Advanced LIGO: our future in gravitational astronomy

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for the LIGO Science Collaboration

NAM 2008

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LIGO Scientific Collaboration

LIGO

LSC

University of Maryland 1856

Michigan

University of Strathclyde

ACIGA

Montana State University

Loyola University New Orleans

University of Washington

Trinity University

San José State University

University of Wisconsin UW Milwaukee

ANU
The Australian National University

Syracuse University Founded AD 1870

University of Glasgow

Università degli Studi del Sannio

UTB TSC

The University of Western Australia

1754

NASA
Goddard Space Flight Center

LSU

California Institute of Technology 1891

Northwestern University

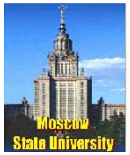
R·I·T
Rochester Institute of Technology 1829

Andrews University

Massachusetts Institute of Technology 1861

Southeastern Louisiana University

The University of Texas at Austin


Moscow State University

The University of Adelaide Australia

PAN

University of Massachusetts Amherst 1863

Carleton College Northfield, Minn. AD 1866

GEO 600

Embry-Riddle Aeronautical University

University of Southampton

PennState 1855

Cardiff University

UIB
Universitat de les Illes Balears

Washington State University

UF University of Florida

The University of Mississippi 1848

Charles Sturt University

University of Rochester

NAOJ

University of Minnesota

Southern University Agricultural & Mechanical College

Hobart and William Smith Colleges

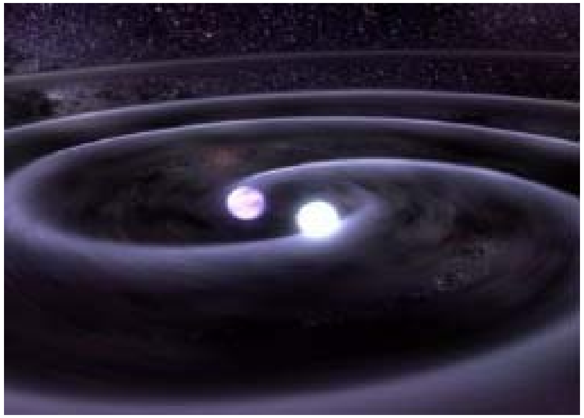
William Smith College 1908

Science & Technology Facilities Council
Rutherford Appleton Laboratory

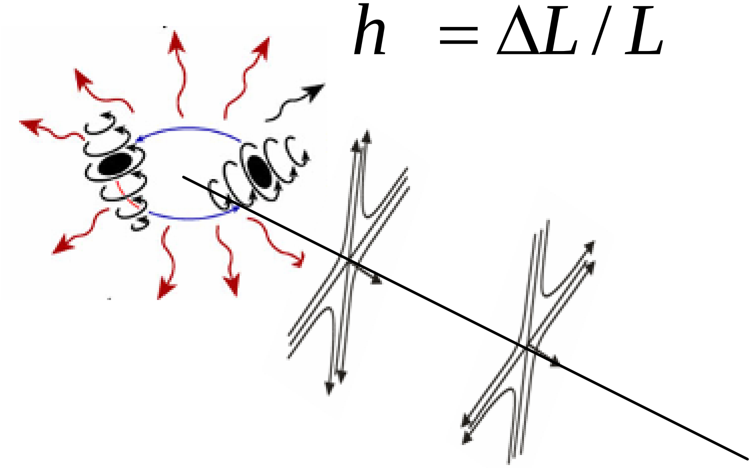
Universität Hannover

Gravitational Waves

- Einstein (in 1916 and 1918) recognized gravitational waves in his theory of General Relativity
  - necessary consequence of Special Relativity with its finite speed for information transfer
- Time-dependent distortions of space-time created by the acceleration of masses
  - propagate at the speed of light
  - transverse waves
  - characterised by strain-amplitude h



$$h = \Delta L / L$$



Science snapshot: the searches

Bursts

- *usually no waveform model*
- supernova core-collapse
- NS or BH formation
- coalescence at end-point of inspirals
- open to surprises!

Continuous

- *quasi-sinusoidal waveform with doppler modulation*
- radiation from pulsars
- possibly radiation from LMXBs
- radio-quiet neutron stars

Inspiral (compact objects)

