Spying on the quickly variable optical sky

Millisecond Pulsars and more

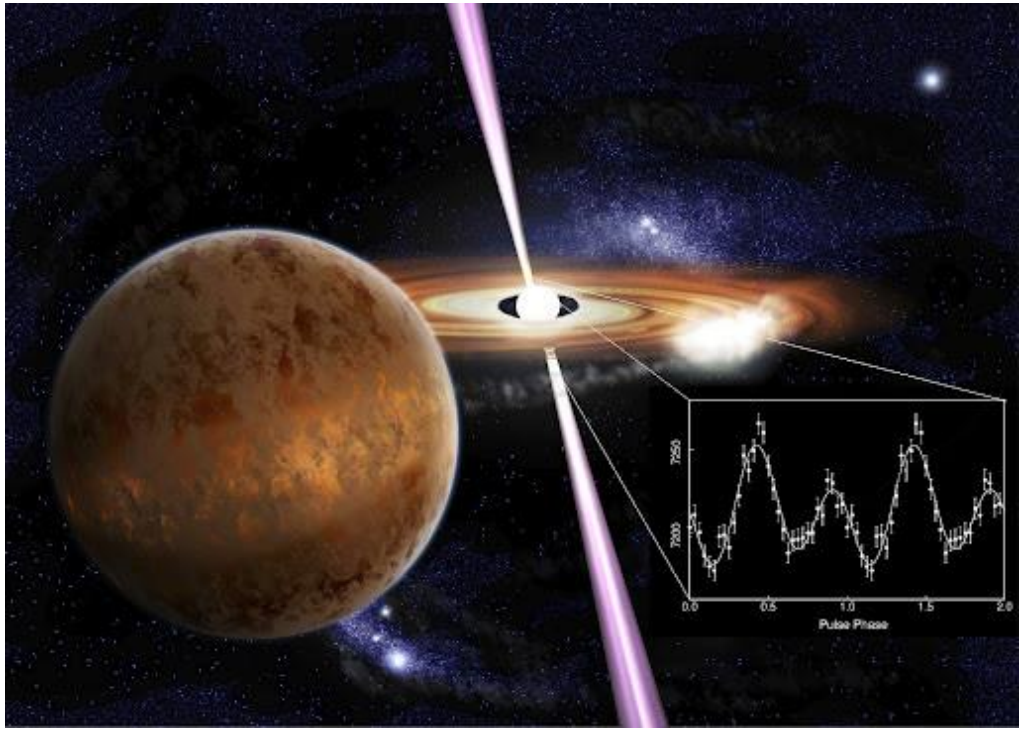
Alessandro Papitto

CNOC XII – Cefalù 27.9.2022

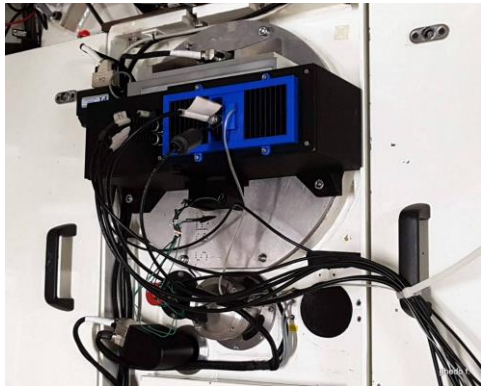
High-time resolution optical astronomy

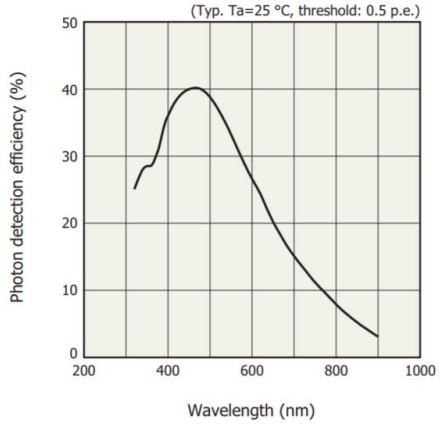
What powers optical pulsations of millisecond pulsars?
Accretion vs Rotation power

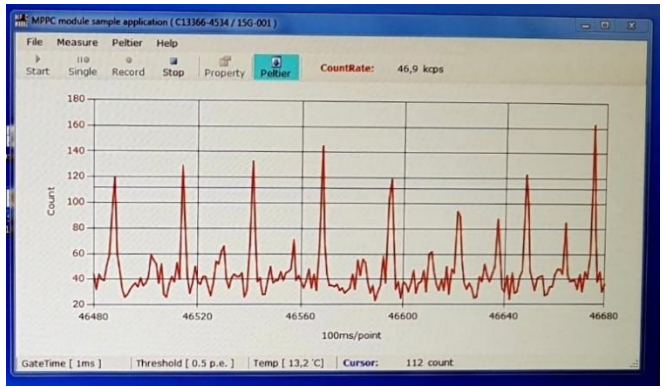
What are the prospects to
overcome the limits of other bands?



The Silicon Fast Astronomical Photometer







Meddi+ 2012, Ambrosino+ 2013, 2015, Ghedina, Leone, Cecconi+ 2018, Ghedina+2022

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], G. L. Israel[3], A. Ghedina[7], L. Di Fabrizio[7] and L. Riverol[7]

PSR J1023+0038

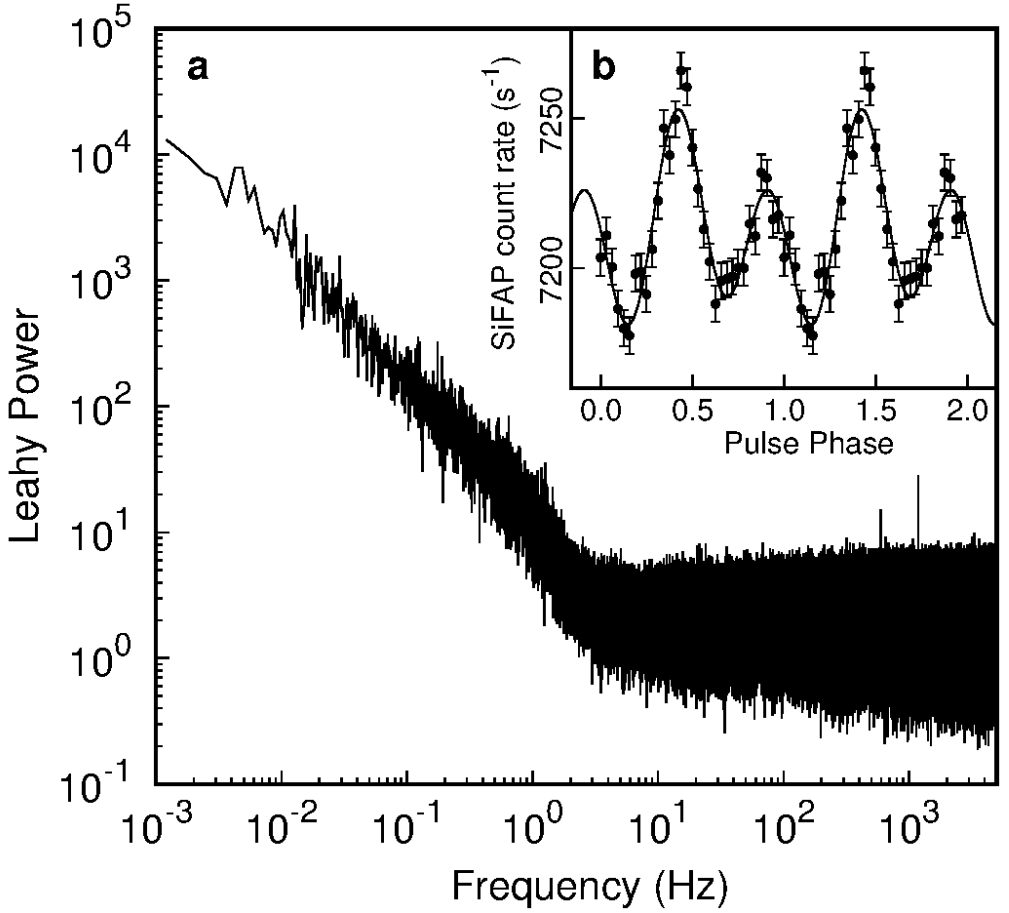
Count rate ~ 10000 c/s (V ≈ 16.5 mag)

