Analysis of the pulsating tail of the SGR1806-20 hyperflare of Dec. 27th, 2004 using the LIGO detectors

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What happened on Dec. 27th, 2004?

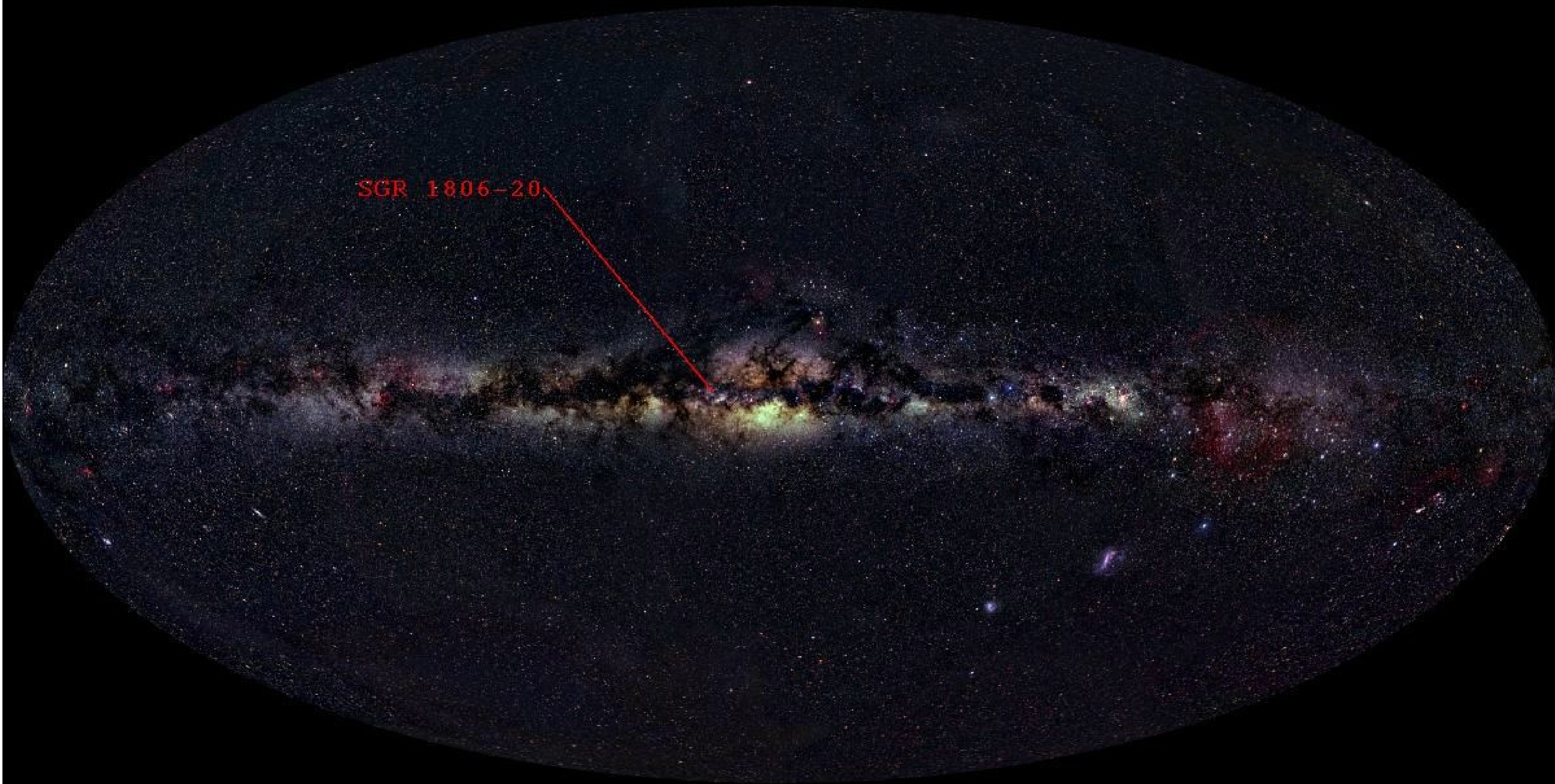
SGR1806-20 emits a record flare [7]

- located a distance of [7.5:15] kpc
- energy released: ~10^{46} ergs
- pulsating tail lasting six minutes is observed
  - » pulsating frequency: neutron star rotation period (7.56 s)

