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RAPID VARIATION IN THE CIRCUMSTELLAR 10 MICRON EMISSION OF α ORIONIS

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ABSTRACT

The spatial distribution of 10 μm continuum flux around the supergiant star α Orionis was measured on two occasions separated by an interval of 1 yr. A significant change in the infrared radiation pattern on the sub–arc second scale was observed. This change cannot be explained plausibly by macroscopic motion but may be due to a change in the physical properties of the circumstellar dust.

Subject headings: infrared: sources — stars: circumstellar shells — stars: late-type — stars: supergiants

I. INTRODUCTION

Many supergiant stars of late spectral type have circumstellar shells of gas and dust. Direct observation of the dust is possible through high spatial resolution observations of 10 μm continuum radiation (McCarthy, Low, and Howell 1977; Low 1979; Sutton *et al.* 1977; Bloemhof, Townes, and Vanderwyck 1984). In the case of the oxygen-rich star α Orionis, roughly 37% of the stellar flux at 11 μm is spatially extended (Gillett, Merrill, and Stein 1971; Sutton *et al.* 1977) and is attributed to thermal emission from warm silicate grains.

A noninterferometric imaging technique with sufficient spatial resolution to distinguish the extended and photospheric flux components was used initially in 1983 February (Bloemhof, Townes, and Vanderwyck 1984, hereafter Paper I). Images of α Orionis showed a distinct east-west asymmetry not present in other sources. In this *Letter*, we report additional observations of α Orionis made 1 yr later and compare them with images obtained on the first observing run.

II. OBSERVATIONS

The observations reported in Paper I were made on 1983 February 22; those reported in this *Letter* were made on 1984 February 12 and 13. On each occasion, the 3 m Infrared Telescope Facility (IRTF) on Mauna Kea was used, and a broad spectral window was defined by an interference filter passband edge at 8.3 μm and the cutoff wavelength of our HgCdTe photodiode detectors at 10.3 μm. This window contains the peak wavelength of the silicate emission feature, which occurs at 9.7 μm. Our observing procedure consists of allowing the source to drift through the field of view of a stationary telescope, while signals are rapidly recorded from an array of infrared detectors dispersed in the declination direction. Each detector subtends an angle of 0".2 × 0".2 and provides a cross section through the focal-plane brightness distribution combining very high spatial resolution with independence from detector responsivity calibration. Further technical details of the method are discussed in Paper I.

Under good atmospheric conditions, the scale of seeing fluctuations at infrared wavelengths may be smaller than the scale of the telescope point-spread function. Diffraction at a circular aperture implies that the point-spread function of a 3 m telescope is an Airy pattern with a full width at half-maximum of roughly 0".6 if the effective wavelength of observation is 9 μm. Paper I exhibited the measured profile of the telescope point-spread function obtained on a spatially unresolved star, α Bootis; the profile was in excellent agreement with the predictions of diffraction theory.

Our single-detector scans accurately represent the brightness distribution in the focal plane. However, at the extremely high spatial resolution explored by these measurements, slight imperfections in the IRTF optics become important in making deductions about source structure, particularly when imaging relatively faint, extended dust emission around a bright stellar photosphere. We have found that image details are sensitive to the precise focal setting of the telescope, and that images slightly out of focus show spurious structure comparable to or brighter than actual dust emission. The key to identifying such spurious structure is the observation of known point sources. When observing stars with spatially extended emission, the photosphere, owing to its dominant surface brightness, may be used as a fiducial point source to judge focus: the width of the central peak of an image profile is expected to be minimal at best focus.

Experience with the drift scan observing technique at the IRTF has shown that a single best image cannot be chosen on the basis of central peak width alone, as that width is essentially constant over too wide a range of focal settings. Since focal errors spuriously enhance the secondary maxima of the point-spread function (Born and Wolf 1983), it may be that the best images are those in which extended structure is minimal. Given the subtleties of imaging near the diffraction limit, we have taken image structure to be real only if prominent in all images over a range of settings near best focus.