Pulse amplitude ~ 1%

Variable between observations

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

-> Nicolò Pinciroli Vago's talk on Wednesday



nature astronomy

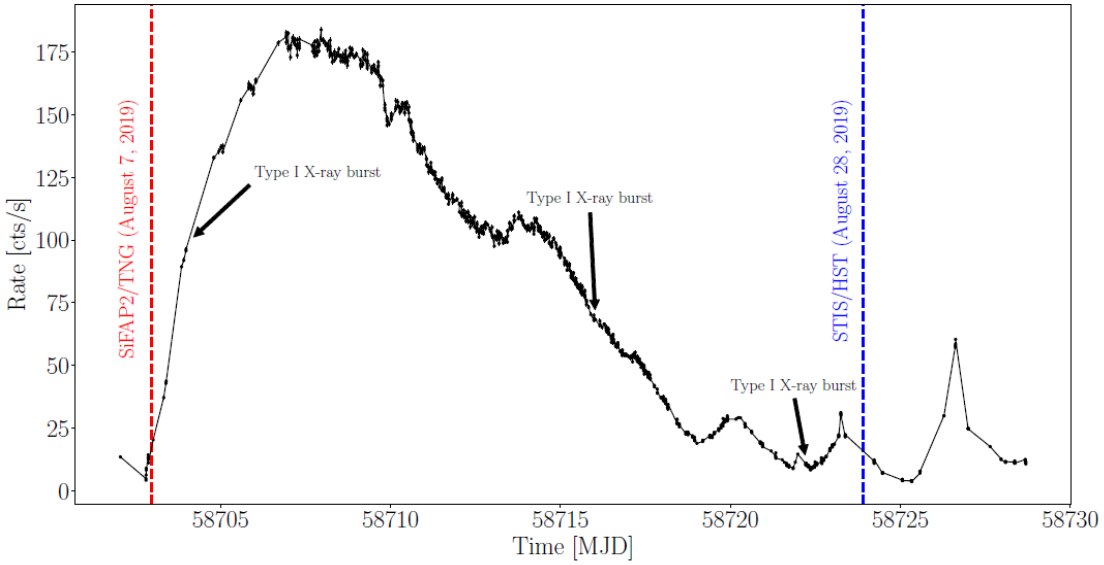
LETTERS

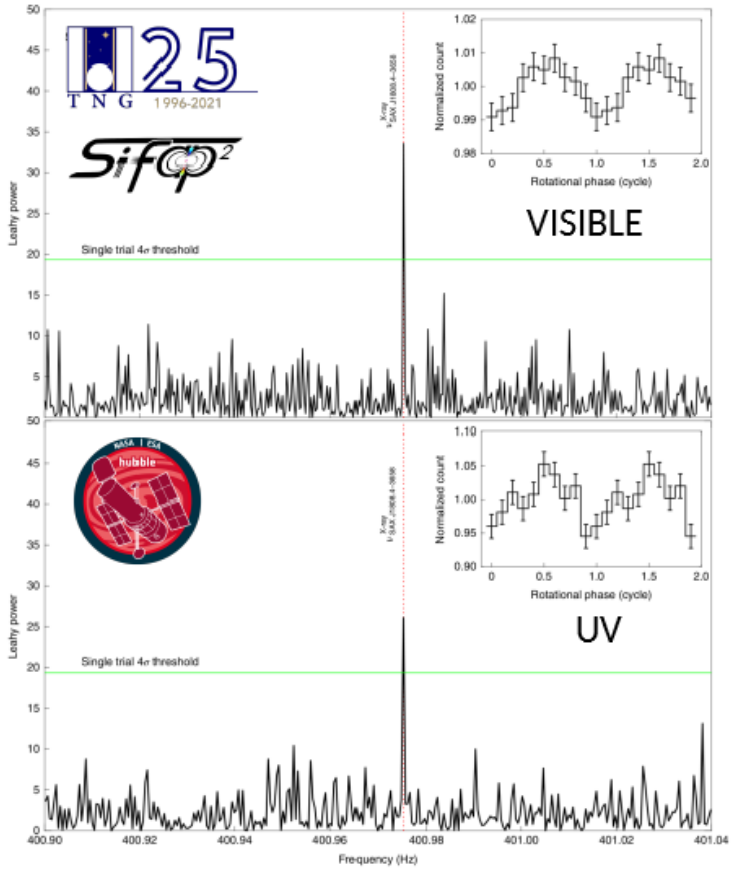
https://doi.org/10.1038/s41550-021-01308-0

Check for updates

Optical and ultraviolet pulsed emission from an accreting millisecond pulsar

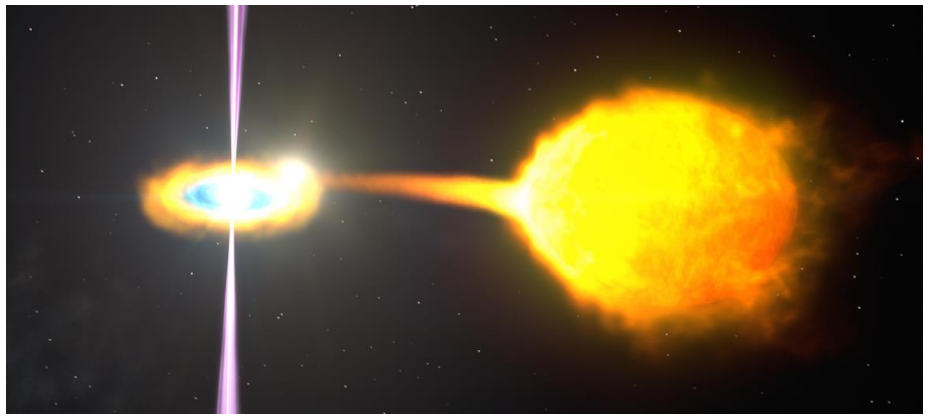
F. Ambrosino[1,2,3,22] ✉, A. Miraval Zanon[4,5,22] ✉, A. Papitto[1], F. Coti Zelati[5,6,7], S. Campana[5], P. D'Avanzo[5], L. Stella[1], T. Di Salvo[8], L. Burderi[9], P. Casella[1], A. Sanna[9], D. de Martino[10],

