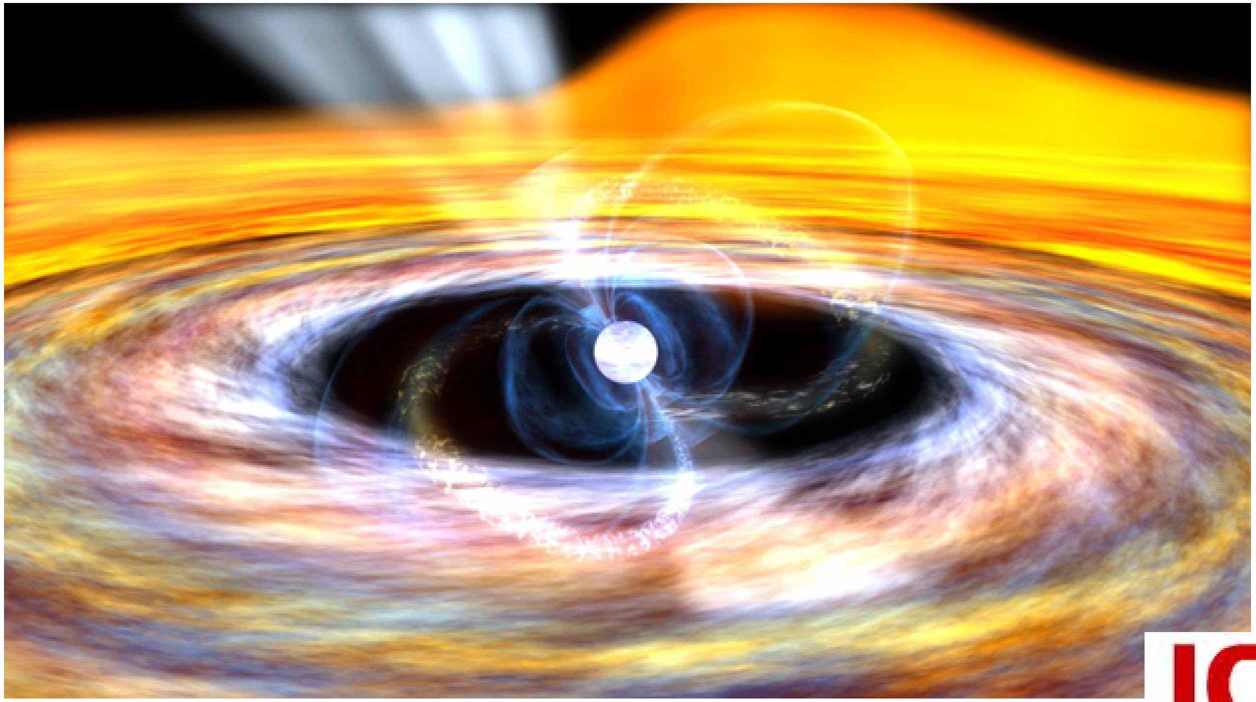
Swinging between accretion and rotation power in binary millisecond pulsars



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ICE IEEC CSIC

Transitional millisecond pulsars

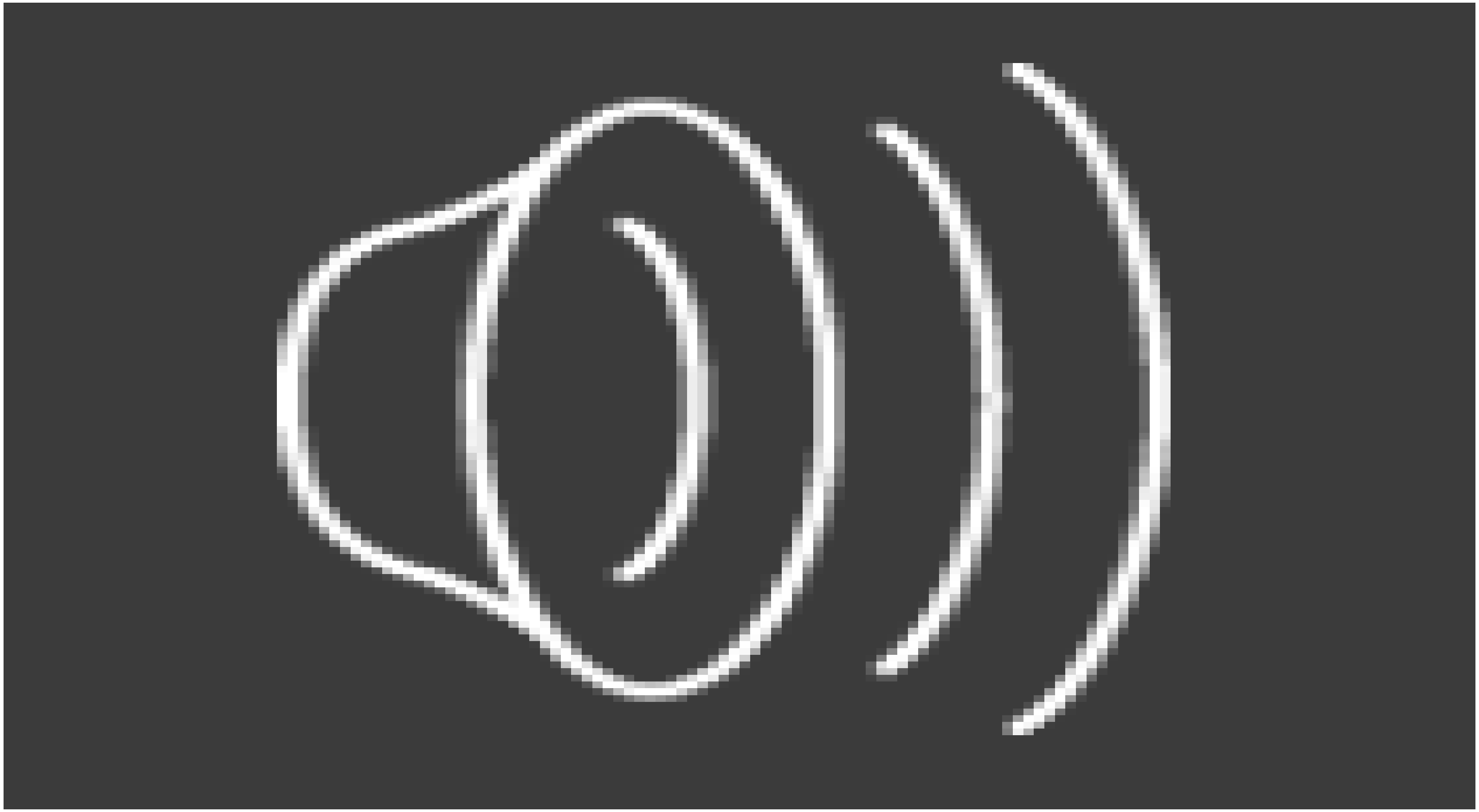
Bridging between pulsars powered by
the rotation of their magnetic field (**radio pulsars**) and
mass accretion (**X-ray pulsars**)

I. A full scale transition from a pulsar in M28, IGR J18245-2452

II. An intermediate case, PSR J1023+0038

III. Breaking news, a transition from XSS J12270-4859

Rotation powered pulsars: beacons from the radio to the gamma-rays



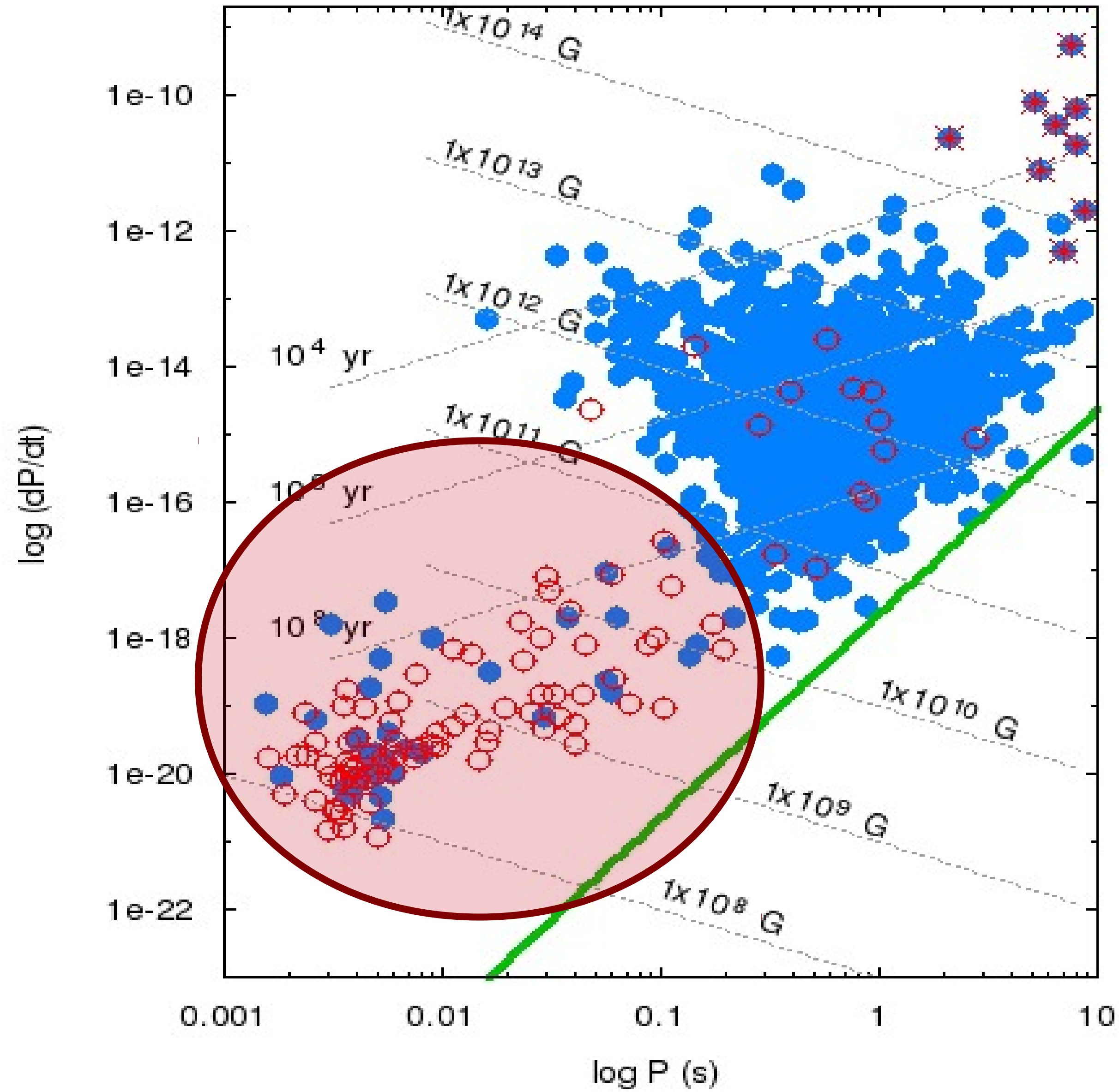
The fundamental plane of pulsars

Millisecond pulsars

[Backer+ 1982 Nature]

- weakly magnetised
- often in GCs

  → old systems

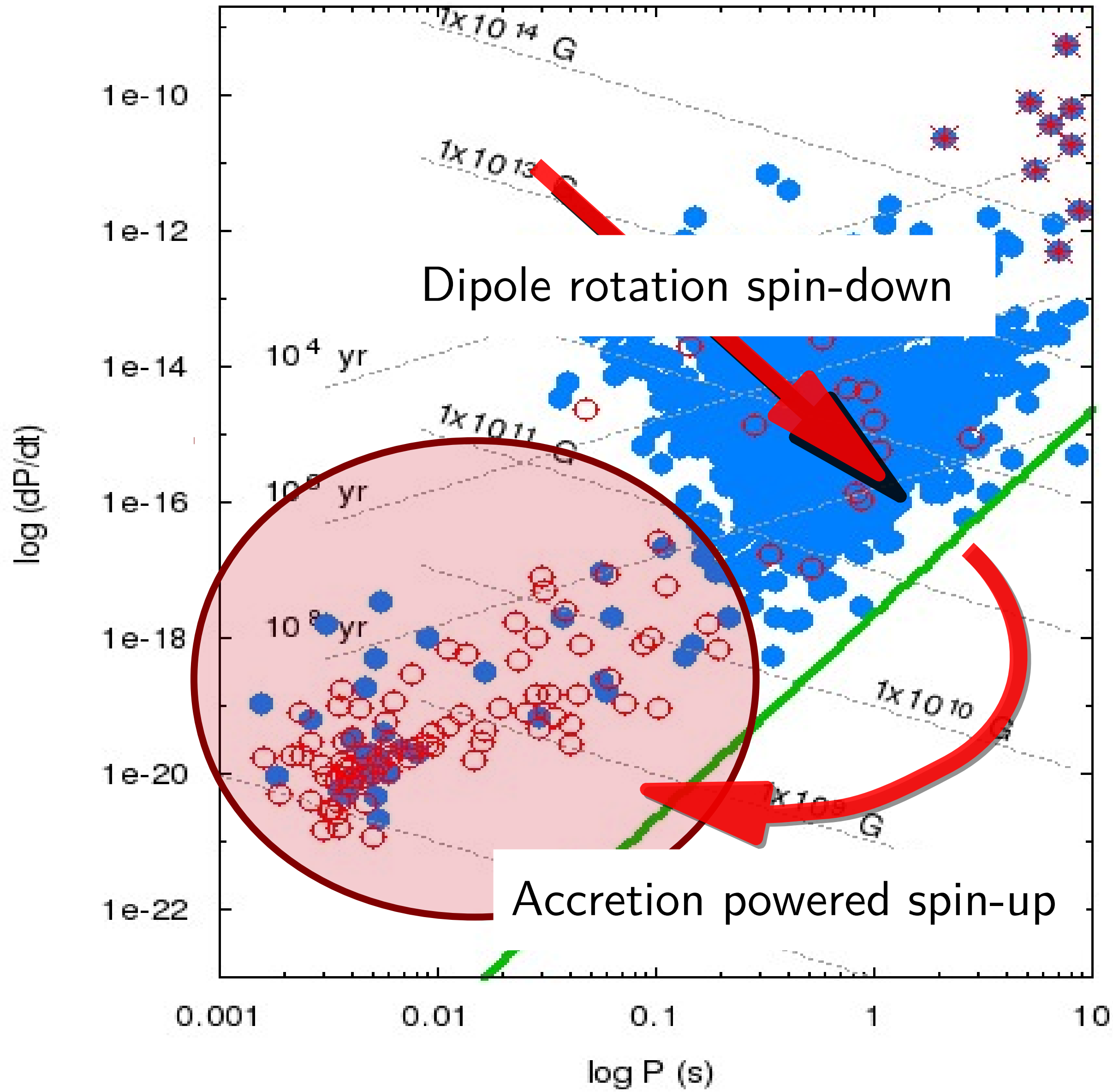


Recycling neutron stars

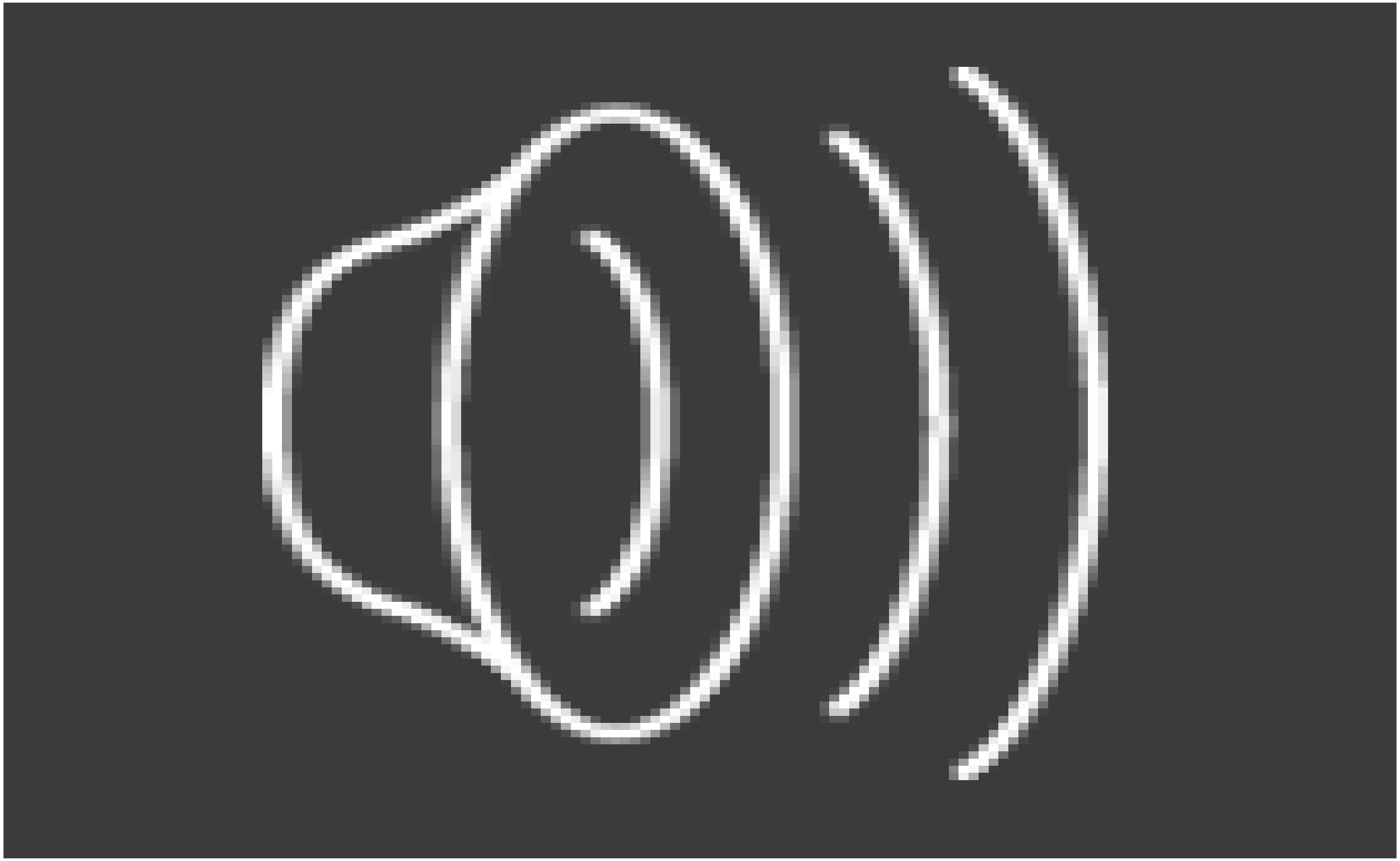
Millisecond pulsars

- old systems
- often in binaries

[Bisnovatyi-Kogan & Komberg 1974, Alpar+, Radhakrishnan+ 1982]



