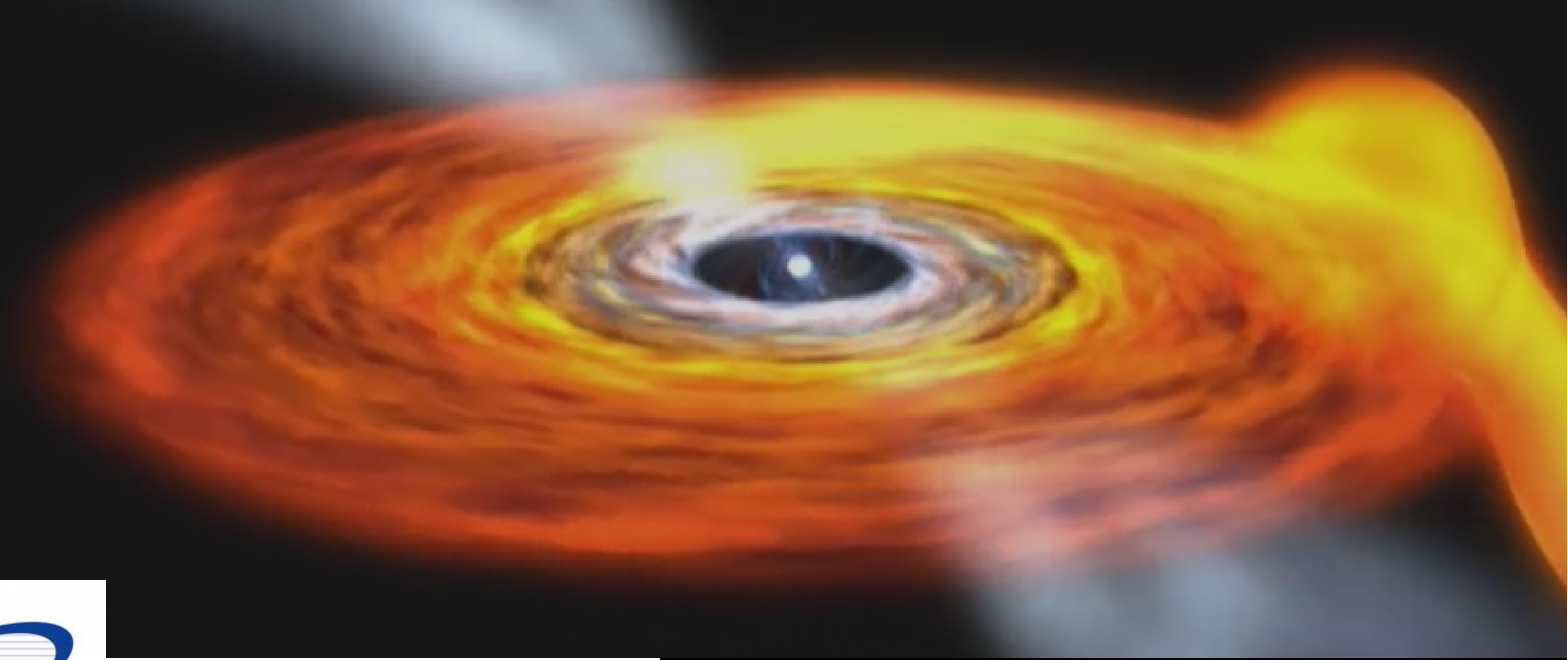
Accretion and rotation power in transitional millisecond pulsars

Alessandro Papitto



MARIE CURIE ACTIONS

INAF

OAR Osservatorio Astronomico di Roma

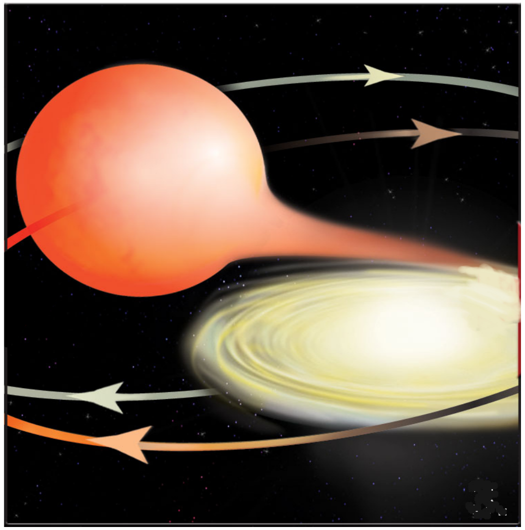
7.2.2017 – High throughput X-ray astronomy in the eXTP era – Rome (Italy)

