LIGO's First Detection of Gravitational Waves

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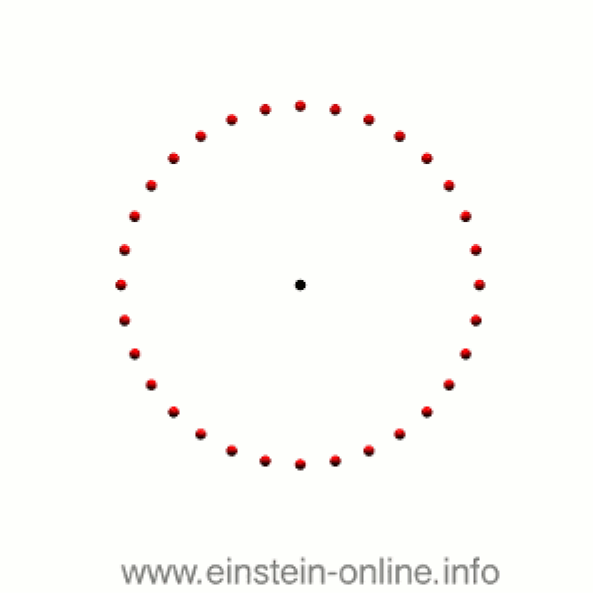
(Image and movie credits: LIGO.org)

What are gravitational waves?

Spiraling Black Holes
Animation created by the Simulating eXtreme Spacetimes (SXS) project

What do they look like?

- A ring of test particles that is 'hit' by a gravitational wave perpendicular to the screen will be deformed like this:



- They are very weak! the relative variation in size is one part in 10^{22}. This is the equivalent of measuring the distance from here to Alpha Centauri (4.37 light years) with a precision of microns.

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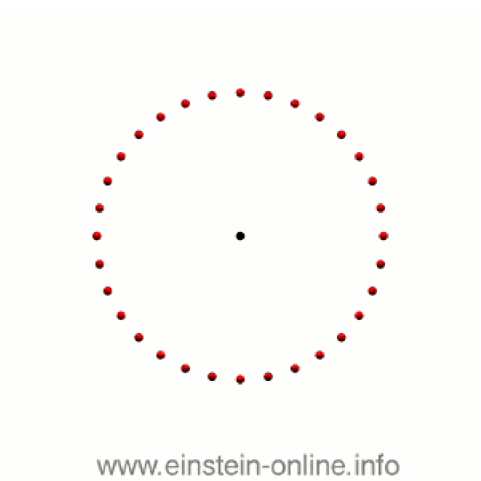
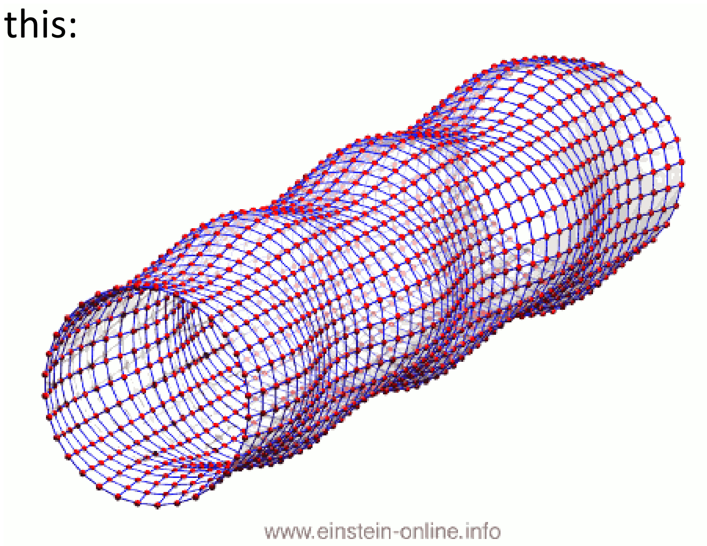




Gravitational waves do not interact with matter/fields between source and observer $\Rightarrow$ they shine a light in phenomena otherwise obscured by gas and dust (e.g., supernovae and GRB engines)

How do you detect GWs?

Most Precise Ruler Ever Constructed
Animation created by T. Pyle, Caltech/MIT/LIGO Lab

How do you detect GWs?

What did LIGO detect on Sept 14, 2015?

The merger of two black holes and the birth of a new one.

<u>Event GW150914</u>

Original black holes:

29 and 36 solar masses ($M_{\odot}$).

