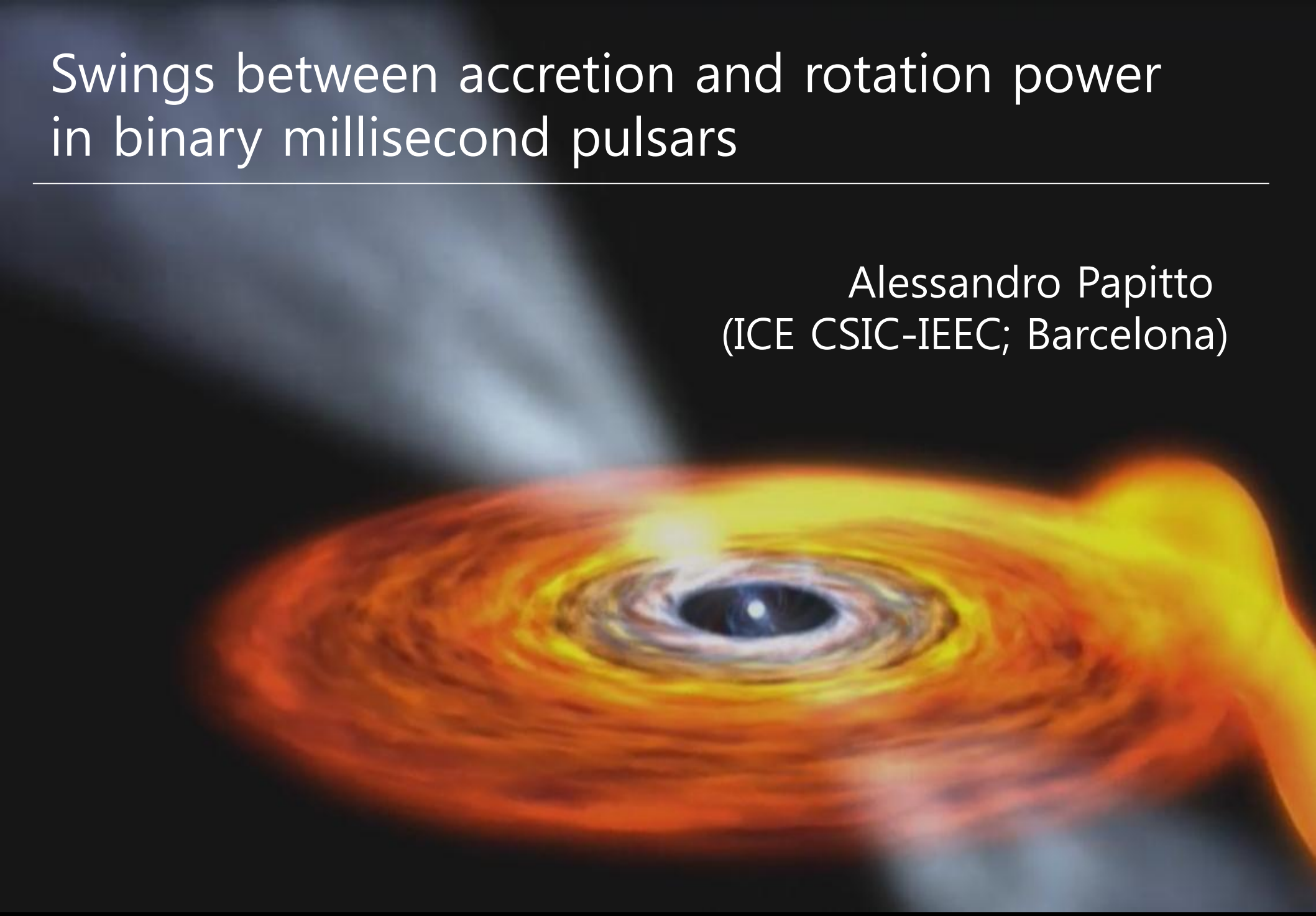
Swings between accretion and rotation power in binary millisecond pulsars

Alessandro Papitto
(ICE CSIC-IEEC; Barcelona)



"The X-ray Universe 2014" –Dublin – 17.6.2014

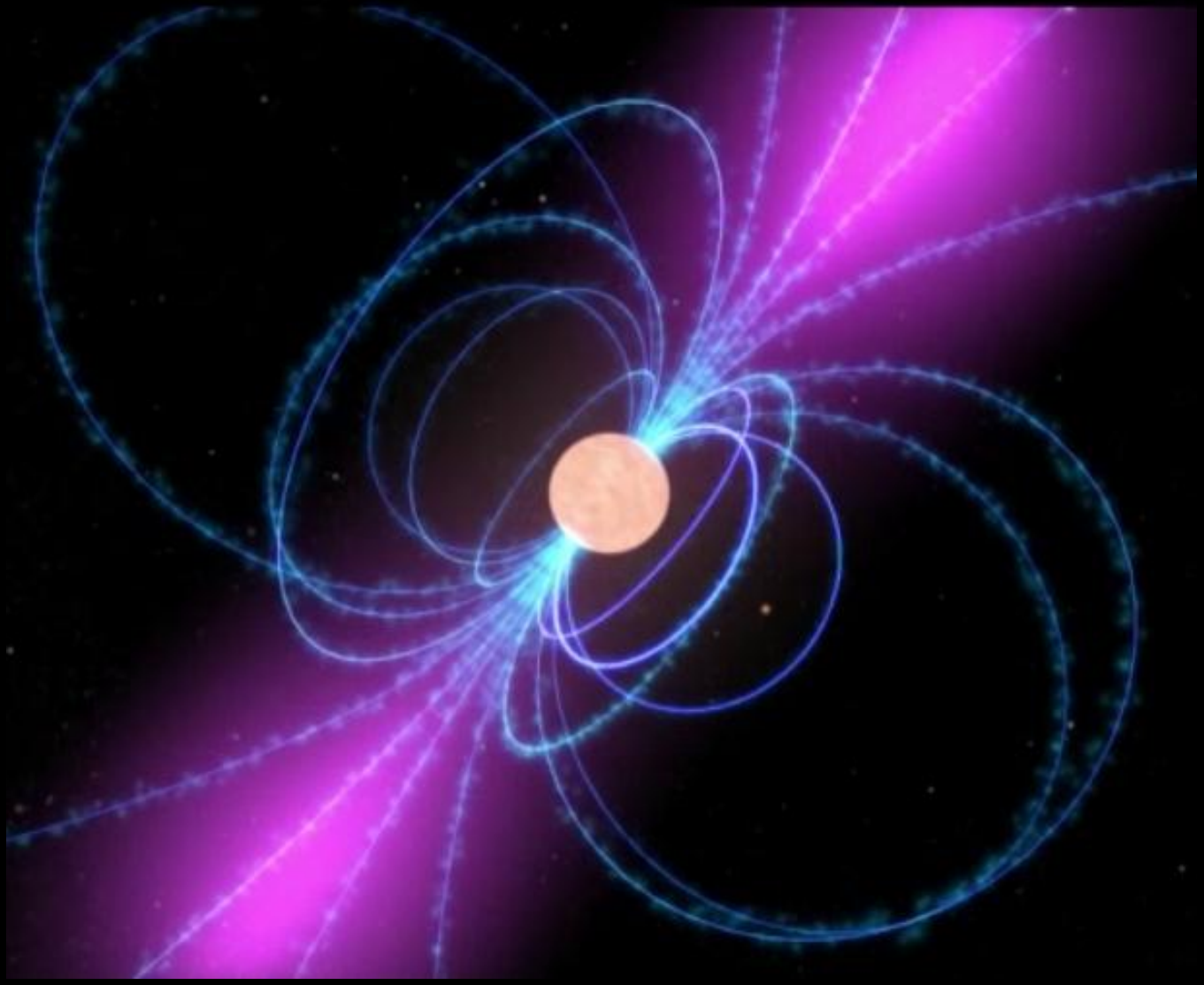
Transitional millisecond pulsars

Radio ms Pulsars
Magnetic field rotation

X-ray ms Pulsars
Mass accretion

Transitional fossils
"(…) any fossilized remains of a life form that exhibits traits common to both an ancestral group and its derived descendant group."
Freeman & Herron (2004), Evolutionary analysis

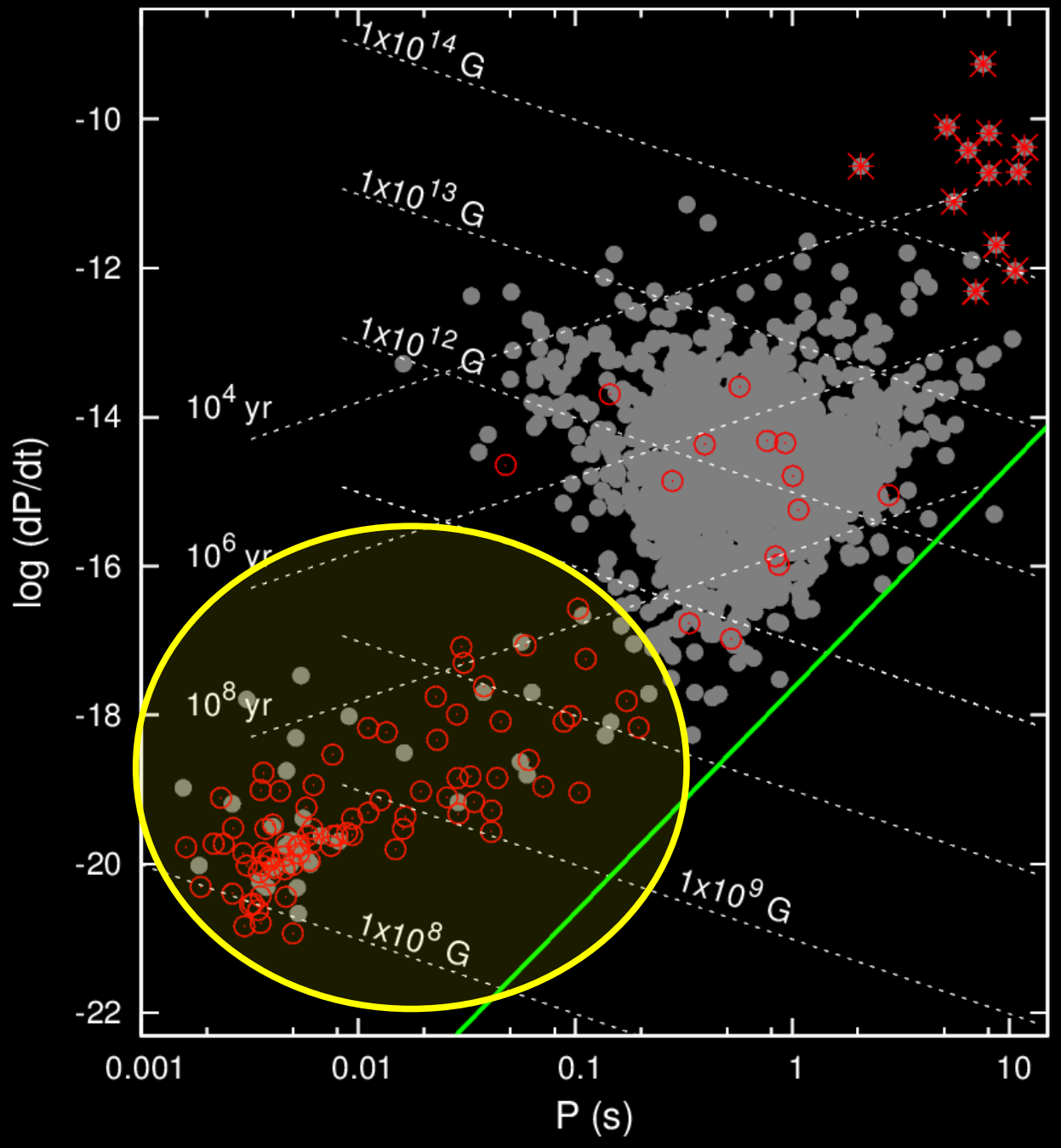
Rotation powered (radio) pulsars



The fundamental plane of pulsars

Millisecond pulsars
Backer+ 1982 Nature]

- weakly magnetized
- often found in globular clusters
  → old systems

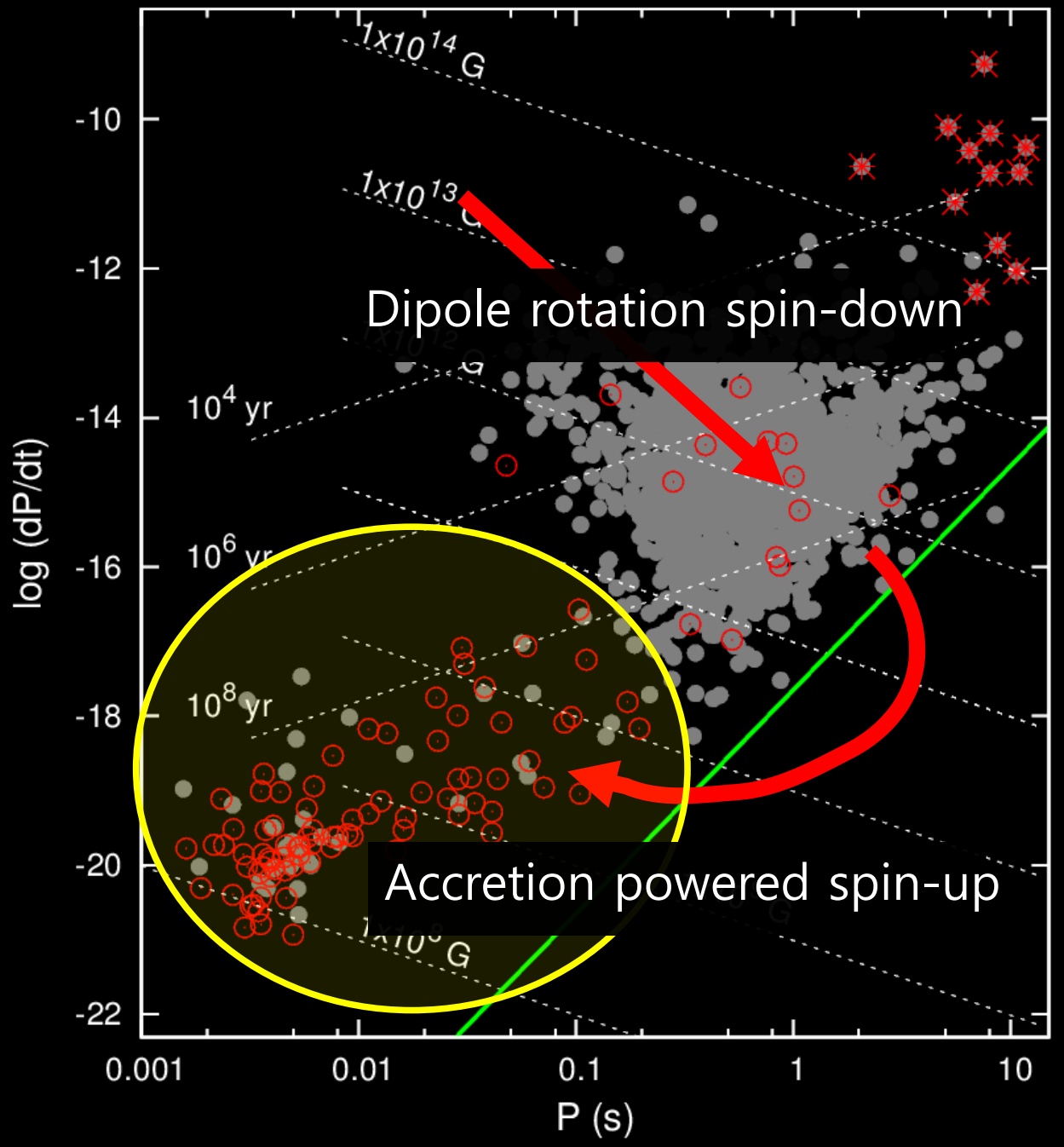


The fundamental plane of pulsars

Millisecond pulsars
Backer+ 1982 Nature]

