

Title: Prospects for GW transients in early Advanced LIGO and Virgo science runs

Date: Feb 06, 2013 02:00 PM

URL: <http://pirsa.org/13020124>

Abstract: Advanced LIGO (aLIGO) and Advanced Virgo (AdV) are kilometer-scale gravitational wave (GW) detectors that are expected to yield the first

direct observations of gravitational waves. I will&nbsp;&nbsp;  describe the

currently projected schedule, sensitivity, and sky

localization accuracy for the GW detector network in the next decade.</span>

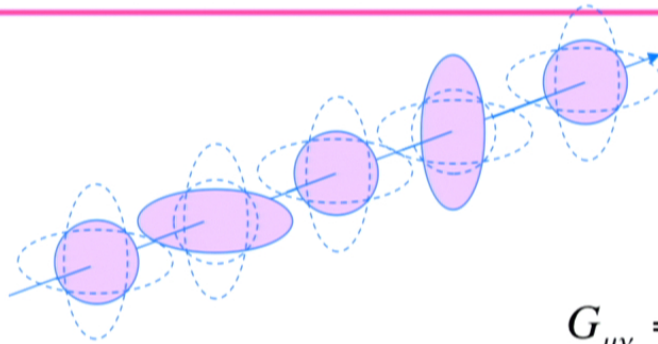
# Prospects for GW transients in early Advanced LIGO and Virgo science runs

Gabriela González  
Louisiana State University

For the LIGO Scientific Collaboration and  
the Virgo Collaboration  
Perimeter Institute  
February 6, 2013



# Gravitational waves

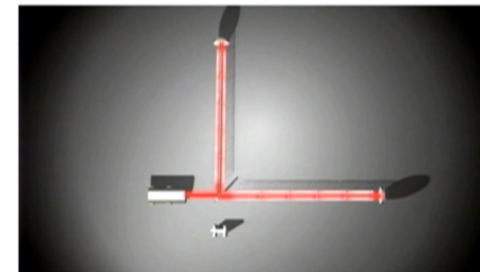
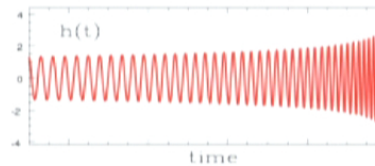
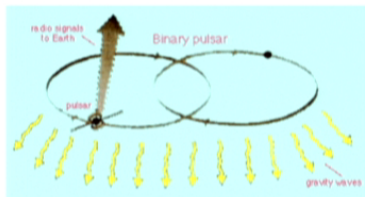


Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

$$G_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu} \quad (= 0 \text{ in vacuum})$$

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \quad h_{\mu\nu} = \frac{2G}{c^4 r} \ddot{I}_{\mu\nu} \quad h = \frac{\Delta L}{L}$$

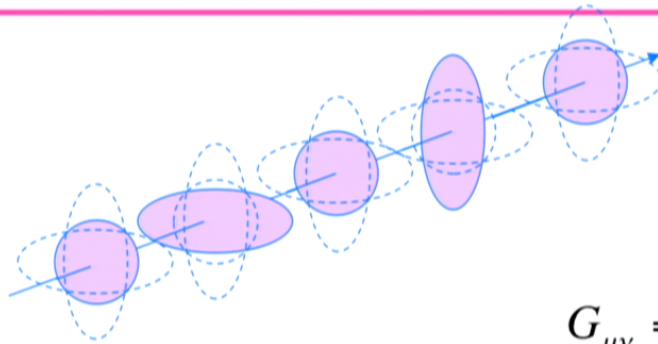
$$h \approx \frac{4\pi^2 G M R^2 f_{orb}^2}{c^4 r}$$



LIGO-G1300012

2

# Gravitational waves

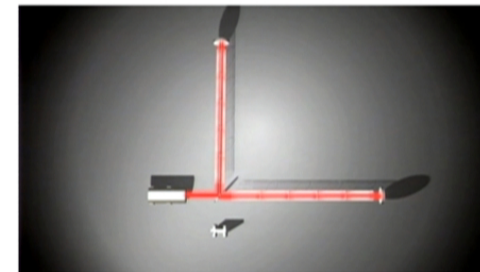
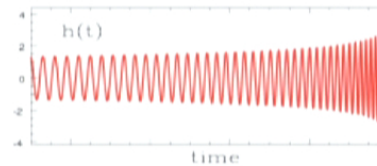
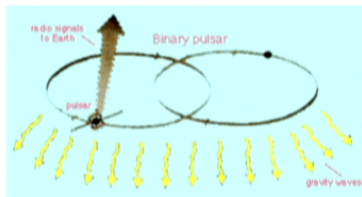


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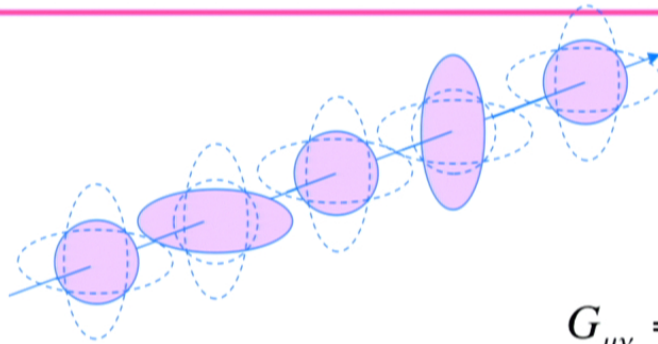
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LIGO-G1300012

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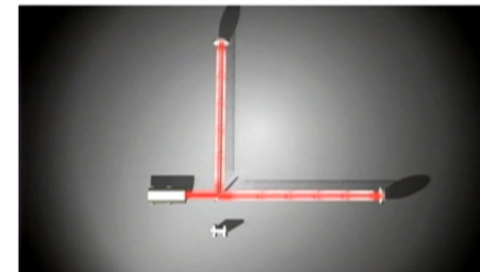
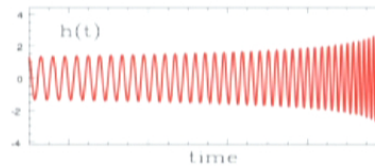
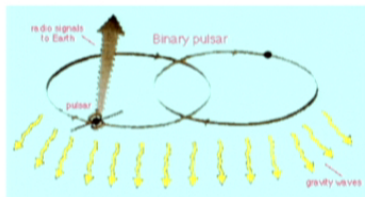


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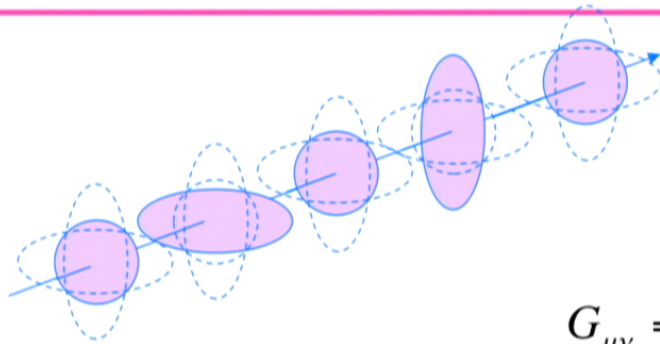
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LIGO-G1300012

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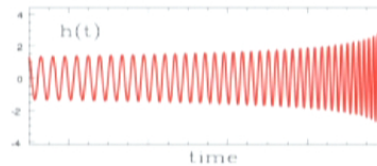
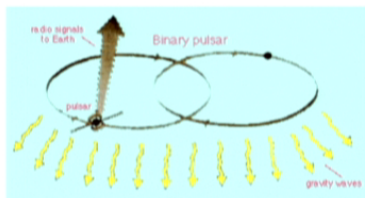


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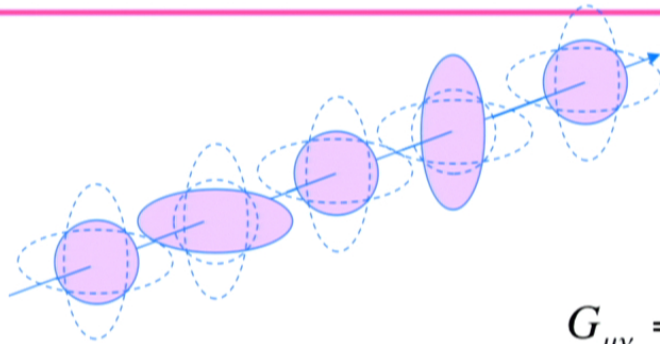
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LIGO-G1300012

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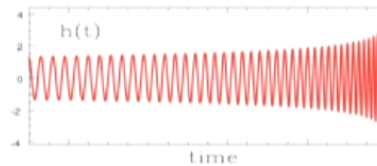
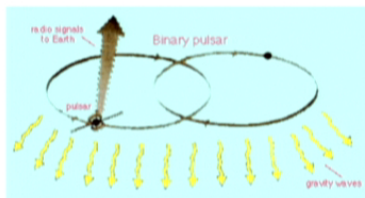


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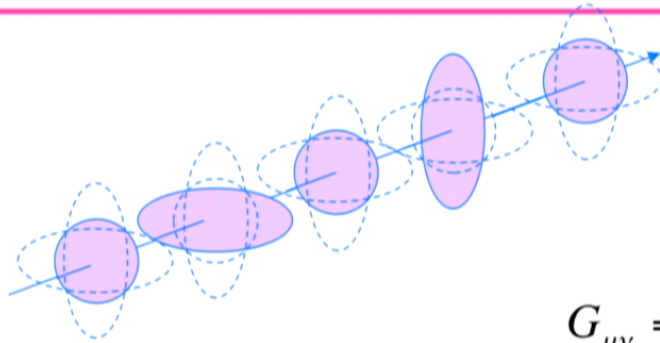
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LIGO-G1300012

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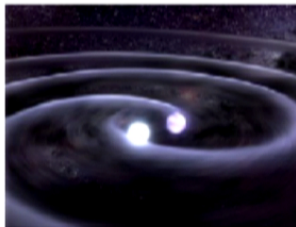


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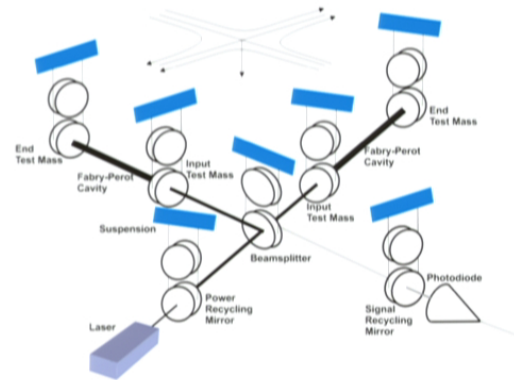
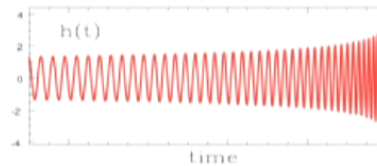
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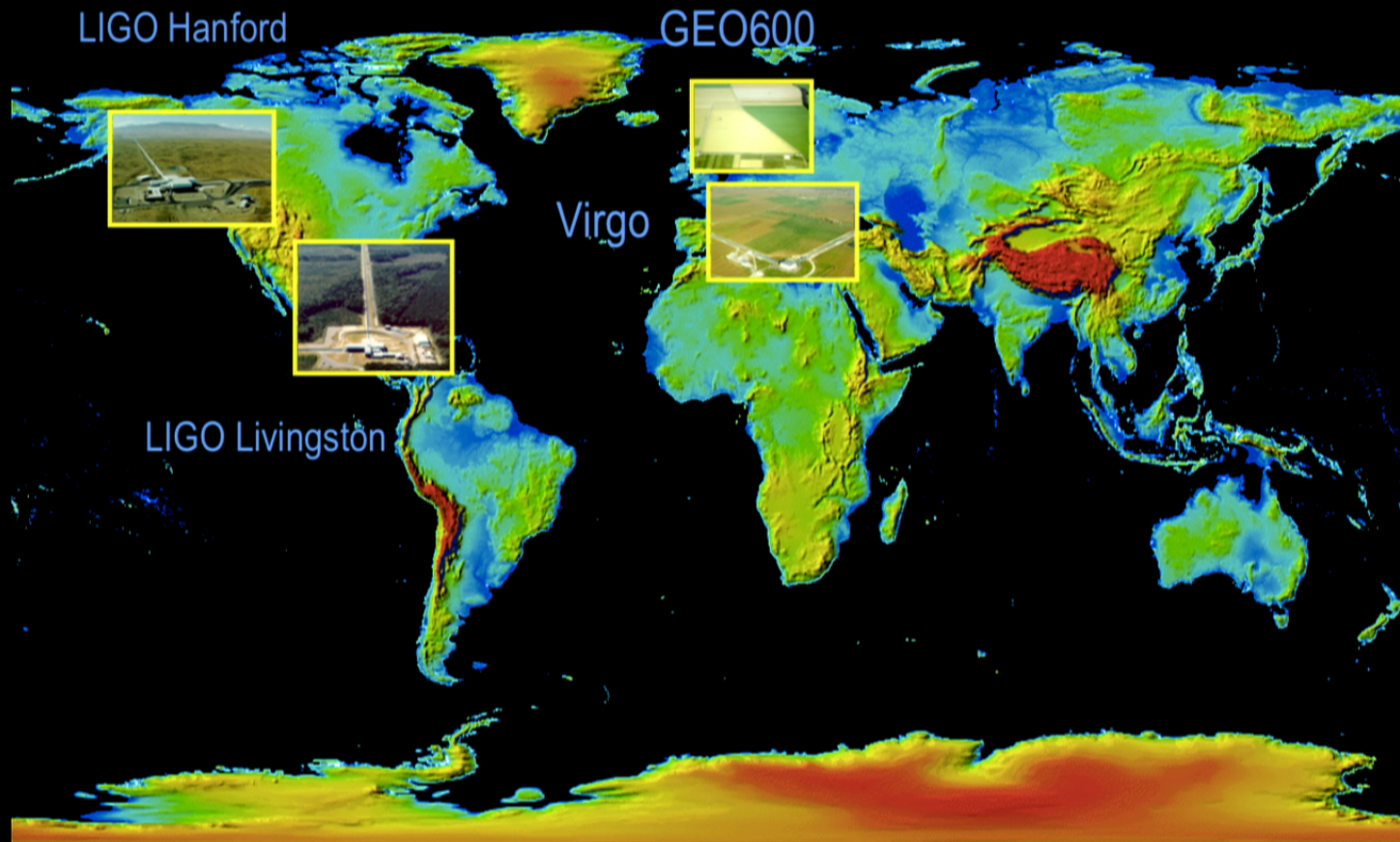


