Search for Gravitational Wave Radiation Associated with the SGR 1806-20 Hyper Flare

Luca Matone, for the LIGO Scientific Collaboration
Columbia University – GECo Group
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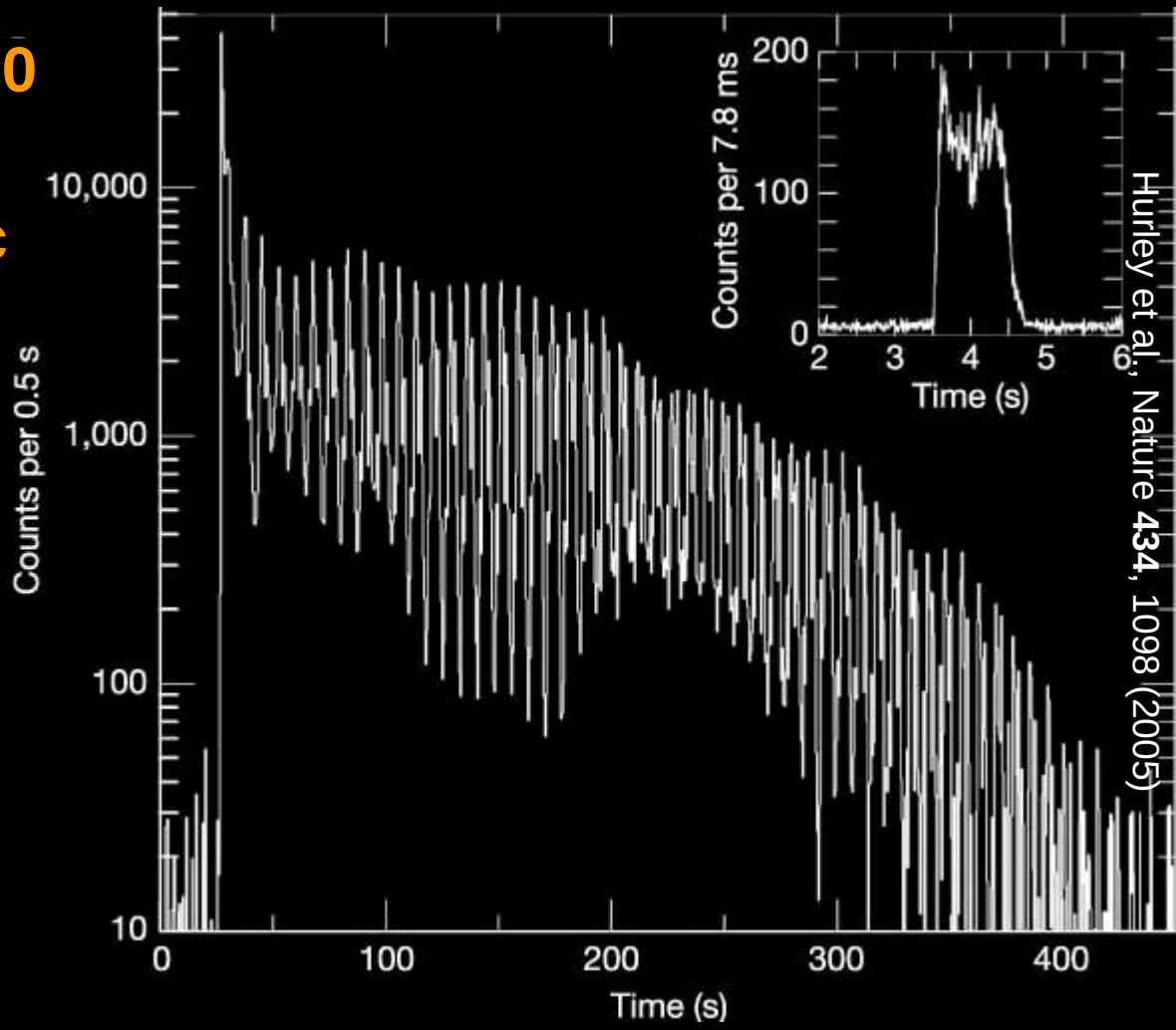
The SGR 1806-20 Hyper Flare of December 27, 2004

