LIGO

LSC

Gravitational wave astrophysics: Are we there yet?

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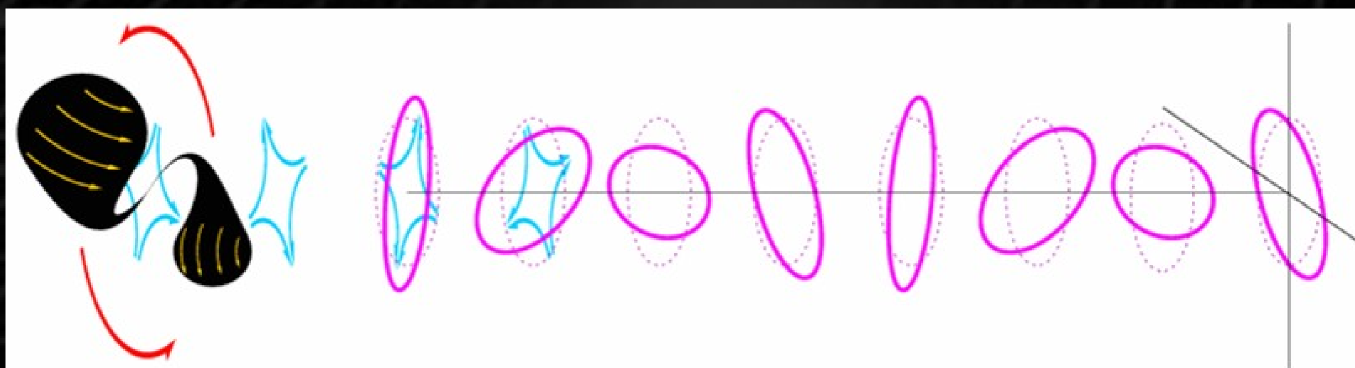
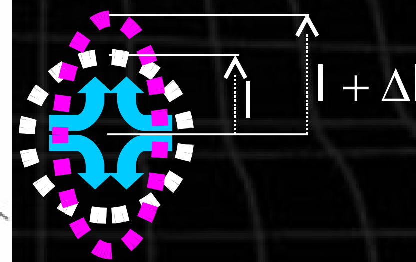
Gravitational waves basics

Source: Bulk Motion Produces Changing Tidal Field

Oscillating Tidal Field Propagates (Unobstructed) to Observer

Observer Detects Distortion Strain





Strain: $\frac{\Delta l}{l}$

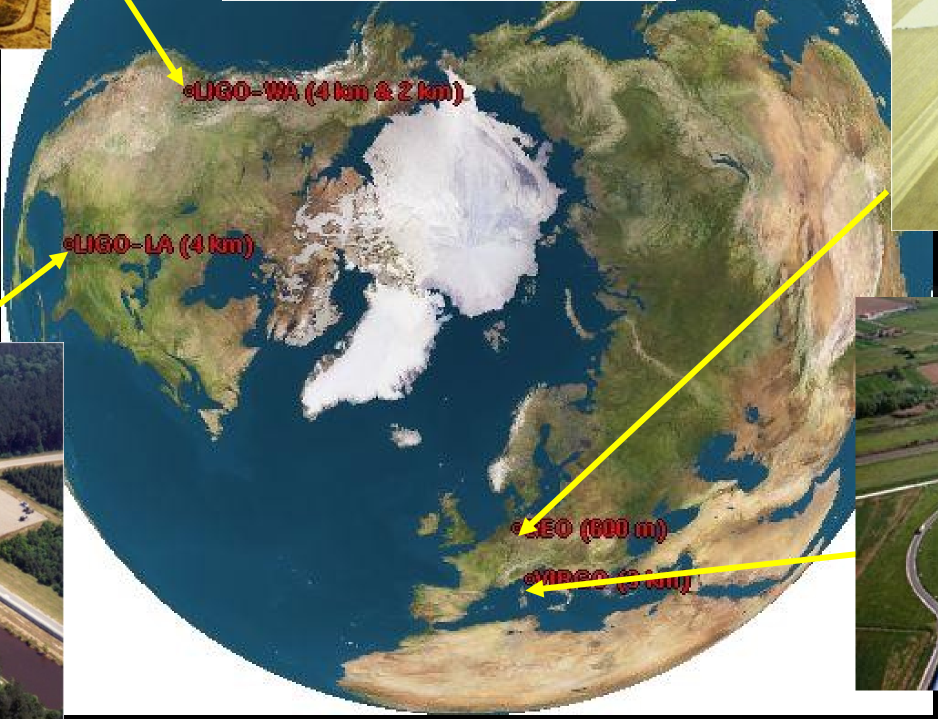
- Detectable gravitational waves (GWs) will only come from the most massive and energetic systems in the universe e.g. black hole binaries, pulsars, supernova, GRBs, etc.
- Indirectly detected by orbital decay seen in several binary pulsar systems e.g. Hulse and Taylor