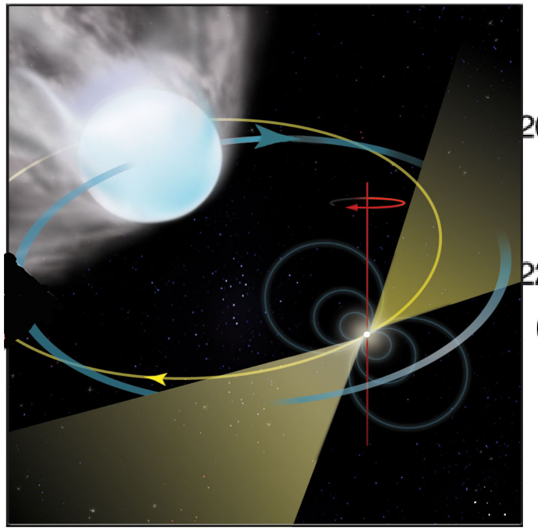
The fundamental plane of pulsars

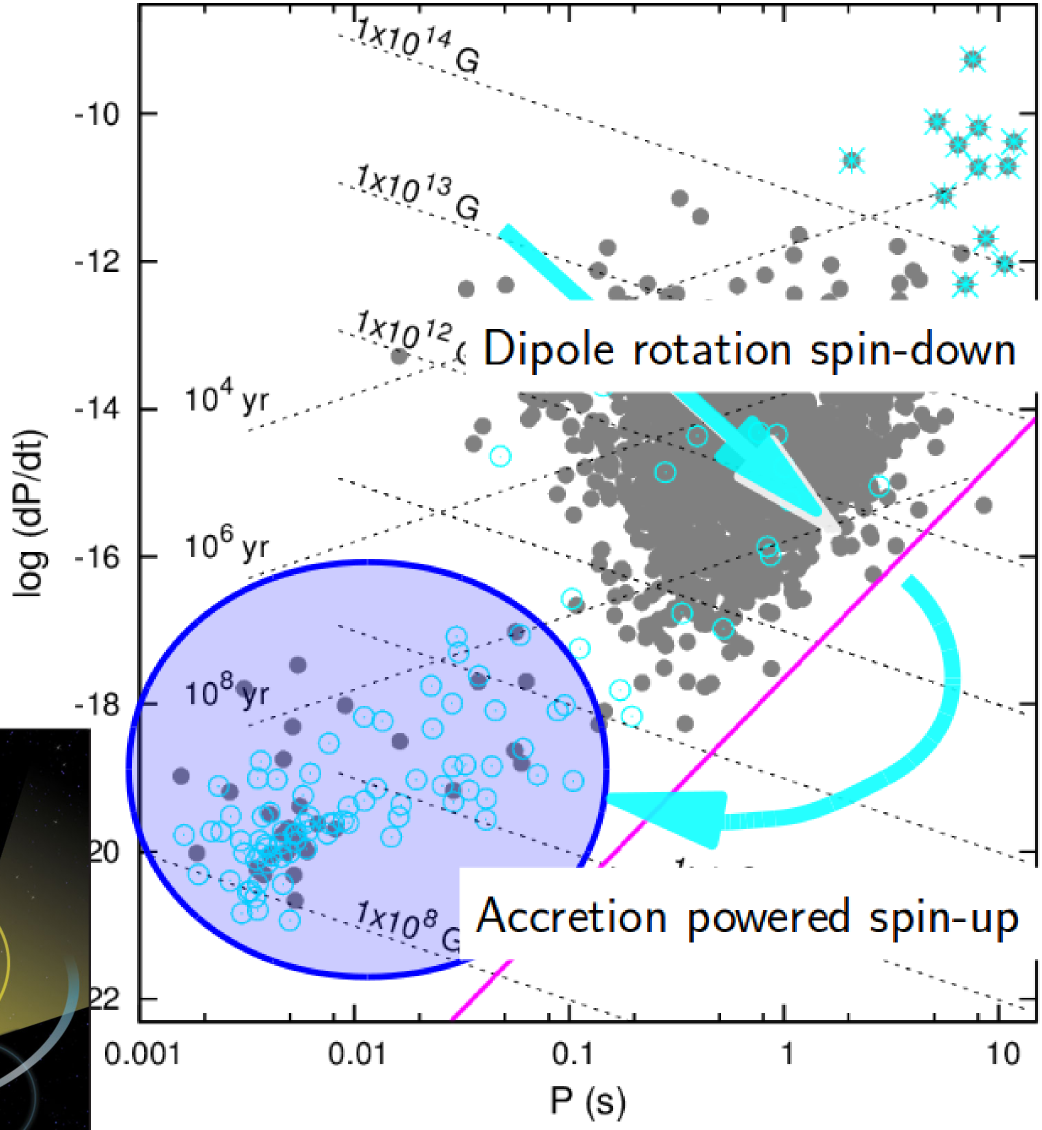
Millisecond pulsars

[Backer+1982, Alpar+1982]

- weakly magnetized
- often found in globular clusters
  $\rightarrow$ old systems
- often in **binaries**







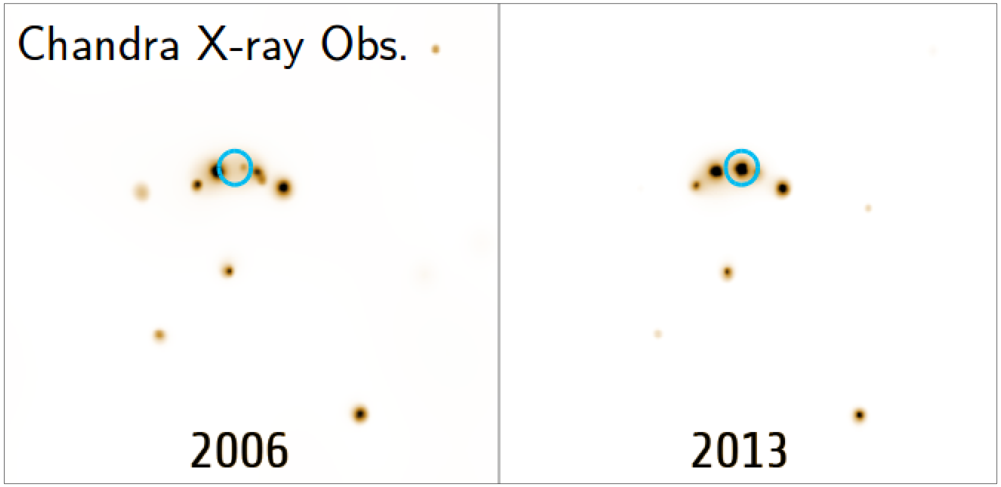
An X-ray transient in the globular cluster M28

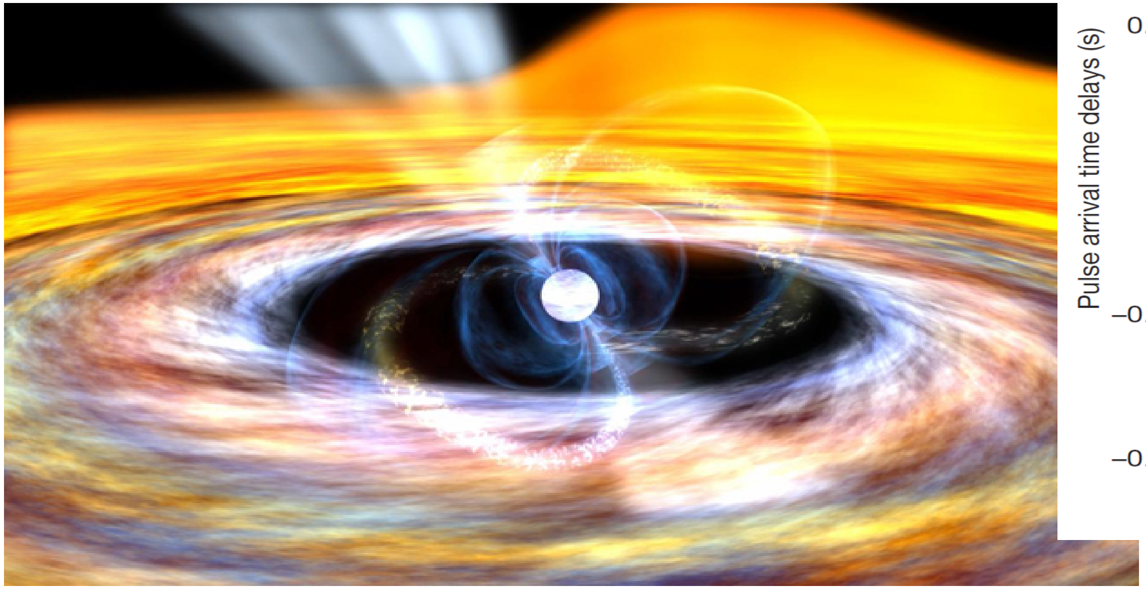
IGR J18245-2452

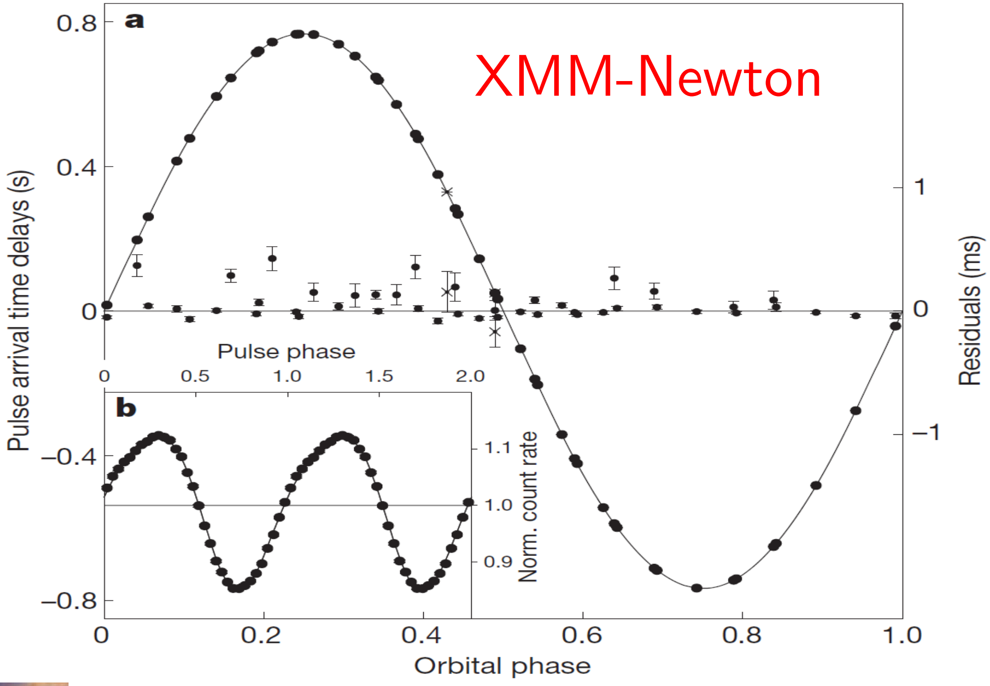
L(X-rays) ~ 5 x 10^{36} erg/s

Pspin = 3.9 ms

Porb = 11 hr







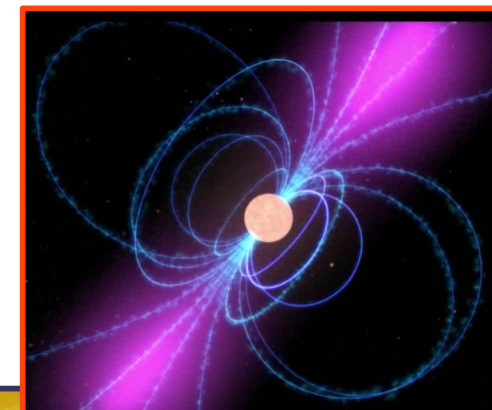
LETTER

doi:10.1038/nature12470

Swings between rotation and accretion power in a binary millisecond pulsar

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)	

