A propeller model for the sub-luminous accretion disk state of transitional millisecond pulsars

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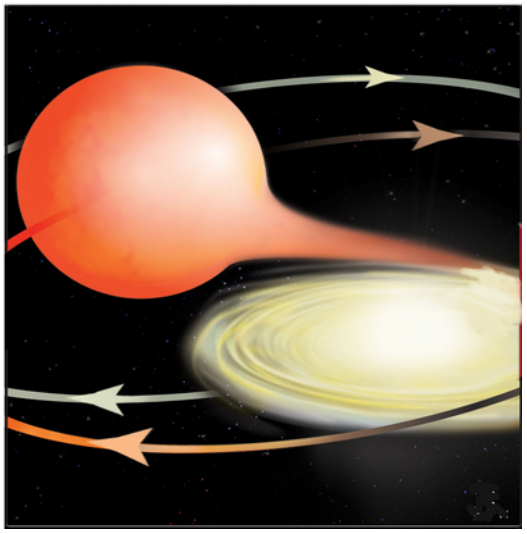
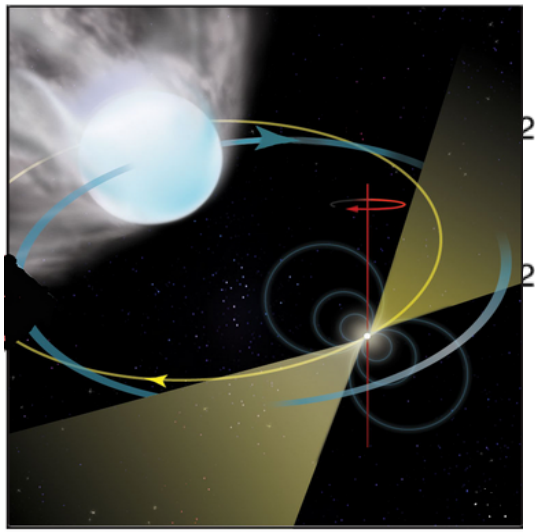
Millisecond Pulsars

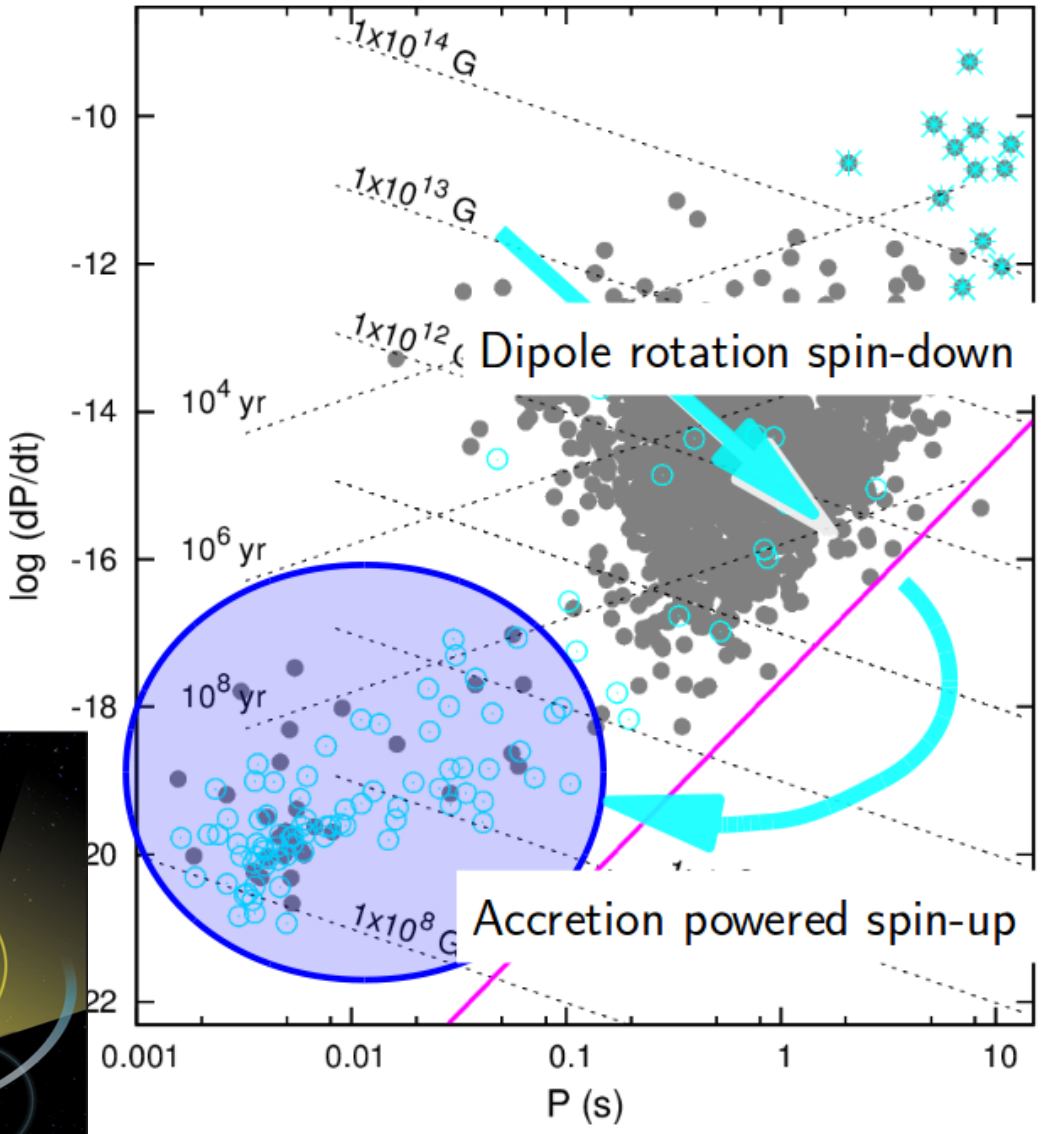
- weakly magnetized
- often found in globular clusters
  $\rightarrow$ old systems
- often in **binaries**

Recycled low-mass X-ray binaries

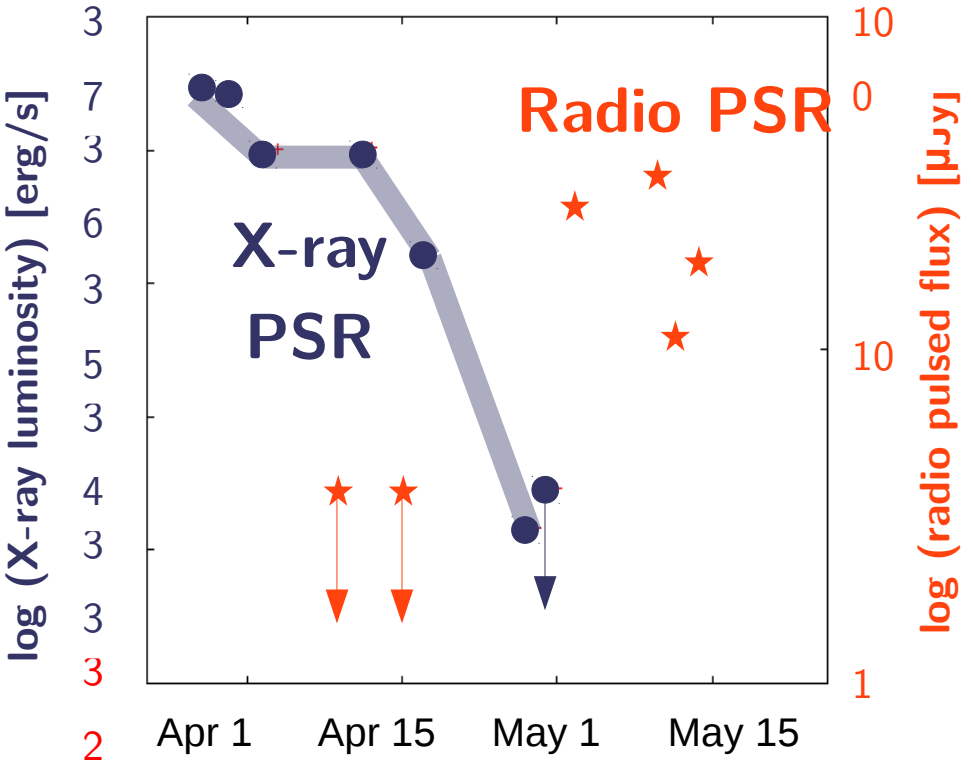
[Backer+1982, Alpar+1982]