The *Magnetar* Model

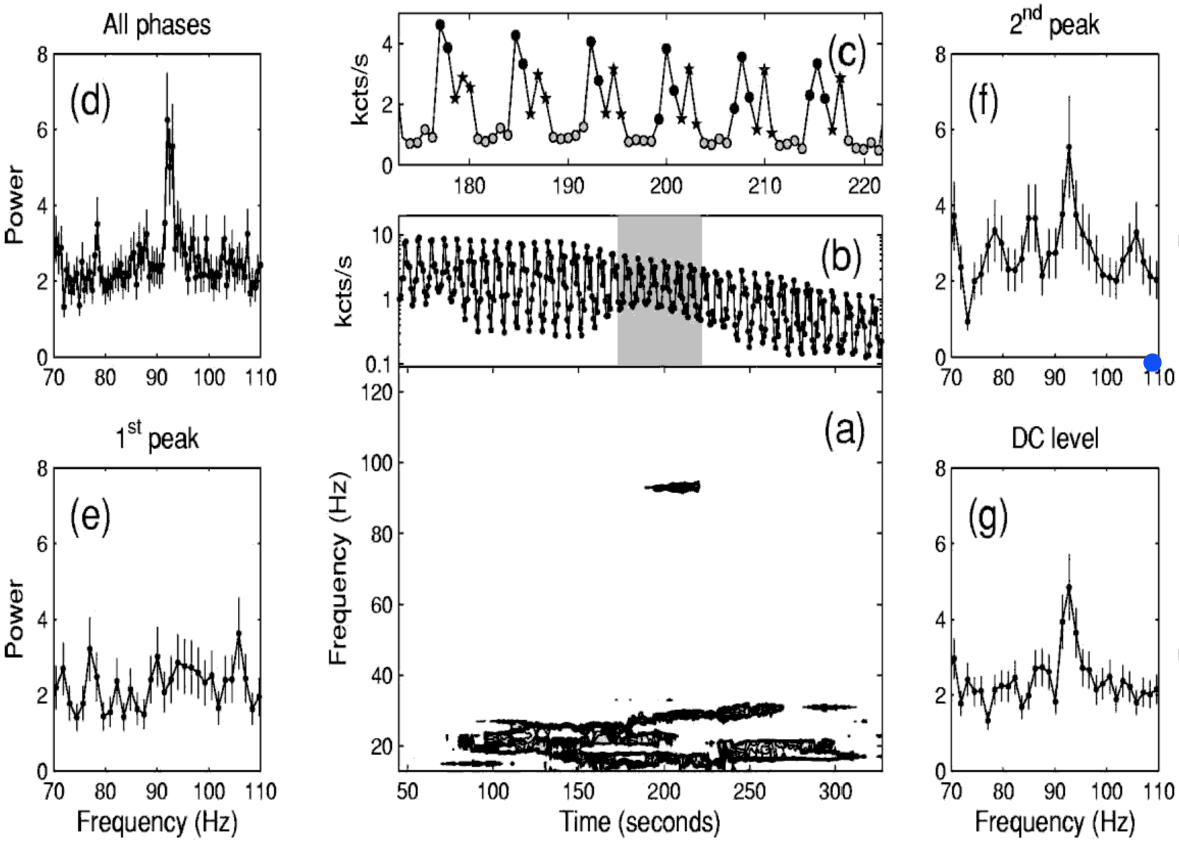
- several observational properties of SGRs can be modelled in terms of *Magnetars* [3,5]
  - » isolated neutron stars with intense magnetic fields (10^{14}-10^{15} G)
  - » SGRs are thought to be due to the energy release by the catastrophic re-arrangement of the neutron star crust and the magnetic field – a *starquake*
- in the presence of starquakes
  - » Global Seismic Oscillations may be excited [11,21]
    - – torsional/toroidal modes of the crust are easiest to excite
    - – crustal spheroidal modes and crust/core interface modes are also possibilities

The Deep Sky



Satellite X-Ray Observations

The *Rossi X-Ray Timing Explorer* (RXTE) observations[12]



- Quasi-periodic Oscillations (QPOs) are observed in the pulsating tail of SGR1806 [12]
  - » 18 Hz, 30.4 Hz and 92.5 Hz
  - » ~170 s after flare lasting for ~50 s
  - » observed on a particular phase of the rotation period
- interpreted as torodial seismic modes
  - » fundamental mode: ~30 Hz (l=2)
  - » 92.5 Hz correspond to l=7

