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# Dust-grain processing in circumbinary disks around evolved binaries

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**Summary.** The number of binary post-AGB stars known in the Galaxy is significant, yet their evolutionary status is far from understood. All these evolved binaries seem to be surrounded by a Keplerian dusty disk. By combining a wide range of observational data and techniques (e.g. infrared spectrography, SED modelling and radial velocity monitoring) we aim at studying the binary nature of our sample stars, as well as the structure and mineralogy of the circumstellar environment. Our analyses show that the dust is highly processed, both in crystallinity and grain size. The presence of cool crystals in the disks shows that either radial mixing is efficient and/or that the thermal history is very different from that in outflows. The physical processes governing the structure of these disks are very similar to the ones observed in protoplanetary disks around young stellar objects.

**Key words:** stars: AGB, post-AGB - stars: evolution - stars: binaries - stars: circumstellar matter

## 1 Introduction

Binary post-AGB stars are not uncommon and a general characteristic is that they all seem to be surrounded by stable Keplerian dusty disks [7]. The orbital elements from our radial velocity monitoring program indicate that these objects must have undergone severe binary interaction, when the primary was at giant dimension, during which the circumbinary disk has been formed. The binaries are now not in contact but the orbits are too short to accommodate a full-grown AGB star. The disks are circumbinary since all orbits detected so far lay well within the sublimation radius of the dust.

Infrared spectra are ideal tracers of the dust in these circumbinary disks. The chemistry can be traced by resonances of the dust species and the feature profiles can be used to constrain the chemico-physical conditions of the dust grains. The temperature distribution of the dust species throughout the disk is probed by the ratios of the strengths of the features of the same species at different wavelengths.

## 2 Observations

Spitzer-IRS high- and low-resolution spectra were obtained for 21 sample stars, ranging from  $10\ \mu\text{m}$  to  $36\ \mu\text{m}$ , with spectral resolutions of respectively  $R \sim 600$  and  $R \sim 100$ . For some stars we obtained additional ground-based N-band infrared spectra with the Thermal Infrared Multi Mode Instrument 2 (TIMMI2), mounted on the 3.6 m telescope at the ESO La Silla Observatory. At submillimetre wavelength there are SCUBA  $850\ \mu\text{m}$  measurements available for a few stars only.

Orbital parameters are determined using radial velocity measurements obtained with the CORALIE spectrograph attached to the 1.2 m Swiss Euler Telescope. So far, orbital parameters for 16/21 sample stars are obtained.

## 3 Mineralogy

### 3.1 General

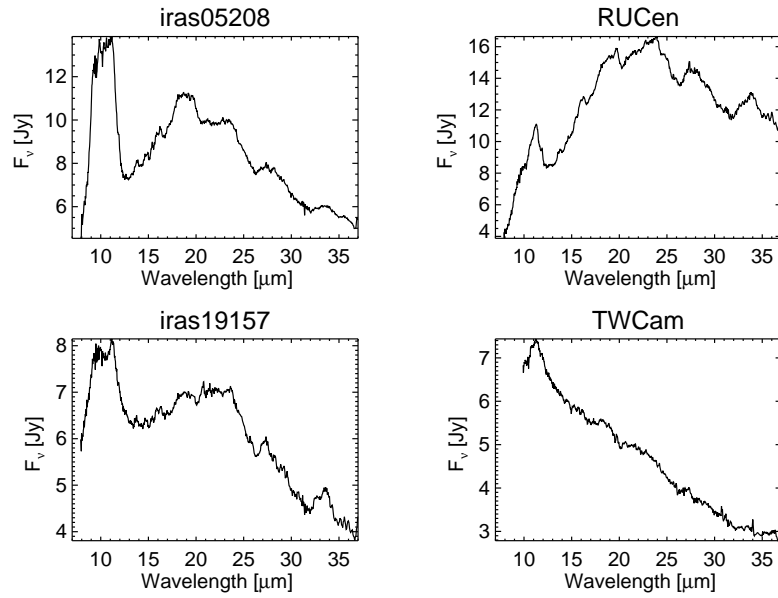
In all objects the dust is oxygen rich and highly crystalline (Fig. 1), with strong emission features which we can identify as features of the Mg-rich end members of crystalline olivine and pyroxene, namely forsterite ( $\text{Mg}_2\text{SiO}_4$ ) and enstatite ( $\text{MgSiO}_3$ ). In none of the spectra there is evidence for a carbon-rich component but two objects do show  $\text{CO}_2$  emission lines. We find a ratio  $^{12}\text{C}/^{13}\text{C}$  smaller than 10, so  $^{12}\text{C}$  is not enriched by the third dredge up during the previous AGB evolution.

