NEW DUST FEATURES IN OXYGEN-RICH ENVELOPES

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Abstract. We report on the discovery of new solid state emission features in the ISO-SWS spectra of evolved oxygen-rich stars. These features appear in cool dust shells and are probably due to crystalline forms of silicates, and crystalline water ice.

1. ISO-SWS observations of oxygen-rich dust shells

Cool evolved stars are often characterized by high mass loss rates via a slow and dense wind, in which dust can easily condense. The thermal emission from circumstellar dust is an important mass loss indicator, but the reliability of mass loss estimates depends on accurate knowledge of the dust properties, which are often not well known. In order to study the composition of the dust shells in oxygen-rich AGB stars, post-AGB stars and planetary nebulae (PNe), the Short Wavelength Spectrometer (SWS) of the Infrared Space Observatory (ISO) was used to obtain full scans between 2.4 and 45 μm of a representative sample of objects. In Figure 1 we show the 30 to 45 μm spectrum of the PN NGC6302, which has one of the richest dust spectra observed so far (see also Waters et al. 1996). The spectrum is an average of 12 detectors, and was rebinned to a resolution of 300.

The spectrum is characterized by a red dust continuum and several broad emission bumps, as well as some sharp, unresolved peaks. The broad emission bumps are probably due to a new dust component, while the sharp peaks are due to forbidden lines ([NeIII], [SIII] and [SiII]), formed in the ionised part of the nebula. In NGC6302, we find bumps at 30.5, 32.8, 33.7, 40.5, 41.5 and 43.1 μm, and also a plateau between about 31.7 and 37.2 μm. We compared the emission bumps with laboratory spectra of solids,

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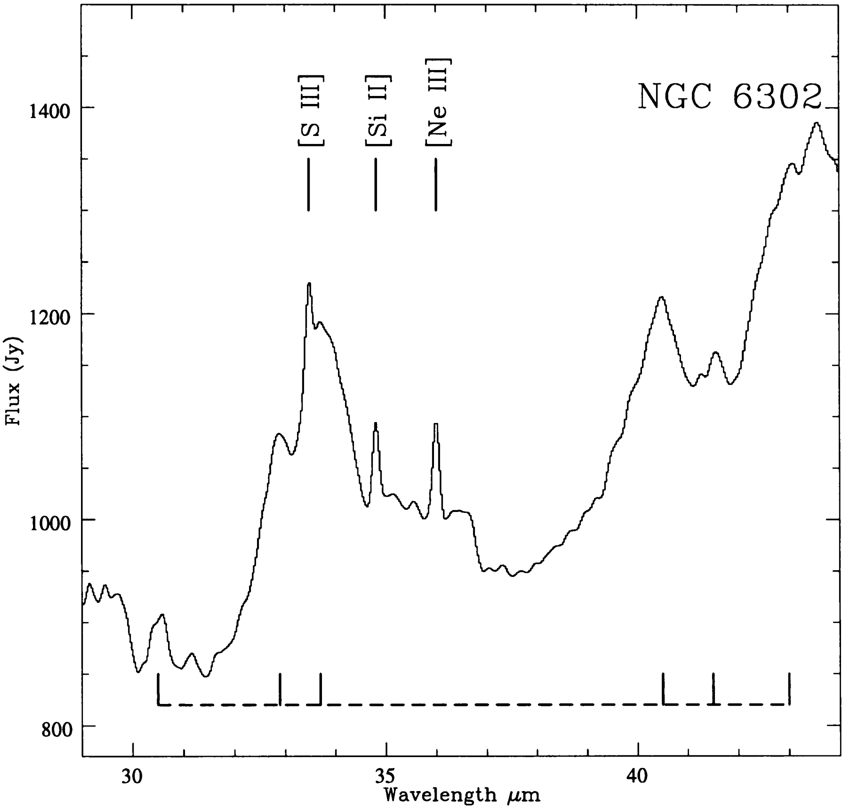