Worldwide detector network

TAMA (300m)

GEO (600m)

LIGO Hanford WA
(4km & 2km)

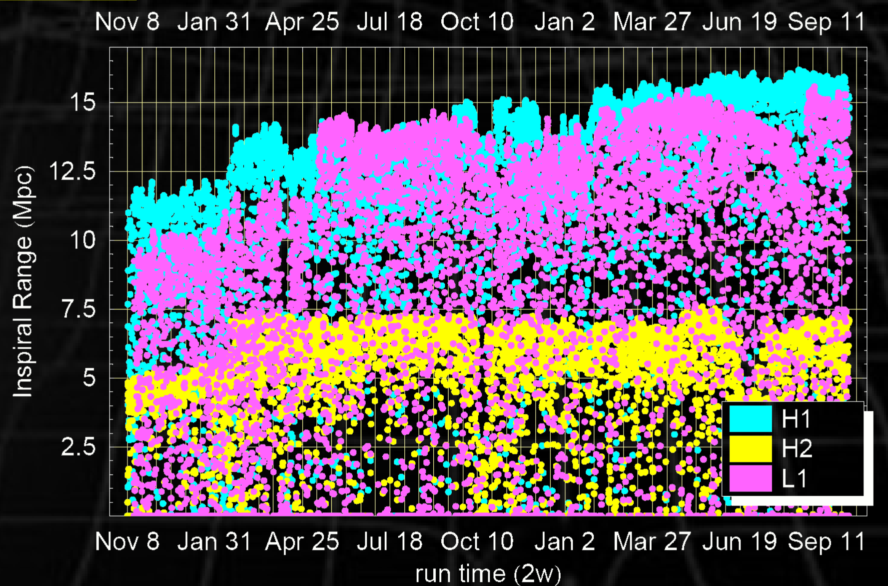


LIGO Livingston LA
(4km)

VIRGO (3km)

