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Unidentified Infrared Emission Bands

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Definition

The term unidentified infrared emission (UIE) bands refers to a family of emission features observed in a variety of astronomical sources, including the aromatic features at 3.3, 6.2, 7.7, 8.6, and 11.3 μm; aliphatic features at 3.4 and 6.9 μm; and broad emission plateaus at 8, 12, and 17 μm, as well as a host of weaker features that are too broad to be atomic or molecular lines.

History

A family of strong infrared emission bands at 3.3, 6.2, 7.7, 8.6, 11.3, and 12.7 μm were first detected in the young carbon-rich planetary nebula NGC 7027 (Gillett et al. 1973; Russell et al. 1977) (Fig. 1) and in the reflection nebula HD 44179 (Russell et al. 1978). Since the initial discovery, these features are now widely observed in ► HII regions, reflection nebulae, planetary nebulae, ► protoplanetary nebulae, and the diffuse ► interstellar medium of our own and other galaxies.

The UIE feature at 3.3 μm was first identified as the C–H stretching mode of aromatic compounds by Knacke (1977). The chemical origin of the UIE features was discussed by Duley and Williams (1981) who assigned the 3.3 and 11.3 μm features to graphitic (aromatic) materials. Subsequently, Léger and Puget (1984) identified the 6.2 μm feature as due to aromatic C–C stretch, the 8.6 μm feature as the C–H in-plane bend, and the 11.3, 12.4, and 13.3 μm features as due to solo, duo, and trio C–H out-of-plane bending modes. Since the UIE bands at 3.3, 6.2, 7.7, 8.6, 11.3, and 12.7 μm almost certainly originate from aromatic materials, they are also sometimes referred to as aromatic infrared bands (AIBs).

Overview

The UIE phenomenon is more than a collection of emission features but is an integrated phenomenon of emission bands, underlying continua, and broad emission plateaus. Also present in astronomical spectra are emission features around 3.4 μm, which arise from symmetric and asymmetric C–H stretching modes of methyl and methylene groups (Puetter et al. 1979; Geballe et al. 1992). The bending modes of these groups also manifest themselves at 6.9 and 7.3 μm (Jourdain de Muizon et al. 1990; Chiar et al. 2000). In addition, there are unidentified emission features at 15.8, 16.4, 17.4, 17.8, and 18.9 μm, which have been observed in protoplanetary nebulae, reflection nebulae, and galaxies.

The emission bands themselves are often accompanied by strong, broad emission plateau features at 6–9, 10–15, and 15–20 μm. The first two plateau features have been identified as superpositions of in-plane and out-of-plane bending modes emitted by a mixture of aliphatic side groups attached to aromatic rings (Kwok et al. 2001). The 15–20 μm plateau feature has been detected in young stellar objects, compact HII regions, and planetary nebulae, but is especially strong in some PPNs

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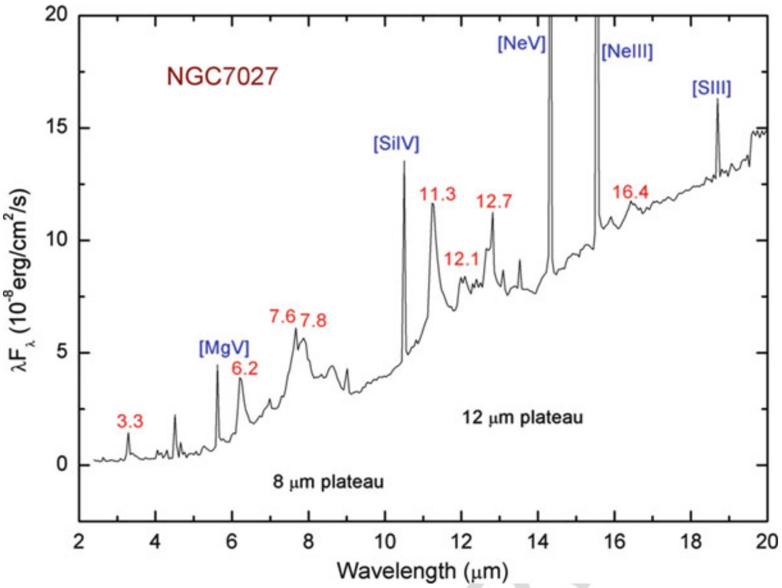

