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Acknowledgements
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The Magnetic Activity of Low-Mass Stars

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ABSTRACT The purpose of this research project is to study magnetically active low-mass stars using data obtained with the Kepler Space Telescope. A sample of low-mass stars was identified in the Kepler Objects of Interest (KOI) database by selecting stars with a temperature below 3,700 K. Data were obtained from the Mikulski Archive for Space Telescopes and analyzed using the MATLAB software. Light curves showing the stellar flux vs time were generated for approximately 20 stars, and features showing stellar flares, star spots and planetary transits were identified. We found a weak relationship between magnetic activity and stellar diameter.

INTRODUCTION

The main purpose of this project is to study magnetic activity of low-mass stars using publically available data from the Kepler Mission obtained the Mikulski Archive for Space Telescopes. Studying magnetic activity through star spots, faculae and flares can help us better understand the astrophysics of low-mass stars. In particular, it can provide a better understanding of how these unique types of stars form and evolve, as well as provide insights into their internal structure, especially the dynamo model (Wright et al., 2011).

In addition, the periodic variations due to magnetic activity can be major sources of noise in the search for small exoplanets, making it more difficult to identify planetary orbits. We used star spots, faculae and flares as tracers of magnetic activity. Star spots or sunspots are regions where the magnetic field is higher than surrounding regions; this causes the regions to appear less bright (Carroll & Ostlie, 2007). Faculae are bright regions that are also associated with magnetic fields. Solar flares are characterized as regions that rapidly release magnetic energy; which causes the light intensities to increase rapidly. All three of these phenomena have been studied on our own star, the sun, and are well understood (see Figure 1) (Ryden & Peterson, 2010). While the primary purpose of the Kepler mission is to identify extrasolar planets, these data are also ideal for studying brightness variations such as

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those caused by star spots, faculae and flares, all indicators of magnetic activity. An example of a change in flux can be seen in Figure 2, where a transit planet is blocking some of the light emanating from the star. What makes this data particularly useful for our project are the long exposure times and high photometric accuracy. The main tools used in the project were MATLAB generated light curves taken from the Mikulski Archive for Space Telescopes. Light curves are graphs of the light intensities or fluxes of stars as a function of time, where the flux is energy per second. All three of the magnetic phenomena we study can be identified in light curves: star flares and faculae cause increases in flux, while star spots cause decreases in flux. (Solar Cycle Progression, 2019)

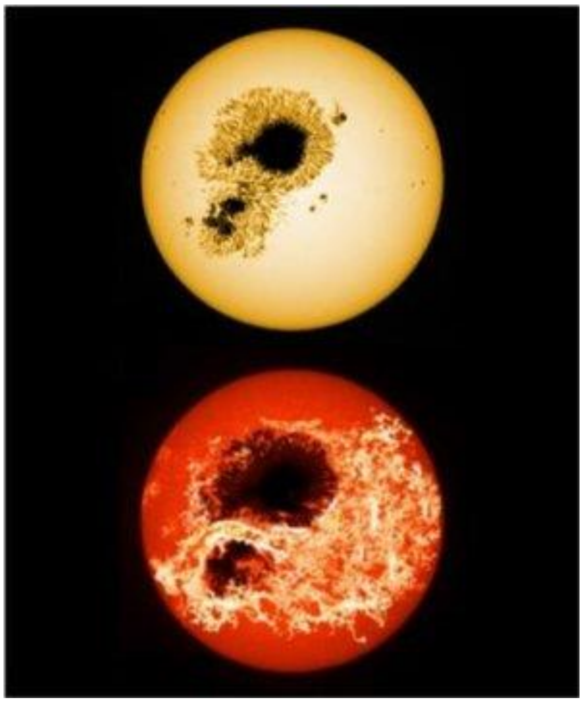

Figure 1. This image is an artist's conception of a so-called superflare star in visible light (top) and in a Ca II line (bottom). The magnetic field within a star spot keeps the temperature lower than its surroundings, thus reducing the flux. Image Credit: Maehara et al., 2017.

METHODS

Data from the Kepler Telescope were collected from the Mikulski Archive for Space Telescopes. The NASA Exoplanet Archive was used to collect information on specific objects (Space Telescope Science Institute, 2019). Graphs were generated with MATLAB. The NASA

Exoplanet Archive at the California Institute of Technology was used to look for specific features of target objects. Relevant data for target objects were catalogued and used through MATLAB to generate graphs to study features of the light curves of target objects. Our study focused on stars with temperatures below 3,700 K.

Star spots seen from a light curve are expected to reduce the flux by about 1% over a short period of time. Flares produce spikes or increases of the light intensity by up to 4.5%. We selected a pool of KOIs (Kepler objects of interest), using the downloadable FITS (Flexible Image Transport System) data from the Kepler archive. Then we found the average flux for a given period, and used this average to look for strong peaks and deep troughs.