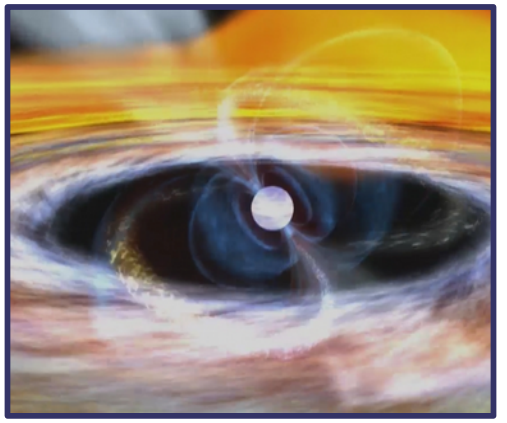


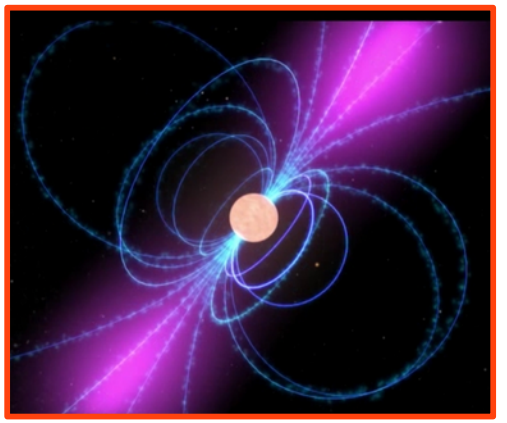


A swinging millisecond pulsar in M28



Xray PSR accretion powered



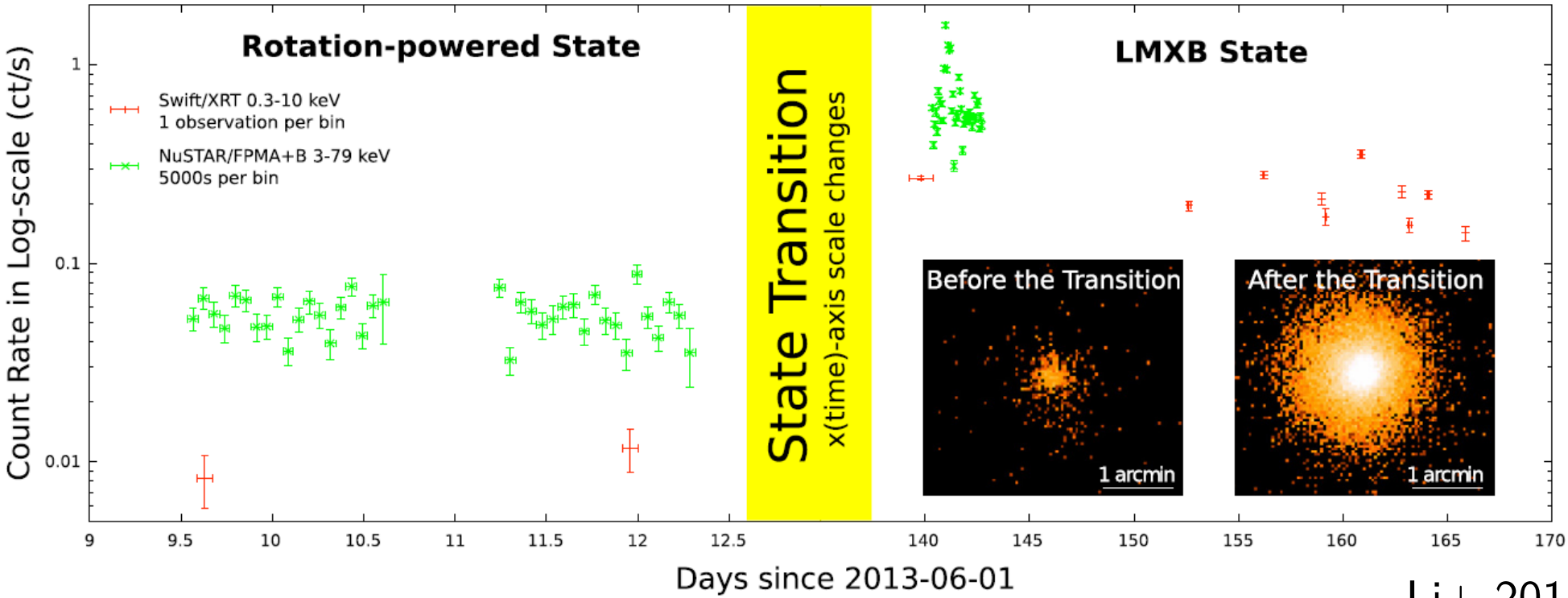


Rotation powered **Radio PSR**

Mass in-flow rate

Papitto et al. 2013, Nature

State transitions to a sub-luminous disk state



Li+ 2015

PSR J1023+0038 (Archibald+ 2009, Stappers+ 2014)

XSS J12270-4859 (de Martino+ 2011, 2013, Bassa+ 2014, Roy+2015)

X-ray properties

$L_X \sim 5 \times 10^{33}$ erg/s for 5-10 years

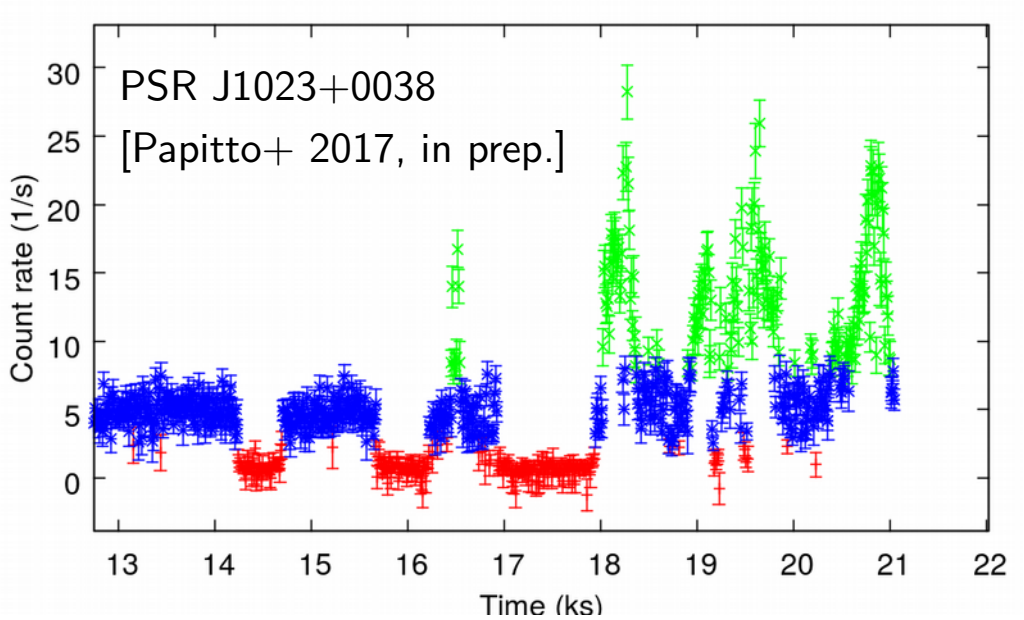
Intermediate between outburst ($10^{36\text{-}37}$ erg/s) and quiescence ($10^{31\text{-}32}$ erg/s)

