KEPLER SPACE TELESCOPE MEASUREMENT OF VARIABILITY IN 623 NEARBY LOW MASS STARS: ROTATION AND FLARES

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ABSTRACT: We analyzed light-curves of low-mass stars collected by the Kepler Mission. The light curves show the brightness of the stars over a course of four Kepler cycles (12 months). We hypothesize that low-mass stars that have higher rotation rates and show more variability should be more active (i.e. exhibit more flares) than stars that are flat and rotate slowly. Our objectives were to find trends such as flares and rotation by analyzing the light curve diagrams of these M-dwarfs. To manipulate and format our data we used codes written in C, and to graph it we used the program Supermongo (sm). From our analysis, we found that stars that are variable and have short, periodic rotations also show flares. The flares mainly appear at random.

(A) INTRODUCTION: All the stars observed in this research are red dwarfs (classified with the letter "M" on the standard classification scale, so that they are sometimes called "M dwarfs"). A red dwarf is a small and relatively cool star on the "main sequence," which means that it is burning hydrogen into helium. Red dwarfs are the most common type of star in the Milky Way Galaxy (70%). Stellar models indicate that red dwarfs with less than 35% of the Sun's mass are fully convective. Hence, the helium produced by the thermonuclear fusion of hydrogen is constantly remixed throughout the star. Because of this convection, red dwarfs build strong magnetic dynamos that give rise to chromospheric and coronal heating, which can be detected in X-rays and the radio. The stong magnetic loops also create dark spots on the surface of the star, which are cooler areas that form on the stellar surface as a result of the magnetics fields flowing through the surface. This make the star very variable, because these dark patches cause the luminosity of the star to dip, so that when it rotates, the star grows dimmer and brighter due to the movement of the spots across its surface.

