LIGO
Megascience in India

Brian O'Reilly

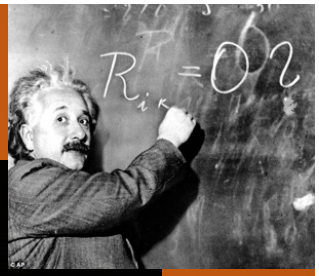
Caltech-LIGO Livingston Observatory

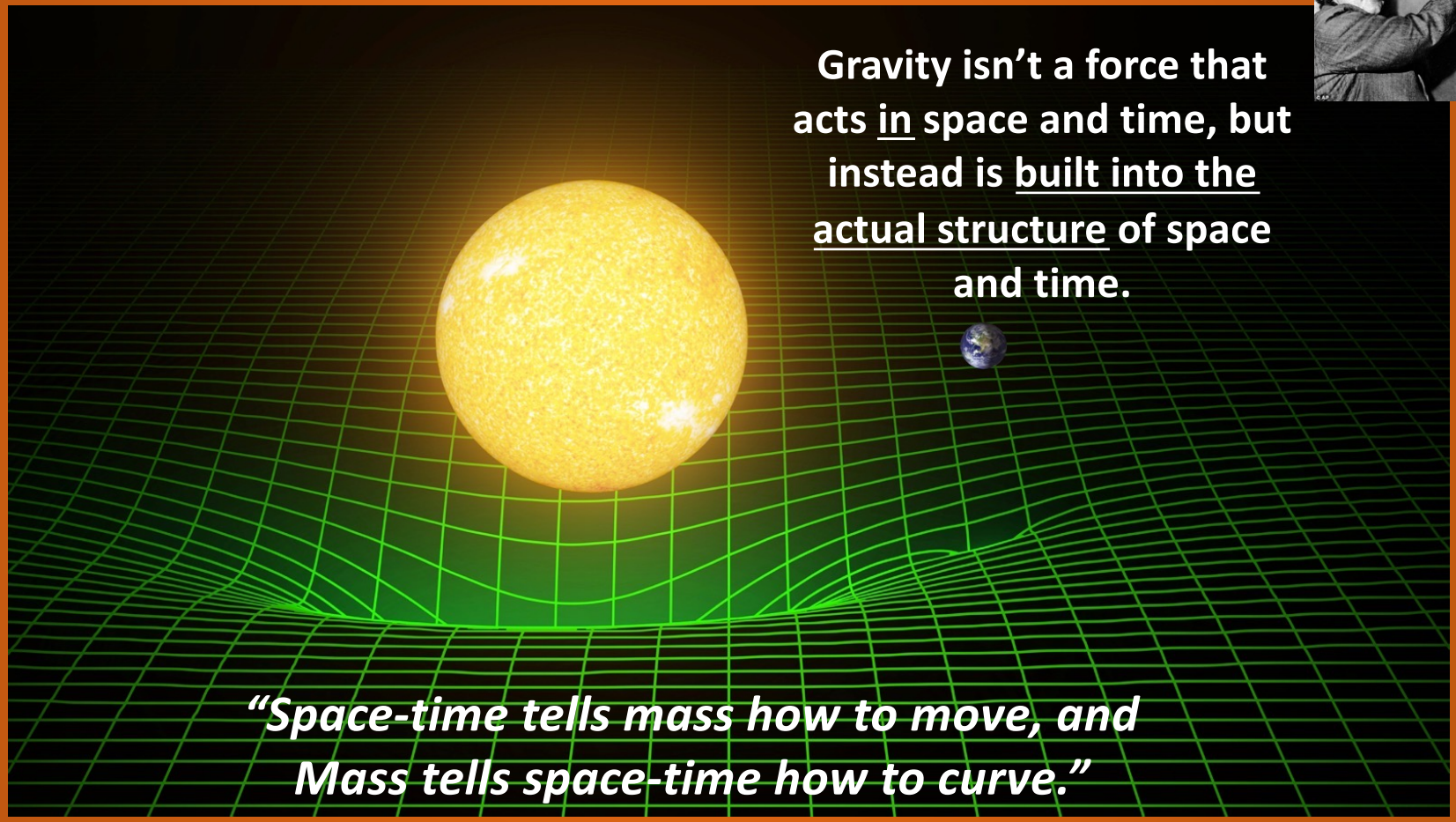
Gravitational Waves and Detectors

Newton's Gravity 1687 AD

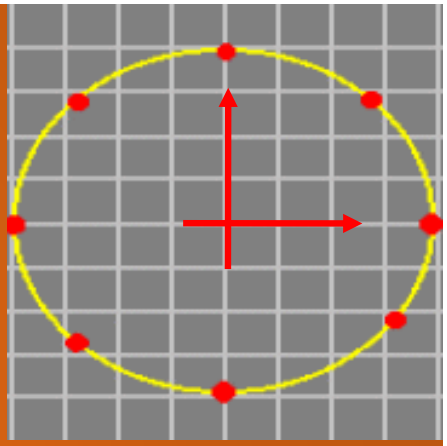
- Gravity is an attractive force, like magnetism
- Explains apples falling from trees, moon orbiting earth, planetary orbits etc..
- BUT…
  - No explanation for how gravity propagates
  - Precise observation of the orbit of Mercury showed behavior Newton's theory could not explain.

1915: Theory of General Relativity





What are gravitational waves?



- Gravitational waves are very weak, or if you prefer spacetime is very “stiff”.
- We need **huge masses** moving **very fast** in order to have detectable signals: Astrophysics.
- LIGO detects displacements of its optics about 1000 times smaller than a proton diameter.
- Equivalent to measuring distance to second nearest star to the thickness of a human hair.

Modeled (Known Waveform)

Unmodeled (Unknown Waveform)

Short Duration

Credit: Bohn, Hébert, Throwe, SXS

Compact Binary Coalescences

- Black hole – black hole
- Black hole – neutron star
- Neutron star – neutron star