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

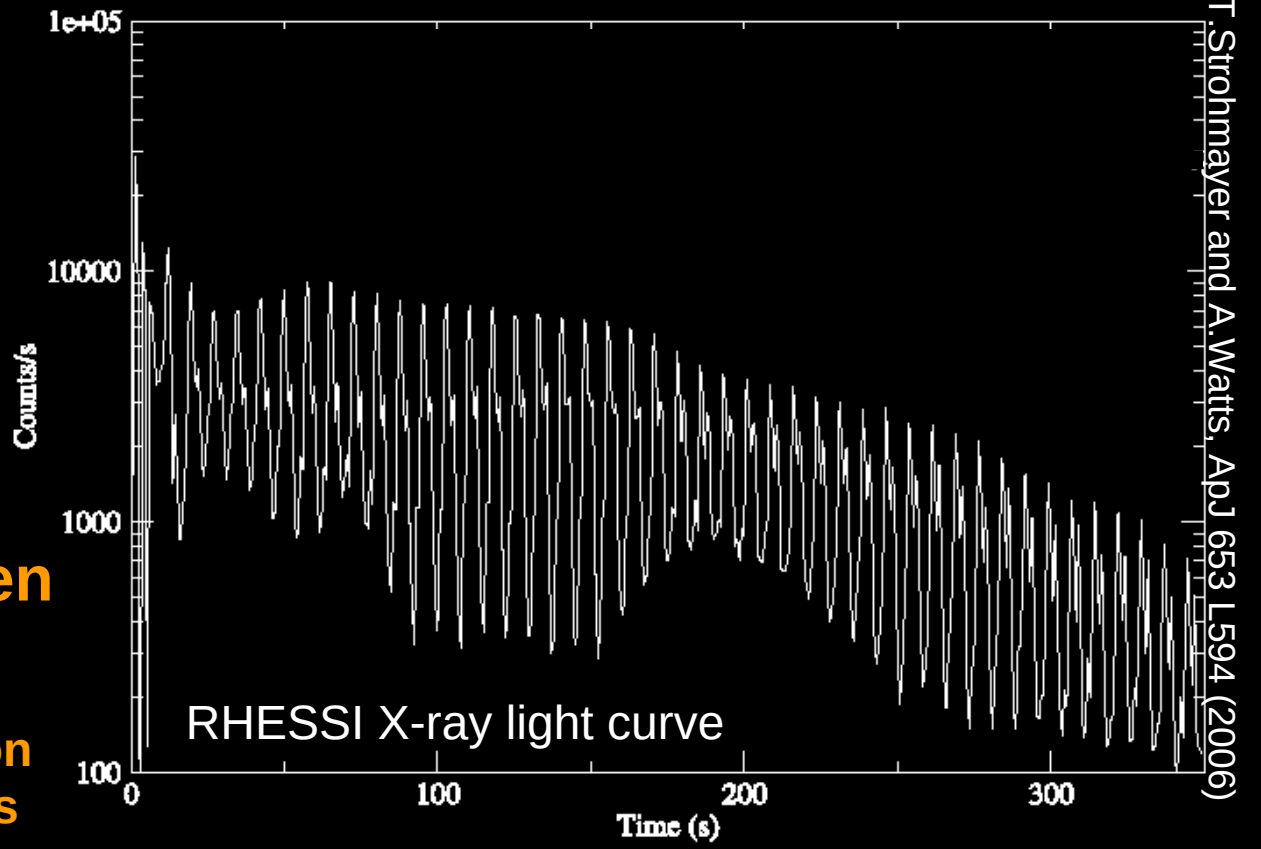
RHESSI X-ray light curve (20 -100 keV)



