Monitoring of X-ray Binary Pulsars with Fermi/GBM

Peter Jenke

GBM Pulsar Monitor

PI C. A. Wilson Hodge

Large Area Telescope

20 MeV - 300 GeV

Triggering, localization and spectroscopy

Gamma Ray Burst Monitor

12 Sodium Iodide detectors

8.0 - 1000 keV

Triggering, localization and spectroscopy

2 Bismuth Germanate detectors

200 keV - 40 MeV

spectroscopy

Bridges gap between NaI and LAT

Small size vs. long observations

GBM is not an imagining instrument but has the advantage that it observes the entire unocculted sky all the time.

Large Instantaneous Field of View

>40,000 s/day for a typical source

For pulsed sources, the GBM pulsar monitor relies on Fourier techniques to extract the pulsed portion of a signal. Nevertheless, we often find ourselves relying on MAXI and Swift/BAT to inform us when a source might be detectable in GBM.

GBM Data Types

CTIME
- 8 channels (8-1000 keV for NaIs)
- 256 ms resolution
- Locations, long event search

CSPEC
- 128 channels (8-1000 keV for NaIs)
- 4.096 s resolution
- Spectroscopy

CTTE
- 128 channels (8-1000 keV for NaIs)
- 2μs precision
- Spectroscopy, timing, short event search

Untriggered Science

<u>GBM Earth Occultation Monitor</u> (GEOM)

-PI Peter Jenke (Formerly C. A. Wilson-Hodge)

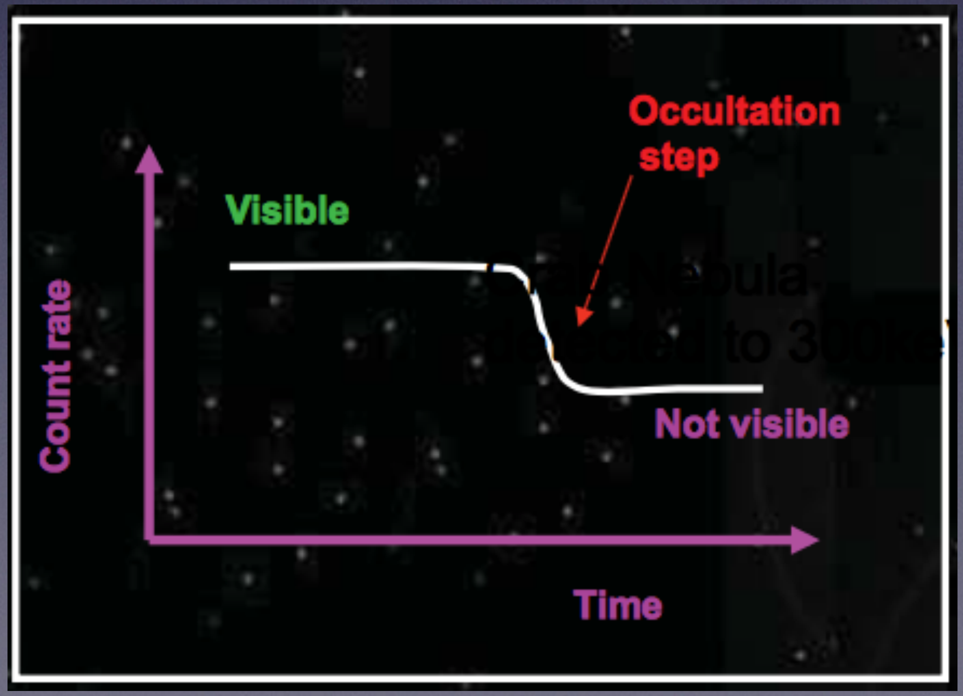
-Currently monitoring daily fluxes for over 200 sources.

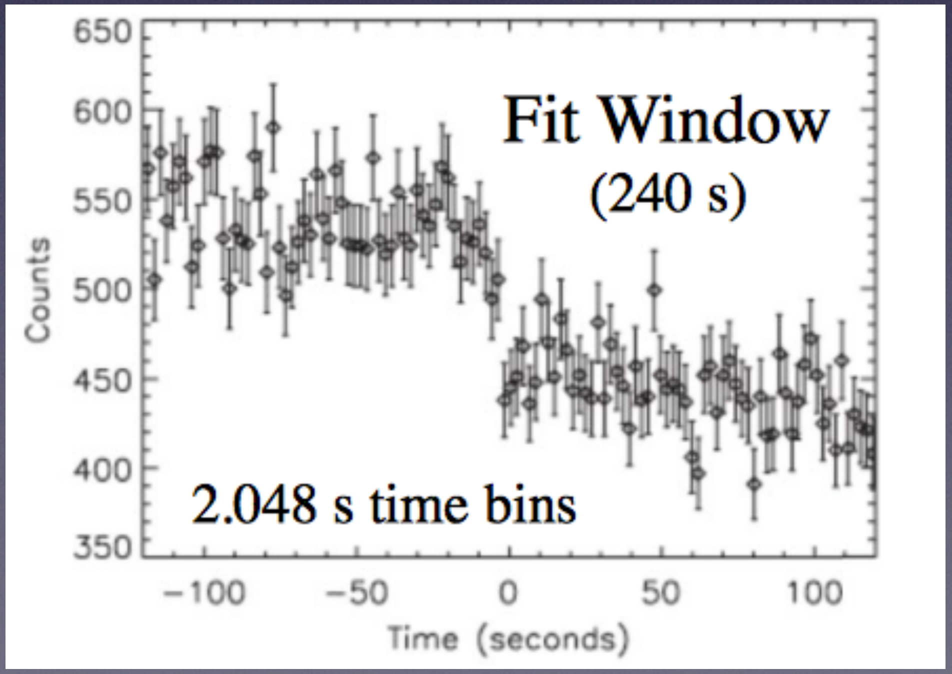
https://gammaray.nsstc.nasa.gov/gbm/science/earth_occ.html

C. A. Wilson-Hodge, et al., Three years of Fermi GBM Earth Occultation Monitoring: Observations of Hard X-ray/Soft Gamma-Ray Sources," ApJS 201, 33 (2012)

C. A. Wilson-Hodge, P. Jenke, et al.,\When a Standard Candles Flilckers," ApJ 727, L40 (2011).

G. L. Case, P. Jenke, et al., Observations of Soft Gamma Ray Sources >100 keV Using Earth Occultation with GBM," ApJ 729,105C (2011).





X-Ray Burst Monitor

-PI Peter Jenke (currently unfunded)

-Type 1 XRBs, untrggered GRBs, long events.

https://gammaray.nsstc.nasa.gov/gbm/science/xrb.html

P. A. Jenke, et al., The Fermi-GBM 3-Year X-ray Burst Catalog" ApJ (2016).

Terrestrial Gamma-ray Flashes (TGFs)

-PI Michael Briggs

-Most Prolific observations of TGFs

-Primarily BGOs

http://fermi.gsfc.nasa.gov/ssc/data/access/gbm/tgf/

GBM Pulsar Monitoring

- -PI C. A. Wilson-Hodge (Formerly M. H. Finger)
- -Monitoring spin frequency and pulsed flux from 39 accreting pulsars
- -Frequency and pulsed flux histories for 36 accreting pulsars
- -Sensitive to pulsations from .5 – 1000s

https://gammaray.nsstc.nasa.gov/gbm/science/pulsars.html

Finger, M. H., Bildsten, L., Chakrabarty, D., et al. 1999, ApJ, 517, 449

GBM Pulsar Monitoring

1) Daily Blind Search

-Search for pulsations from unknown sources.
-Search for pulsations from unmonitored transients.
-Even see low frequency QPOs from BH binaries GRS 1915+105.
-Events are extracted during the cleaning process for the XRB monitor and some automatic processing is performed (Location, light curves, background est., hardness ratios, rough class identification.)
-Results are not published but maybe subscribed to. We can send out daily email results.

2) Dedicated Search at Know Frequencies

-Search around known spin frequencies and frequency derivatives.
-Utilize orbital ephemeris if known.
-Results are published on the web page

Daily Blind Search

1. Data preparation and background subtraction
   - Visual inspection of CTIME channel 1 data (12-25 keV)
   - Removal of periods of high space craft rotation, SAA passage, Solar flares, Particle events, Triggered GRBs and any other abrupt changes in count rate (XRBs) that prevent a good fit to a smooth background
   - An empirical background model is fit to each detector and each of the first 3 channels (8-50 keV) with terms to account for the occultation steps of bright sources such as the Crab, Cyg X-1 and Sco X-1. The background model is subtracted from the data (residual data).
2. Source fluxes (8-50 keV) are determined for 26 directions along the Galactic plane plus the LMC and SMC assuming a generic pulsar energy spectrum
3. Source fluxes are Fourier transformed and searched for significant pulsations.

Dedicated Search

1. Source fluxes (8-50 keV) are similarly determined for the specific pulsar position and assumed energy spectrum.
2. Appropriate lengths of data are fit to a Fourier expansion in pulse phase using a rough phase model for each source (resid profiles)
3. Times are barycentered using the JPL Planetary ephemeris DE200 (Standish 1990).
4. Corrections for orbital motion are obtained if an orbital ephemeris is available
5. Short intervals (suitable for the individual source) are combined and searched for significant pulsations in up to three harmonics around the expected frequency and possibly frequency derivative.

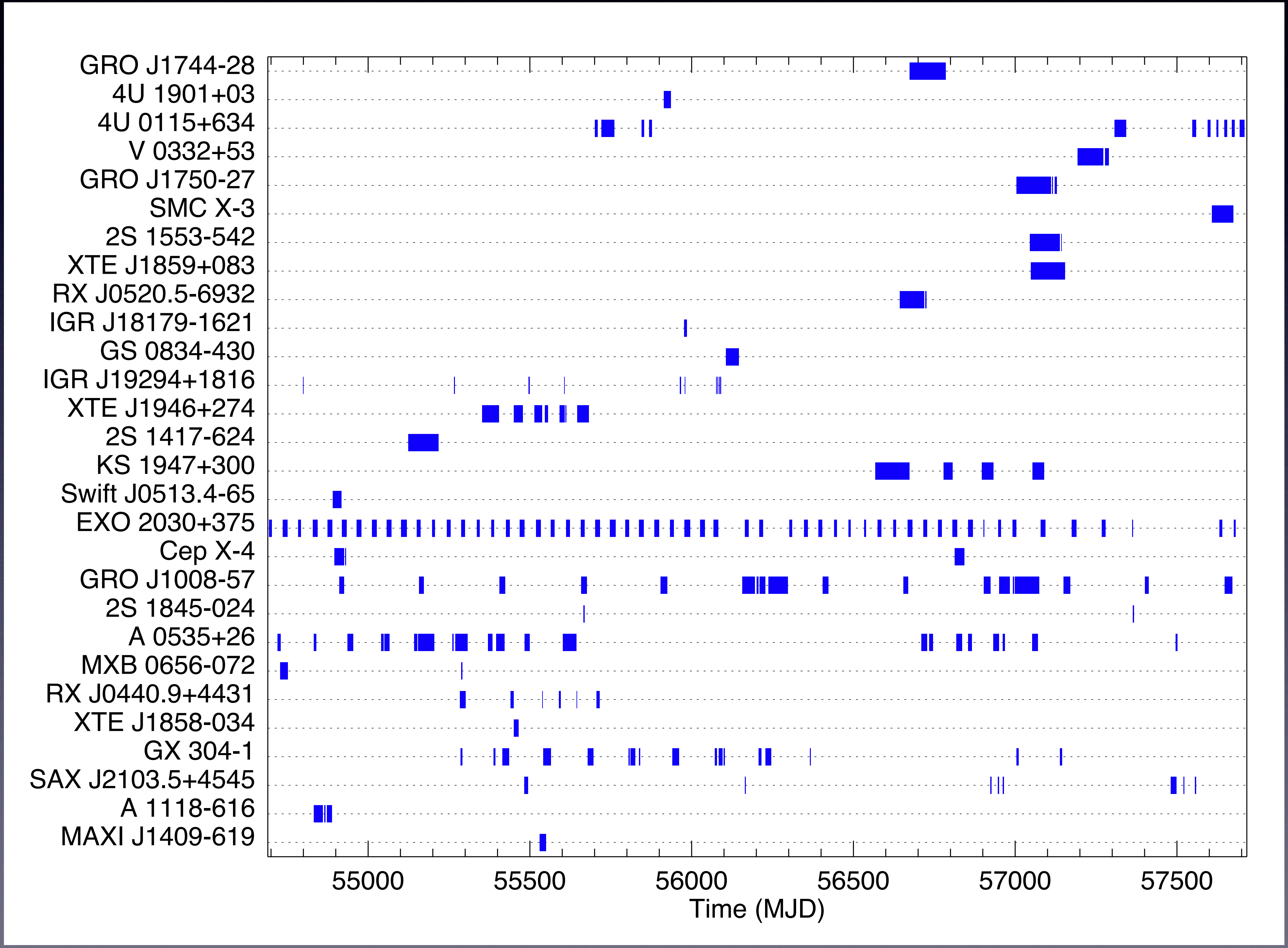
https://gammaray.nsstc.nasa.gov/gbm/science/pulsars.html

