Magnetic B stars observed with BRITE: Spots, magnetospheres, binarity, and pulsations

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Magnetic B-type stars exhibit photometric variability due to diverse causes, and consequently on a variety of timescales. In this paper we describe interpretation of BRITE photometry and related ground-based observations of four magnetic B-type systems: ϵ Lupi, τ Sco, a Cen and ϵ CMa.

1 Introduction

Approximately 10% of mid- to early-B stars located on the main sequence show direct evidence of strong surface magnetism. Studying the photometric variability of such systems provides insight into their multiplicity and physical characteristics, rotation, surface and wind structures, and pulsation properties. For example, in late- and mid- B-type stars (below about spectral type B2) magnetic fields stabilise atmospheric motions and allow the accumulation of peculiar abundances (and abundance distributions) of various chemical elements. At earlier spectral types, magnetic fields channel radiatively-driven stellar winds, confining wind plasma to produce complex co-rotating magnetospheres. Some magnetic stars are located in close binary systems, where photometric variability may reveal eclipses, tidal interaction and (potentially) mass and energy transfer effects. Finally, some magnetic B stars are located in an instability strip, and exhibit β Cep and SPB-type pulsations.

The bright magnetic B stars observed by the BRITE-Constellation have been preferential targets of spectropolarimetric monitoring within the context of the BRITEpol

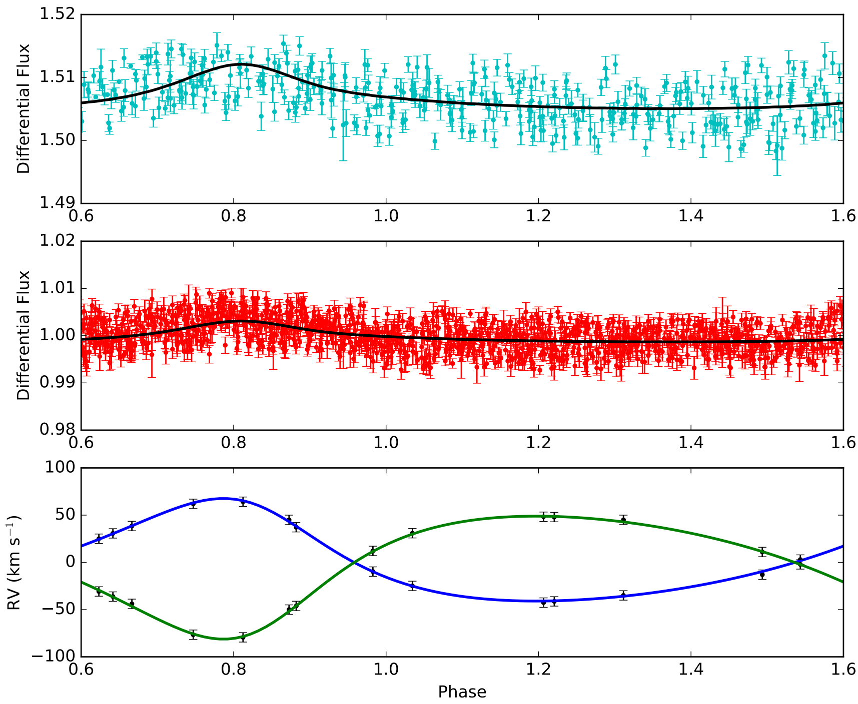

Fig. 1: Phased photometry (Upper panel – BRITE blue, middle panel – BRITE red) and radial velocities (lower panel) of ϵ Lupi, compared with the predictions of the heartbeat model (curves).

survey (see the paper by Neiner et al. in these proceedings). In this article we provide brief reports on analysis of BRITE photometry and complementary data for four magnetic B-type stars for which the BRITE observations detect or constrain variability due to these mechanisms.

2 ϵ Lupi

ϵ Lupi is a short-period ($\sim$4.6 d) eccentric binary system containing two mid/early-B stars (B3 V/B2 V, Uytterhoeven et al., 2005). It was observed by the BRITE UBr, BAb, BTr, BLb nano-satellites (see e.g. Pablo et al., 2016) during the Centaurus campaign from March to August 2014, and again by BLb during the Scorpius campaign from February to August 2015.

