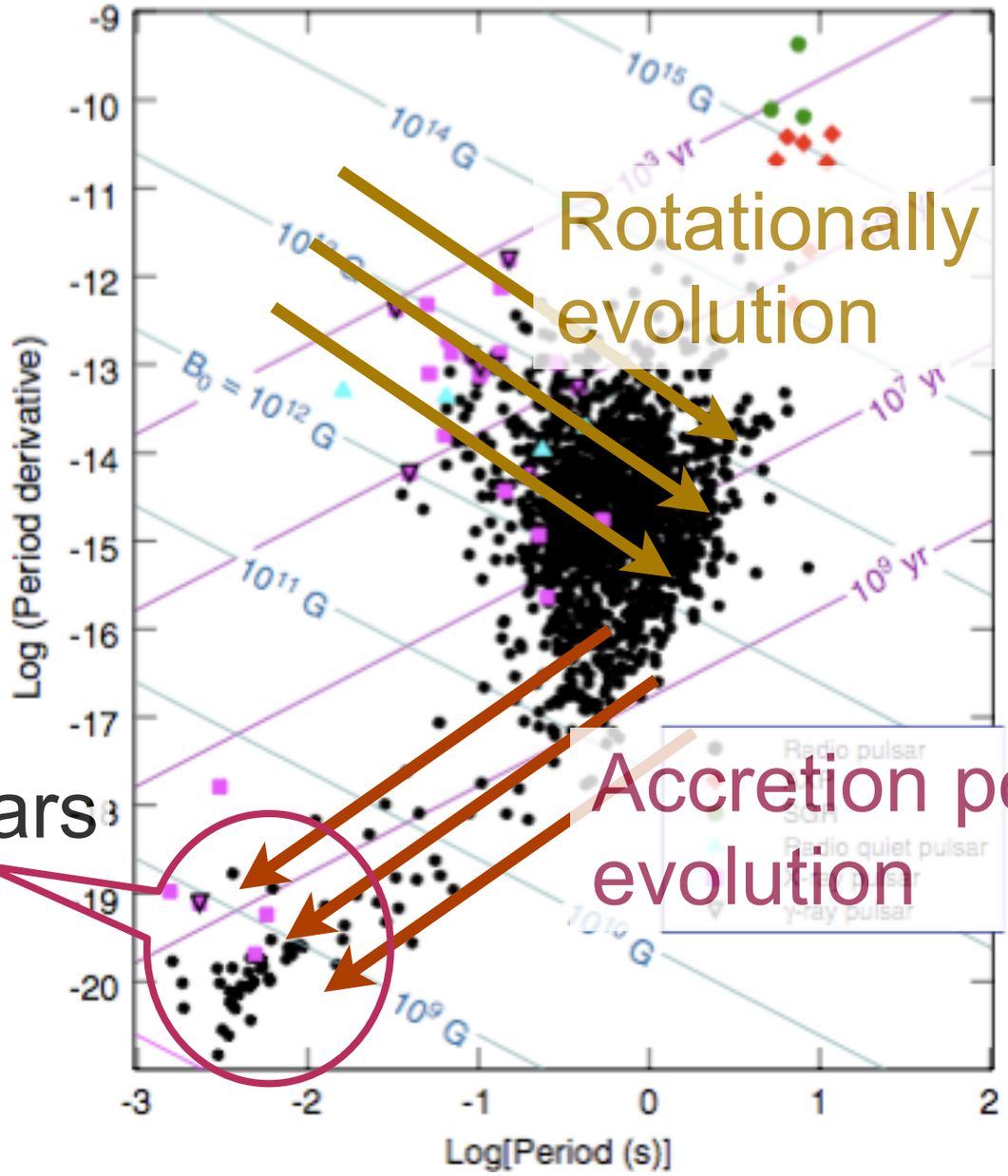
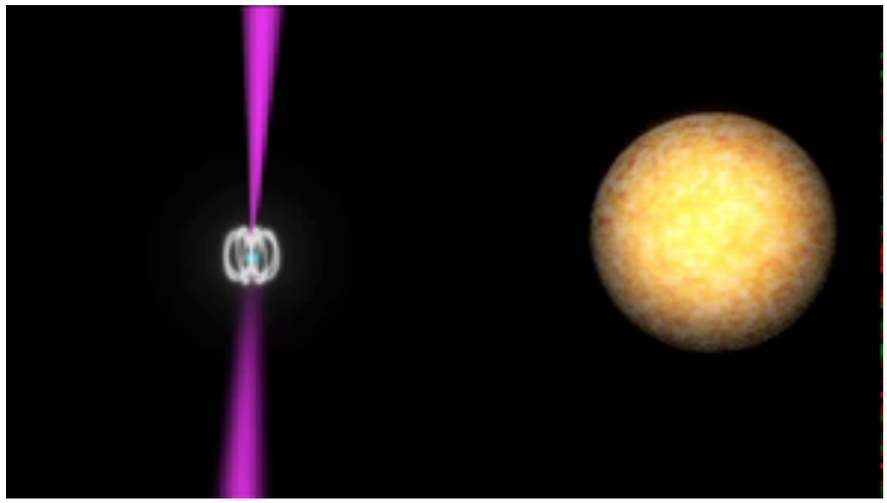
The peculiar X-ray variability of the transitional pulsar IGR J18245-2452

C. Ferrigno, A. Papitto, M. Romanova, E. Bozzo, N. Rea et al.

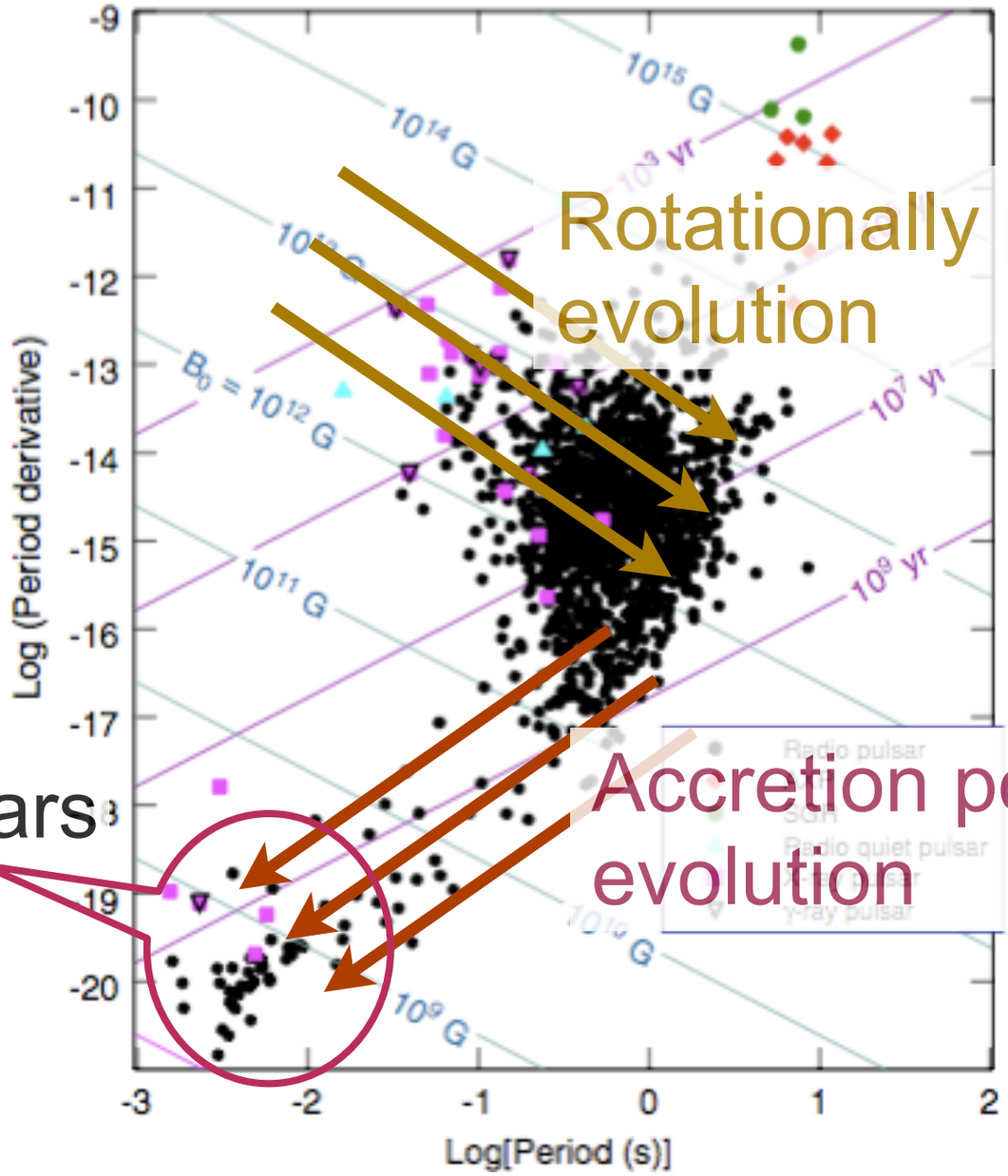
Evolution

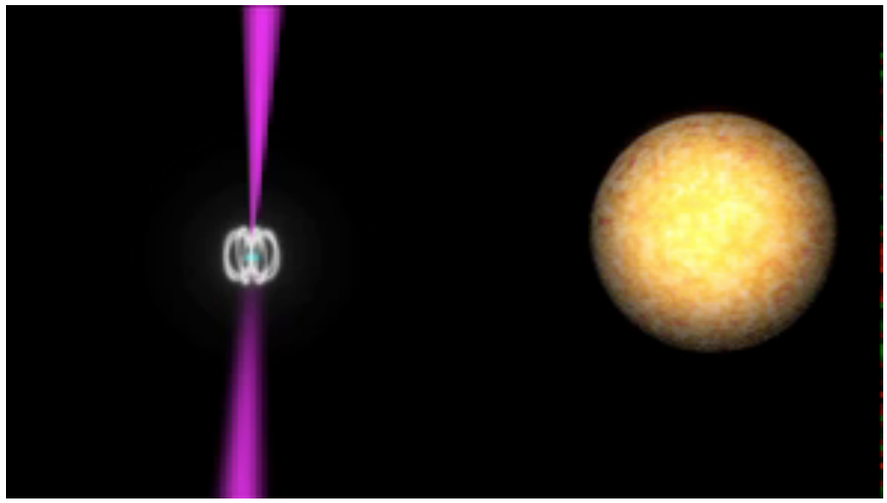




- Accretion of material brings angular momentum and spins-up the pulsar.

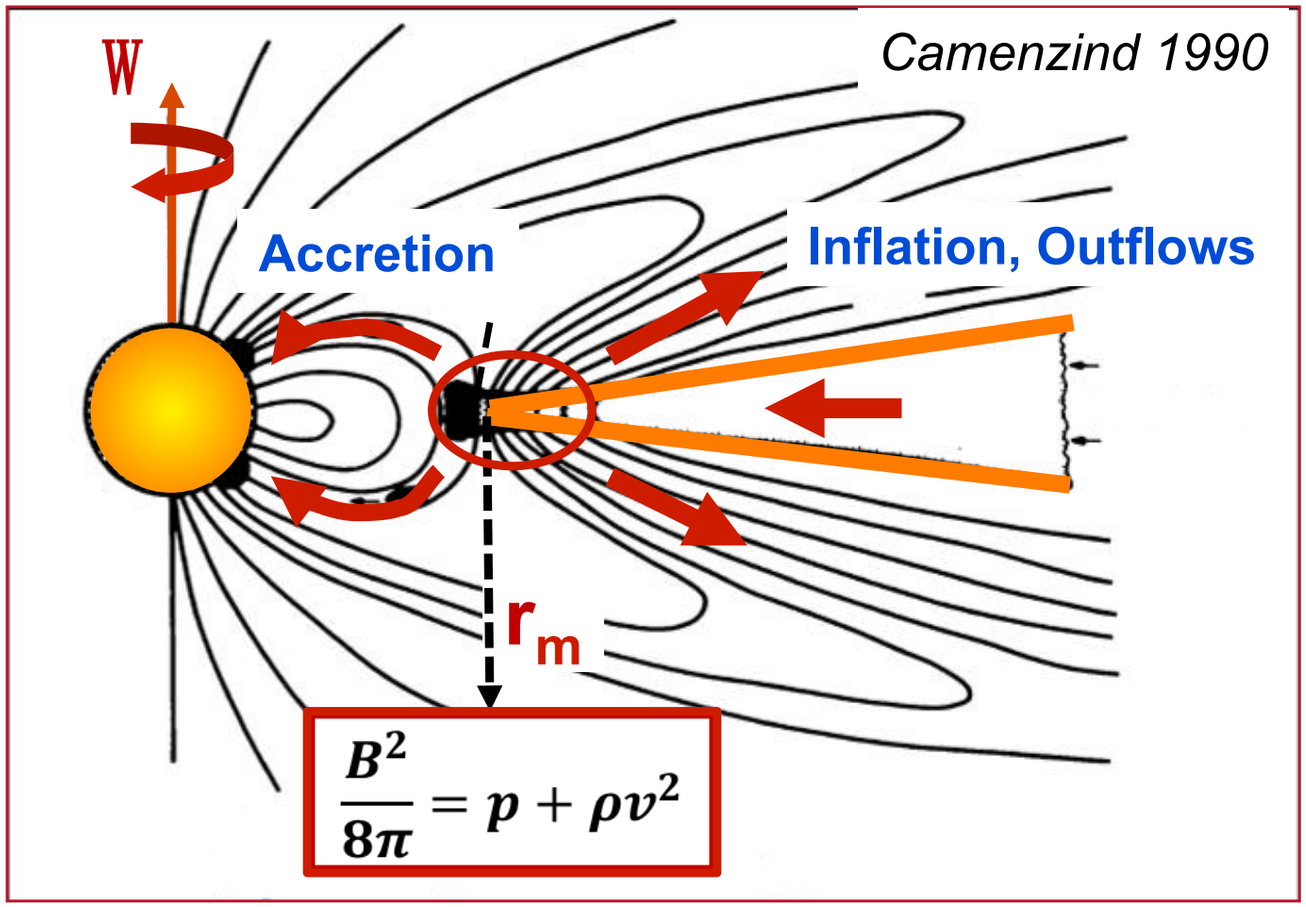
Evolution





- Accretion of material brings angular momentum and spins-up the pulsar.

General view of accretion



- Matter of the disk is stopped by the magnetic pressure
- Accretion in inner parts
- Outflows in outer parts

Characteristic radii

- **Corotation radius**: radius at which the magnetic field rotates at the local Keplerian speed

$$r_{\rm cr} \equiv \left(\frac{GM}{\omega_*^2}\right)^{1/3} \approx 1.5 \times 10^8 \ {\rm cm} \ M_1^{1/3} P_1^{2/3} \ ,$$

- **Alfven radius**: distance from a non- rotating star where the free-fall of a quasi-spherical accretion flow is stopped.

$$r_{\rm A} \equiv \left(\frac{\mu^2}{\dot{M}_{\rm accr}\sqrt{GM}}\right)^{2/7} \approx 3.6 \times 10^8 \ {\rm cm} \ \frac{\mu_{30}^{4/7}}{\dot{M}_{17}^{2/7} M_1^{1/7}}$$

- **Magnetospheric radius**: radius at which magnetic pressure overcomes the ram pressure and flow is trapped by magnetic field $r_m = f\, r_A$, f~0.4

Characteristic radii

- **Corotation radius**: radius at which the magnetic field rotates at the local Keplerian speed

$$r_{\rm cr} \equiv \left(\frac{GM}{\omega_*^2}\right)^{1/3} \approx 1.5 \times 10^8 \ {\rm cm} \ M_1^{1/3} P_1^{2/3} \ ,$$

- **Alfven radius**: distance from a non- rotating star where the free-fall of a quasi-spherical accretion flow is stopped.

