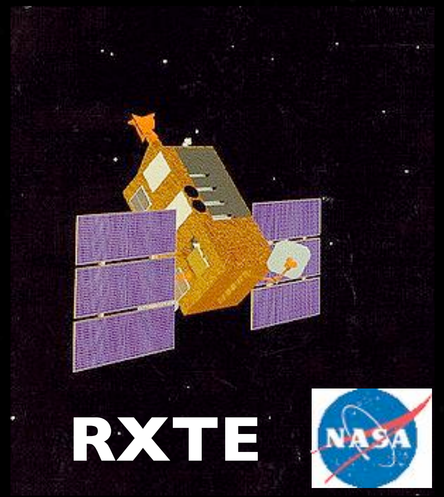
LIGO-RXTE coincidence search for GWs from Sco X-1

Kazuhiro Hayama, Chris Messenger
(AEI Hannover)



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Sco X-1 -- Low-Mass X ray Binary (LMXB)

Questions in Sco X-1, and LMXBs

- Spin frequency
- Mechanism of low (5-20Hz) and high (kHz) frequency QPOs
- Limiting mechanism on the increase in spin frequency due to the accretion torque

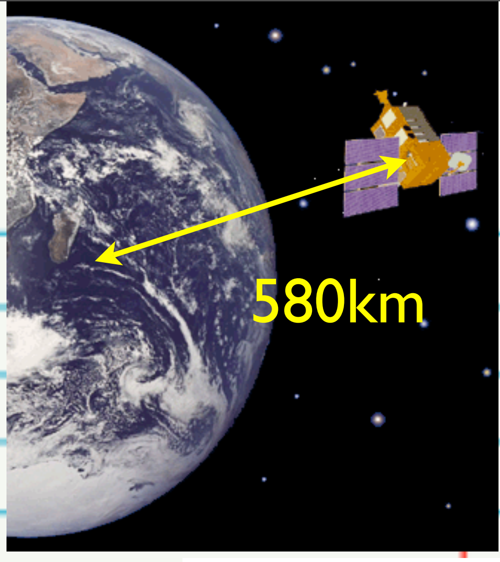
Gravitational waves

- Gravitational radiation for balancing accretion torque (Bildsten,1998)
- GW bursts induced by r-mode
  Typical duration: ~180ms, Egw < ~$10^{-4} M_\odot$ (Drago,A. et al. A&A,2006)
- Bursts by phase changes of NS core due to crust caused by accreting mass. Damping time scale: < ~ 10ms
  (Coccia, E. et al. PRD, 2004)

All mechanisms that generate GW bursts are likely to produce X-ray, gamma-ray and therefore it might be possible a simultaneous detection of photons and GWs.

We propose to analyze both RXTE and LIGO time-series data, and coincidence analysis during S5 data (~ 1 day)

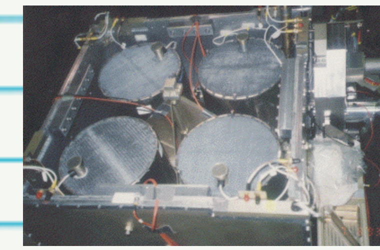
The Rossi X-ray Timing Explorer (RXTE)