Rotation powered **Radio PSR**



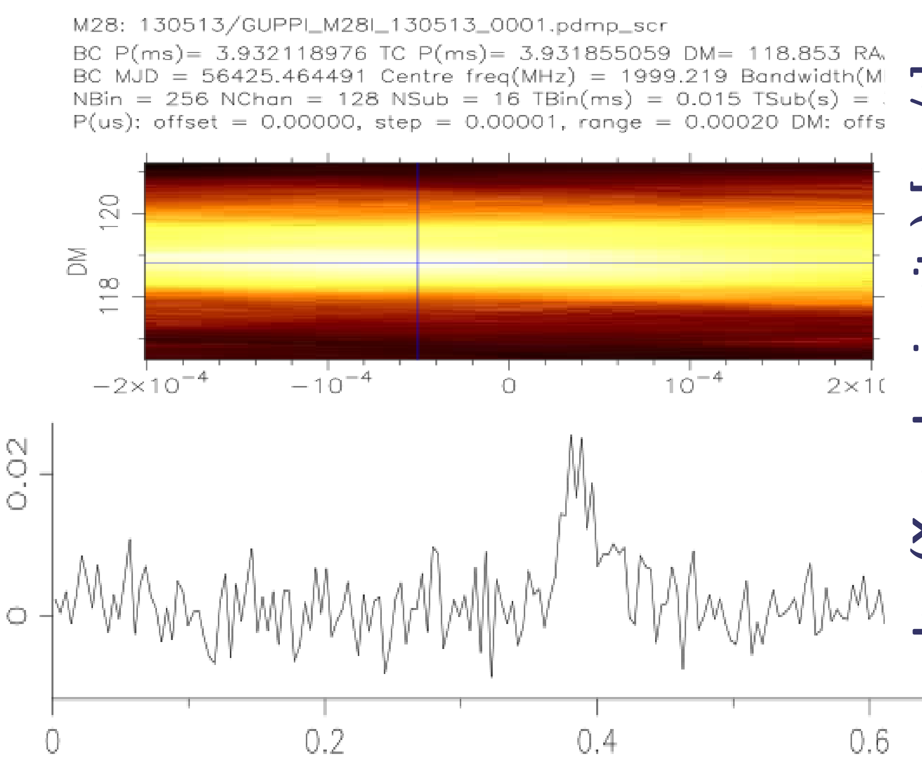
Xray PSR accretion powered

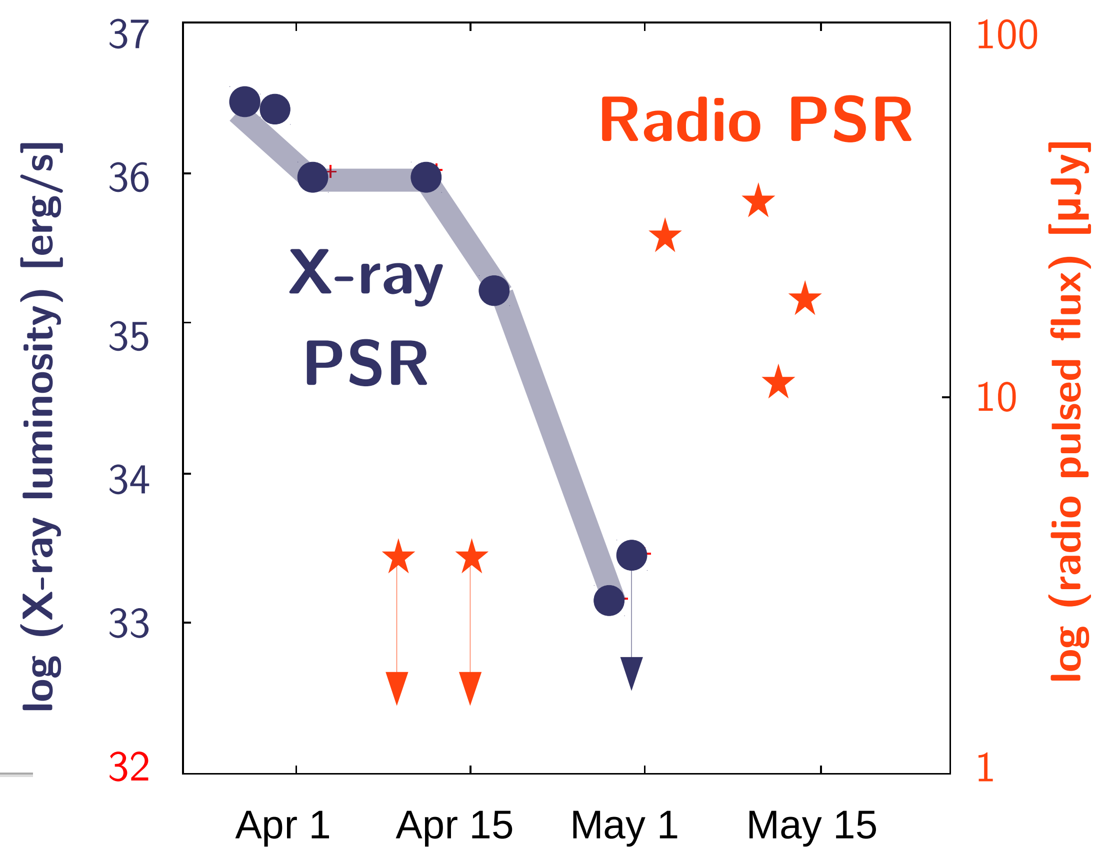
Papitto et al. 2013, Nature

The radio pulsar strikes back

Weak **radio pulsar** signal (~10-50 microJy) detected less than two weeks after the **X-ray pulsar** detection

[Green Bank Telescope, Parkes, Westerbork SRT]



