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# Searching for Blue Straggler Candidates with TESS

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## ABSTRACT

Blue Straggler stars (BSS) are unique main-sequence stars (MSS) that appear more blue and luminous than other MSS in the cluster. 180 BSS candidates were found by compiling 2,600 Open Clusters (OC), out of 7,167, none of which were in the same OC. Categorizing the candidates from pulsator to non-pulsator by using the skew value of their power (PG skew), measured in parts-per-million (ppm), their position on the MS, and the age of the cluster. There are high to low skew tiers, where 15.56% of stars had a high skew, 38.89% have mid-tier skew, and 45.56% have low-tier skew. Also using the skew from the stars' flux (LC skew) to determine if they are binaries. About 95% of the candidates had low-tier and 5% high-tier skews. Most of which exhibited $\delta$ Scuti and $\gamma$ Dor-like pulsations and amplitude ranges. This paper covers only the high and mid-tier PG skew stars, none of which showed high-tier LC skews. Only about 8% of these are analyzed as they are $> 2.5M_{\odot}$, which is about the maximum mass for $\delta$ Scuti and $\gamma$ Dors. Out of those, only 3 stars were found and categorized as BSS.

*Keywords:* asteroseismology – color-magnitude diagram – open clusters – stars: oscillations – stars: variable: Blue Straggler – stars: variable: $\delta$Scuti – stars: variable: $\gamma$Doradus

## 1. INTRODUCTION

BSS exist where they should not, as they appear blue and hot, yet sit on the upper MS burning hydrogen (Fig. 1). Stars with similar compositions have evolved off the MS and gone into the later stages of their evolution. So the question stands, why do BSS exist and how did they come to be? Are they the result of star mergers, including binary mergers or mass transfers (Chen Wang & Taeho Ryu (2025)), or did they accrete more mass in the later stages of their evolution (Hensley (2019)). Both of these are viable hypothesis's and both could be right. But to further investigate the reasons, we need to look at the stars' interiors to understand their evolution. Once we have that piece, the rest will fall into place.

BSS' pulsations align with that of $\delta$ Scuti and $\gamma$ Dors (Joyce A. Guzik et al. (2023)). These are A-F type stars sitting in the instability strip (Simon J. Murphy et al. (2019)), which is around the turn-off point of the MS. There is a decent amount of data to confirm the pulsation modes of $\delta$ Scuti stars, which range from $5-50d^{-1}$ and have amplitudes on the order of mmags (Simon J. Murphy et al. (2019)). $\gamma$ Dors have pulsation modes which range from $0.5-4d^{-1}$ and have amplitudes on the order of mmags as well, though are typically smaller than $\delta$ Scuti's (Joyce A. Guzik et al. (2023)). Since these stars are usually $1.2-2.5M_{\odot}$ (Grigahcène et al. (2010)), we

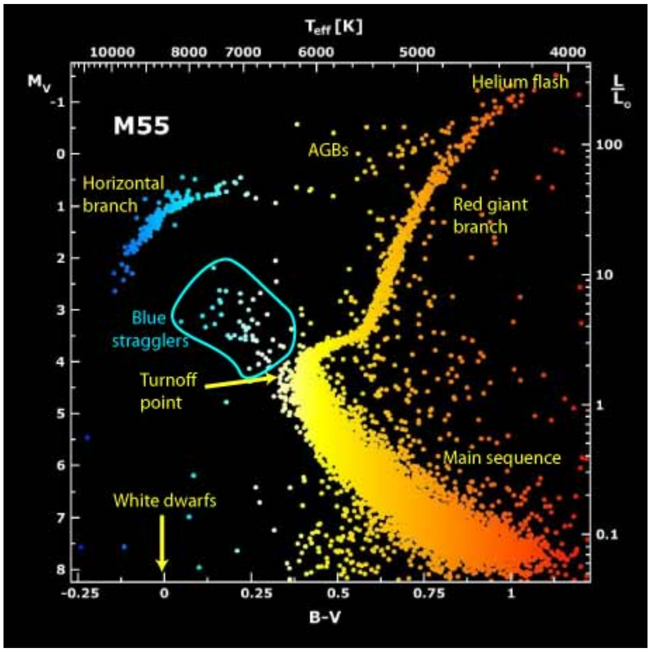



**Figure 1.** *CMD of where BSS are located on the MSS. This is a great visual of where we can look for more BSS and the region which I selected to get my data from (Jerjen (2007)).*

can look at the mass range of the BSS candidates and compare their pulsation ranges.

