Search for Gravitational Wave Radiation Associated with the Pulsating Tail of the SGR 1806-20 Hyperflare of December 27, 2004 using LIGO

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The 2004 Indian Ocean Earthquake

- Sumatra - Andaman Earthquake (December 26th, 2004)
- Spectra of seismographic data (Canberra, Australia)
- Event delivered a blow to our planet causing it to ring like a bell for weeks
- Computed from 240 hours of data

The SGR 1806-20 hyperflare of December 27, 2004

- The Soft Gamma-Ray Repeater SGR 1806-20 emits a record flare
- \(d \sim 6 - 15 \text{ kpc}\), energy released by flare: \(\sim 10^{46}\text{ergs}\);
- pulsating tail lasting six minutes is observed
  - pulsating frequency: neutron star rotation period (7.56s)
  - all three giant flares (March 1979, August 1998 and December 2004) have shown pulsating tails

RHESSI X-ray lightcurve (25 – 100 keV band)

Magnetar Model and Objective of the Analysis

- Magnetar model, NS with intense magnetic field
- energy release -> crust / magnetic field catastrophic re-arrangement (starquake)
- QPOs observed (~20Hz-2kHz)
  » measured with RXTE and RHESSI
  » similar phenomenology in SGR 1900+14
- Assuming QPOs are mechanically driven
  » measure GW radiation associated to periods and frequency of the observations
- This talk: preliminary results for the 92.5Hz QPO using a 10Hz bandwidth

X-ray lightcurve

Overview of the Analysis

- **post-S3, pre-S4** *(Astrowatch program)*
  - H1 only at the time of the event

- Looking for tens-of-seconds long signals
  - narrow band
  - veto data corresponding to short glitches
  - unknown frequency content and evolution BUT QPO bandwidth is measured

- Search algorithm
  - provides a constant sensitivity over plausible phase space
Conditioning (I) Filtering

- Bandpassing data
  - 92.5Hz (band containing the putative GW signature)
  - 82.5Hz and 102.5Hz (for noise rejection)
  - bandwidths = 10Hz
Conditioning (II)
Data Quality Flag

Power in 1s long segments vs. time

Identify fast signatures (glitches)
- Calculate segment power (<1s)
- Place threshold and generate veto

Configuration file
- Data selection
  - On-source data
  - Off-source data
  - Simulated data
- Injections
- Conditioned
- Search algorithm
  - On-source excess
  - Off-source excess
- Sensitivity
- Upper Limit / Detection

Power [AU]

Time [s]

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Search Algorithm

- Measure power in three bands
- Determine excess power $\Delta P$
  - $\Delta P = P_{qpo} - P_{avg}$
  - sensitivity increase (common mode rejection)

Configuration file

Data selection

Injections

On-source data

Off-source data

Simulated data

Conditioning

Search algorithm

On-source excess

Off-source excess

Sensitivity

Upper Limit / Detection

Search Sensitivity

- Determine sensitivity via waveform injections
- Define injected waveform strength $h_{\text{rss-det}}^{\text{inj}}$:

$$h_{\text{rss-det}}^{\text{inj}} = \sqrt{\int_{-\infty}^{+\infty} |h(t)|^2 \, dt}$$

- Define search sensitivity
  » as the injected $h_{\text{rss-det}}^{\text{inj}}$ such that 90% of the measured energy ($h_{\text{rss-det}}^2$) is above the background median

Injected $h_{\text{rss-det}}^{\text{inj}} = 5.07e-22$ strain/Hz

Background with injections

Background median

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Search sensitivity for the 92.5Hz QPO observed from 170s to 220s after the beginning of the flare.

Search bandwidth set to 10Hz centered on 92.5Hz.
Sensitivity vs. Sine-Gaussian quality factor

Off-Source Injections – SG

$h_{\text{rss-det}}^{\text{inj}}$ [strain/rHz] vs. $Q$

- 125ms, $4\sigma$
- 125ms, $3\sigma$
- 125ms, $2\sigma$
- 5.1005e-22
Off-Source Injections – PM

Sensitivity vs. Phase Modulation Depth (Modulation frequency = 100mHz)

$\left| h_{\text{rss-det}}^{\text{inj}} \right| \times 10^{-22}$ vs. Modulation Depth [Hz$_{\text{peak}}$]

- 125ms, 4σ
- 125ms, 3σ
- 125ms, 2σ
- 5.1005e-22

$\left| h_{\text{rss-det}}^{\text{inj}} \right|$ [strain/Hz]
On-source preliminary results for the 92.5Hz QPO
On-source (92.5Hz QPO)

- No significant departure from background – no GW detection
- Placing Feldman-Cousins 90% UB $h_{\text{rss-det}}^{90\%}$

\[
\begin{align*}
  h_{\text{rss-det}}^{90\%} &= 9.50 \times 10^{-22} \text{ strain/rHz} \\
  h_{\text{rss-det}}^{90\%} &= 7.19 \times 10^{-22} \text{ strain/rHz} \\
  h_{\text{rss-det}}^{90\%} &= 4.67 \times 10^{-22} \text{ strain/rHz} \\
  h_{\text{rss-det}}^{90\%} &= 4.53 \times 10^{-22} \text{ strain/rHz}
\end{align*}
\]

On-Source: Sample Upper Limit


On-source: $-5.0 \times 10^{-2}$ sigmas, UL = [0.00000e+00, 5.15116e-22] strain/Hz

Data
Normal fit
On-Source

N. of events

C.D.F

Measured Energy $h^2_{rss-det}$
Detector strain-noise equivalent and 90% Upper Bounds

Preliminary
• Assuming
  » isotropic emission
  » equal amount of power in both polarizations (circular polarization/unpolarized)

• $E_{\text{gw}}^{\text{iso}}$ is a characteristic energy radiated in the duration and frequency band we searched from a source at a distance of 10kpc
  » $E_{\text{gw}}^{\text{iso}} = 4.3 \times 10^{-8} M_{\text{sun}} c^2$ for the 150-260s UB of $h_{\text{rss-det}}^{90\%} = 4.5 \times 10^{-22}$ strain/rHz
  » this energy ($7.7 \times 10^{46}$ erg) is comparable to the energy released by the flare in the electromagnetic spectrum ($1.6 \times 10^{46}$ erg (at 10kpc), K.Hurley et al., *Nature 434*, 1098 (2005))
Conclusion

• Developed a method, based on the excess power algorithm, designed to search for tens of seconds long narrow band signals

• Estimated the search sensitivity using software injections

• Preliminary results on the GW strength associated to the 92.5Hz QPO
  » best case: $h_{\text{rss-det}}^{90\%} = 4.5 \times 10^{-22}$ strain/rHz

• In terms of a characteristic energy (isotropic emission, equal amount of power in both polarization states)
  » $E_{gw}^{\text{iso}} = 4.3 \times 10^{-8} M_{\odot} c^2$ for the 150-260s UB of $h_{\text{rss-det}}^{90\%} = 4.5 \times 10^{-22}$ strain/rHz
  » comparable to the emitted energy in the electromagnetic spectrum

• Next step:
  » address other QPO frequencies along as well as their second harmonic
  » address flares from SGR 1806-20 and SGR 1900+14 during the fifth science run (S5)