LIGO-G1300012

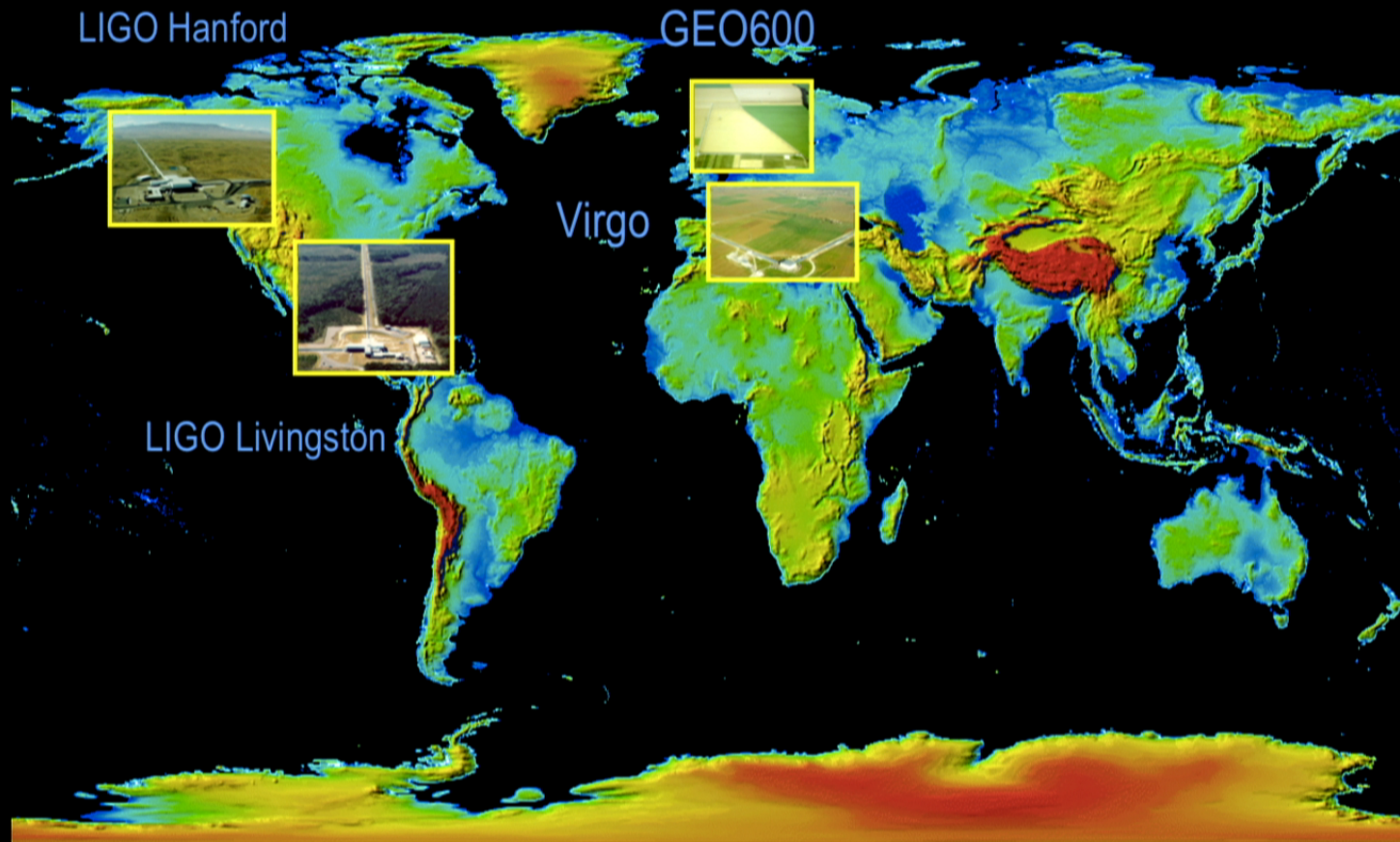




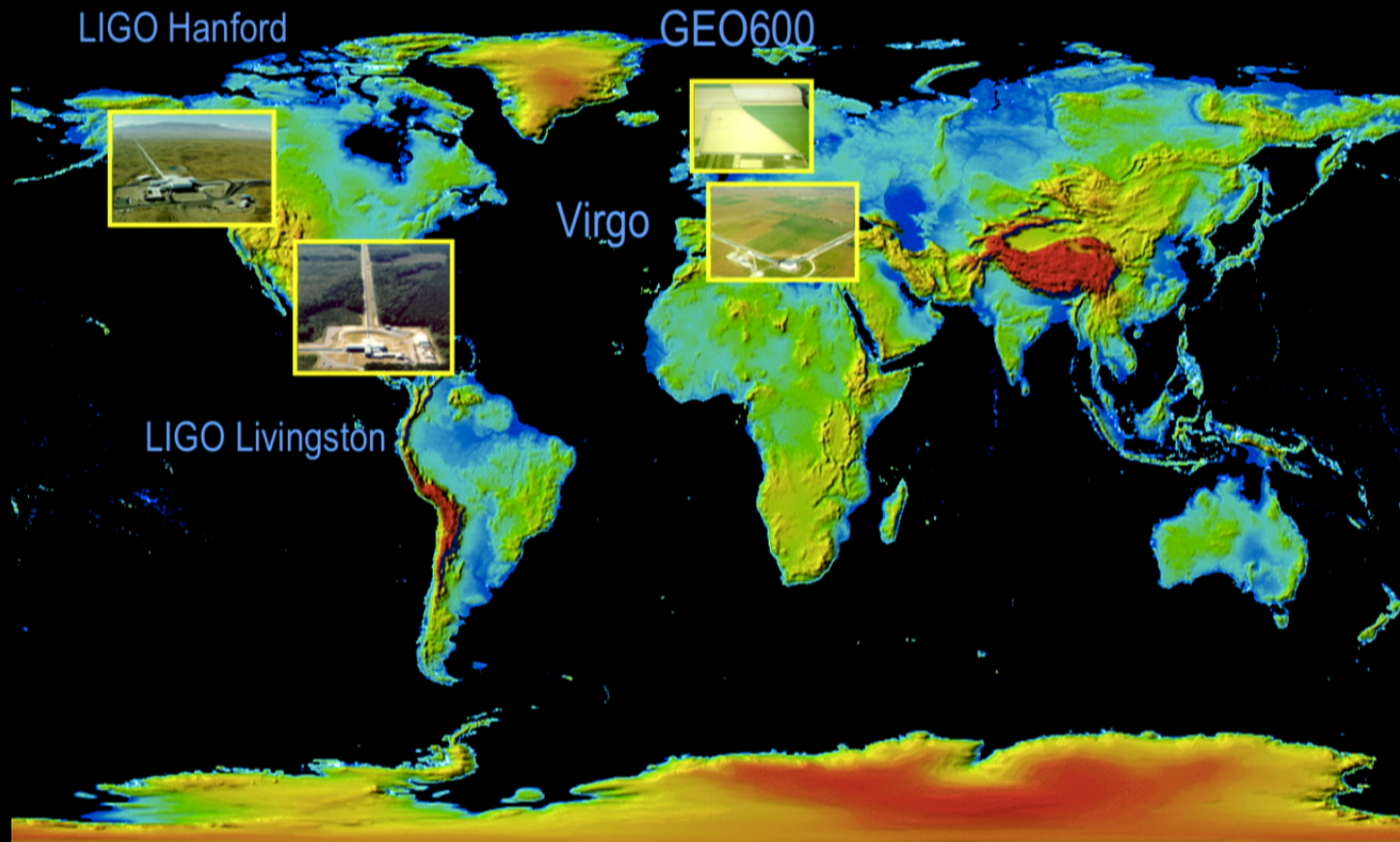
# *The GW Detector Network 2005-2010*



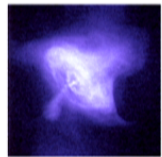
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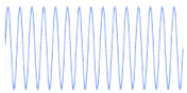
# *The GW Detector Network 2005-2010*



# LIGO Detectors 2009-10 (S6)

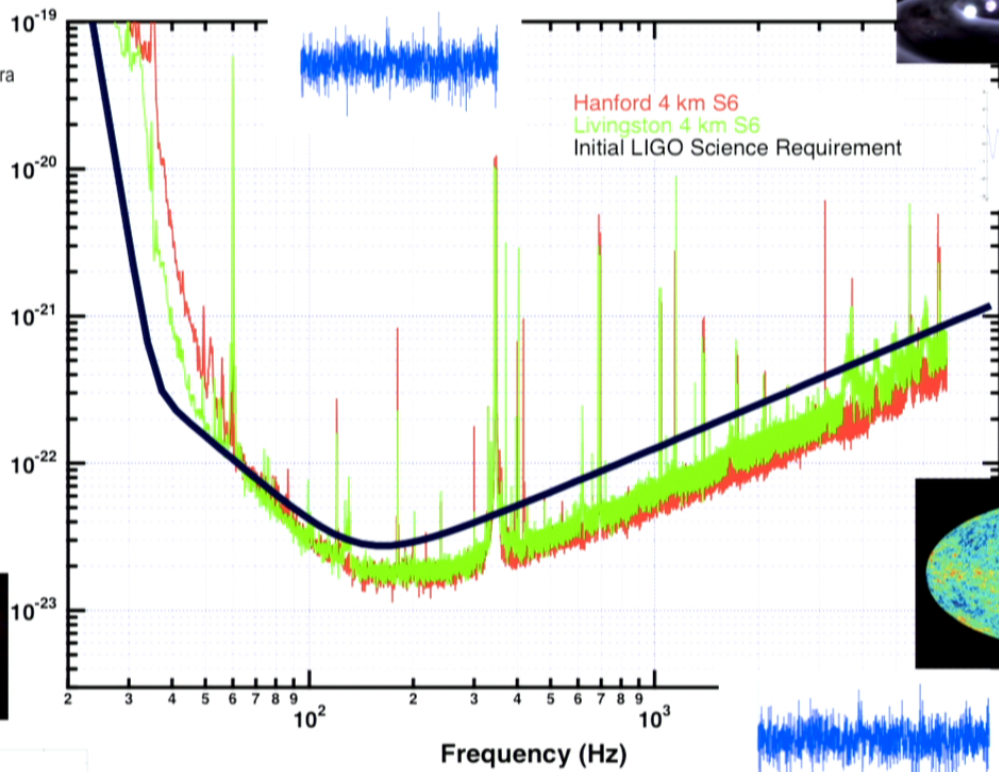


Crab pulsar (NASA, Chandra Observatory)

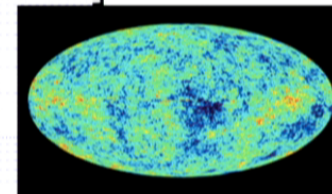
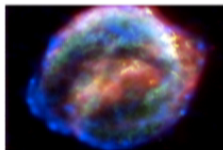
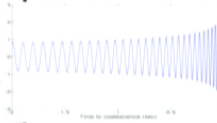
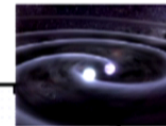


Strain ( $1/\sqrt{\text{Hz}}$ )

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Hanford 4 km S6  
Livingston 4 km S6  
Initial LIGO Science Requirement



