LIGO-India: An introduction

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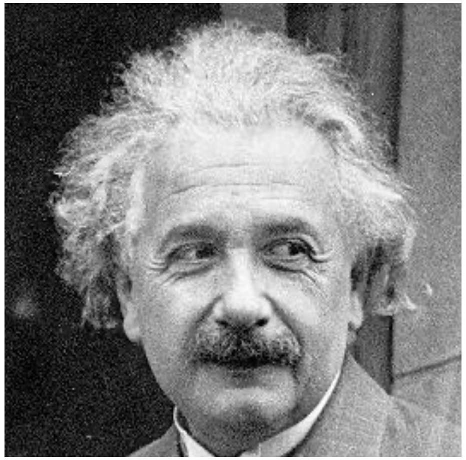
General theory of relativity: What is gravity?

Isaac Newton described the properties of gravity:

- It acts between all objects that have mass
- Its strength depends on the amount of mass and the distance between the objects
- **Gravity causes things to accelerate, so it must be a force**

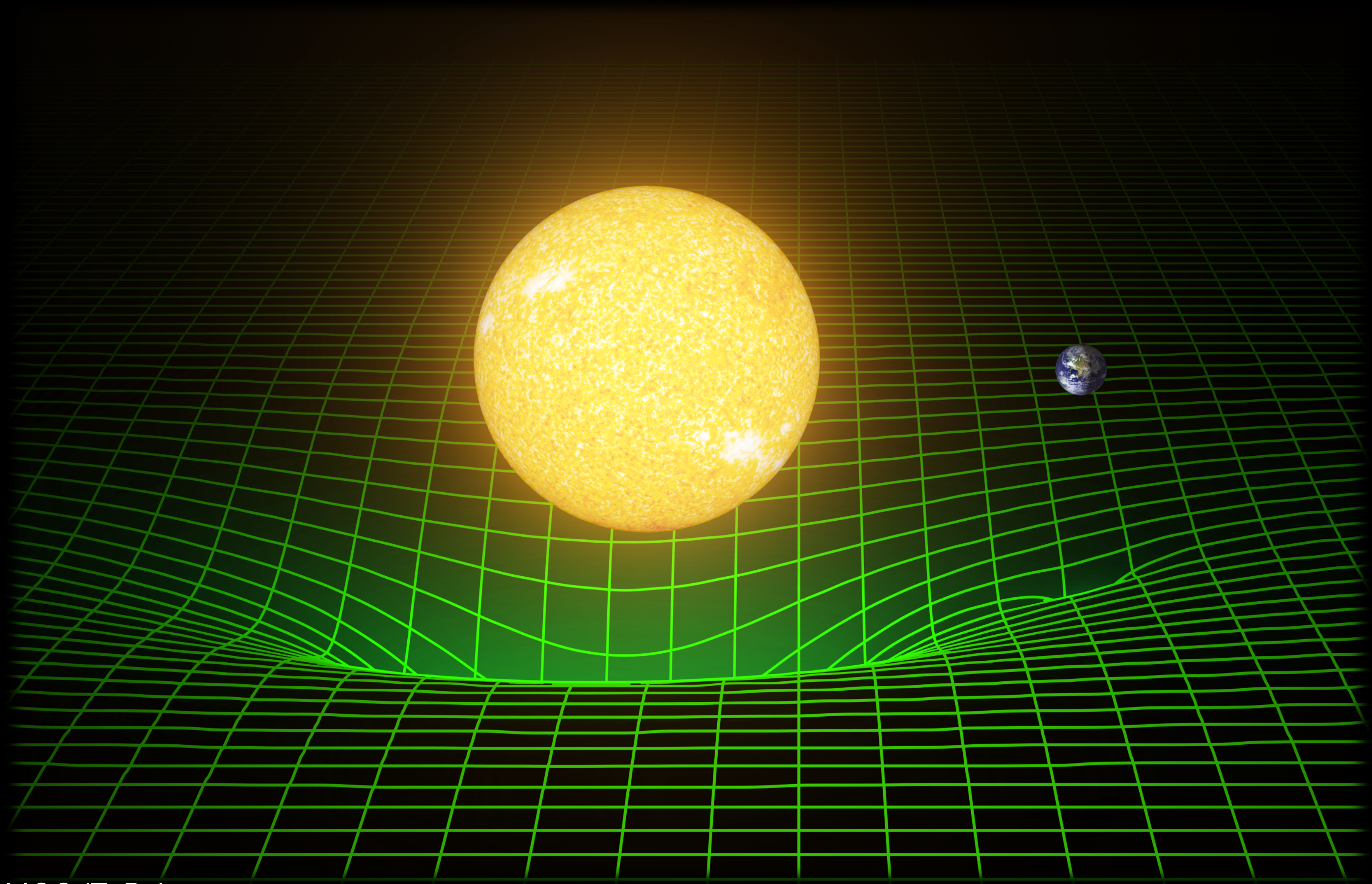


Albert Einstein realised that space and time must be fundamentally connected for the laws of physics to be self-consistent ⇒ ***spacetime***

His 1915 **general theory of relativity** says that gravity is really ***curvature** in the geometry of spacetime*, caused by the presence of mass

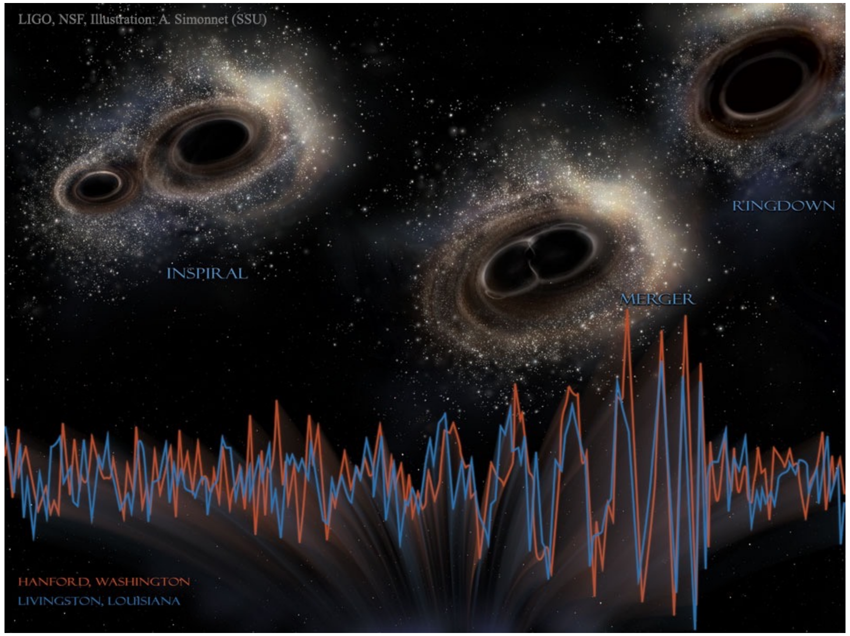
- **Gravity is not a force!**
- Things naturally move along “straight” paths in the curved spacetime

Gravity:
Curved Spacetime



Credit: LIGO/T. Pyle

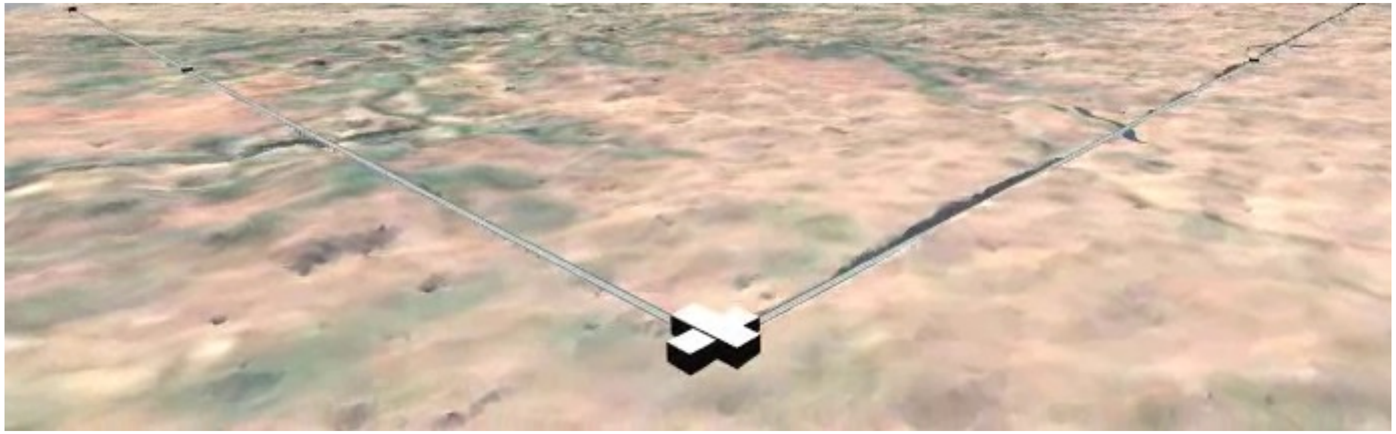
Gravitational Waves



40 authors from Indian institutions in discovery paper

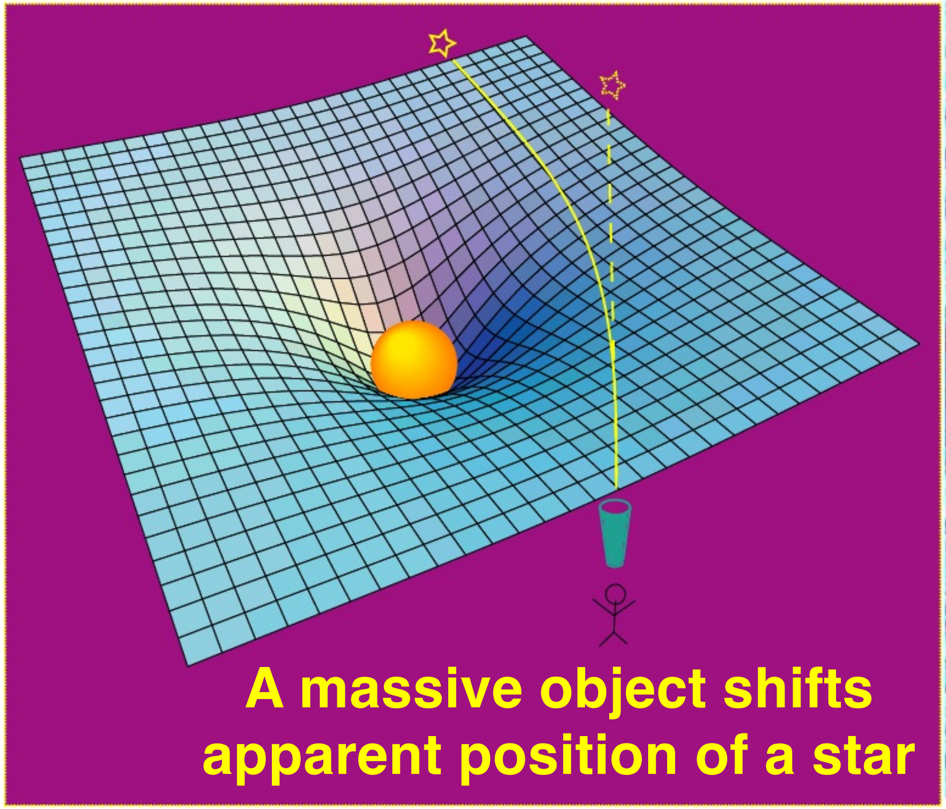
Detection of Gravitational Waves received the top awards in science, marking a glorious beginning of Gravitational Wave Astronomy

