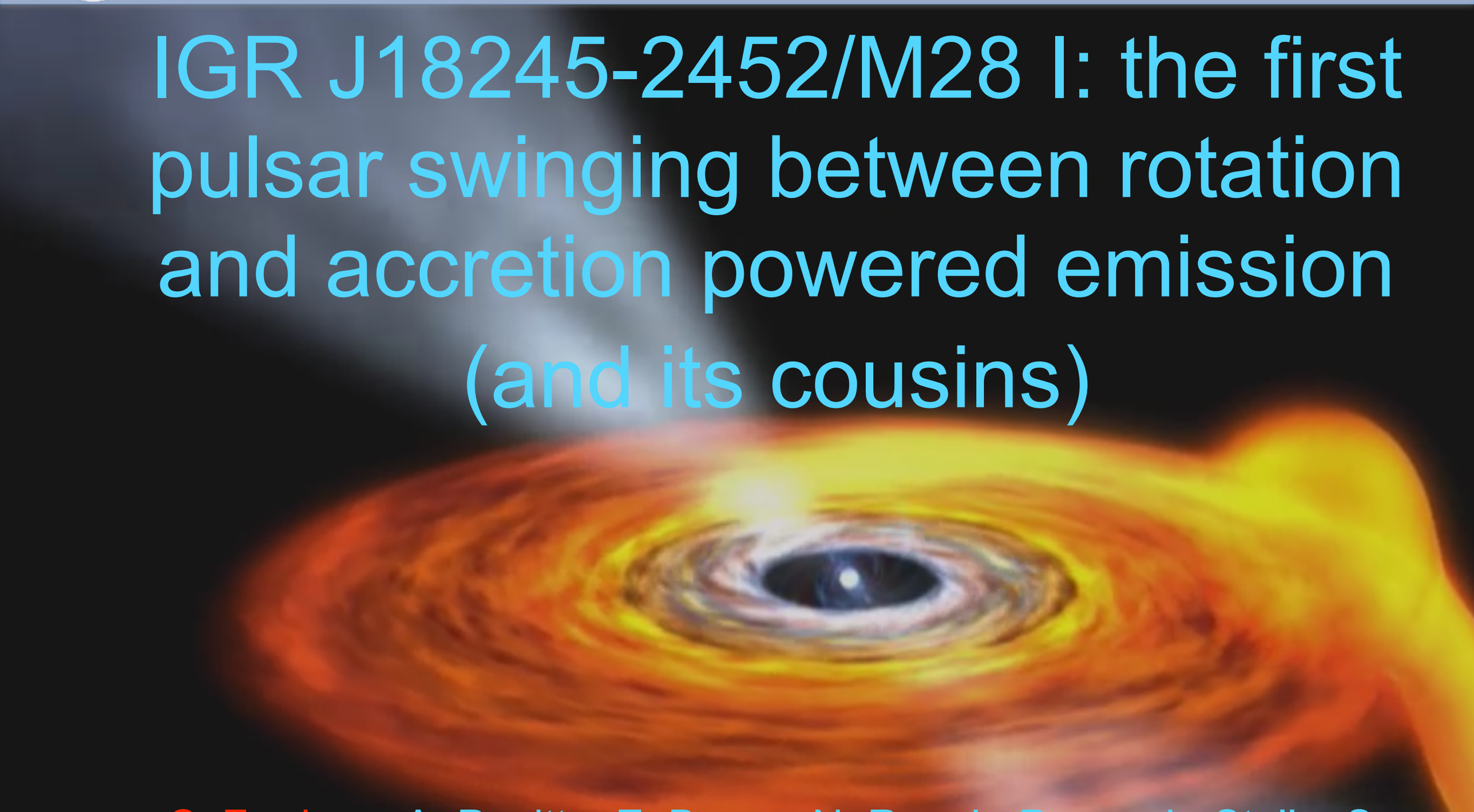
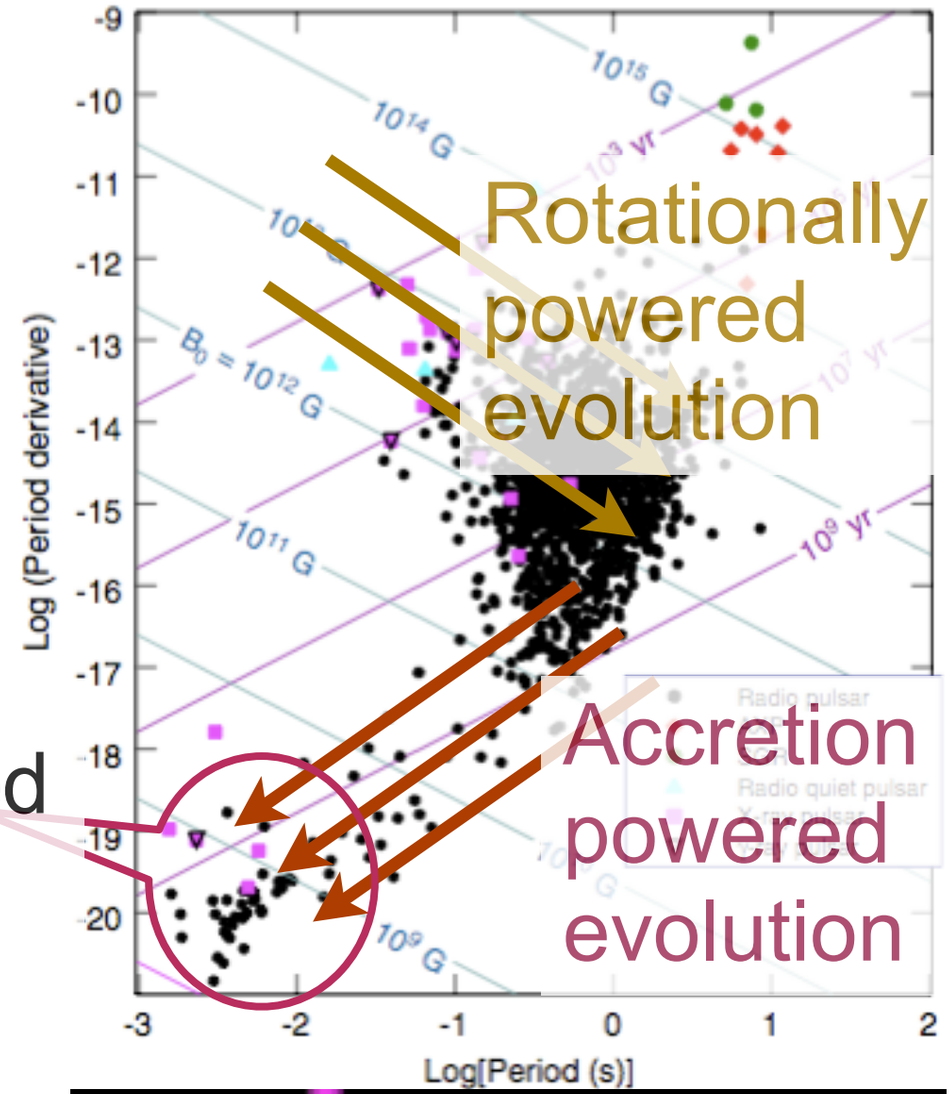
IGR J18245-2452/M28 I: the first pulsar swinging between rotation and accretion powered emission (and its cousins)

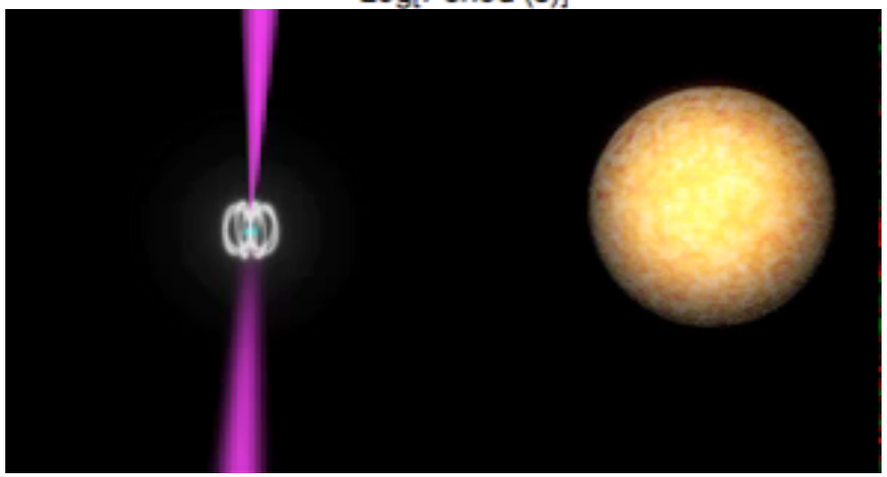


C. Ferrigno, A. Papitto, E. Bozzo, N. Rea, L. Pavan, L. Stella, S. Campana, M. Filipovic, M. Wieringa

Introduction

Recycled pulsars

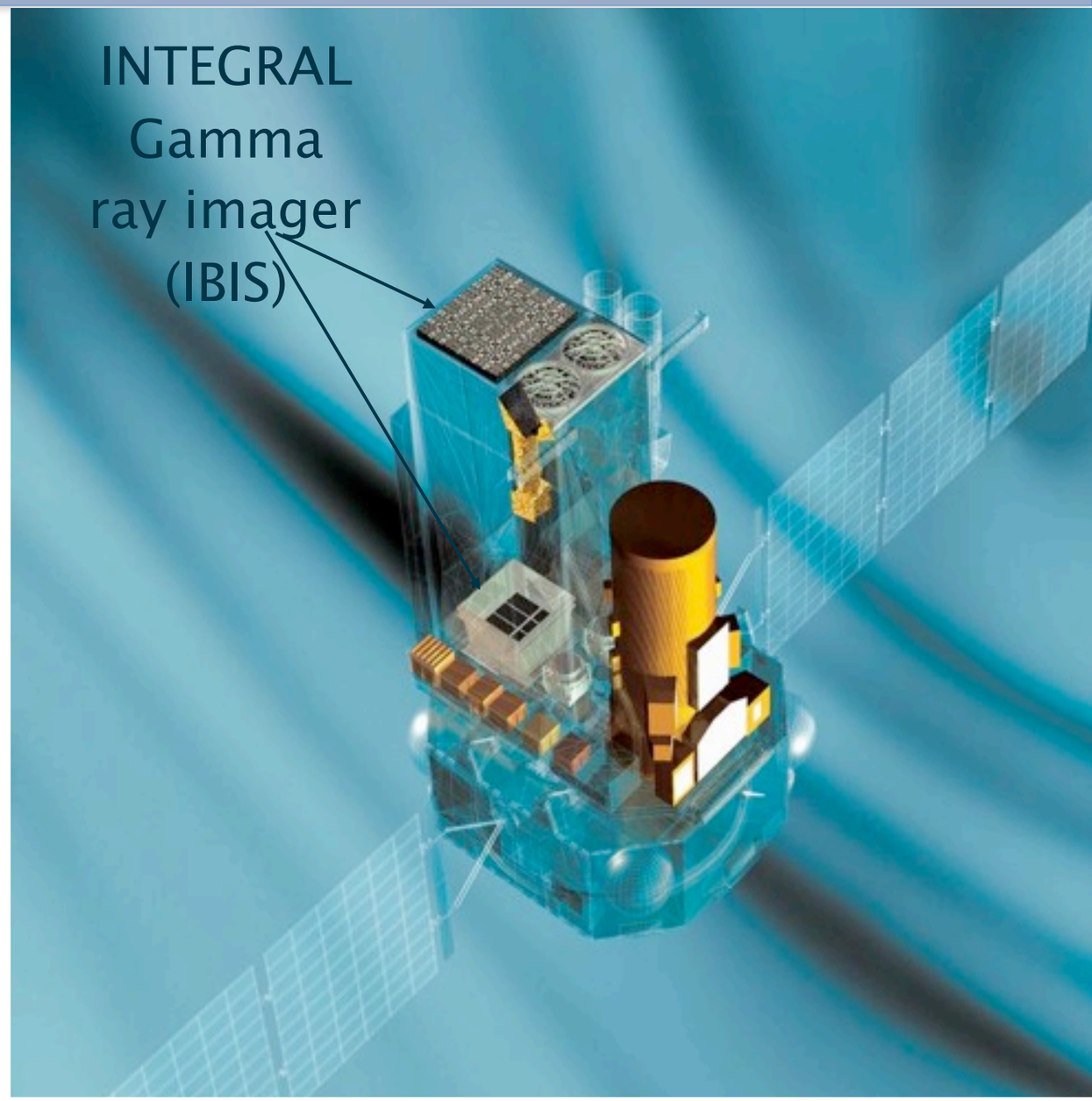




- Accretion of mass brings angular momentum and spins-up the pulsar. Recycling scenario proposed in 1982.
- First accreting ms pulsar discovered in 1998: SAX 1808.4-3658
- First evidence of relic accretion disc in an active radio pulsar in 2009: PSR J1023+0028

- Where are the transitional systems?

