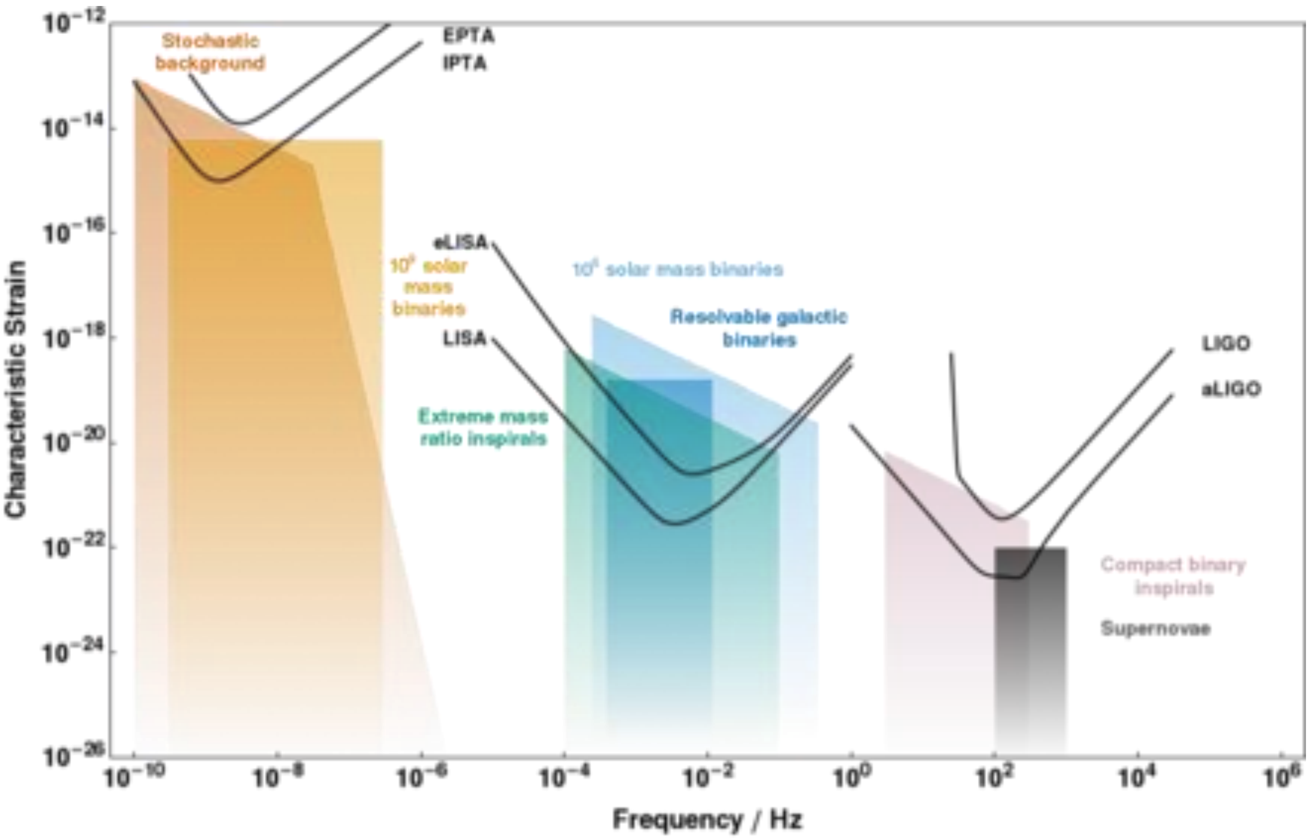
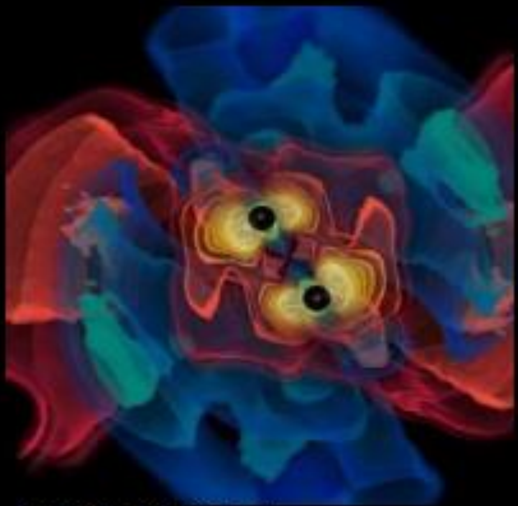
GW Policy:

The Future: G3 Detectors



Barry C Barish
LIGO Laboratory
1-Sept-2017

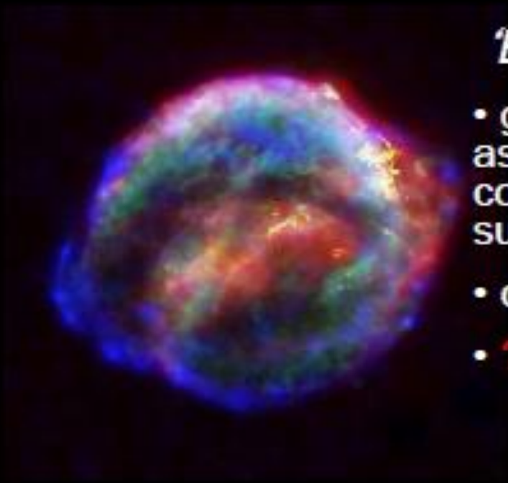
Context of G3: Where will we be?



