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Treatment of Opacities in Stellar Modeling and Asteroseismology

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Abstract. We have tested the effect of the new generation of OPAL opacities as well as a more sophisticated way of interpolating in the opacity data. Models have been computed for the binary system α Centauri and constraints given by asteroseismology are discussed.

1. Introduction

Alpha Centauri is the nearest binary system to the Sun. It is a visual binary system and has two solar-like components, α Cen A and B. Both stars can reasonably be assumed to have the same age and a recent spectroscopic analysis (Neuforge & Magain 1997) has shown that they have the same chemical composition.

For a given physical assumption, the theoretical models of α Cen A and B depend on nine *free parameters:* the masses M_A and M_B of each component, the age t of the system, its hydrogen content X, its metallicity Z, the two convection parameters α_A and α_B, the distance D of the system, and its orbital semi-major axis a. These parameters have to be adjusted so that the models reproduce a set of observables within their error bars. In the α Cen system, the *observables* and their 1-σ error bars are the following ones: the parallax of the system $\pi = 0.''74212 \pm 0.0014$ (Hipparcos 1997), the orbital period $P = 79.92 \pm 0.01$ yr and the apparent orbital semi-major axis $a' = 17''.515 \pm 0''.05$ (Heintz 1982), the mass ratio $\frac{M_B}{M_A+M_B} = 0.454 \pm 0.002$ (Kamper & Wesselink 1978), the visual magnitudes $m_{v,A} = -0.01 \pm 0.005$, $m_{v,B} = 1.33 \pm 0.005$ (Ochsenbein et al. 1984), the effective temperatures $T_{eff,A} = 5830 \pm 30\mathrm{K}$, $T_{eff,B} = 5255 \pm 50\mathrm{K}$, the surface gravities $\log g_A = 4.34 \pm 0.05$, $\log g_B = 4.51 \pm 0.08$ and the logarithmic abundance ratio of iron to hydrogen, relative to the corresponding ratio for the Sun, [Fe/H] $\simeq [Z/X] = 0.25 \pm 0.06$ (Neuforge & Magain 1997). Note that the error bar on [Fe/H] includes a 10% uncertainty on $(Z/X)_\odot$.

We use the method of Brown et al. (1994) to determine the values of the parameters. A reference model is computed for an initial and reasonable guess of the parameters. These are then adjusted in order to lead to a satisfactory fit (χ^2 minimum) between the models and the observables.

2. Input physics and models

The calibrations were performed with the Liège stellar evolution code originally developed by Henyey et al. (1964). The input physics is described in Neuforge et al. (1997). Our models do not include diffusion.

In Case I, the interior opacities are OPAL opacities taken from Iglesias et al. (1992). In Case II, the interior opacities are the revised version of the previous ones (Iglesias & Rogers 1996) and the interpolations between the tables are performed by specific procedures written by the OPAL group rather than linearly. For the same set of input parameters, the differences between the Case I and Case II reference models mainly arise in the convection zone, due to the opacity change between $\log T = 4$ and 5.5.

The SVD procedure leads for Case I (resp. Case II): $M_A(M_\odot) = 1.124 \pm 0.012$ (1.124 ± 0.012), $M_B(M_\odot) = 0.936 \pm 0.011$ (0.937 ± 0.011), $X = 0.691 \pm 0.026$ (0.698 ± 0.017), $Z = 0.030 \pm 0.003$ (0.030 ± 0.004), t(Gyr) $= 5.41 \pm 1.44$ (5.99 ± 1.05), $\alpha_A = 2.27 \pm 0.26$ (2.39 ± 0.25), $\alpha_B = 2.31 \pm 0.40$ (2.51 ± 0.42), D(pc) $= 1.347 \pm 0.003$ (1.347 ± 0.003), a(AU) $= 23.60 \pm 0.08$ (23.60 ± 0.08).

In each case, the residuals of the fit are all much smaller than the observational errors: the change in physics remains thus hidden in slight parameter adjustments.

3. Testing oscillation constraints

We attempted to discriminate between models computed with the two sets of OPAL opacities using p-mode oscillation frequencies. Although no ambiguous detection has been reported yet, oscillation data of low degree might nevertheless soon be obtained for α Cen A (Kjeldsen & Bedding 1997). For the Case II reference model, we calculated p-modes oscillation frequencies in α Cen A for $l = 0, 1, 2, 3$ and for $1300 \mu Hz \leq \nu_{nl} \leq 3300 \mu Hz$. These p-mode oscillation frequencies were added to the observables previously derived from the Case II reference model so as to form a more extended set of "observations" to be fitted by Case I models. The error on each individual frequency has been assumed to be 2 μHz.

The residuals of the fit are again observationally insignificant: parameter adjustments in Case I models allow us to reproduce the "observations" provided by the Case II models. Thus, adding α Cen A oscillation frequencies data does not allow us to distinguish between the two sets of opacity data.

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