- weakly magnetized
- often found in globular clusters
  → old systems
- often in binaries

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

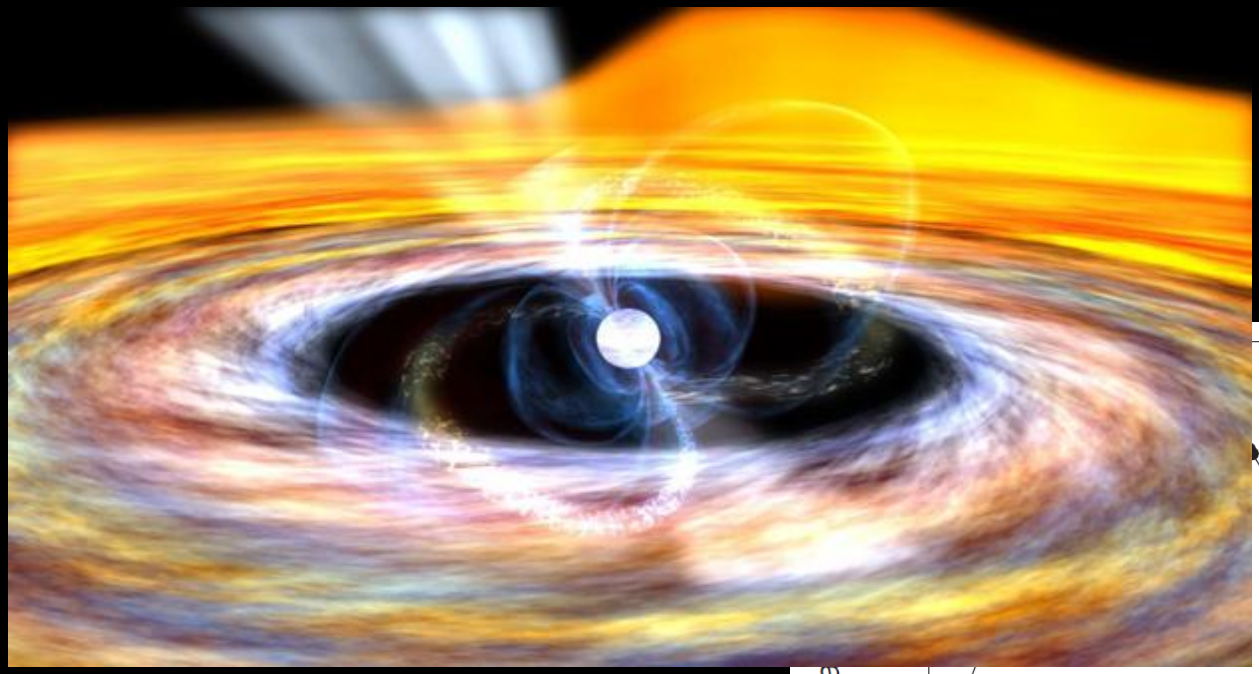


Spinning up neutron stars

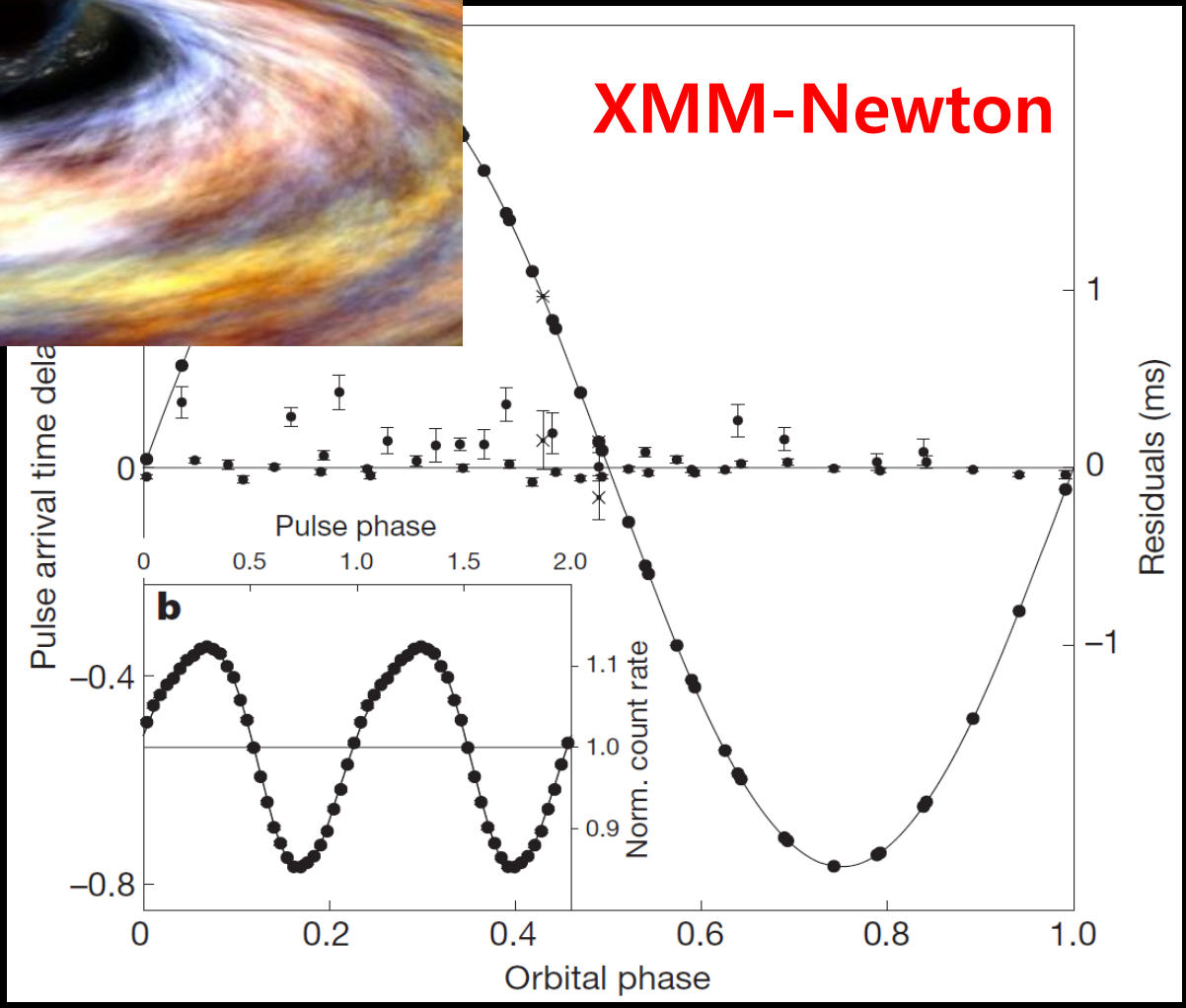
A new transient in M28, IGR J18245-2452

X-ray luminosity ~ few x 10^{36} erg/s → accretion power

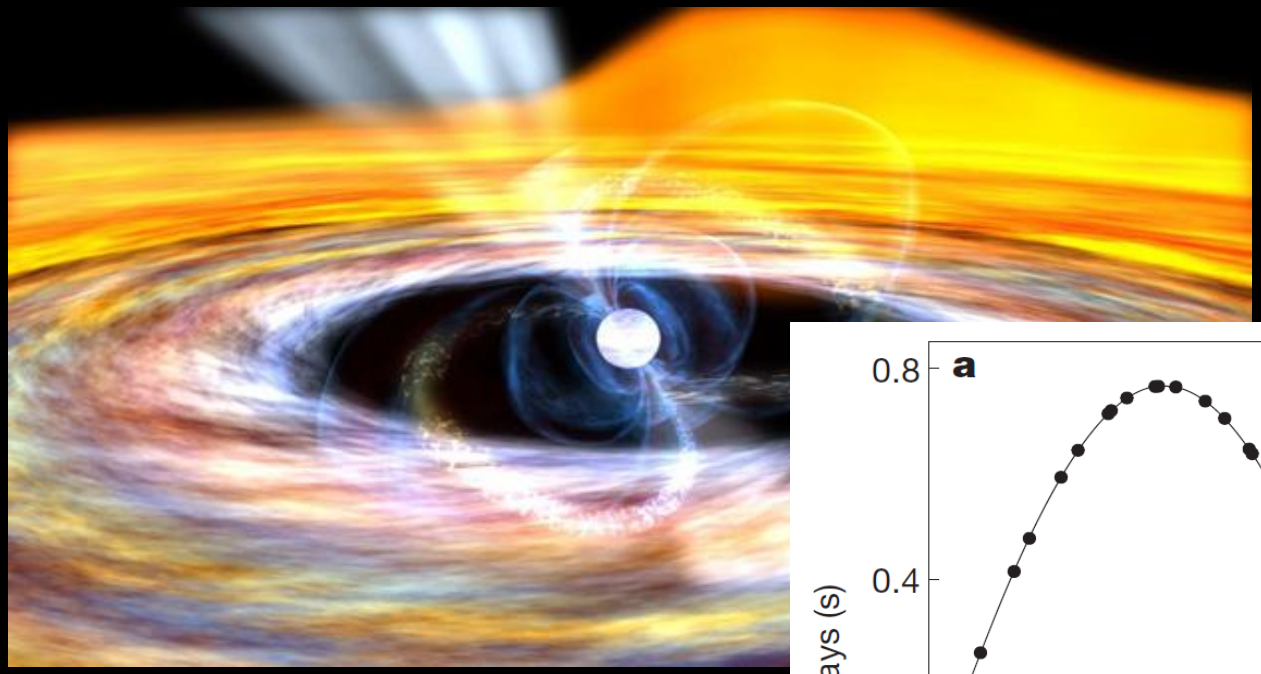
XMM discovery of an accreting millisecond pulsar

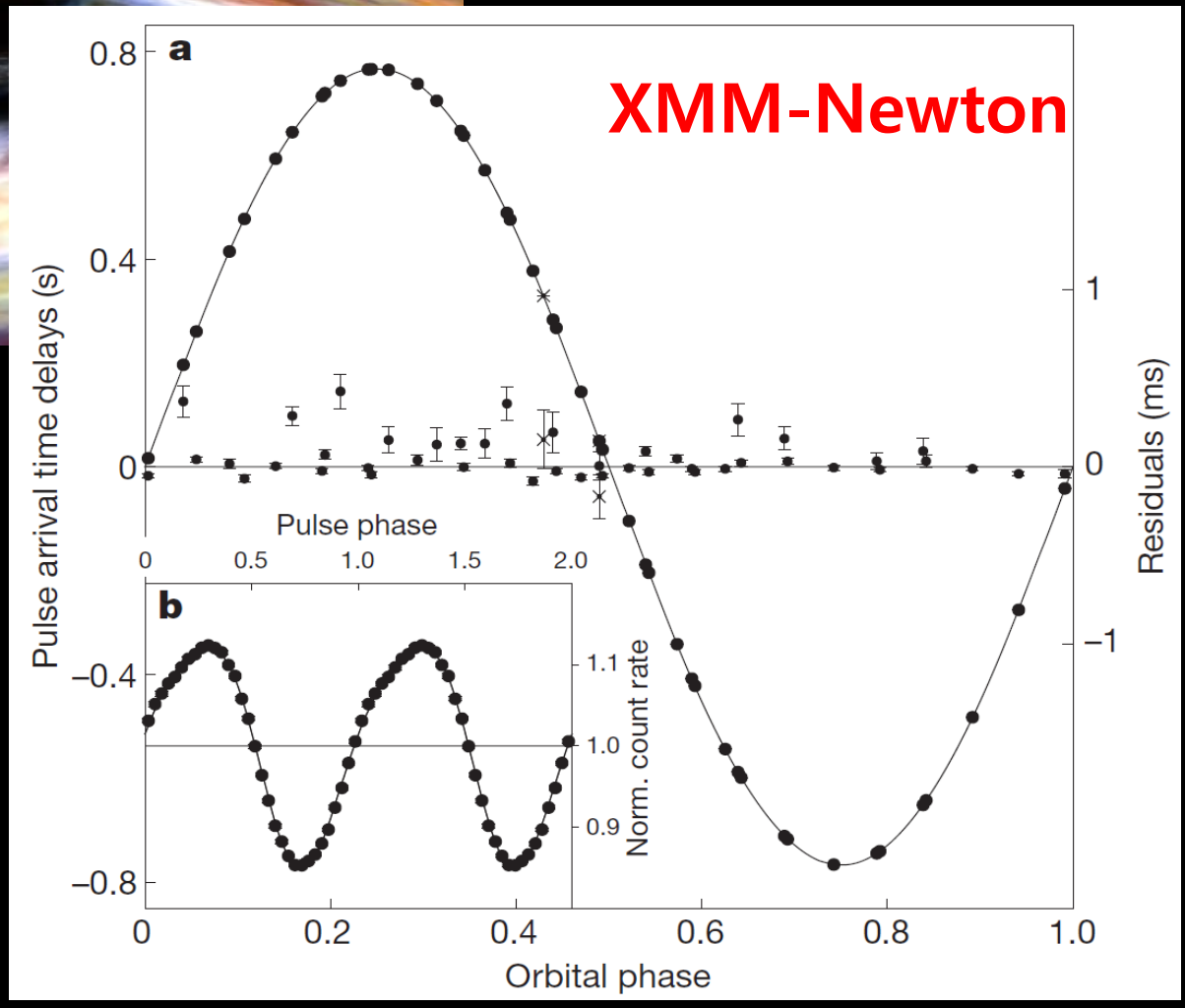


Pspin = 3.9 ms
Porb = 11.0 hr
Mcomp ~ 0.2 Msun



XMM discovery of an accreting millisecond pulsar

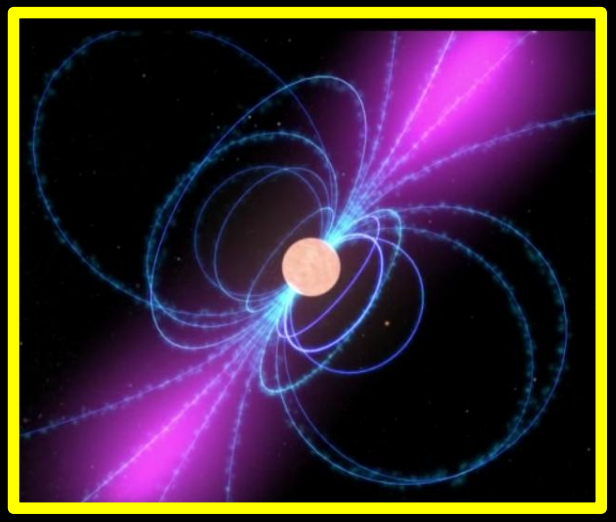




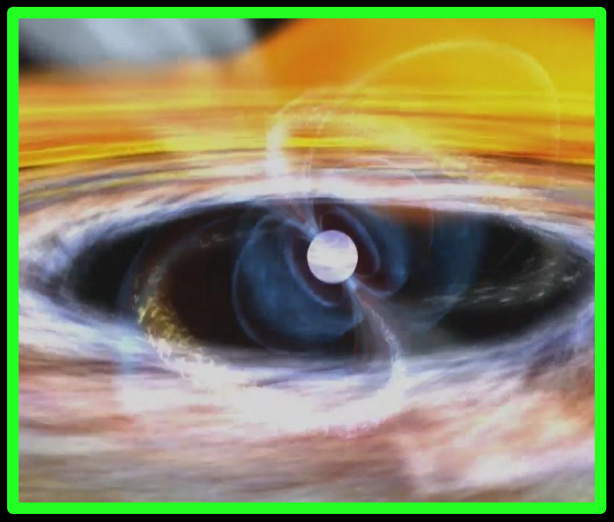
Pspin = 3.9 ms
Porb = 11.0 hr
Mcomp ~ 0.2 Msun

Discovery of a transitional pulsar

Radio PSR (rotation power)



X-ray pulsar (accretion power)