Magnetic fields associated with both the primary and secondary components were reported by Shultz et al. (2015), making ϵ Lupi the first known doubly-magnetic massive star binary. The (variable) proximity of the two components led Shultz et al. (2015) to speculate that their magnetospheres may undergo reconnection events during their orbit. Such events, as well as rotational modulation by surface structures and the suspected β Cep pulsations of one or both components, could introduce brightness fluctuations potentially observable by BRITE.

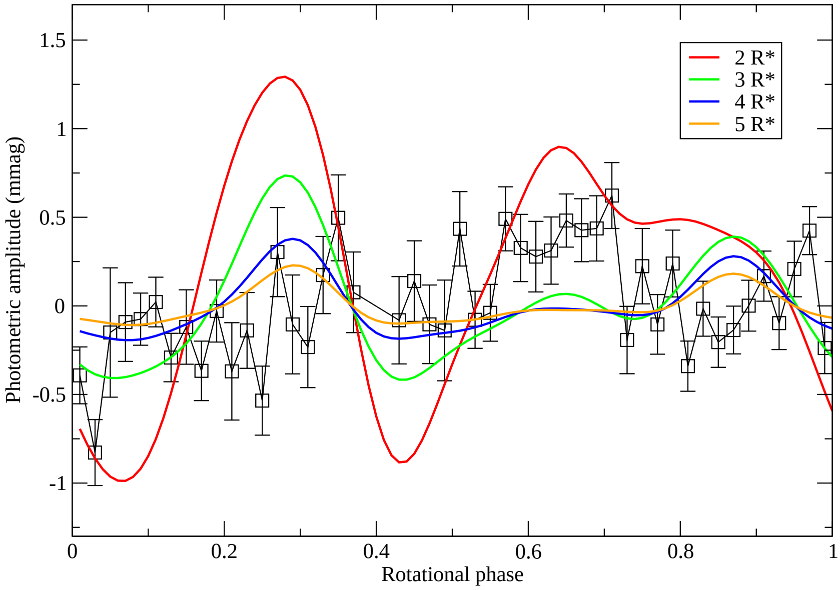

Fig. 2: BRITE red filter photometry of τ Sco, compared with the predictions of ADM models computed assuming pure scattering. The different colours correspond to source surface radii ranging from 2-5 R_{*}.

The periodogram of the BRITE photometry shows power at the known orbital period. When the data are phased accordingly, both the red (BTr+UBr) and blue (BAb) lightcurves exhibit a subtle, non-sinusoidal modulation with peak flux occurring at the same phase as the orbital RV extremum (i.e. periastron). We interpret this modulation as a "heartbeat" effect (e.g. Thompson et al., 2012), resulting from tidally-induced deformation of the stars during their close passage at periastron. Assuming this phenomenon, we have successfully modeled the lightcuves and RV variations using the PHOEBE code (version 1, Prša & Zwitter, 2005, see Fig. 1).

3 τ Sco

τ Sco is a hot main sequence B0.5 V star that was observed by BAb, UBr, BLb, and BHr during the Scorpius campaign from February August 2015. Donati et al. (2006) detected a magnetic field in the photosphere of this X-ray bright star, varying according to a rotational period of 41 d. They modeled the magnetic field topology, finding it to be remarkably complex. Ignace et al. (2010) acquired Suzaku X-ray measurements of τ Sco. They found that the very modest phase variation of the X-ray flux was at odds with the predicted variability according to the 3D force-free extrapolation of the magnetosphere reported by Donati et al. (2006).

