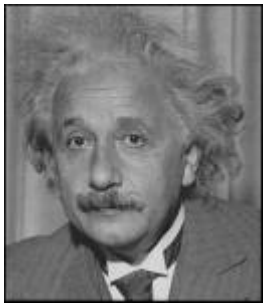
Opening the Gravitational Wave Window

Gabriela González
Louisiana State University

For the LIGO Scientific Collaboration and
the Virgo Collaboration

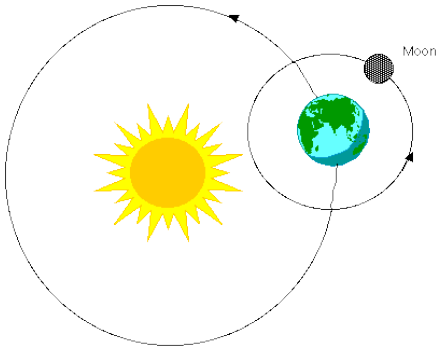
2014 CAP Congress - Sudbury, Ontario (Laurentian University)
June 18, 2014

Einstein's gravitation



When masses move, they wrinkle the space time fabric, making other masses move…

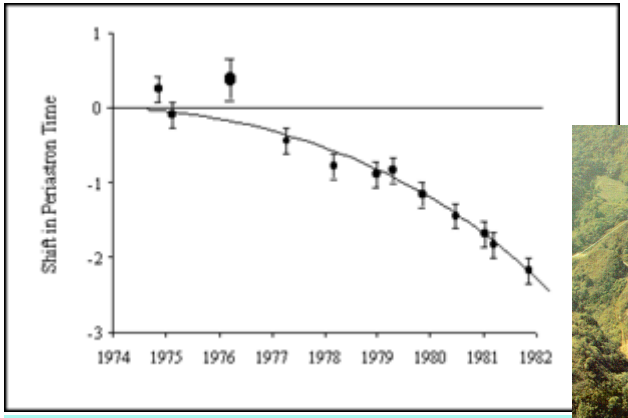
Explains just as well as Newtons' why things fall and planetary motion…

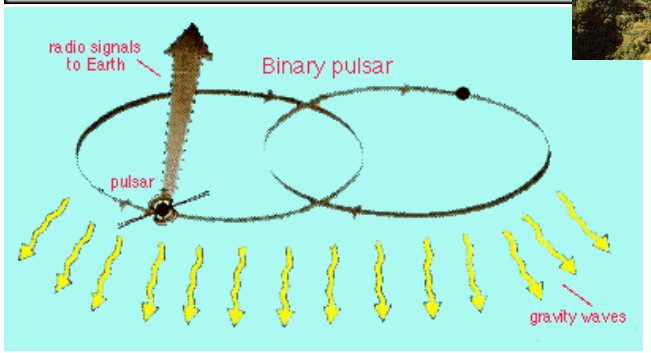


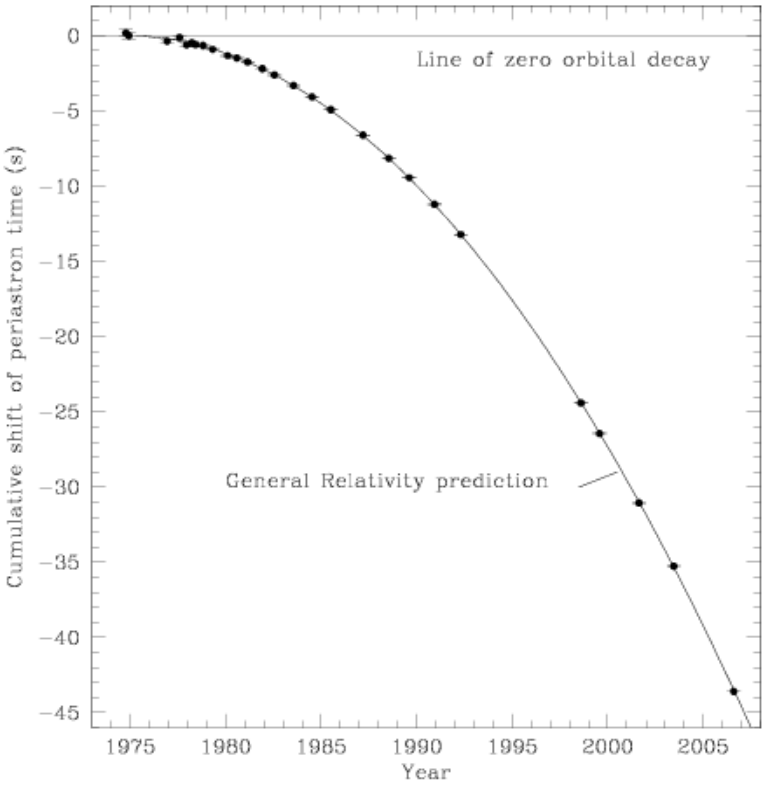
.. but it also predicts **gravitational waves** traveling away from moving masses!

Gravitational Waves: they exist!

Hulse, Taylor
Nobel Prize 1993





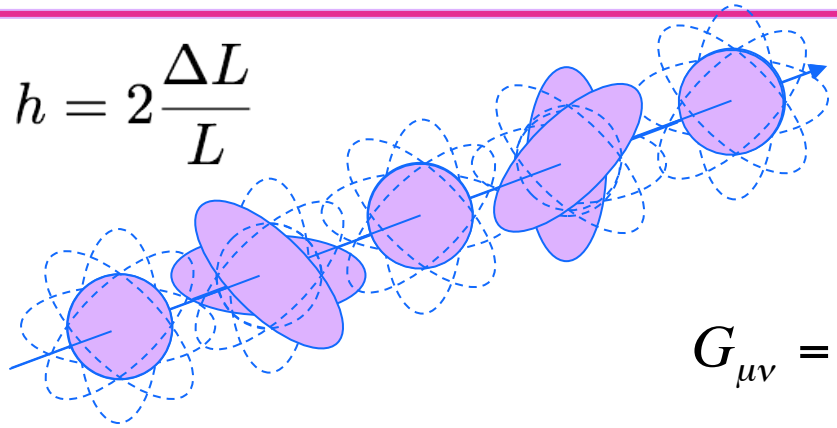


Weisberg, Nice & Taylor, 2010
(Courtesy Joel Weisberg)

Binary systems lose energy due to gravitational radiation (Hulse and Taylor, PSR 1913+16), showing up in their orbital parameters.

Gravitational waves

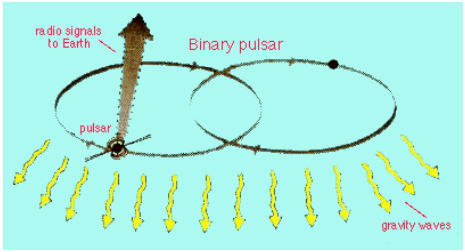
$$h = 2\frac{\Delta L}{L}$$



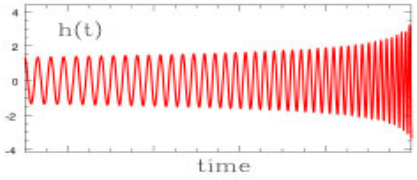
Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

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

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h_{\mu\nu} \sim \frac{2G}{c^4 r} \ddot{I}_{\mu\nu}$$