Monitoring



- Hard X-ray monitors with large field of view (tens of degrees), arcminute angular resolution and a few millicrab sensitivity

IGR J18245-2452

IGR J18245-2452: a new hard X-ray transient discovered by INTEGRAL

ATel #4925; *D. Eckert (ISDC, Switzerland), M. Del Santo, A. Bazzano (INAF/IAPS Rome, Italy), K. Watanabe (FGCU, USA), A. Paizis (INAF-Milano, Italy), E. Bozzo, C. Ferrigno (ISDC, Switzerland), I. Caballero (CEA, France), L Sidoli (INAF-IASF Milano, Italy), L. Kuiper (SRON, Netherlands)*
*on **29 Mar 2013; 11:18 UT***
Distributed as an Instant Email Notice Transients
Credential Certification: E. Bozzo (enrico.bozzo@unige.ch)

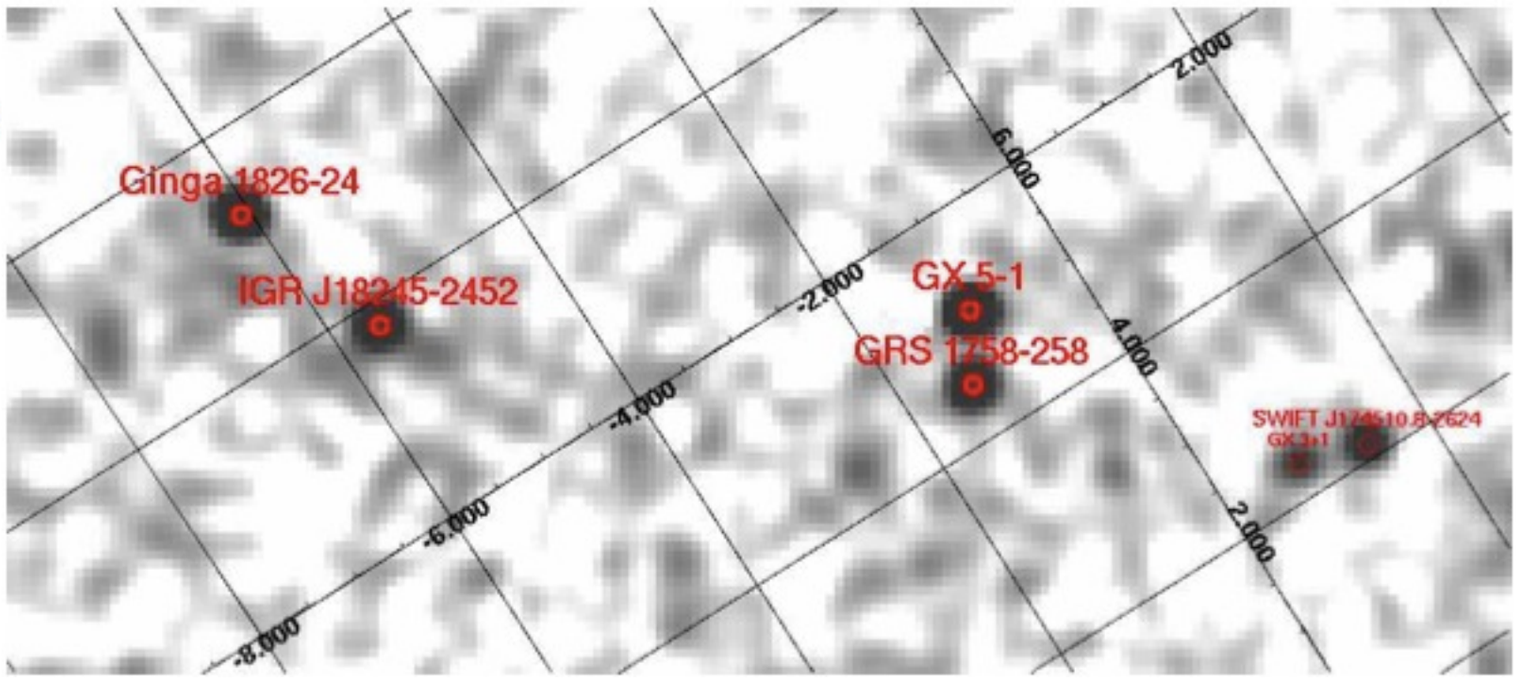
Subjects: X-ray, Gamma Ray, Request for Observations, Black Hole, Neutron Star, Transient

Referred to by ATel #: 4927, 4929, 4934, 4959, 4960, 4961, 4964, 4981, 5003

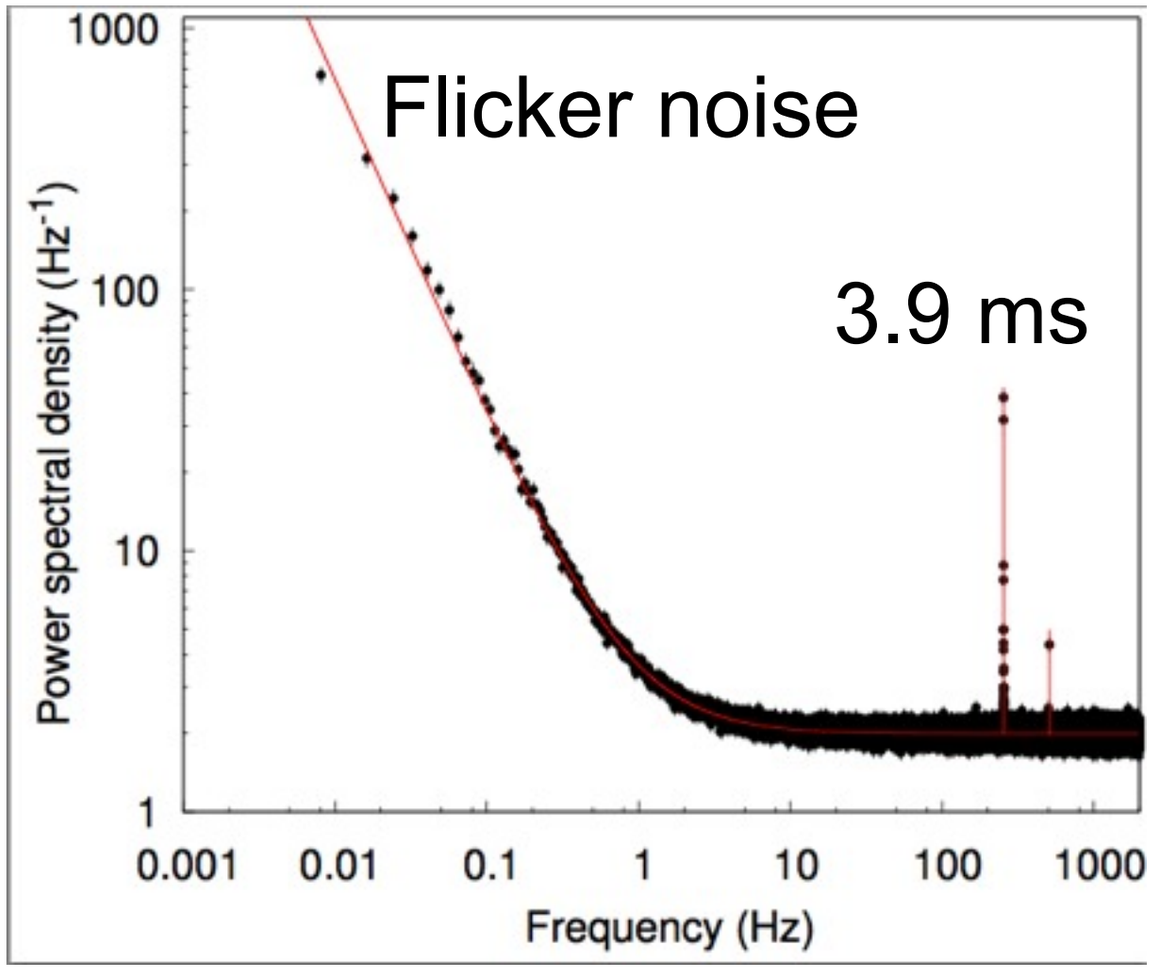
During the observations of the Galactic Center performed on 2013 March 28 from 2:56 to 17:38 (UTC), the hard X-ray imager IBIS on-board INTEGRAL detected a new transient source, dubbed IGR J18245-2452, at:
RA=276.1383
DEC=-24.8793
with an associated uncertainty of 1.4 arcmin (all uncertainties

- We triggered Swift, XMM-Newton, Chandra,INTEGRAL, ATCA follow-up observations
- Others have looked into the HST archive

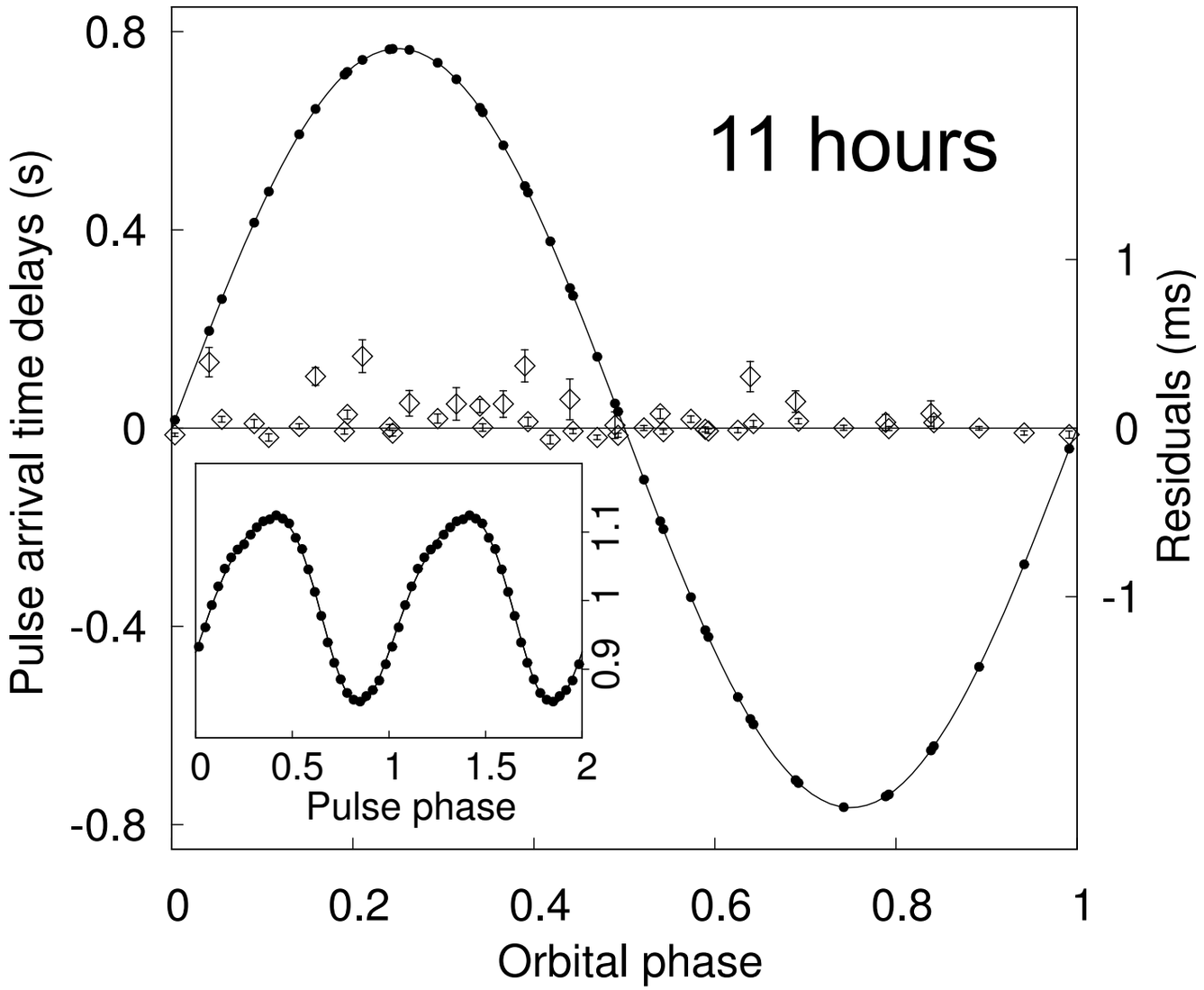
- Discovered during the quick-look of INTEGRAL data
- Located in the globular cluster M 28



It is the 15th accreting millisecond pulsar



30 ks + 70 ks XMM-Newton TOOs



Papitto et al. (Nature 501, 517-520, 2013)

Unique !!

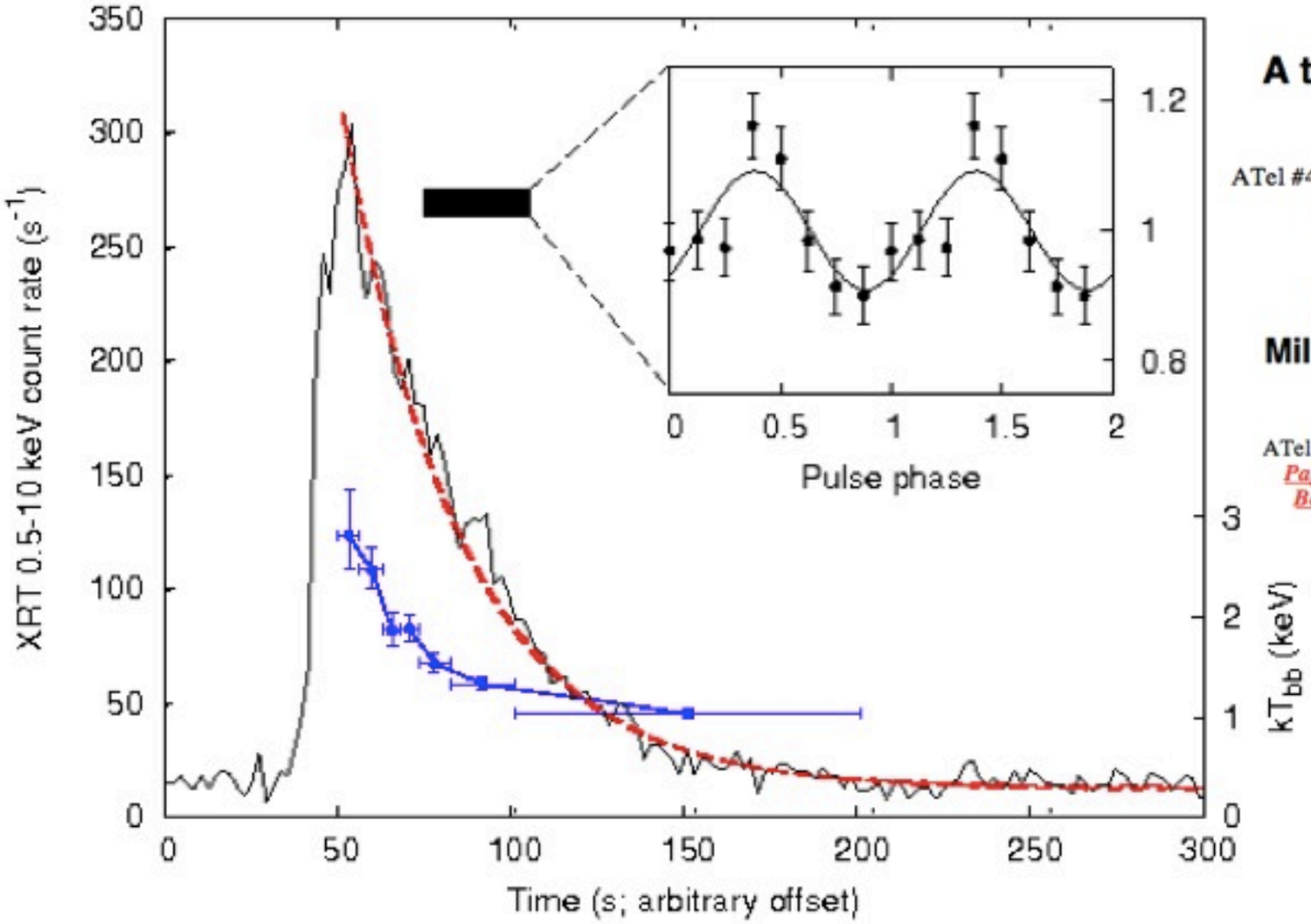
Table 1: Spin and orbital parameters of IGR J18245–2452 and PSR J1824–2452I.

