Theoretical Modelling of Dust Shells around AGB Stars

E. Paravicini Bagliani, M. Marengo and G. Silvestro

Istituto di Fisica Generale, Universitá di Torino, 10125 Torino, Italy

Abstract.

A numerical code is developed, which integrates the equation of non-grey radiative transfer through a spherically symmetric dust shell around an evolved AGB star. The code computes, by an iterative method, a self-consistent thermal structure of the envelope, for multiple grain components of carbon- and oxygen-rich material. The emergent radial brightness distribution at different wavelengths is calculated taking into account the effect of non-isotropic scattering, absorption and thermal reemission by grains. Our model results, for different sets of stellar and nebular parameters, are compared with observational data on oxygen- and carbon-rich AGB stars with envelopes of different optical depths.

Key words: Stars: evolution — Stars: circumstellar shells — Radiative transfer

1. CIRCUMSTELLAR ENVELOPES OF AGB STARS

The last stages of evolution of stars with small and intermediate masses (1-8 $M_{\odot}$) are governed by mass loss. Thousands of stars on the Asymptotic Giant Branch (AGB) are observed to have infrared (IR) excess, due to circumstellar dust which forms in the outflow of the star. The radiation from the dust shell includes contributions from several layers having different physical parameters, and the interpretation of its complex spectrum demands appropriate theoretical modelling. Radiative transfer in circumstellar dust shells around evolved stars has been discussed by many authors (Rowan-Robinson, 1980; Griffin, 1990; Justtanont & Tielens, 1992). In the last few years, the advent of mid-IR cameras made it possible to spatially resolve some circumstellar dust shells and thus obtain information on their geometrical structure (Persi et al.,1992). New laboratory and astronomical data on the dust grains are now becoming available, that will allow more accurate chemical characterization of the sources. Our numerical code will make use of such new data for giving an interpretation of the photometric and imaging observations collected with the TIRCAM infrared camera.

2. ANALYTICAL DESCRIPTION OF THE MODEL

The model is based on the hypotheses: (1) spherical symmetry of the dust shell, with an $n(r) \propto r^{-2}$ density distribution, consistent with steady outflow at a constant velocity; (2) balance between absorption and emission by the dust grains, which ensures flux conservation in the envelope; (3) LTE dust radiation at the local temperature T(r).

Following Rowan-Robinson (1980), the radiative transfer equation is solved separately for the three components of the radiation intensity: $I_\nu^{(1)}$, the light from the central star; $I_\nu^{(2)}$, the radiation from grains; $I_\nu^{(3)}$, the scattered light. The temperature profile $T(r)$ is evaluated by an iterative method: the zero-order approximation accounts for the stellar radiation alone, then each new iteration leads to a new temperature distribution, subject to the condition of flux conservation, until $T(r)$ is found to be stabilized within the required accuracy. A procedure is employed which corrects the temperature profile in order to account for the whole radiative flux.

The code is used to calculate the temperature distribution at ~60 radial points through the dust shell, and the emergent spectrum at up to 130 wavelength points from 0.4 μm to 250 μm.

The model parameters are:

- d_*, stellar distance from the Sun;
- T_*, stellar temperature;
- R_*, stellar radius;
- a , dust grain radius (around 0.1 μm);
- R_1, R_2, inner and outer radius of dust shell
- τ_{10}, optical depth of dust shell at $\lambda = 10$ μm

2.1. The model opacity profile

An excess of oxygen in the envelope favours the formation of silicate dust grains, which are globally responsible for a broad emission/absorption band at 9.7 μm, and a feature in emission at 20 μm. On the other hand, an excess of carbon would give rise to dust rich in graphite, amorphous carbon, and a small but significant amount of SiC, which is detectable through its emission feature at 11.3 μm. We use the "dirty silicate" model of Jones & Merril (1976) for the grain absorption and scattering efficiency of an oxygen-rich envelope; the graphite, amorphous carbon, and SiC opacity profiles of C-rich envelopes are from Draine & Lee (1984), Martin & Rogers (1987) and Chan & Kwok (1990) respectively.

