NORTHWESTERN UNIVERSITY

White Dwarf Binaries

Deanne Coppejans

Elmar Körding, James Miller-Jones, Christian Knigge, Michael Rupen, Gregory Sivakoff, Patrick Woudt, Paul Groot, Raffaella Margutti, Payaswini Saikia, AAVSO

CIERA
CENTER FOR INTERDISCIPLINARY EXPLORATION AND RESEARCH IN ASTROPHYSICS

Image credit: M. Garlick/University of Warwick/ESO

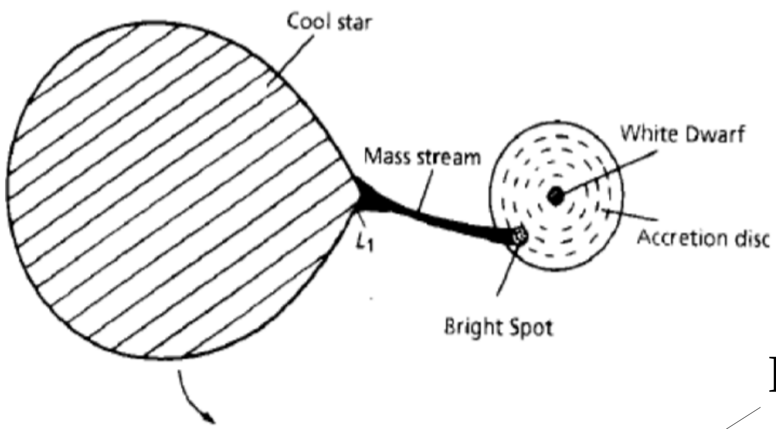
Contents

- Jets in Cataclysmic Variable stars?
- Radio VLBI vindicates outburst theory
- A new class of radio transient
- Flare rates in close stellar binaries
- White dwarf pulsar
- Future outlook

1

Jets in Cataclysmic Variables?

Jets in Cataclysmic Variables?



Cataclysmic Variables (CVs)

Magnetics

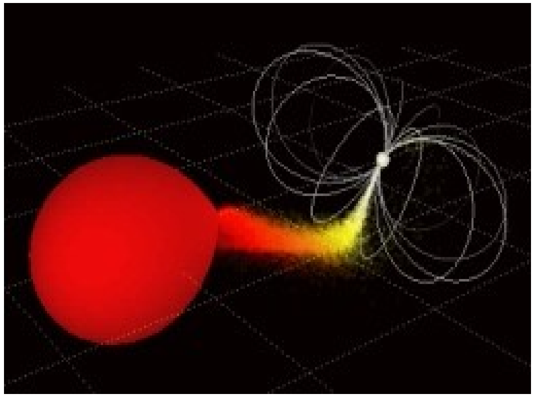
Non-magnetics
(B $\lesssim 10^6$ G)

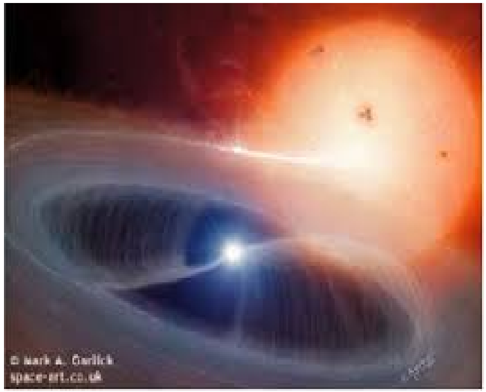
Polars
(B $\gtrsim 10^7$ G)

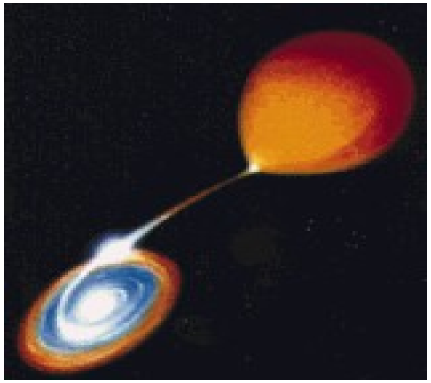
Intermediate Polars
($10^6 \lesssim$ B $\lesssim 10^7$ G)

Dwarf Novae

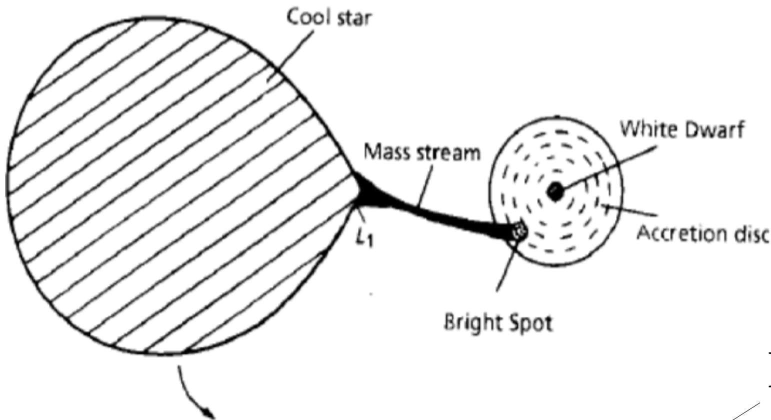
Novalikes







Jets in Cataclysmic Variables?



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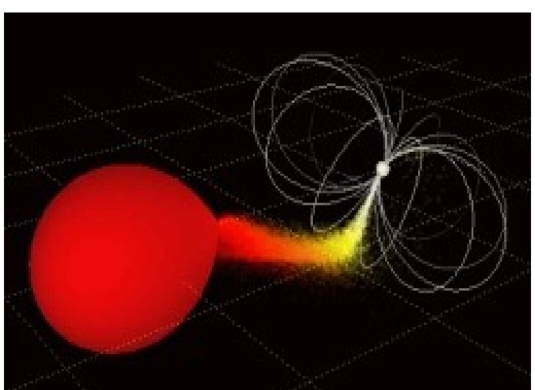
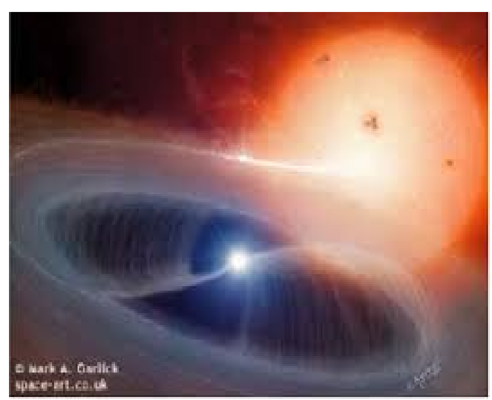
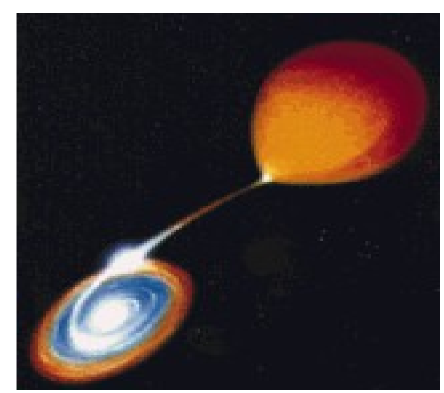
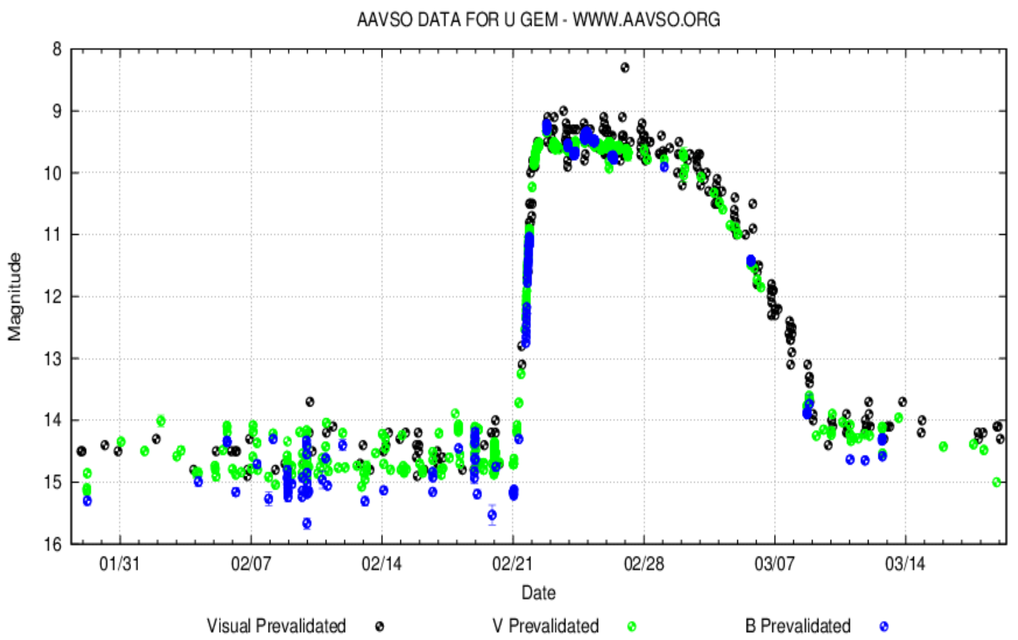






Jets in Cataclysmic Variables?

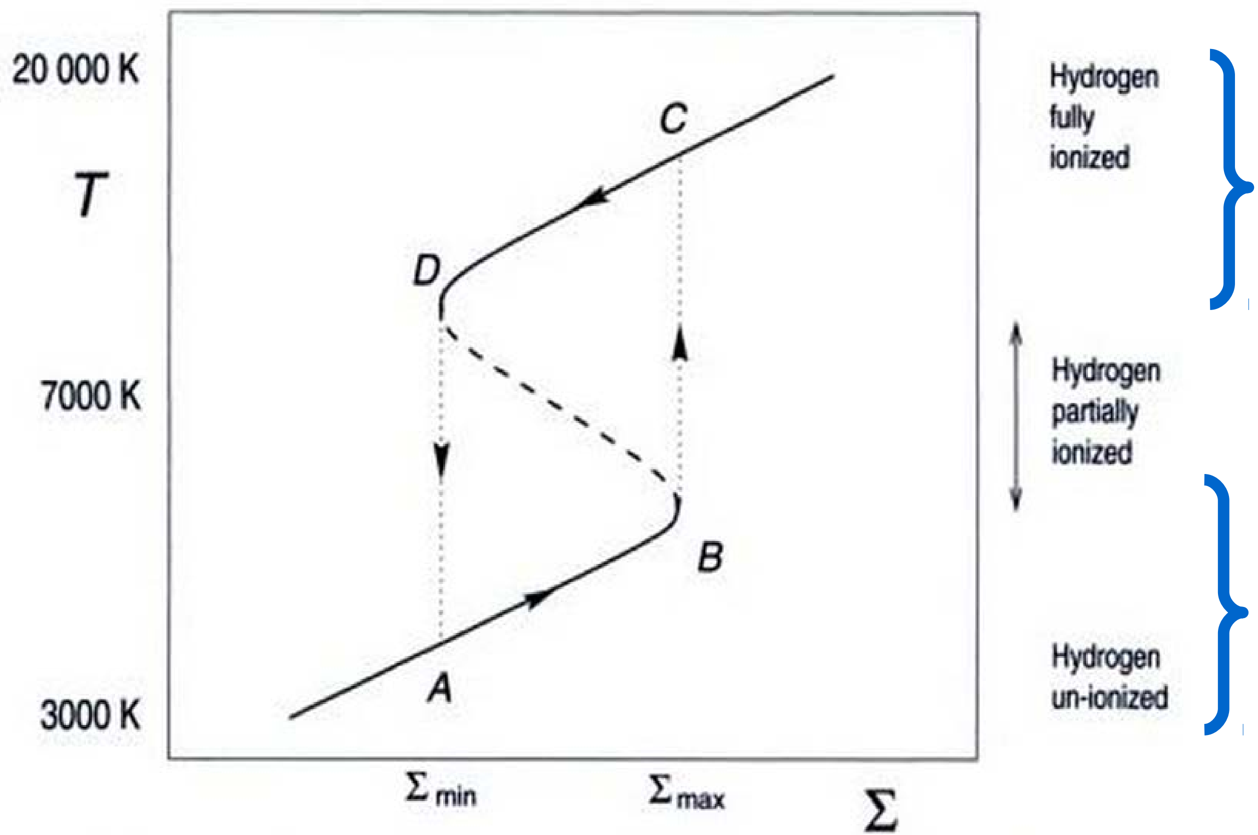
DN:

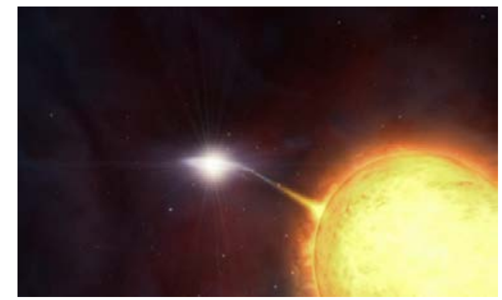


Novalikes: **Always in outburst**

Jets in Cataclysmic Variables?

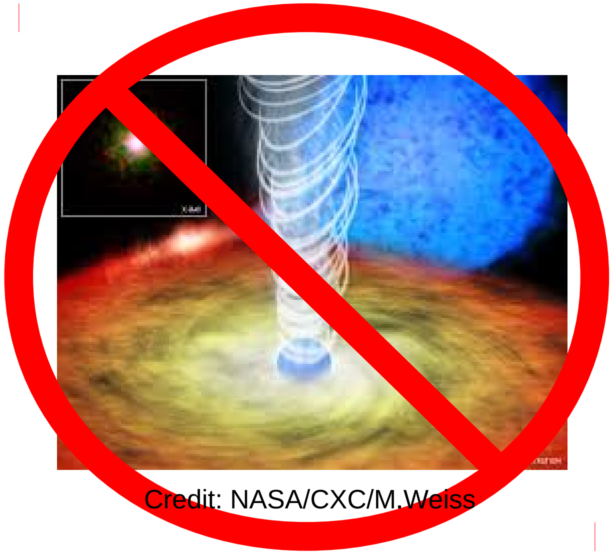
Disc Instability Model





Credit: Hellier figure 5.7 illustrating the Disc Instability Model (Osaki 1974 & Meyer & Meyer-Hofmeister 1981)

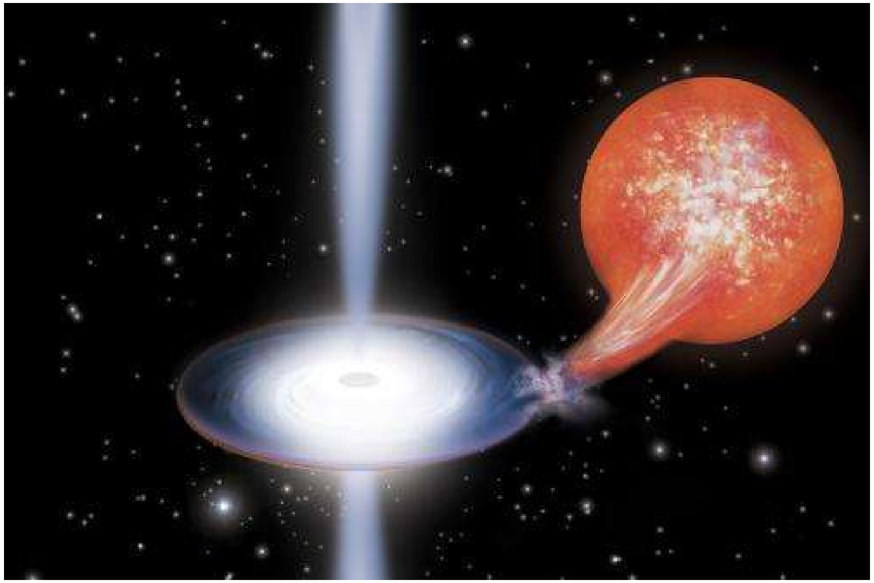
Jets in Cataclysmic Variables?



