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Connection between flares and orbital position of exoplanets

A glimpse at Kepler-96 and beyond

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Abstract. The increase of satellite missions aiming to discovery and study new exoplanets, resulted not only in the increment of the amount of known exoplanets, but also the observation of superflares in solar-like stars. Using Kepler's mission photometric data we analysed 6 stars identitifying flares and obtaining orbital parameters (orbital position and orbital distance) through the light curves. We also relate the number of flares with a few stellar parameters (age, effective temperatue and stellar mass).

Resumo. O aumento de missões espaciais com o objetivo de descobrir e estudar novos exoplanetas resultou não apenas no aumento da quantidade de exoplanetas conhecidos, mas também na observação de superflares em estrelas semelhantes ao Sol. Utilizando dados fotométricos da missão Kepler analisamos 6 estrelas identificando flares e obtendo parâmetros orbitais (posição orbital e distância orbital) através das curvas de luz. Também relacionamos o número de flares com alguns parâmetros estelares (idade, temperatura efetiva e massa estelar).

Keywords. superflare – exoplanet – orbital position

1. Introduction

Understanding stellar flares and their frequency is key to the planetary habitability studies due to the sudden intensification of radiation emission across the electromagnetic spectrum - specially in certain wavelengths such as in the UV-band which is harmful to life as we know it (Estrela R. 2019).

The increase of satellite missions (e.g. Corot, Kepler and TESS) aiming to discovery and study new exoplanets, resulted not only in the increment of the amount of known exoplanets, but also the observation of superflares in solar-like stars. These intense stellar flares release energy of the order of 10^{36} ergs which is 10^{6} times more energetic than a regular solar flares (Forbes 2000).

Since, solar white-light flares are very energetic rare transient events associated with the rise in the emission of the visible part of the electromagnetic spectrum (Najita 1970), the intense stellar flares rise a lot of questions about the mechanisms that drive such energetic events in isolated solar-like stars. A possible model to explain that is the presence of a close-in planet, which may play the same role as a secondary star in a binary system (Rubenstein 2000). Tidal effects on the surface of the stars (Ferraz-Mello 2013) and the intertwined magnetic fields may generate enough stress in the magnetic field lines to trigger a magnetic reconnection releasing copious amounts of energy in a short scale of time - from minutes to hours.

Maehara (2012) investigated a small sample of data from the beginning of the operation of the Kepler mission to characterize superflares, and identify possible relationships between these superenergetic events and presence of planets. His sample showed the occurrence of 365 superflares, considering data from observations of 83 thousand stars, in a period of 120 days. However, the absence of planetary transits associated with the stars in which superenergetic events were detected then indicating that these events occurred in stars even in the absence of planets, suggesting a rare association between both.

In this work, we identify and analyze flares associated with the host stars of the most massive planets using the data available from the Kepler mission to determine the orbital position of the planet with respect to the star's line of sight - primary transit.

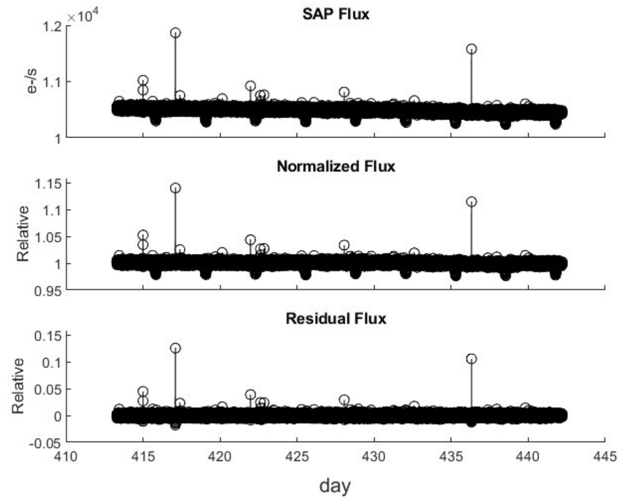

Figure 1. A Kepler-485's light curve exemplifying the steps in data processing.