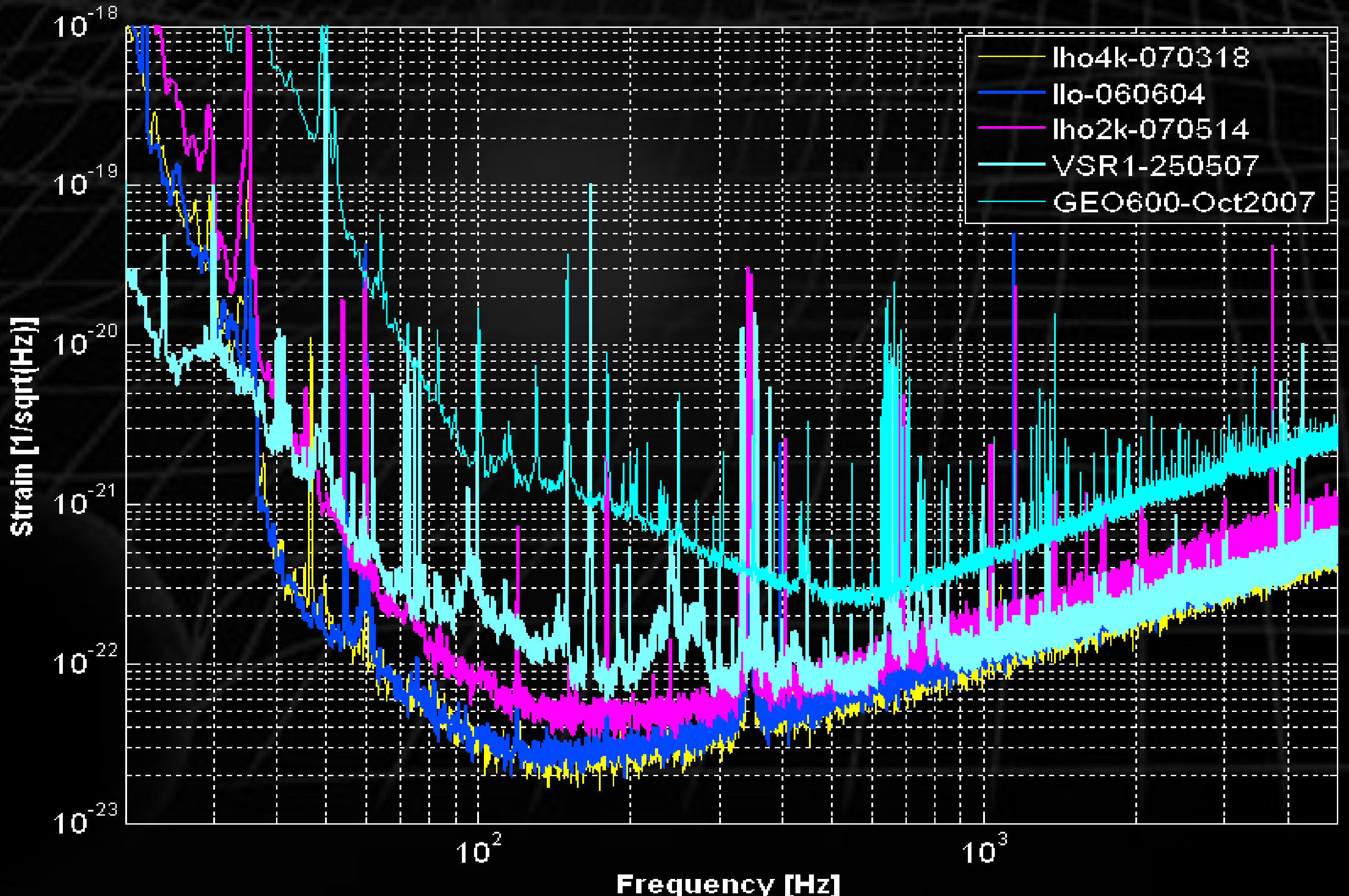
Fifth science run

- S5 started in Nov 2005 and ended Oct 2007
  - LIGO collected 1 year of triple coincidence data at design sensitivity
  - Duty cycle: ~75% per interferometer, 53% triple coincidence
- GEO joined
  - in overnight & weekend mode January 20th 2006
  - in 24/7 mode May 1st 2006 (Duty cycle: ~91%)
  - back in overnight & weekend mode Oct. 2006 – Oct. 2007
- VIRGO joint May 18th 2007 (VSR1)
  - Duty cycle: 81%



- A figure of merit is the range to which a NS/NS binary (1.4 $M_{\odot}$) is seen at SNR of 8
  - LIGO: 4km range 15 Mpc, 2km range 7 Mpc
  - VIRGO: range 4 Mpc

Fifth science run (S5)



