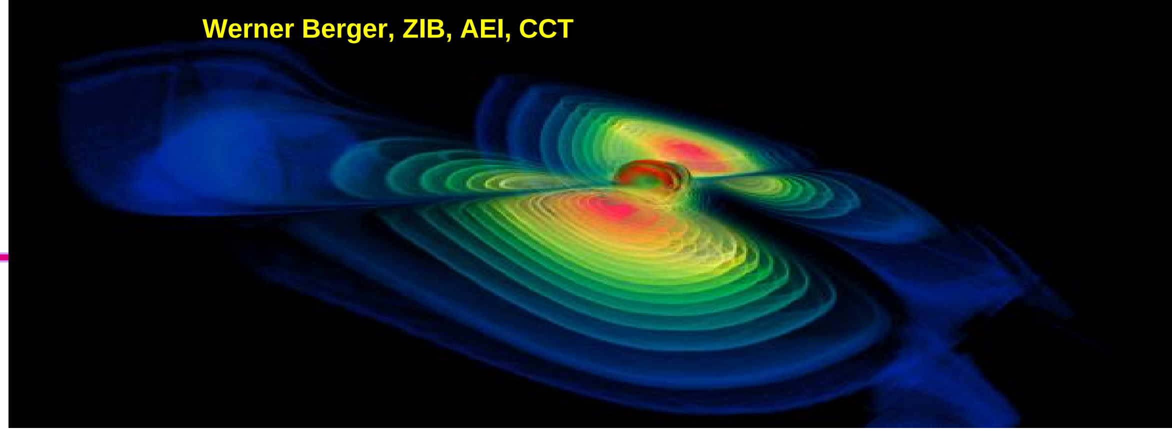


Searches for gravitational waves from astrophysical sources

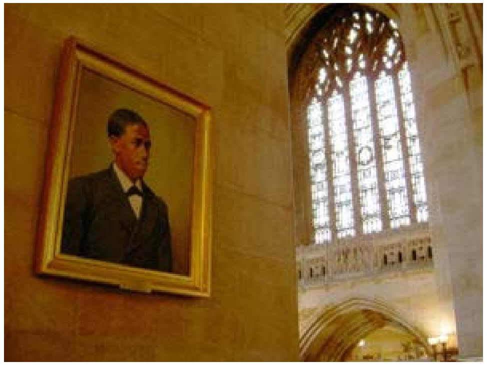
Gabriela González
Louisiana State University
On behalf of the LIGO Scientific Collaboration

APS meeting, April 14 2007

Edward A. Bouchet Award

"To promote the participation of under-represented minorities in physics"

Edward Bouchet, Yale '76 PhD (that is 1876!!) was the first African American Physics PhD, and the sixth in in the US. Bouchet was unable to find a university teaching position after college, and took a position at the Institute for Colored Youth (ICY), where he taught for 26 years.



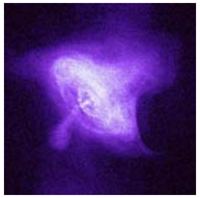
Bouchet portrait at Yale

In 2004, there were 506 Physics PhD granted, of which only 9 (2%) were African-American and 7 (2%) were Hispanic. Also, 16% of the total were granted to women (aip.org/statistics/)

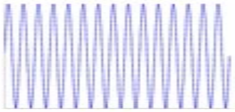
The US population in 2004 was 13% African-American, 14% Hispanic; the female population was 51% of the total (census.gov/popest/).

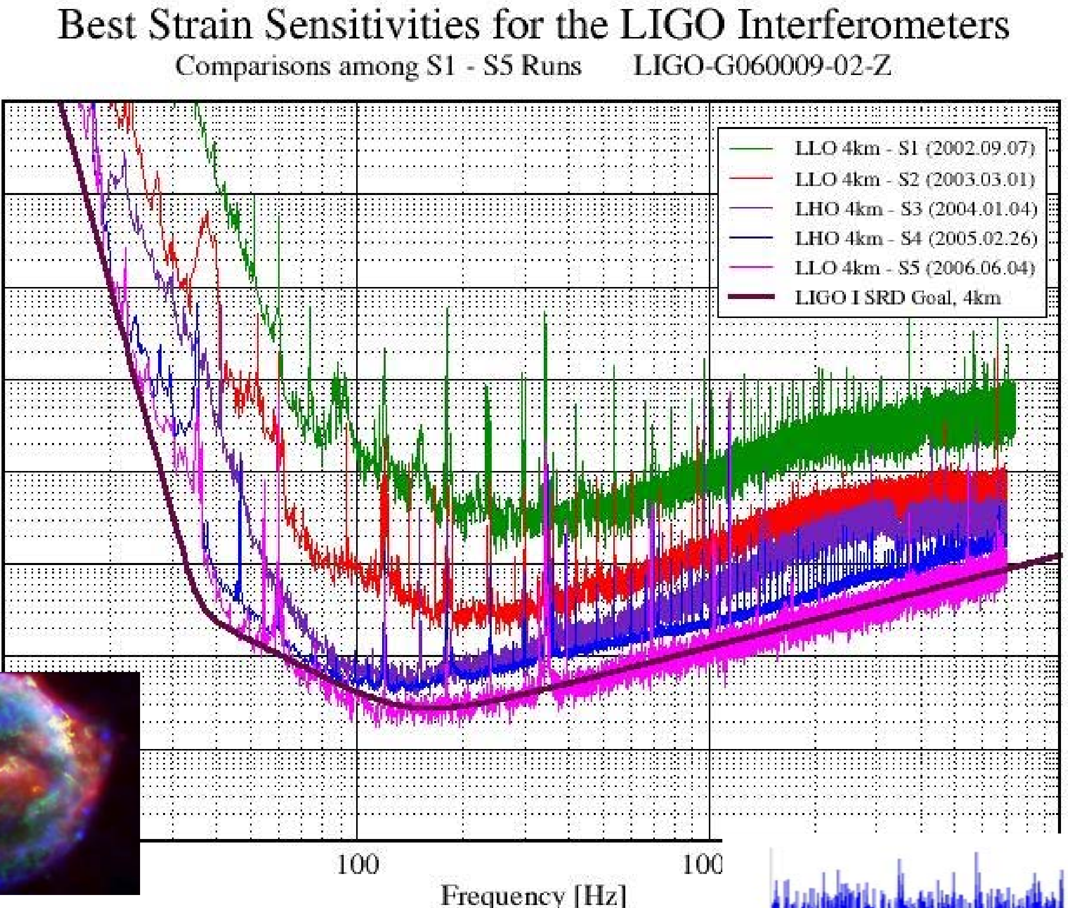
Sun 1:15pm: Session K6 CSWP: Enhancing the Physics Enterprise through Gender Equity

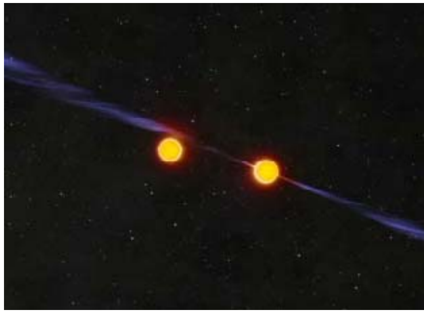
GW sources



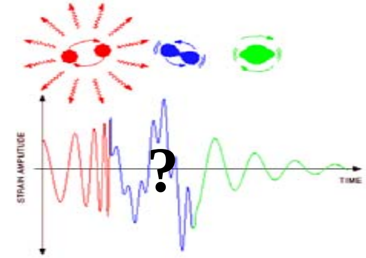
Crab pulsar (NASA, Chandra Observatory)

