Observations of Accreting Pulsars with the Fermi-GBM

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(NASA/MSFC) for the GBM pulsar and occultation teams

Teams

- GBM Pulsar Team
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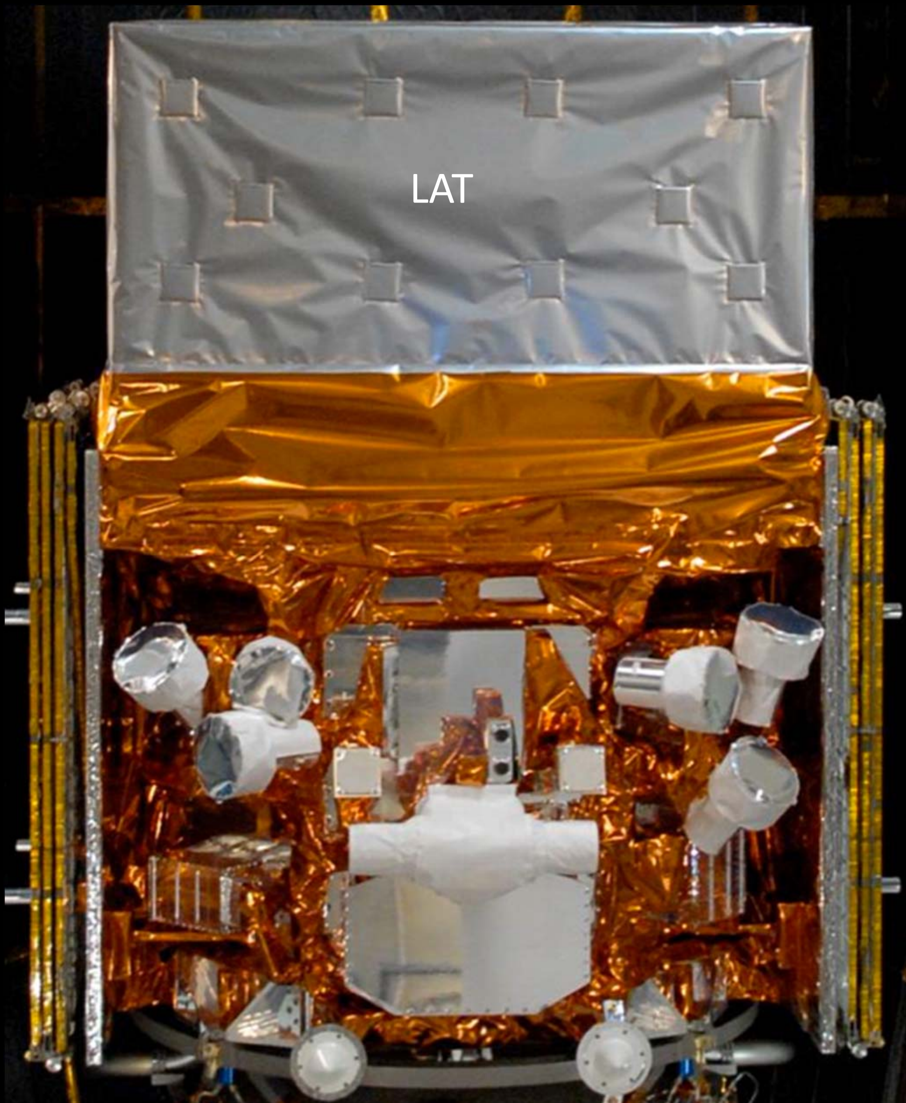
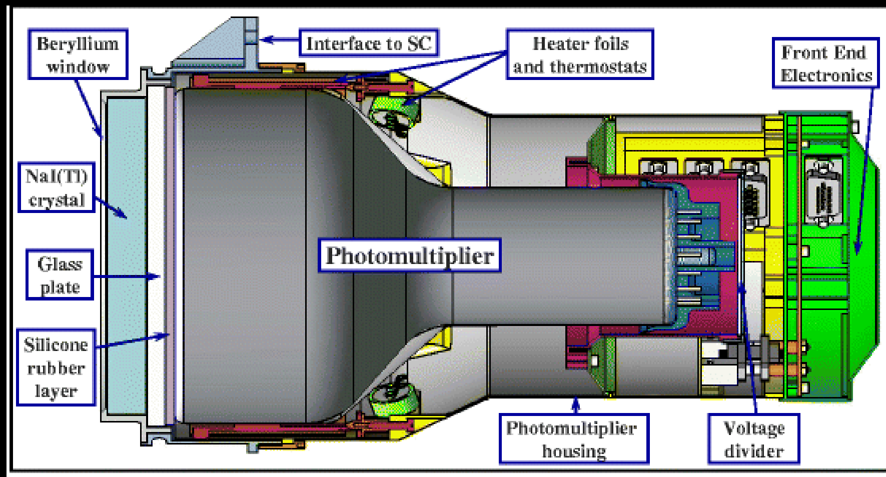
Outline

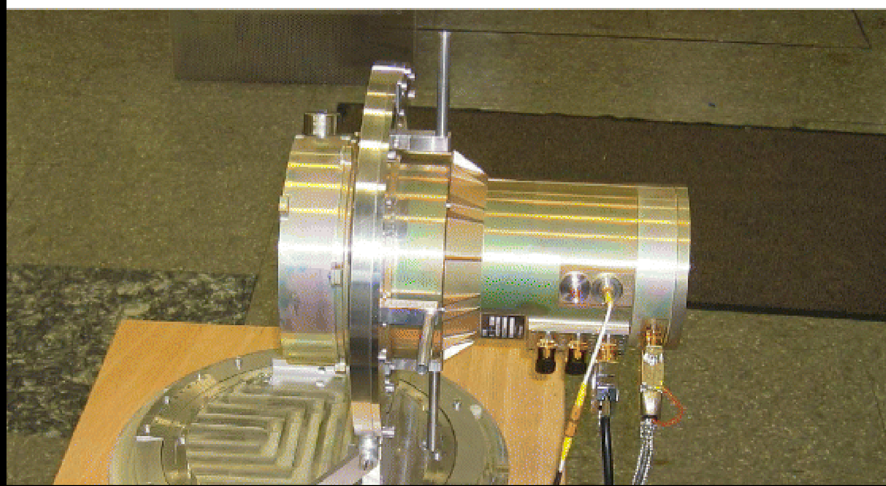
- Introduction
  - Fermi GBM
  - Techniques
    - Pulsed frequency and pulsed flux monitoring
    - Earth occultation monitoring
- Detected Source classes
- Science topics
  - Torque switching
  - QPO in A0535+262
  - Outburst behaviors
- Summary and Conclusions

Instrumentation



GBM Detectors





NaI Detectors. The NaI(Tl) Scintalators are 127 mm in diameter and 12.7 mm thick. The detectors covers the 8 keV - 1 MeV band.

Pulsed Frequency and Pulsed Flux Monitoring

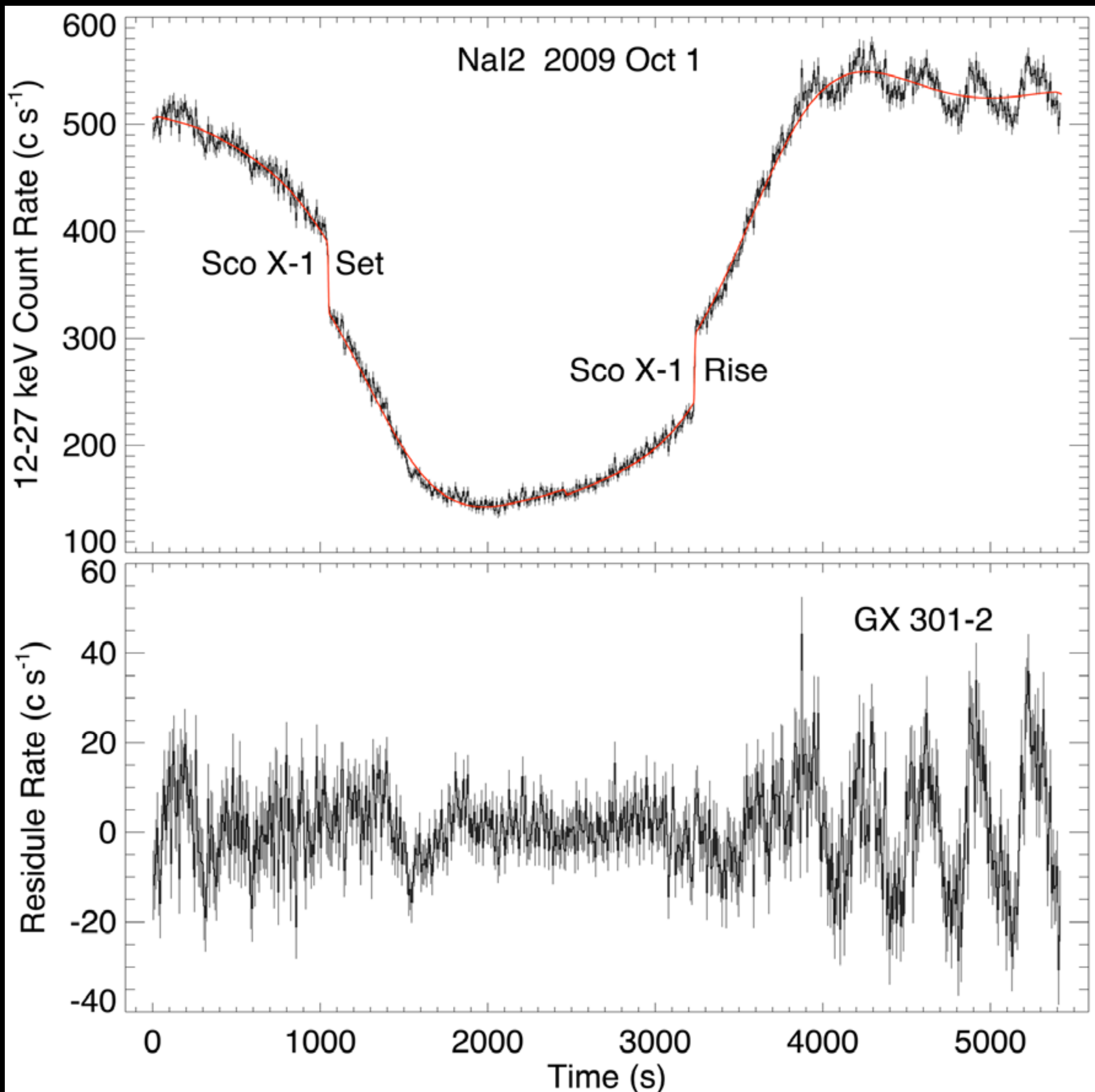
The analysis of GBM observations of pulsars presents two main challenges:

- The background rates are normally much larger than the source rates, and have large variations.
- The responses of the detectors to a source are continuously changing because of Fermi's continuous re-orientation.

