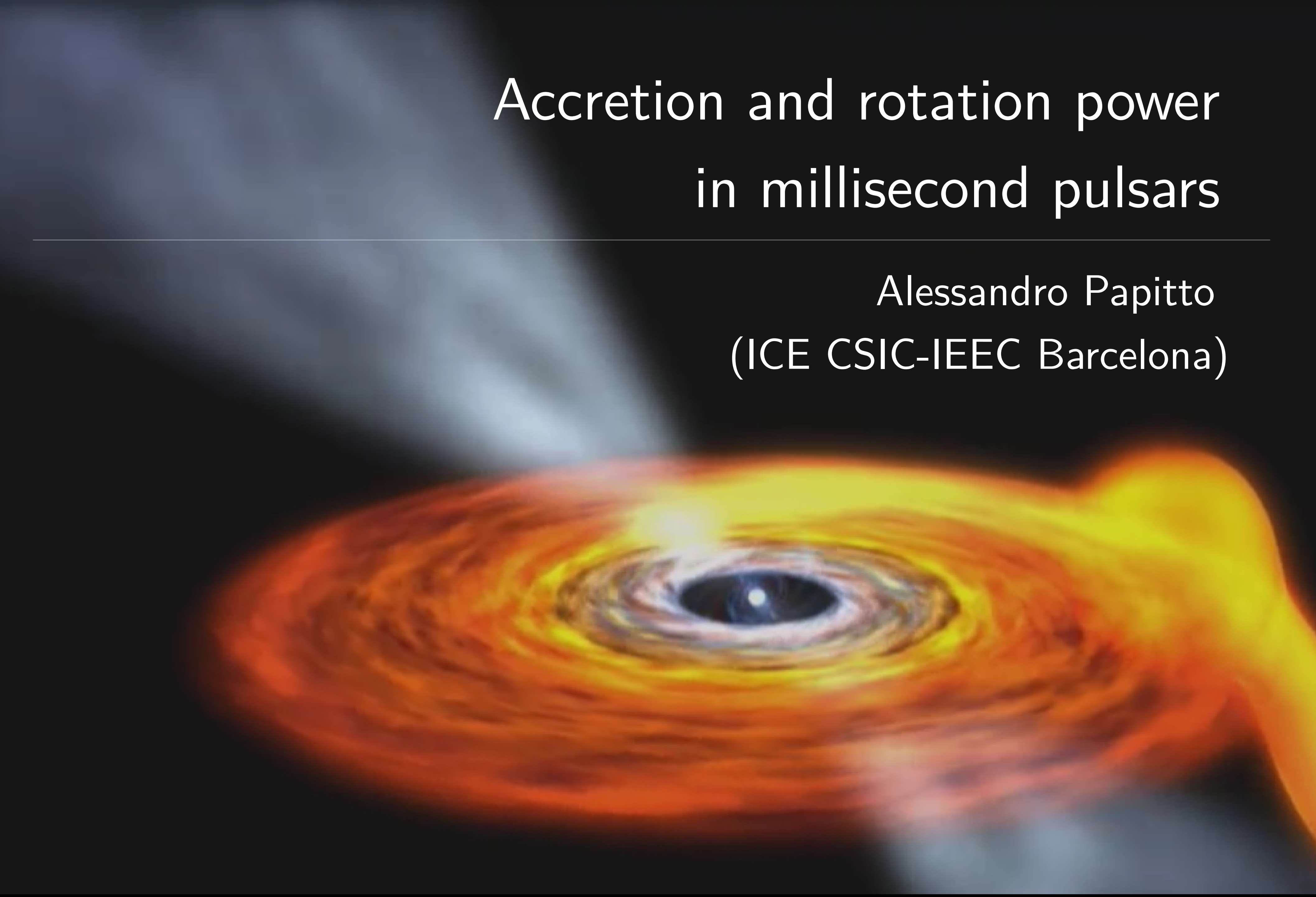
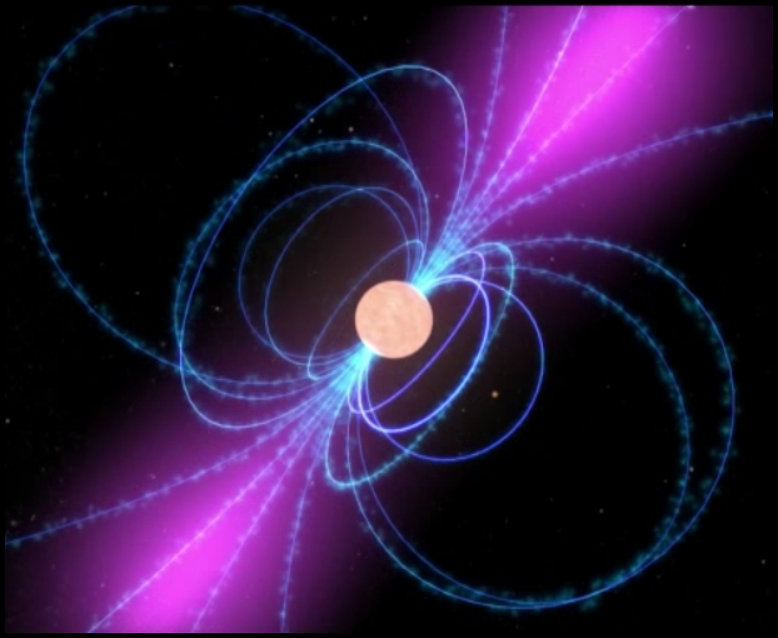


Accretion and rotation power in millisecond pulsars

Alessandro Papitto
(ICE CSIC-IEEC Barcelona)

16.12.2015 – 28th Texas Symposium on Relativistic Astrophysics – Geneve (Switzerland)

Rotation and accretion powered pulsars



Credits: NASA's Goddard Space Flight Center

The fundamental plane of pulsars

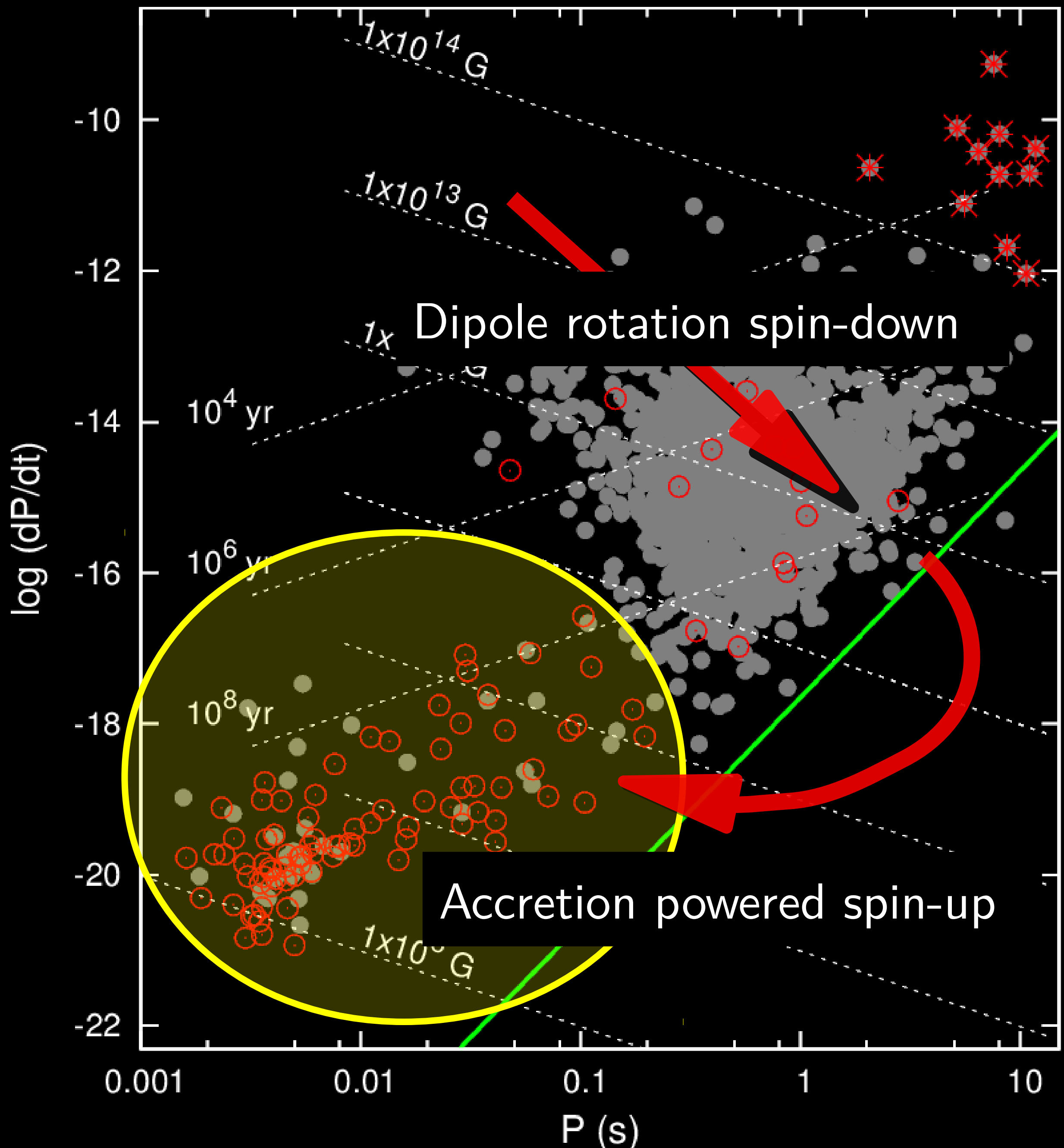
Millisecond pulsars

[Backer+ 1982 Nature]

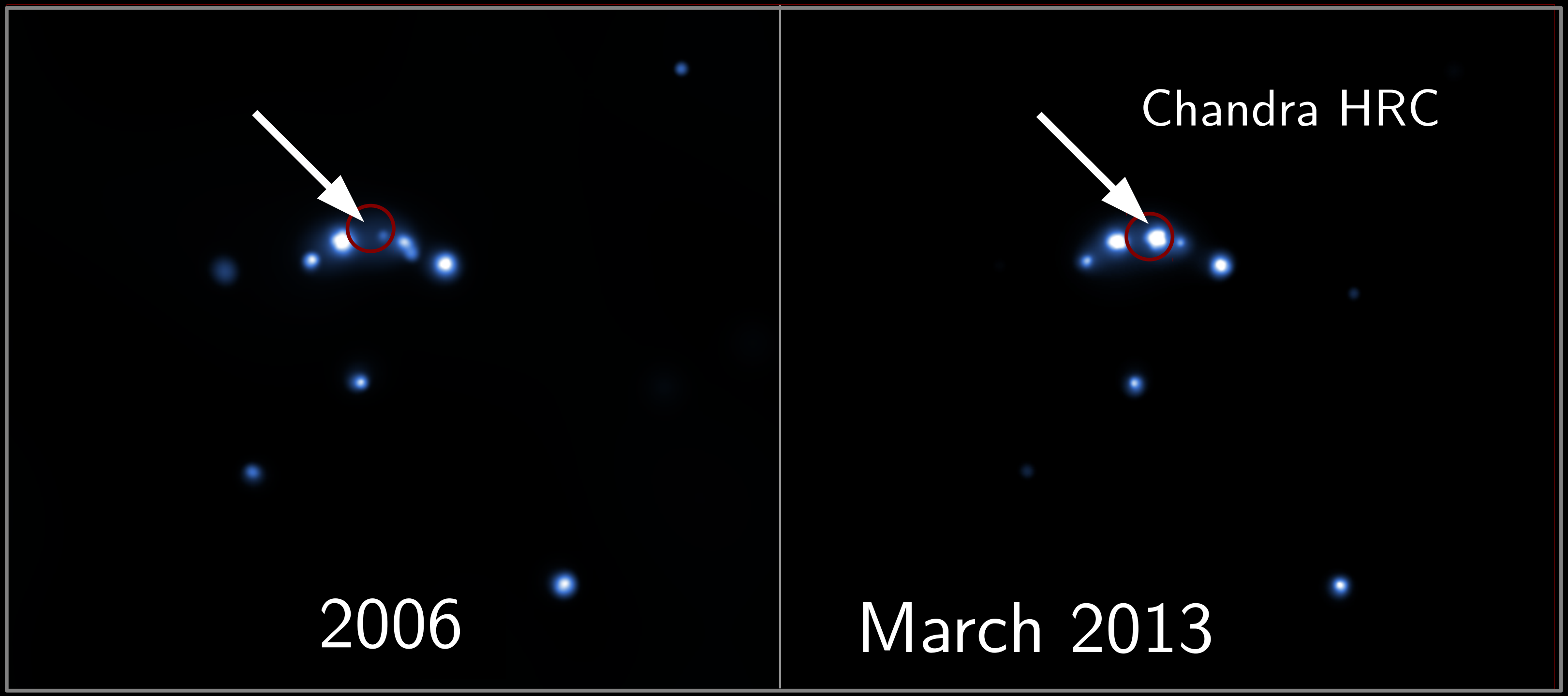
- weakly magnetized
- often found in globular clusters