2. Methodology

The FITS raw data were treated with linear interpolation as showed in the first frame of Figure 1. The flux was adjusted by subtracting the background flux and low frequency variations such as stellar rotation and telescope precession to only then be normalized as presented in the second frame of Figure 1.

The third frame of Figure 1 brings the residual flux obtained by extracting the mean flux from the normalized one. All of our analysis is based upon the detection of abrupt variations in the light curve's residual flux which generate the points of interest flagged to be manually analysed and classified as flares if they

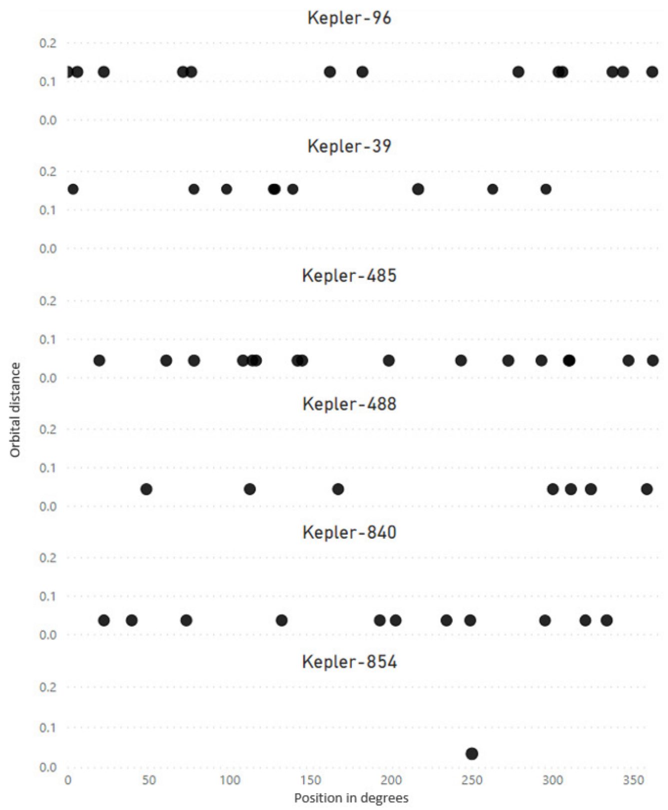

Figure 2. Multiple scatter plot for the isolated planetary systems analysed.

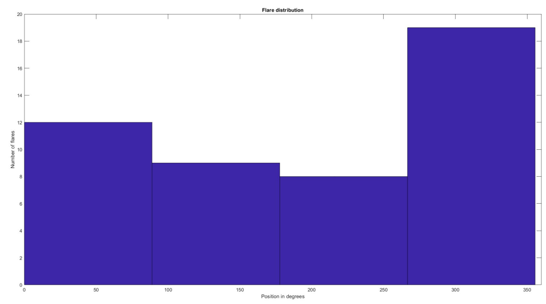

Figure 3. Histogram dividing the position of the flares into quadrants.

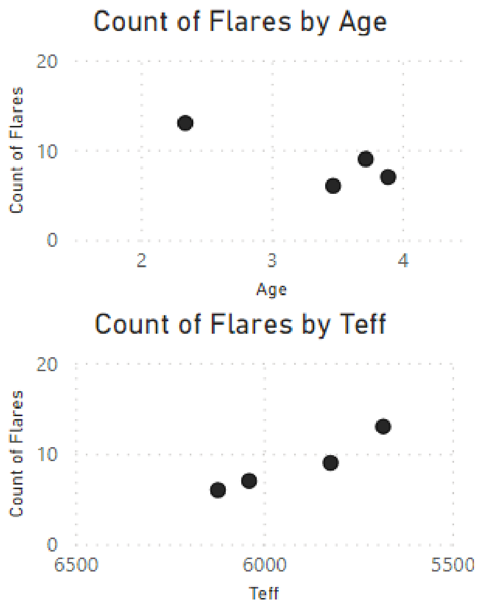

Figure 4. Number of flares by age and effective temperatute, respectively.

are multiple consecutive points, cosmic rays or instrument's artifacts if they are single points.