The initial steps of the pulsed data analysis are:

- Data Screening
- Background subtraction of the NaI detector count rates
- Determination of fluxes from remaining rates

Background Subtraction



The rates in each channel of the 12 NaI detectors are fit with a model with the following components:

- Models for bright sources.
- A stiff empirical model that contains the low-frequency component of the remaining rates.

The fits are made independently for each channel and subtracted from the rates.

Estimating Pulsed Fluxes

For a given source we combine the rate residuals over detectors and obtain an estimate of the variable part of the source flux. Using a model of the source spectrum and the time dependent detector responses we compute the source induced rate μ_{ik} expected in detector *i* at time t_k if the source has unit flux in the channel's energy range. The variable part of the flux $\tilde{f}_k$ is then estimate by minimizing

$$\chi_k^2 = \sum_i \frac{(\tilde{r}_{ik} - \tilde{f}_k \mu_{ik})^2}{\sigma_{ik}^2}$$

where $\tilde{r}_{ik}$ is the residual rates and σ_{ik} the associated errors.

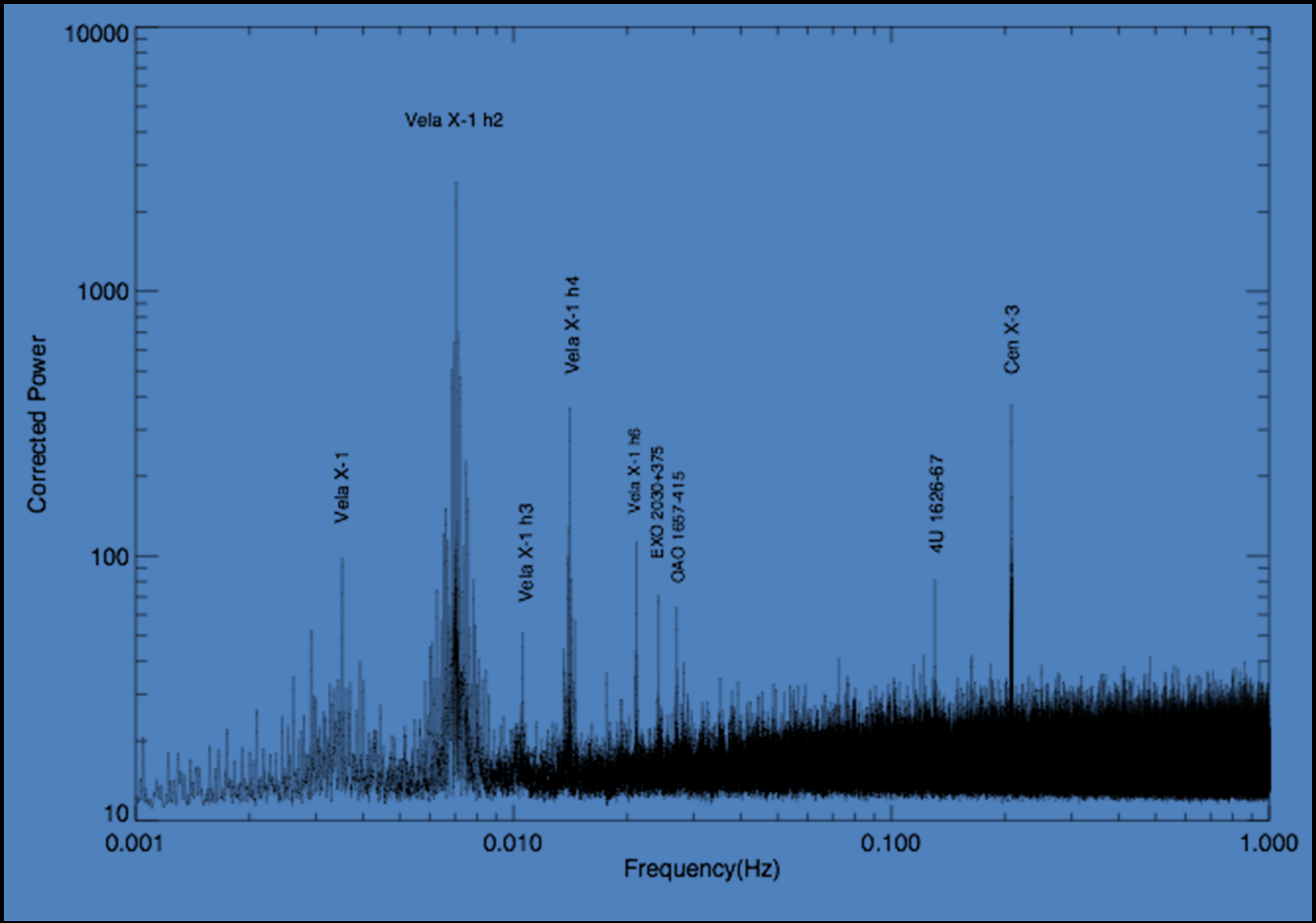
Pulse Searches

We have implemented two different pulse search strategies:

- Daily Blind Search. For this we compute fluxes from a days data for 24 source directions equally spaced on the galactic plane. For each direction we do an FFT based search from 1 mHz to 2 Hz.

- Source Specific Searches. These are searches over small ranges of frequency and sometimes frequency rate based on phase shifting and summing pulse profiles that are made from short intervals of data, using barycentered and possibly orbitally corrected times. Typical exposure times are ~40 ks/day.

Blind Pulse Search



Blind pulse search in 20-50 keV band, for 2010 January 8.

http://gammaray.nsstc.nasa.gov/gbm/science/pulsars

GBM Pulsar Project

http://gammaray.nsstc.nasa.gov/gbm/science/pulsars/

GBM Pulsar Project

GBM-related pulsar publications from the Gamma-Ray Astronomy team are listed here.

GBM Accreting Pulsar Histories

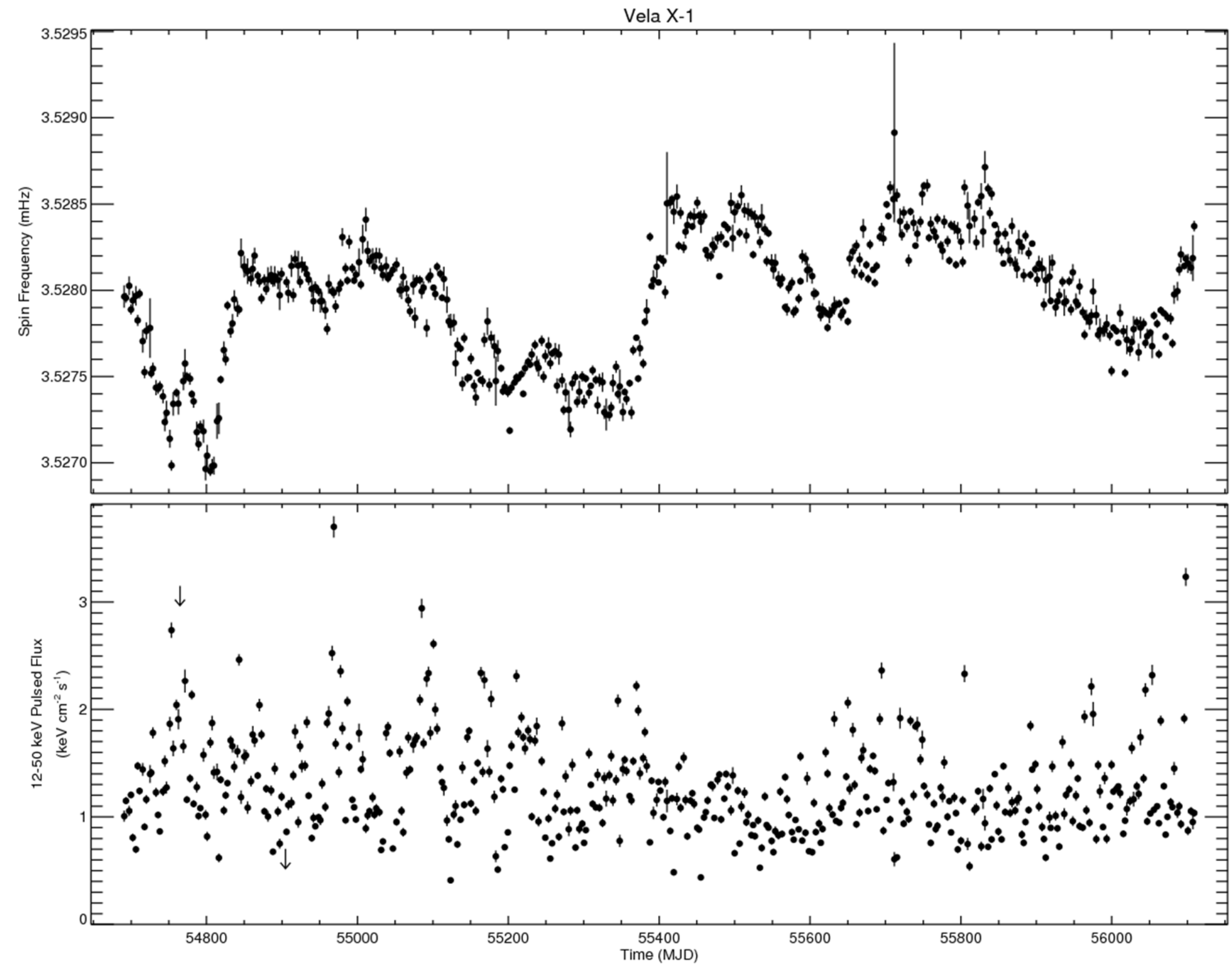
For each source we plot the history of pulse frequency and pulsed flux measured using the Fermi Gamma-Ray Burst Monitor (GBM) NaI detectors. For these measurements we use the CTIME data which normally has 0.256 s time bins, and eight energy channels. Our analysis normally uses channels 1 (12-25 keV) and 2 (25-50 keV). The integration interval used varies from source to source, ranging from one to four days. For eclipsing systems each egress to ingress interval is divided into an integral number of equal parts, with no measurement made during the eclipse. The measured frequencies are barycentered. For sources where the binary orbit is known, the frequencies are corrected for the binary motion. The R.M.S. pulsed flux is given in the energy band in which the pulse search was made. This usually includes only the first and second harmonics. These results are preliminary. Please contact Mark Finger for further information.

