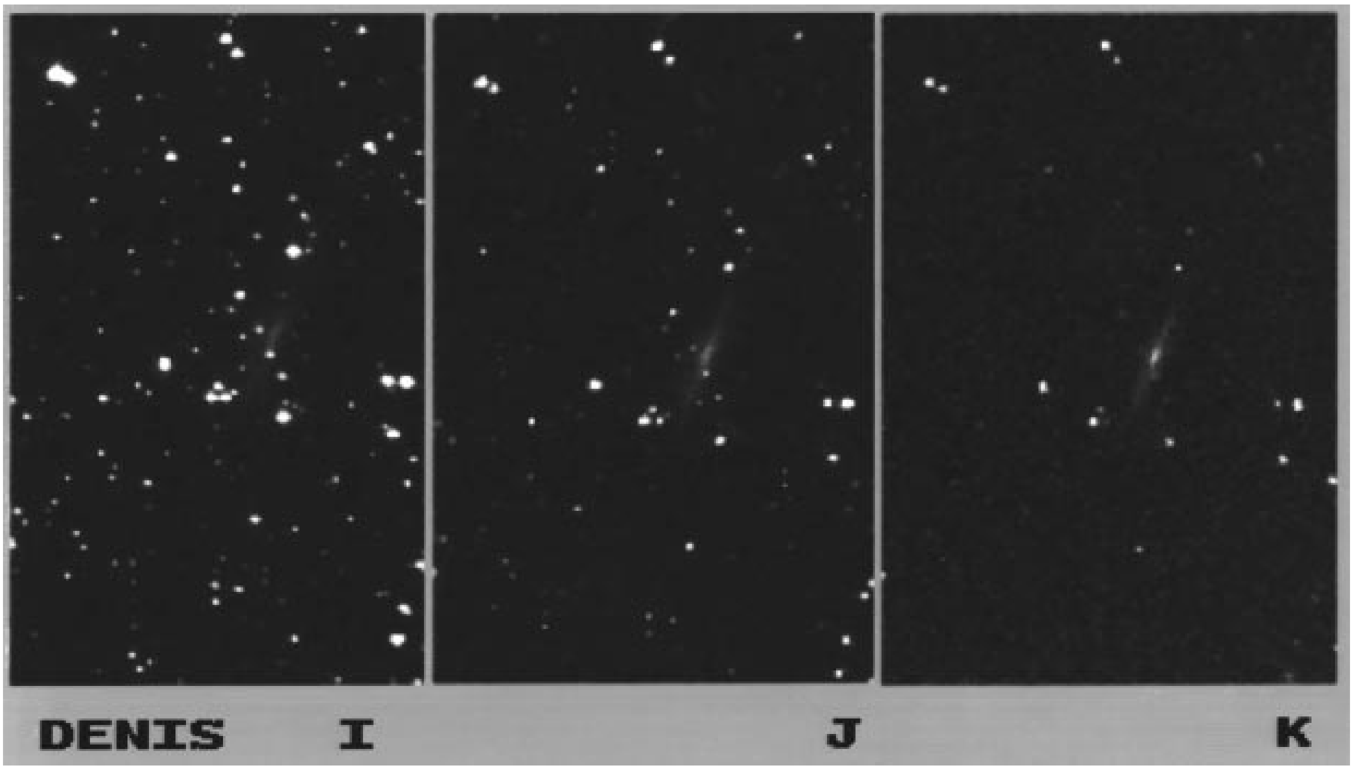

Figure 9: The galaxy IRAS 07395-2224, located at b = 0.2° as seen in the 3 DENIS bands from left to right: I, J, K_s. Notice that this edge-on spiral appears prominently in the K_s band. DENIS is expected to pick up many such galaxies in the zone of avoidance.

in a number of promising results. A small fraction of the archived data has been exploited, so far. Several fruitful collaborations have started within the consortium institutes and with ISO teams. Owing to the huge amount of data to analyse, we expect that the interest in DENIS products in the astronomical community at large, and in particular within the ESO community, will grow as the survey progresses; we also expect that the 2-micron point source catalogue will be available, at least partly, for the first light of the VLT.