Detected Persistent Pulsars

SOURCE NAME & GBM LINK	LII (DEG)	BII (DEG)	PERIOD (S)	SWIFT LINK	MAXI LINK	SIMBAD LINK
GX 1+4	1.94	4.79	159.7	GX 1+4	GX 1+4	V* V2116 Oph
Her X-1	58.20	37.50	1.24	Her X-1	Her X-1	V* HZ Her
Vela X-1	263.06	3.90	283.5	Vela X-1	Vela X-1	V* GP Vel
Cen X-3	292.10	0.30	4.80	Cen X-3	Cen X-3	V* V779 Cen
GX 301-2	300.10	1.25	681.6	GX 301-2	GX 301-2	V* BP Cru
4U 1626-67	321.79	-13.09	7.67	4U 1626-67	4U 1626-67	V* KZ TrA
4U 1538-52	327.42	2.16	525.0	H 1538-522	4U 1538-52	V* QV Nor
OAO 1657-415	344.40	0.31	37.1	EXO 1657-419	OAO 1657-415	OAO 1657-41

Fermi
Gamma-ray Burst Monitor

Transient Results



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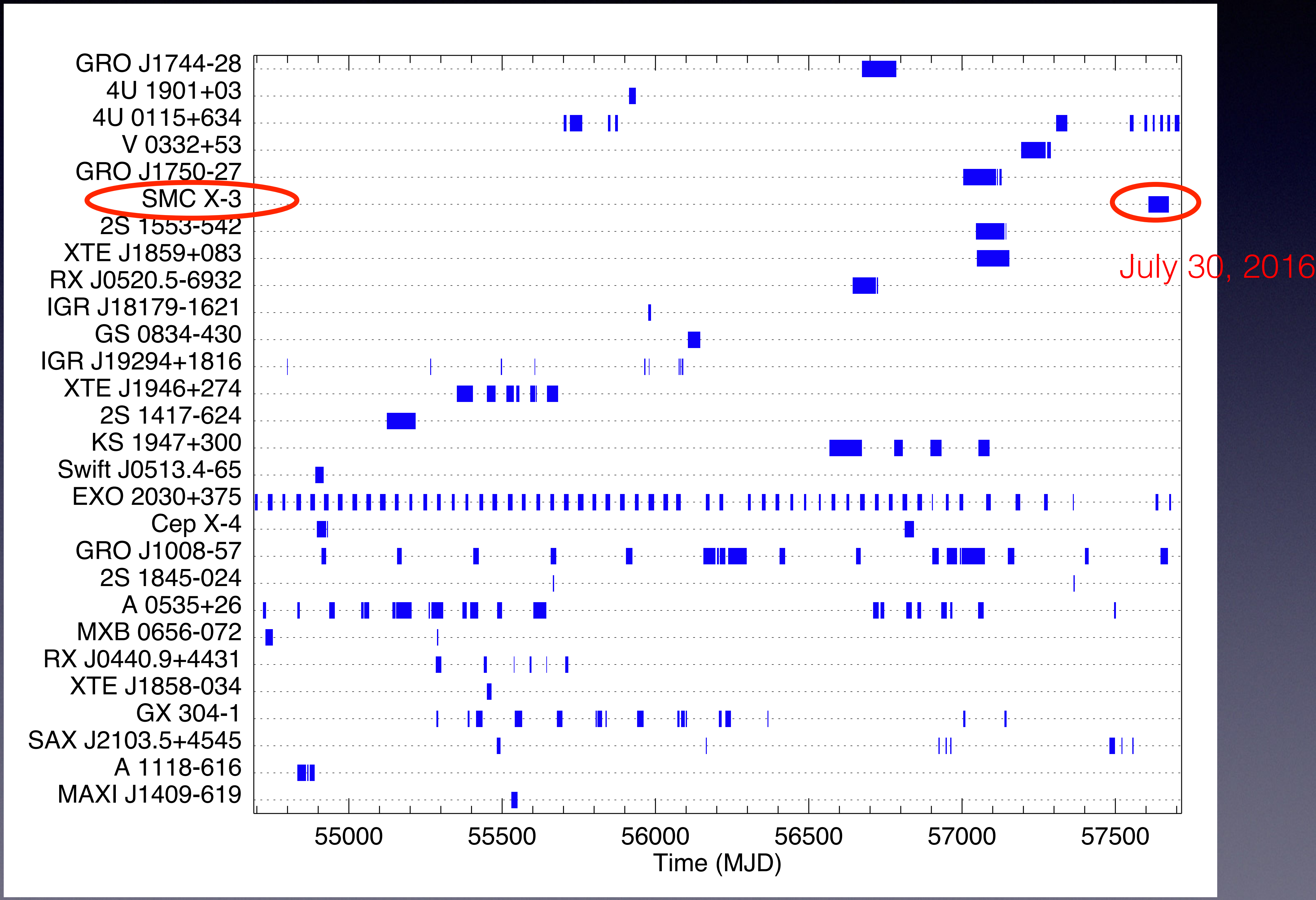
Transient Results



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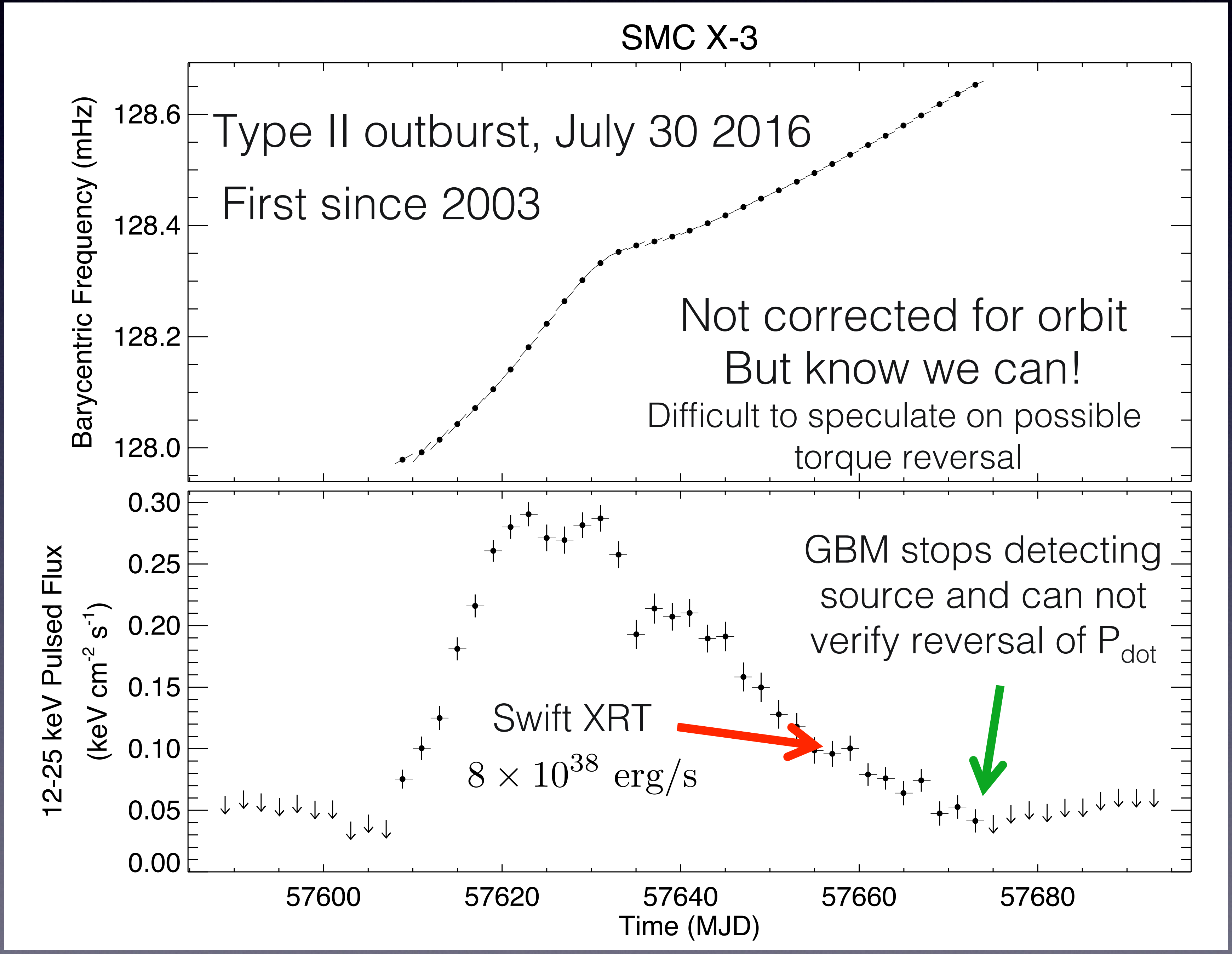
Atel #9348, Negoro et al.

