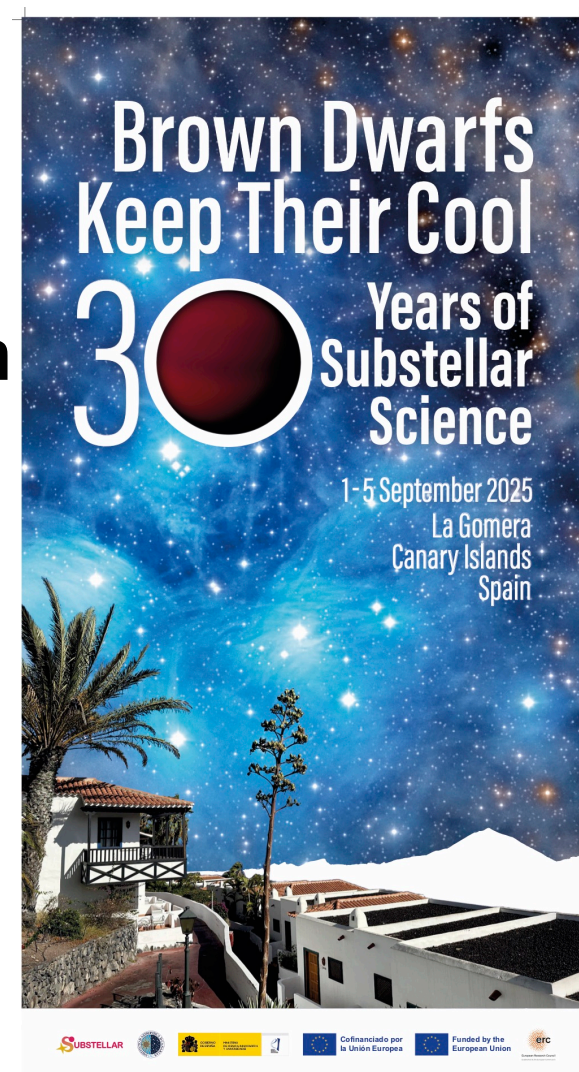La Gomera, 4 September 2025

Complex Periodic Variables:
an approach for planetary formation
at the substellar frontier

Víctor J. S. Béjar

IAC

Collaborators: Shan, Y., Murgas, F., Kaur, S., Viganò, D., Curiel, S., Girat, J. M. and the Muscat2 and CARMENES collaboration

Brown Dwarfs Keep Their Cool
30 Years of Substellar Science
1-5 September 2025
La Gomera
Canary Islands
Spain

What is a Complex Periodic Variable star?

- These are **young**, **low-mass fast rotating stars**

- Present **periodic** absorption features (**"disps"**) at the stellar **rotation period**

- **Bouma et al. 2024** has compiled **50 CPVs** from TESS lightcurves

- **Other names**: complex rotators, Transient flux dips, **scallop shell stars (**Rebull et al. 2016, Stauffer et al. 2017, Zhan et al. 2019, Günther et al. 2022, Koen 2023, Bouma et al. 2024)
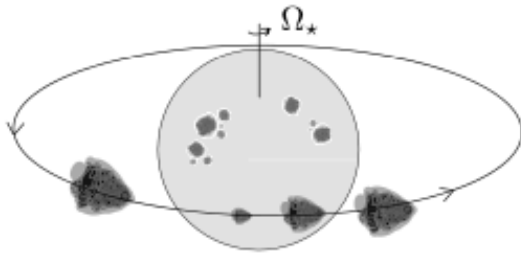
WHY THEY ARE INTERESTING?
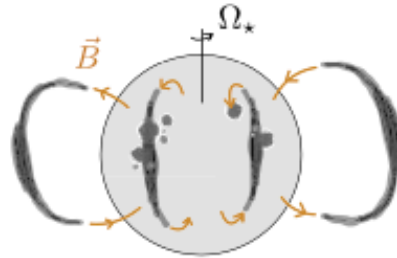**VLMs rotation evolution, planet formation and substellar frontier**
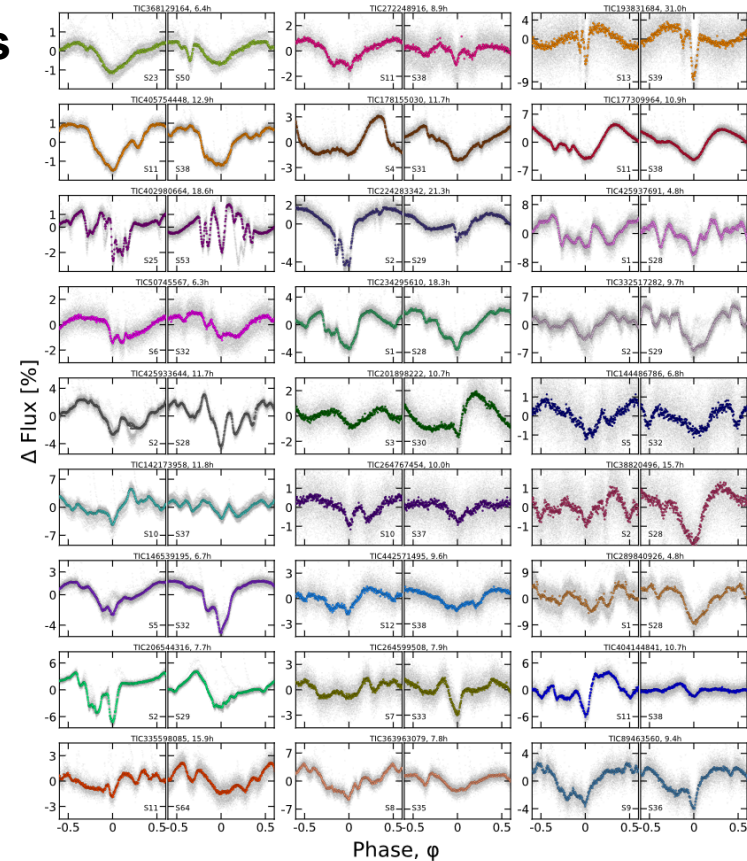
Bouma et al. 2024

What is a Complex Periodic Variable star?

Possible scenarios:
- **- warp discs** at **different viewing angles**
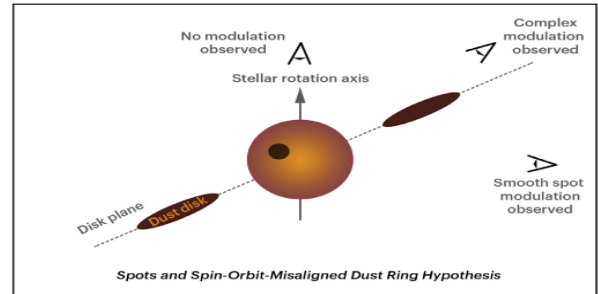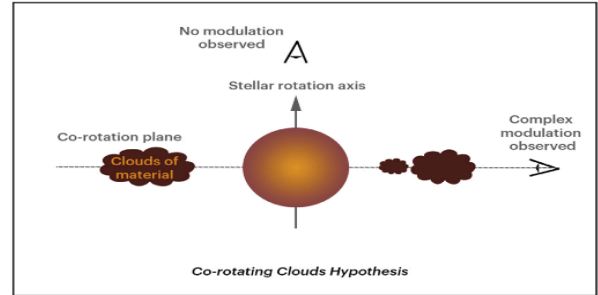- **- co-rotating material (gas or dust)**
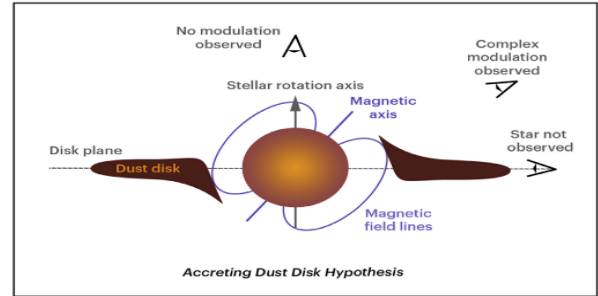- **- spot occultation by a misaligned disc**

