Search for Gravitational Waves from Soft Gamma Repeaters

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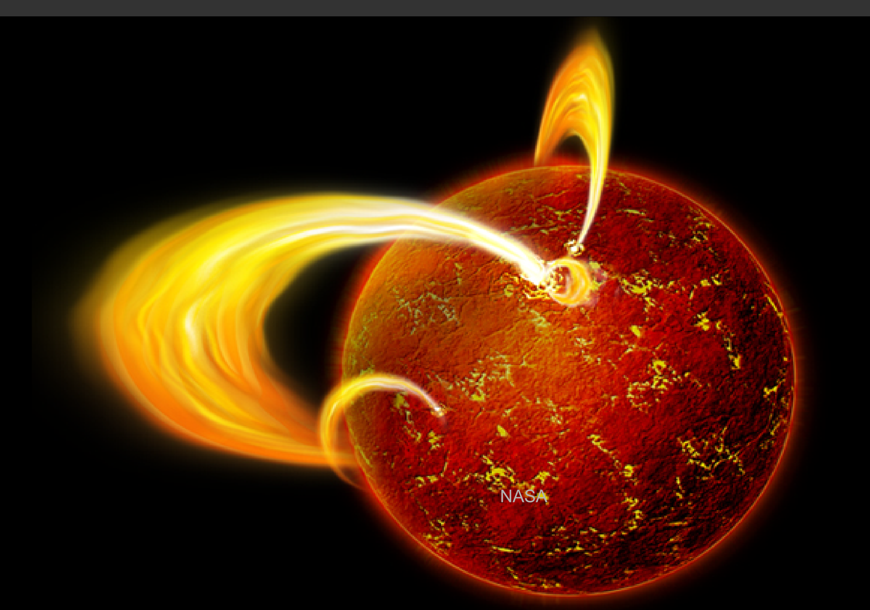
SGRs & AXPs: Magnetars

Soft gamma repeaters (SGRs) and anomalous X-ray pulsars (AXPs) sporadically emit short bursts of soft gamma 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.



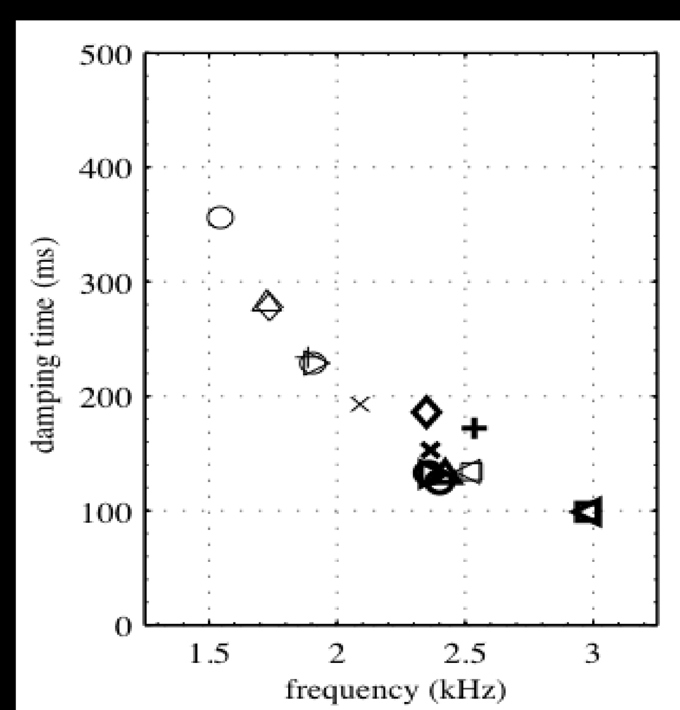
SGRs are promising gravitational wave (GW) sources. In the "magnetar" model SGRs are neutron stars (NS) with exceptionally strong magnetic fields, 10^{15} G [2]. SGR bursts may result from the interaction of the field with the solid NS crust, leading to crustal deformations and catastrophic cracking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

Prompt Searches

Analysis is performed with the Flare pipeline [5,6] in ±2 s GW data signal regions around burst trigger times provided by IPN satellites. We assume GW bursts occur within ±0.5 s of EM burst. Loudest signal region events are compared to the background to estimate detection significance.

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 set loudest event upper limits on (isotropic) GW energy at 90% detection efficiency using 1) circularly and linearly polarized ringdowns (RDC, RDL) in the 1 to 3 kHz region; and 2) 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].)

