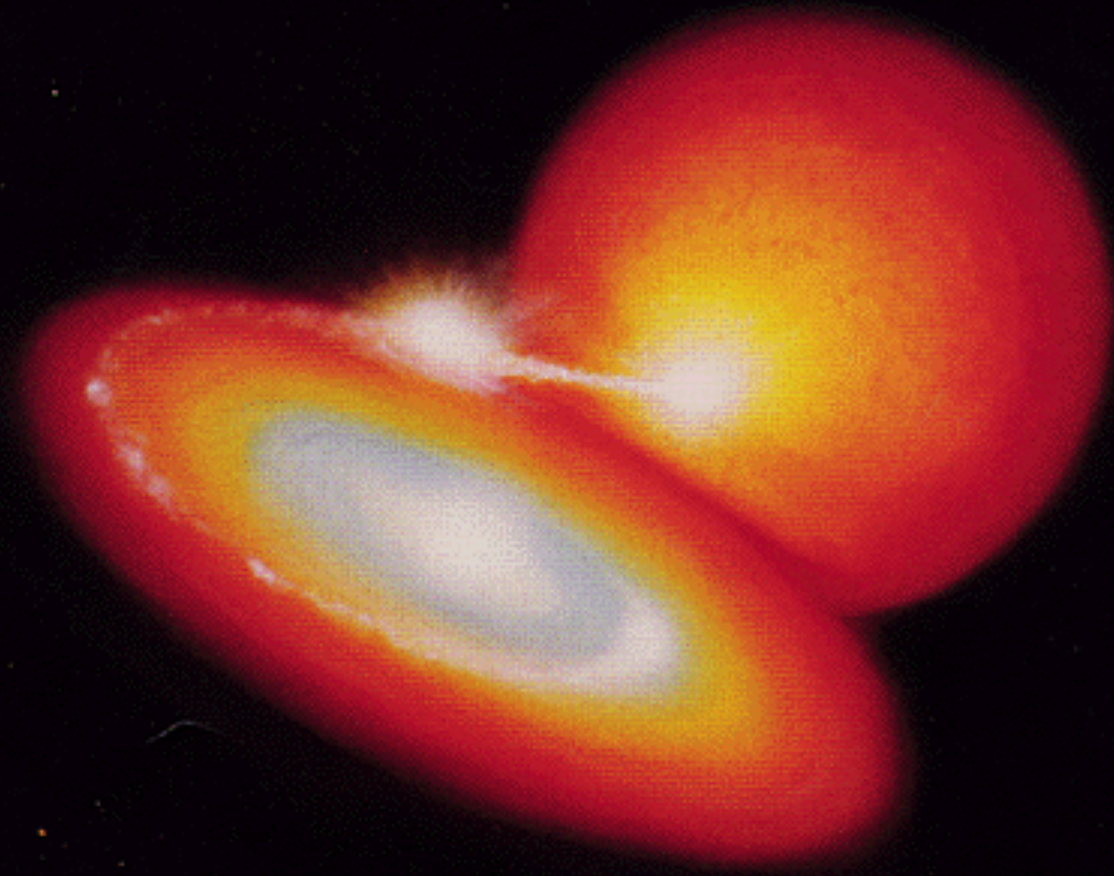


# Transient and Compact Objects

## Multiwavelength Observations of Cataclysmic Variables and related objects

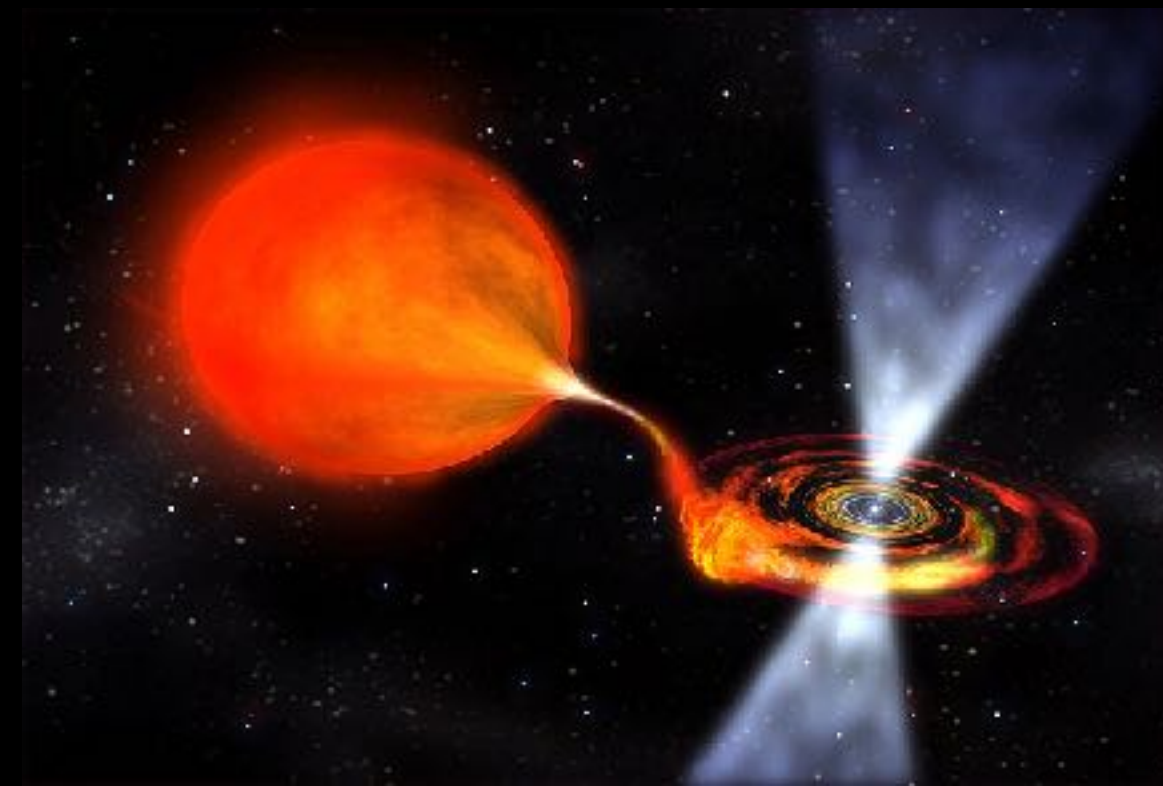
Collaborators: Rob Fender, Paul Groot, Elmar Koerding, Deanne Coppejans, Christian Knigge, Greg Sivakoff, James Miller-Jones, Dave Williams, David Buckley, Zwido Khangale, Retha Pretorius, Dante Hewitt, Joris Kersten, Kira Hanmer, Emil Meintjes, Ingrid Pelisoli, Manisha Caleb, Ben Stappers, Ian Heywood, Marisa Geyer, Noel Castro-Segura, Kenzo Sandenberg, Venu Prayag

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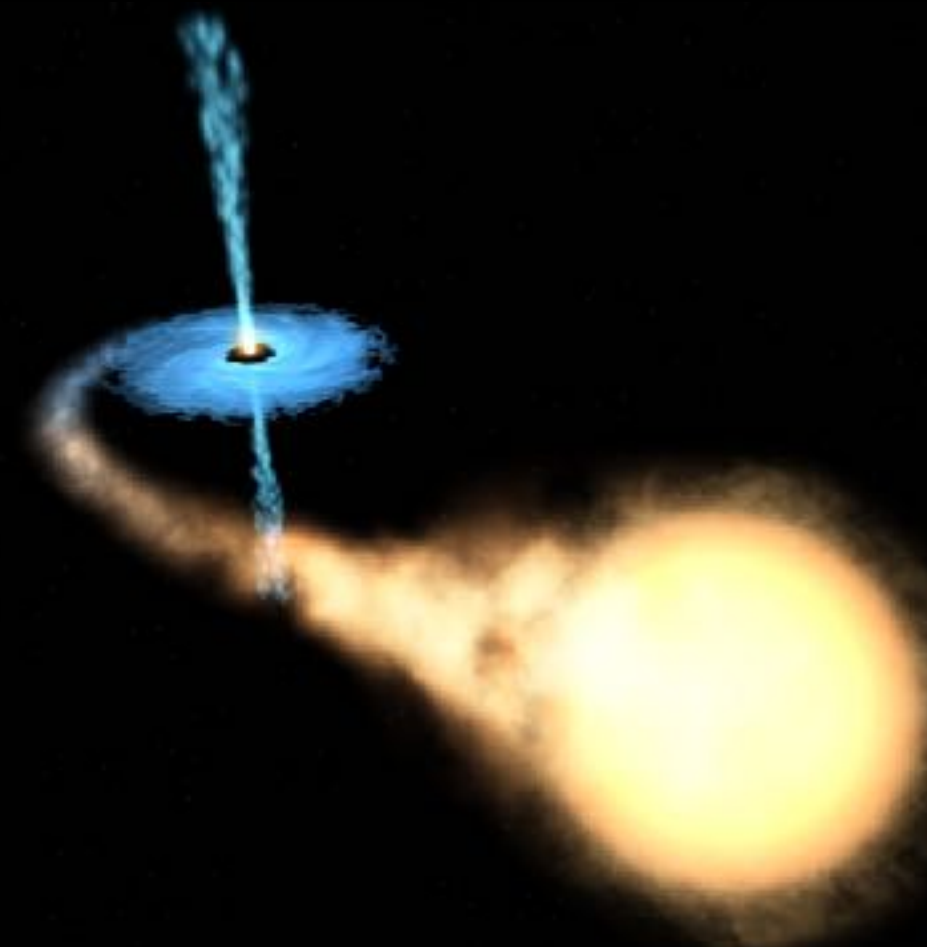
white dwarf  
+ low mass red dwarf