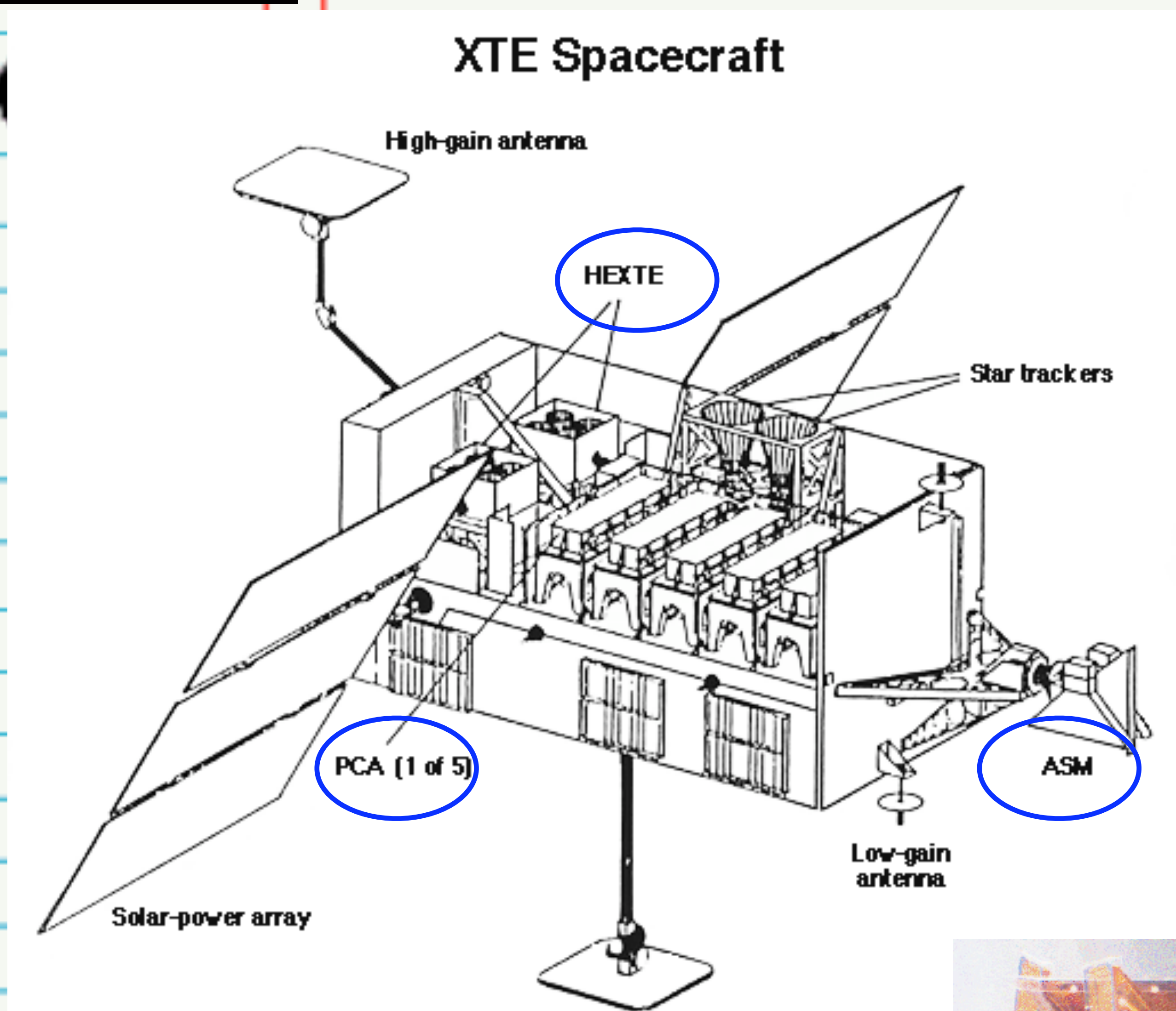


from 30 Dec. 1995
to the present

High Energy X-Ray Timing Experiment (HEXTE)

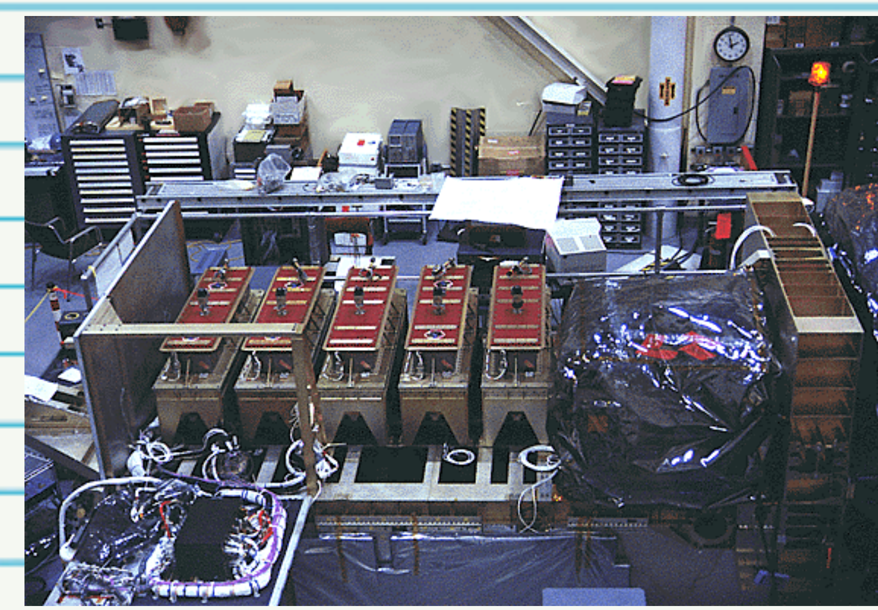
15-250 keV energy range





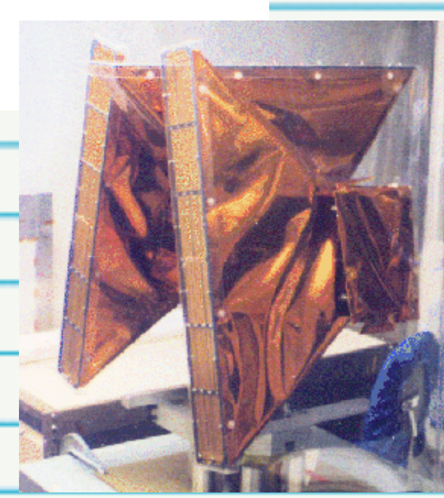
Proportional Counter Array (PCA)