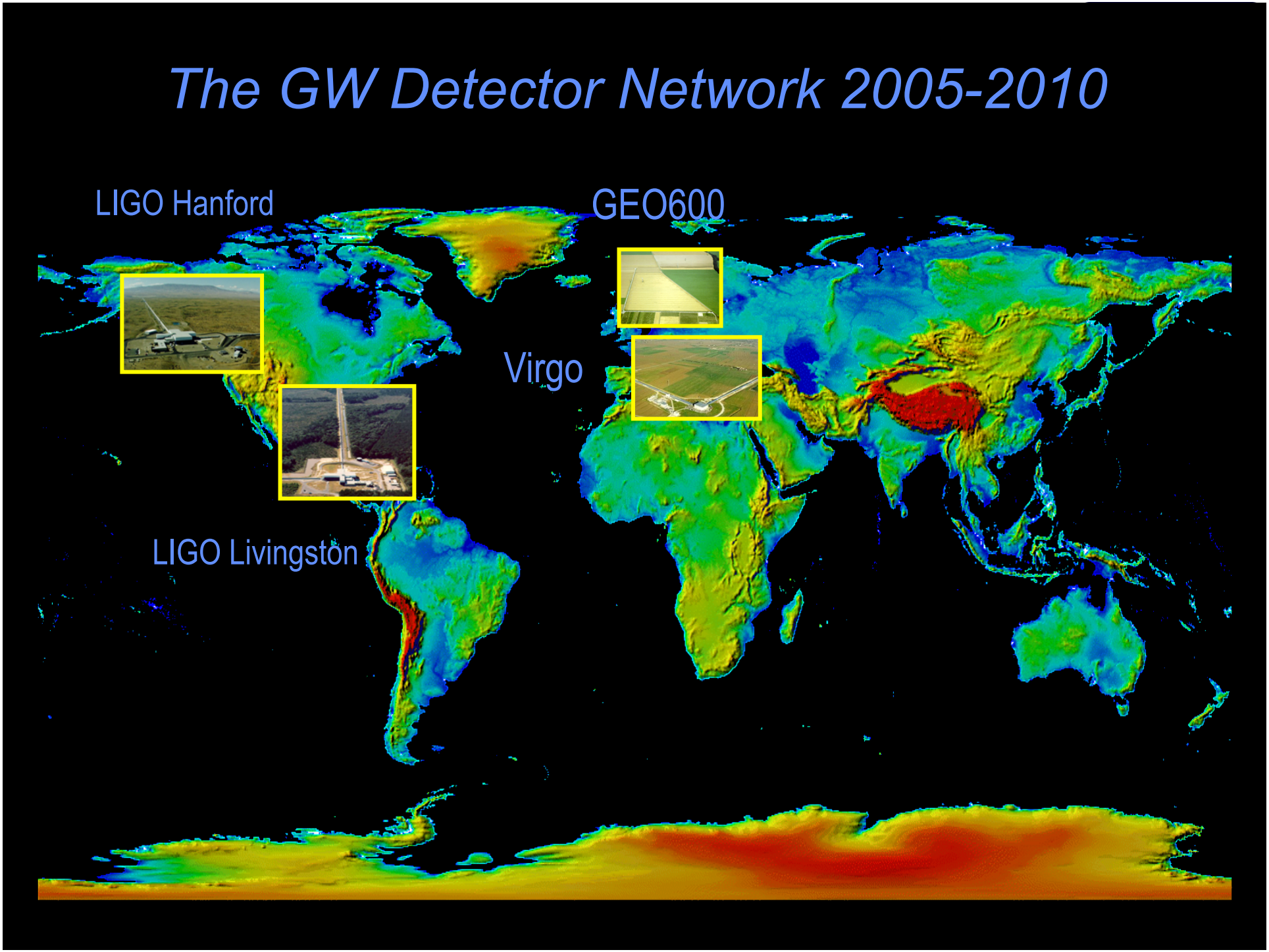


$$h_{\mu\nu} \sim \frac{R_1 R_2}{Dr}$$



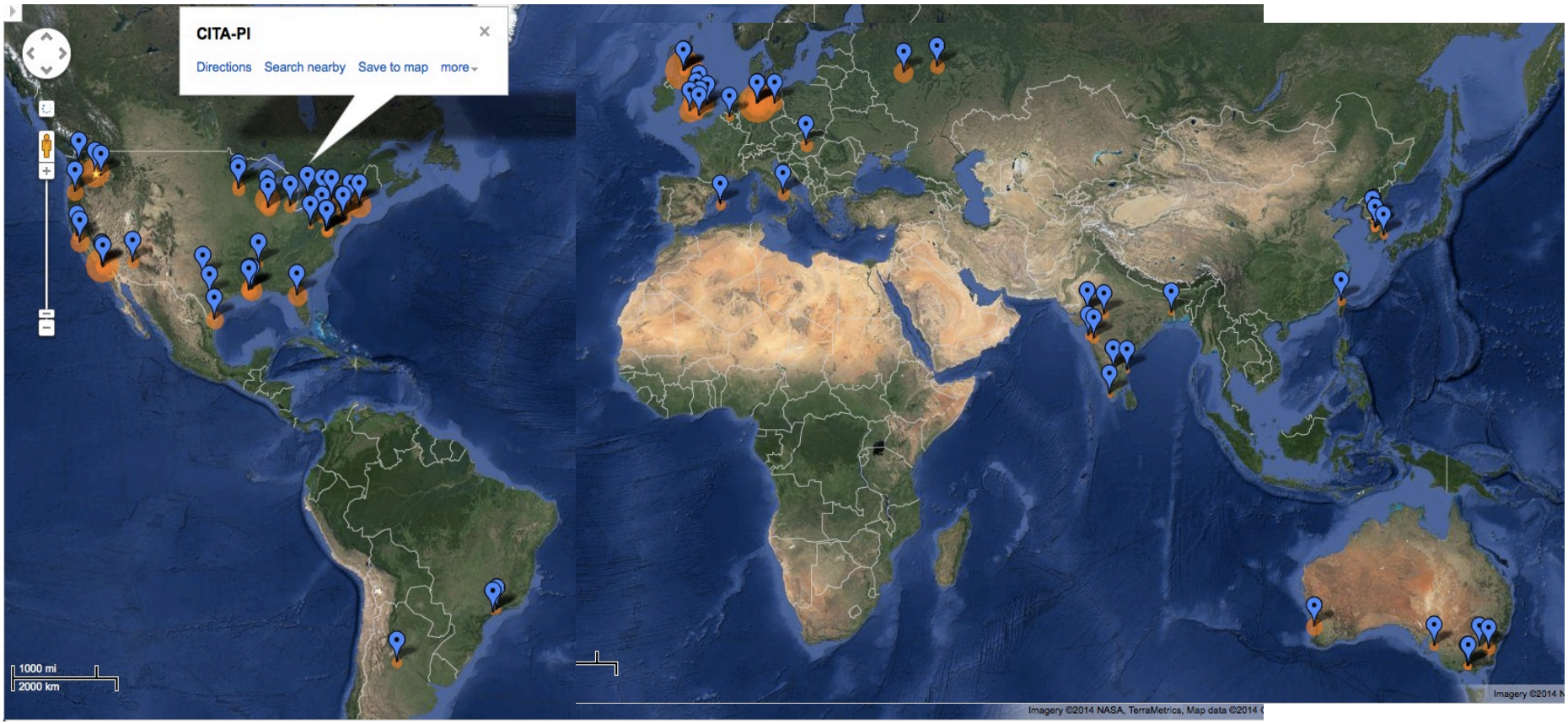
A NS-NS coalescence in the Virgo cluster has $h \sim 10^{-21}$ near Earth:
changes the distance between the Sun and the Earth by ~ one atomic diameter, and changes 1km distance by ~10^{-18} m

The GW Detector Network 2005-2010



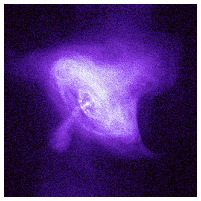
LIGO Scientific Collaboration

- 900+ members, 80+ institutions, 16 countries

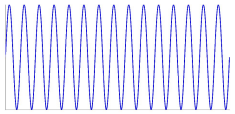


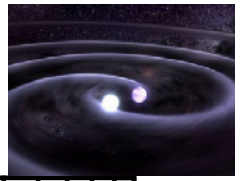
www.ligo.org

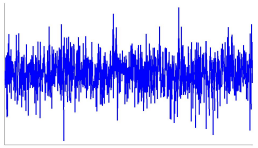
LIGO Detectors 2009-10

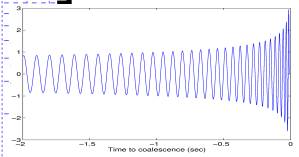


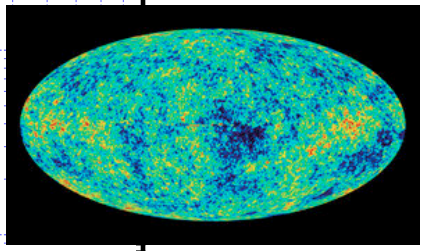
Crab pulsar (NASA, Ch
Observatory)



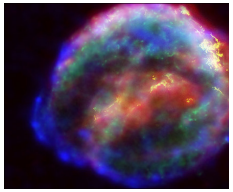


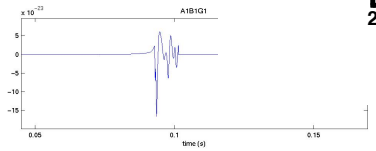






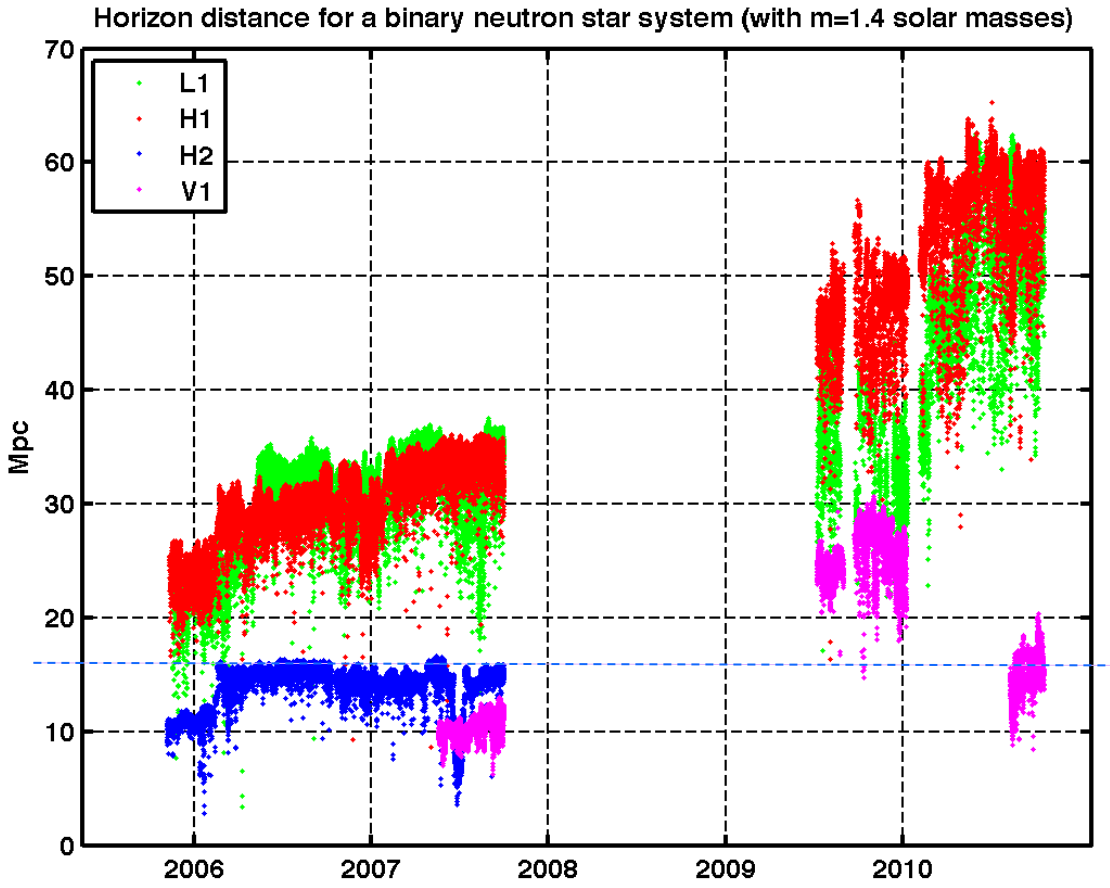
NASA, WMAP



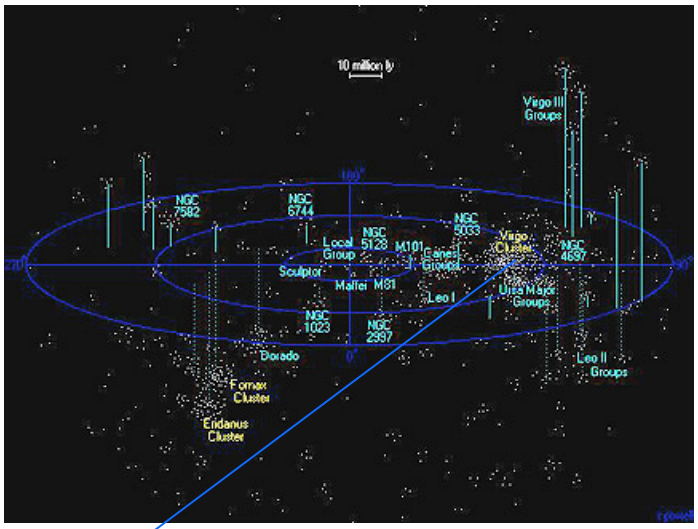


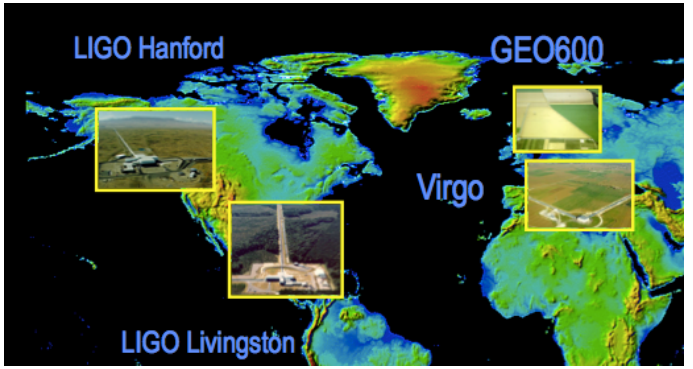
Find all LSC results and publications in www.ligo.org - science tab