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R Doradus: the Biggest Star in the Sky

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What is the biggest star in the sky? Here we are not speaking of absolute size in kilometres, but in apparent size as seen from the Earth. The obvious answer is the Sun, which has an angular diameter of half a degree. But which star comes next? The answer has long been assumed to be Betelgeuse (alpha Orionis), which appears to be about 35,000 times smaller than the Sun (depending on the wavelength at which you observe). In fact, Betelgeuse was the first

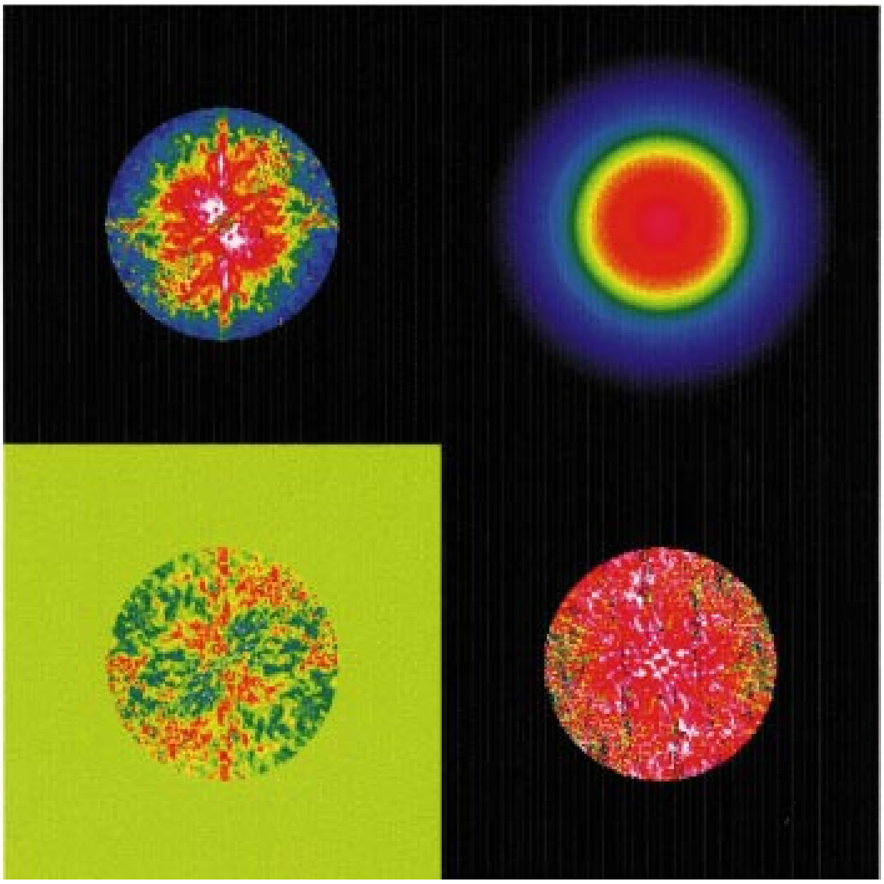

Figure 1.

star apart from the Sun to have its angular diameter measured (Michelson & Pease, 1921).

Betelgeuse is a red supergiant and its large apparent size is due both to its extremely large physical diameter (about 700 times that of the Sun) and to its relative closeness (about 200 pc). Several other nearby red giant and supergiant stars are resolvable with diffraction-limited 4-m-class telescopes. Not only can the angular diameter of these stars be measured directly (e.g., Tuthill et al., 1994b), but in some cases (e.g., Betelgeuse) features on the stellar surface have been detected (Buscher et al., 1990). In the case of some Mira stars, significant elongation has been found (Wilson et al., 1992, Haniff et al., 1992, Tuthill et al., 1994a).

Here we report observations of the star R Doradus, which has not previously been observed at high angular resolution. R Dor is an M8 giant and is the brightest, and presumably closest, star with such a late spectral type. Based on its infrared brightness, Wing (1971) predicted that R Dor (HR 1492) could be larger than Betelgeuse. We observed R Dor with SHARP on the NTT (infrared) using the technique of aperture masking. Other results, not presented here, were obtained with MAPPIT on the AAT. We indeed find that R Dor exceeds Betelgeuse in angular size.

