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ORGANICS IN THE DIFFUSE INTERSTELLAR MEDIUM

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ABSTRACT Near infrared spectra (2.8 - 3.7 μm) along a variety of sightlines which sample varying amounts of extinction contain a broad feature near 3.0 μm (3300 cm^{-1}) and/or a complex feature near 3.4 μm (2950 cm^{-1}), the latter of which is attributed to saturated aliphatic hydrocarbons in interstellar grains. The C-H stretch absorption features near 3.4 μm arise from diffuse interstellar dust. There exists a remarkable similarity in the spectral structure of these diffuse dust hydrocarbon features in comparisons to UV photolyzed laboratory ice residues and a carbonaceous component of the Murchison meteorite. A significant amount of the cosmic carbon in the ISM ($\sim$10%) is tied up in the carrier of the 3.4 μm band. A weak absorption feature at 3.28 μm (3050 cm^{-1}), which is characteristic of aromatic hydrocarbons and may be due to interstellar PAHs, is seen in the diffuse dust spectra.

INTRODUCTION

The composition of dust in the interstellar medium (ISM) is important because this dust is a source of material which ultimately forms stars and solar systems. Organic material has been observed in the diffuse interstellar medium (Adamson, Whittet, & Duley, 1990; Wickramasinghe & Allen, 1980; Sandford *et al.* 1991(hereafter paper I); Pendleton *et al.* 1992 (hereafter paper II)) and in primitive solar system bodies such as comets (Tokunaga and Brooke, 1990; Brooke, Tokunaga, and Knacke, 1991), meteorites (Cronin and Pizzarello, 1990; Ehrenfreund *et al.* 1991) and possibly asteroids (Cruikshank 1987, 1989; Cruikshank and Brown 1987; Mueller *et al.* 1992). D/H isotope measurements of hydrocarbon extracts from the Murchison meteorite show strong D-enrichments indicating an interstellar origin for at least some of the hydrocarbons (de Vries *et al.* 1992). Comparisons of the diffuse ISM spectra to meteoritic spectra show remarkable similarities between the features attributed to saturated aliphatic hydrocarbons in the diffuse medium and absorption features seen in the meteoritic spectrum (paper II). Thus, comparisons of the diffuse dust organics and

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organic material in primitive solar system bodies may simultaneously provide information regarding the origin of organics in both settings.

THE DIFFUSE INTERSTELLAR MEDIUM

Infrared studies hold the greatest promise for gaining a clearer understanding of the chemical identity of organics in the ISM, because all fundamental vibrational frequencies of biologically interesting molecules occur in the mid- infrared (2-20 μm). As illustrated in Figure 1a, 2.8 - 3.8 μm observations of the galactic center show that these spectra contain a broad feature at 3.0 μm (3300 cm^{-1}) and a complex feature near 3.4 μm (2950 cm^{-1}). Within cosmic abundance constraints, the most likely candidates responsible for the features seen near 3.0 μm and 3.4 μm are the O-H and C-H stretching vibrations, respectively. In H bonded compounds, a broad ($\delta\nu = 300$ cm^{-1}) O-H feature generally dominates the spectrum at frequencies shortward of 3.3 μm. Bands longward of 3.3 μm (below 3000 cm^{-1}) arise from the aliphatic hydrocarbons.

The strength of the O-H feature relative to the C-H feature varies among the galactic center sources IRS 3, 6, and 7, (figure 1a), while the profile of the C-H feature appears similar in all three. The strength of the two features is not correlated among the sources studied in papers I and II, thus confirming an earlier suggestion by MacFadzean *et al.* (1990) that the O-H and C-H features in the galactic center arise from different carriers. The galactic center sources studied are all within a few arc-seconds of each other, therefore they are sampling the same diffuse dust and variations from source to source must be primarily due to local variations in dust composition. The identification of an absorption feature with a specific molecule can be greatly aided by moderate resolution spectroscopy over the 2-13 μm range. Hydrocarbons which absorb in the 3 μm region will have corresponding features in the 5-8 μm window. To date, the only 5-8 μm spectra of diffuse medium dust is the galactic center data shown in Figure 1b (courtesy of Tielens, Allamandola, Bregman, and Witteborn). While the resolution in Figure 1b is not high enough to unambiguously identify the aliphatic absorption features, the figure suggests a match of the 6.85 and 7.6 μm features to laboratory residues (see figure 6b) which further the identification of the 3.4 μm features with the aliphatic hydrocarbons. Additional observations in this wavelength region along lines of sight other than the galactic center are required to complete this type of identification.