Credit: AEI, CCT, LSU

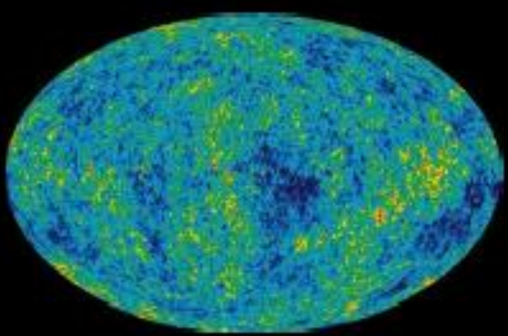
Coalescing Binary Systems

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



'Bursts'

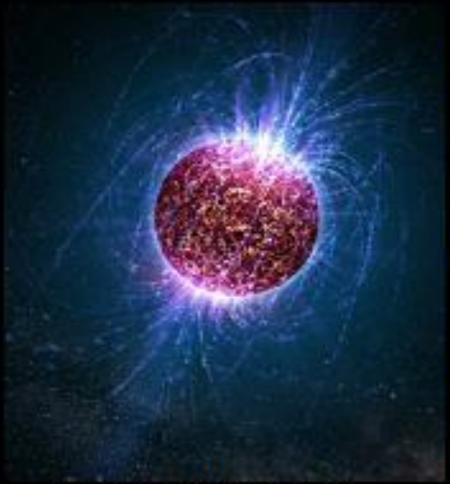
- galactic asymmetric core collapse supernovae
- cosmic strings
- ???



NASA/WMAP Science Team

Stochastic GWs

- Incoherent background from primordial GWs or an ensemble of unphased sources
- primordial GWs unlikely to detect, but can bound in the 10-10000 Hz range



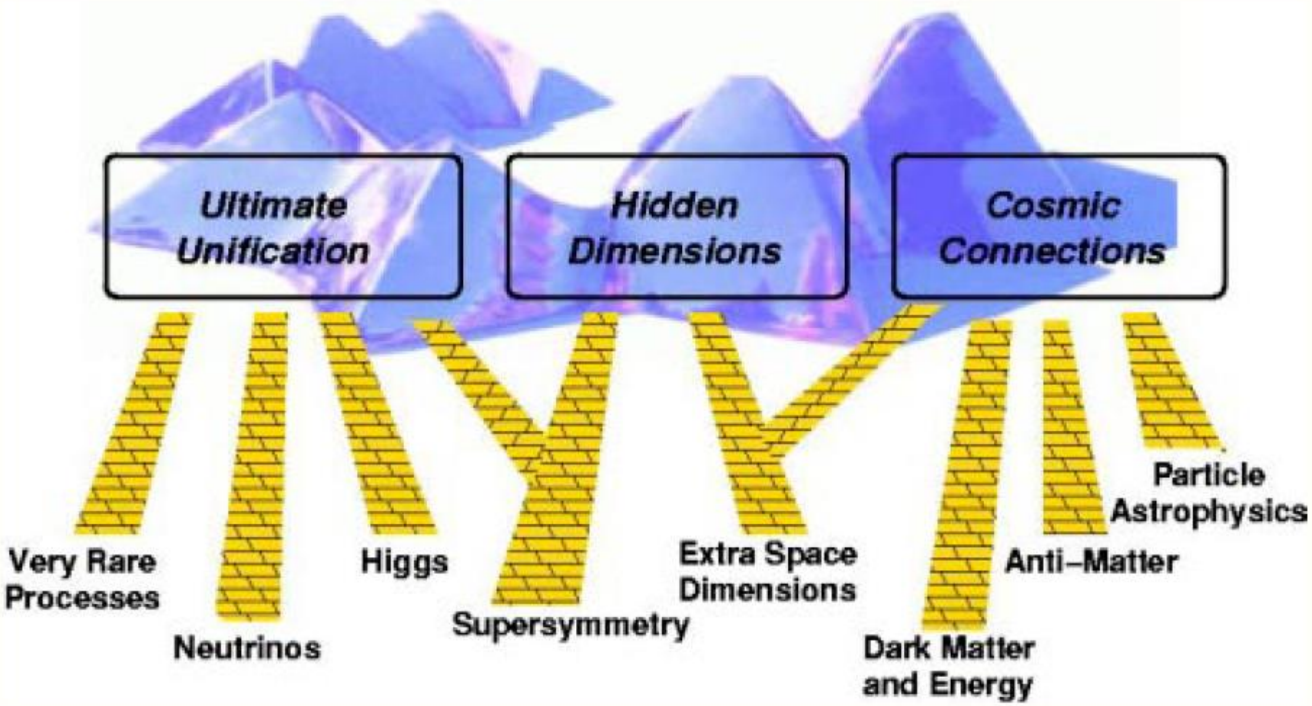
Casey Reed, Penn State

Continuous Sources

- Spinning neutron stars
- probe crustal deformations, 'EOS, quarki-ness'