Another parameter that is insightful when analyzing the data is the PG skew. This is derived from the star's pulsation amplitude and it is a measure of how much the star oscillates. Pulsators and non-pulsators can be categorized by their PG skew value (Simon J. Murphy et al. (2019)), where the more positive the skew, the more/larger the pulsations. The closer the skew is to zero, the less pulsations will occur. The LC skew is used to find binary stars by looking at the more negative skew, instead of the more positive. The larger change in flux there is, the more negative the LC skew will be. Both of these are important, because if BSS are in fact remnants of a type of merger or are currently merging. You would be able to decipher which stars have a higher probability of doing so by seeing if their LC skew is negative or not and if they have a high PG skew.

Since BSS appear younger than they actually are, we look for them in older clusters. Globular clusters are the best option for this as they can be up to 12Gyr old. The goal of this project was to search elsewhere, to see if they are just as abundant in OC as well and to test just how young of a system they can exist in. Though, most of the clusters used are of ages $< 100Myr$, where the ideal age is about $\geq 500Myr$ (M. J. Rain et al. (2021)). After the previously mentioned parameters are applied, the data is then filtered to look for clusters around this age. Some younger clusters are analyzed to compare the differences as well.

## 2. METHODS

### 2.1. *Color Magnitude Diagram*

The 2,630 OCs are from the *J/A+A/686/A42* catalog (Hunt, Emily L. & Sabine Reffer (2024)), selecting the upper MS region where BSS reside to find candidates. The selection process was arbitrary, saying stars with a $G_{mag} < 13$ and a $B_p - R_p < 1$ are in the approximate region where BSS fall inside of (Fig. 2). This worked for most of the clusters, but some OC were rather thin, and did not have a lot of stars to choose from. Overlayed on the plot is an isochrone from MIST (Choi et al. (2016)) to show about where the MSS turn-off is located in the OC. The age for the isochrone is from the *J/A+A/686/A42* catalog which gives the age of the OC that the stars are in.

### 2.2. *Pulsations*

The *lightkurve* python package (Lightkurve Collaboration et al. (2018)) with a short cadence input, exposure time of 120s, was used to get the candidates' light curve and power spectrum. The reason for the short cadence was so a nyquist frequency of $\approx 360d^{-1}$ could be found, getting the full spectrum of frequencies in order to observe the rapid pulsations. The TESS Input Catalog is not as up to date with short

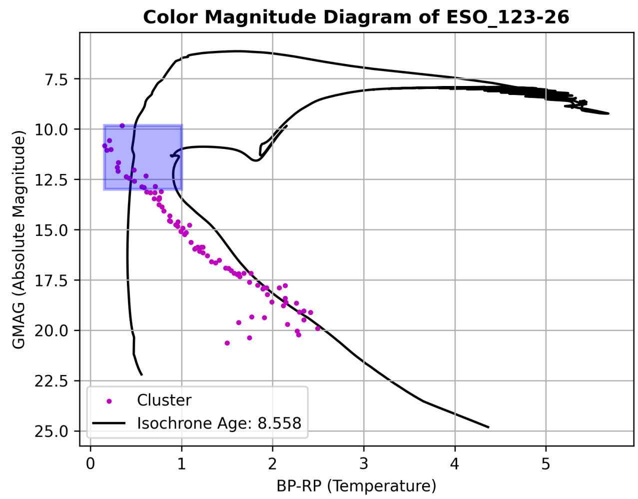



**Figure 2.** *CMD of TIC 382510339 in the OC* $ESO\_123-26$ *with an isochrone plotted on the CMD with an age of 361Myr. Showing the region where BSS candidates are selected from using the arbitrary* $G_{mag}$ *and* $B_p - R_p$ *ranges.*

cadence data as hoped, so data with short exposure times is not abundant. After collecting the short cadence data, some were filtered out if their maximum power was $< 10^{-4}ppm$. This was done so only stars with pulsations large enough were to be examined. After this was applied, around 180 stars were found as BSS candidates.

## 2.3. *Skew*

About half of the 180 stars had a high/mid-tier PG skew. Their pulsation frequencies range from $0.01d^{-1}$ to $60d^{-1}$, which align with that of $\delta$ Scuti and $\gamma$ Dor ranges (Simon J. Murphy et al. (2019) and Joyce A. Guzik et al. (2023)). Some of these stars are seen to be eclipsing binaries, which have high pulsations due to stellar interactions (Fig. 3). This is seen by the negative LC skew value and the strange pulsations the star emits.