handra X-ray Observatory

Burst Sources

- Supernova

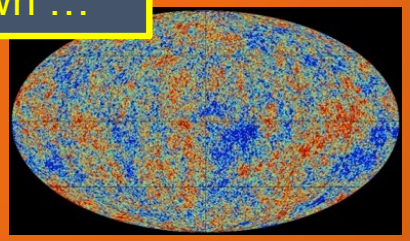
And hopefully the unknown …

Long Duration

Credit: Casey Reed, Penn State

Continuous Sources

- Spinning neutron stars



Credit: Planck Collaboration

Stochastic Background

- Primordial GWs from the Big Bang

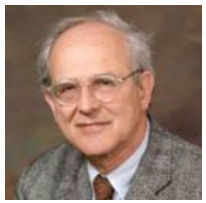
Original Concept, 1972 - R. Weiss

QUARTERLY PROGRESS REPORT

APRIL 15, 1972

No. 105

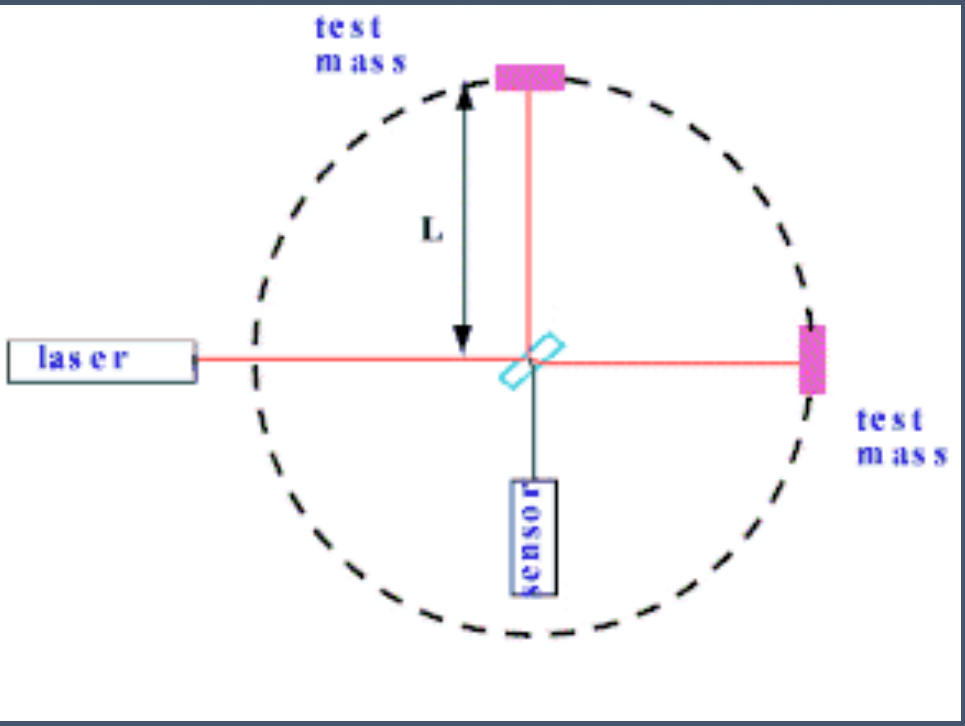
MIT



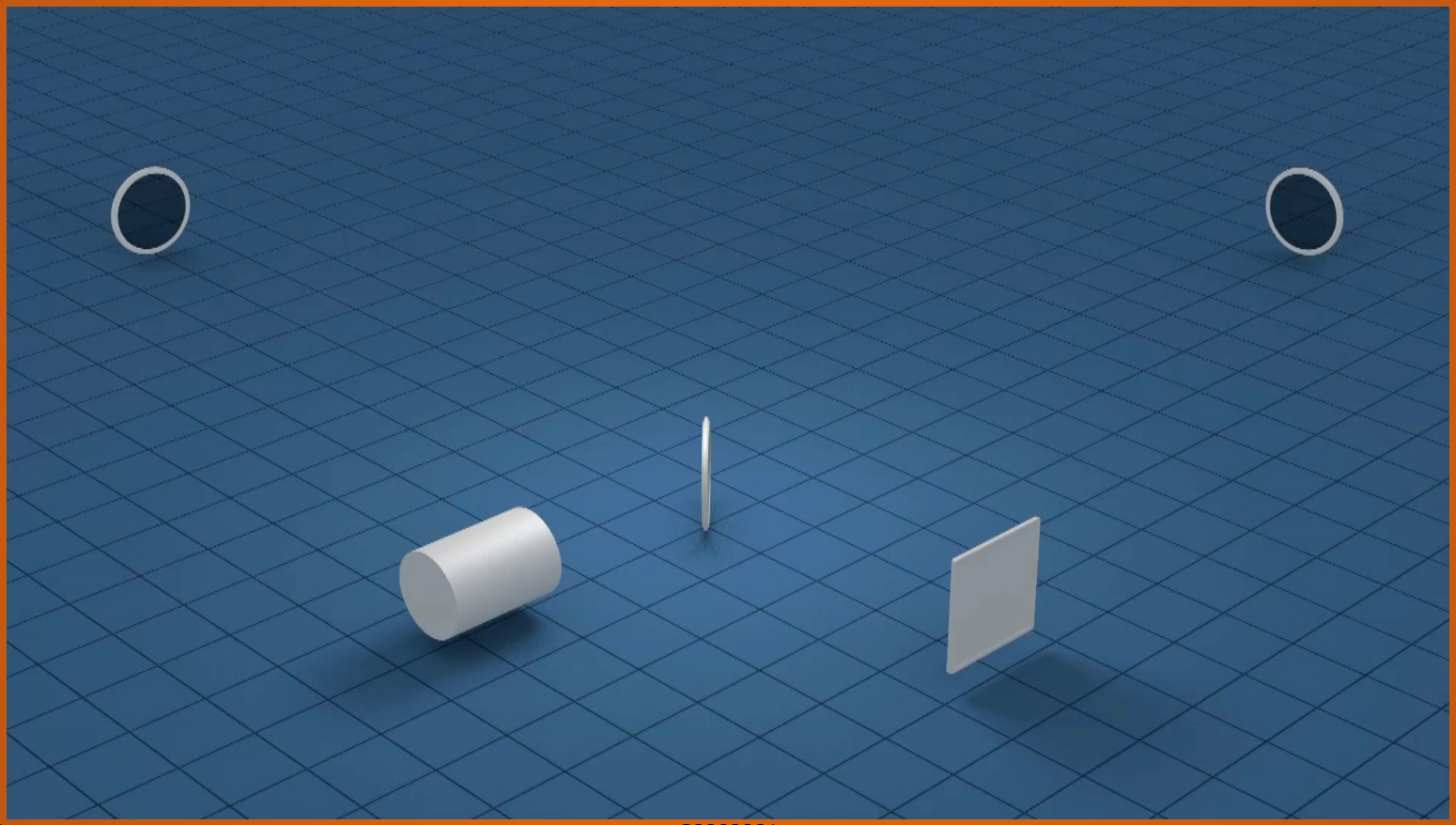
Rai Weiss, MIT

Fig. V-20. Proposed antenna.

