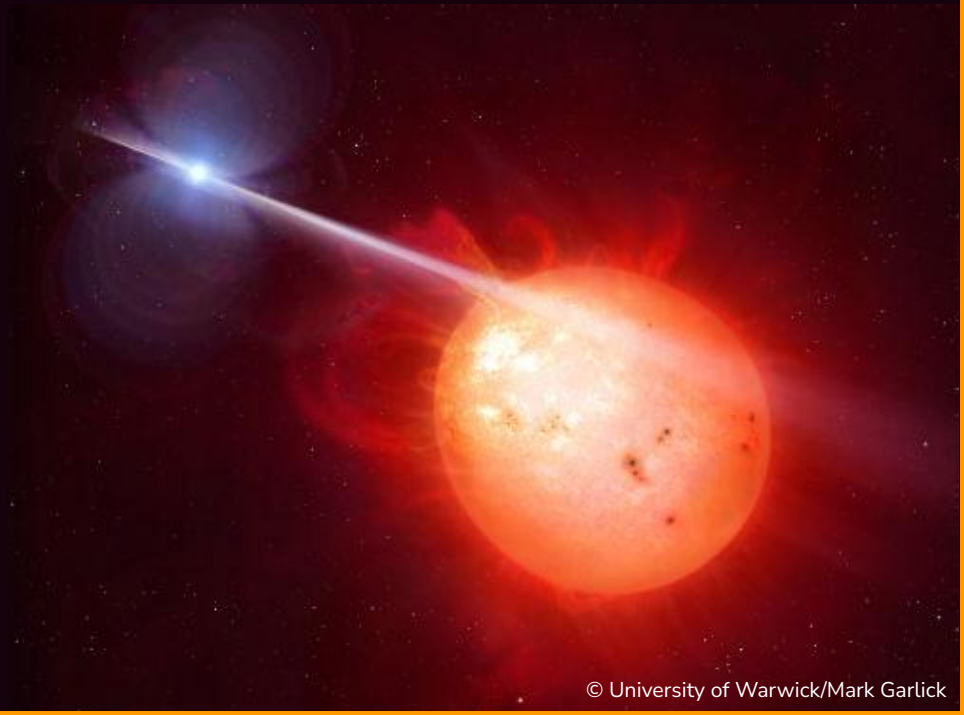
Pulsars and propellers:

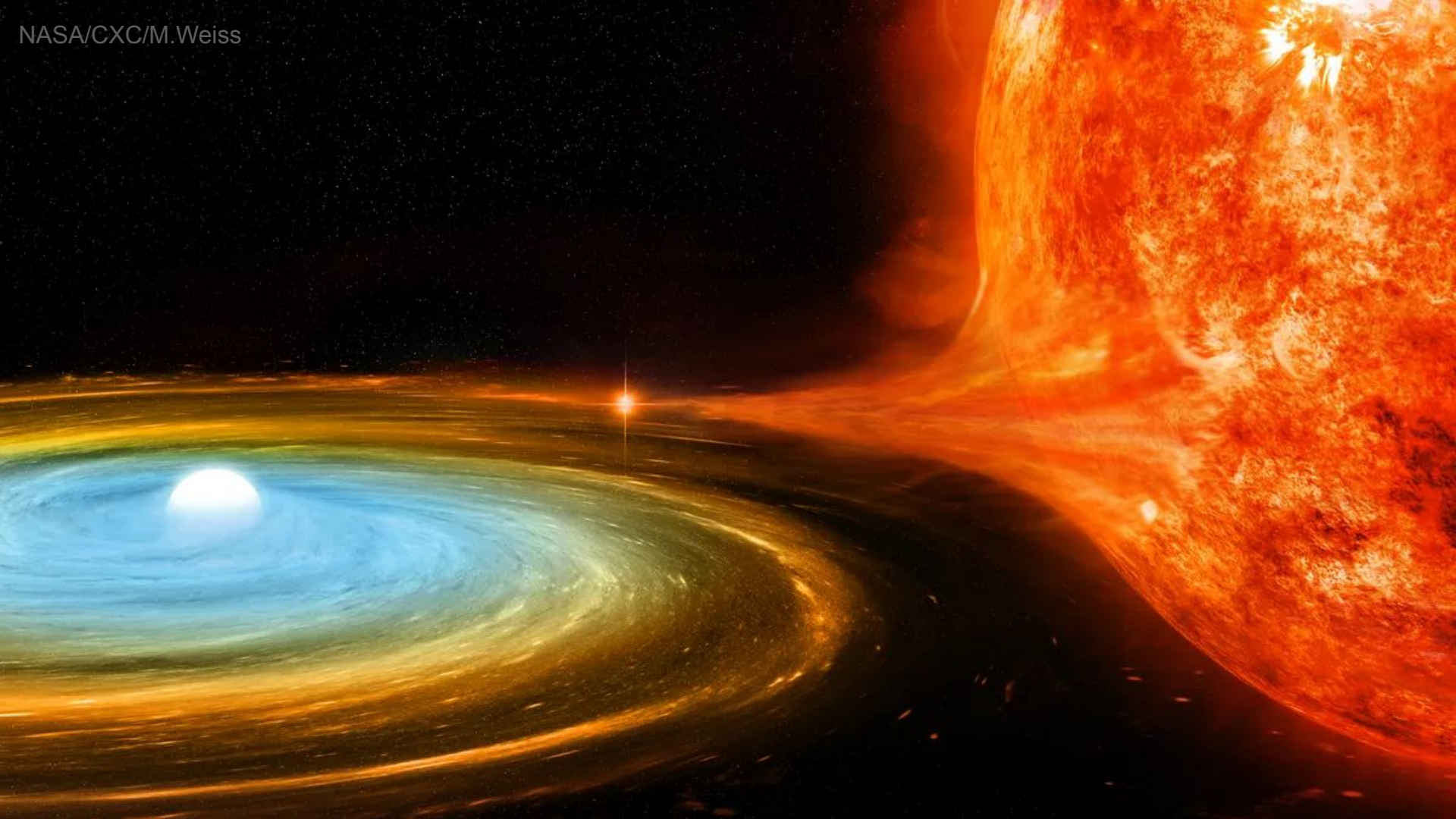
X-ray and radio emission from the most mysterious white dwarf binaries

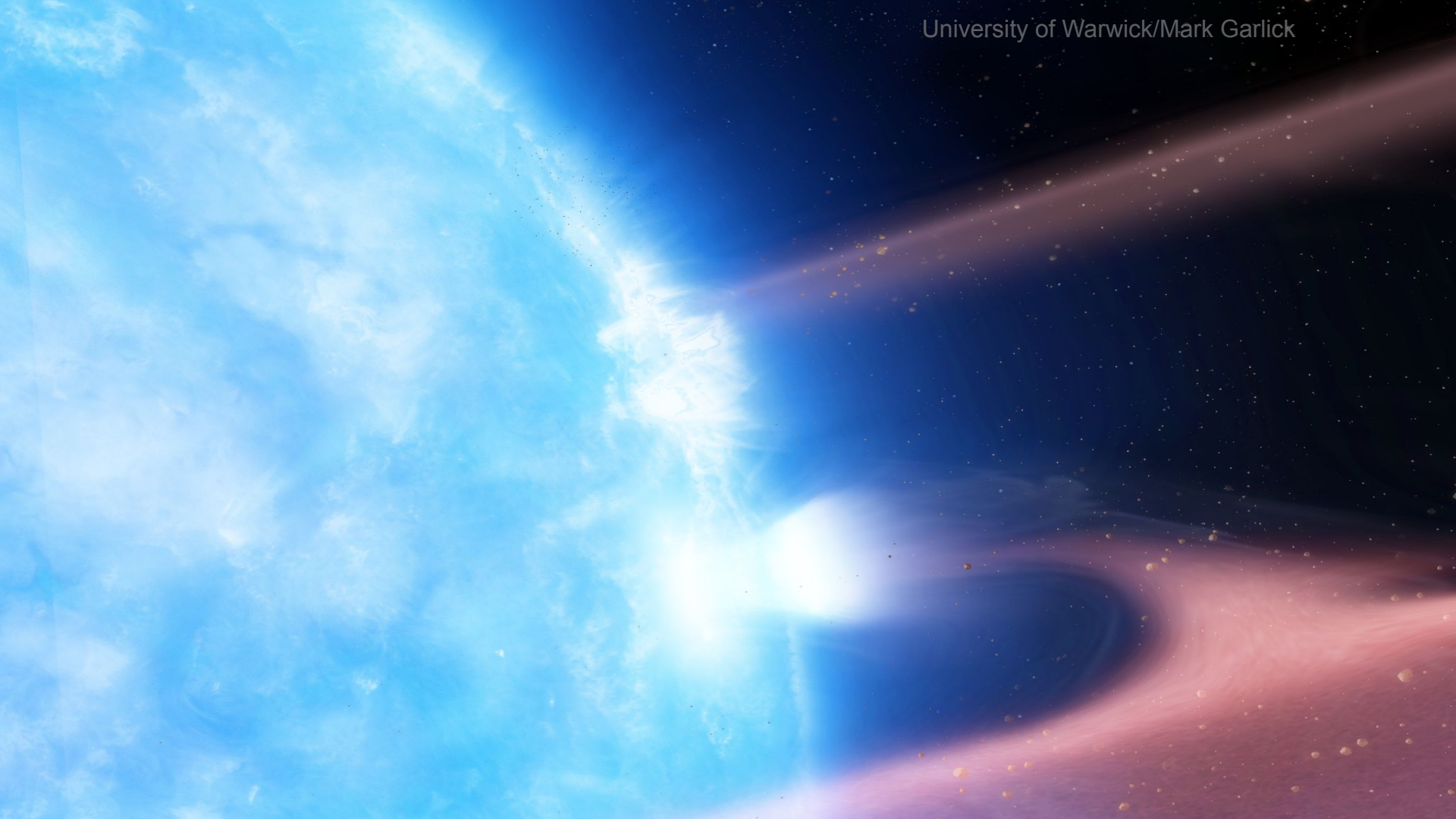
Ingrid Pelisoli

Royal Society University Research Fellow

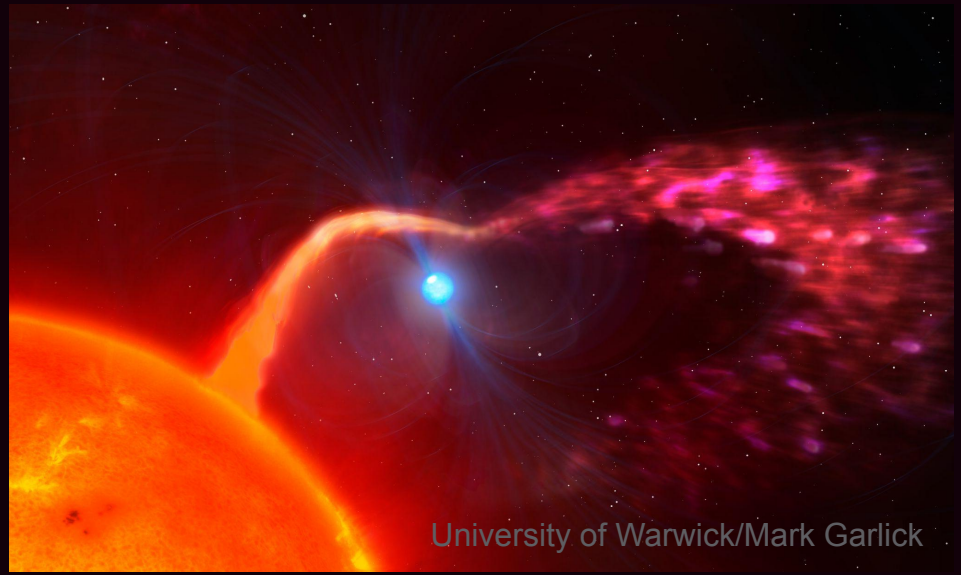
University of Warwick



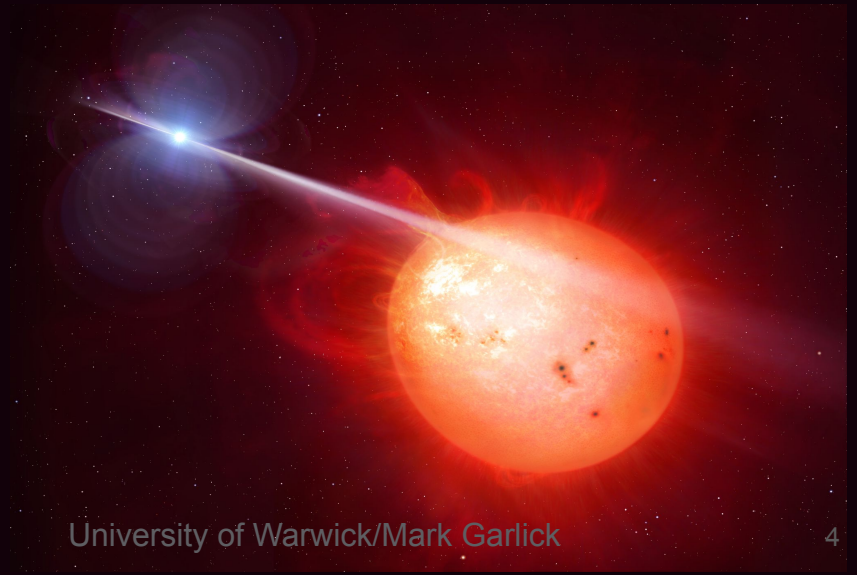

NASA/CXC/M.Weiss


University of Warwick/Mark Garlick

X-ray and radio emission from non-accreting white dwarfs

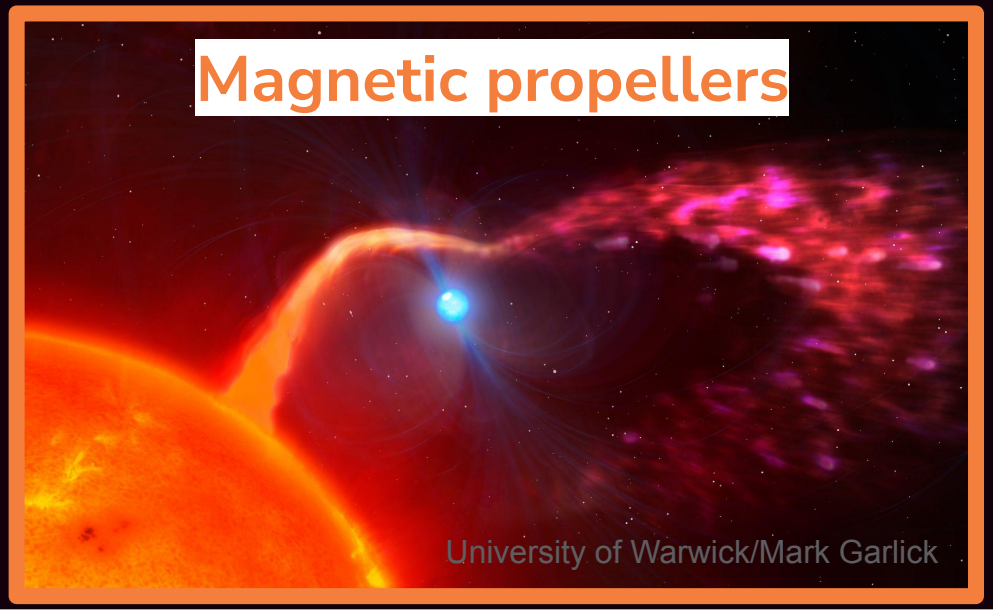


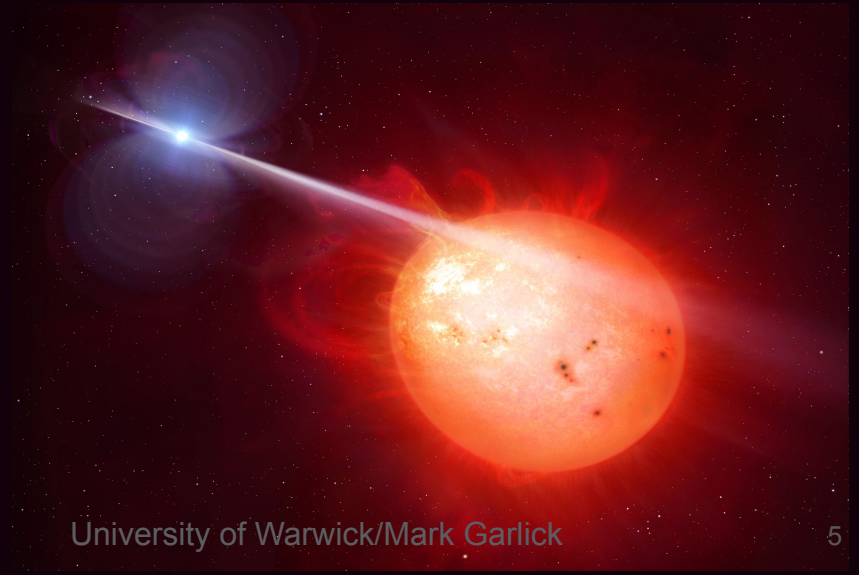
University of Warwick/Mark Garlick



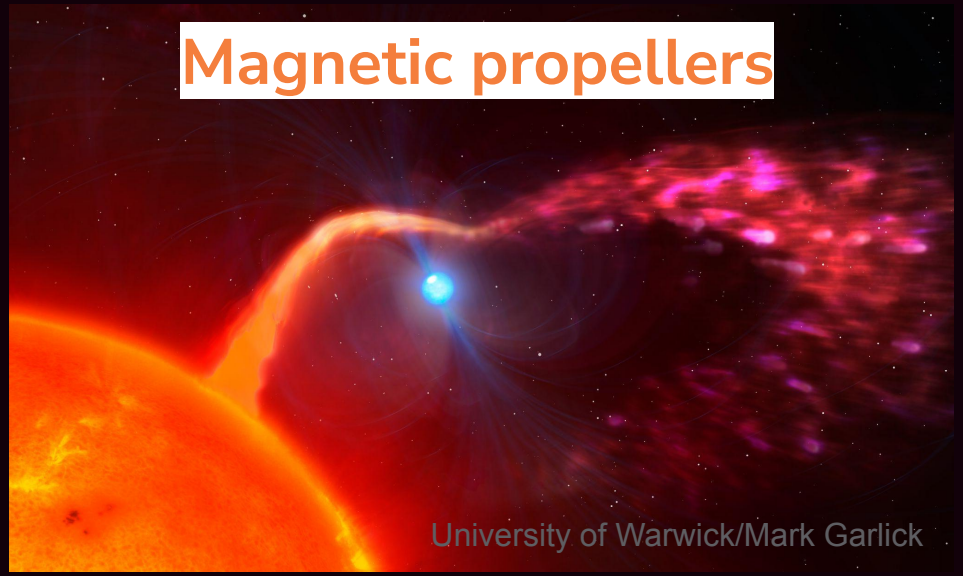
University of Warwick/Mark Garlick

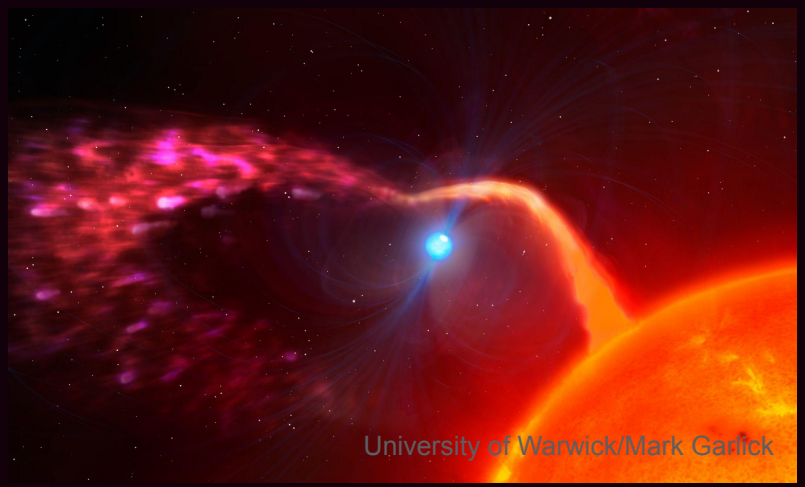
X-ray and radio emission from non-accreting white dwarfs





