Complex Periodic Variables

star-planet-disc interaction at the substellar frontier

V. J .S. Béjar[1,2], Y. Shan[3,4], F. Murgas[1,2], M. Mallorquín[1,2], S. Kaur[5,6], D. Viganò[5,6], S. Curiel[7], J. M. Girat[5,6], M. R. Zapatero Osorio[8], and the Muscat2 and CARMENES collaboration

1 Instituto de Astrofísica de Canarias, La Laguna (Tenerife), Spain
2 Departamento de Astrofísica, Universidad de La Laguna, La Laguna (Tenerife), Spain
3 The Science Library, University of Oslo, Oslo, Norway
4 Institut für Astrophysik, Georg-August-Universität, Göttingen, Germany
5 Institut de Ciències de l'Espai (ICE-CSIC), Cerdanyola del Vallès, Barcelona, Spain
6 Institut d'Estudis Espacials de Catalunya (IEEC), Castelldefels, Barcelona, Spain
7 Instituto de Astronomía, Universidad Nacional Autónoma de México (UNAM), Ciudad de México, México
8 Centro de Astrobiología (CSIC-INTA), Villanueva de la Cañada, Madrid, Spain

ABSTRACT

Complex Periodic Variable (CPV) stars, are a fascinating new class of young, fast rotating very low-mass stars, which shows transit-like dips at the co-rotation radius. Although the physical mechanism of these dips is currently unknown, they could be related to the presence of dust material in a debris disk or evaporated from a planet, or to the ejection of coronal gas material from the stars. We present the latest results of a photometric, spectroscopic, radial velocity and astrometric monitoring campaign spanning several years in the optical and radio of 2M0508-21, a young, fast rotating (6.7h) M5 binary system belonging to β Pic (~20 Myr). These studies allowed us to perform a comprehensive multi-band photometric and spectroscopic characterization of the dips and determine the orbit of their binary systems, representing a unique opportunity to shed light on this phenomenon.

email: **vbejar@iac.es**

Introduction

Complex Periodic Variable (CPV) stars, also called 'scallop shell' stars, are a fascinating new class of young, fast rotating very low-mass stars recently identified with Kepler and TESS (Rebull et al. 2016, Stauffer et al. 2017, Bouma et al. 2024), which shows transit-like dips at the co-rotation radius.

2M0508-21: the star

- It s a **young**, very **low-mass** (M5) **fast rotator** (Prot=6.7h) of the CARMENES sample
- It belongs to the **β Pic** Young Moving Group (**10-30 Myr**, Miret-Roig et al. 2018)
- It has strong **Hα emission** and **lithium** absorption lines, and strong radio emission (Kaur et al. 2024)
- The **TESS** light curves show **two co-rotating dips** (Fig. 1)

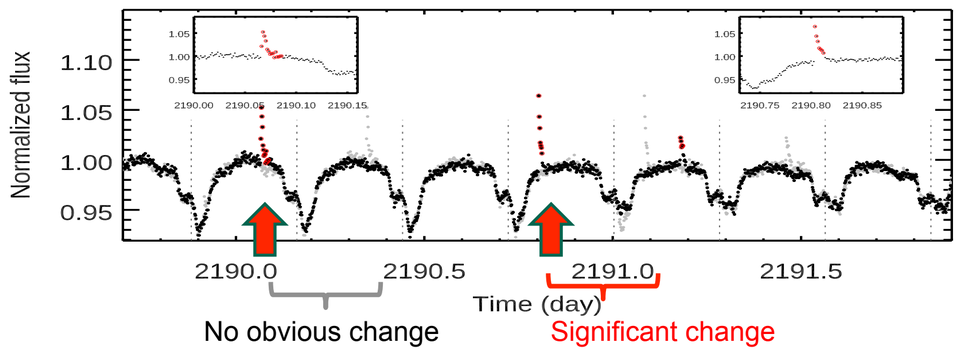


Figure 1. TESS light curve, flare and dips: Some prominent flares (red) produce sudden changes of dips, but not all flares are followed by changes.

