The nature of short-term dips in high-precision satellite light curves of chemically peculiar stars

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Abstract The advent of extensive photometric surveys such as Kepler, CoRot, TESS, or BRITE missions has enabled us an unexpected discovery of short-term dips in the phase light curves of most magnetic chemically peculiar stars of the upper main sequence. We speculate that this characteristic type of stellar variability is caused by repeating transits of semi-transparent structures of stellar plasma trapped in the corotating magnetospheres of stars with a global magnetic field. In the light curves of such stars, we typically observe several dips with a typical depth from fractions of mmag to several mmag, the configuration of which is persistent in the scale of decades. The occurrence of photometric dips, frequency, and prominence in the light curves of rotationally modulated objects allows us to judge magnetospheres' dimensions and strength, making this analysis a universally available instrument for diagnosing stellar magnetic fields. An analysis of the dips is demonstrated using examples of several CP targets.s: 51 Psc, 53 Aur, HR 2461 and 45 Leo.

Introduction The light curves of magnetic, chemically peculiar stars typically show periodic variability due to surface spots that in most cases can be modeled by low-order harmonic expansion. However, high-precision satellite photometry reveals tiny complex features in the light curves of some of these stars that are difficult to explain as caused by a surface phenomenon under reasonable assumptions. These features might originate from light extinction in corotating magnetospheric clouds supported by a complex magnetic field dominated by higher-order multipoles see e.g. [1] [2]. For the mentioned four variable stars of the early spectral type, all available relevant data taken by the photometric satellite TESS in the highest available quality were collected to obtain detrended light curves, further to determine the type of variability and its causes, in the case of periodic variability, decide on its linear ephemeris and the parameters of their phase light curves. We analyzed 181 414 individual photometric measurements with a typical uncertainty of 0.25 mmag, taken in 8 sectors of the TESS sky survey between 2018 and 2023. We also show radial velocities of the studied systems obtained at observatory Stará Lesná (SL) and Skalnaté Pleso (SP) between 2013-2019. The detailed description of spectroscopic observations for all four systems can be found in [3].

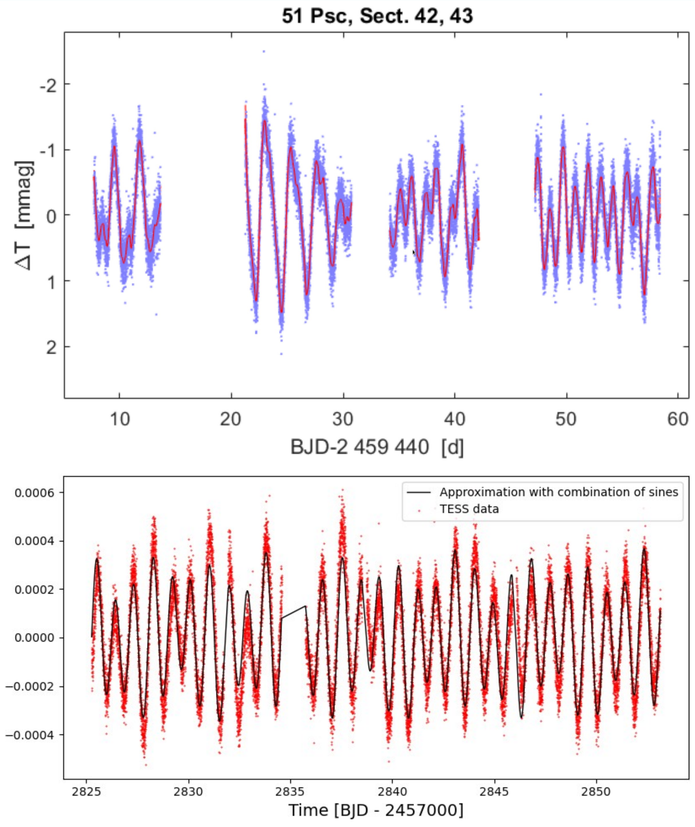

Fig. 1 Light curve of 51 Psc in neighboring sectors 42 and 43. Both the shape and the amplitude of the light curve change (*top*). Comparison with 42 Peg (*bottom*).