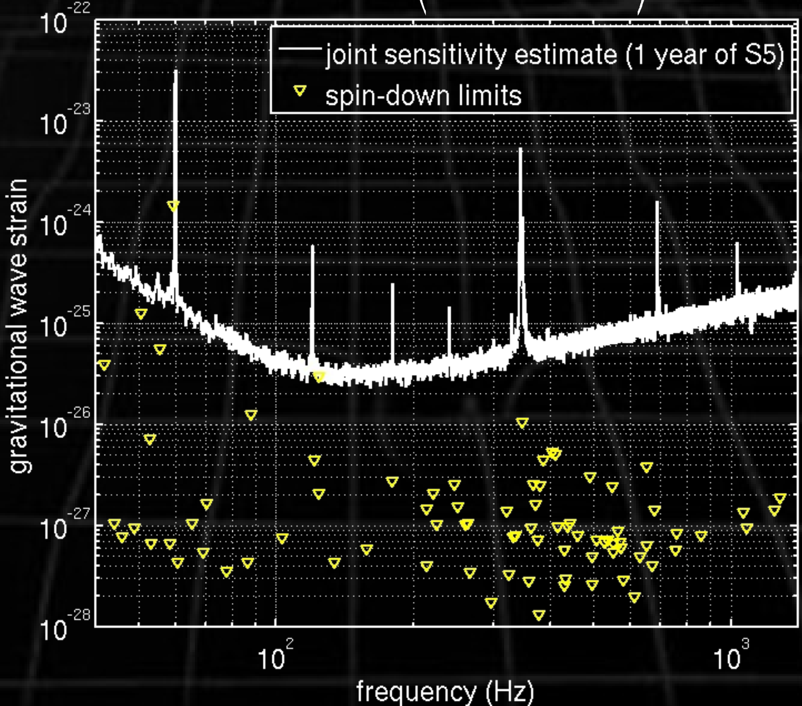
Astrophysical searches

- Continuous waves
  - Rapidly rotating deformed neutron stars
    - Known radio pulsars (using radio and X-ray observations to provide signal phase) and unknown sources
  - Coherent and semi-coherent searches
  - Targeted (supernova remnants, globular clusters, galactic centre, X-ray sources) and all-sky searches
- Compact binary coalescences
  - late stage neutron star or black hole binary inspirals, mergers and ring-downs
- Transient searches
  - Coincident excess power from short duration transient sources
  - External triggers: GRBs, X-ray transients, radio transients, supernova, neutrino obsevations
- Stochastic background
  - Cosmological i.e. from inflation
  - Combined background of astrophysical sources

Crab pulsar search

- Known pulsars provide an enticing, well defined, target for GW searches
- Crab pulsar has largest spin-down rate of any known radio pulsar at 3.7×10^{-10} Hz/s
- Assuming all energy is dissipated by GW emission we can set a spin-down upper limit on the strain at 1.4×10^{-24} ($I_{zz}=I_{38}=10^{38}$kgm^2, r=2 kpc)
  - largest for any pulsar within the LIGO band and beatable with several months of LIGO fifth science run data (S5)
- Nebula emission and acceleration are powered by the spin-down, but uncertainties in the error budget could leave ~80% of the available energy unaccounted for

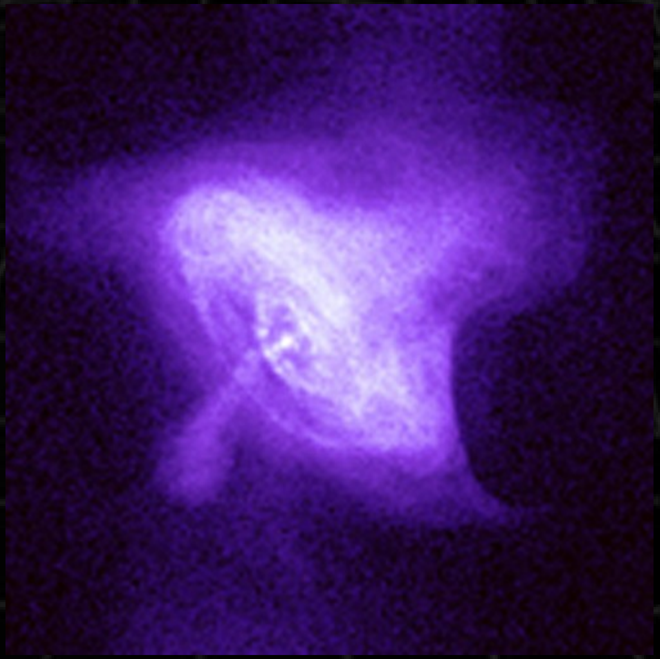
$$h_0^{spin-down} = \left(\frac{5}{2} \frac{G I_{zz} \dot{\nu}}{c^3 r^2 \nu} \right)^{1/2}$$



