10 Years of Accreting Pulsars with Fermi GBM

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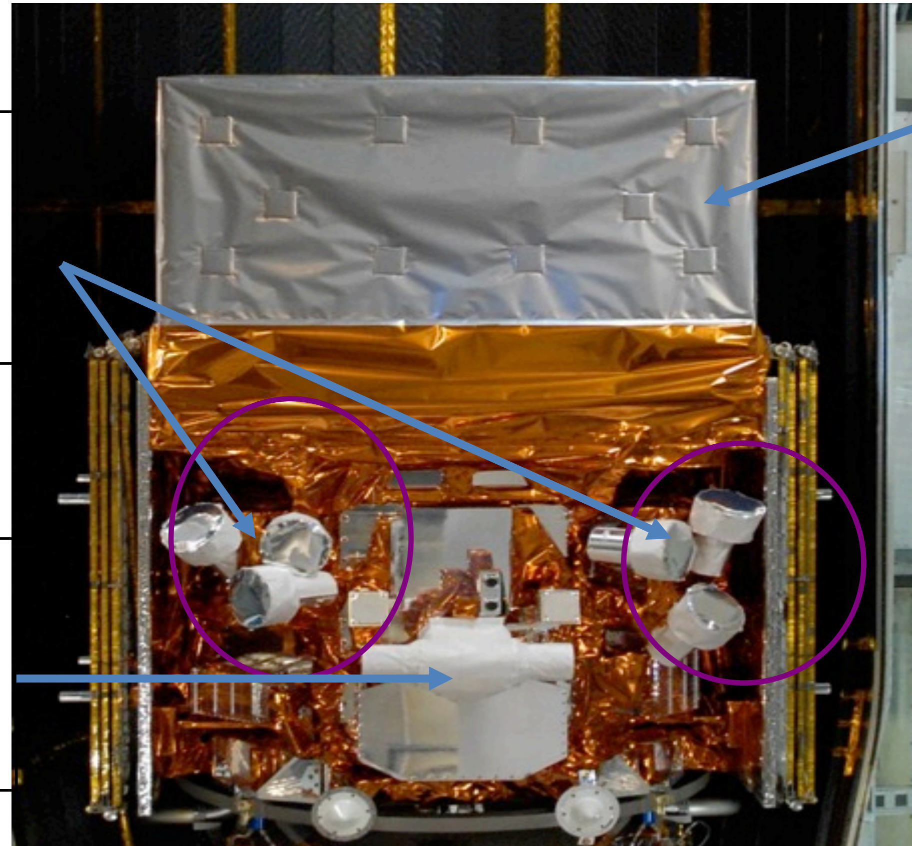
Outline

- Introduction to Accreting Pulsars
- Pulsar monitoring techniques with GBM
- Highlights from 10 years
  - 4U1626 torque reversal
  - OAO 1657-415 transient cccretion disk
  - 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)