Earlier speculation which attributed the 3.4 μm (2941 cm^{-1}) band to the diffuse interstellar medium (Allen & Wickramasinghe 1981; Willner & Pipher 1982; Jones, Hyland, & Allen 1983; Wickramasinghe & Allen 1983; Allamandola 1984; Butchart 1986; Tielens & Allamandola 1987) was confirmed through the work of Adamson,Whittet, & Duley (1990) who obtained spectra of VI Cygni #12 and paper I, which presented higher signal-to- noise spectra towards objects along several lines of sight. The C-H stretch features observed towards GC IRS3, IRS6, and several WC stars are quite similar to the spectra of galactic center IRS7. The strength of these features correlates with visual extinction toward

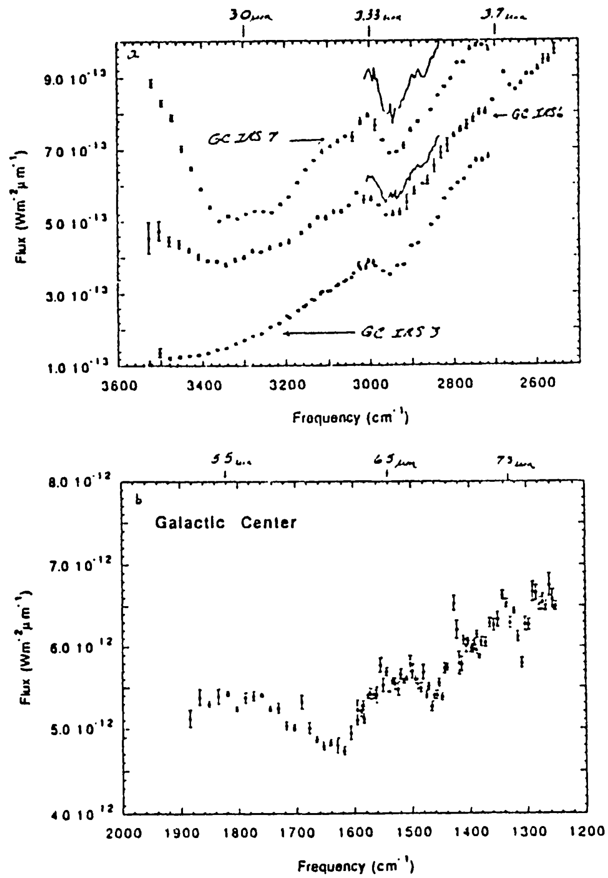

Fig. 1a Flux spectra of Galactic Center sources IRS 7, 6, and 3, obtained at the NASA IRTF using the CGAS 32 channel linear array. R$\sim$ 200 for the low resolution data and R$\sim$700 for the high resolution data, the latter are offset for clearer display. (1b) The 5-8 μm spectrum of the galactic center taken with the Faint Object Grating Spectrometer (FOGS) from the KAO (Tielens *et al.* 1993) (R$\sim$100). The 11″ aperture included GC IRS7 and IRS3.

these objects. The similarity in profiles and the correlation with A_v strongly suggests that the C-H absorption in the spectra of these and other objects shown in Figure 2 arises from carbonaceous material in the diffuse interstellar medium.

The C-H stretch in aromatic hydrocarbons is also evident in some of the spectra presented here. The best example can be seen in the spectrum of AFGL 2104, shown in Figure 3, where a weak absorption feature is seen near 3.28 μm (3050 cm^{-1}). This absorption could be due to larger, amorphous, carbonaceous material as well as individual PAHs frozen out onto grains.