Detected Persistent Pulsars

Source Name & GBM link	LII (deg)	BII (deg)	Period (s)	Swift link	RXTE link	MAXI link	Simbad link
GX 1+4	1.94	4.79	159.7	GX 1+4	gx1+4	GX 1+4	V* V2116 Oph
Her X-1	58.20	37.50	1.24	Her X-1	herx1	Her X-1	V* HZ Her
Vela X-1	263.06	3.90	283.5	Vela X-1	velax1	Vela X-1	V* GP Vel
Cen X-3	292.10	0.30	4.80	Cen X-3	cenx3	Cen X-3	V* V779 Cen
GX 301-2	300.10	1.25	681.6	GX 301-2	gx301-2	GX 301-2	V* BP Cru
4U 1626-67	321.79	-13.09	7.67	4U 1626-67	x1627-673	4U 1626-67	V* KZ TrA
4U 1538-52	327.42	2.16	525.0	H 1538-522	x1538-522	4U 1538-52	V* QV Nor
OAO 1657-415	344.40	0.31	37.1	EXO 1657-419	x1657-415	OAO 1657-415	OAO 1657-41

Detected Transient Pulsars

Source Name & GBM Link	LII (deg)	BII (deg)	Period (s)	Swift link	RXTE link	MAXI link	Simbad link
IGR J18179-1621	14.60	-0.22	11.82	IGR J18179-1621			
XTE J1858+034	36.82	-0.06	219	XTE J1858+034	xtej1858+034	XTE J1858+034	[KRL2007b] 348
4U 1901+03	37.16	-1.25	2.76	4U 1901+03	x1901+031	4U 1901+03	4U 1901+03
IGR J19294+1816	53.44	0.20	12.45	IGR J19294+1816	igrj19294+1816		IGR J19294+1816
XTE J1946+274	63.21	1.40	15.8	XTE J1946+274	x1942+274	XTE J1946+274	3A 1942+274
EXO 2030+375	77.15	-1.24	41.33	EXO 2030+375	exo2030+375	EXO 2030+375	V* V2246 Cyg
SAX J2103.5+4545	87.13	-0.68	358.61	SAX J2103.5+4545	saxj2103.5+4545	SAX J2103.5+4545	GSC 03588-00834
Cep X-4	99.01	3.31	66.32	Ginga 2138+56	cepx4	Cep X-4	V* V490 Cep
4U 0115+63	125.92	1.03	3.61	4U 0115+634	x0115+634	4U 0115+63	V* V635 Cas
V 0332+53	146.05	-2.19	4.37	V 0332+53	v0332+53	V 0332+53	V* BQ Cam
RX J0440.9+4431	159.85	-1.27	205.26	LSV+44 17	lsv+4417	LSV+4417	TYC 2905-121-1
A 0535+26	181.50	-2.64	103.5	1A 0535+262	x0535+262	A 0535+262	HIP 26566
MXB 0656-072	220.20	-1.76	160.4	MXB 0656-072	x0656-072	MXB 0656-072	2E 0655.8-0708
GS 0834-430	262.02	-1.51	12.3		gs0834-430	GS 0834-430	Ginga 0834-430

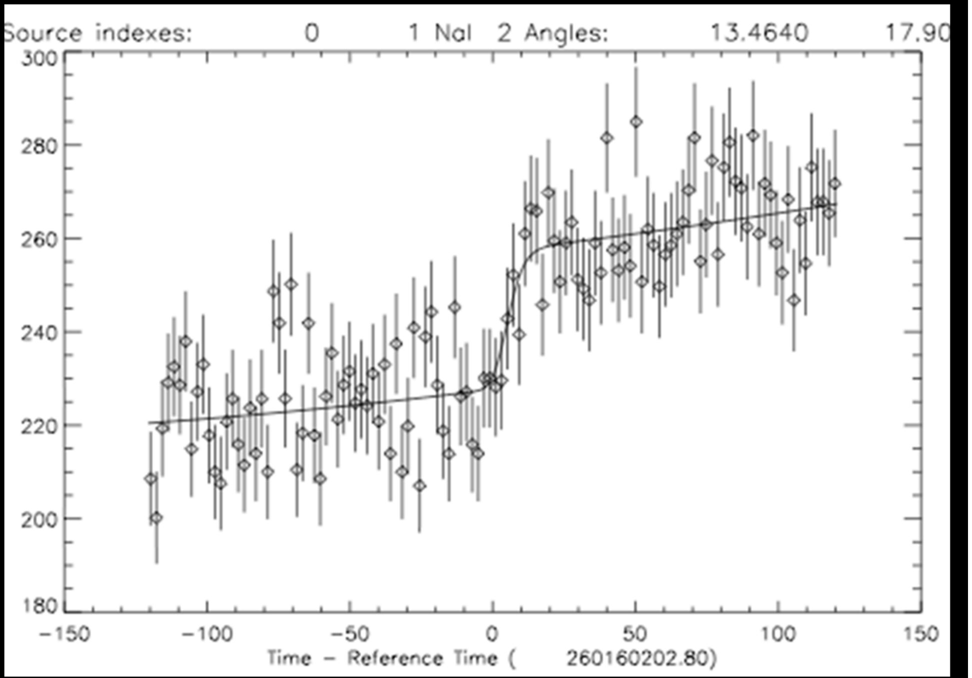


P_{spin} = 283 s, P_{orbit} = 8.96 d, wind-fed supergiant

GBM Earth Occultation Monitoring

The observed count rate in a 240-s window of data is fitted by a model consisting of a quadratic background plus source terms.

$$r(t,E_{ch}) = b_0(E_{ch}) + b_1(E_{ch}) \cdot (t - t_0) + b_2(E_{ch}) \cdot (t - t_0)^2 + \sum_{i=1}^{n} a_i(E_{ch}) \cdot S_i(t,E_{ch}) \quad (2)$$



The source count rate is modeled using an assumed energy spectrum, convolved with the atmospheric transmission function and folded through the detector response matrix

$$S(t,E_{ch}) = R(E_{ph},E_{ch},t)\left(T(E_{ph},t))\int_{E_{ph}} f(E_{ph})dE_{ph}\right) \quad (3)$$

GBM Earth occultation Monitoring (2)

- Using the first 3 years of GBM data, a catalog of 209 sources was monitored, with 99 sources detected, including 41 of 52 LMXBs, 31 of 39 HMXBs, 12 of 19 BHCs, 12 of 71 AGN, the Ophiuchus Cluster, the Sun, and the Crab.
- 7 BHCs, 1 AGN (Cen A), and the Crab are detected above 100 keV.
- Typical source exposure times are 3ks/day.

Wilson-Hodge et al. 2012, ApJ, Accepted, arXiv:1201.3585

http://heastro.phys.lsu.edu/gbm

GBM Occultation Project

http://heastro.phys.lsu.edu/gbm/ Reader gbm pulsar

MSFC Sharepoint ACES catalog NewXRayMissions wiki Physics of the Cosmos AXTAR | Google Groups GRBFitInterv...ration Wiki Main Page – ...Occultation

GBM Occultation Flux Histories

The Fermi Gamma-Ray Burst Monitor (GBM) is not a pointed or imaging instrument. To determine fluxes for known sources, we measure the change in the count rate observed in the NaI (or BGO) detectors when the source enters or exits Earth occultation. The measured counts in each energy channel are converted to fluxes using an assumed spectrum for each source. For these measurements we currently use CTIME data, with 0.256-s resolution and 8 energy channels covering 8 keV to 1 MeV. Our technique uses all 8 energy channels, but for most sources the majority of the signal is in the 12-25 keV and 25-50 keV bands.

Description of plots:

Four energy bands are plotted for each source. Daily, two-day, or four-day averages are plotted, depending upon the source intensity. Red diamonds denote > 5-sigma statistical significance (possible detections), blue diamonds denote < -3-sigma statistical significance (usually an indication of interference or background problems). Each plot shows the long-term average as a dashed line, which is shown in pink if the long-term average statistical significance is > 10 sigma. Long-term averages include all plotted data, usually for the full Fermi mission to date, except for recently added sources.

Caveats:

1. These light curves are quick-look data only for observation planning purposes. Please contact the occultation project PI colleen.wilson@nasa.gov for more detailed analysis.
2. The position of the Sun is calculated at the time of each occultation, so it is not listed in the main table.
3. Sources in the galactic center region suffer from source confusion. Please treat galactic center sources with caution and correlate with other instruments before relying on these light curves.
4. Because the position of the Earth's limb on the sky repeats at the precession period of the Fermi orbit, apparent periods in the range of 50-55 days (or multiples thereof) may be present in the data and are likely to be spurious.
5. Significant negative (blue points) and positive (red points) close in time are often indicative of source interference problems. For example, the very bright outburst of A0535+262 in December 2009 caused such problems in several sources.

We ask that when results from these analyses are used, they be referenced as "Fermi GBM Earth occultation results provided by the Fermi GBM Earth occultation Guest Investigation teams at NASA/MSFC and LSU."

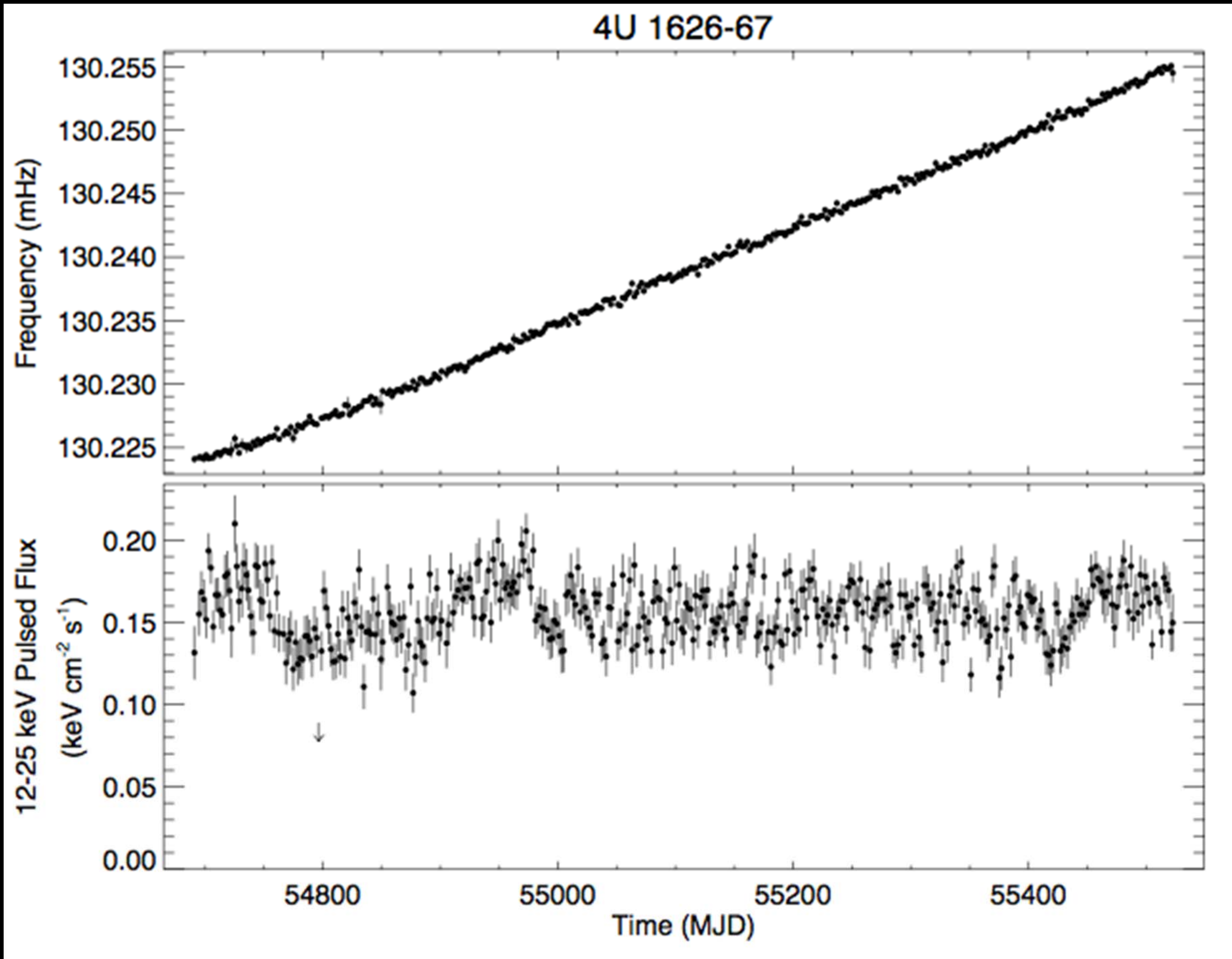
GBM-related publications from the Gamma-Ray Astronomy Occultation team are listed here.

