Amplitude modulation in δ Sct stars:

statistics from an ensemble of *Kepler* targets

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Take home message: 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:

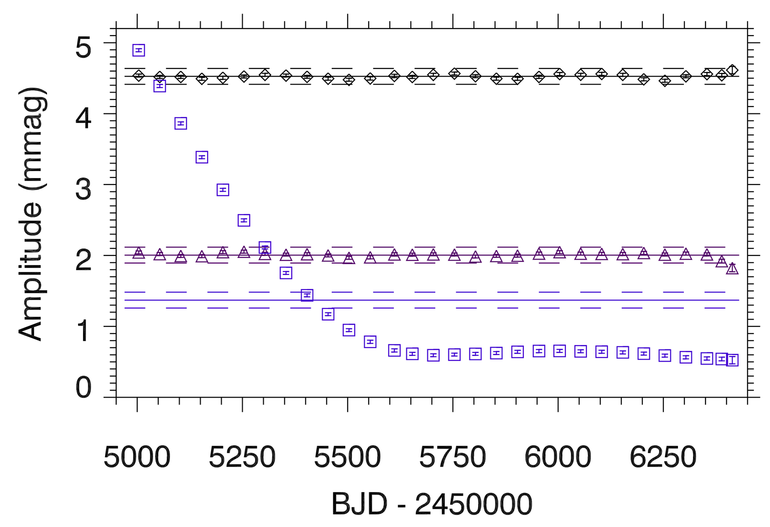
- **Resonant mode coupling** between a child and two parent modes, which appears as periodic amplitude modulation [4].
- **Non-linear distortion model** from the stellar medium not responding linearly to the pulsation wave, or the emergent flux variation not being a linear transformation of the temperature variation producing harmonics and combination frequencies [3].

Searching for amplitude modulation

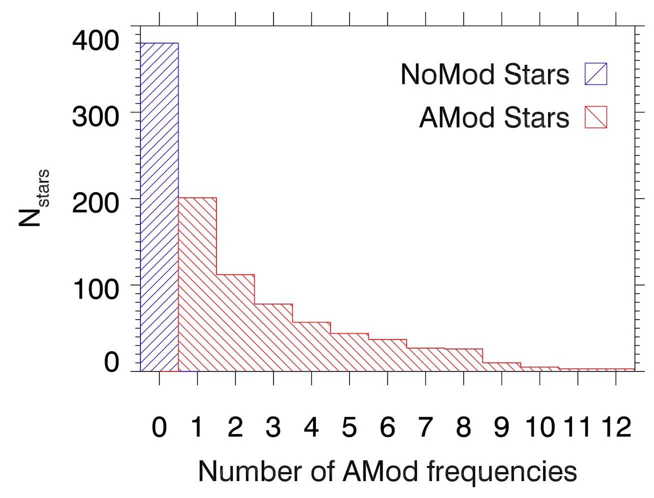
1. An ensemble of 983 δ Sct stars between $6400 \leq T_{\rm eff} \leq 10000$ K that were continuously observed by the *Kepler* Space Telescope for 4 yr was compiled.

2. 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].

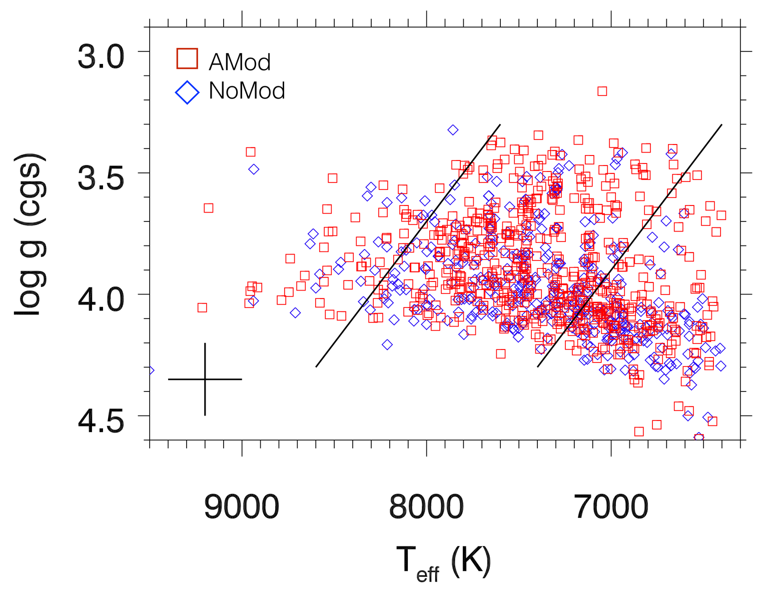
3. A star is classed as **AMod** if more than half of the amplitude bins lie more than ±5σ from the mean value in at least one pulsation mode. Otherwise, a star is classed as **NoMod**.



4. 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**.



