Accretion-driven Millisecond X-ray Pulsars and the Discovery of the First Eclipsing Event

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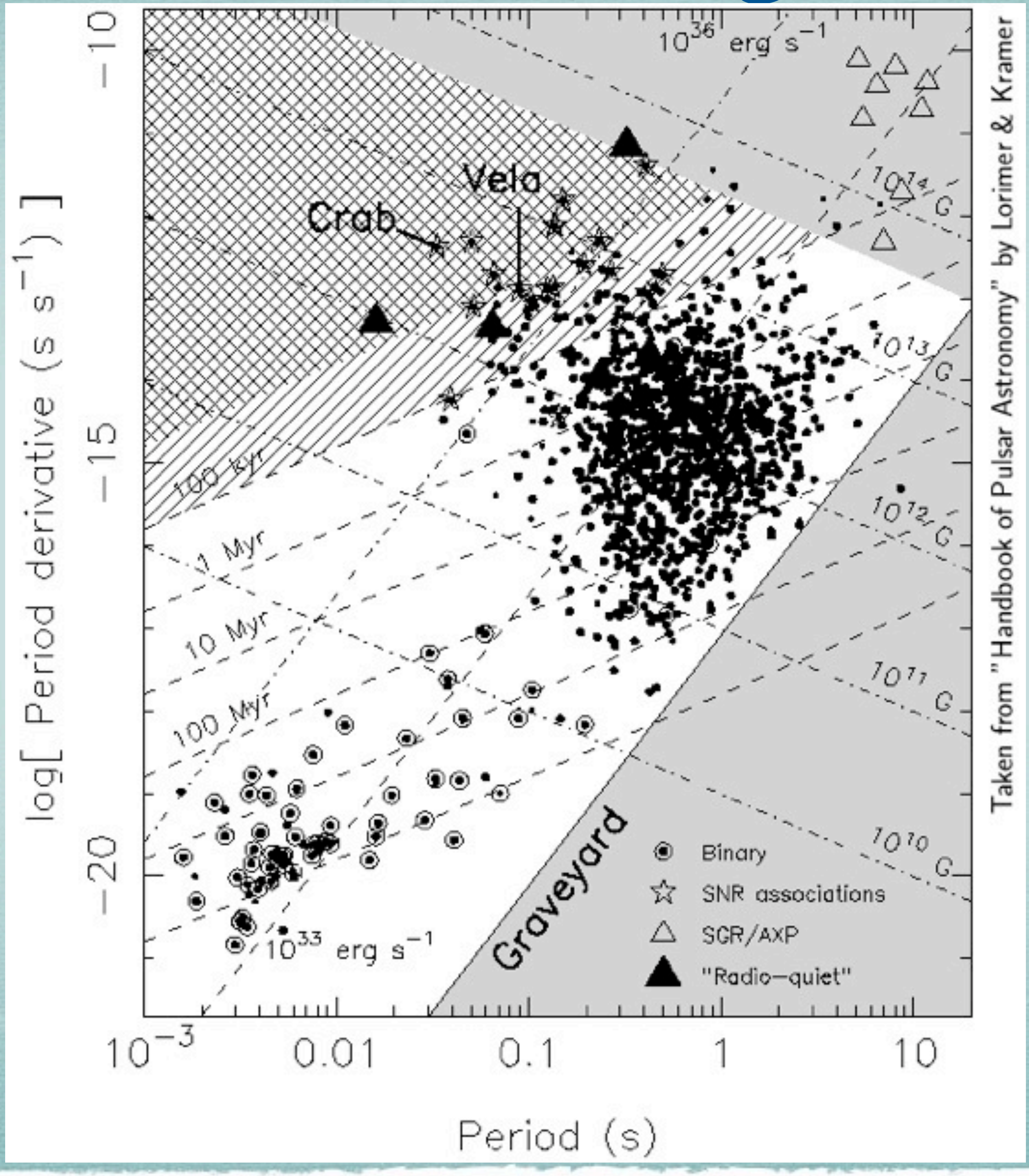
Outline

- Classification of Pulsars
- Accretion-driven Millisecond X-ray Pulsars (AMXPs)
- Discovery of the first eclipsing Event
- Summary

Pulsar Basic

- Pulsars
  - Isolated
    - Radio
      - Rotation-powered Pulsars
      - Millisecond Pulsars
      - Rotational Radio Transients
    - Optical Pulsars
    - X-ray (i.e. Magnificent 7)
    - Gamma ray (i.e. Geminga, Lupin Lin's talk)
    - Magnetar
      - Anomalous X-ray Pulsars(AXPs)
      - Soft Gamma-ray Repeaters(SGRs)
  - Binary
    - Accretion-powered (Radio Quiet)
      - LMXB(i.e. AMXPs)
      - HMXB
    - Radio Loud
      - Millisecond Pulsars
      - Double Pulsars/Pulsar + NS
      - Pulsar + Main sequence star

P-P(dot) Diagram



Accretion-driven Millisecond X-ray Pulsars

According to the recycling scenario, millisecond radio pulsars are produced by spin up via the transfer of angular momentum through accretion. During the phase (~10 Gyrs), they would be expected to emit X-ray pulsations.

Therefore one would expect some accreting neutron stars to be observed as accretion powered X-ray pulsars in the process of spinning up in the millisecond range.

Periodic variability of AMXPs

The blackbody emission from the hot spot where the magnetic funnel flow impacts the neutron star surface, transforming the kinetic energy into radiation. Since the funnel flow is relativistic, a shock is expected to appear.

