Analyzing Intermediate Frequencies of Hybrid Stars

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Abstract

Kepler Space Telescope light curve data have allowed us to consider a set of frequencies in a new frequency regime to consider the behavior of stars. These intermediate frequencies contain higher frequencies than γ Doradus stars and lower ones than δ Scuti stars. Studying all possible information on the oscillations of these stars from light curve data necessitates the continuity of the data across all frequencies. Fast Fourier Transforms are used to show at various peaks within the data.

Introduction

Data Collection

In short, the data collected from the hybrid star candidates came from a paper describing the results of a search of Delta Scuti and Gamma Doradus stars from the Kepler Space Telescope. To expand on this description, the authors selected 150,000 stars whose KIC parameters imply a location in or near the δ Sct and γ Dor instability strips. They also wanted to ensure that they considered stars outside the ground-based instability strip to confirm that the red edge of the instability strip is not the result of ground-based sensitivity limits. We reduced the sample to 2768 from the results of a 2012 paper. (Pinsonneault et al., 2012). Those stars were tested on software, removed all outliers, performed a fast Fourier transform (FFT) on the light curve, and plotted the resulting power spectra on a single page for convenience. The remaining stars were assigned categories based on criteria that define the following three stars we will mention in more explicit detail. These categories are Gamma Doradus, Delta Scuti, and hybrid (essentially a combination of Gamma Doradus and Delta Scuti, as the name implies.) The hybrid star candidates split into three categories: Gamma Doradus-dominated hybrids, Delta Scuti-dominated hybrids, and ones where the Gamma Doradus and Delta Scuti amplitudes are within a magnitude of three of each other are considered “equal.”

Delta Scuti

Delta Scuti stars are pulsating stars situated in the cepheid instability strip and have pulsation periods between 30 minutes and 5 hours. They are a group of pulsating A-type stars. The amplitudes in the radial velocity of Delta Scuti variable star generally lie in the range of 2-30 km/s. Most are less than 10 km/s. Combining radial velocities obtained during several different observations confounds asteroseismology research. In particular, possible beat phenomena and determining a period are two reasons. The two primary interior regions of a Delta Scuti star comprise a convective core and a (mostly) radiative envelope. Both parts in the interior contain a specific family of pulsation modes: gravity modes (g-modes) within the star's core and pressure modes (p-modes) in the star's envelope. Through Delta Scuti stars evolving along the main sequence, the shape of the interior changes. The convective core shrinks and becomes more compact, whereas the envelope expands; as a result, its mean density decreases. For our purposes, we can say g-mode periods decrease, and p-mode periods increase. As we will see, the instability strips of both Delta Scuti and Gamma Doradus stars overlap; therefore, stars with both behaviors (i.e., stars showing pulsations excited by different excitation mechanisms) should exist. They are called hybrid stars.

Gamma Doradus

Gamma Doradus stars are a group of pulsating F-type stars. There are over 60 known Gamma Doradus stars (Handler, 1999). They lie in a small region on, or just above, the main sequence that partly overlaps the cool edge of the Delta Scuti instability strip. Most Gamma Doradus stars are multi-periodic. As a result, pulsations are hard to observe from the ground due to the relatively low amplitude and have an average period of approximately one day. The Gamma Doradus phenomenon, as it is currently known, consists of variable stars of high-order (n), low-degree (ℓ), and non-radial, g-mode oscillations. Although it is conceivable that variations such as those of the stars in this class may occur outside of this region, likely, other mechanisms of variability would then dominate. An object put forth considered as a confirmed Gamma Doradus variable star must not vary exclusively by different characteristics, including p-mode pulsations (e.g., Delta Scuti stars), rotational modulation of dark, cool, magnetically-generated starspots; rotational modulation of bright, hot, abundance-anomaly regions; duplicity-induced variations; or other rotational effects. We cannot reject star candidates pulsating stars showing a hybrid between Gamma Doradus and Delta Scuti-type behavior. The following section will discuss this behavior.

