Source tracking for Sco X-1

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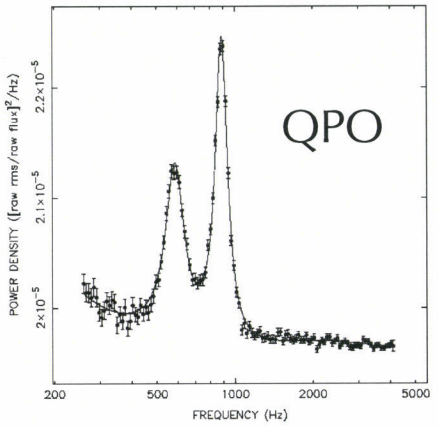
Abstract

Measured spin frequencies of Neutron stars in Low Mass X-ray Binaries (LMXBs) show that there is a limiting mechanism on the increase in spin frequency due to the accretion torque. One possible limiting mechanism may be gravitational radiation, making LMXB sources such as Sco X-1, the strongest X-ray source in the sky, important from the view of GW detection. Most current models assume the GW radiation emitted to be a continuous signal. It is quite possible, however, that the nature of this signal is different. We adopt an "eyes-wide-open" approach and propose to monitor Sco X-1 for burst-like signals. In our approach, data from multiple detectors is optimally combined to yield time series for the estimated h+ and hx components emanating from the location of Sco-X1. These time series are then scanned for a variety of burst-like signals. We report simulation results on the detectability of un-modeled bursts and long, quasi-monochromatic gravitational wave signals from Sco X-1, using excess power method and a template based search respectively.

Sco X-1

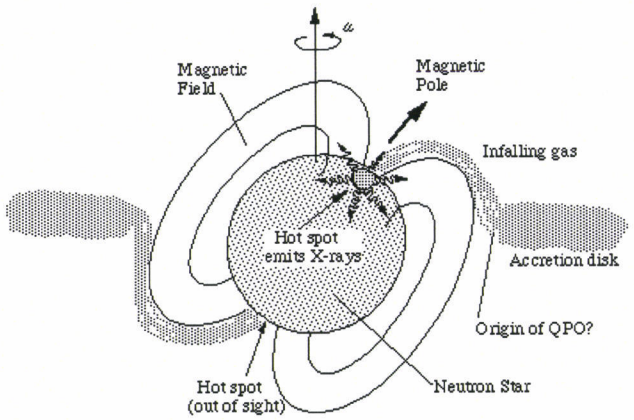
- Low-mass X-ray binary, the strongest X-ray source on the sky
- In Sco X-1, high energy X-ray emission events, such as Quasi-Periodic Oscillations are observed.
- Search for continuous periodic GW signals has been completed using LIGO S2 data(PRD76 082001, 2007)



RXTE, NASA

Astronomical parameters

right ascension	α	16h 19m 55.0850s
declination	δ	$-15^o\,38'\,24.9''$
proper motion (α direction)	μ_α	0.00036 arcsec yr^{-1}
proper motion (δ direction)	μ_δ	0.0141 arcsec yr^{-1}
distance	d	2.8 ± 0.3 kpc
orbital period	P	68023.84 ± 0.08 sec
time of periapse passage	$\bar{T}$	731163327 ± 299 sec
projected semi-major axis	a_p	$(4.33 \pm 0.54) \times 10^8$ m
eccentricity	e	$< 3 \times 10^{-3}$
QPO's frequency separation	$237 \pm 5\,\text{Hz} \leq \Delta\nu_{\text{QPO}} \leq 307 \pm 5\,\text{Hz}$	



NASA

Gravitational waves from Sco X-1

Possible GW excitation sources for Sco X1:

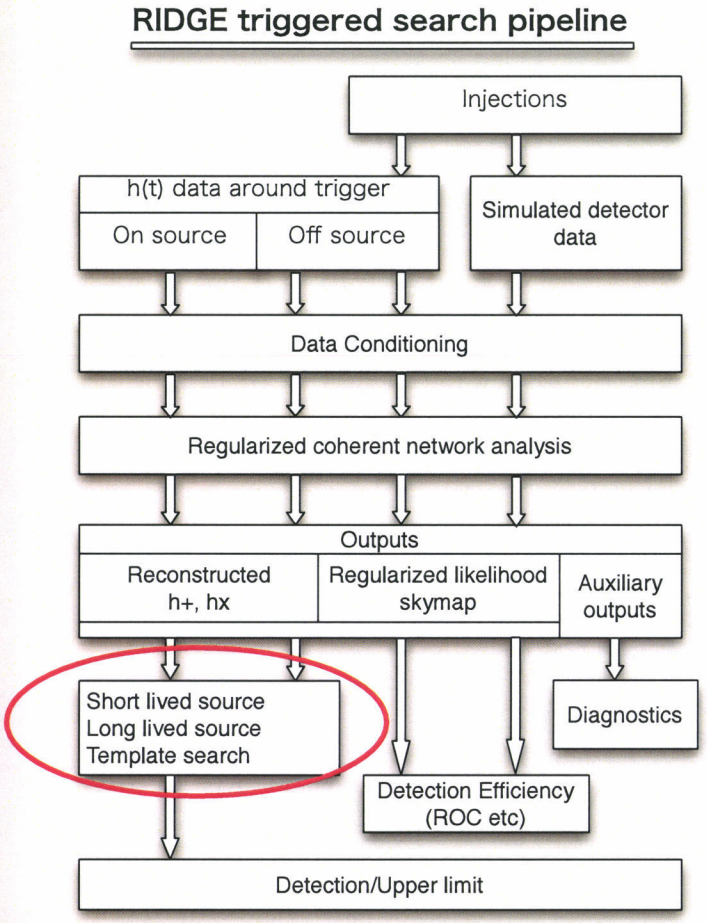
- X-ray bursts
- Quasi-periodic oscillation
- r-mode in young neutron star
- Accreting onto neutron star

We look for GWs that are associated not only with X-ray burst but also quiet phase of Sco X-1.

Our approach is
Monitor Sco X-1 using the global network of detectors.

Interferometric gravitational wave detector network

Coherent network analysis and Reconstruction of h+/hc

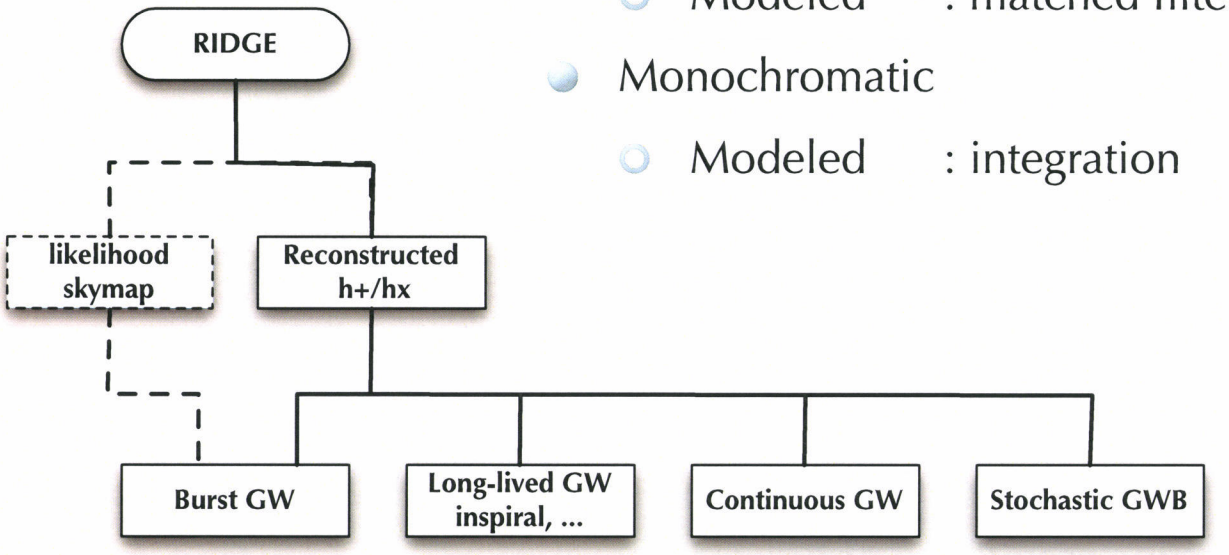


- RIDGE: a fully coherent network analysis pipeline. Hayama et al. CQG 2007
- RIDGE reconstructs polarization waveforms for any given direction on the sky.
- This feature makes it possible to monitor a specific known source for bursts or other types of signals by analyzing reconstructed h_+, h_x time series.
- Suitable for long-lived GW (SGR, LMXBs, ...)
- Source tracking: first linearly combine data from all detectors and then look for a variety of possible signal

