Fermi GBM Monitoring of Accreting Pulsars

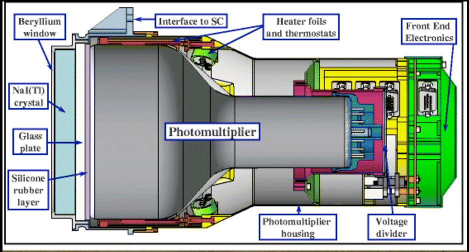
Mark H. Finger,
Elif Beklen, P. Narayana Bhat, David Buckley,
Ascension Camero-Arranz, Malcolm J. Coe,
Valerie Connaughton, Peter Jenke, Gottfried Kanbach,
Ignacio Negueruela, William S. Paciesas,
Colleen A. Wilson-Hodge

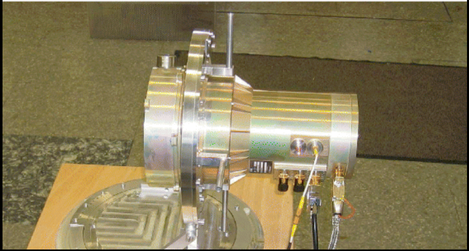
Outline of Talk

- GBM observations and pulsed source analysis
- Accreting pulsars classes and the detected sources
    - Outflows from donor star and source classes
    - Detected sources
    - Examples from detected classes
- Science topics
    - Torque switching
    - Spin-down torques
    - QPO in A0535+26
- 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.

Data Analysis

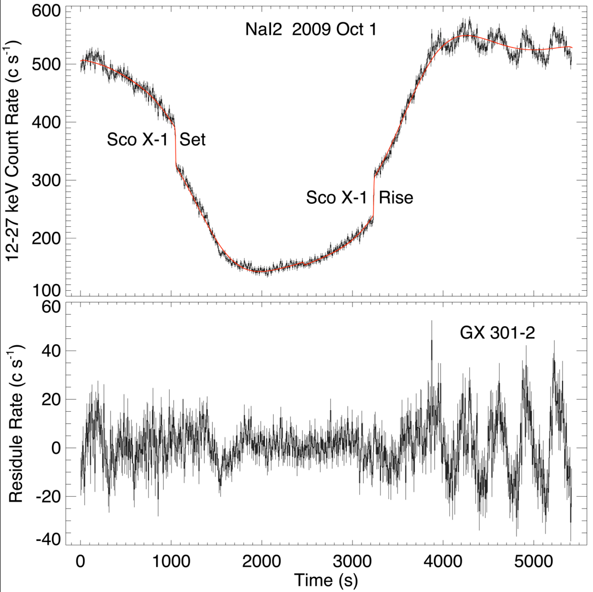
The analysis of GBM observations of pulsars presents two main challenges:

- 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 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 is 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 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.

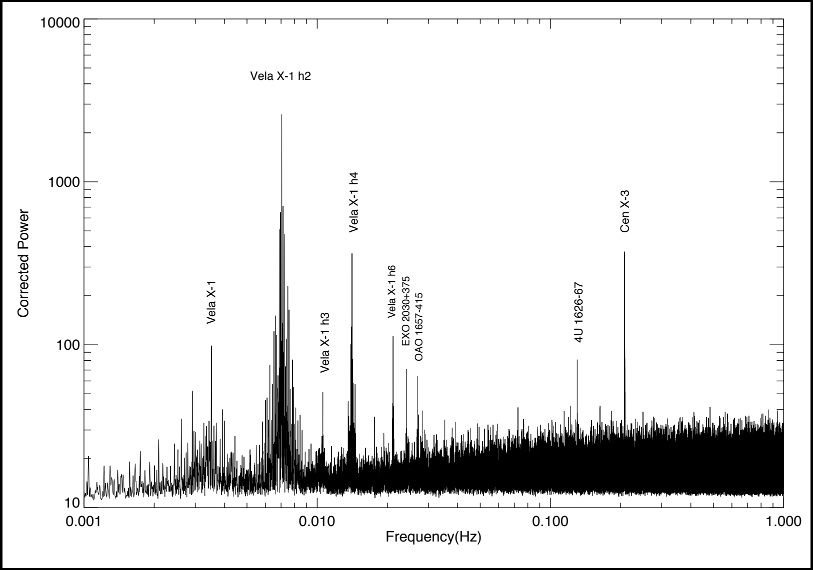
Pulse Searches

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.

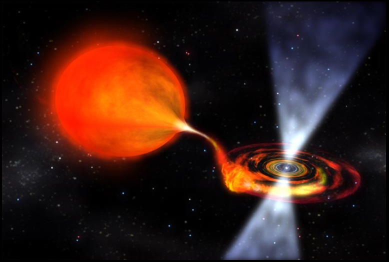
- Source Specific Searches. These are searches over small ranges of frequency and sometimes frequency rate based on phase shifting and summing pulse profiles that are made from short intervals of data, using barycentered and possibly orbitally corrected times.

