N87-15108

The 3.1 μm Ice Band in Infrared Reflection Nebulae

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Recent observations show that infrared reflection nebulae are common phenomena in star forming regions. For instance, infrared reflection nebulae have been observed in the lobes of bipolar outflow sources where the geometry is such that the illuminating star is heavily obscured, possibly by a disk, but radiation escapes through the poles to illuminate the dust adjacent to the star. Near infrared scattered light can be used to probe the properties of the dust grains, the nature of the embedded source, and the geometry of the nebula. We have made extensive observations of two nearby infrared reflection nebulae, Orion Molecular Cloud 2 IRS1 (OMC-2/IRS1) (Pendleton et al, 1986 Ap.J., in press) and Cepheus A IRS6a (Cep-A/IRS6a). In the case of OMC-2/IRS1 we were able to constrain the properties of the illuminating source, IRS1, from a combination of far infrared and near infrared data. We found the luminosity and temperature of OMC-2/IRS1 to be ~500 $L_\odot$ and ~1000K, respectively. Both sources show deep absorption features in reflected light at 3.1 μm. The 3.1 μm feature, commonly attributed to water ice, appears in the spectrum taken along the line of sight to the illuminating source as well as toward the nebula in OMC-2/IRS1. The origin of the feature in the reflected light is unclear. It may be produced by the grains in the nebula or it may result from pure extinction, either in the circumstellar shell of the star or in foreground material. Figure 1 shows the observed 2.2-3.8 μm spectra of Cep-A/IRS6a.

We are using Mie scattering models of ice coated grains to study the constraints on the properties and location of grains that could produce a feature similar to that observed in OMC-2 and Cep-A. Mie scattering models of ice coated silicate grains with total grain radii $0.03 \leq a \leq 1.5$ μm were calculated over the wavelength range $2.2 \leq \lambda \leq 3.8$ μm. Figure 2 shows the differential scattering cross section, $dC_{sca}/d\Omega$, versus wavelength for several grain sizes and a scattering angle of 60 degrees. In all cases $dC_{sca}/d\Omega$ reaches a minimum at wavelengths shortward of 3.1 μm (~2.85 μm), in fact the scattering cross section appears to be quite large at the wavelength where the 3.1 μm feature is the most pronounced. We conclude that scattering by ice particles alone could not be responsible for the 3.1 μm feature observed in infrared reflection nebulae. However, when extinction and scattering by non-icy particles is included in the analysis it appears possible to reproduce a 3.1 μm band similar to the observations. We have calculated scattering by graphite and silicate grains. The results suggest for a Mathis, Rumpl, and Nordsieck (Mathis et al, 1977, Ap.J., 217, 425) grain distribution that graphite is the dominant contributor to the near infrared continuum scattering.

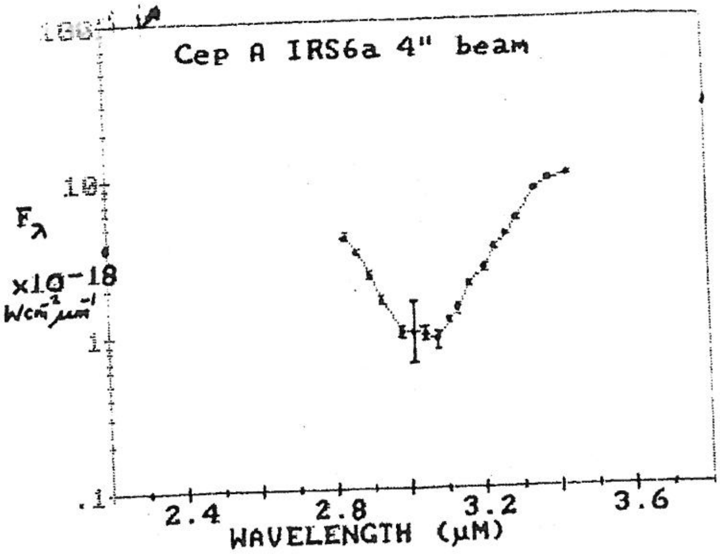

FIGURE 1 The 2.2-3.8 μm spectra of the infrared reflection nebula in Cep A (IRS6a) taken at the NASA IRTF. The feature at ~3.1 μm is generally attributed to water ice.

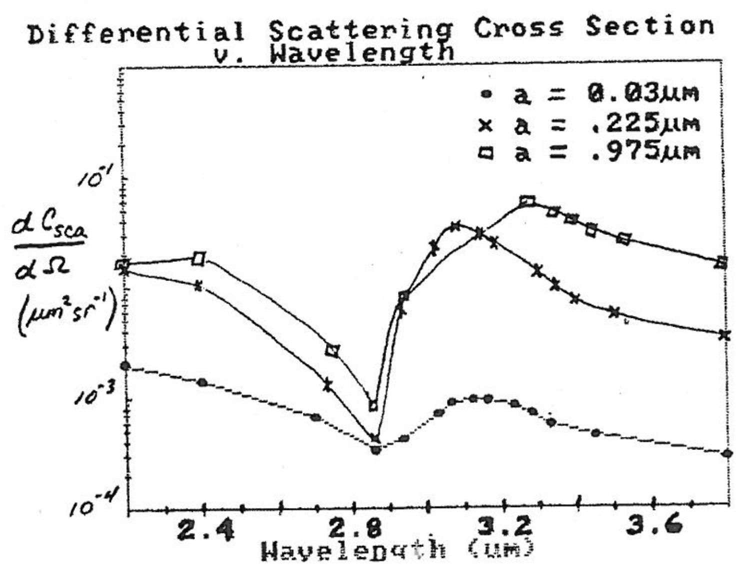

FIGURE 2 The differential scattering cross section, $dC_{sca}/d\Omega$, at a scattering angle of 60 degrees, for ice coated silicate grains as a function of wavelength. The grain size, a, includes both the core and mantle. The curves for 0.03 and 0.225 μm have been multiplied by factors of 1E6 and 1E2, respectively. Note that in scattering the ice band feature reaches a minimum at ~2.85 μm compared to ~3.1 μm in absorption.