Particle Physics

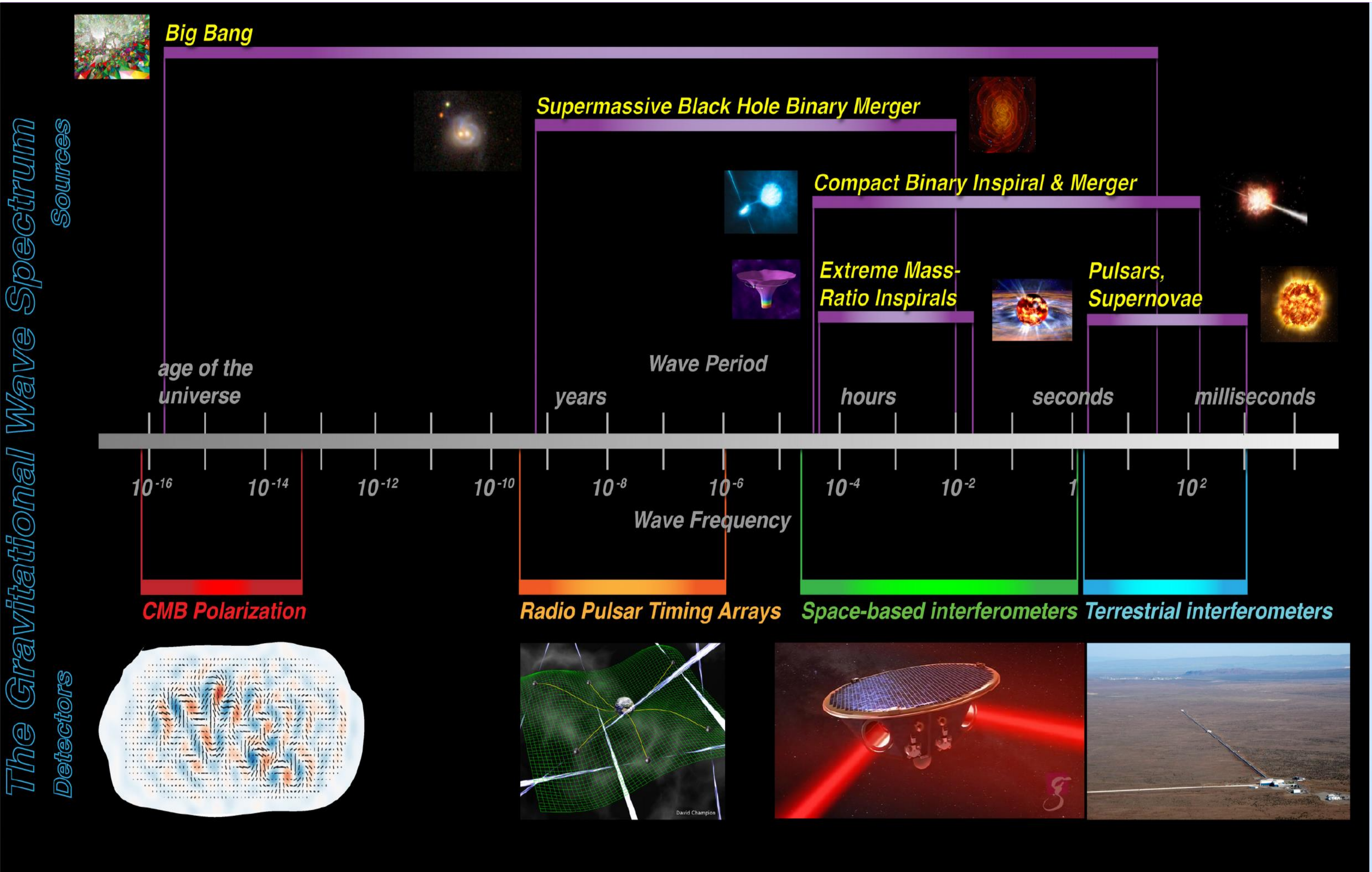
The Science of Matter, Energy, Space and Time



