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IMAGING AND MODELING RAPID ROTATORS: α CEP AND α OPH

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We present sub-milliarcseond resolution observations of two nearby rapid rotators α Cephei and α Ophiuchi, obtained with the CHARA array. We reconstruct an aperture synthesis image for α Cep. We also construct gravity darkening models for both stars and precisely determine their geometry, polar and equatorial radii and temperatures, as well as their fractional rotation speed.

A large fraction of hot stars are rapid rotators with rotational velocities more than 120 km s^{-1} (Abt & Morrell 1995; Abt et al. 2002). The centrifugal force from rapid rotation makes a star oblate and causes the "Gravity Darkening" phenomenon (von Zeipel 1924a,b). It can also affect stars' fundamental properties such as luminosity, abundance, and evolution (e.g., Pinsonneault 1997; Meynet & Maeder 2000; Maeder et al. 2007).

Although spectroscopy is the most basic and traditional way to study rapid rotators and has provided invaluable information about these stars, resolving the stellar surface with stellar interferometers can provide more direct and further insight into the basic properties of these stars, such as their geometry, brightness distribution, and temperature, etc. In recent years, long baseline interferometers have studied several nearby rapid rotators, which have not only confirmed the oblateness and the basic picture of gravity darkening, but have also found deficiencies in the standard gravity darkening model, suggesting the need for more detailed studies and model-independent images of rapid rotators.

We thus observed two rapid rotators α Cep and α Oph in 2006, using the CHARA array (ten Brummelaar et al. 2005) and the MIRC combiner (Monnier et al. 2006). The details of our observations and data reduction procedure and be found in (Monnier et al. 2007; Zhao et al. 2008).

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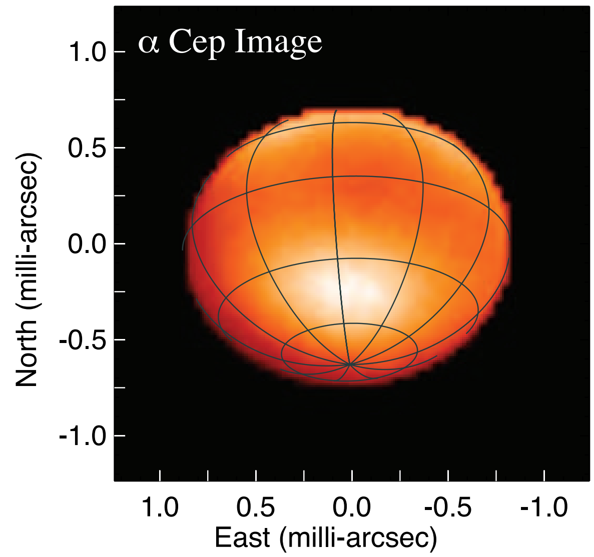

Fig. 1. Reconstructed Image of α Cep. The contours show the local brightness temperatures of the stellar surface. The total χ^2_ν of the image is 1.10. The resolution of the image is 0.68 milliarcsec.

The star α Cephei (α Cep, Alderamin, HR 8162, V=2.46, H=2.13, d=14.96pc) is an A8V main sequence star (Gray et al. 2003). Figure 1 shows the reconstructed image of α Cep (${\chi_\nu}^2 = 1.10$), obtained with the MACIM application (Ireland et al. 2006). The photosphere of the star is well resolved and appears elongated along the east-west direction. The bright region at the bottom with $T_{\rm eff}$ above 7000K is later identified close to the pole and the dark belt below 6500K is the equator — a direct confirmation of the gravity darkening effect.

We also construct a Roche-von Zeipel gravity darkening model for α Cep to fit the data, following the prescription described in Aufdenberg et al. (2006). Figure 2 shows the gravity darkening model with a non-standard β of 0.22. The total χ^2_ν of the model is 1.18. The model shows that α Cep has an inclination of $55^\circ\!.7\pm6^\circ\!.2$, a position angle of $-178^\circ\!.8\pm4.3$, and a fractional angular rotation speed of 94%. The polar temperature of α Cep is 8588K, while its equatorial temperature is 6574K. Its polar radius is $2.16\pm0.04\,R_\odot$, about 21% smaller than its equatorial radius, $2.74\pm0.04\,R_\odot$. Assuming a mass