The *Ramaty High Energy Solar Spectroscopic Imager* (RHESSI) observations

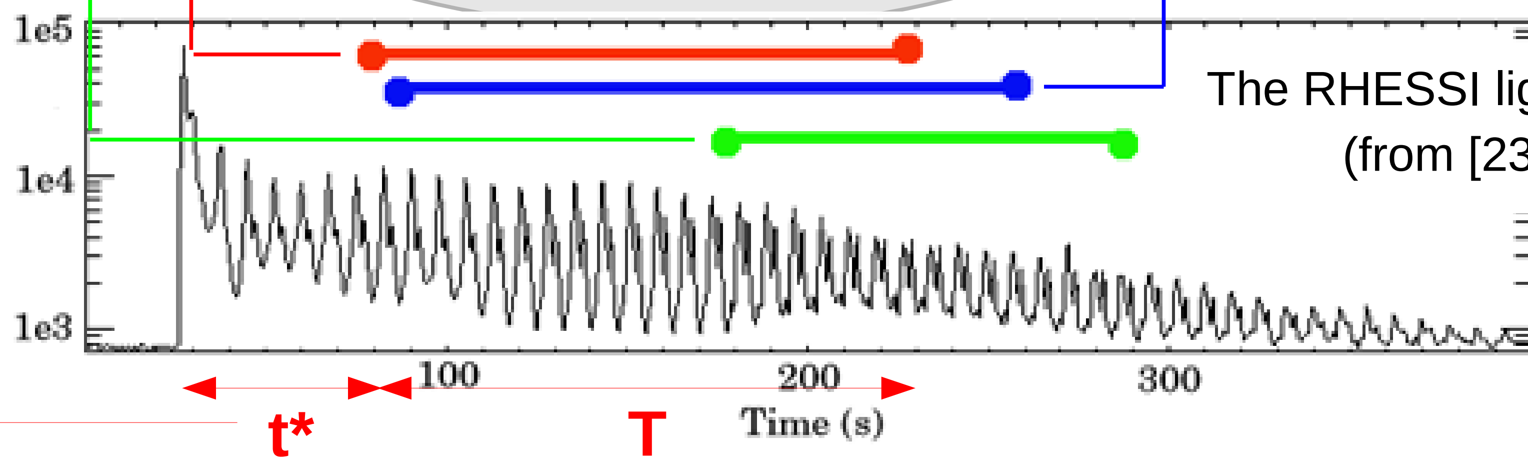
- Authors [13] re-analyse data from the pulsating tail of the giant flare from SGR1900+14. They observe a similar phenomenology:
  - » Plausible association of four QPOs with the l=2, 4, 7, and 13 toroidal modes of the neutron star's crust (10-100 Hz)

- Authors [22] analyse the pulsating tail of SGR1806-20 with a different satellite (RHESSI) confirming the RXTE finding
  - » additional QPOs at 18 Hz and 626.5 Hz
  - » nature of 18 and 30 Hz is unclear, the 626.5 Hz would fit with the n=1 crustal mode
  - » satellite is more sensitive – observation times are larger than the RXTE observations

Satellite	f [Hz]	Interval of observation [s]
RXTE	18.1	200-300
RHESSI	17.9	60-230
RHESSI	25.7	60-230
RXTE	30.4	200-300
RHESSI	30	60-230
RXTE	92.5	170-220
RHESSI	92.7	150-260
RHESSI	626.5	50-200

QPO and its first harmonic in LIGO band

QPOs observed for a period **T** a time **t*** after flare peak



The RHESSI lightcurve (from [23])

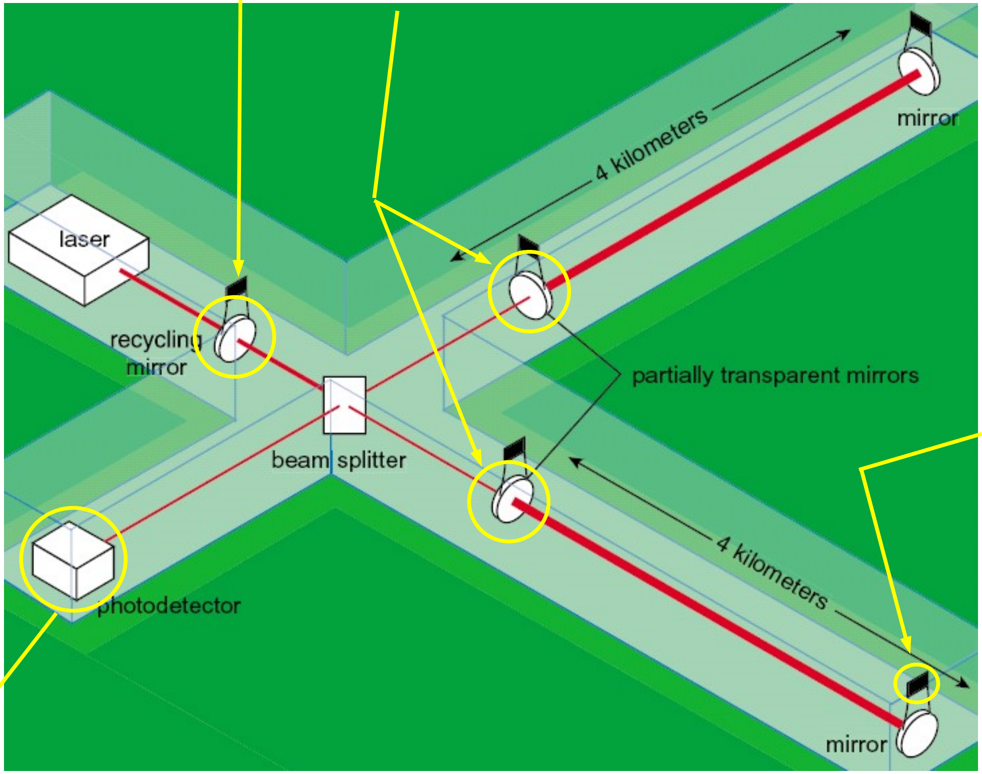
What is LIGO?

