Is there a future for LIGO underground?

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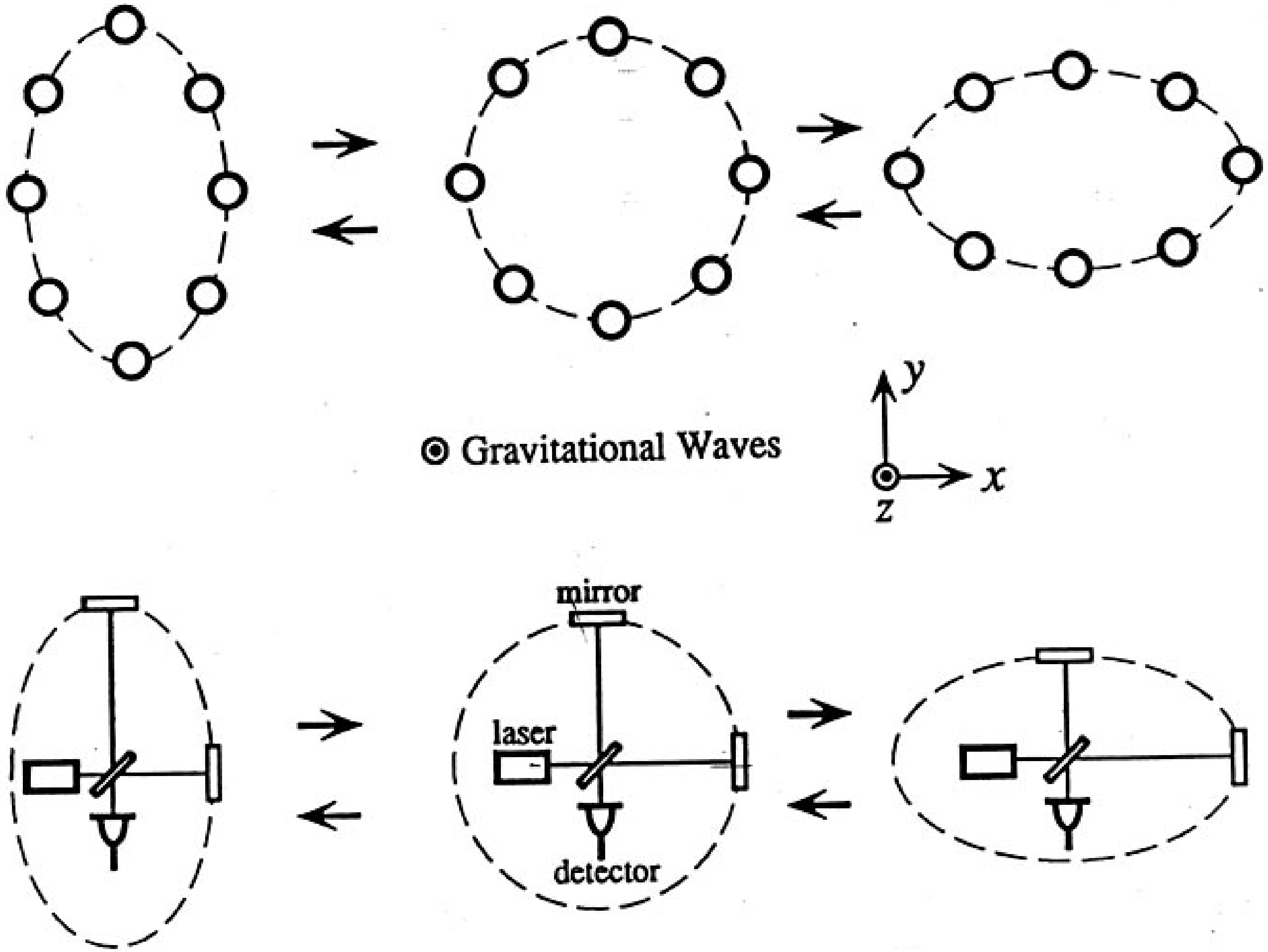