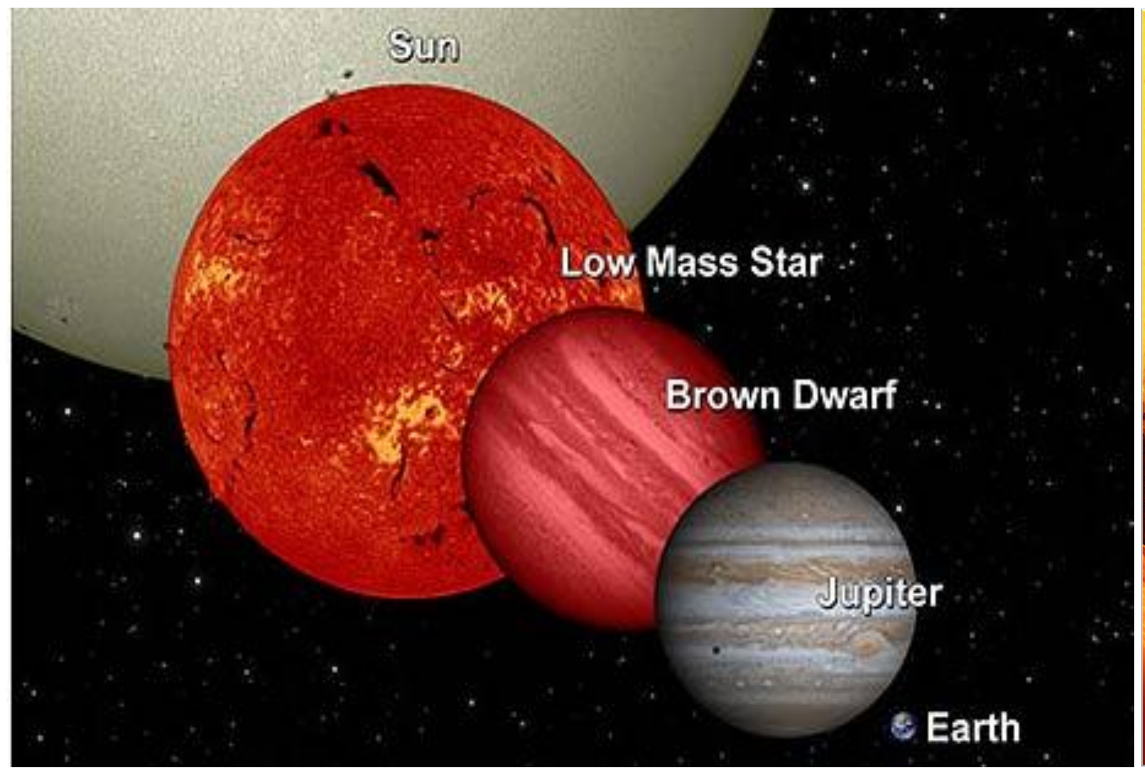


Image 1: A comparison of a Low Mass Star (or red dwarf) to other celestial bodies – Sun, Brown Dwarf, Jupiter, and Earth.

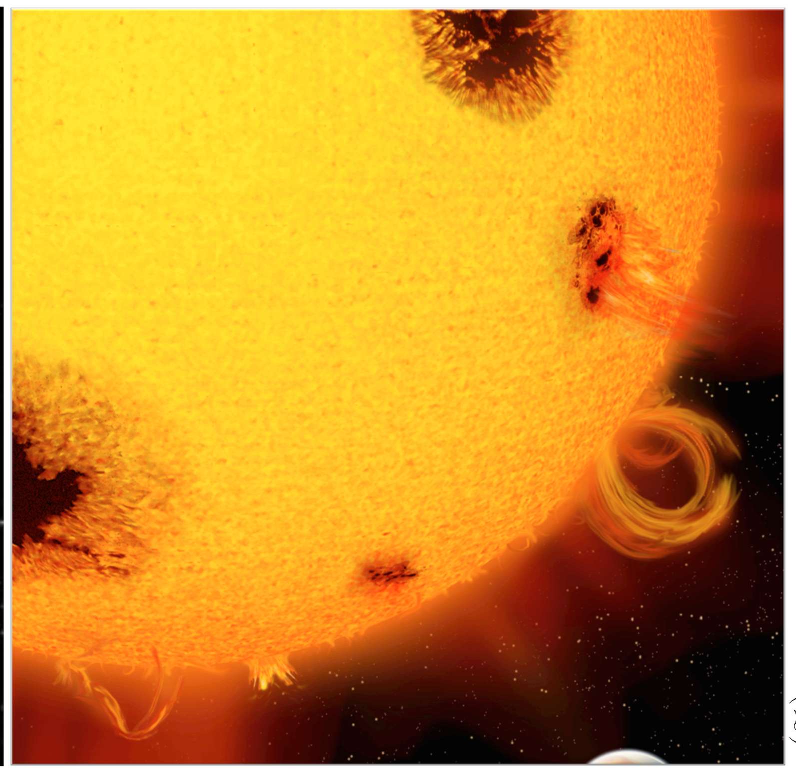
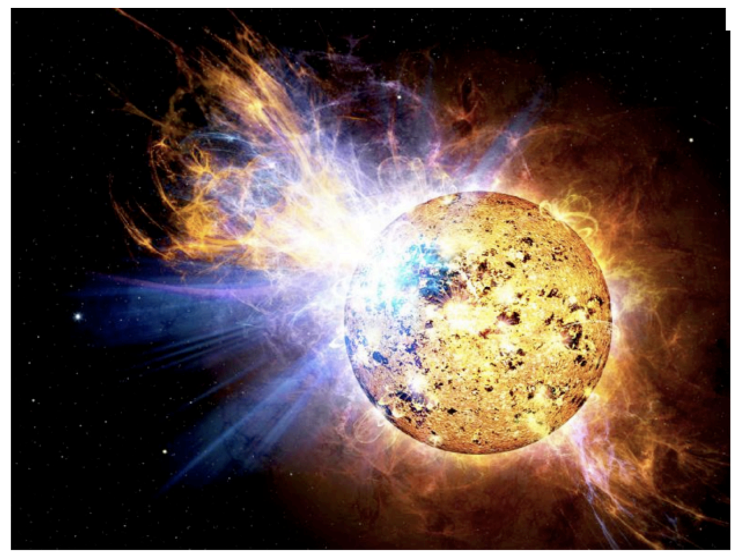


Image 2: Artist rendition of large spots and magnetic loops on the surface of a red dwarf.