Sequences of short (0.1s) exposures were taken of R Dor and two near-by unresolved stars, α and γ Ret (HD 27256 and HD 27304), using the SHARP camera on the NTT in the Johnson J band. The NTT entrance aperture was covered with an annular mask (see Bedding et al., 1993). The purpose of the mask is to reduce the effects of seeing on the accuracy of the measurement, with the beneficial side effect of attenuating the flux to a level which can be managed by the detector. The moduli squared of the Fourier transforms of 300 frames were averaged for each star. Calculating the ratio of the mean spectra from R Dor and the unresolved stars calibrates for instrumental and atmospheric attenuation of the mean spectra. The result is the two-dimensional visibility function squared of R Dor: it shows a decrease towards larger angular frequencies which indicate that the source is resolved. Figure 1 shows a sample calibrated visibility function (top-left panel). A non-linear least-squares fit of a model of the visibility function for a uniformly illuminated disk, with the apparent diameter as the only parameter, is applied. The top-right panel shows the model fitted to the data shown in the top left panel. The difference between observations and model is seen in the lower-left panel: the curved features are instrumental residuals from the spiders of the telescope, the remainder being the noise. For comparison, the bottom-right panel shows the visibility of one of the reference stars calibrated by the other one.

The mean diameter of R Dor we obtain from these data is 0.0587 ± 0.0026 (1 sigma) arcsec, uniform disk equivalent. This is the average of 11 model fits

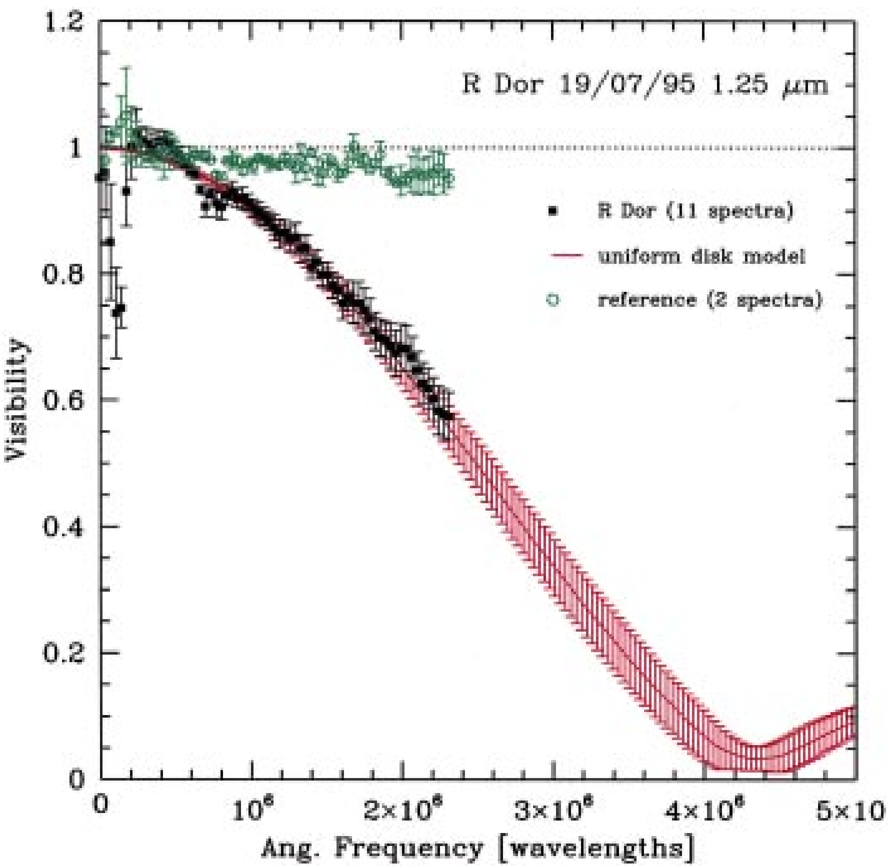

Figure 2.

to the corrected mean power spectra which result from all but one combinations between 3 sets of observations of R Dor and 4 sets of reference-star observations. There is no significant indication of a deviation from circular symmetry of more than 2 per cent. Smaller deviations are easily explained by residual artifacts in the visibility data.

Figure 2 shows radial plots (averages over the azimuth) of the compensated spectra. The black, heavy dots are the azimuth averages of the R Dor spectra. The origin of the dip near 1 lp/arcsec may be related to seeing variations; this region was excluded from the fitting process. The red curve shows the average and the variation of the non-linear fits to the data. The green, open circles show azimuth averages of inter-calibrated reference data to demonstrate the significance of the R Dor measurements.