X-ray and radio emission from non-accreting white dwarfs





Magnetic propellers:

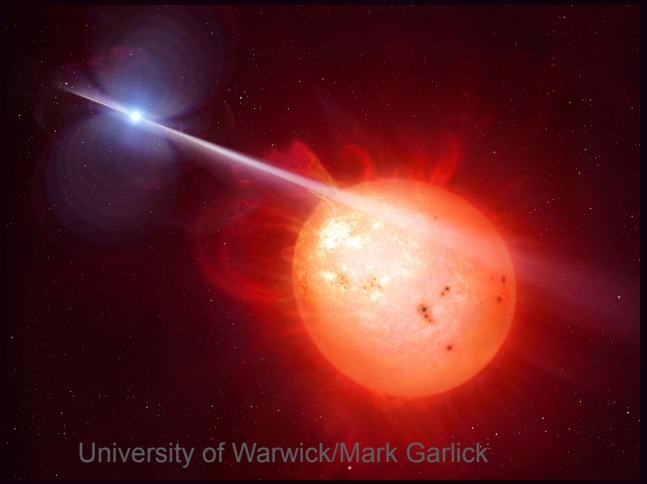
AE Aquarii

LAMOST J024048.51+195226.9

Binary white dwarf pulsars:

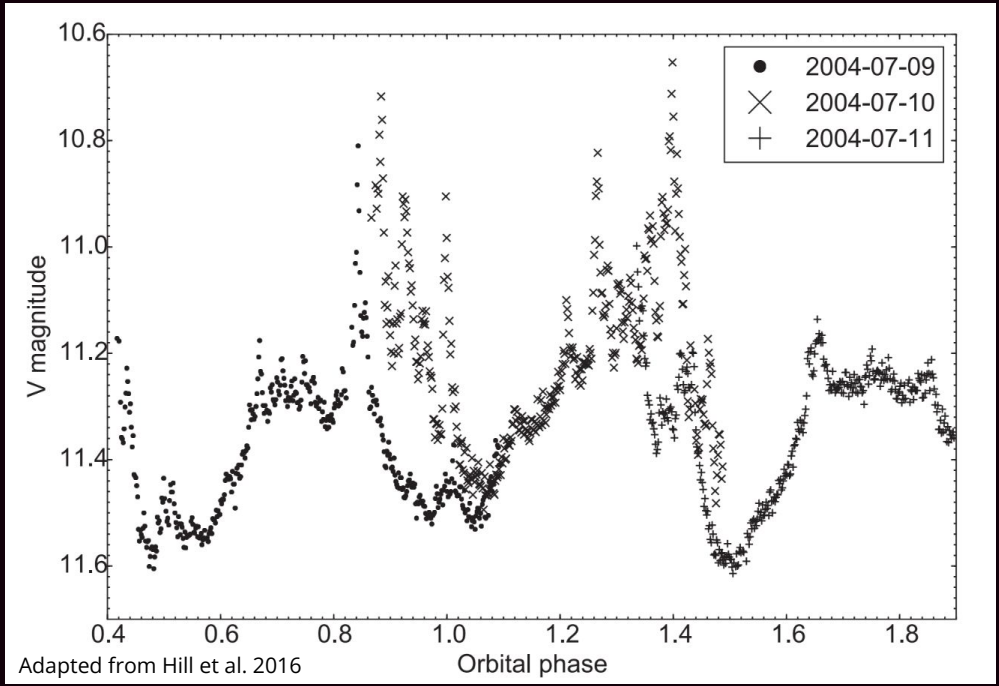
AR Scorpius

J191213.72–441045.1



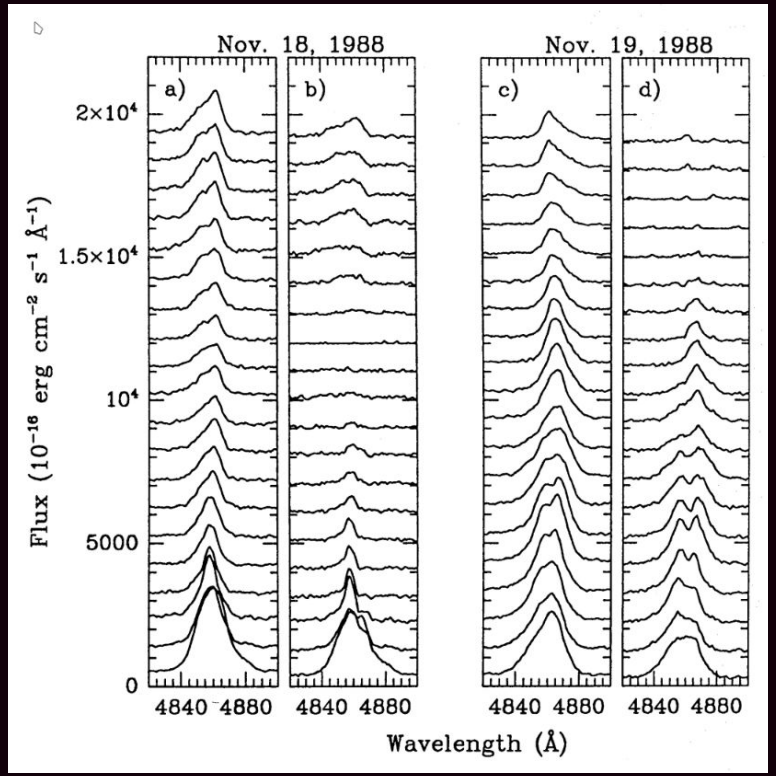
DISCLAIMER!

The first propeller: AE Aqr



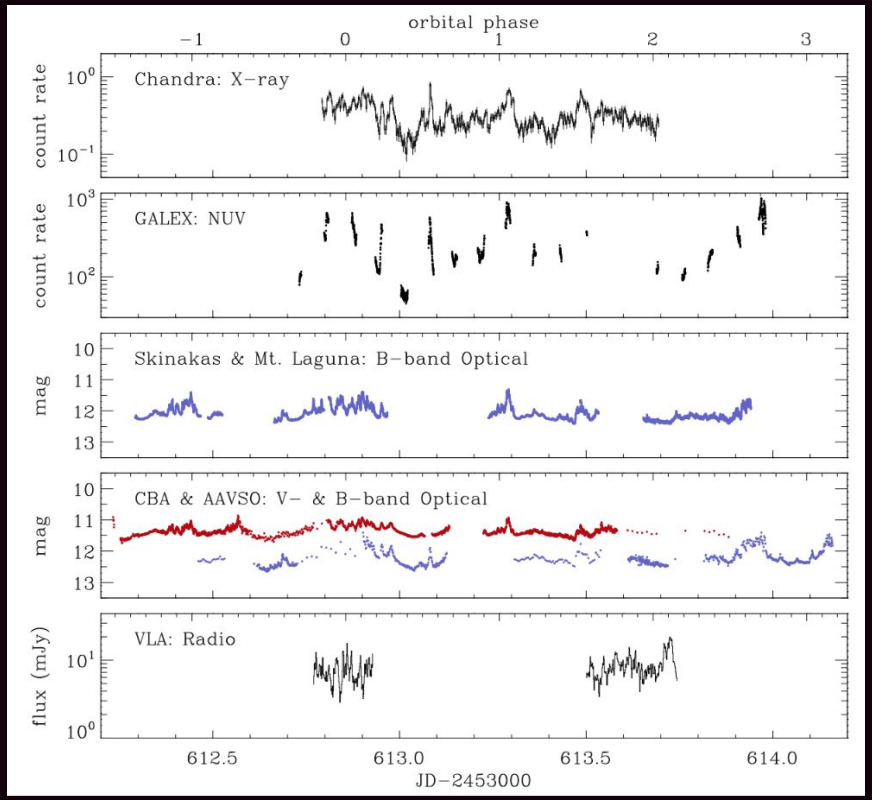
*orbital period = 9.88 h (Walker 1965)

Flares also noticeable in spectra



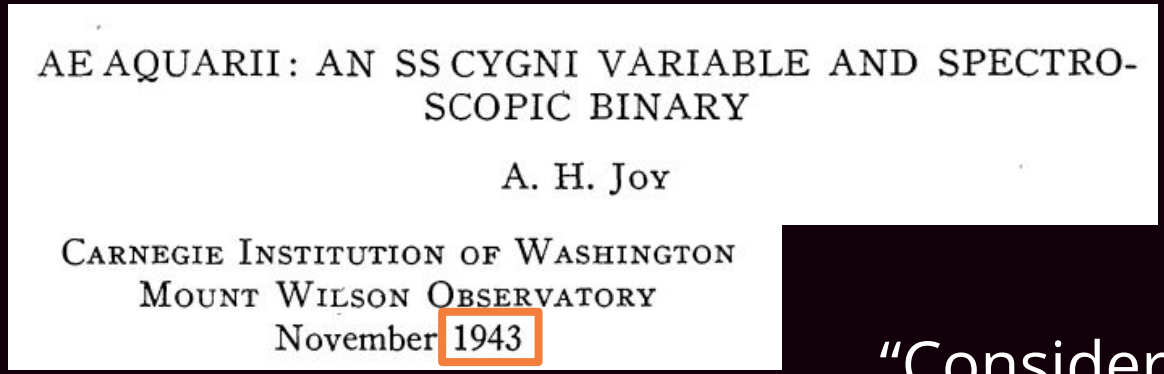
Adapted from Reinsch & Beuermann 1994

Emission from radio to X-rays



Adapted from Mauche et al. 2012

Flaring behaviour was a puzzle for decades



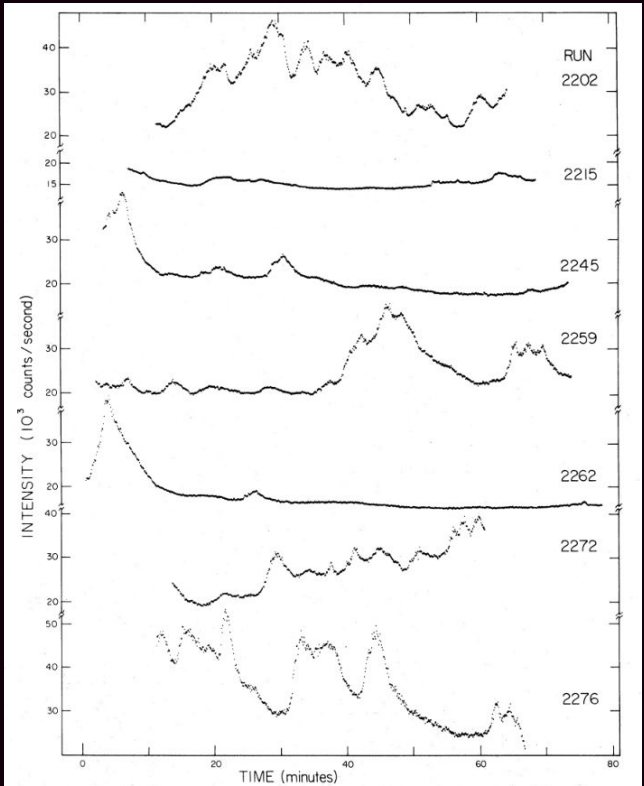
AE AQUARII: AN SS CYGNI VARIABLE AND SPECTROSCOPIC BINARY

A. H. Joy

Carnegie Institution of Washington
Mount Wilson Observatory
November 1943

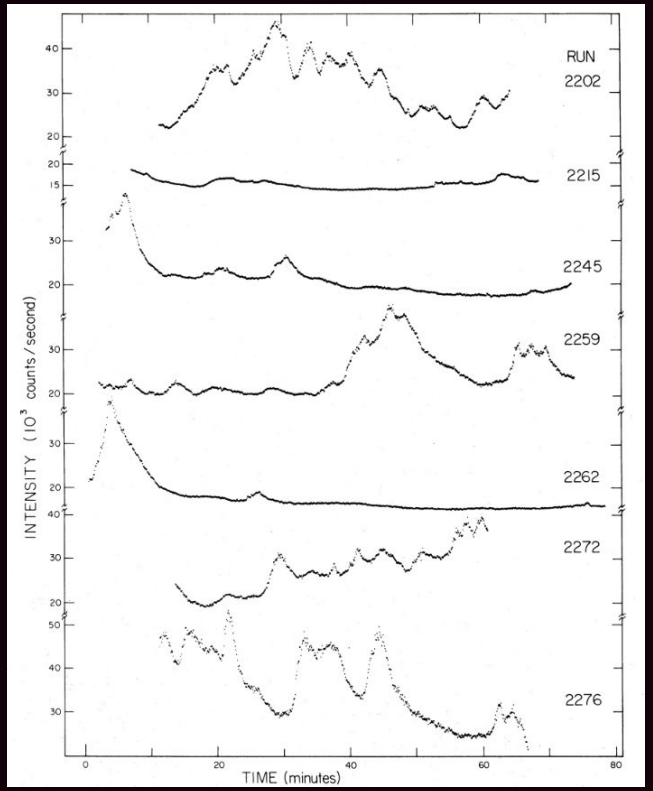
"Considerable changes take place from day to day in the structure and perhaps in the width of the emission lines."

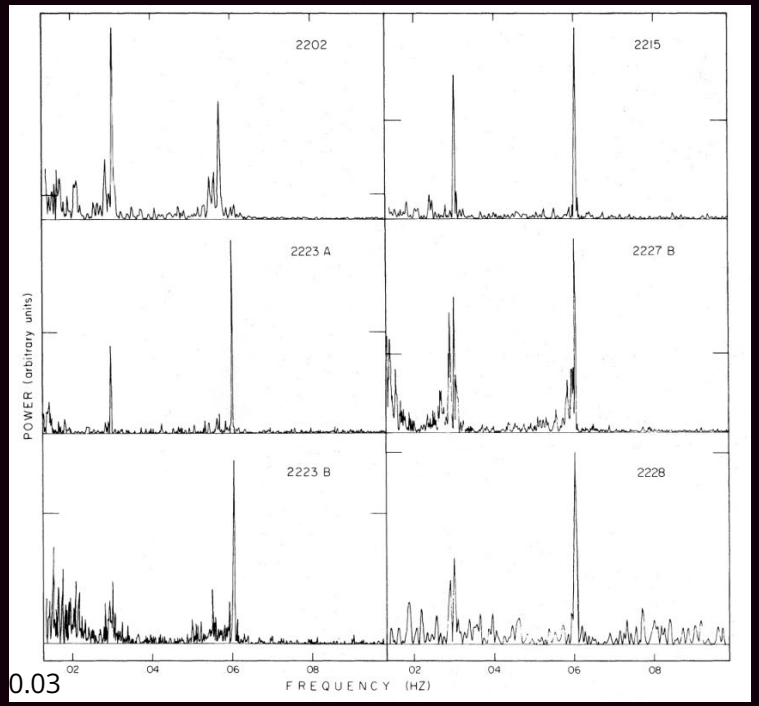
Flaring behaviour was a puzzle for decades