An estimate of the joint LIGO sensitivity for known pulsar searches using 1 year S5 data, and spin down upper limits for known millisecond pulsars

Crab pulsar search

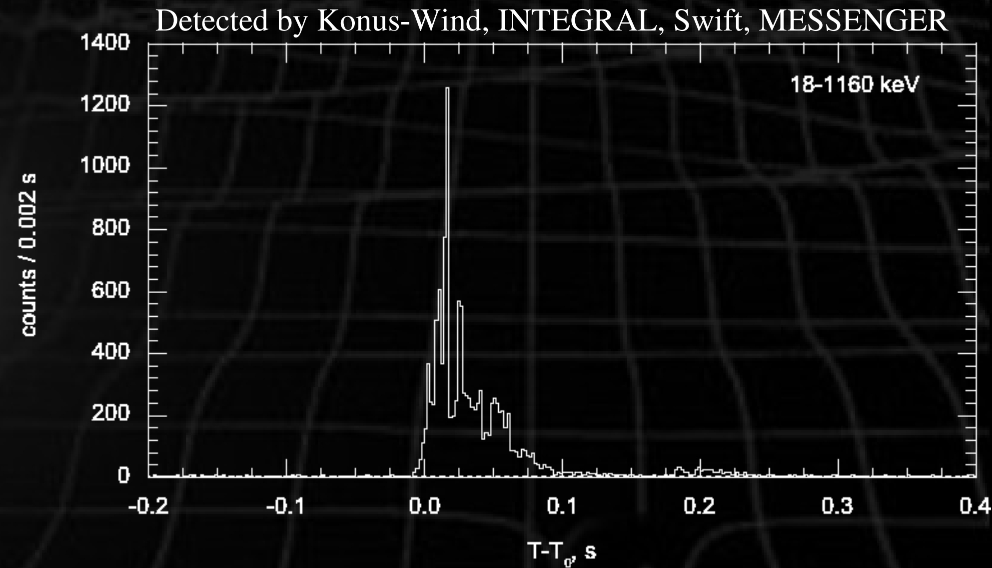
- Using 9 months of combined LIGO S5 data no GW signal from the Crab pulsar was seen, but…
  - We have a limit on the GW amplitude of $h_0 = 3.4\times10^{-25}$ - a factor of 4.2 lower than the classical spin-down limit
  - The ellipticity result of 1.8×10^{-4} is into the range permitted by some exotic quark star equations of state (Owen, *Phys. Rev. Lett*, 2004, Lin, *Phys. Rev. D*, 2007, Haskell et al, *Phys. Rev. Lett.*, 2007)
  - Constrains the amount of the available spin-down power radiated away via GWs to less than 6%
  - Observational constraints of pulsar orientation (Ng and Romani, *Ap. J.*, 2007) can be used and improve our limit to be 5.3 times lower than spin-down
  - Pulsar's braking index of n=2.5 shows that pure GW emission is not responsible for spin-down (n=5), and from this Palomba (*A&A,* 2000) suggest a spin-down limit 2.5 times lower than the classical one – still beaten by our result
- Represents new regime being probed only through GW observations!