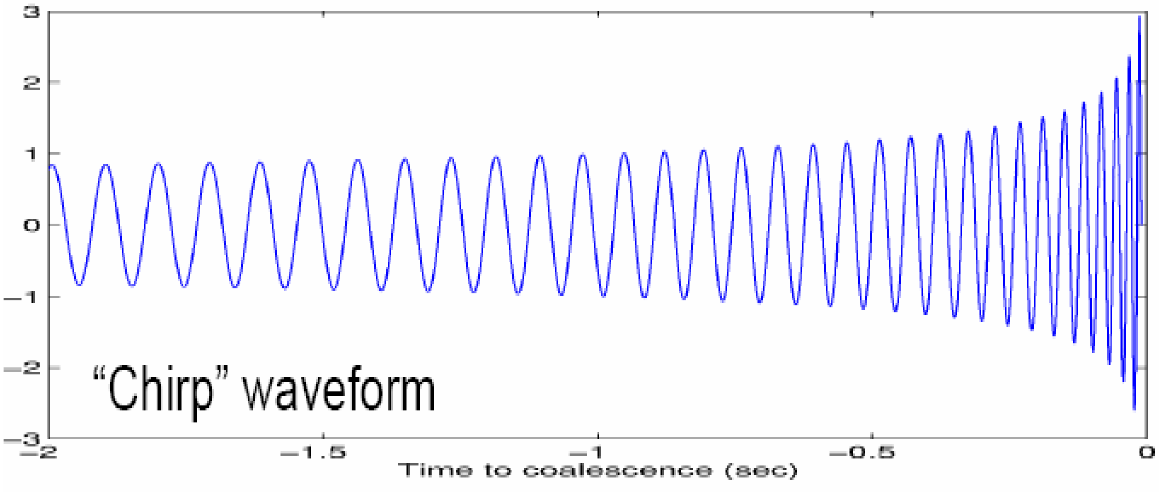
- *accurately kown waveforms allow match filtering*
- end point of binary NS/BH systems
- waveform depends on small no. of parameters
- most reliable amplitude
- estimates of rates
    - observations of binary pulsars
    - population models