Blind Pulse Search

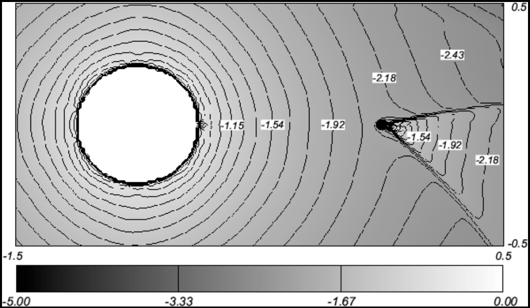


Blind pulse search in 20-50 keV band, for 2010 January 8.

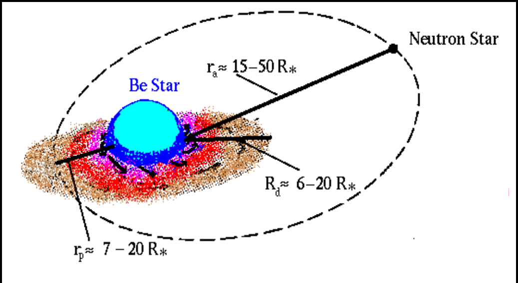
Donor Star Outflow Types



Roche-lobe over-flow



Stellar Wind

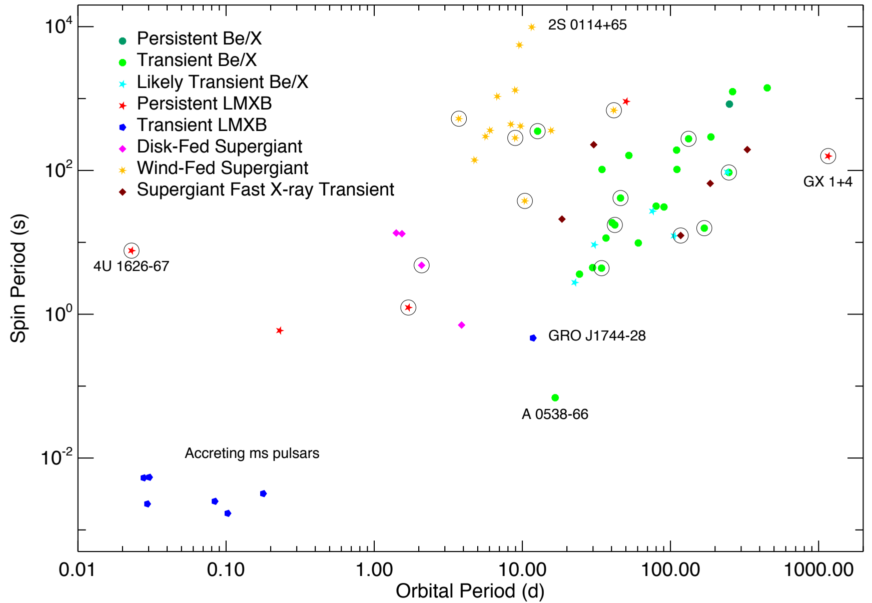


Be disk outflow

Accreting Pulsar Classes

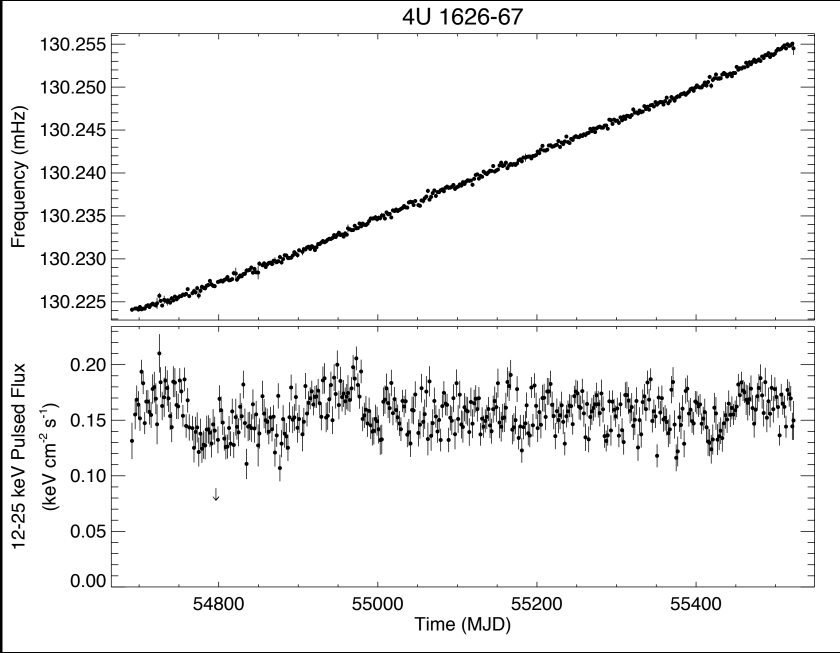
- **Roche Lobe Overflow**
  - Supergiant — Persistent — Persistent supergiant binary - disk fed
  - Low mass
    - Persistent — Persistent low-mass binary - disk fed
    - Transient
      - GRO J1744-28
      - Millisecond accreting pulsar system
- **Stellar Wind**
  - Supergiant
    - Persistent — Persistent supergiant binary - wind fed
    - Transient — Supergiant Fast X-ray Transient
  - Red giant — Persistent — Symbiotic binary
- **Be star Disk**
  - Be/Oe
    - Persistent — Persistent Be/X-ray binary
    - Transient — Transient Be/X-ray binary