  $\rightarrow$ old systems
- often in binaries

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



A new transient in M28, IGR J18245-2452

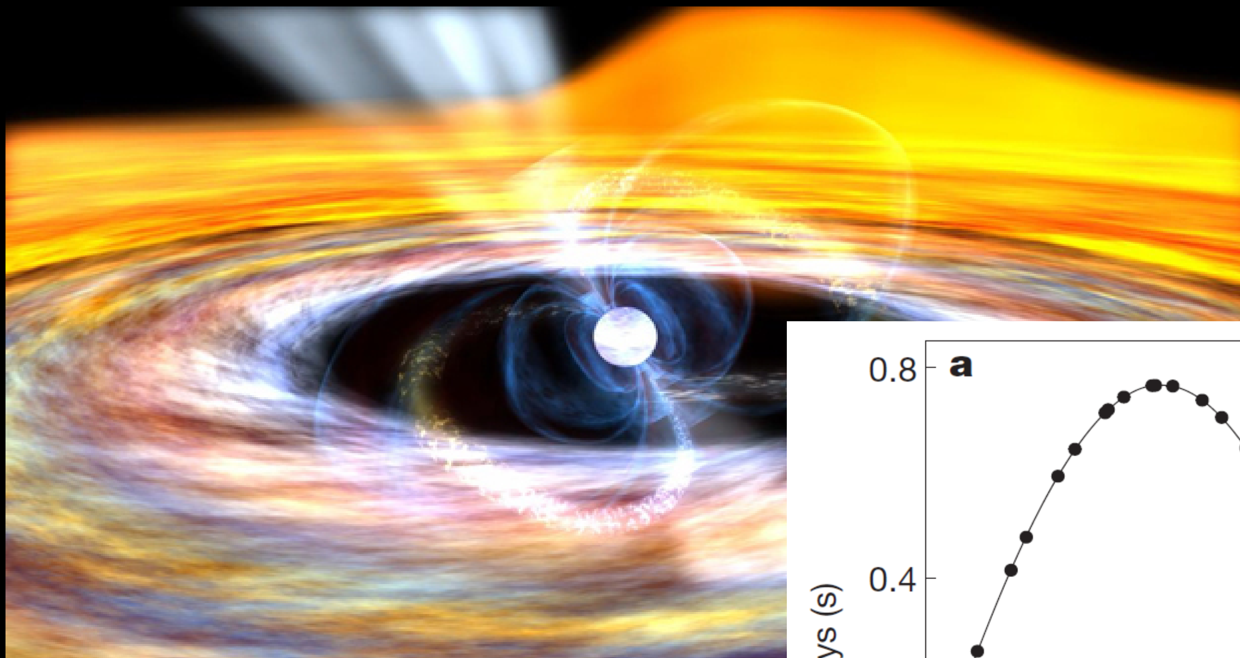


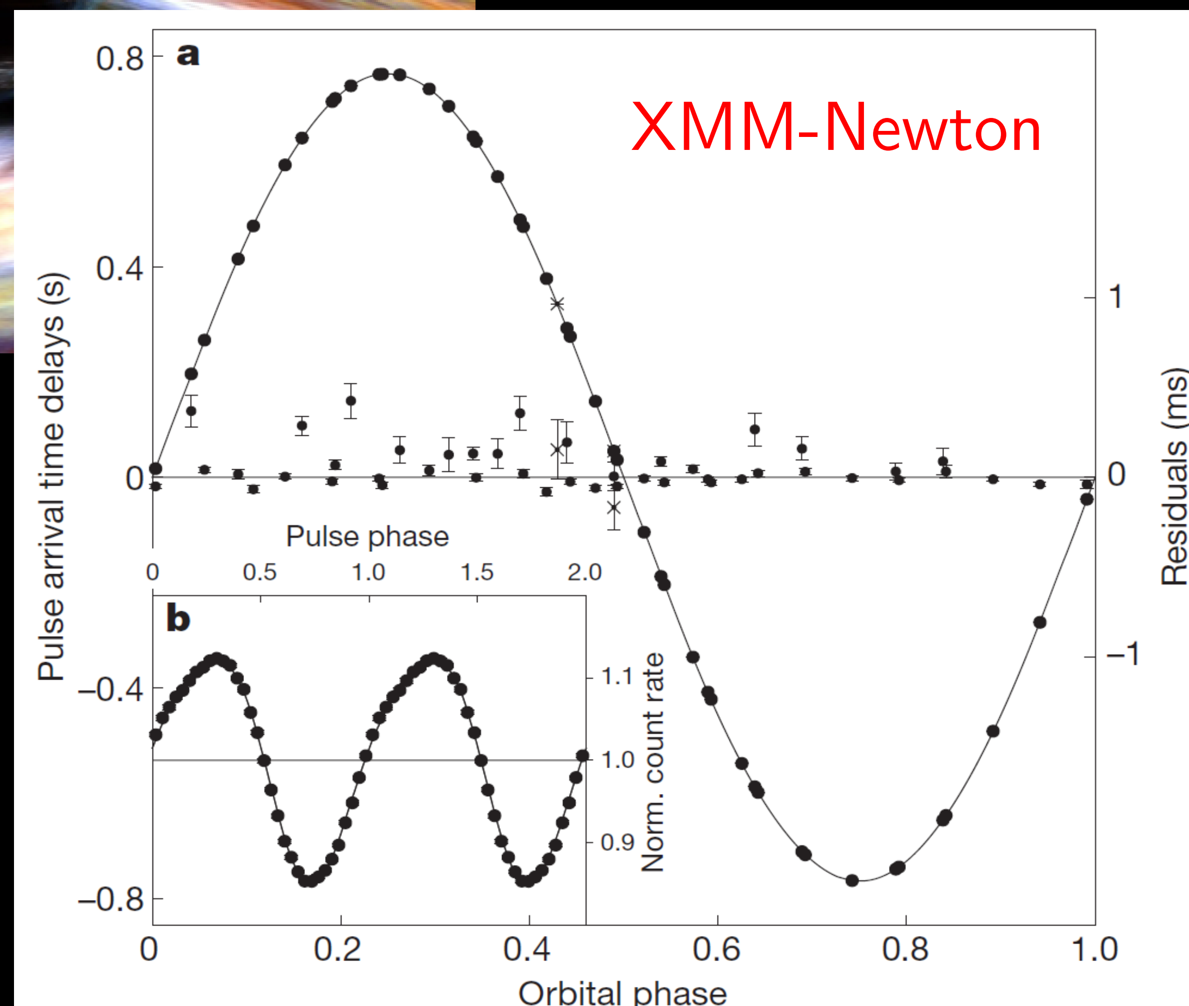
X-ray luminosity ~ few x 10^{36} erg/s → accretion power

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)

Discovery of an accreting millisecond pulsar





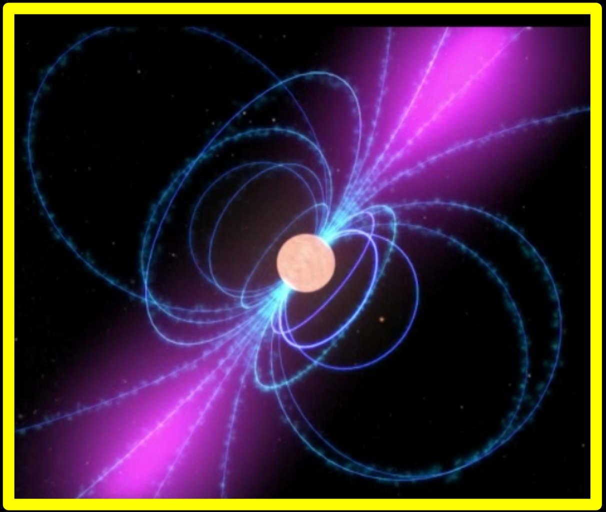
Pspin = 3.9 ms

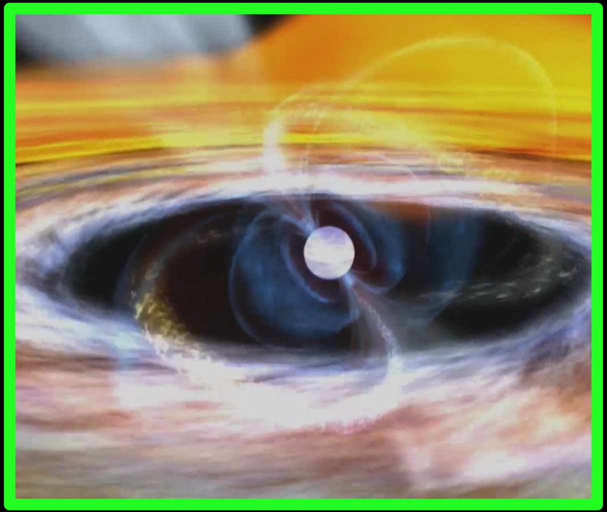
Porb = 11.0 hr

Mcomp ~ 0.2 Msun

Discovery of a transitional pulsar

Radio PSR (rotation power) → **X-ray pulsar** (accretion power)



