OPEN PANEL DISCUSSION ON INTERSTELLAR GRAIN MODELS

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ABSTRACT. A summary of the open discussion is provided. Topics ranged over composite particles, the 10 μm silicate feature, HAC, predictions, the 2200 Å feature, carbon depletion, and far ultraviolet extinction.

1. INTRODUCTION

During the afternoon of the fourth day of the meeting, a session was held on alternative "interstellar dust models". Presentations were made by Greenberg, Mathis, and Williams on "core-mantle particles", "carbon and silicate particles", and "silicate–hydrogenated amorphous carbon (HAC) particles", respectively. Written versions appear above in these proceedings. An open discussion was then held for an hour with the above three as panelists. I was in the role of moderator and undertook to provide a written summary which appears below. I have worked from a transcript of the tapes, some months after the event; names were associated with voices where necessary using notes by Allamandola and Snow.

On reviewing the extensive text, I decided against a blow-by-blow presentation with verbatim quotations. Instead, with some heavy editing and extensive paraphrasing, I have tried to distill the essence of the discussion; some points of the discussion might have been addressed in the individual written submissions as well. The order of presentation reflects the free flow of the discussion; I have regrouped items only slightly where appropriate.

The open discussion provided a valuable forum in which participants had an opportunity to identify strong and weak points in various models and to bring out observations and laboratory work relevant to discrimination among them. The discussion could have continued well beyond the time we had made available. Regrettably, my summary removes some entertainment value inherent in the tapes; suffice it to say that a common parenthetical note in the transcript is "laughter – prolonged", which testifies to the spirited and spontaneous nature of the exchanges!

2. COMPOSITE PARTICLES

Russell asked Mathis whether a bump in the extinction curve of his composite grains, just past 100 μm, would be a useful diagnostic in discriminating among

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different models; what caused the bump? In responding, Mathis doubted whether he could trust an artifact like that. The basic problem with calculations for the composite particles is how to combine three indices of refraction of three separate materials (silicate, amorphous carbon, and graphite, not to mention vacuum) in each grain. There are two well-known rules, both of which have real problems, and Huffman had claimed that the wrong one was chosen. The combination might be achieved within the formalism of the discrete dipole approximation, but with some difficulty in the infrared according to Draine.

3. THE 10 μm SILICATE POLARIZATION FEATURE

Hildebrand referred to the observational work by Aitken, Bailey, Roche and Hough on the polarization spectrum at the 10 μm silicate resonance. The position angle does not change across the feature. He had found a fairly good fit using the astronomical silicate of Draine and Lee if the grains were taken to be oblate spheroids of axial ratio near 1.5, but not if plates or needles. Adding a grain mantle does not improve the fit, but rather makes it worse. Martin recalled that in his review he had reported on some extensive calculations with dielectric mantles on silicates. The mantle affects the extinction profile not nearly so much as the polarization profile, the latter profile being the difference between two cross sections, both of which are being changed. A mantle does indeed make the polarization profile hard to fit, with polarization reversal when the mantle volume is comparable to the volume of the grain core. Although confocal spheroids might be the wrong model they do show the qualitative feature of shifting the peak in the polarization profile toward longer wavelengths relative to the extinction profile, consistent with what is observed.

At least intuitively, Mathis felt that these problems encountered with fully coated core-mantle grains might be mitigated in a composite grain consisting of separated fragments of silicate in a matrix consisting largely of vacuum. Greenberg commented that each of the three models, whether composite particles, or silicates coated with organic refractories or HAC, would seem to have problems. He thought it would be worth pursuing whether the grain shape or the 10 μm refractive index could be adjusted to make the polarization from a mantled particle acceptable.

4. THE 10 μm SILICATE PROFILE

Draine was struck that the emissivity/extinction profiles of circumstellar silicates and interstellar diffuse material were essentially indistinguishable, as shown by Aitken and Roche. How could this apparent invariance be consistent with any of the models in which silicates are either coated or in close proximity to other materials? Would one not expect a distortion, dependent on environment? Greenberg speculated that different profiles arising from intrinsically different shapes might occur if the emitting circumstellar particles were rather spherical, but subsequently coagulated into more or less cylindrical particles in the interstellar medium. Mathis asked Roche whether the observed emission profile could be independent of radiative transfer, so that it could be related directly to the absorption profile in the interstellar medium. Roche affirmed that there were small differences in the emission profiles for a range of stars, but these might reasonably be due to different grain temperatures in the range 200–300 K, so that the derived emissivity is generally the same as from diffuse absorption. Russell added that profiles in a wide range of

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H II regions and molecular clouds could be fit accurately with the emissivity profile obtained by dividing the Trapezium emission by a blackbody. He felt this was a critical point to be addressed by models.