GBM Earth Occultation Monitored Sources

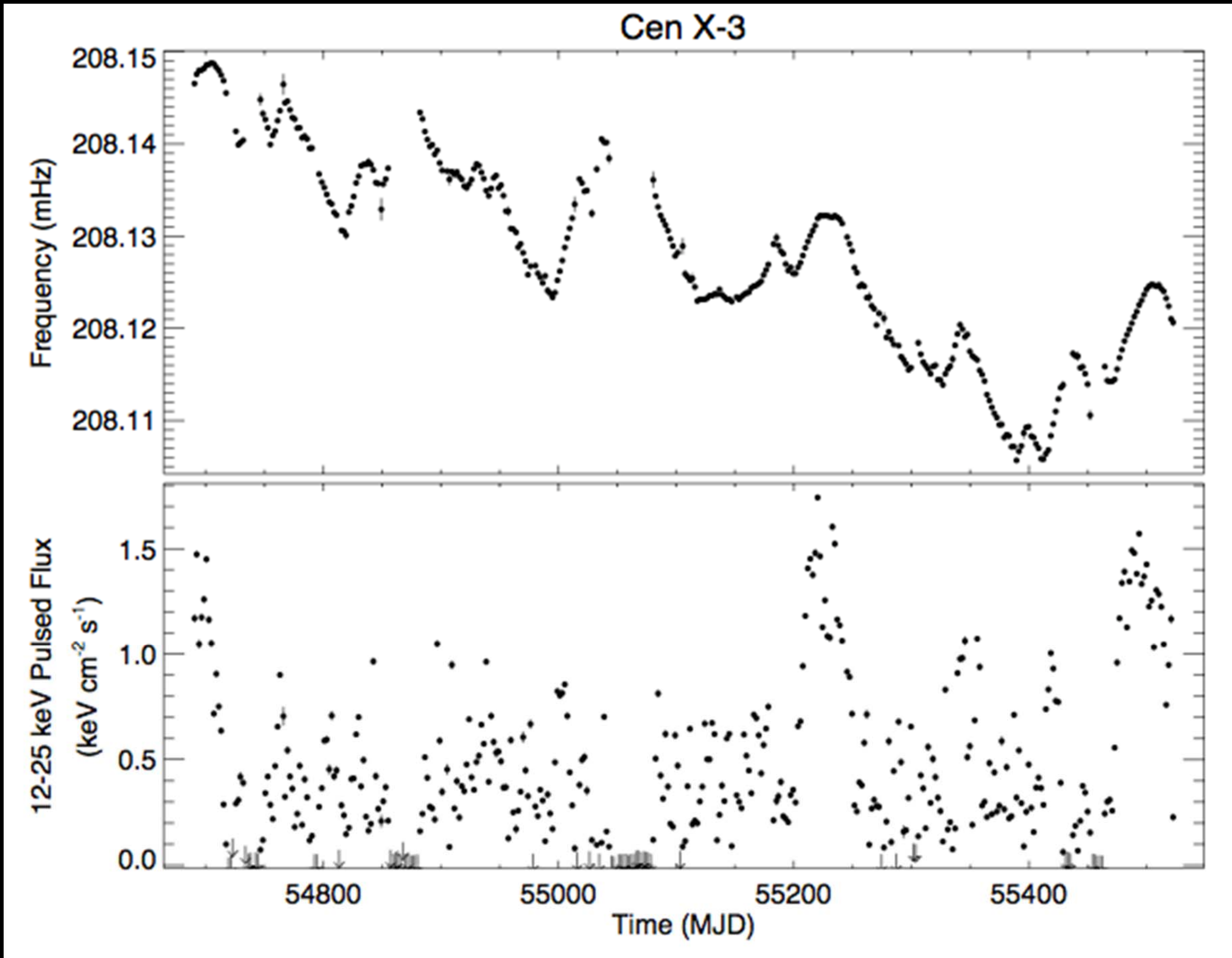
#	Source name	RA (deg)	Dec (deg)	*l* (deg)	*b* (deg)	Object Type
1	SUN	0.000	0.000	96.337	-60.189	Star
2	IGR J00234+6141	5.740	61.685	119.561	-1.000	CV
3	V709 CAS	7.204	59.289	120.042	-3.456	CV/DQ Her
4	BD+6270	9.300	61.380	121.227	-1.445	Star
5	FERMIJ0109+6134	17.445	61.558	125.115	-1.236	AGN
6	SMCX-1	19.275	-73.433	300.412	-43.569	HMXB/NS
7	3A0114+650	19.511	65.292	125.710	2.564	HMXB/NS
8	4U0115+634	19.630	63.740	125.922	1.026	HMXB/NS
9	PKS 0116-219	19.740	-21.690	173.445	-81.707	AGN
10	PKS 0142-278	26.260	-27.560	218.089	-78.095	AGN
11	PKS 0215+015	34.450	1.750	162.132	-54.413	AGN
12	S4 0218+35	35.270	35.940	142.598	-23.485	AGN
13	PKS 0235-618	39.220	-61.600	283.193	-51.296	AGN
14	LSI+61 303	40.132	61.229	135.675	1.086	Gamma-ray binary
15	PKS 0244-470	41.500	-46.860	261.837	-60.092	AGN
16	ALGOL	47.040	40.960	148.973	-14.897	Star
17	NGC1275	49.950	41.510	150.576	-13.263	AGN/Sy 2
18	GKPER	52.799	43.905	150.955	-10.104	CV/DQ Her
19	PKS 0332-403	53.560	-40.140	244.763	-54.073	AGN/BL Lac

Persistent Sources Detected

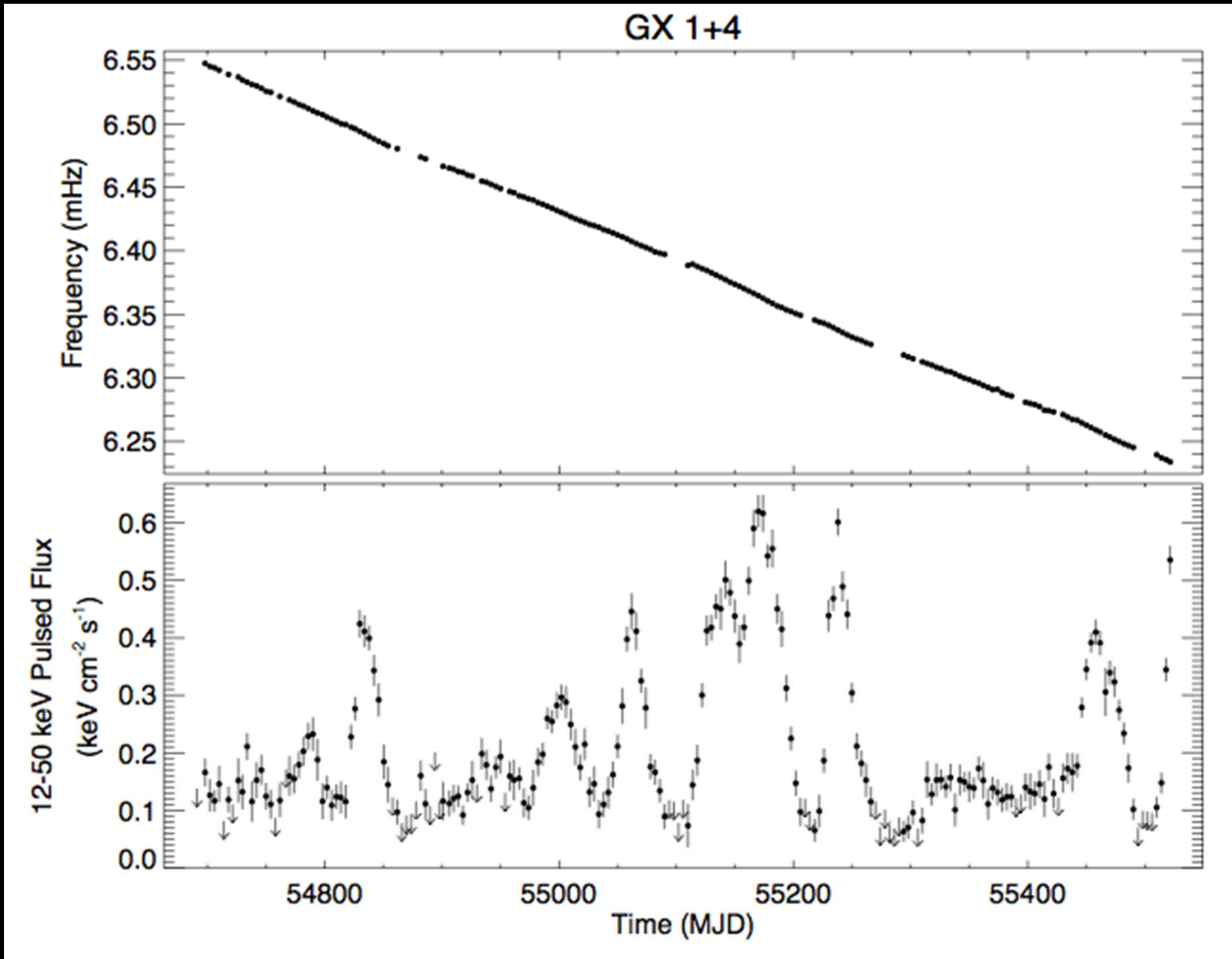
Name	Spin Period (s)	Orbital Period (d)	Type
Her X-1	1.24	1.70	Disk-fed LMXB (Eclipsing)
Cen X-3	4.80	2.09	Disk-fed Supergiant (Eclipsing)
4U 1626-67	7.63	0.023	Disk-fed LMXB (Super-Compact)
OAO 1657-415	37.1	10.4	Wind-fed Supergiant (Eclipsing)
GX 1+4	158	1161	Symbiotic XRB (red giant+ns)
Vela X-1	283	8.96	Wind-fed Supergiant (Eclipsing)
4U 1538-52	525	3.73	Wind-fed Supergiant (Eclipsing)
GX 301-2	686	41.5	Wind-fed Supergiant