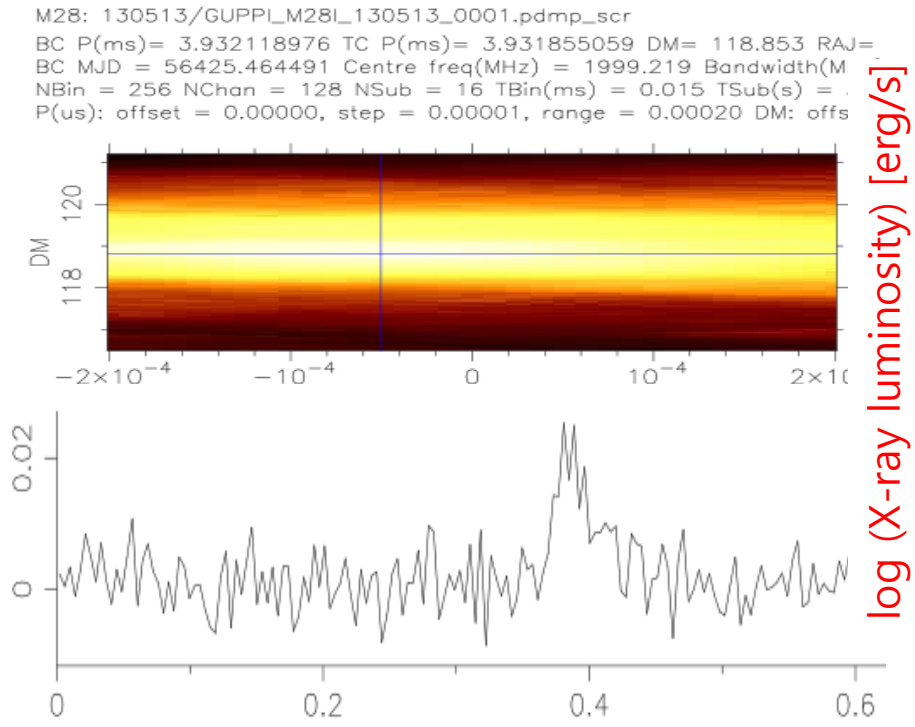


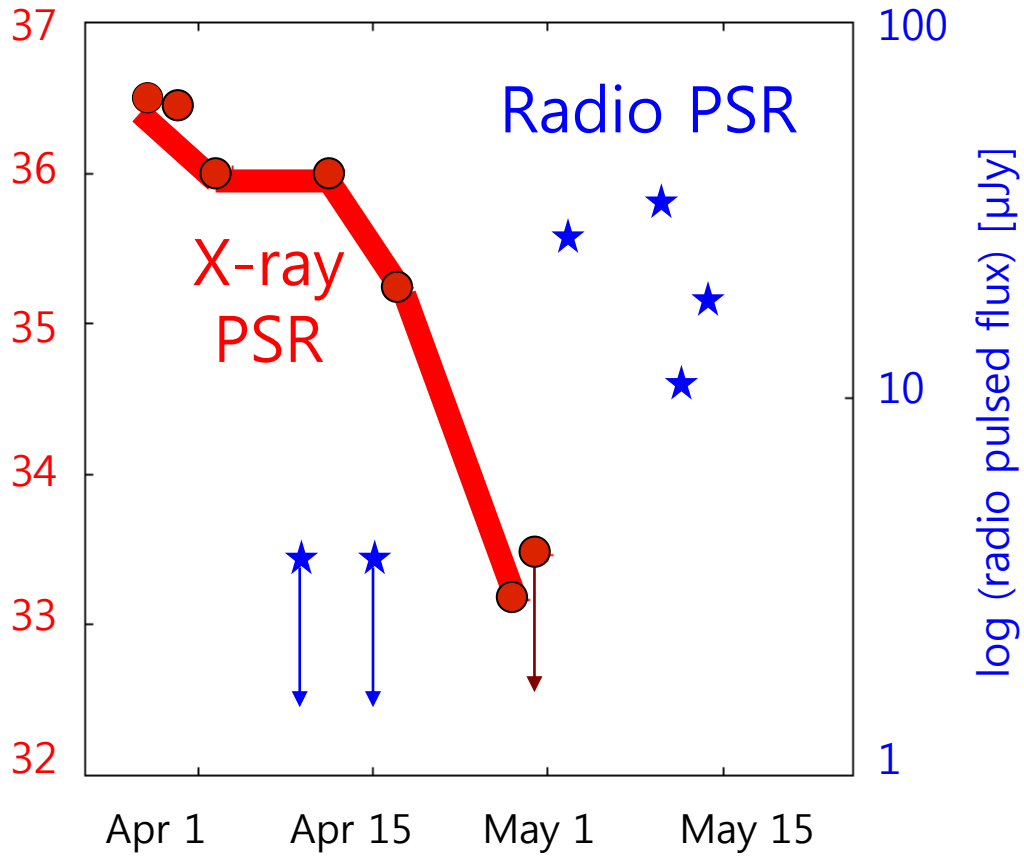
Parameter	IGR J18245–2452	PSR J1824–2452I
Right Ascension (J2000)	$18^h\ 24^m\ 32.53(4)^s$	
Declination (J2000)	$-24°\ 52'\ 08.6(6)''$	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852641(2)	3.93185(1)
Spin period derivative	$< 2 \times 10^{-17}$	
RMS of pulse time delays (ms)	0.1	
Orbital period (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)	

Papitto et al. 2013, Nature, 501, 517

Reactivation of the radio pulsar

Weak radio signal (~10-50 microJy) detected
less than two weeks since the end of the X-ray outburst
(GBT, PKS, WSRT)

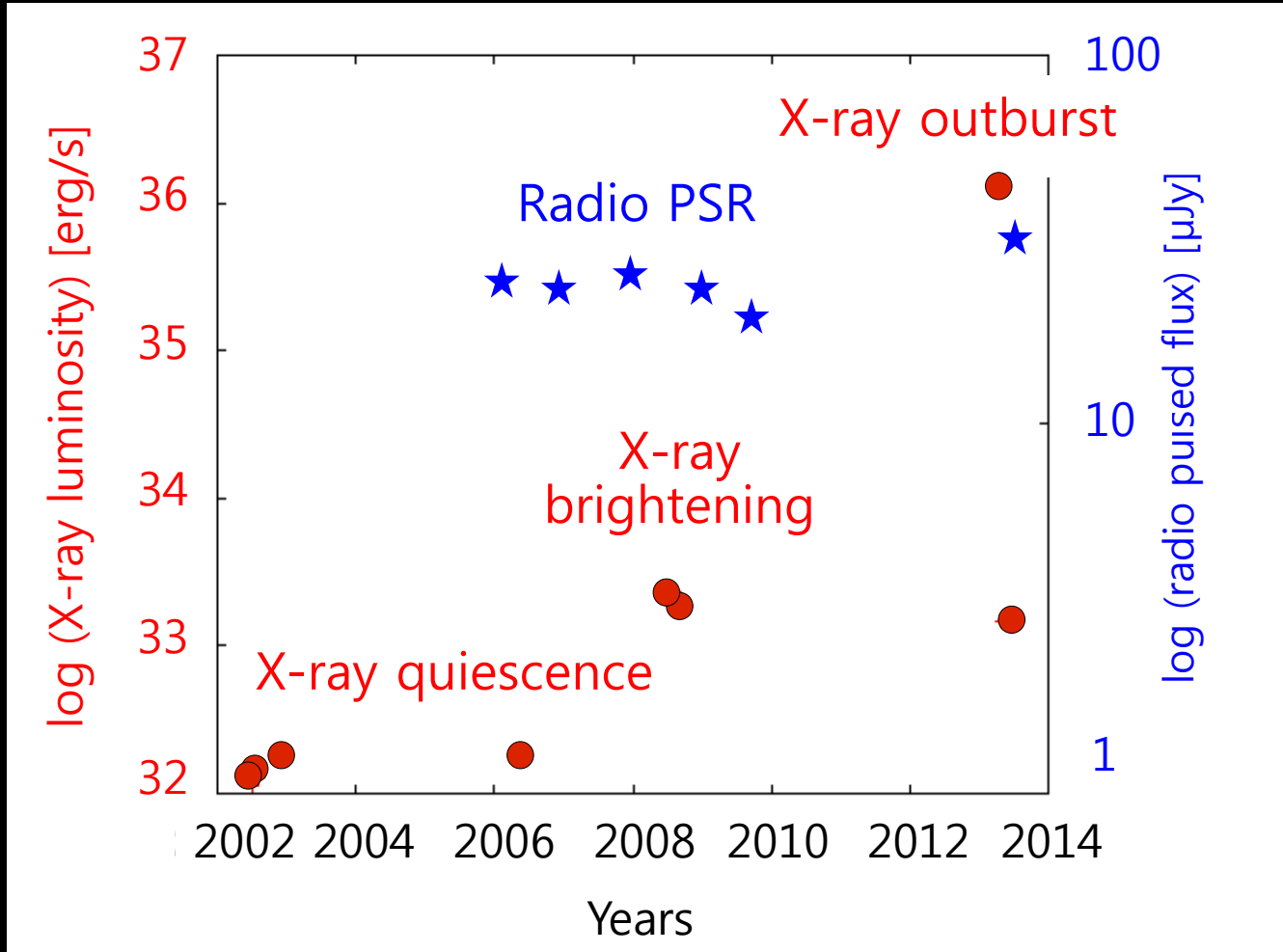




M28: a decade of observations

Radio pulsar faint and irregularly eclipsed

Past **accretion events** (X-ray & optical brightening)

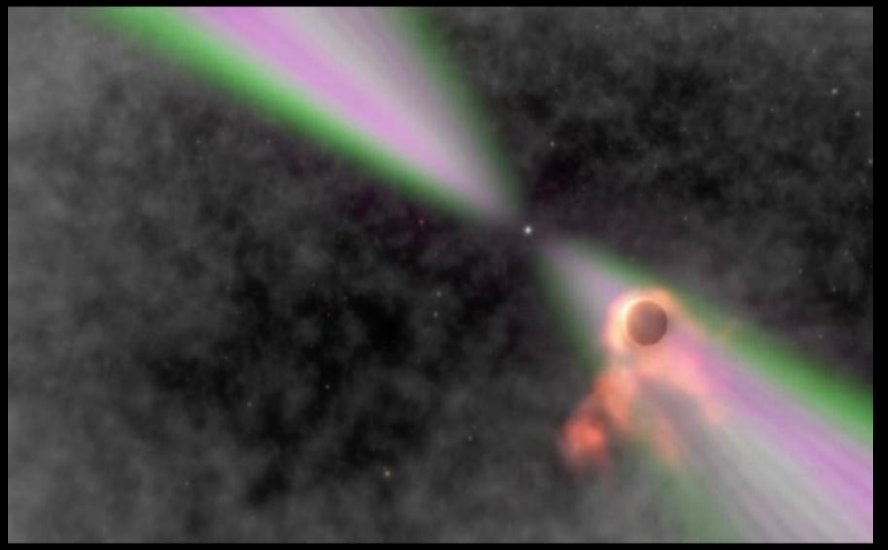


Papitto+ 2013
Pallanca+ 2013
Linares+ 2014

Swings driven by mass in-flow rate variability

Low Mass in-flow rate:
Magnetic field dominates

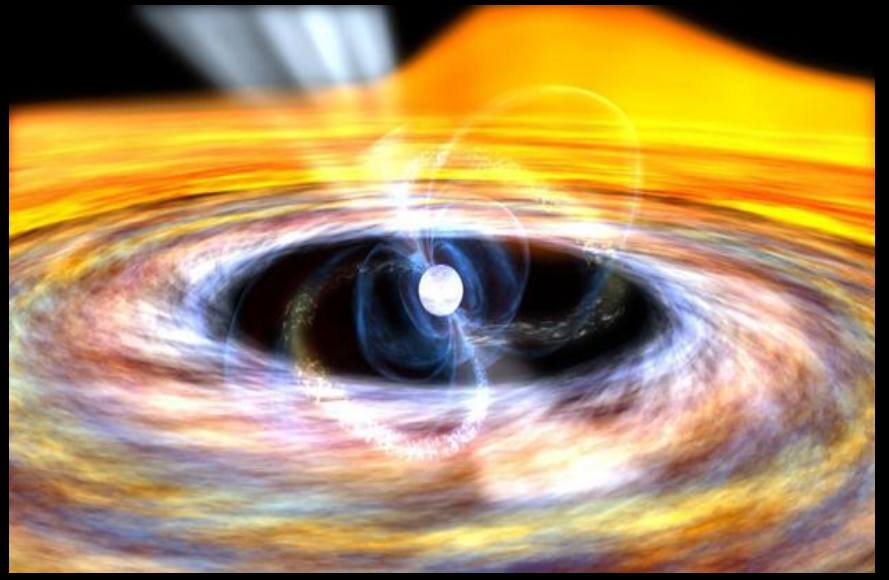
→ rotation powered **Radio PSR**



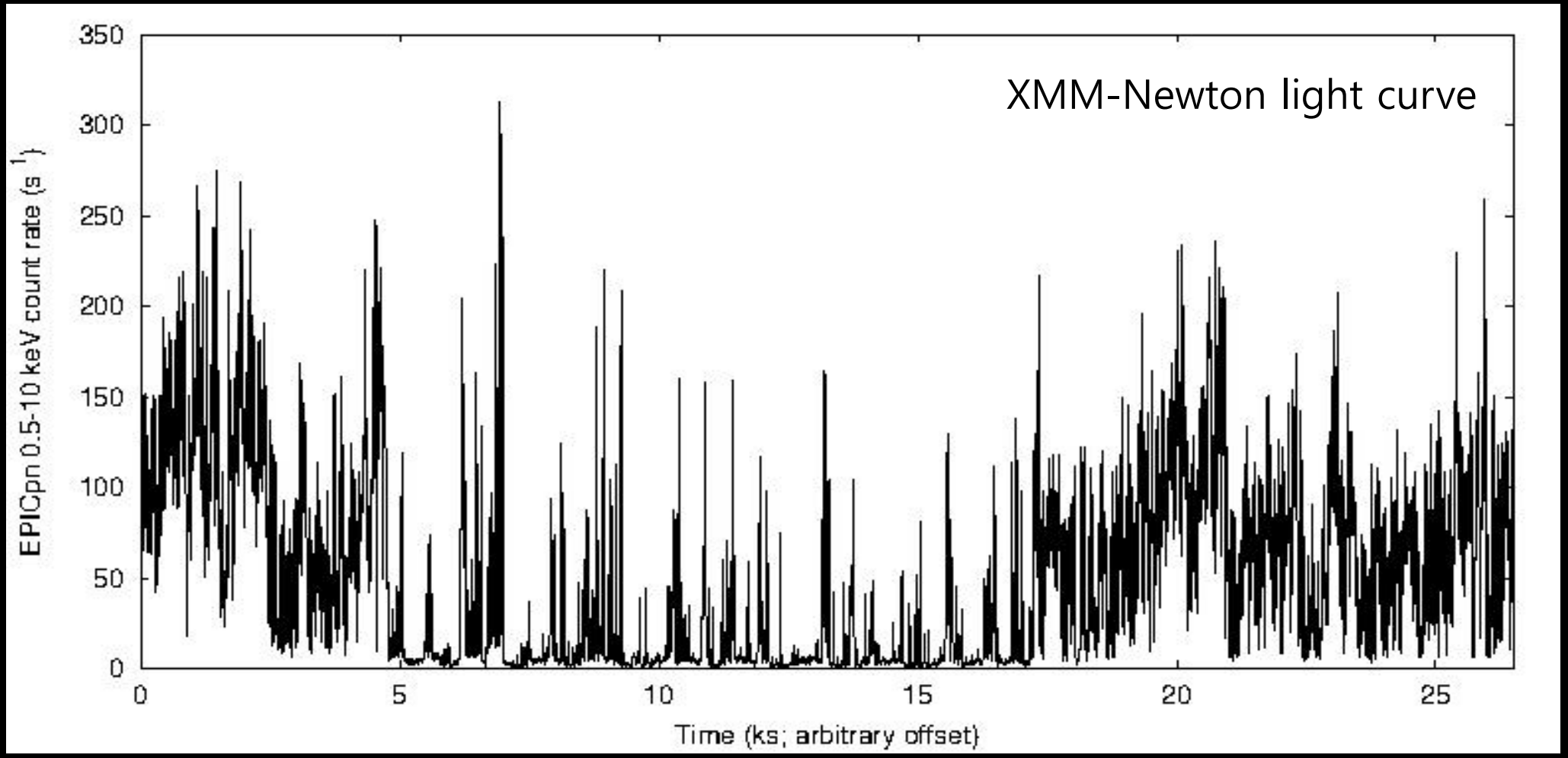
High Mass in-flow rate:
Gravity dominates