Spinning up neutron stars

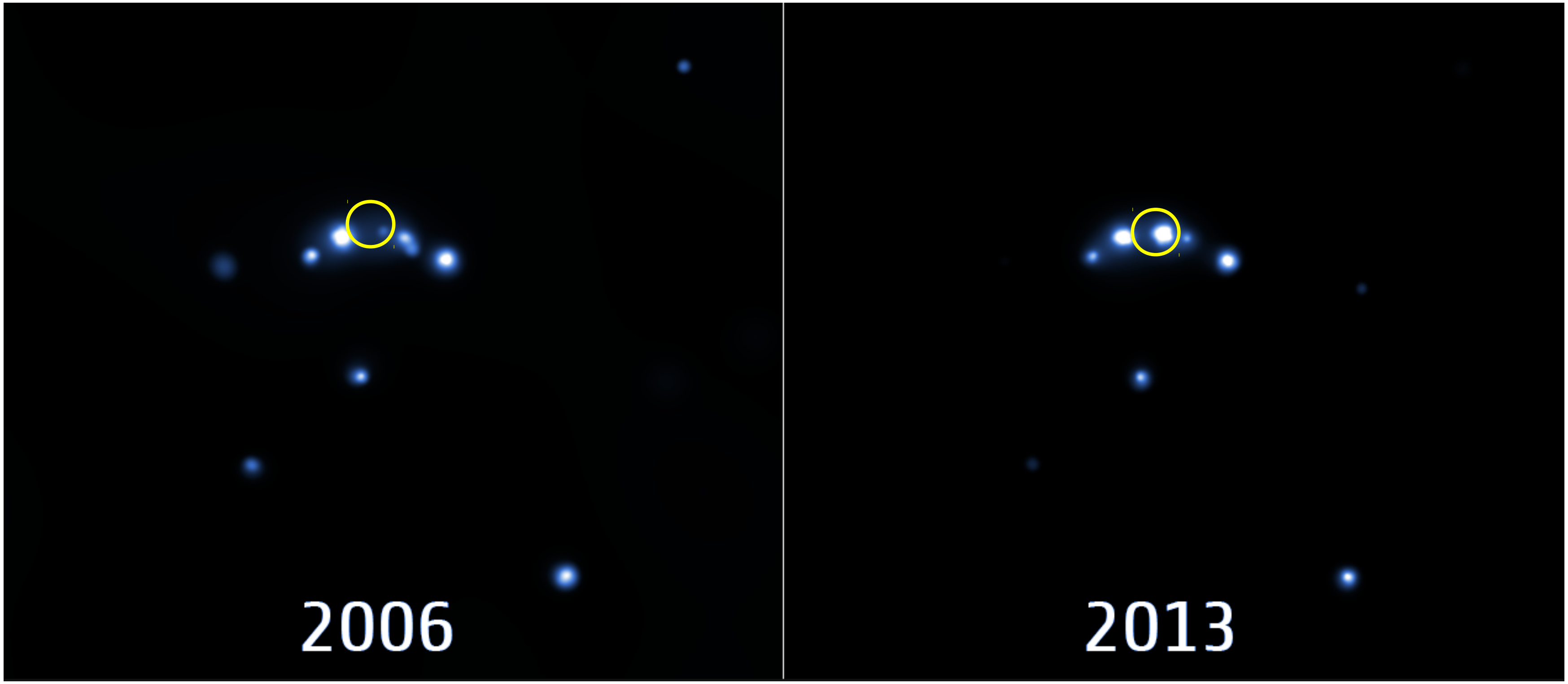


A new X-ray transient in M28 – IGR J18245-2452 (March 2013)

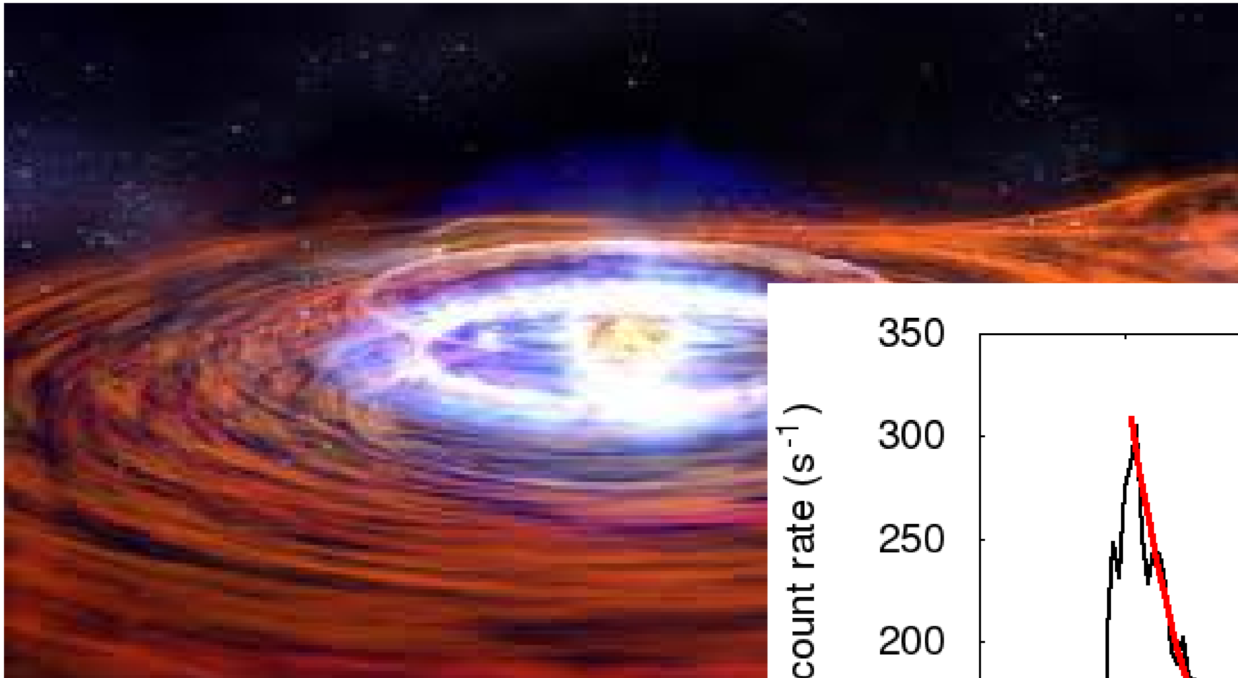
Globular Clusters are incubators of low mass X-ray binaries

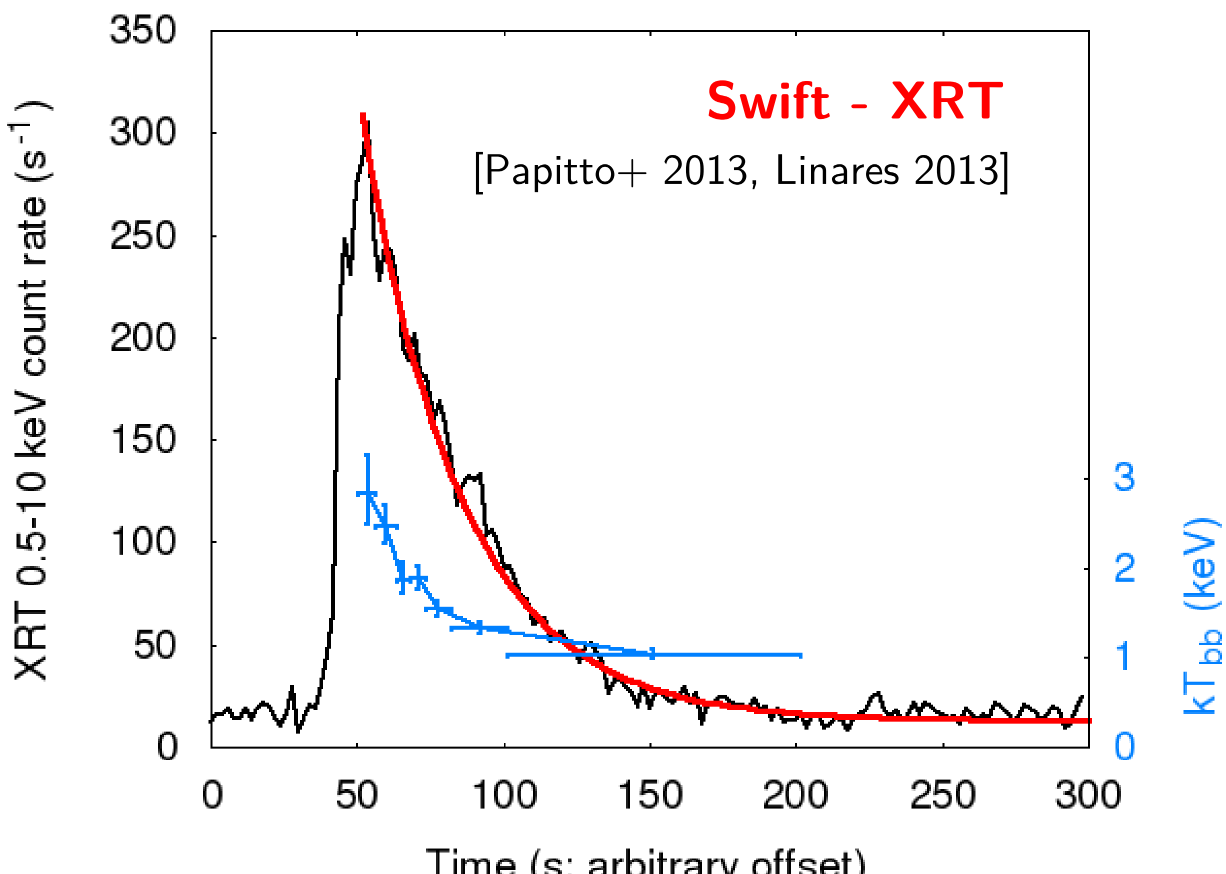
INTEGRAL monitoring of transients

X-ray luminosity $\sim$ few x 10^{36} erg/s $\rightarrow$ accretion power

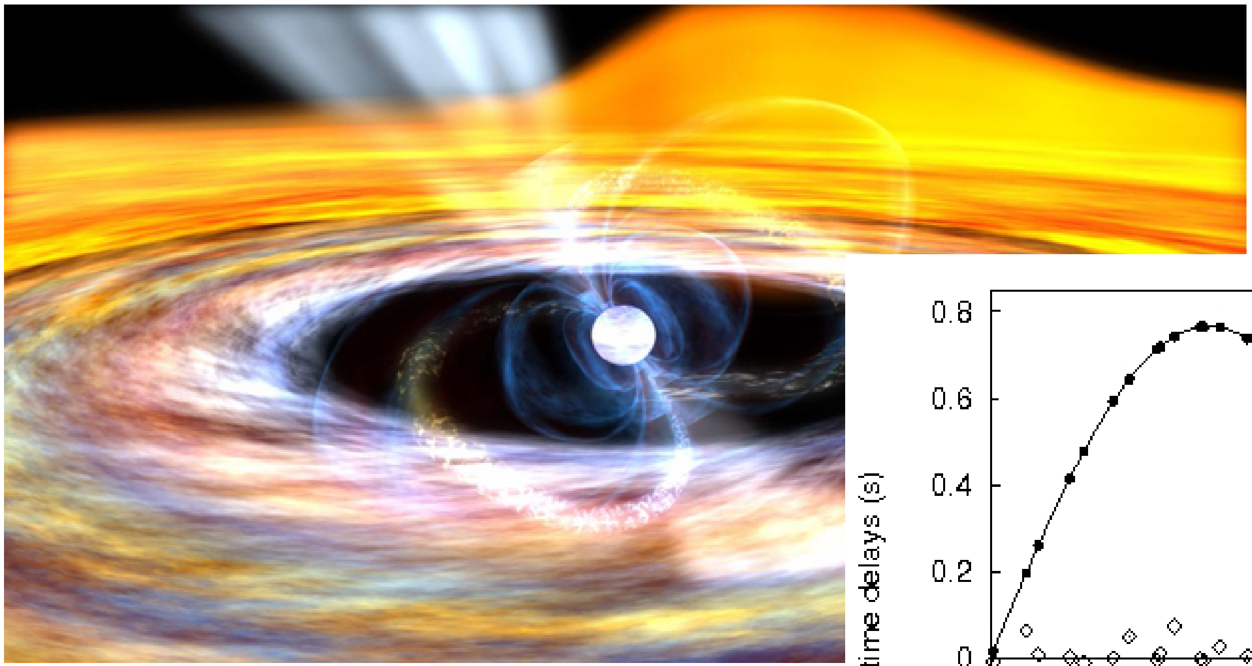


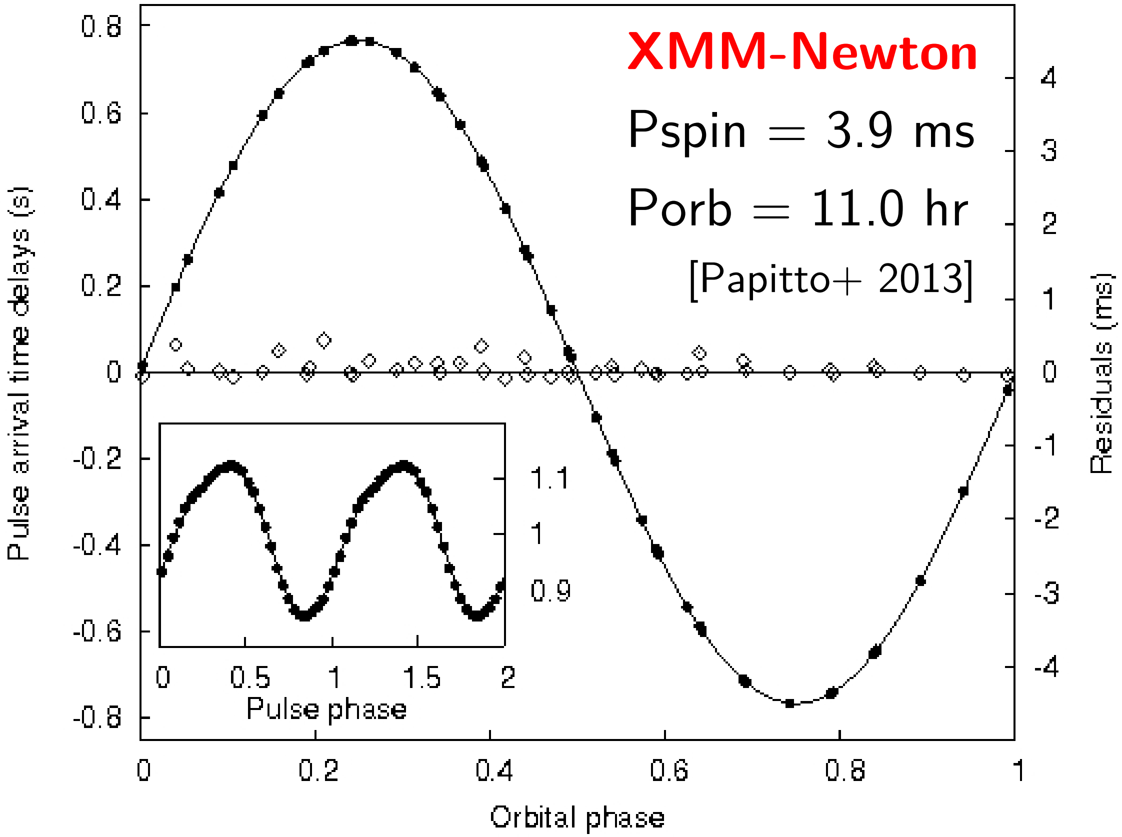
IGR J18245-2452 as a thermonuclear burster





IGR J18245-2452 is an accreting millisecond pulsar





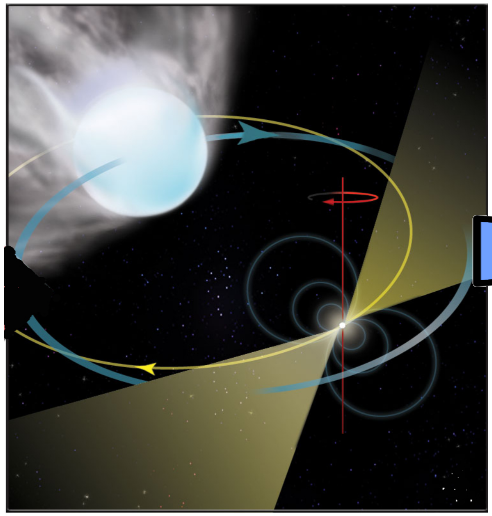
IGR J18245-2452 was a rotation powered pulsar

The first system showing at different times, rotation and accretion powered pulses

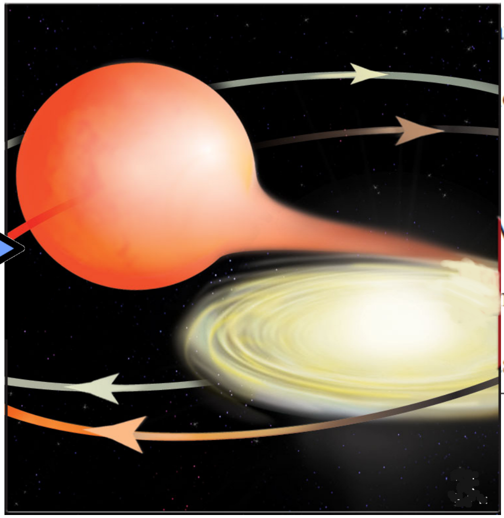
Table 1: Spin and orbital parameters of IGR J18245–2452 and PSR J1824–2452I.