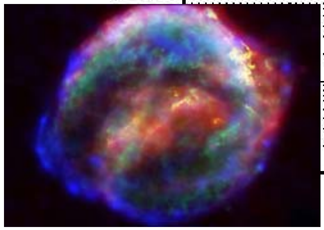




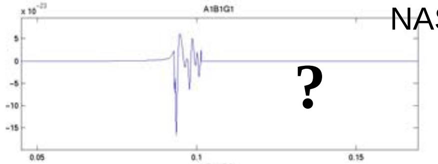


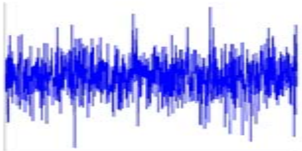
John Rowe, CSIRO

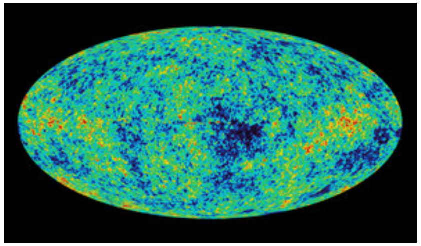




NASA, HEASARC





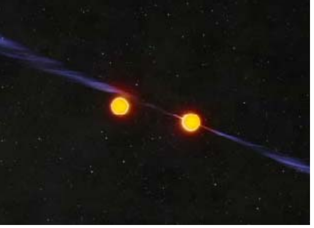


NASA, WMAP

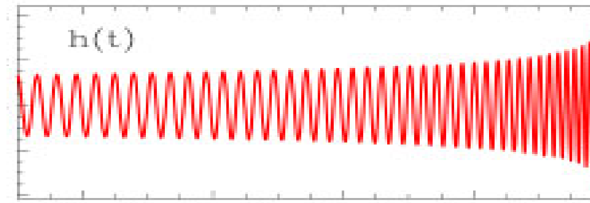
Observational results in www.ligo.org

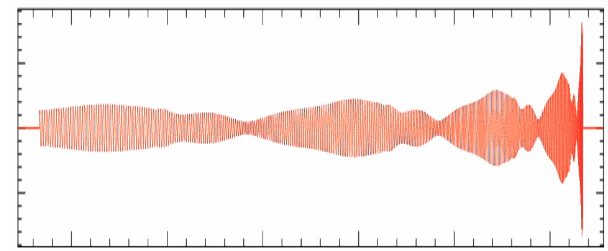
Mon 10:45am, R12: Gravitational Waves For and By LIGO

Mon 1:30pm, T11: Gravitational Wave Astronomy



GW searches: binary systems

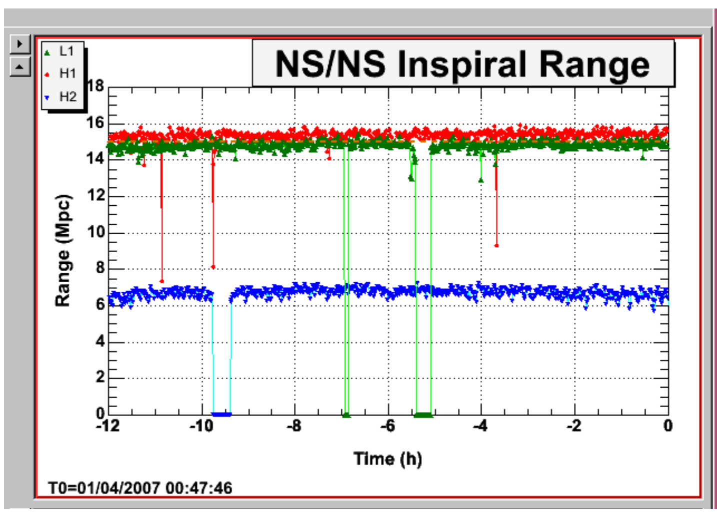




Use calculated templates for inspiral phase ("chirp") with optimal filtering.

Waveform parameters:
distance, orientation, position,
m_1, m_2, t_0, ϕ (+ spin, ending cycles …)

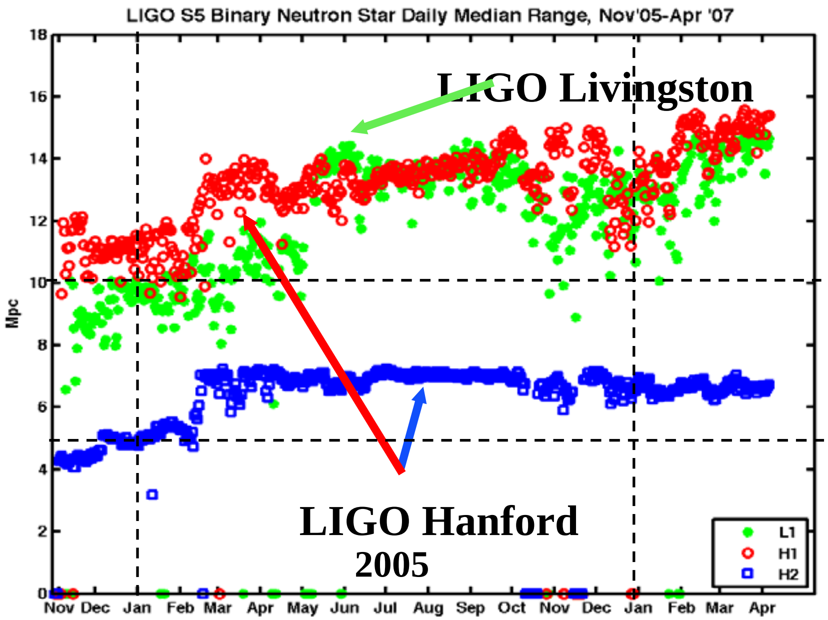
We can translate the "noise" into distances surveyed.
We monitor this in the control room for *binary neutron stars*:



If system is optimally located and oriented, we can see even further: we are surveying <u>hundreds of galaxies</u>!

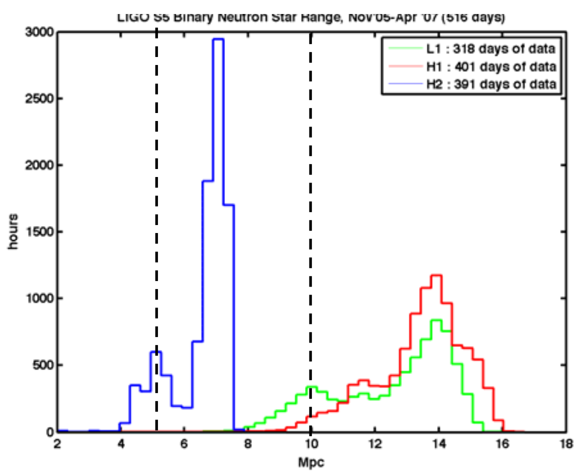
Electronic logs are public! www.ligo.caltech.edu

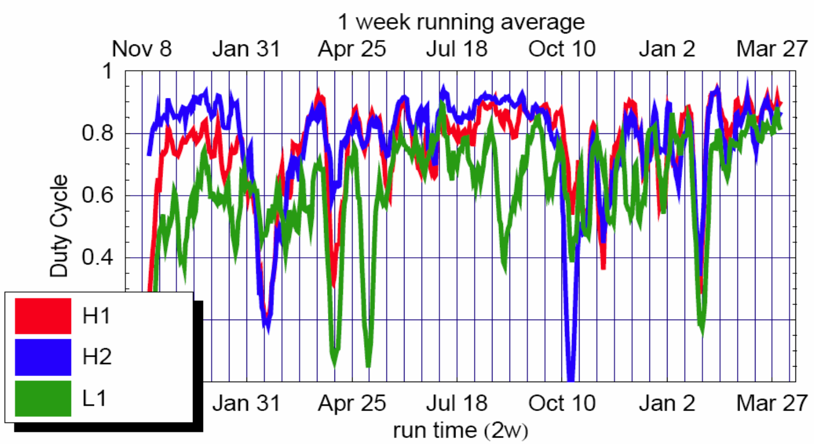
A digression: S5 so far…

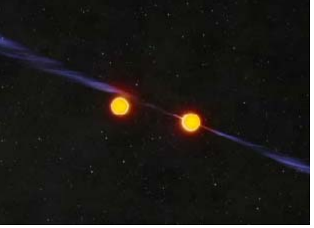


Science-mode statistics for S5 run
Up to Apr 08 2007 19:21:05 UTC
Elapsed run time = 12483.4 hours = 520 days
----------------------- Whole run so far --------------

