1. Modelling dynamic AGB atmospheres

Stars on the Asymptotic Giant Branch (AGB) represent low- to intermediate mass objects ($\sim$0.8-8$M_\odot$) in a late evolutionary phase and are characterised by large extensions (few 100$R_\odot$), low effective temperatures (<3500K), and high luminosities (up to a few 10$^9L_\odot$). Eventually, these red giants become unstable to strong radial pulsations, resulting in large-amplitude (AV of up to 10$^9$) variability with long periods (few 10 to several 100$^0$).

In the cool and relatively dense environments of the very extended (few 100$R_\odot$) AGB atmospheres molecules can efficiently form. Due to the stellar pulsation, the atmospheric structure is periodically modulated, shock waves emerge and propagate outwards through the atmosphere. Dust formation takes place in the wake of the shock waves, radiation pressure on the dust grains leads to the development of a slow but dense stellar wind (typ. 10-20km/s) with mass loss rates of up to 10$^{-4}M_\odot$/yr.

We use dynamic model atmospheres (DMA) from Höfner et al. (2003) to simulate the complex processes taking place in the outer layers of AGB stars. One example is shown in Figs.1+2. By solving radiative transfer (RT) based on these models, we derive various quantities – as synthetic spectra and photometry – which can be compared to observations.

2. Spectral synthesis

The formation of dust and its influence on atmospheric dynamics could be handled numerically in a consistent way mainly for long period variables (LPVs) with carbon-rich chemistry, due to the special properties of amorphous carbon dust (Höfner et al. 2003). For recent advances in the oxygen-rich case cf. talk by S. Höfner.

DMAs provide snapshots of the temporally variable atmospheric structure at certain instances of time (Fig.1), serving as input for subsequent RT calculations. Under the assumption of equilibrium chemistry and LTE we compute synthetic spectra from the visual to the IR including all relevant opacity sources. Fig. 3 shows some typical spectra. OS data was used to account for C-bearing molecules (cf. legend), which are responsible for the characteristic line-rich spectra of late-type giants. Synthetic photometry (Fig. 4) is then computed by folding the spectra with filter response curves and applying adequate zeropoints.

3. Spectral variations + lightcurves

Fig. 5 shows the significant spectral variation during the lightcycle of the used atmospheric model for a C-type Mira. With changes coupled to the sinusoïdally varying luminosity of the model, the spectra of the dynamic phases do not look like the spectrum based on the initial model at any time. Thus, hydrostatic and dust-free model atmospheres are only of limited use for the interpretation of observations of such very evolved late-type giants.

Time-series synthetic photometry for broad-band Johnson filters is shown in Fig.6. A comparison with observational data, e.g. the C-type Mira RU Vir, reveals that our models are able to reproduce the principal behaviour of Miras quite well, especially the characteristic decrease in amplitude from the visual to the IR and the relation J$\lambda$/K$\lambda$ known from observational studies.

4. Comparison with observational results

The modelling results were compared to observations in various ways, as for example by NIR colour-colour diagrams as shown in Figs.7+8, evidencing that our DMAs resemble the global atmospheric structures of pulsating, mass-losing Miras reasonably well. The above presented synthetic photometry (Nowotny et al., in prep.) represents another proof of the quality of the models, in addition to other results published in the past, as for example wind properties (mass loss rates, terminal velocities; Höfner et al. 2003), low-resolution spectra (Gautschy-Loidl et al. 2004), or line profile variations (Nowotny et al. 2005ab, Nowotny 2005c).

References:

Nowotny 2005c, PhD thesis, Univ. Vienna, Austria

Acknowledgements:
The work was supported by the FWF under project numbers P18939-N16 and P19503-N16.