The Paths and Goals of Particle Physics

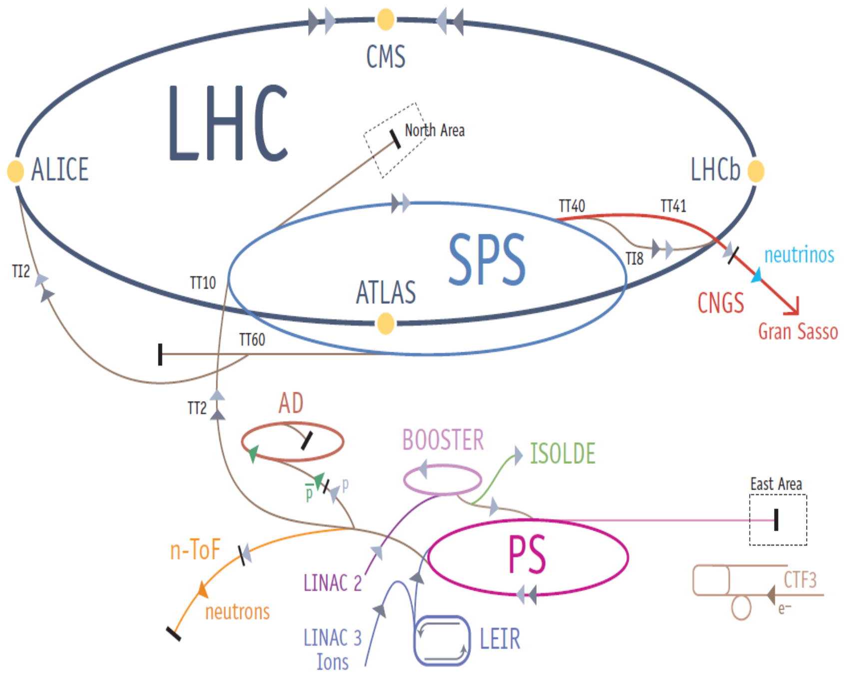
LIGO

Gravitational Waves

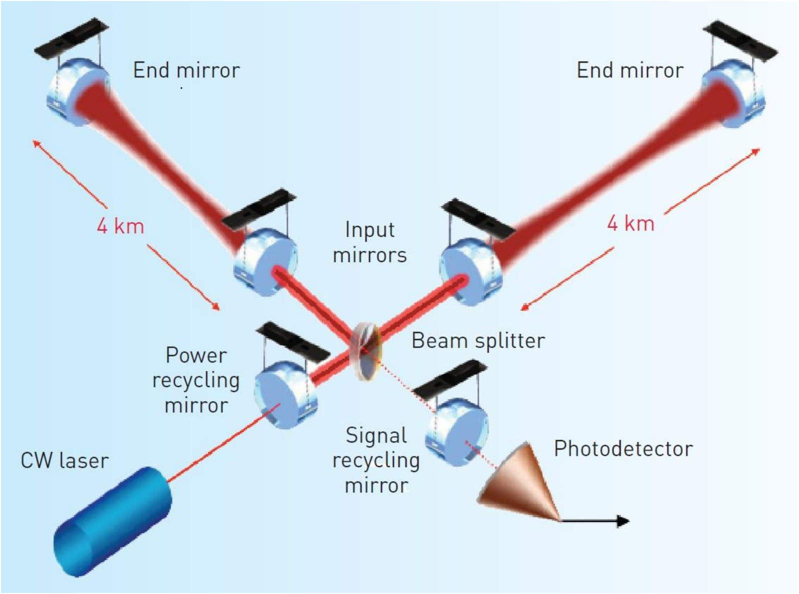


Primary Tools

Particle Physics
Accelerators



Gravitational Waves
Interforometers



General Structures

- IUPAP / C11 – ICFA
- Community ~ 10 K
- Theory / Experiment
- Large Facilities
- Accelerator R&D

- 'Closed' Scientific Collaborations
- Multiple Instruments for 'Confirmation'

- IUPAP / GWIC
- Community ~ 1.5 K
- Theory / Experiment
- Large Facilities
- Interferometer R&D

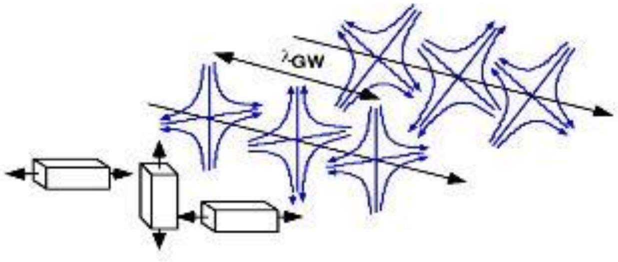
- 'Open' Scientific Collaborations
- Multiple Instruments for 'Scientific Capability'

Einstein's Theory of Gravitation
Gravitational Waves

- Using Minkowski metric, the information about space-time curvature is contained in the metric as an added term, $h_{\mu\nu}$. In the weak field limit, the equation can be described with linear equations. If the choice of gauge is the *transverse traceless gauge* the formulation becomes a familiar wave equation

$$(\nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2})h_{\mu\nu} = 0$$

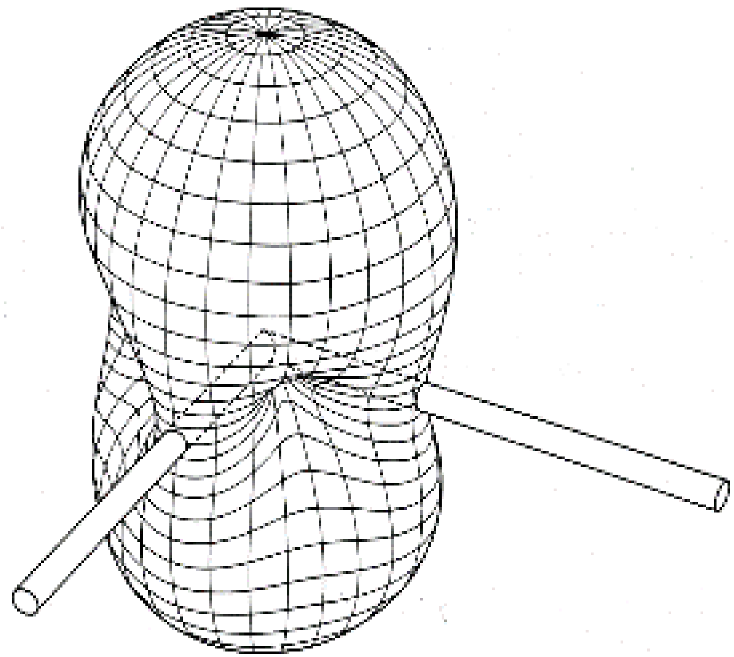
- The strain $h_{\mu\nu}$ takes the form of a plane wave propagating at the speed of light (c).



