LIGO

LIGO

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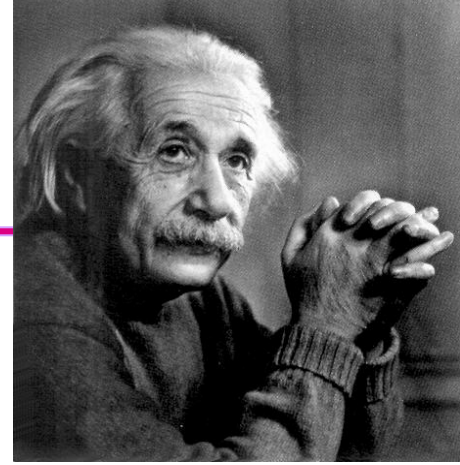
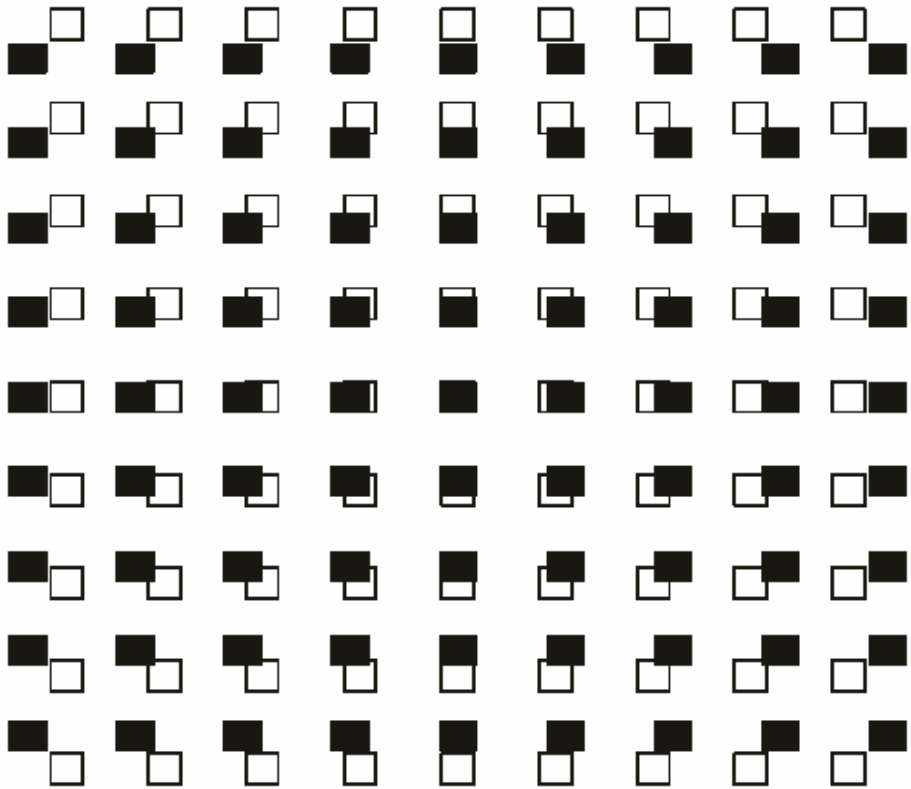
What is LIGO?

- **L**aser **I**nterferometer **G**ravitational-wave **O**bservatory
- LIGO's mission is to use Gravitational Waves as a completely new window on to the universe
  - » Analogous the change in perspective made when going from optical observation to cosmic radio waves, or x-rays – an entirely new view
- GWs are produced by accelerating mass: e.g., supernovae
  - » The biggest signals made by the most violent, extreme events in the universe
  - » GWs are not attenuated by matter – can see through dust, intervening galaxies, dark matter
- GWs are ripples in space-time – to be observed as variations in the apparent distance between objects as the wave passes
  - » Effect is tiny….

