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AN IMAGE RECONSTRUCTION OF ALPHA ORIONIS

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ABSTRACT

An interferometric image reconstruction of α Ori in the visible indicates that dust condensation may well occur close to the stellar disk.

Subject headings: interferometry — stars: circumstellar shells—stars: diameters—stars: supergiants

I. INTRODUCTION

This *Letter* describes an attempt to reconstruct an image of the star α Ori from a map of fringe visibilities obtained on 1980 November 30 with the CFH Telescope in Hawaii. The data were obtained through a 90 Å bandwidth filter centered at 5350 Å. This particular spectral window was selected because it avoids strong molecular absorption bands in the stellar spectrum. Both the visibility map and the technique used have been described and discussed in a previous *Letter* (Roddier and Roddier 1983). Not only does the visibility map show a clear departure from rotational symmetry but also its azimuthal average is found to be inconsistent with that of a stellar disk, whichever limb darkening coefficient is assumed. Two possible interpretations were discussed. One interpretation is that a large fraction of the light comes from scattering by an irregular dust envelope close to the stellar disk. The other is that large structures such as hot convective cells or bright prominences produce the observed effect. The result of the study presented here favors the first interpretation.

II. THE RECONSTRUCTION TECHNIQUE

Our visibility map is an estimate of the modulus of the Fourier transform of the irradiance distribution in the object. If the phase was known, an image of the object would be obtained by taking the inverse Fourier transform. Because of the missing phase information, this is not possible. However, the irradiance distribution in the object must satisfy obvious constraints such as positiveness and bounded support (limited extent). It has been shown that these conditions put considerable restriction on the possible solutions for a two-dimensional object (Fienup 1978; Bruck and Sodin 1979; Bates 1982). Although examples have been given of objects having the same Fourier transform modulus (Huiser and Van Toorn 1980), the solution is expected to be unique in most cases.

Several algorithms have been proposed to reconstruct an object from the modulus of its Fourier transform (Fienup 1978; Gull and Danniell 1978; Fright and Bates 1982; Bruck and Sodin 1983; Chalasinska-Macukow and Arsenault 1985). We have attempted to use the algorithm proposed by Fienup (1978), but it did not converge properly. Fienup's algorithm is known to converge slowly in case of objects with nearly circular symmetry and with little structure; however, the most likely explanation is that our map contains observational errors so that there is no exact solution toward which the algorithm can converge. In fact, the algorithm did converge, although very slowly, toward solutions compatible with our observational data; i.e., with a Fourier transform modulus within the error margin of our observations. However, the result was highly dependent on the random object chosen to initiate the iterative process. All the images obtained showed a disk with structures around it, but these images seemed distorted and had a speckled appearance typical of images produced by distorting optics. This implies that the phase was not properly recovered.

Clearly there is no single solution consistent with our data, which means that additional constraints are needed. The maximum entropy algorithm, which seeks to find the smoothest solution, provides an attractive additional constraint since it tends to avoid "speckled" solutions. We have used the algorithm proposed by Gull and Daniell (1978). As explained in their paper, the algorithm stops when the image obtained is consistent with the error margin assumed in the observed data. The algorithm converged quite regularly toward a solution nearly independent of the random input with which it was started. This solution is presented in Figure 1*a* (Plate L2). We have attempted also to start Fienup's algorithm with the