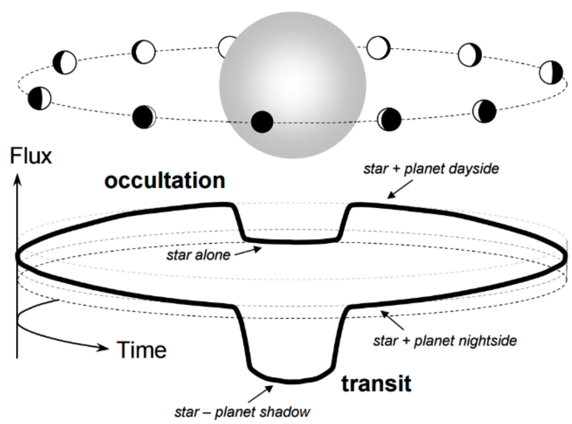

Figure 2. The image above is a visual representation of what happens when a planetary orbit is seen edge-on, and the planet moves in front of and behind the star during parts of its orbit. The line below the sphere is the light curve of the star. The dip labeled *star-planet shadow* is a consequence of the transiting planet blocking the star's light. The dip labeled *star alone* is due to the star blocking the reflected light from the planet. Star spots cause similar decreases in the flux, allowing us to identify them as Kepler light curves. Image Credit: Ofir, 2016.

RESULTS

Figure 3 depicts a typical example of a KOI. This object has been selected for study because its temperature falls below the maximum temperature of stars in our sample (3,700 K) and was flagged in the NASA Exoplanet Archive to contain a confirmed exoplanet.

The large drops in flux seen in Figure 3 are due to magnetically active star spots. The peaks in intensity are understood to be flares on the disk of the star facing the telescope. The graph shows deep troughs alongside troughs that are not as large. These smaller troughs are due to small areas on the surface of the star that give off less light that the surrounding area.

This is what makes the exoplanet so essential to the study; it serves as a configuring tool. A particular characteristic of this figure is the single large peak that seems to insinuate that there was a star flare or a plage, both of which are magnetic phenomena. Figure 4 shows a similar phenomenon on the surface of the star KOI 8351704.

KOI 8351704, shown in Figure 4, much like KOI 6435936, is a typical star in the KOI sample. But note that the scale of the vertical axis has changed to indicate that KOI 6435936 has higher flux peaks than KOI 8351704. This becomes interesting when considering the relative sizes; the larger the star, the larger the relative flare peaks.

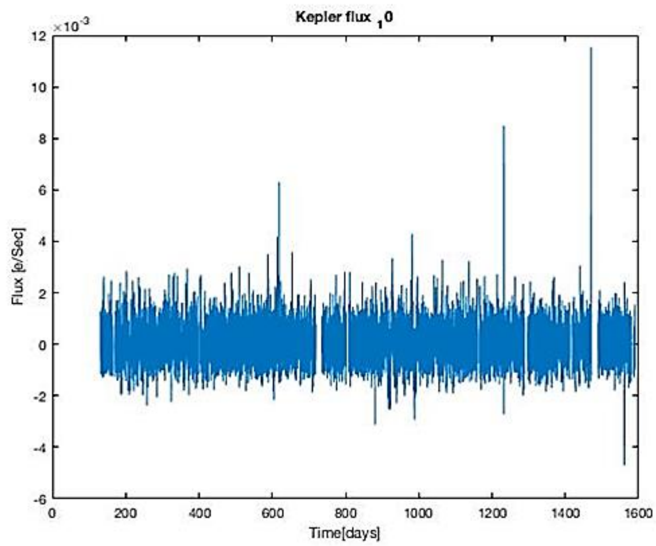

Figure 3. The light curve of KOI 6435936, which has a flare count of 11 and star spot count of 24. It has an effective stellar temperature of 3,593 K. This object is 49 % of the size of our sun

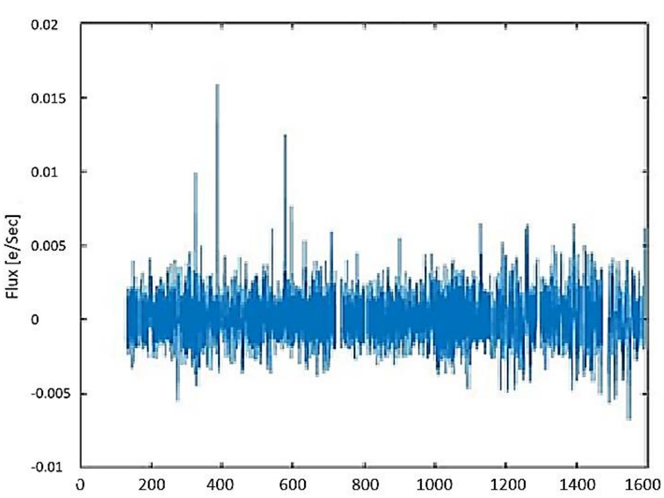

Figure 4. The light curve of KOI 8351704. It has a flare count of 6 and star spot count of 8. It has an effective stellar temperature of 3,568 K. This object was 39 % of the size of our sun.