(B) SOURCE OF OUR DATA: The Kepler Mission utilizes a telescope whose only instrument is a large digital camera, composed of 42 CCDs (charge coupled devices). The Kepler Mission continually monitors the brightness of over 145,000 main sequence stars in a fixed field of view (115 square degrees, around 0.28 % of the sky). We procured data from the Kepler Mission Data Archive, focusing on subset of 623 stars known to be red dwarfs. While the Kepler Mission was designed to identify planets by indicating when a portion of a light curve drops below the average due to a planet's movement across its star, the telescope can also detect spots on the surface of a star and also flares. A flare would show up as an sharp, brief increase in luminosity, instead of a drop as in planet eclipses.. Our data cames from stars observed from Kepler "Quarter Six" to "Quarter Nine", covering a period of one year.

Left: The Kepler Space Telescope

Right: artist depiction of a bright flare occuring on the syrface of a red dwarf.



(D) MEASURING THE ROTATION PERIODS: As a star rotates, star spots on its surface will face earth at times and face away from earth at other times. While a star spot is facing earth, the star emits slightly less light because star spots are darker than the rest of the star. The amplitude of light detected from a rotating star will fluctuate with each rotation. By measuring the length of this fluctuation we can determine the time it takes the star to complete a full rotation, or in other words, the rotation period of the star.

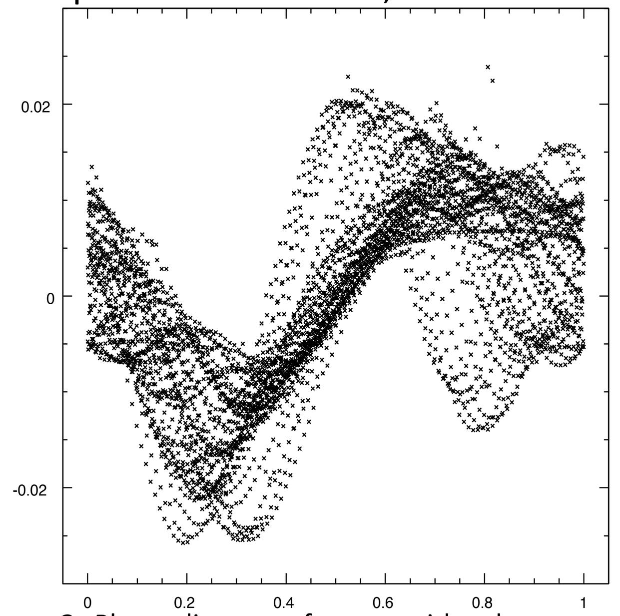


Figure 3: Phase diagram of a star with a long rotation period. The star spots are changing so quickly that by the end of the quarter its behavior is completely different than it was at the beginning. The spots have moved on the surface, or they have changed.