The thermal radiation emitted by the hot spot can the be Comptonized by the shock and upscattered to higher energies (Poutanen & Gierlinski 2003)

Other properties of AMXPs

Quasi-periodic Oscillations (QPOs):

Apart from the coherent millisecond variability, AMXPs show quasi-periodic variability on timescales of milliseconds up to hundred seconds (Linares et al. 2005, 2007, 2008) However, the origin of this phenomenon is not yet clear.

Thermonuclear (runaways) X-ray Bursts:

usually called Type I X-ray Bursts

Burst Oscillations:

which are observed with a frequency close to neutron star spin. Only three AMXPs found with burst oscillations so far. (SAX J1808.4-3658, XTE J1814-338 and Aql X-1)

List of AMXPs found up to date

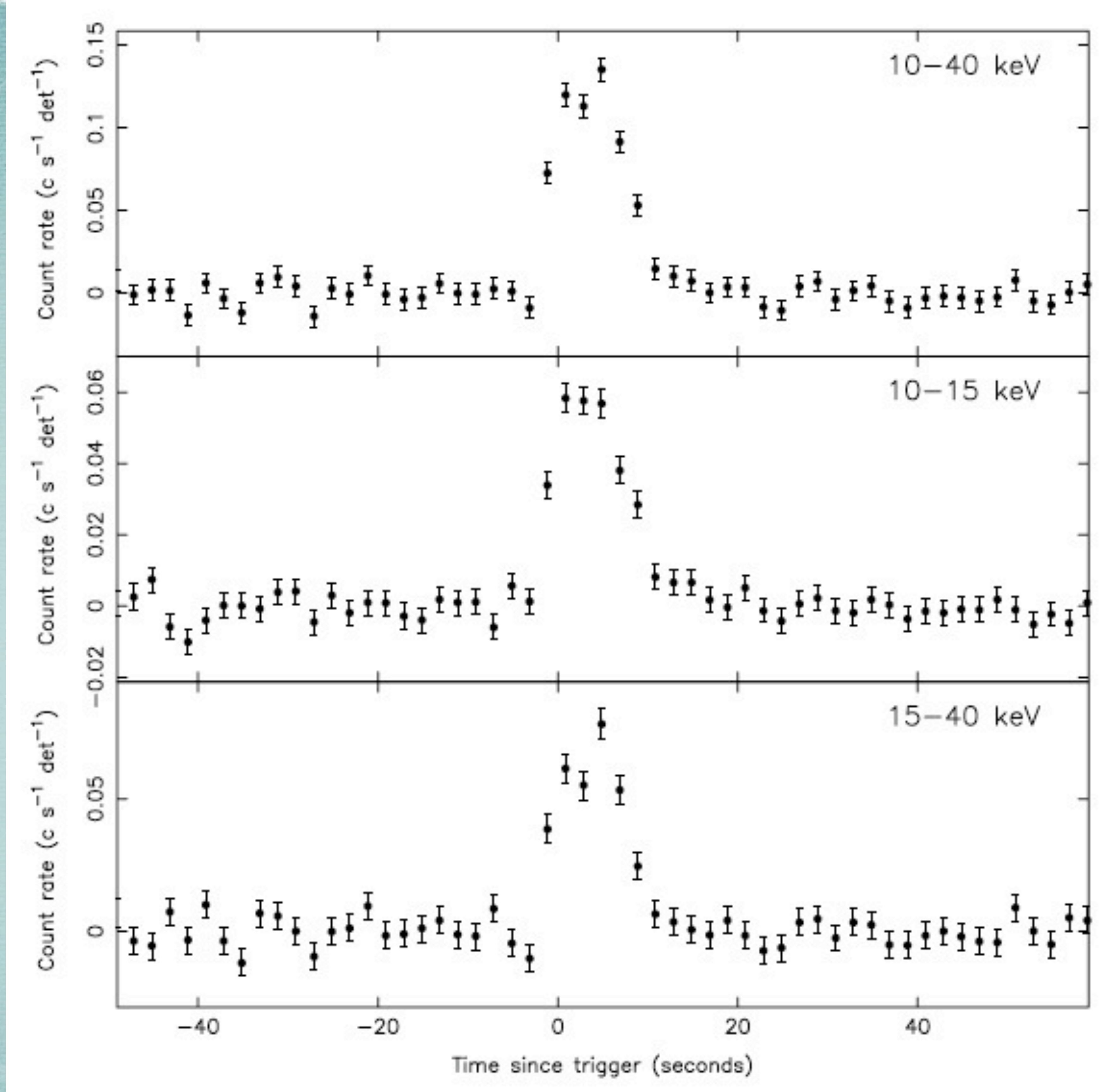
Name	ν Hz
IGR J00291+5934	$598.892 \pm 2e - 08$
Aql X–1	$550.274 \pm 9e - 04$
SAX J1748.9–2021	$442.361 \pm 5e - 08$
XTE J1751–305	$435.318 \pm 4e - 08$
SAX J1808.4–3658	$400.975 \pm 6e - 09$
HETE J1900.1–2455	$377.296 \pm 5e - 09$
XTE J1814–338	$314.357 \pm 1e - 09$
IGR J17511–3057	$245\pm ?$
NGC 6440X2	$205.893\pm ?$
XTE J1807–294	$190.624 \pm 8e - 08$
XTE J0929–314	$185.105 \pm 9e - 09$
SWIFT J1756.9–2508	$182.066 \pm 7e - 08$
SWIFT J1749.4–2807	$517.920 \pm 1e - 08$

The first accreting millisecond X-ray Pulsar was discovered in 1998 (SAX J1808.4-3658, Wijnands & van der Klis 1998)