SMC X-3

Be/X-ray Binary



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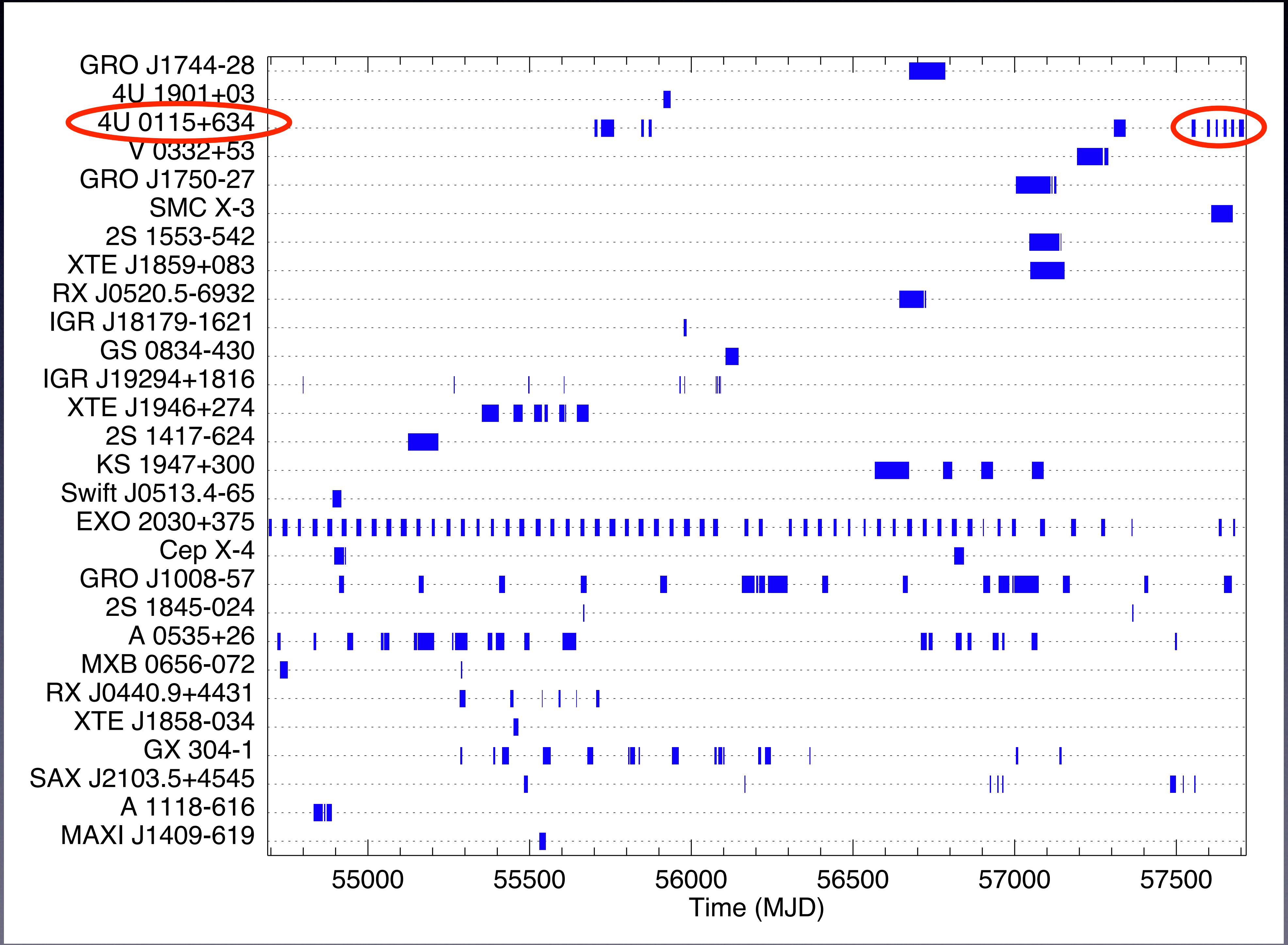
Gamma-ray Burst Monitor

Transient Results



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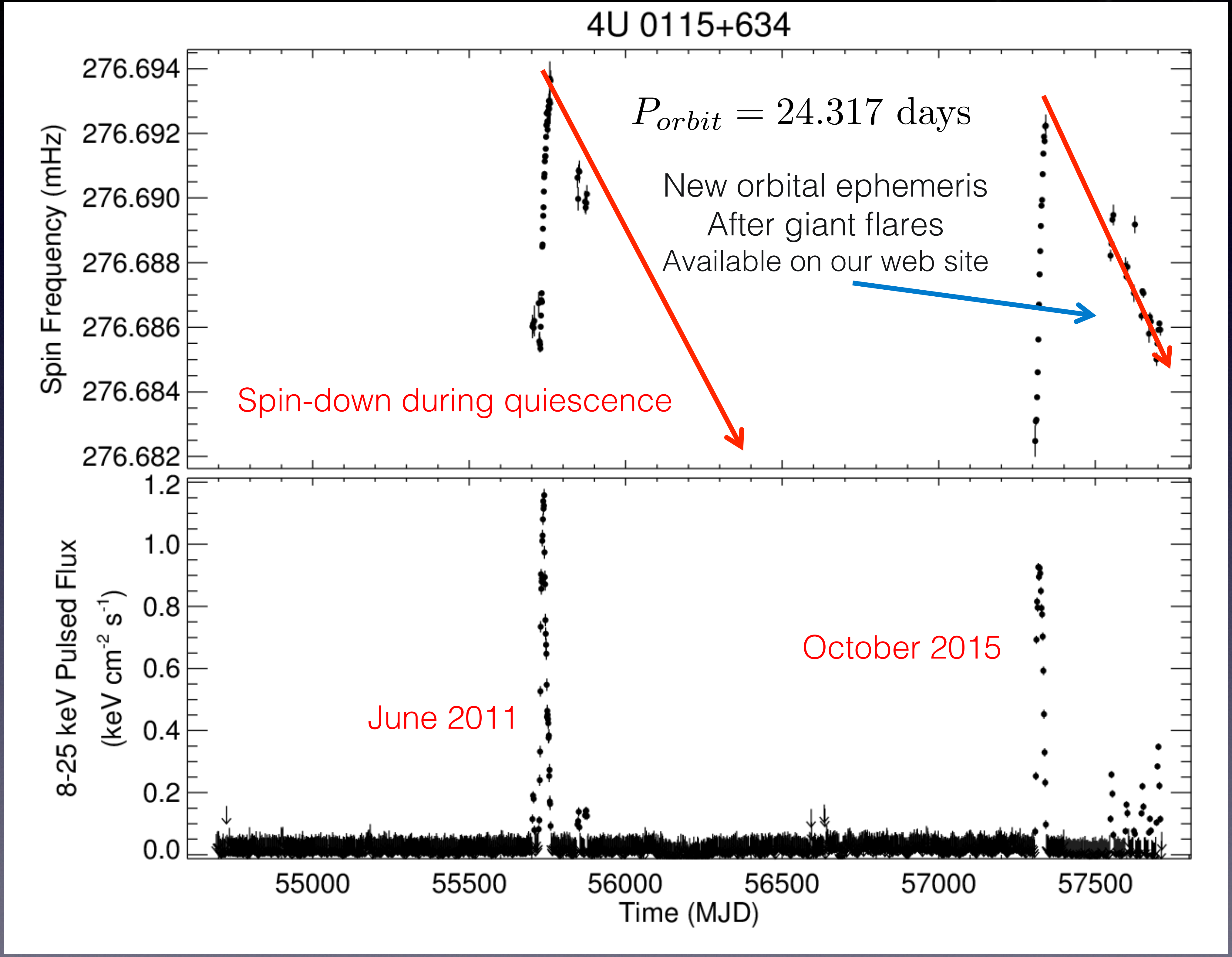
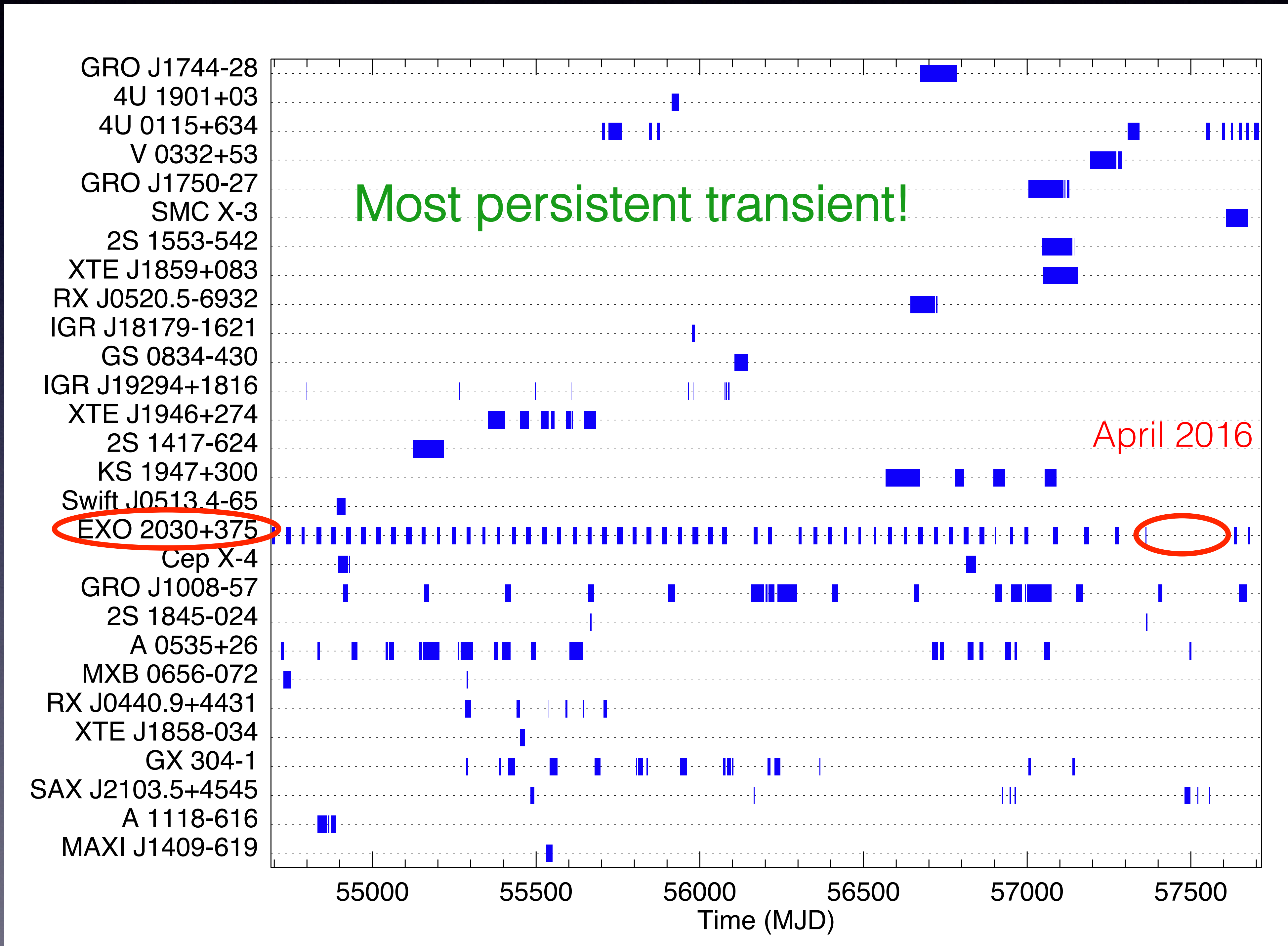
Be/X-ray Binary