ELECTROMAGNETICALLY COUPLED BROADBAND GRAVITATIONAL ANTENNA



Michelson interferometer

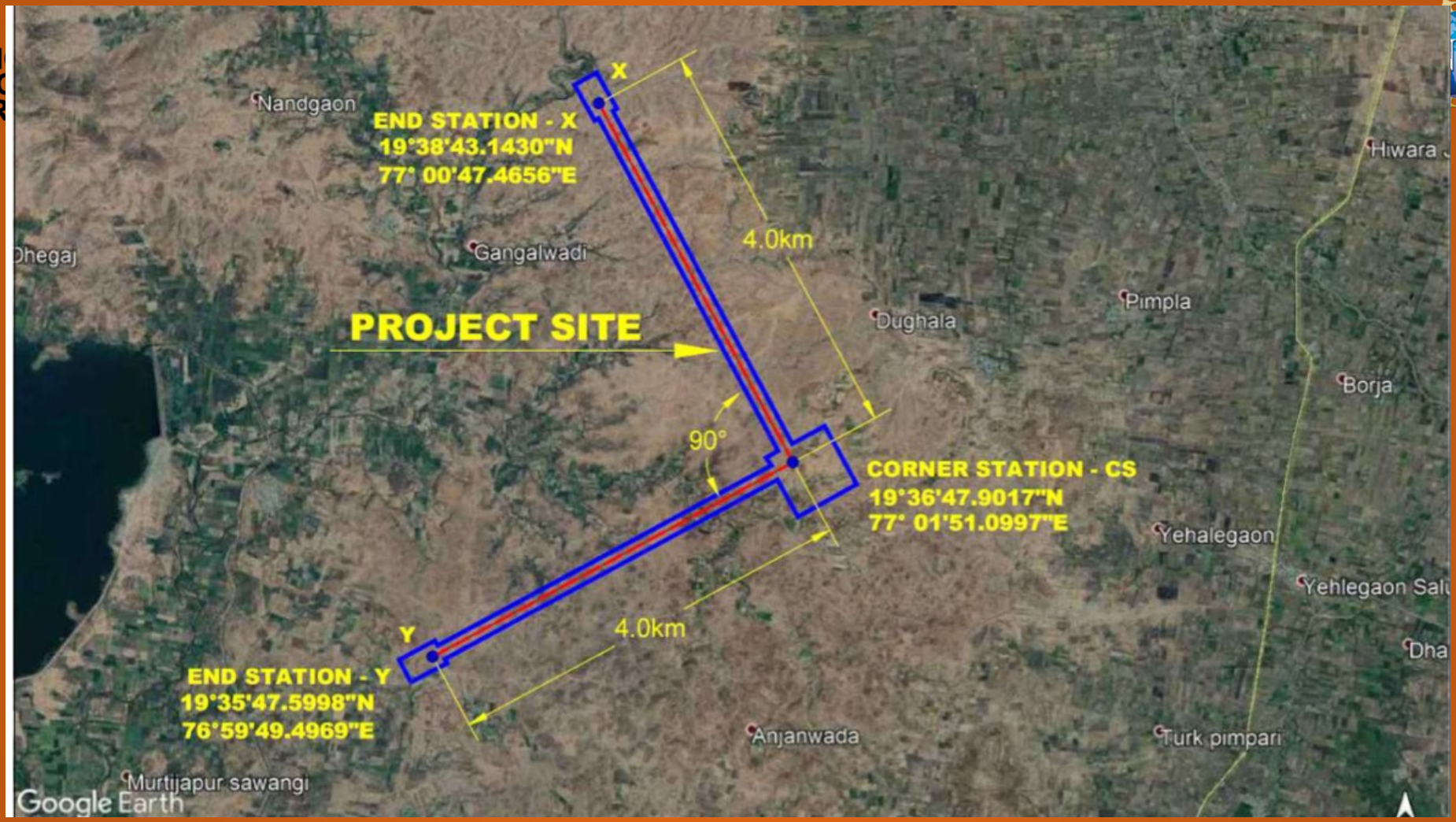



LIGO Livingston Observatory, LA


LIGO Hanford Observatory, WA


Virgo, Italy


Surat
Aundha
site
Nagpur
Nashik
Aurangabad
Hingoli
MAHARASHTRA
Mumbai
Nanded
Pune
TELANGANA


X
END STATION - X
19°38'43.1430"N
77° 00'47.4656"E
4.0km
PROJECT SITE
90°
CORNER STATION - CS
19°36'47.9017"N
77° 01'51.0997"E
4.0km
Y
END STATION - Y
19°35'47.5998"N
76°59'49.4969"E
Nandgaon
Gangalwadi
Dughala
Pimpla
Borja
Yehalegaon
Anjanwada
Turk pimpari
Murtijapur sawangi
Google Earth

Seismic survey, Weather Station, Site office

Site office for LIGO-India Project

Weather station at the LAO site

Site office at the LAO site

LIGO India Project

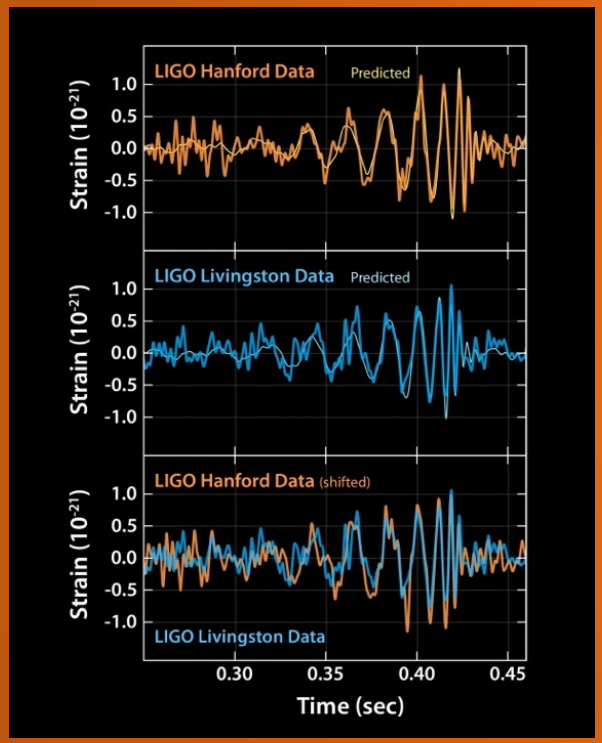
On May 11, 2023 Hon'ble Prime Minister of India laid the foundation stone for the construction of the Observatory.