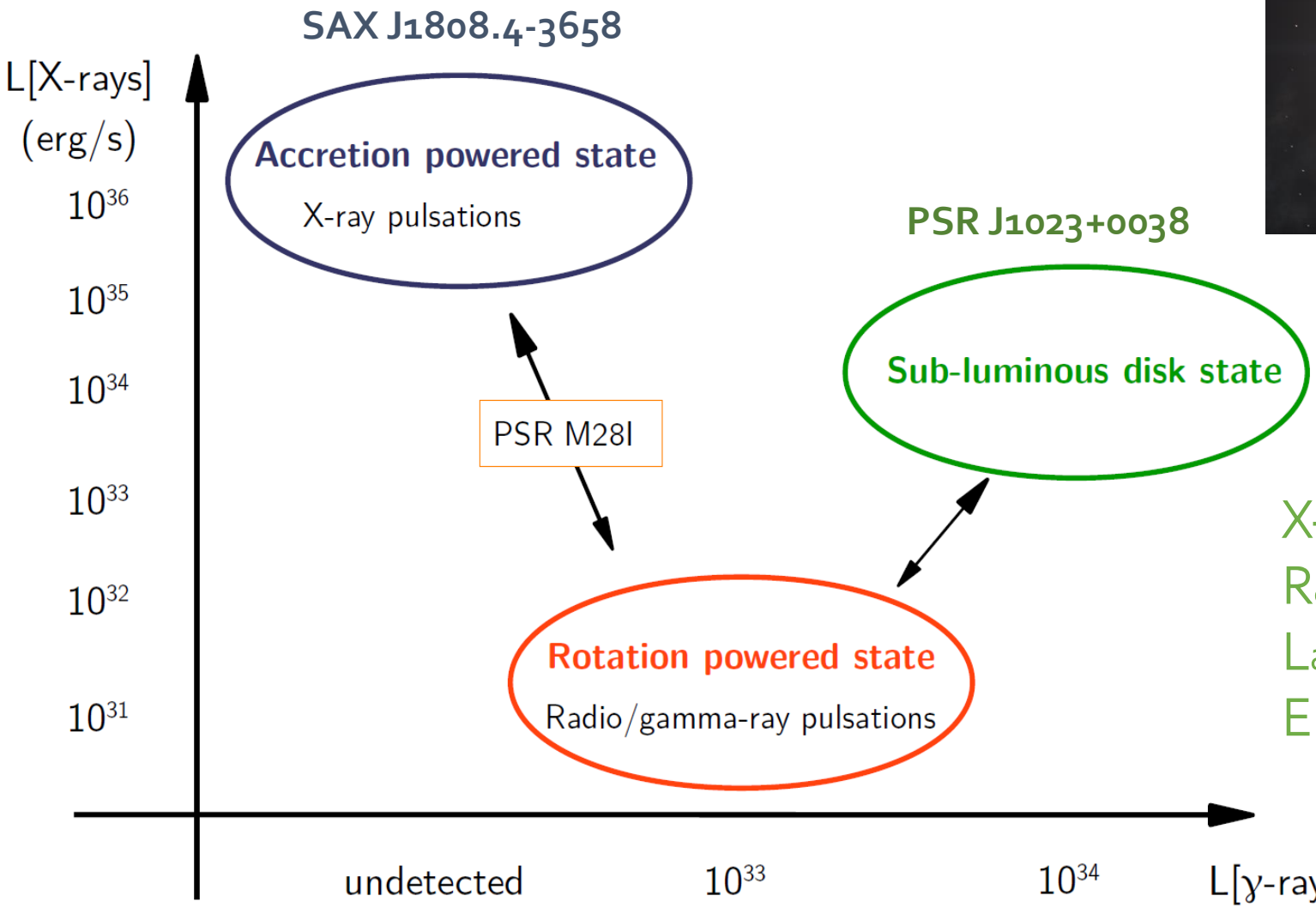




Optical Pulsations observed also in the current outburst

Arianna Miraval Zanon's talk





X-ray/Optical/UV pulses
Radio-psr spin down
$L_{accretion} \approx L_{spindown}$
Enhanced γ-rays

Stunningly bright optical pulsations

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

SAX J1808 $L = 2.7 \times 10^{31}$ erg/s

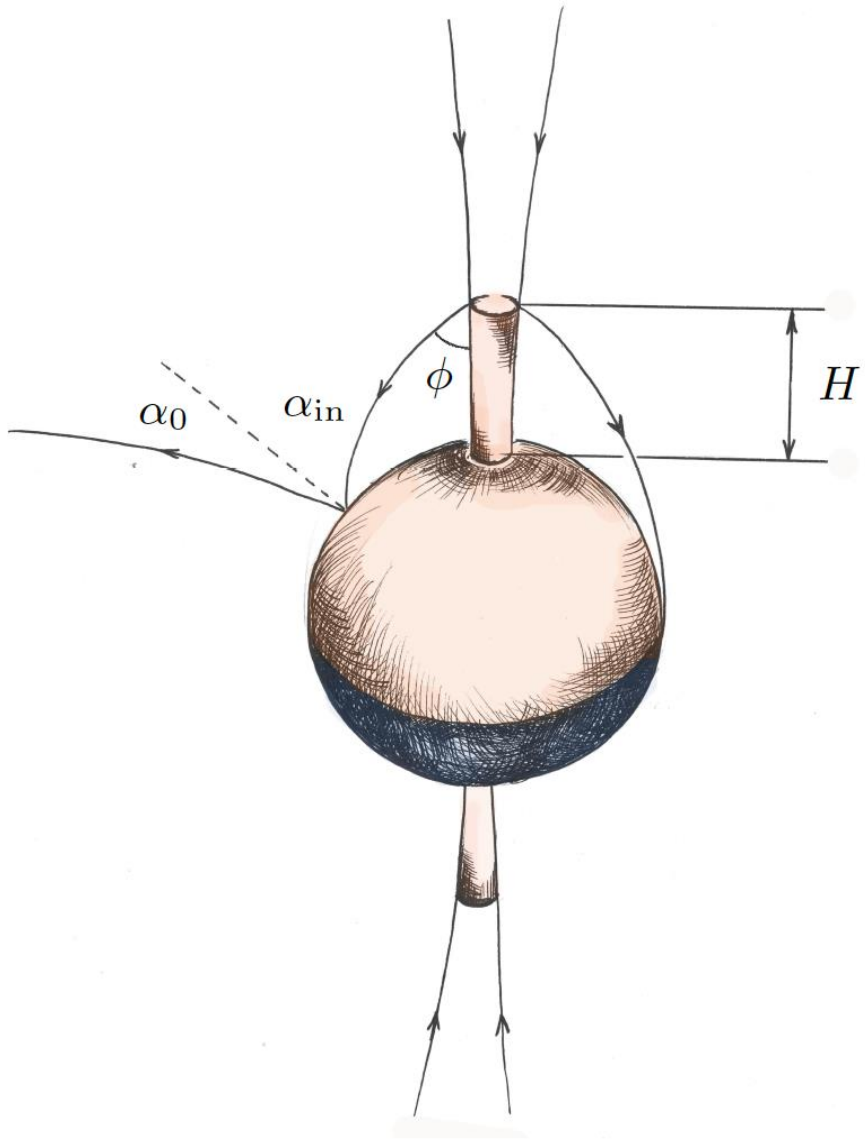
Accretion power?

