# ANALYSIS OF *KEPLER* DATA FOR CHEMICALLY PECULIAR STARS

**A Project Report**

*submitted by*

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*under the guidance of*

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## CERTIFICATE

Certified that the project report entitled **'Analysis of** *Kepler* **data for chemically peculiar stars'** submitted to Aryabhatta Research Institute of Observational Sciences, Nainital, is an authentic record of the work done by **Manu B Jayan** under my guidance during the period October-December 2018.

Dr Santosh Joshi
(Scientist E)
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# DECLARATION

I hereby declare that the project report entitled **'Analysis of *Kepler* data for chemically peculiar stars'** submitted to Aryabhatta Research Institute of Observational Sciences, Nainital, is a record of the work done by me under the guidance of **Dr Santosh Joshi**, Scientist E, during the period October-December 2018.

Manu B Jayan

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Manu B Jayan

## ABSTRACT

*Kepler* missions by NASA is one of the largest habitable-planet hunting missions to be ever launched. Many thousands of planets were discovered by *Kepler* within its 9 year tenure. In this paper, we have used the *Kepler* data that is publicly available to study the properties of 5 stars in the Praesepe cluster. With the help of light curves and periodograms developed from the data, along with the known physical parameters collected, we have tried to analyse each star briefly. Finally we were able to match most of our finding with already proven facts and also to raise forward some contradicting findings.

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# 1 Introduction

*Kepler* mission (Kepler & K2) operated by NASA was aimed to survey our region of milky way galaxy to discover Earth-size and smaller planets in or near the habitable zone and to determine the fraction of stars in our galaxy that might have such planets[2]. By habitable zone, we mean where liquid water exist on the planet's surface. *Keple*r I telescope or simply, the *Kepler* telescope was launched on March 7, 2009. Following the loss of a second reaction wheel on board, Kepler mission was put to an end on May 2013. Then in the following months it was decided to assign the telescope a new mission. And on May 2014, the K2 was declared fully functional as a successor to *Kepler* I mission, using the same telescope. After 9 years of deep space exploration, the telescope ran out of fuel and the mission was declared dead on November 15, 2018. During this tenure, *Kepler* discovered 2,682 exoplanets and more than 2,900 candidate planets are awaiting confirmation.

Apart from the primary mission of detecting earth-size planets, the telescope was assigned a few other secondary missions also. These included determination of distribution of sizes and shapes of the orbits of the discovered planets, estimation of number of planets in a multiple-star system, determination of variety of orbit sizes and planet reflectivities, sizes, masses and densities of short-period giant planets, identification of additional members of each discovered planetary system using other techniques, determining the properties of the host stars etc.

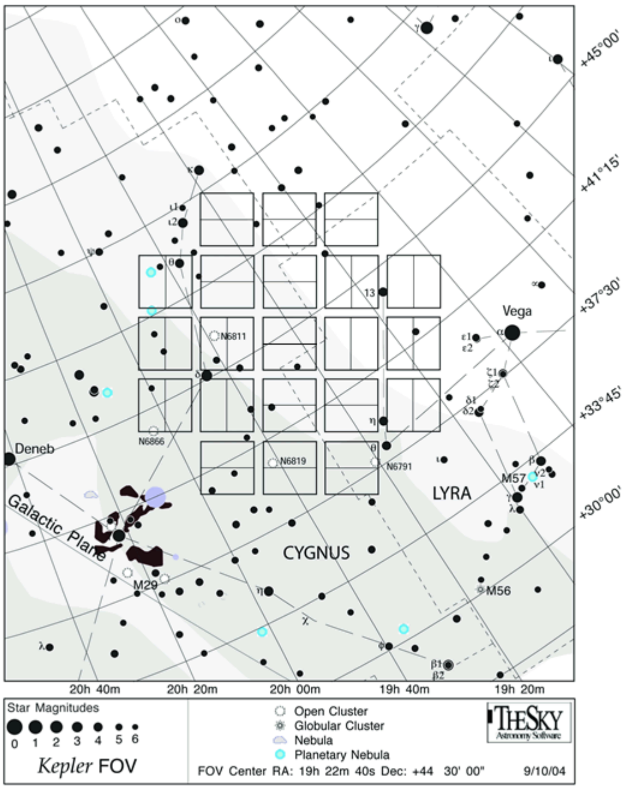


Figure 1: *Kepler*'s field of view[1]

The sole *Kepler* telescope is a photometer, an instrument that measures the brightness variation in stars and 24 CCD detectors. When a planet passes in front of a star (event known as "transit"), there happens tiny dips in the brightness of the star. *Kepler* watches for these dips to discover planets. Another technique called 'verification by multiplicity' was used in case of multiple-planet systems[3]. A star hosting multiple planets is gravitationally stable, while a star that has close companion stars would be a more unstable system because of each star's massive gravity. After a planet has been discovered, its orbital size is calculated from its period and the mass from the calculated period. By evaluating the drop in the brightness of the star, the size of the planet is found. The orbital period and the temperature of the star gives the characteristic temperature of the planet. And finally, from all these it can be decided whether the planet is habitable or not.