QPO Searches

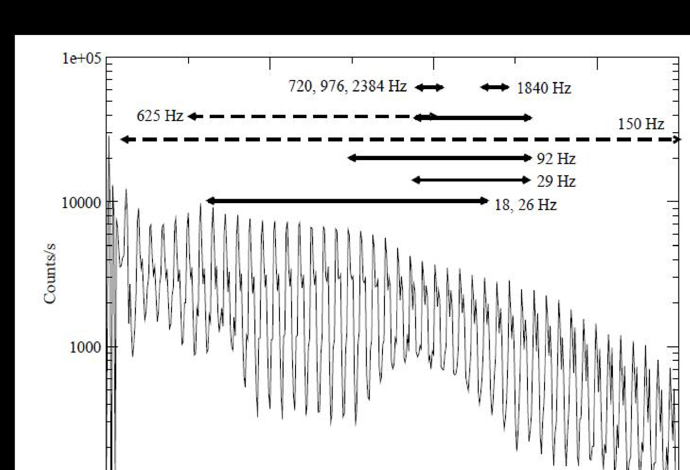
Quasi-periodic oscillations (QPO's) have been observed in the tails of the light curves of the August 1998 SGR 1900+14 and December 2004 SGR 1806-20 hyperflares [12], and may characterize the emitted GW radiation. S5 LIGO data available for over 250 flares will be analyzed.

Our analysis will extend a previously developed search algorithm targeting long duration, narrow-band transients [11] that has been used to analyze the 2004 SGR 1806-20 hyperflare [12]. We will perform an on-source measurement by computing the difference between excess energy summed in 300 s intervals beginning (or ending) at 5 s after (before) an observed flare. Off-source measurements will be performed analogously on background stretches. On-source and off-source distributions will be generated by analyzing all H1-L1 coincident data from S5, and then compared to estimate detection significance.

We will target 92.5 Hz and 84.0 Hz as the QPO bands for SGR 1806-20 and SGR 1900+14, respectively. Upper limits will be established using a 1.28σ detection significance.

LIGO Source	1806-20	1900+14
Triple Coincident	106	43
H1L1 Coincident	9	1
H1H2 Coincident	48	10
H2L1 Coincident	5	0
H1 only data	2	2
H2 only data	7	1
L1 only data	7	0
No Data	20	1
Total	204	58

Approximate number of flares and detector status (S5) [6].



QPO observed during the 2004 SGR 1806-20 hyperflare [13].

GW Emission Models

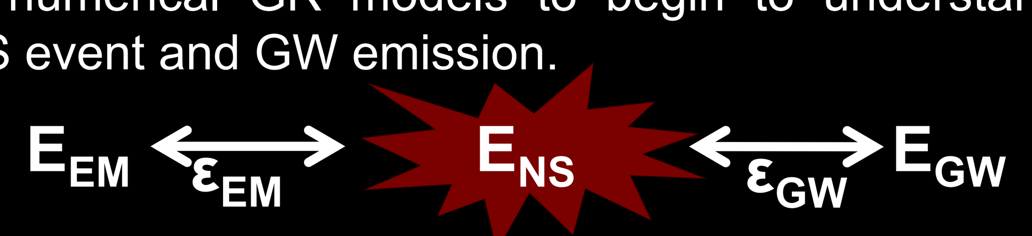
Little has been said about GW emission from magnetars. In Ioka's model [10] which may be the most detailed:

$\gamma \equiv E_{GW} / E_{EM} = 10^4$ possible in the most extreme case

$E_{GW} = 10^{49}$ erg possible in the most extreme case

Our upper limits begin to enter this region.

We expect new results on GW amplitudes in 2010. [14] made significant theoretical progress and it promises directly addressable predictions. Ongoing work[15] uses numerical GR models to begin to understand the relationships between the NS event and GW emission.



