INFRARED APPEARANCE OF DYNAMICAL MODELS FOR CIRCUMSTELLAR DUST SHELLS AROUND LONG–PERIOD VARIABLES

Brightness Distributions

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Abstract. Synthetic brightness profiles resulting from consistent dynamical models for circumstellar dust shells around long–period variables are presented and discussed with respect to a corresponding observation of IRC +10216.

Key words: hydrodynamics – radiative transfer – circumstellar shells – carbon stars – long–period variables – dust – stars: IRC +10216

1. Introduction

Long–period variables and Miras are cool pulsating stars located on the Asymptotic Giant Branch in the HR diagram. These objects generally show high mass loss rates (up to $\approx 10^{-4} M_{\odot}\mathrm{yr}^{-1}$) caused by effective dust formation. In fact, they are the main sources of the galactic dust production and also of a variety of complex chemical species.

2. The Physical Problem

The consistent description of a dust forming envelope around a Mira variable requires the simultaneous solution of the coupled physical problem consisting of time dependent hydrodynamics, thermodynamics, chemistry, and of the dust formation complex (cf. Winters et al. 1994a). The occurrence of dust introduces a strong nonlinear coupling among these different subsystems. By a consistent treatment of this problem, the resulting models are *completely* specified by the four fundamental stellar parameters *stellar mass* $M_\star$, *stellar luminosity* $L_\star$, *photospheric temperature* $T_\star$ and chemical abundances ϵ_i. To describe the pulsation of the star, two additional parameters, the pulsation period P and the velocity amplitude Δu_P at the inner boundary (located inside the photosphere), have to be prescribed (cf. Fleischer et al. 1992).

3. Modelling Method

The system of partial differential equations describing the dust forming stellar atmosphere is written in Lagrangian coordinates, assuming spherical symmetry, and is solved by an explicit integration in time with an internal implicit solution of the energy equation. The numerical method and the behaviour of the dynamical models are discussed in detail in Fleischer et al. (1992). As a result of this calculation the complete radial structure of the dust shell model is obtained at each instant of time. In order to determine the equilibrium temperature, these dynamical models only include an approximate treatment of the radiative transfer problem, which yields no information about the detailed radiation field. Therefore, at selected instants of time the angle and frequency dependent stationary radiative transfer equation is solved in spherical geometry. The method and the results for stationary dust shell models are discussed in detail in Winters et al. (1994a), the application to the dynamical models and the resulting lightcurves are presented in Winters et al. (1994b).

4. Results

4.1 Model Parameters

The model presented here is specified by the following parameters, which are typical for a carbon–rich long–period variable star: $M_\star = 1 M_\odot$, $L_\star = 10^4 L_\odot$, $T_\star = 2600\,\mathrm{K}$, and a carbon to oxygen ratio of $\epsilon_\mathrm{C}/\epsilon_\mathrm{O} = 1.80$, while all other elements have solar chemical abundances ϵ_i. To simulate the pulsation of the star a sinusodial velocity variation of the inner boundary is assumed with period $P = 650\,\mathrm{d}$ and velocity amplitude $\Delta u_\mathrm{P} = 2\,\mathrm{km\,s^{-1}}$.

4.2 Radial structure

The radial structure of this model is shown in Fig. 1 at a given instant of time. As can be seen from the stratification of the flux–mean extinction coefficient (upper diagram), the dust is not distributed homogeneously across the shell but is concentrated in rather thin discrete layers. This dust distribution is caused by the fact, that the physical conditions (i.e. low temperatures and simultaneously sufficiently high densities), neccessary for effective dust formation and –growth are only met for a limited time interval during the pulsation cycle and within a narrow spatial region of the shell. For details we refer to Fleischer et al. (1992). This striking dust distribution shows up to have a significant influence on the hydrodynamical and thermodynamical structure of the shell. Caused by the onion–like dust distribution, the radiative acceleration of the dust grains is also concentrated in discrete layers, as can be seen from the long–dashed curve labelled α (middle diagram, r.h.s. ordinate) which is the outward directed radiative acceleration in units of the local gravitational deceleration. The radiative acceleration acting on the dust grains is closely connected to the velocity structure of the shell (solid line). The strong shocks present in the atmosphere are solely produced by radiative acceleration of the discrete dust layers. Since α exceeds unity close to the star, the material is accelerated to velocities above the escape velocity $v_{\rm esc}$ already at radii below $5\,R_0$. Due to it's opacity, the dust also leads to a pronounced backwarming of the material inside the dust layers as is evident from the steps present in the temperature stratification around $2\,R_0$ and $7\,R_0$ (lower diagram). In summary we find, that the dust completely determines the internal structure of the circumstellar shell, a result that is only revealed by the consistent treatment of the involved physical processes.

