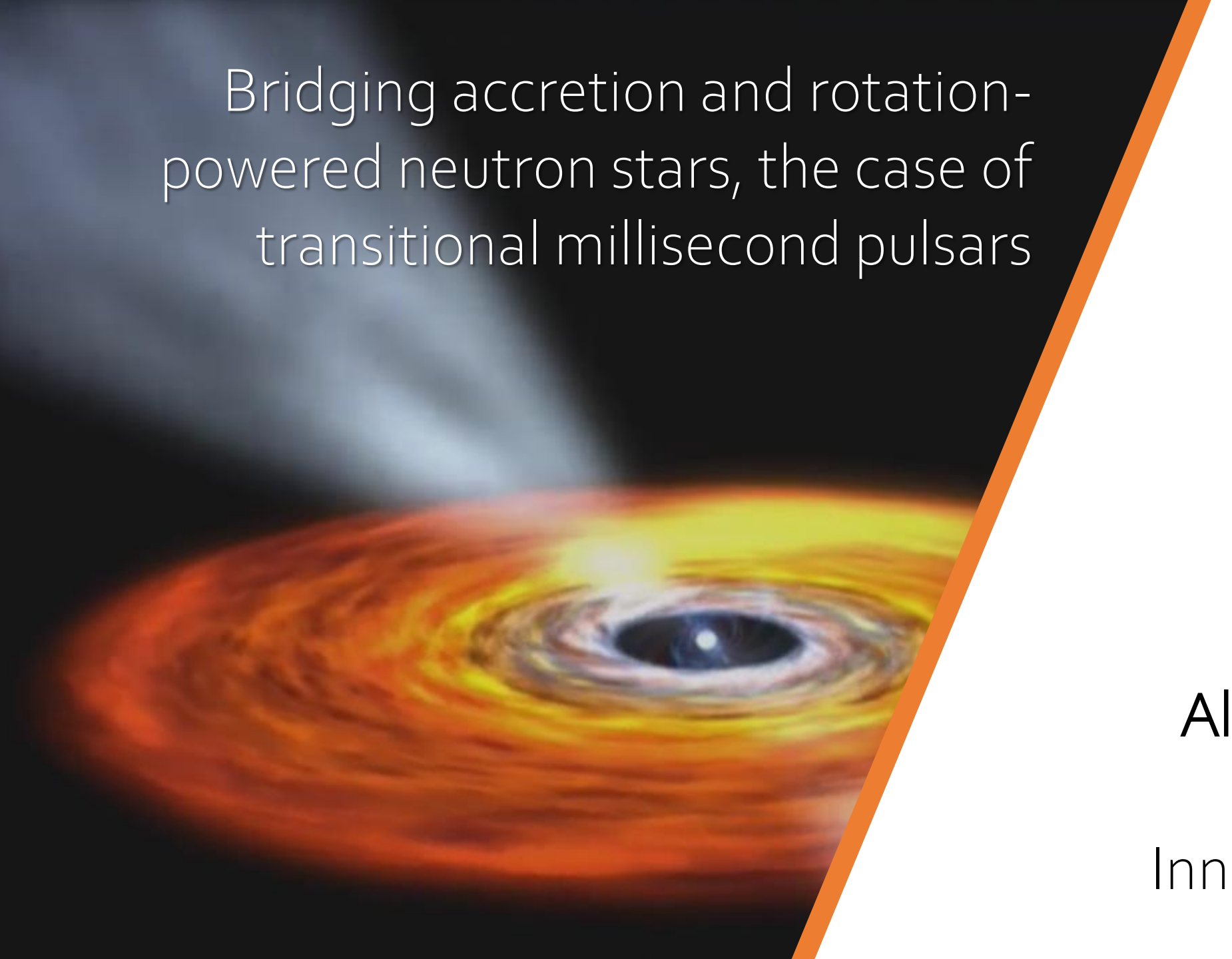
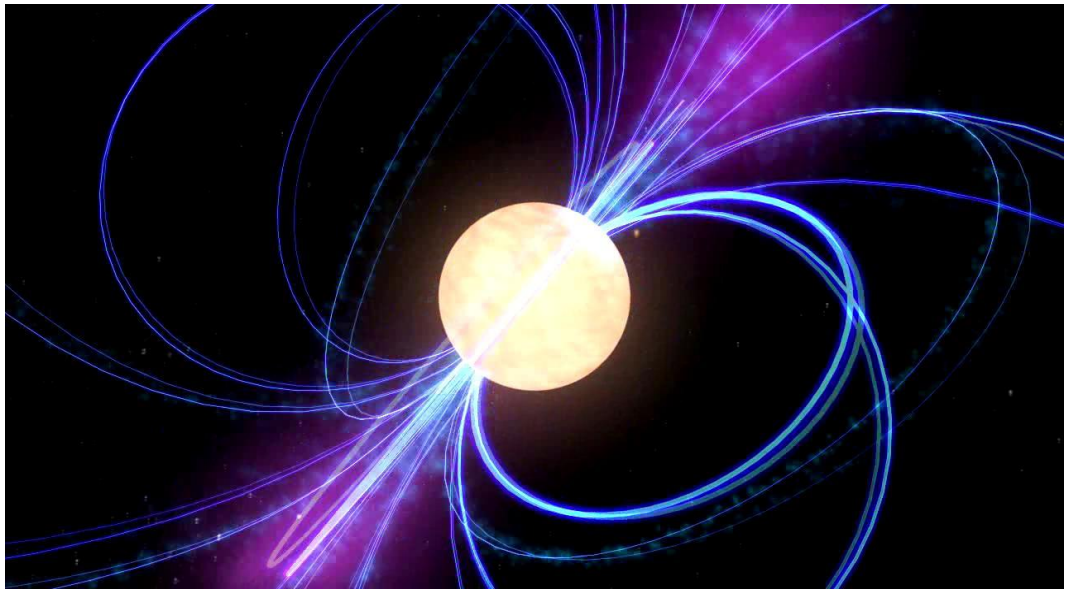
Bridging accretion and rotation-powered neutron stars, the case of transitional millisecond pulsars



Alessandro Papitto

VGRSS VI

Innsbruck 14.4.2023

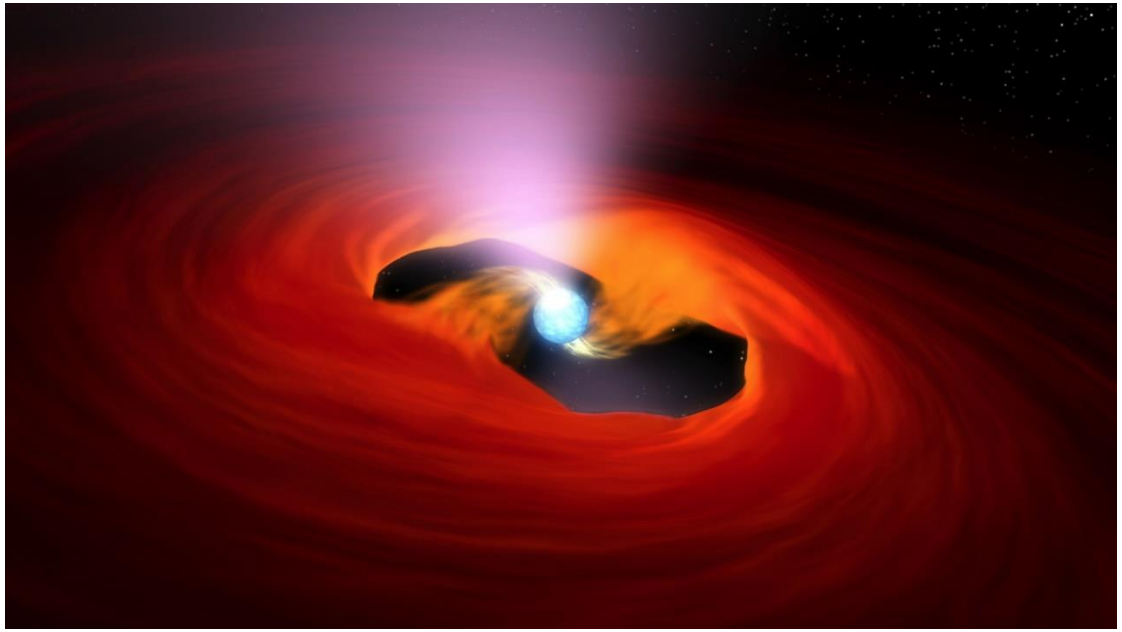


Rotation-powered Pulsars

Rotation of the e.m. field
→ particle acceleration
→ pulses from the radio to the gamma-rays

Accretion-powered Pulsars

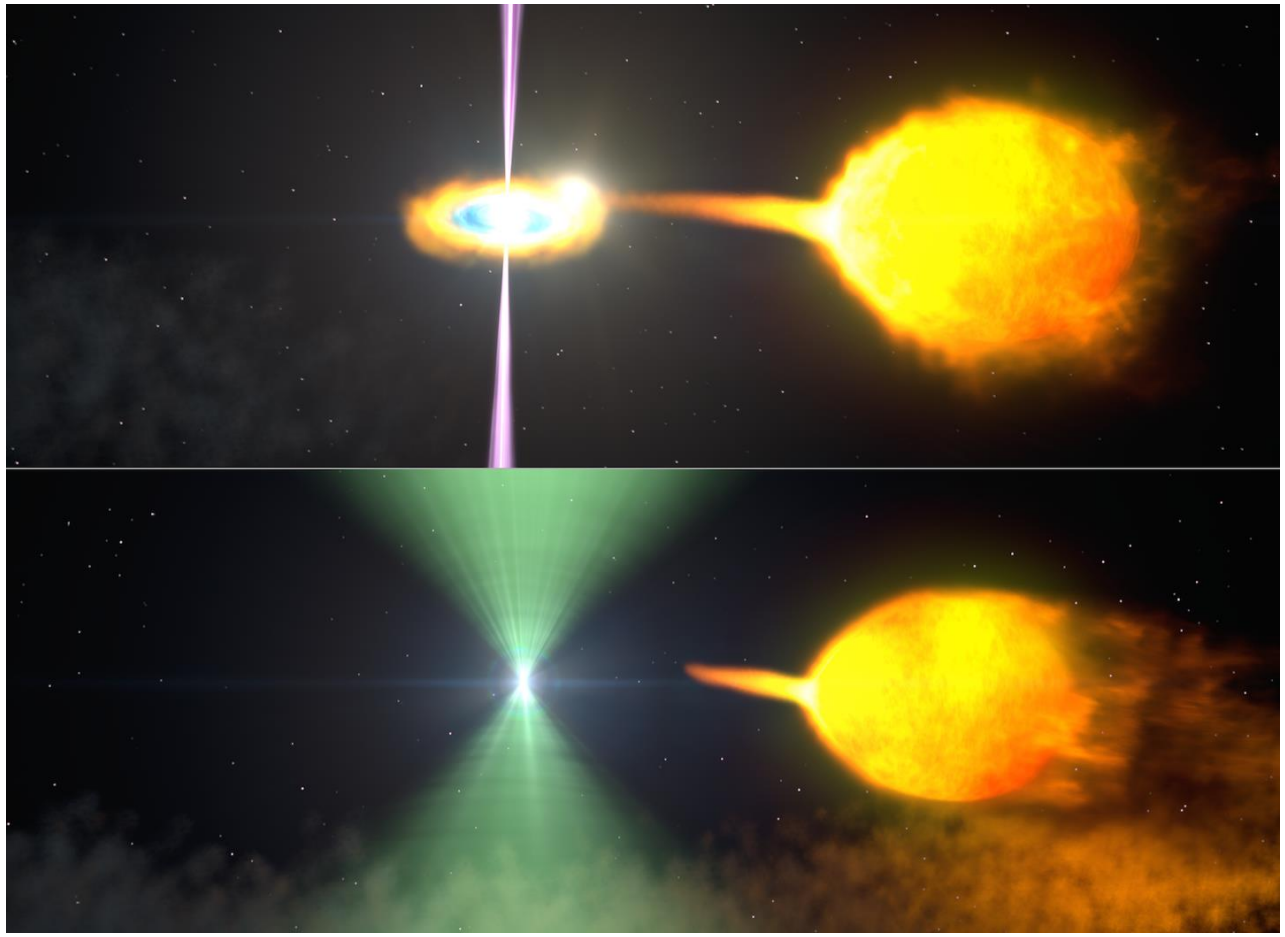
Matter lost by a companion star channeled by the NS magnetic field
→ X-ray emitting hotspots/columns



Can rotation and accretion power coexist?