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)
xis (lt-s)	0.76591(1)	0.7658(1)
omaly (MJD)	56395.216889(5)	
	$\leq 1 \times 10^{-4}$	
$M_\odot$)	$2.2831(1) \times 10^{-3}$	$2.282(1) \times 10^{-3}$
nass ($M_\odot$)	0.174(3)	0.17(1)
ss ($M_\odot$)	0.204(3)	0.20(1)

Papitto+ 2013 Begin 2006



2006 - 2010

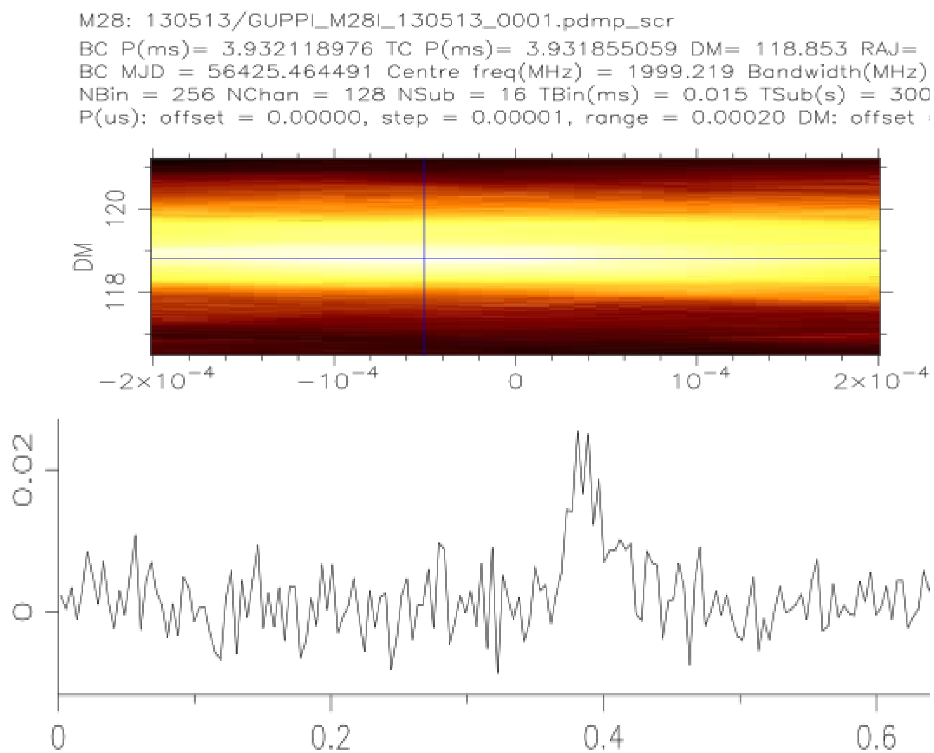


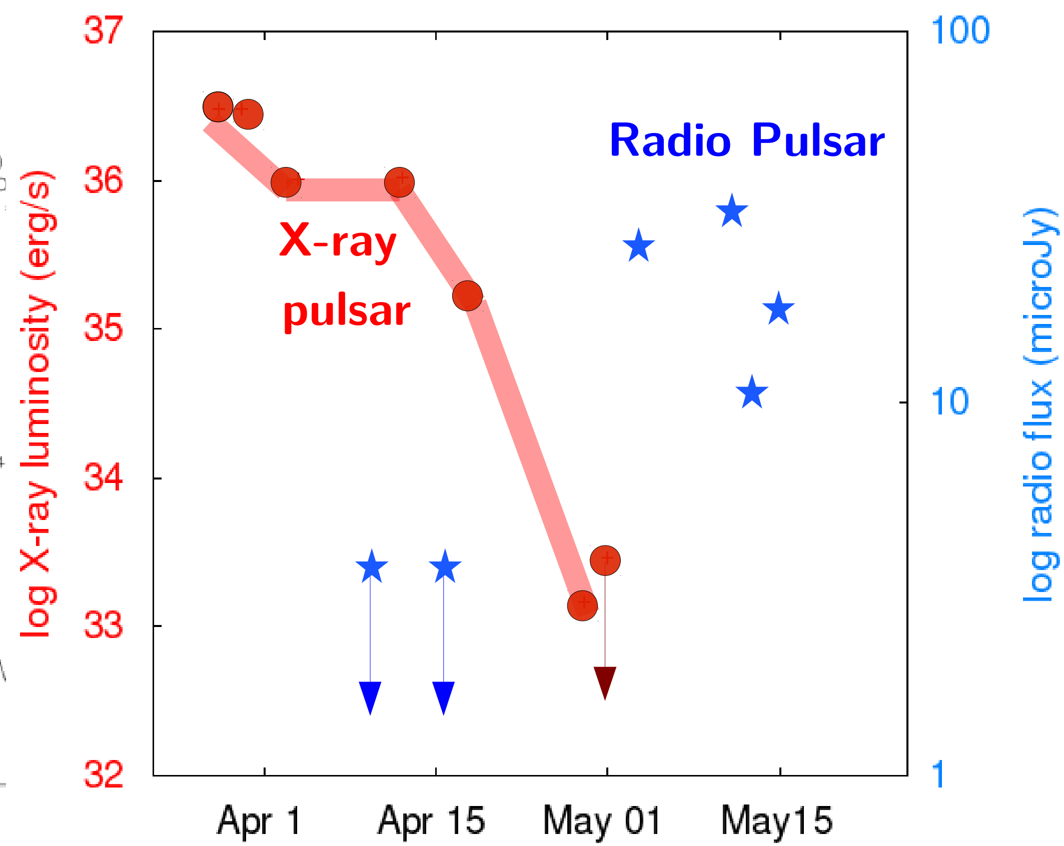
2013

IGR J18245-2452 again as rotation powered pulsar (May 2013)

A few days after the end of the X-ray outburst

multiple detection of a weak radio pulsar (~10-50 microJy) – GBT, PKS, WSRT

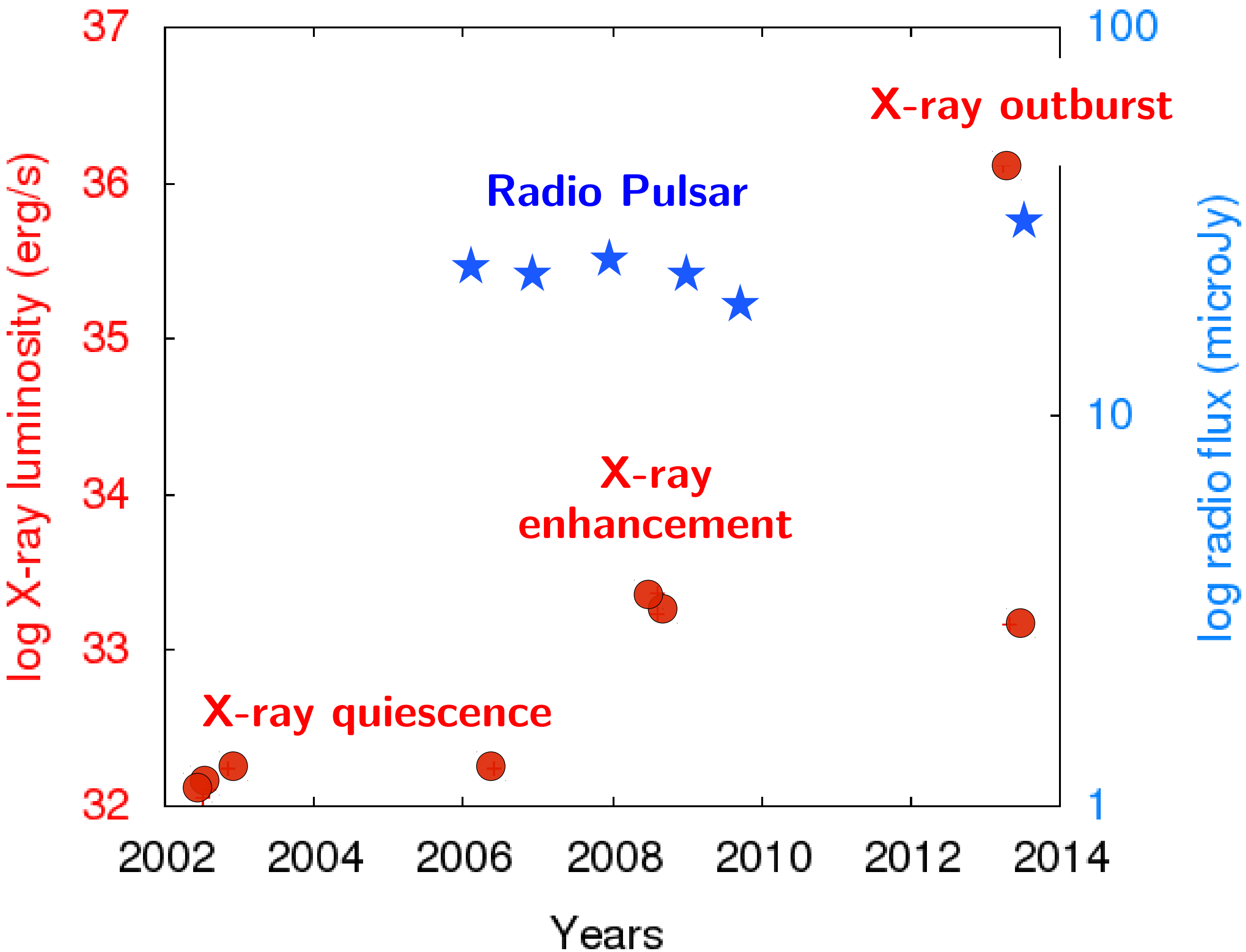




IGR J18245-2452 archival observations

Radio pulsar faint and irregularly eclipsed

Past **X-ray** brightening seen by Chandra - August 2008 (more on this later)



Swings driven by mass in-flow rate variability

Low Mass in-flow rate → Magnetic field dominates

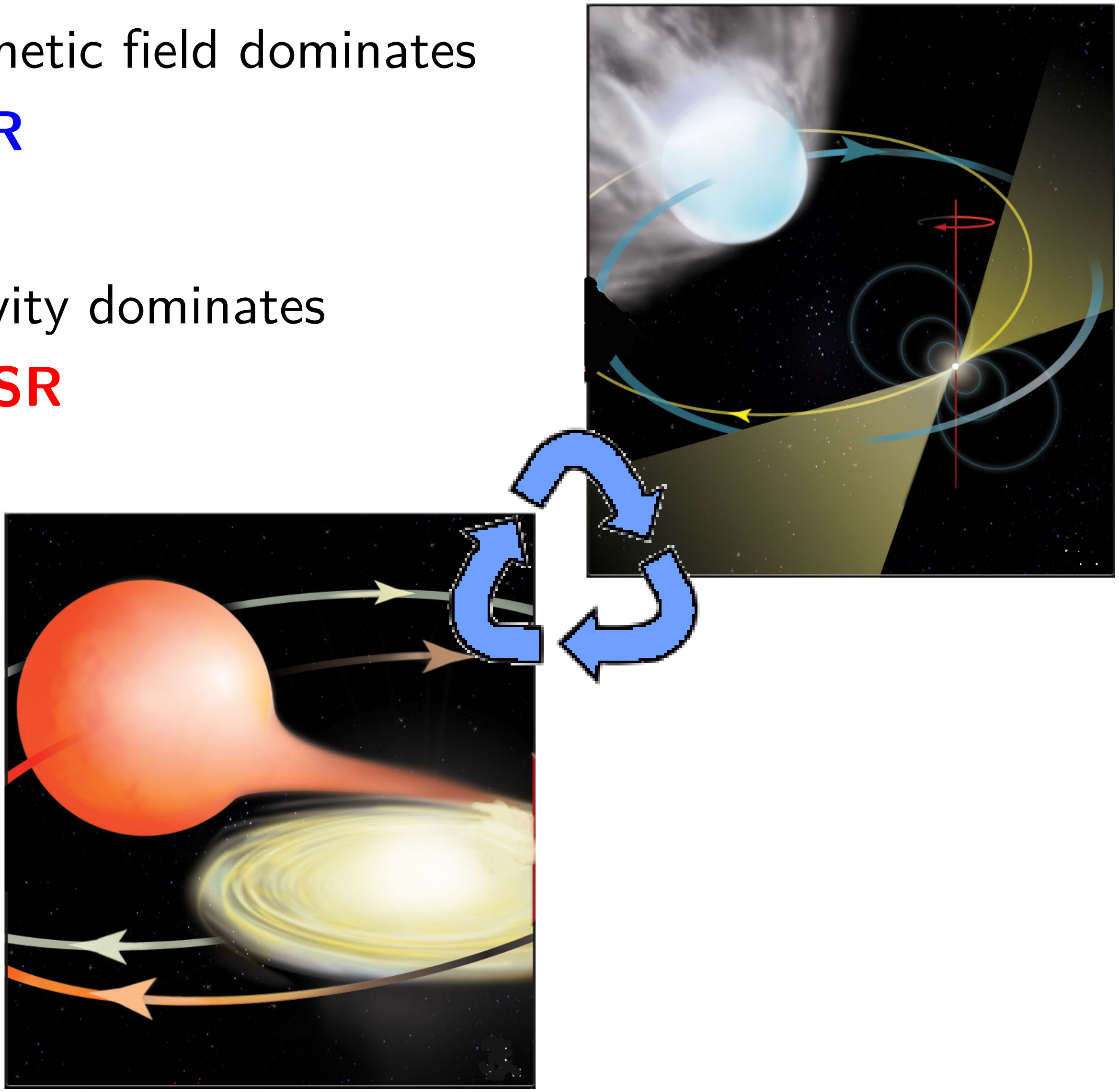
→ rotation powered **radio PSR**

High Mass in-flow rate → Gravity dominates

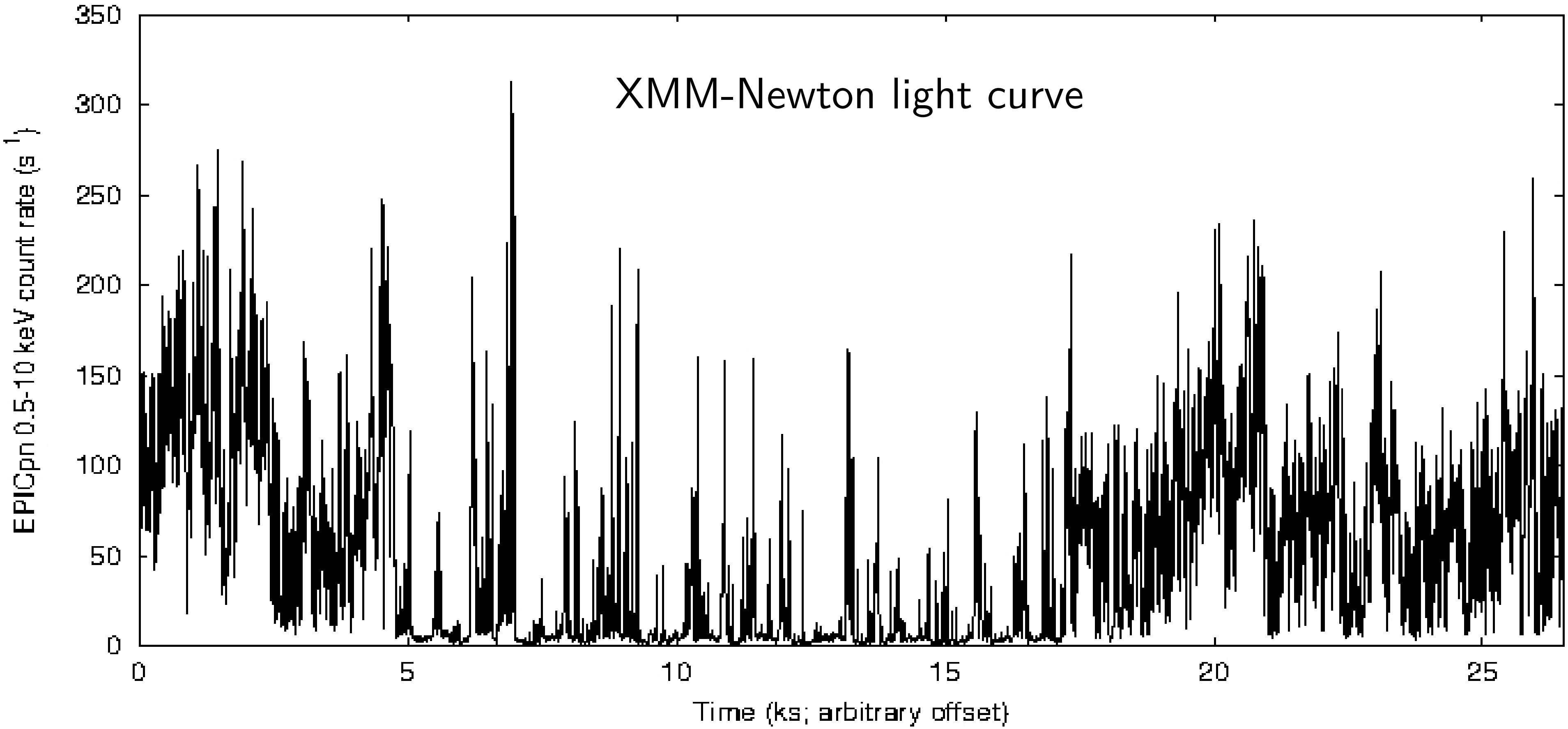
→ accretion powered **X-ray PSR**

[Stella+ 1994; Campana+ 1998;