### Symbiotic Binaries



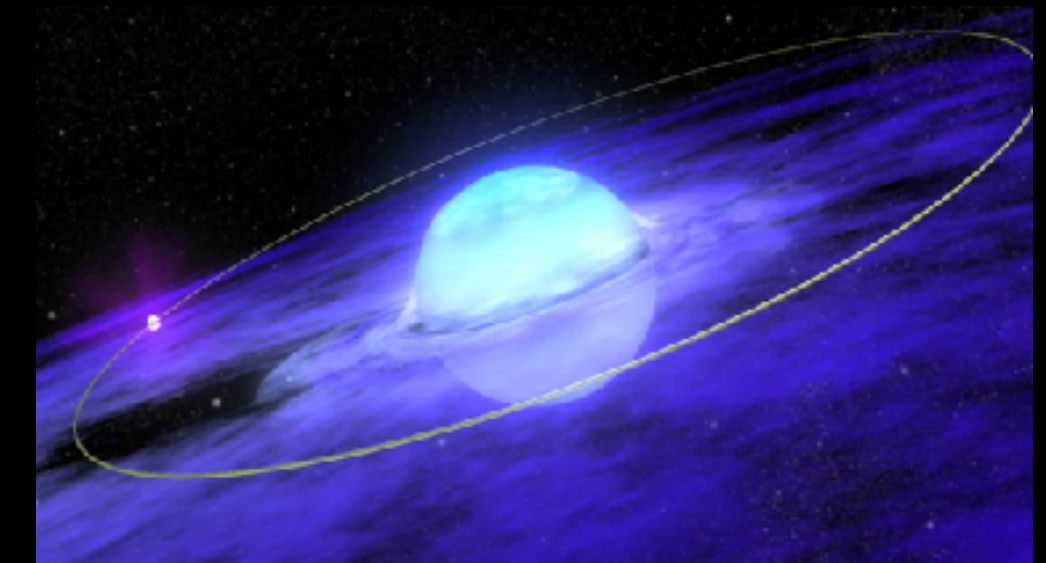
white dwarf  
+ giant companion

### Low mass X-ray binary (LMXB)



neutron star or black hole  
+ low mass red dwarf

### High mass X-ray binary



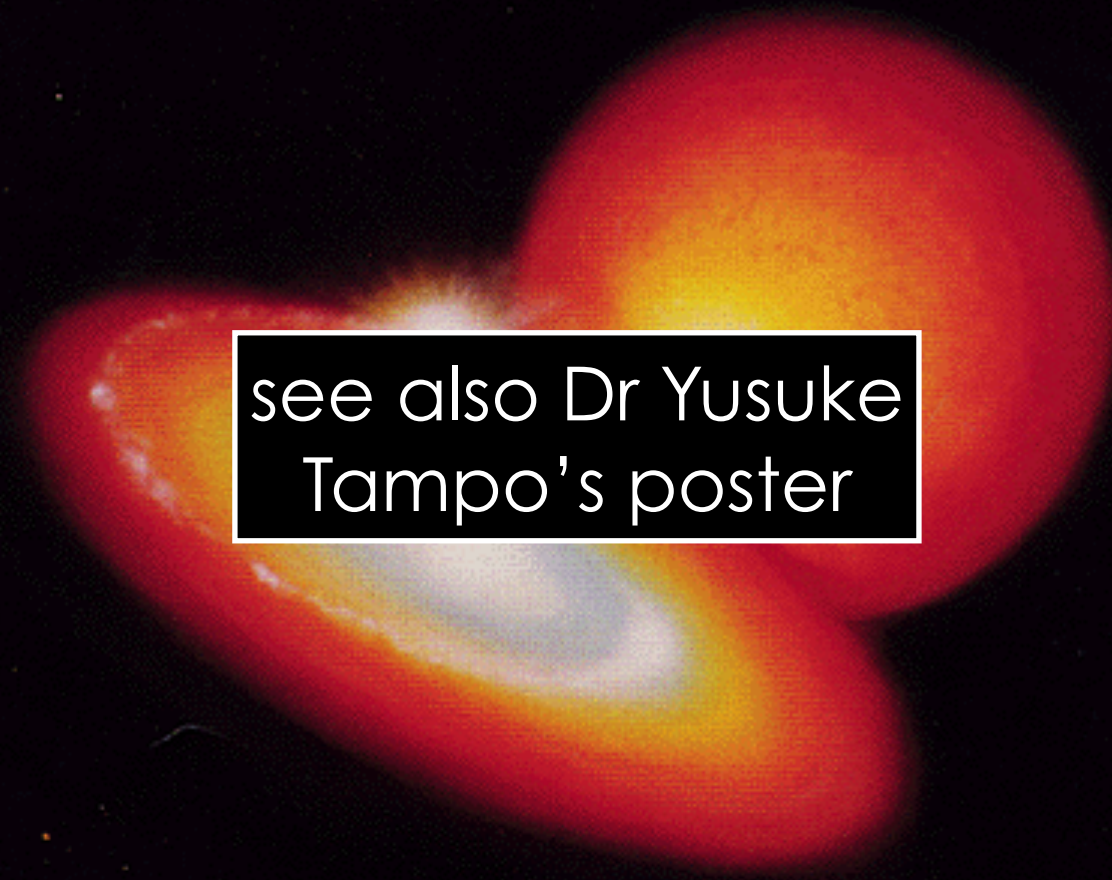
neutron star  
+ Be star

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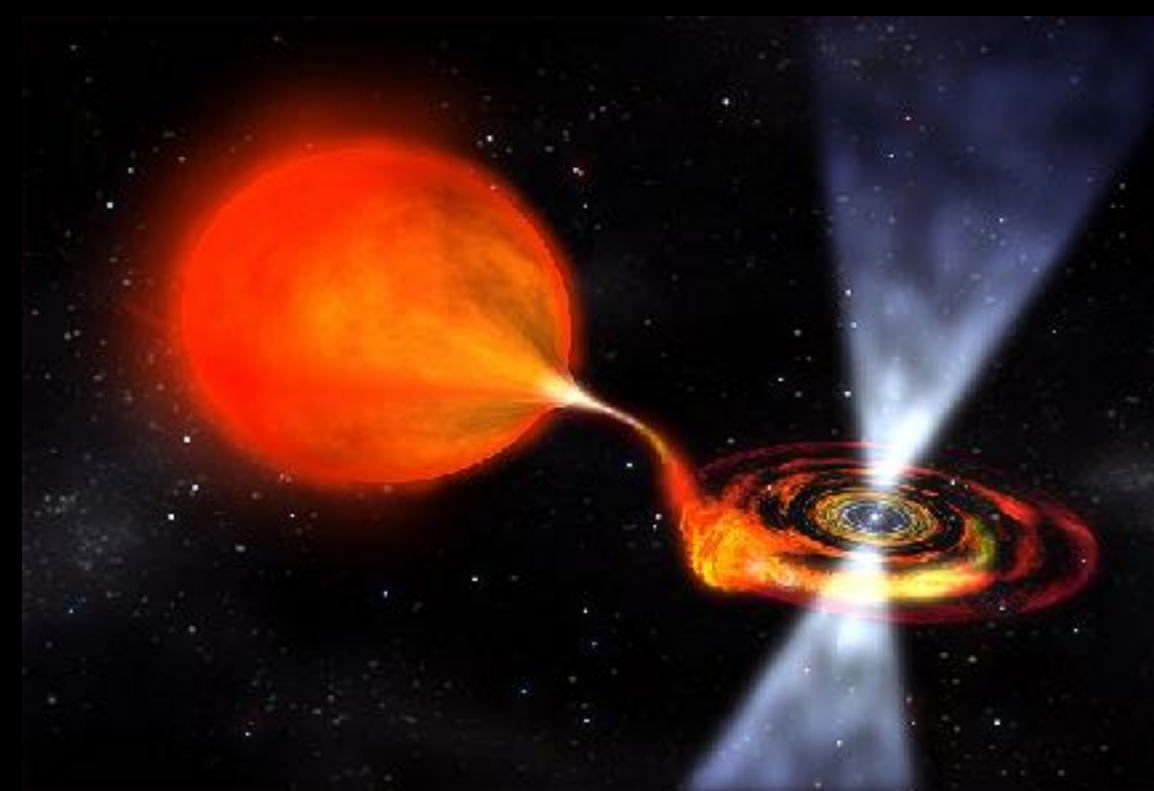
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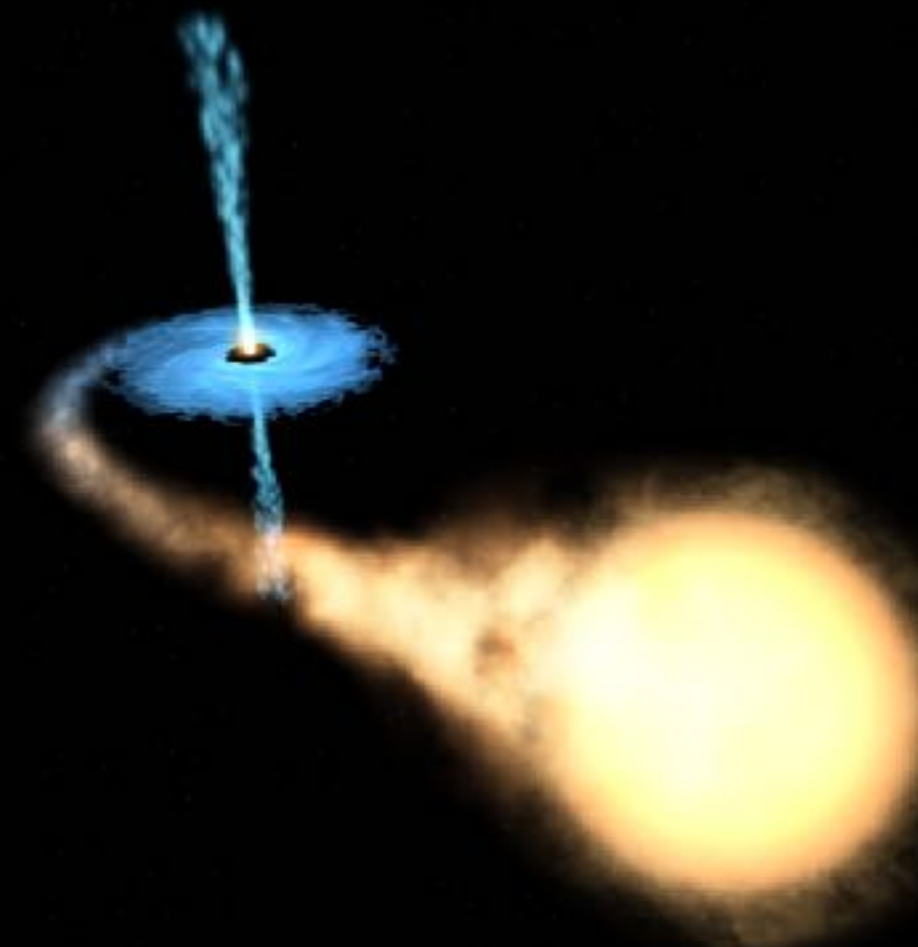
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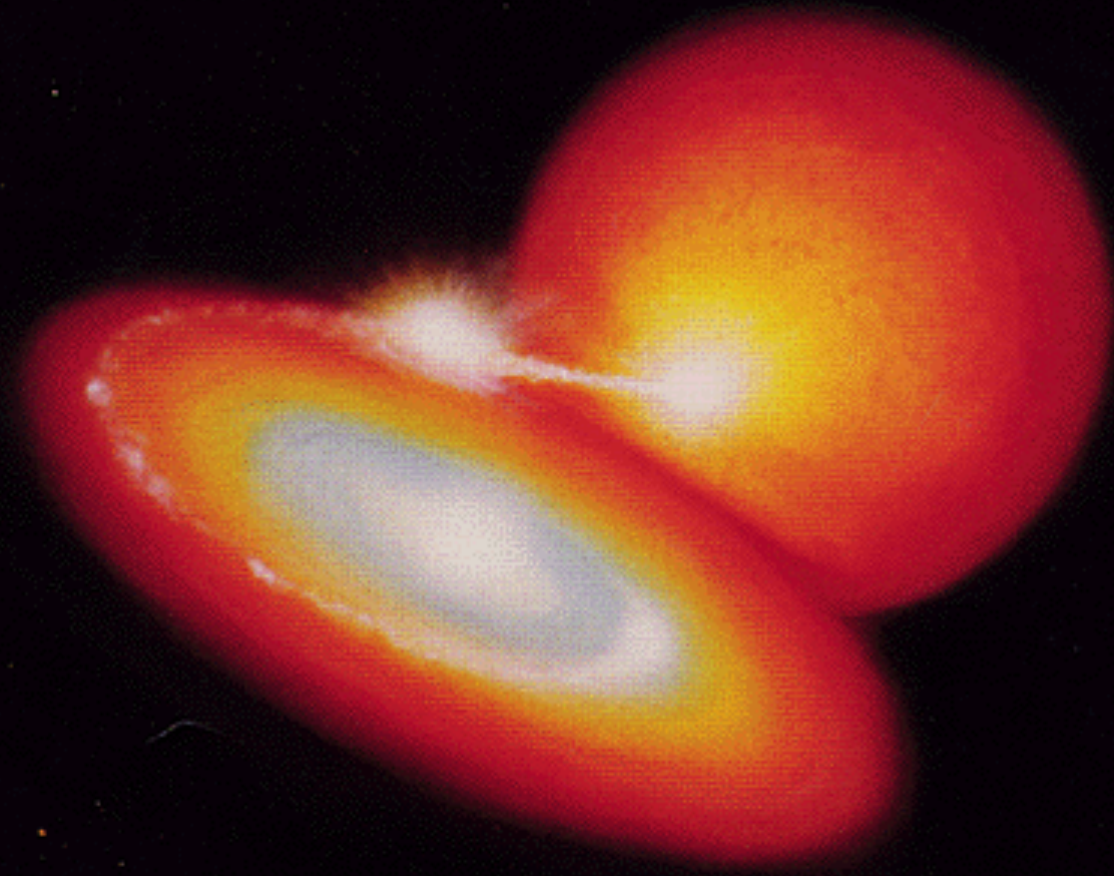
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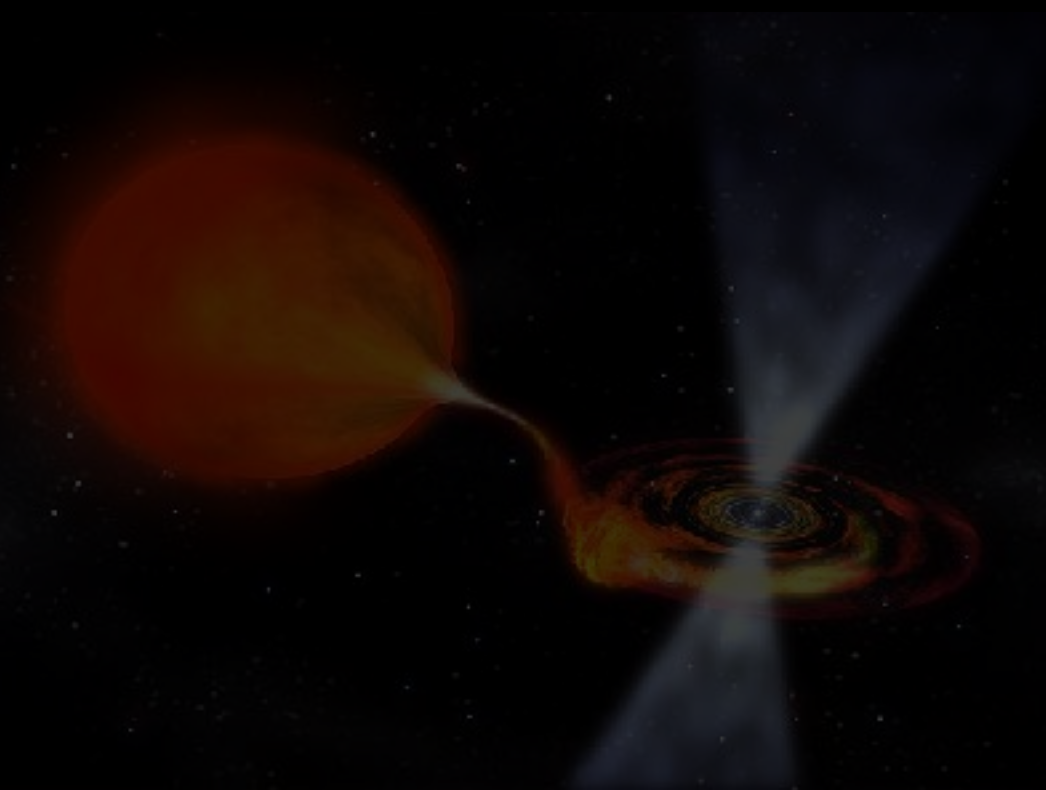
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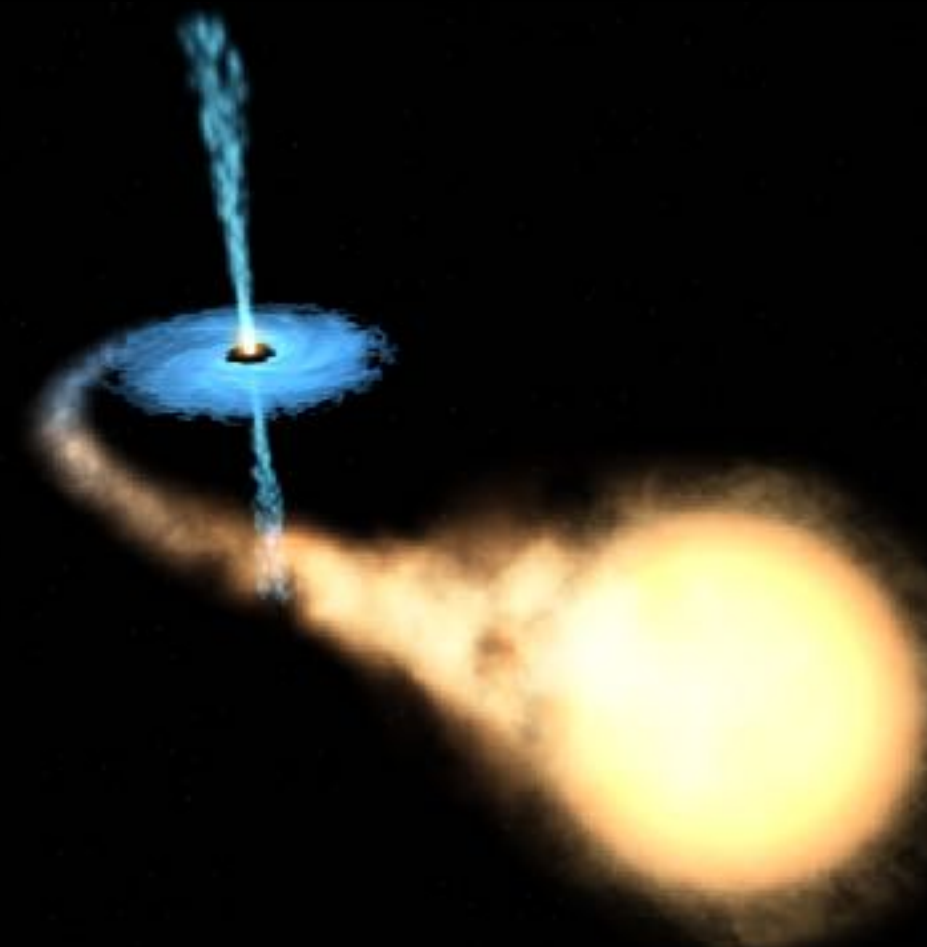
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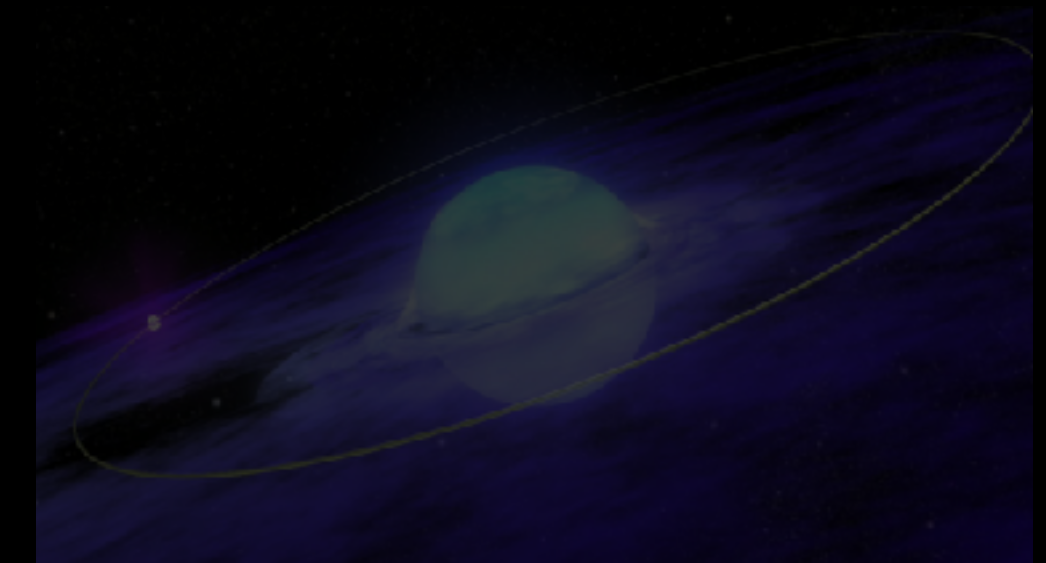
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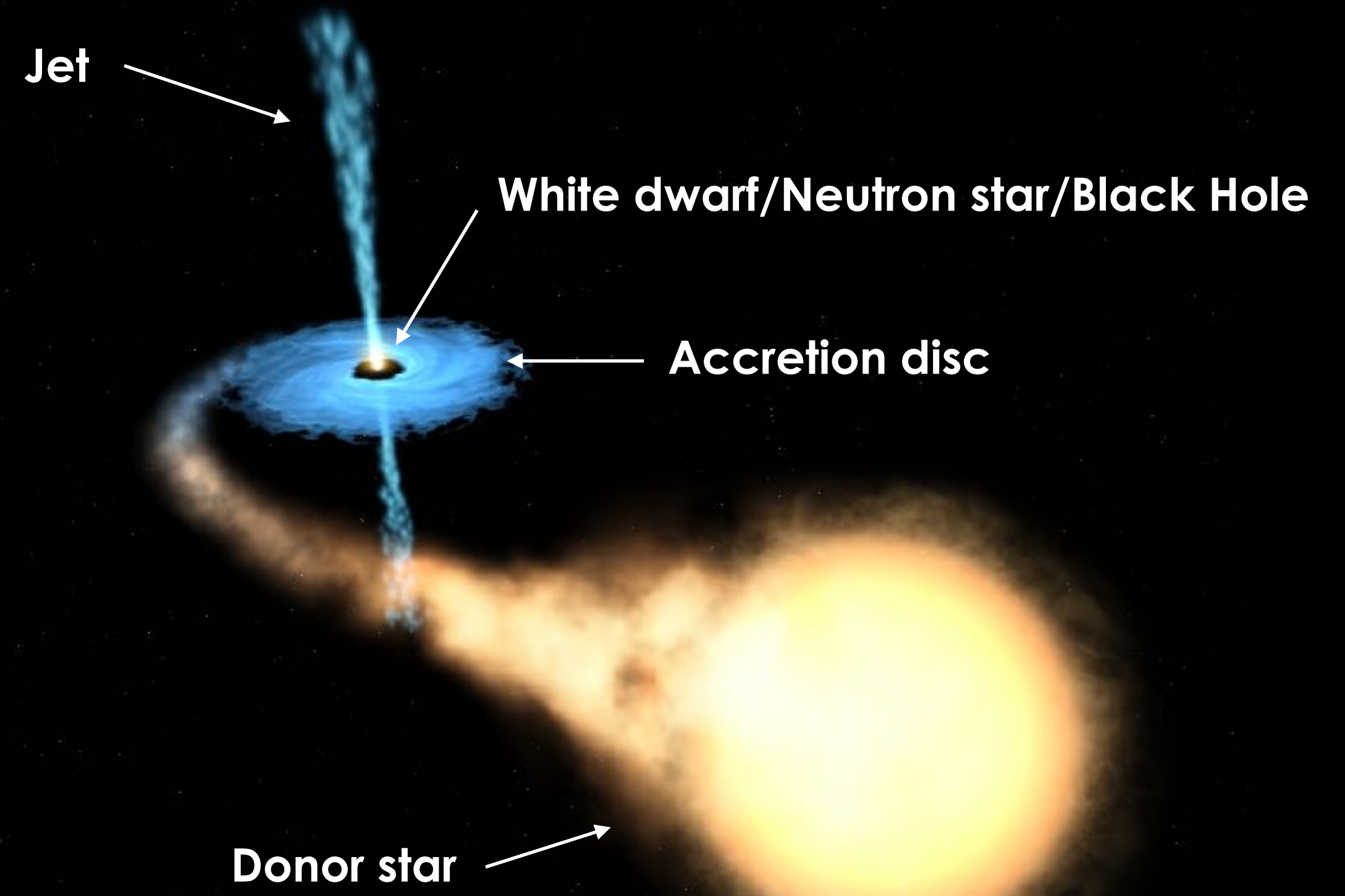
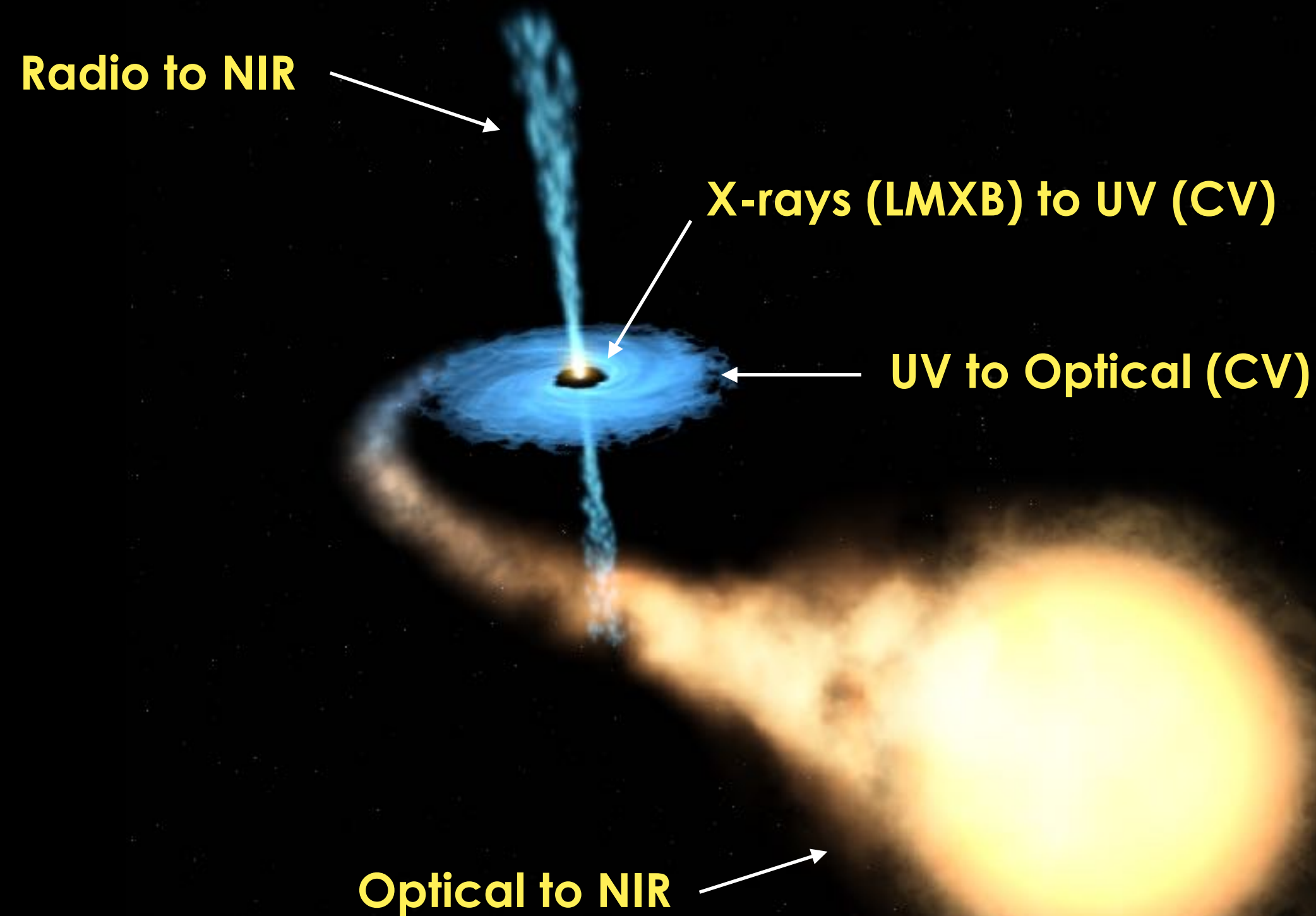
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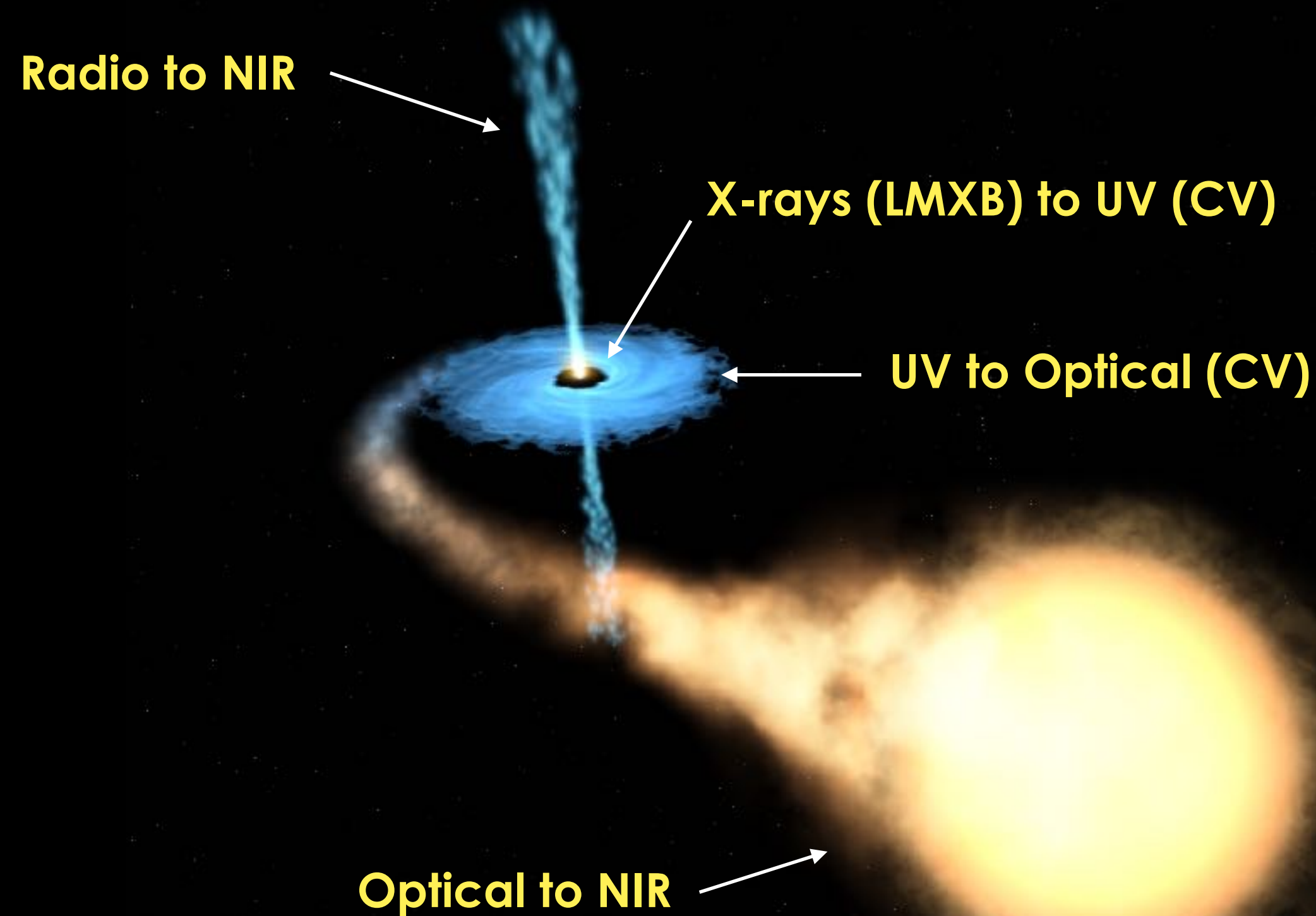
# Transient and Compact Objects

## Multiwavelength Observations of Cataclysmic Variables and related objects



# Transient and Compact Objects

## Multiwavelength Observations of Cataclysmic Variables and related objects



### Optical:

- Radial velocity curves
- Binary components/masses
- Accreting disc state (e.g. thermal viscous disc instability)
- Nature of donor star
- Time evolution

### Radio:

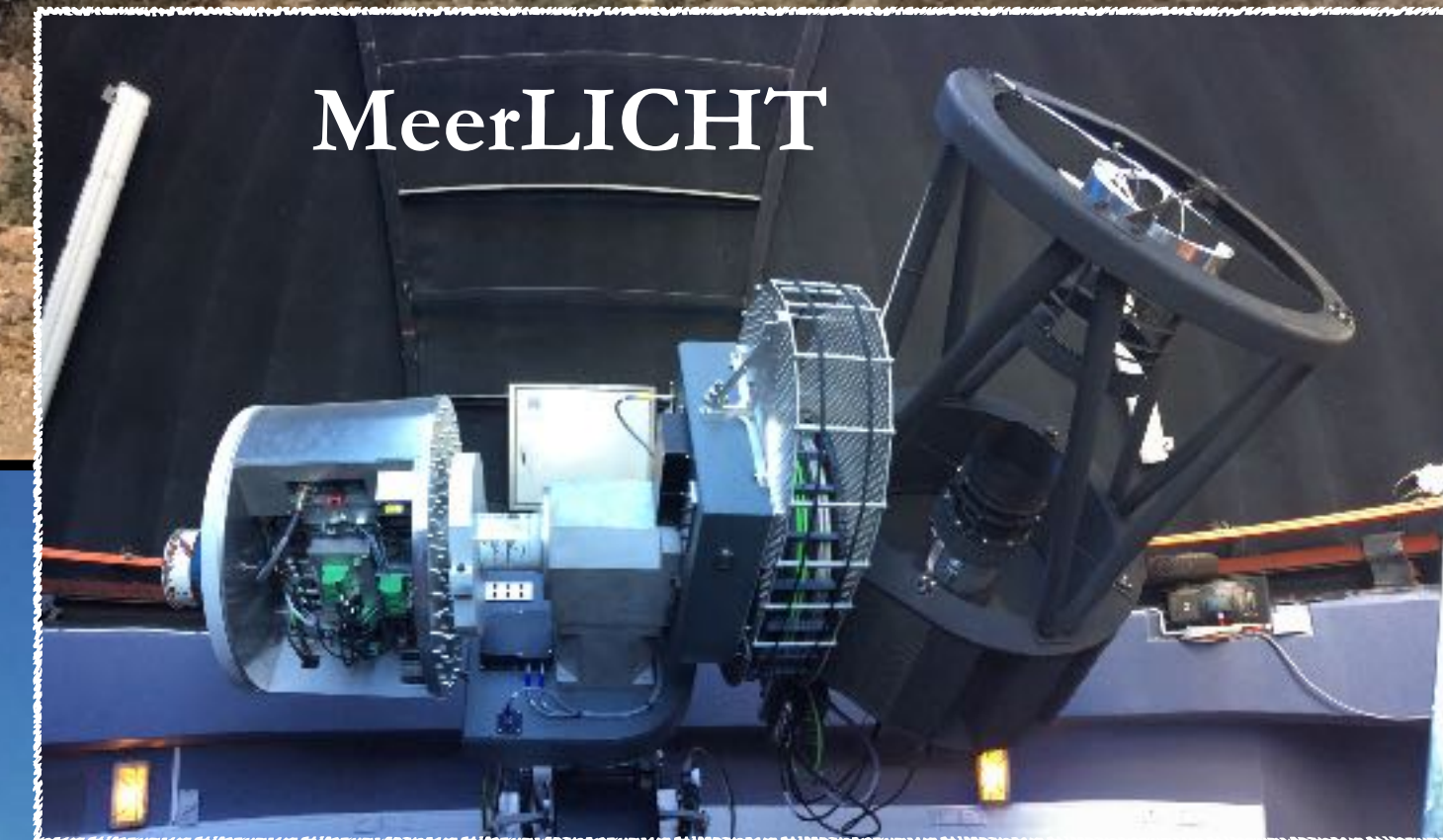
- Total energetics
- Jets yes/no?
- Jet flow velocities
- Magnetic field strengths
- Outflow velocities

### Simultaneous!

- Jet launching
- Relative delays / relative brightness
- Population correlation / rates

wavelengths trace components  
wavelengths trace physics

**MeerKAT → MeerKAT+ → SKA-MID**



ThunderKAT + MeerLICHT:

A radio-driven - optically-supported  
simultaneous view of the transient radio sky



**MeerLICHT → SAAO telescopes → SALT**

# X-ray binaries

# Five years of (weekly) monitoring of GX339-4

## ThunderKAT

Principal Investigators:  
Rob Fender (Oxford)  
Patrick Woudt (UCT)

100+ researchers from 15 countries

20+ postgraduate students (MSc and PhD)

61 papers and >40 ATels

2018-2023

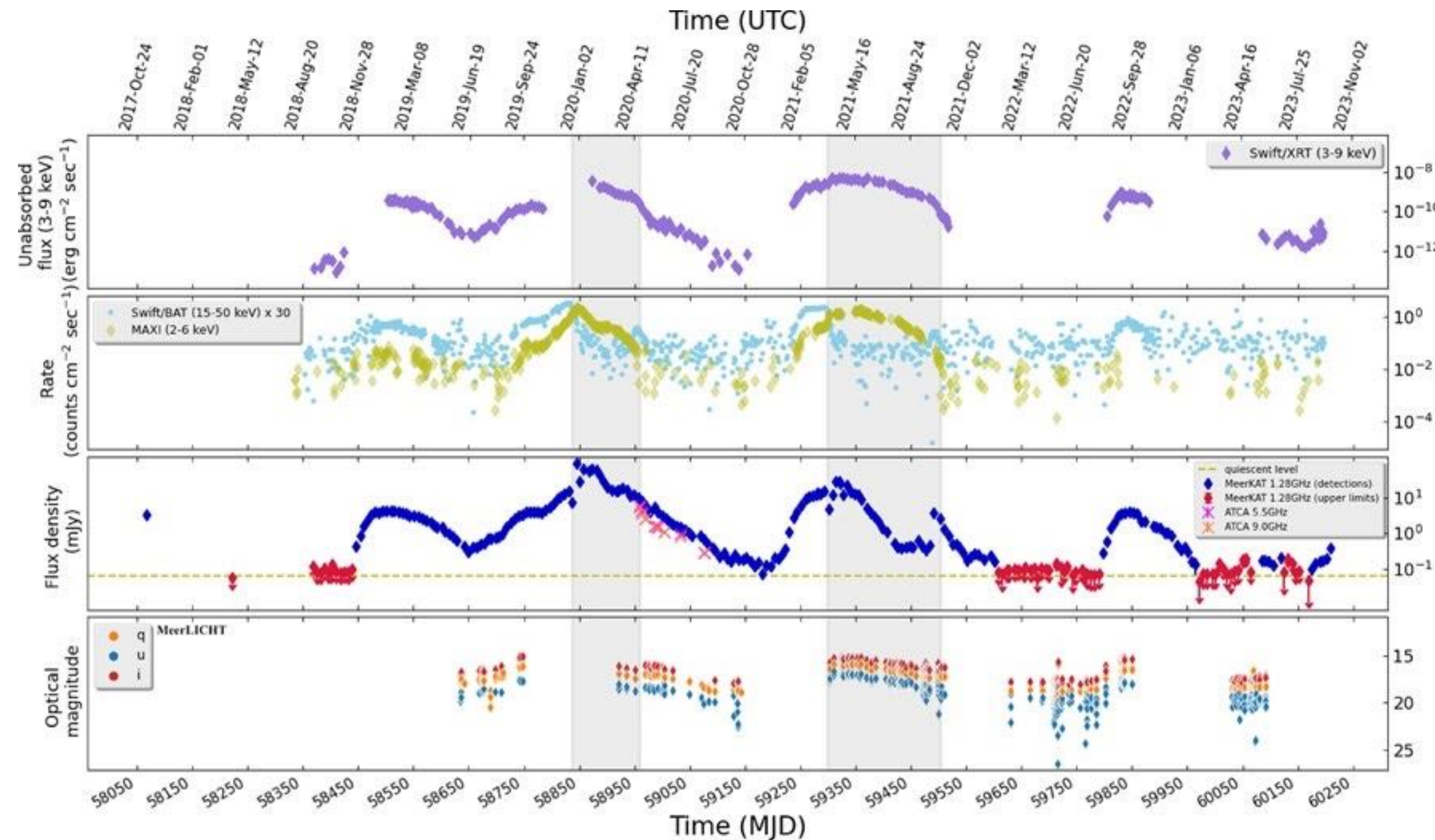
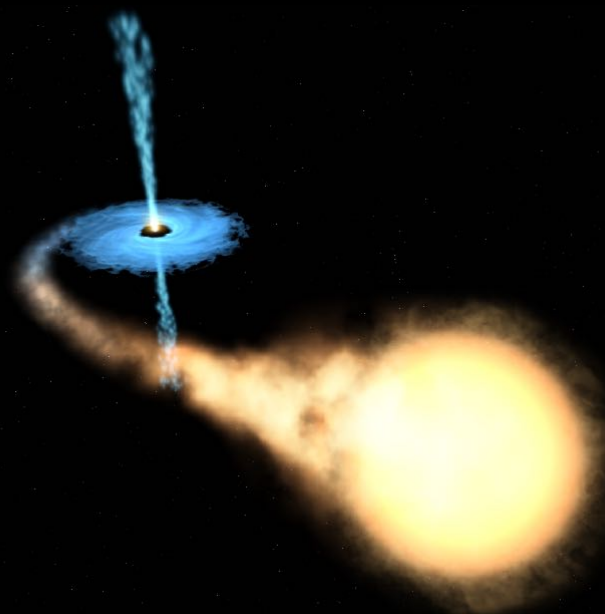


Figure from: Tremou et al. 2026

X-ray: accretion

Radio: outflow/jet

Optical: accretion disk

- Longest and densest quasi-simultaneous **radio**, **X-ray** and **optical** monitoring campaign of a black hole X-ray binary
- Calibrated radio maps available at: <https://doi.org/10.48479/4fpq-sd16>