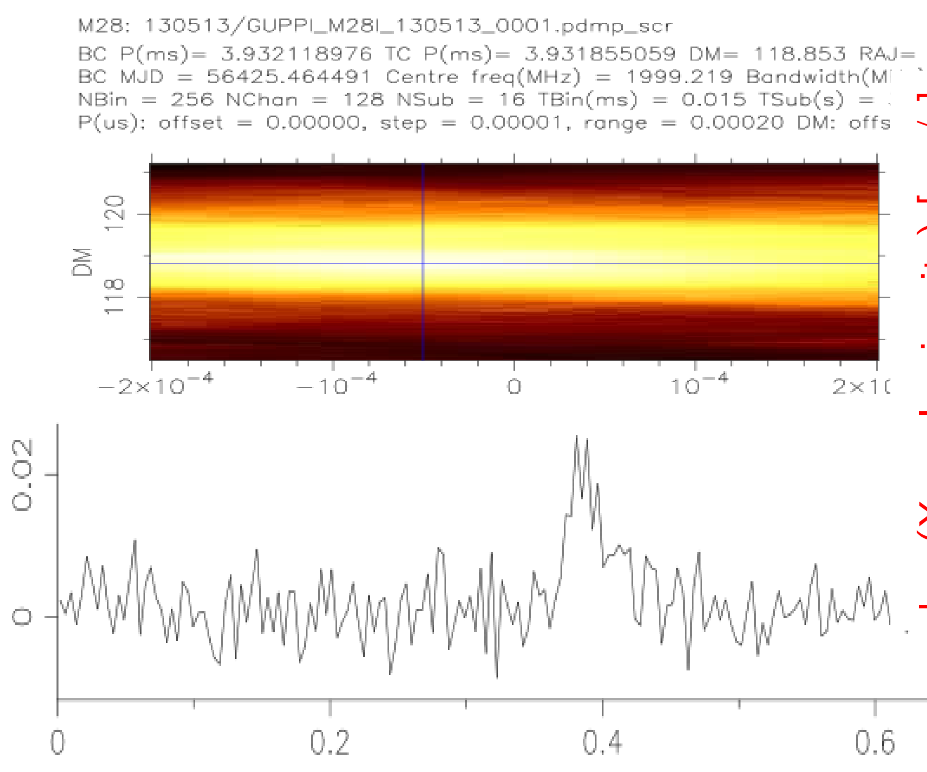


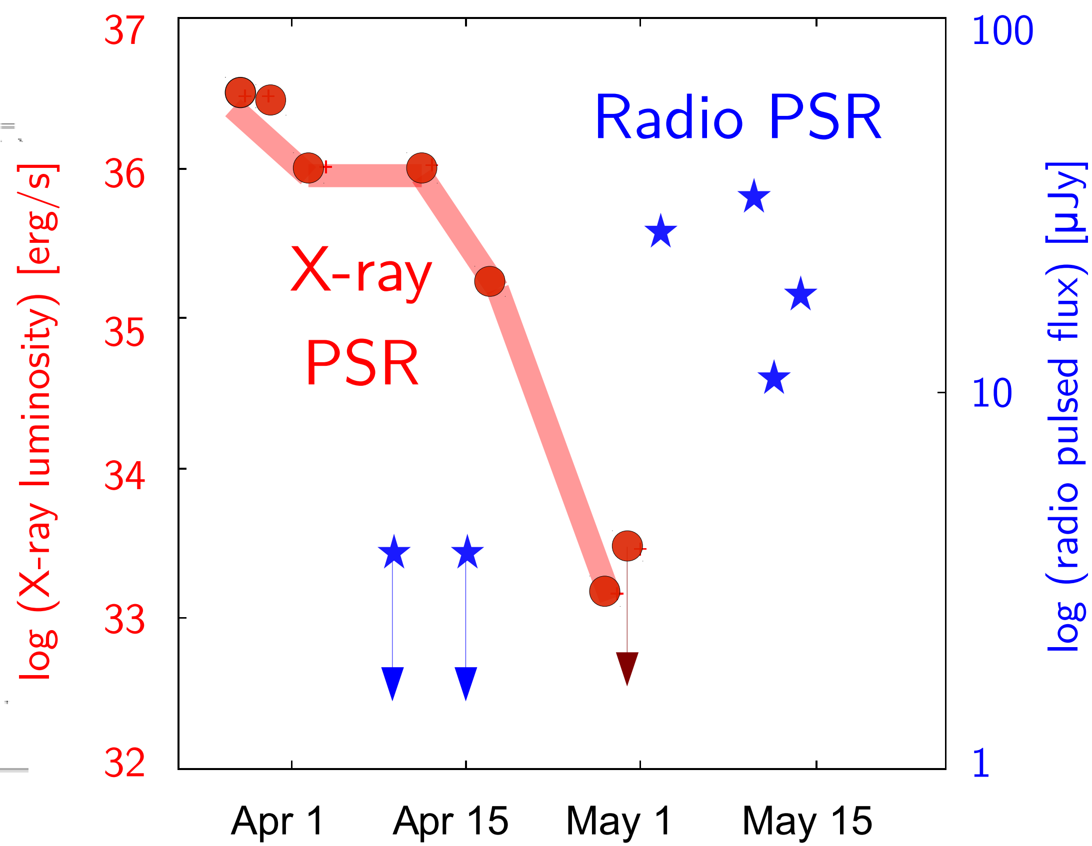
Parameter	IGR J18245–2452	PSR J1824–2452I
Right Ascension (J2000)	$18^h\ 24^m\ 32.53(4)^s$	
Declination (J2000)	$-24^\circ\ 52'\ 08.6(6)''$	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852641(2)	3.93185(1)
Spin period derivative	$< 2 \times 10^{-17}$	
RMS of pulse time delays (ms)	0.1	
Orbital 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 pulsar signal (~10-50 microJy) detected
less than two weeks since the end of the X-ray outburst
(GBT, PKS, WSRT)

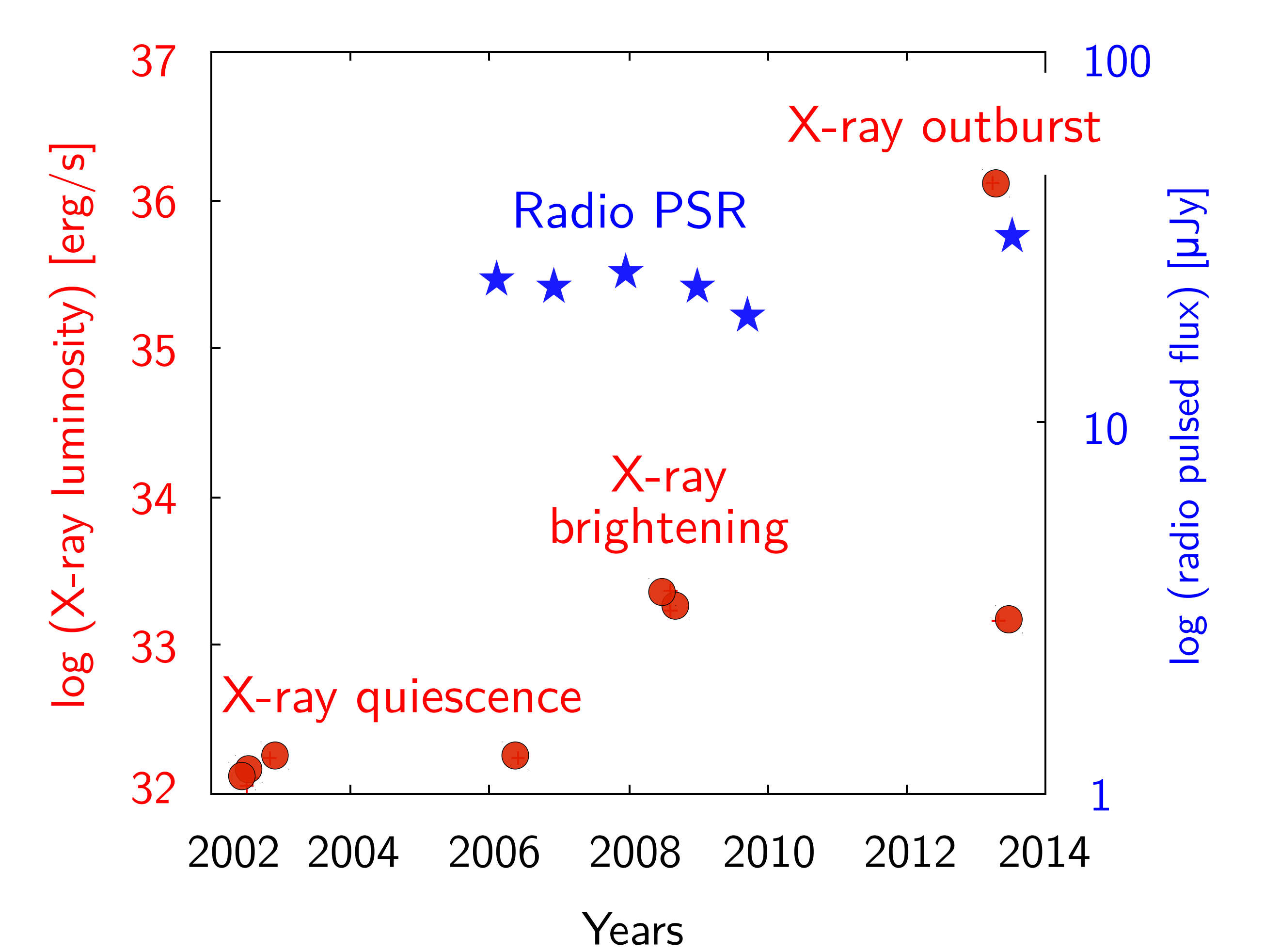




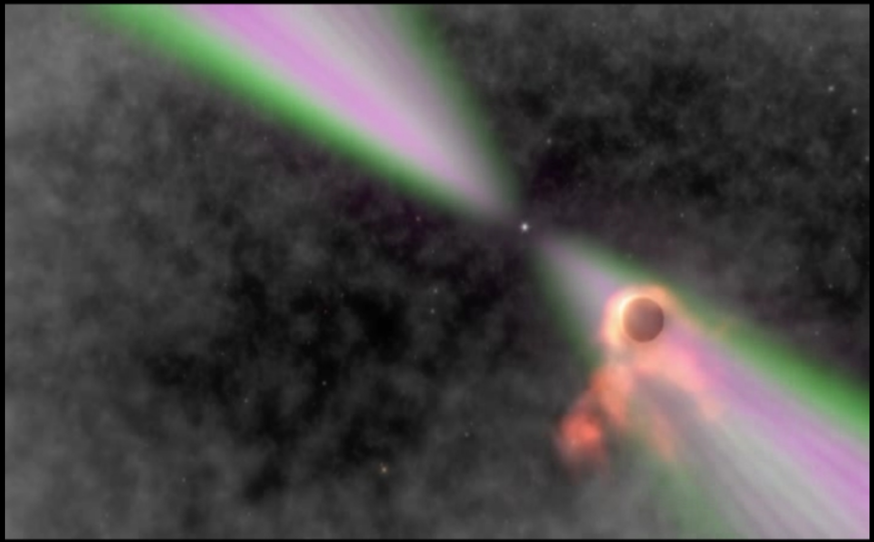
M28: a decade of observations

Radio pulsar faint and irregularly eclipsed

Past **X-ray brightening** seen by Chandra - August 2008



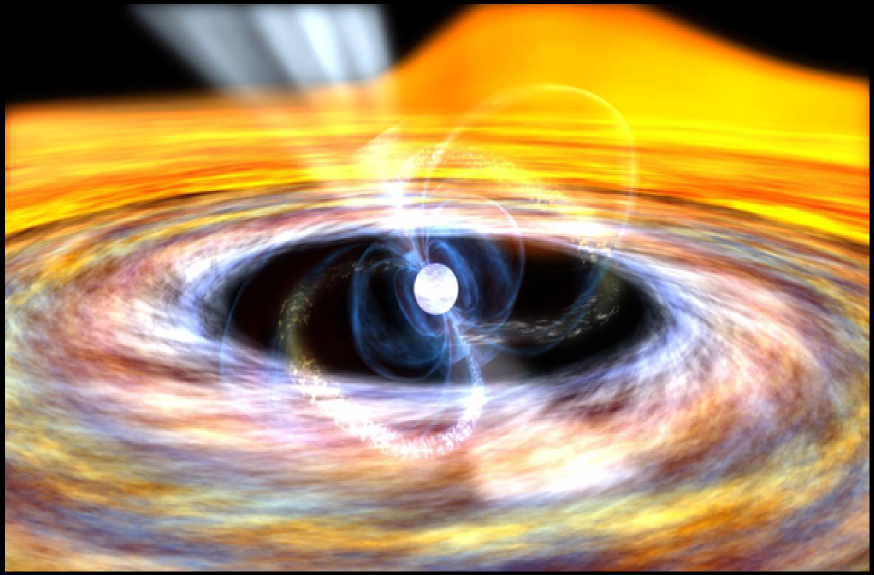
Swings driven by mass in-flow rate variability



Low Mass in-flow rate:

Magnetic field dominates

→ rotation powered **Radio PSR**



High Mass in-flow rate:

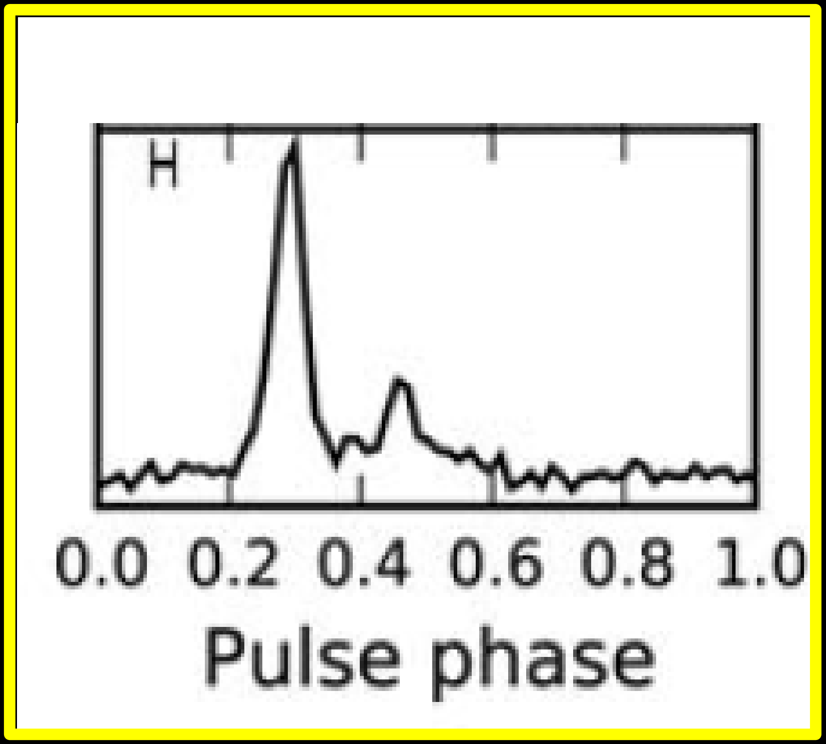
Gravity dominates

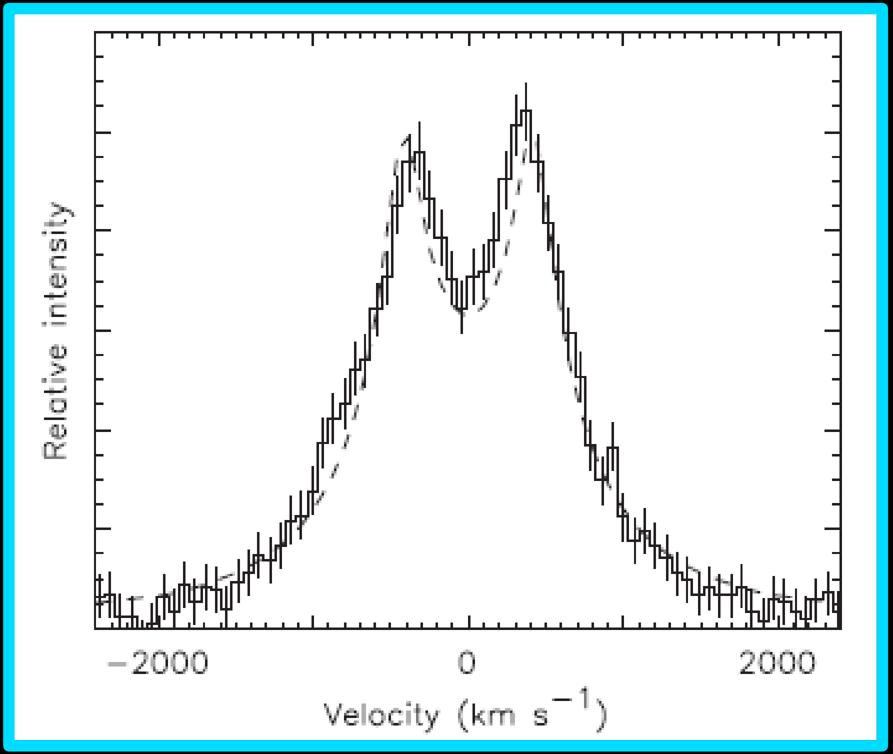
→ accretion powered **X-ray PSR**

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

Credits: NASA's Goddard Space Flight Center

More transitional pulsars: PSR J1023+0038





A 1.7 ms **Radio PSR** in 2009

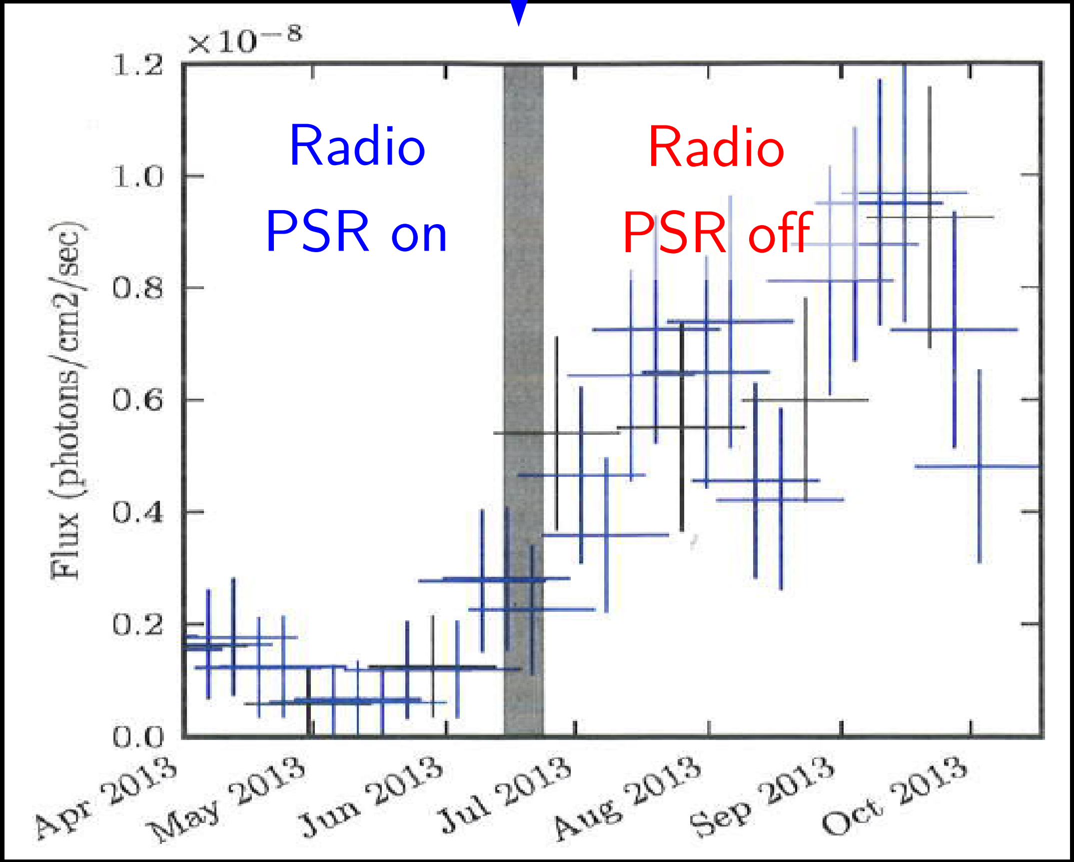
Accretion disk in 2000-01
(but faint in X-rays)