Parameter	IGR J18245–2452	PSR J1824–2452I
Right Ascension (J2000)	$18^h\ 24^m\ 32.53(4)^s$	
Declination (J2000)	$-24°\ 52'\ 08.6(6)''$	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852641(2)	3.93185(1)
Spin period derivative	$< 2 \times 10^{-17}$	
RMS of pulse time delays (ms)	0.1	
Orbital period (hr)	11.025781(2)	11.0258(2)
Projected semi-major axis (lt-s)	0.76591(1)	0.7658(1)
Epoch of zero mean anomaly (MJD)	56395.216889(5)	
Eccentricity	$\leq 1 \times 10^{-4}$	
Pulsar mass function ($M_\odot$)	$2.2831(1) \times 10^{-3}$	$2.282(1) \times 10^{-3}$
Minimum companion mass ($M_\odot$)	0.174(3)	0.17(1)
Median companion mass ($M_\odot$)	0.204(3)	0.20(1)

- Red back: Radio signal is weak and characterized by irregular “eclispes”, due to intra-binary plasma.
- SAX J1808.4-3658 showed only indirect signs of radio activation during X-ray quiescence

Papitto et al. (Nature 501, 517-520, 2013)

Thermonuclear burst



A type-I X-ray burst detected by Swift/XRT from the direction of IGR J18245-2452

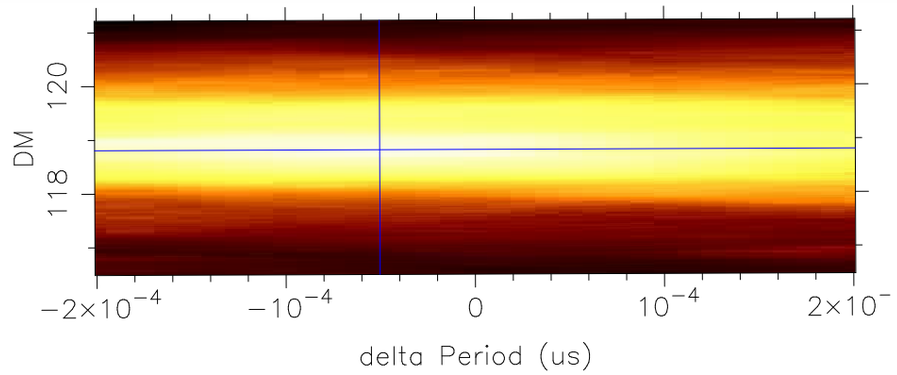
ATel #4959; *A. Papitto (IEEC-CSIC Barcelona), E. Bozzo, C. Ferrigno, L. Pavan (ISDC Geneve), P. Romano (INAF-IASF Palermo), S. Campana (INAF-OAB)*
on 8 Apr 2013; 14:09 UT

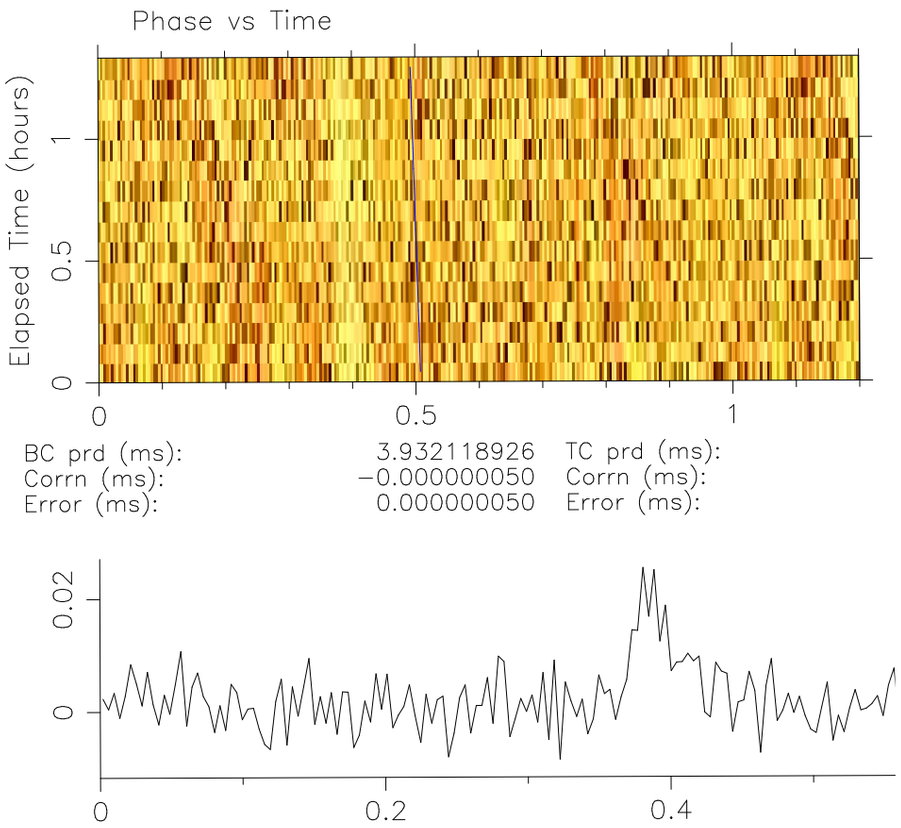
Coherent Pulsations and Burst Oscillations in the Millisecond Pulsar IGR J18245-2452/PSR J1824-2452I in M28

ATel #5086; *A. Riggio, L. Burderi (DSF-UNICA), T. Di Salvo, A. D'Aí (DiFC-UNIPA), A. Papitto (IEEC-CSIC), R. Iaria, N. Robba (DiFC-UNIPA), A. Sanna (DSF-UNICA), E. Bozzo, C. Ferrigno (ISDC-Geneve), N. Rea (IEEC-CSIC), L. Pavan (ISDC-Geneve)*
on 24 May 2013; 21:42 UT

- Only two detected during the monitoring campaign.
- Burst oscillation at 3.9 ms, phase locked with spin modulation
- It is surely an accreting millisecond pulsar !

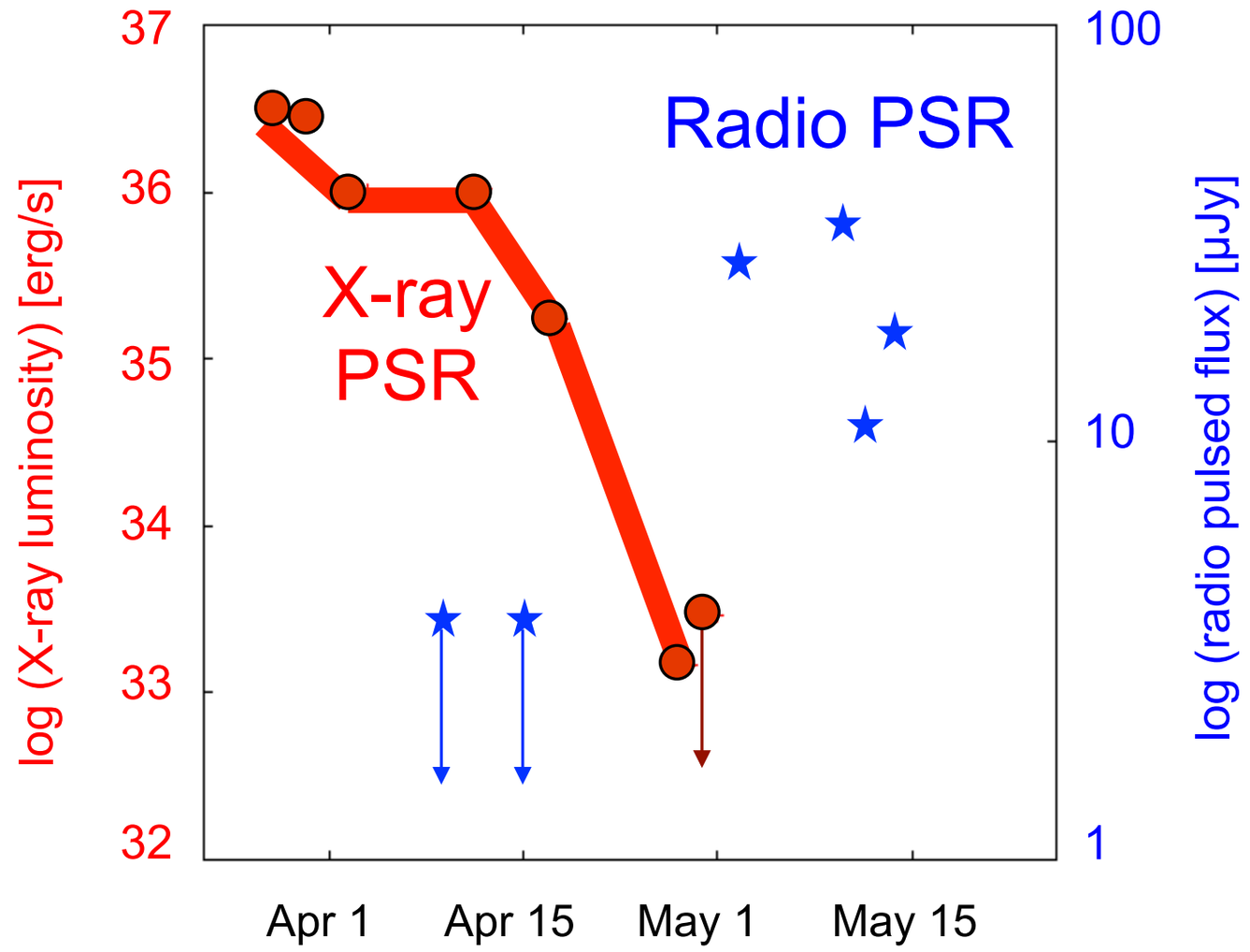
Radio loud again !





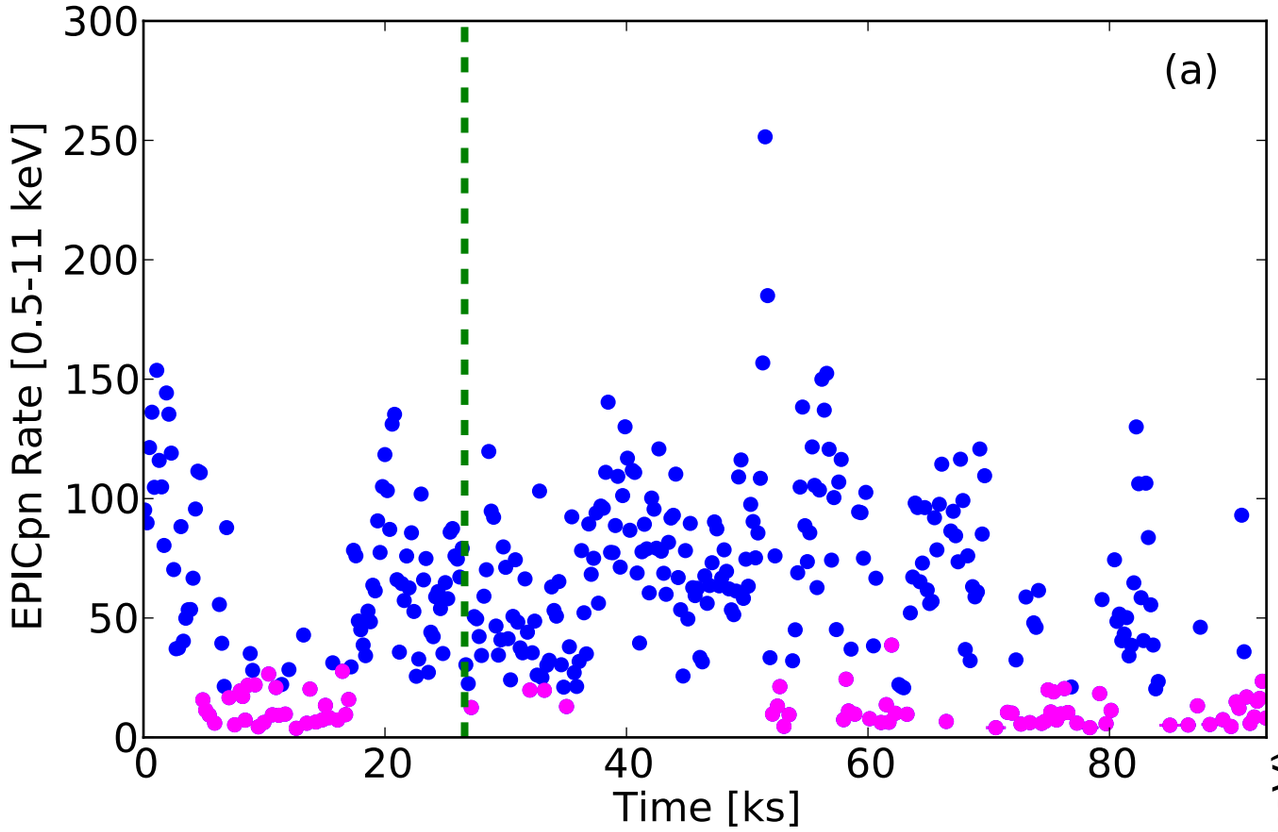
The transient low-mass X-ray binary IGR J18245-2452 is again active as a radio pulsar

ATel #5069; *A. Papitto (IEEC-CSIC), J. W. T. Hessels (ASTRON/UvA), M. Burgay (INAF-OAC), S. Ransom (NRAO), N. Rea (IEEC-CSIC), A. Possenti (INAF-OAC), I. Stairs (UBC), C. Ferrigno (ISDC/U. Geneva), E. Bozzo (ISDC/U. Geneva) on behalf of a larger collaboration*



- Only a few days after the last X-ray detection !

