COLLOQUIUM SUMMARY

THE INTERPLANETARY MEDIUM IS THRIVING

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ABSTRACT. Usually in presenting a summary report of a meeting one tries to pick out the highlights. In the present instance I am tempted to say that the meeting was its own highlight because there were so many fine presentations covering such a wide range of interrelated topics. The organizers are clearly to be congratulated on their timing.

1. MULTIFACETED APPROACH

The first impression one gets is the multifaceted approach, involving new as well as extensions of old techniques brought to bear on the subject of the 'Origin and Evolution of Interplanetary Dust'.

1.1. Spectral range

The classical visual and ultraviolet observations have been extended into the infrared, the far infrared and, most recently, into the submm region. The contributions of IRAS have been outstanding in the infrared while the longward wavelength extension by COBE and the James Clerk Maxwell Telescope (JCMT) are just coming into play.

1.2. Space sensing

The delayed return of the Long Duration Exposure Facility (LDEF) is already providing important but still preliminary new data on space particles while the Soviet Space Station MIR will also be used for such analyses. In both of these, there is the opportunity to study returned samples chemically as well as morphologically and, from tracks etc., dynamically as well (mass, velocity, orbits density). The Galileo spacecraft will enormously extend the data return from the three previous detectors aboard the Pioneer 8 and 9 and the Helios spacecraft which recorded only a few hundred impacts. Further in situ measurements by space vehicles will be coming from the Munich Dust Counter (MDC) aboard the MUSES-A mission of Japan. In the future (according to current plans) the

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CASSINI/NASA mission will return data on the interplanetary particles. The NASA solar probe mission will partially probe dust near the sun.

1.3. Collection

Particles are collected in the atmosphere by high flying airplanes.Many of these are positively identified as being of extraterrestrial origin - so-called interplanetary dust particles (IDP's). Even though many of these are of such low density that their entry is well cushioned by the atmosphere they are somewhat heated and modified in their chemical and morphological structure. Nevertheless they are probably closer to their original form than such other collected particles as meteorites and spherules.

1.4. Chemical and physical analysis

Microprobes for the study of laboratory available samples - whether created in the laboratory or returned with space probes or collected in the earth's atmosphere or at the surface(ground, ocean, antarctic ice) are being exploited for both chemical and morphological data.

1.5. Laboratory simulation

Laboratory simulation of cometary, interstellar, meteoritic materials are providing basic comparisons of the use of techniques for studying the actual materials.

1.6.Theoretical developments

New theories of scattering by fluffy and irregular particles are being applied to both interplanetary and cometary dust particles.

2. MAJOR PROBLEMS.

The major problems which were the focus of the meeting were:

2.1. Sources and sinks of interplanetary particles

2.2. Interrelation between interstellar dust, meteors, meteorites asteroids, comets, stratospheric particles, spherules

2.3. Observations and theories of chemical, and morphological evolution of dust particles, their lifetime and orbits.

3. SPACE DATA.

The accounts by McDonnell, Mandeville, Hüdepohl, and Grün of the past, present and future space efforts give great promise for separating the sources of interplanetary dust - asteroids vs comets vs terrestrial (in the case of LDEF and MIR). We should have a great deal more definitive data on fluxes, orbits, masses and chemical analyses on residual material. Already the Pioneer data revealed the previously unexpected result that the interplanetary particle density certainly has no cut-off beyond 2 AU and falls off very slowly all the way out to 16 AU. But confirmation of the result remains a job for the Galileo detector. In the meanwhile the question of why the zodiacal light (Z.L.) cut-off exists even with the extended dust presence is receiving attention with the answer already being strongly suggested by the IRAS infrared emission data.