- o 2-60 keV energy range
- o time resolution : ~1 microsec



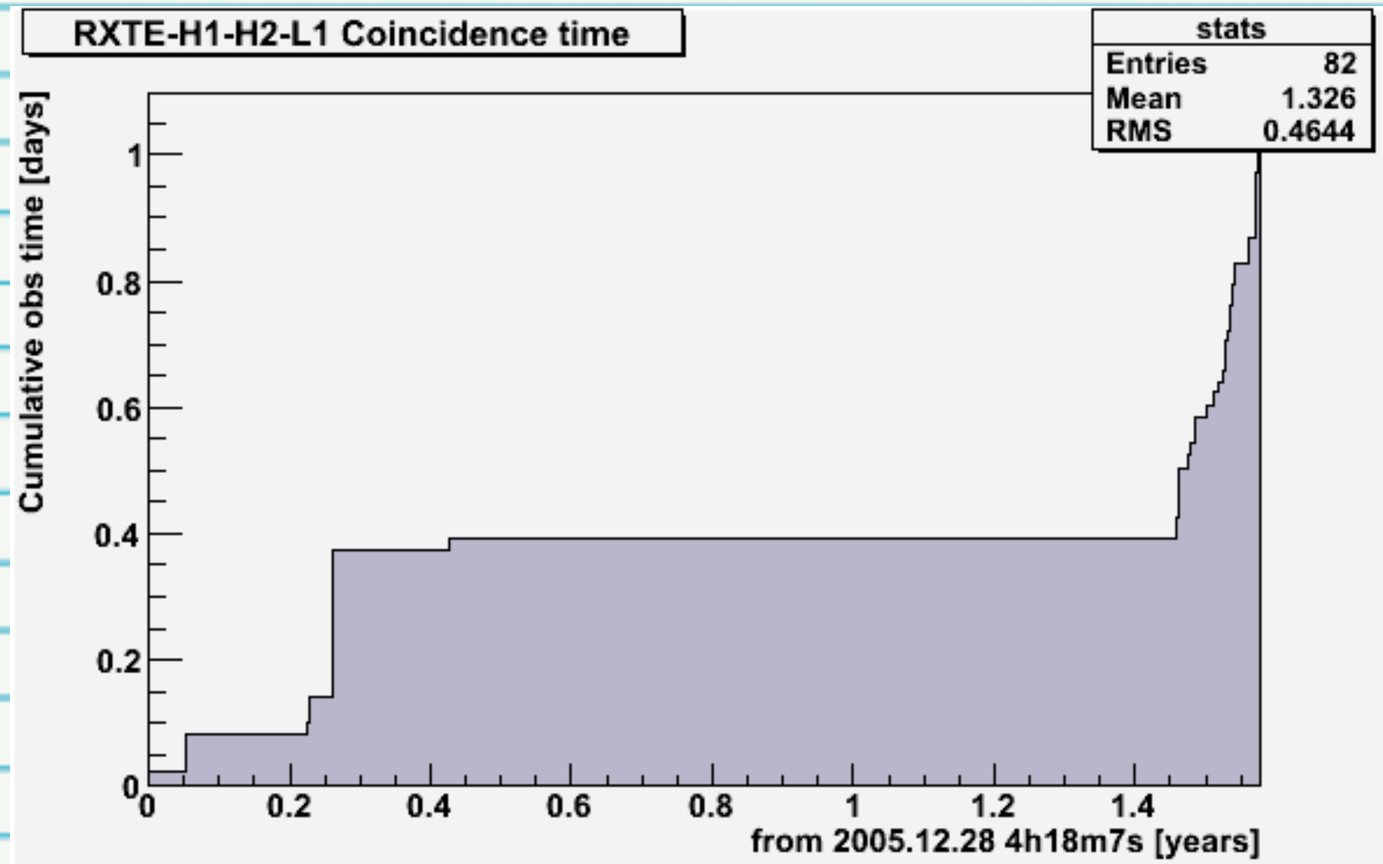
All Sky Monitor(ASM)

2-10 keV energy range



RXTE home page
http://heasarc.gsfc.nasa.gov/docs/xte/xtegof.html

LIGO - RXTE coincident data during S5



Coincident time with S5:
RXTE-H1-H2-L1 : ~1 day
RXTE-H1-L1 : ~1 day
RXTE-H1-L1-V1 : 6.3 min

Should be shorter

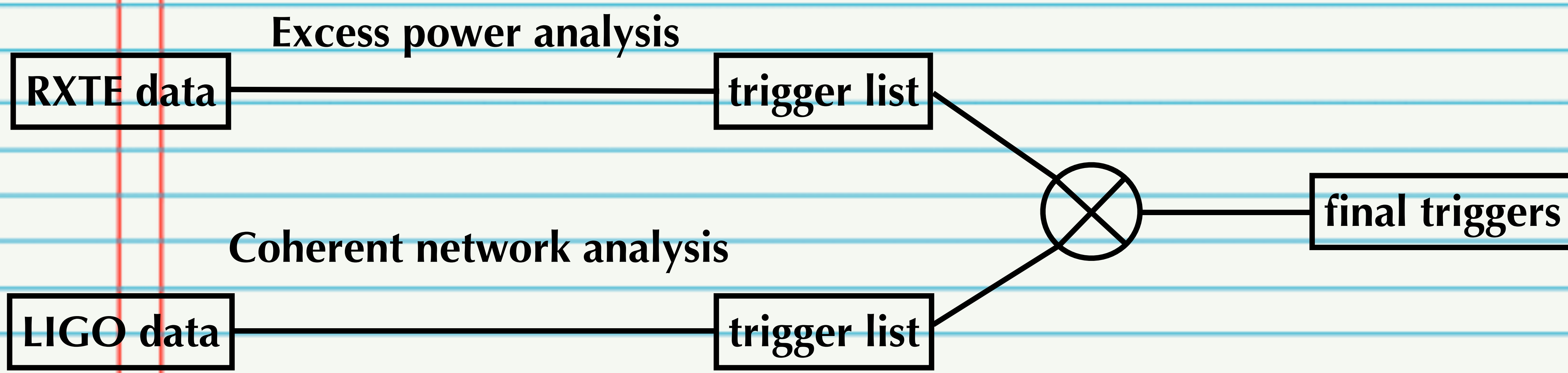
Good News

RXTE mission has been extended to 2010, observations will overlap with the S6 run.