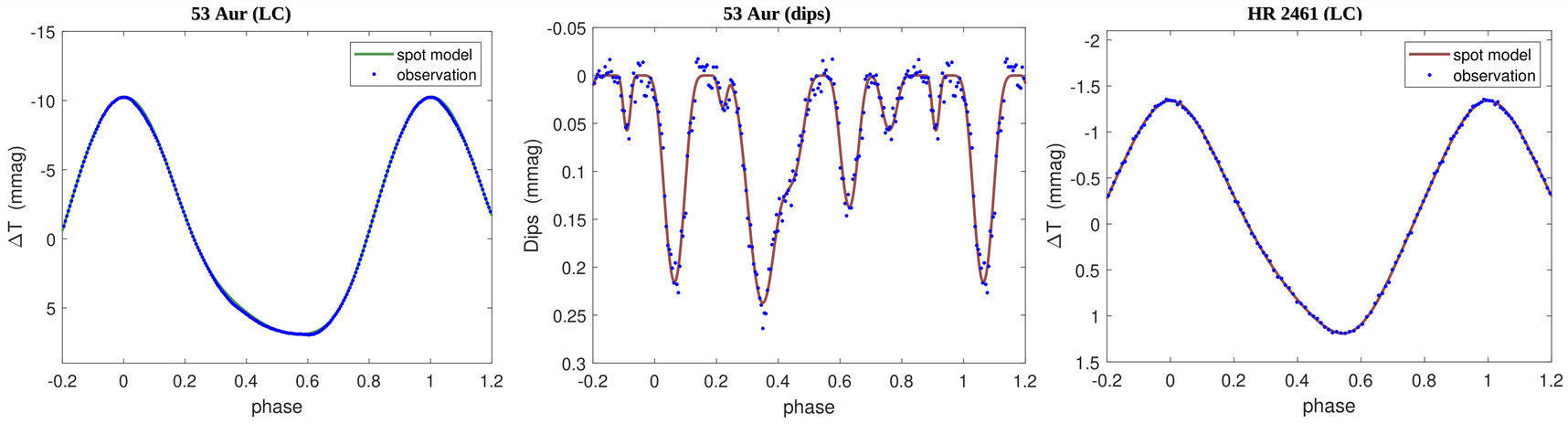

Fig. 2 The model curve of the variability of 53 Aur, caused by photometric spots, is indicated by the green line, 200 bins represent the observed light curve affected by dips (*left*), and dips in the phase curve 53 Aur (*right*).

Fig. 3 Course of light curves 51 Psc in neighboring sectors 42 and 43. Both the appearance and the amplitude of light changes change.

53 Aur (HD47152, B9Mn+F0m, V = 5.7) We have used 77,025 measurements from the sectors: 43, 44, 45, 71, and 72 with a typical accuracy of 0.22 mmag. The light changes are strictly periodic and are caused by the star's rotation with a period P = 2.711 116 2(5) d. The fundamental maximum is M_0 = 2 459 709.37424(19). The light curve is single-wave, slightly asymmetric, with an effective amplitude of 17.4 mmag. Seven narrow depressions (dips) with depths of 0.03 to 0.24 mmag have been conclusively identified in the light curve, indicating the presence of clouds of charged particles trapped in pockets of the star's extensive magnetosphere. This indirectly confirms that 53 Aur contains a magnetic field, and it is a chemically peculiar star. The starlight is attenuated by material bound in the magnetosphere by an average of 0.064(8) mmag.

HR 2461 (HD 47964, B8III, V = 5.7) We have used 31,823 measurements in sectors 6 and 33, with a typical accuracy of 0.28 mmag. The light changes are caused by the uniform rotation of the star with a period P = 4.669 13(2) d, the essential maximum is M_0 = 2 458 880.85(3). The light curve is single-wave, slightly asymmetric, with a small effective amplitude of 2.44 mmag. This can be reduced by light from a possible second component. No signs of dips were found in the curve, however, the light curve agrees with the curves of the mCP stars.