REFERENCES

1. P. M. Woods and C. Thompson, in Compact Stellar X-Ray Sources, ed. W. G. H. Lewin and M. van der Klis (Cambridge University, Cambridge, 2004).
2. R. C. Duncan and C. Thompson, Astrophys. J. Lett. 392, L9 (1992).
3. C. Thompson and R. C. Duncan, Mon. Not. R. Astron.Soc. 275, 255 (1995).
4. N. Andersson and K. D. Kokkotas, MNRAS. 299, 1059 (1998).
5. P. Kalmus et al., Class. Quant. Grav. 24, S659 (2007)
6. P. Kalmus, Ph.D. thesis, Columbia University, 2008. arXiv:0904.4394.
7. O. Benhar, V. Ferrari, and L. Gualtieri, Phys. Rev. D 70,124015 (2004).
8. J. Clark et al. Phys. Rev. D 76, 043003 (2007).
9. Leahy and Tian A&A 461, 1013–1018 (2007)
10. K. Ioka, Mon. Not. R. Astron. Soc. 327, 639 (2001).
11. L. Matone and S. Marka, Class. Quant. Grav. 24, S649657 (2007).
12. B. Abbott et al., Phys. Rev. D 76, 062003 (2007).
13. T. Strohmayer and A. Watts, Astrophys. J. 653, 593 (2006).
14. A. Corsi and B. Owen, LIGO-T0900242 and VIR-NOT-ROM-028A-09
15. P. Kalmus and C. Ott, LIGO-G1000046

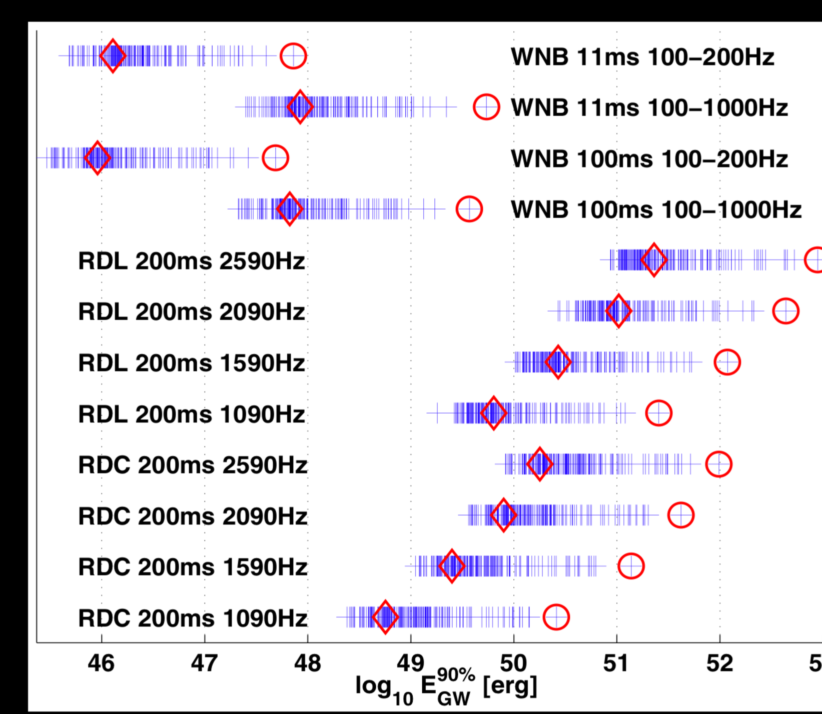
Prompt Search Results

Search included the 2004 **SGR 1806-20 giant flare** (red circles), "GRB" 060806 from SGR 1806-20 (diamonds), and common bursts from SGRs 1900+14 and 1806-20, and the SGR 1900+14 storm (see lightcurve below) .

E_{GW} upper limits for twelve waveforms in the three search bands are shown at right (10 kpc nominal distance, isotropic emission).

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

Abbott et al. PRL 101, 211102 (2008)
No detection.



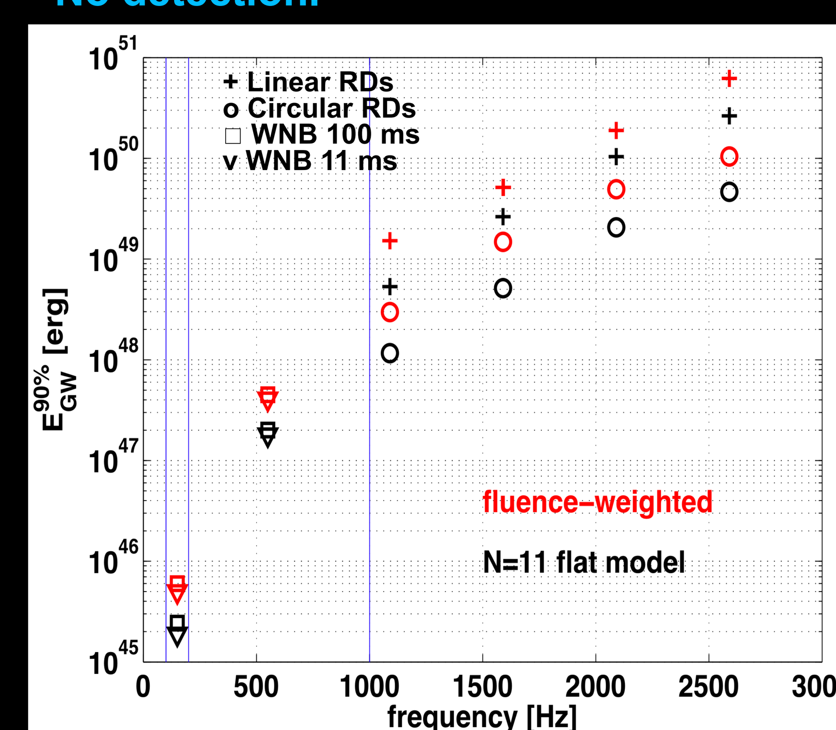
Stacking SGR 1900+14 Storm
(extension of the original prompt search)