Figure 1 shows three image profiles of α Ori (data points) from 1983 February, at slightly different values of the three-digit focal readout of the telescope. The profiles have central

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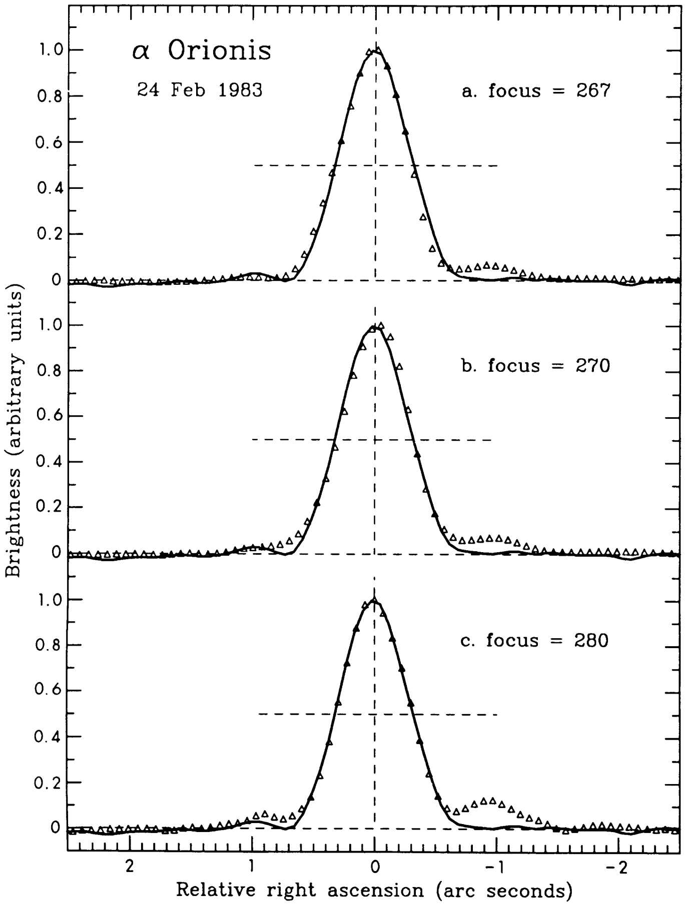

FIG. 1.—Profiles of α Orionis obtained in 1983 February for three slightly different focal settings (*data points*), compared in each case to the profile of the telescope point-spread function measured on the unresolved star α Bootis at a single best focus (*solid lines*). An excess of infrared emission is seen on the west side of α Ori.

peak widths equal to the prediction of diffraction theory, and are hence close to best focus. The data points are compared to the point-spread profile obtained during the same night by observing the unresolved star α Bootis (*solid lines*): this star is known to have essentially no extended emission at 10 μm. On the basis of the auxiliary criterion that extended structure be minimal, Figure 1*a* may represent the best focused image. Some spurious redistribution of flux to the secondary Airy maxima, as may be occurring in Figure 1*b* and Figure 1*c* (the focal setting favored in Paper I), is observed on point sources at slight misfocus. However, on point sources, this effect enhances east and west secondary maxima symmetrically. All three images in Figure 1 reveal the basic asymmetry of the extended emission of α Ori; that asymmetry was present in no other source observed on the 1983 February run.

The focal setting was varied in a rather irregular way during the 1983 February run. For α Ori, roughly 15 images free of electrical glitches were obtained near best focus, and all support the east-west asymmetry pictured in Figure 1. No images were obtained at a focal readout below 267, in the arbitrary units displayed at the control console and labeled in the figure; but subsequent experience with more systematic explorations of IRTF behavior on both sides of best focus suggests that the settings in Figure 1 adequately spanned the telescope's depth of focus.

The overshoot of the eastern baseline is an instrumental effect due to AC coupling in our detector preamplifiers and is expected to be about 1% of the central peak. The scans through α Bootis show experimentally that this effect is not the cause of the asymmetry observed in α Ori.

Figure 2 shows the east-west brightness profile of α Ori obtained in 1984 February (data points), superposed on the point-spread function measured on α Bootis during that same run (*solid line*). A change in the sampling rate accounts for the different spacing of data points in the two figures.

