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Do red giants have short mode lifetimes?

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Abstract. We show evidence that the red giant star ξ Hya has an oscillation mode lifetime, τ, of about 2 days significantly shorter than predicted by theory (τ = 17 days, Houdek & Gough 2002). If this is a general trend of red giants it would limit the prospects of asteroseismology on these stars because of poor coherence of the oscillations.

1. Introduction

The mode lifetime of solar-like oscillations is an important parameter. The interpretation of the measured oscillation frequencies (and their scatter) relies very much on knowing the mode lifetime, but currently we know very little about how this property depends on the stellar parameters (mass, age and chemical composition). The theoretical estimates of mode lifetimes are based on a simplified description of the convective environment in which the damping and excitation of the modes takes place. Measurements of the mode lifetime in different stars will be very helpful for a more thorough treatment of convection in stellar modeling.

In the following we give a short description of the method introduced by Stello et al. (2005) to measure the large frequency separation, $\Delta\nu_0$, and mode lifetime, τ, of the solar-like oscillations in the red giant ξ Hya.

2. Measuring mode lifetime

We use the same data set as in Stello et al. (2004), which is single-site radial velocity observations covering almost 30 days. Fig. 1 shows the power spectrum of the time series. For further details about the observations and data analysis see Stello (2002); Frandsen et al. (2002); Teixeira et al. (2003); Stello et al. (2004, 2005).

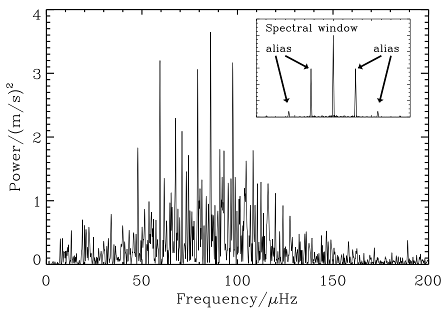

Fig. 1. Power spectrum of ξ Hya. The frequency axis of the spectral window in the inset is scaled to match that of the main plot.

We assume that the mode frequencies, ν_n, of ξ Hya show a simple comb pattern ($\nu_n \simeq \Delta\nu_0 n + X_0$, where $\Delta\nu_0$ and X_0 are constants and n is the mode order) in the power spectrum with only radial modes. This is supported

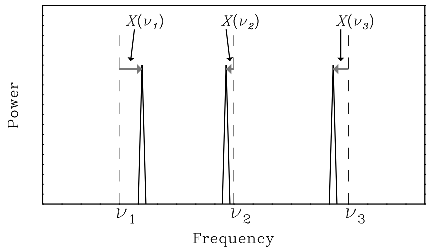

Fig. 2. Schematic illustration of the frequency scatter due to a finite mode lifetime (see text).

both by theory and observation (Christensen-Dalsgaard 2004; Stello et al. 2004). The finite lifetimes of the oscillations will introduce deviations of the measured frequencies from the true mode frequencies and hence from the comb pattern (Anderson et al. 1990). In Fig. 2 we illustrate this by showing, schematically, a comb pattern of 'true' mode frequencies (dashed lines) and the measured frequencies (solid peaks). The deviations, indicated with $X(\nu_i) \equiv (\nu_i - X_0) \bmod \Delta\nu_0$, are independent because each mode is excited independently. Shorter mode lifetimes give larger deviations.

We estimate the mode lifetime from the scatter of the measured frequencies about a regular comb pattern. Our method does not require us to assign the mode order or degree to the measured frequencies. They are therefore allowed to contain false detections from alias and noise peaks.

First, we find the comb pattern that best matches our observed frequencies, $\nu \equiv [\nu_1, \ldots, \nu_{\mathrm{N}}]$. We do this by minimizing the RMS of $X(\nu)$ (called σ_X), with $\Delta\nu_0$ and X_0 as free parameters. This gives us $\Delta\nu_0$ and X_0.

Secondly, we calibrate the minimum of σ_X, $\min(\sigma_X)$, against simulations with known mode lifetime. We simulated the ξ Hya time series using the method described in Stello et al. (2004). The oscillation mode lifetime was an adjustable parameter, assumed to be independent of frequency, while the other inputs for the simulator were fixed and chosen to reproduce the observations (see Stello et al. 2004, Fig. 12). For different values of the mode lifetime, we simulated 100 time series with different random number seeds. For each we measured 10 frequencies $(\nu_1, \ldots, \nu_{10})$ using iterative sine-wave fitting and then minimized σ_X. This provided 100 values of $\min(\sigma_X)$ for each mode lifetime, which we compare with the observations in Fig. 3. Only a few out of the 100 trials with $\tau = 17$ days (corresponding to the damping rate $\eta = 1/(2\pi\tau) \simeq 0.1\,\mu$Hz calculated by Houdek & Gough 2002) have a value for $\min(\sigma_X)$ as high as the observations. We