Adapted from Patterson 1979

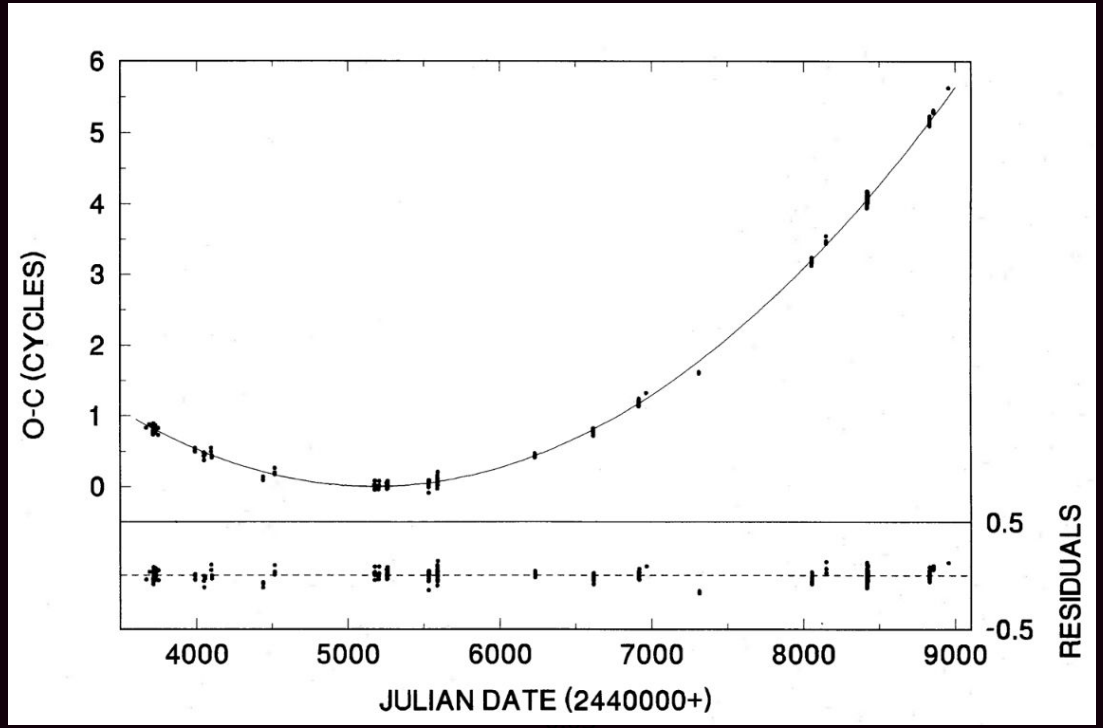
Discovery of a fast spin in AE Aqr: 33 sec





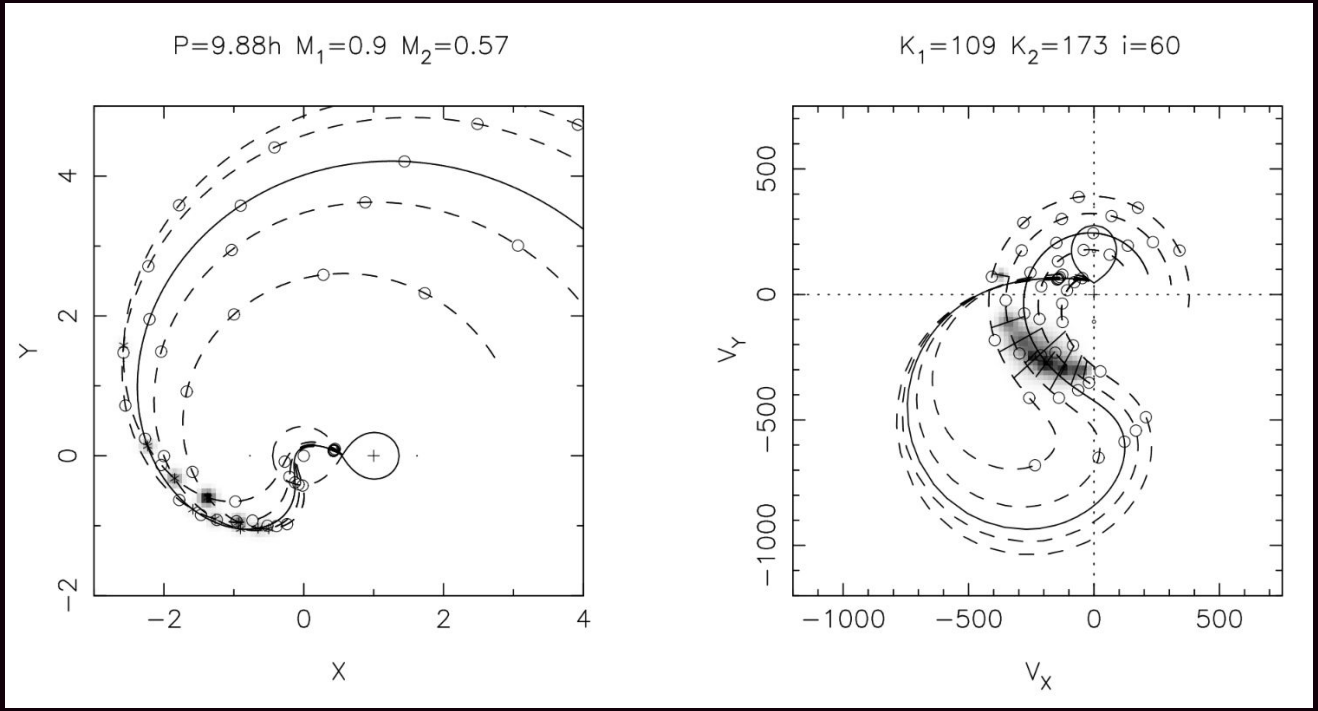
Adapted from Patterson 1979

Discovery of a spin-down in AE Aqr: 5.64×10^{-14} s/s



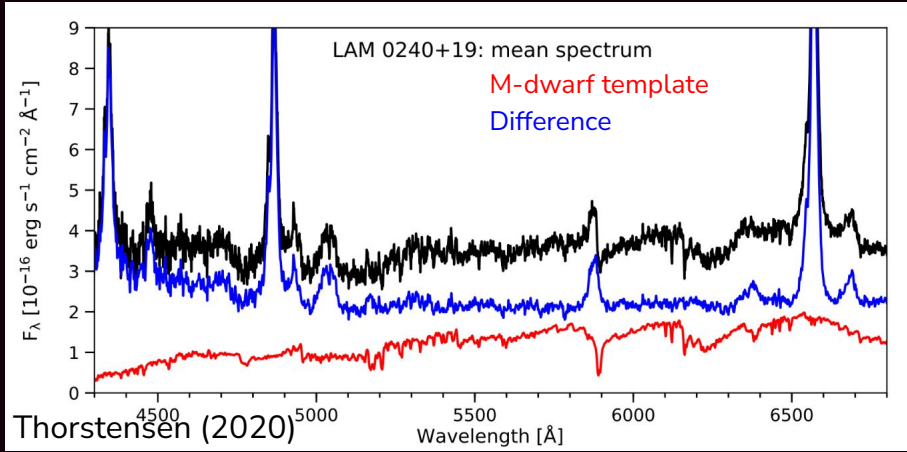
Adapted from De Jager et al. 1994

Development of a propeller model



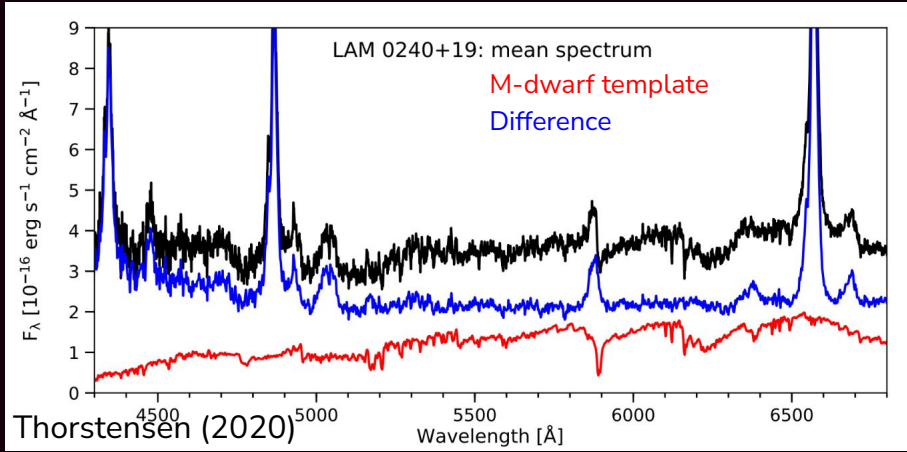
Adapted from Pearson et al. 2003. See also Eracleous & Horne 1996; Wynn et al. 1997; Meintjes & Venter 2003.

Serendipitous discovery of a second propeller: J0240

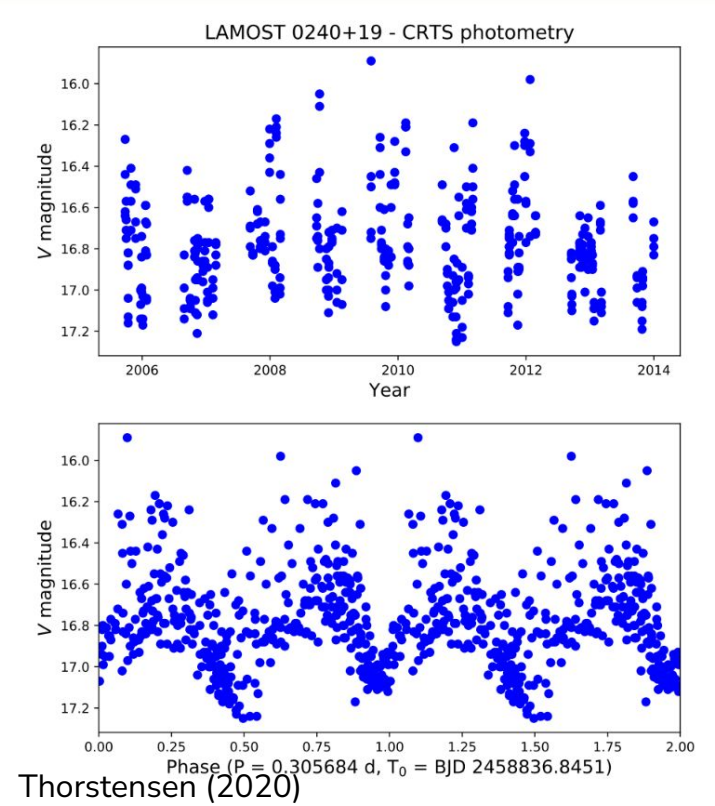


Thorstensen (2020)

Serendipitous discovery of a second propeller: J0240



Thorstensen (2020)



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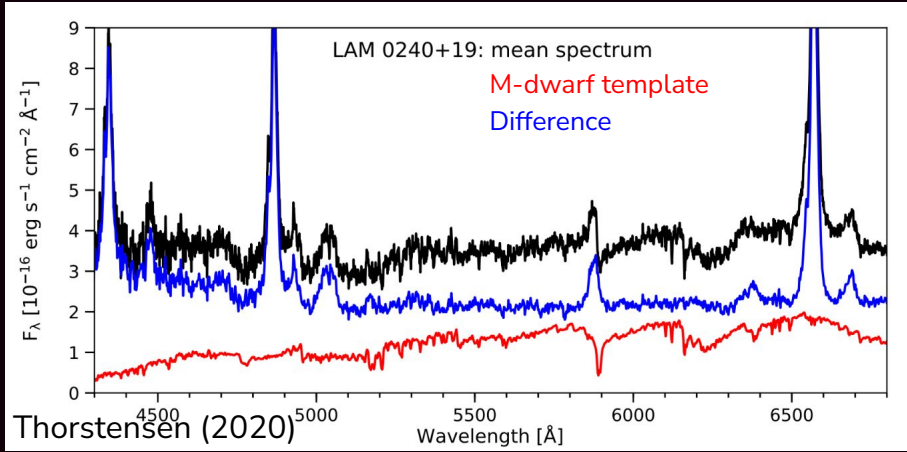
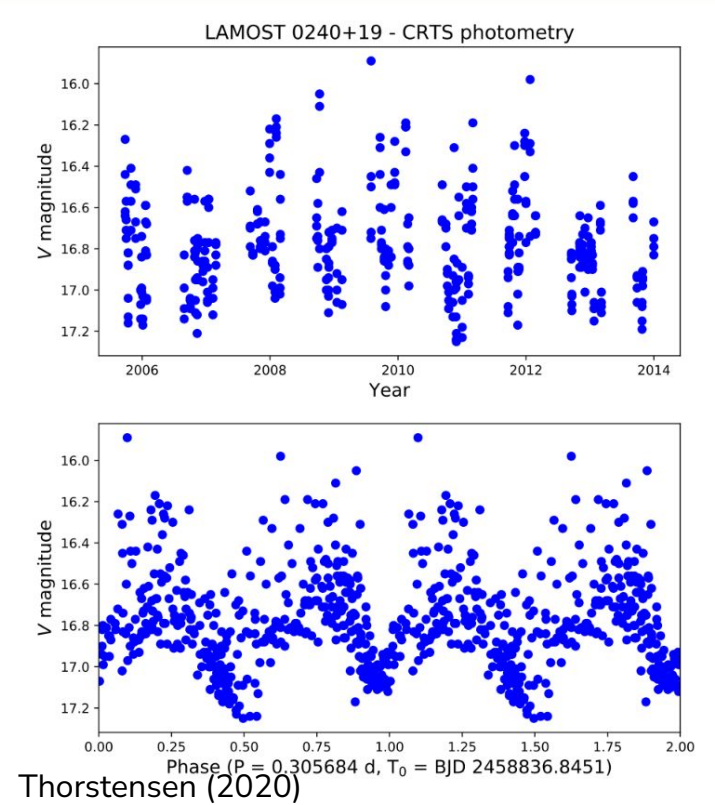


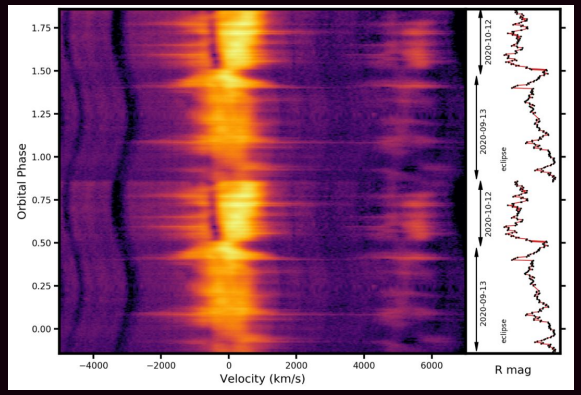
Thorstensen (2020)

Thorstensen (2020): "..spectral and photometric behavior are strikingly reminiscent of the hitherto-unique propeller system AE Aqr".



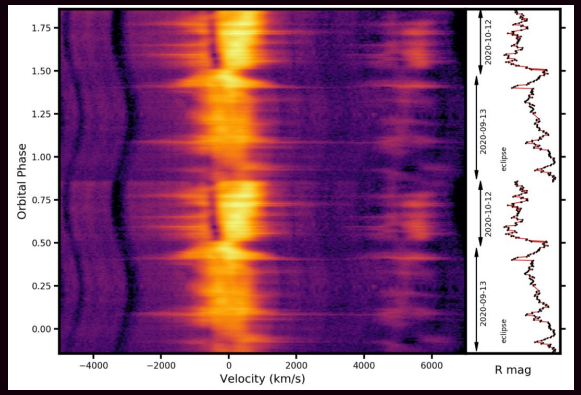
Thorstensen (2020)

Confirmation of propeller: broad emission



Adapted from Garnavich et al. (2021)

Confirmation of propeller: broad emission, radio



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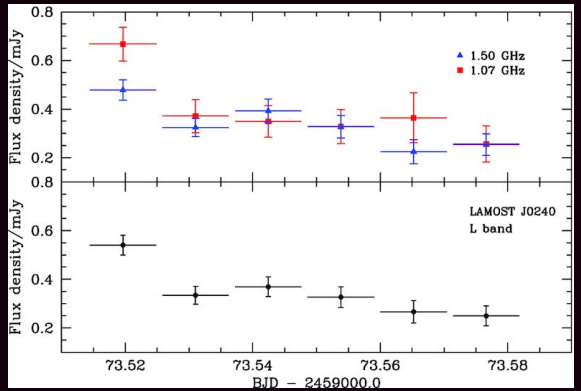
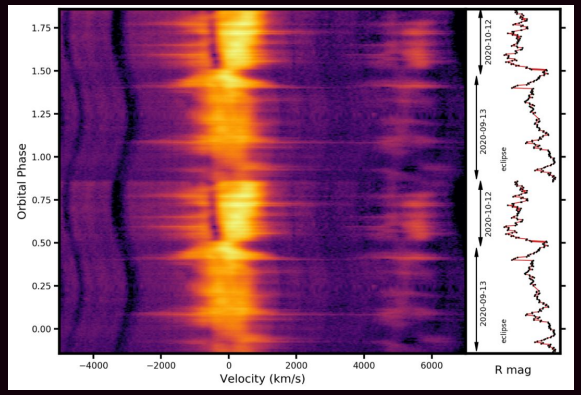


Adapted from Pretorius et al. (2021)

Confirmation of propeller: broad emission, radio, spin



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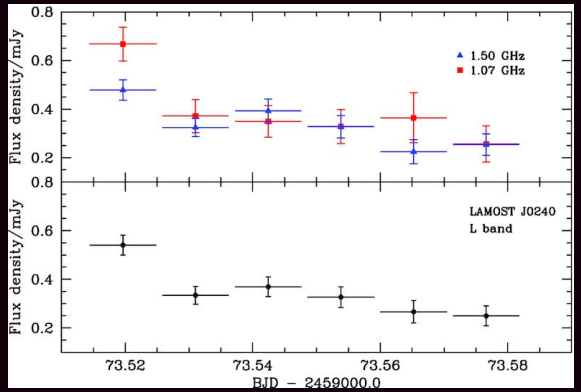

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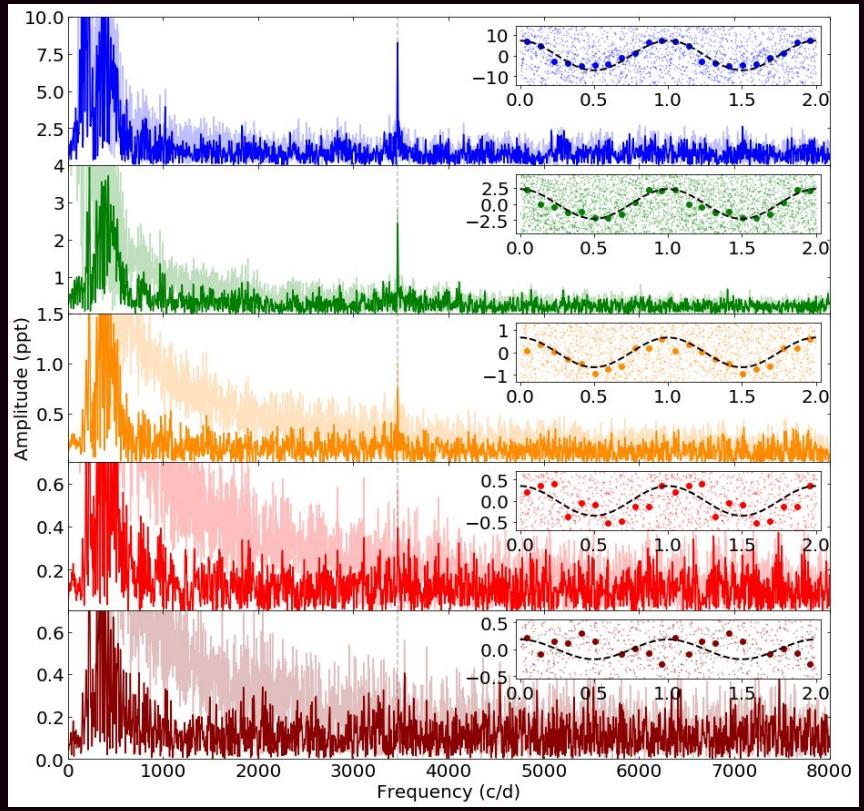