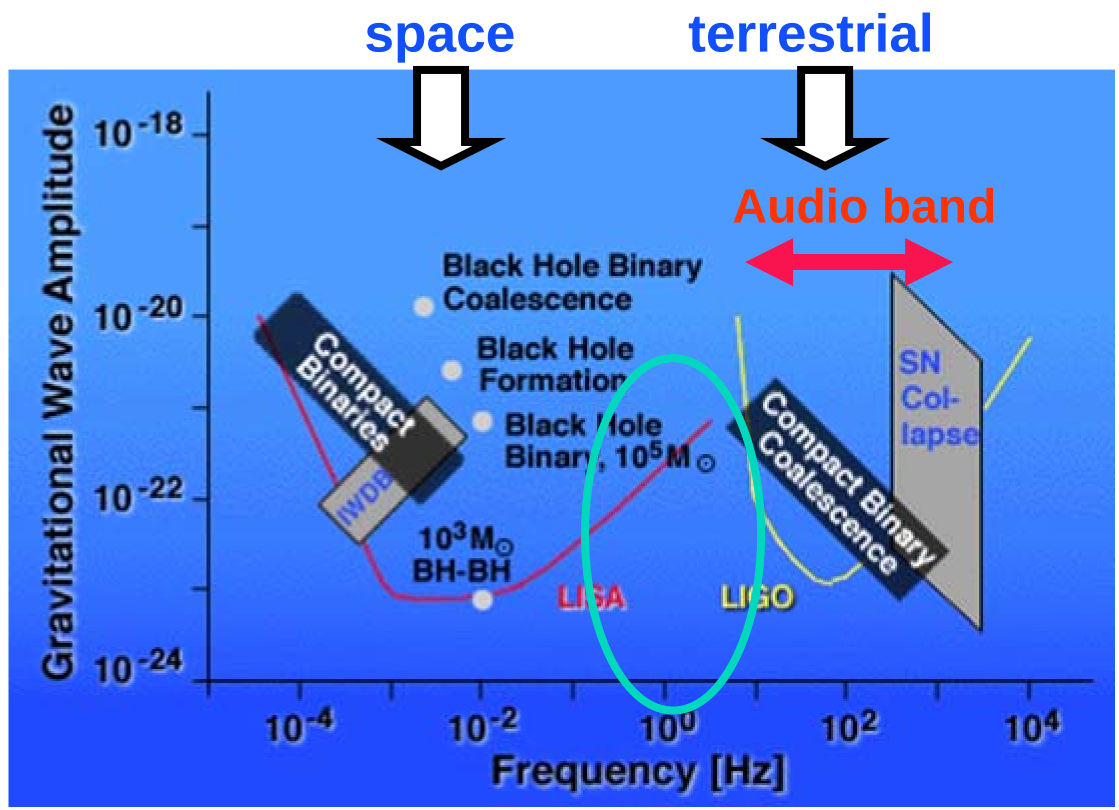
Basic Signature of Gravitational Waves for All Detectors



