A QUICK REVIEW OF INTERSTELLAR GRAINS

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Abstract. This paper reviews the results of the Symposium on Interstellar Grains. It draws some historical lines and emphasizes the questions that require further study.

1. Introduction

This paper summarizes the main points made during the oral presentation of a symposium summary talk. I had the advantage of an evening's preparation and of the fresh impressions from listening to over 90 communications. But the texts, tables and figures of those communications were not yet available to me. For that reason references to individual contributions presented at the Symposium have generally been omitted.

2. Recommended Reading

During this meeting I have heard many references to 'original suggestions' made 1–5 yr ago. Some of these references were correct; others were not, but simply reflected the time at which the authors first became acquainted with interstellar matter. I wish to emphasize that some of the roots of the subject go back deeply in time. A somewhat arbitrary selection of significant early treatments is given in the following list (Table I).

3. Observations

About 25 yr ago a stationary point seemed to have been reached, in which no further relevant observations could be obtained and the remaining task seemed to be interpretation. Yet, history decided otherwise. In 1949 interstellar polarization was discovered by accident and a decade later the far UV and IR regions of the spectrum became

TABLE I
Recommended reading

Eddington (1923)	temperature of gas and dust
Oort (1932)	mass density near galactic plane
Lindblad (1935)	growth of grains
Greenstein (1937)	extinction and radiation pressure
Strömgren (1939)	H II-regions
Spitzer (1948)	charge on grains
Morgan *et al.* (1953)	spiral structure
Van de Hulst *et al.* (1954)	spiral structure

Greenberg and Van de Hulst (eds.), Interstellar Dust and Related Topics, 569–573.

accessible. Altogether, the observations have greatly grown in accuracy, quantity and diversity. Figure 1 summarizes the present situation. The *extinction* curve, then limited to the range 1–3 on the λ^{-1} scale, is now well observed over the range 0–9. The blunt peak near 4.5 (2200 Å), the dip near 6, and the continued rise from 7 to 9, have been added to the familiar features of the extinction curve. *Linear polarization* has been well observed in the classical range 1–3. Somewhere in this range it shows a maximum. The first extensions of these measurements to the UV were reported by Stecher and to the IR by Okuda. They did not yet convince me. Polarization anomalies near the 4430 band were also reported, but the evidence still appears to be conflicting. The few reported observations of interstellar *circular polarization* are a strong appetizer for more. It would be premature to tell now what they mean.

The albedo, or ratio of scattering to extinction efficiency of individual grains, remains a key quantity in the interpretation. Unfortunately, its reliable observation is quite difficult. The situation appears to be that the old monopoly, set by the Henyey-Greenstein (1939) paper, has been taken over by a new monopoly of Lillie and Witt. If the alleged dip observed near $\lambda^{-1} = 4.5$ (see Figure 1) is correct, the discussions of a few days ago indicate that this means incredibly strange particles. Some held that

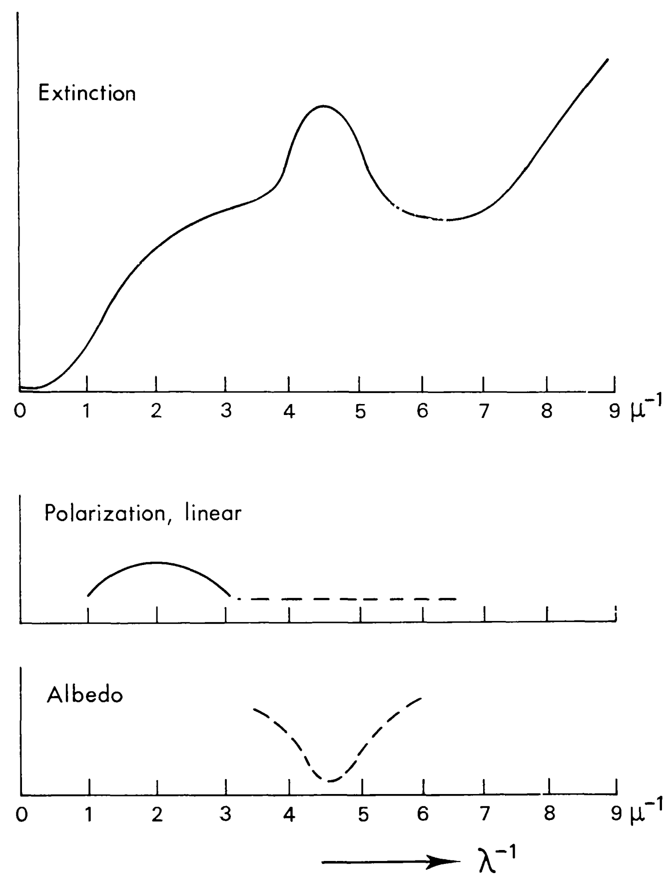

Fig. 1. Rough sketches of curves showing the main observational data from which the nature of the interstellar grains has to be inferred.

nature might well be ahead of our ideas. I feel, more conservatively, that the observations may be allright, but that the interpretation, which was so far based on a very simple model calculation by Van de Hulst and De Jong (1969), would merit a re-examination. An added problem, recognized by all authors, is that determination of the albedo is strongly linked with determination of the asymmetry factor of the scattering diagram.

Finally, impressive new data on the *IR emission* by grains in the range 10 μ to 100 μ were presented by several authors.

4. Interpretation

The leading question is: 'do grains exist' and the classic answer stil holds: "presumably yes, for it is virtually impossible to think up another agent which can produce so much extinction without the dynamical effects of its mass becoming noticeable."

