The infrared emission of carbonaceous particles around C-rich IRAS sources (*)

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Summary. — The IRAS spectra of 23 carbon-rich sources have been fitted by means of an improved theoretical model based on the Leung-Spagna radiative transfer code and using extinction data obtained in our laboratory for different types of amorphous carbon and silicon carbide submicron particles. The agreement between observations and theoretical spectra is rather good. However, a comparison between the IRAS spectrum of the object 12447 + 0425 (RU Vir) and that recently obtained at UKIRT, for the same object but with higher resolution, seems to open new problems.

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1. – Introduction

The presence of amorphous carbon (AC) particles, together with silicon carbide (SiC) grains, around carbon stars is widely accepted [1].

Since 1962 Hoyle and Wickramasinghe [2] suggested graphite as the main condensate in the atmosphere of cool stars; but the non-detection of the 11.52 μm emission feature of graphite [3, 4] and the prevalent physical conditions around the carbon stars seem to favour the production of non-crystalline carbon grains [5, 6]. The presence of amorphous carbon as the main component is also indicated by the best fits of infrared spectra of some carbon stars [7, 8].

On the other hand, Hackwell [9] found that SiC particles should be formed in the carbon star environments, if the temperature of the gas decreases below 1500 K. However, the nature of the SiC component has not been fully assessed so far. In fact, SiC occurs in two crystalline forms: α-SiC, consisting of a mixture of hexagonal and rhombohedrical polytypes, and β-SiC mainly cubic [10]. A statistical analysis [11] of the spectra of carbon stars observed by the InfraRed Astronomical Satellite (IRAS) [12] seems to indicate α-SiC as the likely candidate; however, the presence of β-SiC

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particles cannot be ruled out, as already suggested by Cohen [13] in 1984. It is worth noting that the relative abundance of α and β-SiC in the envelopes of carbon stars could be linked to the evolutionary status of the sources [14]. In order to clarify this point, a systematic analysis of the infrared spectra of carbon stars has to be done on a large sample of objects.

In a previous paper (hereinafter paper I) [15] we have fitted the spectra of eight IRAS sources chosen among the brightest carbon stars and exhibiting a prominent circumstellar emission feature at about 11.3 μm attributed to SiC particles. We obtained good fits between 8 and 20 μm using the optical properties of mixtures of AC and SiC submicron grains produced and characterized in our laboratory [10, 16, 17]. The experimental extinction data were used as input for a simple theoretical model which simulated the dust envelopes by means of a homogeneous and isothermal shell with a spherical geometry.

We found that it is possible to discriminate between the sources containing only α-SiC and those containing both α-SiC and β-SiC. We also attempted an evolutionary interpretation of such diversity but the number of sources was too small to allow any meaningful statistical analysis.

In the present work we have fitted the spectra of an extended sample of 23 IRAS sources, using an improved radiative transfer model [18] which calculates the temperature gradient across the shell for each component of the mixture. This allowed us to extend the fits of the spectra up to 100 μm.

TABLE I. – IRAS *sources and values of the best-fit parameters.*

IRAS name	Name	T_* (K)	τ	$R_*/R_\odot$	R_I/R_*	R_E/R_I	AC (%)	α-SiC (%)	β-SiC (%)
00247+6922	—	1800	3	411	3	10^3	92	8	—
02152+2822	—	1200	10	2600	3	10^3	85	15	—
02270+2619	R For	2300	0.5	232	3	10^3	85	15	—
03374+6229	U Cam	2300	0.5	232	6	10^4	75	15	10
04307+6210	DO 28489	2000	1.5	254	3	10^3	80	12	8
04573+1452	R Lep	1800	1	411	3	10^3	75	15	10
05028+0106	W Ori	2500	0.5	310	4	10^4	85	15	—
05426+2040	Y Tau	2500	0.5	310	4	10^4	80	20	—
06331+3829	UU Aur	2500	0.5	310	4	10^4	90	10	—
06342+0328	—	1300	0.8	1805	3	10^3	85	15	—
07065–7256	R Vol	2000	0.6	254	3	10^3	75	15	10
07098–2012	—	1600	1.7	702	3	10^3	90	10	—
08050–2838	—	2400	5	269	3	10^3	92	8	—
08073–3608	FK Pup	1600	1	702	3	10^3	80	20	—
08340–3357	—	2000	8	254	3	10^3	92	8	—
09521–7508	—	1600	1.5	702	3	10^3	90	10	—
09533–4120	X Vel	1600	0.5	702	3	10^3	75	25	—
10154–4950	XZ Vel	2000	0.8	254	5	10^4	75	15	10
10249–2517	CZ Hya	2000	0.8	254	5	10^4	75	15	10
12427+4542	Y CVn	2400	9.4	269	4	10^4	90	10	—
12447+0425	RU Vir	2400	0.5	269	3	10^3	80	15	5
15082+4808	—	1600	8	702	3	10^2	90	10	—
17556+5813	UY Dra	1800	0.8	411	3	10^3	75	15	10

