10 Years of Accreting Pulsars with Fermi GBM

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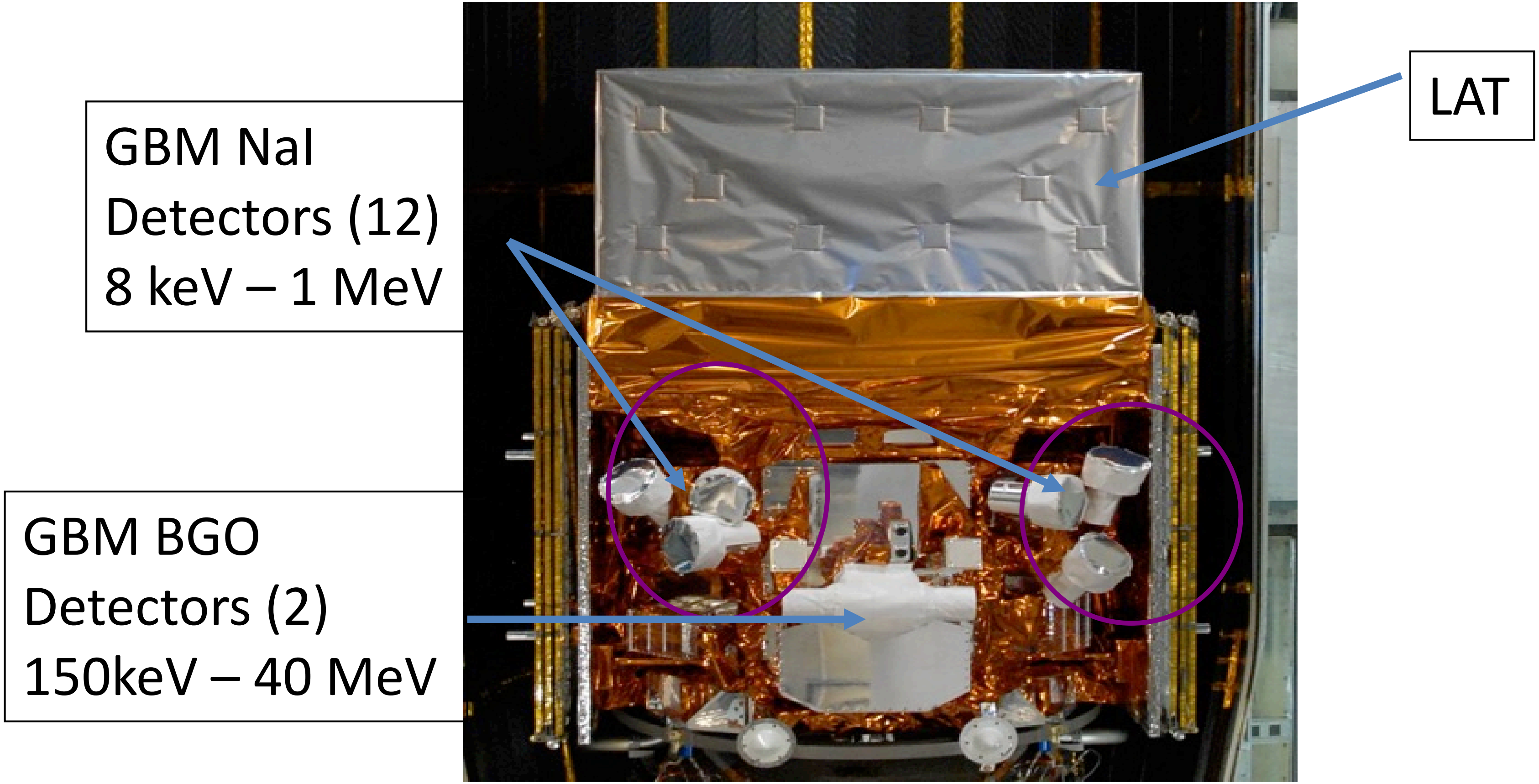
Outline

- Introduction to Accreting Pulsars
- Pulsar monitoring with GBM
- Highlights from 10 years
  - 4U1626 torque reversal
  - A0535+262
  - OAO 1657
  - Long-term periodicty in EXO 2030+375
  - Orbital solutions
  - Swift J0243.6+6124 – the first Galactic ULX pulsar
- The big picture
  - Bimodal spin-distribution
  - Acretion torque modeling
- Summary

Fermi Gamma Ray Burst Monitor (GBM)