So, CVs are used to constrain jet-launching models in compact accretors
(e.g. Livio 1999, Soker & Lasota 2004)

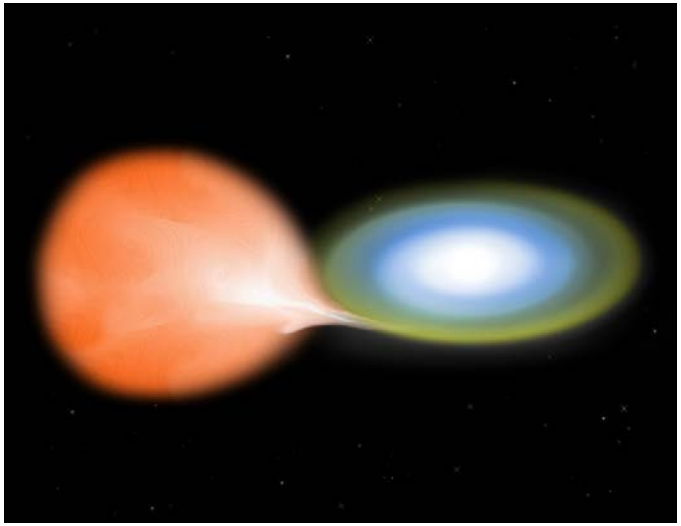
Jets in Cataclysmic Variables?

Fast forward to 2008...



Credit: Riccardo Lanfranchi

VS



Credit: NASA/CXC/M.Weiss

Körding+ 2008

Jets in Cataclysmic Variables?

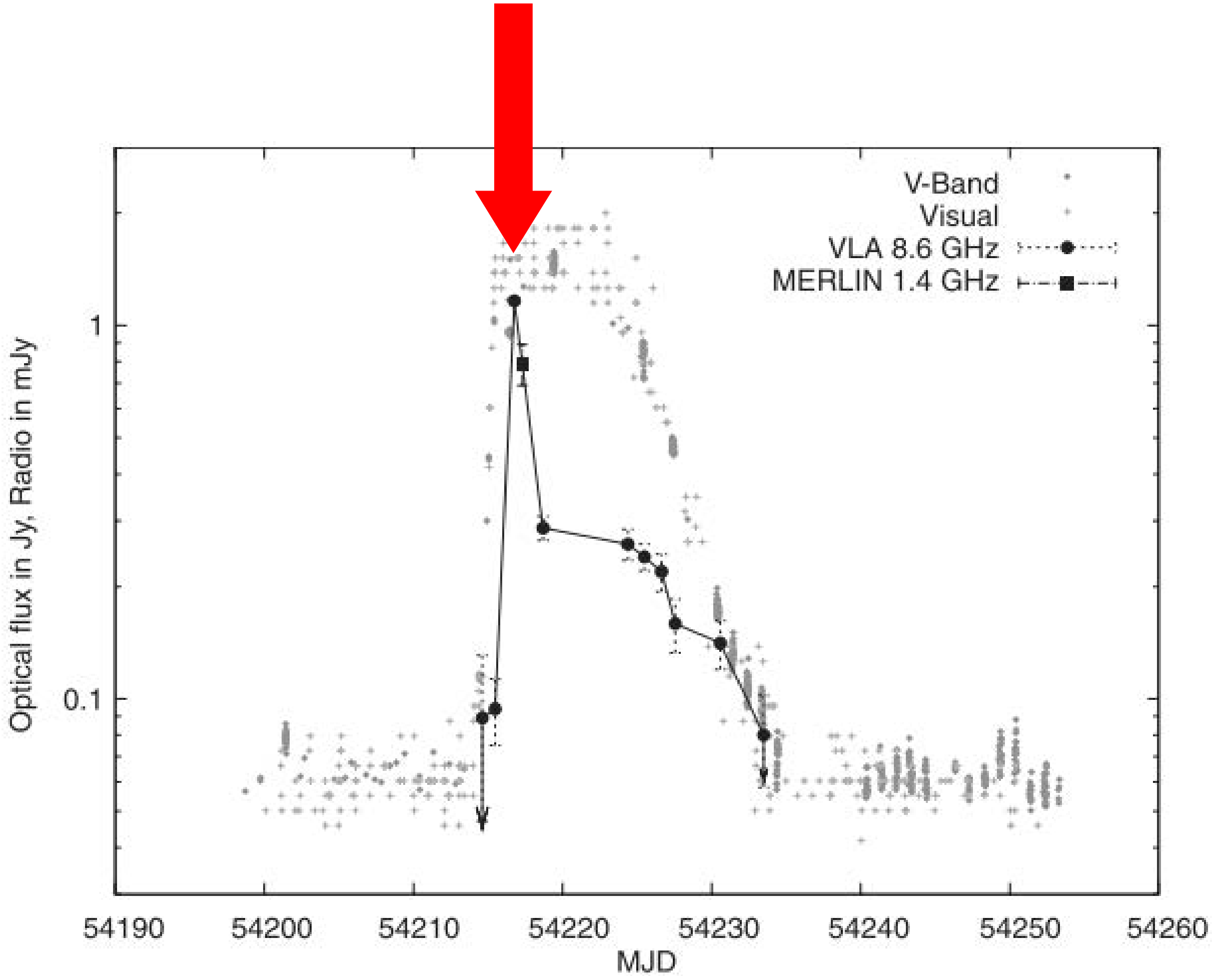
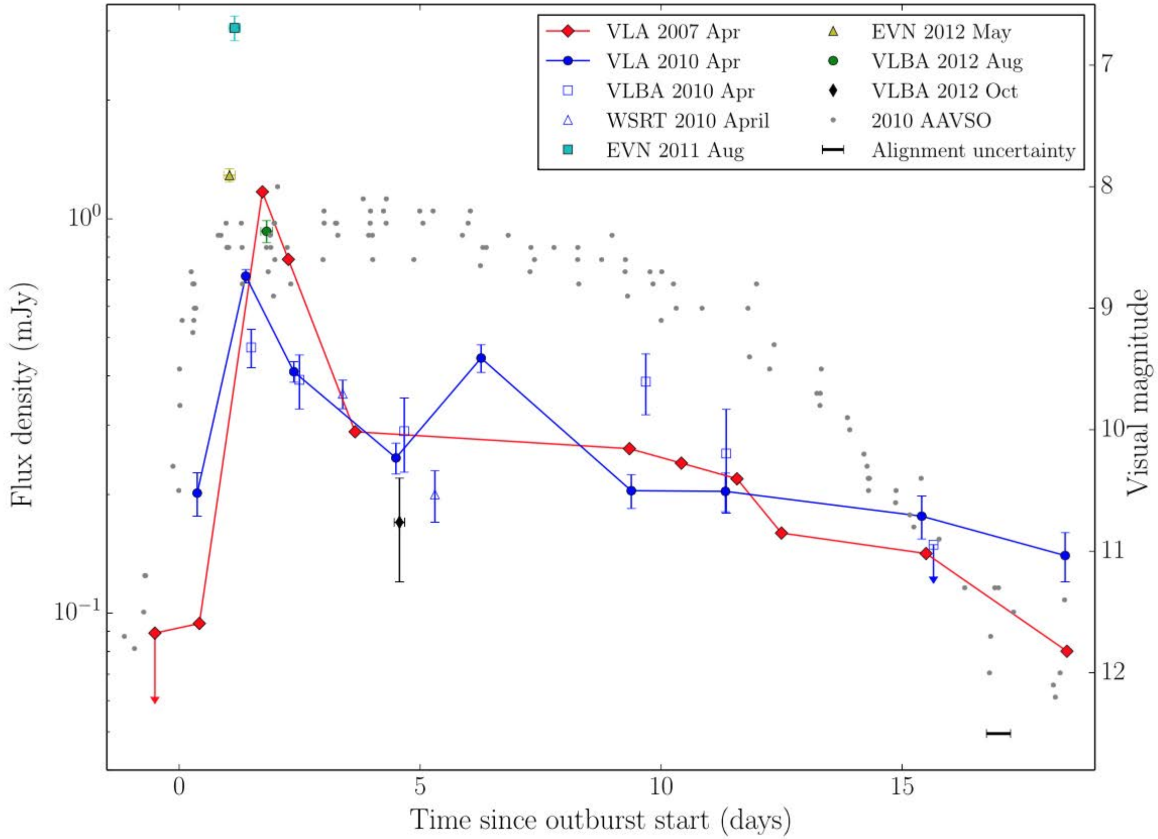


Figure 2 of Körding+ (2008), showing SS Cyg's 1.1 mJy flare at 8.5 GHz on the rise to outburst

- Körding+ (2008): Best explained as synchrotron emission from a **transient jet**

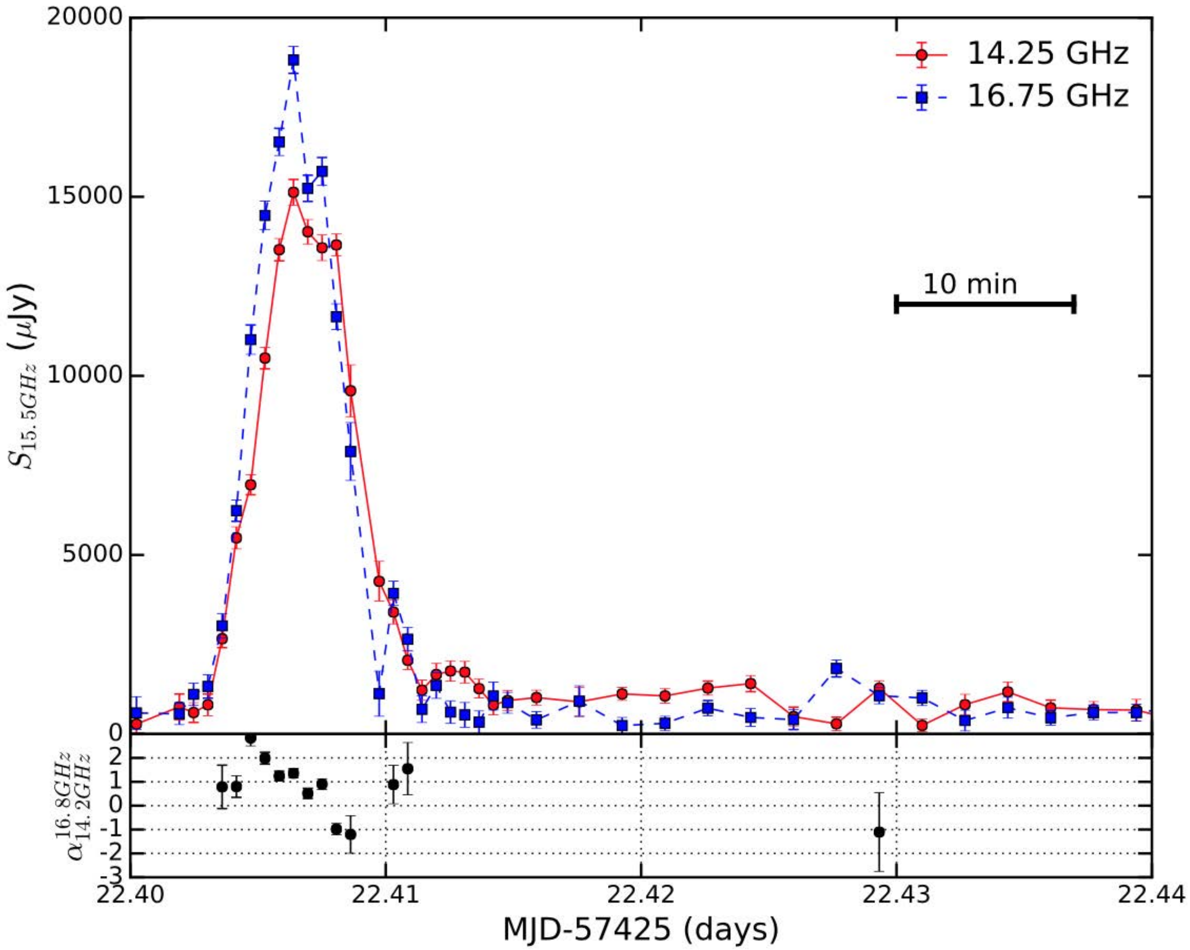
Jets in Cataclysmic Variables?



Russell+ (2016)

- Körding+ (2008): Best explained as synchrotron emission from a **transient jet**
- Miller-jones+ (2011) **confirmed this** in separate outburst
- Russell+ (2016): Behaviour is **reproducible**

Jets in Cataclysmic Variables?



Mooley+ (2017)

- Körding+ (2008): Best explained as synchrotron emission from a **transient jet**
- Miller-jones+ (2011) **confirmed this** in separate outburst
- Russell+ (2016): Behaviour is **reproducible**
- Mooley+ (2017) detected a flare that showed spectral evolution
- V3885 Sgr (Körding+ 2011)

<u>2</u>

VLBI vindicates accretion theory

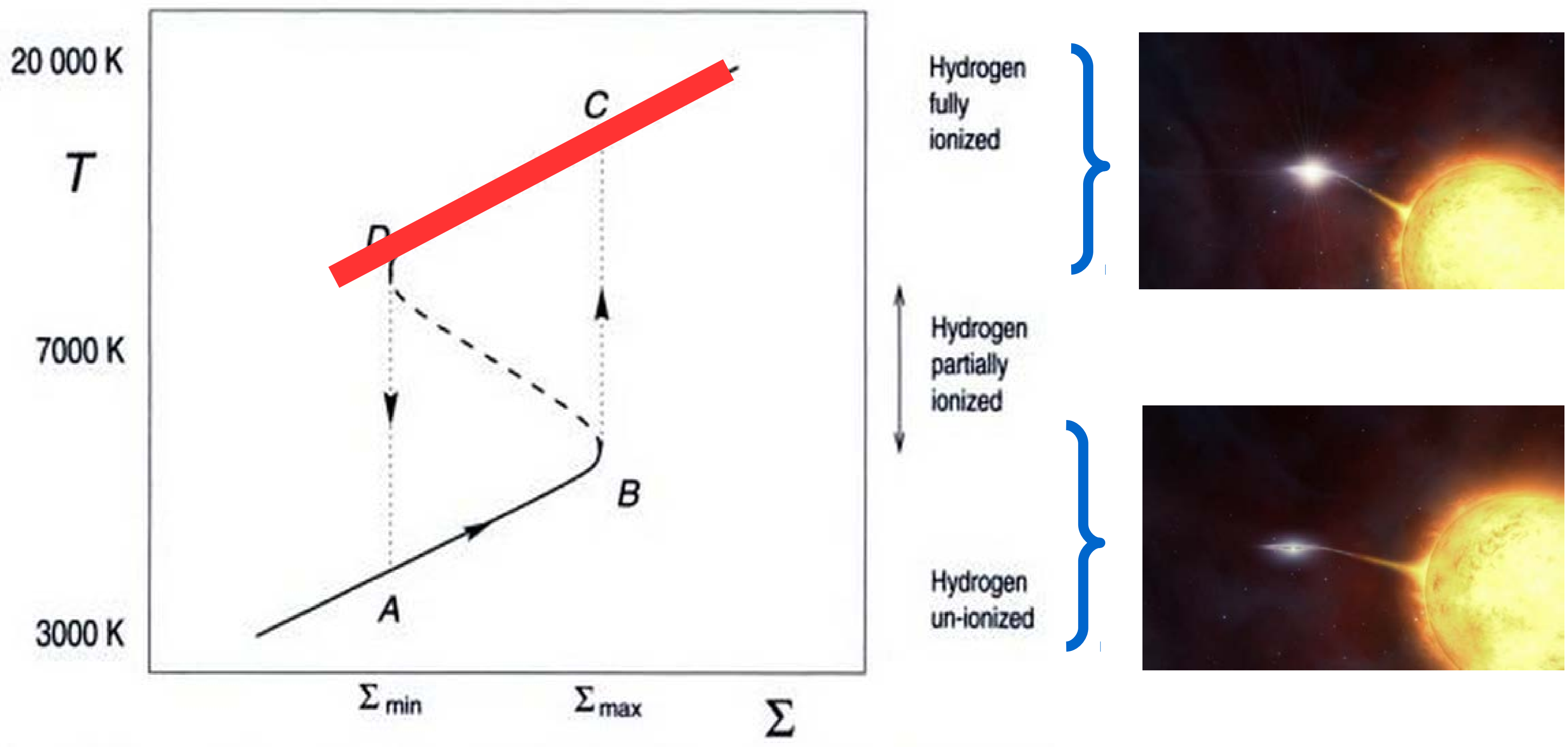
VLBI vindicates accretion theory

The dwarf nova SS Cygni: what is wrong?