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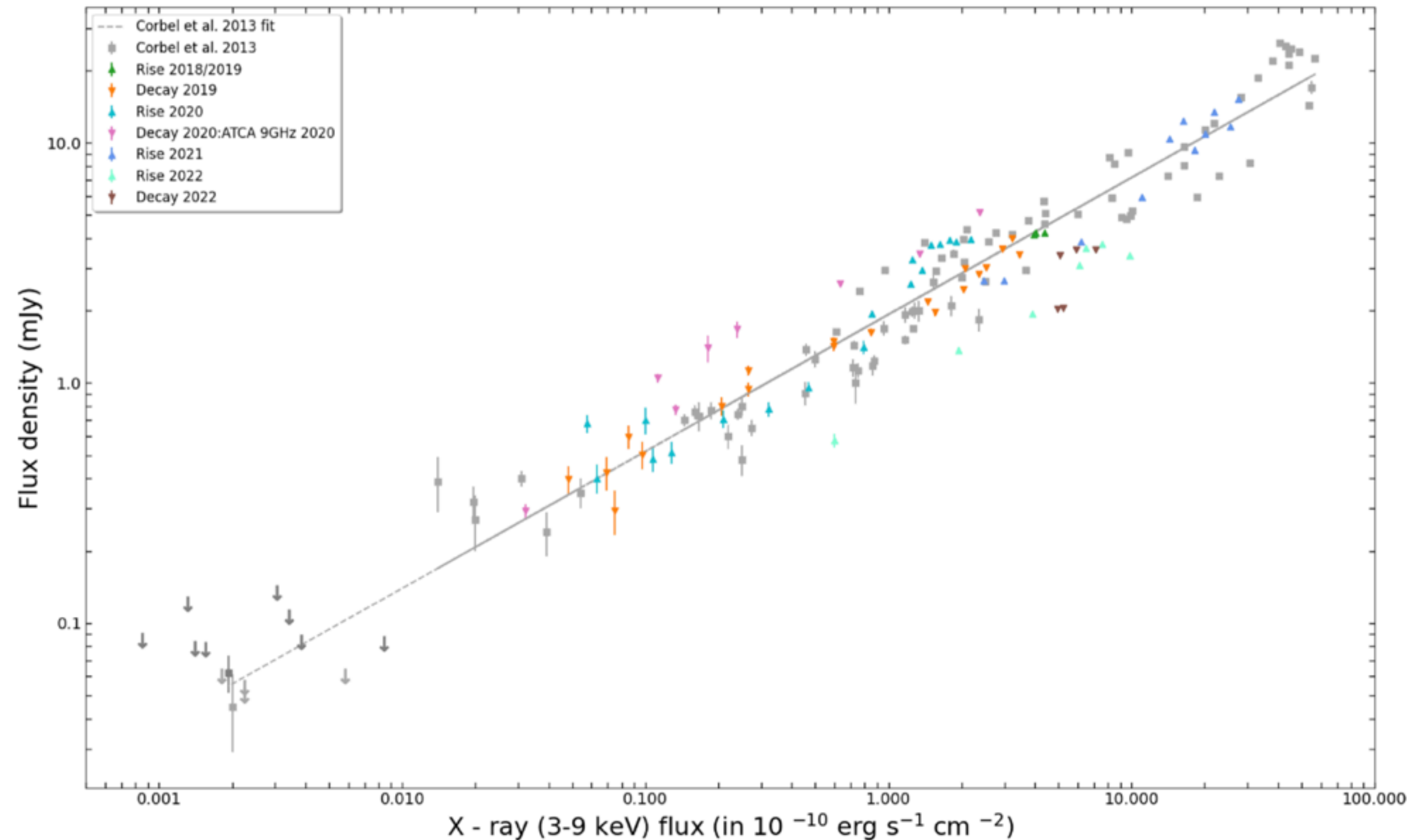
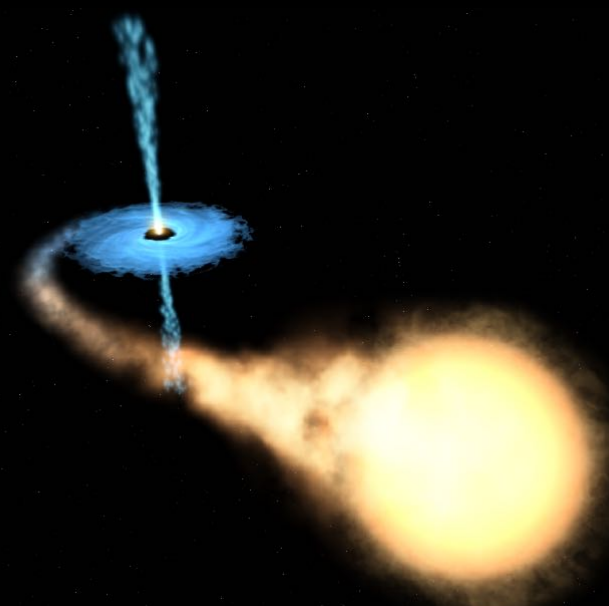


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# X-ray binaries

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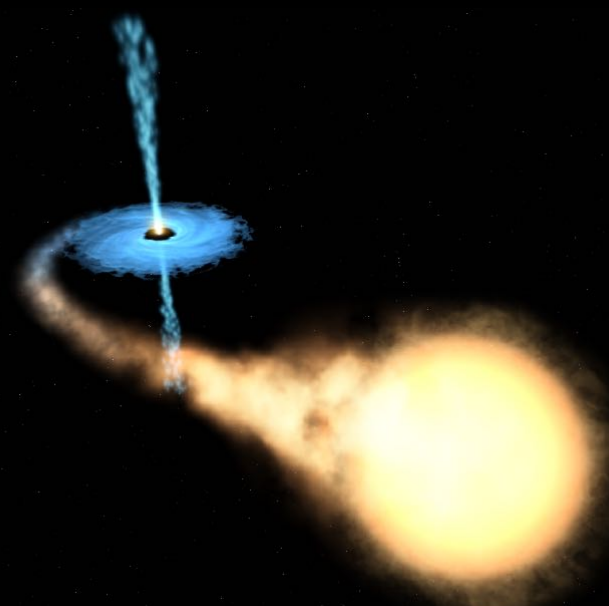
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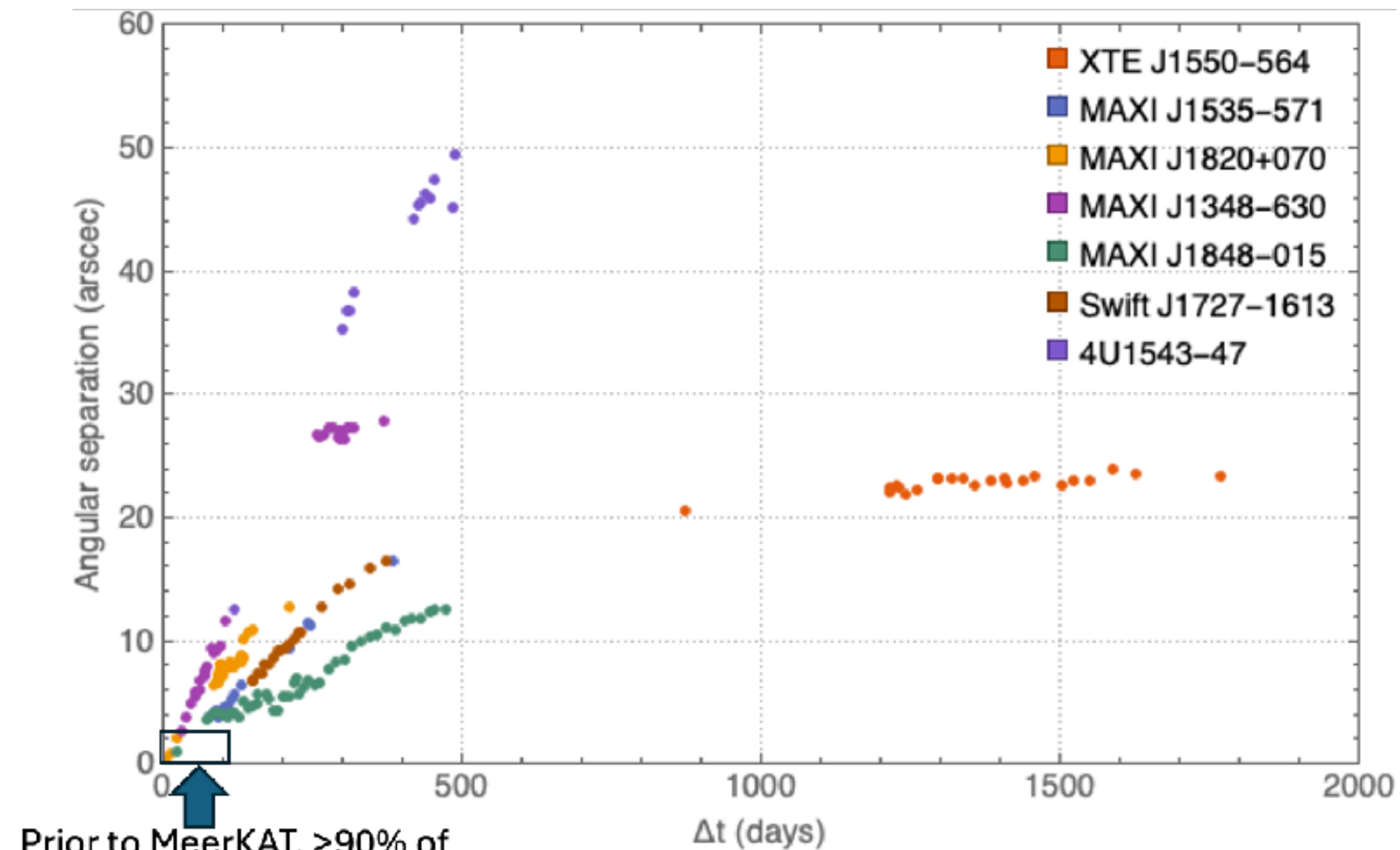
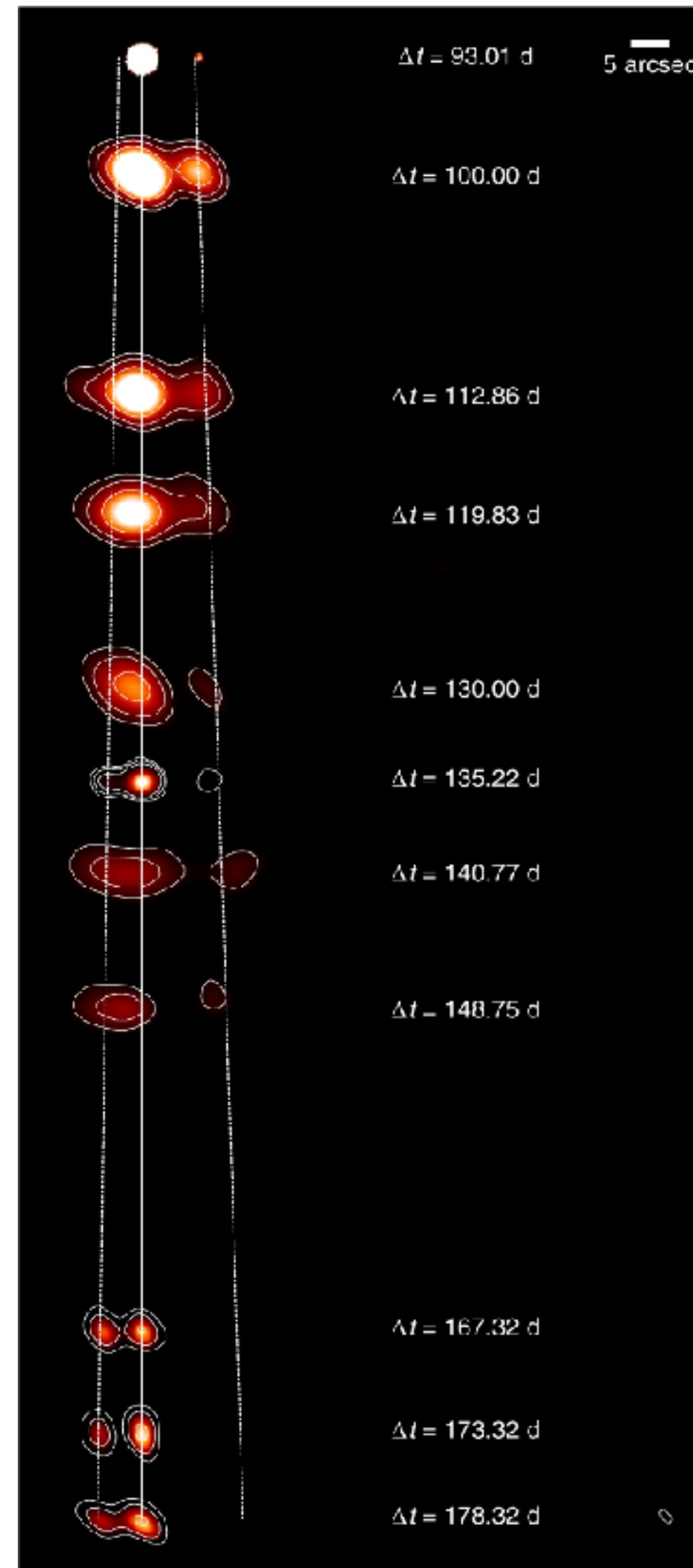
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2018-2023



# Large-scale jets in XRBs observed with MeerKAT



Prior to MeerKAT, >90% of XRB jets were in this box (early and small!)

Figure courtesy of Rob Fender

Bright et al. (1820)  
Russell et al. (1535)  
Carotenuto et al. (1348)  
Bahramian et al. (1848)

Zhang et al. (1543)

Hughes et al. (1727)  
Tremou et al. (GX339)  
Nyamai et al. (GX339)  
Cowie et al. (1518)  
Motta et al. (1915)

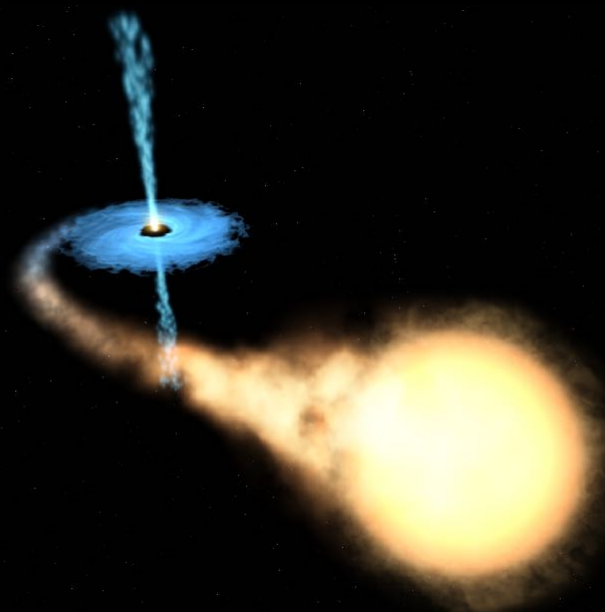
**Unexpected:** Majority of bright X-ray transients produce powerful ejection which propagate for  $> 1$  year and decelerate in the ISM.

**Post 2023: X-KAT** PIs: Motta (INAF) & Fender (Oxford/UCT)

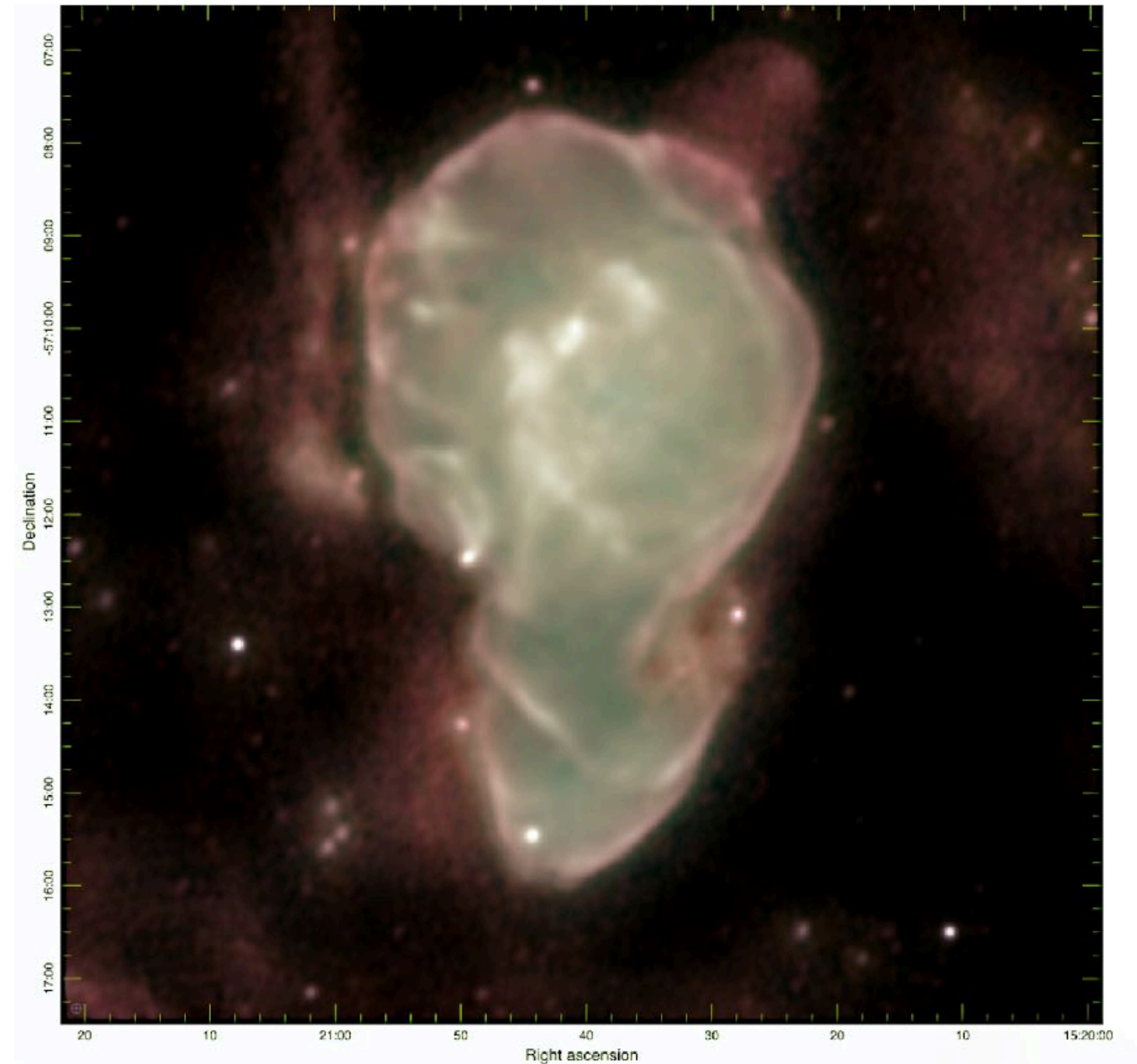
# X-ray binaries



Kelebogile Gasealahwe  
(PhD/PDF)



# The Africa Nebula



Multicolour sub-band image of  
Circinus X-1 (L-band/MeerKAT)

**A relativistic jet from a neutron  
star breaking out of its natal  
supernova remnant.**

UCT PhD student Kelebogile  
Gasealahwe

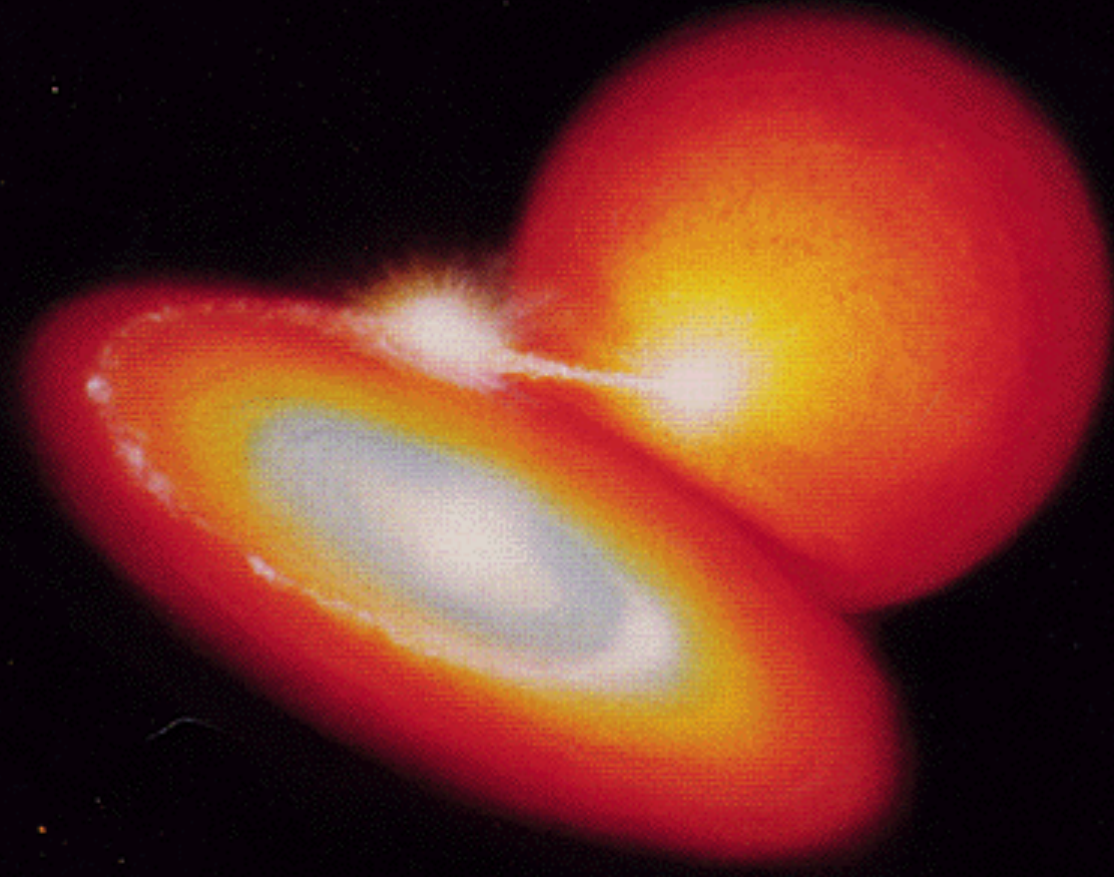
Nicknamed: **The Africa Nebula**

Picture courtesy:  
Gasealahwe/English

<https://apod.nasa.gov/apod/ap250903.html>

## Cataclysmic Variables

(semi-detached white dwarf + red dwarf companion)  $P_{\text{orb}} = 1.3 - 10+$  hrs  $P_{\text{spin,WD}} = 25 \text{ sec} - \text{several hours}$



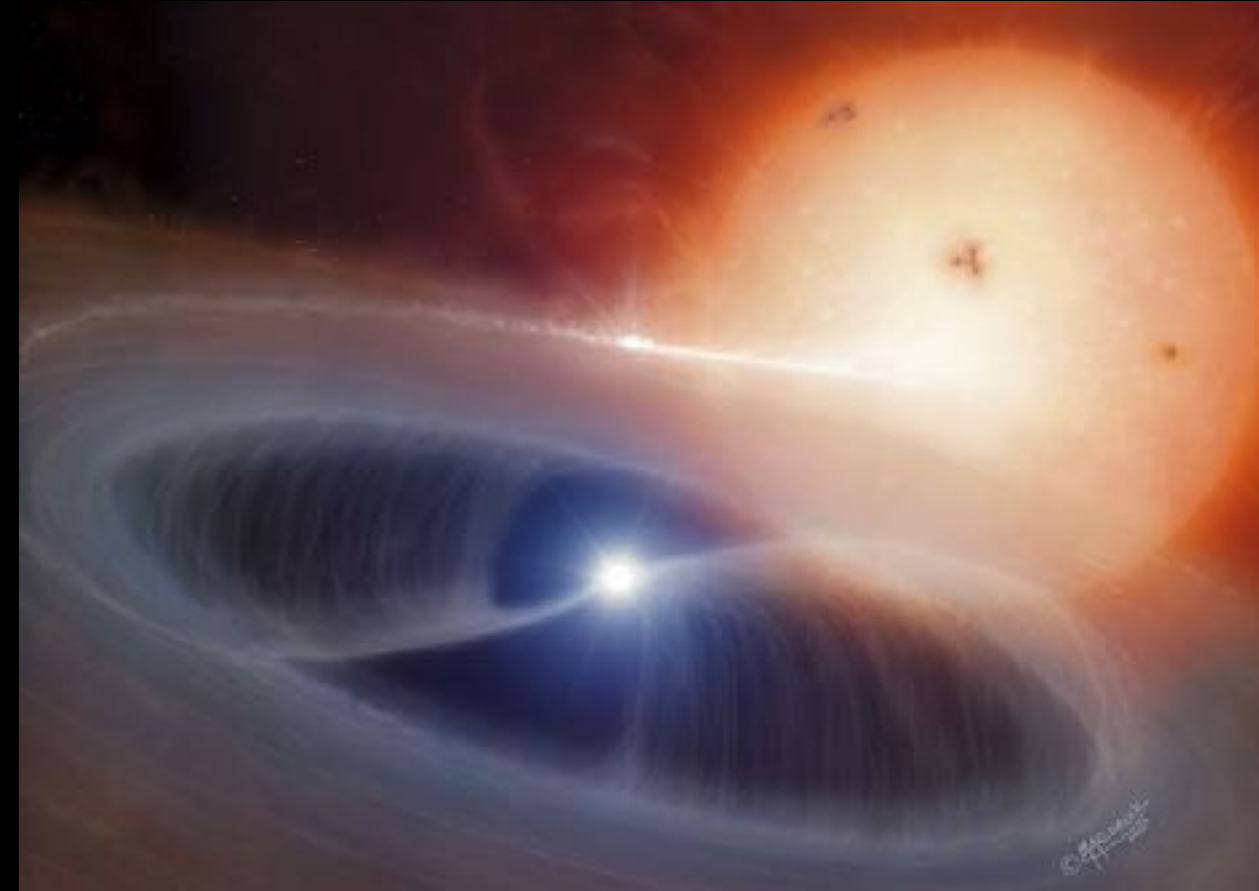
non- or weakly magnetic WD  
[< 1 MG]

dwarf nova / novalike

### dwarf nova outburst:

thermal viscous disc instability  
enhanced mass transfer onto  
WD over period of 1-2 weeks.