Adapted from Pelisoli et al. (2022)

Caveat: dissimilar radio emission

AE Aqr

very luminous

(> 5 mJy at 3 GHz)

unpolarised

positive spectral index

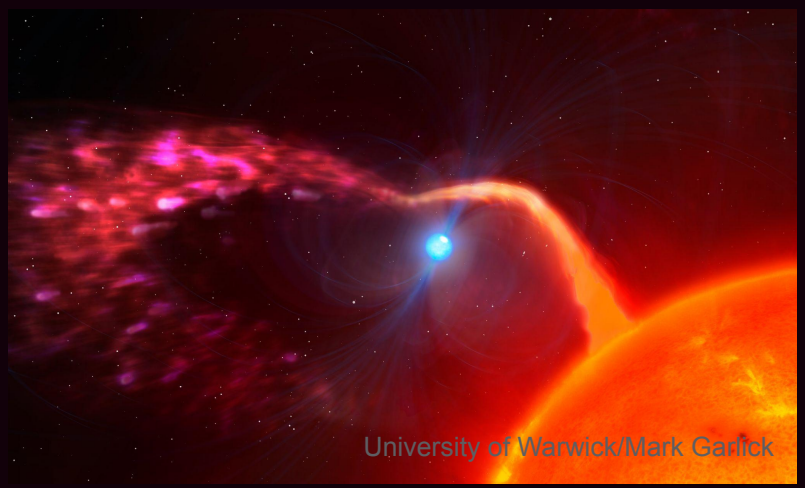
Caveat: dissimilar radio emission

AE Aqr	J0240
very luminous (> 5 mJy at 3 GHz)	relatively faint (< 1 mJy at 3 GHz)
unpolarised	highly circularly polarised
positive spectral index	negative spectral index

Caveat: dissimilar radio emission

AE Aqr	J0240
very luminous (> 5 mJy at 3 GHz)	relatively faint (< 1 mJy at 3 GHz)
unpolarised	highly circularly polarised
positive spectral index	negative spectral index

Barret (2022):
“Synchrotron emission is unlikely”!



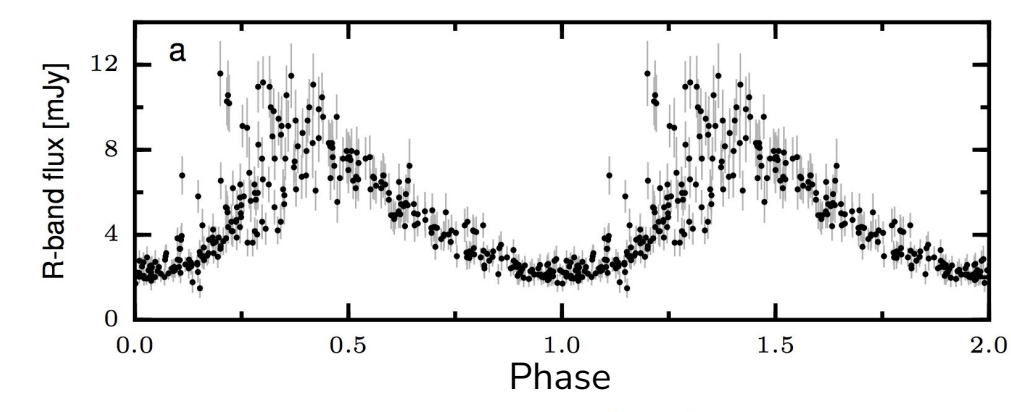
Observed properties:

- Broad emission lines + stochastic flares.
- Fast spinning white dwarf.
- Rapid spin-down.
- Non-thermal emission.

Inferred model:

Highly magnetic white dwarf flunging blobs of material that emit non-thermally.

The first binary white dwarf pulsar: AR Sco

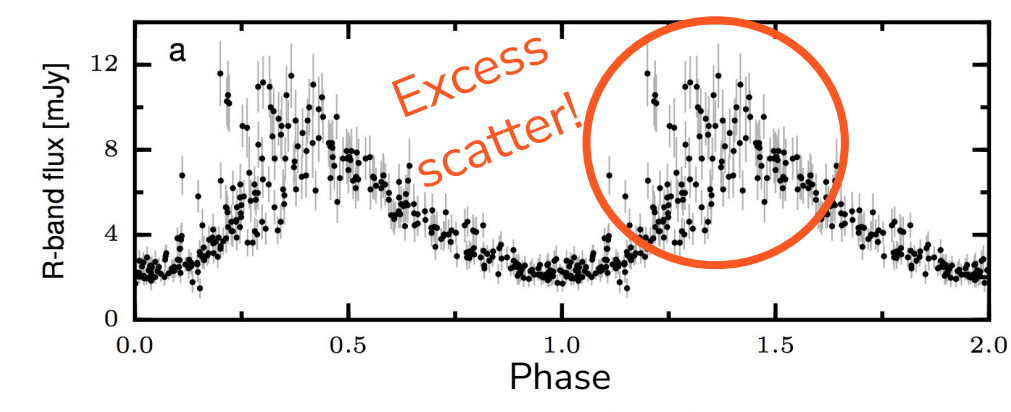


Light curve from the Catalina Sky Survey showing a 3.56-h period.

(30-sec exposures)

Marsh et al. 2016

The first binary white dwarf pulsar: AR Sco

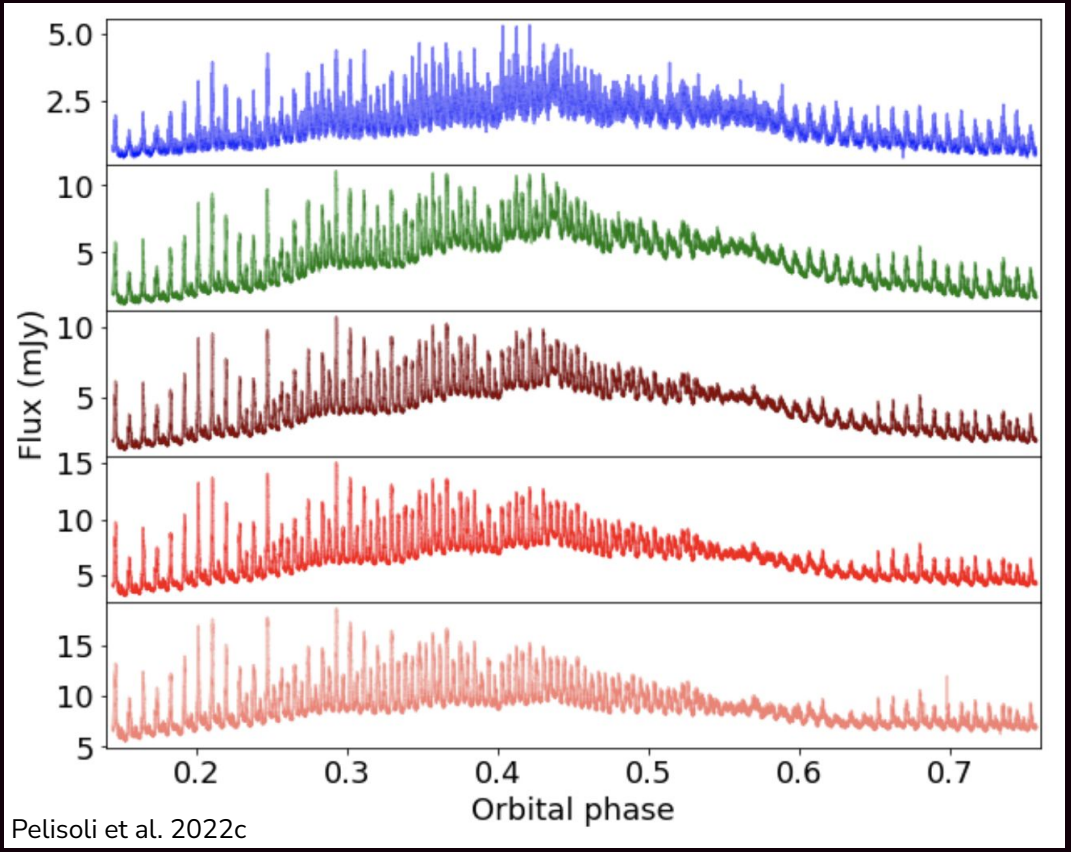


Light curve from the Catalina Sky Survey showing a 3.56-h period.

(30-sec exposures)

Marsh et al. 2016

Detection of strong pulses in the optical

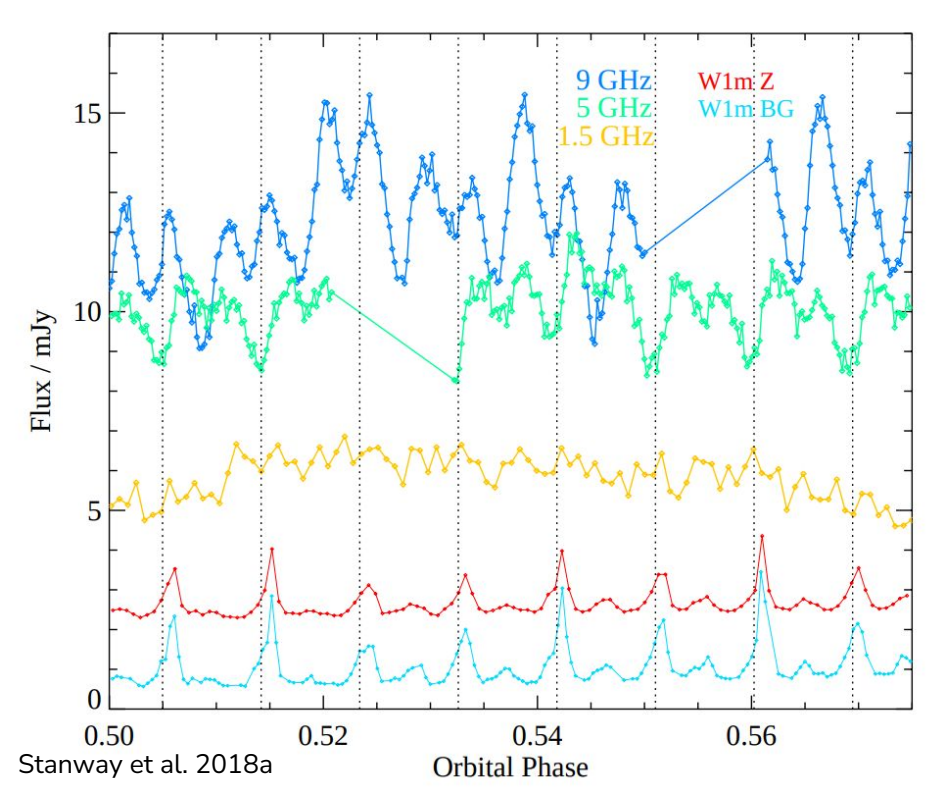


Pelisoli et al. 2022c

High-speed photometry obtained with HiPERCAM.

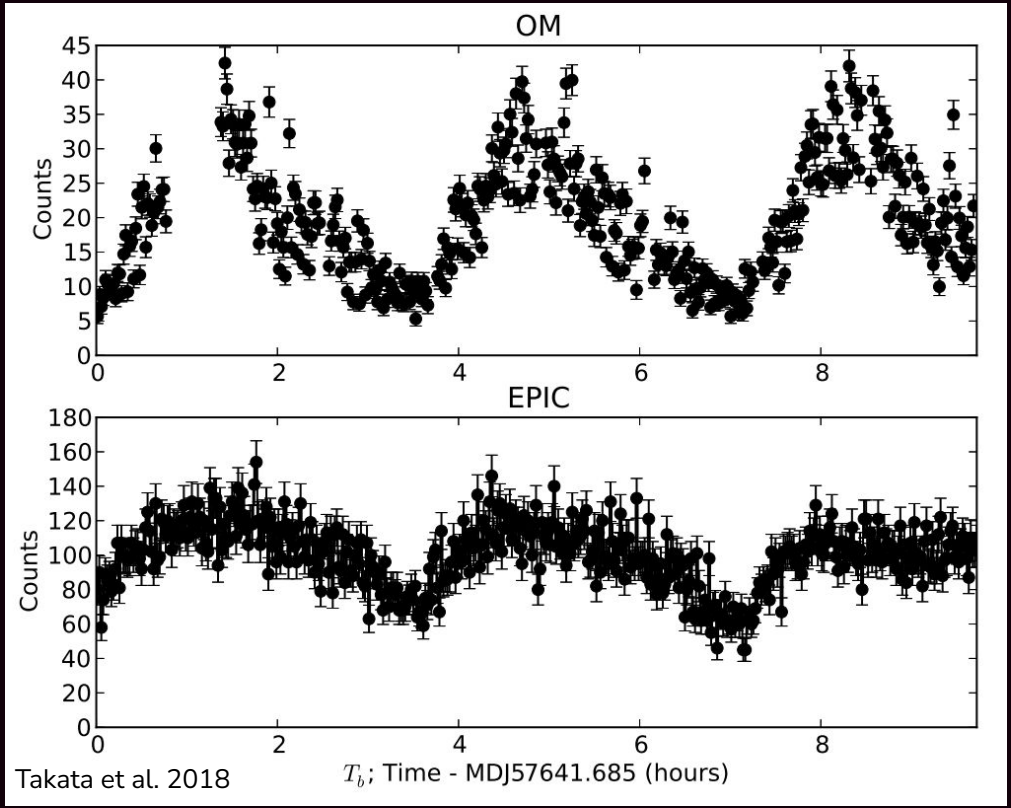
(0.1-sec exposures)

