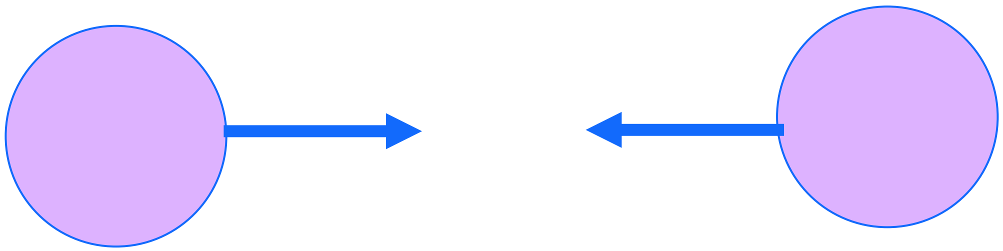
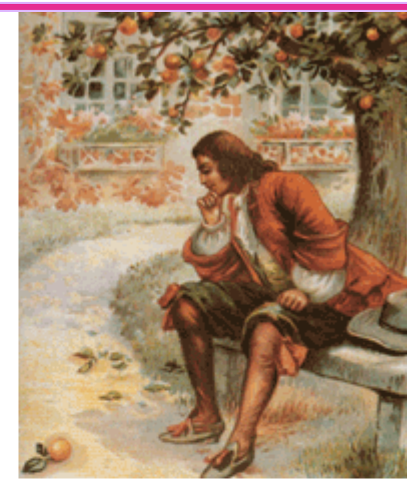
Opening the Gravitational Wave Window

Gabriela González
Louisiana State University

For the LIGO Scientific Collaboration and

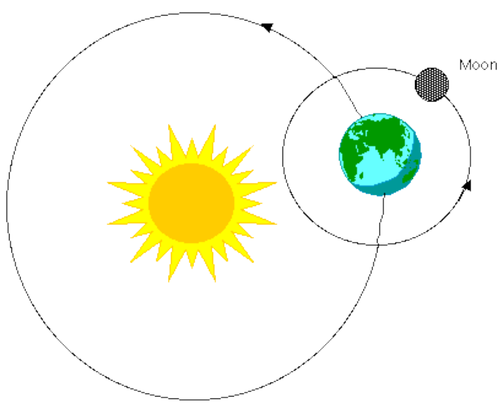
Newtons’ gravity



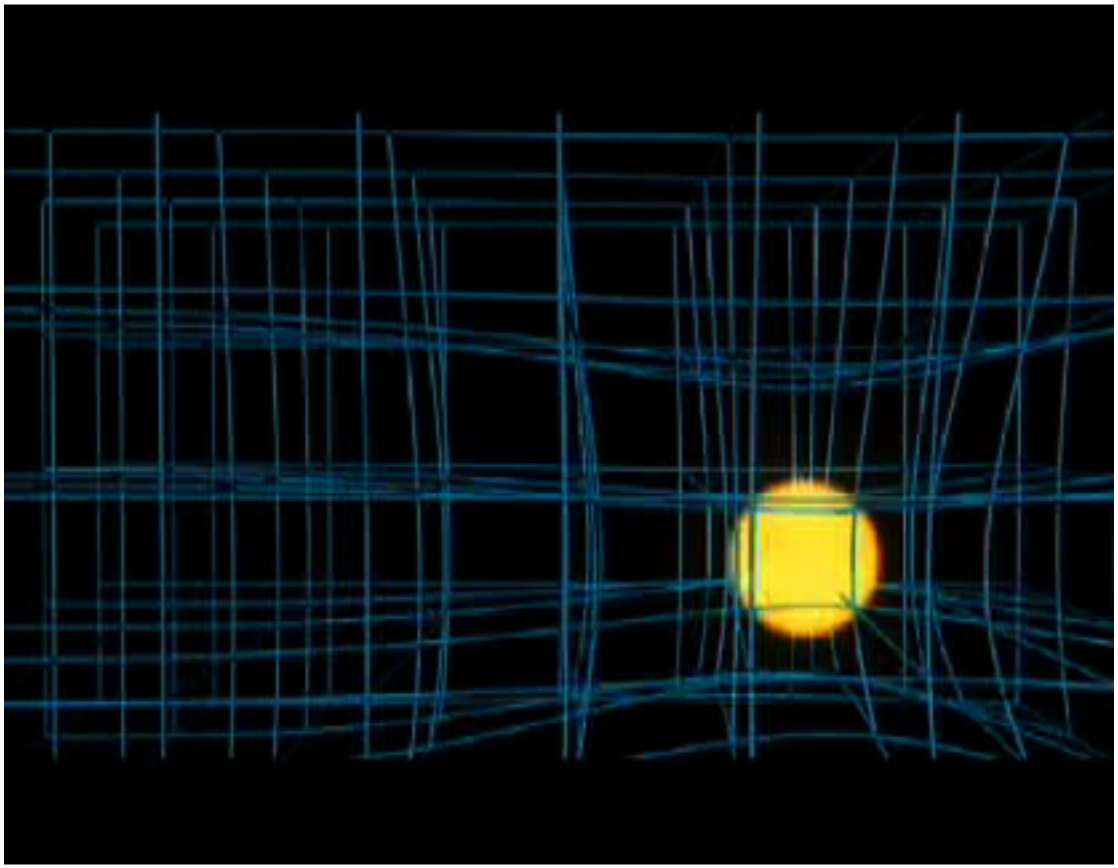


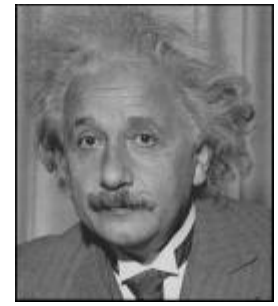
“Newton’s law”: $F = Gm_1m_2/r^2$

Explains why apples fall, why the planets move around the Sun,…



Einstein's gravity

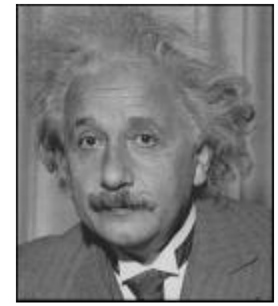


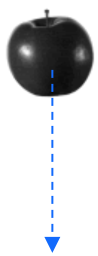


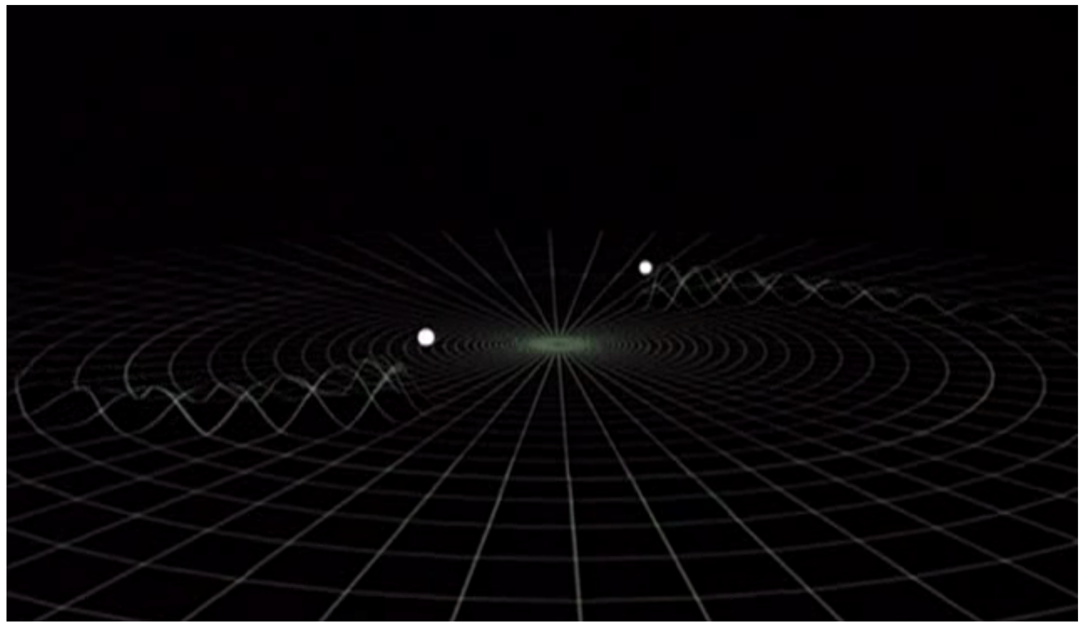
sciencebulletins.amnh.org
And in YouTube!

