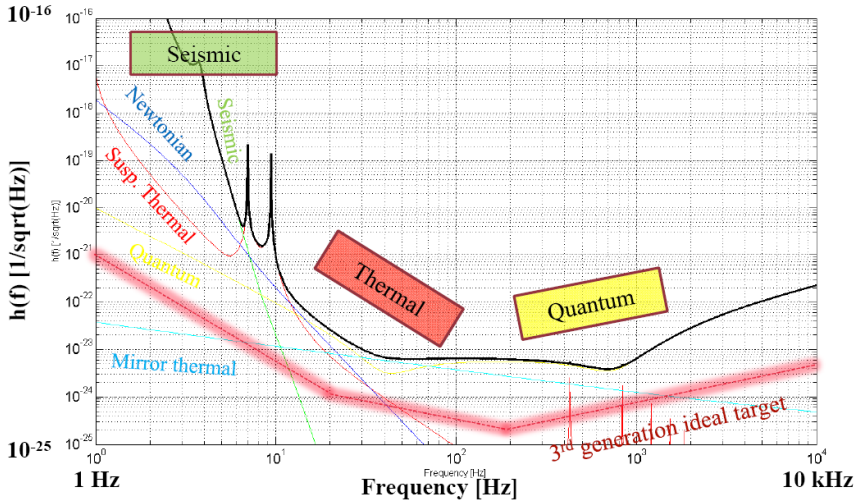
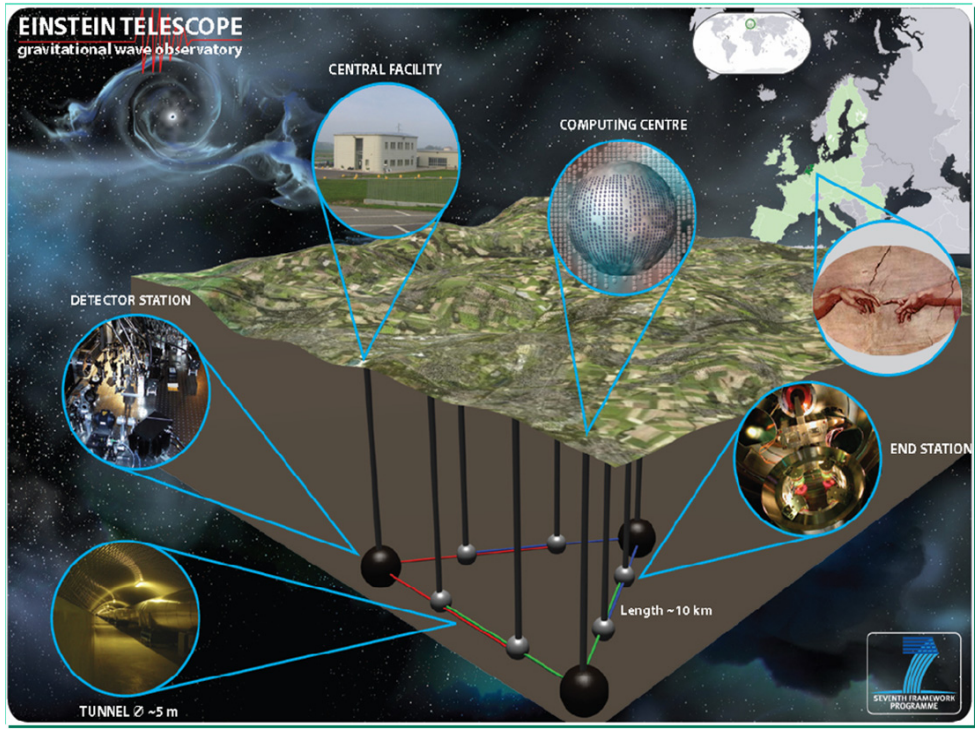
Looking to the Future (Ground-Based)

