Status of Ground-Based Gravitational-wave Interferometers

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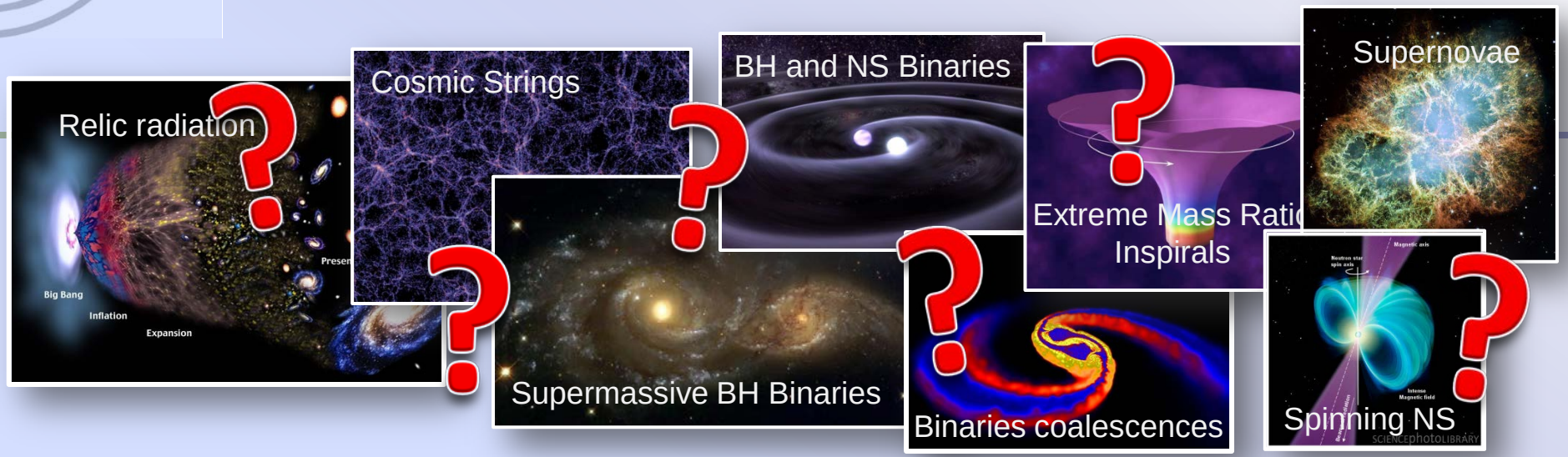
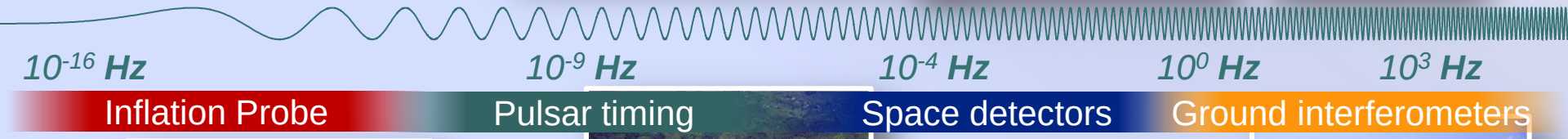
LIGO

Abstract

We present the status of ground based gravitational wave detectors. All observatories are currently in the process of installing second generation instruments with the intend to introduce the era of detection. The regular observations of sources will require a worldwide network of detectors for reliably localizing the sky position. The LIGO project and the implications of LIGO-Indigo will be discussed in detail.