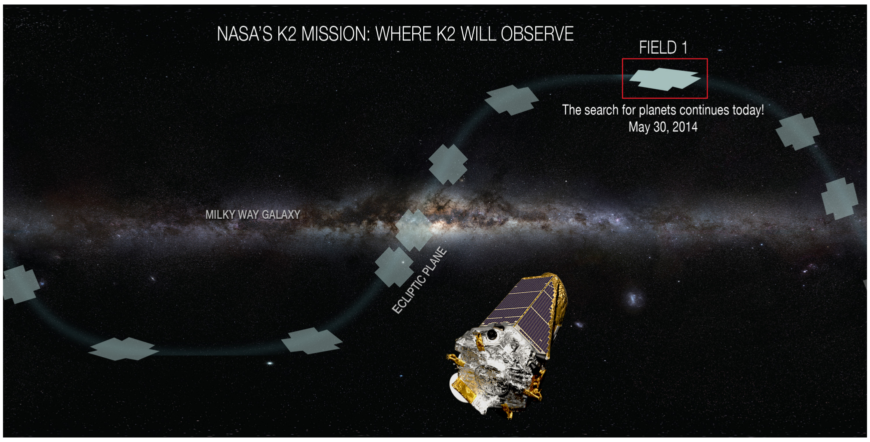


Figure 2: K2's field of view. The telescope will observe region marked in blue lines. After every 80 days, new fov (blue cross) will be targeted[4].

The field of view (FOV) for *Kepler* missions is selected carefully so as to include maximum number of stars and monitor their brightness continuously throughout the year. The FOV must never be blocked by anything at any time, even the sun. *Kepler*'s photometer has a very wide filed of view of about 12° in diameter in the Cygnus and Lyra constellations near the galactic plane to free it from other bright celestial objects.

*Kepler* observes the stars in white light, with a band-pass of 430-890 nm FWHM. Aperture photometry of the whole FOV is collected every 6 s and is stored on the instrument itself. Many such 6 s observations are summed up to make a total exposure time of 30 min and then it is transmitted to Earth. This is called long cadence (LC) data. *Kepler* also observes some stars in the short cadence (SC) mode which have an exposure time of 1 min. Only 512 slots are available for SC mode and hence vast majority of stars are observed primarily every 30 min. Every 3 months, the telescope is re-aligned so as to keep its solar panels pointed towards Sun. This creates a gap of a day or so every 3 months in the time series, which is otherwise continuous. Each 3 months duration is called as a campaign and there has been 20 campaigns conducted within its lifetime of 9 years. Apart from the small drifts and jumps, the data has excellent accuracy.

Chemically peculaiar stars(CP stars) are stars whose spectra exhibit abundance anomalies that manifest as extreme over- or under- abundances of various chemical elements. In simple words, they are stars with distinctly unusual metal abundances, at least in their surface layers. The spectral anomalies are caused by radiative diffusion which pushes certain elements to the surface of the star and gravitational settling of other elements in the atmosphere. The former scenario causes over abundance and the latter causes under abundances of respective elements.

A variable star is a star whose brightness as seen from earth fluctuates. This variation may be caused by the actual fluctuations in the flux or by something partly blocking the light. Stars in which there is actual variation in the light are termed as pulsating variable stars. The periodic expansion and contraction of the surface layers causes the pulsation in them. Different types of pulsating variable stars are distinguished by their periods of pulsation and the shapes of their light curves. These in turn are a function of mass and evolutionary stage of the star.

# 2 Target Objects

The Nainital-Cape survey is a joint program between Aryabhatta Research Institute of Observational Sciences (ARIES),India and South African Astronomical Observatory(SAAO), South Africa to search for pulsational variability in chemically peculiar stars in the northern hemisphere. The target selection criteria of the survey was to choose Stromgren photometric indices similar to those known in CP stars exhibiting pulsational variability. For the survey, the stars were observed using three-channel fast photometer attached attached to 1.04 m Sampurnanand telescope, ARIES and 0.5 m, 0.75 m and 1.0 m telescopes of SAAO. The 5 stars studied in this paper are TYC 1395-855-1, BD +192046, HD 73135, BD +192045 and HD 73045. They were chosen as they all have similar brightness.

# 3 Research Methodology

The fits files from campaign 5 & campaign 8 for these stars were obtained from Mikulski Archive for Space Telescopes (MAST), hosted by the website of Space Telescope Science Institute (STScI). C05 started on 27 April, 2015 and ended on 10 July, 2015. The C18 got initiated on 3 January, 2016 and extended till 23 March, 2016. The time-series photometric data was extracted from these files using a fortran program. Data is the cleaned for outliers and null values using python programs. The corrected light curves were visually inspected and were found to be of good quality to be used for further analysis.

The corrected light curves were then used to generate periodograms based on Lomb-Scargle (after Lomb (1975)[5] and Scargle (1982)[6]). Frequency, amplitudes and corresponding periods of the targets were determined from these periodograms. Using known formulas, radial pulsation constant (Q) was also calculated for different periods for the stars. Based on this Q value and other information collected from previous studies, effort has been made to identify what these extracted periods correspond to; such as pulsation, rotation etc.

# 4 Stellar Parameters

In parallel, we also collected different physical and chemical parameters for the target stars from various literature. These were used for aiding this study and also to compare with the information inferred from our analysis of the *Kepler* data. Also, from the known formulas, we have calculated values of more such parameters. The data is tabulated and given in appendix.

# 5 Discussion

Fig [3] & fig [4] shows the light curves plotted for all the 5 stars for both the campaigns- C05 & C18. For making the visual comaprison between the campaigns easy, we have eliminated the difference in time series between the 2 campaigns. The light curves clearly shows the variability characteristics of the stars. Among these, HD 73135, BD +192045 & HD 73045 turns out to be more interesting targets as they very well exhibit the pulsation in their light curves.