Transient Results



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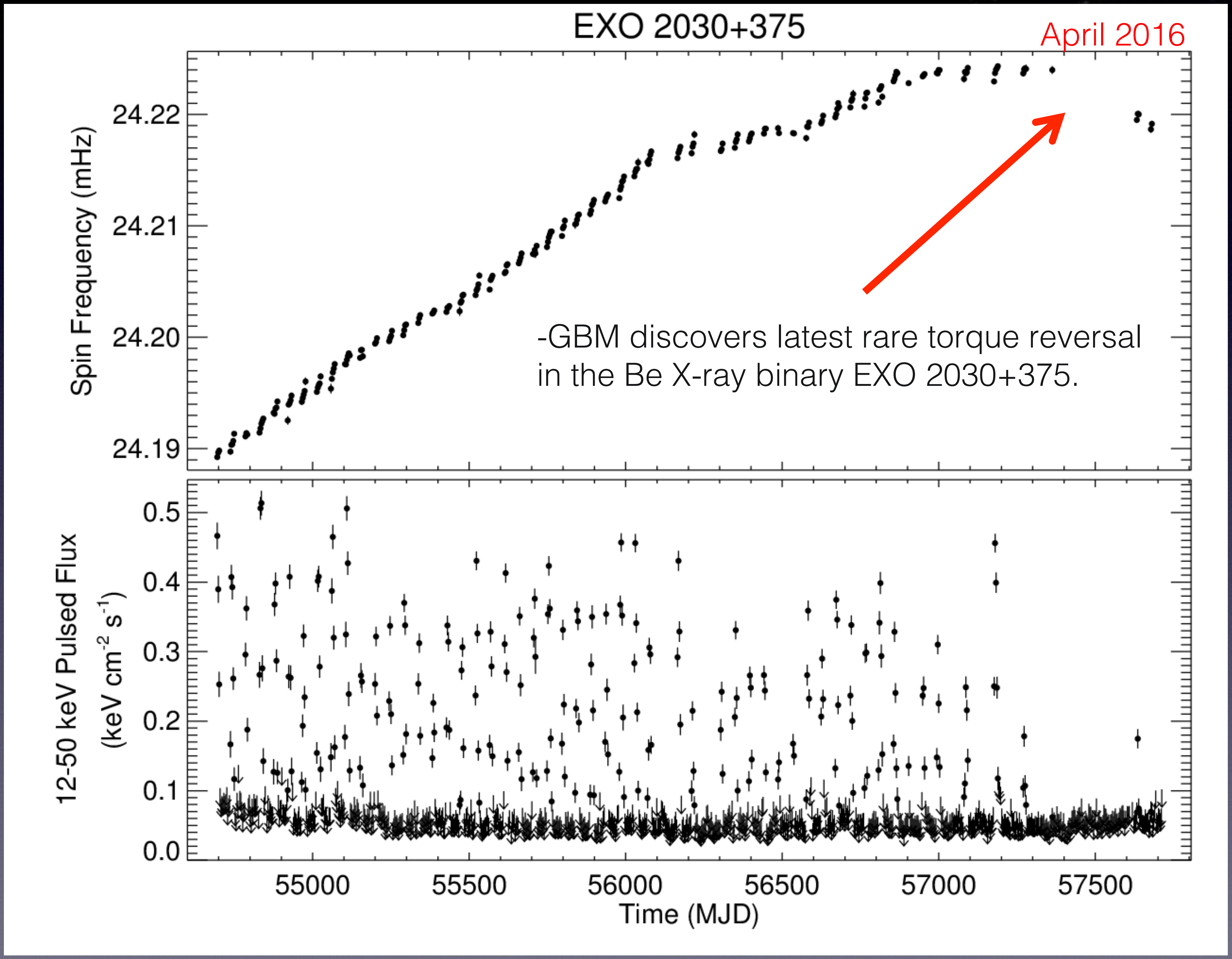
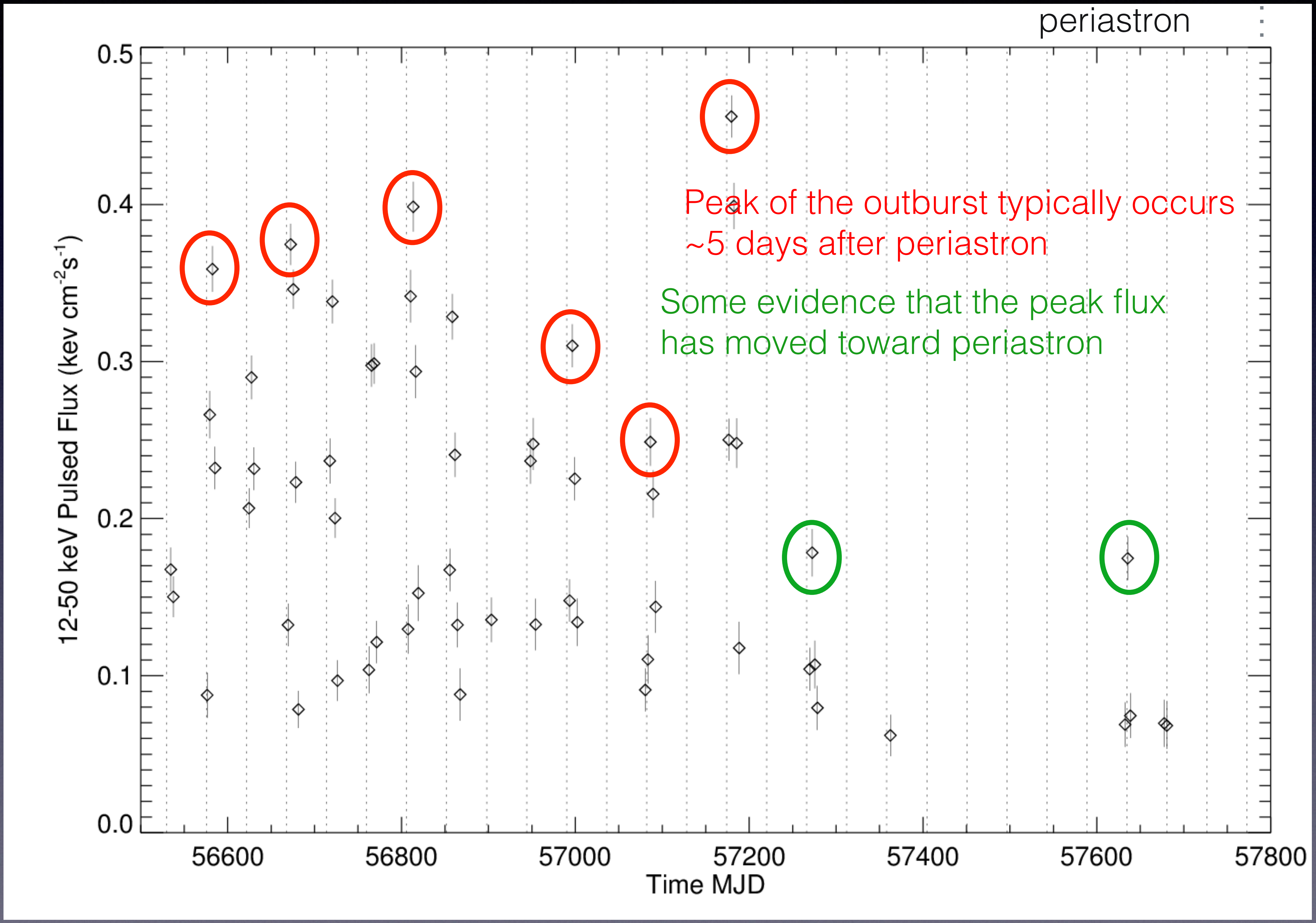
Gamma-ray Burst Monitor


EXO 2030+375
April 2016
-GBM discovers latest rare torque reversal
in the Be X-ray binary EXO 2030+375.
Spin Frequency (mHz)
24.22
24.21
24.20
24.19
12-50 keV Pulsed Flux
(keV cm^{-2} s^{-1})
0.5
0.4
0.3
0.2
0.1
0.0
55000
55500
56000
56500
57000
57500
Time (MJD)

EXO 2030+375



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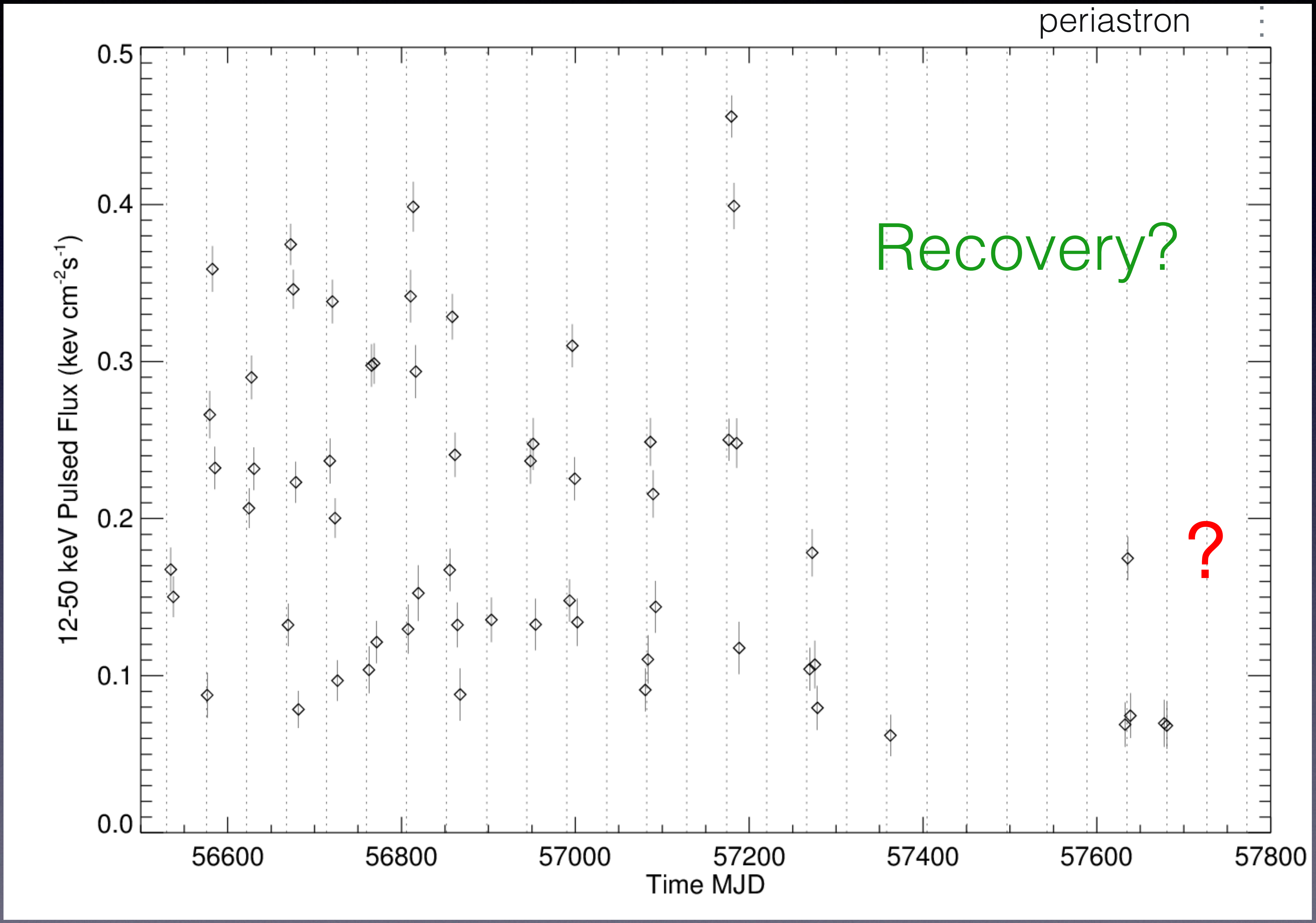
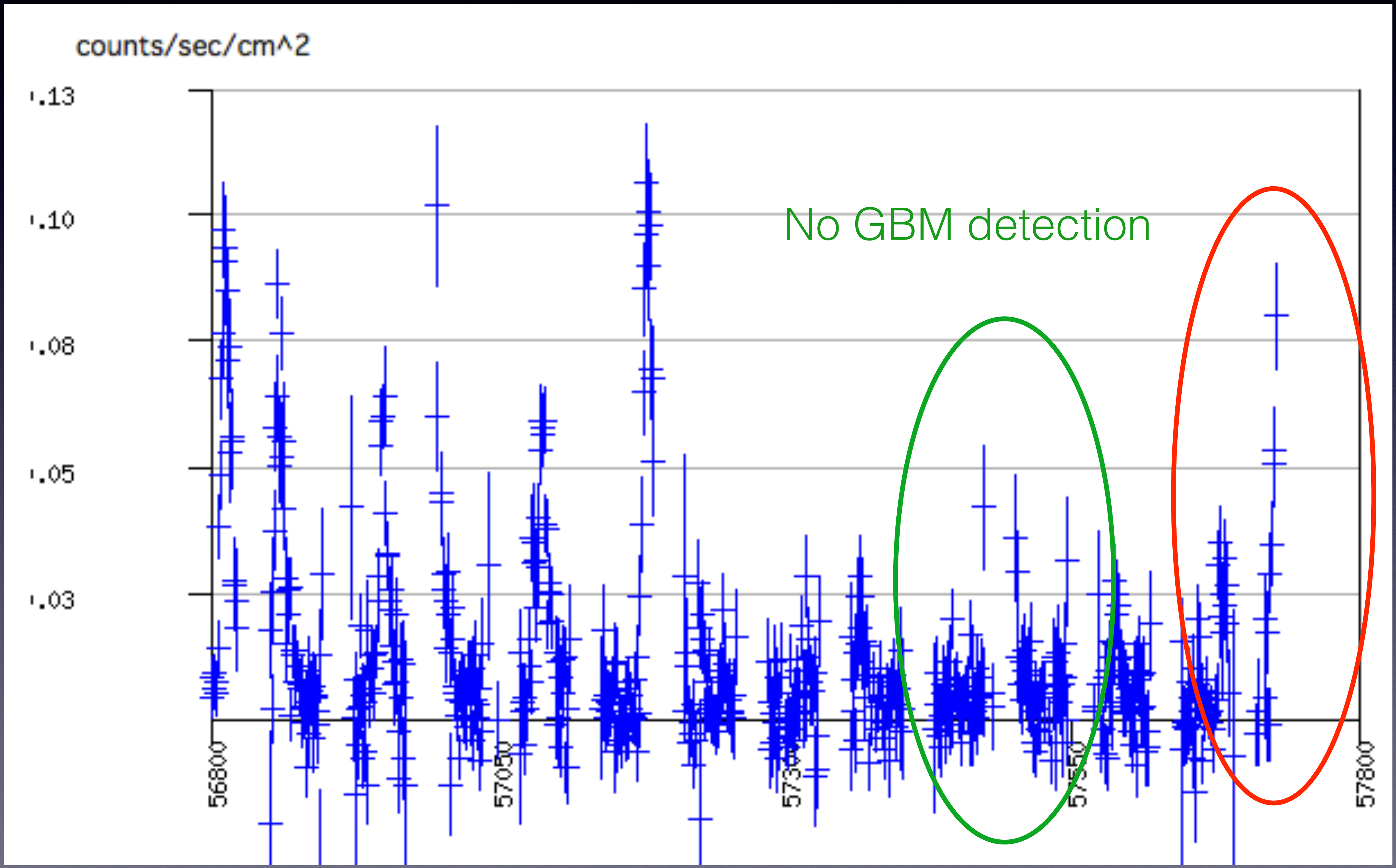
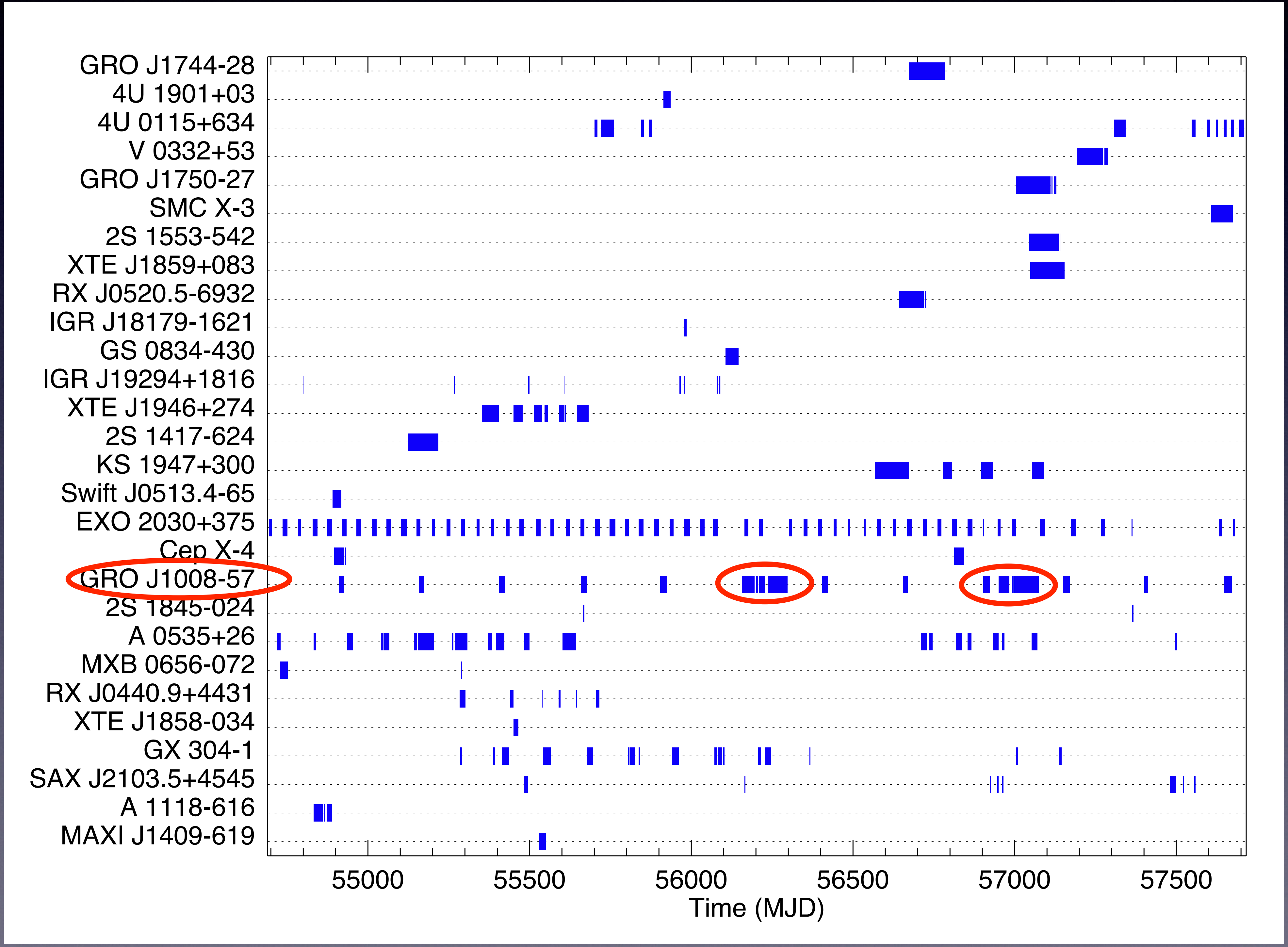
EXO 2030+375