Final black hole:

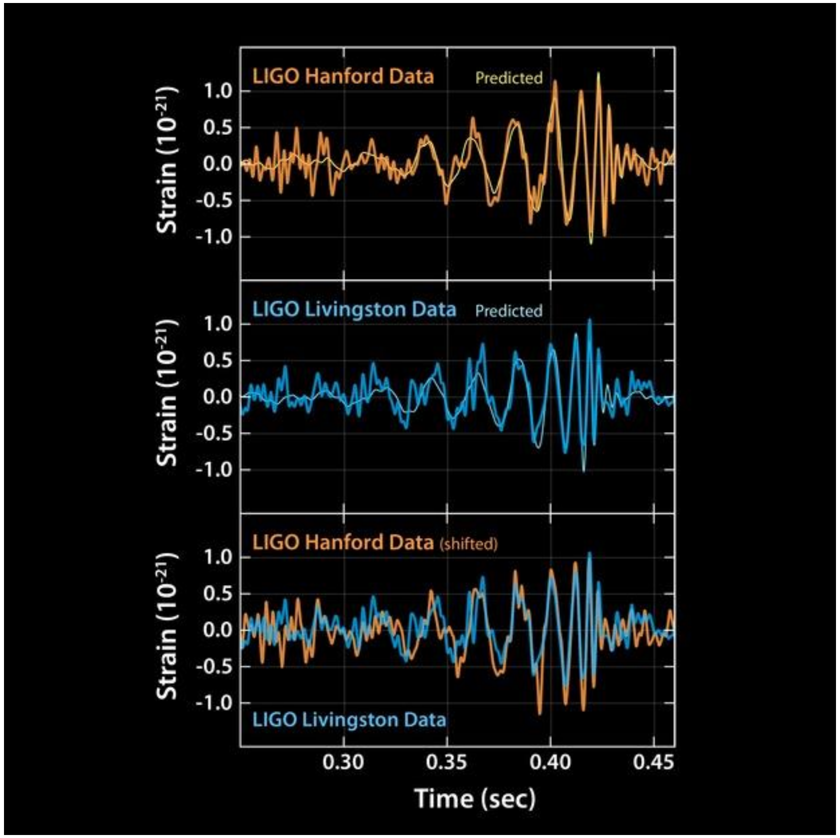
62 $M_{\odot}$ with dimensionless spin 0.67

Energy emitted: 3 $M_{\odot}$

Power emitted: 200 $M_{\odot}$ /s

(140 billion trillion times that of the Sun)

Most powerful explosion recorded not including the Big Bang!

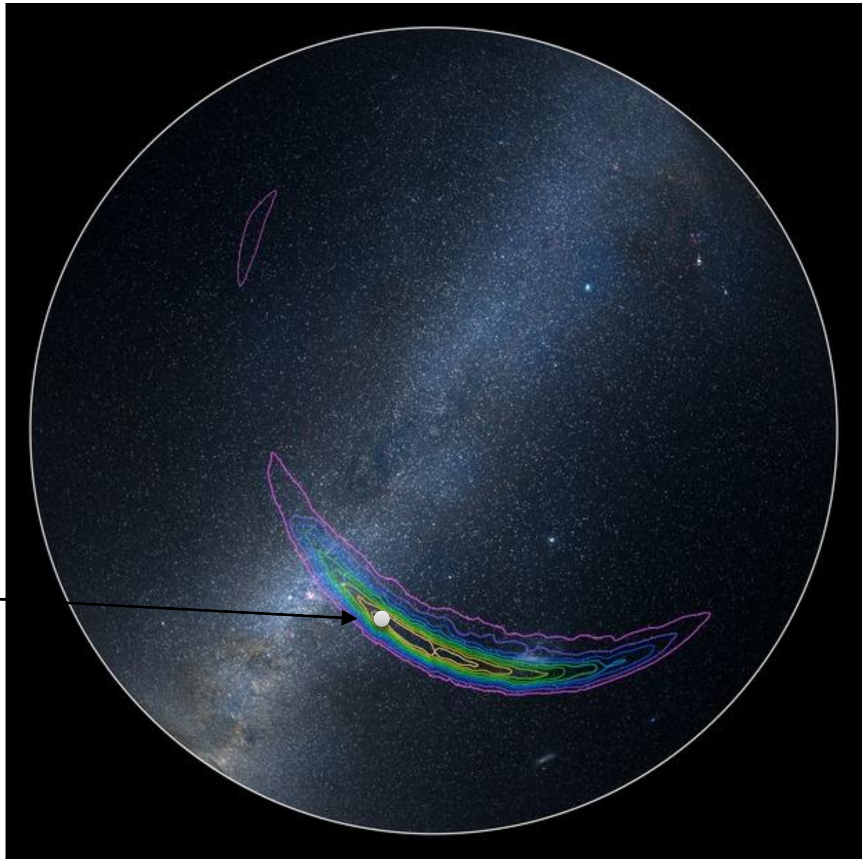


Where did this happen?