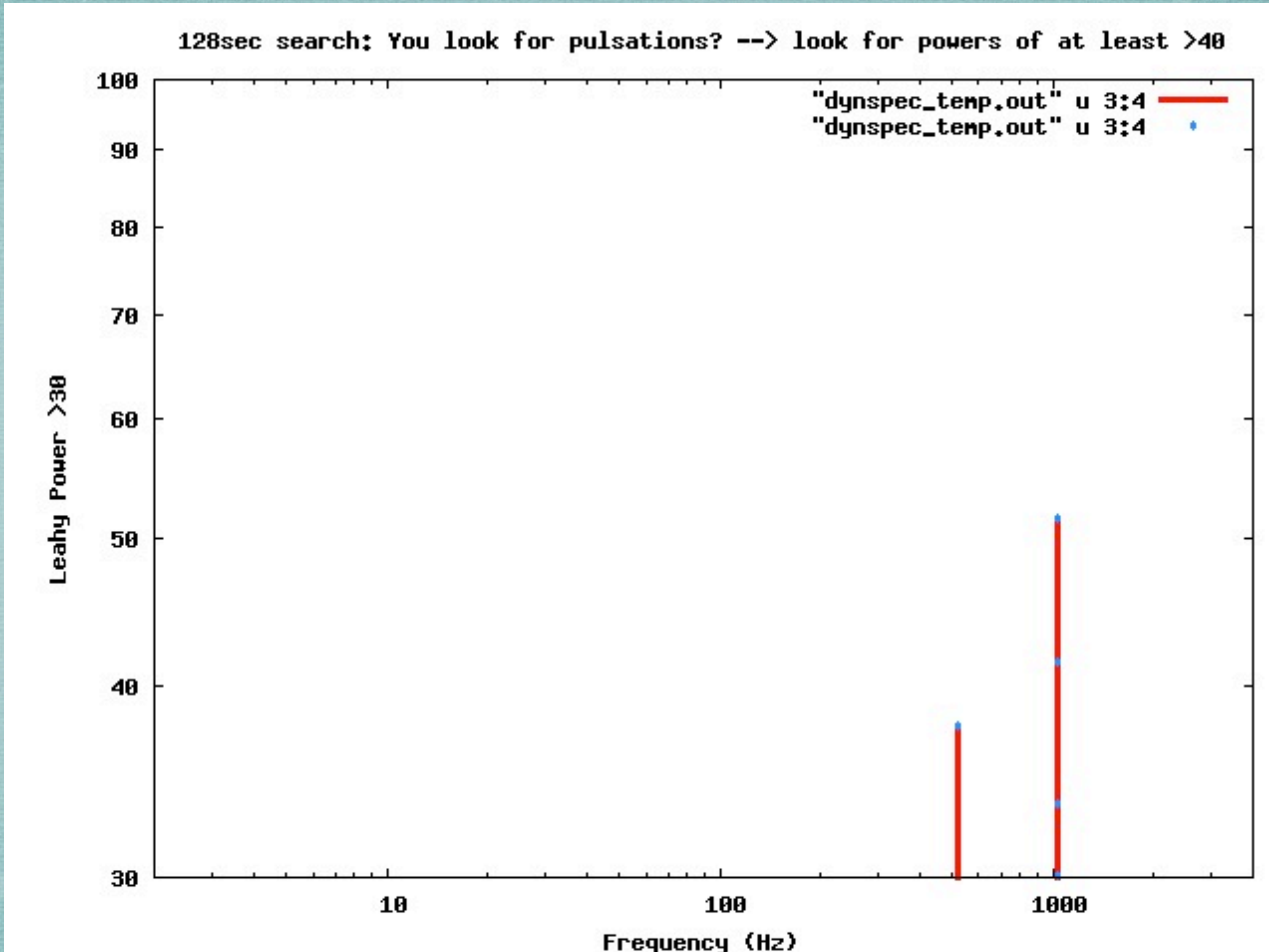
Note:
All AMXPs are LMXBs.
Frequencies are ranging from ~ 180-600 Hz.

Discovery of the First Eclipsing AMXP Swift J1749.4-2807

- First discovered by Swift/BAT as GRB060602B
- Later was realized it is an accreting neutron star binary system instead of GRB (Wijnands et al. 2009)
- Outburst in April 2010 detected by Integral with RXTE, Swift/XRT and Chandra follow-ups
- Eclipses found in RXTE and Swift observations



The Swift/BAT lightcurve of GRB060602B in different energy range. (Wijnands et al. 2009)


128sec search: You look for pulsations? --> look for powers of at least >40
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Frequency (Hz)

Type I Burst by Integral (Ferrigno et al. 2010, ATel#2648)