The Laser Interferometer Gravitational Wave Observatory (LIGO)

Measure strain $h = \Delta L/L \sim 10^{-21}$ @ 100 Hz

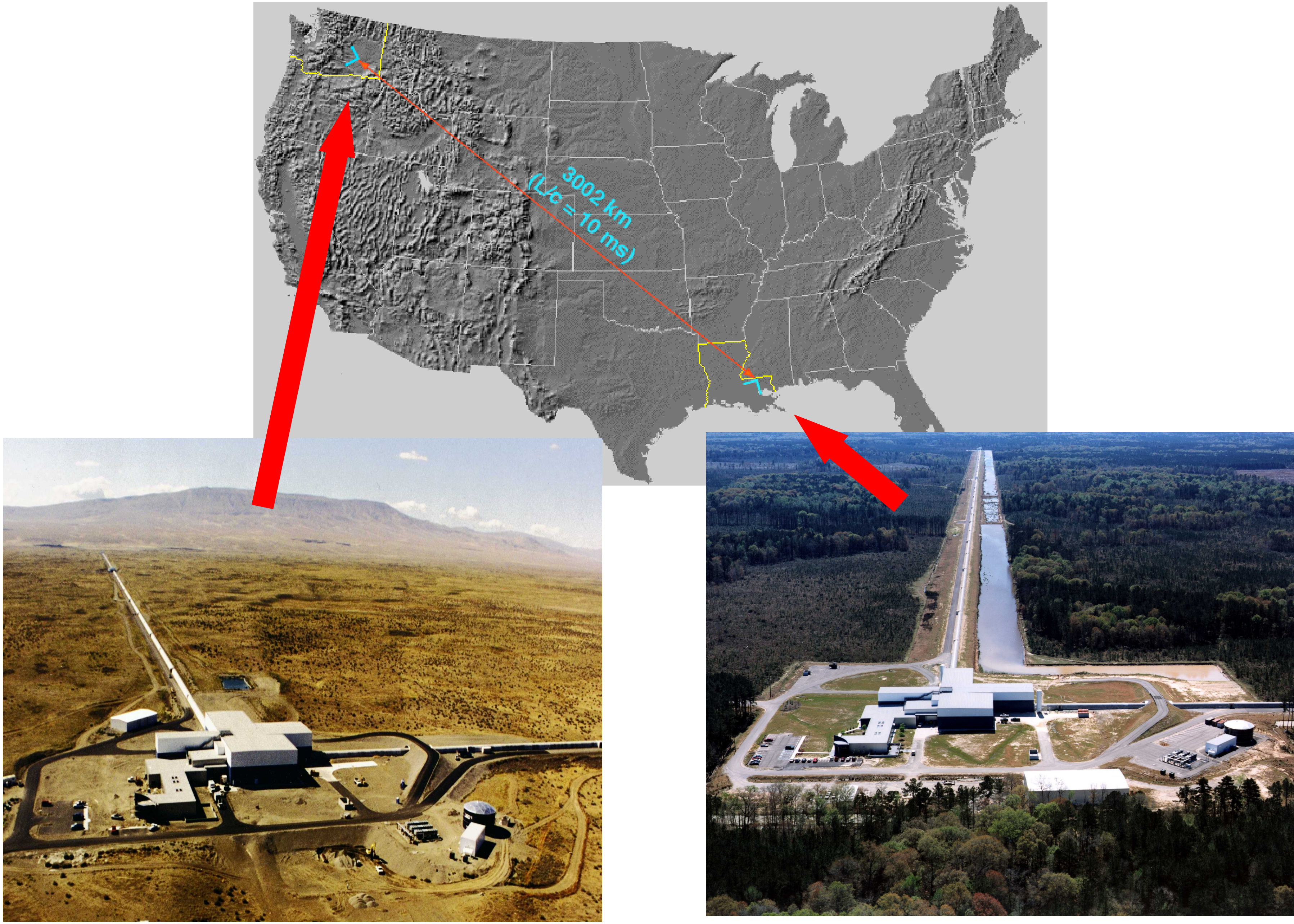
Decrease the Shot Noise limit
(decrease the quantum fluctuations in the number of photons detected by introducing a recycling mirror)

Amplify the signal from a putative GW
(increase the effective optical path)



Signal $\alpha\ \Delta$L

Decrease the Seismic Motion
(a series of attenuation stages to decrease noise due to natural and anthropogenic sources. Last stage is a pendulum like suspension)



Hanford Observatory (H1,H2)
2 km and 4 km interferometer

Livingston Observatory (L1)
Single 4 km interferometer

Objective of the Analysis

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- identify a potential Gravitational Wave (GW) signature associated to the observed QPO or place most stringent Upper Limit

Scope of this poster:

- at the time of the event, the H1 detector was collecting data
- estimate the performance of H1 to the observed QPOs (first and second harmonic) for various bandwidths

How?