LIGO
INDIA



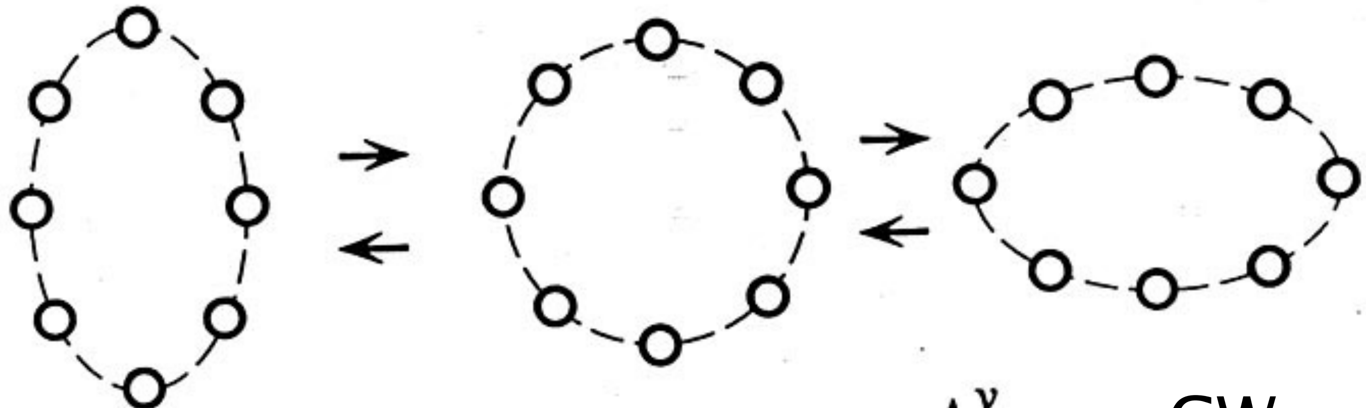
LIGO-India is a great opportunity for science, human resource development and technology spin-offs.

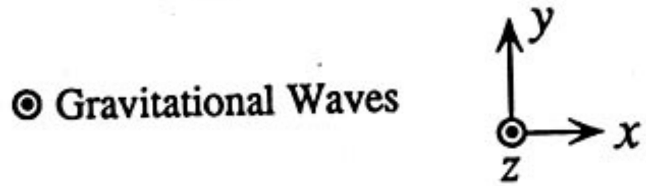
Einstein's General Relativity changed our view of space and time



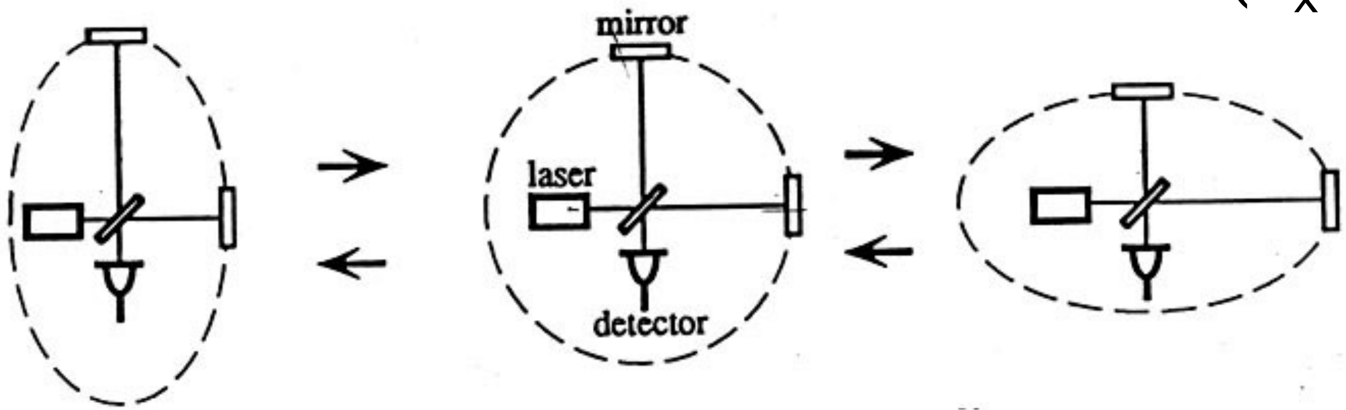
Empty space and time have real physical properties.
Space has shape, stiffness and a maximum speed for information transfer

Basic idea for gravitational wave detection





GW
amplitude h
= $(R_x - R_y)/R$

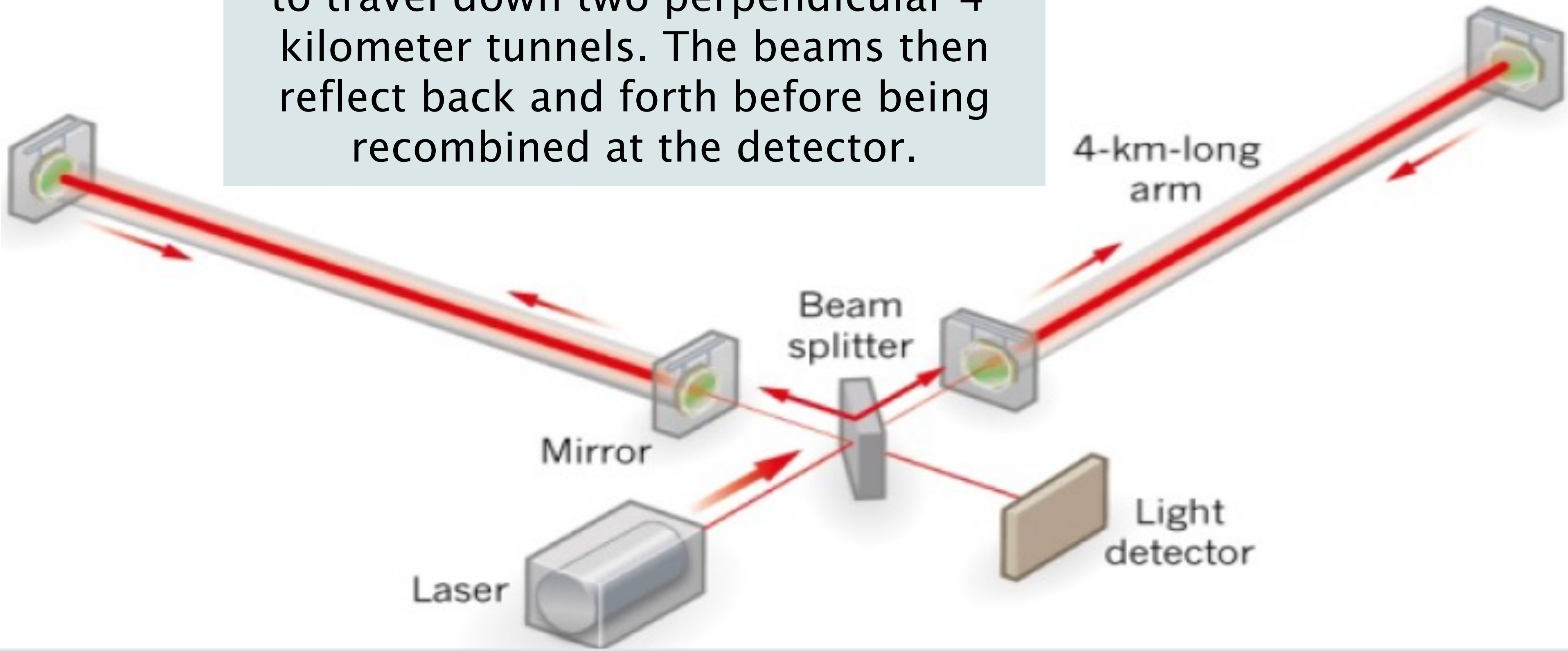


Spatial asymmetry induces relative phase shifts on light in arms

LIGO

(Laser Interferometer Gravitational-Wave Observatory

In a LIGO facility, a laser beam is split to travel down two perpendicular 4-kilometer tunnels. The beams then reflect back and forth before being recombined at the detector.