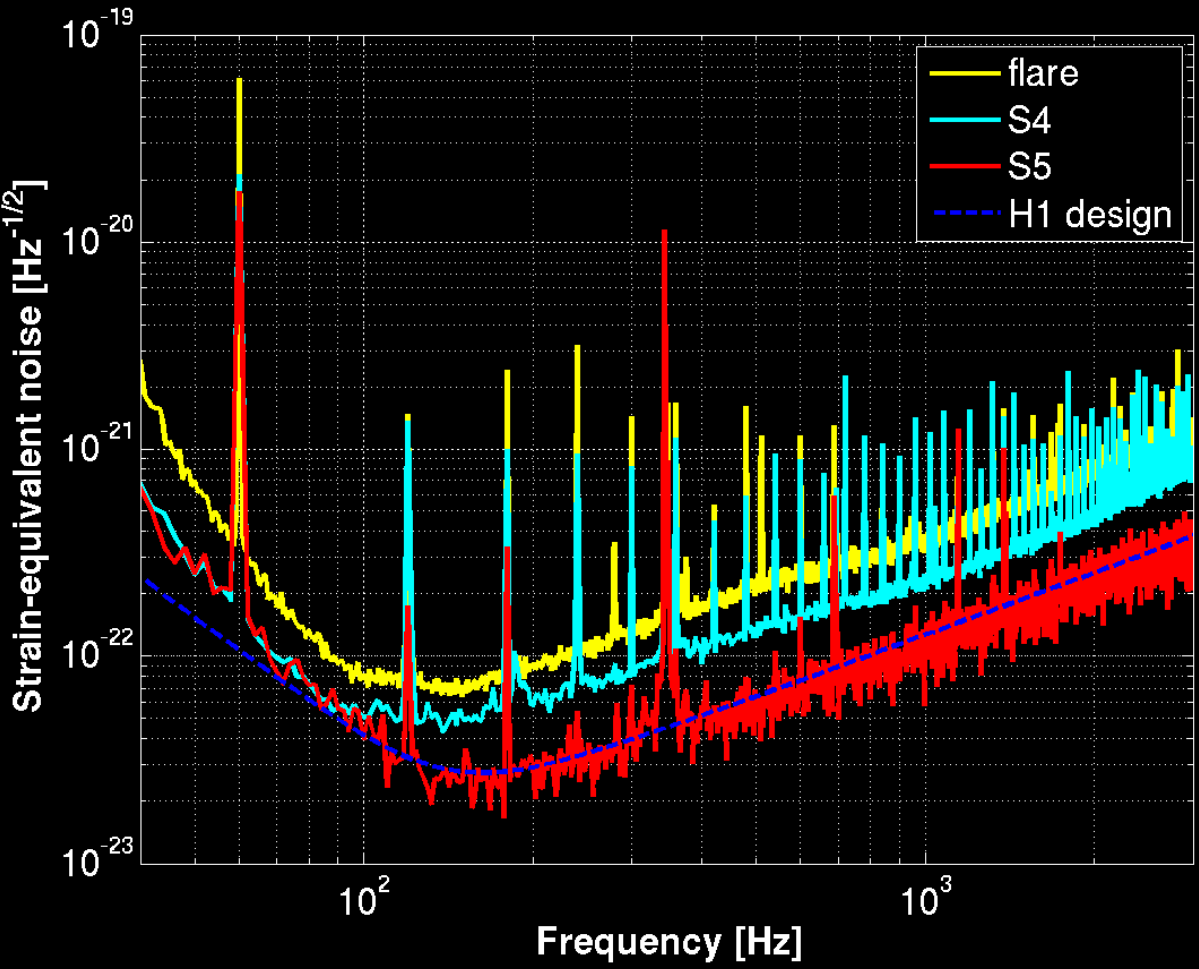
Hurley et al., Nature **434**, 1098 (2005)

Discovery of High Frequency QPOs and Search Objective

- **High Frequency QPOs (Israel et al. 2005, Watts & Strohmayer 2006)**
  - **RXTE and RHESSI**
  - **SGR 1900+14**
- **Plausibly mechanically driven**
- **Objective**
  - **Measure GW radiation associated to periods and frequency of observations**