4. ZL CLOUD MODELS.

The classical ideas for various spatial models for the visual scattering properties of the interplanetary particles were summarized by Kneissel and some further suggestions were made by Hovenier. An interesting new conceptual approach using the gegenschein as a means of choosing among several models for the spatial distribution was reported by Hong with the proviso of the need for much more precise data. Some observed ultraviolet zodiacal light scattering properties were used by Lillie to indicate the possible presence of submicron particles resembling the cores of the core-mantle interstellar particles. The infrared properties of the dust were shown by Levasseur-Regourd to require models of the ZL particles in which both size distribution and chemical or morphological structure depend on distance from the sun and distribution out of the ecliptic. Such ideas, involving a radial dependence on material density and, by inference, albedo, have been either deduced of were deducible, from the earlier Helios data and the material density falloff of meteors whose orbits carry them further from the sun. Now the infrared data on albedo may be used to deduce the same property which is being called degree of fluffiness. As the theory of Greenberg and Hage on comet dust implies, the increase of dust fluffiness easily explains the slower temperature decrease with distance than $r^{-0.5}$ for $r > 0.5$ AU, perhaps as slow as $r^{-0.3}$.

5. WHAT ARE THE SOURCES OF THE INTERPLANETARY DUST PARTICLES?

Is it possible to explain the Zodiacal Light, and the chemical and morphological structure of collected stratospheric particles and the meteorites in a coherent way, and what is the link to interstellar and circumstellar dust? This question deservedly received the most attention and was viewed from a variety of approaches.

5.1. Mineralogical and chemical analysis and laboratory simulations.

This approach alone was the subject of 20% of the oral presentations and the posters. Results on stratospheric particles, spherules, meteorites, and comet dust were presented along with laboratory simulations on relevant ices and minerals. The first talk on this by Bradley laid the foundation for much of the later discussion. The micron and submicron grain dimensions in the fine grained morphology of interplanetary dust particles requires the use of microprobes. The mineralogical composition of the particles generally falls into two categories -anhydrous and hydrated (layer) silicates.The existence of purely anhydrous phases in some particle precludes the earlier presence of liquid water and seems to demonstrate that these are direct descendants of cometary debris. The particles which have both hydrated and anhydrous phases would appear to be similar to CI and CM (the most 'primitive') meteorites. A further distinction is in the porosities of these two particle types with the former being much fluffier - closer to cometary as shown by the Greenberg-Hage model.

However, along with the positive distinctions there are enough particles of mixed characteristics to raise the question of whether comets and asteroids form totally discontinuous population types or whether perhaps there are at least some intermediate type bodies. We still do not know that comets are all born at the same distance from the sun and, in fact, there are some who suggest that there is evidence of different birthplaces from their orbits. In any case both meteorites and comet debris show mineralogical signatures of interstellar dust with the former sometimes indicating an earlier state (asteroidal) involving liquid water. The range of studies using laboratory and theoretical simulations of formation and evolution of silicates and other material constituents presumed relevant to asteroidal and cometary formation was impressive and too numerous to mention individually. The importance of such studies can not be overemphasized. Analysis of laboratory created samples under controlled conditions and development of standards for various types of detectors will provide a reliability basis for the analysis of solar system particles. One example was the chemical identification of comet infrared emission by laboratory created organics, another was the infrared study of SiO/water mixtures by Sakata's group. Another was the considera-tion of silicate-water interaction measured over time depending on temperature with relevance to the creation of hydrated silicates found in asteroidal meteorites. The Bussoletti group presented an example of spectra of laboratory produced glassy and crystalline silicates for comparison with cometary spectra.

5.2. Asteroid and cometary debris trails and tails.

Asteroidal and cometary debris trails should be the most direct evidence for the source of debris in the solar system other than the comet dust observation. From these one may attempt to make estimates of the dust mass input. Only preliminary results are yet available from IRAS studies of comet trails which provide data on the very low velocity component of short period comet dust debris.The fact that the brightest IRAS bands associated with the principal Hirayama asteroid families led Sykes to conclude that they result from collisions. However he also pointed out

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that, in general, the dust production rates are not correlated with the local asteroidal concentration. Although the detection of zodiacal dust bands and cometary debris trails by IRAS may not yet be sufficient to explain all that is required to give the observed zodiacal light, the application of the new capabilities for detecting the largest masses in dust streams using submillimeter observations, may provide the required deficit. These large particles, relatively invisible in the infrared, could erode or break up to supply the needed dust seen in the visible. Long period comets do not have trails locally so that one must provide a firm theoretical foundation to calculate what happens to the dust which leaves the comet at all velocities and masses. Apparently, according to the latest such calculations on orbits and ejection times presented by Fulle, the mass input by long period comets is quite similar to that provided by short period comets.

