Activity and Cool Spots on the Surfaces of Stars with Planetary Systems and G-type Stars with Superflares from Kepler Observations

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Based on the photometric observations obtained with the Kepler telescope, we investigated the properties of the active regions (cold spots) on the surfaces of stars with planetary systems (exoplanets) and G type superflare stars. Three methods for determining the spottedness (S) of stellar surfaces were used. We studied the dependencies of the spottedness of the stars with exoplanets on the effective temperature and on the period of their axial rotation. In most cases the spottedness of stars with planetary systems does not exceed 5% of the area of their surface. The properties of active regions (cool spots) on the surfaces of 279 G-type stars in which more than 1500 superflares with energies of 10^{33}–10^{36} erg were analyzed. Three groups of stars with different surface spottednesses can be distinguished in a plot of superflare energy vs. cool-spot area. It is confirmed that the flare activity is not related directly to circumpolar active regions, since the majority of the points on the diagram lie to the right of the dependence for $B = 1000$ G and $i = 3°$.

1 Observational data and methods of analysis

Using the high-accuracy photometric observations obtained with the Kepler telescope, we studied the properties of the active areas (cool spots) on the surfaces of stars with planetary systems. The analysis was carried out using the data on 737 objects for which the rotation periods were estimated in [1] and reliable estimates of atmospheric parameters were available. Three methods of stellar surface spottedness estimation from the photometric observations were reviewed (the values $S1$, $S2$, and $S3$). On the example of two stars (KOI 877 and KOI 896) from the full sample of 737 stars, we compared the results of the $S1$–$S3$ estimation with the three mentioned methods. It was found that the results of the accurate calculations ($S1$) and estimations ($S2$) by the method of [2] correspond to each other, although the values of the latter are systematically higher.

It was shown that the method proposed in [3] and modified by us in [2] can be applied to a large enough sample of objects and, most importantly, it

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V. Grinin et al. (eds) Radiation mechanisms of astrophysical objects. Yerevan: Edit Print, 2017, pp. 241–244.

yields homogeneous data which can be used for statistical estimation and finding dependencies of general nature. This allowed us from the brightness variability data for 34 030 objects from [4] to find the S parameters for the analysis of the distribution of the S on the effective temperature for different objects.

For the late type stars with planetary systems, we used the data from Table 1 in [1] for 12 Quarters of observations (Q3–Q14). In the final sample we included the data on 737 objects for which in [1] the rotation periods were estimated and reliable estimates of the atmospheric parameters were available (the effective temperature and gravities) and which are not eclipsing binaries (i.e., their photometric variability is associated mainly with the cold spots). According to [1], the estimated rotation periods for the 737 stars under study are in the range of 0.9 to 62 days and the values of the photometric variability R_{var} are in the range of 0.18 to 64 mmag.

Based on our approach we used the specified technique for the analysis of activity of 279 stars in which Shibayama et al. [5] have reported 1547 superflares. For this purpose, we used the data of Table 2 from [5], which contained information both about the photometric variability of these stars and their flare activity.

2 The dependence of the spottedness on the effective temperature and rotation period

We examined the variation of the spottedness ($S2$) for the stars with planetary systems as a function of the effective temperature of these objects and the period of their axial rotation. The $S2$ value for these stars in most cases does not exceed 5% of the area of their surface. The three objects for which it exceeds 5 percent were examined in detail. We have not found any indications that the magnetic activity of a star with exoplanets has any special features that distinguish it from the activity of the stars from a wider sample from [4]. It was found that for the stars with effective temperatures smaller than 5750 K, the spottedness values decrease monotonously with the stellar rotation period decrease. The absence of stars with small S values (smaller than 0.002) was established for the stars with effective temperatures lower than 5750 K and rotation periods up to 10 days. The stars with effective temperatures higher than 5750 K have a very small spottedness for fast-rotating stars, which increases for the objects with the rotation periods of about 20–25 days.

In the case of G-type superflare stars we carried out additional analyses of diagrams plotting the energy of superflares against parameters of the stellar activity (the area of their magnetic spots) and also conducted more extensive studies of the activity of two stars with the highest numbers of superflares [5]. For this aim, we analyzed the properties of the active regions (cool spots) on the surfaces of 279 G stars displaying more than 1500 superflares with energies of 10^{33}–10^{36} erg.