LIGO-Virgo detectors 2005-2010



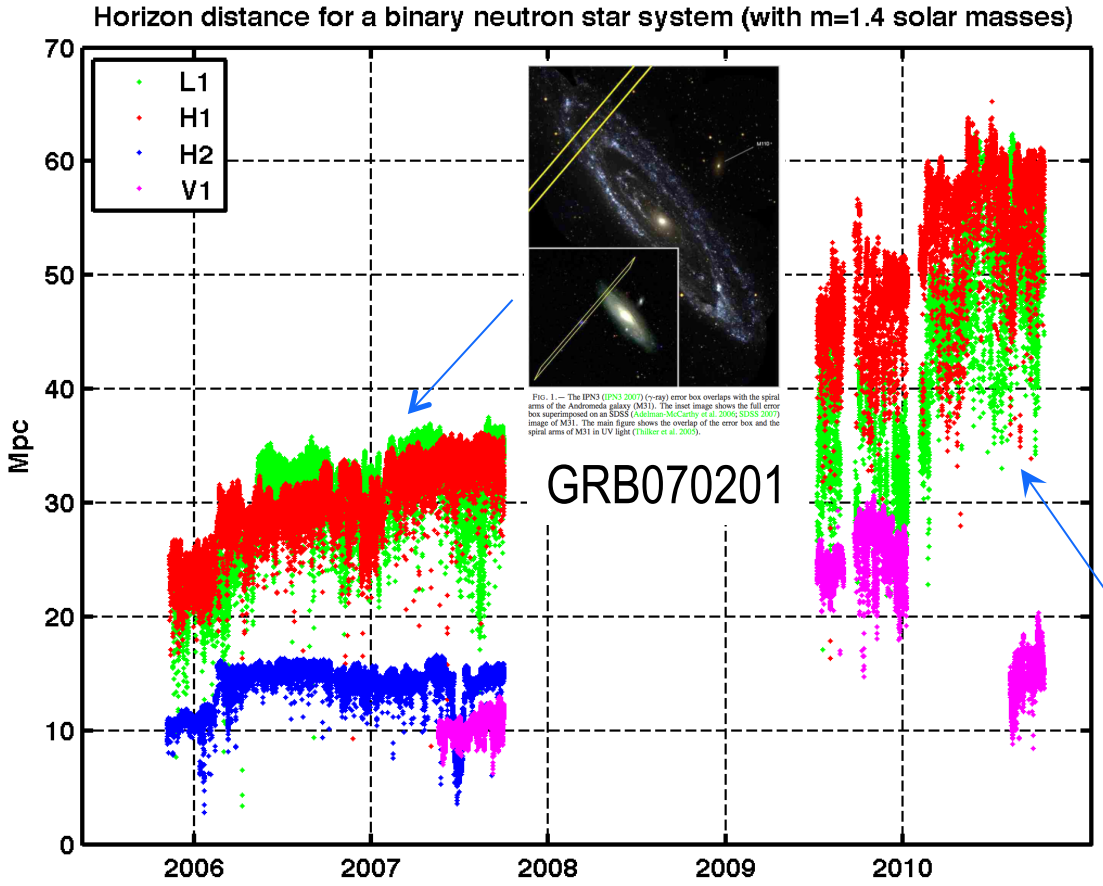
atlasofthe universe.com





Some interesting results 2005-2011

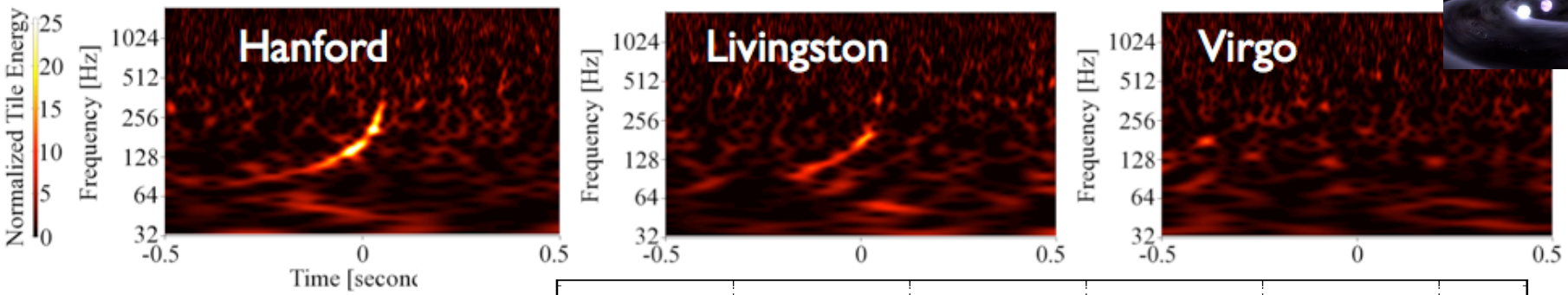
Astrophys. J. **681** (2008) 1419

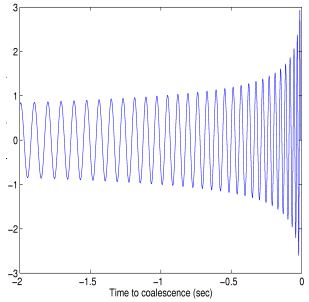


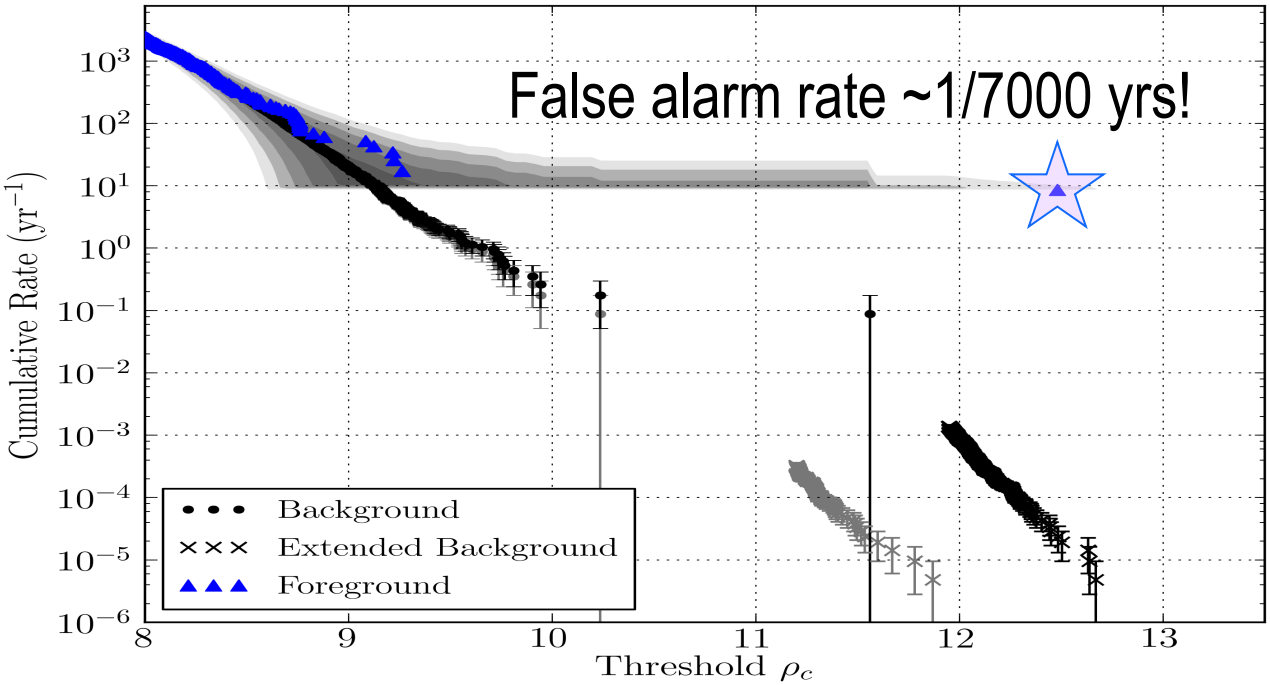
GW100916

Phys. Rev D85 (2012) 082002

Sept 16, 2010: "Big Dog trigger"







