P-MODE OSCILLATIONS OF α CEN A

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Abstract. Models of α Cen A & B have been computed using the masses determined by Pourbaix et al. (2002) and the data derived from the spectroscopic analysis of Neuforge and Magain (1997). The seismological data obtained by Bouchy and Carrier (2001, 2002) do help improve our knowledge of the evolutionary status of the system. All the constraints are satisfied with a model which gives an age of about 6 Gyr for the binary.

Keywords: stars: binaries: visual – stars: individual: α Cen – stars: oscillations – stars: evolution

1. Introduction

The binary system Alpha Centauri offers a unique opportunity to test our knowledge of stellar physics in solar-type stars other than the Sun. Its proximity allows very good determinations not only of its parallax but also of its orbital parameters so that the masses and the luminosities of both components can be determined. In addition, effective temperatures and chemical compositions can be obtained through spectroscopic analyses. Recently, solar-like p-mode oscillations have been discovered in α Cen A from ground-based analysis (Bouchy and Carrier, 2001; Carrier et al., 2002; Bouchy and Carrier, 2002).

In a very recent calibration and stability analysis, Thévenin et al. (2002) have found that the asteroseismological constraints, namely the large and small frequency spacings, required a slight decrease in the mass assigned by Pourbaix et al. (2002) to α Cen A.

Using an entirely new numerical code and a slightly different physics, we find models for the α Cen binary system which agree not only with all the non asteroseismic constraints, including the masses and the requirement of the same age for both components, but also with the asteroseismic constraints, including the frequencies themselves.

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2. Observational Constraints

We adopt the masses determined by Pourbaix et al. (2002), i.e., $M_A/M_\odot = 1.105$ and $M_B/M_\odot = 0.934$. From their spectroscopic analysis of the α Centauri system, Neuforge and Magain (1997) have determined the effective temperature, the gravity and the metallicity of both components. The effective temperatures are given by $T_{\mathrm{eff},A} = 5830 \pm 30$K and $T_{\mathrm{eff},B} = 5255 \pm 50$K. The gravities are given by $\log g_A = 4.34 \pm 0.05$ and $\log g_B = 4.51 \pm 0.08$. For the metallicity, they obtained $[\mathrm{Fe/H}]_A = 0.25 \pm 0.02$ and $[\mathrm{Fe/H}]_B = 0.24 \pm 0.03$. To deduce Z/X, we assume that this ratio is proportional to the abundance ratio Fe/H and we adopt the solar value $(Z/X)_\odot = 0.023$ with an uncertainty of 10 %, given by Grevesse and Sauval (1998). We then have the same value for both components of α Cen: $Z/X = 0.040 \pm 0.005$. However, Grevesse and Sauval (private communication) now favour a lower value $(Z/X)_\odot = 0.0209$ with the same uncertainty. With this value, we would have $Z/X = 0.037 \pm 0.004$. It seems safe to say that Z/X is between 0.033 and 0.045.

3. The Models

A number of evolutionary sequences have been computed from the main sequence with CLÉS (Code Liégeois d'Évolution Stellaire).

We have computed a number of models for both components, with different initial chemical compositions, defined by (X, Z), and convection parameter α. We require that both components of the binary system reach their respective positions in the HR-diagram at the same age. This requirement of simultaneity determines a line in the (X, Z)-diagram to the right of which the B component reaches its observed position in the HR-diagram after the A component has already left its own observed position. This constraint, together with the constraint on the Z/X value, delimits a permitted area in the (X, Z) diagram.

4. Asteroseismology of α-Centauri

We have calculated the oscillation frequencies of α Cen A using a standard adiabatic code, for a grid of models where the mass M_A is fixed at the value determined by Pourbaix et al. (2002), i.e., $M_A = 1.105 M_\odot$. The only free parameters are α, X, and Z, and the last two can only vary within the permitted area.

The oscillation mode (l=0, n=21) is the one with the highest amplitude in the Bouchy and Carrier (2002) spectrum, and we assumed therefore that it is the best observationally determined mode. Therefore, for each sequence of evolution, and within the error boxes on (T_{eff}, $L/L_\odot$), we determined the model for which the oscillation frequency of the mode (l=0, n=21) fits exactly the observed frequency.

TABLE I
Mode frequencies (in μHz) of α Cen A.