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

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

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

50 x beaming required



Stunningly bright optical pulsations

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

SAX J1808 $L = 2.7 \times 10^{31}$ erg/s

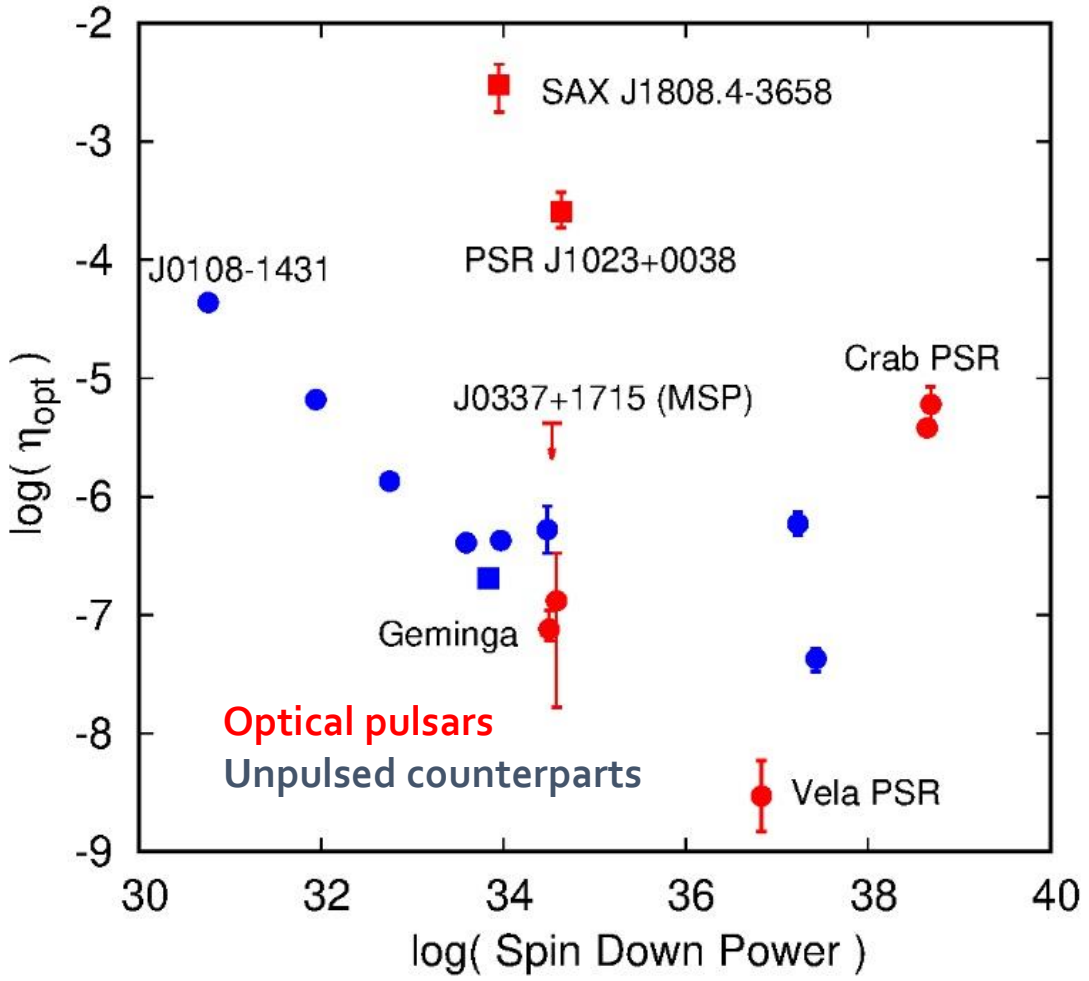
Rotation power?

Known isolated pulsars

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

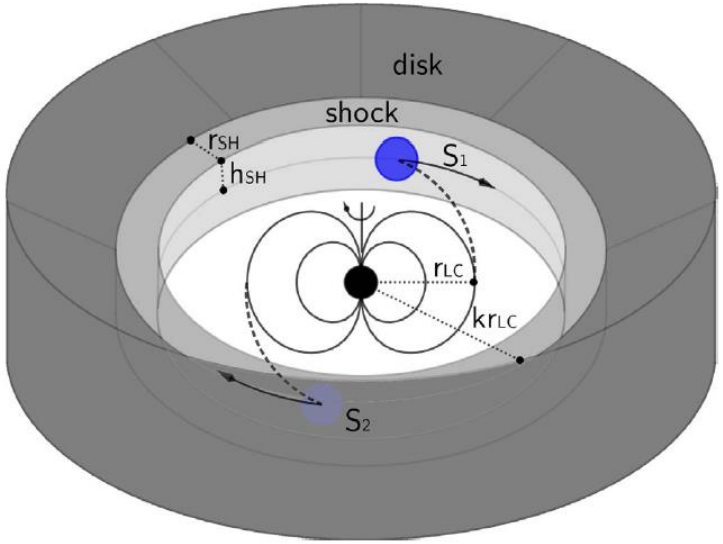
Spin powered MSPs

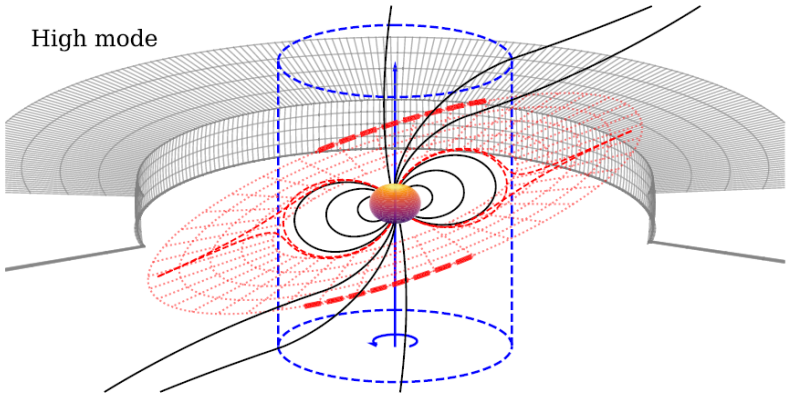
$L < 10^{-5}\ L_{sd}$



Updated from Ambrosino, Papitto+ 2017

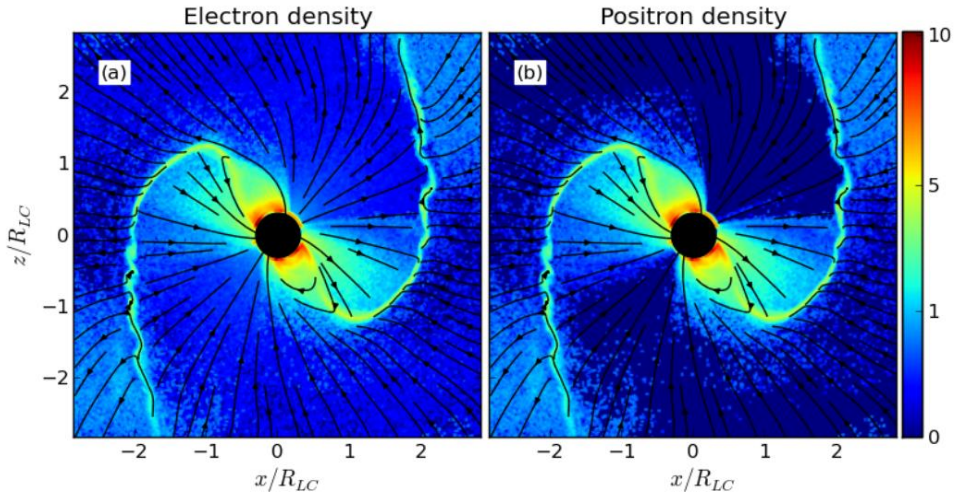
Very bright optical pulsations. Accretion, spin power, or both?