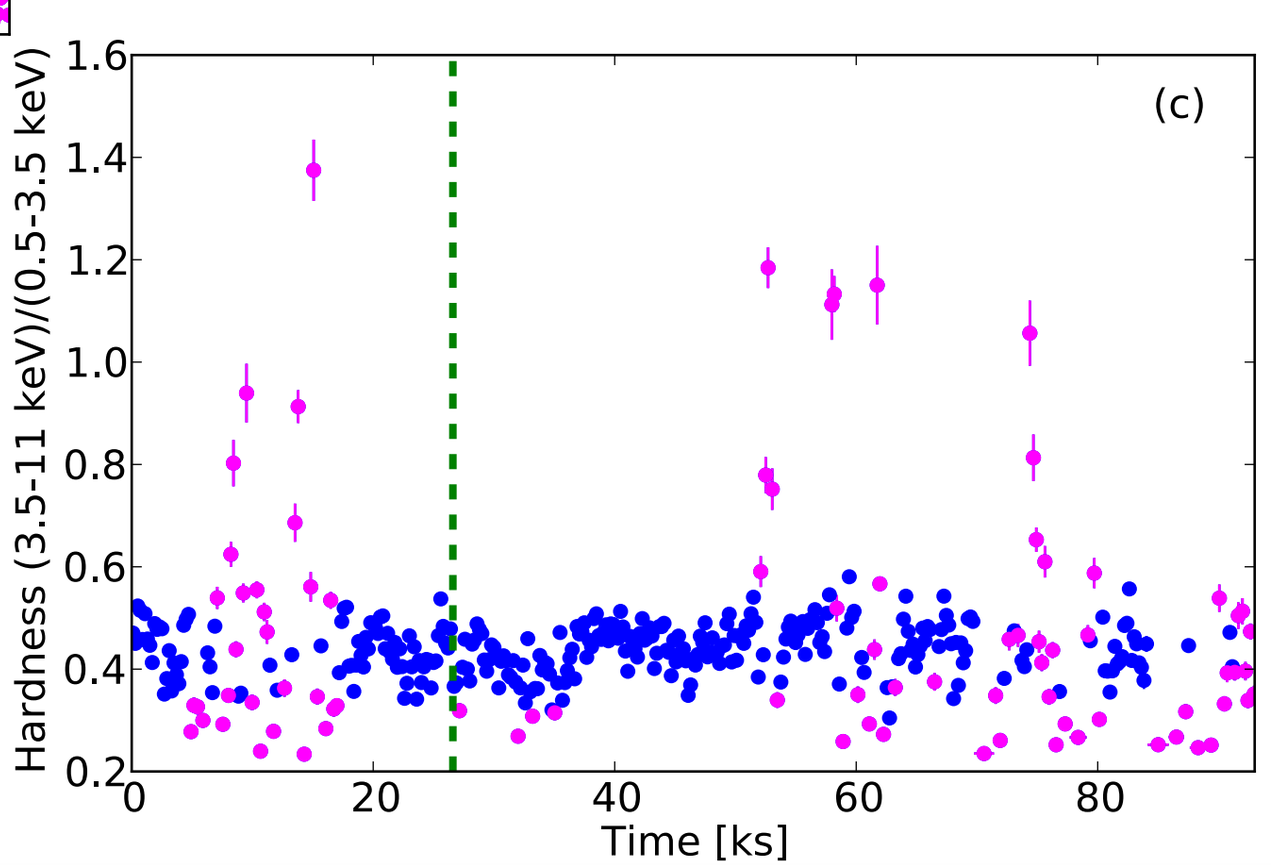
XMM-Newton light curve



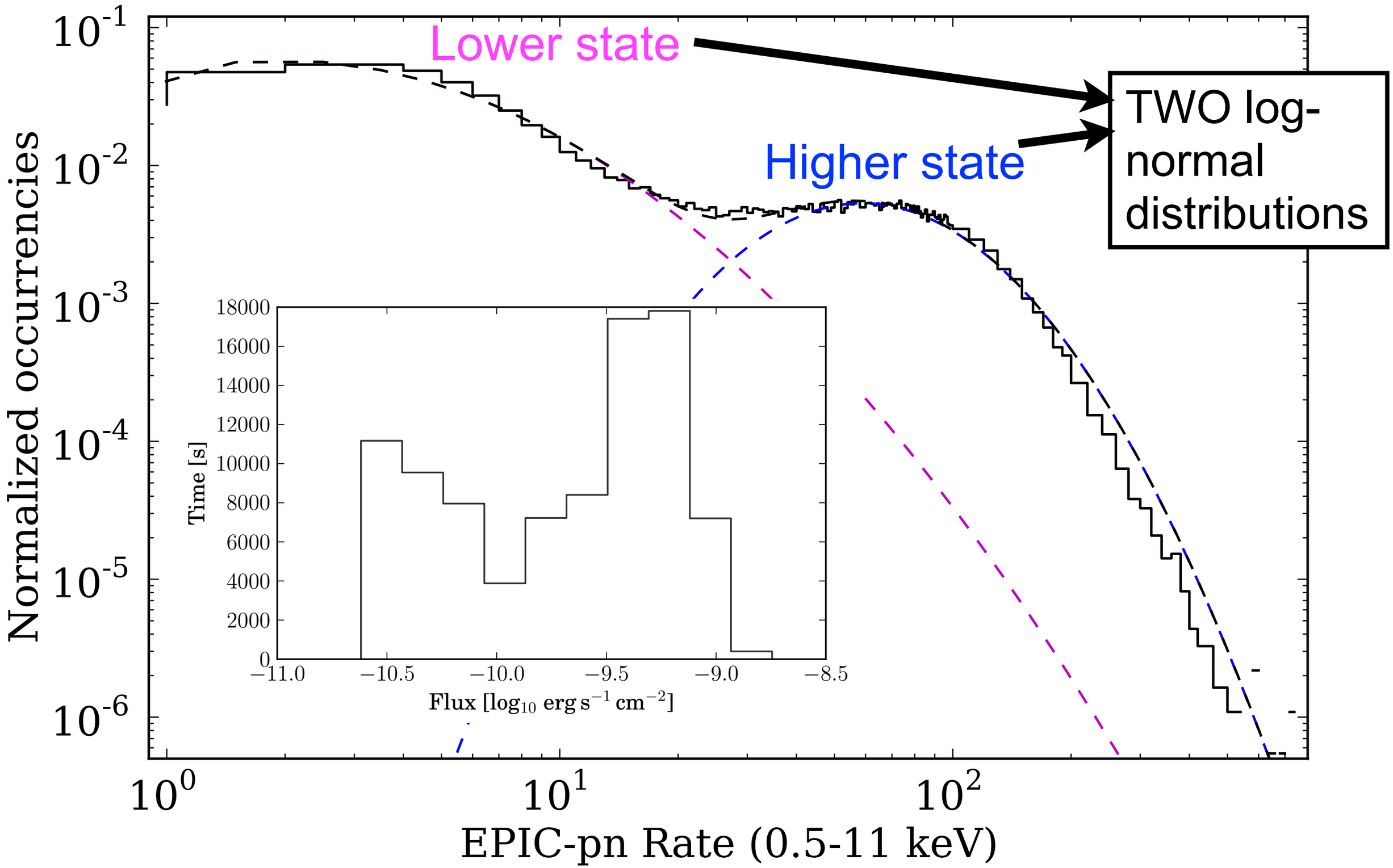
- Very interesting variability, unique among AMSP.
- Episodes of enhanced hardness at low flux
- No orbital dependency.

$$\frac{\text{Hard 3.5-10 keV}}{\text{Soft 0.5-3.5 keV}}$$

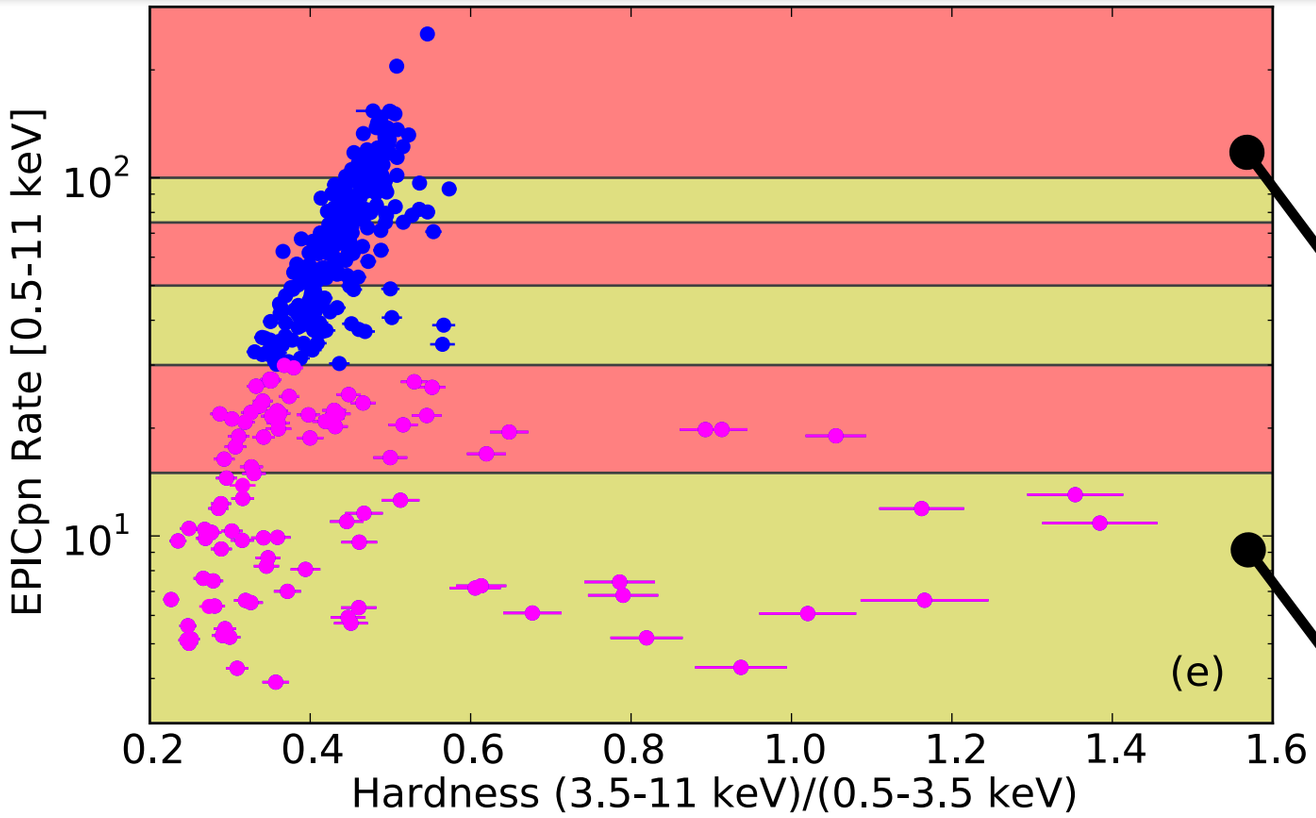
Ferrigno et al. A&A (2014)