Gravitational Waves

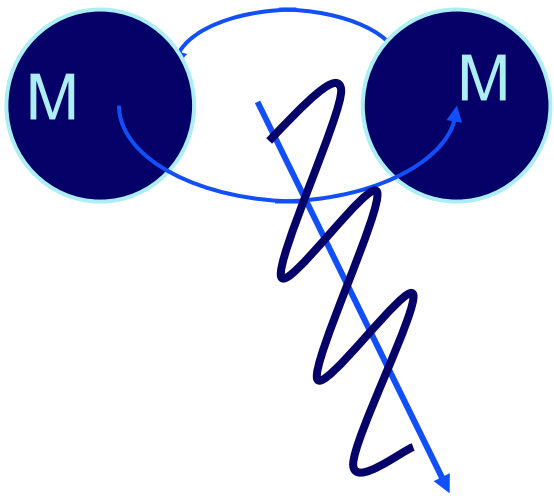


- Einstein's General Theory of Relativity predicts gravitational radiation
  - » Analogous to electromagnetic radiation – transverse waves, carrying energy, speed of light, due to accelerations of 'charge'
  - » Amplitude measured as the dimensionless strain in space, $h = (\Delta L)/L$
- Quadrupolar – *x* axis shrinks while *y* axis grows, then vice versa, as wave passes



Gravitational Waves

- A very weak effect: only astrophysical events make presently conceivably measurable effects
- A 'binary inspiral' of two solar-mass stars at the Virgo cluster (18 Mpc away) will cause a change in apparent length of a meter stick of ~10^{-21} meters
- …a 10m stick would see a change of 10^{-20} m, 100m → 10^{-19} m…



$$M \approx 10^{30}\ \text{kg}$$
$$R \approx 20\ \text{km}$$
$$f \approx 400\ \text{Hz}$$
$$r \approx 10^{23}\ \text{m}$$