Data analysis on reconstructed h_+/h_x

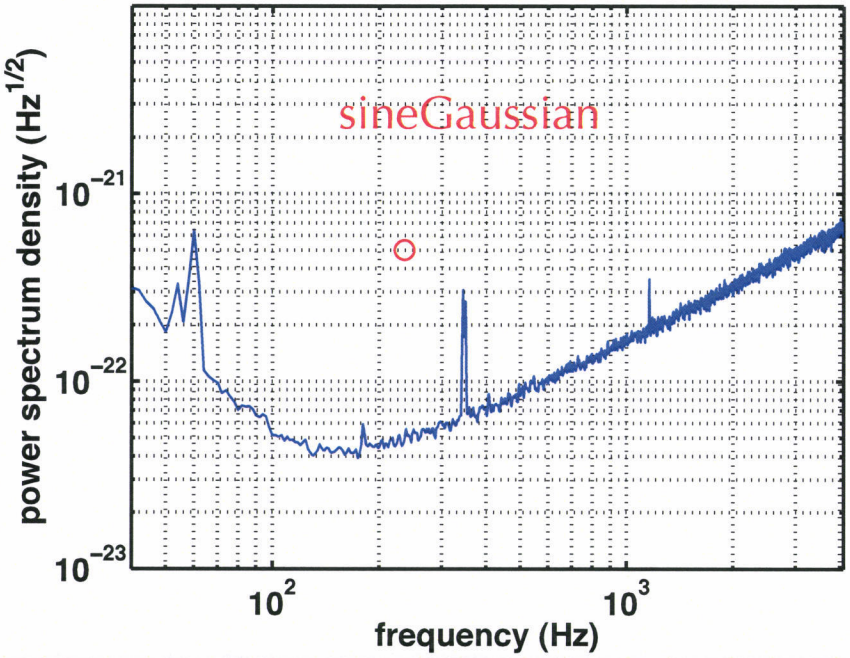
Demonstrations in this poster

- Burst GW
  - Un-modeled: excess power (Anderson et al, PRD 2001)
  - Modeled : matched filtering
- Long-lived GW -- binary inspiral
  - Modeled : matched filtering
- Monochromatic
  - Modeled : integration