A state transition must have occurred, even if unobserved

Archibald et al. 2009, Science

June 2013, a new state transition

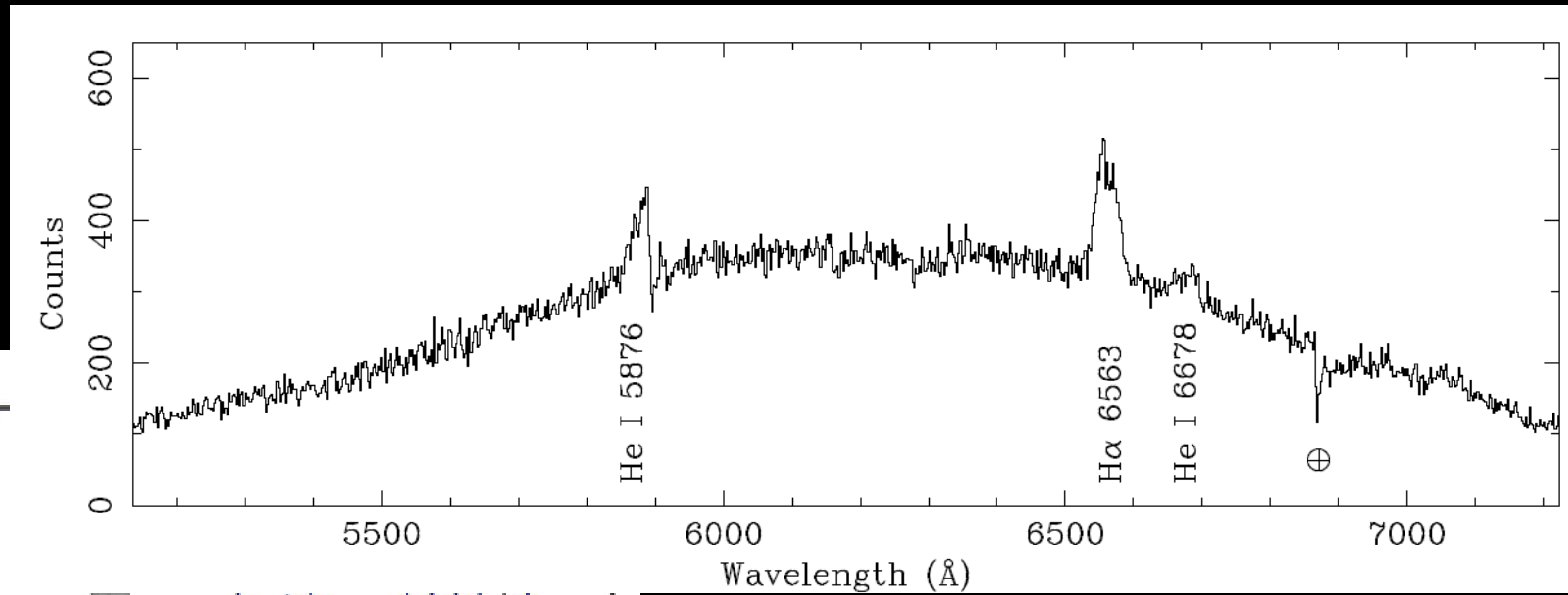
Radio pulsar disappears

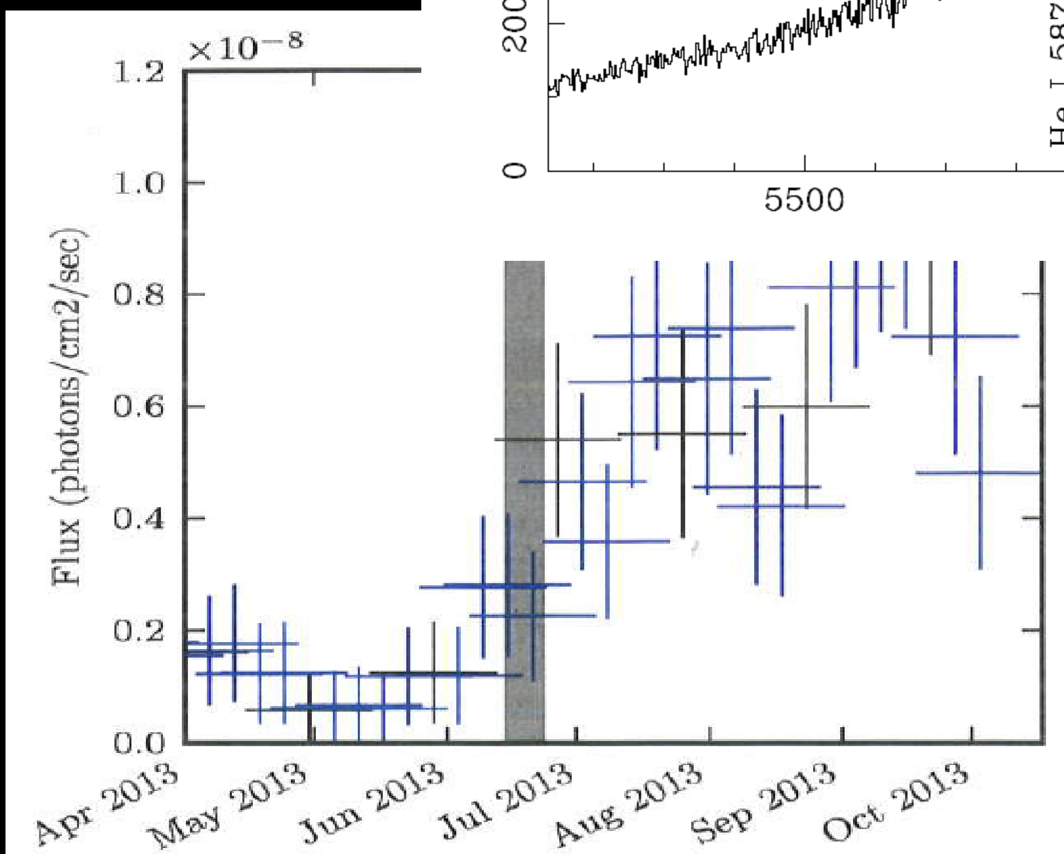


5-fold increase of gamma-ray flux

Stappers+ 2013, ApJ

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

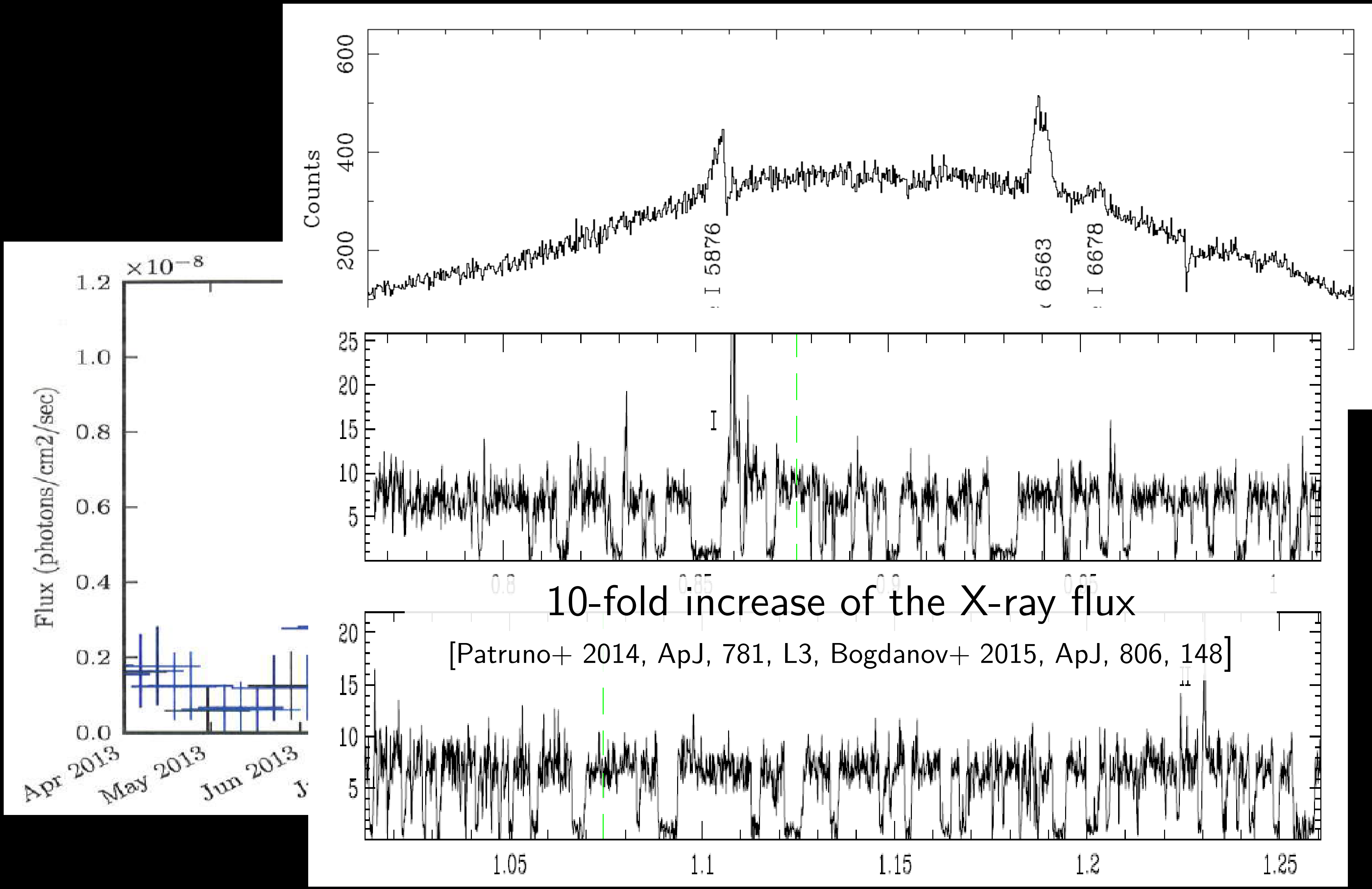




Broad double-peaked optical emission lines

Halpern+ 2013, Atel 5514

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



10-fold increase of the X-ray flux

[Patruno+ 2014, ApJ, 781, L3, Bogdanov+ 2015, ApJ, 806, 148]

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

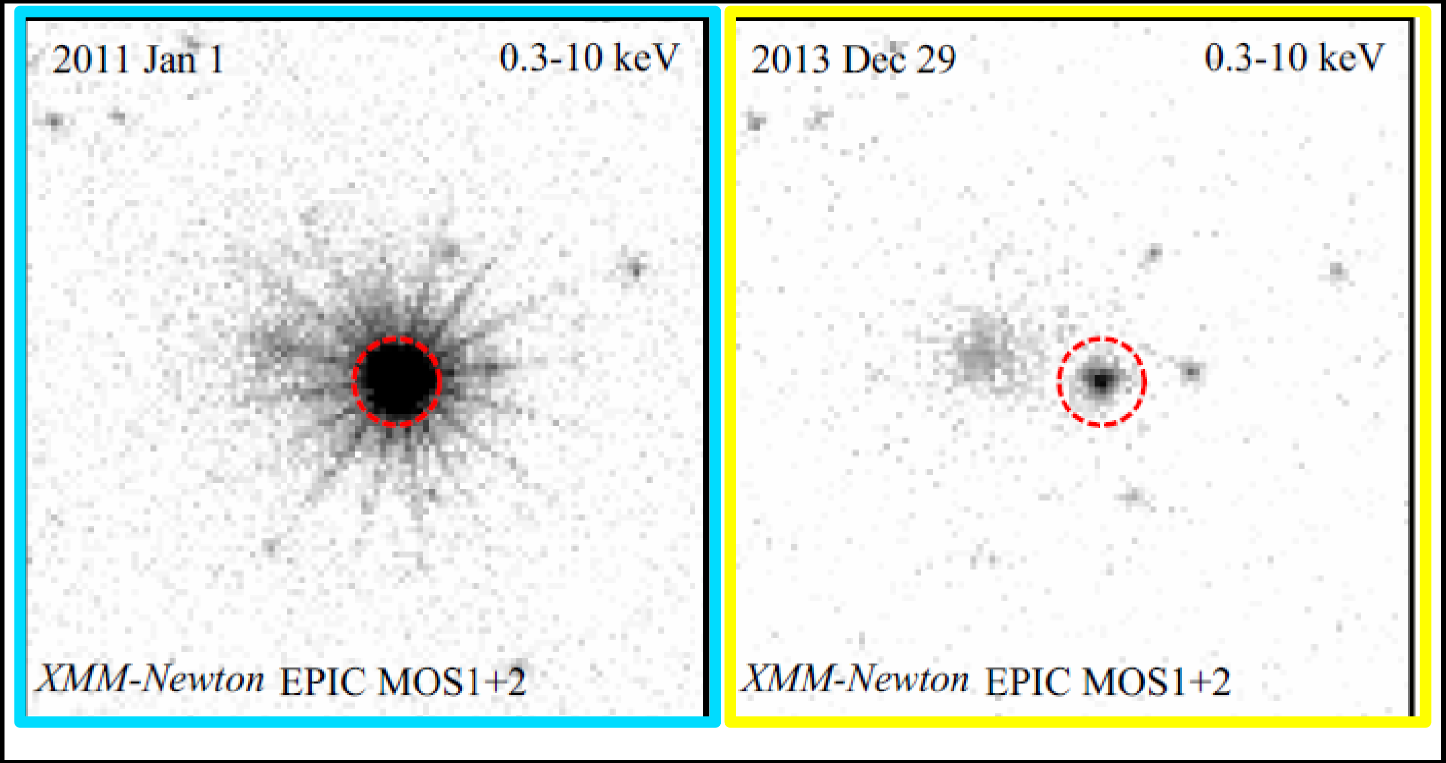
[De Martino+2010,2013; Saitou+2010; Hill+2011]

Detected as a **Radio PSR**

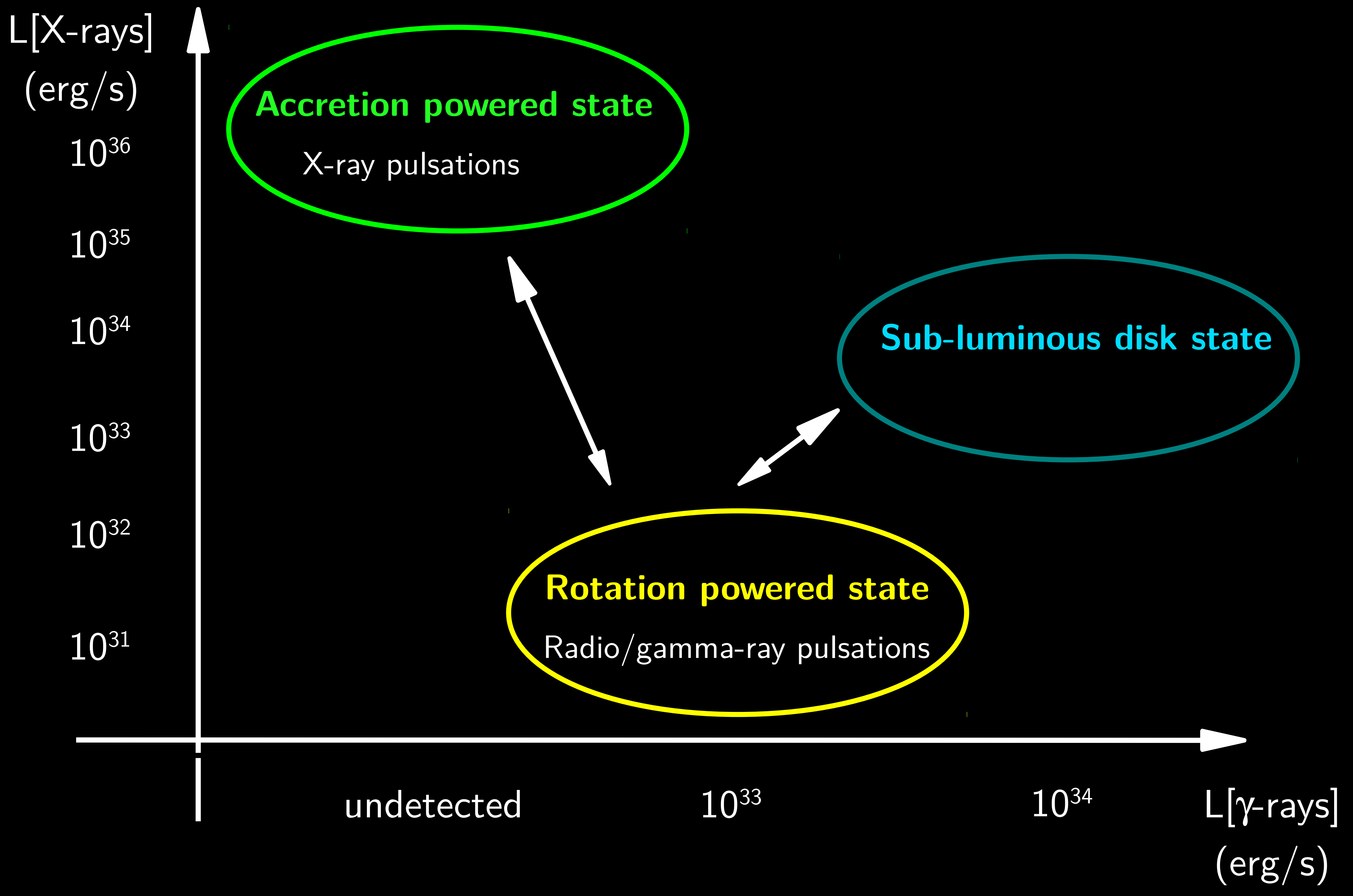
Very faint in X-rays (~10^{32}) erg/s

No disk

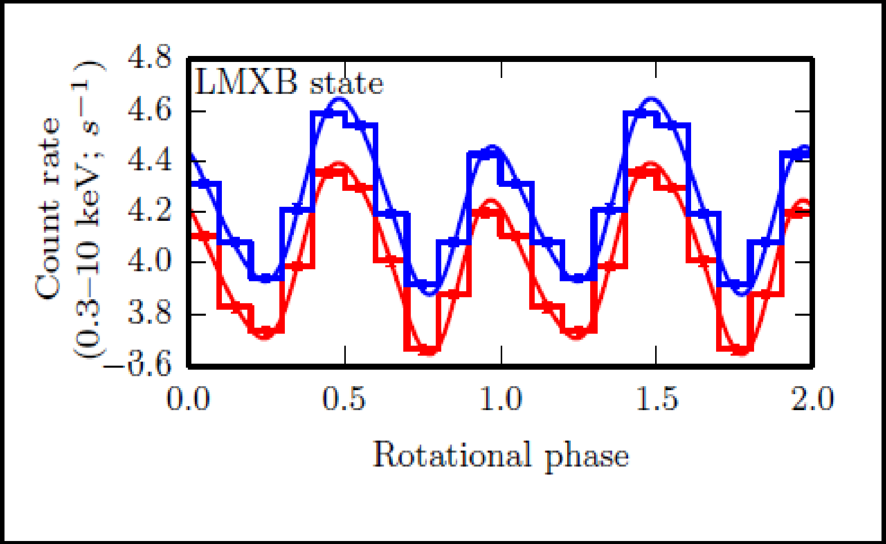
[Bassa+2014, Bogdanov+2014, Roy+ 2014]