Einstein's gravitation

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

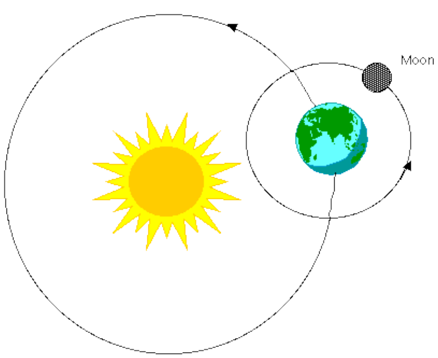






Explains just as well as Newtons' why things fall and planetary motion…

Einstein's messengers,
National Science Foundation video
www.einsteinsmessengers.org

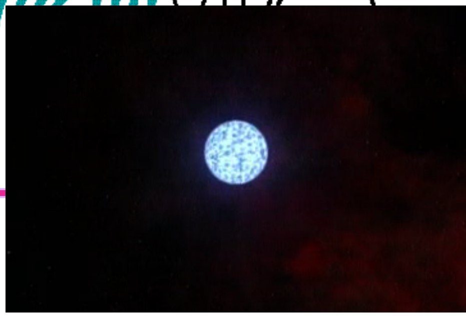


.. but it also predicts gravitational waves traveling away from moving masses!

LIGO-G1301143

Where do gravitational waves come from?

From stars living in galaxies…

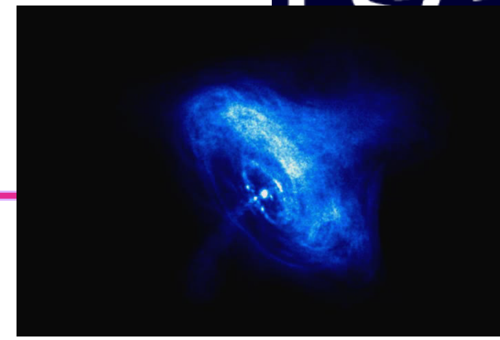


Supernova explosions
(that form a BH or a NS)

Where do gravitational waves come from?

Credits: Animation: NASA/CXC/D.Berry & A.Hobart

From stars living in galaxies…



Rotating stars (pulsars)

Where do gravitational waves come from?

Credit: NASA/CXC/ASU/J.Hester et al.
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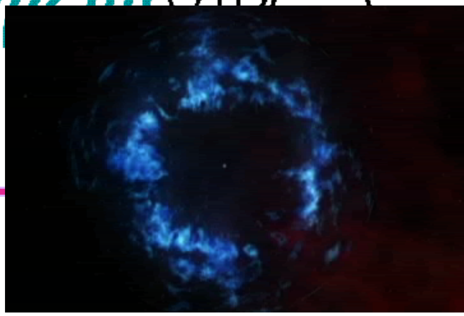
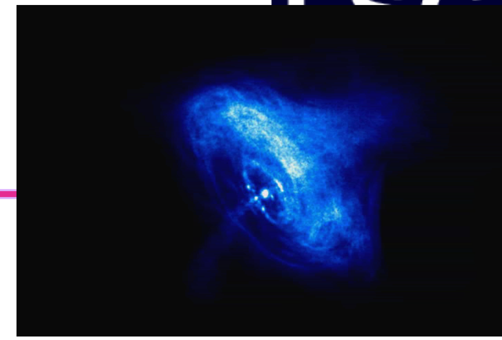
From stars living in galaxies…

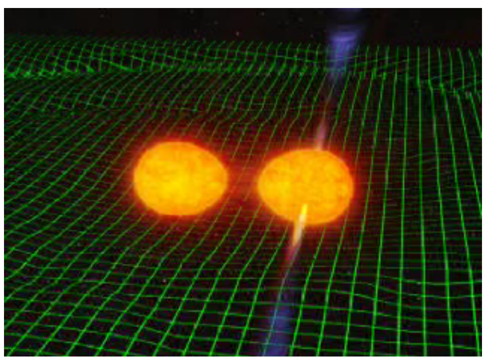


Supernova explosions



Rotating stars (pulsars)

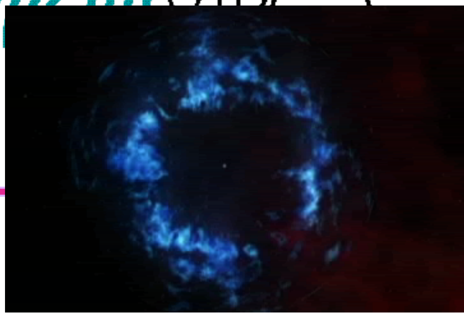
Where do gravitational waves come from?

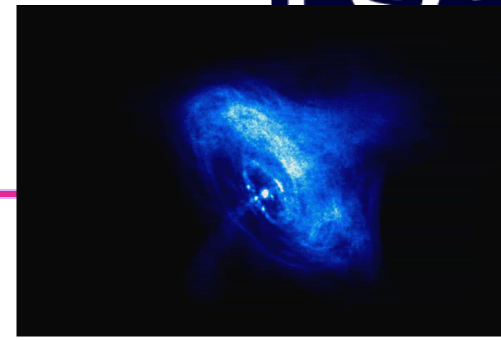


Binary systems coalescing into a black hole

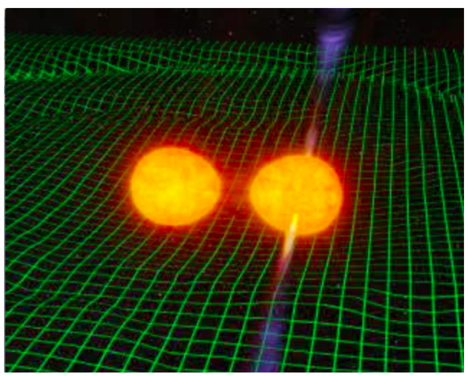
Credit: John Rowe

From stars living in galaxies…

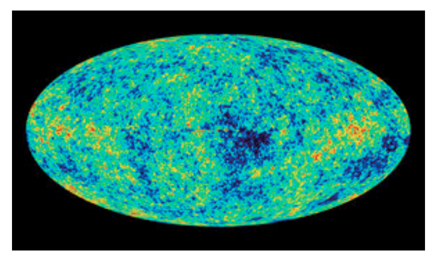

Supernova explosions


Rotating stars (pulsars)