→ accretion powered **X-ray PSR**

Stella+ 1994; Campana+ 1998; Burderi+ 2001

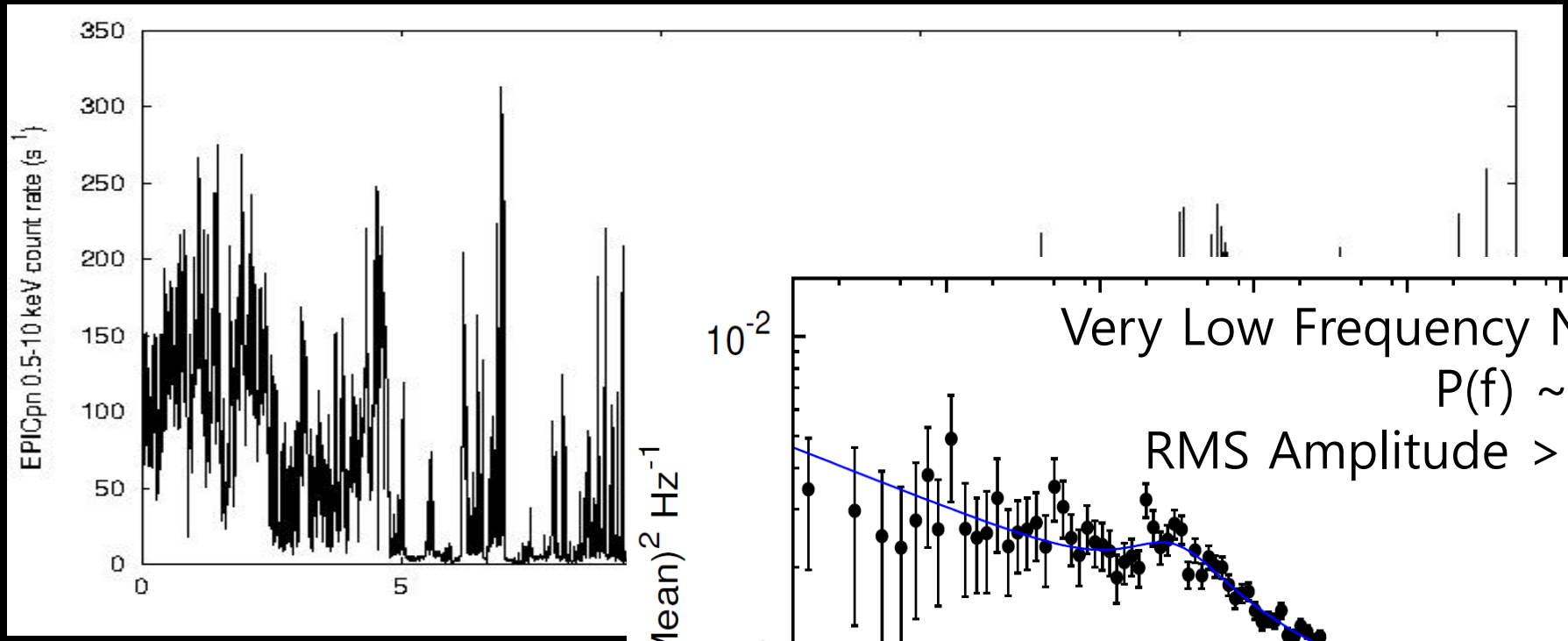


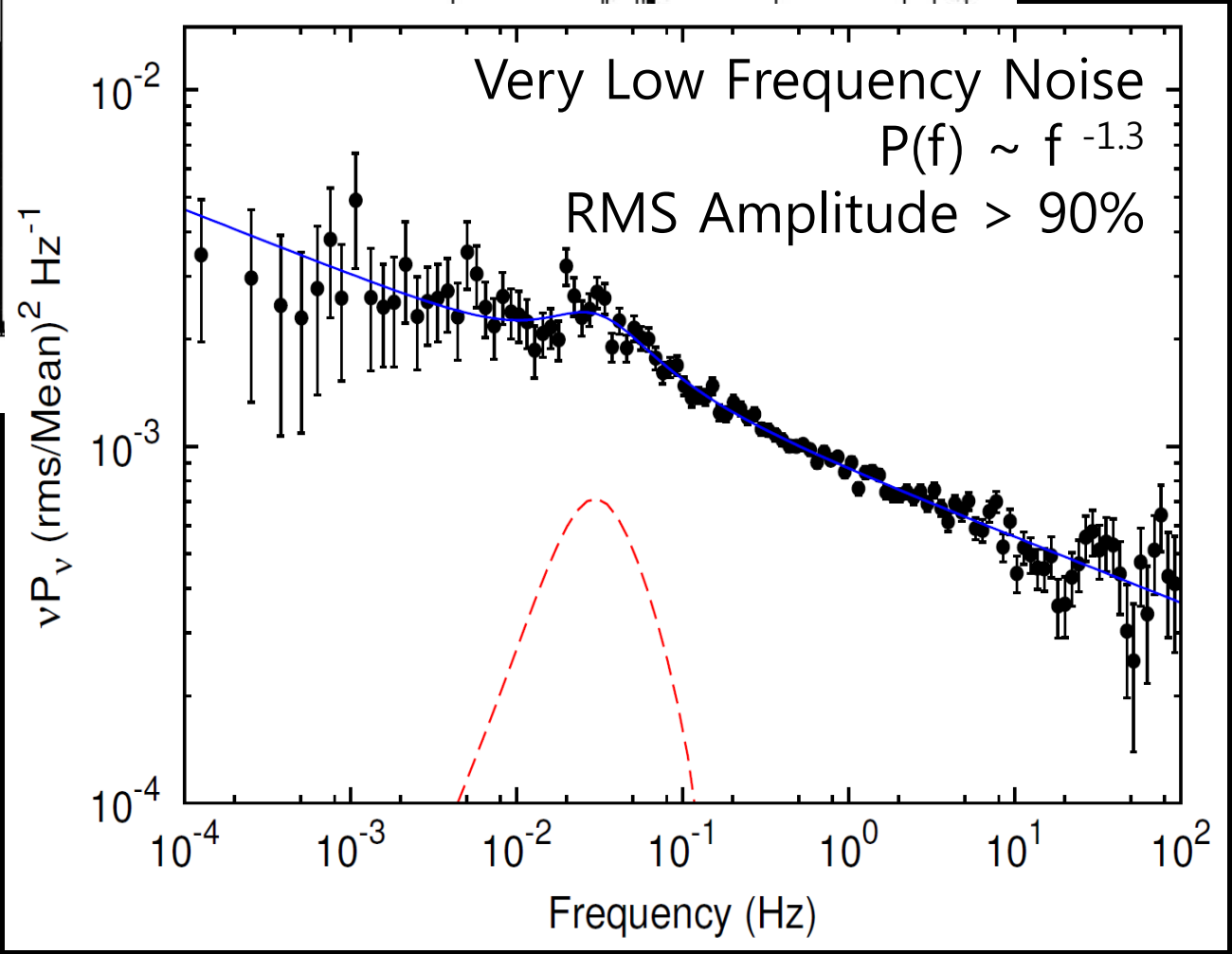
IGR J18245-2452: X-ray flux variability



Ferrigno, Bozzo, Papitto, Rea +, A&A, 2014,

IGR J18245-2452: X-ray flux variability

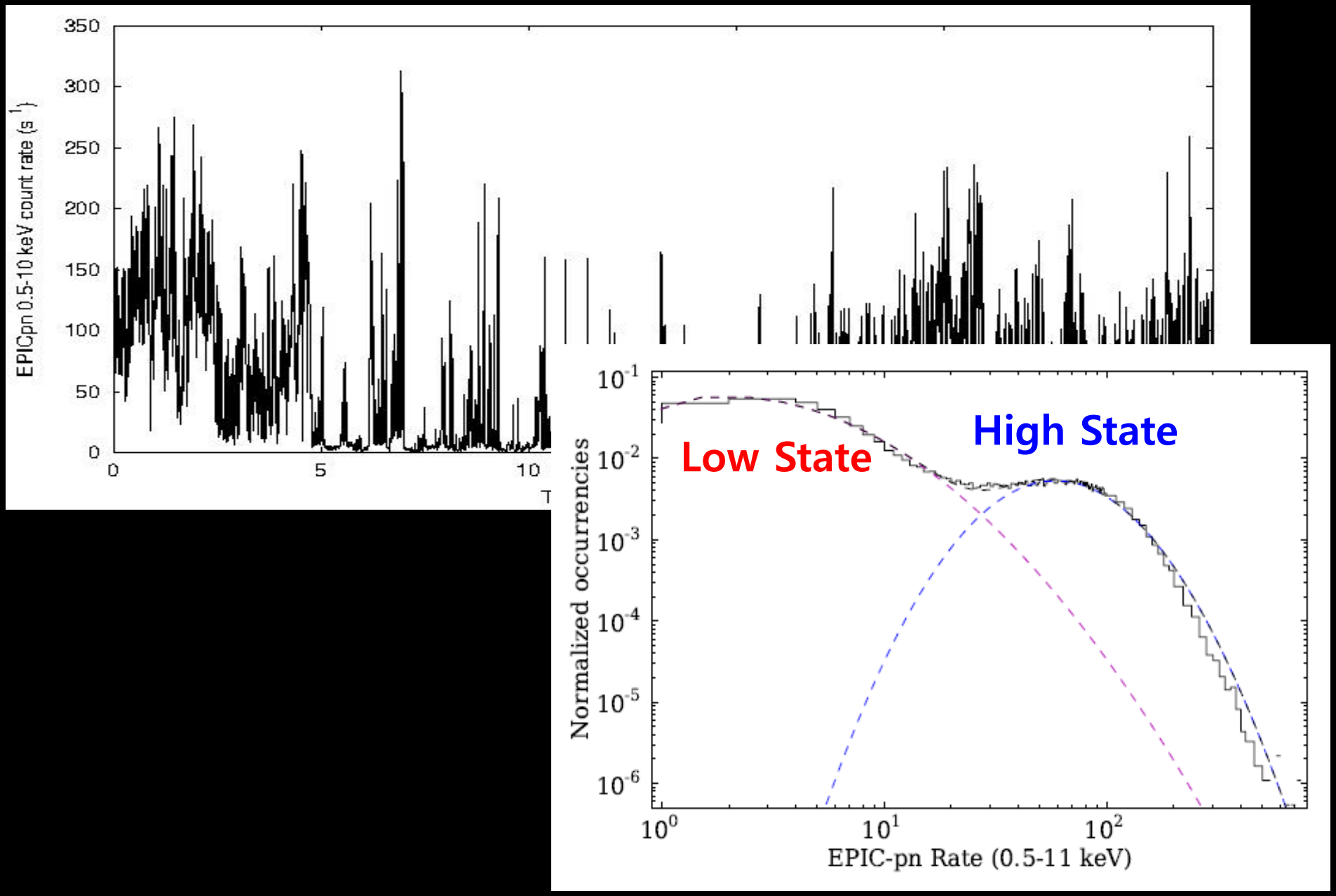




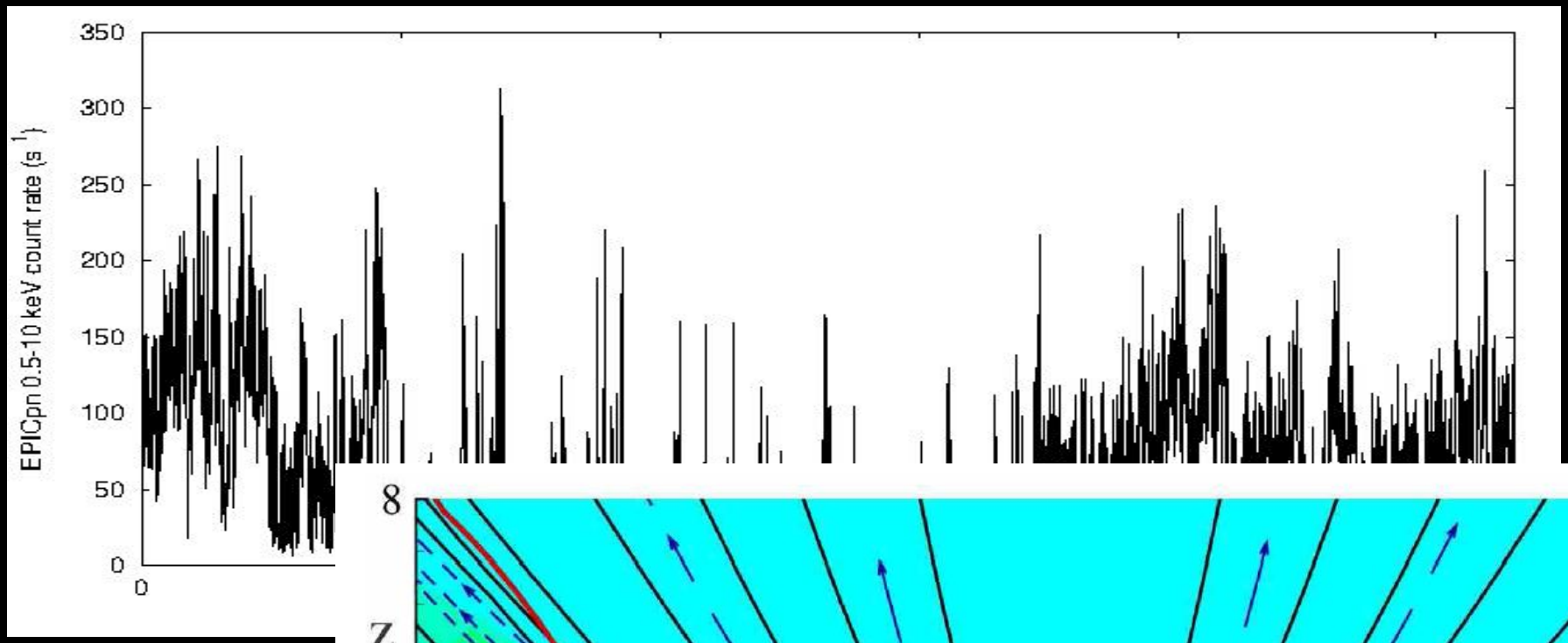
cut off < 10^{-4} Hz

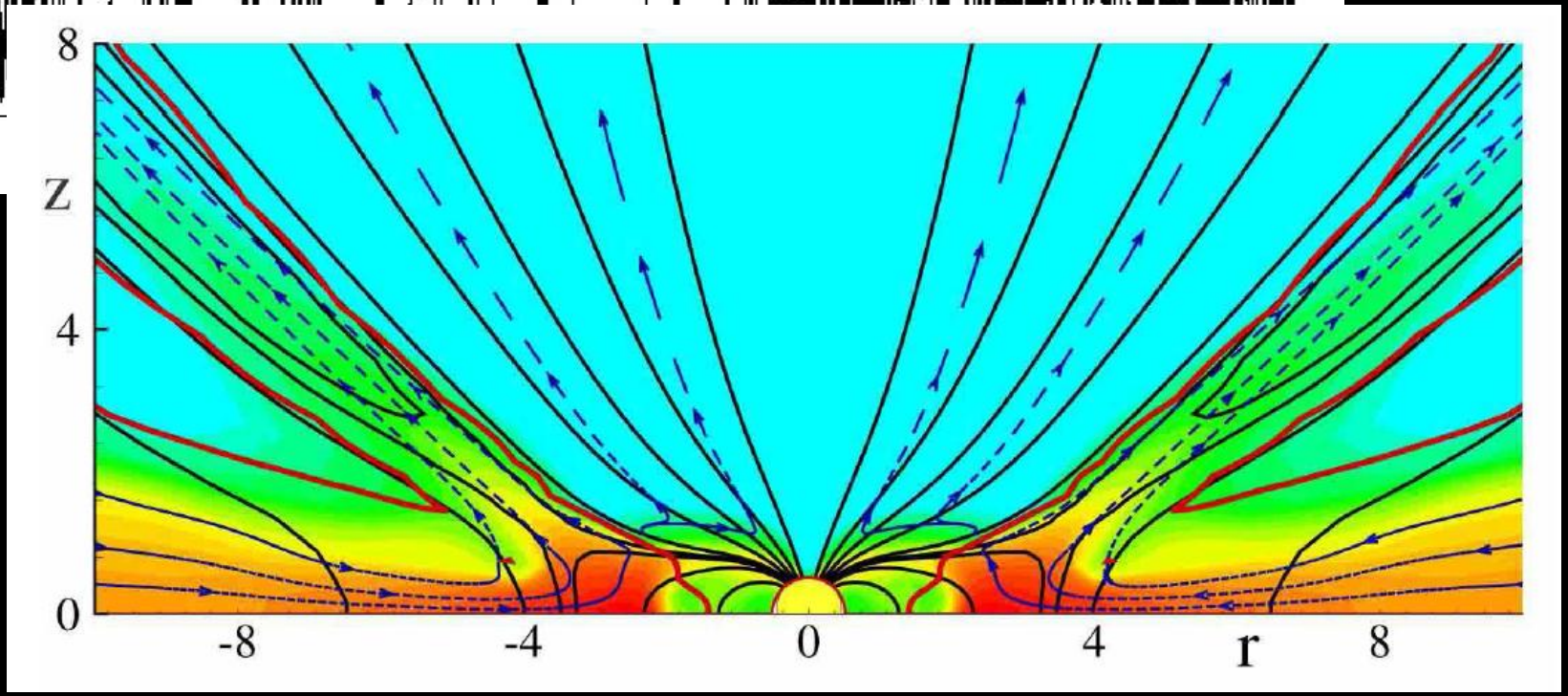
accretion rate
fluctuations
at the outer disk?
[Lyubarskii 1997]