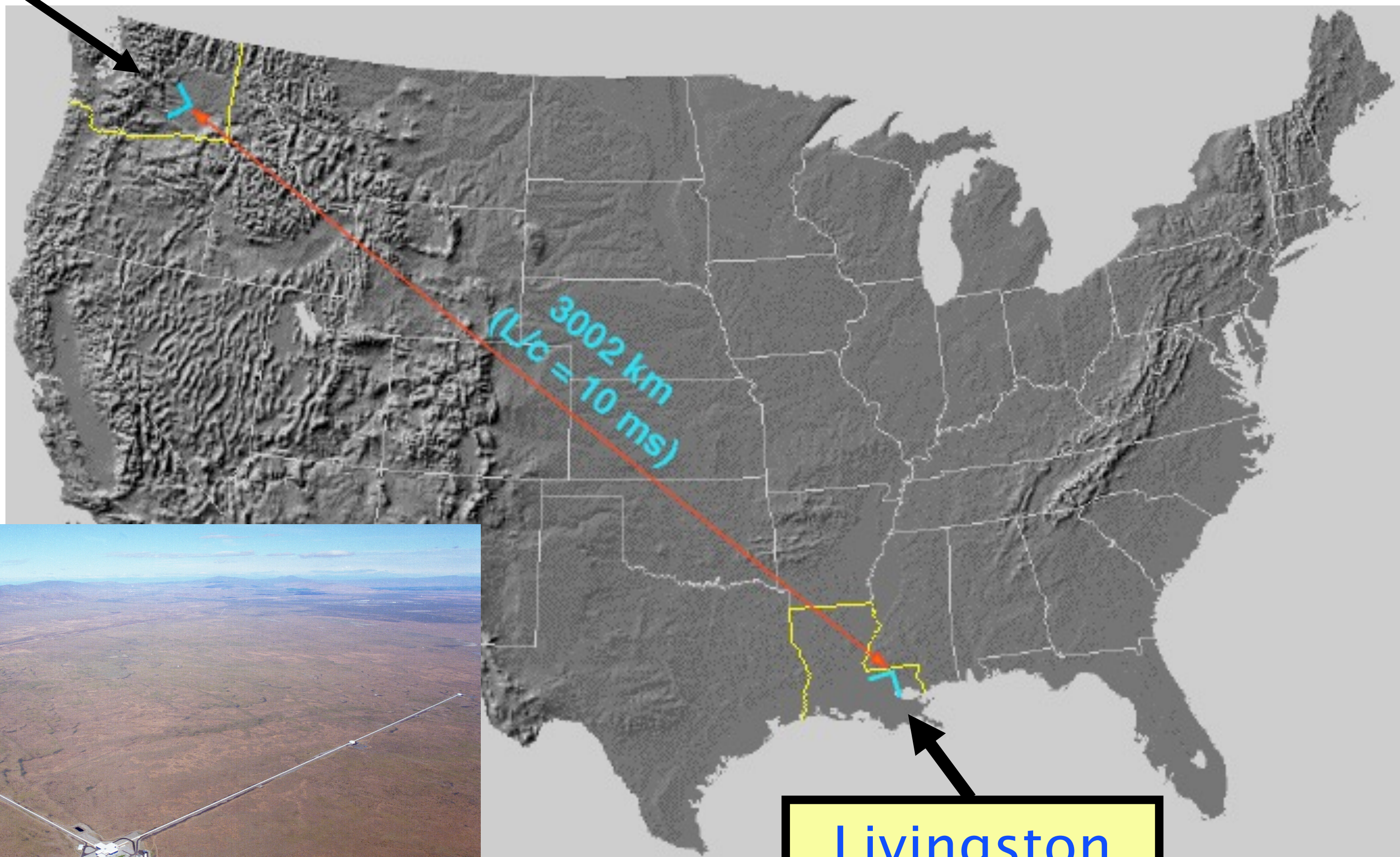


When a gravitational wave passes LIGO, the tunnels deform slightly and the distance travelled by each beam changes so that they no longer cancel out. This produces a measurable signal at the detector.

Expected deformation=10^{-18} **m for 4 km arms.**

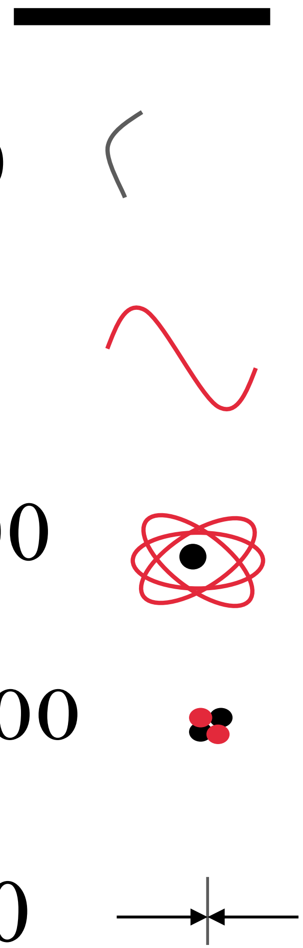
The two current LIGO Observatories

Hanford Observatory



Livingston Observatory

LIGO Measures displacements of 10^{-18} Metre: how small is it?



One metre

÷10,000 — Human hair, about 100 microns

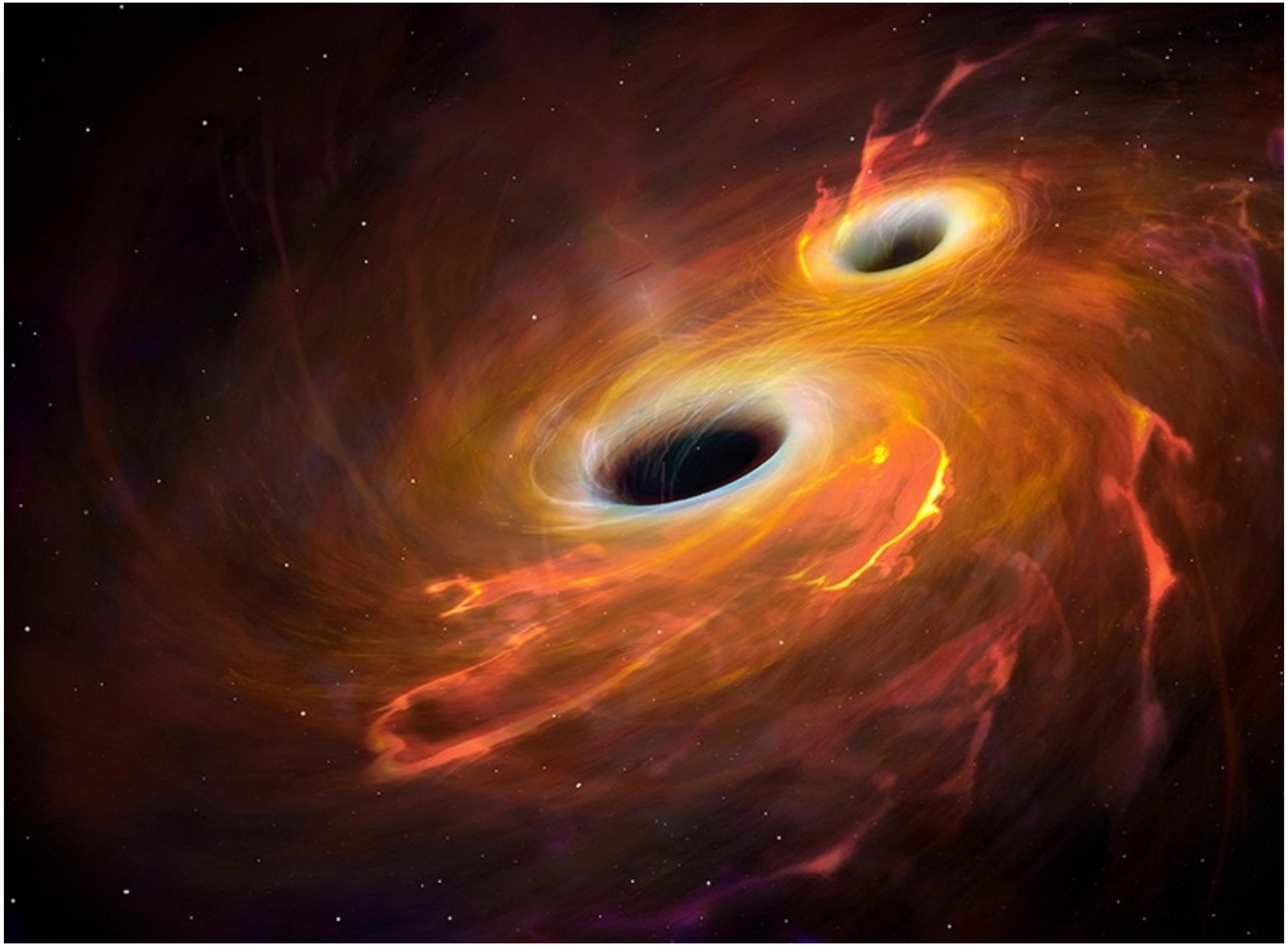
÷100 — Wavelength of light, about 1 micron

÷10,000 — Atomic diameter, 10^{-10} metre

÷100,000 — Nuclear diameter, 10^{-15} metre

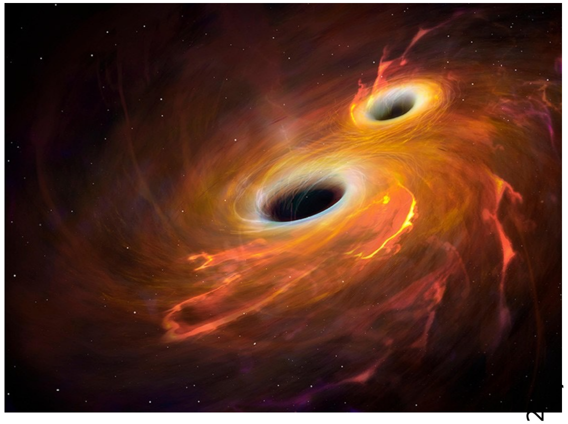
÷1,000 — LIGO sensitivity, 10^{-18} metre