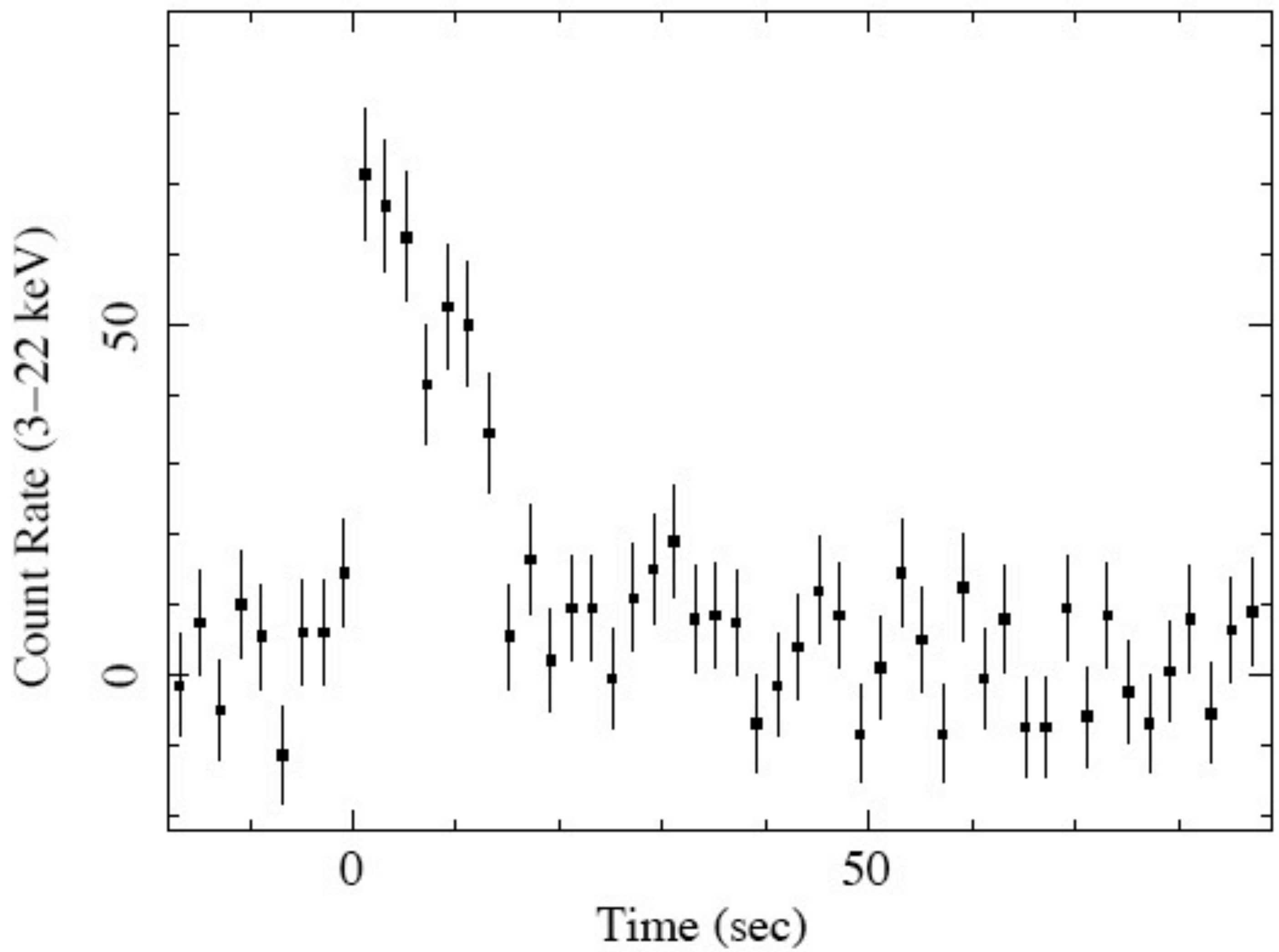
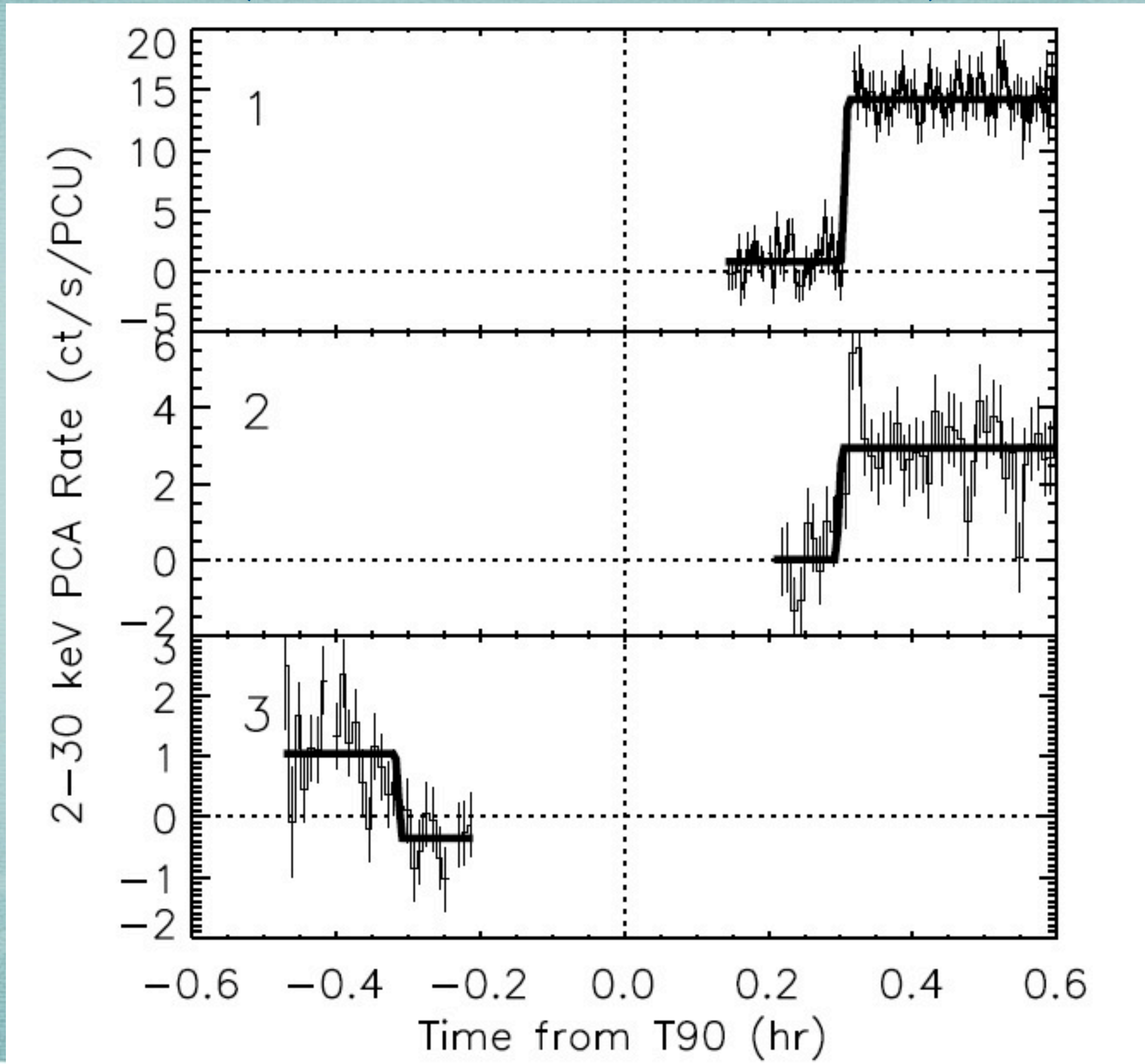