Two flux states



Propeller inhibition of accretion

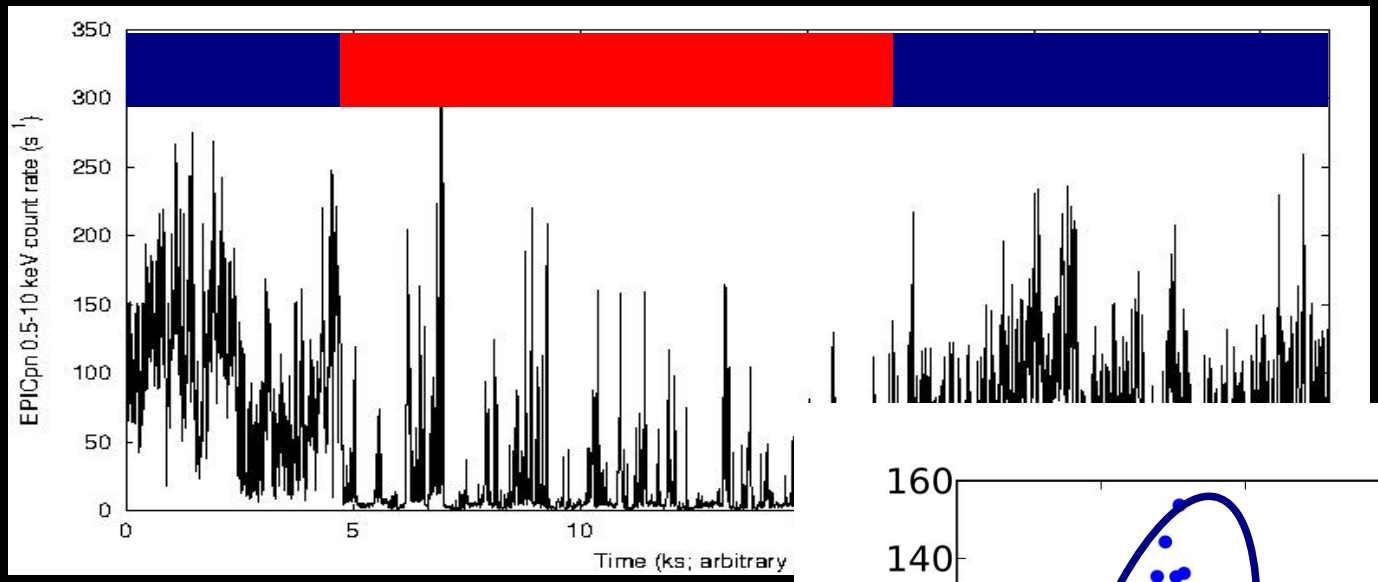




[Romanova+ 2008]

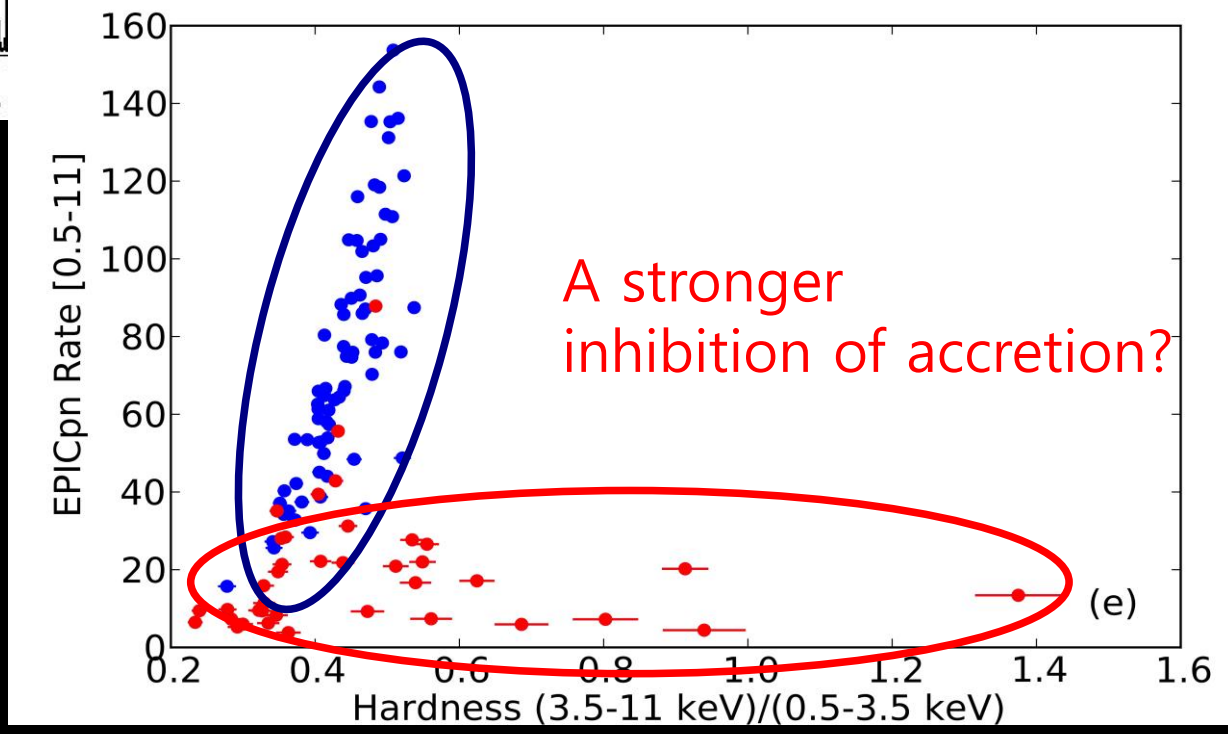
IGR J18245-2452: patterns of variability

Average spectrum is hard (Comptonization with Γ~1.4)

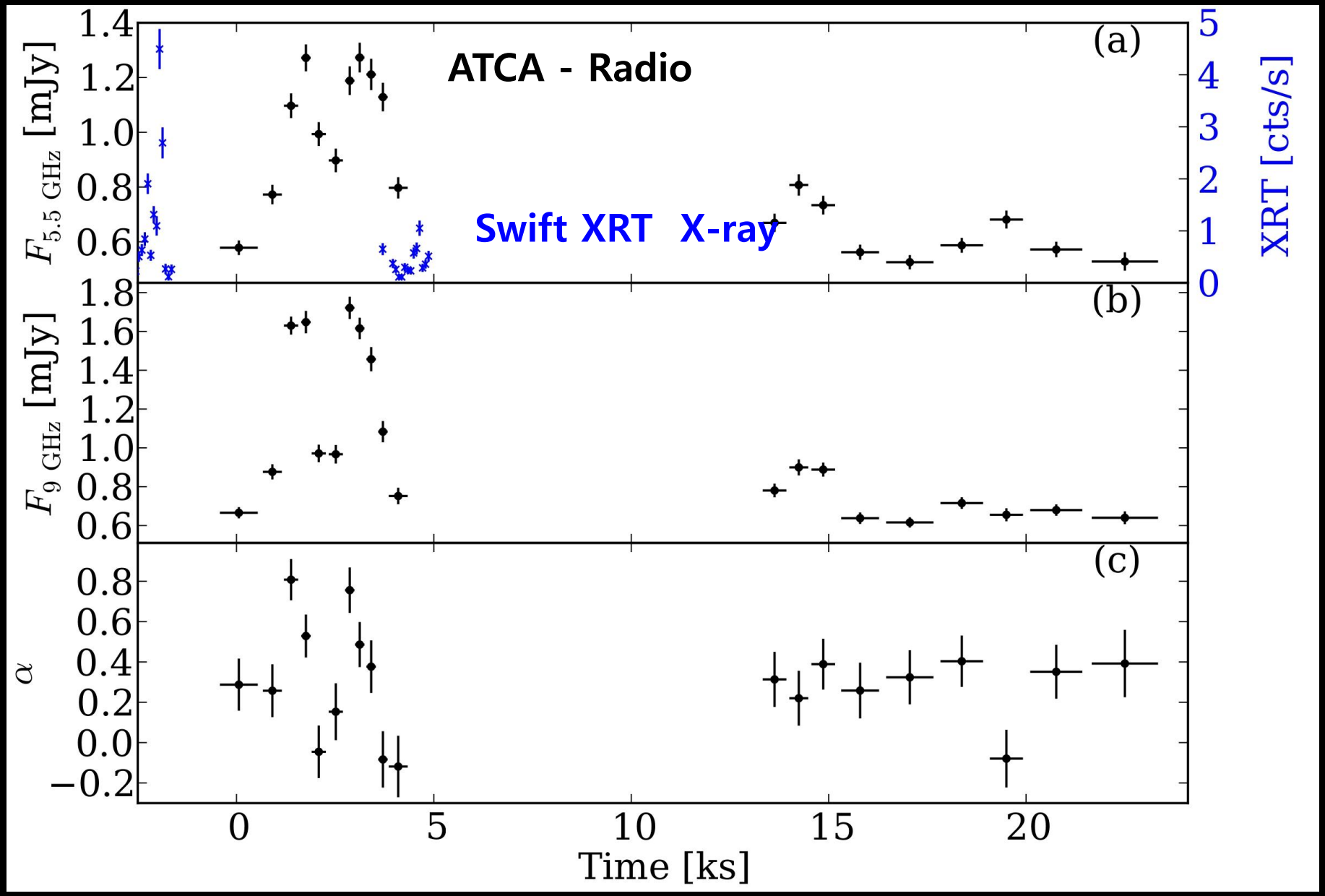


High state - Larger flux; constant hardness; stronger pulse profile

Low state - Lower flux; variable hardness; weaker pulse profile

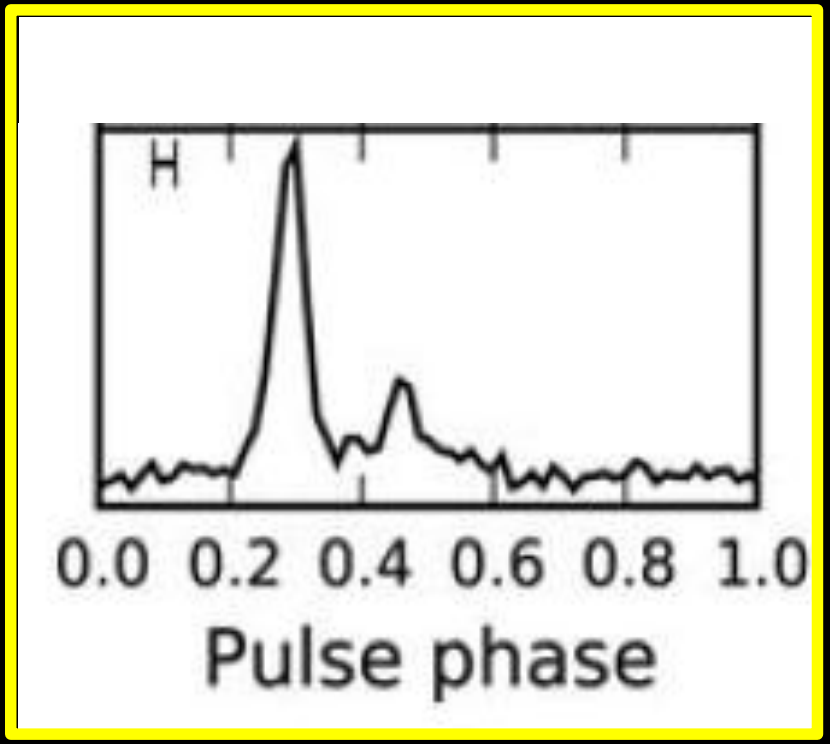


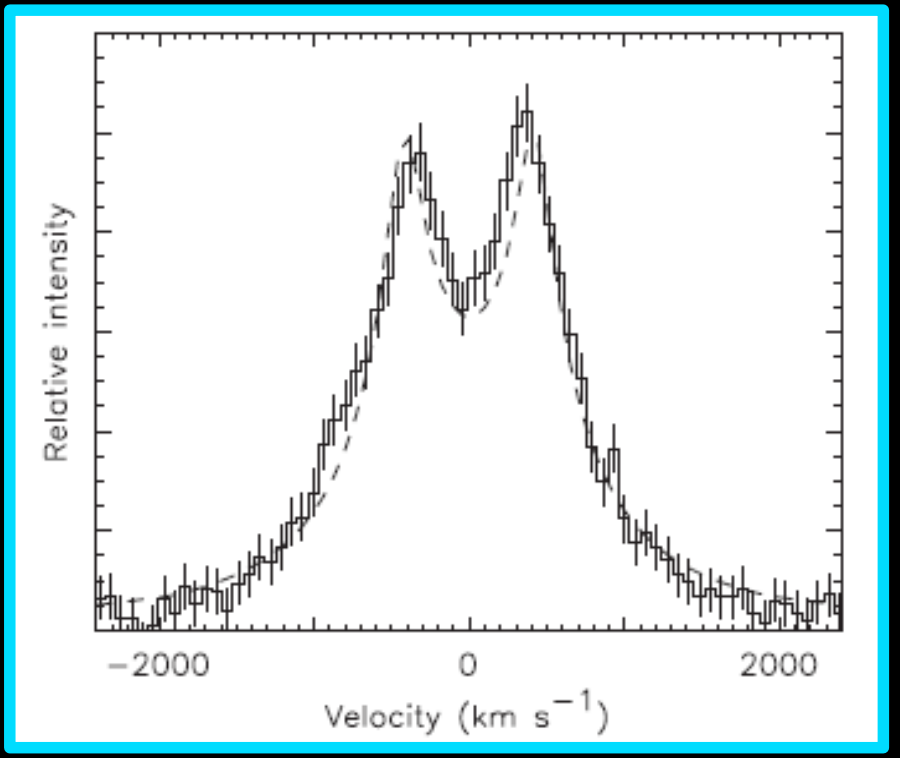
IGR J18245-2452: variable radio emission



A flurry of fossils...

