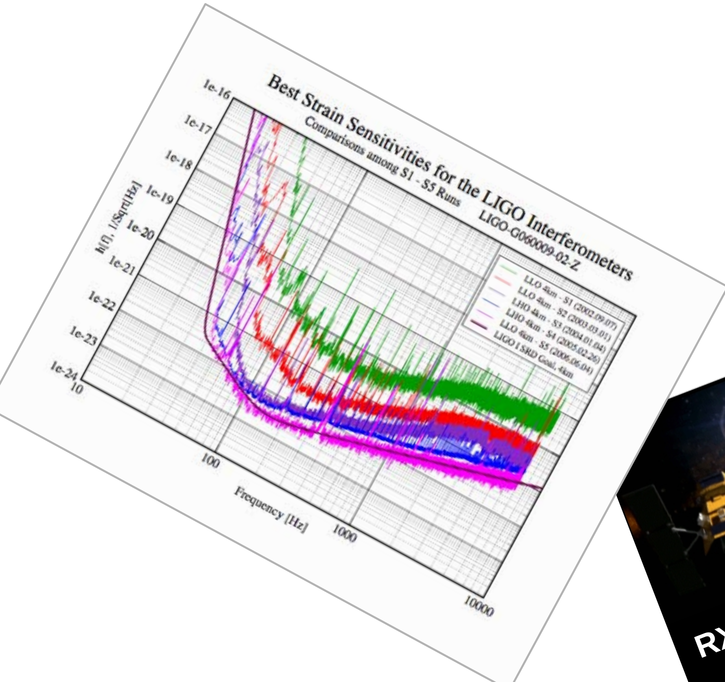
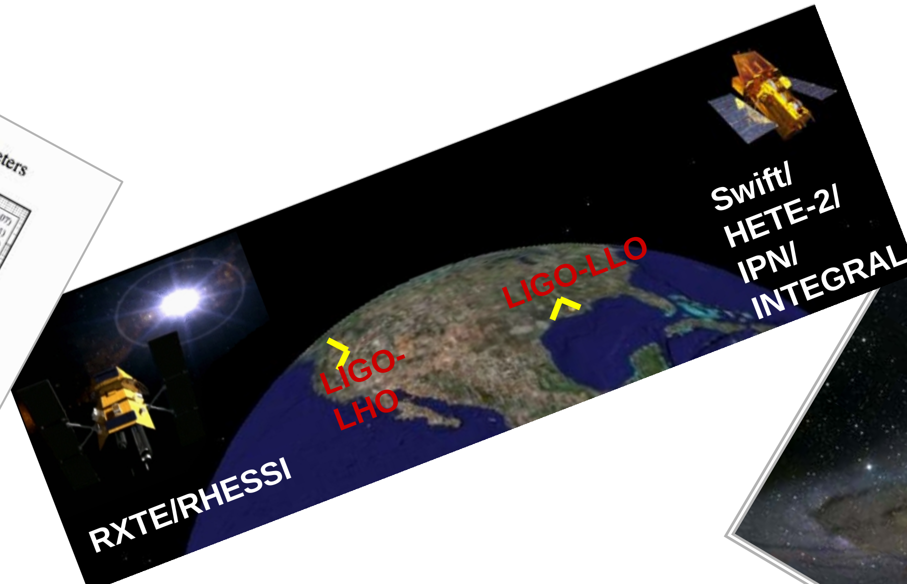
Astrophysically Triggered Searches for Gravitational Waves