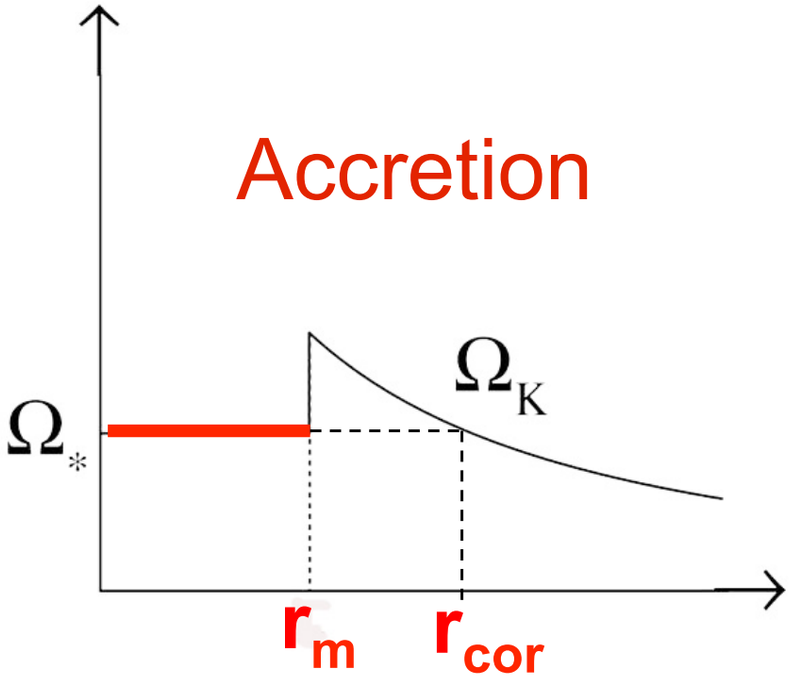
$$r_{\rm A} \equiv \left(\frac{\mu^2}{\dot{M}_{\rm accr}\sqrt{GM}}\right)^{2/7} \approx 3.6 \times 10^8 \ {\rm cm} \ \frac{\mu_{30}^{4/7}}{\dot{M}_{17}^{2/7} M_1^{1/7}}$$

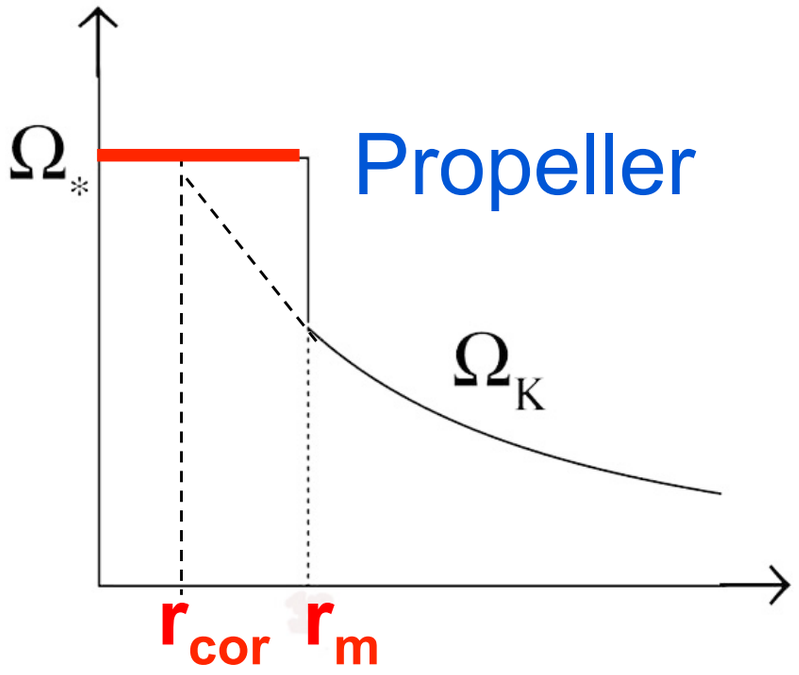
- **Magnetospheric radius**: radius at which magnetic pressure overcomes the ram pressure and flow is trapped by magnetic field $r_m = f\, r_A$, f~0.4

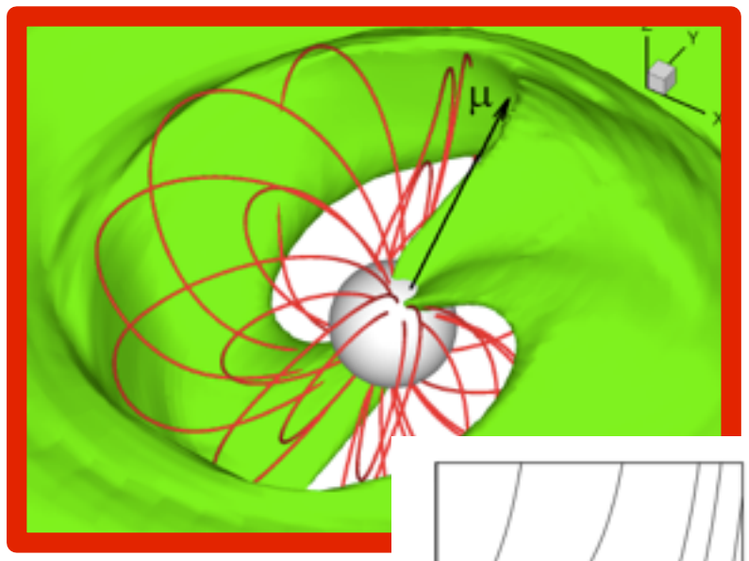
Propeller and accretion

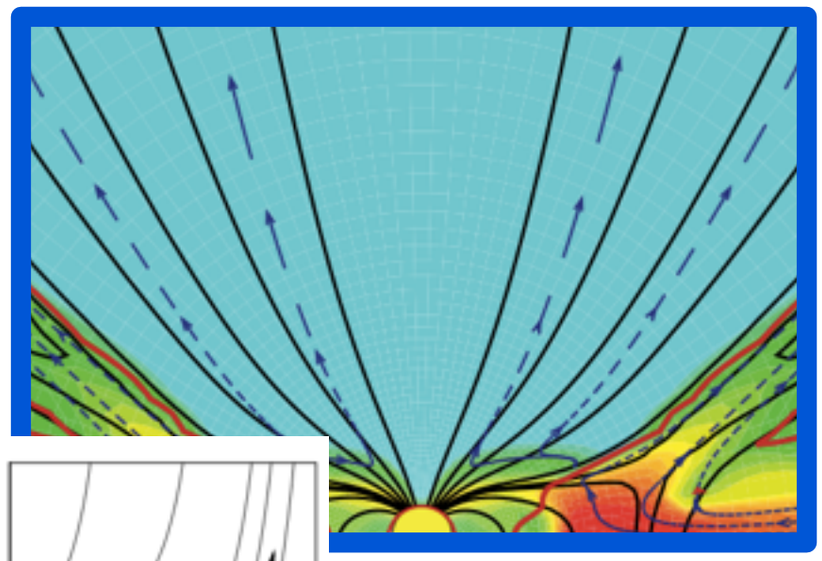
Inner disk rotates faster than magnetosphere

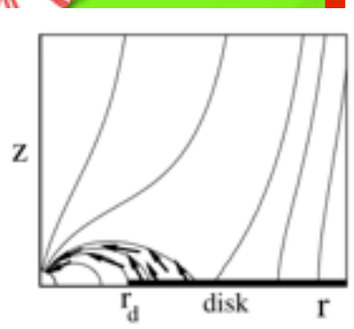
Matter is funnelled to the surface by B-field

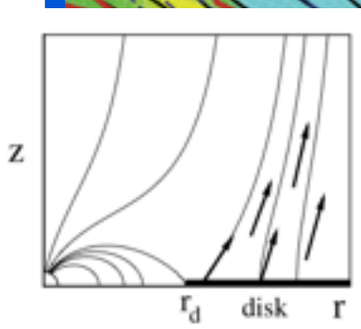






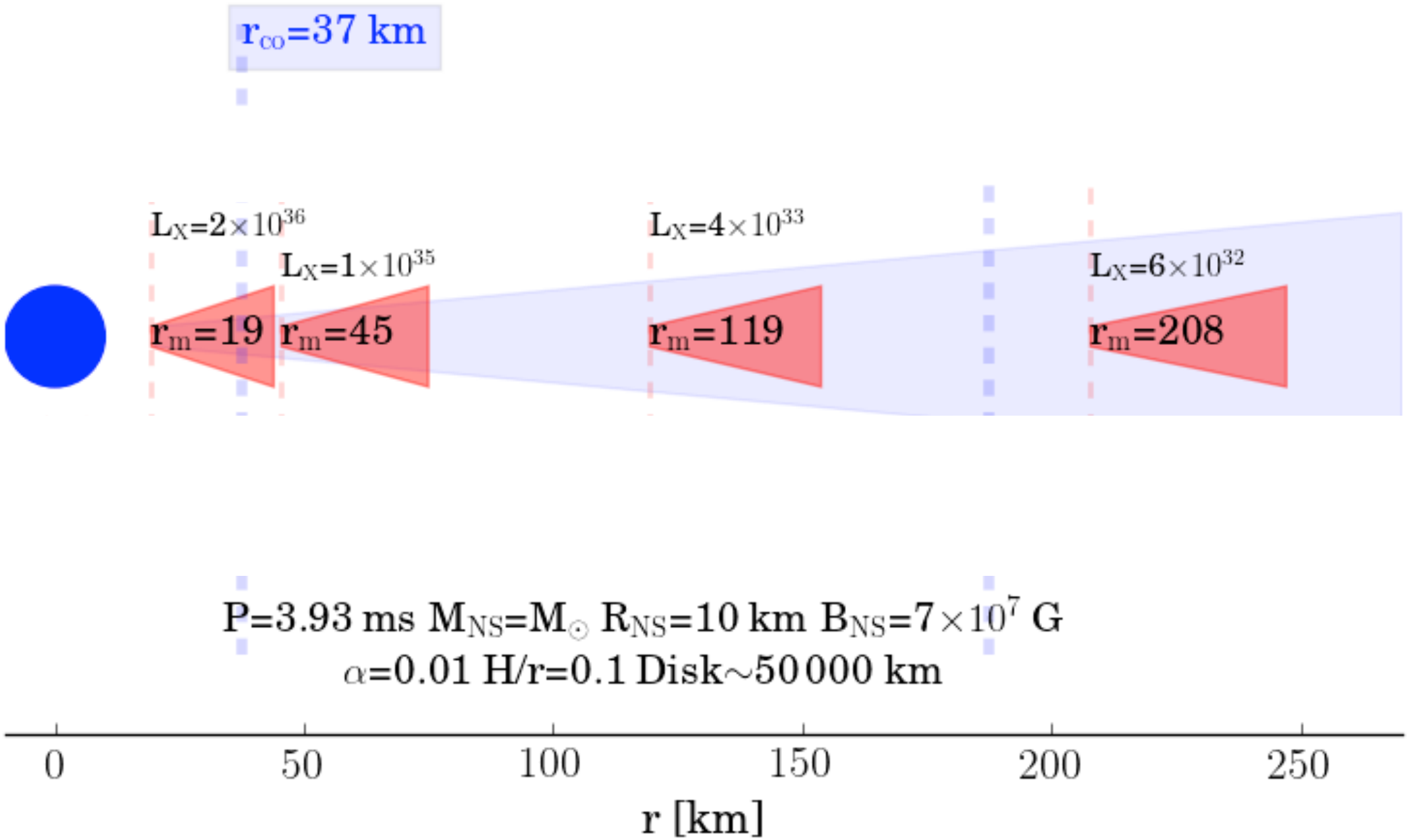






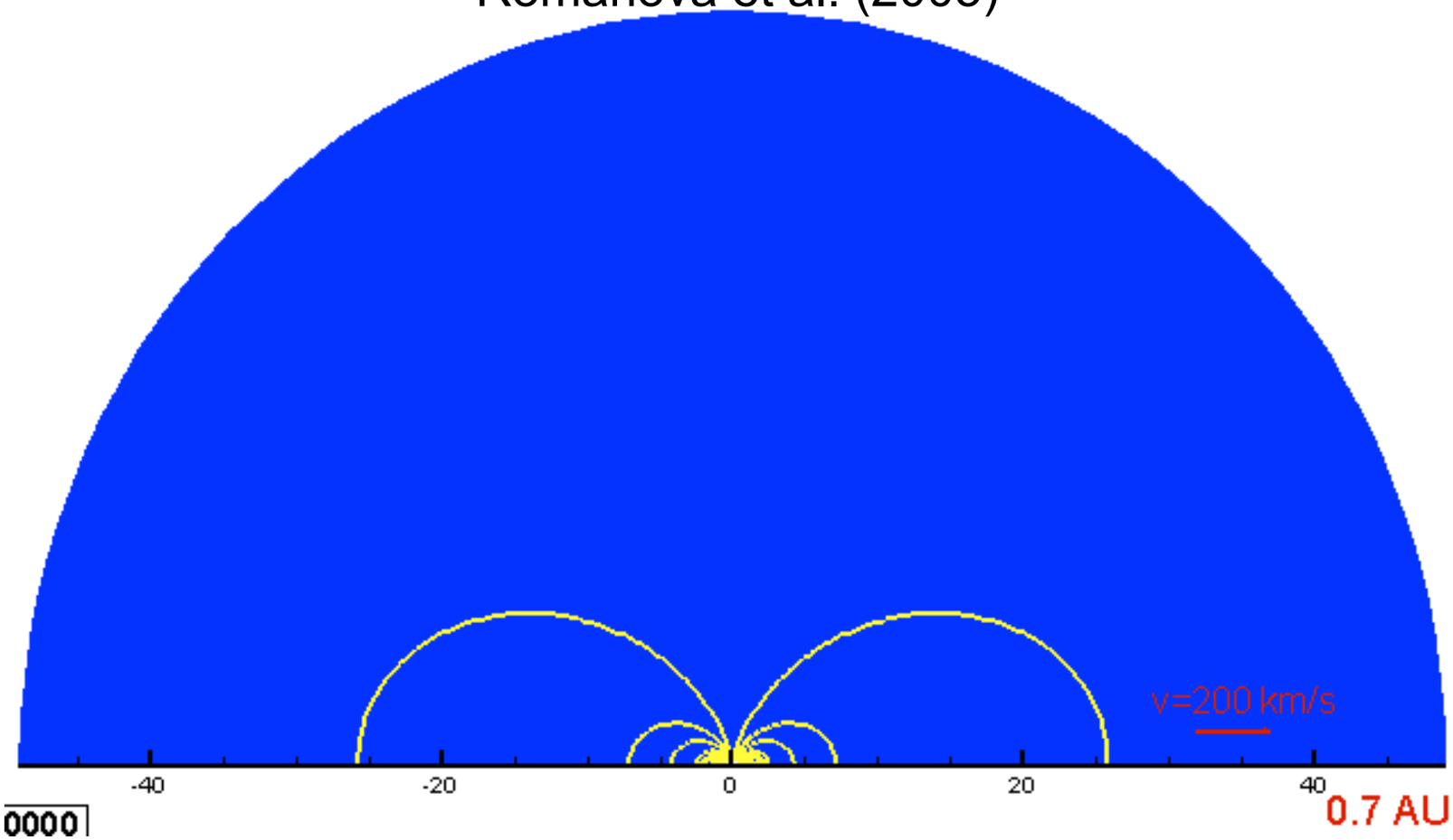
Magnetosphere rotates faster than accretion flow and matter can be centrifugally ejected.