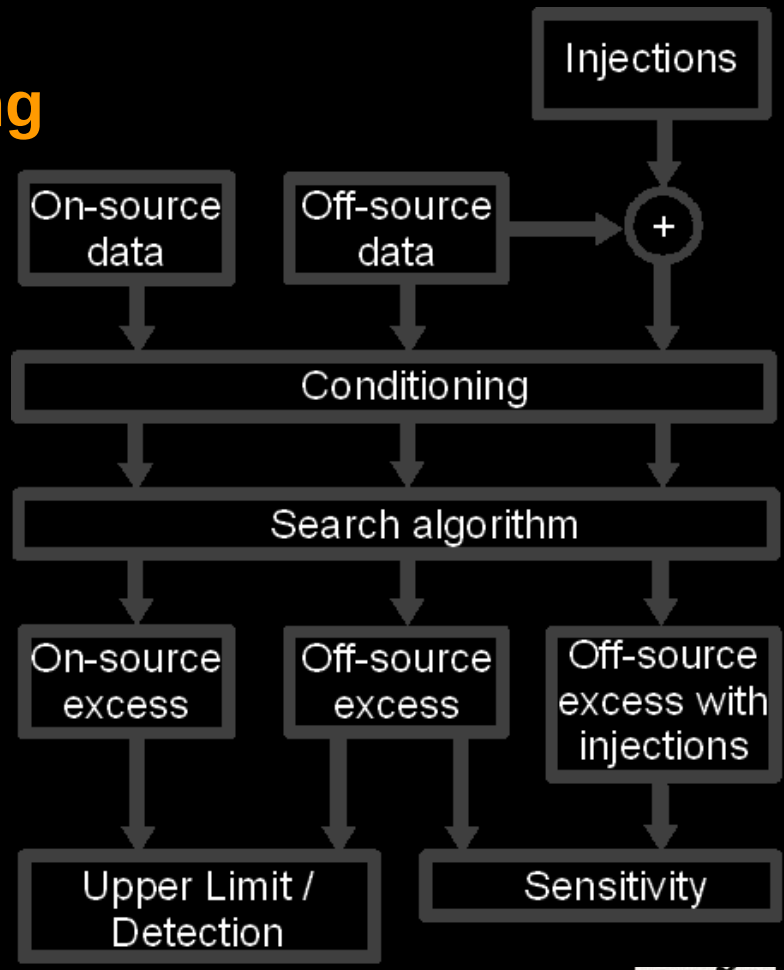
Detector Sensitivity



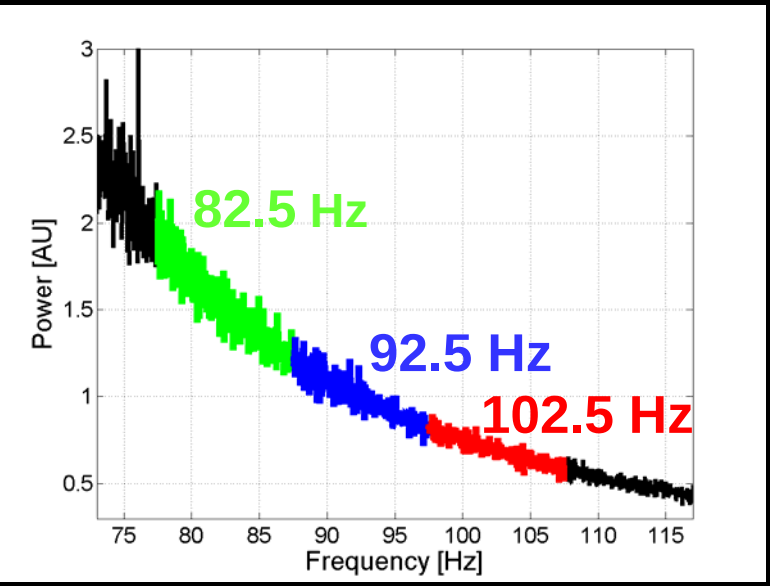
- **Epoch**
  - **Post-S3, pre-S4**
  - ***AstroWatch* program**
- **Single detector**
  - **H1: Hanford 4 km long interferometer**
- **Strain equivalent noise at 100 Hz**
  - **~9 x 10^{-23} strain/rHz**

Excess Energy Measure

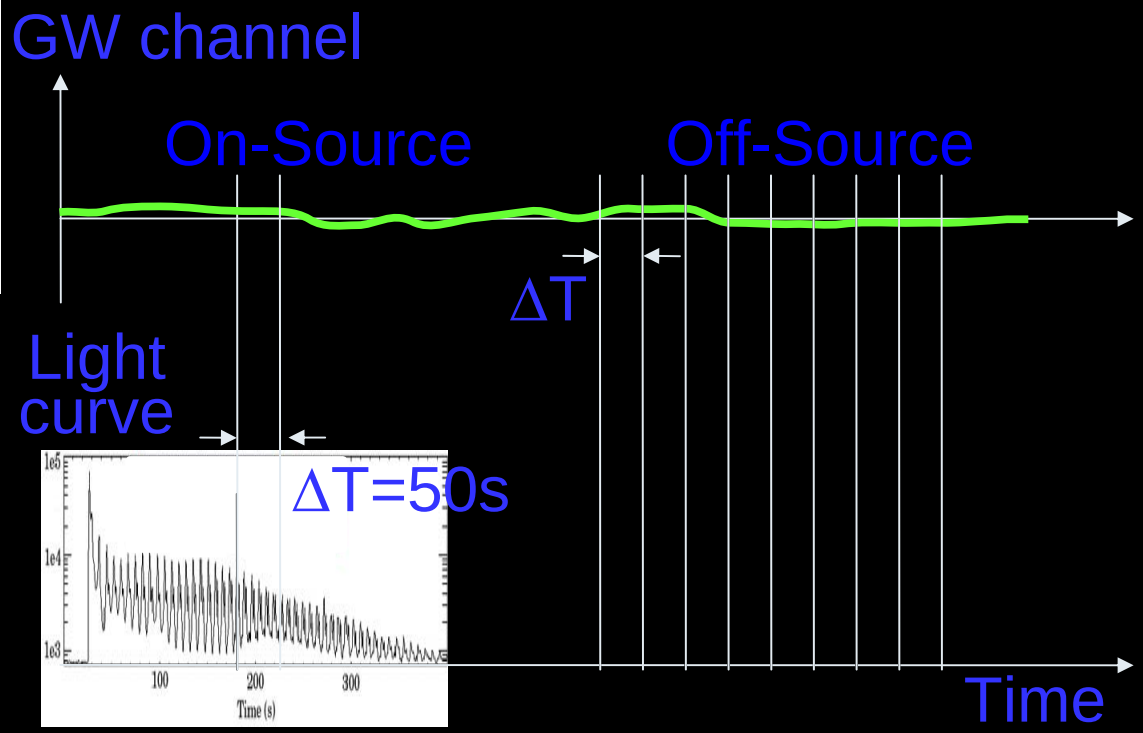
- **Search for tens-of-seconds long signals**
  - **Narrow band**
  - **Veto data corresponding to short duration glitches**
  - **Unknown frequency content and evolution**
  - **QPO frequency and bandwidth is measured**
- **Search algorithm**
  - **Provides a constant sensitivity over phase space**