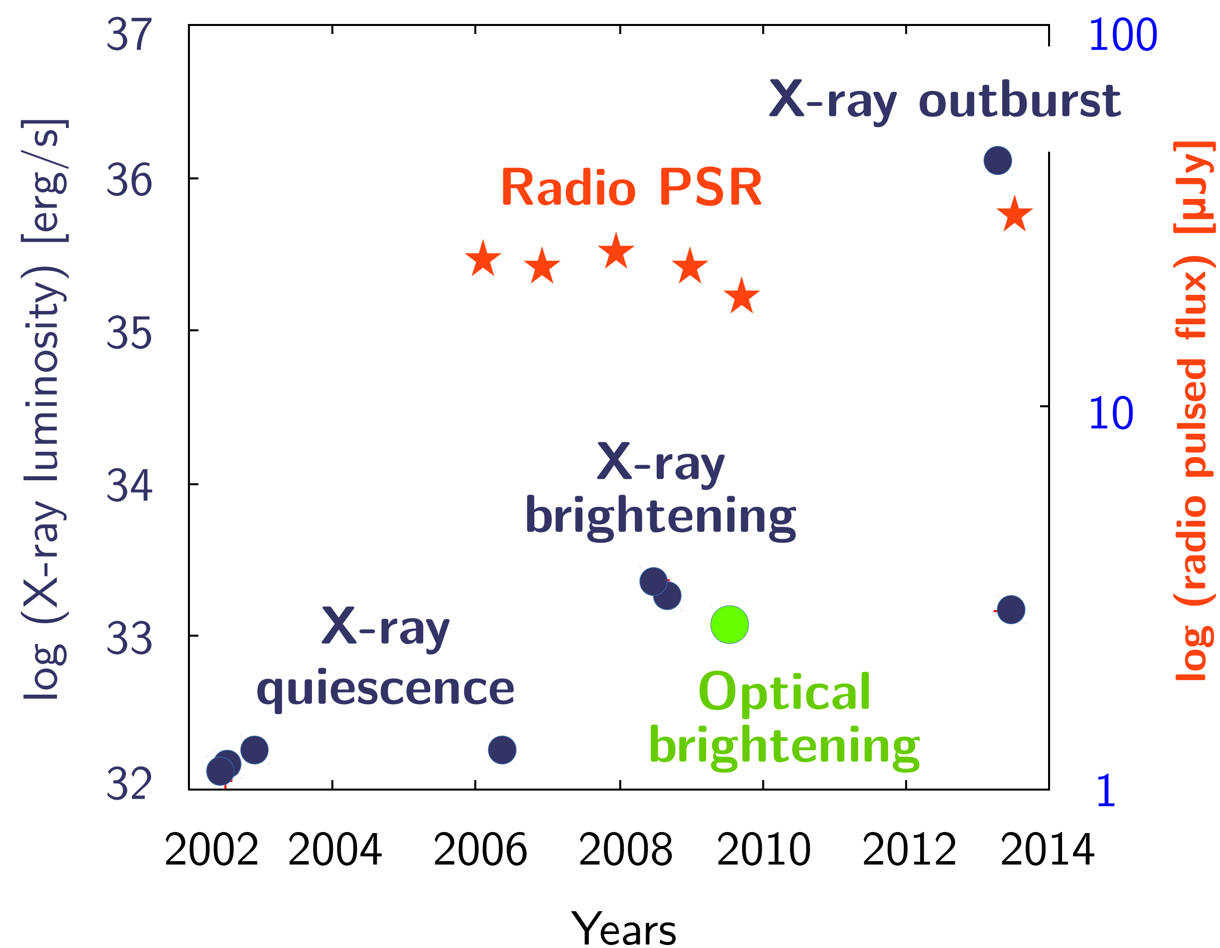


Swinging between accretion and rotation power

Radio pulsar faint and irregularly eclipsed

Two past **accretion states** seen by Chandra & HST

[Papitto+ 2013, Pallanca+ 2013, Linares+2014]

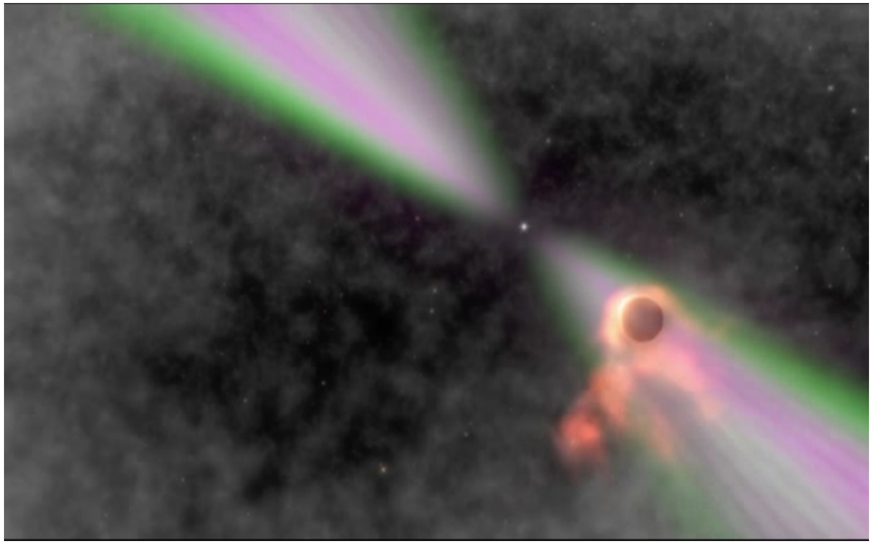


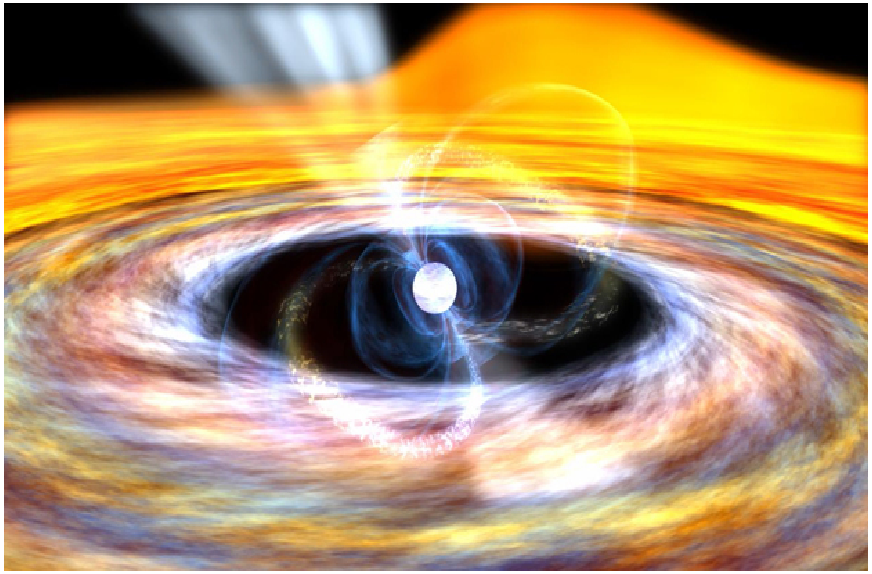
Mass in-flow rate drives the variability

Low Mass in-flow rate:

Magnetic field dominates

$\rightarrow$ rotation powered **Radio PSR**





High Mass in-flow rate:

Gravity dominates

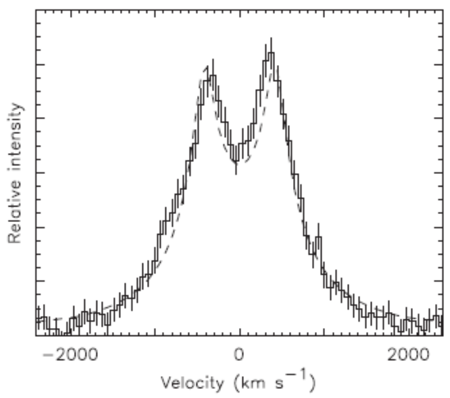
$\rightarrow$ accretion powered **X-ray PSR**

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

Credits: NASA's Goddard Space Flight Center

PSR J1023+0038

2000-01 **Accretion disk** Hα line



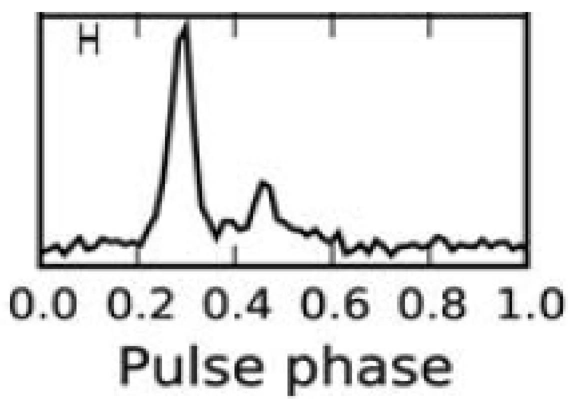
Radio PSR (d=1.4kpc; P=1.7ms)

Irregular eclipses (a redback)

Also a gamma-ray pulsar

[Archibald+ 2009, Science]

2009-13



2013 ...