In scale

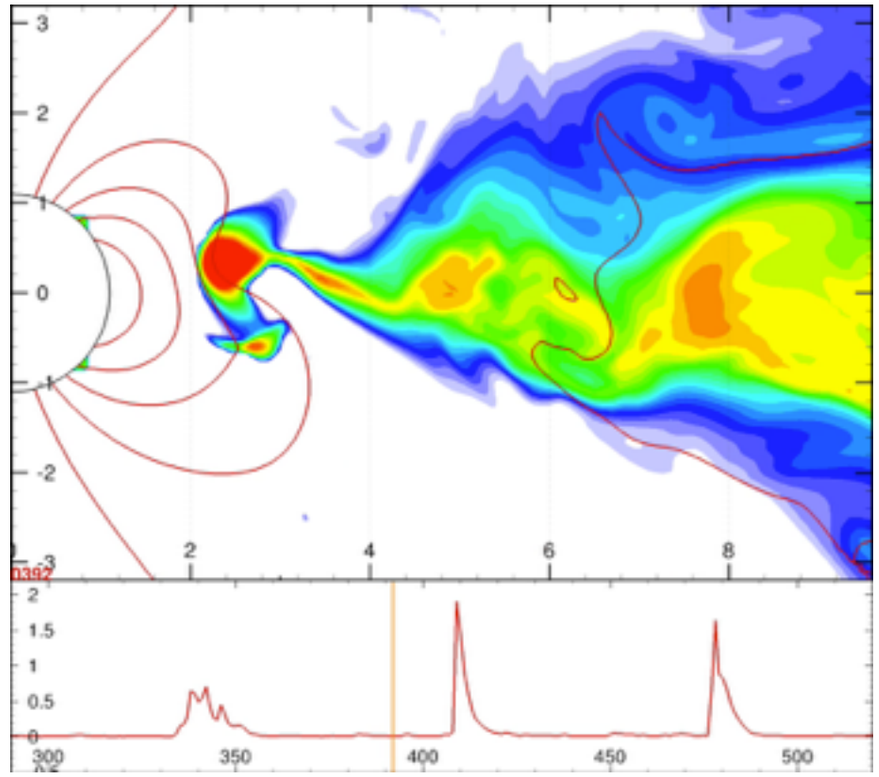

r_{co}=37 km
L_X=2×10^36
L_X=1×10^35
L_X=4×10^33
L_X=6×10^32
r_m=19
r_m=45
r_m=119
r_m=208
P=3.93 ms M_{NS}=$M_\odot$ R_{NS}=10 km B_{NS}=7×10^7 G
α=0.01 H/r=0.1 Disk∼50 000 km
0
50
100
150
200
250
r [km]

Propeller accretion

Romanova et al. (2005)



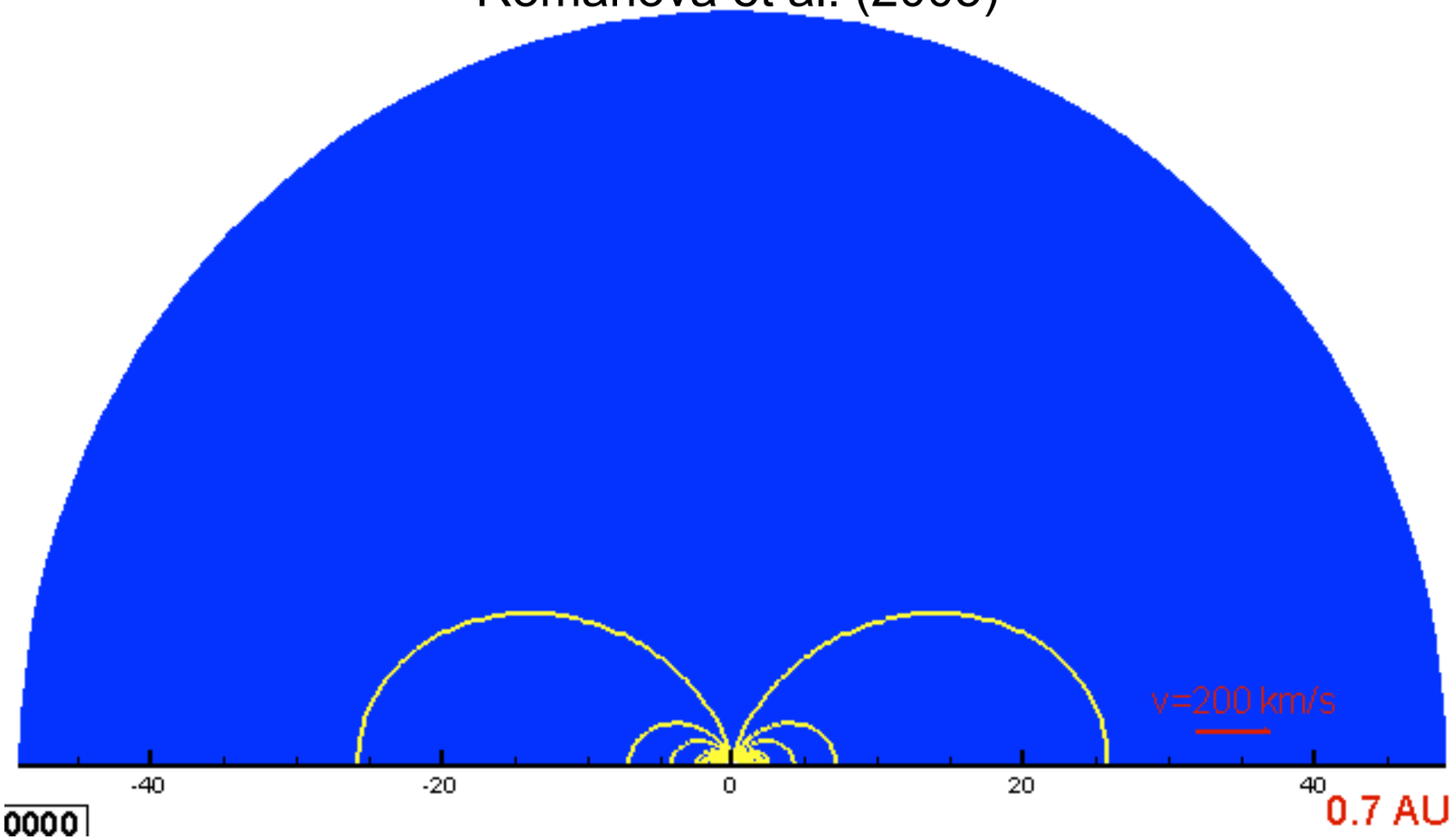
Lii et al. (2014)



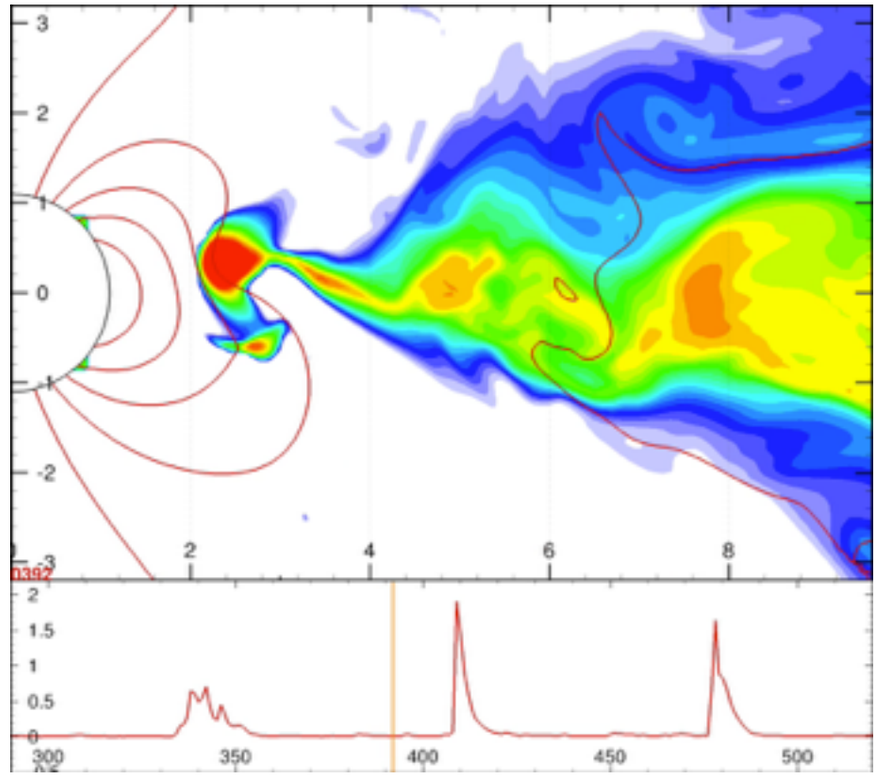
- For lower accretion rate, pressure of matter lowers and collimated outflow of matter and angular momentum appears.
- Centrifugally driven at the inner boundary of accretion disc.
- Matter is partly accreted and partly expelled. Episodic accretion.
- Neutron Star spins down efficiently

Propeller accretion

Romanova et al. (2005)



Lii et al. (2014)



- For lower accretion rate, pressure of matter lowers and collimated outflow of matter and angular momentum appears.
- Centrifugally driven at the inner boundary of accretion disc.
- Matter is partly accreted and partly expelled. Episodic accretion.
- Neutron Star spins down efficiently

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)

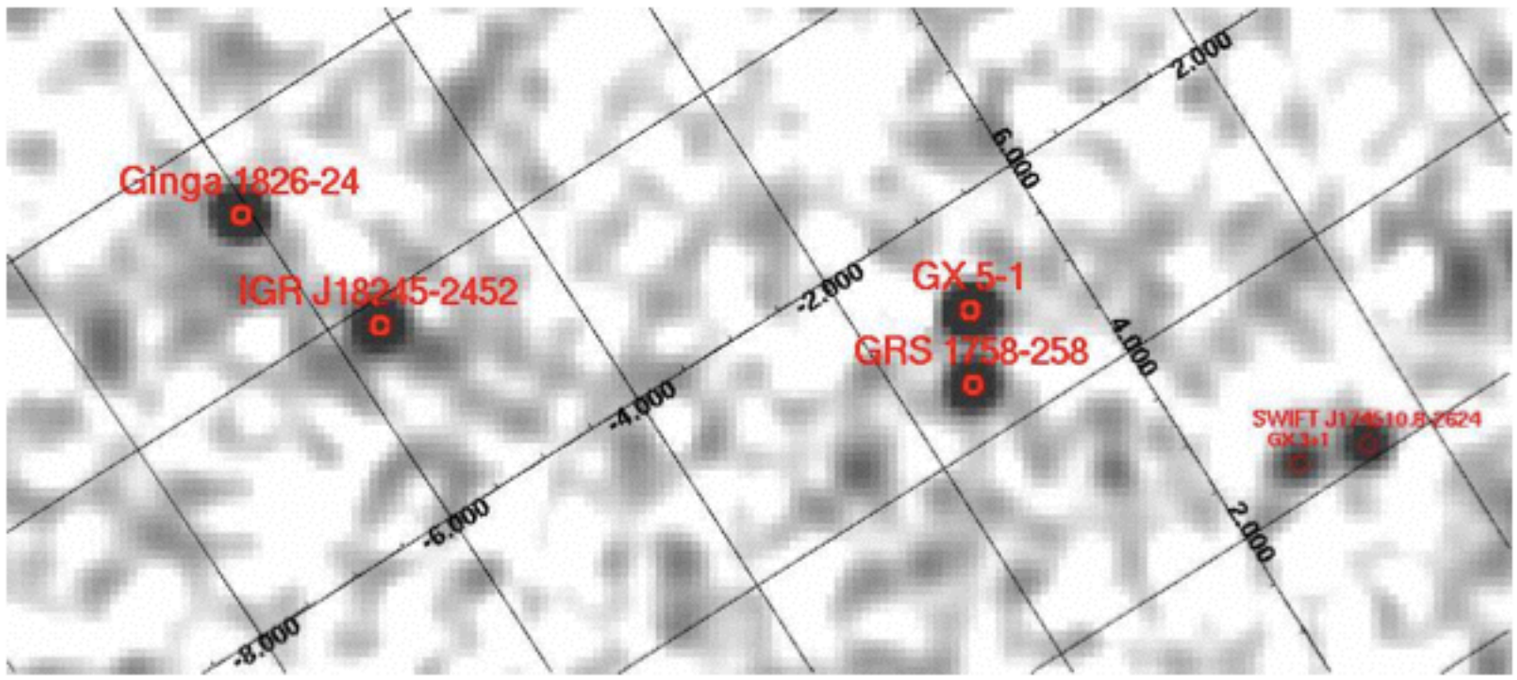
Subjects: X-ray, Gamma Ray, Request for Observations, Black Hole, Neutron Star, Transient

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

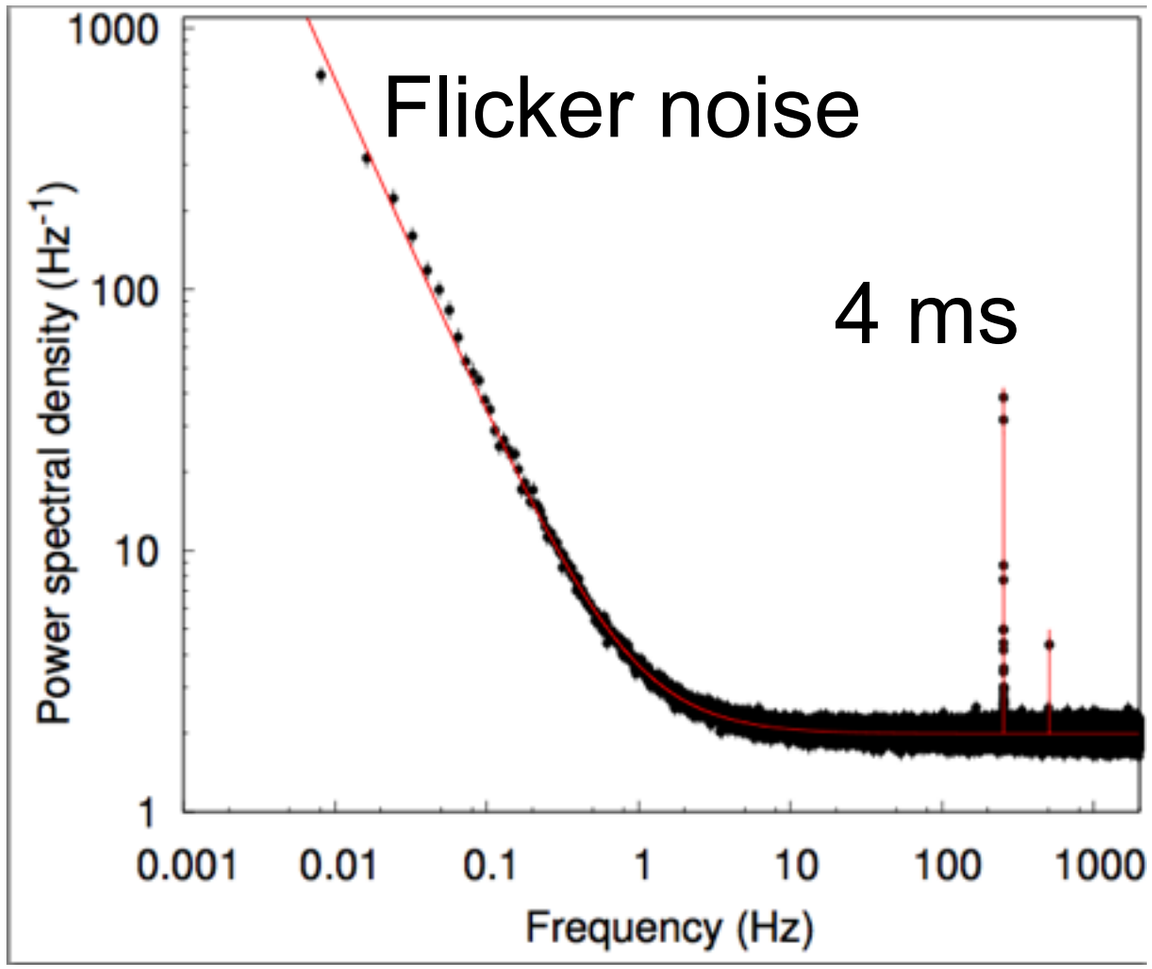
During the observations of the Galactic Center performed on 2013 March 28 from 2:56 to 17:38 (UTC), the hard X-ray imager IBIS on-board INTEGRAL detected a new transient source, dubbed IGR J18245-2452, at:
RA=276.1383
DEC=-24.8793
with an associated uncertainty of 1.4 arcmin (all uncertainties