Distance: 410 Mpc or 1.3 Billion light-years
(redshift $z = 0.1$)

90% confidence area: 600 deg^2
(full moon area: 0.2 deg^2)

With LIGO India: 2-7 deg^2



Has a new era of GW Astrophysics started?

arXiv.org Search Results

Back to Search form | Next 14 results

The URL for this search is http://arxiv.org/find/all/1/ti:+GW150914/0/1/0/all/0/1

Showing results 1 through 25 (of 39 total) for ti:GW150914

1. arXiv:1604.00955 [pdf, other]
   AGILE Observations of the Gravitational Wave Event GW150914
   M. Tavani, C. Pittori, F. Verrecchia, A. Bulgarelli, A. Giuliani, I. Donnarumma, A. Argan, A. Trois, F. Lucarelli, M. Marisaldi, E. Del Monte, Y. Evangelista, V. Fioretti, A. Zoli, G. Piano, P. Munar-Adrover, L.A. Antonelli, G. Barbiellini, P. Caraveo, P.W. Cattaneo, E. Costa, M. Feroci, A. Ferrari, F. Longo, S. Mereghetti, G. Minervini, A. Morselli, L. Pacciani, A. Pellizzoni, P. Picozza, M. Pilia, A. Rappoldi, S. Sabatini, S. Vercellone, V. Vittorini, P. Giommi, S. Colafrancesco, M. Cardillo
   Comments: 20 pages, 6 figures. Submitted to the Astrophysical Journal Letters on April 1, 2016
   Subjects: **High Energy Astrophysical Phenomena (astro-ph.HE)**

2. arXiv:1603.08955 [pdf, other]
   Theoretical Physics Implications of the Binary Black-Hole Merger GW150914
   Nicolas Yunes, Kent Yagi, Frans Pretorius
   Comments: 39 pages, 15 figures, submitted to Phys. Rev. D
   Subjects: **General Relativity and Quantum Cosmology (gr-qc)**; High Energy Astrophysical Phenomena (astro-ph.HE); High Energy Physics - Phenomenology (hep-ph); High Energy Physics - Theory (hep-th)

3. arXiv:1603.08338 [pdf, ps, other]
   Primordial black hole scenario for the gravitational wave event GW150914
   Misao Sasaki, Teruaki Suyama, Takahiro Tanaka, Shuichiro Yokoyama
   Comments: 7 pages, 1 figure
   Subjects: **Cosmology and Nongalactic Astrophysics (astro-ph.CO)**; General Relativity and Quantum Cosmology (gr-qc)

4. arXiv:1603.06585 [pdf, ps, other]
   XMM-Newton Slew Survey observations of the gravitational wave event GW150914
   E. Troja, A. M. Read, A. Tiengo, R. Salvaterra
   Comments: 6 pages, 3 figures, 2 tables. Accepted for publication in ApJ Letters
   Subjects: **High Energy Astrophysical Phenomena (astro-ph.HE)**; Instrumentation and Methods for Astrophysics (astro-ph.IM)

5. arXiv:1603.02635 [pdf, other]
   Contraints on cosmological viscosity from GW150914 observation
   Gaurav Goswami, Subhendra Mohanty, A. R. Prasanna
   Comments: 5 pages, 3 figures
   Subjects: **High Energy Physics - Phenomenology (hep-ph)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); General Relativity and Quantum Cosmology (gr-qc)

6. arXiv:1602.08764 [pdf, other]
   iPTF Search for an Optical Counterpart to Gravitational Wave Trigger GW150914
   M. M. Kasliwal, S. B. Cenko, L. P. Singer, A. Corsi, Y. Cao, T. Barlow, V. Bhalerao, E. Bellm, D. Cook, G. E. Duggan, R. Ferretti, D. A. Frail, A. Horesh, R. Kendrick, S. R. Kulkarni, R. Lunnan, N. Palliyaguru, R. Laher, F. Masci, I. Manulis, A. A. Miller, P. E. Nugent, D. Perley, T. A. Prince, R. A. Quimby, J. Rana, U. Rebbapragada, B. Sesar, A. Singhal, J. Surace, A. Van Sistine
   Comments: Revised
   Subjects: **Instrumentation and Methods for Astrophysics (astro-ph.IM)**; High Energy Astrophysical Phenomena (astro-ph.HE)

7. arXiv:1602.08759 [pdf, other]

What do these papers report?

- 12 papers from the LIGO and Virgo Scientific Collaborations
  - First direct evidence of Binary Black Holes that inspire and merger within the age of the Universe
  - BHs are relatively heavy ($M \geq 25\ M_{\odot}$) $\Rightarrow$ weak massive stellar winds $\Rightarrow$ low metallicity environments.
- 12 papers from EM & Neutrino counterpart searches (all but one with negative results)
- 7 papers about the possible association between a Fermi GBM event and GW150914
- 8 about GW150914 detection implications for gravitational theory

Observing Strong & Dynamical Gravitational Fields

First observations of strong gravitational fields:

- Solar sytem gravitational tests: $M/R \sim 10^{-5}$; GW150914: $M/R \sim 1$

GW150914 merger places constraints on:

- The type of final object (gravastars & boson stars are ruled out)

GW150914 radiation mechanism places constraints on:

- The presence of dipole radiation (e.g. due the scalar fields)
- BH mass leakage due to large extra dimensions
- Time variation of Newtonian constant G (Local Position Invariance)
- Lorentz Invariance effects in emission

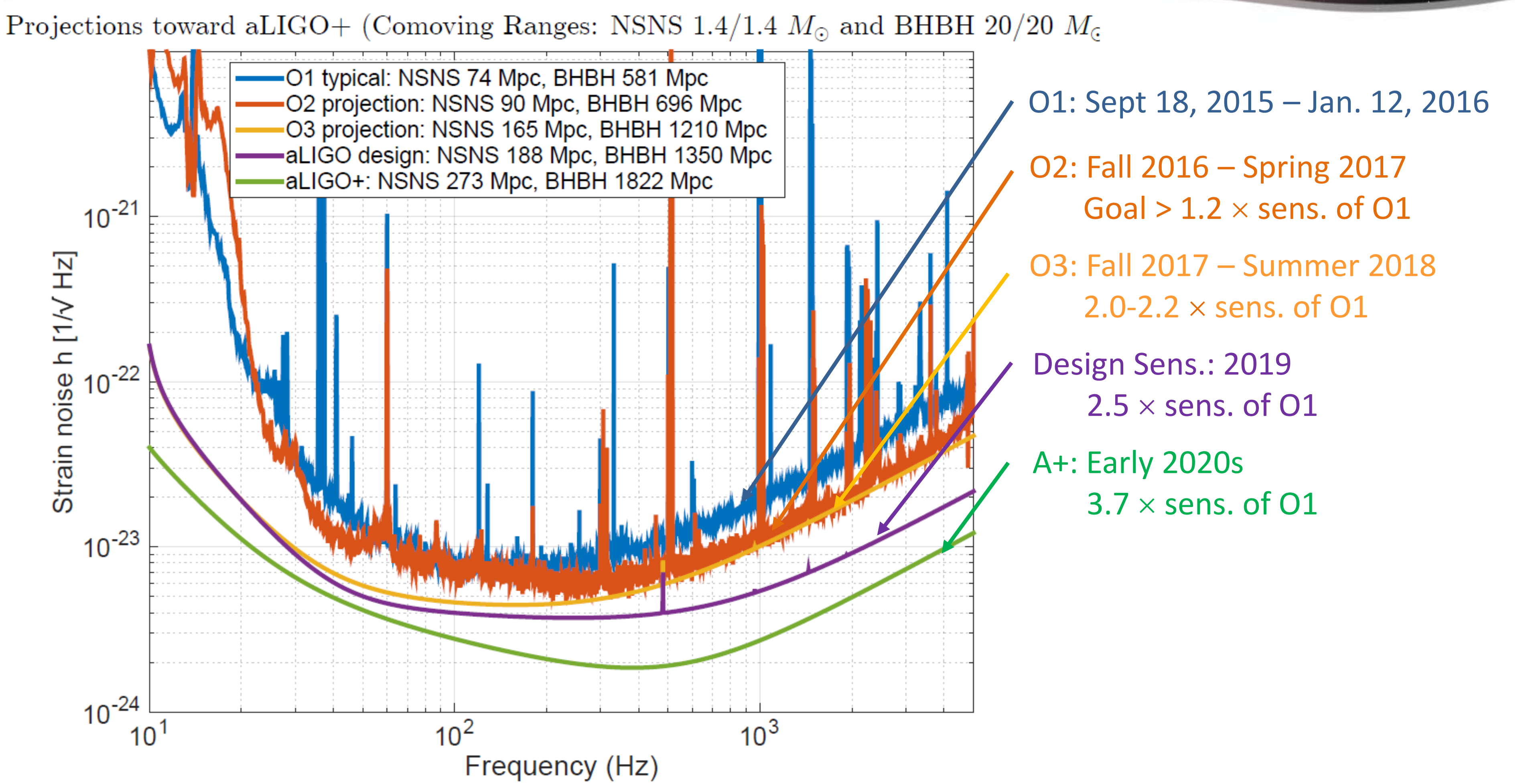
GW150914 propagation mechanism places constraints on:

- Dispersion relation of GWs
  - Graviton mass (10^{-22} eV or 2 10^{-58} Kg)
  - Lorentz Invariance effects in propagation
  - Shapiro delay freq.-dependent violations
  - Cosmological fluids viscosity

Abbott et al., Blas et al., Chirenti & Rezzolla, Ellis et al., Goswami et al., Kahya & Desai, Yunes et al.