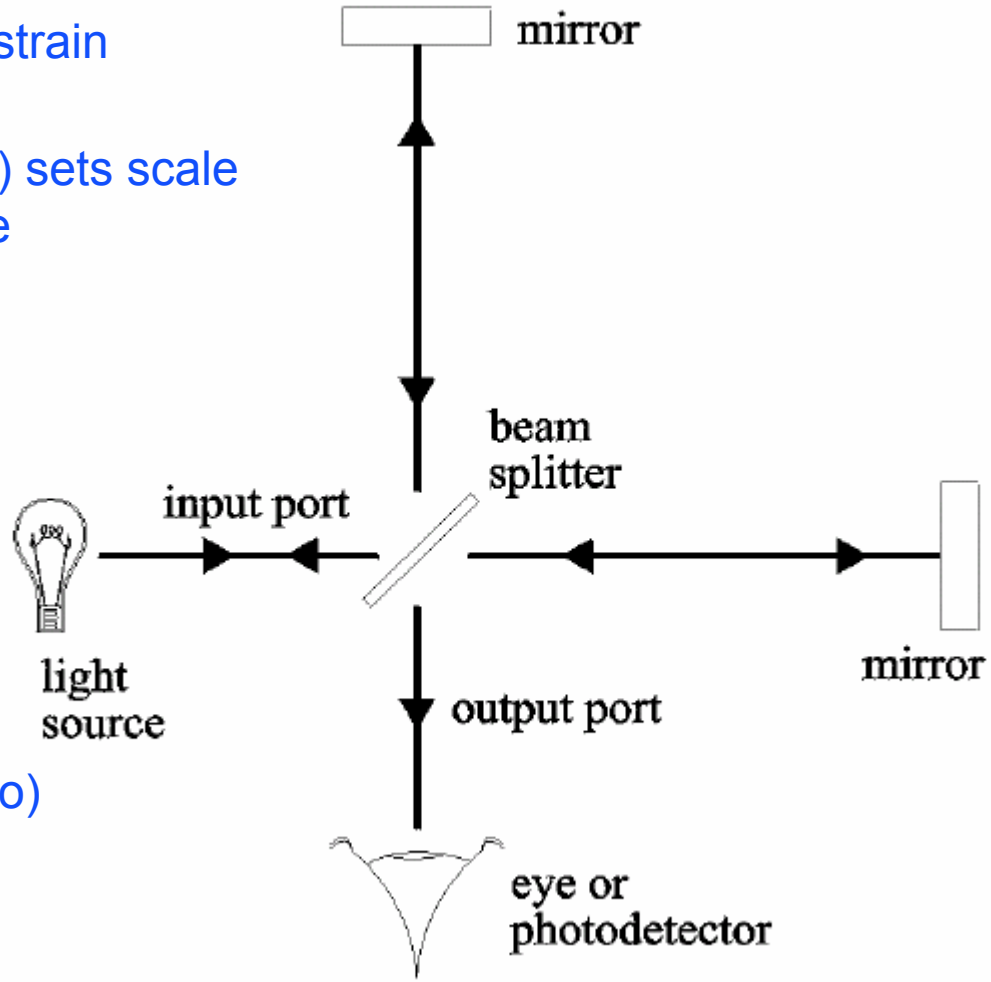
→ $h \sim 10^{-21}$

Interferometry

- Rainer Weiss in 1972:
- Use laser interferometry to sense the strain for the expected quadrupolar signal
- Wavelength of light (typically 1 micron) sets scale for measurement 'ruler'; split the fringe

- However, an instrument of ~4km is needed to have an astrophysically interesting sensitivity
- Light must travel in a good vacuum to avoid scintillation
- Need two instruments, separated, to claim detection (and get directional info)

→ Detector must be big!



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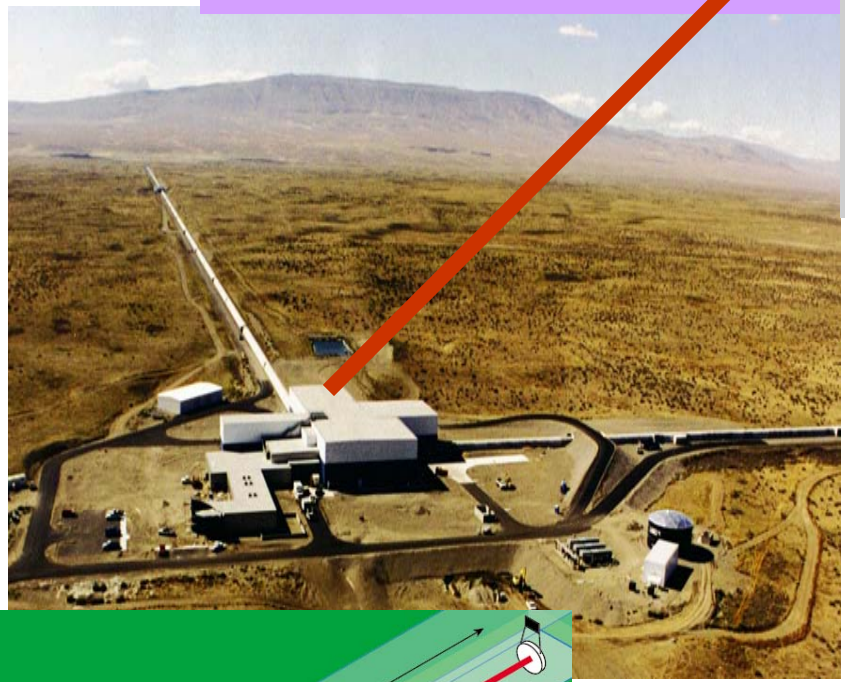
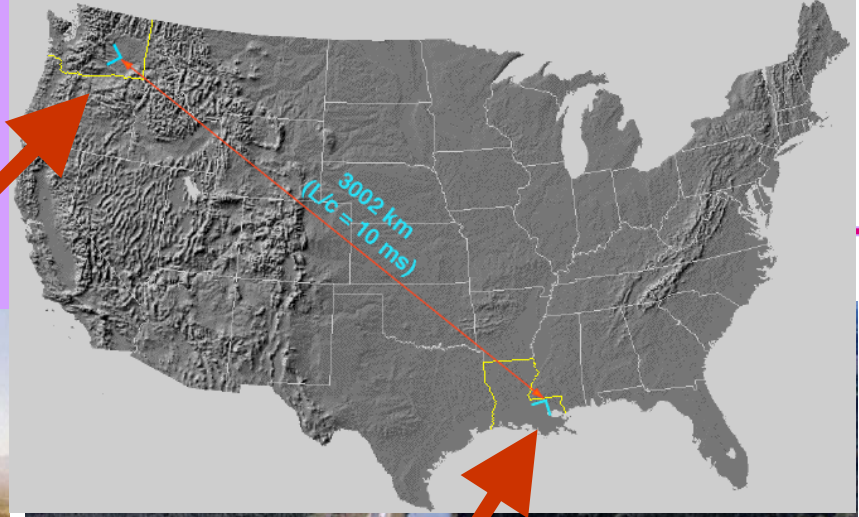
LIGO Hanford Observatory [LHO]