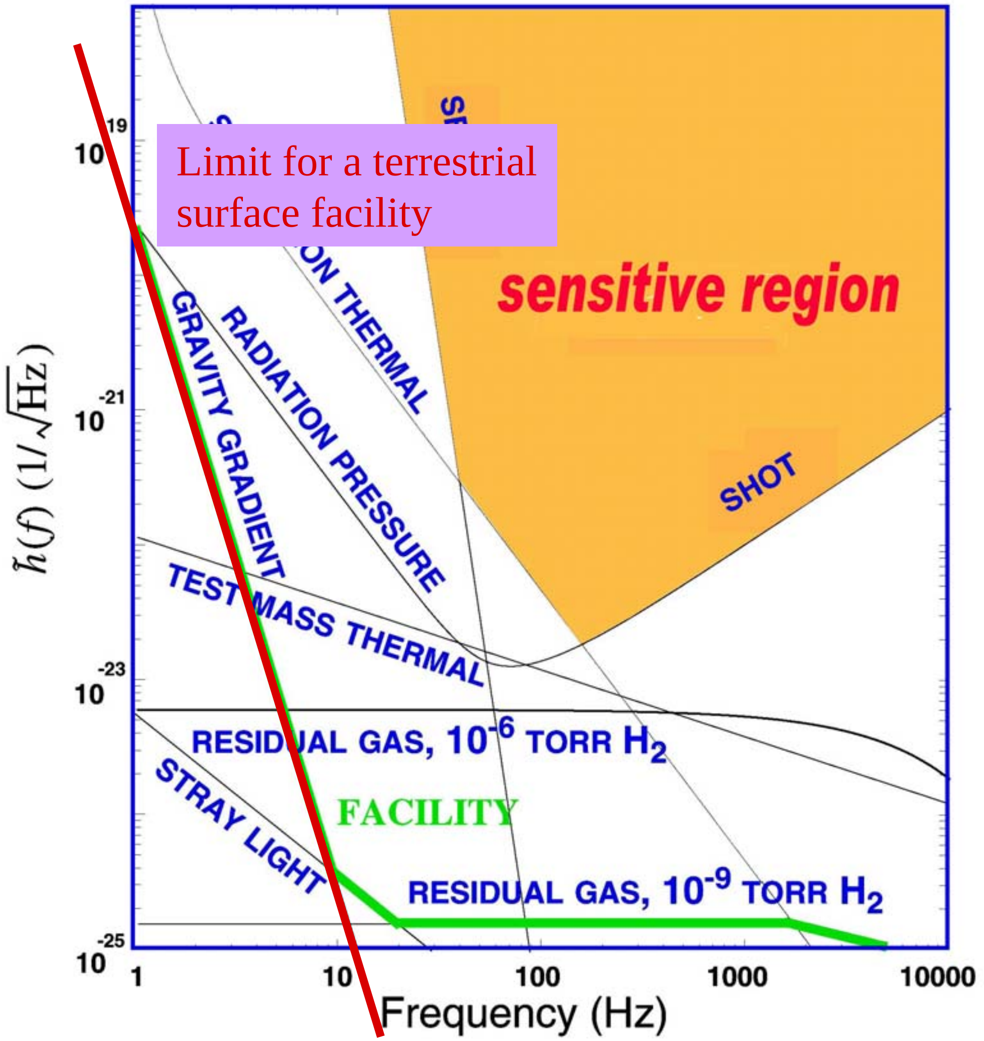
Different Frequency Bands of Laser-Based Detectors and Sources