Investigation of the symmetry of the circumstellar emission of α Ori in 1984 February is complicated by the asymmetry of the point-spread function, which has an exaggerated secondary maximum to the east of the main peak due to slight optical errors in the telescope during that observing run. However, for reexamining the western side of α Ori for the dust cloud observed in 1983 February, this point-spread function is ideal, having virtually no western secondary maximum to cause confusion. The primary point of interest in Figure 2 is evident immediately and is supported by images over a wide range of focus: in contrast to the measurements 1 yr earlier, there is little discernible circumstellar emission to the west of α Ori. The discrete bright cloud on that side, observed during the 1983 February run, has disappeared or at least substantially declined in intensity in the intervening year. From Figure 2, an upper limit on the measured intensity 0″.9 to the west of the star is about 3% of the intensity of the photosphere. The precise amount of emission remaining is difficult to determine, as the 1984 February measurement is near the general limit of repeatability of the drift scan technique with our current understanding of telescope optics; however, it appears that the surface brightness of the western dust cloud has dropped by a factor of at least 2 in just under 1 yr.

The 1984 remeasurement is based on several focal runs over two successive nights. The western profile of α Ori showed excellent repeatability. The eastern profile was also repeatable

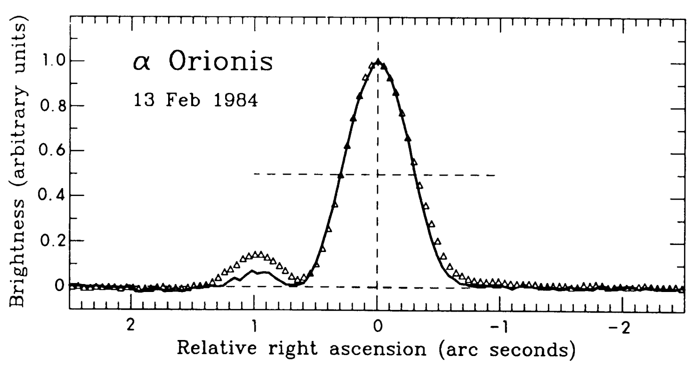

FIG. 2.—Profile of α Orionis obtained in 1984 February (*data points*), compared to the profile of the telescope point-spread function measured on α Bootis (*solid line*). While the large peak on the eastern side of α Ori may be enhanced by spatially extended emission from dust, it is fundamentally an artifact of telescope optics and is clearly visible in the 1984 point-spread function. The relevant feature is the surface brightness to the west of α Ori, which has declined significantly since 1983 February (cf. Fig. 1).

in shape but showed more variation in its relative intensity with focal setting. For this reason, Figure 2 should not be considered typical with regard to structure on that side: readers are cautioned against deconvolving the point-spread function to obtain the dust intensity to the east of α Ori.

In addition to observing α Boo later in the night, a check on the point-spread function was made in the early evening by observing α Tau just before α Ori. That check provides a further indication that the point-spread function of the IRTF does not change significantly during the night. Of course, this assumption is crucial to our interpretation of α Ori images from the 1983 February run.

On that 1983 run, observations of α Sco provided clear evidence that the point-spread function did not vary with telescope elevation. Telescope collimation was not changed during the run; collimation drifts would probably not influence imaging since one-dimensional slit-scan tests conducted by Howell (1985) indicate that small adjustments in collimation have little effect on the IRTF point-spread function.

Nonetheless, from 1983 February to 1984 February, the point-spread function changed significantly. The three hard points defining the position of the IRTF primary mirror were found to be out of adjustment in early 1985, causing a tilt that would effectively lead to off-axis imaging, and possibly a comatic aberration such as we observed in 1984 February (cf. Born and Wolf 1983). No information is available on when this misadjustment occurred, but it may have worsened between our two observing runs. Such shifts probably do not occur during a single night: while the α Ori profiles of 1983 February bear superficial resemblance to an aberrated point-spread function, it seems unlikely that the telescope optics would shift into alignment during the few hours between observing α Ori and observing the point source α Boo.