Stochastic

- look for corelated background
- many faint sources
- cosmological background

Example: Binary Inspiral “Chirp” signal

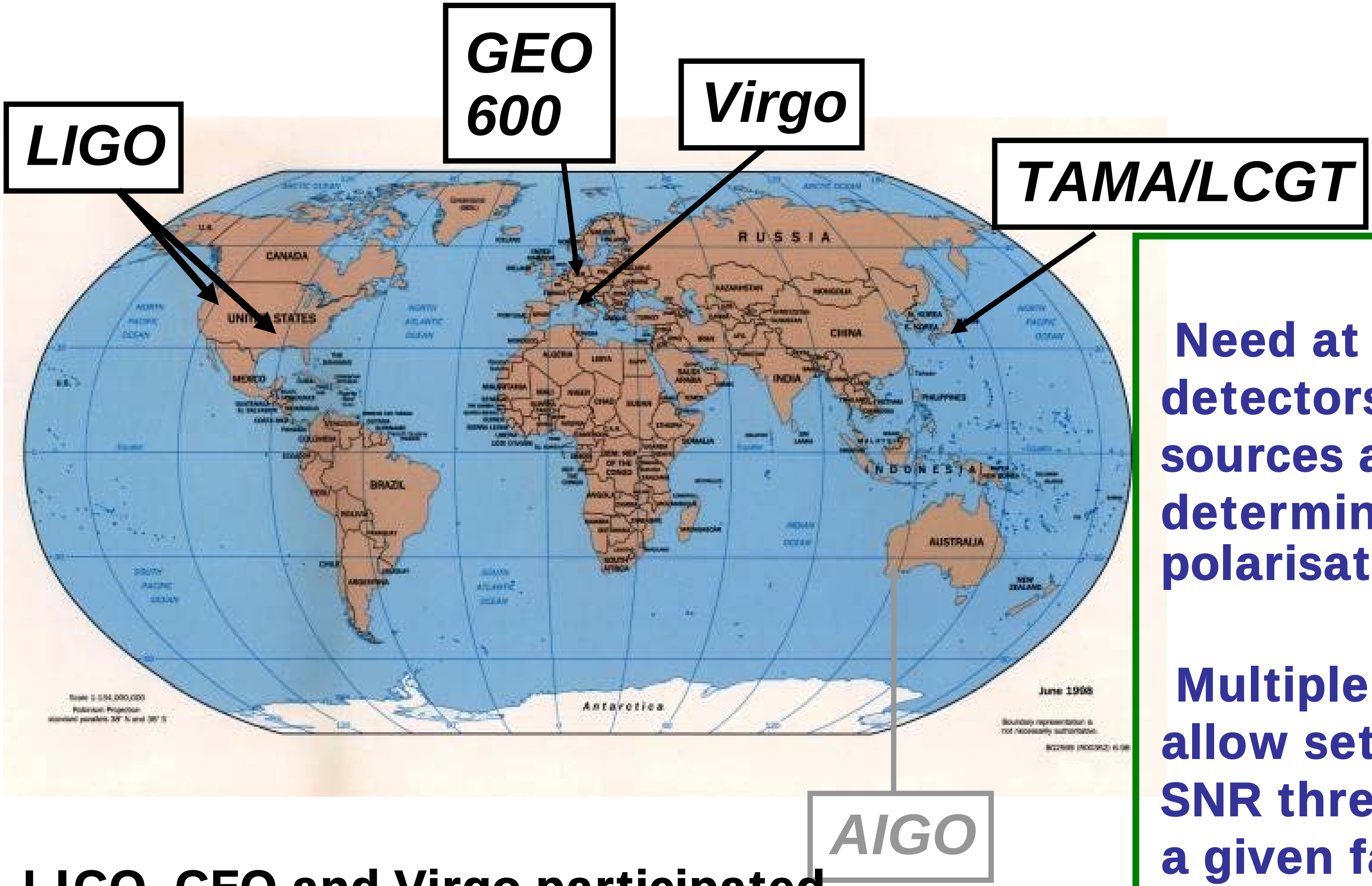
Neutron Star Merger



- Chirp parameters give masses of the two bodies (NS or BH), distance from Earth (not redshift), orientation of orbit
- Require high SNR for detection (8 or more) so parameter estimation can be quite good
- Optical observations may also give redshift
- Gamma/X-ray observations may also link with GRB (some GRBs are associated with compact binary mergers – SWIFT observations)
- exciting opportunities for multi-messenger searches

Simula
by Ma

The Global Network of GW Detectors



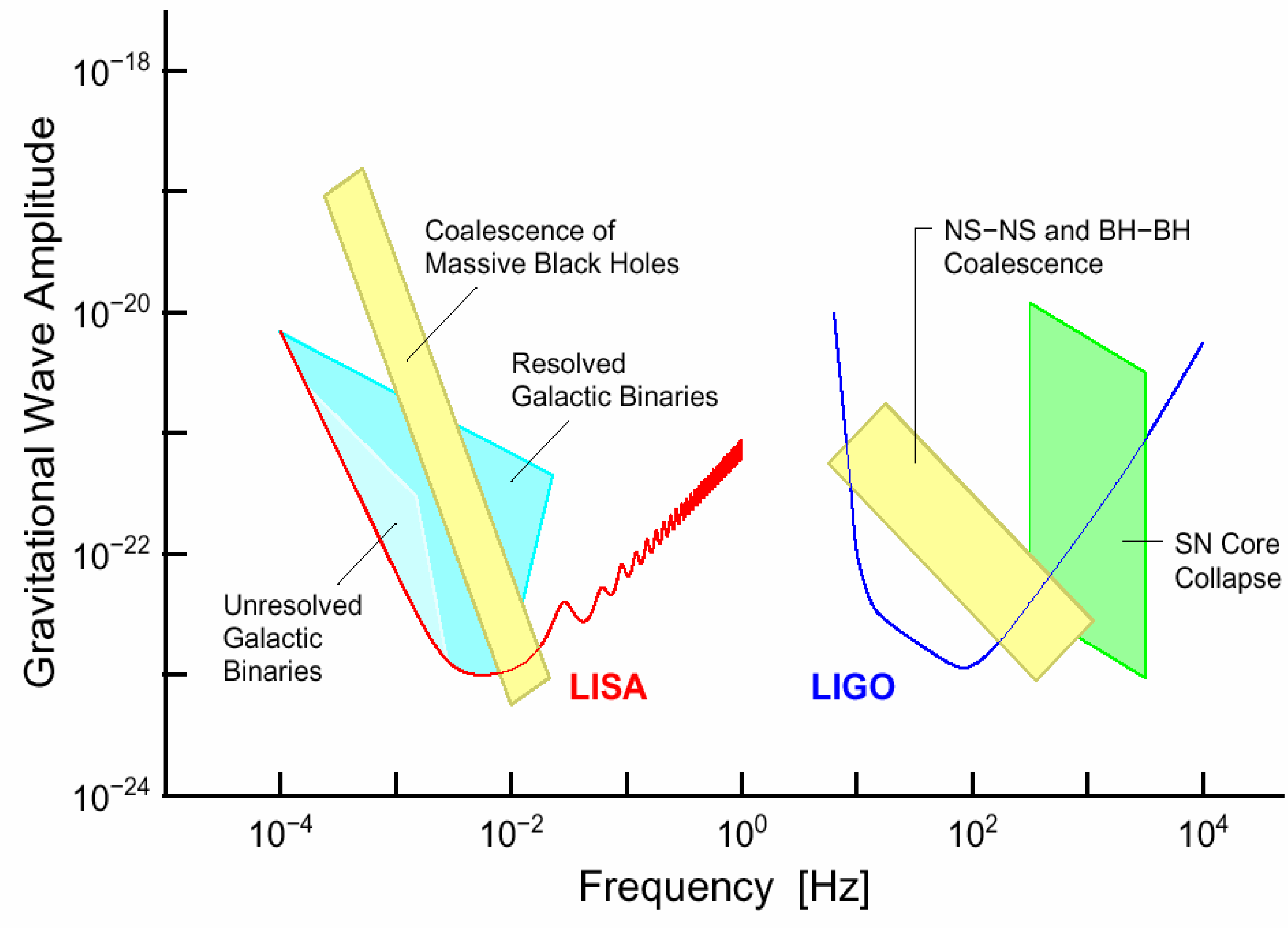
Need at least 4 detectors to locate sources and determine wave polarisation