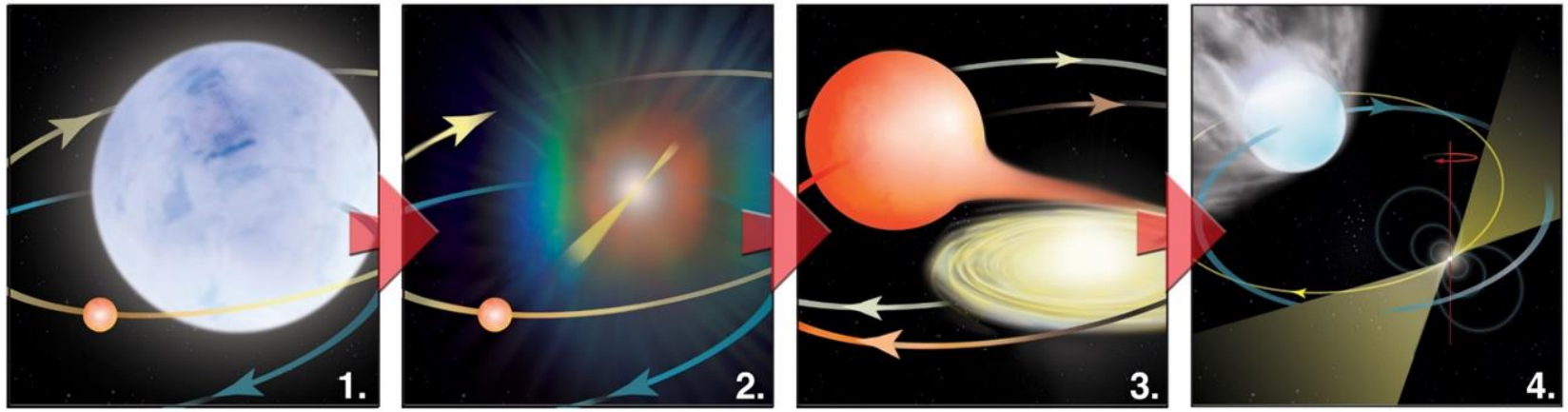
Transitional millisecond pulsars

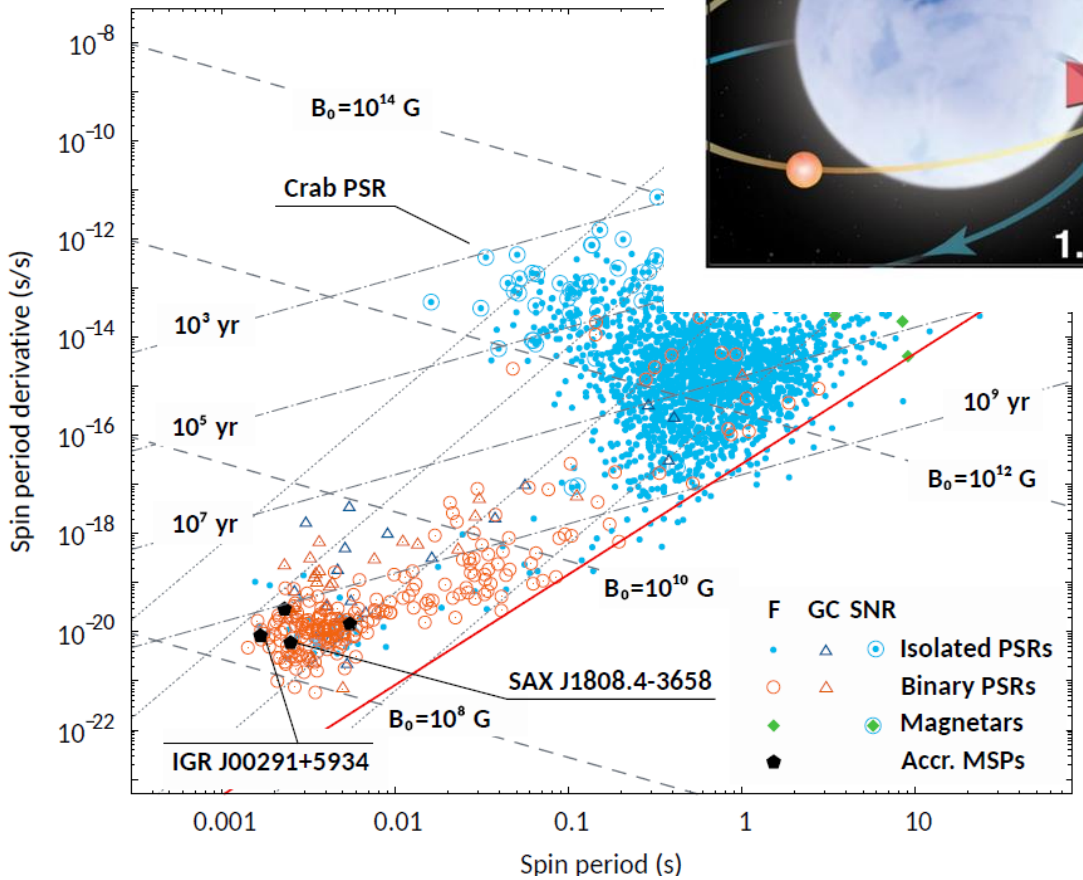
Optical/UV millisecond pulsars



Millisecond pulsars are recycled Low mass X-ray binaries

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

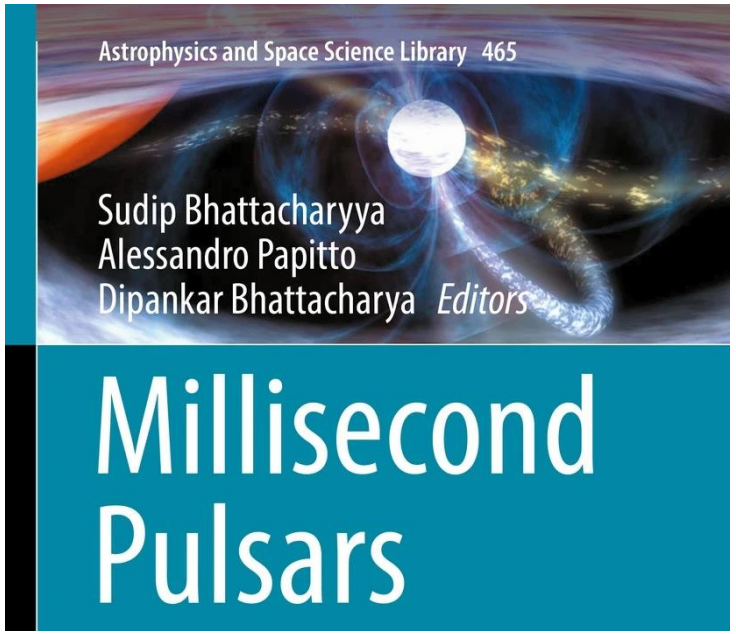


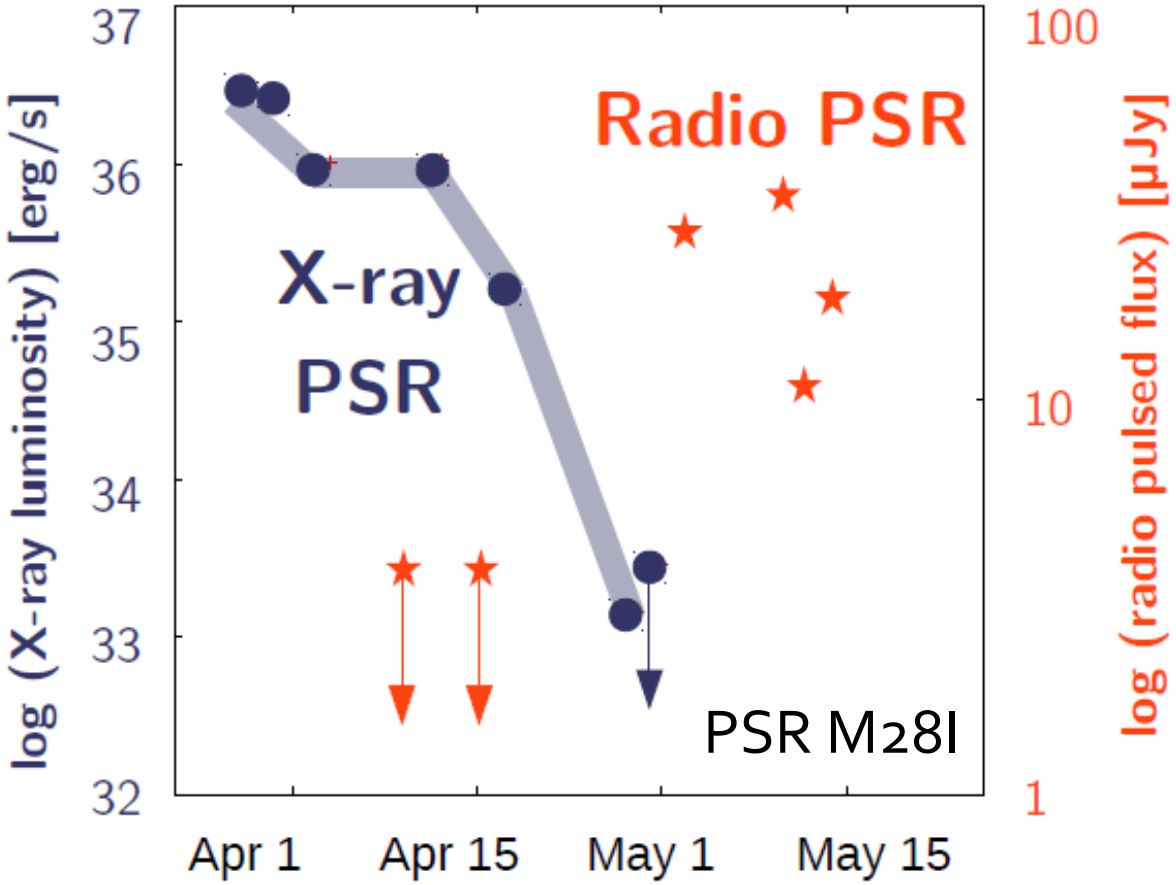


Swings between rotation and accretion power in binary transitional millisecond pulsars

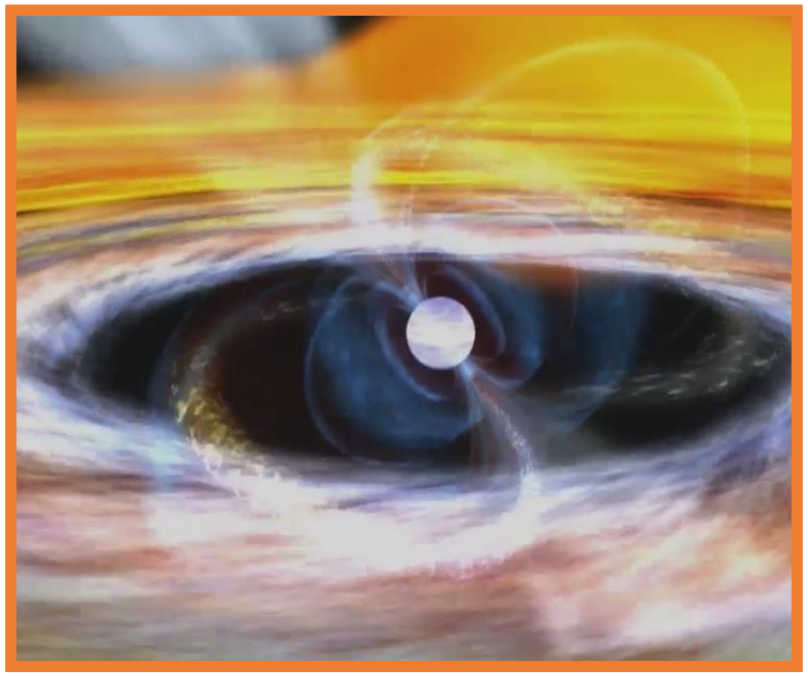
Archibald+ 2009; Papitto+ 2013; Bassa+ 2014