Science

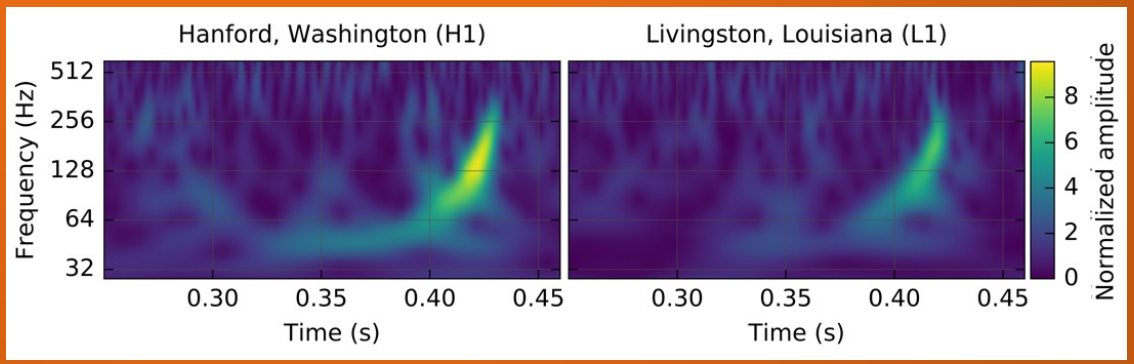
LIGO Scientific Collaboration

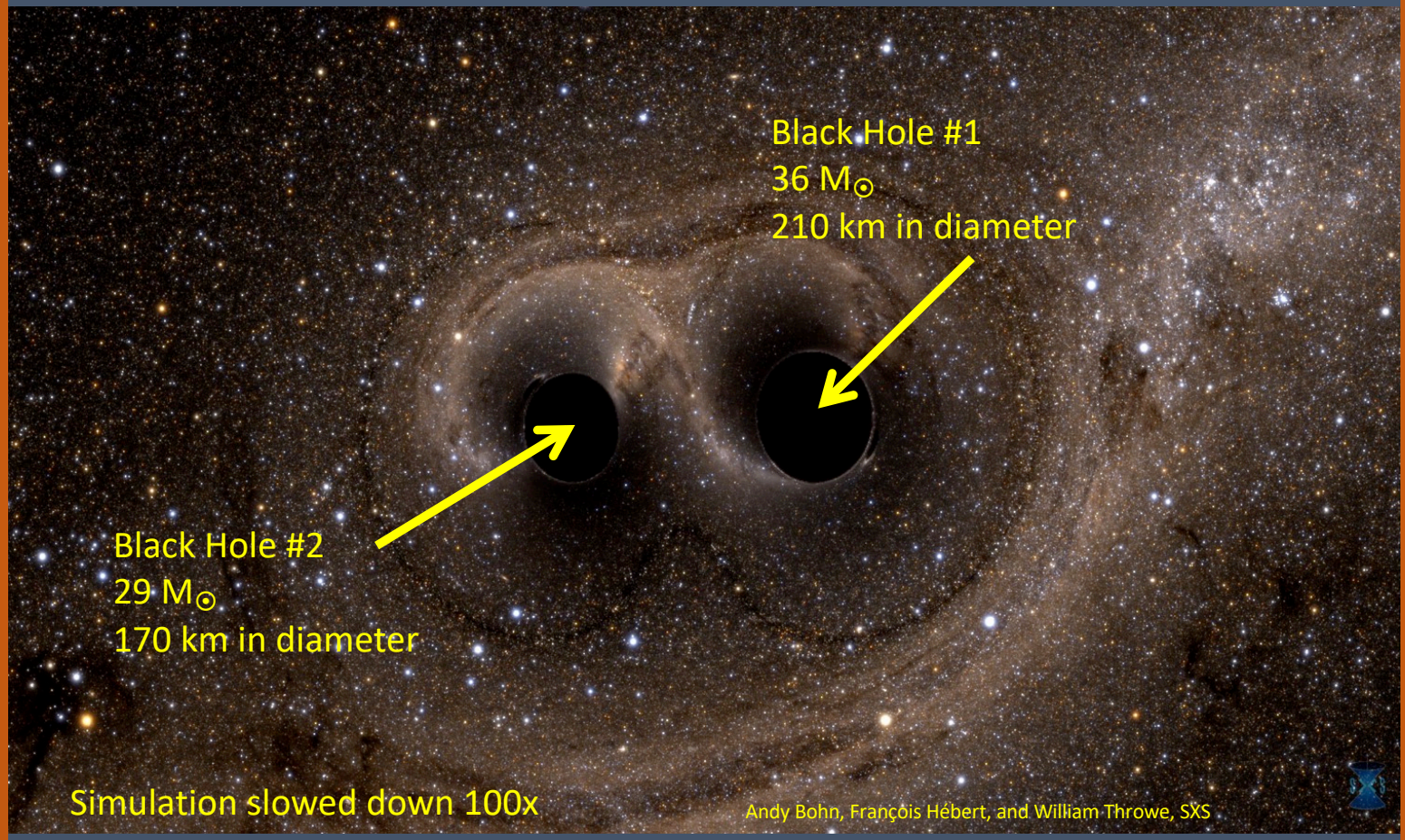
LIGO-India Scientific Collaboration

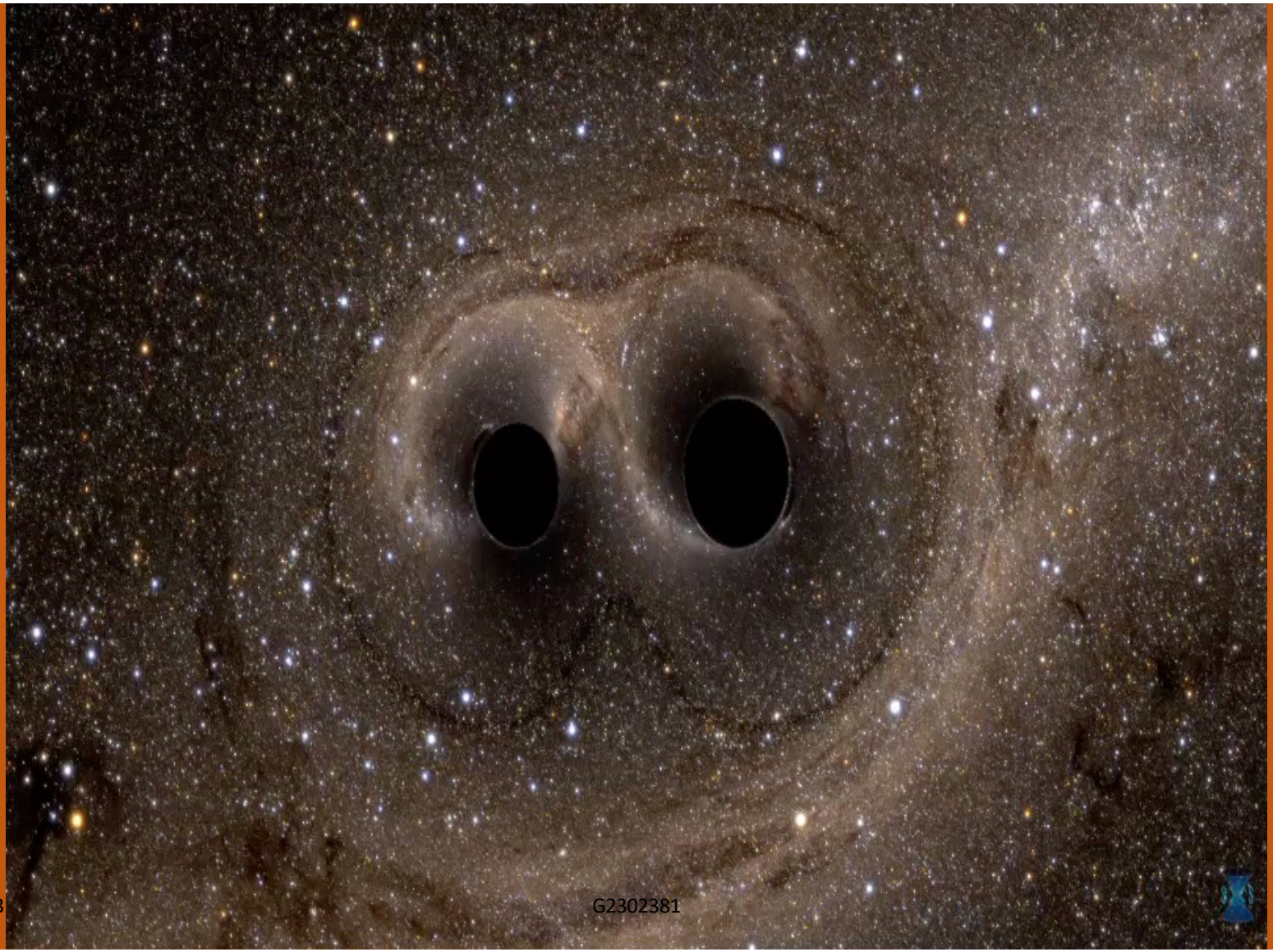
GW150914: The First and Still Champion!



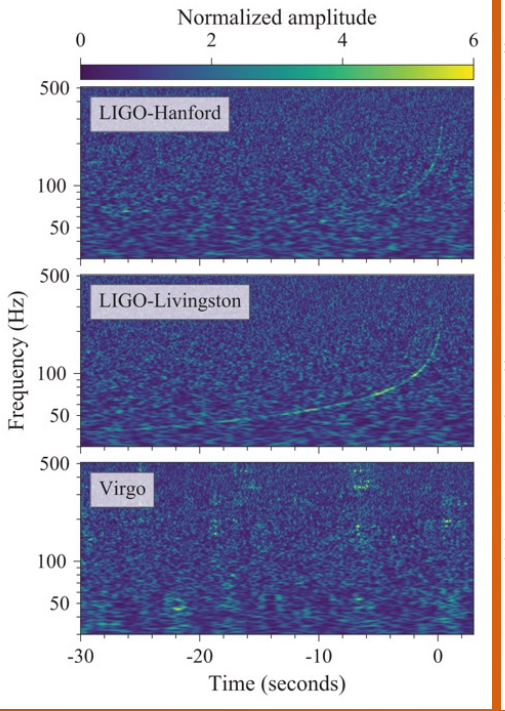
- Discovered at the very beginning of the Advanced LIGO Observing era.
- Two~30 $M_\odot$ black holes merging ~400 Mpc from Earth (z~0.1).
- ~3 $M_\odot$ radiated in GWs, peak luminosity ~3.6×10^{56} erg/s,
- Peak strain at the detectors: 10^{-21}
- To date the highest peak amplitude signal detected.