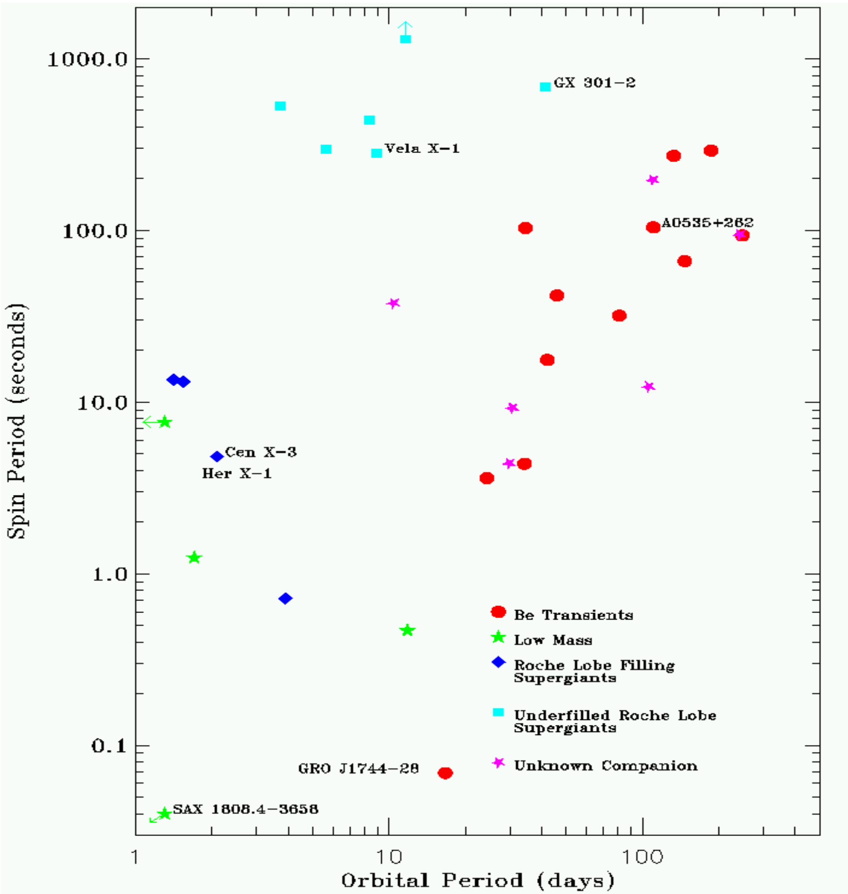


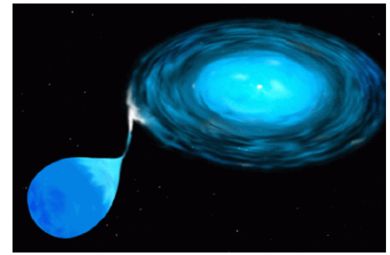
GBM NaI
Detectors (12)
8 keV – 1 MeV

GBM BGO
Detectors (2)
150keV – 40 MeV

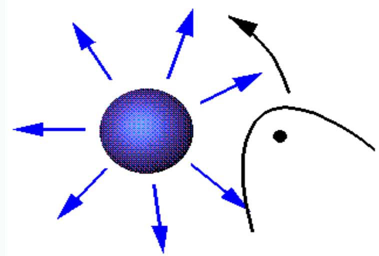
LAT

Accreting X-ray Pulsars

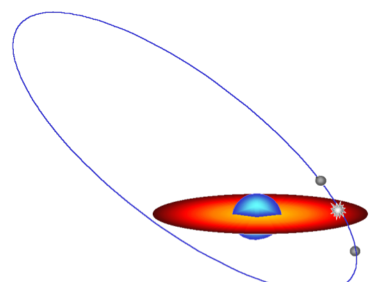




Roche lobe overflow

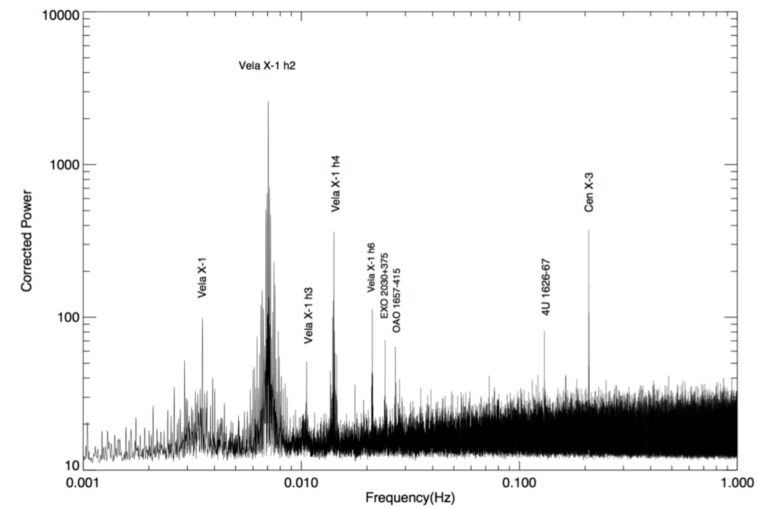


Wind accretion



Be star's circumstellar disk

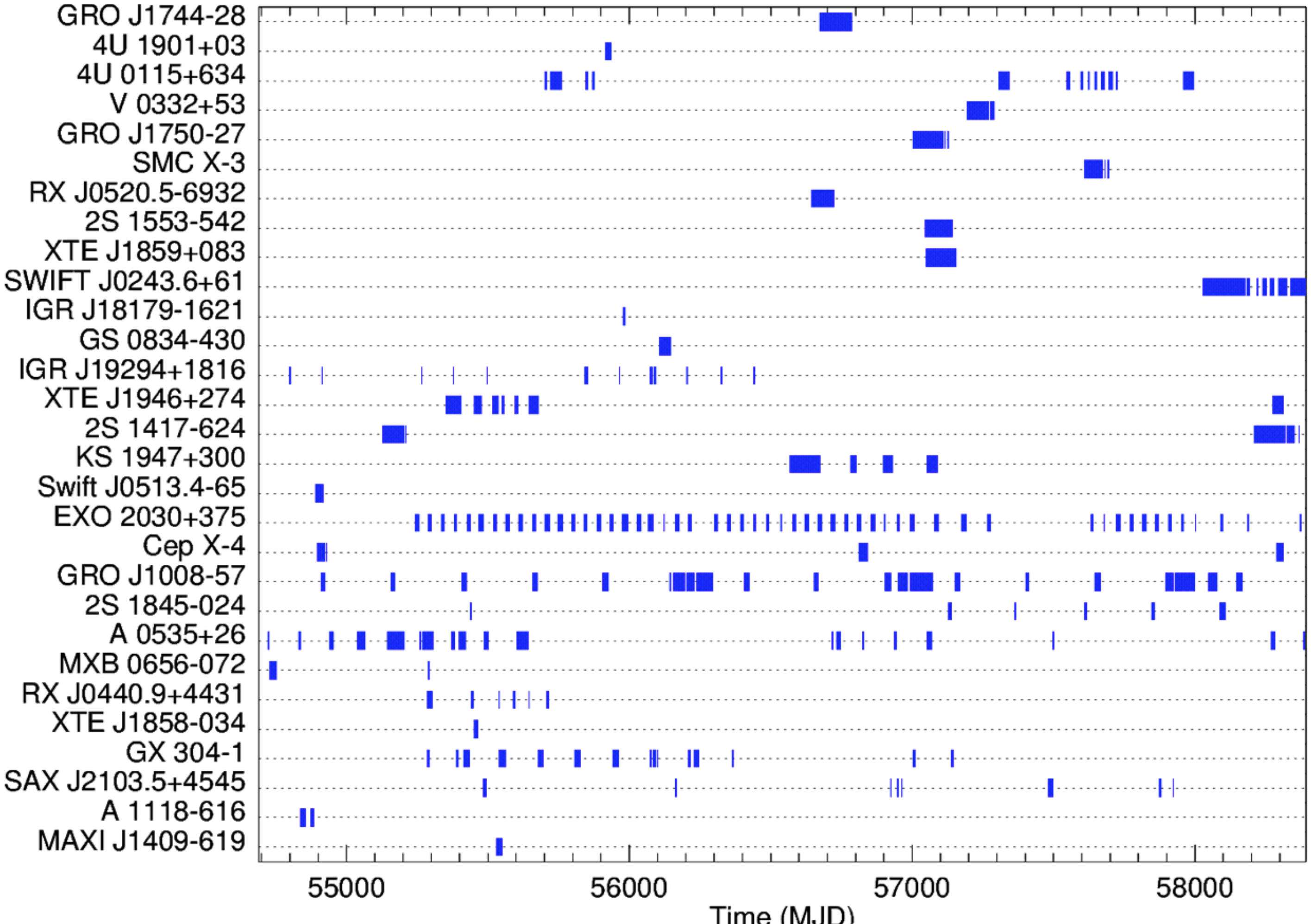
GBM Pulsar Searches



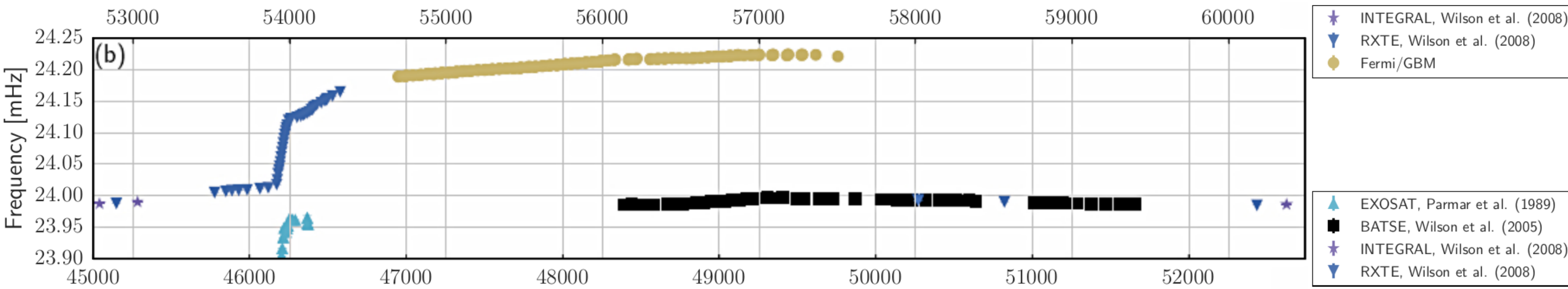
- Daily Blind Search
  - 24 source directions equally spaced on the galactic plane + LMC and SMC.
  - Each direction - FFT based search from 1 mHz to 2 Hz.
- Source Specific Searches.
  - Small ranges of frequency and frequency derivative
  - Phase shifting and summing pulse profiles from short intervals 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