2. – Model description

As reported in the previous section, the simplified model used in paper I allowed us to fit quite well the spectra of some IRAS sources in the wavelength range 8–20 μm. However, when we tried to extend the fit up to 100 μm, we found that an isothermal shell is not able to account for the emission in the whole spectrum. To overcome this problem we have adopted an improved model which allows one to calculate the equilibrium temperature of the grains of the various species at different distances from the central star. The input parameters of this model, based on the Leung-Spagna radiative transfer code [18], are: the star temperature T_*; the exponent γ of the

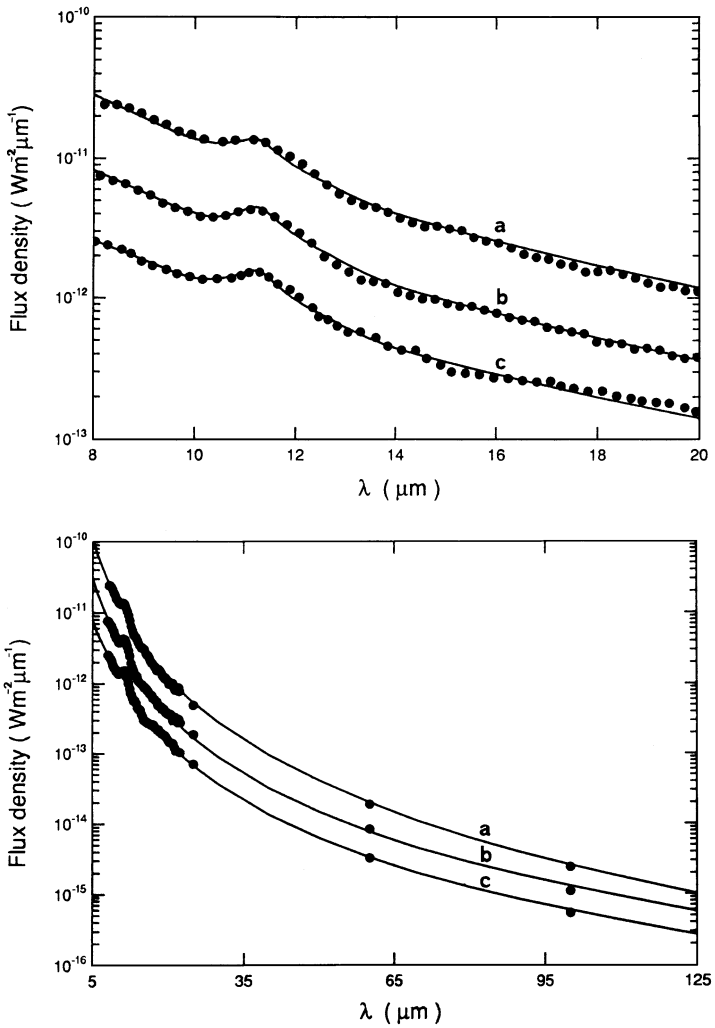

Fig. 1. – Best fits of the observed IRAS spectra of: (a) 12447 + 0425 (RU Vir), scaled by a factor of 2; (b) 05426 + 2040 (Y Tau); (c) 10249–2517 (CZ Hya). In the lower box the whole spectral range is shown, while in the upper box the features of the region around 11.3 μm is presented in more detail.

number density law, $n_g \propto R^{-\gamma}$; the optical depth τ of the envelope at 5500 Å; the ratios R_I/R_* and R_E/R_I, where R_* is the stellar radius while R_I and R_E are the inner and outer radius of the shell, respectively. Other model parameters are the experimental extinction cross-sections of the dust grains, and the relative amount of each component of the mixture.

We have used a three-component mixture of AC, α-SiC and β-SiC submicronic grains, which has been experimentally tested [19] and already successfully used in paper I. The relative amount of each component of the mixture has been chosen in agreement with the expected elemental abundances in the envelopes of carbon stars [19]. Moreover we have assumed for the density index a value $\gamma = 2$, which is widely accepted for carbonaceous grains [20].