See review by Papitto & de Martino 2022



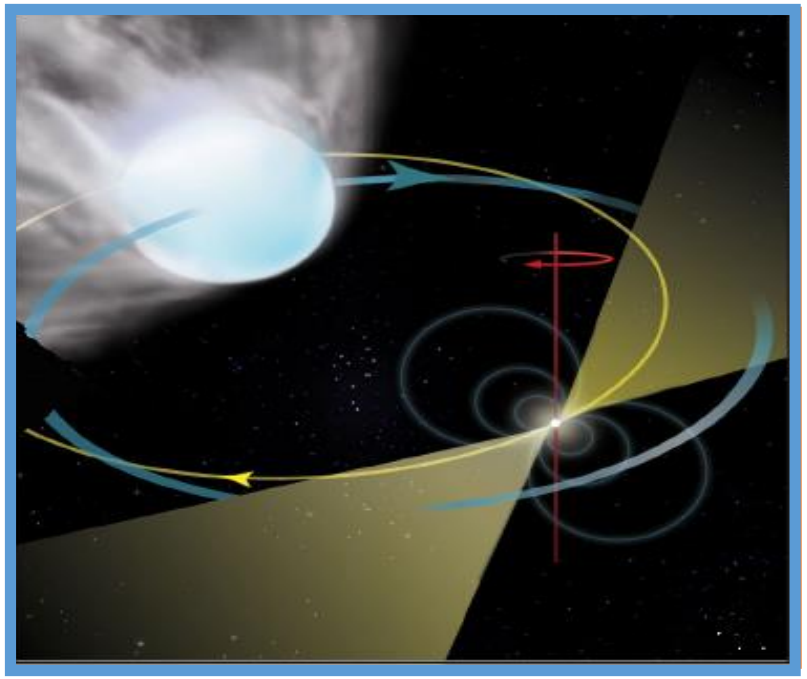


Mass in-flow rate

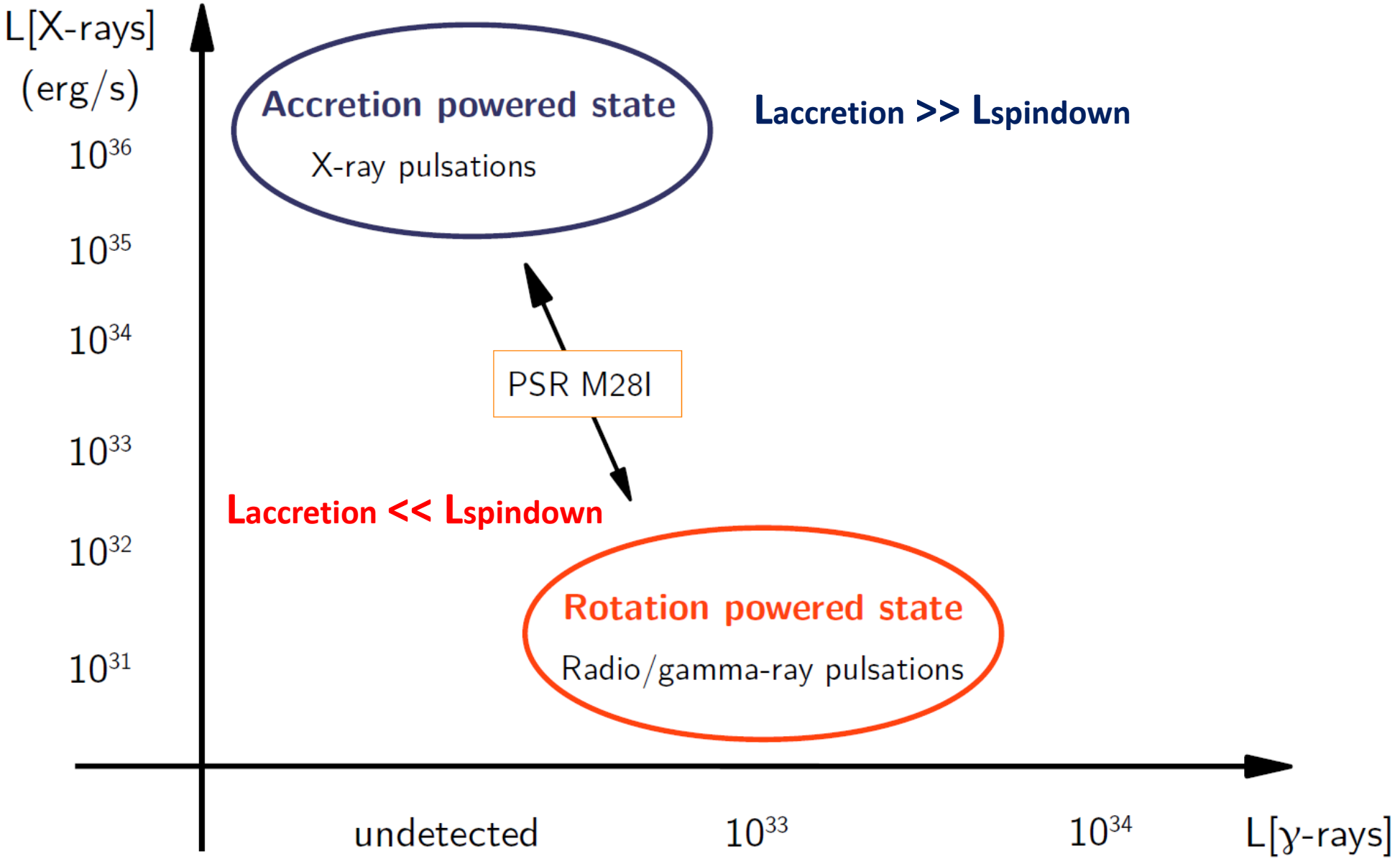


High mass in-flow rate
Gravity dominates
Accretion-powered (X-ray) PSR

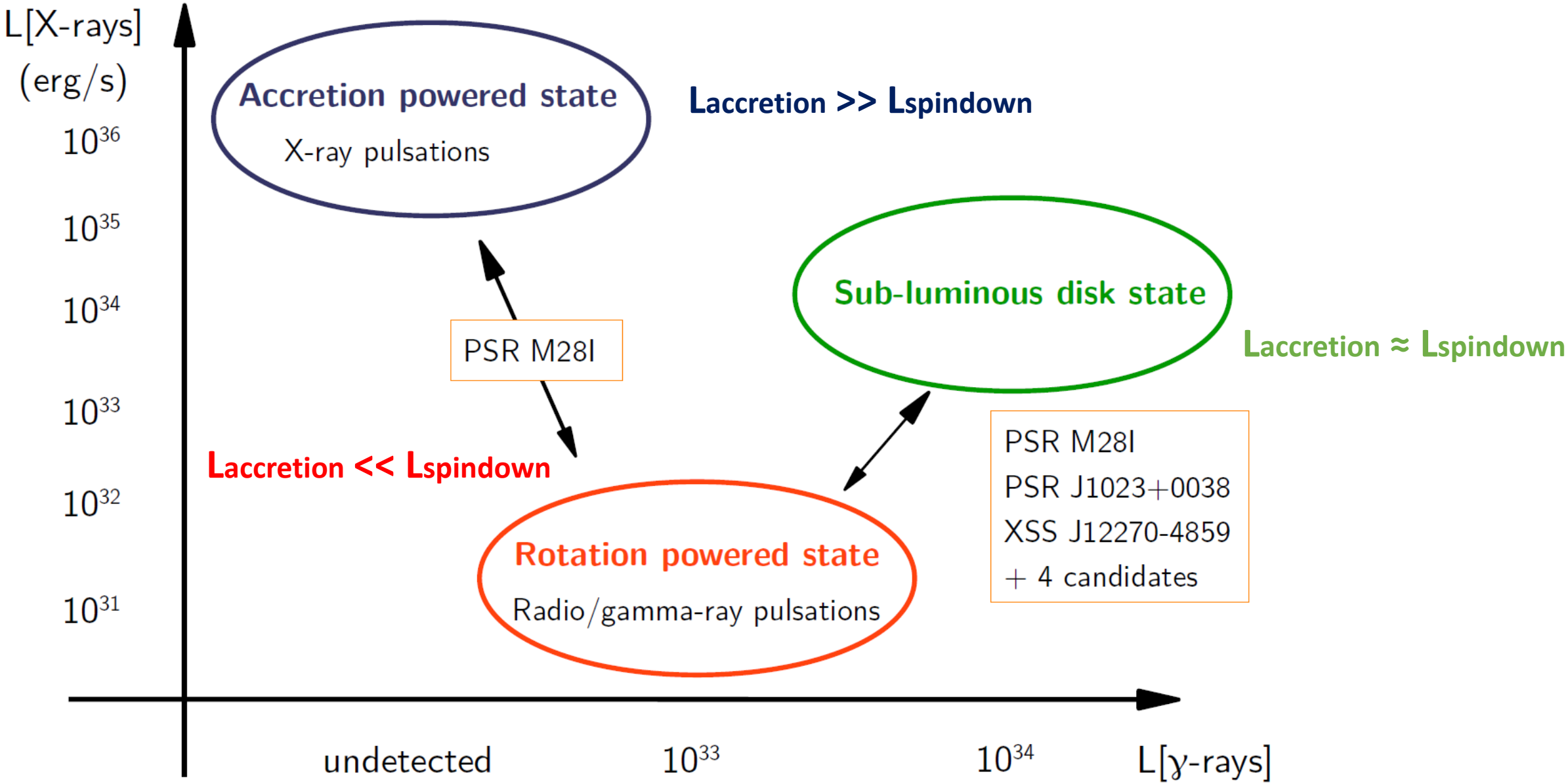
Low mass in-flow rate
Pulsar wind dominates
Rotation-powered (radio) PSR