Search Algorithm



- **Determine *excess* energy**
  - $\Delta E = E_{QPO} - E_{avg}$
  - **Common mode rejection**

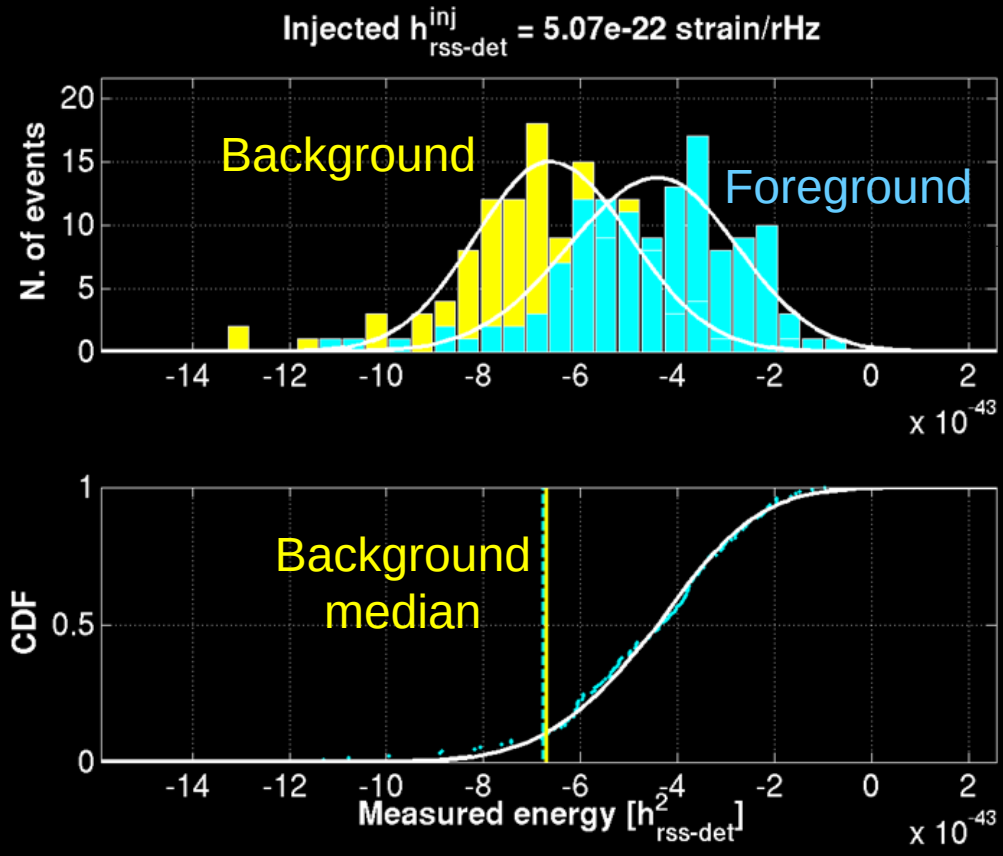


- **Measure signal energy in three adjacent frequency bands**

Search Sensitivity

- **Determine sensitivity via injections**
  - **Injected waveform strenght $h_{rss\text{-}det}$**
- **Sensitivity $h^{sens}_{rss\text{-}det}$**
  - **injected $h_{rss\text{-}det}$ such that 90% of the resulting ΔE is above background median**

$$h_{rss-det} = \sqrt{\int_{t_1}^{t_1+\Delta t} \left| h_{det}(t) \right|^2 dt}$$