Cautioning against statements that there was just one type of silicate, Nuth reminded the assembly of two poster presentations which showed vastly different 10 and 20 μm features. He challenged the observers to put the same kind of effort into observing the silicate features as is expended on the subtleties of the PAH's, arguing for larger returns. Rengarajan echoed the same sentiment, referring to an upcoming poster based on IRAS LRS spectra. Williams acknowledged that there are many silicates; the one in his model was chosen for its glassy properties which showed that it was amorphous with broad and smooth features at 10 and near 20 μm.

5. HAC

Greenberg asked Williams about the albedo in his model: if the major extinction was coming from the very small silicate-HAC particles whose extinction was primarily absorption (albedo zero), and if the other particles happened to be of the classical size (albedo 0.5–0.7), the effective albedo would be only of the order of 0.2. In response, Williams maintained that the albedo of the small particles is not necessarily low. There is a finite probability for re-emission of the photon which is absorbed by an island of the HAC. Inverting the problem, the albedo information indicates what that probability is and how it varies with wavelength. In the model, the vast bulk of extinction was indeed produced by the small HAC-coated particles. The extinction of the large particles was rather independent of wavelength over a wide range. Greenberg wondered how this could be consistent with the large particles producing the standard wavelength dependence of polarization in the optical. Williams said the polarizing component was similar in size distribution to the Mathis prescription. On a related query about the low ratio of polarization to total extinction implied by the model, Jones answered that the observations could be matched with efficiently aligned particles.

Wolfire wondered what the HAC models predicted for the observability of the 7.7 μm stretching band in the interstellar medium, there being to date no detection of the band. Duley responded that an answer to this general question would require a knowledge of how the grains changed in the interstellar radiation field, and that appropriate laboratory data were not available. It seemed to Wolfire that there were about as many bonds in HAC as in silicate, and it would have to be a phenomenally weak stretching vibration to disappear.

Léger voiced concern that presently only half of the information available was being used: absorption data, but not emission data, are being modelled. An exception was the HAC model, but he disagreed strongly on whether an individual HAC island could keep its heat long enough to radiate. Molecular physicists have tried for many years to localize energy in a large molecule and have never succeeded. The issue could perhaps be resolved by experiment, of which some are contemplated. Léger questioned if the HAC model could account for 3.4 μm absorption but 3.3 μm emission; PAH models with a component of very small molecules could achieve this selectivity. Duley predicted on the spot that there would be a diffuse 3.4 μm (as opposed to 3.3 μm) emission component, according to the HAC model;

the wavelength would change with environment, unprocessed material showing predominantly 3.4 μm emission. d'Hendecourt wondered if this was in accord with available observations.

6. PREDICTIONS

For the record, what specific predictions are made by the three models? Williams volunteered to stand by a number. The HAC-silicate model gives a direct prediction of carbon depletion for stars for which far ultraviolet extinction is available, which could be checked within years. Another relates to the red emission, a natural consequence of having this luminescent material, HAC; the model makes quite specific predictions of the wavelength of this red emission and how that changes with the nature of the material. Other predictions can be examined in more detail in a paper in MNRAS; these relate the bump strength to various aspects of the extinction curve in the visual and ultraviolet and also to the ratio of total to selective extinction. Associated with the OH^- site that is claimed to be responsible for the 2200 Å bump should be an infrared feature at 2.9 μm, very weak and broad but nevertheless a prediction.

Greenberg maintained that the core mantle model predicted the presence of organic mantles long before the 3.4 μm absorption feature was discovered. It also predicted the possibility of having various ice mixtures in molecular clouds and it seemed to him rather curious that even though half of the interstellar material is in molecular clouds, only grains in diffuse clouds had been discussed up to this point. (Mathis interjected that was where we have observations to fit, by and large). Predictions relating to photoprocessing of mantles have been one of the main contributions of the Leiden group. Greenberg urged Mathis to describe what would happen if one were to take his very open fluffy particle, put it in a molecular cloud, and then have all the atoms and molecules diffuse through the structure. What kind of a peculiar substance would result? Would it have an ice band? Mathis stated that the particle would accumulate ice and even yellow stuff too; he did not disagree that there are mantles. Greenberg claimed that the coating would not be just superficial, but would penetrate it, filling up the interstices, producing a solid particle totally different from a particle which is made up of normal types of material.