Clumps

Prominences

Bouma et al. 2024

Accreting Dust Disk Hypothesis

Co-rotating Clouds Hypothesis

Spots and Spin-Orbit-Misaligned Dust Ring Hypothesis

Günter et al. 2022

2M0508: The star

| Parameter	Value	Reference
Identifiers		
Name	2MASS J05082729–2101444	2MASS
	Karmn J05084–210	Cab16
Astrometry and kinematics		
α (epoch J2016.0)	05 08 27.335	Gaia DR3
δ (epoch J2016.0)	-21 01 44.578	Gaia DR3
$\mu_\alpha \cos\delta$ (mas yr^{-1})	34.31 ± 0.04	Gaia DR3
μ_δ (mas yr^{-1})	-12.68 ± 0.05	Gaia DR3
π (mas)	20.70 ± 0.06	gaia DR3
d (pc)	48.30 ± 0.14	gaia DR3
γ (km s^{-1})	22.21 ± 0.23	Laf20
U (km s^{-1})	-12.9 ± 0.6	This work
V (km s^{-1})	-18.9 ± 0.6	This work
W (km s^{-1})	-6.2 ± 0.5	This work
Stellar kinematic group	β Pic	Schn19
Photometry		
G (mag)	13.068 ± 0.003	gaia DR3
J (mag)	9.716 ± 0.024	2MASS
Ks (mag)	8.833 ± 0.019	2MASS
Photospheric parameters		
Spectral type	M5.0 V	Riaz06
$T_{\rm eff}$ (K)	$3233 \pm 22 \pm 50$	Mar21
$\log g$ (cgs)	4.52 ± 0.10	Mar21
[Fe/H] (dex)	-0.38 ± 0.07	Mar21
Activity and rotation		
$v \sin i$ (km s^{-1})	25.2 ± 2.5	Rein2018
$P_{\rm rot}$ (d)	0.280455 ± 0.00001	This work
<Bf> (G)	6700 ± 700	Rein22
pEW(Hα) (Å)	-17.39 ± 0.09	Scho19
$\log \mathrm{H}\alpha/L_{\rm bol}$	-3.283 ± 0.021	Scho19
$\log L_{\rm X}/L_{\rm J}$	-2.3 ± 0.2	1RXS
Physical parameters		
$L_\star$ ($10^{-3}\,L_\odot$)	19.5 ± 2	This work
$R_\star$ ($R_\odot$)	0.439 ± 0.025	This work
$M_\star$ ($M_\odot$)	$0.198^{0.030}_{-0.025}$	This work
$\sin i_\star$	0.318 ± 0.050	This work
Age (Myr)	20–25	Mir18

H$_\alpha$ (6562.8 Å)

Li (6707.8 Å)
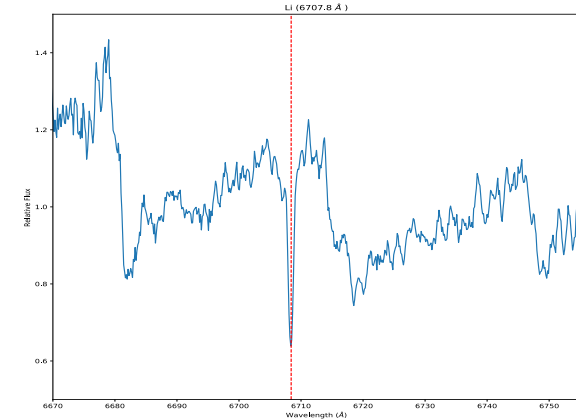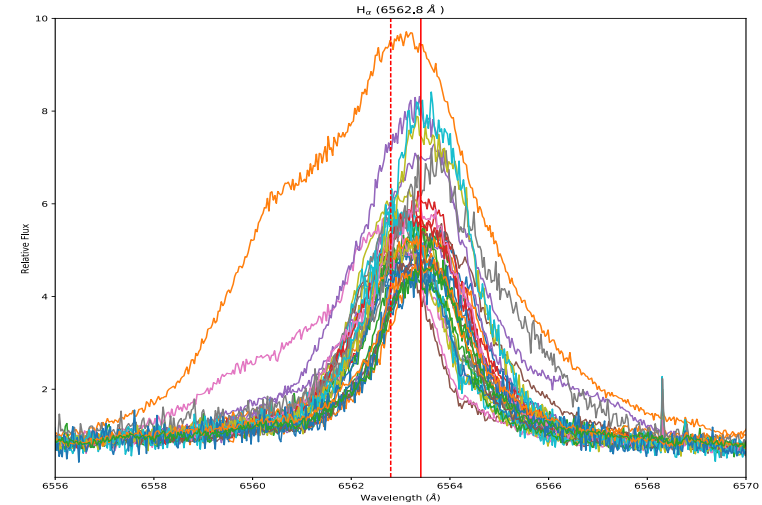
- This is a **young**, very **low-mass** (M5) **fast rotator** (Prot=6.7h) of the CARMENES sample
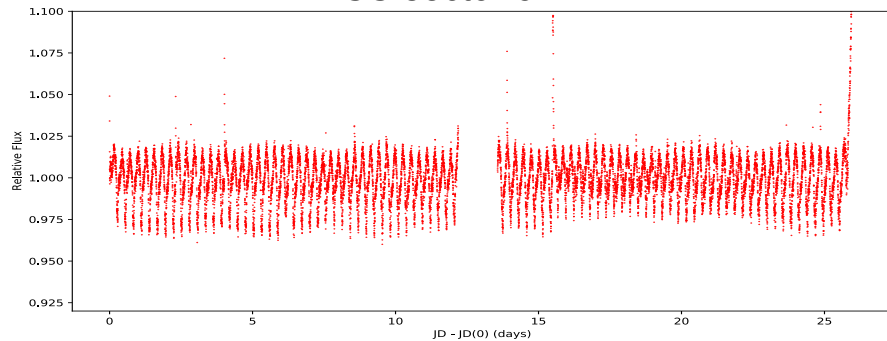- Strong **Hα emission** and **lithium** absorption lines
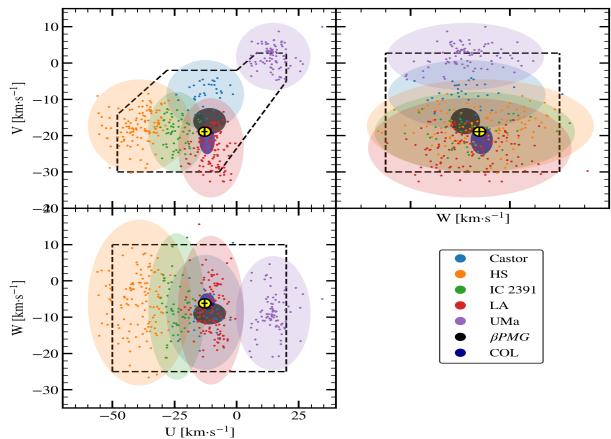
2M0508: The age

- It belongs to the **β Pic** Young Moving Group (**20-25 Myr**, Miret-Roig et al. 2018)