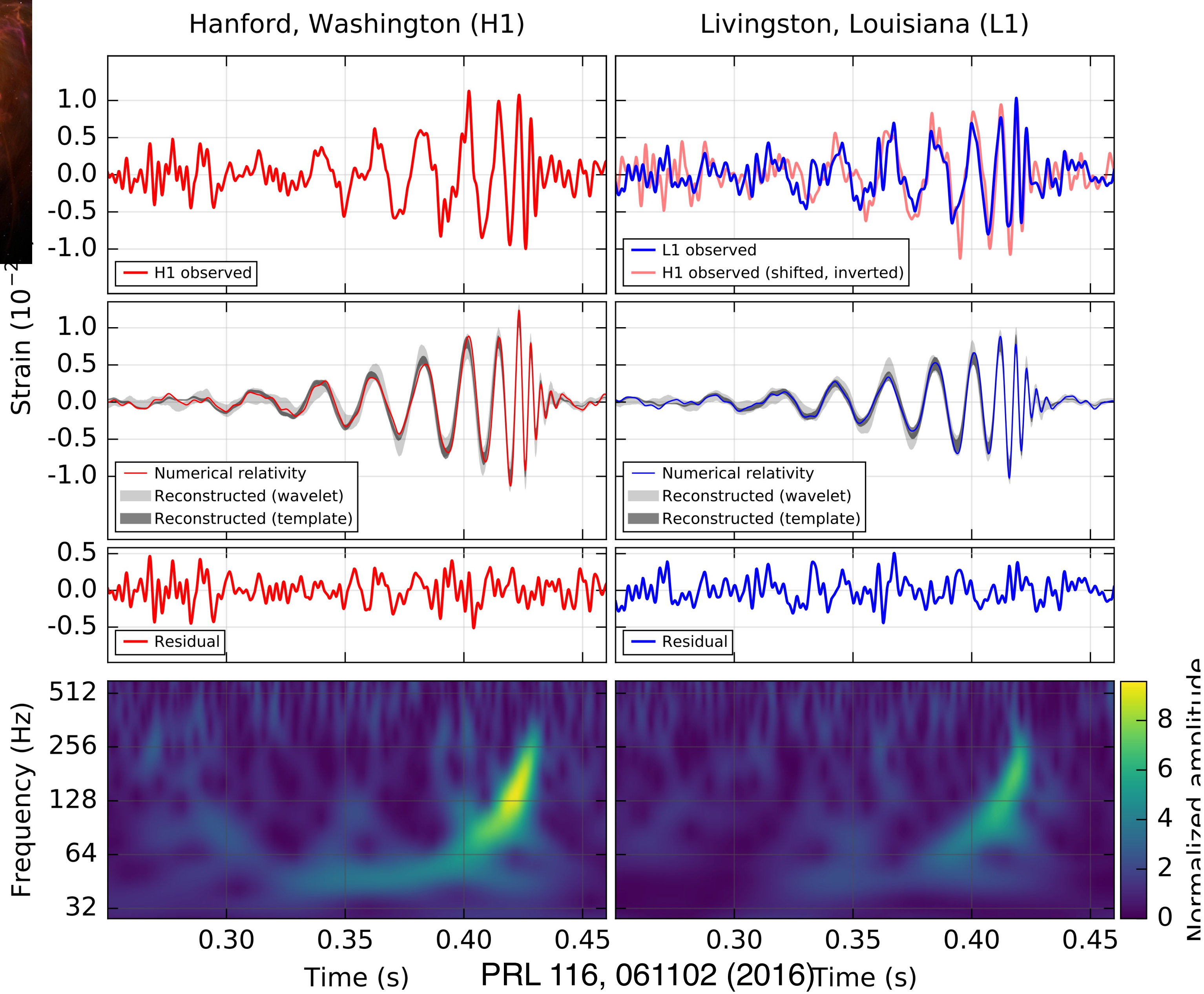
Two black holes merge



Credit: Science Photo Library/Alamy

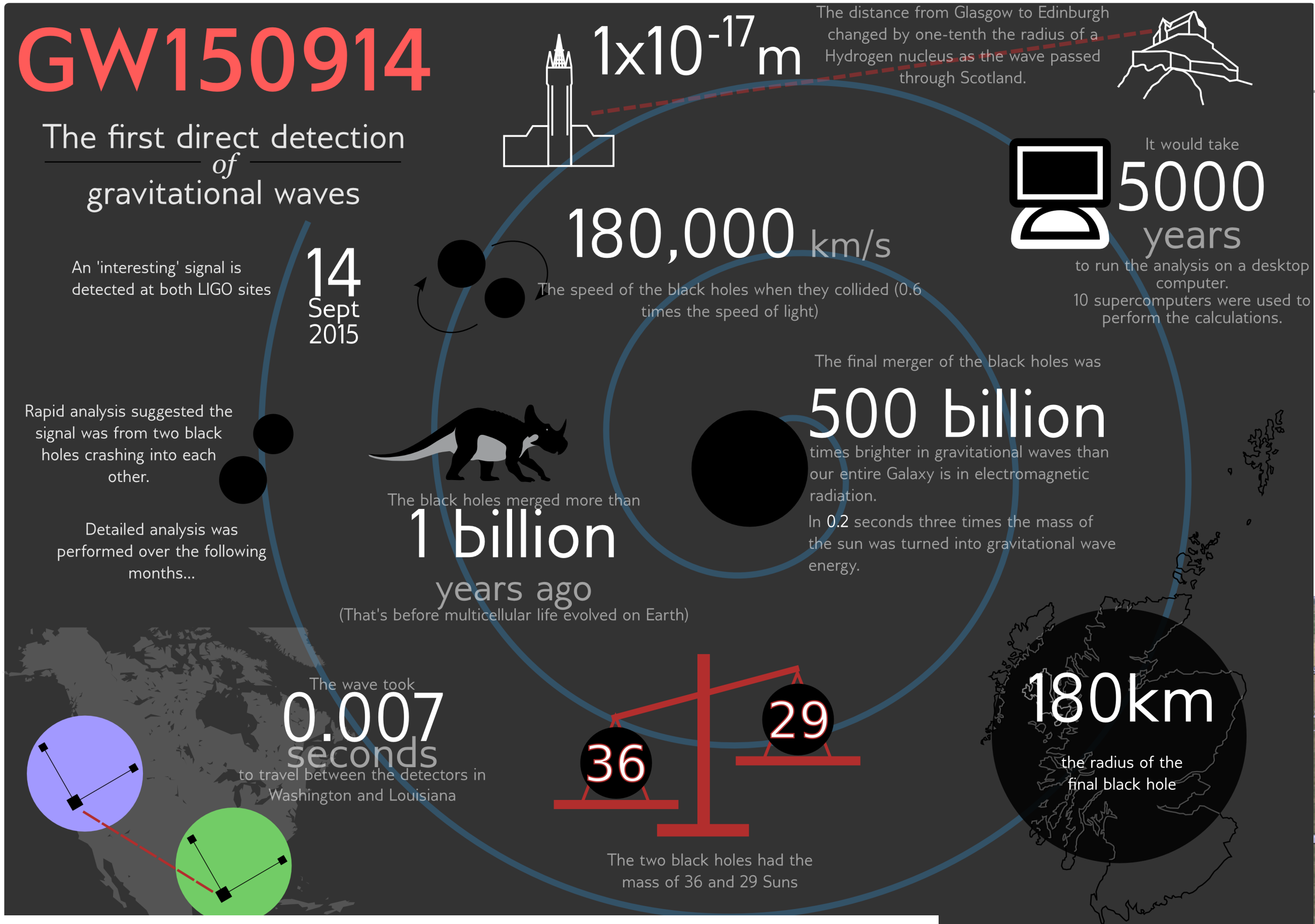
The first detection: Sep 14, 2015





PRL 116, 061102 (2016)

How massive were these black holes?



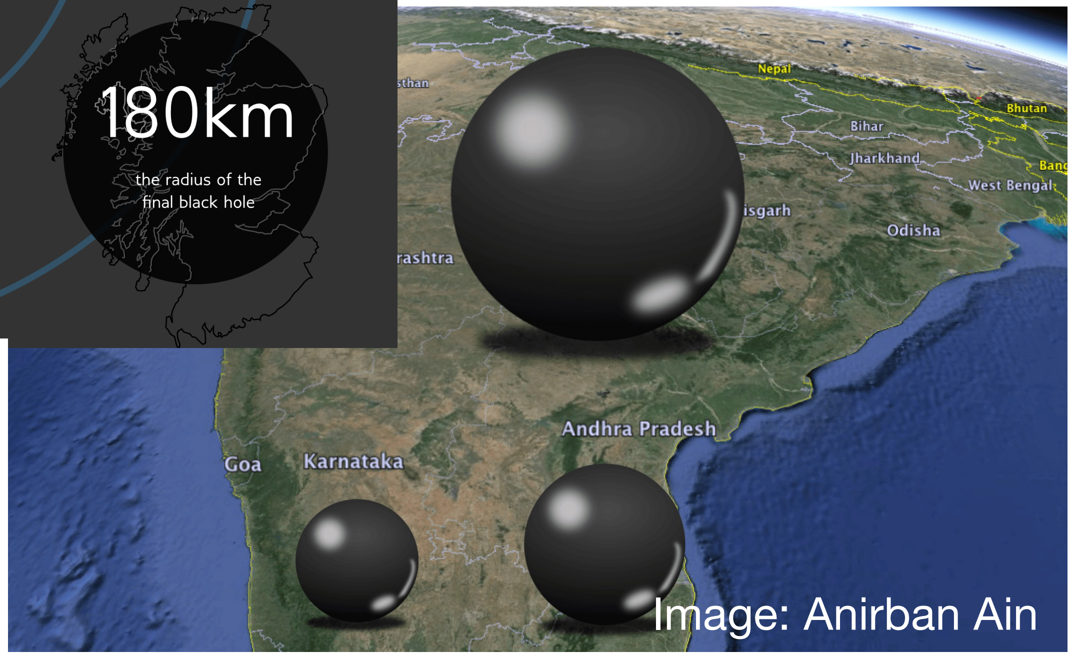
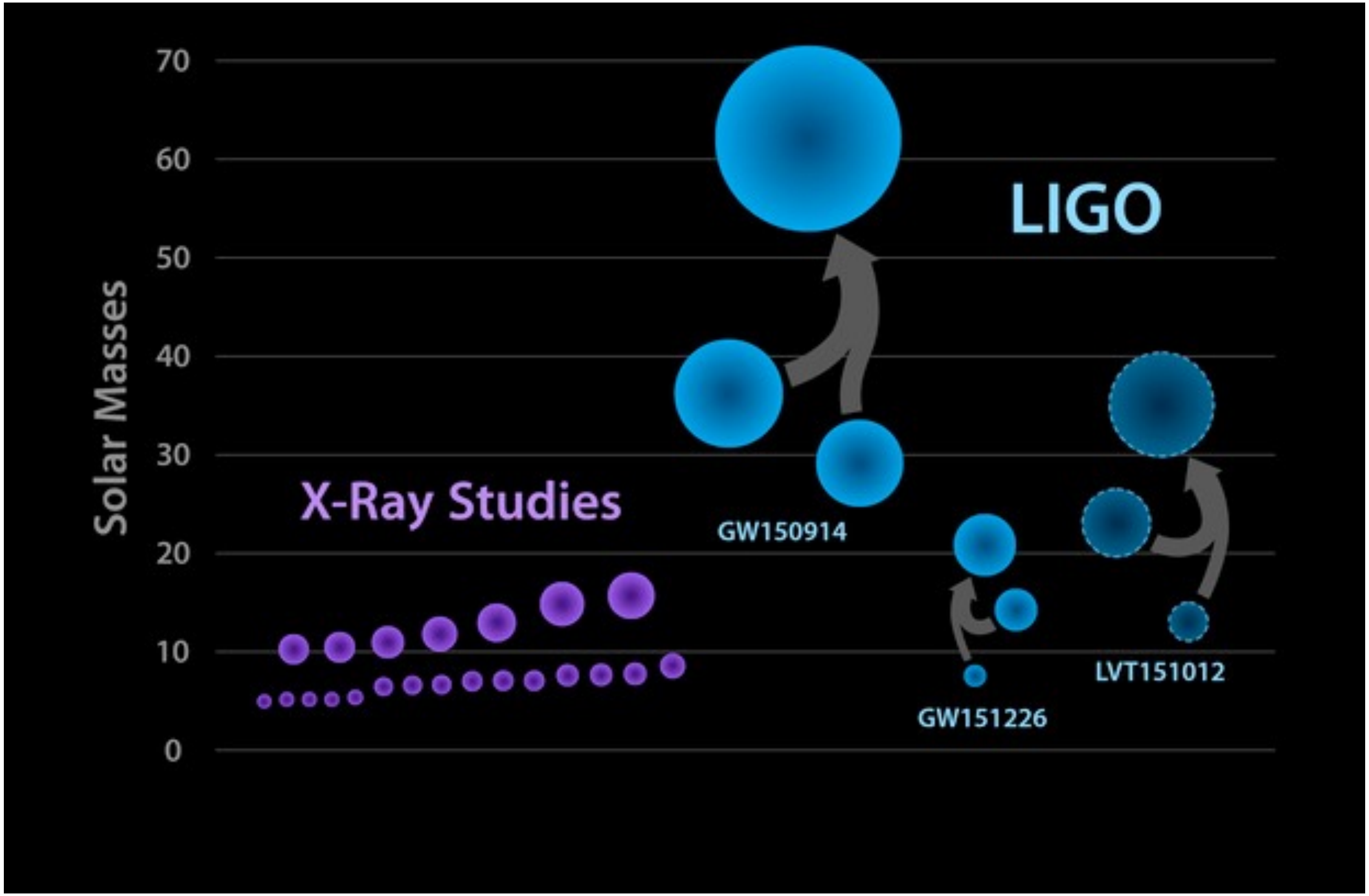