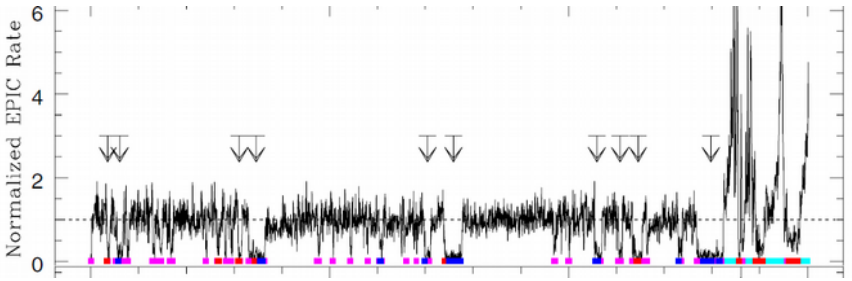
X-ray moding on ~10s timescales

High Mode

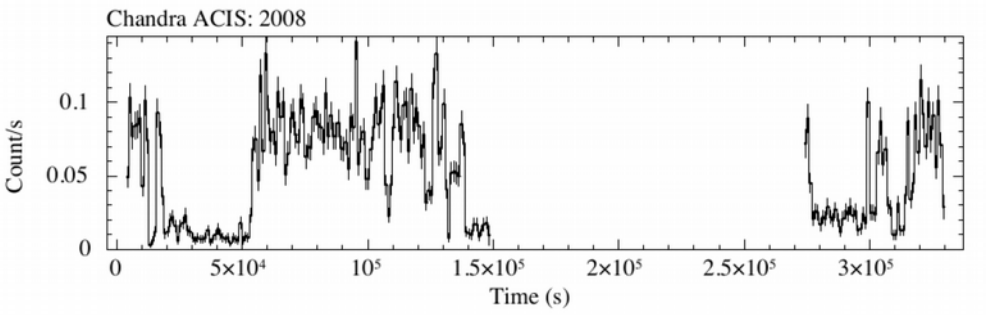
Low Mode

Flaring



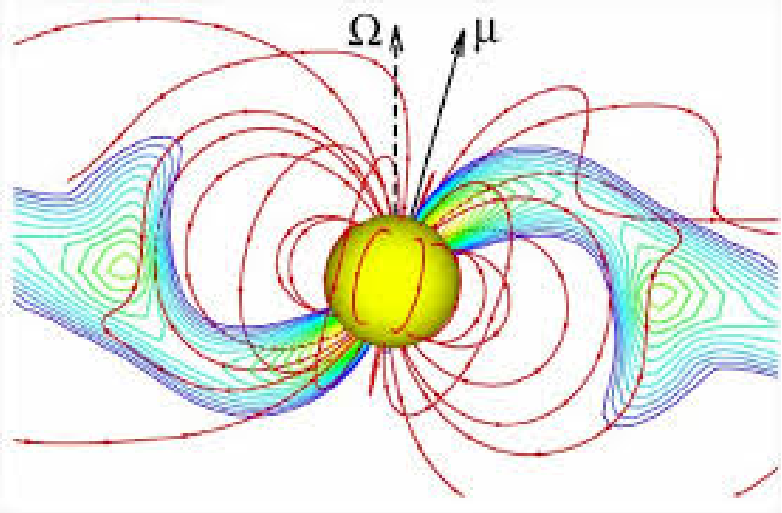


XSS J12270-4859 [De Martino+ 2011]



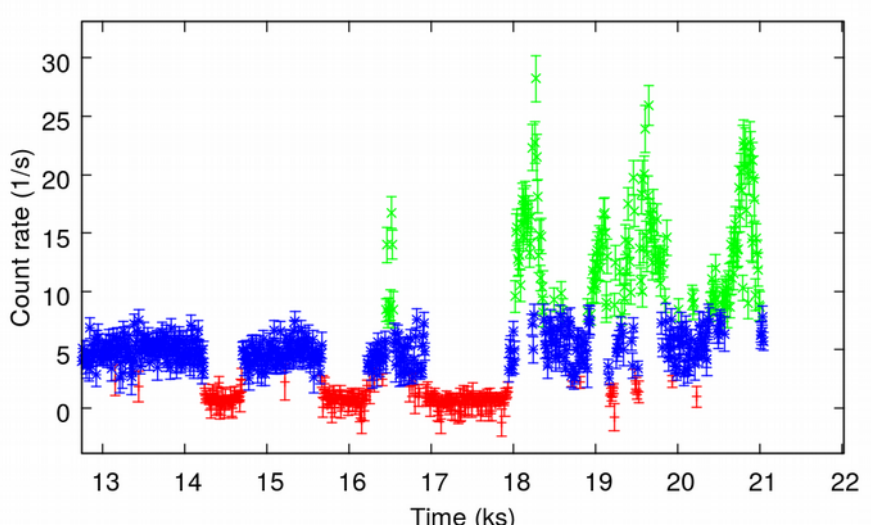
IGR J18245-2452 [Papitto+ 2013, Linares+ 2013]

Coherent X-ray pulsations

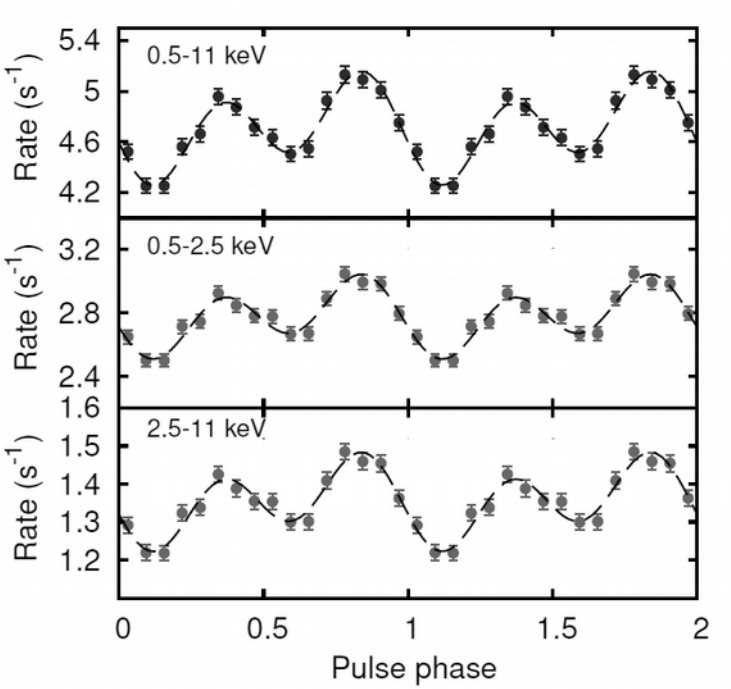


Accretion onto hotspots

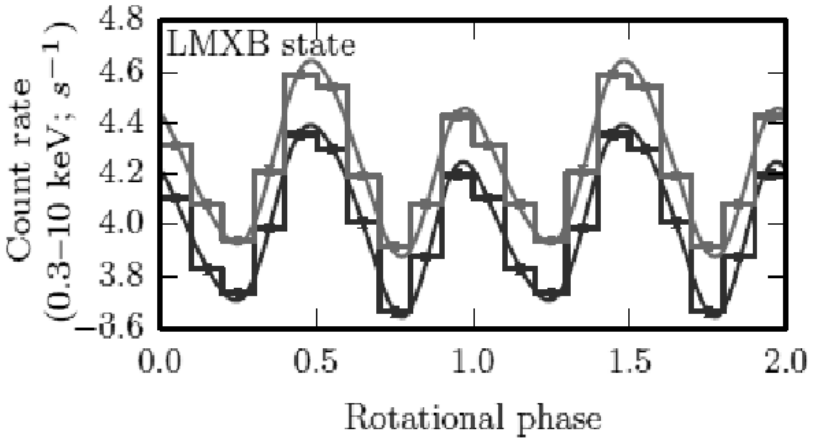
Pulsations seen only in the **high mode**