Burderi+ 2001]

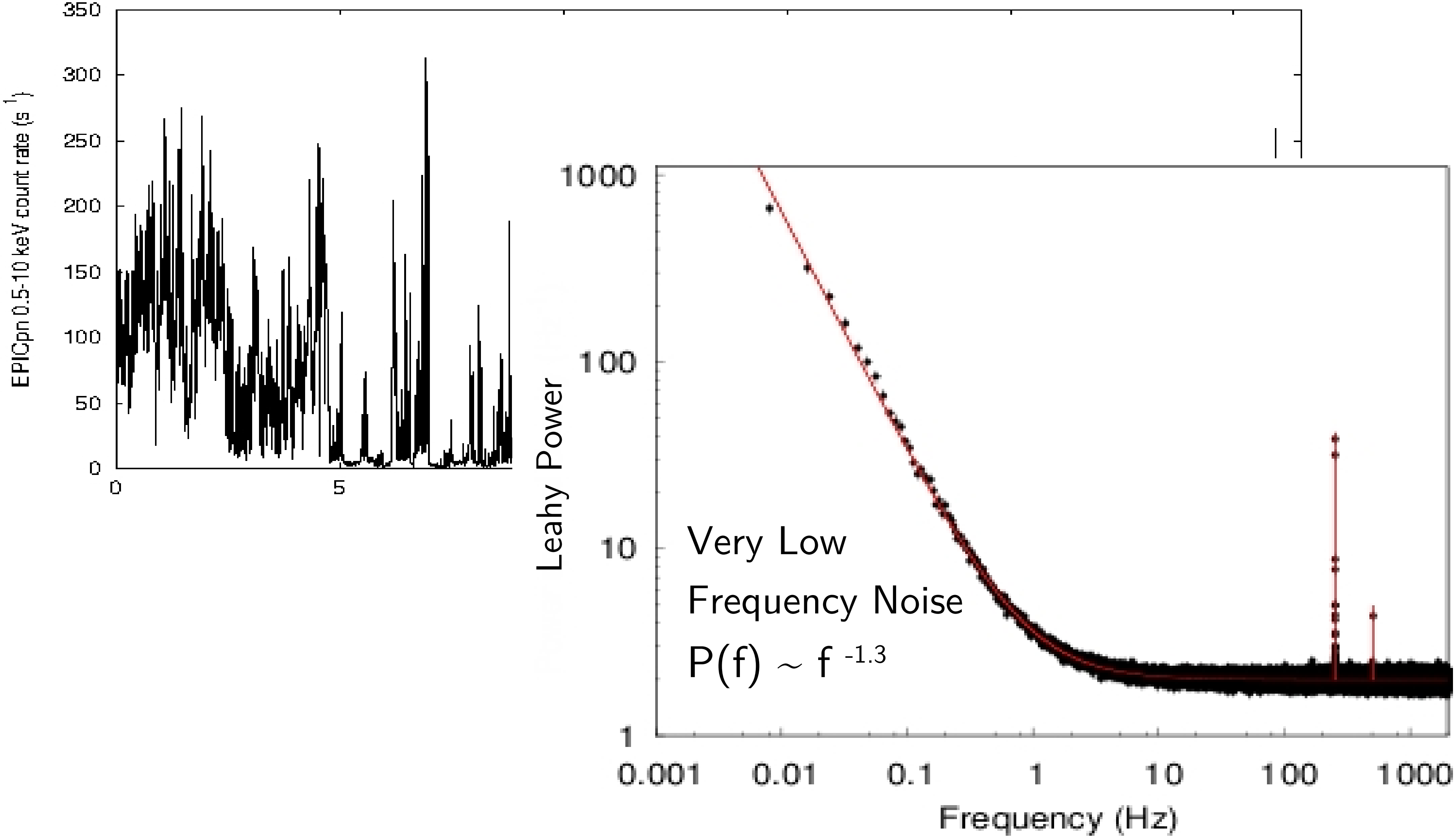


IGR J18245-2452: X-ray flux variability

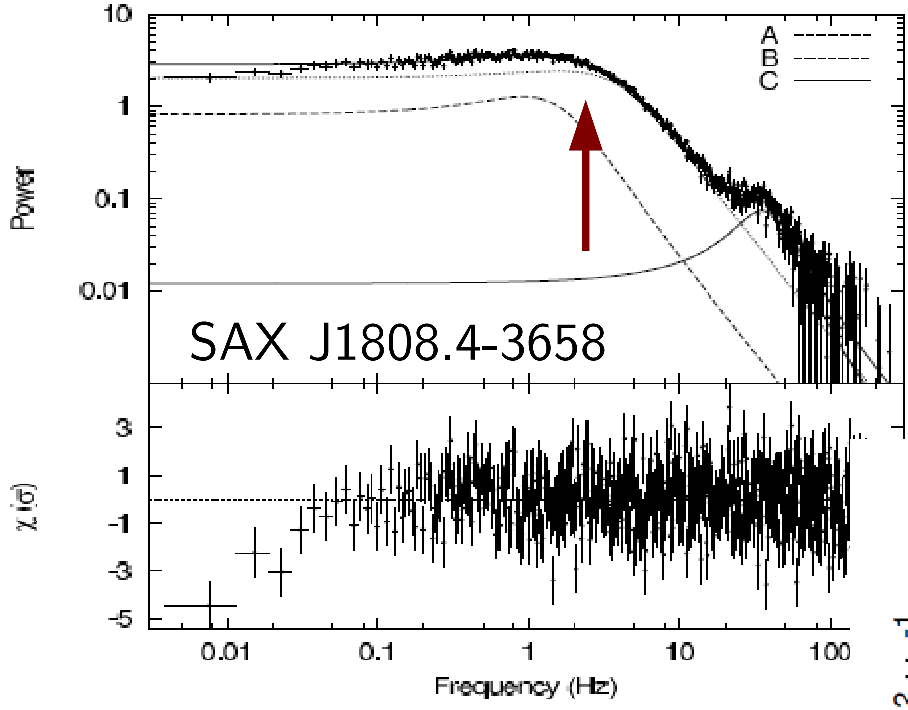


Ferrigno, Bozzo, Papitto, Rea +, A&A, 2013 submitted

IGR J18245-2452: X-ray flux variability



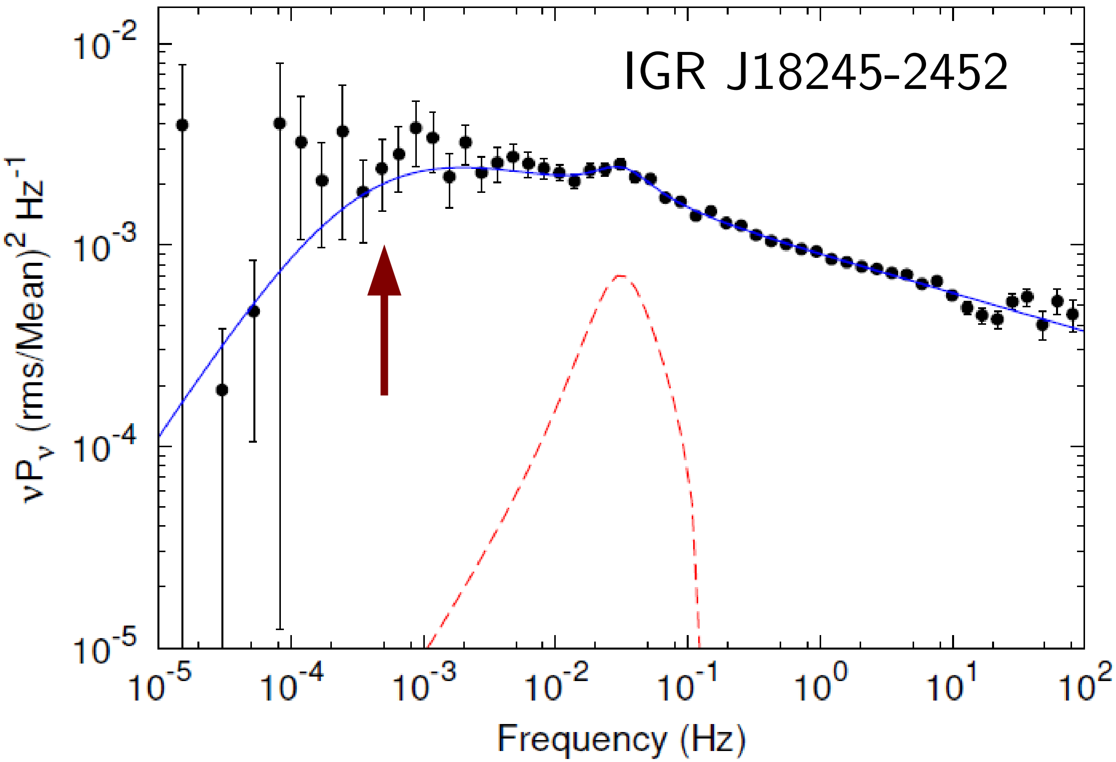
IGR J18245-2452: X-ray flux variability



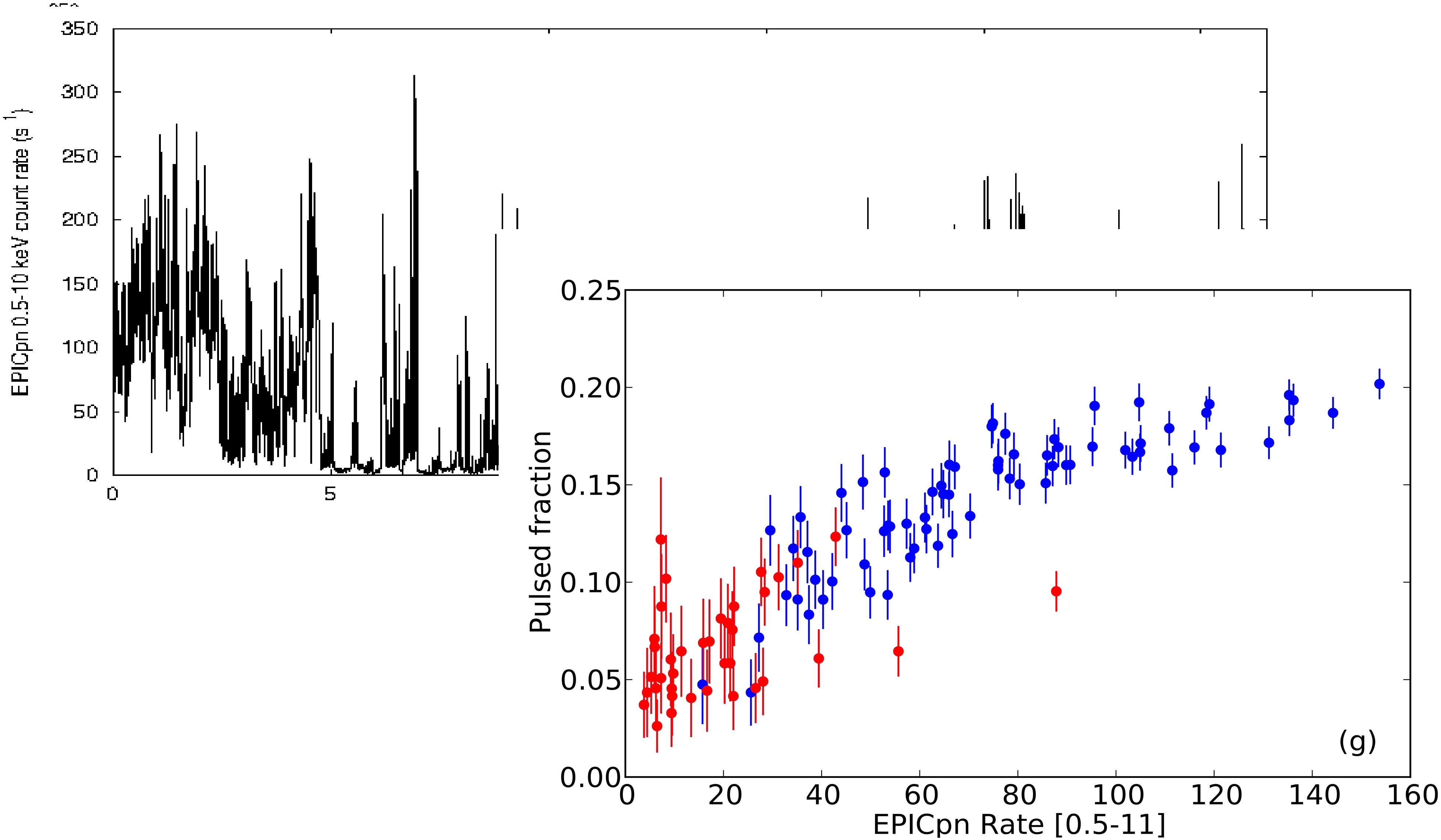
Noise of Accreting ms pulsars usually cut off at ~1 Hz

Here ~few x 10^{-4} Hz

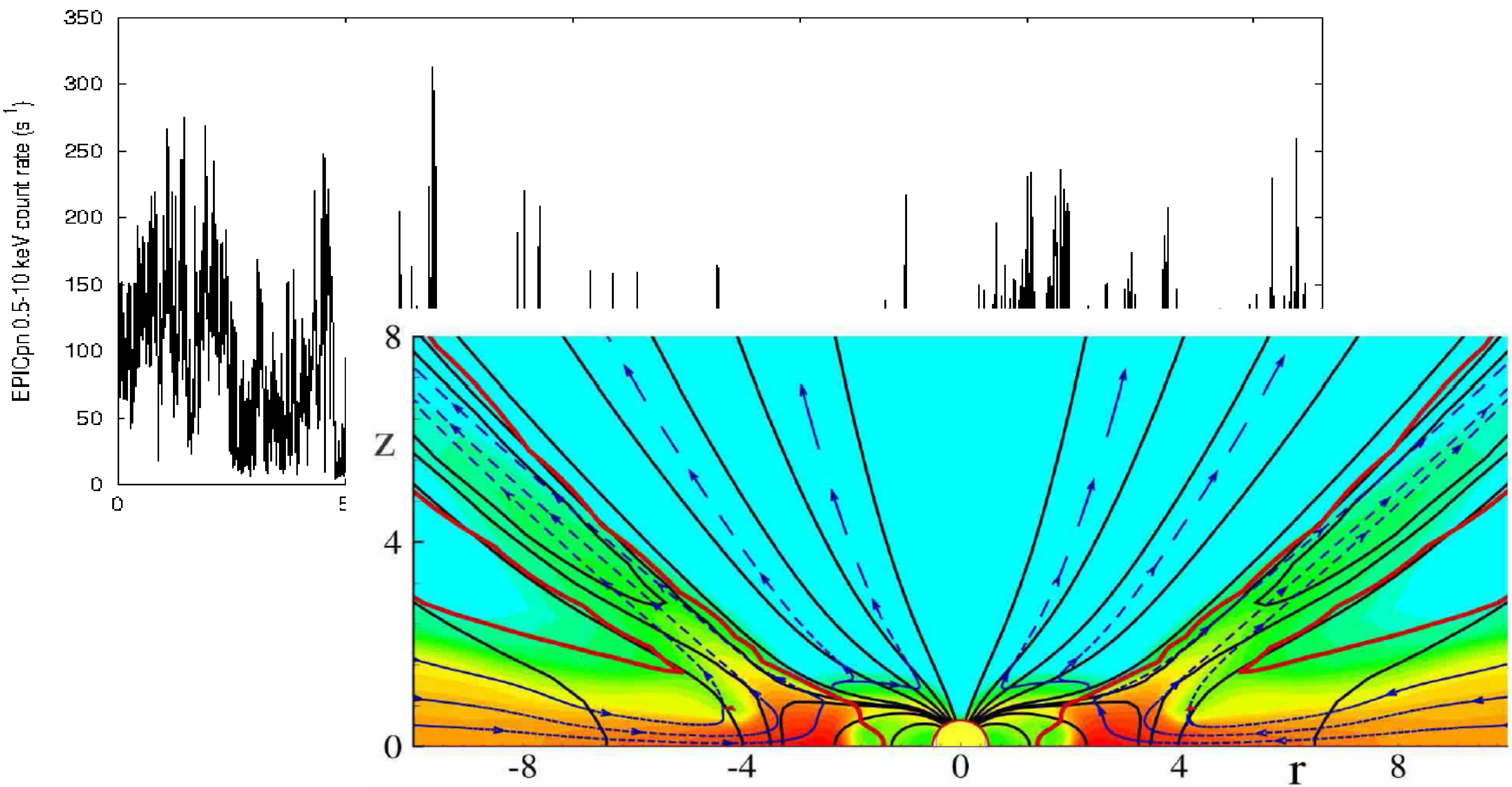
Accretion rate fluctuations at the outer disk? [Lyubarskii 1997]