Search Sensitivity
92.5 Hz QPO, 170s-220s

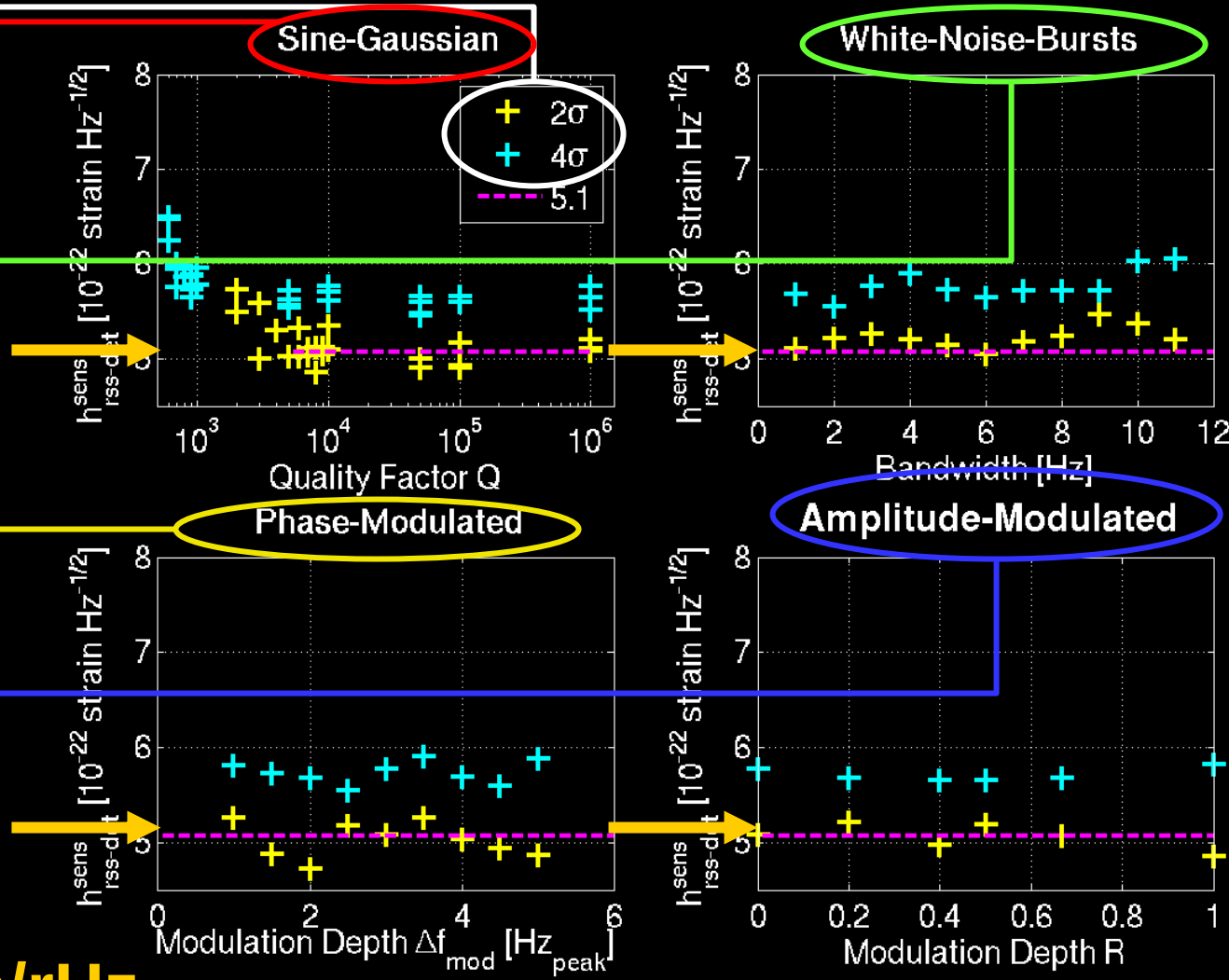
Data quality cut

Sine-Gaussian Waveforms

White-Noise Bursts

Phase-Modulated Waveforms

Amplitude-Modulated Waveforms



$h^{sens}_{rss-det}$

5.1×10^{-22} strain/rHz

On-source results (92.5 Hz QPO)

