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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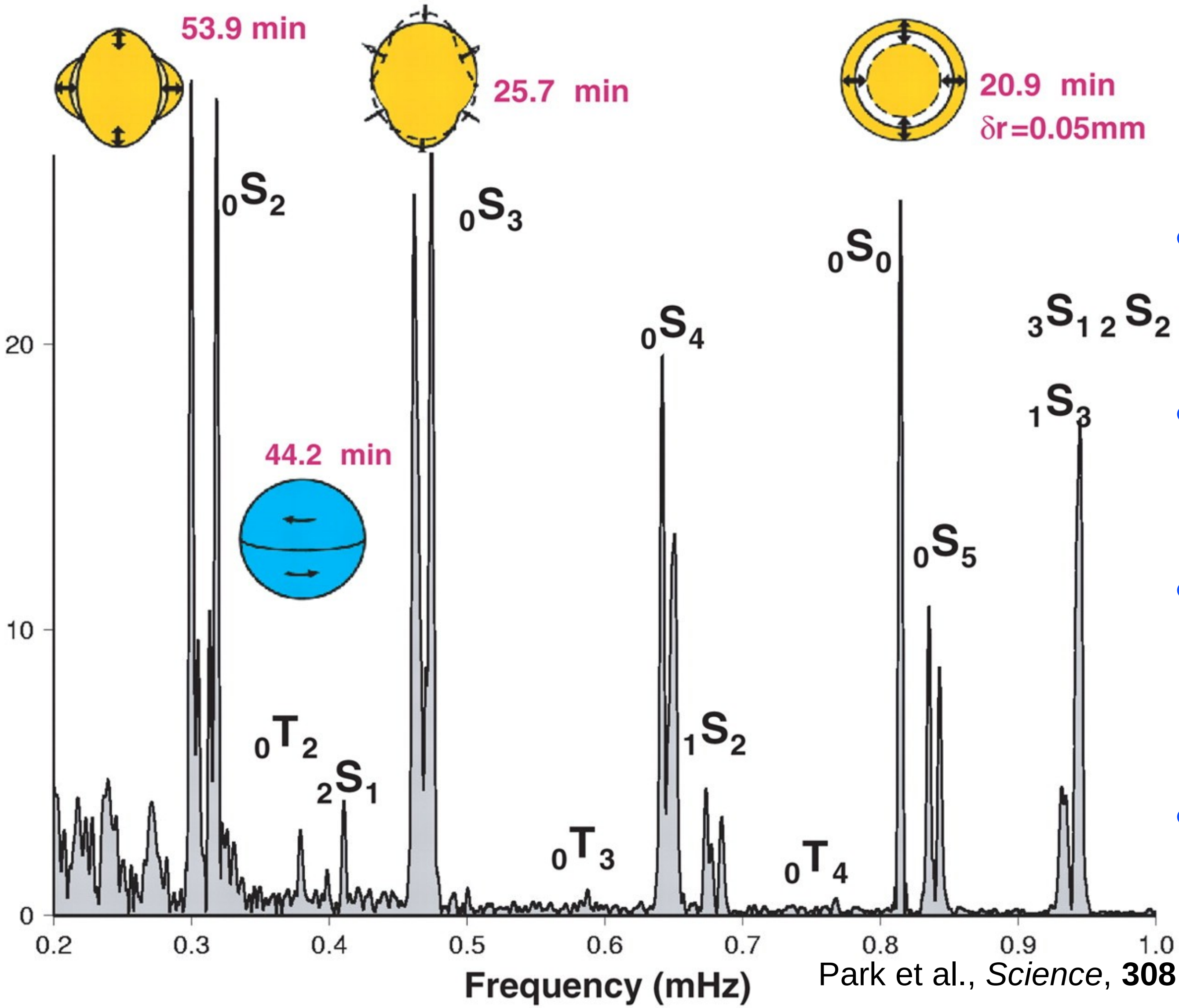
The 2004 Indian Ocean Earthquake



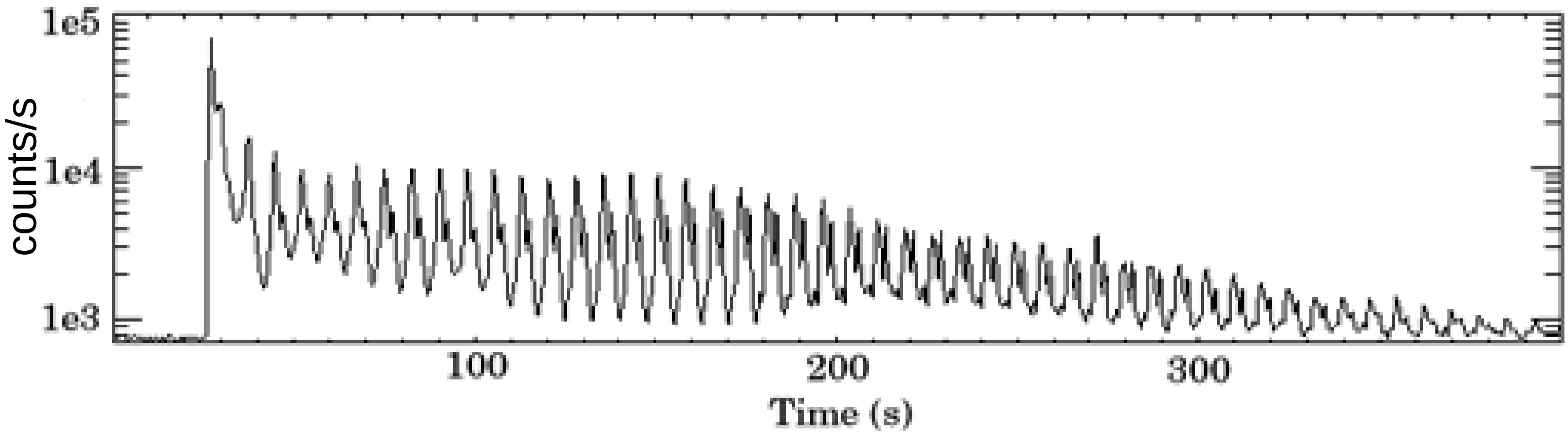
- Sumatra - Andaman Earthquake (December 26th, 2004)
- Spectra of seismographic data (Canberra, Australia)
- Event delivered a blow to our planet causing it to ring like a bell for weeks
- Computed from 240 hours of data

Park et al., *Science*, **308**, 1139 (2005)

The SGR 1806-20 hyperflare of December 27, 2004

- The Soft Gamma-Ray Repeater SGR 1806-20 emits a record flare
- d ~ 6 - 15 kpc, energy released by flare: ~10^{46}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