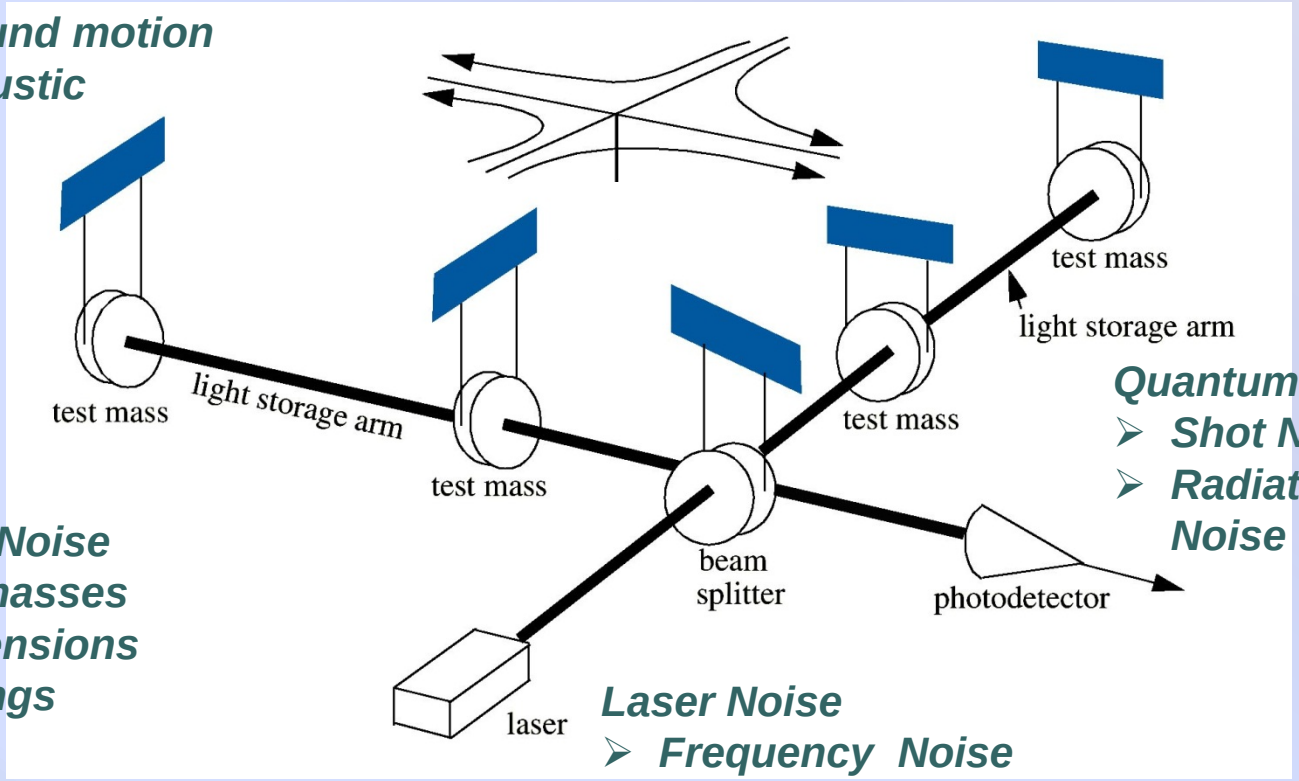
Gravitational Waves





Gravitational Wave Signal and Fundamental Noise Sources

Vibrational Noise
- ***Ground motion***
- ***Acoustic***

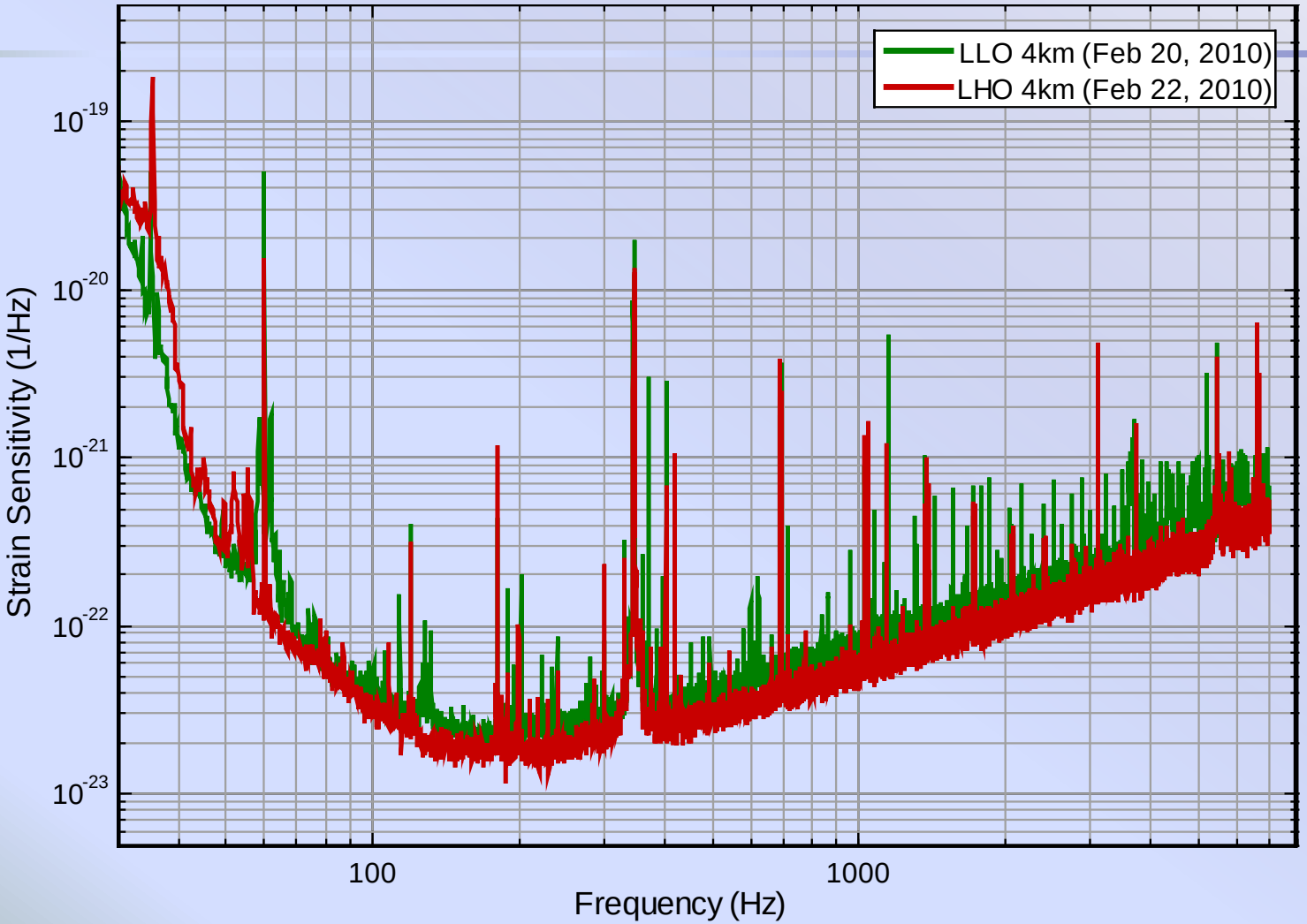


Quantum Noise
- ***Shot Noise***
- ***Radiation Pressure Noise***

Thermal Noise
- ***Test masses***
- ***Suspensions***
- ***Coatings***

Laser Noise
- ***Frequency Noise***
- ***Intensity Noise***

Sensitivity Sixth Science Run



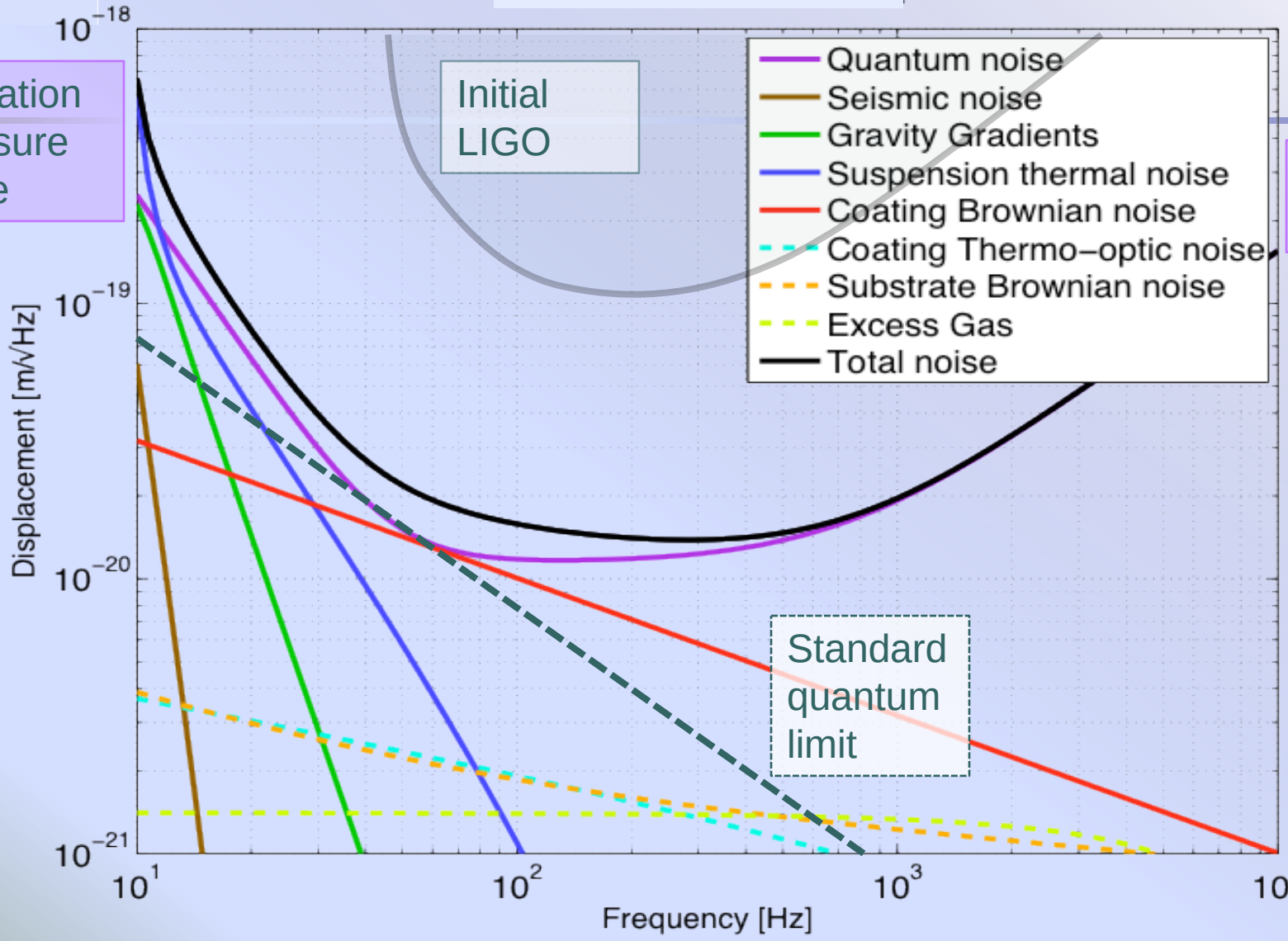
