ASTEROSEISMIC MODELLING OF PROCYON A

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ABSTRACT

We present our preliminary results of modelling the F5 star Procyon A, including the comparison between the two different evolutionary codes that have been employed: ASTEC (Aarhus STellar Evolution Code) (Christensen-Dalsgaard, 2008b) and GARSTEC (Garching Stellar Evolution Code) (Weiss & Schlattl, 2008). Aarhus adiabatic pulsation package (ADIPLS) (Christensen-Dalsgaard, 2008a) has been used to calculate the frequencies of the models. Our modelling is compared to the preliminary frequency analysis of ground-based observations (see Poster P-II-015) which suggests two different mode identification scenarios (labelled A and B in that poster).

The position of the star in the H-R Diagram (HRD) that we adopted is relatively uncertain: T_{eff}=6530±90K (Fuhrmann et al. 1997) and $\log(L/L_{sun})$=0.85±0.06 (Steffen, 1985). We did not put an additional constraint on the radius for the time being, although we do compare the stellar mean density inferred from the analysis with the value 0.172±0.005 ρ_{sun}, obtained from the measured radius using the angular diameter 5.404±0.031 mas (Aufdenberg et al. 2005) and the revised Hipparcos parallax (285.93±0.88 mas), and the adopted mass 1.463±0.033 (Girard et al. 2000, Gatewood and Han 2006). The method we use is to compute several grids of standard models scanning through a parameter space formed by varying the mass, initial H, He and heavy-element abundances, and the mixing-length parameter, in order to find the evolutionary tracks lying inside the observational limits in the HRD. This procedure is followed by the calculation of the oscillation frequencies of the models having properties that are in agreement with the observations. Once we have those, we apply on the frequencies the corrections related to near-surface effects (Kjeldsen et al. 2008). Then we compare the corrected model frequencies with a preliminary set of observed frequencies (see Poster P-II-015). This work is on-going and we present preliminary results from an intermediate step of our work.

How we apply the near-surface effect corrections …

The method, which is described in detail by Kjeldsen et al. (2008), is based on an emprical law. It has been seen in the Sun that the difference between observed and calculated frequencies (Fig.1) can be fitted by a power law given by equation (1), with values of *a* and *b* to be determined. Equations (2) and (3) suggest that in order to get the mean density of the star correctly, we need *r* to be as close to 1 as possible. Using observed frequencies, they obtain the value of *b* as 4.90 for the Sun, and they show that the method is applicable also to some other (solar-like) stars as well. In this work, we use the solar *b* value and calculate *r* using equation (5), and *a* using equation (6). Once we have *r* and *a*, we correct the model frequencies using equation (4).

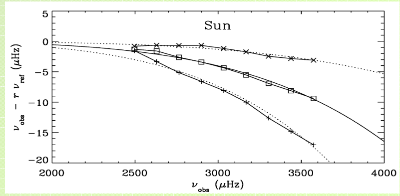

Figure1. Difference between observed and calculated frequencies for radial modes in the Sun, for different models of the Sun. (Fig. 1 of Kjeldsen et al. 2008)

$$\nu_{\rm obs}(n) - \nu_{\rm best}(n) = a\left[\frac{\nu_{\rm obs}(n)}{\nu_0}\right]^b \quad (1)$$

$$\nu_{\rm best}(n) = r\nu_{\rm ref}(n) \quad (2) \qquad \bar{\rho}_{\rm best} = r^2\bar{\rho}_{\rm ref} \quad (3)$$

$$\nu_{\rm obs}(n) - r\nu_{\rm ref}(n) = a\left[\frac{\nu_{\rm obs}(n)}{\nu_0}\right]^b \quad (4)$$

$$r = (b-1)\left[b\,\frac{\nu_{\rm ref}(n)}{\nu_{\rm obs}(n)} - \frac{\Delta\nu_{\rm ref}(n)}{\Delta\nu_{\rm obs}(n)}\right]^{-1} \quad (5)$$

$$a = \frac{\langle\nu_{\rm obs}(n)\rangle - r\langle\nu_{\rm ref}(n)\rangle}{N^{-1}\sum_{i=1}^{N}\left[\nu_{\rm obs}(n_i)/\nu_0\right]^b} \quad (6)$$

Details can be found in Kjeldsen et al. (2008).

Scenario A (We used MAP_1 (see Poster P-II-015), with $\Delta\nu_0$=54.59μHz)

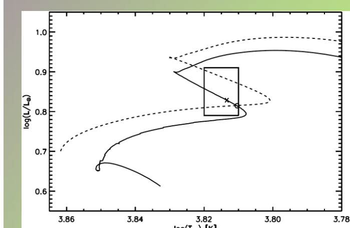

Figure2. Two examples of evolutionary tracks, for scenario A, out of many that pass through the error box. Dashed line shows the track for an ASTEC model (marked with a circle), while the solid line shows the track for a GARSTEC model (marked with a cross).