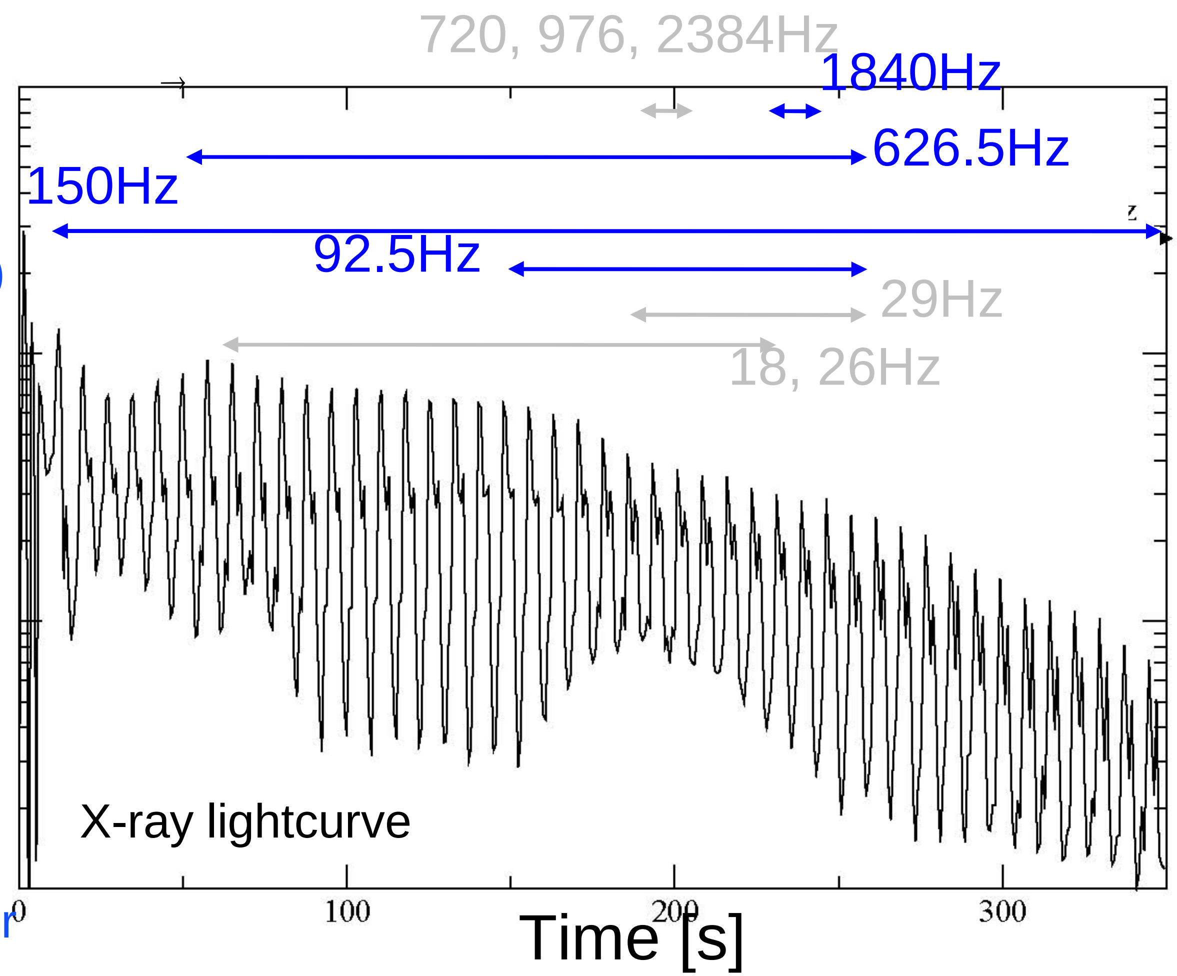
RHESSI X-ray lightcurve (25 – 100 keV band)



A.Watts and T.Strohmayer, *ApJ* **637** L117 (2006)

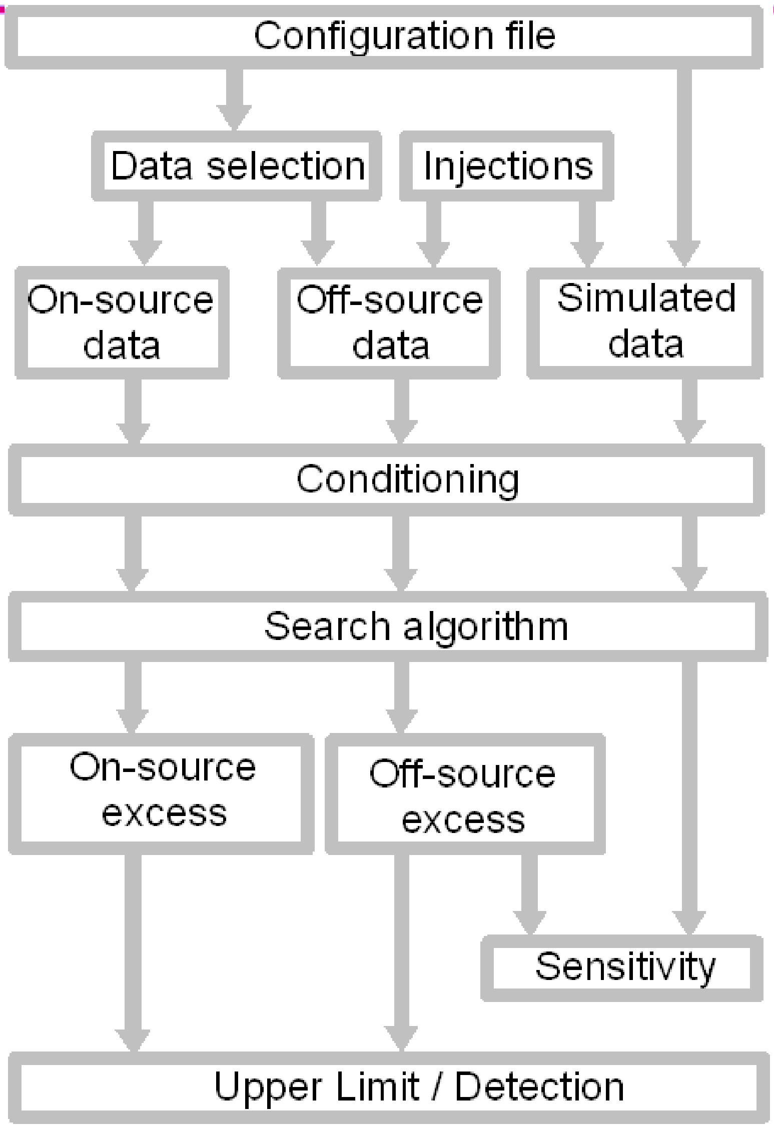
Magnetar Model and Objective of the Analysis

- 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



T.Strohmayer and A.Watts, *ApJ* **653** L594 (2006)