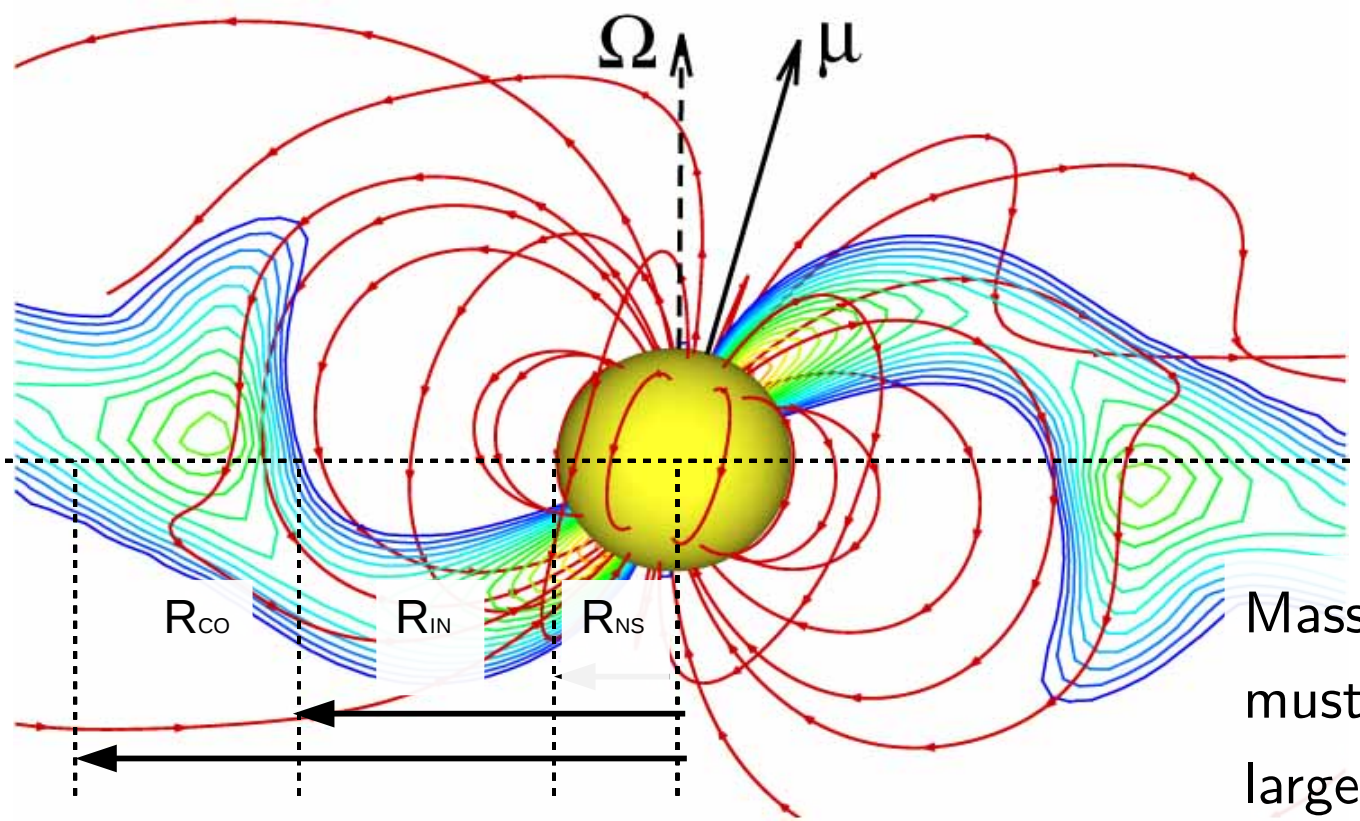
XSS J12270-4859 [Papitto+ 2015, MNRAS]



PSR J1023+0038 [Archibald+ 2015, ApJ]



The faintest X-ray pulsators



Mass in-flow rate in the disk must be ~50-100 times larger than accretion rate on the surface

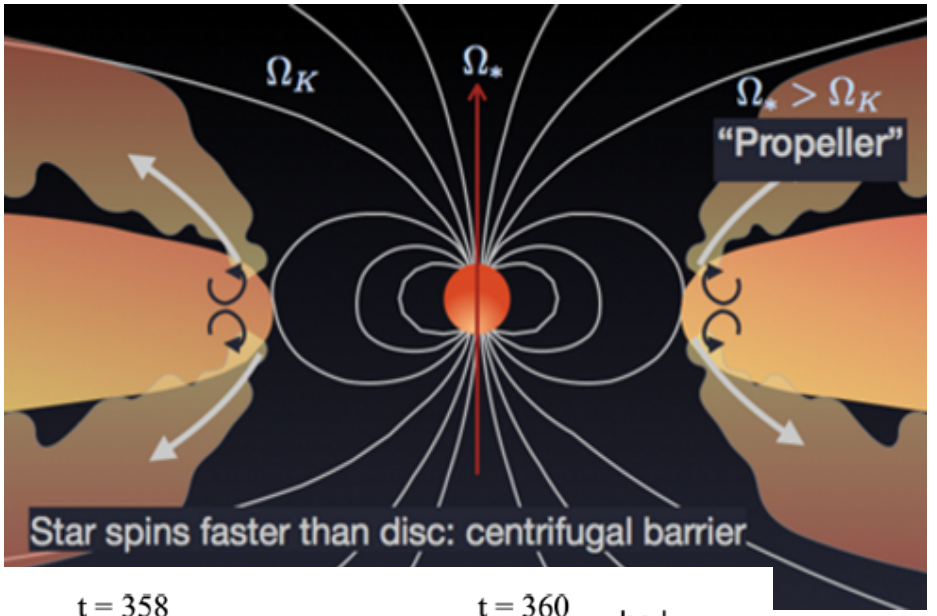
95% disk mass ejected?

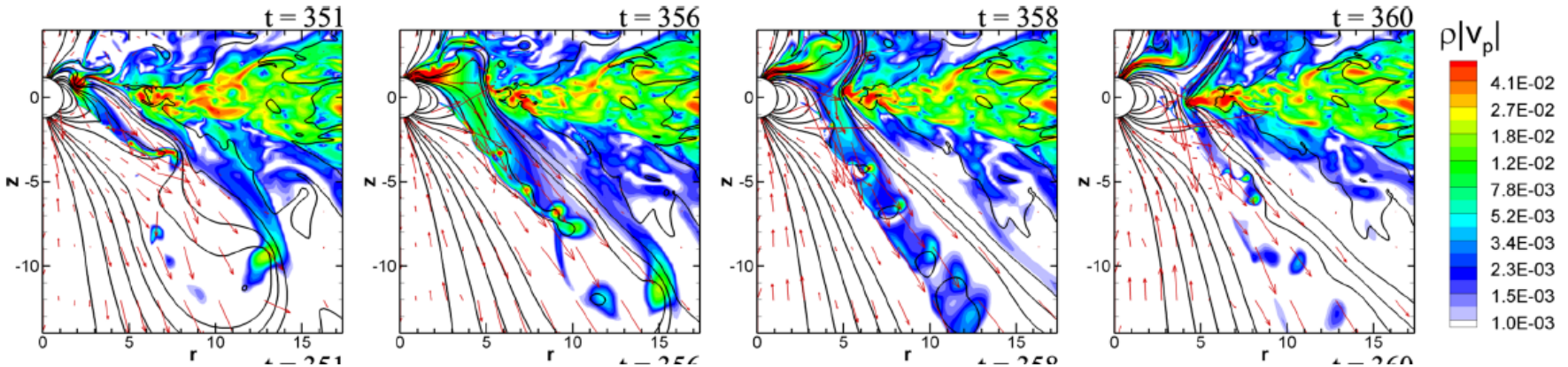
[Papitto+ 2015, MNRAS]

Propeller ejection

- Low X-ray luminosity
- Partial accretion produces X-ray pulsations,

  as described also by MHD simulations [Lii, Romanova+ 2014]