Pulses also detected in radio



Stanway et al. 2018a

Pulses also detected in X-rays

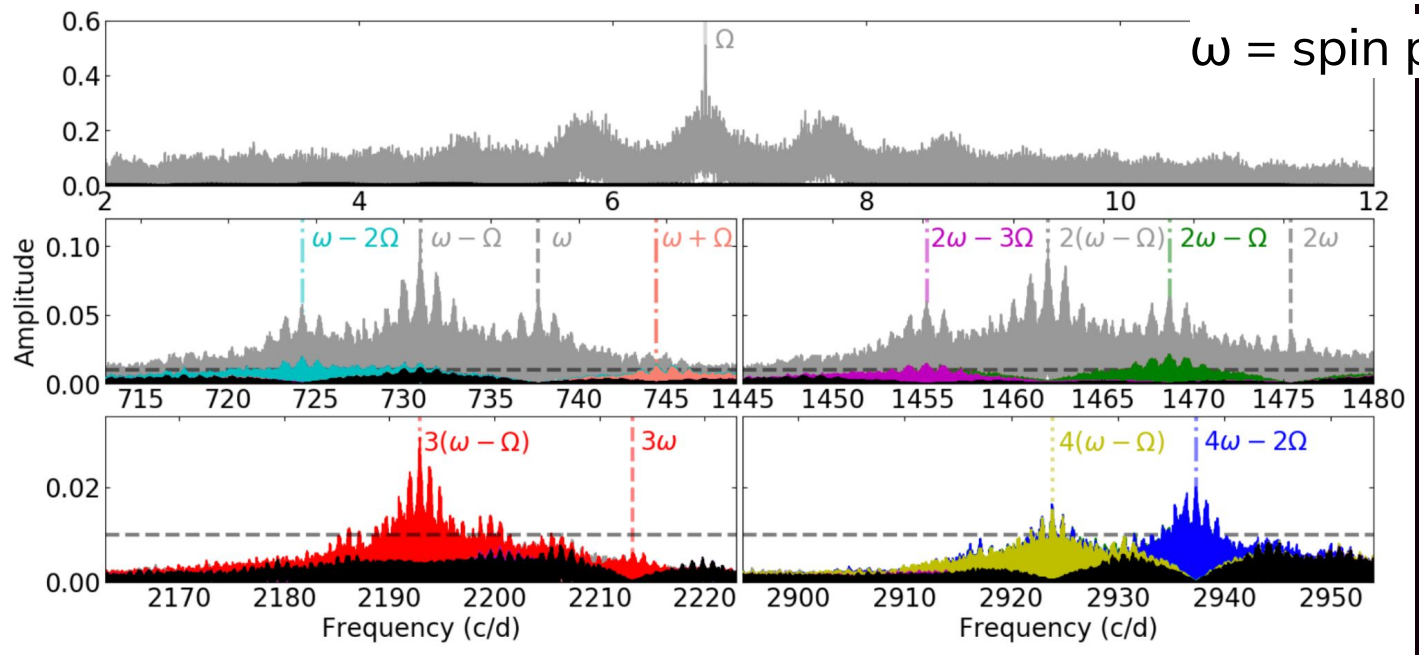


Takata et al. 2018

Binary white dwarf pulsars: AR Sco

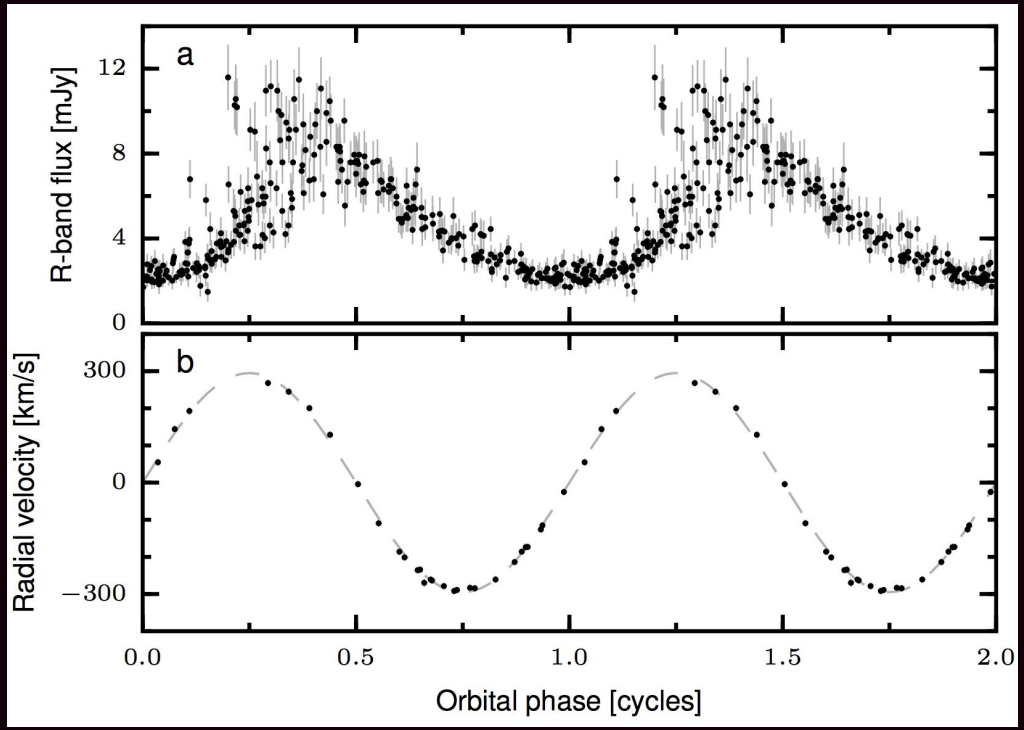
Ω = orbital period = 3.56 h

ω = spin period = 1.95 min



Pelisoli et al. 2022c

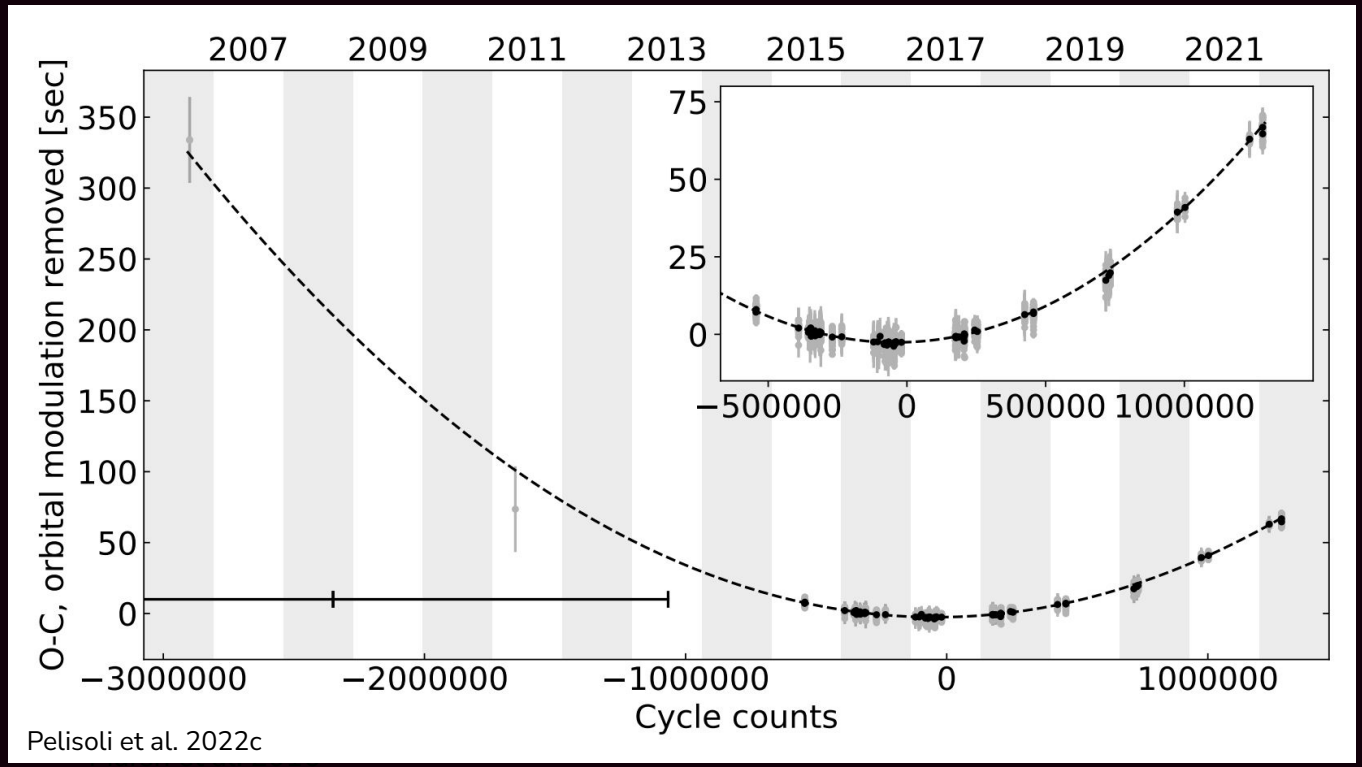
Binary white dwarf pulsars: AR Sco



Marsh et al. 2016

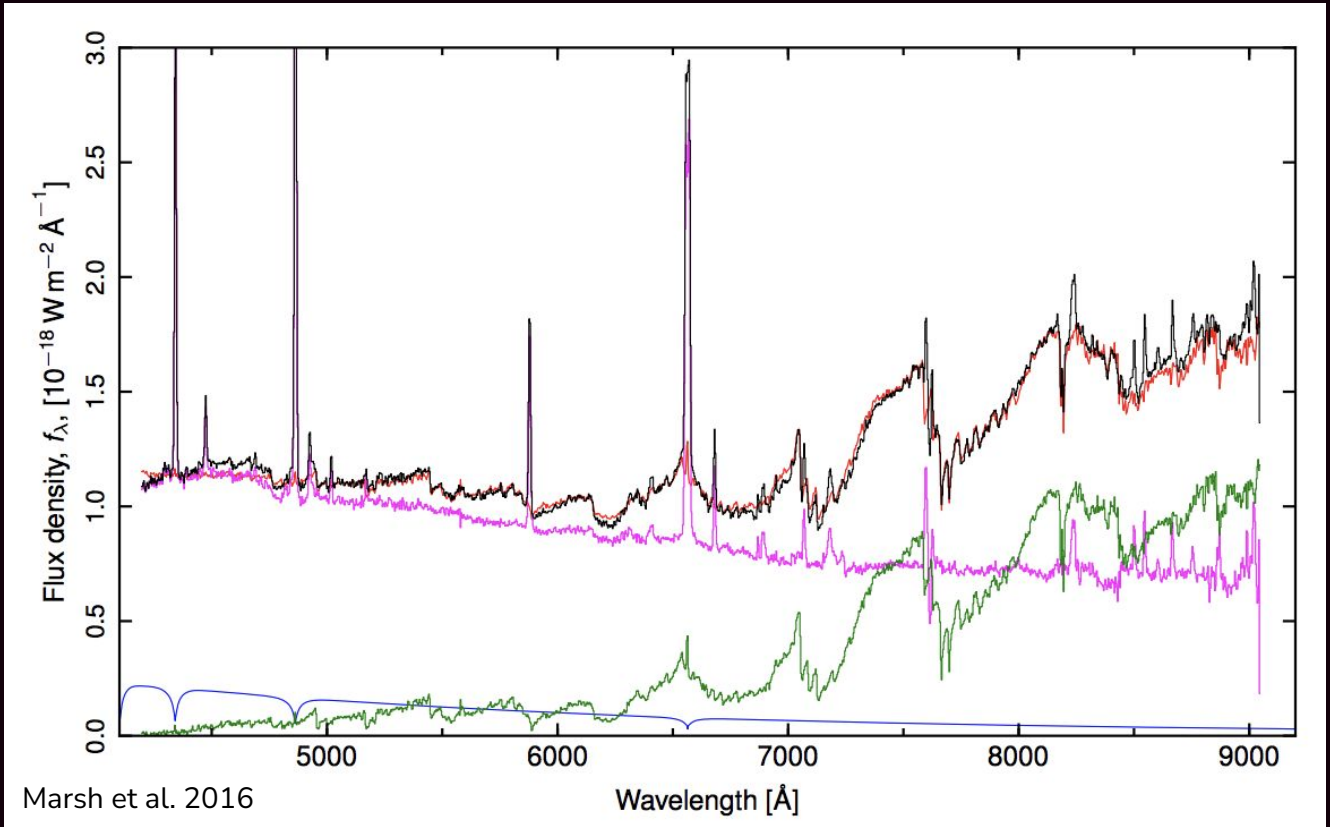
Variability observed originally is due to orbital modulation!

Spin-down in AR Sco: 6.62×10^{-13} s/s



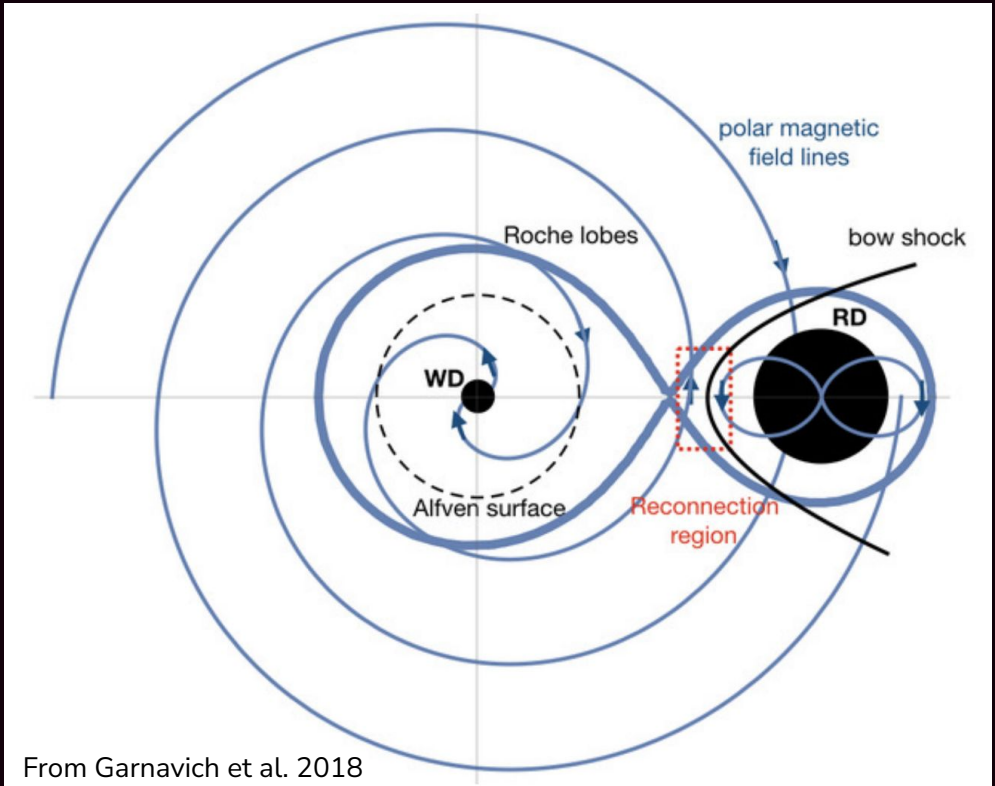
Pelisoli et al. 2022c

Narrow emission lines: no mass transfer



Marsh et al. 2016

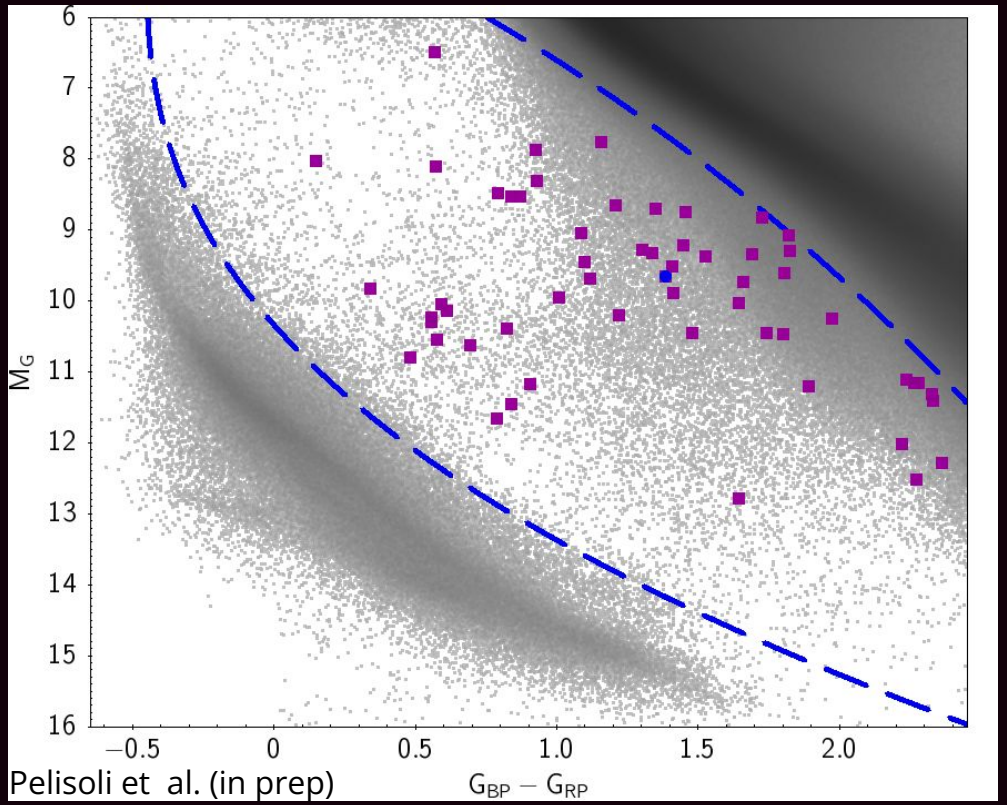
Development of a ~~pulsar~~ binary interaction model



From Garnavich et al. 2018

Finding a second pulsar: J1912

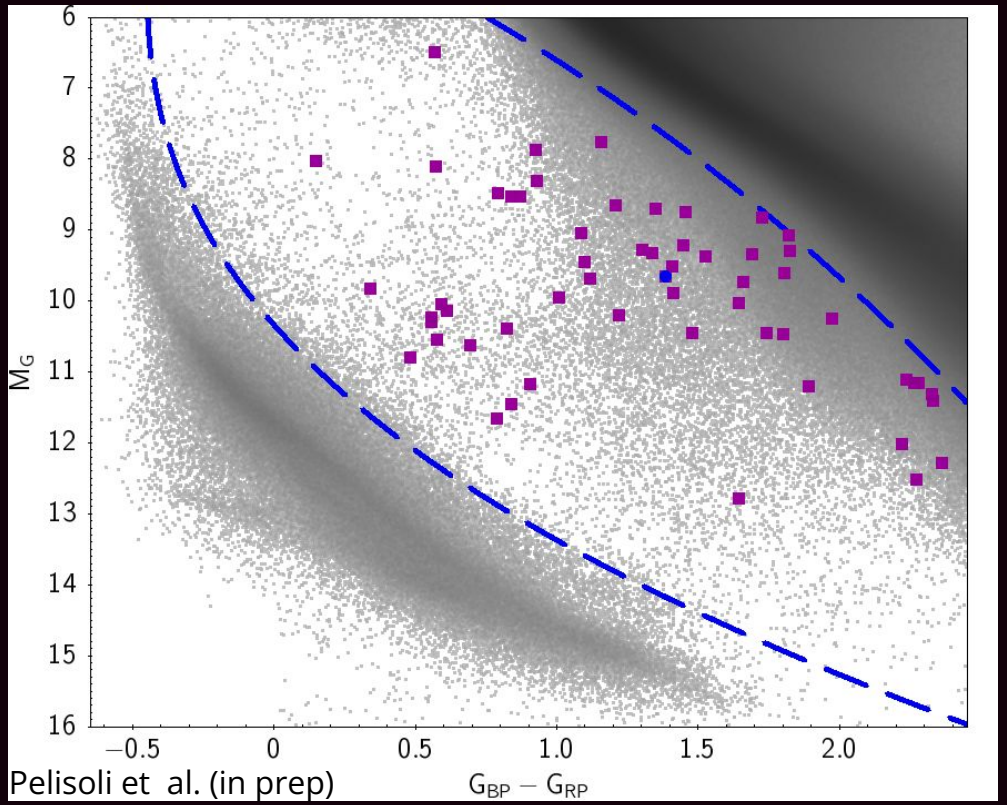
Finding a second pulsar: J1912



Pelisoli et al. (in prep)