Orbital and Spin Periods of Accreting Pulsars

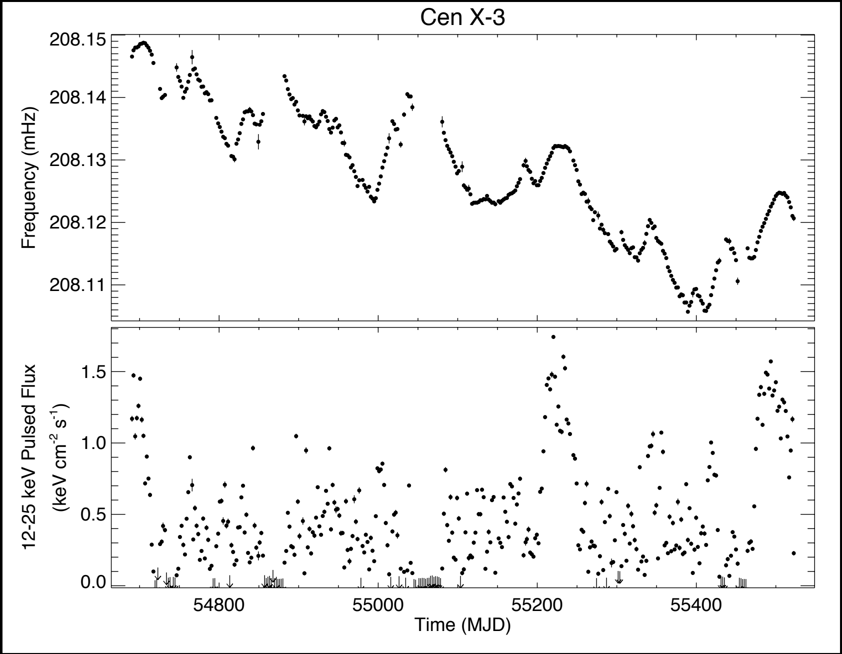


Persistent Sources Detected

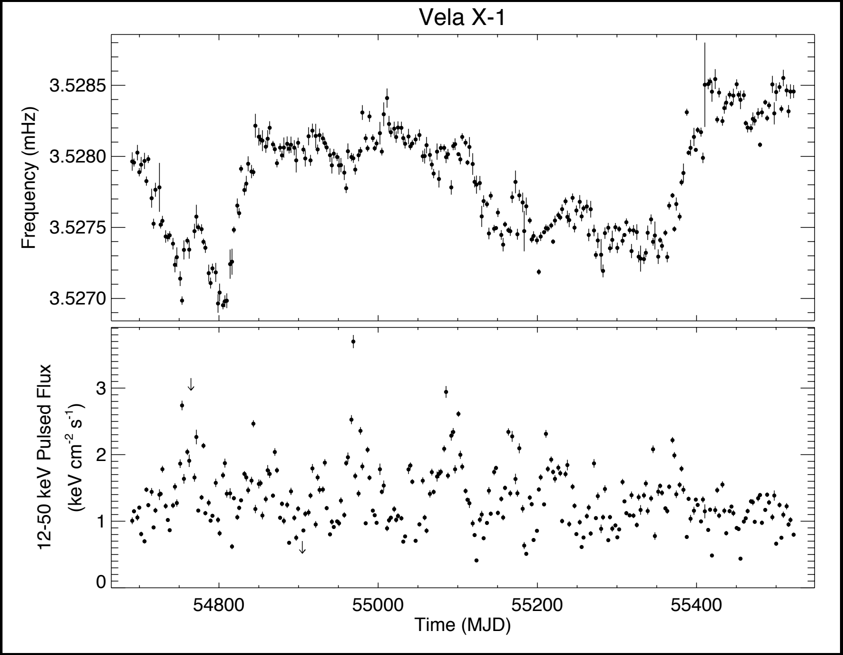
Name	Spin Period (s)	Orbital Period (d)	Type
Her X-1	1.24	1.70	Disk-fed LMXB (Eclipsing)
Cen X-3	4.80	2.09	Disk-fed Supergiant (Eclipsing)
4U 1626-67	7.63	0.023	Disk-fed LMXB (Super-Compact)
OAO 1657-415	37.1	10.4	Wind-fed Supergiant (Eclipsing)
GX 1+4	158	1161	Symbiotic XRB (red giant+ns)
Vela X-1	283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



