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Infrared spectrophotometry of NGC 7023 with ISOCAM*

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Abstract. We present spectrophotometric observations of the reflection nebula NGC 7023 obtained with the ISOCAM Circular Variable Filter (CVF) in the spectral range 5.15 to 16.5 μm. Maps in the 16 μm continuum emission and in the Unidentified Infrared Bands (UIBs) have been obtained. The continuum emission peaks at the dense interface between the surrounding molecular cloud and the inner photodissociated region. The whole spectrum (UIBs and continuum) becomes systematically harder closer to the exciting star. Our observations show that it is entirely due to the same category of carriers, probably PAHs heated transiently by single photons, and that the systematic spectral changes inside NGC 7023 are due to changes in the size distribution or/and ionization degree of these particles.

Key words: ISM: NGC 7023 - ISM: dust - ISM: molecules - ISM: reflection nebulae - infrared: ISM: lines and bands - infrared: ISM: continuum

1. Introduction

NGC 7023 is one of the most extensively studied reflection nebulae. It is illuminated by the Herbig B3Ve star HD 200775 at a distance of 440 pc (Whitcomb et al. 1981). This star creates a photodissociation region in the surrounding molecular cloud which is seen through far–IR dust emission and molecular millimeter–wave emission (Casey 1991; Fuente et al. 1996). A conspicuous interface lies at about 40″ to the north–west (Chokshi et al. 1988). It contains dense filaments and is visible in molecular lines (Fuente et al. 1996), near–IR images (Sellgren et al. 1992) and in the emission of vibrationally excited H_2 (Lemaire et al. 1996). [C II] 158 μm and [O I] 63 μm emission from this region has been observed by Chokshi et al. (1988). Another less–well studied interface and filament is visible 70″ to the south of the star.

Strong emission of NGC 7023 in the Unidentified Infrared Bands (UIBs) at 3.3, 3.4, 6.2, 7.7, 8.6 and 11.3 μm has been observed by Sellgren et al. (1985). Extended red fluorescence perhaps produced by the carriers of the UIBs has been studied by Watkin et al. (1991).

We present here spectrophotometric observations obtained with the ISOCAM long–wavelength camera equipped with Circular Variable Filters (CVF). These observations have allowed a complete mapping of a $3' \times 3'$ field with $6'' \times 6''$ pixels in the wavelength range 5.15 to 16.5 μm. Section 2 describes briefly the observations and reductions; Section 3 reports on the results, Section 4 contains the discussion of these results and Section 5 gives the conclusions.

2. Observations and reductions

The observations have been made with the infrared camera ISOCAM on board the Infrared Space Observatory. Full scans of the two CVFs of the long–wavelength channel of the camera have been obtained, for an on–source total exposure of 3400 seconds. The pixel size was $6'' \times 6''$ and the total field of view $3' \times 3'$. The observing details are the same as explained in Cesarsky et al. (1996b); a full description of ISOCAM and ISO can be found in Cesarsky et al. 1996a and Kessler et al. 1996.

3. Results

Fig. 1 is a map of the continuum emission of NGC 7023 at 16 μm. Apart from the emission of HD 200775 and of its surroundings, it is dominated by the emission from the two interfaces mentioned in the introduction. The peak is located on the dense filaments. At larger distances where one finds the bulk of the dense molecular gas, the 16 μm emission is fainter.

Fig. 2 and 3 are maps of the UIB emission at 6.2 and 11.3 μm respectively. These maps have been obtained by measuring the intensity of the respective band above a continuum on each

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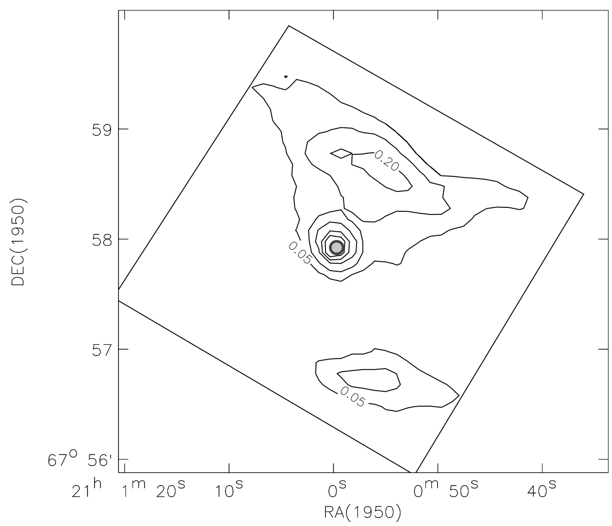

Fig. 1. Map of the 16 μm continuum emission in NGC 7023. The inner rectangle represents the foot print of ISOCAM on the sky. In this and following maps, the star HD 200775 is shown as a shaded dot.