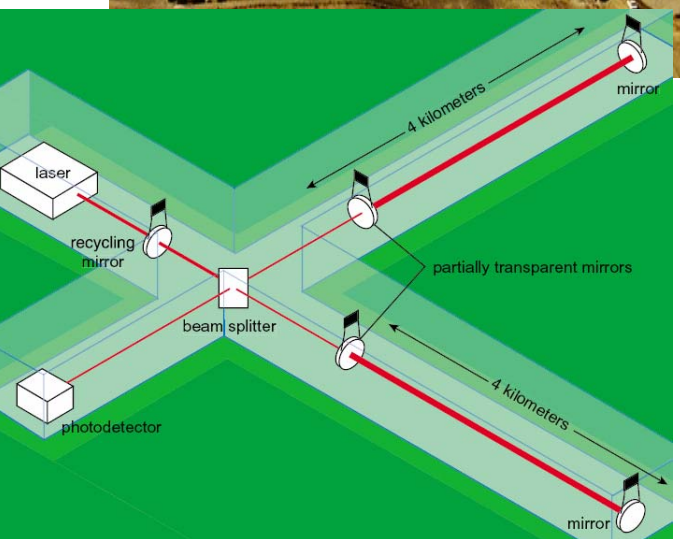
2 km + 4 km interferometers in same vacuum envelope





LIGO Livingston Observatory [LLO]

Single 4 km interferometer



- Two separated observatories for detection confidence, directional information
- Initial planned sensitivity just enough to plausibly see signals; evolution to greater sensitivity in the mission
- Proposed in ’89, construction starting ’95, construction finished on time and on budget

LIGO
beam tube

- LIGO beam tube under construction in January 1998
- 65 ft spiral welded sections
- girth welded in portable clean room in the field