PSR J1023+0038





A 1.7 ms **Radio PSR**

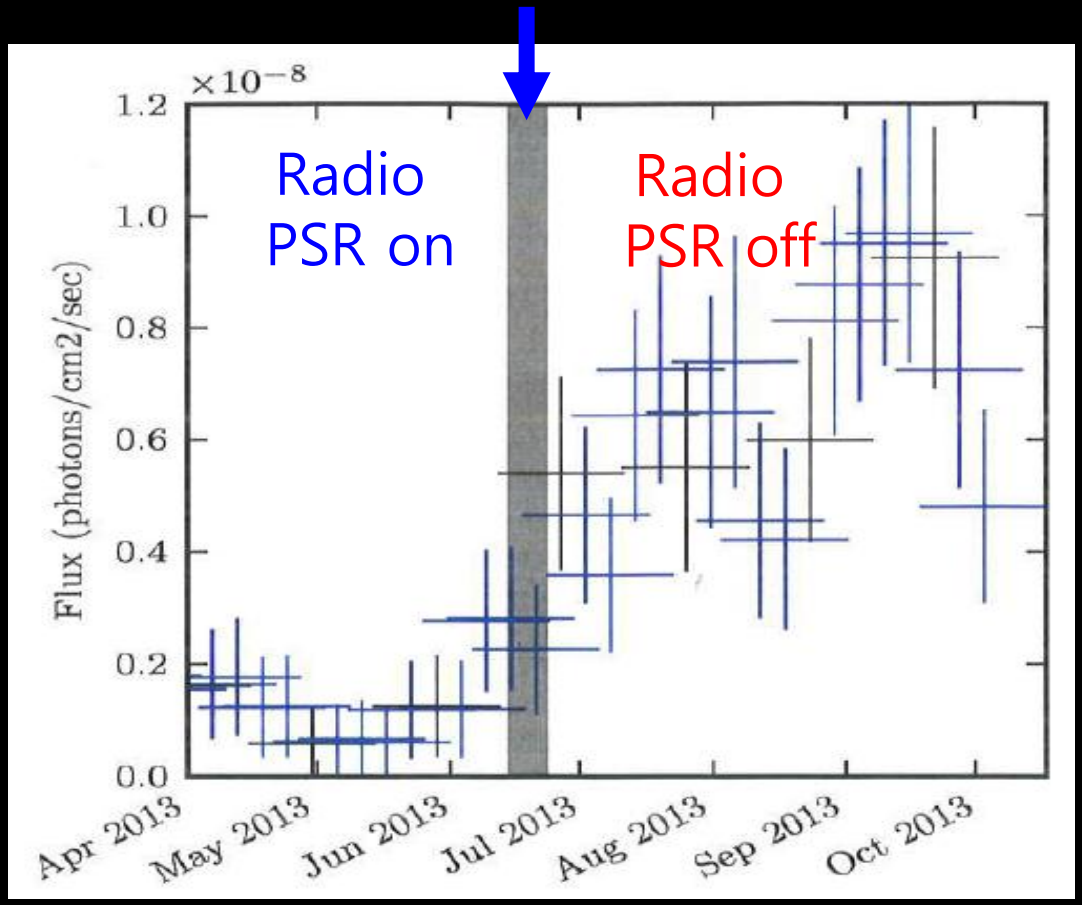
Accretion disk in 2000-01
(but faint in X-rays, no pulses)

A state transition must have occurred, even if unobserved

Archibald et al. 2009, Science

PSR J1023+0038: June 2013, a new state transition

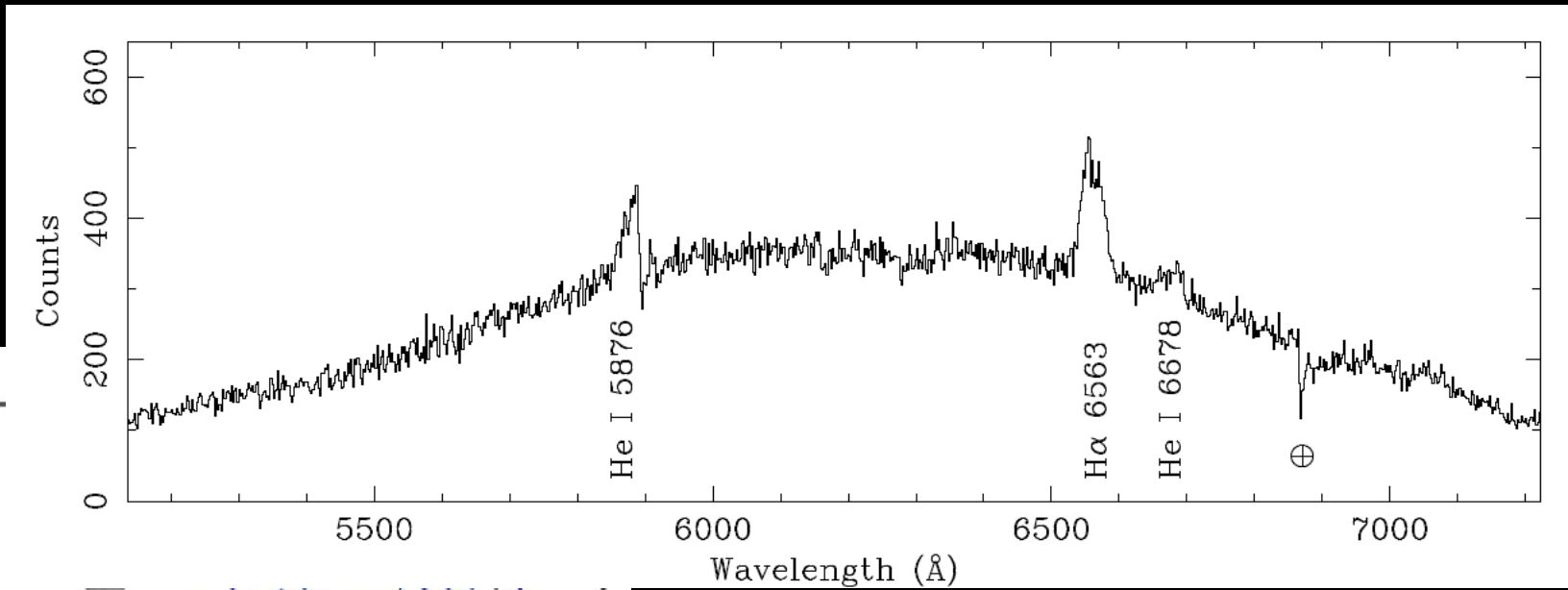
Radio pulsar disappears

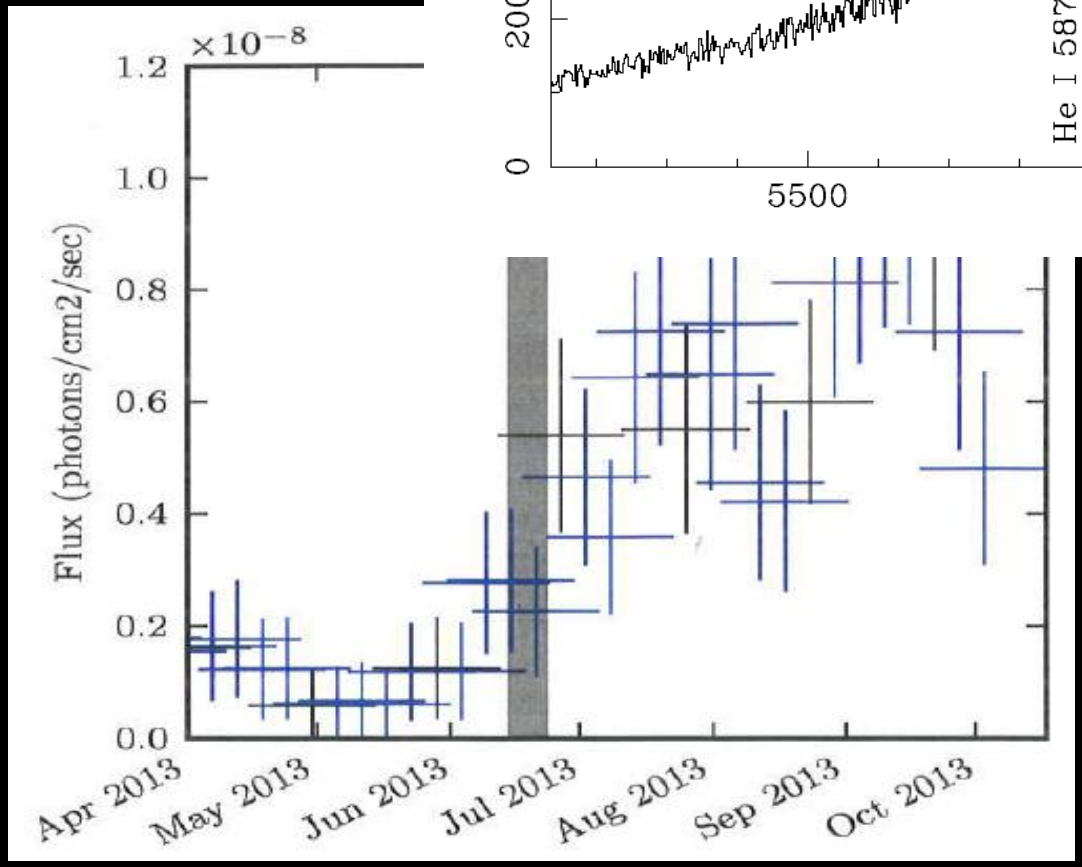


5-fold increase of gamma-ray flux

Stappers+ 2013, arXiv:1311.7506

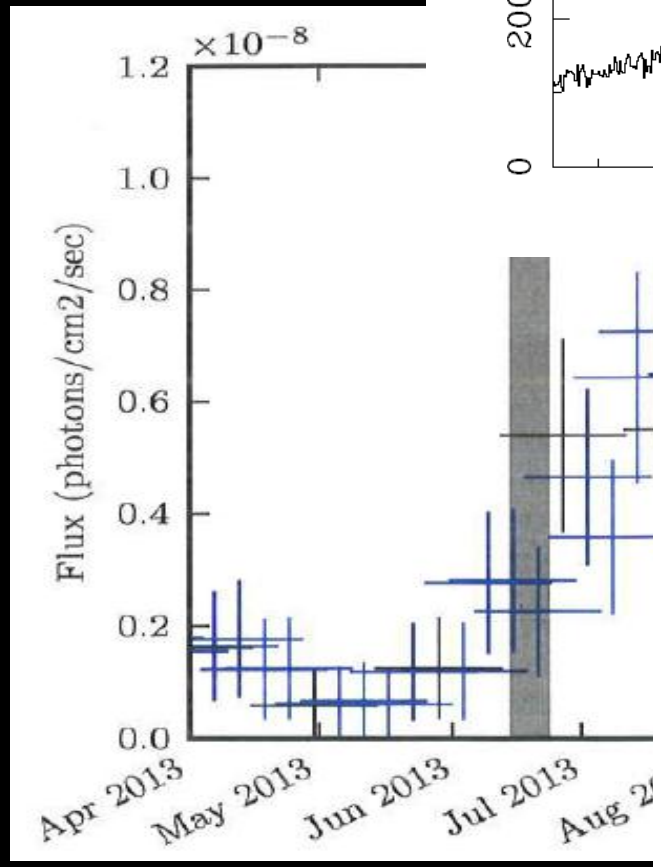
PSR J1023+0038: June 2013, a new state transition

