Open Access Online Journal on Astronomy and Astrophysics
Acta Astrophysica Taurica
www.astrophysicatauricum.org

Acta Astrophys. Tau. 3(2), 27–29 (2022)

On the temperature of starspots

I.Yu. Alekseev, R.E. Gershberg

Crimean Astrophysical Observatory, Nauchny 298409
e-mail: `ilya-alekseev@mail.ru`

Submitted on October 26, 2021

ABSTRACT

A number of models of the zonal spottedness of stars with solar-type activity show a certain correlation between starspot temperatures and temperatures of quiet photospheres.

Key words: Stars: starspots

No stellar surface inhomogeneities can be seen from Earth. The very existence of starspots and their physical parameters can be ascertained only with the help of particular indirect studies. In the first quantitative model of stellar spottedness, on the basis of the light curve of the red dwarf binary system FF And Krzeminski (1969) "gathered" all the inhomogeneities into one spot, placed it into the center of the stellar disk, and, postulating the temperature of a spot to be 350 K lower than that of the quiet photosphere, estimated its size. In the subsequent years, a number of works were carried out determining four parameters for stars with one presumable spot: starspot coordinates, their sizes, and temperatures.

Then the two-spot models were widely applied in which after subtracting from the light curve of the first spot the parameters of the second one were searched; there were also attempts to feel the third spot. But this direction proved to be dead-end. The point is that after establishing physical identity in activity of flare red dwarfs and the Sun (Gershberg, Pikel'ner, 1972) one would expect some similarity in the spottedness nature of these objects, whereas the mentioned models with the primary and secondary spots in no way could approach the pattern of solar spottedness.

The first reliable statistical characteristics of spot parameters of flare red dwarfs were obtained in the framework of the proposed and developed in Crimea zonal model of stellar spottedness (Alekseev, Gershberg, 1996a, b, c, 1997). This models suggests that – by analogy with the Sun – spots are located on stars along two bands parallel to the equator, whereas the rotation of a star with inhomogeneous distribution of spots in longitude yields the photometric effect that is identical to the effect of continuous spottedness bands with variable width. The objective is a search for four parameters of these bands: their distance to the equator, their width, the parameter of inhomogeneity in longitude and temperature. The first calculations of the zonal models resulted particularly in the fact that the spotted regions have temperatures from 4000 K for solar-type stars and 2500–3000 K for the coolest M dwarfs, whereas the differences in temperatures of the undisturbed photospheres and spots reach 2000 K for hot and 300 K for cool stars (Alekseev, 2001).

Red points in Figure 1 show the results of calculating zonal spottedness of stars with solar-type activity to this day (Alekseev, Kozhevnikova, 2017, 2018); they cover 26 objects. In figure to the left – the temperatures of spots for different photosphere temperatures, to the right – differences in the temperatures of quiet photospheres and spots for different photosphere temperatures. The red line is the nearest second-order approximation

$$T_{\rm spot} = (-8.69 \cdot 10^{-5})(T_{\rm phot})^2 + 1.252\, T_{\rm phot} - 409.2 \qquad (1)$$

constructed through the points. Their mean square deviation from the curve amounts to 280 K. When drawing the third-order curve nearest to these points the value of their mean square deviation somewhat decreased – up to 230 K, but an abrupt non-monotony of this curve makes it inappropriate to replace (1).

Regardless of the Crimean results, Berdyugina (2005) in a comprehensive survey on sunspots and starspots considered the available methods for estimating their temperatures, which along with photometry and colorimetry of the studied stars include the results of Doppler imaging, modeling of molecular bands and the ratio of spectral line depths. The author obtained a dependence of the spot temperature on the photosphere one, which was qualitatively similar to ours, for 29 stars of different spectral types and luminosity classes. In Fig. 1, the blue diamonds show her results for dwarf stars. As for AB Dor and BY Dra variables, Berdyugina provides two temperature estimates for each obtained by using the same method (Table 6 in the mentioned review), and we averaged these estimates. As a result of two different methods – Doppler imaging and analysis of molecular bands of TiO – two substantially different estimates of the temperature of spots were presented for EK Dra. Based on all these values, the blue line is drawn by means of the least square procedure