Pulsed fraction correlates with X-ray flux



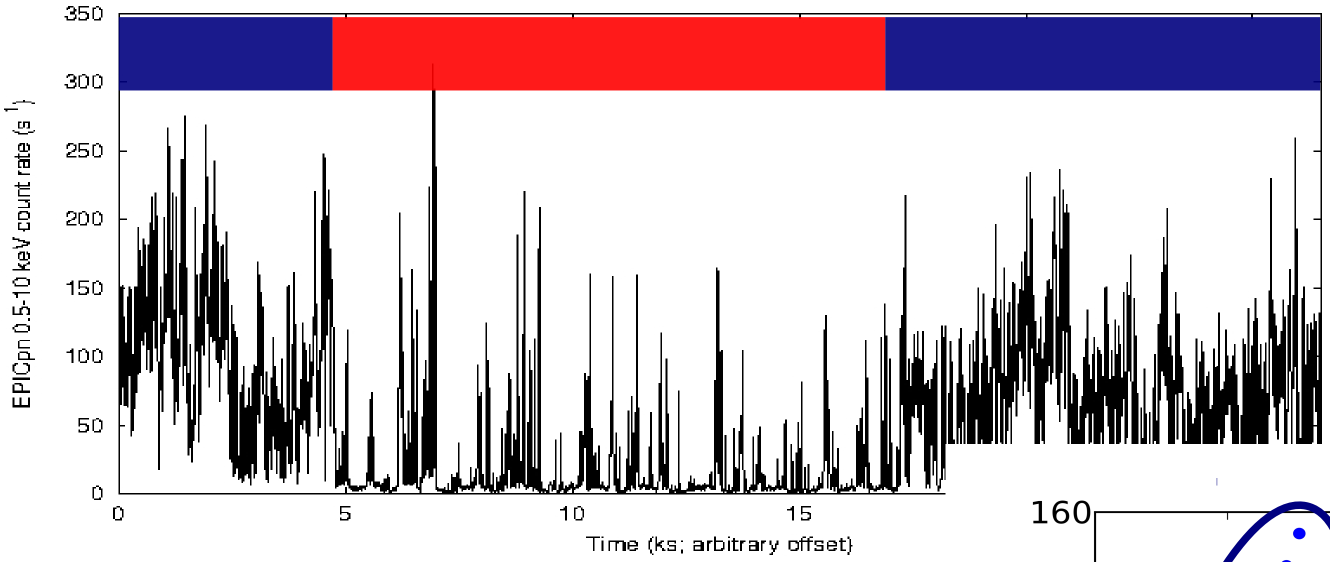
Propeller inhibition of accretion?



Total inhibition of accretion never reached (pulse observed even at lowest flux)

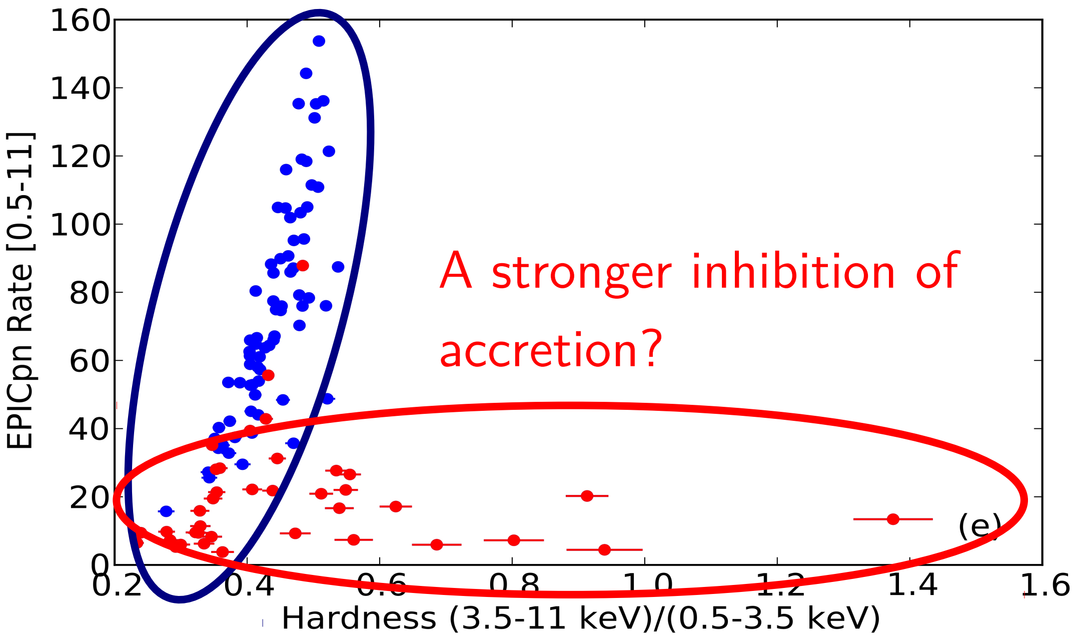
IGR J18245-2452: patterns of variability

Average spectrum is hard (Comptonization with $\Gamma \sim 1.4$)



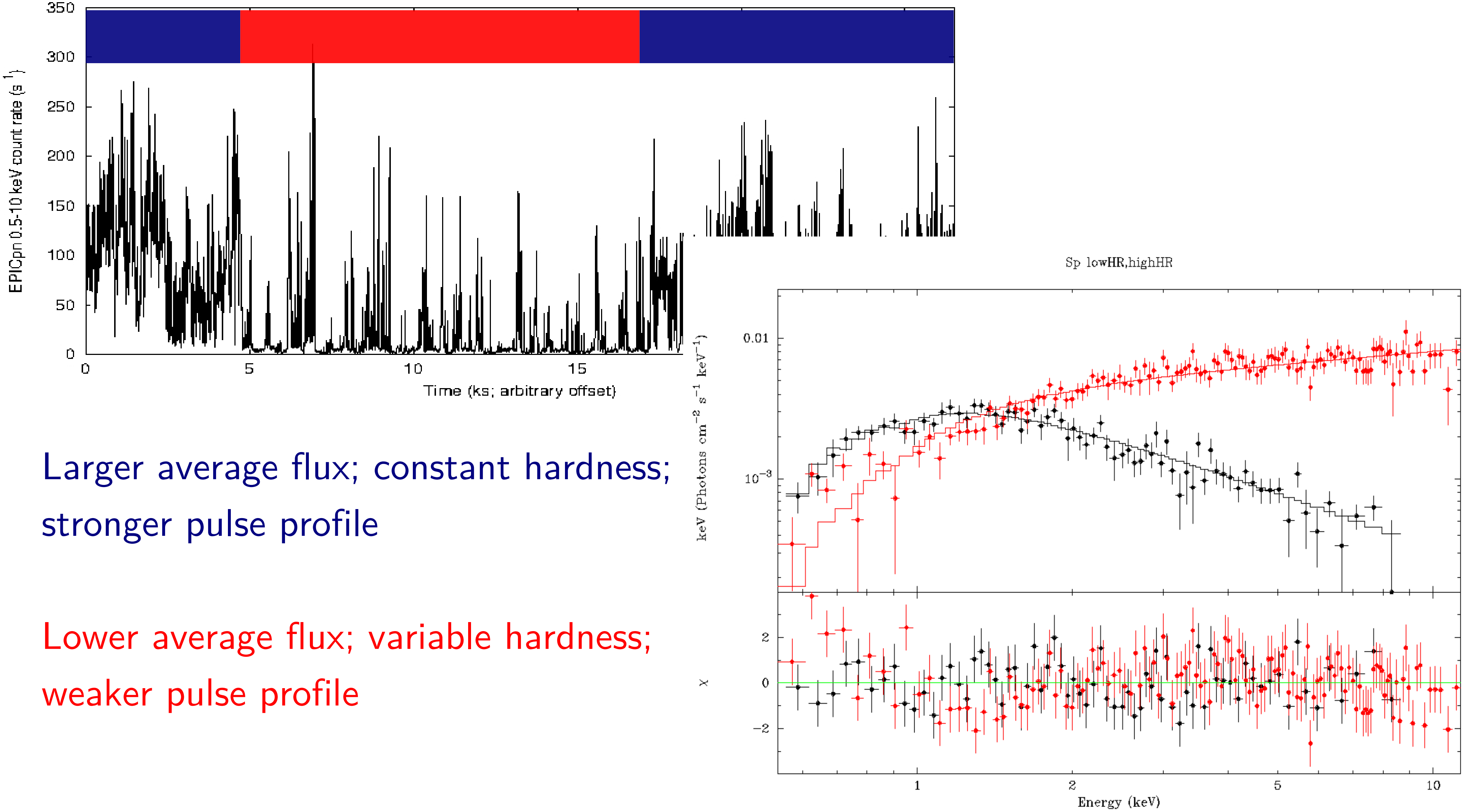
Larger average flux; constant hardness; stronger pulse profile

Lower average flux; variable hardness; weaker pulse profile



IGR J18245-2452: patterns of variability

Average spectrum is hard (Comptonization with Γ∼1.4)



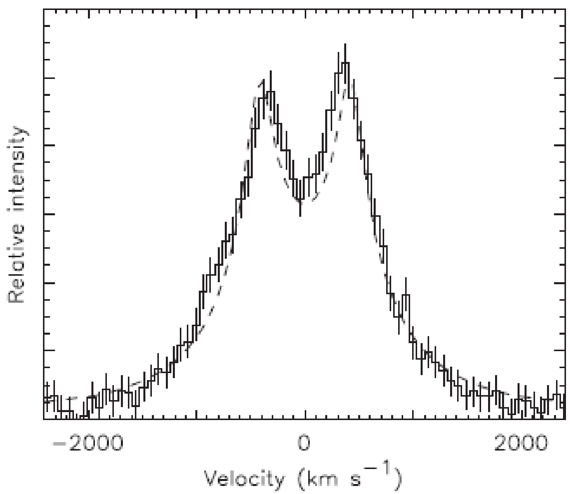
Larger average flux; constant hardness; stronger pulse profile

Lower average flux; variable hardness; weaker pulse profile

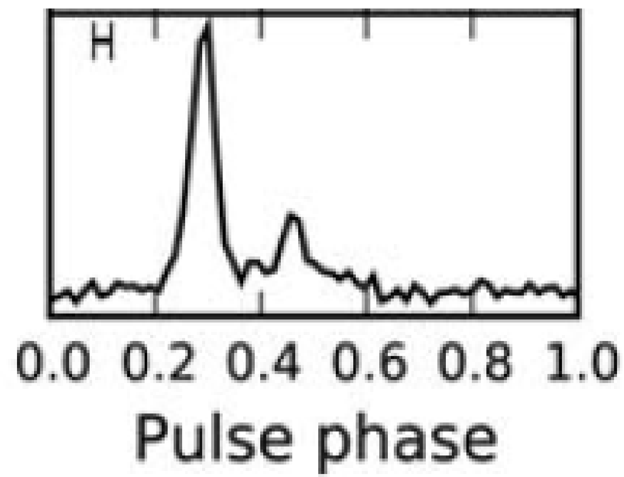
Where to go next?

A Radio Pulsar/X-ray Binary Link

Anne M. Archibald,[1*] Ingrid H. Stairs,[2,3,4] Scott M. Ransom,[5] Victoria M. Kaspi,[1]
Vladislav I. Kondratiev,[6,5,7] Duncan R. Lorimer,[6,8] Maura A. McLaughlin,[6,8]
Jason Boyles,[6,8] Jason W. T. Hessels,[9,10] Ryan Lynch,[11] Joeri van Leeuwen,[9,10]
Mallory S. E. Roberts,[12] Frederick Jenet,[13] David J. Champion,[3] Rachel Rosen,[8]
Brad N. Barlow,[14] Bart H. Dunlap,[14] Ronald A. Remillard[15]



An accretion disk in 2000-01

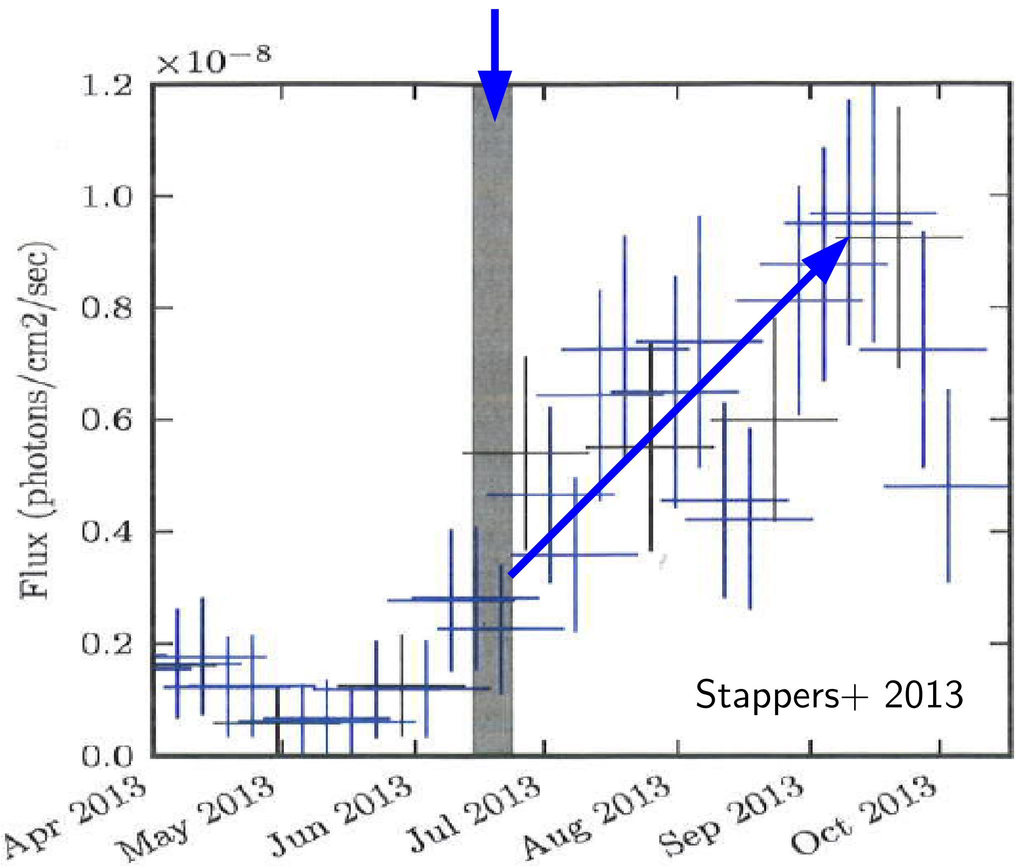


A rotation powered pulsar nowadays

Radio pulse are irregularly eclipsed (ongoing mass transfer)

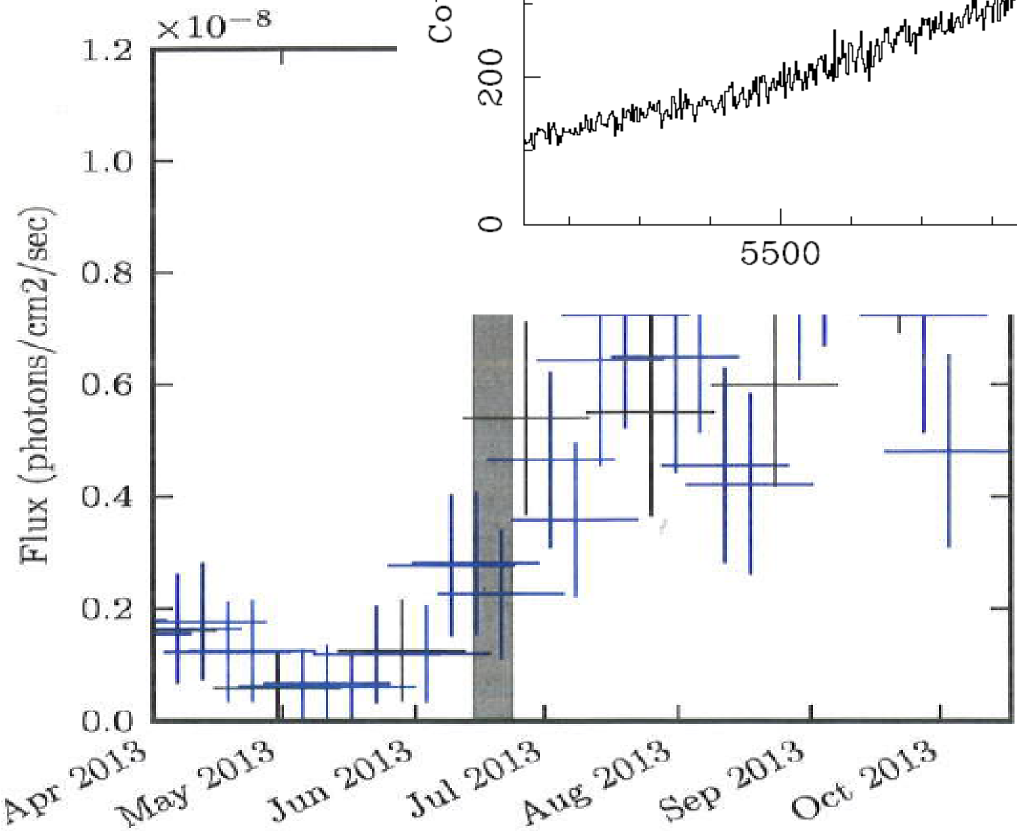
PSR J1023+0038: June 2013, a forming accretion disc

