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Carbon Star Dust Features: the 21 and 30 μm Features

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Abstract. Some characteristics of the 21 and 30 μm features observed in carbon star dust shells are briefly discussed.

1. The 30 μm Feature

This feature was discovered by Forrest, Houck & McCarthy (1981) from *Kuiper Airborne Observatory* observations of carbon stars in the 16 to 30 μm wavelength range. The feature is generally observed in higher optical depth dust shells, or in objects that have evolved off the asymptotic giant branch (AGB). The feature is particularly strong in the G-type and F-type post-AGB object spectra, for unknown reasons.

The feature cannot be observed from the ground due to atmospheric absorption, so most of the data we have on the feature comes from *Infrared Space Observatory (ISO)* or *Spitzer Space Telescope (Spitzer)* spectroscopy. We do not have a survey of objects with the feature, only pointed observations of individual stars that have been observed by these satellites. *ISO* observed the feature in the spectra of 63 carbon-rich objects. *Spitzer* provided the spectra of ∼140 more objects with the feature, including some S-type star spectra with weak 30 μm features. We observe variations in the feature shape and peak wavelength, particularly in the post-AGB phase, which are not understood.

The carrier was proposed to be a mixture of simple metal sulphides, primarily MgS, in Nuth *et al.* (1985). This has been the favoured explanation since then, but there are unresolved concerns about whether the S abundance is high enough to produce this strong feature. We are severely hampered in assessing these sulphide carriers because the optical constants (n, k) have not been measured for them at wavelengths <1 μm, and so realistic radiative transfer models cannot be made to compare with the available observations. It has been suggested that MgS does not form grains by itself, but rather that it coats other grains (SiC, amorphous carbon) which already are present in carbon star dust shells. There is no trace of such coatings on pre-solar carbon grains isolated from meteorites, so it not clear to me that this is a viable idea.

Whatever the carrier is, observations suggest that the feature becomes weaker or is absent in carbon stars in lower metallicity systems such as the Small Magellanic Cloud. The carrier also does not survive in the interstellar medium, as there is no trace of the feature in the extinction curve. We also know of some highly obscured carbon stars which lack the 30 μm feature, and it is not clear why the carrier is absent.

My opinion is that MgS is probably not the carrier of the feature. The few alternatives which have been proposed in the literature have not been given much attention. I believe that we need to get proper optical constants for MgS and related grains, and make realistic models to see whether these can match the observations. We will not make fundamental progress while we lack basic information about the proposed carriers.

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2. The 21 μm Feature

This is a rare feature that is only present in carbon-rich post-AGB stars of G-type to late B-type. It was discovered from the *Infrared Astronomical Satellite* Low Resolution Spectrograph data by Kwok, Volk & Hrivnak (1989) in four objects. Although the feature can be observed from the ground, the best observations we have of the feature are from *ISO* and *Spitzer*. There are a total of only 26 objects known to definitely have the feature: 19 in the Galaxy, 6 in the Large Magellanic Cloud, and 1 in the Small Magellanic Cloud. There are approximately 15 more possible detections of the feature, but these are very weak or otherwise questionable. The feature does not appear to show the kind of variations in peak wavelength or shape that the 30 μm feature does.

The feature is unusual in that it appears to be transient. There is no convincing detection of the feature in any carbon star or planetary nebula spectrum. It appears early in the post-AGB evolution and disappears by the time the star evolves to early B-type. It always seems to be accompanied by the 30 μm feature and the unidentified infrared (UIR) bands, with wide variations in the relative strengths. No clear correlations between the features have been demonstrated. In the discovery paper it was suggested that the feature is due to a transient molecule, but no good candidate for this has been found. There have also been suggestions that the feature is due to dust grains, such as TiC or FeO dust, but in such a case it is not clear why the feature disappears as the star evolves. There are around a dozen carriers proposed in the literature, none of which has gained general support in the community. Many of the proposed carriers are related to polycyclic aromatic hydrocarbons, since these are generally thought to be the carriers of the UIR bands which accompany the 21 μm feature.

Abundance analysis has been carried out for many of the stars whose spectra show the 21 μm feature. They are found to generally be of lower metallicity than average in their host system, and have strong s-process element enhancements. They are also generally carbon-rich, although in a few cases the measured C/O ratios in the stars are $\sim$1 with moderate uncertainties. I assume that the stars are all carbon-rich because the circumstellar dust shells have carbon-based dust and no trace of silicate dust. While it has sometimes been stated in the literature that all carbon-rich post-AGB stars of G- and F-type with strong s-process element enhancement have the 21 μm feature, there are at least two exceptions to this that I know of. It is not clear whether the strong dredge-up experienced by these stars is needed to produce the feature.

At this time the identity of the 21 μm feature carrier is an open question. I tend to believe that the carrier is a molecule rather than a dust grain. If we could take spectral polarimetry observations across the feature we should be able to definitively determine whether the carrier is a dust grain. I think that finding more early post-AGB objects in the hope of observing the feature as it appears would be extremely important in determining the carrier. If we can observe changes in the feature over time (decades? centuries?) that may also give us the key to finding the true nature of the carrier.

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