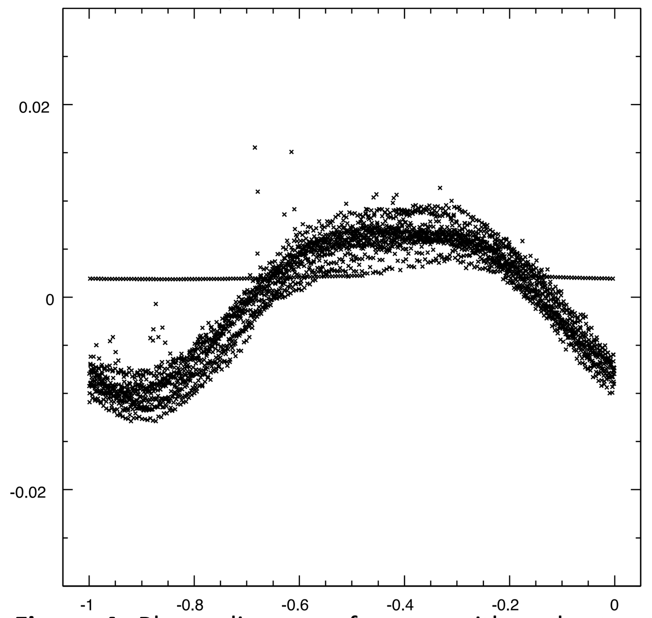


Figure 4: Phase diagram of a star with a short rotation period of 3.9 days. Its star spots are not very variable as its behavior stays constant throughout the quarter. This means that the same spots remain for a long time at the same place on the surface.

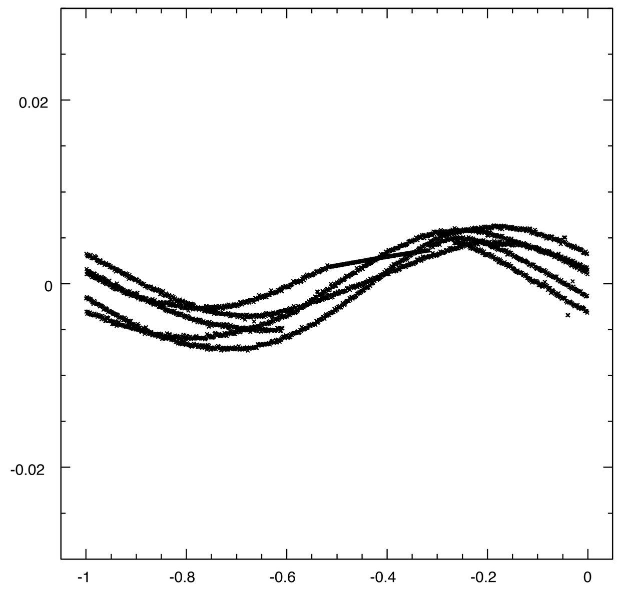


Figure 5: Phase diagram of a star with a very short rotation period. The star's behavior is very similar every rotation so the graph is very compact.

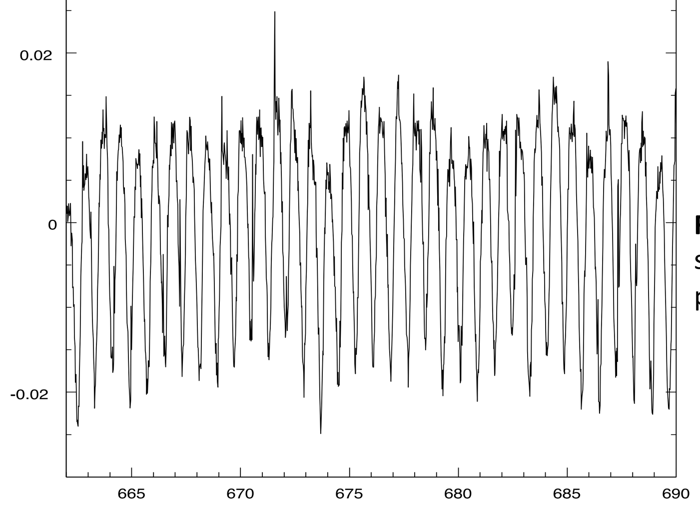


Figure 6: A light curve of a star with a very short rotation period of 0.79 days.