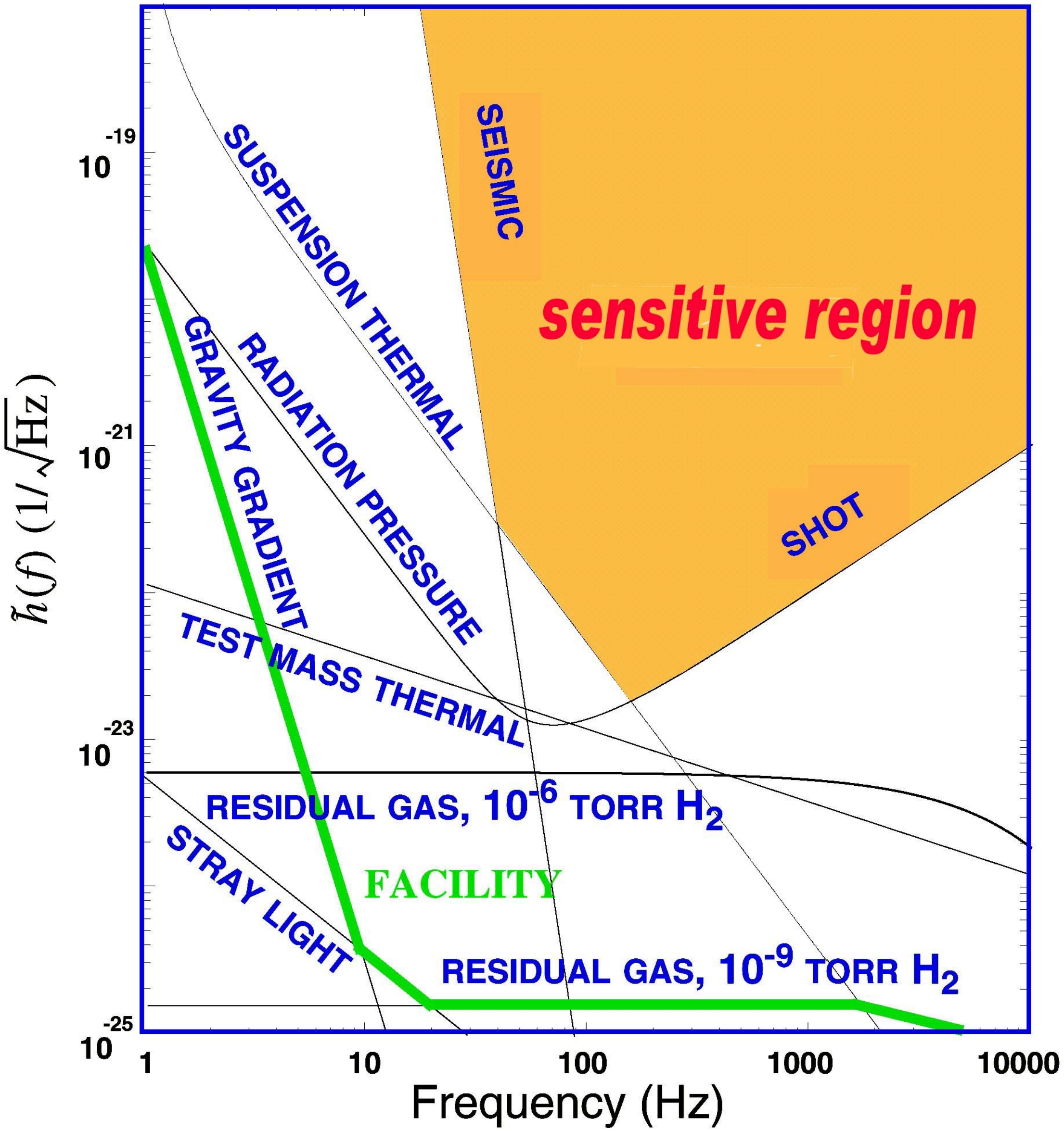
Image: Anirban Ain

Known Stellar-Mass Black Holes
June 2016



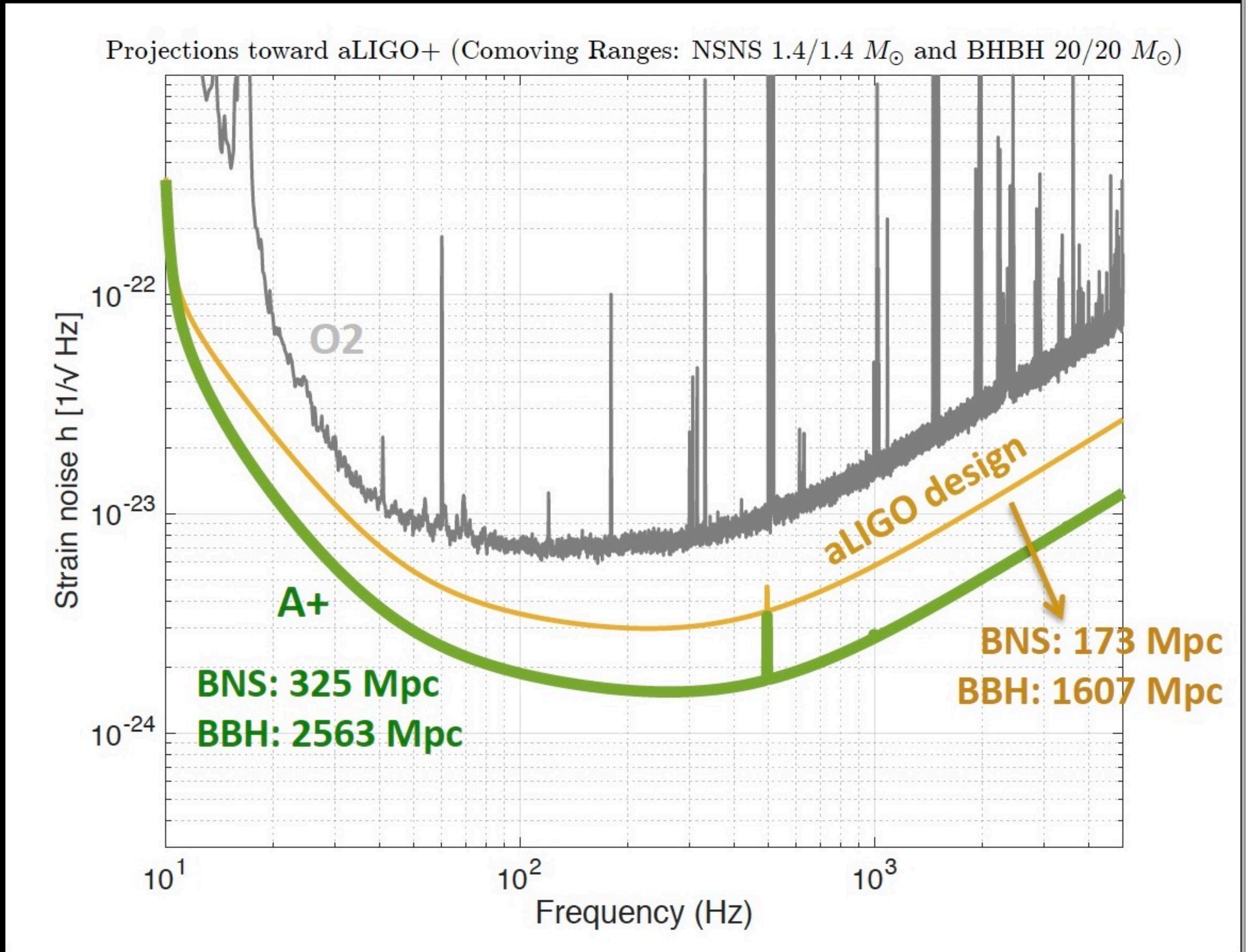
Noise Limits the Sensitivity of Interferometers

- 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 problems with the lasers, electronics

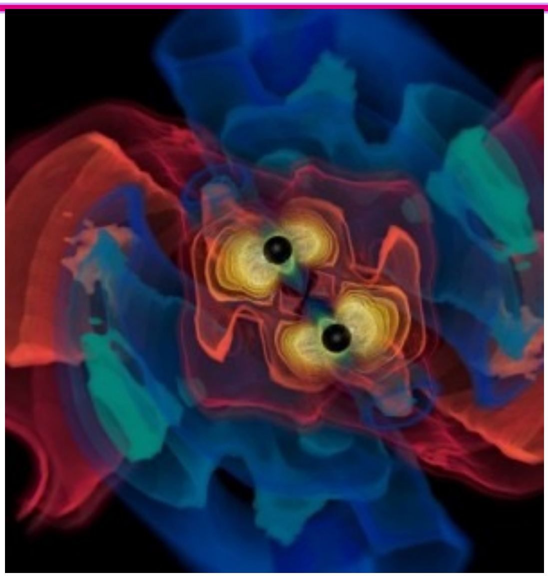


A+: a mid-scale upgrade to Advanced LIGO

- Reduced quantum noise
  - Improved optical losses
  - Improved readout
  - Frequency-Dependent Squeezing
- Reduced thermal noise
  - Improved mirror coatings
- Observing by mid-2024



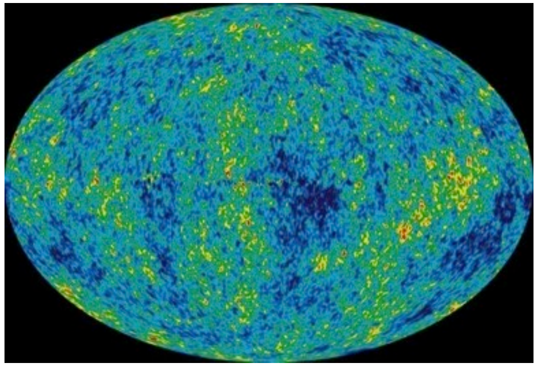
What else do we expect to learn from this new frontier?