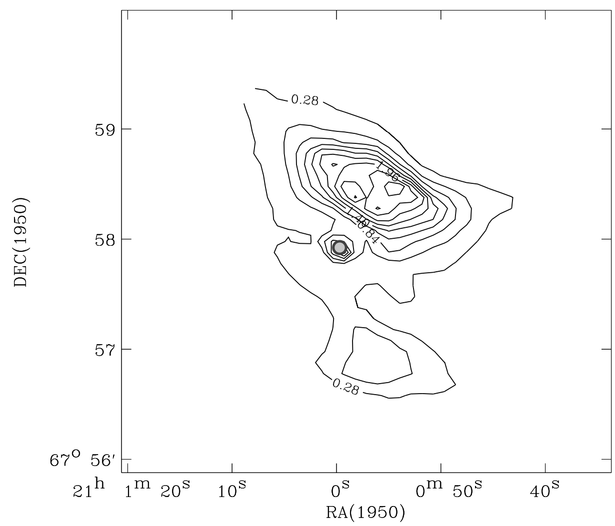

Fig. 2. Map in the 11.3 μm UIB.

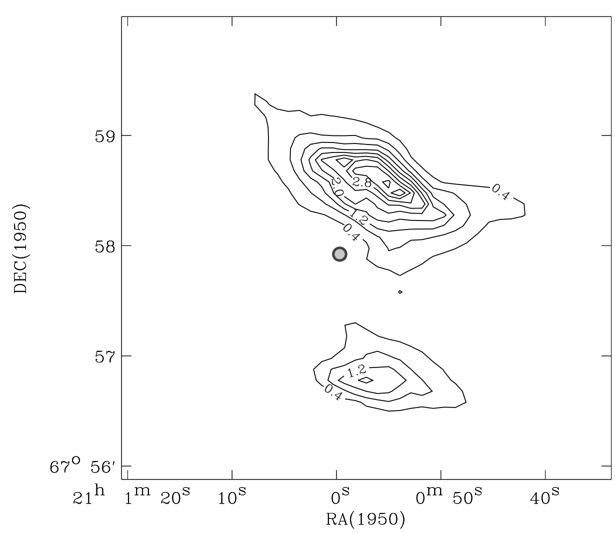

Fig. 3. Map in the 6.2 μm UIB.

side, thus the emission of broad features underlying respectively the 6.2, 7.7 and 8.6 μm and the 11.3 and 12.7 μm band complexes is not included. These features will be discussed later. There is actually faint UIB emission over the whole observed field, outside the brightest regions which are displayed here. Maps in the 7.7 μm and in the 12.7 μm bands are very similar to those at 6.2 and 11.3 μm respectively and are not shown.

While the 6.2 and 11.3 μm maps have a general similarity with the 16 μm continuum map of fig. 1 there are conspicuous differences. At 11.3 μm the north–west peak emission is slightly inside the 16 μm peak, and at 6.2 μm this is even more pronounced. At 6.2 and 7.7 μm the angular resolution is sufficient to distinguish two peaks in the radial distribution, one of which coincides with the 11.3 or 12.7 μm peak and the other one is closer to the star by about 12″. All these peaks are clearly *inside* the dense filaments. South of HD 200775 the relative distributions are similar although the peaks are less well defined.

Another way to present these results is to consider band ratios. Fig. 4 is a map of the intensity ratio of the 6.2 and 11.3 μm UIBs. It should be considered as indicative only: as the angular resolution is not the same for the two bands and as the signal to noise ratio is poor in the weaker regions. Nonetheless, the iso–ratio contours show clearly that the band ratio tends to decrease with increasing distance from the star; the ratio spans a factor of about 2.7 times.