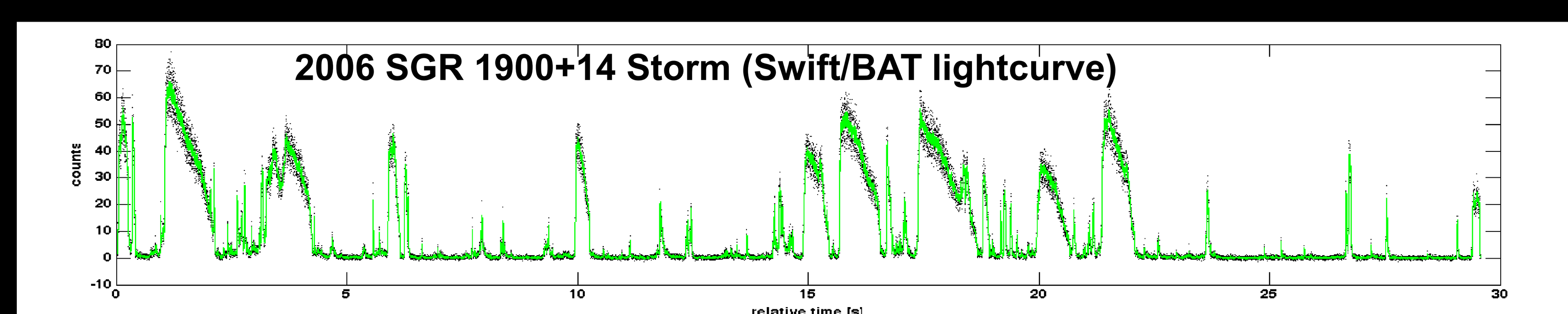
GW data near individual EM bursts were stacked (time-aligned) according to rising edges of EM bursts. Two stacking models were used: 1) the 11 most EM-energetic bursts; 2) all bursts weighted according to EM fluence ("fluence-weighted").

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

Stacking gave **12x sensitivity gain** (N=11 flat model).
Best f-mode upper limit of **10^{48} erg.**

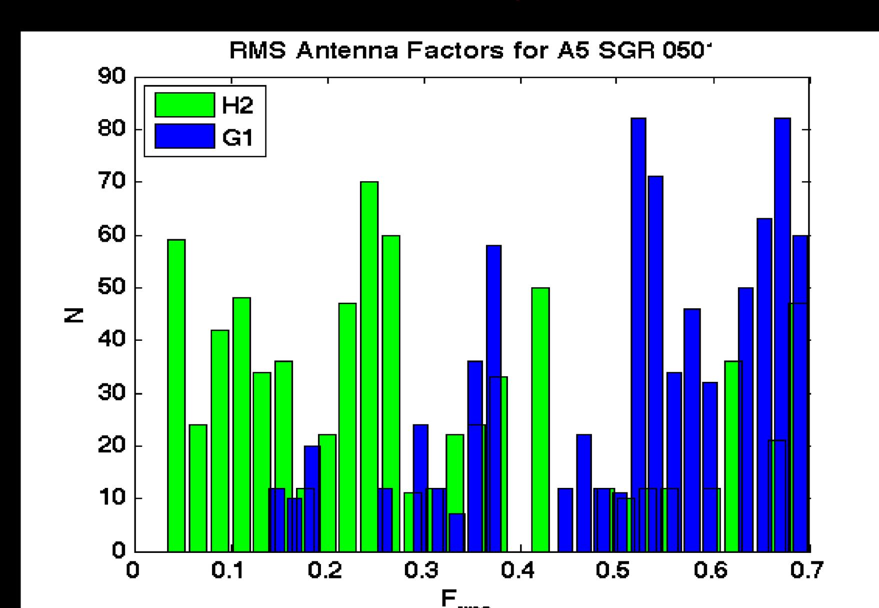
Abbott et al. ApJ 701, L68-L74 (2009)
No detection.