**SS Cyg:** analogy to XRBs  
jets?



moderately magnetic WD  
(1-10 MG)

intermediate polar

### fastest WD rotator:

LAMOST J0240+19 with a  
spin period of 24.9 sec  
(6 IPs with  $P_{\text{spin}} < 1 \text{ min}$ )

**AE Aqr:** propellor system  
with  $P_{\text{spin}}$  of 33 sec



strongly magnetic WD  
[10-200 MG]

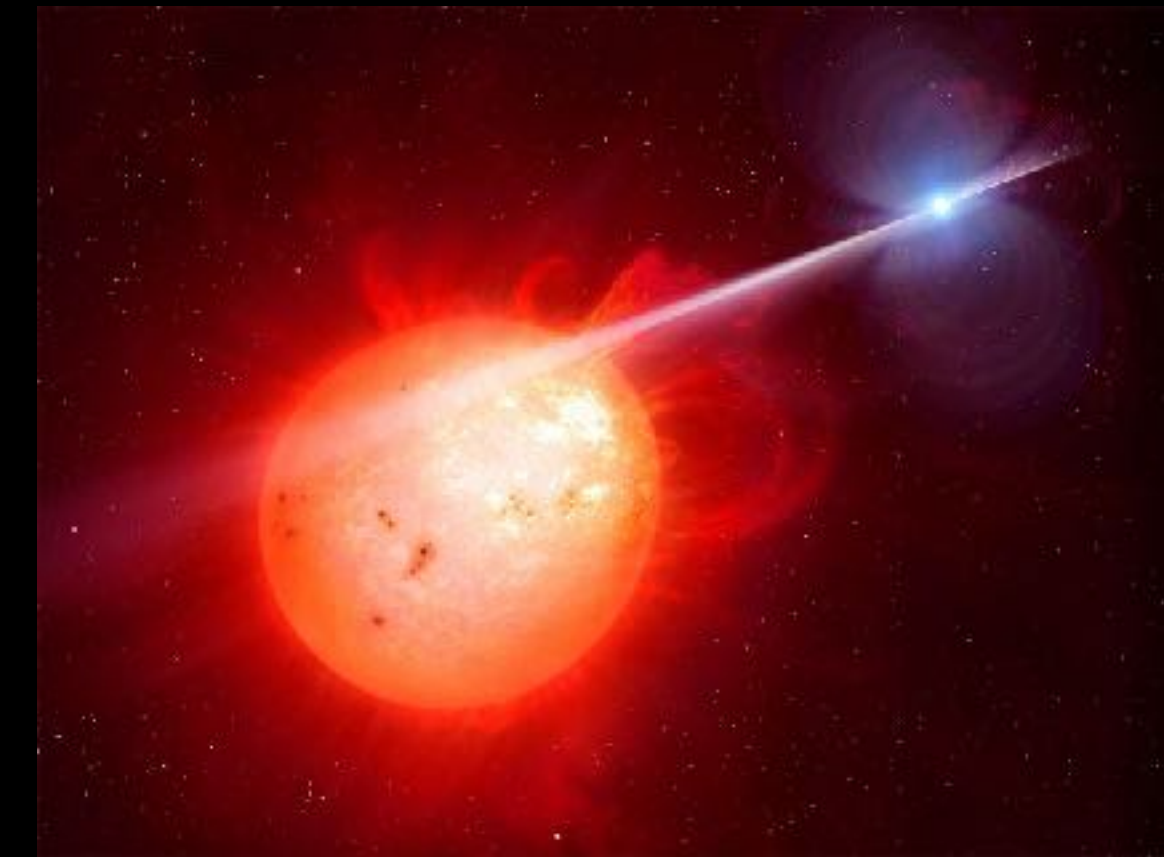
polar

### No accretion disc:

Accretion follows directly  
from the inner Lagrangian  
point onto magnetic field lines

**AM Her:** WD with strongest  
magnetic field in a CV

## White Dwarf Pulsars (detached white dwarf binary)



strongly magnetic WD  
[10-200 MG]

WD pulsar

### No stable accretion:

Interaction of magnetic  
field of white dwarf and  
magnetic field of companion

**AR Sco:**  $P_{\text{spin}}$  of 117 sec  
in 3.56 hr binary

# Cataclysmic Variables

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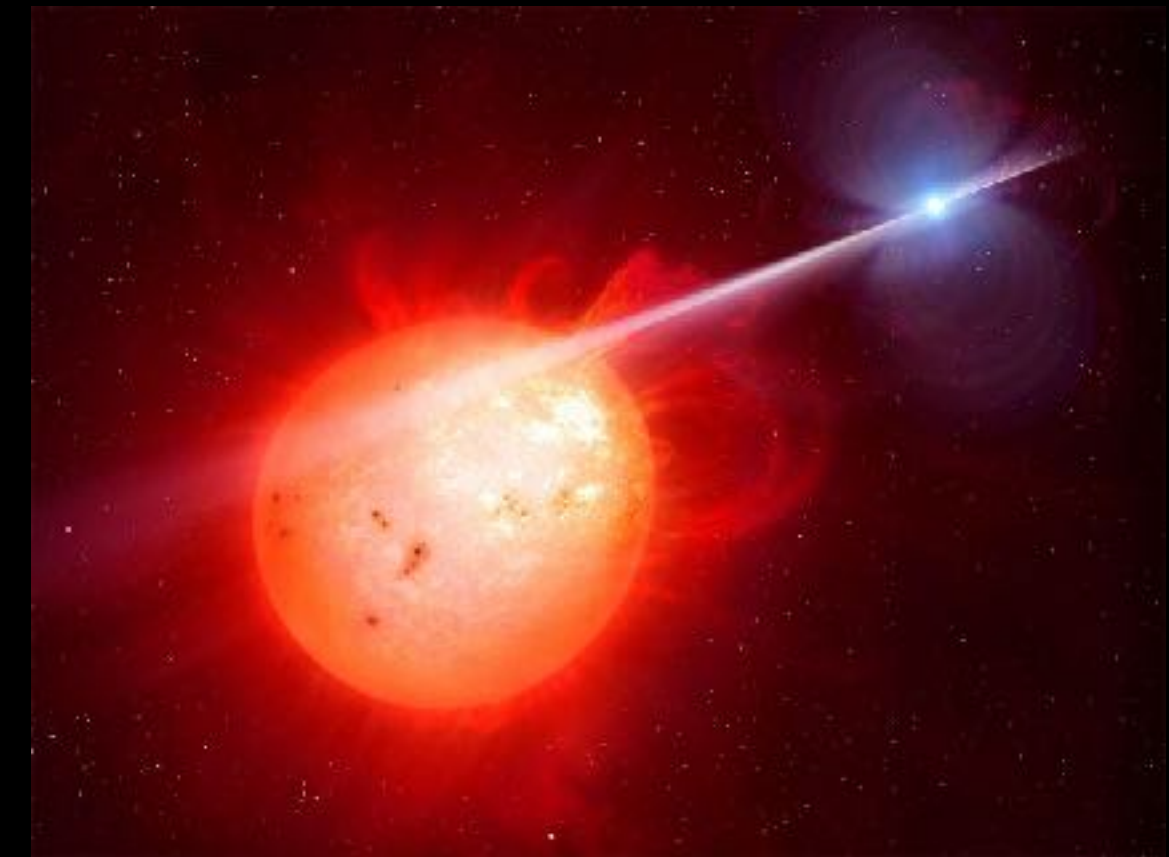
variations in magnetic field strength of the WD

variations in mass transfer rate

Volume limited sample (150 pc)  
Pala et al. 2020  
42 CVs (77% complete)

# White Dwarf Pulsars

(detached white dwarf binary)



non- or weakly magnetic WD  
[< 1 MG]

dwarf nova / novalike

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thermal viscous disc instability enhanced mass transfer onto WD over period of 1-2 weeks.

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strongly magnetic WD  
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WD pulsar

### No stable accretion:

Interaction of magnetic field of white dwarf and magnetic field of companion

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# dwarf novae and nova-likes

## Radio emission from **non-magnetic CVs**

### Non-magnetic Cataclysmic Variables (ThunderKAT on MeerKAT)

- dwarf novae in outburst (disc instability)
- nova-likes (disc permanently in high state)

#### ThunderKAT

Principal Investigators:  
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Patrick Woudt (UCT)

100+ researchers from 15  
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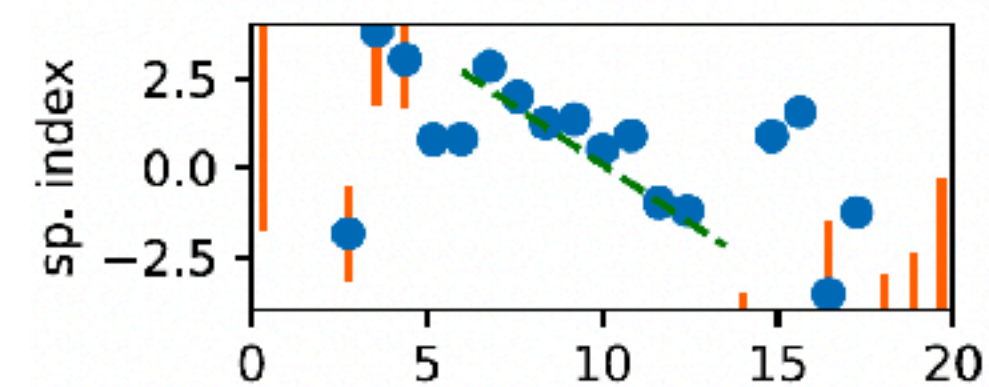
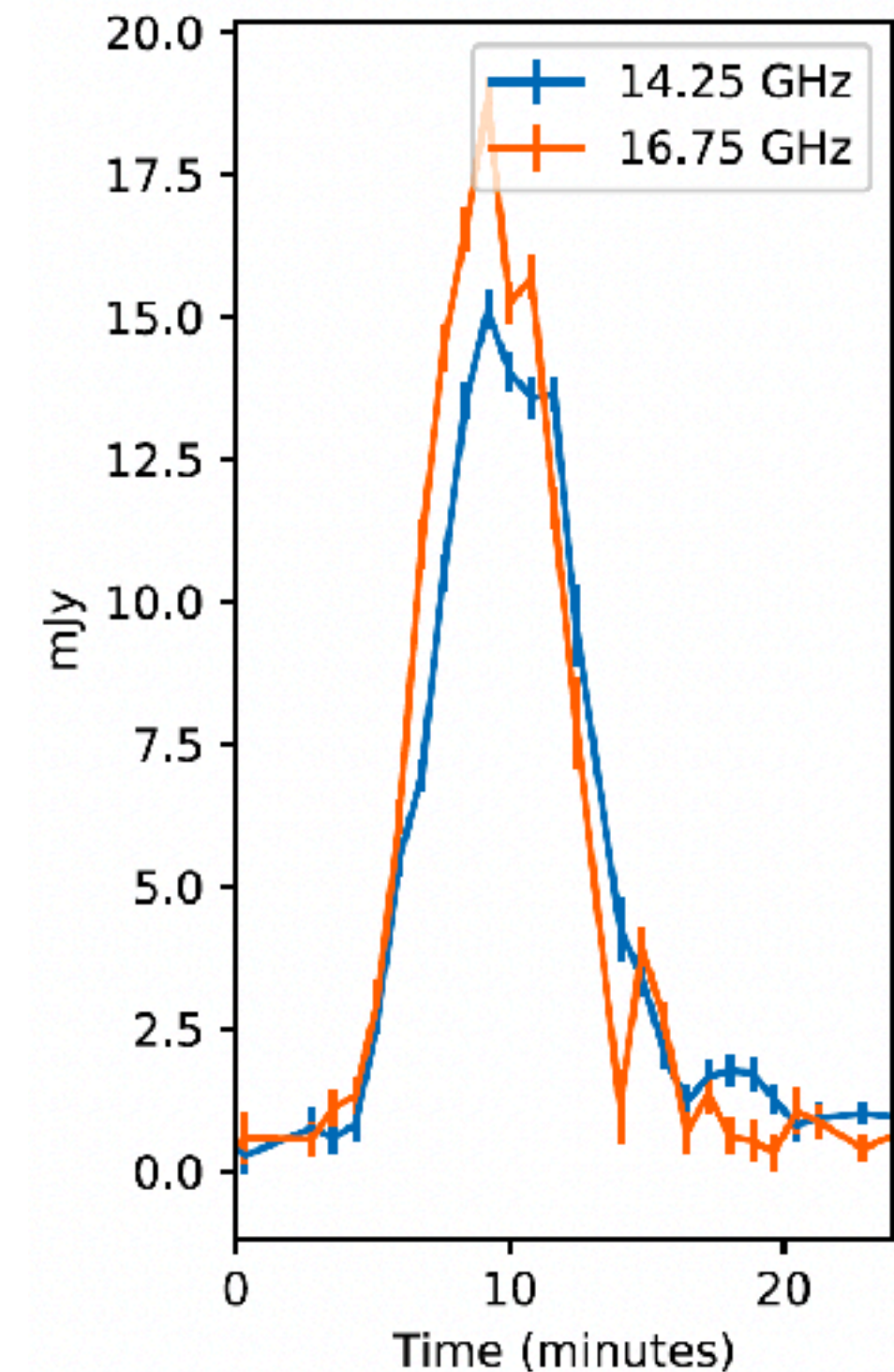
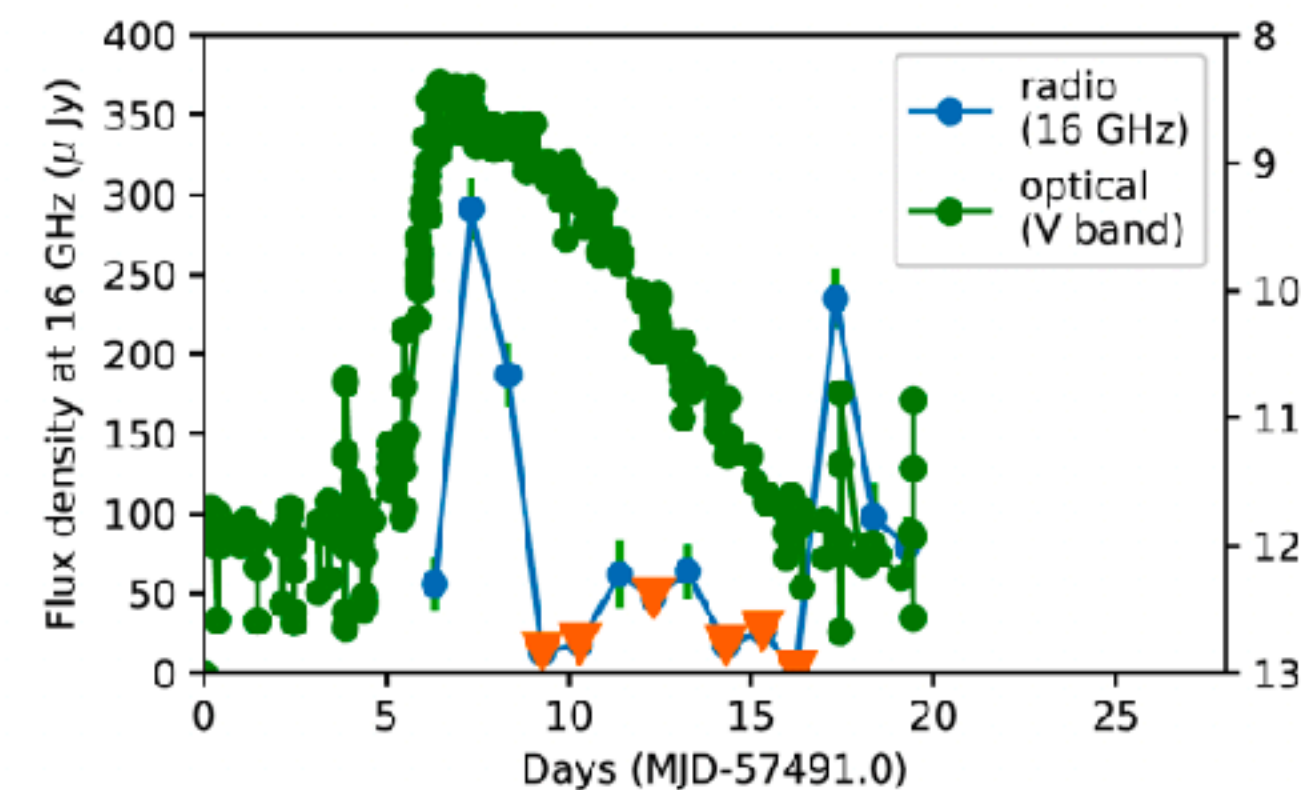
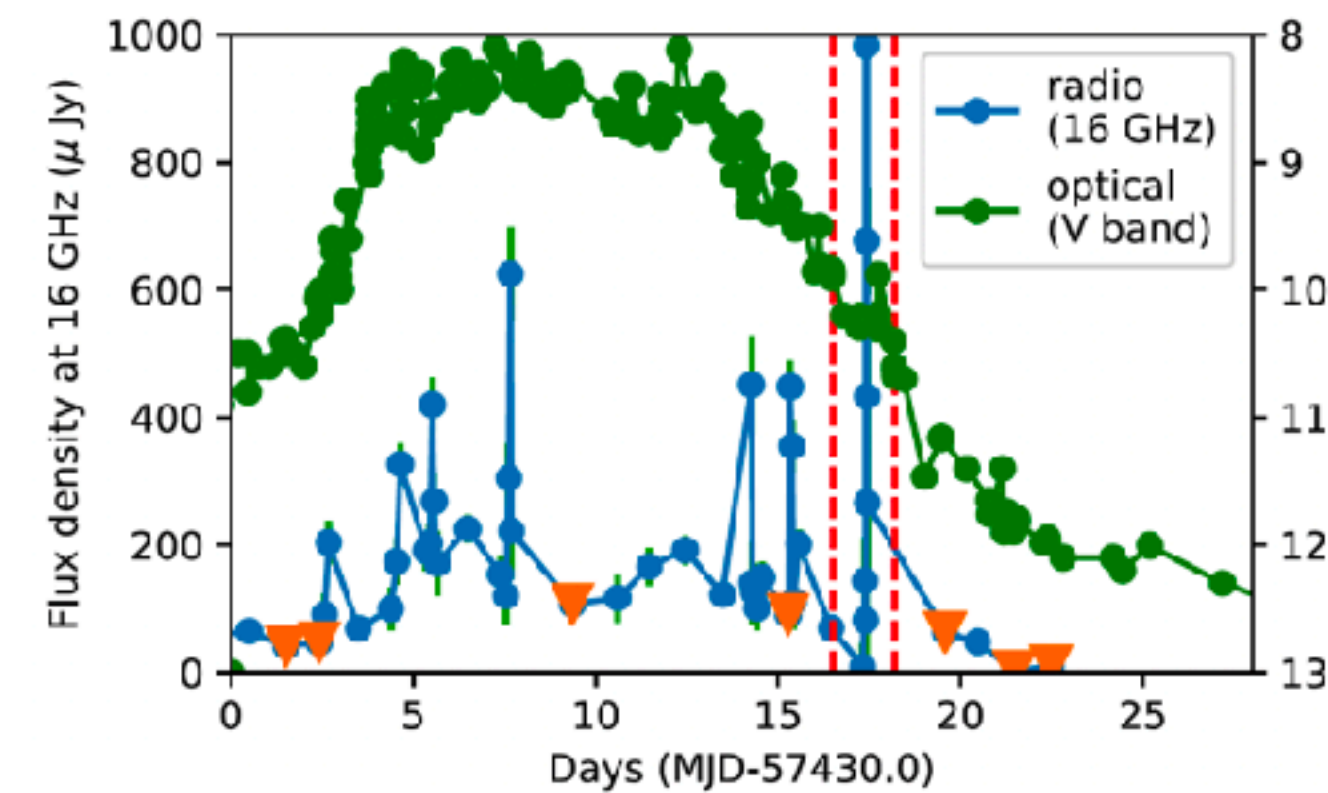
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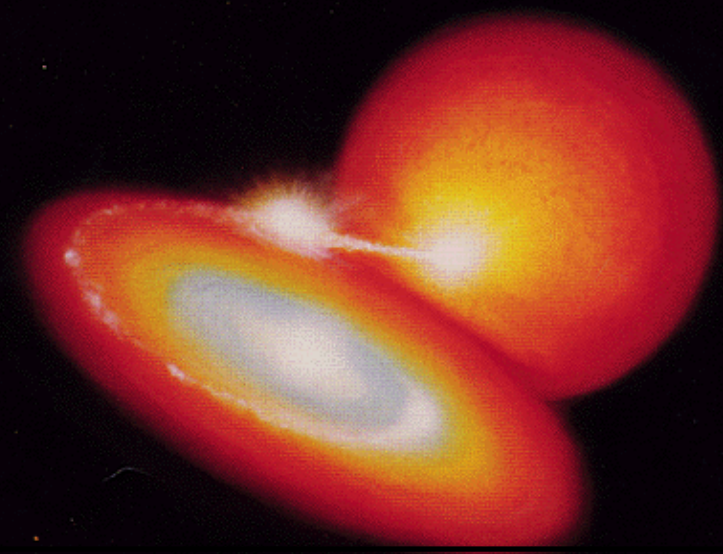
2018-2023

### SS Cygni

- dwarf nova ( $P_{\text{orb}} = 6.60$  hr)
- variable radio emission during outburst
- late time flare ( $E > 10^{33}$  erg)
- synchrotron emission
- best studied DN at radio frequencies



Figures from: Fender et al. 2019



# dwarf novae and nova-likes

## Radio emission from **non-magnetic CVs**

With ThunderKAT we completed the following surveys at L-band (1.3 GHz):

1. volume limited sample of **nova-likes** ( $< 350$  pc): 4/11 detected.
2. long-term monitoring campaign of two nova-likes (V603 Aql and V3885 Sgr)
3. **extensive sample of nearby dwarf novae** ( $< 300$  pc): 3/13 detected.
4. dwarf nova outbursts in IP Peg, RU Peg and V426 Oph in **L+S3 band** (0.9-3.2 GHz)



Joris Kersten (PhD)

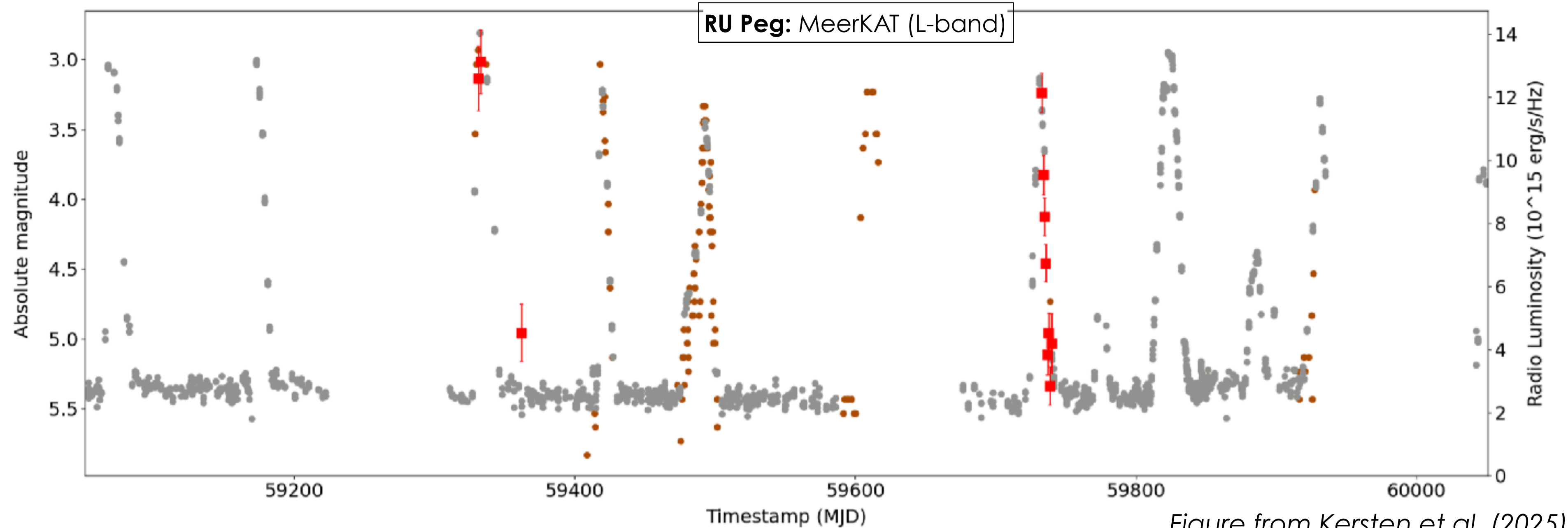
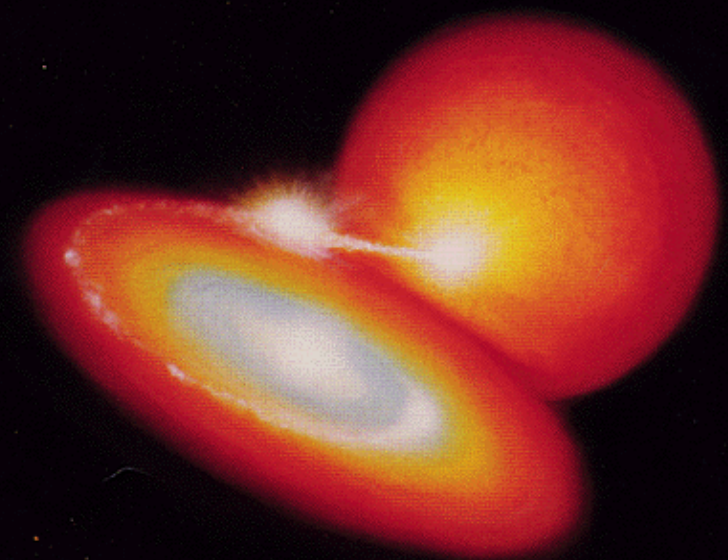


Figure from Kersten et al. (2025)