3. MODEL RESULTS

Our model evaluates the temperature profile $T(r)$ for optically thin and thick, O- and C-rich envelopes. The spectral energy distribution λF_λ is estimated in a wide range of wavelengths for envelopes with different parameters and various dust grain opacity profiles. The spectral features are reported for optically thin and thick models of O-rich and C-rich envelopes of AGB stars.

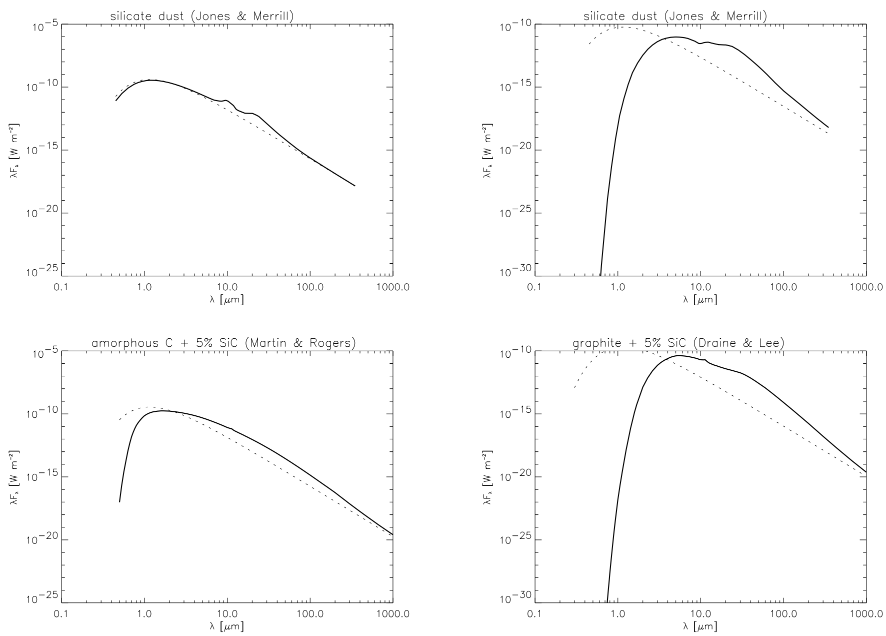

Fig. 1.— Simulations of AGB envelopes with different optical depth and composition: (A) $\tau_{10\mu m} = 0.1$, (B) $\tau_{10\mu m} = 9.0$, (C) $\tau_{10\mu m} = 0.1$ and (D) $\tau_{10\mu m} = 1.0$. The envelope's dust is O-rich in model (A) and (B), and C-rich in (C) and (D). The dotted line is the black-body spectra at the star's temperature (2500 K).

4. DIRECTIONS OF FUTURE WORK

We want to:

- obtain a detailed fitting of the spectrum of individual sources; the dust opacity profiles will be modified in order to take into account recent astronomical and laboratory data for various materials. Comparison of our model results with observation will permit to improve estimates of mass loss rates along the AGB sequence;
- start a program of coordinated IR camera observations and model building of a wide grid of spectra to account for the spectral profiles of cool stars with different characteristics;

- model the variability of IR spectra caused by stellar (Mira-like) variability;
- model the dynamics of mass loss, in order to follow the time development of the geometrical structure of circumstellar shells with different radial density distributions for the dust. This will require a detailed investigation of the region between the envelope's inner radius and the outer layers of the stellar atmosphere, where the dust forms.

REFERENCES

Chan, S. J., and Kwok, S. 1990, A&A, 237, 354

Draine, B. T., and Lee, H. M. 1984, ApJ, 285, 89

Griffin, I. P. 1990, MNRAS, 247, 591

Jones T. W., and Merrill, K. M. 1976, ApJ, 209, 509

Justtanont, K., and Tielens, A. G. G. M. 1992, ApJ, 389, 400

Martin, P. J., and Rogers, C. 1987, ApJ, 332, 374

Persi, P., Shivanandan K., Busso, M., et al. 1992, OATo internal report, No. 22/92

Rowan-Robinson, M. 1980, ApJS, 44, 403