Credit: AEI, CCT, LSU

__Coalescing Compact Binary Systems__: Neutron Star-NS, Black Hole-NS, BH-BH

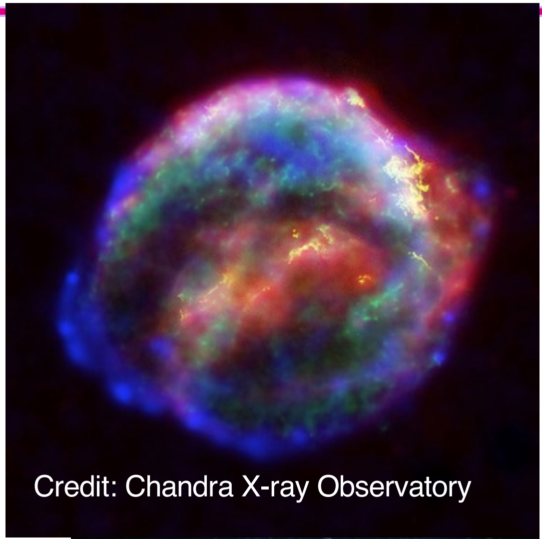
- Strong emitters, well-modeled,
- (effectively) transient



NASA/WMAP Science Team

__Cosmic Gravitational-wave Background__

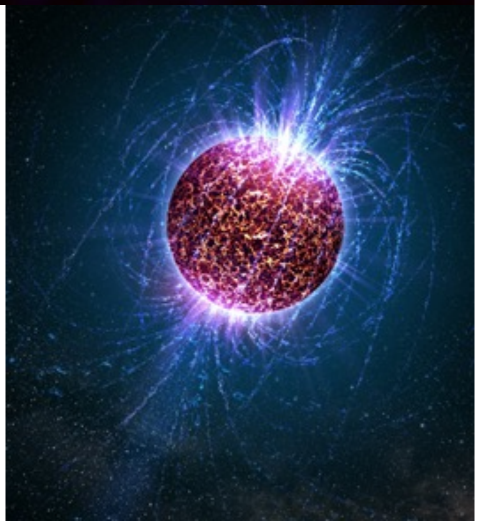
- Residue of the Big Bang
- Long duration, stochastic background



Credit: Chandra X-ray Observatory

__Asymmetric Core Collapse Supernovae__

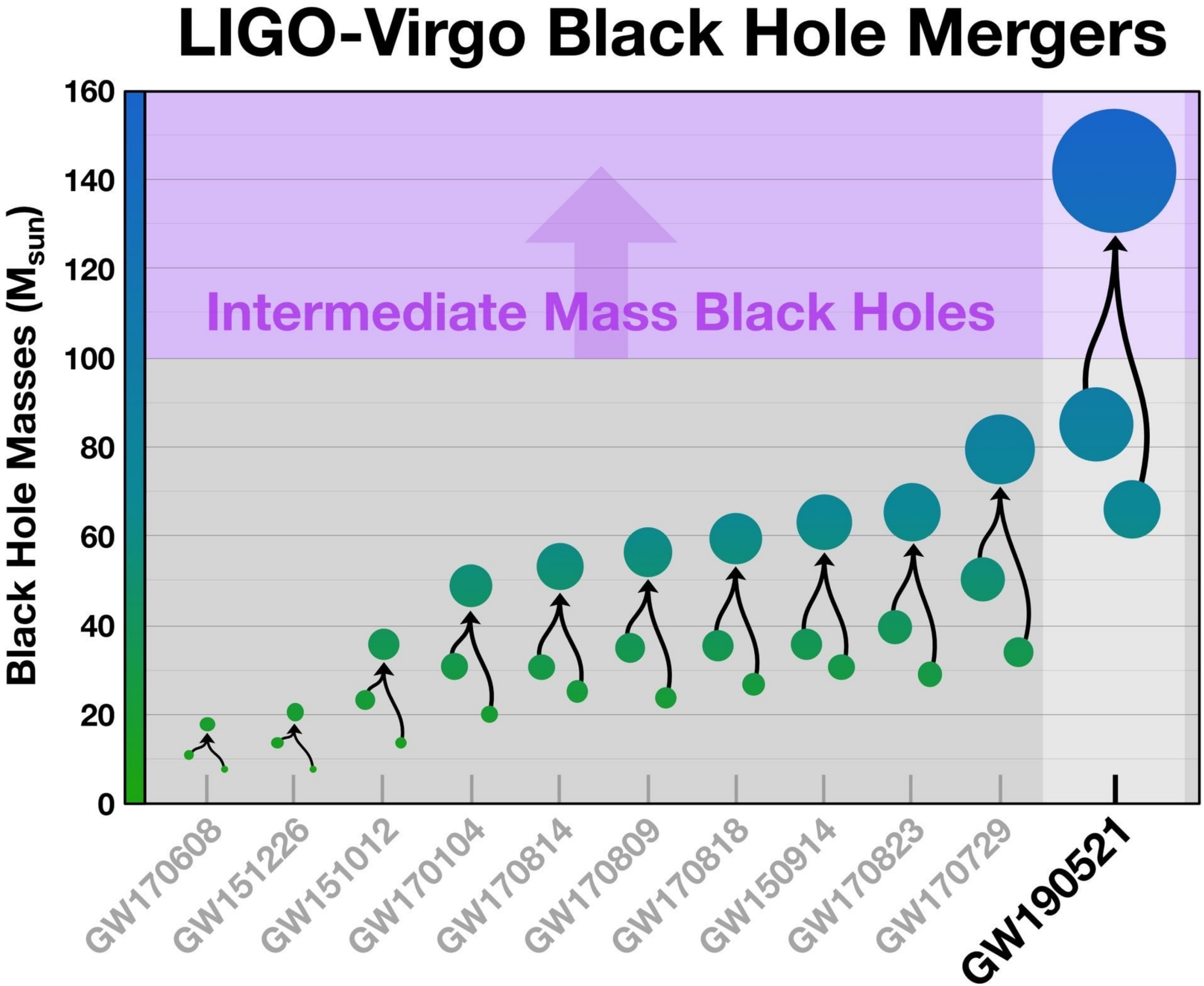
- Weak emitters, not well-modeled ('bursts'), transient



Casey Reed, Penn State

__Spinning neutron stars__

- (nearly) monotonic waveform
- Long duration


LIGO-Virgo Black Hole Mergers
Black Hole Masses (M_{sun})
160
140
120
100
80
60
40
20
0
Intermediate Mass Black Holes
GW170608
GW151226
GW151012
GW170104
GW170814
GW170809
GW170818
GW150914
GW170823
GW170729
GW190521

