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PRECISE CANOPUS ANGULAR DIAMETER MEASUREMENT FROM AMBER/VLTI, PHOTOSPHERIC STRUCTURES SUSPECTED

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Abstract. Direct measurements of fundamental parameters and photospheric structures of post-main-sequence intermediate-mass stars are required for a deeper understanding of their evolution. Based on near-IR long-baseline interferometry we aim to resolve the stellar surface of the F0 supergiant star Canopus, and to precisely measure its angular diameter and related physical parameters. We used the AMBER/VLTI instrument to record interferometric data on Canopus: visibilities and closure phases in the H and K bands with a spectral resolution of 35. The available baselines ($\simeq 60 - 110$ m) and the high quality of the AMBER/VLTI observations allowed us to measure fringe visibilities as far as in the third visibility lobe. We determined an angular diameter of $\theta = 6.93 \pm 0.15$ mas by adopting a linearly limb-darkened disk model. From this angular diameter and Hipparcos distance we derived a stellar radius $R = 71.4 \pm 4.0 R_{\odot}$. In addition to providing the most precise angular diameter obtained to date, the AMBER interferometric data point towards additional photospheric structures on Canopus beyond the limb-darkened model alone. A promising explanation for such surface structures is the presence of convection cells. We checked such a hypothesis using first order star-cell models and concluded that the observations are compatible with the presence of surface convective structures. This direct detection of convective cells on Canopus from interferometry can provide strong constraints to radiation-hydrodynamics models of photospheres of F-type supergiants.

1 Introduction

The evolved star Canopus (α Carinae, HD45348) is a F0 supergiant (F0Ib) star, the second brightest star (V $= -0.72$) in the night sky, just after Sirius. To constrain evolutionary models it is quite important to have precise measurements of fundamental stellar parameters, such as the effective temperature, luminosity, radius. The most precise angular diameter θ measurements can be obtained by modern long baseline interferometers. In this work we present precise measurements of the angular diameter (and other derived physical parameters) of Canopus obtained with the AMBER beam-combiner instrument (Petrov et al. 2007), installed at the ESO-VLTI (Glindemann et al. 2004) located at Cerro Paranal in Chile. This work is based on observations performed at the European Southern Observatory, Chile under ESO Program 078.D-0295(A). A detailed description of the results is given by Domiciano de Souza et al. (2008).

2 Observations and data reduction

The AMBER observations were performed at spectral resolution $R = \lambda/\Delta\lambda \simeq 35$ in the H and K bands, using three Auxiliary Telescopes (ATs) placed on the VLTI stations A0, K0, and G1. A relatively complete uv-plane coverage was obtained on Canopus and the calibrator star (HD79917) thanks to observations performed over 3 nights (2007 April 6, 7, 8) spanning $\simeq 2$ h each night and several projected baselines ranging from $\simeq 60$ m to $\simeq 110$ m. The data was reduced using the standard routines of the AMBER Data Reduction Software (called amdlib) version 2.1[1]. Tatulli et al. (2007) describe the principles of the AMBER-DRS routines allowing the conversion of raw-data frames into individual complex visibilities. Depending on the night and on the wavelength λ, the relative uncertainties on the visibilities were estimated as $\sigma_V(\lambda)/V(\lambda) \leq 0.1$ in the H band and $\sigma_V(\lambda)/V(\lambda) \leq 0.07$ in the K band.

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[1]Available at http://www.jmmc.fr/data_processing_amber.htm

3 Model fitting and physical parameters

The visibilities measured on Canopus are shown in Fig. 1. To determine the angular diameter of Canopus we fitted a linearly limb-darkened disk (LLD) model[2] to both H and K band observed visibilities. The free parameters of the model are the LLD angular diameter θ, and the H and K band LLD coefficients ϵ_H and ϵ_K.

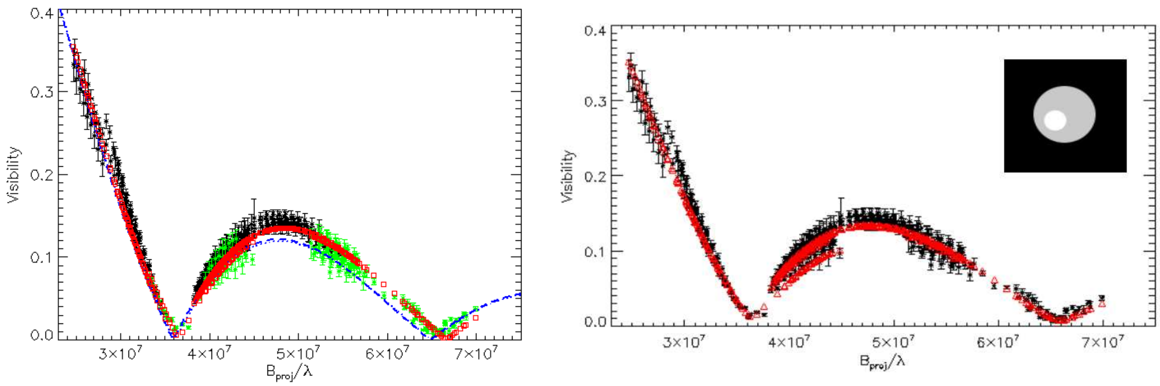

Fig. 1. *Left:* AMBER/VLTI visibility amplitudes and uncertainties in the H (green) and K bands (black). The model visibilities (red squares) were calculated with a linear limb-darkened (LLD) disk model fitted to the data. We also show the theoretical visibilities (dots for H and dashes for K) expected for Canopus from a LLD disk with parameters determined by Claret (2000). Clearly, these LLD models do not account for the observations, especially after the first minimum. *Right:* Visibility of the model with a spot of angular diameter of 36% of the star angular diameter and a flux of 3% plotted as red triangles over the observed visibility in black. In the upper right corner an illustration of such a model. A more satisfactory fit is obtained with models including photospheric structures.

The parameters derived from a Levenberg-Marquardt (L-M) least-squares fit are fit are: $\theta = 6.93 \pm 0.15$ mas, $\epsilon_H = 0.04 \pm 0.01$, and $\epsilon_K = -0.07 \pm 0.01$. From the Hipparcos distance $d = 95.9 \pm 4.9$ pc (Perryman et al. 1997) we derive a linear radius $R/R_\odot = 71.4 \pm 4.0$ for Canopus. Depending on bolometric fluxes existing in the literature, the measured θ provides two estimates of the effective temperature: $T_{\rm eff} = 7284 \pm 107$ K and $T_{\rm eff} = 7582 \pm 252$ K.

The reduced χ^2 of the fit is $\chi^2_{\rm red} = 7.0$, suggesting that the LLD disk cannot completely explain the observations. One promising explanation for the failure of the LLD disk model is the presence of convective photospheric cells introducing fine scale structures in the intensity maps that are detectable by stellar interferometry. We have attempted to explain the interferometric observations of Canopus by adopting simple exploratory models where the granular cells are mimicked by circles of uniform brightness added to a larger uniform disk representing the stellar photosphere itself with a total flux arbitrarily fixed at 1. These models provide better fits to the visibilities than the LLD model. For example, by fitting a single cell added to the stellar surface we obtain $\chi^2_{\rm red} = 4.0$ for $\theta_{\rm cell} = 36\%\theta$ and a total cell flux of 0.035 (Fig. 1 right).

References

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[2] $I(\mu)/I(1) = 1 - \epsilon(1 - \mu)$, where I is the specific intensity, and μ is the cos of the angle between the line of sight and the emergent intensity.