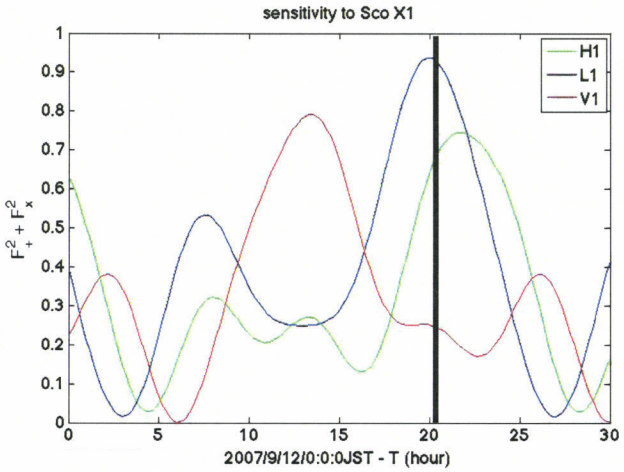


Detection of Burst GW

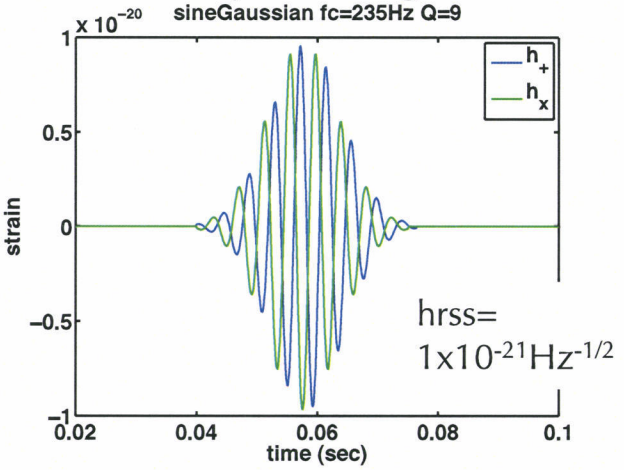
- Data: Simulated LHO 2km/4km, LLO, VIRGO noise
- Injected signal: sineGaussian, 235Hz, Q=9, hrss=[3, 5]x$10^{-22}$$Hz^{-1/2}$, Circular polarization.



Antenna pattern to Sco X-1

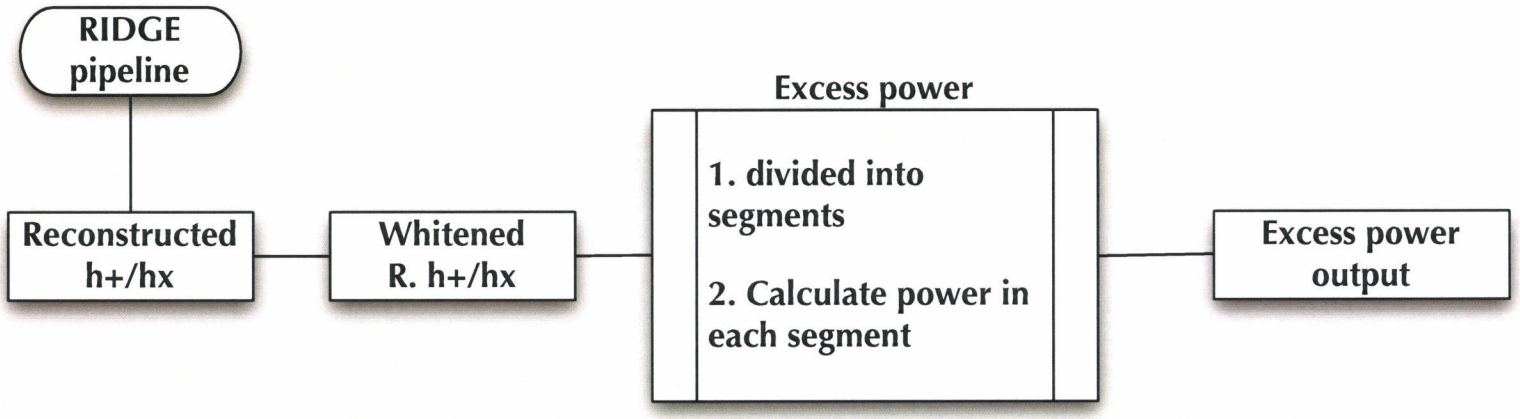


Injected signal



Excess power on reconstructed h+/hx

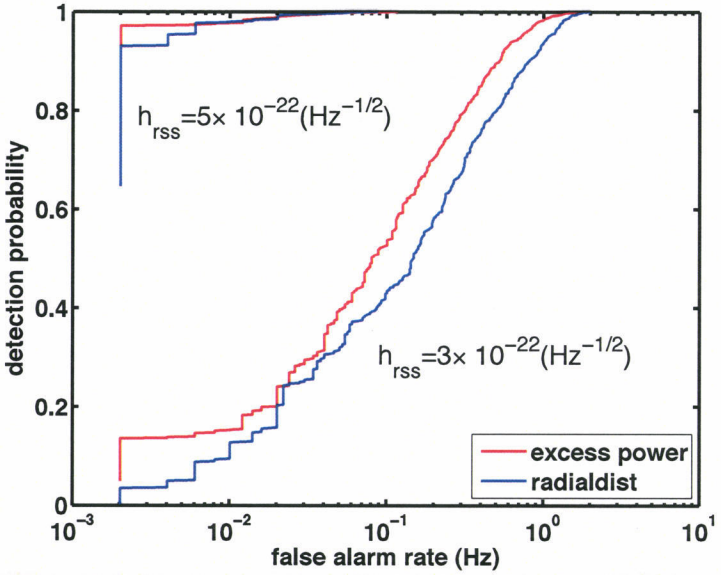
- Reconstructed h+/hx is contaminated with noise which is colored.
- Reconstructed h+/hx are whitened by a whitening filter, coefficients of which are estimated by noise-only data.
- The data is divided into segments with a given length and integrated over each segment.