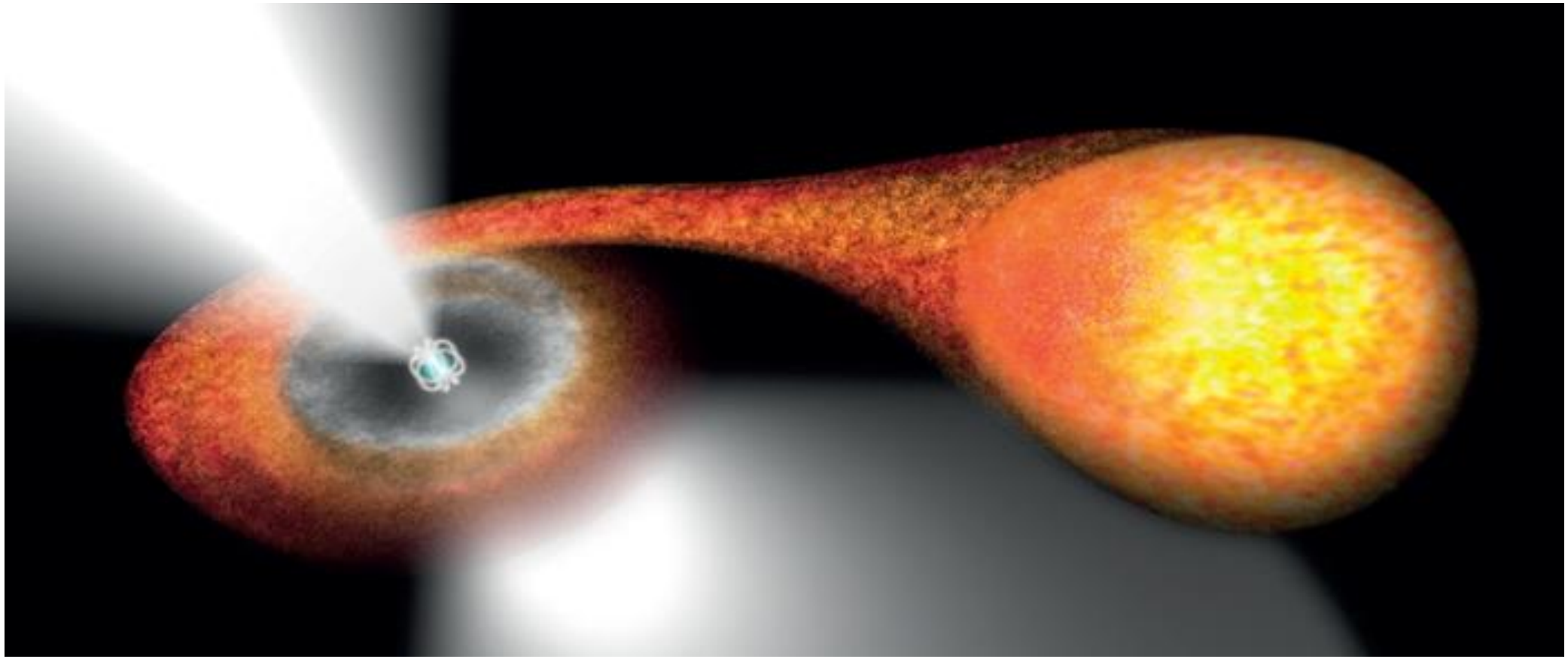
Transitional Millisecond Pulsars



Transitional Millisecond Pulsars

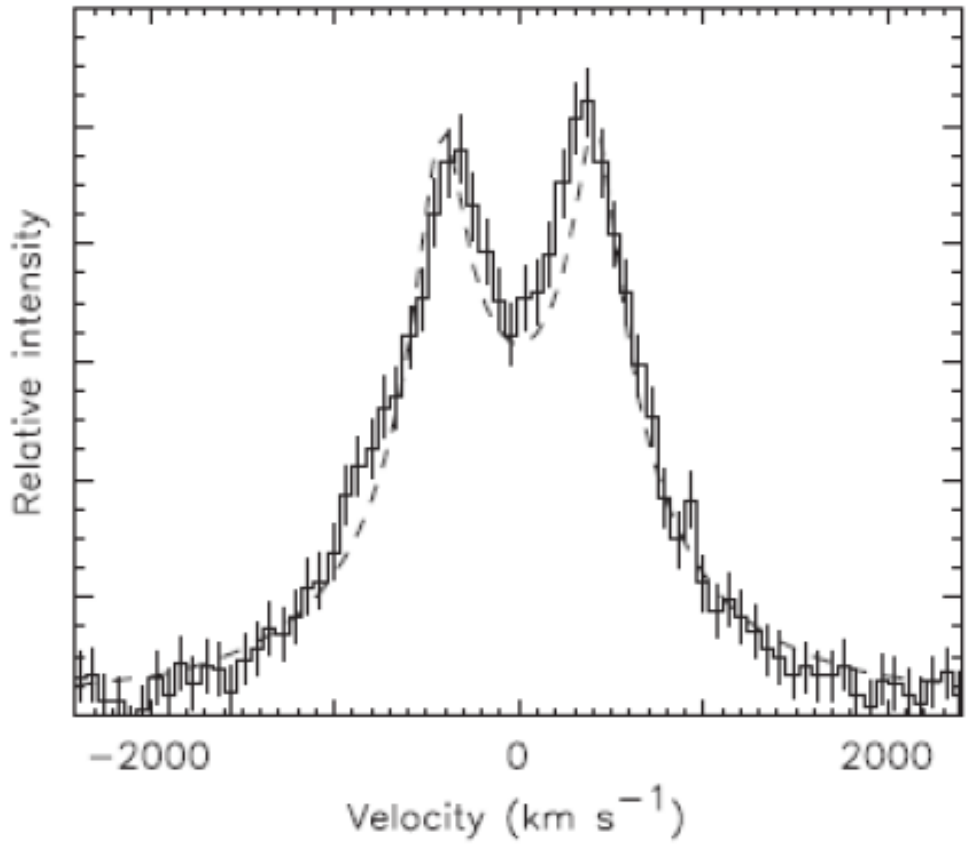


An enigmatic sub-luminous disk state



Accretion-power features

Accretion Disk



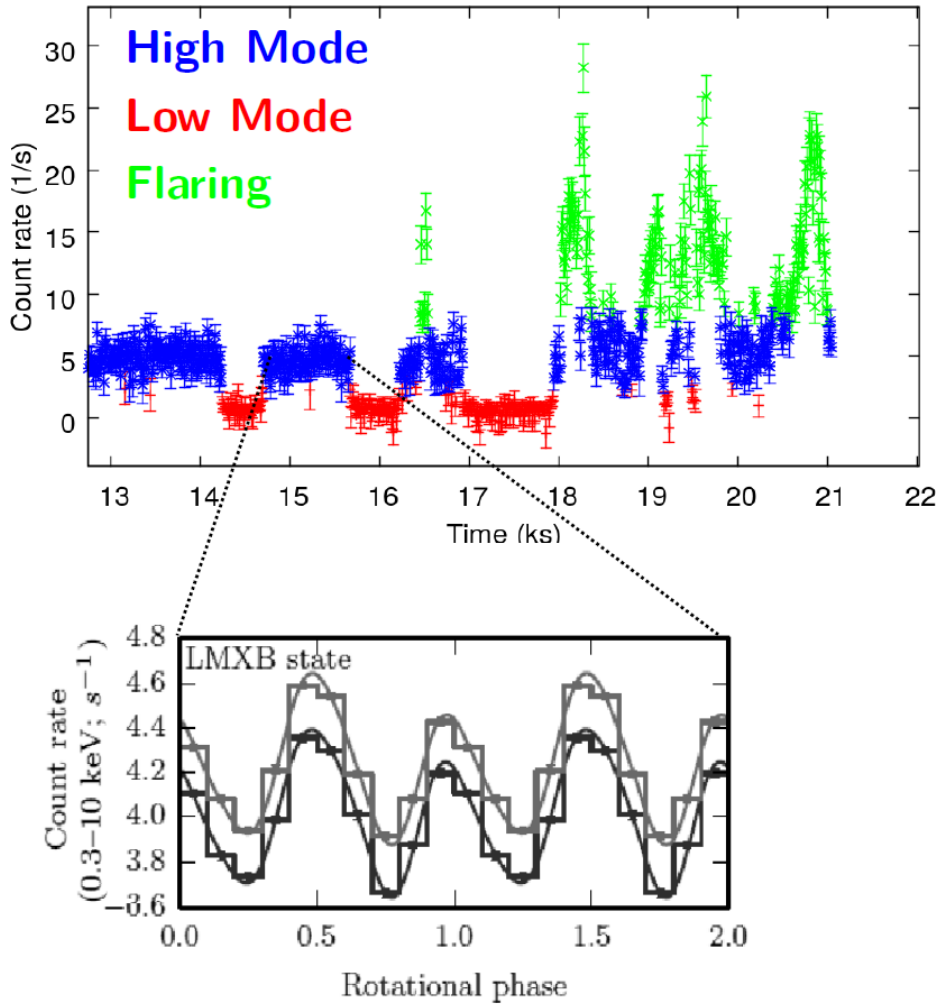
Thorstensen+ 2000

Accretion-power features

Accretion Disk

X-ray variable emission

X-ray pulsations



Archibald+, Bogdanov+ 2015, Papitto+ 2015

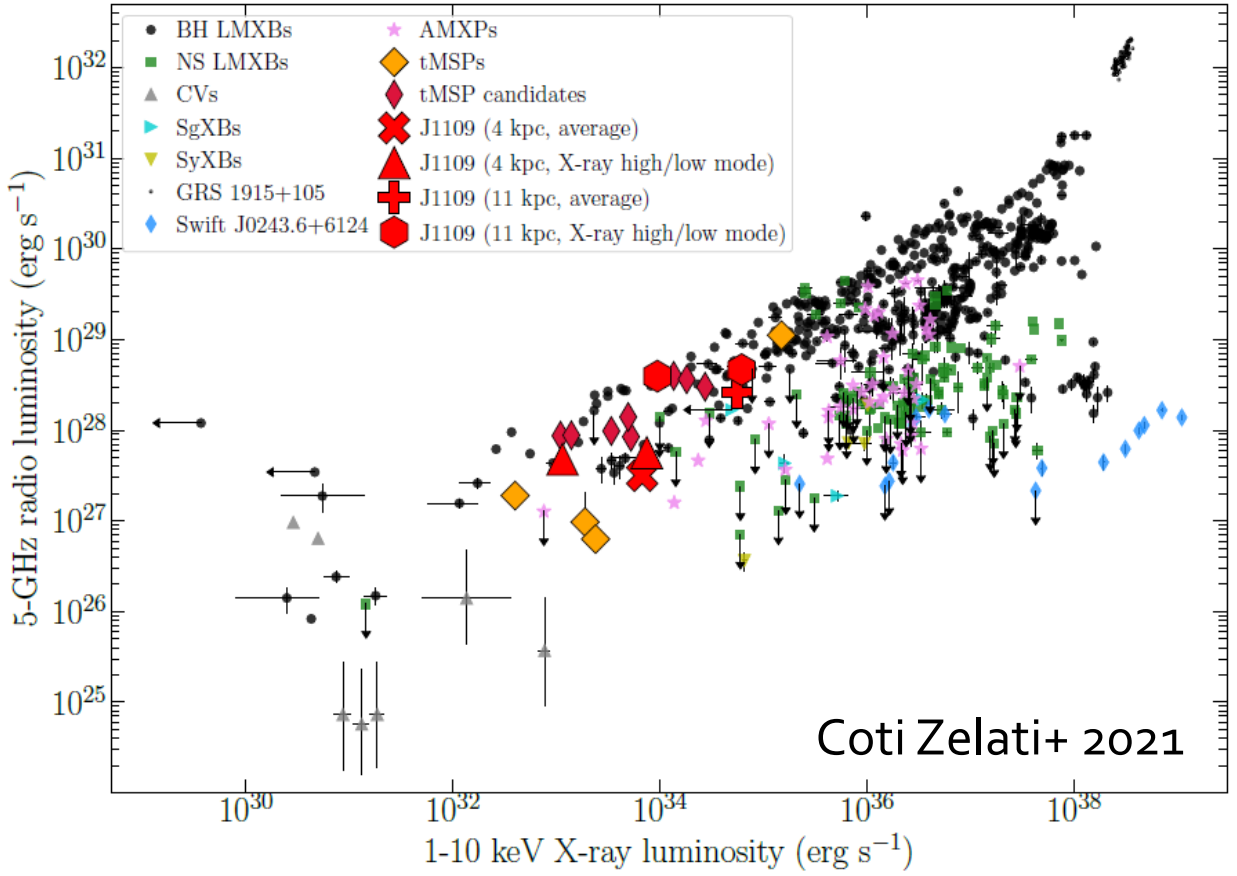
Accretion-power features

Accretion Disk

X-ray variable emission

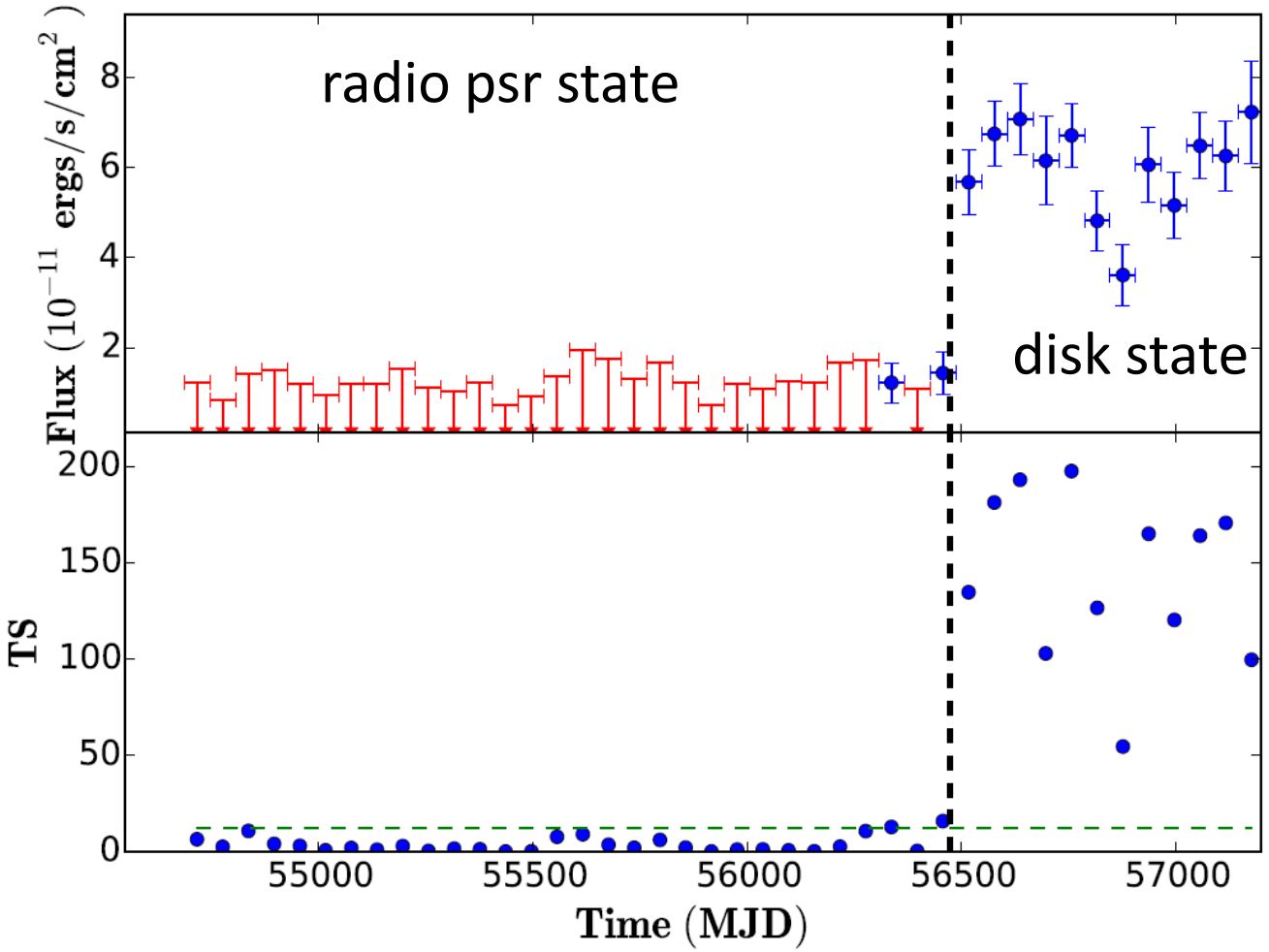
X-ray pulsations

Bright radio jets



Rotation-power features

Fermi LAT light curve

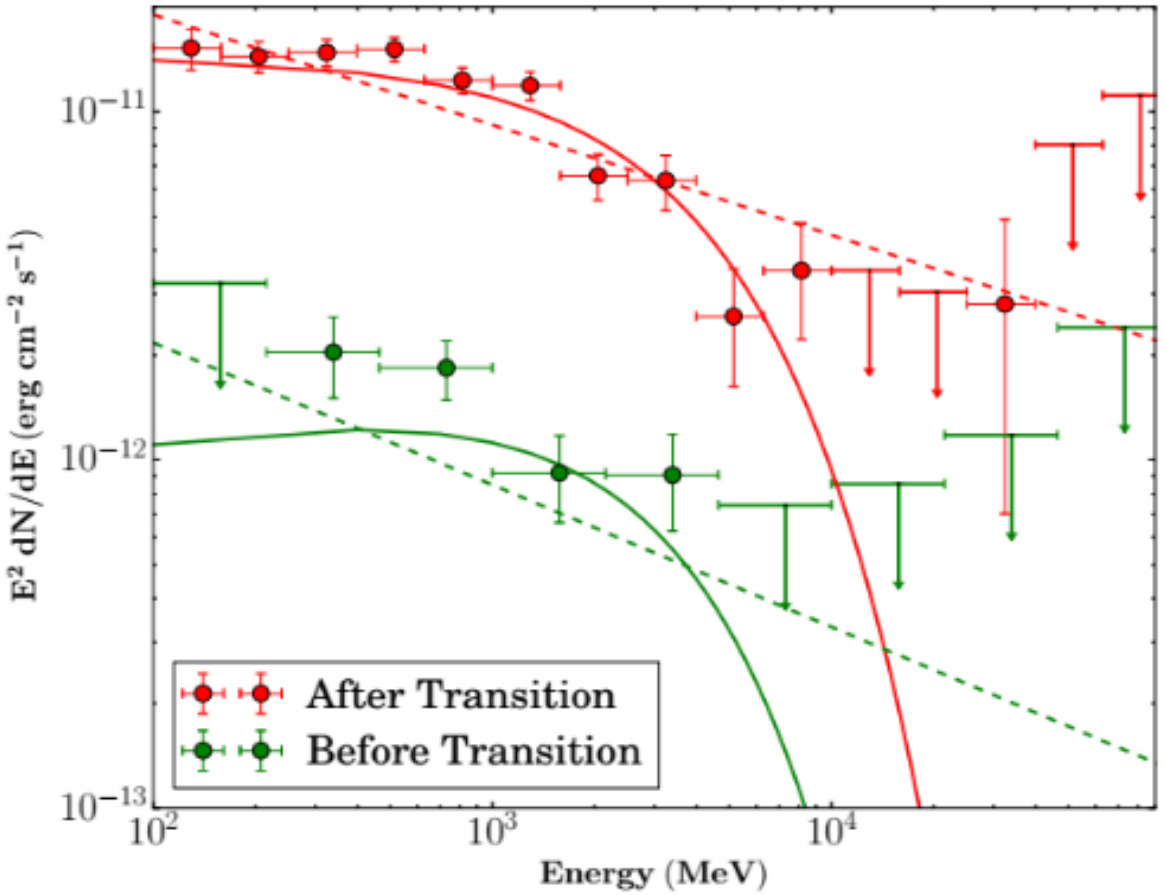


Low-mass γ-ray binaries

Stappers+ 2013, Torres+ 2017
see the review by Torres & Li 2022

Rotation-power features

Fermi LAT spectra

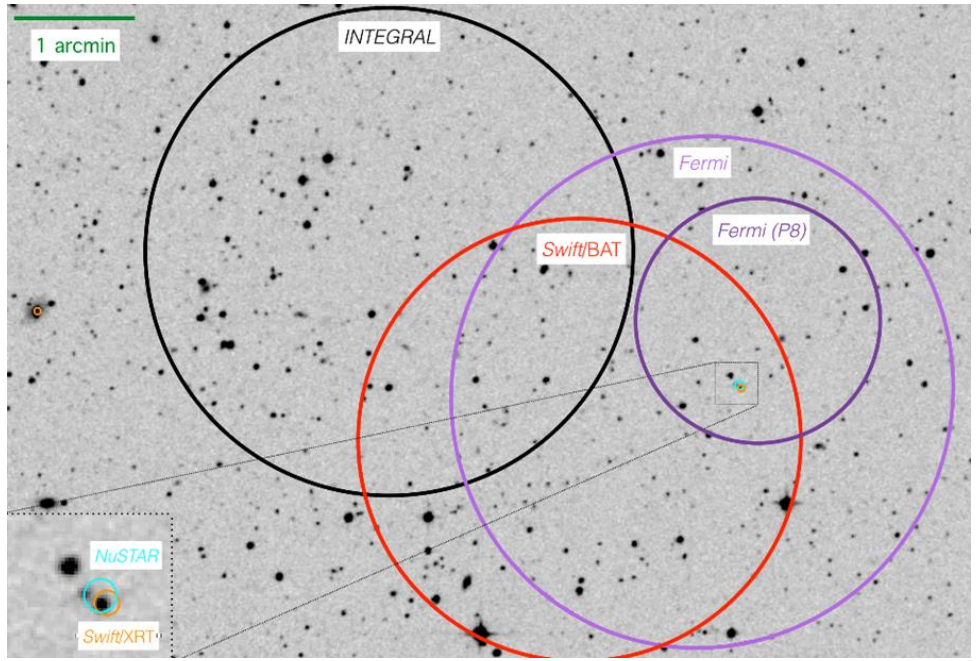


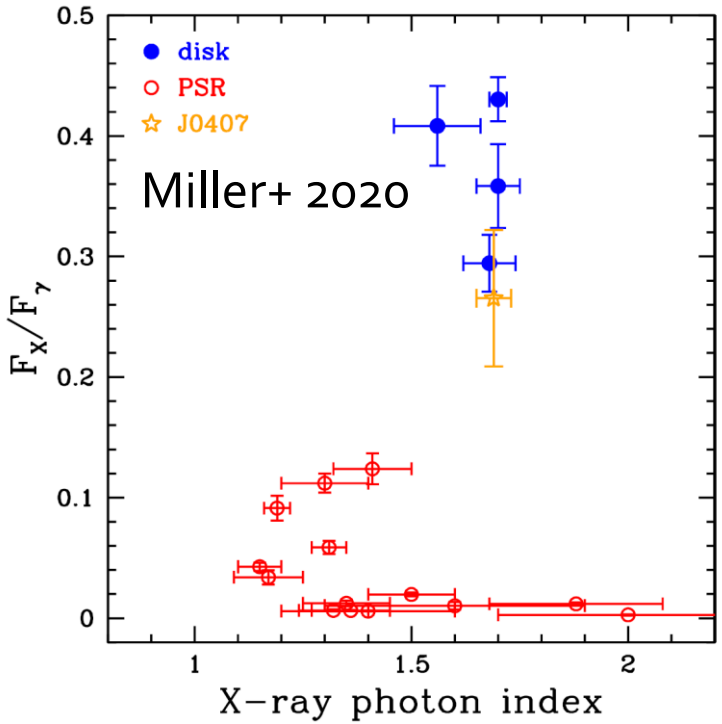
Low-mass γ-ray binaries

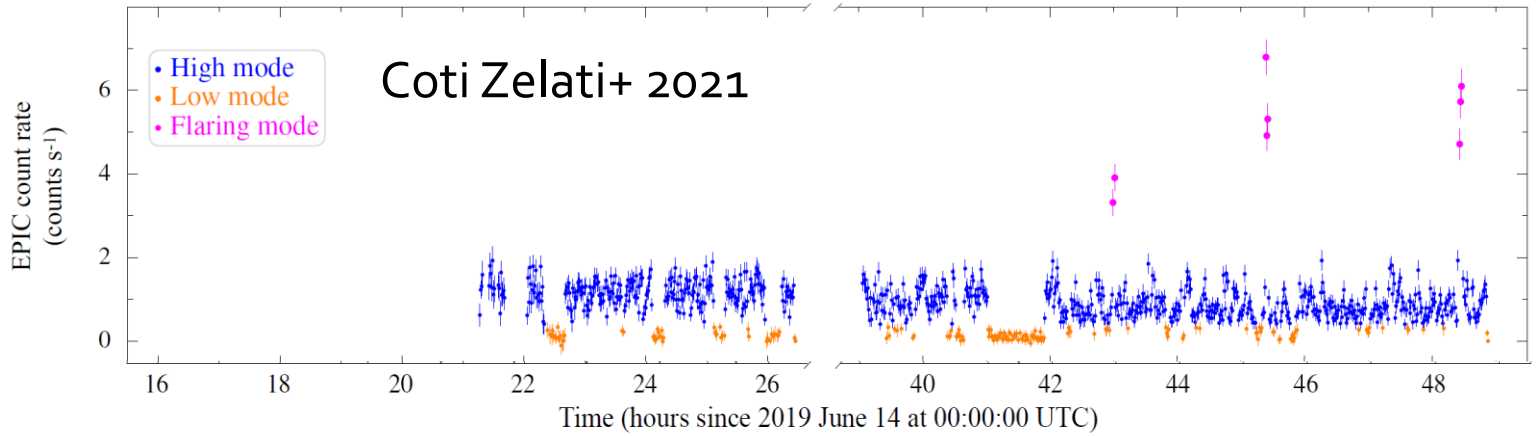
Stappers+ 2013, Torres+ 2017
see the review by Torres & Li 2022

How to identify a transitional MSP?