- It is **overluminous** in Color-Magnitude diagrams

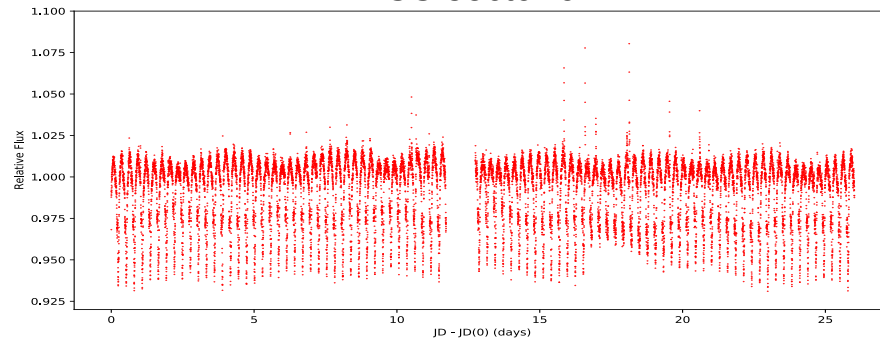- It has **NUV excess** and **stronger X-ray** and **Hα** emission than older M dwarfs
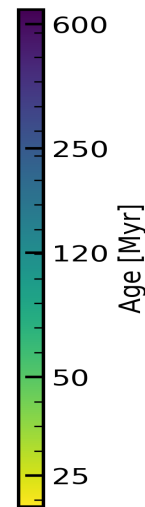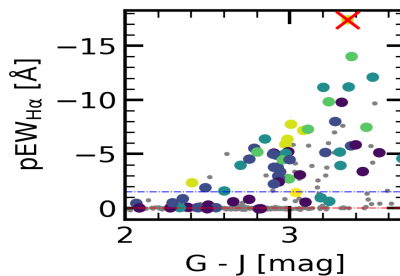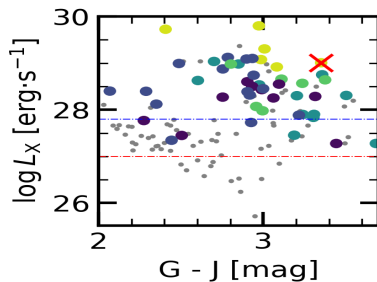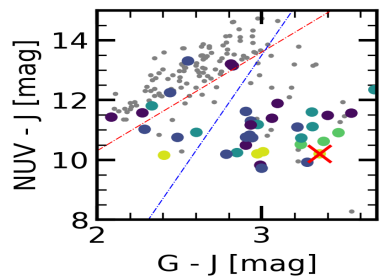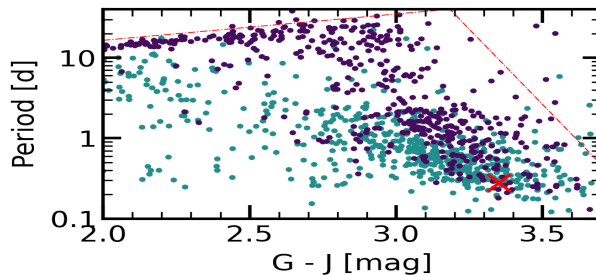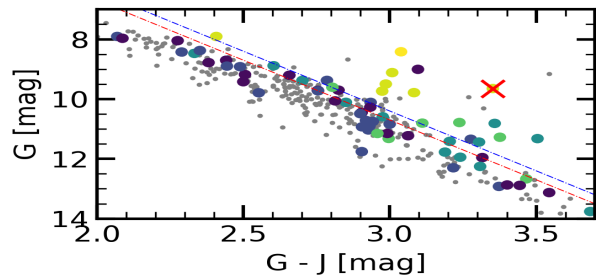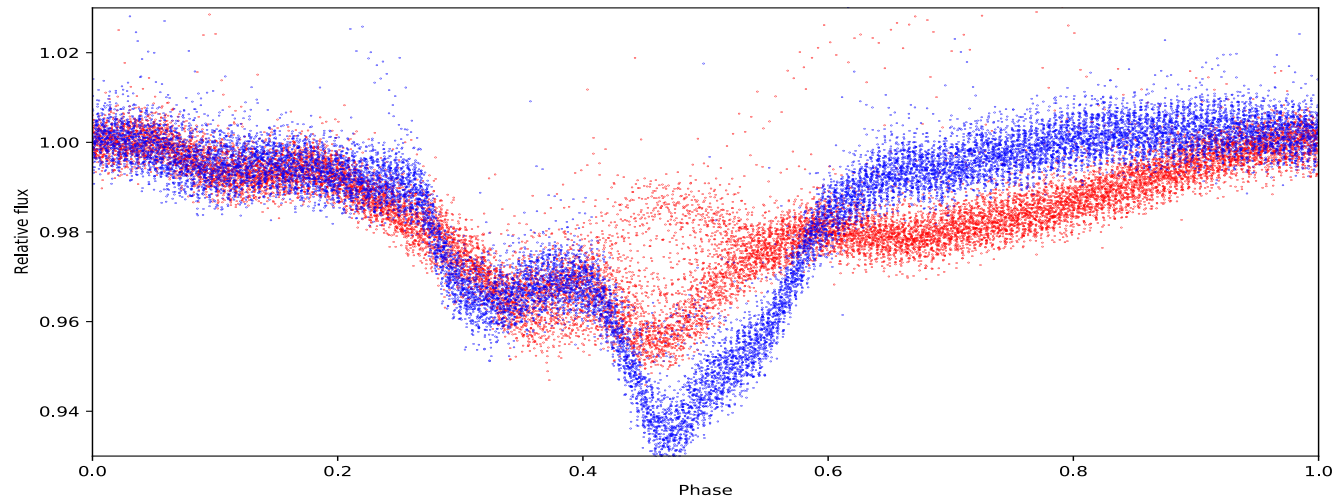
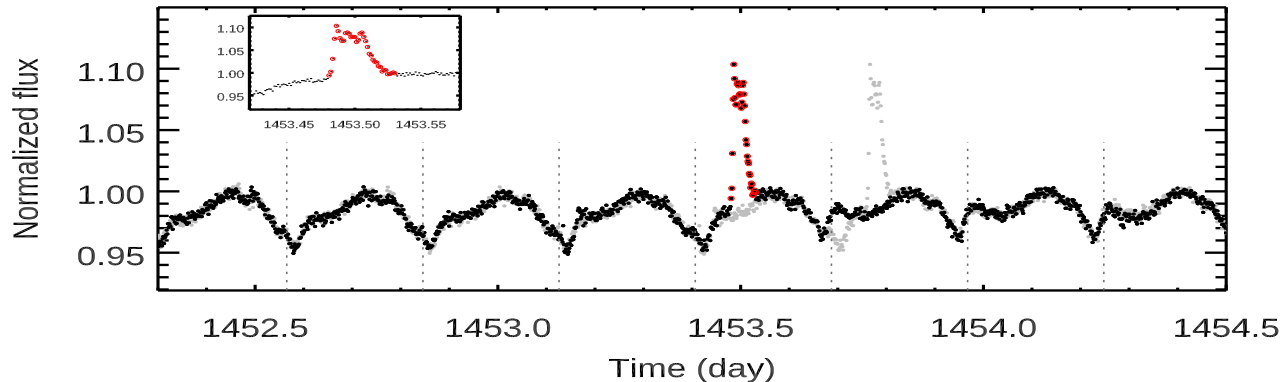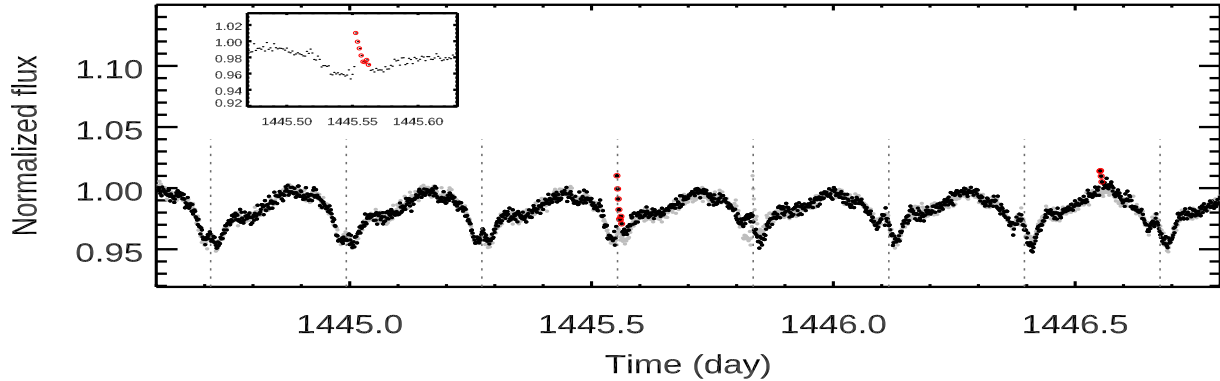# 2M0508: TESS Light Curve