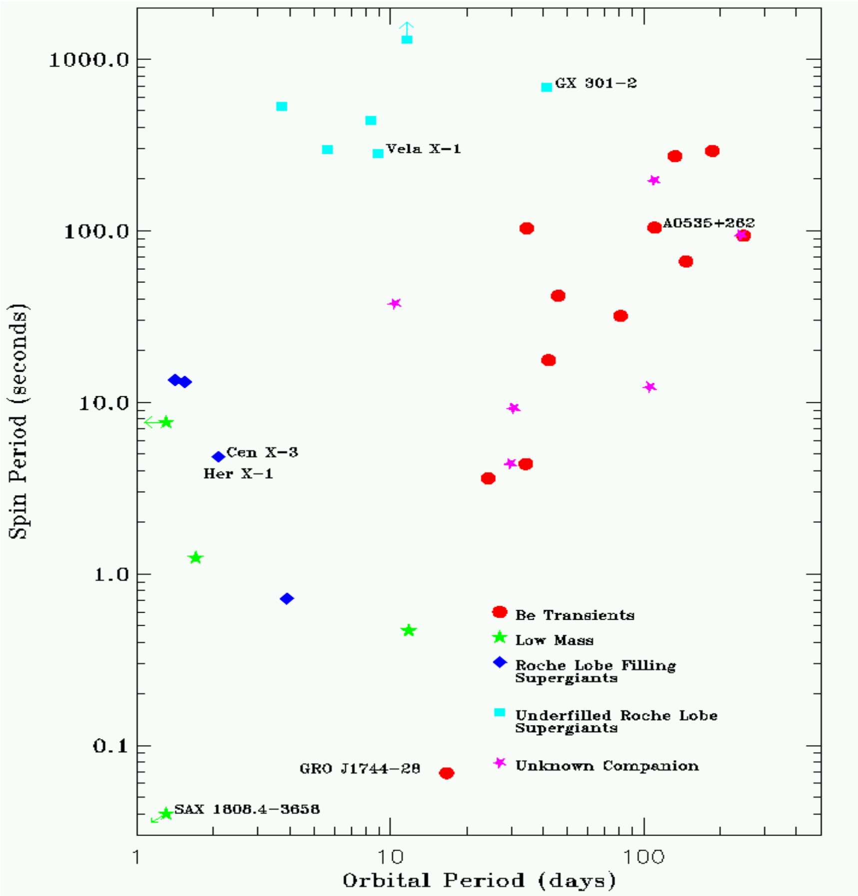


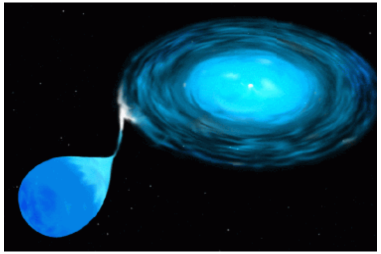
GBM NaI
Detectors (12)
8 keV – 1 MeV

GBM BGO
Detectors (2)
150keV – 40 MeV

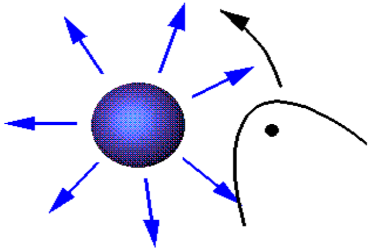
LAT

Accreting X-ray Pulsars

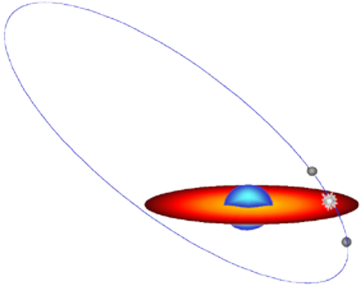




Roche lobe overflow



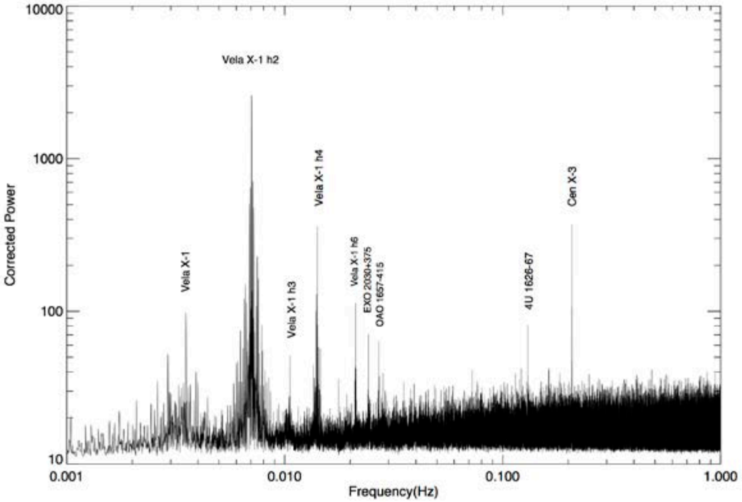
Wind accretion



Be star’s circumstellar disk

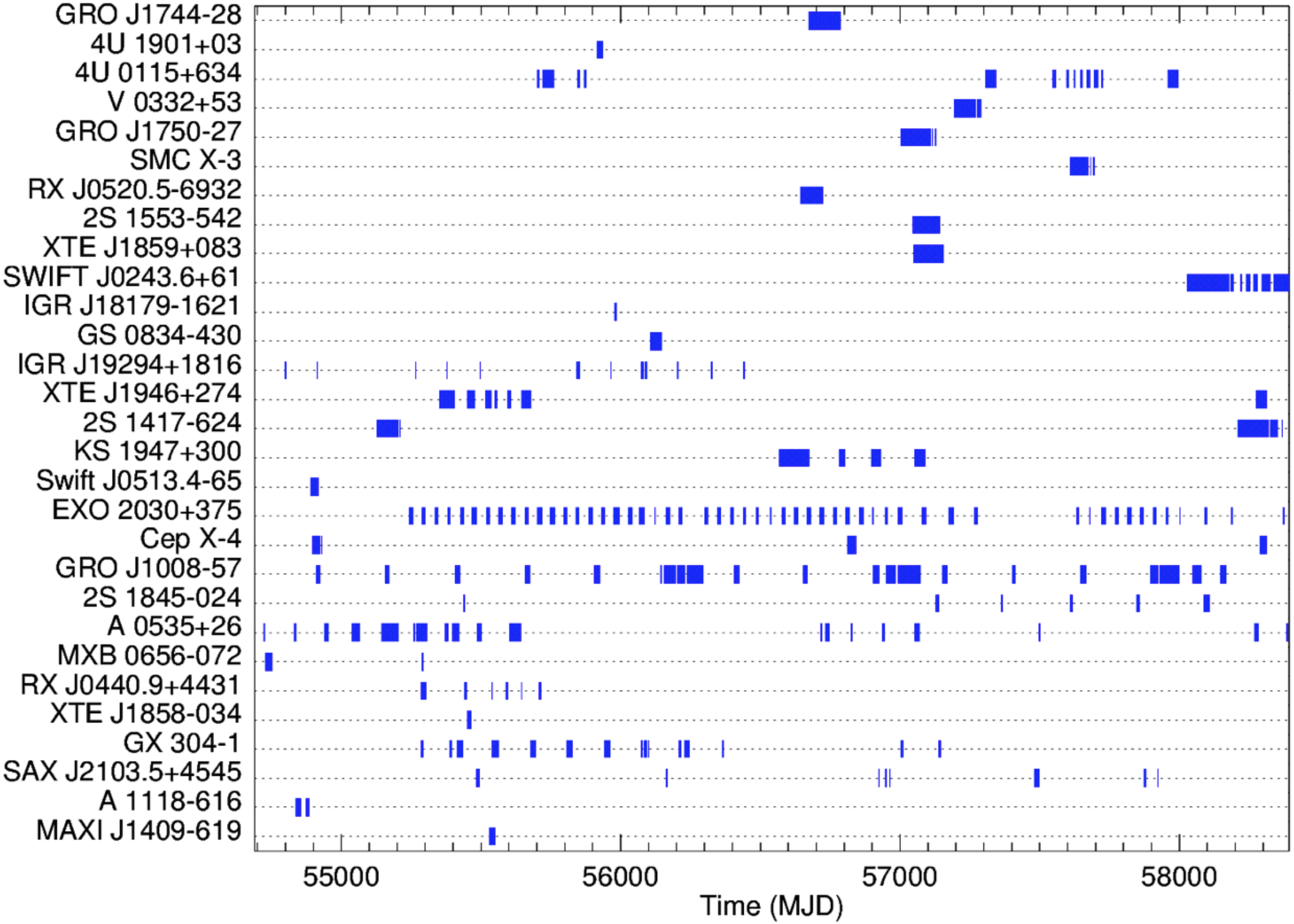
GBM Pulsar Searches

- Daily Blind Search
  - 24 source directions equally spaced on the galactic plane + LMC and SMC.
  - Each direction - FFT based search from 1 mHz t 2 Hz.
- Source Specific Searches.
  - Small ranges of frequency and frequency derivative
  - Phase shifting and summing pulse profiles from short intervals of data
  - Barycentered and possibly orbitally corrected times.
  - Typical exposure times are ~40 ks/day.
- Detections – Total of 40 systems monitored
  - 8 of 8 persistent sources
  - 29 of 32 transients

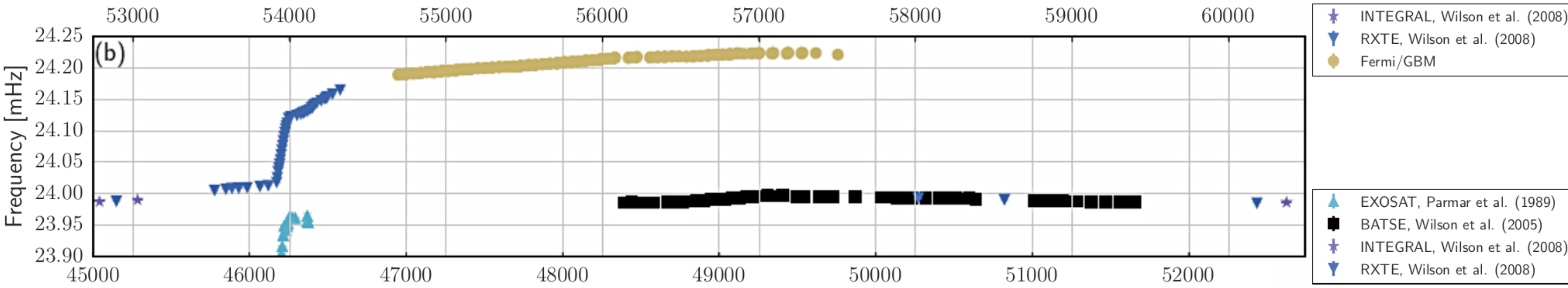


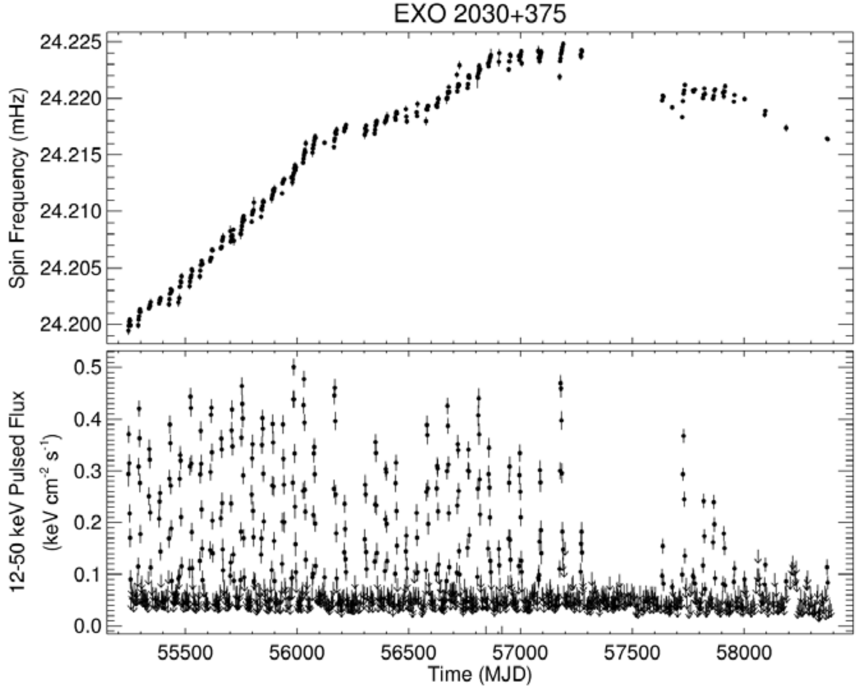
Fermi GBM: the eyes that see them changing