L(X-ray)/L(γ–ray) ≈ 0.25-0.5
X-ray high/low modes (also flaring states)
Flat-spectrum variable radio counterpart
Optical orbital modulation & lines





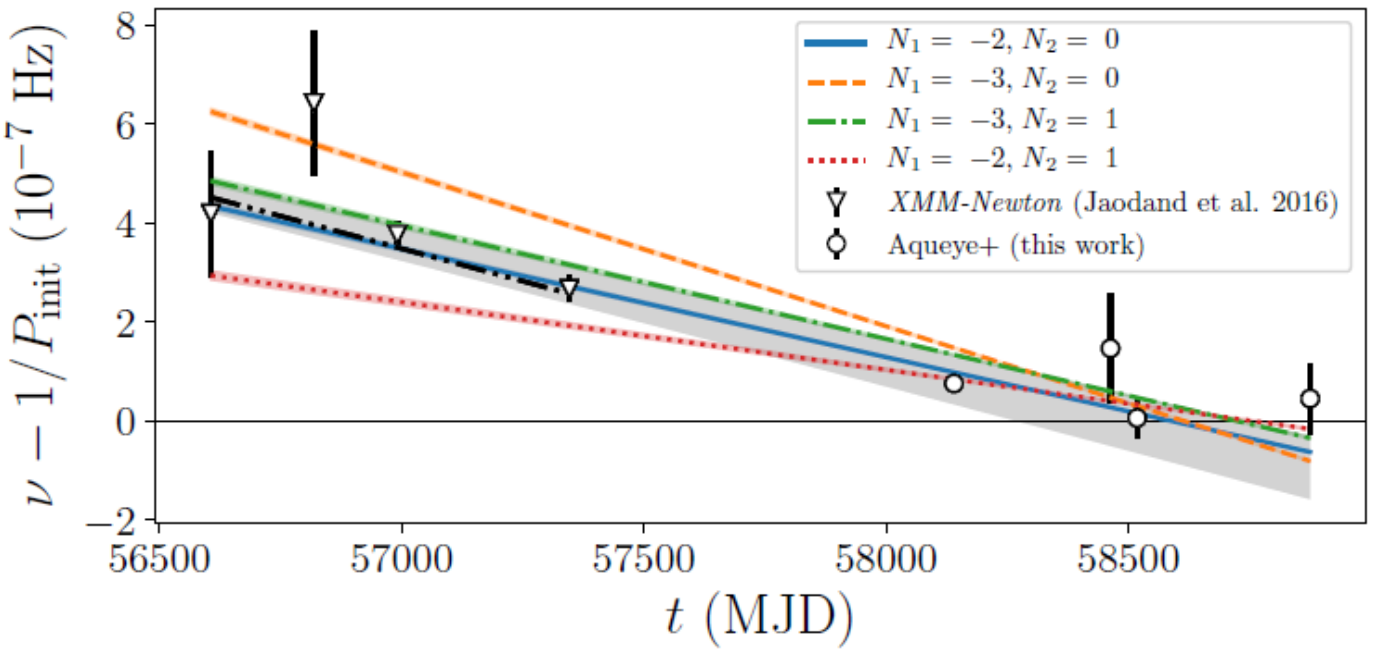


TMSPs	ν (Hz)	P_{orb} (hr)	$\tilde{M}_d$ ($M_\odot$)	Donor Type	Obs. states
PSR J1023+0038	592	4.75	0.16	MS	RP,SLD
XSS J12270–4859	592	6.91	0.25	MS	RP,SLD
IGR J18245–2452	254	11.0	0.21	MS	RP,SLD,OUT

Candidate TMSPs	ν (Hz)	P_{orb} (hr)	Modes	Gamma-rays	Obs. states
RXS J154439.4–112820	-	5.8	yes	yes	SLD
CXOU J110926.4–650224	-		yes	yes	SLD
4FGL J0407.7–5702	-	-	?	yes	SLD
3FGL J0427.9–6704	-	8.8	flares	yes	SLD
4FGL J0540.0-7552	-	-	flares	yes	RP(?),SLD

See Papitto & de Martino 2020 & references therein

Rotation-power features



Low-mass γ-ray binaries

Radio pulsar spin-down

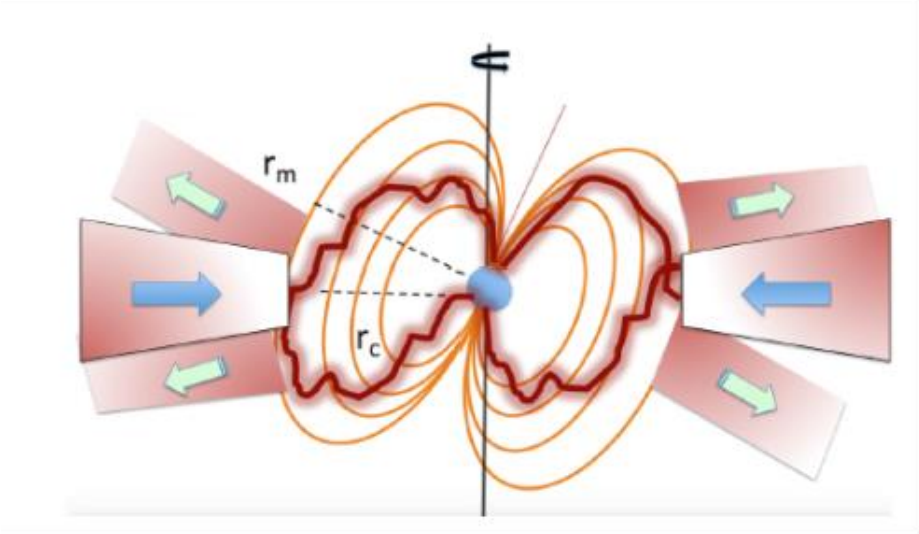
Jaodand+ 2016, Burtovoi+ 2021

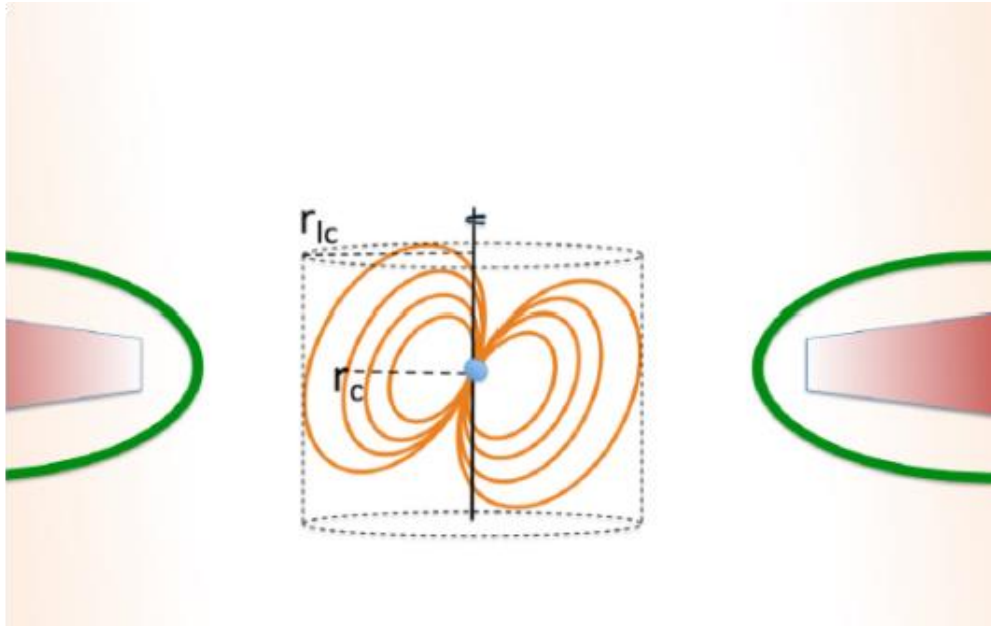
What powers the sub-luminous disk state emission?

- Enshrouded rotation-pwd pulsar [Coti Zelati+ 2014, Takata+ 2015]

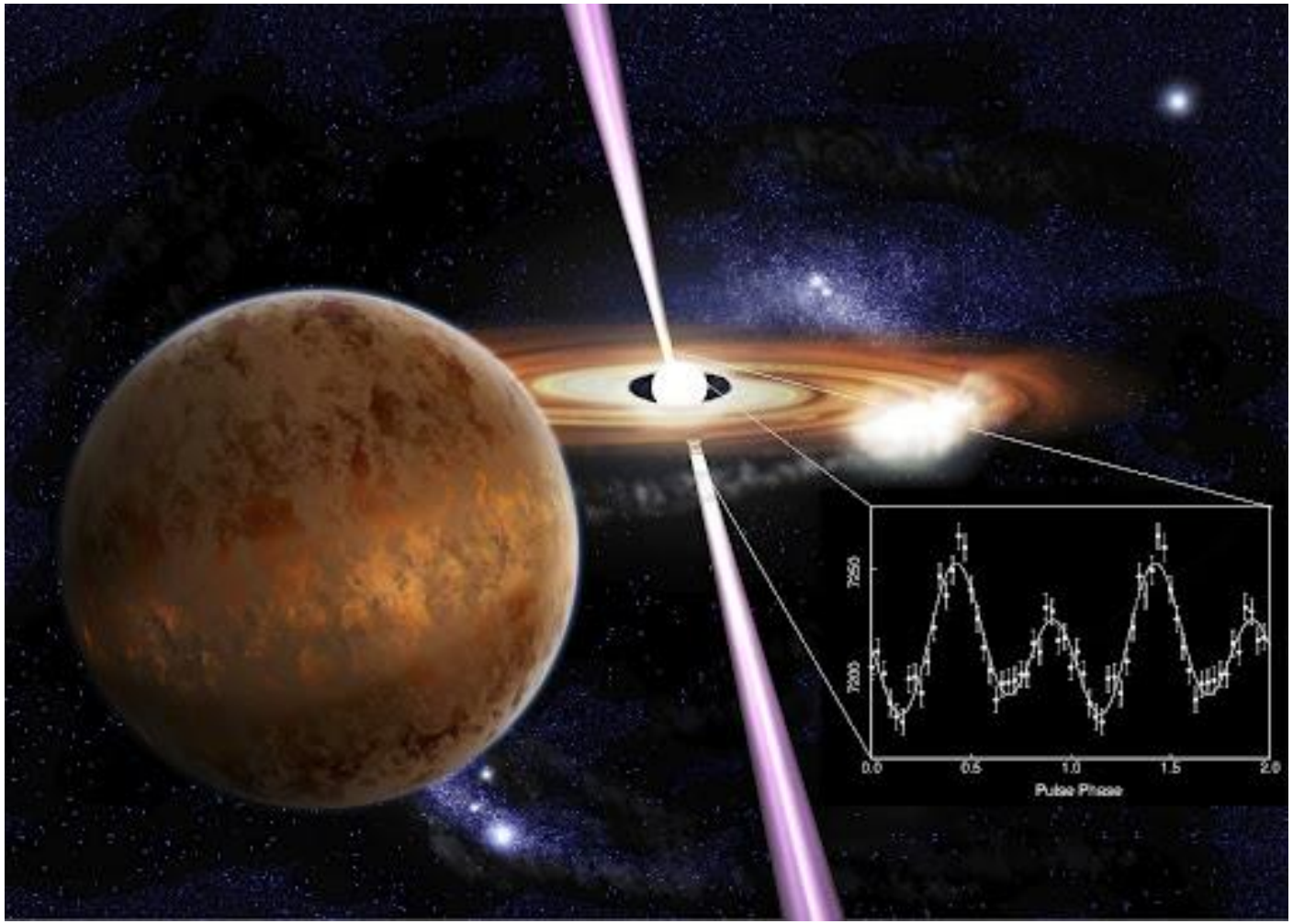
- Propellering pulsar [Papitto+ 2014, Papitto & Torres 2015]

- Mode switching → changes of state [Linares+ 2014, Campana+2016]