COMPARISON OF THE ISM TO THE MURCHISON METEORITE

Figures 4a and b compare the 3-4μm and 5-8μm galactic center spectrum, respectively, to the spectrum of the hydrocarbons in Murchison meteorite (Cronin and Pizzarello, 1990; deVries *et al.* 1992). Figure 4a shows the remarkable match

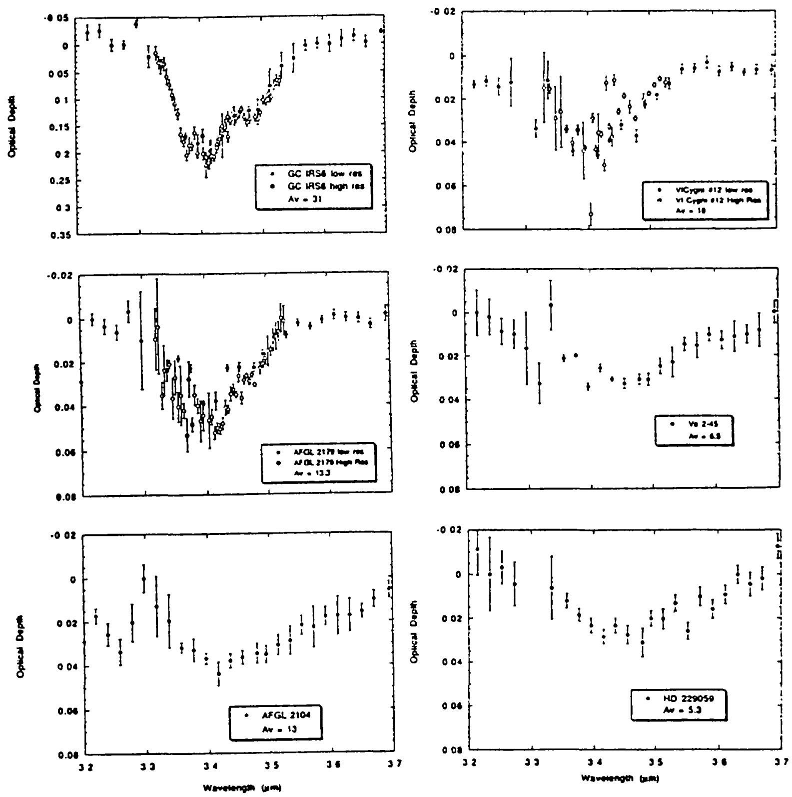

Fig. 2 Optical depth plots for the 3.2 - 3.7μm (3125 - 2703 cm^{-1}) region of GC IRS6, AFGL 2179, AFGL 2104, VI Cygni # 12, Ve2-45, and HD 229059. High resolution data is superposed on the low resolution data for GC IRS6, AFGL 2179 and VI Cygni # 12.

in detailed peak positions, widths, and substructure in the 3.4μm C-H stretch region between the galactic center IRS7 spectra and the meteorite. In the meteorite sample spectra, the 3.4μm features were attributed to the C-H stretches of predominantly highly branched, aliphatic hydrocarbons. Comparisons of the Orgueil and Murchison meteorites (Ehrenfreund *et al.* 1991) to earlier observations of the galactic center (Butchart *et al.* 1986) also showed a strong similarity in the 3.4 μm region.

The spectral comparison in the 5-8μm (2000 - 1250 cm^{-1}) region shows differences, however. The greatest discrepancy is at 6 μm, where O-H local to the galactic center complicates the comparison to diffuse dust. Lines of sight which do not contain significant O-H absorption will probe the diffuse medium for other groups such as C=O (1690 - 1760 cm^{-1}) and C=C (1640 - 1680 cm^{-1}) that may be present in Figure 4b. The meteoritc feature near 1720cm^{-1} in Figure 4b has been found to increase in strength as the sample is exposed to air (Chang, private communication), and in fresh samples it does not appear to be nearly so pronounced. Therefore, one might expect the comparison of meteoritic samples which have not been excessively exposed to air to the diffuse medium