The observed angular diameter of an M star can be strongly affected by the atmospheric extensions. Within bands of high opacity (such as the TiO bands) the star can appear 50 per cent larger than in continuum regions of the spectrum. It is therefore important to compare diameters for different stars only for measurements made in the continuum. A limb-darkening correction may also have to be applied, but this correction is somewhat ad-hoc due to the lack of reliable model atmospheres. Opacity effects and limb darkening are smallest in the infrared and stellar diameter measurements should preferably be taken in this region of the spectrum.

The uniform-disk diameter of Betelgeuse at 2.2 microns has been measured to be 44 mas (Dyck et al., 1992). Thus, R Dor appears to be the largest star in the sky.

Despite its classification as semi-regular, R Dor is in many ways closer to the Miras than to other SRb stars. Its period is near the peak of the Mira period distribution function (250–350 days), while SRb stars almost always have much shorter periods (e.g., Kerschbaum & Hron, 1992). Its late spectral type and large J–K are also more typical of Miras than other M-type stars (Feast, 1996). Using a bolometric magnitude at the epoch of our measurement of –0.96, we derive an effective temperature of 2740 ± 190 K from the measured diameter. Assuming that R Dor is closely related to the Mira variables, as seems likely, we can apply the period-luminosity relations for Miras in the LMC given by Feast 1996. We obtain a distance of 61 ± 7 pc and a luminosity for R Dor of 6500 ± 400 $L_\odot$. Our distance for R Dor agrees with estimates of 60 pc by Judge & Stencel, 1991, and 51 pc by Celis, 1995. This distance, together with our observed angular diameter, implies a stellar radius of 370 ± 50 $L_\odot$. From the pulsation equation $\bar{Q} = \bar{P}\,(\bar{M}/M_\odot)^{1/2}\,(\bar{R}/R_\odot)^{-3/2}$ and assuming Q = 0.04 days (appropriate for first overtone pulsation), we derive a mass of 0.7 ± 0.3 $M_\odot$. All the derived parameters are consistent with a classification of this star as Mira-like, with the effective temperature being slightly higher than the average for Miras.

All previous measurements of the radii of Miras fall in the range 400–500 $R_\odot$, which is taken by Haniff et al., 1995, as evidence that Miras are associated with a well-defined instability strip. The fact that R Dor shows a more irregular pulsation behaviour but with many characteristics of a Mira is consistent with it lying near the edge of such a strip. Miras have been found to show surface structures and/or ellipticity: if R Dor is related to the Miras, it may be expected that it also shows these effects. MAPPIT/AAT observations of R Dor indeed show non-zero closure phases, indicative of asymmetries or surface structure. R Dor is clearly an excellent candidate for more detailed observations with the VLT and VLTI.

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Molecular Hydrogen Towards T Tauri Observed with Adaptive Optics

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1. Introduction

Although T Tauri is the prototype of a large class of pre-main-sequence objects (the T Tauri stars), it is actually very peculiar. First, the optical primary (T Tau N) has an infrared companion (T Tau S) at a separation of ~ 0.7″, which is completely obscured at visible wavelengths, but may dominate the bolometric luminosity of the system (Dyck et al., 1982, Ghez et al., 1991). Infrared companions have been found near a number of other pre-main-sequence stars, but their presence seems to be the exception rather than the rule (Zinnecker and Wilking, 1992). Second, and even more surprisingly, strong extended 2.121 μm H_2 (v = 1 – 0) S(1) rovibrational emission was found from T Tau (Beckwith et al., 1978). Despite extensive searches, H_2 emission with comparable strength has been found in very few other pre-main-sequence stars (e.g. Carr, 1990). Finally, there are two Herbig-Haro objects at right angles associated with T Tau (Schwartz, 1975, Bührke et al., 1986), giving rise to the suspicion that two misaligned pairs of jets emanate from the two components of the binary.

Taking a closer look at the environment of T Tau, and at the relation of the gas to the two stellar components requires spectral line imaging with the highest possible angular resolution. Van Langevelde et al. (1994) present an image of T Tau in the H_2 (v = 1 – 0) S(1) line with a resolution of 0.8″, but the central region of this image had to be blanked because of saturation[1]. More recently, Herbst et al. (1996) observed T Tau with the MPE imaging spectrometer 3D; these observations cover a field of 8″ × 8″ with a resolution of ~ 0.7″. A complicated structure was detected on this scale, which was interpreted as an

[1]Note that Figure 1 in van Langevelde et al. (1994) is labelled incorrectly. The correct image size is ~ 26″, rather than ~ 52″.