LIGO - RXTE Coincident analysis

Mechanisms that generate GW bursts → X-ray, gamma-ray

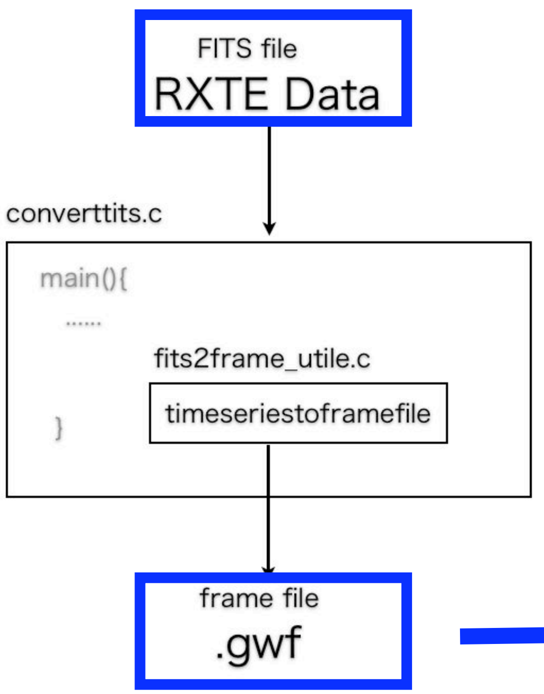
Simultaneous detection of photons and GWs.



- To generate RXTE event trigger list by excess power analysis
- To generate GW event trigger list by source tracking
- To do coincidence analysis by two trigger lists

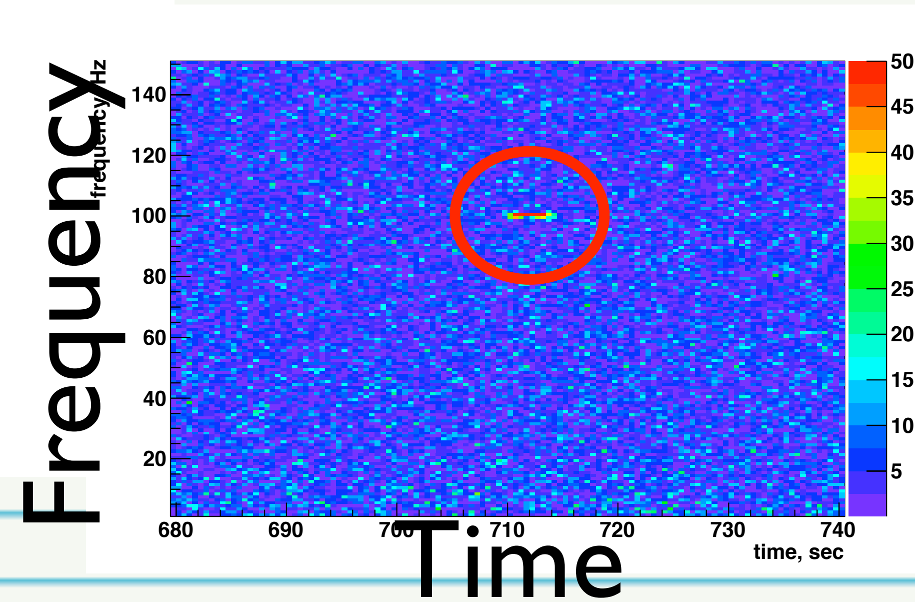
Method used in LIGO-TAMA burst search(**Phys. Rev. D 72, 122004 (2005)**)

LIGO - RXTE Coincident analysis



RXTE data analysis

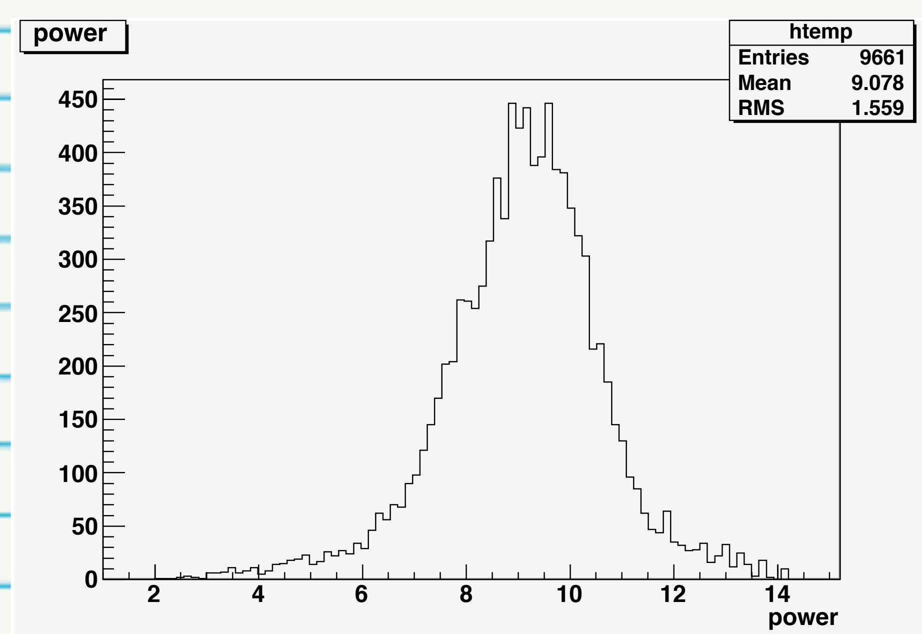
- Convert RXTE FITS file to frame file
- Apply excess power method (existing LSC pipeline)