There exists a hole in the coverage afforded by currently planned terrestrial and space-based gravitational-wave detectors



What Limits Sensitivity of Interferometers?

- Seismic noise & vibration limit at low frequencies
- Atomic vibrations (Thermal Noise) inside components limit at mid frequencies
- Quantum nature of light (Shot Noise) limits at high frequencies
- Myriad details of the lasers, electronics, etc., can make problems above these levels



Gravity gradients: low-f limit for terrestrial detectors

- First estimated by Saulson (1984) prior to LIGO construction
  - » Revisited by Hughes and Thorne (1998) after LIGO sites were selected and seismic backgrounds characterized
  - » Limits detection band of surface terrestrial detectors to f > 10-20 Hz
- Lower-f operation a rationale for space-based detectors
  - » LISA is optimized for a much lower band (10^{-4} – 10^{-2}) Hz
  - » Seto, Kawamura and Nakamura (2001) introduce idea of DECIGO to target band around 0.1 Hz
- Campagna, Cella and DeSalvo introduce idea of gravity-gradient mitigation in an underground detector optimized for lower-f operation at an Aspen Workshop (2004)

Scientific rationale to push for lower frequency operation

- Binary neutron star inspirals have longer dwell times at lower frequencies; more opportunity to integrate up signals
- Black hole binaries merge at lower frequencies as the mass rises
- Known radio pulsars exist in larger numbers at lower frequencies