- Since gravity is spin 2, the waves have two components, but rotated by 45^0 instead of 90^0 from each other.

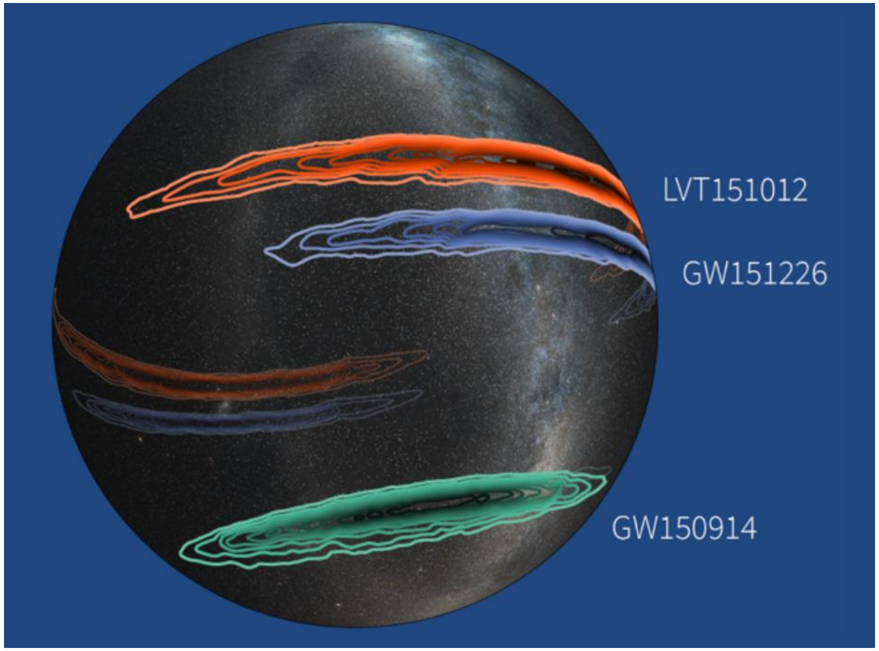
$$h_{\mu\nu} = h_+(t - z/c) + h_x(t - z/c)$$

Source Localization Using Time-of-flight

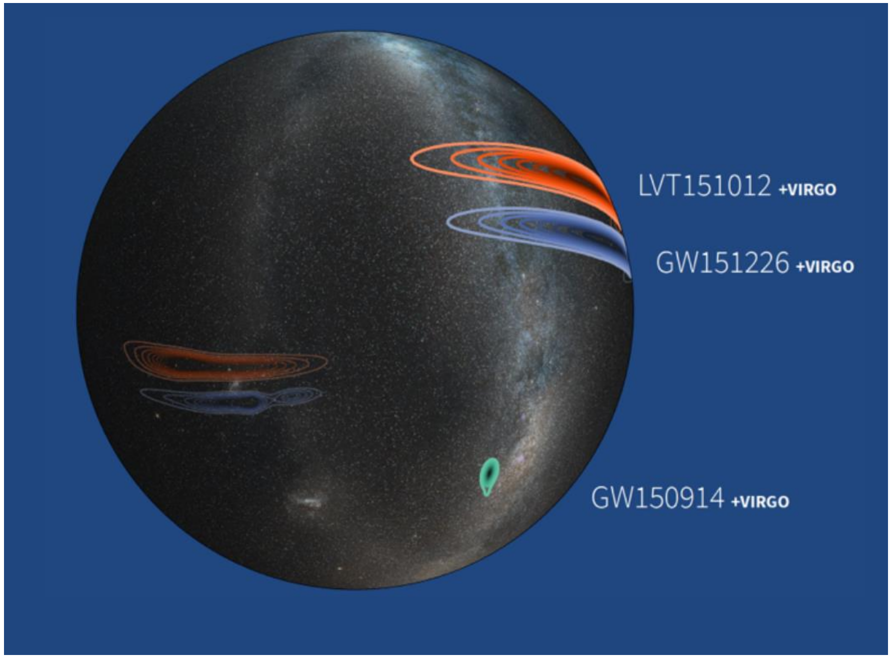


- LIGO detectors are nearly omni-directional
  - Individually they provide almost no directional information
- Array working together can determine source location using timing and amplitudes