Sample	Hours	Duty factor
H1	9340.1	74.8 since Nov 4, 2005
H2	9644.3	77.3 since Nov 4, 2005
L1	7784.5	63.6 since Nov 14, 2005
H1+H2+L1	6108.4	49.9 since Nov 14, 2005
(H1orH2)+L1	7054.2	56.5 since Nov 4, 2005
One or more LIGO	11124.5	89.1 since Nov 4, 2005
One or more LSC	11841.6	94.9 since Nov 4, 2005

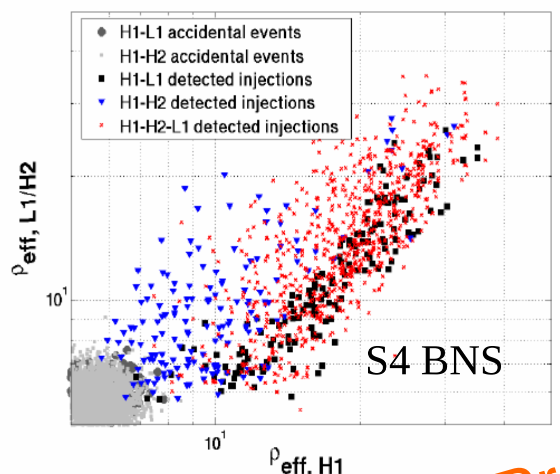


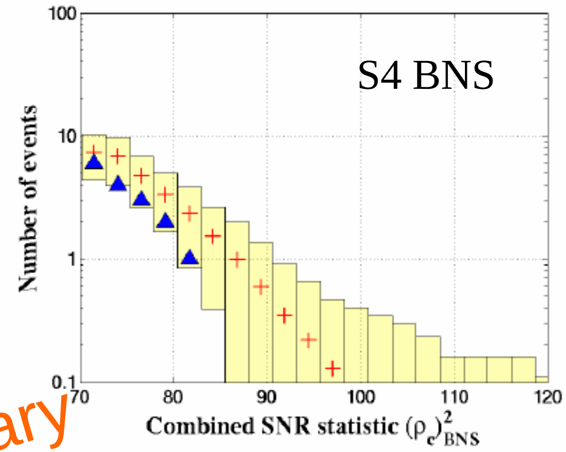




GW searches: binary systems

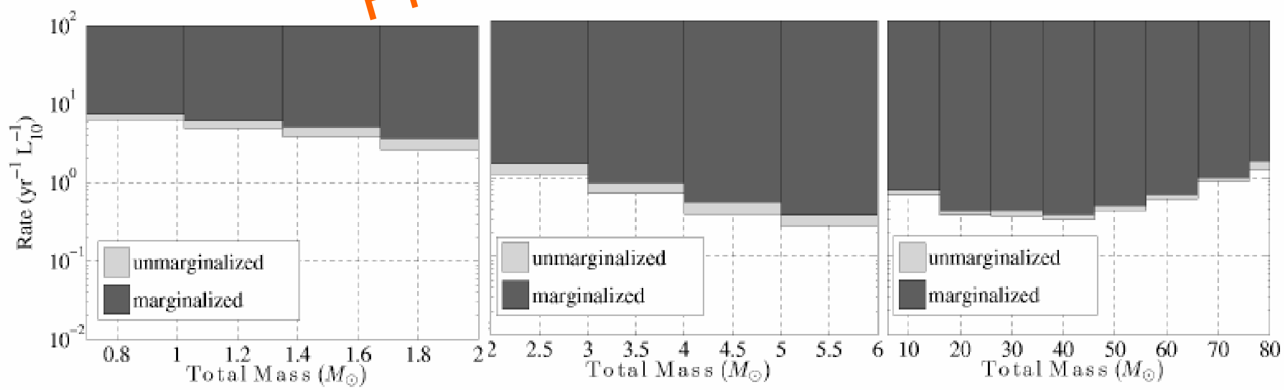
- Use two or more detectors: search for double or triple *coincident* “triggers”
- Can infer masses and “effective” distance.
- Estimate false alarm probability of resulting candidates: detection?
- Compare with expected efficiency of detection and surveyed galaxies: upper limit

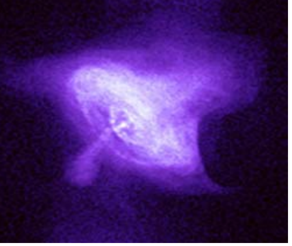




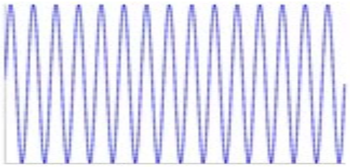
Preliminary

S5 talk
by D. Keppel,
R12 Mon 10:45AM
S3/S4 talk
by T. Cokelaer,
T11 Mon 2:06 PM

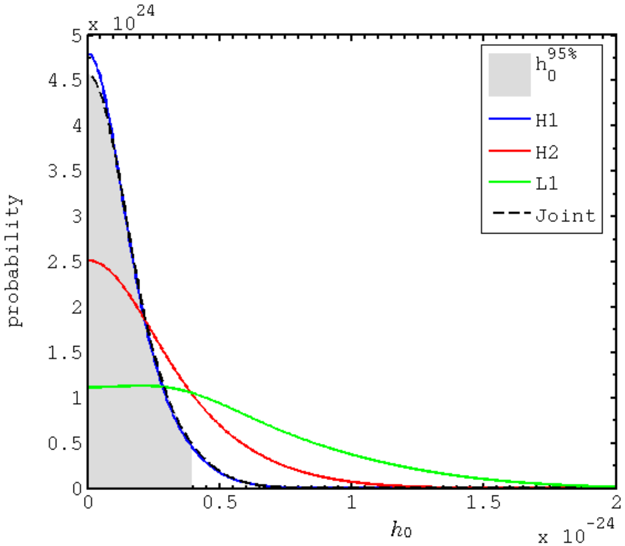




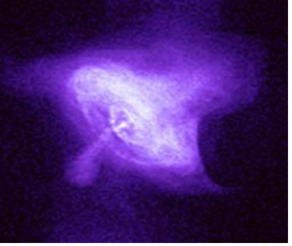
GW searches: spinning compact objects



- Rotating stars produce GWs if they have asymmetries,
  if they wobble or through fluid oscillations.
- There are many known pulsars (rotating stars!) that would produce GWs in the LIGO frequency band (40 Hz-2 kHz).
  - @ Targeted searches for 97 known (radio and x-ray) systems in S5: isolated pulsars, binary systems, pulsars in globular clusters…
- There are likely to be many non-pulsar rotating stars producing GWs.
  - @ All-sky, unbiased searches; wide-area searches.
- GWs (or lack thereof) can be used to measure (or set up upper limits on) the ellipticities of the stars.
- Search for a sine wave, modulated by Earth's motion, and possibly spinning down: easy, but computationally expensive!



http://www.einsteinathome.org/



GW searches: pulsars

Lowest GW strain upper limit:

PSR J1623-2631

(f_{gw} = 180.6 Hz, r = 3.8 kpc)

$h_0 < 4.8\times10^{-26}$

Lowest ellipticity upper limit:

PSR J2124-3358

(f_{gw} = 405.6 Hz, r = 0.25 kpc)

$\varepsilon < 1.1\times10^{-7}$

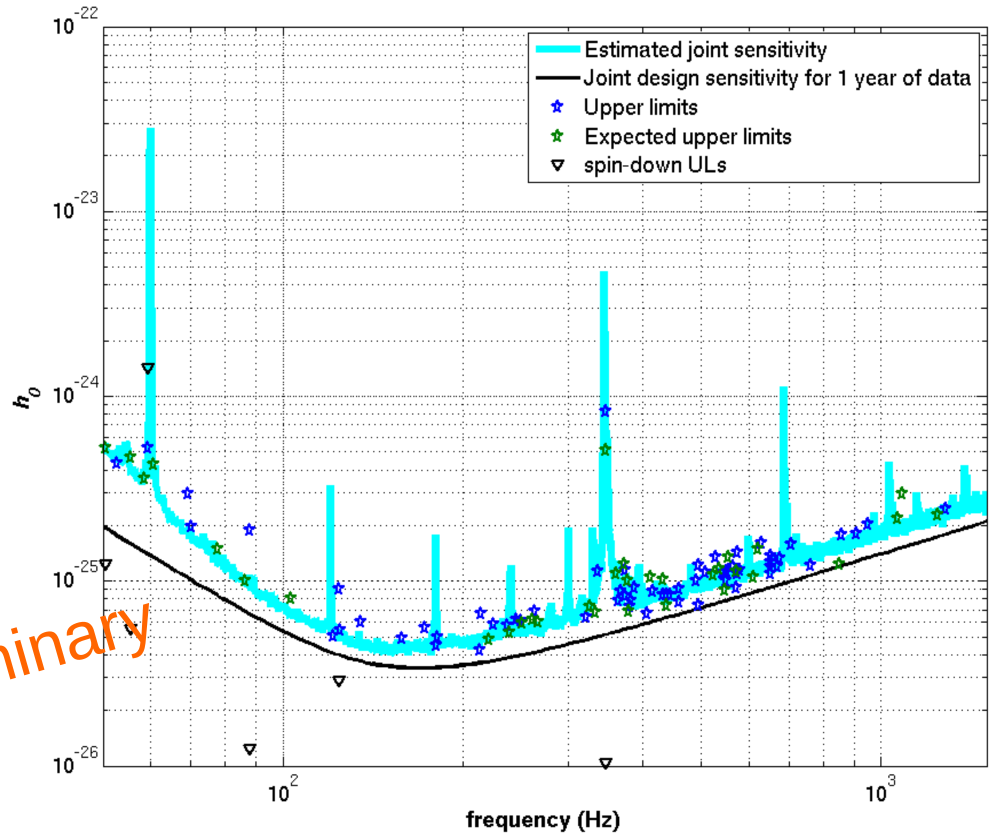
S5, Crab results by M. Pitkin, T11 Mon 1:42PM

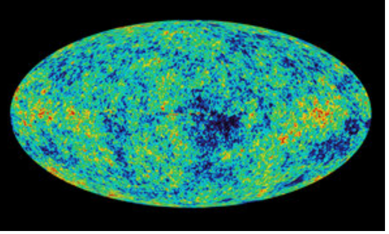
S5 Broadband search talk by V. Dergachev, T11 Mon 1:54PM

S4 all-sky search by K. Riles, T11 Mon 2:30PM

Einstein@Home search, B. Owen, Y12 Tue 1:30PM

Upper limits on GWs from targeted pulsars:



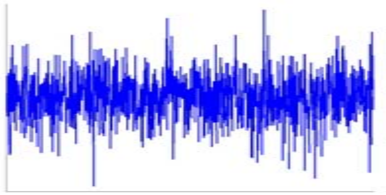


GW searches: Stochastic Background

A primordial GW stochastic background is a prediction from most cosmological theories. It can also result from unresolved astrophysical sources.

Given an energy density spectrum $\Omega_w(f)$, there is a strain power spectrum:

$$\Omega_{GW}(f) = \frac{1}{\rho_c}\frac{d\rho_{GW}(f)}{d\ln f}$$

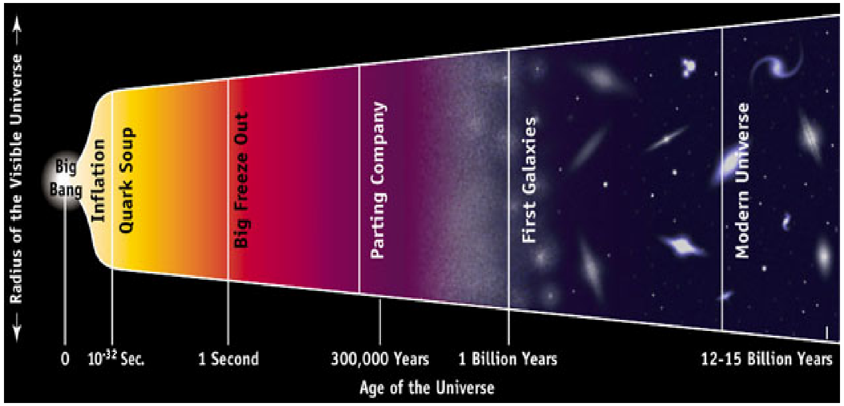


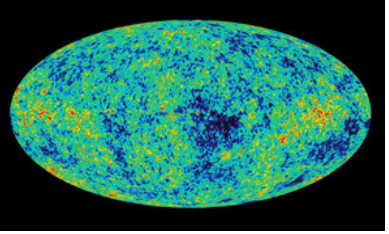
$$S_{\rm gw}(f) = \frac{3H_0^2}{10\pi^2} f^{-3}\Omega_{\rm gw}(f)$$

$$h(f) = S_{\rm gw}^{1/2}(f) = 5.6\times10^{-22}\, h_{100}\sqrt{\Omega_0}\left(\frac{100\mathrm{Hz}}{f}\right)^{3/2}\mathrm{Hz}^{1/2}$$

The signal can be searched from *cross-correlations* in different pairs of detectors: L1-H1, H1-H2, L1-ALLEGRO, LIGO-VIRGO… the farther the detectors, the lower the frequencies that can be searched ($\lambda_{GW} \geq 2D$)

The signal can be searched assuming an isotropic, or using spatial resolution.

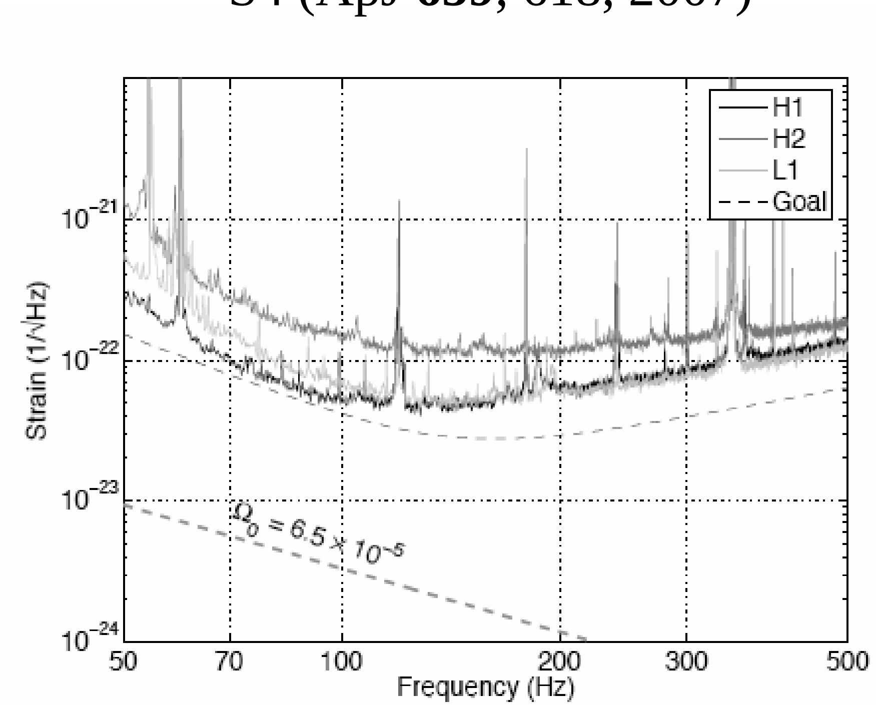




GW searches: Stochastic Background

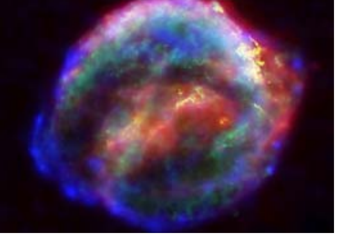
S4, astro-ph 0703234

S4 (ApJ **659**, 618, 2007)