Narrow band RMS monitoring of the GW channel at the frequency of interest

- from the RXTE observations
  - » f=92.5Hz (and 185Hz)
  - » Δf=1.67Hz, 4.17Hz and 8.33Hz
- from the RHESSI observations
  - » f=92.7Hz (and 185.4Hz), 626.5Hz (and 1253Hz)
  - » Δf=0.83Hz, 1.67Hz, 4.17Hz and 8.33Hz

Example

RXTE Observation

t*=170s

T=50s

f=92.5Hz

using Δf=1.67Hz

On-source segments

- time segments corresponding to the QPO observation periods

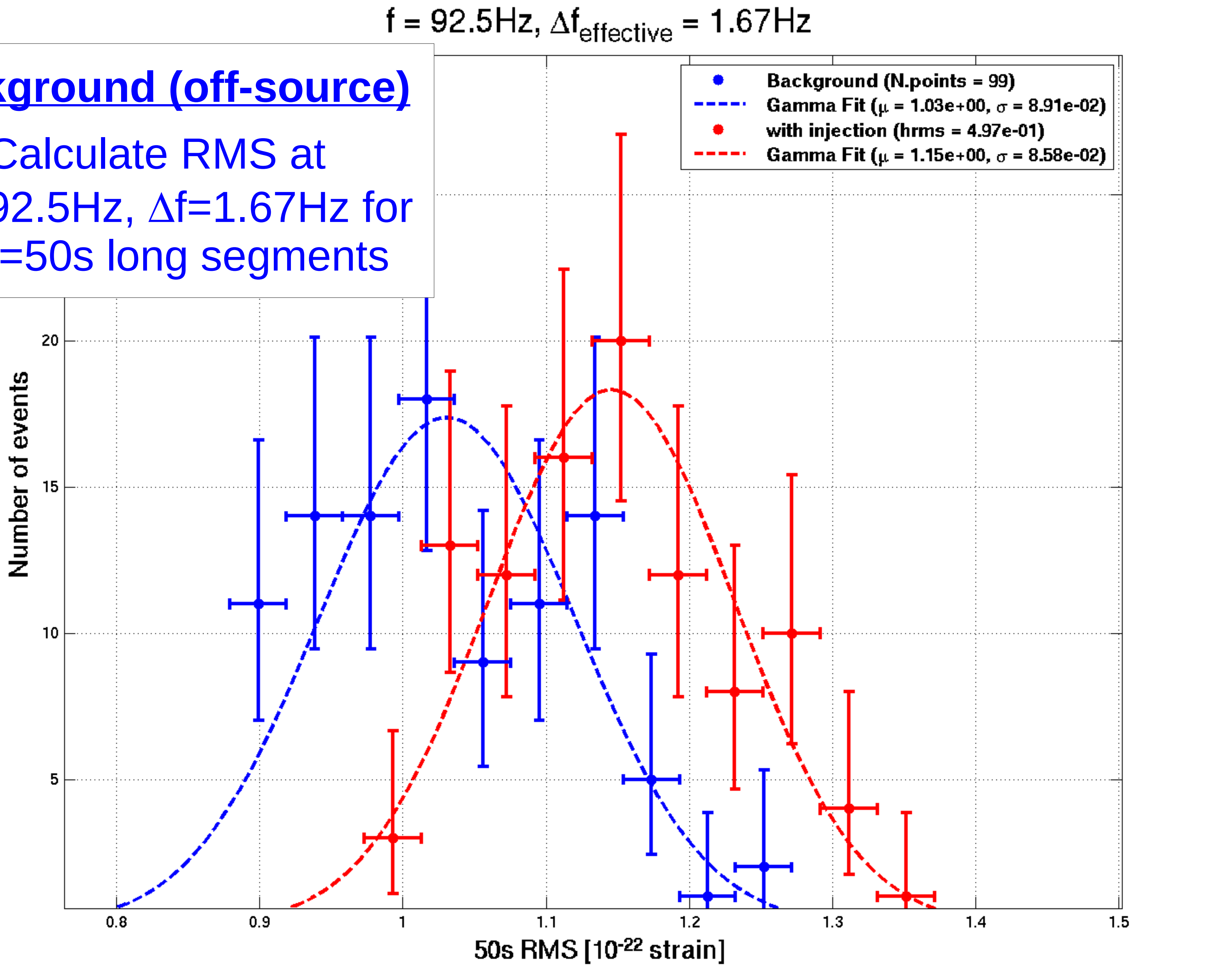
Off-source segments