In nearly all the spectra there appears to be a shift from the amorphous  $18\ \mu\text{m}$  feature towards the right, when comparing with synthetic spectra of amorphous olivine and pyroxene. This points to the dominance of Mg-rich amorphous dust, also in the amorphous component. The lack of iron detected in the silicates is surprising since we expect the refractory iron to be present in the dust. Photospheric depletion in iron, which we detect in a sample of our stars [5], can be understood when the iron is indeed locked up in the circumstellar dust grains and not in the gas-phase [8] (see also Reyniers in these proceedings). If both the crystalline and amorphous silicates are devoid of iron, this could mean that iron is stored in metallic iron or iron-oxide [6].

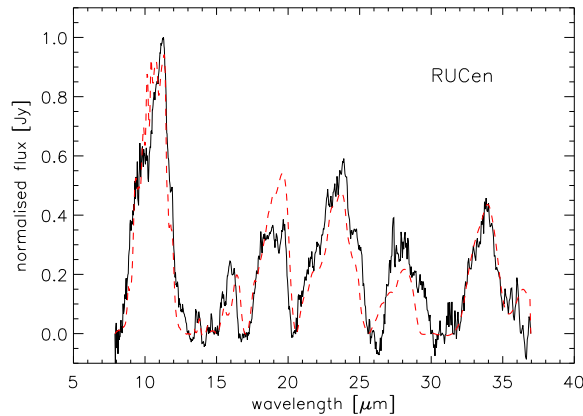
### 3.2 Spectral syntheses

We fit the observed crystalline emission features of our sample stars with synthetic spectra of forsterite and enstatite [4]. We have access to a large sample of mass absorption coefficients of various dust shapes and sizes. Since different dust shapes result in different emission profiles, as a first step, we use the observed emission profiles to determine the best adopted forsterite dust opacity description. The best fit is obtained when using small ( $< 0.1\ \mu\text{m}$ ) forsterite particles in the CDE (continuous distribution of ellipsoids) approximation and big ( $1.5\ \mu\text{m}$ ) forsterite particles in the DHS (distribution of hollow spheres) approximation. We use the same dust size distribution for enstatite since this is physically more plausible.

As a next step we perform a full spectral fitting of the continuum subtracted emission features, using the forsterite and enstatite approximations deduced above and allowing different dust temperatures and dust fractions. A good fit can be achieved by allowing only two different dust temperatures between 50 K and 1500 K (Fig. 2).



**Fig. 1.** Four of our sample stars, showing the large variety in observed infrared spectra. The first three stars are dominated by strong emission features from crystalline silicates. TW Cam is nearly featureless, except for the strong 11.3  $\mu\text{m}$  forsterite feature.



**Fig. 2.** Continuum subtracted and normalized spectrum of RU Cen. Overplotted our best model fit using a forsterite-enstatite mixture with dust temperatures of 150 K and 600 K [3].

## 4 SED fitting

A study of the spectral energy distributions (SEDs) of our sample stars shows that the SEDs of all sample stars are very similar. Dust excess starts near sublimation temperature ( $\approx 1500$  K), irrespective of the parameters of the central star [1]. Our first attempt to model the SEDs using a spherically symmetric model failed, since we could not model simultaneously the SED and the observed infrared spectra, within acceptable evolutionary timescales.

