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Abundance analysis of α Cen A: the 3D hydrodynamical approach

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Abstract. We have performed 3D radiative hydrodynamical simulations of the surfaces of the well known metal rich system α Centauri. We present preliminary results of the iron abundance analysis of the component A. We found significant smaller overabundances (~0.16 dex) as generally found in the literature. Our objective is to explore consequences of this new metallicity in terms of splitting of eigenmodes by re-analyzing the work of Thévenin et al. (2002).

Key words. Stars: abundances – Stars: atmospheres – Stars: Population I – Galaxy: abundances

1. Introduction

The α centauri system is a reference in stellar physics. The two components, α Cen A (G2V) and α Cen B (K1V), have been extensively studied since they are close (1.3pc) and similar to the Sun. The proximity, binarity, presence of solar-like oscillations and since recently the possibility to resolve its angular diameter by new generation of interferometers (e.g. VLTI, VINCI+AMBER, Kervella et al. 2003, Bigot et al. 2006) make this system one of the best constrained. It is then particularly interesting for testing both stellar evolution, atmospheric models and study physical processes at work in stars other than the Sun. Its chemical composition has been extensively studied over the past decades. It is known to be a metal-rich system but its overabundance is still debated (from 0.1 to 0.25 dex). This amplitude is a serious source of uncertainty in stellar evolution models and therefore in asteroseismic diagnostics. In respect to this problem we decide to improve the determination of its chemical composition by 3D hydrodynamical simulations of the atmosphere.

2. The 3D hydrodynamical simulations

The numerical code used for this work has been developed for the study of solar and stellar granulation (e.g. Nordlund 1982, Nordlund & Dravins 1990, Stein & Nordlund 1998) and line formation (e.g. Asplund et al. 2000). It solves the non-linear, compressible equations of mass, momentum and energy conservation on a Cartesian mesh. It uses the realistic equation-of-state and opacities of the MARCS code (Gustafsson et al. 1975 and updates). The radiative cooling/heating is obtained by solving LTE transfer at each time step along several inclined rays. The line-blanketing is taken

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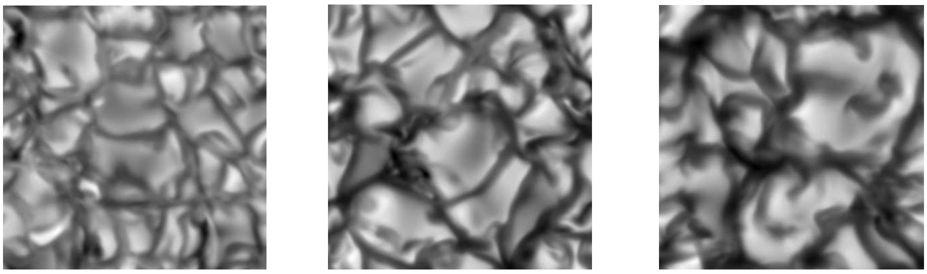

Fig. 1. Disk-center surface intensities of α CenB (left), Sun (middle) and α CenA (right) at a representative time of their simulations. The dimensions are 6000 × 6000 kms.

into account through the opacity binning technique of Nordlund (1982). An horizontal periodic boundary condition and transmitting vertical boundaries are used.

We have obtained time-dependent 3D models of the surface layer of α Cen A&B (Fig. 1). We used a grid of sufficiently high resolution (x,y,z) = 253 × 253 × 163 to get accurate line profiles. Our models match the values proposed in Eggenberger et al. (2004): $T_{\rm eff}$ = 5780 and 5230 K with $\log g$ = 4.30 and 4.50 respectively for the A and B components. We improve Nordlund & Dravins (1990) simulations of α Cen by using much better grid resolution (was 32^3), compressible hydrodynamics (instead of anelastic), new ODF from Castelli & Kurucz (2004) which are all crucial for accurate abundance determination.

3. New Iron abundance in α cen A and its applications

3.1. Observations, data reduction and [Fe/H] determination

The observation of α Cen A were carried out with the HARPS spectrograph installed on the ESO's 3.6m telescope at La Silla. The data which cover a wavelength region in the visible (380-690nm) were collected in 2005 and kindly provided by F. Bouchy.