Accretion disk Hα line

Brighter in X-rays and γ-rays

(few x 10^{33} erg/s)

No radio pulses

[Patruno+ 2014, Stappers+ 2014, Bogdanov+ 2015]

XSS J12270-4859

2003-13

Accretion disk Hα line

X-rays (few x 10^{33} erg/s)

γ-rays (few x 10^{33} erg/s)

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

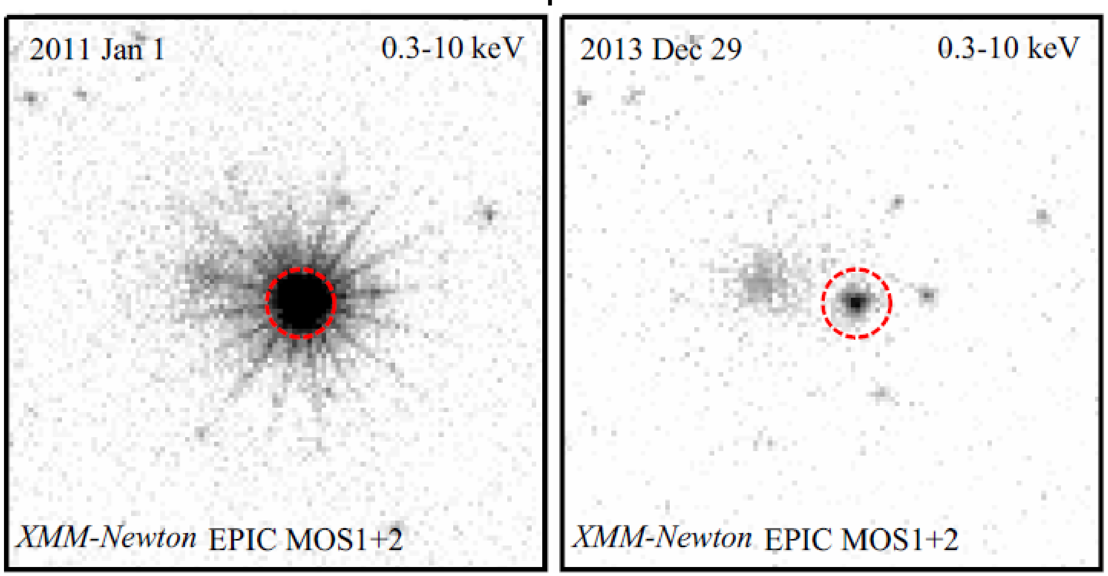
2013 ...

Radio PSR (P=1.7ms)

Irregular eclipses (a redback)

Also a gamma-ray pulsar

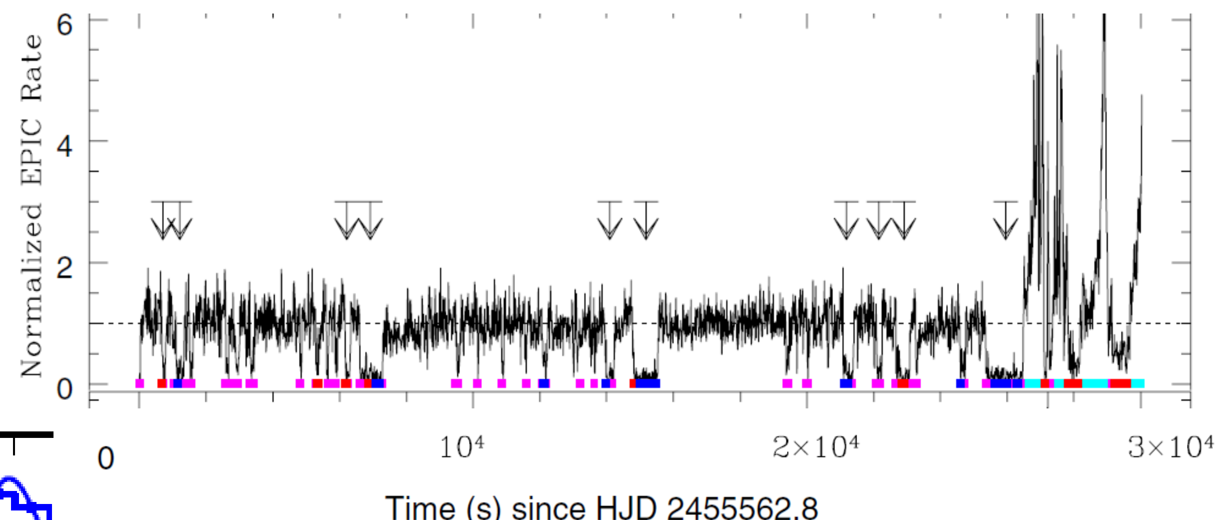
[Bassa+2014, Bogdanov+2014, Roy+ 2014]

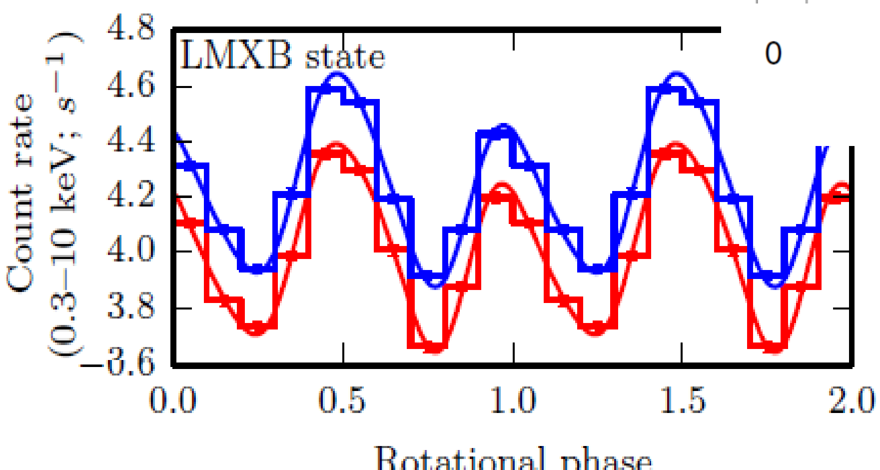


The enigma of the sub-luminous disk state

X-rays (L_X~$5x10^{33}$ erg/s)

- Fainter than during outburst
- Peculiar variability [e.g. de Martino+ 2011, Ferrigno+ 2014, Bogdanov 2015]
- Accretion powered X-ray pulsations [Archibald+ 2015, Papitto+ 2015]





The enigma of the sub-luminous disk state

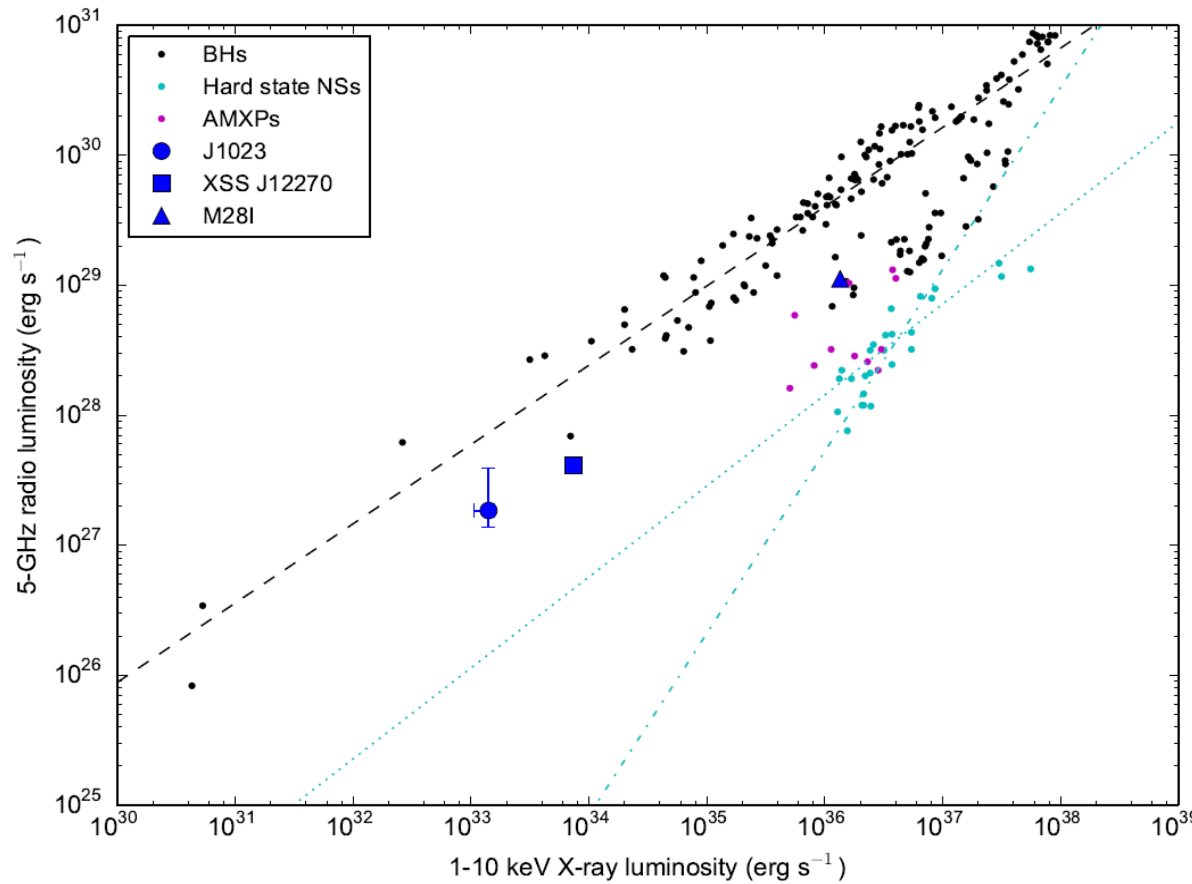
X-rays (L_X~$5x10^{33}$ erg/s)