51 Psc (HD2913, B9V, V = 5.9) We have used 39,551 TESS measurements from the sectors 42, 43, and 70. The effective amplitude of light changes is only 1.73 mmag. Changes that exceed the noise several times occur on a scale of days but do not show any periodicity. The type of variability remains unclear, it is not a rotational variability, which fundamentally questions the stars' belonging to magnetic CP stars. However, if we compare LC of 51 Psc with LC of 42 Peg, we can see some similarity. The second object is slowly pulsating B star with period of oscillations ~ 23h. Therefore, the variability of 51 Psc (spectroscopy confirmed its binarity) could be interpreted as pulsations of one of the componets in the system.

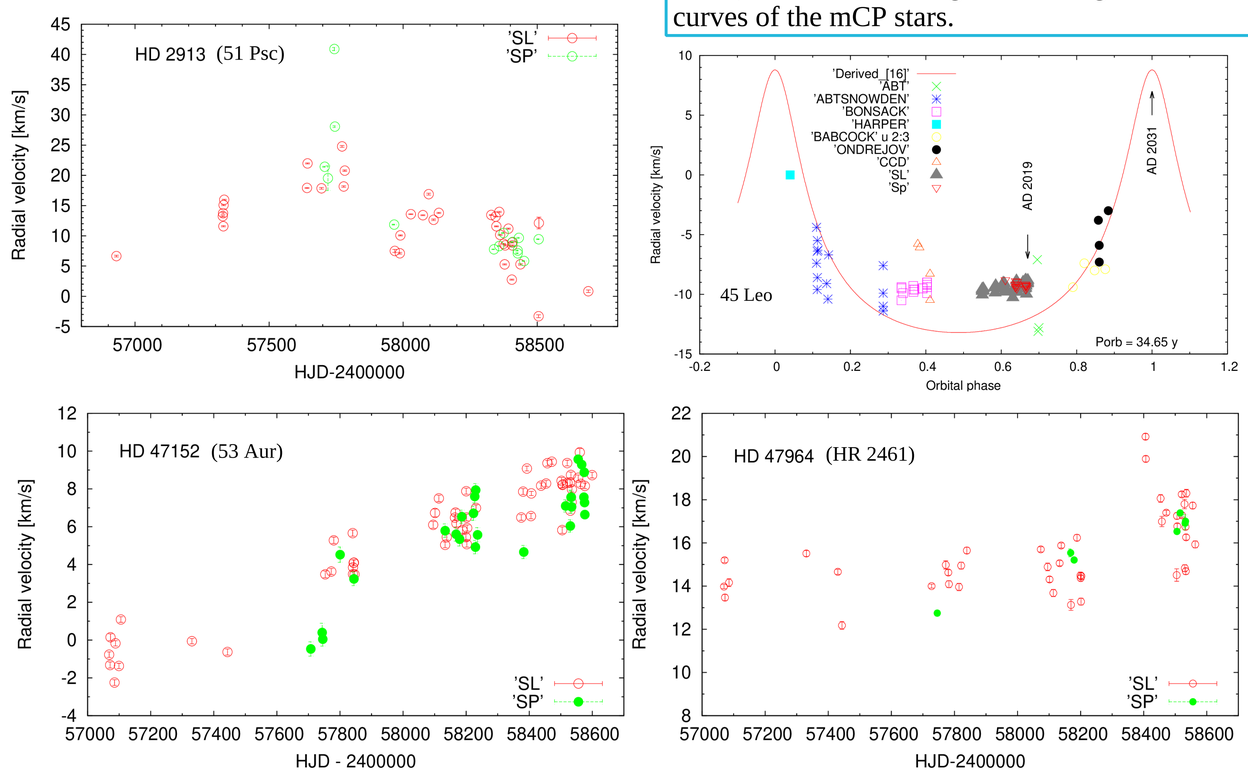

Fig. 5 The radial velocity curves of the studied systems obtained at observatory Stará Lesná (SL) and Skalnaté Pleso (SP). In the case of 45 Leo also historical RVs were added.