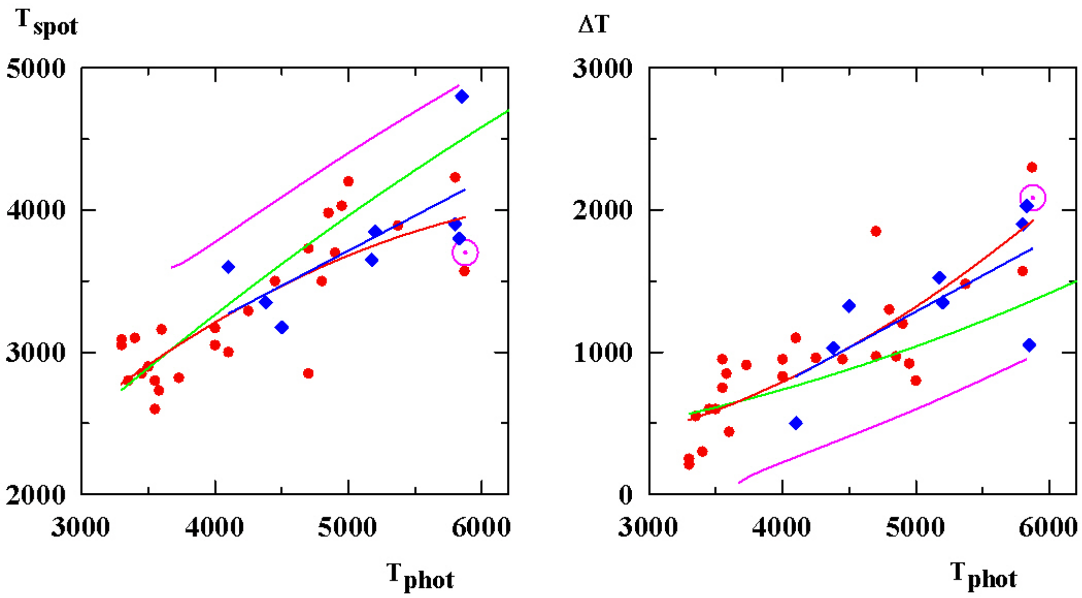

Fig. 1. Dependence of the spot temperatures on the photosphere temperatures. Red circles and the line are the calculations of Alekseev, Kozhevnikova (2017, 2018) and their square approximation (1). Blue diamonds and the line are the data of Berdyugina (2005) for dwarf stars and approximation (2). The green line denotes the approximation of Herbst et al. (2021), the pink line – calculations of Johnson et al. (2021)

$$T_{\rm spot} = 0.4926\, T_{\rm phot} + 1251. \quad (2)$$

The mean square deviation of points from the line is 340 K.

Berdyugina performed calculations using a narrower interval of photospheric temperatures than the zonal model calculations. But the red and blue lines in Fig. 1 practically coincide on the overlapping interval of these temperatures.

Herbst et al. (2021) somewhat changed the method of Berdyugina and calculated starspot temperatures for almost the same sample of stars with photosphere temperatures ranging from 3300 to 6400 K. Their results are represented by the green line in Fig. 1. This line practically coincides with our red line up to the photosphere temperatures of 4900 K, then it begins to go upward, and the divergence of about 5500 K reaches approximately 500 K. According to the estimates of Herbst et al. (2021) the corresponding width of the error band is from 470 K (M stars) to 680 K (G stars).

Johnson et al. (2021) calculated the starspot temperatures for four photospheres from M2 to G2 using the one-dimensional stellar atmosphere models with magnetic fields taken into account. Their results are shown in Fig. 1 by the pink line which is systematically higher by 400 K than all the considered lines.

Our conclusion that the photosphere temperature decisively determines the temperature of spots can be confirmed by the following circumstance. In 1974–1992, the observations of EV Lac used for constructing stellar zonal spottedness models were carried out at CrAO (Alekseev, Gershberg, 1996b). The spottedness pattern proved to be very different in various years: the maximal width of the spottedness band was in the range between 16.5 and 6.1 degrees, whereas the minimal one – between 0.00 and 0.94 of the maximal width. Nonetheless, the mean spot temperature for all epochs calculated from 19 models turned out to be practically constant: 3052 ± 33 K. We calculated these zonal spottedness models for EV Lac using the stellar temperature of 3300 K given by Pettersen (1976). For such a photosphere temperature the ratio (1) yields a spot temperature of 2776 K, which is 276 K lower than its model calculations and corresponds to the derived above mean square deviation of model calculations from the approximation (1).

In the coming century, when studying stellar spottedness the Doppler imaging has widely been applied in which on the basis of high-resolution spectral observations the spottedness regions are localized over the whole stellar surface (Strassmeier, 2009). However, it can only be applied to fairly bright stars with considerable axial rotation, whereas the purely photometric method of zonal spottedness is free from these restrictions and can arguably yield the correct statistics of stellar spottedness depending on spectral and evolutionary characteristics of the analyzed objects.

Thus, the consideration of Fig. 1 and difficulties with deriving initial data for using not Crimean methods allows us to recommend the curve (1) for the direct estimation of starspot temperatures based on effective temperatures of stellar photospheres. Consequently, the spot temperature can be excluded from the number of sought-for parameters of stellar spottedness determined by the solution to the system of nonlinear equations both in zonal models and while resolving light curves in one band or determining massively the areas of starspots in cosmic photometric surveys.

References

Alekseev I.Yu., 2001. Low-Mass Spotted Stars. Odessa: Astroprint.

Alekseev I.Yu., Gershberg R.E., 1996a. Astron. Rep., vol. 40, p. 538.
Alekseev I.Yu., Gershberg R.E., 1996b. Astron. Rep., vol. 40, p. 528.
Alekseev I.Yu., Gershberg R.E., 1996c. Astrophysics, vol. 39, p. 33.
Alekseev I.Yu., Gershberg R.E., 1997. Astron. Rep., vol. 41, p. 207.
Alekseev I.Yu., Kozhevnikova A.V., 2017. Astron. Rep., vol. 61, no. 3, p. 221–233.
Alekseev I.Yu., Kozhevnikova A.V., 2018. Astron. Rep., vol. 62, no. 6, p. 396–411.
Berdyugina S.V., 2005. Liv. Rev. Solar Phys., vol. 2, p. 8.
Gershberg R.E., Pikel'ner S.B., 1972. Comments Astrophys. Space Phys., vol. 4, p. 113.
Herbst K., Papaioannou A., Airapetian V.S., Atri D., 2021. Astrophys. J., vol. 907, p. 89.
Johnson L.J., Norris C.M., Unruh Y.C., Solanki S.K., Krivova N., et al., 2021. arXiv e-prints (arXiv:2104.11544v1).
Krzeminski W., 1969. In Kumar S.S. (Ed), Low luminosity stars. Gordon and Breach Sci. Publ., p. 7.
Pettersen B.R., 1976. Inst. Theor. Astrophys., Univ. Oslo, Rep., no. 46, pp. 1–25.
Strassmeier K.G., 2009. Astron. Astrophys. Rev., vol. 17, p. 251.