

## INFRARED ABSORPTION DUE TO HYDROGENATED AMORPHOUS CARBON IN THE DIFFUSE INTERSTELLAR MEDIUM

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Received 1994 March 7; accepted 1994 May 10

### ABSTRACT

The infrared absorption spectrum of hydrogenated amorphous carbon (HAC) deposited at  $\sim 77$  K is shown to provide an excellent fit to spectra of GC IRS 7 and Cyg OB2 no. 12 in the  $3.4\ \mu\text{m}$  band. Up to  $\sim 30\%$  of available carbon may be present in this material. This form of HAC is not present in the material associated with NGC 7538 IRS 9 and other protostars, but a good fit to the short-wavelength wing of the absorption band in these objects is obtained with material that has been UV irradiated. The difference spectrum at shorter wavelengths shows the  $2880\ \text{cm}^{-1}$  “diamond” absorption reported by Allamandola et al. An absorption feature at  $2880\ \text{cm}^{-1}$  which may be attributable to tertiary CH in diamond-like carbon is commonly observed in HAC samples having large bandgap energy. The carbonaceous dust present in protostellar environments may therefore be a mixture of a wide bandgap diamond-like component with UV-processed diffuse cloud material.

*Subject headings:* dust, extinction — infrared: ISM: lines and bands — ISM: clouds

### 1. INTRODUCTION

The possibility that a form of hydrogenated amorphous carbon (HAC) could be a component of the dust in diffuse clouds was suggested by Duley & Williams (1983) on the basis of the then available observational and laboratory data. It was postulated that this material is formed by direct accretion on silicate cores in diffuse interstellar clouds. This identification was based on the similarity between laboratory absorption spectra of HAC in the  $3\text{--}4\ \mu\text{m}$  region and that of the Galactic center source IRS 7 over the same spectral range. Subsequently, much additional observational data (Sandford et al. 1991 and references therein) and laboratory data on HAC (Duley 1993 and references therein) have become available. In addition, distinctly different IR absorption spectra have been reported for the diffuse interstellar medium (Sandford et al. 1991) and for dense clouds associated with protostars such as NGC 7538 IRS 9 (Allamandola et al. 1992). The suggestion that spectral features in the astronomical source can be associated with a carbonaceous solid component that changes in various astrophysical environments is generally supported by these observations, and HAC remains as a prime candidate as the absorber in diffuse clouds. However, a detailed comparison between the absorption spectrum of HAC in the  $3\text{--}4\ \mu\text{m}$  region and that of GC IRS 7 using currently available data has not been reported to date.

### 2. RESULTS AND DISCUSSIONS

We have previously reported on the spectral properties of HAC deposited at cryogenic temperature ( $\sim 77$  K) from a carbon-hydrogen plasma (Ogmen & Duley 1988). Under these deposition conditions, which involves collisional quenching of a laser-induced carbon plasma in a  $\text{H}_2/\text{He}$  gas cooled to 77 K prior to deposition, the spectrum of HAC in the  $\text{CH}_n$  stretch region consists of a structured peak centred at  $2925\ \text{cm}^{-1}$ .

Spectra were recorded using a NICOLET SX20 FTIR spectrometer at a spectral resolution of  $5\ \text{cm}^{-1}$ . Figure 1 shows a comparison between the absorbance associated with this band in HAC and that of the GC IRS 7 source and of Cyg OB2 no. 12 using the observational data reported by Sandford et al. (1991). The excellent agreement between laboratory and observational data in this case supports the association of the astrophysical absorption near  $3.4\ \mu\text{m}$  with HAC. A similar, but not identical fit, has been obtained with the IR spectrum of the carbonaceous residue resulting from UV irradiation of a  $\text{H}_2\text{O}:\text{CH}_3\text{OH}:\text{NH}_3:\text{CO}$  mixture (Sandford et al. 1991).

The amplitude of the absorbance at  $3.4\ \mu\text{m}$  in the spectrum of GC IRS 7 ( $A_v = 34$ ) implies a column density  $N(\text{CH}_n) \sim 2.8 \times 10^{18}\ \text{cm}^{-2}$  and that  $\sim 11\%$  of available carbon along this sight line is present in  $\text{CH}_n$  associated with HAC. The total amount of carbon tied up in HAC will depend on the level of hydrogenation, and could be 2–3 times this value, implying that 20%–30% of available carbon is in HAC along the path to GC IRS 7. Sandford et al. (1991) have estimated that  $N(\text{CH}_n) \sim 7.4 \times 10^{17}\ \text{cm}^{-2}$  along the same line of sight using band strengths for pure saturated aliphatic hydrocarbons. They conclude that between 2.6% and 35% of available carbon could be associated with the  $3.4\ \mu\text{m}$  absorber. The present derived abundance of HAC is therefore compatible with these limits.