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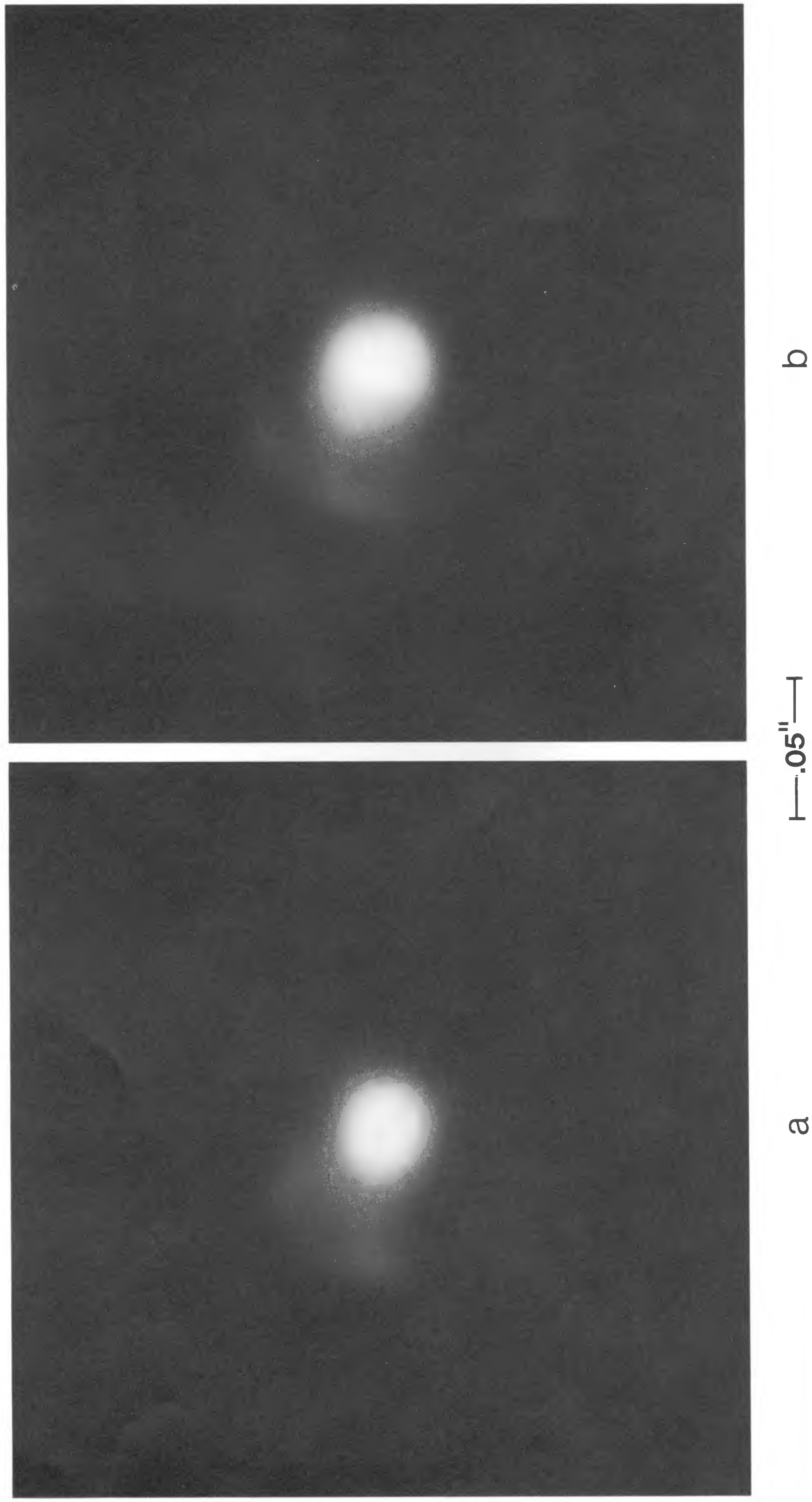

FIG. 1.—Reconstructed images of a Ori

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maximum entropy solution and the maximum entropy algorithm with Fienup's solution. In all cases we obtained a result very similar to Figure 1*a*.

Figure 1*a* clearly shows a stellar disk with circumstellar structure. This result favors the first interpretation presented in our previous *Letter* (Roddier and Roddier 1983). Indeed, we have shown that the azimuthal average of the observed visibilities was consistent with that of a stellar disk with a 37 milli-arsec diameter surrounded with an envelope (see Fig. 2 of our previous *Letter*). If this interpretation is correct, the high-frequency part of the visibility curve is essentially produced by the disk, and an improved image can be obtained by extrapolating the visibility function along the dashed line in Figure 2 of our previous *Letter*. Figure 1*b* shows the reconstructed image when our data are extrapolated half-way up to the first zero of the Bessel function. The appearance of an incomplete shell is striking. The effect is even more pronounced when the interpolation is done up to the first zero, but spurious details start to build up on the disk.

