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NEW EMISSION FEATURES IN THE INFRARED SPECTRA OF TWO *IRAS* SOURCES

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ABSTRACT

We present infrared spectra of *IRAS* sources 21282+5050 and 03035+5819 (AFGL 437). The observations include ground-based 3 μm spectroscopy and the 7.7–22.5 μm low-resolution spectra from *IRAS*. The well-known emission features at 3.3, 3.4, 7.7, 8.6, and 11.3 μm are present. Additionally, new emission features at 3.46, 3.51, and 3.56 μm are detected. Together with the feature at 3.40 μm, they arise on top of a broad plateau which clearly emerges above the 3 μm continuum. Wings are present on the edges of the 3.3 μm feature. The *IRAS* spectra also reveal an emission plateau above the continuum extending longward from 11.5 μm. These observations are discussed in the context of the PAH hypothesis.

Subject headings: infrared: sources — infrared: spectra — interstellar: grains — interstellar: molecules — molecular processes.

I. INTRODUCTION

Infrared emission features at 3.3, 3.4, 6.2, 7.7, 8.6, and 11.3 μm have been detected in various objects, including planetary nebulae, reflection nebulae, H II regions, and extragalactic objects (see reviews by Aitken 1981 and Willner 1984). Although attributed to dust particles, the carriers of this "family" of features had never been convincingly identified (see review by Allamandola 1984). The situation changed when Léger and Puget (1984) showed that the wavelengths of the main absorption bands in the infrared spectrum of a certain molecule (coronene) approximately matched those of the emission features. In particular, the 3.3, 6.2, 7.7, 8.6, and 11.3 μm features were each identified with a fundamental vibrational mode (respectively, C—H stretch, C=C stretch, C=C skeletal, C—H bend in-plane, and C—H bend out-of-plane) of a molecular species. Allamandola, Tielens, and Barker (1985) proposed a similar explanation and described the excitation mechanism. This class of molecules is known as "polycyclic aromatic hydrocarbons" (PAHs). If the identification is correct, PAHs may contain up to 10% of the carbon in the objects where they are observed and thus be a major component of the general ISM. They may influence the average interstellar extinction curve in the 2200 Å region and, when ionized, could be responsible for the diffuse interstellar bands in the visible (Léger and d'Hendecourt 1985; van der Zwet and Allamandola 1985). Additionally, their existence could affect strongly the interpretation of *IRAS* survey data, particularly in the 12 μm band (Puget, Léger, and Boulanger 1985; Draine and Anderson 1985).

Although the basic PAH identification is promising, recent 3 μm spectra have revealed additional features which, along with the 3.4 μm feature, are not easily identified. In two objects with 3.3 μm features, a much brighter emission feature has been found at 3.53 μm (Blades and Whittet 1980; Allen *et al.* 1982). Some objects with 3.3 μm features have been found to have a plateau of emission extending from 3.4 to 3.6 μm (Geballe *et al.* 1985).

In order to locate additional bright sources of the "unidentified" emission features for further studies, we have utilized the *IRAS* database of Low Resolution Spectra (LRS). The two *IRAS* sources presented in this *Letter* were selected because they have strong emission features at 7.7, 8.6, and 11.3 μm. We present low (CVF) and medium (grating) spectral resolution observations from 3.0 to 3.8 μm for both objects. Although their 3 μm spectra proved to be very similar, the two objects are in other respects quite different. The *IRAS* broad-band photometric data (Table 1) show the

TABLE 1
IRAS BROAD-BAND DATA

BAND	*IRAS* INBAND SURVEY FLUXES (W m^{-2}) 21282+5050	03035+5819
Band 1 (12 μm).......	6.45×10^{-12}	3.92×10^{-12}
Band 2 (25 μm).......	3.70×10^{-12}	1.98×10^{-11}
Band 3 (60 μm).......	8.40×10^{-13}	2.68×10^{-11}
Band 4 (100 μm)......	1.51×10^{-13}	1.31×10^{-11}

infrared spectrum of 21282+5050 to peak in the middle-infrared and to decrease strongly toward longer wavelengths; optically, it looks like a compact starlike object. The infrared spectrum of 03035+5819 (AFGL 437) peaks in the far-infrared and is similar to that of a compact H II region; indeed, the source is visually extended, showing up as a diffuse patch on the red Palomar Sky Survey plate (see also Wynn-Williams *et al.* 1981).