4. Discussion

It is clear that there is a gradient in the emission properties of the carriers. If these carriers are small grains of carbonaceous material in thermal equilibrium (Guillois et al. 1996 and references herein) it is expected that the grains closer to the star are hotter and radiate relatively more since the radiation field is stronger. However the emission properties of these grains do not match well the spectrum observed by us in NGC 7023 (Fig. 5) as their emission bands at 6.2, 7.7 and 8.6 μm are not sufficiently contrasted compared to the observations. Smaller polycyclic aromatic grains or large molecules heated by single photons, hereafter PAHs (see e.g. Sellgren et al. 1985 and references herein, Léger & Puget 1984; Allamandola et al. 1985) might give a better match.

Fig. 5 (full line) shows a spectrum obtained at the peak of the 16 μm emission (see Fig.1). We have not subtracted the zodiacal light from this spectrum, but it is not expected to give a significant contribution. No fine–structure line emission is visible in the whole field except perhaps very near the exciting star, showing that the UV radiation of the star is not hard enough to ionize neon or argon; carbon is ionized (by HD 200775) as

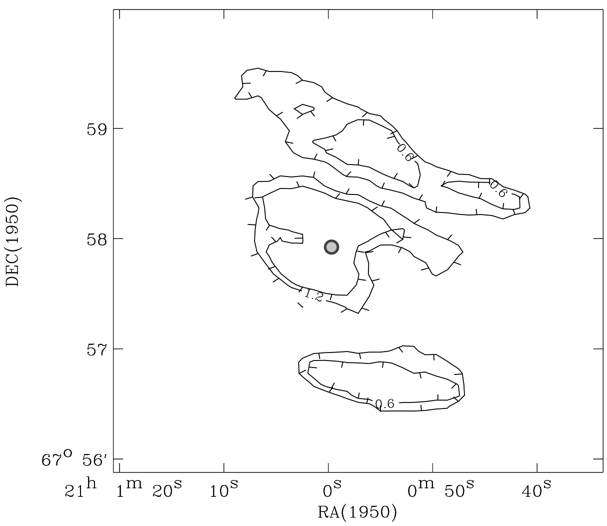

Fig. 4. Map of the intensity ratio of the 6.2 and 11.3 μm bands. Iso–ratio contours represent ratios of 0.6, 0.8, 1.0, 1.2, 1.4, and 1.6.

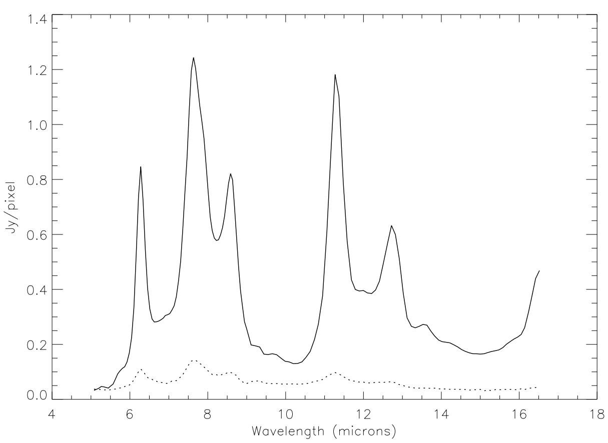

Fig. 5. Full CVF spectra at two representive positions in the observed field. The full line plot was obtained at the peak of the 16 μm emission (see Fig 1) and it is representative of a sloping up continuum emission. The dotted line is representative of a sloping down continuum emission; it was obtained midway between HD 200775 and the South continuum peak. The ordinates give Jy/pixel and should be divided by 36 to give Jy per square arcsecond. The upturn at 16 μm is probably an artefact.

the [C II] 158μm line is observed (Chokshi et al. 1988). The UIBs are conspicuous and the continuum outside is weak although clearly present. Other spectra near the peaks of the 16 μm continuum emission (both the North–West and the South peaks) show also a continuum raising towards longer wavelengths and stronger 11.3 and 12.7 μm emission with respect to the shorter–wavelength bands. Away from the continuum peaks and closer to the exciting star, the spectra show stronger short–wave UIB emission with respect to the long–wave bands and flat – or sloping down – continuum emission. A typical example is shown in Fig.5 as a dotted line. In fact, the variations in the band ratio can be seen in Fig. 4.

Attempts at a gaussian decomposition of the 6.2, 7.7 and 8.6 μm band complex or of the 11.3 and 12.7 μm complex show that in both cases a broad component is superimposed on the narrow bands. The ratios between the bands and these underlying broad components are remarkably uniform over the field.