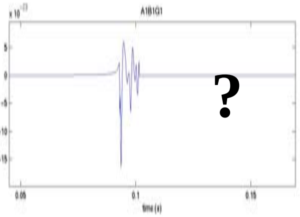


S5 result will be 10-100x better than S4
Advanced LIGO can reach $\Omega_0 \sim 10^{-9}$-10^{-10}
Big Bang, CMB Constrains $\Omega_0 < 10^{-5}$
Predictions?
Cosmic strings (?) $\sim 10^{-8}$-10^{-5}
Inflation $\sim 10^{-14}$ --? (10^{-10} in some models with “preheating”)

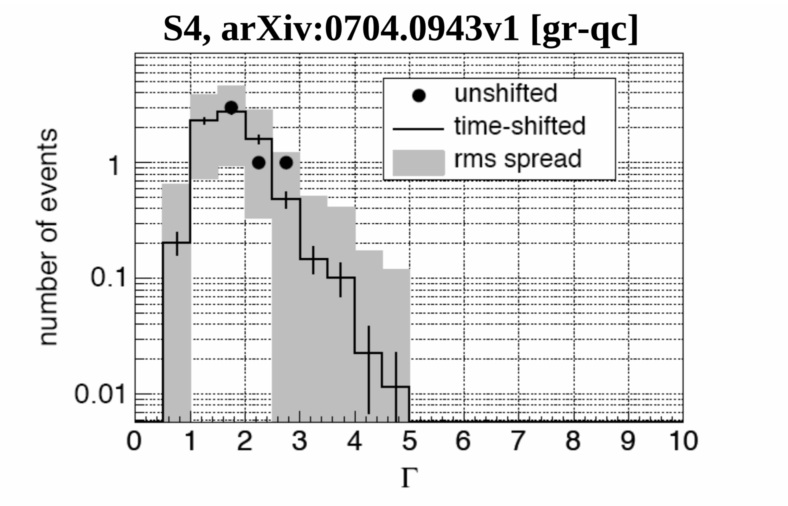
S4 talk by B. Whiting,
U11 Mon 3:30PM



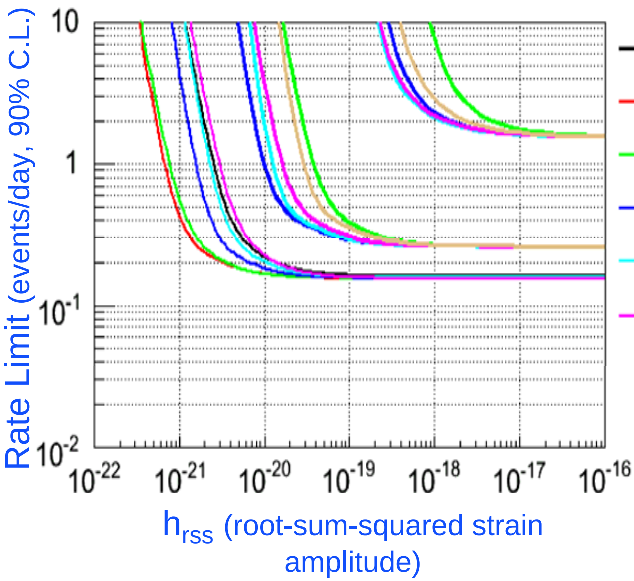
GW searches: bursts

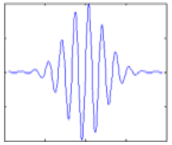


- Search for <u>triple coincident</u> triggers with a wavelet algorithm
- Measure waveform consistency
- Set a threshold for detection for <u>low false alarm probability</u>
- Compare with efficiency for detecting simple waveforms



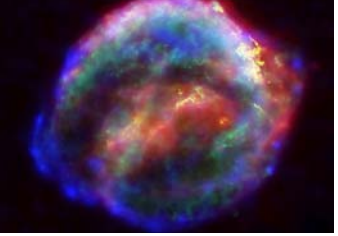
Limit on rate vs. GW signal strength sensitivity





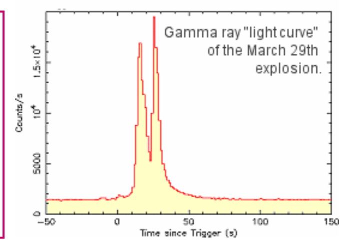
S5 search, L. Cadonati, R12 Mon 11:09 AM
S5 coherent search, I. Yakushin, R12 Mon 11:21AM
S5 coincidence search, K. Thorne, T11 Mon 3:06 PM
S5 "noise" talk by S. Desai, R12 Mon 10:57AM

For a 153 Hz, *Q* =8.9 sine-Gaussian,
S5 can see with 50% probability:
~ 2 × 10^{-8} $M_\odot c^2$ at 10 kpc,
~ 0.05 $M_\odot c^2$ at 16 Mpc (Virgo cluster)



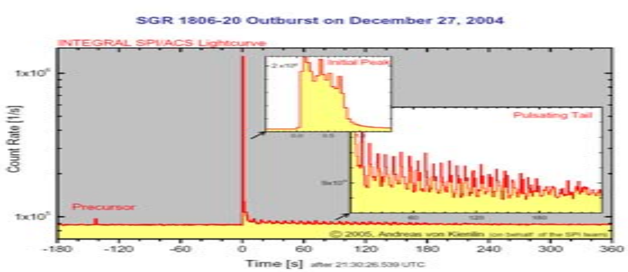
GW searches: triggered bursts

HETE GRB030329 (~800 Mpc SN): during S2, search resulted in no detection (**PRD** 72, 042002, 2005)



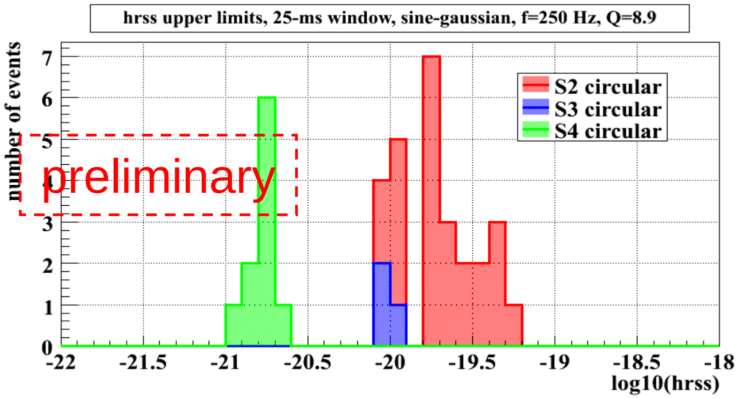
Soft Gamma Repeater 1806-20

- galactic neutron star with intense magnetic field (~10^{15} G)
- Record γ-ray flare on Dec 27, 2004
- quasi-periodic oscillations found in RHESSI and RXTE x-ray data
- search S4 LIGO data for GW signal associated with quasi-periodic oscillations-- no GW signal found
- astro-ph/0703419
- Talk by L. Matone, T11 Mon 2:42PM



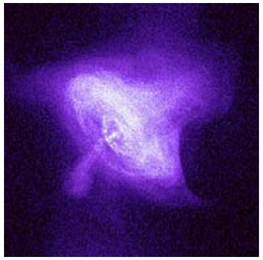
Gamma-Ray Bursts

- search LIGO data surrounding GRB trigger using cross-correlation method
- no GW signal found associated with 39 GRBs in S2, S3, S4 runs
- set limits on GW signal amplitude
- 53 GRB triggers for the first five months of LIGO S5 run
- Talk by I. Leonor, U11 Mon 4:06PM

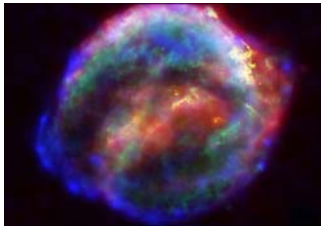


When will we see something?