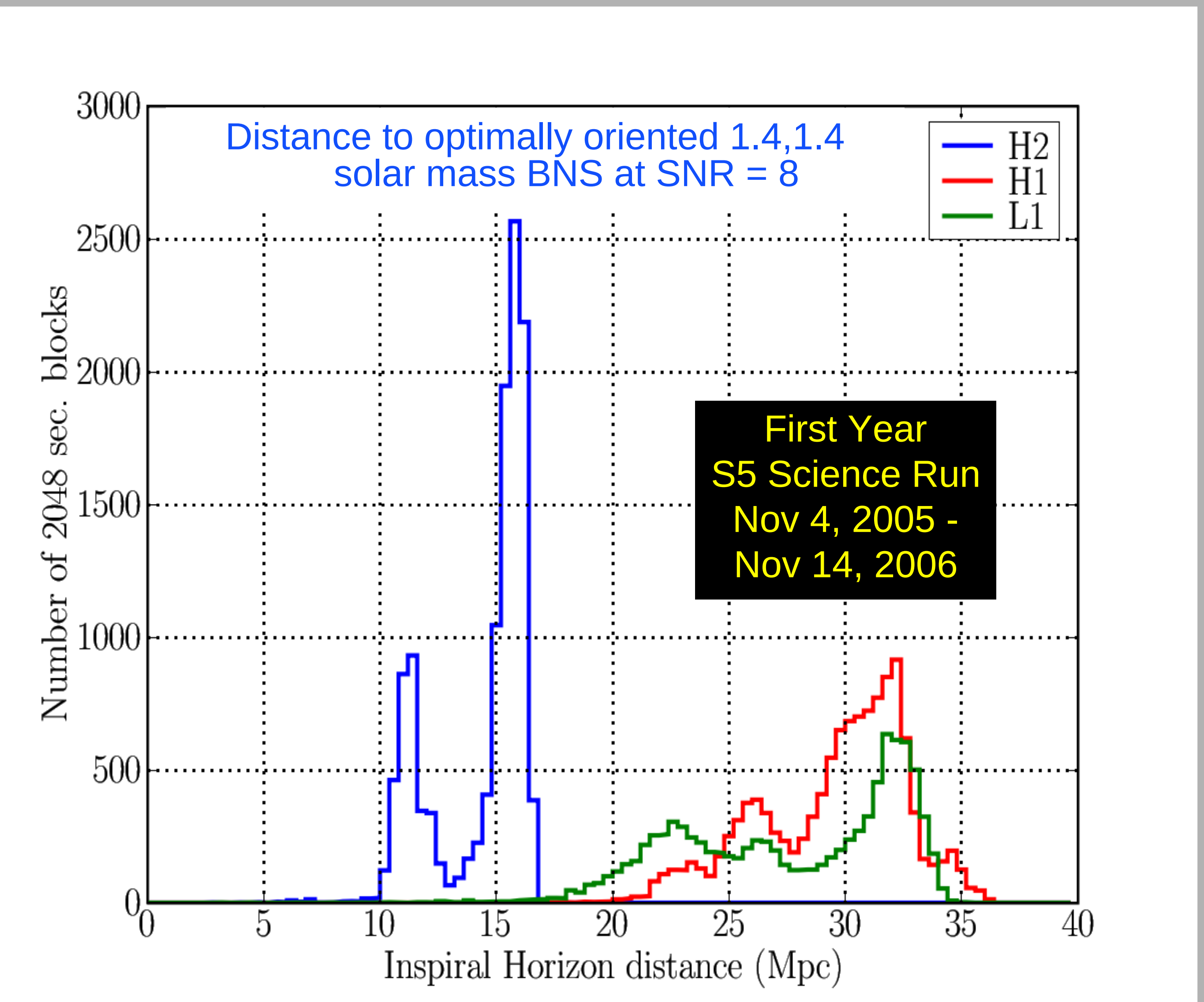


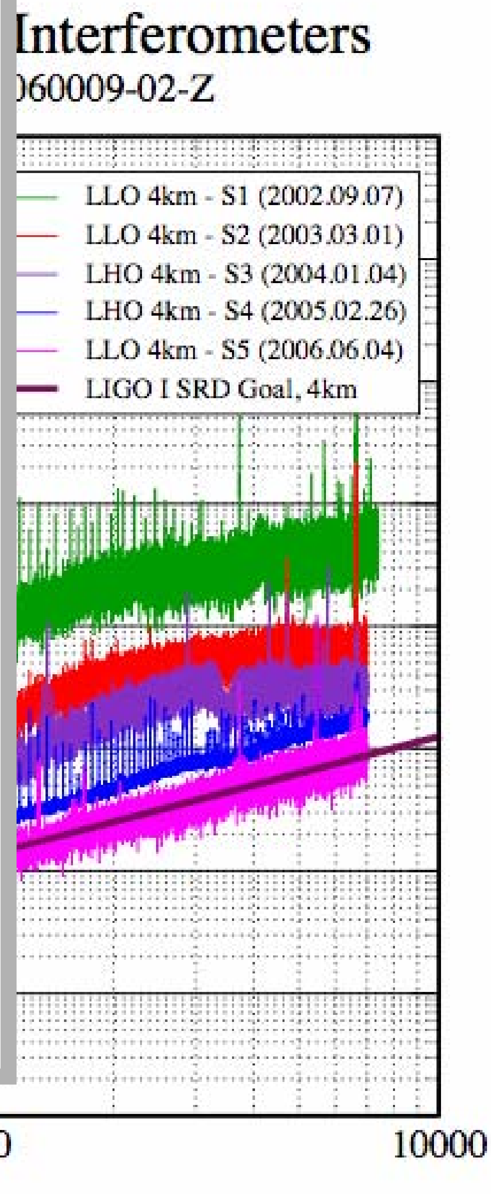
Szabolcs Márka

for the LIGO Scientific Collaboration

Amaldi 2007, Sydney, Australia

Capabilities of Modern Gravitational Wave Detectors





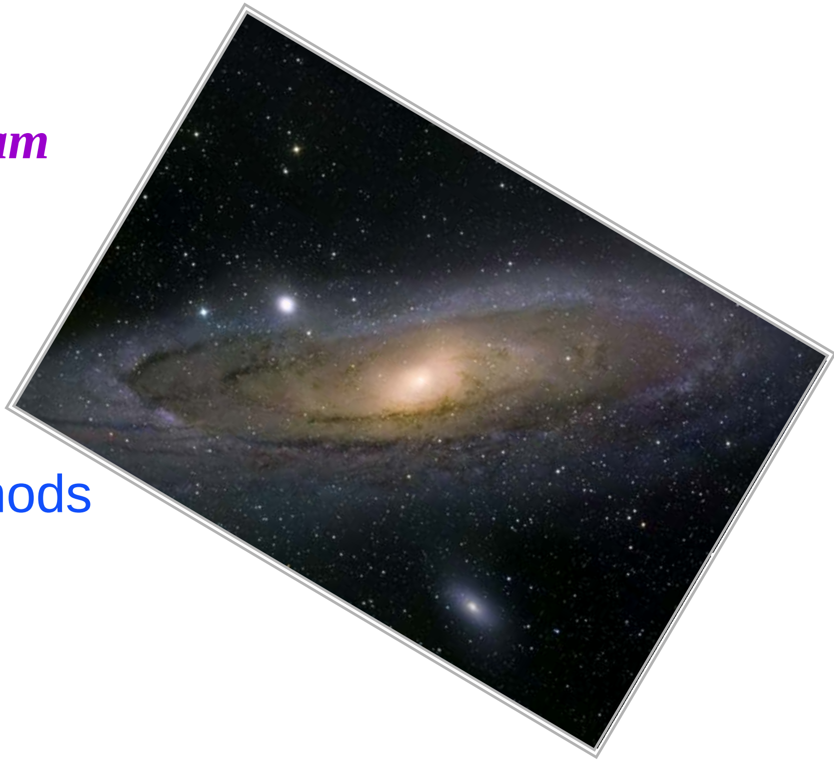
Motivation, Rationale and Topics

Astrophysical observation based association between gravitational waves and

- Gamma-ray bursts (GRBs) *1*
- Short hard GRBs (in the context of compact binary inspirals) *3*
- Soft gamma-ray repeater (SGR) flares
- SGR quasiperiodic oscillations *2*
- Optical supernovae
- Neutron star quasi-normal modes
- Neutrinos *Y. Aso : M6 Sat. 8:30am*
- …