# dwarf novae and nova-likes

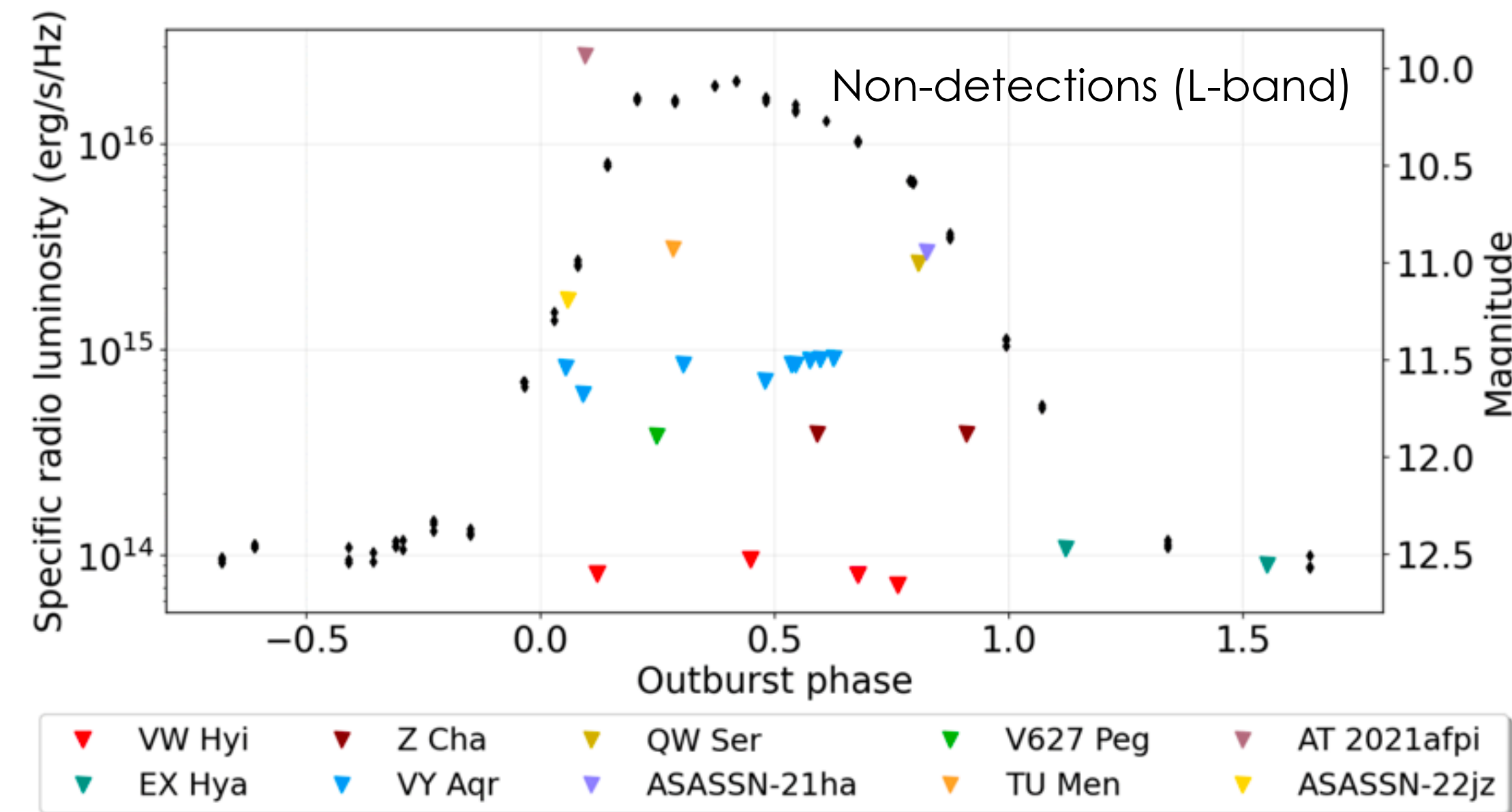
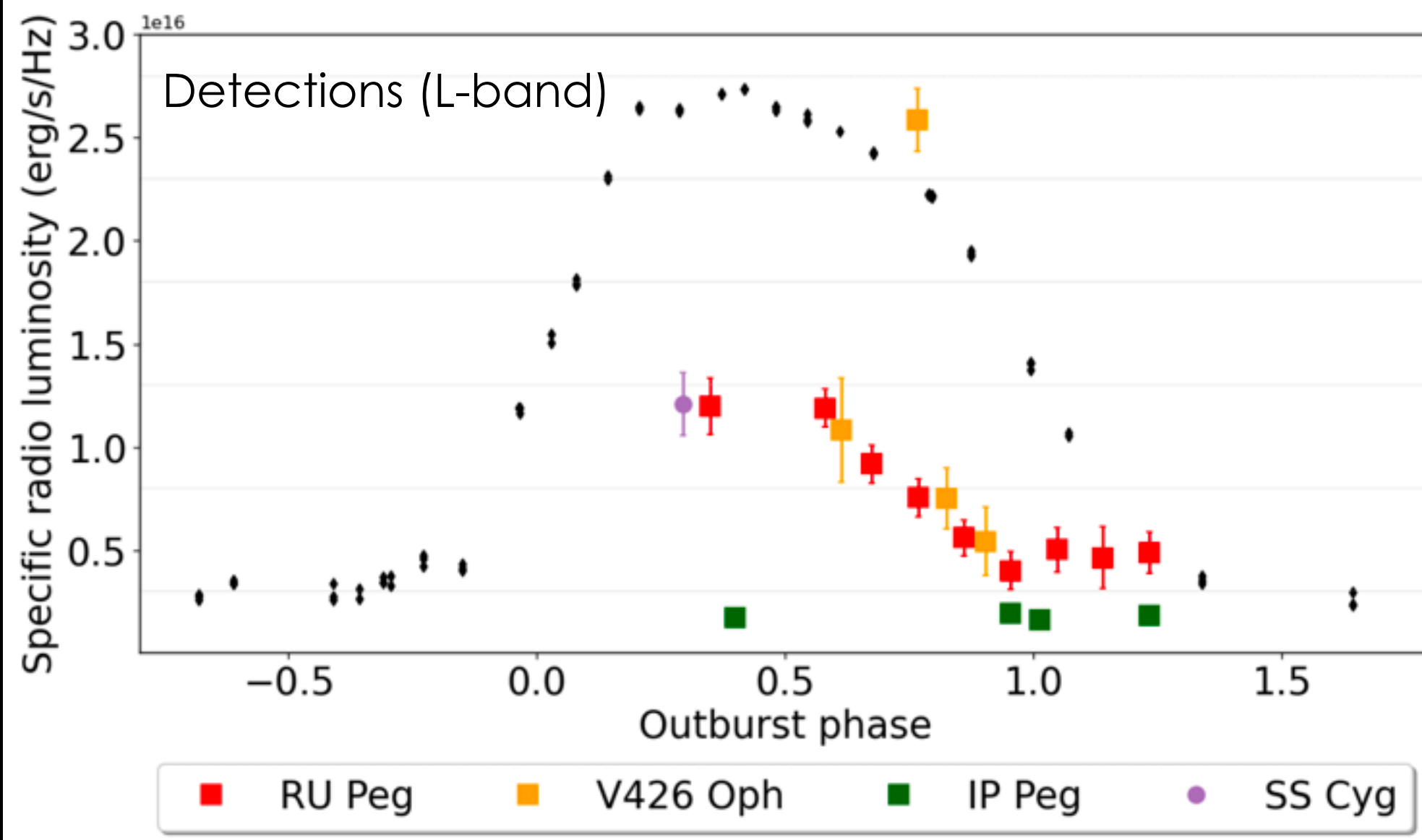
## detections and non- detections



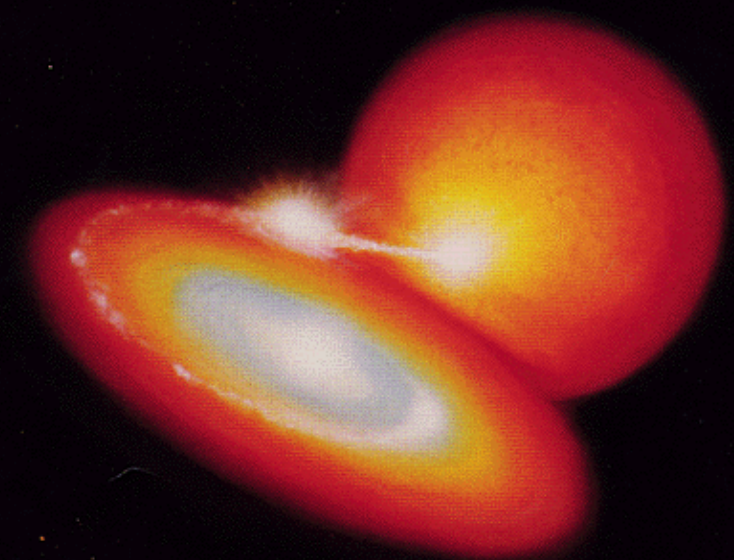
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Kersten et al. (in preparation)



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3. extensive sample of nearby **dwarf novae** (< 300 pc): 3/13 detected.
4. **dwarf nova outbursts** in IP Peg, RU Peg and V426 Oph in **L+S3 band** (0.9-3.2 GHz)

Source	Spectral index	Frequency Range	Observations
RU Peg (DN)	$-0.24 \pm 0.23$	0.9-3.2 GHz	14 April 2023
V603 Aql (NL)	$-0.25 \pm 0.12$	0.9-3.2 GHz	26 February 2023

From Kersten et al. (in prep)

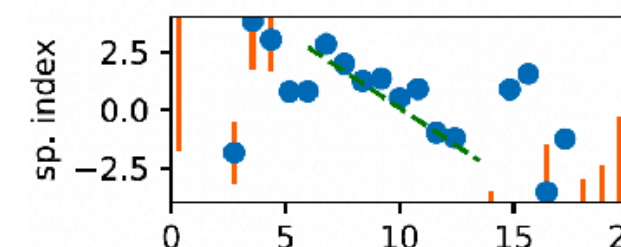
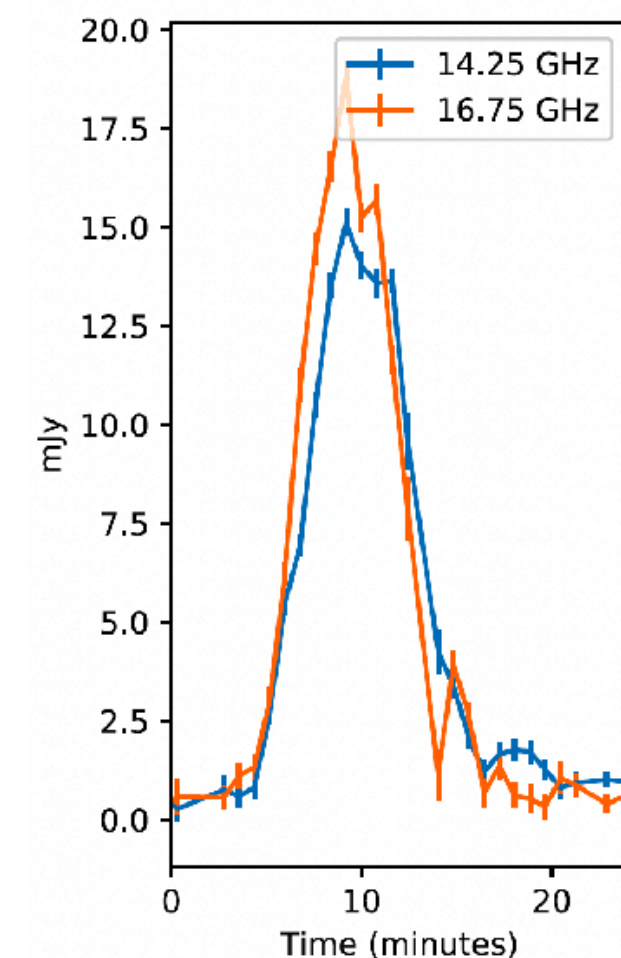
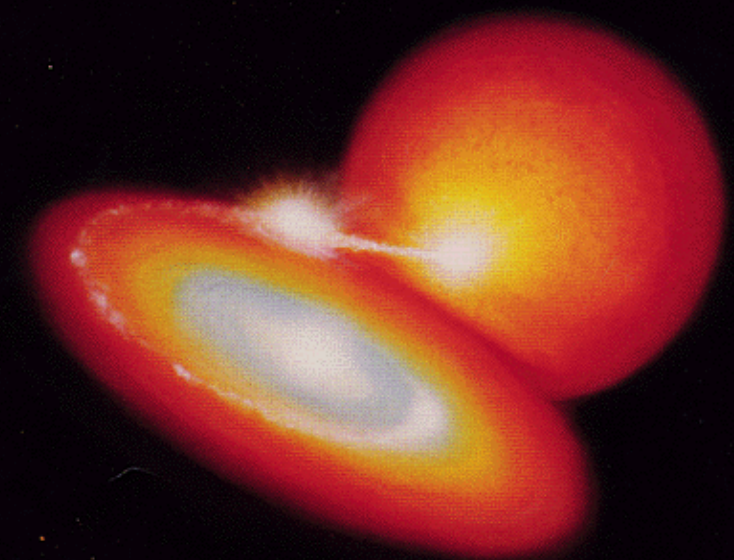


Figure of SS Cyg flare from Fender et al. 2019

# dwarf novae and nova-likes

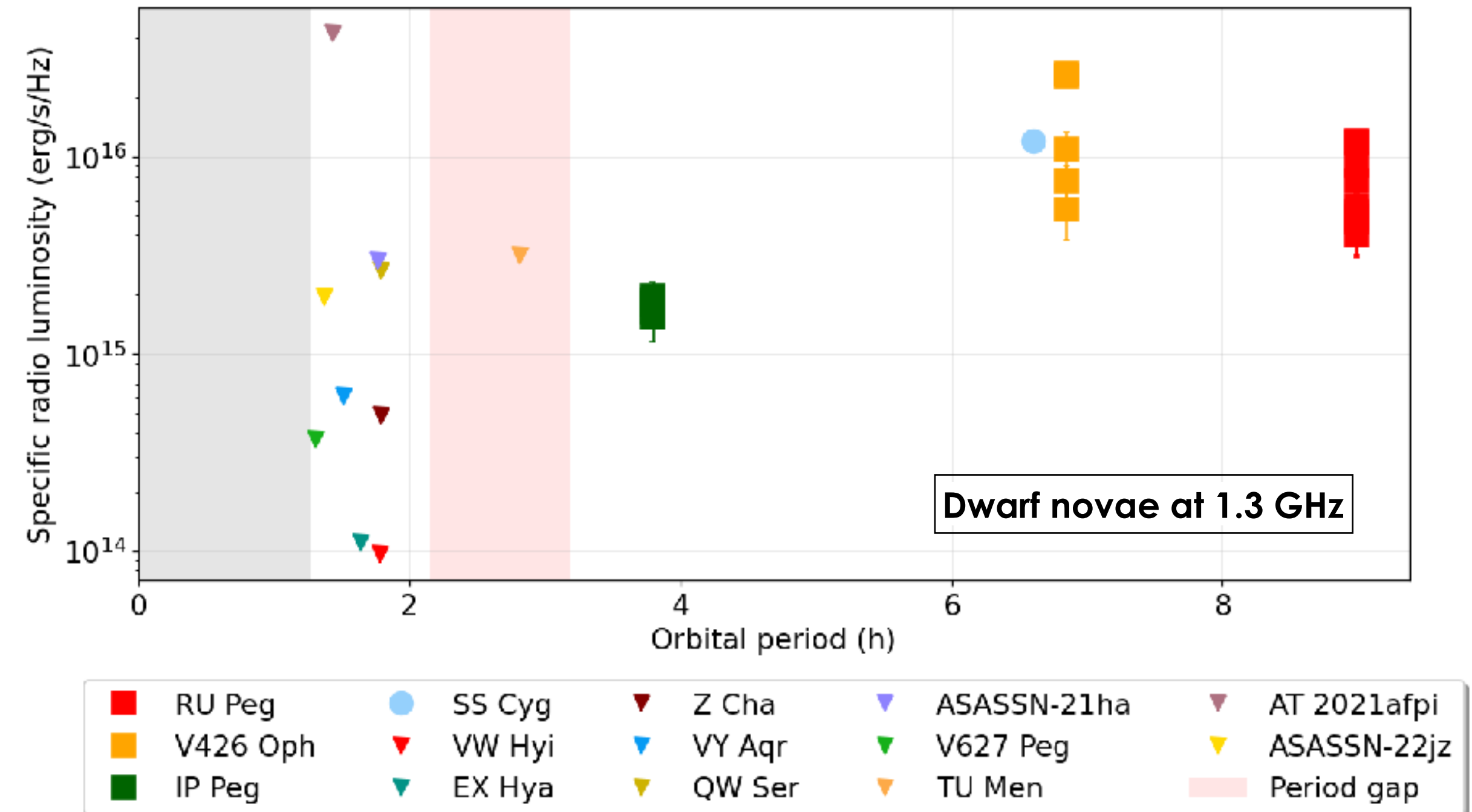
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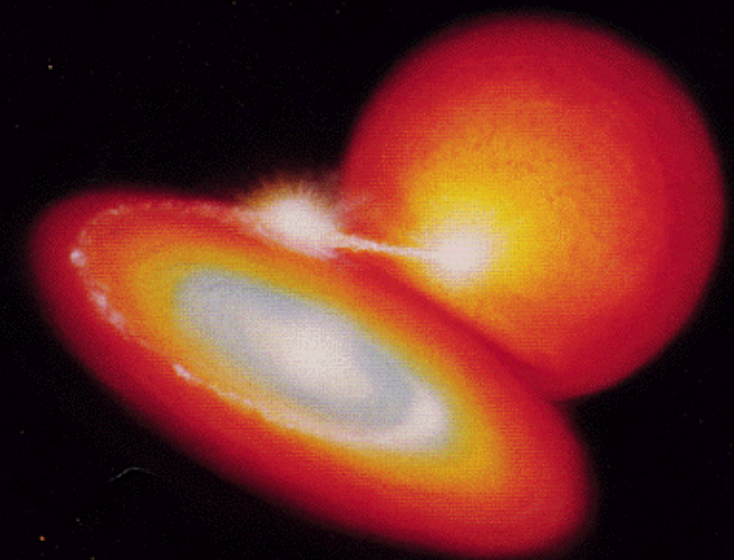
Extensive sample of nearby dwarf novae (< 300 pc):

- 3 new **SS Cyg-like** dwarf nova radio emitters ( $P_{\text{orb}} = 3.8, 6.8$  and  $9.0$  hrs, respectively)
  - ◆ IP Peg, V426 Oph and RU Peg
- **repeatable behaviour** with occasional late-time flares at end of outburst
- **nature of the emission:** consistent with synchrotron emission (similar to SS Cyg)
- **Many significant non-detections** including VW Hyi (54 pc!) and many other short-period SU UMa and WZ Sge systems (Kersten et al., in prep).



# dwarf novae and nova-likes

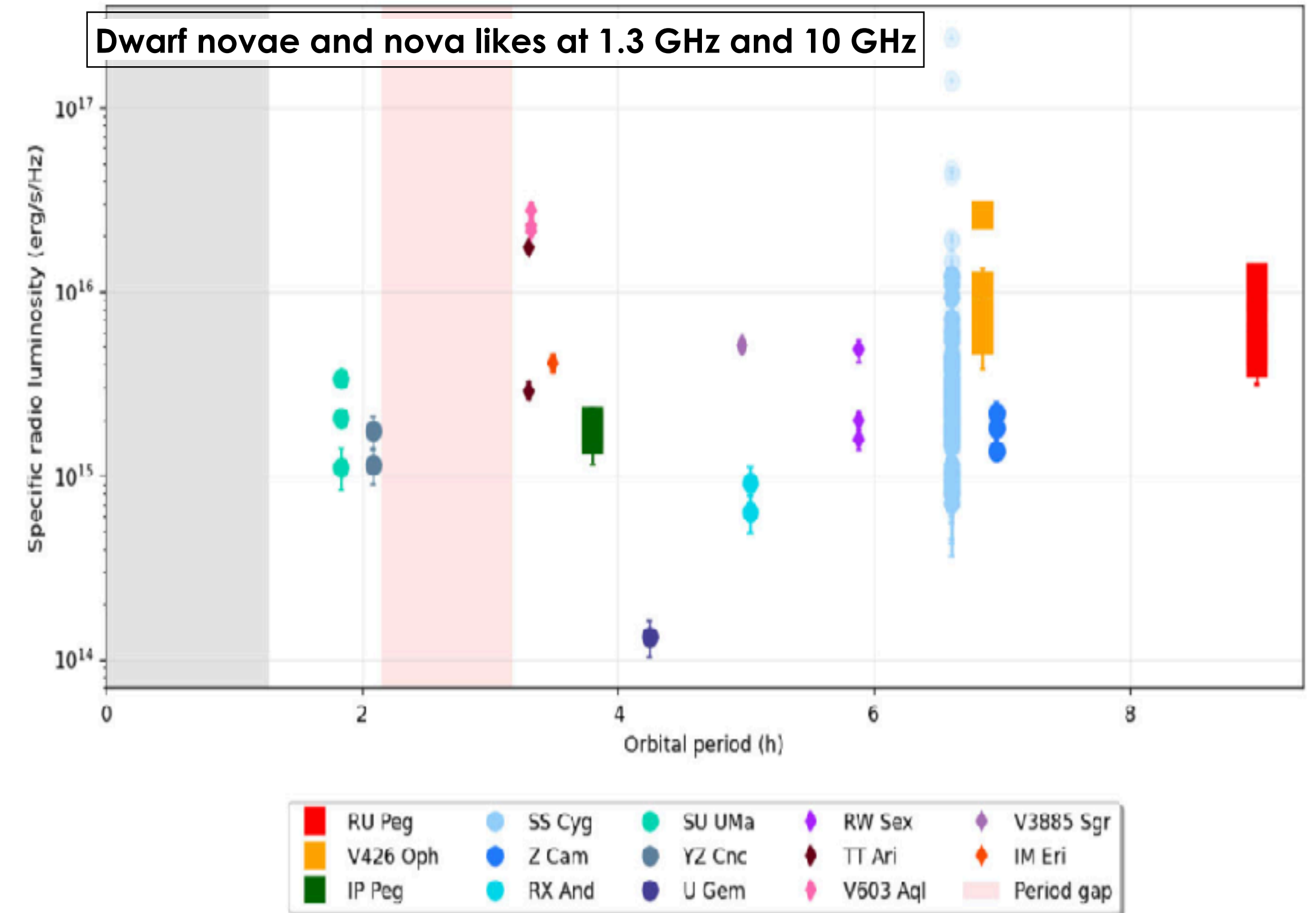
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# magnetic CVs

## Radio emission from magnetic CVs

### MeerKAT observations of mCVs

- UZ For (2018): coordinated MeerKAT/MeerLICHT/SALT
- LAMOST J0240+19 (2020): fastest WD rotator ( $P_{\text{spin}} = 24.93$  s) - twin of AE Aqr
- MeerKAT Open Time (2023): 20 Polars not observed by VLA, observable from MeerKAT (one detected BL Hyi)



Zwido Khangale (PhD/PDF)

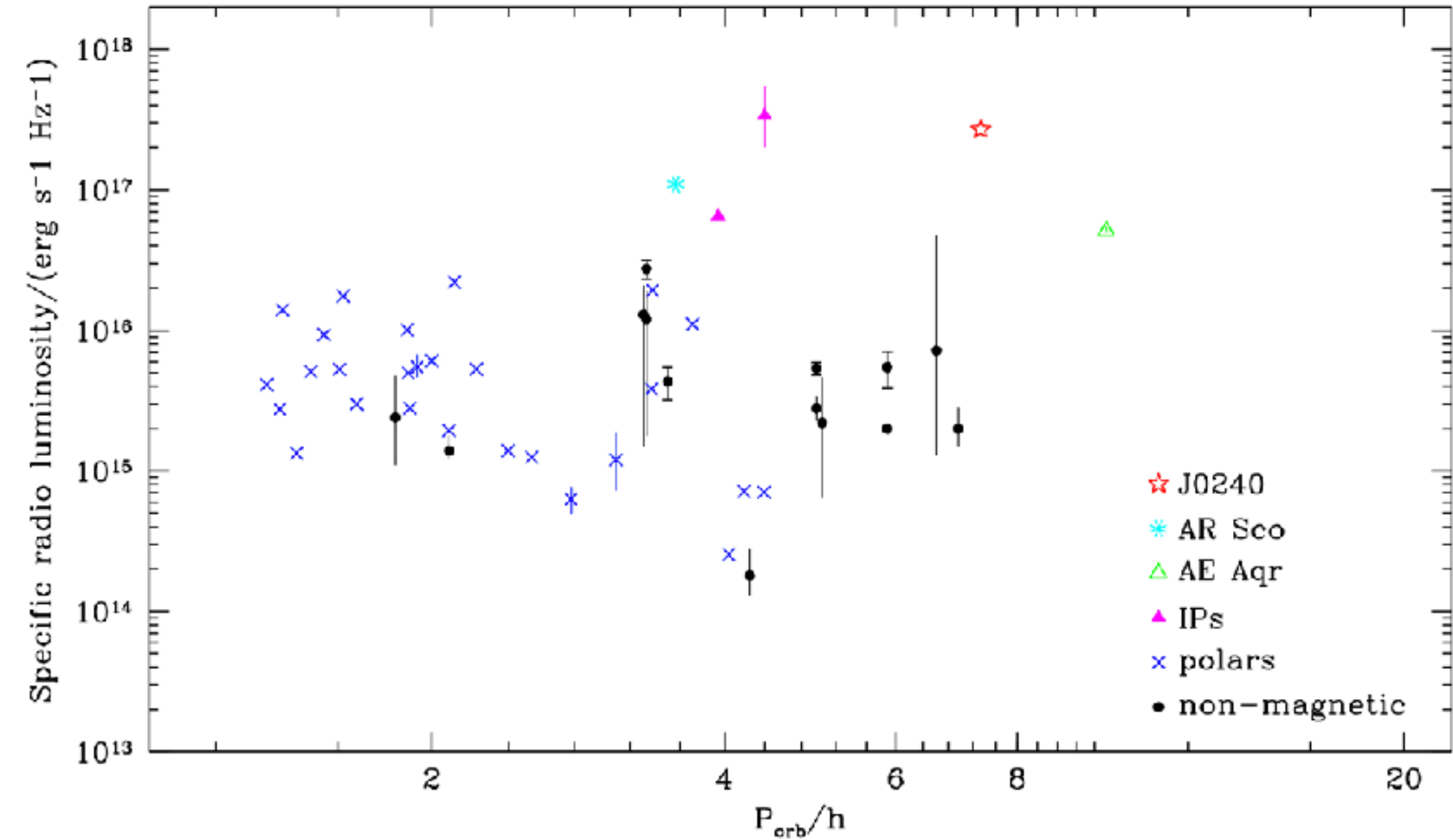


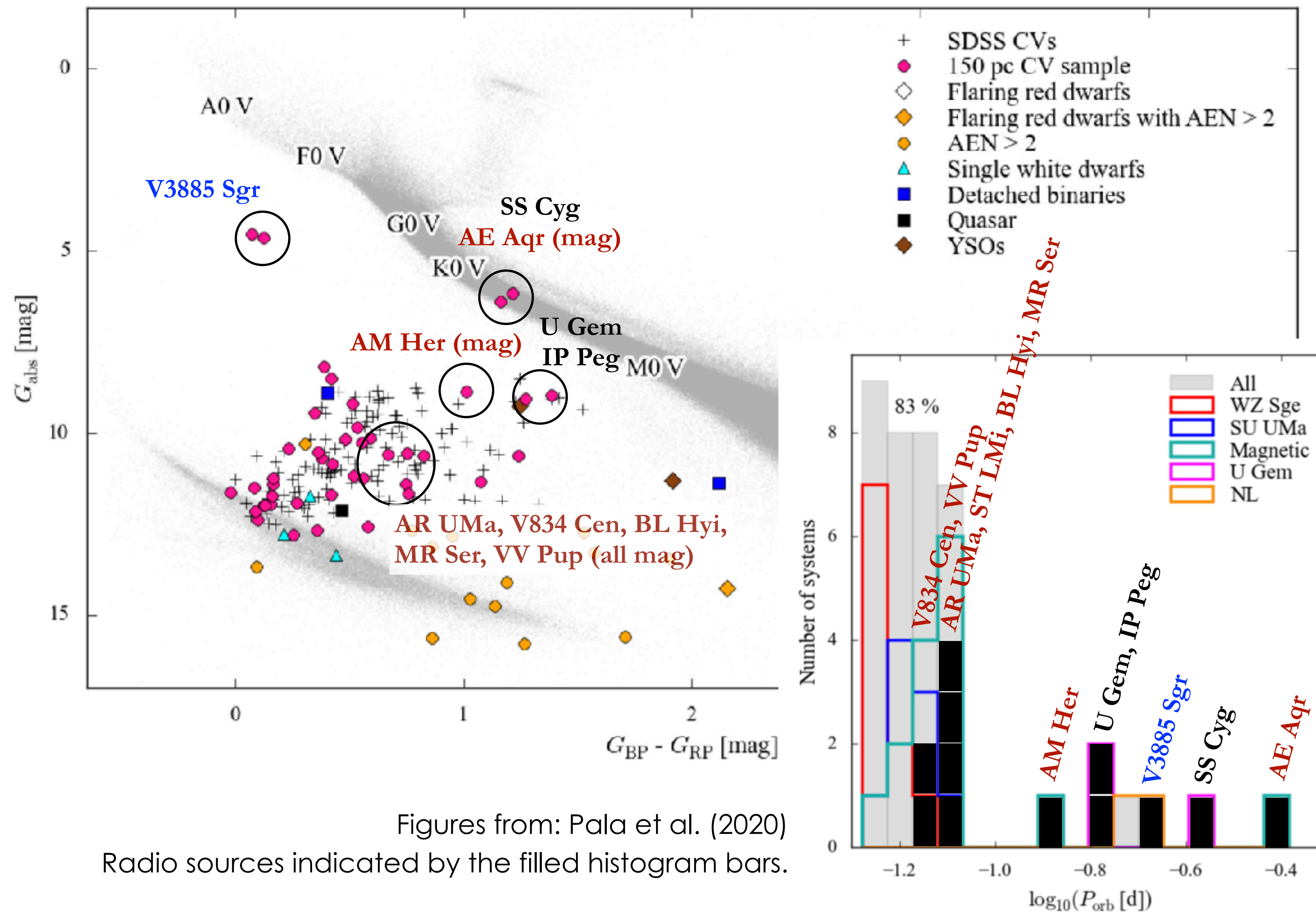
Figure from: Pretorius et al. MNRAS 503, 3692 (2021)

### Nature of the radio emission:

- **polars:** electron cyclotron maser emission (Barrett et al. 2020)
- **LAMOST J0240+19:** synchrotron, expanding magnetised blobs (propellor system)



# Radio emission from Cataclysmic Variables - a census



Figures from: Pala et al. (2020)

Radio sources indicated by the filled histogram bars.