TYC 1395-855-1 has its amplitude varying from -0.0005 & 0.0005 mmag. The variability observed is very small, as little as 0.001 mmag from bottom to top and this falls within the noise level. The periodogram after pre-whitening has also been plotted. The amplitude of the peaks remain roughly the same for both the campaigns. The highest peak has an amplitude of 0.000042 mmag and the frequency is 0.057 cycles per day for C05 and 0.099 for C18. This corresponds to a period of 17.54 and 10.10 days respectively. There is a considerable difference in the frequency hosting the peaks in the periodograms between both the campaigns for all stars. This is the effect of many other external factors and hence this small difference can be neglected. For BD +192046, only the LC data was available. The light curve shows variability of about 0.0015-0.002; that too well inside the noise level. Here, the dominant period is about 5.29 days with an amplitude of 0.00006 mmag. 2 other peaks of magnitude 0.000043 are visible immediately before and after the frequency of 10 c/d. It was understood that both these stars do not show pulsational variability. HD 73135 requires some attention here as it exhibit pulsational variability. The light curve changes its shape and form as we move from the beginning to the end of both campaigns. Since this is noticed in both the campaigns, it can be understood that this change in flux is periodic. The difference in flux at the thinnest part of the light curve is almost 0.0004 mmag. To the end of the campaign it has a higher value of about 0.0006 mmag and above. Another interesting feature is that, though the flux changes with time, the maximum flux of the star remains almost constant here ($\approx$ 0.0002mmag). But nearing the end of the campaign there is an increased dip in the flux as its magnitude changes from $\approx$ 0.0002 to $\approx$ 0.0005. In the fourier transform of C05 data of HD 73135, we can see a very clear peak at 0.696 c/d (1.43 days). But this frequency has a reduced amplitude in the C18 data. Here the dominant period is 1.54 days. These values, both 1.43 and 1.54 is believed to be the pulsational period.

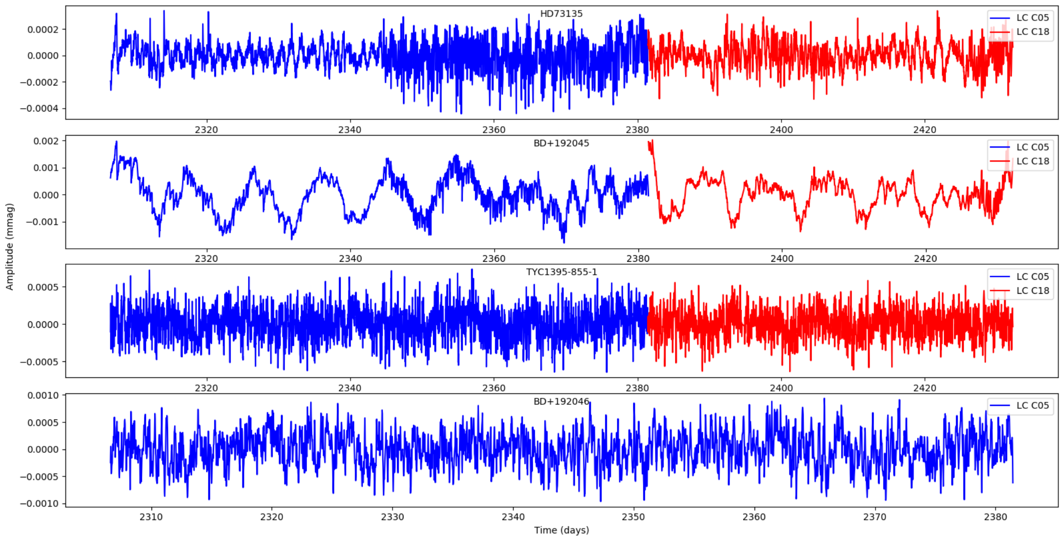


Figure 3: Light curves of 3 target stars from C05 & C18. It is to be noted that the difference in time between th 2 campaigns have been subtracted for the ease of visual comparison.

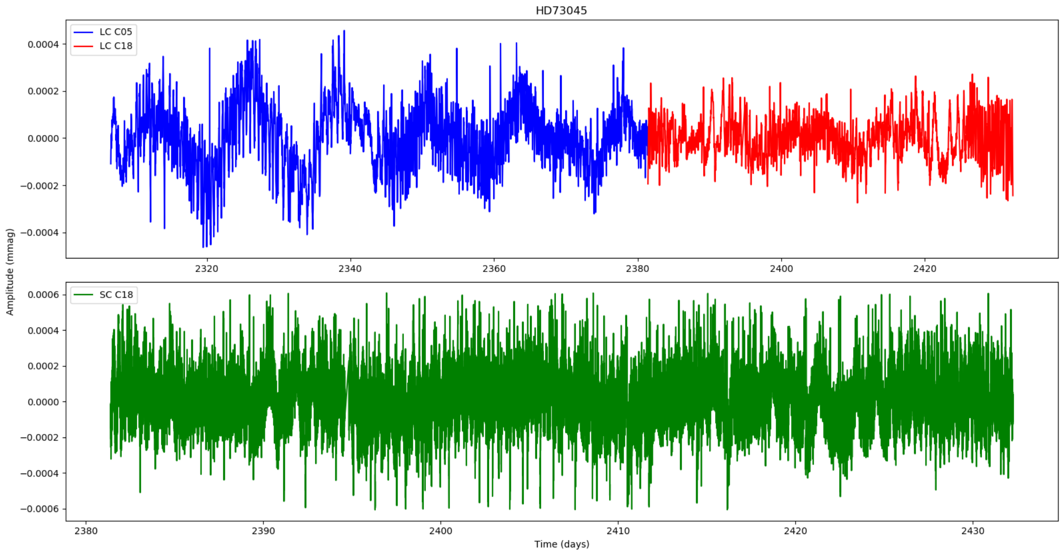


Figure 4: Light curves of HD 73045 from C05 & C18. It is to be noted that the difference in time between th 2 campaigns have been subtracted for the ease of visual comparison.