2M0508-21: the dips

Strong flares may produce temporal **abrupt changes** of **dips** (Fig. 1). Dips **smoothly evolve** in timescales from tens of **days** to **years**, but are **persistent** for **more** than **seven years** and remain at a **similar phase** (Fig. 2). The co-rotating **material** is **misaligned** with the stellar spin axis and binary orbit (Fig. 3).

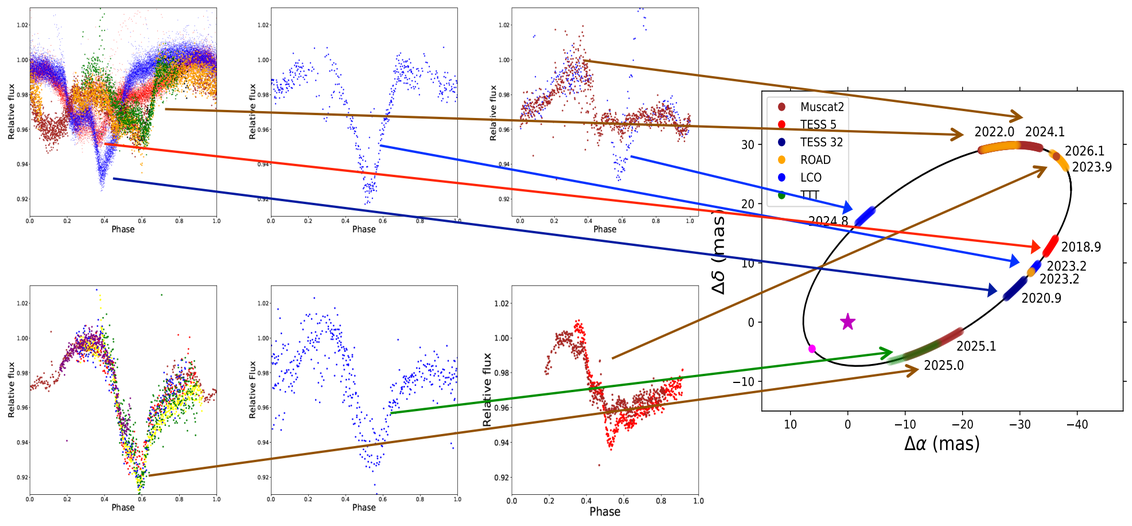


Figure 2. TESS, Muscat2, LCO and TTT phase light curves: The different instruments and epochs are indicated with the representation of the binary orbital phase (Béjar et al. in prep.).