Develop methods to

- Localize Gravitational Wave Repeaters
- Take advantage of network analysis methods
- Recover information about the waveform
- Determine precise directionality
- …

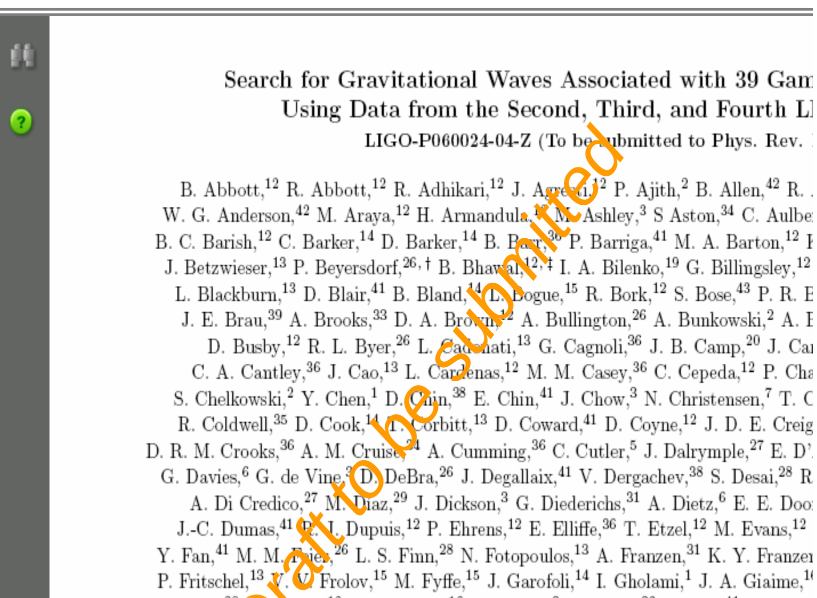


Astrophysical observation based search for association between gravitational waves and Gamma-ray bursts

Gravitational-wave bursts coincident with GRBs - Results

- Search for short-duration gravitational-wave bursts (GWBs) coincident with GRBs
  - using S2, S3 and S4 data from LIGO
  - Analysis based on pair-wise cross-correlation of two interferometers
  - Target GWB durations: < 100 ms; Bandwidth: 40-2000 Hz

- **No gravitational-wave burst signal found associated with 39 GRBs in S2,S3,S4 runs**


Search for Gravitational Waves Associated with 39 Gam
Using Data from the Second, Third, and Fourth LI
LIGO-P060024-04-Z (To be submitted to Phys. Rev.

B. Abbott,[12] R. Abbott,[12] R. Adhikari,[12] J. Agresti,[12] P. Ajith,[2] B. Allen,[42] R.
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R. Coldwell,[35] D. Cook,[14] T. Corbitt,[13] D. Coward,[41] D. Coyne,[12] J. D. E. Creig
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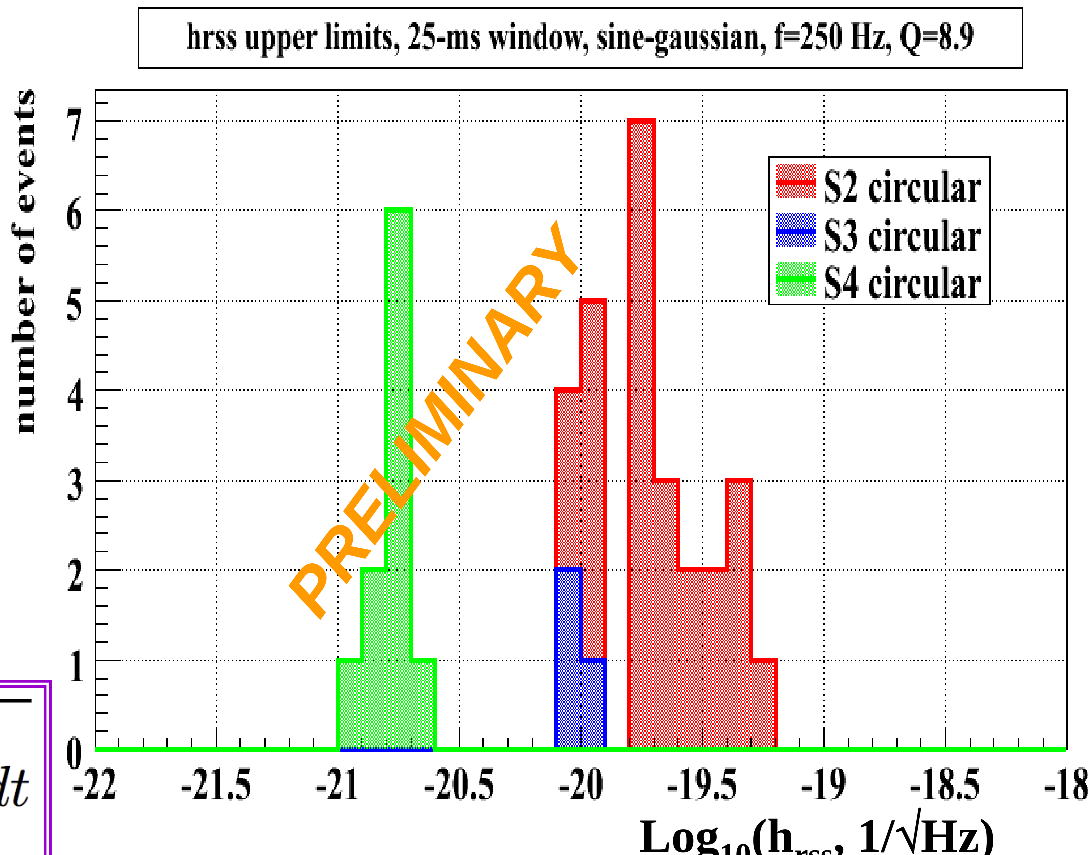
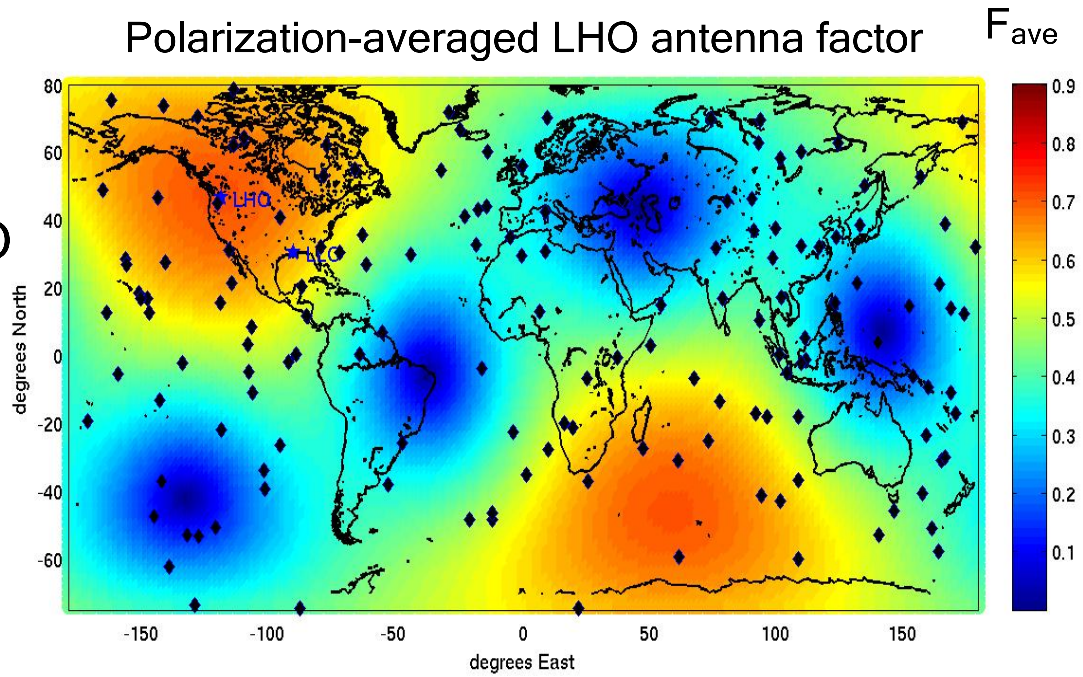
Draft to be submitted