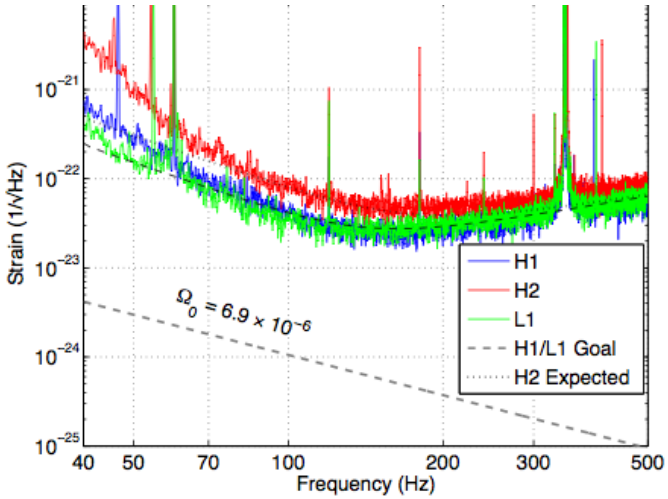
Phys. Rev D85 (2012) 082002

You can get (and listen to!) the detector data and other details: http://ligo.org/science/GW100916/

http://ligo.org/news/blind-injection.php

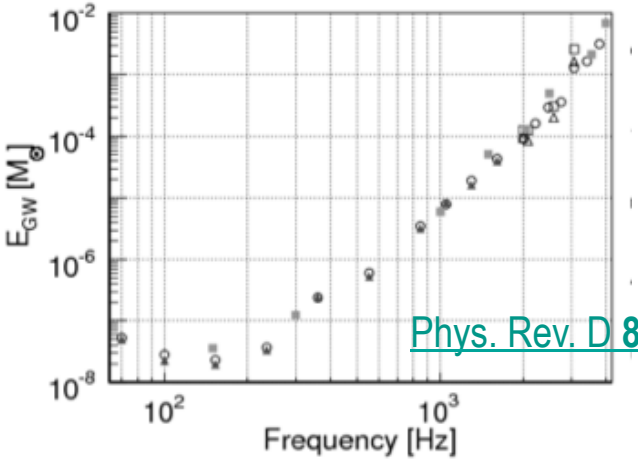
Some other LVC Results

Upper limit on GW stochastic background



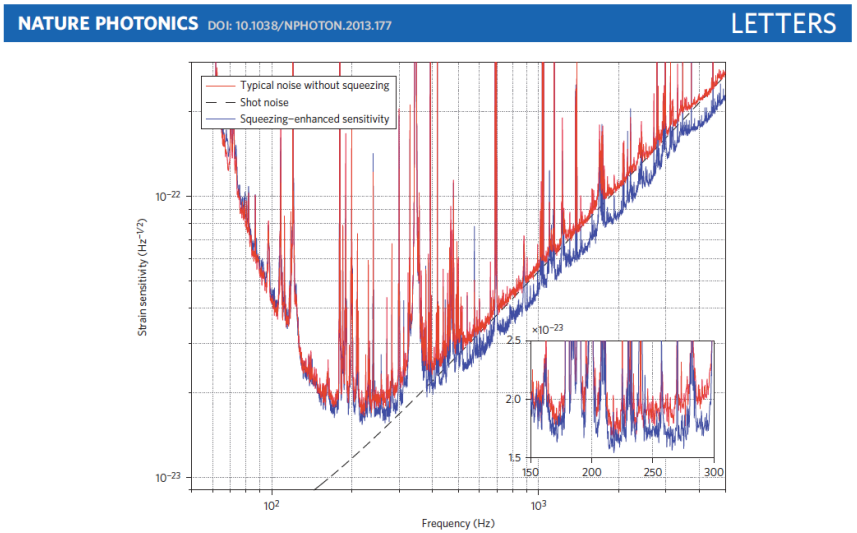
Nature **460** (2009) 990

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

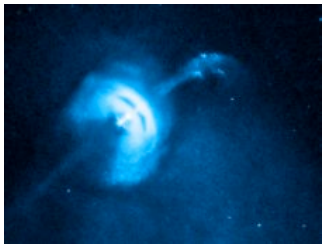


Phys. Rev. D **81** (2010) 102001

Quantum-enhanced sensitivity!



Upper limits on GW emissions from Crab and Vela pulsars



(X-ray: NASA/CXC/Univ of Toronto/ M.Durant et al; Optical: DSS/Davide De Martin)

NASA/CXC/ASU/J Hester *et al.* (Chandra); NASA/HST/ASU/J Hester *et al.* (Hubble)

Astrophys. J. **737** (2011) 93

Astrophys. J. **722** (2010) 1504

www.ligo.org/science

Home Español LIGO Lab Join LSC/internal

LSC LIGO Scientific Collaboration

news magazine Advanced LIGO science students/teachers/public multimedia partners about

Introduction Popular Articles LSC Scientific Publications Science Summaries Data Releases GW-EM Alerts

SUMMARIES OF LSC SCIENTIFIC PUBLICATIONS

We now feature, for each new research article, a summary written for the general public with a downloadable and printable flyer in PDF format.

2014

Jun 4, 2014	Searching for the Continuous Sounds of Unknown Neutron Stars in Binary Systems [flyer]
May 15, 2014	Leveraging the GEO600 Detector to Search for Gravitational Waves from Gamma-ray Bursts [flyer]
Apr 15, 2014	Searching for gravitational waves associated with gamma-ray bursts detected by the InterPlanetary Network [flyer]
Apr 09, 2014	Observing the Invisible Collisions of Intermediate Mass Black Holes [flyer]
Mar 26, 2014	Ringing of the Cosmic Bells: A Search for Black Hole Vibrations [flyer]
Feb 24, 2014	All-sky Search for Continuous Gravitational Waves in the Virgo Data [flyer]
Jan 16, 2014	Can we Hear Black Holes Collide? Testing Our Search Methods using Numerically Generated Gravitational-wave Signals [flyer]

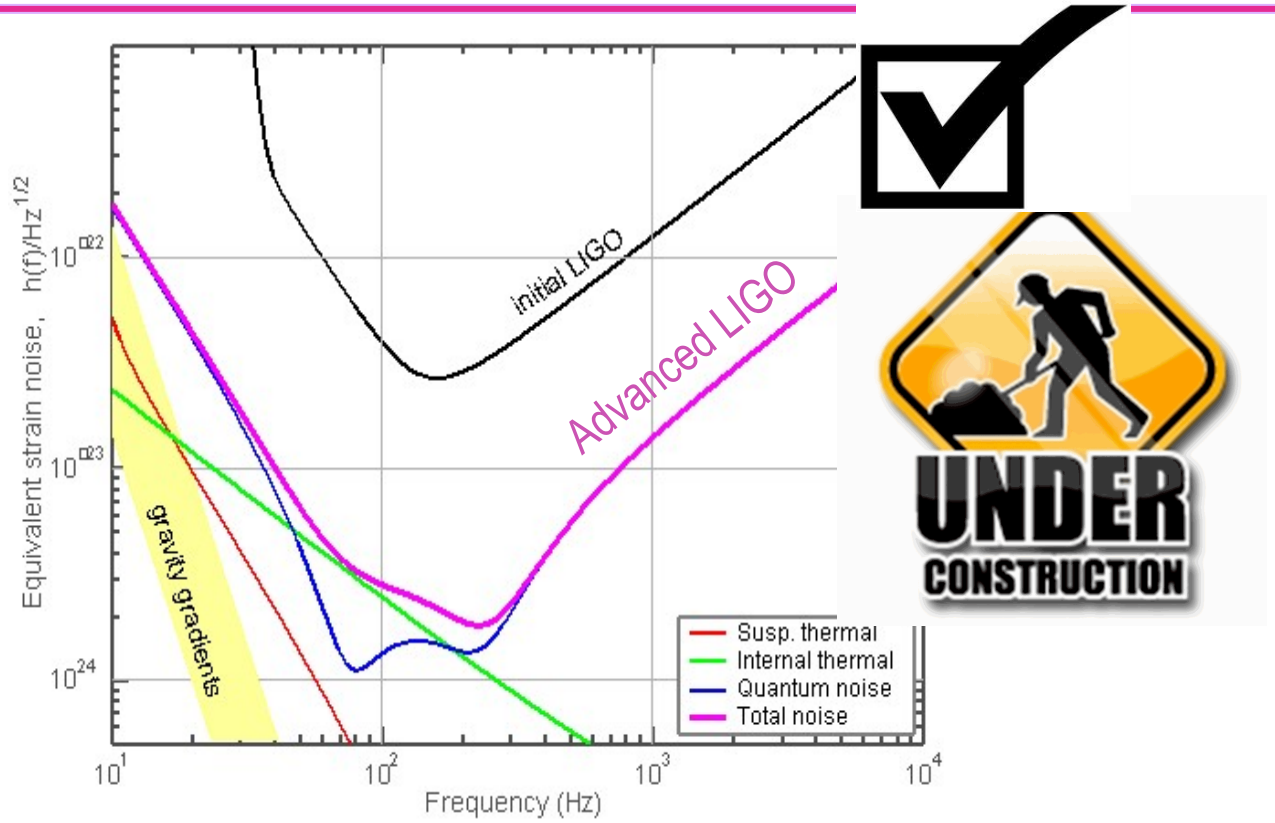
2013

Nov 14, 2013	Do Cosmic Strings Exist? [flyer]
Nov 14, 2013	Searching for Continuous Gravitational Wave Signals with the Hough Transform [flyer]
Oct 16, 2013	Scanning the Skies for Cosmic Explosions: First Search for Optical Counterparts to Gravitational Waves [flyer]
Oct 04, 2013	A Search for Long-lived Gravitational Waves Associated with Long Gamma-ray Bursts [flyer]
Sep 26, 2013	How High Are Pulsar "Mountains"? [flyer]
Sep 26, 2013	Listening for the Hum of Neutron Stars in the Center of Our Galaxy [flyer]
Aug 02, 2013	The Quantum Enhanced LIGO Detector Sets New Sensitivity Record [flyer]
Apr 05, 2013	What Gravitational Waves Can Tell Us About Colliding Stars and Black Holes [flyer]

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)

Now under construction: Advanced LIGO



~10 times better than initial LIGO

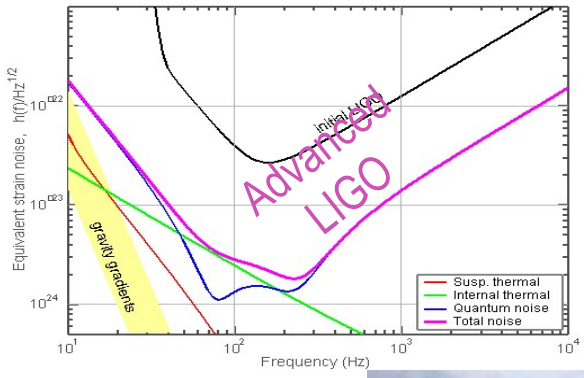
Installation in progress, going very well, almost done !!