The flux variation for BD +192045 is very evident from fig [3]. It is about 0.004 mmag. It is also interesting to see a prominent difference in the shape of light curves between C05 & C18. Though the amplitudes remain almost the same for both campaigns, in C18 we can see a broader peak. Within a periodic cycle, it has to be assumed that the star remains brighter for most part of the time with a dip in the light lasting for only a day or two. If the variability is due to surface spots, it implies that they are changing over the course of a few years.

HD 73045 has remained a target of interest for scientist and observers for a very long time. A large amount of data is already available for the star. Here we have both LC & SC data from campaign 18 and the LC data from C05. The pulsational variability is very clear in the C05 data whereas it is not much understood from C18. The magnitude ranges from about -0.0004 to 0.0004 in C18. The difference in amplitude is about 0.0004 for LC C18 data and a larger difference in magnitube of about 0.0012 can be seen in SC C18 data. As observed for BD +192045, the change in the shape of light curves can be seen across the 2 campaigns here also. This must also be attributed to the changes in surface spot occurred within one year, between 2015 & 2016.

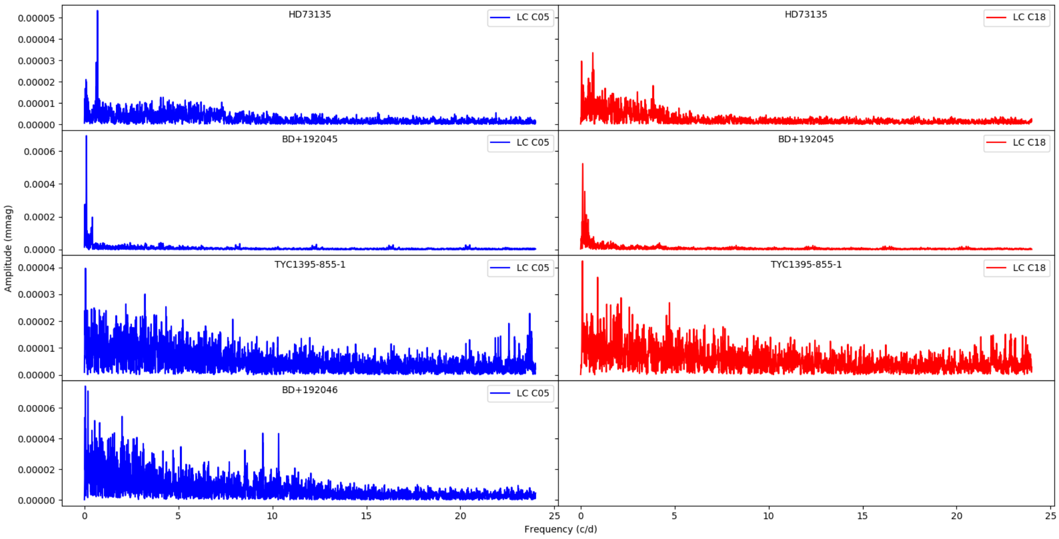


Figure 5: Periodograms of 3 target stars from C05 & C18.

The periodogram for BD +192045 gives us a dominant peak of amplitude 0.00065 mmag (0.00059 mmag for C18) with a frequency of 0.106 c/d (0.113 c/d for C18). The corresponding period is about 9.43 days (8.85 days) and this must be rotational period. All the other frequencies and periods holds a very small amplitude value here. While examining the periodogram of HD 73045, the first thing noticeable is the huge difference in amplitude of the highest peak between the 2 campaigns. In C05, it is about 0.0001 mmag with a period of ≈13.15 days and it is only 0.00003 mmag (0.00004 mmag in SC data) with a period of 12.34 days. This difference in amplitude can be very clearly understood from fig [6]. Since SC data is available for this star, we have used it to examine the frequencies greater than 24 c/d. There are no frequencies that requires much attention between 24 c/d to 734 c/d.

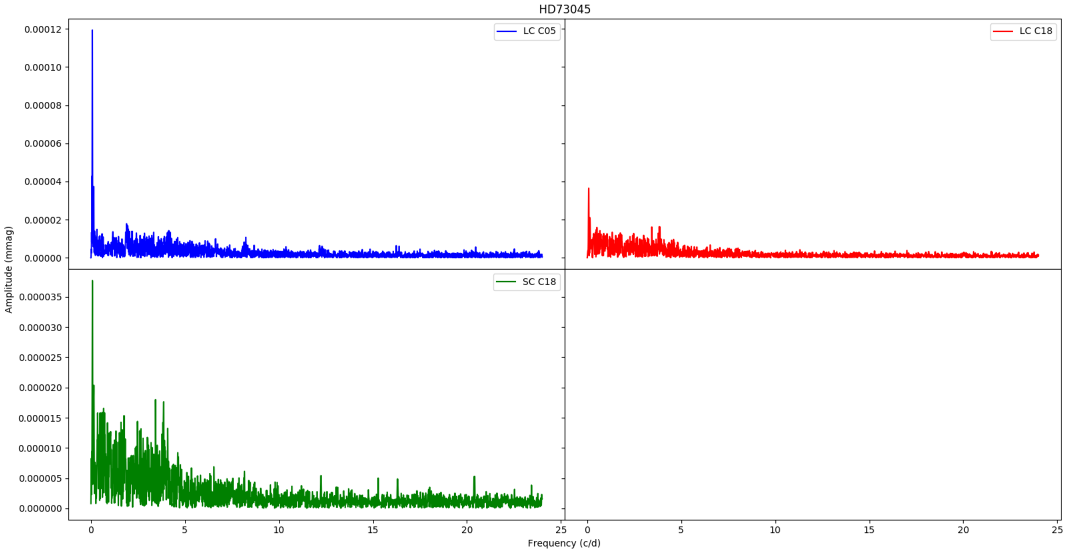


Figure 6: Periodograms of HD 73045 from C05 & C18.