P_{spin} = 7.63 s, P_{orbit} = 0.023 d, disk-fed LMXB



P_{spin} = 4.80 s, P_{orbit} = 2.89 d, disk-fed supergiant



P_{spin} = 158 s, P_{orbit} = 1161 d, Symbiotic XRB

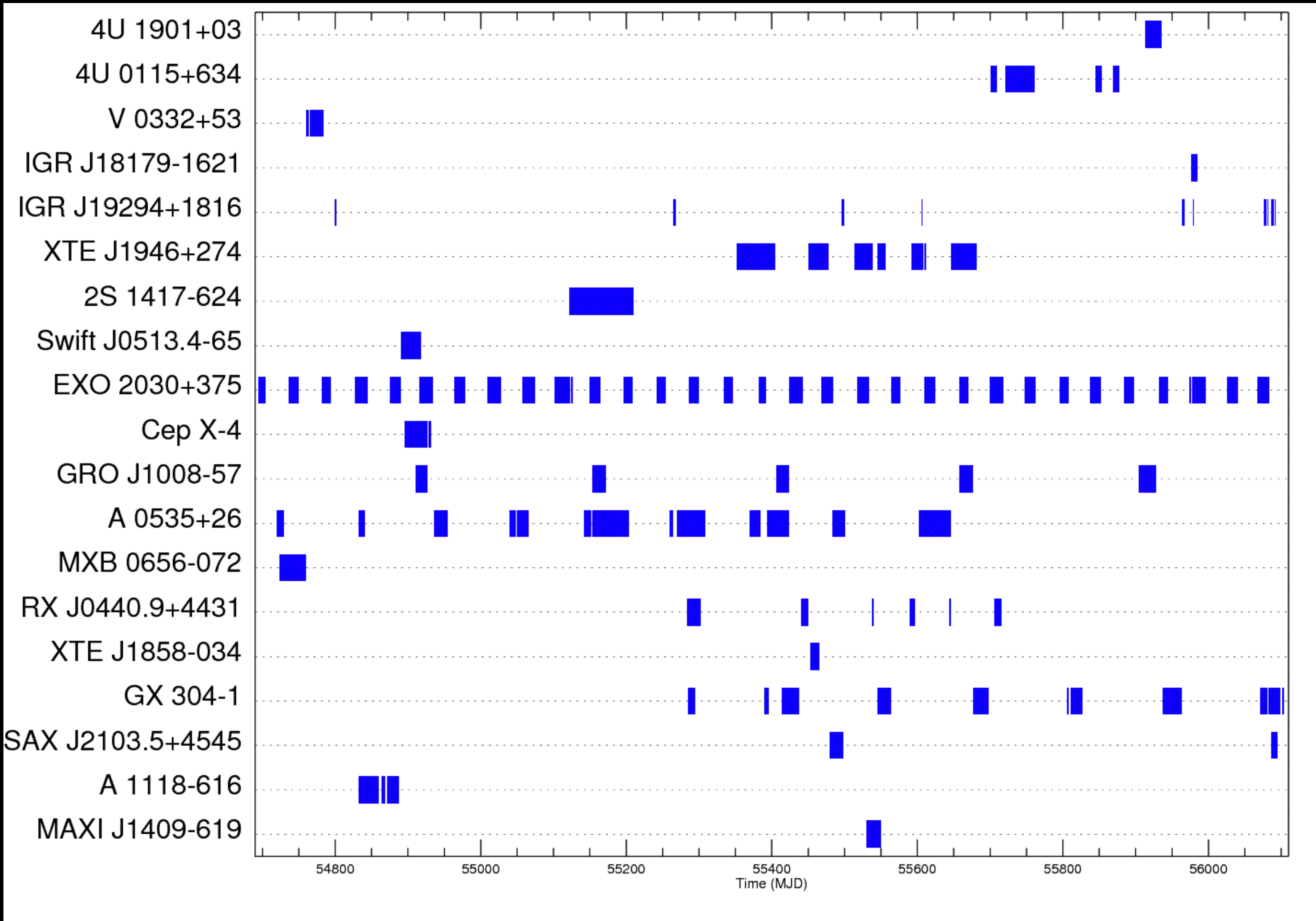
Transient Sources Detected (1)

Name	Spin Period (s)	Orbital Period (d)	Type
4U 1901+03	2.76	22.5	Be/X-ray Binary
4U 0115+634	3.61	24.3	Be/X-ray Binary
V 0332+53	4.37	34.2	Be/X-ray Binary
IGR J18179-1621	11.82		
GS 0834-430	12.3		Be/X-ray Binary
IGR J19294+1816 *	12.4	117.2	SFXT or Be/X-ray Binary
XTE J1946+274	15.8	169.2	Be/X-ray Binary
2S 1417-624	17.5	42.1	Be/X-ray Binary
Swift J0513.4-6547 *	27.3	?	likely Be/X-ray Binary (in LMC)
EXO 2030+375	41.3	46.0	Be/X-ray Binary
Cep X-4	66.3	?	Be/X-ray Binary
GRO J1008-57	93.7	248	Be/X-ray Binary
A 0535+26	103	111.1	Be/X-ray Binary

Transient Sources Detected (2)

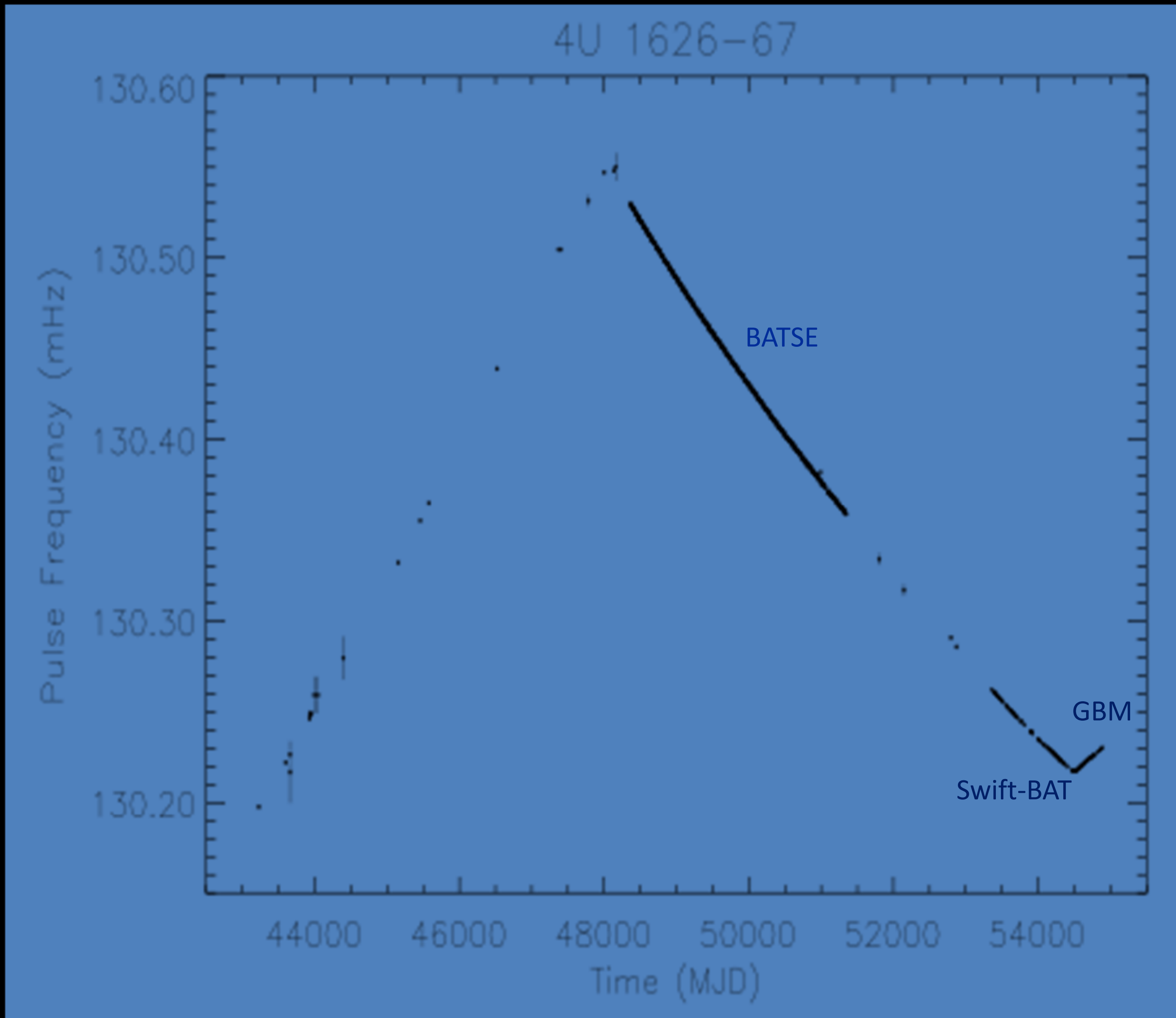
Name	Spin Period (s)	Orbital Period (d)	Type
MXB 0656-072	160	?	Be/X-ray Binary
LSV+44 17	205	~150	Be/X-ray Binary
XTE J1858+034	219		Be/X-ray Binary
GX 304-1	276	132.5	Be/X-ray Binary
SAX J2103.5+4545	352	12.68	Be/X-ray Binary
A 1118-615	407	?	Be/X-ray Binary
MAXI J1409-619	504		