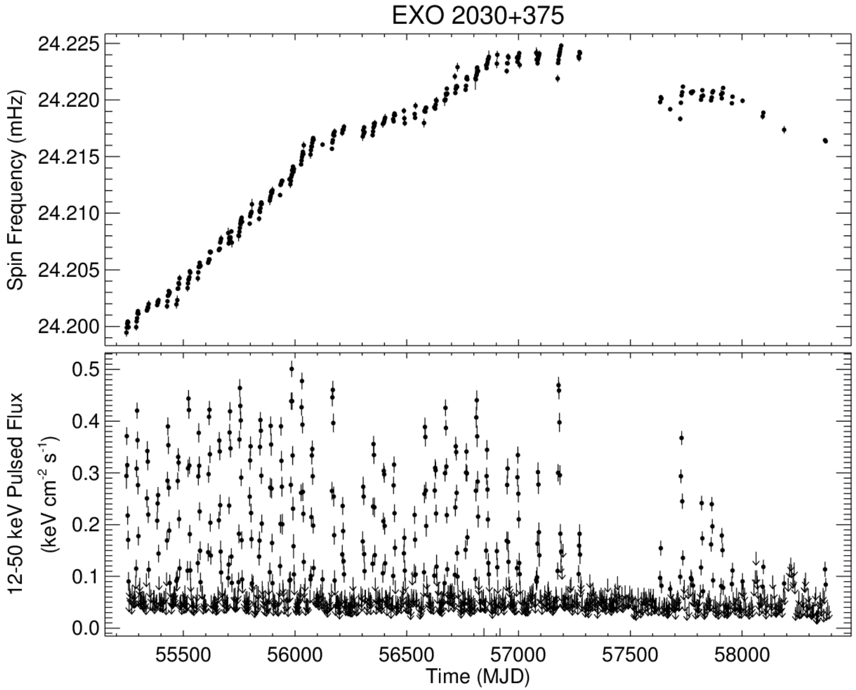
Fermi GBM: the eyes that see them changing

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



~21 year cycle in EXO 2030+375?

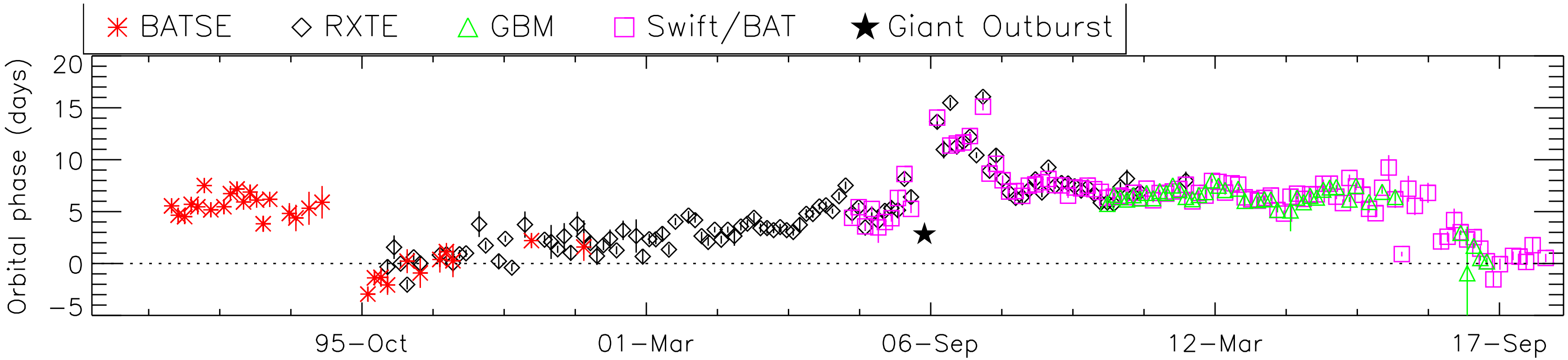




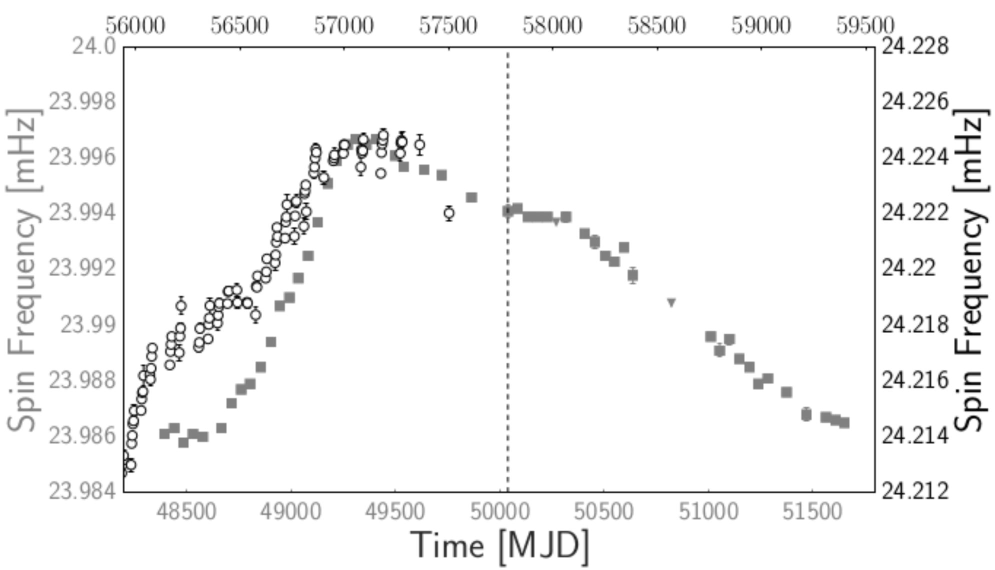
Starting in 1985 and 2006, EXO 2030+375 showed a similar trend in the spin-frequency: after a steep spin-up, a less steep spin-up period follows, which is accompanied by a spin-down period (currently observed).

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

~21 year cycle in EXO 2030+375?