M. R. Schreiber[1] and J.-P. Lasota[2,3]

VLBI vindicates accretion theory

Disc Instability Model



Credit: Hellier figure 5.7 illustrating the Disc Instability Model (Osaki 1974 & Meyer & Meyer-Hofmeister 1981)

VLBI vindicates accretion theory

REPORTS

An Accurate Geometric Distance to the Compact Binary SS Cygni Vindicates Accretion Disc Theory

J. C. A. Miller-Jones,[1*] G. R. Sivakoff,[2,3] C. Knigge,[4] E. G. Körding,[5]
M. Templeton,[6] E. O. Waagen[6]

Distance = ~~159±12 pc~~ 114±2 pc

Miller-Jones+ 2013: SS Cyg is a "normal" CV

3

A new class of radio transient

Is SS Cyg’s radio emission unique?

A new class of radio transient

Prior to 2008...

- 1980s: Large number of surveys[1,2,3,4]
- Only 2 detections out of 50 observations (Benz et al. 1996)
- Only three were detected: SU UMa[1], EM Cyg[2], and TY Psc[3]
- CVs were not detected in follow-up observations
- Proposed emission mechanisms: Thermal, synchrotron, gyrosynchrotron or cyclotron maser

Magnetic CVs...

- Large number of surveys
- 8 CVs out of 20 (Mason & Gray 2007)
- Only AM Her[6], AR UMa[7] and AE Aqr[8] are persistent radio emitters
- Proposed emission mechanisms: Synchrotron, gyrosynchrotron or cyclotron maser

[1]Benz et al. 1983, [2]Benz & Gudel 1989, [3]Turner 1985, [4](Cordova 1983, Fuerst et al. 1986, Echevarria 1987, Nelson & Spencer 1988), [5](Dulk et al. 1983, Bastian 1987, Beasley et al. 1994), [6](Chanmugam & Dulk 1982, Dulk et al. 1983, Mason & Gray 2007), [7]Mason & Gray 2007, [8](Bookbinder & Lamb 1987, Bastian et al. 1988, Abada-Simon e al. 1993, Meintjes & Venter 2005)

A new class of radio transient

Credit: NRAO/AUI/NSF

A new class of radio transient

VLA observations

- 4 Novalike systems (TT Ari, V603 Aql, V1084 Her, RW Sex)

Image courtesy of NRAO/AUI

Novalikes are radio emitters

(Coppejans+ 2015)

TT Ari, V603 Aql, RW Sex, V1084 Her

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

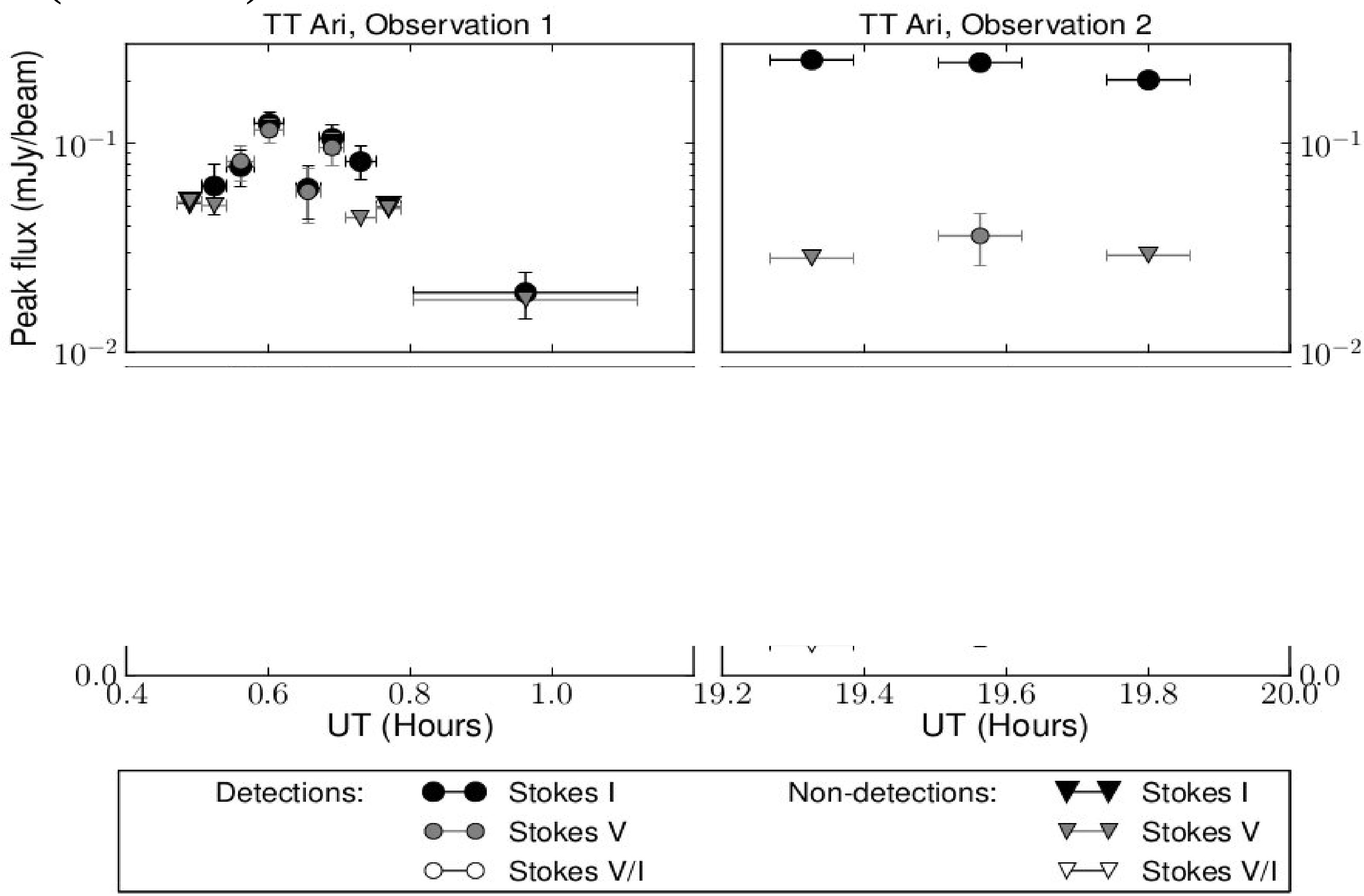
MNRAS **451,** 3801–3813 (2015) doi:10.1093/mnras/stv1225

Novalike cataclysmic variables are significant radio emitters

Deanne L. Coppejans,[1★] Elmar G. Körding,[1] James C. A. Miller-Jones,[2] Michael P. Rupen,[3] Christian Knigge,[4] Gregory R. Sivakoff[5] and Paul J. Groot[1]

A new class of radio transient

TT Ari (Novalike)



Coppejans+ 2015

A new class of radio transient

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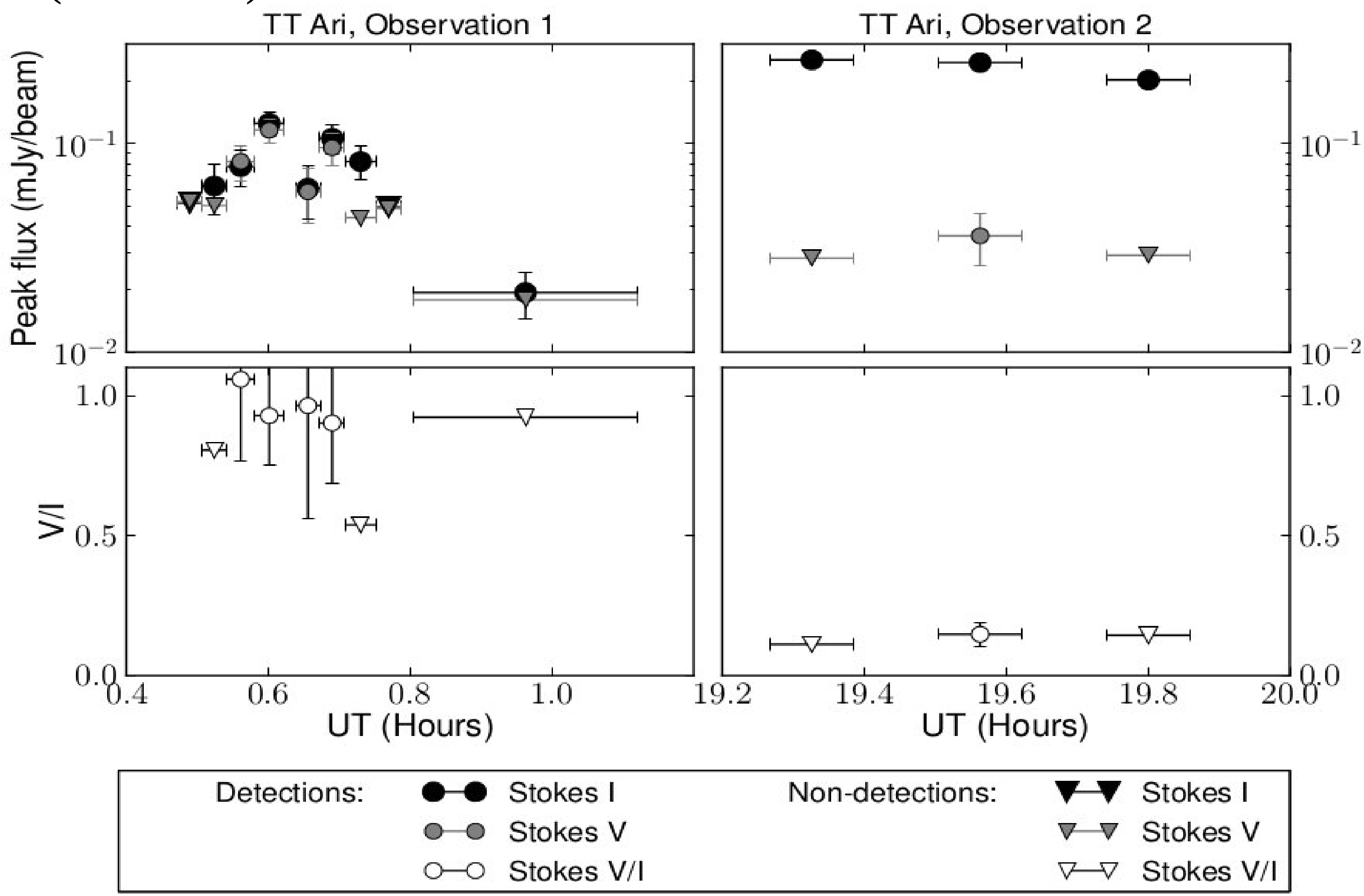

Coppejans+ 2015

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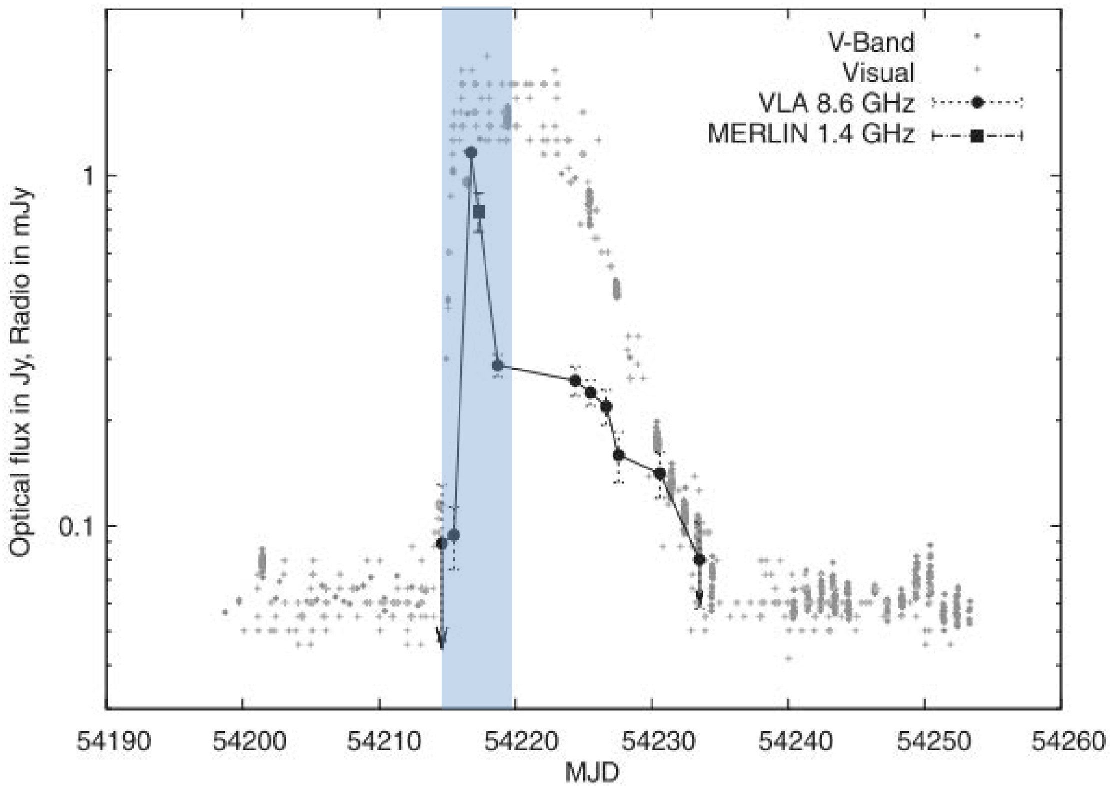
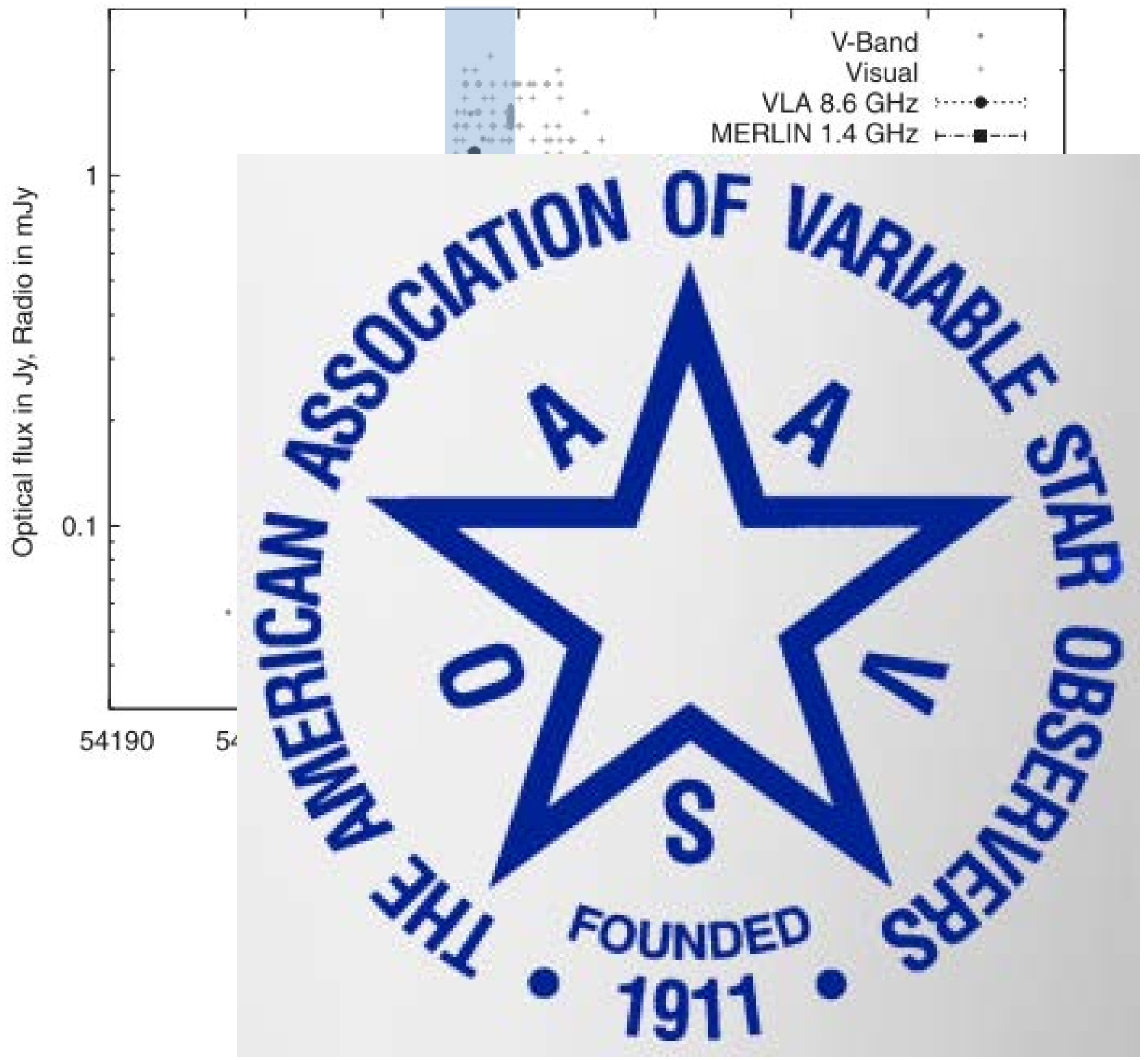