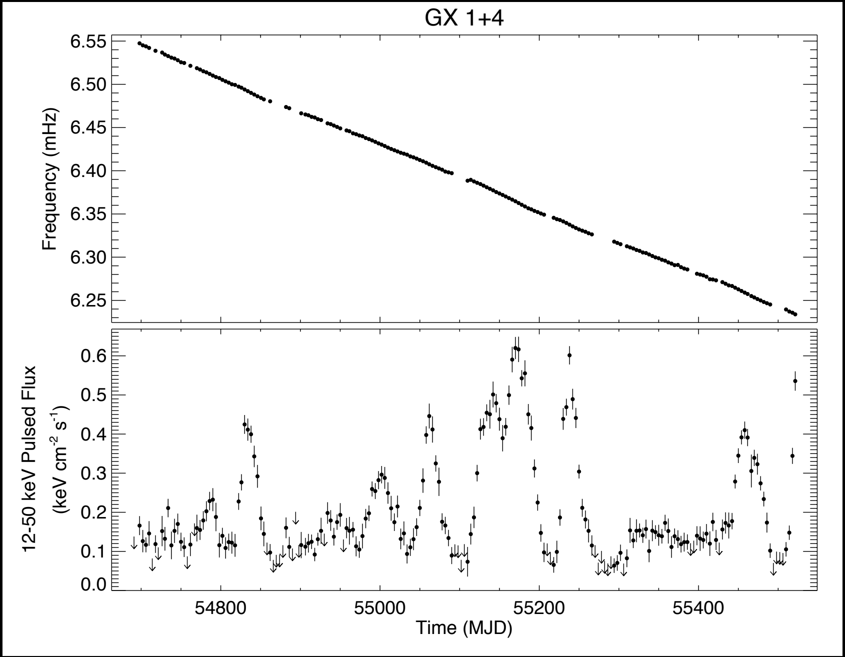
P_{spin} = 7.63 s, P_{orbit} = 0.023 d, disk-fed LMXB