Malacaria et al. in prep

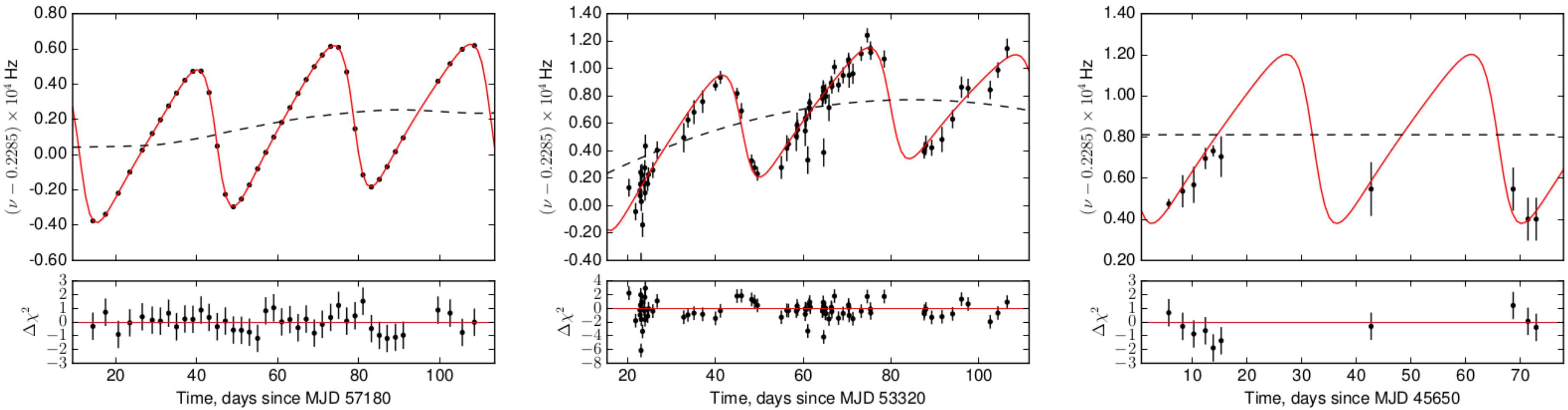


In 1995 and 2017, EXO 2030+375 also showed a feature in the orbital phase of the outburst peak: outbursts go from peaking 6-7 days after periastron to somewhere BEFORE the periastron (Wilson et al. 2008, Laplace et al. 2017)

Laplace et al. (2017)

Orbital solutions: V 0332+53

Doroshenko et al. 2016



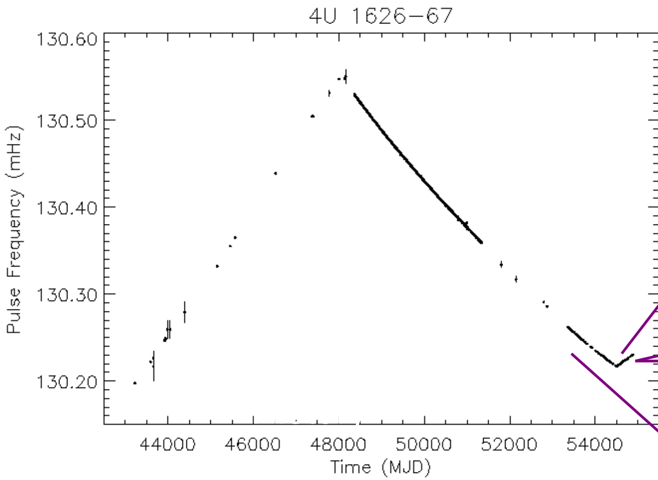
Fermi GBM, RXTE, Tenma data during three major outbursts of the source (note the error bars!). Reconstructed intrinsic pulsar frequencies (black dashed lines) modulated by motion along the orbit with best-fit parameters (red line). Best-fit orbital parameters are published.

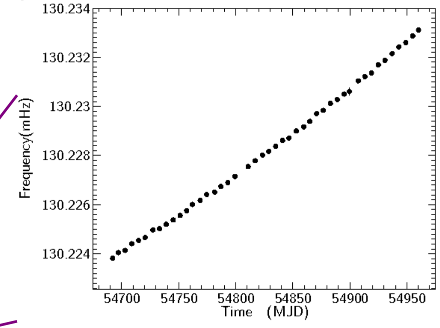
Orbital solutions with Fermi GBM data

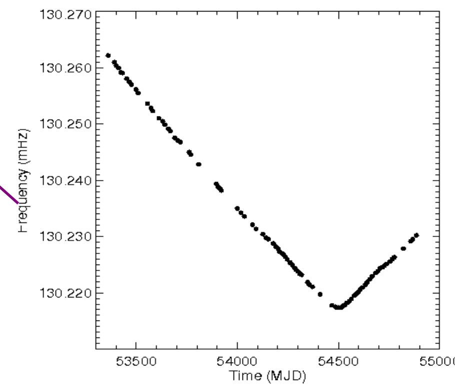
- Ge et al. 2017, Doroshenko et al. 2017, Jenke et al. 2017, Wilson-Hodge et al. 2018 (Swift J0243.6+6124)
- Sugizaki et al 2017 (GS 0834-430, KS 1947+300, GRO J1008-57)
- Tsygankov et al. 2017 (SMC X-3)
- Coe et al. 2015 (Swift J0513.4-6527=LXP 27.2)
- Marcu-Chetham et al. 2015 (XTE J1946+274)
- Sugizaki et al 2015 (GX 304-1)
- Tsygankov et al. 2015 (2S 1553-542)
- Kuehnel et al .2014 (RX J0520.5-6932)
- Jenke et al. 2012 (OAO 1657-415)
- Jenke & Finger 2011 (4U 1901+03)
- Several new and/or updated orbital solutions on our website

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

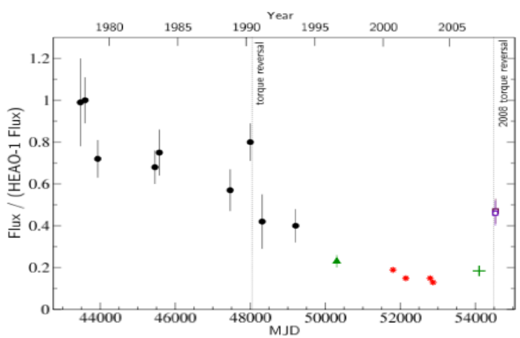
4U 1626-67 A Torque Reversal







Torque reversal centered in 2008 Feb 4 lasting ~150 days



Camero-Arranz et al. 2010

. Ultracompact LMXB

. P_{pulse}= 7.66 s

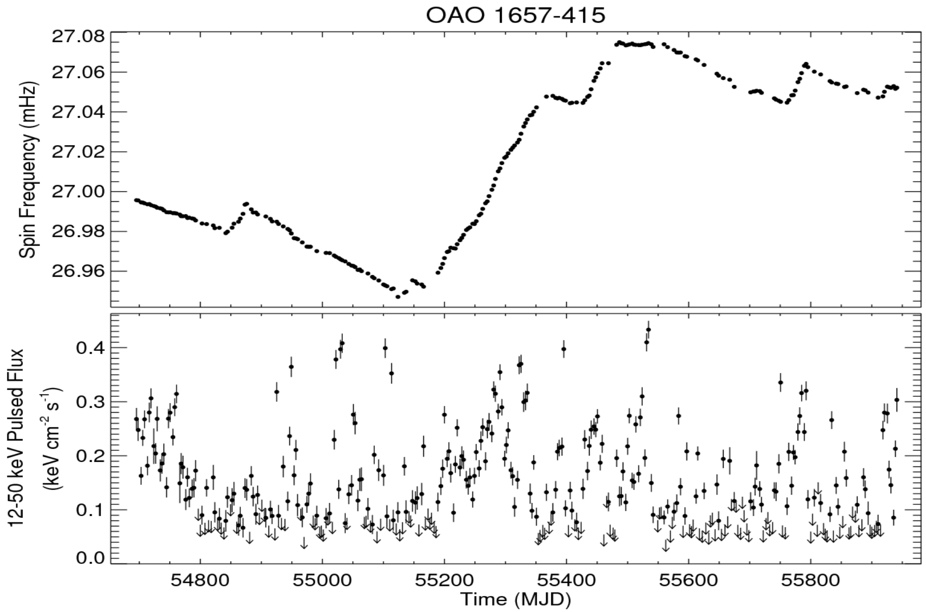
. Porb = 42 min orbit.