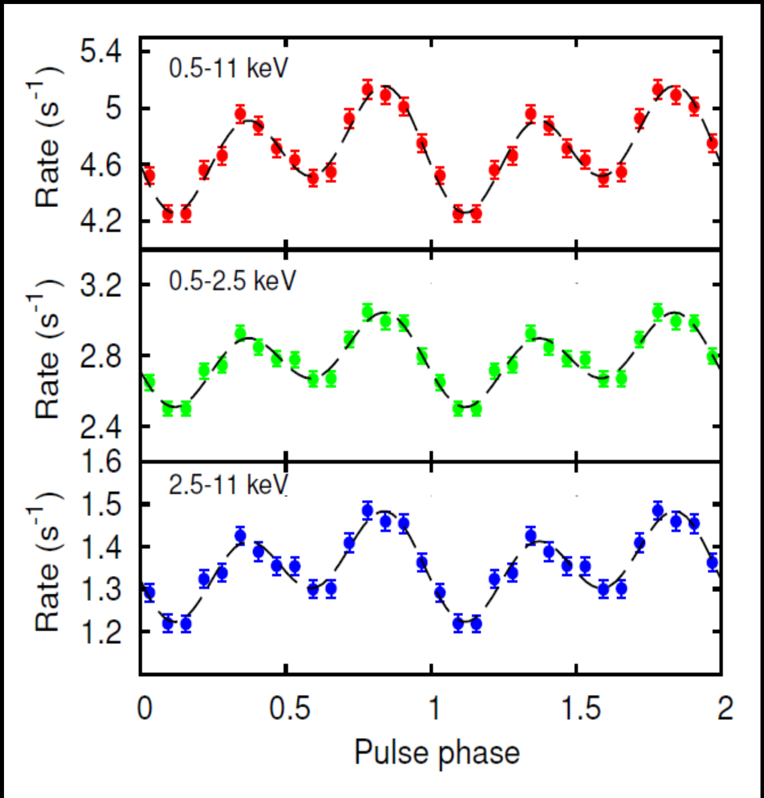
The three states of millisecond pulsars



Sub-luminous disk state: X-ray pulsations



PSR J1023+0038
Archibald et al. 2015

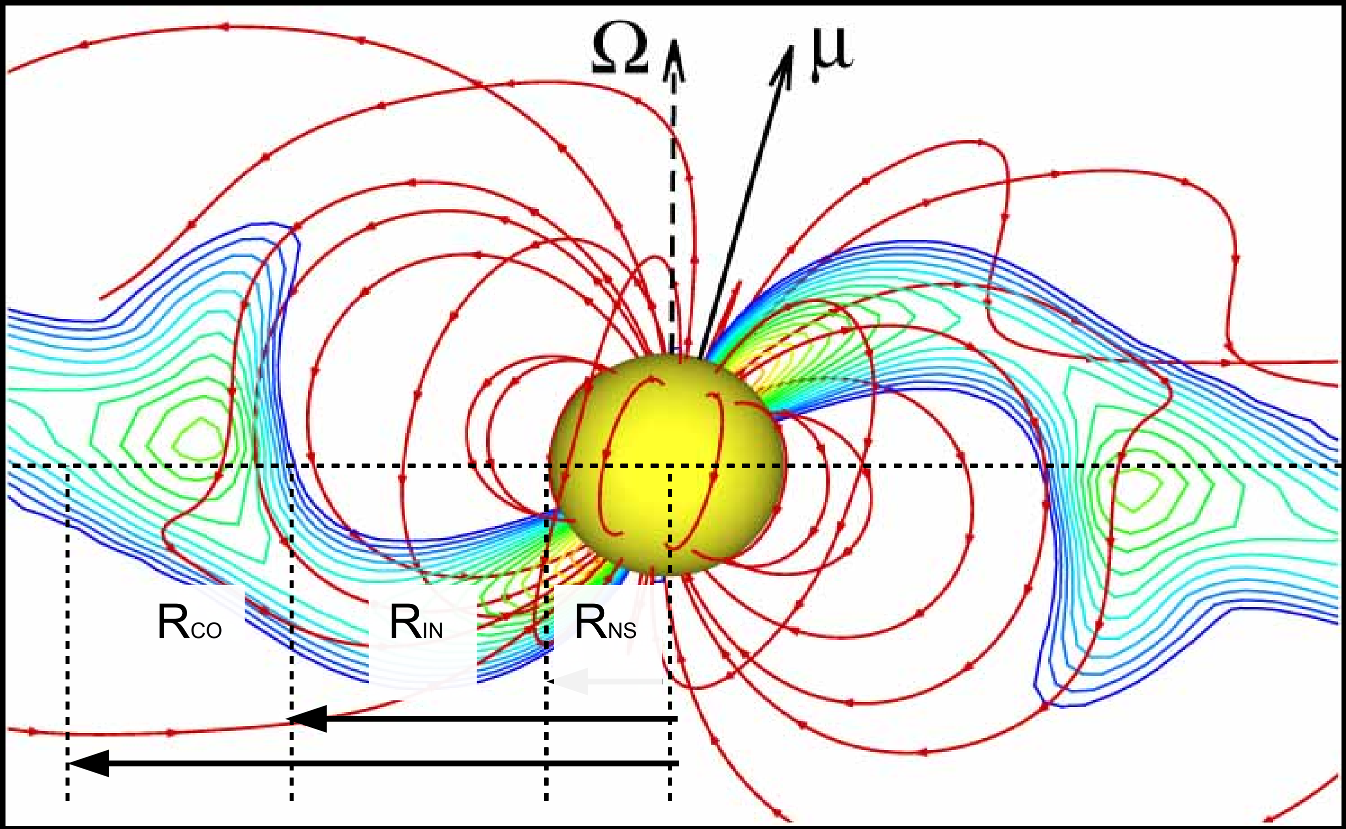


XSS J12270-4859 - Papitto et al. 2015

Pulsed flux ~10 times larger than during radio pulsar state
→ accretion powered pulsations

X-ray luminosity ~1000 times lower than in accreting ms pulsars

Implication of X-ray pulsations

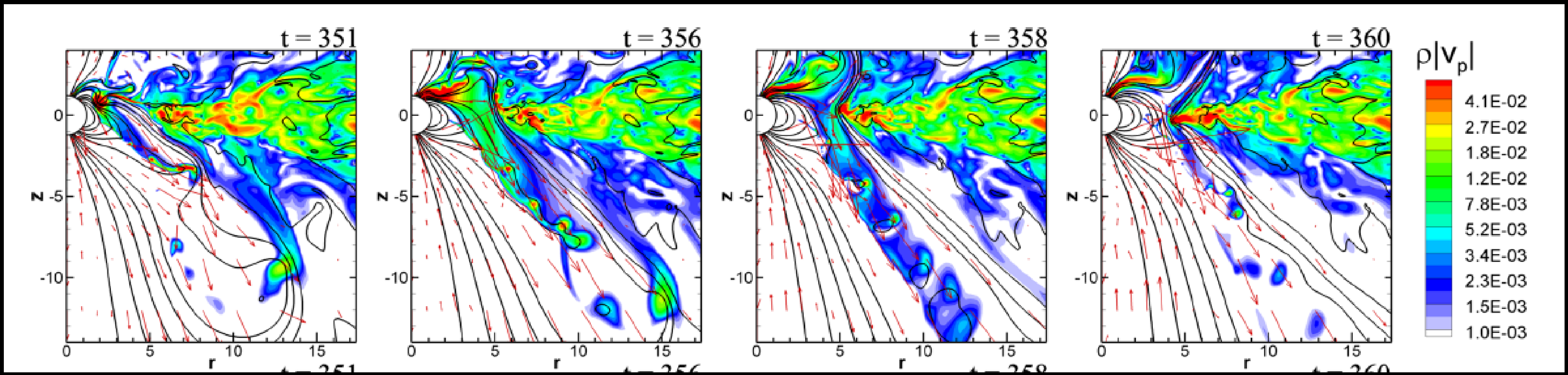


The mass accretion rate on the NS surface is 100 times smaller than the one required to keep the magnetosphere inside the corotation radius

$(dM/dt)_{NS} \sim 10^{-2}\ (dM/dt)_{disk}$

>95% of the inflowing mass ejected?

Propeller outflows

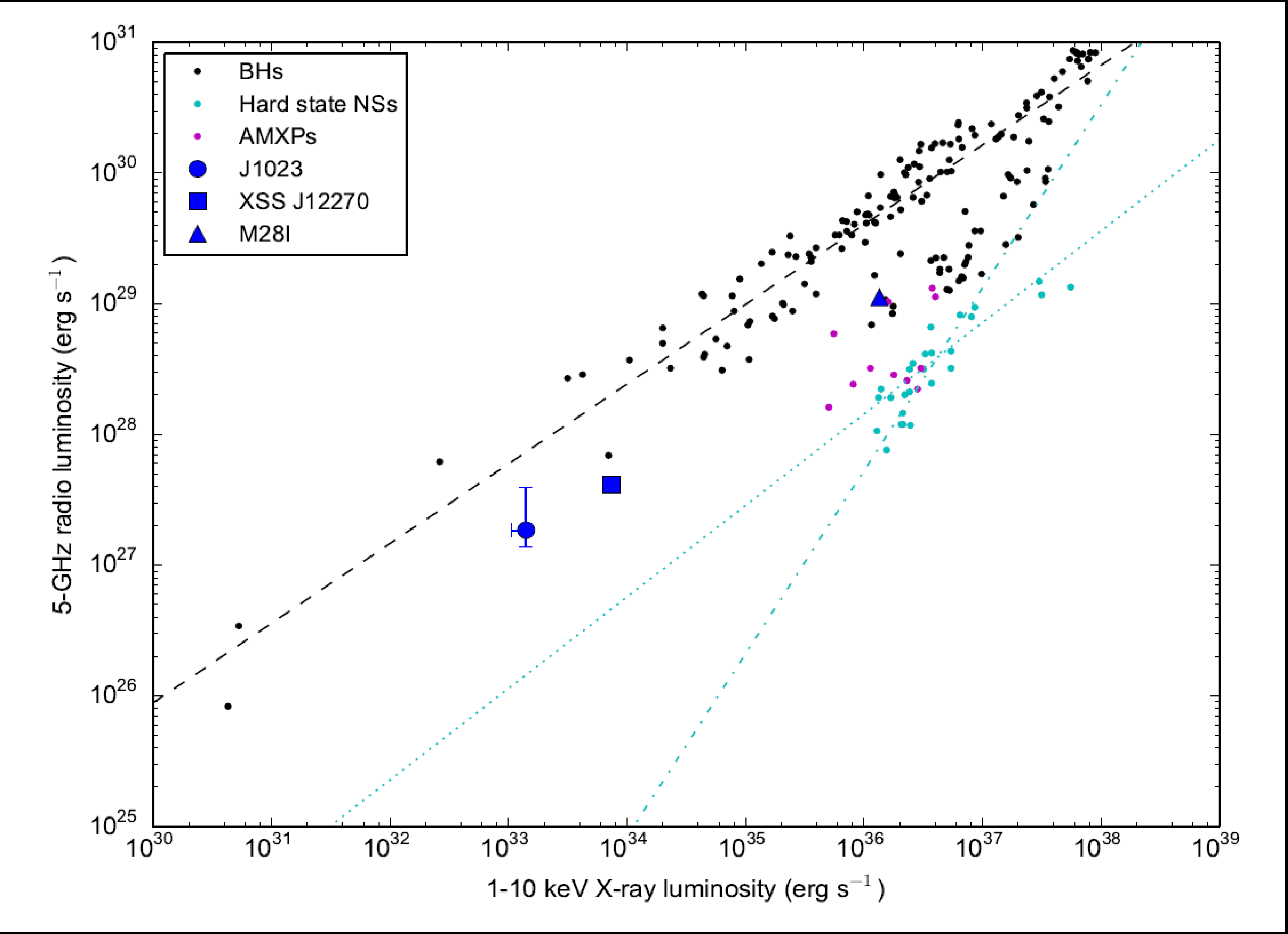


3d MHD simulations of propeller ejection of matter

Lii, Romanova+ 2014 – for a disk terminated close to the corotation surface, part of the inflowing mass manages to accrete and part is launched in an outflow.