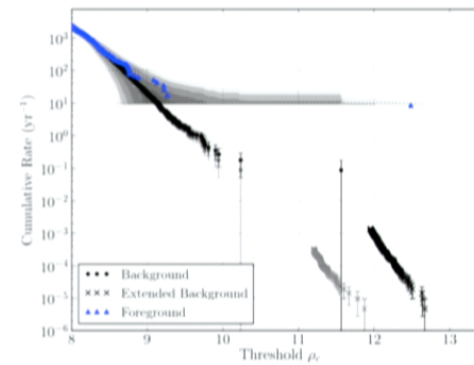
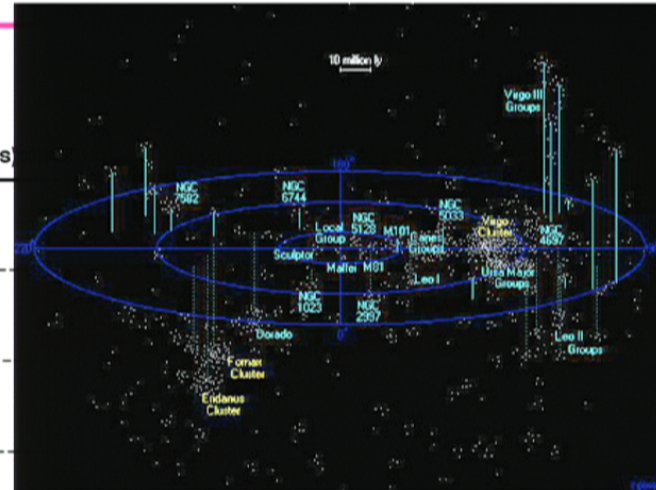
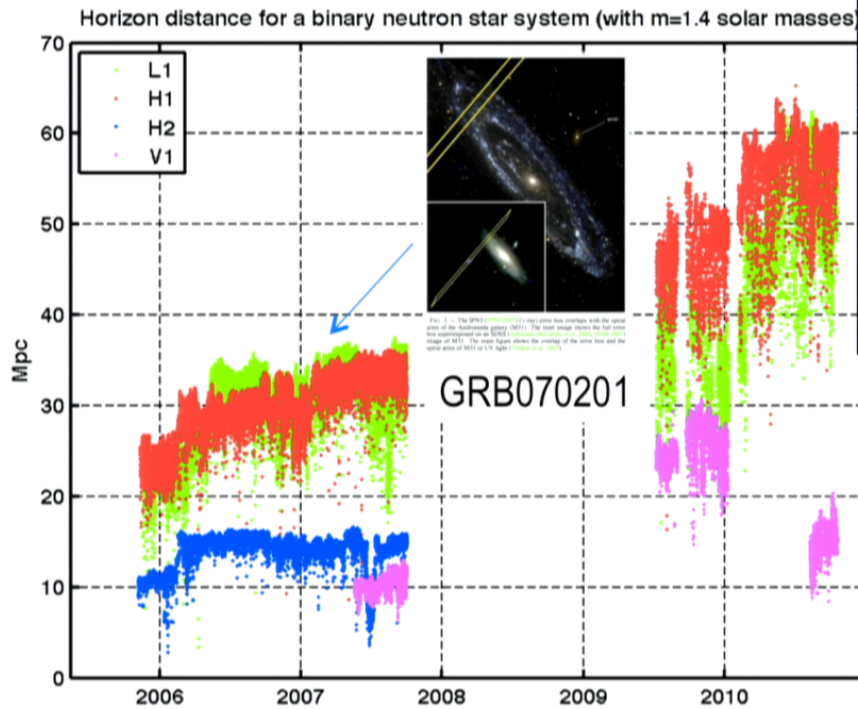
NASA, WMAP



Find all LSC results and publications in [www.ligo.org](http://www.ligo.org)  
<https://www.lsc-group.phys.uwm.edu/ppcomm/Papers.html>

# LIGO-Virgo detectors 2005-2011

[Astrophys. J. 681 \(2008\) 1419](#)



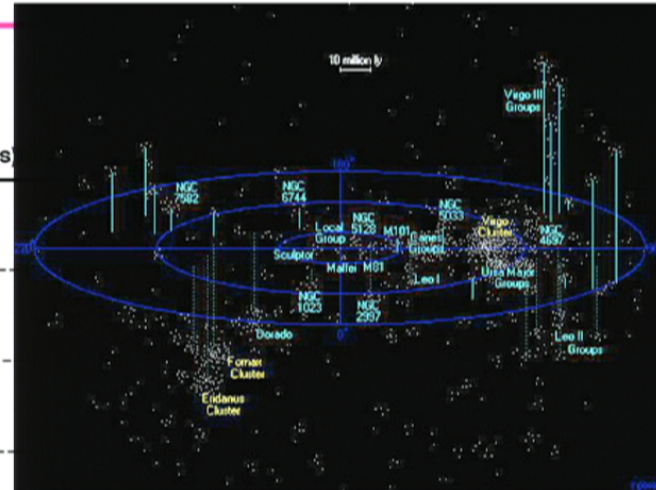
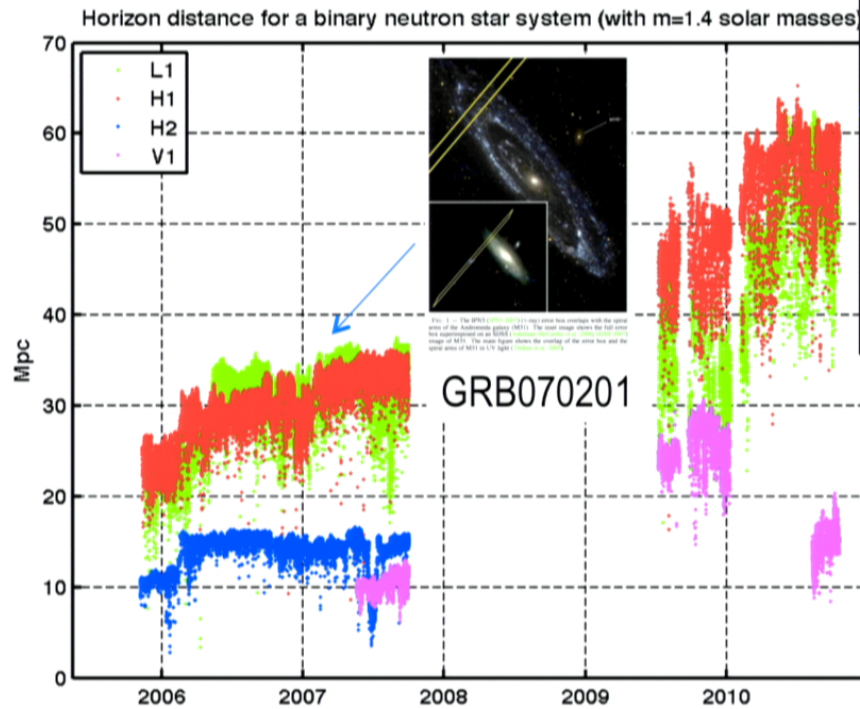
[Phys. Rev D85 \(2012\) 082002](#)

LIGO-G1300012

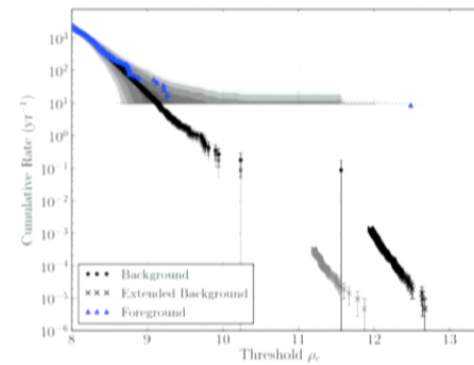
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[Astrophys. J. 681 \(2008\) 1419](#)



atlasoftheuniverse.com



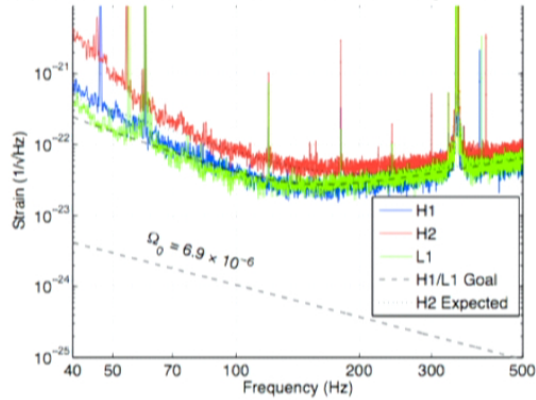
[Phys. Rev D85 \(2012\) 082002](#)

LIGO-G1300012

6

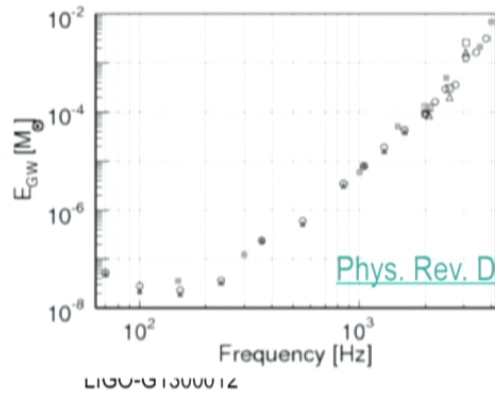
# Some LVC Results from 2005-2011

Upper limit on GW stochastic background



[Nature 460 \(2009\) 990](#)

Upper limit on GW energy emitted by generic sources at 10 kpc



[Phys. Rev. D 81 \(2010\) 102001](#)

## SUMMARIES OF LSC SCIENTIFIC PUBLICATIONS

We now feature, for each new research article, a summary written for the general public. Summaries are listed in reverse chronological order.

- Oct 01, 2012** [Dance of the Dead Stars: A Search for Massive Binary Black Hole Coalescences](#)
- Aug 03, 2012** [Hunting Continuous Gravitational Waves with the Einstein@Home Distributed Computing System](#)
- May 15, 2012** [New Cosmic Messengers: First Joint Search for Gravitational Waves and High Energy Neutrinos](#)
- May 11, 2012** [A Search for Gravitational Waves from Gamma-Ray Bursts](#)
- May 08, 2012** [X-Rays and Gravitational Waves: LIGO and Virgo Point the Way for the Swift Satellite](#)
- Apr 02, 2012** [Virgo Data Characterization and Impact on Gravitational Wave Searches](#)
- Mar 14, 2012** [Sensitivity of LIGO and Virgo Gravitational Wave Detectors to Compact Binary Inspirals](#)
- Feb 15, 2012** [Listening for gravitational-waves with "ears wide open"](#)
- Feb 06, 2012** [Optical, X-ray, and Radio Telescopes Seek Explosive Sources of Gravitational Waves](#)
- Jan 31, 2012** [Search for Gravitational Waves from Intermediate Mass Binary Black Holes](#)
- Jan 23, 2012** [Implications for the origin of GRB 051103 from LIGO observations](#)
- Jan 11, 2012** [First Low-Latency LIGO+Virgo Search for Binary Inspirals and their Electromagnetic Counterparts](#)
- Jan 03, 2012** [Directional limits on persistent gravitational waves using LIGO S5 science data](#)
- Dec 21, 2011** [Upper limits on a stochastic GW background using LIGO and Virgo interferometers at 600-1000 Hz](#)
- Dec 01, 2011** [A search for gravitational waves from inspiraling neutron stars and black holes](#)
- Sep 11, 2011** [A gravitational wave observatory operating beyond the quantum shot-noise limit](#)