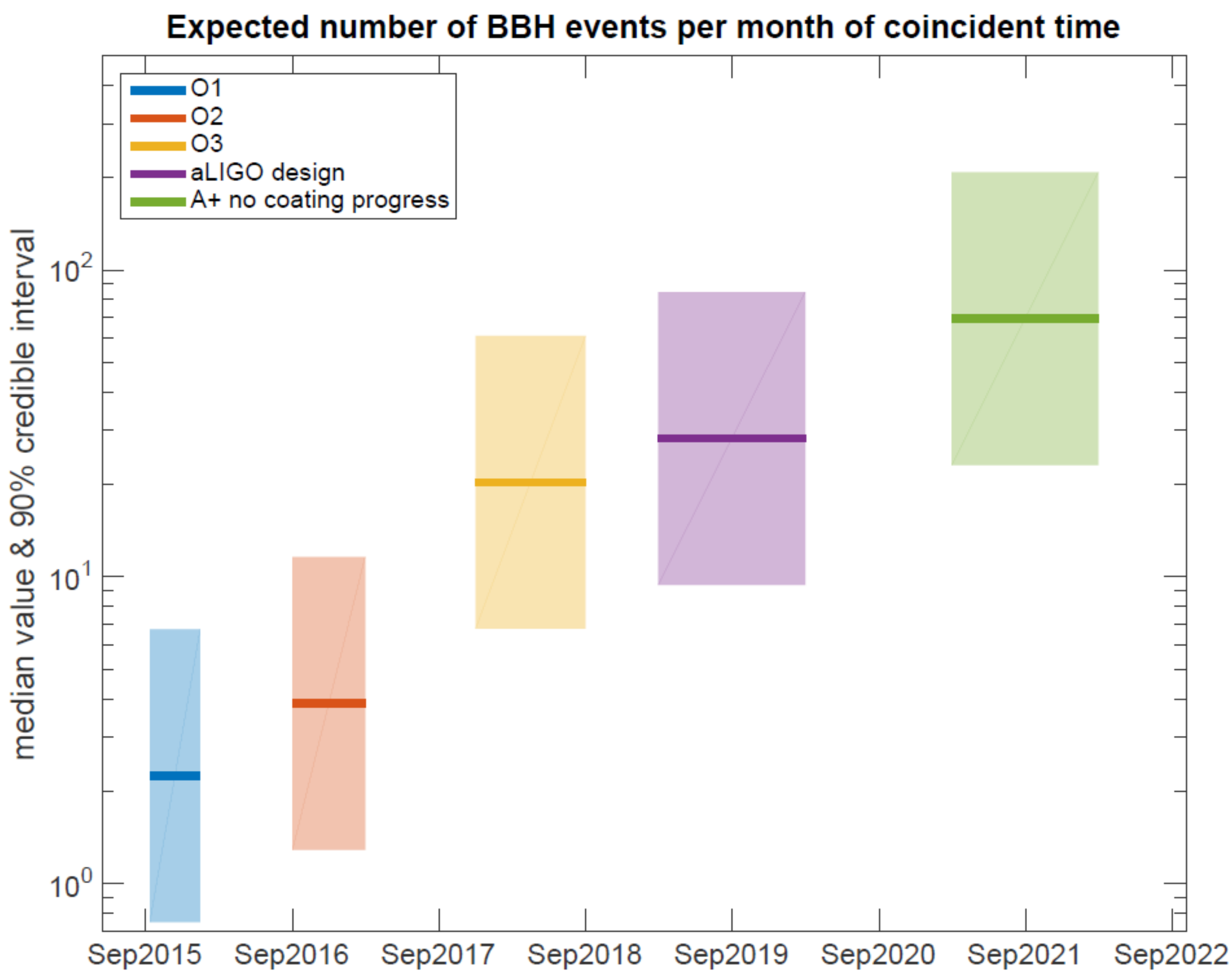
Advanced LIGO

Comissioning & Future Upgrades



Advanced LIGO

Estimated Event Rates



What is Next for LIGO?
LIGO India

- In 2012 NSF approved the delay in installation of the 2nd Hanford interferometer, studying the possibility of a LIGO India site.
- In Feb. 2016, the Indian Gov. approved (in principle) the construction of LIGO India.
- Last week NSF and Indian Dep. of Atomic Energy (DAE) and Dep. of Science and Techn. (DST) signed the MoU in the presence of the Indian Prime Minister N. Modi.
- Construction to start in 2017 and operations around 2023