Scenario B (We used MAP_5 (see Poster P-II-015), with $\Delta\nu_0$=55.01μHz)

We present a few models out of many that have densities in agreement with the observed value as well as having more or less similar frequency pattern to the observations. Yet, it is interesting that the two codes have so far suggested different evolutionary status for the star, in both scenarios. The postMS ASTEC models having similar initial conditions to that of postMS GARSTEC models, did not have a density in agreement with the observations. This disagreement leads us to scan the parameter space in greater detail.

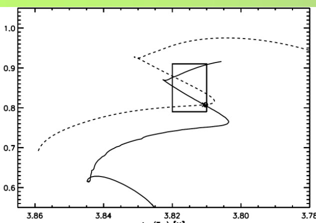

Figure5. Same as Fig. 2, for scenario B

CASE A	M/M_{sun}	initial element abundance	alpha	R/R_{sun}	mean density (ρ_{sun})	age (Gyr)	correction terms	Δv (μHz) before and after correction
ASTEC	1.47	X=0.70 Z=0.017	1.75	2.039	0.1733	1.76 (starting from ZAMS)	r=1.0005 a=-0.853	before:54.95 after:54.72
GARSTEC	1.4475	X=0.7026 Z=0.0174	1.744	2.046	0.1690	2.516 (starting from preMS)	r=0.9943 a=-0.01	before:54.90 after:54.60

Table1. Properties of the selected ASTEC and GARSTEC models for scenario A

CASE B	M/M_{sun}	initial element abundance	alpha	R/R_{sun}	mean density (ρ_{sun})	age (Gyr)	correction terms	Δv (μHz) before and after correction
ASTEC	1.475	X=0.70 Z=0.018	2.15	2.0262	0.1773	1.92 (starting from ZAMS)	r=1.0059 a=-3.725	before:56.21 after:55.54
GARSTEC	1.427	X=0.7068 Z=0.0174	1.744	2.0215	0.1728	2.82 (starting from preMS)	r=1.0214 a=-2.618	before:55.38 after:55.5

Table2. Properties of the selected ASTEC and GARSTEC models for scenario B

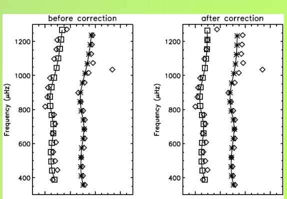

Figure3. Echelle diagram for the ASTEC model for scenario A. (diamonds: observations, squares: model freq. l=0, stars: model freq. l=1)

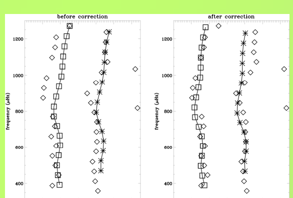

Figure4. Echelle diagram for the GARSTEC model for scenario A. (diamonds: observations, squares: model freq. l=0, stars: model freq.l=1)

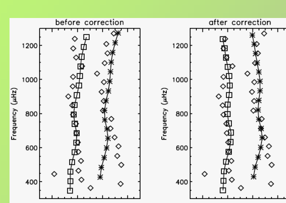

Figure6. Echelle diagram for the ASTEC model for scenario B. (diamonds: observations, squares: model freq. l=0, stars: model freq. l=1)

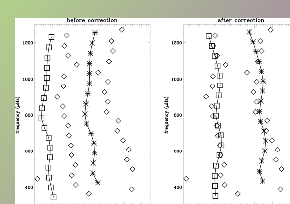

Figure7. Echelle diagram for the GARSTEC model for scenario B. (diamonds: observations, squares: model freq. l=0, stars: model freq.l=1)

What we see from the above figures is that; scenario A results in a better fit in the Echelle diagram than scenario B, since the low frequency range in scenario B has not so far seemed reproducable. On the other hand, the preliminary models for the scenario A indicate the absence of near-surface effects, which is expected to be seen in solar-like stars. However, these results suggest more detailed analysis along with improvement of the physics used in the models.

DISCUSSION

Although Procyon A has always been a preferred target for asteroseismic investigations, the unfortunate combination of large line widths and modest rotational splitting makes the ridge investigation rather difficult for this star. Following the two possible identification scenarios suggested by the preliminary analysis (see poster P-II-015), we present the obstacles we face in our modelling attempts. We have not yet reached to a conclusion either about the evolutionary status or global parameters of the star. As seen from the above discussion, none of the identification scenarios is strongly favoured, either. However, we believe that what we see in Procyon will guide us to improve our understanding of such stars, thus prove the efforts in asteroseismology are worth!

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