periastron
Recovery?
?
12-50 keV Pulsed Flux (kev cm^-2 s^-1)
0.0
0.1
0.2
0.3
0.4
0.5
56600
56800
57000
57200
57400
57600
57800
Time MJD

MAXI 4–10 keV light curve



Transient Results



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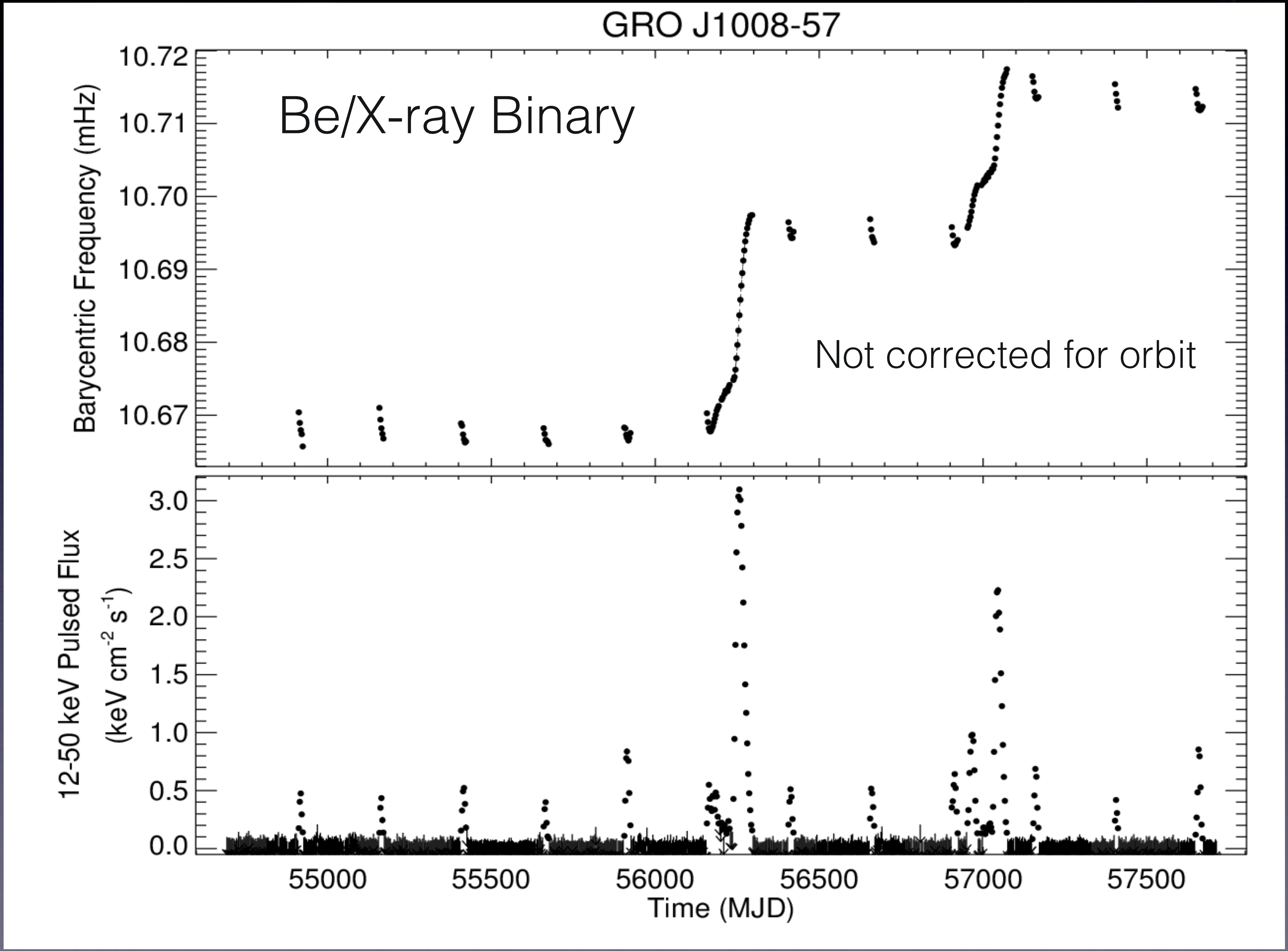
GRO J1008-57
Be/X-ray Binary
Not corrected for orbit
Barycentric Frequency (mHz)
10.72
10.71
10.70
10.69
10.68
10.67
12-50 keV Pulsed Flux
(keV cm^{-2} s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
55000
55500
56000
56500
57000
57500
Time (MJD)

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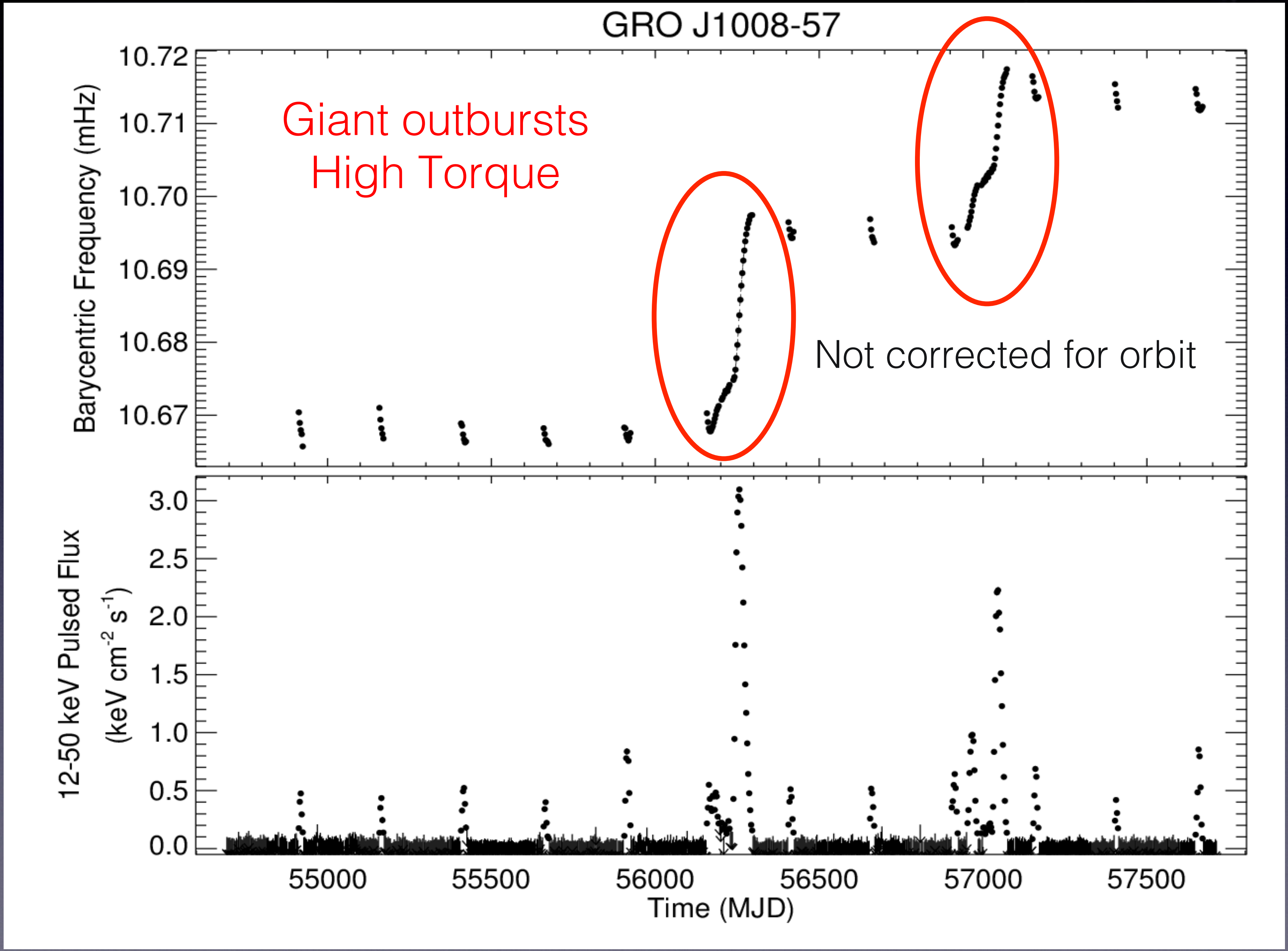
Gamma-ray Burst Monitor