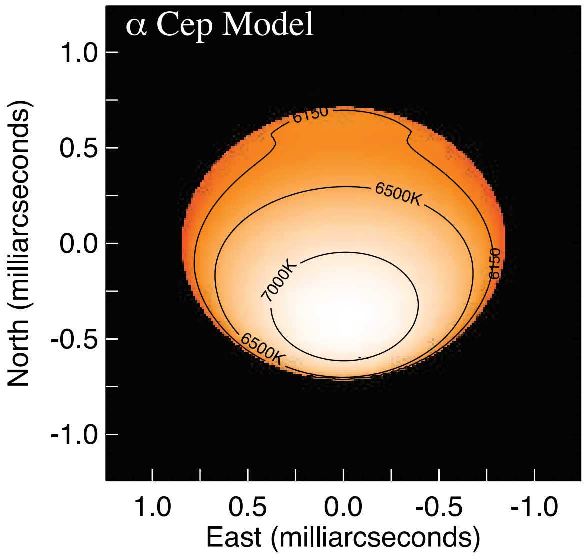

Fig. 2. Gravity darkening model of α Cep. The contours indicate the local brightness temperatures on the surface of the star, overplotted with the temperature contours from Figure 1. The model has a total χ^2_ν of 1.18. The resolution of the image is 0.68 milliarcsec.

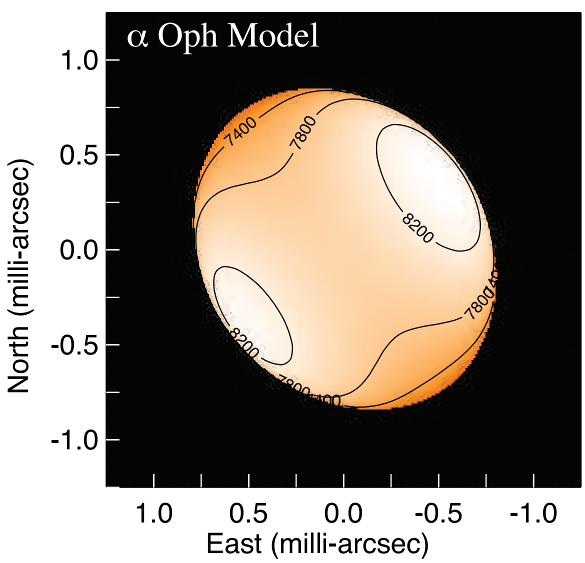

Fig. 3. Gravity darkening model for α Oph. The contours indicate the local brightness temperatures on the surface of the star. The resolution of the data is 0.52 milliarcsec. The total χ^2_ν of the model is 0.91.

of $2\,M_\odot$, the model gives a V$\sin i$ of 225 km s^{-1}, well within its observed range of $\sim$180 km s^{-1} to $\sim$245 km s^{-1} (e.g., Royer et al. 2007; Abt & Morrell 1995).

The star α Ophiuchi (α Oph, Rasalhague, HR 6556, V = 2.09, H=1.66, d=14.68pc) is a nearby subgiant binary system (Lippincott & Wagman 1966). The primary is the subject of this study, and is a A5IV subgiant (Gray et al. 2001). Its V$\sin i$ ranges from 210 km s^{-1} to 240 km s^{-1} (e.g., Abt & Morrell 1995; Royer et al. 2002), implying it is spinning at a significant fraction of its break-up speed of $\sim$270 km s^{-1}. Figure 3 shows the standard gravity darkening model for α Oph, also using the von Zeipel law as for α Cep. The model shows that the photosphere of α Oph is also elongated and has two bright polar areas and a dark equator. Its radius at the equator is $2.87\pm0.02\,R_\odot$, $\sim$20% larger than that of the poles. It is seen nearly equator-on with an inclination of $87.^\circ7 \pm 0.^\circ4$, and a position angle of $-53.^\circ9 \pm 1.^\circ2$. The star is rotating at 88.5% of its break-up speed and the polar temperature is 9300K, $\sim$1840K hotter than that of the equator. Assuming a mass of $2.1\,M_\odot$, the model gives a V$\sin i$ of 237 km s^{-1}, also within its observed range. We have also tried to fit a non-standard β model for α Oph. However, because α Oph is nearly equator-on, β is highly degenerate with the inclination, and higher resolution observations are thus needed to lift the degeneracy.

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