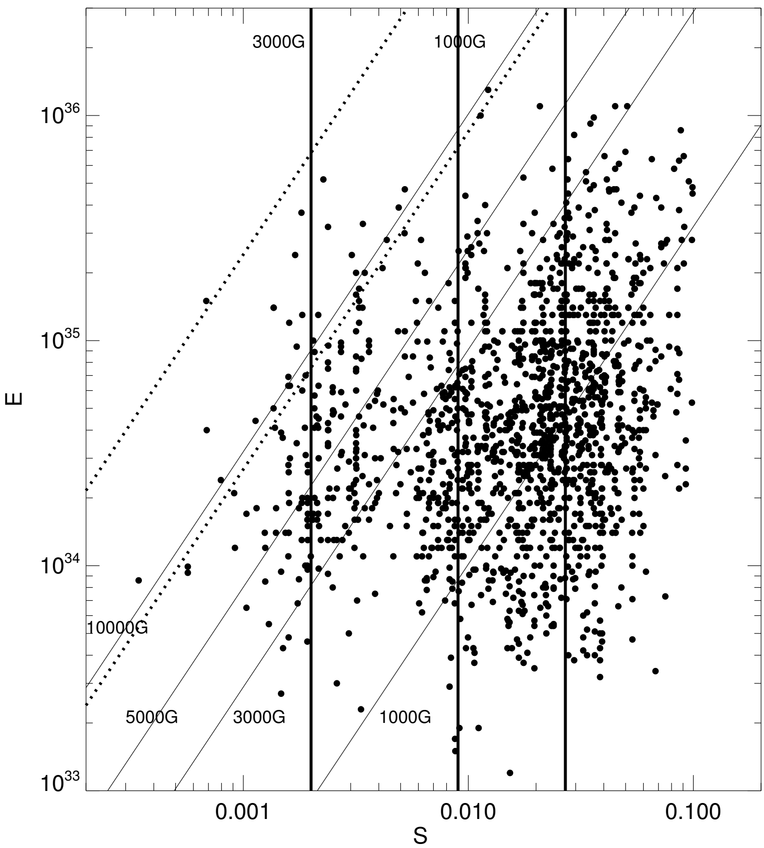

Figure 1: Comparison of the superflare energy E with the spotted area S.

We supplemented the conclusion of [5] that the maximum energy of superflares is independent of the stellar rotational periods P with the suggestion that the entire range of variations of the flare energies is independent of P. Analysis of the diagrams displaying comparisons of the superflare energy and the area occupied by cool spots (Fig. 1) suggests the possible existence of three groups of objects: stars whose spotted areas S exceed 1–1.1 % of the visible area of the star (the most numerous group), stars for which S more than 0.9 %, and stars for which S is less than 0.1 %. The majority of points on this diagram lie to the right of the dependence corresponding to $B = 3000$ G and $i = 90°$ (the first two groups of objects). Based on our new, more precise determinations of the parameter S we have confirmed the conclusion of [6] that the flare activity is not directly related to circumpolar active regions, since the vast majority of points in Fig. 1 lie to the right of the dependence for $B = 1000$ G and $i = 3°$ (the stars are essentially viewed pole-on). Our analysis of stars from a sample including objects with more than 20 superflares indicated that substantial variations in the flare energy can be achieved in the presence of only small variations in S for a single star (the range of flare energy can reach two orders of magnitude with essentially the same area occupied by magnetic spots). Only two objects in the sample displayed substantial variations in their spottedness (by factors of five to six; KIC 10422252 and KIC 11764567). Variations in the flare energy by orders of magnitude were observed for any level of spottedness.

3 Results

Using the high-accuracy photometric observations obtained with the Kepler telescope, we studied the properties of the active areas (cool spots) on the surfaces of stars with planetary systems. The analysis was carried out using the data on 737 objects. We have not found any indications that the magnetic activity of a star with exoplanets has any special features that distinguish it from the activity of the stars from a wider sample.

We also analyzed the properties of active regions (cool spots) on the surfaces of 279 G-type stars in which more than 1500 superflares with energies of 10^{33}–10^{36} erg were detected. Diagrams of superflare energy against activity parameters of the stars (the area of their magnetic spots) were considered. The range of variation of the superflare energies (up to two orders of magnitude) is realized over the entire interval of rotation periods. It is proposed that the plot of superflare energy vs. rotational period is bimodal. Three groups of stars with different surface spottednesses can be distinguished in a plot of superflare energy vs. cool-spot area. The range of variation of the flare energy within a group is roughly the same for these three groups. Most of the points on this diagram lie to the right of the dependence corresponding to $B = 3000$ G and an inclination $i = 90°$ (the first two groups of objects). It is confirmed that the flare activity is not related directly to circumpolar active regions, since the majority of the points on the diagram lie to the right of the dependence for $B = 1000$G and $i = 3°$.

Additional detailed information can be found in our publications [7, 8, 9, 10].

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