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About Procyon modeling

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Abstract. Models of Procyon satisfying the actual observational constraints, particularly the asteroseismic ones, are discussed. It is shown that much more accurate frequencies must be obtained by asteroseismic observations especially in the low frequency domain below 800 μHertz to determine the Procyon evolutionary stage.

1. Observations

Two-site observations of Procyon A have been carried out by Martić et al. (2004 - M04). Peaks of frequencies of acoustic modes with degrees ℓ=0, 1, 2 have been identified in the power spectrum in the frequency range 300 – 1400 μHz (M04, Eggenberger et al 2004 - E04). The observers give a measure of the mean large frequency spacing $< \Delta\nu >$ (defined hereafter): $\sim 53.5 \pm 0.5\,\mu$Hz (M04) and $\sim 55.5 \pm 0.5\,\mu$Hz (E04) (Figure 1).Observational constraints on mass, effective temperature, radius and metallicity, are summarized in Table 1 (ref. in Provost et al. 2004).The last constraint is derived from galaxy chemical evolution.

2. Characteristics of the models

1.38	$< M/M_{\odot} <$	1.48
6480	$< T_{\rm eff} <$	6580
2.023	$< R/R_{\odot} <$	2.073
-0.08	$< [Fe/H]_S <$	-0.02
1	$< \Delta Y/\Delta Z <$	4

Models satisfying all the above constraints have been computed with the CESAM code (Morel 1997) and updated physics (Provost et al, in progress). The microscopic diffusion is taken into account with an additional mixing process according to Morel & Thévenin (2002). They are either in the main sequence (MS) or in post main sequence (PoMS). The MS models correspond to masses 1.42 to 1.48 $M_{\odot}$, with a small amount of core overshoot. They have a small convective core less than 0.1 $R_{\star}$, ages from 1400 to 2000 Myr and high values of Y_i ($\geq$ 0.3) and $(Z/X)_i$ ($\geq$ 0.030). The PoMS models have smaller masses, smaller Y_i and $(Z/X)_i$ and larger ages (Figure 2). The uncertainty on the radius induces an uncertainty on the age of about 40 to 80 Myrs. Note that due to the properties of its white dwarf companion, it is expected that the age of Procyon A has to be at least 2000 Myr (Kervella et al 2004).

3. Seismic properties of the models

Adiabatic frequencies have been computed in the observed frequency range for the set of models. The spectrum of the PoMS models contains some mixed and gravity type modes. We compare the theoretical and observed large and small spacings.

$$\Delta\nu_{n,\ell} = \nu_{n,\ell} - \nu_{n-1,\ell},$$

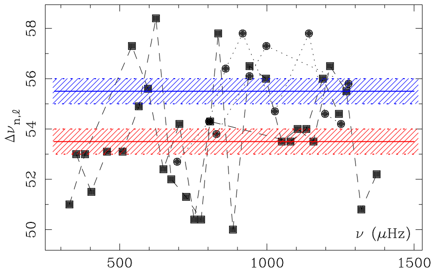

Fig. 1. Large frequency spacings for degrees $\ell = 0, 1$ for frequencies of M04 (square) , and E04 (dot). $< \Delta\nu >$ is indicated with its uncertainty for the two sets of observations.

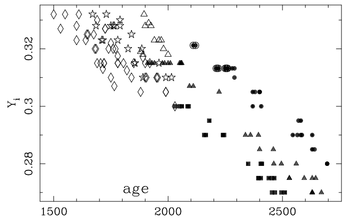

Fig. 2. Initial helium versus age for MS (open symbols) and PoMS (filled symbols) models. Circle 1.38 $M_\odot$; triangle 1.42 $M_\odot$: stars 1.44 $M_\odot$; square 1.45 $M_\odot$; losange 1.46 $M_\odot$.

$$\delta\nu_{01} = 2\nu_{n,\ell=0} - (\nu_{n,\ell=1} + \nu_{n-1,\ell=1}).$$

In the high frequency range, higher than 800 μHz, most of our models have a mean large spacing $< \Delta\nu >$ larger than 54μHz. However the uncertainty on the radius induces an uncertainty on $< \Delta\nu >$ of about 1μHz. The large spacings have a different behavior for degree $\ell = 0$ and 1 in the lower part of the frequency domain, below 800 μHz, due to the presence for PoMS models of mixed modes (Figure 3).

The behavior of $\delta\nu_{01}$ is very different according the evolutionary stage of the models. For MS models, $\delta\nu_{01}$ decreases with the frequency ($S_1 \leq 0$) while for PoMS ones, it increases ($S_1 \geq 0$) (Figure 4). In conclusion, the importance of the small frequency spacing $\delta\nu_{01}$ to determine the stage of evolution of Procyon and to discriminate between the models is pointed out. Detection and accurate determination of frequencies of degrees $\ell = 1$ in the low frequency range, where mixed modes may appear, are urgently needed to go further.

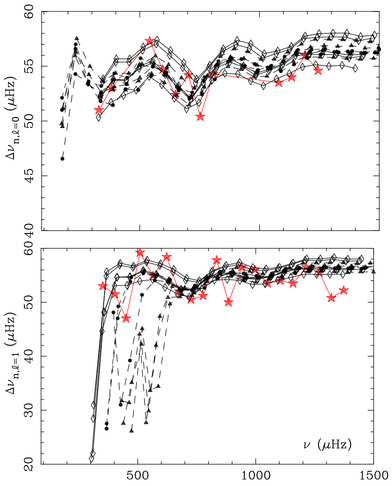

Fig. 3. Large frequency spacings for ℓ=0 (up) and 1 (down) for MS/PoMS models (full/dashed line) with 1.38, 1.42, 1.45 and 1.46 $M_\odot$ compared to M04 observations (stars).

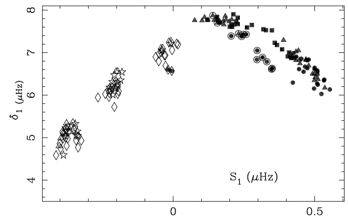

Fig. 4. Behavior of the small spacing $\delta\nu_{01}$ with the frequency (same symbols than in Fig. 2): $\delta\nu_{01}$ has been approximated in the high frequency range (800 – 1400 μHz) by: $\delta\nu_{01} \approx \delta_1 + S_1(n - n_0) + \gamma_1(n - n_0)^2$, where n is the radial order. MS models are grouped according to the values of the core overshoot parameter: ζ = 0.2, 0.1, 0 (from left to right).

References

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