1.2 m diameter - 3mm stainless
50 km of weld….and not one leak

LIGO

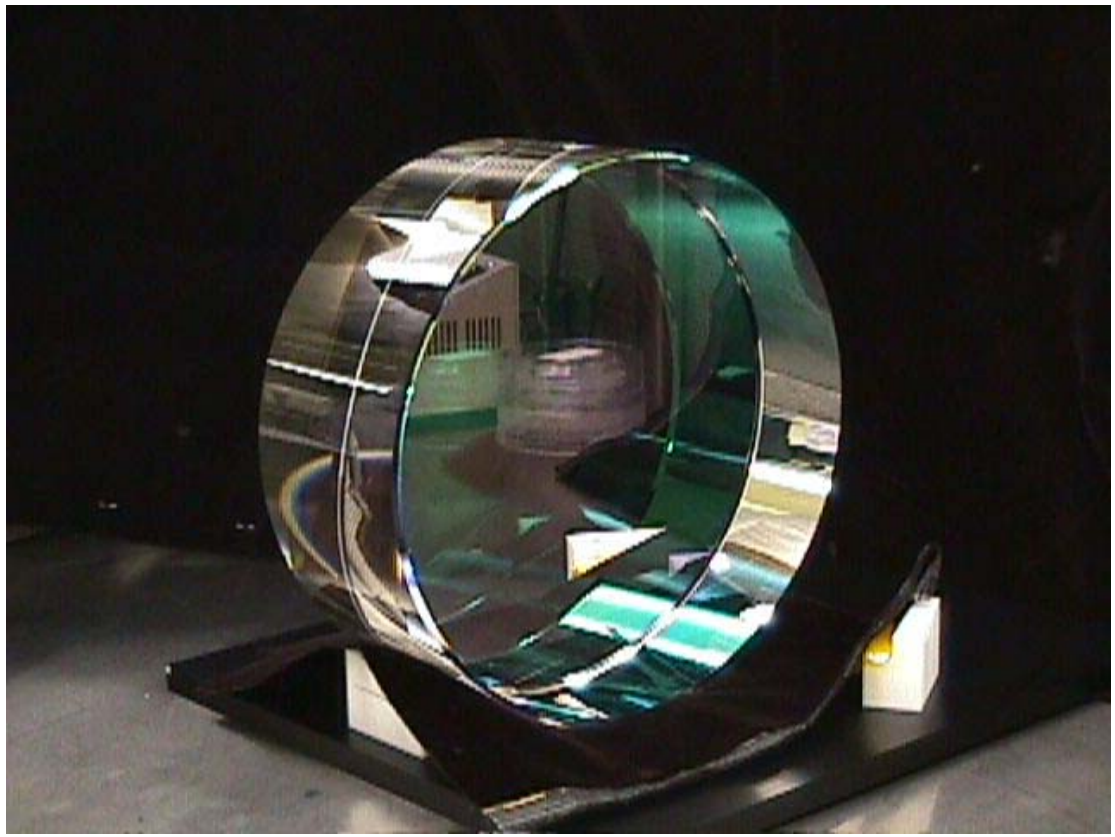
vacuum equipment

LIGO Optic

Substrates: SiO_2
25 cm Diameter, 10 cm thick
Homogeneity < 5×10^{-7}
Internal mode Q's > 2×10^{6}