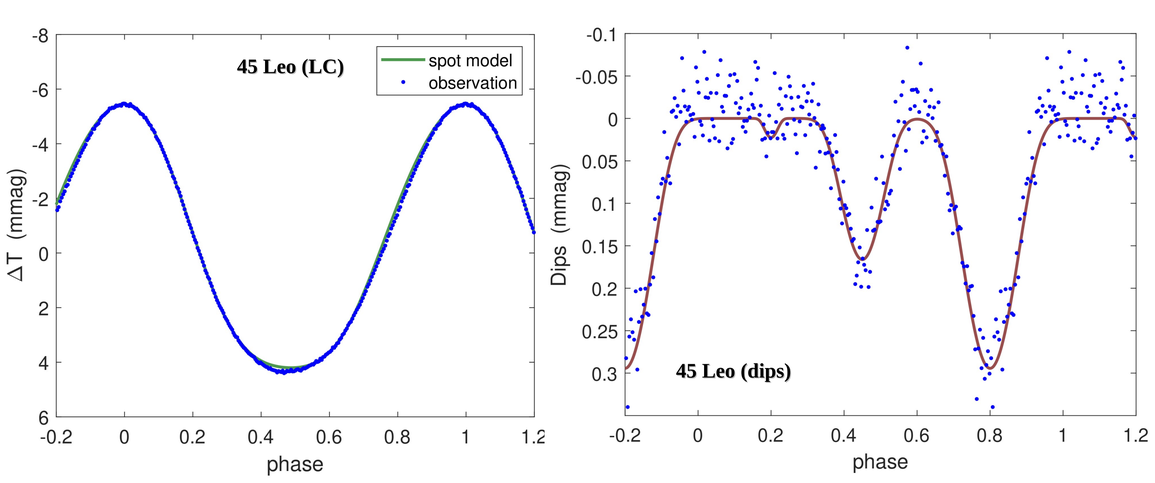

Fig. 4 Model curve of the variability of 45 Leo, caused by photometric spots, is indicated by the green line, the observed dip-wrapped light curve is represented by 200 bins (left), and dips in the phase curve 45 Leo (right).

45 Leo (HD90596, B9.5IV, V = 6.04) The 33,015 measurements from the sectors 45, 46, and 72, with a typical accuracy of 0.24 mmag were used. The light changes are strictly periodic, caused by the star's rotation with a period of 3.223 271(2) d, the fundamental maximum occurs at M_0 = 2 459 552.8003(7). The light curve is single-wave, slightly asymmetric, with an effective amplitude of 9.8 mmag. Three dips with depths of 0.02 to 0.35 mmag have been conclusively identified, indicating a presence of clouds of charged particles trapped in pockets of the star's extensive magnetosphere. This indirectly confirms that the object 45 Leo contains a magnetic, chemically peculiar star. The starlight is attenuated by material bound in the magnetosphere by an average of 0.11(6) mmag.

Conclusion We analyzed 181,414 individual photometric measurements with a typical uncertainty of 0.25 mmag. The data for all four targets were taken from the archive of the TESS sky survey between 2018 and 2023. The LCs of two stars studied here (53 Aur and 45 Leo) show narrow depressions (dips) indicating the presence of clouds of charged particles trapped in pockets of the star's extensive magnetosphere. This indirectly confirms that the objects contain magnetic field and they are CP stars. No signs of dips were found in the LCs of HR2461 and 51 Psc. The object does not seem to show variability typical for CP stars. Concerning spectroscopy, two targets were known before as very long-period binaries.: 53 Aur and 45 Leo. Our 6-year running observations represent only a fraction of their orbital periods. The RVs of 51 Psc confirm its binarity. HD 47964 (HR2461) would seem to show a constant RV have not been for the last group of observations, with a RV increase of about 3 km/s. While the internal accuracy of determination of the radial velocities is far better than 1 km/s, the rapid rotation and a relative lack of spectral lines affect their precision. More spectra are needed to confirm the binarity of the studied systems.

References

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