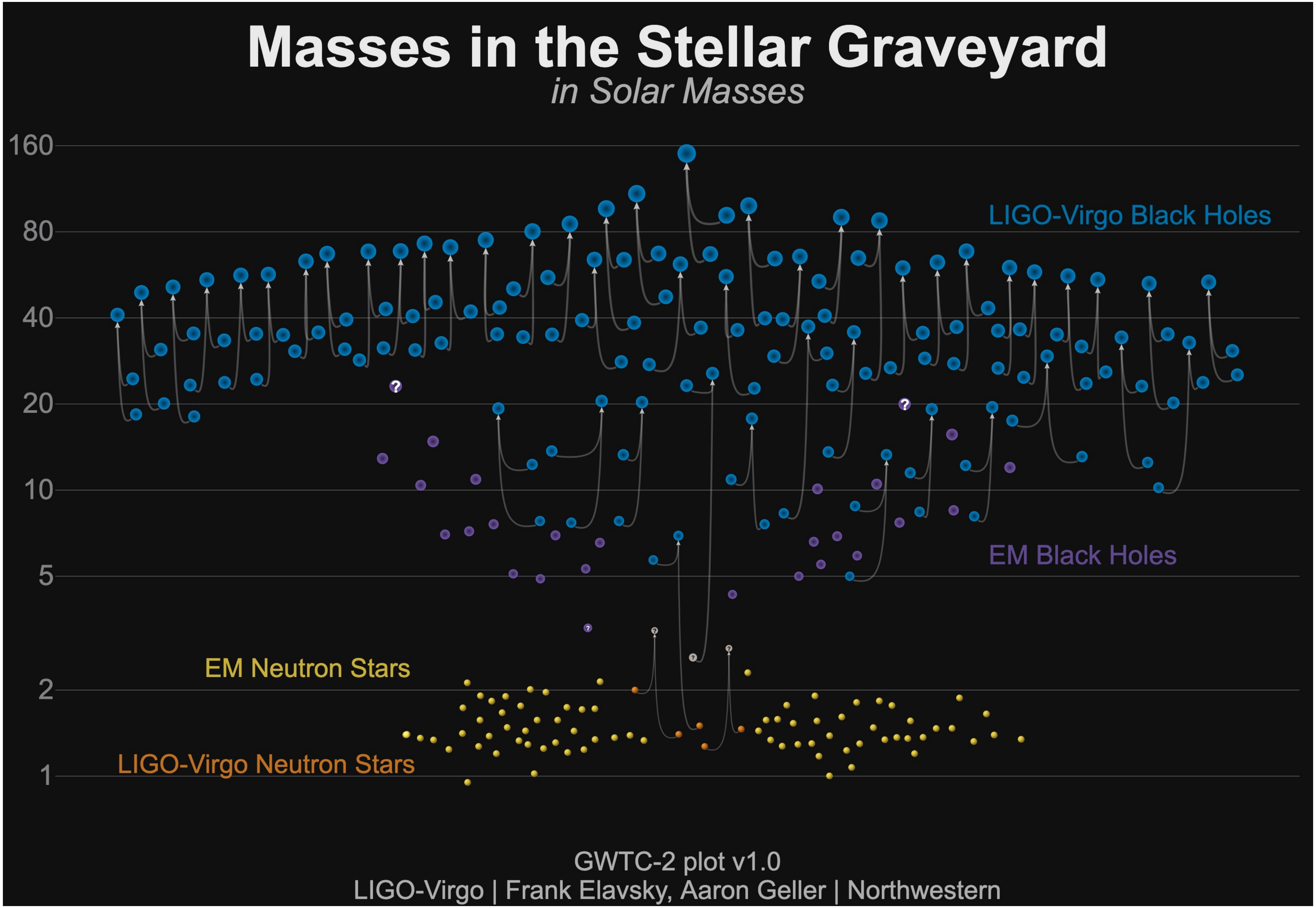
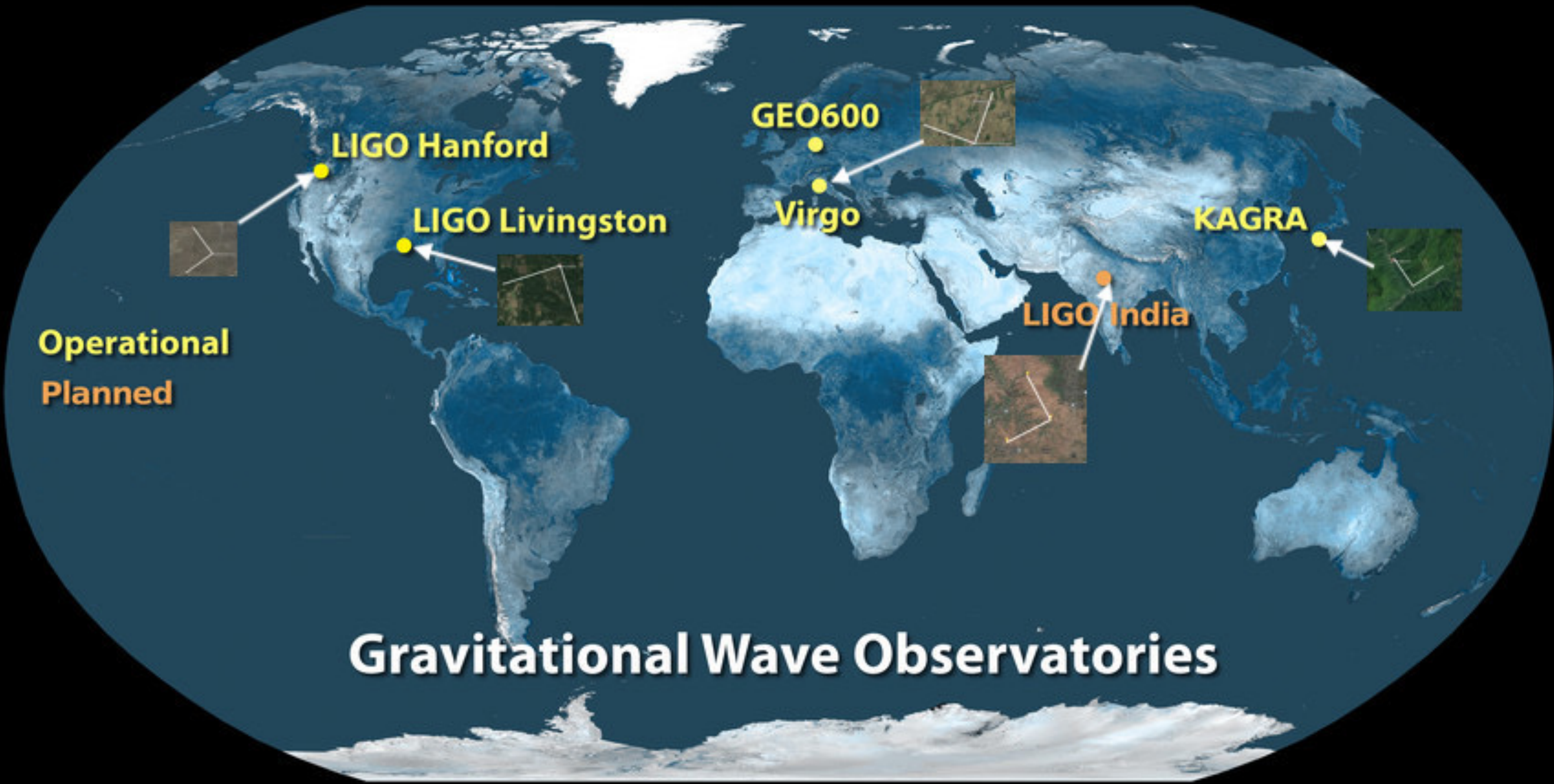


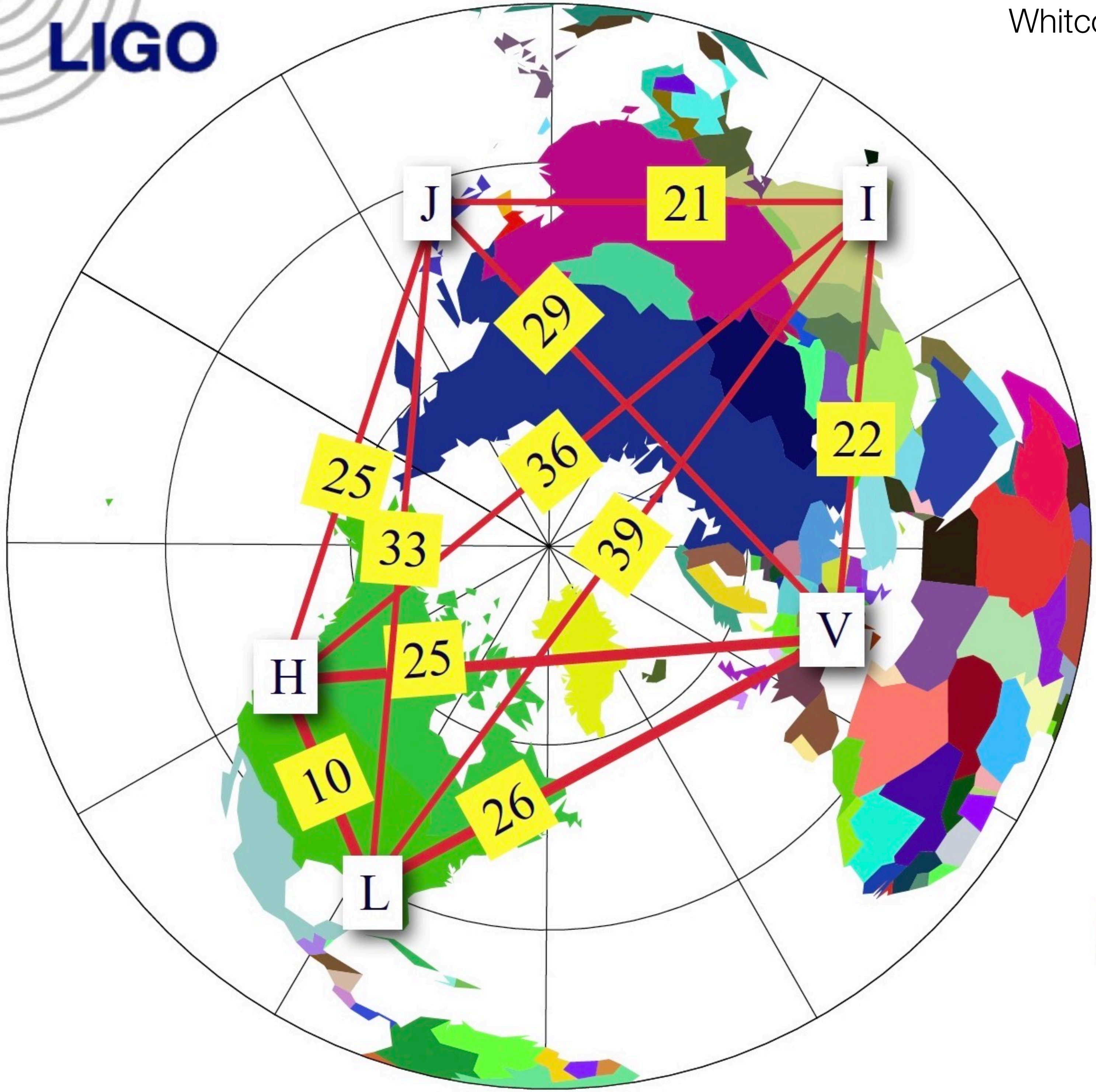
Image credit: LIGO

Global Network of GW Observatories 2026

Largest baseline ~ 12000 km provided by LIGO-India



Detector Networks



Baselines

in light travel time (ms)

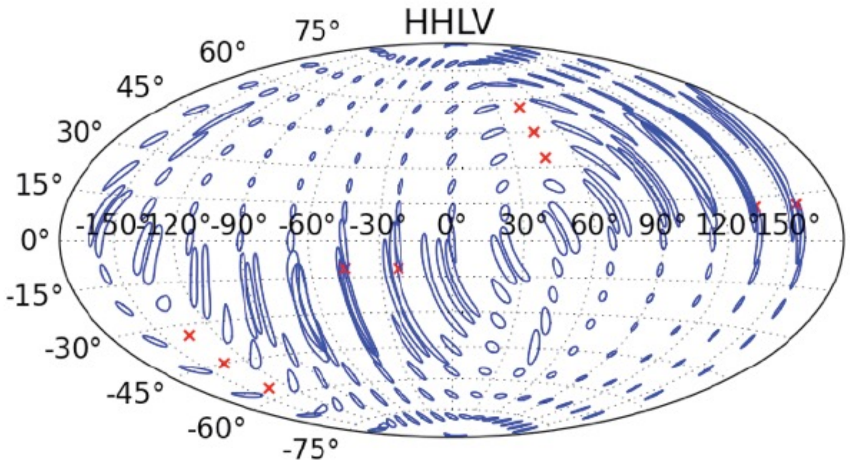
Detector Networks

Whitcomb LIGO-G1100991-v3

- Assume LIGO-India is at
  - (latitude, longitude) = (14.2333028N, 76.4333147E)
- Two networks consisting of four detectors
  - HILV, HHLV
- Four networks consisting of three detectors
  - HIL, HIV, HLV, ILV
- Baseline in light travel times (in ms)