56 candidates with similar characteristics to AR Sco

Finding a second pulsar: J1912

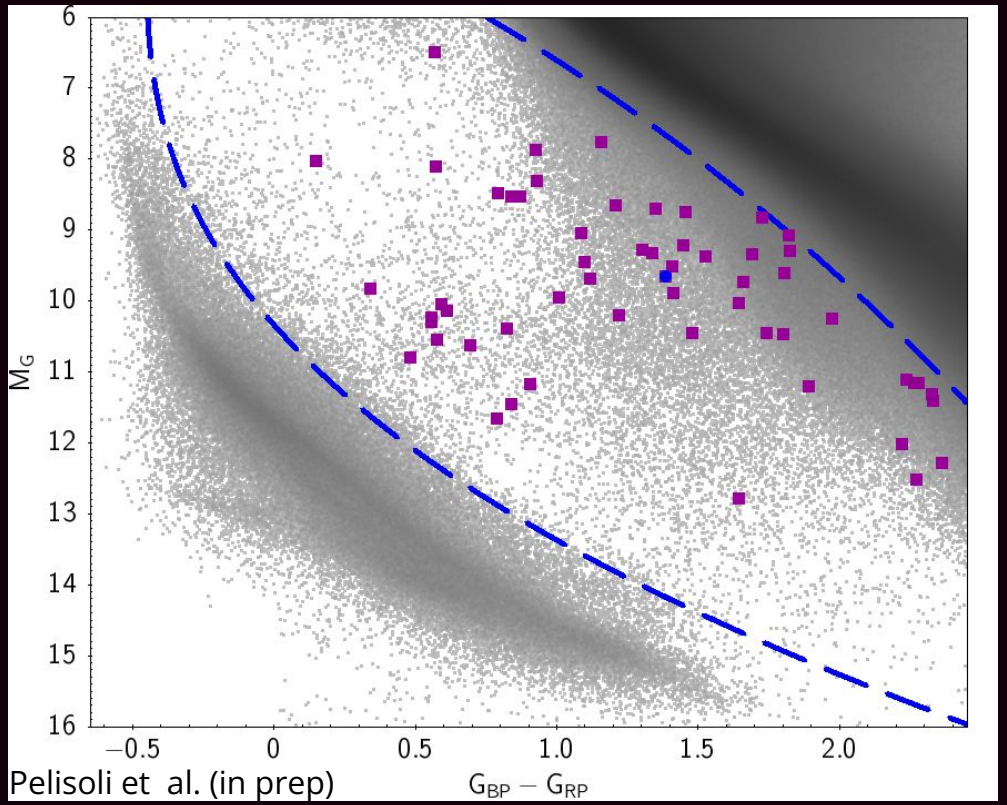


Pelisoli et al. (in prep)

56 candidates with similar characteristics to AR Sco:

- colour-magnitude
- infrared variability
- infrared colours

Finding a second pulsar: J1912



Pelisoli et al. (in prep)

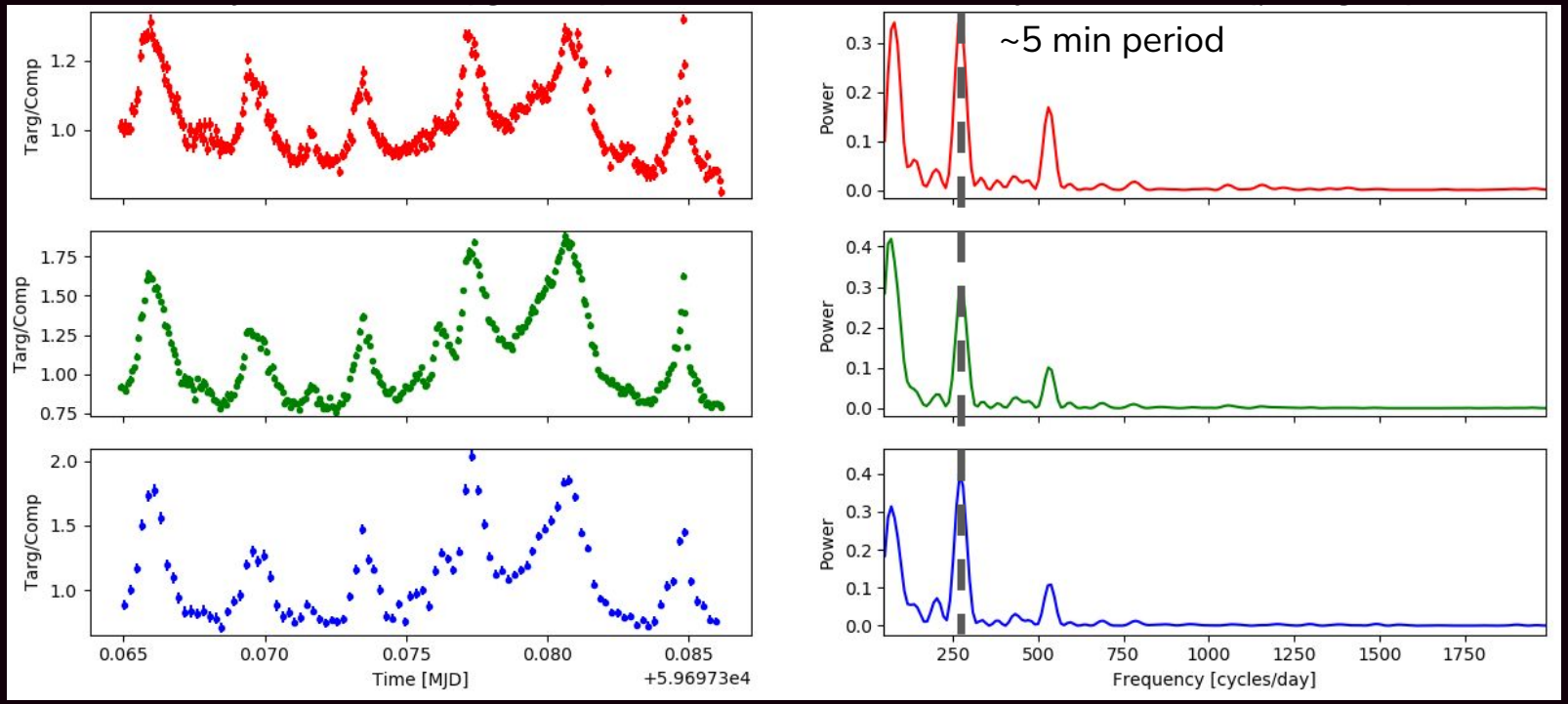
56 candidates with similar characteristics to AR Sco:

- colour-magnitude
- infrared variability
- infrared colours

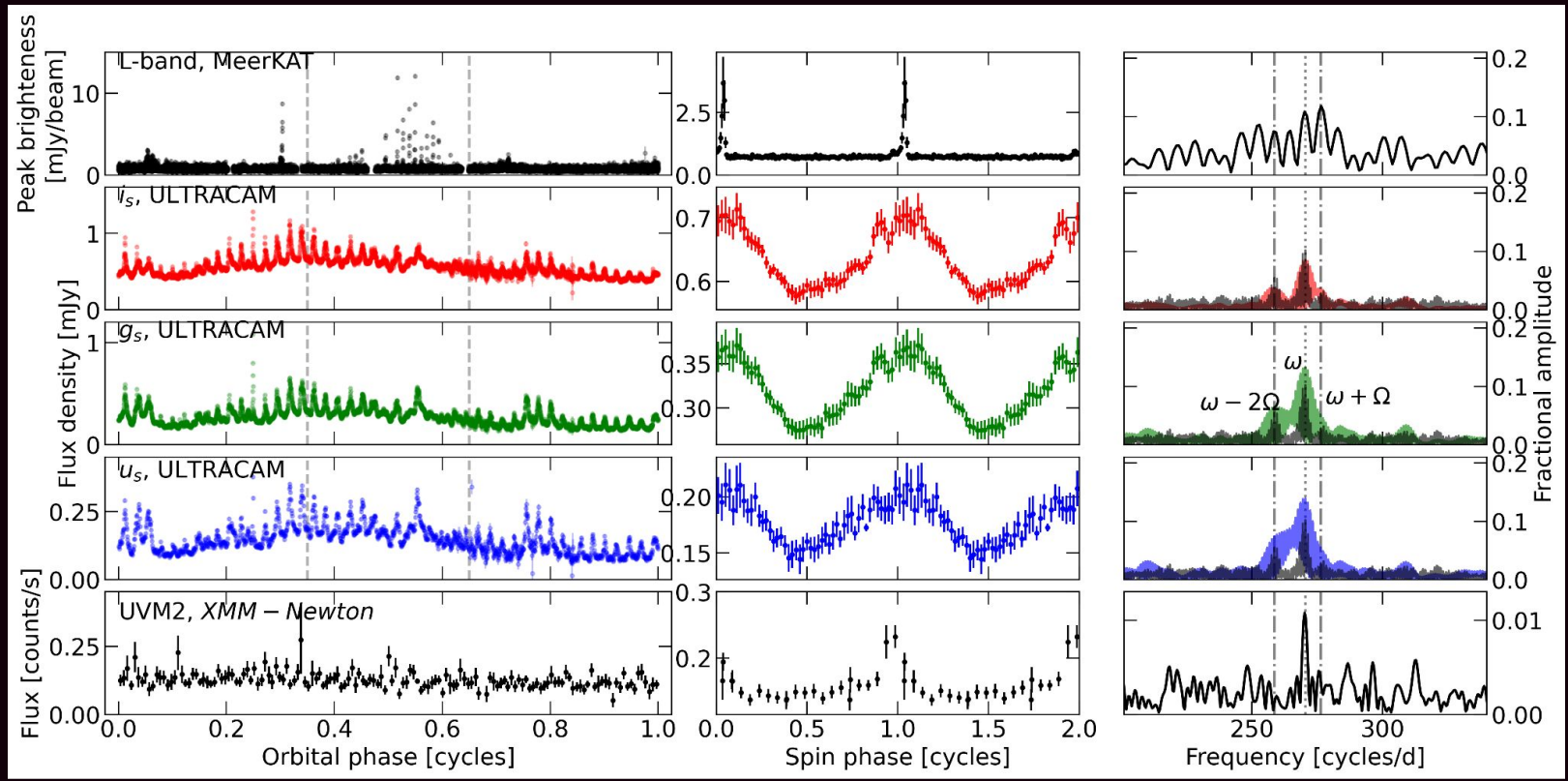
Follow-up:

- light curves
- spectra

Preliminary data showed a possible fast spin

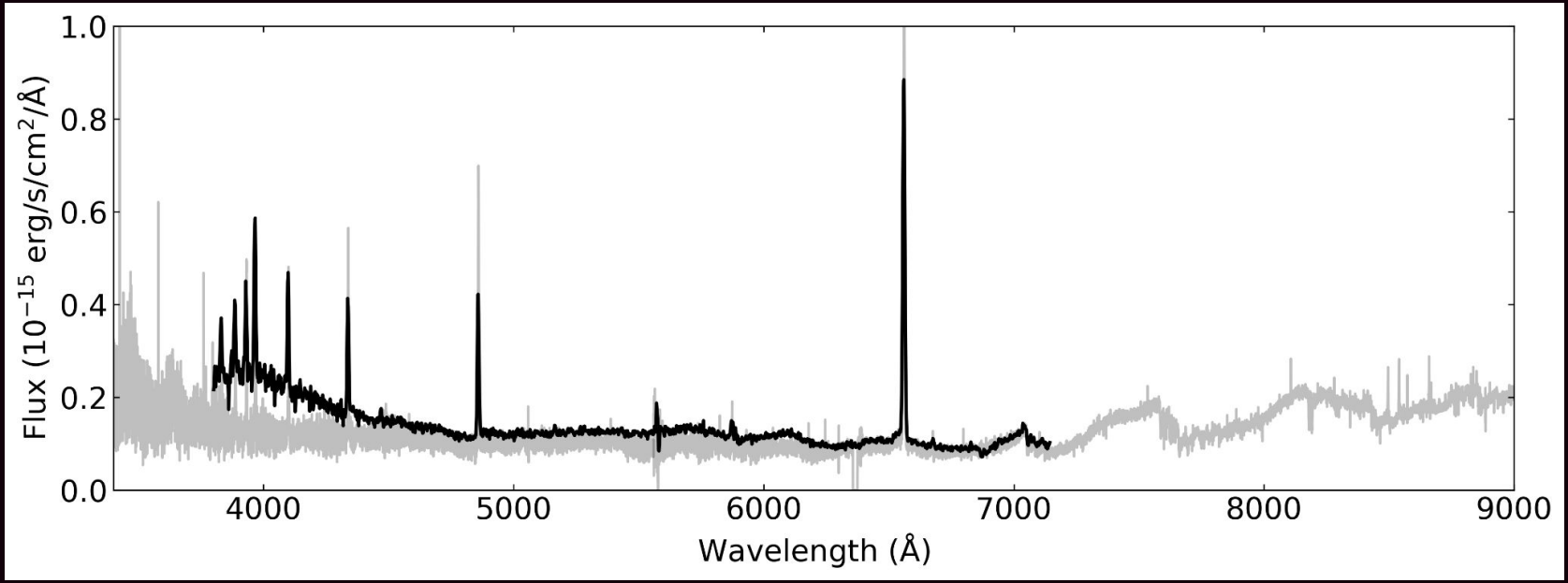


Pulses then detected from radio to X-rays

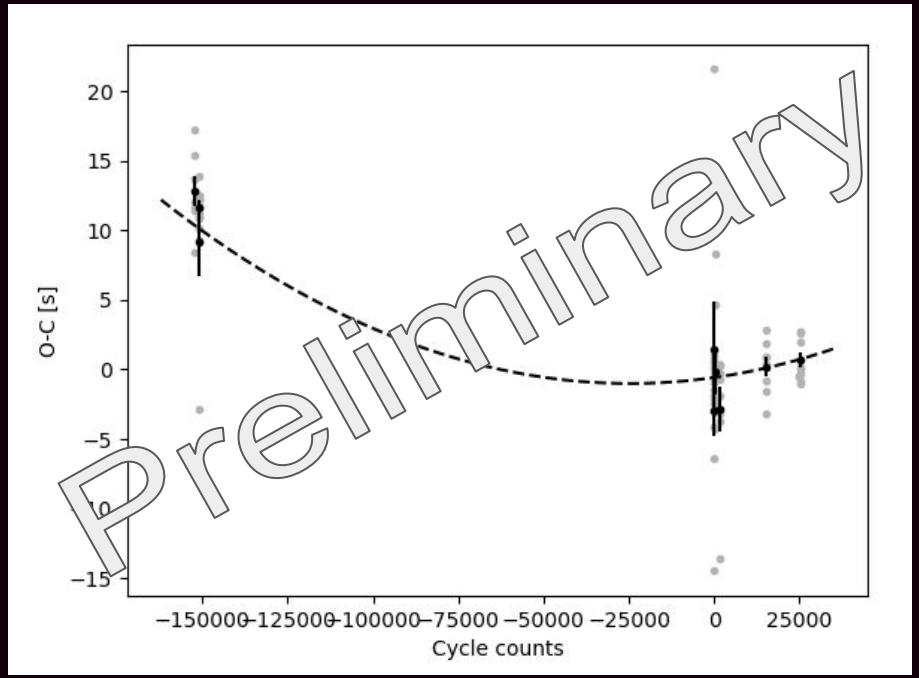


Updated version of plot from Pelisoli et al. 2023

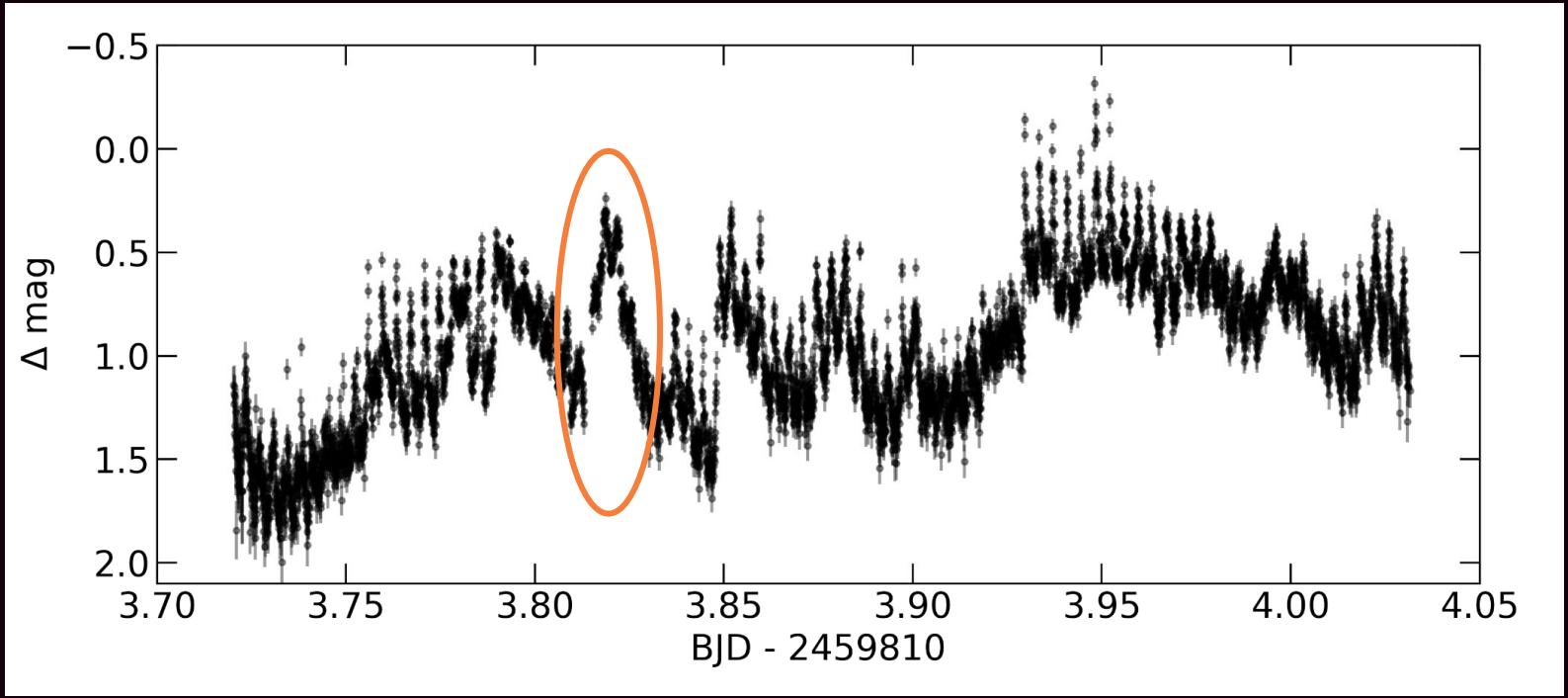
Narrow lines indicating no persistent mass transfer



Recent detection of a spin-down



Caveat: possible flaring behaviour



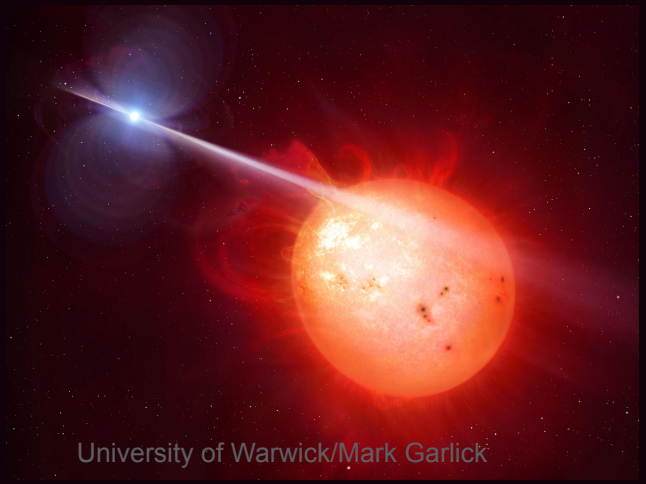
Pelisoli et al. 2023

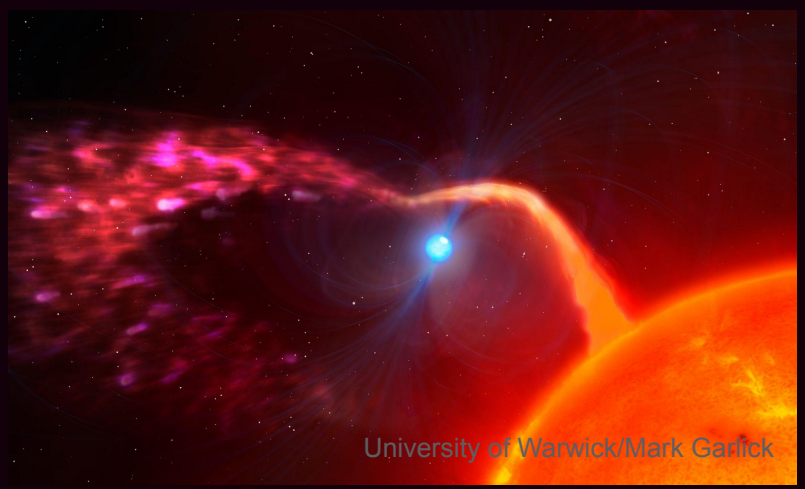
Observed properties:

- Narrow emission lines + periodic pulses.
- Fast spinning white dwarf.
- Rapid spin-down.
- Non-thermal emission.

