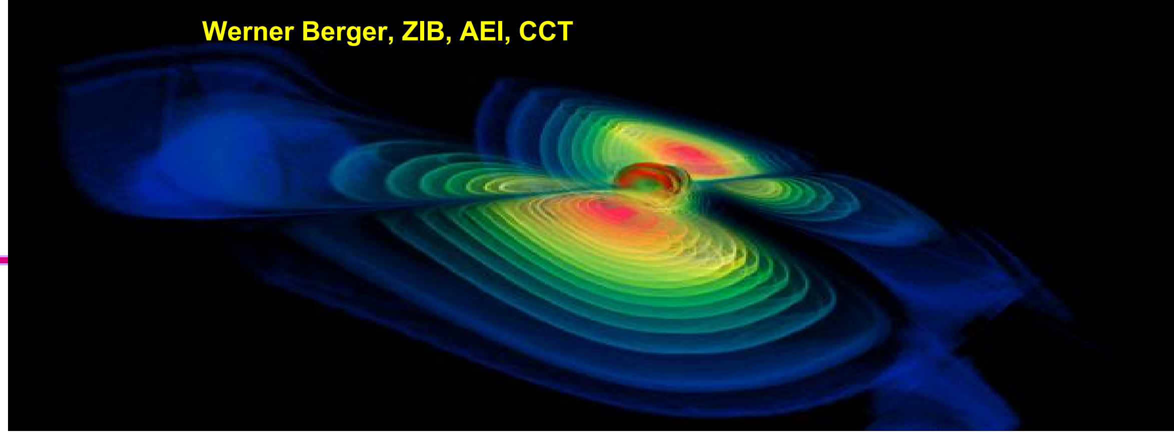
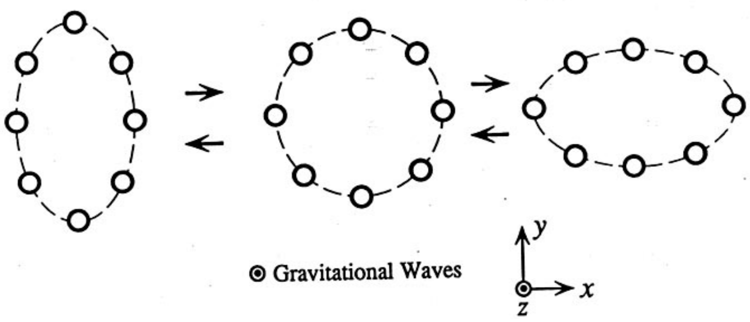


Searching for gravitational waves with LIGO detectors

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

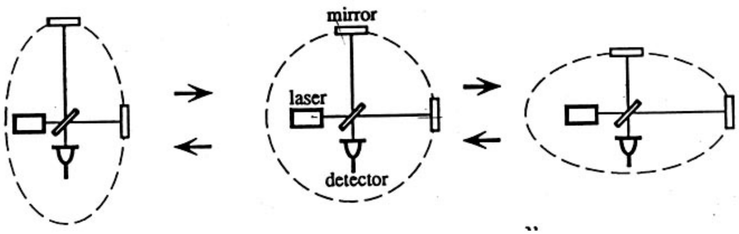
SNO Collaboration Meeting
Baton Rouge, LA
February 2008

Gravitational waves



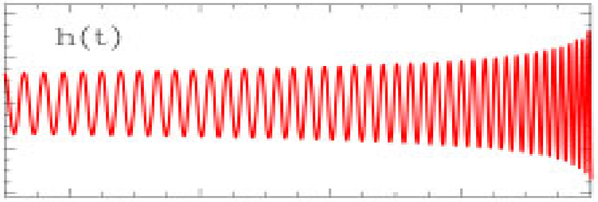
Gravitational waves are quadrupolar distortions of distances between freely falling masses: “ripples in space-time”

Michelson-type interferometers can detect space-time distortions, measured in “strain” h=ΔL/L.

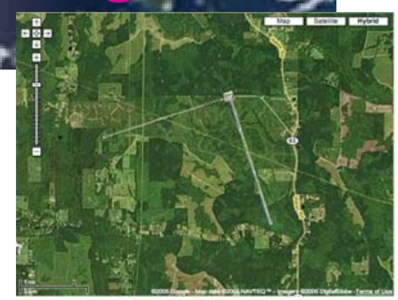


Amplitude of GWs produced by binary neutron star systems in the Virgo cluster have $h=\Delta L/L \sim 10^{-21}$

QuickTime™ and a YUV420 codec decompressor are needed to see this picture.