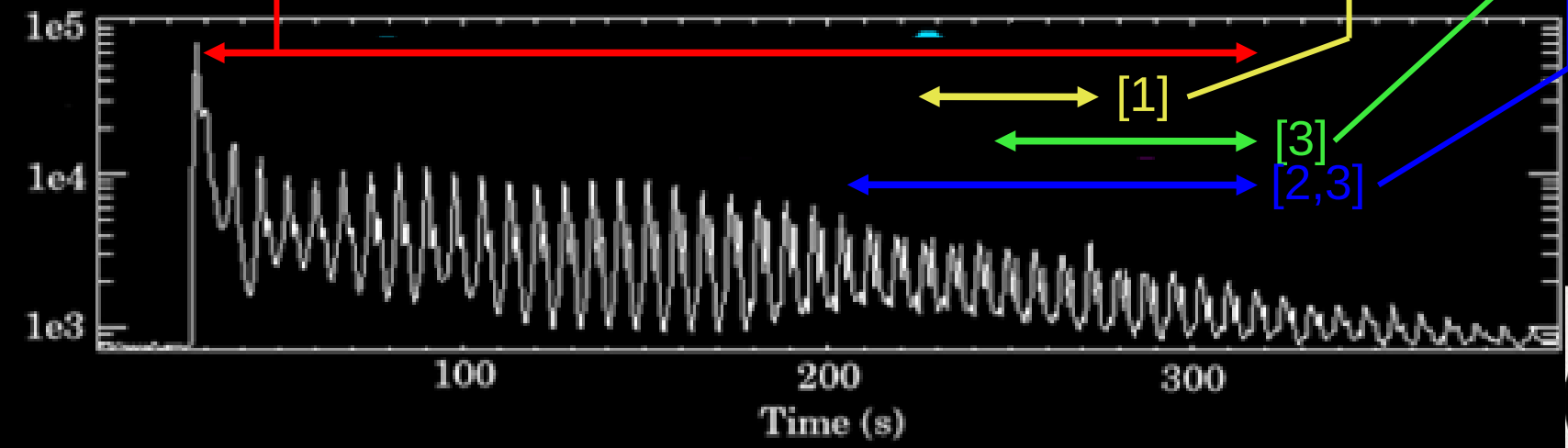
- No significant departure from background
  - no GW detection
- Placing Feldman-Cousins 90% UL

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

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

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

$h^{90\%}_{rss\text{-}det} = 9.50 \times 10^{-22}$ 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)

Observation	Frequency [Hz]	Bandwidth [Hz]	Interval [s]	Duration [s]	$\text{Threshold}_{\text{non-det}}$ [10^{-22}strain $\text{Hz}^{-1/2}$]	$h^{90\%}_{\text{rss-det}}$ [10^{-22}strain $\text{Hz}^{-1/2}$]
e,f	92.5	10	150-260	110	18.0	$2.75\ ^{+0.47}\ ^{+0.70}\ ^{+0.16}\ ^{+0.77} = 4.53$
g			190-260	70	15.7	$2.90\ ^{+0.43}\ ^{+0.74}\ ^{+0.17}\ ^{+0.75} = 4.67$
d			170-220	50	14.4	$5.15\ ^{+0.35}\ ^{+1.32}\ ^{+0.31}\ ^{+0.37} = 7.19$
			0-260	260	22.5	$5.06\ ^{+1.42}\ ^{+1.30}\ ^{+0.30}\ ^{+2.21} = 9.50$
control freq.	185.0	8	150-260	110	19.0	$9.48\ ^{+0.51}\ ^{+2.43}\ ^{+0.57}\ ^{+0.27} = 12.8$
			190-260	70	17.6	$8.17\ ^{+0.40}\ ^{+2.09}\ ^{+0.49}\ ^{+0.1?} = 11.0$
			170-220	50	16.5	$8.03\ ^{+0.30}\ ^{+2.06}\ ^{+0.48}\ ^{+0.2?} = 10.8$
			0-260	260	24.1	$11.4\ ^{+1.06}\ ^{+2.91}\ ^{+0.68}\ ^{+0.0?} = 15.1$
h	150.3	17	0-350	350	30.2	$12.4\ ^{+1.78}\ ^{+3.16}\ ^{+0.74}\ ^{+0.0?} = 16.7$
control freq.	300.6	30	0-350	350	70.3	$26.4\ ^{+4.46}\ ^{+6.75}\ ^{+1.58}\ ^{+0.0?} = 36.0$
i	626.5	10	50-200	150	53.4	$25.6\ ^{+1.76}\ ^{+6.56}\ ^{+1.54}\ ^{+0.0?} = 33.9$
l			190-260	70	47.4	$19.4\ ^{+1.23}\ ^{+4.97}\ ^{+1.17}\ ^{+0.0?} = 25.7$
			0-260	260	60.1	$28.2\ ^{+2.70}\ ^{+7.22}\ ^{+1.69}\ ^{+0.0?} = 37.6$
control freq.	1253.0	10	50-200	150	114	$49.4\ ^{+4.10}\ ^{+12.64}\ ^{+2.96}\ ^{+0.0?} = 65.6$
			190-260	70	89.0	$30.6\ ^{+2.69}\ ^{+7.84}\ ^{+1.84}\ ^{+0.00} = 40.7$
			0-260	260	107	$53.5\ ^{+4.50}\ ^{+13.71}\ ^{+3.21}\ ^{+0.00} = 71.2$
m	1837.0	10	230-245	15	94.7	$34.6\ ^{+1.26}\ ^{+8.86}\ ^{+2.08}\ ^{+0.00} = 45.6$
			0-245	245	192	$54.9\ ^{+11.72}\ ^{+14.05}\ ^{+3.29}\ ^{+0.00} = 76.5$