Petit et al. (in prep.) have sought to explain this discrepancy by reconsidering the

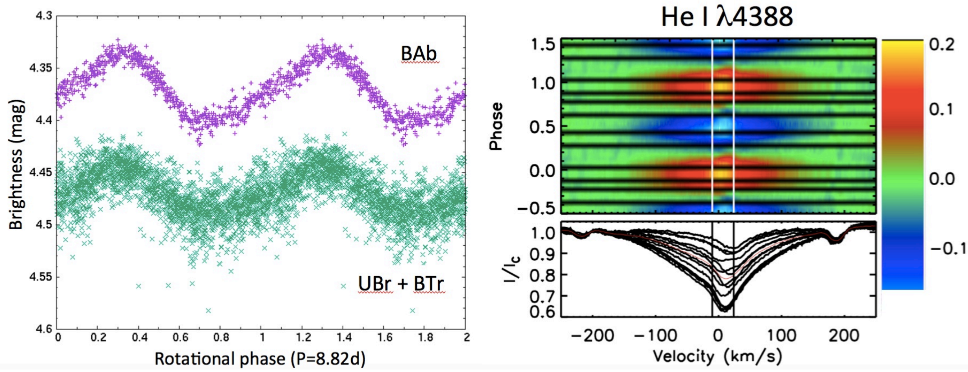

Fig. 3: *Left panel* – BRITE photometry of a Cen (upper curve – blue filter, lower curve – red filter) phased according to the stellar rotation period. *Right panel* – Dynamic spectrum of the rotational variability of the He I λ4388 line, showing the extreme changes in line strength.

physical scale of the closed magnetospheric loops of τ Sco. New modeling of system using the Analytic Dynamical Magnetosphere (ADM) formalism (Owocki et al., 2016) yields predictions of the X-ray variability as a function of the adopted mass-loss rate (as quantified by the "source surface" of the extrapolation).

These same ADM models have been used in conjunction with BRITE photometry to constrain the distribution of cooler plasma surrounding the star. Adopting a pure electron scattering approximation, we have computed the expected brightness modulation as a function of source surface distance (Fig. 2). The very high quality of the BRITE red photometry allows us to rule out models with source surface radii smaller than 3 R_*.

4 a Cen

a Cen is a Bp star of intermediate spectral type ($T_{\rm eff} \sim 19$ kK) that exhibits extreme variations of its helium lines during its 8.82 d rotational cycle. It was observed during the Centaurus campaign from March to August 2014 by UBr, BAb, BTr, and BLb.

Bohlender et al. (2010) used high resolution spectra to compute Doppler Imaging maps of the distributions of He, Fe, N and O of a Cen, revealing in particular a more than two-order-of-magnitude contrast in the abundance of He in opposite stellar hemispheres. They also discovered that the He-poor hemisphere shows a high relative concentration of ^{3}He.

The BRITE photometry of a Centauri exhibits clear variability according to the previously-known rotational period (Fig. 3, left panel). It also reveals marginal variability at frequencies that may correspond to pulsations in the SPB range. Using a collection of 19 new ESPaDOnS and HARPSpol Stokes V spectra, in addition to archival UVES spectra (e.g. Fig. 3, right panel), new self-consistent Magnetic Doppler Imaging maps have been derived of the stellar magnetic field and the abundance distributions of various elements, including Si (Fig. 4). These maps will be used as basic input for modeling the two-colour BRITE lightcurves (e.g. Krtička et al., 2009).