Signing of LIGO India MoU

Indian PM meets with NSF and LIGO delegations

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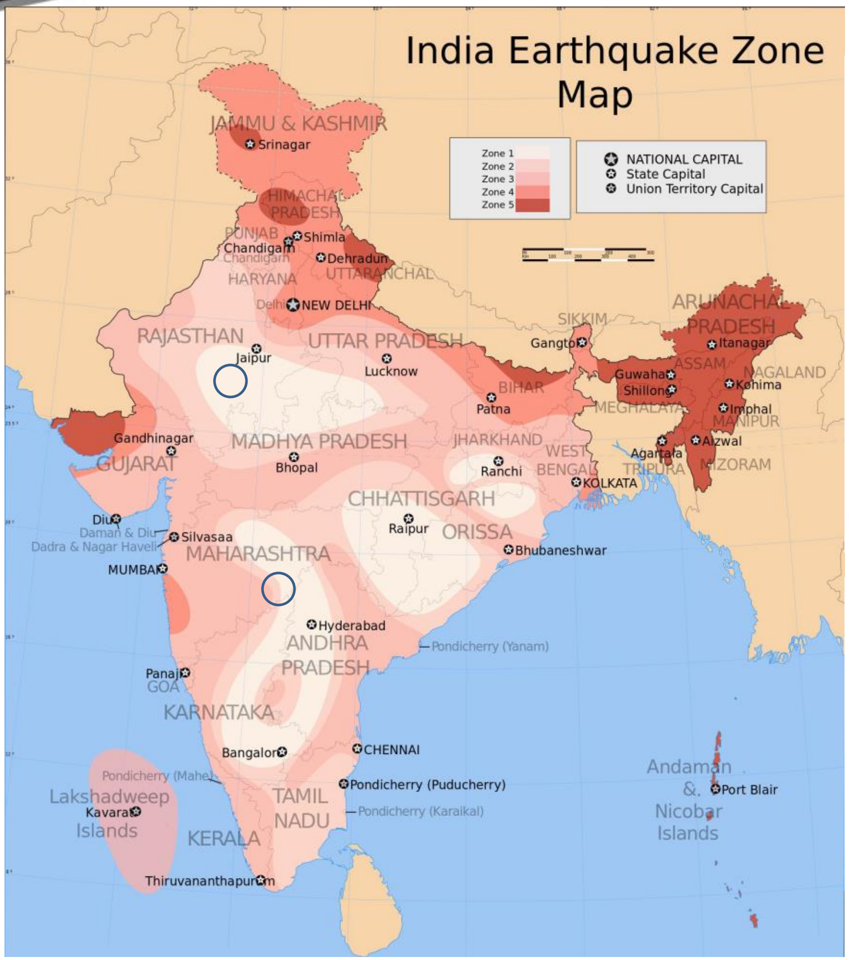
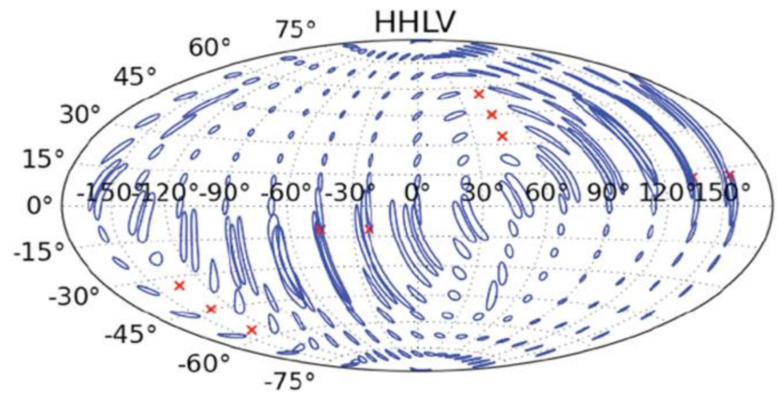
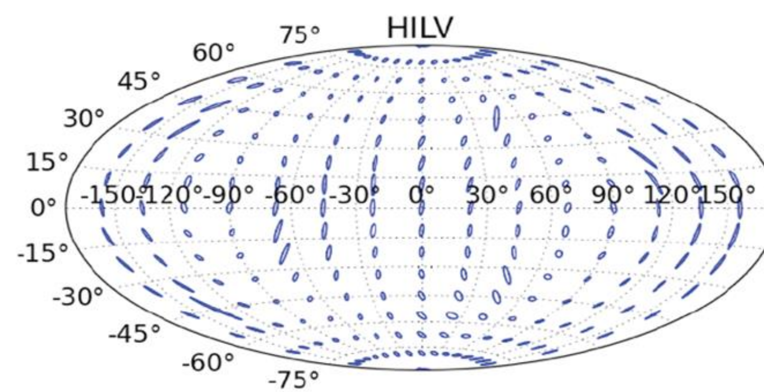




