

## Upward Revision of the Individual Masses in Alpha Cen: Implications for the Evolutionary State of the System

C. Neuforge<sup>1,3</sup>, D. Pourbaix<sup>2</sup>, A. Noels<sup>1</sup> and R. Scuflaire<sup>1</sup>

<sup>1</sup>*Institut d'Astrophysique et de Géophysique, University of Liège, Belgium.*

<sup>2</sup>*Royal Observatory of Belgium*

**Abstract.** A new calibration of the  $\alpha$  Cen system is presented. It shows that a theoretical model consistent with the observations and with the higher masses determined by Pourbaix (1999) can be obtained. Our model of  $\alpha$  Cen A has a convective core. This could serve as a discriminant in a future asteroseismological calibration of the system.

### 1. Introduction

The previous determinations of the orbital parameters of the binary system  $\alpha$  Cen (Kamper & Wesselink 1978, Heintz 1982 and Hipparcos 1997) lead, through a calibration of the system (Neuforge & Noels 1998), to the following masses for each component:  $M_A = 1.12 M_\odot$  and  $M_B = 0.94 M_\odot$ . These results are very close to those obtained with the parallax of Demarque, Guenther, & van Altena (1986):  $M_A = 1.09 M_\odot$  and  $M_B = 0.91 M_\odot$ .

Pourbaix (1999) has performed a new orbital parameters determination based on a simultaneous adjustment of the visual and spectroscopic data. His analysis leads to upward revisions of the distance to  $\alpha$  Cen and of the individual masses of both components:  $M_A = 1.16 \pm 0.031 M_\odot$  and  $M_B = 0.97 \pm 0.032 M_\odot$ .

In this work, we examine the effects of these revisions on the evolutionary state of the system, with a special emphasis on  $\alpha$  Cen A and discuss the implications on the importance of future asteroseismology data.

### 2. Model parameters and observations

A calibration of the  $\alpha$  Cen system consists in adjusting the parameters contained in the theoretical models of the system so that these models reproduce the available observables within their error bars.

The parameters are the following ones: the masses  $M_A$  and  $M_B$  of each component, the age  $t$  of the system, its initial hydrogen content  $X$  and its initial

---

<sup>3</sup>Chargé de Recherches of the Belgian Fund for Scientific Research

metallicity  $Z$ , the two convection parameters  $\alpha_A$  and  $\alpha_B$ , the distance  $D$  of the system and the orbital semi-major axis  $a$ .

The observables constraining the models are: the parallax of the system  $\pi = 0''.737 \pm 0''.0026$ , the orbital period  $P = 79.90 \pm 0.013$  yr, the orbital semi-major axis  $a = 23.88 \pm 0.080$  AU, the fractional mass  $\frac{M_B}{M_A+M_B} = 0.45 \pm 0.013$  (Pourbaix 1999), the visual apparent magnitudes  $m_{v,A} = -0.01 \pm 0.005$ ,  $m_{v,b} = 1.33 \pm 0.005$  (Hoffleit & Jaschek 1982), the effective temperatures  $Te_A = 5830 \pm 30$  K,  $Te_B = 5255 \pm 50$  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 heavy elements to hydrogen, relative to the corresponding ratio for the Sun,  $[Z/X] = 0.25 \pm 0.06$  (Neuforge & Magain 1997). Moreover, the helium content of the system,  $Y = 1 - X - Z$ , must lie in the interval  $[0.23, 1]$ .

To constrain our models, we considered the orbital period and the fractional mass determined by Pourbaix (1999) instead of his derived individual masses. These masses being dependent quantities, our choice ensures that our solution will lead to an orbital period and a fractional mass located within the observational error bars.

### 3. Input physics and models

The calibrations were performed with the Liège stellar evolution code based on a first version originally developed by Henyey, Forbes, & Gould (1964). The Debye-Huckel corrections (Noels, Scuflaire, & Gabriel 1984) are included in the equation of state of Bodenheimer et al. (1965), the nuclear reaction rates are those of Fowler, Coughlan, & Zimmerman (1975), the treatment of the photospheric layers is taken from Krishna Swamy (1969), the interior opacities are OPAL opacities taken from Iglesias & Rogers (1996), the low- $T$  opacities ( $T \leq 10^4$  K) are from Neuforge (1993) and the bolometric corrections are taken from Flower (1996). Our models do not include diffusion and settling.

We use the method presented in Brown et al. (1994) to calibrate the system. The model is linearized in the parameters. The initial guess of the parameters should thus be close enough to the real solution.

The solution of the calibration is:  $M_A = 1.17 M_\odot$ ,  $M_B = 0.96 M_\odot$ ,  $X = 0.686$ ,  $Z = 0.030$ ,  $t = 2.7$  Gyr,  $\alpha_A = 1.86$ ,  $\alpha_B = 2.1$ ,  $D = 1.3568$  pc,  $a = 23.88$  AU.

The masses are mainly determined by the orbital period and the fractional mass of the system.

### 4. Implications on asteroseismology

We computed one  $\alpha$  Cen A model (Model 1) with the parameters derived from our calibration. The parameters and the physical characteristics of this model are presented in Table 1. We verified that our model agrees with the observational constraints. Table 1 also presents the results of a previous calibration (Model 2) performed with the same input physics and data except for the orbital parameters which have been taken from Kamper & Wesselink (1978), Heintz

(1982) and Demarque et al. (1986). The bolometric corrections are also slightly different, but their effect is negligible on the calibration.