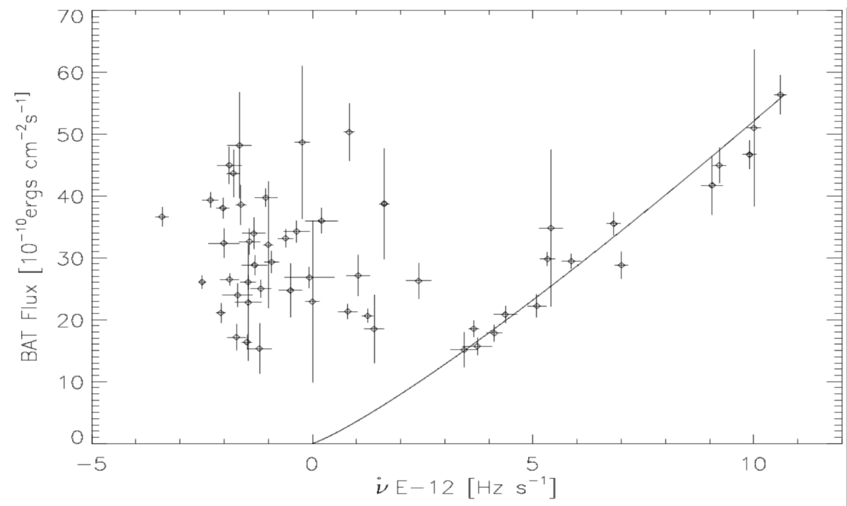
. B= (2.4-6.3)x10^{12}G

. 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

Evidence for a transient accretion disk in OAO 1657-415

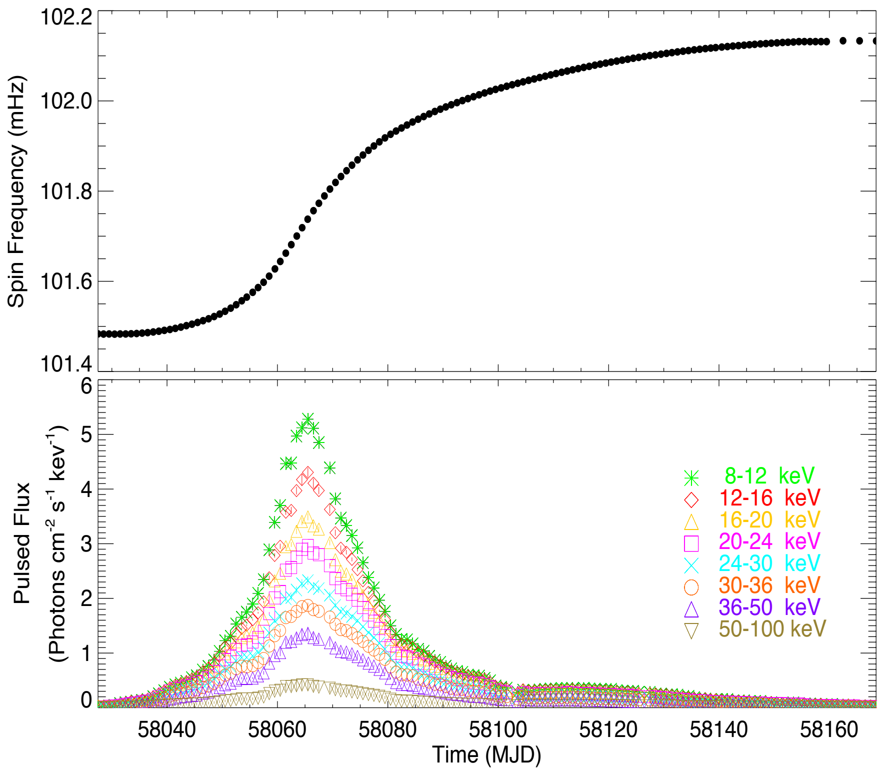


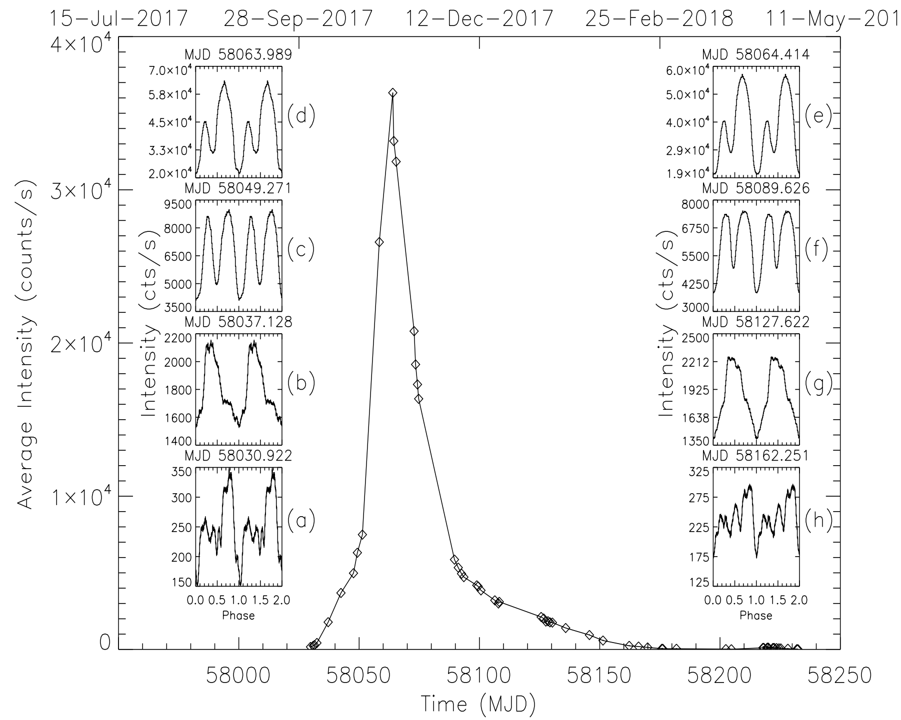


Jenke et al. 2012

- 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: Pdot/P = $(-3.40 \pm 0.15) \times 10^{-6}$ yr^{-1}