We have then plotted the location of our target stars in the HR diagram (fig [8]). Also shown is the zero-age main sequence and evolutionary tracks for models with 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4 $M_\odot$. The red and blue edges of $\delta$ Sct and $\gamma$ Dor stars calculated by Dupret et al. (2004)[7] have also been included in the figure. HD 73045 & HD 73135 falls within the $\delta$ Sct instability as evident from the plot. They both have a mass $\approx$ 1.8 $M_\odot$ and this matches with their position near the evolutionary track for 1.8 $M_\odot$ model. BD +192045 falls outside this instability strip, but it is still very close to the strip. Only photometric data was available for this star and we strongly believe that, if plotted with more accurate spectroscopic data BD +192045 would be positioned within the red and blue edges of $\delta$ Sct. This HR diagram also suggests the pulsational characteristics of these 3 stars. The other 2 stars fall well outside $\delta$ Sct instability strip as they do not exhibit pulsations. Their physical parameters such as temperature, mass etc. matches with their locations in the HR diagram.

The standard pulsation relation may be expressed in terms of observable quantities as

$$\log\mathrm{Q} = -\,6.454\; + \log P\; + 0.5\log g\; + 0.1\,M_{\mathrm{bol}}\; + \log T_{\mathrm{eff}}\,, \tag{1}$$

(Martinez et al. 1999) where Q is the radial pulsation constant and P is pulsation period. According to Stellingwerf (1979)[8], Q = 0.033 for fundamental-mode pulsation, Q = 0.025 for first-overtone pulsation and Q = 0.020 for second-overtone pulsation for standard late-A and early-F star models. It is known that $\delta$ Sct stars have pulsation periods between 0.5 hrs and 6 hrs. We have calculated the Q values of our targets using eqn.(1) for possible pulsation frequencies and results are tabulated below. In BD +192046, though we have obtained Q value for first-overtone at $\approx$ 1.596 c/d and second-overtone at 2.002 c/d, the corresponding periods are 0.626 day & 0.5 day which are outside the known pulsation periods for $\delta$ Sct stars.

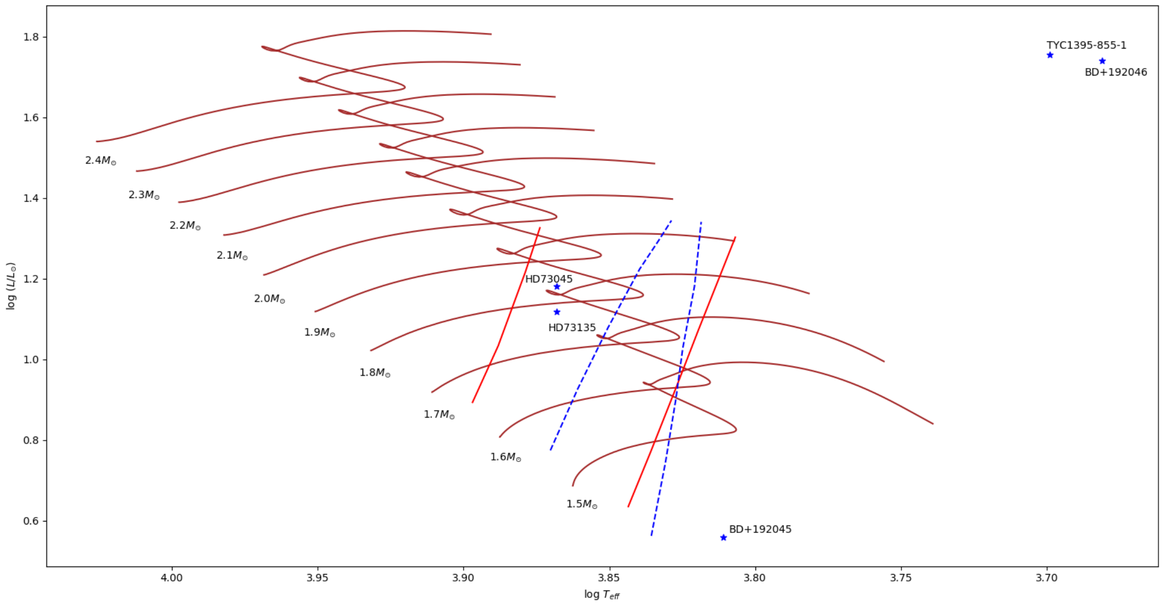


Figure 7: Location of the target stars in the theoretical HR diagram. Zero-age main sequence and evolutionary tracks for models with 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4 $M_\odot$ is also shown. The $\delta$ Sct instability strip for the p1 radial mode calculated by Dupret et al. (2004)[7] is shown in red solid lines and $\gamma$ Dor instability strip for $l$=1, calculated by Dupret et al. (2004) is shown in blue dashed lines.

| Frequency | Q |
|---|---|
| 4.3379172 | 0.012 |
| 3.2223424 | 0.016 |
| 2.2038143 | 0.024 |
| 0.0575263 | 0.907 |

| Frequency | Q |
|---|---|
| 2.1513095 | 0.024 |
| 1.3855197 | 0.038 |
| 0.9071612 | 0.058 |
| 0.0996733 | 0.524 |

Table 1: Pulsation constant (Q) for a few frequencies of TYC 1395-855-1 (Left: C05 & Right: C18).