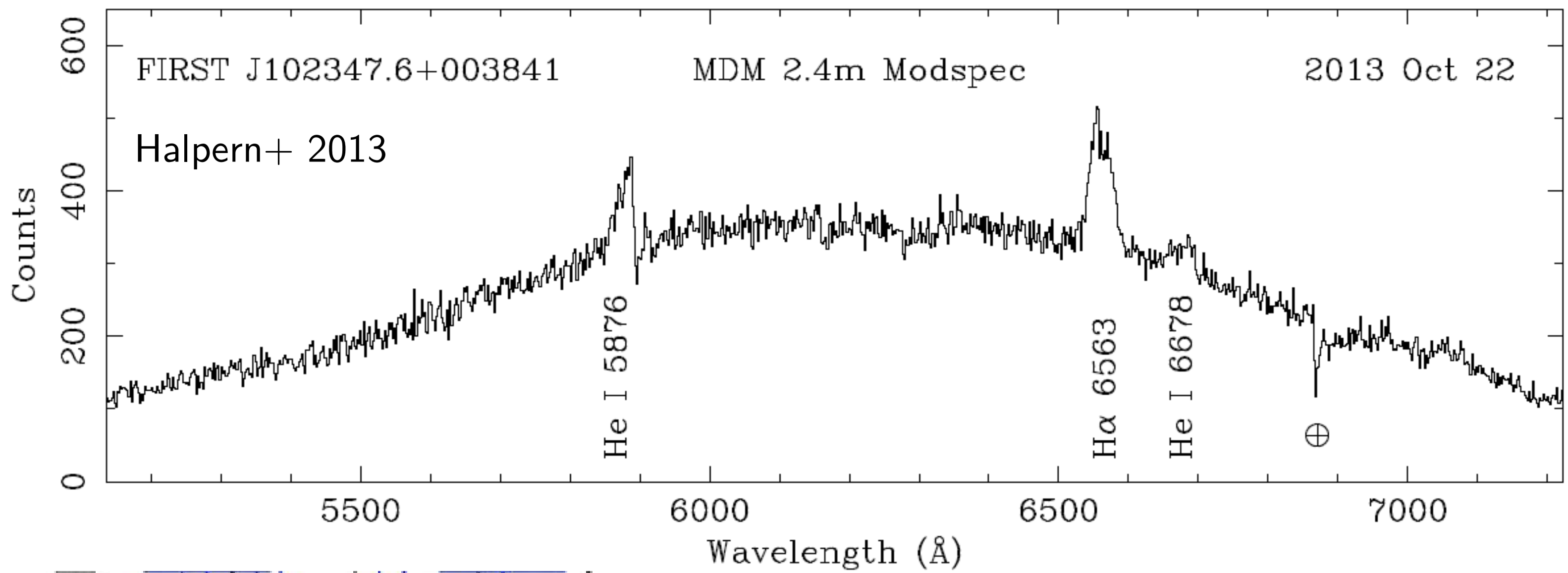
Radio pulsar disappears



5-fold increase of gamma-ray flux

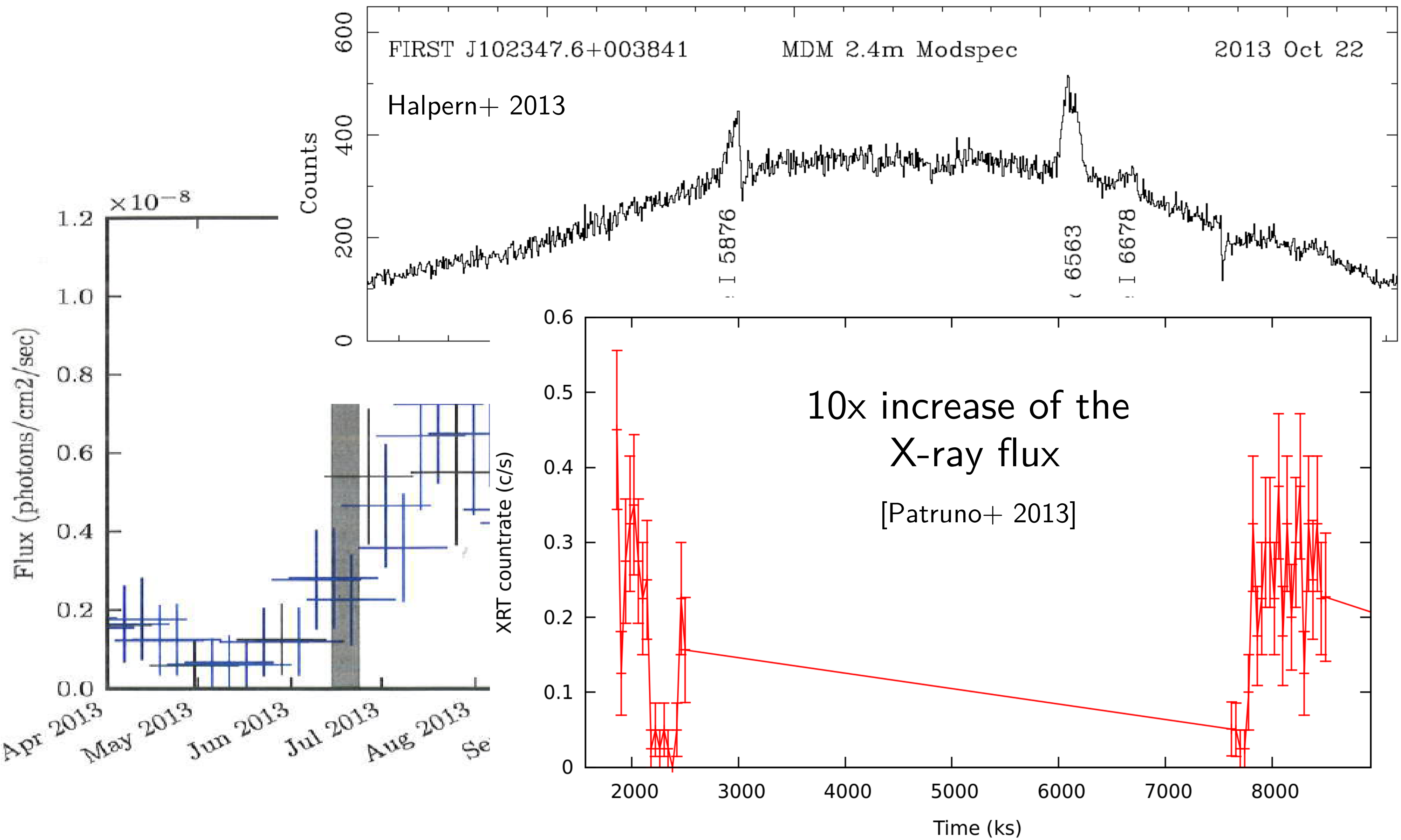
PSR J1023+0038: June 2013, a forming accretion disc



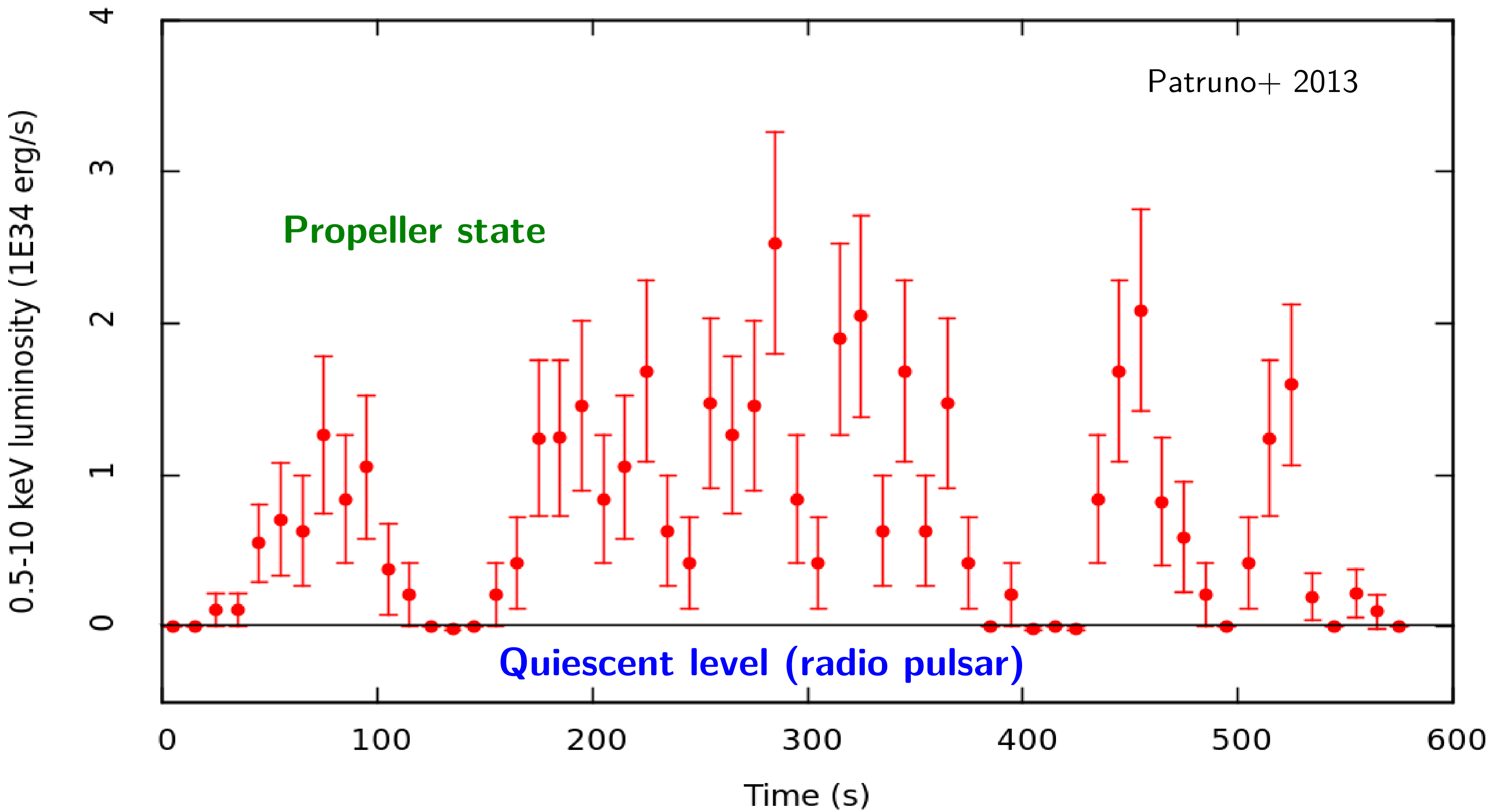


Broad double-peaked optical emission lines

PSR J1023+0038: June 2013, a forming accretion disc



PSR J1023+0038: X-ray variability



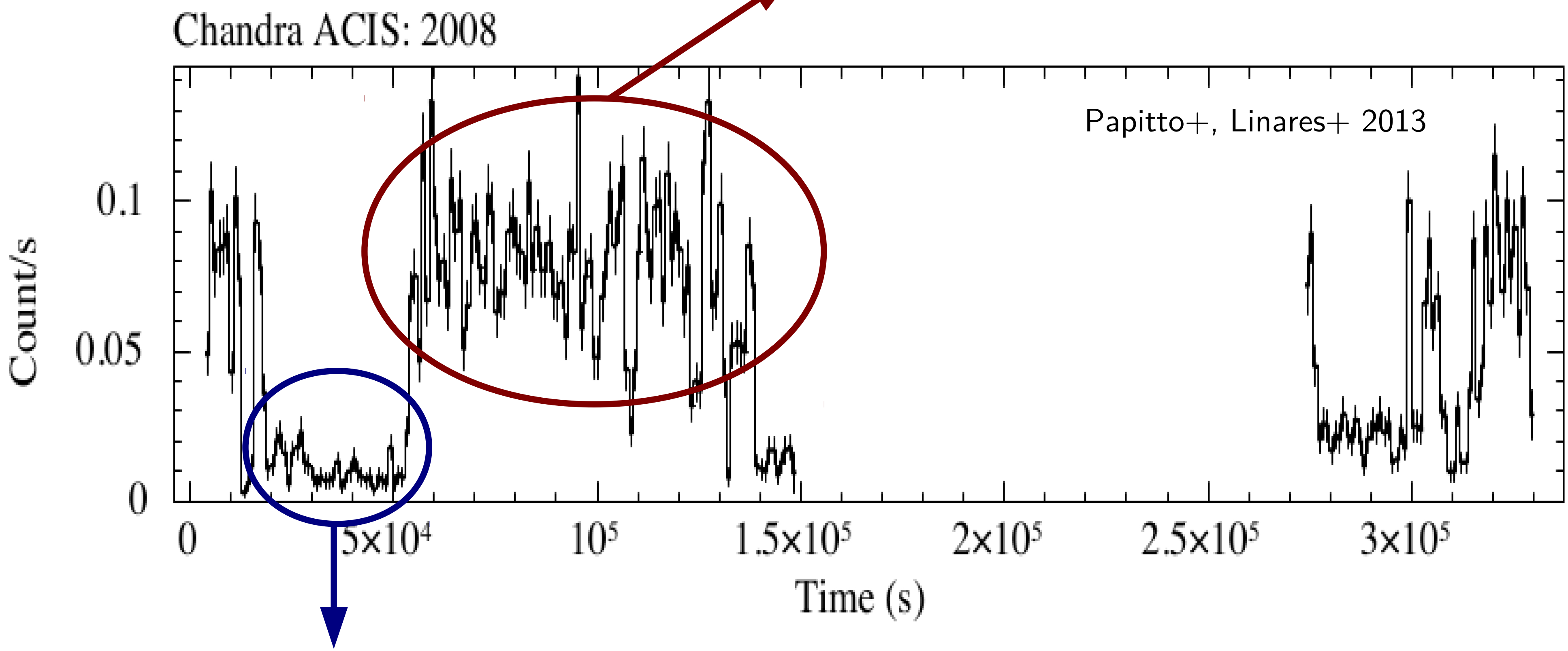
At peak → L(X-ray)~$3x10^{34}$ erg/s

With bolometric corrections equals the spin down power (→ need for accretion power)

At minimum → L(X-ray) $\lesssim$ $3x10^{32}$ erg/s (→ compatible with rotation-powered)

PSR J1023+0038: similarities with IGR J18245-2452

Propeller pulsar (~5E33 erg/s)

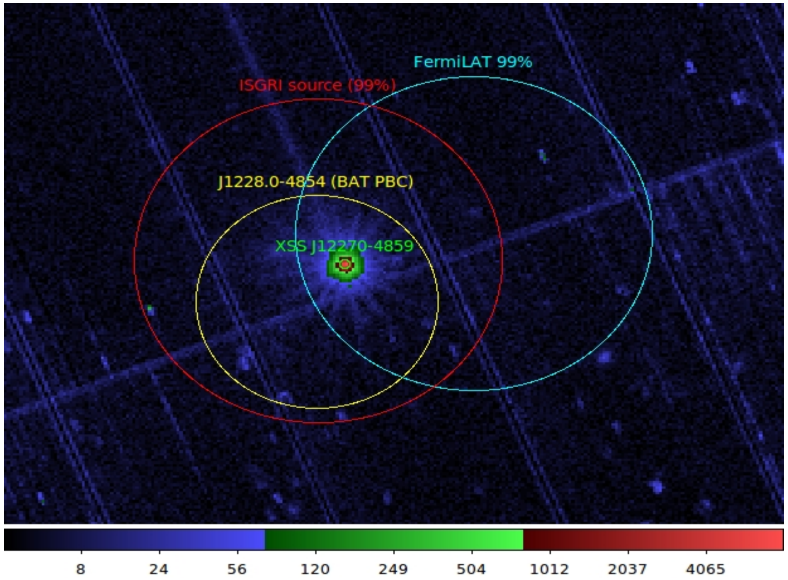


Rotation powered pulsar (~5E32 erg/s)

A gamma-ray bright low-mass X-ray binary: XSS J12270-4859

L(X-rays) ~ 2 x 10^{34} d_{2kpc}^{2} erg/s

L(γ-rays) ~ 2 x 10^{34} d_{2kpc}^{2} erg/s



Flares and dips in soft X-rays

No pulsations detected in radio and X-rays

Optical continuum: K2-K5 star + disc

Broad Hα, Hβ and He II detected indicate accretion disk

[De Martino+ 2010,2012; Saitou+ 2010; Hill+ 2011]

Radio
Γ=1.5

Opt/UV
K2-K5 star
+
disc

X-rays
Γ=1.7

γ-rays
Γ=2.1
Ecut=4.1 GeV

A millisecond pulsar in propeller?