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



~20 year periodicity in EXO 2030+375

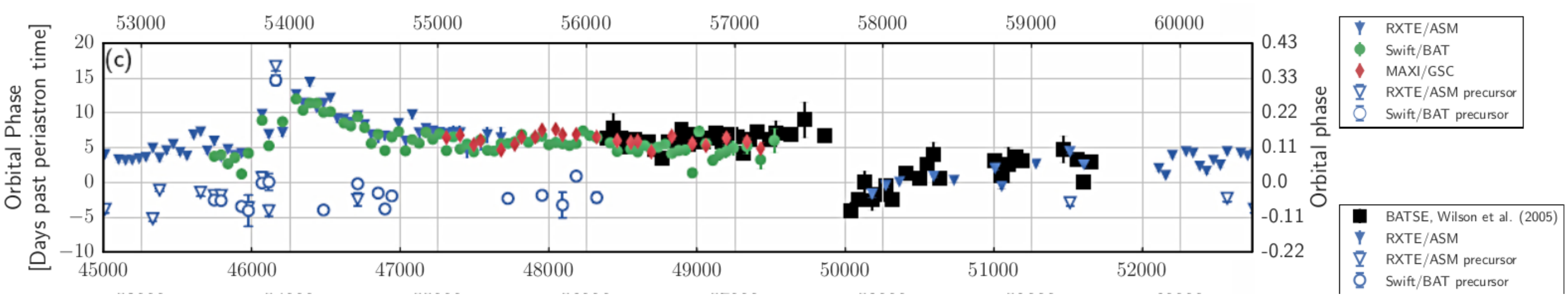


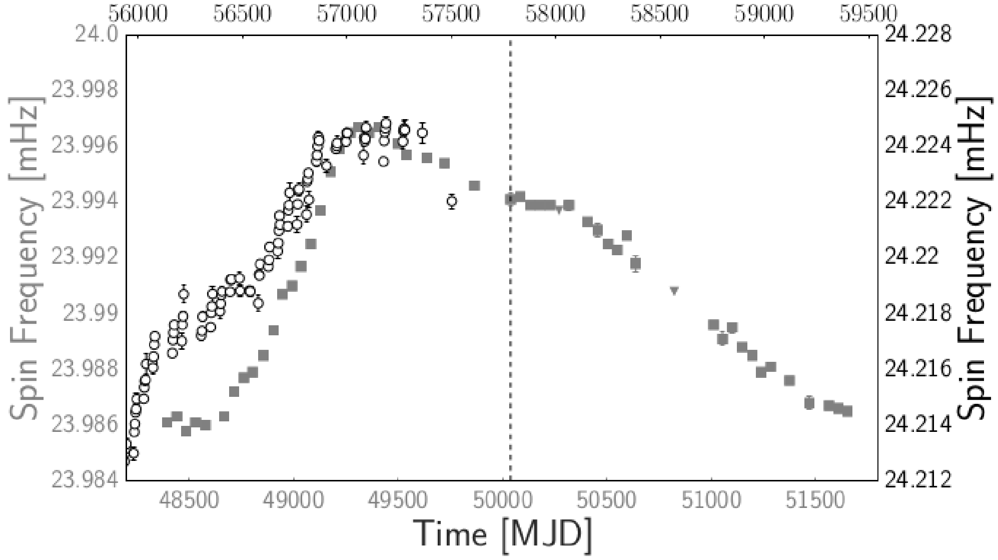


Every ~20 years EXO 2030+375 shows a similar trend of the frequency: after a steep spin-up, a less steep spin-up period follows, which is accompanied by a spin-down period (currently observed).

Kozai-Lidov oscillations in the Be disk? The instability brings the Be disk to be more eccentric, which in turn brings to develop Type II outbursts, with consequent disruption of the Be disk and then spin-down… (time scales seem to support the hypothesis)

~20 year periodicity in EXO 2030+375



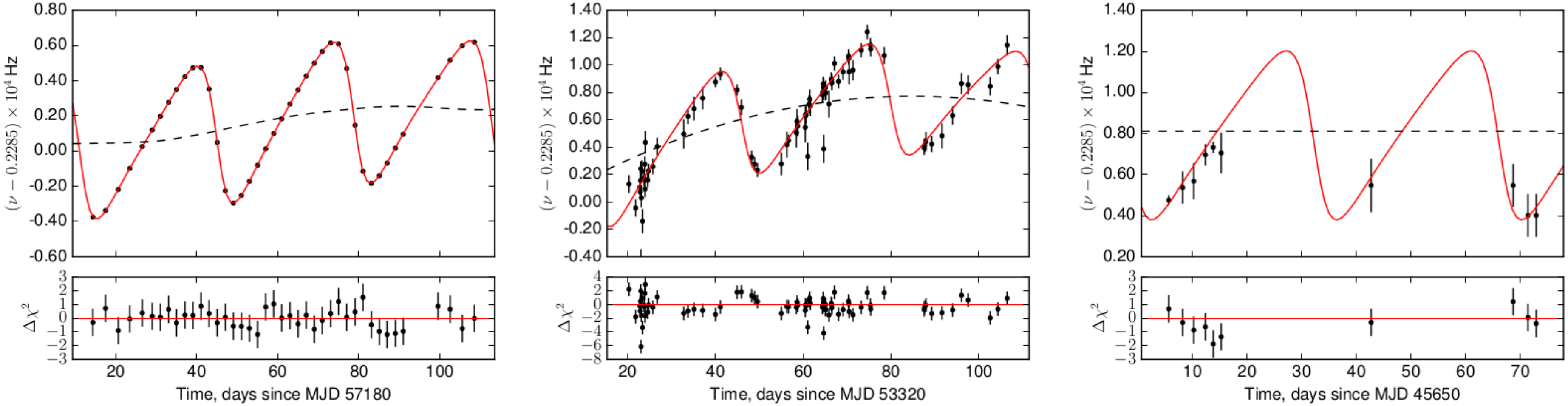


Figures from Laplace et al. (2017)

Every ~20 years EXO 2030+375 also shows a feature in the orbital phase of the outburst peak: outbursts go from peaking at ~0.15 in orbital phase to somewhere BEFORE the periastron (Wilson-Hodge et al 2008, Laplace et al. 2017)

Orbital solutions: V 0332+53

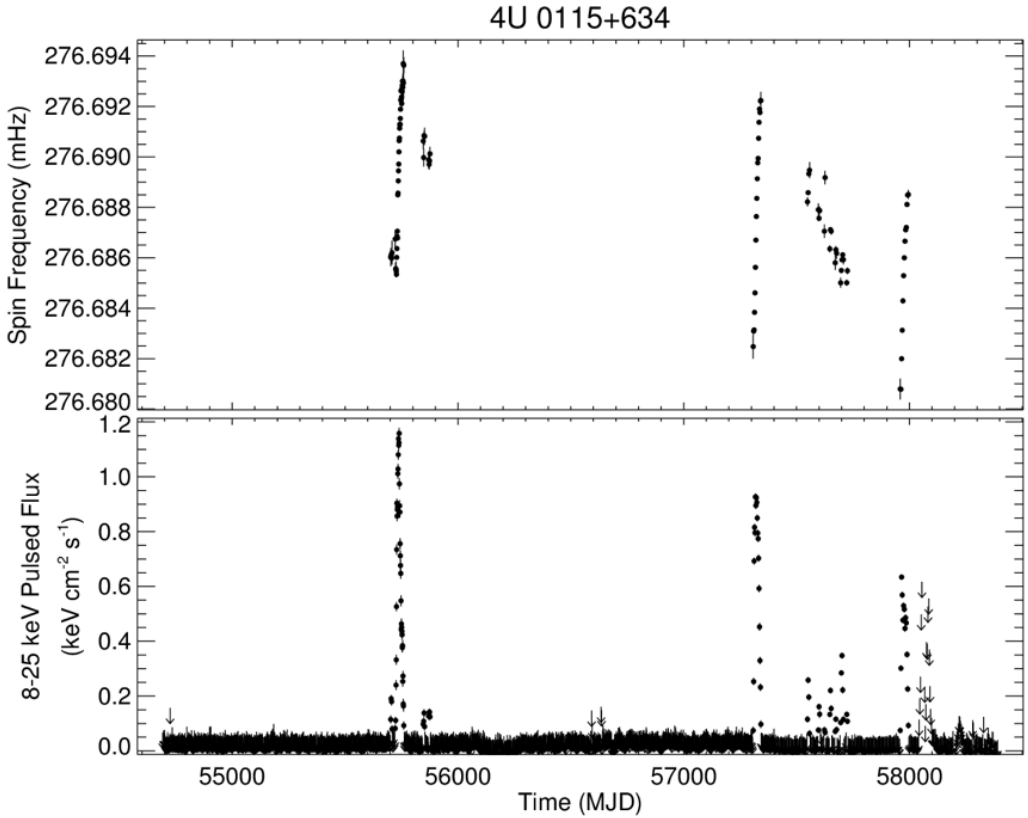
Doroshenko et al. 2016



Fermi GBM, RXTE, Tenma data during three major outbursts of the source (note the error bars!). Reconstructed intrinsic pulsar frequencies (black dashed lines) modulated by motion along the orbit with best-fit parameters (red line). Best-fit orbital parameters are published.