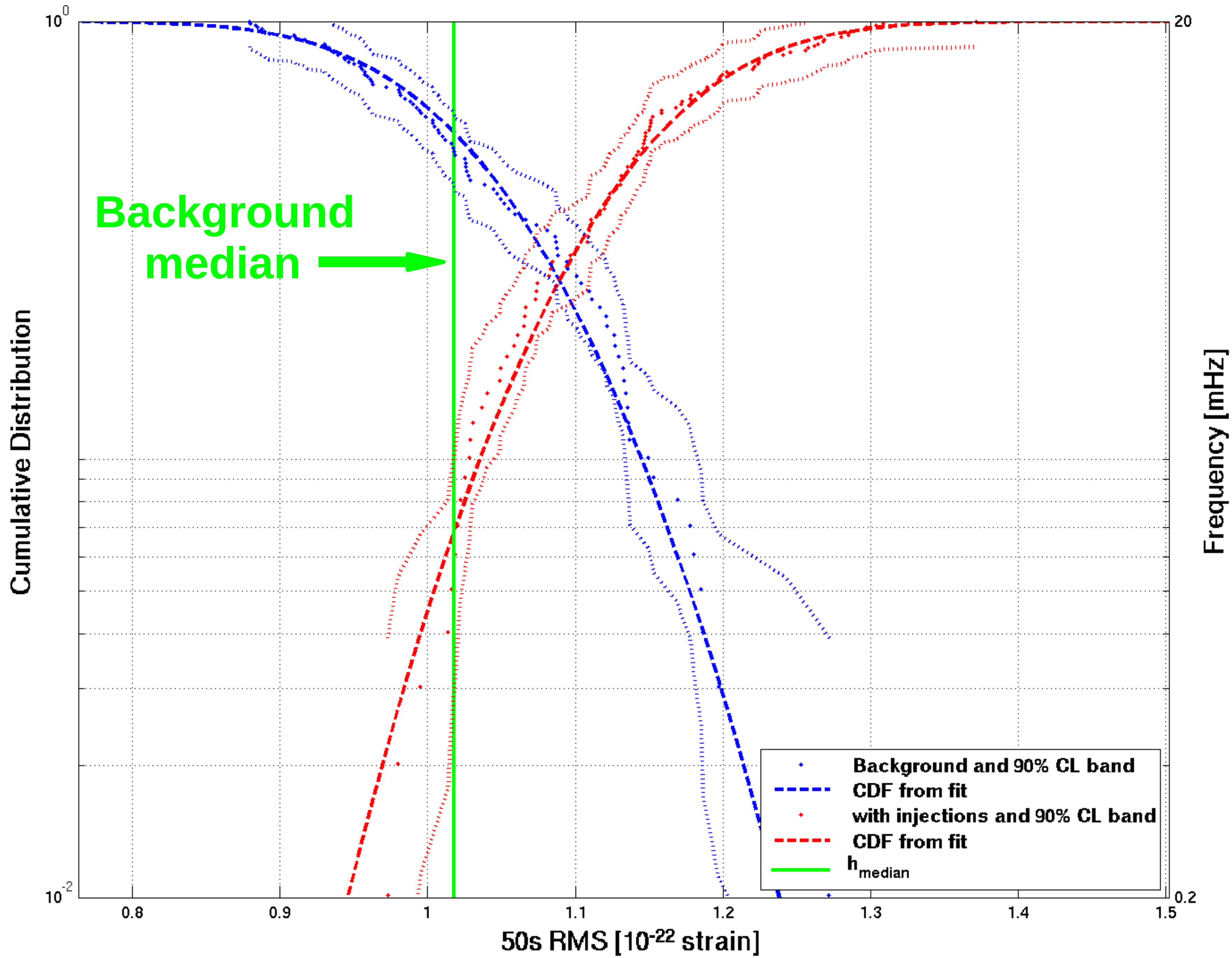
- time segments corresponding to periods after the end of the 6-min long pulsating tail

Background estimation

Background (off-source)

Calculate RMS at f=92.5Hz, Δf=1.67Hz for T=50s long segments





Background
median
Cumulative Distribution
Frequency [mHz]
50s RMS [10^{-22} strain]
10^0
10^{-2}
20
0.2
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Background and 90% CL band
CDF from fit
with injections and 90% CL band
CDF from fit
h_{median}