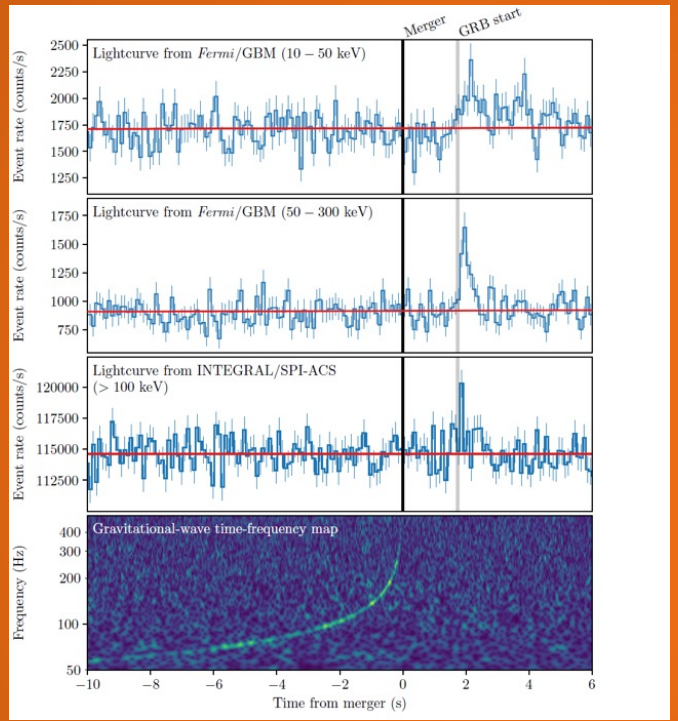


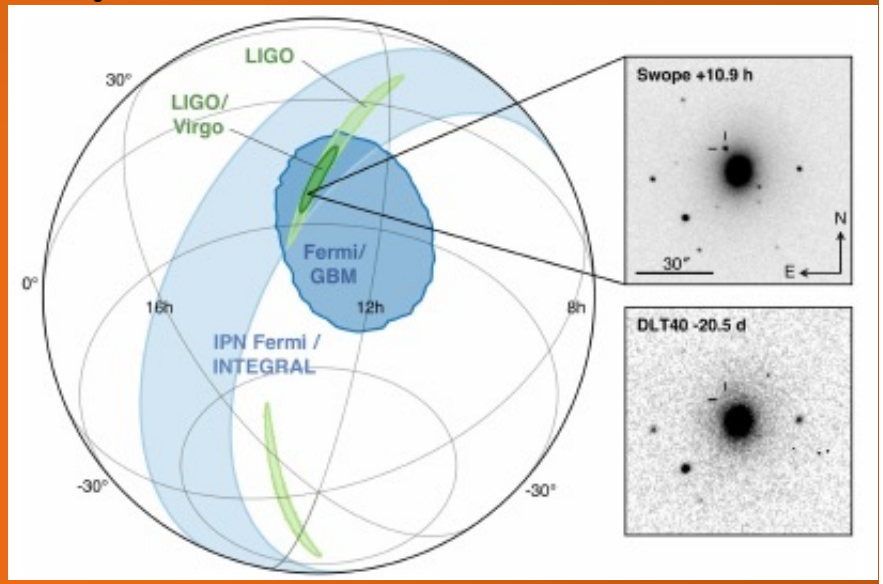

Black Hole #1
36 M⊙
210 km in diameter
Black Hole #2
29 M⊙
170 km in diameter
Simulation slowed down 100x
Andy Bohn, François Hébert, and William Throwe, SXS