	Observations[a]			Our model		
	$l=0$	$l=1$	$l=2$	$l=0$	$l=1$	$l=2$
n = 15			1833.1	1730.5	1778.5	1828.0
n = 16	1841.3	1887.4	1934.9	1834.9	1882.8	1932.6
n = 17		1991.7	2041.5	1939.3	1987.7	2038.1
n = 18		2095.6	2146.0	2044.4	2093.7	2144.7
n = 19	2152.9	2202.8	2251.4	2150.8	2200.4	2251.7
n = 20	2258.4	2309.1	2358.4	2257.5	2307.5	2358.7
n = 21	**2364.2**	2414.3	2464.1	**2364.2**	2414.4	2465.9
n = 22	2470.0	2519.3	2568.5	2471.0	2521.5	2573.1
n = 23	2573.1	2625.6		2578.0	2629.0	2681.0
n = 24	2679.8	2733.2	2782.9	2685.5	2736.9	2789.2
n = 25	2786.2	2837.6	2887.7	2793.4	2845.2	2897.6

[a] Bouchy and Carrier (2002).

We calculated the modes $l = 0$, $l = 1$ and $l = 2$ for n=15 to 25. The results are summarized in Table I. We then calculated the large frequency spacings $\Delta\nu_{l,n} = \nu_{l,n} - \nu_{l,n-1}$ and the small frequency spacings $\delta\nu_{0,n} = \nu_{l,n} - \nu_{l+2,n-1}$ and their averages over n=15 to 25. We have also calculated the small spacings $\delta\nu(n) = \nu_{n+1,0} + \nu_{n,0} - 2\nu_{n,1}$.

5. Discussion and Conclusions

Our best model satisfies all the observational constraints and corresponds to $X = 0.70$ and $Z = 0.0275$ for the chemical composition, $\alpha_A = \alpha_B = 1.8$ for the mixing-length parameter (the value for the sun is 1.77), and yields an age of 6.41Gyr for the α Cen system.

The average of the large spacings is slightly larger than the one obtained from the observations, but those large spacings remain within the error bars, as shown in Figure 1. The values for the small spacings fall within the error bars as well, as shown in Figure 1. The small frequency spacings $\delta\nu(n)$ are slightly larger than the observed ones, but fall within the error bars, except for the largest frequencies. Finally, we note that this solution was found for a value of the mixing-length parameter α very close to the solar value.

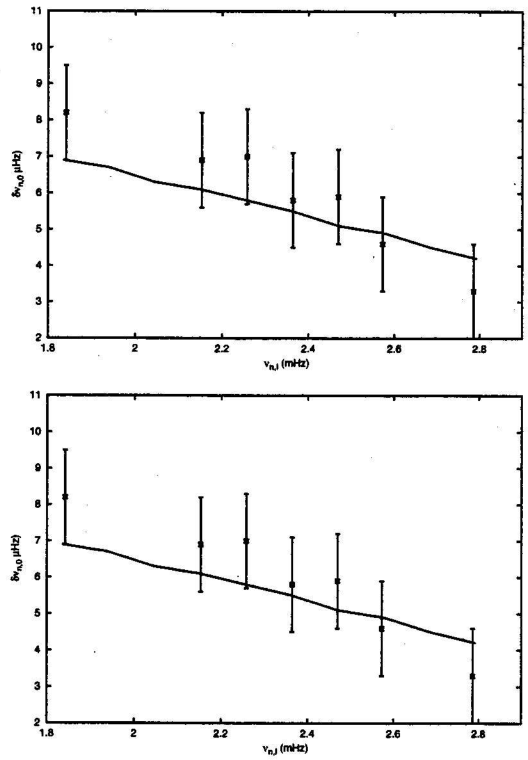

Figure 1. Large and small frequency spacings as a function of the frequency. The symbols indicate the values obtained by Bouchy and Carrier (2002), with error bars of $\pm 1.3\mu$Hz. The three lines correspond to our model for $l = 0$, $l = 1$ and $l = 2$.

References

Bouchy, F. and Carrier, F.: 2001, *A&A* **374**, L5.

Bouchy, F. and Carrier, F.: 2002, *A&A* (in press).

Carrier, F., Bouchy, F., Meynet, G., Maeder, A., Provost, J., Berthomieu, G. and Thévenin, G.: 2002, in: C. Aerts, T.R. Bedding and J. Christensen-Dalsgaard (eds.) *Radial and Nonradial Pulsations as Probes of Stellar Physics*, *A.S.P. Conf. Ser.* **259**, 460.

Grevesse, N. and Sauval, A.J.: 1998, *Space Sci. Rev.* **85**, 161.

Neuforge-Verheecke, C. and Magain, P.: 1997, *A&A* **328**, 261.

Pourbaix, D., Nidever, D., McCarthy, C., Butler, R.P., Tinney, C.G., Marcy, G.W., Jones, H.R.A, Penny, A.J., Carter, B.D., Bouchy, F., Pepe, F., Hearnshaw, J.B., Skuljan, J., Ramm, D. and Kent, D.: 2002, *A&A* **386**, 280.

Thévenin, F., Provost, J., Morel, P., Berthomieu, G., Bouchy, F. and Carrier, F.: 2002, *A&A* (in press).