Event list

Example of RXTE data analysis using WaveBurst:

Histogram of power of triggered events



GPS time:
Time overlapped with LIGO S5

Triggered events by WB:
9961 events
Bandwidth : 32 -- 500Hz
Duration : 1 -- 380ms

RXTE data is open in public from NASA webpage

LIGO - RXTE Coincident analysis

LIGO data analysis

- **Directional search**
  - Tracking Sco X-1 with multiple detectors
  - Coherent Network Analysis

$$\underbrace{\begin{bmatrix} x_1(t) \\ \vdots \\ x_d(t) \end{bmatrix}}_{\mathbf{x}} = \underbrace{\begin{bmatrix} F_{1+}(\theta,\phi) & F_{1\times}(\theta,\phi) \\ \vdots & \vdots \\ F_{d+}(\theta,\phi) & F_{d\times}(\theta,\phi) \end{bmatrix}}_{\mathbf{A}} \underbrace{\begin{bmatrix} h_+(t) \\ h_\times(t) \end{bmatrix}}_{\mathbf{h}} + \begin{bmatrix} n_1(t) \\ \vdots \\ n_d(t) \end{bmatrix}$$

data = detector response x gravitational wave + noise

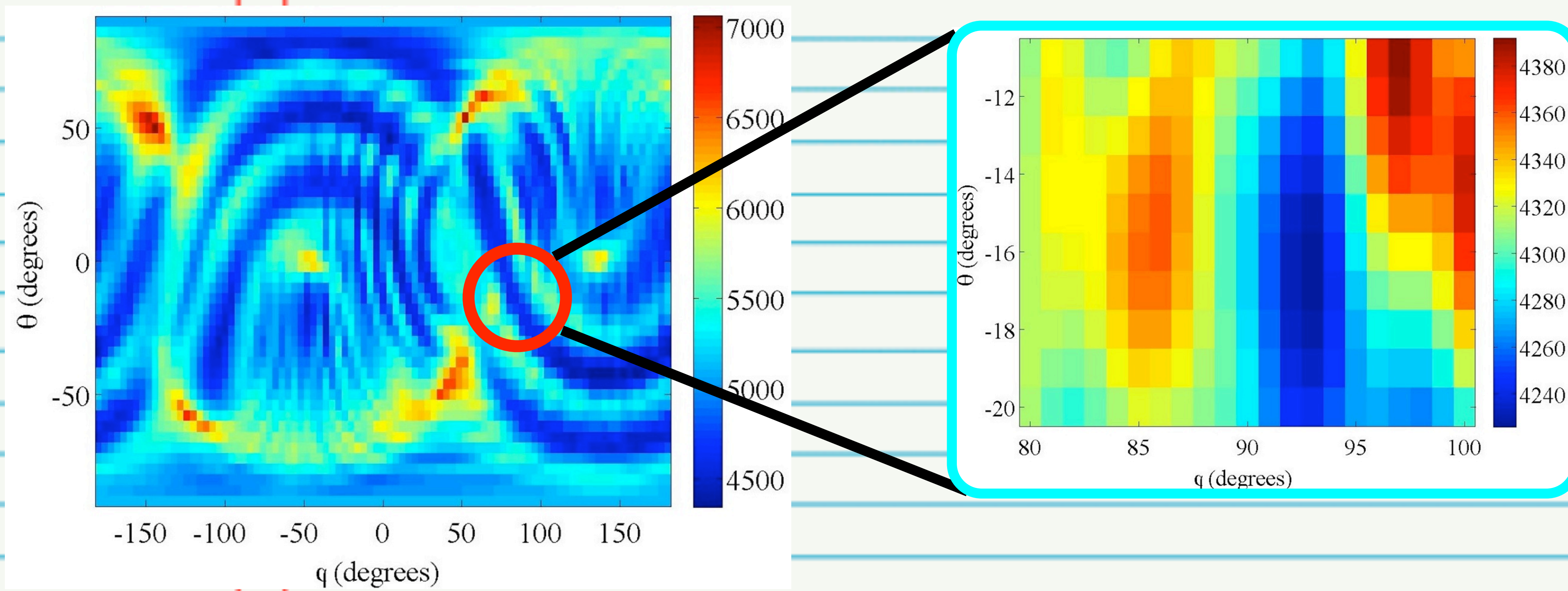
$$L = \mathrm{argmin}\,(\| \mathrm{x} - \mathrm{Ah} \|) \qquad h = (A^T A)^{-1} A^T x$$