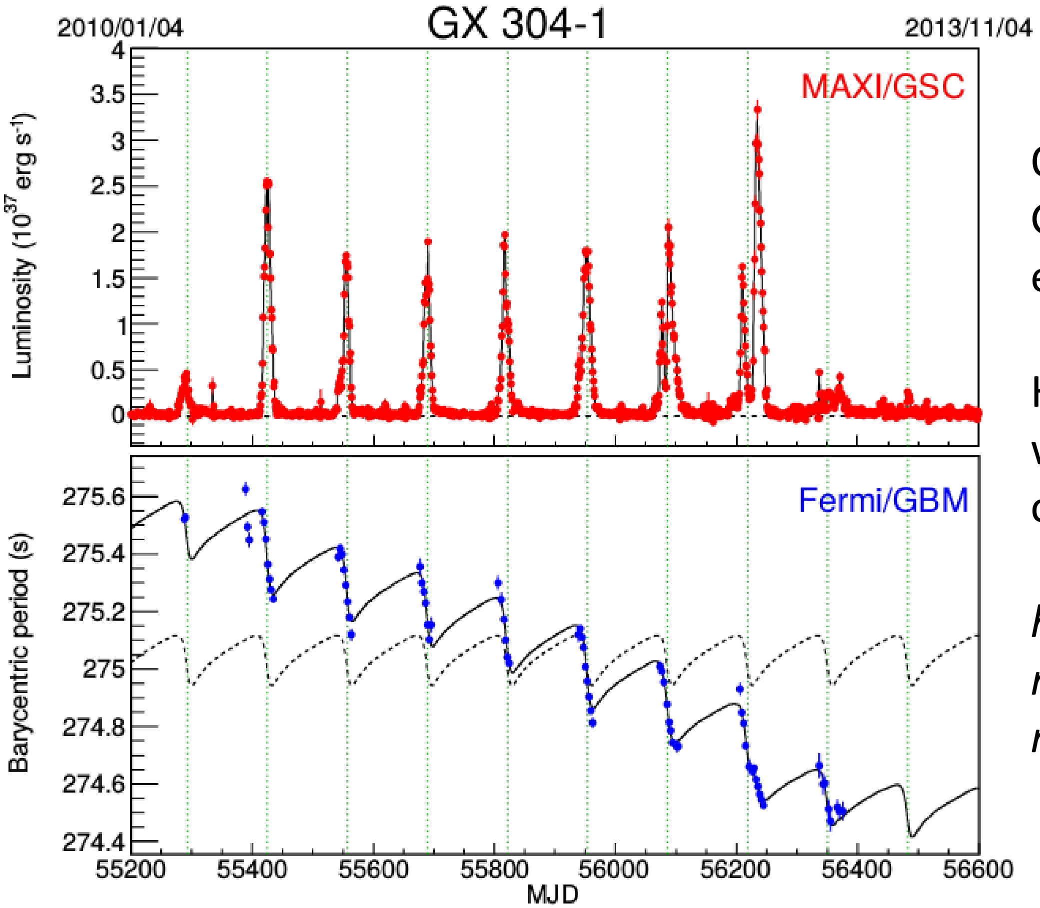
Orbital solutions: 4U 0115+634

https://gammaray.nsstc.nasa.gov/gbm/science/pulsars/lightcurves/4u0115_fig1.png



Orbital solutions available on the GBM website (by P. Jenke).
Note the steep spin-down during quiescence (even steeper towards the last outburst).

Sugizaki et al. 2015

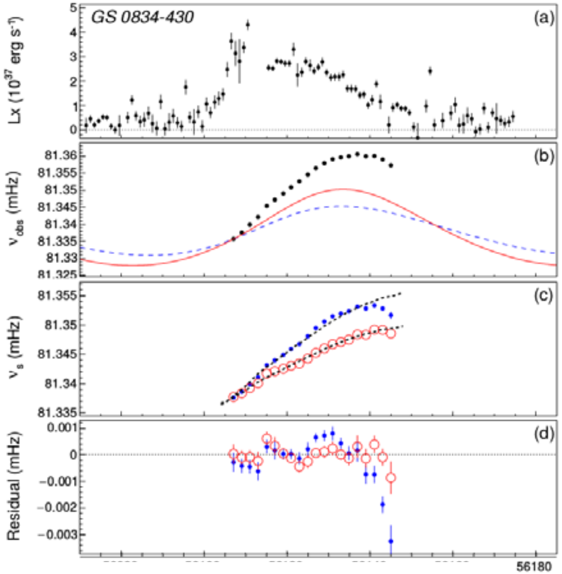


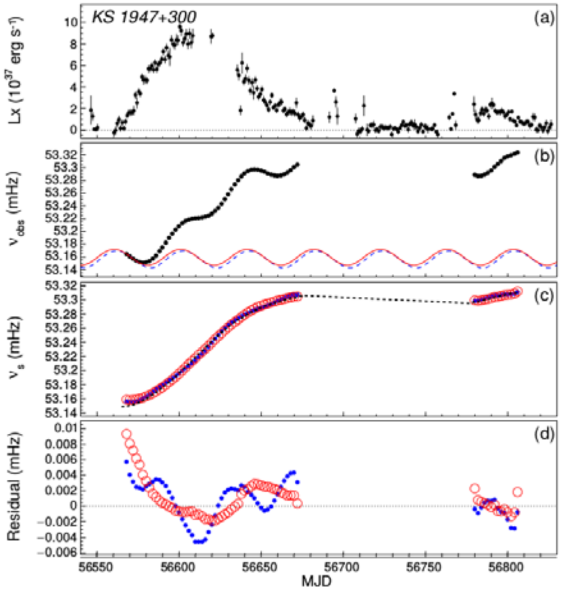
Orbital solutions employed Fermi GBM long observations data (Sugizaki et al. 2015)

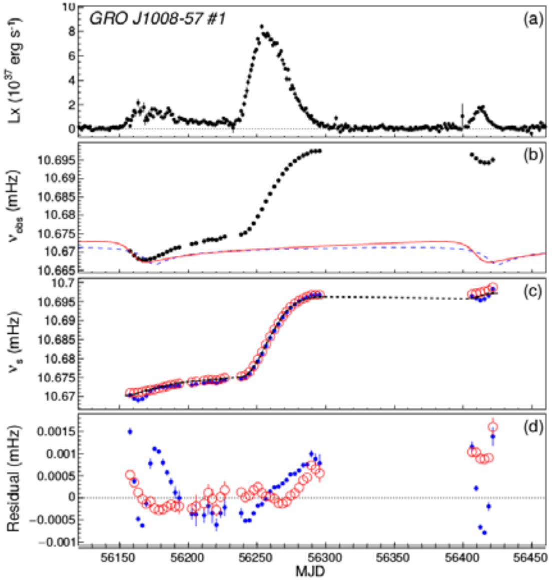
However, a more updated solution was found by P. Jenke and is available on GBM website:

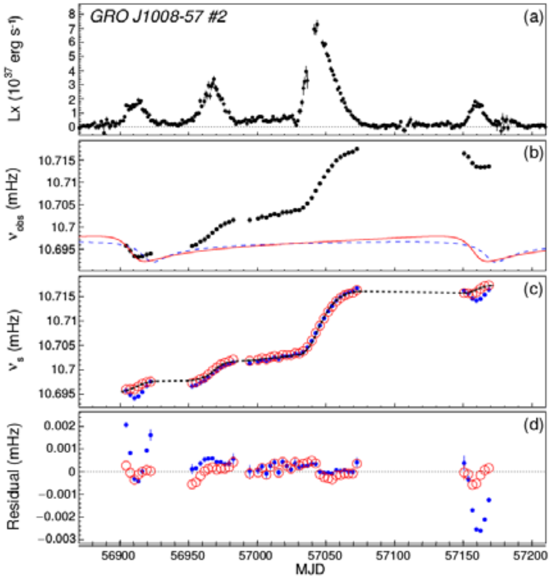
https://gammaray.nsstc.nasa.gov/gbm/science/pulsars/lightcurves/gx304m1.html

Orbital solutions: more systems (Sugizaki et al. 2017)