Körding+ (2008)

Dwarf Novae difficulties:

- Flare predicted during rise
- Outbursts unpredictable
- Need to confirm outburst before triggering observations
- Takes time to get on telescope

A new class of radio transient



Dwarf Novae difficulties:

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Solution:
AAVSO campaign 505

A new class of radio transient

Dwarf Novae are radio emitters

(Coppejans+ 2016)

U Gem, SU UMa, Z Cam, RX And, YZ Cnc

Monthly Notices
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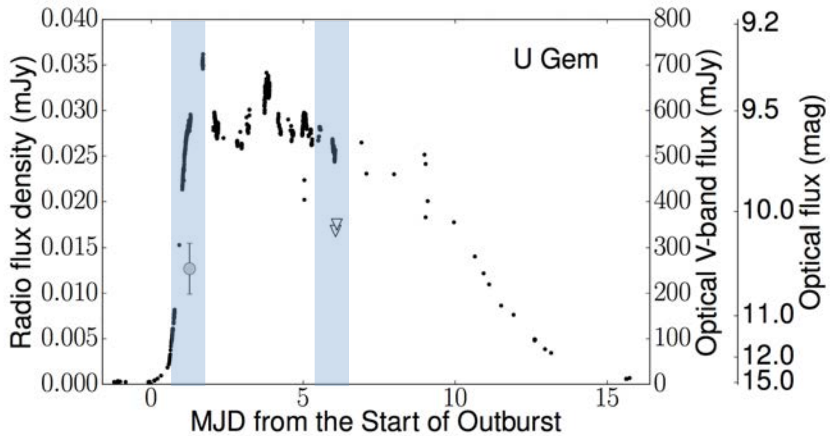
ROYAL ASTRONOMICAL SOCIETY

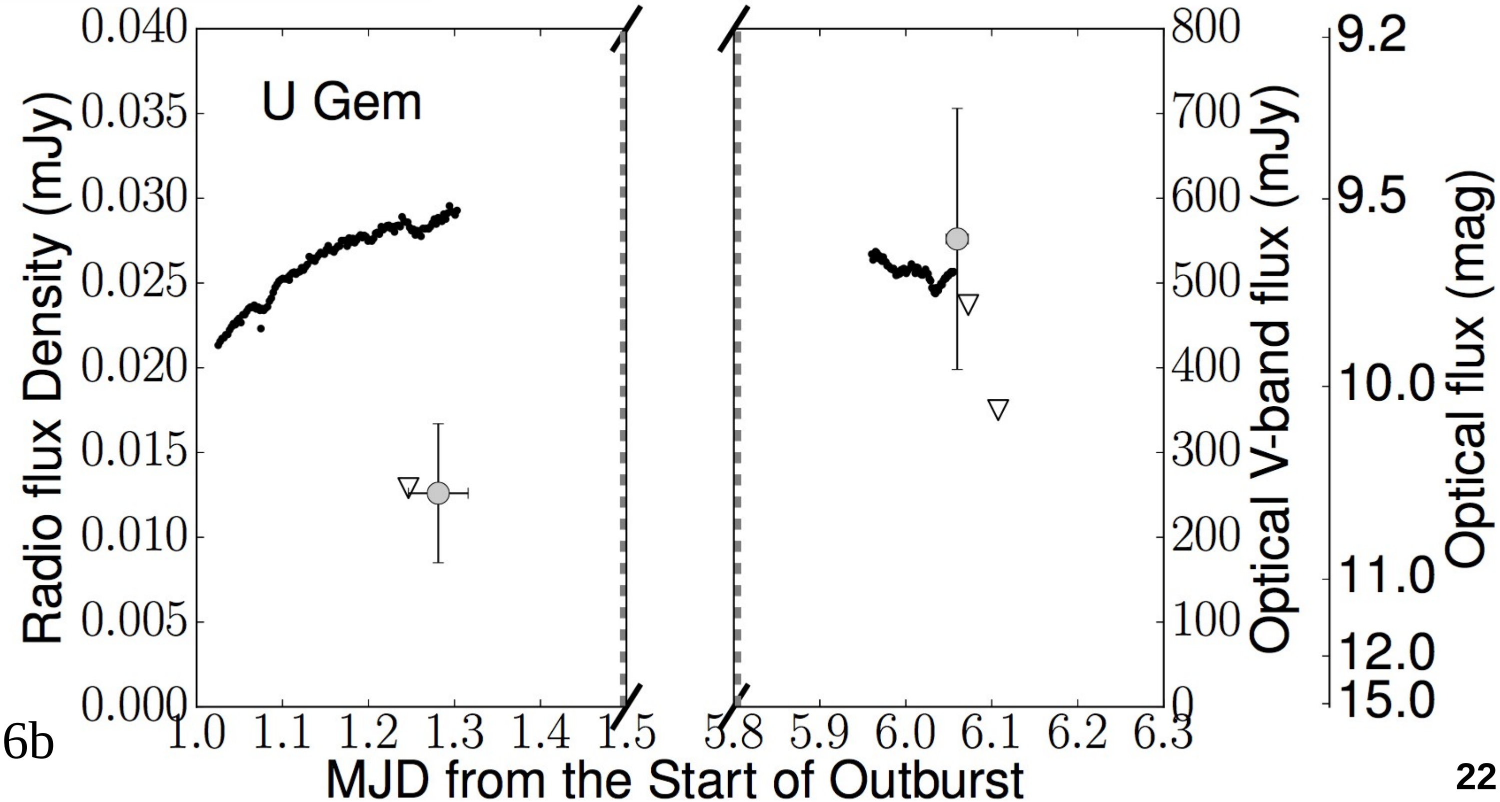
MNRAS **463,** 2229–2241 (2016) doi:10.1093/mnras/stw2133
Advance Access publication 2016 August 24

Dwarf nova-type cataclysmic variable stars are significant radio emitters

Deanne L. Coppejans,[1★] Elmar G. Körding,[1] James C. A. Miller-Jones,[2] Michael P. Rupen,[3] Gregory R. Sivakoff,[4] Christian Knigge,[5] Paul J. Groot,[1] Patrick A. Woudt,[6] Elizabeth O. Waagen[7] and Matthew Templeton

A new class of radio transient





Coppejans+ 2016b

A new class of radio transient

- Radio specific luminosity: **$L_{10\ GHz}$ ~ $4x10^{15}$ to $4x10^{16}$ erg s^{-1} Hz^{-1}**
  Radio luminosity: **L ~ $4x10^{25}$ to $4x10^{26}$ erg s^{-1}**
- Variability : **200s – days**
- Spectral indices: **Steep to inverted**
- Polarization: **One source showed circular polarization**

Object	**Spectral index ($F=\nu^{\alpha}$)**
RW Sex	-0.5 ± 0.7
TT Ari, obs 1	1.6 ± 0.1
TT Ari, obs 2	0.7 ± 0.3
V603 Aql, obs1	0.54 ± 0.05
V603 Aql, obs2	0.16 ± 0.08
Dwarf novae	Not constrained

Coppejans+ (2015), Coppejans+ (2016b)

A new class of radio transient

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- Variability : **200s – days**
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Radio luminosity was not dependent on:

- orbital period
- orbital phase
- sub-class
- outburst type
- optical luminosity

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Caveat – emission is highly variable

Coppejans+ (2015), Coppejans+ (2016b)

Possible radio emission mechanisms for CVs

Bremstrahlung
(Cordova+ 1983, Fuerst+ 1986)

Cyclotron maser emission or gyrosynchrotron emission
(e.g. Chanmugam+ 1982, Meintjes+ 2005, Mason+ 2007)

Synchrotron emission:
- A jet like SS Cyg? (Körding+ 2008)
- Or magnetic reconnections in the disk? (Meintjes+ 2017)
- Or shocks?

A new class of radio transient

<u>Optically thick bremstrahlung</u>

<u>Optically thin bremstrahlung</u>

Coppejans+ (2015), Coppejans+ (2016b)

A new class of radio transient

Synchrotron or gyrosynchrotron emission

- Spectral indices
- brightness temperature
- polarization fraction
- variability time-scales

Consistent except for TT Ari

Coppejans+ (2015), Coppejans+ (2016b)

A new class of radio transient

Synchrotron or gyrosynchrotron emission

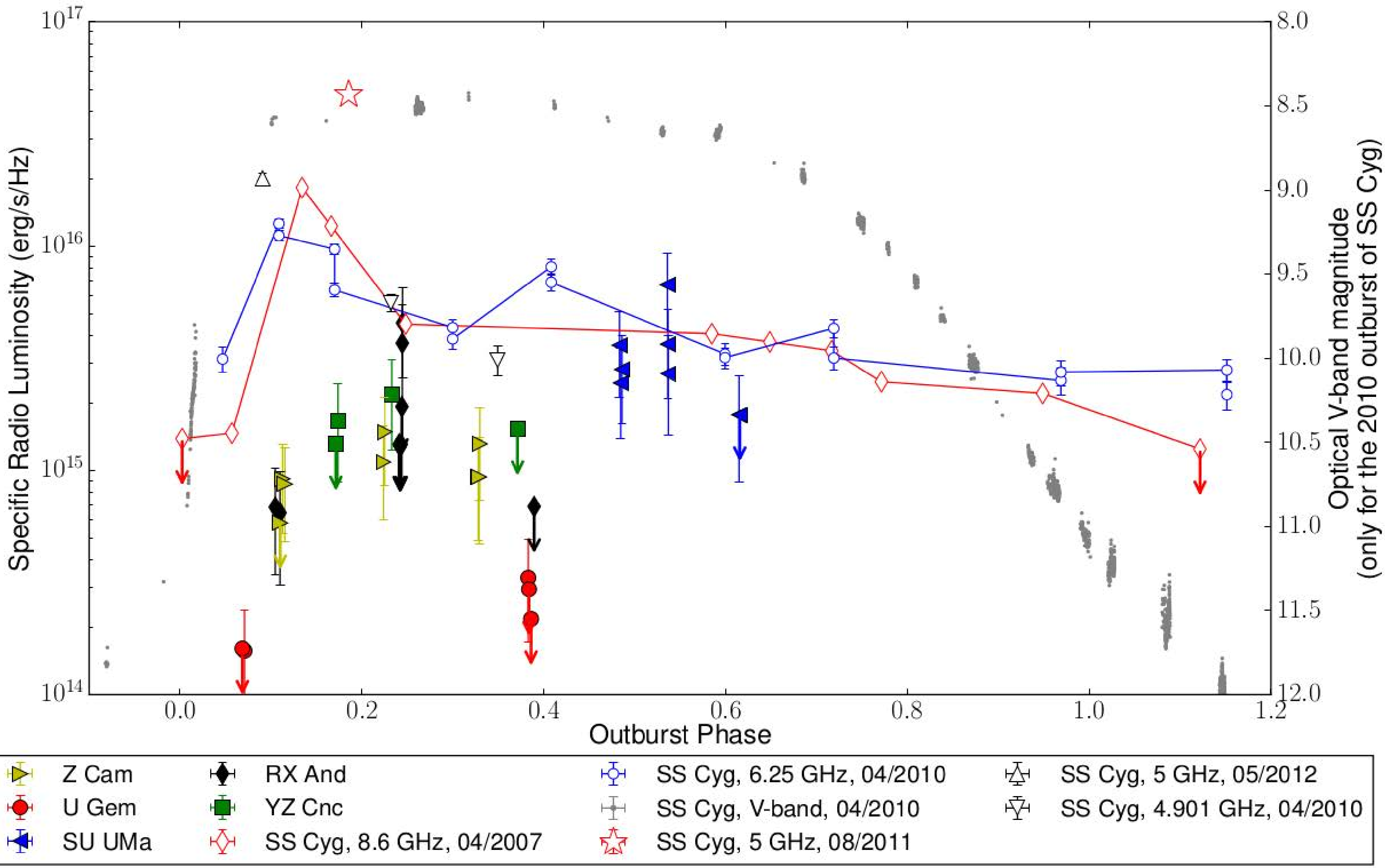
- Spectral indices
- brightness temperature
- polarization fraction
- variability time-scales

✓ **Consistent except for TT Ari**

Comparison to SS Cyg?

Coppejans+ (2015), Coppejans+ (2016b)

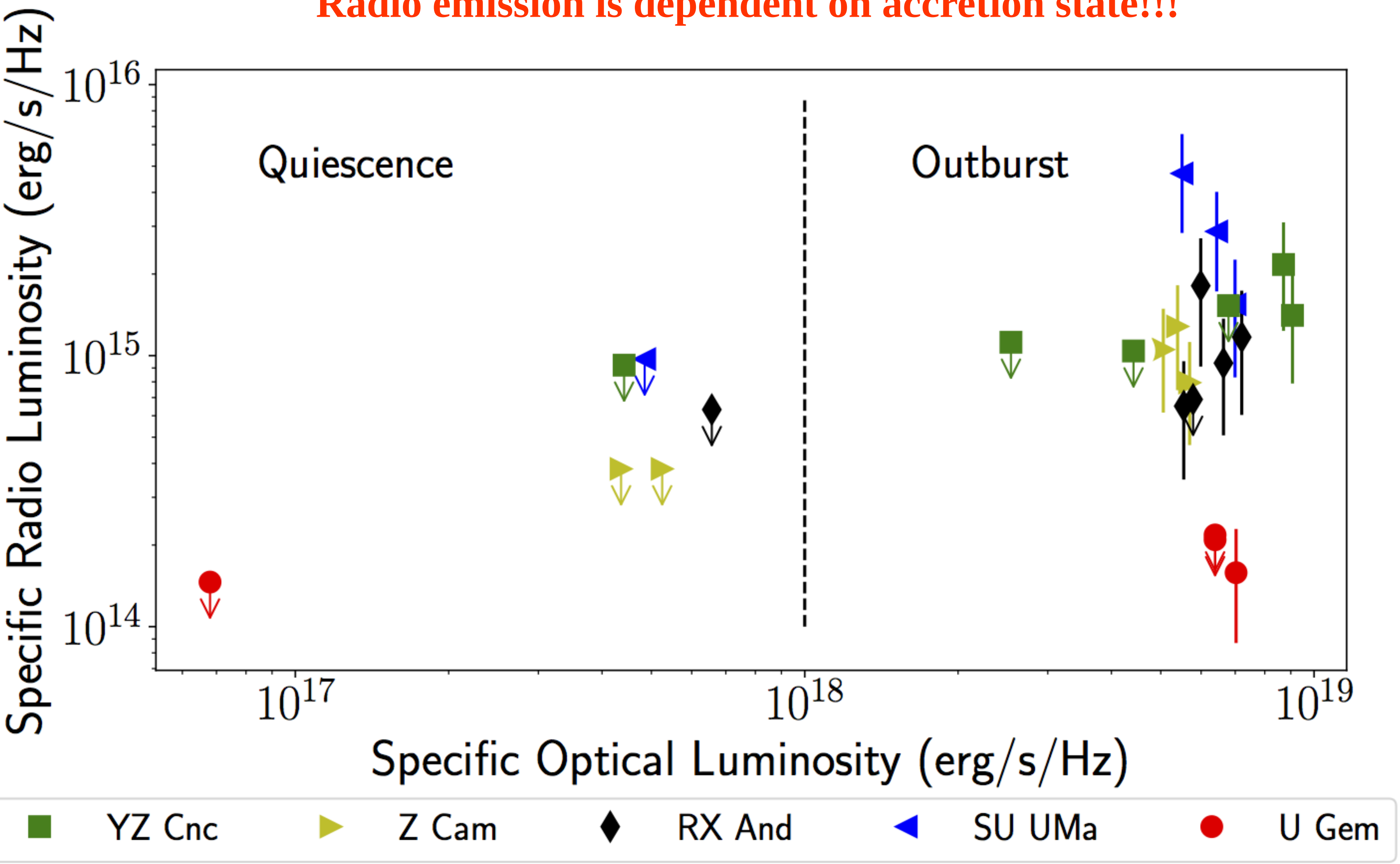
A new class of radio transient



Coppejans+ (2016b)

A new class of radio transient

Radio emission is dependent on accretion state!!!

