GRAPHITE GRAINS, CARBON DEPLETION AND THE 2200 Å FEATURE

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Abstract. In a recent paper Millar has shown that if one assumes that the carbon depleted from the gas phase is all tied up into small graphite grains the observational data raise serious doubts against the hypothesis that these particles are responsible for the 2200 Å extinction hump. In the present paper it is shown that this problem may be overcome if the presence in the interstellar space of graphite grains with sizes greater than 0.02 μ is taken into account. The derived ratios between the masses of large grains, which do not contribute to the ultraviolet extinction hump, and those of the small ones varies from region to region of the sky and are consistent with those evaluated in the circumstellar shells of carbon stars. Moreover, the largest sizes of the graphite particles we find are in agreement with those needed to fit the interstellar extinction curve over the wavelength range 0.11 − λ < 1 μ.

1. Introduction

The pronounced hump observed at ∼2200 Å in the extinction curves of starlight has been widely attributed to graphite grains (Stecher, 1965, 1969; Wickramasinghe and Guillaume, 1965; Stecher and Donn, 1965; Bless and Savage, 1972; Gilra, 1972; Greenberg and Hong, 1974; Wickramasinghe and Nandy, 1974; Blanco et al., 1980). Other materials have also been proposed in the past such as irradiated quartz (Wickramasinghe, 1971), silicates (Huffman and Stapp, 1977), diatomic alkaline-earth oxides like MgO and CaO (Duley, 1976) and even organic molecules (Hoyle and Wickramasinghe, 1977).

Very recently Millar (1979), analyzing ten stars, has shown that the strength of the extinction feature is not in agreement with carbon depletion towards these stars if small graphite grains are assumed to be responsible for the hump. Among various possibilities this author cites the possible presence of the missing carbon in molecules (less probable) or in core-mantly particles. In addition, the fact that this carbon could be tied up in large grains which do not contribute to the UV extinction hump is also mentioned.

Aim of this paper is to show that this last possibility is actually real as it seems to be supported both from theory and experimental observations.

2. Calculations and Discussion

A first indication that large grains may exist in the interstellar space comes from the work of Mathis et al. (1977). They fitted the observed interstellar extinction between 0.1 μ and 1 μ by means of a very general particle size distribution of several uncoated
materials taking into account cosmic abundances constraints and combinations up to three materials at a time.

Graphite appeared to be a necessary component of each good mixture providing also excellent fits of the 2200 Å feature with a power law \( n(a) \propto a^{-3.5} \) in the size distribution which ranged from a radius \( a = 0.005 \mu \) up to about \( 1 \mu \). In addition to the above argument, photometric and spectrophotometric observations by Bergeat et al. (1976) of 25 carbon stars show that small and large grains are produced in their atmospheres.

The data, as well as dynamical constrains, imply the picture of a two component distribution of particles. Small grains with \( a \approx 0.003 \mu \) produce selective extinction at short wavelengths (\( \lambda \leq 0.55 \mu \)) but are unlikely to justify the thermal emission from the stars. On the contrary, the observed constancy of the color temperature over the wavelength range 0.55–1.25 \( \mu \), or even up to 2.2 \( \mu \) for some stars, indicates that the infrared emission is grey and largely dominated by large grains with radius \( a \approx 1.5–2.5 \mu \).

Finally, analogous considerations are derived by Cohen (1979) who has studied 16 cool AFGL carbon stars. He found that the circumstellar extinction due to small grains is tipically of the order of 5–15 mag while the neutral extinction by large grains should be of the order of 5 mag. It is worthwhile to note, in the context of our problem, that the contribution in mass of these last particles is the most important.

All the previous considerations seem to justify in our opinion the possibility of the existence of large graphite particles in the interstellar space in addition to small grains. In this light we want now to check if all the carbon depleted from the interstellar gas phase and not locked into small graphite grains, may be in the form of larger grains which do not contribute to the ultraviolet extinction hump.

Following Millar’s approach in calculations we may write

\[
[n_a(0) - n_c]m_c = M_{tot}, \tag{1}
\]

where \( n_a(0) \) and \( n_c \) are the initial and present carbon number densities and \( m_c \) the mass of a carbon atom.

Equation (1) is the starting one in Millar (1979) where, however, we consider the total mass of dust grains according to the size distribution \( n(a) \propto a^{-3.5} \) found by Mathis et al. (1977) instead of the contribution of small grains alone. After some manipulations we obtain

\[
\frac{n_c}{n_a(0)} = 1 - \frac{E(\lambda_m - 3320)}{\alpha'N} = 1 - \frac{X}{\alpha'}, \tag{2}
\]

where \( E(\lambda_m - 3320) \) is the extinction of the hump alone as tabulated by Savage (1975) and \( \lambda_m \) is the wavelength at the peak. \( N \) is the total hydrogen column density and

\[
\alpha' = \frac{\alpha}{R_M + 1}. \tag{3}
\]

The value of \( \alpha = 3.27 \times [c] \times m_c \times \frac{Q_{ext}(\lambda_m)}{4a_p^2} \) is the same found by Millar; where \([c]\) is the carbon solar abundance, \( p \) the graphite density and \( Q_{ext}(\lambda_m)/a_c \) the ratio between the extinction efficiency at \( \lambda_m \) and the radius of small particles producing the extinction.