Credit: NASA/CXC/SAO

Triggered searches

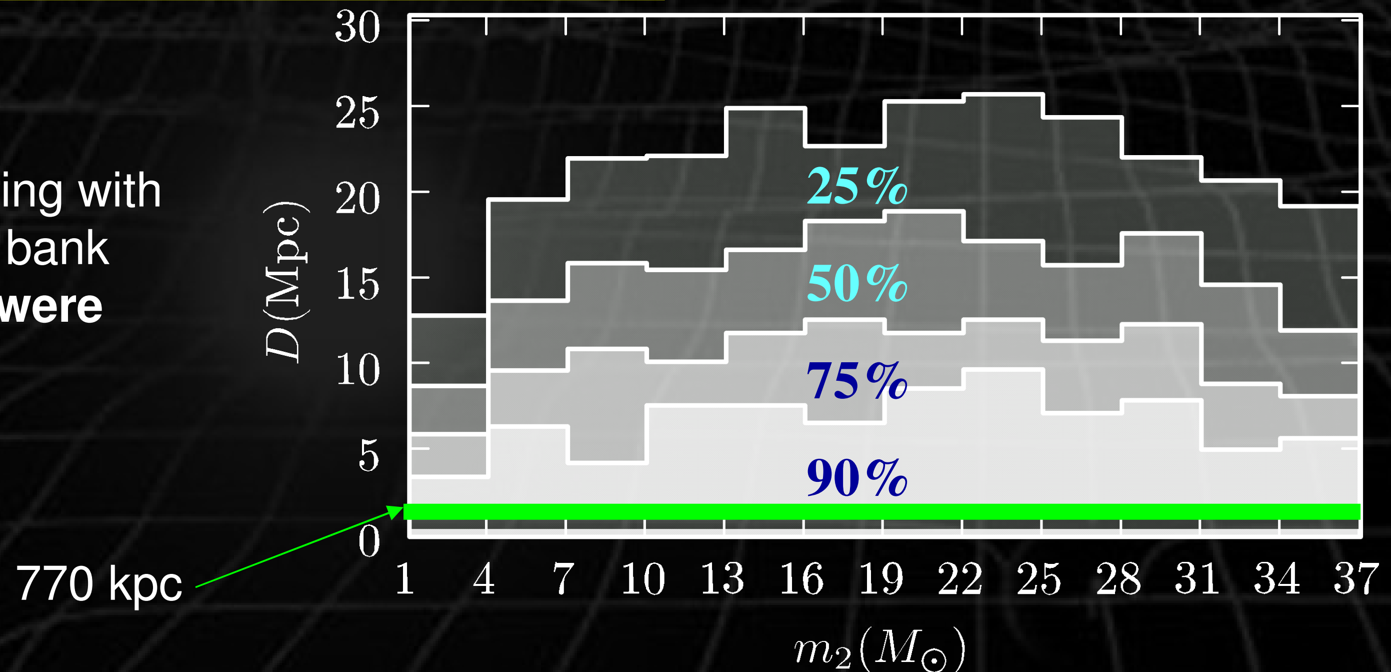
- 213 GRB triggers during S5 (mainly from Swift, INTEGRAL, IPN, HETE-2)
  - time and positional information for GW search
  - allows better background rejection e.g. higher sensitivity to GWs
  - more confidence in detection (eventually) and allows more source information to be extracted



- Particularly interesting short, hard event, GRB070201, observed with a position coincident with spiral arms of M31 – distance 770 kpc
- Possible progenitors for short GRBs:
  - NS/NS or NS/BH mergers: Emits strong gravitational waves
  - Soft gamma-ray repeater (SGR): May emit GWs, but weaker

GRB070201 model based inspiral search

Using matched filtering with an inspiral template bank **no plausible GWs were identified**