Coincident "lock" in ~2014 (already achieved at LLO!),
science runs starting in 2015

with increasing sensitivity to follow.

In progress: Advanced LIGO
Ten times better!

Vacuum system – same as initial LIGO

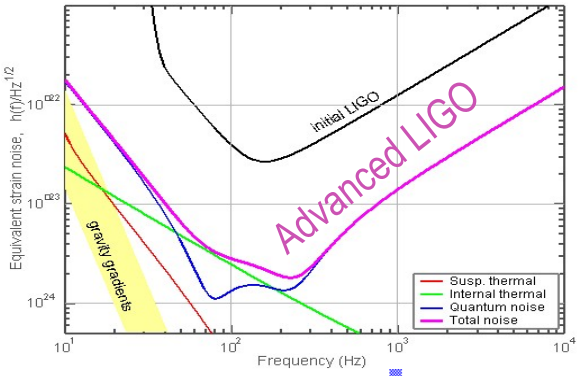


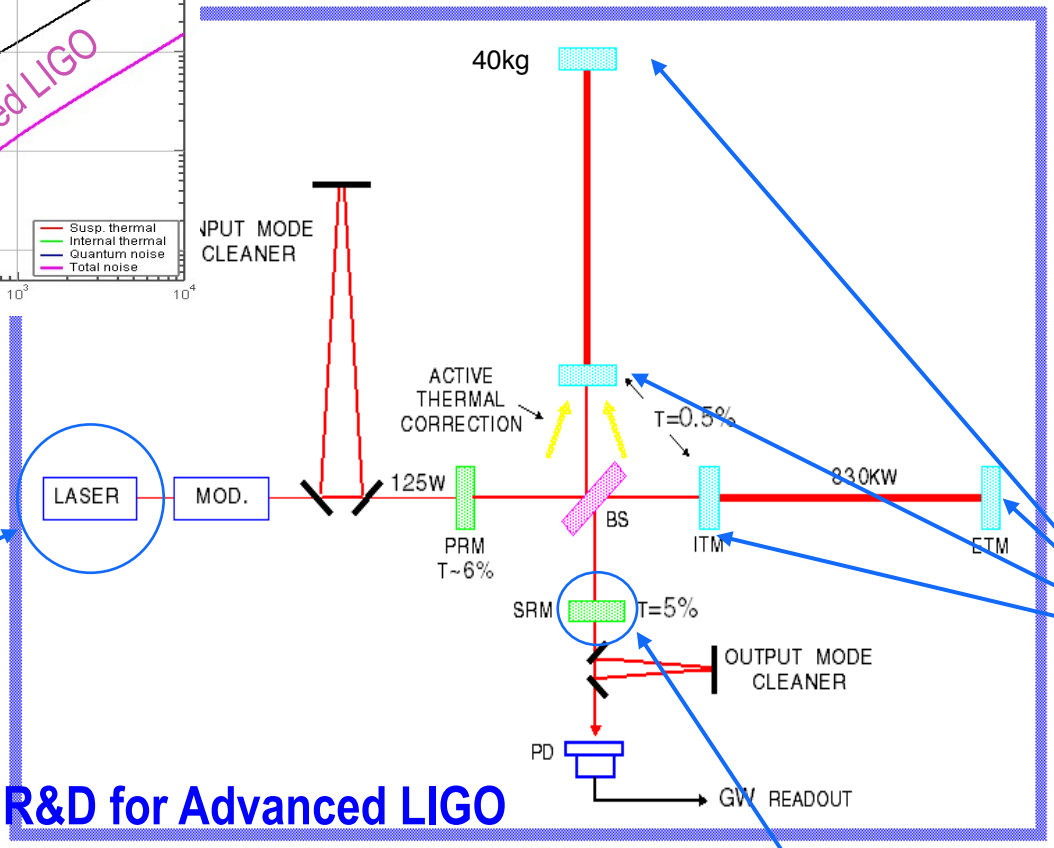
LIGO-G1400667

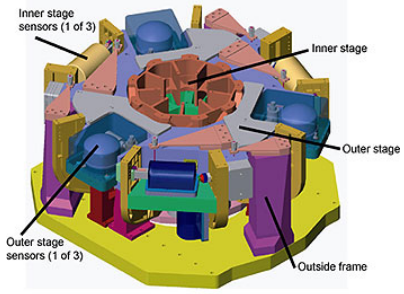
US NSF funding for Advanced LIGO: 2008-2015.

What's advanced in Advanced LIGO?

Major technological differences between LIGO and Advanced LIGO

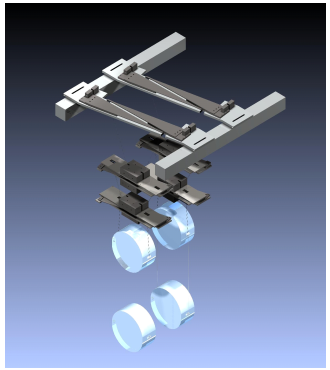






Active vibration isolation systems

Quadruple pendulum: Silica optics, welded to silica suspension fibers

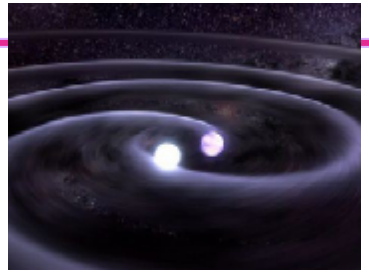


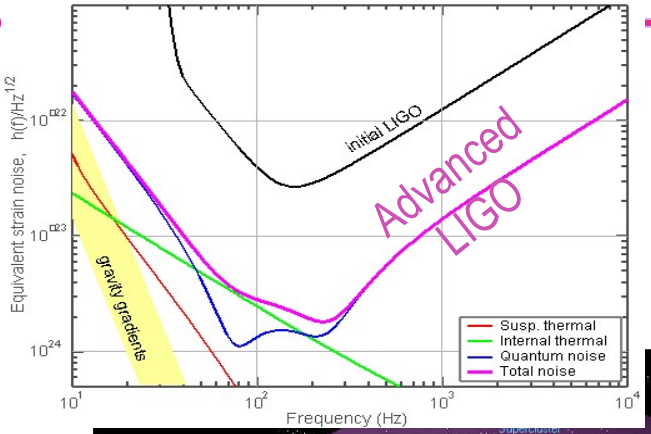
High power laser (180W)

Advanced interferometry Signal recycling

More details on R&D for Advanced LIGO and for future detectors in Riccardo Bassiri's talk this afternoon

What will Advanced LIGO see ?





Neutron Star Binaries:

Initial LIGO:

Average BNS reach ~15 Mpc → rate ~1/50yrs

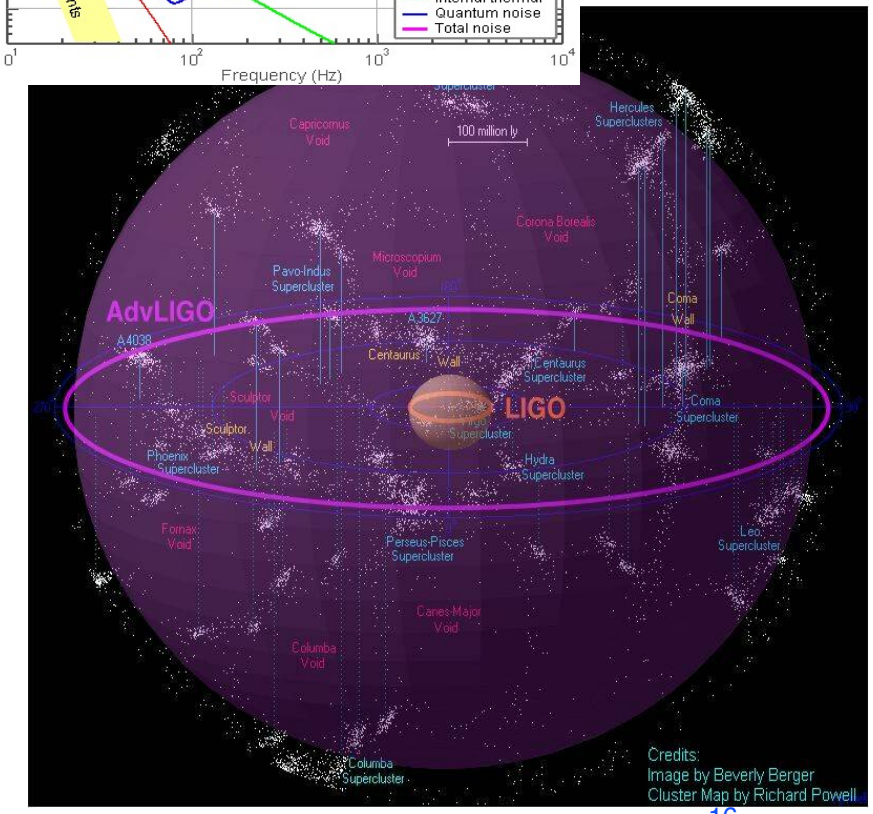
Advanced LIGO: ~ 200 Mpc

"Realistic rate" ~ 40/year (but can be 0.4-400)

Other binary systems:

NS-BH: 0.004/yr → 10/yr

BH-BH: 0.007/yr→ 20/yr

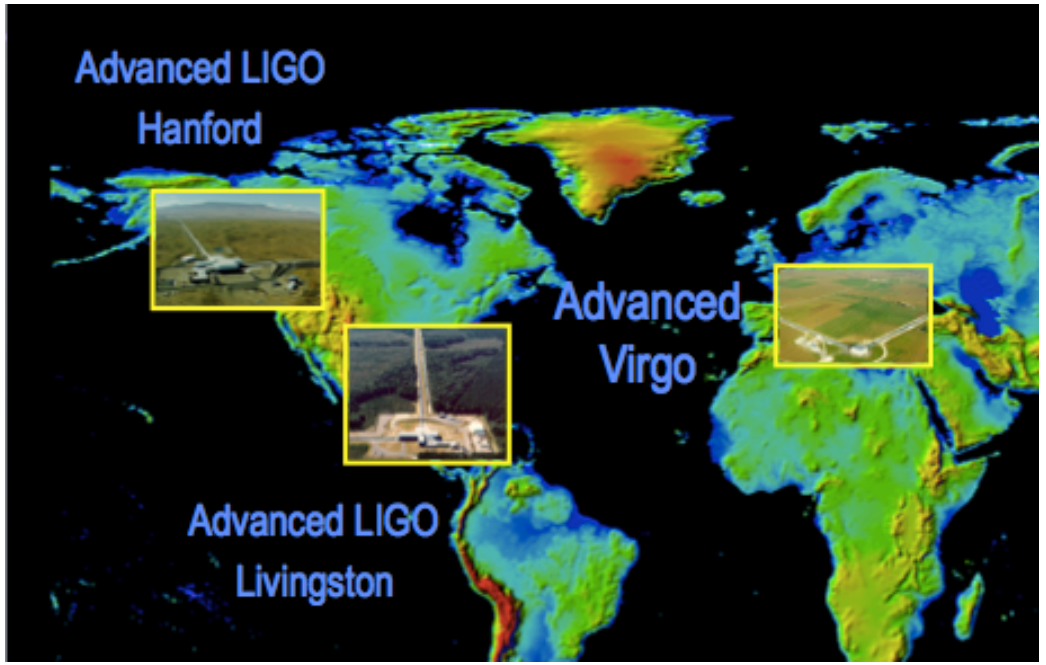


Class. Quant. Grav. **27**, 173001 (2010)