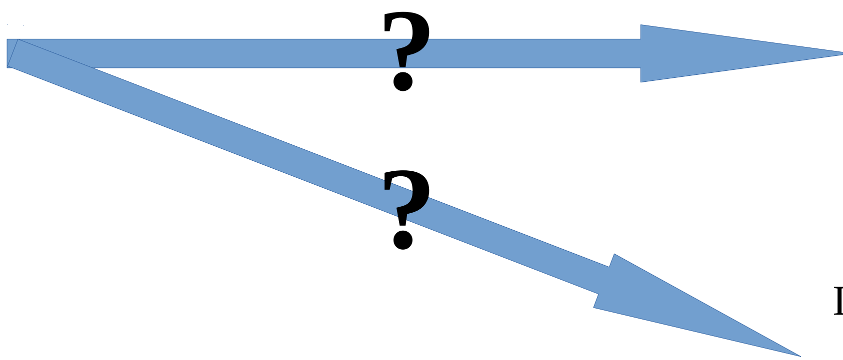


Coppejans+ (in prep)

A new class of radio transient

Cyclotron Maser emission

- Typically flaring emission, high polarization fractions
- TT Ari ✓



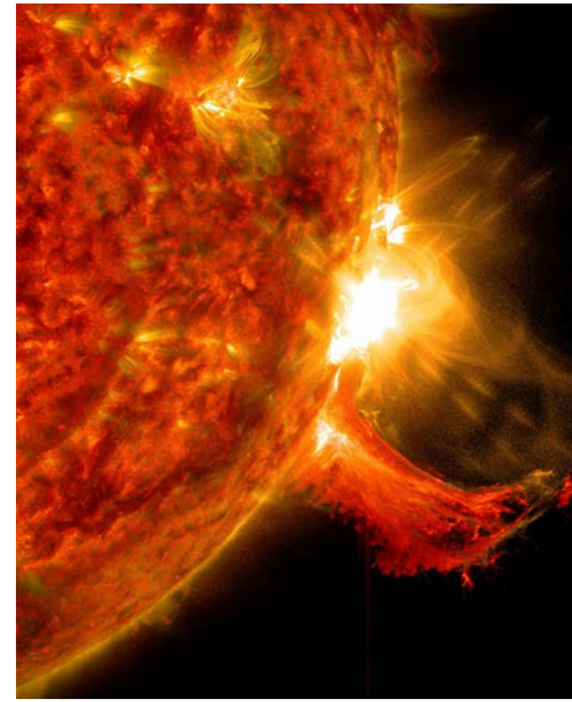
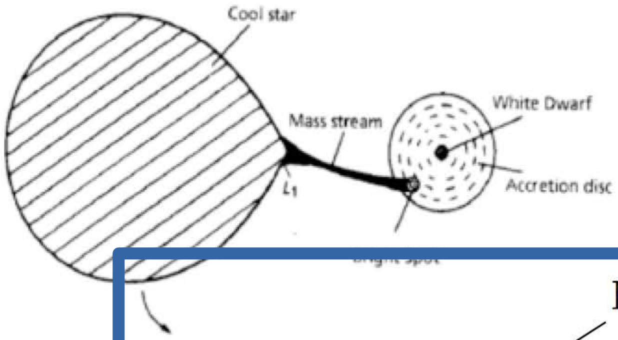


Image Credit: NASA/SDO/ Wiessinger

- Other CVs don't show this behaviour
  So, not preferred mechanism in other CVs

Coppejans+ (2015), Coppejans+ (2016b)

A new class of radio transient



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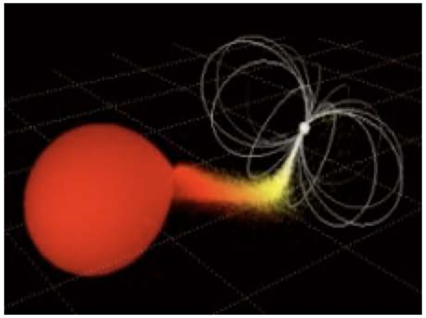
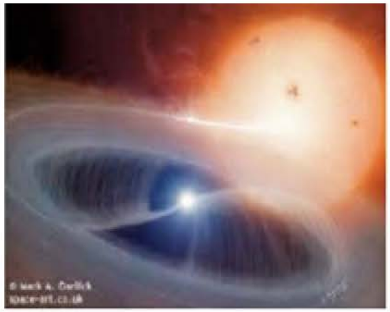
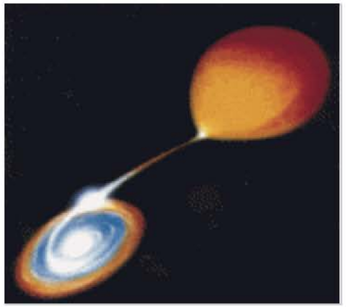
- Non-magnetics ($B \lesssim 10^6$ G)
  - Dwarf Novae
  - Novalikes







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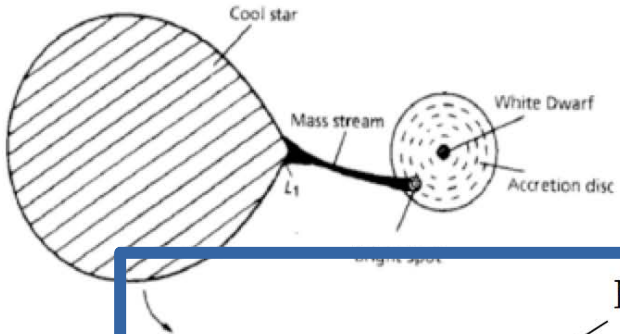

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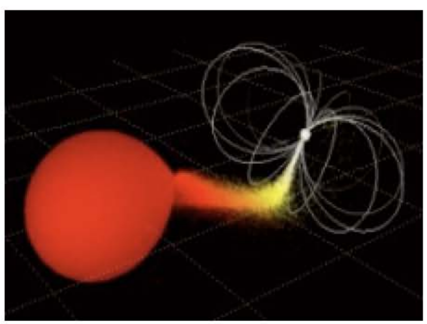
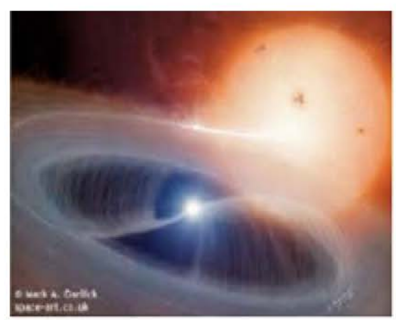
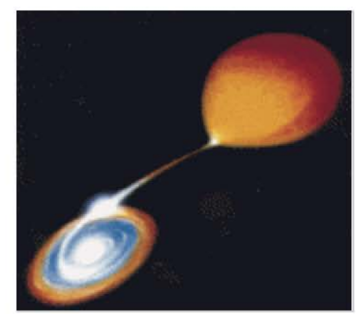
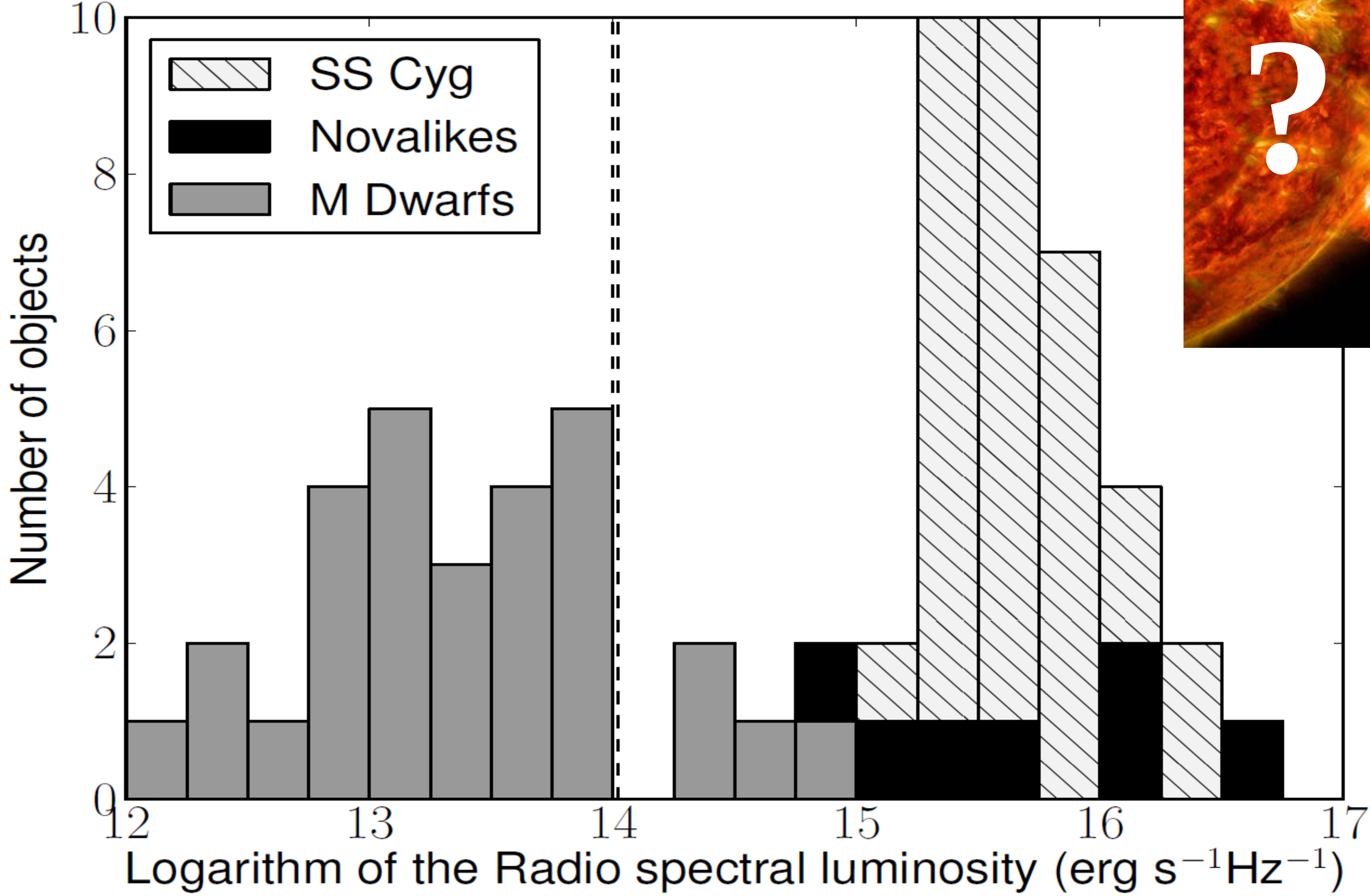






Barrett+ 2017: Detected 19/121 magnetic CVs

A new class of radio transient

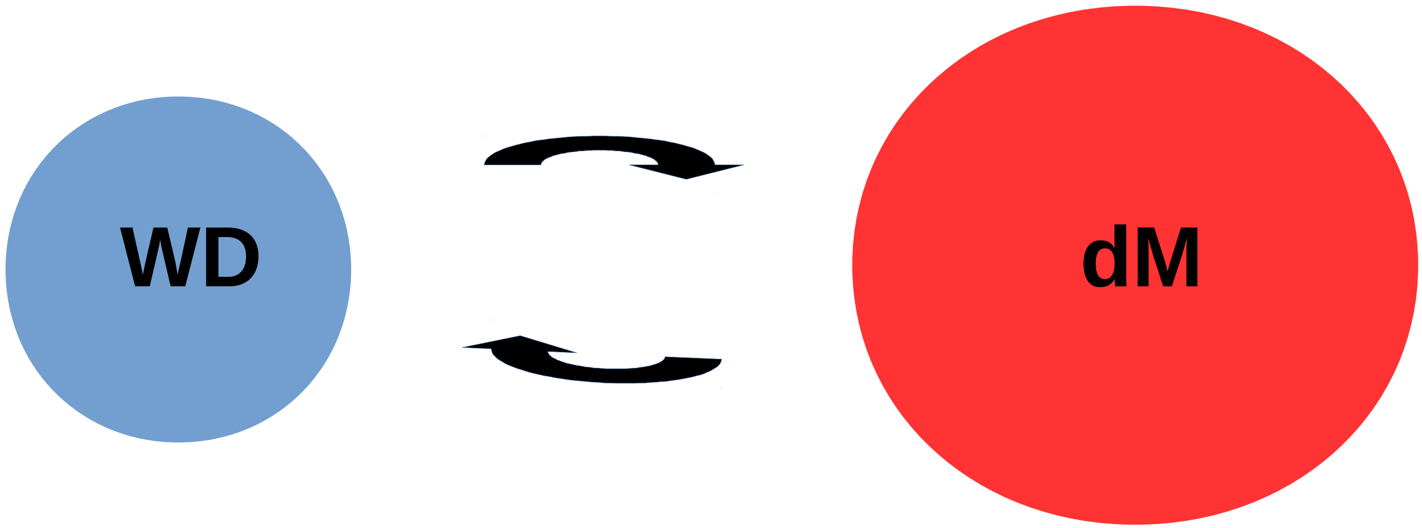


Coppejans et al. 2015, Luminosities from McLean et al. 2012, upper-edge of quiescence from Guedel et al. 1993

4

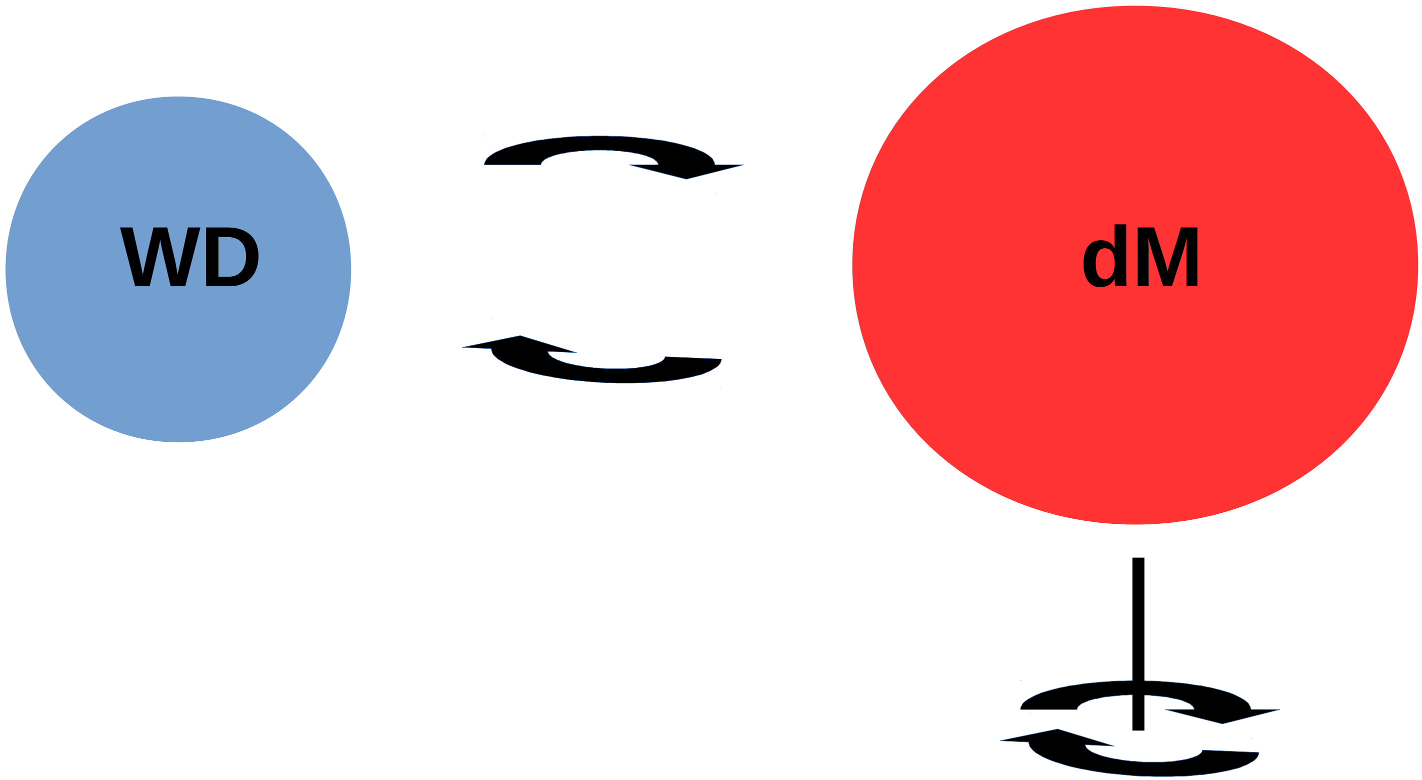
Flare rates in close stellar binaries

Close WD + M-dwarf binaries



Flare rates in close stellar binaries

Close WD + dM binaries

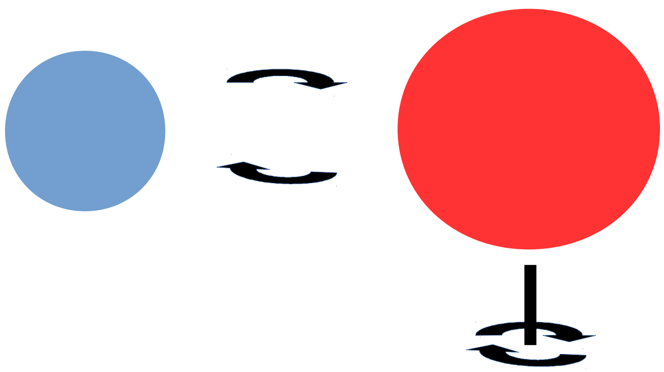


Morgan+ 2012: dMs with close companions are more likely to be magnetically active (from Hα) and remain active for longer than field dMs