Fig. 1 *Infrared Space Observatory (ISO)* spectrum of the planetary nebula NGC 7027 showing the UIE bands (labeled in *red* with the wavelength of peak emission in units of microns). Broad emission plateaus around 8 and 12 μm as well as a strong underlying continuum can be seen. The *narrow lines* (in *blue*) are *atomic lines*

t1.1 **Table 1** Vibrational mode identification of some of the UIE bands

	λ(μm)	Mode
t1.2		Mode
t1.3	λ(μm)	Aromatic (sp^2)
t1.4	3.29	=C—H stretch
t1.5	6.2	C=C stretch
t1.6	7.6–8.0	C—C stretch
t1.7	8.6	=C—H in-plane bend
t1.8	11.3, 12.7, 13.4	=C—H out-of-plane bend
t1.9		Aliphatic (sp^3)
t1.10	3.38	Asymmetric CH_3 stretch
t1.11	3.42	Asymmetric CH_2 stretch
t1.12	3.49	Symmetric CH_3 stretch
t1.13	3.51	Symmetric CH_2 stretch
t1.14	3.46	—CH stretch
t1.15	6.85	$CH_{(2,3)}$ asymmetric deformation
t1.16	7.25	$CH_{(2,3)}$ symmetric deformation
t1.17		Plateau features
t1.18	6–9	Superposition of aliphatic in-plane bending modes
t1.19	10–15	Superposition of aliphatic out-of-plane bending modes
t1.20	15–20	Superposition of C–C–C skeleton modes?

(Zhang et al. 2010). A possible origin of this broad feature arises from C–C–C in-plane and out-of-plane bending of aromatic rings (van Kerckhoven 2000).

The UIE features are always associated with a strong emission continuum which cannot be explained by free-free emission, reflected starlight, or thermal dust emission heated by stellar photons. For example,

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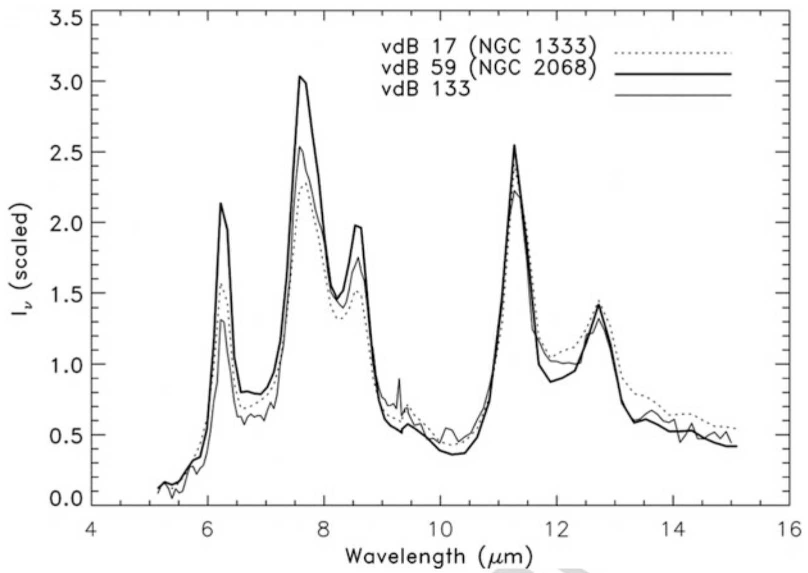

Fig. 2 ▶ *ISO* spectra of the UIE features in three reflection nebulae from the van den Berg catalog, having very different central star temperatures (Figure from Uchida et al. (2000))

scattered starlight is expected to be strongly polarized, but the observed continuum emission is unpolarized. In the diffuse interstellar medium, the strength of the UIE features is strongly correlated with the dust continuum, suggesting that the emission bands are physically related to the continuum (Kahanpää et al. 2003) (Table 1).

The UIE features are seen in very different radiation environments, and their emission peak wavelengths and profiles also vary. The energy sources responsible for the excitation of the features have temperatures ranging from tens of thousands of degrees in planetary nebulae (the central star temperature of NGC 7027 is 200,000 K), to ~30,000 K in HII regions, and to only thousands of degrees in reflection nebulae and protoplanetary nebulae. The UIE features seen in the reflection nebula NGC 7023 are very similar to those seen in the planetary nebula NGC 7027 in spite of the very different intensities of UV background in the two nebulae. Figure 2 shows that the UIE features have very similar profiles, although the central stars of these reflection nebulae have very different temperatures, ranging from 6,800 to 19,000 K.

A variety of chemical structures have been suggested as the carriers of the UIE bands. These include ▶ polycyclic aromatic hydrocarbon (PAH) molecules (Léger and Puget 1984), small carbonaceous molecules (Bernstein and Lynch 2009), hydrogenated amorphous carbon (HAC), soot and carbon nanoparticles (Hu and Duley 2008), quenched carbonaceous composite (QCC, Sakata et al. 1987) particles, kerogen and coal (Papoular et al. 1989), petroleum fractions (Cataldo et al. 2002), and mixed aromatic/aliphatic organic nanoparticles (MAON, Kwok and Zhang 2011). A complete explanation to the UIE phenomenon has to account for the peak wavelengths and profiles of the emission features, the broad emission plateaus, as well as the underlying continua.

See Also

▶ Planetary Nebulae
▶ Polycyclic Aromatic Hydrocarbons

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