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

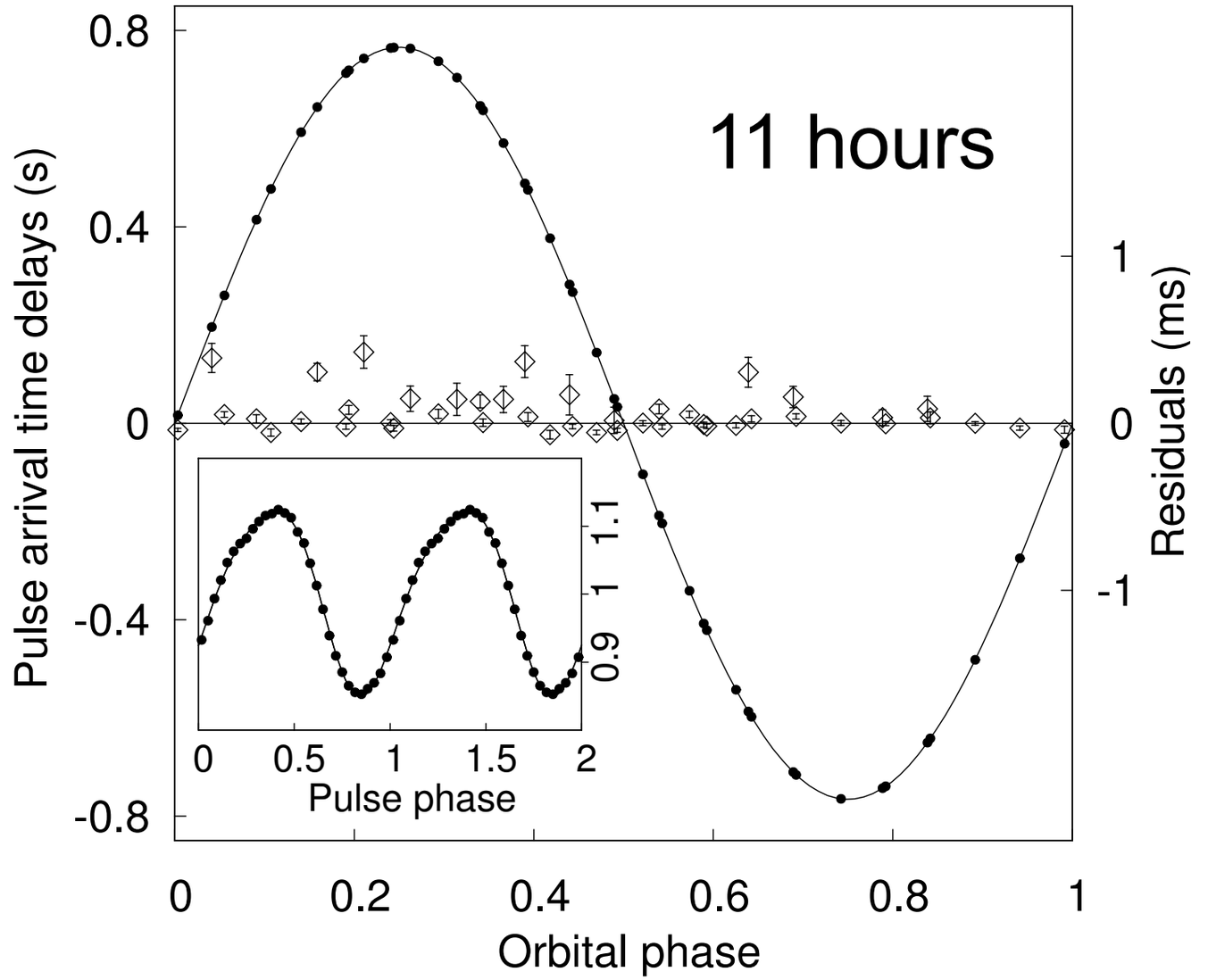
- Discovered during the quick-look of INTEGRAL data
- Located in the globular cluster M 28



It is the 15th accreting millisecond pulsar

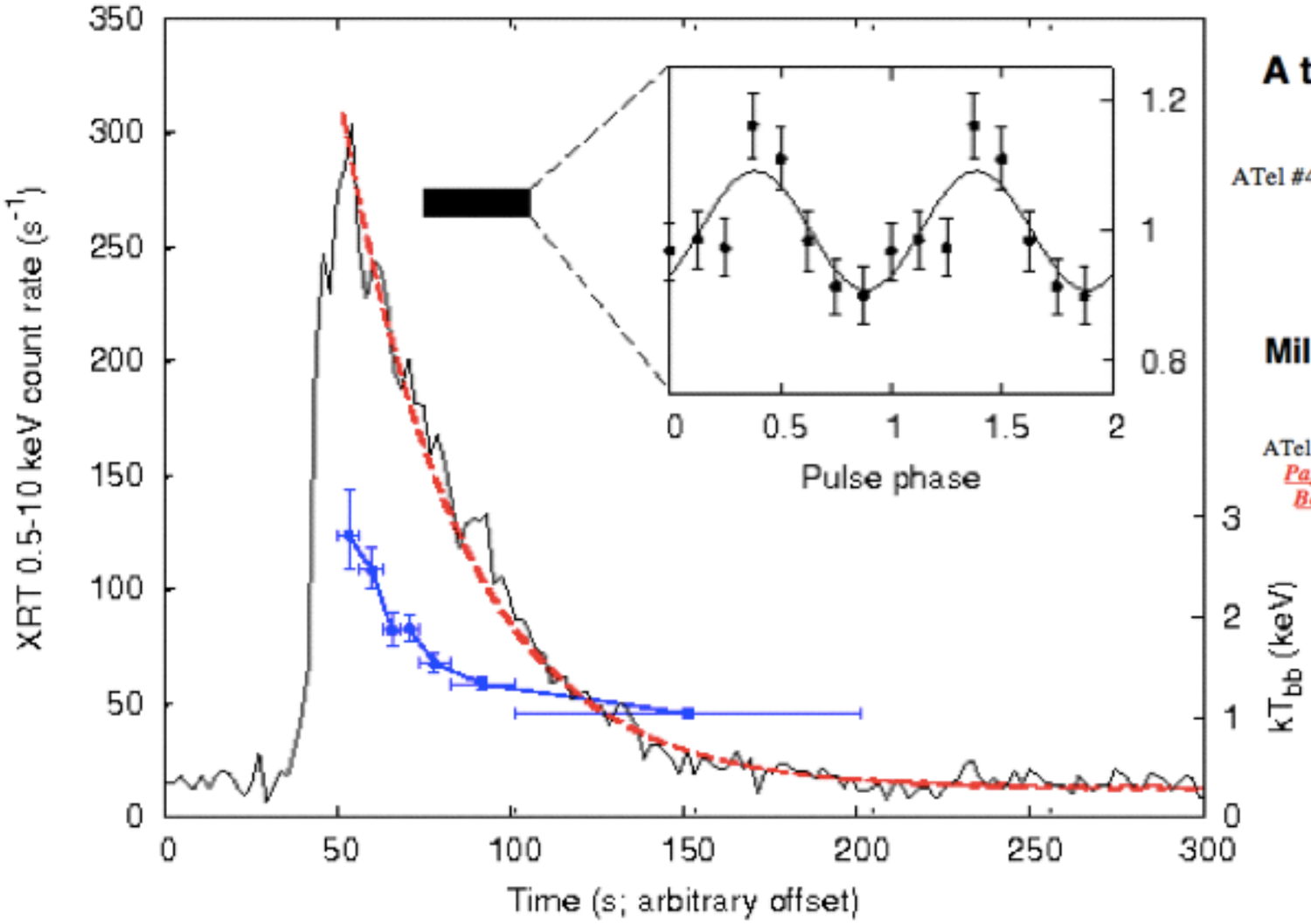


30 ks + 70 ks XMM-Newton TOOs



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

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'Ai' (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 one detected during the Swift/XRT monitoring.
- Burst oscillation at 3.9 ms, phase locked with spin modulation
- It is an accreting millisecond pulsar !

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)

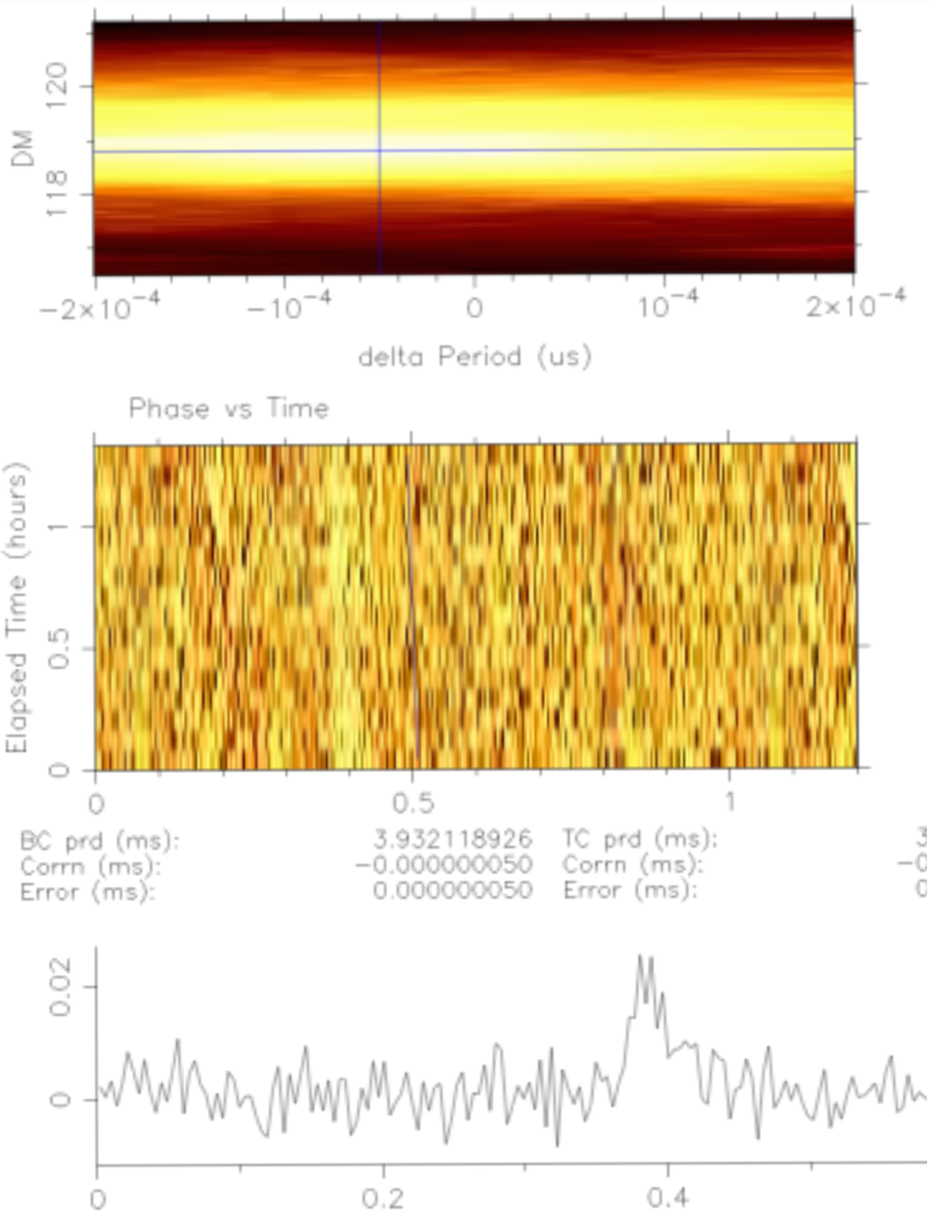
In literature

- The only rotation-powered pulsar showing a full X-ray outburst.
- PSR J1023+0038 and XSS J12270-4859 swing from/to radio powered emission and weak accretion phase with an accretion disk.

Red back: Radio signal is weak and characterized by irregular "eclispes", due to intra-binary plasma.