## Pala et al. sample (150 pc)

Detections (12/42 = 29%):

NLs (1): V3885 Sgr

DNe (3): U Gem, IP Peg, SS Cyg

Magnetic (8): AR UMa, V834 Cen, ST LMi, BL Hyi, MR Ser, VV Pup, AM Her, AE Aqr

Non-detections (MeerKAT):

NLs (1): IX Vel (marginal)

DNe (4): VW Hyi (!), V627 Peg, Z Cha, VY Aqr (!)

Magnetic (1): EX Hya, V379 Tel

# Overview of White Dwarf pulsars

white dwarf  
pulsars  
and  
long-period  
radio  
transients

## White dwarf pulsars:

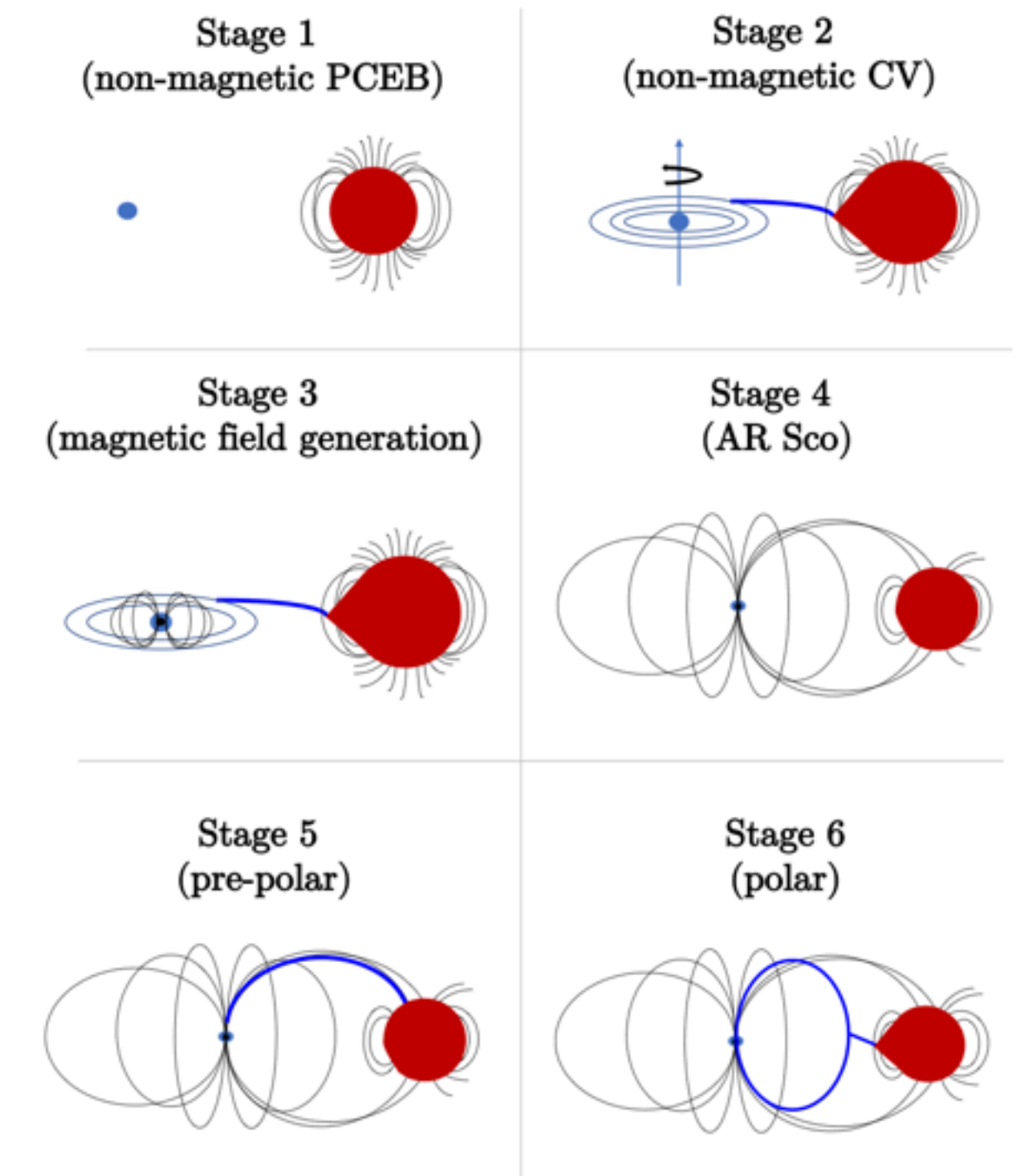
- strongly magnetic white dwarf
- pulsed non-thermal emission (radio to X-ray)
- M dwarf companion star
- no stable mass transfer

## Spin periods:

- minutes: AR Sco, J1912-4410, J2306+2440, ILT J1634+44
- hours: ILT J1101+5521, GLEAM-X J0704-37

## Modes of discovery (to date):

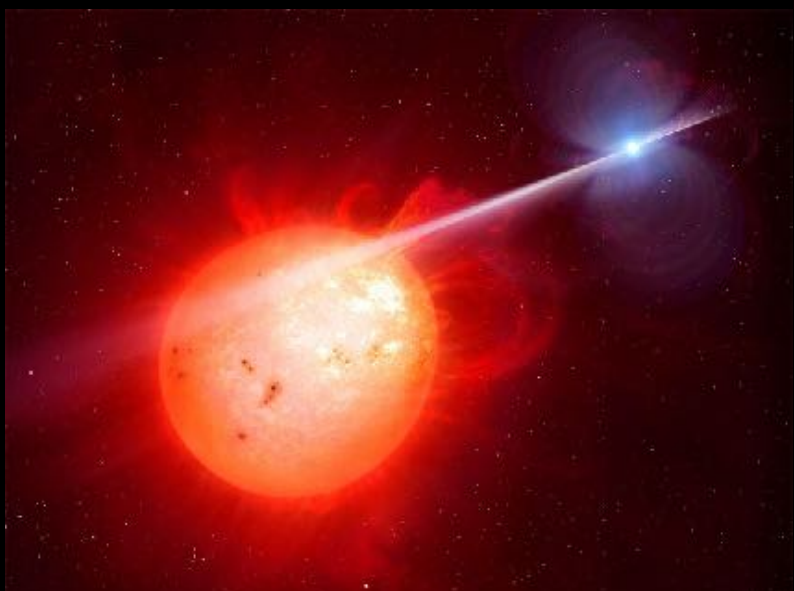
- optical: AR Sco / J1912-4410 / J2306+2440
- radio (LPTs): ILT J1101+5521 / GLEAM-X J0704-37 / ILT J1634+44 (++ growing list)



Possible evolutionary sequence:  
Schreiber et al. 2021

# white dwarf pulsar J1912-4410

## J1912 properties



# Overview of J1912-4410

## J1912-4410: second WD pulsar

- Twin of AR Sco (1<sup>st</sup> WD pulsar)
- WD / M dwarf binary with orbital period of 4.03 hr
- Spin period of the white dwarf is 5.32 minutes
- Narrow radio pulse on spin period at orbital phase 0.4-0.6

## Key properties of J1912-4410:

- $d = 237 \pm 5$  pc
  - $M_{\text{WD}} = 0.59 \pm 0.05 M_{\text{Sun}}$
  - $B_{\text{WD}} \leq 50$  MG
  - inclination:  $59 \pm 6$  degrees
  - $T_{\text{eff, WD}} = 11485 \pm 90$  K
- from: Pelisoli et al. (2024)

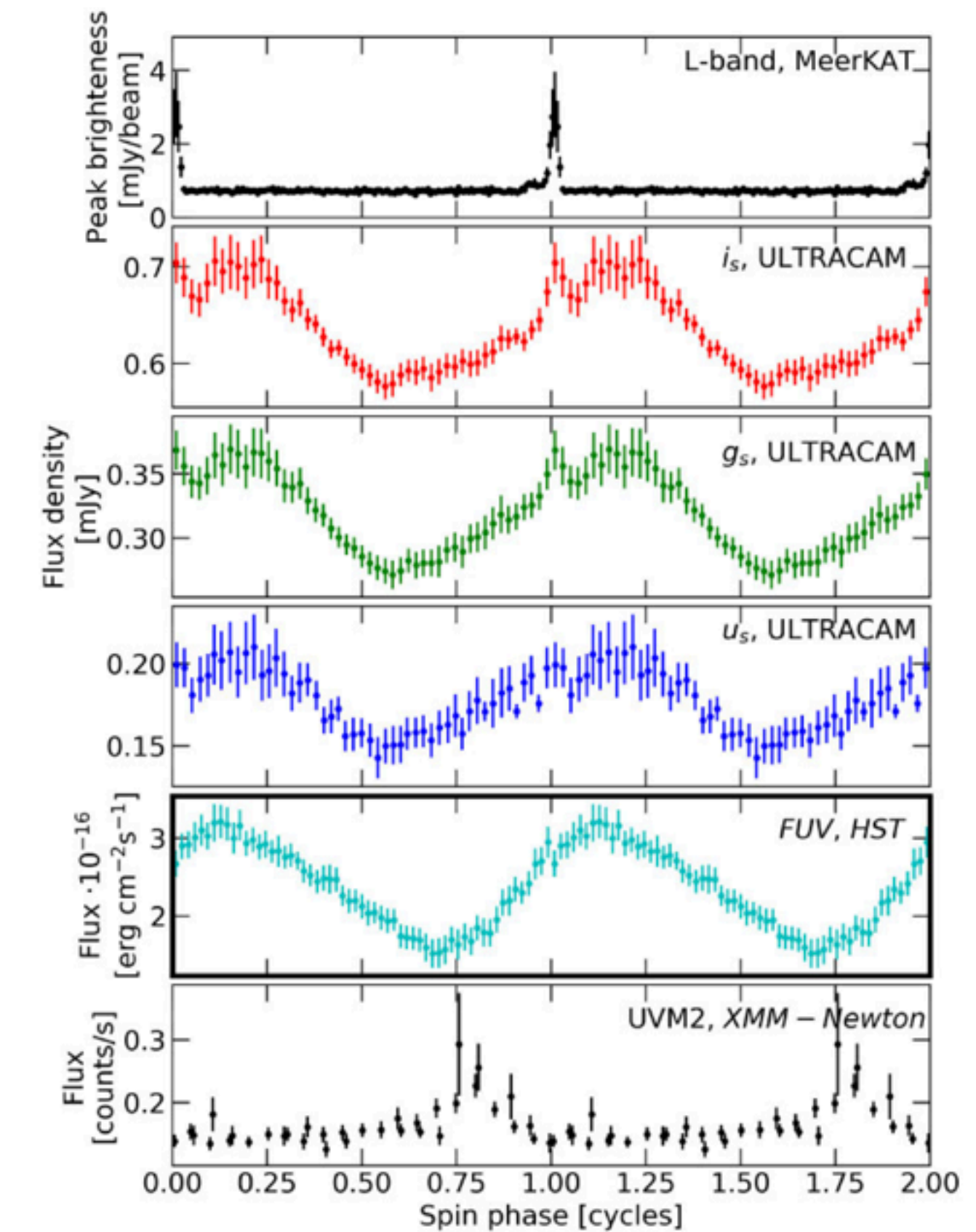


Figure from: Pelisoli et al., (2024)

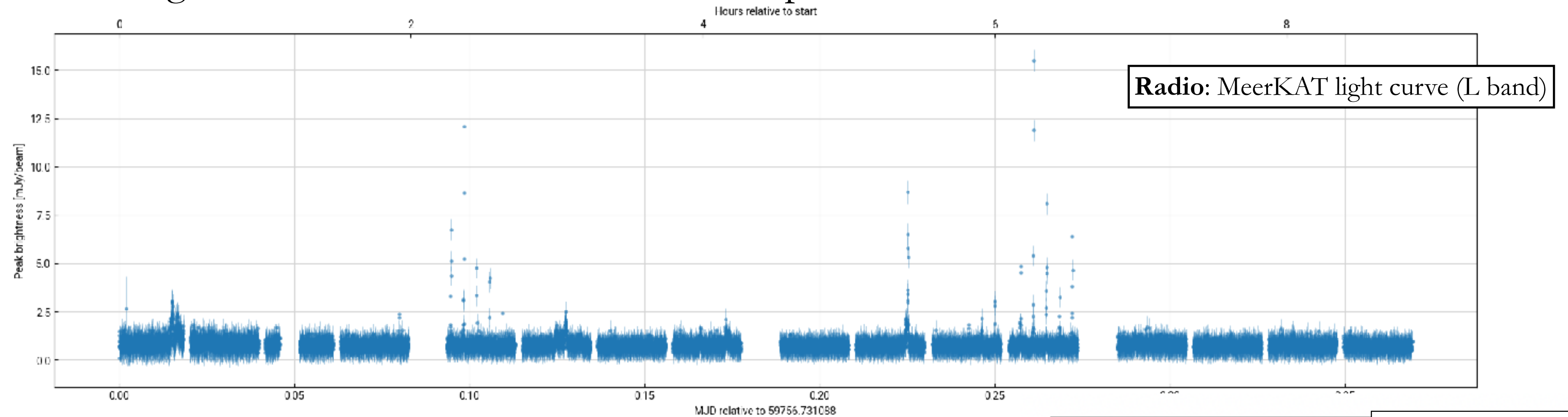
white dwarf  
pulsar  
J1912-4410

MeerKAT  
fast imaging

# MeerKAT observations of J1912-4410

Fast imaging (2/8 seconds) now routinely done on MeerKAT

- radio light curve of the second white dwarf pulsar at 2-sec time resolution

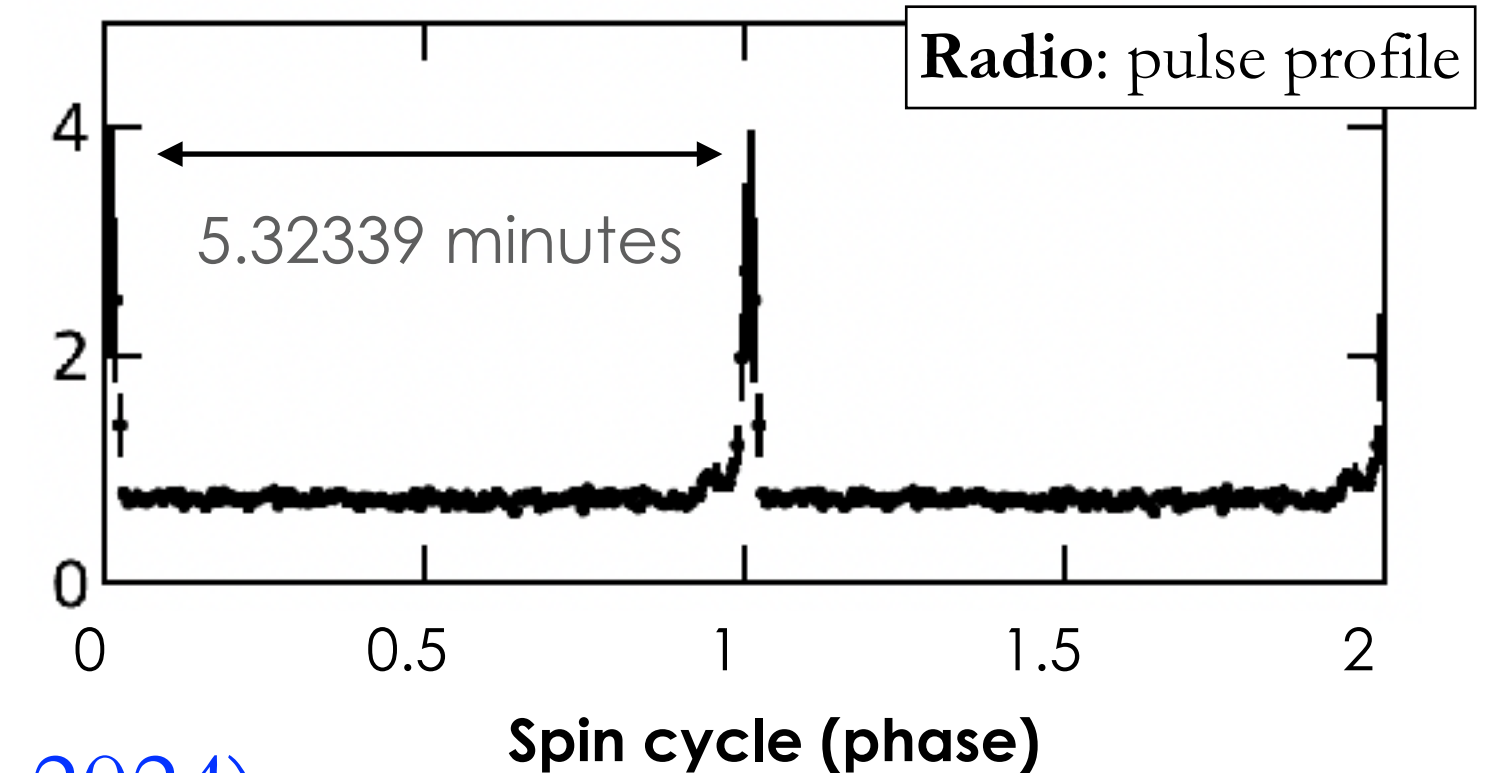


- 8 hr long MeerKAT observation (2x binary orbit)
- Pulse profile sharp and narrow (width  $\sim 10$  seconds)

Rule of thumb for fast L-band imaging with MeerKAT

2 sec: 1 square degree with depth of NVSS

8 sec: 1 square degree with depth of FIRST (e.g. Heywood 2024)



# white dwarf pulsar J1912-4410

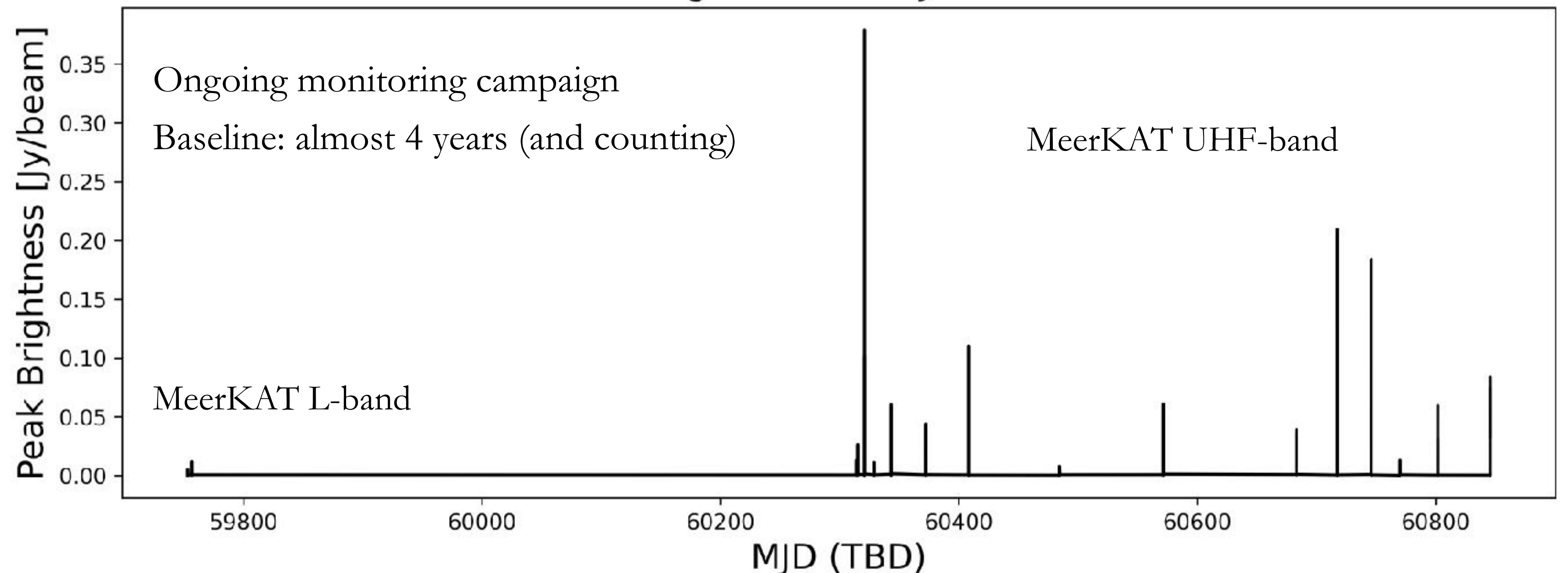
## MeerKAT observations of J1912-4410

- Multi-year monitoring campaign (UHF) - started in January 2024
- **Fast imaging** (2 sec) [OxKAT and PolKAT] and **fast timing** (PTUSE)

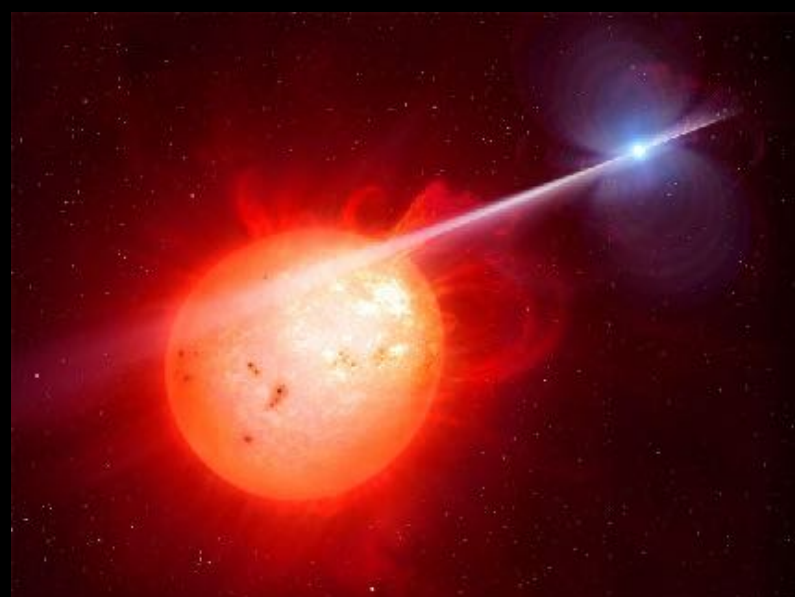
### Key objectives:

- Determine accurate pulse period and period derivative
- Understand the nature of the radio emission mechanism

Radio light curve for J1912-4410



Emil Meintjes (MSc)



