CANADA-FRANCE-HAWAII TELESCOPE

No code

Zaire

Investigating the Applegate effect in the post-common-envelope binary V471 Tau

Semester : 2020B

Science Cat. : Stars and stellar population

Abstract

This proposal tackles the key question of whether a magnetic mechanism can be responsible for the observed eclipse timing variations seeing in the V471 Tau system. This mechanism, known as the Applegate effect, is theoretically predicted to operate in several binary systems, but yet no definitive proof of its action has been found. We will address this question by using spectropolarimetric time-series to reconstruct the magnetic field of the K dwarf companion and to obtain the surface differential rotation of the star. Together with previous observations performed at ESPaDoNS, we will be able to discuss if an Applegate effect can be the responsible mechanism for the eclipse timing variations observed in the system.

Telescopes

Telescope	Observing mode	Instruments
CFHT	QSO Regular	ESPaDOnS

Applicants

Name	Affiliation	Email	Country		Potential observer
Bonnie Zaire	Institut de Recherche en Astrophysique et Planétologie (IRAP)	bonniezaire@gmail.com	France	Pi	
Jean-Francois Donati	CNRS / Univ de Toulouse (IRAP / OMP)	jean-francois.donati@irap.omp.eu	France		
Baptiste Klein	IRAP	baptiste.klein@irap.omp.eu	France		

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Requested Time (exposure + overheads) in hours (in nights for Classical)

15.6

Overall scheduling requirements

2020/11/29 to 2020/12/04

We request a total of 15.6h, spanning in 5 consecutive days. The observations will take place in three different nights with 5.2h of observation each. An interval of one day is asked from one observation to the other. This setup requires observations from mid-October to late December to achieve the requested hours with an airmass <1.5.

Observing runs

Run	Instrument	Seeing	Config	Details
A	ESPaDOnS	< 1.00" (ESPaDOnS)	Observing mode: Polarimetry Read-out mode : Normal	Stokes V polarimetry We request a total of 15.6h, spanning in 5 consecutive days. The observations will take place in three different nights with 5.2h of observation each. An interval of one day is asked from one observation to the other. This setup requires observations from mid-October to late December to achieve the requested hours with an airmass <1.5.

Targets

Field	RA	Dec	Epoch		Runs	Moon	Seeing Lower	Seeing Upper	S/N	Magnitude	Diameter	Comments
V* V471 Tau	03:50:24.97	+17:14:47.4	J2000		A	full	0.1	1	110	9.373		wavelength of the SN: 596 nm

Science justification

Overall context: Several binary systems display eclipse timing variations when considering a linear ephemeris to predict the time of mid-eclipse. Two main explanations exist: (i) the existence of a third body that perturbs the orbit of the system or (ii) the existence of magnetic induced modulations in the orbital period of the system that are caused by an Applegate Effect (Applegate J. H., 1992, ApJ, 385, 621). In this work we will focus on the second mechanism.

One key ingredient for the Applegate mechanism is the magnetic field amplification by dynamo action in the convective envelope of one of the companions. This mechanism occurs when the magnetic field, which transports angular momentum inside the star, changes the gravity profile and consequently the period of rotation of the star. This mechanism is often suggested to operate in synchronized binary systems, in which a change in the period of the synchronized star would directly reflect in the orbital period of the system, resulting in eclipse timing variations. However, its feasibility requires a cyclic behaviour in the magnetic field and a significant variation in the differential rotation. These information are both challenging to be acquired for a star and demand detailed analysis in specific targets.

Specific objective of the proposal: V471 Tau is an ideal object to investigate the existence of magnetic variability and differential rotation fluctuation, with several authors ruling in favour of an Applegate effect operating in the system (Völschow M., et al., 2016, A&A, 587, A34; Navarrete F. H., et al., 2018, A&A, 615, A81; Navarrete F. H., et al., 2020, MNRAS, 491, 1043). This eclipsing binary system is composed by a K dwarf main-sequence star and a hot white dwarf star (Nelson B., Young A., 1970, PASP, 82, 699). In the last 50 years, V471 Tau has been exhaustively observed in an attempt to understand the evolution of binary systems. The current scenario for V471 Tau indicates that the system is a pre-cataclysmic variable that, in early stages, has undergone a common-envelope phase (Paczynski B., 1976, IAU Symposium Vol. 73, p. 75). As in most pos-common-envelope binary systems, eclipse timing variations are observed (Young A., Lanning H. H., 1975, PASP, 87, 461). The existence of a third body perturbing the orbit of the system was disclaimed with an image of the binary system obtained with the instrument SPHERE (Hardy A., et al., 2015, ApJ, 800, L24). The Applegate effect seems to be the most plausible mechanism driving the periodic variations in the orbital period.