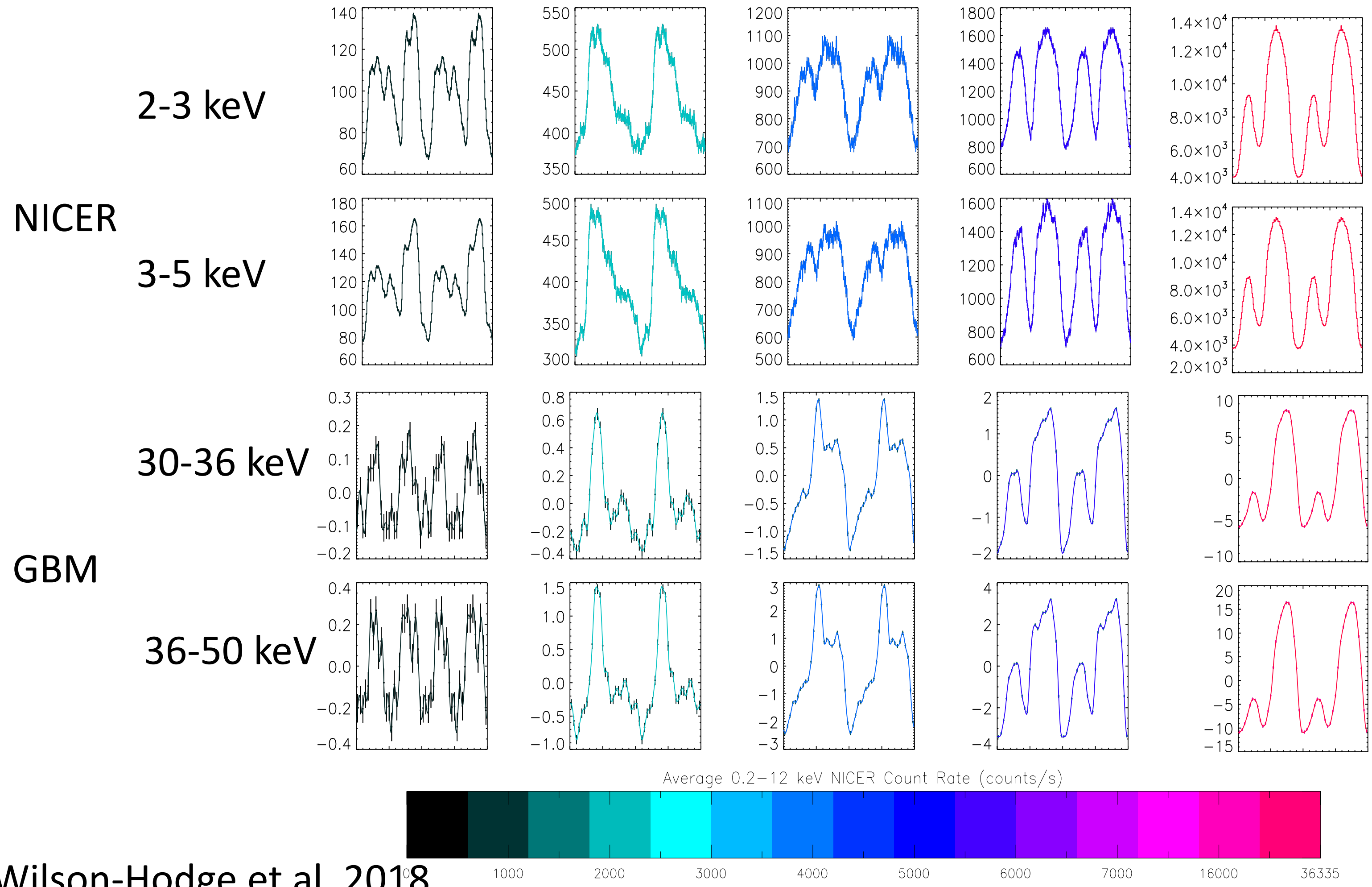
Swift J0243.6+6124: The First Galactic Ultraluminous X-ray Pulsar