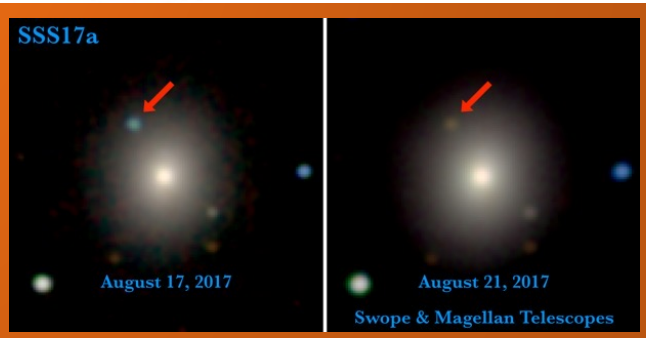


GW170817: The superstar



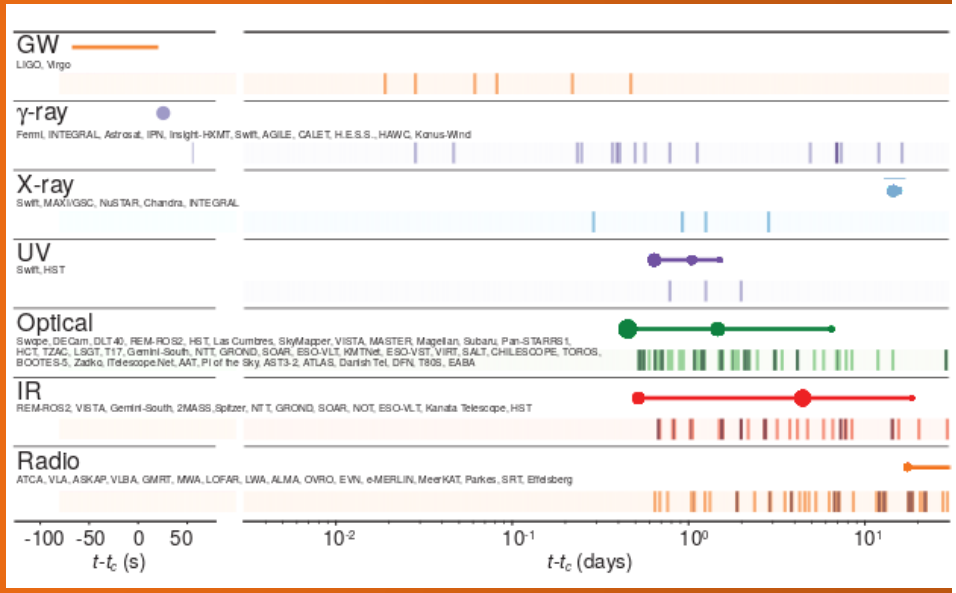




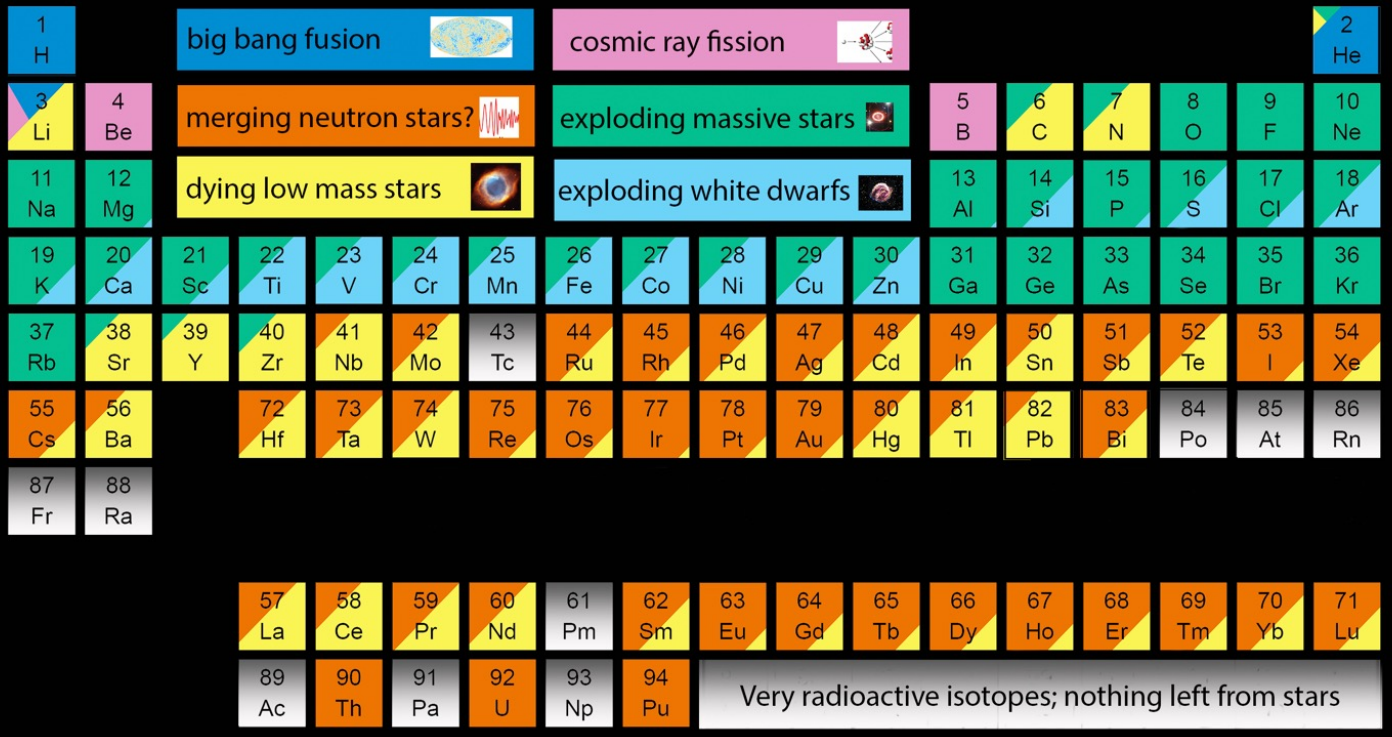


GW170817

- Short GRBs are merging Neutron Stars (Kilonova).
- GWs travel at the speed of light.
- First GW measurement of the Hubble constant.
- GW constraints on composition and size of neutron stars:
  - Tidal Deformability
  - Radius
  - Equation of State
  - Maximum mass
- BNS mergers as producers of heavy elements.



The Origin of the Solar System Elements

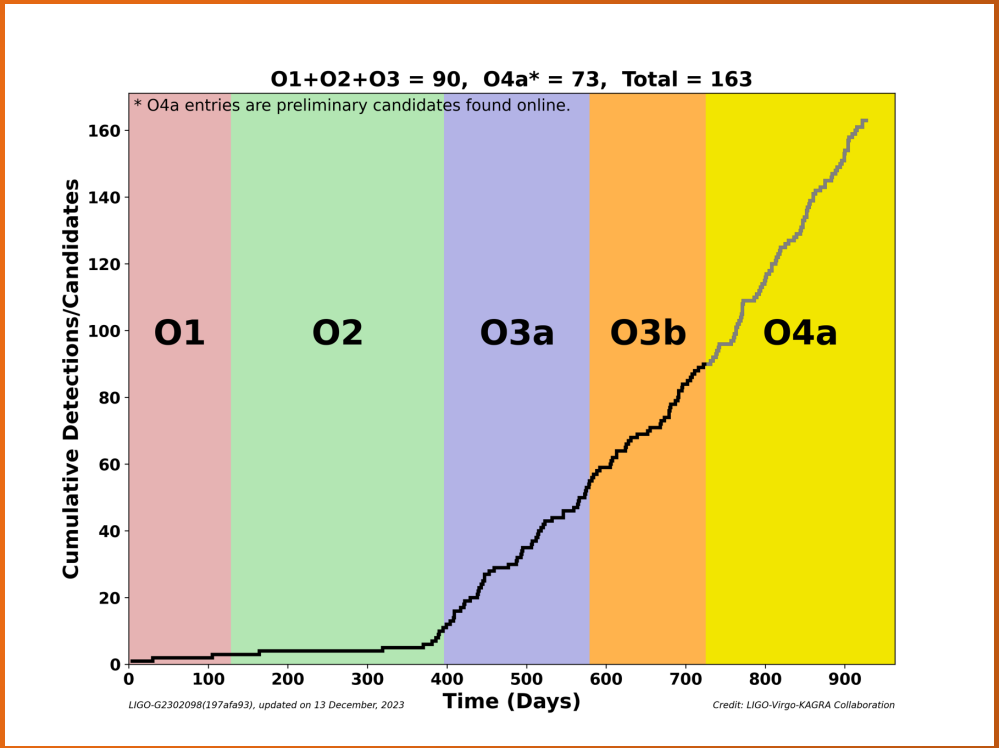


Graphic created by Jennifer Johnson
http://www.astronomy.ohio-state.edu/~jaj/nucleo/

Astronomical Image Credits:
ESA/NASA/AASNova

Current Status: O4 Run

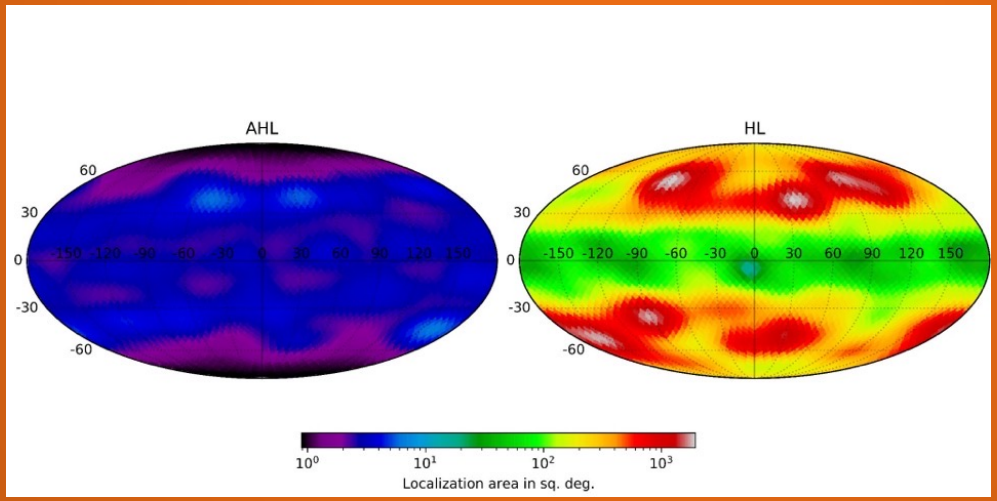
- Currently in the middle of the fourth observing run of the advanced detector era.
- 71 GW candidate events detected in O4a, close to doubling our total number of events (if they survive offline analysis).
- O4a will end on January 16, 2024
- O4b will begin March 16, 2024 and run until the end of the year.