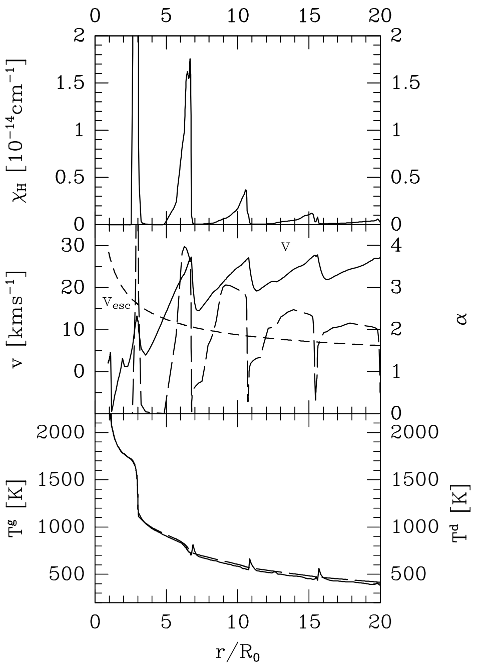

Fig. 1. Radial structure of the model.

4.3 Intensity Profile and Brightness distribution

The discrete spatial dust distribution also leads to directly observable implications, in producing e.g. a step–like distribution of the synthetic *intensity profiles* of the dust shell. In Fig. 2a) the intensity profiles are plotted at three different wavelengths as a function of the impact parameter p (in units of the stellar radius, lower abscissa) and on an angular scale (upper abscissa). Thereby a distance of 200 pc is assumed. For this distance, the step–like structures subtend an angle $\phi < 0.1\,$arcsec, which is hardly resolved by a single ground–based infrared telescope. A common solution of this problem is of course to use interferometric techniques, which measure the Fourier transform of the intensity distribution, i.e. the visibility function of the shell. A more direct way to get information about the intensity profile is to reconstruct the *brightness distribution* of the shell (i.e. the 2–D intensity profile integrated over one spatial coordinate) from a lunar occultation lightcurve. The resulting synthetic brightness distributions of the model are shown in Fig. 2b).

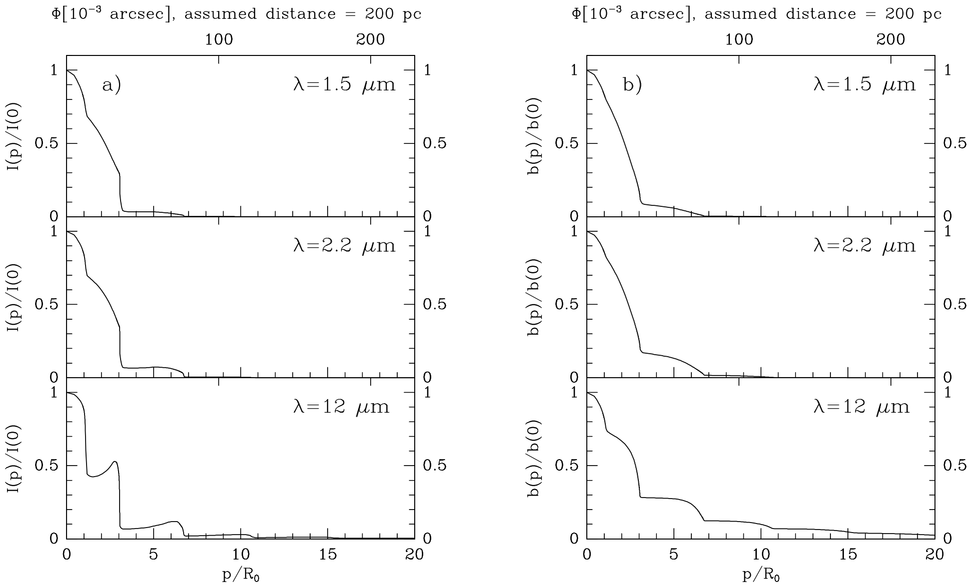

Fig. 2. a): Intensity profiles and b): brightness distribution of the dust shell model at different wavelengths.

5. Discussion

Fortunately, the best observed dust enshrouded C-star, IRC +10216, is located in a region of the sky, that is sporadically crossed by the lunar disk. Very recently, the brightness profile of IRC +10216 was reconstructed from a lunar occultation lightcurve with an angular resolution of $2 \cdot 10^{-3}$ arcsec by Dr. Andrea Richichi (1993, private communication). In this observed brightness profile several quite regular steps are present, which look very similar to the structures shown in the lower diagram of Fig. 2b). Although our calculation was not performed to model any individual object, synthetic and observed brightness profile show rather good agreement. In particular, the angular separation between successive steps occurs on the same scale of a few stellar radii both, in the model and in the observation as well. This fact puts strong support to the reliability of the consistent model calculations and leads to the conclusion, that these models possibly can *physically* explain the structures present in the observed brightness profiles of dust shells around long–period variable stars whithout introducing arbitrary ad–hoc assumptions.

References

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