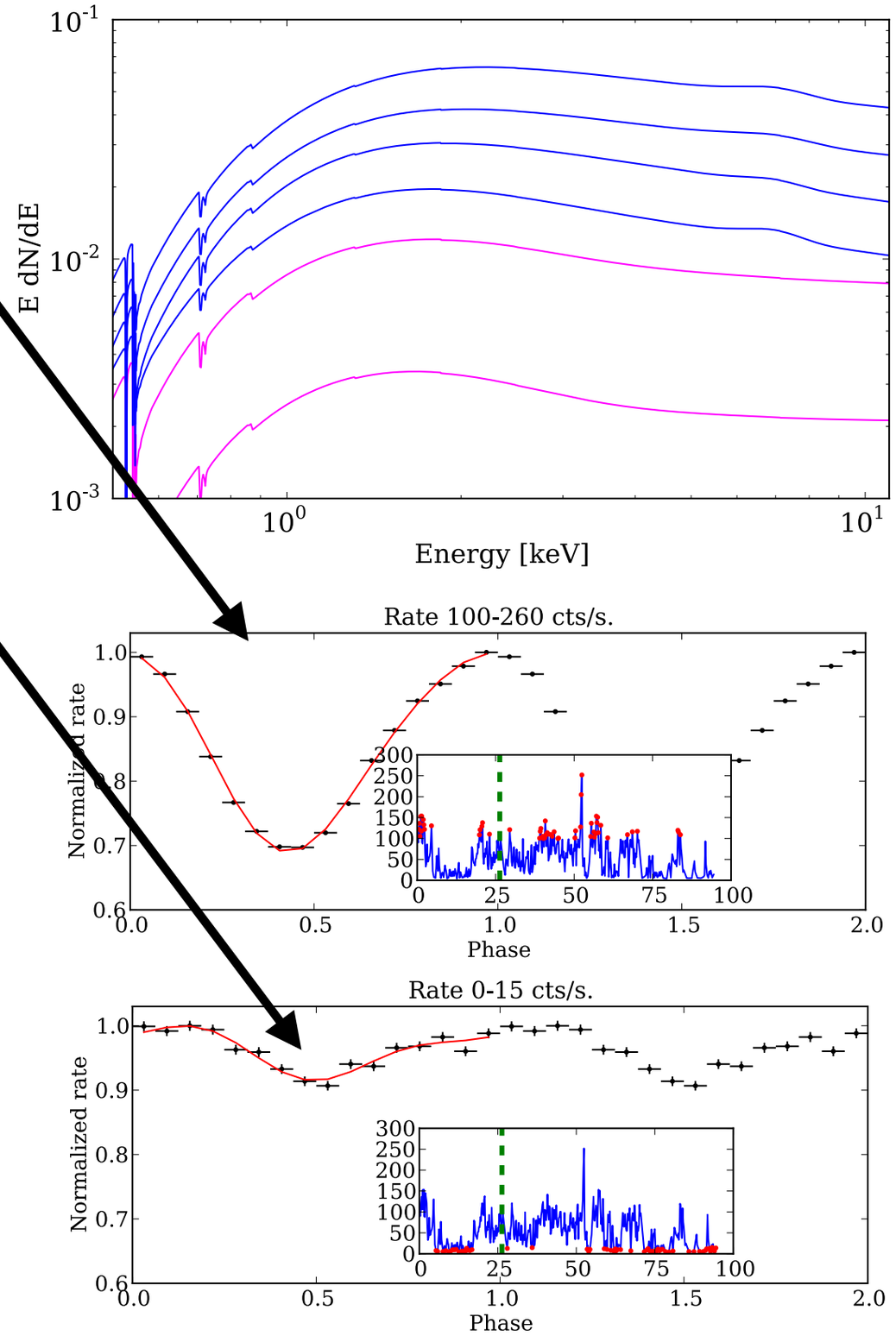


Two accretion states



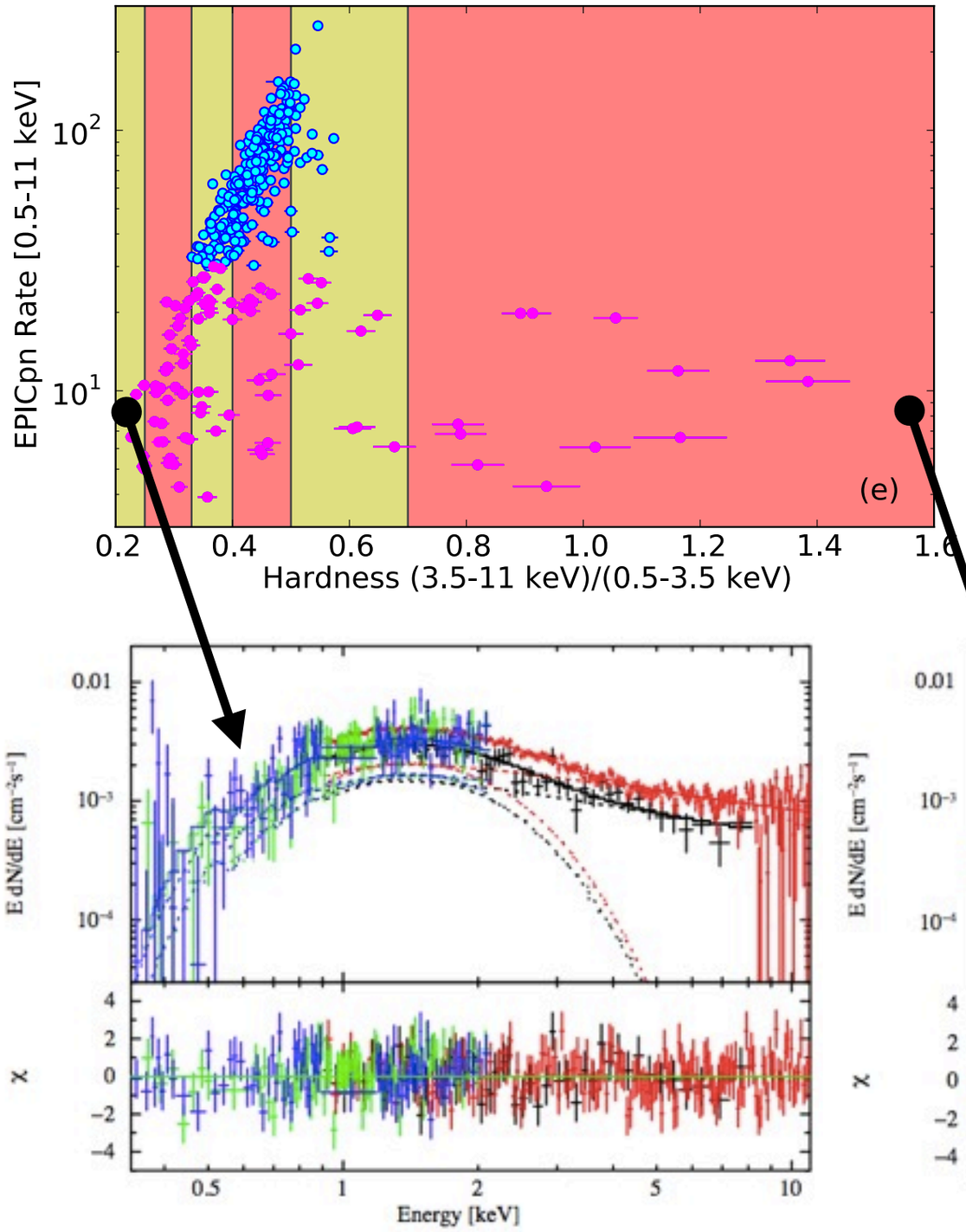
Luminosity dependence





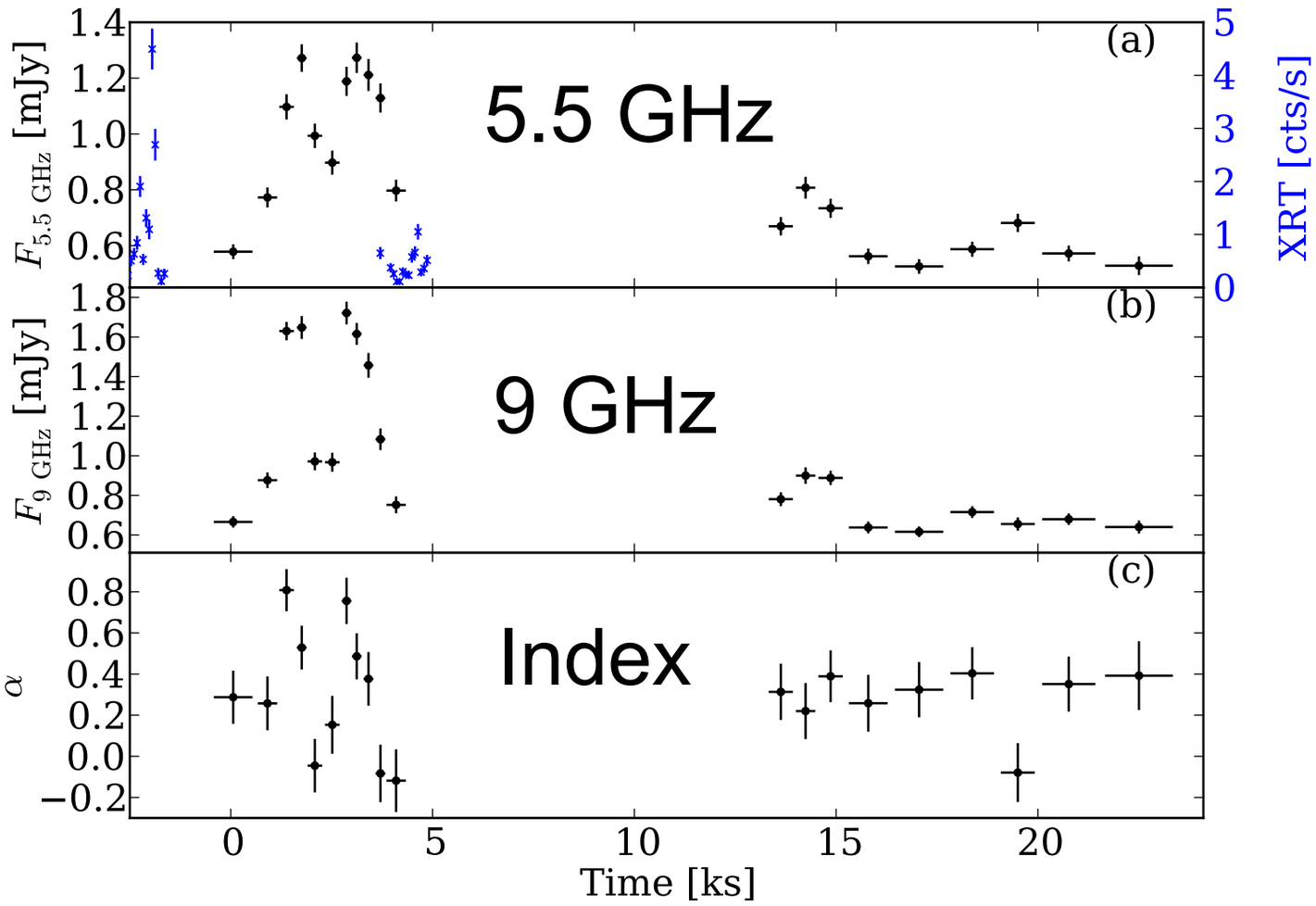
- Broad Iron line and Comptonization spectrum
- Sinusoidal profile with high pulsed fraction
- Black-body and hard Compton tail
- Low pulsed fraction and two harmonics

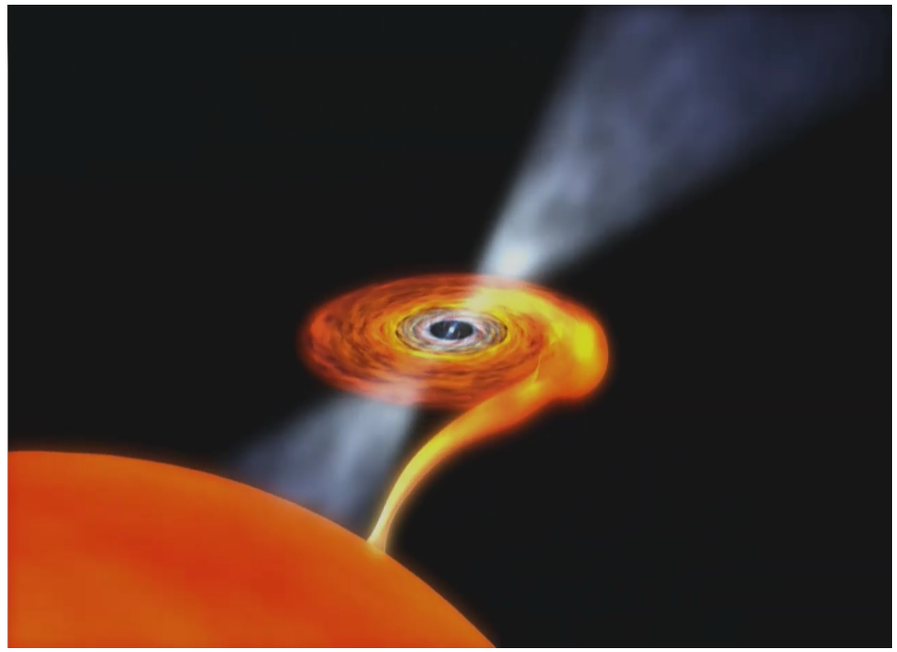
Hardness dependency



- From black-body and Comptonization to partially covered power-law
- Is this a signature of ejection episodes?