KOI 5648449, shown in Figure 5, was chosen because of its unique (low) temperature for a star of its size. This did not change the fact that the flare and star spot count was within the range of the other stars in the KOI pool. It was flagged as "false positive" in the KOI database because this star is likely to be part of an eclipsing binary star system. An eclipsing binary star system is a grouping of stars that orbit each other around their center of mass (Martín, Cabrera, Martioli, Solano, & Tata, 2013). Although it was cool for its size, it demonstrated strong magnetic behavior during observation.

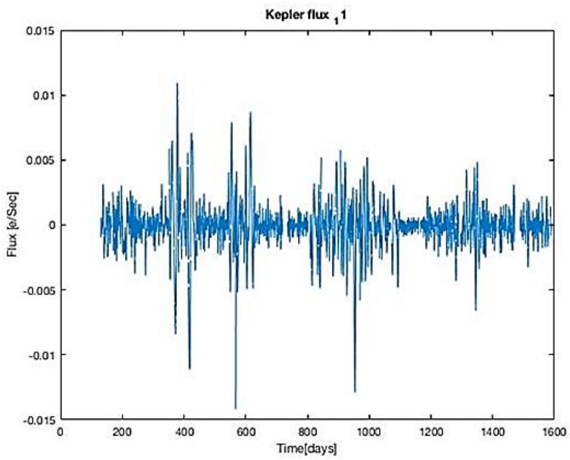

Figure 5. The light curve of KOI 5648449, which has a false positive flag of the stellar eclipse type. This object holds a flare count of 6 and star spot count of 8. It has a stellar temperature of (3,598 K). This object is 101 times the size of our sun, showing that this was not a low-mass star but a larger star that had cooled significantly, so its temperature is much lower than expected for its size. This indicates some cooling due to star spots.

Figure 6 shows KOI 10002261, which is interesting because of its small size and very low temperature. This object has not yet been confirmed to contain an exoplanet, so it is considered an exoplanet candidate. It has one of the two lowest flare counts recorded in our sample. It was also flagged as "false positive" in the KOI database because this star is likely to be part of an eclipsing binary star system. The eclipse of the binary can be demonstrated by long periodical drops in flux seen Figure 6. The reason this KOI is included in this pool is that its lightcurve has a large number of troughs. This suggest that these troughs are caused by star spots. However the transit candidacy means that there could be other phenomena that cause this behavior in the light curve. KOI 10002261 is the only star in our sample that behaves in this manner.

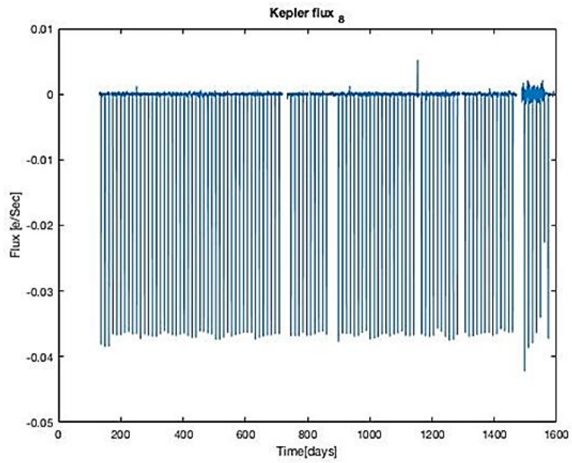

Figure 6. The light curve of KOI 10002261, which has a flare count of 1 and star spot count of 5. It has an effective stellar temperature of 2,661K. This star also has a false positive flag of the stellar eclipse type. This object is about 10 % of the size of our sun.

DISCUSSION

Our research shows that there is a weak relation between magnetic activity and stellar diameter. On average, stars with larger diameters have a slightly higher flare frequency. The three stars with the highest flare frequency in our sample have an average flare count of 23 over an approximate 4 year span (4.3 yrs) for this data set, while on average the flare count of the sun is larger (213x) from 2014 to 2017 (Space weather live). It seems the magnetic activity for low-mass stars are on average lower, compared to the magnetic activity of stars of larger mass and diameter.

The next step in our research will be to expand the data set we have already analyzed, while keeping the temperature range the same (below 3,700 K). This will allow us to further establish the relationship between stellar size and magnetic activity in a more precise manner.

ACKNOWLEDGEMENTS

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