Recent analysis of data collected with ESPaDoNS in 2004 and 2005 unveiled a **magnetic variability** at the K dwarf surface (Zaire B.R., Donati J.F., Klein B., 2020, in preparation). Fig. 1 shows the reconstructions of the surface field of the K dwarf star for both years. The results indicate that a dynamo mechanism operate within the convective zone of the K dwarf, which is a necessary ingredient for action of the Applegate mechanism. Moreover, this first analysis shows a significant fluctuation in the differential rotation that suggest an inverse correlation with the magnetic field strength. Although these results favor the action of an Applegate effect, there is no observational proof that the magnetic field has the cyclic behaviour required to justify the eclipse timing variations.

We propose to apply the Zeeman-Doppler imaging technique (Donati J. F., Semel M., Praderie F., 1989, A&A, 225, 467) to spectropolarimetric data of the K dwarf star to **reconstruct its magnetic topology**. This work will be a follow up of two observational campaigns performed in 2004 and 2005. The 15 years gap between the observation proposed in this work and the last observation performed for the system corresponds to half of the cycle obtained with eclipse timing variations. It represents an opportune time to constrain the magnetic variability and to get hints about the existence of a **cyclic magnetic field**. Furthermore, we can measure the differential rotation at the star surface an extend previous investigations about the **angular momentum distribution** inside the K dwarf companion. Finally, we aim to discuss whether an Applegate mechanism operating in the V471 Tau system could explain the series of observations (2004, 2005, and, now, 2020). If the K dwarf star host a cyclic field generated in a similar fashion that in our Sun, we can expect a change in the ratio energy stored in the poloidal and the toroidal field components. Moreover, it is possible to fortuitously observe a change in the field polarity.