Results from Initial Detectors: Some highlights from LIGO and Virgo

Several ~year long science data runs by LIGO and Virgo
Since 2007 all data analyzed jointly

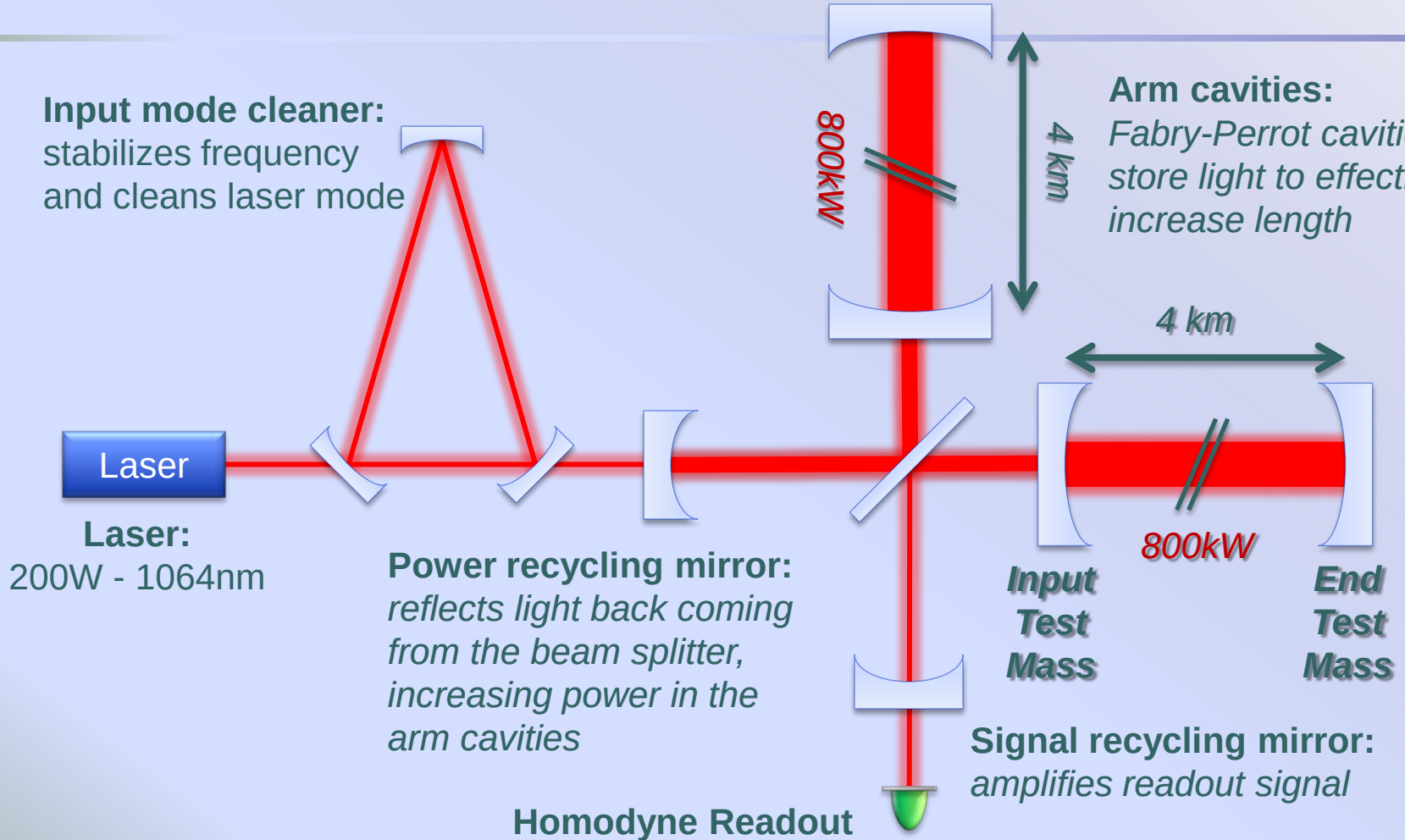
Virgo

- Limits on GW emission from known msec pulsars
  - Crab pulsar emitting less than 2% of available spin-down energy in gravitational waves
- Limits on compact binary (NS-NS, NS-BH, BH-BH) coalescence rates in our local neighborhood (~20 Mpc)
- Limits on stochastic background in 100 Hz range
  - Limit beats the limit derived from Big Bang nucleosynthesis