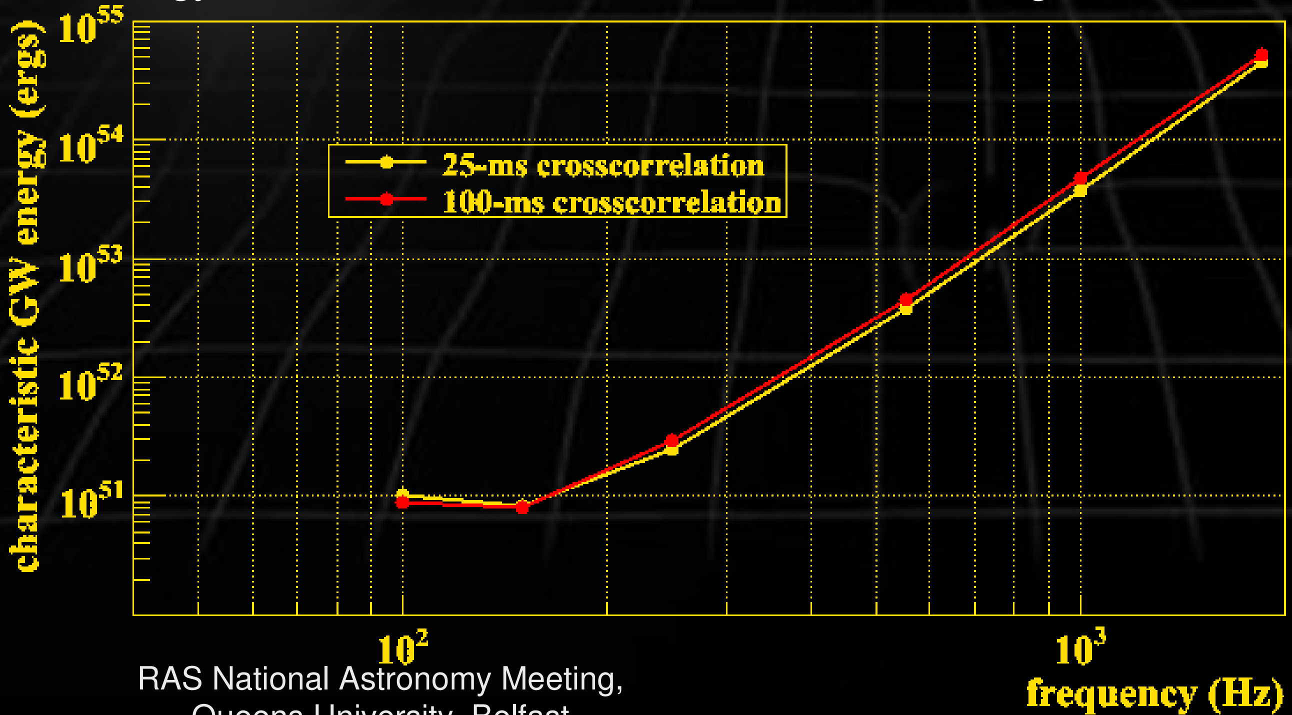


- Exclude compact binary progenitor with masses
  - $1\ M_\odot < m_1 < 3\ M_\odot$ and $1\ M_\odot < m_2 < 40\ M_\odot$ with $D < 3.5$ Mpc away at 90% CL
- Exclude any compact binary progenitor in our simulation space
  - at the distance of M31 at > 99% confidence level