ATCA radio GHz variability

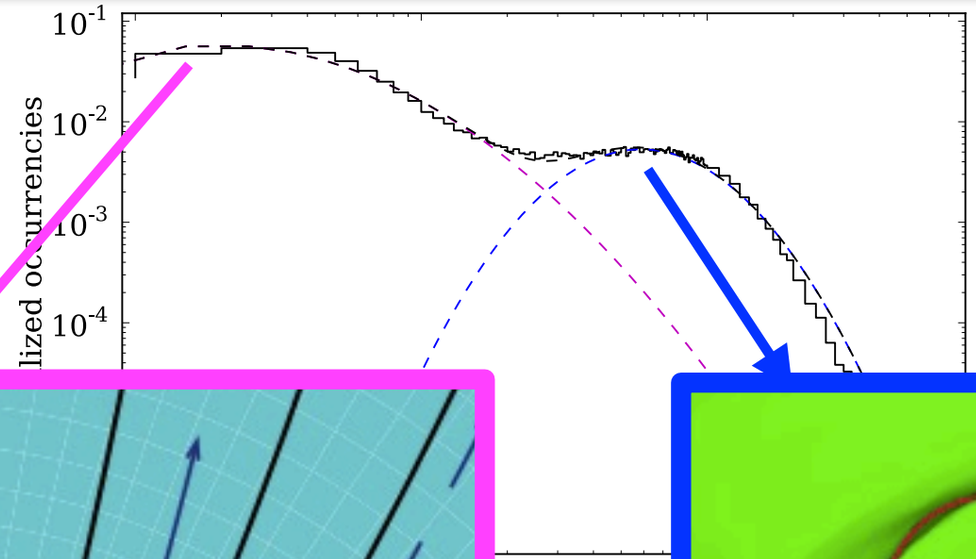




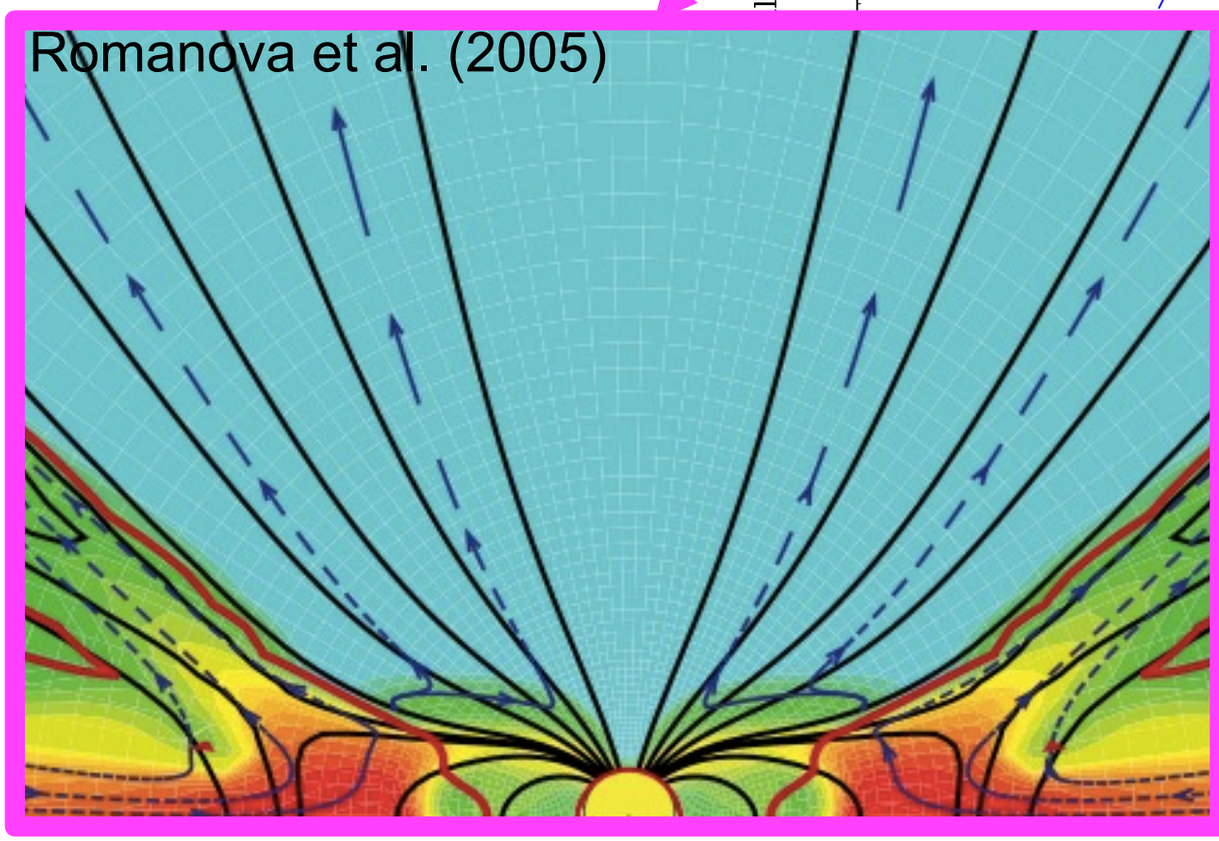
- Optically thick variable radio free-free emission, signature of outflows.
- Quasi contemporary X-ray Swift monitoring is consistent with low source state.

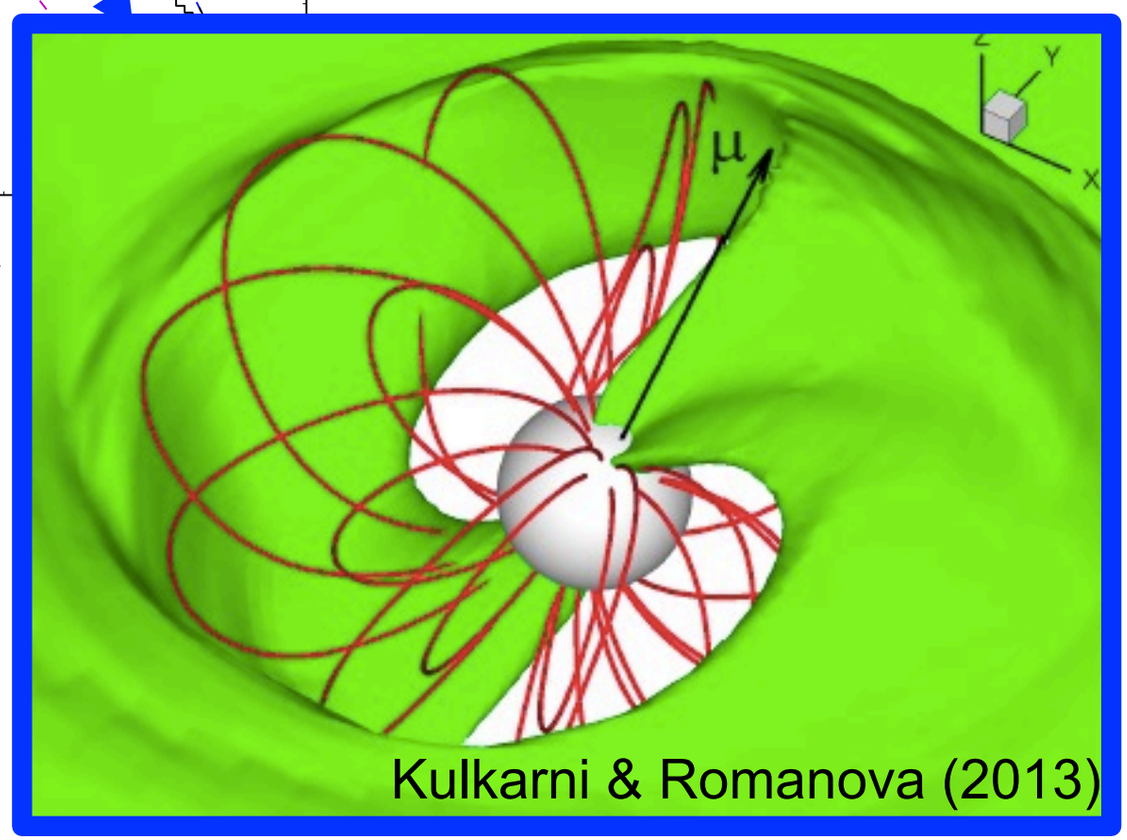
Interpretation

$L_x \sim 10^{35}$ erg/s



$L_x \sim 10^{36}$ erg/s

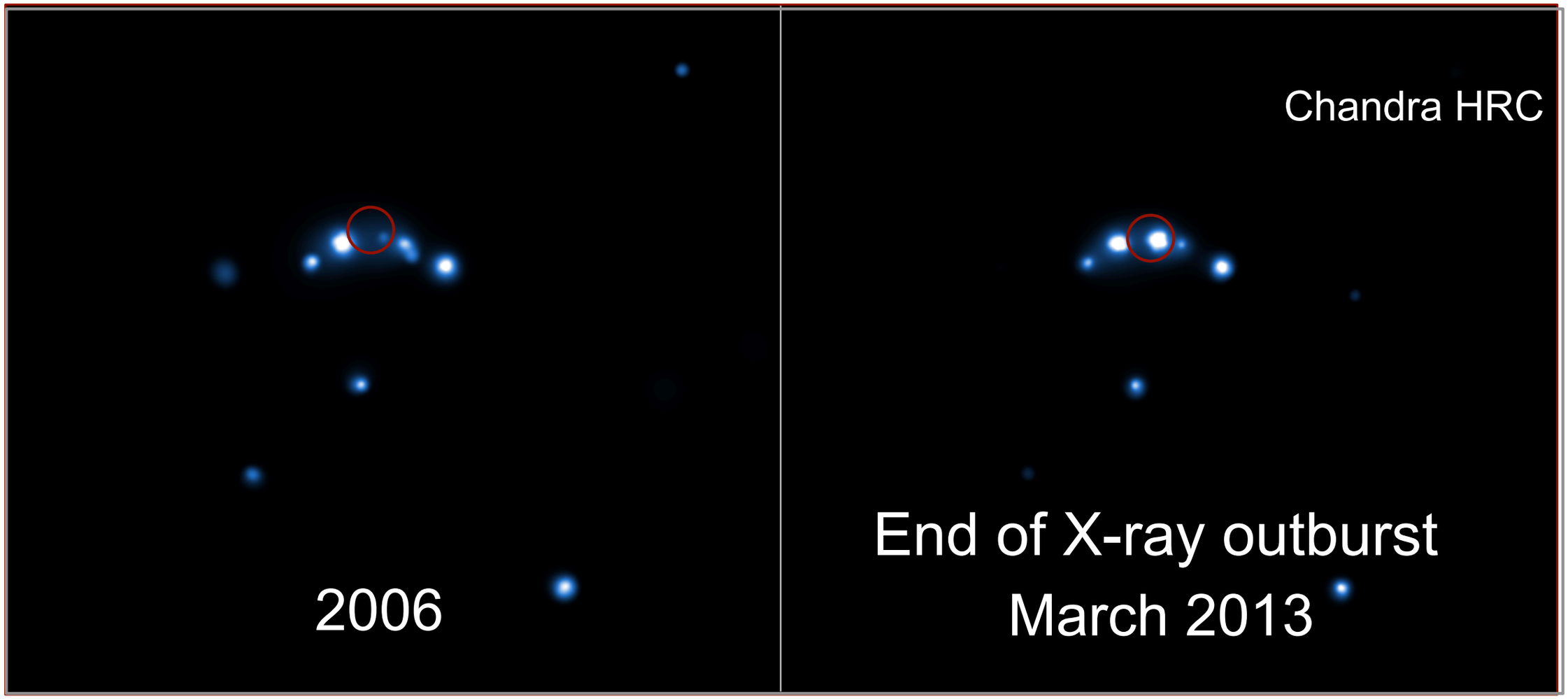




- Low state: propeller accretion and ejection episodes
- High state: variable accretion along field lines

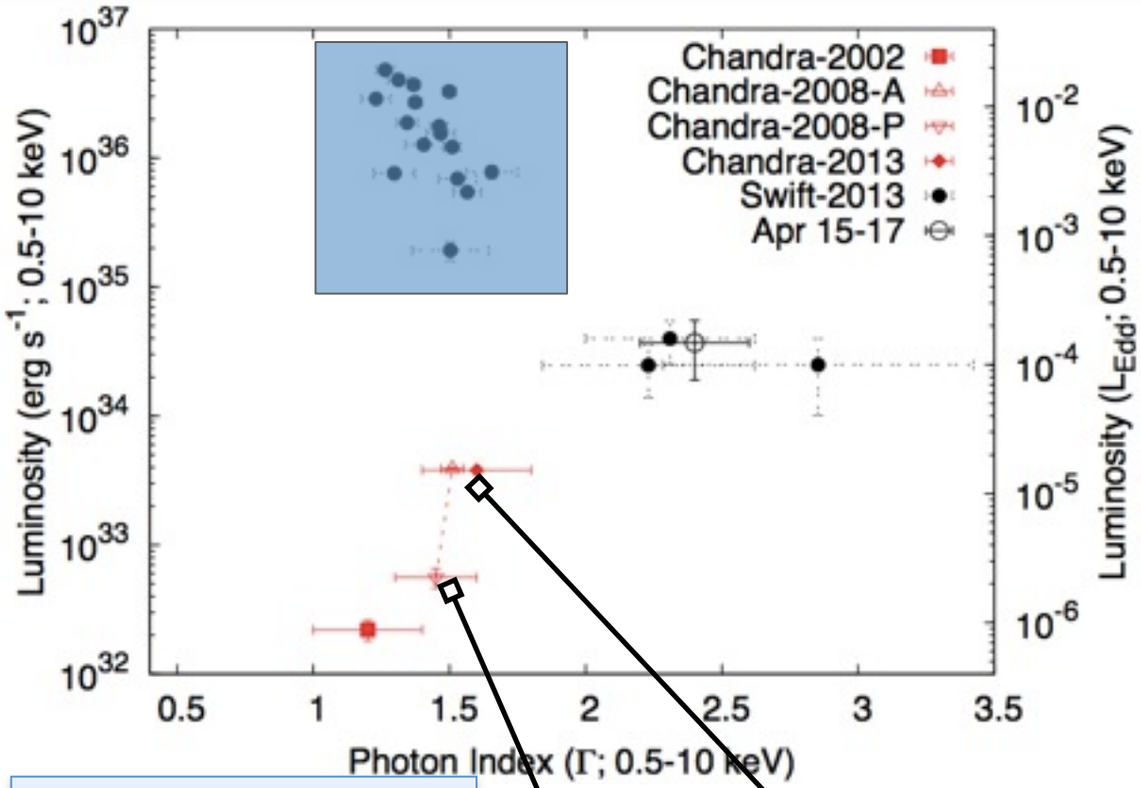
Magnetosphere at the corotation radius

Active in the past

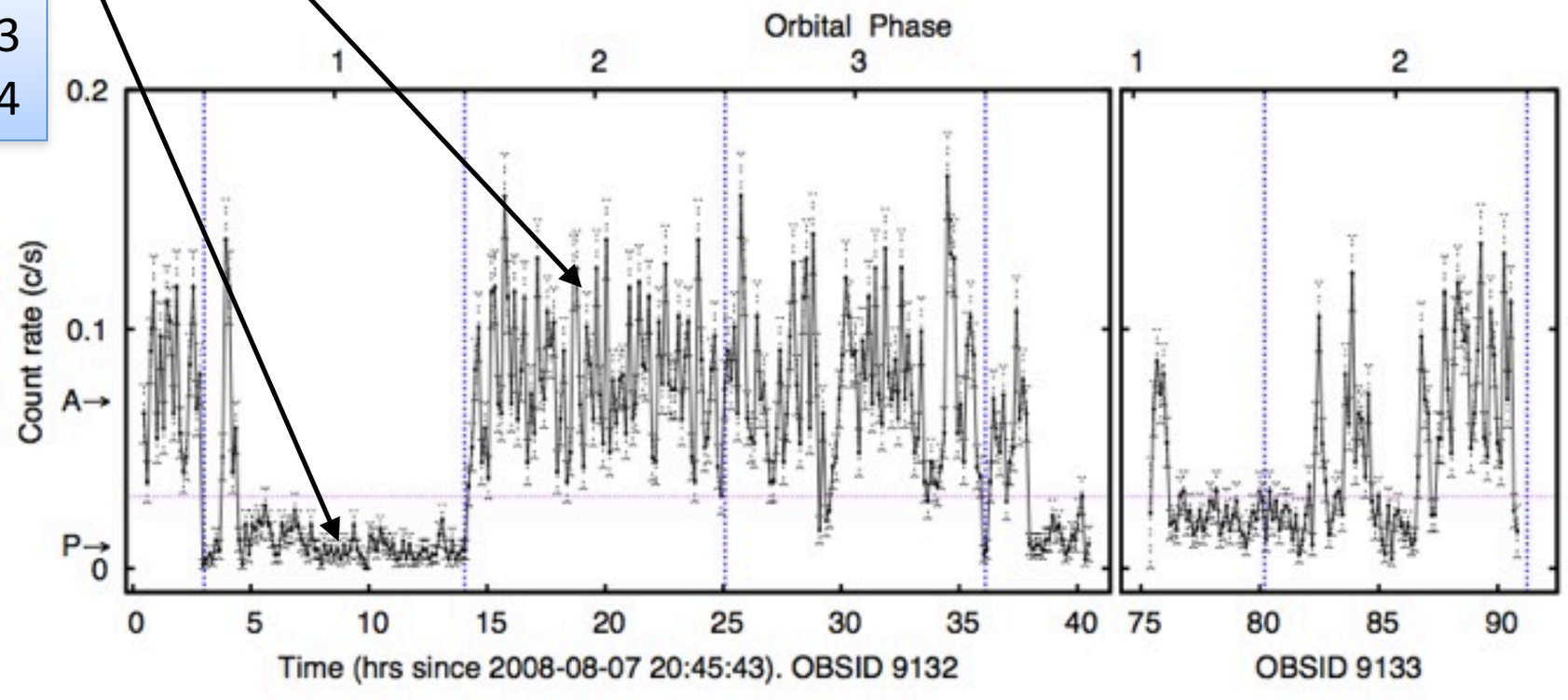


- Archival observations showed activity at intermediate level between quiescence and bright X-ray outburst