Detection Efficiency

- The length of the segments is set to 20msec which is nearly optimal for the injected signal
- To evaluate the performance, ROC for radial distance(*) which is not optimized is putted on.
  - * The radial distance statistic is constructed from the entire sky map for a given segment: it does not use a particular direction.

Receiver Operating Characteristics

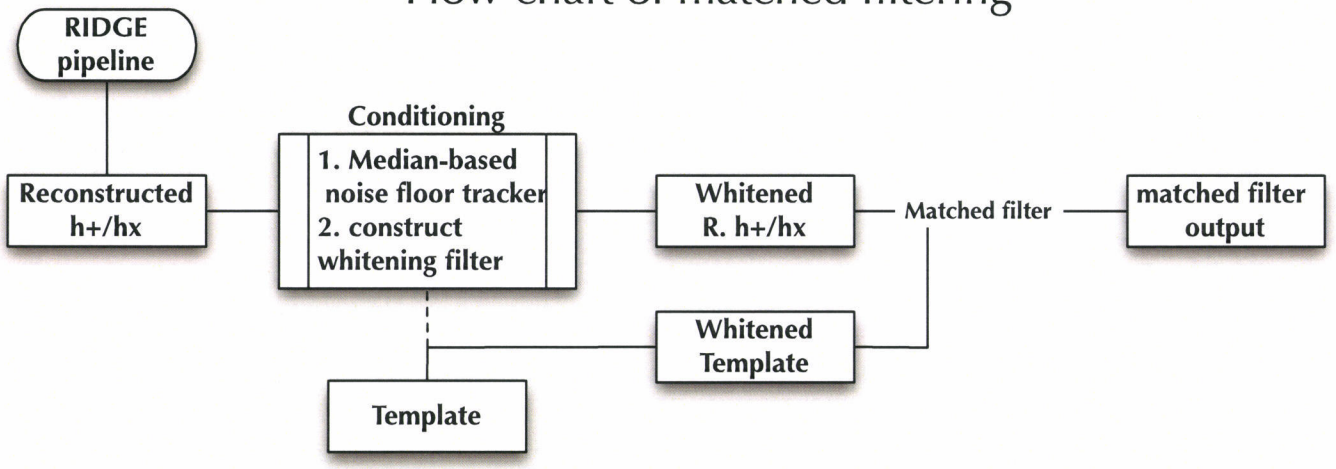


- Though the radial distance is not optimized, the result shows the excess power method on reconstructed h+/hx works well.

Matched filtering on reconstructed h+/hx

- The matched filtering method delivers good performance for modeled signals
- Exponential decay waveforms, which can be modeled by two basic parameters, are a possible type of GW signal from LMXBs
- We study matched filtering method on reconstructed waveforms for detection of such signals.