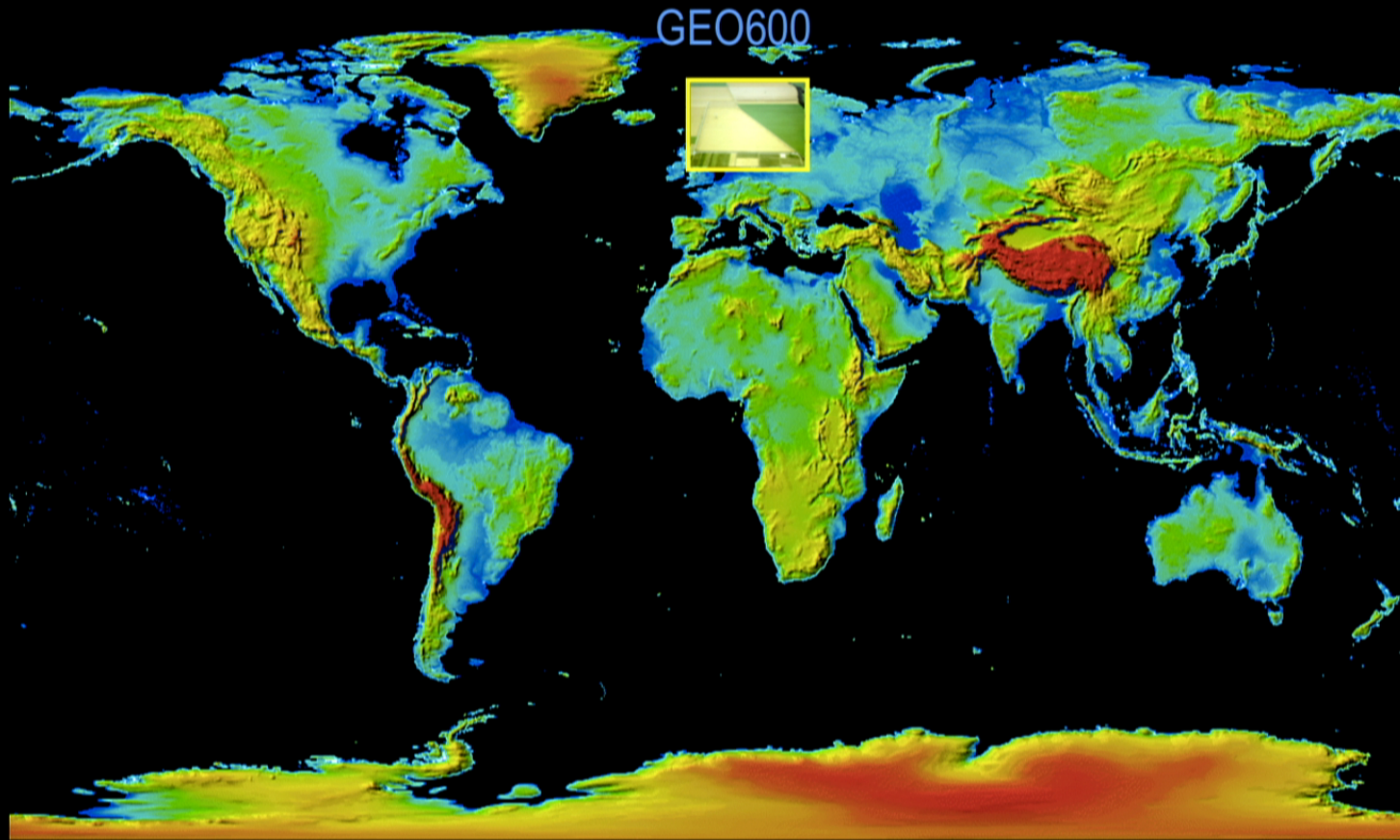
## LOOKING DOWN A DETECTOR ARM



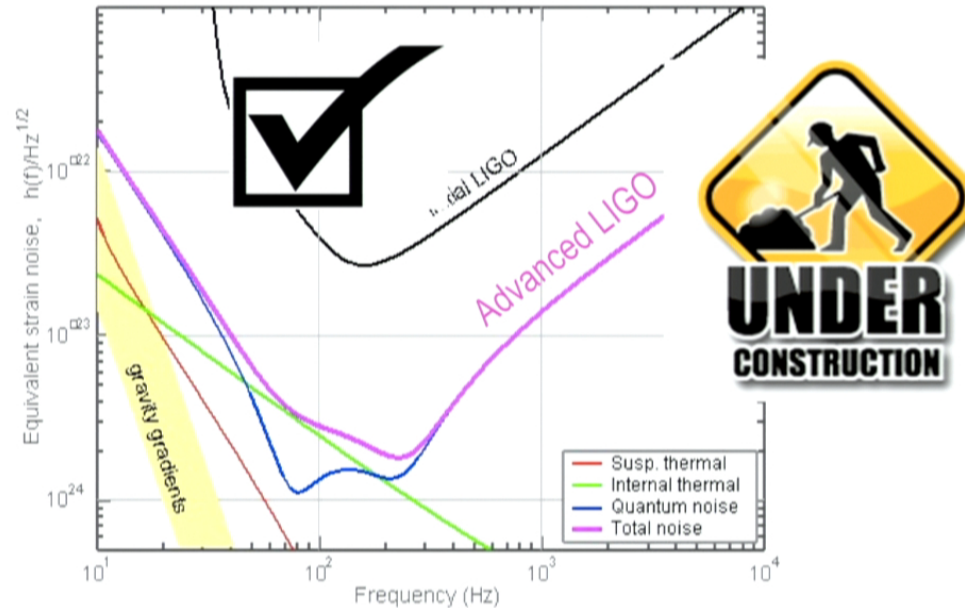
Visitors at LIGO Hanford Observatory gaze down the site's X arm. Half of the 4-kilometer length of the arm is visible in the photo. (Credit: LIGO Laboratory)



# *The GW Detector Network 2013*



# Under construction: Advanced LIGO



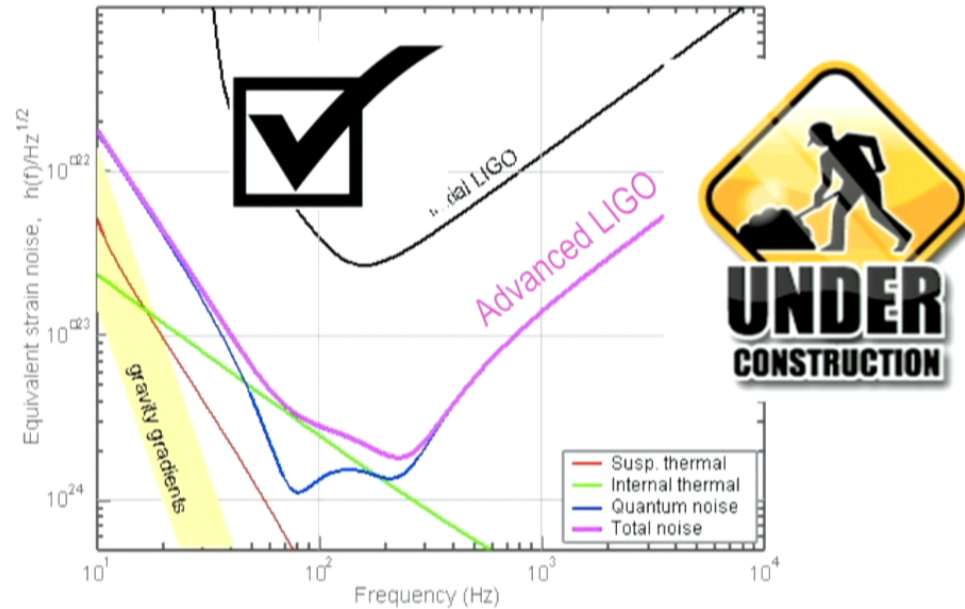
~10 times better than initial LIGO , lower frequencies in band

Installation in progress, going very well!

Coincident “lock” in ~2014, science runs with increasing sensitivity to follow.

LIGO-G1300012

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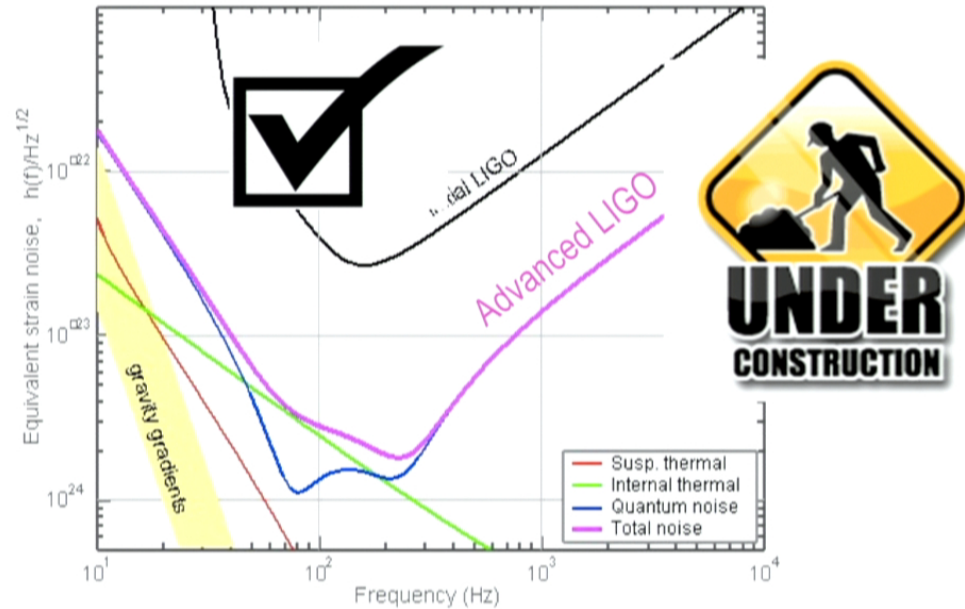
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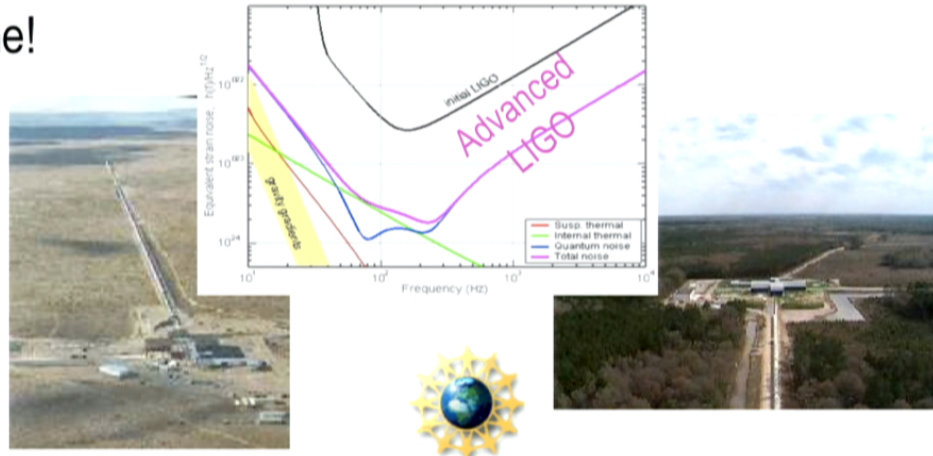
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LIGO-G1300012

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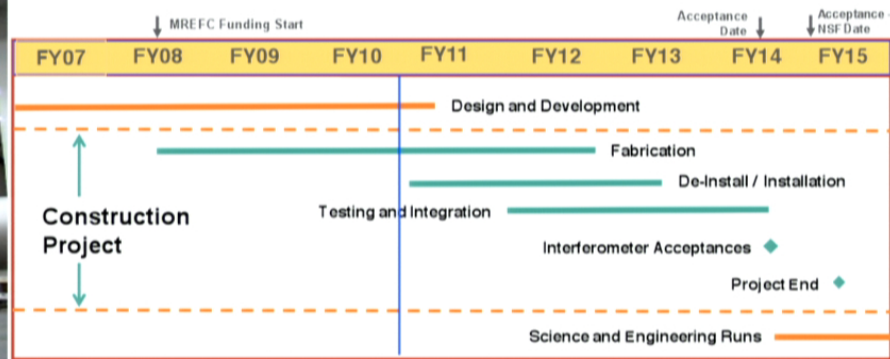
Vacuum system is the same!



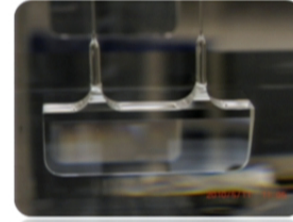
US NSF funding for Advanced LIGO: 2008-2015.