Localization LIGO O1 Events

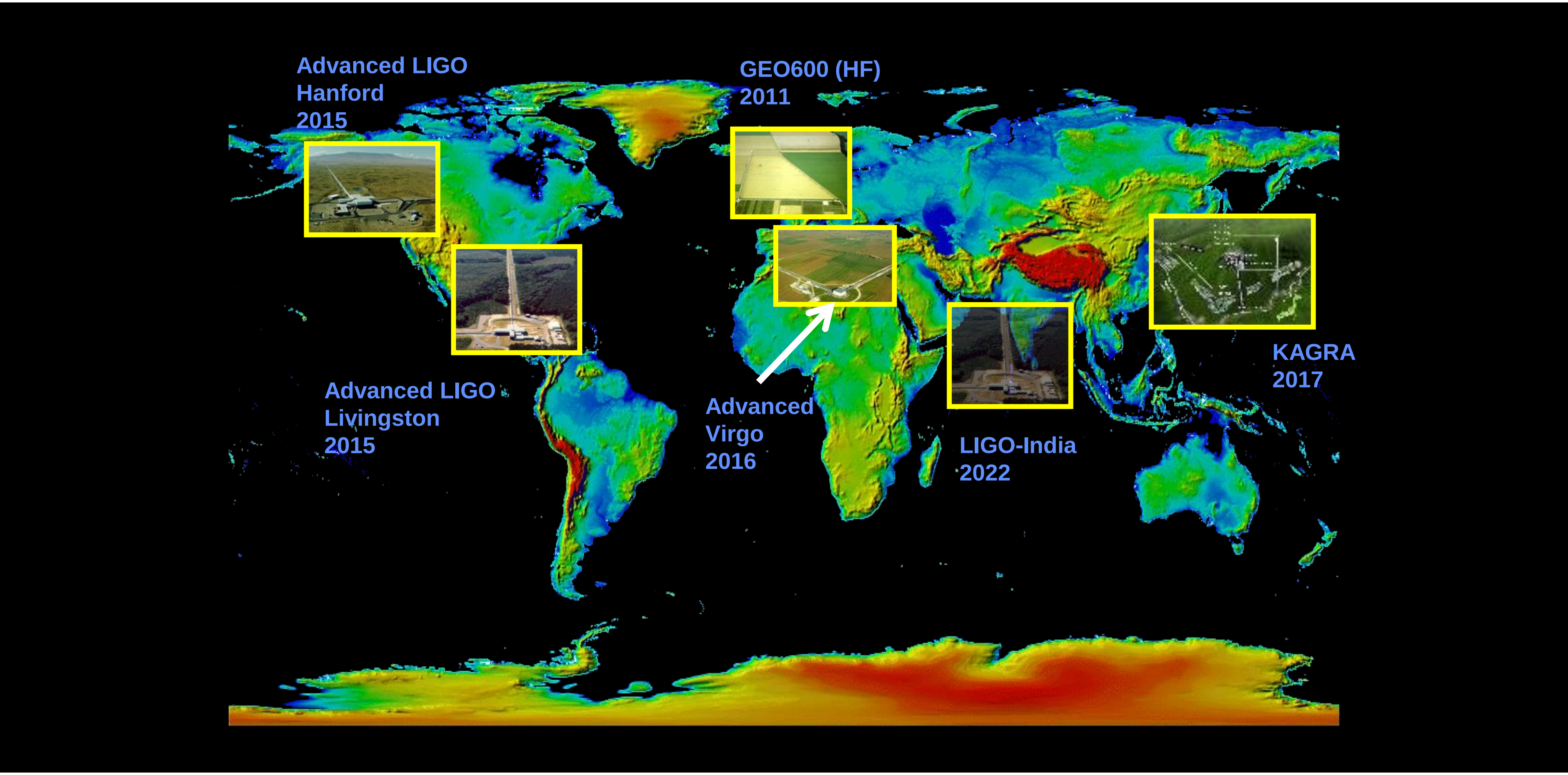


for GW150914: Astrophys. J. Lett. 826, L13 (2016)