5.3. Orbital distribution of meteoroids.

The source of interplanetary particles can be deduced from their orbits in the neighborhood of the earth if these orbits are significantly different for particles coming from comets or asteroids. Remote detection is limited to photographic, radar, and television observations. The most up-to-date survey of these data presented by Steel seems to show that about equal contributions to the interplanetary particle complexes are made by asteroids and comets. But, just as in the data from tails and trails the uncertainties are such that both the absolute amounts and the relative amounts of mass *and* input require much more investigation along these directions to be totally convincing.

5.4. Optical scattering and IR emission by the interplanetary dust cloud.

The simultaneous interpretation of the visible scattered light and the infrared emission by the zodiacal dust cloud has required an expanded approach to the nature of the responsible particles. It is no longer possible to consider simple solid material particles in the theories. The direct evidence for much more complex particles in the form of IDP's and indirect but convincing evidence from comet dust studied by Greenberg and deduced from meteor densities, require new theoretical scattering methods. Not yet fully appreciated is the concomitant need for reinvestigation of the dynamical properties and orbital evolution of complex particles in the solar system. Fluffy aggregated comet dust particles should hardly be visible as zodiacal light particles of *equal mass*. Even IDP's are relatively poor scatterers of visible radiation. If the zodiacal light comes from such low albedo particles we would require a much higher mass. There must exist a hierarchy of fluffiness or, inversely, solidity. This is already evident in the differences between the radial distribution of the effectively scattering and the effectively infrared emitting particles, with the latter extending in their distribution to larger distances from the sun than the former. Could asteroid debris be relatively more responsible for the visibly scattering (more solid) particles and cometary debris for the less scattering - higher infrared emitting - particles? If so, this should show up in the relative degree of concentration of these two different types in and out of the ecliptic; asteroid debris being expected to be more concentrated to the ecliptic. A very important deduction from the existence of low albedo particles is that the most likely cause of such a low albedo is not alone the fluffiness but the presence of material more absorbing than rocky (silicate) material. The inference that this absorbing component is organic - as now proven to exist in cometary dust as well as IDP's - and as shown to exist in meteorites is a critical connecting link between all dust components and leads to a further implication that the ultimate source of solid material in the interplanetary system is interstellar dust. A very novel and potentially important theoretical study of the physical processing of micrometeoroids impacting on the upper atmosphere by Kamijo may provide a connection between the interplanetary particles collected in the upper atmosphere (IDP's) and spherules.

The fact that short period comets and asteroids both are the prime sources of particles in the ecliptic while long period comets are the prime sources of particles out of the ecliptic with probably a smaller contribution from periodic comets would imply that out-of-ecliptic dust is fluffier on the average than dust in the ecliptic. The optical manifestations observed in and out of the ecliptic were shown by Levasseur Regourd to be indeed different in their polarizing properties but whether the corresponding albedos can be the total cause is yet to be determined. In any case we seem to be seeing at least 2 populations of particles.

6. ASTEROID AND COMET ORIGINS.

After having examined and, hopefully, having answered the question of the sources of interplanetary particles, the final stage is to study the material source of the asteroids and comets. The basic question here is to what extent these objects can trace their composition *directly* to the collapsing interstellar cloud out which the solar system was born. Interstellar clouds are well known to contain a wide range of molecular constituents in both the gas phase and solid state -interstellar dust. During the process of collapse to the disk form of the protosolar nebula and subsequent to the turn-on of the sun these constituents must certainly undergo some processing as a result of heating, turbulence and radiation. One class of theories is that all of the solid material was evaporated before being reconstituted into the present solar system bodies, including asteroids and even comets. The current understanding is that at least in comets and, to a lesser extent, in asteroids the interstellar dust grains preserved many of their pre-solar system properties. This theme emerged in a large number of papers presented at the symposium.