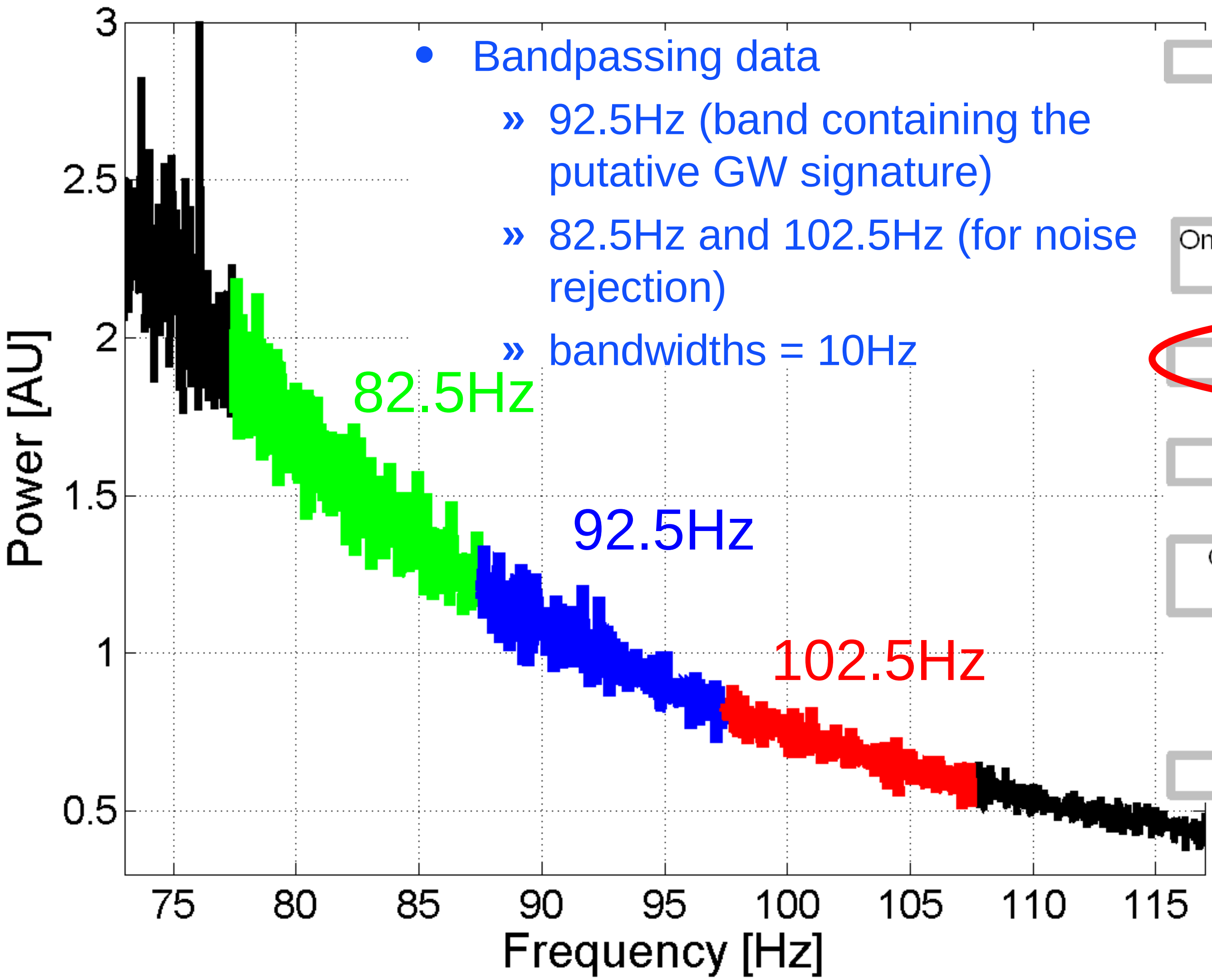
Overview of the Analysis

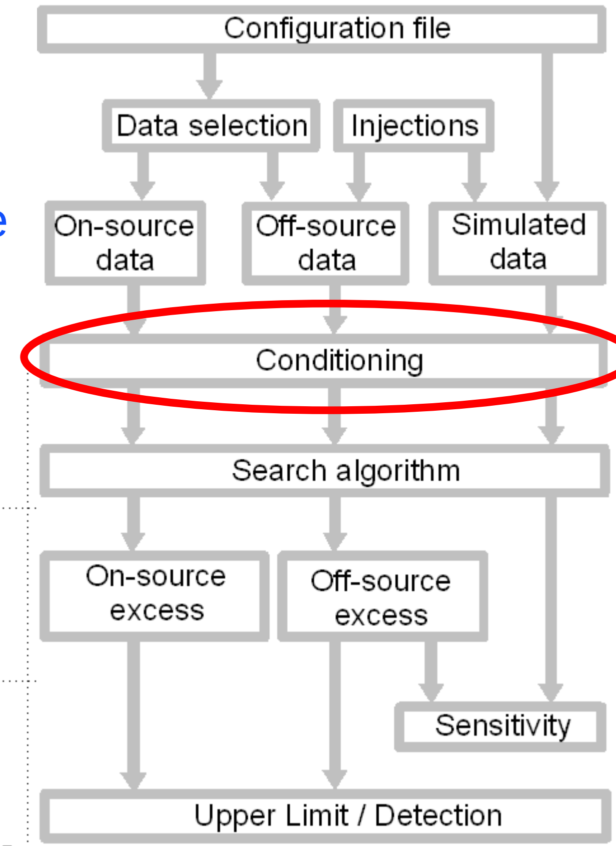


- post-S3, pre-S4 (*Astrowatch* program)
  - » H1 only at the time of the event
- Looking for tens-of-seconds long signals
  - » narrow band
  - » veto data corresponding to short glitches
  - » unknown frequency content and evolution BUT QPO bandwidth is measured
- Search algorithm
  - » provides a constant sensitivity over plausible phase space

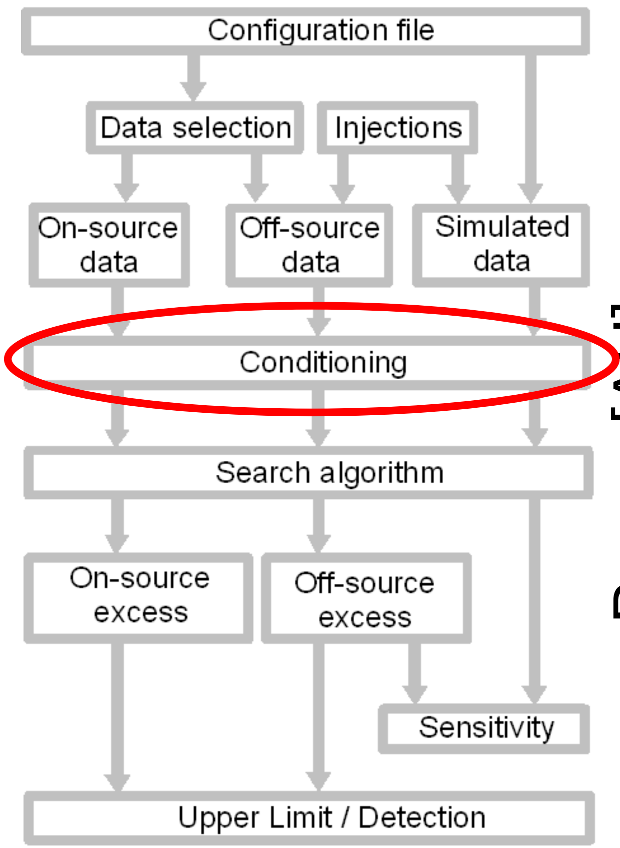
Conditioning (I)
Filtering

- Bandpassing data
  - » 92.5Hz (band containing the putative GW signature)
  - » 82.5Hz and 102.5Hz (for noise rejection)
  - » bandwidths = 10Hz