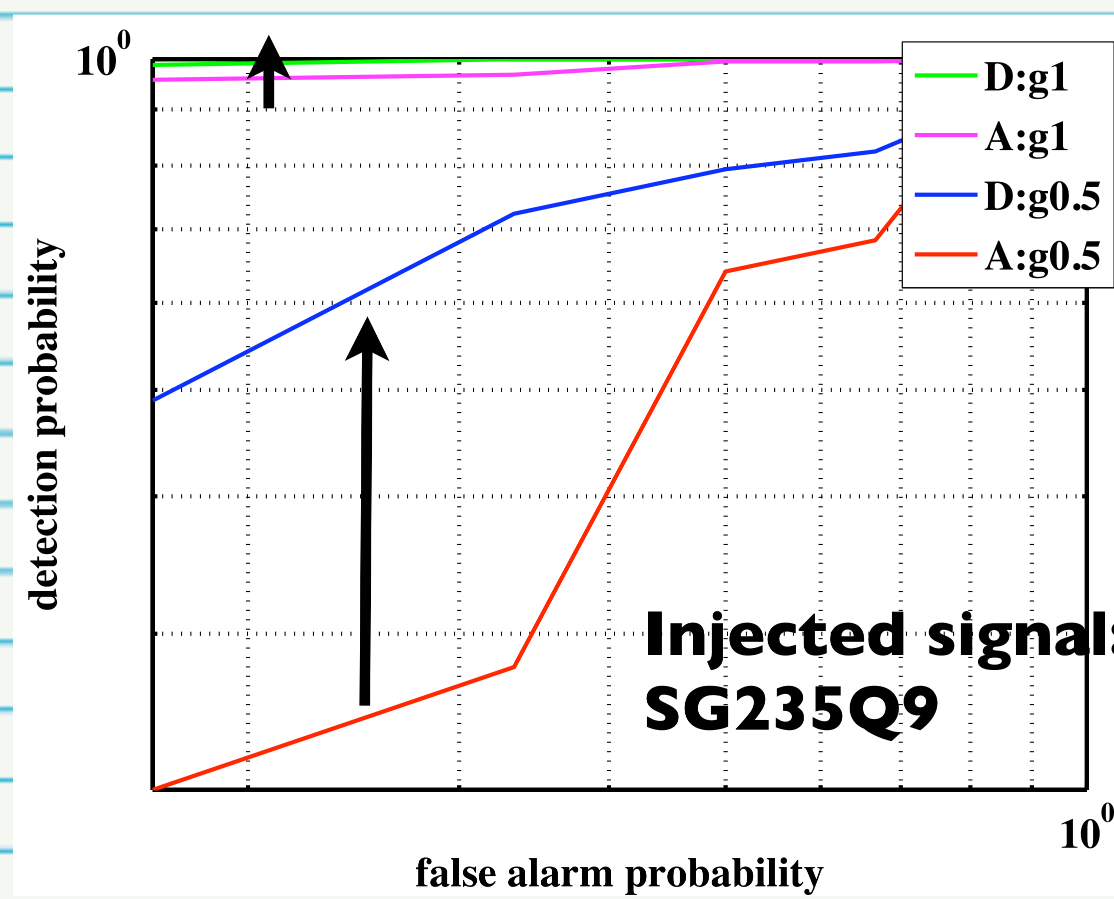
- Improvement of detection efficiency

Regarding directional search, A is known. ⟶ Reduce parameter space

New Veto analysis for directional search

Reduction of sky-map parameter space





D: Directional Search
A: All Sky Search

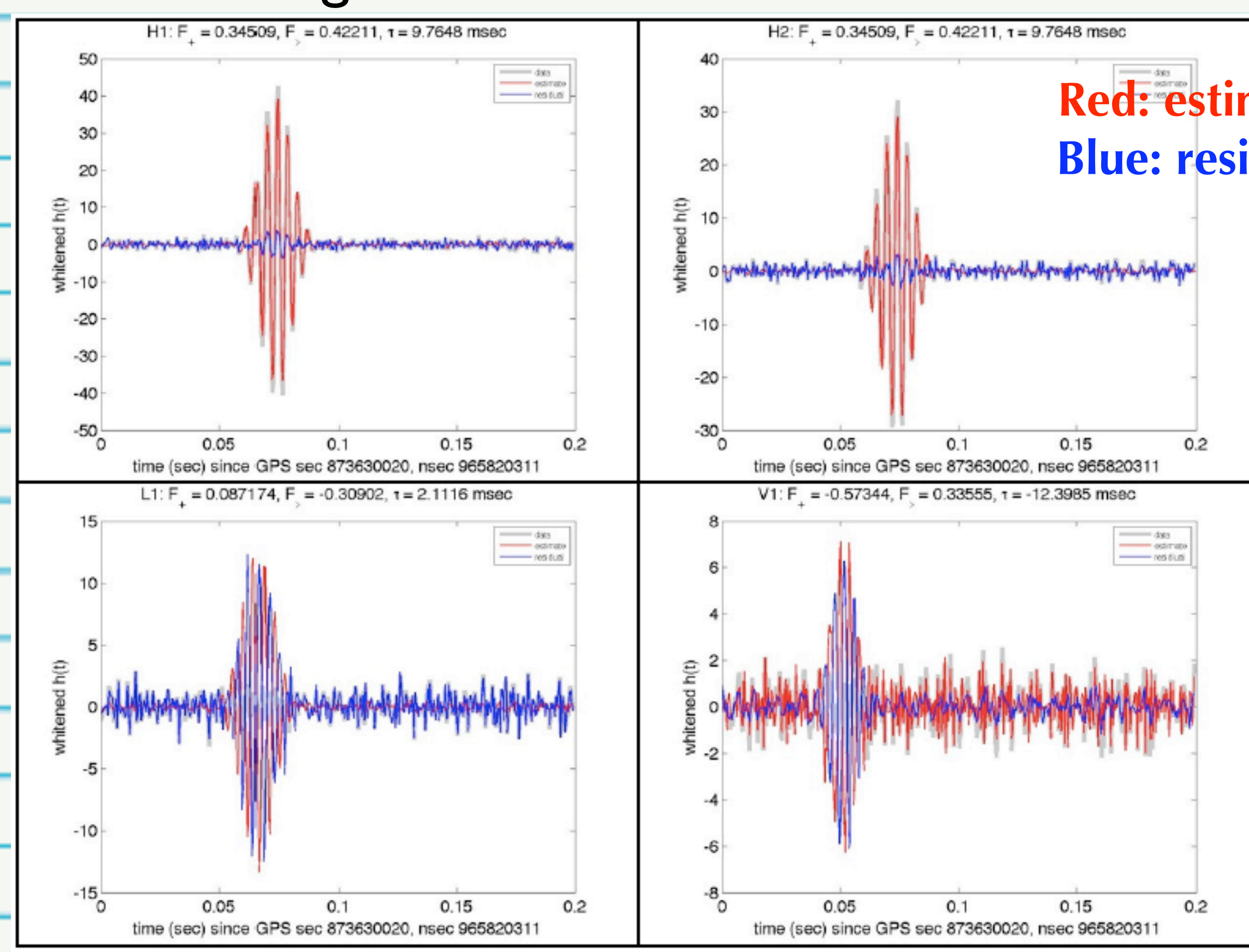
Equal residual veto statistics at Sco X-1