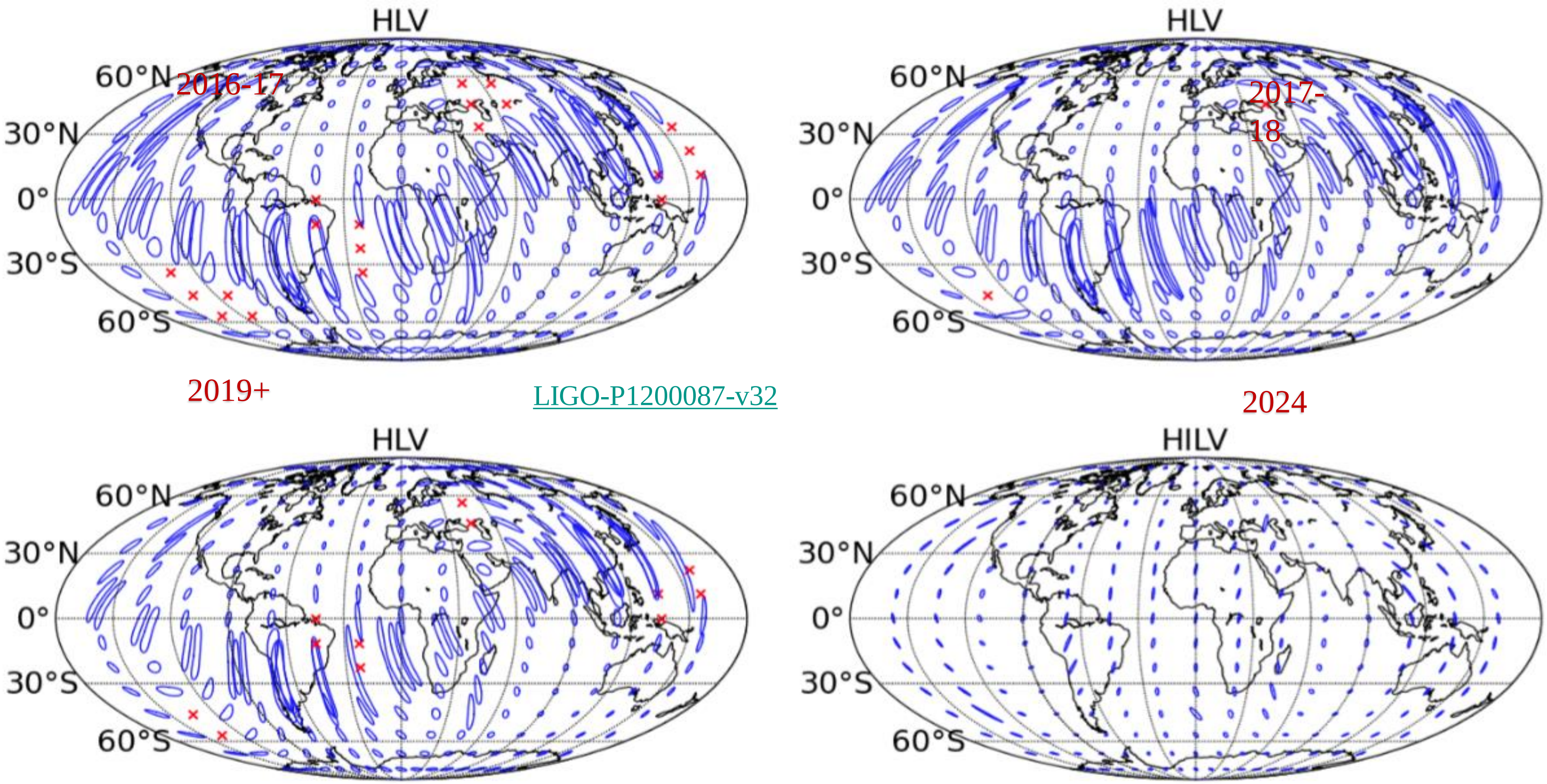


Simulation for 3rd detector at Virgo location with LIGO O1 sensitivity

GW detector network: 2015-2025



Improving Localization



G3: Some Big Issues

Science Motivations and Goals

- GWIC Committee (must be done in the context of projected G2)

Science Goals → Technical Performance

- Frequency vs Sensitivity Goals?
- Network Performance Goals (e.g. Pointing Accuracy)?

Strategic Issues

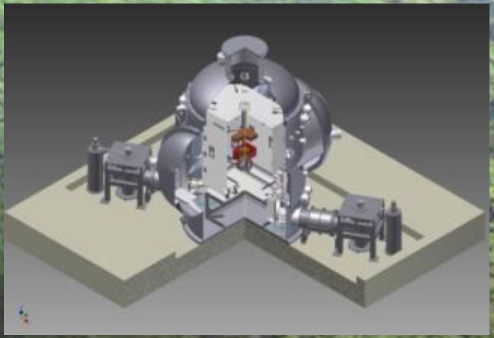
- How many G3 Detectors are required?
- Features/Priorities: Sensitivity vs Frequency; Polarization; Network
- G3 Detectors: Identical or Different?
- How Internationally Organized/Funded/Implemented?
  - Present GW Model: "Collaboration of Collaborations?"
  - Globally Organized, like ILC, SKA?
  - Global w/ Strong Host, like CERN LHC, DUNE?
  - 'Limited' Partnerships, like ALMA, LSST, TMT?

KAGRA

Kamioka Mine

- **Technologies crucial for next-generation detectors;**
- **KAGRA can be regarded as a 2.5-generation detector.**

Cryogenic Mirror



Underground

GWIC – 3G Science Case

CONSTITUTION OF SCIENCE TEAM

- composed of experts relevant to areas of gravitational-wave physics and astronomy
  - experiment/instrument
  - gravitational wave data analysis and science
  - compact binary systems of neutron stars and black holes
  - equation-of-state of extremely high-density matter and neutron star structure
  - cosmology (early Universe, BH seeds, etc.)
  - astrophysics (binary formation and evolution, gamma-ray astronomy, black hole properties, EM afterglows, supernova …)
  - strong field tests of GR

The GWIC Committee

3G SCIENCE CASE TEAM

- 18 members in all including 2 co-chairs
- Matthew Bailes <mbailes@swin.edu.au>
- Marie Anne Bizouard <mabizoua@lal.in2p3.fr>
- Alessandra Buonanno <alessandra.buonanno@aei.mpg.de>
- Adam Burrows <burrows@astro.princeton.edu>
- Monica Colpi <Monica.Colpi@mib.infn.it>
- Matt Evans <mevans@ligo.mit.edu>
- Stephen Fairhurst <FairhurstS@cardiff.ac.uk>
- Stefan.Hild <stefan.hild@glasgow.ac.uk>
- Vicky Kalogera (Co-chair) <vicky@northwestern.edu>
- Mansi M. Kasliwal <mansi@astro.caltech.edu>,
- Luis Lehner <llehner@perimeterinstitute.ca>
- Ilya Mandel <imandel@star.sr.bham.ac.uk>
- Vuk Mandic <mandic@physics.umn.edu>
- Marialessandra Papa <maria.alessandra.papa@aei.mpg.de>
- Sanjay Reddy <sareddy@u.washington.edu>
- Stephan Rosswog <stephan.rosswog@astro.su.se>
- B.S. Sathyaprakash (Co-chair) <bss25@psu.edu>
- Chris Van Den Broeck <vdbroeck@nikhef.nl>

Top Level Science Questions

SOME KEY QUESTIONS THAT MOTIVATE THE SCIENCE CASE

- how and when did black holes at the centre of nuclei form and evolve?
- what is the nature of dynamical spacetime?
- are astronomical black holes the same as black holes of general relativity?
- what is the nature of matter under extreme conditions of density, pressure and temperature?
- what is the physics of supernova and other powerful events in the universe?