# white dwarf pulsar J1912-4410

## spin period

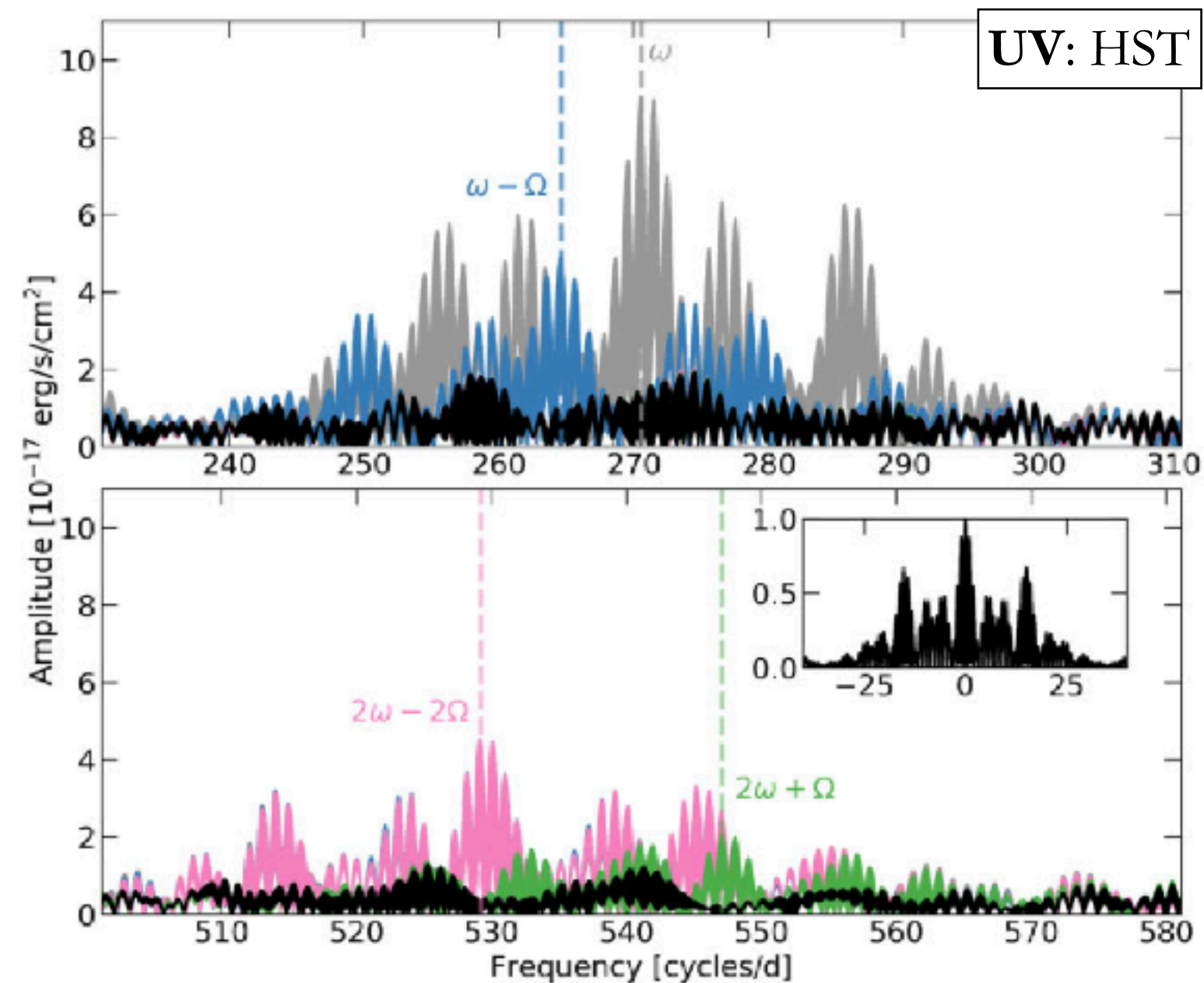
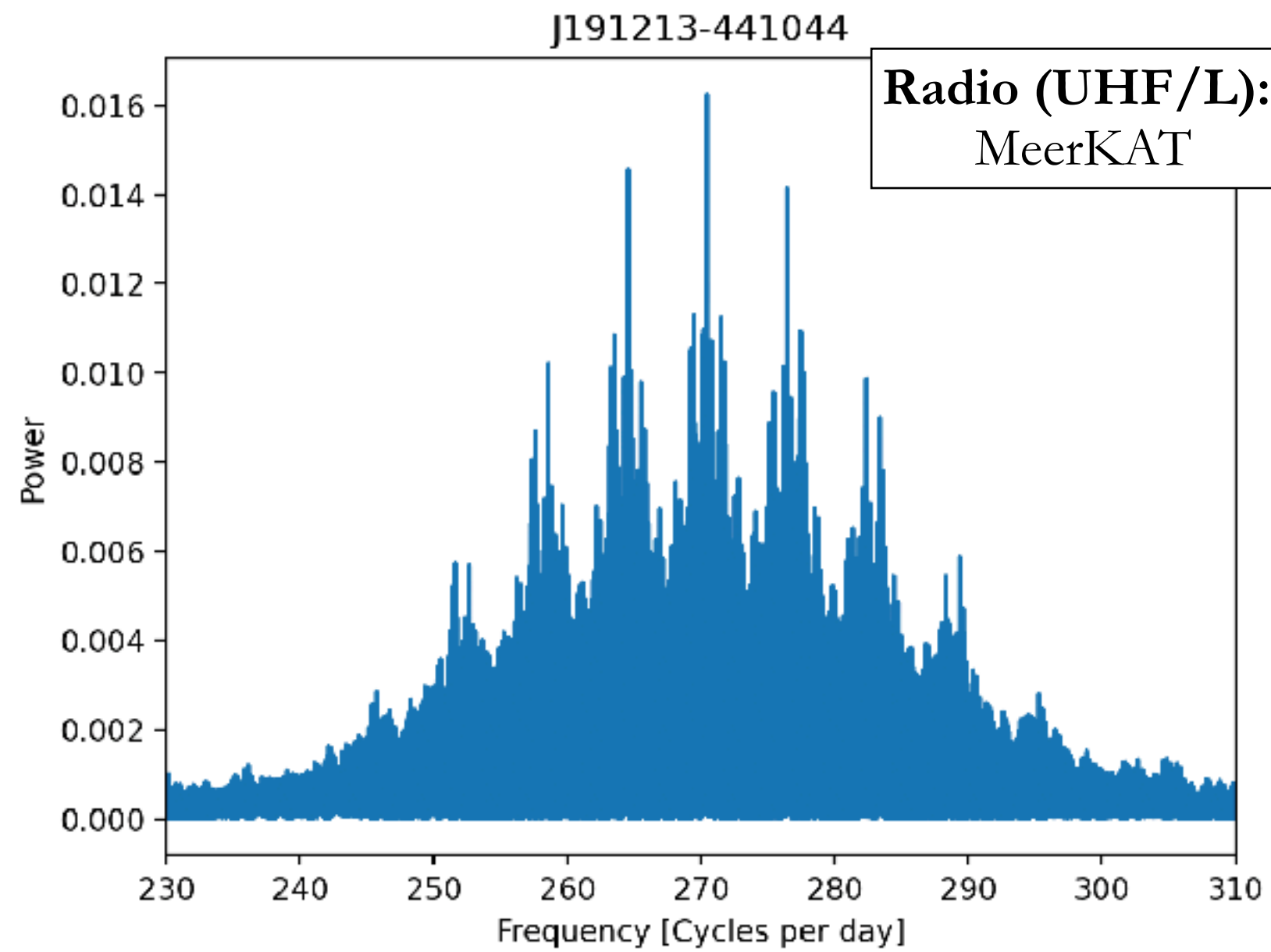
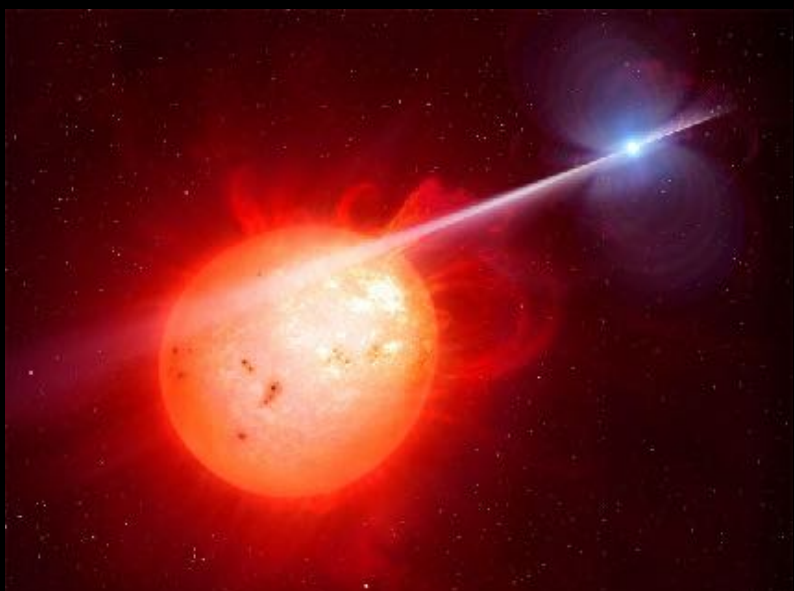


Figure from: Pelisoli et al. 2024

## Radio emission: spin or beat modulation?

- In J1912-4410 the radio emission is clearly modulated at the **spin frequency** of the white dwarf.

$$P_{\text{spin}} = 5.32339227 \text{ (5) min}$$

- In AR Sco the radio emission is also clearly modulated at the spin frequency (Barrett & Gurwell 2025)

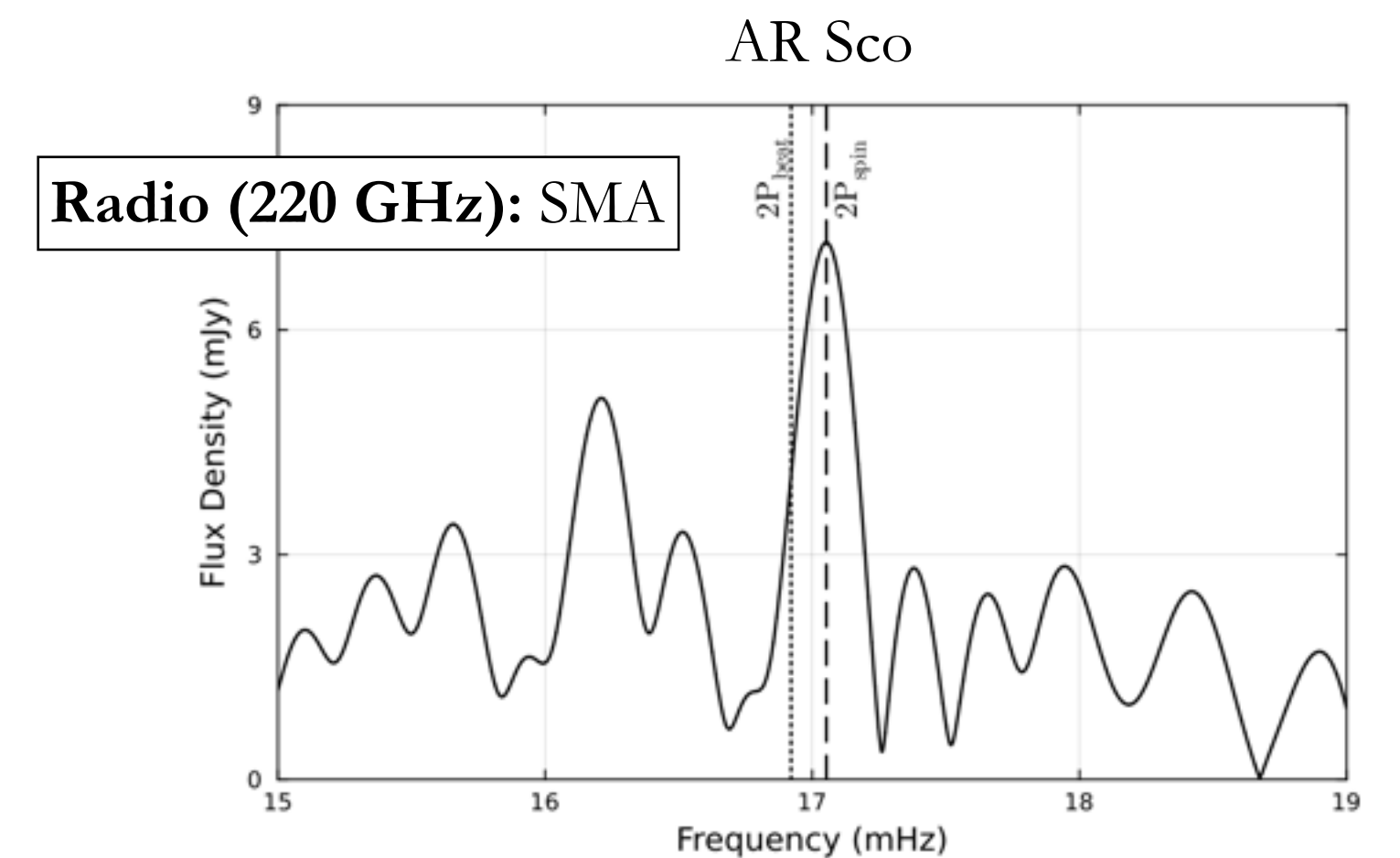
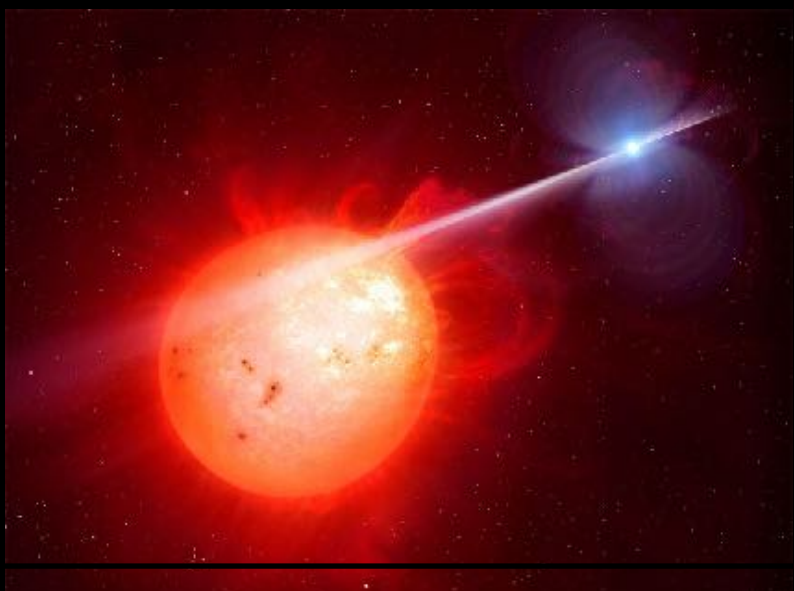


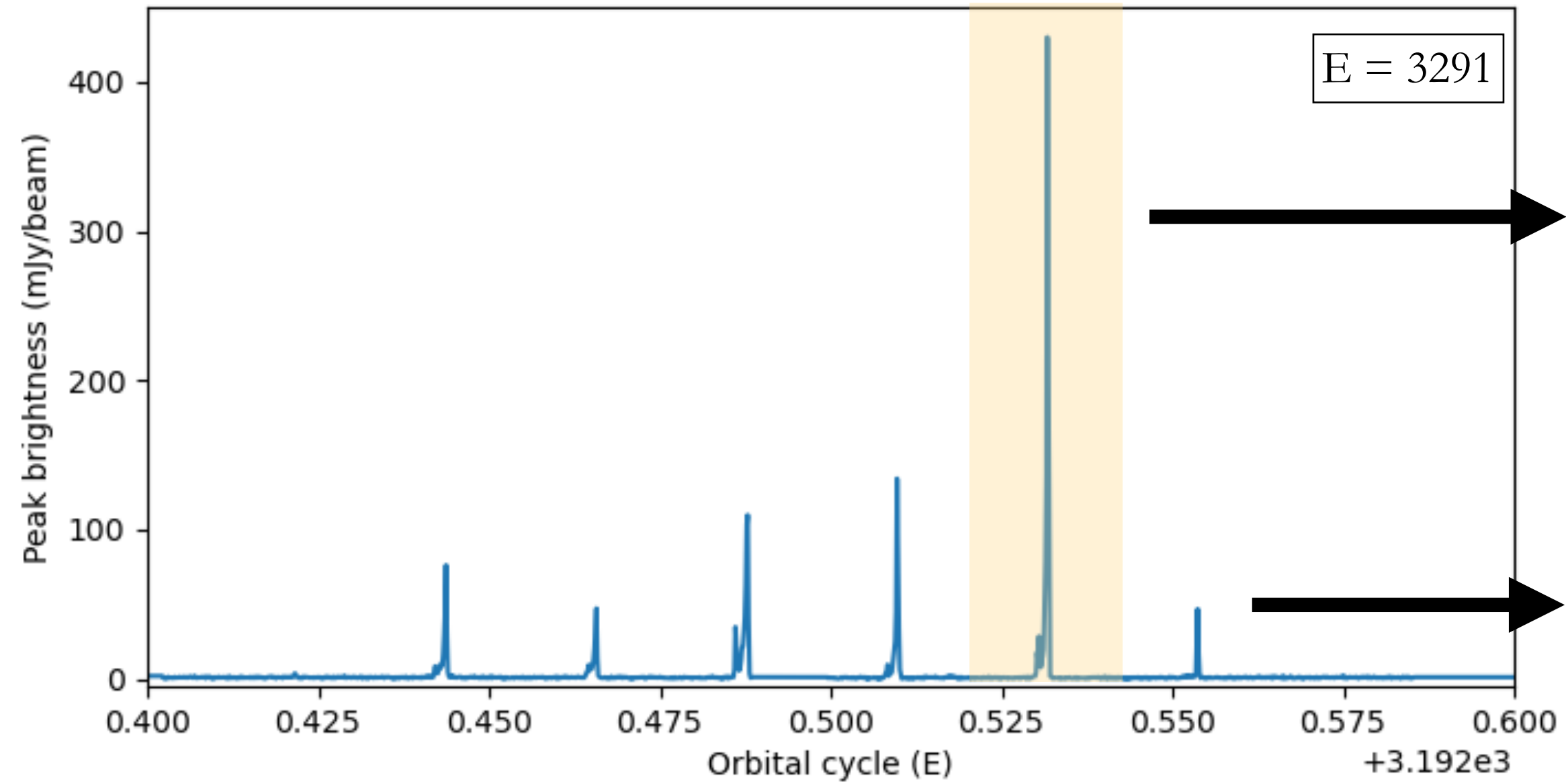
Figure from: Barrett & Gurwell 2025

# white dwarf pulsar J1912-4410

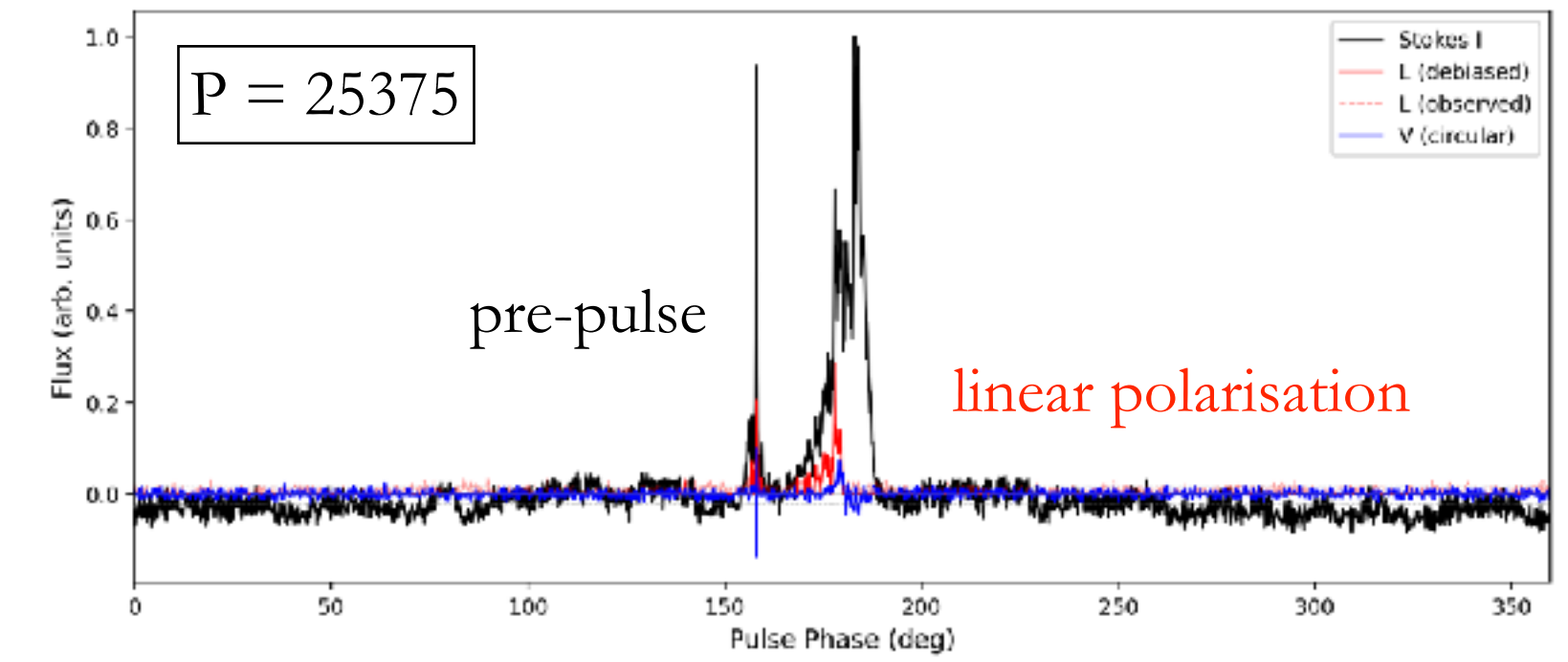
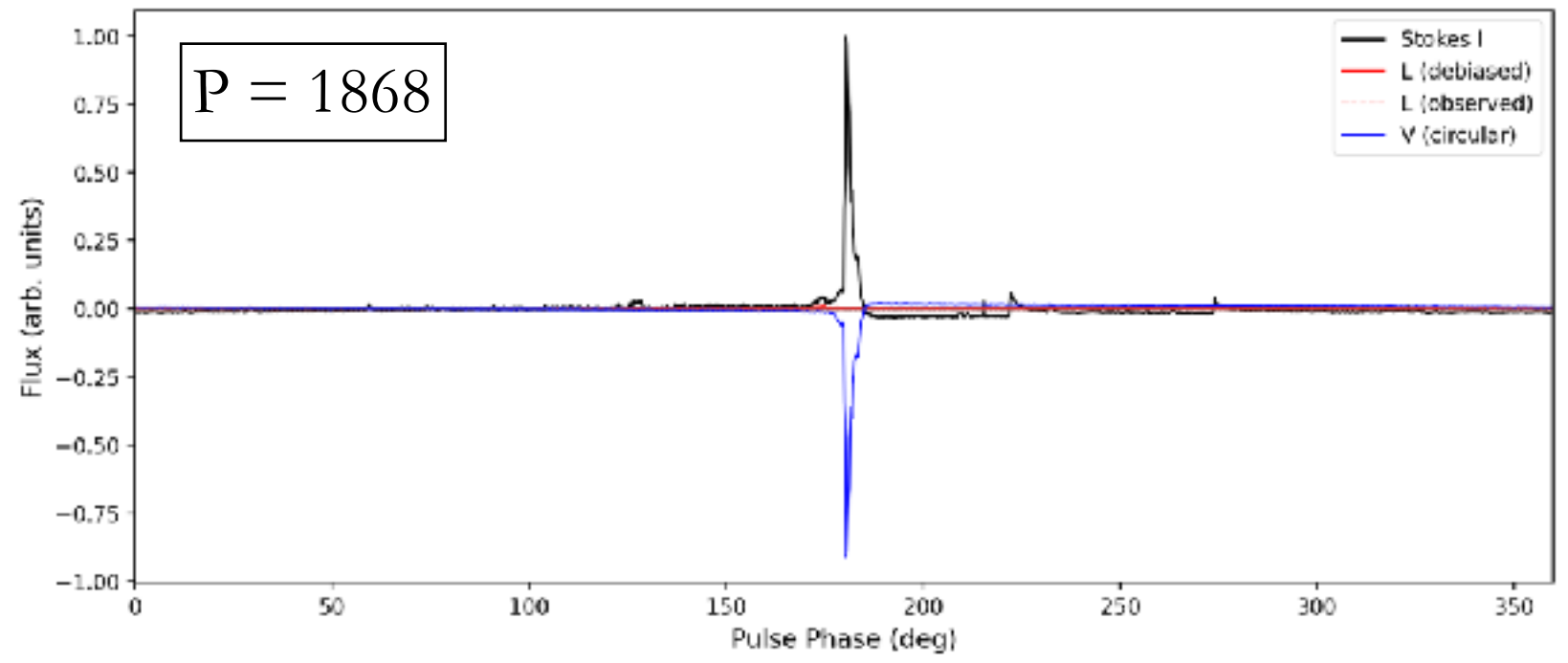
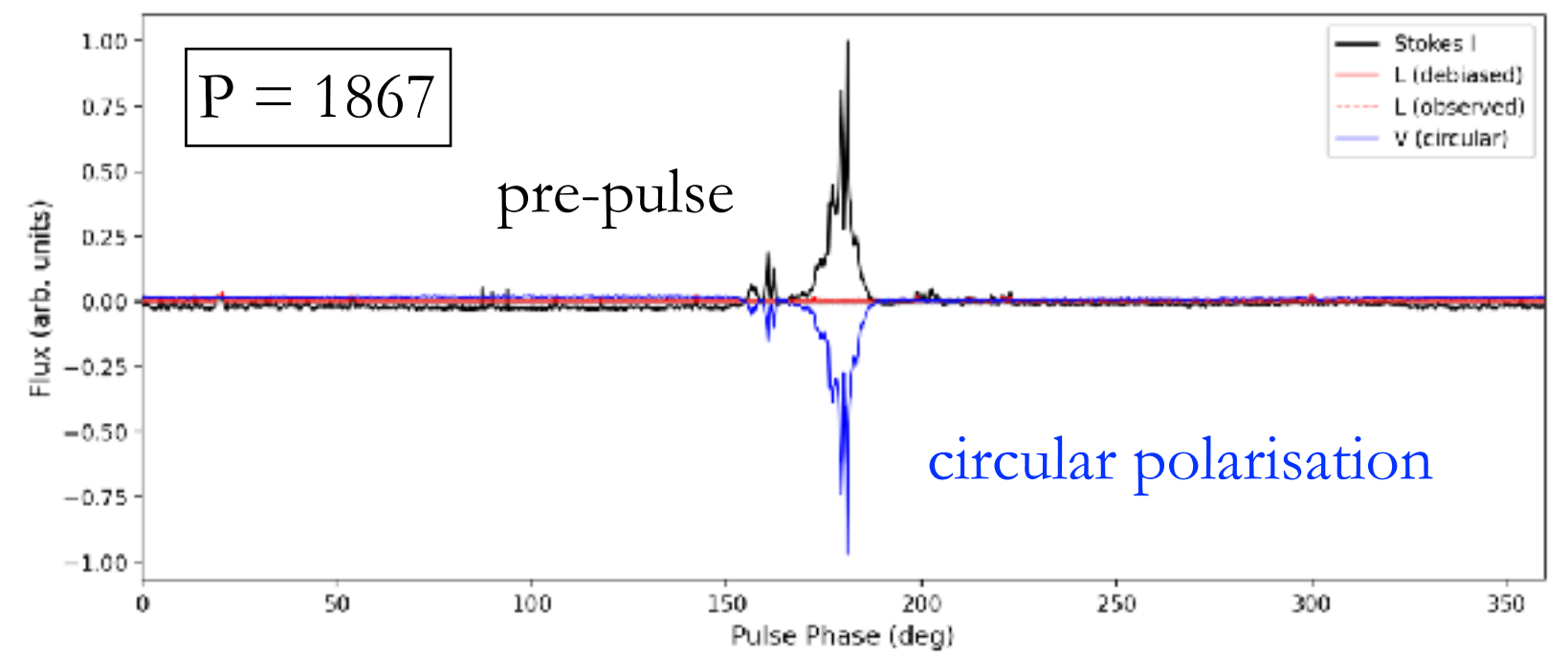
## polarisation



PolKAT imaging (2 second bins)



PTUSE timing (0.16 second bins)

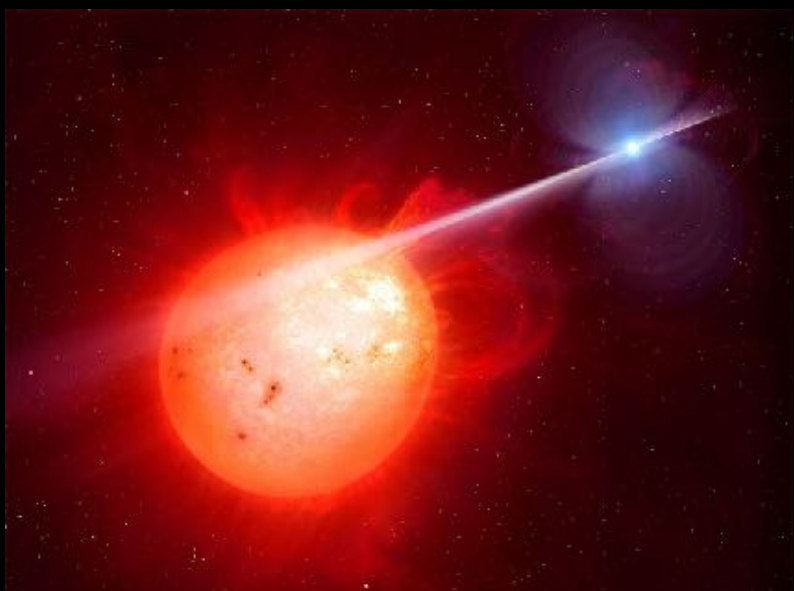


### polarisation

- Variable between strongly circularly polarised pulses (80-100%) and moderately linearly polarised pulses (10-20%)
- PTUSE provides polarisation information (see images on the right)

# white dwarf pulsar J1912-4410

## spin period derivative



### Timing solution for J1912-4410

- Unique timing solution after 3.5 years
- $P_{\text{spin}}$  (radio) = 5.32339227 (5) min
- $\dot{P} = 2.34 \pm 0.64 \times 10^{-12}$  s/s
- spin-down!