Polishing
Surface uniformity < 1 nm rms
Radii of curvature matched < 3%

Coating
Scatter < 50 ppm
Absorption < 2 ppm
Uniformity <10^{-3}



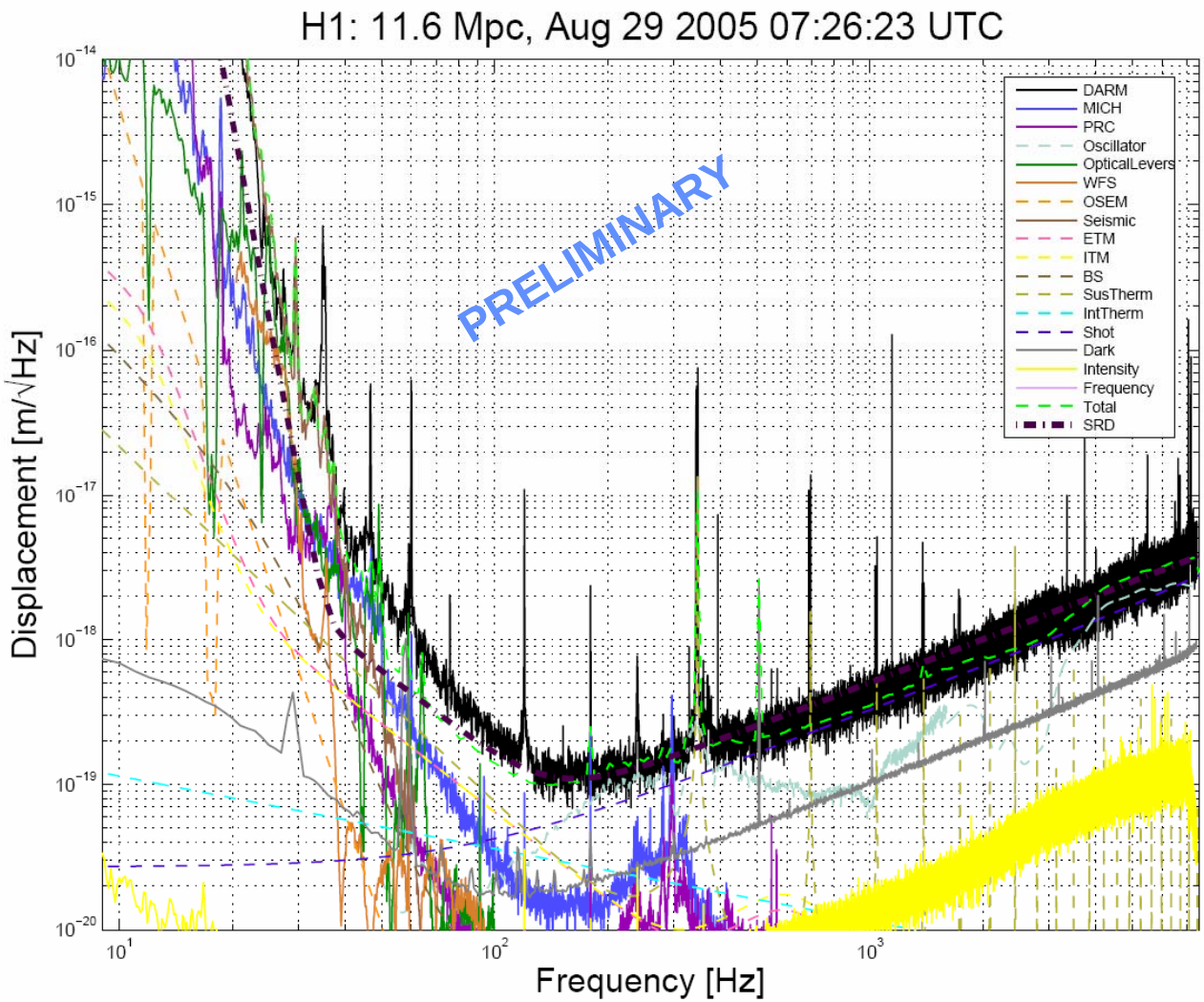
LIGO

Core Optics

installation and alignment

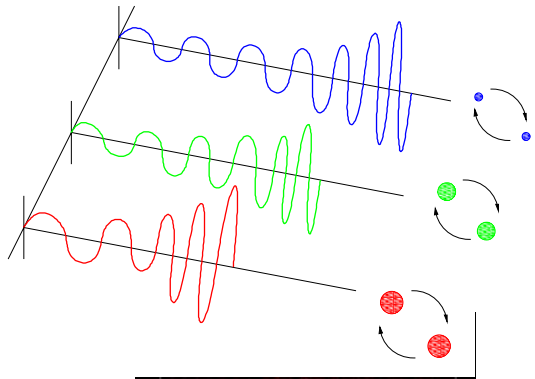
Overall LIGO Status

- Commissioning drawing to a close
- Have run, collected data, analyzed, published – no detections to date
- Significant new 'upper limits' established
- Initial instruments ready to observe at design sensitivity
- Will start long runs in late 2005



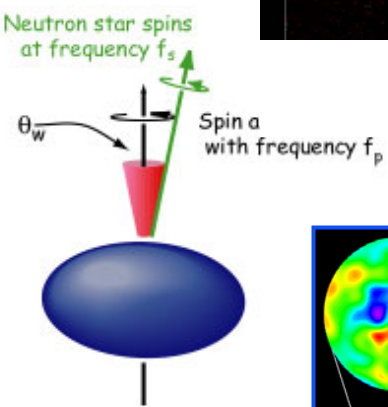
Sources of gravitational waves

- Compact binary inspiral: *"chirps"*
  - » NS-NS waveforms -- good predictions
  - » BH-BH (<10 M_s) – would like better models
  - » search technique: matched templates

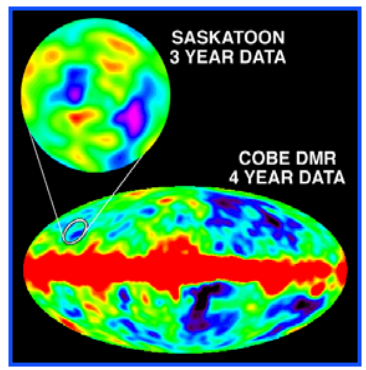


- Supernovae / GRBs / Strings: *"bursts"*
  - » burst signals in coincidence, maybe with signals in electromagnetic radiation, neutrinos
  - » prompt alarm (~ one hour) with neutrino detectors