STAR NAME	ROTATION PERIOD (DAYS)	STAR NAME	ROTATION PERIOD (DAYS)
Kplr006225816	2.2	kplr010002261	12.7
kplr008408875	3.9	kplr010068482	32.4
kplr008451881	43.1	kplr010322366	30.3
kplr008607728	24.1	kplr010515478	13.7
kplr008894567	23.3	kplr010841864	28.8
kplr008957023	45.5	kplr010961247	23.5
kplr009201463	5.3	kplr011352859	24.3
kplr009284206	42.3	kplr011714250	41.3
kplr009834655	14.2	kplr011860280	14.1
		kplr012555642	35.3

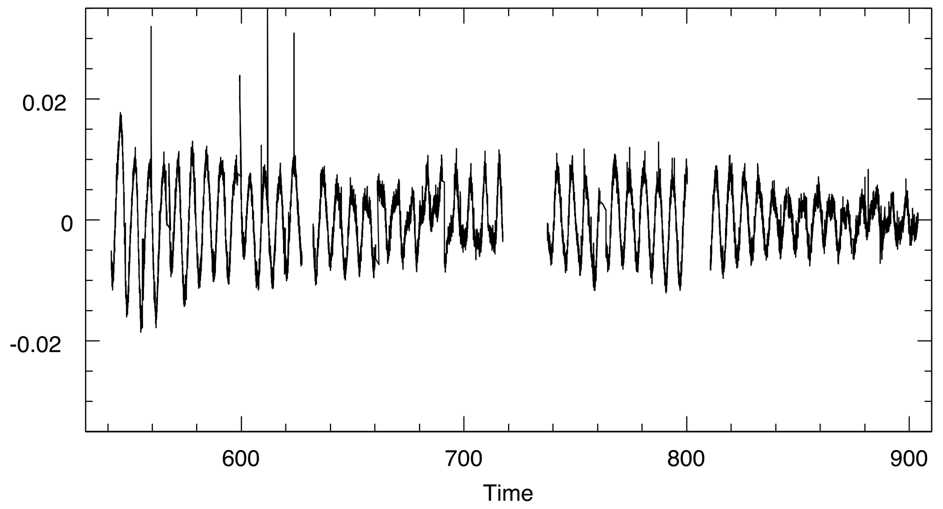


Figure 7: This light curve of a M-star showed much rotation, in addition to a few large flares in the early quarters, and more smaller flares in the later quarters. Time is in days.

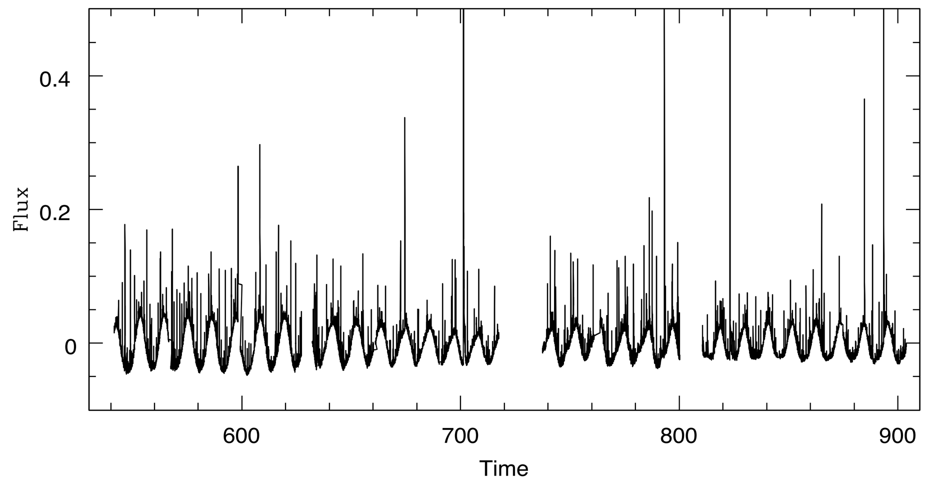


Figure 8: This light curve shows a star with periodic rotation and very strong flares occurring in a regular, almost predictable pattern. Time is in days.

(C) FINDING WHICH STARS ARE TRULY VARIABLE: Variability is caused by starspots, which are cooler areas that form on the stellar surface as a result of the magnetics within the star. These patches cause the luminosity of the star to dip so that when it rotates, the star grows dimmer and brighter due to the movement of the spots on its surface. But a star can look variable just because the data is bad or noisy.

