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UNUSUAL 3 MICRON EMISSION FEATURES IN THREE PROTO–PLANETARY NEBULAE

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ABSTRACT

Medium-resolution 3–4 μm spectra have been obtained of three objects, IRAS 04296+3429, IRAS 22272+5435, and CRL 2688, which are in transition between the asymptotic red giant branch and the planetary nebula phase. All three show unusual 3 μm emission features. The two *IRAS* objects, already unusual in having 21 μm features, have remarkably strong 3.4–3.5 μm emission relative to the usually dominant 3.3 μm feature, with the spectrum of IRAS 04296+3429 being nearly identical to that of IRAS 05341+0852 (previously published). CRL 2688's spectrum bears some resemblance to those of the *IRAS* objects, but its 3.4–3.5 μm emission is not as strong. The relationships between the various emission features are discussed. CRL 2688 may be completing a transition between the "21 μm phase" and the "normal phase," which is associated with dominant 3.3 μm emission, weak 3.4–3.6 μm features and plateau, and a lack of 21 μm emission.

Subject headings: infrared: general — planetary nebulae: general — stars: evolution — circumstellar matter

1. INTRODUCTION

The well-known unidentified emission in the 3 μm region has been shown to consist of a number of discrete spectral features whose strengths and profiles vary widely and thus are due to a number of independent components (Geballe et al. 1985; Jourdain de Muizon, d'Hendecourt, & Geballe 1990; Tokunaga et al. 1991). The dominant emission is almost always the 3.3 μm feature, with a number of weaker features frequently present at longer wavelengths (e.g., Geballe et al. 1985; de Muizon 1986). However, a few examples have been found where this is not the case. In particular, Hyland & McGregor (1989) observed strong 3.4–3.5 μm emission in Nova Cen 1986 (well after the outburst), while Geballe & van der Veen (1990) found similar, but even stronger emission in an evolved star, IRAS 05341+0852.

IRAS 05341+0852 is one of a small class of visible stars, of spectral types F or G, with large far-infrared excesses. These objects are believed to have recently left the asymptotic giant branch (AGB) and to be the evolutionary link between carbon-rich giants and planetary nebulae (PNs; Hrivnak, Kwok, & Volk 1989; van der Veen, Habing, & Geballe 1989). They are sometimes referred to as proto–planetary nebulae, although visually they are considerably more compact than traditional objects of this class. Several of them show an unusual emission feature near 21 μm (Kwok, Volk, & Hrivnak 1989; Hrivnak & Kwok 1991) and additional unusual emission features in the 10 μm band (Buss et al. 1990). Some show the more common features at 6.2 and 7.7 μm (Buss et al. 1990, 1992). The latter features, as well as the 3.3 μm feature, all of which are found in carbon-rich PNs, are generally attributed to aromatic hydrocarbons (Duley & Williams 1981), and frequently to polycyclic aromatic hydrocarbons (PAHs; Leger & Puget 1984; Allamandola, Tielens, & Barker 1989; Shan, Suto, & Lee 1991).

In order to begin exploring the relationship between the unusual mid-infrared emission bands and the 3 μm emission features, we have obtained 3–4 μm spectra of the two 21 μm sources, IRAS 22272+5435 (SAO 34504) and IRAS 04296+3429 (which is associated with a V = 14 star). We also obtained a spectrum of the CRL 2688 (the Egg Nebula), a proto–planetary nebula with extended and unusual visible and infrared morphologies (Westbrook et al. 1975; Smith et al. 1990).

2. OBSERVATIONS

The observations were made at the United Kingdom Infrared Telescope on the nights of 1990 September 27 and 1990 November 29–30 (UT) and used the facility 1–5 μm seven-channel cooled grating spectrometer, CGS2. The aperture diameter was 5″ and the resolution was 0.008 μm. Standard chopping/nodding (30″ EW) techniques were employed. Spectra of F and early G stars were obtained for ratioing and flux calibration.

Each source was observed at the positions of peak 3 μm continuum. For the two *IRAS* objects, this was the location of the associated visible star; for CRL 2688 it corresponded to a position near the southern end of the northern of the two visible nebulous objects.