From astro-ph/0703419

TABLE II: List of frequencies and observation times used in this analysis with the corresponding results. The first column describes the addressed QPO observation, labeled by letters as they appear in Tab. I. A wider range of the detector's sensitivity

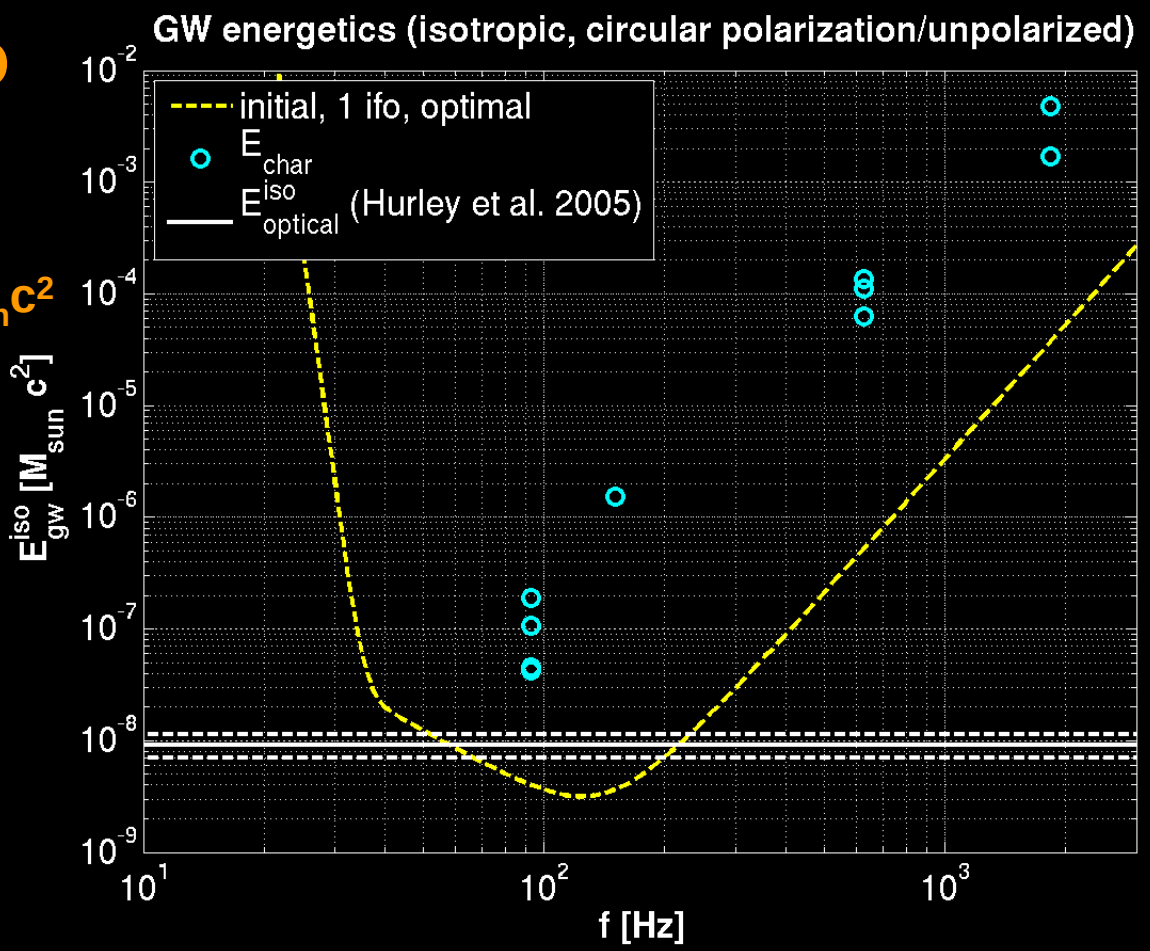
Gravitational Wave Energetics

- **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**

$$E_{GW}^{iso,90\%} = 4.29\times10^{-8} M_{sun} c^2 \times \left(\frac{r}{10kpc}\right)^2 \left(\frac{f_{qpo}}{92.5Hz}\right)^2 \left(\frac{h_{rss-det}^{90\%}}{4.53\times10^{-22}\, strain/\sqrt{Hz}}\right)^2$$

Gravitational Wave Energetics

- **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**



Conclusions

- **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 case for the 92.5 Hz QPO (150s - 260s)
    - $h_{rss\text{-}det}^{90\%} = 4.5 \times 10^{-22}$ strain/rHz
  - Characteristic energy (isotropic, equal power in both polarization states)
    - $E^{iso,\,90\%} = 4.3 \times 10^{-8}\ M_{sun}\ c^2$
    - 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)