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



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

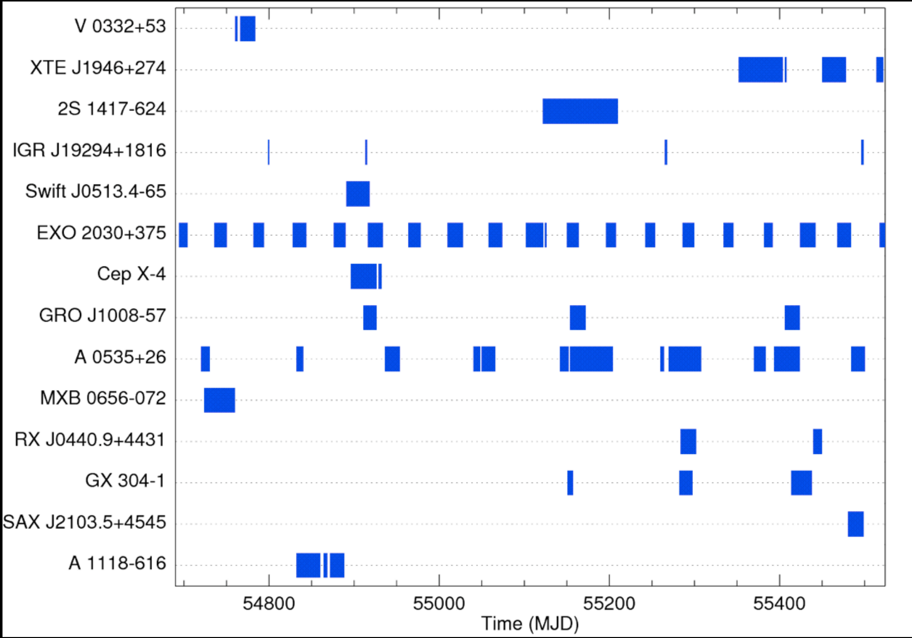


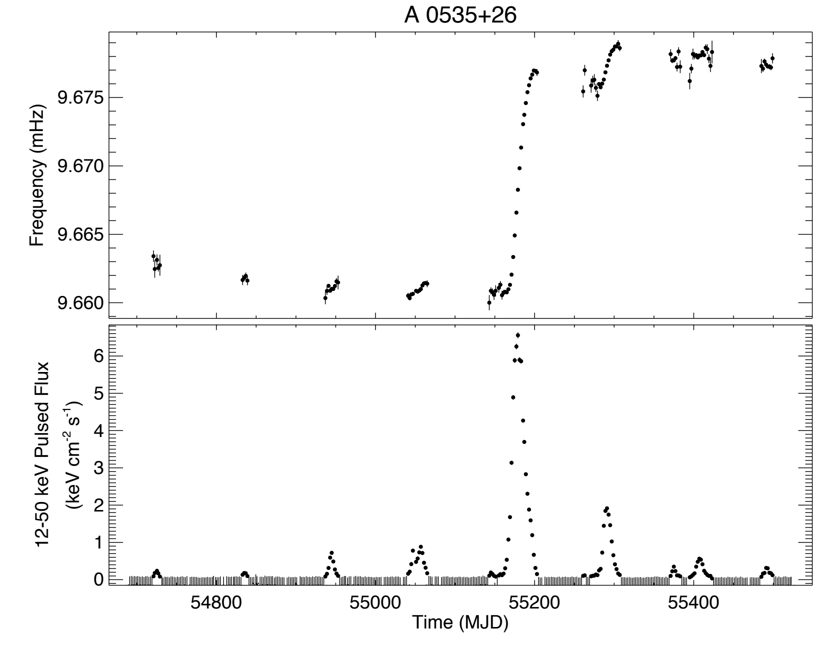
P_{spin} = 158 s, P_{orbit} = 1161 d, Symbiotic XRB

Transient Sources Detected

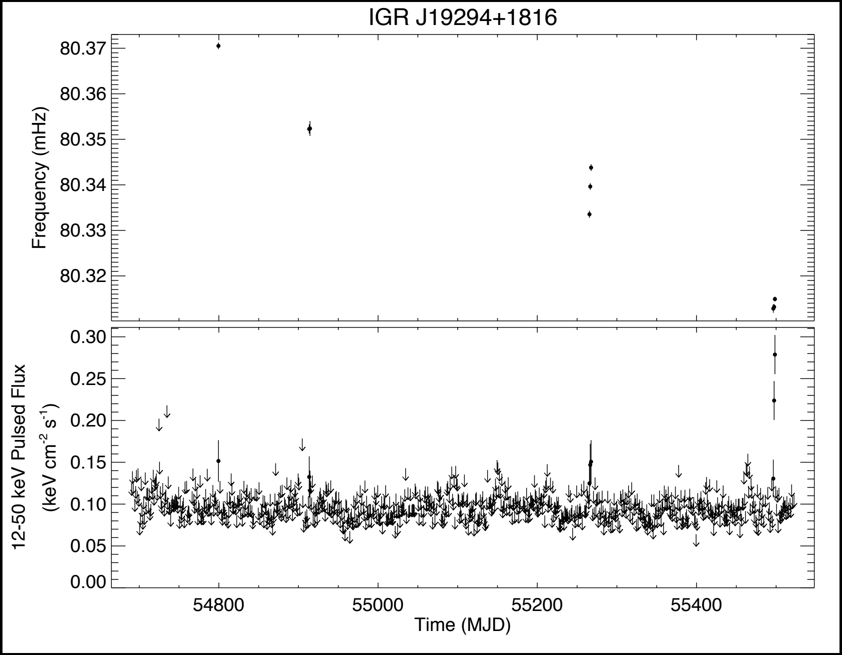
Name	Spin Period (s)	Orbital Period (d)	Type
V 0332+53	4.37	34.2	Be/X-ray Binary
IGR J19294+1816	12.4	117.2	SFXT or Be/X-ray Binary
XTE J1946+274	15.8	169.2	Be/X-ray Binary
2S 1417-624	17.5	42.1	Be/X-ray Binary
Swift J0513.4-6547	27.3	?	likely Be/X-ray Binary (in LMC)
EXO 2030+375	41.3	46.0	Be/X-ray 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
MXB 0656-072	160	?	Be/X-ray Binary
LSV+44 17	205	~150	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