The selection process of high/mid-tier PG and LC skew stars can be seen in Fig. 4, highlighting the different tiers. The pulsation amplitudes of the high PG skew stars have similar ranges maxing around 0.5 mmags. These amplitudes

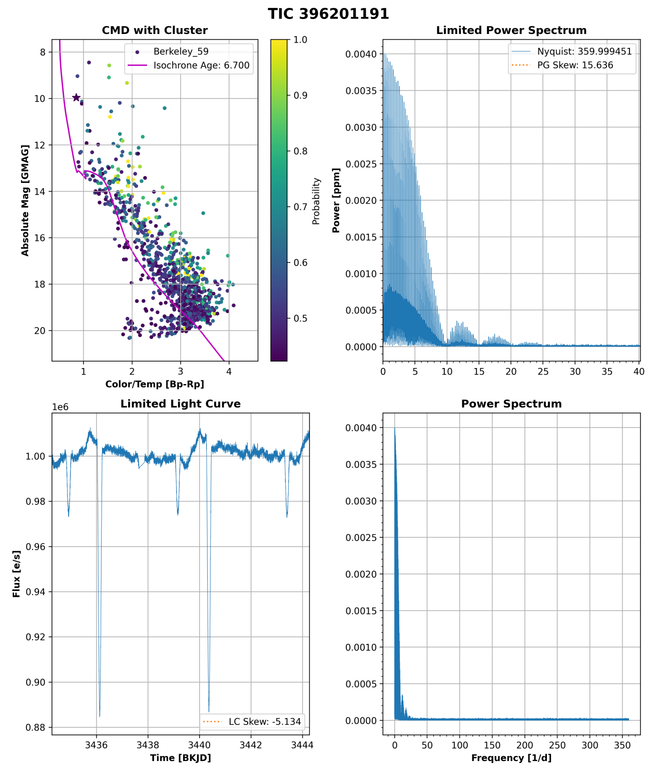



**Figure 3.** *Final plot of TIC 396201191, with an isochrone plotted on the CMD with an age of 5Myr (top-left). A zoomed in plot of the Power Spectrum which shows pulsations due to it being a binary (top-right). A zoomed in Light Curve to see the features of the star which give details on the pulsations (bottom-left). Then, the full Power Spectrum with a nyquist of* $360d^{-1}$ *(bottom-right).*

align with that of $\delta$ Scuti and $\gamma$ Dors (Simon J. Murphy et al. (2019) and Joyce A. Guzik et al. (2023)). Though some of these had amplitudes maxing at 5 mmags, which are most likely due to other interactions, like the binary star.

## 2.4. *Mass to Frequency Ratio*

After the PG and LC skew selection process, the candidates were filtered by looking at their masses relative to their pulsation frequencies (Fig. 5). This is done so that we can exclude actual $\delta$ Scuti and $\gamma$ Dors, which masses range from $1.2 - 2.5M_{\odot}$ (Grigahcène et al. (2010)). Out of the high/mid-tier skew stars, only 38% had masses $> 2.5M_{\odot}$. Most of these were MSS B-type stars that showed mainly $\delta$ Scuti-like

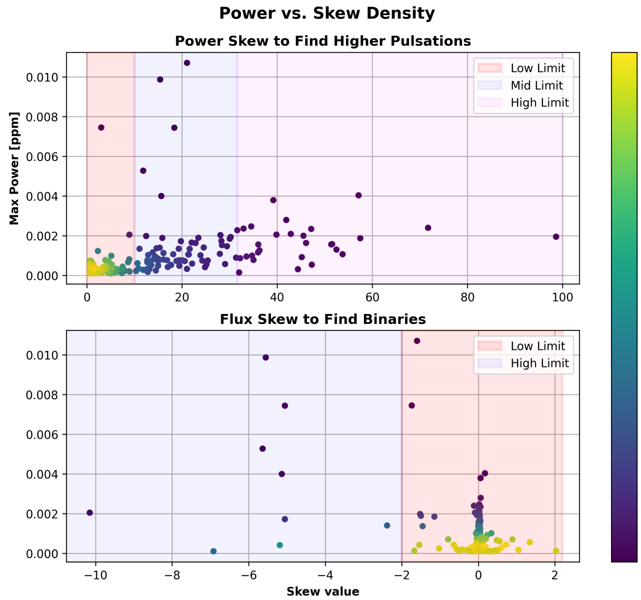



**Figure 4.** *Skew density plot showing the skew tiers from High to Low. The top figure shows the power skew to categorize pulsators from non-pulsators. Where the bottom plot shows the flux skew against power to find binaries.*