GRO J1008-57
Giant outbursts
High Torque
Not corrected for orbit
Barycentric Frequency (mHz)
10.72
10.71
10.70
10.69
10.68
10.67
12-50 keV Pulsed Flux
(keV cm^{-2} s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
55000
55500
56000
56500
57000
57500
Time (MJD)

Orbital model fitting using Swift/BAT or MAXI rates as a proxy for mass accretion via X-ray flux

Torque Model

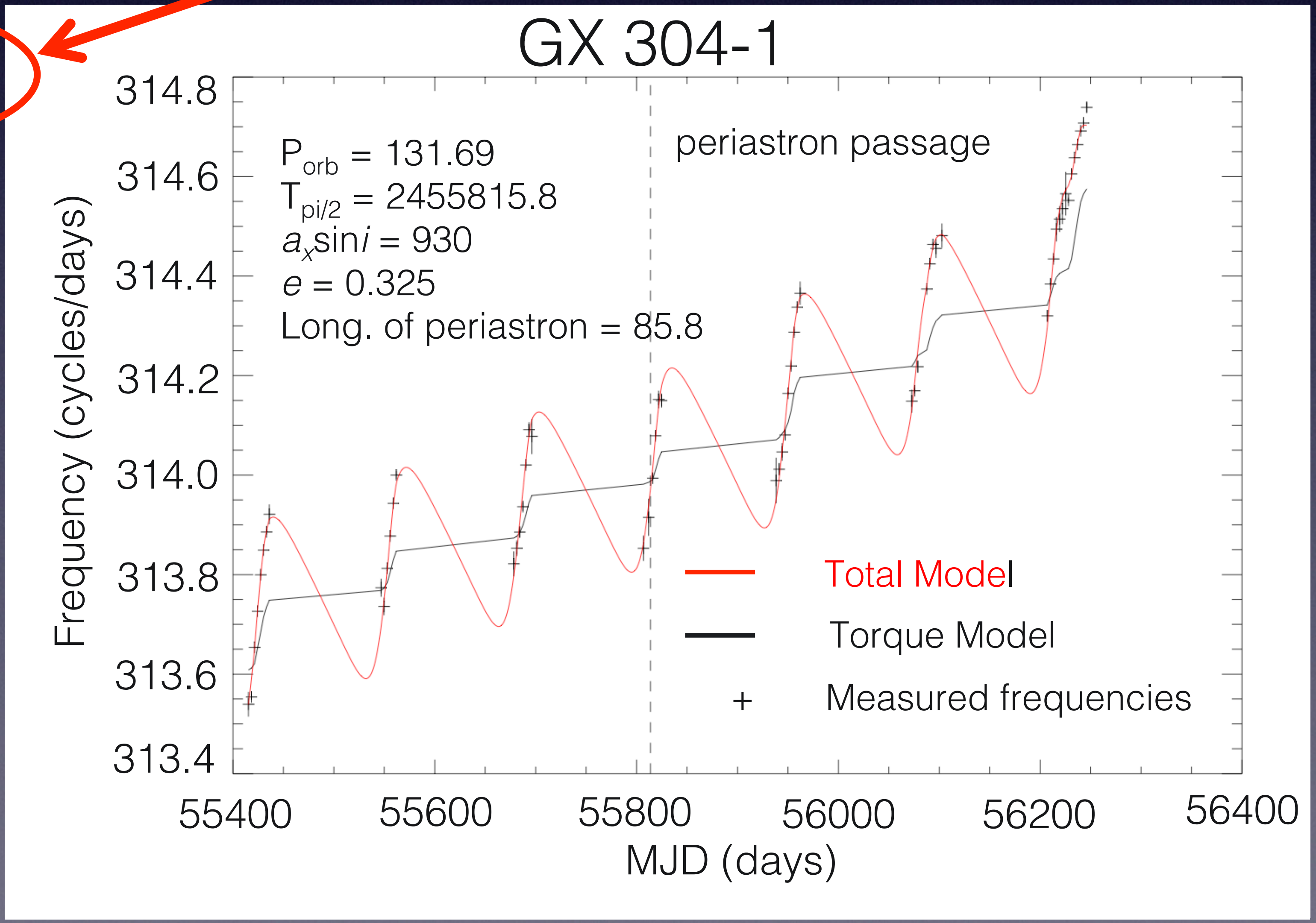
$$\dot{\nu} \propto B^{2/7} F^{6/7}$$

$\dot{\nu}$ = frequency derivative

B = Magnetic Field

F = X-ray Flux

Mutsumi Sugizaki



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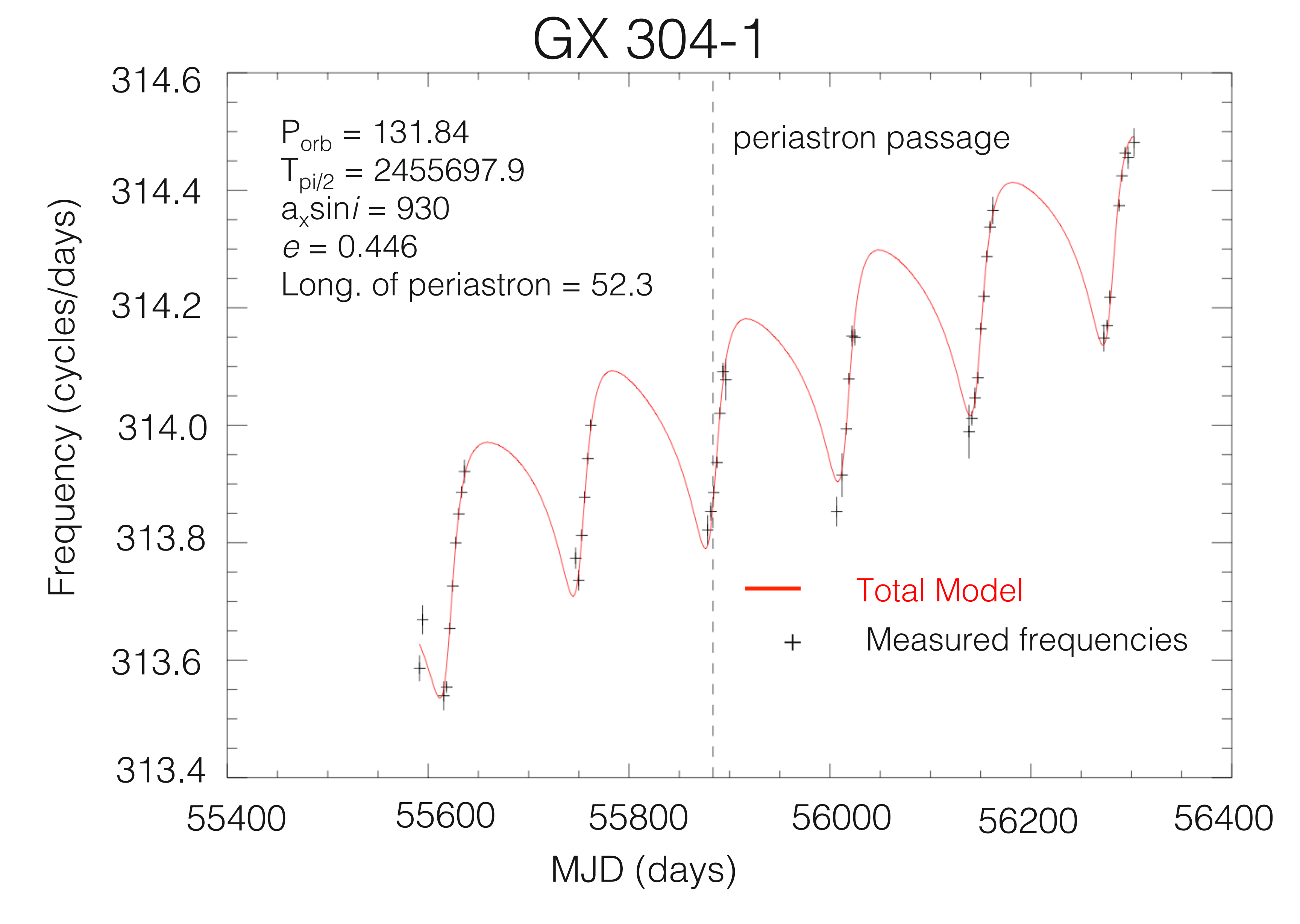
Gamma-ray Burst Monitor