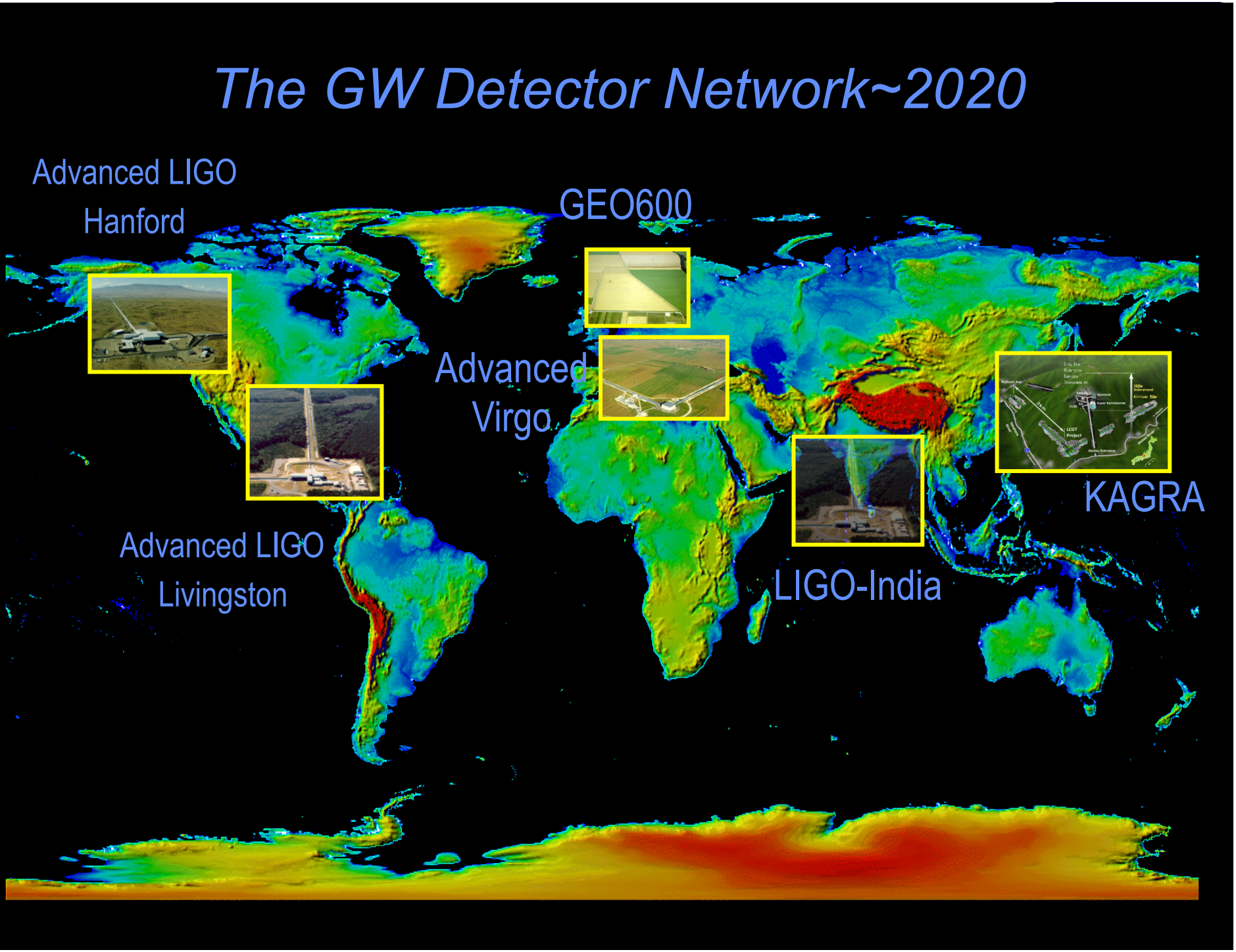
Coming soon near you: Advanced GW Detectors running!

Epoch	Estimated Run Duration	$E_{GW} = 10^{-2} M_{\odot} c^2$ Burst Range (Mpc) LIGO	Virgo	BNS Range (Mpc) LIGO	Virgo	Number of BNS Detections
2015	3 months	40 – 60	–	40 – 80	–	0.0004 – 3
2016–17	6 months	60 – 75	20 – 40	80 – 120	20 – 60	0.006 – 20
2017–18	9 months	75 – 90	40 – 50	120 – 170	60 – 85	0.04 – 100

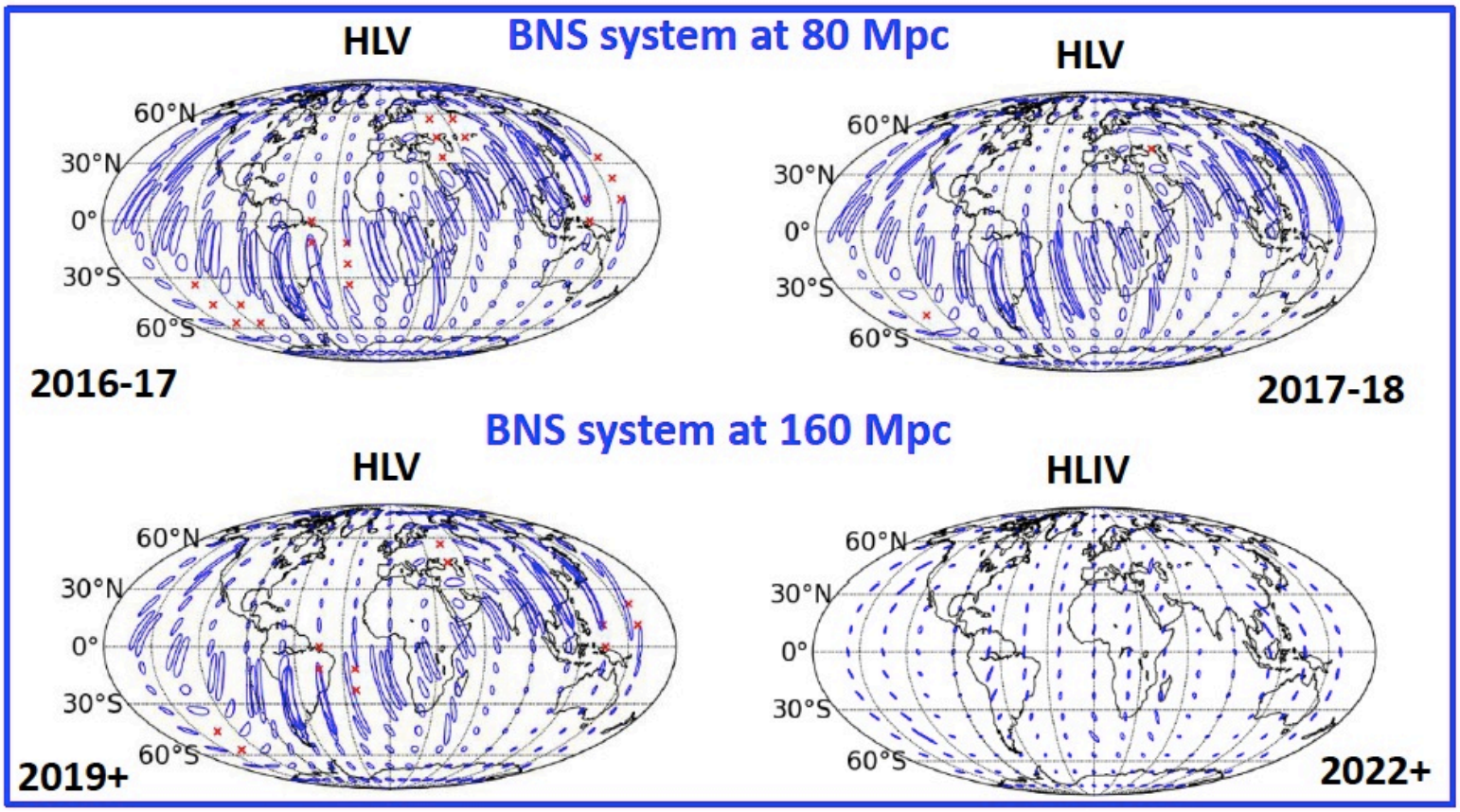
arXiv:1304.0670



The GW Detector Network~2020



More detectors = better localization



Position uncertainties with areas of **tens to hundreds of sq. degrees**

→ 90% confidence localization areas

X → signal not confidently detected

Multi-messenger astronomy: GW/EM observations

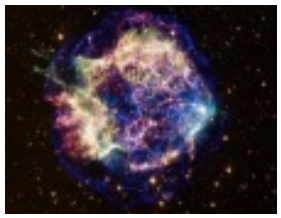
After detecting GW signals, we would like to …

- Consider the signal in its astrophysical context
- Give a precise sky localization, identify host galaxy
- Get more insight into the physics of the progenitors (mass, spin, distance..) and their environment (temperature, density, redshift..)

We will obtain this picture combining gravitational-wave and electromagnetic information: Multi-messenger astronomy!