Transient Outbursts with Detected Pulsations



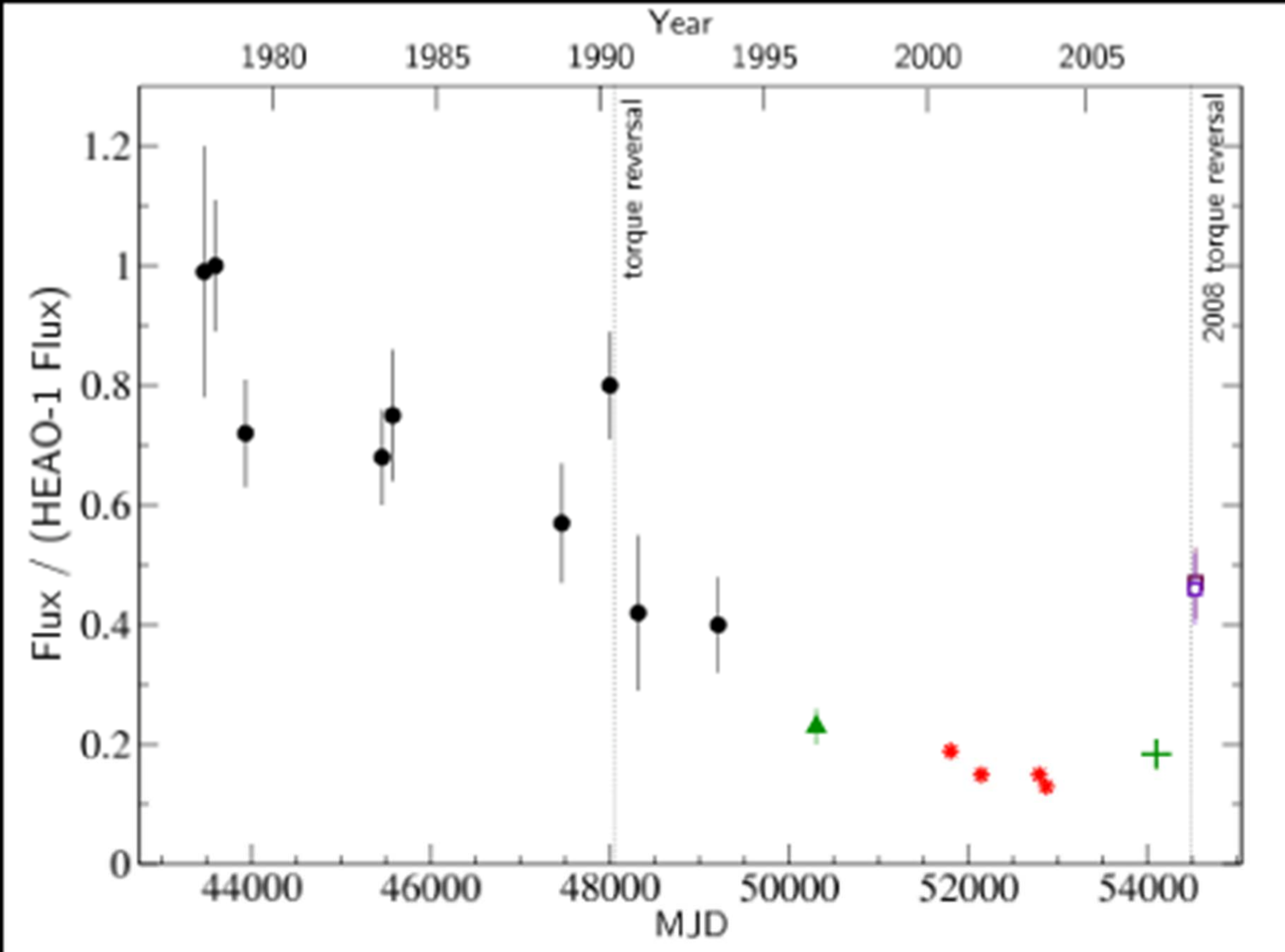
Transient Sources Detected with Earth Occultation

Torque Switching



Camero-Arranz et al. 2010

4U 1626-27 torque switching



Camero-Arranz et al. 2010

4U 1626-27 torque switching

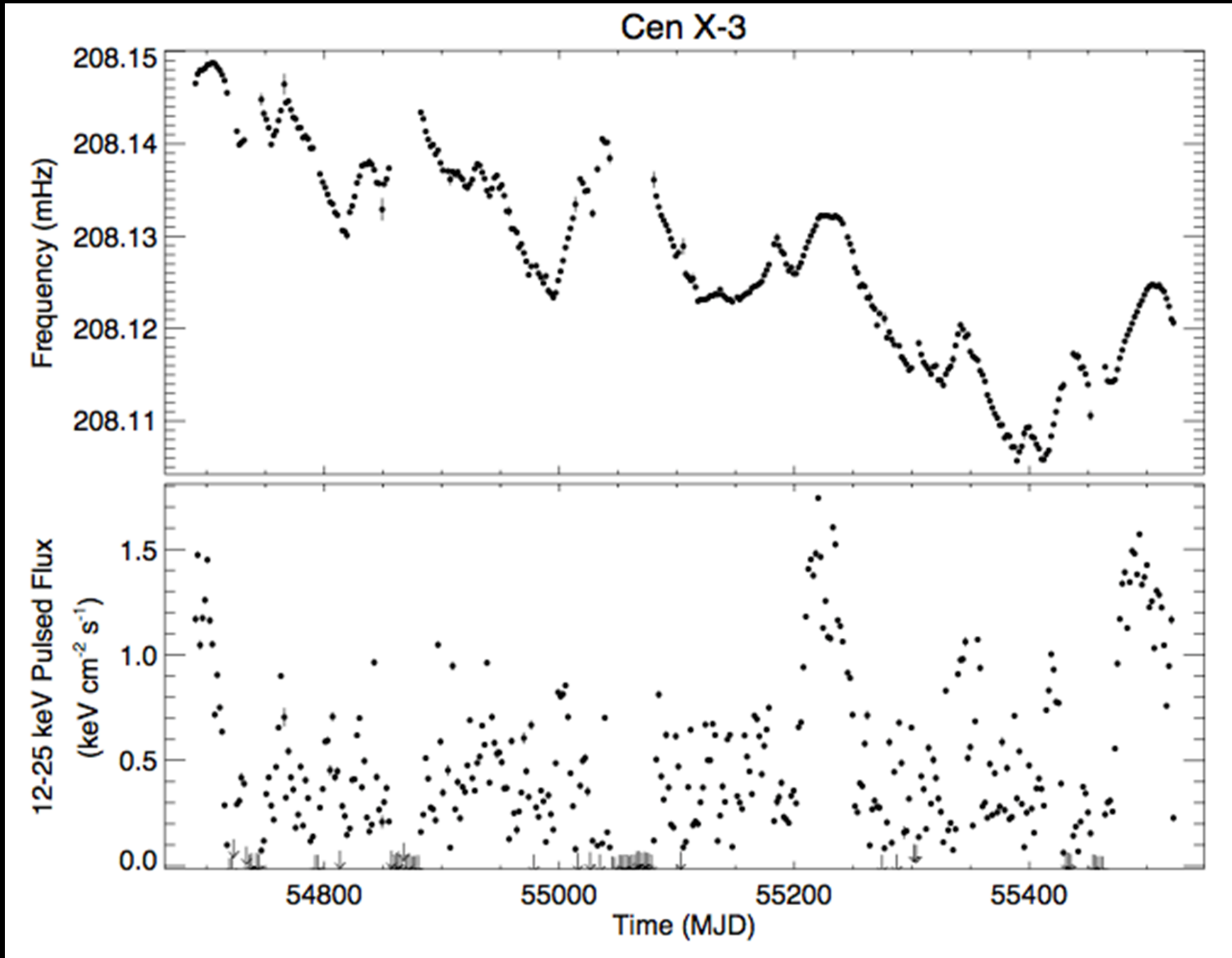
Things to note:

- The reversals are rapid compared to their separation.

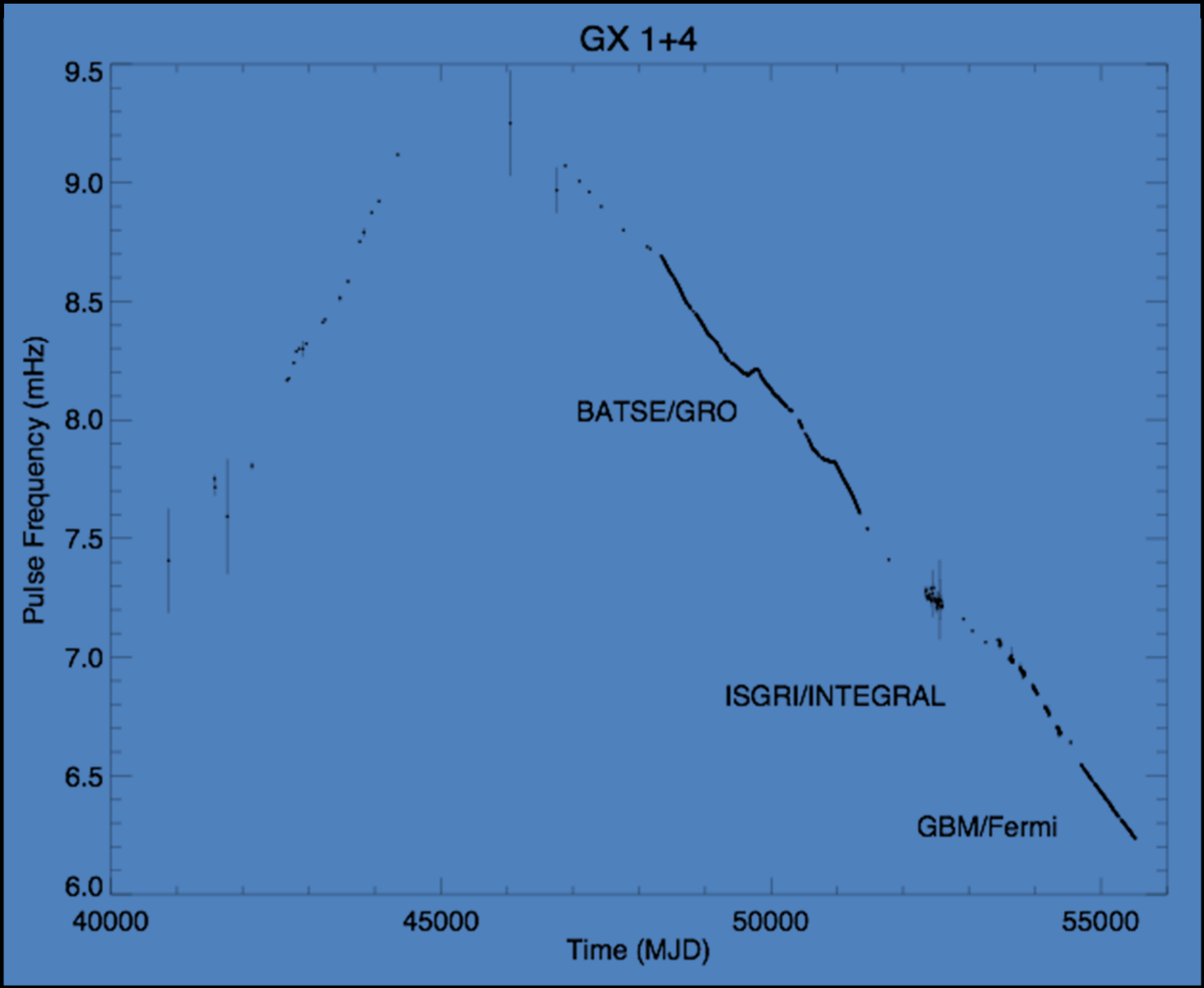
- During the spin-down the frequency rate increased while the flux decreased. This is inconsistent with a monotonic relationship between flux and frequency rate.