Detected Transient Outbursts



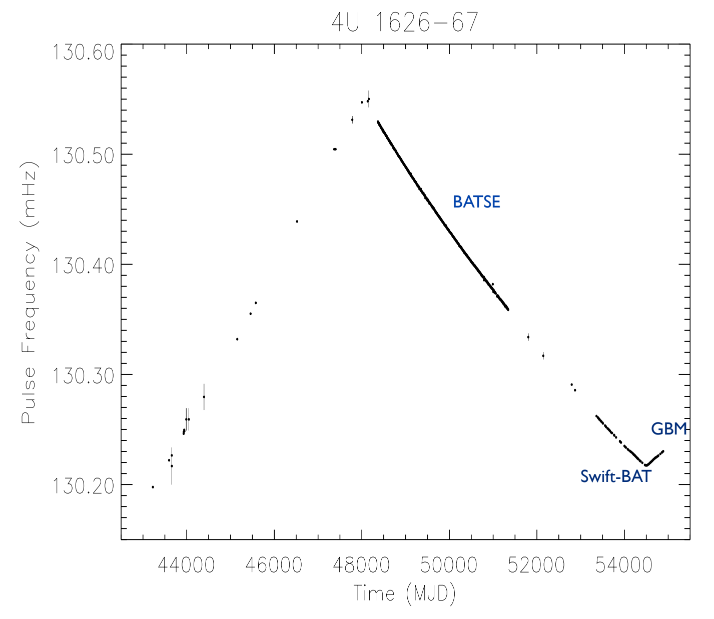


P_{spin} = 103.3 s, P_{orbit} = 111.1 d, Be X-ray Binary



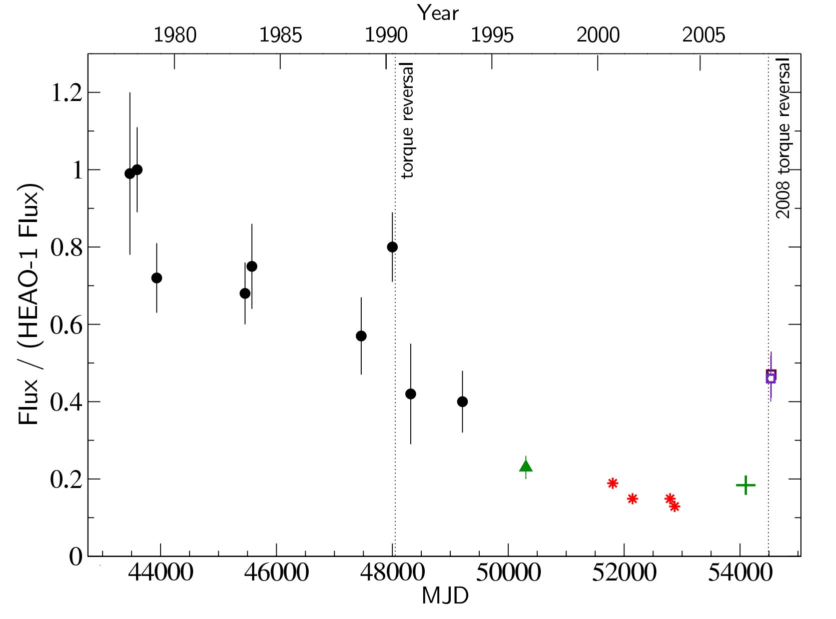
P_{spin} = 12.4 s, P_{orbit} = 117.2 d, SFXT or Be XRB

Torque Switching



Camero-Arranz et al. 2010

4U 1626-27 torque switching



Camero-Arranz et al. 2010

4U 1626-27 torque switching

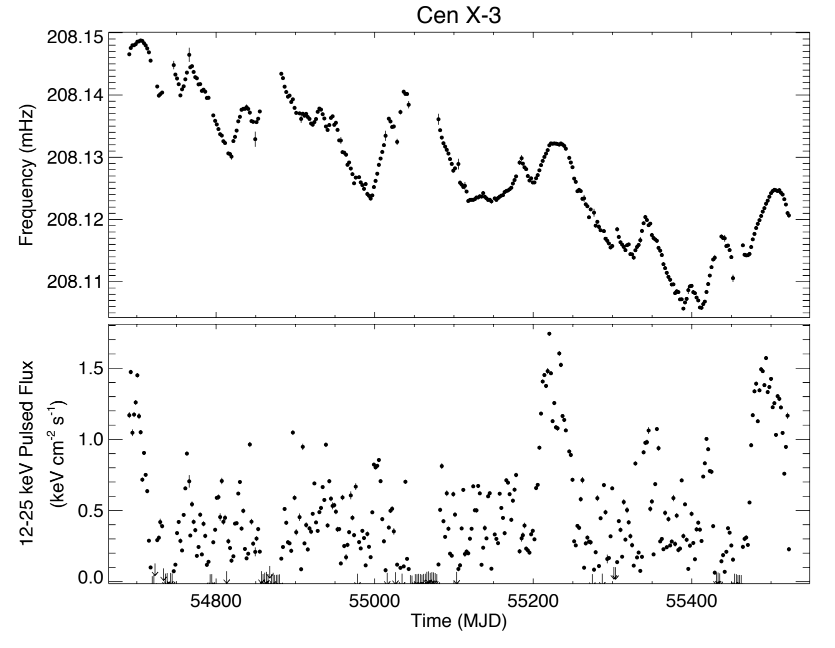
Things to note:

- The reversals are rapid compared to their separation.

