Abstract. The possibility to constrain the mineralogy of dust in AGB circumstellar envelopes with mid-IR ground based imaging observations is discussed. Mid-IR colors are derived for all the AGB sources in the IRAS LRS database with good S/N, to simulate photometric observations with a 10 $\mu$m camera. Radiative transfer modelling is used to reproduce the colors of each individual source, to estimate the envelope physical, chemical and evolutionary status. Real observations are then compared with the model data, to test the modelling technique and the results of the simulations.

This analysis shows a larger scatter for the colors of O-rich sources, in part as a consequence of a larger variety in their composition and mass loss history, and in part for the absence of a single “astronomical silicates” dust able to explain the complexity of features observed in O-rich spectra. Mixtures of amorphous carbon and SiC, on the other hand, can explain all the C-rich envelopes.

Simulated images at 10 and 20 $\mu$m are finally used to select a subsample of AGB sources that can be spatially resolved using different IR telescopes, to investigate the spatial symmetry of the envelope before its transition into a Planetary Nebula.
Mid-IR color-color diagrams of IRAS AGB sources

From the spectra of AGB sources in the IRAS LRS catalogue we computed the mid-IR photometry at 8.5, 9.8, 11.2, 12.5 and 18.0 \( \mu m \); these wavelengths are centered on the dust feature of silicates (9.8 and 18.0 \( \mu m \)) and SiC (11.2 \( \mu m \)), or allow to define the continuum thermal emission of dust having temperatures around 300 K, where the spectral energy distributions of AGB envelopes is maximum (8.5 and 12.5 \( \mu m \)). The 10\% filters set of mid-IR cameras usually provides this photometric system.

Color color diagrams at these wavelengths discriminates between the chemistry and the physical state of the envelopes. In the above figure, red supergiants or AGB sources without dust features are blue, O-rich sources with 9.8\( \mu m \) silicate feature in emission and absorption are yellow and red respectively, and C-rich sources with SiC emission feature are green.
Envelope characterization with mid-IR colors and confirmation with observational data

The color color diagrams show that the colors $[8.5]−[12.5]$ and $[8.5]−[18.0]$ are sensitive to the optical depth of the envelopes, and thus to their amount of dust (more dust, redder the color), regardless to its chemical composition, while the colors $[8.5]−[9.8]$ and $[8.5]−[11.2]$ are able to separate silicates or carbonaceous dust.

All the C-rich sources are above the black-body curve in the “SiC feature diagram”, while O-rich sources are placed above or below the black-body curve in the “Silicate feature diagram” according to their 9.8µm feature in emission or absorption. All the red supergiants in the sample are along the black body curve, at $T_{eff} \geq 2000$ K, while the featureless sources having lower $T_{eff}$ are either C-rich without SiC feature or (in most cases) O-rich envelopes with silicate feature on the verge to be self absorbed.

This source separation is confirmed by observational data: the figure below shows the colors of 17 AGB envelopes observed at the TIRGO observatory with the mid-IR cameras TIRCAM and CAMIRAS, superposed to the “Silicate feature” diagram of the IRAS sample.
Radiative transfer modelling

Mid-IR colors are very sensitive to the opacities used to model the spectra of AGB envelopes, and thus provide a test for their detailed dust chemical composition. For C-rich sources, for example, the $[8.5] - [11.2]$ color is directly correlated to the abundance ratio of SiC respect to amorphous carbon, as shown below (the black lines are models with increasing $\tau_V$, from left to right):

The case of O-rich sources is more complex, since the shape of the silicate feature (and hence the position on the color color diagram) is very sensitive to many physical parameters of the model, and in particular to the stellar spectral shape. An “Engelke” function (modified Planck blackbody with $T_B$ depending on $\lambda$) can reproduce the effect of H$^-$ ions opacity, but the SiO absorption (up to 20% at 10 $\mu$m) should be taken into account with a suitable model.
The models also show that the distribution of O-rich sources on the “Silicate feature” diagram is very sensitive to the temperature of the inner border of the dusty envelopes (that defines the dust condensation temperature and/or the time spent since the last major mass loss event). In the figure below most of the O-rich sources in the sample can be fitted with a $T_{\text{subl}}$ below 600 K, but do exists envelopes with cooler dust.