Advanced LIGO Sensitivity

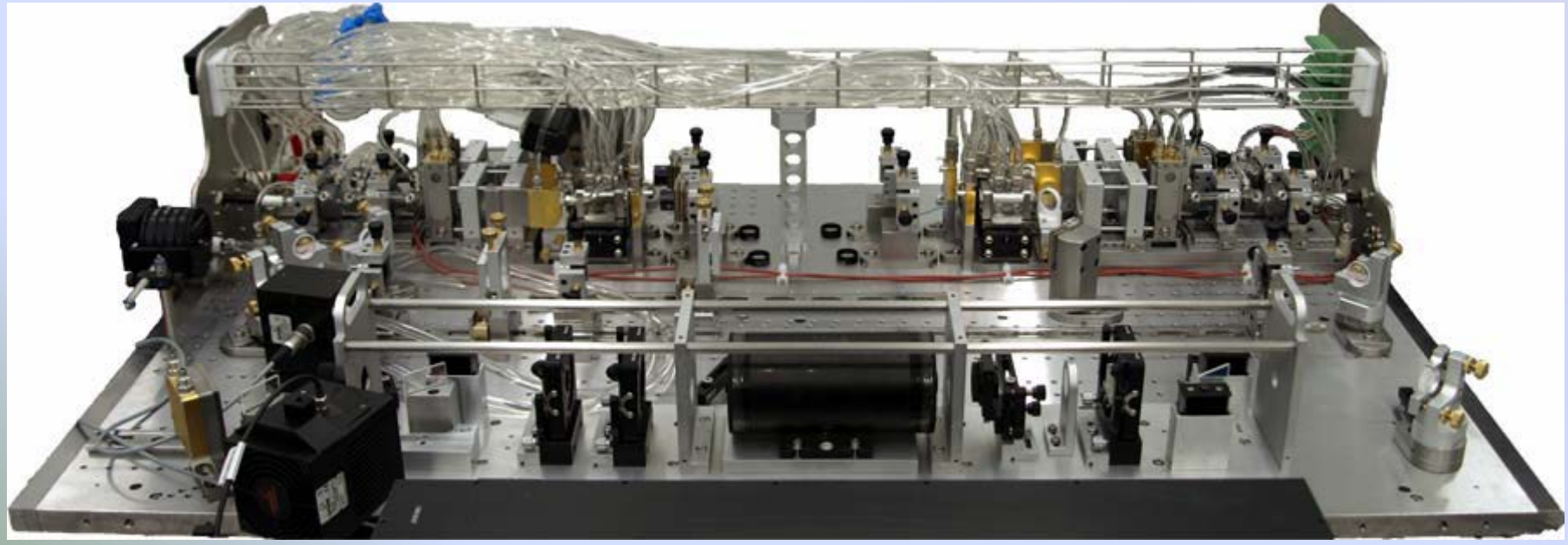


The Advanced LIGO Detector



Advanced LIGO PSL

- Designed and contributed by Albert Einstein Institute
- Higher power: 10W -> 180W
- Better stability
  - 10x improvement in intensity and frequency stability