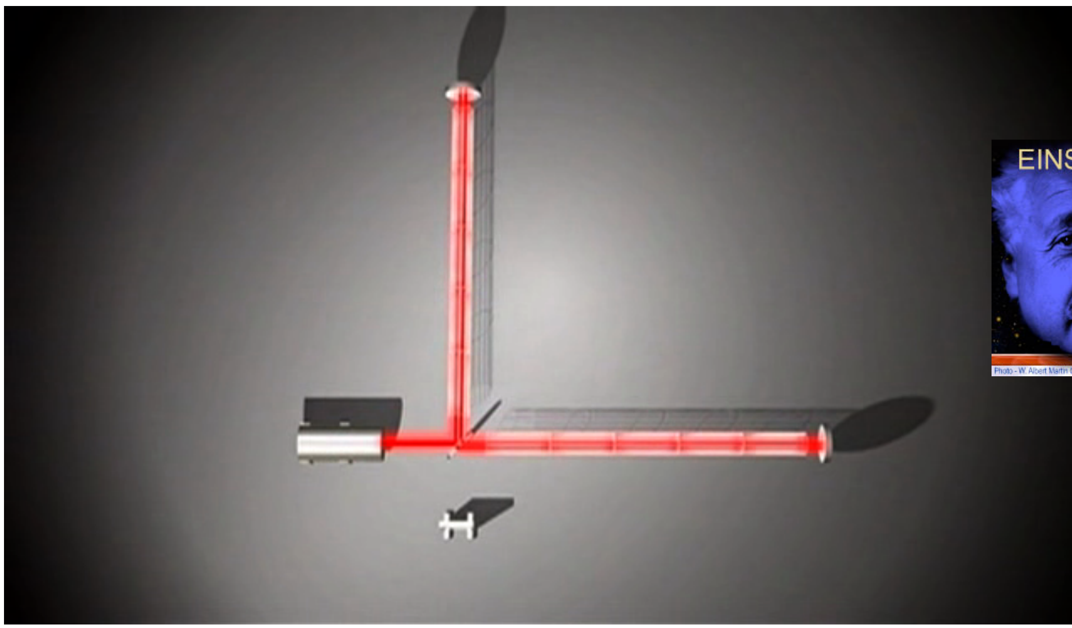
Where do gravitational waves come from?

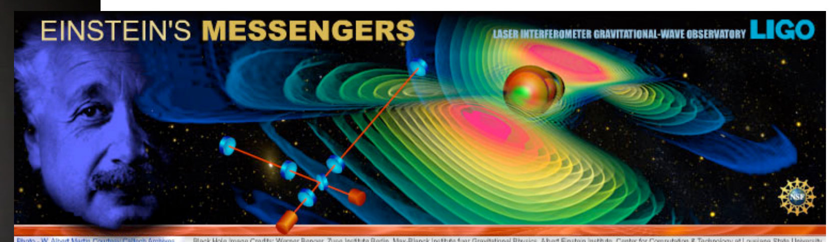

Binary systems coalescing into a black hole

..and from the beginning of the Universe!


Credit: NASA/WMAP

How to detect gravitational waves with an interferometer



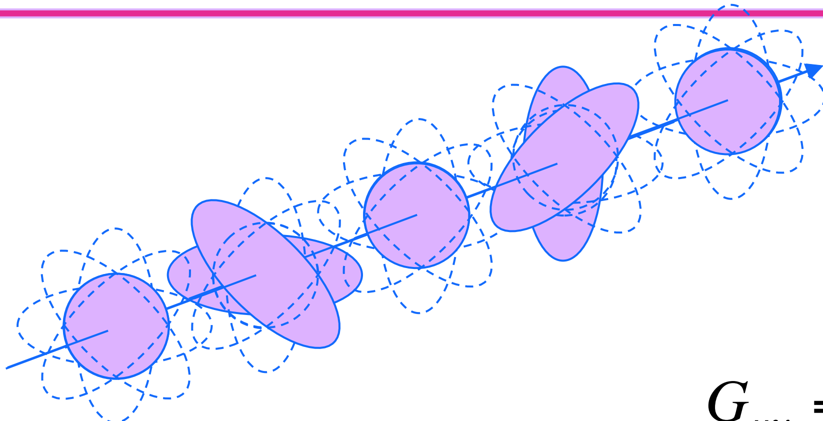


Einstein's messengers,
National Science Foundation video

http://www.einsteinsmessengers.org/

LIGO-G1301143

Gravitational waves: how big?

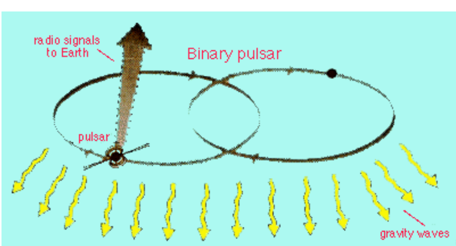


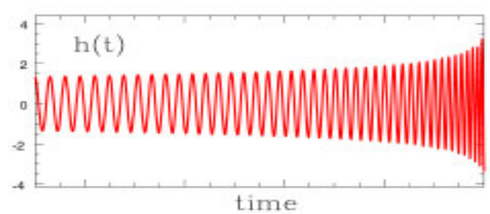
Gravitational waves are quadrupolar distortions of distances between freely falling masses. They are produced by time-varying mass quadrupoles.

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

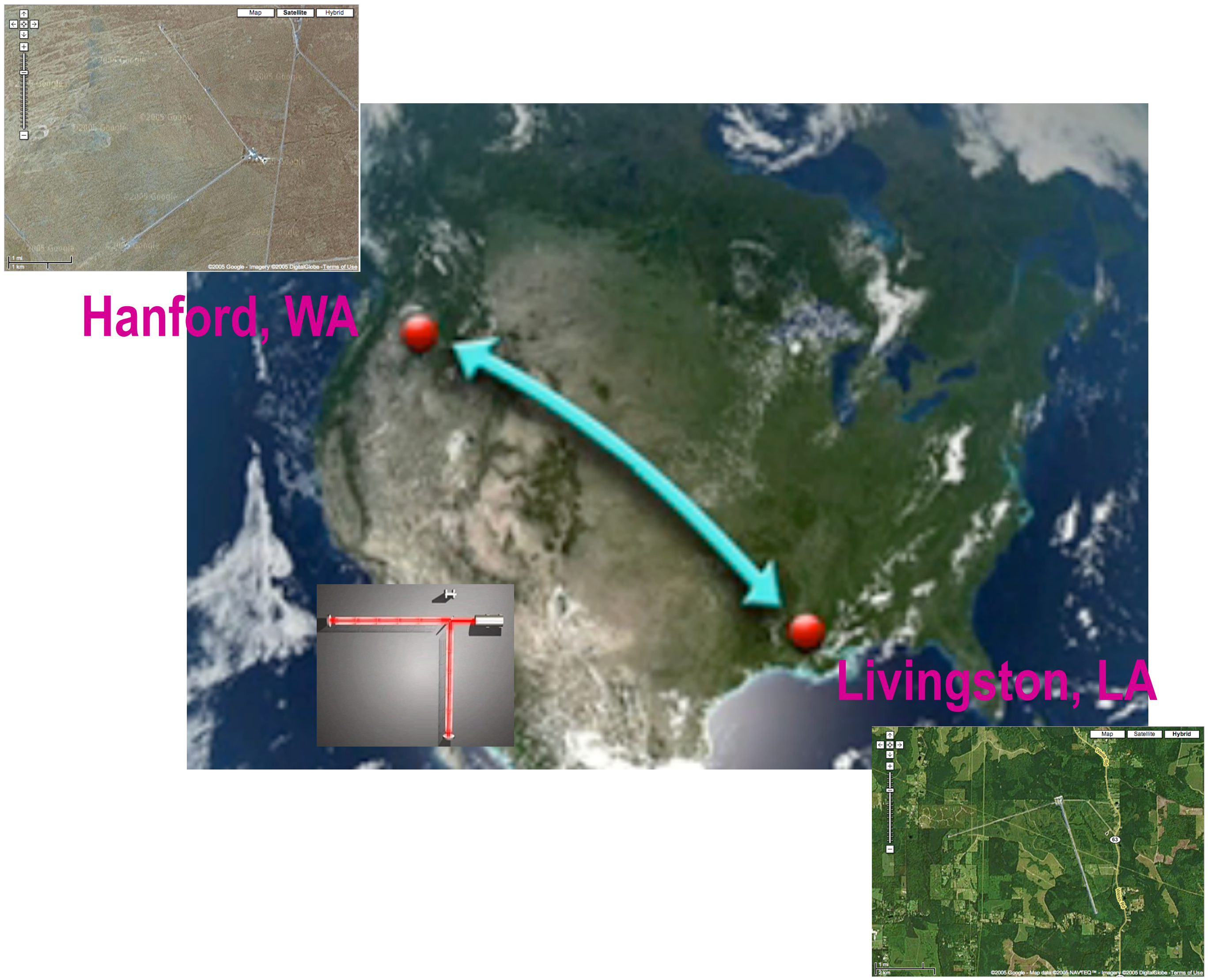
$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu} \qquad h_{\mu\nu} = \frac{2G}{c^4 r} \ddot{I}_{\mu\nu} \qquad h = \frac{\Delta L}{L}$$