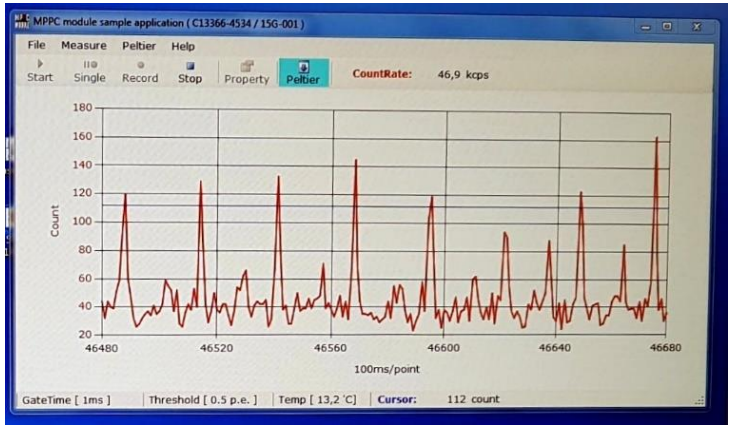


The enigma of optical/UV millisecond pulsars



High time resolution optical astronomy

SiFoP²



nature astronomy

LETTERS

DOI: 10.1038/s41550-017-0266-2

Optical pulsations from a transitional millisecond pulsar

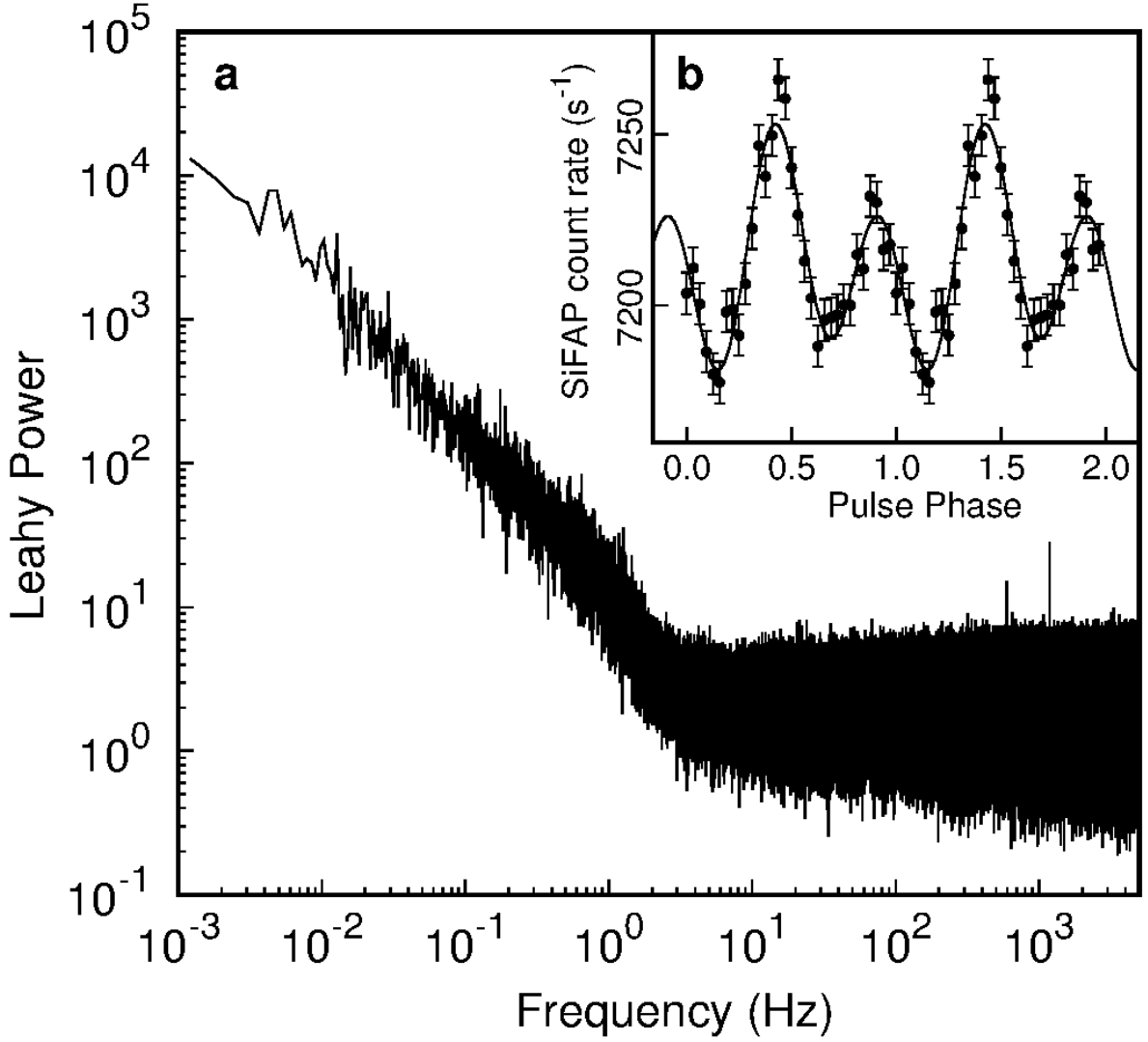
F. Ambrosino[1,2], A. Papitto[3*], L. Stella[3], F. Meddi[1], P. Cretaro[4], L. Burderi[5], T. Di Salvo[6] A. Ghedina[7], L. Di Fabrizio[7] and L. Riverol[7]

PSR J1023+0038

Count rate ~ 10000 c/s (V ≈ 16.5 mag)

Pulse amplitude ~ 1%

L_{pulsed} ~ few x 10^{31} erg/s ≈ 0.03% $L_{SpinDown}$



Stunningly bright optical pulsations

PSR J1023 L = (1-2) x 10^{31} erg/s

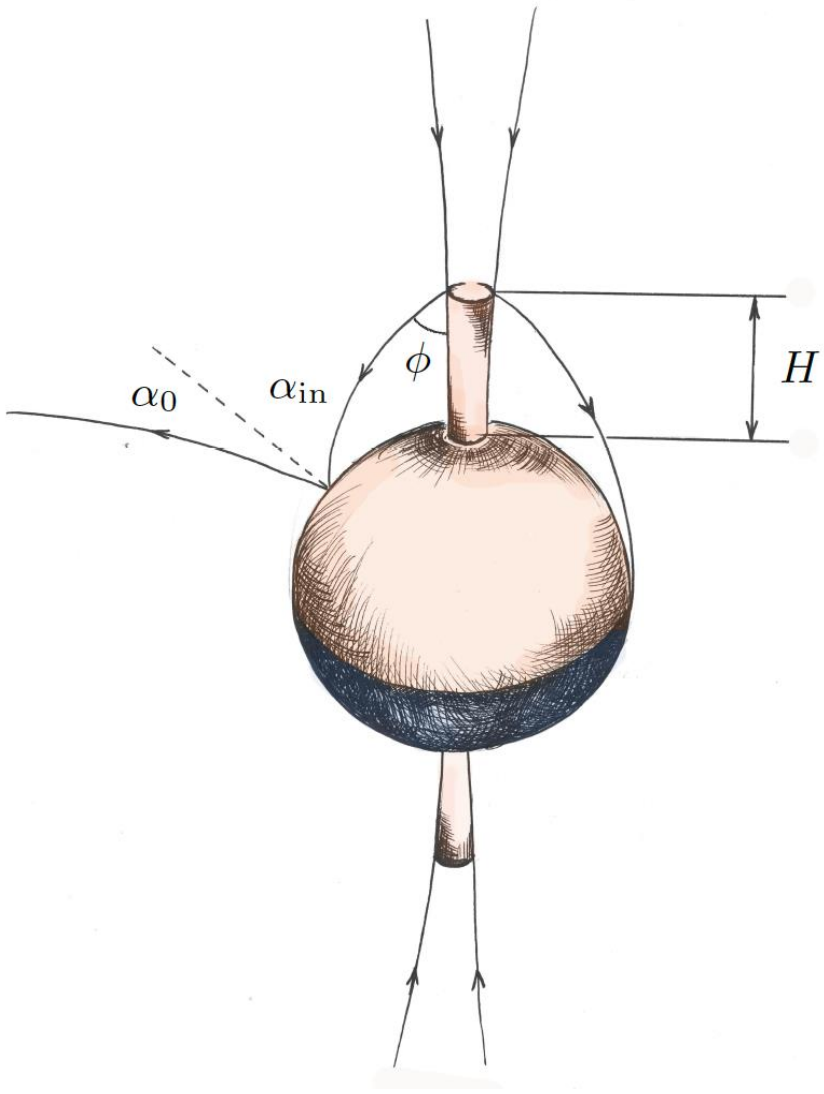
Accretion power?

$E_{cyclotron}$ = 1 (B/10^8 G) eV

$$L_{\rm cyc} = A_{\rm spot} \int_{\nu_l}^{\nu_h} (2\pi k T_e \nu^2/3c^2) d\nu$$

$$= 2.9 \times 10^{29} \left(\frac{A_{\rm spot}}{10^{12}\ {\rm cm}^2}\right)\left(\frac{kT_e}{100\ {\rm keV}}\right) {\rm erg\ s^{-1}}.$$

50 x beaming required



Stunningly bright optical pulsations

PSR J1023 $L = (1\text{-}2) \times 10^{31}$ erg/s

$= 2 \times 10^{-4} L_{sd}$

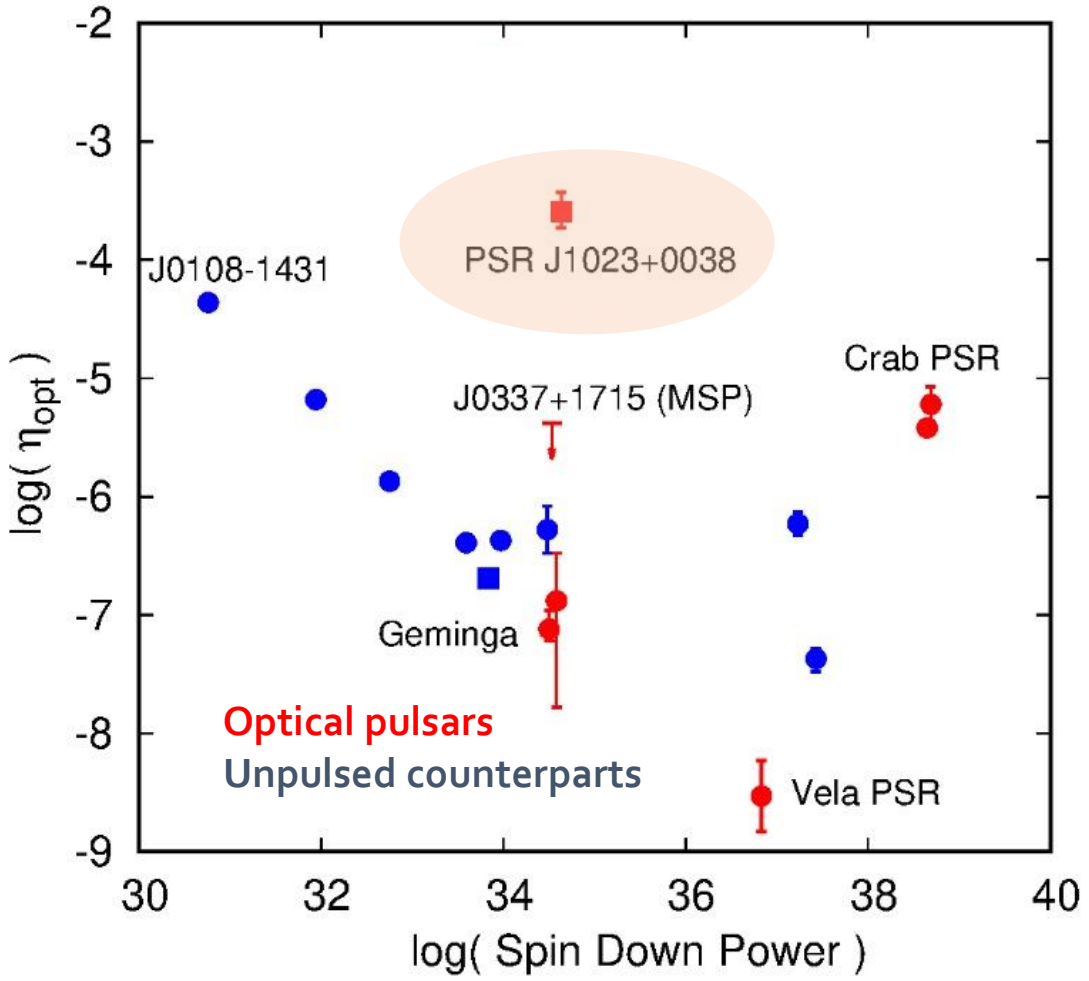
Rotation power?

Known isolated pulsars

$L = 10^{-5}\text{-}10^{-8} L_{sd}$

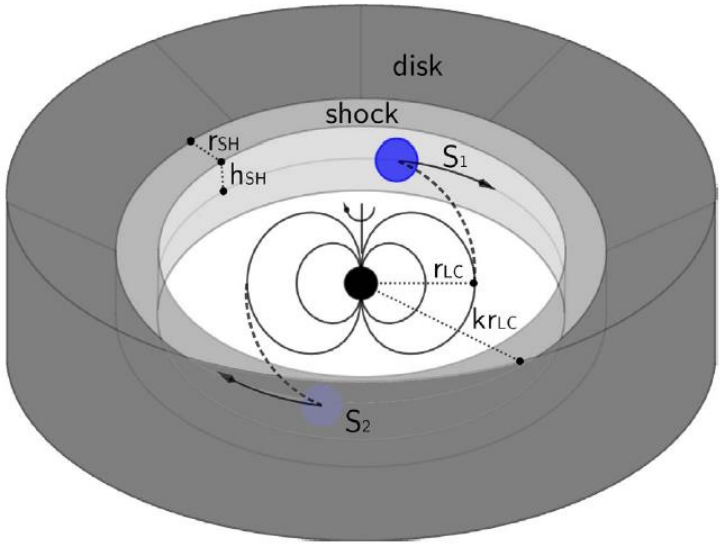
Spin powered MSPs

$L < 10^{-5} L_{sd}$

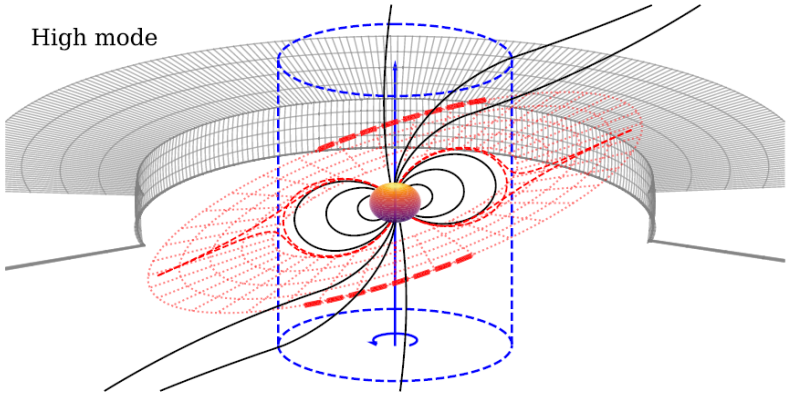


Updated from Ambrosino, Papitto+ 2017

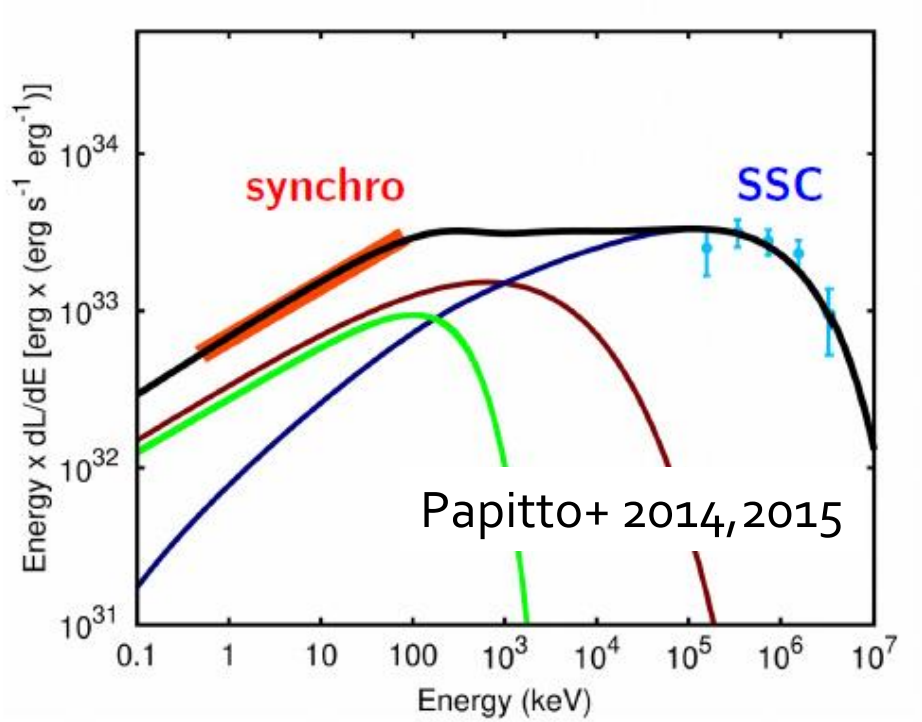
Accretion, rotation power, or both?