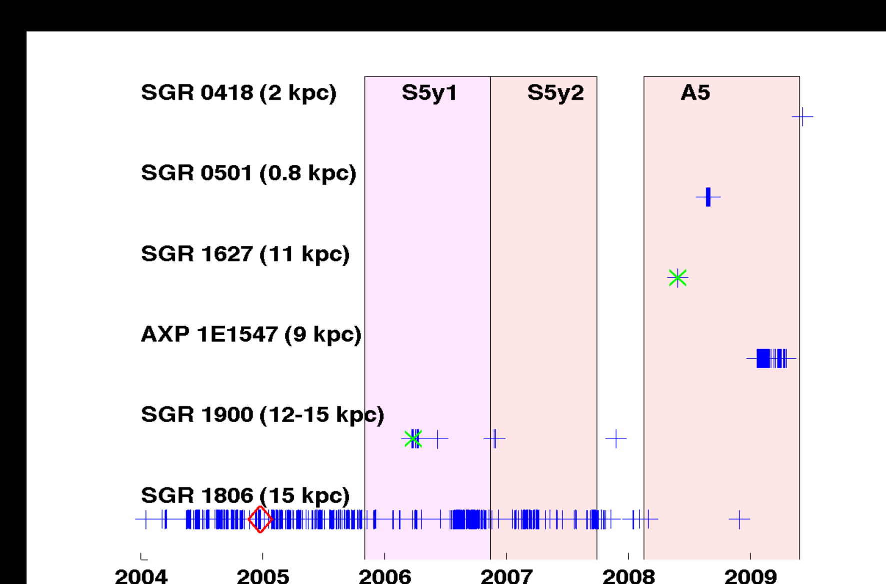


Ongoing Prompt Searches:
Recent bursts including nearby SGR 0501+4516

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



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



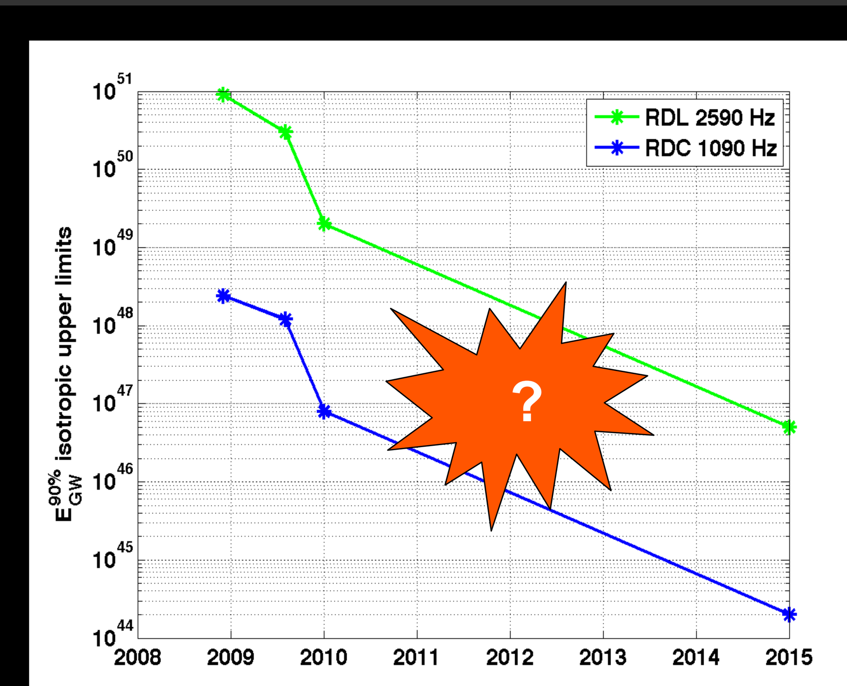
Magnetar bursts 2004 through 2009.
Red diamond – giant flare
green stars – storms

Future Searches

Advanced LIGO and Advanced Virgo are expected to give an additional 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 magnitude might come from:
- -SGR @ 250 pc or less
- -stacking SGR0501 bursts
- -new and clever methods



We are also working to develop an online version of the Flare pipeline that will enable us to perform automated low-latency multi-messenger searches of GRBs and SGRs. Online Flare will substantially reduce the delay between trigger detection and GW data analysis results.

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