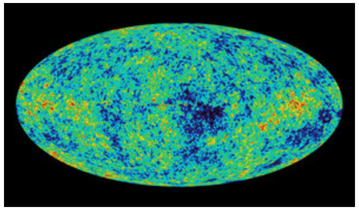
Predictions are difficult… especially about the future (Y. Berra)



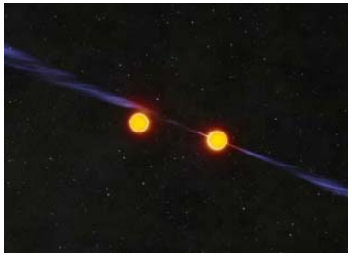
- Rotating stars: we know the rates,
  but not the amplitudes: how lumpy are they?



- Supernovae, gamma ray bursts:
  again rates known, but not amplitudes…



- Cosmological background:
  optimistic predictions are very dependent on model…
- Binary black holes:
  amplitude is known, but rates and populations highly unknown… Some estimates promise S5 results will be interesting!



- Binary neutron stars:
  amplitude is known, and galactic rates and population can be estimated:
  For R~86/Myr, initial LIGO rate ~1/100 yrs.

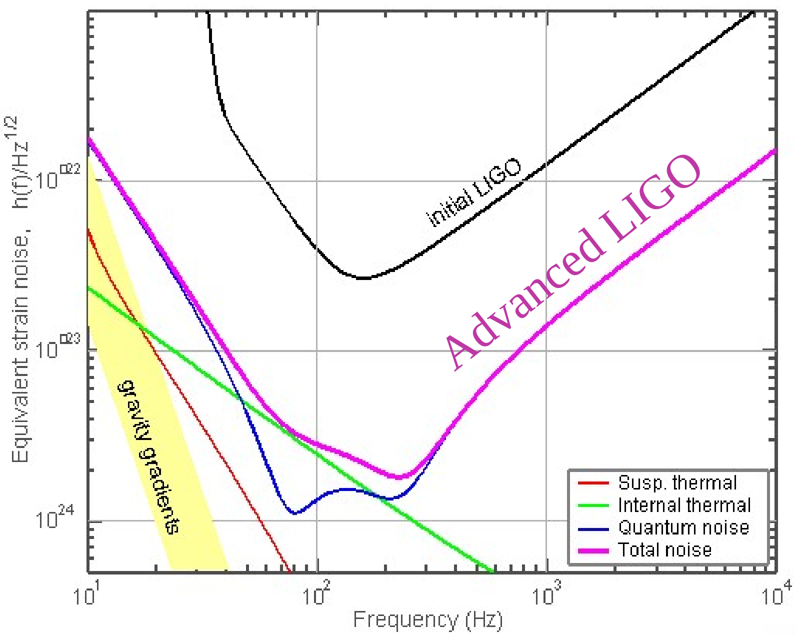
LIGO detectors: future

Neutron Star Binaries:

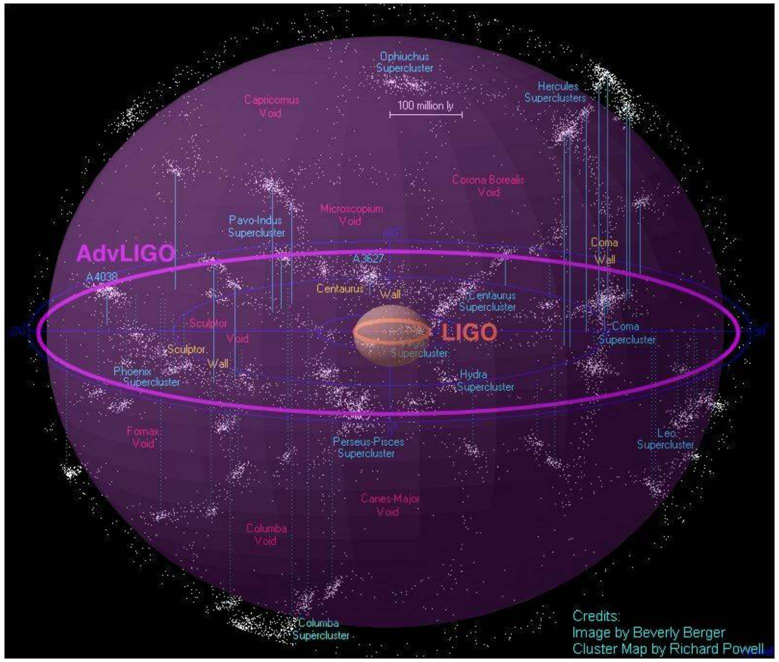
Initial LIGO: ~15 Mpc →

Advanced LIGO: ~200-300 Mpc

Most likely rate ~ 40/year !



D. Reitze, H5 Sunday 8:30am



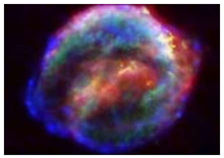
x10 better amplitude sensitivity

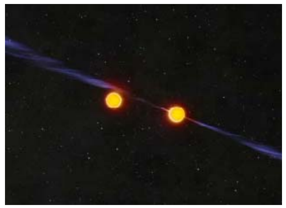
⇒ x1000 rate=(reach)^3

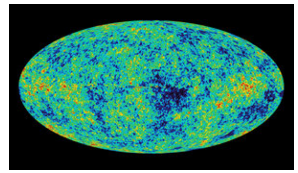
⇒ 1 year of Initial LIGO < 1 day of Advanced LIGO !

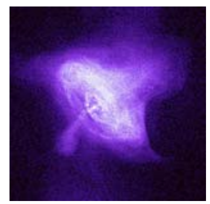
NSF Funding in FY'08 presidential budget request.