Multiple detectors allow setting lower SNR thresholds for a given false alarm rate

LIGO, GEO and Virgo participated in S5 (>1 year) completed 10/07

Frequency bands

<<1 Hz observe in space | >>1Hz observe on ground



Ground-based detectors: ingredients

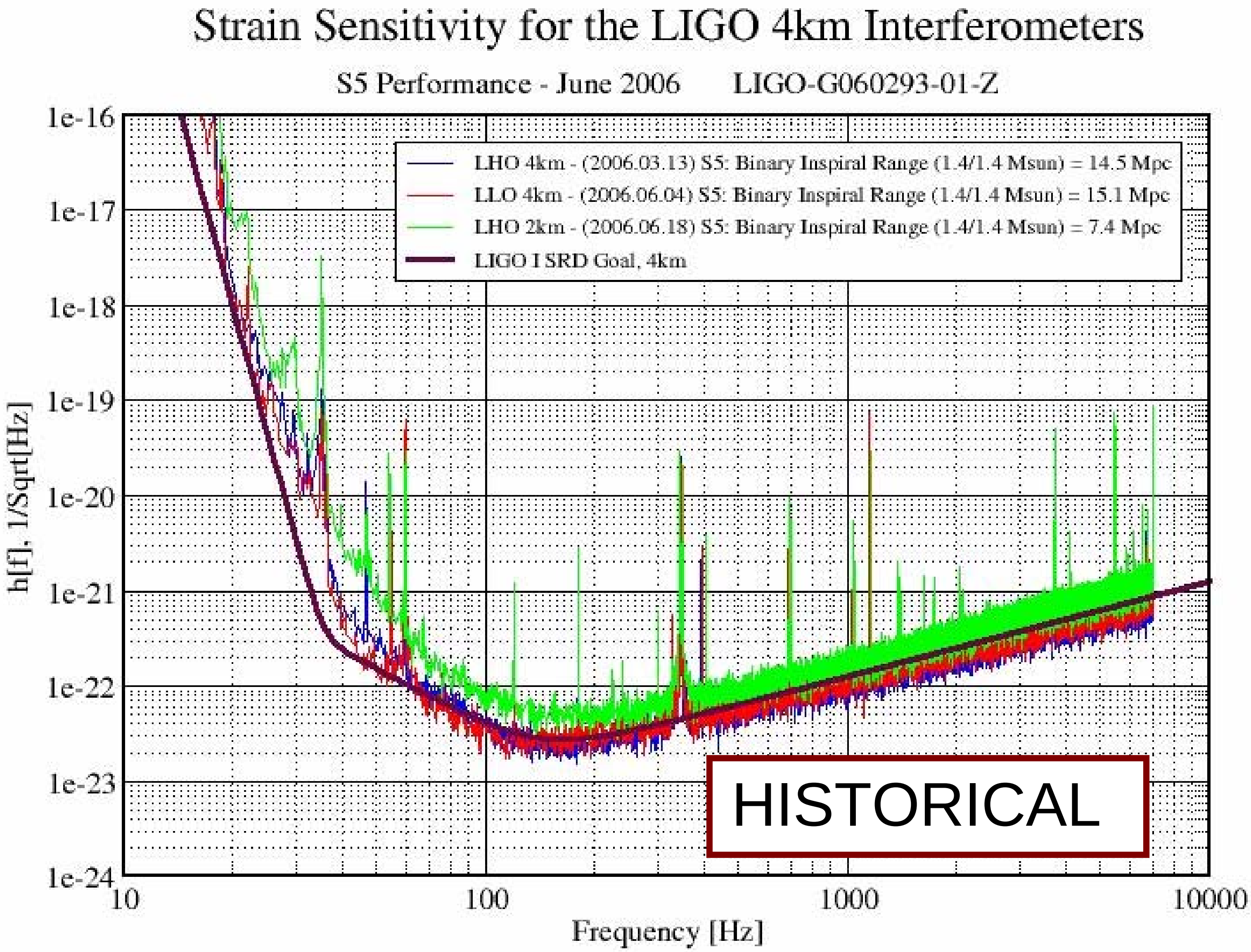
Laser interferometer

- sense changes in the separation of mirrors baseline of ~4 km
- sensitivity better than ~1 attometre on 10ms timescales
- use multiple reflections to enhance (~100)
- still must sense to of order 10^{-10} of a fringe ($\lambda \sim 1\mu$m)
    - requires 10^{20} photons (>1J) so low-loss optics and high power lasers 10~200W @1064nm
- avoid scattered light: 1aW can ruin performance

Quiet, isolated mirrors

- isolation from ground vibration: factor 10^{12} at 10 Hz
    - this turns out to be relatively easy (fine engineering, not cheap)
- much harder to avoid thermal vibrations, akin to Brownian motion
    - requires mirrors and parts of the supports to be made from low dissipation materials such as fused silica

It is possible!