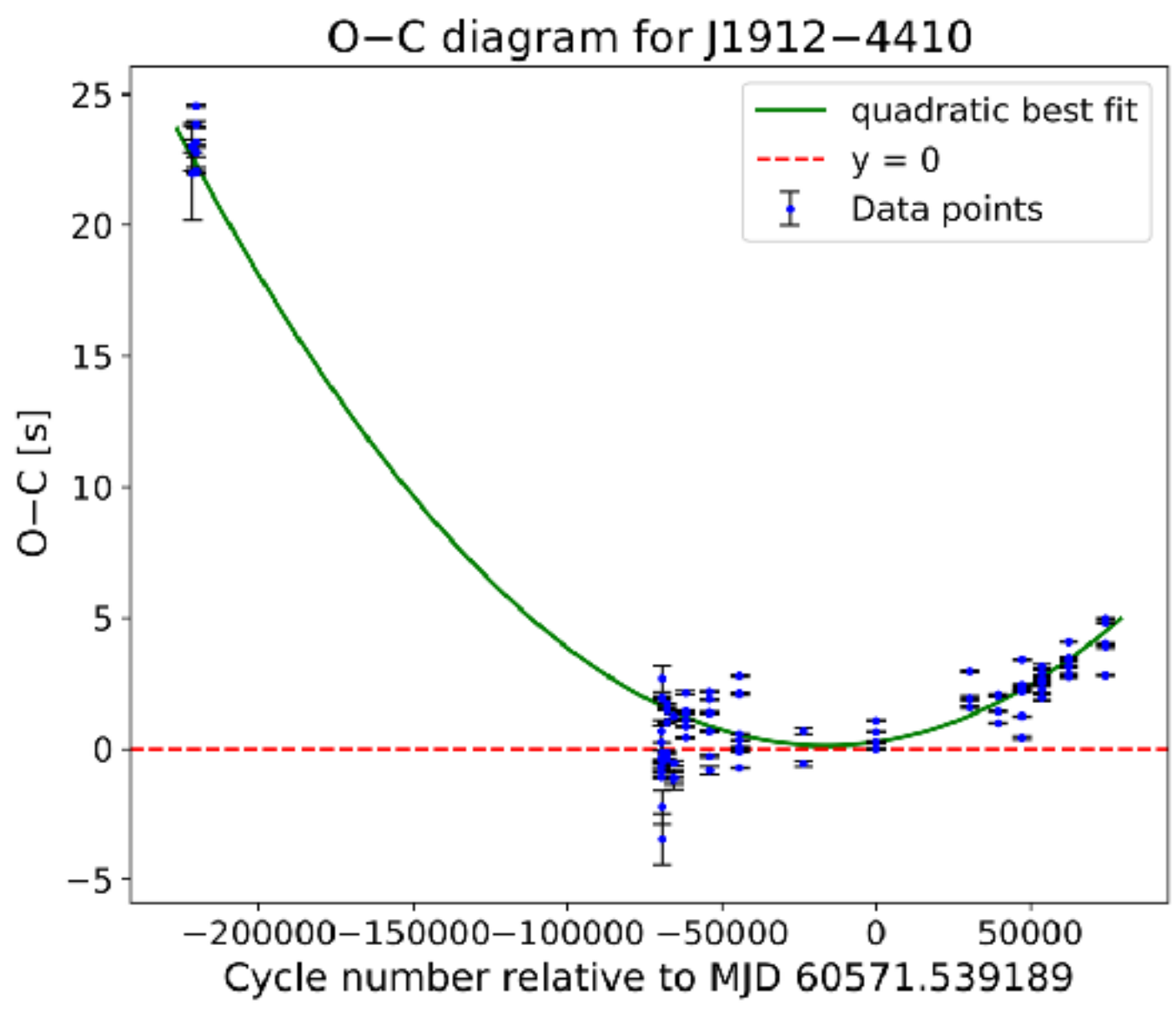


Figure courtesy of Emil Meintjes (MSc)

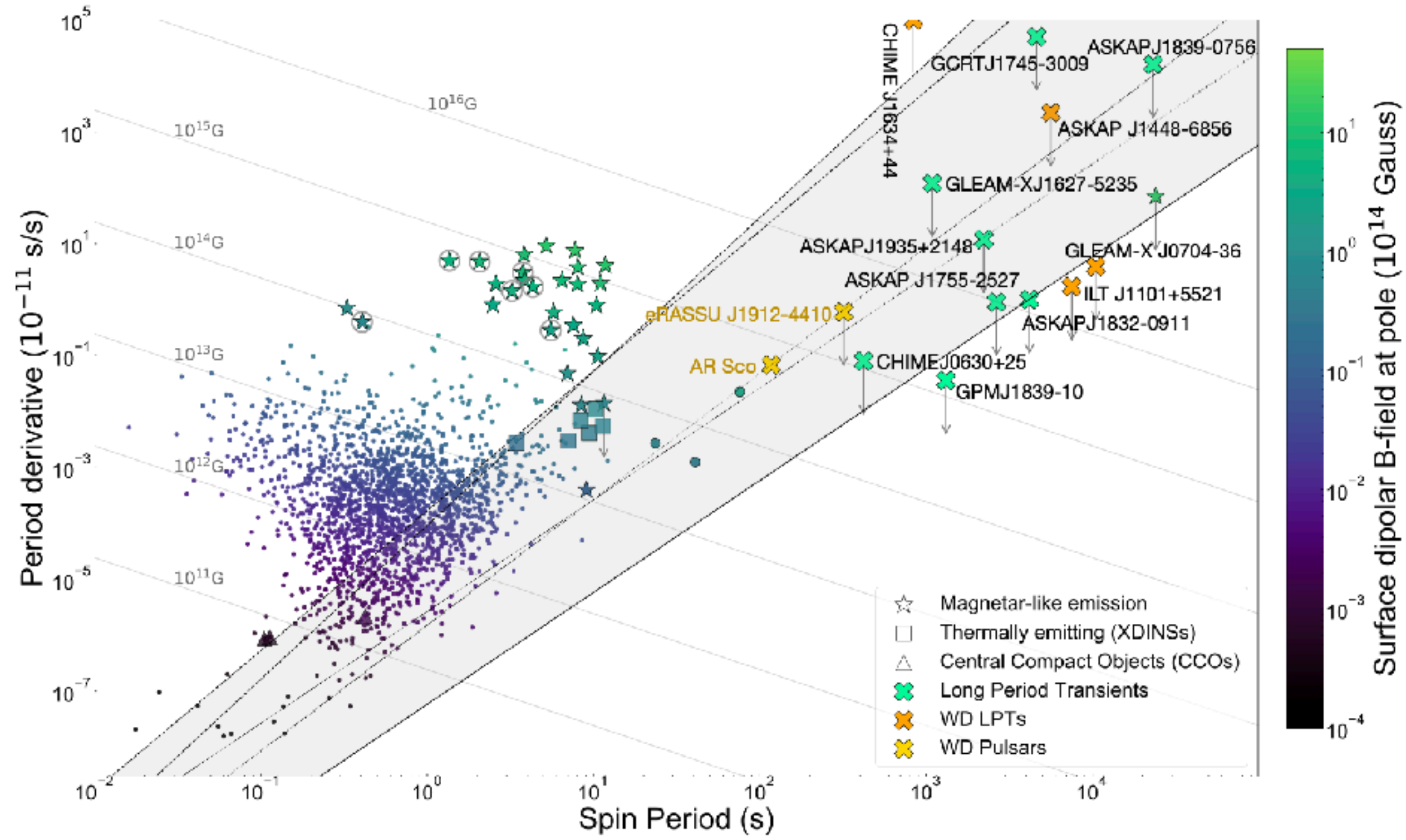
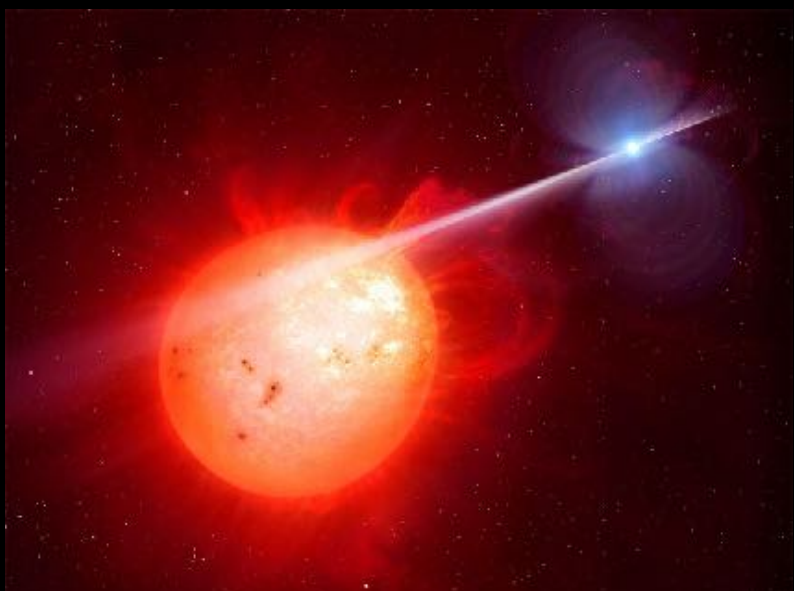


figure from: Rea, Hurley-Walker & Caleb (2026)  
 new measurement for J1912-4410 indicated by (☆)

# white dwarf pulsar J1912-4410

## spin period derivative



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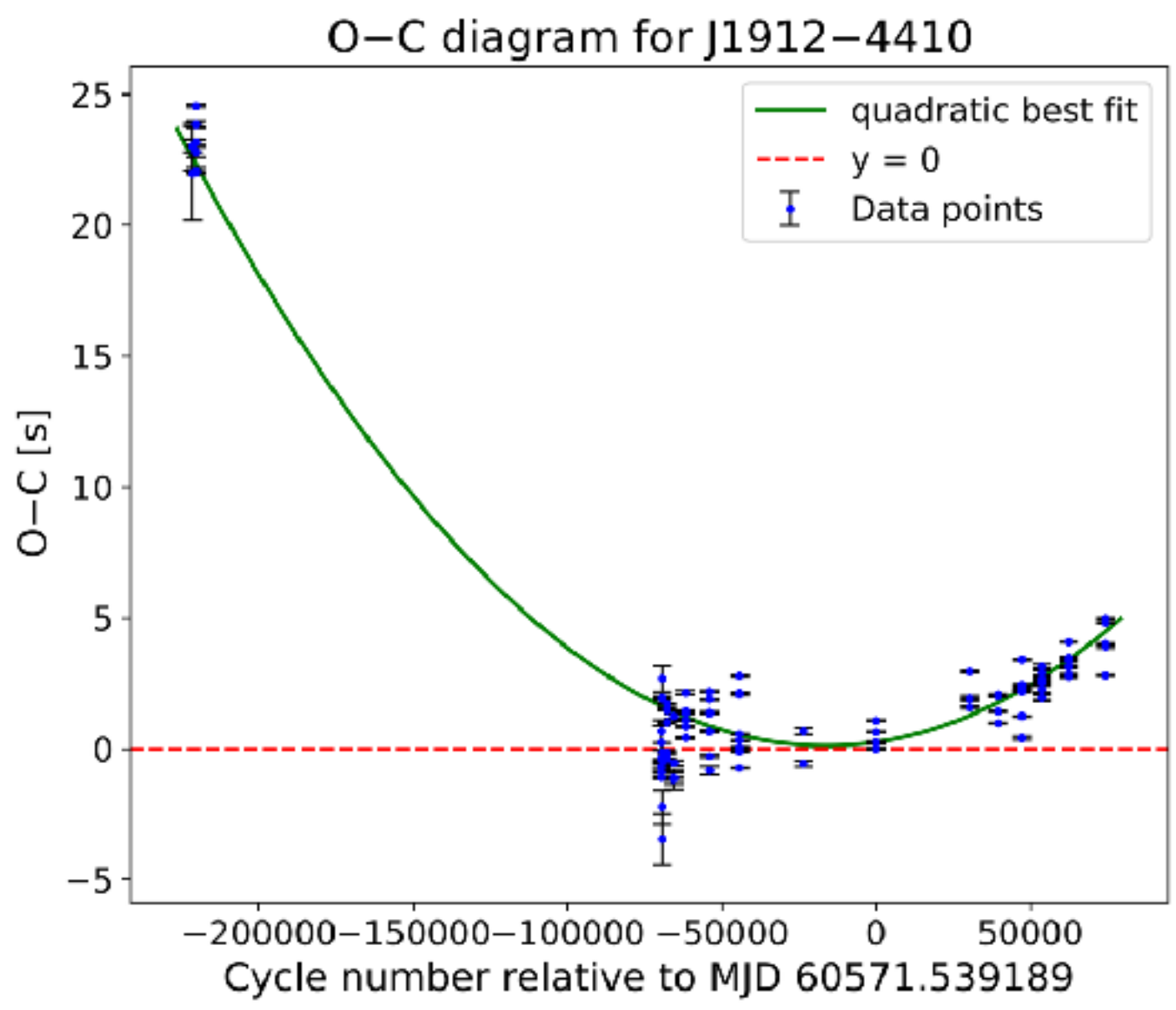


Figure courtesy of Emil Meintjes (MSc)

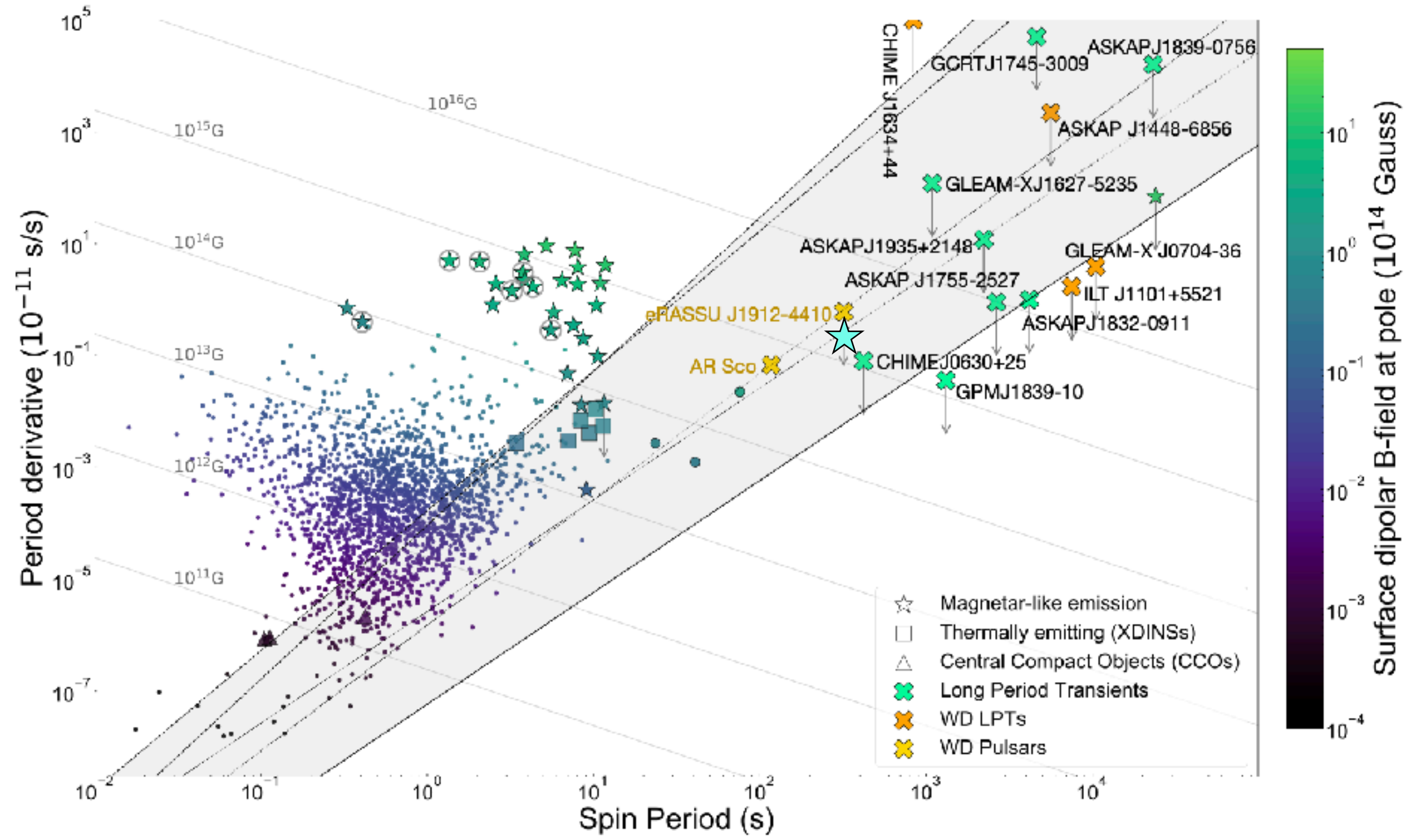


figure from: Rea, Hurley-Walker & Caleb (2026)  
 new measurement for J1912-4410 indicated by (☆)

# white dwarf pulsar J1912-4410

## working model

### Key observational evidence (from the MeerKAT data):

- WD spinning down: radio luminosity consistent with spin-down luminosity of a WD
- Radio pulses seen around orbital phase 0.4 - 0.6 (grow and decay in strength)
- Structured pulse profile with strong variations from pulse to pulse
- Polarisation changing from strong circular (80-100%) to mild linear (10-20%)
- Steep spectral index of the pulses (-3)

### Interpretation (work in progress):

- Interaction magnetic fields WD/RD
- Radio emission from polar regions WD
- Strong circular polarisation consistent with ECME, but ...
  - strong variations in polarisation
  - broad band emission with steep spectral index (synchrotron)

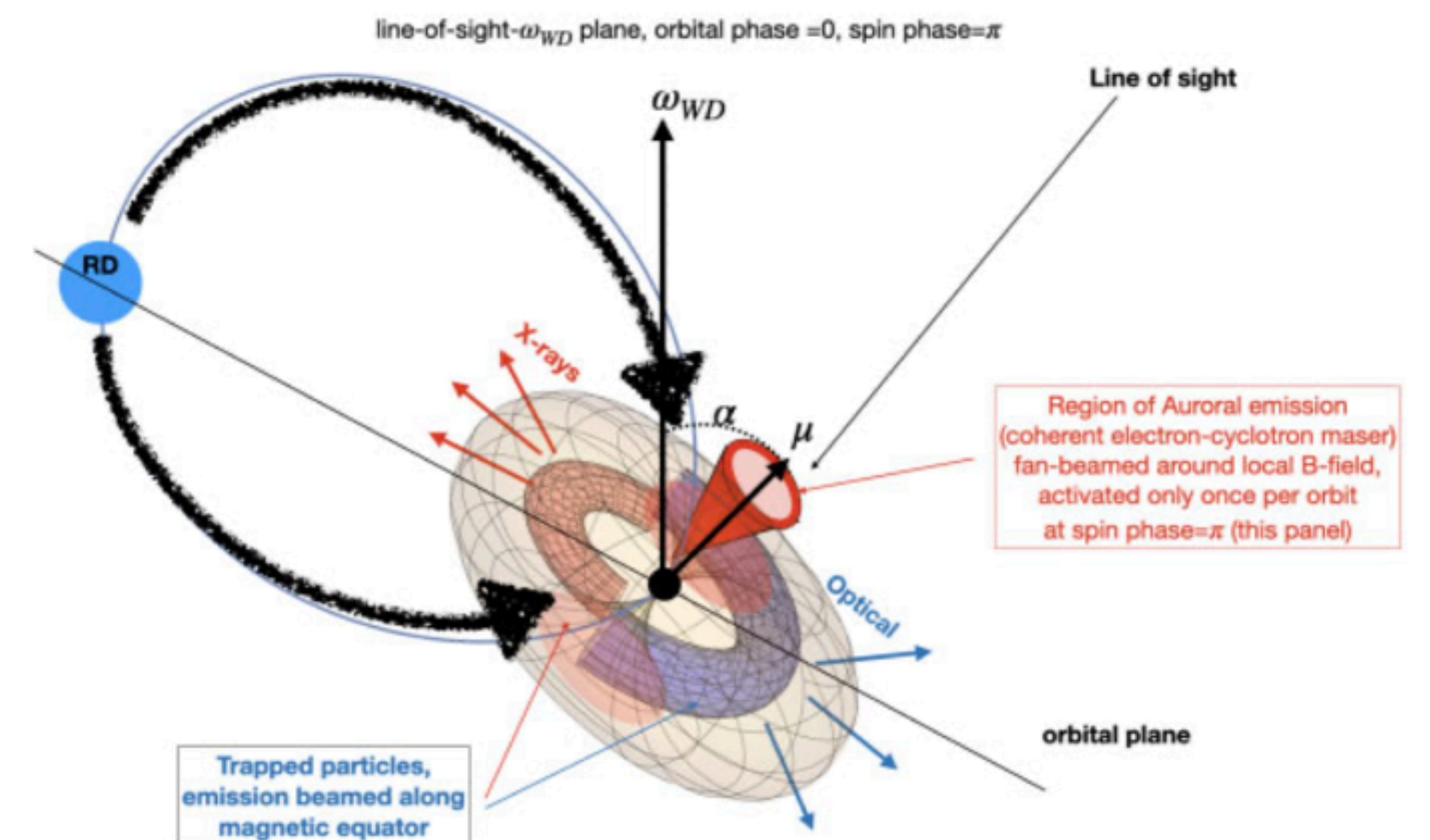


figure from: Pelisoli et al. (2024)

# Future prospects for radio transient astrophysics

Between now and SKA: MeerKAT+ and Band 5b (8.5 - 15 GHz) on MeerKAT

SKA (MID): Science verification (AA2: 2029, AA\*: 2031), cycle 0 (2032), KSPs (2035)

African VLBI network: AMT (Namibia), SKA-MID dish at BIUST (Botswana)

Picture: @SARAO

First MeerKAT+ antenna  
(February 2024)

Picture: @SARAO

First SKA-Mid antenna  
(July 2024)

Picture: @SKAO

# Concluding remarks



- ▶ Broad range of CVs observed with MeerKAT (novae, dwarf novae, nova-likes, magnetic CVs). Range of emission mechanisms: synchrotron (novae, dwarf novae, nova-likes) and electron cyclotron maser emission (magnetic CVs). **Mostly long-period dwarf novae detected in radio during outburst. Next step: Expand volume limited samples to 300 pc and 500 pc!**
- ▶ Fast imaging with MeerKAT (and other current facilities): **opening up unbiased (radio) discovery of population of white dwarf pulsars** (and more generally long period transients). NB: TRON!
- ▶ Link between white dwarf pulsars (and long period transients) and CVs: **phase in magnetic CV evolution? Do we see narrow pulsed radio emission in accreting CVs?**