TESS sector 5

TESS sector 32

The star has a **regular rotation** pattern, lot of **flares** and **two** regular but **slightly variable dips**
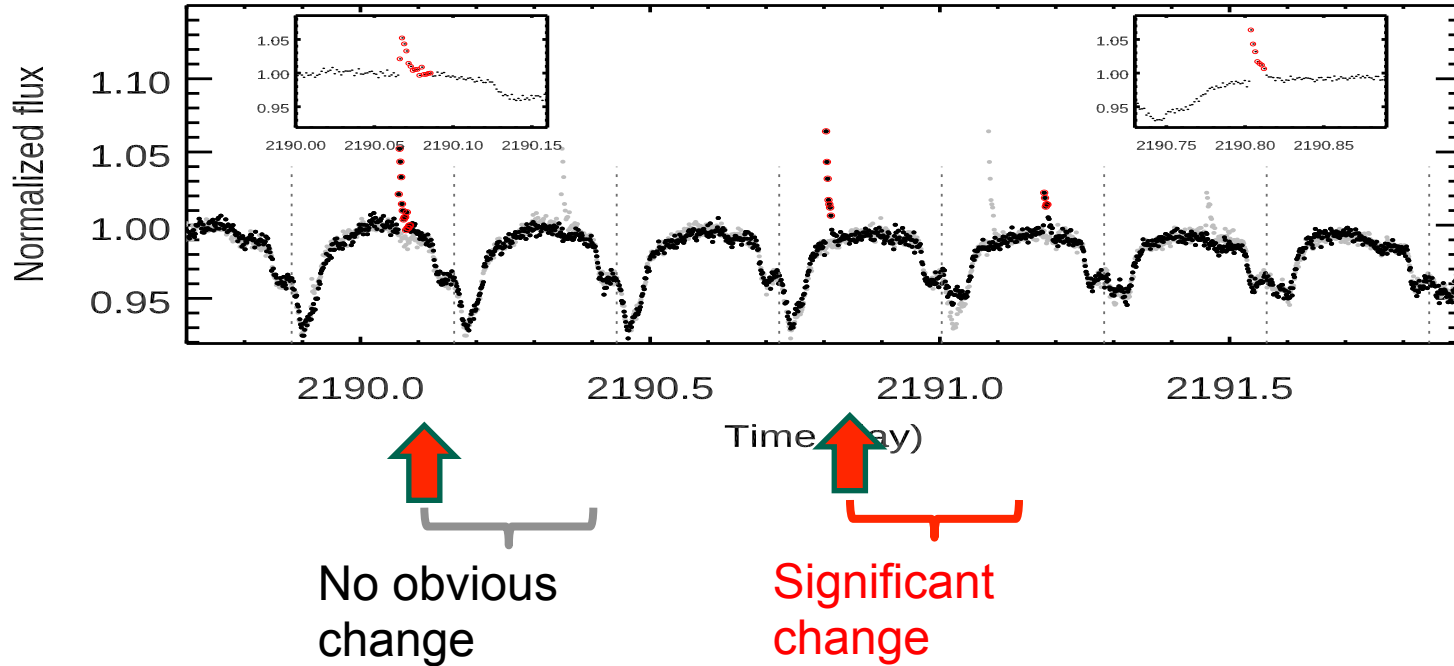
2M0508: TESS Flares and dips

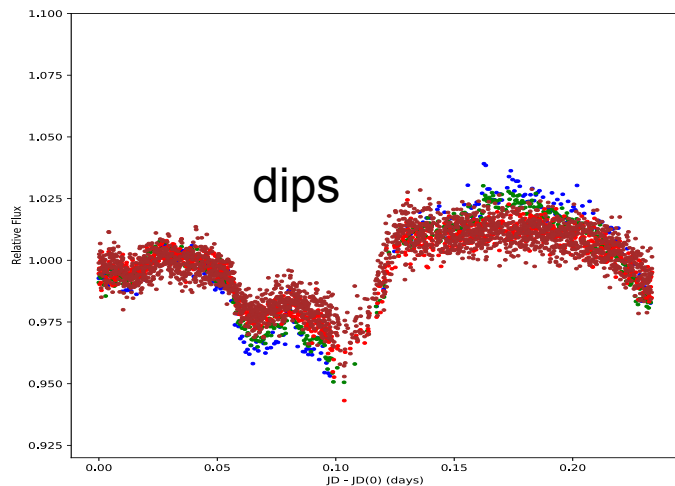After some prominent flares, sudden changes of dips appears
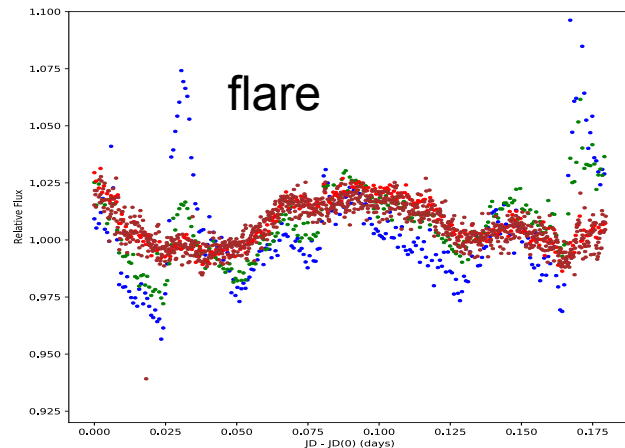
2M0508: TESS Flares and dips

...but most flares are NOT followed by sudden state changes
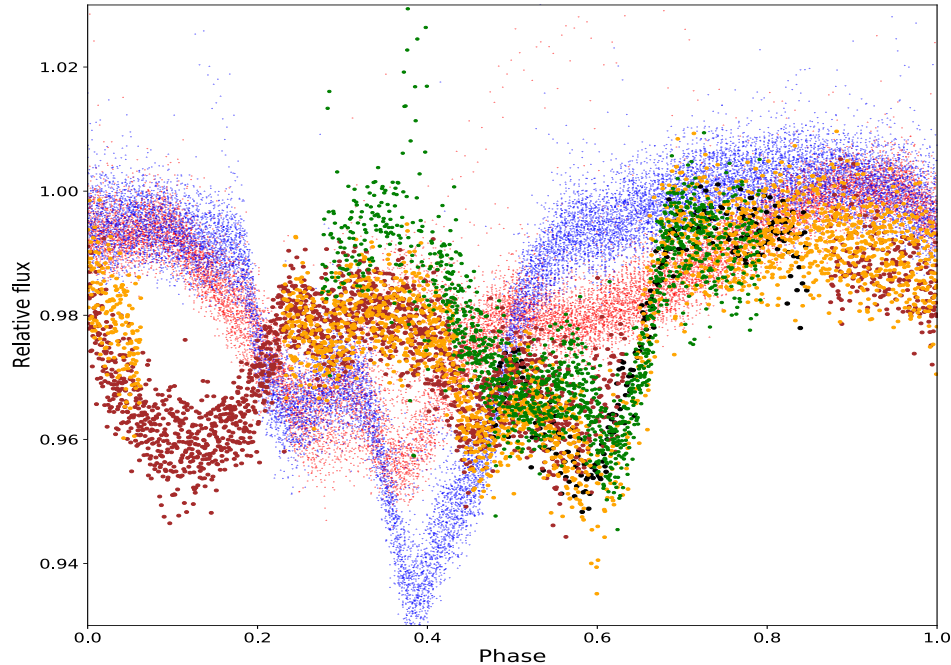
2M0508: Chromaticity of dips
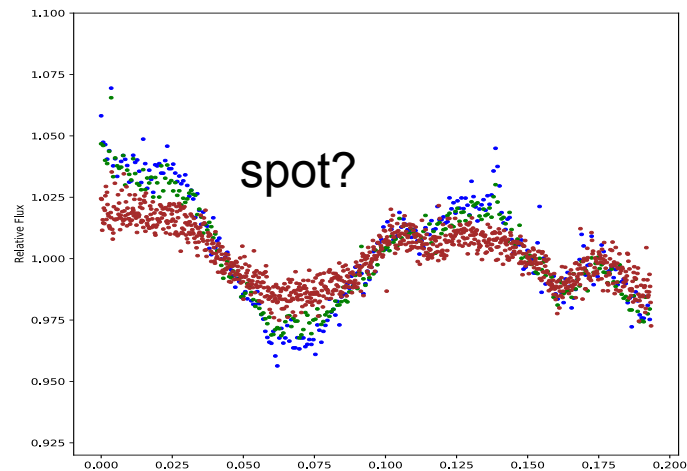
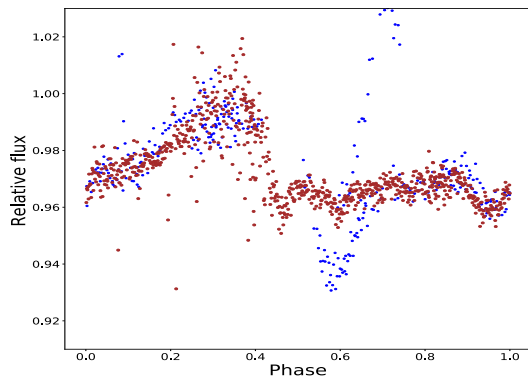- **Dips** are **slightly chromatic**, but **spots** and **flares** are more **chromatic**