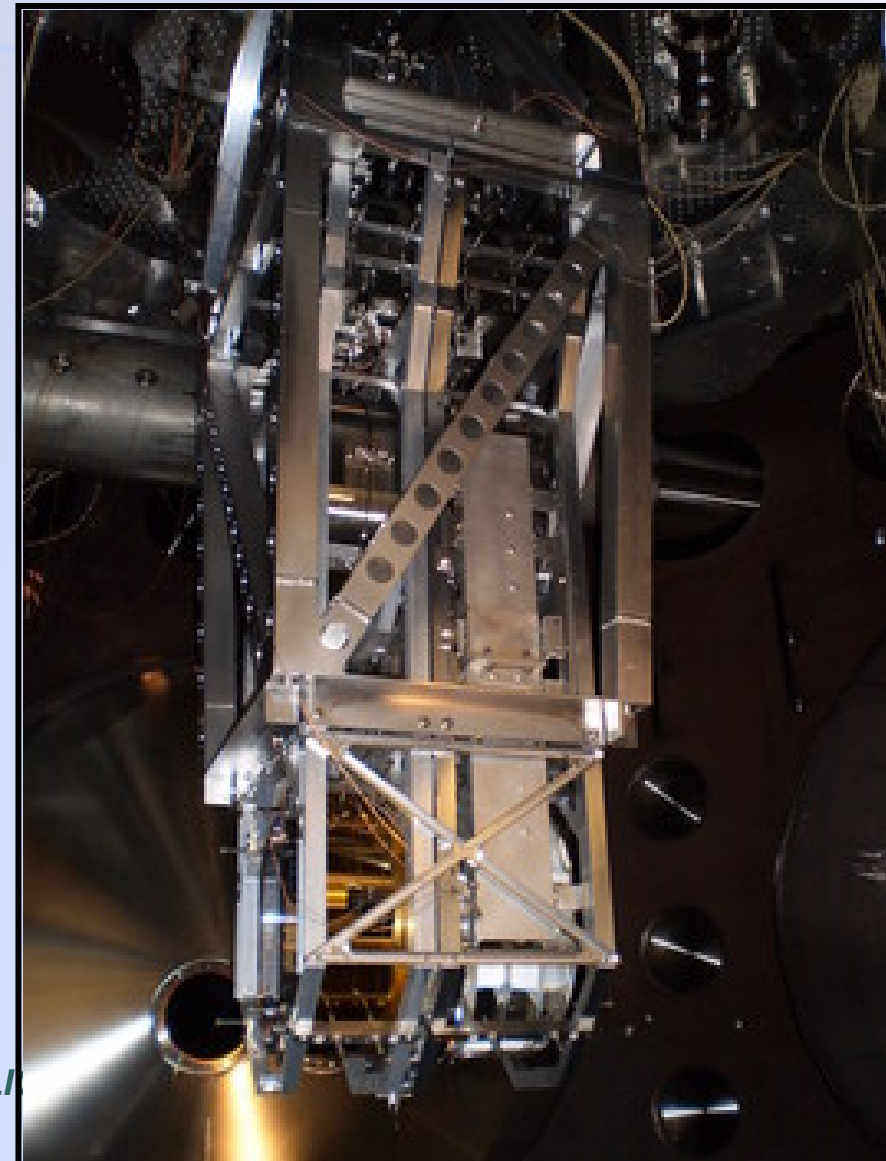


Advanced LIGO Seismic Isolation

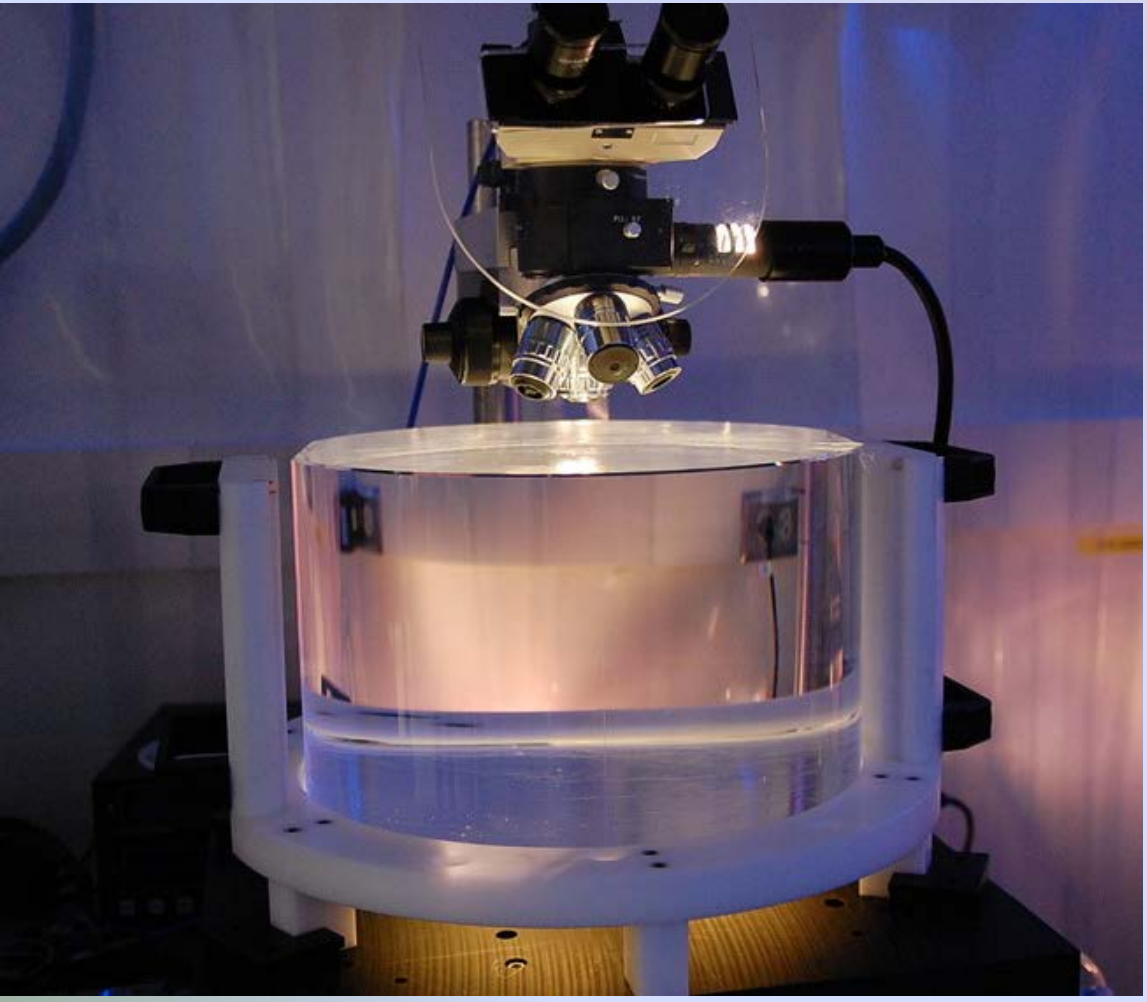
- Two-stage six-degree-of-freedom active isolation
  - Low noise sensors, low noise actuators,
  - Digital control system to blend outputs of multiple sensors, tailor loop for maximum performance

Advanced LIGO Suspensions

- UK designed and contributed test mass suspensions
- Silicate bonds create quasi-monolithic pendulums using ultra-low loss fused silica fibers to suspend interferometer optics
  - Pendulum Q ~10^5 -> ~10^8
- Electrostatic actuators for alignment and length control