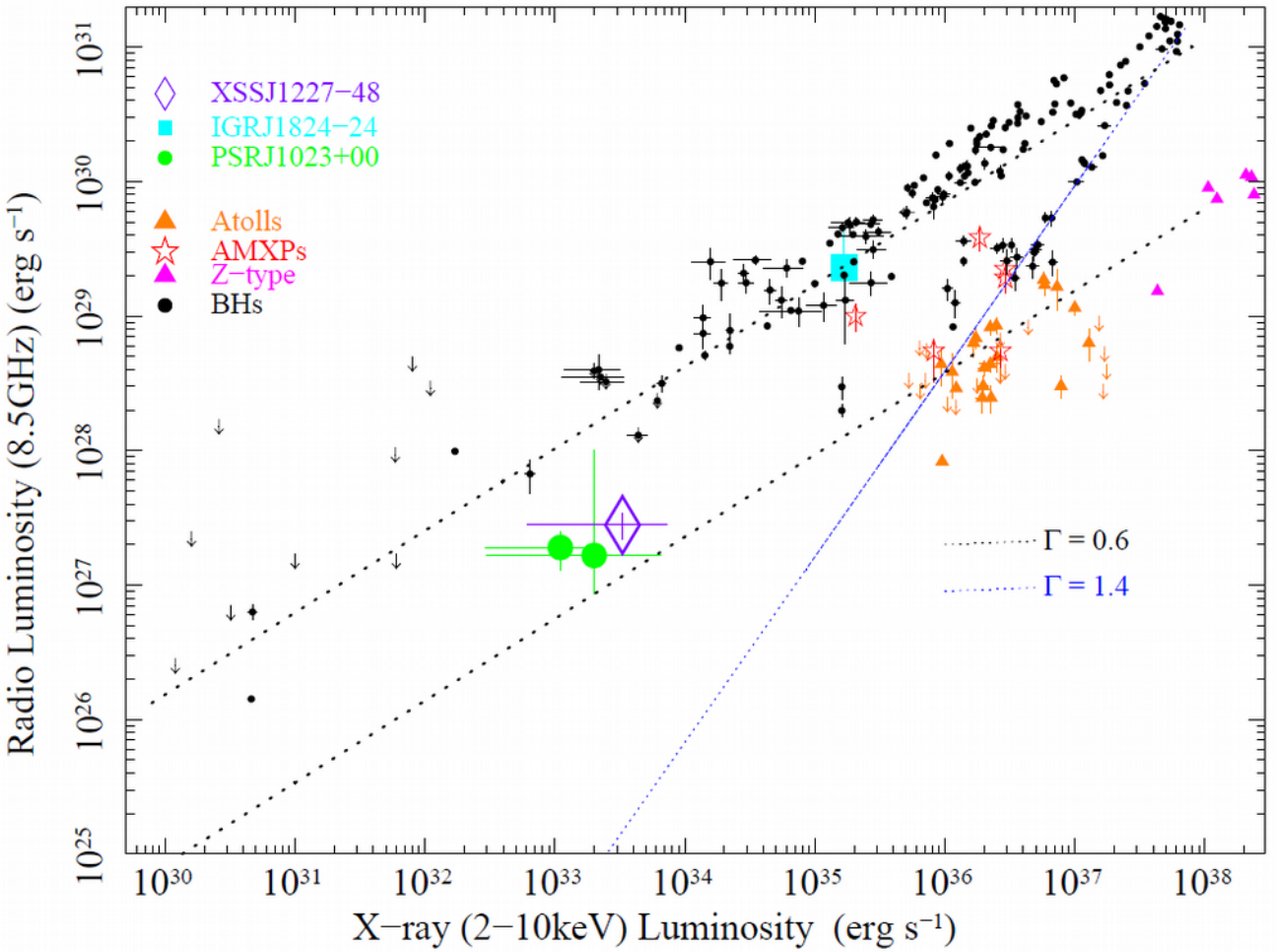


Radio-bright accreting neutron stars

S_ν (10GHz) ~ 0.05-0.5 mJy

Flat spectral shape

BH-like brightness

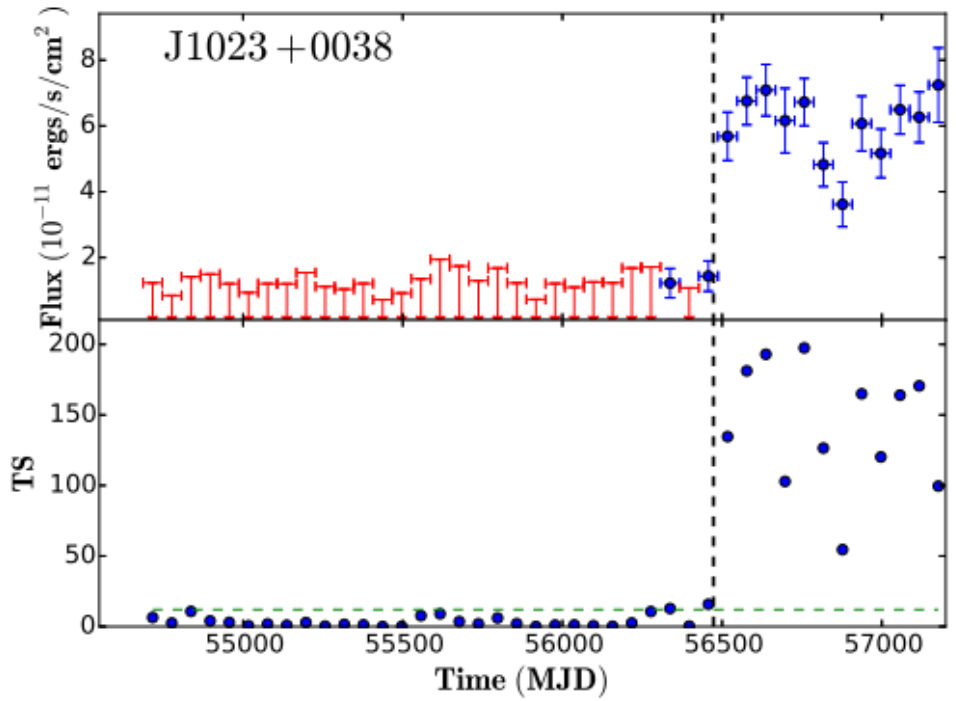


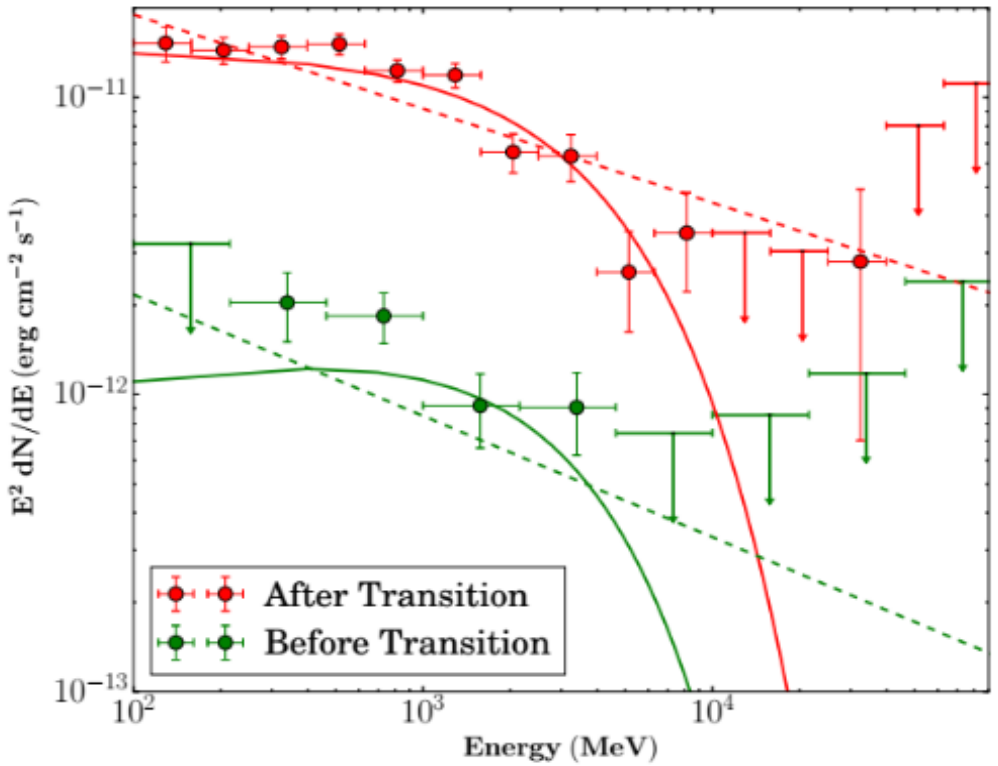
Courtesy of D. de Martino

The first low-mass gamma-ray binaries

Gamma-ray brighter when in the accretion disk state

L(gamma-rays)~$10^{33\text{-}34}$ erg/s ~ L(X-rays)





[Stappers+ 2014, Torres, Papitto+ 2017]