3. RESULTS

Flux-calibrated spectra of IRAS 04296+3429, IRAS 22272+5435, and CRL 2688 are displayed in Figure 1. The flattened spectra in Figure 2 were achieved by dividing by blackbody functions, whose temperatures were 1250, 3200, and 500 K, respectively. The 3.3 μm feature and other unidentified emission features dominate the spectra in Figure 2. As Brγ emission at 2.166 μm is absent in all of these objects (Thronson 1982; Kwok, Hrivnak, & Geballe 1992), H I 9–5 emission at 3.297 μm does not contribute to the 3.3 μm feature.

The most striking aspect of these spectra is the strength of the 3.4–3.5 μm emission relative to that of the 3.3 μm feature. IRAS 04296+3429 has the most remarkable set of features, with a considerably larger flux in its 3.4–3.5 μm band than in its 3.3 μm feature. To within the observational uncertainties, the profile of its 3 μm emission is identical to that of IRAS 05341+0852, observed by Geballe & van der Veen (1990). The

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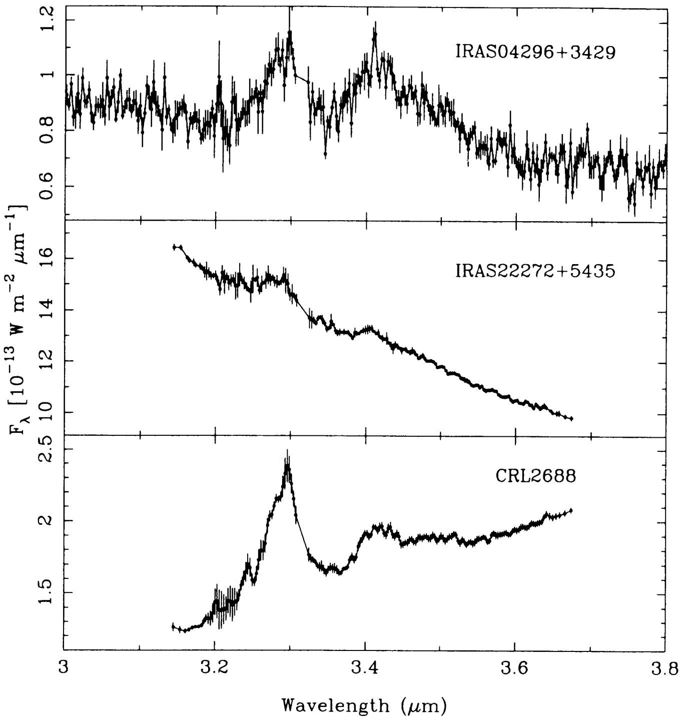

FIG. 1.—Flux-calibrated spectra of three proto–planetary nebulae. The instrumental resolution is 0.008 μm and the sampling is $\sim$0.0025 μm. The lower two spectra have been slightly smoothed, and have a resolution of 0.010 μm. Error bars are $\pm 1\ \sigma$.

emission in IRAS 22272+5435 has a spectral profile similar to those in the above two objects, but the 3.4–3.5 μm emission, although strong, is not quite as prominent. The two *IRAS* objects observed here, along with IRAS 05341+0852 and Nova Cen 1986, appear to form a distinct class of 3 μm emission objects, separate from that of the PNs and H II regions.

In CRL 2688, the 3.3 μm feature is dominant, but the 3.4–3.5 μm emission is still unusually strong relative to the 3.3 μm feature. The ratio of the peak intensities of the features at 3.4 and 3.3 μm is $\sim$0.4 in CRL 2688, compared to values of <0.2 for the PNs and H II regions observed by Geballe et al. (1985) and 0.06–0.26 for HD 44179 and the Orion Bar (Geballe et al. 1989). In addition, the profile of the 3.4–3.5 μm emission in CRL 2688 resembles those of the two *IRAS* objects. The peak wavelength of the 3.4–3.5 μm emission is $\sim$3.41 μm in all three objects observed here (compared to 3.40 μm for more typical sources). In CRL 2688 the profile near this peak (but not its strength relative to the 3.3 μm feature) is similar to that of the weak 3.41 μm feature in HD 44179, another C-rich proto–planetary nebula (Geballe et al. 1989).