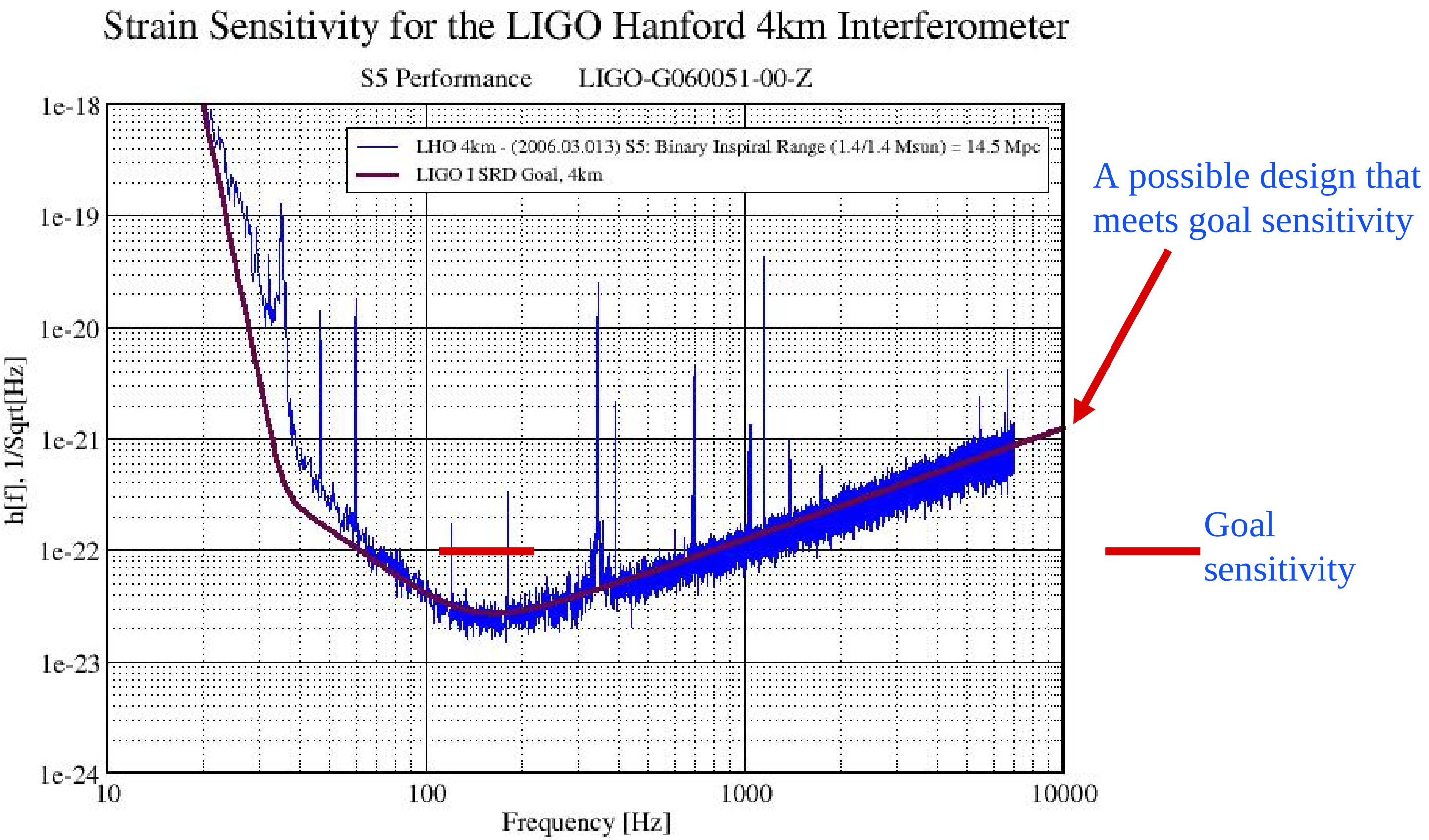
North America: Laser Interferometer Gravitational-Wave Observatory

LIGO (Washington)
(4-km and 2km)

LIGO (Louisiana)
(4-km)

Funded by the National Science Foundation; operated by Caltech and MIT; the research focus for ~ 500 LIGO Scientific Collaboration members worldwide.

