GRAVITATIONAL WAVES from SGR BURSTS

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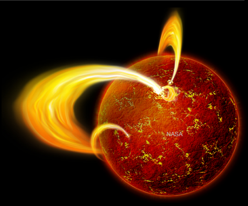
SGRs & AXPs: Magnetars

Soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs) sporadically emit short bursts of soft γ-rays with peak luminosities commonly up to 10^{42} erg/s [1]. Rare giant flare events, 10^3–10^4 times brighter, are among the most luminous events in the Universe [1]. 3 of 5 known galactic SGRs have each produced a giant flare.



SGRs are promising gravitational wave (GW) sources. In the "magnetar" model SGRs are neutron stars (NS) with exceptionally strong magnetic fields, 10^{15} G [2]. SGR bursts may result from the interaction of the field with the solid NS crust, leading to crustal deformations and catastrophic cracking [3] with potential excitation of the star's nonradial GW-damped f-modes [4].

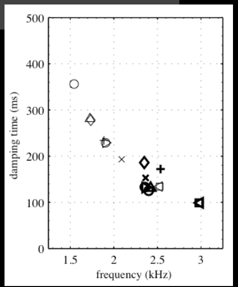
The Searches

EM burst trigger times provided by IPN satellites
Analysis performed with Flare pipeline [5,6]
We target three frequency bands in GW data:

- 1 to 3 kHz where f-modes live
- 100 to 200 Hz max detector sensitivity
- 100 to 1000 Hz for full coverage

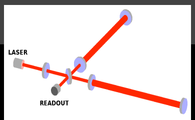
We use ±2 s signal regions in GW data. This assumes GW burst occurs within ±0.5 s of EM burst. Loudest signal-region events are compared to background to estimate detection significance.

We set loudest event upper limits on (isotropic) GW energy at 90% detection efficiency using: circularly and linearly polarized ringdowns (RDC, RDL) in 1 to 3 kHz region; white noise burst (WNB) waveforms at low frequencies.



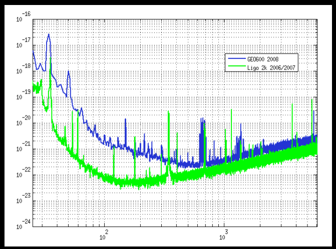
Predicted f-mode time constants and frequencies, for a variety of NS masses and equations of state, from [7]. Figure from [8].

The GW Interferometers



LEFT: LIGO had two GW detectors in Washington with baselines of 4 km and 2 km and one 4 km detector in Louisiana; the 2 km detector was recently decommissioned in preparation for Advanced LIGO. Virgo has a 3 km detector near Pisa. GEO has a 600 m detector in Germany.

BELOW RIGHT: GEO and LIGO 2 km noise curves.

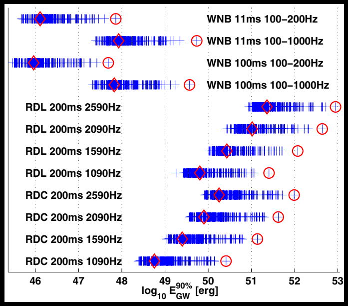


First Search: Giant Flare + 189 small flares

Abbott et al. PRL 101, 211102 (2008)
No detection.
E_{GW} upper limits shown at right (10 kpc nominal distance, isotropic)
190 bursts from SGRs 1900+14 and 1806-20 (1st year of LIGO's 5th science run, or "S5y1")

Includes pre-S5 2004 **SGR 1806 giant flare** (red circles) and "GRB" 060806 from SGR 1806 (diamonds)

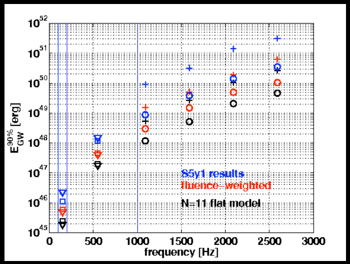
Best f-mode upper limit of **2×10^{48} erg**
Best f-mode upper limit on **$\gamma \equiv E_{GW} / E_{EM}$ is 2×10^4** (giant flare).



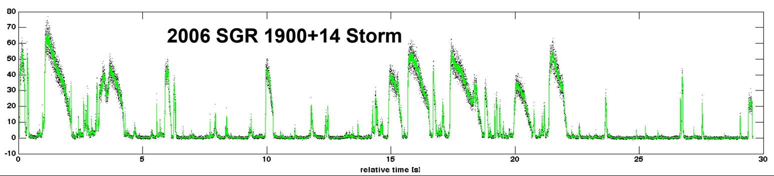
Stacked Search: SGR 1900+1Storm

Abbott et al. ApJ 701, L68-L74 (2009)
No detection.
Storm was analyzed as single event in first search.
GW data near individual EM bursts were stacked (time-aligned) according to rising edges of EM bursts. Two stackings were used: 1) the 11 most EM-energetic bursts; 2) all bursts weighted according to EM-energy.

We assume variation in delay between GW and EM emission is small compared to GW burst signal duration.



Stacking gave **12x sensitivity gain.** Best f-mode upper limit of **10^{48} erg.**



GW Emission Models

Little has been said about GW emission from magnetars. In Ioka's model [10] which may be the most detailed:

- $\gamma \equiv E_{GW} / E_{EM} = 10^4$ not unreasonable
- $E_{GW} = 10^{49}$ erg not unreasonable

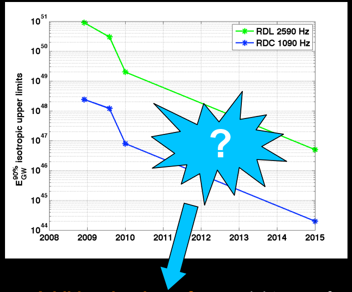
Our upper limits begin to enter this region.

We expect new predictions on GW amplitudes in 2010. Two of us (P. Kalmus and C. Ott) are using numerical GR models to do so.

Future Searches

Advanced LIGO is expected to give an addition 100x in energy sensitivity beginning in 2015.

f-mode upper limits from 800 pc could then be as low as **10^{44} erg**. Will it be enough for detection?

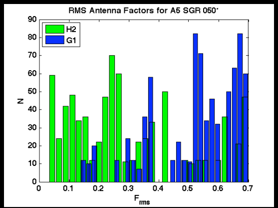


Additional orders of mag might come from:

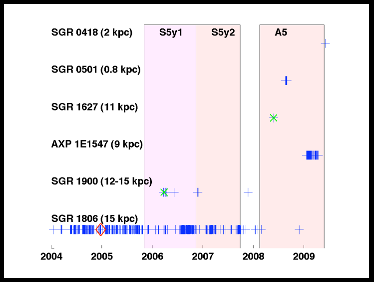
- SGR @ 250 pc or less
- stacking SGR 0501 bursts
- clever new methods

Ongoing: Recent bursts including nearby SGR 0501+4516

Bursts from 6 magnetars, during the 2nd year of LIGO's 5th science run (S5y2) and Astrowatch commissioning period (A5). **SGR 0501+4516** (discovered 2009) is likely **800 pc from Earth** [9]. We thus expect **E_{GW} limits at least 10x lower** than before.



ABOVE: Antenna geometry during SGR 0501 bursts was more favorable for GEO than for LIGO 2 km.



LEFT: Magnetar bursts 2004 thru 2009. Red diamond is giant flare; green stars are storms.

References

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