| Frequency | Q |
|---|---|
| 10.3326048 | 0.004 |
| 9.4916658 | 0.004 |
| 2.3204814 | 0.017 |
| 2.0020352 | 0.020 |
| 1.5964903 | 0.025 |
| 1.500144 | 0.027 |
| 1.3968895 | 0.029 |
| 1.2961237 | 0.031 |
| 1.2445369 | 0.032 |

Table 2: Pulsation constant (Q) for a few frequencies of BD +192046 (C05).

| Frequency | Q |
|---|---|
| 4.1915969 | 0.097 |
| 4.0646866 | 0.100 |
| 4.0519959 | 0.101 |
| 0.8101228 | 0.503 |
| 0.0712045 | 5.733 |
| 0.0425911 | 9.584 |

| Frequency | Q |
|---|---|
| 3.8560939 | 0.106 |
| 3.8201575 | 0.107 |
| 3.0209375 | 0.135 |
| 1.1504766 | 0.355 |
| 0.1120199 | 3.644 |
| 0.0545082 | 7.489 |

Table 3: Pulsation constant (Q) for a few frequencies of HD 73135 (Left: C05 & Right: C18).

| Frequency | Q |
|---|---|
| 0.8506733 | 2.560 |
| 0.0930933 | 23.395 |
| 0.0414061 | 52.600 |
| 0.0262079 | 83.103 |
| 0.0101066 | 215.498 |

| Frequency | Q |
|---|---|
| 0.3475477 | 6.267 |
| 0.113289 | 19.224 |
| 0.0595172 | 36.594 |
| 0.0385886 | 56.440 |
| 0.0146143 | 149.029 |

Table 4: Pulsation constant (Q) for a few frequencies of BD +192045 (Left: C05 & Right: C18).

| Frequency | Q |
|---|---|
| 4.1435213 | 0.468 |
| 4.0664396 | 0.477 |
| 1.910278 | 1.016 |
| 0.3205423 | 6.056 |
| 0.151056 | 12.851 |
| 0.1391372 | 13.952 |
| 0.0757862 | 25.616 |
| 0.0611977 | 31.722 |
| 0.0357982 | 54.229 |

| Frequency | Q |
|---|---|
| 3.8687507 | 0.502 |
| 3.8148443 | 0.509 |
| 3.7748432 | 0.514 |
| 0.6014252 | 3.228 |
| 0.489784 | 3.964 |
| 0.446796 | 4.345 |
| 0.1642818 | 11.817 |
| 0.1481925 | 13.100 |
| 0.0811859 | 23.912 |

| Frequency | Q |
|---|---|
| 4.0829352 | 0.475 |
| 3.8699954 | 0.502 |
| 3.8323699 | 0.506 |
| 3.8137603 | 0.509 |
| 3.4365915 | 0.565 |
| 0.445366 | 4.359 |
| 0.1521728 | 12.757 |
| 0.0830141 | 23.385 |
| 0.051738 | 37.522 |

Table 5: Pulsation constant (Q) for a few frequencies of HD 73045 (Left: LC C05, Middle: LC C18 & Right: SC C18).

# 6 Conclusion

All the 5 stars were studied using light curves and periodograms, in this paper. From the light of this study, it can be assumed that HD 73135, BD +192045 and HD 73045 show pulsational variability. We could identify a considerable change in the shapes of light curves of BD +192045 & HD 73045 and this is believed to be associated with the changes in surface spots. In HD 73135, we observed an increased dip in the flux along the end of both the campaigns. It is clear that BD +192045 has the highest variability among all the 3 stars. From a dip to a peak, there is a difference of $\approx 0.004$ mmag in the light curve. But the star does not fall within the $\delta$ Sct instability in the HR diagram and we believe this is because it was plotted using less accurate photometric data rather than the more accurate spectroscopic data. In HD 73045, we see a very clear variability pattern in C05 data, but this is not very distinct in C18 data. While examining for the mode of pulsation, BD +192046 showed matches with the known values for radial pulsation constants for first- and second- overtone. But the corresponding periods are not known to be pulsation periods for $\delta$ Sct stars. We expected to find fundamental mode pulsation in HD 73135, BD +192045 and HD 73045, but none of them showed matching values. This contradicts the findings in Breger & Bregman (1975)[9], which states that fundamental mode of pulsation is dominant in stars having an effective temperature $< 8000$ K.

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# Appendices

Appendix 1: Stellar Parameters

| TYC 1395-855-1 | | |
|---|---|---|
| $T_{eff}$ (K) | 5002 (±136.5) | [12] |
| R ($R_\odot$) | 9.606 (±3.418) | [12] |
| M ($M_\odot$) | 0.978 (±0.1885) | [12] |
| $v_{rad}$ ($kms^{-1}$) | 16.20 (±0.26) | [13] |
| log g ($cms^{-1}$) | 2.427 (±0.460) | [12] |
| $\rho$ (sun) | 0.0009705 (±0.006924) | [12] |
| d (kpc) | 0.3633985 (±0.0090328) | [13] |
| | 0.7859 (±0.2496) | [12] |
| plx (mas) | 2.7518 (±0.0684) | [13] |
| $M_{bol}$ (mag) | 2.5895 | |
| log L ($L_\odot$) | 1.755 (±0.470) | |
| | 2.730 (±0.730) | [14] |
| (Fe/H) (sun) | -0.641 (±0.350) | [12] |
| RA (°) | 129.2570330 | [12] |
| DEC (°) | 19.0274040 | [12] |
| pmRA (mas/yr) | -16.340 (0.097) | [13] |
| pmDE (mas/yr) | -4.694 (0.058) | [13] |

Table 6: Stellar parameters of TYC 1395-855-1.