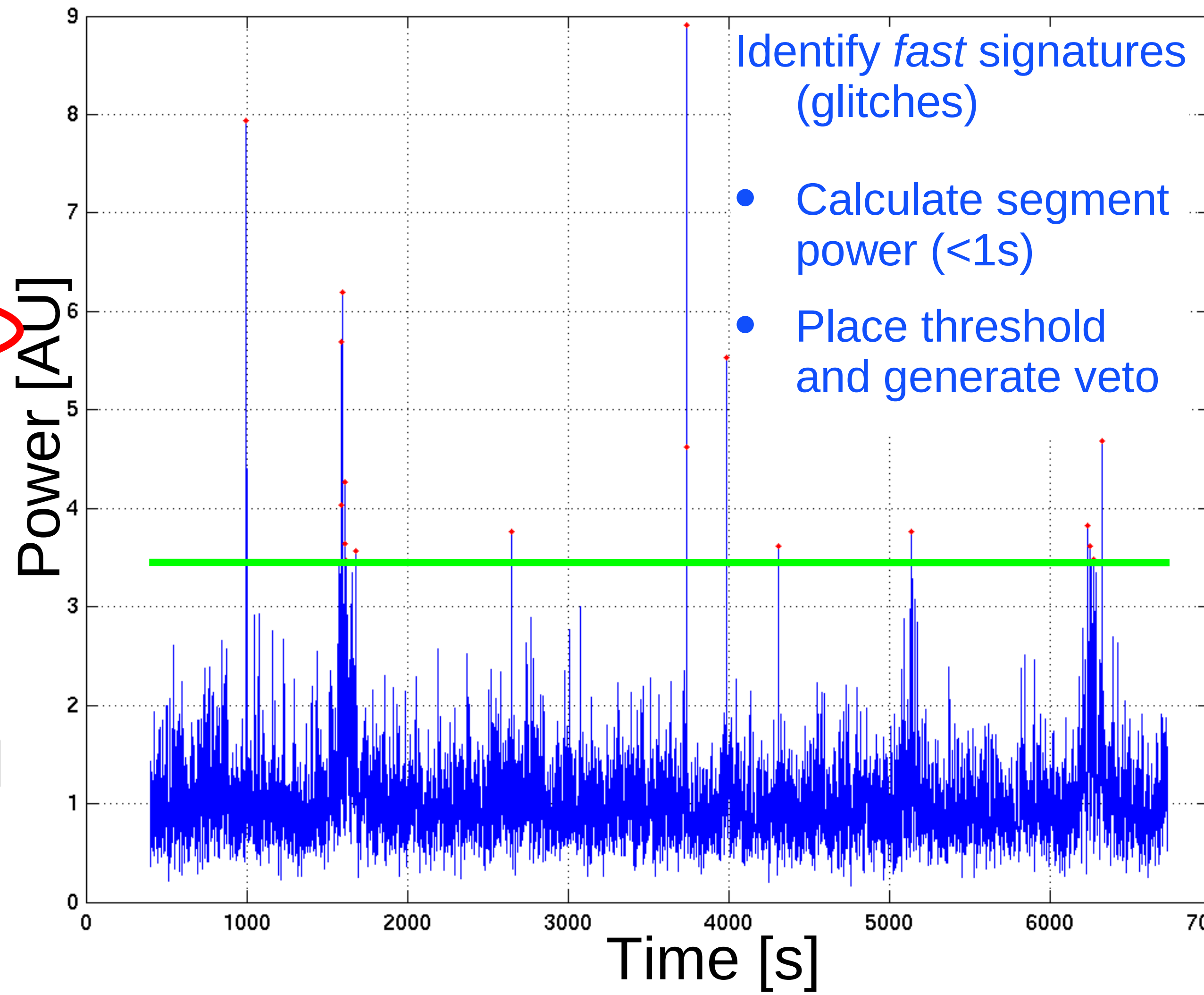
Conditioning (II)
Data Quality Flag



Power in 1s long segments vs. time

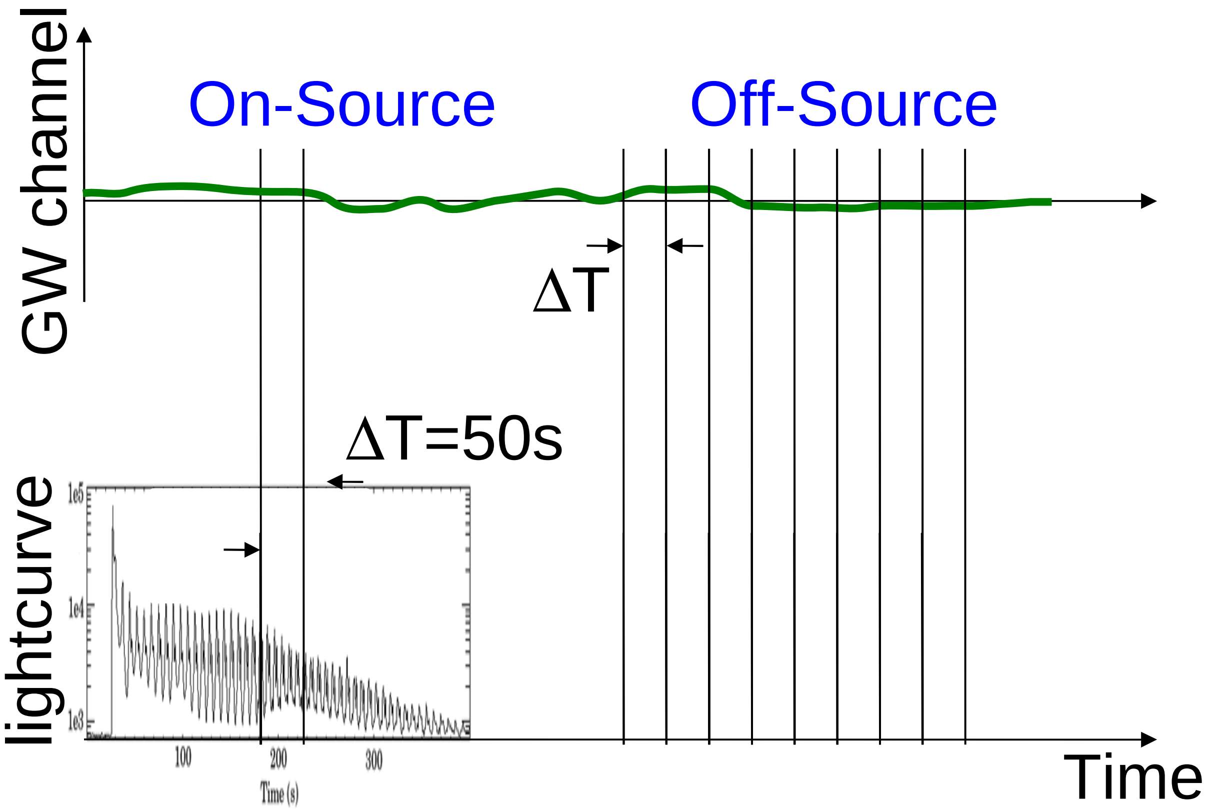
Identify *fast* signatures (glitches)

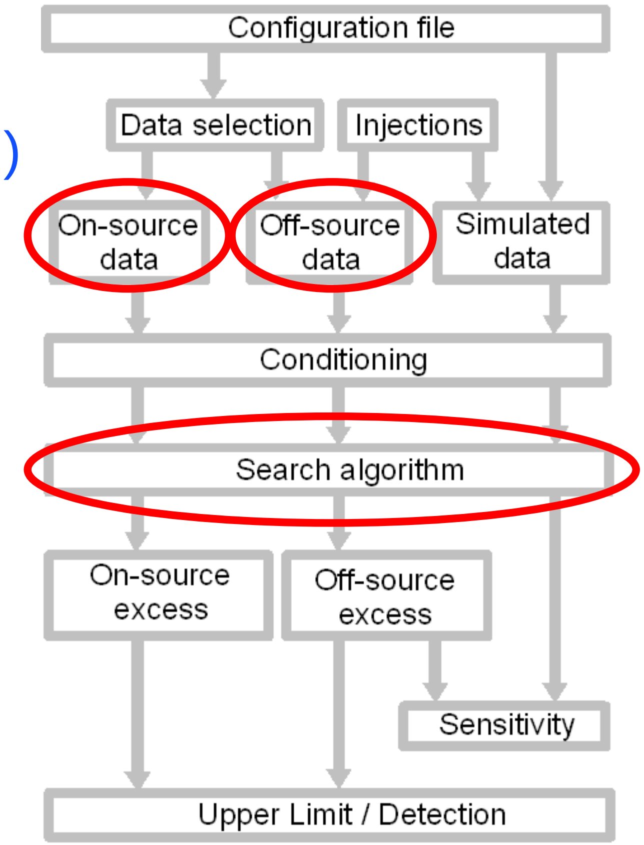
- Calculate segment power (<1s)
- Place threshold and generate veto