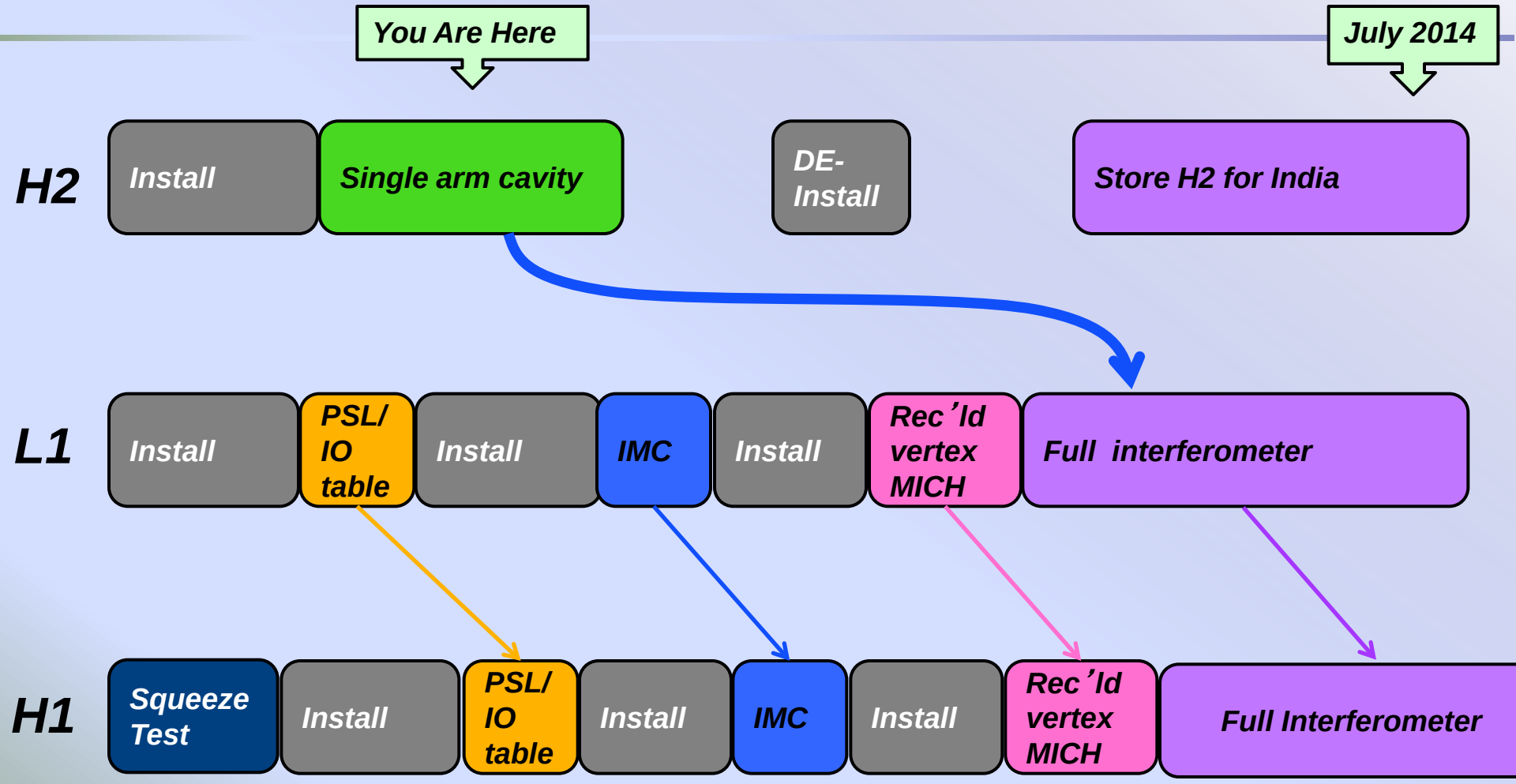


Advanced LIGO Mirrors

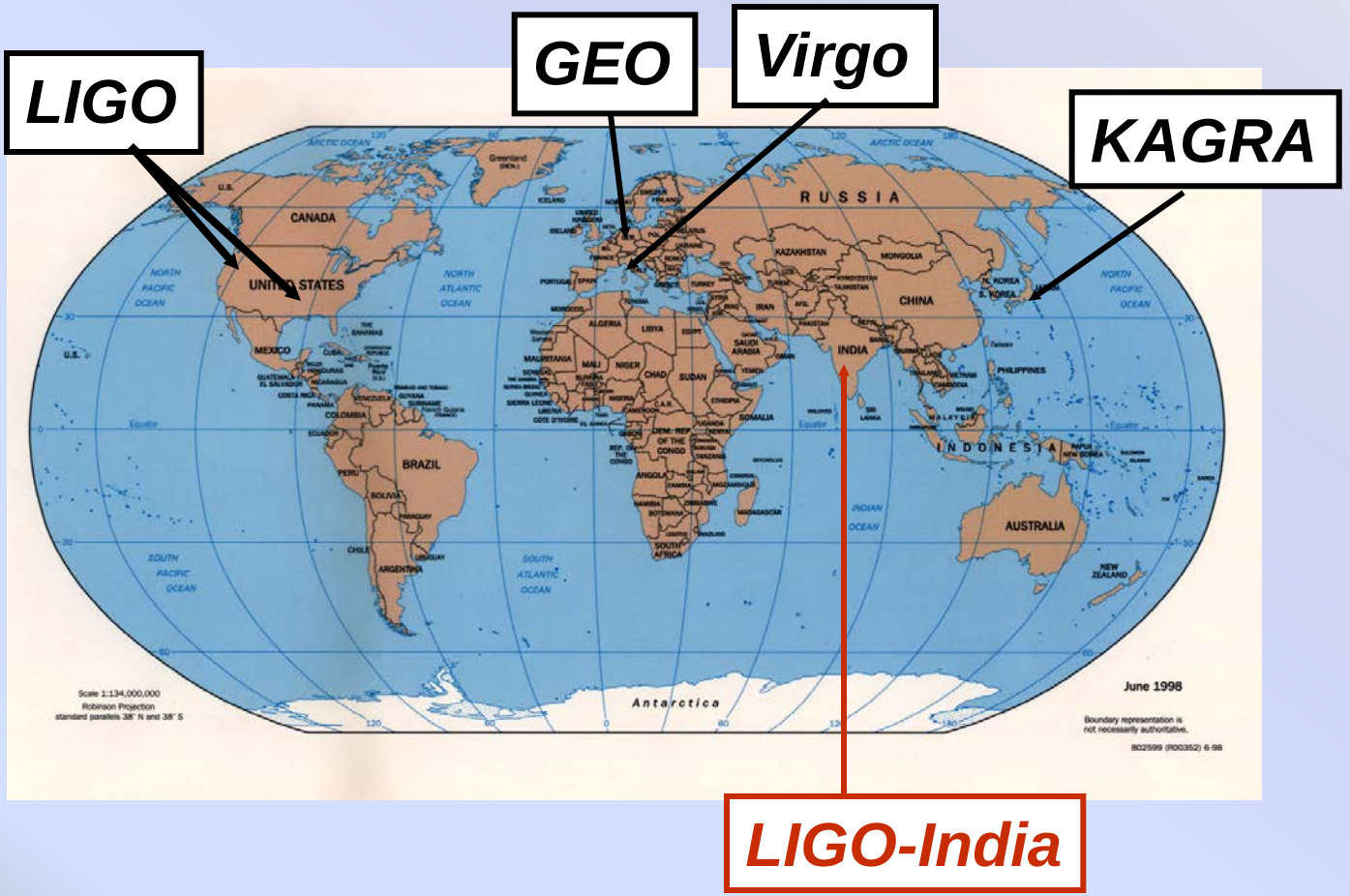


- Larger size
  - 11 kg -> 40 kg
- Smaller figure error
  - 0.7 nm -> 0.35 nm
- Lower absorption
  - 2 ppm -> 0.5 ppm
- Lower coating thermal noise