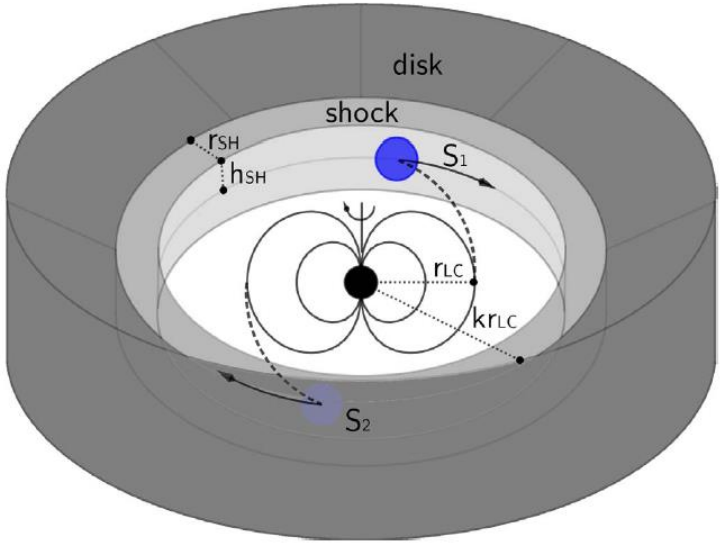
Pulsar wind terminated by the accretion disk at r≈100 km [Papitto+ 2019, Veledina+ 2019]



Synchrotron → Optical/X-rays
Inverse Compton → Gamma-rays

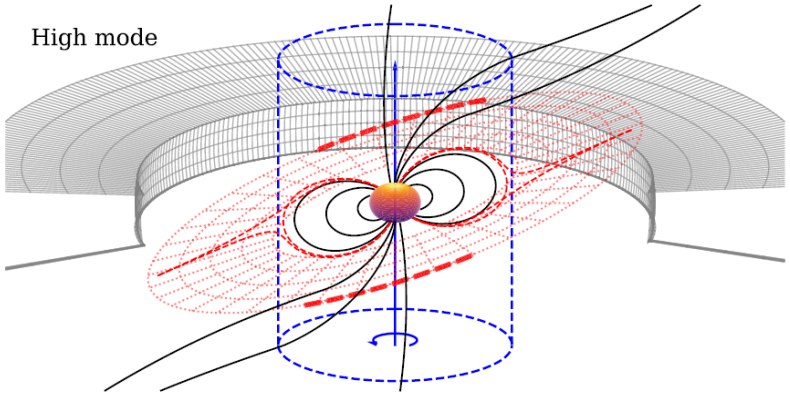


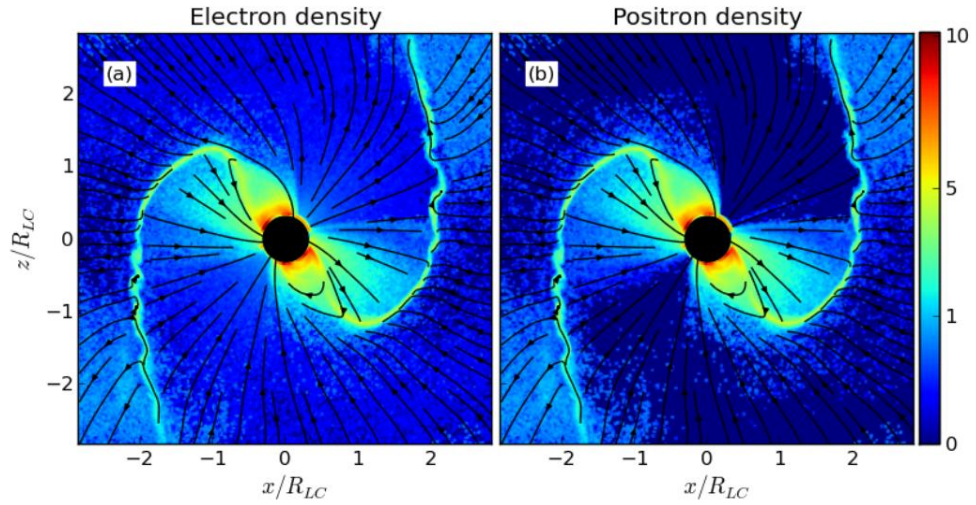
Accretion, rotation power, or both?



Pulsar wind terminated by the accretion disk [Papitto+ 2019, Veledina+ 2019]

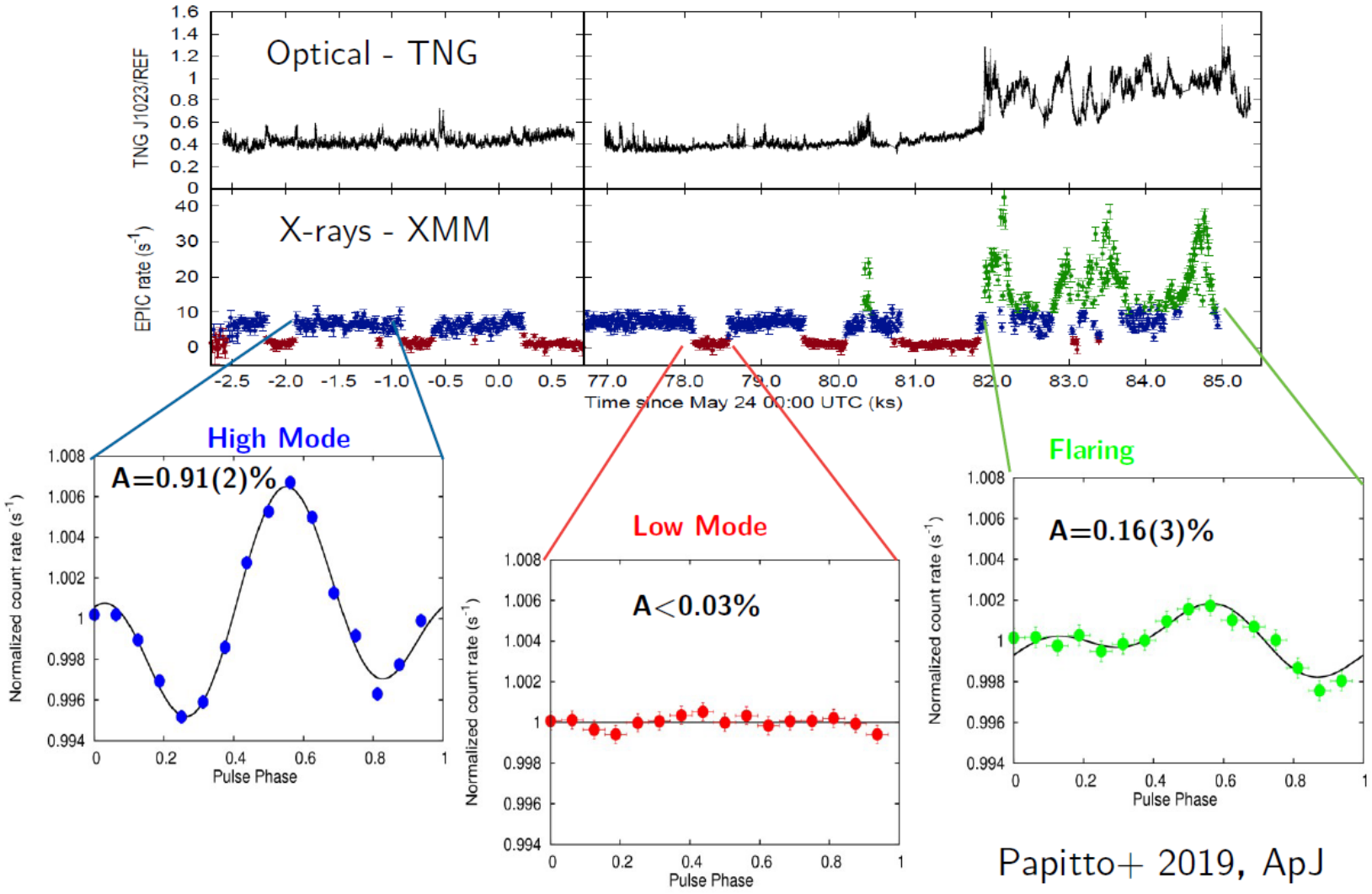
Optical and X-ray pulses from the interaction between the **pulsar striped wind** and the termination shock