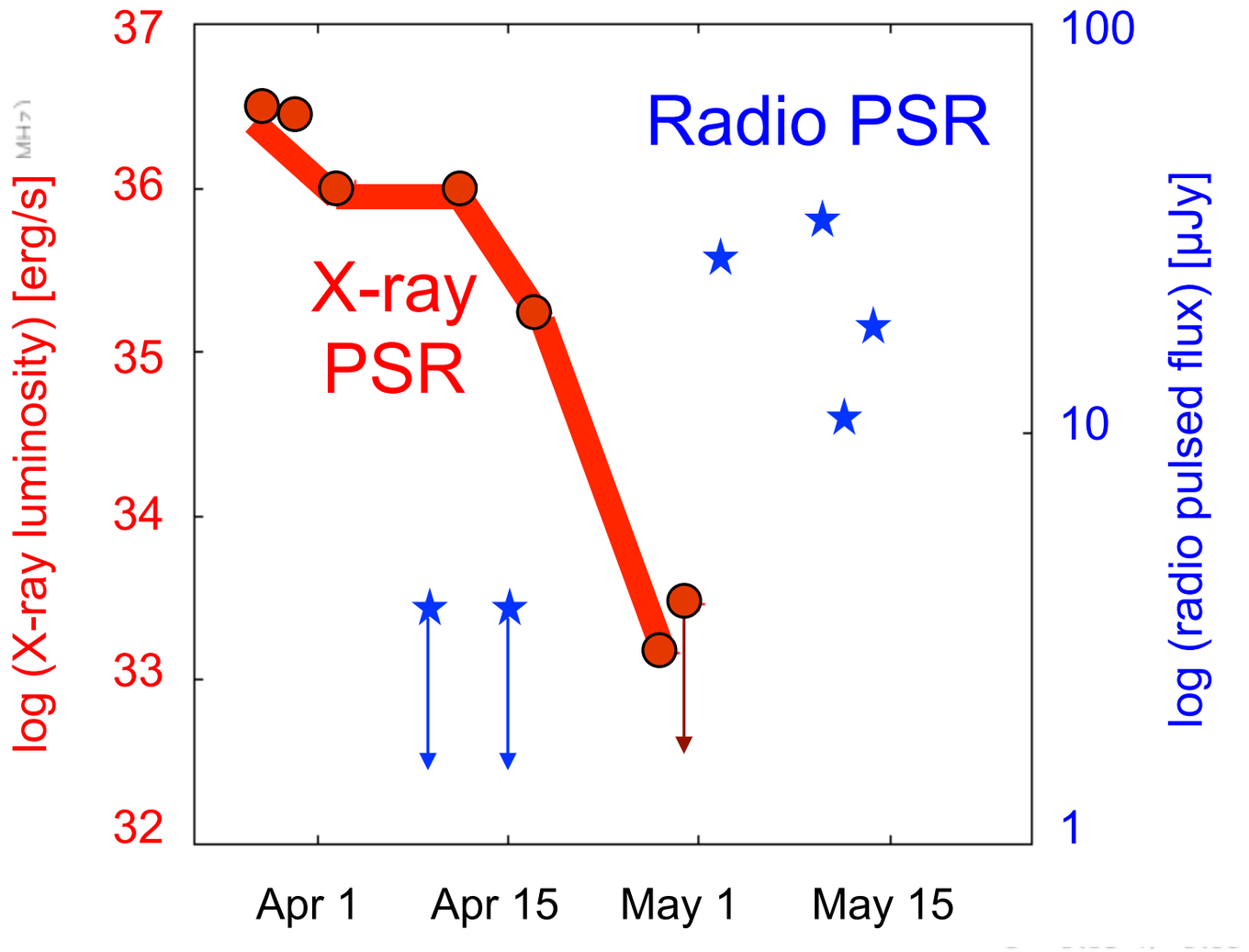
Papitto+ (2013)

Radio loud again !



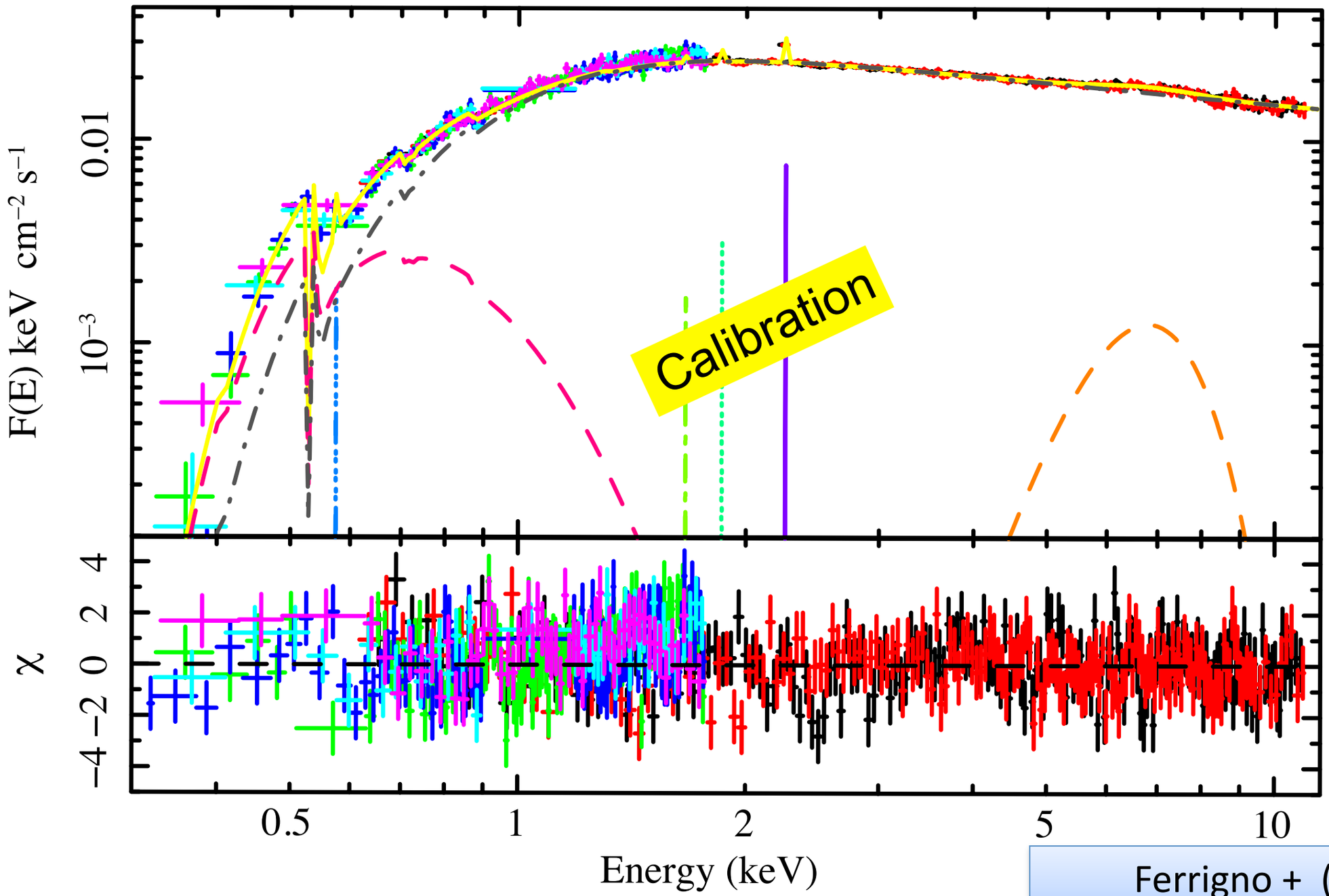
The transient low-mass X-ray binary IGR J18245-2452 is again active as a radio pulsar

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 !

Average X-ray spectrum

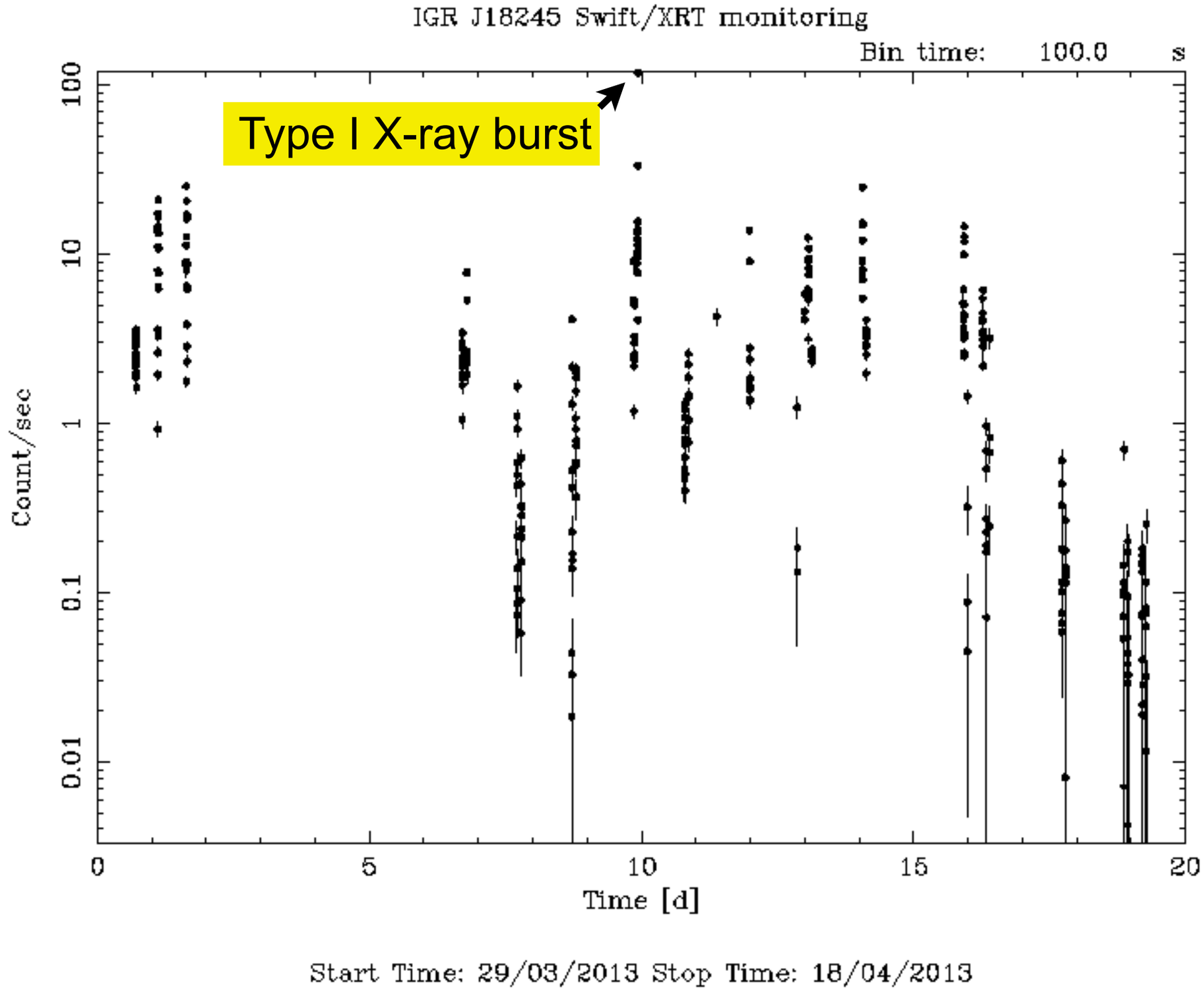


Ferrigno + (2014)

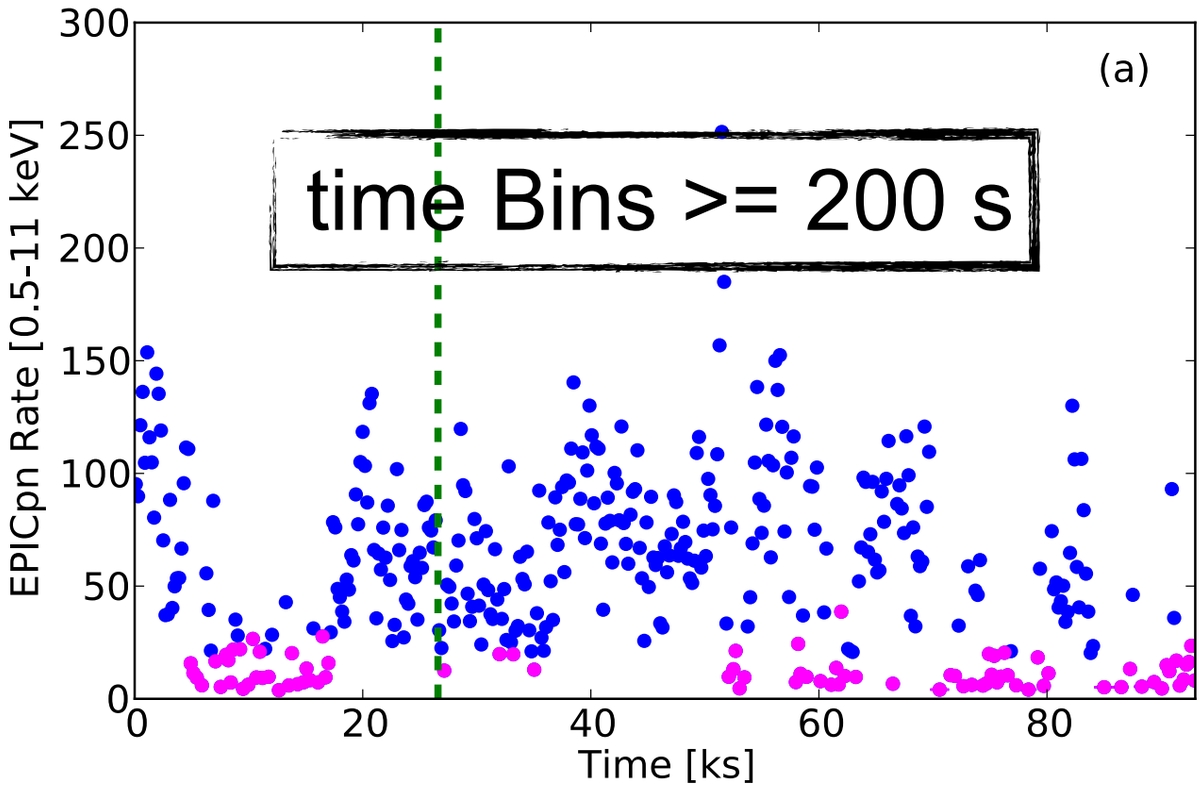
- Comptonization + Disk + Broad iron line + (calibration lines)

Pronounced variability

- Atypical variability fror seconds to hundreds of seconds
- Typical outburst duration
- Unfrequent type I X-ray bursts (only two in the whole campaign)