The CVF ISOCAM spectrum obtained in the ρ Ophiuchi cloud (Boulanger et al. 1996) at a location where the radiation field is fainter by two orders of magnitude than in NGC 7023 is very similar to the spectrum shown on Fig. 5. This yields a very strong support to the idea that one is dealing with very small grains or molecules heated out of equilibrium by single photons (the PAH hypothesis). Comparing more closely the spectra, one sees that the ratio of the 11.3–12.7 μm to 6.2–8.6 μm bands in the ρ Ophiuchi cloud is intermediate between the two NGC 7023 spectra. The same is true for the continuum at 9–11 μm and at 14–16 μm and for the continuum/band ratio. There is a general softening of the spectrum from the region near HD 200775 in NGC 7023, to the ρ Ophiuchi cloud, then to the 16 μm peak in NGC 7023. It is unlikely that the continuum at 9–11 μm is affected by the silicate band in any of the targets. Clearly all this suggests that the bands, the broad underlying features and the continuum are all due to the same category of carriers. The origin of the broad features and of the continuum is not clear and will not be discussed here; there is a possibility that they are due to the unresolved emission by a large number of different molecules (Boulanger et al. 1996; Moutou et al. 1996). We suggest that there is a single parameter which determine the relative change of all the spectral components. Obviously, this parameter cannot be the intensity of the radiation field. It could be the PAH size distribution, PAH ionization or PAH dehydrogenation.

i) PAHs of smaller size radiate at shorter wavelengths as they reach higher peak temperatures after excitation by a single photon. If this is the correct explanation, our observations might suggest that the size distribution favors smaller PAHs in the inner region of NGC 7023. A possibility is that the smallest PAHs are trapped in grain mantles and are released when the mantles are evaporated by the radiation field of the star or destroyed by some other process. As the interface is eating through the molecular cloud away from the star, the released small PAH are left behind and the size distribution is changed. This explanation is similar to that proposed by Bernard et al. (1993) to account for the large variations of the 12/100 μm brightness ratio observed with IRAS in the general interstellar medium. Another possibility is that the larger PAHs are broken by the radiation field into smaller ones.

ii) PAH radiate more efficiently the UIBs when they are ionized once as PAH^+ (De Frees et al. 1993; Pauzat et al. 1995), and the ratio of the 11.3–12.7 μm to 6.2–8.6 μm bands decreases strongly from ions to neutrals (Verstraete et al. 1996). In the dense molecular cloud and the filaments, PAH^+ recombine with electrons due to the higher density and are relatively less abundant than in the less dense region nearer to the star. This may explain the variation in the band ratio. Perhaps mechanisms i) and ii) are acting together.

iii) PAH hydrogenation is measured by the 12.7/11.3 μm band ratio (Verstraete et al. 1996). This ratio is similar in the considered spectra thus the degree of hydrogenation is about the same.

5. Conclusions

We have presented the first images of the distribution of the emission in the continuum and in the UIBs in the reflection nebula NGC 7023. We have achieved a resolution of the order of 6″ corresponding to about 0.01 pc. From these images several conclusions are reached.

1. The continuum emission at 16 μm is concentrated in the inner region of the molecular cloud which surrounds the exciting star HD 200775, and its peak coincides with the dense interface and filaments between this cloud and the photodissociated medium around the star.

2. Faint UIB emission is seen in all the $3' \times 3$ field. This emission is strong near the interface; the UIBs at 11.3 and 12.7 μm peak near the interface, while the UIBs at 6.2, 7.7 and 8.6 μm are relatively stronger somewhat nearer to the star.

3. From their spectra and space distribution, we conclude that the UIBs as well as the underlying broad features and continuum are not emitted by coal grains in NGC 7023 but are due to smaller carbonaceous particles heated transiently by single–photon absorption (the PAH hypothesis).

4. There is a systematic hardening of the whole 5–16 μm spectrum (including the UIBs, the broad features and the continuum) when ones goes from the interface of NGC 7023 to the part of the ρ Ophiuchi cloud studied by Boulanger et al. (1996) and then to regions of NGC 7023 closer to the exciting star. This hardening, which is not related to the intensity of the radiation field, may correspond to a variation in the size distribution of PAHs or to a change in the PAH ionization ratio, or to both. Further studies are needed to clarify this point.

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