$$h_{\rm rss} \equiv \sqrt{\int \left(|h_+(t)|^2 + |h_\times(t)|^2\right) dt}$$



GRB triggers from GCN for the LIGO S5 run

- 157 GRB triggers from November 4, 2005 to March 31, 2007
  - ~70% with double-IFO coincidence LIGO data
  - ~40% with triple-IFO coincidence LIGO data
  - ~25% with redshift
  - ~10% short-duration GRBs
  - all but two have position information



LIGO sensitivity depends on GRB position

- energy radiated by a source in gravitational waves:

$$E_{GW} \sim \frac{c^3}{G} D^2 f_c^2 h_{rss}^2$$

- we might expect to be sensitive to GW bursts out to a distance of:

$$D \sim 20\ \mathrm{Mpc} \left(\frac{250\,Hz}{f_c}\right)\left(\frac{10^{-21}\,Hz^{-1/2}}{h_{rss}}\right)\left(\frac{E_{GW}}{0.5\,M_{sun}c^2}\right)^{1/2}$$

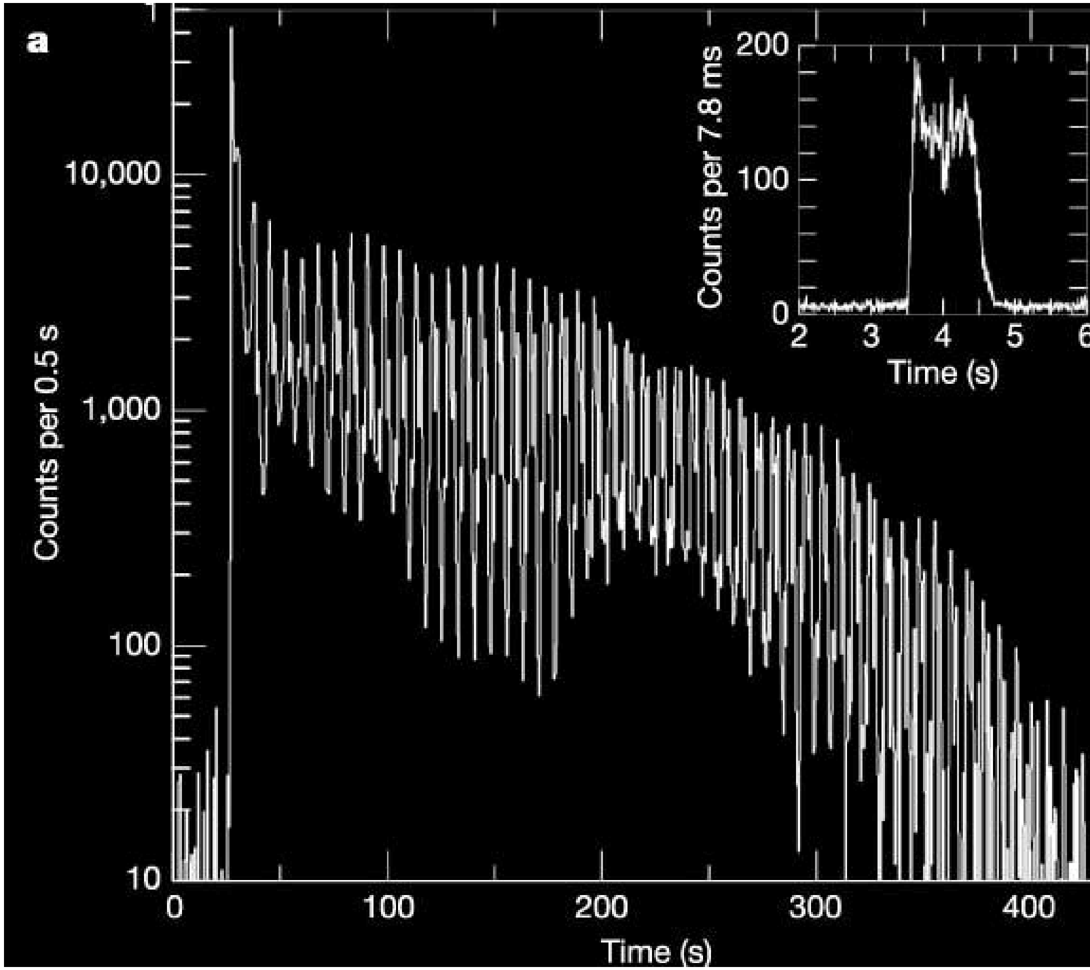
factor depends on GW polarization, source position and orientation

