Tracing AGB Mass Loss by (Synthetic) High-Resolution IR Spectroscopy

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Abstract. We report on recent advances in line profile modelling of different near-infrared (NIR) molecular absorption features based on dynamic model atmospheres for pulsating and mass-losing AGB stars (Mira variables).

AGB stars have extended cool atmospheres where molecules form efficiently. This results in a wealth of molecular features dominating the spectra in the visual and IR. Eventually, the stars become unstable to radial pulsations (e.g. Miras). The outer layers of such objects are levitated and the atmospheric structure is periodically modulated by the emerging shock waves. Efficient dust condensation takes place in the wake of the shocks, and radiation pressure on the formed grains leads to the development of a stellar wind and even more extended atmospheres. The complex non-monotonic velocity fields in AGB atmospheres (e.g. shock fronts) with macroscopic motions on the order of 10 km·s⁻¹ severely influence the shapes of individual spectral lines (Doppler shift).

Time series NIR spectroscopy has proven to be a valuable tool to study the kinematics in AGB atmospheres. The line-rich late-type spectra make the highest spectral resolutions (a few × 10⁴) necessary. Molecular features of different vibration-rotation bands originate in separated regions of different atmospheric depth. Radial velocities (RV) derived from wavelength shifts of the lines provide clues on the velocities in the respective line-forming regions. Thus, we can trace the velocity field throughout the outer layers by monitoring line profiles of different lines (see Nowotny 2005). Particularly useful in this context are absorption features of CO in the NIR (e.g. Hinkle et al. 1982).

Dynamic model atmospheres are needed to reproduce the complex, time-dependent atmospheric structures of Miras properly and for subsequently reproducing observational quantities, such as line profile variations. Recently, we presented results of our line profile modelling (Nowotny et al. 2005a,b) utilising the models of Höfner et al. (2003). These models represent pulsation-enhanced dust-driven winds, the most widely accepted scenario for AGB mass loss (at least for C stars; not as clear in the O-rich case: see Woitke or Höfner in this volume). Figure 1 shows an example of the atmospheric structure of a typical model together with illustrative line profiles. CO ∆ν = 3 lines (1.6 μm) sample low atmospheric layers affected by the pulsation of the stellar interior and show a characteristic behaviour (discontinuous, S-shaped RV-curve over the lightcycle; line doubling at phases of light maximum) interpreted as a shock wave propagating through the region of line formation. CO ∆ν = 2 lines (2.3 μm) probe the dust-forming layers and show broadened, asymmetric profiles with some varia-
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Figure 1. Complex structures of AGB atmospheres (note the characteristic non-monotonic velocity fields) illustrated by one phase of a dynamic model. The different properties of various molecular lines and the significant influence of gas velocities lead to a complex line formation process, as demonstrated by strongly differing synthetic profiles of selected CO lines of the $\Delta v=3/2/1$ vibration-rotation bands (with/without velocity effects taken into account in the radiative transfer calculations). Adapted from Nowotny et al. (2005a).

tions (but not coupled to the lightcycle). CO $\Delta v = 1$ lines (4.6 $\mu$m) originate in the wind region and show characteristic P Cygni profiles.

By comparing the results of our line profile modelling (line profiles, their variations, derived RVs and estimated line-forming regions) with observational results (e.g. Hinkle et al. 1982) we show that state-of-the-art dynamic models are able to reproduce qualitatively the behaviour of different lines sampling various depths. A fine-tuning of the model parameters to get quantitatively fitting RVs, combined with including other observable quantities (e.g. low-resolution spectra) in such comparisons, may eventually lead to models which fit specific objects – and to a better understanding of AGB mass loss processes.

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References

Nowotny, W. 2005, PhD thesis, University of Vienna, Austria