Search Algorithm

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





LIGO

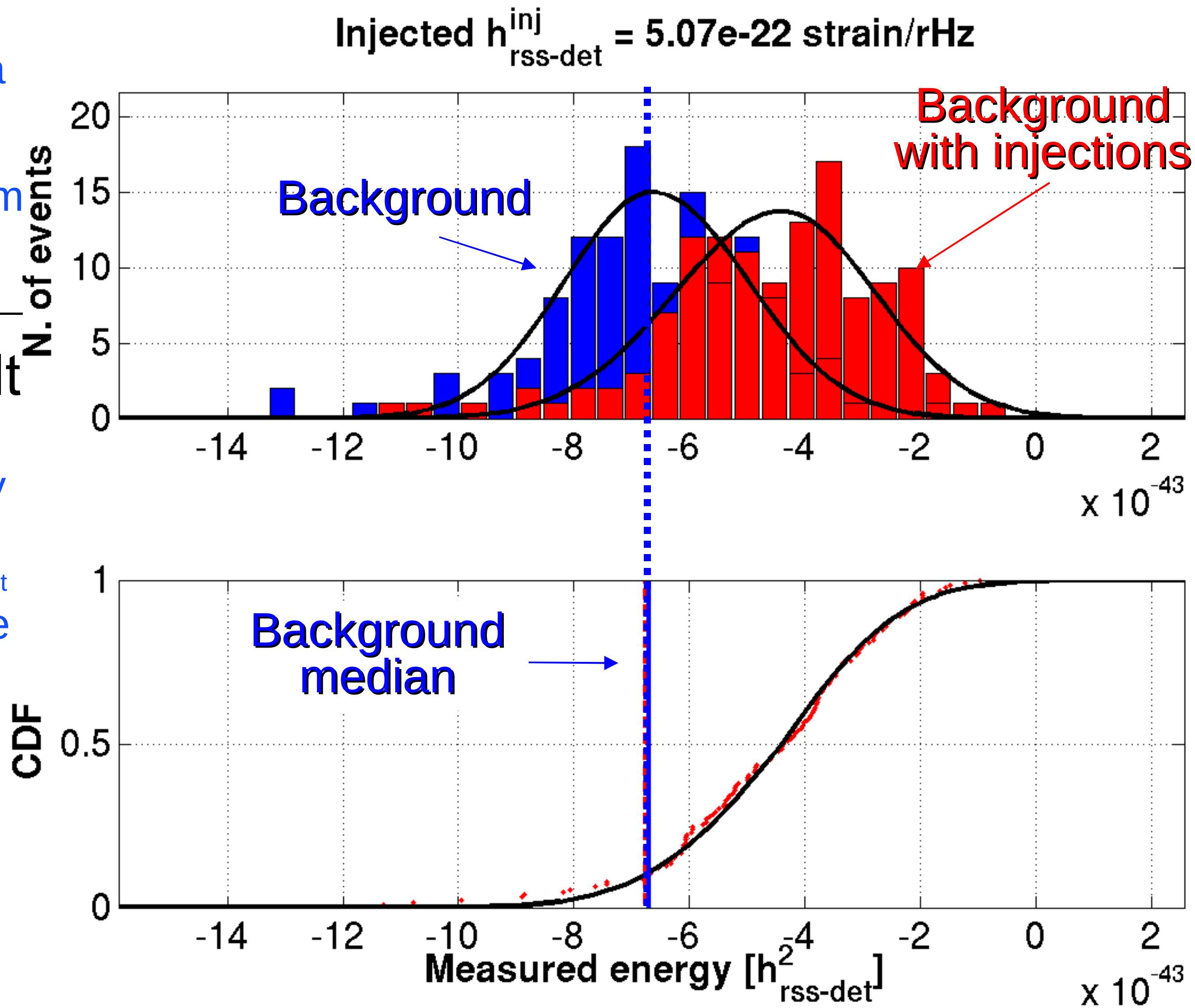
Search Sensitivity

GECo

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

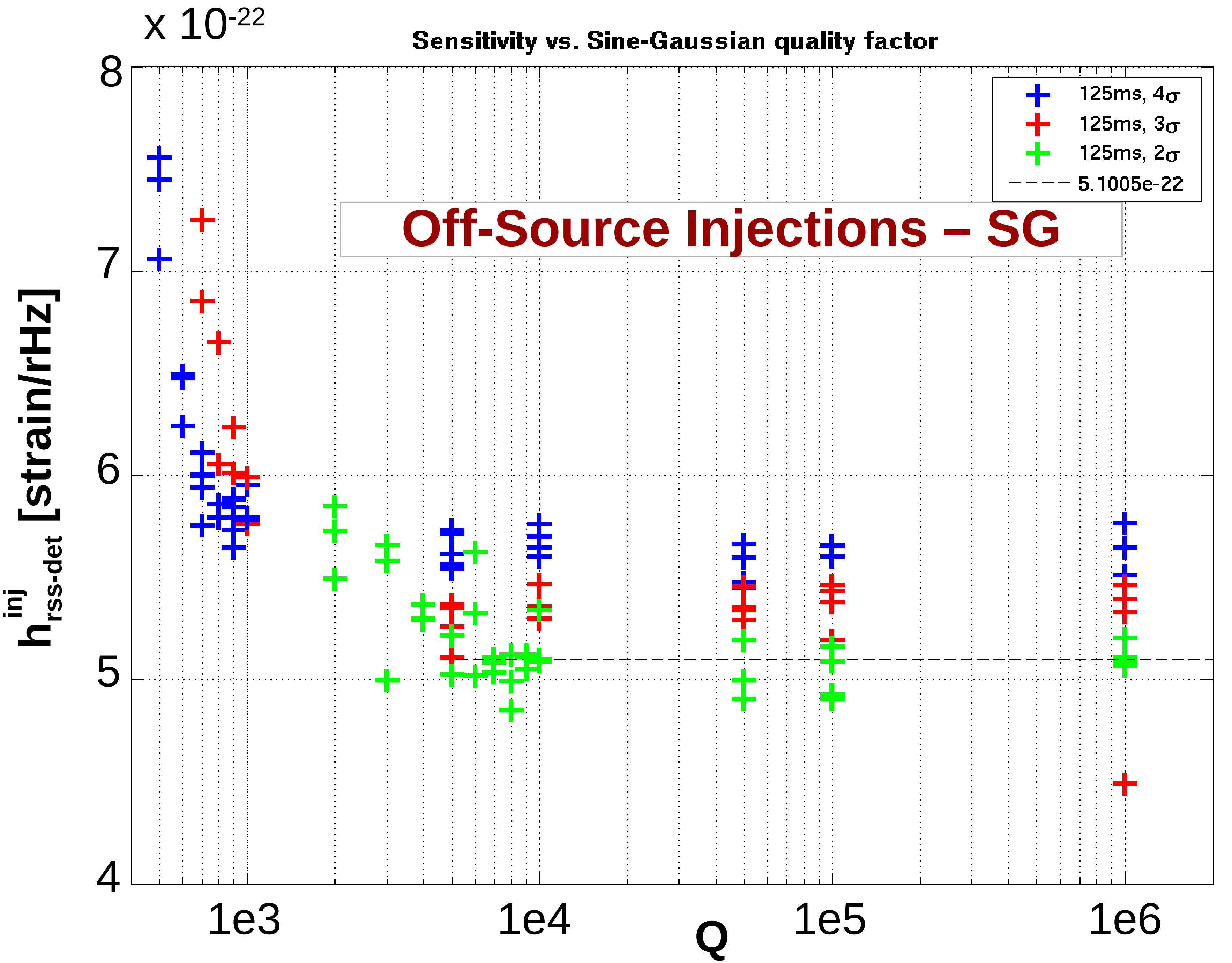
$$h^{inj}_{rss-det} = \sqrt{\int_{-\infty}^{+\infty} |h(t)|^2 dt}$$