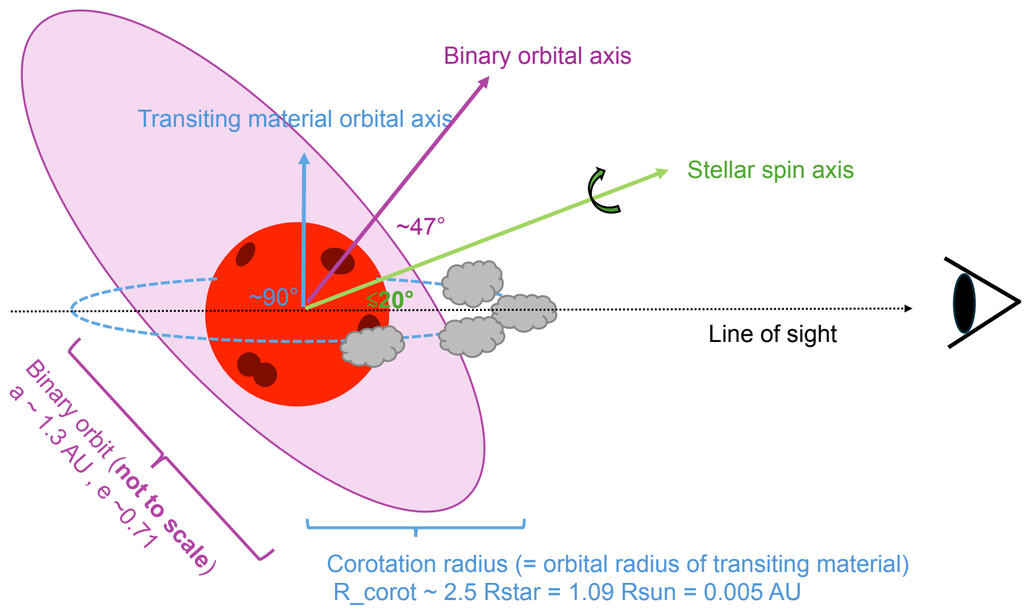


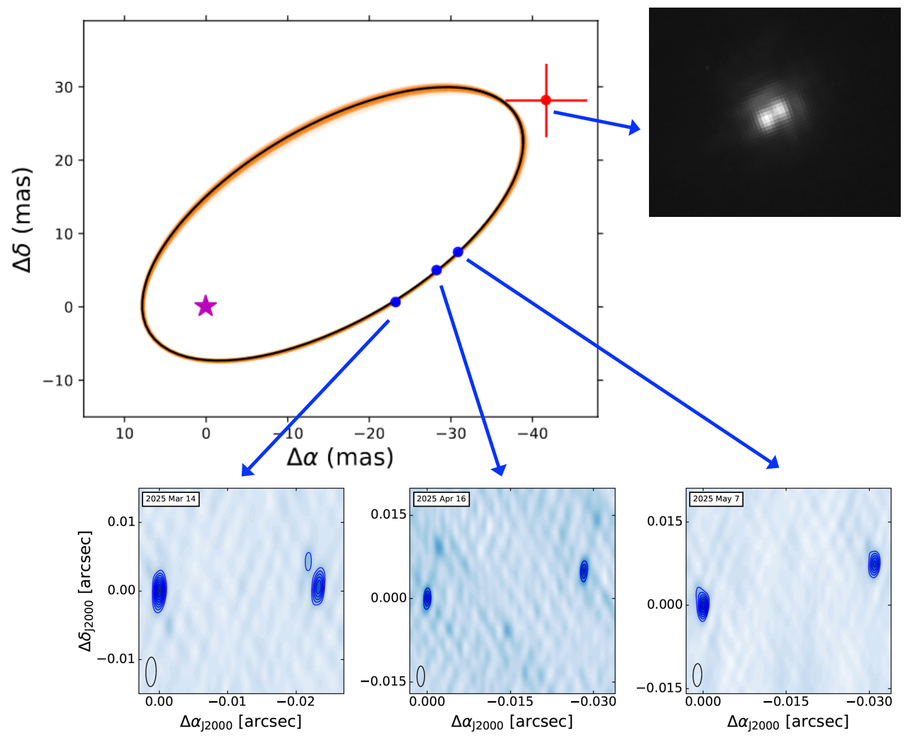
Figure 3. System architecture cartoon, based on observed constraints in the transiting material inclination, host stellar spin axis, and binary orbital axis.

2M0508-21: the binary

The combined **astrometry** from **Keck AO NIRC2** and **VLBA**, and **CARMENES radial velocity** data (Curiel et al. 2026) provides these orbital fit (Fig. 4) parameters:

- **P = 801.5** ± 1.1 **d**, **e =0.711** ± 0.008,
- a = 27.02 ± 0.25 mas (i.e., **1.305** ± 0.013 **au**)
- $\mathbf{M_{tot} \sim 0.462\ M_\odot}$, 0.25-0.30 $M_\odot$ (if Gaia parallax is larger)

The object seem to be slightly **subluminous** assuming an **equal mass** binary (Fig. 5)