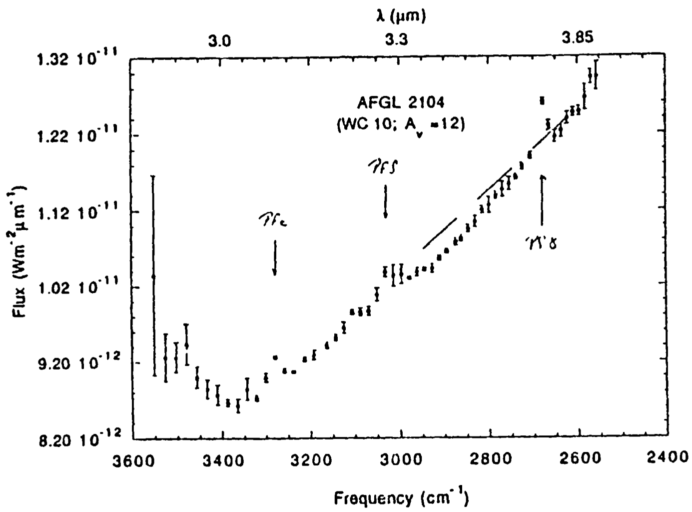

Fig. 3 Low resolution flux spectrum of AFGL 2104 taken with CGAS at the NASA IRTF. Details are the same as those given for Figure 1a. A typical baseline for the C-H feature (dashed line) is shown. The Pfund hydrogen lines from the standard star have been marked.

to be much improved along lines of sight that are not hampered by significant O-H absorption.

Another region where the comparison shows a mismatch is in the 6.8 and 6.9 μm region, which strongly emphasizes the need for improved astronomical data in this region. Such a mismatch may indicate that although the C-H stretching region (3-4μm) appears quite similar in the diffuse dust observations, the meteorite, and the laboratory simulation experiments, identification based on this region alone may lead to erroneous conclusions. If the 5-8 μm features do not match up as expected based on the identification from the C-H stretching region, then some additional components or processing occurred that affected the organics in the meteorites.

COMPARISON OF ISM TO LABORATORY ANALOGS

The relative peak heights of the features attributed to the saturated aliphatic hydrocarbons in the diffuse medium spectra imply that the the diffuse medium material likely contains short chains such as -CH_2-CH_2-CH_3. The evidence of a weak absorption feature near 3.3 μm (3050 cm^{-1}) in the diffuse spectra suggests the short chains of aliphatics may contain side groups of PAH's. This is consistent with the results of paper I which found the addition of electronegative groups to simple hexane-like materials provided significantly improved matches to the diffuse medium spectra.

Infrared spectra of UV photolyzed mixtures of molecular interstellar ice analogs reproduce many of the major spectral features attributed to ice in dense clouds (Tielens & Allamandola 1987; Allamandola, Sandford, and Valero 1988). Upon heating to 200K, after the volatiles have left, the spectrum of the IR

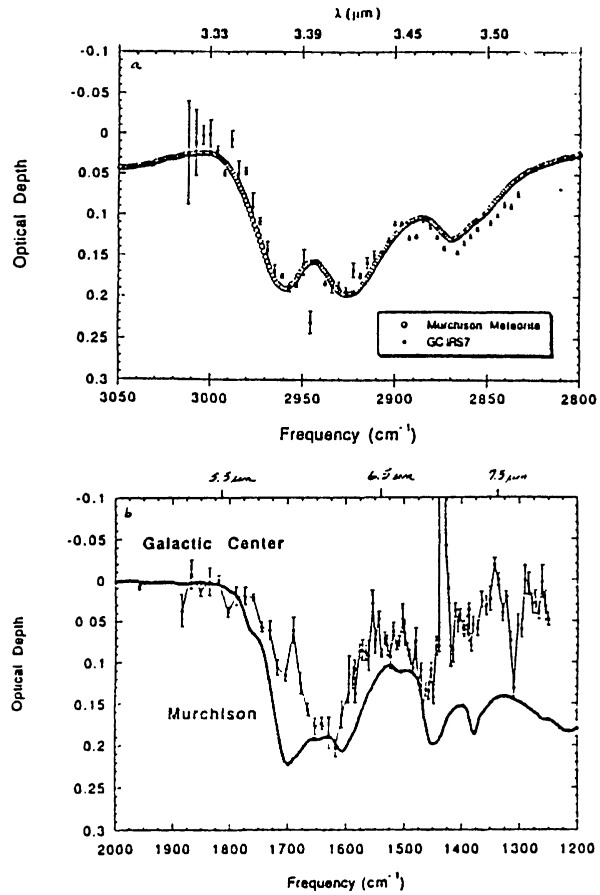

Fig. 4a 3.1 - 3.8μm (3226 - 2632 cm^{-1}) absorbance plot of a Murchison meteorite sample (solid points) (de Vries *et al.* 1992) normalized at 3.37μm (2935 cm^{-1}) to galactic center IRS7 data (open points). (b) 5-8 μm optical depth comparisons of the Murchison meteoritic data (solid points) with the galactic center (open points) FOGS data (Tielens *et al.* 1993).