2M0508: Evolution of dips

Dips and **spots evolve** in **timescales** from **tens of days** to **years**, but dips are **persistent** at a similar or slightly evolving rotation phase (0.35 in 2018, 0.4 in 2020, 0.65 in 2022, 0.55 in 2023 and 0.6 in 2024)
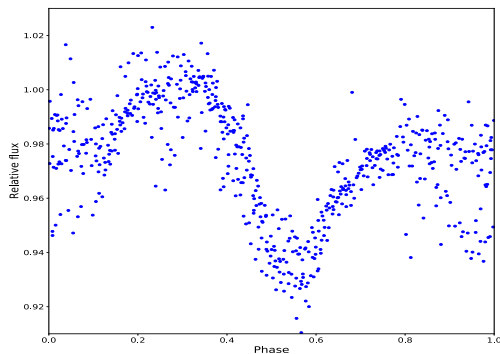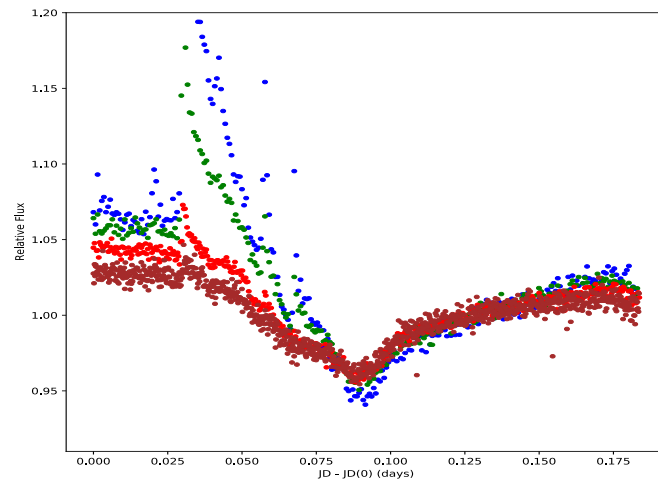
2M0508: Evolution of dips

LCO+Muscat2 2024

- **Dips** and **spots evolve** in **timescales** from **tens of days** to **years**, but dips are **persistent** at a similar rotation phase

- In 2025 only **one "double" achromatic dip** is present
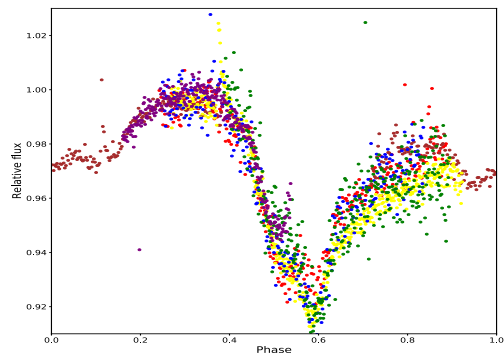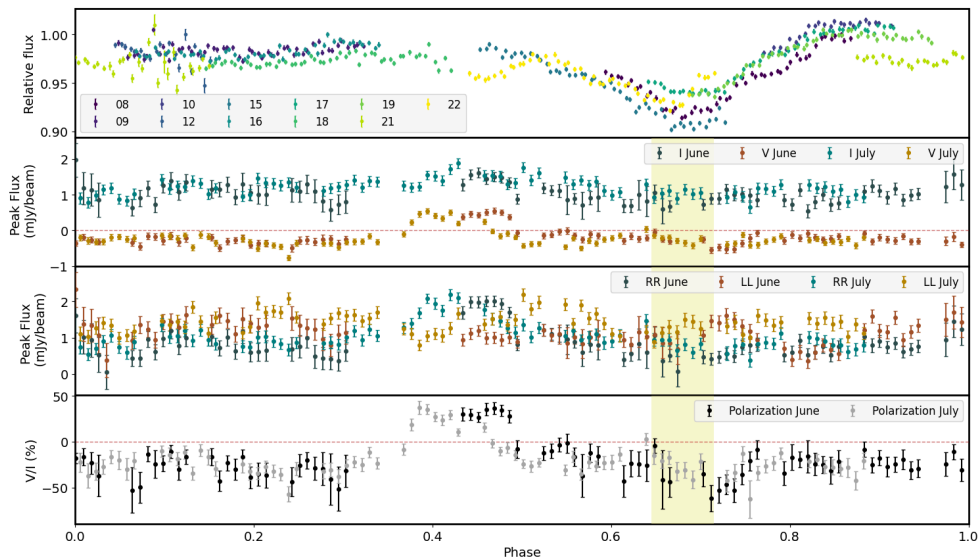

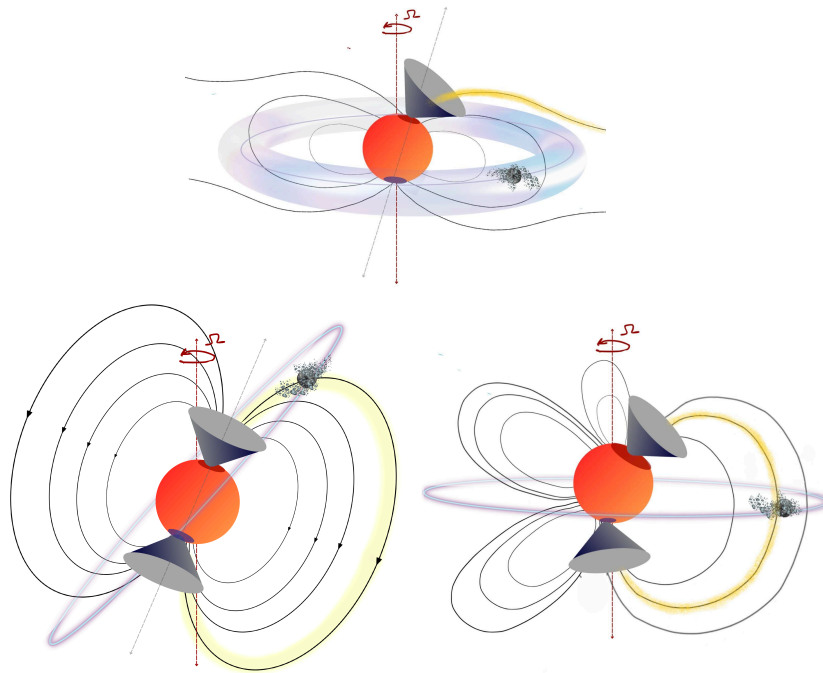Muscat2 2025

TTT80 2025

Muscat2 g,r,I,z 28 Jan 2025

2M0508: Radio observations with GMRT

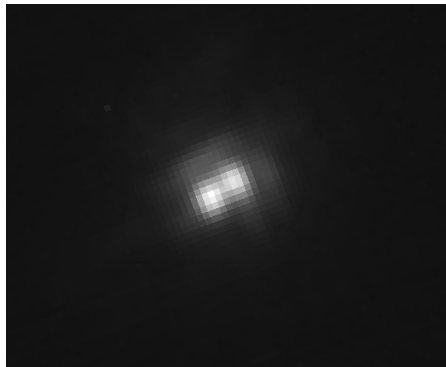GMRT observations (June/July 2023)