Initial LIGO detectors are working



Binary Neutron Stars: Initial LIGO Target Range

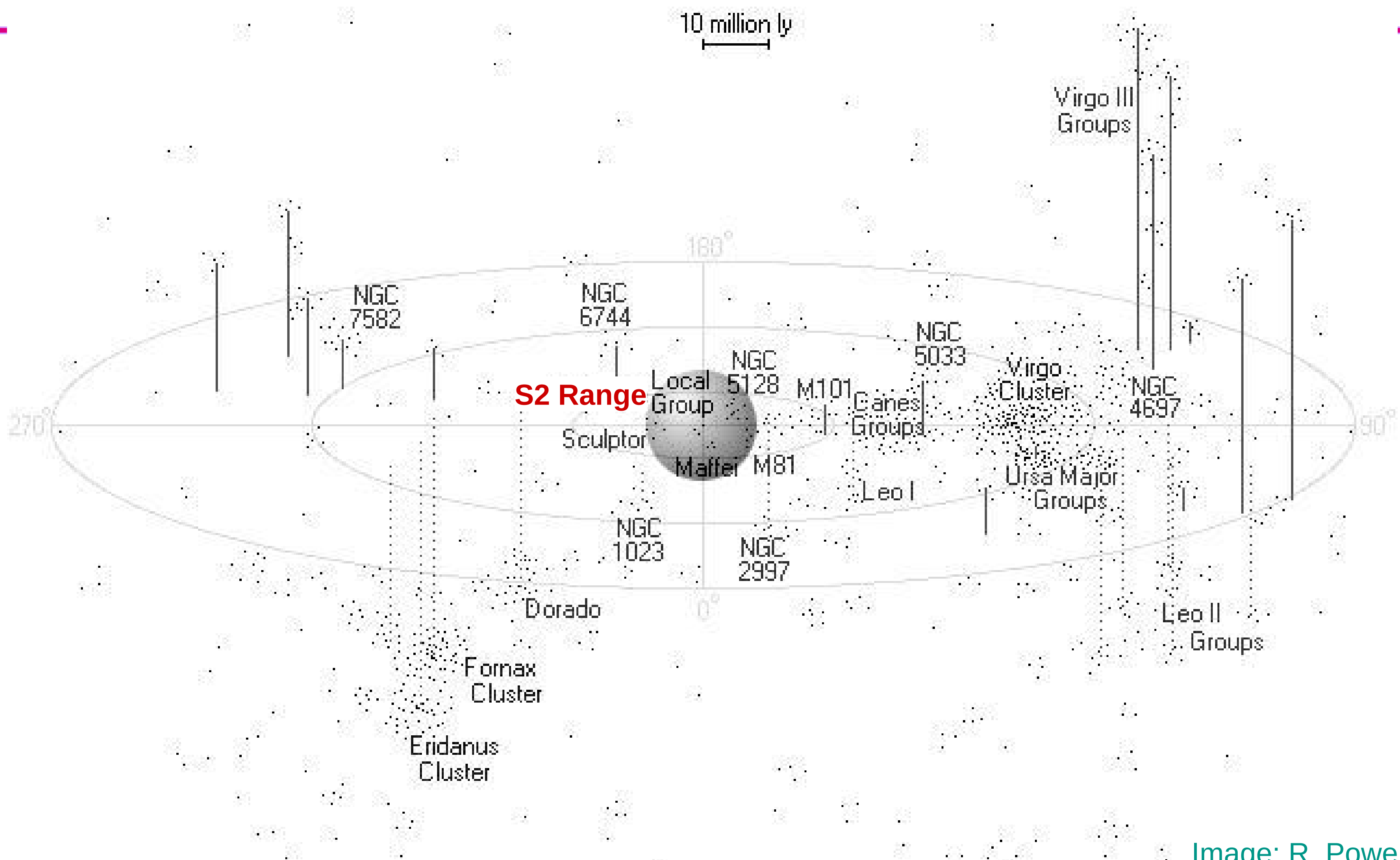
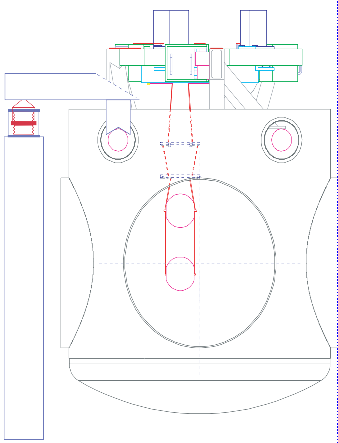