- The spin-up to spin down reversal occurred at a higher flux than the spin-down to spin-up reversal. This is inconsistent with a single-valued relationship between flux and frequency rate.

Cen X-3 torque switching



GX 1+4 Torque Switching



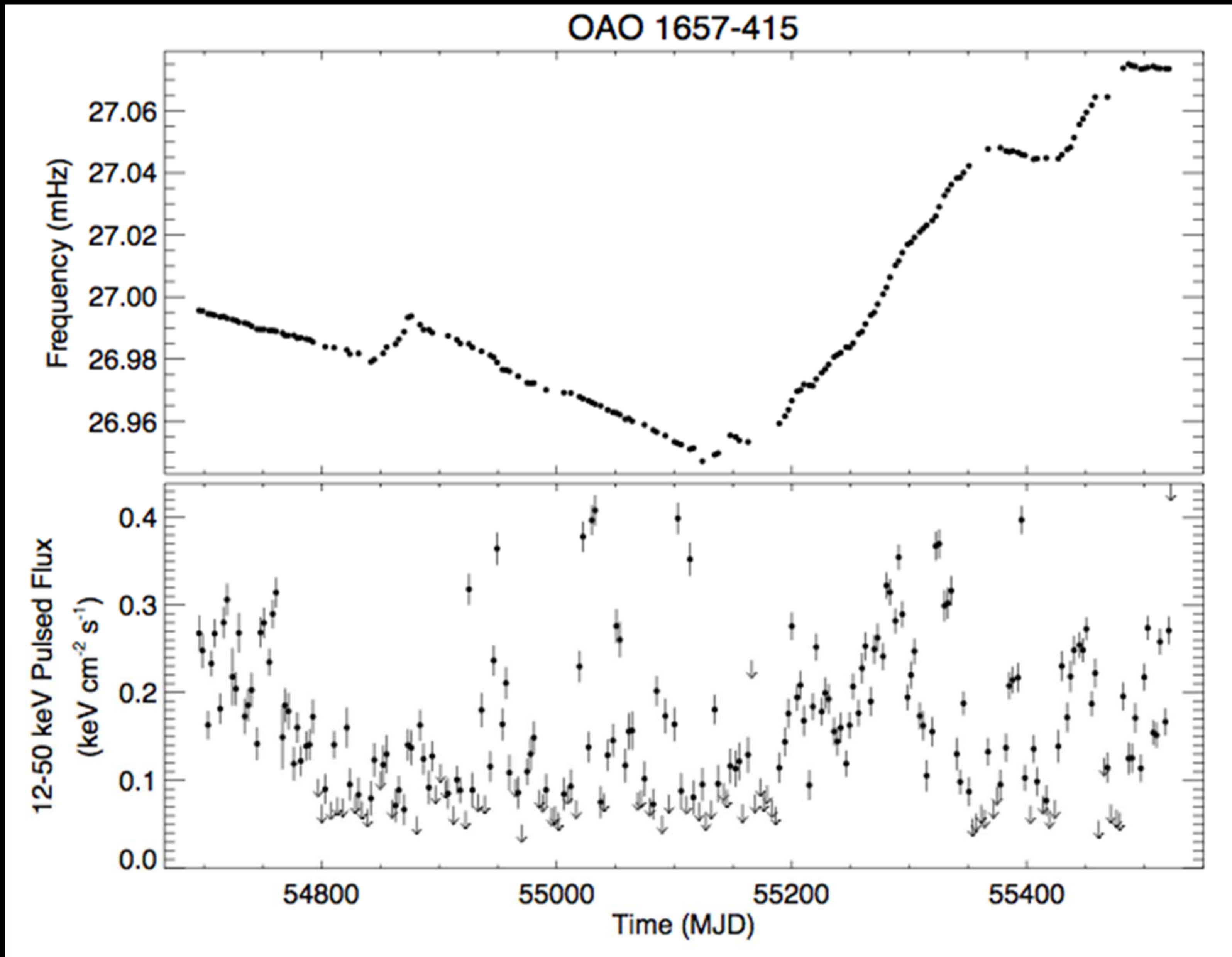
GX 1+4 Torque Switching

Things to note:

- During the spin-down changes in frequency rate are anti-correlated with changes in flux. This supports the proposal a retrograde accretion disk during spin-down.

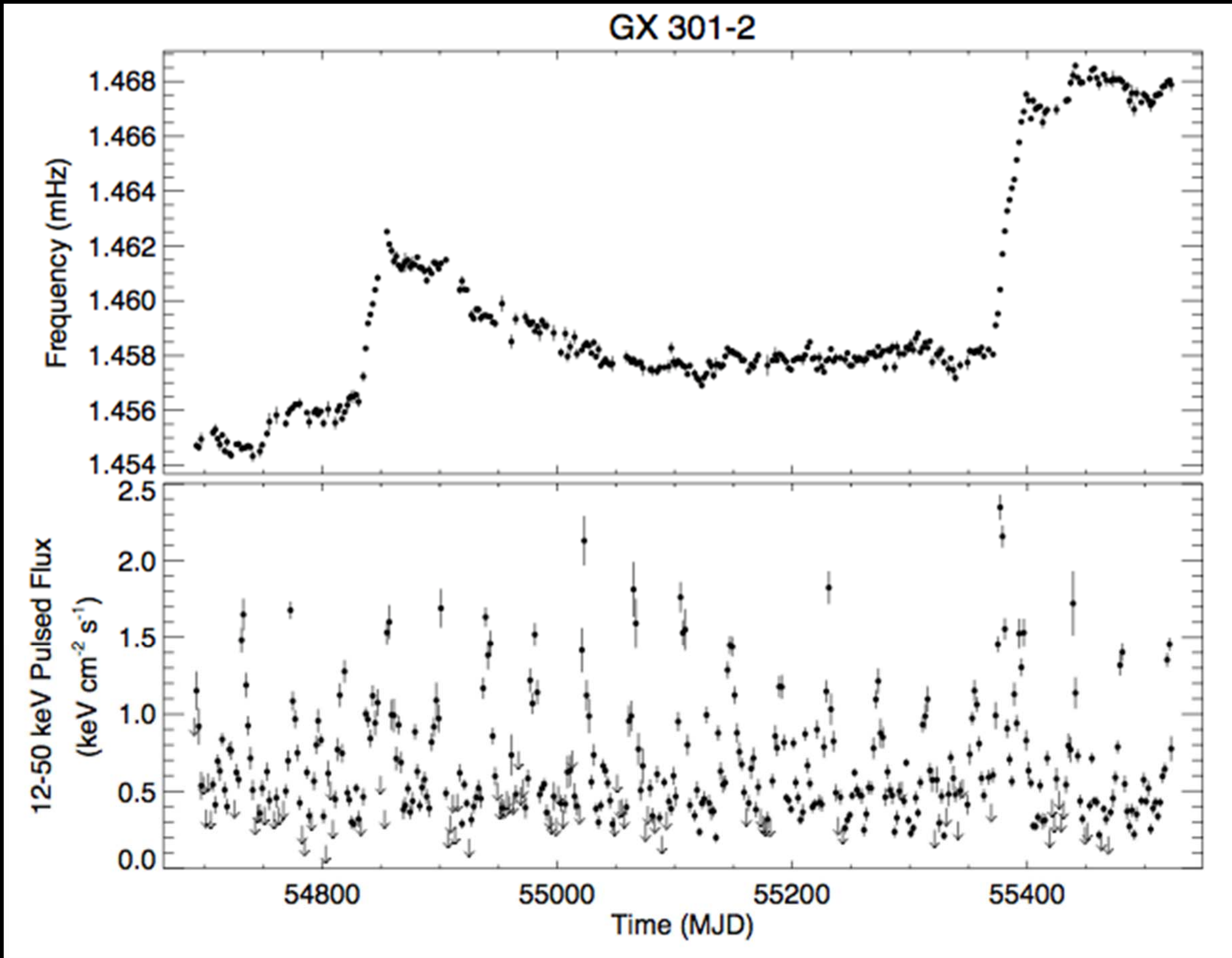
- Two short-lived episodes of spin-up were seen with BATSE.

OAO 1657-415 torque switching



GBM

GX 301-2 torque switching?