residue from the irradiated ice mixtures closely matches the 3-4 μm diffuse medium spectrum (Figure 5a). Figures 5a and 5b compare spectra from a UV photolyzed residue to the 3-4 μm and 5-8 μm galactic center spectra, respectively. The noteworthy match in the 3-4μm region is consistent with a model in which the diffuse medium hydrocarbon component is a complex mixture of interlinked, aliphatic hydrocarbons which were produced in UV rich regions of dense molecular clouds and perhaps then only slightly modified in the diffuse medium.

SUMMARY

Observations of the interstellar medium in the 2.8 - 3.7μm region generally contain either a broad absorption feature near 3.0μm (3300 cm^{-1}), a complex absorption feature centered near 3.4 μm (2950 cm^{-1}), or both. The lack of correlation between the strengths of these two bands indicates that they do not arise from the same carrier. New observations of several lines of sight toward

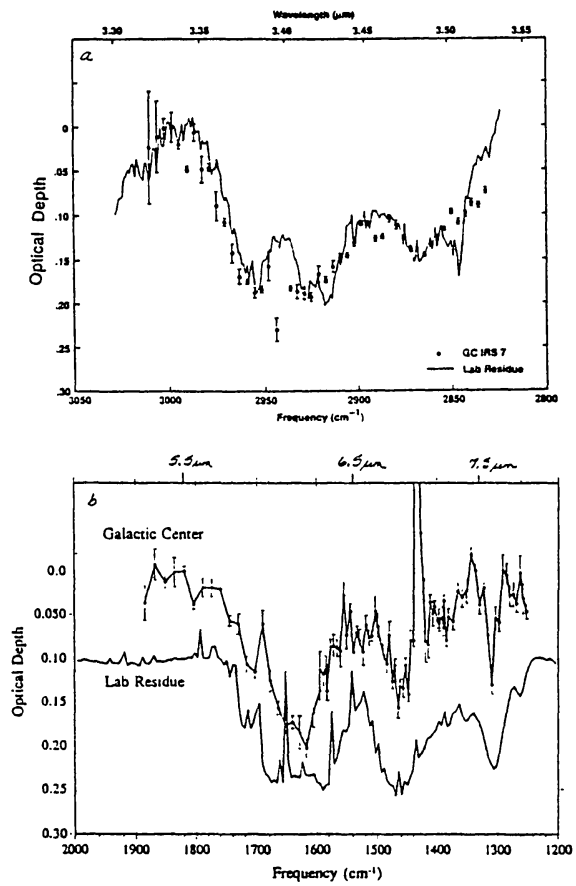

Fig. 5a Comparison between the optical depth profile of the C-H stretching feature towards GC IRS7 (points) and the C-H feature measured from a laboratory residue in the $3\mu m$ region (line). (b) The same residue compared to the 5-$8\mu m$ FOGS data of the galactic center (courtesy of Tielens, Allamandola, Bregman, and Witteborn). The residue was produced by depositing an $H_2O : CH_3OH : NH_3 : CO : C_3H_8$ = 10:5:1:1:1 ice at 10K, irradiating it with UV photons, and warming it to 200K.

a variety of stellar sources within our galaxy show additional evidence that the absorption feature near 3.4 μm, attributed to the C-H stretch in saturated aliphatic hydrocarbons, arises from diffuse material. A weak feature near 3.28 μm (3050 cm^{-1}) which is attributed to the aromatic C-H stretch arising from interstellar aromatic hydrocarbons is reported. The broad absorption feature near 3.0 μm, attributed to the O-H stretch, does not appear in the spectra towards most objects obscured only by diffuse medium dust. The abundances of the diffuse hydrocarbons are correlated with visual extinction. From the strength of the observed features, the percent of cosmic carbon in the ISM that is tied up in the carrier of the aliphatic band is $\sim$ 10%. The data show that a lower limit of 1-12% of the cosmic carbon is tied up in the aromatic C-H.