Hybrid Stars

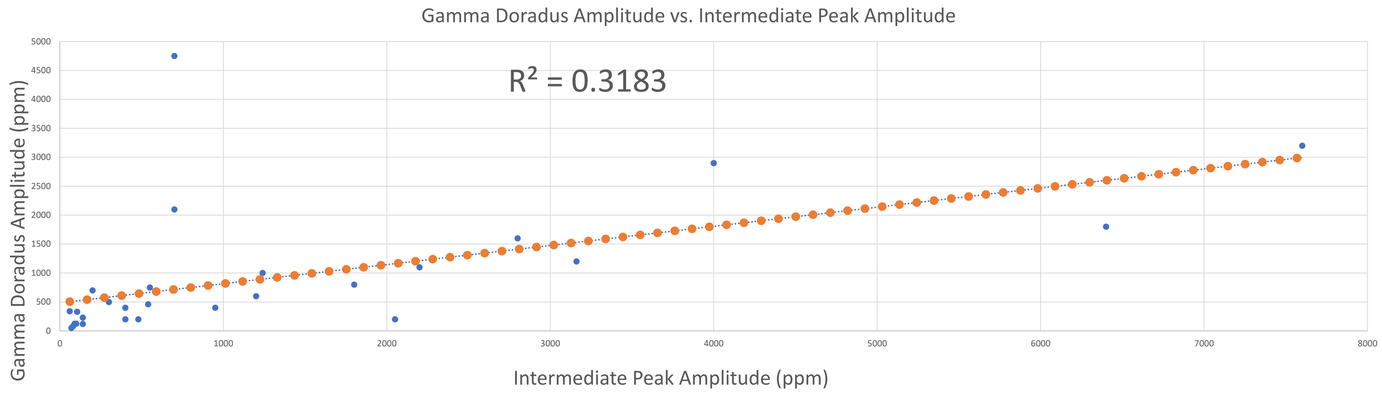
Three features define a hybrid star: frequencies become detected in the Delta Scuti and Gamma Doradus frequency domains; the amplitudes in the two regimes are roughly comparable; at least two independent frequencies exist in both regimes, with amplitudes higher than 100 ppm. Two types exist for our purposes, as defined:

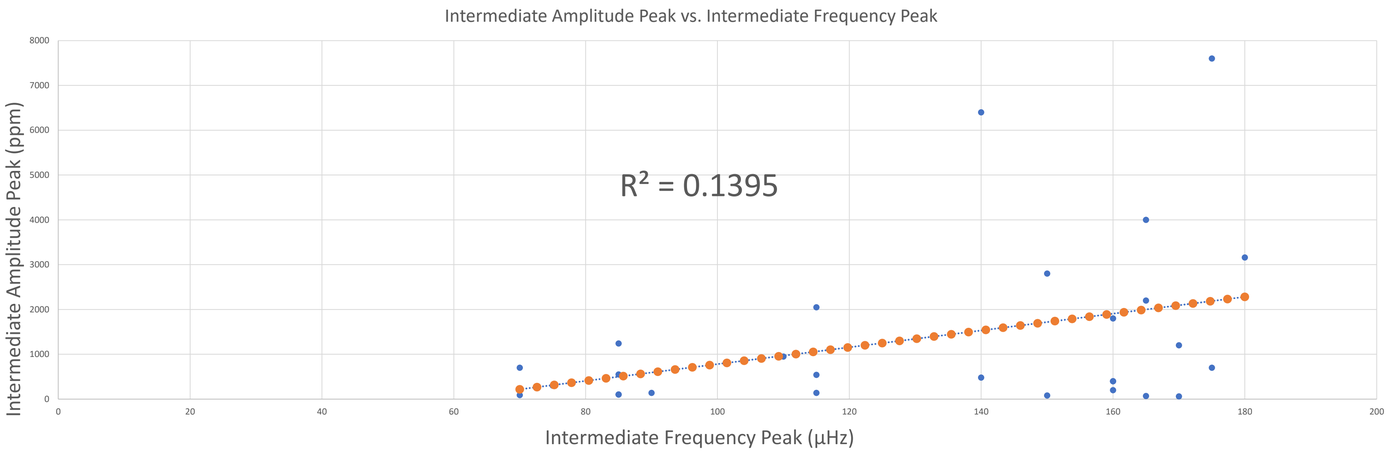
- Delta Sct/Gamma Dor hybrid: predominant frequencies in the frequency domain ≥ 5 d^{-1}, but several lower frequencies are of comparable amplitude
- Gamma Dor/ Delta Sct hybrid: predominant frequencies in the frequency domain ≤ 5 d^{-1}, but several higher frequencies are of comparable amplitude