- Fainter than during outburst
- Peculiar variability [e.g. de Martino+ 2011, Ferrigno+ 2014, Bogdanov 2015]
- Accretion powered X-ray pulsations [Archibald+ 2015, Papitto+ 2015]

Radio (~0.05-0.5 mJy)

- Flat spectral shape
- BH-like brightness

[Hill+ 2011, Deller+ 2015]



The enigma of the sub-luminous disk state

X-rays (L_X~$5x10^{33}$ erg/s)

Fainter than during outburst

Peculiar variability [e.g. de Martino+ 2011, Ferrigno+ 2014, Bogdanov 2015]

Accretion powered X-ray pulsations [Archibald+ 2015, Papitto+ 2015]

Radio (~0.05-0.5 mJy)

Flat spectral shape

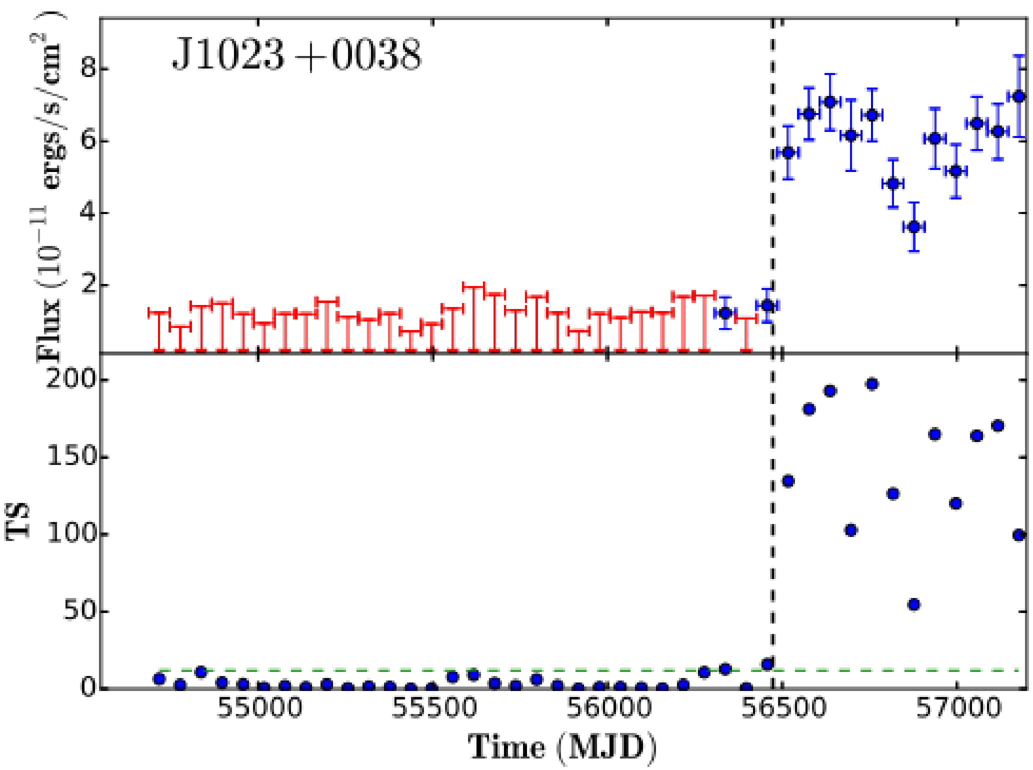
BH-like brightness

Gamma-rays

Same luminosity than Xrays

First low-mass γ-ray binaries

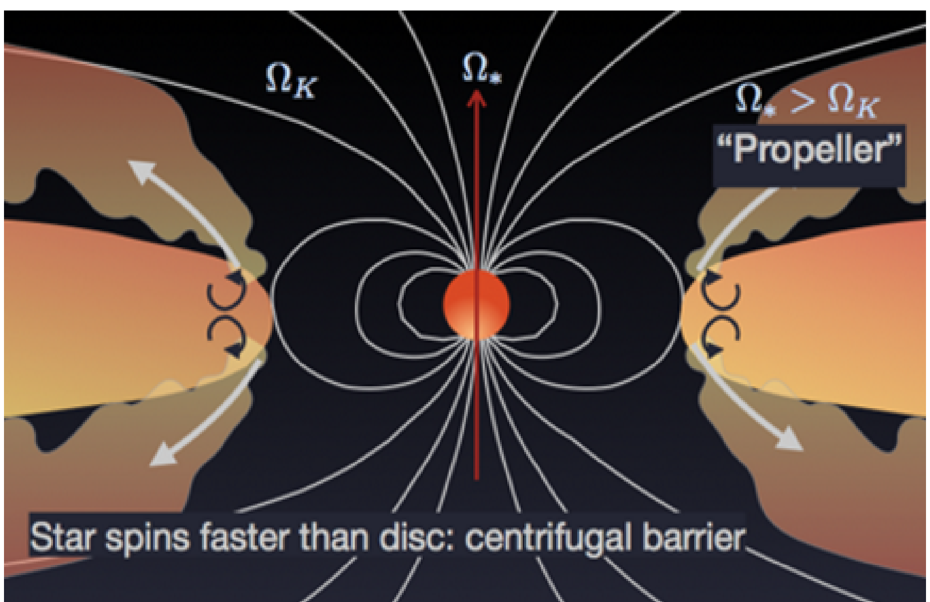
[e.g. Torres+ 2017]