II. OBSERVATIONS

Three sets of observations are reported here: the *IRAS* spectra (7.7–22.5 μm), ground-based CVF 3 μm spectra, and ground-based grating 3 μm spectra. The *IRAS*-LRS (Wildeman, Beintema, and Wesselius 1983) spectra were obtained in 1983 and are shown in Figure 1. Two wavelength ranges, 7.7–13.5 μm and 11–22.5 μm, were recorded simultaneously with respective fields of view of 6′ × 5′ and 6′ × 7′.5. Good-quality spectra, such as the ones of these objects, are obtained only for sources less than ~ 30″ in diameter. In each wavelength band, the resolving power increases with wavelength and varies from 10 to 40. The spectra have been calibrated using the survey calibration (*IRAS Explanatory Supplement* 1985).

The 3 μm spectra were obtained in 1985 September and November at the United Kingdom Infrared 3.75 m telescope (UKIRT) at Mauna Kea Observatory (Hawaii). Source 21282+5050 was found at R.A.(1950) = $21^h28^m15^s.1$, decl.(1950) = +50°50′47″, 4″ from the *IRAS* position, and 03035+5819 was observed at the maximum of 3.3 μm emission: R.A.(1950) = $03^h03^m31^s.8$, decl.(1950) = +58°19′15″, 13″ from the *IRAS* position. Spectra were first measured using a Circular Variable Filter (CVF), at a resolving power of 100 ($\Delta\lambda \approx 0.035$ μm). The wavelength coverage was 3.0–3.8 μm (3330–2630 cm^{-1}). The aperture diameter was 12″.4. The CVF spectra are shown in Figures 2*a* and 2*b*. Higher resolution spectra were obtained with a seven channel cooled grating spectrometer (Wade 1983), at a resolution ≈ 0.0075 μm, and with a 5″ diameter aperture. The September spectra covered the interval 3.1–3.8 μm (3220–2630 cm^{-1}). *IRAS* 21282+5050 was reobserved in November over the interval 3.2–4.1 μm. The September grating spectra are shown in Figures 2*c* and 2*d*. The data have been Hanning (triangle) smoothed, lowering the resolution to $\Delta\lambda \approx 0.009$ μm. All of the UKIRT spectra were flux-calibrated by observing standard stars, measured close in airmass to the objects. Flux calibration is thought to be accurate to ±20%. *IRAS* 03035+5819 was found to be extended (≈ 20″) at 3 μm by Wynn-Williams *et al.* (1981); our measurements are consistent with this. The flux levels for 21282+5050 in Figures 2*a* and 2*c* suggest that it may be extended on a scale of a few arcseconds.