Current Progress



Global Network



VIRGO

- Virgo
  - European collaboration, located near Pisa
  - Single 3 km interferometer, similar to LIGO in design and specification
  - Advanced seismic isolation system (“Super-attenuator”)
- Advanced Virgo
  - Similar in scope and schedule to Advanced LIGO
- Joint observations with LIGO since May 2007

GEO

- GEO Collaboration
  - GEO as a whole is a member of the LIGO Scientific Collaboration
  - GEO making a capital contribution to Advanced LIGO
- GEO600
  - Near Hannover
  - 600 m arms
  - Signal recycling
  - Fused silica suspensions
- GEO-HF
  - Up-grade underway
  - Pioneer advanced optical techniques

KAGRA

- Project approved July 2010
  - Lead institution: Institute for Cosmic Ray Research
  - Other participants include University of Tokyo, National Astronomical Observatory of Japan, KEK, …
- Key Design Parameters
  - Underground
  - Sapphire test masses cooled to <20K
  - 150W Nd:YAG laser
  - Five stage low frequency (soft) suspension
  - Promises sensitivity similar to Advanced LIGO

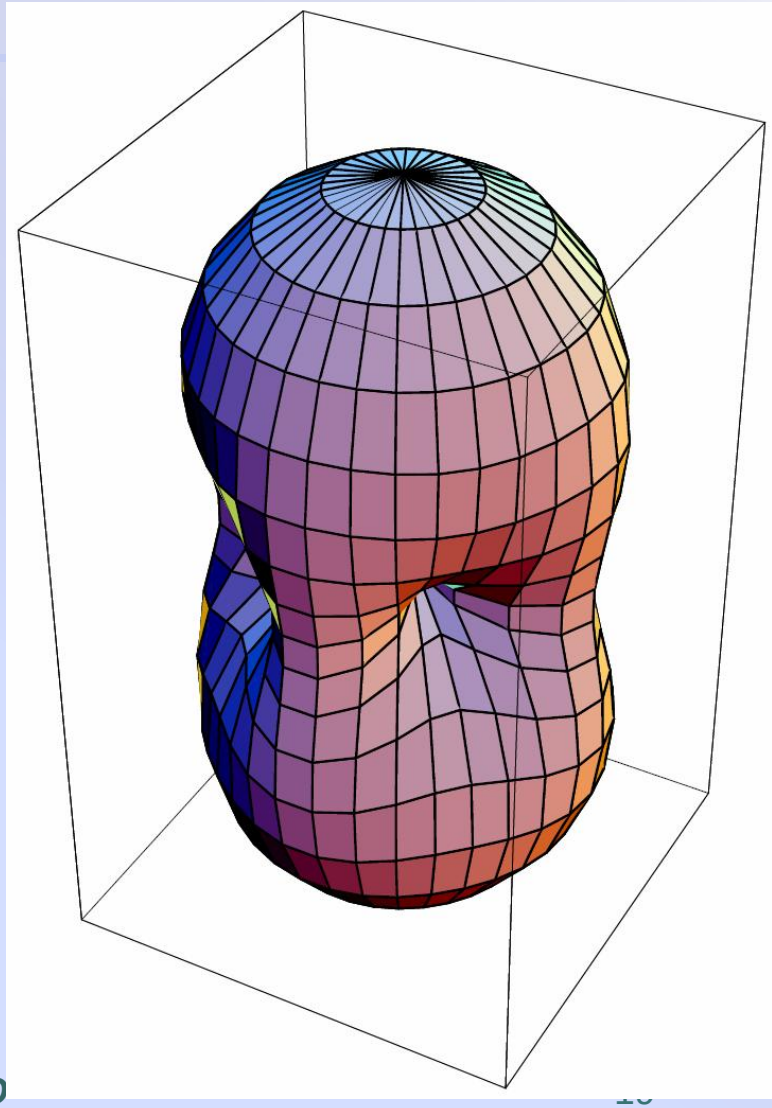
LIGO-India Concept

- A direct partnership between LIGO Laboratory and IndIGO collaboration to build an Indian interferometer
  - LIGO Lab (with its UK, German and Australian partners) provides components for one Advanced LIGO interferometer from the Advanced LIGO project
  - India provides the infrastructure (site, roads, building, vacuum system), “shipping & handling,” staff, installation & commissioning, operating costs
- LIGO-India would be operated as part of LIGO network to maximize scientific impact
- Awaiting formal approval by the Governments