- Pulsars in our galaxy: *"periodic"*
  - » search for observed neutron stars (frequency, doppler shift)
  - » all sky search (computing challenge)



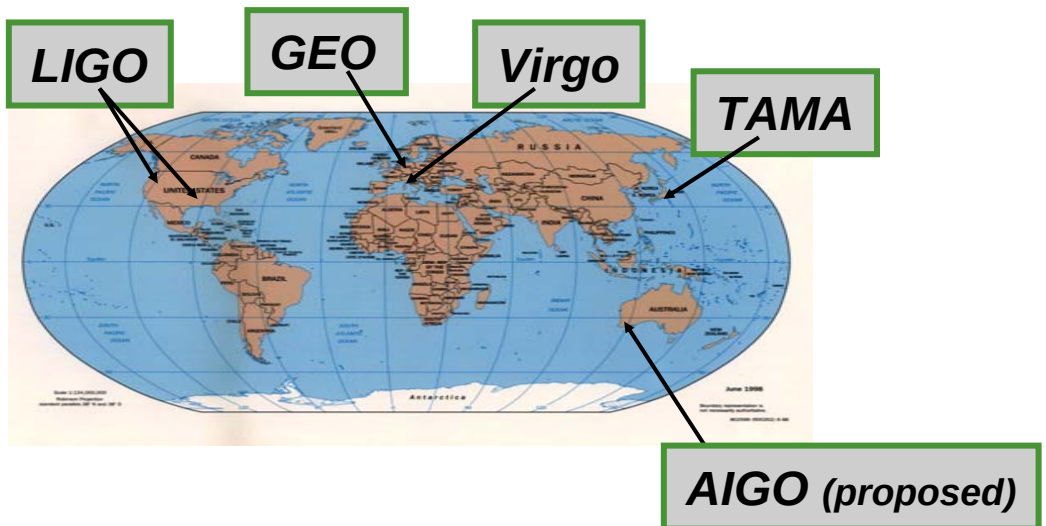
- Cosmological Signals *"stochastic background"*



LIGO Community

- LIGO Laboratory: Caltech and MIT, and the staff at the observatories
- LIGO Scientific Collaboration: ~400 people, ~40 institutions, US + international collaborators
- Very strong and tight collaboration, with shared responsibilities

- Other detectors in Germany, Italy, Japan
- US instruments the most sensitive to date, and by design
  - » After initial observation, will join with others for joint observation
- Second generation instruments proposed around the world



LIGO Education

- Currently, 8 graduate students in the ~25 person MIT LIGO Lab; heavy undergraduate engagement, large SURF program at Caltech, a number of teaching universities engaged in our Collaboration
- Many graduates of the LIGO Lab have stayed in the field, become faculty; others gone on to industry jobs (strong optics, mechanics, controls, quantitative analysis skills)
- NSF-supported Public Education Program: Caltech with Southern University (Baton Rouge), LA Board of Regents, and the Exploratorium
  - » Building an outreach center at the Louisiana LIGO site
  - » Hands-on exhibits, coupled with tours
- Informal outreach at MIT through visits to grade schools, tours of classes to Lab, etc.
- Wonderful project for students
  - » Brand-new field, with open horizon
  - » Chance to think about fundamental questions of space, time, the universe
  - » Sensitivity limited by fundamental physics – quantum, thermal fluctuations
  - » Ground-breaking technologies, applicable in science, industry
  - » Soldering irons, milling machines, and computers: a chance to really build something that has never been built before

LIGO Future

- LIGO proposed and designed to house several generations of detectors
- Advanced LIGO proposed to follow initial LIGO observation run
- Factor of 10 more sensitive → 1000x greater volume, many more sources
- Anticipate several GW events per day
- The start of the 'Gravitational Wave Astronomy' we've been working for!

- Thanks to the NSF and the US taxpayers for their strong support