pulsations. These are most likely $\beta$ Cephei stars, which sit on the upper MSS, burning hydrogen, and have masses between $8M_{\odot}$ and $25M_{\odot}$ (Salmon et al. (2022)). The main reason we can exclude these from our analysis is due to the OC age, as the $\beta$ Cephei would be found in younger clusters.

After, three stars of masses around $3M_{\odot}$ and are in OC of ages $> 100Myr$ were selected for analysis. Two other stars showed some promising features, but were cut-out due to the OC ages around $19Myr$.

## 3. FURTHER ANALYSIS

### 3.1. *TIC 188774365*

TIC 188774365 is shown in Fig. 6 with a mass of $2.79M_{\odot}$. It has a PG skew of 47.27, so large pulsations were detected, with a positive LC skew of 0.078. The principle pulsation frequency was found to be at $11.74d^{-1}$ with an amplitude of $0.542 \cdot 10^{-3}$ ppm, or 0.5 mmags. All of which are in range of $\delta$ Scuti pulsations

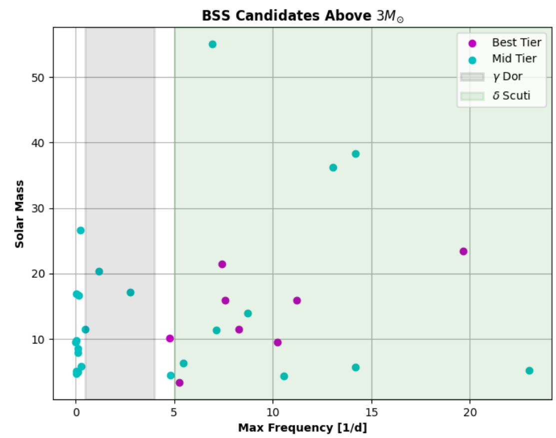



**Figure 5.** *Comparing the candidates' masses to their pulsation frequencies. Selecting the regions which are in range of $\delta$ Scuti and $\gamma$ Dor frequencies while being $> 2.5M_{\odot}$.*

(Simon J. Murphy et al. (2019)). The age of the OC is about $320Myr$, which is in the range of where BSS can exist in a cluster (M. J. Rain et al. (2021)). Looking at the isochrone fitting, it is above the MSS turn-off. Because of these details, TIC 188774365 is confidently a BSS.

### 3.2. *TIC 382510339*

TIC 382510339 is shown in Fig. 7 with a mass of $2.92M_{\odot}$. It has a PG skew of 10.85, so decent pulsations were detected, with a positive LC skew of 0.061. The principle pulsation frequency was found to be at $7.464d^{-1}$ with an amplitude of $0.351 \cdot 10^{-3}$ ppm, or 0.4 mmags. All of which are in range of $\delta$ Scuti pulsations (Simon J. Murphy et al. (2019)). The age of the OC is about $361Myr$, which is in the range of where BSS can exist in a cluster (M. J. Rain et al. (2021)). Looking at the isochrone fitting, it is above the MSS turn-off. Because of these details, TIC 382510339 is confidently a BSS.

### 3.3. *TIC 40102236*

TIC 40102236 is shown in Fig. 8 with a mass of $3.37M_{\odot}$. It has a PG skew of 44.36, so large pulsations were detected, with a positive LC skew of 0.005. The principle pulsation fre-