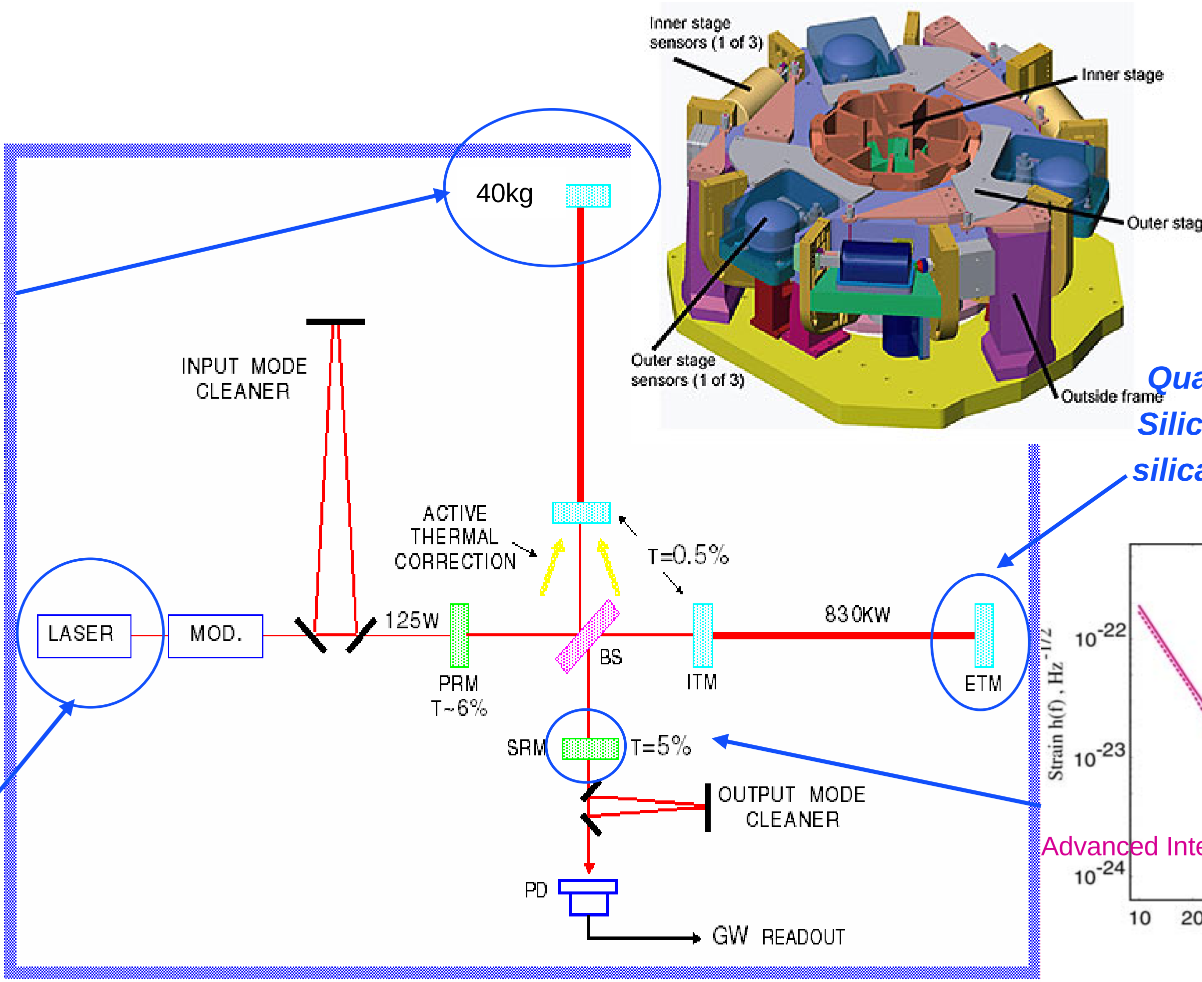
Image: R. Powell

What's next? Advanced LIGO…

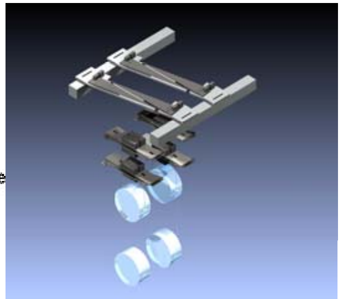
Major technological differences between LIGO and Advanced LIGO



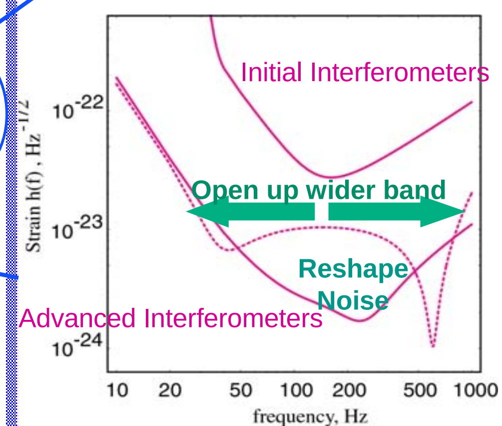
Active vibration isolation systems



High power laser (180W)