Fairhurst 2011

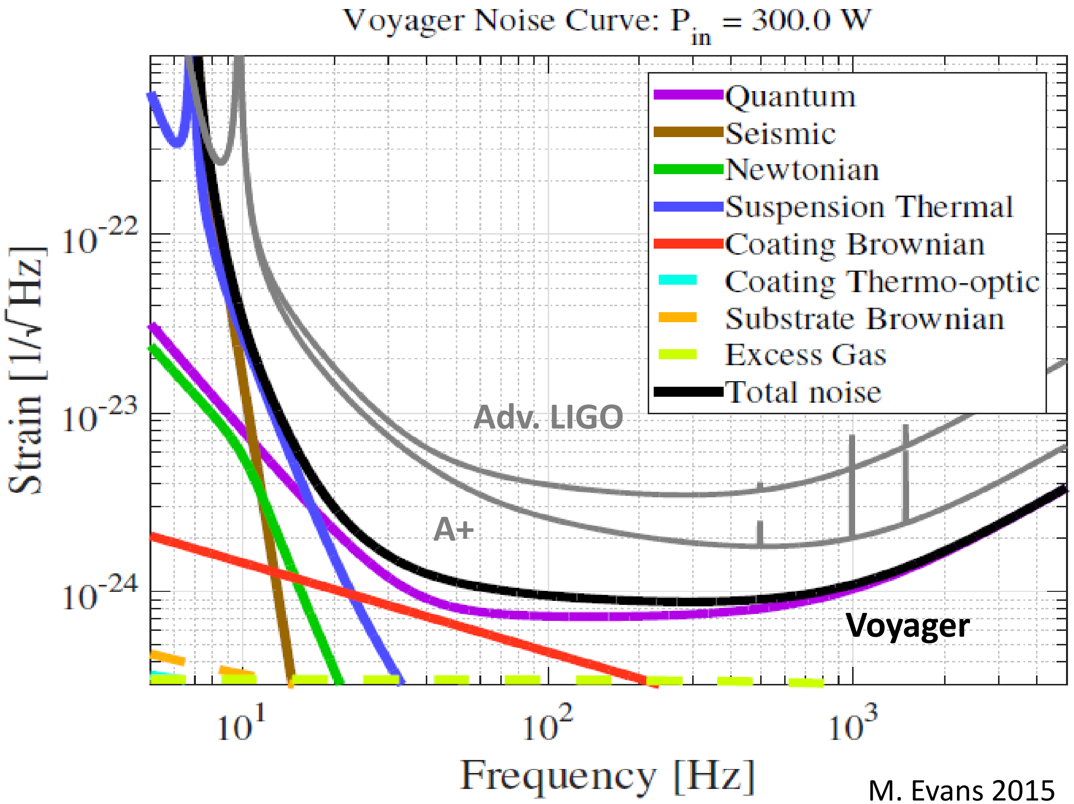
Red crosses denote regions where the network has blind spots



Currently two sites are under consideration.
Decision to be announced next week.

What is Next for LIGO? Voyager

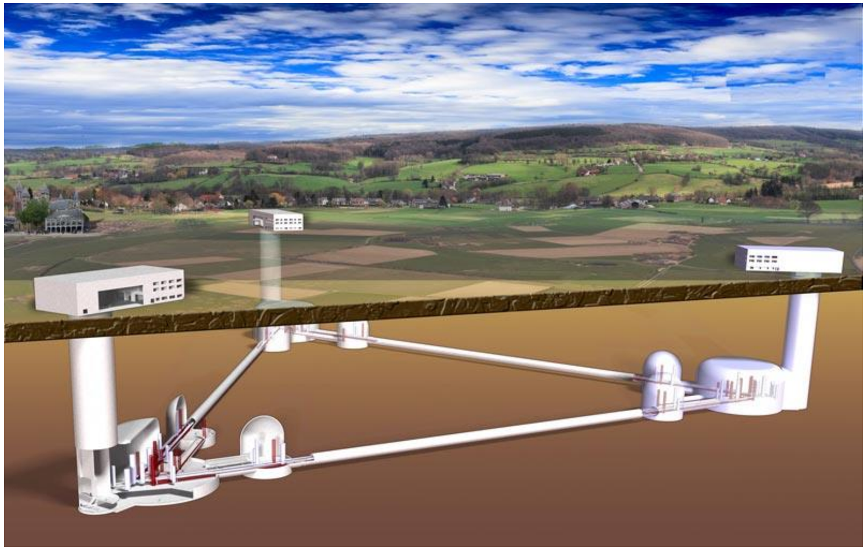
- Voyager represents a design of the best that can be done with the current LIGO sites.
- It could start in middle to late 2020s.
- New laser (1550nm, 300W).
- Larger and cryogenic mirrors and suspensions (sapphire).



M. Evans 2015

What is Next for LIGO? Cosmic Explorer / Einstein Telescope

- Design studies are very preliminary (ET) or non-existent (CE).
- Construction would start in 10-15 years.
- ET: Underground, triangular geometry, 10km arm-length,
- CE: L-shaped, 40km arm-length



Thank you!

After half a century unwavering support from NSF and the stoic efforts of the gravitational physics community, LIGO has detected GWs marking the dawn of a new field.