Motivation for Advanced LIGO

- Aim for reliable, frequent detections

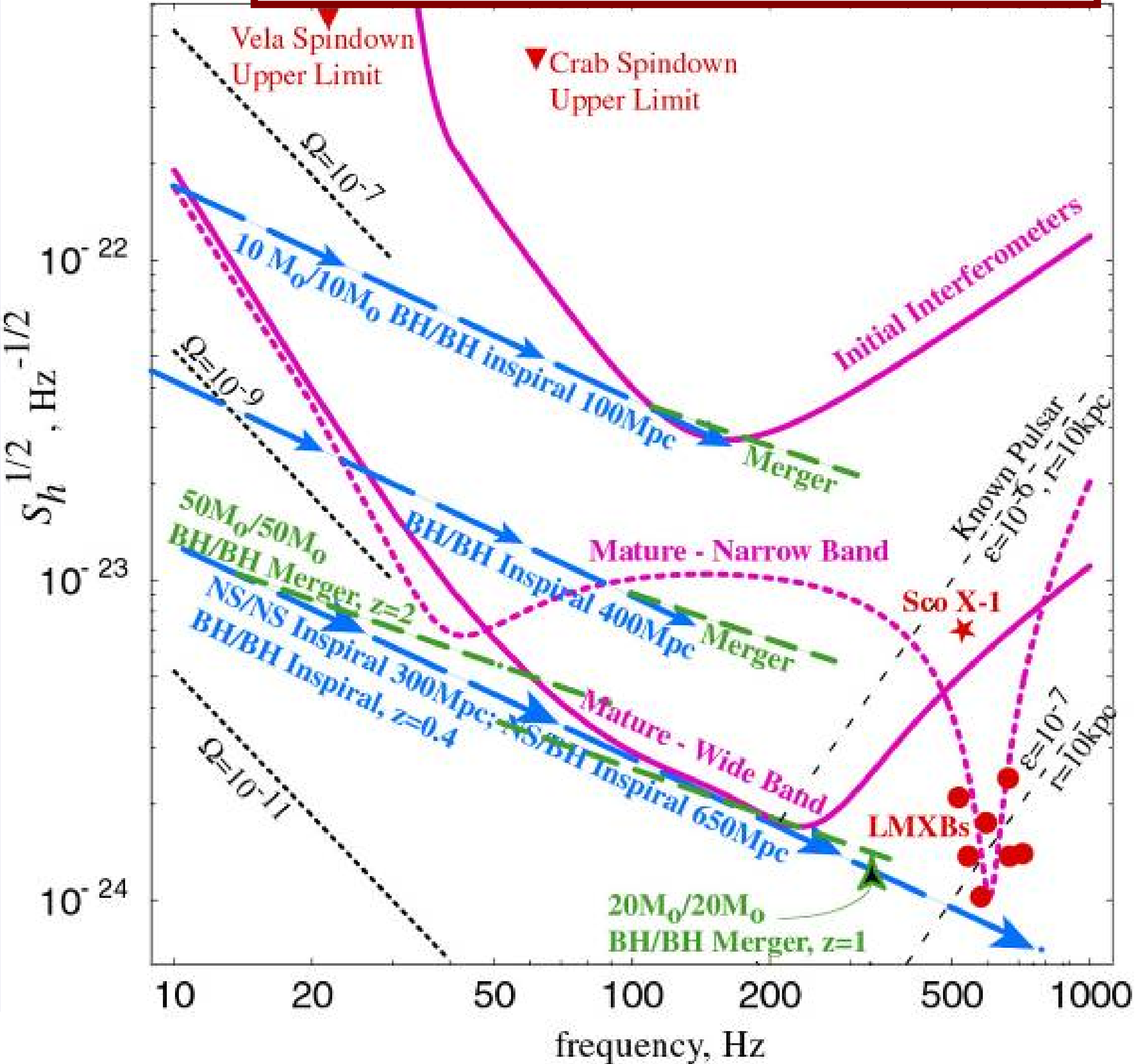
- Requires 10~15x better peak amplitude sensitivity

- GW detectors measure amplitude so the range is increased by 10~15x out to >>100Mpc for inspirals

  ⇒ 1000~3000x rate (number of sources increases approx. as cube of range)

- Note figure already includes required SNR factors for detection (all signals at or above magenta lines are detectable)

Not formal design goals



Advanced LIGO

- Incorporate technology from GEO600 and other new ideas to upgrade the LIGO detectors
  - Active anti-seismic system operating to lower frequencies
  - Lower thermal noise suspensions and optics
  - Higher laser power
  - More sensitive and more flexible optical configuration

R&D phase completed, construction project ready to start!