It is worthwhile to note that the values of all the input parameters have been chosen taking into account all the relevant information available in the literature and the possible relations that might exist among them. In particular, the stellar radius has been evaluated for a given star temperature, according to the empirical relation given by Bergeat *et al.* [21].

3. – Results and conclusions

The present sample of 23 objects, listed in table I, is more extended than the original sample considered in paper I. Although such a number is not sufficient to perform a thorough statistical analysis, it is, however, large enough to assess a reliable procedure able to reduce the uncertainties on the input parameters.

In table I the values of the best-fit parameters used in modelling each source are reported. As we have already stressed, these parameters have been selected close to

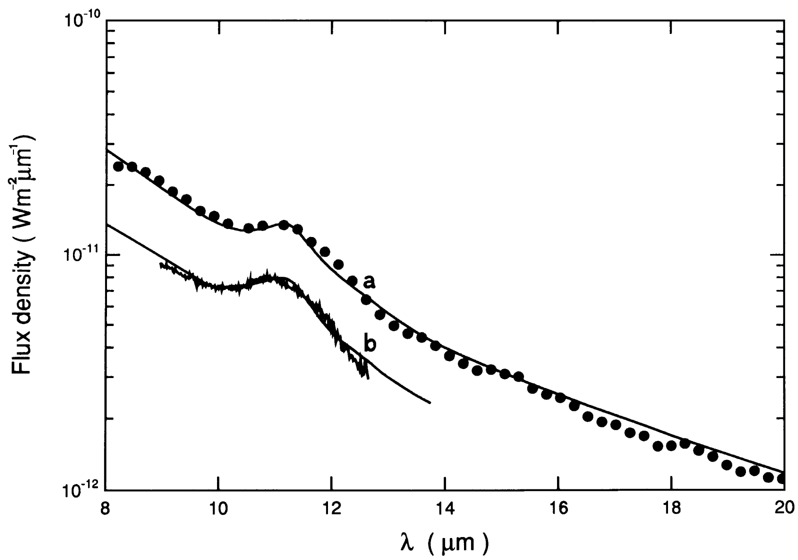

Fig. 2. – Comparison between the best fit of the IRAS spectrum (scaled by a factor of 2) of the object 12447 + 0425 (RU Vir) (a) and that of the UKIRT spectrum of the same source obtained on May 1994 by means of CGS3 spectrometer (b).

the values given in the literature, when available. The optical depths τ have been checked against the existence of an optical counterpart.

As can be seen from table I, in all the sources α-SiC grains should be present, while only 8 cases require β-SiC particles in significative amounts, although as a minor component.

Figure 1 shows, as an example, the best fits of the emission spectra of three sources of the sample, in the wavelength range 8–100 μm. Since the IRAS data at 25, 60 and 100 μm were obtained with broad bandpass filters [22], we calculated the color correction factors, necessary to obtain flux values at the effective wavelength of the filters. This has been done by means of an interpolation of the factors listed in table VI.C.6 of the IRAS Catalog and Atlas Explanatory Supplement [23].

The fits are quite good, but it is interesting to note that in a few cases, not shown in the figure, there is a discrepancy in the long-wavelength wing of the SiC feature. This difference in the shape of the emission band could be due to grain size distributions different from that of our laboratory dust samples. These aspects may be clarified with further theoretical, experimental and observational work. In this respect new observations at higher spectral resolution can be of great importance. In fact, in fig. 2 we show the best fit of the high-resolution spectrum of RU Vir, obtained in May 1994 at UKIRT (United Kingdom InfraRed Telescope), compared with that of the IRAS spectrum of the same source (12447 + 0425). The UKIRT observation refers to our program for searching SiC in a selected sample of carbon stars. The comparison of the two observed spectra in fig. 2 shows an evident variability, both in the continuum and the band profile, of the flux emitted by the source. The fit of the spectrum (b) has been obtained with the following values of the model parameters: $T_* = 2000$ K, $\gamma = 2$, $\tau = 0.9$, $R_I/R_* = 4$ and $R_E/R_I = 10^4$, with 70% of AC, 10% of α-SiC and 20% of β-SiC. In spite of the fact that these values have been chosen with the only purpose to fit the observed spectrum, the overall result is unsatisfactory and opens new questions concerning the variability of this class of sources. As an example one cannot exclude a time variation in the composition and/or size distribution of the grains due to the stellar variability.

New observations of improved quality (UKIRT, ISO) taken at different epochs of the variability cycle can be of great help since, at present, the resolution and the S/N ratio of the observed spectra are worse than those achieved for the laboratory data. On the other hand experimental work is needed to account for other possible components of the dust mixture and to better reproduce the real grain size distribution.

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