Background (off-source) with software injection

Performance of H1

- useful number to characterize the sensitivity search

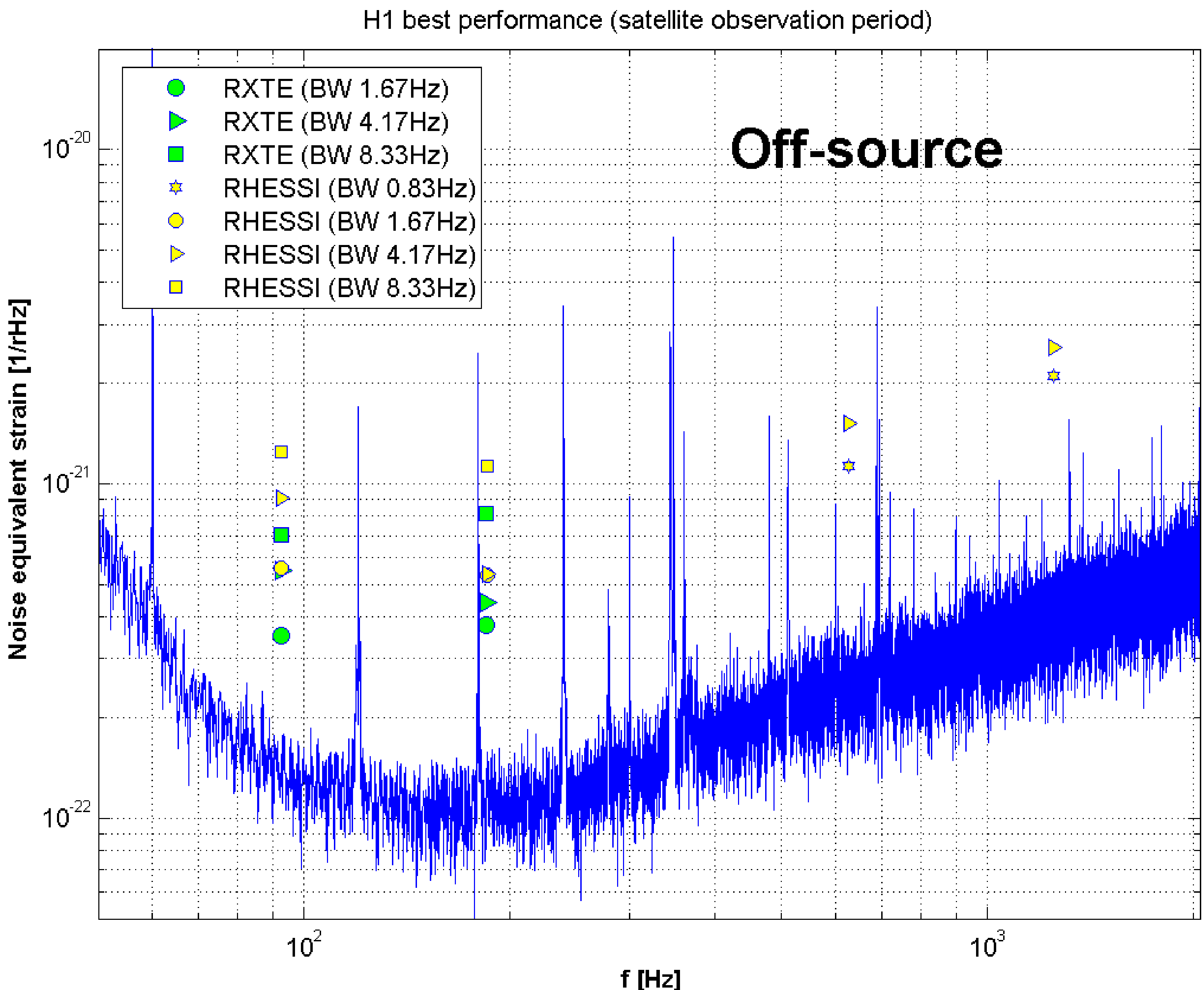
software injection of monotonic signal to estimate performance

- determine injection RMS such that the resulting signal is 90% of the time greater than background median
  - » upper curve of the 90% confidence belt is used