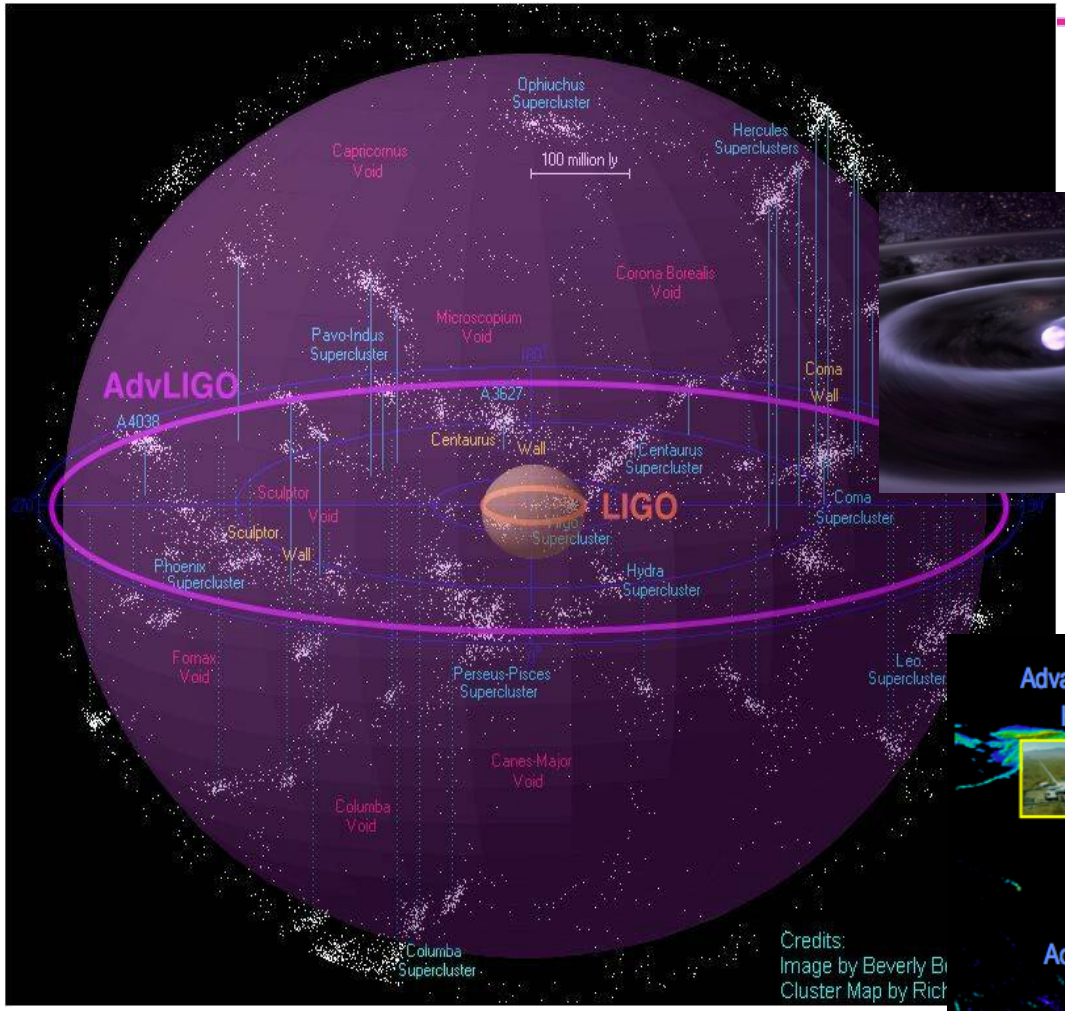
- LSC and Virgo opened a call to sign agreements for the identification of EM counterparts to GW triggers in Advanced detectors starting in 2015.
- We received more than 60 applications from 19 countries, with about 150 instruments covering the full spectrum, from radio to high-energy gamma-rays!
- Shortly after a few detections, LSC/Virgo will publicly release GW triggers for follow up.

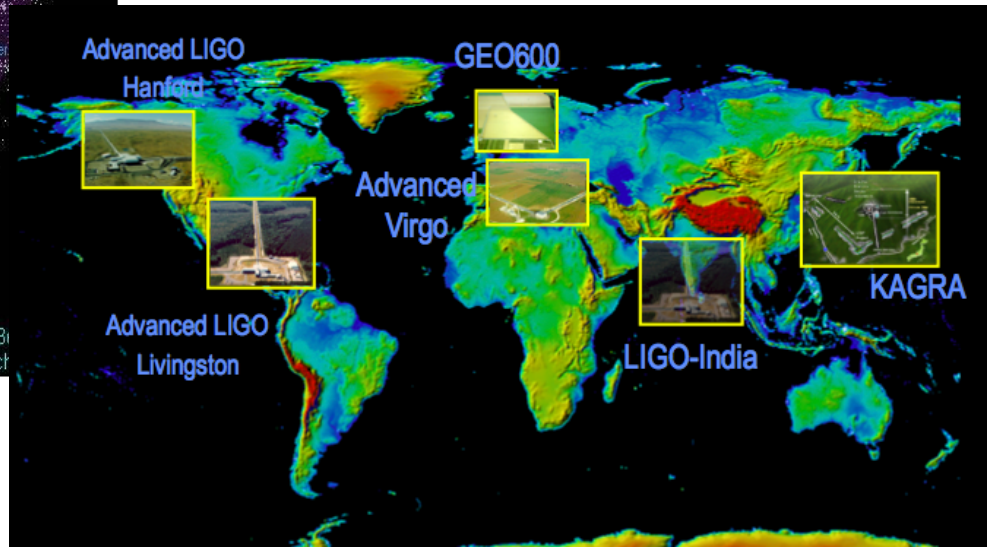
More details in Kipp Cannon's talk on "The Exploding Sky" talk this afternoon



Gravitational waves are coming!