Next, we have to ask what determines the shape of the extinction curve: is it mainly a matter of size or mainly a matter of composition ? This dilemma is shown by Figure 2. If size effects predominate, for grains with a refractive index m that does not vary strongly with wavelength, the theoretical curve links the extinction to the ratio of circumference to wavelength, $2\pi a/\lambda$. When only the curve between $\lambda^{-1} = 1$ and 3 was available, it seemed natural to match this to part of the theoretical curve and thus fix the size (Figure 2a). This classical explanation also meant that grains in their size distribution should be like men: a range of sizes, yet rather uniform in the predominant size. This consequence is a little awkward in view of the large variations that may exist in circumstances leading to grain growth. The alternative to the classical explanation is that at least certain features of the curve are caused by a fixed substance and bound to a fixed λ like an absorption line in the spectrum. The emphasis then falls on composition rather than size (Figure 2b). Presumably the correct explanation will be a combination of these extremes but we are still far from a complete theory.

Serkowski has shown that the polarization curves lead to a more uniform curve if plotted against $\lambda/\lambda_{\text{max pol.}}$. This is one way to partially eliminate the size effects and the

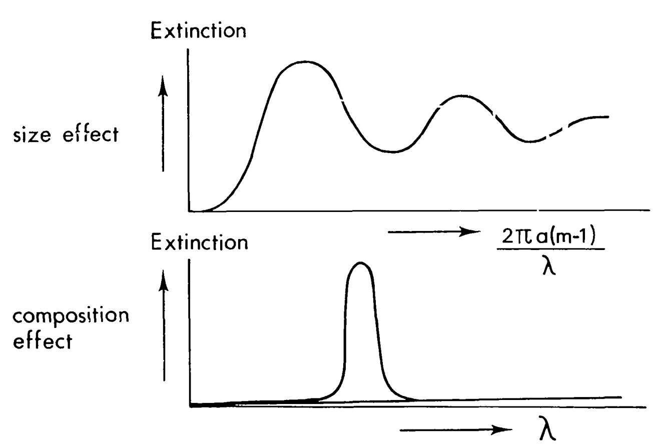

Fig. 2. Contrast between two extreme approaches to interpret the extinction curve.

suggestion made in the discussion, that the extinction curve should be treated similarly, is worth pursuing.

About *shapes* even less can be said than about sizes. The extinction curves for most assumed shapes cannot be found in practice from theory, but may be obtained from microwave model measurements (Greenberg *et al.*, 1961). A constant warning sign should be up against papers in which conclusions are drawn from simplified formulae beyond the range of their validity.

5. Distribution

In the old (pre-1940) times it was customary to distinguish between the general interstellar medium and the dark clouds. This distinction about vanished when it became clear that the 'general extinction' could well be the combined effect of all clouds along the line of sight.

In recent years the insight has emerged that grains must somehow fit into the evolutionary sequence leading to spiral arms and other details of galactic structure. This makes careful distinctions necessary in interpreting the observations and this was the aim of many papers presented at this Symposium. From large to small objects we may distinguish:

External galaxies
Spiral arms / Galactic centre
Local dependence on cosec *b*
Dark nebuale / Reflection nebulae
Circumstellar clouds
Protostars / Novae.

To this we should add the comment that external galaxies and the galactic centre entered hardly at all in our discussions. These subjects, e.g., the beautiful results on molecular lines at the galactic centre, were left to other symposia and in this respect we followed a long tradition to treat interstellar extinction as a rather local subject.

6. Theory and Experiment

Any attempt to put the grains into an evolutionary context leads to questions regarding the physics and physical chemistry of the grains. Although this subject again is about 30 yr old, very little is known with certainty. The number of bold suggestions has multiplied, the number of firm facts has not. I feel that only a careful theoretical approach, combined with judiciously interpreted laboratory experiments, can help. And the observation, or non-observation, of some molecules can be a big help in ruling out certain alternatives.

Let me mention a few questions under this heading.

Smoke or dust ? All interpretations agree that the grains are formed from the gas phase, presumably on condensation nuclei, like smoke, and not broken up from a larger body like dust.

How hostile is the environment ? Our approach in the forties (Oort and Van de Hulst, 1946; Van de Hulst, 1949) assumed a rather gentle environment in which soft particles of 'dirty ice' could and should grow. There are at least three changes which all point to a more hostile environment: the presence of low-energy cosmic rays (LECR), a pervading UV continuum at 10–13 eV, and finally, the fact that some grains are known to be present even in H II-regions. This opens the possibility, pursued by many authors, that only hard grains or hard cores of grains remain.

Where does nucleation occur ? We now think that nuclei spontaneously formed in space as poly-atomic molecules, do not have a chance to survive because of LECR. (De Jong and Kamijo, 1973). Two possibilities remain. One is that condensation nuclei leave a star like smoke leaves a candle flame. The other is that non-volatile cores survive the formation of stars and H II-regions in one spiral arm and start the formation of new dust grains upon arrival in the next density wave.

How large are the accomodation and sticking coefficients ? Good guesses have been made since many decades but the number of really relevant experiments is extremely limited. For instance, the process of formation of H_2 molecules from H-atoms collecting with a cold surface, has only recently been the subject of quantitative interpretation (Marenco *et al.*, 1971).

Alignment theory is another favorite subject, absolutely needed in order to interpret the polarization data. It is a tricky problem, but perhaps not so beset with fundamental physical uncertainties as some of the others mentioned. It has been well discussed at this symposium.

Dynamics of grains in grain-gas mixtures has a variety of consequences in processes on the largest scale (galactic structure) and on the smallest scale (star formation). It falls near the borderline of the subject matter discussed in this Symposium.

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