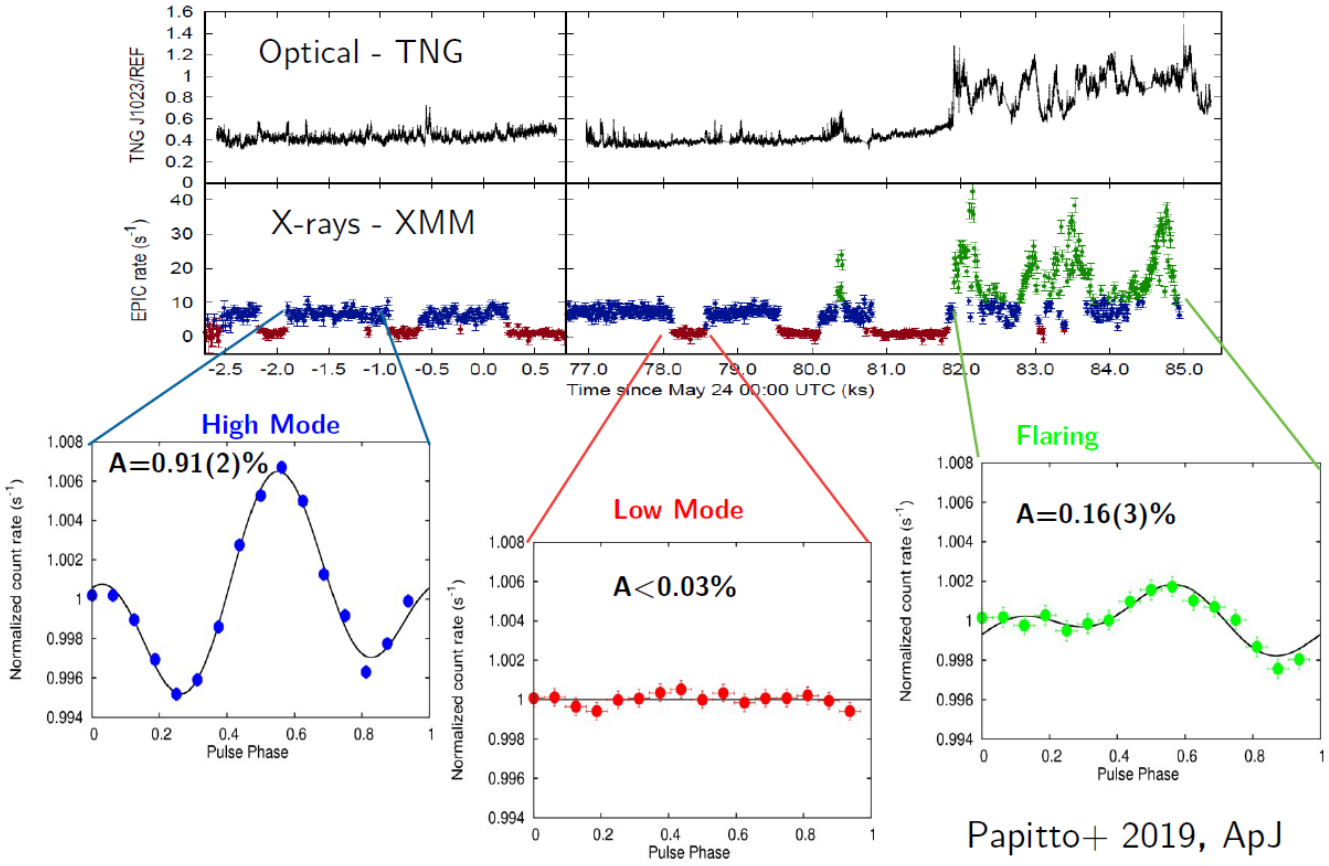
Pulsar wind terminated by the accretion disk [Papitto+ 2019, Veledina+ 2019]

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



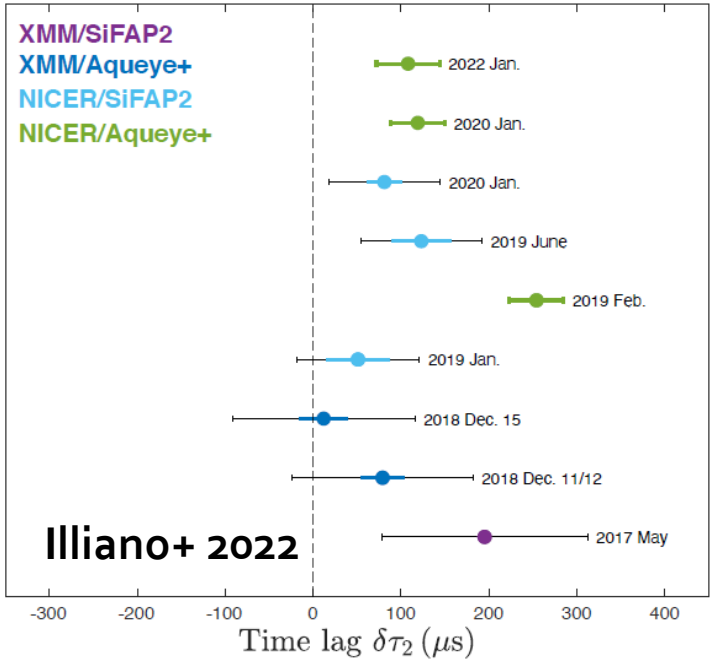
See the review by Cerutti & Beloborodov 2017

PSR J1023+0038 - Pulsating in unison & (almost) in phase at optical and X-ray energies