The interstellar aliphatic C-H band profiles compare favorably with the spectra of laboratory residues. This suggests that the diffuse interstellar medium hydrocarbon component consists in large part of complex, interlinked, aliphatic hydrocarbons that were produced in dense molecular clouds and subsequently were only slightly modified in the diffuse medium. Comparison of the same interstellar spectra to the spectra of extracts from the Murchison meteorite show a remarkable match in detailed peak positions, widths, and substructure in the C-H stretch region (3.4 μm). In the meteorite sample spectra, the 3.4μm features were attributed to the C-H stretches of predominantly methylated, cyclic, aliphatic hydrocarbons. Comparisons of the meteoritic data to diffuse dust spectra in the 5-8μm region reveals some small dissimilarities, however. A thorough comparison of the organic materials in the diffuse ISM, primitive solar system bodies, and lab residues will help unravel the organic chemical complexity of the interstellar medium and determine whether the organic compounds in the primitive solar system bodies originated in the ISM, arose by synthesis within the protosolar nebula, or resulted from the alteration of either the interstellar or nebular compounds by subsequent processing on the parent bodies.

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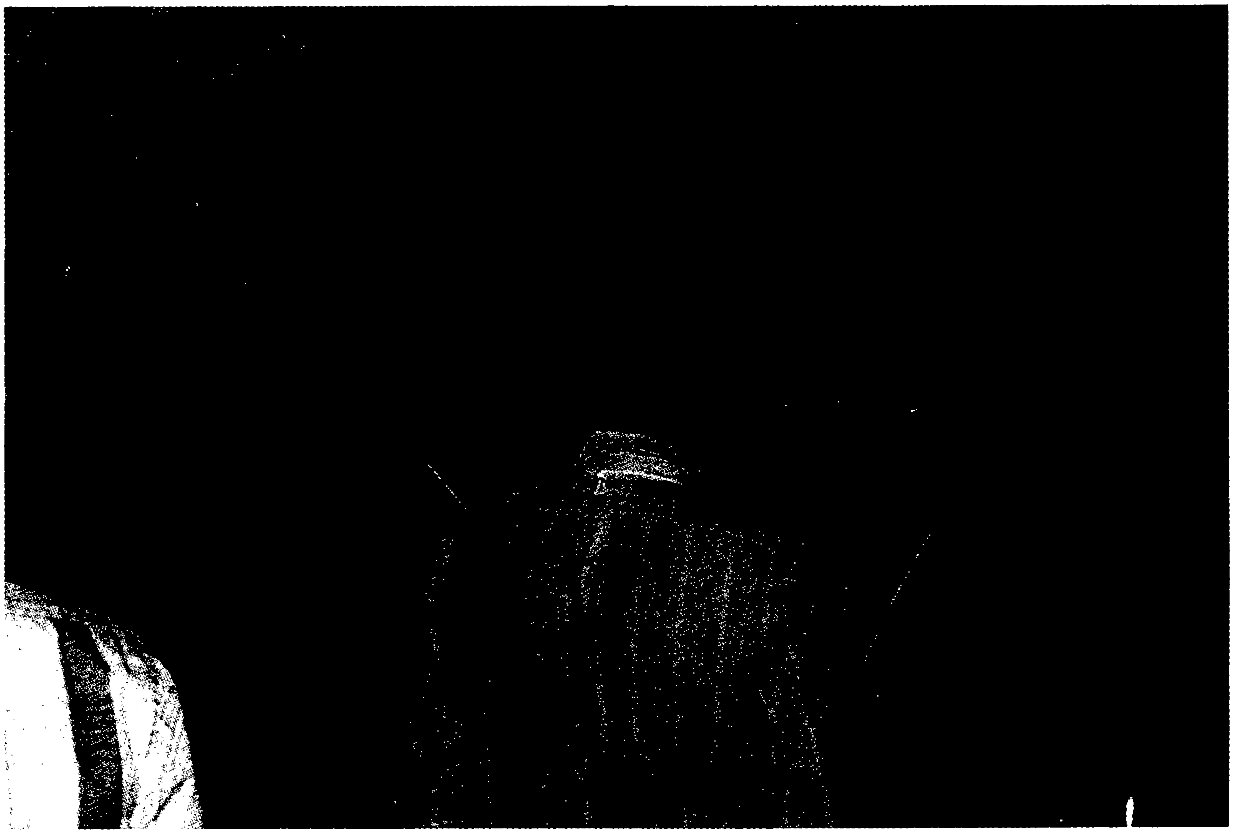