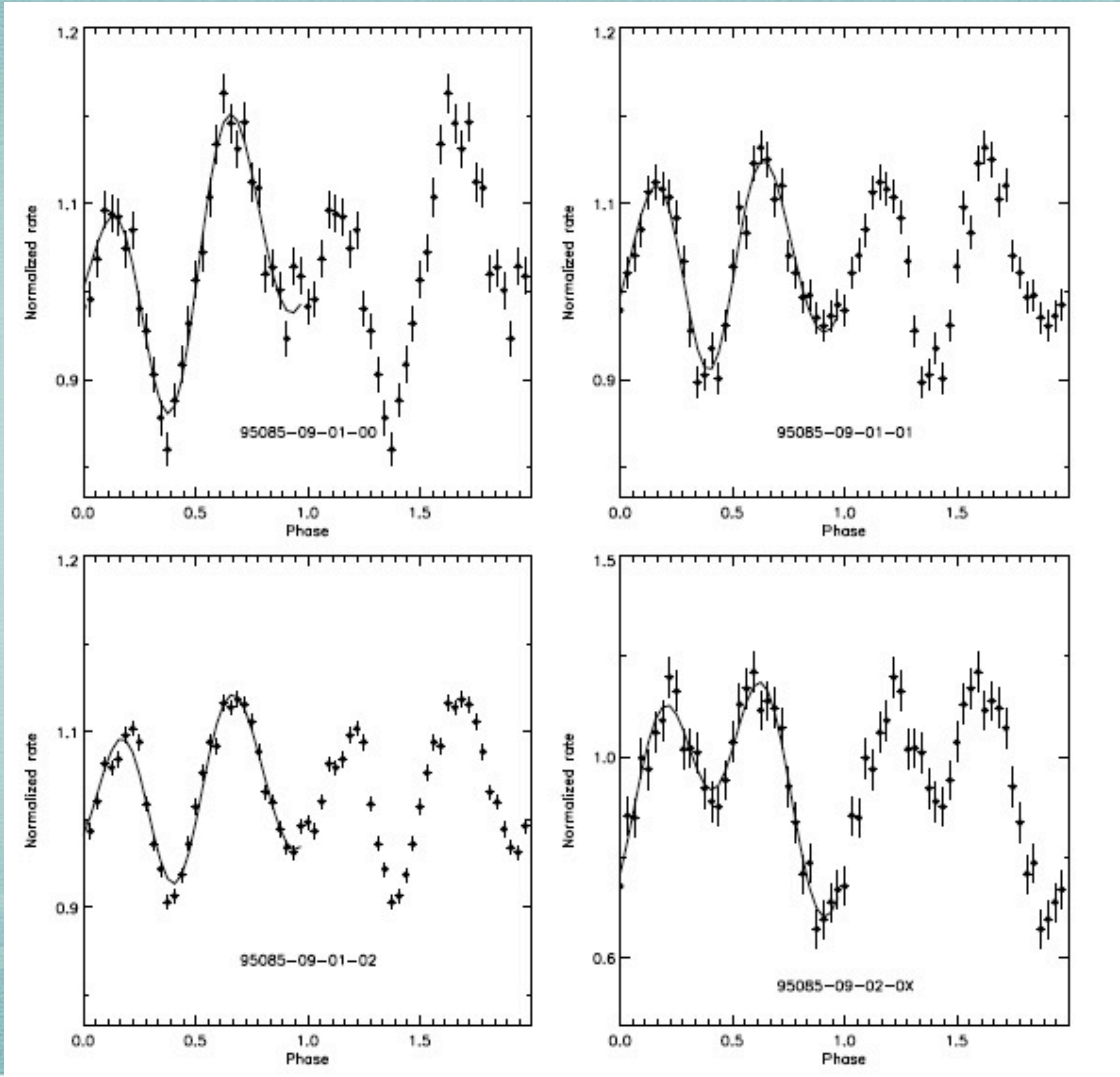