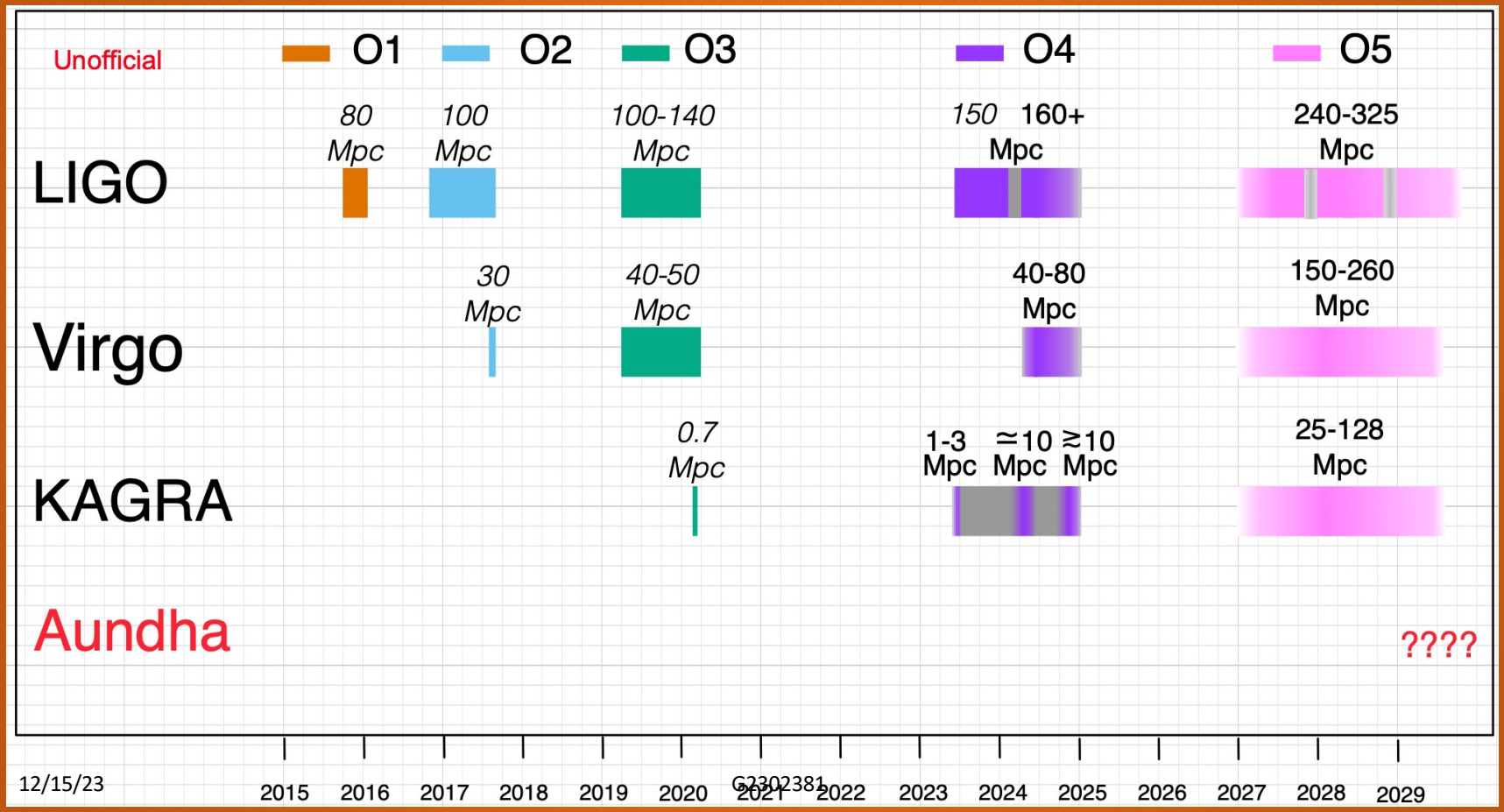
LIGO Aundha Observatory

The GW Network in the 2030's

- Having at least a 3-detector network is essential to localizing GW signals in the sky for follow-up by electromagnetic observers.



Future Plans

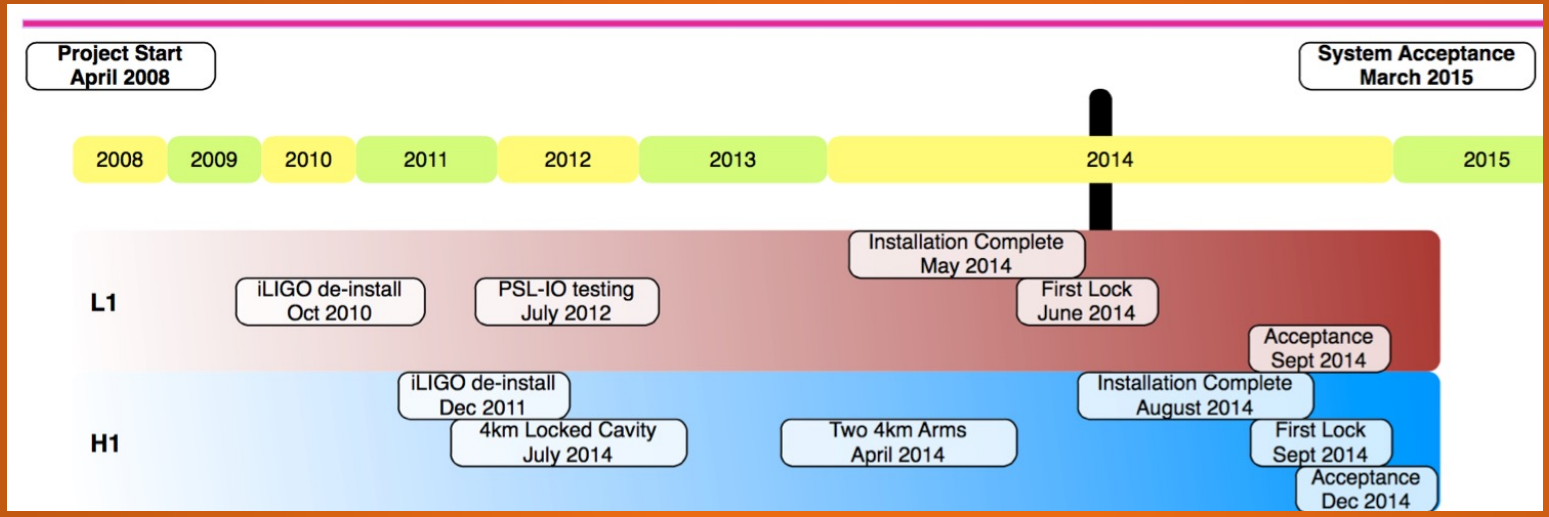


LIGO-India

- We are firmly in the era of Gravitational Wave Observations
- But it is still early days with fewer than 200 events so far discovered.
- The next decade will greatly expand our knowledge of GW sources, refine our tests of GR, allow an independent measurement of the Hubble constant and provide opportunity for exciting new discoveries.
- The LIGO Aundha Observatory will be a critical component of the global GW network.