Mathis thought that other distinctions might be made on the basis of extinction near the Lyman limit, and polarization in the ultraviolet. He predicted that the 3.4 μm absorption feature would be locally weaker than on the path towards the Galactic center; the latter does not have ice but certainly has regions which are not typical of the diffuse interstellar medium. Locally there would not be much highly processed organic refractory material. VI Cyg 12 is a star which one could look at; how large is the ratio of the 3.4 μm feature to A_V relative to that for the Galactic center? Whittet reported on recent observations at UKIRT which detected tentatively a weak feature. The ratio was about three times less than towards the Galactic centre, to Mathis' satisfaction. Williams pointed out that low 3.4 μm absorption was a characteristic of his model too; from laboratory samples Duley found the ratio was 10^{-3}–10^{-2}.

7. THE 2200 Å FEATURE

Sedlmayr asked if the 2200 Å feature had been observed in a carbon star, which would provide a clear distinction between the models: Williams' model attributes the feature to a silicate component which cannot occur in a carbon star, while other models used graphite. Mathis disagreed with the basis of the test, since it was his view that carbon stars produced amorphous carbon rather than graphite particles. The 2200 Å feature is not present, but two weird objects (both very hydrogen poor; one is R Cor Bor) do have bumps at 2400 Å, characteristic of amorphous carbon. Could small amorphous carbon bits be heated and reprocessed close to stars like reflection nebula B stars and so be graphitized?

The question was reformulated by Williams in the context of his model; is the 2200 Å feature observed in oxygen-rich stars, which are likely to make just silicates? Snow said the answer was negative in several cases studied.

Greenberg was of the view that graphite has much in its favour. But one constraint is to reproduce a correlation between the bump and the visual extinction. If graphite is indeed made in stars, and the grains causing the visual extinction are made between the stars to a large extent, is this a problem? Is there a bump-producing material which can be directly associated with the particles which provide the visual extinction? Linear carbon molecules produced on shattering the mantles are being investigated.

8. CARBON DEPLETION

Mathis was disturbed by what the HAC-silicate model predicts for the carbon depletion. His own model, starting out with amorphous carbon cooked into graphite, keeps the graphitic component more-or-less constant between that incorporated in the composite grains and that which is free-flying producing the bump. The amount of carbon in the gas is unimportant. If there were a tight correlation between the depletion and the strength of the bump, the model would have to be adjusted.

The existence of predictions for a number of stars was re-emphasized by Williams. Unfortunately, there is at present only one line of sight on which carbon depletion is reasonably well determined, roughly 60% of the solar abundance. What fraction of the solar abundance of carbon is locked up in the grains in the other models? Over all carbon components, the value is about 70% for Mathis' model. Greenberg's latest model has 30% of the carbon in the organic refractory mantles, 25% in the graphite, and an additional 10% distributed in the PAH's, thus 65% in total.

9. FAR ULTRAVIOLET EXTINCTION

Fitzpatrick asked which of the three models could accommodate something like an SMC extinction curve. If the bump were removed, do the models have anything that looks linear, as observed? Williams answered in the affirmative, as did Mathis, confessing to using Duley's amorphous carbon to produce the far ultraviolet rise. Duley explained that the SMC-like extinction comes from having more carbon with diamond-like coordination and less of the graphitic carbon that gives rise to the visual extinction. Massa worried about curvature in the extinction from the diamond-like component, but Duley responded that it was not extreme.

d'Hendecourt observed that graphite-like material usually absorbs very strongly at 2200 Å, and asked why this band seems to disappear in the HAC model. Duley commented that there is very strong continuum absorption through the 2200 Å region, with an absorption coefficient close to 10^5 cm^{-1}. But there is no selective feature or resonance superimposed on it. No 2200 Å band has been observed in his laboratory in amorphous samples (simple thin films deposited on a low-temperature substrate) ranging from no H content up to about 10^{22} cm^{-3}.

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