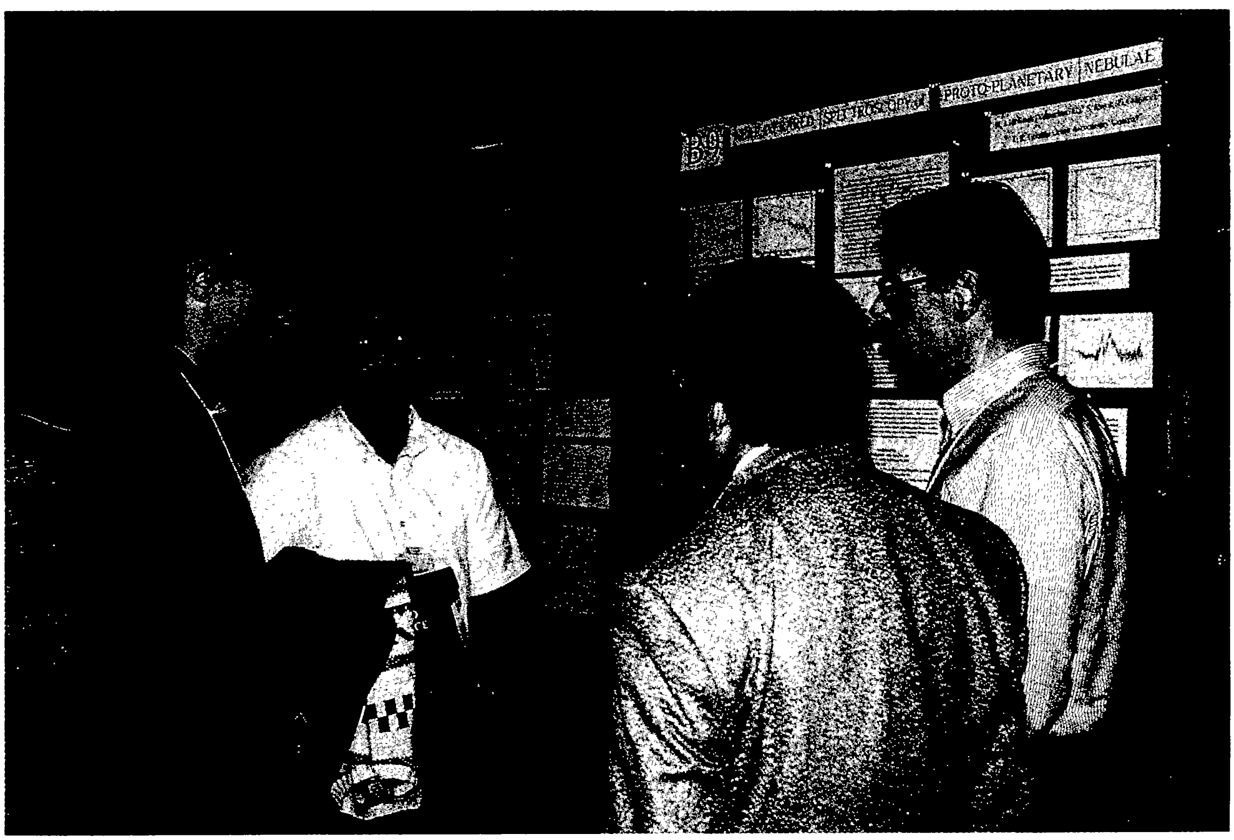
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