Table 1. Model parameters (mass, initial hydrogen content, initial metallicity, age and convection parameter) and physical characteristics (visual magnitude, effective temperature  $Te$  (in K), central hydrogen content  $X_c$ , central temperature  $T_c$  (in K) and central density  $\rho_c$  (in  $\text{g}/\text{cm}^3$ )) of the calibrated models of  $\alpha$  Cen A.  $\Delta\nu$  and  $\delta\nu$  are respectively the large and the small p-mode frequency separations (in  $\mu\text{Hz}$ ).

	Model 1	Model 2
Model parameters		
$M_A$	1.17	1.088
X	0.686	0.680
Z	0.030	0.030
t	2.7	6.2
$\alpha_A$	1.86	2.3
Physical characteristics		
$m_{v,A}$	-0.01	-0.01
$Te_A$	5848	5826
$X_c$	0.359	0.006
$T_c$	1.725E7	1.873E7
$\rho_c$	1.271E2	3.003E2
$\Delta\nu$	107.5	106.8
$\delta\nu$	8.71	5.71

Both  $\alpha$  Cen A models lie on the main sequence, but model 1 has a small convective core, as a result of its higher mass.

We also computed the p-mode oscillation frequencies in both models for  $l = 0, 1, 2, 3$  and for  $1300 \mu\text{Hz} \leq \nu_{nl} \leq 3300 \mu\text{Hz}$ . Although no ambiguous detection has been reported yet, oscillation data of low degree might nevertheless soon be obtained from  $\alpha$  Cen A (Kjeldsen & Bedding 1997). We computed the large and the small p-mode frequency separations,  $\Delta\nu = \langle \nu_{n,l} - \nu_{n-1,l} \rangle_{(l,n)}$  and  $\delta\nu = \langle \nu_{n,l=0} - \nu_{n-1,l=2} \rangle_{(n)}$ .  $\nu$  is the frequency of the p-mode and  $n, l$  are respectively its order and its degree.  $\Delta\nu$  is an indicator of the mean density of the star.  $\delta\nu$  decreases as the star evolves and gives clues on its evolutionary status.

Model 1 is more massive and therefore younger and less evolved than Model 2, as indicated by its higher central hydrogen content and its small frequency separations. The small frequency separations of this more massive model differ from those of Model 2 by amounts much larger than the expected observational error bars. The different models could thus be discriminated through an asteroseismological calibration of the  $\alpha$  Cen system.

## 5. Conclusions

We have performed a calibration of the  $\alpha$  Cen system using the new orbital parameters determined by Pourbaix (1999). This analysis shows that one can find a theoretical model consistent with all the available observations and with the higher masses determined by Pourbaix. Unlike the previous calibrations based on older orbital parameters, our derived model of  $\alpha$  Cen A has a convective core and is less evolved than the previous models. This could serve as a discriminant in a future asteroseismological calibration of the system.

## References

- Bodenheimer, P., Forbes, J.E., Gould, N.L., & Henyey, L.G. 1965, *ApJ*, 141, 1019
- Brown, T.M., Christensen-Dalsgaard, J., Weibel-Mihalas, B., & Gilliland, R.L. 1994, *ApJ*, 427, 1013
- Demarque, P., Guenther, D.B., & van Alena, W.F. 1986, *ApJ*, 300, 773
- Flower, P. 1996, *ApJ*, 469, 355
- Fowler, W.R., Coughlan, G.R., & Zimmerman, B.A. 1975, *ARA&A*, 13, 69
- Grevesse, N., & Noels, A. 1993, in *Origin and Evolution of the Elements*, Prantzos, N., Vangioni-Flam, E., & Casse, M., Cambridge: Cambridge University Press, 14
- Heintz, W.D. 1982, *Observatory*, 102, 42
- Henyey, L.G., Forbes, J.E., & Gould, N. L. 1964, *ApJ*, 139, 306
- Hipparcos Main Catalogue, I/239 1997, CDS, Strasbourg
- Hoffleit, D., & Jaschek, C. 1982, in *The Bright Star Catalogue*, Hoffleit, D., & Jaschek, C., New Haven: Yale University Observatory, 4th ed.
- Iglesias, C.A., & Rogers, F.J. 1996, *ApJ*, 464, 943
- Kamper, K.W. & Wesselink, A.J. 1978, *AJ*, 83, 1653
- Kjeldsen, H., & Bedding, T.R. 1997, in *Fundamental Stellar Properties: the Interaction between Observation and Theory (IAU Symposium 189)*, T.R. Bedding, A.J. Booth, & J. Davis, Dordrecht: Kluwer, 279
- Krishna Swamy, K.S. 1969, *ApJ*, 145, 74
- Neuforge, C. 1993, *A&A*, 274, 818
- Neuforge-Verheecke, C., & Magain, P. 1997, *A&A*, 328, 261
- Neuforge-Verheecke, C., & Noels, A. 1998, in *A Half Century of Stellar Pulsation Interpretation: a Tribute to Arthur N. Cox (ASP Conf. Ser., 135)*, P.A. Bradley & J.A. Guzik, San Francisco: Astron. Soc. Pacific, 264
- Noels, A., Scuflaire, R., & Gabriel, M. 1984, *A&A*, 130, 389.
- Pourbaix, D. 1999, these Proceedings

**Discussion**

*Popper:* Did you find the same age from the two components, and can you say what the age is?

*Pourbaix:* We actually adopted the same age for the two components. We found 3 Gyr, but the uncertainty is rather large (7 Gyr!)