The LIGO project



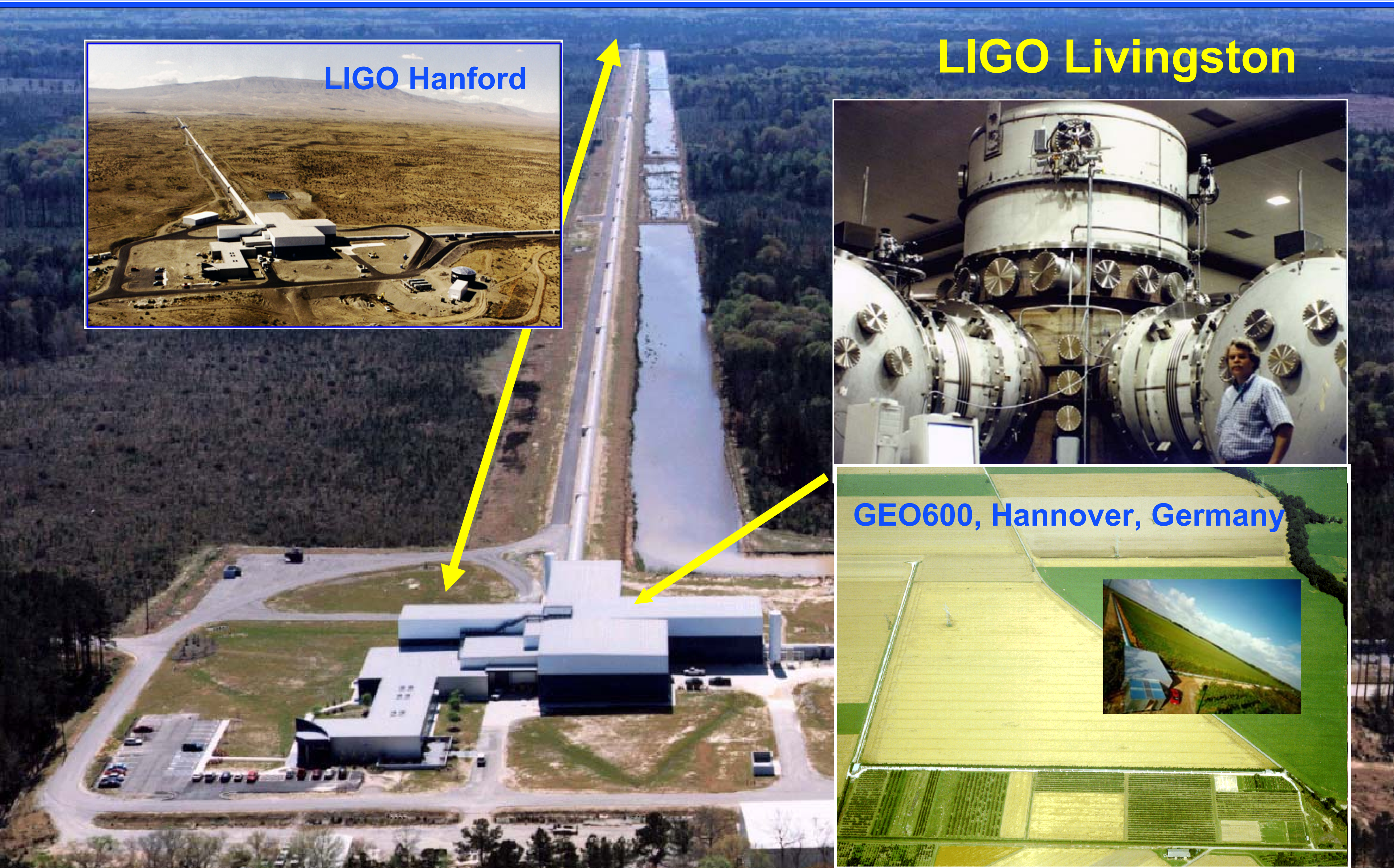
Lunch time at LSC Summit

Hundreds of people working on the experiment and looking at the data:

LIGO Scientific Collaboration

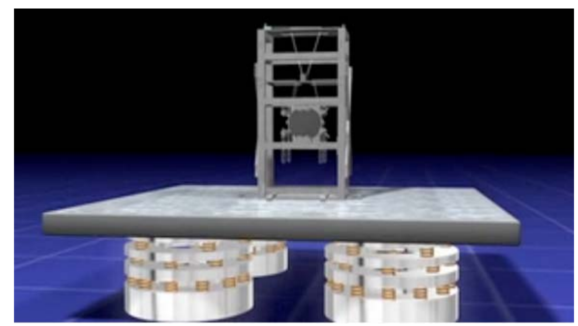
www.ligo.org

LIGO today



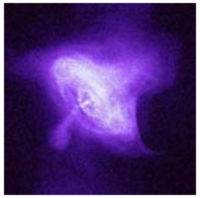
GW Detection: a difficult and fun experiment

QuickTime™ and a
Animation decompressor
are needed to see this picture.

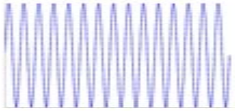


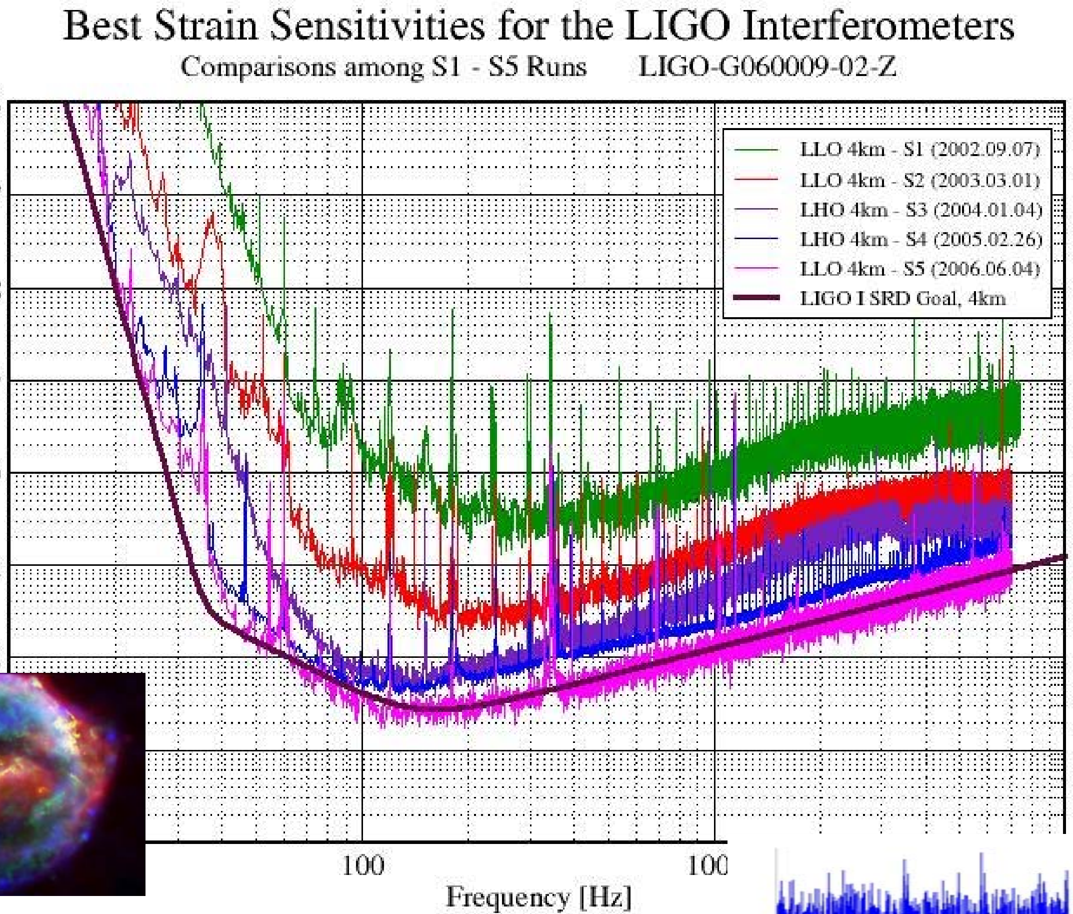
QuickTime™ and a
Animation decompressor
are needed to see this picture.