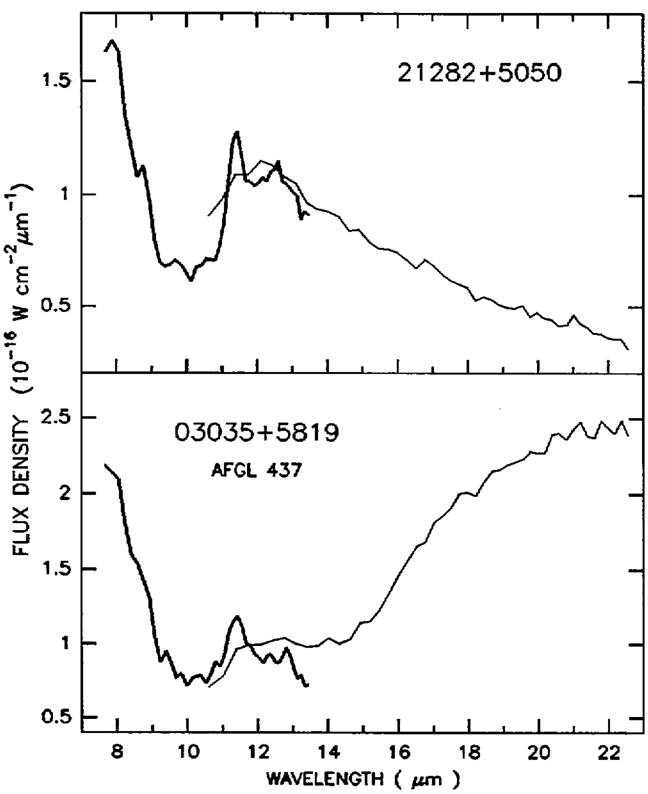

FIG. 1.—*IRAS*-LRS spectra of the two sources. Band 1 (7.7–13.5 μm) and band 2 (11–22.5 μm) are represented. In the overlapping range the spectral resolution is ~ 40 in band 1 and ~ 10 in band 2. The various features are described in the text.

III. RESULTS

In the 3 μm CVF spectra of both sources (Figs. 2*a* and 2*b*) three emission features appear clearly. They are a strong and narrow feature at 3.3 μm, a weaker and narrow one at 3.40 μm, and a plateau extending from 3.35 to 3.6 μm on which the 3.40 μm feature is superposed. The presence of the 3.3 μm feature in AFGL 437 has been reported previously by Kleinmann *et al.* (1977). In earlier papers the 3.40 μm feature and the plateau were not distinguished from one another and were collectively referred to as the 3.4 μm feature.

The most significant new result of the 3 μm spectroscopy of these sources is the detection of three new emission features having peaks at 3.460±0.005 μm, 3.515±0.005 μm, and 3.565±0.010 μm (corresponding respectively to the frequencies 2890±5, 2845±5, and 2805±10 cm^{-1}). All of these features are clearly seen in the grating spectra (Figs. 2*c* and 2*d*); some of them are marginally evident in the CVF spectra (Figs. 2*a* and 2*b*). All three are present in the spectrum of 21282±5050, but only the first two are detected in 03035+5819. These two also appear weakly in the spectrum of HD 44179 by Geballe *et al.* (1985), although not mentioned by them. The feature at 3.56 μm in 21282+5050 is rather weak; however, its presence in that source was confirmed in the 1985 November spectrum. Along with the 3.40 μm feature, the new features are superposed on the plateau emission. The width of each new feature is ~ 0.03 μm (FWHM). Their peak intensities are all less than that of the 3.40 μm feature and decrease with increasing wavelength. In both sources, the features at 3.40 and 3.46 μm present a shoulder on their long wavelength edge, possibly indicating the presence of blended features.

The 1985 November grating spectrum of 21282+5050 confirms the detection and strength of all the features from 3.0 to 3.6 μm and indicates that there are no additional new features in the wavelength interval 3.6–4.1 μm. A weak (F = 1.3 ±