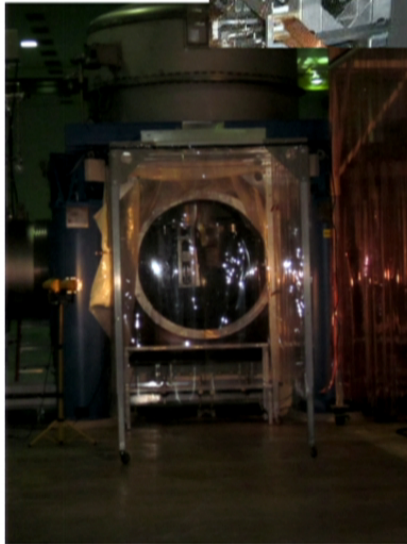
LIGO-G1300012



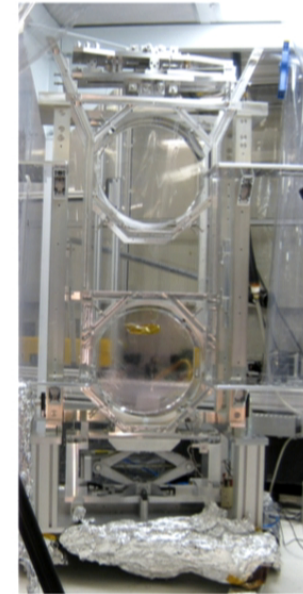
# Initial vs Advanced LIGO



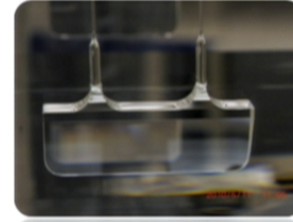
Simple pendulums become monolithic, quadruple pendulums with better quality optics  
Prototypes being tested, optics are polished



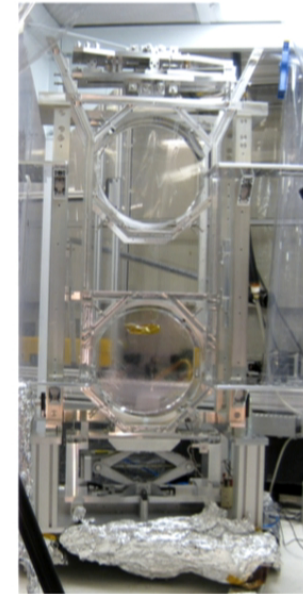
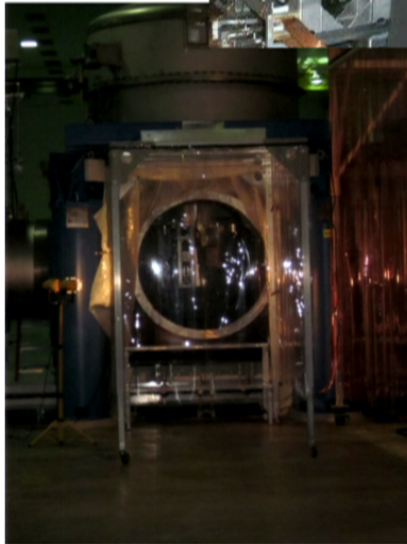
LIGO-G1300012



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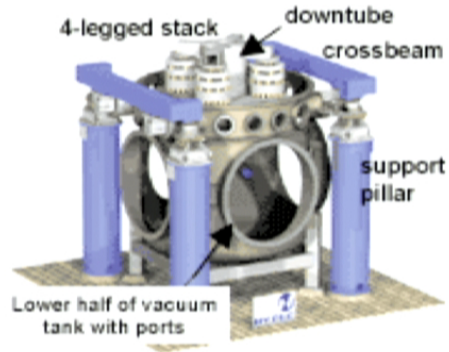


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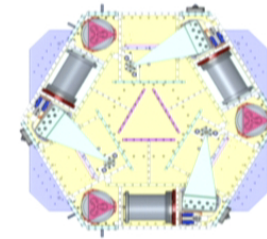
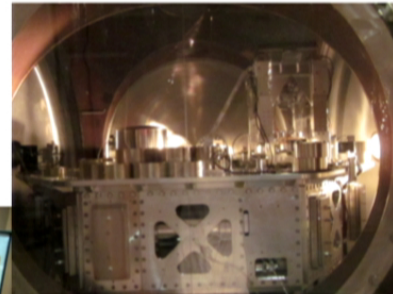
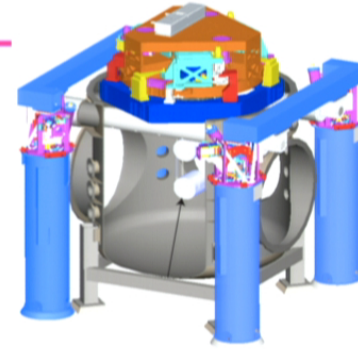


LIGO-G1300012

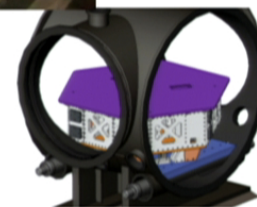
# Initial vs Advanced LIGO



Seismic isolation goes from passive to active  
HAM SEI tested in S6  
Most chambers have now their "SEI" installed.



LIGO-G1300012





# More on Adv LIGO: LIGO magazine in [www.ligo.org](http://www.ligo.org)

The screenshot shows the LIGO Scientific Collaboration website. At the top right, there are navigation links: home, Español, LIGO Lab, community/environment, join, and LSC/internal. The main header features the LSC logo and the text "LIGO Scientific Collaboration". Below this is a secondary navigation bar with links: news, magazine, Advanced LIGO, science, students/teachers/public, multimedia, partners, and about. The main content area is divided into three columns. The left column features a large banner for "LIGO MAGAZINE issue 1/2012" with the headline "construction: Advanced LIGO p. 14" and the text "First issue of LIGO Magazine". The middle column contains a video player titled "Gravity: Making Waves" with a play button and a progress bar showing 0:00 / 7:39. The right column contains a paragraph of text: "LIGO Scientific Collaboration is a dynamic group of more than 800 scientists worldwide who have joined together in the search for gravitational waves from the most violent events in the universe. Learn more about gravitational waves and the LSC here!". Below this text are two orange buttons: "LEARN MORE!" and "GET INVOLVED!". A blue starburst graphic with the text "LIGO MAG IS HERE!" is positioned above the buttons. The bottom left of the screenshot shows the text "LIGO-G1300012".

LIGO-G1300012

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# Detection Rates

## Neutron Star Binaries:

Initial LIGO:  $\sim 15$  Mpc  $\rightarrow$  rate  $\sim 1/50$  yrs

Advanced LIGO:  $\sim 200$  Mpc

“Realistic rate”  $\sim 40$ /year

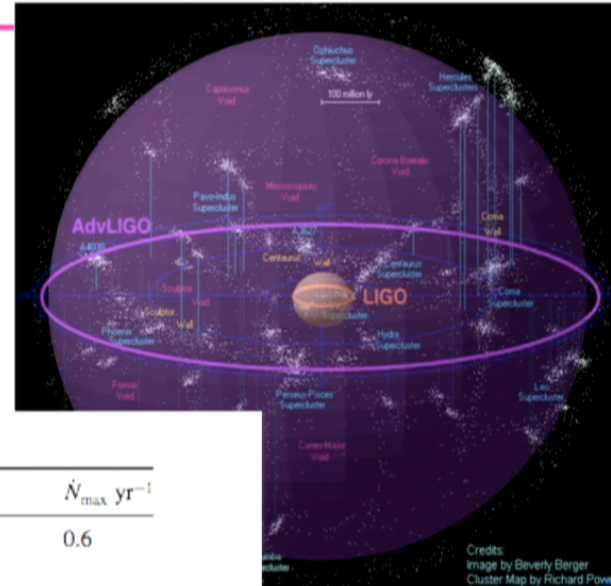
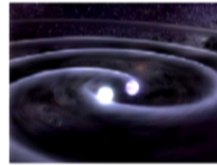


Table 5. Detection rates for compact binary coalescence sources.

IFO	Source <sup>a</sup>	$\dot{N}_{\text{low}} \text{ yr}^{-1}$	$\dot{N}_{\text{rc}} \text{ yr}^{-1}$	$\dot{N}_{\text{high}} \text{ yr}^{-1}$	$\dot{N}_{\text{max}} \text{ yr}^{-1}$
Initial	NS-NS	$2 \times 10^{-4}$	0.02	0.2	0.6
	NS-BH	$7 \times 10^{-5}$	0.004	0.1	
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Class. Quant. Grav. **27**, 173001 (2010)

LIGO-G1300012

# Detection Rates

## Neutron Star Binaries:

Initial LIGO: ~15 Mpc → rate ~1/50yrs

Advanced LIGO: ~ 200 Mpc

“Realistic rate” ~ 40/year

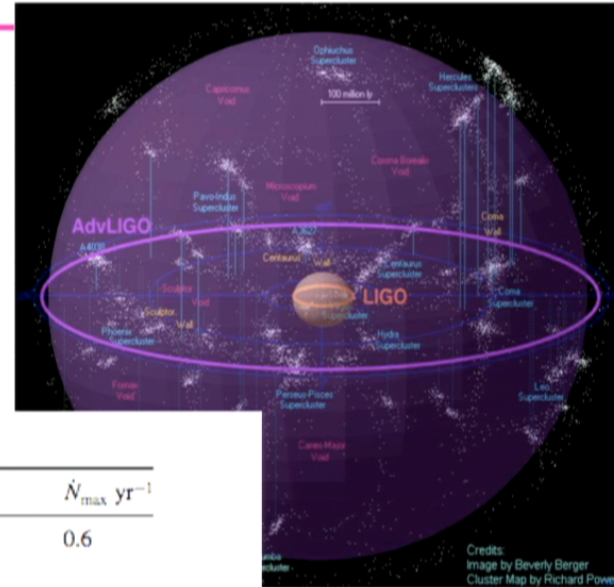
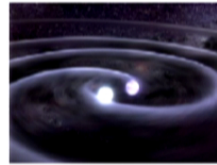


Table 5. Detection rates for compact binary coalescence sources.

I/O	Source <sup>a</sup>	$\dot{N}_{\text{low}} \text{ yr}^{-1}$	$\dot{N}_{\text{rc}} \text{ yr}^{-1}$	$\dot{N}_{\text{high}} \text{ yr}^{-1}$	$\dot{N}_{\text{max}} \text{ yr}^{-1}$
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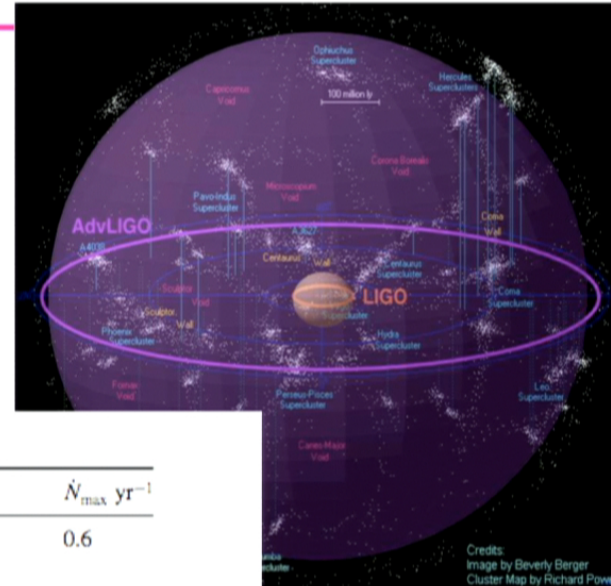
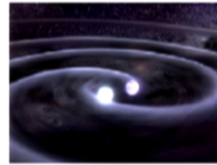


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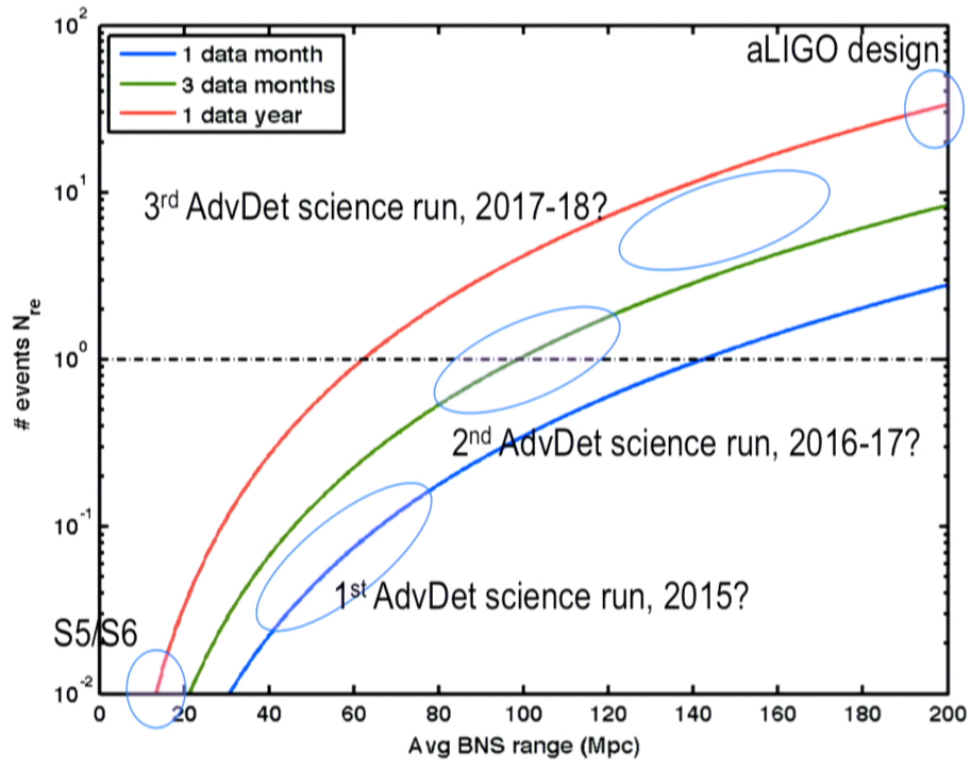
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Class. Quant. Grav. **27**, 173001 (2010)

LIGO-G1300012

# Detection Rates

$$N_{re} = \frac{T_{obs}}{\text{Mpc}^3 \text{Myr}} \times \frac{4}{3} \pi D_{avg,BNS}^3$$