Flow chart of matched filtering



Burst-like gravitational waves

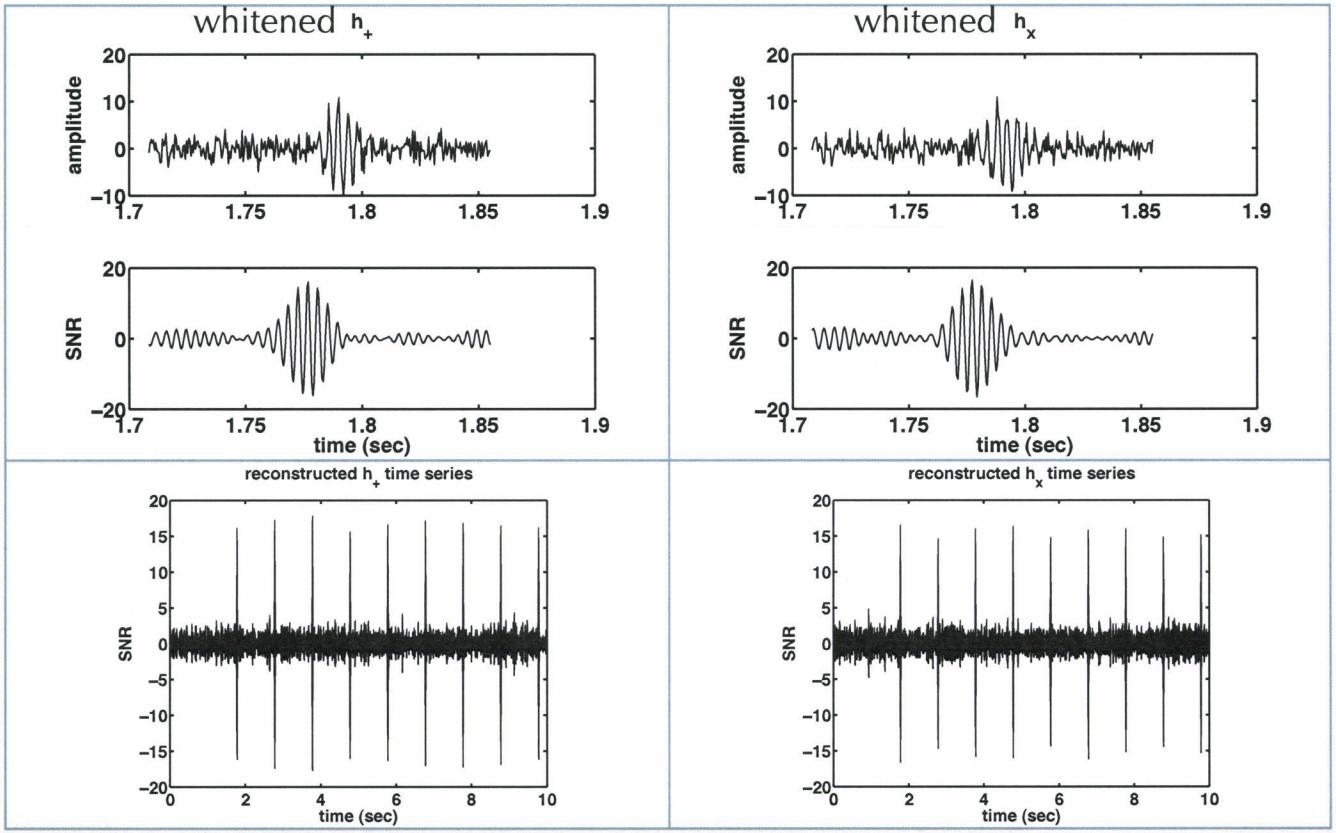
- Detection of sineGaussian signals
- The injected signal: sineGaussian 235Hz, Q=9, hrss=$5\times10^{-22}Hz^{-1/2}$
- Demo. of the detection of ringdown is in our poster on pulsar glitches

Hayama et al. Coherent network search for detection of pulsar glitches

Top:
Conditioned data

Middle:
Corresponding matched filter output
The template is the same as the injected signal

Bottom:
Matched filter output
As the figure shows, Injected signals in every seconds are detected with SNR >15

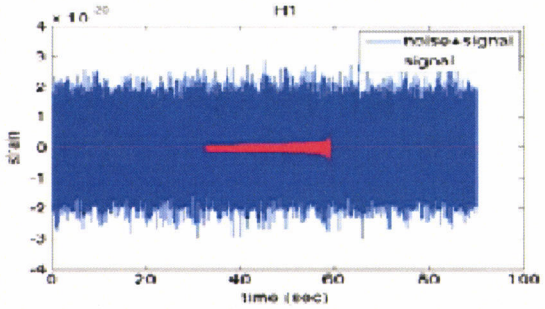


long-lived gravitational waves: inspiral

- Injected signal: 1.4sol-1.4sol inspiral
- Detector loction: H1, H2, L1
- Detector noise: White Gaussian noise