Installation starts 2011

Planned operation 2014

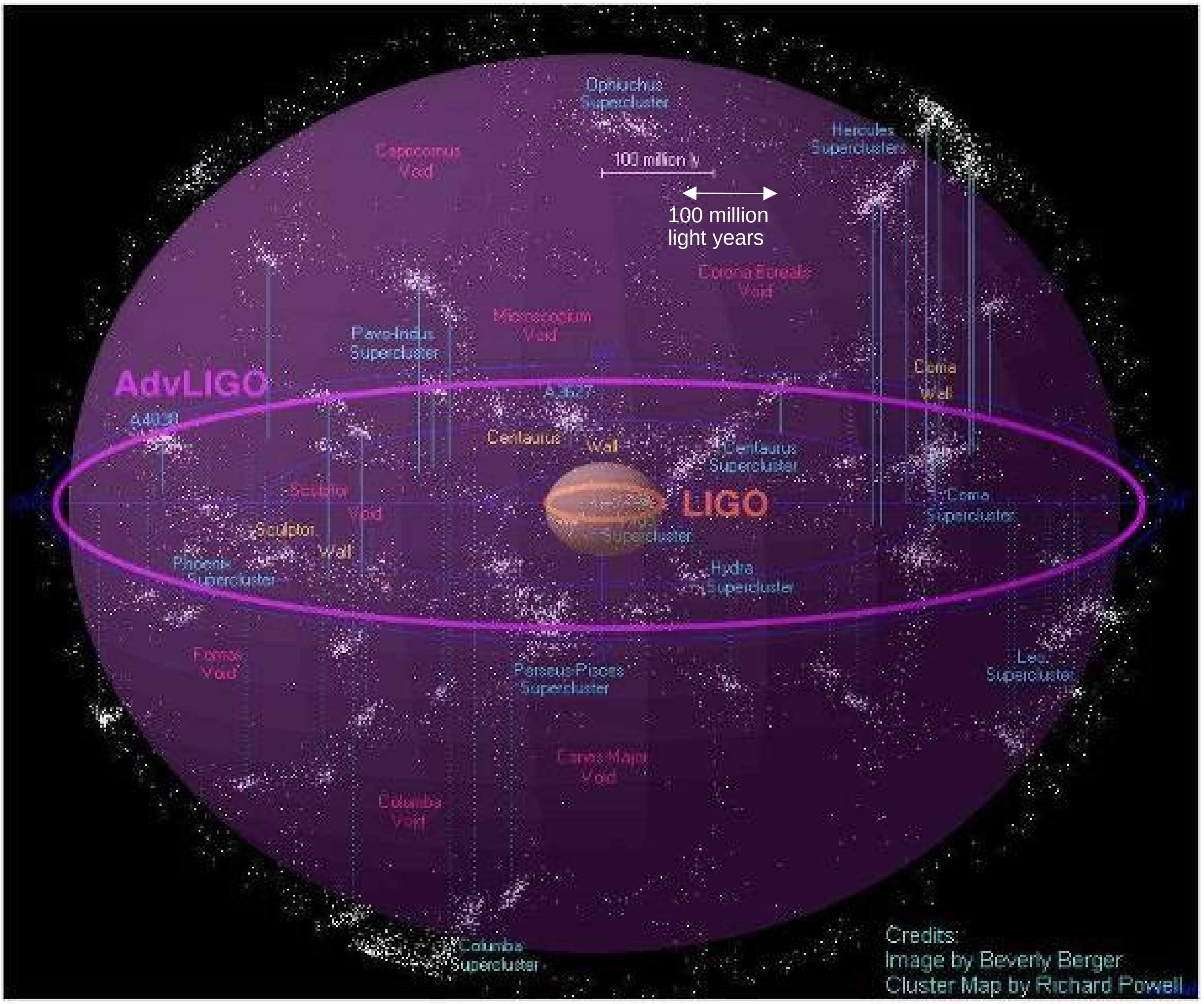
UK funding approved 2004 (PPARC/STFC)

D funding approved 2005 (MPG)

US funding start expected soon (NSF)