LIGO-G1300012

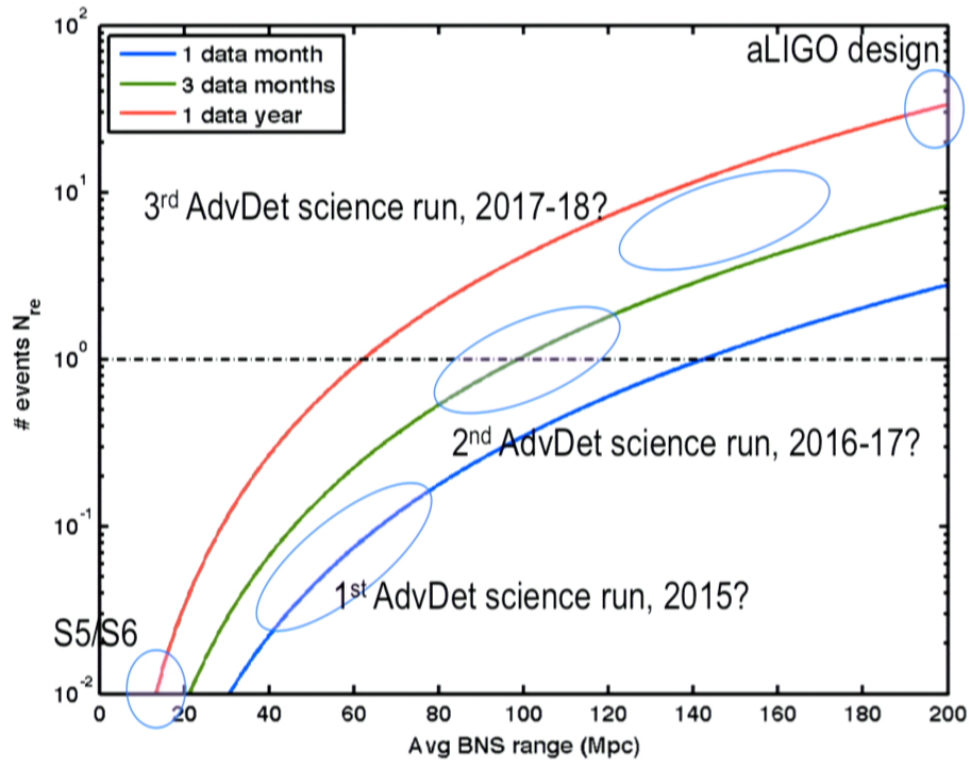
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- Real rates can be 100 times smaller, 10 times higher<sup>2</sup>.
- NS-BH or BH-BH systems can be seen much farther.
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- With more (similarly sensitive) detectors, the rate increases  $\propto \sqrt{N}$

<sup>1</sup>: [Phys. Rev D85 \(2012\) 082002](#)

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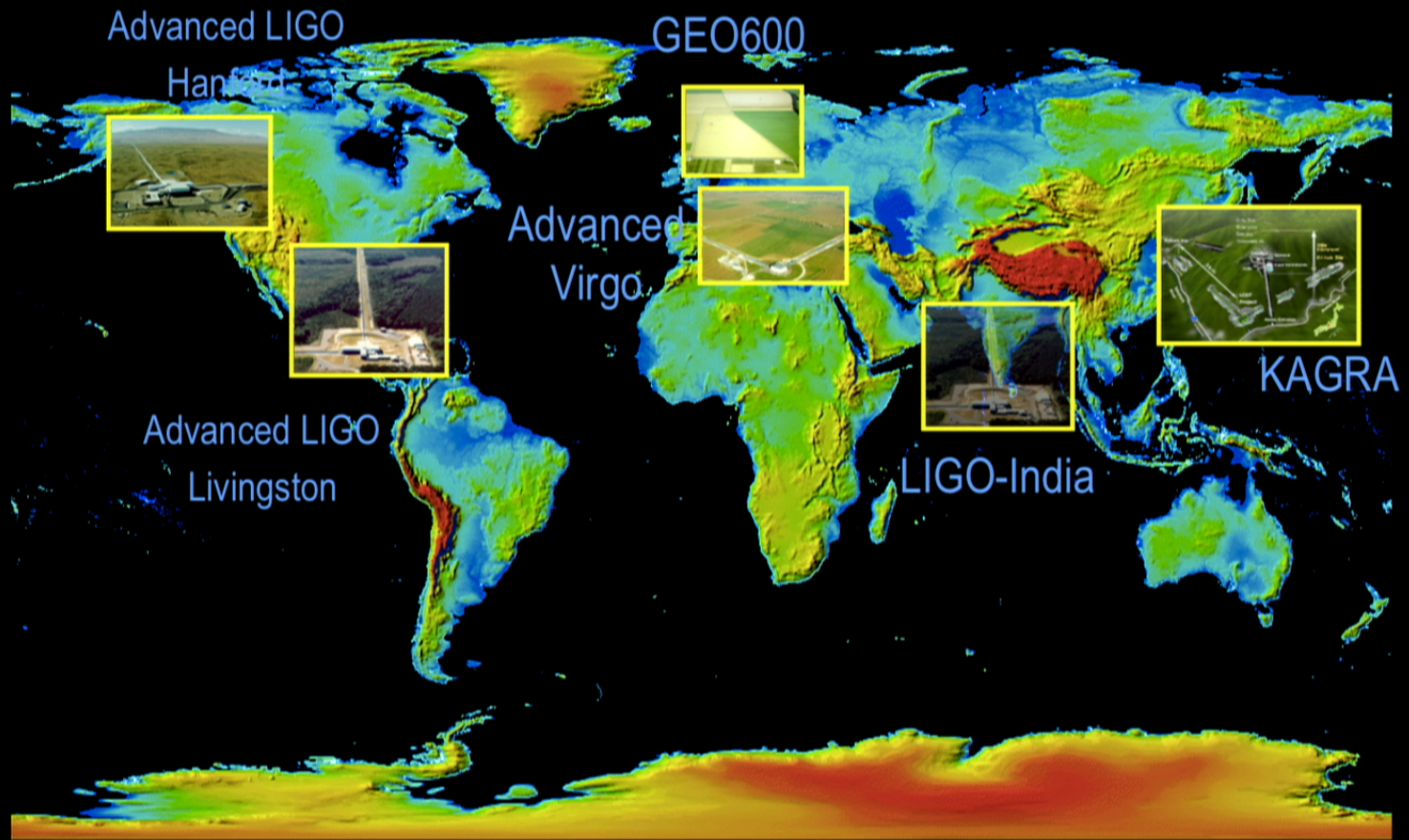
LIGO-G1300012

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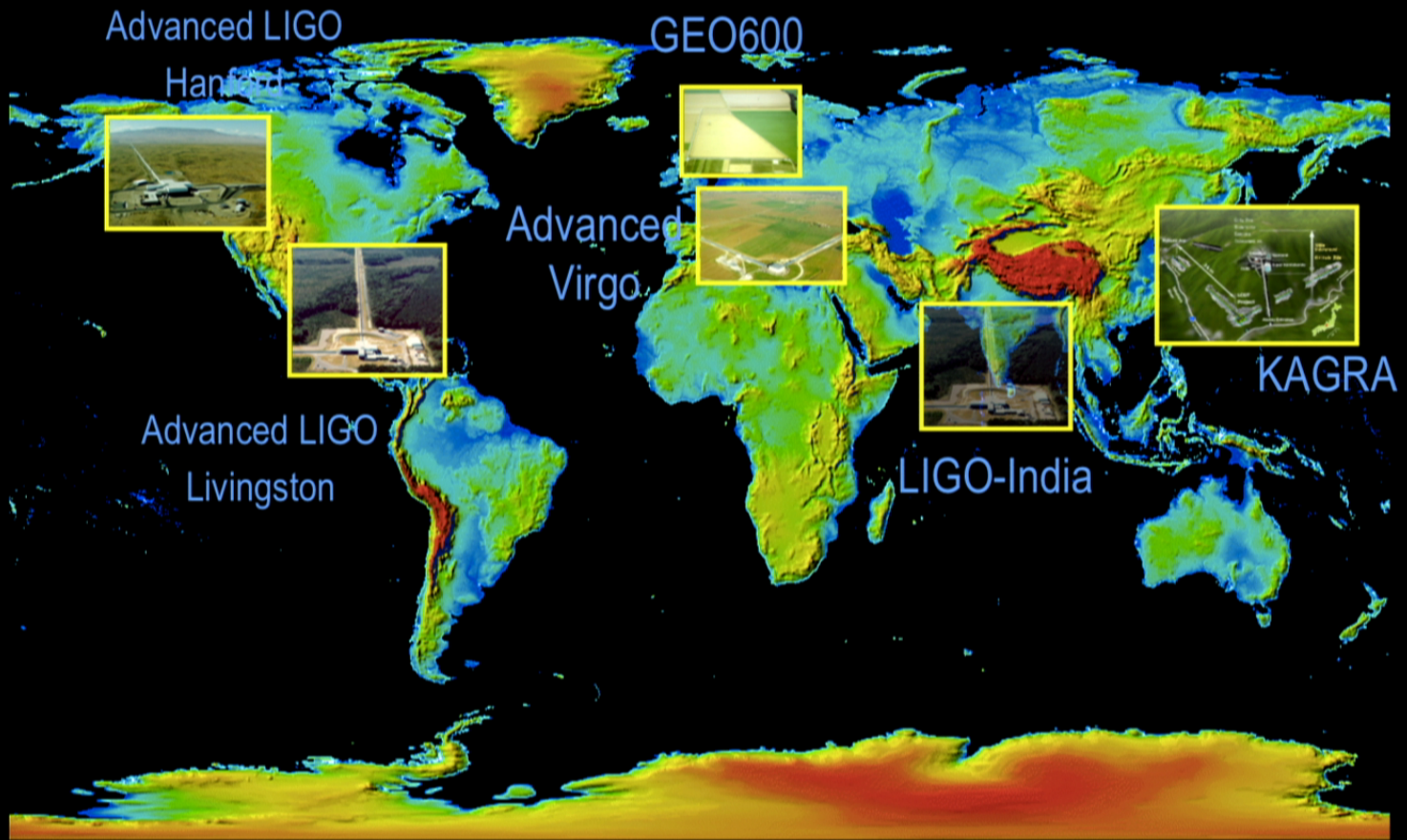
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# The GW Detector Network~2020