$$h \approx \frac{4\pi^2 GMR^2 f_{orb}^2}{c^4 r}$$

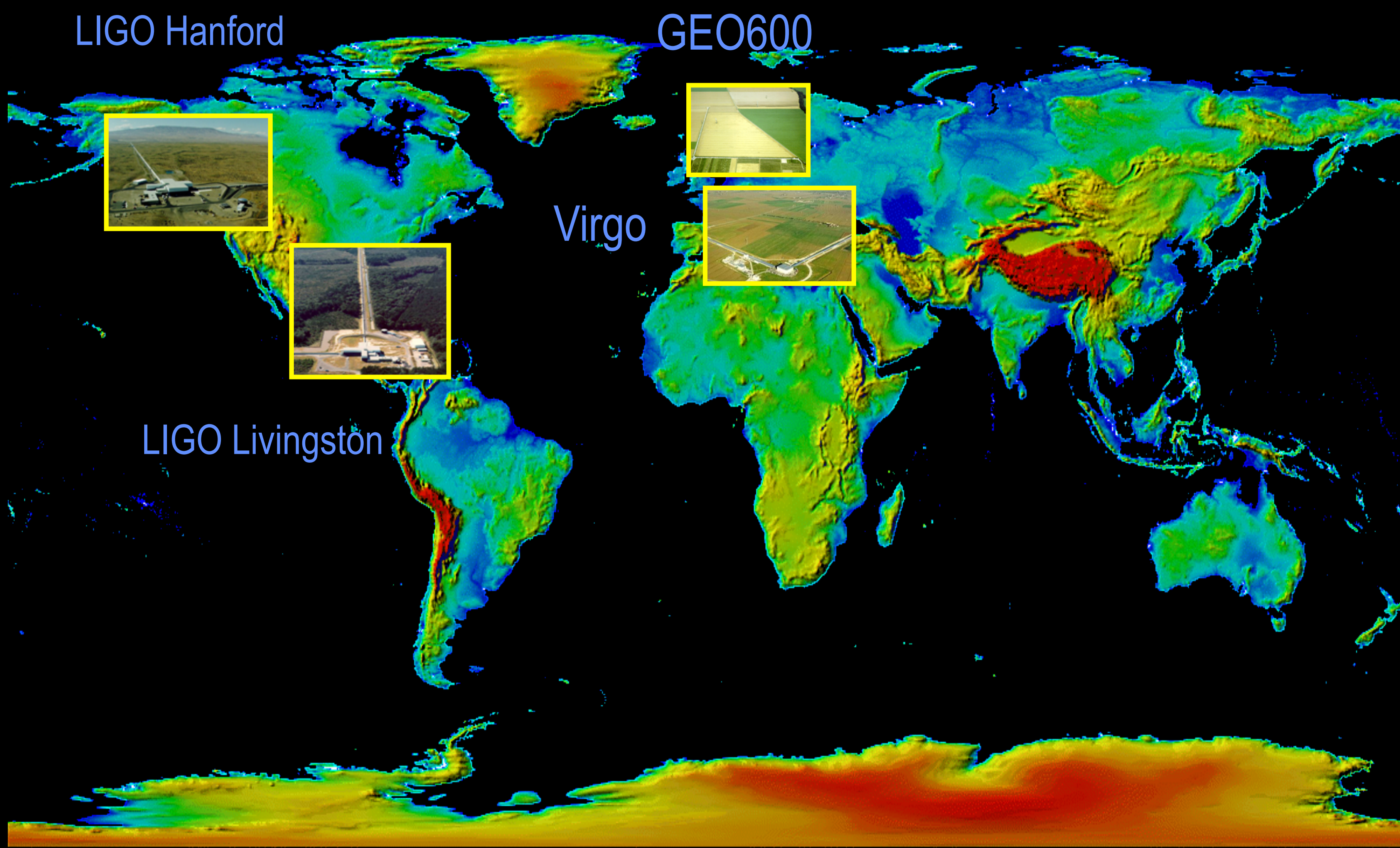




The LIGO Observatories



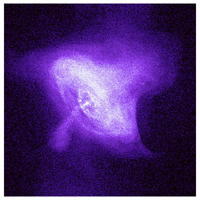
The GW Detector Network 2005-2010



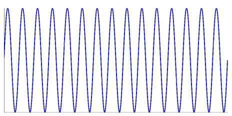
LIGO Scientific Collaboration
www.ligo.org

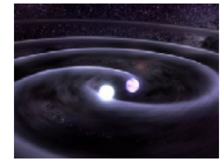
- 900+ members, 86+ institutions, 17 countries

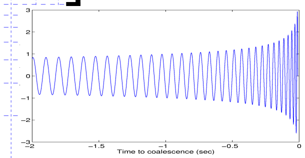
LIGO Detectors 2009-10 (S6)