The 3 μm spectra of PNs and H II regions are distinguished in part by a plateau of emission that can extend as far as 3.60 μm (e.g., Geballe et al. 1985). The low-resolution 3 μm spectrum of IRAS 22272+5435 obtained by Buss et al. (1990, Fig. 1) appears to have a plateau extending beyond this. However, the present spectrum shows that the emission in IRAS 22272+5435 extends only to $\sim$3.55 μm. The emission feature in IRAS 04296+3429 also extends to $\sim$3.55 μm, although the signal-to-noise ratio is too low for an accurate determination of the edge. In CRL 2688, the long-wavelength edge of the emission is $\sim$3.53 μm.

4. DISCUSSION

4.1. *Relationship to the 21 Micron Feature*

To date, five objects in transition between the AGB and PN phases have been reported to possess the bright emission feature at 21 μm (Kwok, Volk, & Hrivnak 1989; Hrivnak & Kwok 1991). Two of them, IRAS 22272+5435 and IRAS 04296+3429, have been shown here to have remarkably strong 3.4–3.5 μm emission. A third 21 μm object, IRAS 07134+1005, has been found to have rather normal 3 μm emission (Kwok, Hrivnak, & Geballe 1990). The other two previously reported 21 μm sources have not yet been observed at 3 μm. IRAS 05341+0852, which also has strong 3.4–3.5 μm emission (Geballe & van der Veen 1990), recently also has been shown to possess a weak 21 μm feature (Hrivnak, Kwok, & Geballe, unpublished). CRL 2688, whose 3 μm emission features bear some resemblance to those of the strong 3.4–3.5 μm emitters, has no 21 μm emission feature (Hrivnak & Kwok 1991). The 21 μm feature has not been detected in PNs or H II regions showing the 3.3 μm feature (Jourdain de Muizon, Cox, & Lequeux 1989; see also Kwok, Volk, & Hrivnak 1989). *There is a clear correlation between the strong* 3.4–3.5 μm *emission and the* 21 μm *feature, since all three objects which display a strong* 3.4–3.5 μm *feature also possess the* 21 μm *feature* (*excluding Nova Cen 1986 for lack of Q-band spectroscopy*). *However, the absence of strong* 3.4–3.5 μm *emission in at least one of the objects with the* 21 μm *feature* (07134+1005) *implies that the unusual features are not emitted by the same species.*

The objects possessing 21 μm features are believed to be carbon rich, with central stars having surface temperatures of 5000–7000 K. Thus the UV fluxes from these stars are low compared with those powering nebulae that show the "normal" 3 μm unidentified emission bands. Buss et al. (1990) concluded that the molecules or clusters producing the 21 μm

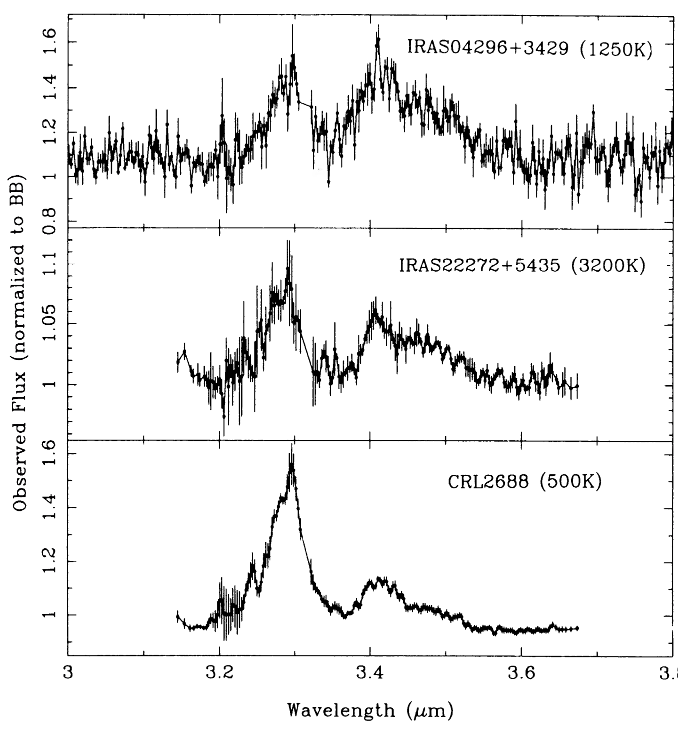

FIG. 2.—Spectra of the three proto–planetary nebulae divided by blackbody functions. The blackbody temperatures are given in the figure.

feature, as well as the distinctive 6–9 μm and 11–13 μm emission features seen by them in these objects, are excited into emission by visible radiation. This is in contrast to the situation in PNs, where molecules producing the 3.3 μm and other infrared emission features are believed to be excited by UV radiation.