Flare rates in close stellar binaries

Morgan+ 2016:

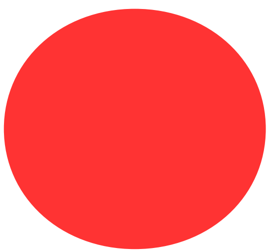
Close WD + dM binaries



- Sample Size: 181
- Source: SDSS Stripe 82
- 71 Magnetically Active (Hα)
- Separation Classes:
  - Very close: <0.1au
  - Close: 0.1-1au
  - Wide: 1-100au

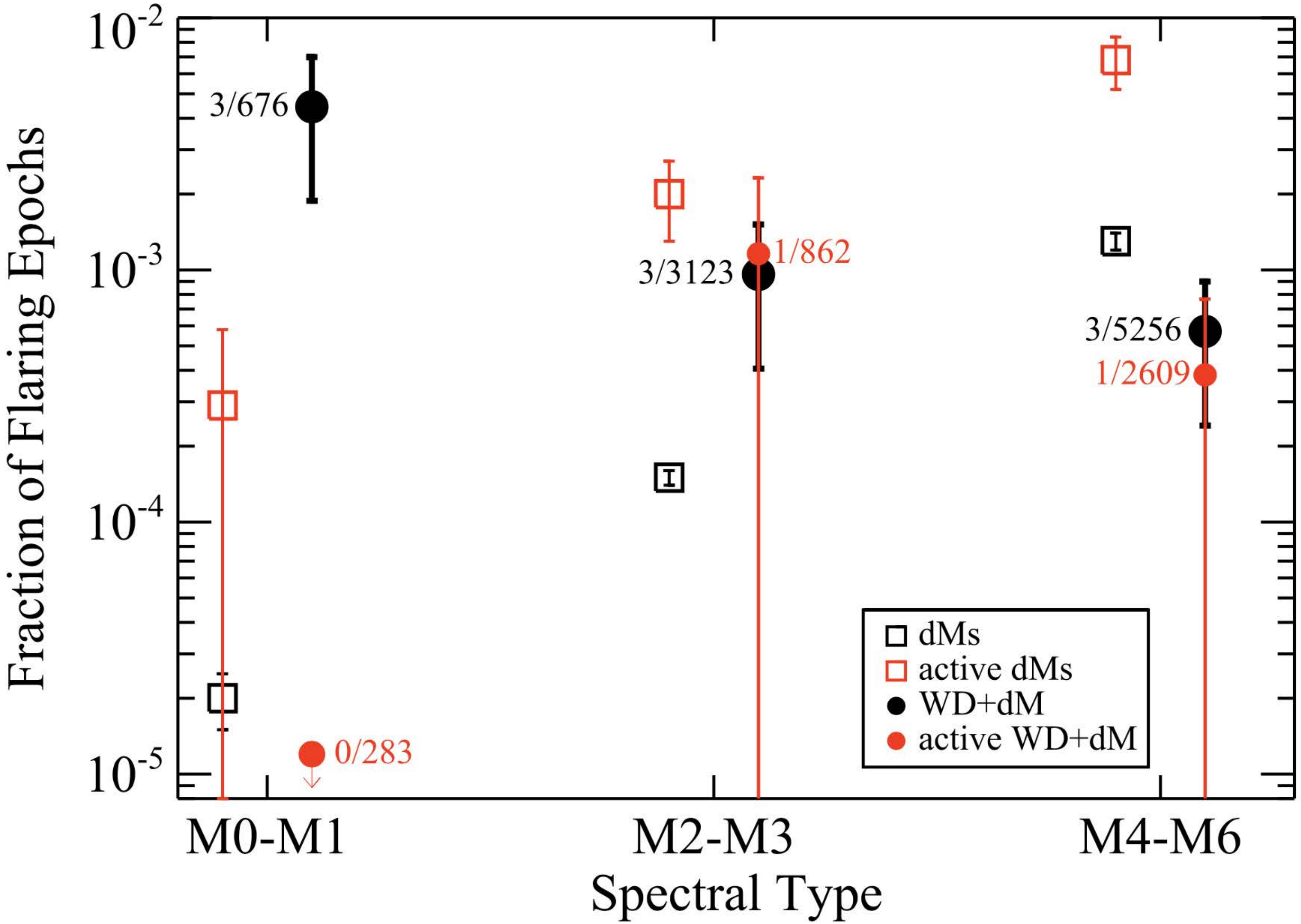
VS

Field dMs



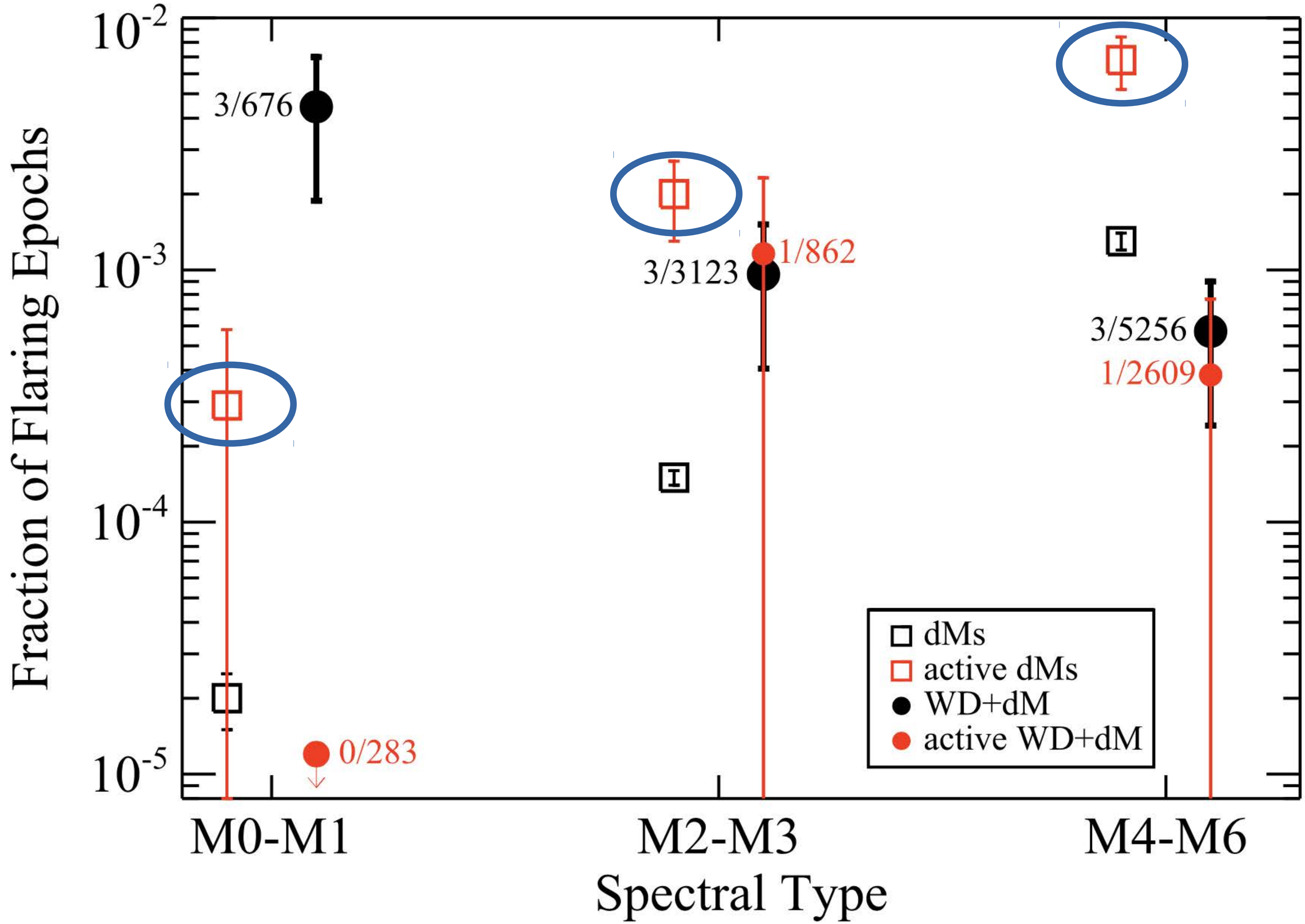
- Sample Size: 236
- Source: SDSS Stripe 82, Kowalski+ 2009