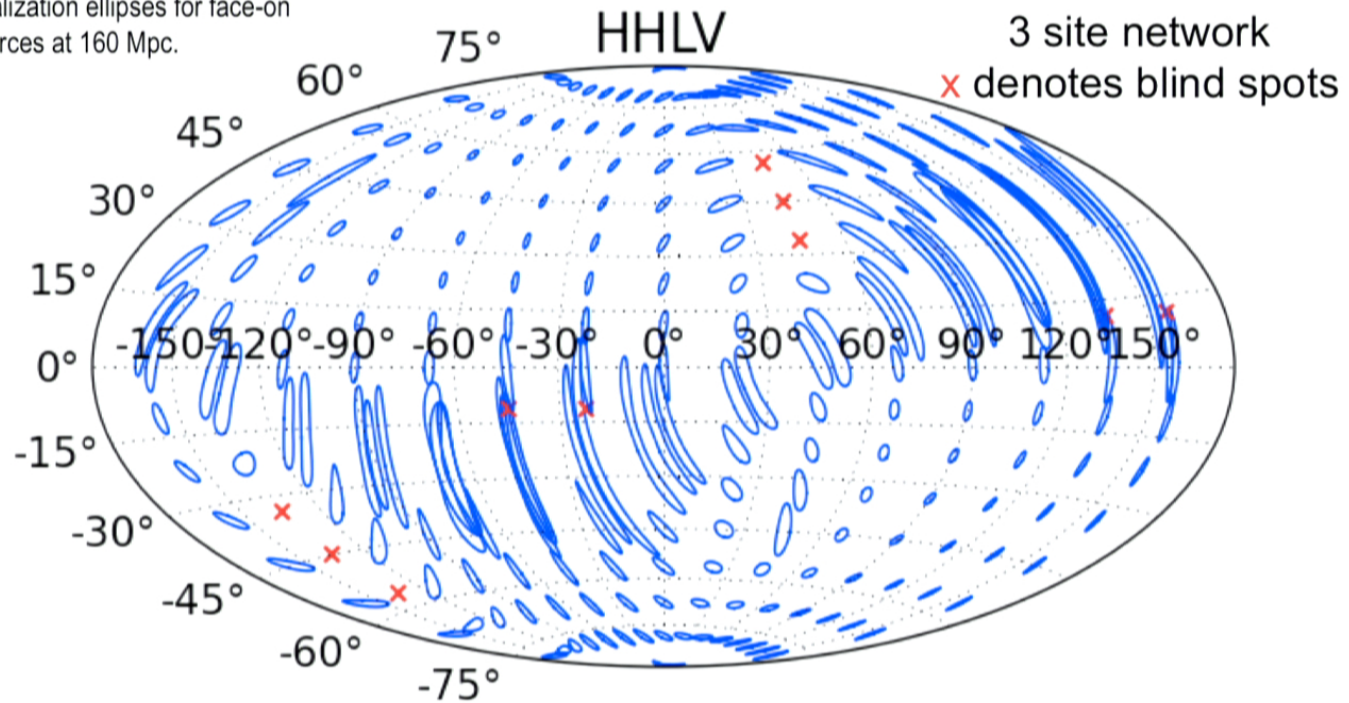
# The GW Detector Network~2020





# BNS Merger Localization: Hanford-Livingston-Virgo

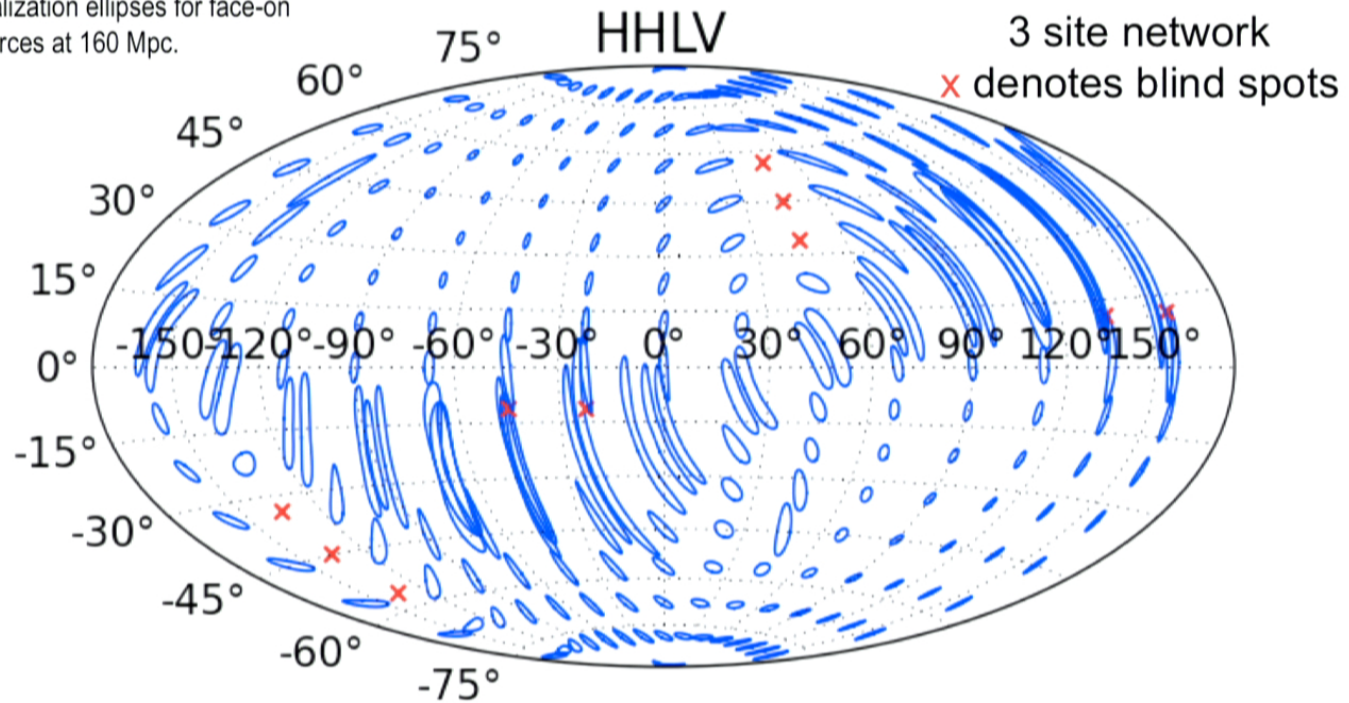
90% localization ellipses for face-on  
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S. Fairhurst, "Improved source localization with  
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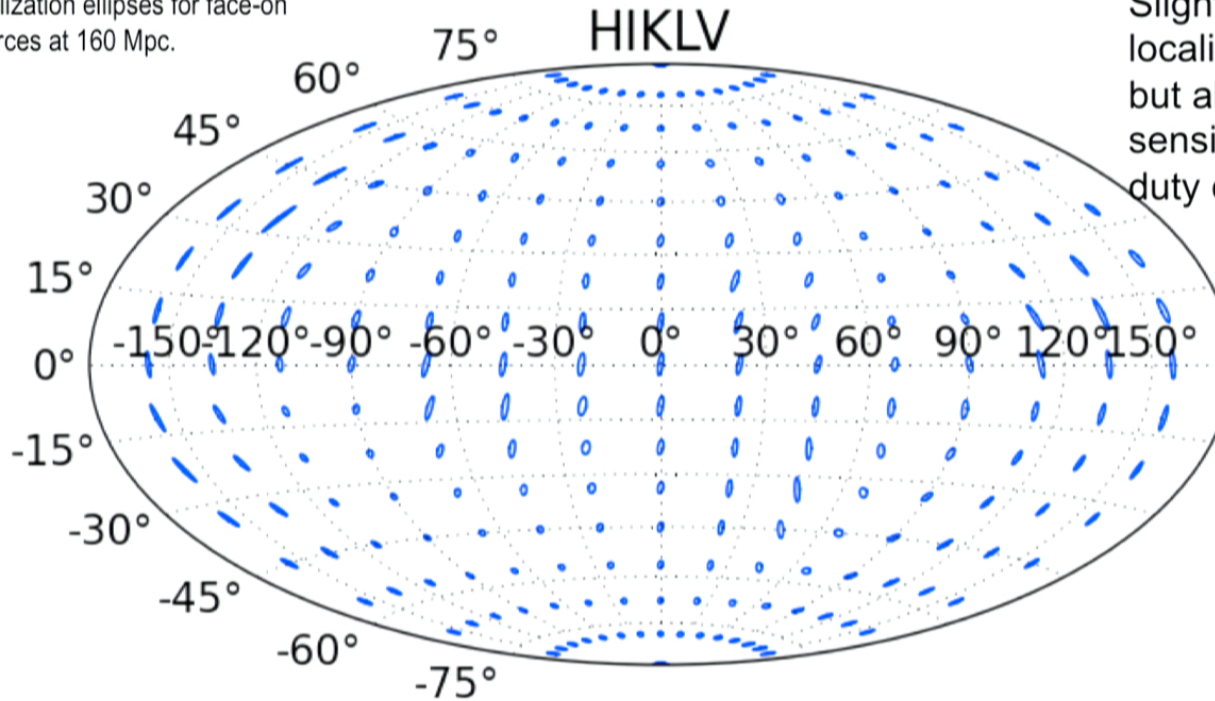


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# BNS Localization: Hanford-Livingston-Virgo-India-KAGRA

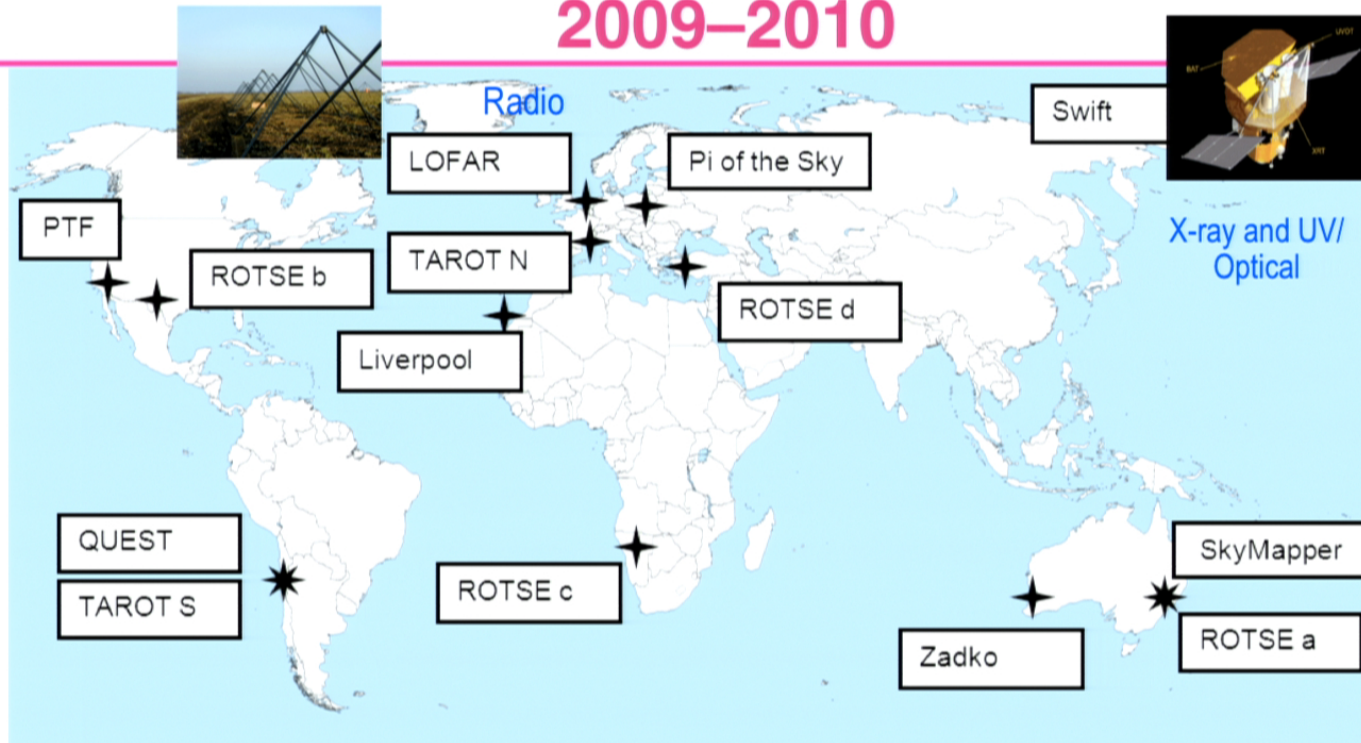
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5 site network: Slightly better localization, but also better sensitivity and duty cycle!



S. Fairhurst, "Improved source localization with LIGO India", [arXiv:1205.6611v1](https://arxiv.org/abs/1205.6611v1)

# EM Observing Partners 2009–2010

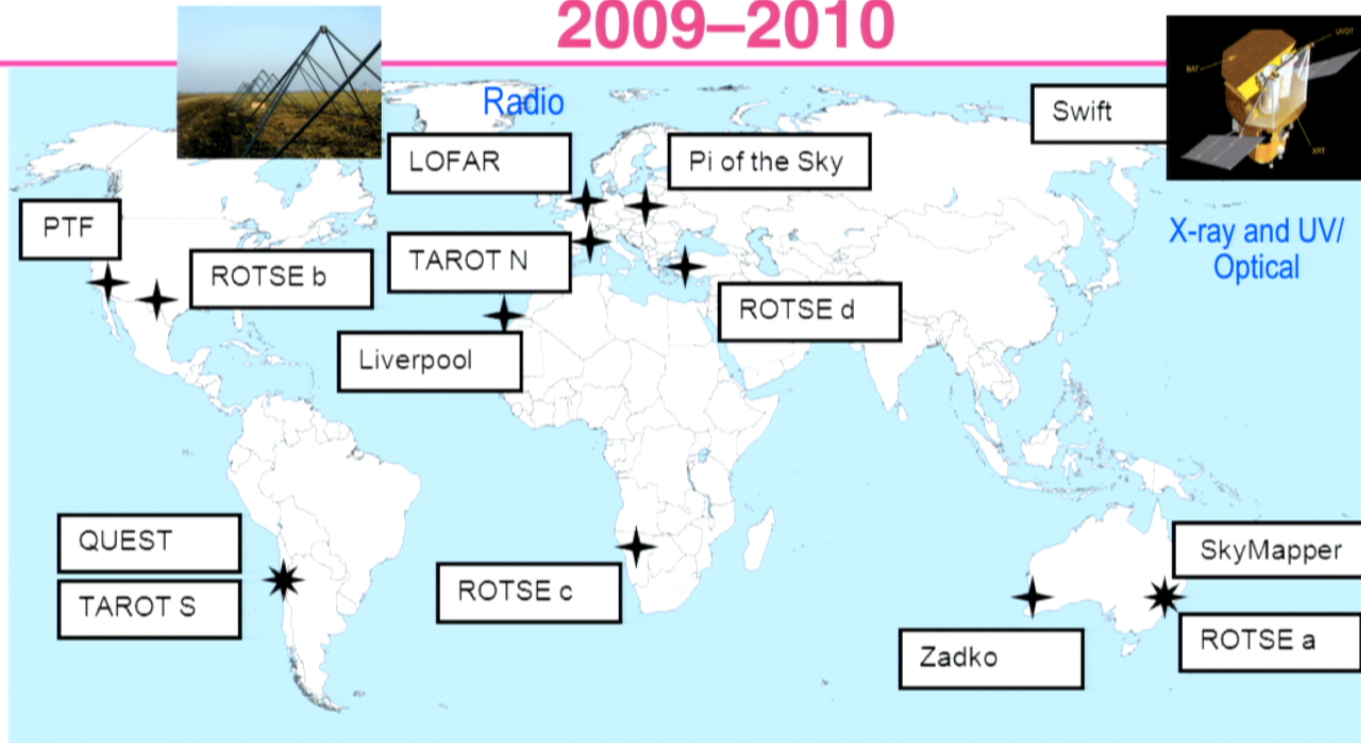


- Mostly (but not all) robotic wide-field optical telescopes
  - Many of them used for following up GRBs and/or hunting for supernovae
- **Nine event candidates followed up by at least one scope**
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LIGO-G1300012

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LIGO-G1300012

22

# GW-EM follow up

## LSC AND VIRGO POLICY ON RELEASING GRAVITATIONAL WAVE TRIGGERS TO THE PUBLIC IN THE ADVANCED DETECTORS ERA



The LSC and Virgo recognize the great potential benefits of multi-messenger observations, including rapid electromagnetic follow-up observations of GW triggers. Both Collaborations (the LSC and Virgo) will partner with astronomers to carry out an inclusive observing campaign for potentially interesting GW triggers, with MoUs to ensure coordination and confidentiality of the information. They are open to all requests from interested astronomers or astronomy projects which want to become partners through signing an MoU. They encourage colleagues to help set up and organize this effort in an efficient way to guarantee the best science can be done with gravitational wave triggers.