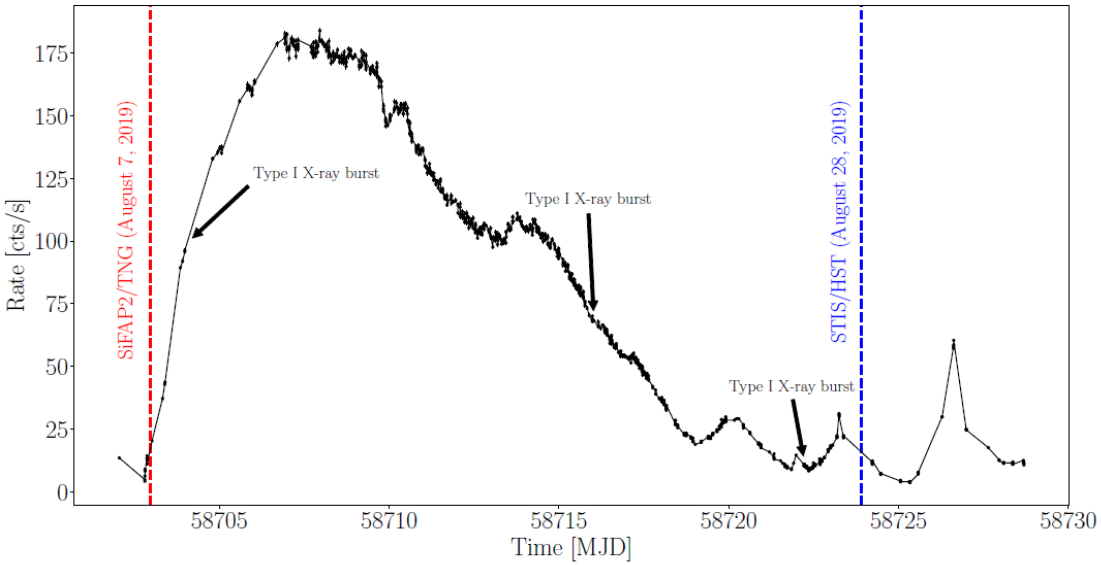


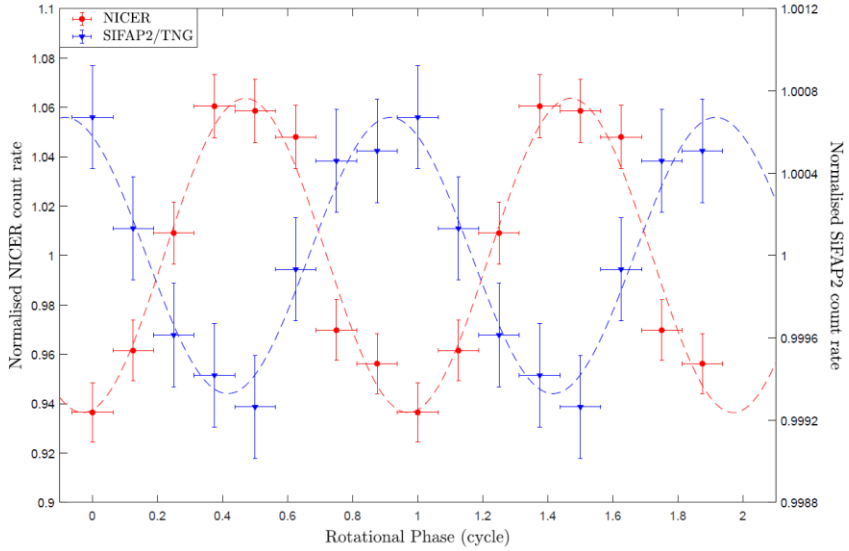
Papitto+ 2019, ApJ

See Giulia Illano & Maria Cristina Baglio's talks



SAX J1808.4-3658: Optical pulsations from an accreting MSP



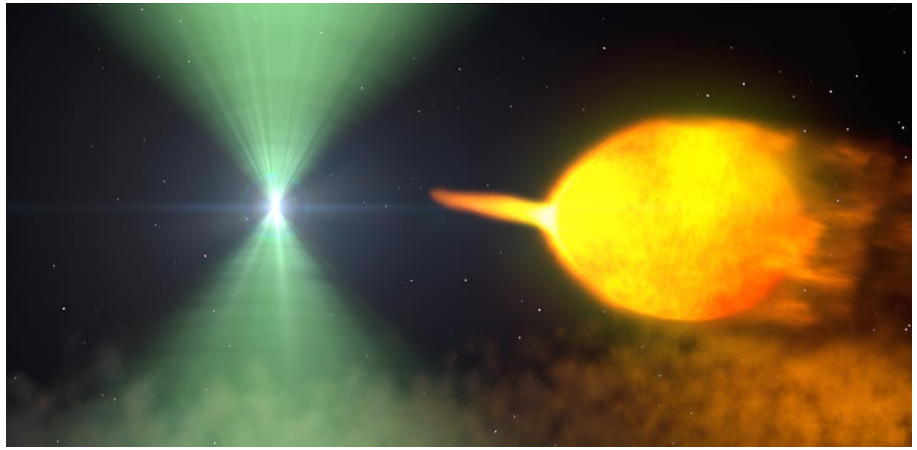


Do accretion and rotation power coexist?

Does accretion produce optical pulsations much brighter than expected?

Arianna Miraval Zanon's talk

Millisecond Pulsars show optical pulsations
How many out there? What physical process?



Rotation-powered MSPs

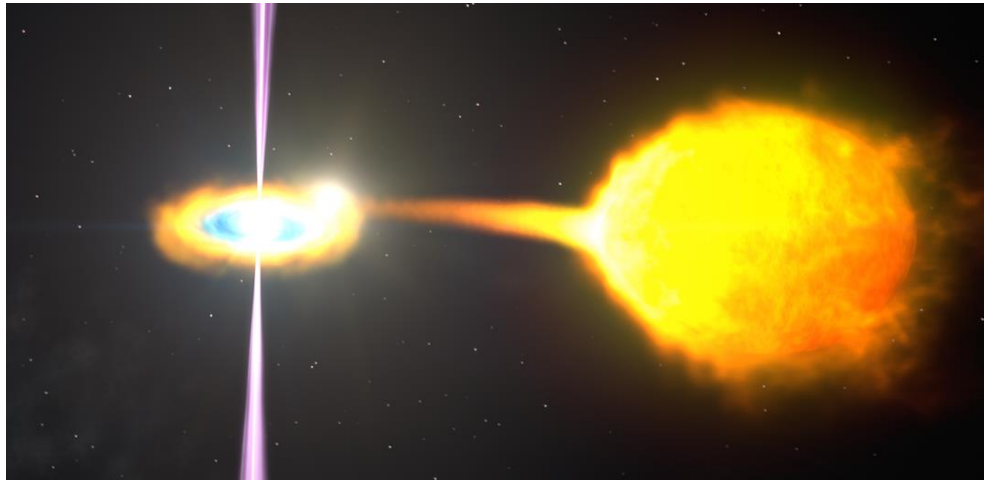
Redbacks and black widow pulsars

$A_{opt} < 0.1\,\%$

Candidate Transitional MSPs

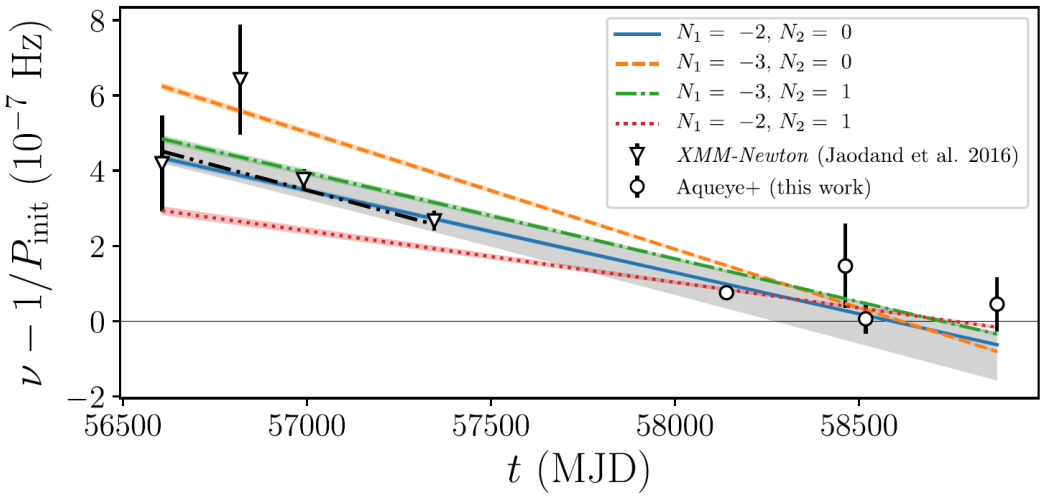
$A_{opt} < 1.5\,\%$ (in PSR J1023+0038 was 1%)

[Turchetta master thesis; Illiano+ in prep.]



Millisecond pulsar timing in the optical band

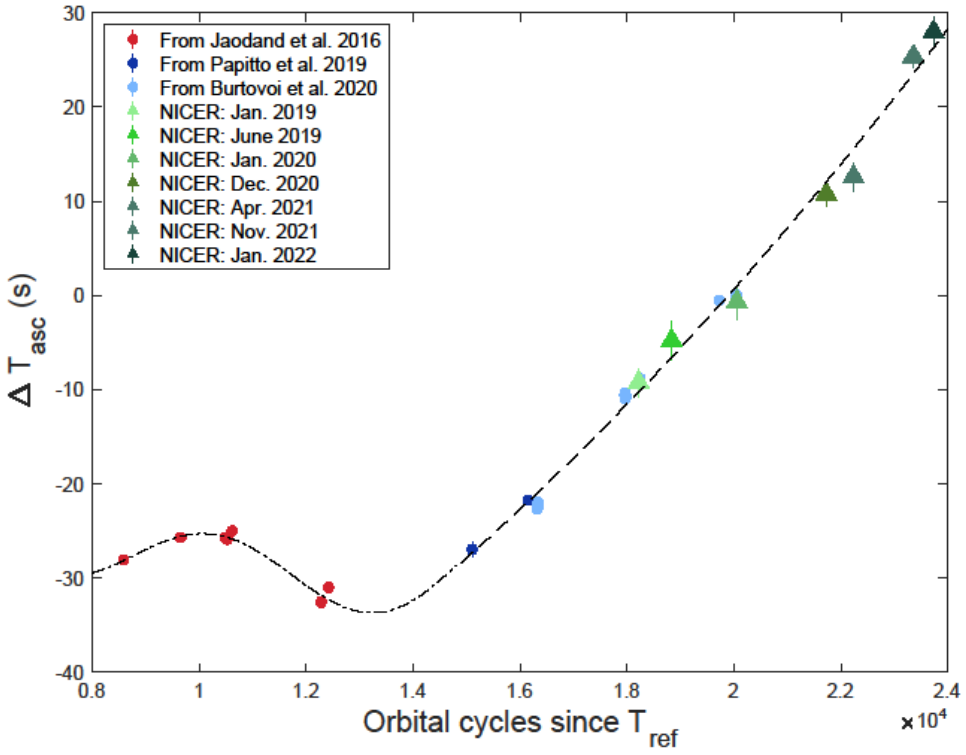
Aqueye+ @ Asiago Observatory



$\dot{\nu}_{DISK}$ = -2.53 (4) x 10^{-15} Hz/s

$\dot{\nu}_{DISK}$ / $\dot{\nu}_{RADIO-PSR}$ ≈ 1.05

[see also Jaodand+ 2016, 2021]



Smoother orbital expansion
$(dP/dt)_{app}$=+1.6(6)x10^{-11}

Zampieri+ 2019, Burtovoi+ 2020, Illiano+ 2022 (in prep.)