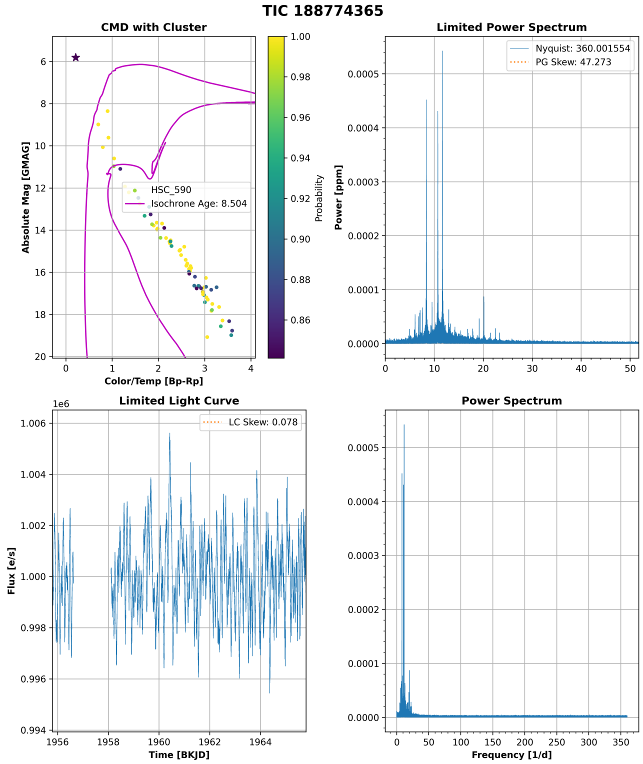



**Figure 6.** *Final plot of TIC 188774365, in the OC $HSC\_590$ with an isochrone plotted on the CMD with an age of 320Myr (top-left). A zoomed in plot of the Power Spectrum which highlights frequencies in range of $\approx 8-20d^{-1}$ (top-right). A zoomed in Light Curve to see the features of the star which give details on the pulsations (bottom-left). Then, the full Power Spectrum with a nyquist of $360d^{-1}$ (bottom-right).*

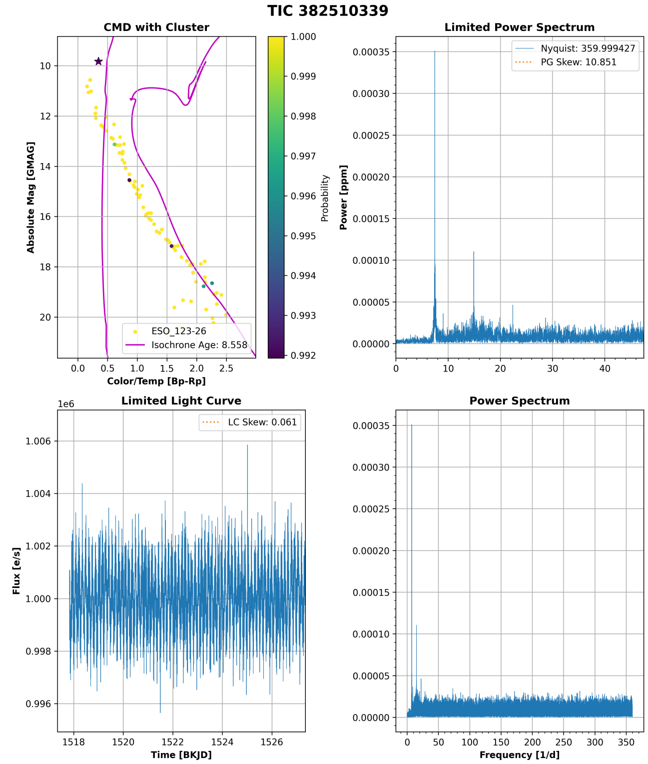



**Figure 7.** *Final plot of TIC 382510339, in the OC $ESO\_123-26$ with an isochrone plotted on the CMD with an age of 361Myr (top-left). A zoomed in plot of the Power Spectrum which highlights frequencies in range of $\approx 7.5-23d^{-1}$ (top-right). A zoomed in Light Curve to see the features of the star which give details on the pulsations (bottom-left). Then, the full Power Spectrum with a nyquist of $360d^{-1}$ (bottom-right).*

quency was found to be at $5.24d^{-1}$ with an amplitude of $0.313 \cdot 10^{-3}$ ppm, or 0.3 mmags. The pulsation frequencies are similar to that of TIC 382510339. All of which are in range of $\delta$ Scuti pulsations (Simon J. Murphy et al. (2019)). The age of the OC is about $118Myr$, which is relatively young, but is approximately in the range where BSS can exist (M. J. Rain et al. (2021)). Since the OC is young, there is a high probability that this is a $\beta$ Cephei. But looking at the isochrone fitting, it is above the MSS turn-off. Which makes it more likely to be a BSS, not a $\beta$ Cephei.