Advanced LIGO

Rates for inspirals should increase from of order 1/30 years to of order 30/year

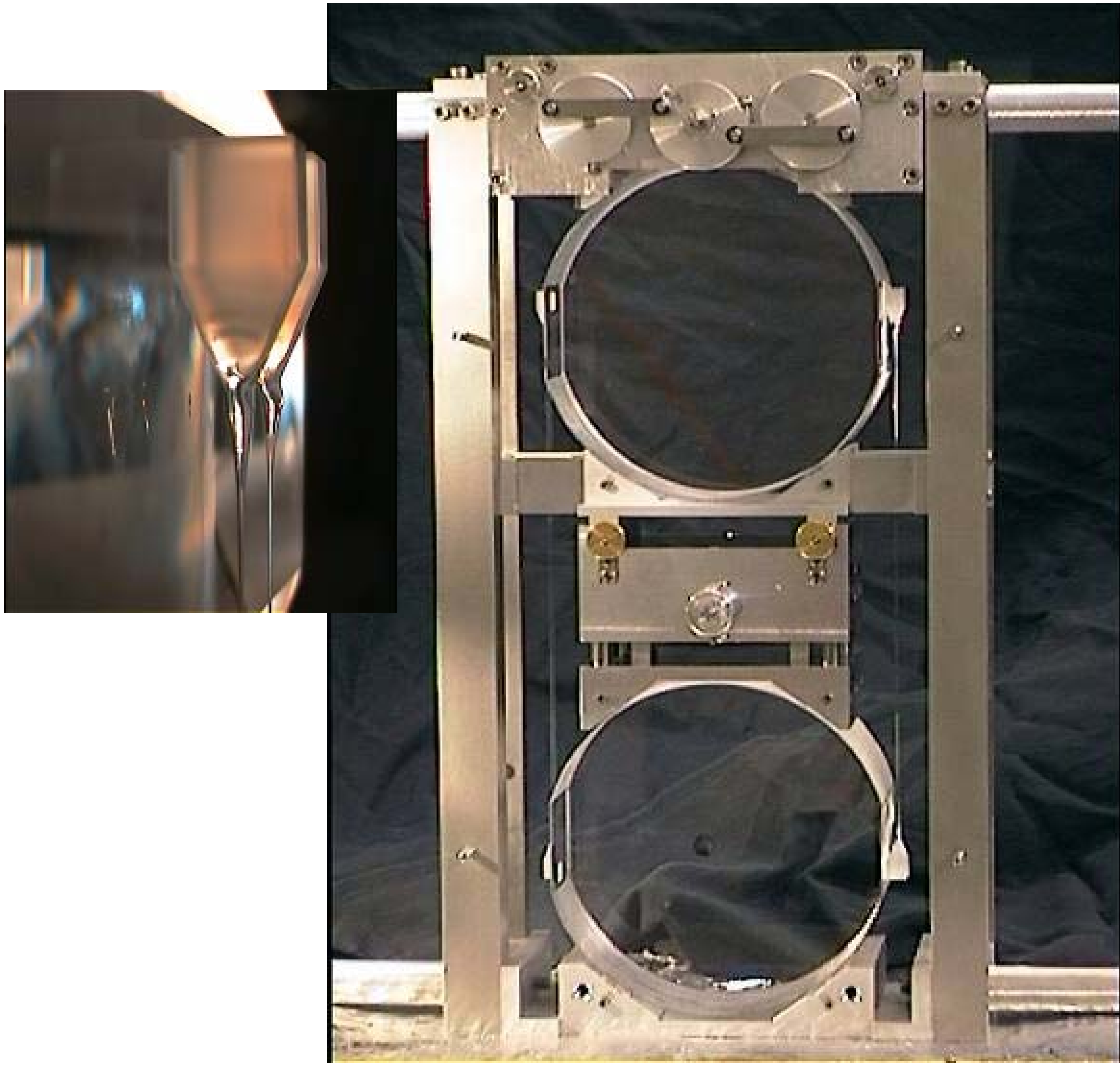


Credits:
Image by Beverly Berger
Cluster Map by Richard Powell

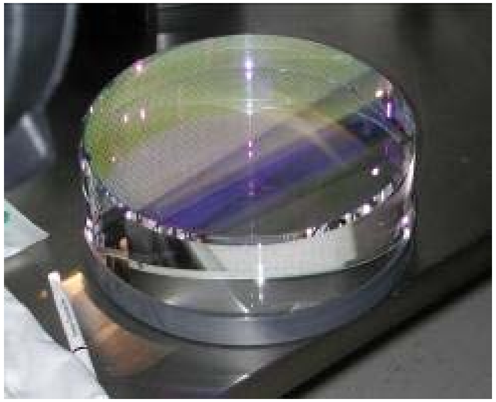
GEO600 quasi-monolithic silica suspension technology

Suspension fibres

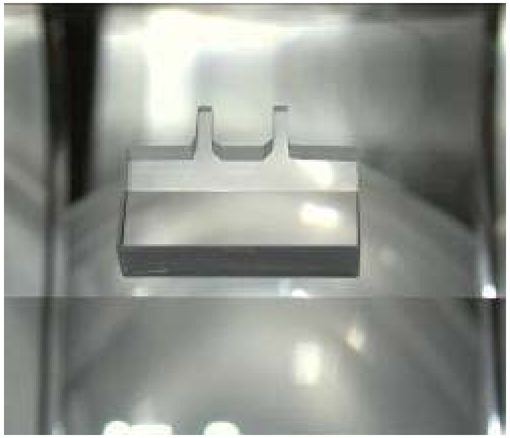
- use fused silica in GEO for low loss
- welded to ears bonded by a specially developed “silicate bonding” technique
- transferred to become a key technology for Advanced LIGO



Suspending ~10kg on 4 fine silica fibres takes care!



