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Infrared studies of circumstellar matter of evolved stars

B. G. Anandarao

Physical Research Laboratory, Ahmedabad 380009, India

1. Introduction

Stars lose mass at a much more rapid rate during their evolution beyond hydrogen burning main sequence phase. All of the low and intermediate mass stars lose mass at the rate of 10^{-9} - 10^{-7} $M_{\odot}$/yr during the red giant branch (RGB) phase and at the rate of 10^{-7} - 10^{-4} $M_{\odot}$/yr during the asymptotic giant branch (AGB) phase of the post-main sequence evolution. Understanding as to how these stars lose their mass is one of the fundamental problems in astronomy and astrophysics (Wood 1990). Observationally, we can study the mass loss rates by measuring the intensities of emission lines from the gas phase molecules as also by measuring the infrared radiation emitted by the dusty (silicate or siliconcarbide) outer envelopes assuming a reasonable estimate on the gas to dust ratio (usually around 200). Further, we are also interested in the geometry in which these stars lose mass - in a spherically symmetric fashion or in axially symmetric way or in clumps etc. Then we need to understand the physical processes by which such a mass loss occurs in AGB stars. We confine here only to the infrared observations for determining the mass loss rates and constraining the models. One may refer to the recent review article by Habing (1996) for details.

2. Estimation of mass loss from infrared observations

The Infrared Astronomical Satellite (IRAS) provided a great wealth of information on the infrared radiation from celestial objects. For more than a decade the data base provided by the IRAS was the only one of its kind till the recent advent of Infrared Space Observatory (ISO) and the HST. Several studies have been taken up in the last one decade to understand the late type stars and their circumstellar environments (e.g., Jura 1986; Little-Marenin 1986; Parthasarathy & Pottasch 1986; Rao & Nandy 1986). Basically one could identify two types of dust grains in the circumstellar shells namely the silicates and the siliconcarbide grains with possible mixed grains (Jura 1986; Little -Marenin 1986; Willems & de Jong 1986, 1988; Lloyd-Evans 1990). Further, in the color-color plots of the IRAS bands, one could approximately identify the various stages of the stellar evolution for intermediate mass stars - the main sequence colors distinctly differing from the giant branch stars with silicate-rich envelopes and these from the later stage carbon-rich stars with SiC dust shells and finally the OH-IR stars (e.g., Habing 1996). One could also find some interesting correlations between the infrared excess (as defined by a particular color-color plot) and the stellar pulsational parameters - like the amplitude and the period (Jura 1986; Whitelock et al. 1987). This showed that there exists a relationship between the pulsations and the mass loss itself. Feast et al. (1989) and Whitelock et al. (1994) discussed the period-luminosity relationship and its implications on the helium shell flashes in Miras.

We at PRL take up a study involving a reasonably large (about 50 -100 stars) sample of oxygen-rich Mira variables to estimate the dust parameters in their circumstellar shells using the IRAS data. Firstly, we showed that the color index S25/S2 represents the true infrared excess better than other indices assumed so far by other workers. Secondly, we have estimated dust parameters using a simple radiative model (Anandarao & Rao 1985; Anandarao et al. 1987) and showed that there exists a good correlation between the mass lost and the pulsational period (Anandarao et al. 1993). This can be understood in the following way. A Mira star of a given mass evolves with increasing mass loss rate (Whitelock et al. 1991). And as the mass loss rate increases the cumulative mass increases. This, combined with the fact that higher mass stars have larger pulsational periods and amplitudes would explain the observed trends. We have also estimated the mass loss rates which agree with those found from different techniques. Furthermore, we have estimated the dust condensation distance from the photosphere to be a few stellar radii assuming that the condensation temperature for silicates is 1000-1500 K (Tielens 1990).

3. Constraints on the theoretical modelling

Theoretical studies showed that the mass loss by the radiation pressure alone (via the dust grains) is much less than what is observed (Bowen 1988). While suggestions of Alfven waves (Hearn 1990) or acoustic waves (Pijpers & Hearn 1989; Pijpers & Habing 1989) have been made with some success especially for the later one, by far the best model seems to be the one that involves pulsationally driven mass loss in presence of dust formed close to the star (Bowen 1988). The pulsations essentially levitate the matter increasing the scale height of the stellar atmosphere. It is easy to show that as the scale height increases the mass loss increases. The dust present close to the star absorbs the radiation and the momentum thus gained is transferred to the levitated gas via a presumably strong collisional coupling. So it is important to know how close to the star would the dust condense. Our estimates (Anandarao et al. 1993) showed that the silicate dust would condense at a few stellar radii.