Fig. 1. The type-I X-ray burst detected by INTEGRAL/JEM-X2 from SWIFT J1749.4-2807. The JEM-X (3-20 keV) net light curve is shown (background subtracted). The time bin is 2 s and the start time of the burst is 2010 April 13 at 16:51:18 (UTC).

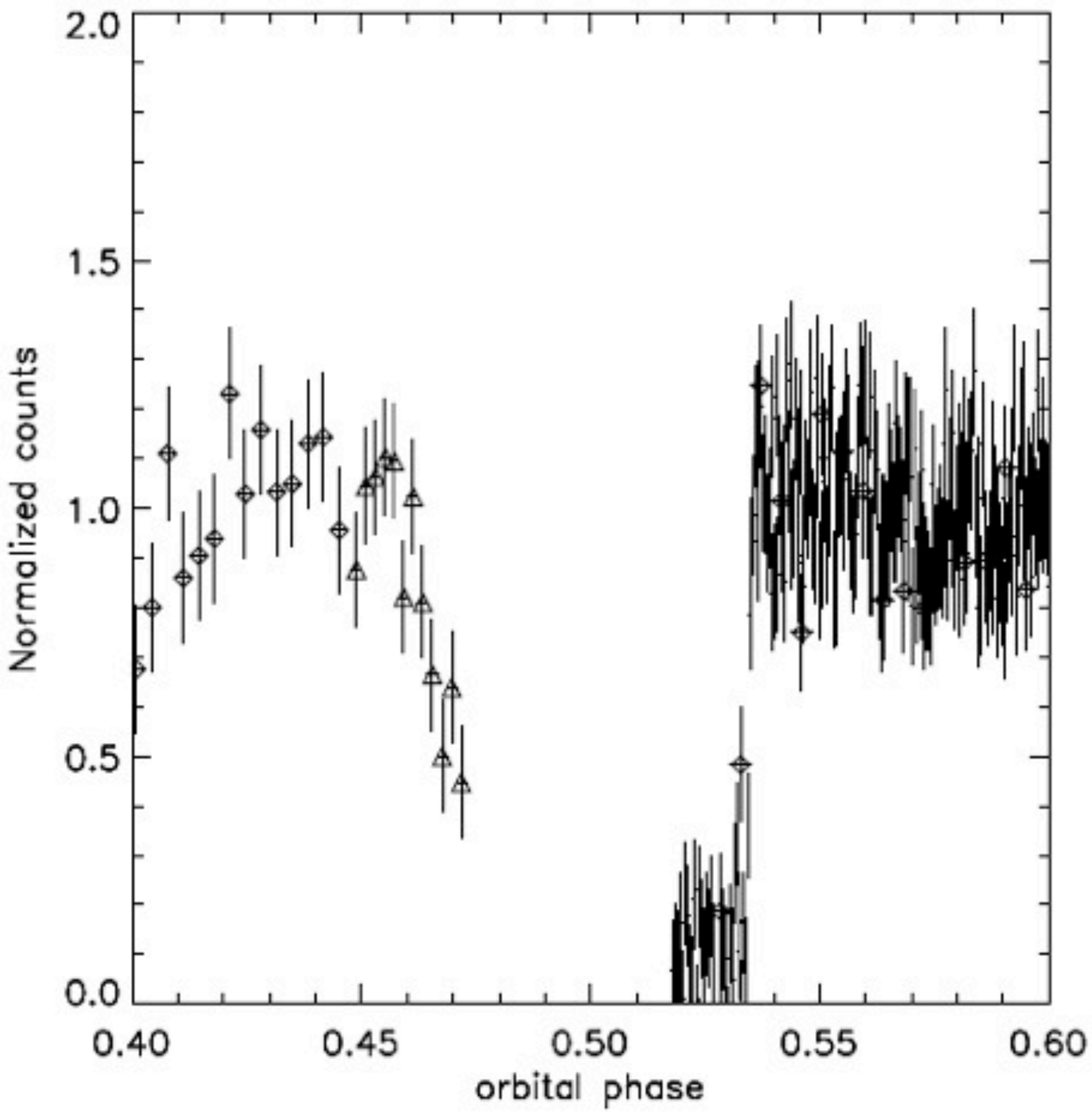
Eclipses found by RXTE (Altamirano et al. 2010)