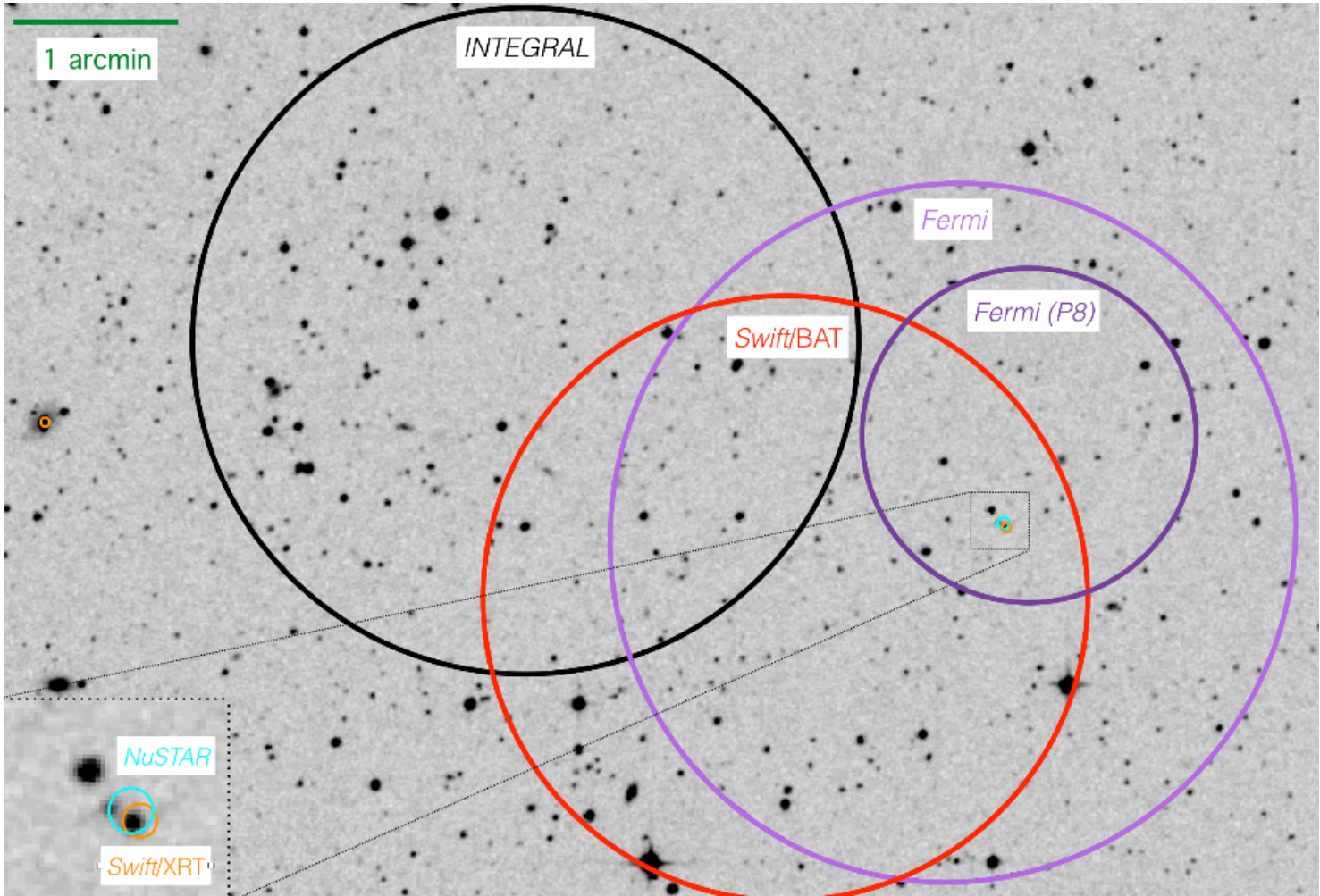
Gamma-rays unveil transitional ms pulsars

Look for typical optical and Xray variability compatible with Fermi LAT error circle

3FGL J1544.6-1125
[Bogdanov+ 2015]

3FGL J0427.9-6704
[Strader+ 2016]

& more to come



Particle acceleration from propellering magnetosphere

Ecut ~ few GeV

→ magnetospheric origin? (but matter is flowing in)

→ charge accelerated at the turbulent propeller disk-magnetospheric interface

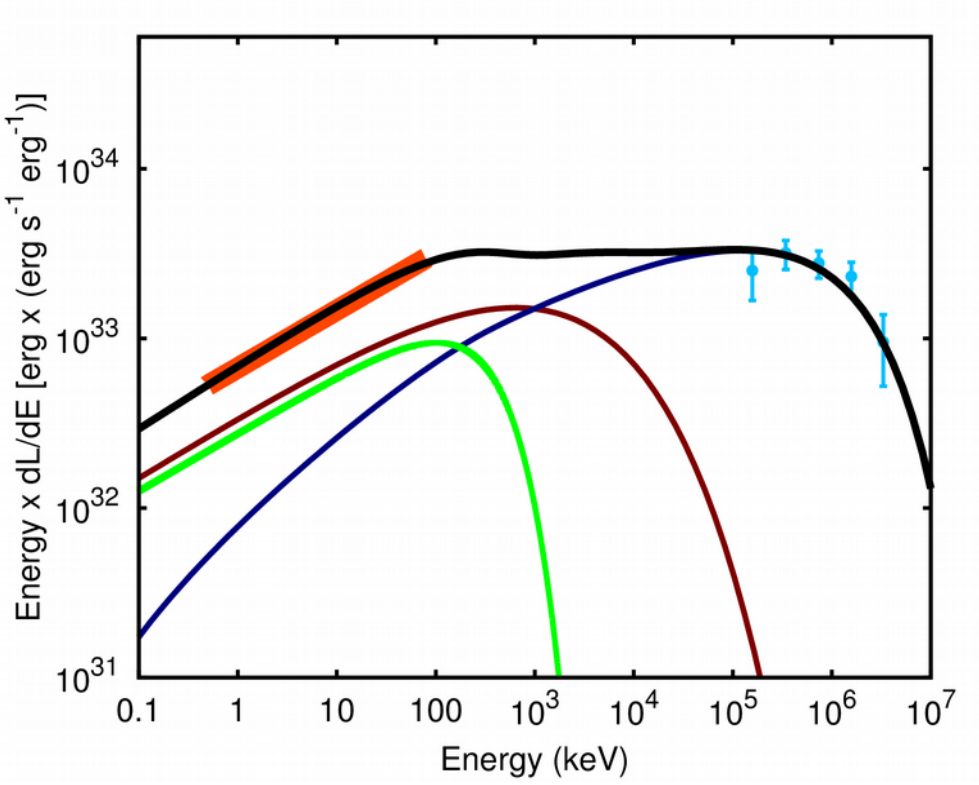
→ **synchrotron** (up to MeV)

→ **self-synchro Compton** (up to GeV)