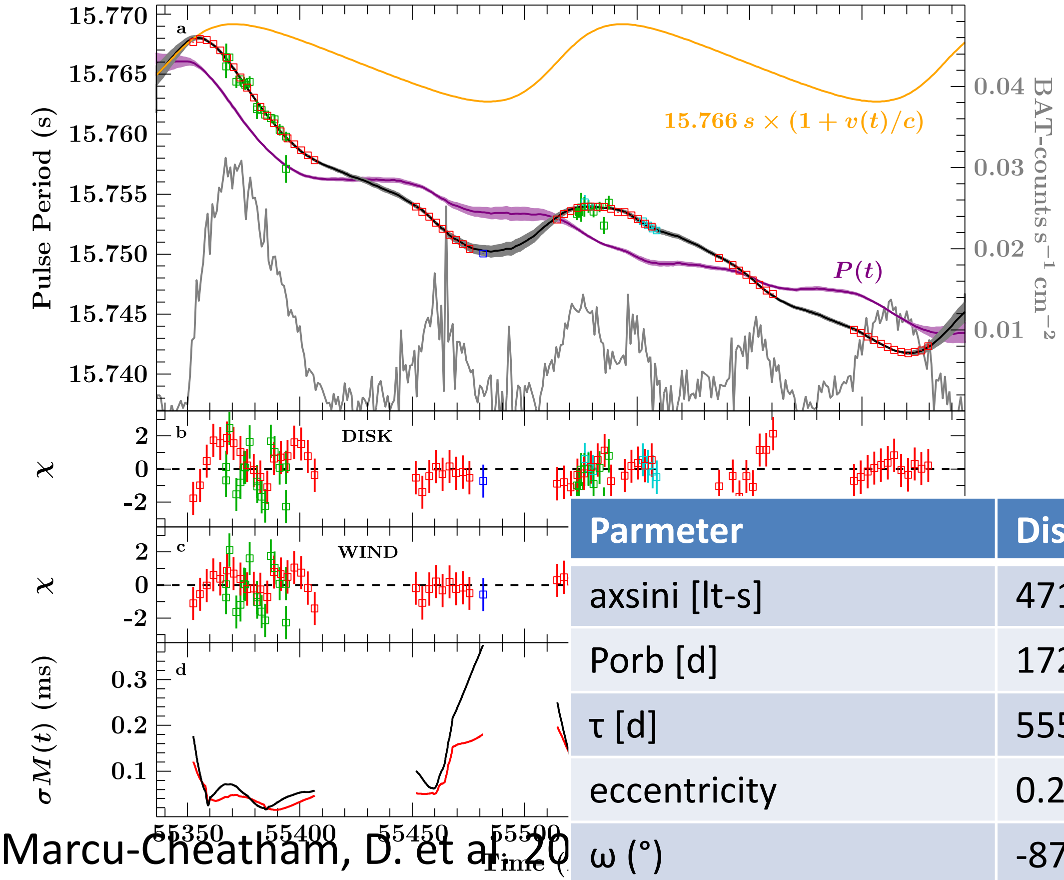








XTE J1946+274 –New Orbital Solution

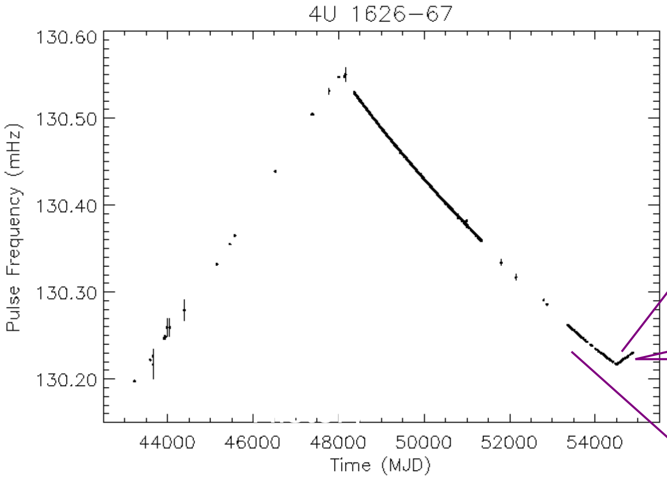


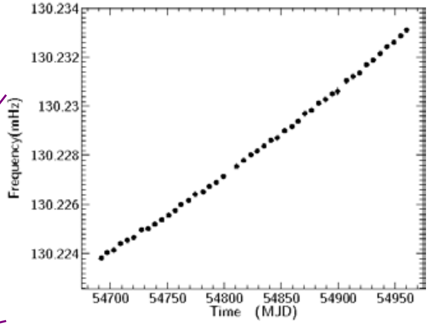
Marcu-Cheatham, D. et al. 20

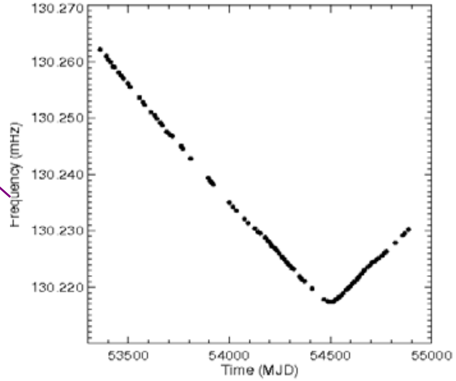
- Discovered with RXTE in 1998
- 15.8 s pulsations with BATSE
- Active 1998-2001, 2010-11
- GBM (red) – spin periods, RXTE (green), Swift/BAT (grey) – fluxes
- 2-3 outbursts per orbit
- GBM data crucial to orbit determination

Parmeter	Disk	Wind
axsini [lt-s]	$471.2^{+2.6}_{-4.3}$	$471.1^{+2.7}_{-2.8}$
Porb [d]	172.7±0.6	171.4±0.4
τ [d]	$55514.8^{+0.8}_{-1.1}$	$555515.5^{+0.8}_{-0.7}$
eccentricity	0.246±0.009	0.266±0.007
ω (°)	$-87.4^{+1.5}_{-1.7}$	$-87.1^{+1.2}_{-1.0}$

4U 1626-67 A Torque Reversal







. Ultracompact LMXB

. P_{pulse}= 7.66 s

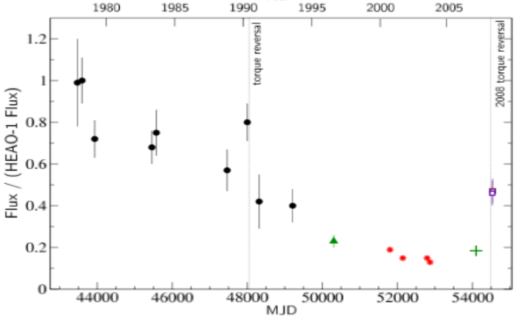
. Porb = 42 min orbit.

. B= $(2.4\text{-}6.3)\times10^{12}$G

. Distance 5-13 kpc

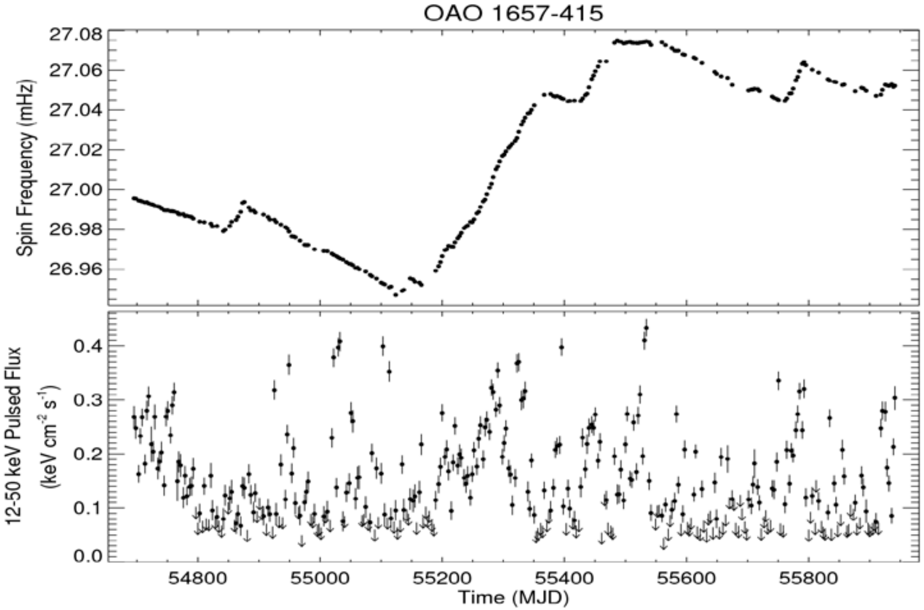
- Rapid reversals with respect to separation
- dv/dt increased while F decreased
- Inconsistent with monotonic relationship
- Spin-down to spin-up reversal occurred at a lower flux than spin-up to spin-down

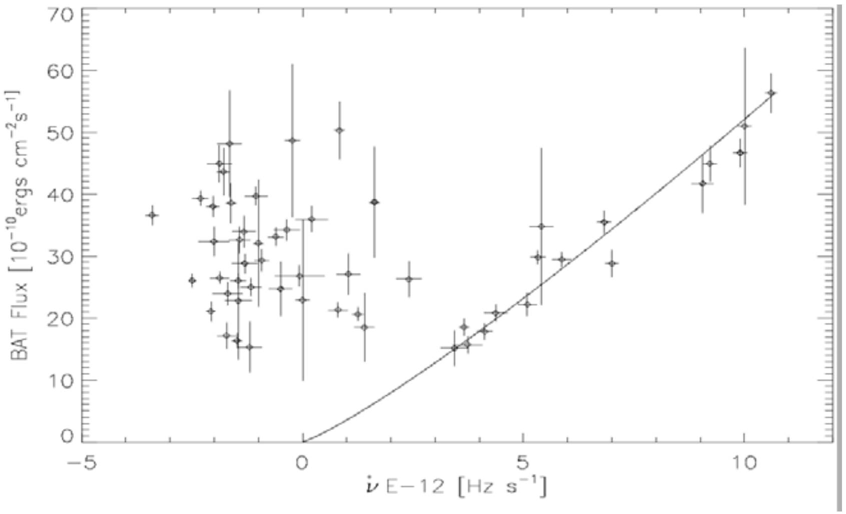
Torque reversal centered in 2008 Feb 4 lasting ~150 days