GRB070201 SGR search

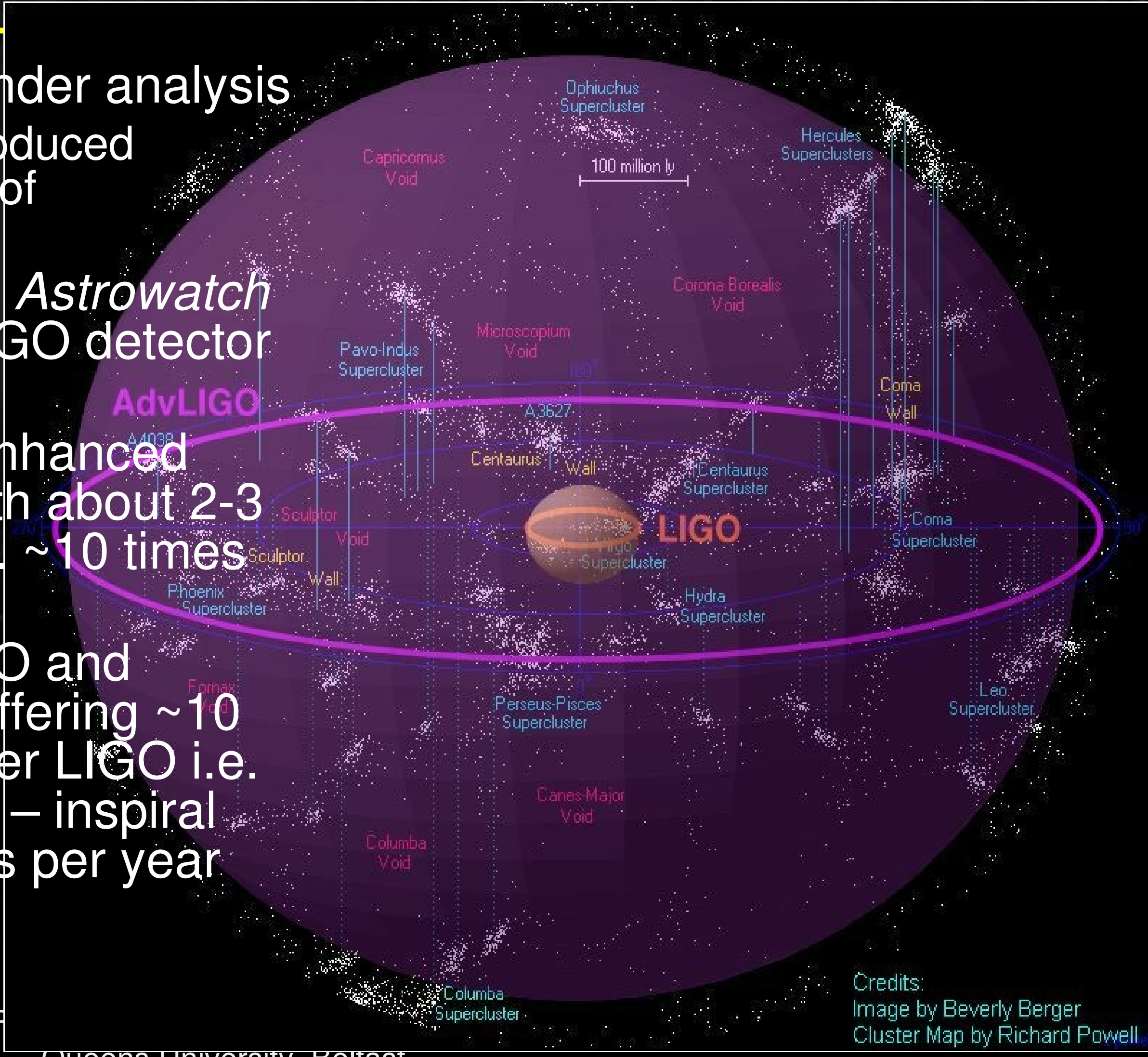
- A hypothesised model for the GRB is an SGR giant flare
- Energy release in γ-rays is consistent with SGR model
  - measured γ-ray fluence = 2×10^{-5} ergs/cm^2 (Konus-Wind)
  - Corresponding γ-ray energy, assuming isotropic emission, with source at 770 kpc (M31): ~10^{45} ergs
  - SGR models predict energy release in GW to be no more than ~10^{46} ergs

Limits on GW energy release from GRB 070201 are consistent with an SGR model in M31 (can not exclude it)



Future searches

- There is still S5 data under analysis
  - more results to be produced including some more of astrophysical interest
- Currently in a period of *Astrowatch* – GEO600 and 2km LIGO detector are taking data
- In 2009 we will have Enhanced LIGO and VIRGO+, with about 2-3 times the sensitivity i.e. ~10 times the volume covered
- In 2014 Advanced LIGO and VIRGO will be online offering ~10 times the sensitivity over LIGO i.e. 1000 times the volume – inspiral event rates of 10s-100s per year



Conclusions

- No detection… yet!
- However, current gravitational wave data is starting to probe new regimes and yield novel astrophysics
- We would like to strengthen the links between the traditional astronomy community, theorists and the gravitational wave community
  - We need events to look at (positions, times, energies) to get the maximum information out of observations
  - We need good theoretical models to help fine tune our search methods
  - Have *true* multi-messenger astronomy