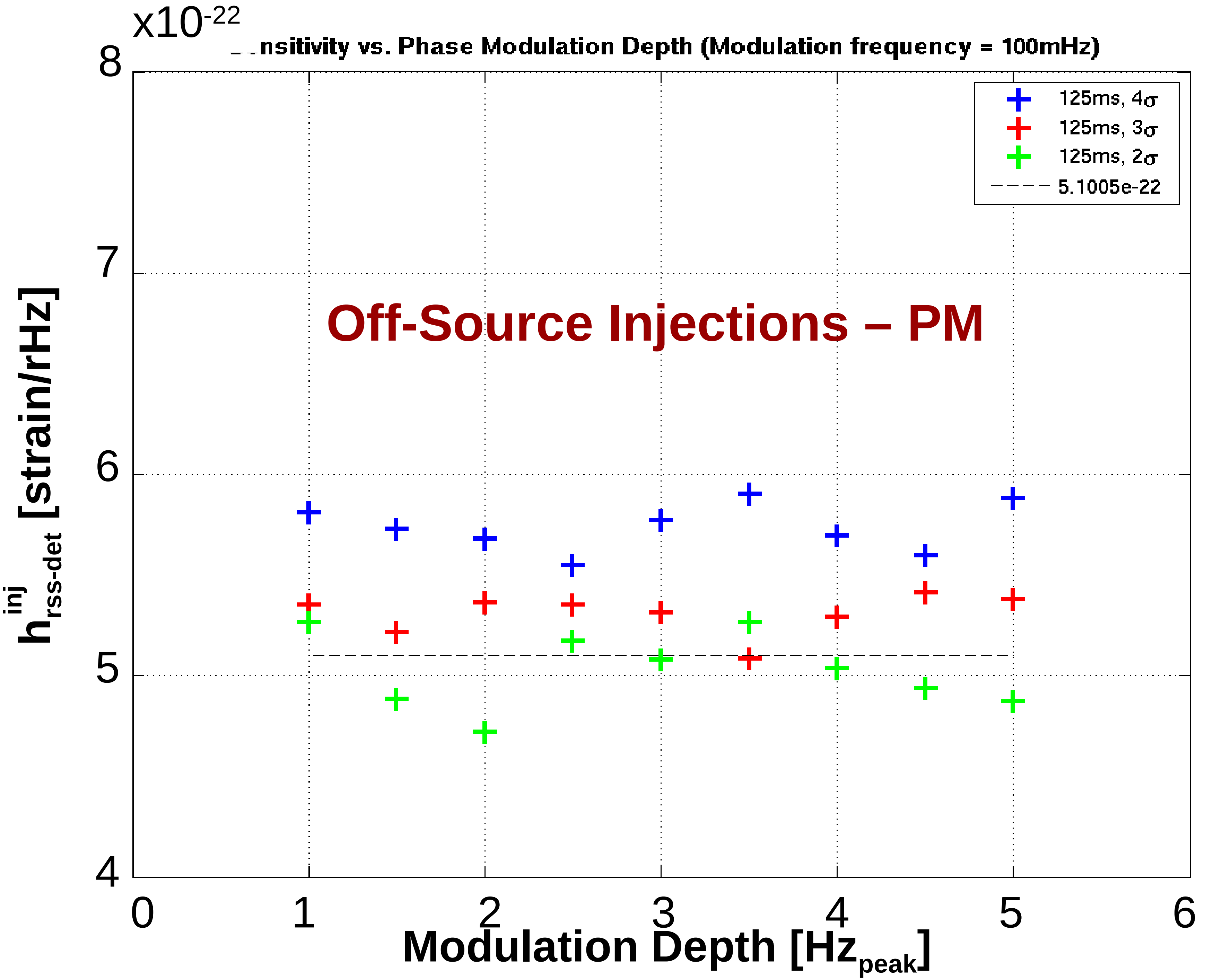
- Define search sensitivity
  - » as the injected $h^{inj}_{rss\text{-}det}$ such that 90% of the measured energy ($h^2_{rss\text{-}det}$) is above the background median



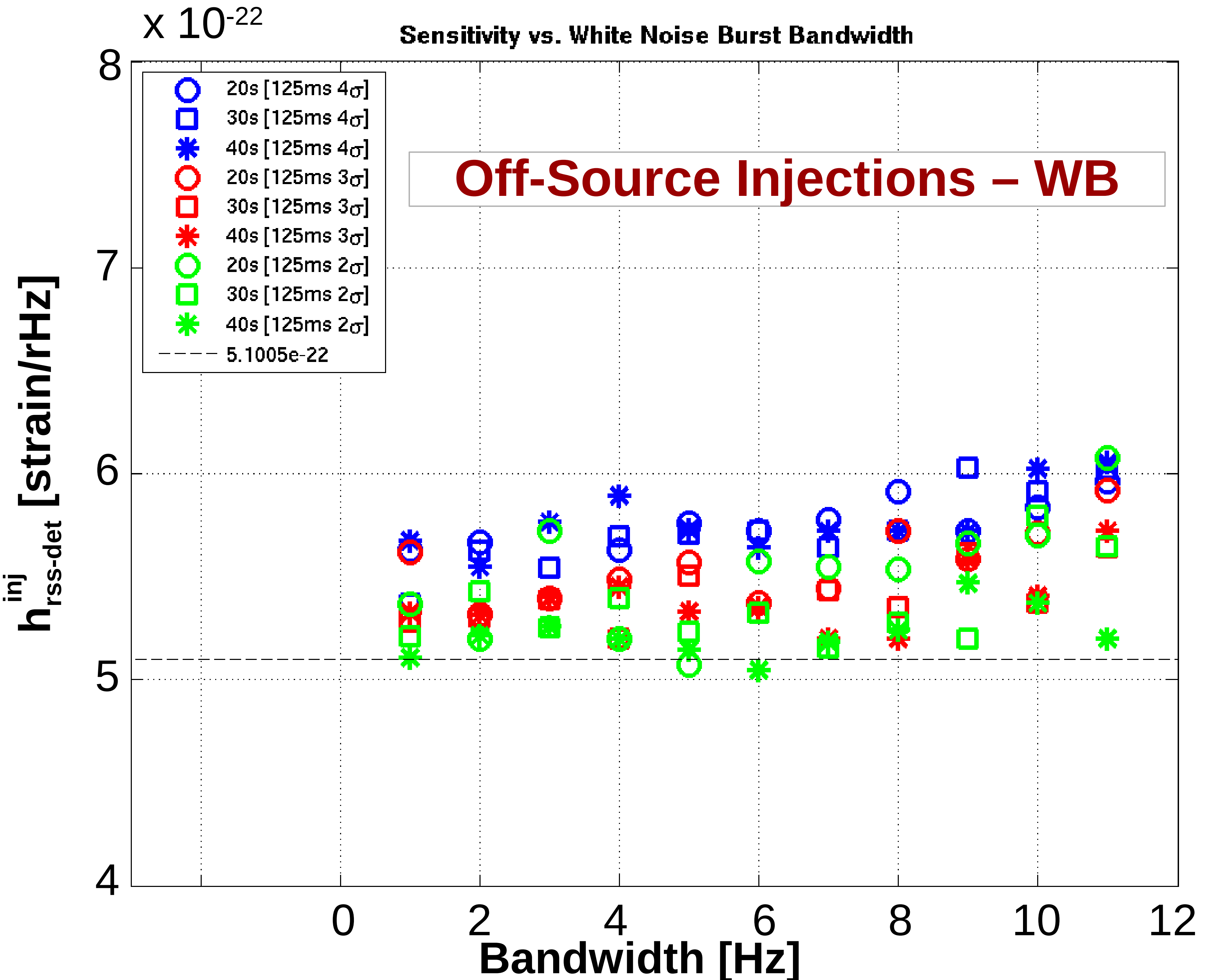
Search sensitivity for the
92.5Hz QPO observed from 170s to 220s after the beginning of the flare

Search bandwidth set to 10Hz centered on 92.5Hz


x 10^-22
Sensitivity vs. Sine-Gaussian quality factor
125ms, 4σ
125ms, 3σ
125ms, 2σ
5.1005e-22
Off-Source Injections – SG
8
7
6
5
4
h^inj_rss-det [strain/rHz]
1e3
1e4
1e5
1e6
Q



x10^-22
..nsitivity vs. Phase Modulation Depth (Modulation frequency = 100mHz)
125ms, 4σ
125ms, 3σ
125ms, 2σ
5.1005e-22
Off-Source Injections – PM
h^inj_rss-det [strain/rHz]
Modulation Depth [Hz_peak]
8
7
6
5
4
0
1
2
3
4
5
6


x 10^-22
Sensitivity vs. White Noise Burst Bandwidth
20s [125ms 4σ]
30s [125ms 4σ]
40s [125ms 4σ]
20s [125ms 3σ]
30s [125ms 3σ]
40s [125ms 3σ]
20s [125ms 2σ]
30s [125ms 2σ]
40s [125ms 2σ]
5.1005e-22
Off-Source Injections – WB
8
7
6
5
4
0
2
4
6
8
10
12
Bandwidth [Hz]
h inj rss-det [strain/rHz]