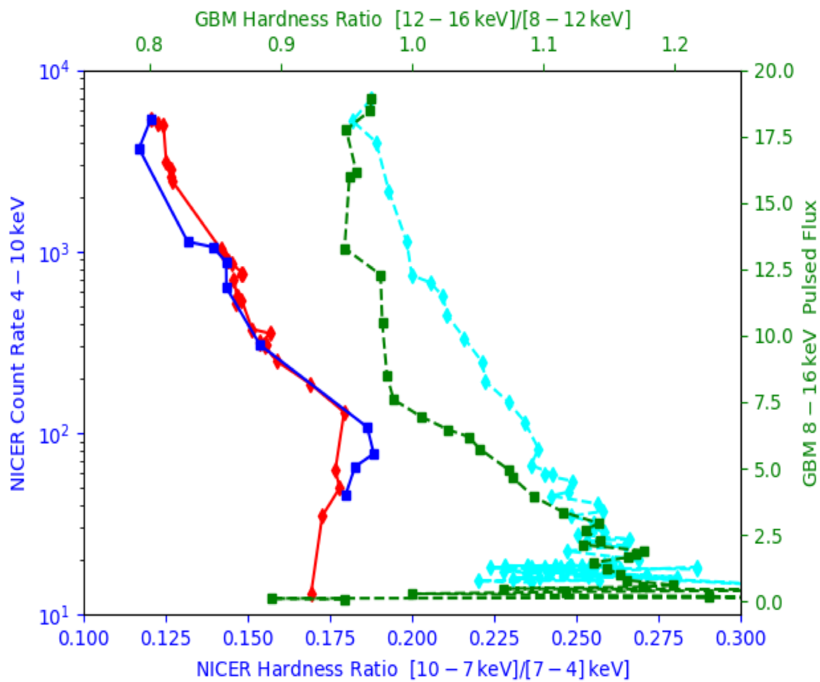
Wilson-Hodge et al. 2018

Swift J0243.6+6124:Pulse profile evolution

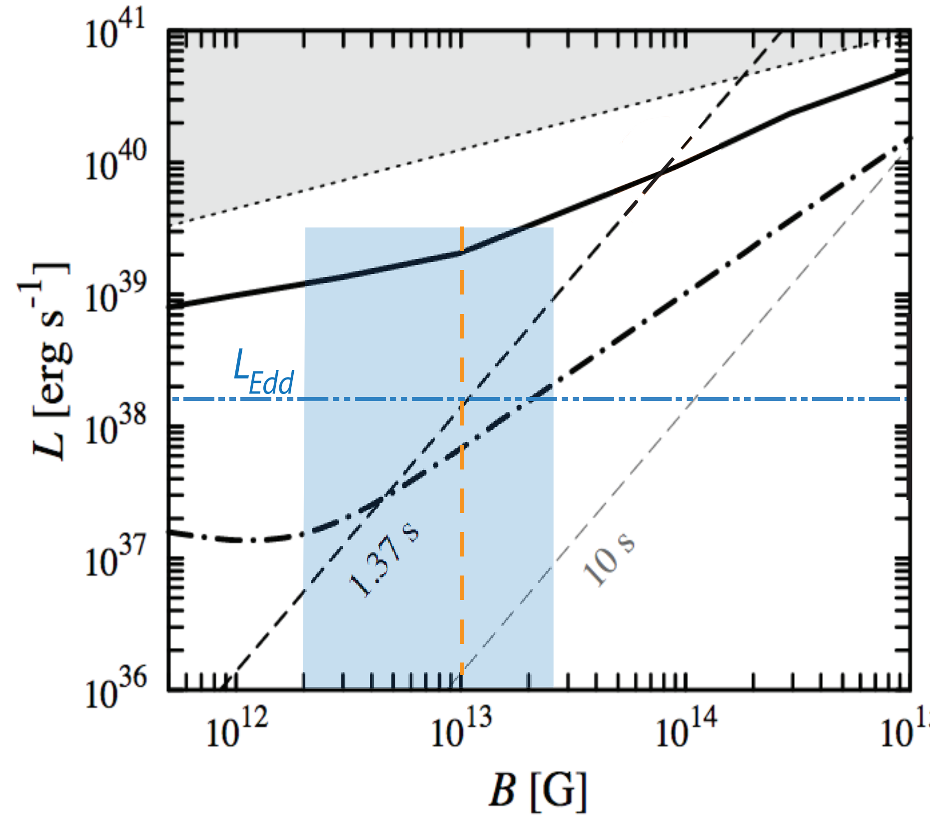


Wilson-Hodge et al. 2018

Swift J0243.6+6124: Critical Luminosity Transition



Wilson-Hodge et al. 2018

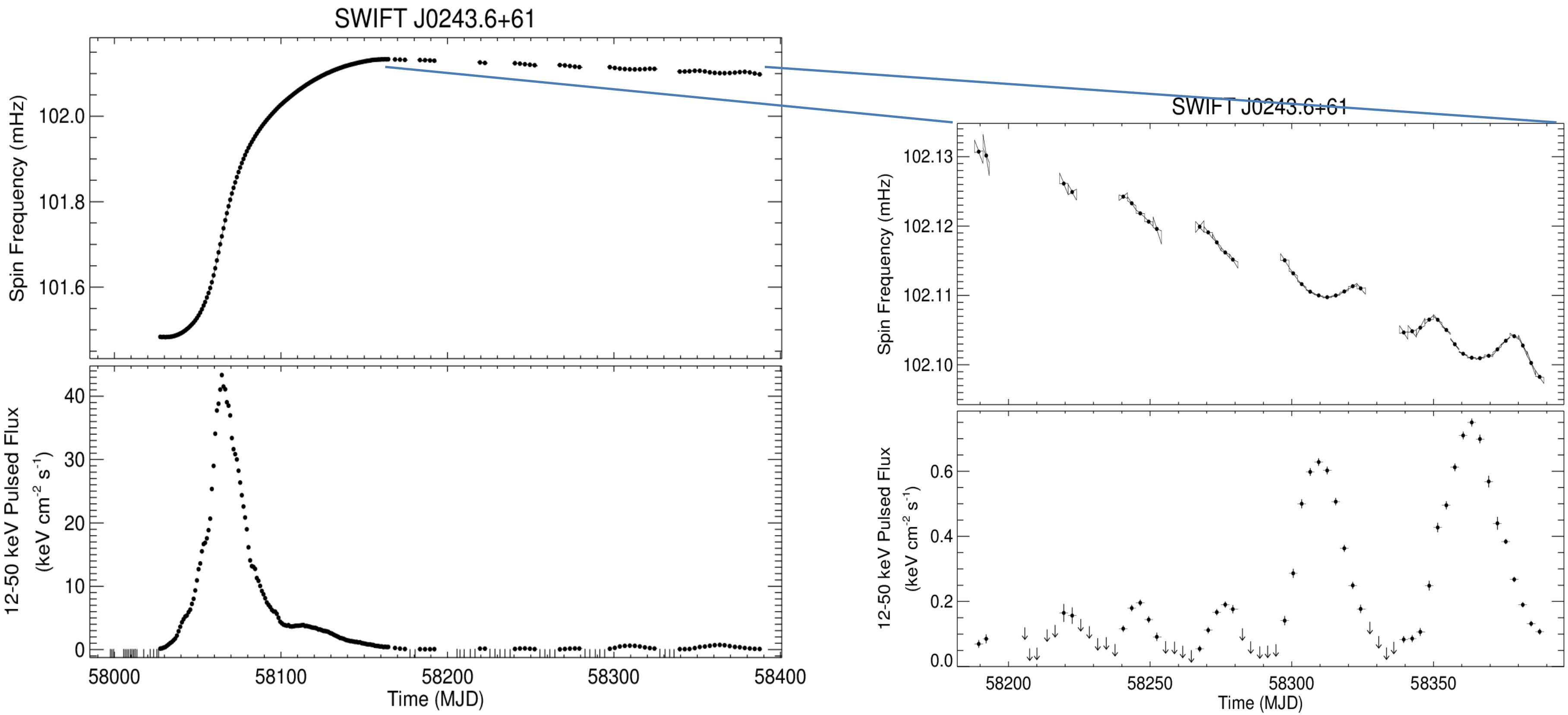


Wilson-Hodge et al. 2018; Adapted from Mushtukov et al. 2015

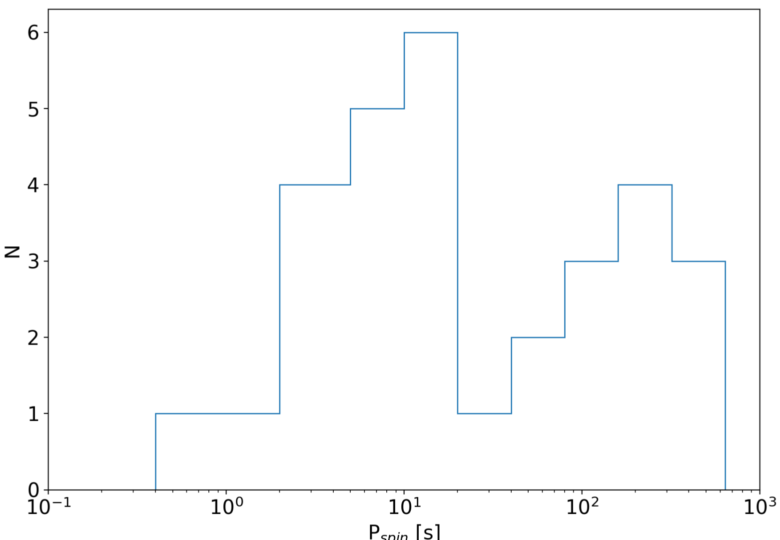
Swift J0243.6+6124: Comparisons with ULX pulsars in other galaxies

- Properties like known ULX pulsars (Kaaret et al. 2017)
  - Peak luminosity ~2 x 10^{39} erg s^{-1} (d=7 kpc; 0.1-10 keV) (>10^{39} ergs s^{-1})
  - normal outbursts peaking around 10^{37} erg s^{-1} (0.1-10 keV)
  - Spin period ~9.8 s (0.43-32 s)
  - Peak spin-up rate (2.23+/-0.02)x10^{-10} Hz/s (>10^{-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.
  - Evidence for jets in radio (van den Eijnden et al. 2018)

