SILICATES AS PROBES OF THE MASS LOSS HISTORY OF OXYGEN-RICH EVOLVED STARS.

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Introduction: In the late stages of stellar evolution, intermediate mass stars undergo severe mass loss (up to 10^{-4} solar masses per year) while ascending the Asymptotic Giant Branch (AGB). The outer layers of the star are enriched with elements produced by the nuclear processes in the core of the evolved star. These elements include C, N and O, where in most cases oxygen is more abundant than carbon. When the circumstellar material cools due to expansion, gaseous SiO, together with iron and magnesium, will condense, thus forming silicates. As observations have shown [1], we can identify amorphous and crystalline silicates, whereas the different types probably originate at different temperatures and densities.

One reason to study the infrared spectrum of AGB stars is that the emission and absorption features of crystalline and amorphous silicates will provide us with information on the physical and chemical conditions in the circumstellar dust shell. However, this is still future work. We intend to derive the temperature and density gradients, thus revealing the mass loss history of oxygen-rich AGB stars, and finally we may be able to put constraints on the nature of the mass loss mechanism. Here we will present spectra of oxygen-rich evolved stars obtained with the Infrared Space Observatory (ISO). We will analyze the relation between the spectral features of silicates and the energy distribution.

The energy distribution: The dust shell surrounding the central star causes a re-distribution of the emission. Radiation from the star, in the visible wavelength region, is (partly) absorbed by the dust, and re-emitted in the infrared region, thus causing an infrared excess. In case of a high mass loss rate, and high column densities towards the central star, the dust shell will be optically thick at visible wavelengths and sometimes even in the near-infrared. The central star is then completely obscured. This is the case for OH/IR stars. Bedijn [2] models the energy distribution using the dust shell surrounding oxygen-rich stars due to (accelerated) mass loss. In this study the optical properties of amorphous silicate are taken in to account. This provides a measure of the optical depth, since the amorphous silicate features at 9.7 and 18 micron are in emission for low column densities. The features go into self-absorption and absorption for increasing column density. Moreover, for increasing optical depth, the $\tau = 1$ surface will migrate outwards to lower temperatures, which causes a redwards shift of the peak of the energy distribution for increasing mass loss.

From observations performed with ISO it becomes clear that the crystalline silicate features will become stronger for higher integrated mass loss. It is generally believed that annealing of the amorphous material into crystalline dust will happen only at high temperatures, i.e. above the glass temperature. In high mass loss objects, the density at the inner edge of the dust shell is higher. In that case, the dust condensation may start at a higher temperatures and the dust stays at those high temperatures for a longer period. Thus we increase the duration of the annealing period, which leads to a higher abundance of crystalline silicates.

Observations: We present the combined Long Wavelength Spectrometer (LWS) and Short Wavelength Spectrometer (SWS) ISO data of Miras and OH/IR stars with different mass loss rates, e.g. OH26.5, WX Psc, OH104.9 and OH127.8. The infrared spectra span the wavelength range from 2.4 - 195 micron, which includes practically all of the flux emitted by the sources.

Analysis: The objects are ordered with increasing optical depth, using the 10 micron silicate band, as well as the peak position of the energy distribution. We find that the crystalline silicate features become stronger for cooler shells. The *pseudo-continuum*, i.e. the thermal emission from the dust shell, is determined in order to ascertain the presence of absorption and emission features. In cases when the dust shell is optically thick at the near-infrared, we find that the peak of the pseudo-continuum is at approximately 20 micron, which corresponds to a dust temperature of approximately 145 K. The spectral features of our sample are compared with pure emission spectra, like those of NGC 6302 and AFGL 4106 [3], in order to determine the shape of the absorption features, and the optical depth at different wavelengths. The identification of the several crystalline features is done using laboratory spectra.

Results: We find that the amorphous silicates show extremely broad absorption bands; depending on what pseudo-continuum one defines, the 18 micron band is well in absorption until approximately 25-30 micron. Next to amorphous silicates, another material, like FeO, may contribute to this absorption feature. On the other hand, crystalline silicates occur already in emission at 25 micron and longwards. Depending on which pseudo-continuum is selected, the crystalline silicate features may be in emission, superposed on the broad amorphous silicate absorption band. This implies that the crystalline and amorphous dust grains may not have the same spatial distribution, possibly due to a different radial distribution or due to deviations from spherical symmetry.

References: [1] Waters, L.B.F.M., Molster F.J., de Jong, T. et al, 1996, Astron. Astrophys. 315, L361. [2] Bedijn, P.J., 1987, Astron. Astrophys. 186, 136. [3] Molster, F.J., Waters, L.B.F.M., Trams, N. et al, 1999, Astron. Astrophys., *in press*.