PLANETARY NEBULAE: THEIR EVOLUTION AND ROLE IN THE UNIVERSE
IAU Symposium, Vol. 209, 2003
S. Kwok, M. Dopita, and R. Sutherland, eds.

2-D Radiation Transfer Model of Non-Spherically Symmetric Dust Shell in Proto-Planetary Nebulae

Kate Y. L. Su

Steward Observatory, University of Arizona, USA

Kevin Volk, & Sun Kwok

Department of Physics & Astronomy, University of Calgary, Canada

1. Introduction

Resent high-resolution optical imaging has directly revealed reflection nebulosity around proto-planetary nebulae (PPNs), the transition objects between asymptotic giant branch (AGB) stars and planetary nebulae (Sahai et al. 1998, Su et al. 1998, Ueta et al. 2000, Su et al. 2001). The existence of bipolar nebulae observed in the PPN phase suggests the presence of asymmetry in the AGB circumstellar dust shell. In order to model these objects, a self-consistent radiation transfer model is necessary. As a first attempt, we construct an approximate two-dimensional dust radiative transfer model to simultaneously fit the spectral energy distribution (SED) and images of a centrally-heated dust envelope.

2. The Model

Limited by spacing, here we only summarize the effects of different parameters in the model, and the details of this model is described in Su 2000. The dust envelope is assumed to be axially symmetric. The density distribution has radial cutoffs at r_{in} and r_{out}, and can be generally written as $\rho(r,\theta)$, where θ goes from $0°$ at the pole to $90°$ at the equator. To reproduce the searchlight beam structures seen in some PPNs, cavities can be put in the density distribution simply by assuming a open-cone structure, in which the density is reduced by factor of τ_{scale}. The viewing angle i is defined as $0°$ if the object is viewed along the pole (pole-on), and $90°$ if it is viewed along the equator (edge-on). We obtain 2-D solutions to the source function by first obtaining the dust temperature distribution from results of 1-D models for the both polar and equatorial directions, and then interpolating between them. We use a power-law interpolation function to estimate the values at any (r,θ). The interpolation formula used for the density is given as:

$$\rho(\theta) = \rho(\theta = 0) + \left(\rho(\theta = \frac{\pi}{2}) - \rho(\theta = 0)\right) \left[\frac{2\theta}{\pi}\right]^{N_d}$$

The power index N_d determines how density varies in the latitudinal direction. The N_d values signify the departure from the spherical symmetry. Larger N_d values represent the case that most material is confined in the equatorial direction so that the stellar light can be scattered in a wide range of latitudinal angle;

https://doi.org/10.1017/S007418090020836X Published online by Cambridge University Press

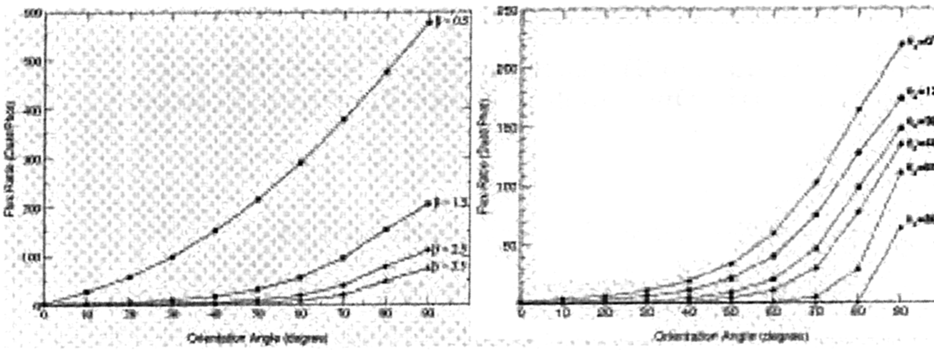

Figure 1. RDP calculated from simulated SEDs at different orientations with different degrees of asymmetry in the CSE. When the degree of asymmetry is large (large N_d or large θ_o), RDP is similar for most of orientations.

i.e., the lobes in the optical reflection nebulosity are fatter and shorter. On the other hand, small N_d values represent the case that the density has much less latitudinal dependence so that the stellar light can escape only within a limited angles near the two polar directions; i.e., the lobes in the optical reflection nebulosity are slimmer and longer. However, the width of the optical reflection lobes is determined by the cavity opening angle if there is a cavity in the density distribution. For an optically-thin axi-symmetric dust envelope, the ratio of dust to photospheric flux (RDP) stays the same at different orientations since the central star can be directly seen in an optically-thin environment. However, the optical images should bear some hints of the orientation with one of the bipolar lobes brighter than the other one and the central star off-centered. For an optically-thick axi-symmetric dust envelope, the RDP is higher as the orientation increases toward edge-on. Our simulations (Figure 1) show that the effects of the RDP at different orientations is a combination of the orientation and the degree of asymmetry departure from spherical symmetry, which is characterized as N_d and opening angle θ_o. The RDP is not sensitive to the orientation angle when the degree of asymmetry is large (Su et al. 2001).

References

Sahai, R. et al. 1998, ApJ, 493, 301

Su, K. Y. L. 2000, Ph.D. dissertation, University of Calgary

Su, K. Y. L., Volk, K., Kwok, S., & Hrivnak, B. J. 1998, ApJ, 508, 744

Su, K. Y. L., Hrivnak, B. J., & Kwok, S. 2001, AJ, 122, 1525

Ueta, T., Meixner, M., & Bobrowsky, M. 2000, ApJ, 528, 861

https://doi.org/10.1017/S007418090020836X Published online by Cambridge University Press