Figure 1. SWS 30-45 μm spectrum of the O-rich planetary nebula NGC6302. Indicated are some forbidden lines, and the new dust features (dashed line with tick marks). Notice also the plateau between about 32.3 and 36.8 μm.

and found good agreement between the position of some observed bumps with those of *crystalline* silicates such as pyroxenes and olivine (e.g. Koike et al. 1993; Jäger et al. 1994). Crystalline olivine shows a strong peak near 33.7 μm, and in addition the lab spectra show a peak near 23.5 μm which is also evident in our SWS spectrum (not shown). Pyroxenes show peaks near 40.5 μm and 34 μm; the latter may blend with the olivine peak. The peak near 43 μm is tentatively identified with crystalline water ice; if this identification is correct, a feature near 162 μm is also expected. The features at 30.5 and 41.5 μm as well as the plateau are unidentified.

In the SWS spectra of O-rich stars studied so far, broad emission near

9.7 and 18 μm due to *amorphous* silicates is often found in addition to the bumps between 20 and 45 μm. This indicates that we are dealing with a *mixture* of amorphous and crystalline materials. Laboratory spectra of amorphous silicates do not show structure beyond 20 μm (e.g. Jäger et al. 1994). It is not easy to identify individual components that make up the amorphous dust component, because of the width and blending of the stretching and bending modes of the Si–O bonds in amorphous silicates. The crystalline component however, with its clear spectral signature at wavelengths beyond 20 μm, allows a much more detailed inventory of the kind of silicates that exist in the dust shells surrounding evolved stars.

The occurence of crystalline material seems restricted to objects with cool dust shells, i.e. colour temperatures less than $\sim$ 300 K. A low colour temperature can result from two effects: (i) a very high dust optical depth due to a high mass loss (AGB), (ii) the dust shell is detached because the mass loss recently stopped (post-AGB). The dust seen in post-AGB stars and PNe represents mass loss at the very end of the AGB, when probably the mass loss rate was very high.

The observations are consistent with two hypotheses: (a) the crystalline component forms from the amorphous material as the dust cools, or (b) it forms near the star in the dust forming layer together with the amorphous component. We believe that the first hypothesis is unlikely, because annealing requires heating of the dust grains, but in fact they cool. The second hypothesis requires that the physical conditions in the dust forming layers of AGB stars depend on the mass loss rate (i.e. the colour of the AGB star), and that for low mass loss rates (blue objects) only amorphous dust forms, while for high mass loss rates (red objects) both amorphous and crystalline dust form. It is not clear what would cause this difference in dust condensation behaviour; it may be related to the temperature structure of the atmosphere.

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References

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Koike, C., Shibai, H., Tuchiyama, A. 1993, MNRAS 264, 654
Waters, L.B.F.M. et al. 1996, A&A 315, L361

Discussion

Omont: Regarding the observed 43 μm feature, have you considered the shape of the spectral features of the various kinds of ice: amorphous, with impurities, etc., studied for instance by Schmitt et al.? Is there already a composite ISO spectrum combining SWS and LWS data for any of the objects you discussed?
Waters: We are considering several possibilities for the identification of the 43 μm feature. At present crystaline ice seems the most promising candidate. We have not yet combined SWS with LWS spectra.

Jenniskens: You found a band near 43 μm that could be ice but is too narrow in comparison to laboratory spectra of the 45 μm ice band. I would like to comment that David Blake and I predicted that you might find such a thing (Jenniskens & Blake 1996, ApJ 473, 1104). The typical laboratory spectrum is measured from warmed vapor deposited ice, which contains a significant amorphous component in the crystalline domain, while the water ice on circumstellar grains is deposited very slowly at high dust grain temperatures. That can allow growth of relatively large cubic crystals and the resulting infrared spectrum will be different, with narrower bands. At present there is a lack of laboratory spectra of such ices, because only very slow deposition at relatively high temperature may prevent the disorder of the deposit. Typical vapor deposits at 120 K do contain such disordered components.