## 4. DISCUSSION AND CONCLUSION

Two stars were confidently categorized as BSS, with one other that has a probability of being a $\beta$ Cephei. In the future, the tests will be expanded by analyzing the stars' spectrums and their rotational velocities and running star merger simulations. This is so that their evolutionary stages can be firmly confirmed and to see if they can be re-produced using the merger simulations. If a star is the result of a merger, it will have a high rotational velocity and should have high abundance of metals, in this case. By looking at these parameters, TIC 188774365 and 382510339 can be categorized more precisely. Better isochrone fitting will also be added, as the current version does

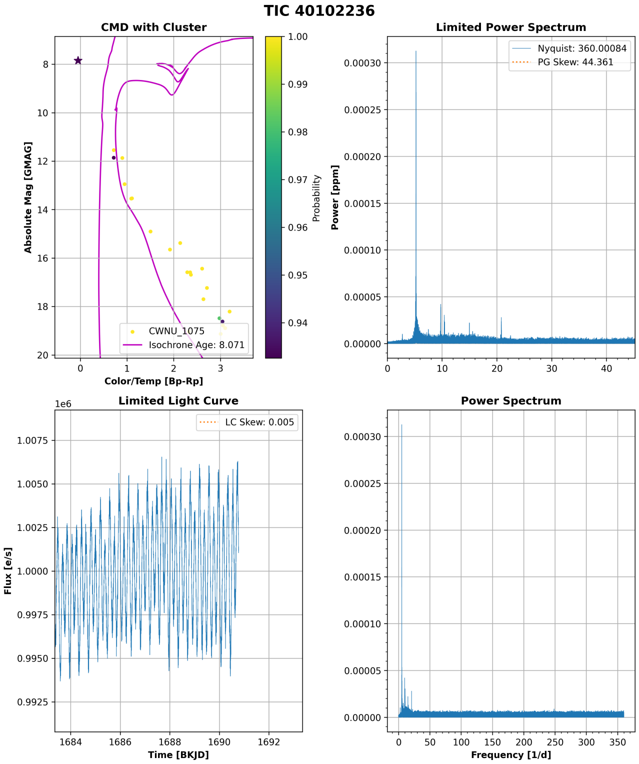



**Figure 8.** *Final plot of TIC 40102236, in the OC CWNU_1075 with an isochrone plotted on the CMD with an age of 118Myr (top-left). A zoomed in plot of the Power Spectrum which highlights frequencies in range of* $\approx 5.24 - 21d^{-1}$ *(top-right). A zoomed in Light Curve to see the features of the star which give details on the pulsations (bottom-left). Then, the full Power Spectrum with a nyquist of* $360d^{-1}$ *(bottom-right).*

not accurately fit to the structure of the cluster, shown in the CMD and final plots. This will help identify the MSS turn-off to find BSS more accurately. The region selection will also be made more accurately by not using arbitrary values. This will be implemented alongside the isochrone fitting, so that only the region above the MSS turn-off is selected. Only 2,630 clusters out of 7,167 were analyzed, so in the future the rest of the clusters will be compiled to search for BSS. The search may also be expanded to globular clusters, so that a comparison between the results can confirm the BSS categorization. In all, the project was a success, but could use more parameters, and will continue to be further developed.

# APPENDIX

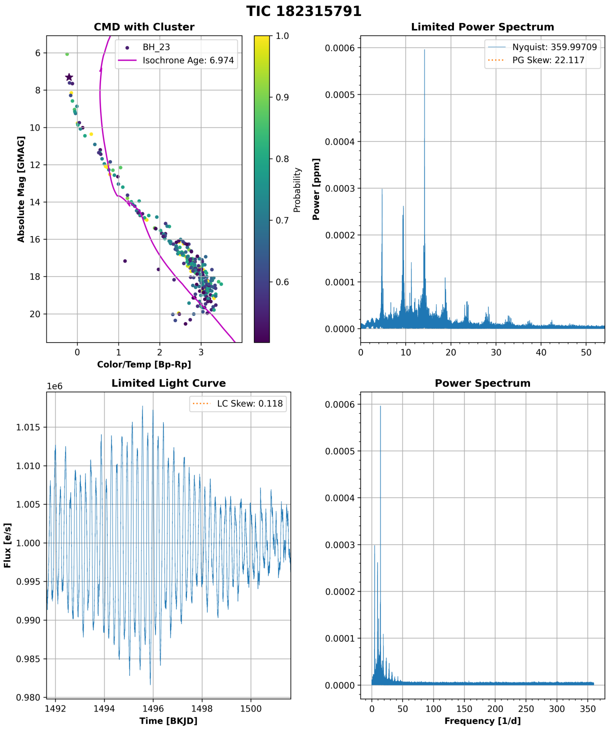
*In addition to the following, everything can be found on my GitHub (RavingRoss (2023)).*