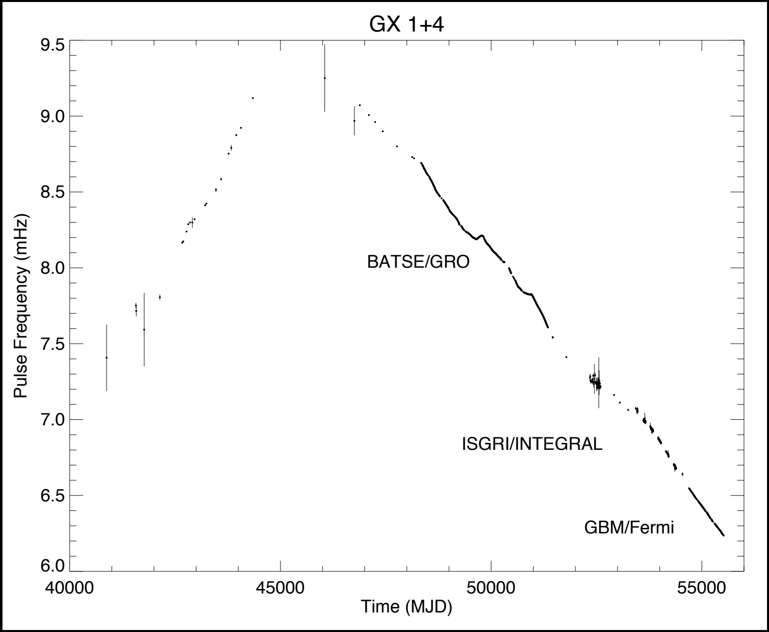
- During the spin-down the frequency rate increased while the flux decreased. This is inconsistent with a monotonic relationship between flux and frequency rate.

- 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



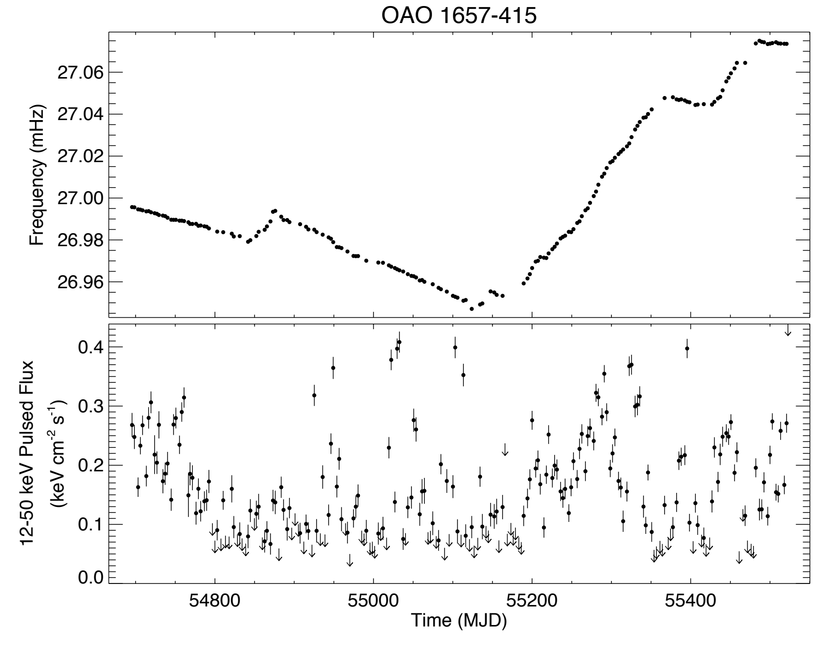
GX 1+4 Torque Switching

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.

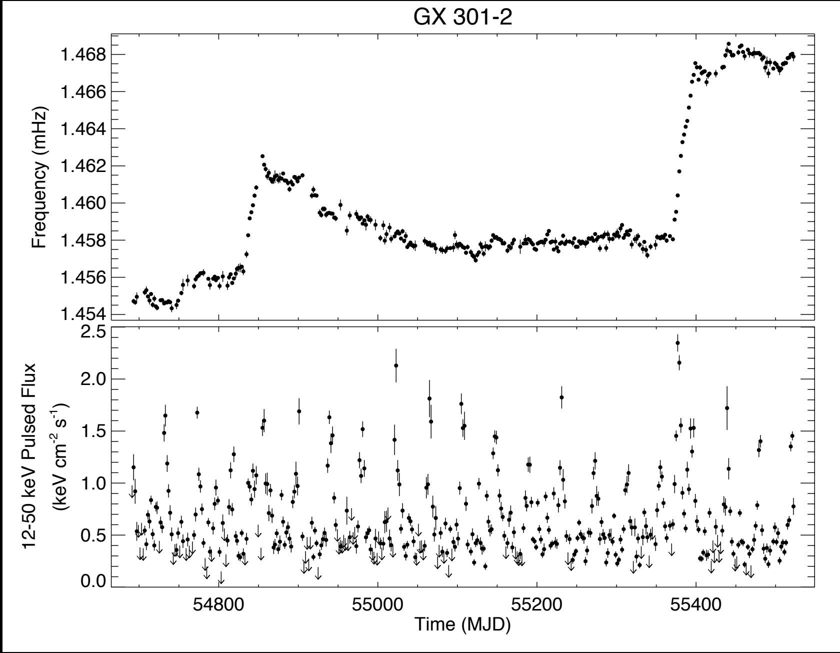
- Two short-lived episodes of spin-up were seen with BATSE.