Quadruple pendulum: Silica optics, welded to silica suspension fibers



Advanced interferometry Signal recycling

Binary Neutron Stars: AdLIGO Range

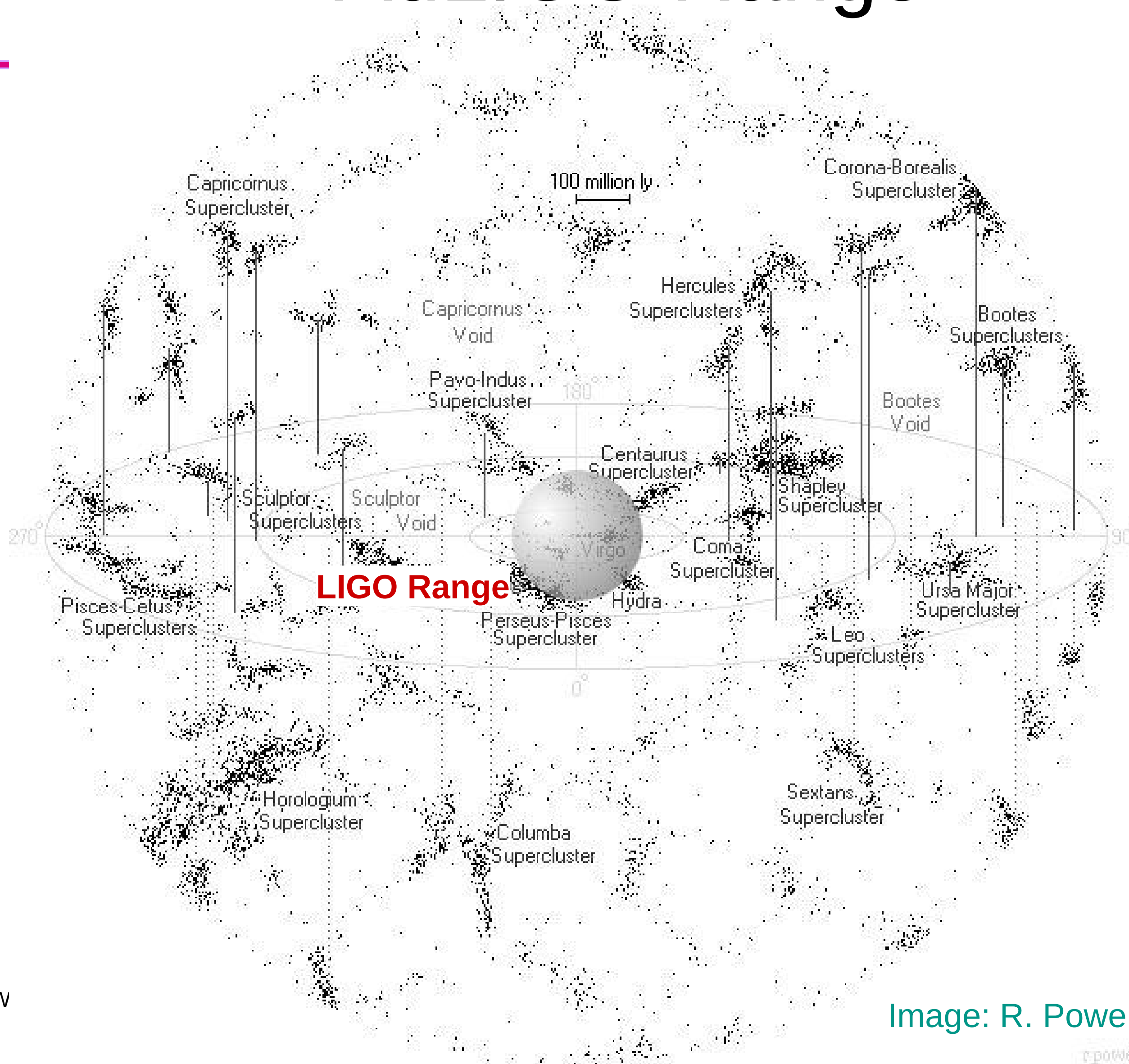


Image: R. Powell

Future Plans for Terrestrial Detectors

- LIGO long-term search (~one integrated year) using initial LIGO
- Virgo has made steady progress in commissioning, hope to begin science searches in near future
- Increased networking of resonant bars with interferometers
- Advanced LIGO (AdLIGO), approved by US National Science Board, planning a detector construction start for FY2008: PPARC funding in place in UK; funding being worked in Germany
- Japan working on a design for a large-scale, underground detector with cryogenic mirrors (LCGT)

What would an underground version of LIGO look like

- Long arms: probably 3-4 km, perhaps longer
- Equilateral triangle, rather than “L” shaped?
- Corner and end stations comparable to current surface facilities, with clean-room environments
- “Shaped” excavations at corners and ends to optimize gravity gradient noise?
- Thermal noise mitigation: by cryogenics(?), subtraction(?), or use of extremely low-loss materials
- Quantum noise mitigation: large mirrored test masses, QND or squeezing techniques using relatively low laser power
- Very-low-frequency seismic isolation systems
- Large vacuum system with cryogenics to trap contaminants
- Vibration-free pumping

TBD: Requirements and Concept

- Acquire seismic data from existing and planned sites
- Model gravity-gradient noise in existing and potential environments
- Identify constraints from other users of underground facilities; is coexistence feasible?
- Identify construction and life-cycle costs; is it more economical to build far below Earth's surface or far above?
- Experience the next generation of GW detector technology as the push toward lower frequencies continues; develop schemes to reduce the non-terrestrial noise sources
- At this point a smaller prototype detector may make sense

Closing remarks…

- We are experiencing a rapid advance in the sensitivity of searches for gravitational waves
- A decade from now, gravitational-wave astronomy should be commonplace, using detectors on Earth's surface and in space
- A significant coverage gap will likely be filled eventually, by an underground and/or a space-based detector.