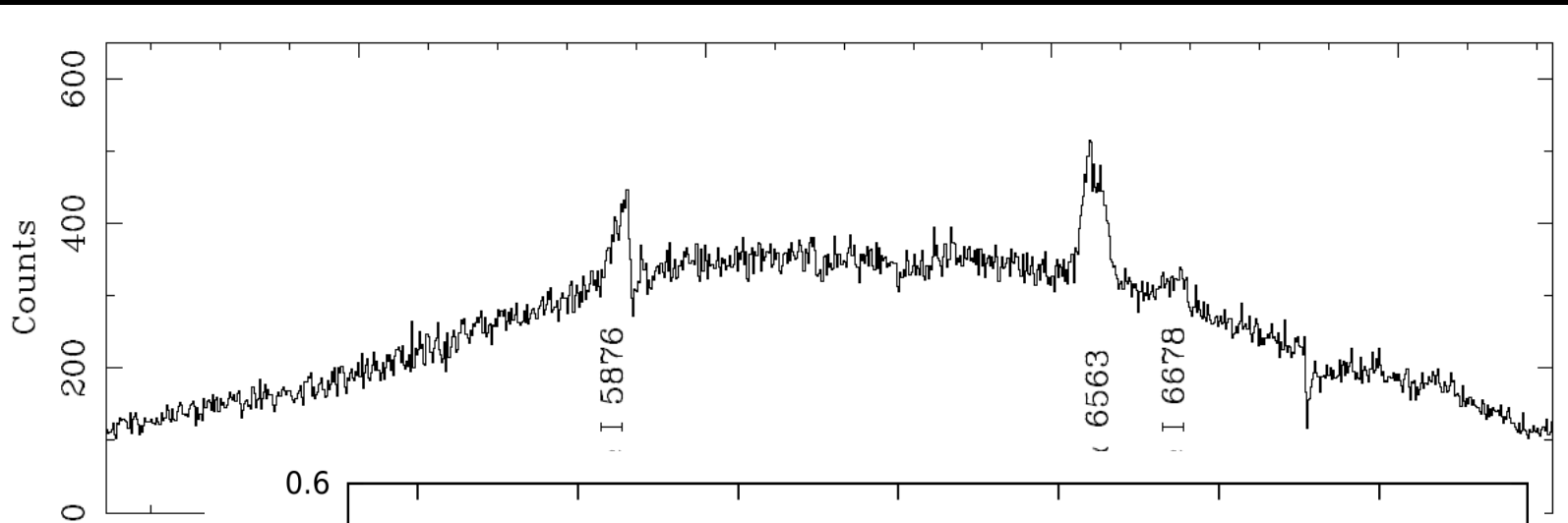


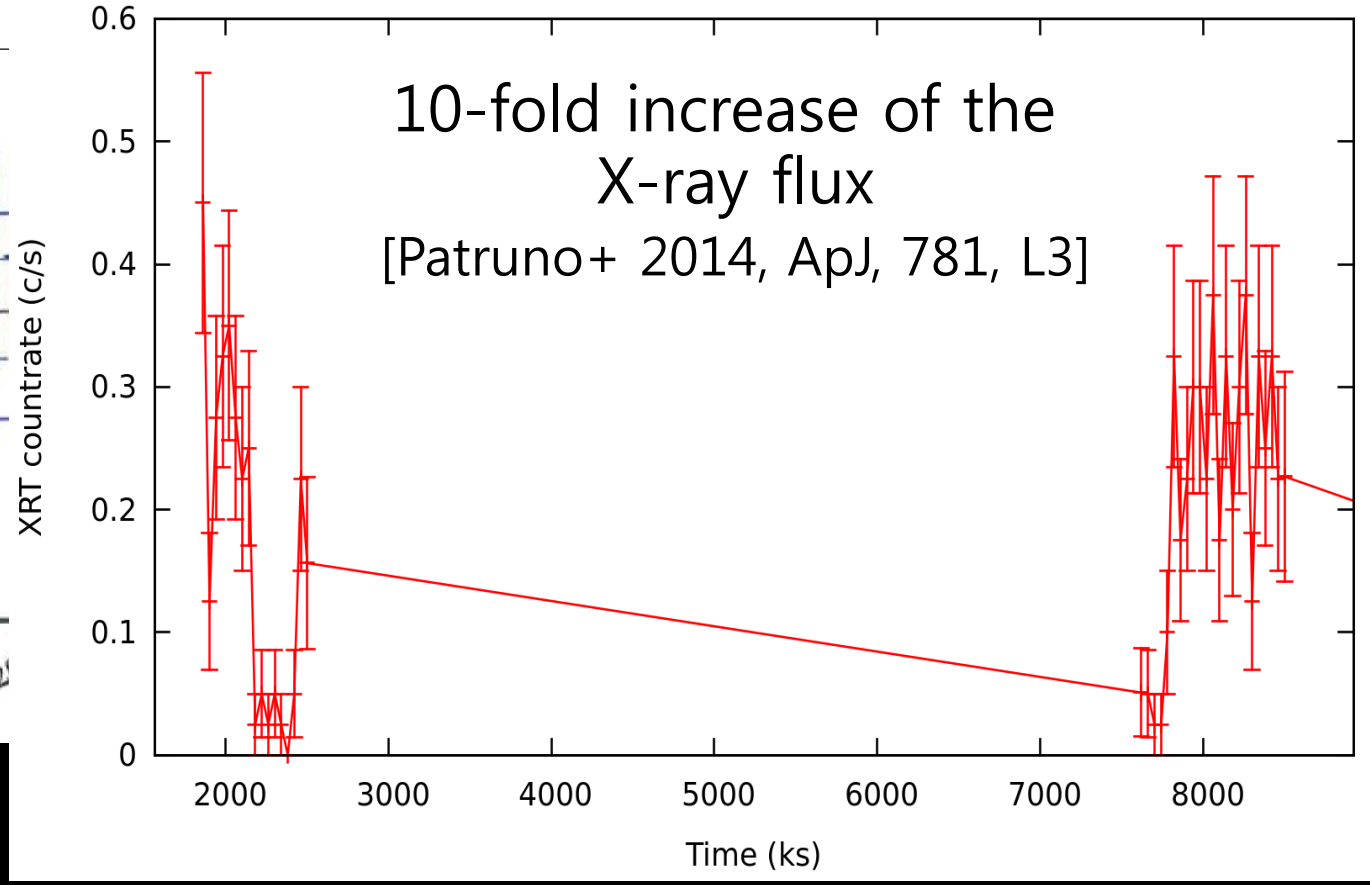


Broad double-peaked optical emission lines
Halpern+ 2013

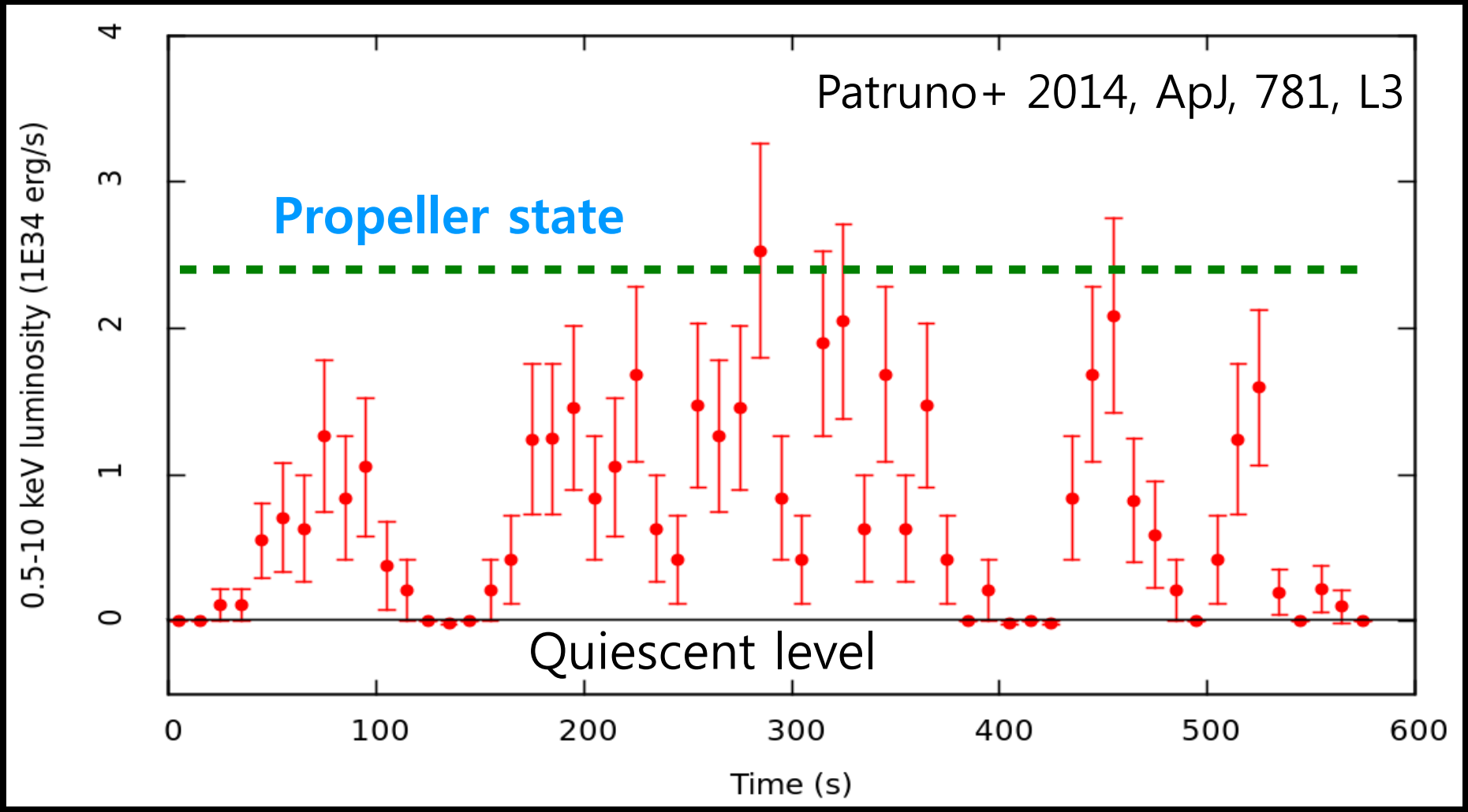
PSR J1023+0038: June 2013, a new state transition







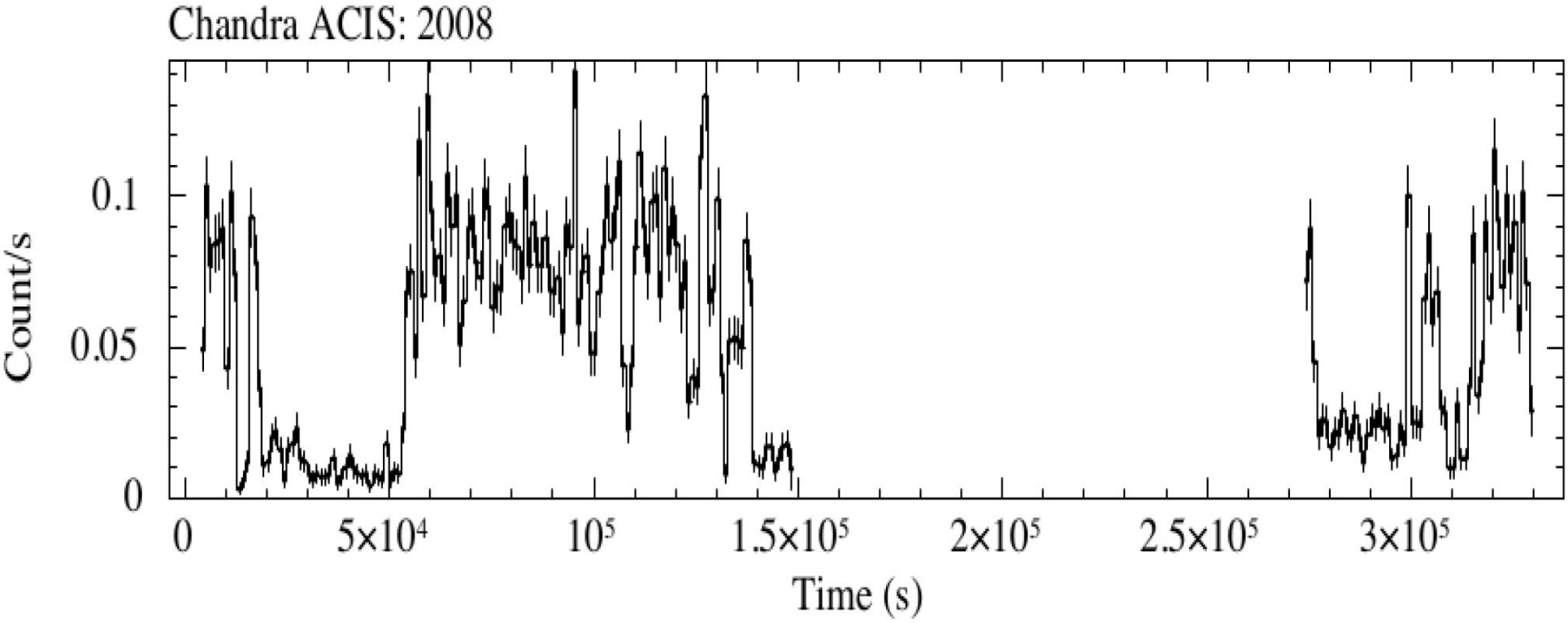
PSR J1023+0038: X-ray variability



At peak → L_X ~ 10^{34} erg/s → Accretion power (propeller)

At minimum → $L_X \lesssim 3 \times 10^{32}$ erg/s (→ compatible with rotation-power)

PSR J1023+0038: similarities with IGR J18245-2452



Papitto+ 2013, Nature, 501, 517; Linares+ 2014, MNRAS, 438, L251

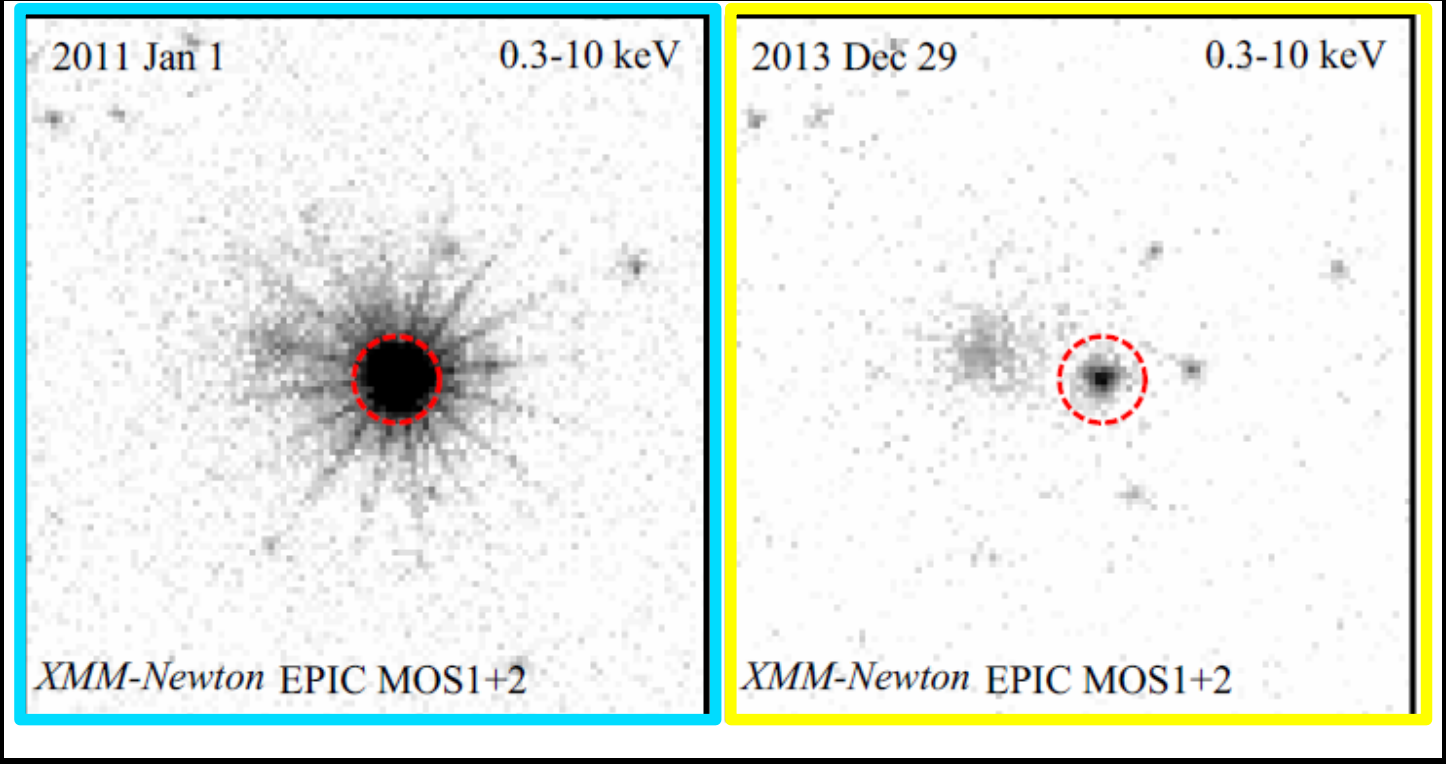
A third transitional pulsar: XSS J12270-4859

Sub-luminous (~10^{34} erg/s) in X-rays
- X-ray variability
- Low mass companion and disk
- Gamma-ray bright

[De Martino+2010,2013; Saitou+2010; Hill+2011]

Detected as a **Radio PSR**
faint in X-rays (~10^{32} erg/s)
No disk

[Bassa+2014, Bogdanov+2014, Roy+ 2014]

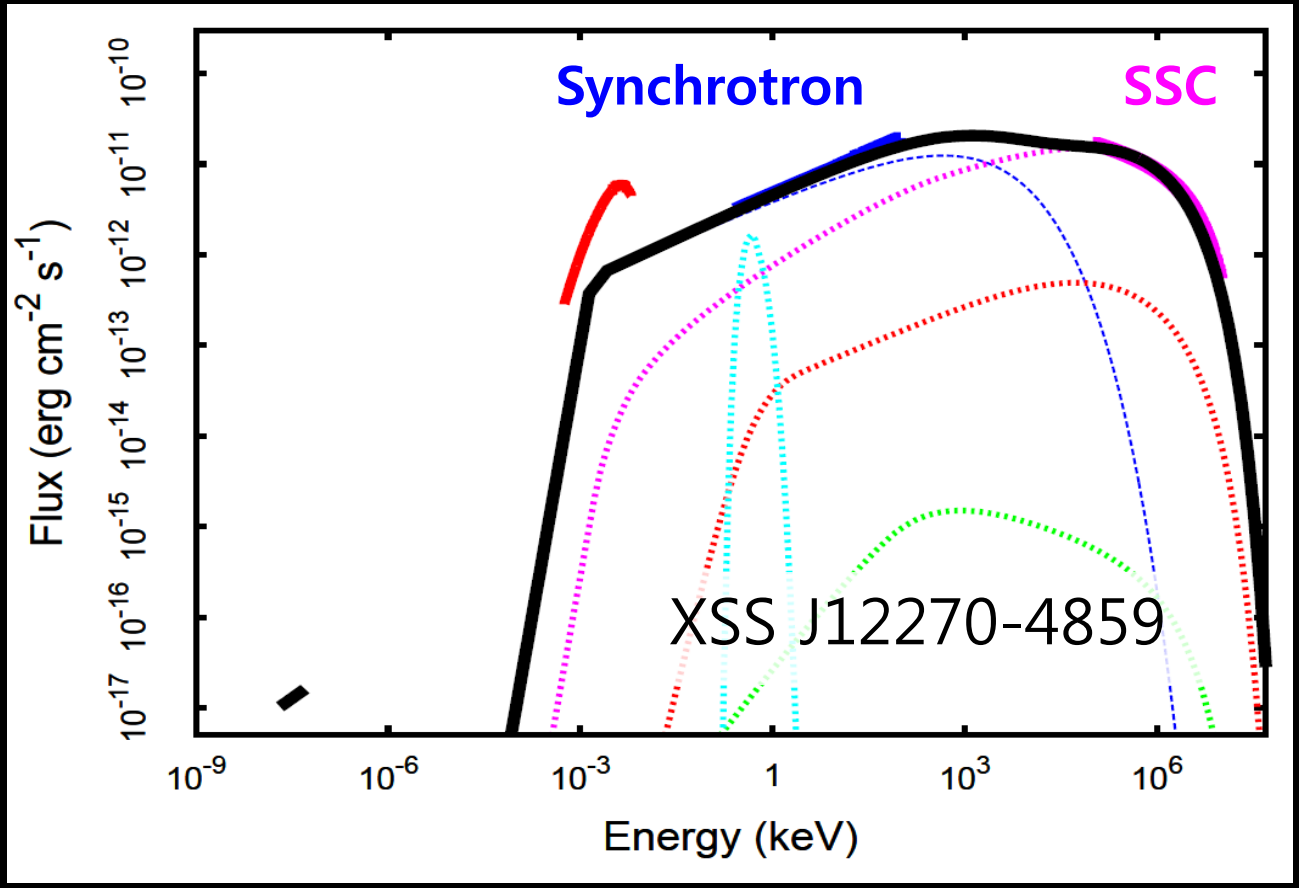


Nature of the sub-luminous intermediate state

Accretion or rotation power? Electron acceleration mechanism?