- SNR

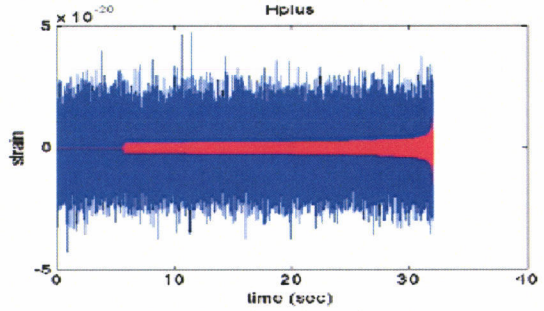
  (H1, H2, L1)=(22.2,22.2,5.5)

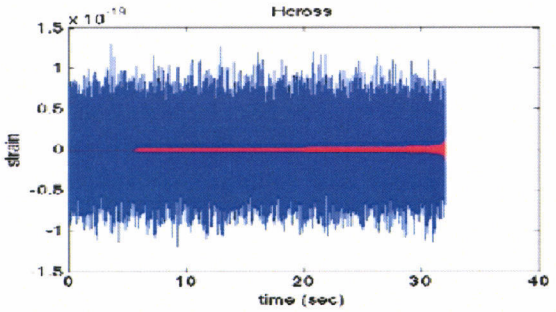


- SNR

  h_+: 28.5

  h_x: 7.5



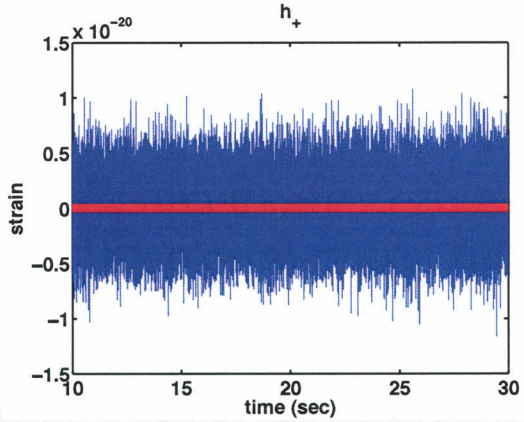


Periodic gravitational waves

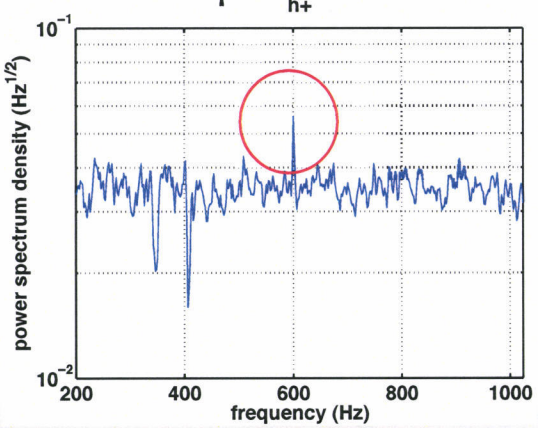
- Gravitational waves which are introduced as a mechanism to arrest accretion torques can be an important source for the advanced LIGO (L. Bildsten astro-ph0212004)
- We study the detection of periodic gravitational waves by the data analysis on reconstructed h+/hx
- This enable to search for h+ and hx independently.
- The reconstructed h+/hx are whitened and the spectrum care calculated.

Injected periodic waves : 600Hz, hrss=$2\times10^{-21}Hz^{-1/2}$

conditioned h+



spectrum



Summary

- We propose to do source tracking for Sco X-1, the brightest X-ray emitting low-mass X-ray binary using a coherent network analysis approach
- Coherent network analysis can reconstruct both polarization waveforms. This enable to do analysis h+/hx independently. This opens up the possibility of searching for a wide variety of signals after optimally (and linearly) combining data from a network of detectors
- We show data analysis for bursts/modeled/continuous sources on reconstructed h+/hx using simple excess power method, matched filter method.
- We find that, even in its present simple form, the idea of source tracking is a viable and promising one.
- An important issue is how to deal with GW signals that occur in the data and which have no connection with Sco-X1 as they may affect the reconstructed h+,hx time series for the latter. We are investigating this at present.