Relativistic electrons up to $\gamma \sim 10^4$ from shocks at the magnetospheric boundary

Synchrotron emission ($B \sim 5 \times 10^6$ G)

Synchrotron self-Compton emission

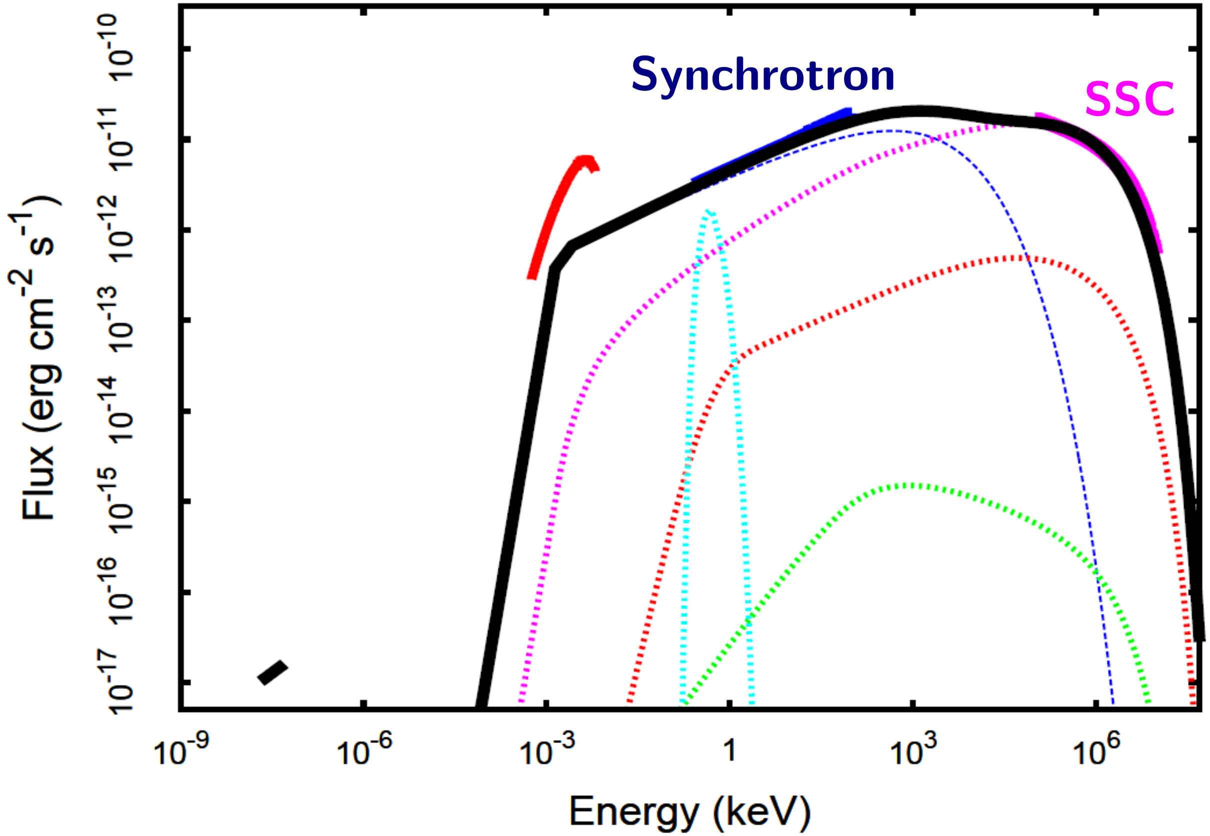
(electron density $\sim 10^{18}$ cm-3)

The SED is reproduced for typical

parameters of MSP

($B \sim 4 \times 10^8$ G; Rin~40km)

and acceleration parameter ~ 0.01-0.1



[Previous]

A possible state transition in the low-mass X-ray binary XSS J12270-4859

ATel #5647; C. G. Bassa (ASTRON), A. Patruno (Leiden/ASTRON), J. W.T. Hessels (ASTRON/UvA), A. M. Archibald (ASTRON), E. K. Mahony (ASTRON), B. Monard (Kleinkaroo Observatory), E. F. Keane (Swinburne), S. Bogdanov (Columbia), B. W. Stappers (Manchester), G. H. Janssen (ASTRON), S. Tendulkar (Caltech)
on **10 Dec 2013; 11:41 UT**
Credential Certification: Alessandro Patruno (patruno@strw.leidenuniv.nl)

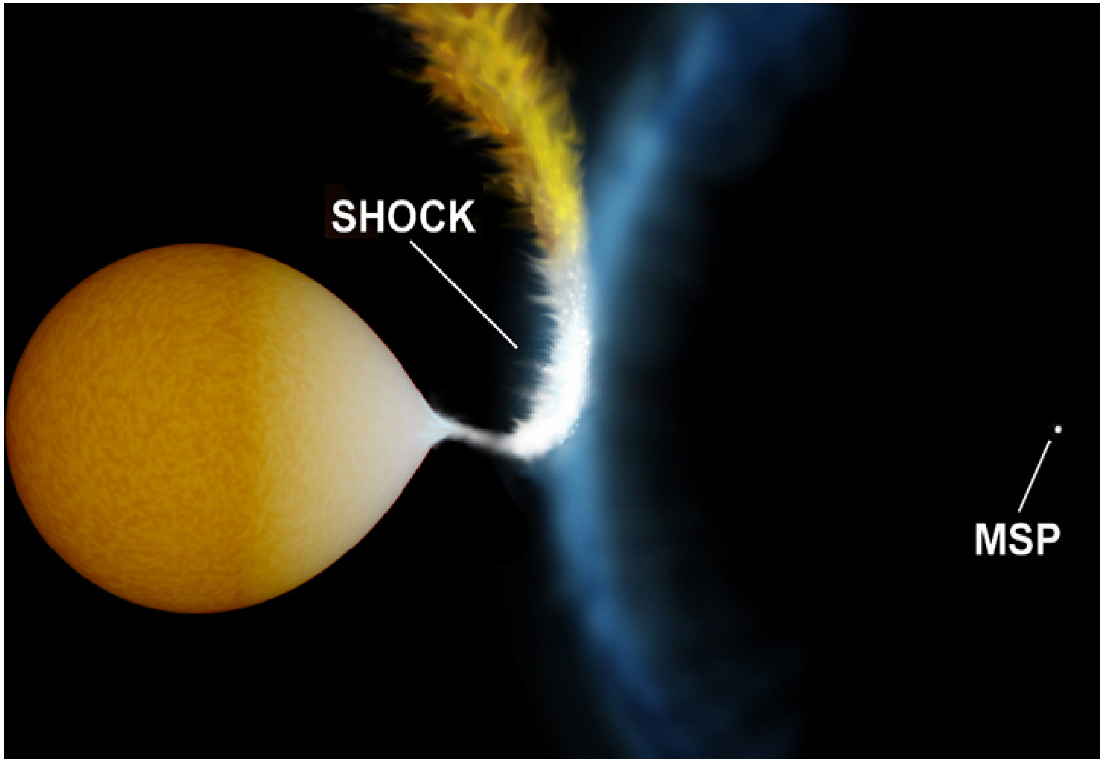
Decrease of optical, X-ray and gamma-ray flux

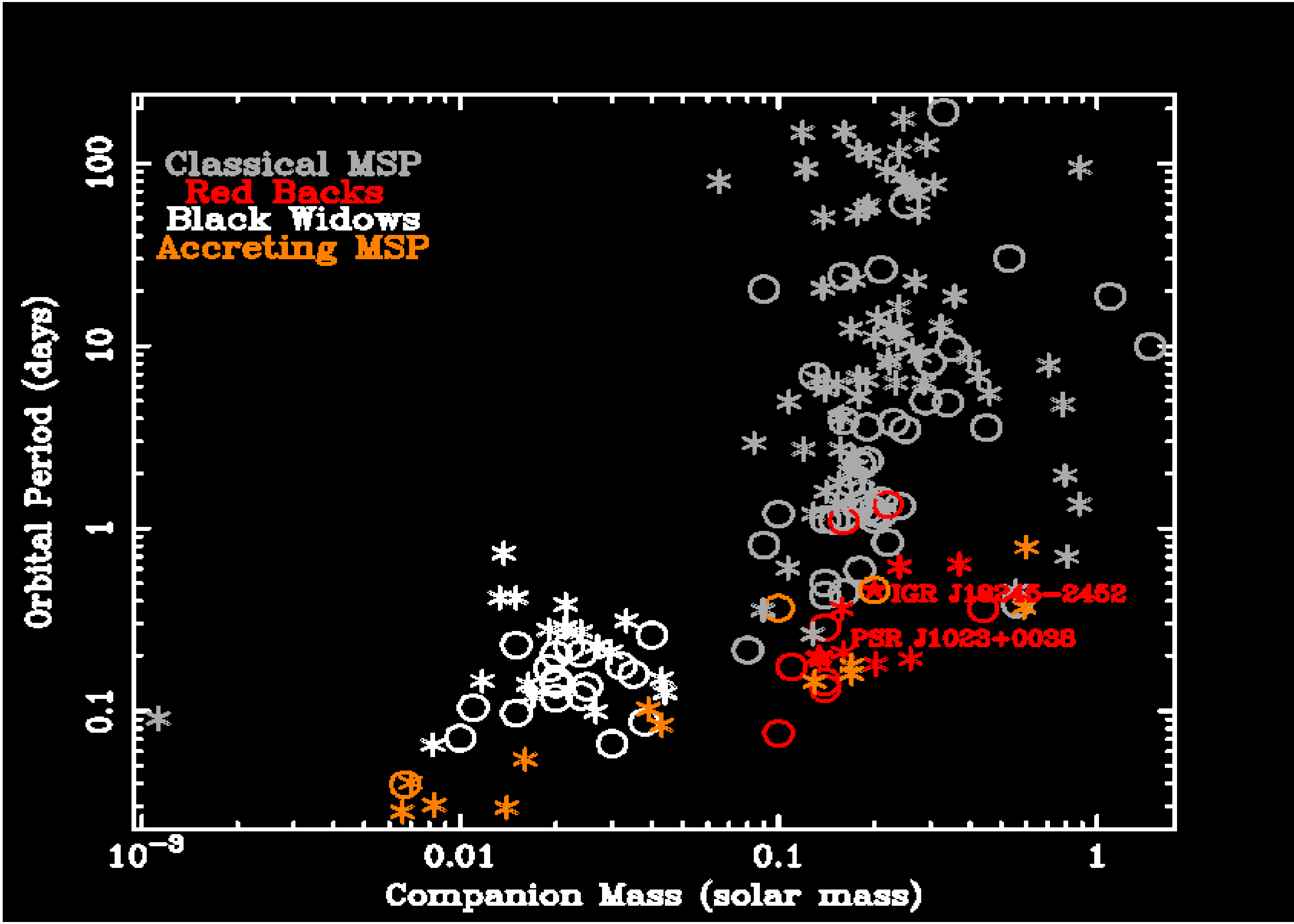
A transition from an accretion (propeller) to a rotation pwd state?

Transitional pulsars to be searched among spiders

Mass transfer has to continue even when a radio pulsar is on

Pulsars ejecting transferred mass are recognized from radio eclipses




Classical MSP
Red Backs
Black Widows
Accreting MSP
IGR J18245−2452
PSR J1023+0038
Orbital Period (days)
100
10
1
0.1
10^{-3}
0.01
0.1
1
Companion Mass (solar mass)

A radio millisecond pulsars renaissance

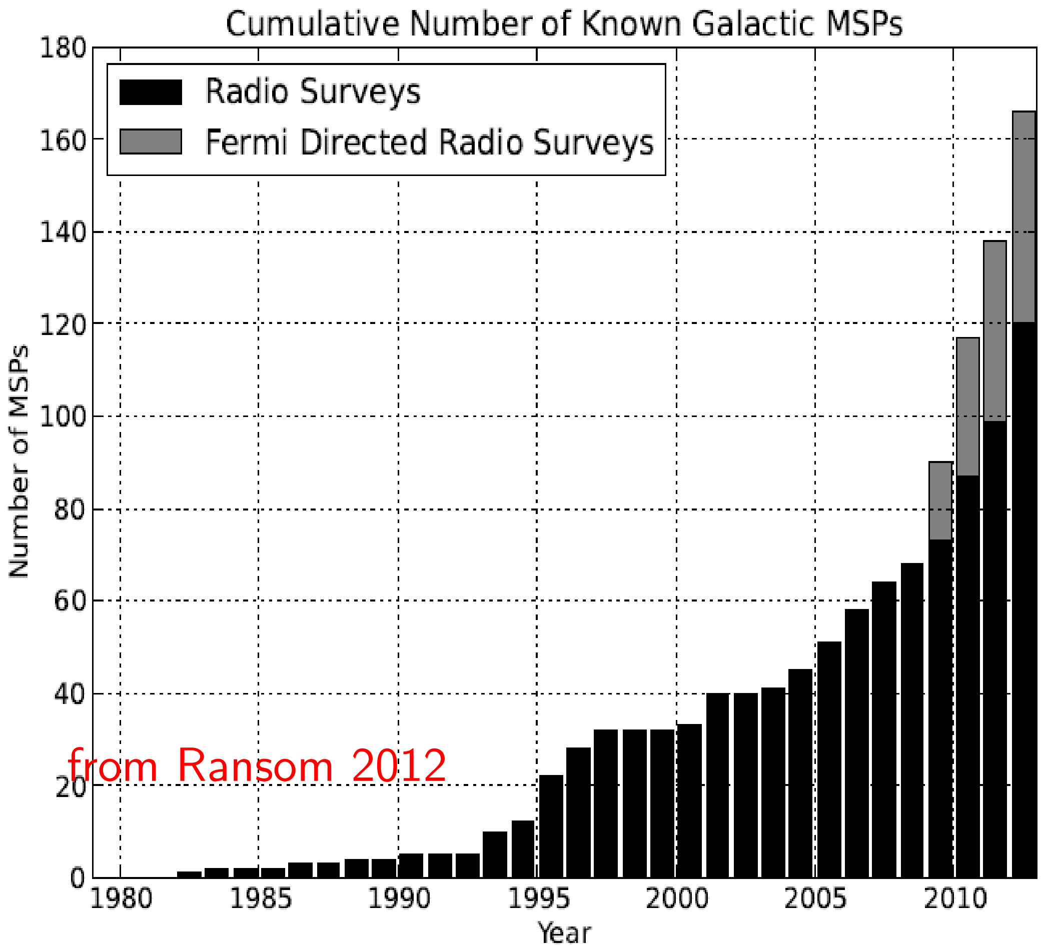
Millisecond pulsars have a relatively large spin down power

$$dE/dt \sim \mu^2 \nu^4$$

MSP are bright gamma-ray emitters

Gamma-rays in transitional pulsars also from inter-binary shocks

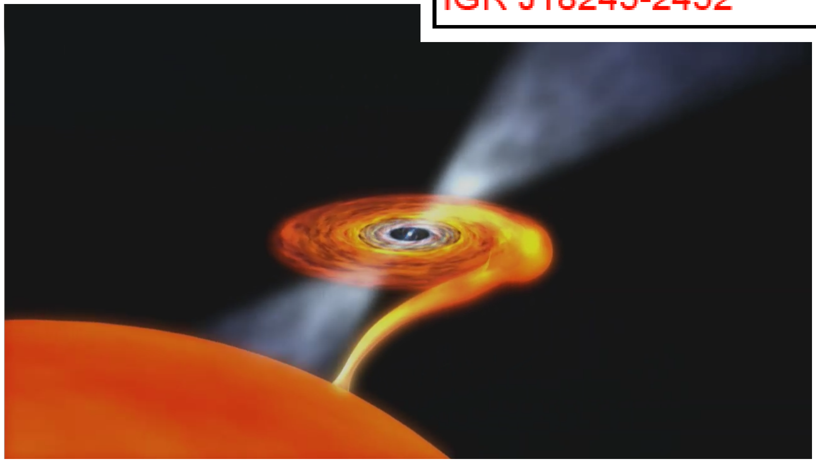
$\rightarrow$ fundamental role of Fermi/LAT