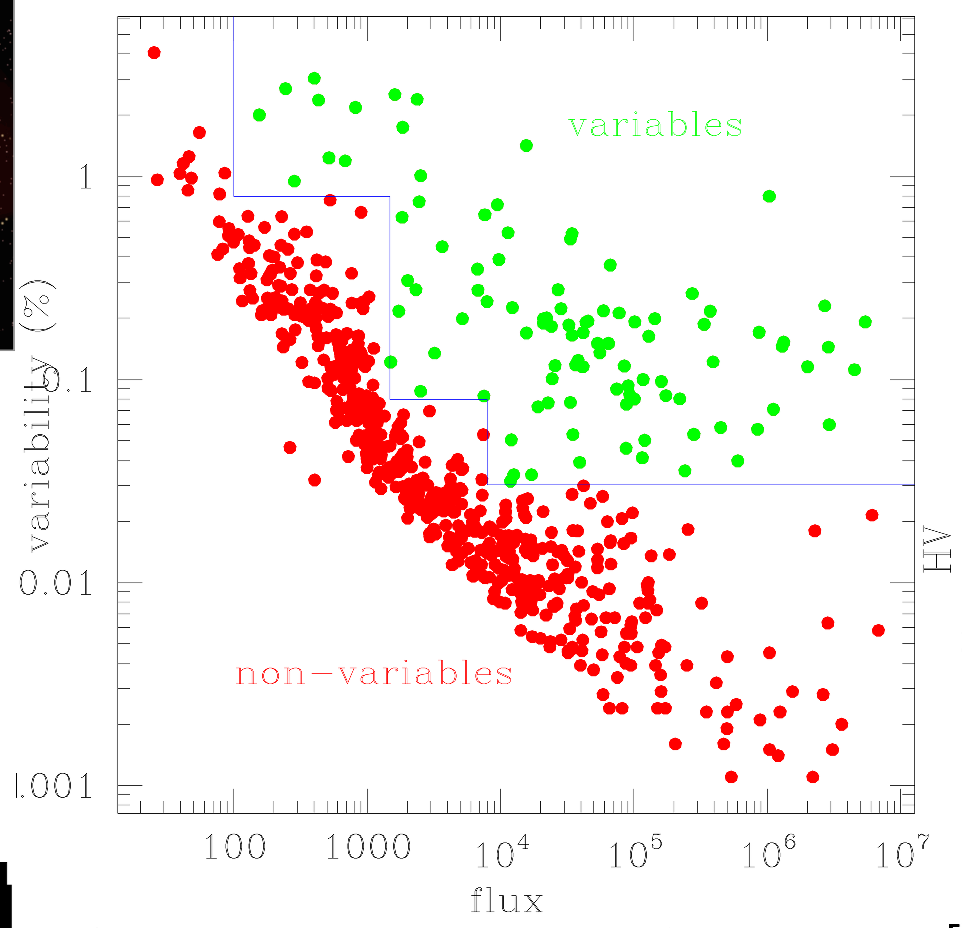


Figure 1: The plot above shows how we identify the stars that are intrinsically variable. For each star, we calculate the mean flux and how much the flux at any given time deviates from this mean flux, on average (the Sigma). We estimate how variable each star is by calculating the ratio between the Sigma and the mean. Next we plot the value of the log of the mean on the x-axis of the graph, against the log of the variability (Sigma) on the y-axis. We find that the non-variable stars, whose "variability" is really just due to the noise in the data, fall into one grouping (low Sigma) while the true variables are scattered above this group (high Sigma). To pick out the variable stars, we define a boundary (the blue line) that selects stars that fall above a certain percent variability for a given value of the mean flux.