Camero-Arranz et al. 2010

Evidence for a transient accretion disk in OAO 1657-415

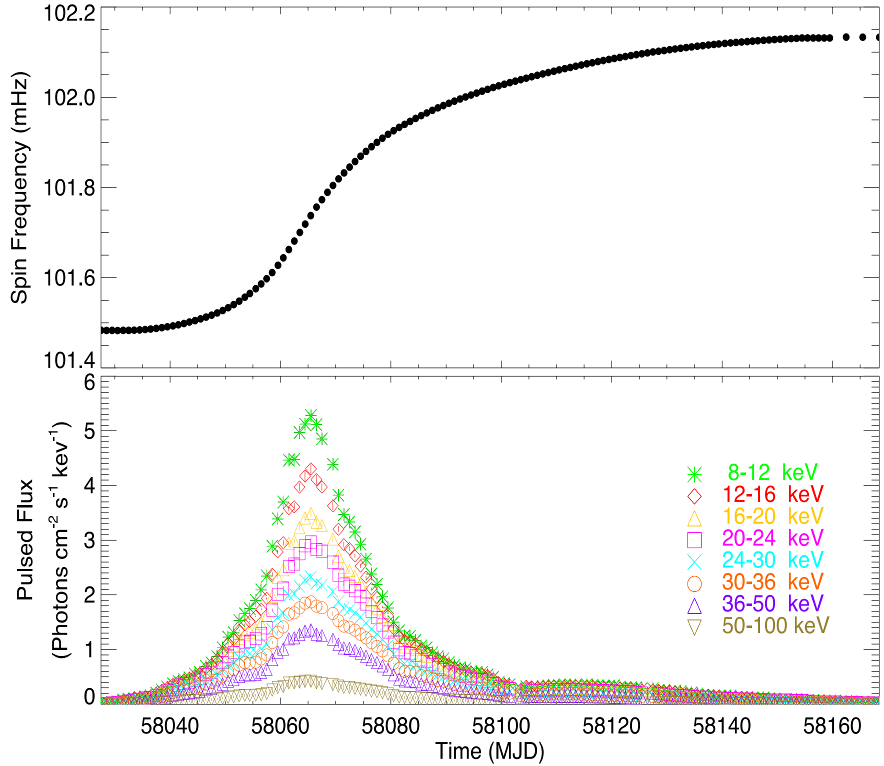


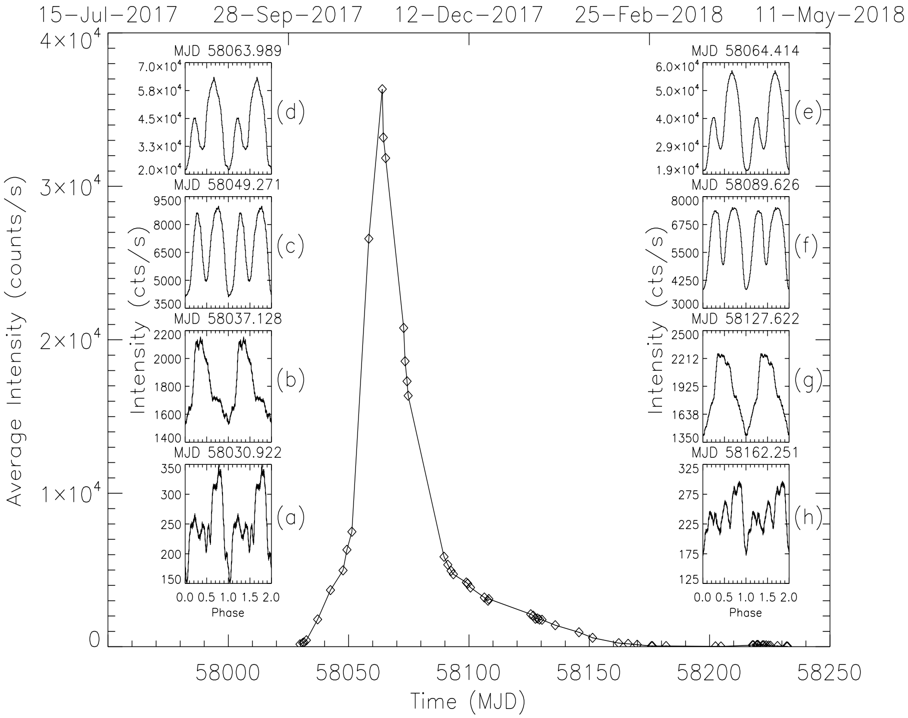


Jenke et al. 2012

- OAO 1657-415 is a 37-s pulsar orbiting a supergiant every 10.4 days
- Two modes of accretion appear to be present
  - Steady spin-up where the spin-up rate and flux are correlated – stable accretion disk
  - A random walk in spin frequency – unstable transient disk – prograde and retrograde
- Statistically significant orbital decay: $\dot{P}/P = (-3.40 \pm 0.15) \times 10^{-6}\ \mathrm{yr}^{-1}$