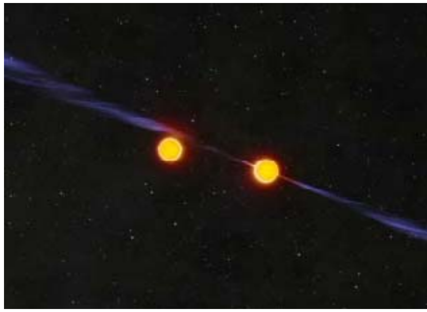
GW sources



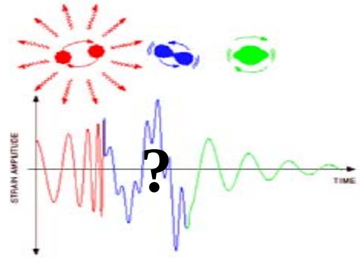
Crab pulsar (NASA, Chandra Observatory)

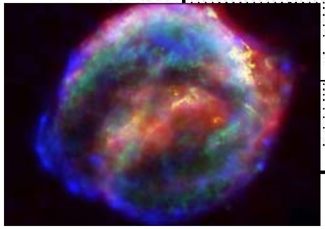




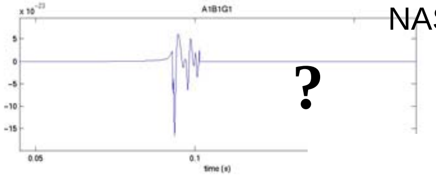


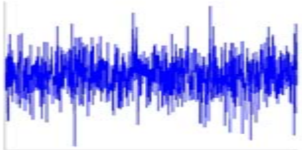
John Rowe, CSIRO

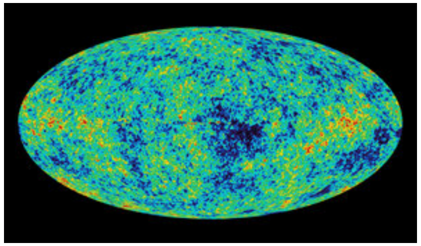




NASA, HEASARC

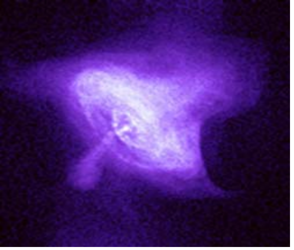




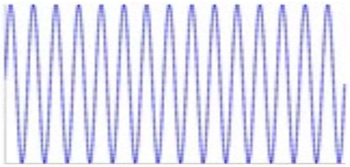


NASA, WMAP

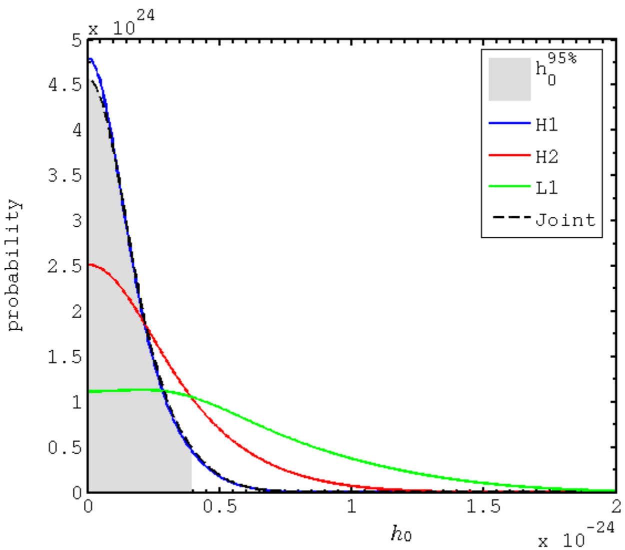
Observational results in www.ligo.org



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!

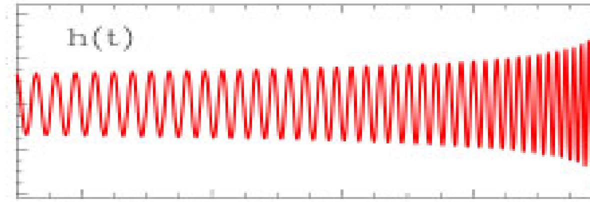


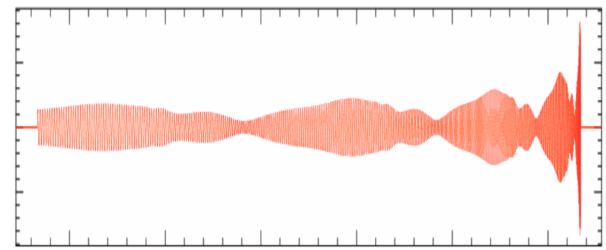
http://www.einsteinathome.org/

GW searches: binary systems

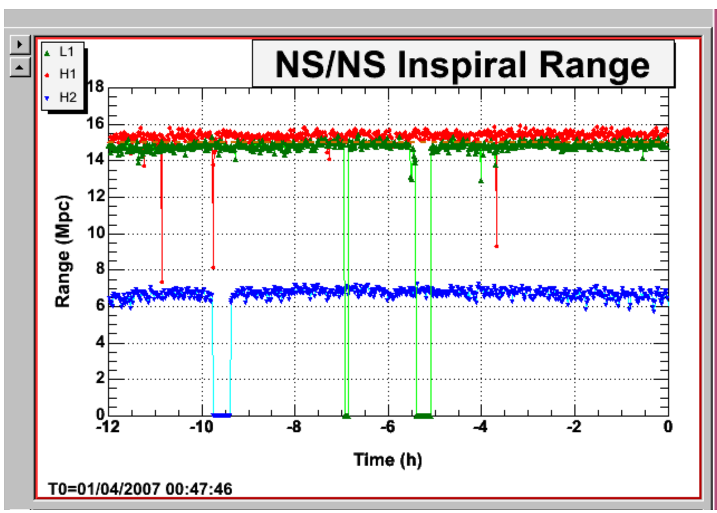
Use calculated templates for inspiral phase (“chirp”) with optimal filtering.