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



Bimodal spin-period distribution: mind the gap

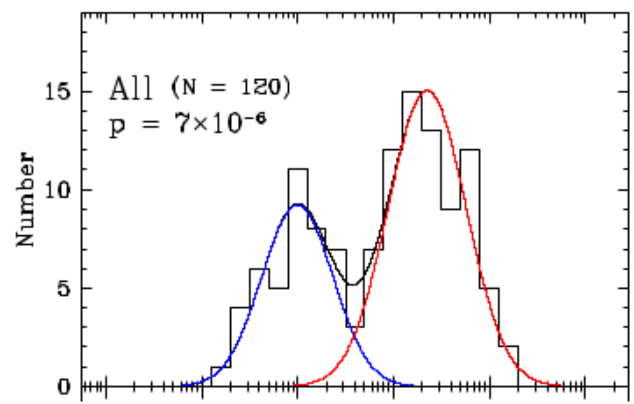


Malacaria et al. in prep

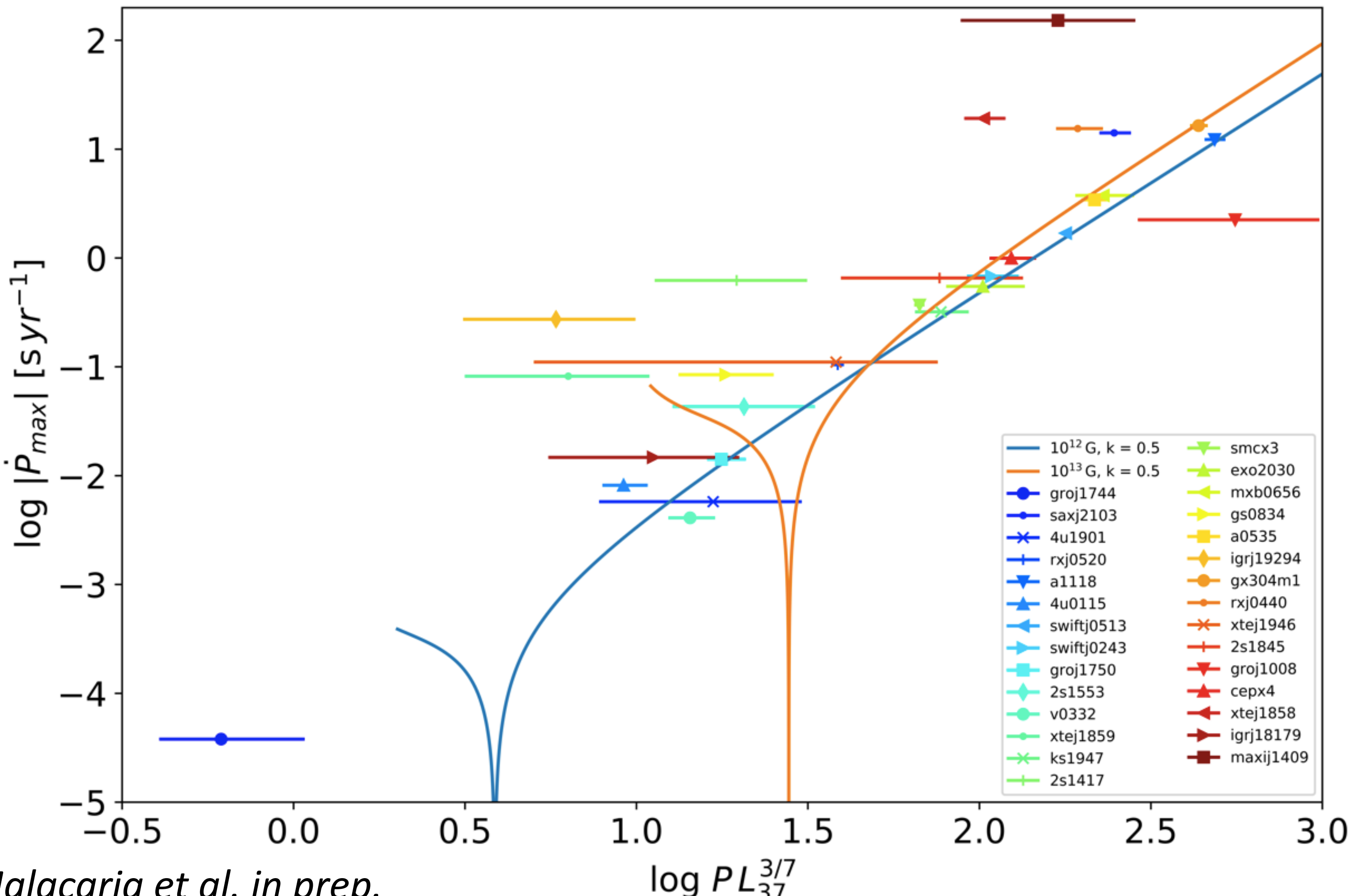
GBM pulsars Galactic sample (before this, only samples including Galactic + SMC + LMC)

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



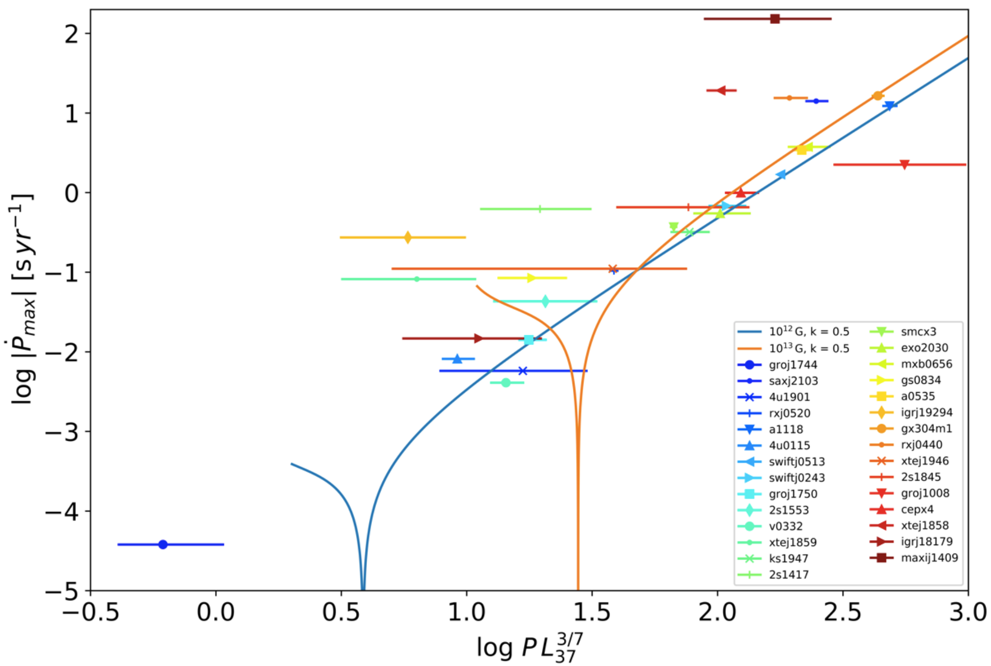
Accretion torque modelling: Ghosh&Lamb vs GBM pulsars



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 in a Roche-lobe overflow LMXRB
    - Evidence for a ~21 year cycle in a Be/X-ray binary
    - 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