ON THE NATURE OF INTERSTELLAR GRAINS

F. HOYLE* and C. WICKRAMASINGHE

Dept of Applied Mathematics and Astronomy, University College, Cardiff, Wales

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Abstract. Data on interstellar extinction are interpreted to imply an identification of interstellar grains with naturally freeze-dried bacteria and algae. The total mass of such bacterial and algal cells in the galaxy is enormous, \( \sim 10^{40} \) g. The identification is based on Mie scattering calculations for an experimentally determined size distribution of bacteria. Agreement between our model calculations and astronomical data is remarkably precise over the wavelength intervals \( 1 \mu^{-1} < \lambda^{-1} < 1.94 \mu^{-1} \) and \( 2.5 \mu^{-1} < \lambda^{-1} < 3.0 \mu^{-1} \). Over the more restricted waveband 4000–5000 Å an excess interstellar absorption is found which is in uncannily close agreement with the absorption properties of phytoplankton pigments. The strongest of the diffuse interstellar bands are provisionally assigned to carotenoid–chlorophyll pigment complexes such as exist in algae and pigmented bacteria. The 2200 Å interstellar absorption feature could be due to 'degraded' cellulose strands which form spherical graphitic particles, but could equally well be due to protein–lipid–nucleic acid complexes in bacteria and viruses. Interstellar extinction at wavelengths \( \lambda < 1800 \) Å could be due to scattering by virus particles.

Ever since the existence of interstellar grains was first recognized over half a century ago, astronomers have striven unceasingly to understand their properties – sizes, shapes and composition – and how they might be formed. These questions have assumed a growing importance over the past decade mainly from a conviction that grains play a crucial role in controlling many astrophysical processes. A vigorous effort on the part of many astronomers has led to a welter of new observational data, to much theorizing and heated controversy, but little in the way of agreement or understanding. The nature of interstellar grains remains to this day a major unsolved problem in astronomy (see, for example, Hoyle and Wickramasinghe, 1962; Wickramasinghe, 1967; Martin, 1978).

The wavelength dependence of interstellar extinction is perhaps the most direct observational test of interstellar grain models. The observed interstellar extinction at visual wavelengths has an average value of \( \sim 2 \) mag kpc\(^{-1} \) in directions close to the plane of the galaxy. This datum combined with other scattering and polarization observations leads to the result that grains are strongly dielectric, with radii \( \sim 10^{-6} \) cm, and that they make up a few percent by mass of all interstellar matter. With an overall composition of interstellar matter similar to the composition of the Sun's outer layers, we thus find that a significant fraction of all C, N, O atoms in interstellar clouds is in the form of grains. About \( 10^{45} \) g of interstellar grains exist throughout the galaxy. Since the typical turn-over time of interstellar matter into stars is \( \sim 10^9 \) yr, grains must be re-supplied at an average rate of \( \sim 10^{31} \) g yr\(^{-1} \).

* Honorary Professorial Fellow.

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The requirement that \( \sim 3\% \) by mass of the interstellar material is in the form of dielectric grains imposes stringent constraints on the composition of grains. Cosmic abundances of Mg and Si are too low by a factor of \( \sim 5 \) for the bulk of grains causing visual extinction to be in the form of either silicates or metallic oxides. Graphite particles, which are electrically conducting for electric vector parallel to the basal planes, cannot make up more than \( \sim 10\% \) of the mass density of grains so as to be consistent with data on the diffuse galactic light and interstellar polarization – both observations requiring predominantly dielectric grains.

A wide range of materials involving the abundant CNO elements in various combinations with H remains in the field of possible grain compositions. There are two distinct types of such material that we shall need to consider: icy inorganic grains, made up mainly of H\(_2\)O, and organic grains which are made up of a mixture of organic molecules and/or biochemicals. Grains comprised of H\(_2\)O ice do not seem able to fit the astronomical data. For a size distribution of ice grains that result from growth and destruction processes of the type considered by van de Hulst (1949), model calculations of interstellar extinction are at variance with astronomical observations in the waveband \( 1 \mu^{-1} \leq \lambda^{-1} \leq 3 \mu^{-1} \). The curve in Figure 1 (van de Hulst No. 1) is the cal-

![Fig. 1. Points represent Nandy's (1964) extinction data for stars in the Cygnus direction. Curve is the normalized extinction calculated for a size distribution of ice spheres of refractive index \( n = 1.33 \). The distribution function is van de Hulst's (1949) distribution \( f \) with a size parameter \( r_1 = 0.34\mu \). Normalization is to \( \Delta m = 0.409 \) at \( \lambda^{-1} = 1.62 \mu^{-1} \); \( \Delta m = 0.726 \) at \( \lambda^{-1} = 1.94 \mu^{-1} \).]