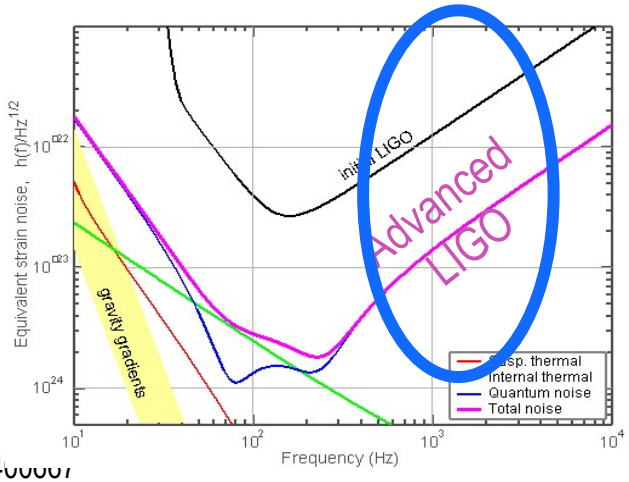
www.ligo.org

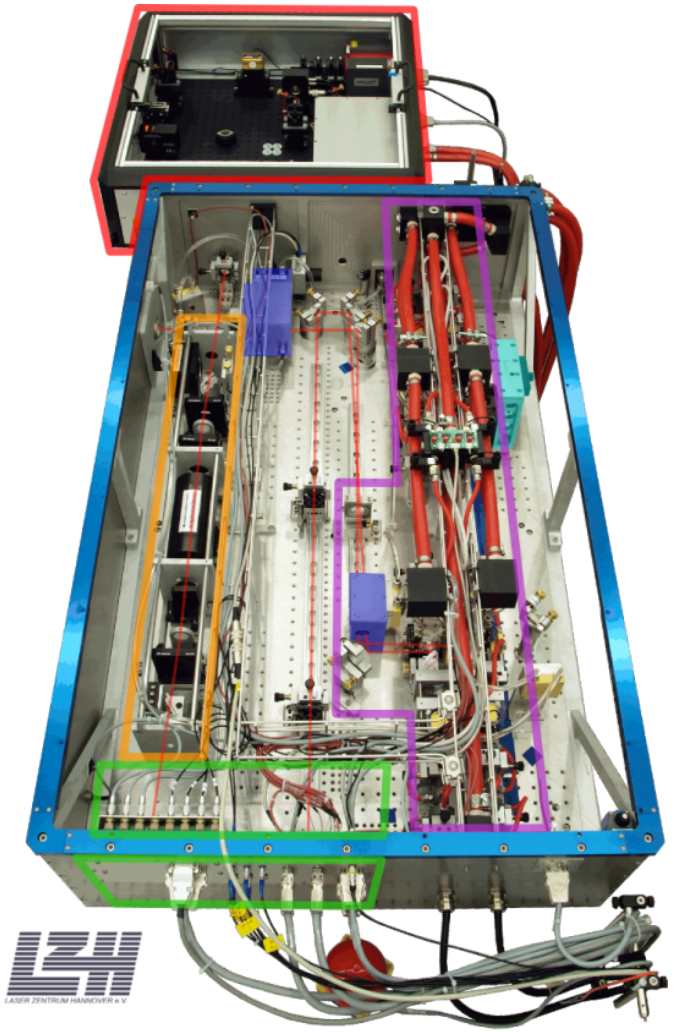




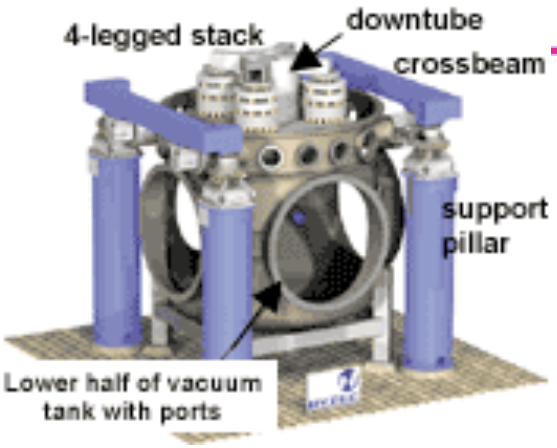
Initial vs Advanced LIGO

Lasers become more powerful: 10W ➔ 200 W

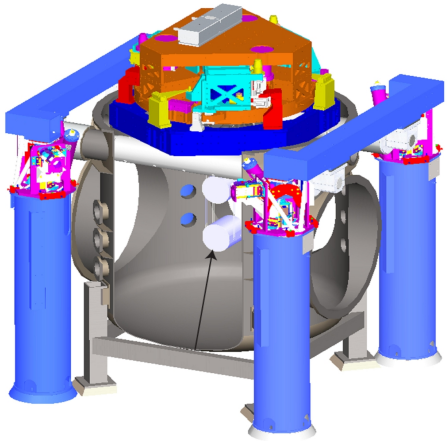


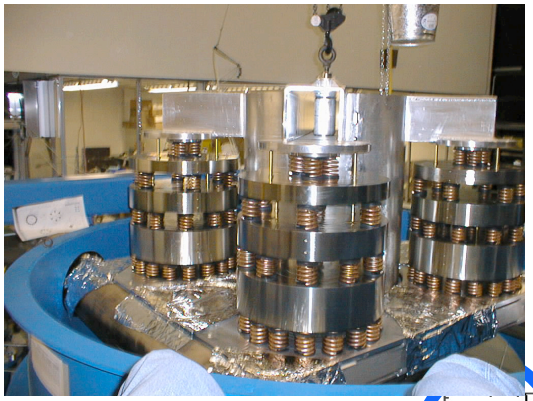


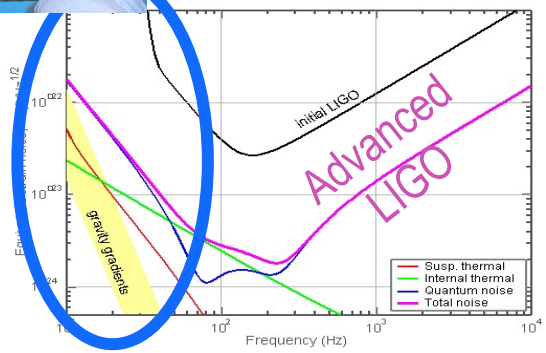
Initial vs Advanced LIGO



Seismic isolation goes from passive to active.

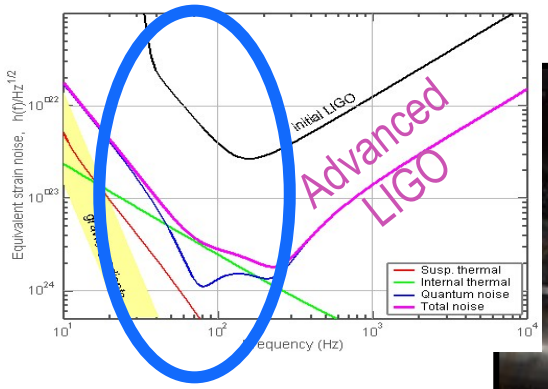


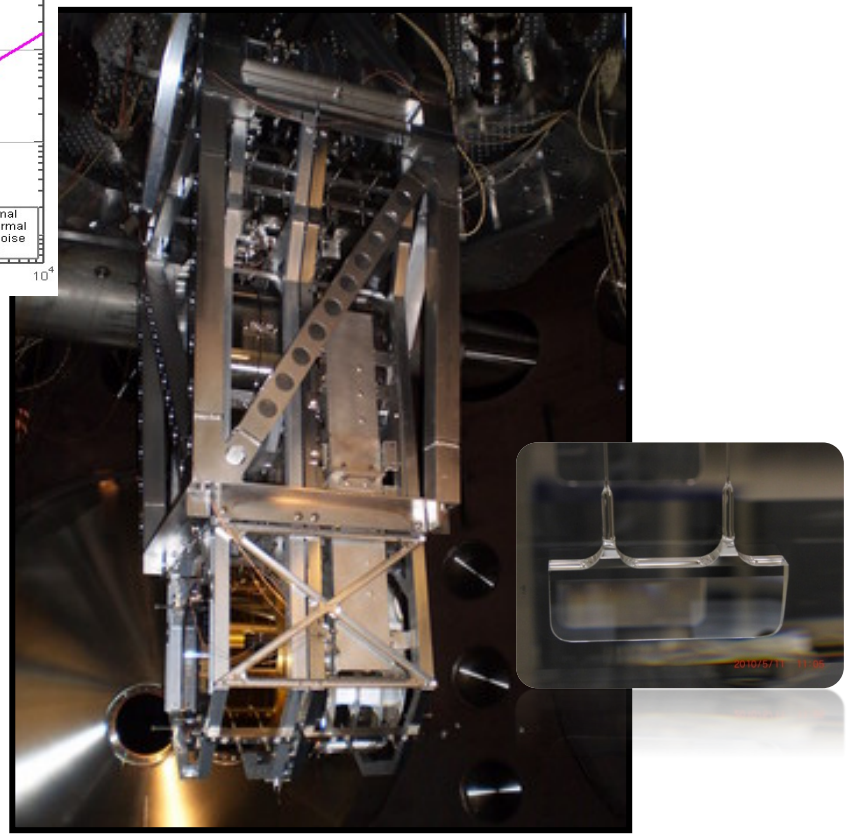


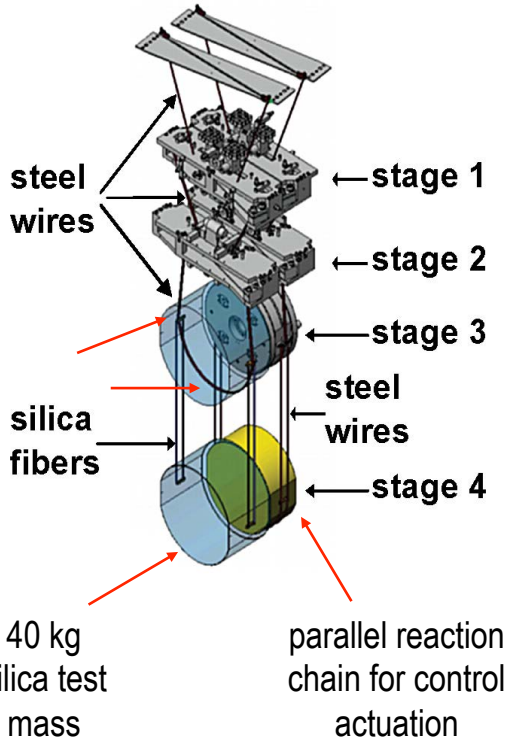


Initial vs Advanced LIGO

10 kg test masses on simple pendulums become 40 kg monolithic suspensions in quadruple pendulums, with better quality optics







More on LIGO: LIGO magazine in www.ligo.org

LIGO MAGAZINE

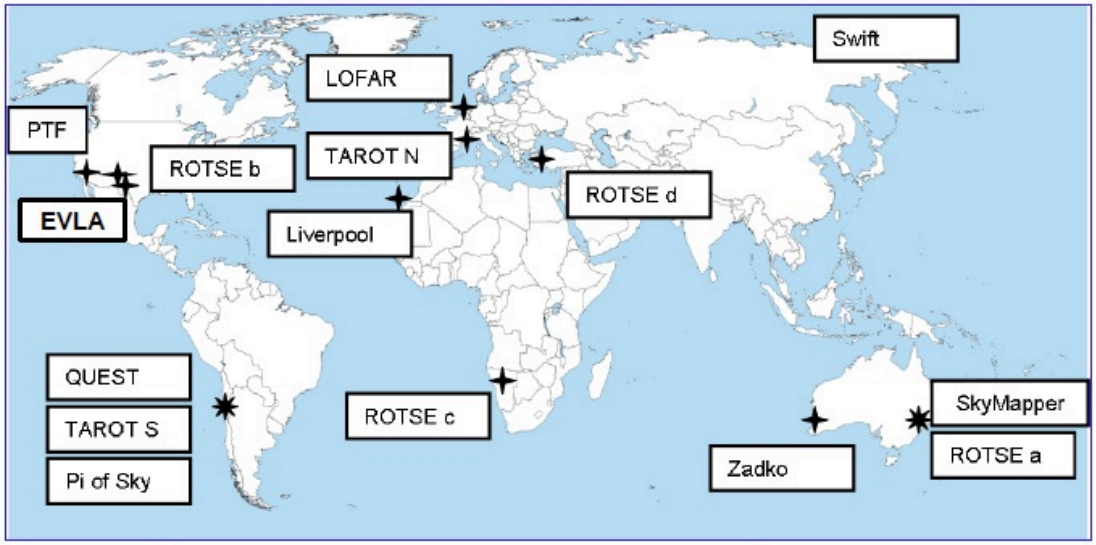
Issue 1

Issue 2

Issue 3

Issue 4

Multi-messenger astronomy 2010 (initial detectors)



Optical Telescopes

(FOV, limiting magnitude)

TAROT SOUTH/NORTH
3.4 deg², 17.5 mag

Zadko
0.17 deg², 20.5 mag

ROTSE
3.4 deg², 17.5 mag

QUEST
9.4 deg², 20.5 mag

SkyMapper
5.7 deg², 21 mag

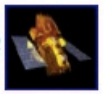
Pi of the Sky
400 deg², 11.5 mag

Palomar Transient Factory
7.8 deg², 20.5 mag

Liverpool telescope
21 arcmin², 21 mag

X-ray and UV/Optical Telescope

Swift Satellite
XRT-FOV **0.16** deg²
Flux 10^{-13} ergs/cm²/s



Radio Interferometer

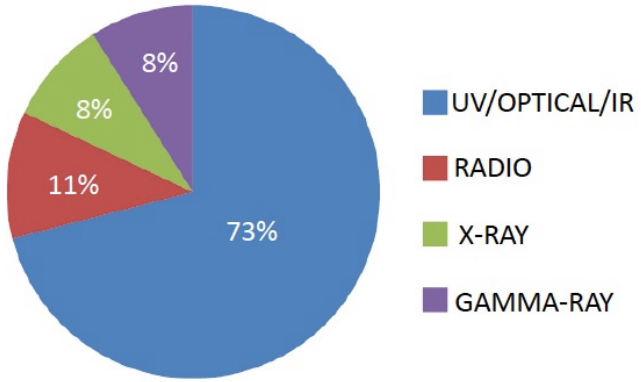
LOFAR
30 - 80 MHz
110 - 240 MHz
Maximum **25** deg²

EVLA

5 GHz - **7** arcmin²

Call for interest in EM counterparts to GW candidates

- After the first four published GW events, LSC and Virgo will promptly release public triggers to be followed up.
- To initiate the multi-messenger from the very beginning, LSC and Virgo opened a call to sign agreements for the identification of EM counterparts to GW triggers in Advanced detectors starting in 2015.
- We received more than 60 applications from 19 countries, with about 150 instruments covergin the full spectrum, from radio to high-energy gamma-rays!



The GW Detector Network~2016