Amplitude modulation in δ Sct stars: statistics from an ensemble of Kepler targets

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Abstract

The majority of δ Sct stars are non-periodic pulsators, in which the visible pulsation energy is not conserved over 4 yr. Where does the pulsation mode energy go?

Introduction

We present the results of a search for amplitude modulation of pulsation modes in 983 δ Sct stars from Bowman et al. (2016). The δ Sct stars are p mode pulsators and are found at the intersection of the main-sequence and the classical instability strip on the HR diagram [1]. Non-linearity can be caused by:

- Resonant mode coupling between a child and two parent modes, which appears as periodic amplitude modulation [2].
- Non-linear distortion model from the stellar medium not responding linearly to the pulsation wave, or the emergent flux variation not being a linear transformation of the temperature variation producing harmonics and combination frequencies [3].

Searching for amplitude modulation

An ensemble of 983 δ Sct stars between 6400 ≤ Teff ≤ 10000 K that were continuously observed by the Kepler Space Telescope for 4 yr was compiled.

A maximum of 12 pulsation modes above A ≥ 0.1 mmag were extracted from a star’s amplitude spectrum. The amplitudes and phases for each pulsation mode were tracked over 4 yr for each star in 30 bins, creating an amplitude modulation catalogue [1].

A star is classed as AMod if more than half of the amplitude bins lie more than ±5σ from the mean value in at least one pulsation mode. Otherwise, a star is classed as NoMod.

The number of AMod pulsation modes in each star is shown as a histogram to the right, with more than 60% of δ Sct stars classed as AMod.

Amplitude modulation is common across the classical instability strip on the HR diagram, suggesting that the possible causes are unrelated to stellar structure.

Modelling mode coupling

Coupled modes must satisfy: \( v_1 = n v_2 \pm m v_3 \) and \( \phi_1 = n \phi_2 \pm m \phi_3 \) where n and m take integer values [2]. To distinguish resonant mode coupling from a non-linear distortion model, a child mode amplitude is modelled using:

\[ A_1 = \mu_c (A_2 A_3) \]

where \( \mu_c \) is the coupling coefficient. Non-linearity in the form of mode coupling produces large values of \( \mu_c \) because mode energy is being exchanged. Non-linearity in the form of a non-linear distortion model produces small values of \( \mu_c \) as the combination frequency mimics the parent modes [2].

Case study: KIC 4733344

The amplitude spectrum and tracking plot for the AMod δ Sct star KIC 4733344 are shown below, and has the stellar parameters of:

\[ T_{\text{eff}} = 7200 \pm 250 \ \text{K} \]
\[ \log g = 3.50 \pm 0.25 \ \text{(cgs)} \]

Child mode amplitudes were modelled for different families of frequencies with an example shown in red below, which required small values of \( \mu_c \) indicating non-linearity in the form of combination frequencies from a non-linear distortion model and not resonant mode coupling [1].

In this δ Sct star and many others, the visible pulsation energy is not conserved, so where does the mode energy go if not to other pulsation modes?

Conclusions

- Amplitude modulation is common among δ Sct stars.
- The total visible pulsation energy is not conserved in many stars.
- Amplitude modulation is unrelated to \( T_{\text{eff}} \) and \( \log g \).
- Different forms of non-linearity can be interpreted using mode coupling models.

References