Astrophysical observation based search for gravitational waves due to quasiperiodic oscillations associated with soft gamma-ray repeater (SGR) flares

The SGR 1806-20 Hyper Flare of December 27, 2004

- Soft Gamma-ray Repeater SGR 1806-20 emits a record flare
- Distance [6 - 15] kpc
- Energy ~10^{46} erg
- Pulsating tail lasting six minutes

RHESSI X-ray light curve (20 -100 keV)



- High Frequency QPOs (Israel et al. 2005, Watts & Strohmayer 2006)
  - » RXTE and RHESSI
  - » SGR 1900+14
- Plausibly mechanically driven

Objective:

Measure GW radiation associated with periods and frequency of observations

Results (92.5 Hz QPO) – SGR1806-20 Hyperflare

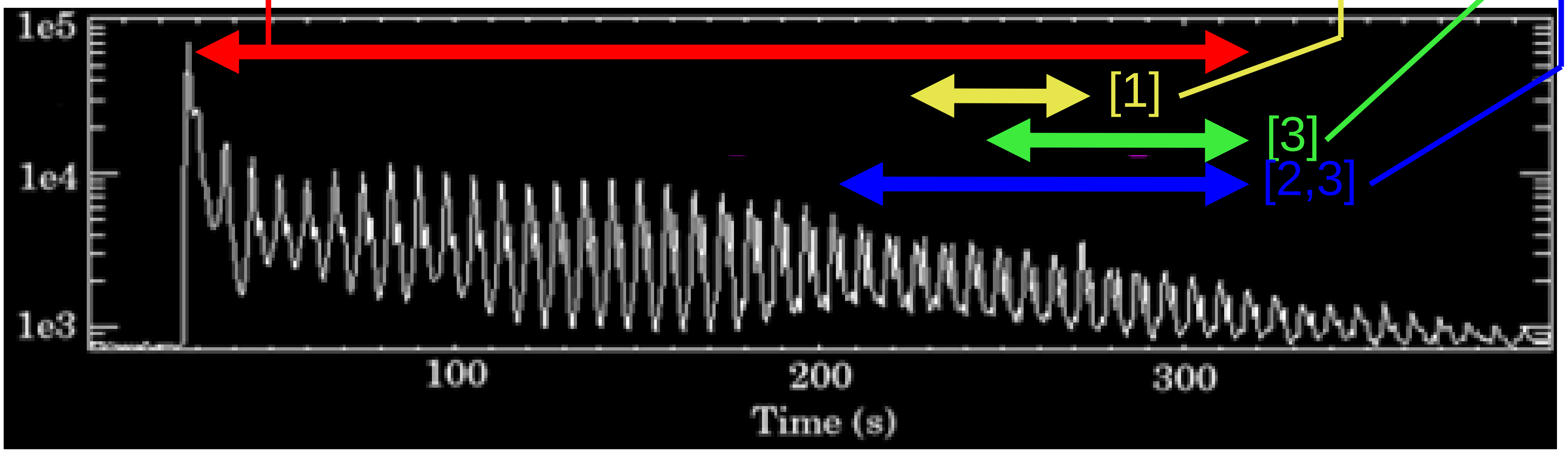
- No significant departure from background
  - no GW detection