| BD +192046 | | |
|---|---|---|
| $T_{eff}$ (K) | 4802 (±116) | [12] |
| R ($R_\odot$) | 10.740 (±1.899) | [12] |
| M ($M_\odot$) | 1.116 (±0.2785) | [12] |
| log g ($cms^{-1}$) | 2.427 (±0.2375) | [12] |
| $\rho$ (sun) | 0.0009396 (±0.0010139) | [12] |
| d (kpc) | 0.4207338 (±0.0129753) | [13] |
| | 0.6719 (0.10518) | [12] |
| plx (mas) | 2.3768 (±0.0733) | [13] |
| $M_{bol}$ (mag) | 1.667 | |
| log L ($L_\odot$) | 1.741 (±0.264) | |
| (Fe/H) (sun) | -0.316 (±0.300) | [12] |
| RA (°) | 129.1439080 | [12] |
| DEC (°) | 18.8537000 | [12] |
| pmRA (mas/yr) | -9.467 (±0.118) | [13] |
| pmDE (mas/yr) | -15.900 (±0.071) | [13] |

Table 7: Stellar parameters of BD +192046.

| HD 73135 | | |
|---|---|---|
| $T_{eff}$ (K) | 7374 (±372) | [12] |
| | 7400 | [15] |
| R ($R_\odot$) | 2.117 (±0.406) | [12] |
| M ($M_\odot$) | 1.740 (±0.1485) | [12] |
| log g ($cms^{-1}$) | 3.991 (±0.1485) | [12] |
| $\rho$ (sun) | 0.1690 (±0.08755) | [12] |
| d (kpc) | 0.2093583 (±0.0030287) | [13] |
| | 0.2062 (±0.04379) | [12] |
| | 0.20619 (±0.04329) | [15] |
| plx (mas) | 4.7765 (±0.0691) | [13] |
| $M_{bol}$ (mag) | 2.0167 | |
| | 4.970 (±0.270) | [14] |
| | 4.85 (±1.03) | [16] [17] |
| (Fe/H) (sun) | 0.046 ( 0.120) | [12] |
| RA (°) | 129.3259450 | [12] |
| DEC (°) | 18.8699680 | [12] |
| L ($L_\odot$) | 11.76 | [15] |
| $V_{rad}$ ($kms^{-1}$) | 10.60 (±3.90) | [16] [18] |
| Hp (mag) | 8.6689 | [16] |
| V (mag) | 8.584 | [19] |
| | 8.57 | [20] |
| | 8.5 | [21] |
| | 8.59 | [18] |
| U-V (mag) | 2.318 | [19] |
| pmRA (mas/yr) | -9.518 ( 0.104) | [13] |
| | -10.48 (±1.06) | [17] |
| pmDE (mas/yr) | -1.921 (±0.059) | [13] |
| | -2.36 (±0.82) | [17] |
| Spectral type | A2 | [20] [21] |
| CP class | CP1 | [20] |
| Cluster | Praesepe (NGC 2632) | |

Table 8: Stellar parameters of HD 73135.

| BD +192045 | | |
|---|---|---|
| $T_{eff}$ (K) | 6517 (±199) | [12] |
| | 6515 (±19) | [22] |
| | 6369 | [23] |
| R ($R_\odot$) | 1.655 (±0.554) | [12] |
| | 1.391 | [24] |
| M ($M_\odot$) | 1.386 (±0.156) | [12] |
| | 1.523 | [25] |
| | 1.368 | [24] |
| f(M) ($M_\odot$) | 0.0126 (±0.0072) | [26] |
| log g ($cms^{-1}$) | 4.128 (±0.221) | [12] |

| | | |
|---|---|---|
| | 4.34 | [22] |
| $\rho$ (sun) | 0.3085 ($\pm$0.2054) | [12] |
| d (kpc) | 0.2222963 ($\pm$0.0177007) | [13] |
| | 0.1749 ($\pm$0.059505) | [12] |
| plx (mas) | 4.4985 ($\pm$0.3582) | [13] |
| log L ($L_\odot$) | 0.558 ($\pm$0.113) | |
| (Fe/H) (Sun) | 0.026 ($\pm$0.135) | [12] |
| RA (°) | 129.1243730 | [12] |
| DEC (°) | 18.9658550 | [12] |
| P (days) | 9.1745 | [27] |
| | 4.142 | [24] |
| $P_o$ (days) | 1267.98 ($\pm$0.55) | [26] |
| asini (Gm) | 79.0 ($\pm$15.0) | [26] |
| e | 0.869 ($\pm$0.015) | [26] |
| $M_{bol}$ (mag) | 9.14 ($\pm$0.01) | [28] |
| vsini (kms$^{-1}$) | 17 | [22] [24] |
| | 13.2 ($\pm$0.4) | [26] |
| $v_{rad}$ (kms$^{-1}$) | 35.08 ($\pm$2.06) | [13] |
| | 36.90 ($\pm$0.19) | [26] |
| V (mag) | 9.42 | [27] |
| | 9.409 | [29] |
| | 9.50 | [22] |
| Ks (mag) | 8.30 | [27] |
| | 8.300 ($\pm$0.021) | [29] |
| | 8.299 ($\pm$0.021) | [25] |
| | 8.30 ($\pm$0.01) | [30] [31] |
| J (mag) | 8.51 ($\pm$0.02) | [30] |
| | 8.512 ($\pm$0.024) | [25] |
| H (mag) | 8.36 ($\pm$0.01) | [30] |
| B-V (mag) | 0.451 | [22] |
| | 0.454 | [24] |
| | 0.490 | [23] |
| V-Ks (mag) | 1.121 | [27] |
| pmRA (mas/yr) | -39.023 ($\pm$0.544) | [13] |
| | -35.8 ($\pm$1.1) | [32] [25] |
| | -34.60 | [31] |
| | -34.6 ($\pm$1.2) | [28] |
| pmDE (mas/yr) | -6.466 ($\pm$0.350) | [13] |
| | -13.4 ($\pm$1.2) | [32] [25] |
| | -12.60 | [31] |
| | -12.6 ($\pm$1.2) | [28] |
| A(Li) | 1.75 | [23] |
| A(Be) | 0.70 ($\pm$0.26) | [22] |
| Periodic behaviour | Single Period | [27] |
| Spectral type | F6V | [29] |
| | F2.8 ($\pm$1.6) | [28] |
| Binary system | Yes | [23] |
| Binary type | SB | [33] |

| | | |
|---|---|---|
| Cluster | Praesepe (NGC 2632) | |

Table 9: Stellar parameters of BD +192045.