with S. D. Mohanty

Equal residual veto(ERV)

- ML method tries to minimize residual (=energy of |detector response - reconstructed detector response|)
- This minimization causes over-fitting (below)
- Value of residual can be used for veto
- ERV reject signals which have large residual [e.g. H1-H2 glitches, L1 glitches]

H1-H2 glitch　　　　simulated data

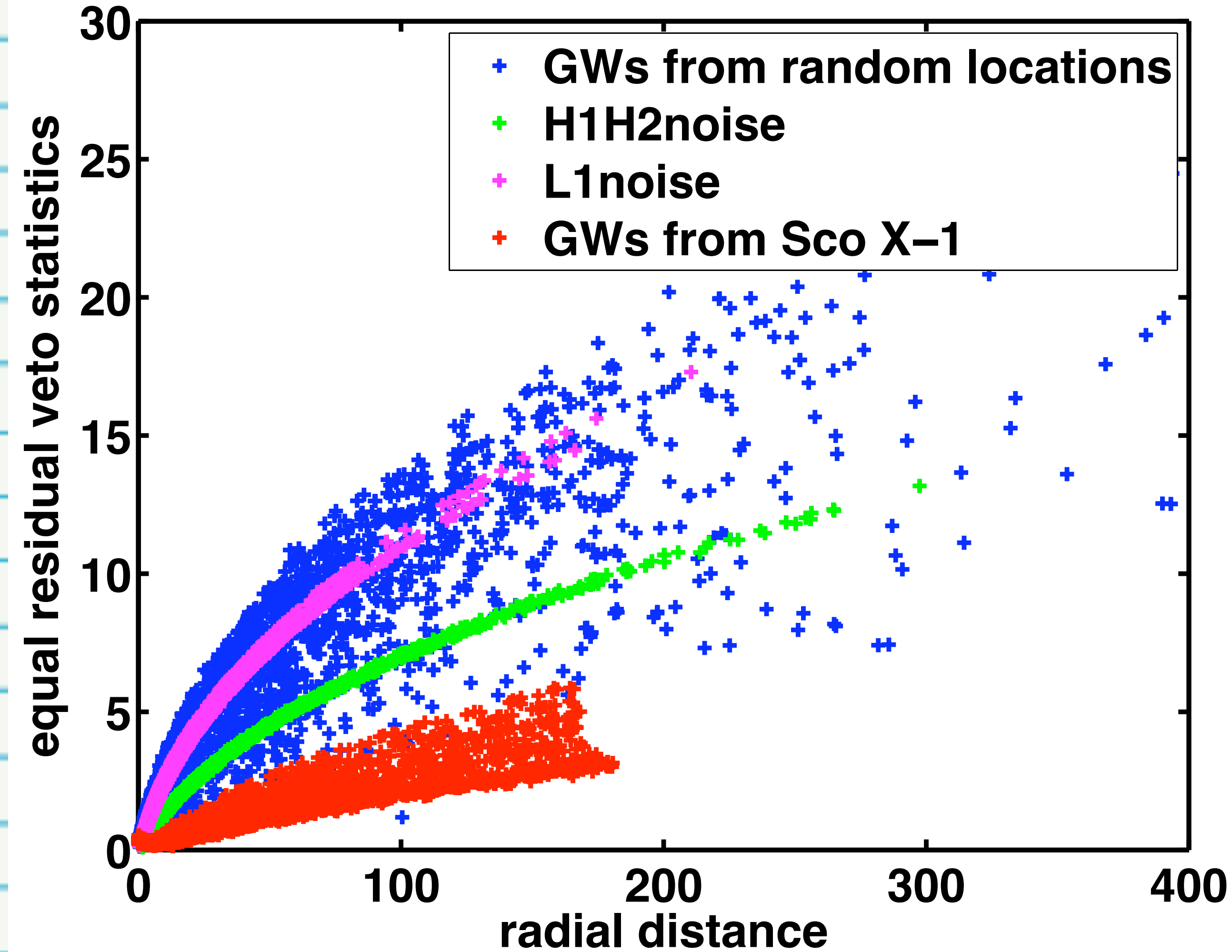


Equal residual veto statistics at Sco X-1

Since signals such as L1 glitches, GWs from other directions have larger residuals at Sco X1 location than GWs from Sco X-1,
giving threshold, we can kill H1H2, L1 glitches and GWs from other directions