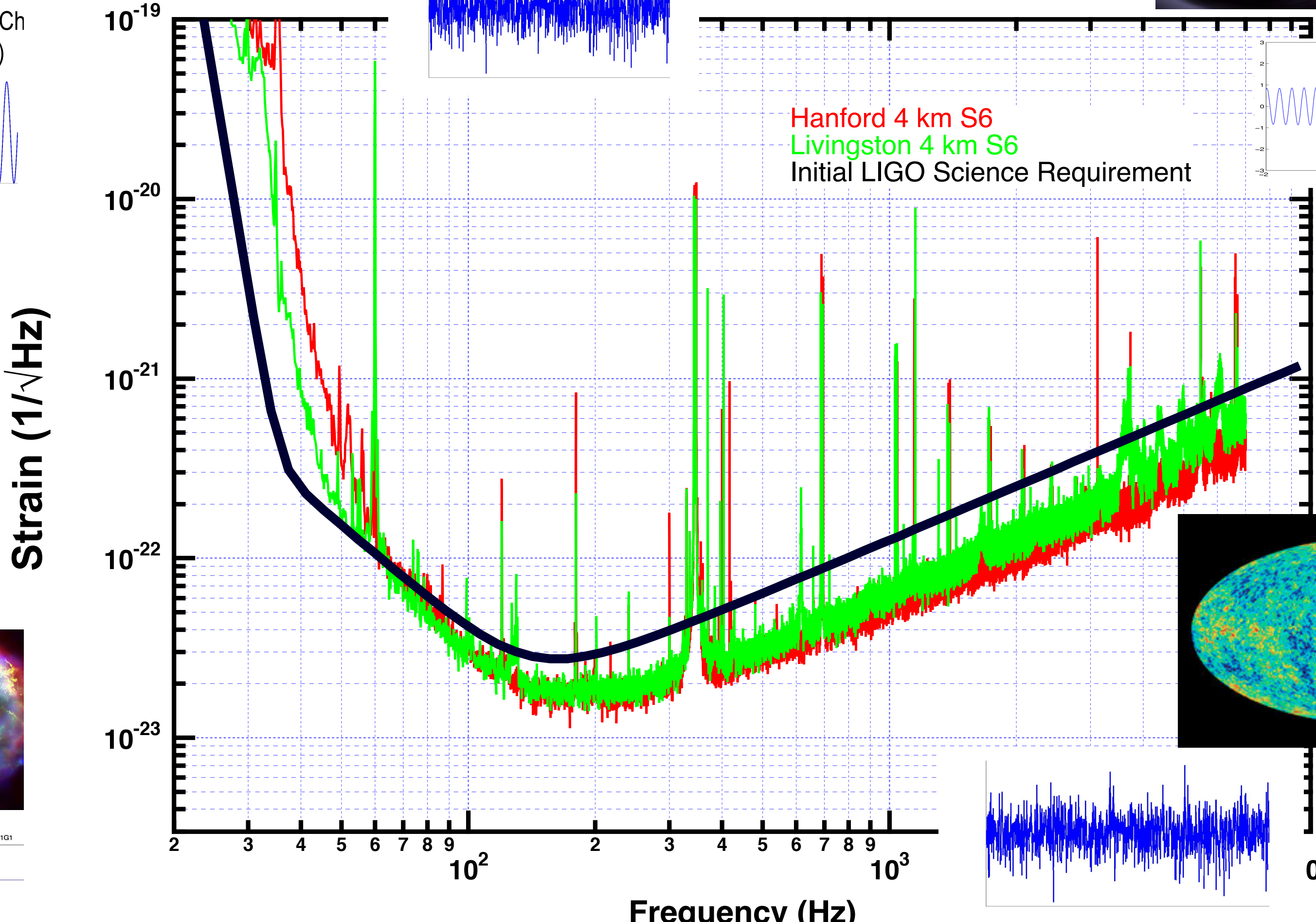


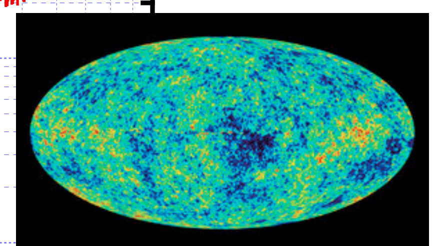
Crab pulsar (NASA, Ch
Observatory)



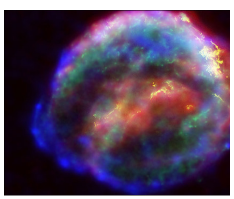


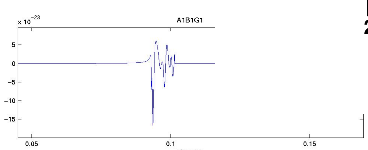






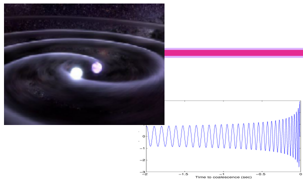
NASA, WMAP





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

Some interesting results 2005-2011



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

Horizon distance for a binary neutron star system (with m=1.4 solar masses)

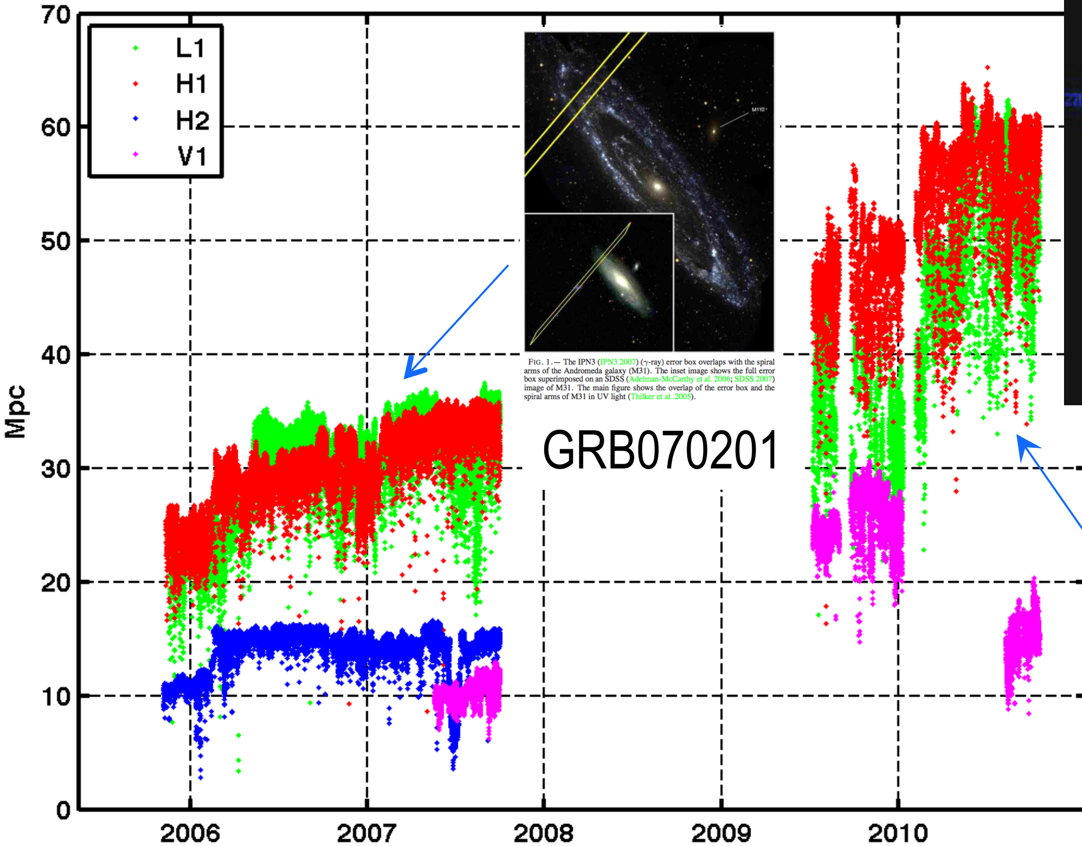
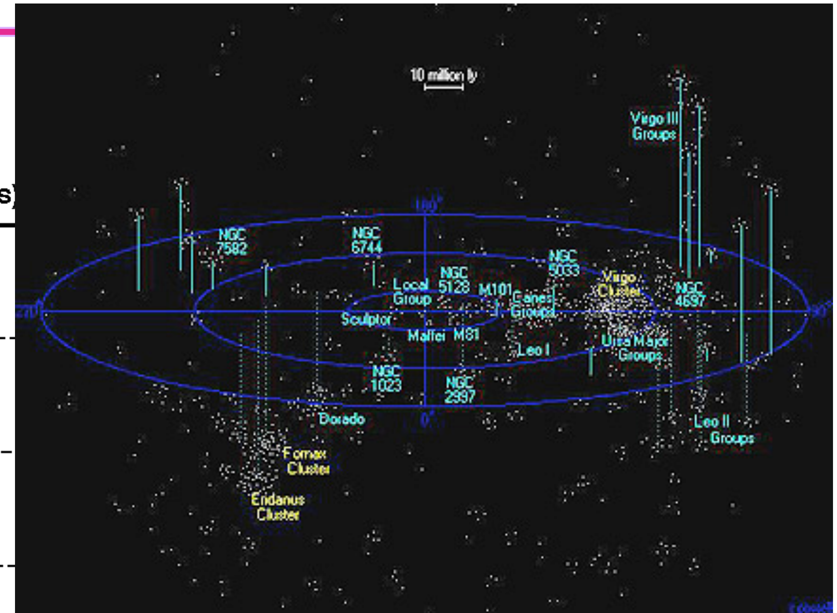