Kaur et al. 2024

The system is a strong radio emiter and shows variable polarızatıon emıssıon, likely produced by two components: gyro-synchrotron and auroral emission
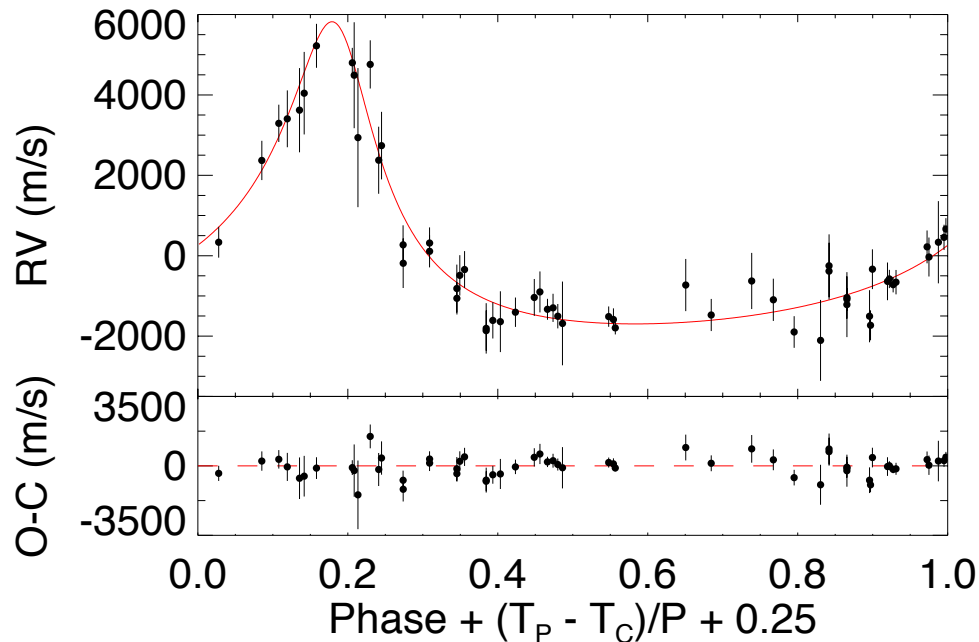
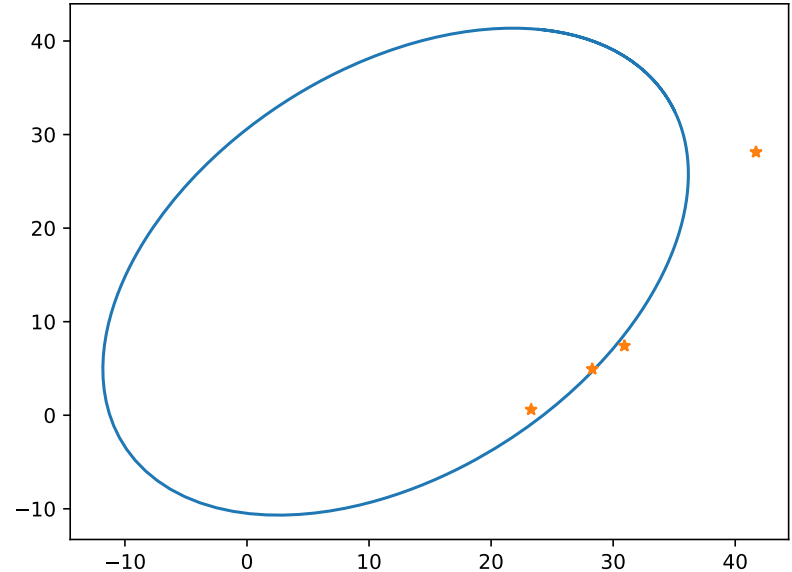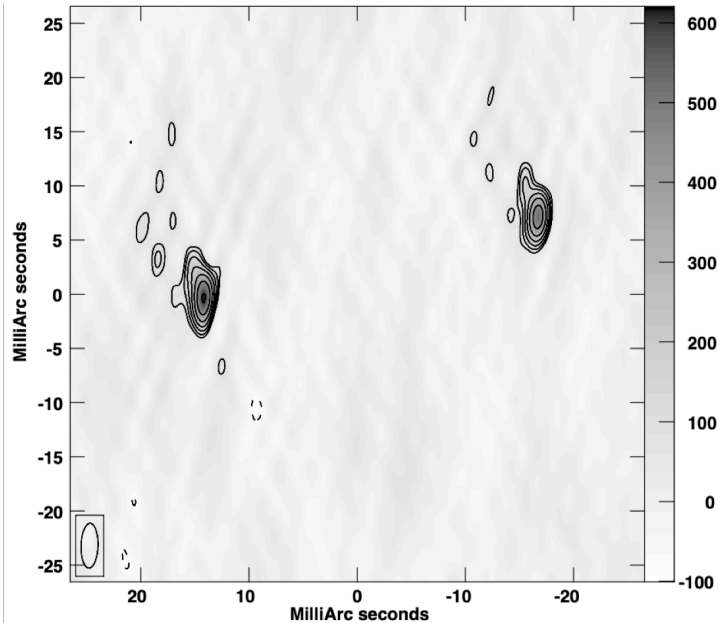# 2M0508: The binary

Keck NIRC AO archive data
(8 October 2012)

P_{orb}~800d

- Equal mass binary with a separation of **~50 mas**, physical separation is **~2.4 AU** in **2012.8**

- A ~**800d** signal (FAP<0.1%) probably related to companion. A **keplerian fit** gives a period of **~800 d**, an amplitude of **K~5 km/s, e=0.55**

2M0508: Resolving the binary with VLBA

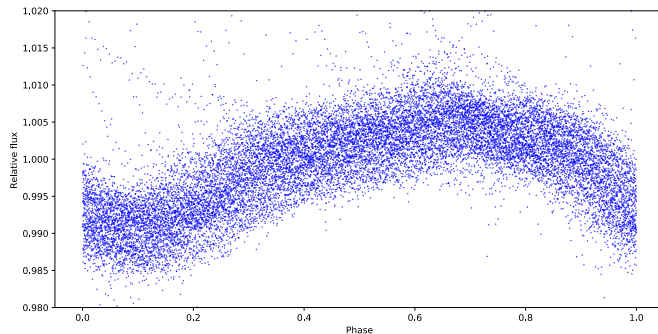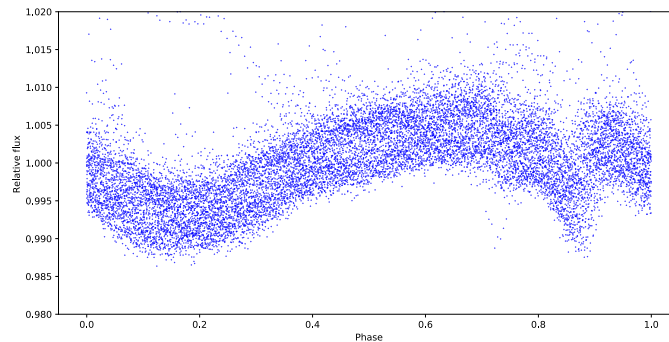VLBA observations (Spring 2025)

- The combined (astrometry+RV) fitt gives P = 821±2.4 days, e =0.66±0.03, a = 29.70±0.83 mas (i.e., 1.434±0.04 au) and M_{tot} ~ 0.58 $M_\odot$/ 0.25 $M_\odot$ (if Gaia parallax is larger)