Inferred model:

Magnetic field of white dwarf and companion interact and accelerate electrons.





Propellers:

- Broad emission lines + stochastic flares.
- Fast spinning white dwarf.
- Rapid spin-down.
- Non-thermal emission.

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Highly magnetic white dwarf flunging blobs of material that emit non-thermally.

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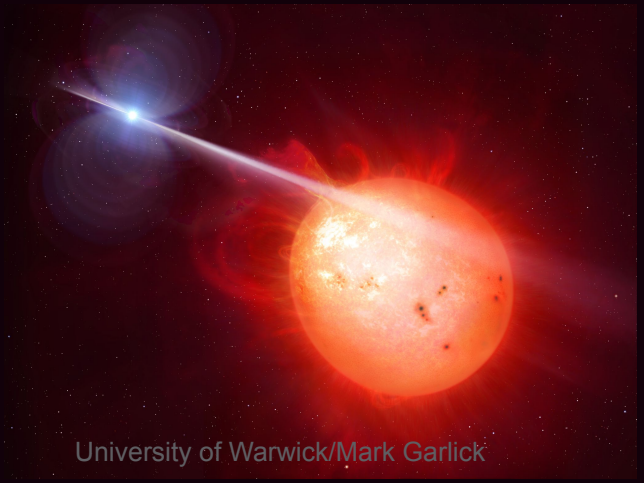
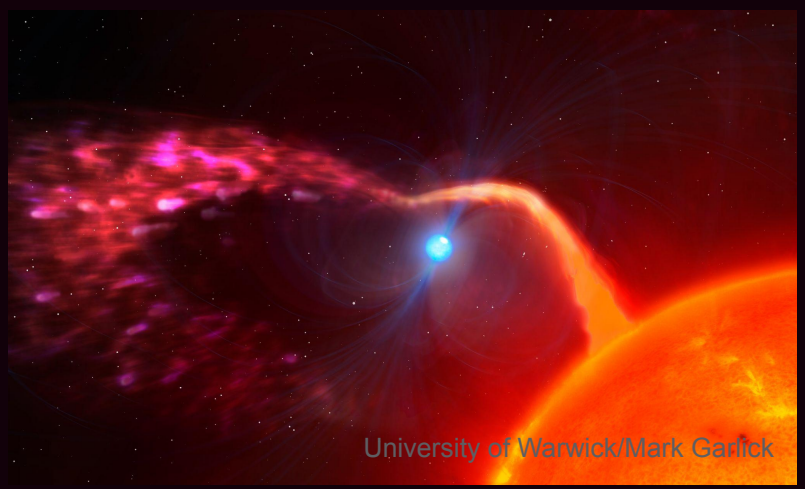
Magnetic fields of white dwarf and companion interact and accelerate electrons.





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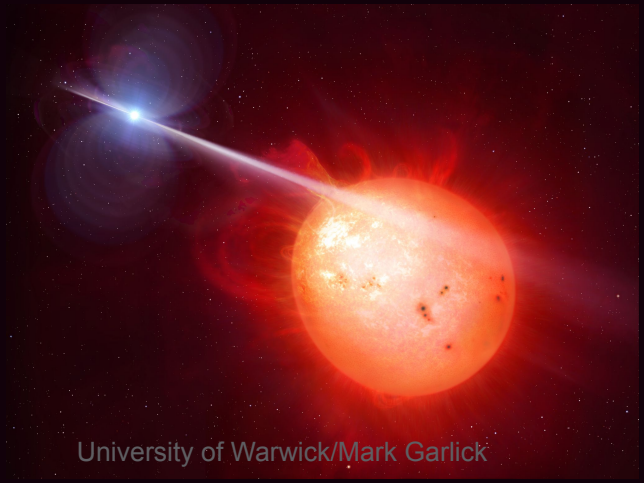

What makes propellers and binary pulsars different from normal cataclysmic variables?

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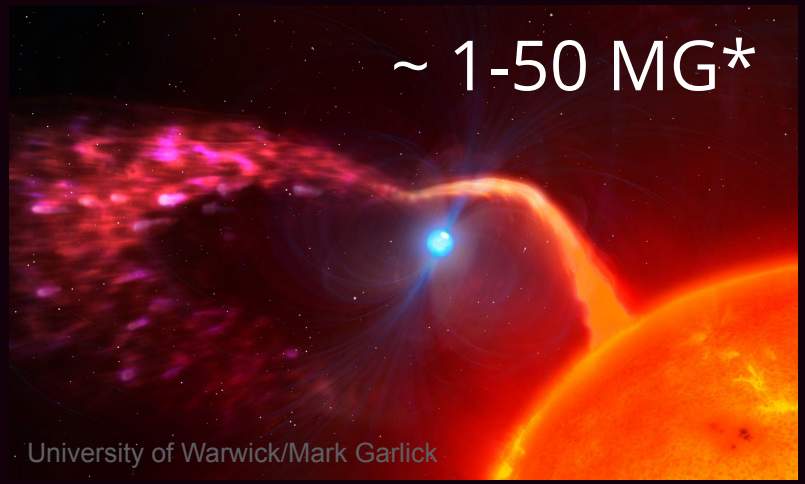

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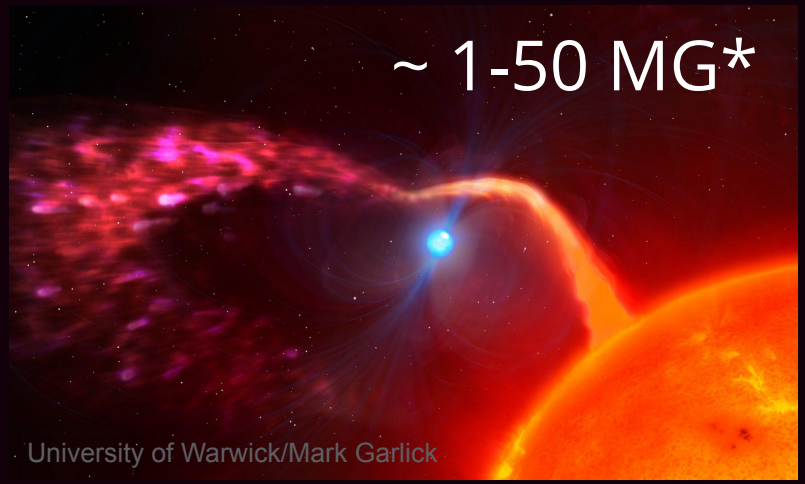

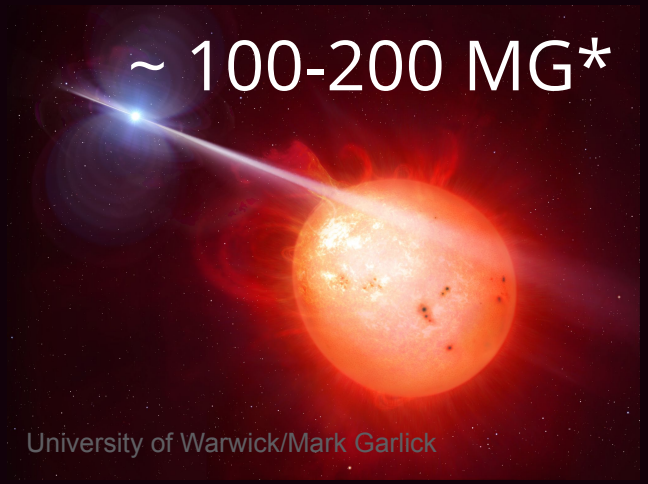

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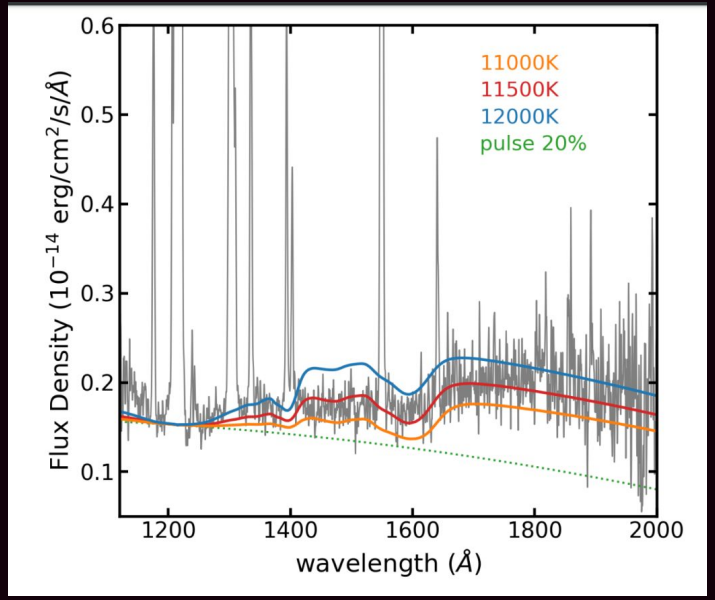

AR Sco: <100 MG (Garnavich et al. 2021)

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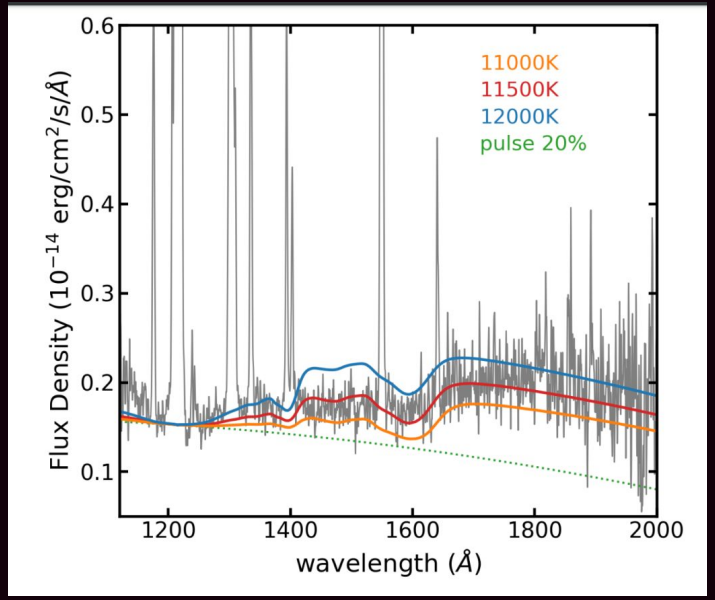

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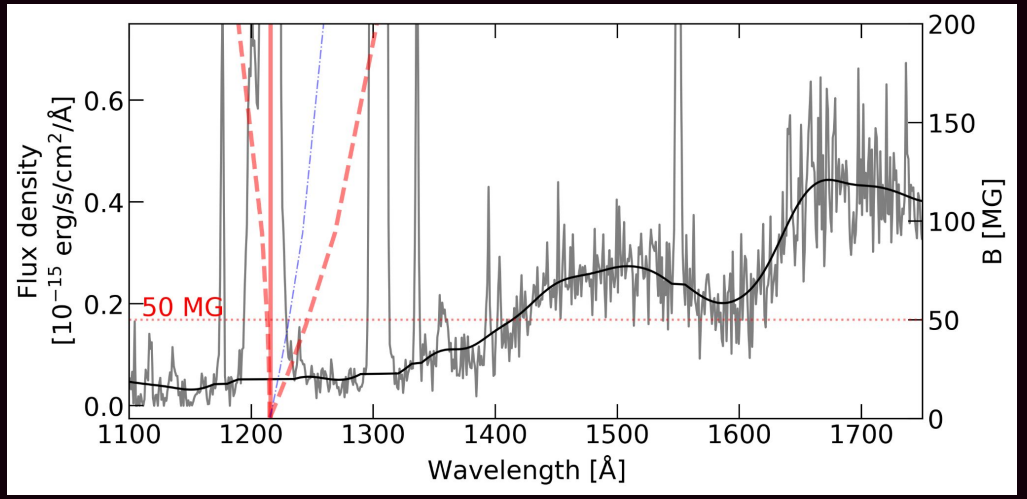

J1912: <50 MG (Pelisoli et al. 2024a)

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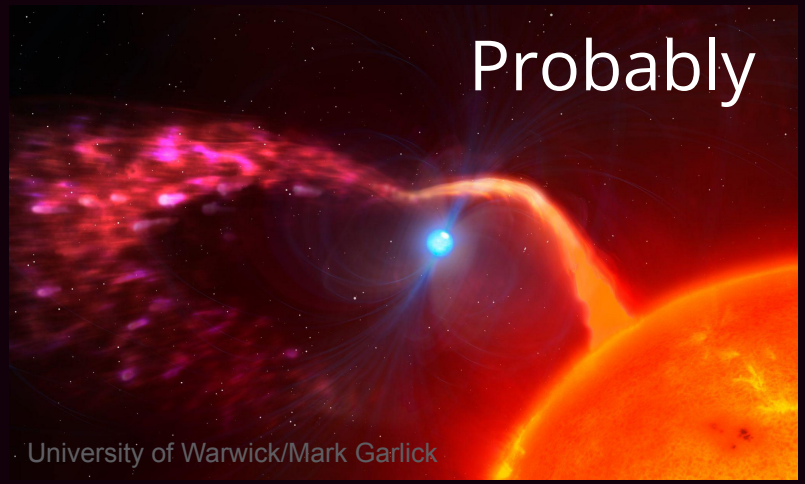

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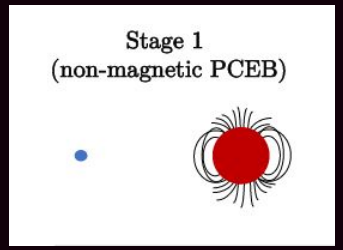
Option 2: they’re not different

A possible evolutionary model

Schreiber et al. 2021, NatAs, 5, 648



1. Slowly rotating white dwarf in a detached binary.

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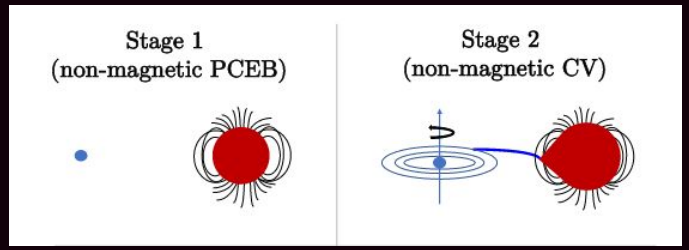

1. Slowly rotating white dwarf in a detached binary.
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It is observed as a normal cataclysmic variable.

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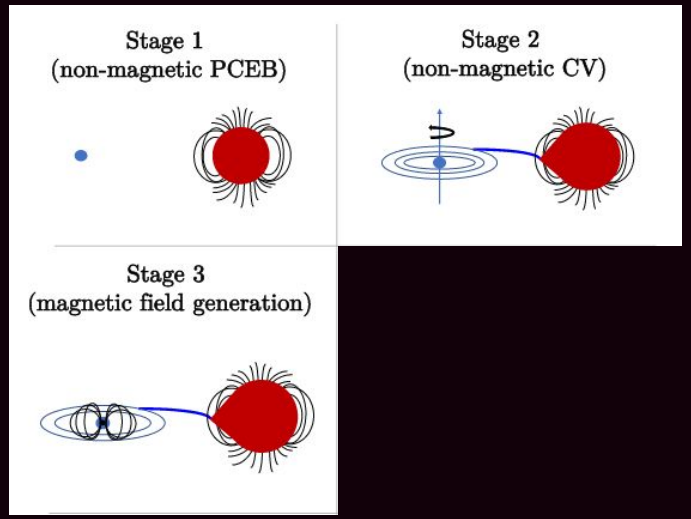

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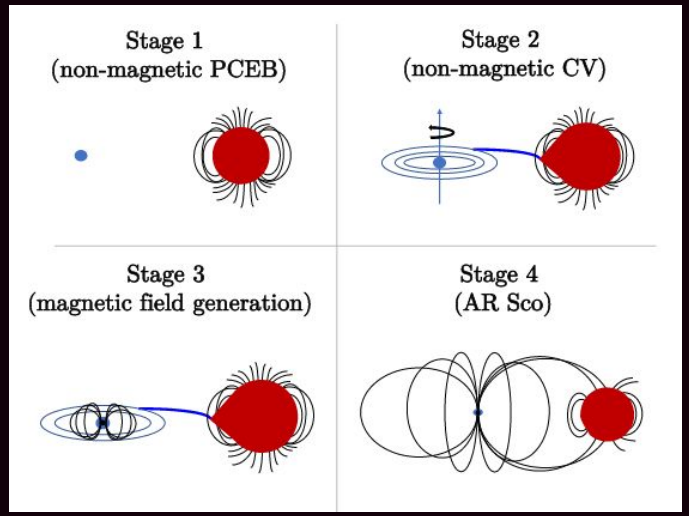

1. Slowly rotating white dwarf in a detached binary.
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4. When the field connects with the field of the secondary, the system becomes detached.