Flare rates in close stellar binaries



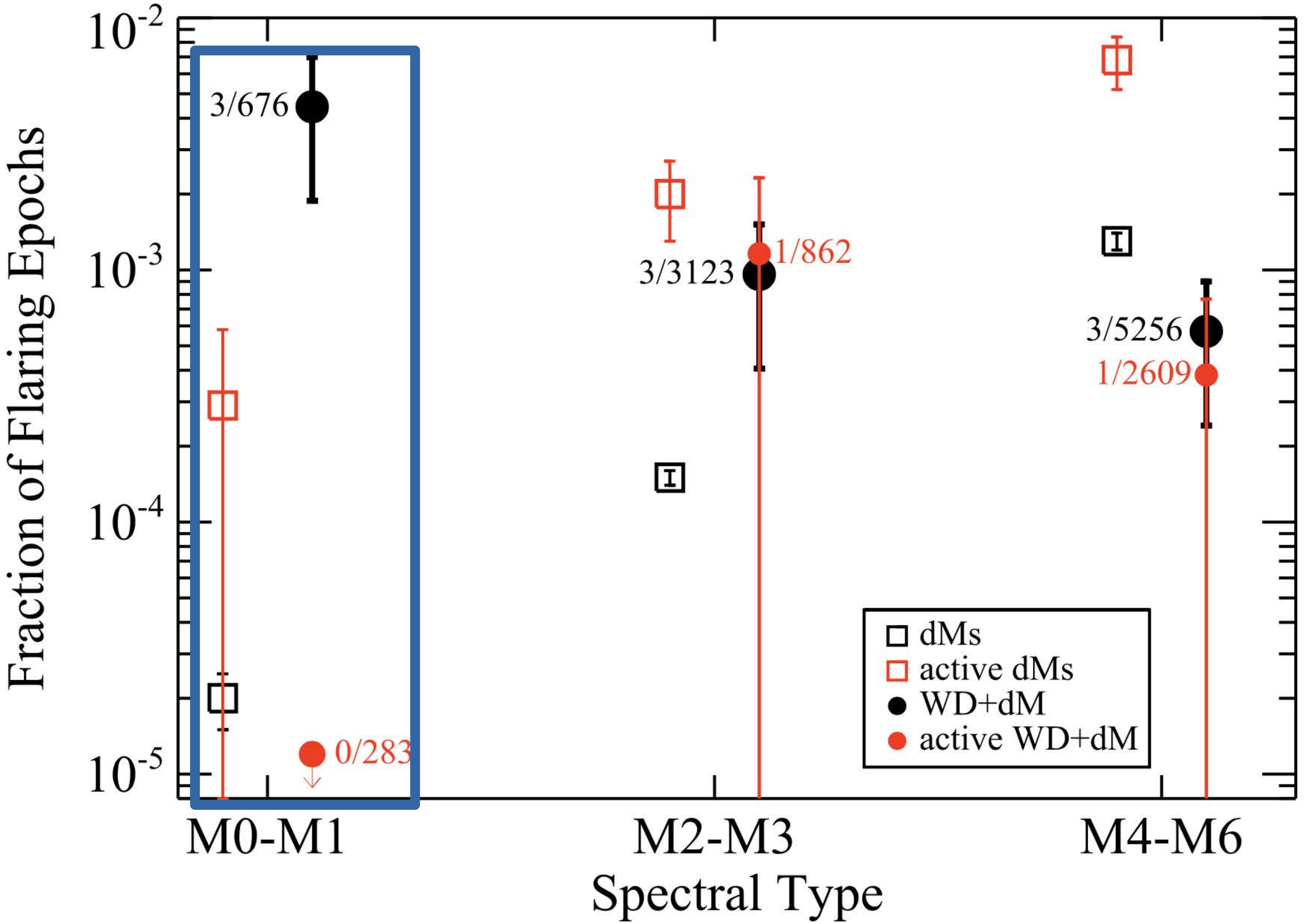
Morgan+ 2016

Flare rates in close stellar binaries



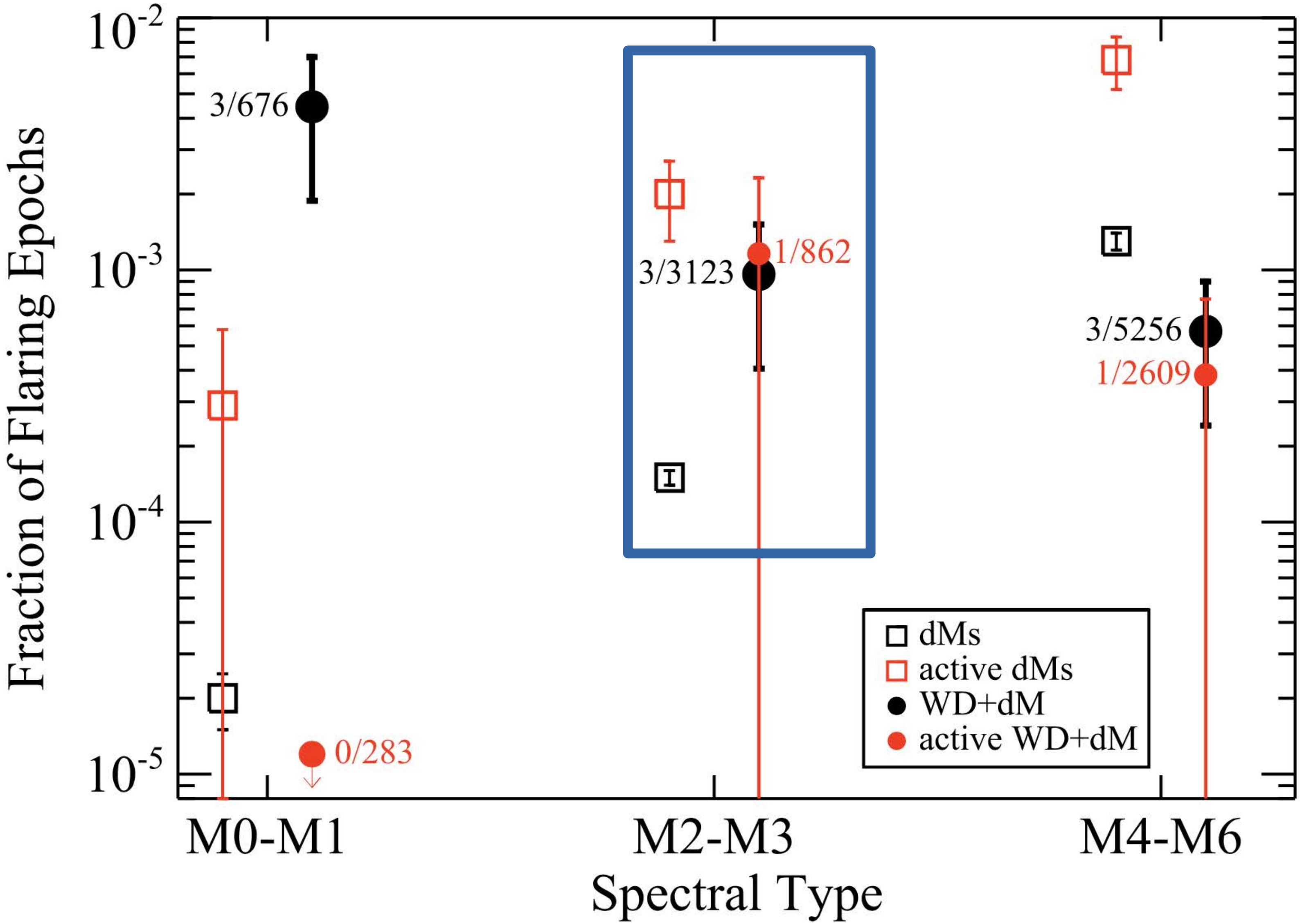
Morgan+ 2016

Flare rates in close stellar binaries



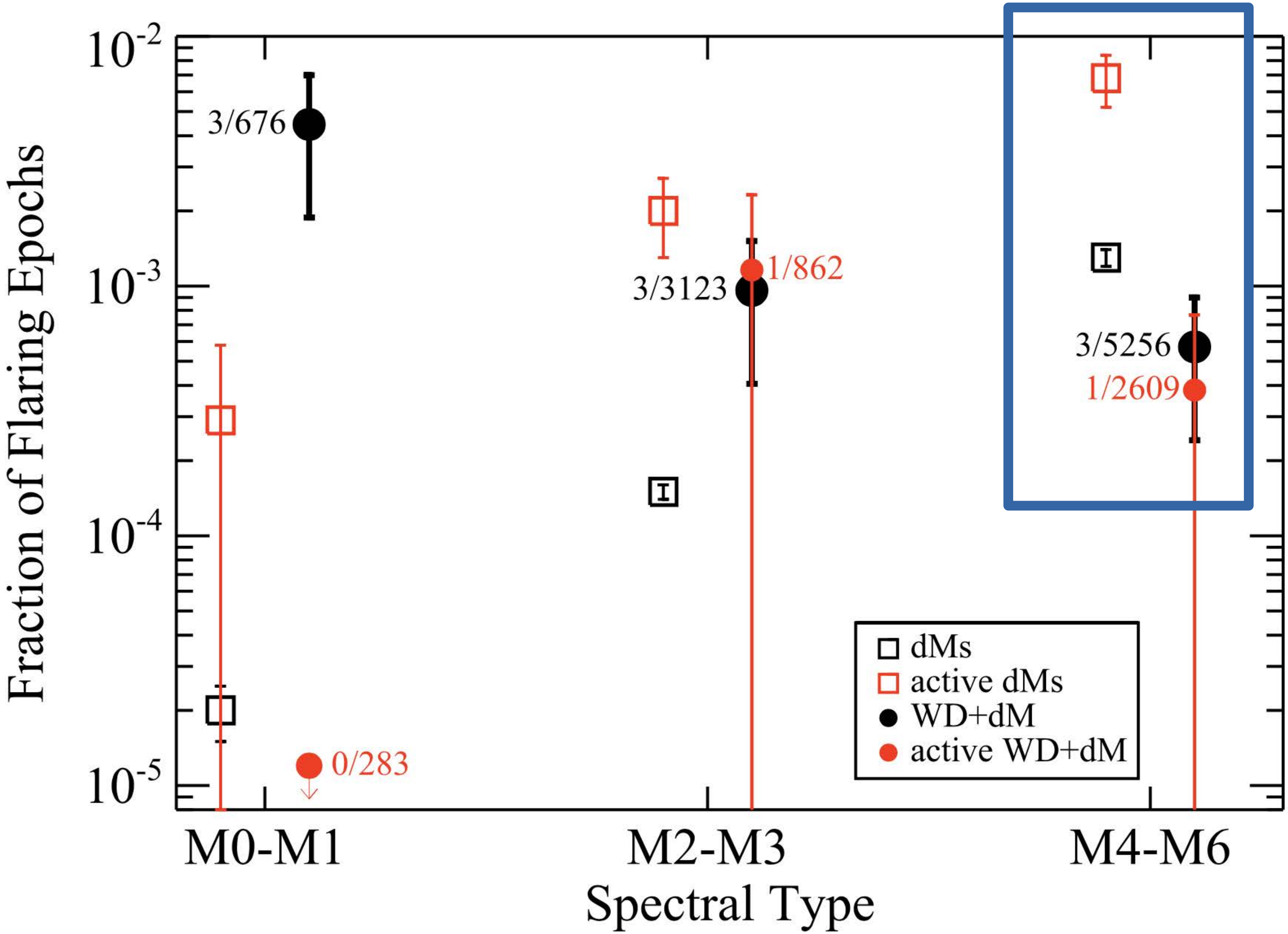
Morgan+ 2016

Flare rates in close stellar binaries



Morgan+ 2016

Flare rates in close stellar binaries



Morgan+ 2016

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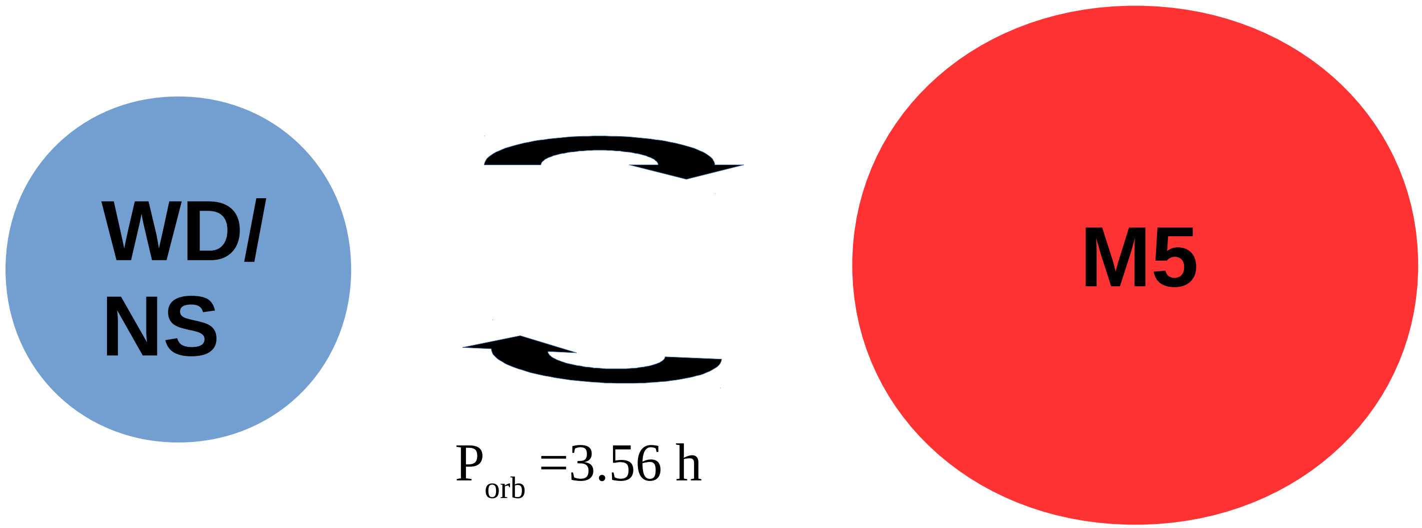
White Dwarf Pulsar

White dwarf pulsar

Marsh+ 2017

AR Scorpii



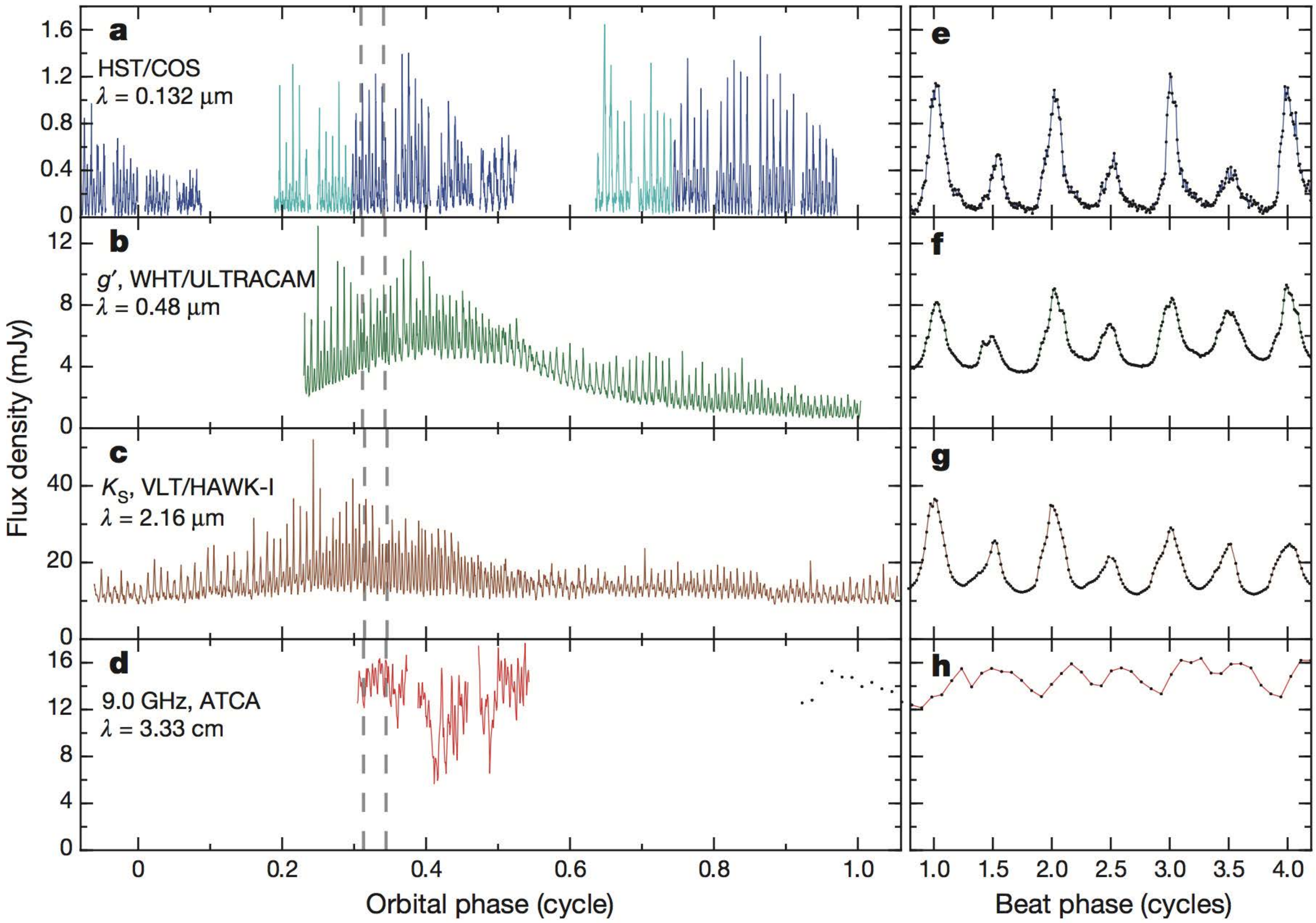
$0.81\ M_{sol} \leq M_1 \leq 1.29\ M_{sol}$

$0.28\ M_{sol} \leq M_2 \leq 0.45\ M_{sol}$

- No signs of accretion
- Distance = $[M_2/0.3M_{sol}]^{1/3}(116\pm16)$ pc
- $q=M_2/M_1>0.35$

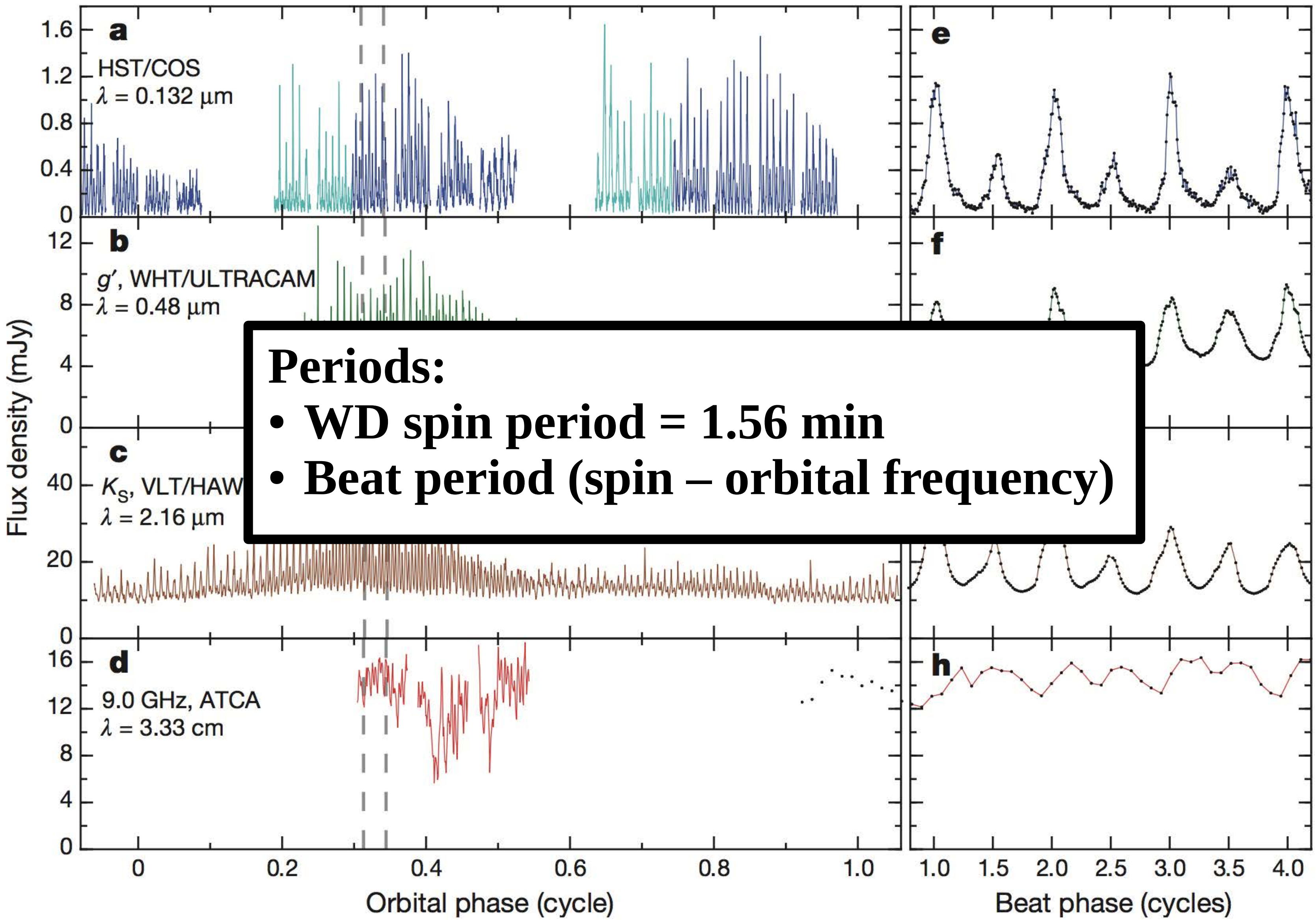
White Dwarf Pulsar

Marsh+ 2017



White Dwarf Pulsar

Marsh+ 2017



Periods:

- **WD spin period = 1.56 min**
- **Beat period (spin – orbital frequency)**

White Dwarf Pulsar

Marsh+ 2017:

Luminosity = 1.7×10^{25} W

Two processes could power the luminosity:

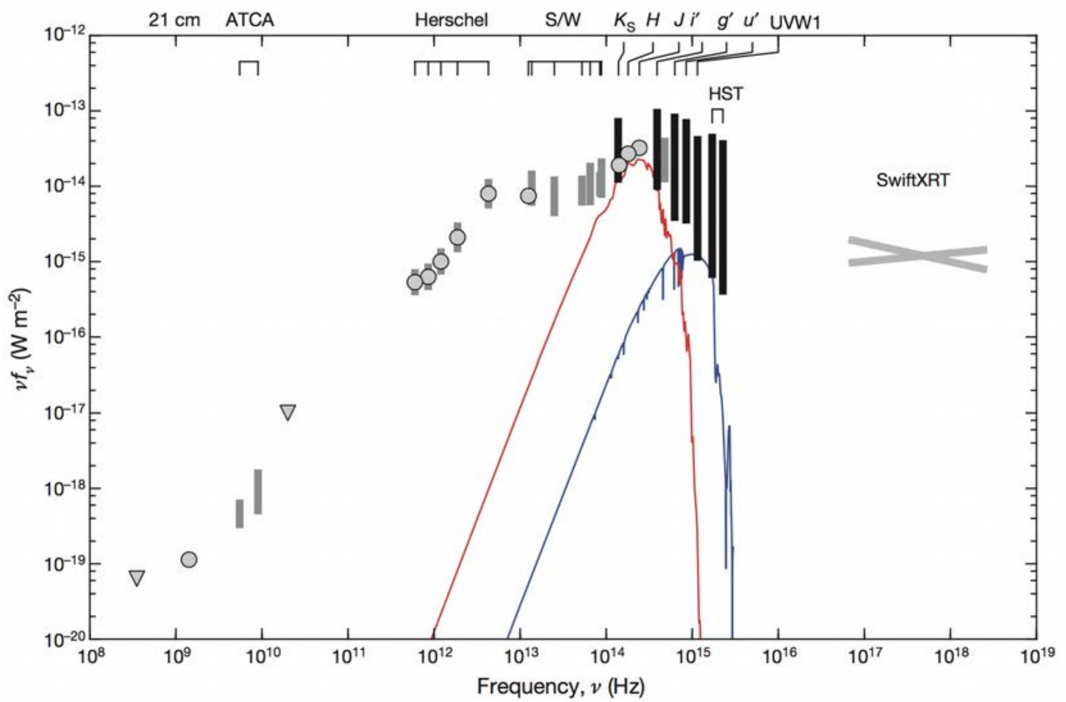
- IF Spin down (timescale = 10^7 yr) : Only WD could power
- IF accretion powered :
  - $M_{NS} \approx 1 \times 10^{-14}\ M_o yr^{-1}$
  - $M_{WD} \approx 1.3 \times 10^{-11}\ M_o yr^{-1}$ BUT no signs of accretion…

Indications that it is a WD:

- Distance
- X-ray luminosity = 4.9×10^{23} W
- Spin period = 1.95 m
- Component masses

No equivalent emitters:

This combination of pulsed emission, broadband synchrotron emission, short pulsation period, and <10% CP are unique



White Dwarf Pulsar

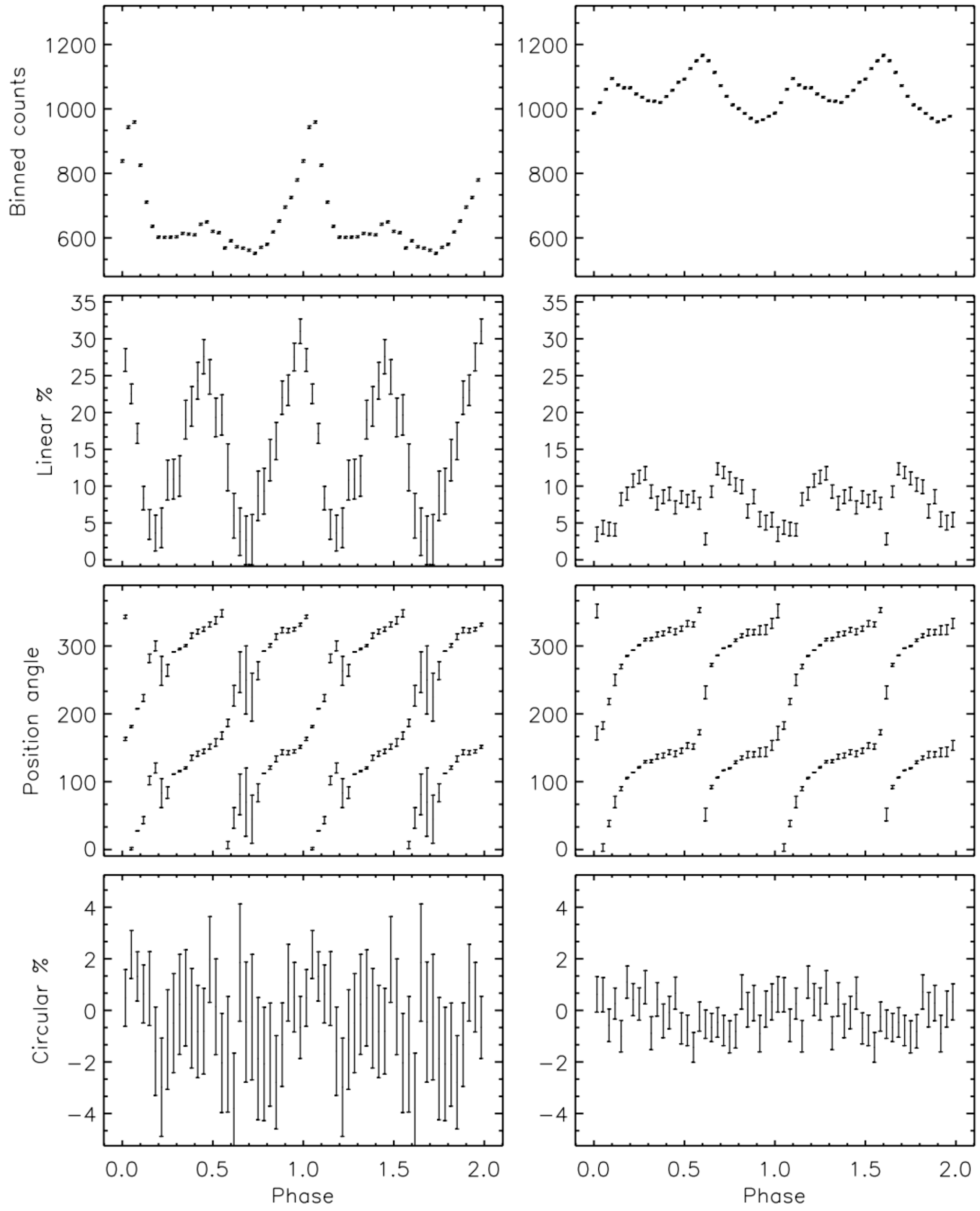
Buckley+ 2017

Binned counts

Linear %

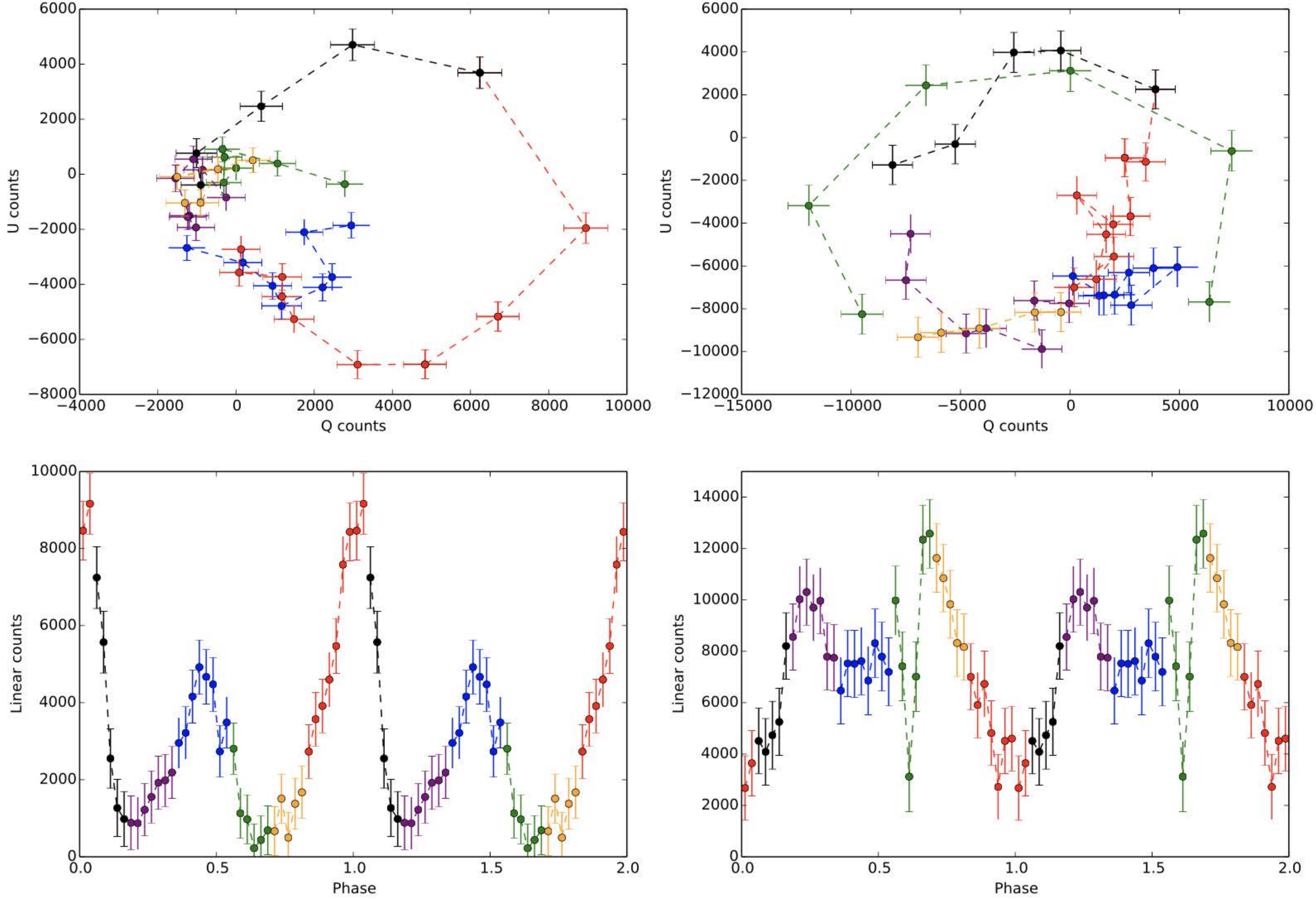
Polarization Angle

Circular %



White Dwarf Pulsar

Buckley+ 2017



White Dwarf Pulsar

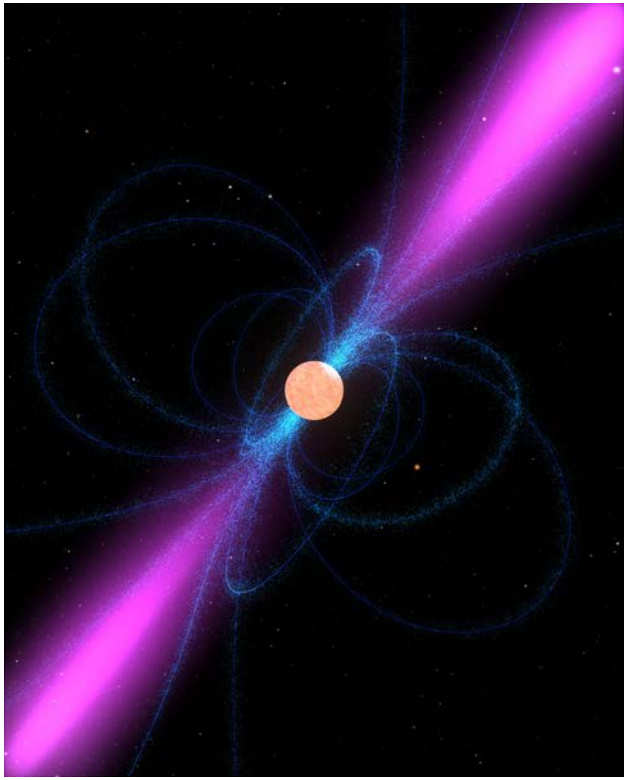


Image credit: NASA

Marsh+ 2016, Buckley+ 2017

- Most of luminosity is being driven by rotational kinetic energy losses
- Behaves like a rotation powered pulsar
- Magnetic (up to 500 MG)
- No outflow or jet (Marcote+2017)
- Evolutionary stage of polars?
- Model:
  - WD magnetosphere interaction with secondary coronal loops (radio/IR)
  - Light cone (optical)
  - Striped wind? (optical)

Future outlook

Important recent developments:

- Possibility of jets in Cataclysmic Variables
- Radio as a new investigative tool (e.g. radio parallax)
- Cataclysmic Variables are a new class of radio transient
- Impact of binarity on flare rates
- White dwarf pulsar

(My favourite) implications:

- Question regarding jets in CVs is important for accretion/jet theory
- Flare rates in binary systems is important for habitability studies
- Imposters
- Avenues to study different accretion scenarios
- CVs could potentially be used to test dynamo theory at extreme stellar rotation rates

How does the radio emission scale with physical properties?

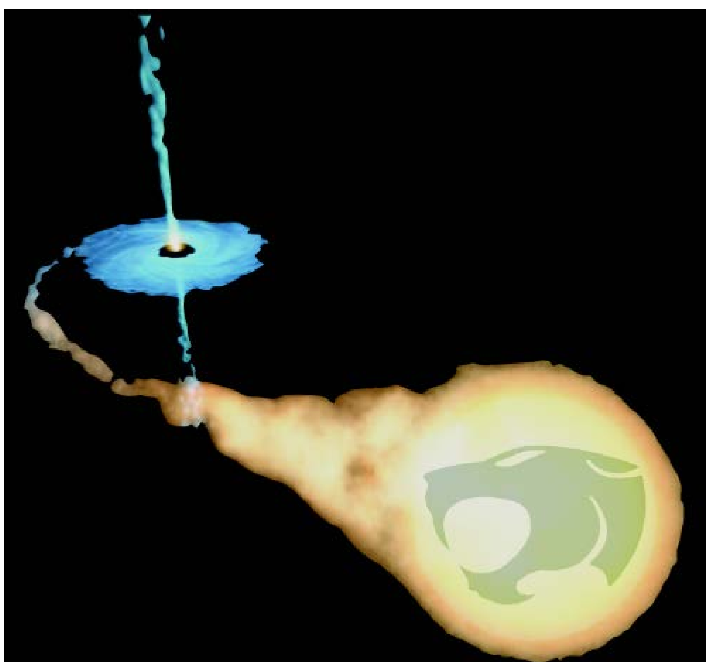
Next steps:

- Newly accessible and exciting field
- Currently we have sparsely sampled data – do we need large samples or detailed studies?

Future outlook

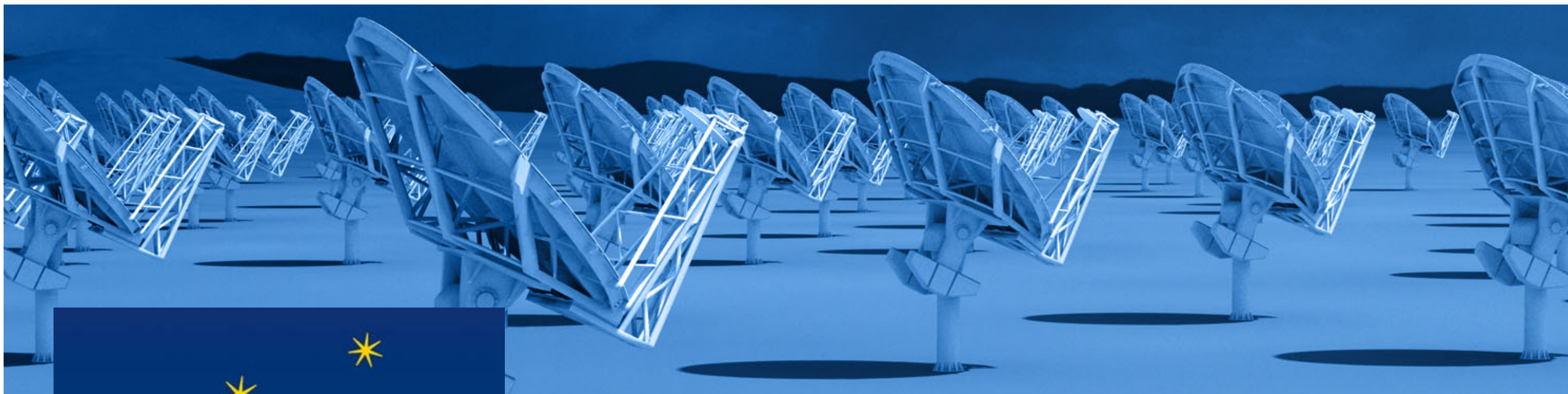
MeerKAT

ThunderKAT



MeerLICHT

Next Generation VLA



ALMA

SKA

SQUARE KILOMETRE ARRAY