DG CVn: another CPV
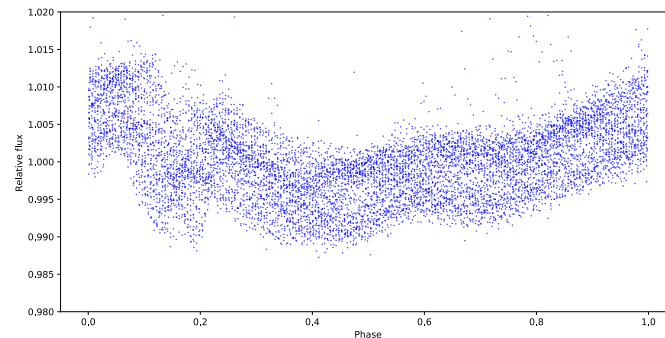

TESS sector23 April 2020

TESS sector50 April 2022

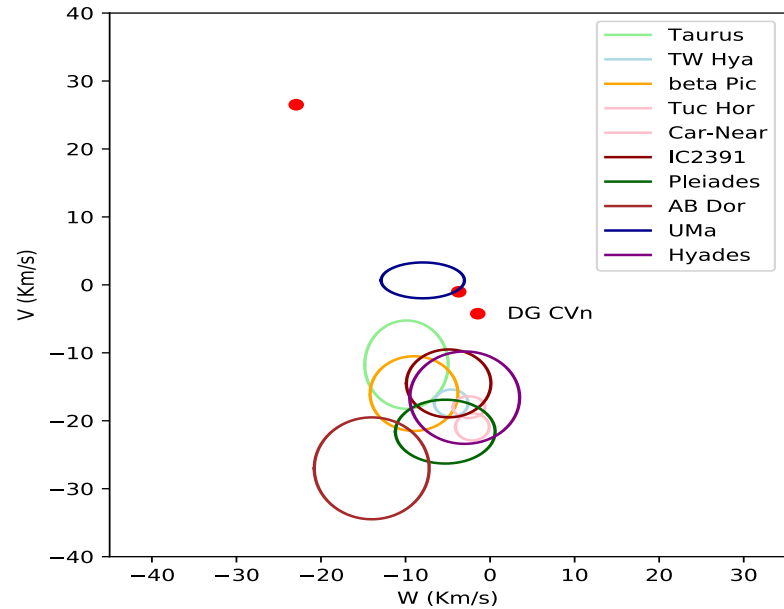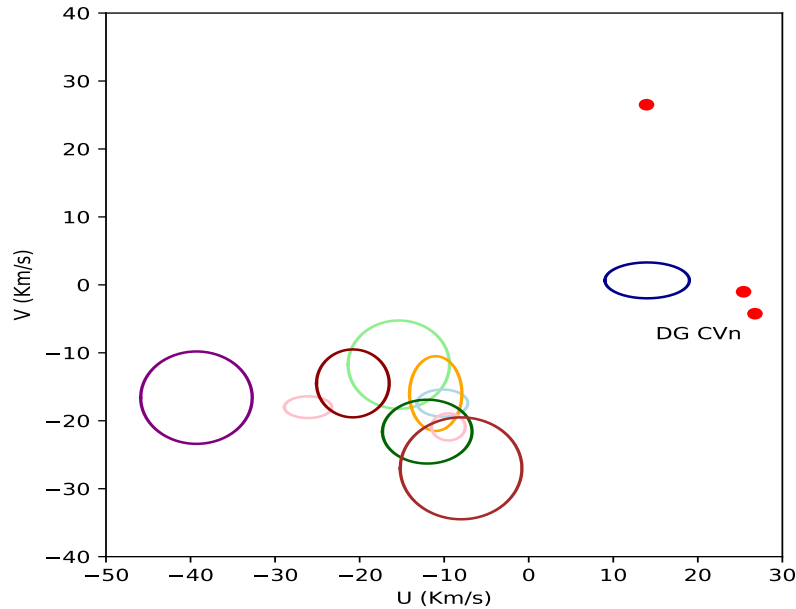- This is a young **M4** dwarf **binary**

- P_{rot}=6.438h, P_{rot2}=2.6h , Bouma et al. 2024

- AB Dor member (~150 Myr) at 18pc
and **CPV** (Bouma et al. 2024)

- **Strong radio emitter** (LOFAR: Yiu et al. 2024, Kaur et al. 2025)

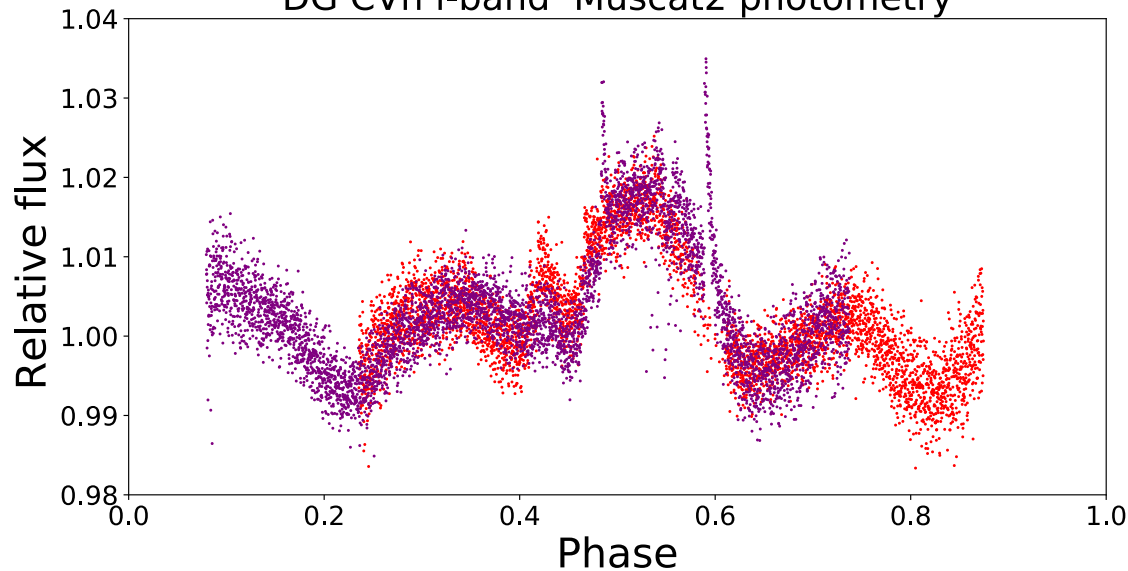TESS sector77 April 2024

DG CVn: kinematic

No GAIA DR3 available. No RV from Gaia.
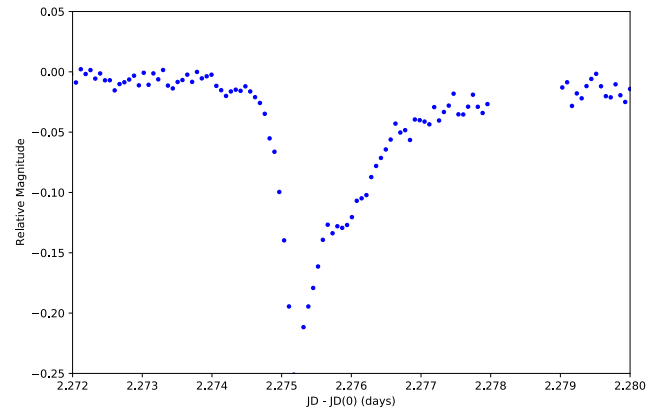RV variable (last measurement from SPIRou)