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





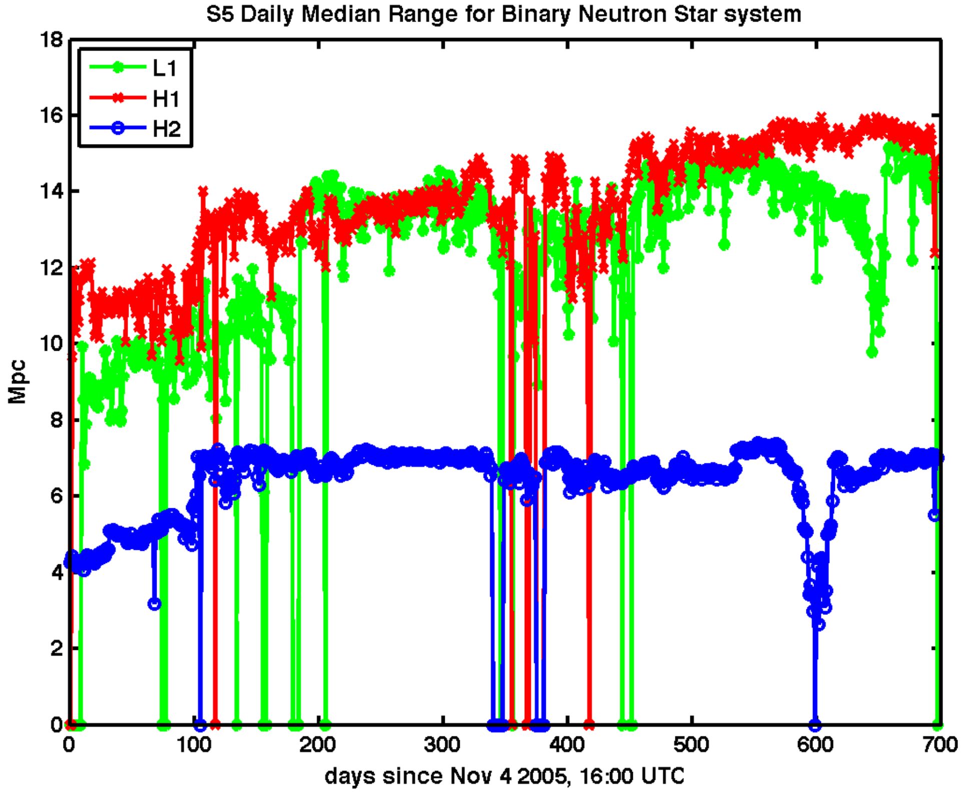
We can translate the “noise” into distances surveyed.
We monitor this in the control room for *binary neutron stars*:

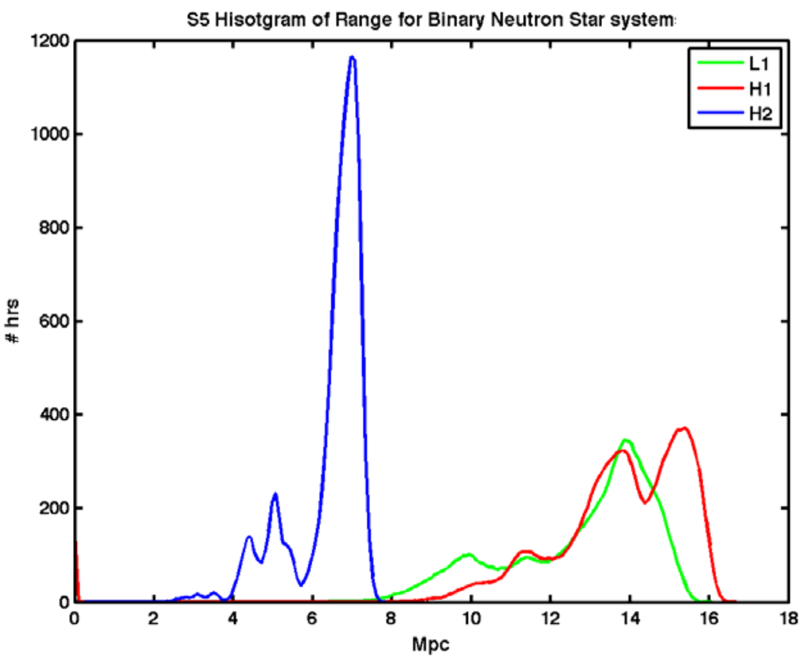


If system is optimally located and oriented, we can see even further: we are surveying hundreds of galaxies!

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

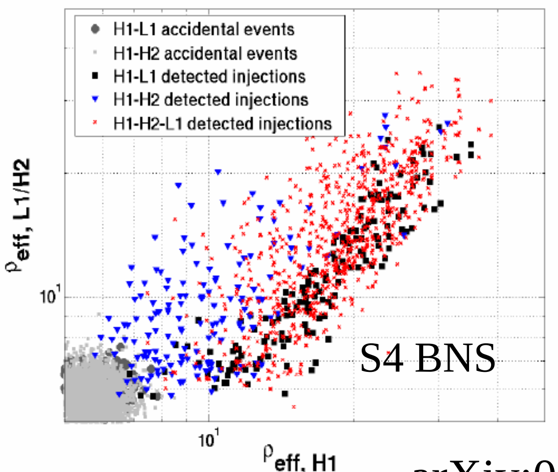
LSC S5 run

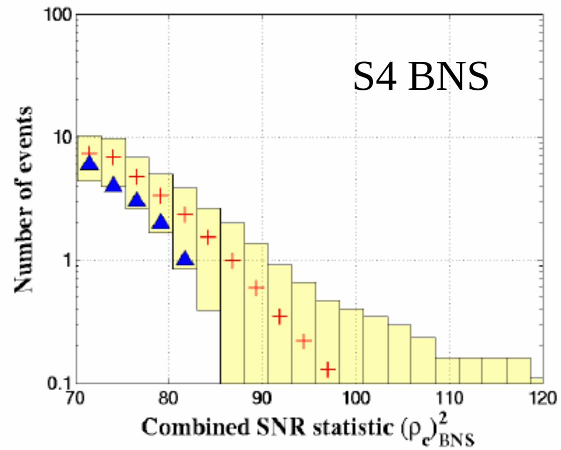

S5 Daily Median Range for Binary Neutron Star system
L1
H1
H2
Mpc
0
2
4
6
8
10
12
14
16
18
0
100
200
300
400
500
600
700
days since Nov 4 2005, 16:00 UTC


S5 Hisotgram of Range for Binary Neutron Star system
L1
H1
H2
hrs
0
200
400
600
800
1000
1200
0
2
4
6
8
10
12
14
16
18
Mpc