Injected signals:
SG235Q9 signals as H1H2, L1 glitches, GWs . hrss are (0-10]e-21$Hz^{-1/2}$.

simulated data



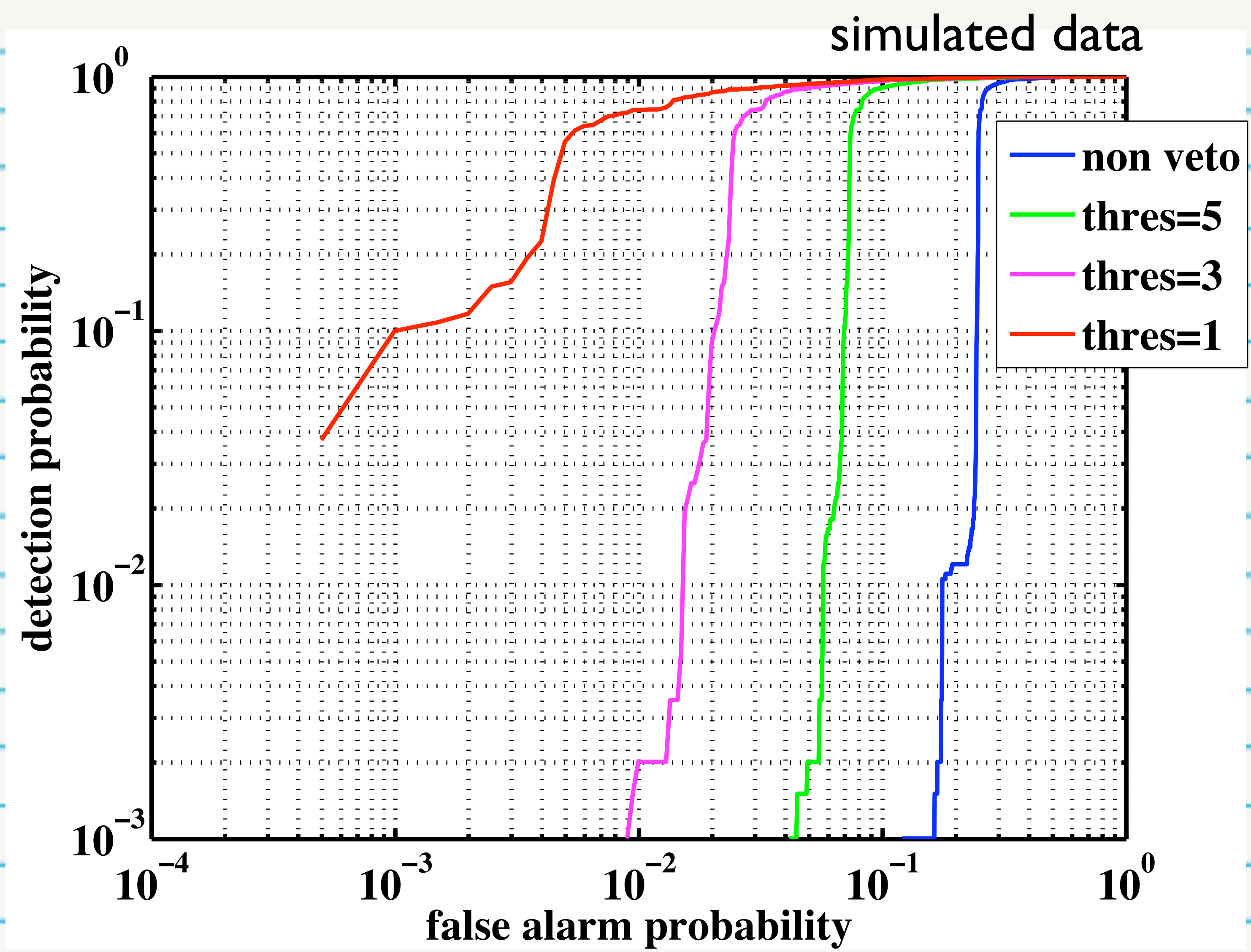
Radial distance:

$$R_{\rm rad} = \left[\left(\frac{\max_{\theta,\phi}\mathrm{S}(\theta,\phi)}{\max_{\theta,\phi}\overline{\mathrm{S}}_0(\theta,\phi)} - 1\right)^2 + \left(R_{mm}\frac{\min_{\theta,\phi}\overline{\mathrm{S}}_0(\theta,\phi)}{\max_{\theta,\phi}\overline{\mathrm{S}}_0(\theta,\phi)} - 1\right)^2\right]^{1/2}$$

$$\overline{\mathrm{S}}_0(\theta,\phi) = \mathrm{E}\left[\mathrm{S}(\theta,\phi)|\text{no signal in data}\right]$$

Equal residual veto statistics at Sco X-1

- GWs from Sco X1 are injected (SG235Q9)
- H1H2 glitches, L1 glitches with [0--10]e-21Hz$^{-1/2}$ are injected (SG235Q9)
- Events above given thresholds of the veto are removed
- Reasonable threshold can improve detection efficiency



Summary

- We proposed RXTE -- LIGO coincidence analysis method.
- Both RXTE and LIGO data are analyzed by LSC burst pipelines which are well tested and reviewed.
- We also hope serendipity that we find a new X-ray event with *new* tools in X-ray astronomy.

RXTE location