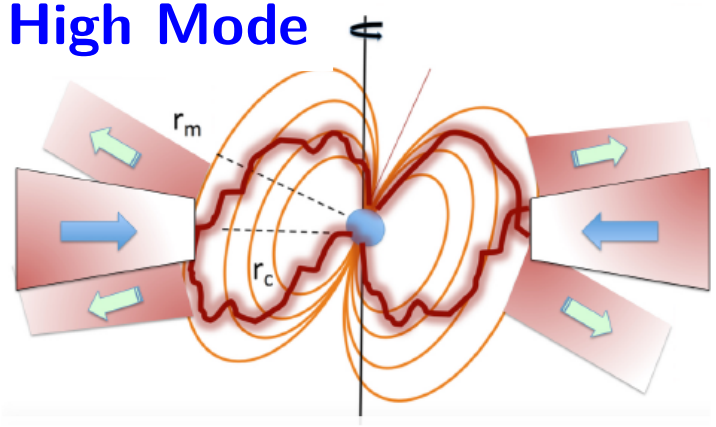
Good modelling for Rin ~ 2 Rco

Papitto & Torres 2015, ApJ

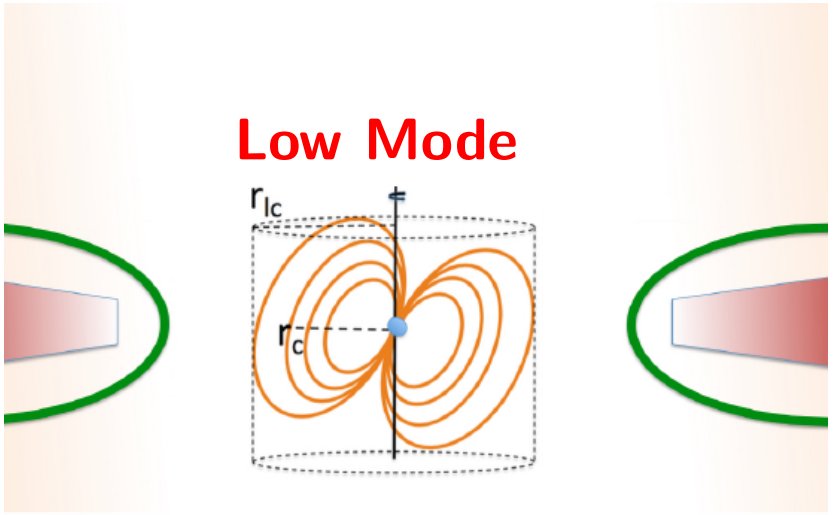
Papitto, Torres, Li, 2014, MNRAS



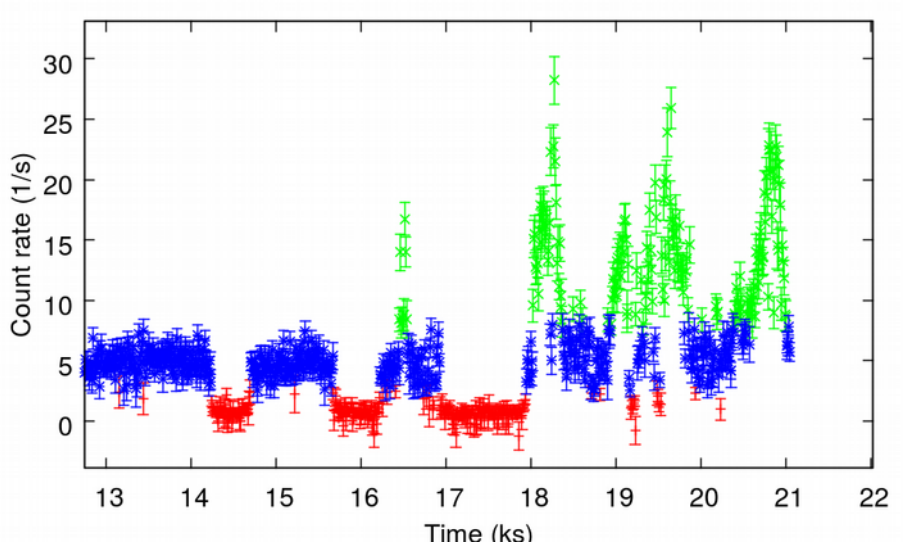
State transitions yield X-ray moding?

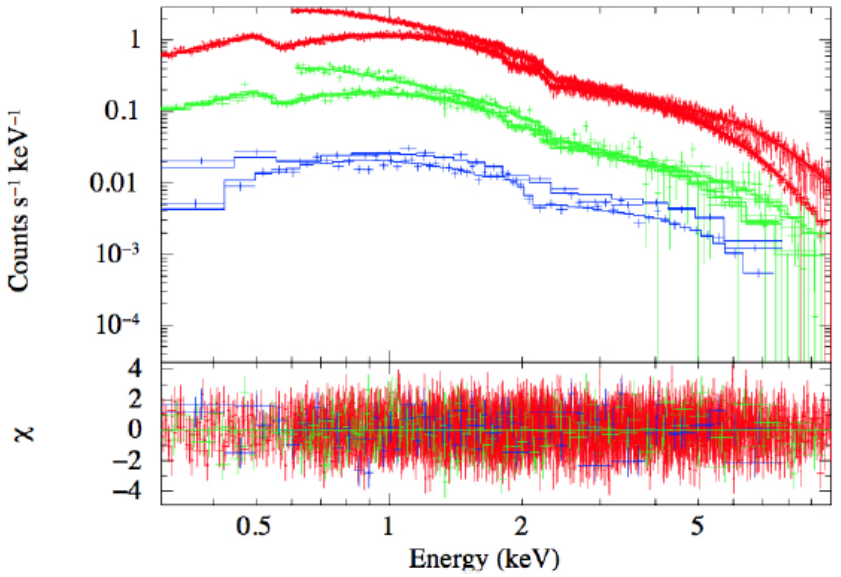


propeller and partial accretion



radio pulsar turning on?





Campana, Coti Zelati, Papitto+ 2016 (see also Linares 2014)