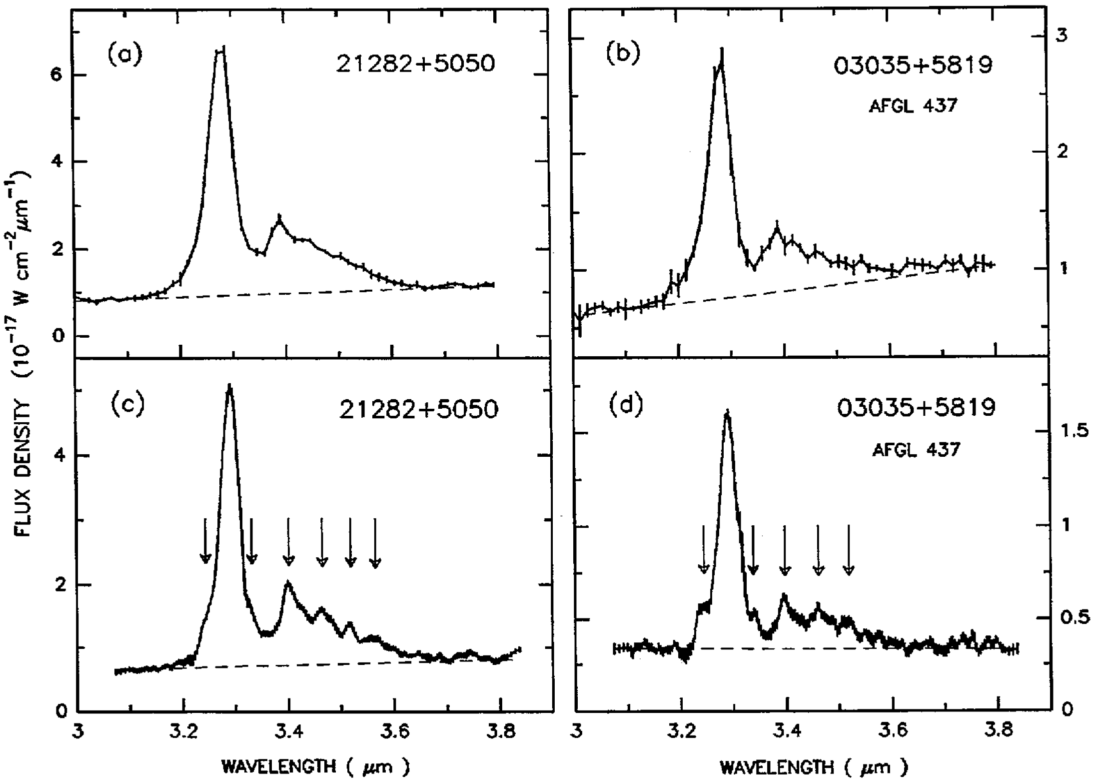

FIG. 2.—(*a*) and (*b*) CVF spectra ($R \approx 100$) of the two sources, from 3.0 to 3.8 μm. The baseline is drawn through the end points of the spectrum. (*c*) and (*d*) Grating spectra ($R \approx 400$) of the two sources, from 3.1 to 3.8 μm. The 3.3 μm feature dominates the spectra. The 3.40 μm and all the new features and wings are indicated by the arrows.

0.3×10^{-20} W cm^{-2}) and unresolved Brα line appears in the November spectrum at 4.05 μm. The weak feature seen (Fig. 2*c*) in the spectrum of 21282+5050 at 3.74 μm, the wavelength of the Pfγ line, was not confirmed.

The grating spectra of both sources also reveal details not seen at lower resolution in the shape of the 3.3 μm feature which is resolved. Its width is 0.045 ± 0.005 μm (FWHM). In both sources, two wings are apparent on the edges of 3.3 μm feature, displaced from its center by 0.05 μm (46 cm^{-1}). They are particularly prominent in the spectrum of 03035+5819.

The LRS spectra (Fig. 1) of the two sources have similar shapes shortward of 12 μm and three features in common at 7.7, 8.6, and 11.3 μm. Due to the short wavelength cut-off of the LRS only the long wavelength slope of the 7.7 μm feature is evident, with the 8.6 μm feature appearing on it as a shoulder. From 12 to 23 μm the slopes of the two spectra differ significantly. In 21282+5050, the emission feature at 11.3 μm is narrower than usual in other *IRAS*-LRS sources (de Muizon and Habing 1985). The weak and narrow emission feature at 12.6 μm appears to be real, since it is present on all the individual spectra. It is also clear that in the 7.7–13.5 μm spectrum, the emission longward of the 11.3 μm feature does not reach the continuum. Therefore in 21282+5050 there is a plateau of emission from 11.5 to about 15 μm. In 03035+5819, the shapes of the features at 7.7, 8.6, and 11.3 μm are more similar to what is observed in other objects (e.g., the Red Rectangle). There is also an excess between 11.5 and 13 μm, similar to the plateau reported by Cohen, Tielens, and Allamandola (1985). The two weak features at 12.4 and 12.8 μm should not be given much credence until high-resolution and more sensitive spectra are obtained in this wavelength range.