6.1. Interstellar dust

Currently we have knowledge of a wide variety of material constituents of

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the dust. Some of these are volatiles in the form of frozen ices, the others being relatively non-volatile or refractory. However even the refractories have varying degrees of volatility. The major refractory components which have been observed may be characterized as silicates and organics. The former category is probably dominated by amorphous magnesium/iron silicates, produced by stars. The latter consist of (1) complex organic molecular mixtures created as residues from ultraviolet processing of 'ices' in space; (2) large aromatic molecules called PAH's (polycyclic aromatic hydrocarbons) and; (3) other yet uncertain carbon or carbonaceous molecules.The connection of these constituents with what is found in interplanetary particles involves not only *what* they are but *how* they are configured. The most abundant of the carbon materials appear as organic mantles on the silicates. Another property of great importance in establishing the *cosmic dust connection* is the interstellar dust size, or size distribution. Theoretical modelling of interstellar polarization and extinction show that the bulk (by mass) of the interstellar particles consist of tenth micron silicate cores with organic mantles whose mean, or characteristic, volume is about twice that of the silicates. in pre-solar interstellar space the dust grains have substantial outer mantles of frozen molecules generally dominated by H_2O and CO but containing many other species such as CO_2, CH_3OH, H_2CO with a total of 10-15 well identified by solid state infrared spectroscopy. What role do these 'ices' play in the pre and early solar system chemistry and are these completely or partially evaporated before the formation of asteroids and comets? In the same way that one may question where in the pre-solar nebula, the silicates are preserved or evaporated one may also question where and to what extent the ices and the organics may have been preserved before becoming a part of the larger bodies.

6.2 Interstellar dust-comets

The invited review by Yamamoto was a careful consideration of the former question and he presented persuasive arguments to show why, in the regions where comets are formed, the H_2O ice and some of the molecules trapped in it are maintained in place on the aggregating grains. However he suggested that under some conditions the more volatile constituents like CO are expected to partially or fully evaporate so that one may expect to observe some variability in the CO abundances from one comet to the other depending on the initial formation region. Accordingly, in all cases the organics and obviously the silicates should be preserved. In the paper by Hage some of the consequences of considering unaltered interstellar dust to be the ingredients of comets were taken up in some detail. Of major interest was the conclusion that the observational properties of comet can best (probably *only*) be satisfied if comets are very fluffy aggregates of interstellar dust as modelled by Greenberg;that is, not only the chemical composition but also the size and configuration is relevant. Thus the source of low albedo interplanetary particles is naturally explained along with low density meteors. Although the interplanetary particles known as chondritic IDP's are also fluffy, their degree of fluffiness is considerably less (by a factor of about 5). Nevertheless they bear sufficient resemblances in morphological structure to aggregated interstellar dust(but with reduced organics) to have evolved to their present state by natural processes occurring during their up to 10,000 year sojourn in the interplanetary space (heating, solar wind, photolysis) and their atmospheric entry. And, furthermore, such physical changes are just what are needed to explain the greater amount of particles with decreasing albedos further removed from the sun. Sandford drew the connection between interstellar and comet dust and IDP's via their correlated mineralogical properties and (inferred) orbits of the latter. Those particles with higher-than-average earth encounter velocities and therefore relatively eccentric orbits contain predominantly anhydrous silicates as observed in comet dust.

6.3 Interstellar dust-asteroids

Establishing asteroidal connections with interstellar dust has to be done via meteorites and other debris. Since already interstellar matter must have undergone substantial metamorphosis not only during but after parent body formation the problem is much more difficult than for comets. Among other things water can not have survived in solid form. But there is evidence that in liquid form it had effects which can be deduced from meteorites and IDP's. For example, Sandford suggests an asteroidal source for those IDP's which have predominantly layer-lattice silicates which result from hydration in the presence of liquid water. His reason is that these IDP's indicate very low encounter velocities implying low inclination prograde orbits implying asteroidal debris. If liquid water survives in asteroid formation then trapped CO_2 may also have survived. This may perhaps be the source of carbonates in meteorites. It would interesting to determine whether there exists a correlation between the presence of carbonates and hydrated silicates because both indicate the presence of liquid water at some stage of formation of the parent body.