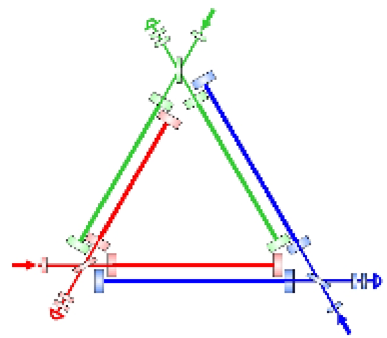
Einstein Telescope

Mature 3G Concept

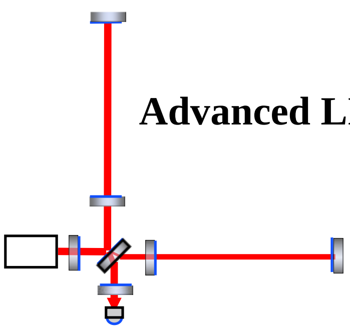
The Einstein Telescope: x10 aLIGO

- Deep Underground;
- 10 km arms
- Triangle (polarization)
- Cryogenic
- Low frequency configuration
- high frequency configuration

Einstein Telescope 10 km



Advanced LIGO



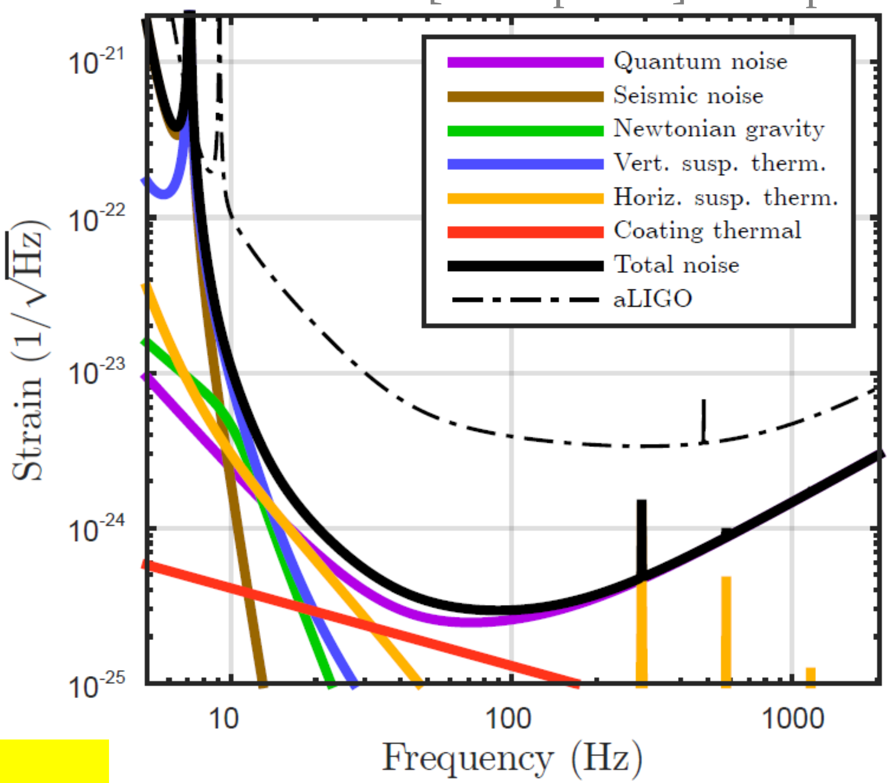
Cosmic Explorer

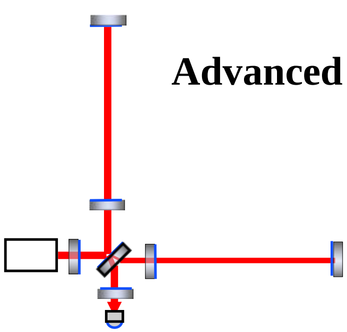
Preliminary Concept

The Cosmic Explorer: x10 aLIGO

- Earth's Surface;
- 40 km arms
- Advanced LIGO Technology +
- Squeezed Light

arXiv:1607.08697v3 [astro-ph.IM] 11 Sep 2016





3G R&D Critical r & D

Initial / Adv LIGO/Virgo Technical Developments

- » Fabry-Perot arm cavities
- » Laser stabilization
- » Diode-pumped Nd:YAG lasers
- » Supermirrors (polishing and coatings)
- » Multi-stage active seismic isolation
- » Fused silica suspensions
- » Digital control systems

3G -- New Technical Developments:

- » Longer arms
- » Squeezed quantum states
- » Lower thermal noise coatings
- » Low noise cryogenics
- » Newtonian noise cancellation
- » Adaptive controls

Next Steps (~5 years)

- Science Case (GWIC study + …..)
  - Top-level Technical Requirements and priorities
- Detector Concepts (ET, CE or ??)
  - Based on technical requirements set by Science Case
- Global Concept for "3G"
  - How many detectors? How different??
  - Define required technology R&D needed
  - Estimate costs (minimal system, options, etc)
  - Define global organization or coordination
- Politics:
  - Other physicists / scientists; public; funding agencies
- Submit Funding Proposal(s)