- Einstein Telescope (ET): there is currently a design study underway to investigate 3rd generation detectors in Europe
- ET would aim for x10 sensitivity increase over Advanced Detectors and operation down to 1Hz
  - Underground operation
  - High laser power
  - Cryogenic operation
  - ≈10km arm lengths

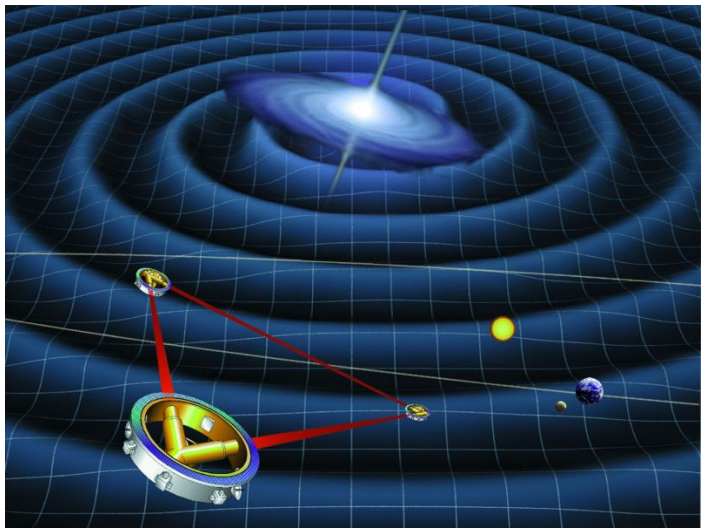


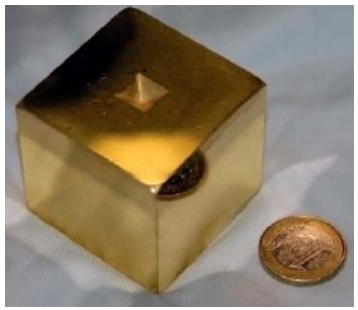


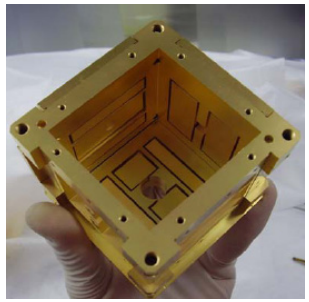
http://www.et-gw.eu/

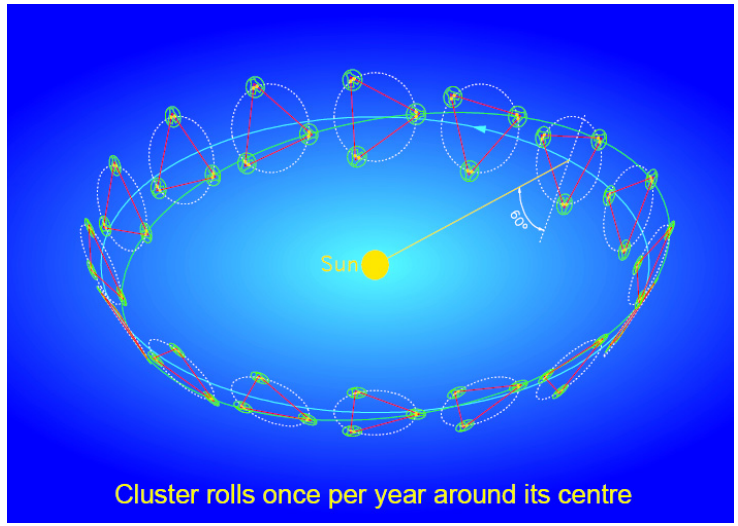
Looking to the Future (Space-Based)

- LISA: a joint ESA-NASA mission scheduled for around 2018
- 3 spacecraft with 5 x10^6 km arm length (measuring separation to ≈10^{-12}m)
- Drag fee control of spacecraft (spacecraft follows test mass)
- Sensitivity from 10^{-4}Hz-10^{-1}Hz => complimentary to ground-based detectors









LIGO Scientific Collaboration