Preparing the optic

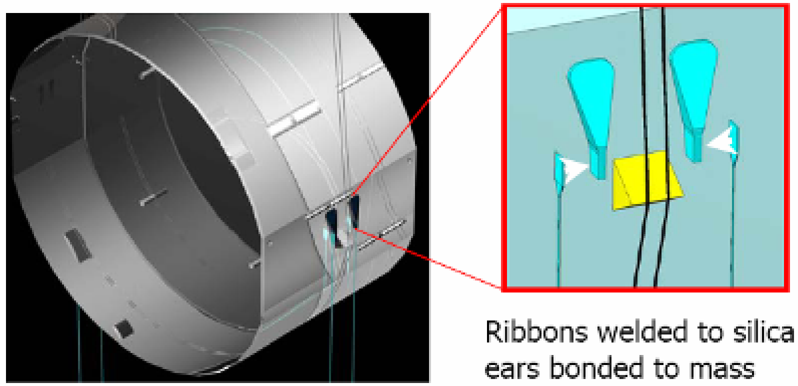


Silica ‘ears’ bonded to masses

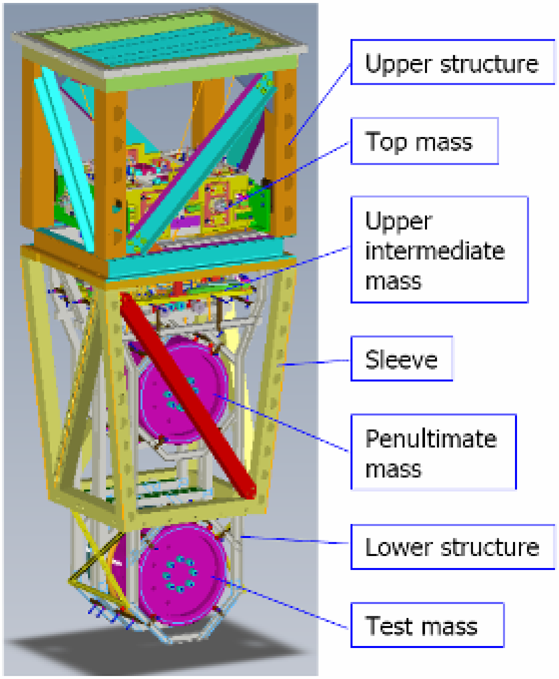
Welding fibres to the ears

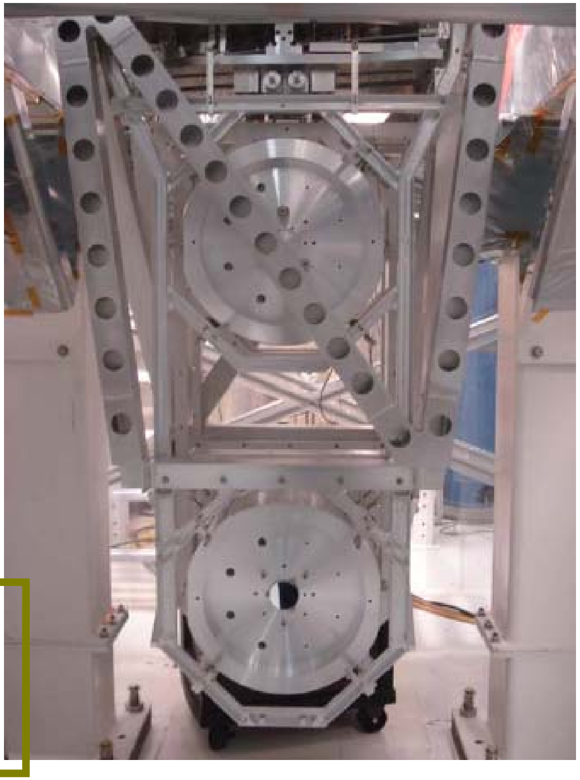
Advanced LIGO suspensions

- 3 and 4 stage suspensions based on GEO600 triple design
- Final prototype currently being assembled at MIT test facility
- Final stages of fabrication-tooling tests underway at Glasgow


Ribbons welded to silica ears bonded to mass

Quad Noise Prototype





- engineering model under test at MIT

Advanced LIGO UK

- PPARC (now STFC) £8.9 M grant to Glasgow and Birmingham, with RAL, Strathclyde and Cardiff as partners
- Main deliverables
  - provide optical substrates and the main suspensions for 3 interferometers, plus associated control electronics

Conclusion

- The next few years will bring the opening of this new field of observational science
  - detections are not guaranteed with the 1st generation detectors, but are certainly possible with the detectors operating at design sensitivity
- Advanced LIGO is approved and ready to start fabrication
  - essentially guaranteed observations and rich science
  - reaches to cosmological distances (approaching 1 Gparsec)
- Space interferometry (LISA) extends the science reach to lower frequencies (0.1 mHz to 0.1 Hz approx.)
  - can probe deep cosmological distances
  - a major source of noise is the GW background!