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 $h^{90\%}_{rss\text{-}det}$

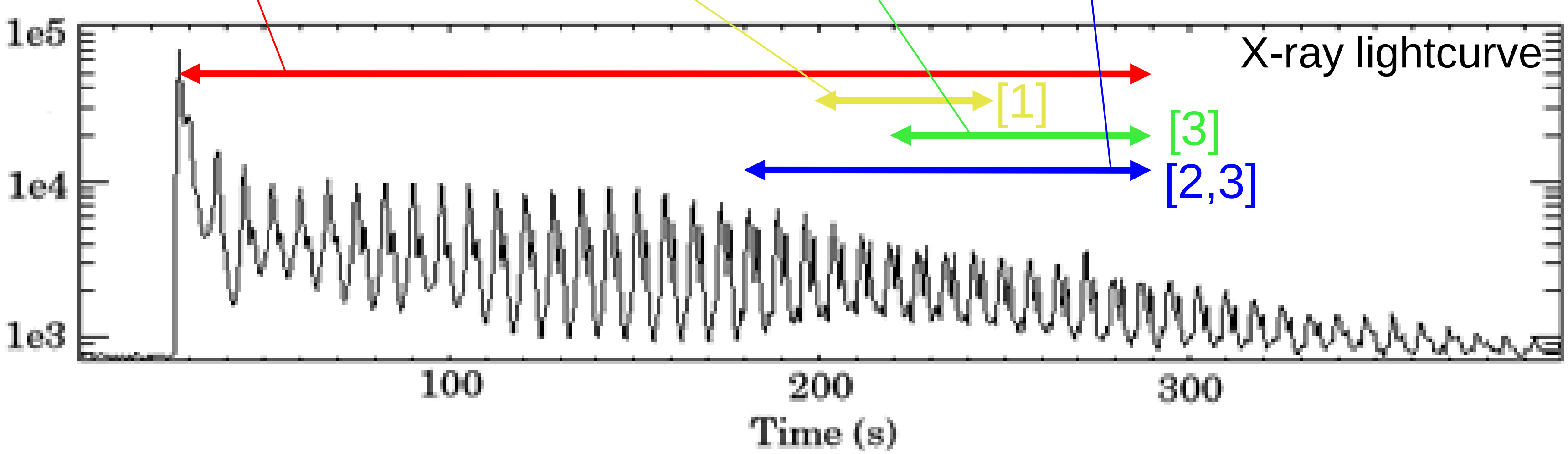
Preliminary

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

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

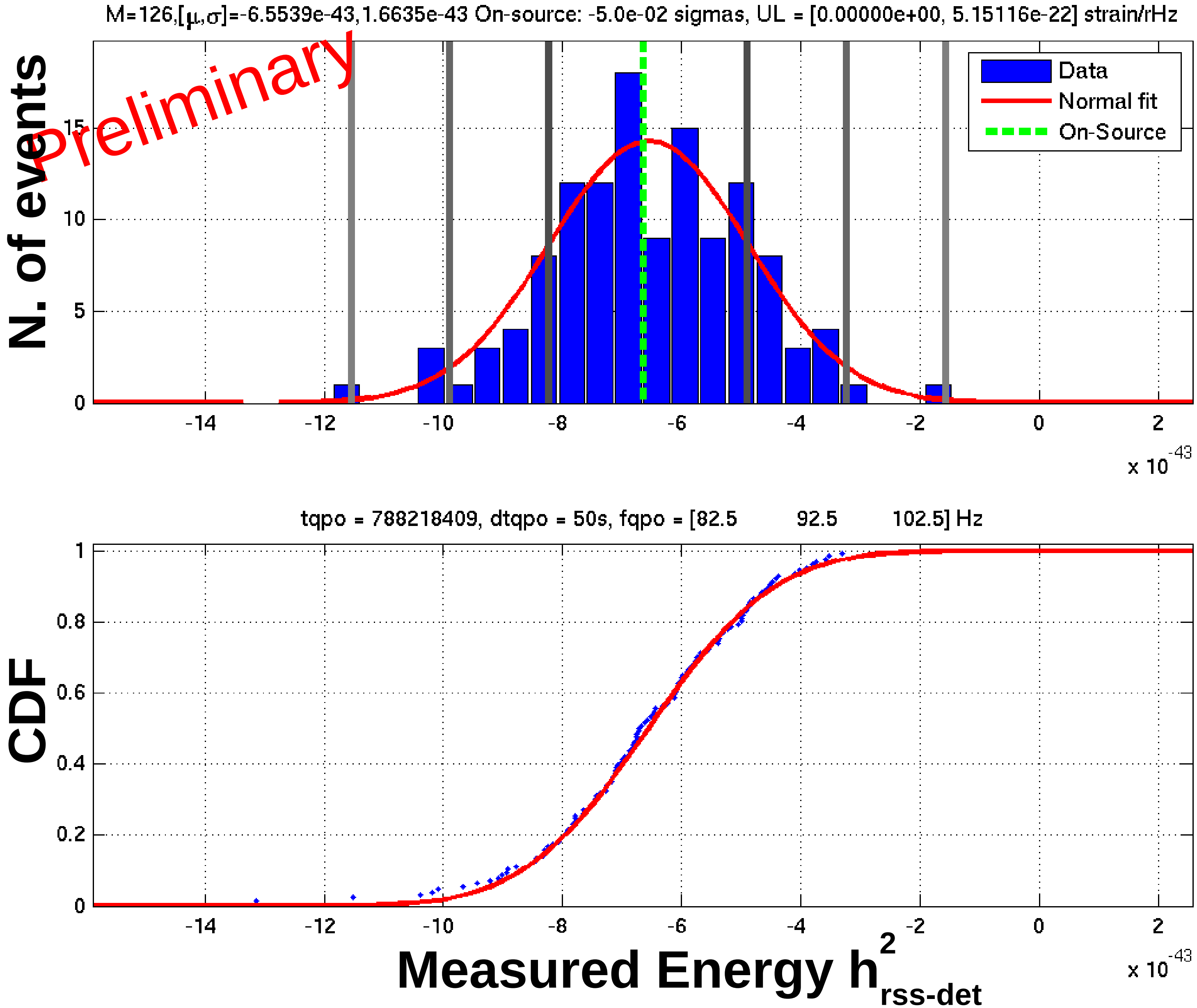
$h^{90\%}_{rss\text{-}det}$ = **4.67 x 10^{-22} strain/rHz**