	H	I	L	V
H	-	36.50	10.04	27.33
I	36.50	-	39.23	22.27
L	10.04	39.23	-	26.51
V	27.33	22.27	26.51	-

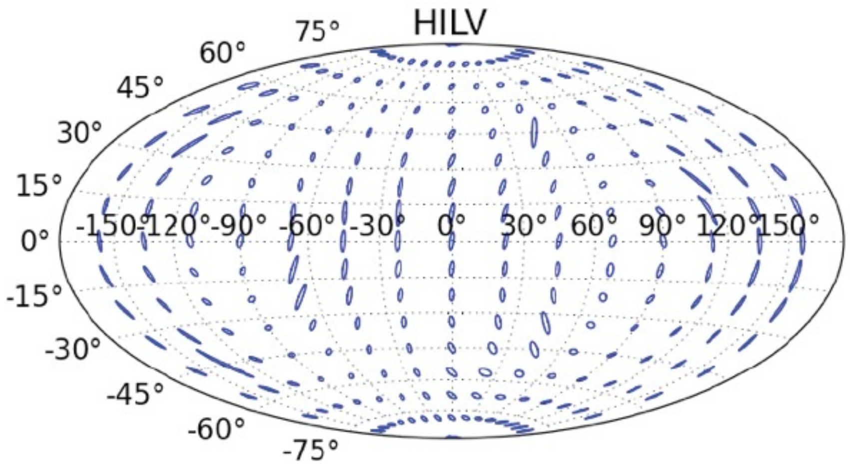
Effect of Adding LIGO-India to the LIGO+Virgo Network



Red crosses denote regions where the network has blind spots

Fairhurst 2011

LIGO+Virgo only



Fairhurst 2011

With LIGO-India

LIGO-India

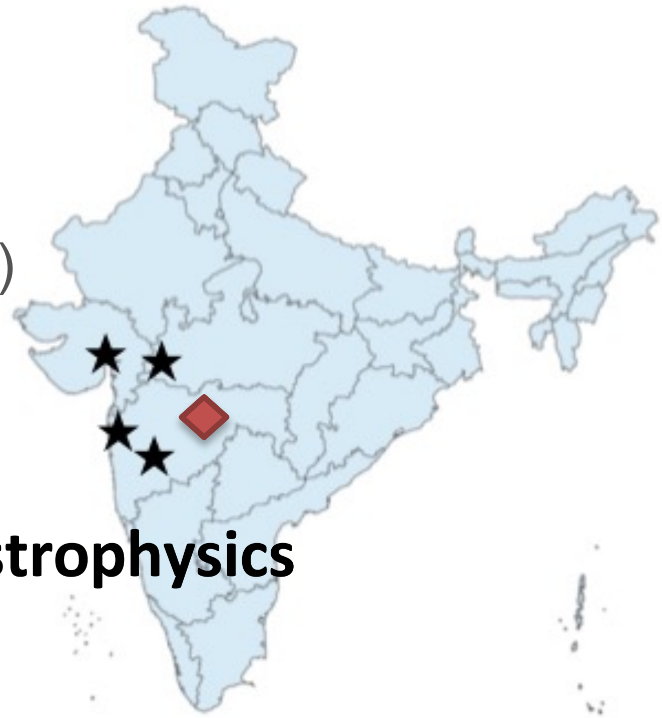
Laser Interfermetric Gravitational-Wave Observatory in India

LIGO-India: Institutions

Funding agencies:

NSF(USA), **DAE**(India) & **DST**(India)

Institutions: LIGO Lab., Caltech & **MIT** (USA)



1. **Inter-University Centre for Astronomy & Astrophysics (IUCAA), Pune**
   IUCAA is the key science stakeholder
2. **Institute for Plasma Research (IPR), Gandhinagar**
3. **Raja Ramanna Centre for Advanced Technology (RRCAT), Indore**
4. **Directorate of Construction, Services and Estate Management (DCSEM), Mumbai**

Last three affiliated to Dept of Atomic Energy

Major Responsibilities Among the lead Institutes

- Site Acquisition, Site Development and Civil Infrastructure: DCSEM
- Site Identification, Site characterization: IUCAA
- GW science, Data Handling, Storage & Analysis: IUCAA
- Human Resource Development, Scientific collaboration, among the International and the Indian GW community: IUCAA
- Vacuum Facility Setup , Vacuum Controls and Monitoring : IPR
- Controls* & Data Acquisition: IPR
- Interferometer Detector: RRCAT
- 3rd Generation & Upgrades Technology Development: RRCAT

*RRCAT is responsible for interfacing the front end controls with the detector sub systems, while IPR is responsible for the Supervisor control

Site characterisation & preparation

Automatic Weather Station

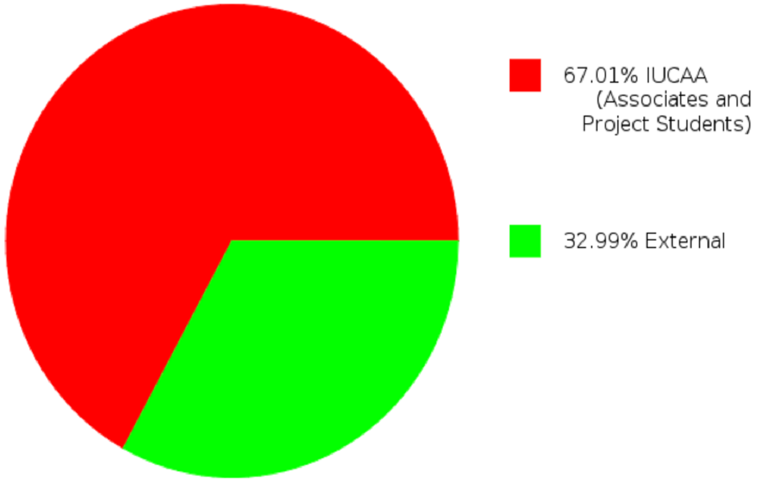
(Installation is over and station is in operation)

RCC Works for construction Site office

Fencing work at the acquired site

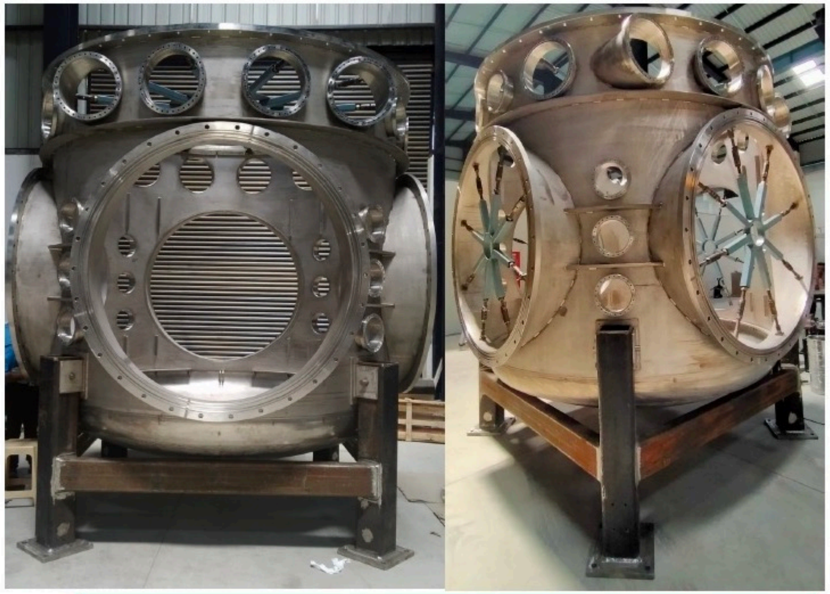
Computational facility for LIGO At IUCAA

- **Sarathi cluster**
  - 249 nodes, 7896 CPU cores 3840 Intel Xeon G6248 cores, RAM: 5-10GB/core, storage: 250TB, 10G and 2x25G interconnect
- Scope for prototyping GPU based codes: 10 NVIDIA K40 cards
- Building can accommodate infrastructure needed for LIGO-India



Vacuum chambers: construction now

BSC Lower Shell
Metrology Check



BSC Lower Shell Ready for assembly

BSC Upper Shell

Basic Symmetric Chamber (lower shell)
Prototype under construction

EPO Activities Near The Site

Social Media

LIGO India

Page | Inbox | Notifications 84 | Insights | Publishing Tools | Pro

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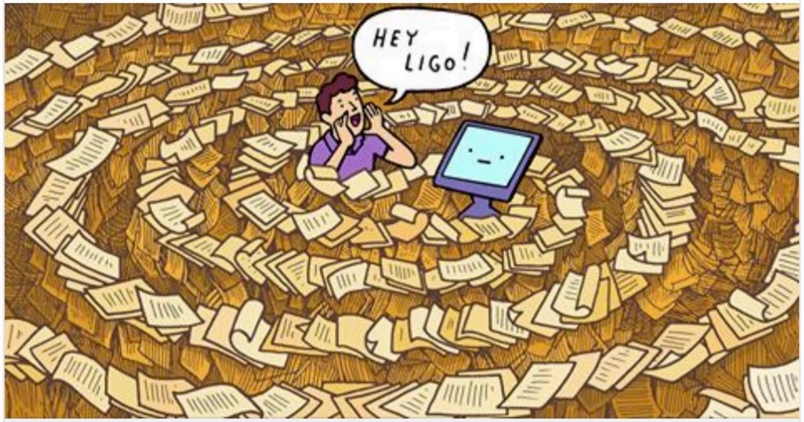
Nikhil Mukund Menon,
a graduate student from @IUCAApune working at #LI
was the principal architect of #HeyLIGO, the Siri/Alex
learning ba...

See more



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The Laser Interferometer Gravitational-Wave Observatory has a new...

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590 Tweets

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Official | LIGO-India: An advanced gravitational-wave (GW) observatory to be located in India, as part of a worldwide network of GW observatories | #LIGOIndia

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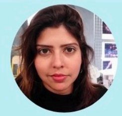
LIGO-INDIA — 8 MARCH 2021

Women of LIGO-India

Meet the women behind this Mega-Science project



Debarati Chatterjee
Professor

Anupreeta More
Data Scientist

The LIGO-India project is a planned third-generation Gravitational Wave detector, forming a part of an international network of detectors. It is one of the upcoming Mega-Science projects in Astronomy and will help to develop