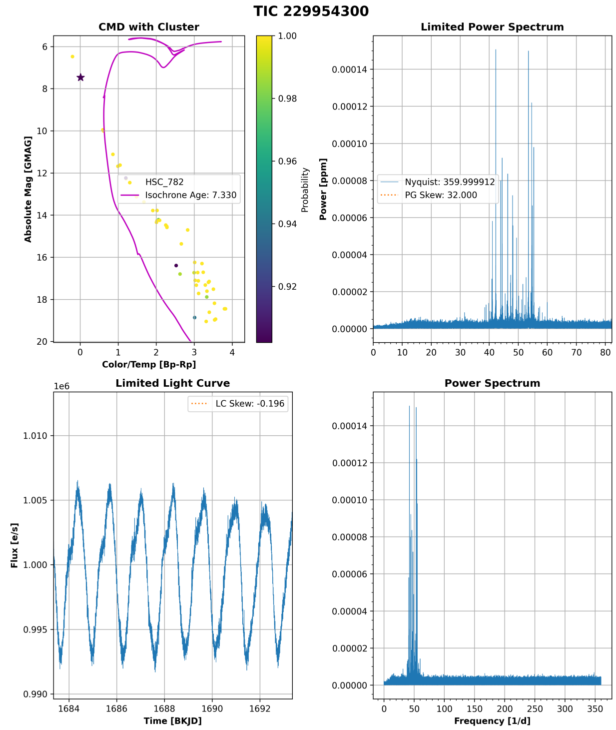
## A. TABLE 1: STAR DETAILS

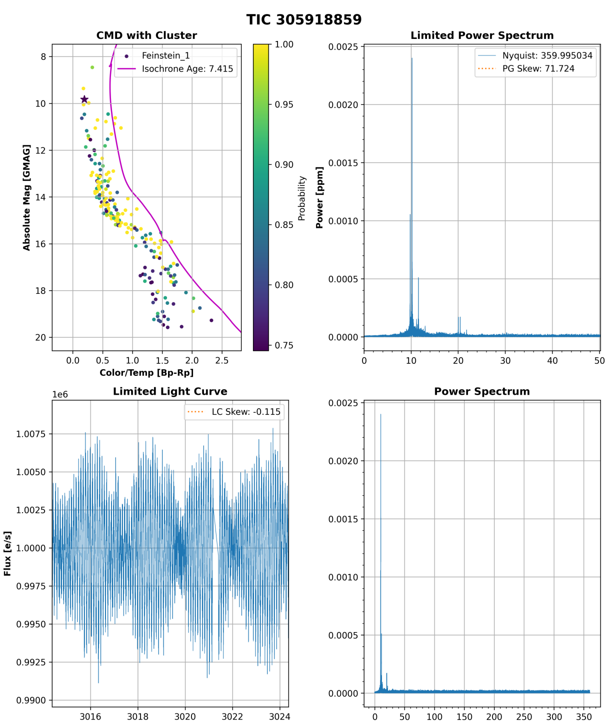
| | **TIC 188774365** | **TIC 382510339** | **TIC 40102236** |
|---|---|---|---|
| **Gaia DR3** | 1365497616683816064 | 5294002188274352384 | 2072419065786863232 |
| **RA, DEC (deg)** | 261.6843393, 48.260042 | 117.1572026, -60.0341756 | 300.4394283, 38.7352632 |
| **pmRA, pmDEC** | -0.33810317, -4.40725892 | -3.31234223, 11.04889268 | 2.88173978, 0.33511295 |
| **Absolute G-Magnitude** | 5.802926 | 9.831653 | 7.848515 |
| **Bp-Rp (Temperature)** | 0.209671 | 0.348022 | -0.049837 |