$h^{90\%}_{rss\text{-}det}$ = 4.53 x 10^{-22} strain/rHz

$h^{90\%}_{rss\text{-}det}$ = 4.67 x 10^{-22} strain/rHz

$h^{90\%}_{rss\text{-}det}$ = 7.19 x 10^{-22} strain/rHz

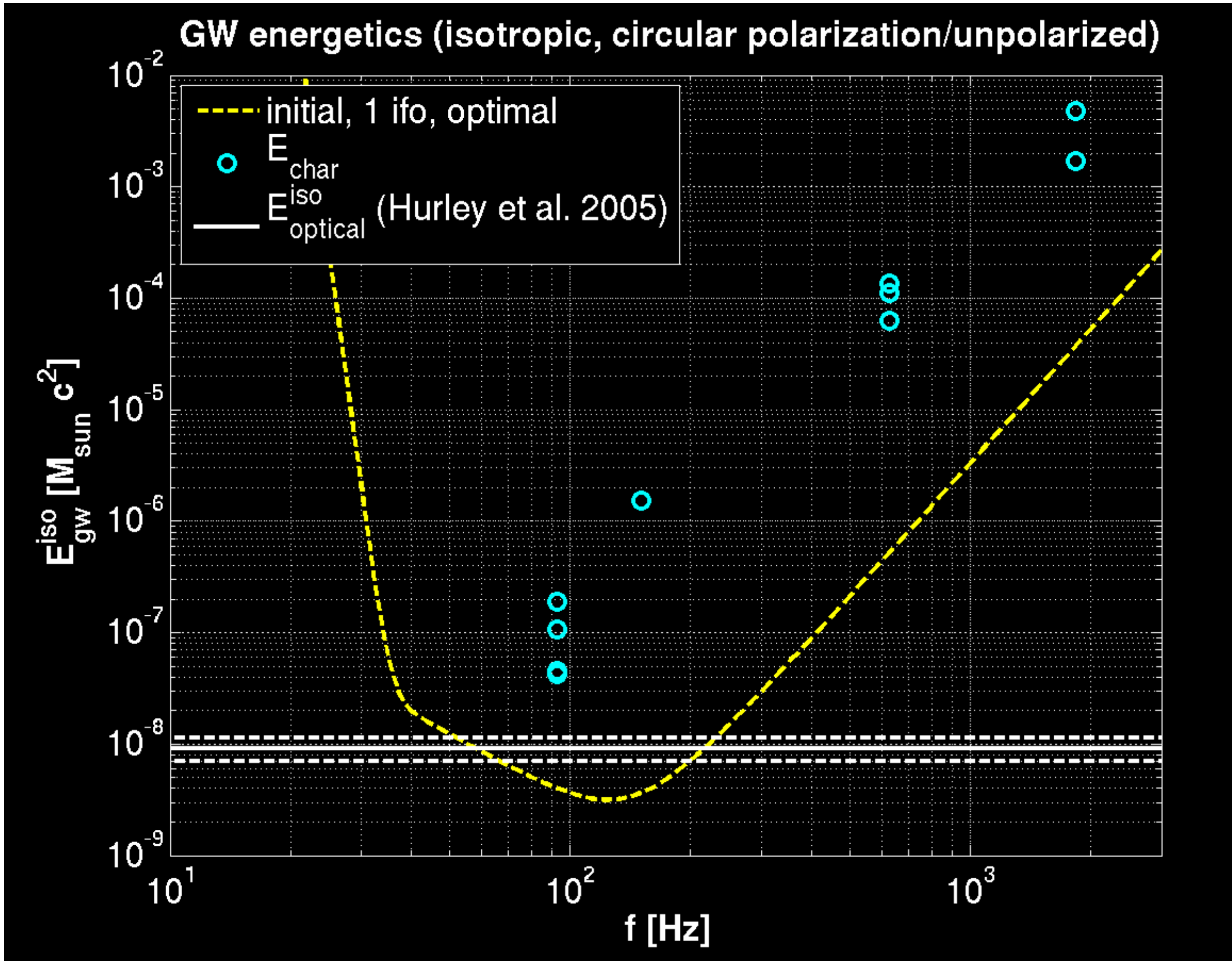
$h^{90\%}_{rss\text{-}det}$ = 9.50 x 10^{-22} strain/rHz



[1] G.Israel et al, *ApJ* **628** L53 (2005)
[2] A.Watts and T.Strohmayer, *ApJ* **637** L117 (2006)
[3] T.Strohmayer and A.Watts, *ApJ* **653** L594 (2006)

Gravitational Wave Energetics – SGR1806-20 Hyperflare

- For the 92.5Hz QPO observation (150s-260s)
  - » $E^{iso,90\%} = 4.3 \times 10^{-8}\ M_{sun}c^2$
- This energy is comparable to the energy released by the flare in the electromagnetic spectrum



- Assuming
  - » Isotropic emission
  - » Equal amount of power in both polarization (circular/unpolarized)
- $E^{iso,\ 90\%}$ is a characteristic energy radiated in the duration and frequency band we searched

Results – SGR1806-20 Hyperflare

- Excess energy algorithm
  - » Designed to search for tens of seconds long narrow band signals
  - » Estimated the search sensitivity using software injections
- Upper bounds on the GW strength associated to the observed QPOs
  - » Best limit for the 92.5 Hz QPO (which corresponds to the 150s - 260s interval)
    - – $h_{rss\text{-}det} = 4.5 \times 10^{-22}$ strain/rHz
  - » Characteristic energy (isotropic, equal power in both polarization states)
    - – $E^{\text{iso, 90\%}} = 4.3 \times 10^{-8} M_{\text{sun}} c^2$
    - – comparable to the emitted energy in the electromagnetic spectrum
- Next step:
  - » address flares from SGR 1806-20 and SGR 1900+14 during the fifth science run (S5)
  - » strain equivalent noise improvement (~3x at 150 Hz)
  - » exploiting multiple data streams (cross-correlation)

Astrophysical observation based search for association between gravitational waves and short hard GRBs (in the context of compact binary inspirals)

EM Observations - GRB 070201

detected by Konus-Wind, INTEGRAL, Swift, MESSENGER

- Described as an *"intense short hard GRB"* (GCN 6088)
- Duration ~0.15 seconds, followed by a weaker, softer pulse with duration ~0.08 seconds
- R.A. = 11.089 deg,
  Dec = 42.308 deg,
  error = 0.325 sq. deg

Antenna responses of LIGO Hanford:

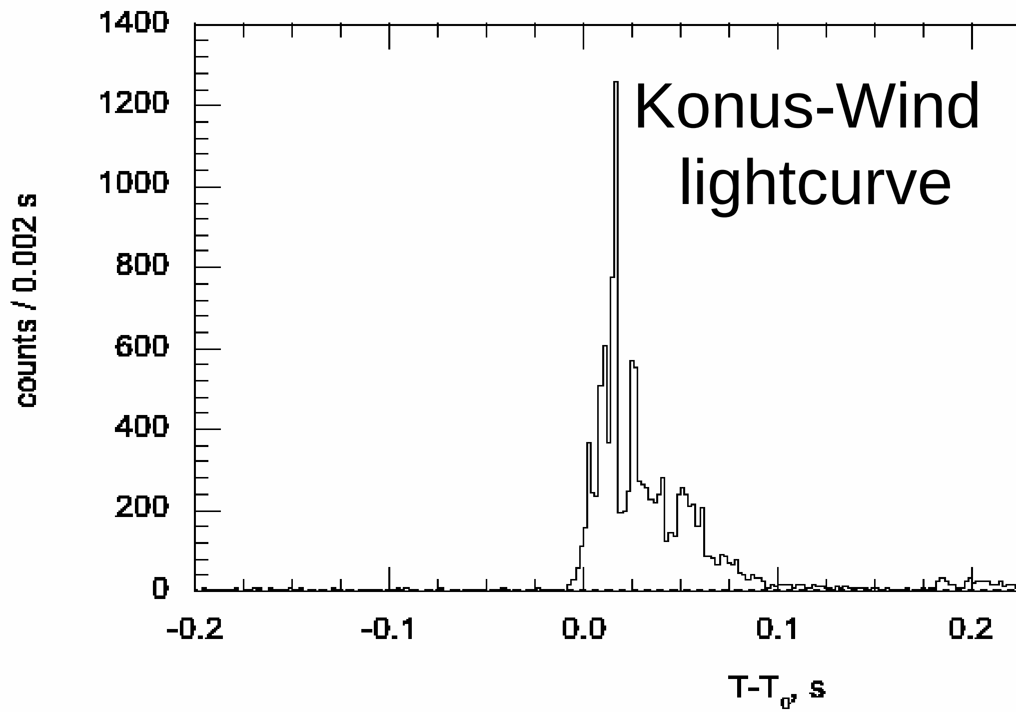
$$F_{RMS} = \sqrt{F_+^2 + F_\times^2} / \sqrt{2} = 0.304$$

$$h(t) = F_+(\theta,\phi,\psi)h_+(t) + F_\times(\theta,\phi,\psi)h_\times(t)$$

$E_{iso} \sim 10^{45}$ ergs

if at M31 distance

(more similar to SGR energy than GRB energy)

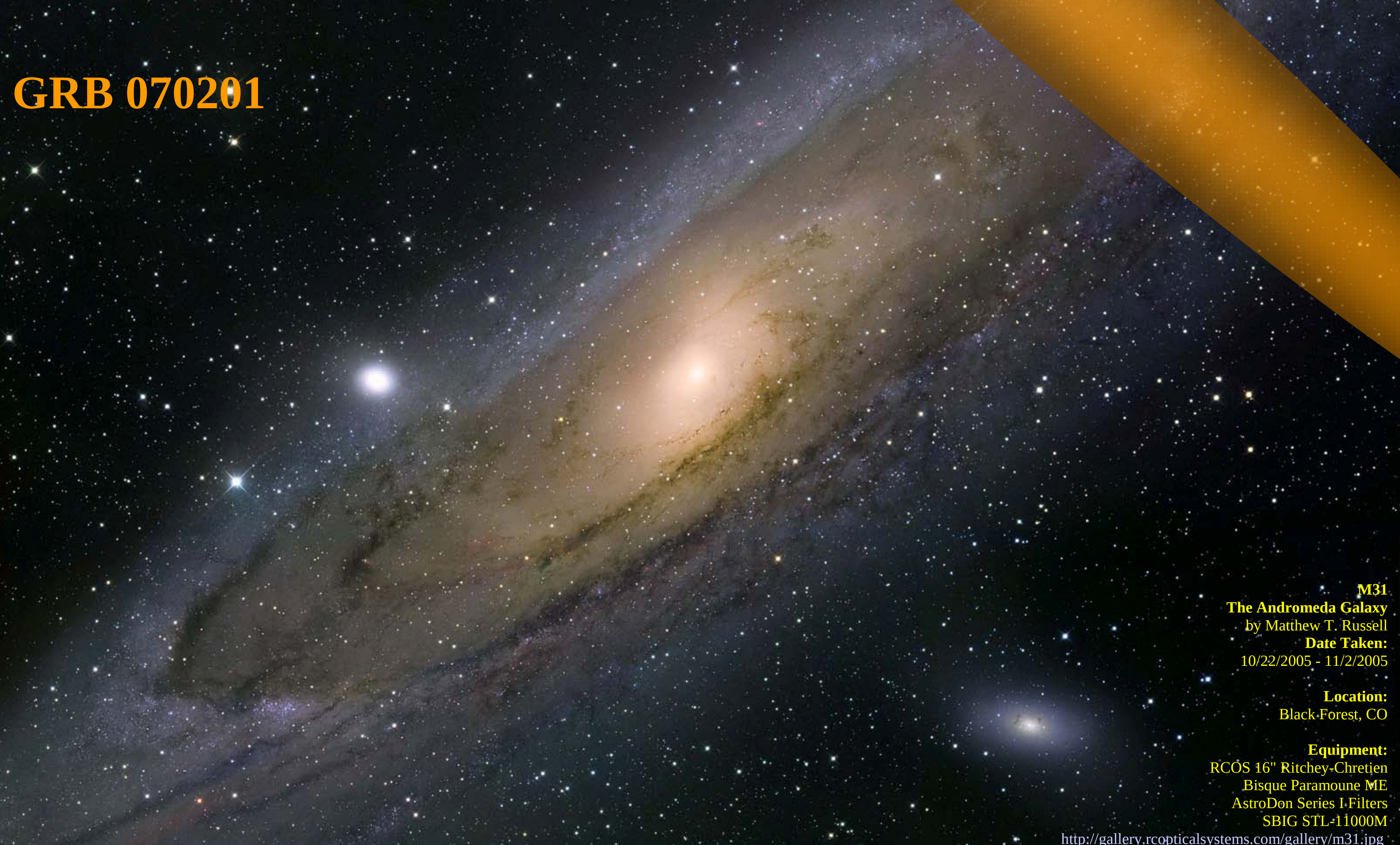


Refs:

GCN: http://gcn.gsfc.nasa.gov/gcn3/6103.gcn3

"…The error box area is 0.325 sq. deg. The center of the box is 1.1 degrees from the center of M31, and includes its spiral arms. This lends support to the idea that this exceptionally intense burst may have originated in that galaxy (Perley and Bloom, GCN 6091)…" from GCN6013

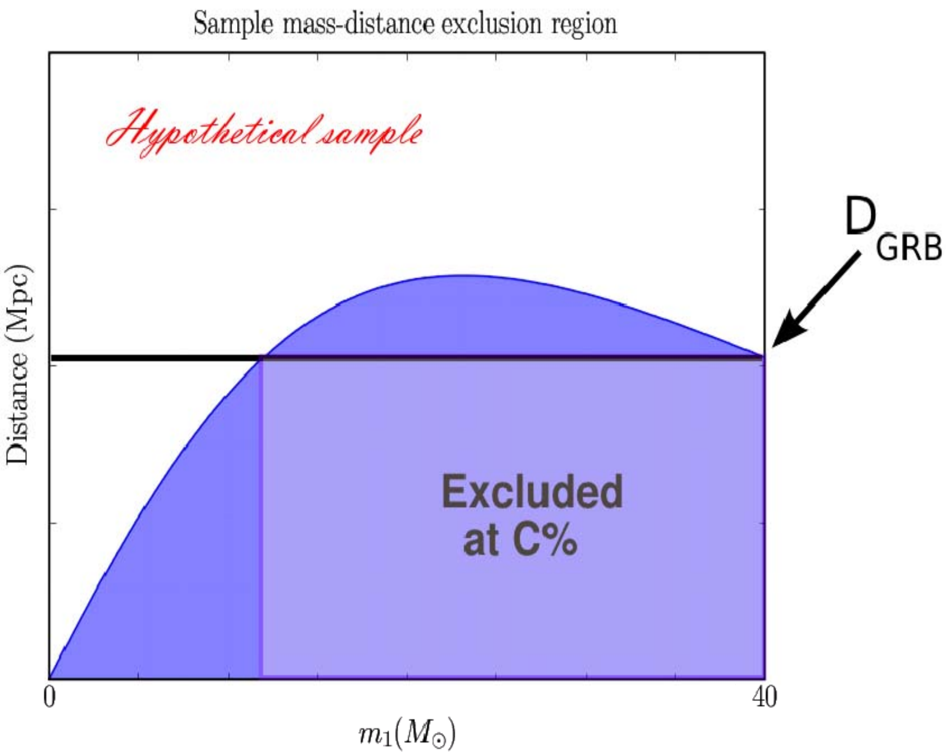
GRB 070201



What Can We Learn? - GRB 070201

- **In the case of a detection:**
  - » Confirmation of a progenitor (e.g. coalescing binary system)
  - » GW observation could determine the distance to the GRB

- No-detection:
  - – Exclude progenitor in mass-distance region
  - – With EM measured distance to hypothetical GRB, could exclude binary progenitor of various masses
  - – Possible statements on progenitor models
  - – Bound the GW energy emitted by a source M31



Search for compact binary inspirals - GRB 070201

- **LSC analyzed data around time of GRB070201 for compact binary inspiral**
  - Use non-spinning templates spanning

    $1\ M_\odot < m_1 < 3.0\ M_\odot$ & $1.0\ M_\odot < m_2 < 40.0\ M_\odot$.
  - Based on past experience, the search is also sensitive to binaries with spinning objects representative of astrophysical expectations.

- **No plausible gravitational waves from compact binary inspiral were identified**
  - Analysis used a preliminary calibration

Preliminary

Results - GRB070201 cont'd

- It is unlikely that a compact binary progenitor in M31 was responsible for GRB070201

- A paper is in preparation which will quantify these statements and present full results.
  - » In particular, issues relating to calibration, spin effects, and other systematic uncertainties are being addressed

Transient Search – GRB070201

$$h_{\mathrm{rss}} \equiv \sqrt{\int \left(|h_+(t)|^2 + |h_\times(t)|^2\right) dt}$$

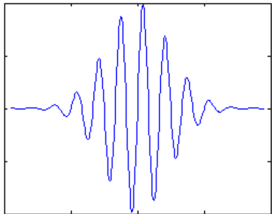
- Wide bandwidth:

  40 Hz to 2000 Hz
- **No detections were made**

- Sensitivity is around $h_{RSS}^{90\%} \approx 10^{-21}$ $1/\sqrt{\mathrm{Hz}}$ for the sensitive frequency range of LIGO

Preliminary

- Corresponds to $E_{ISO} \sim 10^{-4}$-10^{-3} $M_{\odot}c^2$ ($\sim 10^{50}$ - 10^{51} ergs) energy emitted in gravitational waves at the distance of M31 within a ~100ms period
  - The achievable sensitivity with the present detectors does not exclude present models of SGRs at the M31 distance
    - (de Freitas Pacheco 1998; Ioka 2001a,b; Horvath 2005)



Conclusions

Astrophysical results from triggered searches for gravitational waves

- Search for short-duration gravitational-wave bursts (GWBs) coincident with GRBs using S2, S3 and S4 data from LIGO
  - » No detections
- SGR1806-20 hyperflare QPO search
  - » No detection
  - » Limits: comparable to the emitted energy in the electromagnetic spectrum
- Search for gravitational-waves coincident with GRB070201
  - » No plausible gravitational waves from compact binary inspiral or short transients were identified that could be related to GRB070201 and inconsistent with the noise
  - » The achievable sensitivity with the present detectors does not exclude present models of SGRs at the M31 distance
  - » It is unlikely that a compact binary progenitor in M31 was responsible for GRB070201
  - » A paper on the GRB070201 search is in preparation which will quantify these statements and present full results

…and the future is bright…