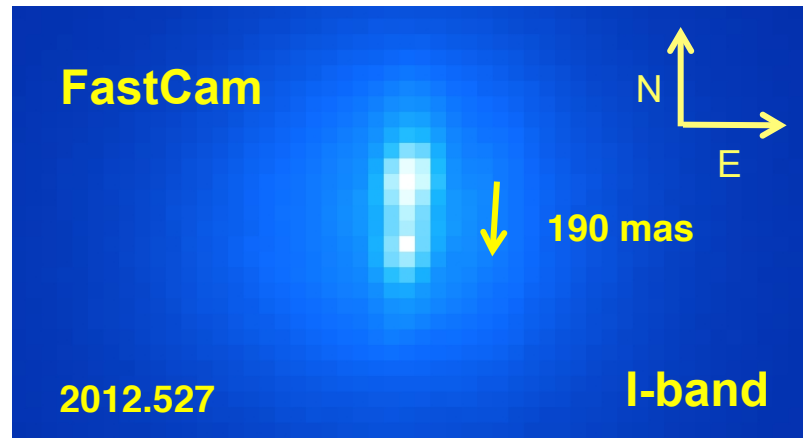# Muscat2 and TTT 2025 photometric campaign
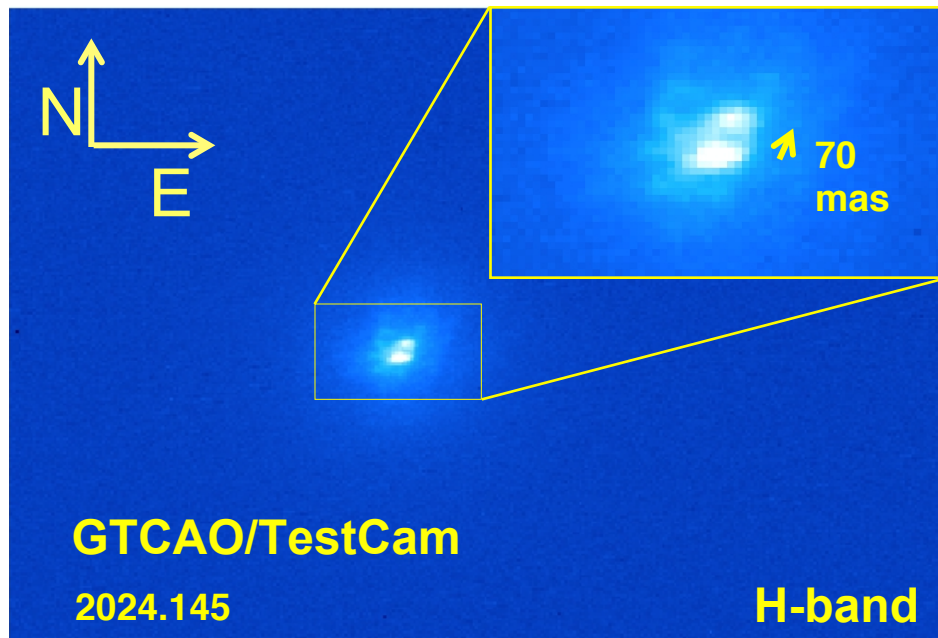

DG CVn i-band Muscat2 photometry

Phased light curve to twice the rotation period

TTT data shows some smaller dips with exocomet-like features

DG CVn: another binary

GTCAO/TestCam
2024.145
H-band
70 mas
N E

FastCam
2012.527
190 mas
I-band
N E

- Young **M dwarf binary**, resolved by Beuzit et al. 2004 and Cortes-Contreras et al. 2014.

- We further **resolved** the system to a separation of 70 mas **with GTCAO**

Summary and final remarks

- **2M0508** and **DG CVn** are two **"Complex Periodic Variable" binary stars**

- They are **fast rotating** (~6-7h) **very low-mass** (~0.2 $M_{\odot}$) stars with ages (**<100 Myr)**

- They show **strong** variable and polarized **radio emission**

- The present **regular** but slightly **variable** and slightly **chromatic dips**

- **RV, AO** images and **VLBA** can provide **dynamical masses and** precise **orbits**

- **Dips** can be explained by **co-rotating dust material** from a **debris disc** or **disrupting planet** or **gas** from a **coronal mass ejections**

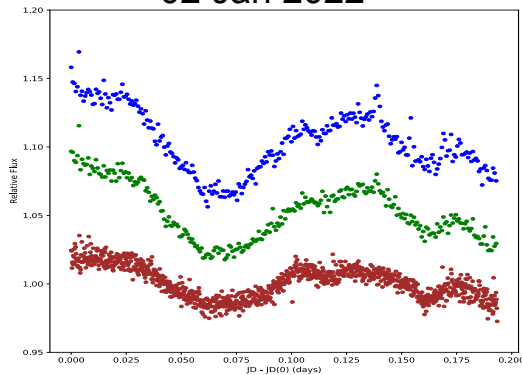- **Binary CPVs may provide** determination of **substellar frontier** at **young ages**
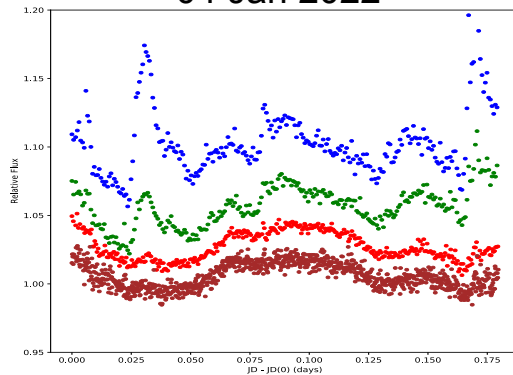
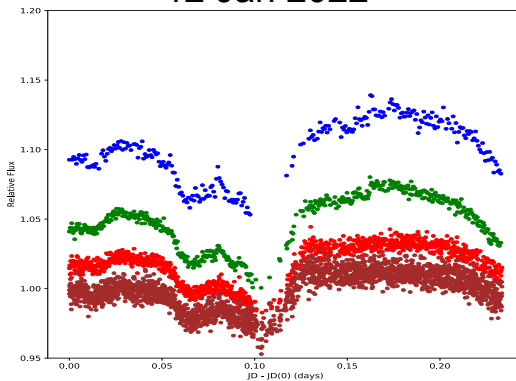# 2M0508: Mucat2 data
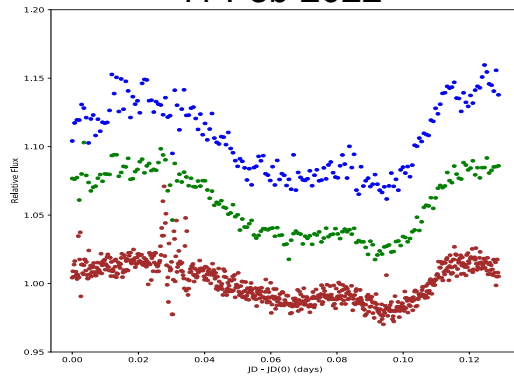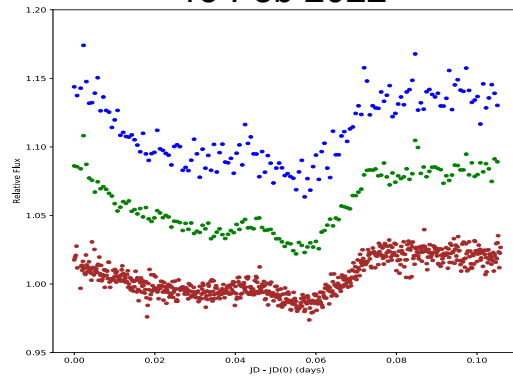

21 Dec 2021
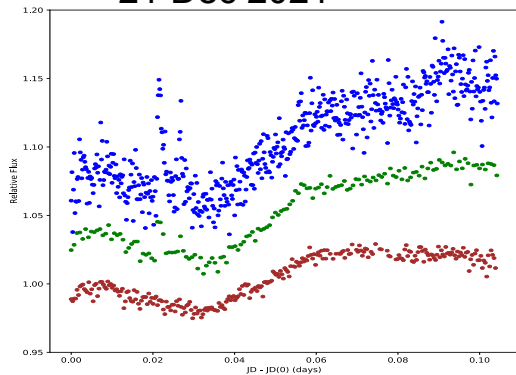
02 Jan 2022

04 Jan 2022

12 Jan 2022

11 Feb 2022

13 Feb 2022

Muscat2 **multicolor photometry** in **g** (blue), **r** (green), **i** (red), and **z** (brown) bands
Covering 6-8h during 6 nights