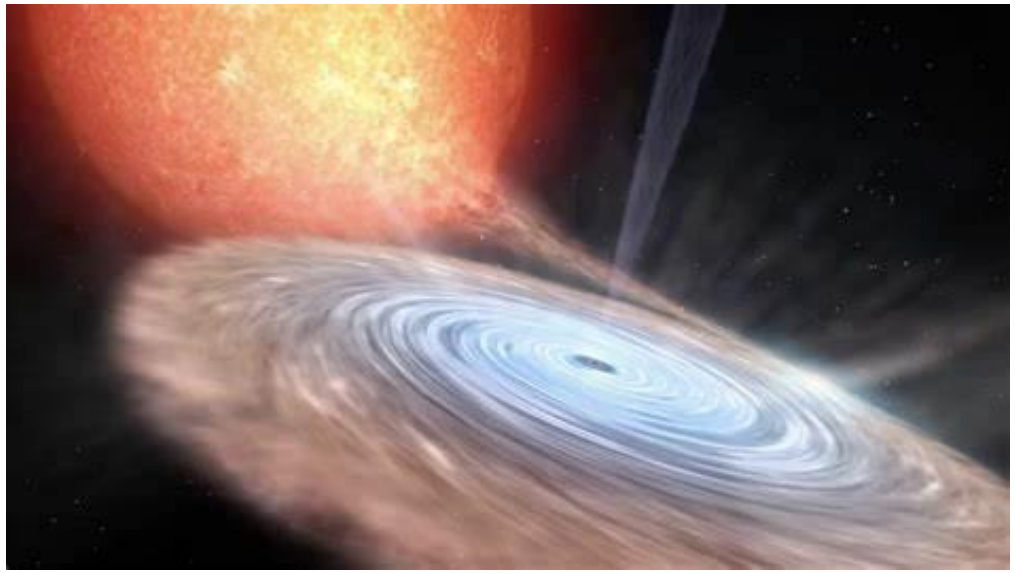
Searching for (optical) pulsations from accreting NS

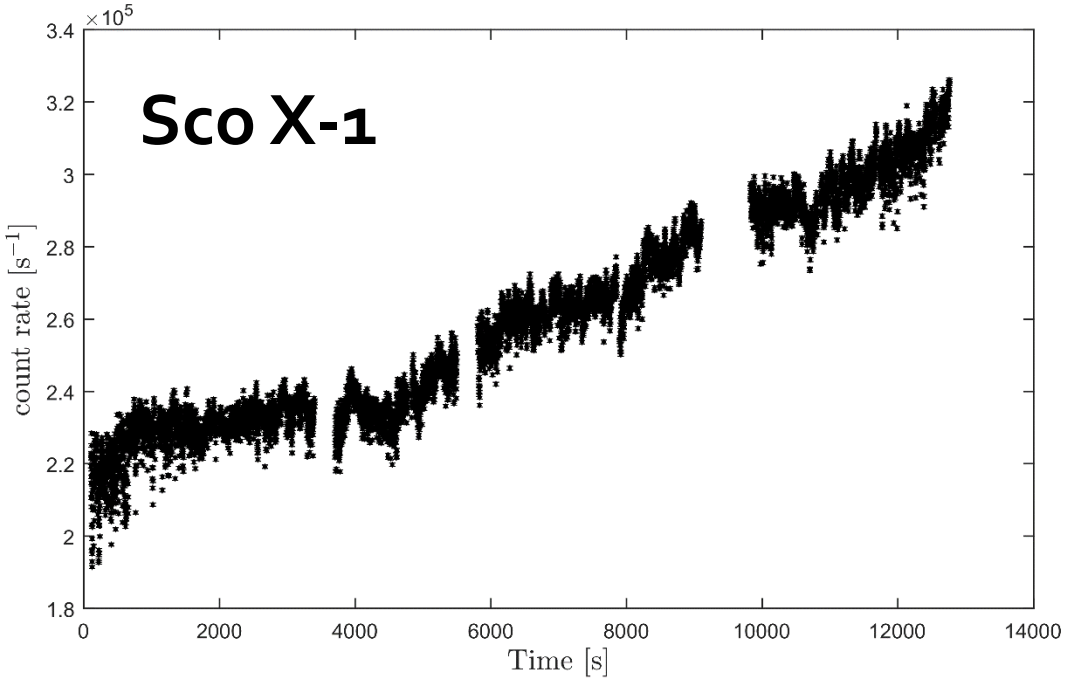
Only 10% of accreting neutron stars show X-ray pulsations

Pulse sensitivity ~ $N_{phot}^{-1/2}$ (A ~ 0.01 % in a few hours from brightest sources)