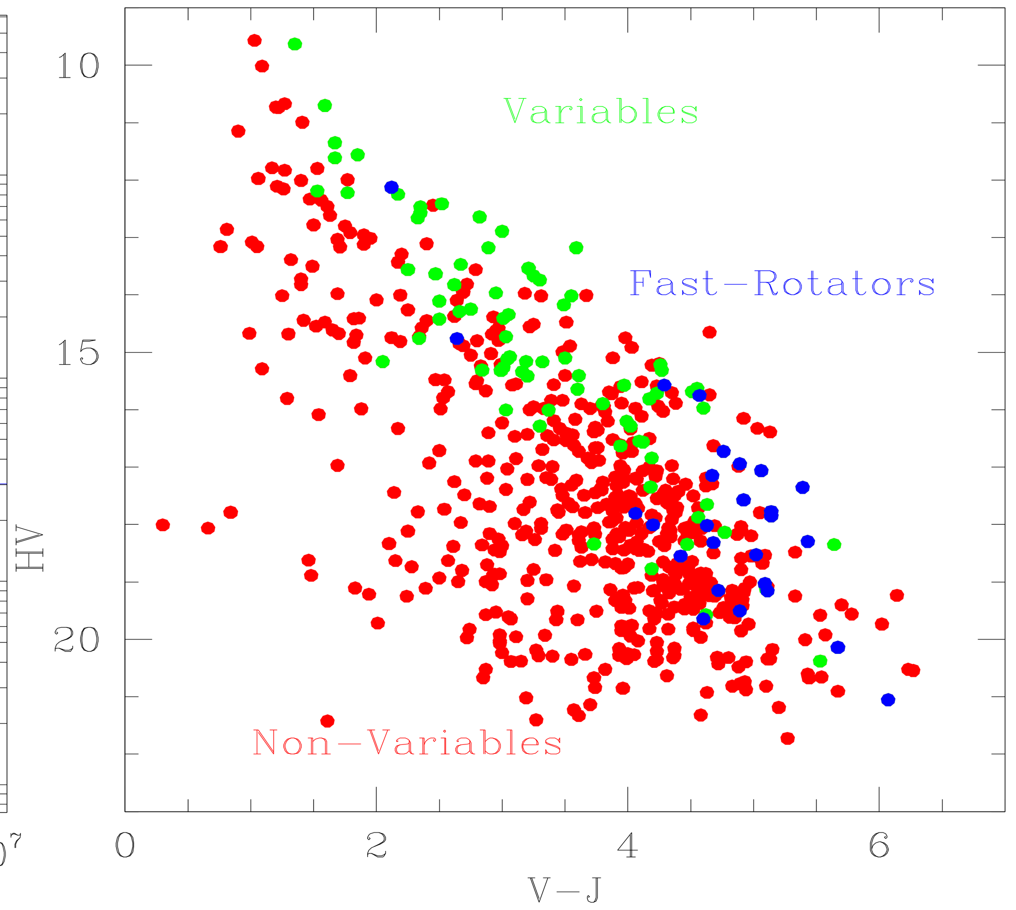


Figure 2: This plot of corrected magnitude (HV) against color (V-J) shows that our stars fall along the classical "main sequence". Stars that fall below the main sequence line are older, while stars above the line are younger. The HV value is the star's magnitude (or brightness) and the V-J value is the difference between the visible and infrared magnitudes of a star. The HV value determines how bright a star is; a smaller value means that a star is more luminous. The V-J indicates the color of the star which is also a proxy for mass. A larger V-J value means a redder and less massive star. Because the variable stars in our plot are present at all the V-J values, it demonstrates that mass does not affect variability. The variable stars however fall above the main sequence line, which indicates that there is a trend between age and variability, showing that younger stars tend to be more variable. The plot also shows another trend between the fast rotators and mass: because most of the fast rotators have greater V-J values, this shows that low mass stars have faster rotation rates than massive stars.