Swift J0243.6+6124: The First Galactic Ultraluminous X-ray Pulsar





Wilson-Hodge et al. 2018

Swift J0243.6+6124:Pulse profile evolution

2-3 keV

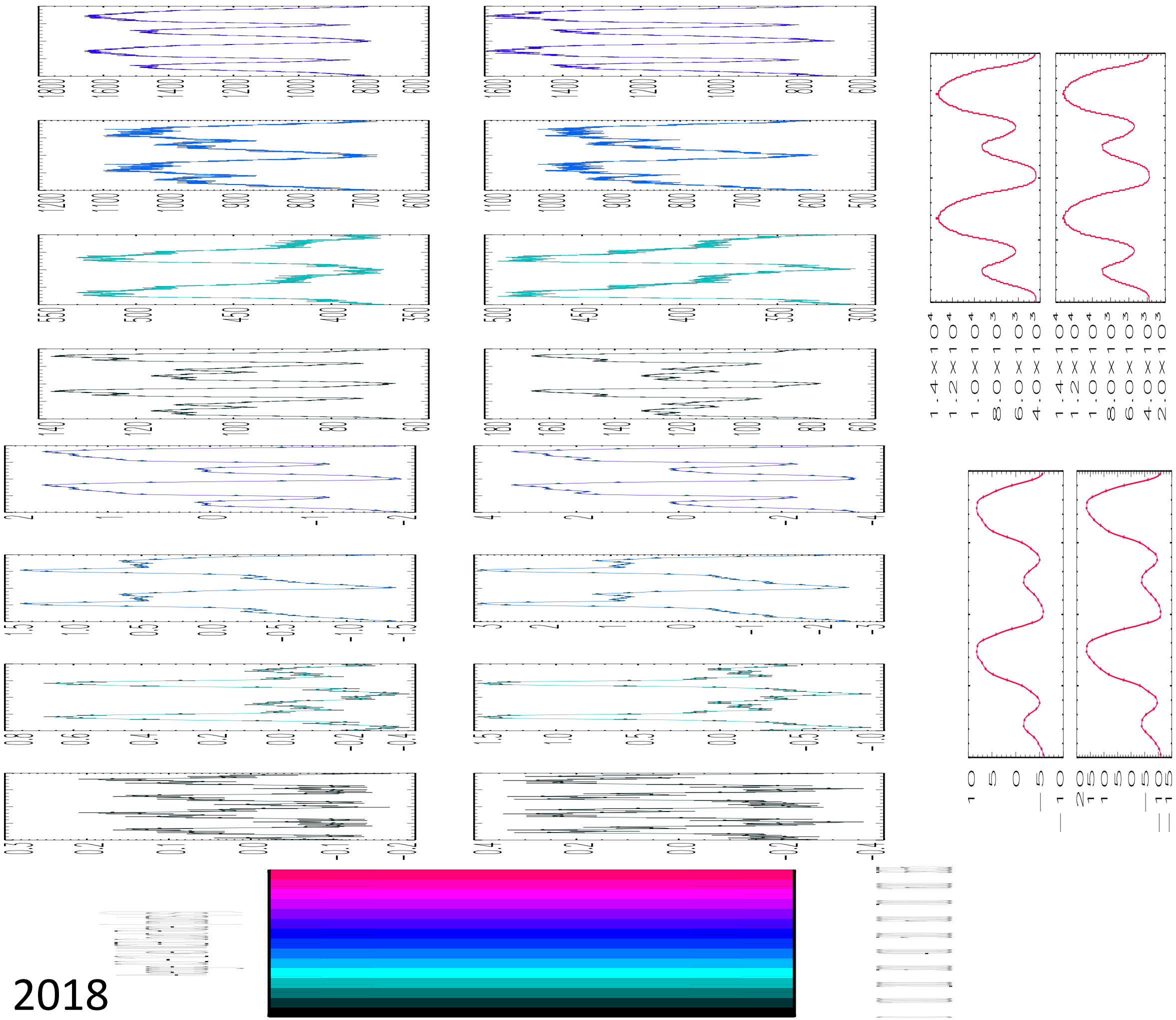
NICER

3-5 keV

30-36 keV

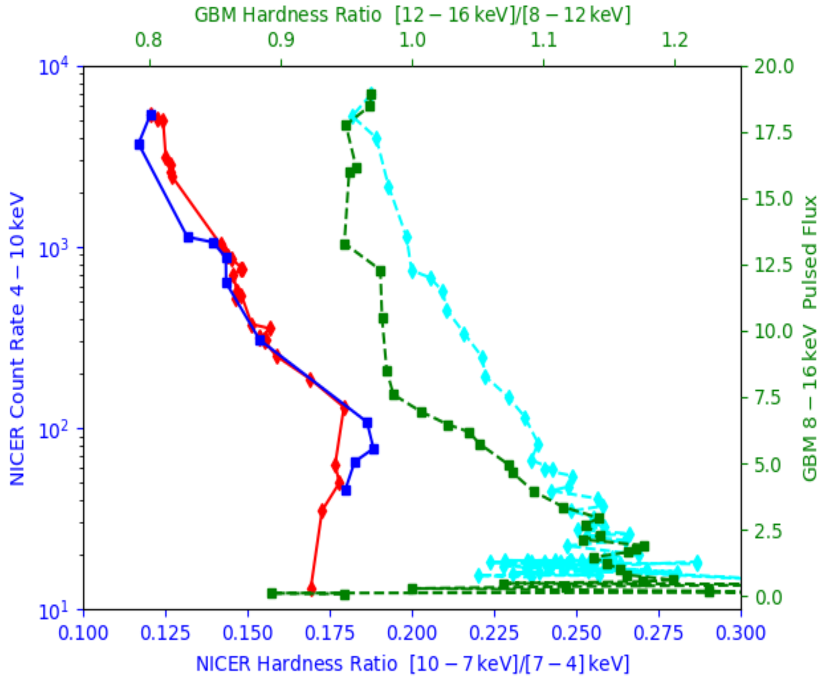
GBM

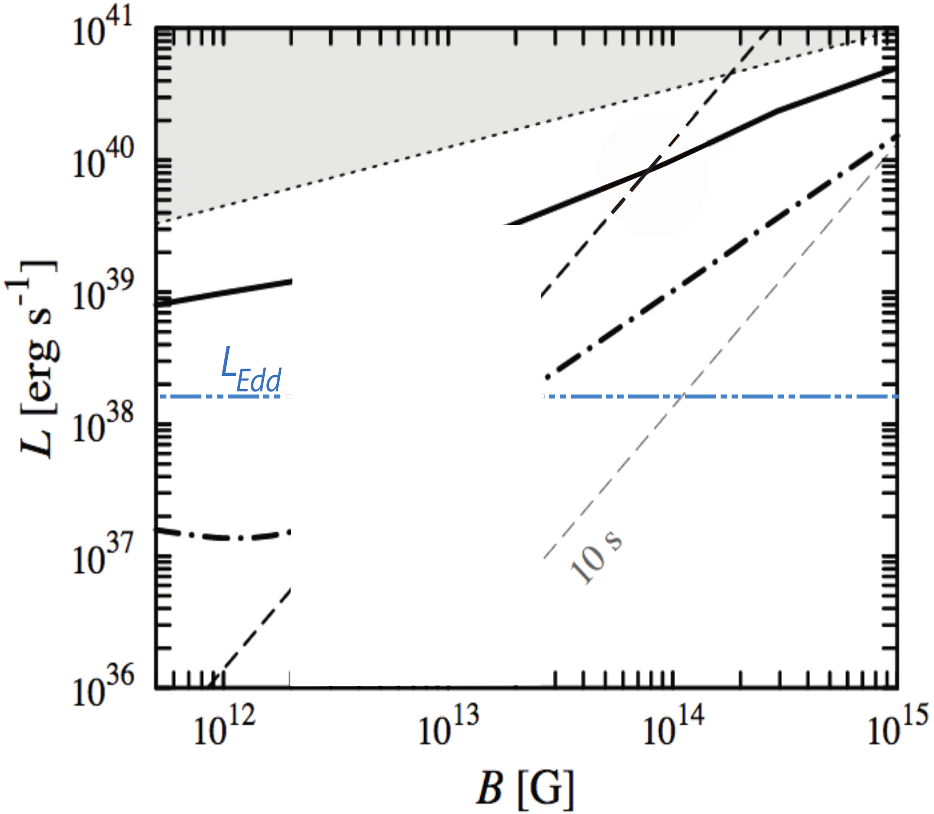
36-50 keV



Wilson-Hodge et al. 2018

Swift J0243.6+6124: Critical Luminosity Transition



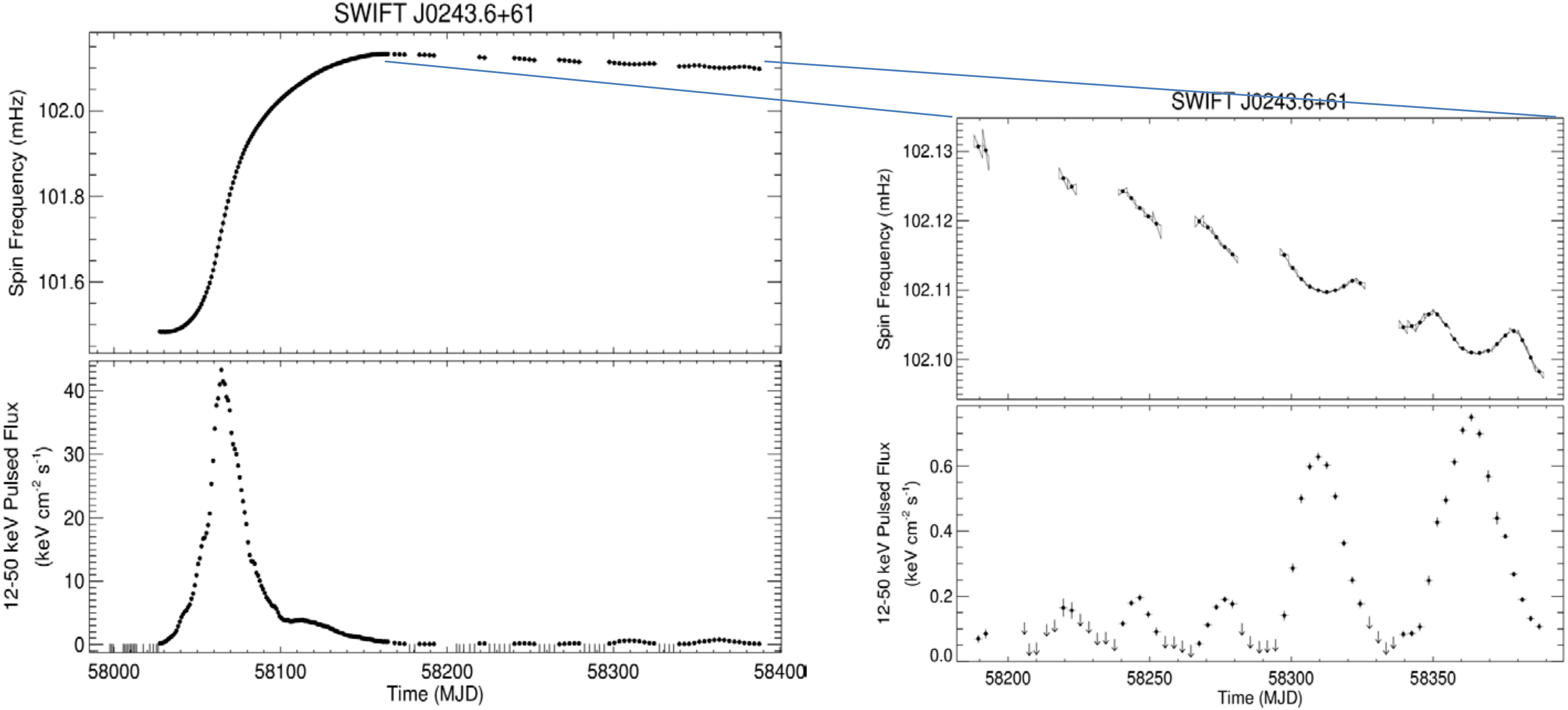


Wilson-Hodge et al. 2018

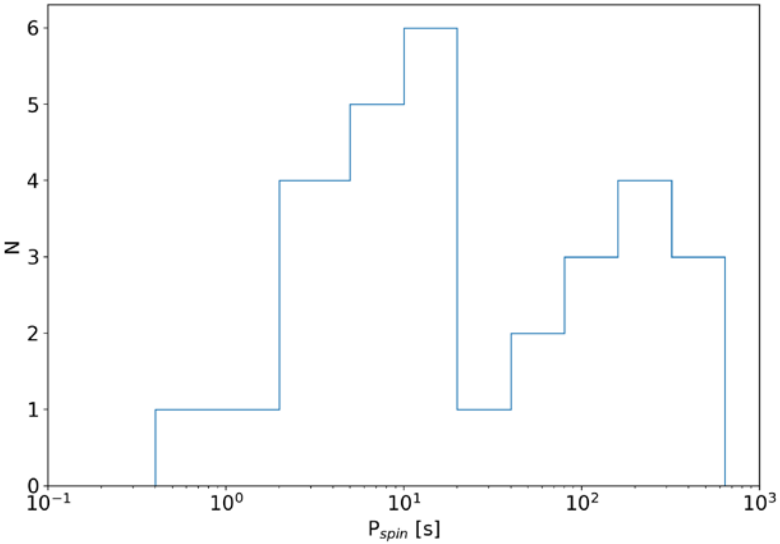
Swift J0243.6+6124: Comparisons with ULX pulsars in other galaxies

- Properties like known ULX pulsars
  - Peak luminosity ~2 x 10^{39} erg s^{-1} (0.1-10 keV)
  - normal outbursts peaking around 10^{37} erg s^{-1} (0.1-10 keV)
  - Spin period ~9.8 s
  - Peak spin-up rate (2.23+/-0.02)x10^{-10} Hz/s
  - RMS Pulsed fraction increasing with energy and with intensity
    - 8%-33% (0.2-1 keV)
    - 22%-95% (8-12 keV)
  - Evidence for strong magnetic field of ~10^{13} G
- Properties unlike known ULX pulsars
  - Pulse profile definitely not sinusoidal.
  - Source was not known before it was detected as a pulsar in outburst.