IV. DISCUSSION

The major significance of this research is the discovery of three new emission features at 3.46, 3.51, and 3.56 μm, which appear together with the previously known emission features at 3.3 and 3.40 μm, and the 3.4–3.6 μm plateau. No specific identification can be made at present for the new features. The widths of the new features as well as the absence in these spectra of lines such as [Ne II] 12.8 μm, [S III] 18.7 μm, and Pfγ 3.74 μm indicate that the new features are not atomic emission lines. It seems most likely that they are related to the "family" which includes the 3.3, 3.4, 6.2, 7.7, 8.6, and 11.3 μm features and the plateaux at 3.4–3.6 μm and 12 μm. Because much of this family is well fitted by laboratory spectra of PAHs, we will discuss the new features in this context.

Based on the presently available data there appears to be a hierarchy in the occurrence of the various 3 μm emission features. The 3.3 μm feature is always present whenever any other features are present. For the 3.4 μm feature to be present, only the 3.3 μm feature need be present. For the plateau to be present, both the 3.3 and 3.4 μm features must be present and for the 3.46, 3.51, and 3.56 μm features to be present all of the above (with the possible exception of the plateau—see the spectrum of HD 44179 in Geballe *et al.* 1985) are required. This hierarchy may be understandable in terms of a range of stability and/or complexity of the molecules responsible for producing the various features. If the molecules are PAHs, the mixture must be somewhat limited since only a limited number of PAHs are stable enough to survive in the ISM (Reed and Tennent 1971; Léger and d'Hendecourt 1985). The typical size of the hypothetical PAHs are estimated to be 20–50 carbon atoms (Léger and Puget 1984; Allamandola, Tielens, and Barker 1985). Laboratory spectra of only a few of the PAHs of this size have been published. The existence of a mixture of PAHs is also suggested by the 12 μm plateau which is observed in many *IRAS*-LRS spectra having the 7.7, 8.6, and 11.3 μm features. As pointed out by Léger and Puget (1984), the exact wavelength position of the out-of-plane CH bending mode, responsible for the 11.3 μm feature, depends on the number of adjacent H atoms on a ring. The more H atoms that are adjacent, the longer the wavelength of the bending mode becomes (Bellamy 1966; Clar *et al.* 1981). The predominance of the 11.3 μm feature points to molecules with a majority of solo H (no adjacent CH). However, the emission observed from 11.5 μm to about 15 μm might indicate the presence of molecules with duo and trio H (one or two adjacent CH). Identification of the 12 μm plateau with PAHs has also been suggested by Cohen, Tielens, and Allamandola (1985).

The relationship of the plateau and narrow features between 3.4 and 3.6 μm to the dominant 3.3 μm feature may be analogous to that of the 12 μm plateau to the 11.3 μm feature. In the former case it is the precise wavelength of the C—H stretch which depends on the nature of the molecule considered. In an unsaturated hydrocarbon such as an aromatic, the mode occurs at ~ 3030 cm^{-1} (3.3 μm). In a saturated hydrocarbon such as an alkane (Bellamy 1966), the C—H vibration lies in the frequency interval 2962–2853 cm^{-1} (3.38–3.51 μm). This interval is similar to the frequency range of the new lines reported in this *Letter*. We thus suggest that these lines could be due to PAHs, on which are attached molecular subgroups such as $-CH_3$ or $-C_2H_5$. Infrared spectra of methyl- and ethyl-coronene have been obtained in CsI matrices (Léger and d'Hendecourt 1986). They all show a series of features spanning the range 3.37–3.55 μm, together with the strong 3.3 μm feature. However, none of these series coincides exactly with the complete set of observed features, so that a precise identification is not yet possible. Many other possibilities remain to be examined. For example, similar but smaller molecules such as toluene ($C_6H_5CH_3$) and xylene [$C_6H_5(CH_3)_2$] are easily ionized and photodissociated in a strong UV field, producing the ion $C_7H_7^+$ ($C_6H_5CH_2^+$) whose infrared spectrum is not yet known (Dunbar 1973*a*, *b*; Omont 1986). The wings on the 3.3 μm feature may also help to constrain the identification of this and other features. It is possible that a Fermi resonance between the 3.3 μm fundamental and a harmonic of another vibrational mode could create a doublet which appears as wings on the fundamental (e.g., Herzberg 1945). However, such effects are difficult to recognize and are not specific to a particular molecular structure.

Additional laboratory studies of PAHs are necessary for more precise identification of the new features.

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