After the published discovery of gravitational waves with data from LSC and/or Virgo detectors, both the LSC and Virgo will begin releasing especially significant triggers promptly to the entire scientific community to enable a wider range of follow-up observations. This will take effect after the Collaborations have published papers (or a paper) about 4 GW events, at which time a detection rate can be reasonably estimated. The releases will be done as promptly as possible, within an hour of the detected transient if feasible. Initially, the released triggers will be those which have an estimated false alarm rate smaller than 1 per 100 years.



Partners who have signed an MoU with the LSC and Virgo will have access to GW triggers with a lower significance threshold and/or lower latency, according to the terms of the MoU, in order to carry out a more systematic joint observing campaign and combined interpretation of the results.

Throughout the Advanced Detectors era, the LSC and Virgo will release appropriate segments of data from operating detectors corresponding to detected gravitational waves presented in LSC/Virgo authored publications, at the time of the publication, including the first claimed detection of gravitational waves.

The text of this policy was approved by LSC Council on March 21<sup>st</sup>, 2012; it was approved by the EGO Council on May 4<sup>th</sup>, 2012.

The LIGO Data Management Policy LIGO-M1000066 will take precedence in how LIGO data are released should this policy and the LIGO DMP be in potential conflict.

[dcc.ligo.org](http://dcc.ligo.org), LIGO-M1200055

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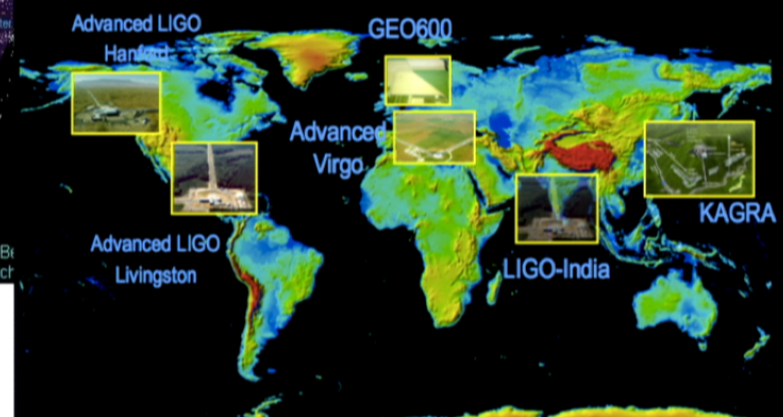
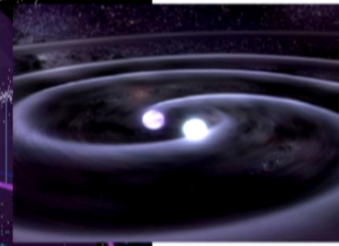
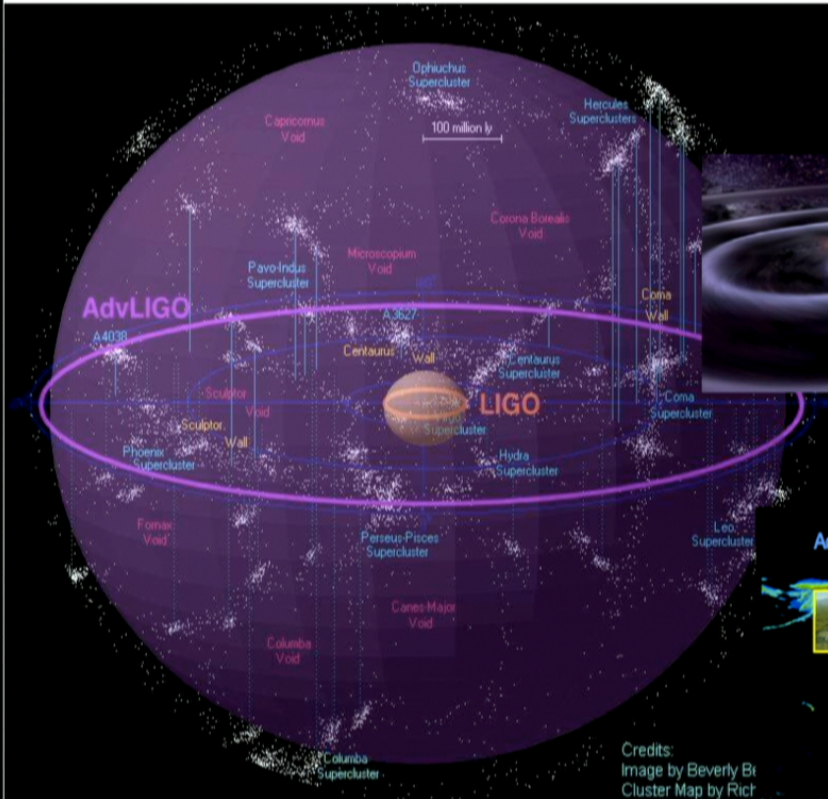
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# Gravitational waves are coming!

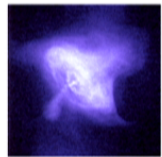
[www.ligo.org](http://www.ligo.org)



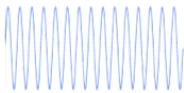
Credits: Image by Beverly B Cluster Map by Rich

LIGO-G1300012

# LIGO Detectors 2009-10 (S6)

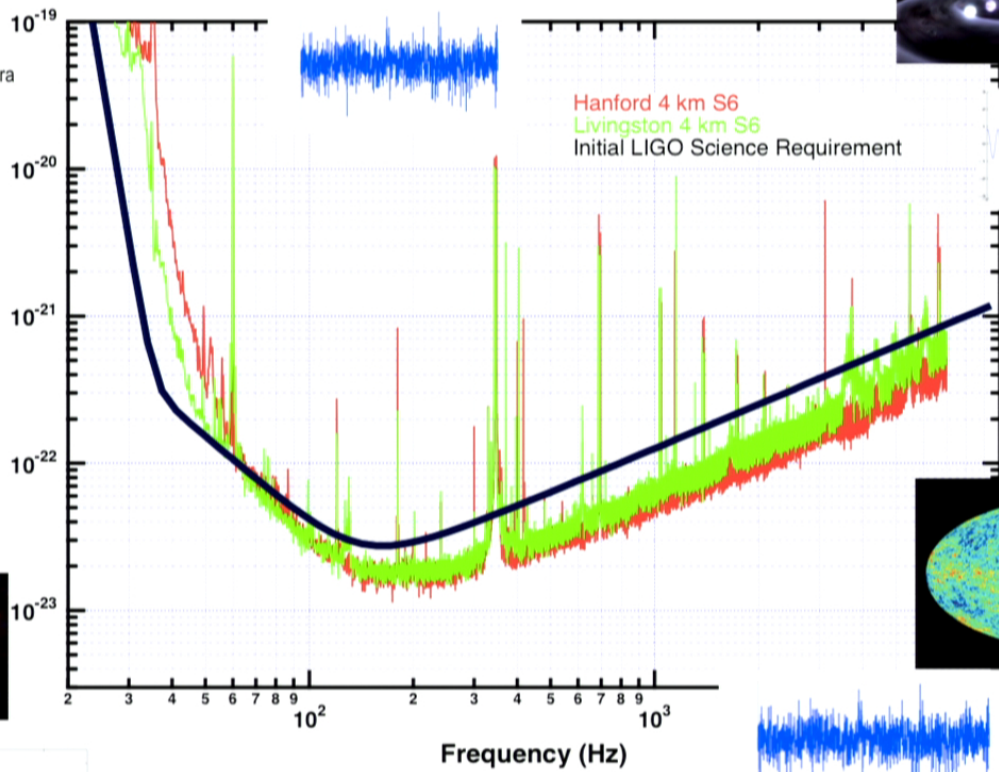


Crab pulsar (NASA, Chandra Observatory)

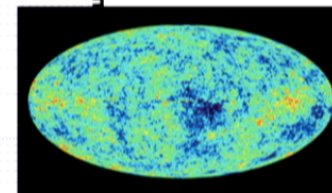
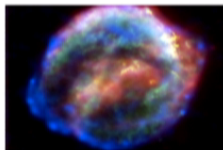
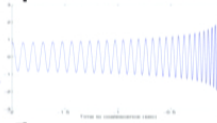
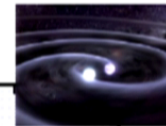


Strain ( $1/\sqrt{\text{Hz}}$ )

Strain ( $1/\sqrt{\text{Hz}}$ )



Hanford 4 km S6  
Livingston 4 km S6  
Initial LIGO Science Requirement

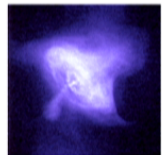


NASA, WMAP

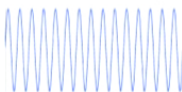


Find all LSC results and publications in [www.ligo.org](http://www.ligo.org)  
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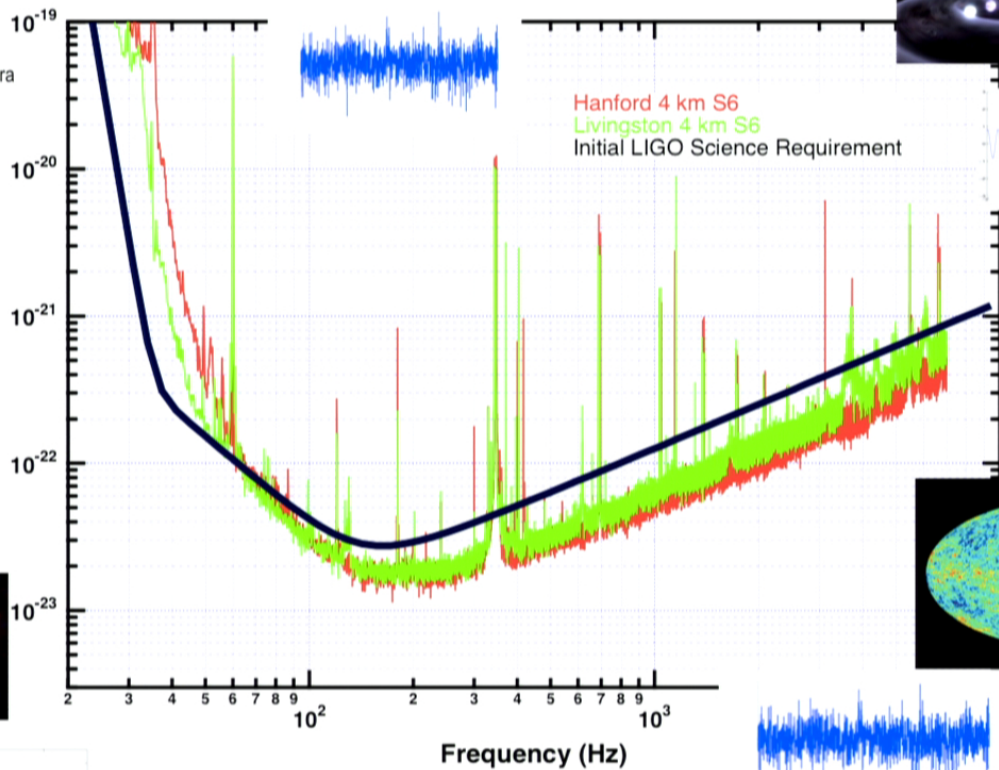


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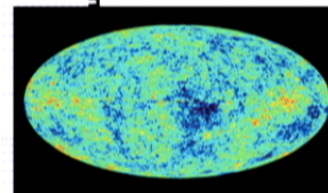
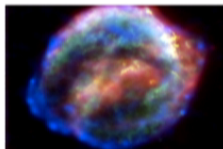
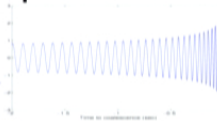
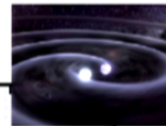


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# *The GW Detector Network 2013*