Orbital model fitting Using a polynomial background

Poorer Fit and probably wrong



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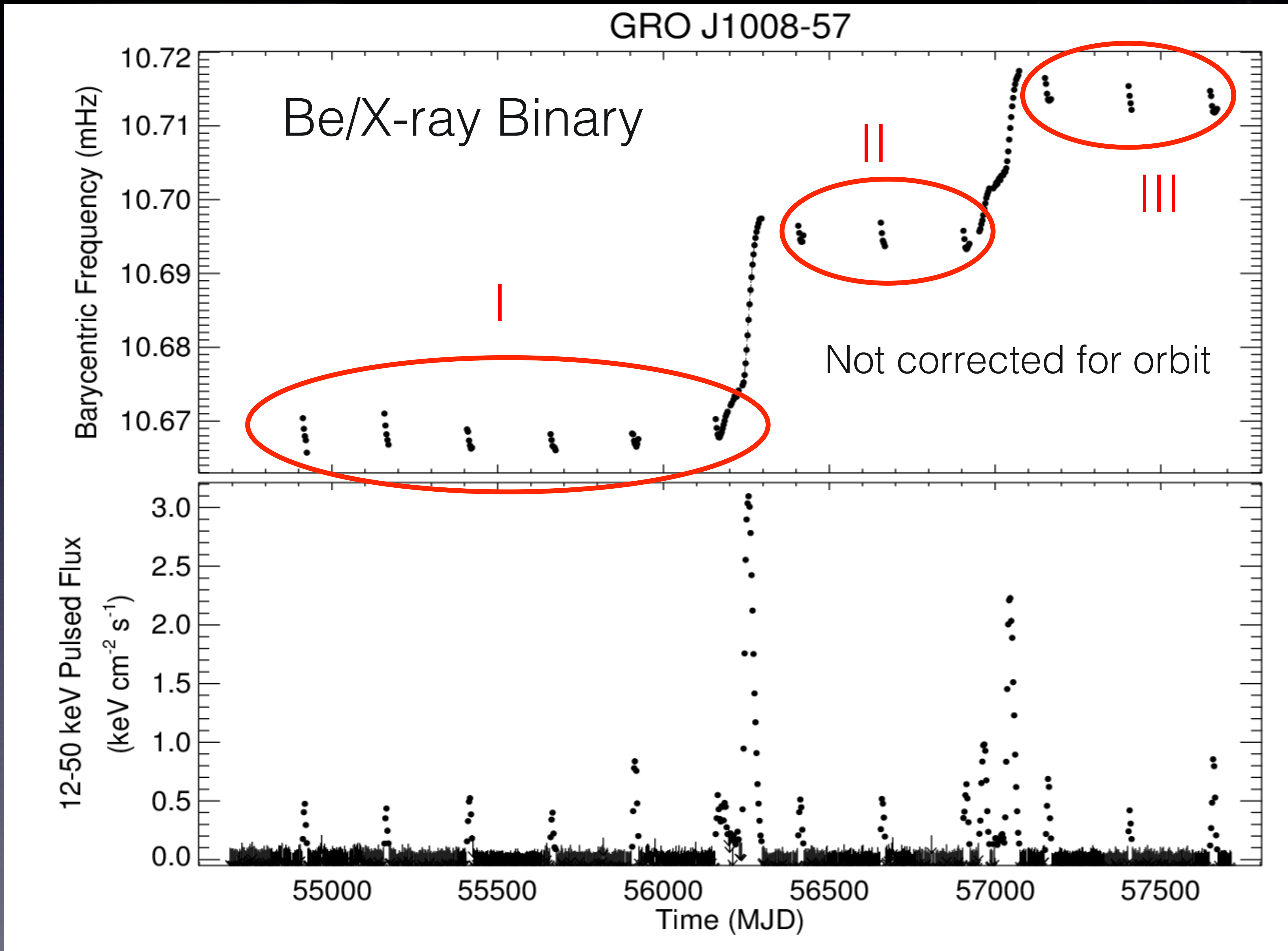
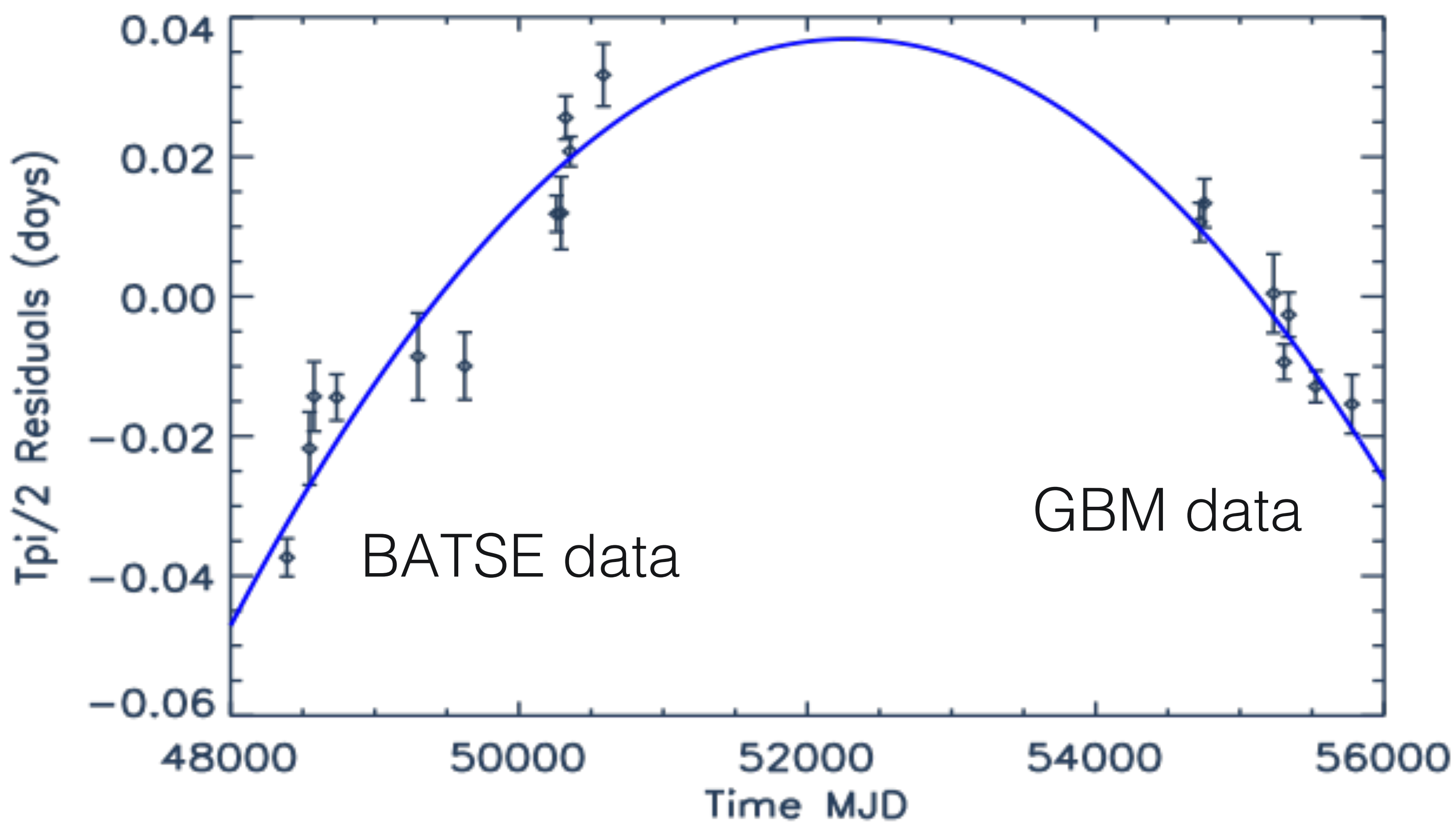

GRO J1008-57
Be/X-ray Binary
I
II
III
Not corrected for orbit
Barycentric Frequency (mHz)
10.72
10.71
10.70
10.69
10.68
10.67
12-50 keV Pulsed Flux
(keV cm^{-2} s^{-1})
3.0
2.5
2.0
1.5
1.0
0.5
0.0
55000
55500
56000
56500
57000
57500
Time (MJD)

P. A. Jenke, et al., Orbital Decay and Evidence of Disk Formation in the X-ray Binary Pulsar OAO 1657-415," ApJ, 759, 124 (2012).

Long Term Monitoring of the Wind-Fed HMXB

OAO 1657-415 Orbit Decay



Important for understanding how different X-ray binary populations might be related through evolution

$$T_{\pi/2} = T_o + nP_{orbit} + \frac{1}{2}n^2 P_{orbit}\dot{P}_{orbit}$$

$$\dot{P}_{orbit} = (-9.74 \pm 0.78) \times 10^{-8}$$

Future Work

- Continue to update and publish orbital ephemerides.
- Implement CTTE data in blind and dedicated search and add more high frequency sources.
- Add long term frequency histories that incorporate data from BATSE.
- Improve collaborative efforts and increase our manpower.

Fermi

Gamma-ray Burst Monitor

The Three Year X-ray Burst Catalog
Type I XRBs

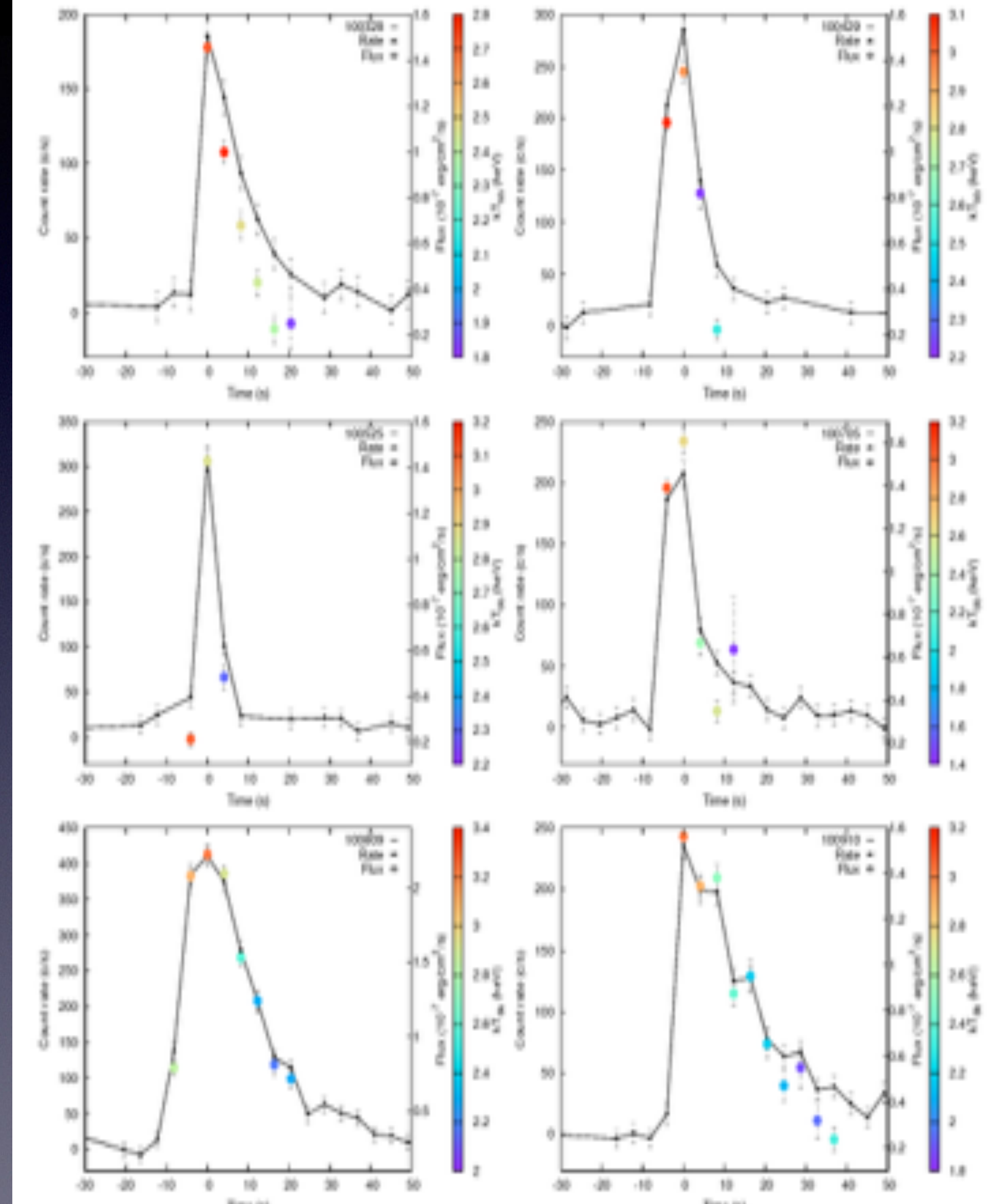
752 Thermonuclear XRBs
267 Transient Events from accretion flares
65 Untriggered GRBs