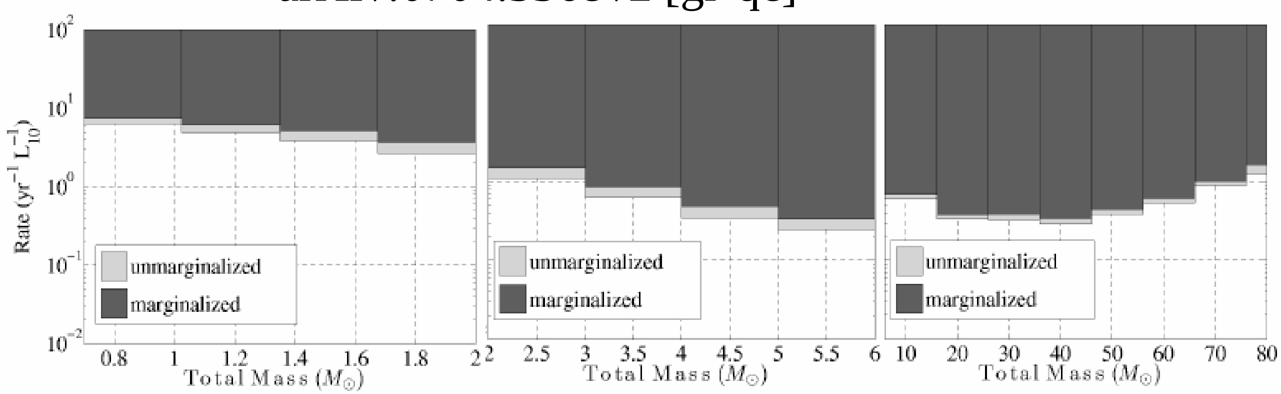
GW searches: binary systems

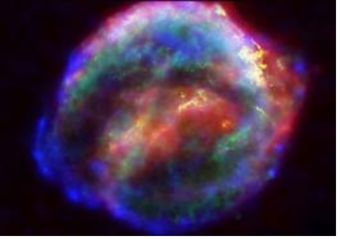
- Use two or more detectors: search for double or triple *coincident* “triggers”
- Can infer masses and “effective” distance.
- Estimate false alarm probability of resulting candidates: detection?
- Compare with expected efficiency of detection and surveyed galaxies: upper limit



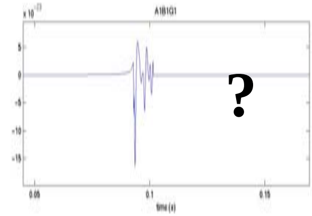


arXiv:0704.3368v2 [gr-qc]



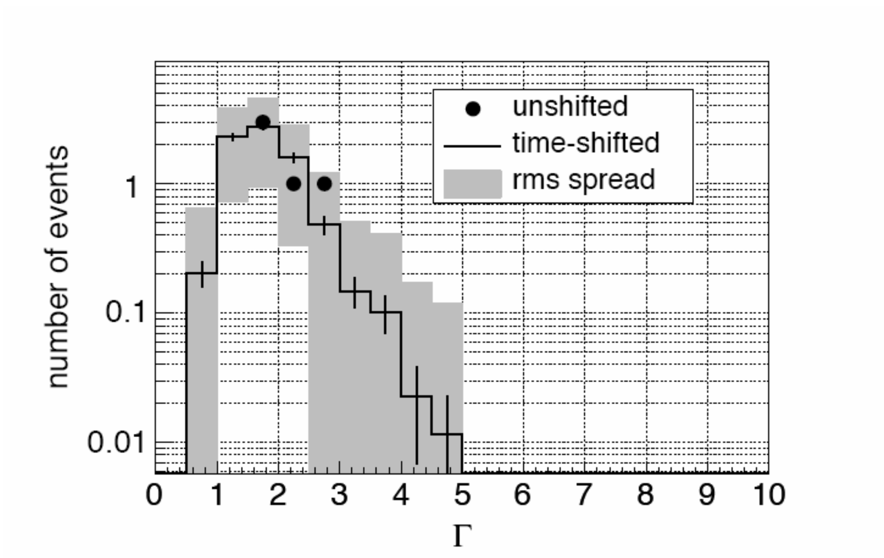


GW searches: bursts

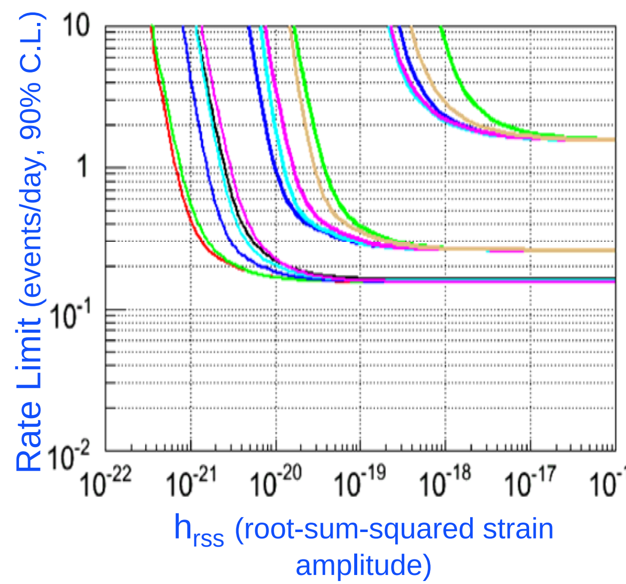


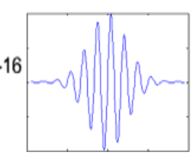
- Search for <u>triple coincident</u> triggers with a wavelet algorithm
- Measure waveform consistency
- Set a threshold for detection for <u>low false alarm probability</u>
- Compare with efficiency for detecting simple waveforms

S4, arXiv:0704.0943v1 [gr-qc]

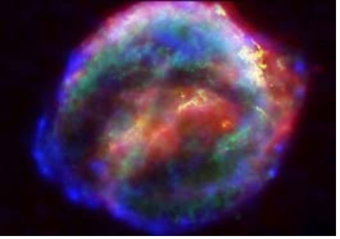


Limit on rate vs. GW signal strength sensitivity



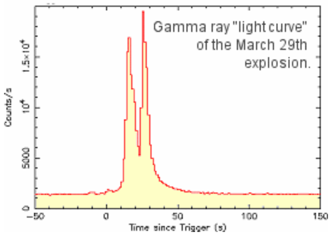


For a 153 Hz, *Q* =8.9 sine-Gaussian,
S5 can see with 50% probability:
$\sim 2 \times 10^{-8}\ M_{\odot} c^2$ at 10 kpc,
$\sim 0.05\ M_{\odot} c^2$ at 16 Mpc (Virgo cluster)



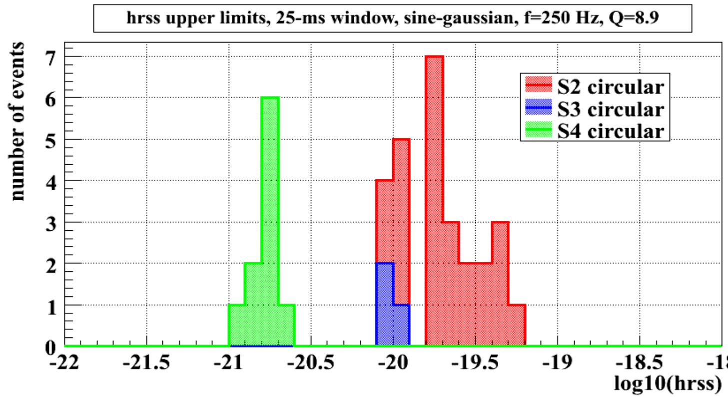
GW searches: triggered bursts

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



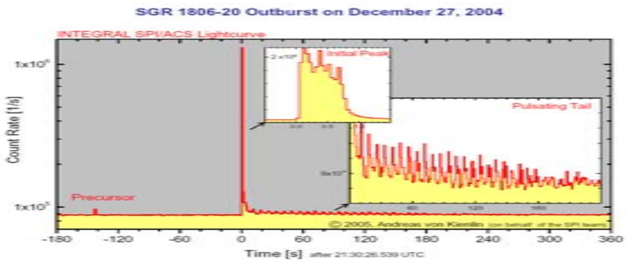
Gamma-Ray Bursts

- 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
- PRD 76 (2007) 042001



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
- **PRD** 76 (2007) 062003



GRB 070201

- Short GRB (T_{90}=0.15 s)
- Possible compact binary merger (NS/BH)
- Possible SGR
- Error-box of location overlay M31($D \approx$770 kpc)
- arXiv:0711.1163 (ApJ)