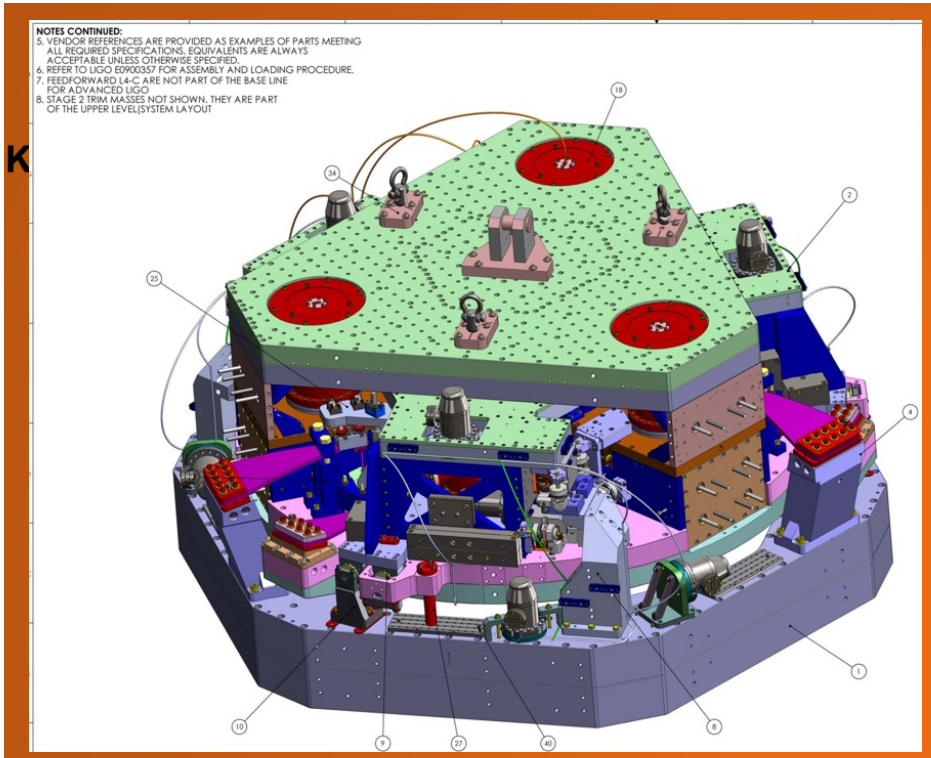
Extra Slides

Timeline: Advanced LIGO 2008 to 2015



- LIGO Aundha should be able to move much more rapidly from installation to acceptance.
- Benefits from the experience at LIGO-US sites.

K


NOTES CONTINUED:
5. VENDOR REFERENCES ARE PROVIDED AS EXAMPLES OF PARTS MEETING ALL REQUIRED SPECIFICATIONS. EQUIVALENTS ARE ALWAYS ACCEPTABLE UNLESS OTHERWISE SPECIFIED.
6. REFER TO LIGO E0900357 FOR ASSEMBLY AND LOADING PROCEDURE.
7. FEEDFORWARD L4-C ARE NOT PART OF THE BASE LINE FOR ADVANCED LIGO
8. STAGE 2 TRIM MASSES NOT SHOWN. THEY ARE PART OF THE UPPER LEVEL|SYSTEM LAYOUT

LIGO-India Training & Testing Laboratory

A dedicated laboratory building has been constructed meeting the unique requirements (vibration isolated floor slab, low acoustic noise and dust free clean ambience, etc.,) of LIGO-India Project related activities. The HVAC with HEPA filter is in the final phase.

80K Long Cryopump Fabrication & Testing

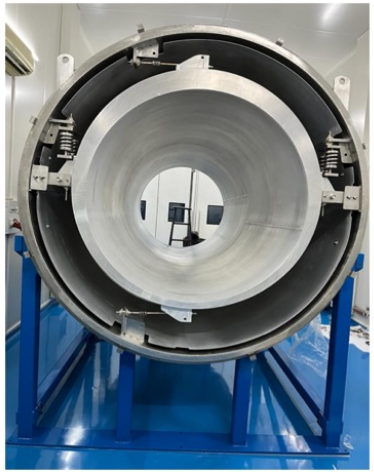


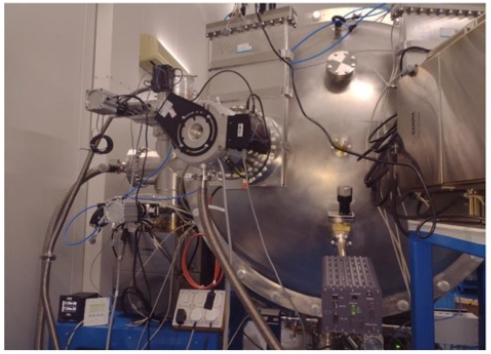


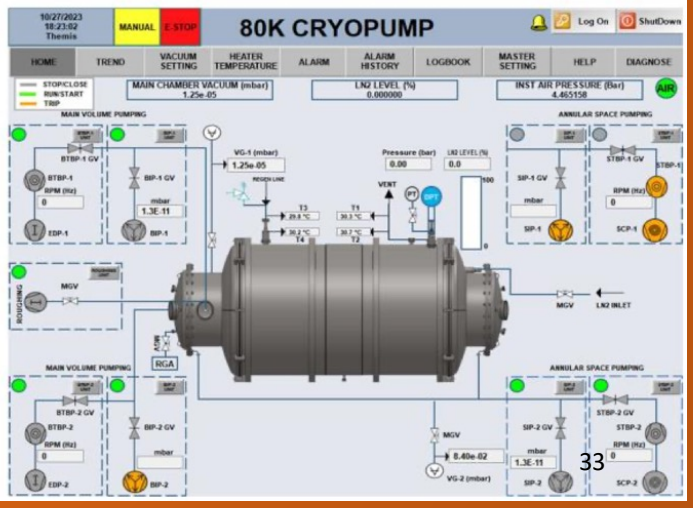
Insulated and cold shock tested


Al shield fabrication

80K Long Cryopump Assembly Integration & Testing

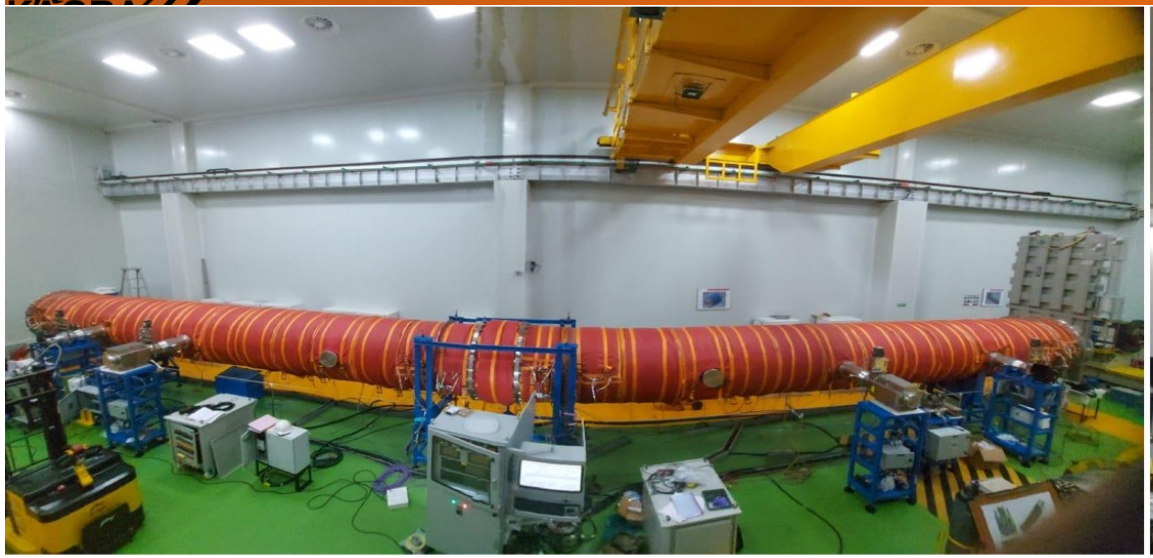






G2302381

2 x 10m Vacuum Vessel Integration and Testing



List of equipment's Integrated with Vacuum Vessel (IVV)-

- **Roughing Pump – 1 nos. (100 m^3 /min)**
- **Turbo Molecular Pump – 2 Nos, (Each of 850 l/s)**
- **Ion Pump – 2 nos, Each (Each of 800 l/s)**
- **RGA - 2 nos. (100 AMU)**
- **Combination Gauge – 3 nos. (Range - Atm – $5e10^{-10}$ mbar)**
- **Cold Cathode Gauge – 2 nos. (Range - Atm – 10^{-9} mbar)**
- **Large Gate valve – 1250 mm (50 inch)**

Annulus Pumping:

- **Turbo Molecular Pump – 2 Nos. (Each of 75 l/s)**