The Kepler-96 is known for having several flares and therefore it was used to validate our models and constrain free parameters.

The orbital distances were obtained through Kepler's third law (equation 1) relating the planet's orbital period - T, and the stellar mass - m_s.

$$a = \sqrt[3]{\frac{G m_s T^2}{4\pi^2}} \qquad (1)$$

3. Analysis

The light curves of the 6 stars considered simple-isolated-planetary-systems with the most massive exoplanets were analyzed. The position of the exoplanet around the star in the moment of the flare with respect to the observer's line of sight is presented in Figure 2 for which the planet is in front of the star at 0° or 360° and behind the star at 180°.

Kepler-96 had 85% of its events while the planet was facing the observer and only 15% of the observed flares occured when the star was in between the planet and the observer. Kepler-488 and Kepler-840 had 71% and 55% of their flares when the planet was facing the observer, respectively.

The distribution of approximately 60% of all the flares taking place while the planets were in the line of the sight of the observer in Figure 3 might suggest that the exoplanet can influence somehow such energetic events, nonetheless this sample needs to be enriched with more stars to gain statistical relevance.

We identified 120 events in the data available from the Kepler mission for these stars, for white-light flares lasting just a few minutes, it seems difficult to find evidence of significant variations in long cadence light curves, as a result only 17% of the flares come from long cadence light curves. This number would be even lower if not for the lack of short cadence light curves in the dataset, from the total of 302 FITS only 130 were of short cadence.

Having said that, white-light flares are more efficiently detected in short cadence light curves being responsible for 83% of the observed events.

Ploting the number of flares in Figure 4 against its age and effective temperature we found that:

I) The number of flares diminishes with the aging of the star;

II) The number of flares rises with cooler effective temperature;

These statistical behavior has already been presented by Shibayama (2013).

On the other hand, the first graphic in Figure 5 is controversial, the number of flares seems to increase with the orbital distance. It is worth to note that, a lack of short cadence data may have contributed to such effect. Besides that, cyclic effects may dominate over orbital distance contributions in the time scale of the Kepler mission. More data points could corroborate this statistical behavior.

The second graphic in Figure 5 indicates that the number of flares falls with increasing stellar mass which also corrobo-

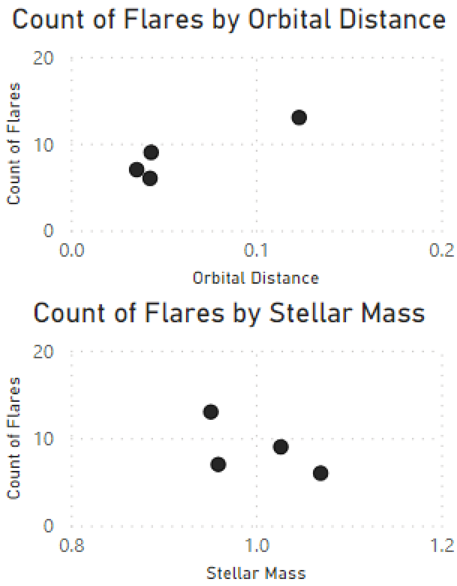

FIGURE 5. Number of flares by orbital distance and stellar mass, respectively.

rate with the statistical behavior identified by Shibayama (2013) when analysing superflares on solar-type stars.

4. Conclusion

The study of flares in white-light using photometry proved to be more effective at short cadence, due to the lack of sensitivity of light curves at long cadence - less than 17%, to record rapid variations in the star's brightness, with the duration of just a few minutes.

Our methodology corroborate with the statistical behavior observed by Shibayama (2013) in superflares on solar-type stars for parameter such as stellar age, effective temperature and stellar mass. Raising a controversial question about the influence which the exoplanet exerts on the star and its energetic transient phenomena. Is the orbital parameters of the exoplanet really connected to such events?

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