| HD 73045 | | |
|---|---|---|
| $T_{eff}$ (K) | 7186 (±252) | [12] |
| | 7581 (±186) | [20] |
| | 7268 | [15] |
| | 7139.6 (±252.2) | [34] |
| | 7199 | [35] |
| | 7570 (±200) | [36] [37] |
| | 7524 (±81) | [38] |
| Log $T_{eff}$ (K) | 3.880 | [39] |
| R ($R_\odot$) | 2.221 (±0.42) | [12] |
| | 1.674 | [24] |
| | 2.124 (±0.522) | [38] |
| M ($M_\odot$) | 1.739 (±0.139) | [12] |
| | 1.83 (0.17) | [20] |
| | 1.747 | [25] |
| | 1.628 | [24] |
| f(M) ($M_\odot$) | 0.0662 (±0.0021) | [40] [41] |
| L ($L_\odot$) | 13.10 | [15] |
| log L ($L_\odot$) | 1.18 (±0.21) | [20] |
| log g ($cms^{-1}$) | 3.959 (±0.132) | [12] |
| | 4.05 (±0.2) [36] | [37] |
| $\rho$ (sun) | 0.1369 (±0.075235) | [12] |
| d (kpc) | 0.2825258 (±0.0113425) | [13] |
| | 0.2183 (±0.04529) | [12] |
| | 0.21834 (±0.045851) | [15] |
| plx (mas) | 3.5395 (±0.1421) | [13] |
| | 4.390 (±0.370) | [14] |
| | 4.58 (±0.95) | [16] |
| (Fe/H) (sun) | 0.046 (±0.120) | [12] |
| RA (°) | 129.2000140 | [12] |
| DEC (°) | 18.8828060 | [12] |
| P (days) | 1.2499 (±0.0006) | [20] |
| | 13.0114 | [27] |
| | 8.475 | [24] |
| $P_o$ (days) | 436 | [21] [42] |
| | 435.57 (±0.96) | [43] [40] |
| asini (Gm) | 68.01 (±0.70) | [40] [41] |
| e | 0.3 | [21] |
| | 0.320 (±0.009) | [43] [41] [40] |
| $M_{bol}$ (mag) | 8.38 (±0.01) | [28] |
| vsini ($kms^{-1}$) | 12.1 (±1.1) | [20] |
| | 10.0 | [24] [21] [37] |
| | 10.0 (±0.5) | [36] |

| | | |
|---|---|---|
| | 14.1 (±0.2) | [40] |
| $v_{rad}$ ($kms^{-1}$) | 35.20 (±0.07) | [16] [43] [40] |
| | 24.5 | [44] |
| | 35.5 (±2.6) | [18] |
| | 27.9 | [36] [37] |
| Hp (mag) | 8.6881 | [16] |
| V (mag) | 8.63 | [20] |
| | 8.602 | [19] |
| | 8.62 | [27] [45] [43] |
| | 8.610 | [46] [18] |
| | 8.6 | [21] |
| | 8.656 | [40] |
| Ks (mag) | 7.94 (±0.03) | [30] [27] |
| | 7.944 (±0.034) | [25] |
| J (mag) | 8.04 (±0.01) | [30] |
| | 8.036 (±0.020) | [25] |
| H (mag) | 7.95 (±0.01) | [30] |
| pmRA (mas/yr) | -36.146 (±0.210) | [13] |
| | -35.7 (±0.9) | [32] |
| | -35.4 (±0.9) | [28] |
| | -35.71 (±0.95) | [17] |
| pmDE (mas/yr) | -13.005 (±0.126) | [13] |
| | -11.4 (±0.8) | [32] |
| | -13.6 (±0.9) | [28] |
| | -11.79 (±0.78) | [17] |
| U-V (mag) | 2.295 | [19] |
| B-V (mag) | 0.301 | [34] |
| | 0.31 | [21] |
| | 0.314 | [40] |
| U-B (mag) | 0.12 | [21] |
| V-Ks (mag) | 0.676 | [27] |
| b-y (mag) | 0.218 (±0.013) | [46] |
| | 0.211 | [21] [45] |
| ((v-b)-(b-y)) (mag) | 0.195 (±0.007) | [46] |
| | 0.199 | [21] [45] |
| ((u-v)-(v-b)) (mag) | 0.749 (±0.020) | [46] |
| | 0.759 | [21] [45] |
| $B_z$ (G) | -1 (4) | [36] [37] |
| A(Li) | 2.910 (±0.153) | [34] |
| Periodic behaviour | Single Period | [27] |
| Spectral Type | A3-F5 | [20] [21] |
| | A3/A9/F3 | [40] |
| CP class | CP1 | [20] |
| Binary system | Yes | [34] [44] |
| Binary type | SB1 | [40] [33] |
| Cluster | Praesepe | |

Table 10: Stellar parameters of HD 73045.