from Ransom 2012

Accreting Millisecond Pulsars: a growing family

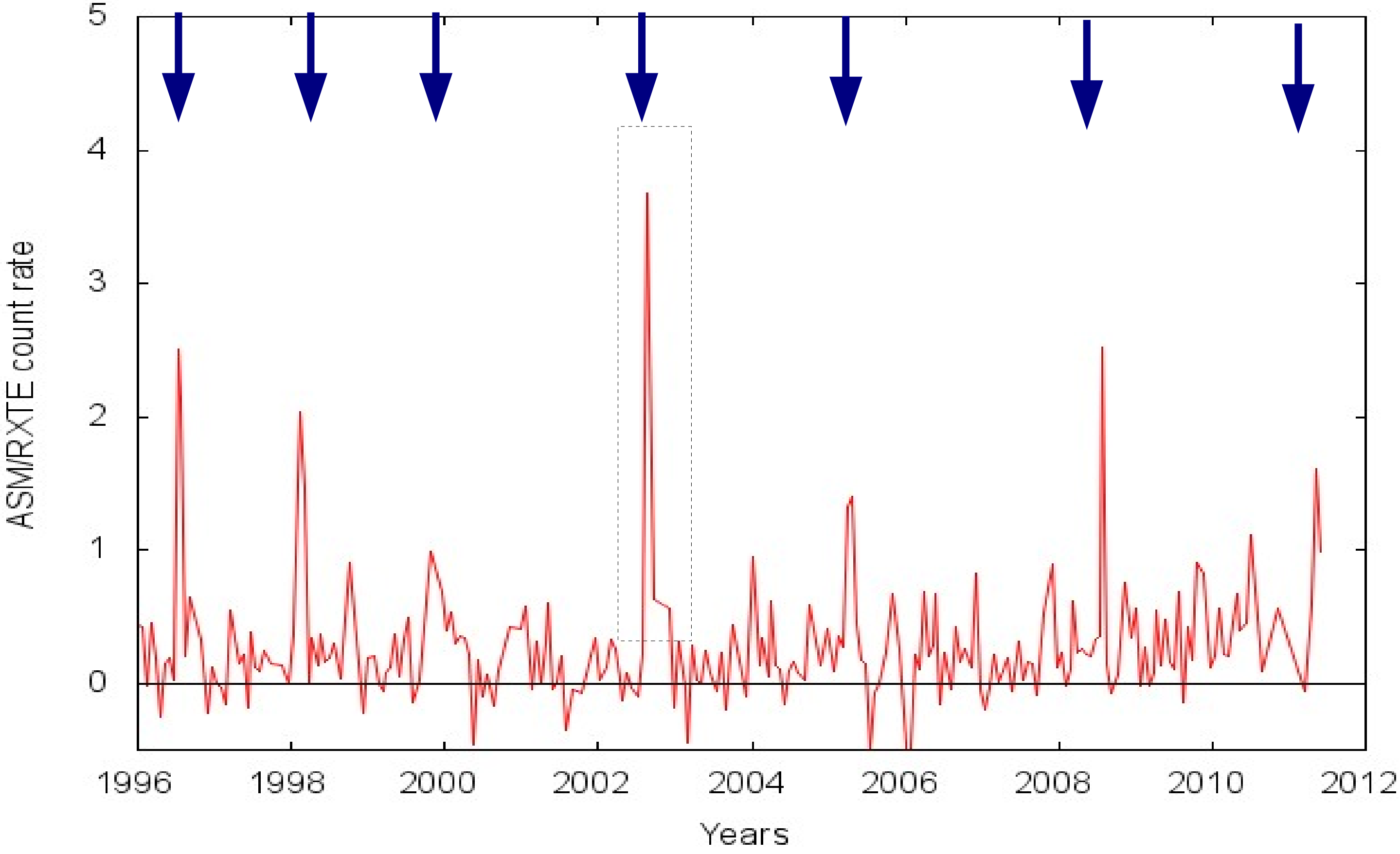
Name	P_{Spin} [ms]	P_{Orb} [min]	$M_{C,Min}$ [M_{sol}]	Discovered
SAX J1808.4-3658	2.5	120	0.043	Apr. 1998
XTE J1751-306	2.3	42	0.014	Apr. 2002
XTE J0929-314	5.4	44	0.083	Apr. 2002
XTE J1807-294	5.2	40	0.0066	Feb. 2003
XTE J1814-338	3.2	258	0.17	Jun. 2003
IGR J00291+5934	1.67	150	0.039	Dec. 2004
HETE J1900.1-2455	2.6	84	0.016	Jun. 2005
Swift J1756.9-2508	5.5	54	0.007	Jun. 2007
NGC 6440 X-2	4.86	57	0.0067	Aug. 2009
IGR J17511-3057	4.1	208	0.13	Sep. 2009
Swift J1749.4-2807	1.9	530	0.6	Apr. 2010
IGR J17498-2921	2.5	230.4	0.17	Aug 2011
IGR J18245-2452	3.9	661.5	0.17	March 2013



+ 2 intermittent pulsars (Aql X-1, SAX J1748.9-2021)

Weak X-ray transients (Lpeak $\sim 10^{36}$ erg/s)

Accreting Millisecond Pulsars: a realm of transients

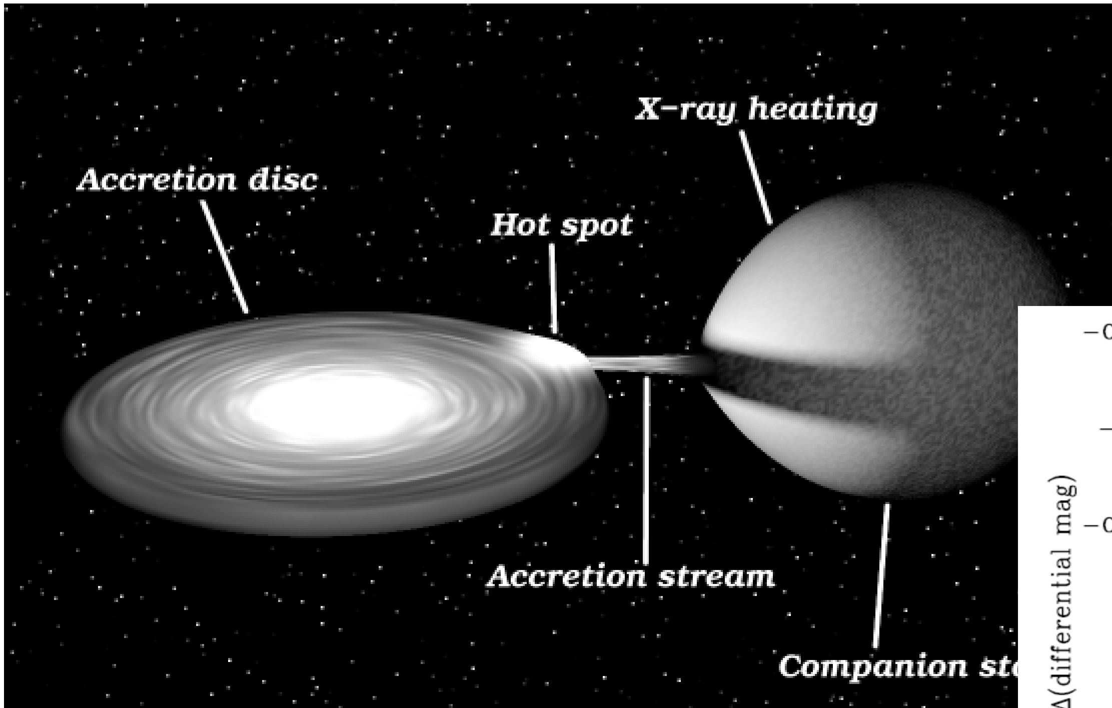


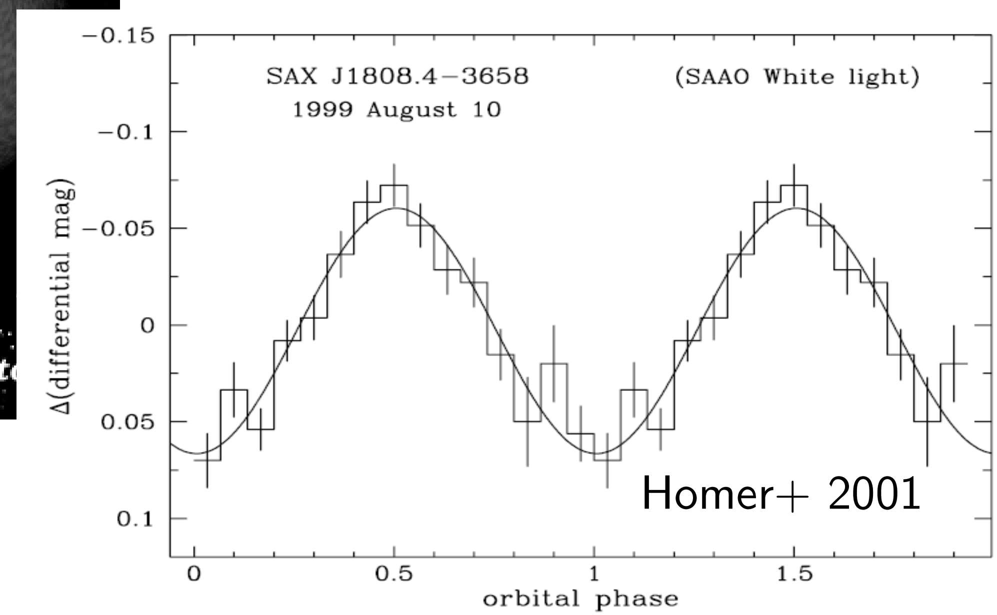
X-ray outbursts every few years

A radio pulsar switching on during X-ray quiescence?

[Stella+ 1994; Campana+ 1998; Burderi+ 2001]

Accreting millisecond pulsars: irradiation of the companion

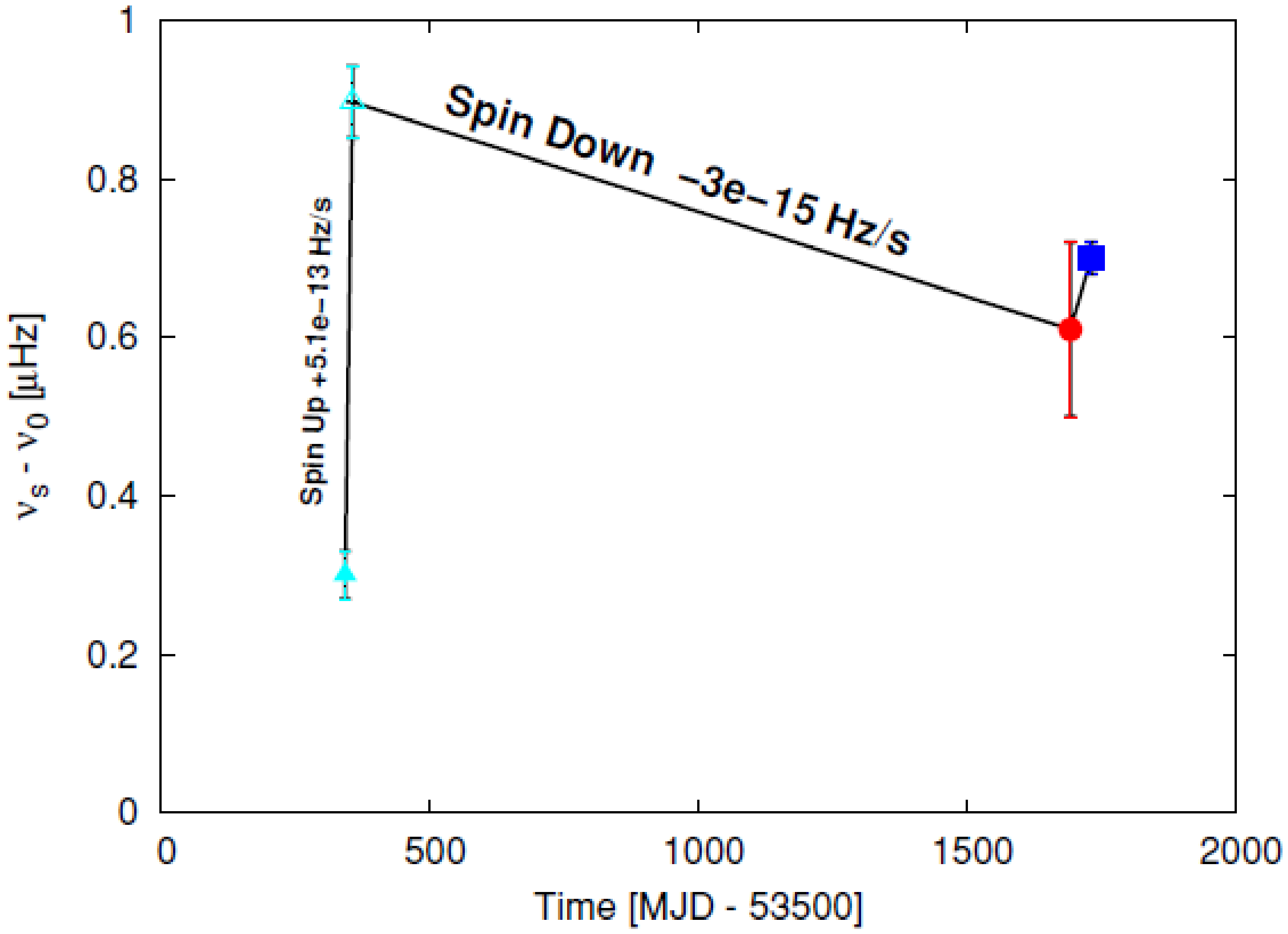




The spin down power of a radio pulsar illuminates the companion

[Burderi+2003; Campana+2004, D'Avanzo+ 2009,2011; Cornelisse+ 2009]

Accreting millisecond pulsars: spin down during quiescence

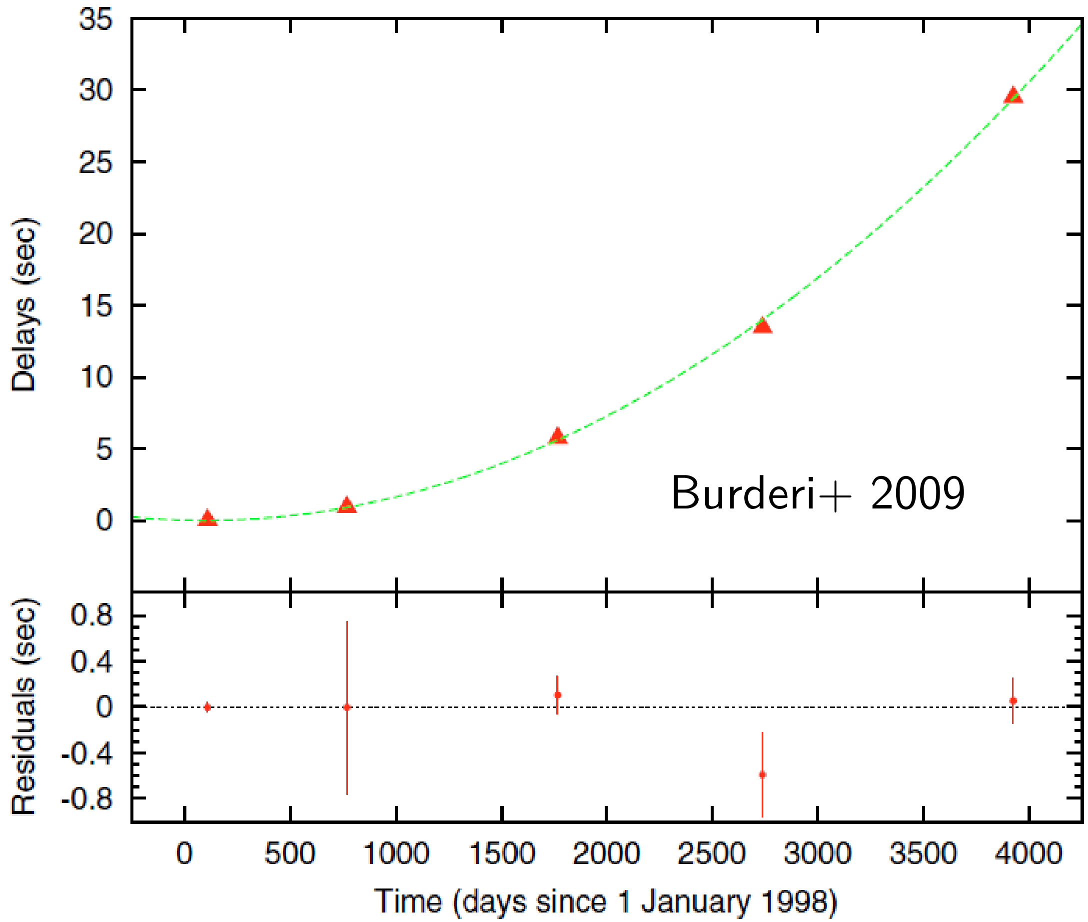


[Hartman+2008; Hartman+2009; Papitto+ 2010; Hartman+ 2010]

Accreting millisecond pulsars: fast orbital evolution

Mass ejection during quiescence
[Di Salvo+ 2008; Burderi+ 2009]

Short term transfer of angular momentum
between donor and orbit
[Hartman+ 2008, 2009; Patruno+ 20



Accreting millisecond pulsars: search for a rotation pwd pulsar in quiescence

Searches for rotation powered pulsations during quiescence in radio (Burgay+ 2003; Iacolina+ 2011) and gamma-ray (Xing+ 2012) so far not successful

Absorption and smearing of radio pulses is the largest for close systems (IGR J18245-2452 is the AMSP with the longest orbital period)

Increase statistics of gamma-ray photons, while keeping updated ephemerides

Fermi Gamma-ray Space Telescope

Summary

IGR J18245-2821 is the definitive proof of an evolutionary link between accreting and rotation powered ms pulsars

Fast ($\sim$days) swinging between accretion and rotation powered states

Transitions set by variations of the mass accretion rate

A puzzling light curve, hardness and pulse variability. A propeller interpretation?