Swift J0243.6+6124: Recent Observations with Fermi GBM



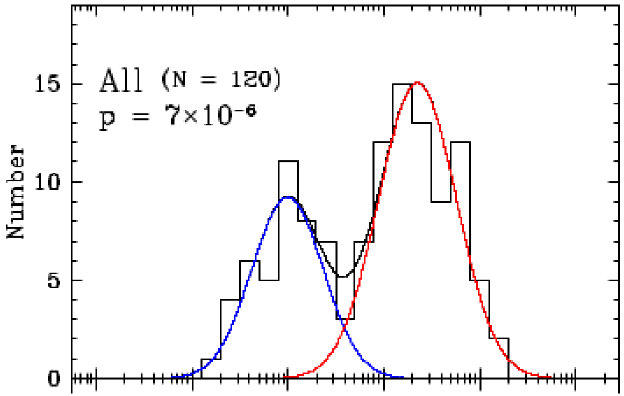
Bimodal spin-period distribution: mind the gap



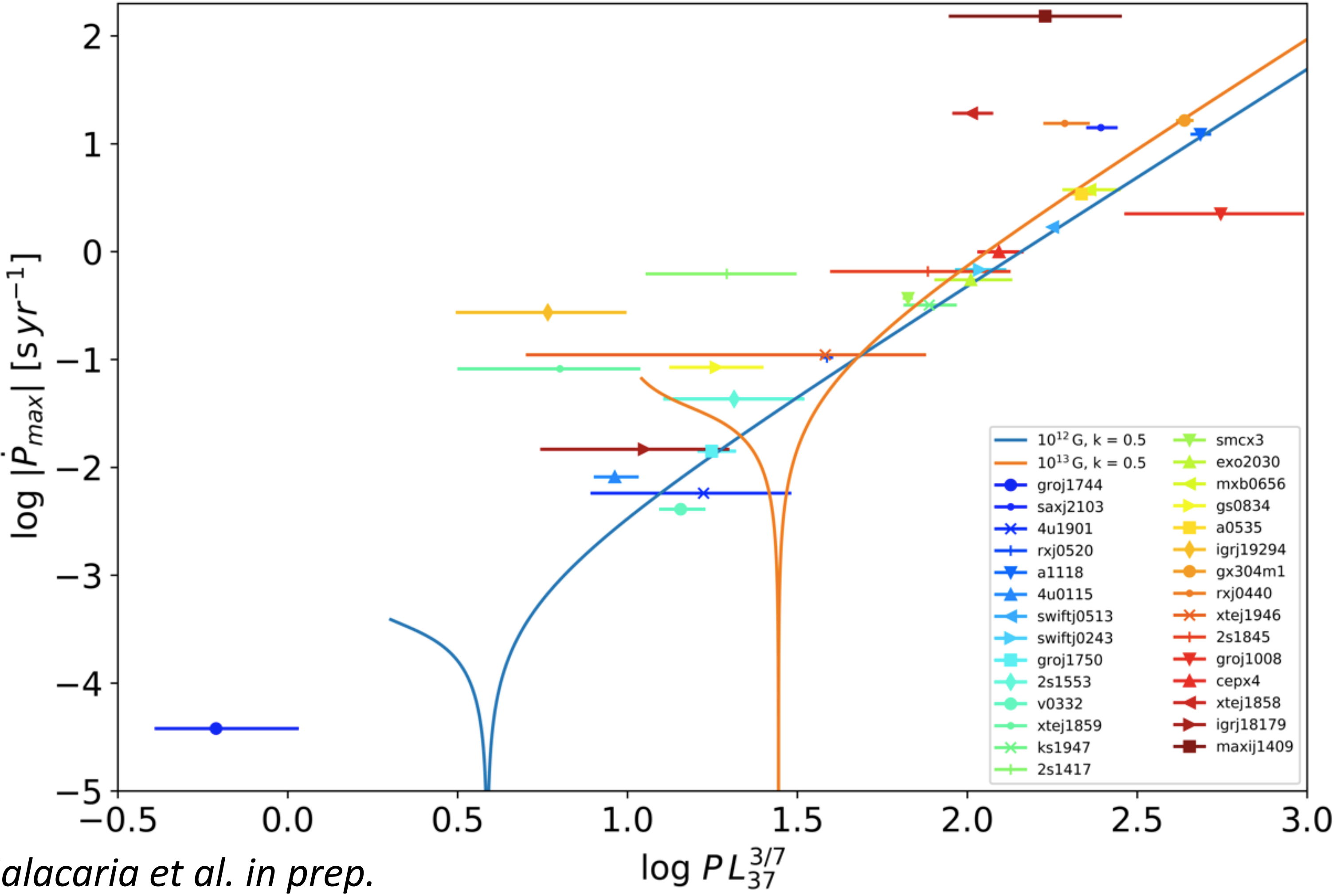
GBM pulsars Galactic sample (before this, only samples including Galactic + SMC + LMC)

Our sample shows a different ratio!

- Two separated distributions of the spin period (note the gap at ~40 seconds):
- **Knigge et al. 2011:** e$^-$-capture Supernovae produce Nss with shorter spin periods, while iron-collapse Supernovae produce Nss with longer spin periods
- **Cheng et al. 2014:** ADAF disks form during Type I outbursts and are inefficient to spin-up the NS (producing slower Nss), while thin disks formed during Type II outbursts are more efficient to spin-up the NSs



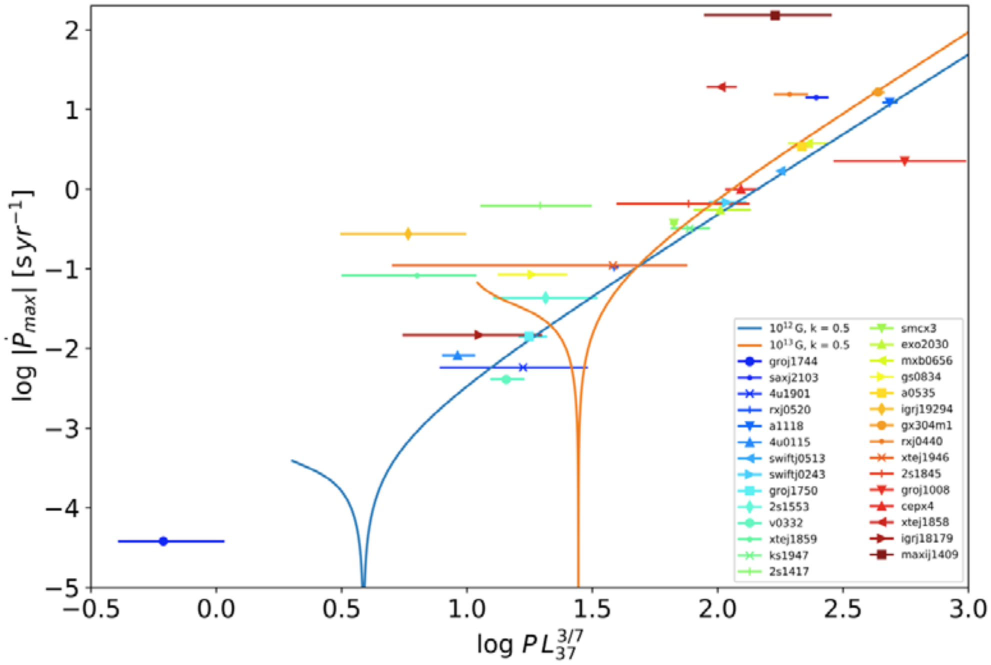
Accretion torque modelling: Ghosh&Lamb vs GBM pulsars



Malacaria et al. in prep.

Accretion torque modelling: Ghosh&Lamb vs GBM pulsars

Malacaria et al. in prep.



GAIA Data Release 2 is used to damp the uncertainty on luminosity (the major uncertainty).

Data are found to correlate in the plot: the Ghosh&Lamb model still holds!

Once the uncertainties are constrained, estimates of other key parameters can be done (magnetic field, equilibrium period, fastness parameter, etc.)

Summary

- Highlights of 10 years of Fermi GBM pulsar monitoring include
  - Individual sources
    - Torque reversals
    - Evidence for a ~20 year periodicity
    - Evidence for a transient accretion disk in a wind-fed system
    - Orbital solutions for a number of systems
    - Be X-ray binary that appears to be a Galactic ULX pulsar
  - Ensemble of sources
    - Bimodal spin-distribution
    - Spin-period/luminosity correlations follow Ghosh & Lamb model