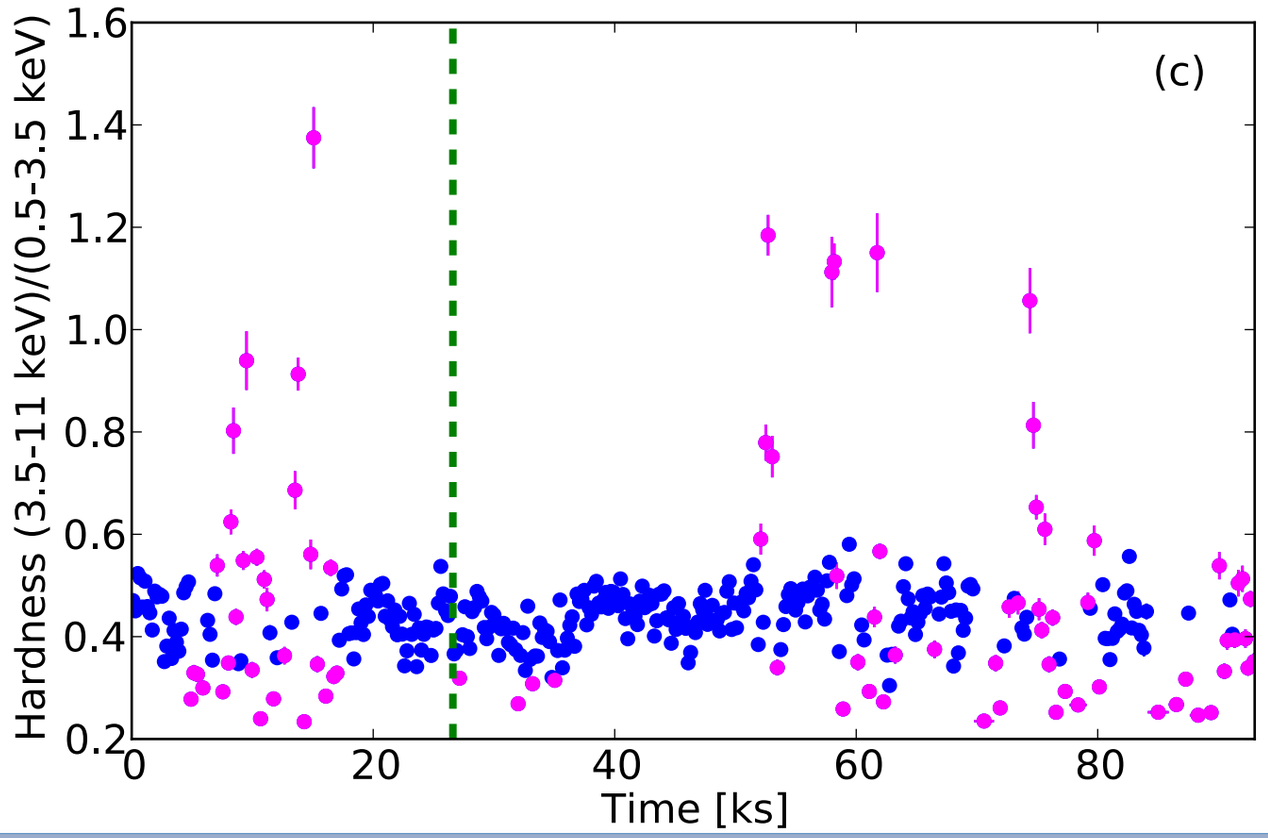
XMM-Newton light curve



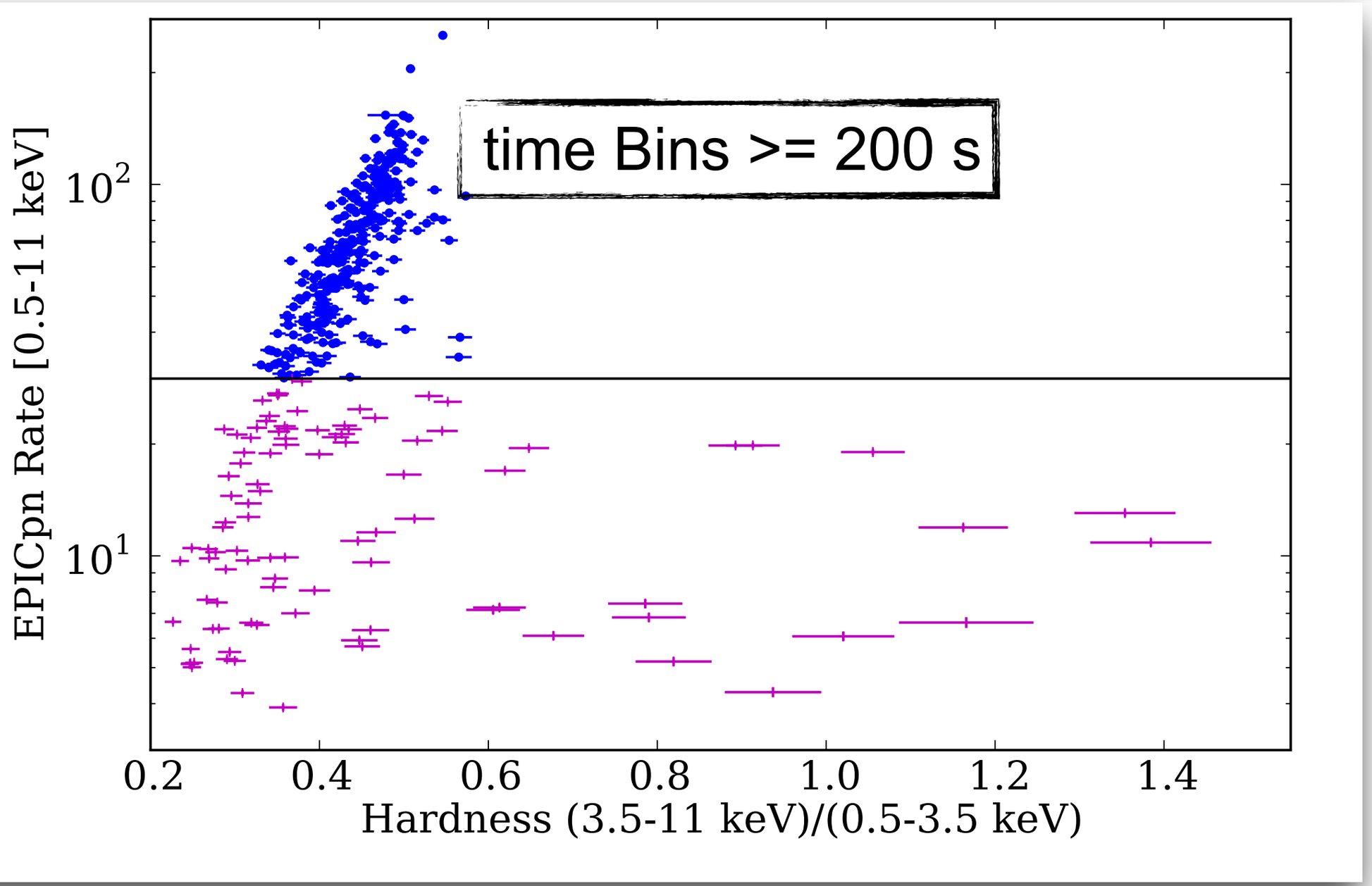
- Very interesting variability, unique among AMSP.
- Episodes of enhanced hardness at low flux
- No orbital dependency.

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

Ferrigno + (2014)



Two branches



- Blue: higher flux, limited Hardness variation
- Magenta: lower flux, swings of hardness, what are they?