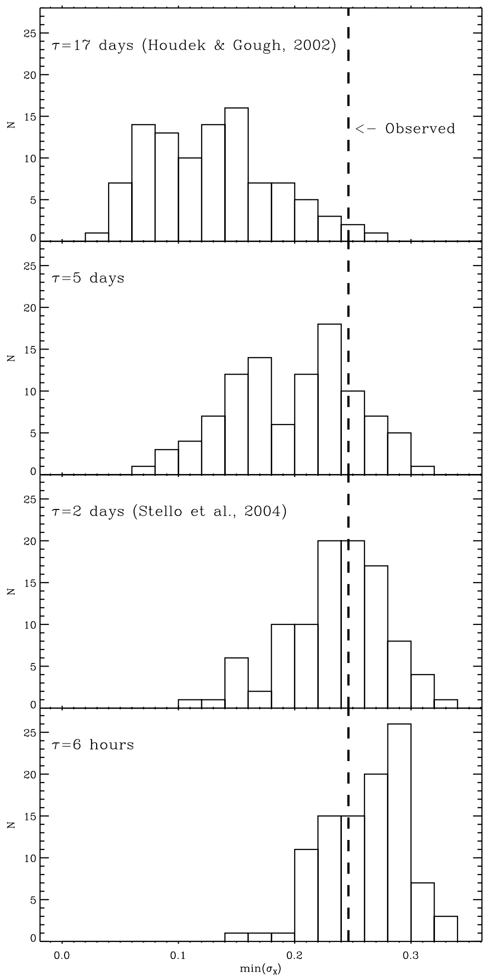

Fig. 3. Distribution of $\min(\sigma_X)$ from 100 simulations with different mode lifetimes: 17 days, 5 days, 2 days, and 6 hours. The dashed line indicates the value from the observations.

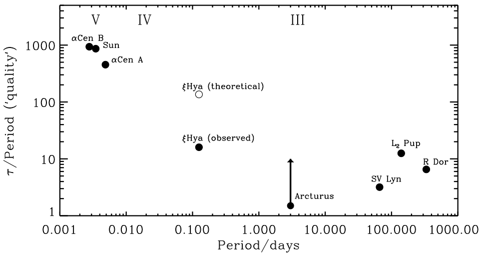

Fig. 4. Measured oscillation 'quality' factor vs. period. Empty symbol shows theoretical value. Arrow indicates lower limit. Luminosity classes are indicated. Values from: α Cen B, Kjeldsen et al. (2005); Sun, Chaplin et al. (1997); α Cen A, Kjeldsen et al. (2005); ξ Hya (theoretical), Houdek & Gough (2002); ξ Hya (observed), Stello et al. (2005); Arcturus, Retter et al. (2003); L_2 Pup, Bedding et al. (2005); SV Lyn and R Dor, Dind (2004).

find the best match with observations for mode lifetimes of about 2 days, in good agreement with Stello et al. (2004). However, we note that there is also a reasonable match for all mode lifetimes less than a day, as their distributions all look very similar to the bottom panel. Randomly distributed peaks also show similar distributions to $\tau = 6$ hours. Hence, if the mode lifetime of ξ Hya is only a fraction of a day it would definitely destroy any prospects for asteroseismology on this star.

In Fig. 4 we plot the ratios between the measured mode lifetime and period (the oscillation 'quality' factor) as a function of period for selected stars. Roughly speaking, the 'quality' factor is the number of cycles over which the oscillation is coherent, and the higher this number, the better we can determine the frequency. The observed point for ξ Hya indicates there is a steep decline in the quality factors for stars above the main sequence in the Hertzsprung-Russell diagram. If this is a general trend it will limit the extent by which we can use asteroseismology on these more evolved stars.

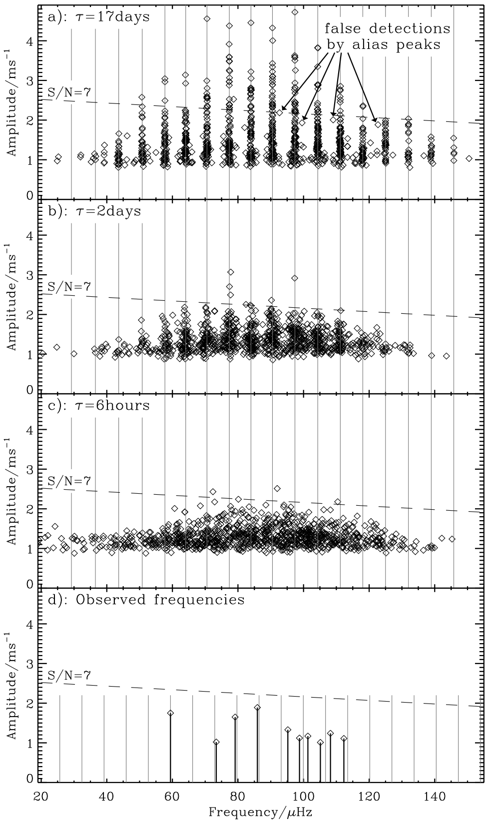

Fig. 5. Each panel shows 1000 measured frequencies and their amplitudes (10 from each of 100 simulations). Mode lifetimes are indicated in each panel. Dashed lines indicate 7 times the input noise, and the solid grey lines are the input frequencies. Panel (d): Observed frequencies and the best matching comb pattern (grey lines).