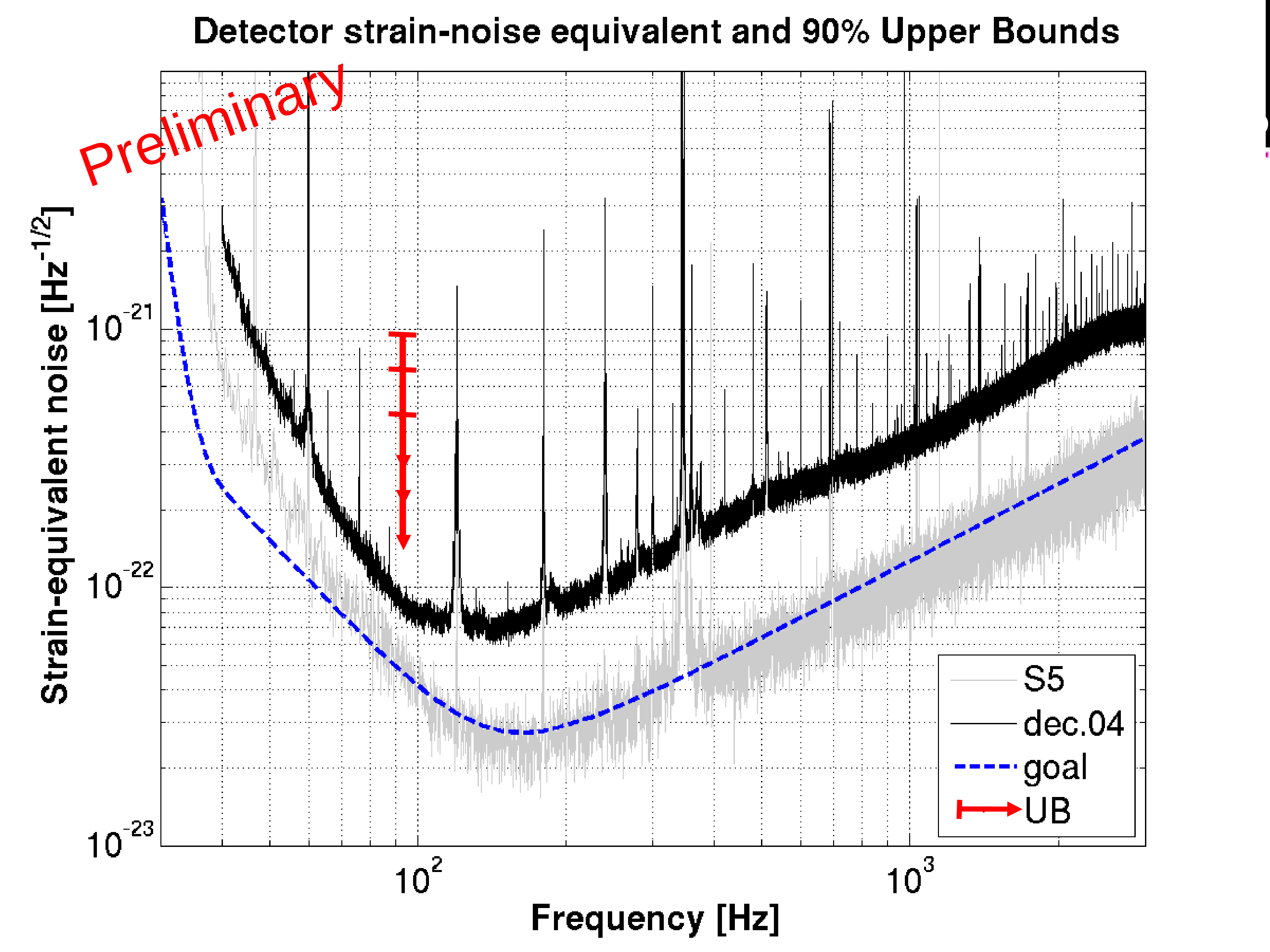
$h^{90\%}_{rss\text{-}det}$ = **4.53 x 10^{-22} strain/rHz**



[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)

On-Source: Sample Upper Limit



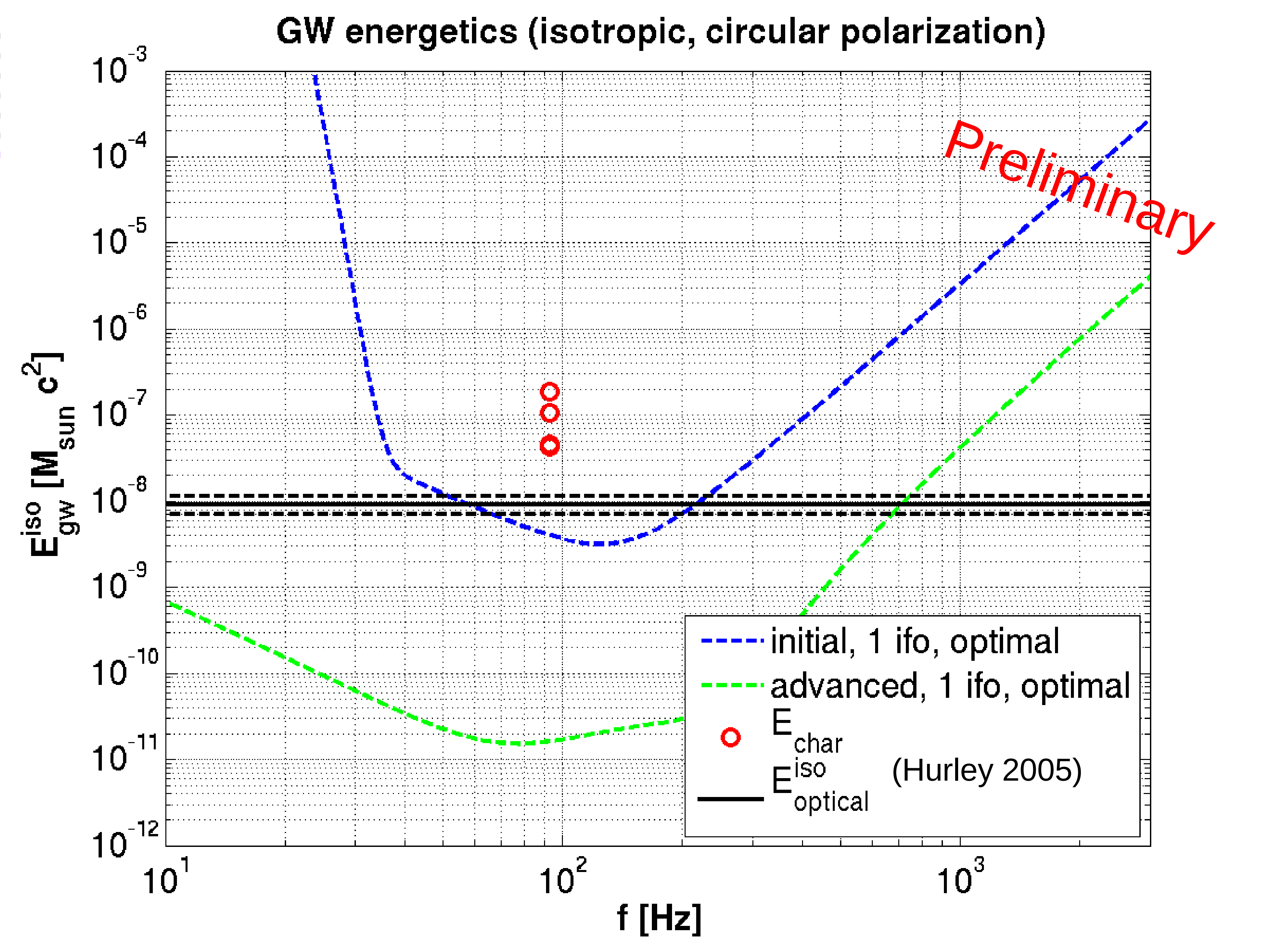


Detector strain-noise equivalent and 90% Upper Bounds
Preliminary
Strain-equivalent noise [Hz$^{-1/2}$]
10^{-21}
10^{-22}
10^{-23}
10^{2}
10^{3}
Frequency [Hz]
S5
dec.04
goal
UB

GW energetics

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

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



GW energetics (isotropic, circular polarization)
Preliminary
initial, 1 ifo, optimal
advanced, 1 ifo, optimal
E_{char}
$E^{iso}_{optical}$ (Hurley 2005)
E^{iso}_{gw} [M_{sun} c^2]
f [Hz]

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: $\mathbf{h^{90\%}_{rss\text{-}det} = 4.5 \times 10^{-22}}$ **strain/rHz**
- In terms of a characteristic energy (isotropic emission, equal amount of power in both polarization states)
  - » $\mathbf{E_{gw}^{iso} = 4.3 \times 10^{-8}\ M_{sun}c^2}$ for the 150-260s UB of $h^{90\%}_{rss\text{-}det} = 4.5 \times 10^{-22}$ 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)