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)

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

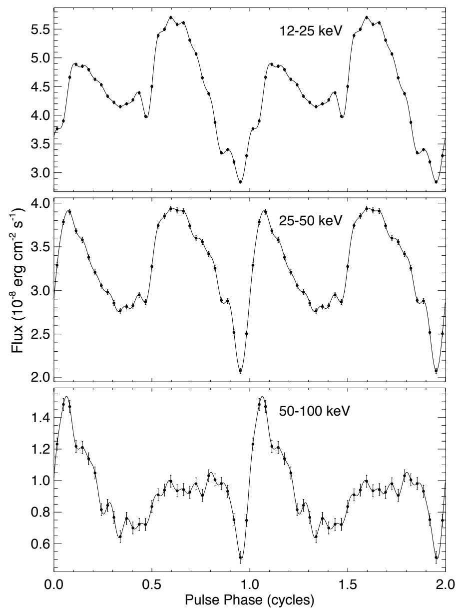
where k < 1 and the co-rotation radius is

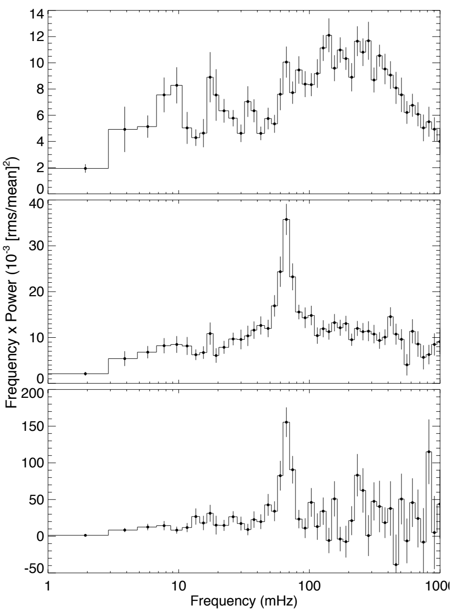
$$r_{co} = (GM)^{1/3}(2\pi\nu)^{-2/3}$$

Source	B (10^{12} G)	period (s)	measured dν/dt (Hz/s)	calculated dν/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

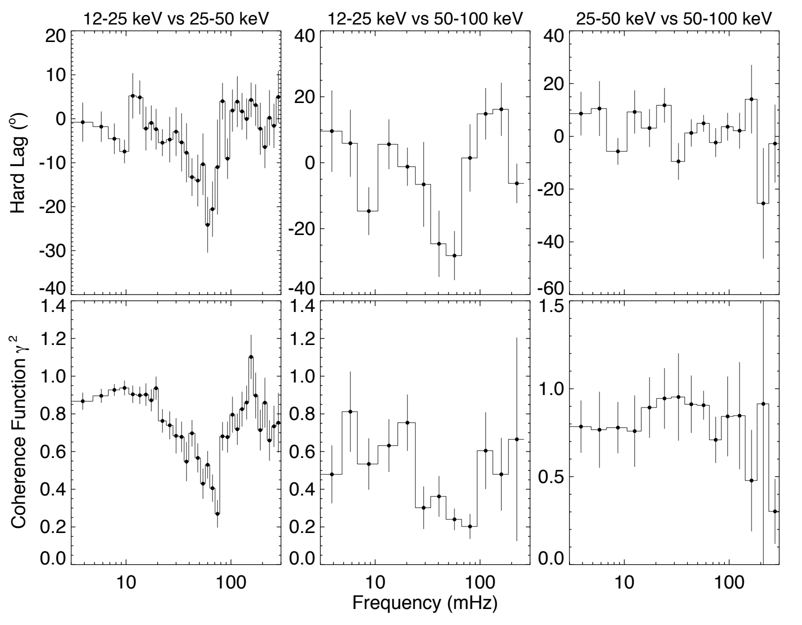
2009 Dec 14





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/