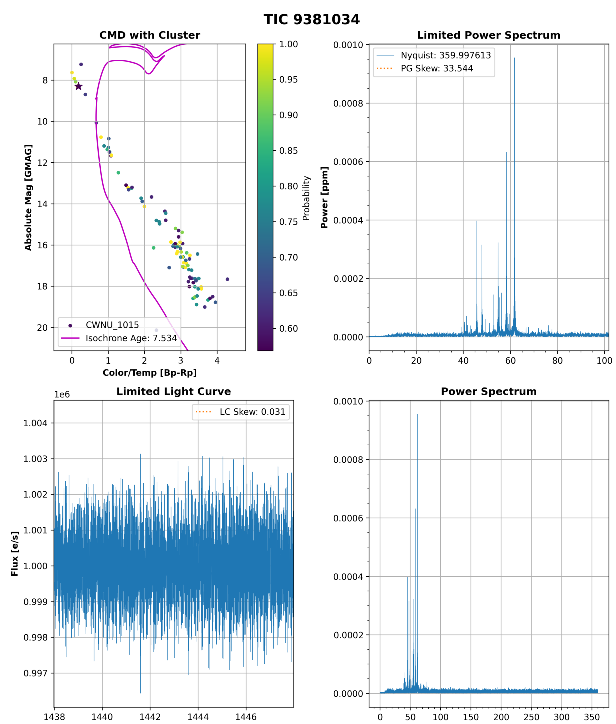
# B. ADDITIONAL FIGURES

*Candidates which did not pass the minimum OC age, but have good pulsations and are most likely $\delta$ Scuti types.*

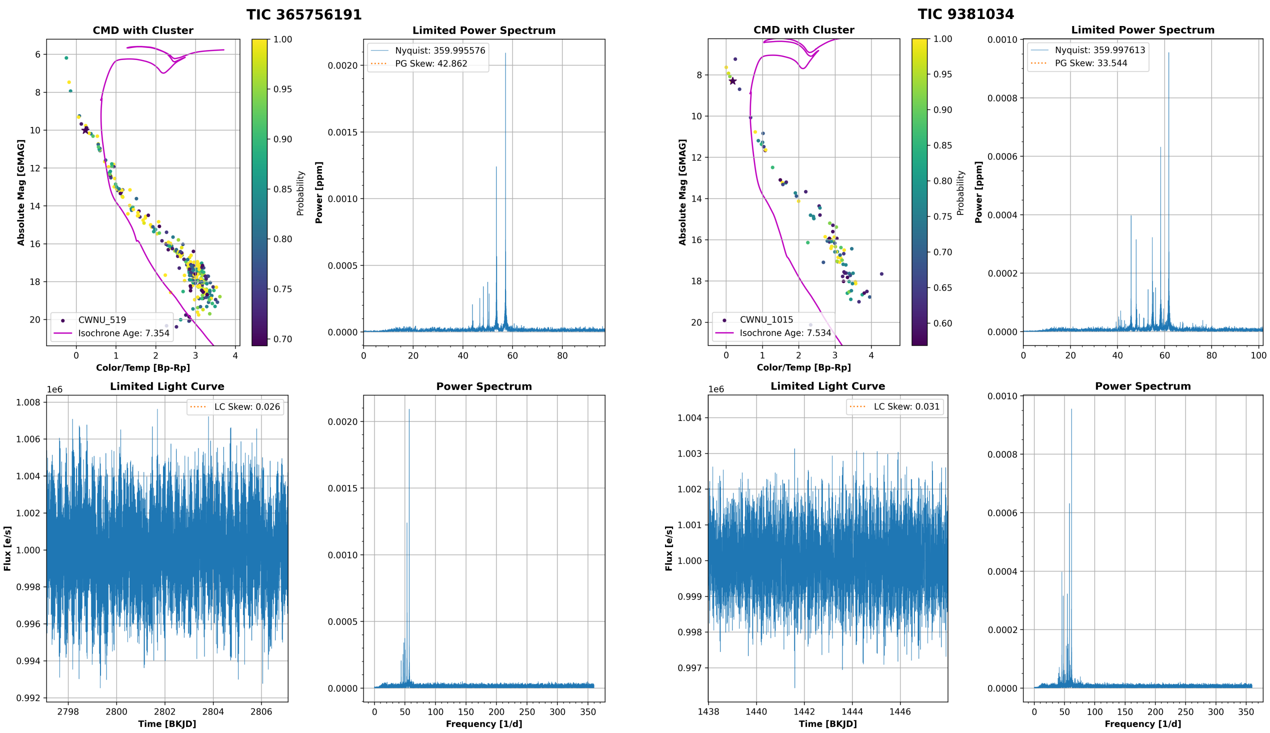


*These could be a $\delta$ Scuti and roAp hybrid!*

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