$\rightarrow$ **Accretion and outflows can coexist**

Radio brightness similar to BHs



Deller + 2015, ApJ

A propeller model: the gamma-ray emission

Ecut ~ few GeV

→ radio pulsar models, GeV electrons of magnetospheric origin

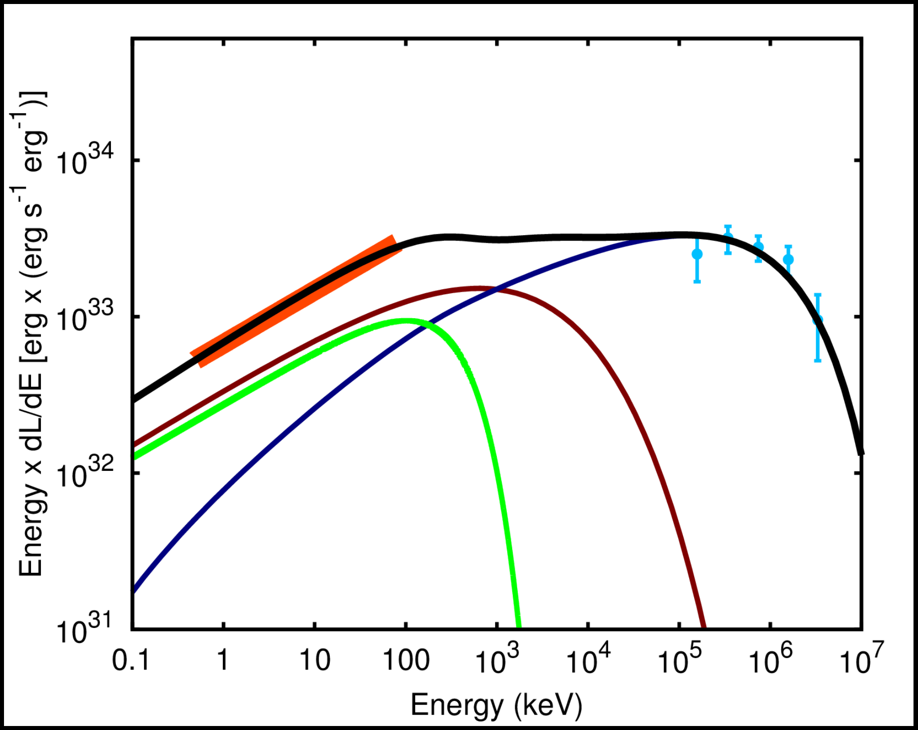
→ propeller model, electrons accelerated at the turbulent disk-magnetospheric boundary

Accelerated electrons into a
strongly magnetized (10^6 G) and
relatively small (~few tens of km)
environment

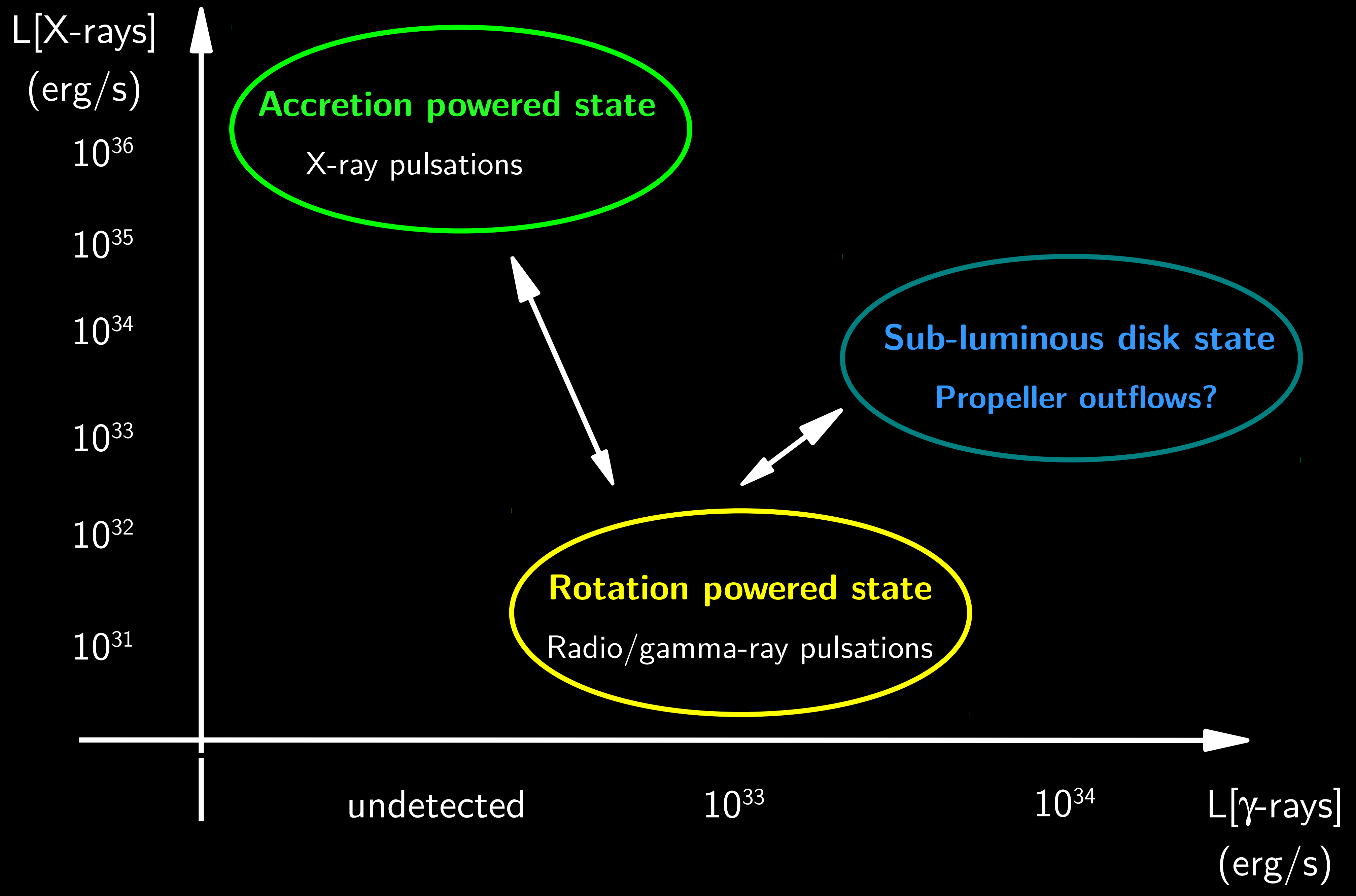
→ **synchrotron** (up to MeV)
→ **self-synchrotron Compton** (up to GeV)

Good modelling for Rin ~ 2 Rco

Papitto & Torres 2015, ApJ
Papitto, Torres, Li, 2014, MNRAS,



The three states of millisecond pulsars



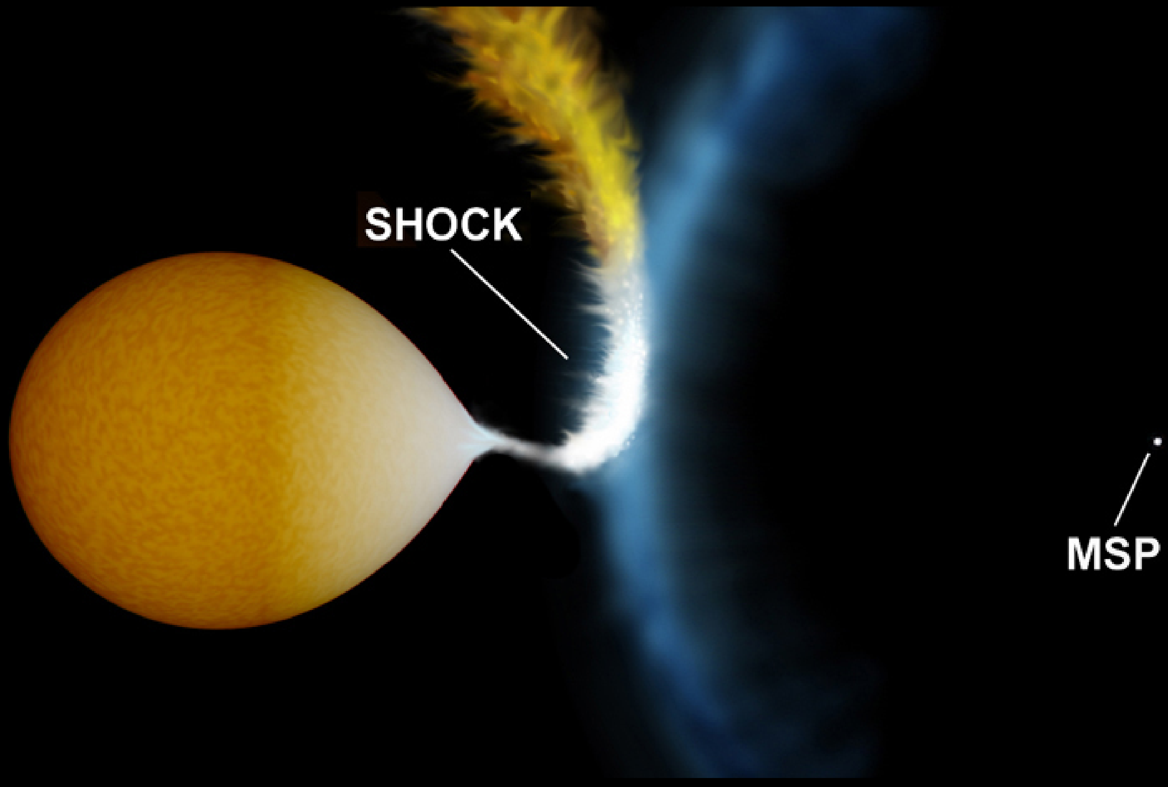
Candidate transitional pulsars

Eclipsing radio pulsars [Fruchter+ 1988]

~50 known; bright gamma-ray sources

- Black widows (Mc < 0.1 Msun)
- Redbacks (Mc ~ 0.2-0.7 Msun)

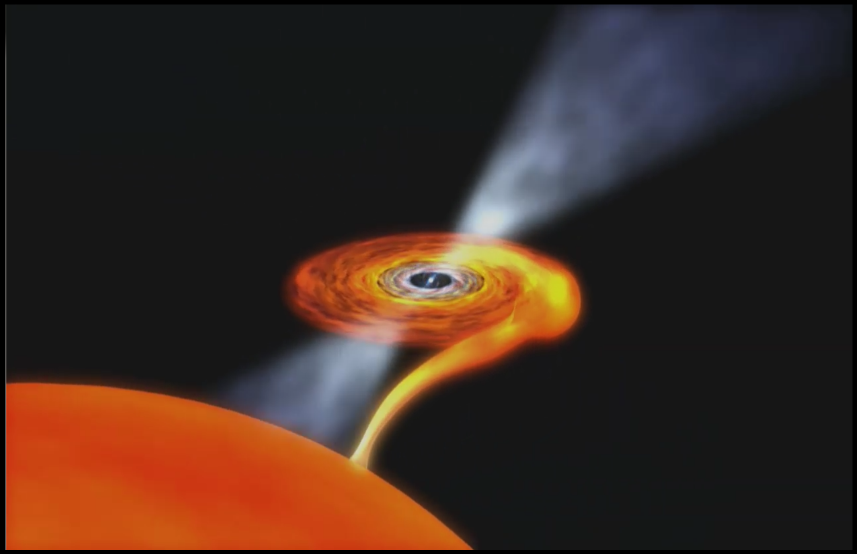
The three transitional pulsars discovered so far are redbacks



Candidate transitional pulsars

Accreting millisecond pulsars

15 known [Wijnands & van der Klis 1998]



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

A **radio PSR** turning on
during quiescence (L$\sim 10^{32\text{-}33}$ 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, expect IGR J18245-2452

[Burgay+2003, Iacolina+2011, Xing+2012]

Does a radio pulsar turn on in quiescence?