It is observed as AR Sco.

Residual mass transfer could explain the flares in J1912.

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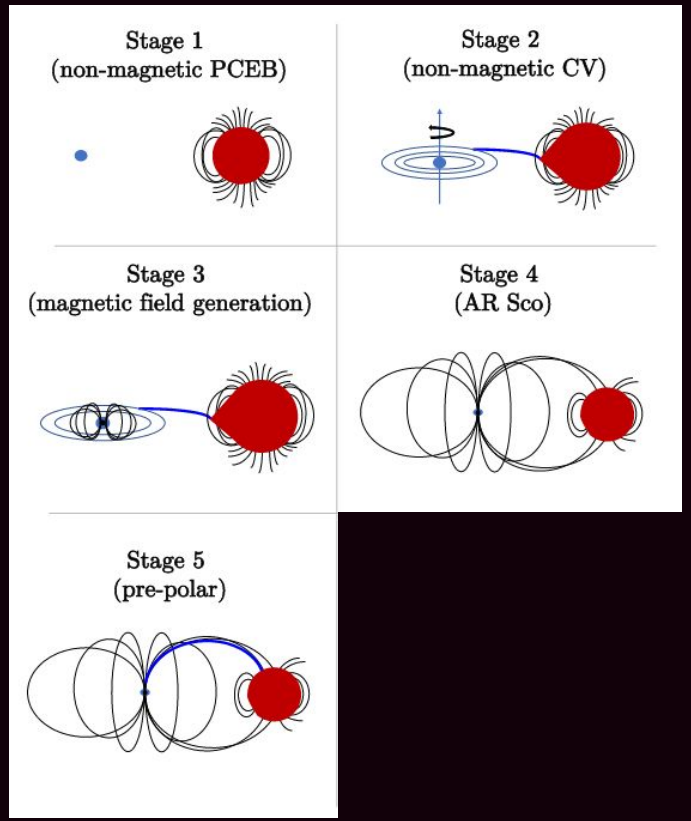

1. Slowly rotating white dwarf in a detached binary.
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It is observed as a pre-polar.

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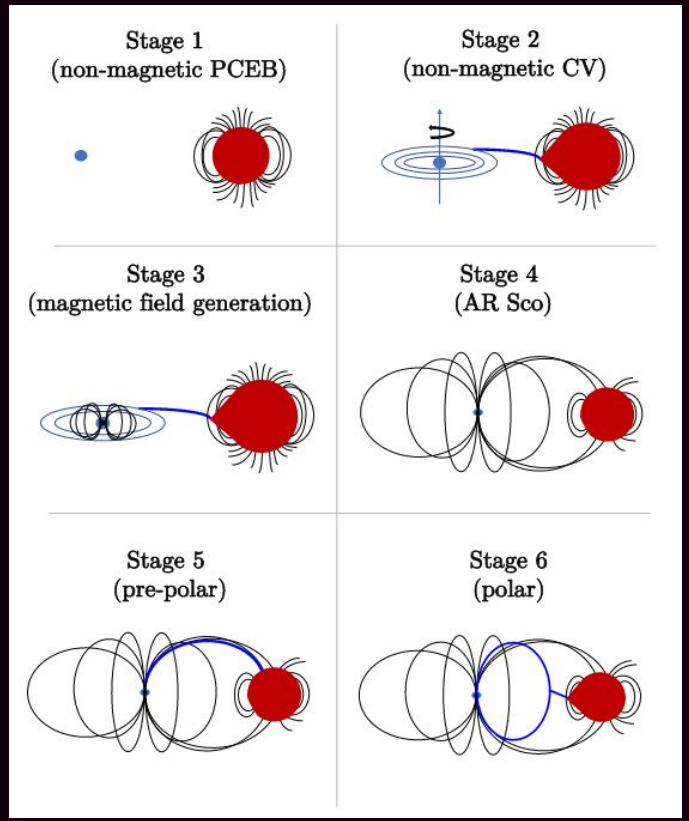

1. Slowly rotating white dwarf in a detached binary.
2. White dwarf is spun-up by accretion.
3. If the white dwarf is crystallising, a strong magnetic field is generated by a dynamo.
4. When the field connects with the field of the secondary, the system becomes detached.
5. The spin of the white dwarf and the orbital motion become synchronised.
6. Mass transfer starts again.

It is observed as a polar.

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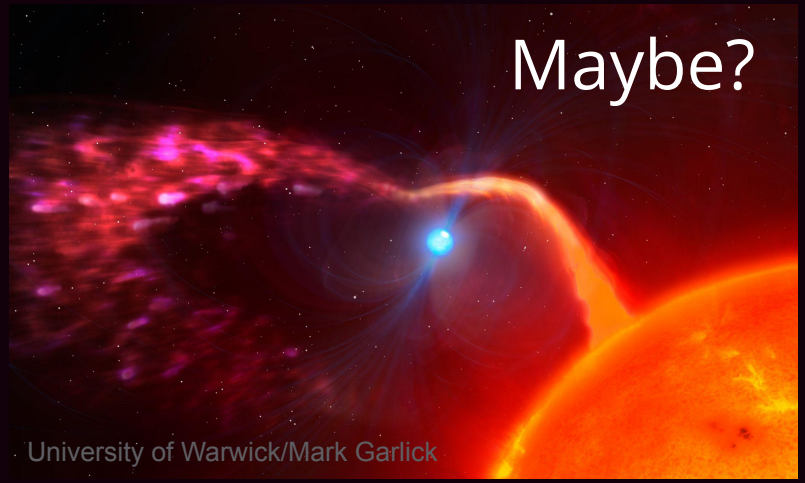
Option 2: they're not different



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Existence could be attributed to occurrence of rapid spin and strong magnetic field.

Existence could be attributed to a stage in the evolution of CVs.

Summary

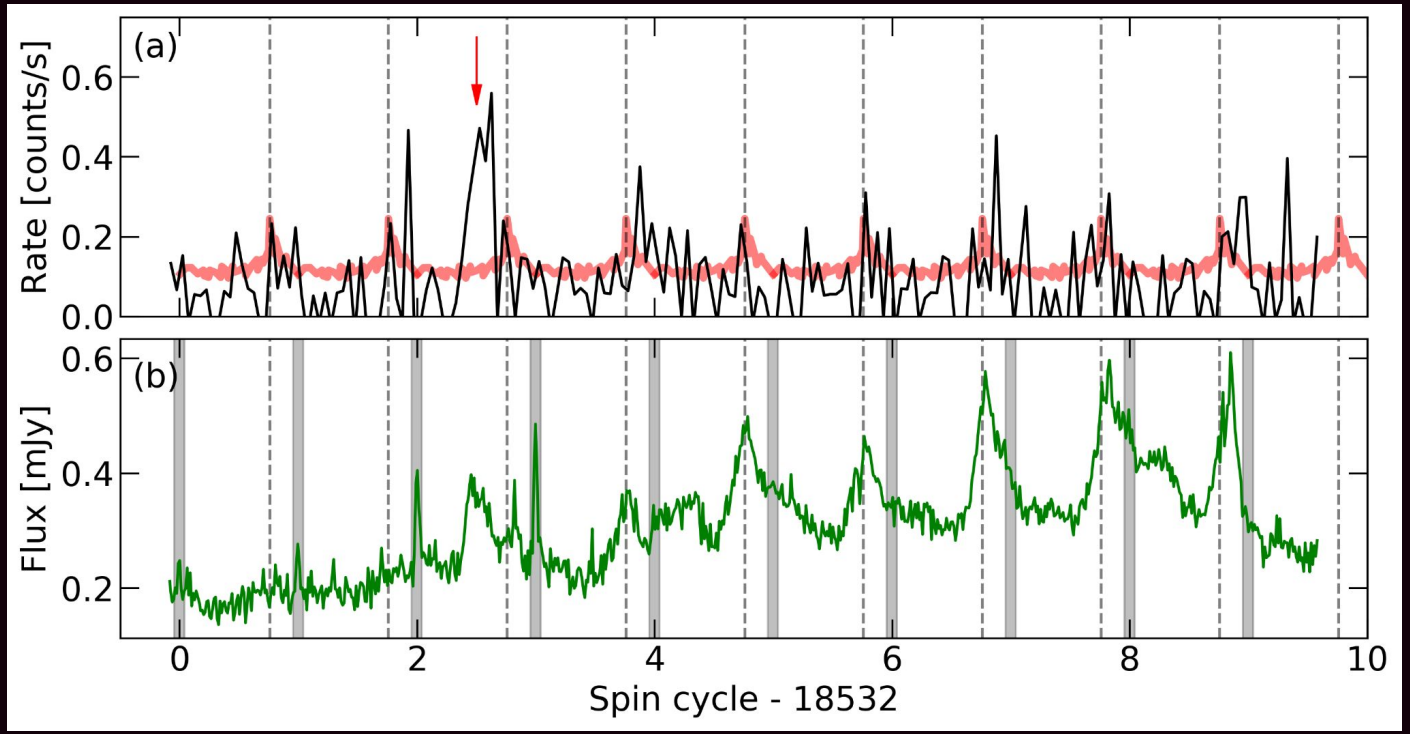
Propellers **Pulsars**

We need more of both!

Scan to read about a search for radio emitting white dwarfs in Pelisoli et al. 2024b

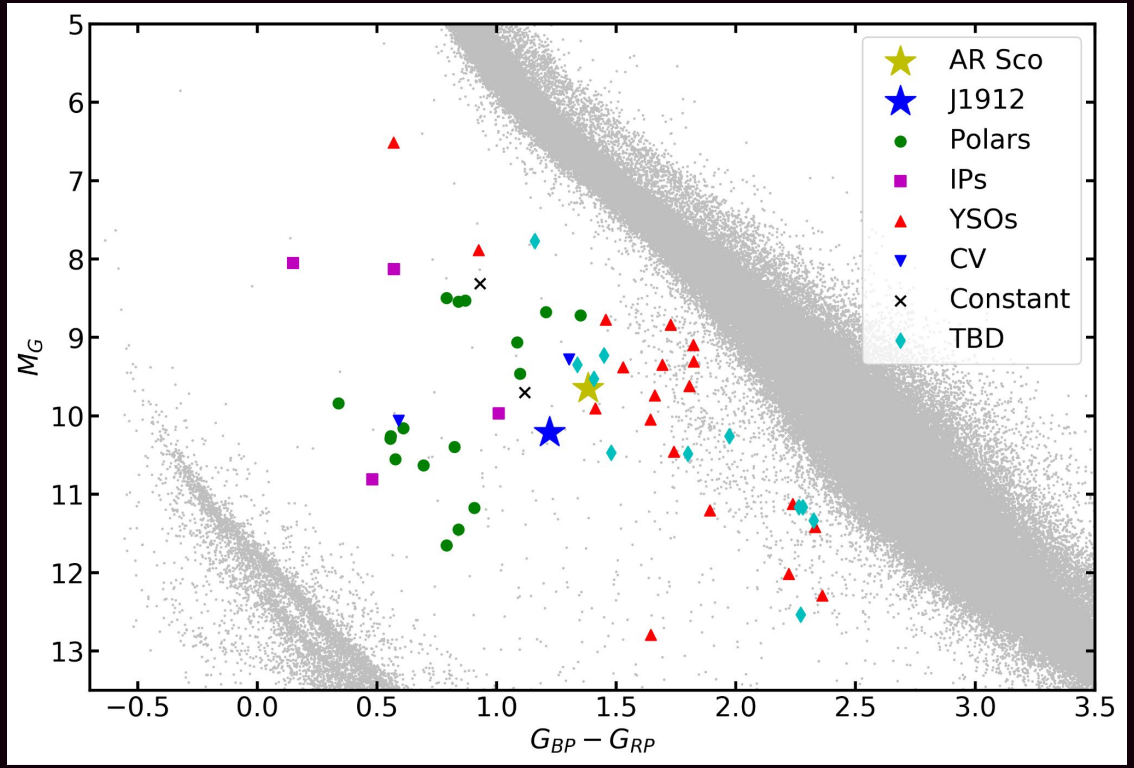
Thanks! – ingrid.pelisoli@warwick.ac.uk

Caveat: possible flaring behaviour

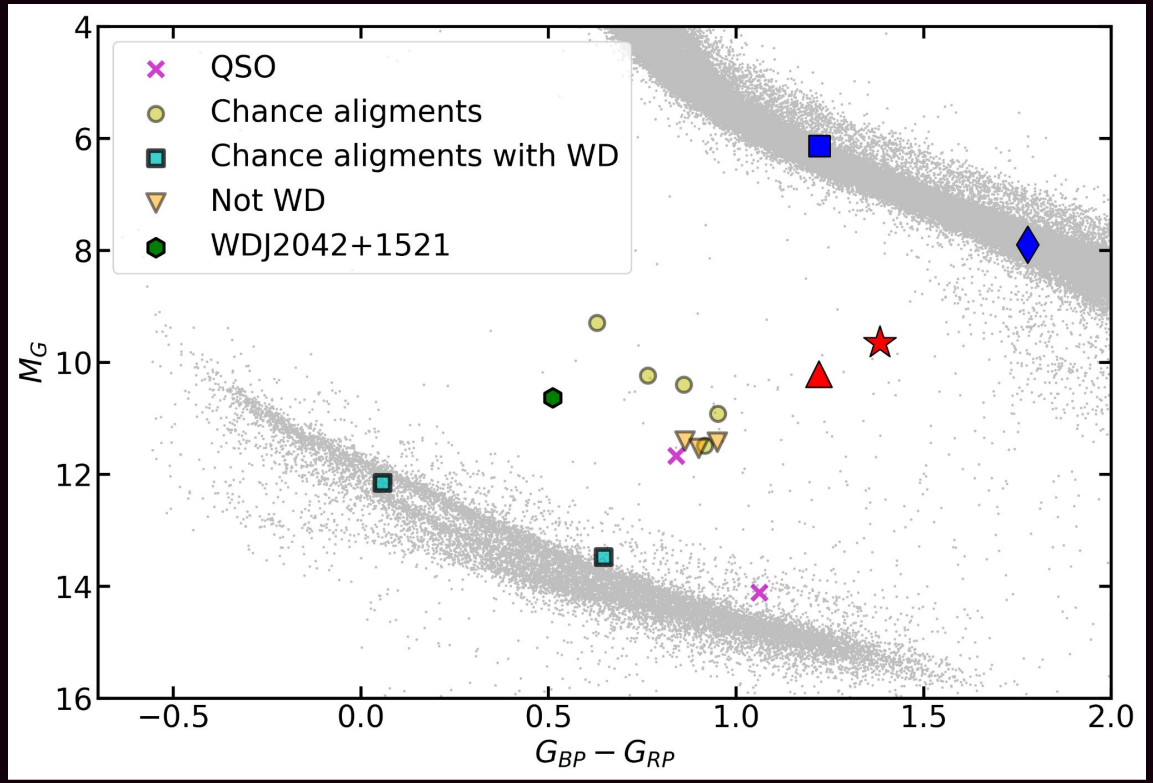


Pelisoli et al. 2023

Results of the full Gaia search



Results of the radio search



X-ray spectrum

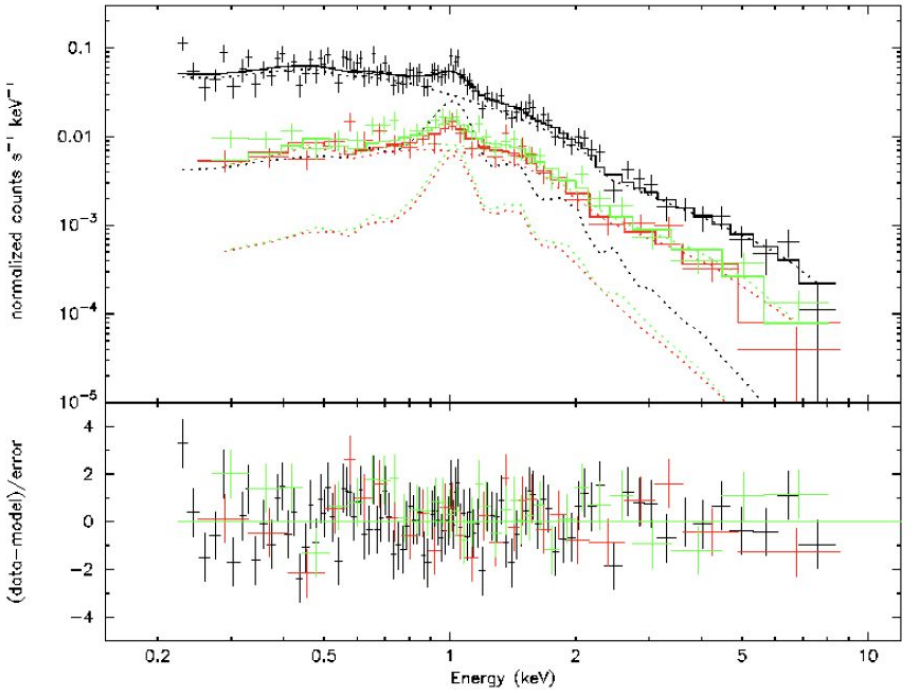


Fig. 7. *XMM-Newton* spectra obtained with EPIC-pn, -MOS1, and -MOS2 with a power-law plus thermal model fit. Lower panel shows the error-normalized residuals (black: pn, red: MOS1, green: MOS2).

Schwope et al. 2023