The large resolving power (R = 110000) and high S/N ratio (~ 500) are particularly well adapted for abundance determination.

The continuum windows were selected by comparison with solar spectrum. The mean level was obtained by a low order spline fit. The line list is based on Asplund et al. (2000). We rejected those which were apparently blended. The oscillator strengths are laboratory measurements provided by the NIST data base and have very good accuracies (~ 7%). For each line we have calculated several line profiles for 4 abundances (7.45 to 8.05) and 6 vsini values (0 to 5 km/s). The collisional broadening was calculated using Anstee & O'Mara (1995) and Barklem & O'Mara (1997) theory. The fit of each line is found by a χ^2 minimization.

Our results show (see Fig. 2) an abundance of [Fe/H]= 7.61 ± 0.05 dex, i.e an overabundance with respect to the Sun of +0.16 dex which is significantly lower than the value commonly found in the literature, e.g. Edvardsson et al. (1993) (+ 0.20dex), Neuforge-Verheecke & Magain (1997) (+0.25dex). We note that a lower abundance was also found by Doyle et al. (2005) (+0.11dex) using 1D models. The projected rotation velocity is vsini = 2.9 ± 0.5 km/s. Using the radius found by Kervella et al. (2003) and the inclination angle of Pourbaix et al. (1999) we derived a rotation period of 21 ± 4 days.

3.2. Applications to asteroseismology.

The new abundance derived for α Cen A is used to re-analyze the paper of Thévenin et al. (2002). We assume that all changes of abundances scale like [Fe/H]. The new metallicity is then Z= 0.0253. The best evolutionary model is found to be $M = 1.100\,M_\odot$ and $R = 1.224\,R_\odot$. It was computed using the

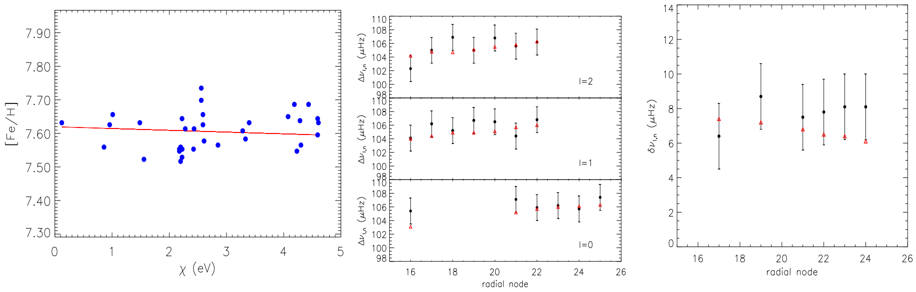

Fig. 2. (Left) Individual [FeI/H] as functions of the excitation potential. Large (Middle) and small (Right) separations of α Cen A as function of the radial node. The filled circles are observed data from Bazot et al, the triangles are theoretical separations.

CESAM code (Morel 1997). Because of its lower metallicity we had to change the helium content and the age (6.15 Gy) in order to put the model into the right error bars in the HR diagram. The oscillation frequencies $\nu_{n,\ell}$ were calculated for various radial n and longitudinal nodes ℓ using a pulsation code that solves the problem of linear perturbations of the adiabatic hydrodynamical equations. We compare computed large $\Delta\nu_{n,\ell} = \nu_{n+1,\ell} - \nu_{n,\ell}$ and small $\Delta\nu_{n,0,2} = \nu_{n,0} - \nu_{n-1,2}$ separations with the seismic observations of Bazot et al. (2007). The first one is a good indicator of the mean density of the star. The small separation is very sensitive to the physical conditions encountered in the stellar core and provide good constrains on the age of the star. As seen in Fig. 2, our model leads to a good fit of both small and large separations.

4. Conclusions

The preliminary results based on 3D hydrodynamical simulations presented in this poster show that the overabundance of iron in the solar twin α Cen A is lower than commonly found, only +0.16 dex. This new abundance leads to a very good fit of pulsation data which is very encouraging. This work will be extended to its companion, α Cen B in order to constrain evolutions of the two components A&B simultaneously.

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