Spin-down in wind accretion

In spherically symmetric accretion the torque on the neutron star is estimated as (Lipunov 1992)

$$\Gamma = 2\pi I\dot{\nu} = -k\mu^2 r_{co}^{-3}$$

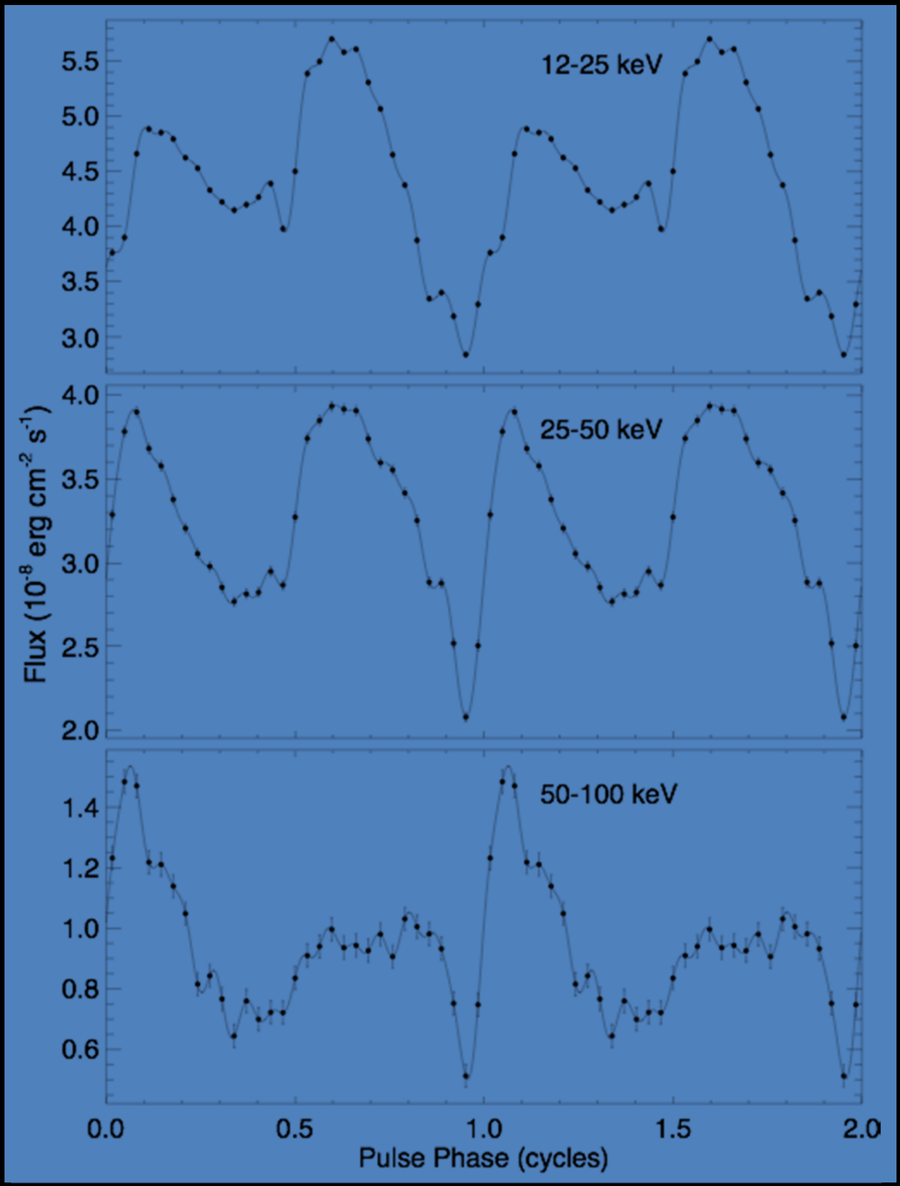
where k < 1 and the co-rotation radius is

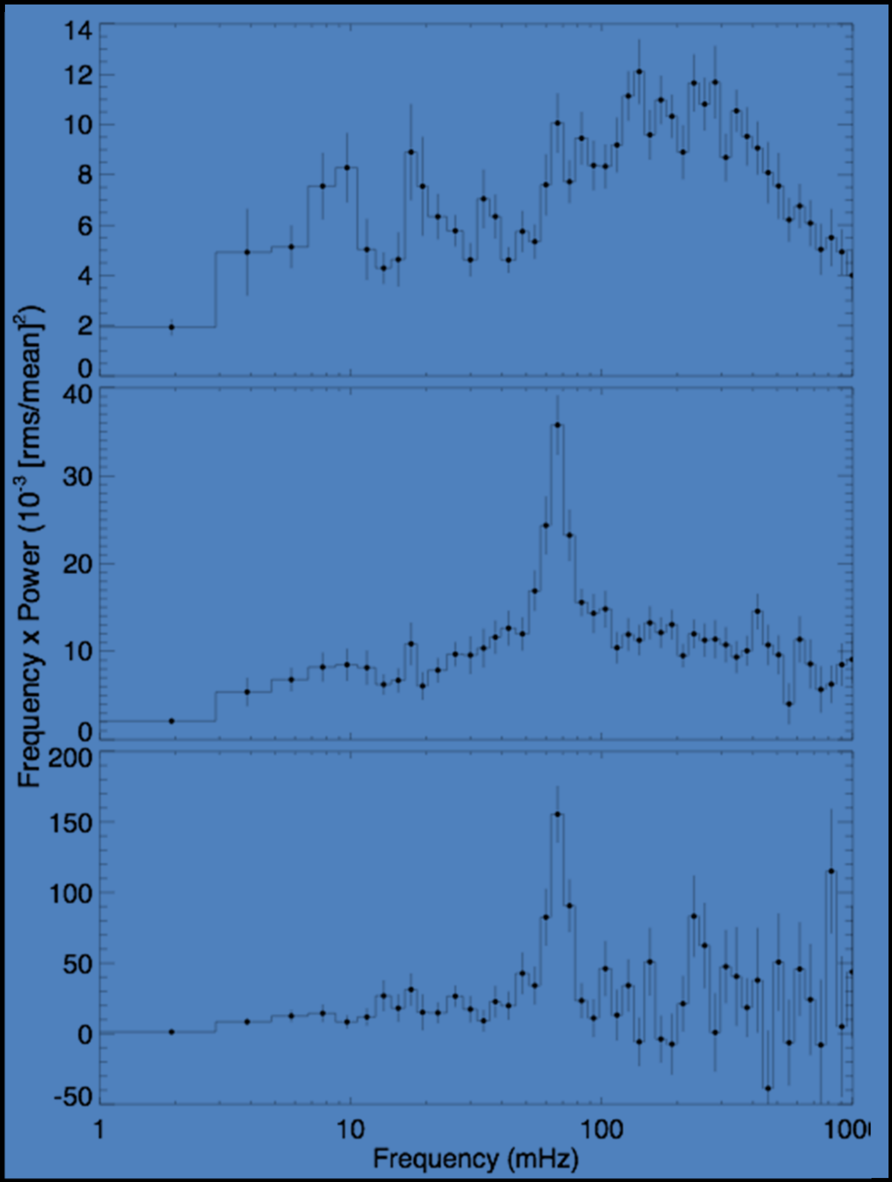
$$r_{co} = (GM)^{1/3}(2\pi\nu)^{-2/3}$$

Source	B (10^{12} G)	period (s)	measured dv/dt (Hz/s)	calculated dv/dt (Hz/s)
OAO 1657-415	?	37.7	-2.0×10^{-12}	$-5.9 \times 10^{-13} \times (B/10^{13})^2$
GX 1+4	?	158.4	-4.4×10^{-12}	$-3.4 \times 10^{-14} \times (B/10^{13})^2$
GX 302-1	3.7	687	-3.0×10^{-13}	-2.4×10^{-16}

A0535+26 QPO

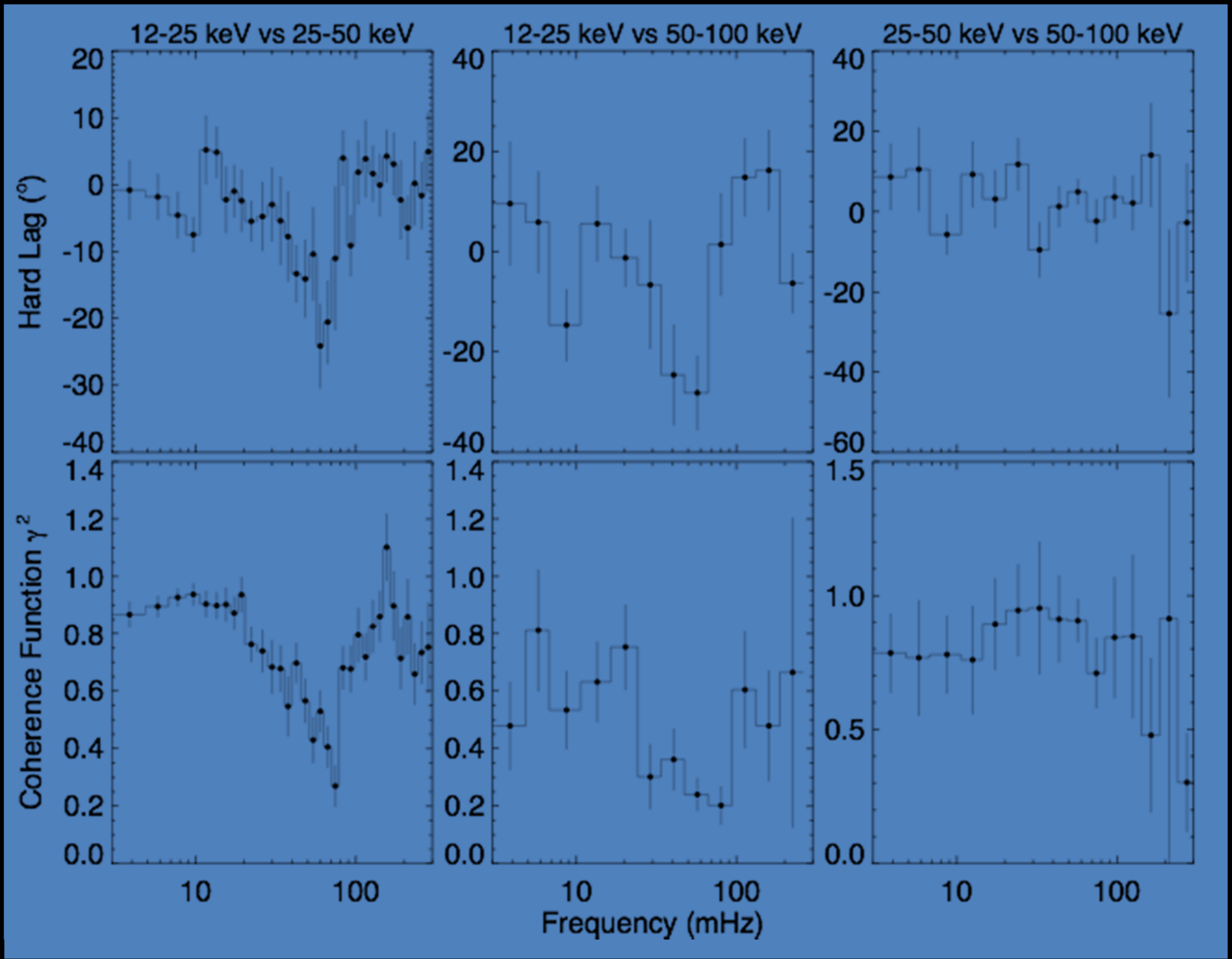
2009 Dec 14





A0535+26 QPO

2009 Dec 14



Conclusions

The full sky coverage of GBM enables long term monitoring of the brighter accreting pulsars allowing:

- Precise measurements of spin frequencies and orbital parameters.

- Study of spin-up or spin-down rates and hence the flow of angular momentum.

- Detection and study of new transient sources or new outburst of known transients.

GBM Pulsar Project
http://gammaray.nsstc.nasa.gov/gbm/science/pulsars/