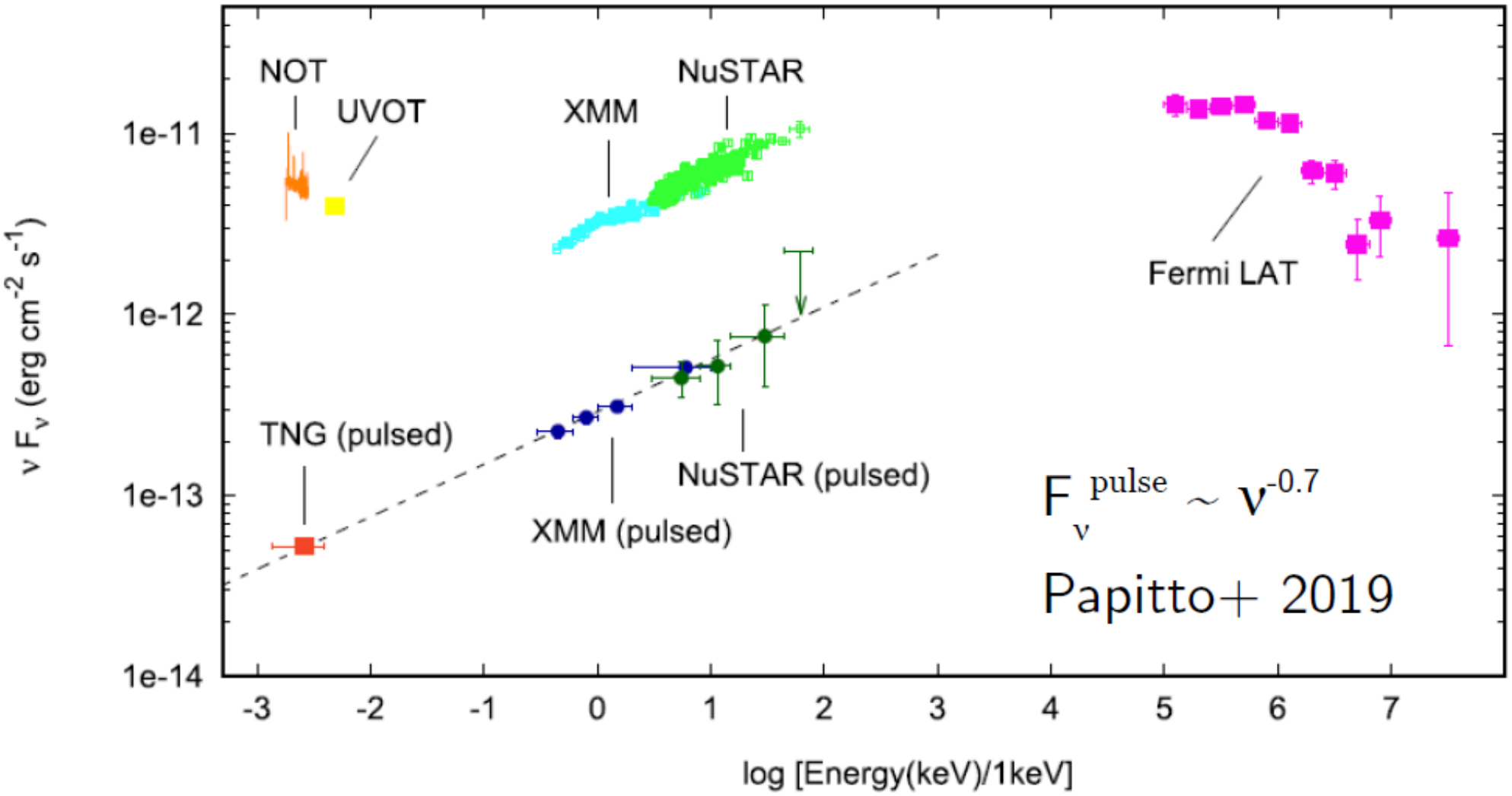
Cerutti & Beloborodov 2017

Pulsating in unison at optical and X-ray energies

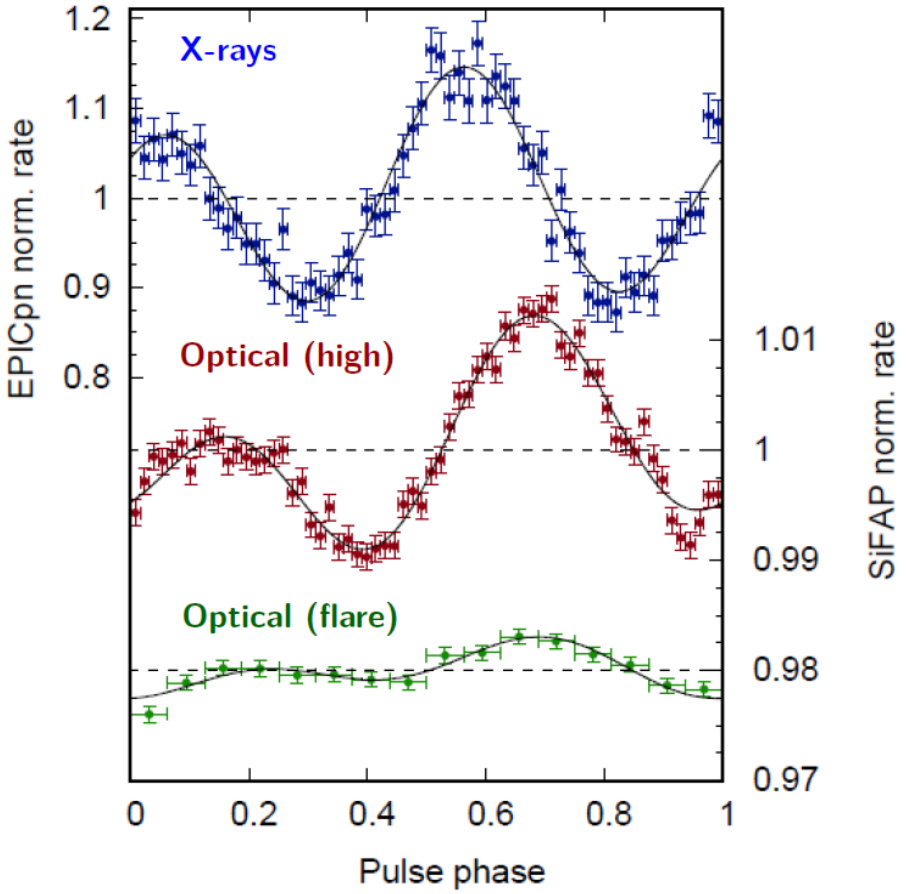


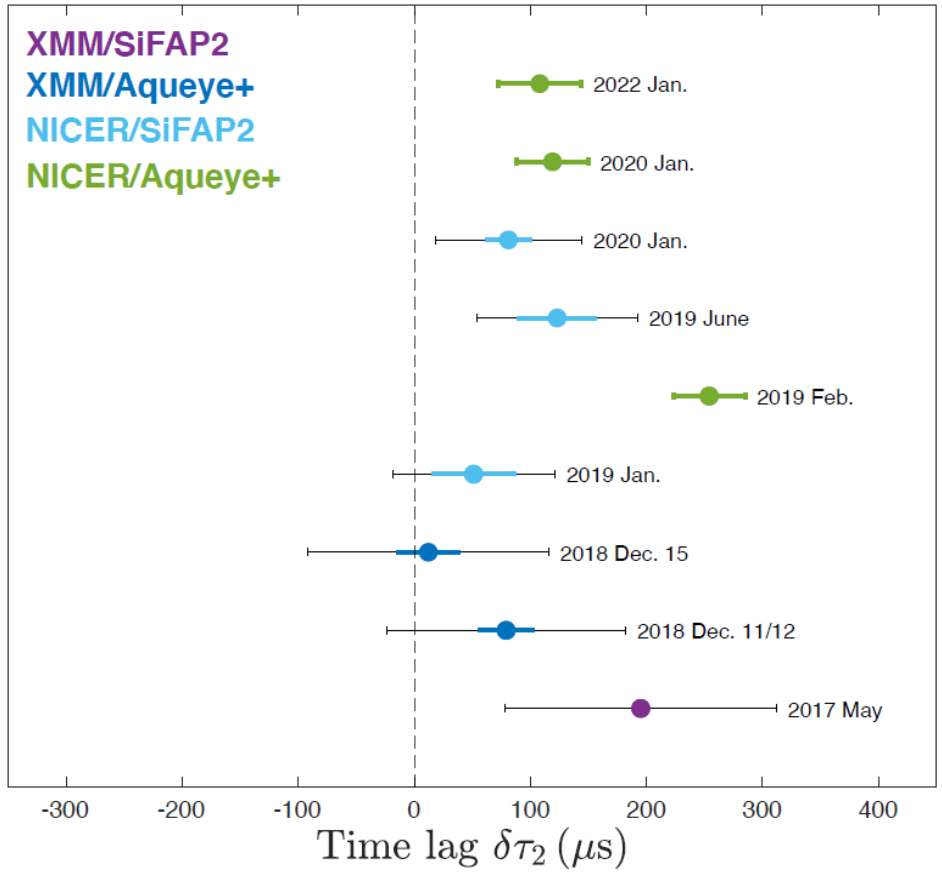
Papitto+ 2019, ApJ

Optical and X-ray pulses compatible with a non-thermal process



Optical pulse lags X-ray pulse by ~ 100-200 μs



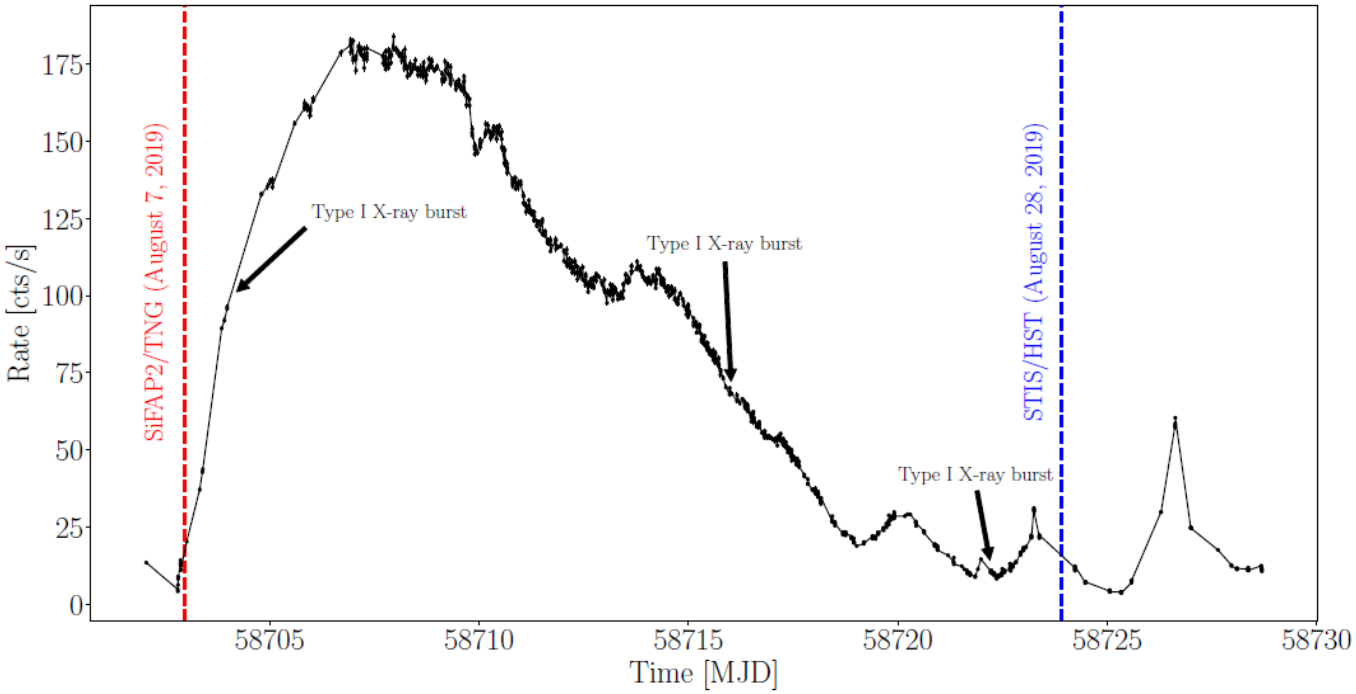


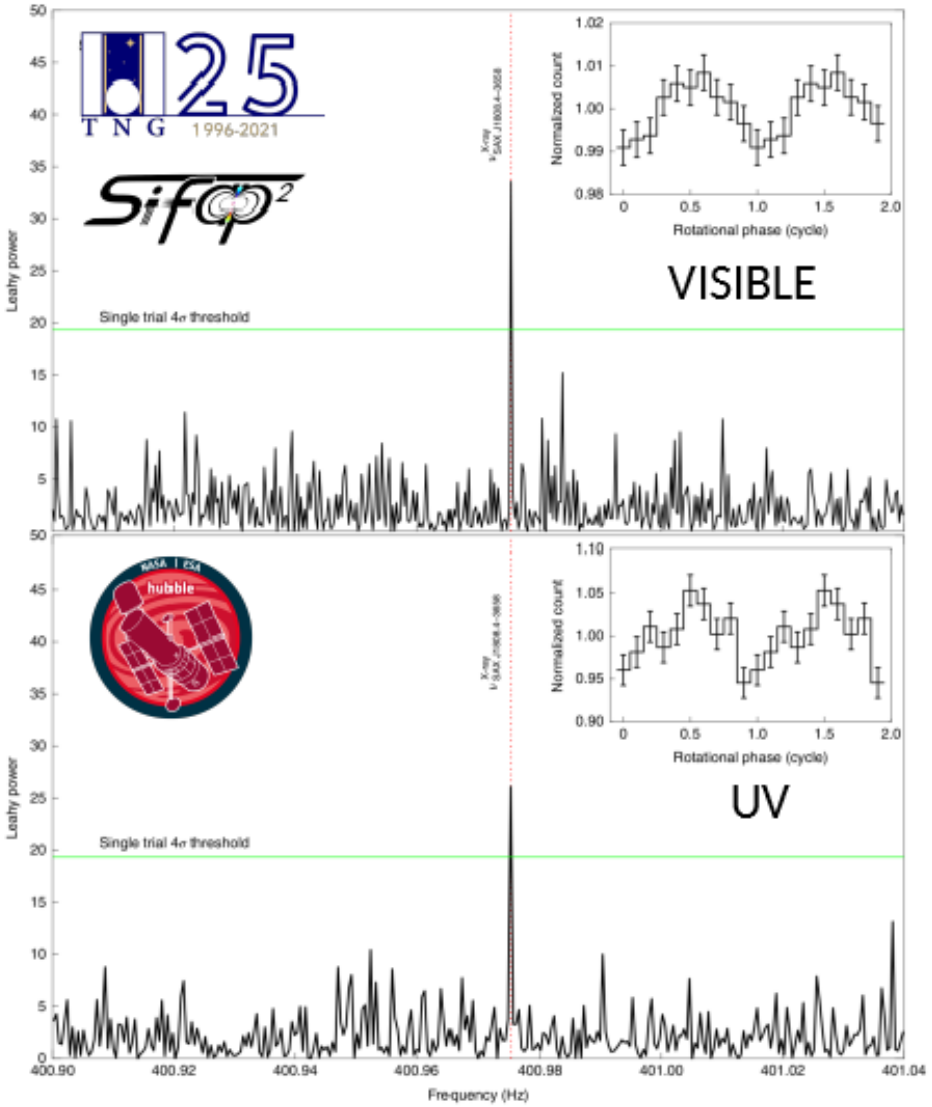
Illiano, Papitto+ 2023a

Optical and ultraviolet pulsed emission from an accreting millisecond pulsar

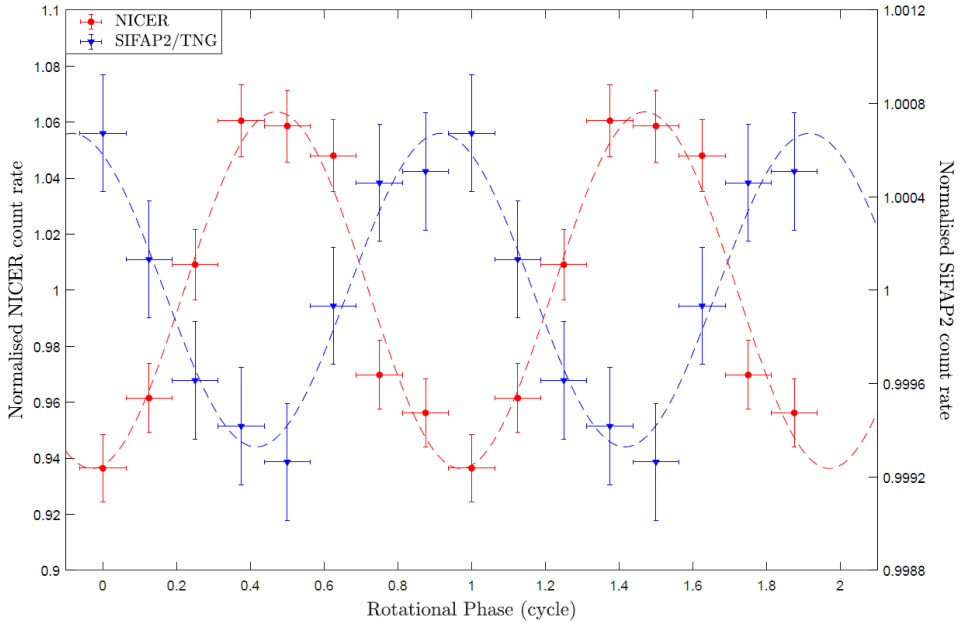
F. Ambrosino[1,2,3,22] ✉, A. Miraval Zanon[4,5,22] ✉, A. Papitto[1], F. Coti Zelati[5,6,7], S. Campana[5], P. D'Avanzo[5], L. Stella[1], T. Di Salvo[8], L. Burderi[9], P. Casella[1], A. Sanna[9], D. de Martino[10],

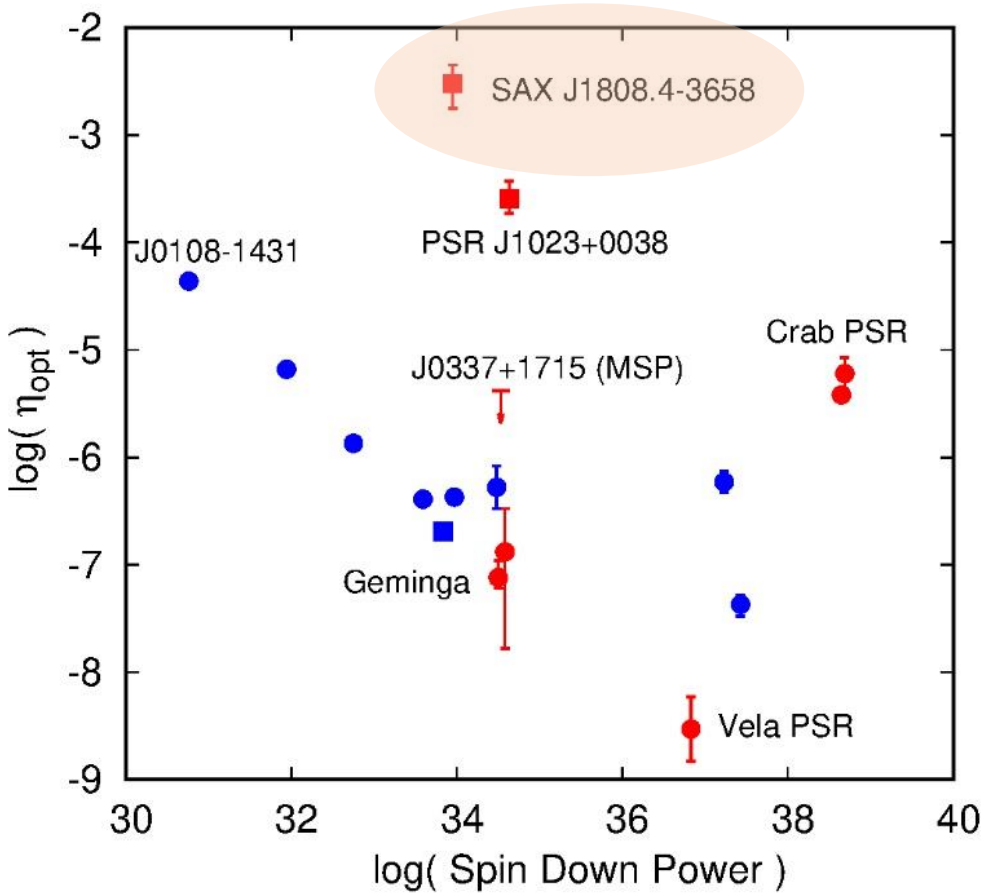
See also Illiano, Papitto+ 2023a; Miraval Zanon+ in prep.





Optical/UV pulsations from an accreting ms pulsar





Do **accretion** and **rotation** power coexist?

Does **accretion** produce optical pulsations much brighter than expected?

Summary

The sub-luminous state of transitional millisecond pulsars in the disk state probe the balancing of accretion and rotation power.

Optical/UV pulses suggest coexistence of rotation and accretion power

Quest for a common model to explain their properties in rotation/accretion/transitional millisecond pulsars