Two accretion states

Lower state

Higher state

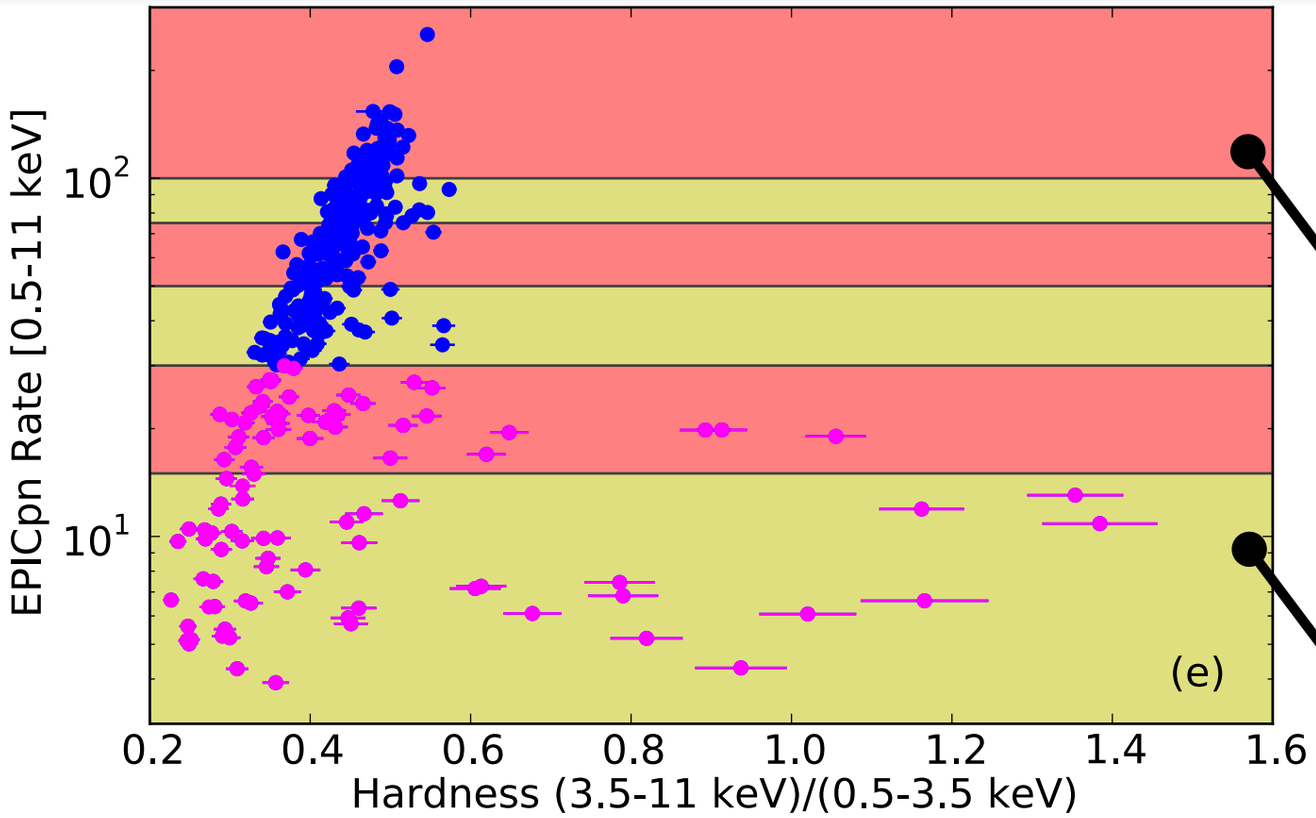
TWO log-normal distributions

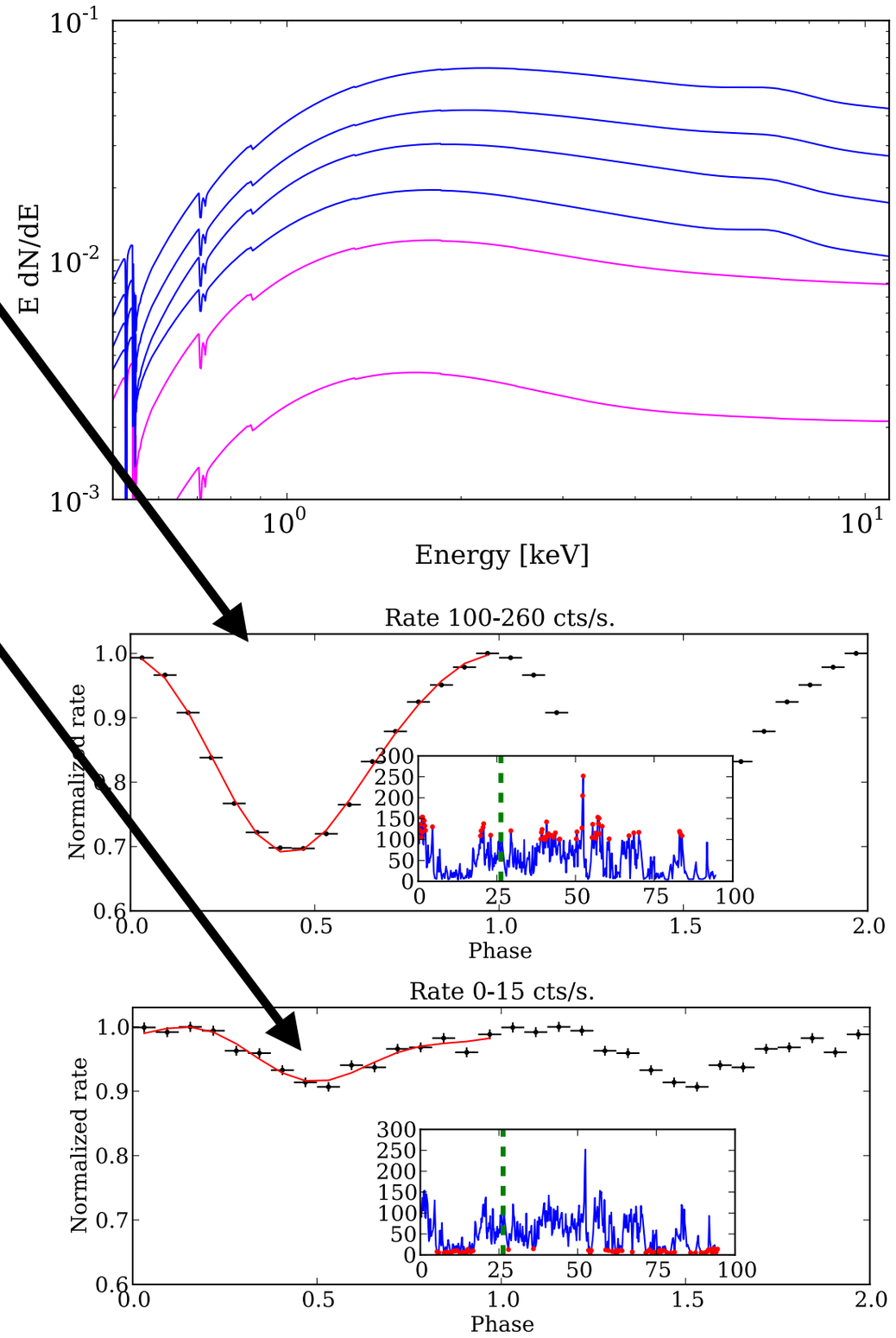
1e35 erg/s

2e36 erg/s

time Bins = 1 s

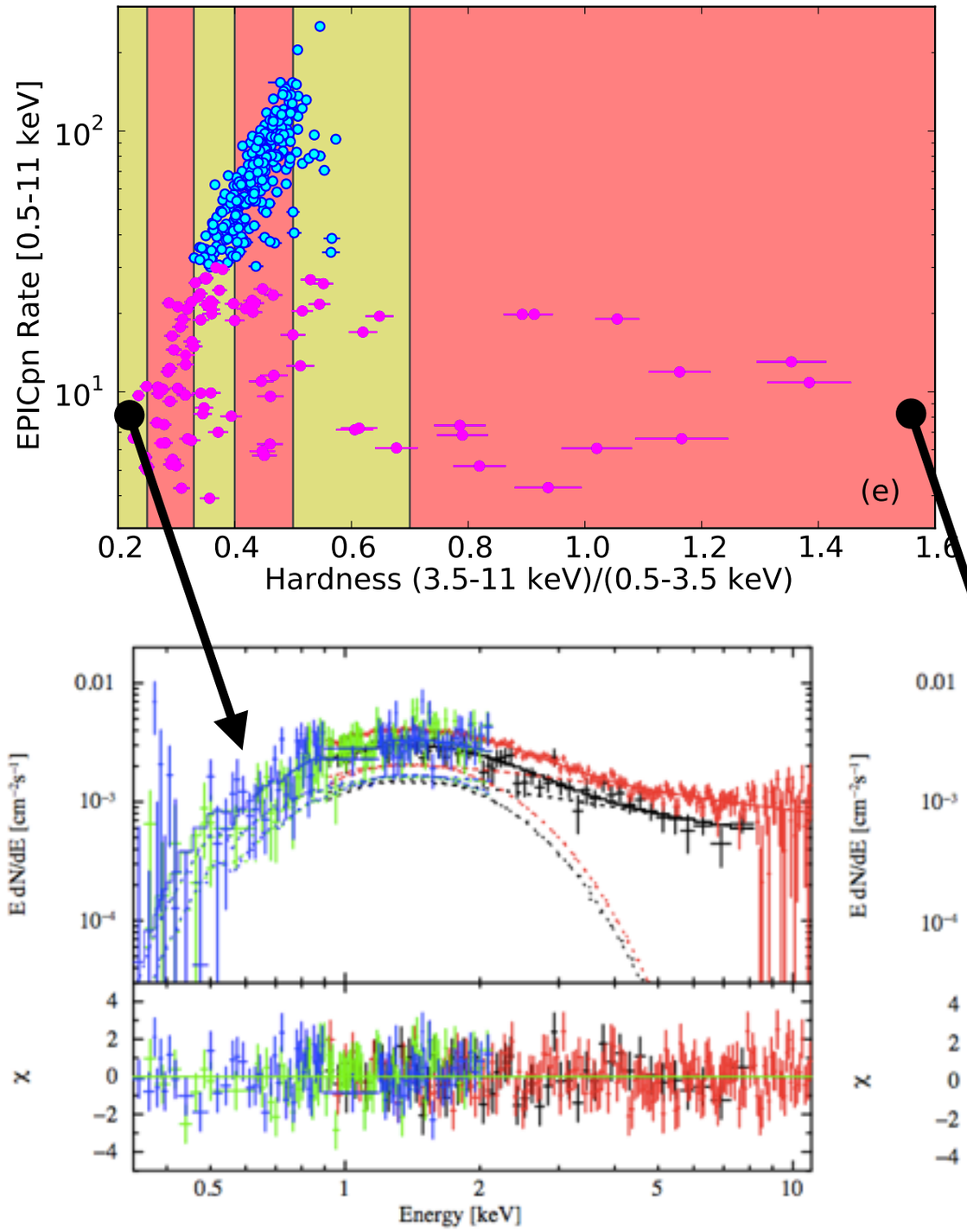
Luminosity dependence





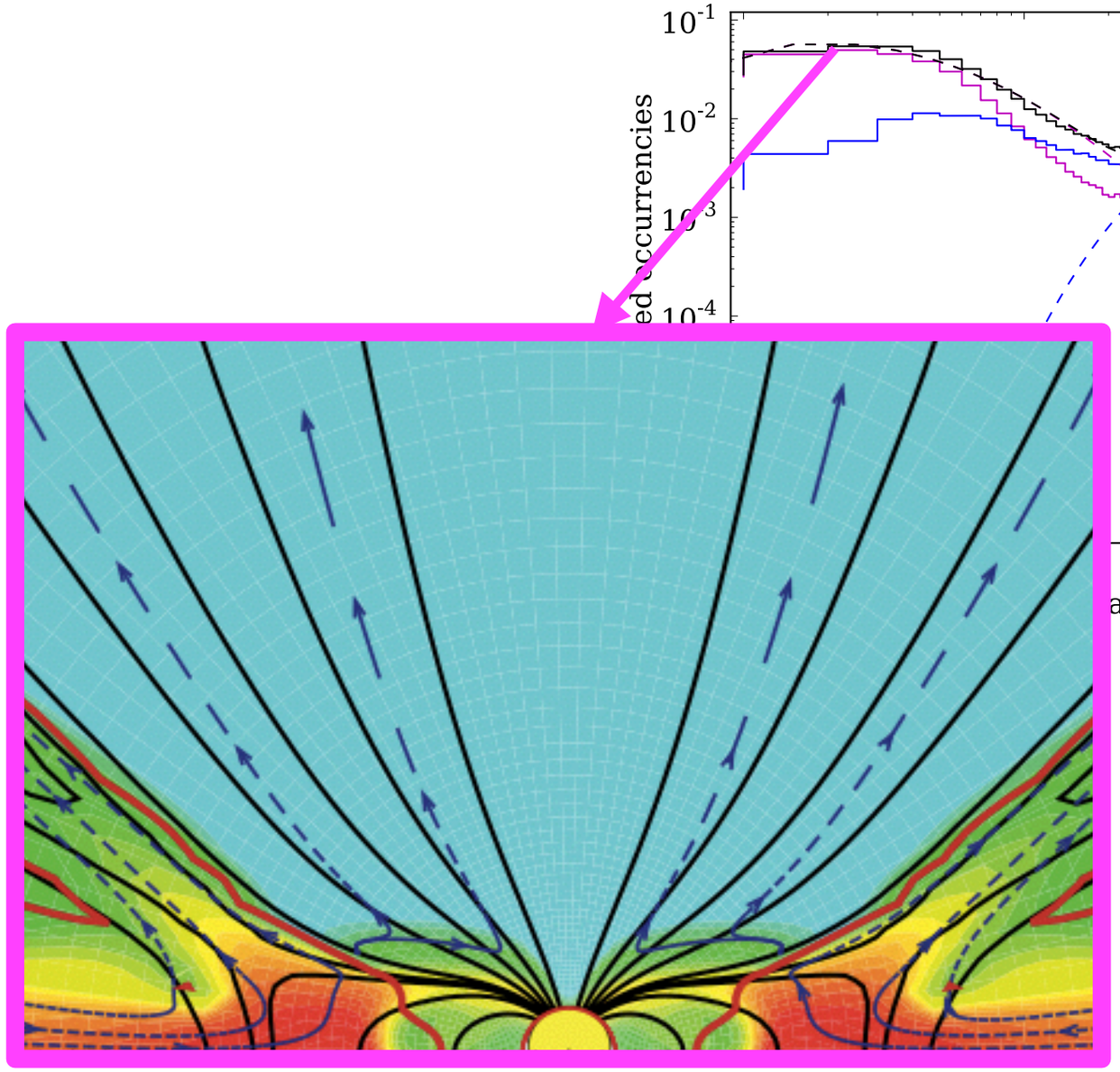
- Broad Iron line and Comptonization spectrum
- Sinusoidal profile with high pulsed fraction
- Black-body and hard Compton tail
- Low pulsed fraction and two harmonics

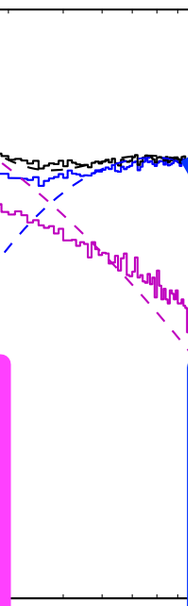
Hardness dependency

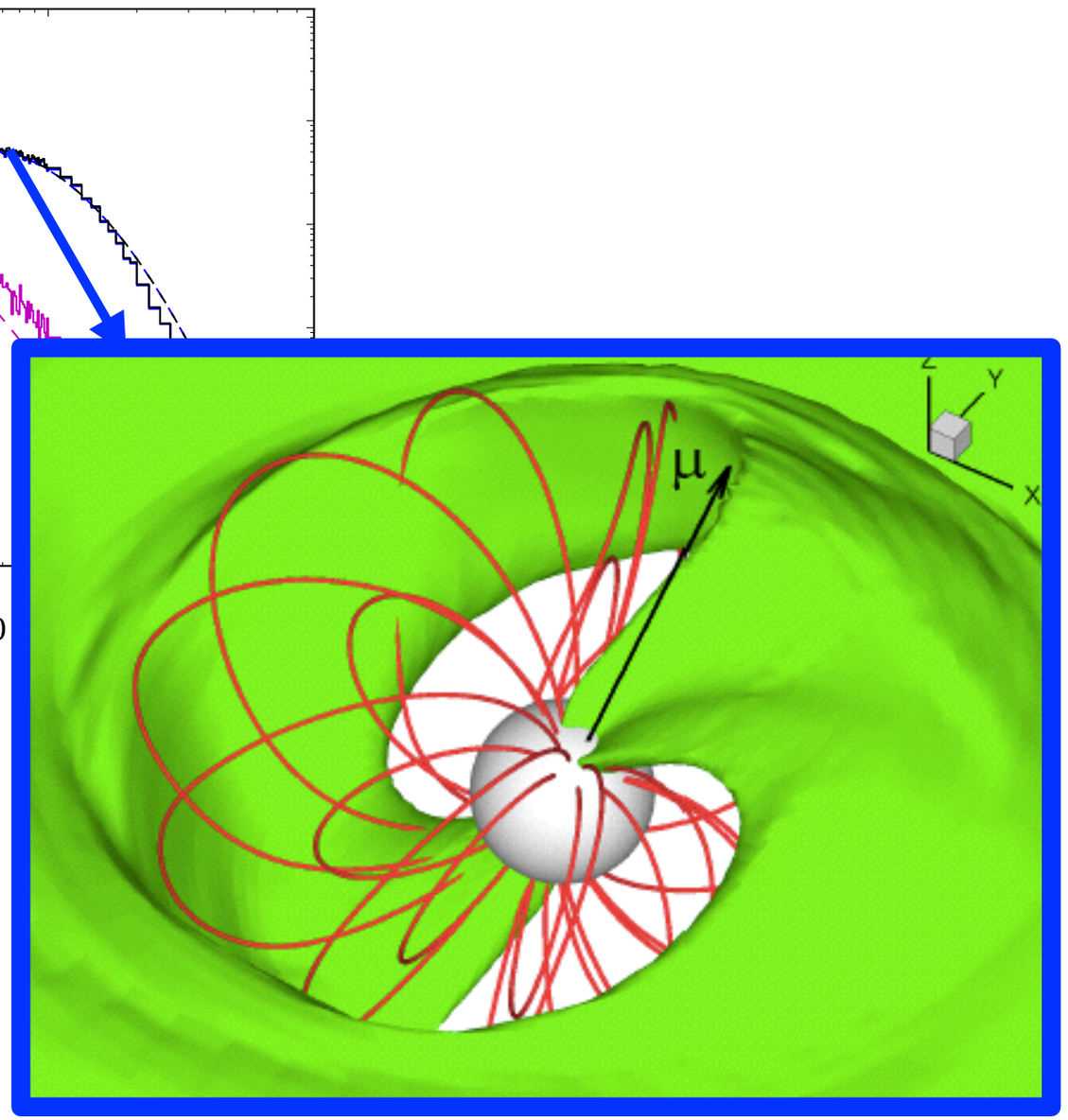


- From black-body and Comptonization to partially covered power-law
- Is this a signature of ejection episodes?

Interpretation



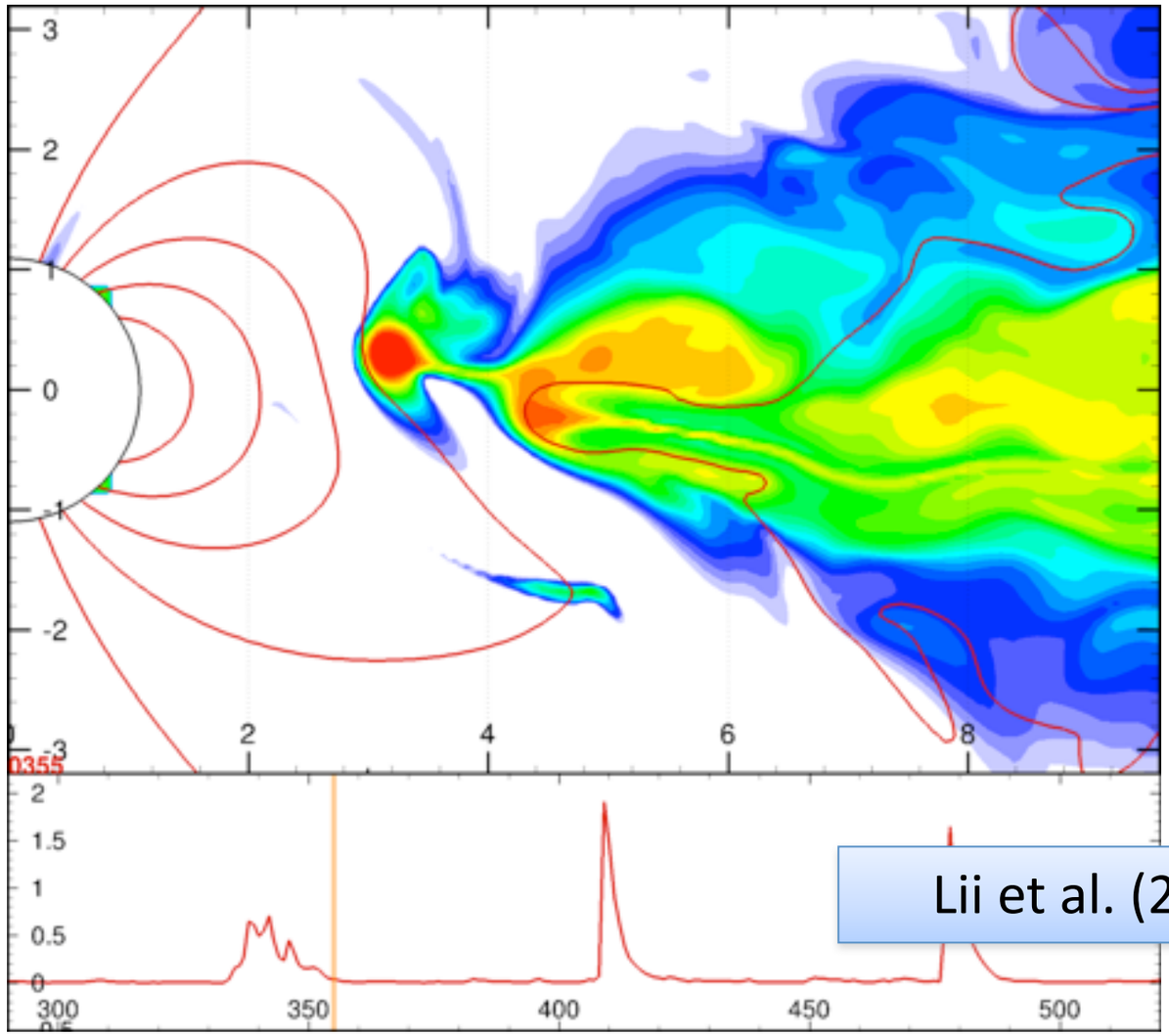




- Low state: propeller accretion and ejection episodes
- High state: variable accretion along field lines

Mixing is always present

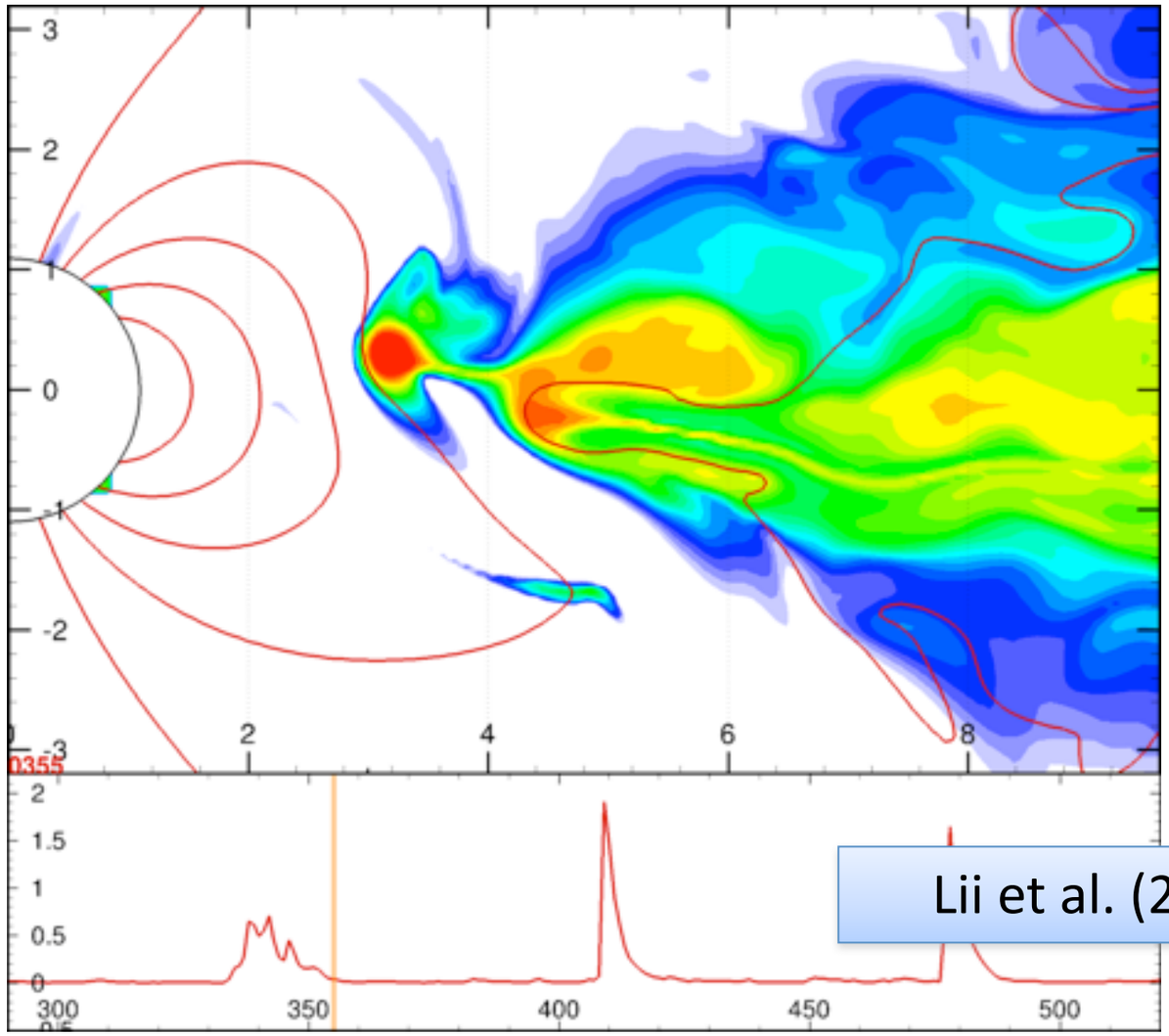
Cyclic accretion



Lii et al. (2014)

- Matter accumulates and then is accreted in cyclic fashion
- Contemporary ejections of material.
- Problem: millisecond scale not reachable with current instruments.