A **Radio PSR** turned on even with a disk (Stappers+2013)
Extremely large spin down energy conversion efficiency needed

A **propelling magnetosphere** (Papitto+ 2014, MNRAS, 438, 2105)

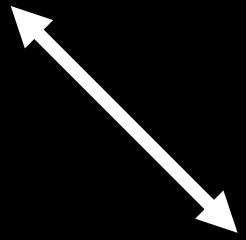


The three states of millisecond pulsars

Accretion powered state

Bright X-ray outburst (~10^{36} erg/s)

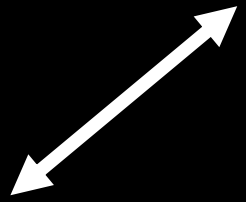
X-ray pulsations



An intermediate (propeller?) state

Sub-luminous accretion (~10^{34} erg/s)

Brighter gamma-ray emission



Rotation powered state

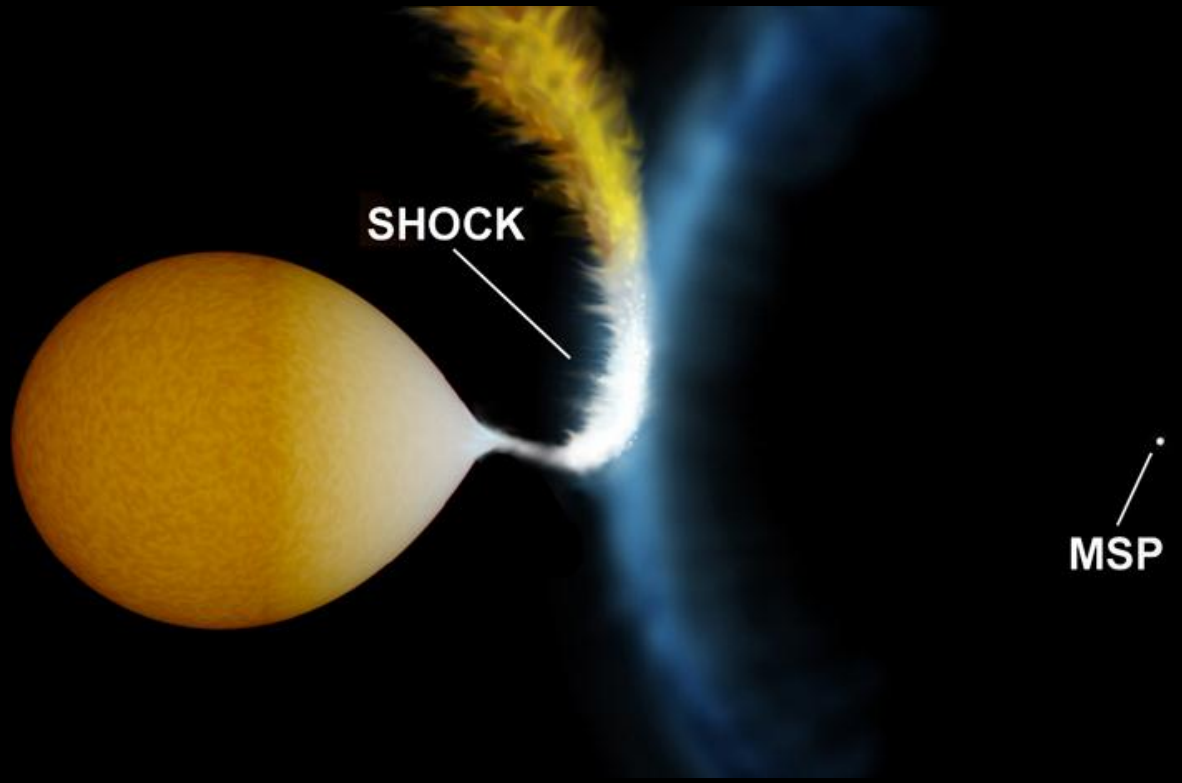
Faint in X-rays (~10^{32} erg/s)

Radio/gamma-ray pulsations

Candidate transitional pulsars

Eclipsing radio pulsars [Fruchter+ 1988]
~50 known; bright gamma-ray sources
Black widows (Mc < 0.1 Msun)
Redbacks (Mc ~ 0.2-0.7 Msun)

The three transitional pulsars discovered so far are redbacks

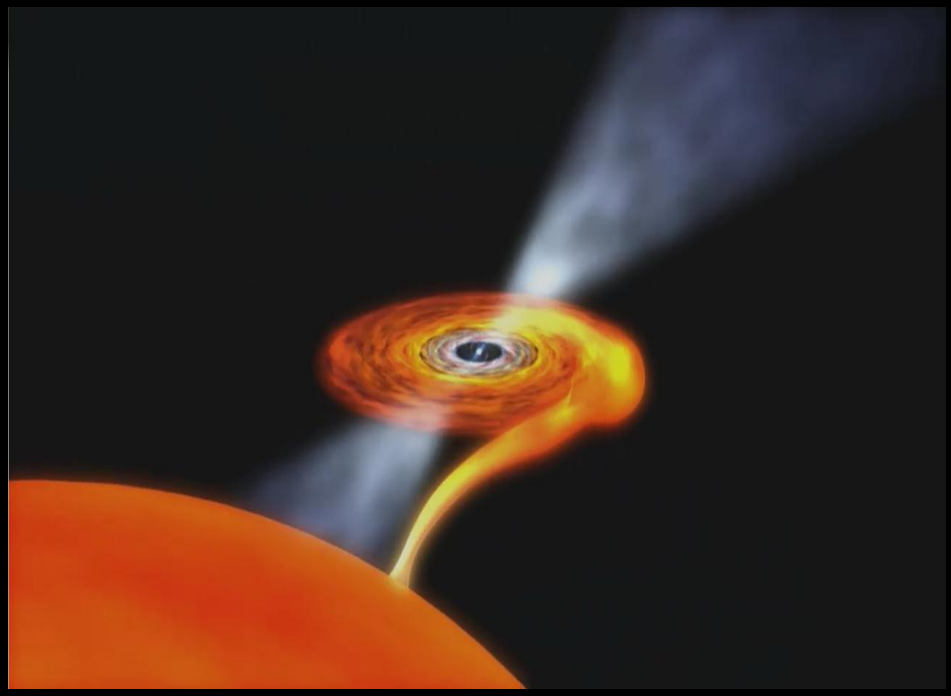


Candidate transitional pulsars

Accreting millisecond pulsars
15 known [Wijnands & van der Klis 1998]

Weak X-ray transients
(Lpeak ~ 1036 erg/s)

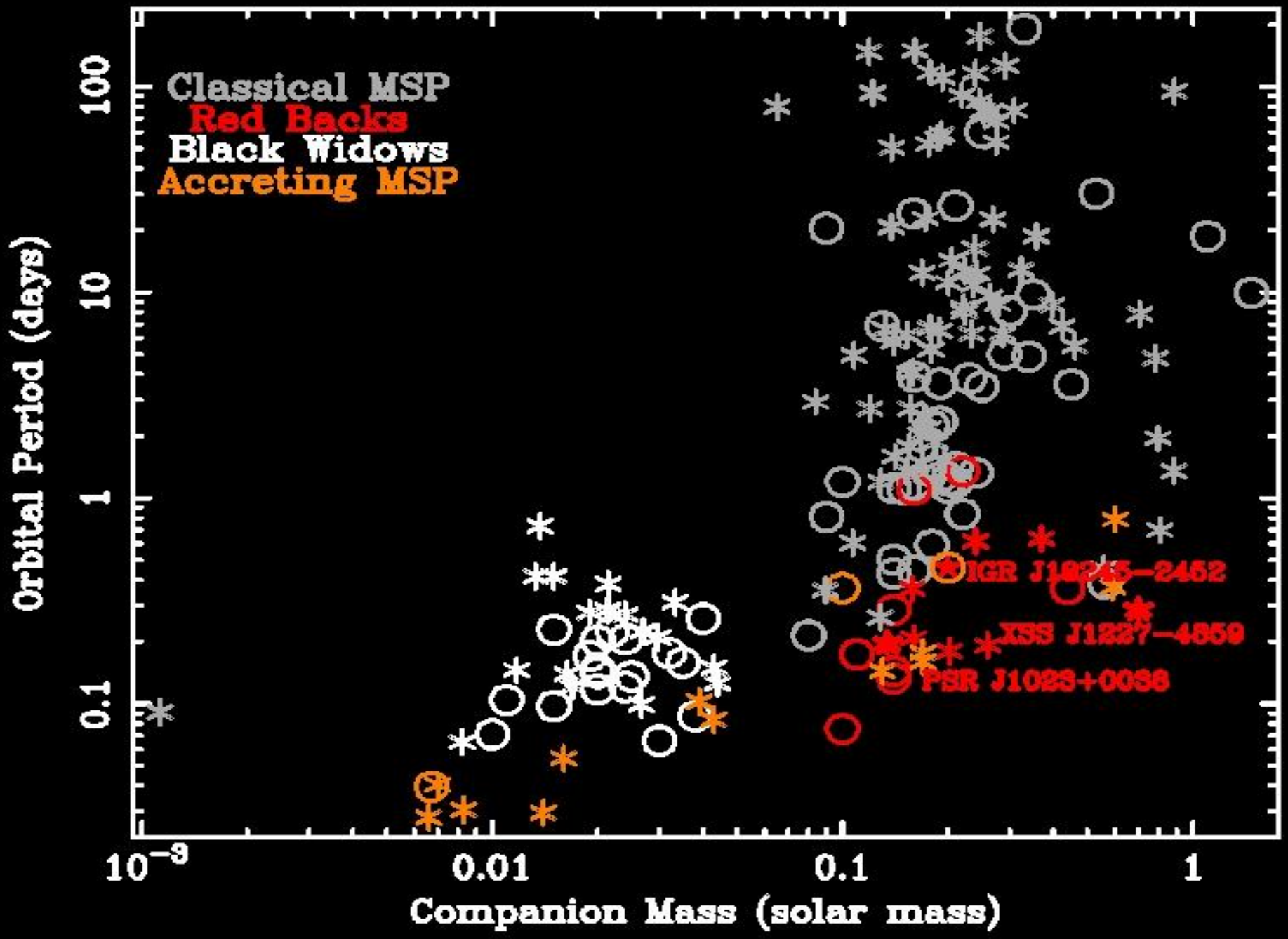
A **radio PSR** turning on
during quiescence
(L~$10^{32\text{-}33}$ erg/s)?



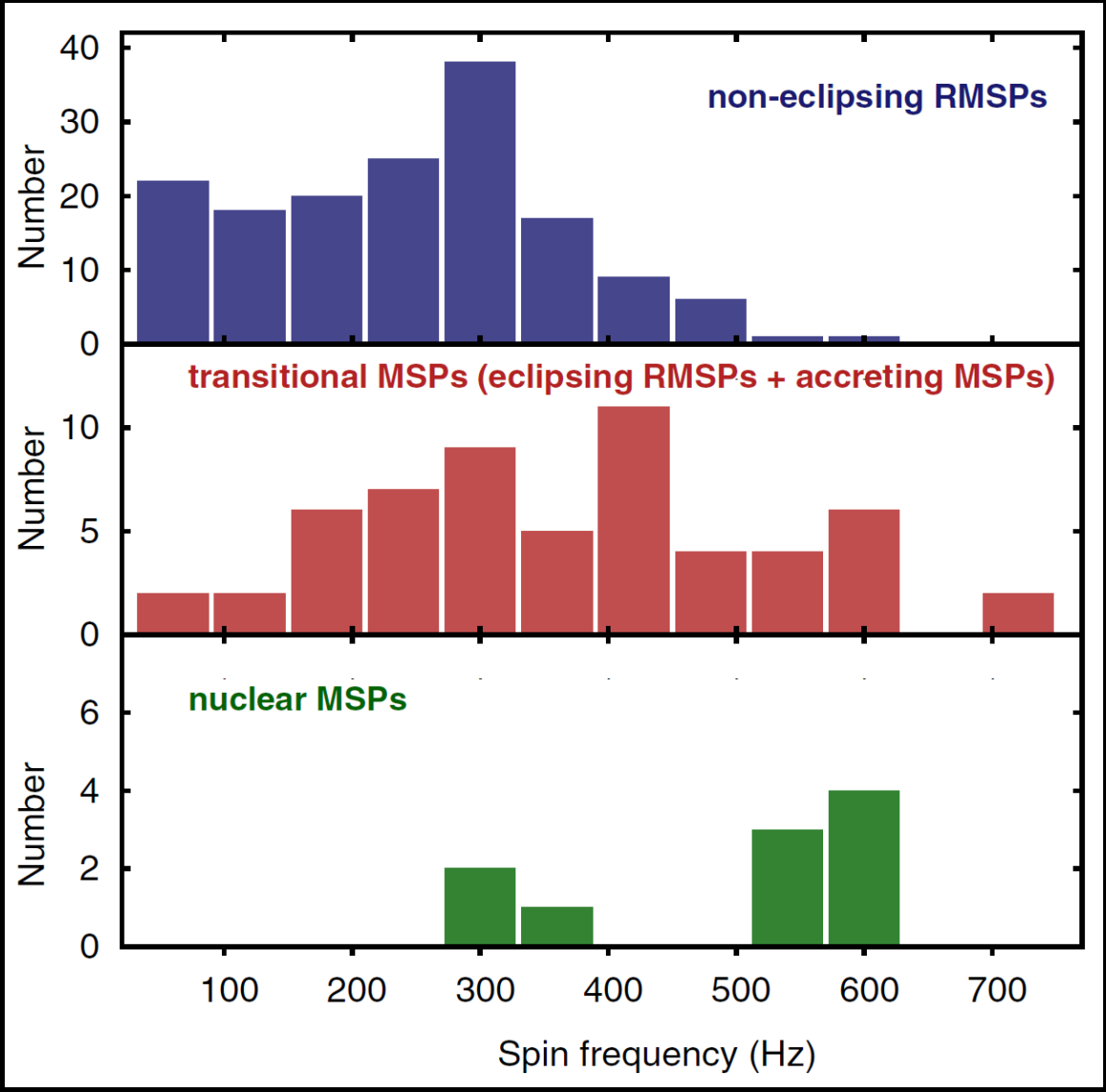
Reprocessed optical light [Burderi+2001, Campana+2002]
Spin evolution [Hartman+2008, Patruno+2009, Papitto+2011]
Orbital evolution [Di Salvo+ 2008, Patruno+2012]

...but no detection in radio and gamma rays, expect M28I
[Burgay+2003, Iacolina+2011, Xing+2012]

A common orbital evolutionary history



A common & intermediate spin distribution



Papitto, Torres, Rea, Tauris, 2014, A&A, in press, arXiv:1403.6775
see also Tauris 2012, Science, 335, 561

Open questions

What drives variations of the mass in-flow rate?
Tidal interactions? Mass accumulation?

Outflows during accretion powered stage
(radio/X-ray correlations)?

Origin of the gamma-ray emission during the intermediate accretion stage (propeller/magnetospheric origin)

Are all millisecond pulsars in close binary systems transitional?

Thank you to...

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