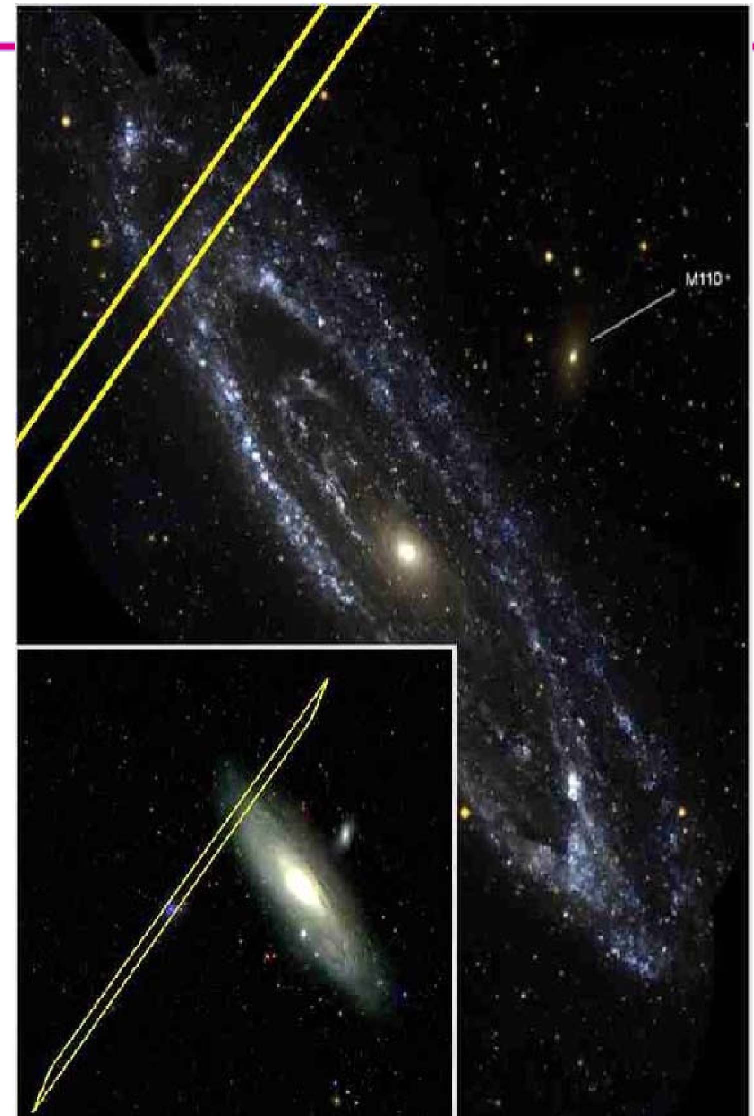
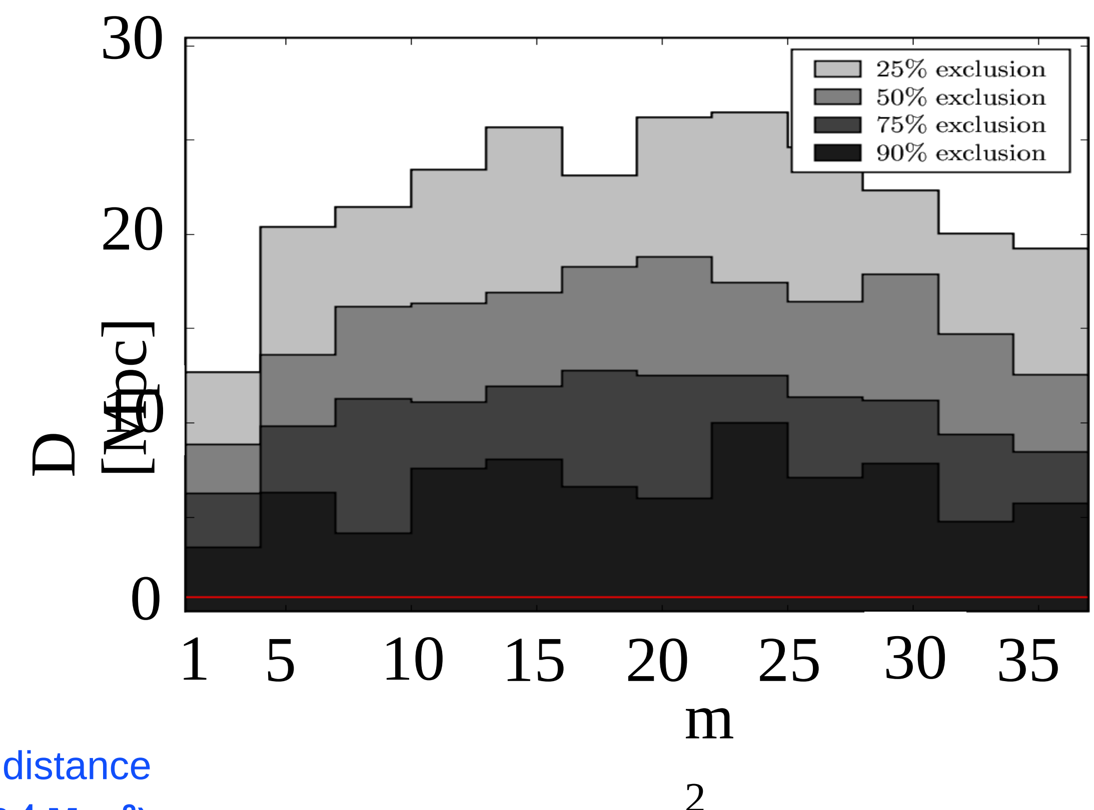


Image: GALEX, SDSS, Google Sky

Results GRB070201

No gravitational wave detected

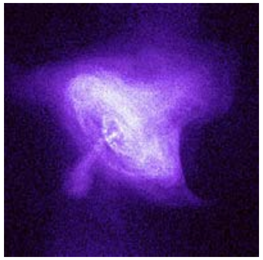
- Inspiral search:
  - Binary merger in M31 scenario excluded at >99% level
  - Exclusion of merger at larger distances: see plot



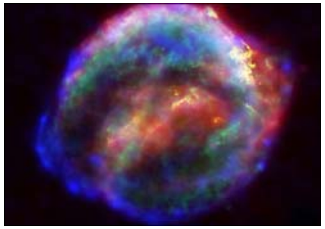
- Burst search:
  - Cannot exclude a SGR in M31 distance
  - **Upper limit: 8x10^{50} ergs (4x10^{-4} M$_{\odot}$c^{2}) (emitted within 100 ms for isotropic emission of energy in GW at M31 distance)**

When will we see something?