(D) IDENTIFYING STELLAR FLARES: A flare is a burst of light greater than the average brightness of a star. Stellar flares occur when accelerated-charged particles (electrons) interact with the plasma medium at active regions around star-spots, which are equivalent to sunspots. At these areas, intense magnetic fields penetrate the photosphere to link the corona to the interior of the star. Powered by the sudden (tens of minutes) release of magnetic-energy stored in the corona, flares usually last less than an hour to two hours. In addition, large flares occur less frequently than smaller ones because they require more energy to be sustained. For instance, the flares in Figures 7-9 are predominantly small and last less than an hour.

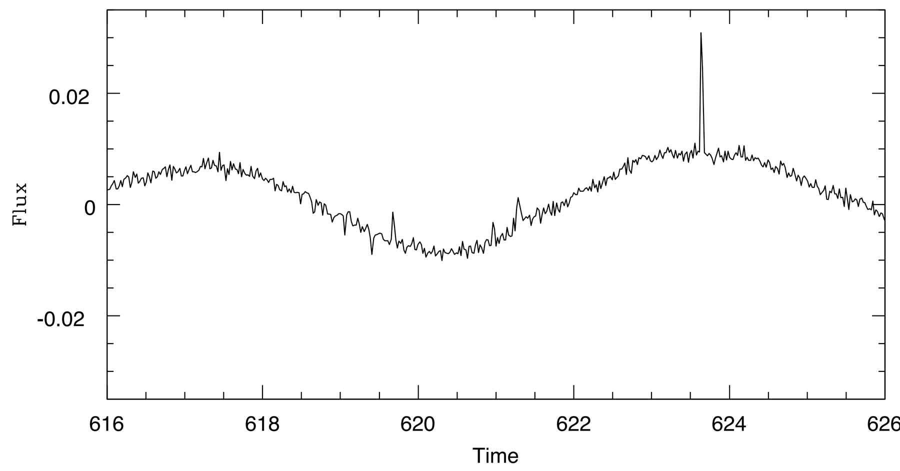


Figure 9: The light-curve above is a close-up of Figure 8. It shows that most of the variability of the M-star is small and due to spots, with brief, occasional flares as occurred on day 623.

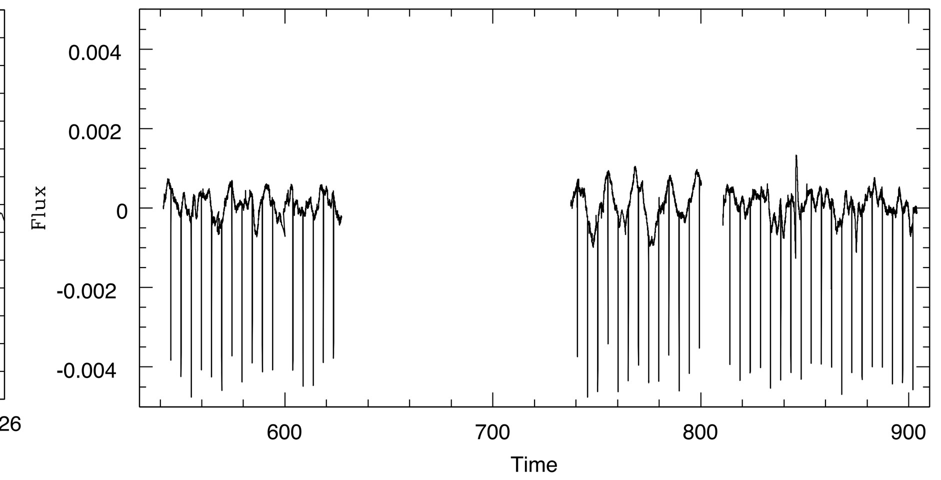


Figure 10: This light curve shows the presence of planet, which eclipses the star every few days, causing the light to dim briefly. Time is in days.

(E) CONCLUSIONS: We originally hypothesized that low-mass stars would have more activity in general, but found that mass was not a factor in variability. Age, however, seem to matter much more: the younger stars are more variable than the older ones. In particular, the fast-rotators were usually low-mass stars.

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