4. Geometry of mass loss

The geometry of mass loss is important to understand the mass loss processes as well as to understand the formation of the morphological shapes in planetary nebulae which represent the ejected shells of the intermediate mass stars. For, if the mass loss is confined to equatorial region rather than in a spherically symmetric shell, then the subsequent ejection of the shells would be more confined to polar regions giving rise to bipolar planetary nebulae. The equatorial density enhancement itself can be produced by tidal interaction in the case of a binary progenitor or by rotation in the case of a single star progenitor. However, there exist only a handful of PNe with confirmed binary central stars. It is also not clear if the giant branch stars possess enough rotational energies to cause equatorial density enhancement. Such questions need greater attention from observations.

Several observations revealed detached dust/gas shells around giant branch stars indicating that the mass loss process is episodic and not a continuous one. Thus the study of circumstellar matter around the AGB stars would reveal their mass loss history. Hawkins (1990) and Waters et al. (1994) identified extended dust shells in some carbon-rich SR variables. From their high spatial resolution (interferometric) observations at 11μm Danchi et al. (1994) found detached dust shells. Their results on R Aqr supported our interpretations of IRAS data (Anandarao & Pottasch 1986). Recently, Izumuira et al. (1996) provided evidence from ISO far-infrared imaging observations that in Y CVn there exist detached shells of matter ejected due to an episodic mass loss happened earlier. In the case of U Ant, Olfsson et al. (1996) have found two detached gas shells. Recent observations of Knapp et al. (1997) have shown molecular winds with two components having different expansion velocities in a majority of AGB stars in their sample.

5. Future observations

High-angular resolution observations in the near-infrared are required to determine the geometry and the extent of circumstellar shells around the AGB stars. Such a study would reveal their mass loss history. These observations should also search for companions for the AGBs.

Infrared observations - especially in the near-infrared region - on a good sample of stars are needed to determine the dust condensation regions more accurately and directly than inferred from the far-infrared data.

Infrared imaging of PNe would reveal if there is a dusty ring present equatorially to confine the PN shells to polar regions. Such a dust ring is presumably the manifestation of fossil mass loss occurred preferentially in the equatorial regions in the AGB stars.

Some of these studies are being taken up at PRL using the NICMOS 3 camera as well as other facilities at the 1.2m Mt. Abu Infrared Telescope.

References

Anandarao B. G., Rao S. R., 1985, BASI, 14, 25.

Anandarao B. G., Pottasch S. R. 1986, A&A, 162, 167.

Anandarao B. G., Taylor A. R., Pottasch S. R., 1988, A&A, 203, 361.

Anandarao B. G., Vaidya D. B., Pottasch S. R., 1993, A&A, 273, 570.

Bowen G. H. 1988, ApJ, 329, 299.

Danchi W. C. et al., 1994, AJ, 107, 1469.

Feast M. W. et al., 1989, MNRAS, 241, 375.

Habing J., 1996, A&AR,

Hearn J., 1990, From Miras to PNe, Eds. Mennessier M. O., Omont A., Gif-sur-Yvette, Editions Frontiers, p. 121.

Izumuira H. et al., 1996, A&A, 315, L221.

Jura M., 1986, ApJ, 303, 327.

Knapp et al., 1997, Abstract (xxx.lanl.gov/abs/astro-ph/9711125).

Little-Marenin I. R., 1986, ApJ, 307, L15.

Lloyd-Evans T., 1990, MNRAS, 243, 336.

Olofsson H. et al., 1996, A&A, 311, 587.

Parathasarathy M., Pottasch S. R., 1986, 154, L16.

Pijpers F. P., Habing H. J., 1989, A&A, 215, 334.

Pijpers F. P., Hearn A. G., 1989, A&A, 209, 198.

Rao N. K., Nandy K., 1986, MNRAS, 222, 357.

Teilens A. G. G. M., 1900, From Miras to PNe, Eds. Mennessier M. O., Omont A., Gif-sur-Yvette, Editions Frontiers, p. 186.

Waters L. B. F. M. et al., 1994, A&A, 281, L1.

Whitelock P. A. et al., 1987, Late Stages of Stellar Evolution, Eds. Kwok S., Pottasch S. R., Reidel, Dordrecht, p. 269.

Whitelock P. A. et al., 1991, MNRAS, 248, 276.

Whitelock P. A. et al., 1994, MNRAS, 267, 711.

Willems F. J., de Jong T., 1986, ApJ, 309, L39.

Willems F. J., de Jong T., 1988, A&A, 196, 173.

Wood P. R., 1990, From Miras to PNe, Eds. Mennessier M. O., Omont A., Gif-sur-Yvette, Editions Frontiers, p. 67.