5. 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: $\nu_1 = n\nu_2 \pm m\nu_3$ 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:

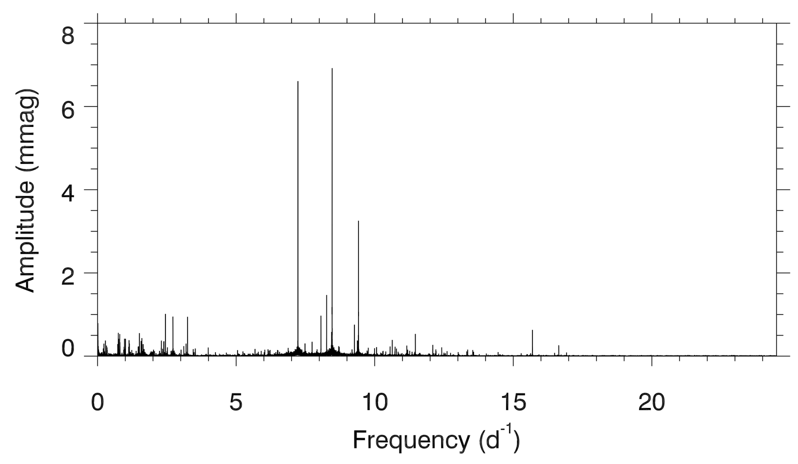
$$A_1 = \mu_C (A_2 A_3)$$

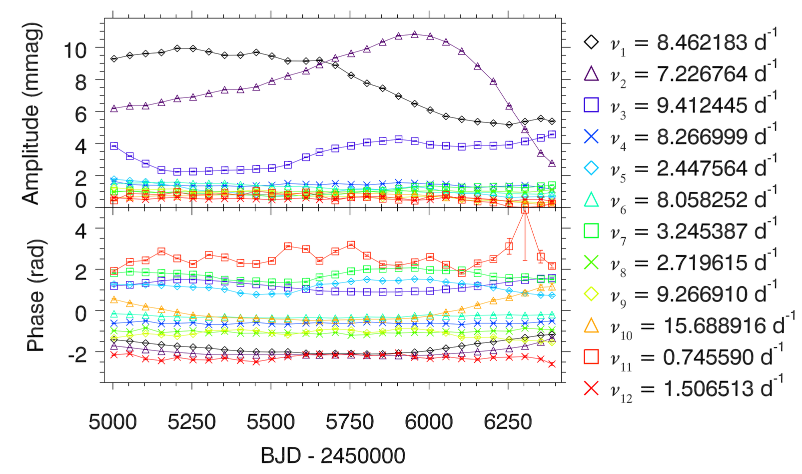
where μ_C is the **coupling coefficient**. Non-linearity in the form of mode coupling produces large values of μ_C because mode energy is being exchanged. Non-linearity in the form of a non-linear distortion model produces small values of μ_C as the combination frequency mimics the parent modes [2].

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:

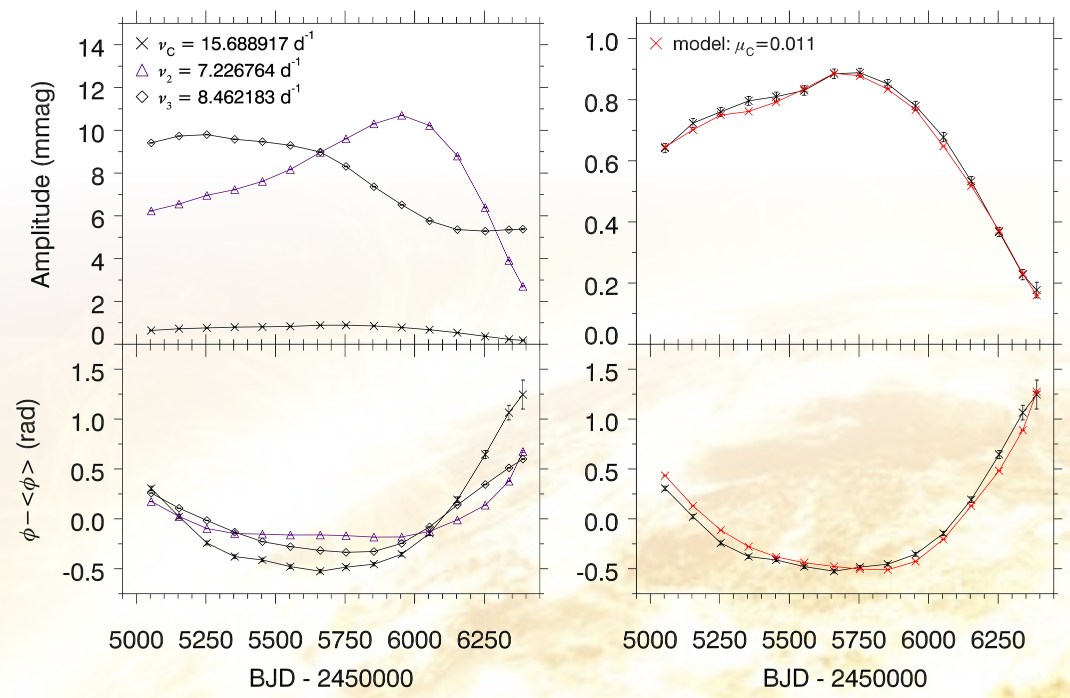
$T_{\rm eff}$ = 7200 ± 250 K $\qquad$ $\log g$ = 3.50 ± 0.25 (cgs)





Child mode amplitudes were modelled for different families of frequencies with an example shown in red below, which required small values of μ_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 $T_{\rm eff}$ and $\log g$.
- Different forms of non-linearity can be interpreted using mode coupling models.

Acknowledgements

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References

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