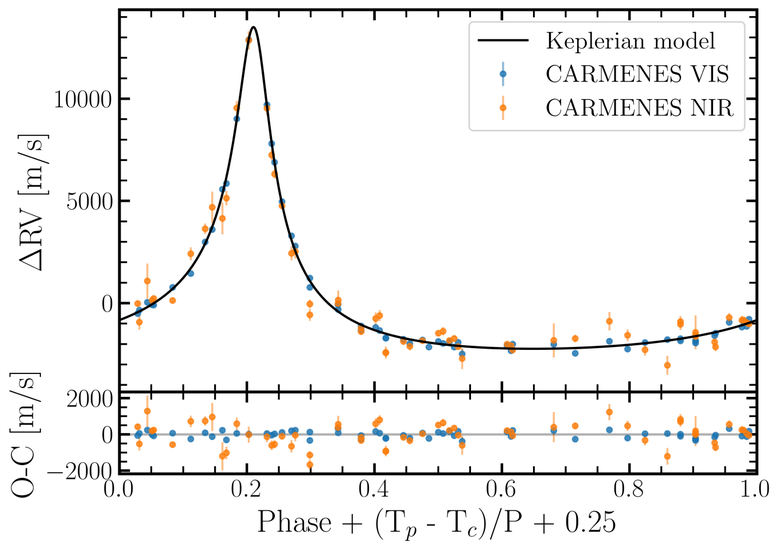
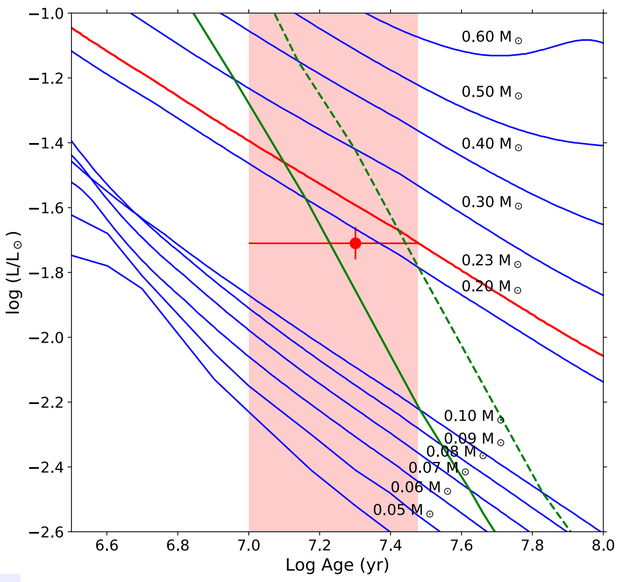


Figure 4. (Upper panel): Orbit of 2M0508-21: Kekc AO NIRC2 (red) and VLBA observations (blue) compared to the best astrometric solution. (lower panel): CARMENES VIS and NIR RV data (solid circles) and the best keplerian model fit (solid line).

Figure 5. Luminosity, age diagram: The red circle represents the luminosity of individual components. Theoretical evolutionary models of Baraffe et al. (2015) are shown in blue lines. The 0.23$M_\odot$ case (corresponding to an equal mass binary) is shown in red. The 1 and 99% lithium depletion boundaries is indicated with solid and dashed green lines.



Conclusions

- **2M0508-21 is a very young (~20 Myr), fast rotating (6.7h) CPV binary with a high eccentric (0.71) orbit of 2.2 years.**
- **Multi-band photometry indicates that the two dips are persistent for more than seven years, show smooth variations from season to season, but may have temporal abrupt changes with strong flares.**
- **The co-rotating material, whether it is gas from plasma prominences or dust from a debris disk, planetesimal clumps or a disintegrating planet, transits near the stellar poles, and is misaligned with the binary orbit.**

References

Baraffe et al. 2015, A&A, 577, A42
Béjar, V. J. S., et al. 2026, in prep.
Bouma, et al. 2024, A&A, AJ, 167, 38
Curiel, S. et al. 2026, A&A, 711, A51
Kaur, S. et al. 2024, A&A, 691, L17
Miret-Roig et al. 2018, A&A, 642, A179
Rebull, M. et al. 2016, AJ, 152, 114
Stauffer, J. et al. 2017, AJ, 153, 152

Acknowledgements:

We acknowledge financial support from grant PID2022-137241NB-C4[1,2] funded by MICIU/AEI/10.13039/501100011033 and ERDF/EU, and the European Cooperation in Science and Technology (COST Action "PLANETS" No. CA22133).