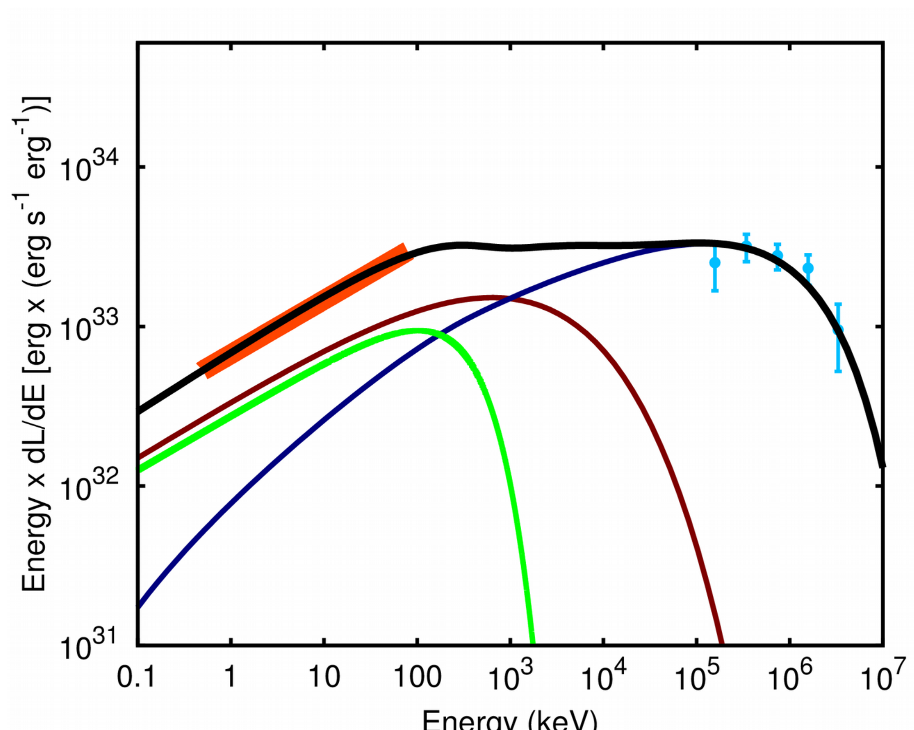


The enigma of the sub-luminous disk state

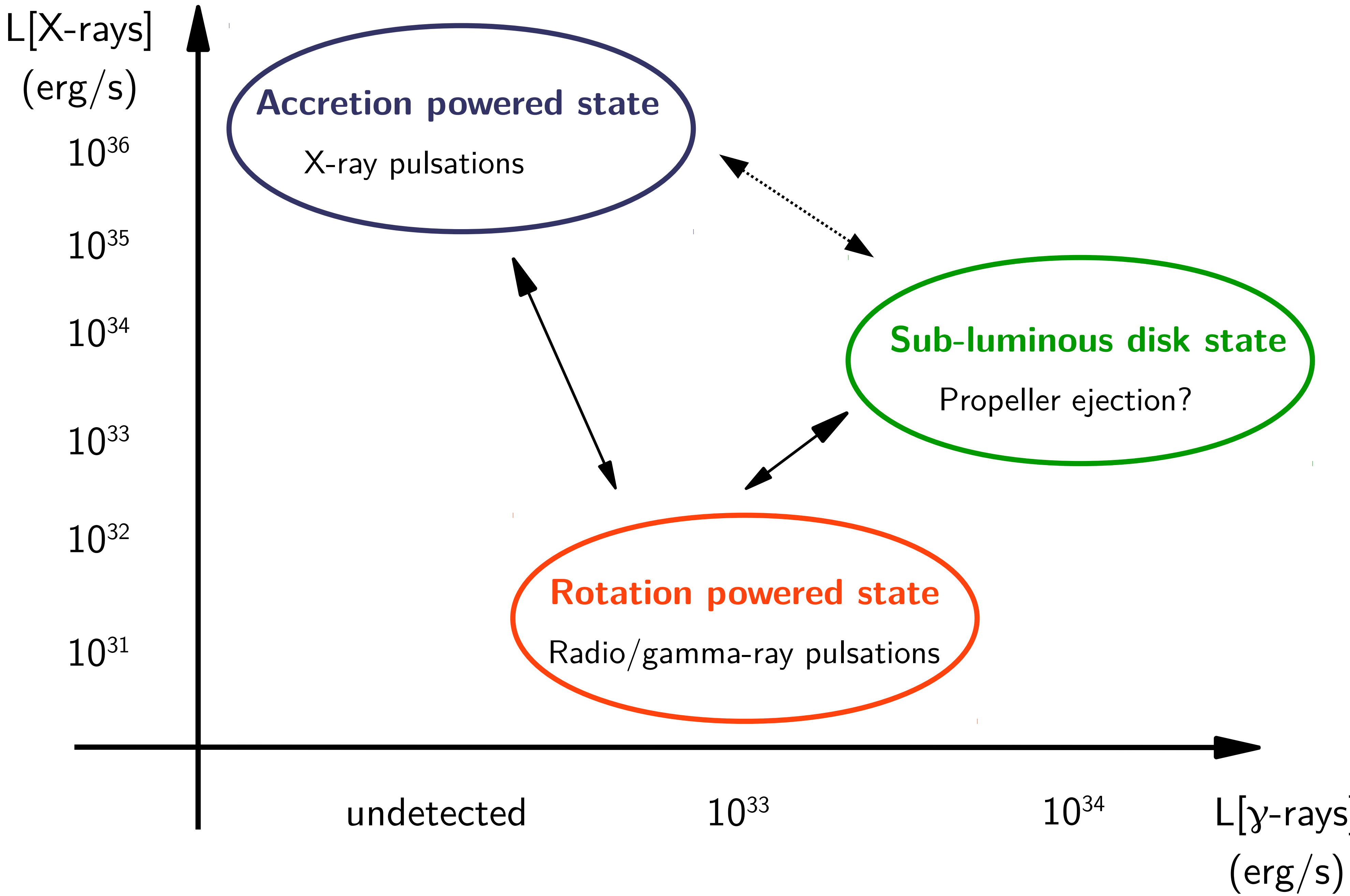
Propeller ejection models [Papitto, Torres, Li 2014, 2015]

- Low & quasi-persistent X-ray luminosity
- Higher mass accretion rate in the disk than on NS
- Outflows (collimated?)
- Particle acceleration at the disk-magnetosphere boundary
  - $\rightarrow$ gamma-ray emission





The three states of transitional ms pulsars

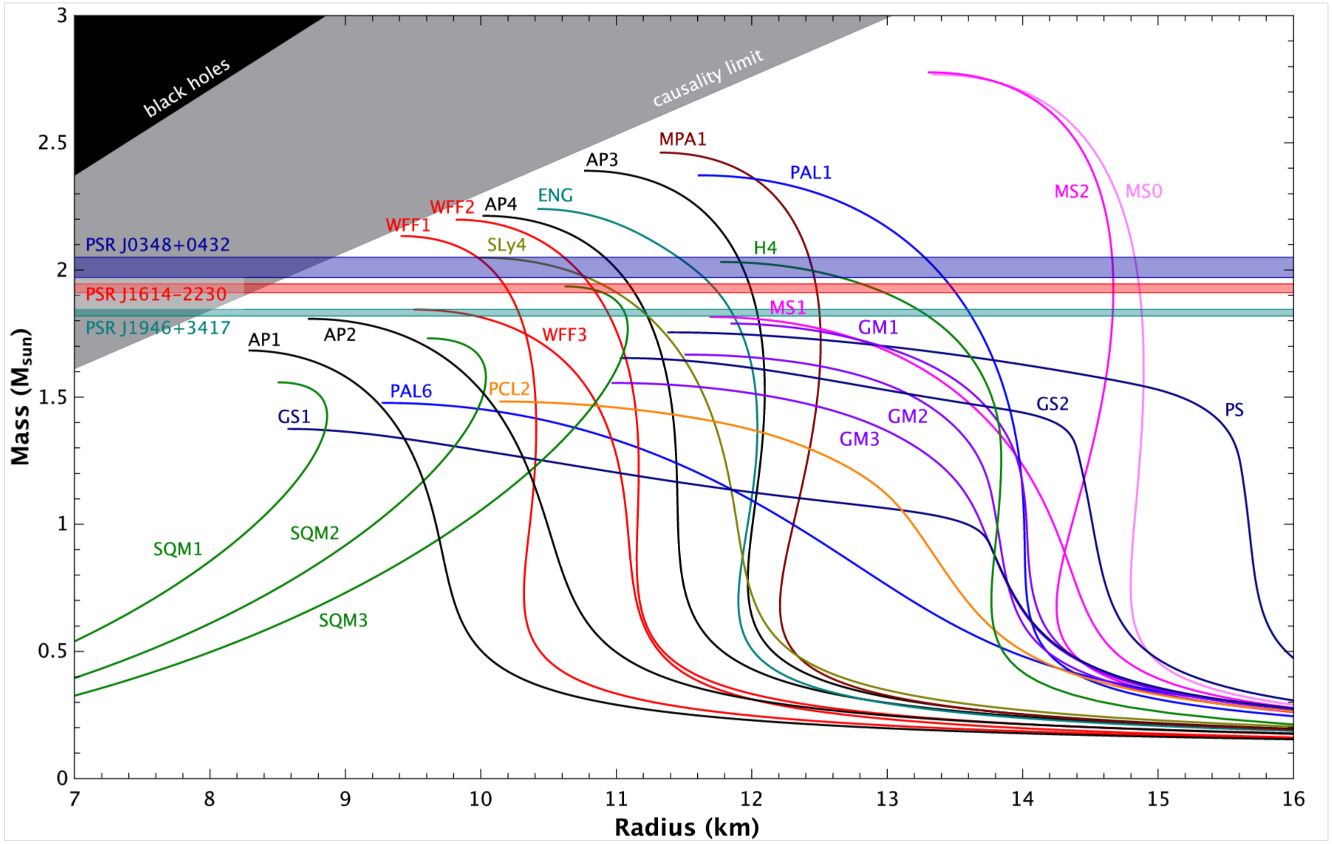


The neutron star equation of state

Equation of state (ρ vs. p) is mapped by **simultaneous measurements of mass and radius**