A variable intermediate state



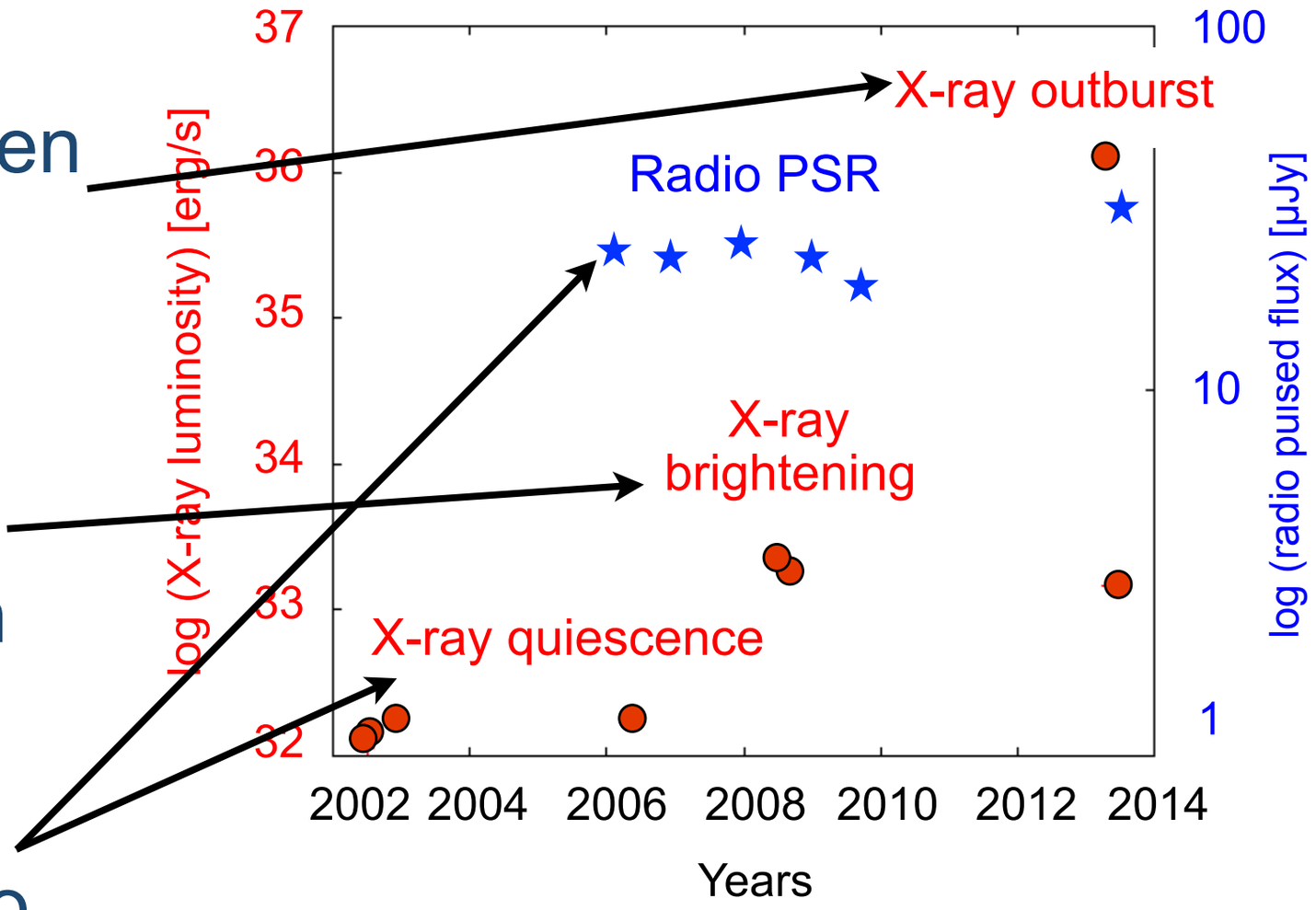
Papitto et al. 2013
Linares et al. 2014



- X-ray propeller phase
- X-ray quiescence and hidden radio activity
- Magnetosphere in and out of the light cylinder

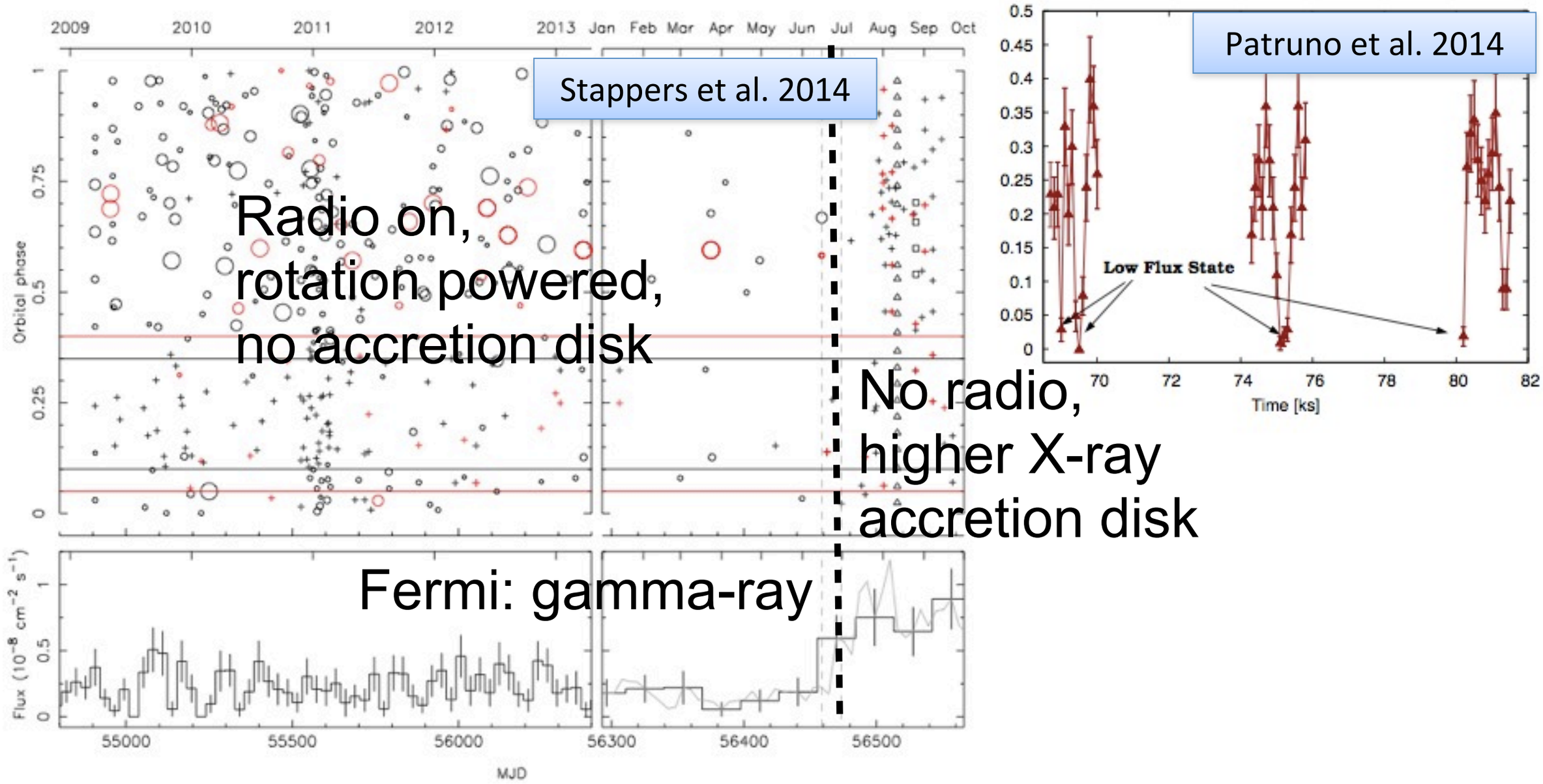
A decade of observations

- Monitored as part of the globular cluster M 28: it is at 5.5 kpc.
- One bright accretion driven outburst. Strong spectral and timing variability.
- Intermediate accretion events: X-ray & optical brightening. Mode switch variability.
- Faint radio pulsar with irregularly eclipses due to outflows.



2013: the year of transitional pulsars

PSR J1023+0038

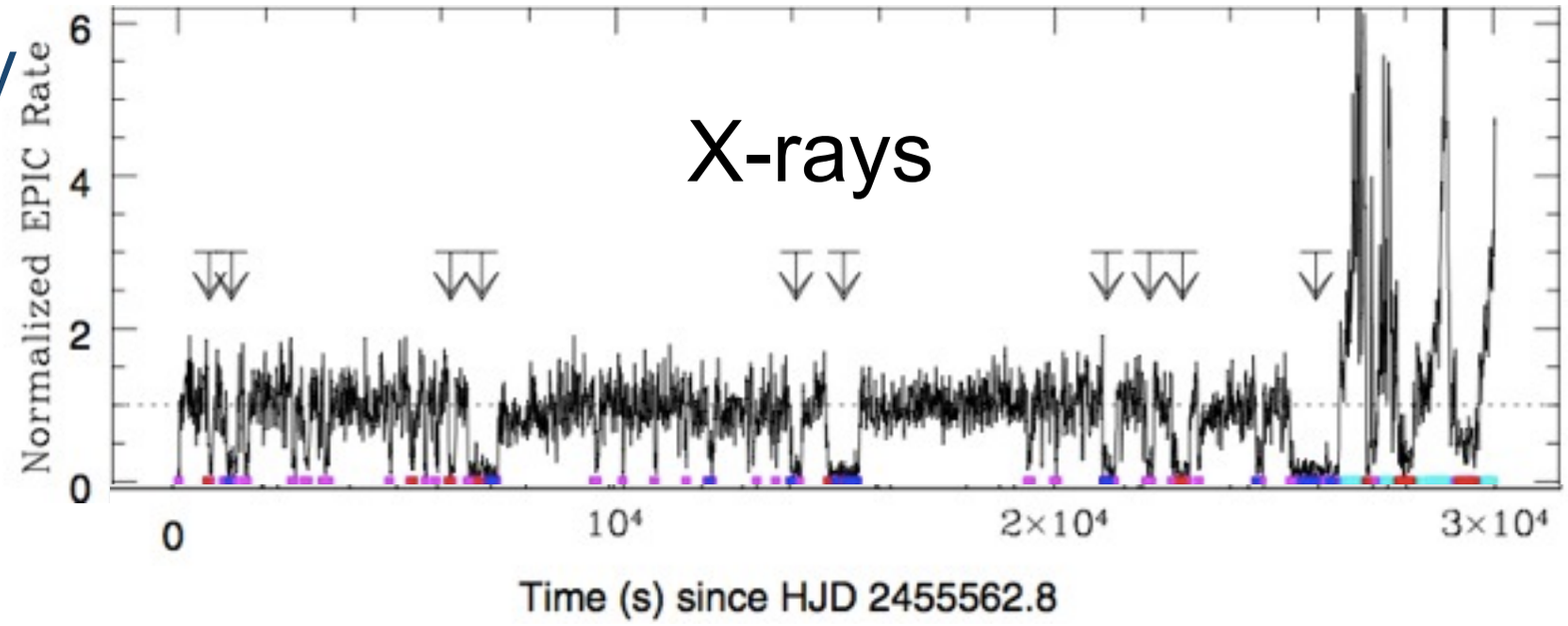


- In late 2013, stop radio and begin higher X-ray plus gamma-ray above the pulsar phase ! Still an active radio pulsar?