Detection would greatly enhance **continuous GW searches**

LIGO/VIRGO CGW group

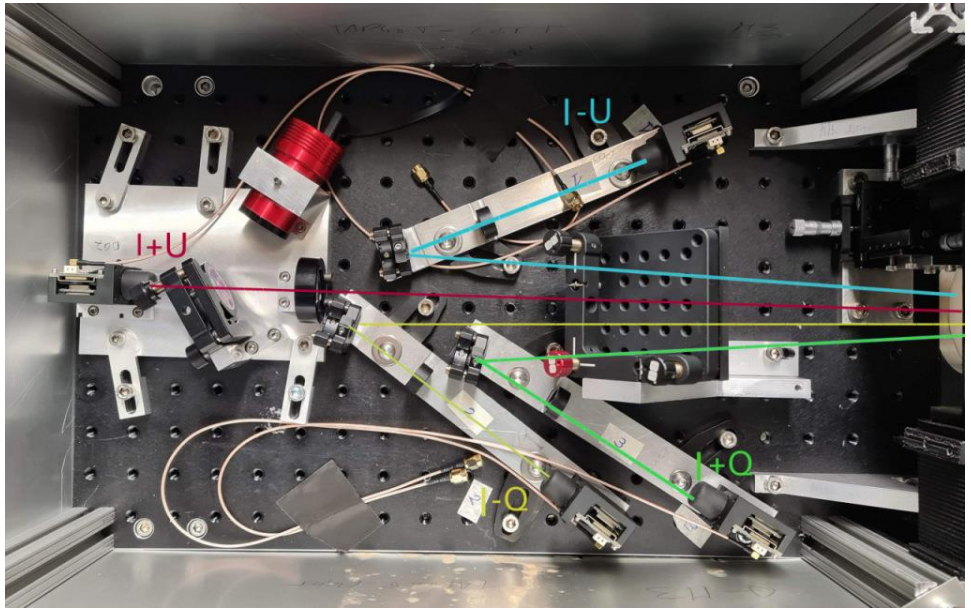


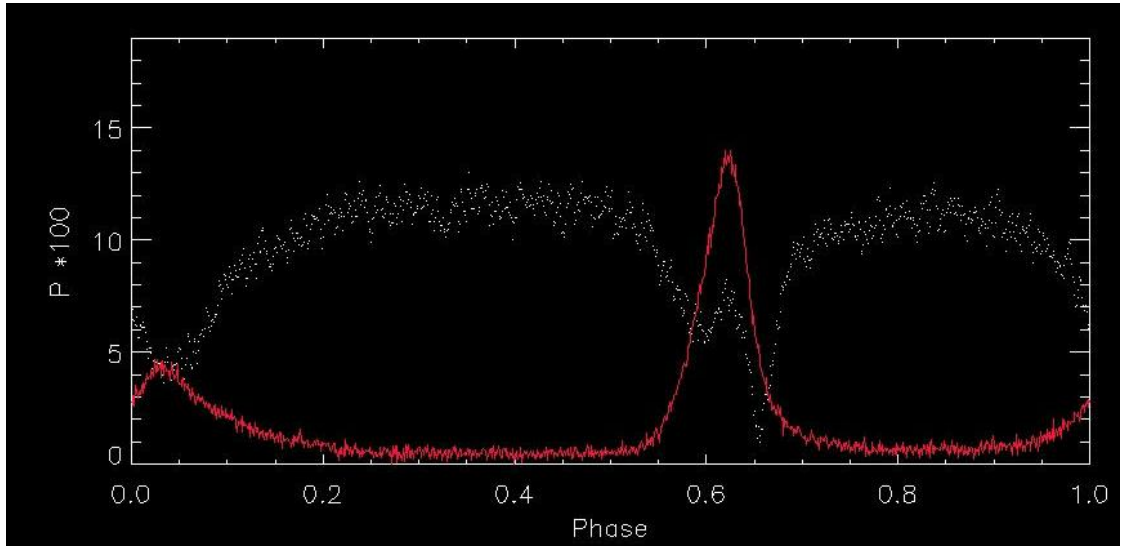


Fast optical polarimetery with SiFAP4XP

First light on 2022, Feb 22 [Ghedina+ 2022]

Ongoing calibration with the Crab PSR [Leone+ in prep.]





SiFAP4XP will complement **IXPE** constraints on accreting MSPs geometry to constrain the neutron star equation of state

Optical millisecond pulsars

PSR J1023+0038 - Transitional

SAX J1808.4-3658 - Accreting

Accretion vs **Rotation** power (or both?)

Optical pulsations from bright LMXBs

Sco X-1 and candidate **continuous GW sources**

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REM

CALL FOR PROPOSALS TNG and REM

AOT 46 (2022B) is now open for proposals.
Applications for observing time for the period

October 1st, 2022 - March 31st, 2023

are solicited and should be submitted by
Friday, May 27th, 2022, 12:00 UT.

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A long list of people to thank

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T. Di Salvo (Univ. of Palermo), D. De Martino (INAF OA Napoli), M. C. Baglio, S. Campana, P. D'Avanzo (INAF OA Brera),

T. M. Belloni (INAF OA Brera), M. Burgay, A. Possenti, A. Pellizzoni (INAF OA Cagliari),

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M. Falanga (ISSI Bern, ISSI Beijing), I. H. Stairs, M. D. Filipovic, J. M. Sarkissian, M.H. Wieringa, G. F. Wong (ATNF)

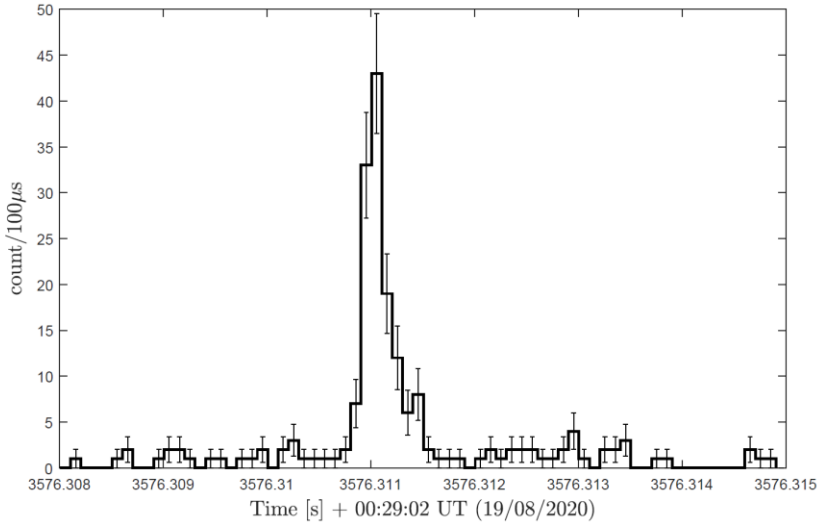
Check Papitto & de Martino 2020 review, arXiv:2010.09060 in 'Millisecond Pulsars', Springer ASSL

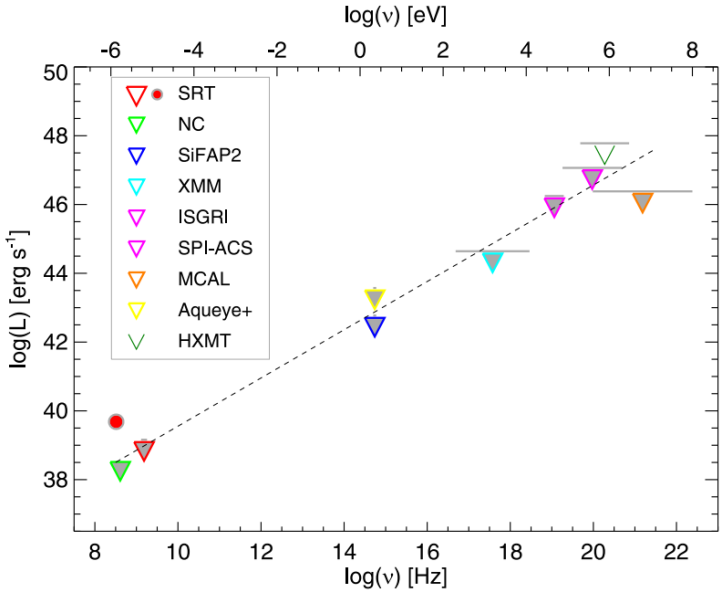
Searching for fast optical variability from FRBs and magnetars

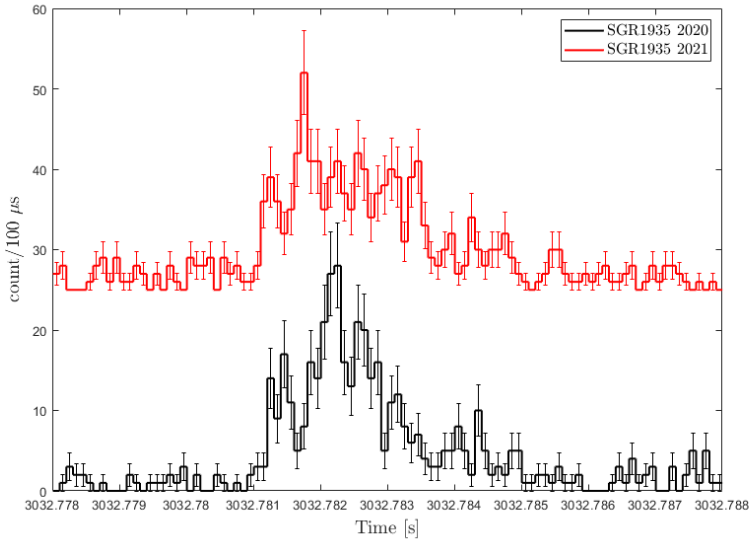
FRB 180916

Often no simultaneous radio observations

[Pilia+ 2020, 2022 in prep.]







SGR 1935+2154

No simultaneous detections at other WLs

[e.g. MAGIC central pixel, Lopez-Oramas+ 2021]

Ongoing characterization of the background flaring behavior in the optical band [Casella+ in prep.]