Radio pulsar not detected, expect than for IGR J18245-2452

[Burgay+ 2003, Iacolina+ 2011] → enshrouding by intervening matter?

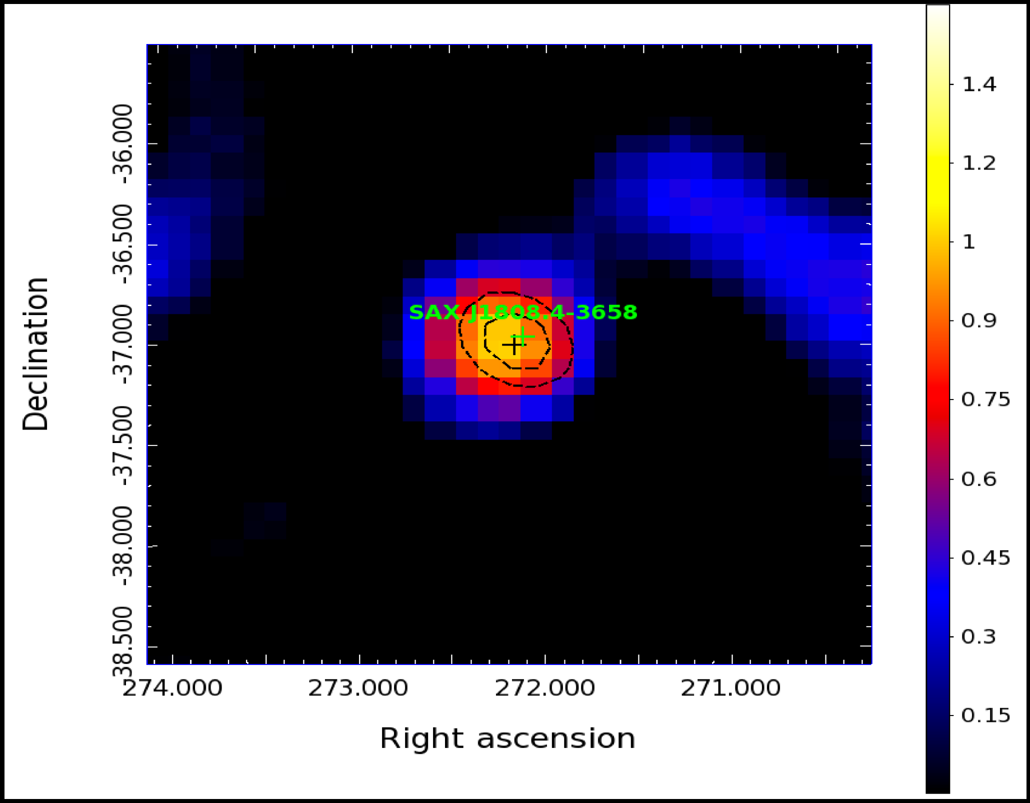
A candidate gamma-ray counterpart for SAX J1808.4-3658

[Xing+ 2015, de Oña Wilhelmi, Papitto+ 2015]

Accurate search for gamma-ray pulsations did not yield to a detection

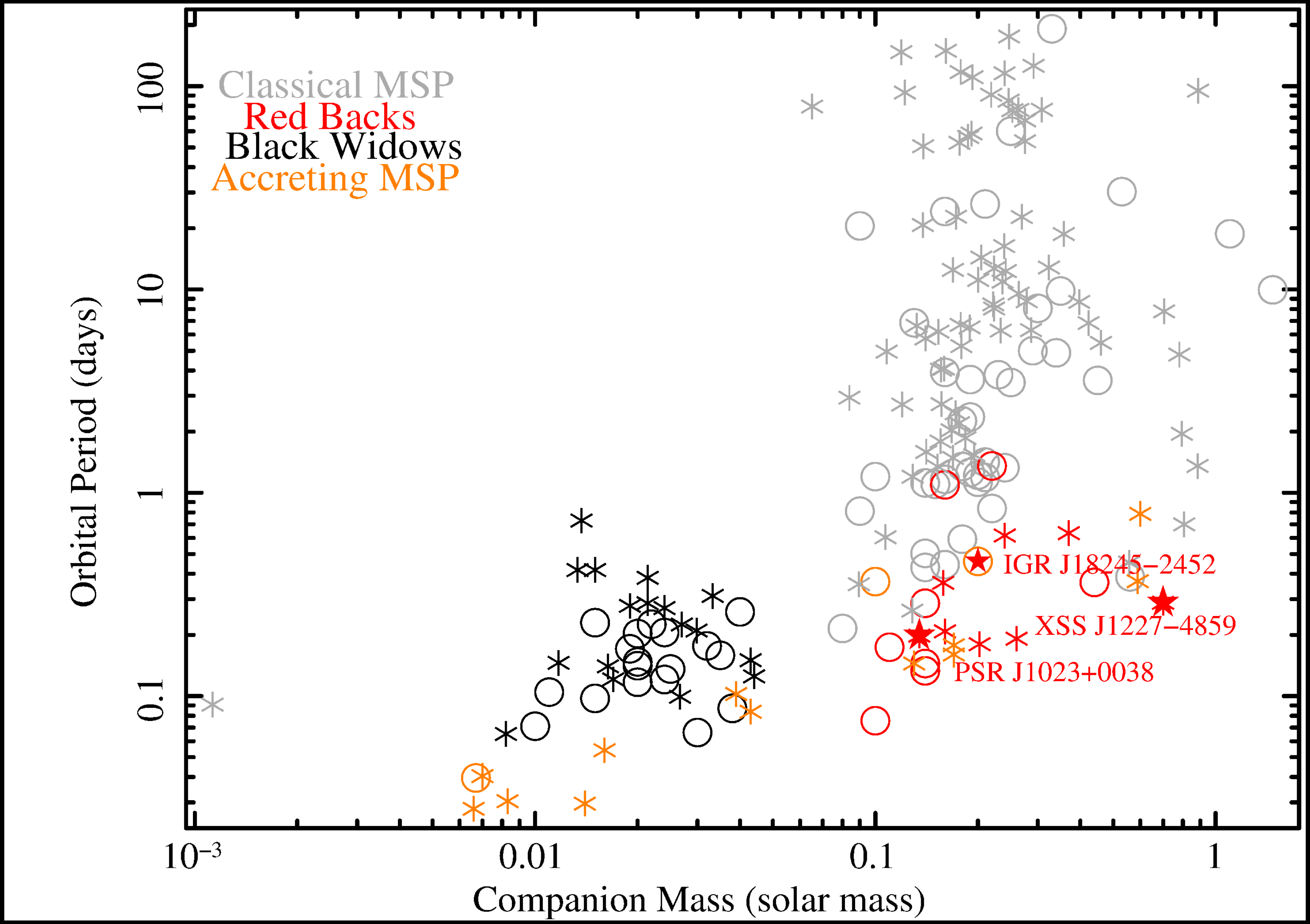
$L\gamma = (3.5 +/- 0.3) \times 10^{33}$ erg cm^{-2}

→ ~30% of the spin down power

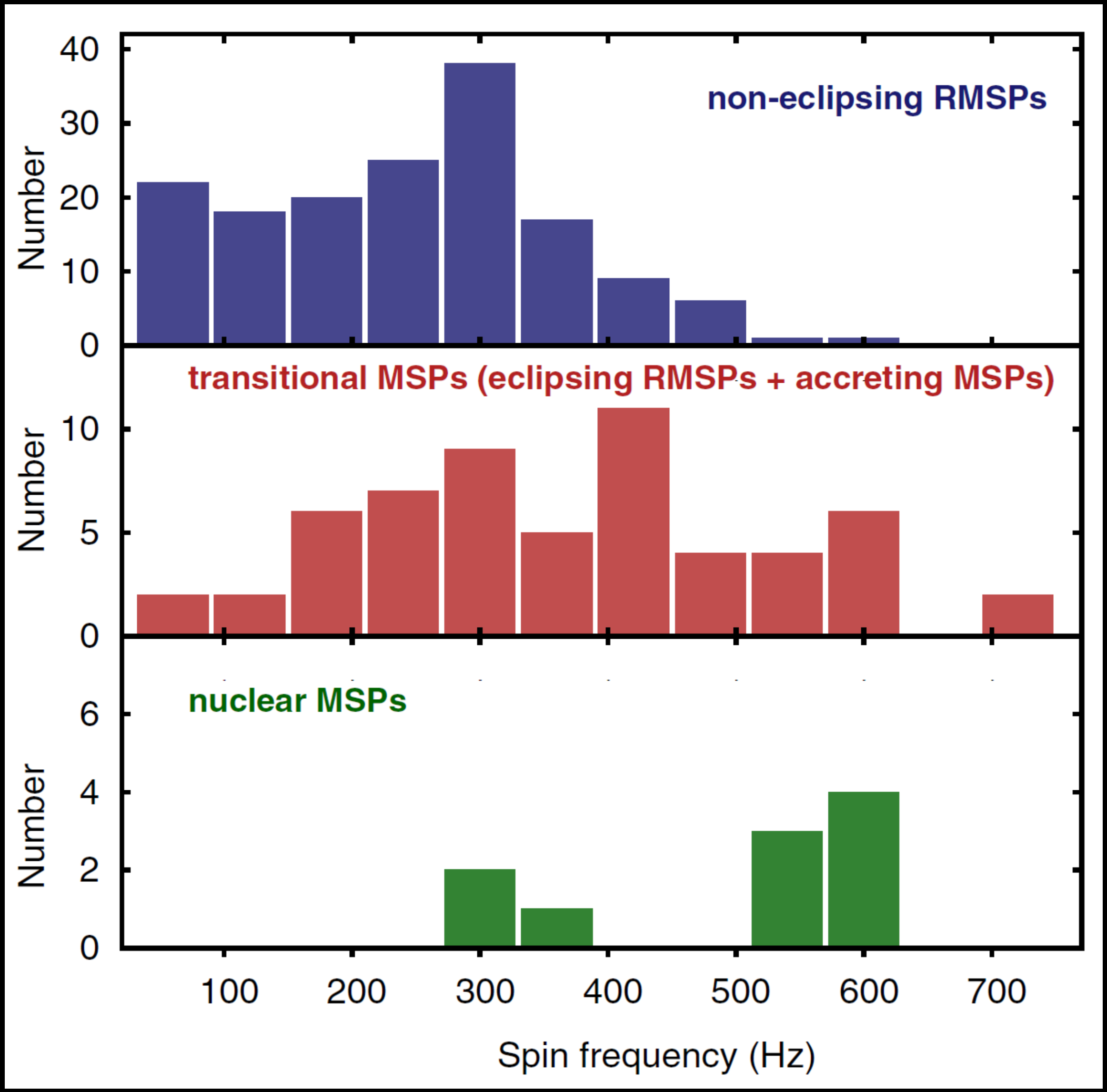


Evolutionary scenarios

Is the transitional phase common? Which evolutionary channels?



An intermediate spin distribution



Papitto, Torres, Rea, Tauris, 2014, A&A

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 sub-luminous accretion disk stage (propeller origin?)

- Are all millisecond pulsars in close binary systems transitional?

Thank you to...

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P. Freire (MPIfR Bonn), M. Falanga (ISSI Bern, ISSI Beijing),

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M. Burgay, A. Possenti, A. Pellizzioni (INAF OA Cagliari)