3. Frequency analysis

We investigated the reliability of the observed frequencies using the simulations described in Sect. 2. The measured frequencies, together with the input frequencies and noise level are plotted in Fig. 5. Apart from the broadening of the mode frequencies due to damping, we also see false detections of alias peaks. This is most easily seen in panel (a) where the damping is less (a few examples are indicated). Our test shows that frequencies are not unambiguous if S/N$\lesssim$7–8, even for mode lifetimes of 17

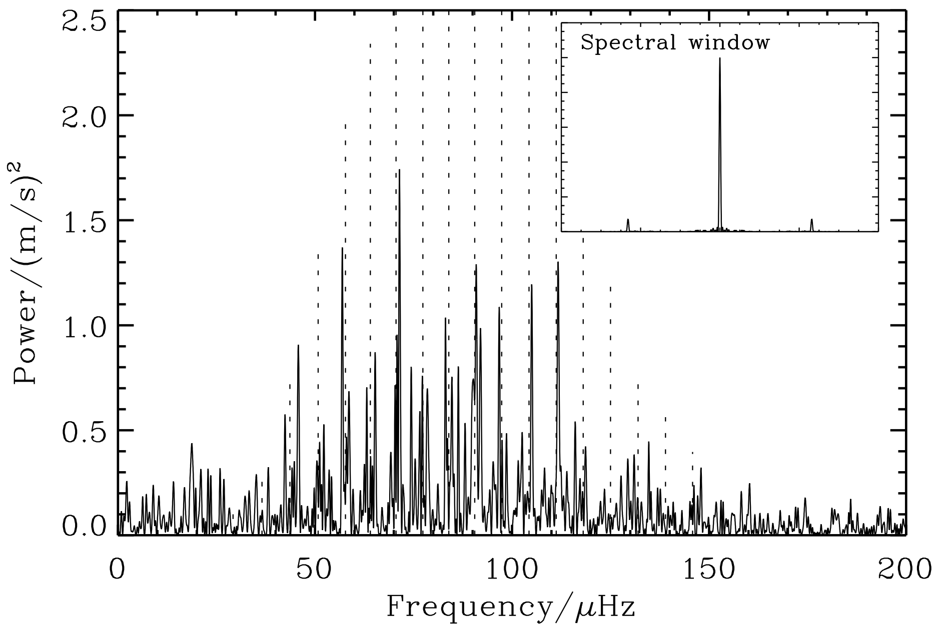

Fig. 6. Power spectrum of simulated two-site time series of ξ Hya (τ = 2 days). Dotted lines indicate the input frequencies.

days. For short mode lifetimes it looks rather hopeless to measure the individual mode frequencies with useful accuracy. The observed frequencies are all with S/N<6.3 and hence cannot be claimed to be unambiguous. The lack of a clear comb pattern similar to Fig. 5 (top panel) in the observed frequencies (bottom panel) also supports a short mode lifetime.

A difficulty in using the current observations of ξ Hya for asteroseismology arises from the severe crowding in the power spectrum. The crowding comes partly from the single-site spectral window, which emphasizes the importance of using more continuous data sets. To illustrate this, we made a power spectrum of a simulated two-site time series shown in Fig. 6. Each mode profile is seen much more clearly, though slightly blended due to the short mode lifetime. Obviously, more can be obtained from such a spectrum than from our present data set (Fig. 1), but a thorough analysis of similar simulations should be done to determine the prospects for doing asteroseismology on ξ Hya.

4. Conclusions

We find that the most likely mode lifetime of ξ Hya is about 2 days, and we show that the theoretical prediction of 17 days (Houdek & Gough 2002) is unlikely to be the true value.

Due to the high level of crowding in the power spectrum, the signature from the p-modes is too weak to determine the large separation to very high accuracy. However, our measurement supports the separation of 6.8 μHz found by Frandsen et al. (2002).

We conclude that the only quantities we can reliably obtain from the power spectrum of ξ Hya are the mode amplitude, mean mode lifetime, and the average large frequency separation.

Our simulations show that none of the measured frequencies from the ξ Hya data set

(Frandsen et al. 2002) can be regarded as unambiguous. Only in the case of a greatly improved window function could it be possible to detect frequencies unambiguously.

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