LIGO detectors: future

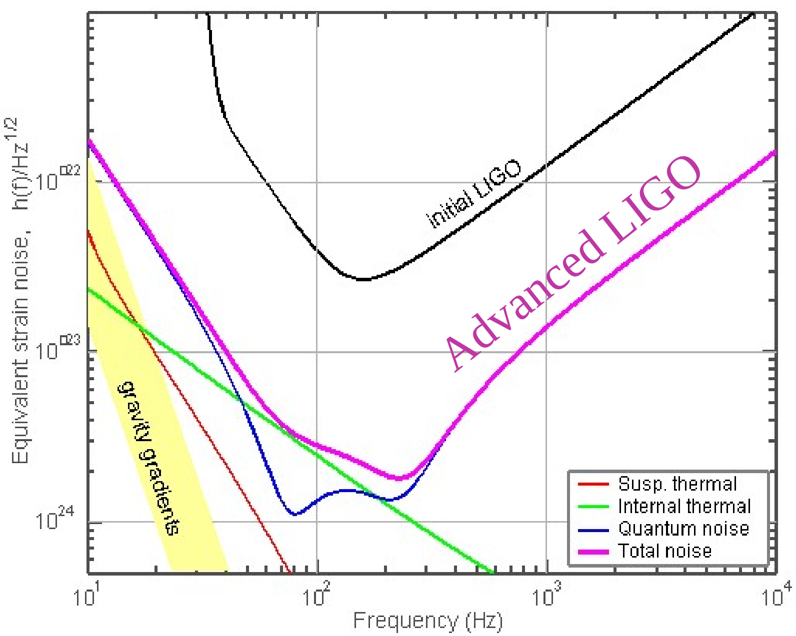


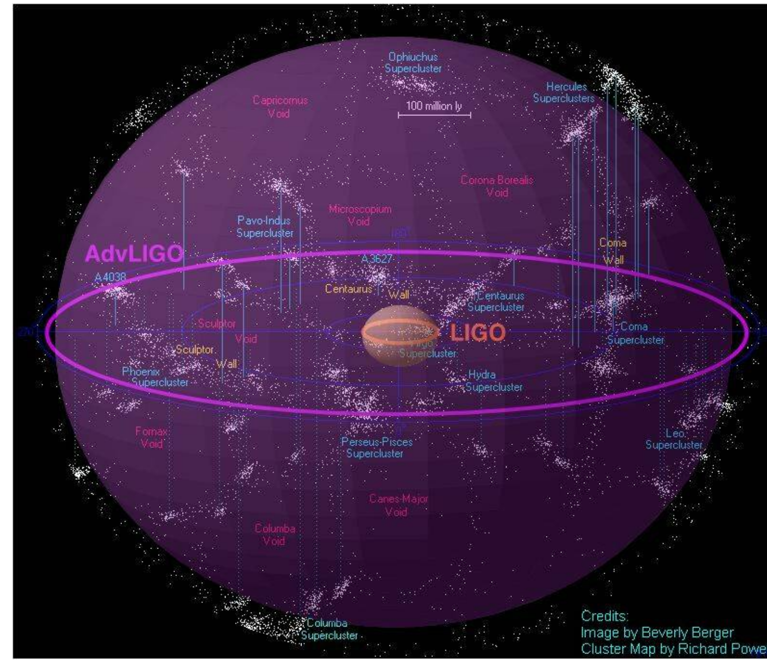






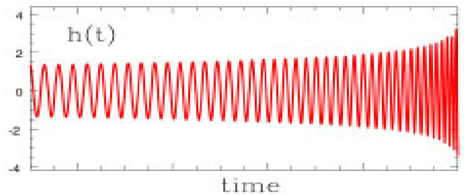
What's out there?





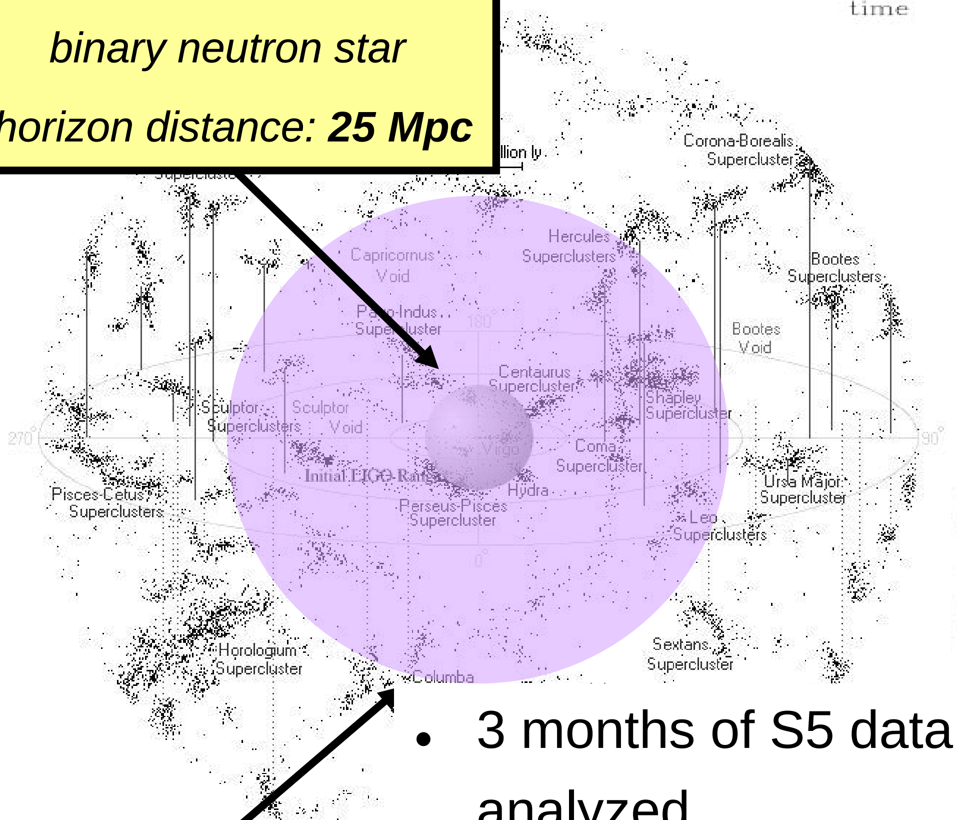
We'll find out!

Searches for coalescing compact binary signals in S5



$f_{coal} \sim 1/M$

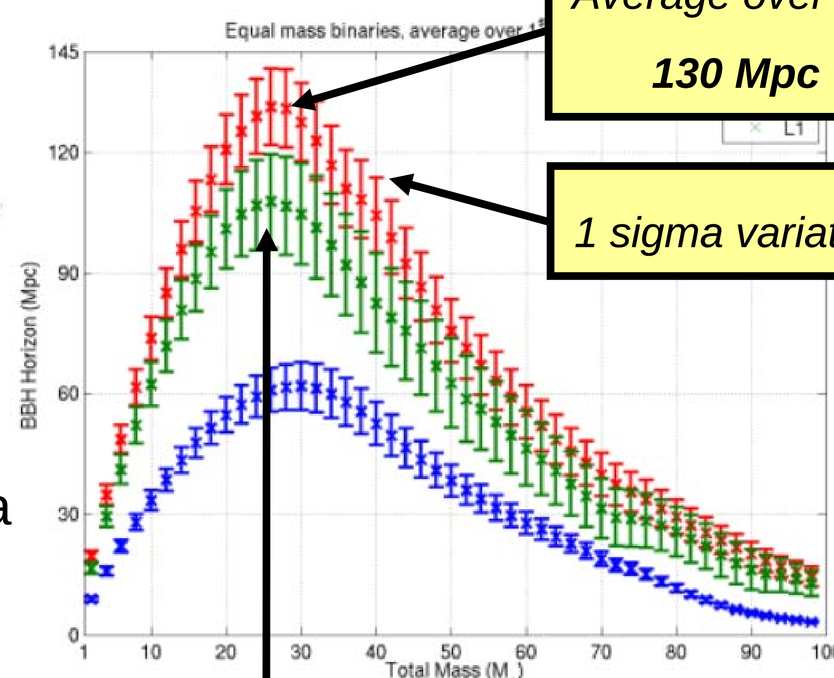
binary neutron star horizon distance: ***25 Mpc***