FIG. 1.— The IPN3 (IPN3 2007) (γ-ray) error box overlaps with the spiral arms of the Andromeda galaxy (M31). The inset image shows the full error box superimposed on an SDSS (Adelman-McCarthy et al. 2006; SDSS 2007) image of M31. The main figure shows the overlap of the error box and the spiral arms of M31 in UV light (Thilker et al. 2005).

GRB070201



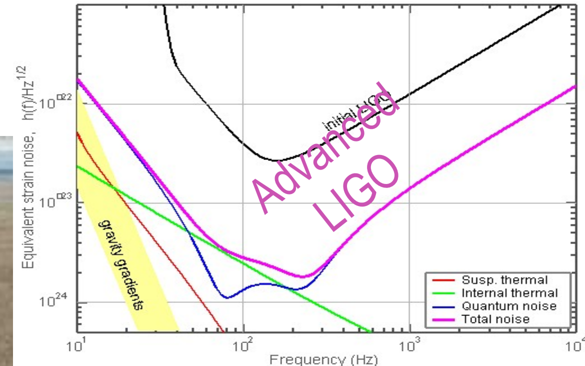
atlasoftheuniverse.com

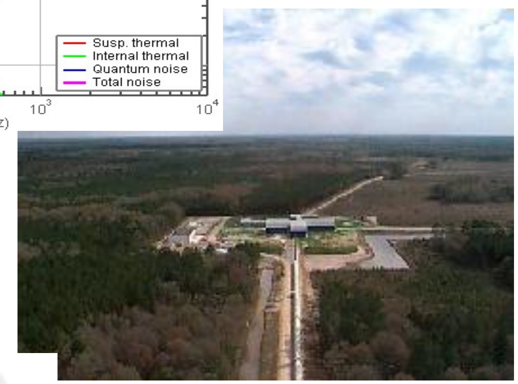
GW100916

Phys. Rev D85 (2012) 082002

In progress: Advanced LIGO

Vacuum system – same as initial LIGO





US NSF funding for Advanced LIGO: 2008-2015.

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

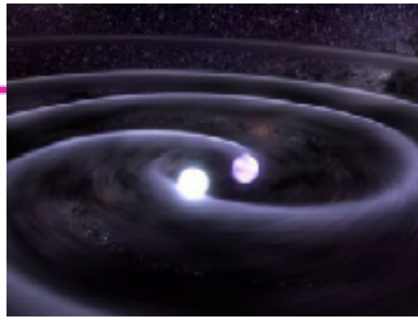
LIGO MAGAZINE

Issue 1

Issue 2

Issue 3

Are we there yet?



Neutron Star Binaries:

Initial LIGO:

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

Advanced LIGO: ~ 200 Mpc

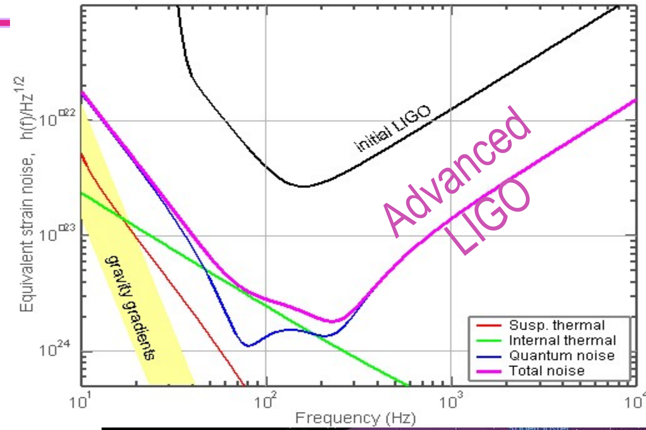
“Realistic rate” ~ 40/year (but can be 0.4-400)

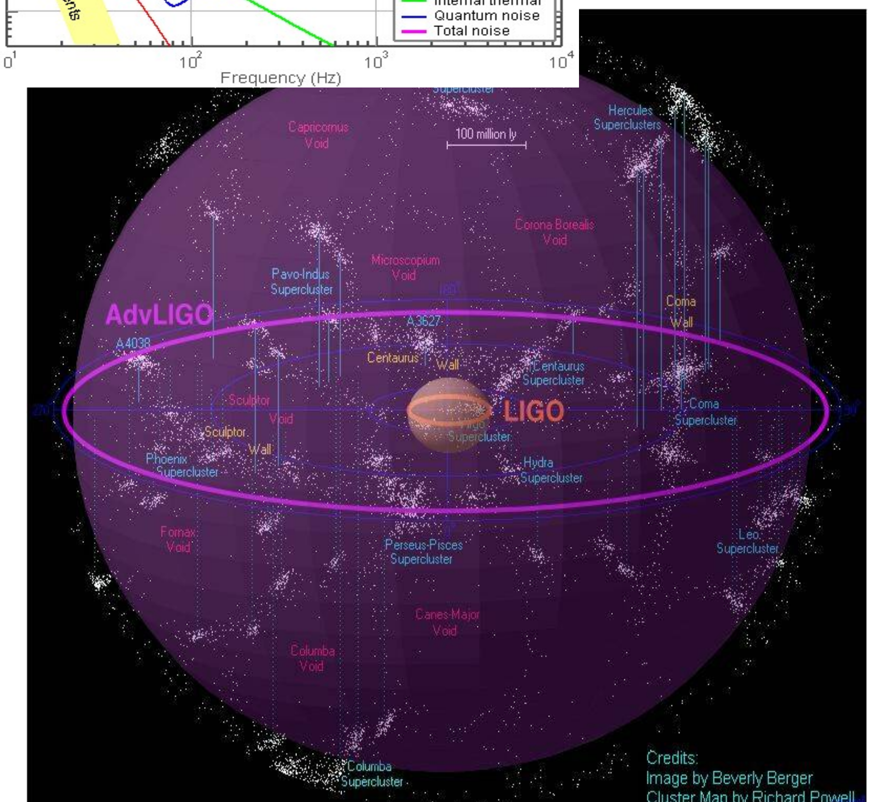
Other binary systems:

NS-BH: 0.004/yr → 10/yr

BH-BH: 0.007/yr→ 20/yr

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

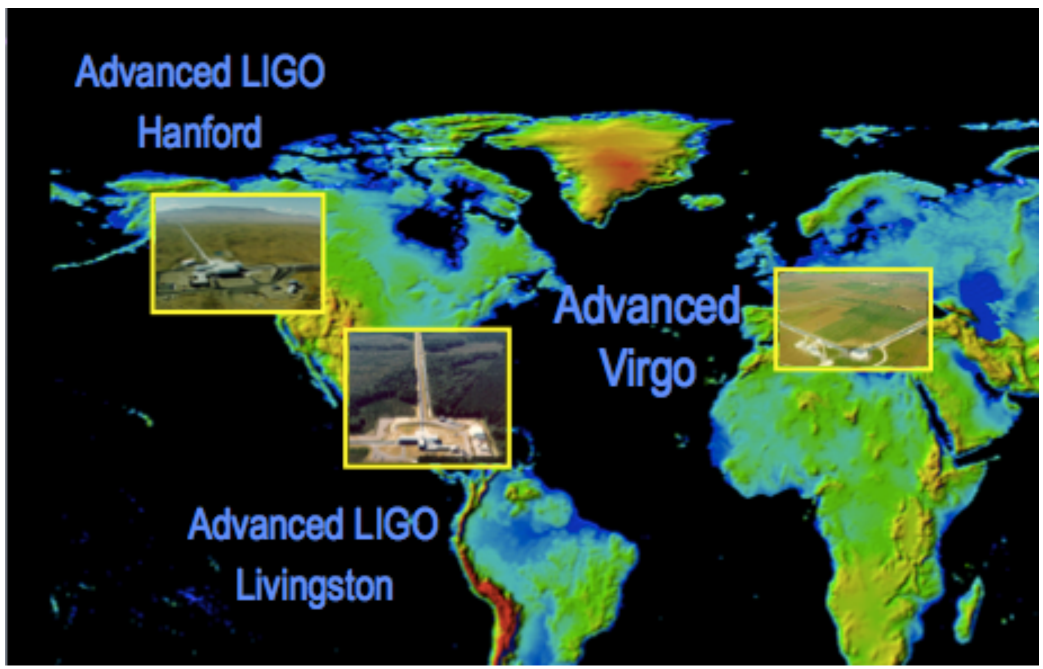




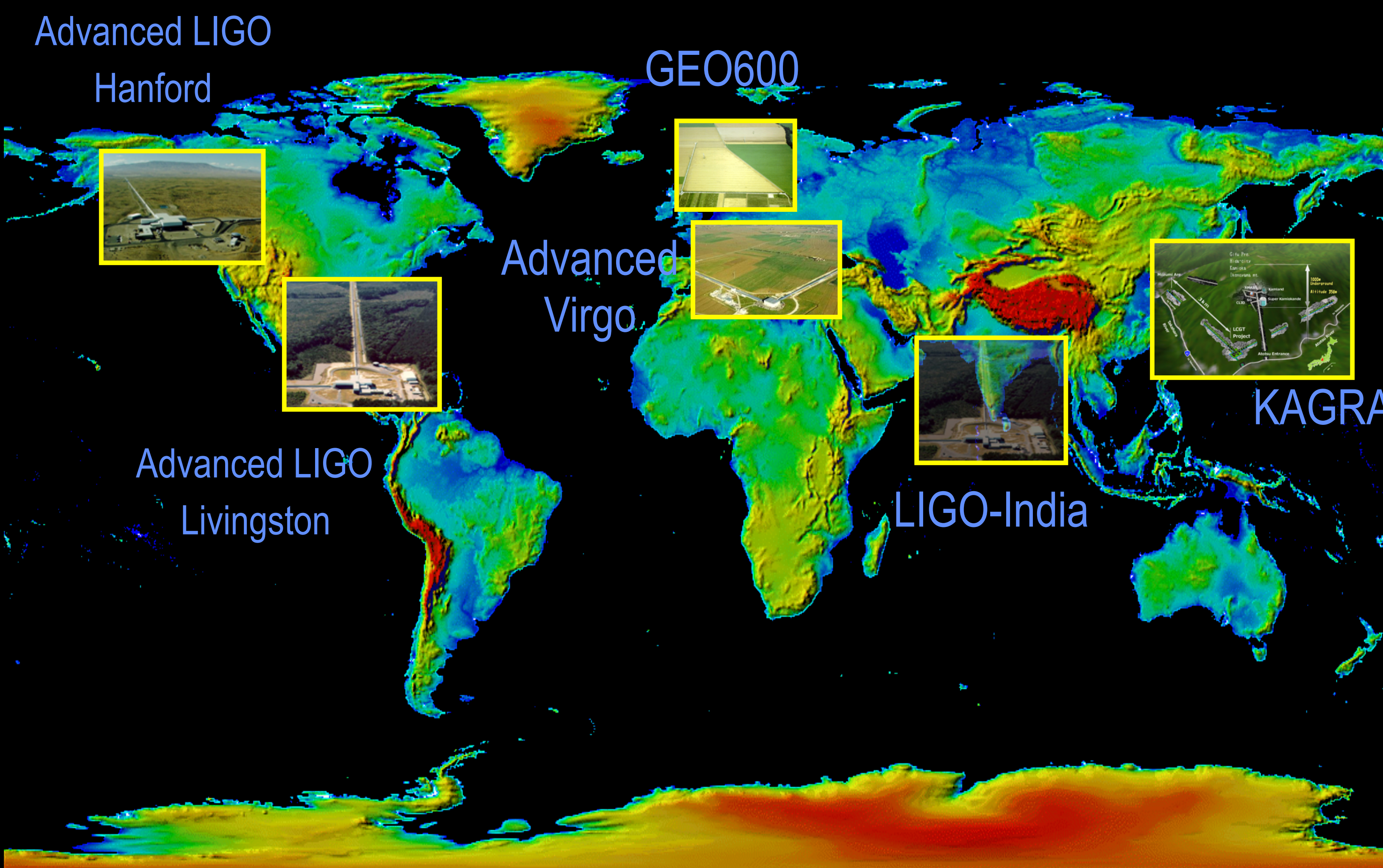
Coming soon near you: Advanced GW Detectors running!