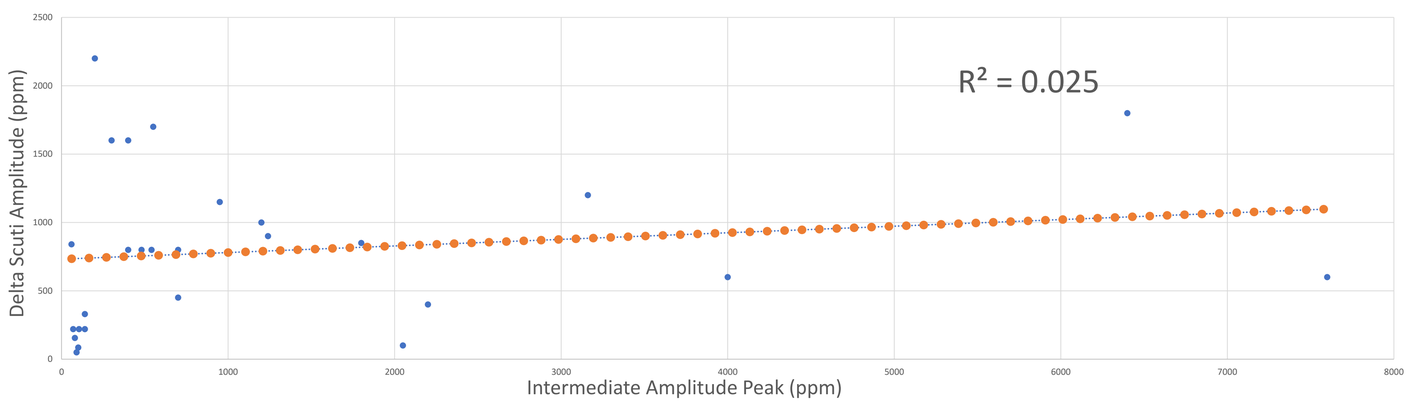
Discussion on Intermediate Frequencies

One can regard a third frequency regime as taking a set of frequencies in between the Delta Scuti and Gamma Doradus frequency regimes. It is called the intermediate frequency regime. Most of the frequency values within the regime have lower amplitude values that could be considered noise. However, we are concerned with the peak amplitudes contained within the regime. Specifically, we are concerned with the variability of the amplitude values at each peak. Using 32 different Kepler stars, we will analyze the correlations between the intermediate frequency regime and the amplitudes presented with the star classifications used in our analysis.

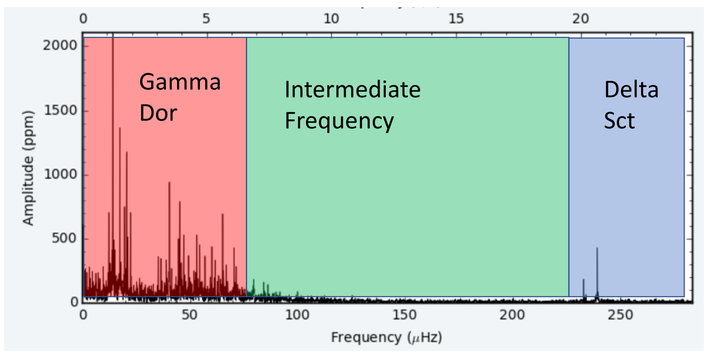
Methods and Results







From the dataset that contains 32 hybrid stars, we created a Microsoft Excel file containing each of the frequency and amplitude peaks for each of the three different star classifications. We performed data entry by taking printouts of the hybrid stars and considering the frequencies at each frequency regime. Those values map to the amplitude values. We created graphs with the trendlines and squares of correlation coefficients for each classification. Considering the squared value of the correlation coefficients is given, it is easy to derive the strength of the association between variables. We could derive a strong association between the Intermediate Amplitude peaks and the Gamma Doradus peaks. This finding helped us conclude a further observation regarding the periods of the stars of the Gamma Doradus dominant hybrid type. The periods of those stars are between 1.5-4 hours on the outer part of the star.



Conclusions

In conclusion, there is a significant correlation between the intermediate frequency amplitudes and Gamma Doradus amplitudes. This correlation means the multi-periodic nature of Gamma Doradus stars can be thought of by an association of a frequency regime and an existing frequency regime. From observing the intermediate peak amplitude values, it is uncertain if there is any observable pattern between the different peaks contained in the hybrid stars. A dataset containing more hybrid stars is needed to make a better conclusion. On the other hand, we concluded a weaker correlation exists between the Delta Scuti amplitudes and the intermediate frequencies. There would need to be further investigated through the Kepler Telescope database to see if other hybrid stars of Delta Scuti dominated can fit a stronger correlation. Not much more is known at this time.

References

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