7. CONCLUSIONS

The study of interplanetary dust has been shown at this meeting to provide a rich field for providing a clearer understanding of the origin and formation of the solar system.
A schematic summary of the meeting is shown in Figure 1.

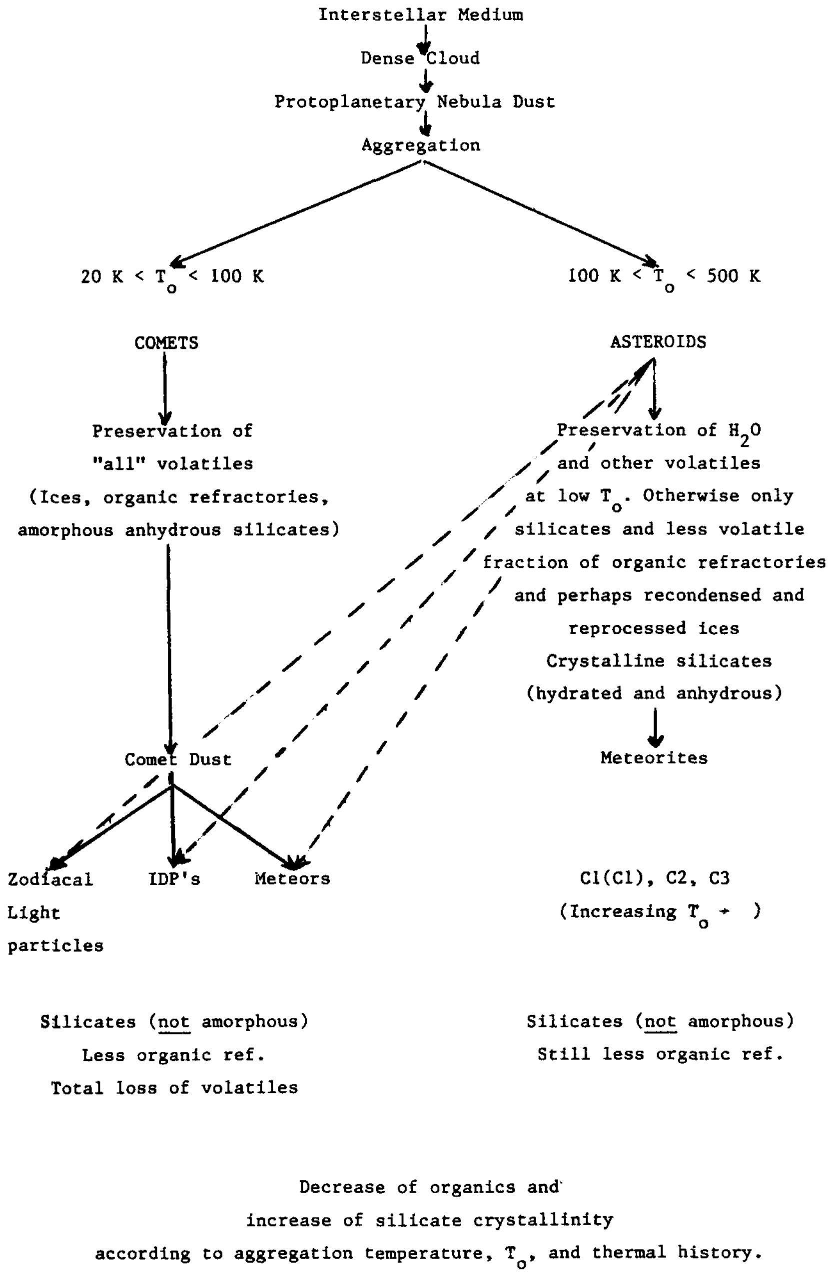

Figure 1. Some suggested pathways from the interstellar to the interplanetary medium.