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

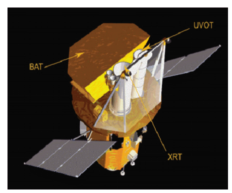


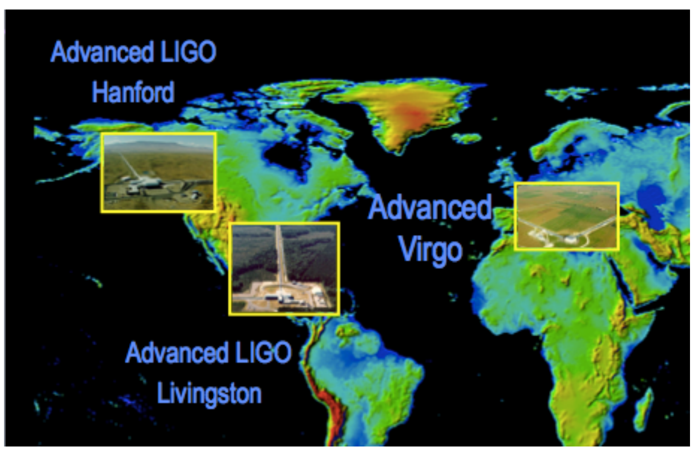
The GW Detector Network~2020

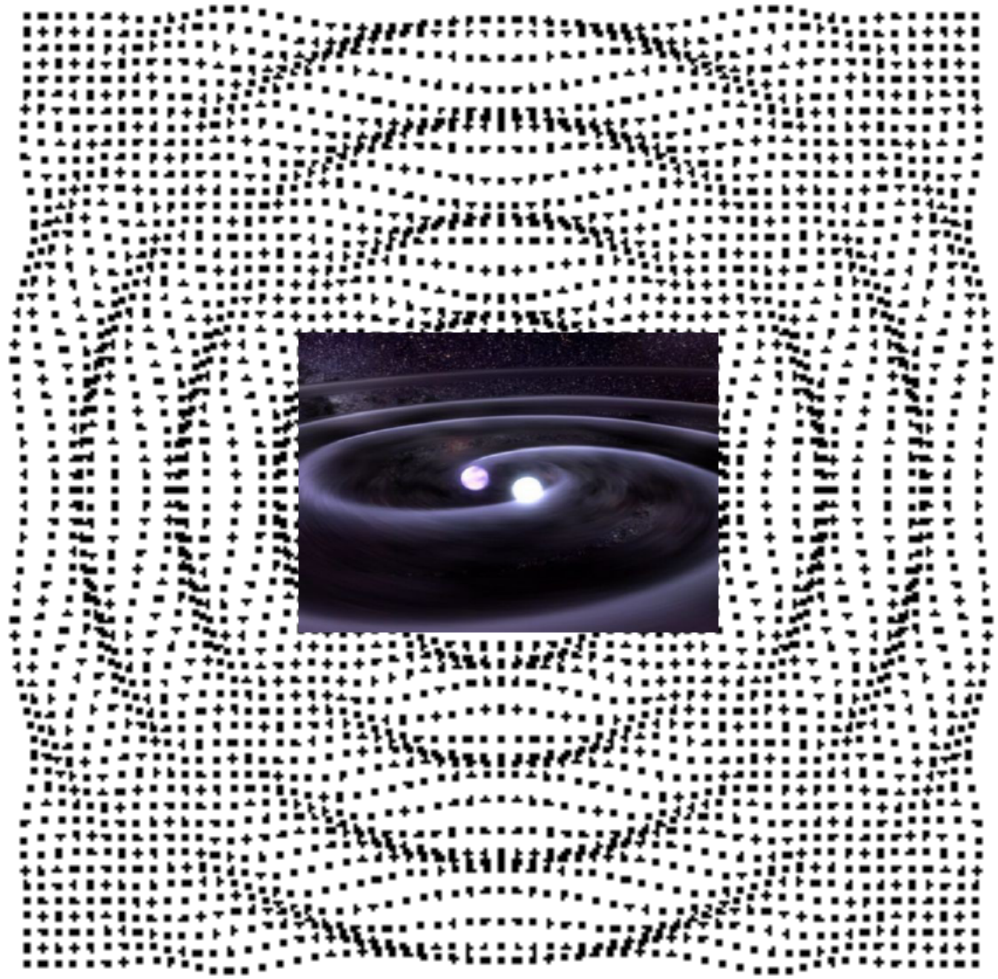


Multi-messenger astronomy

The astrophysical events we expect produce electromagnetic waves, gravitational waves, neutrinos… we need all eyes and ears open!

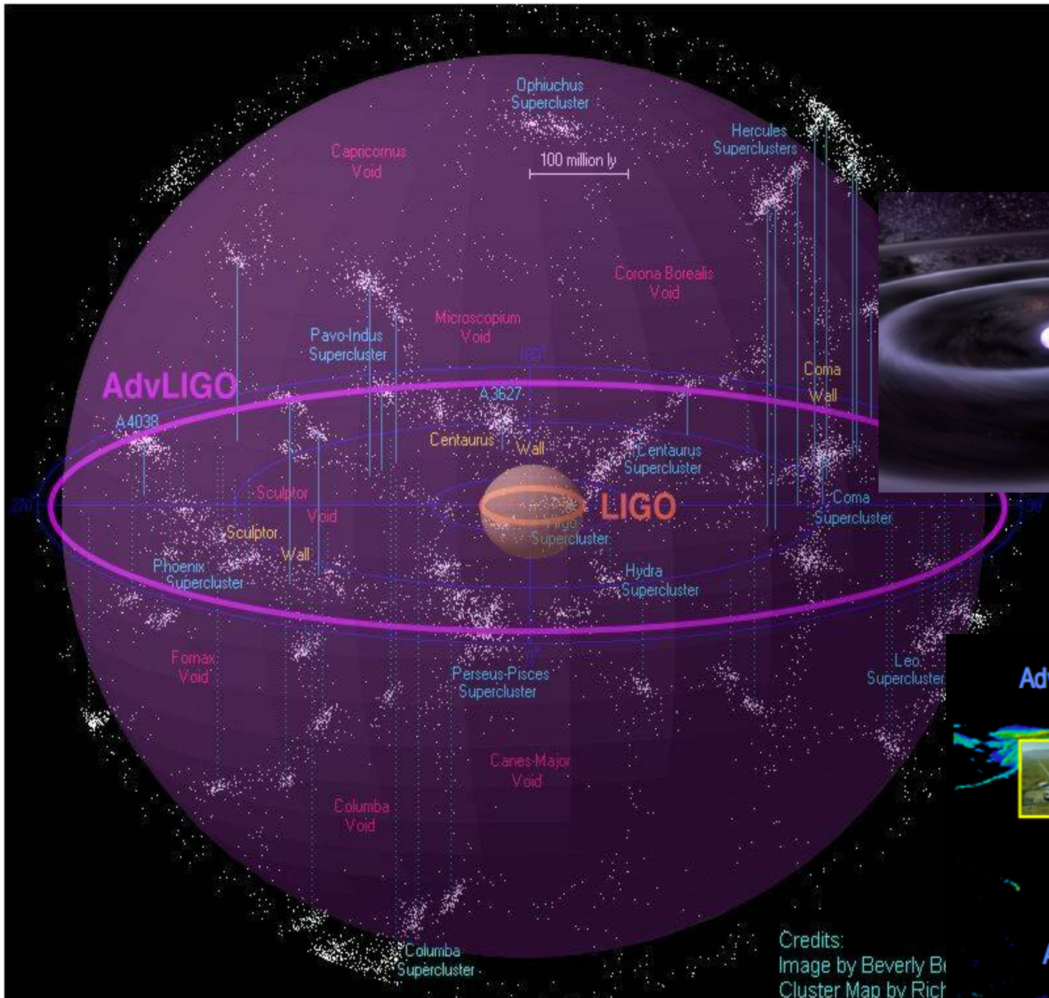


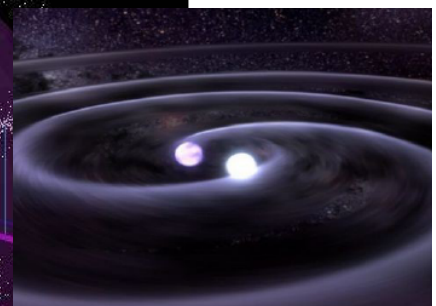




LIGO-G1301143

Gravitational waves are coming!





www.ligo.org