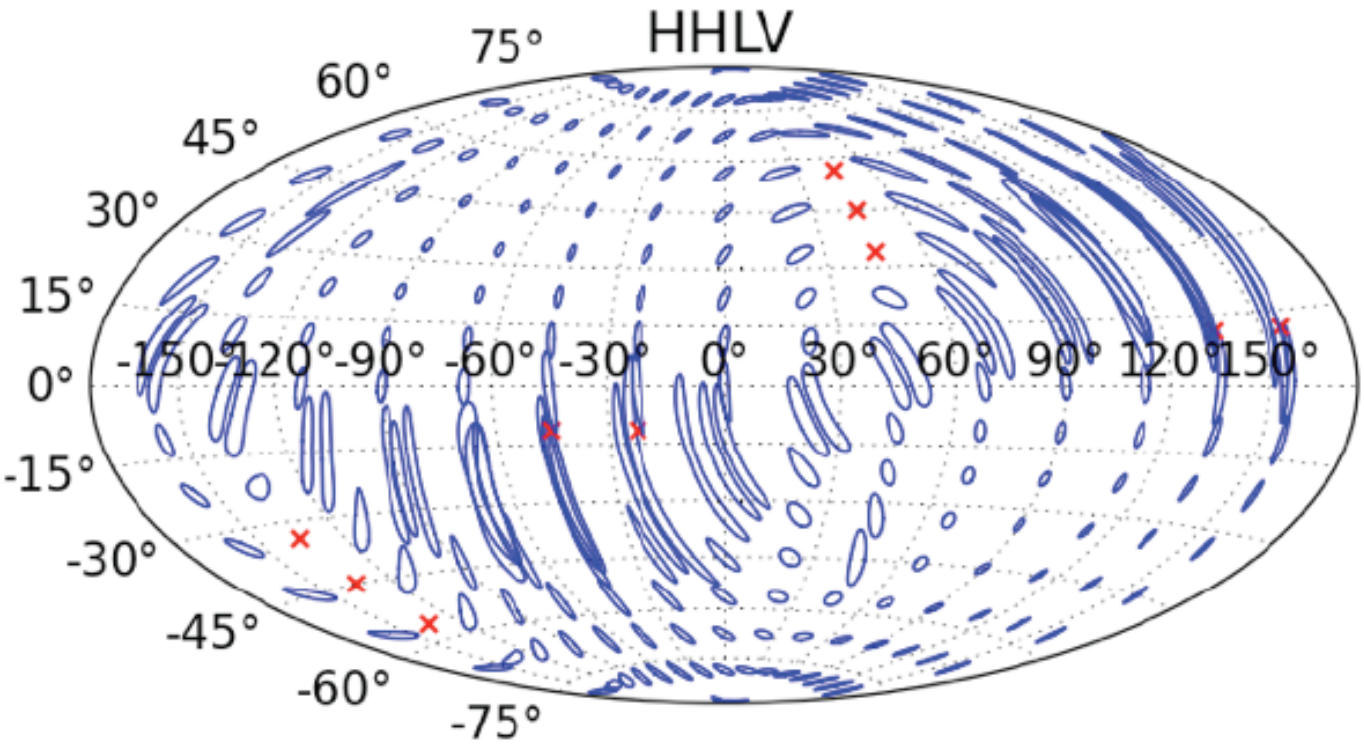
Why a Global Network?

- Source Localization
  - Sky position is determined by triangulation from the arrival times
- Polarization
  - Requires a three dimensional array
- Worldwide coincidence greatly increases confidence

Sky position and polarization measurement are required to extract maximum science!

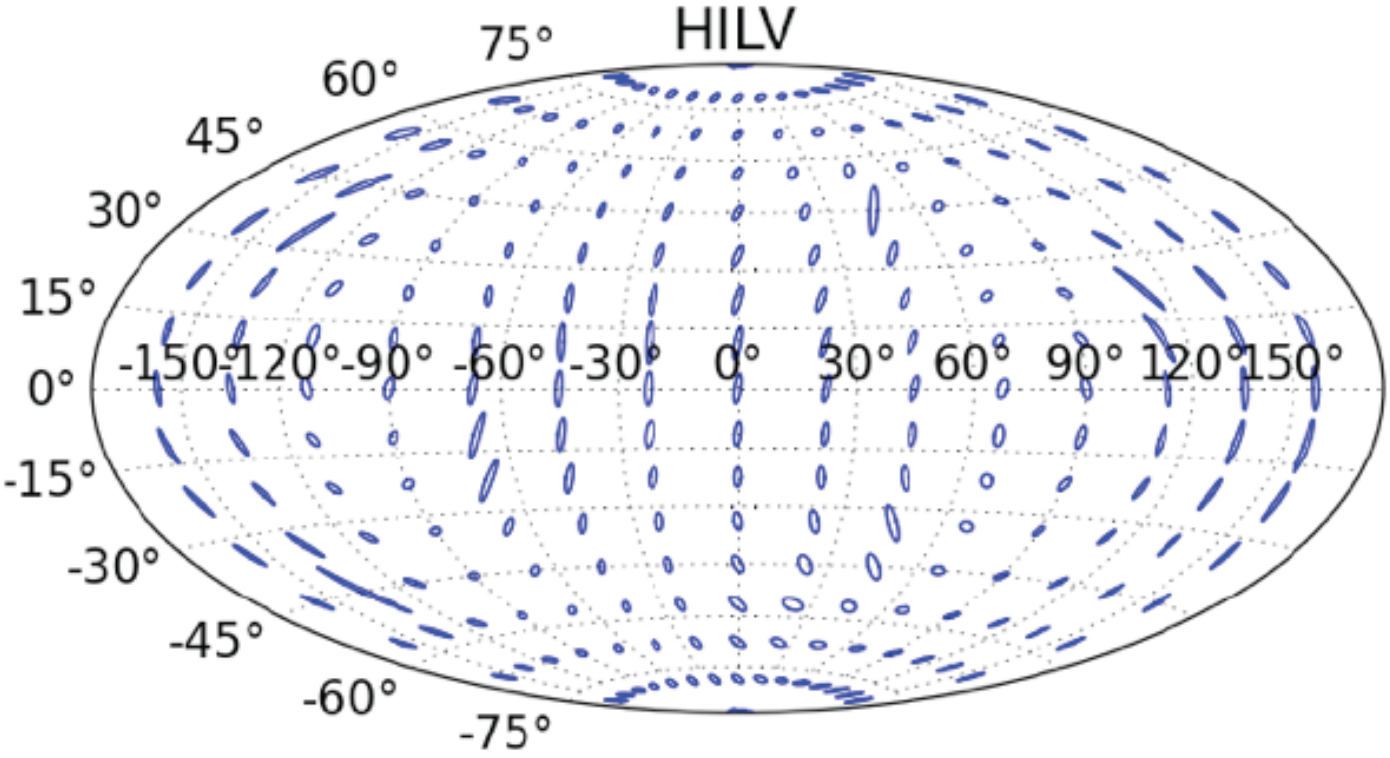


LIGO-Virgo Network



Red crosses denote regions where the network has blind spots

India-LIGO-Virgo Network



LIGO

Final Thoughts

- We are on the threshold of a new era of gravitational wave astrophysics
- First generation detectors have broken new ground in optical sensitivity
  - Initial detectors have proven technique
- Second generation detectors are being installed
  - Will expand the “Science” (astrophysics) by factor of 1000
- In the next decade, emphasis will be on the *network*
  - Groundwork has been laid for operation as a worldwide network
  - India could play a key role