GBM is sensitive to photospheric radius expansion (PRE) bursts

1.4 PRE bursts per day within 10 kpc

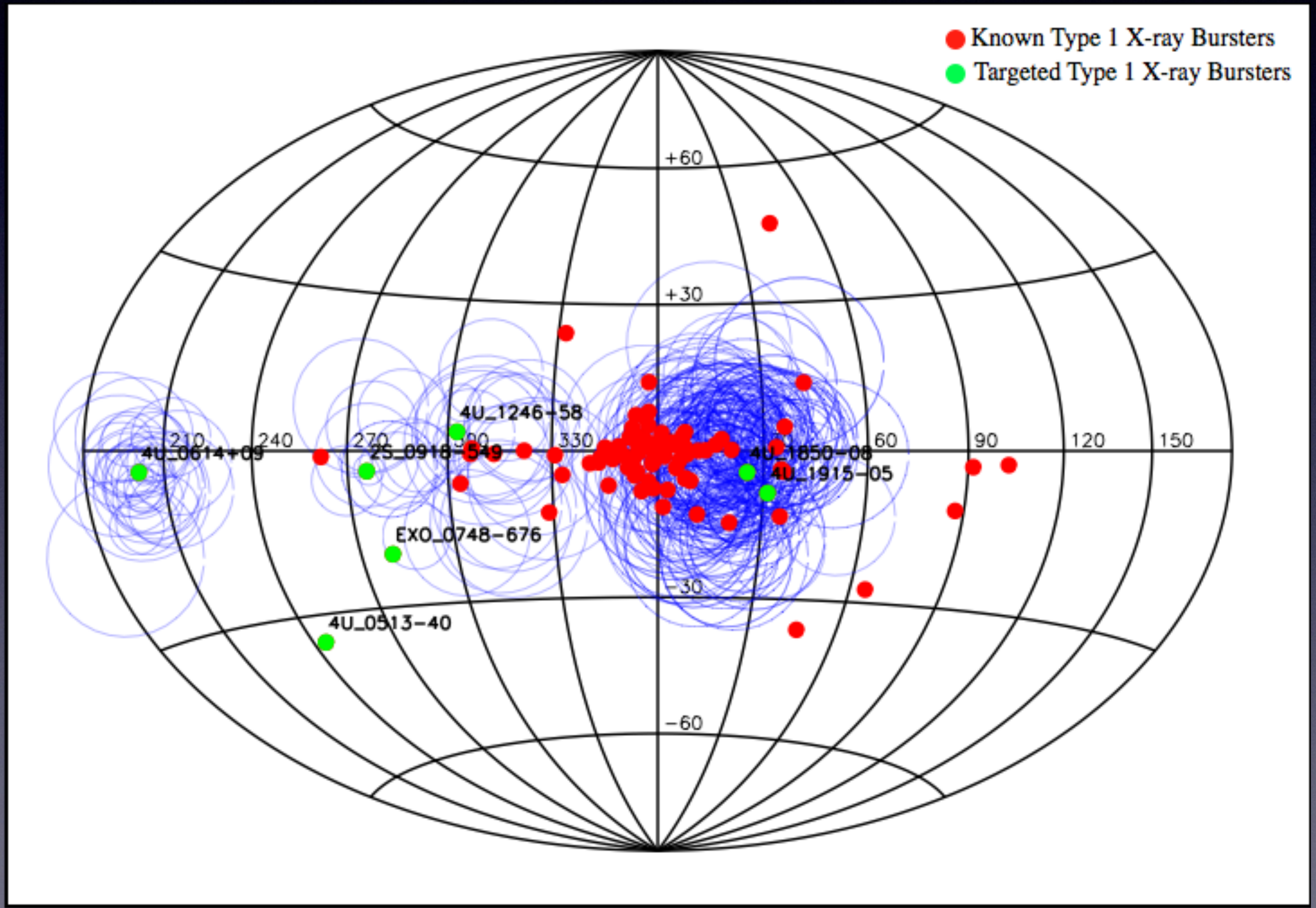
No Quenching after 2014 superburst of 4U 0614+09

4U 0614+09



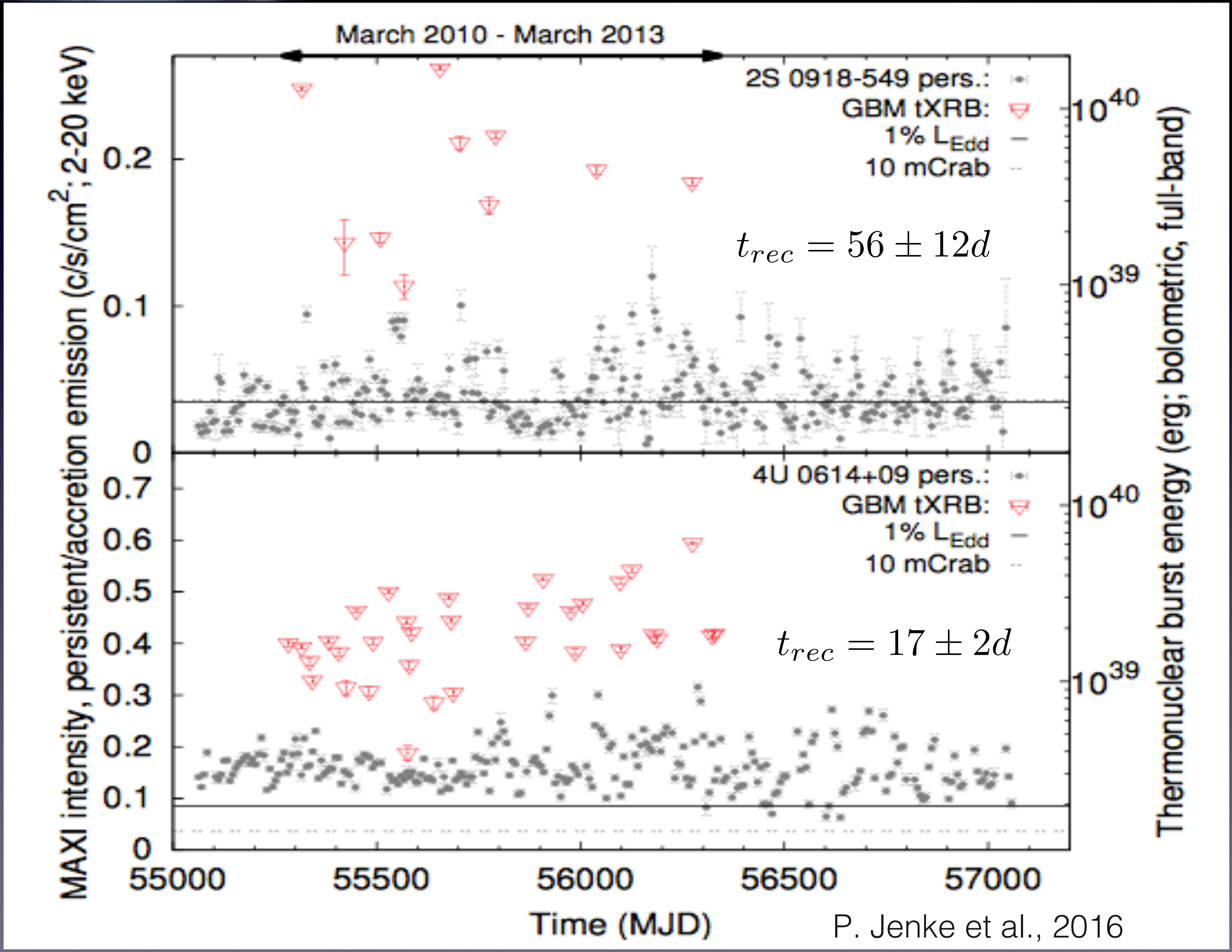
Associations For Low M_{dot} Accretors

- 33 - 4U 0614+09
- 10 - 2S 0918-549
- 4 - SAX J1818.7+1424
- 2 - UW Crb
- 2 – IGR J17062-6143
- 1 – XB 1940-04
- 1 – Ser X-1
- 1 – MAXI J1421-613



Locations are poor. Must use MAXI rates to determine if potential source is active. Automatic checking.


Fermi
Gamma-ray Burst Monitor


March 2010 - March 2013
2S 0918-549 pers.:
GBM tXRB:
1% L_Edd
10 mCrab
$t_{rec} = 56 \pm 12d$
4U 0614+09 pers.:
GBM tXRB:
1% L_Edd
10 mCrab
$t_{rec} = 17 \pm 2d$
MAXI intensity, persistent/accretion emission (c/s/cm^2; 2-20 keV)
Thermonuclear burst energy (erg; bolometric, full-band)
Time (MJD)
55000
55500
56000
56500
57000
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
10^{39}
10^{40}
P. Jenke et al., 2016

Future Work

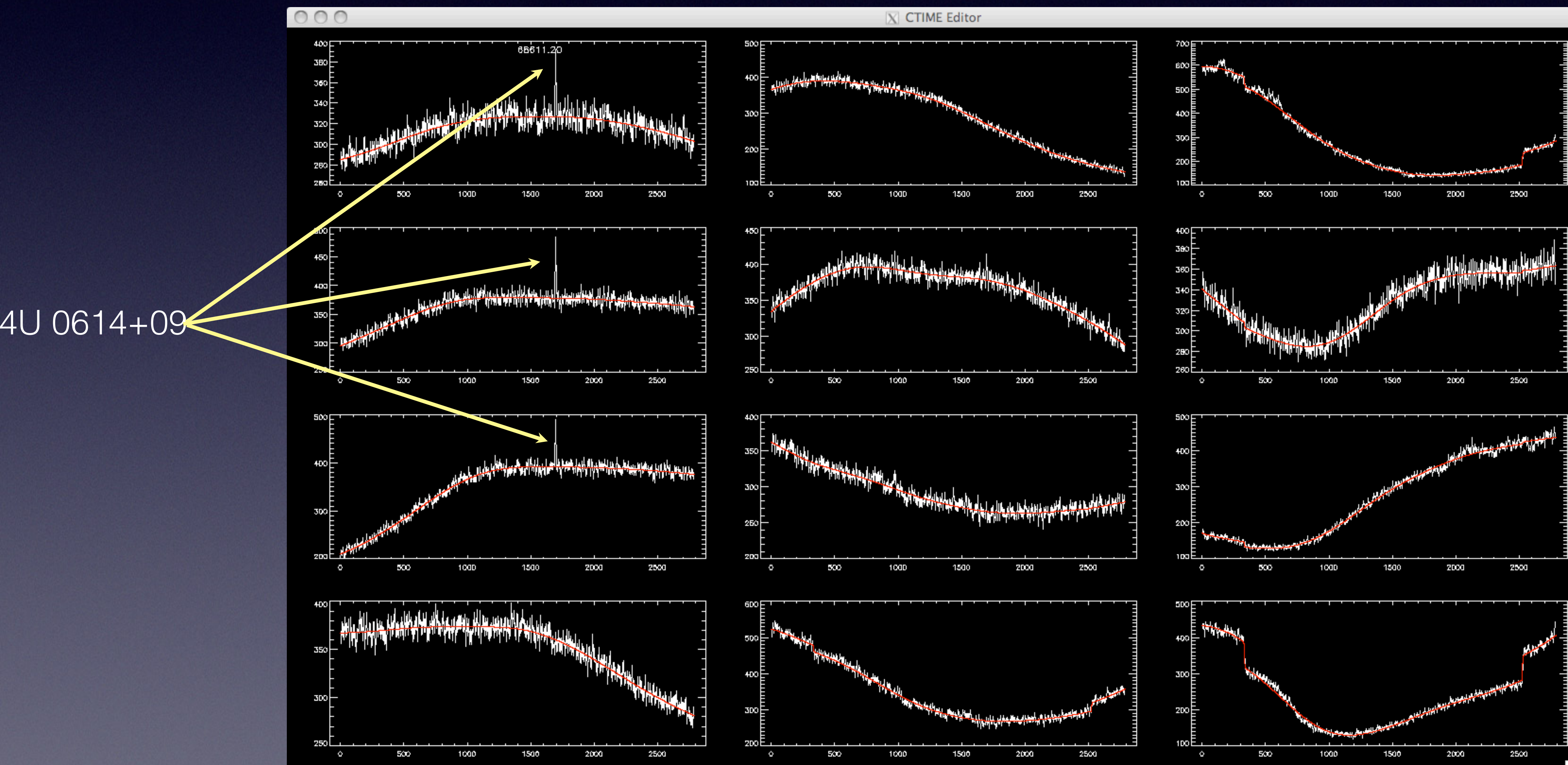
- Continue to collect XRBs from pulsar cleaning.
- Implement CTTE data to improve spectral analysis.
- Improve source classification.
- Cross calibration of GBM XRBs.

Large Instantaneous Field of View

Visual Inspection of CTIME Data

12 NaI detectors
12-25 keV
8 second bins

GBM Pulsar Project
PI Mark Finger



Initiated March 12, 2010