$$h_{rms} \sim 5 \times 10^{-23} \text{ strain}$$

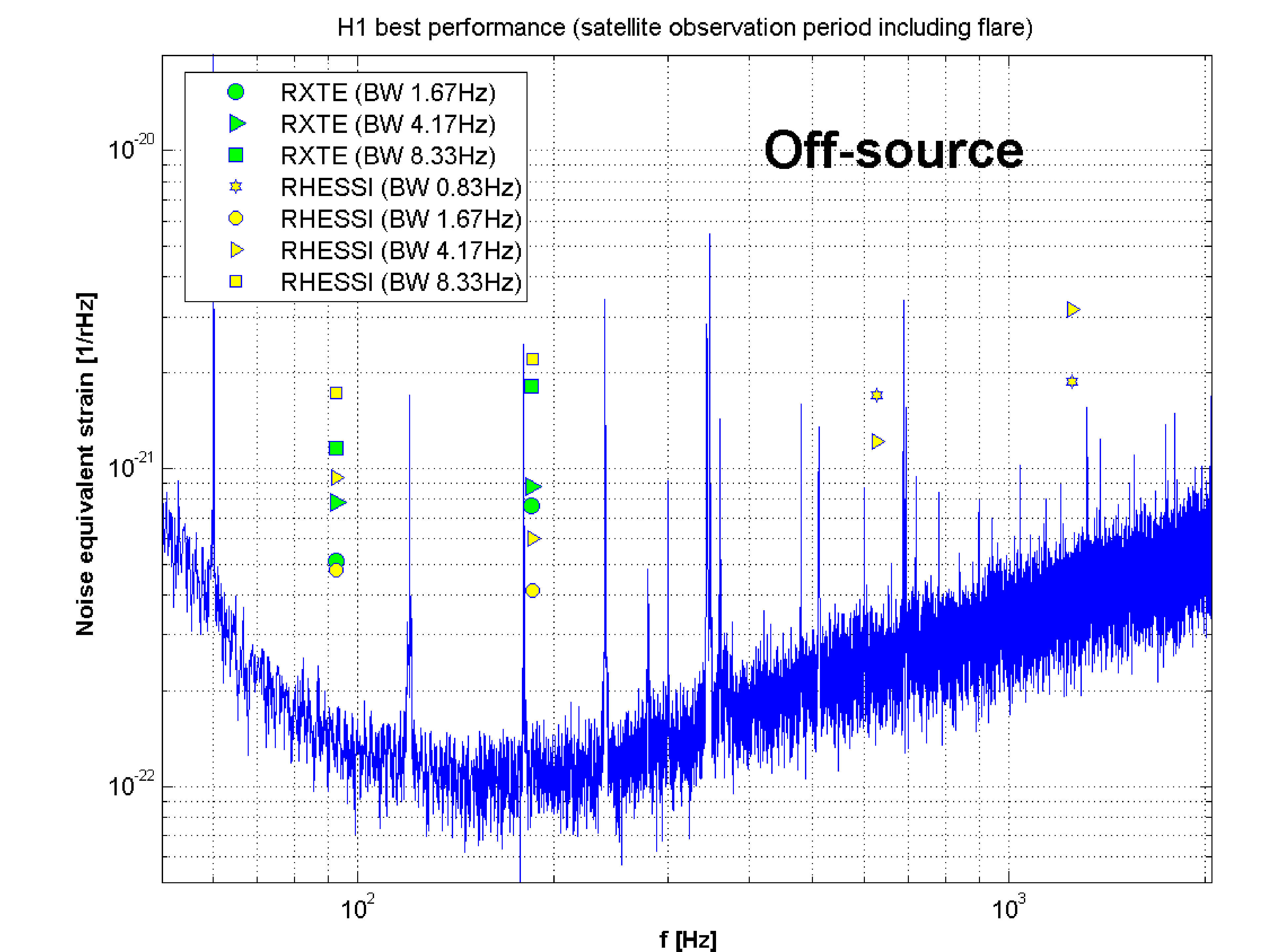
Results

H1 best performance
(satellite observation period)



H1 best performance (satellite observation period)
RXTE (BW 1.67Hz)
RXTE (BW 4.17Hz)
RXTE (BW 8.33Hz)
RHESSI (BW 0.83Hz)
RHESSI (BW 1.67Hz)
RHESSI (BW 4.17Hz)
RHESSI (BW 8.33Hz)
Off-source
Noise equivalent strain [1/rHz]
10^{-20}
10^{-21}
10^{-22}
10^{2}
10^{3}
f [Hz]

H1 best performance (satellite observation period including flare)



H1 best performance (satellite observation period including flare)
RXTE (BW 1.67Hz)
RXTE (BW 4.17Hz)
RXTE (BW 8.33Hz)
RHESSI (BW 0.83Hz)
RHESSI (BW 1.67Hz)
RHESSI (BW 4.17Hz)
RHESSI (BW 8.33Hz)
Off-source
Noise equivalent strain [1/rHz]
10^{-20}
10^{-21}
10^{-22}
10^{2}
10^{3}
f [Hz]

Legend

Green Markers (RXTE observations)

- estimating performance at 92.5 Hz and its double frequency
  - » circles – 1.67 Hz bandwidth
  - » triangles – 4.17 Hz bandwidth
  - » squares – 8.33 Hz bandwidth
- **Yellow Markers (RHESSI observations)**
- estimating performance at 92.7 Hz, its double frequency, 626.5 Hz and its double frequency
  - » stars – 0.83 Hz bandwidth
  - » circles – 1.67 Hz bandwidth
  - » triangles – 4.17 Hz bandwidth
  - » squares – 8.33 Hz bandwidth

Sensitivity of the search

In terms of energy $(E_{gw})^{iso}$

“Best”

$(E_{gw})^{iso} \sim 2 \times 10^{-8} M_{sun} c^2$

QPO at 92.5Hz, Δf=1.6Hz

“Worst”

$(E_{gw})^{iso} \sim 4 \times 10^{-4} M_{sun} c^2$

QPO at 1253Hz, Δf=4.17Hz

$(E_{gw})^{iso}$ would be the lowest detectable energy radiated in the duration and frequency band we searched from a source at a distance of 10kpc that radiates isotropically with equal power in the two independent polarizations. The analysis made use of off-source segments so $(E_{gw})^{iso}$ provides a useful number to characterize the sensitivity of the search.

Conclusions and future plans

Off-source analysis

- provides a measure of H1's performance at the time of the satellite observations

Performance measures indicates the analysis is quite sensitive and interesting

- proximity of the source makes this exciting

Next step:

- provide on-source results

Soft Gamma *Repeaters* (SGRs)

- foresee to repeat the analysis of future flares.

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