An absorption band near  $3045\ \text{cm}^{-1}$  ( $3.28\ \mu\text{m}$ ) attributable to aromatic CH is also commonly observed in the spectrum of HAC (Angus, Koidl, & Domitz 1986; Grill, Patel, & Meyerson 1990). Under certain conditions this feature may consist of two peaks with energies at  $3030$  and  $3060\ \text{cm}^{-1}$  ( $3.30$  and  $3.27\ \mu\text{m}$ ) (Tamor et al. 1989; Dischler, Bubenzer, & Koidl 1983). The single absorption peak at  $3045\ \text{cm}^{-1}$  evolves from low-temperature HAC as the result of thermal processing, while the double peak can be formed during the deposition of HAC if deposition occurs in a PAH-rich environment (Tamor et al. 1989). The single peak at  $3045\ \text{cm}^{-1}$  is then attributed to an increase in  $sp^2$  bonded aromatic rings in HAC, while the double peaked structure is associated with pendant benzene,

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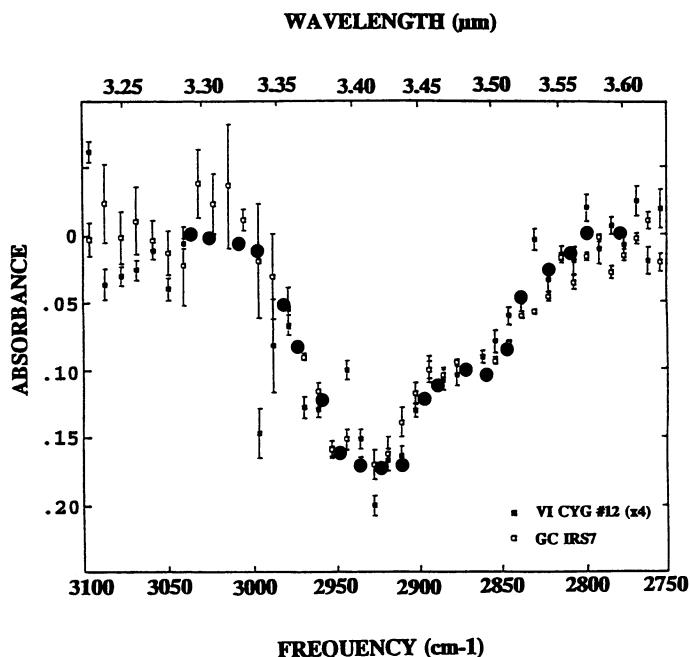


FIG. 1.—Profile of the CH stretching feature observed in GC IRS 7 and VI Cyg no. 12 (Sandford et al. 1991) compared to the absorbance of HAC (filled dots).

that is, phenyl groups bonded to the amorphous HAC network. Under certain conditions (Duley 1993) the strength of the  $3045\text{ cm}^{-1}$  and  $(3030, 3060)\text{ cm}^{-1}$  components can be equal to or exceed that of the  $\text{CH}_n$  feature at  $2940\text{ cm}^{-1}$  ( $3.4\text{ }\mu\text{m}$ ). This suggests that a search for aromatic CH components in the spectrum of GC IRS 7 or other heavily reddened objects may yield valuable information on the composition of HAC and the relationship between HAC and PAH in diffuse clouds.

Figure 2 shows a comparison between the  $3.4\text{ }\mu\text{m}$  spectrum of NGC 7538 IRS 9 (Allamandola 1992) and that of UV-irradiated HAC (Ogmen & Duley 1988). These spectra have been normalized to have the same amplitude at  $2915\text{ cm}^{-1}$ , and have essentially the same spectral dependence on energy between  $3000$  and  $2915\text{ cm}^{-1}$ . Such agreement is not possible using IR spectra of our HAC samples that have not been exposed to UV radiation. The difference between the spectrum of HAC and the observational data at low energies reveals peaks at  $\sim 2880$  and  $2830\text{ cm}^{-1}$ . These are the spectral features previously identified with tertiary CH and  $\text{CH}_3\text{OH}$ , respectively (Allamandola et al. 1992). The residual attributable to tertiary CH when both HAC and  $\text{CH}_3\text{OH}$  components are removed is also shown in this figure.

