Warm gas around AGB stars

Issei Yamamura[1] and Teije de Jong[2]

[1]*Institute of Space and Astronautical Science (ISAS), Yoshino-dai 3-1-1, Sagamihara, 229-8510 Kanagawa, Japan*
[2]*SRON-Utrecht, Sorbonnelaan 2, 3584 CA, Utrecht, The Netherlands*

Observations of AGB red-giants by the ISO/SWS have led to the detections of many molecular features arising from a warm gas layer. Analysis of these molecular features provides important clues to understand the physical / chemical structure of the outer atmospheres and the inner circumstellar envelopes of these stars. The results obtained by the ISO/SWS so far and their impact on the studies of AGB stars are reviewed.

Dioxide molecules with an excitation temperature of several hundred K have been detected in many oxygen-rich stars. The emission band of the CO_2 ν_2 fundamental transition at 15 μm was first found independently by Ryde et al. (1998, Ap&SS 255, 301) and Justtanont et al. (1998, A&A 330, L17). The latter authors also detected the satellite bands at 13.9, 16.2 μm etc. While the fundamental band is seen both in emission and absorption in different stars, the satellite lines are always seen in emission. The intensity ratio between the fundamental band and the satellite bands indicates the presence of multiple CO_2 layers (Ryde et al. 1999, A&A 341, 579) or temperature gradient in the layer (Cami et al. in preparation), and/or the non-LTE effects such as radiative excitation (González-Alfonso & Cernicharo 1999, ApJ 525, 845). The detection of the SO_2 ν_3 band at 7.3 μm (Yamamura et al. 1999a, A&A 341, L9) is rather surprising, since the expected abundance of the molecule in the atmospheres of O-rich giants is quite low according to thermal equilibrium calculations (Tsuji 1973, A&A 23, 411; Woitke et al. 1999, A&A 348, L17). The LTE analysis of the band indicates that a significant fraction of sulfur atoms should be in the form of SO_2. Furthermore, the expected local gas density in the SO_2 layer (at $\sim$ 5 $R_\star$) seems to be at least two orders of magnitude larger than that predicted from the hydrodynamical calculations of model atmospheres (e.g., Höfner et al. 1998, A&A 340, 497). The SO_2 band in the Mira variable T Cep shows time variation, which does not correlate with the optical period.

H_2O has been expected to be present in the atmospheres of O-rich giants. Tsuji et al. (1997, A&A 320, L1) detected the bands even in the spectrum of M2 irregular variable β Peg, which is too hot to posses H_2O in the photosphere. These results indicate that the "warm molecular layer" is also present in these early M-type, non-Mira variable stars. The formation of the layer in these stars should be studied in detail. H_2O dominates the infrared spectra of Mira variables. Yamamura et al. (1999b, A&A 348, L55) demonstrated that the spectra of these stars can be represented by two H_2O layers with different temperatures ($\sim$ 2000 K and $\sim$ 1200 K). In some cases the hot layer extends to almost two stellar radii. Time variation of the features seem to follow the pulsation cycle.

The infrared spectra of carbon stars are dominated by the two most abundant molecules, HCN and C_2H_2 (Yamamura et al. 1998, Ap&SS 255, 351). The spectra turn out to be sensitive to $T_{\rm eff}$ and the C/O ratio (Aoki et al. 1998, A&A 340, 222). It is found that the HCN ν_2 bands in the 14 μm region, especially $\nu_2 = 2^0 \rightarrow 1^1$ at 14.3 μm, are seen in emission, while the C_2H_2 bands in the same region are seen in absorption. This is explained by radiative pumping effects and the different distribution of the two molecules (Cernicharo et al. 1999, ApJ 526, L41). Time variations of the molecular bands in carbon stars are qualitatively reproduced by the hydrodynamic model atmospheres (Loidl et al. 1999, A&A 342, 531).

Finally, atomic / ionic emission lines are detected in some red giants and supergiants (Aoki et al. 1998, A&A 333, L19; Justtanont et al. 1999, A&A 345, 605). These detections are quite interesting, because the excitation region may co-exist, or at least be located very close to the molecular layer in the atmosphere.