III. DISCUSSION

From Figure 1*a*, by comparing the volumes under the central peak and under the western peak, we estimate that the infrared luminosity of the western dust cloud is about 7% of that of the stellar photosphere. Since the photosphere accounts for roughly 63% of the α Ori flux of 5000 Jy, the luminosity of the western cloud is estimated to be about 3×10^{34} ergs s^{-1} in a 10% optical bandwidth at 10 μm. A dramatic decline in this fractionally small component of the total infrared luminosity would not be noticed by photometry.

The marked change in the circumstellar infrared distribution of α Ori in only 1 yr is an unexpected result. Several simple interpretations can be ruled out immediately. Adopting 20 solar masses and 190 pc for the mass and distance of α Ori (Weymann 1962), the orbital period of a close infrared companion would be about 3 yr, while the period of a companion at an orbital radius of 0".9 would be more than 400 yr. Since the stellar envelope is characterized by an outflow velocity of about 10 km s^{-1}, as measured by Doppler shifts of optical absorption lines (e.g., Sanner 1976), motions on the arc second scale would require about 100 yr. Similarly, significant cooling of the grains due simply to their moving further from the star would take much longer than a year.

The dominant heating mechanism for circumstellar dust grains is generally assumed to be absorption of near-infrared continuum radiation from the stellar photosphere. At visual wavelengths, α Ori can vary in intensity by a factor of almost 2 in a few months (Goldberg 1984; Guinan 1984). If the near-infrared radiation varied that rapidly, it might induce rapid changes in the temperature and 10 μm brightness of circumstellar dust grains. However, this effect could cause a reduction in 10 μm emission of no more than 30% if the grains are assumed to start with a temperature of about 250 K (Dyck and Simon 1975; Jones and Merrill 1976; Hagen 1978), and so seems unable to explain the variation we observe. Furthermore, in a program of photometric monitoring of α Ori, Guinan (1985) finds very little change in the blue magnitude from 1983 February to 1984 February. In fact, his data indicate that the star was marginally brighter (by perhaps a tenth of a magnitude) in the second epoch, when the western dust cloud that we observed was faintest. If the near-infrared flux of the star is in phase with the visible light curve, his observations appear to rule out a change in photospheric continuum as an explanation for the change in circumstellar dust brightness. The existence of bright, localized features on or near the stellar surface (Goldberg *et al.* 1981; Roddier and Roddier 1985; Roddier, Roddier, and Karovska 1984) would not change this conclusion, as the reported features would make a small fractional contribution to the total visible continuum.

Chemical energy released by the formation of molecular hydrogen on grain surfaces after sudden and localized nucleation of the grains might account for the luminosity of the western dust cloud of 1983, if rather extreme clumpiness of the stellar outflow is assumed (Bloemhof 1984). The photosphere of α Ori is warm enough that hydrogen gas in the outflow will initially be in atomic form (Zuckerman 1980), and dust nucleation under supersaturated conditions could proceed rather rapidly. Even so, calculations predict a very low duty cycle for excess infrared emission fueled by this mechanism, making our 1983 February observation seem *a priori* unlikely.

An explanation which appears somewhat more plausible is a change in the size of the individual dust grains by agglomeration in the outflowing circumstellar gas and dust. The time scale for grain growth by agglomeration in a dense outflow can be less than a year if the sticking coefficient is high. If individual grains are small compared to the wavelength of light with which they interact, the emitted or absorbed power is proportional to the total volume of grain material, and hence grain growth by condensation of material on the surface will lead to an increase in the 10 μm cloud brightness while growth by agglomeration will not change the intensity at all. However, when individual grains become partially opaque, agglomeration leads to a reduction of cloud brightness by reducing the surface area which absorbs or emits radiation.

Since each of the possible explanations suggested represents a nonreversible change in the dust and gas, and observationally the change has occurred over a time of 1 yr or less, such an event seems likely to have only a small probability of occurring at a given time in a given region of the circumstellar material. Hence, further detections of such localized changes in dust radiation may be difficult, but they would be important in characterizing the phenomenon.

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