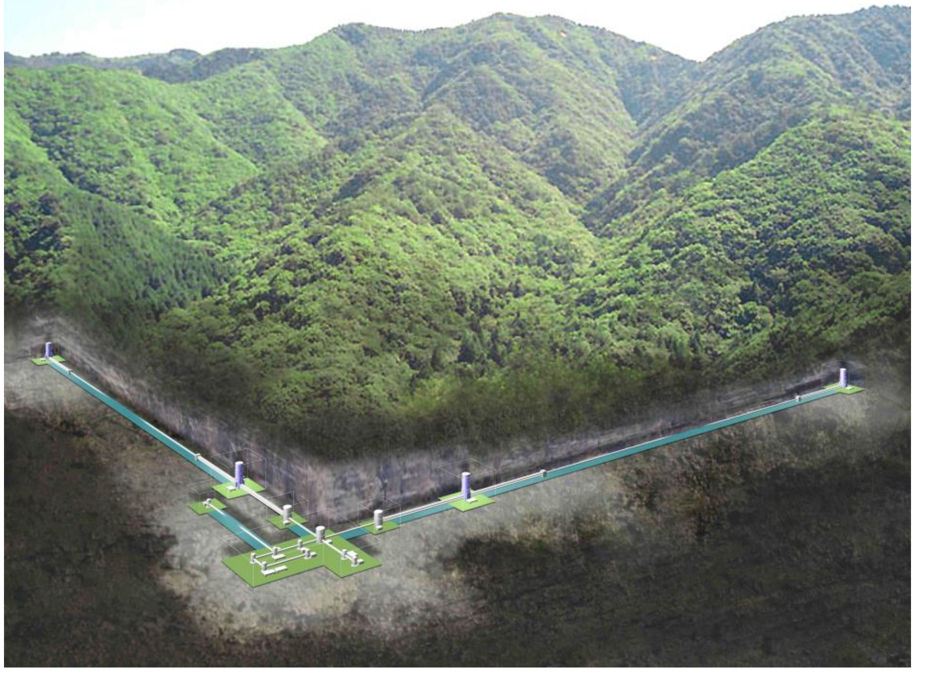
This is just the beginning: stay tuned for the next LIGO paper!

Advanced VIRGO (Cascina, Italy)

- Franco-Italian collaboration (19 institutes across Europe).
- Dimensions: 3km x 3km.
- Initial Virgo observed from 2008 to 2010.
- Advanced Virgo Avanzado is under construction with operations expected in 2016/17.

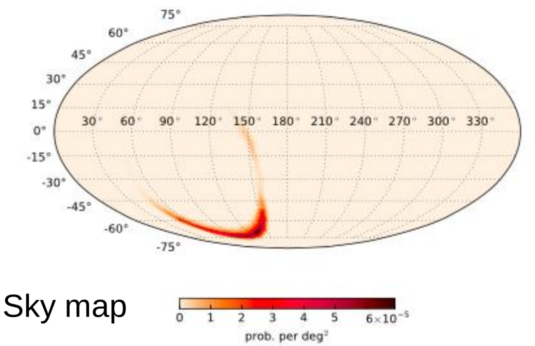
KAGRA (Kamioka, Japan)

- Underground project. Cryogenic mirrors and suspsensions (~123K). 200 scientists from more than 60 Japanese institutions.
- Arm-length 3km x 3km.
- Kagra is under construction, operations are planned for 2018.

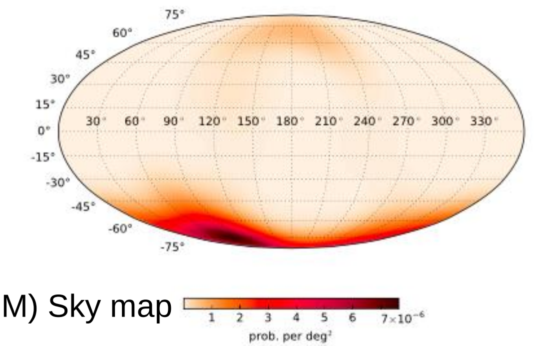


Most asked questions about GWs

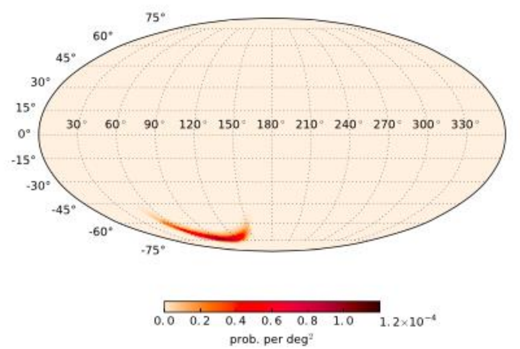
Has an EM counterpart of GW150914 been detected?

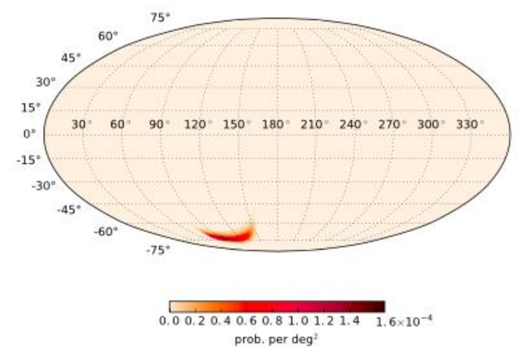


LIGO Sky map



Fermi (GBM) Sky map





LIGO + Fermi Sky maps