In general the radial temperature distribution of a “spherical” O-rich envelope can be derived by fitting all the mid-IR colors plus the IRAS fluxes at 12, 25, 60 and 100 µm, using a standard “astronomical silicate” opacity. To model the details of the silicate feature in the IRAS Low Resolution Spectra, however, in many cases is necessary to mix secondary opacities as oxides (e.g. Al$_2$O$_3$, to reproduce the 13 µm feature observed in a class of O-rich spectra) or pyroxenes and olivines with different stoichiometric proportions.
Mid-IR colors and mass loss rates

Since the color [8.5]−[12.5] is related to the amount of dust in the circumstellar envelope, a correlation between this quantity and the total amount of mass loss (derived from radio-mm observations of the molecular envelope) is expected. In fact this is true only to a certain extent, as shown in the plot below, since the different techniques used to derive $\dot{M}_{\text{gas}}$ (radio) and $\dot{M}_{\text{dust}}$ (mid-IR) probes different parts of the envelope. This result favors mass loss scenarios in which the dust formation varies on timescales shorter than the crossing time of the envelopes at gas escape velocity.

The sources plotted on the diagram above are a subset of the IRAS LRS sample for which there exist current estimates of mass loss rates; one should however consider the large uncertainties in the given values of $\dot{M}$, than can be more than one order of magnitude. The large dots on the plot are the sources observed at TIRGO telescope.
Spatial distribution of the dust

If the spectral information given by mid-IR imaging cameras are less accurate than real spectra, this is compensated by the possibility to have two-dimensional images, that can be used to study the spatial distribution of the dust in the envelope, before its transition to a Planetary Nebula. The images below show two sources observed at TIRGO with the 10 $\mu$m imager CAMIRAS; both sources are resolved despite the small aperture of the telescope (1.5m), as evidenced by the Airy disk (dashed circle). Note the elongation of the O-rich AGB WX Psc and the rectangular shape of the post-AGB Red Rectangle, oriented as the optical X-shaped nebula.

the TIRGO telescope at Gornergratt
Search for extended circumstellar envelopes

In general, AGB circumstellar envelopes are objects too compact to be spatially resolved with a mid-IR camera on small telescopes like TIRGO, even though for 7 out of 13 sources observed with CAMIRAS we were able to detect extended emission outside the instrumental PSF. With a larger aperture telescope, however, the number of sources that can be directly resolved is sensibly larger. For this reason we have simulated images of all the fitted sources in the sample, as seen with the MIRAC imaging camera at the NASA IRTF telescope in Hawaii. The figure below shows, as an example, the model image of the source IRC+10401 at 20 μm (panel a), the instrumental PSF (b), the convolution of the image with the PSF (c) and the real image as it would be seen on the detector array of the camera (d).

Using this procedure we have selected a sample of sources that will be observed in the next run of MIRAC at IRTF, in November 1998, and that are expected to show an extended dust emission of at least 8 arcsecs in diameter.
High resolution imaging of AGB envelopes

High resolution imaging with the new generation infrared interferometers as the Large Binocular Telescope (LBT) will open the possibility to directly investigate the state of the dust in the inner regions of AGB circumstellar envelopes, where dust is formed.

As an example, the 10 µm model of the C-rich CW Leonis is shown in the figure below (a) together with the diffraction limited PSF (b) of a single mirror of LBT (aperture 840 cm). The bright circle in (a) represent the position of the dust condensation zone. Note that this region is no more visible in panel (c), image convolved with the PSF, and (d), its projection on a detector array satisfying the Nyquist criterium. In the image on the right, however, the dust formation ring is still visible: here the image is simulated with a spatial resolution of 0.14 arcsecs, equivalent to the resolving power of LBT in interferometric mode, rebinned on a pixel size of 0.05 arcsecs. This resolution allows scientific analysis aimed to determine the morphology, temperature and density of the region where dust condensates, and provides tests on dust condensation and mass loss theories.