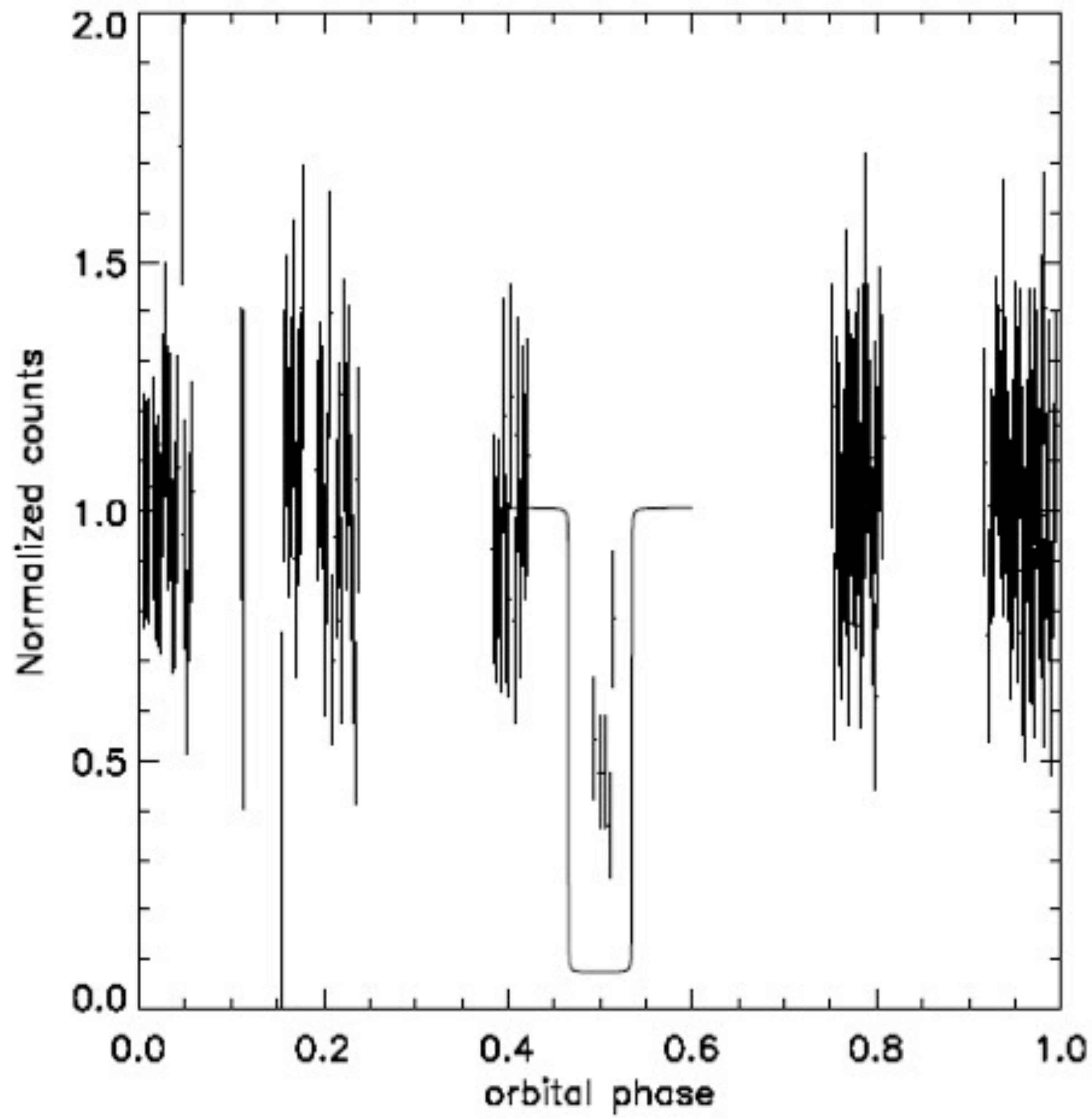


Pulse Profiles of Swift J1749.4-2807 (Ferrigno et al.)