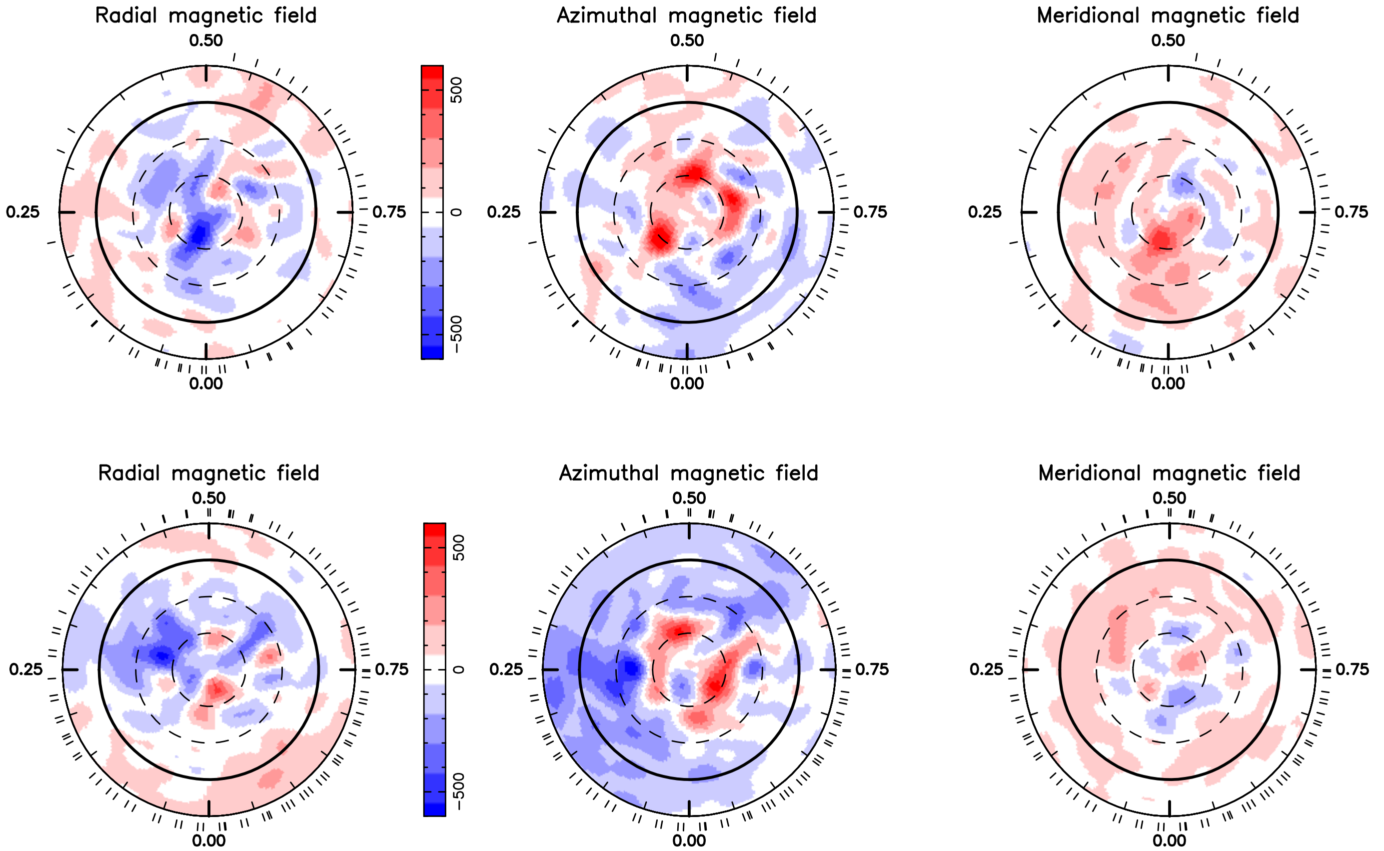

Figure 1: Polar view of magnetic field topology for 2004 (top panels) and 2005 (bottom panels). Columns depict different components of the magnetic field, namely radial, azimuthal and meridional field components. Magnetic field strengths are saturated at 600G, with red shades representing positive values and blue shades negative values.

Observation strategy: The observational strategy is the same adopted in the campaigns performed in 2004B and 2005B. We will use spectropolarimetric time-series to reconstruct the magnetic field of the K dwarf companion and to obtain the surface differential rotation of the star. To achieve this goal we request 15.6 h of observation that will provide $\sim$ 66 Stokes V profiles. The proposed scheme, described in the technical justification, will distribute the observations in a way to increase the coverage of the data with respect to the rotational phase of the K dwarf companion, an important feature for the image reconstruction process.

Technical justification

Observation strategy: The observational setup proposed here follows the one adopted in previous observational campaigns for the same system (performed in 2004B and 2005B). We aim to use the ESPaDoNS instrument in the circular polarization mode to observe the V471 Tau binary system ($\alpha = 03 : 50 : 24.97$, $\gamma = +17 : 14 : 47.43$). We ask for observations every other day spanning in 5 consecutive days. Given the short rotational period of $\sim$ 12.5 h, this scheme of observation maximizes the coverage of the data with respect to the rotational phase of the K dwarf companion. We highlight that the phase coverage is a key factor to achieve our scientific goals. Another possible setup is to adopt a two days interval between each observation, however this would represent an upper limit because placing the observed nights farther apart may compromise the necessary coherence between the data set.

Requested signal-to-noise ratio: We request a **SNR of** 110 **in each individual subexposure**, which results in a SNR of $\sim$220 over each polarimetric sequence. Guided by previous data acquisitions, we can then expect the SNR in the LSD profiles to reach $\sim$ 4000 after summing up all spectral lines of V471 Tau.

Requested time: Using the ESPaDoNS Exposure Time Calculator, we find that at a wavelength of 596 nm the exposure time needed to reach a SNR of 110 is 180 s for an object of magnitude 9.373 and $T_{\rm eff}$ 5066 K, under a seeing of 0.8" and airmass of 1.5. Therefore we suggest full observation sequences totaling 800 s each, including an overhead time for each subexposure of 20 s. We aim at obtaining 66 Stokes V polarimetric sequence (made of 4 individual subexposures) in this campaign. With the estimation described above, this can be achieved with **5.2 h of observation in three different nights**. We thus request a total of **15.6 h = 2 nights** of ESPaDoNS time. Using the 'Object Observability' tool of ESO (http://www.eso.org/sci/bin/skycalcw/observability), one sees that with a airmass $\leq$ 1.5 the requested amount of night hours can be achieved in 2020B **from mid October to late December**.

Students involved

Student	Level	Applicant	Supervisor	Applicant	Expected completion date	Data required
Bonnie Zaire	Doctor	Yes	Jean-Francois Donati	Yes	2021/10	Yes
Baptiste Klein	Doctor	Yes	Jean-Francois Donati	Yes	2020/12	No

Linked proposal submitted to this TAC: No

Linked proposal submitted to other TACs: No

Any other expenditure

Relevant previous Allocations: Yes

Two campaigns of observation were performed for V471Tau using the ESPaDoNS instrument. One in 2004B and another in 2005B.

Due to technical problems (COVID-9), we cannot assess the proposal ID and number of nights of previous campaigns.

No additional remarks

Observing run info :

Run: A backup strategy: Compute etime, order:38, wavelength:596, snr:110, saturation time: 8939, magv:9.373, teff:5066, airmass:1.5, seeing:0.8, omode:polarimetric, rmode:normal, etime:180