binary black hole horizon distance

- 3 months of S5 data analyzed
- 1 calendar yr in progress

Inspiral Horizon distance vs mass

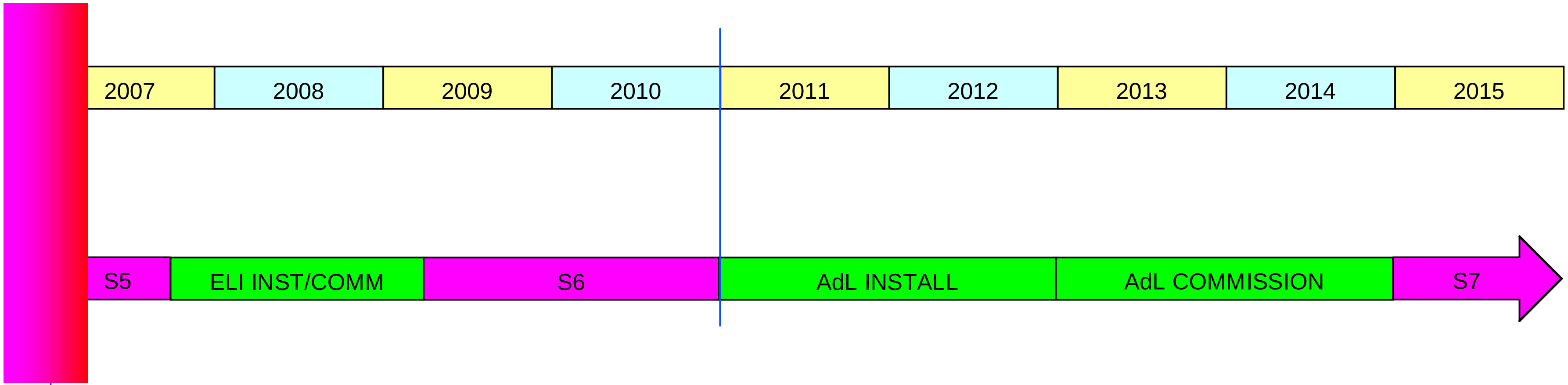


Average over run ***130 Mpc***

1 sigma variation

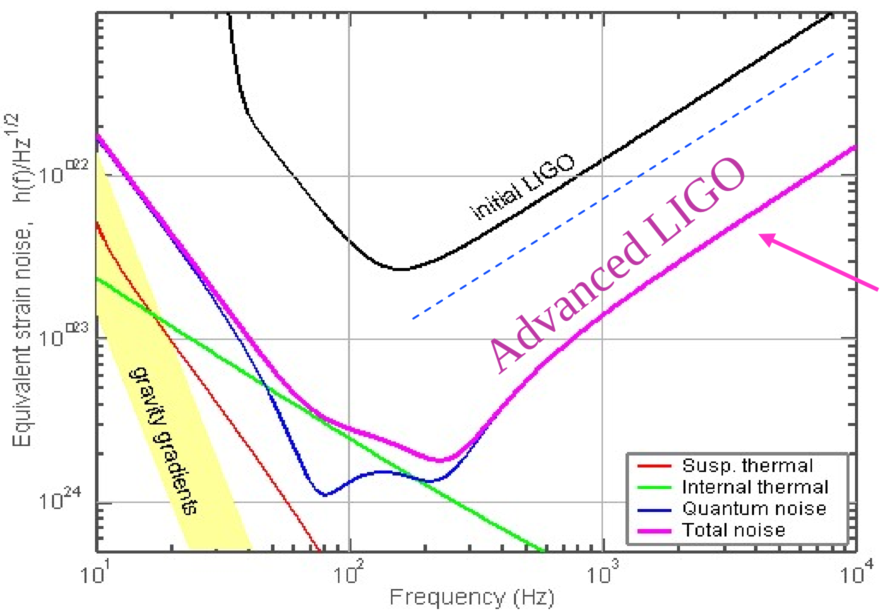
Peak at total mass ~ 25M_{sun}

A possible timeline?

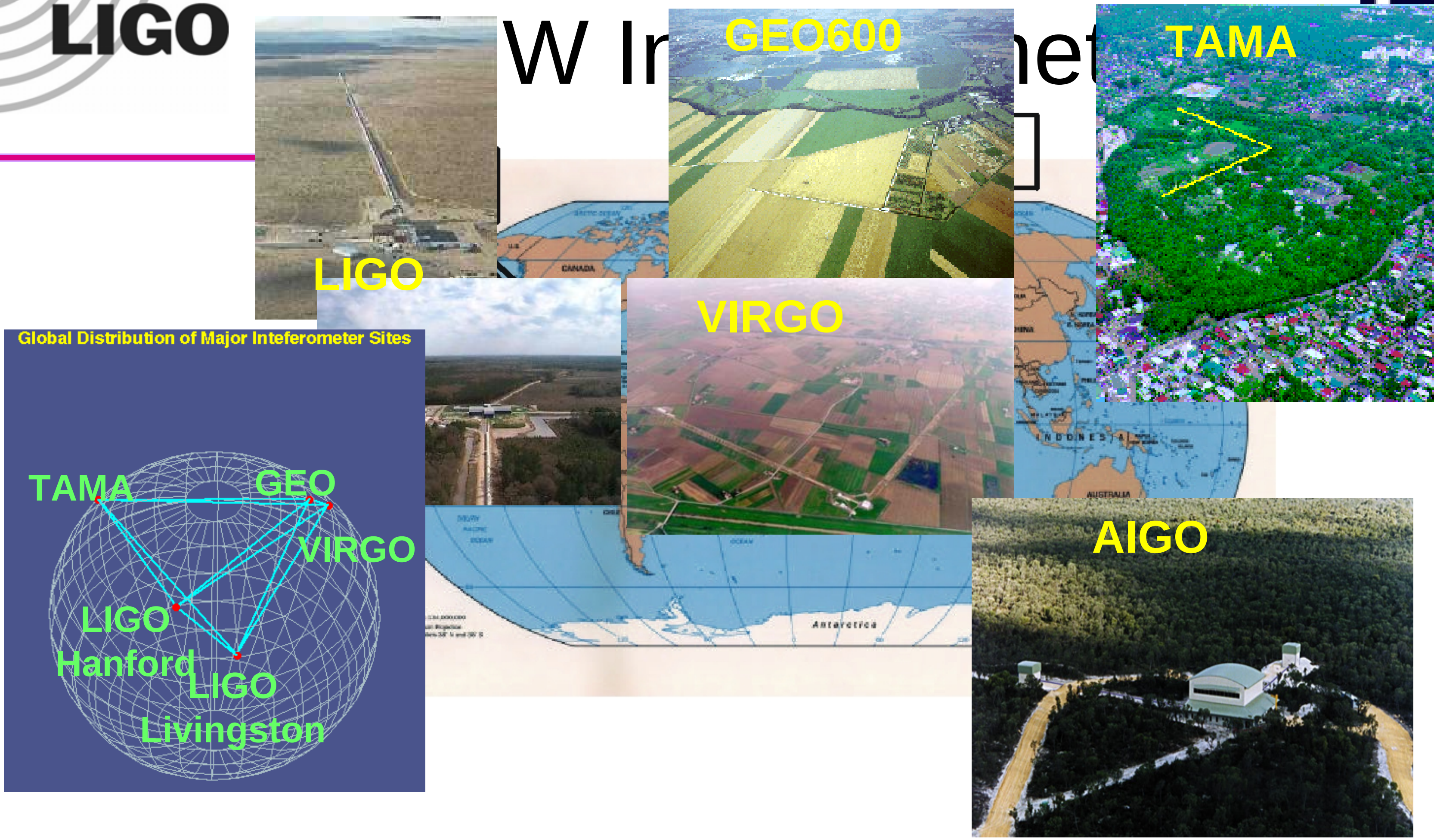


today

BNS: 1/30 yr
BBH: ??



BNS: 1/2days
BBH: we'll measure it!



- Worldwide Network:
  - » GEO and LIGO detectors' data analyzed by LSC
  - » We have coordinated observations and shared data with TAMA
  - » We will start data sharing with VIRGO