XSS J12270-4859

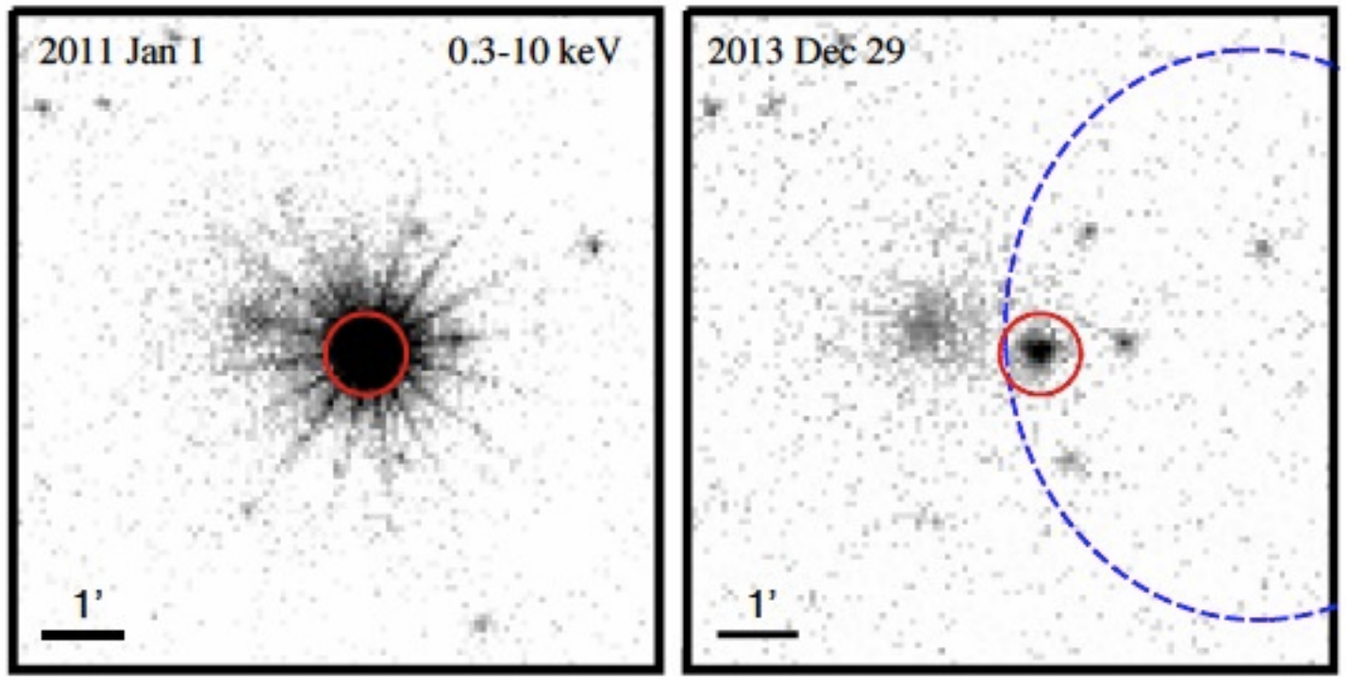
- Before 2013: Gamma-ray loud X-ray low-mass binary pulsar.
- Bimodal switches.

De Martino et al. 2010,2013



- In 2013, X-ray dim with orbital variability: intra-binary shocks.
- gamma-ray dim.
- Switched on as a millisecond radio pulsar.
- Accretion disk disappeared.

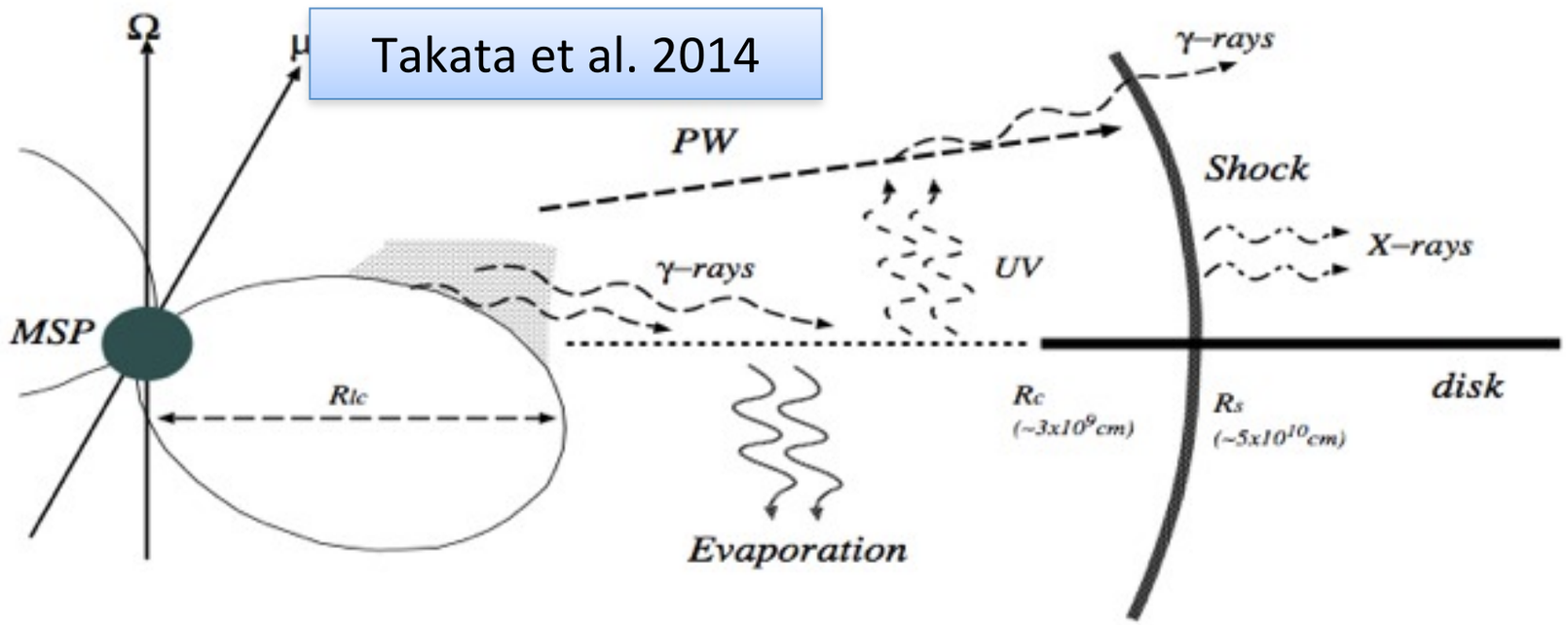
Papitto et al. 2014, Bogdnanov et al. 2014, Roy et la. 2014, Bassa et al. 2014



The new “class” of gamma-ray LMXB

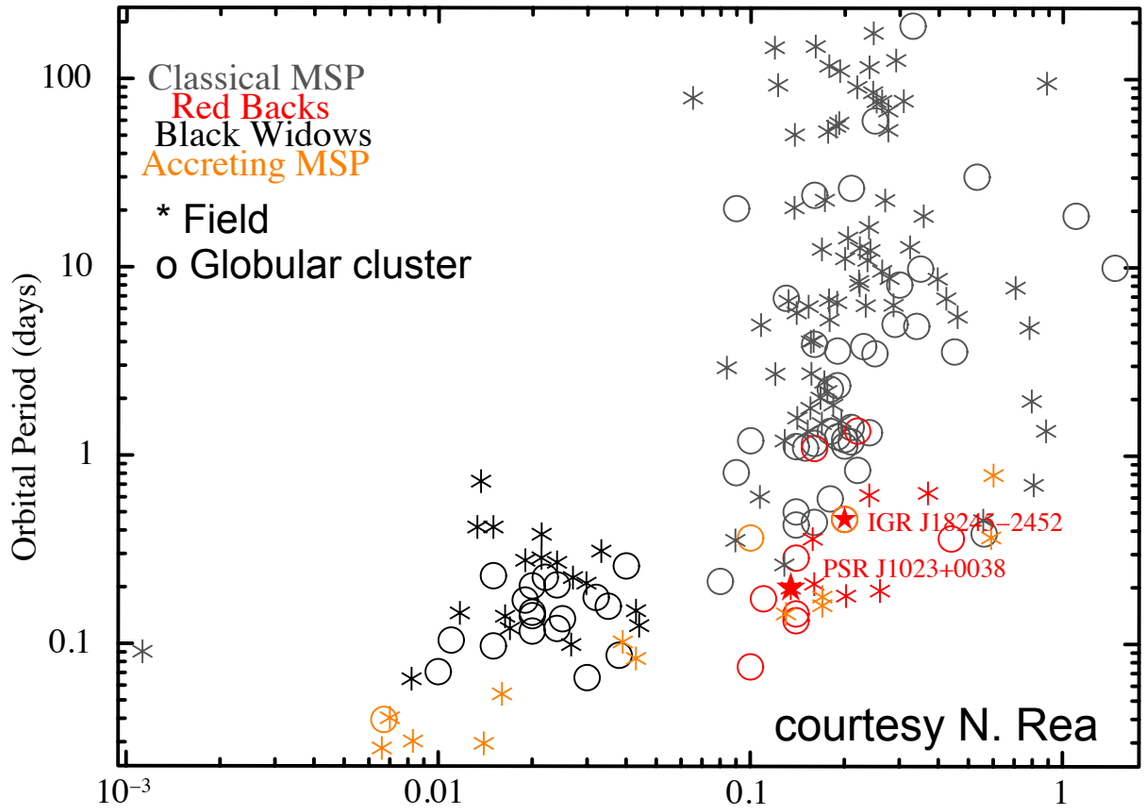
- These transitional systems are the first low-mass X-ray binaries which are gamma-ray loud, but only when they develop an accretion disk and are X-ray variable.

- Proposed to be due to the interaction of the pulsar wind with the surrounding accretion disk (variability not explained !).
- Or very strong outflows/jets.



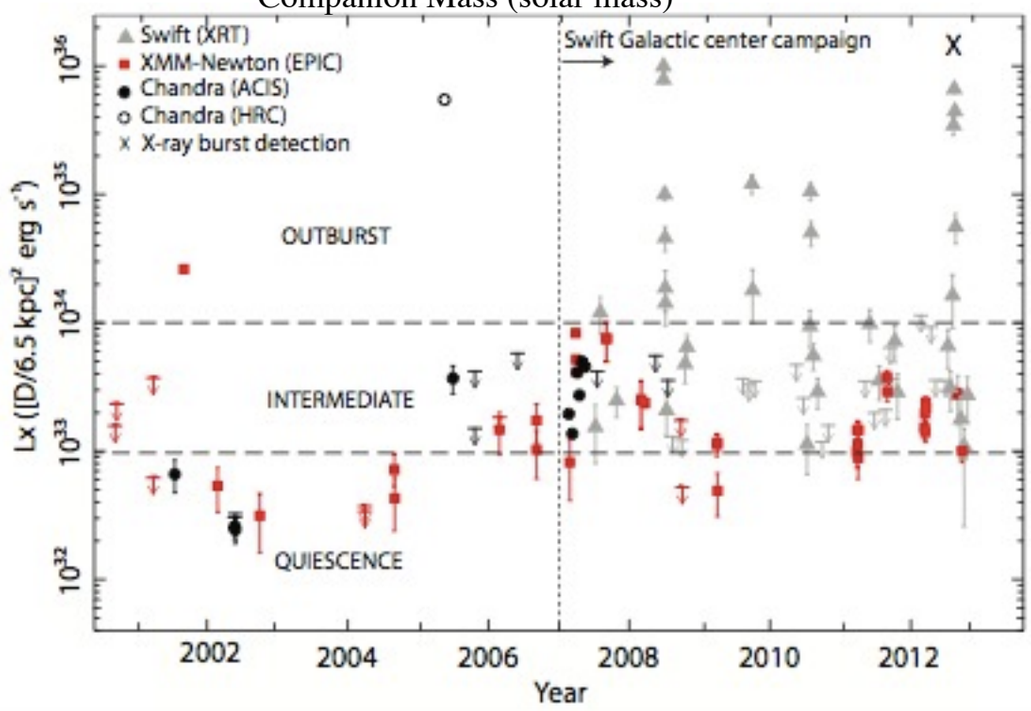
Search for other transitional systems

- Red backs: radio pulsars eclipsing at certain phases due to ablated material from a non degenerate companion !



- Low mass X-ray binaries with variable activity: XMM J174457–2850.3 ?

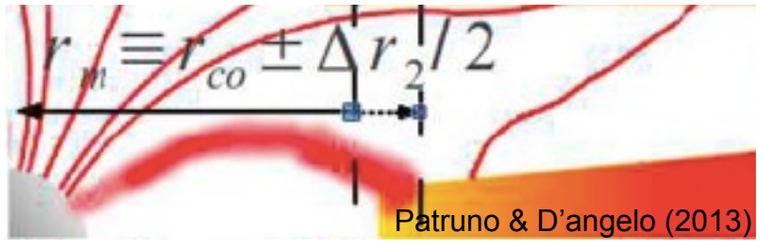
Degenaar et al.. 2014



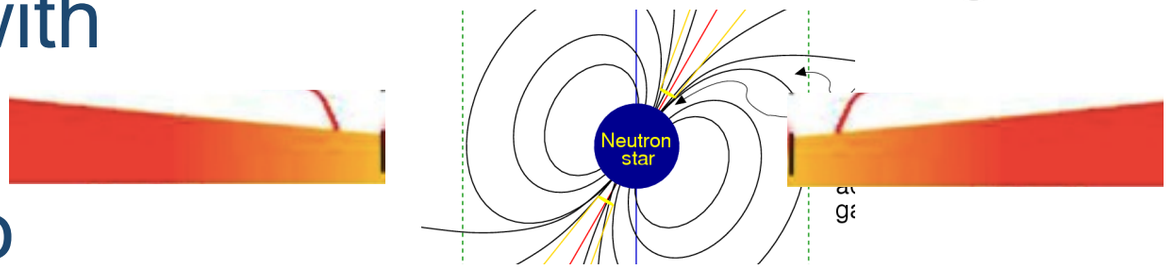
Conclusions

- IGR J18245-2452 is the first system swinging from radio to X-ray accretion and vice versa in time scales of days.
- Peculiar bimodal variability at high L_X interpreted as the switch from “pure” accretion to “propeller” accretion with outflows/jets.
- Low-luminosity variability similar to PSR J1023+0038 and XSS J12270-4859 interpreted as fast transitions from propeller accretion to buried radio emission or enshrouded radio pulsar.
- What is causing the these peculiar variabilities? Is it linked to their transitional nature ?

$L_x \sim 10^{35\text{-}36}$ erg/s



$L_x \sim 10^{33\text{-}34}$ erg/s



$L_x \sim 10^{32\text{-}33}$ erg/s