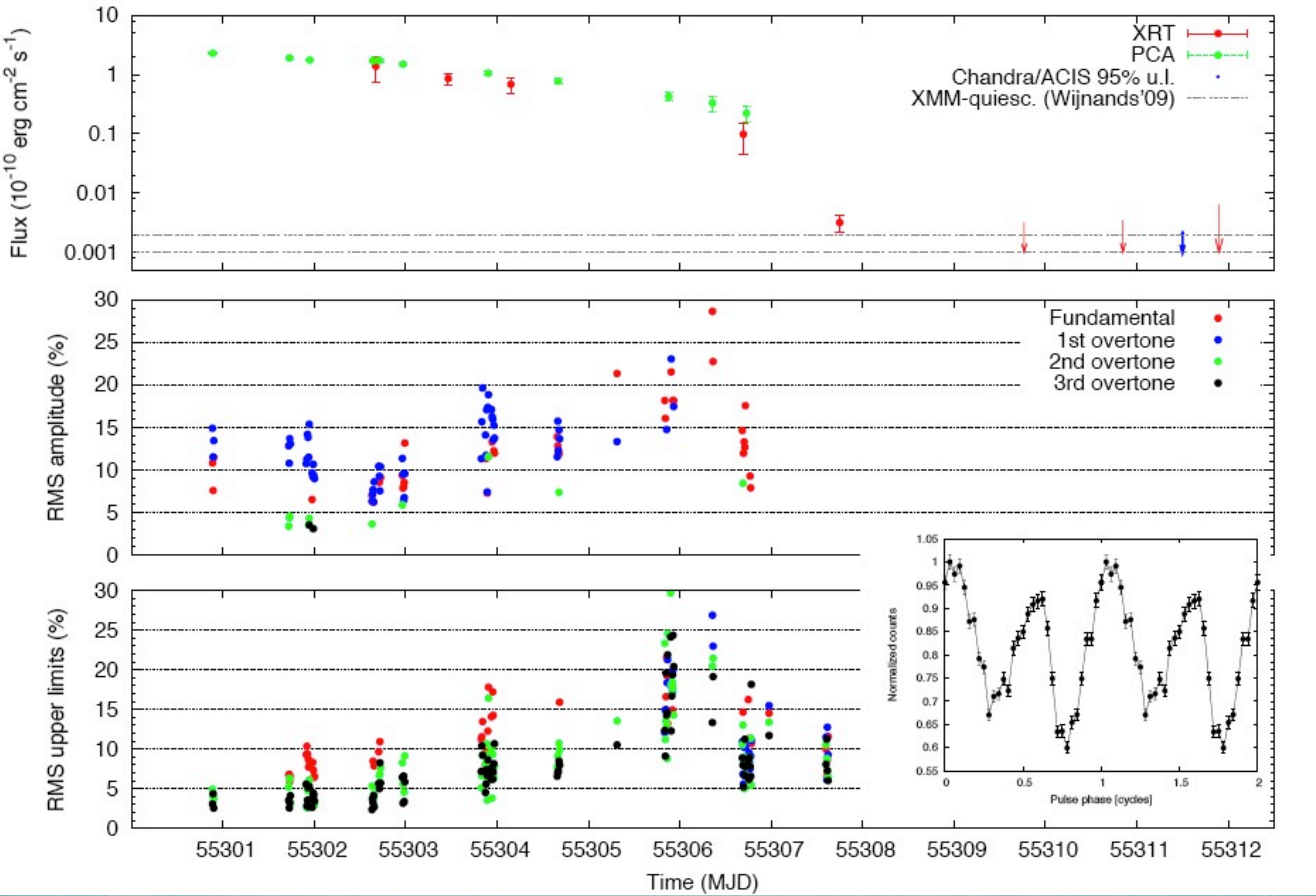
Folded Lightcurves



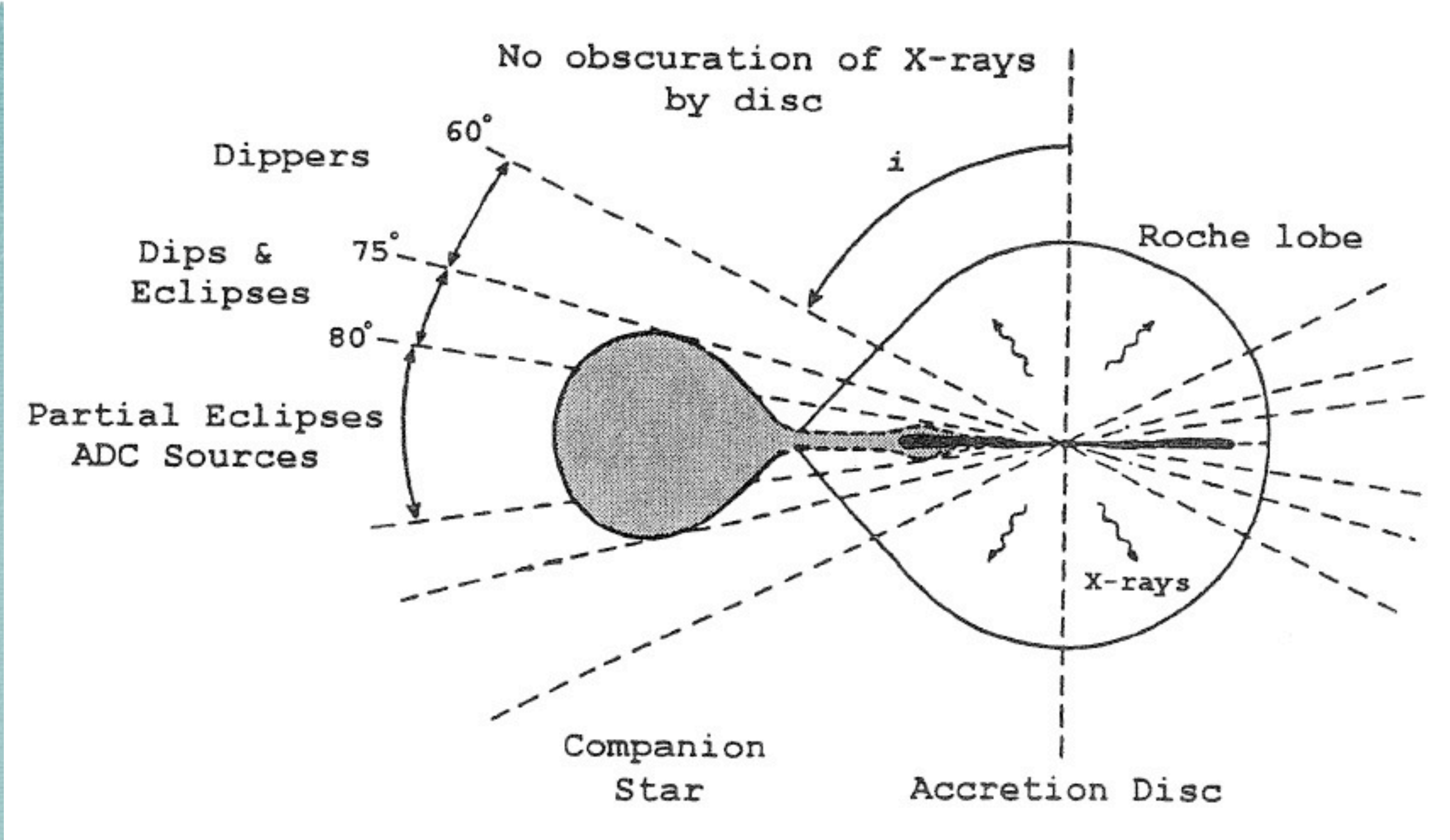


RXTE

Swift/XRT



(Altamirano et al. 2010)



At inclinations close to 90 degree the central source is not visible, only scattered X-rays from a wind or accretion disc corona can be seen (partially eclipsed by the companion star).

Between inclinations of about 60-80 degree the central source is visible, but with dips.

Below 60 degree the central source is always visible.

Pulsar Timing	
Solution Time Range (UTC)	2007-04-14 to 2010-04-20
Barycentric pulse frequency, f_o (Hz)	1035.840027850(65)[a b]
Pulsar frequency derivative, $\|\dot{f}\|$ (Hz s^{-1})	$< 1.5 \times 10^{-12}$ [c]
Projected semimajor axis, $a_x \sin i$ (lt-s)	1.899494(12)
Binary orbital period, P_b (s)	31740.719(8)
Time of ascending node, $T_{\rm asc}$	2455301.1522542(5) [d]
Orbital eccentricity, e	$4.2(1.5)\times10^{-5}$
Pulsar mass function, f_x ($10^{-2} M_\odot$)	5.463(8)
Maximum Power, $Z^2_{\rm max}$	2362
Timing residuals, $\sigma_{\rm toa}$ (μs)	92
Solution quality, χ^2 for ν d.o.f.	225 / 60 d.o.f.

Eclipse Timing	
Eclipse duration, $T_{\rm ecl}$ (s)	2172(13)
Egress duration, s	30(12)
Solution quality, χ^2 for ν d.o.f.	372 / 372 d.o.f.
Joint Solution[e]	
Companion mass, M_c ($M_\odot$)	0.62–0.81
Companion radius, R_c ($M_\odot$)	0.85–0.92
Inclination, i (degrees)	76.65–77.93
Right Ascension (J2000)[f]	$17^{\rm h}49^{\rm m}31\overset{\rm s}{.}94$
Declination (J2000)	$-28°08'05\overset{''}{.}8$

Summary

- There are so far 13 AMXPs found. They might be the link between radio pulsars and radio MSPs.
- The first eclipsing event was found by RXTE and Swift, which helped to constraint the inclination angle, as well as other parameters.
- Further observations and studies are needed to confirm the role of AMXPs in recycling scenario.