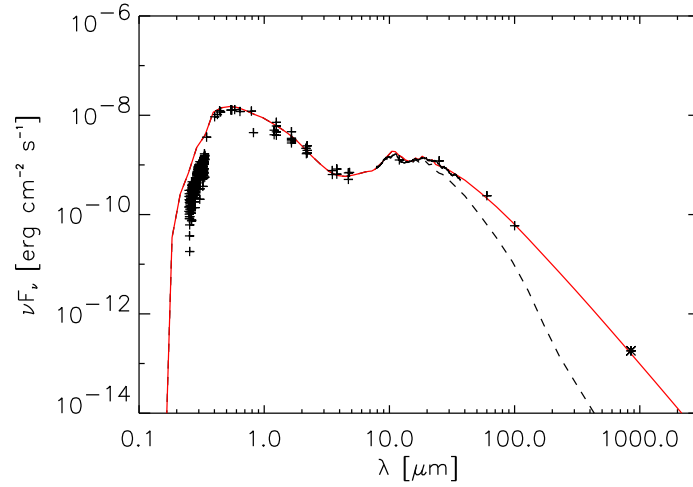
As a next step we performed an SED-fitting using a 2D radiative transfer code assuming a passive disk model [2]. The structure (scale height) of the disk is computed self-consistently using the gas pressure. A significant fraction of large grains ( $850 \mu\text{m}$ ) is needed to account for the high submillimetre flux. Since dust settling times for such large grains are short compared to disk lifetime scales, the picture that emerges is that of an inhomogeneous disk of small grains with a cool midplane of large grains. The small grains will dominate the near- and mid-infrared part of the SED, while the large grains will be the main contributor to the far-infrared part of the SED.

When modelling the near- and mid-infrared part of the SED of one of our sample stars, RU Cen, we find that the feature-to-continuum ratio of the silicate features is too strong in comparison with the ratio observed in the infrared spectra [3]. Including an extra opacity source, like large grains and/or metallic iron, is needed to reduce the strength of the features (Fig. 3).

The SED modelling also gives possible values for the inclination of the system. With these values a minimal mass for the companion star can be estimated, using the mass function and a typical value for the primary of  $M_1 = 0.6 - 1.0 M_\odot$ . For RU Cen, with a mass function of  $f(M) = 0.83 M_\odot$ , this yields a minimal mass for the companion star of  $M_2 = 1.8 - 2.2 M_\odot$ . This means that the companion is likely an unevolved main sequence star, but with a considerable mass.

## 5 Conclusions

Our spectral syntheses and SED modelling give conclusive evidence for the presence of stable Keplerian disks around all our sample stars. Although there is a wide variety in observed infrared spectra, all objects are oxygen-rich and show evidence of strong processing of the dust grains. Nearly all objects show a high degree of crystallinity, with both hot and cool dust present in the disk. The observed crystalline emission features are due to small irregular grains, while the submillimetre flux points to the presence of large grains. The SED modelling is still a degenerate problem so interferometric data is necessary to constrain further the disk geometry (see Deroo, these proceedings). The silicate dominated mineralogy and mass estimates for the companion show that these stars did not evolve on standard evolutionary tracks. The chemical evolution has been shortcut by binary interaction. It is likely that the formation of the circumstellar disk in these objects is closely related to the binary interaction.



**Fig. 3.** SED disk modelling of RU Cen. The dashed line represents the homogeneous disk model consisting of grains between  $0.1 \mu\text{m}$  and  $20 \mu\text{m}$ . The red line gives the disk model with an added blackbody to represent the cool midplane. Crosses represent photometric data and the solid black line the observed Spitzer spectrum. Note that the  $850 \mu\text{m}$  photometric point (asterisk) is an estimation.

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