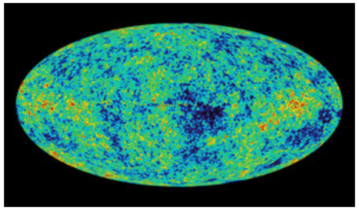
Predictions are difficult… especially about the future (Y. Berra)



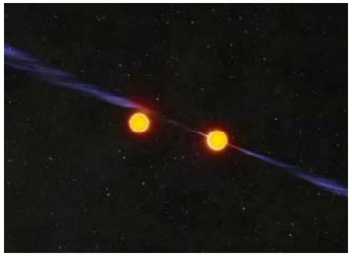
- Rotating stars: we know the rates,
  but not the amplitudes: how lumpy are they?



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



- Cosmological background:
  optimistic predictions are very dependent on model…

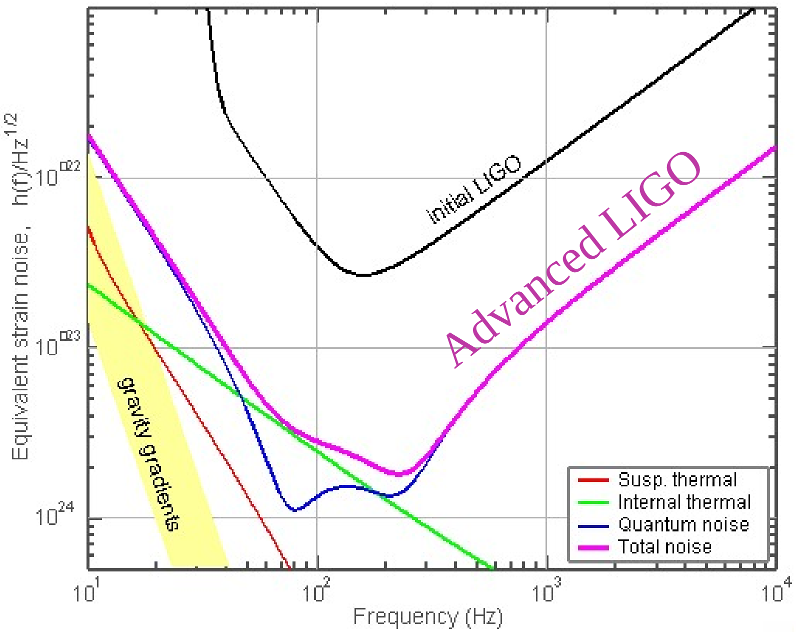


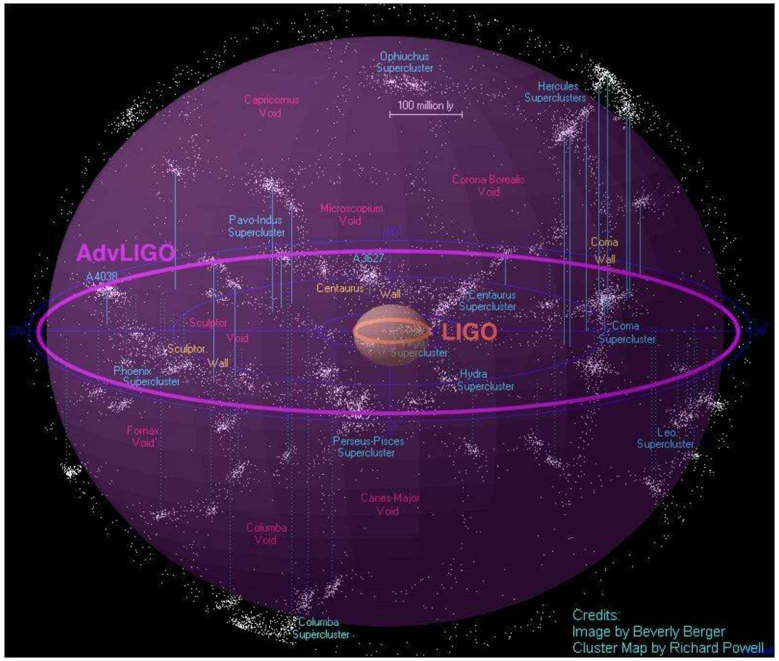
- Binary black holes:
  amplitude is known, but rates and populations
  highly unknown… Some estimates promise
  S5 results will be interesting!
- Binary neutron stars:
  amplitude is known, and galactic rates and population can be estimated:
  For R~86/Myr, initial LIGO rate ~1/100 yrs.

LIGO detectors: future

Neutron Star Binaries:

Initial LIGO: ~15 Mpc →
Advanced LIGO: ~200-300 Mpc
Most likely rate ~ 40/year !