An absorption that may be due to tertiary CH, that is, to H atoms bonded to diamond-like  $sp^3$  bonded carbon, is present in many laboratory spectra of HAC although usually with an intensity which is approximately 50% of that of the  $\text{CH}_n$  peak at  $2920\text{--}2940\text{ cm}^{-1}$  (Ogmen & Duley 1988; Gonzalez-Hernandez et al. 1988; Tamor et al. 1989; Grill et al. 1990). Since the  $2880\text{ cm}^{-1}$  feature is enhanced by an increase in optical bandgap, its appearance can be associated with an enhancement in  $sp^3$  bonded carbon. A high proportion of  $sp^3$  diamond-like carbon in HAC will favour tertiary over primary and secondary CH. The spectrum of NGC 7538 IRS 9 then

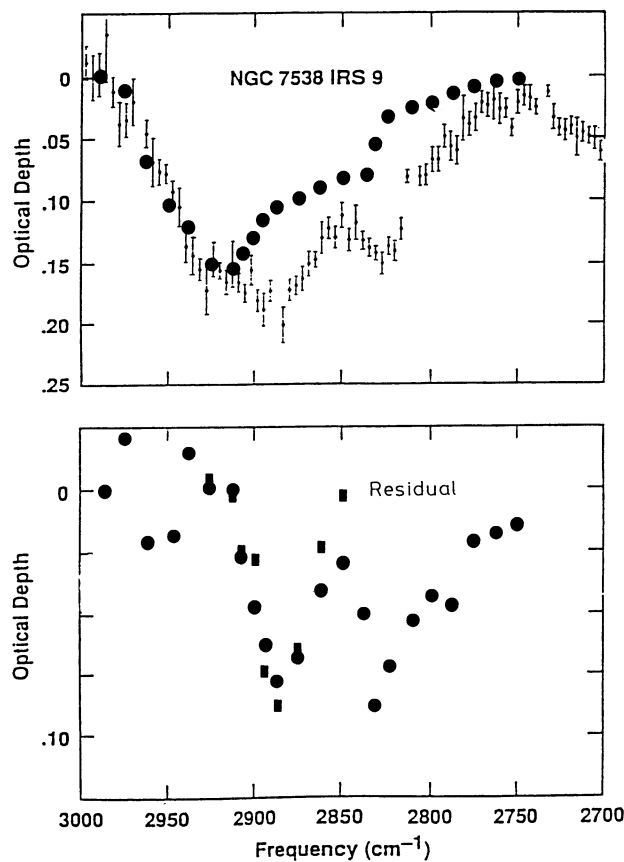


FIG. 2.—Comparison of the CH stretching feature observed in NGC 7538 IRS 9 (Allamandola et al. 1992) with absorbance of UV-irradiated HAC. Lower spectrum: residual after removal of HAC absorbance (circles) and after removal of both HAC and  $\text{CH}_3\text{OH}$  components (squares). The feature at  $\sim 2880\text{ cm}^{-1}$  is attributed to absorption by tertiary CH (Allamandola et al. 1992).

suggests that there has been a mixing of dust in this object, with a diffuse cloud component mixed in with another solid having high  $sp^3$  diamond-like carbon content. Further laboratory work is required to determine the conditions under which tertiary CH can become the dominant functional group in wide bandgap HACs.

### 3. CONCLUSIONS

The spectrum of HAC in the CH stretching region provides an excellent fit to spectra of diffuse cloud dust as typified by GC IRS 7 and Cyg OB2 no. 12. An absorption band due to aromatic CH in HAC should also be present under certain conditions in the spectrum of diffuse cloud material. This may exhibit doublet structure with peaks at  $3030$  and  $3060\text{ cm}^{-1}$ . A modified form of HAC may be present in dense protostellar objects such as NGC 7538 IRS 9. An absorption feature that may be associated with tertiary CH groups is observed at  $\sim 2880\text{ cm}^{-1}$  in HAC's with a large component of  $sp^3$  diamond-bonded carbon.

This research was supported by grants from ADFA and from the NSERCC.

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