Radio pulsar timing
(& companion photometric
and/or spectroscopy)
very effective to measure
neutron star masses
(up to ~2 Msun)

Wex, Freire 2016



The neutron star equation of state

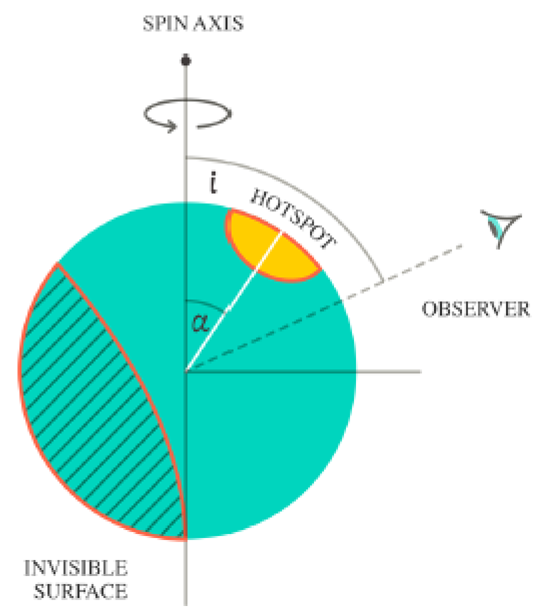
X-ray pulse profiles of millisecond pulsars can probe the neutron star radius
[e.g. Poutanen & Beloborodov 2006; Psaltis+ 2014]

Watts+ 2016

Shape of magnitude and color variations:

→ NS mass-to-radius ratio, radius

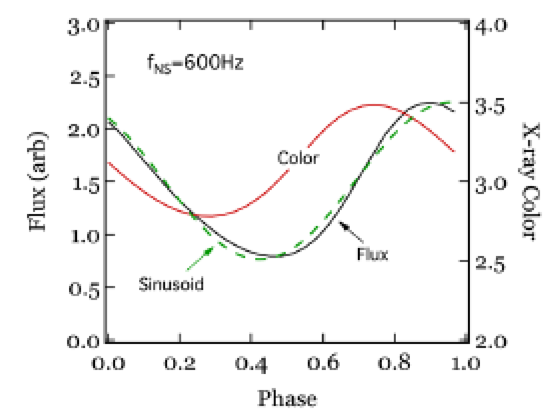
→ but also inclination, spectrum, ...



Measurement of mass and inclination during the radio PSR phase reduces degeneracy and provide a cross check

To measure radius with 5% accuracy:

- 100ks eXTP/LAD obs of PSR J1023 at current flux
- less than 10ks if a bright outburst and/or type-I X-ray burst occurs



Spin distributions

Tranistional MSPs

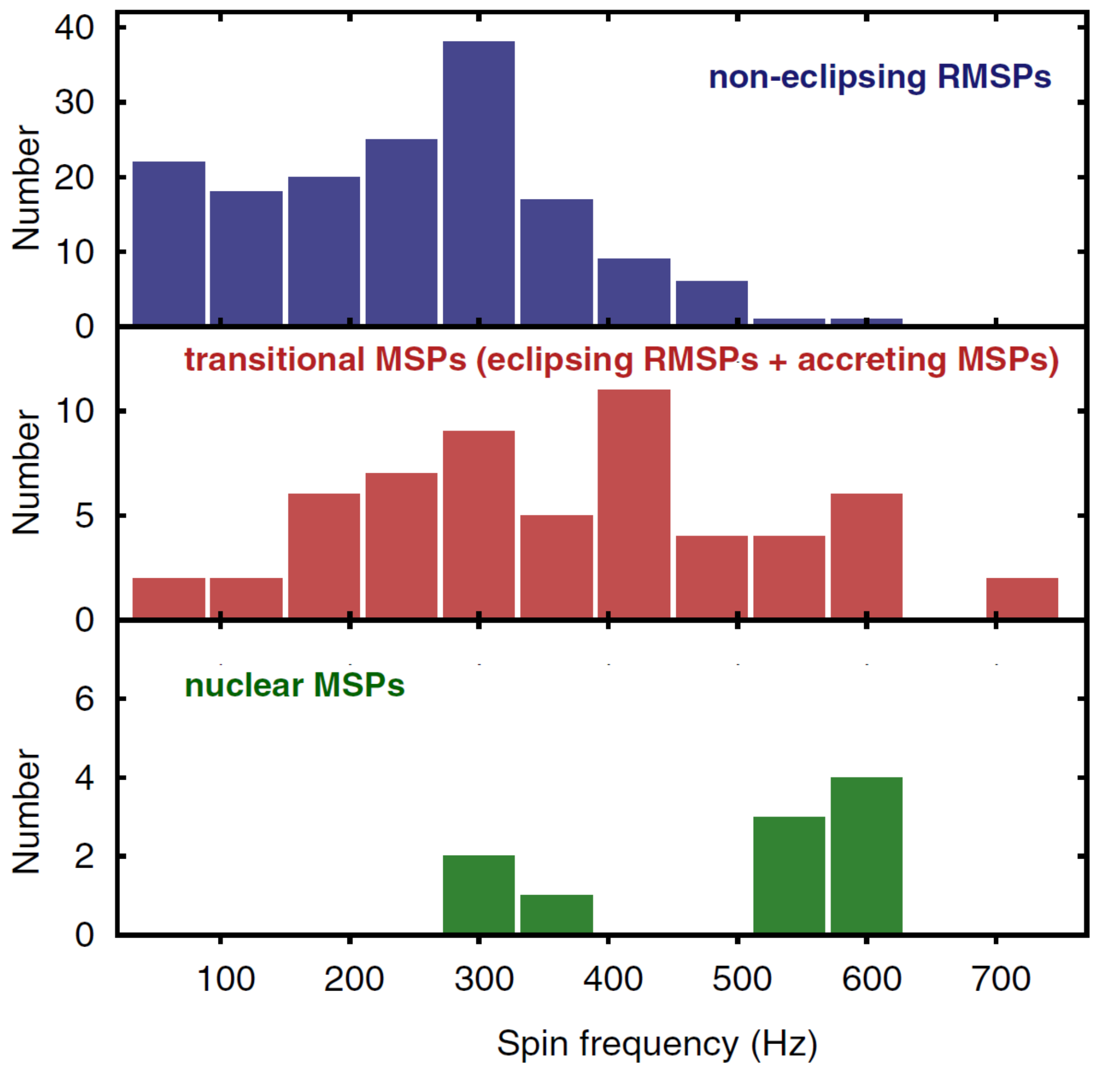
faster than non eclipsing ones

slower than pure accretors

[Tauris+ 2012, Science;
Papitto, Torres, Rea, Tauris+ 2015]

An intermediate evolutionary state?

Crucial to understand what limits the MSP to reach breakup velocity



Open questions

What drives variations of the mass in-flow rate?

Tidal interactions? Mass accumulation?

Accretion and ejection coupling from variability at all wavelenghts (correlations, lags?)

Exploit mass measurement to boost pulse profile modelling & neutron star mass & radius measurement

Are all millisecond pulsars in close binary systems transitional?