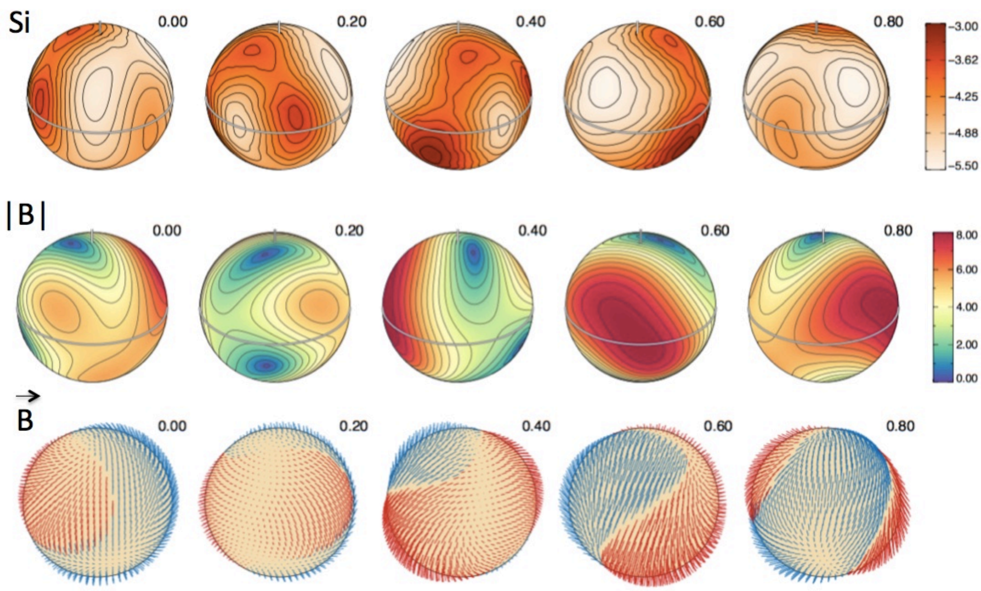

Fig. 4: Magnetic Doppler Imaging maps of a Cen, showing the surface Si distribution (upper row), and the magnetic field modulus and orientation (middle and bottom rows, respectively).

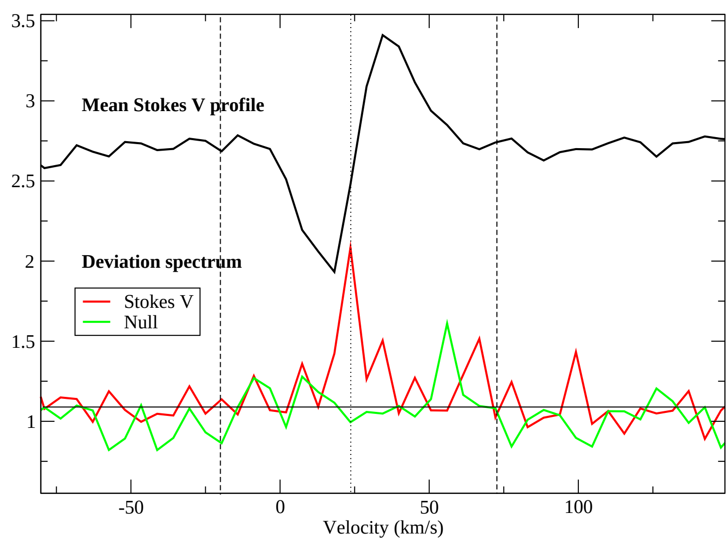

Fig. 5: Results of the variability analysis of over 120 LSD Stokes V profiles of ϵ CMa, showing the mean profile (shifted vertically for display purposes) and per-pixel deviation of both Stokes V and the diagnostic null (N) normalised to their respective uncertainties. The dashed lines show the velocity span of the V profile and its centre-of-gravity. The largest deviation of V occurs near the centre-of-gravity of the profile, and corresponds to only 2σ.

5 ϵ CMa

ϵ CMa is an evolved B1.5 II star. It was observed during the Canis Majoris-Puppis campaign from October 2015 to April 2016 by UBr, BLb, and BTr. A weak magnetic field was detected in photospheric lines of this star by Fossati et al. (2015).

A preliminary analysis of the BRITE photometry reveals no significant variability. However, we have continued to monitor the magnetic field of ϵ CMa, analysing over 120 Stokes V exposures obtained over a span of 125 d, with the aim of (i) detecting rotational modulation and determining the stellar rotational period, and (ii) modeling the surface magnetic field strength and geometry. Variability of the Stokes V profiles — as quantified by a deviation analysis (Fig. 5) — is very weak. At the level of precision of the magnetic data (best error bars of 2 G, median error bar of 4 G), no periodic variability can be inferred. Considering the reported projected rotational velocity and measured angular diameter of the star, the rotational period should be no longer than ~ 25 d. This could imply that the star is viewed close to the rotational pole, that the magnetic axis is aligned with the rotation axis, or that the global field contrast is significantly weaker than expected from a dipole.

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