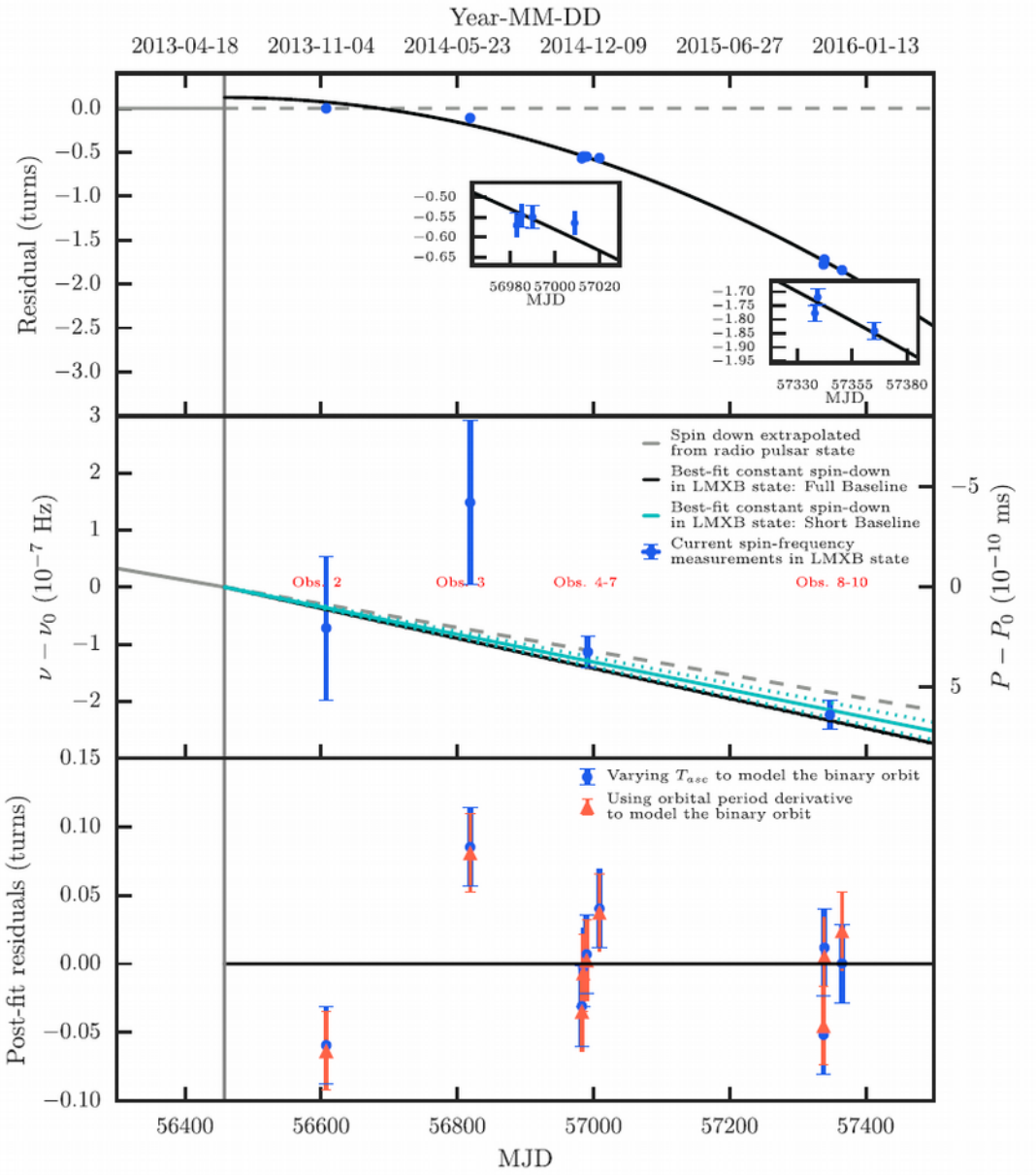
Spin down in the disk state

PSR J1023+0038

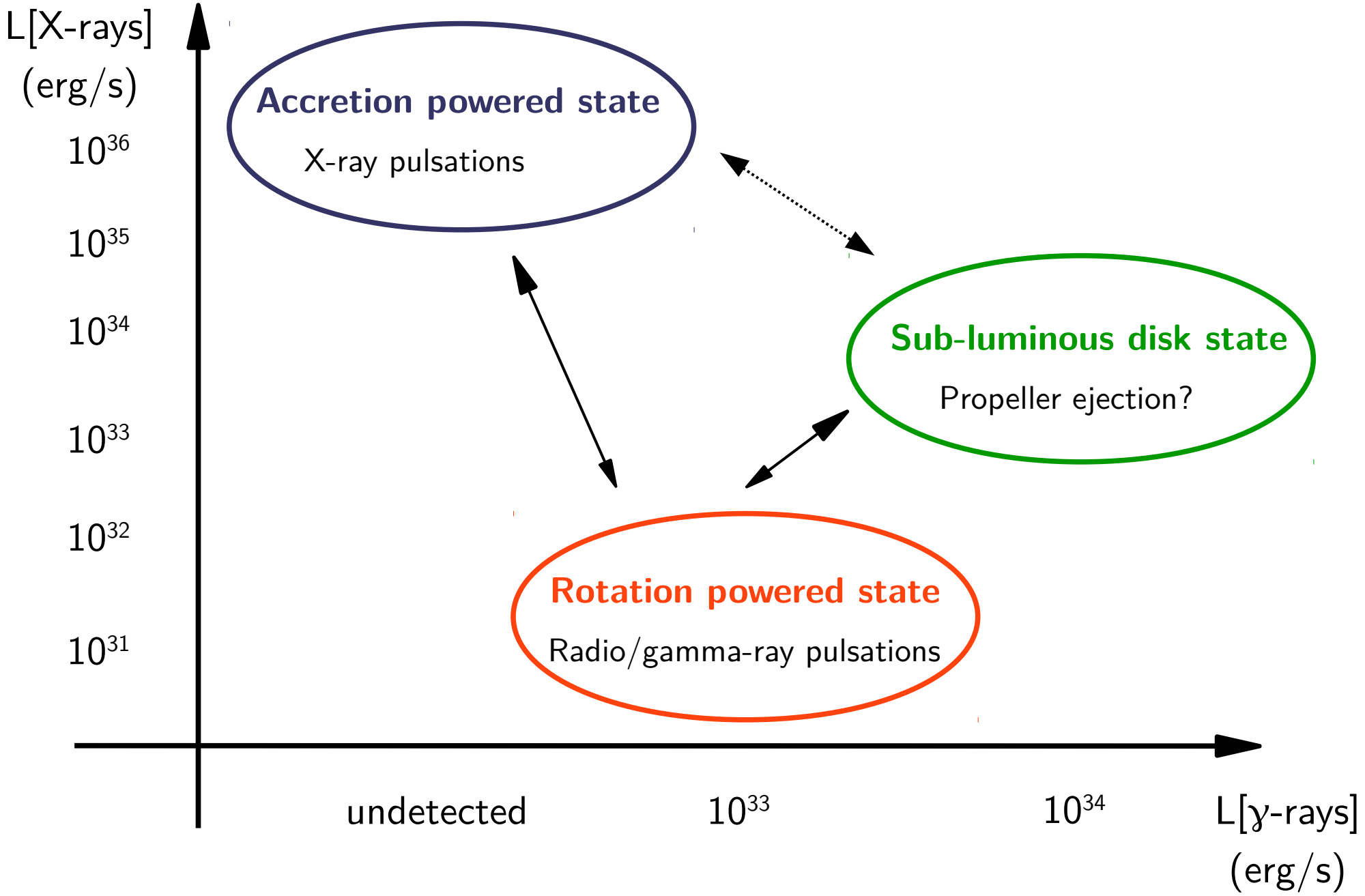
Spin down rate
~30% times larger than
in radio pulsar state
[Jaodand+ 2015]

→ limited effect of
accretion torques

→ ongoing XMM
X-ray timing campaign
[PI: Jaodand, Papitto, Campana]



The three states of transitional ms pulsars



Open questions

Physical mechanisms operating in the sub-luminous disk state

- Accretion, ejection or both?
- Does a radio pulsar turns on? Only during low states?

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

$\rightarrow$ multi wavelength campaign: radio, IR, optical, UV, X-rays

[PI: Jaodand, Papitto, Campana, de Martino]

...stay tuned!

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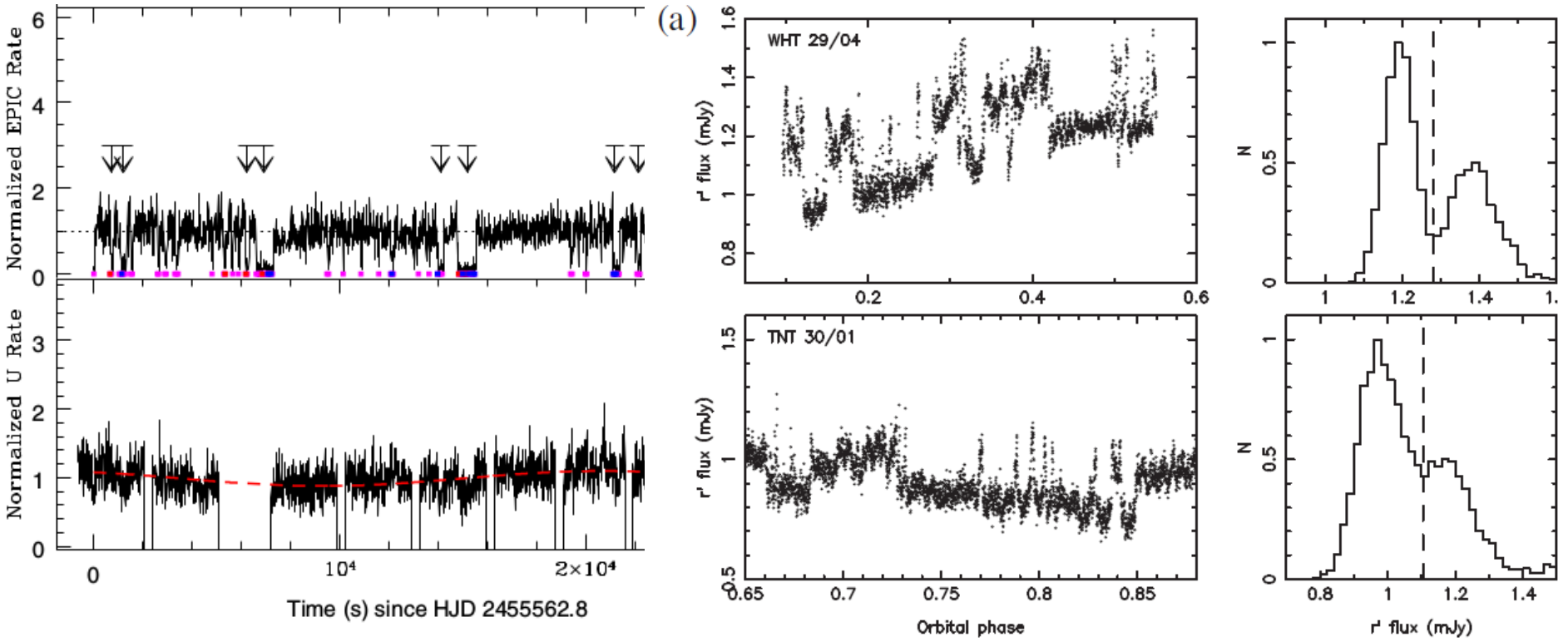
Optical/UV variability

Flares concurrent to Xrays

UV light from reprocessing of the X-ray emission

Moding seen in the optical



[de Martino+ 2013, Shahbaz+ 2015]