III. DISCUSSION

Clearly the solution presented here is not unique and the maximum entropy algorithm must be considered with caution (Fiddy and Greenaway 1978; Dainty, Fiddy, and Greenaway 1979). However, all the solutions found show a small disk with structure around it rather than a large disk with structure on it. This strongly supports the interpretation of a stellar disk partially surrounded with a dust envelope. In this case the object is expected to be fuzzy, and the maximum entropy algorithm should yield the solution closest to reality. Even if the solution is not entirely correct, we believe that the image presented in Figure 1*b* gives a fair account of what the object probably looks like. Is such an image consistent with our knowledge of α Ori?

The shell appearance may be produced either by Mie scattering from dust particles or by electron scattering in the chromosphere of α Ori. Observation of the spectrum of α Ori rules out electron scattering but shows evidence for IR emission from dust particles. IR interferometric measurements (McCarthy, Low, and Howell 1977; Sutton *et al.* 1977) and direct IR imaging (Bloemhof, Townes, and Vanderwyck 1984) confirm that the IR emission comes from a dust shell but seem to indicate that dust condenses at several tens of stellar radii. On the other hand, Tsuji (1978) has shown that if dust starts to condense at a few stellar radii, there is enough of it to scatter an appreciable amount of light in the visible, thus explaining the discrepancy between interferometric measurements and spectrophotometric estimates of the diameter of α Ori.

Monte Carlo calculations of Mie scattering by dust shells show that a maximum of scattered light should be observed at a distance equal to the inner radius of the envelope (Rowan–Robinson 1980; Lefevre, Bergeat, and Daniel 1982). On our reconstructed image such a maximum occurs at a distance of the order of 2–2.5 stellar radii from the stellar center. The similarity between the reconstructed image and the images computed by Lefevre, Daniel, and Bergeat (1983, Fig. 8*a*) is striking. It indicates that the asymmetry may be produced by an elliptical shell. Can dust condense so close to the stellar surface?

A detailed study of the dust formation process by Draine (1981) shows that, assuming a 3600 K effective temperature for α Ori, clean silicate grains would start to condense at 1.8 stellar radii. Because they are clean, they would absorb relatively little stellar radiation and show low IR emission (Lefevre, Bergeat, and Daniel 1982). In any case the IR emission of dust grains at 2.5 stellar radii would not be resolved in the high angular resolution IR observations mentioned above. According to Draine (1981), it is hard to explain how grain formation could occur at distances larger than 10 stellar radii. These results strongly support our interpretation.

The problem remains of the exact angular diameter and effective temperature of α Ori. If our interpretation is correct, the small diameter found is consistent with spectrophotometric estimations (Tsuji 1976) but seems to conflict with the observed dependence of the diameter with wavelength in TiO spectrum. However, as discussed by Balega *et al.* (1982), for a given effective temperature, plane-parallel models tend to overestimate the temperature of the outer atmospheric layers compared to a more appropriate spherical model. Moreover, if dust is present and contributes significantly to the absorption coefficient, then we are looking at higher levels, cool enough to allow the TiO effect to be seen. The dust hypothesis was ruled out in the paper of Balega *et al.* because no significant increase of the diameter is observed at small wavelengths. In fact the opposite should be expected since theoretical models for the emergent spectrum predict an increase of the shell brightness toward the red (Jones and Merrill 1976; Lefevre, Bergeat, and Daniel 1982).

Finally, we should state that an asymmetric envelope will scatter light anisotropically possibly yielding a wrong estimation of the effective temperature from photometric measurements. We believe that a 3600 K effective temperature and a 42 milli-arcsec diameter could probably be made consistent with all the observations.

More recent observations of α Ori using either pupil plane interferometry (Karovska 1984; Roddier, Roddier, and Karovska 1984) or a speckle technique (Petrov 1983) confirms important deviations from circular symmetry and show a significant time evolution of the fringe visibilities. This suggests an intermittent mechanism for the ejection of material. A large amount of dust may well be condensed or condensing when our data were taken in possible relationship with the rapid changes of magnitude and polarization occurring at that time (Guinan 1984). The envelope observed in the IR may have been similarly ejected in the past and blown away by radiation pressure (Draine 1981).

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