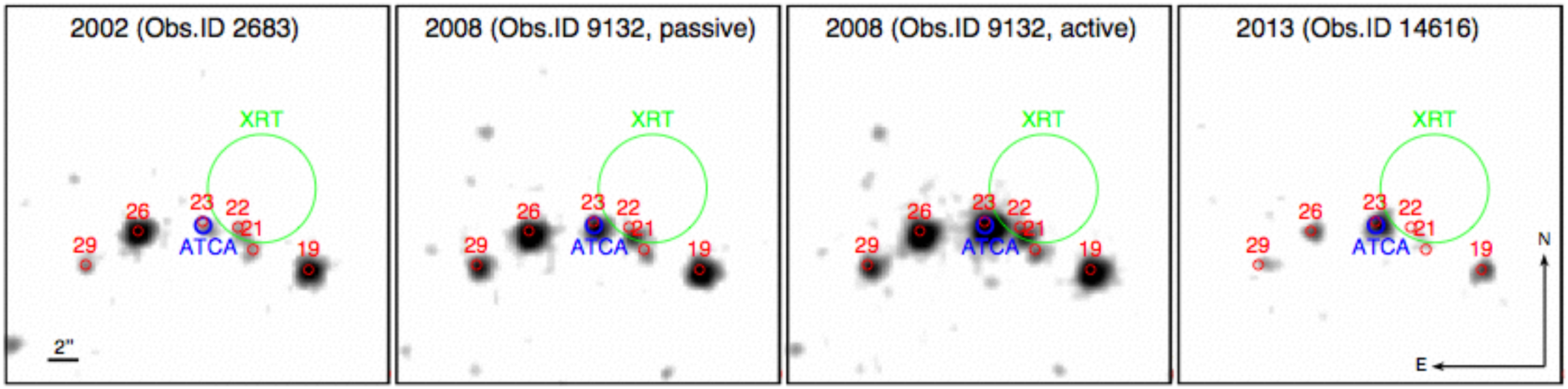
Cyclic accretion

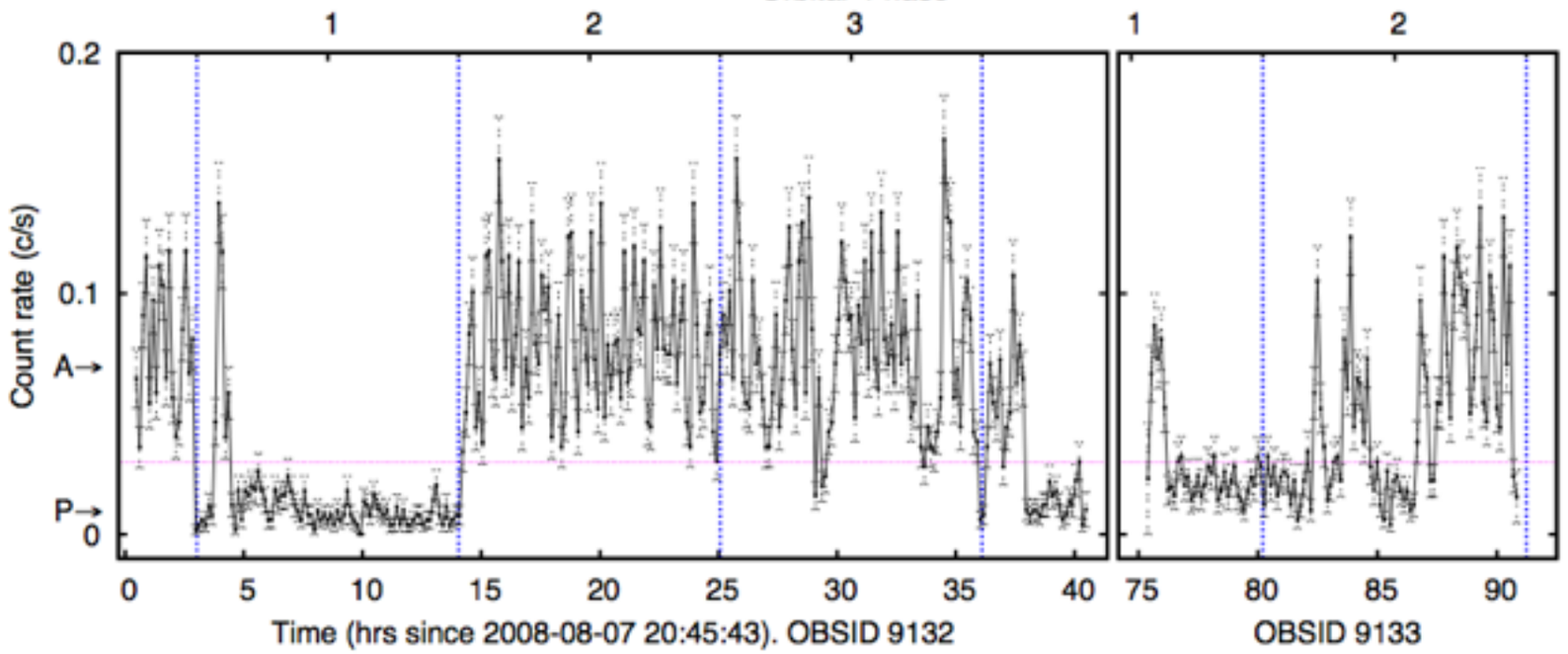


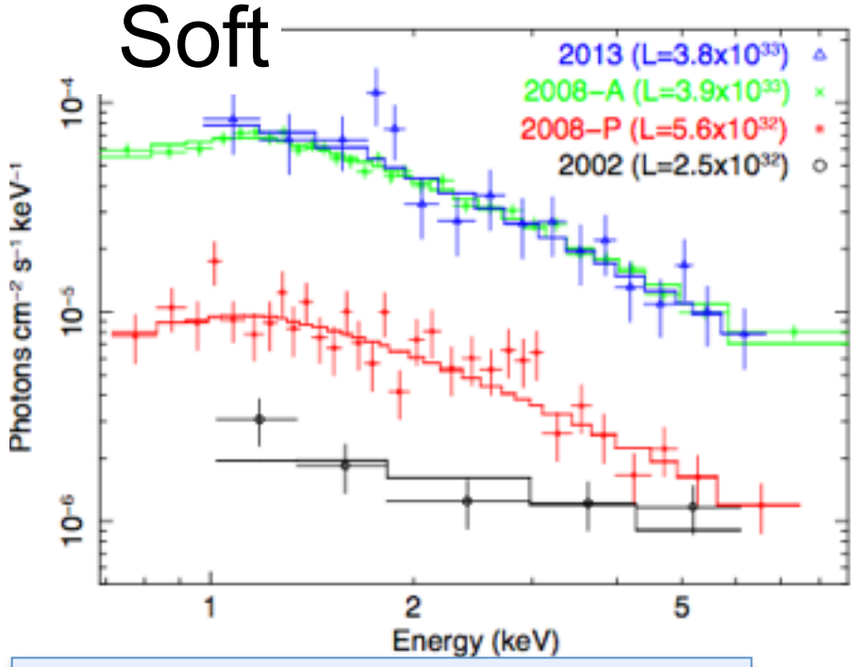
Lii et al. (2014)

- Matter accumulates and then is accreted in cyclic fashion
- Contemporary ejections of material.
- Problem: millisecond scale not reachable with current instruments.

Low-intensity outburst and quiescence





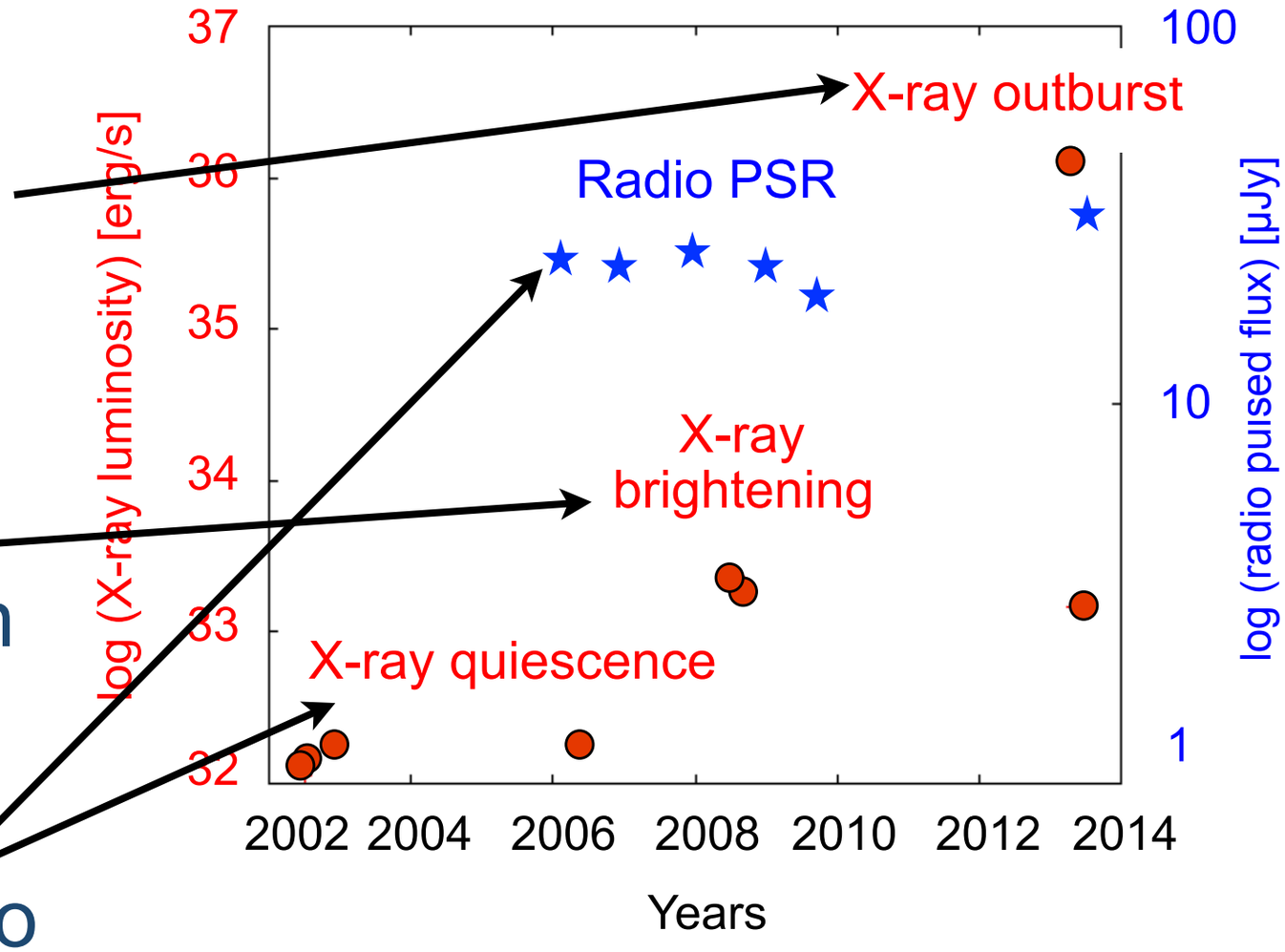


Linares + (2014)

- Lower luminosity outbursts with peculiar switches of intensity but not of spectral shape

A decade of observations

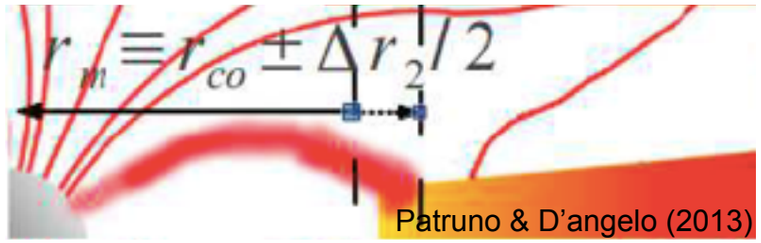
- Monitored as part of the globular cluster M 28: it is at 5.5 kpc.
- One bright accretion driven outburst. Strong spectral and timing variability.
- Intermediate accretion events: X-ray & optical brightening. Mode switch variability.
- Faint radio pulsar with irregularly eclipses due to outflows.



Three variability states

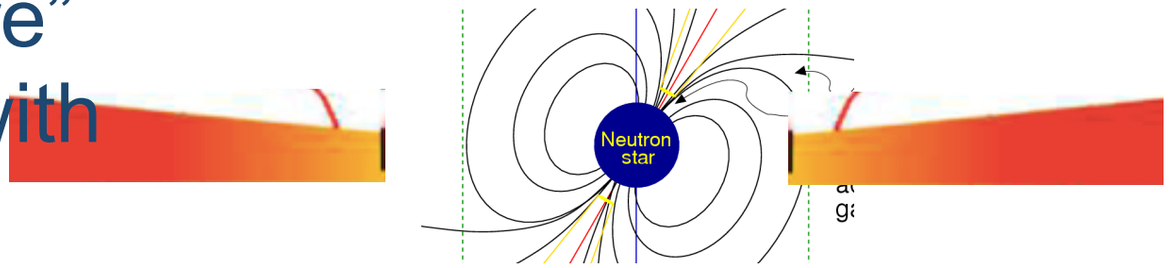
- IGR J18245-2452 is the first and only system swinging from radio to X-ray accretion and vice versa in time scales of days.
- Peculiar bimodal variability at high L_X interpreted as the switch from “pure” accretion to “propeller” accretion with outflows/jets.
- Low-luminosity variability similar to PSR J1023+0038 and XSS J12270-4859 interpreted as propeller accretion or buried radio emission in an 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



Patruno & D’angelo (2013)

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



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