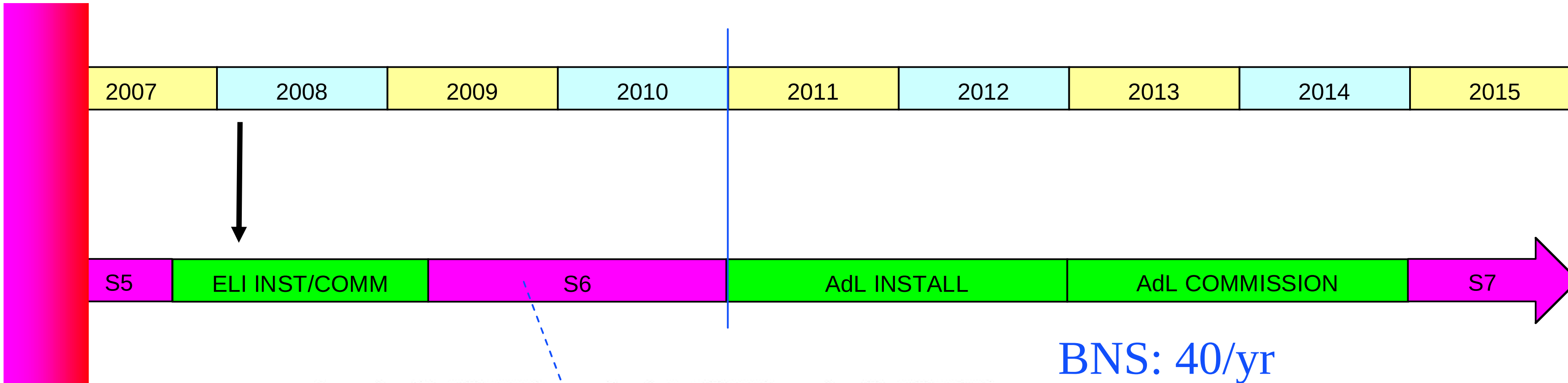
x10 better amplitude sensitivity

⇒ x1000 rate=(reach)^3

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

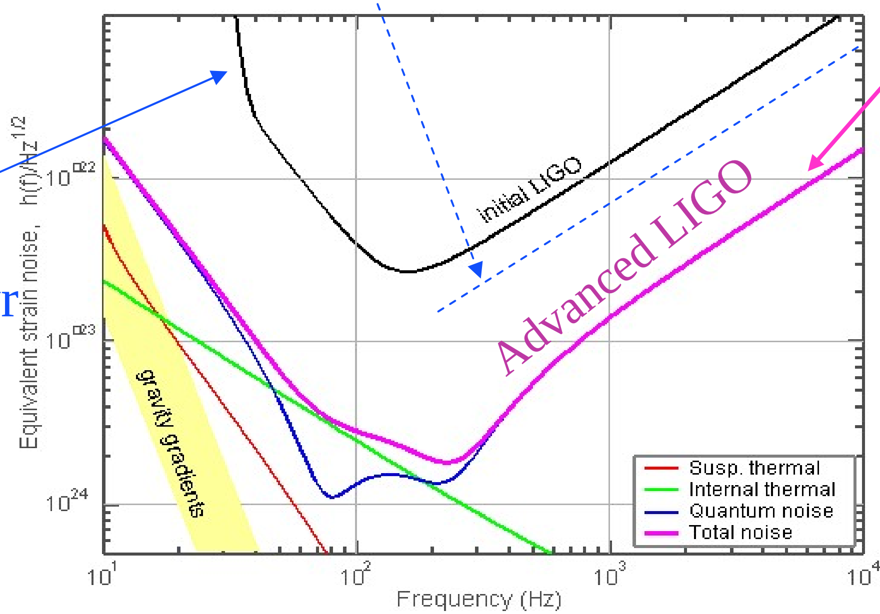
NSF Funding in FY'08 presidential budget request.

A possible timeline?



S5

BNS: 1/100 yr



BNS: 40/yr

Physics and Astronomy to be done!

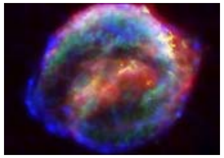
GR strong field tests

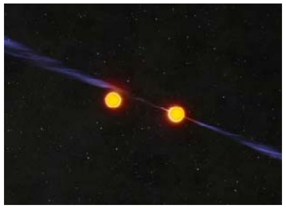
NS physics

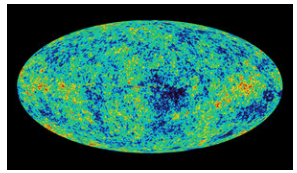
BH population

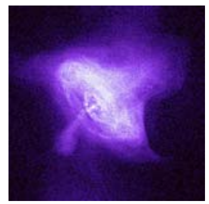
….

LIGO detectors: future

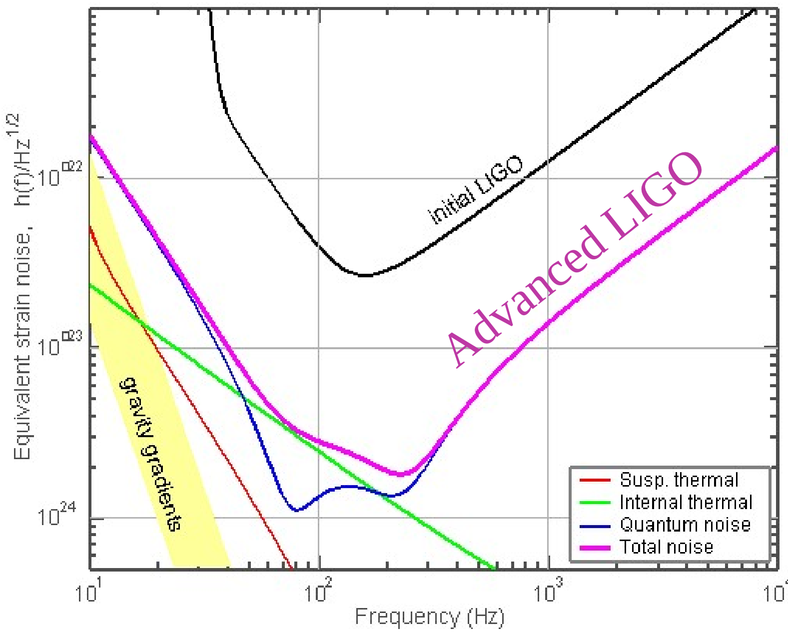


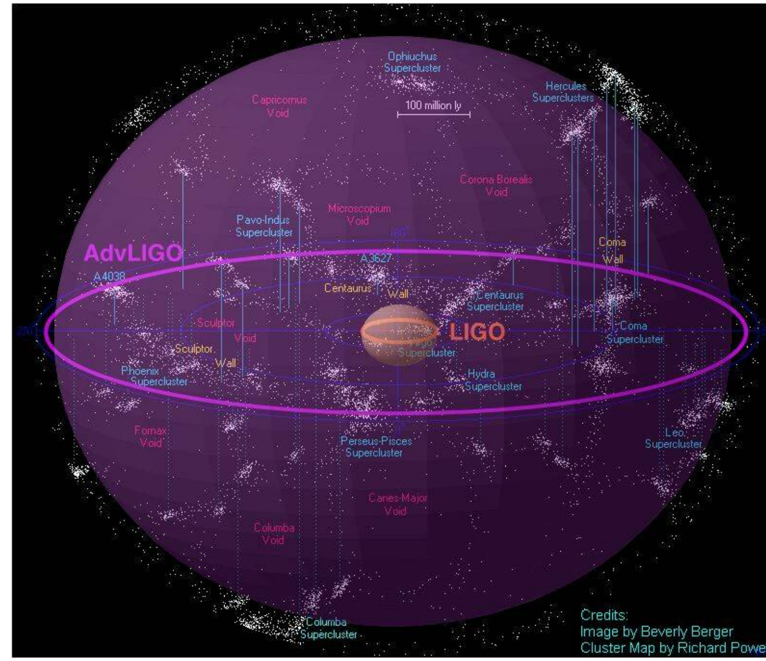






What's out there?





We'll find out!