Because the presence of the strong 3.4–3.5 μm emission is in some way related to the presence of the 21, 6–9, and 11–13 μm features, we suggest that the molecules producing it are also excited by visible radiation. These may not be the same molecular species as those which produce the normal 3.4–3.6 μm features and plateaus seen in H II regions and PNs (see below). However, the observation by Geballe et al. (1989) that the strength of the 3.40 μm feature relative to that of the 3.3 μm feature increases with distance from the exciting star (i.e., with decreasing UV flux) in some objects suggests that the 3.4 μm emitting molecules in the two types of objects are related.

The absence in PNs of the 21 μm feature, the unusual features in the 6–13 μm region, and the strong 3.4–3.5 μm emission may be due in part to physical processes, such as destruction of the emitting materials by proto–planetary nebulae winds or by "graphitization" (Buss et al. 1990), or perhaps destruction by UV radiation, which increases as the PN progenitor continues to lose mass and becomes hotter. CRL 2688 appears to exhibit infrared emission features intermediate between those of post–AGB stars and PNs. One might speculate that it has nearly completed a transition from the "21 μm phase" to the PN phase, in which the normal unidentified bands are present.

4.2. *Chemistry*

Several identifications have been proposed for the carriers of the 3.4–3.6 μm emission features in PNs and H II regions. Barker, Allamandola, & Tielens (1987) and Allamandola et al. (1989) have suggested that the 3.40 and 3.51 μm features are hot bands of the fundamental C-H vibrational stretch at 3.29 μm in PAHs. They also have suggested that overtones and combinations of C-C vibrations may be responsible for the underlying plateau. In contrast, de Muizon et al. (1986) and Jourdain de Muizon, d'Hendecourt, & Geballe (1990) propose that these and other weak features are the fundamental C-H stretches of sidegroups on PAHs. Recent laboratory measurements (Shan, Suto, & Lee 1991) appear to support the latter interpretation. Regardless of which (if any) of these is correct for H II regions and PNs, because of the strength of the 3.4–3.5 μm emission relative to the 3.3 μm emission in IRAS 04296+3429 and IRAS 22272+5435, it is clear that *the* 3.4–3.5 μm *emission in the strong* 3.4–3.5 μm *emitting objects cannot arise from overtones of the* C-H *stretch.*

Whatever the carriers of the "normal" 3.4–3.6 μm unidentified emission bands are, the strong 3.4–3.5 μm emission in post–AGB objects is not due simply to abundance enhancements of the same basic molecules that produce the emission in PNs and H II regions. There are differences both in peak wavelengths and in the spectral profiles, which imply different chemical abundances in the post–AGB objects than in PNs. Because UV and visible photons may not excite the same vibrational modes with the same efficiencies, the distinctive 3.4–3.5 μm profiles also may be due in part to the relative intensities of stellar UV and visual photons, which are different in post–AGB objects, proto–planetary nebulae, and PNs.

A convincing identification for the new 3.4–3.5 μm emission is not yet evident. As an illustration of the problem, we note that one of the objects with strong 3.4–3.5 μm emission, IRAS 22272+5435, shows an unusually strong 6.9 μm emission feature (Buss et al. 1990). The latter wavelength corresponds to the deformation mode in CH_2 and CH_3 groups, which have stretching vibrations in the 3.4–3.5 μm region. Hence one might suspect that the unusually strong 3.4–3.5 μm emission should be assigned to the stretching mode of such groups. However, IRAS 07134+1005, another object which has a strong 6.9 μm emission feature, has little or no emission at 3.4–3.5 μm (Kwok, Hrivnak, & Geballe 1990). The intensity ratio of the deformation and stretching modes is expected to depend on physical conditions (Schutte et al. 1990, Fig. 7). Nevertheless, it is clear that additional observational and laboratory work are required. Only through concerted efforts in all wavelength regions will it be possible to disentangle the spectroscopic complexity of the unidentified infrared features and understand their variations.

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