SUMMARY AND CONCLUSION OF THE COLLOQUIUM

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There is now a satisfactory convergence of the observational results for the absolute intensity of the zodiacal light for elongations larger than 20° to 30°. They are still discrepancies affecting the data for the F-corona but after carefully scrutinizing available data, Koutchmy and Lamy could obtain an axy-asymmetric non-spherical model for the equatorial and polar regions which satisfactorily bridges to the zodiacal light. However, a closer examination reveals several points of concern:
i) the gradient of the brightness which is of utmost importance for retrieving the phase function of interplanetary dust: the "Hawaï" data (Misconi and Weinberg), the PCN data (Nikolsky et al.) and the classical data of Dumont and Sanchez are in disagreement;
ii) a lack of data for the inner zodiacal light;

iii) insufficient out-of-ecliptic data; the on-going analysis of the "Hawaï" data (which benefits from an improved reduction method) and of the "South Africa" data will help partly remedy this situation.
A consensus appears to be reached on the near solar color of the zodiacal light or, to be more precise, a slight reddening down to 2000 Å. The inner zodiacal light and the F-corona are clearly redder than the Sun. Some structure near 2800 Å reported by Feldman et al. is certainly worth of further investigation. Ultraviolet observations of Comet Halley may well provide adequate opportunities. The situation of the polarization of the zodiacal light is less satisfactory as large discrepancies persist. Of major importance for the properties of the dust grains are the behaviours at small and large scattering angles - in particular, the shape of the negative branch - as well as the angle of maximum polarization and its magnitude. The polarization is certainly color dependent but the present data are insufficient for a clear-cut conclusion.

With the background zodiacal light on a firm basis, investigations have started, mainly by the Florida group, to search for fluctuations in

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the brightness indicating small scale structures. Results from ground-based observations are inconclusive, their reliability is always a matter of concern as the fluctuating airglow poses a major problem. This is really a space program further motivated by the impressive results of the IRAS mission. Infrared observations were carried out in the past, but the tremondous achievement of IRAS represents a giant step in our probing the interplanetary dust cloud. Structures are definitively observed for the first time, the so-called interplanetary dust bands as well as irregularities of the profiles near the ecliptic plane. The fact that the data of the D2B ultraviolet satellite do not reveal these bands (Maucherat, private communication) confirmes that they are composed of large grains. If they result from a collision, small micronic and submicronic grains possibly created then have already been swept from the bands. Generally speaking, we must expect a quite different zodiacal cloud in the infrared than in the visible and ultraviolet (as examplified by Comet Iras-Araki-Alcock, 1983d) since they do not relate to the same grains. In particular, we may well expect a different plane of symmetry. When fully exploited, all these data will possibly help to differentiate the dynamical evolution of grains as a function of their size.

The balloon observation of the F-corona at the 1983 eclipse represents a major effort of the japanese astronomical community. Accurate photometry (and polarization) with a television camera is always a difficult task but the data are certainly worth further elaborated reduction. The excess emission observed in the infrared on the west side of the Sun does not really ressemble the "peaks" reported by Peterson and MacQueen. It is further puzzling that this excess tends to vanish beyond 2 microns. Although there probably exists a dust free zone (or zones), with edge enhancement(s) possibly connected to the reinforcements observed in the visible in the equatorial direction, it is not clear if they are permanent stationary features of a local component of the F-corona. Then the relative importance of this local component (scattering at large angles) and of the classical F-corona (diffraction by grains along the line-of-sight) is not clear either.

The investigation of the dynamics of the zodiacal cloud based on the measurement of the Doppler shift is actively pursued with a variety of technics. Fabry-Perot interferograms as obtained by Shcheglov et al. on the F-corona are a powerful technics which should probably be extended to the zodiacal light. It is of interest to note that these authors could well have observed the debris of a Sun-grazing comet. High-resolution spectrographic observations by Robley et al. reveal that the MgI lines may be contaminated by a weak OH system, a situation which could explain some puzzling aspects (e.g., the Gegenschein receding from the Earth at 4 km/sec) of the otherwise impressive results obtained by East and Reay who reject the hyperbolic trajectories found by Fried.

There is one field which does not benefit from the expanding activities of man in space, on the contrary! it is the in-situ sensing of meteroids in the near-Earth region. The reassessed importance of lunar secondary ejecta based on new laboratory simulations is a further

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drawback for the determination of the size distribution of interplanetary dust from lunar microcraters data. However, Zook concludes that in-situ experiments carried out in the early 1960's were not significantly contaminated by space debris and that the lunar microcraters distribution of impact pits larger than 7 microns satisfactorily represents the size distribution of interplanetary dust. If the "solar flare track" lunar clock is rejected as unreliable, then both sources of information are consistent as shown by Grün et al. But the size distribution for grains radii below ≃ 2 micron (or mass below ≃ 10^{-10} g) cannot be directly obtained. As pointed out by Walker during the discussion, one could compare the crater populations on different faces of a large glass deposit to determine the contribution of secondary craters. Alternatively, the deconvolution process worked out by the Canterbury group could be applied again using the new laboratory data on a sample (such as 12054) whose lunar orientation is well known. Because of so many years of effort and improved knowledge on processes taking place on the lunar surface, the true size distribution of impact pits smaller than 7 microns is certainly within reach.

The complexity of the near-Earth region is revealed by new analysis of in-situ observations realized in the sixties. While the 1962 Explorer 46 data lead Kessler to conclude that nearly all the penetrations were from exhaust product from solid rocket motors, Barsukov et al. consider that the 1964 Elektron 1 and 3 data were not severely contaminated and reveal structures in the distribution of meteoritic matter in orbit around the Earth, similar to the "swarms" registered by HEOS-2.

Deep-space, in-situ measurements are not (yet!) subject to contamination and the continuying analysis of the Helios data gives, for the first data, direct information on the radial variation of the micrometeoroid flux between 0.3 and 1 AU. Contrary to all expectations and to a straightforward conclusion from the results of the zodiacal light experiment, the "ecliptic" flux levels off at 0.5 to 0.6 AU or even decreases further in! Theoretical studies are now required to understand this result while we are expecting more surprises from the forthcoming Galileo/ISPM missions.

To the new and challenging problem of distinguishing interplanetary dust from man-made space debris (and eventually, from simulated interplanetary materials by Strong et al.), investigators are responding with a new generation of detectors of amazing ingeniosity which, of course, benefits from past experience and improved technology. Combining orbital, chemical and isotopic information should unambiguously allow to decipher the impacts on the LDEF detectors.

The field of laboratory measurements of interplanetary dust grains, which already produced significant astrophysical results, has now reached a phase of rapid development for, at least, three reasons:
i) the routine collection program managed by NASA; this will greatly increase the number of IDG available for analysis and improve the

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statistical significance of the results;
ii) the parallel use of a large variety of complementary analysis techniques;
iii) the new methodology for the measurements which consists in studying each particle individually and establishing its extraterrestrial origin on the basis of several criteria, large D excesses, presence of solar flare tracks and solar-type gases.
As it is the case for a new, rapidly expanding field, more and more refined and detailed results have been presented which probably preclude a synthesis for the time-being. The limited subset of "chondritic" dust grains, which have been thoroughfully measured by the St Louis group, indicates from infrared transmission spectra, that these grains fall into three classes, "layer-latticed silicates", "pyroxenes" and "olivines". Worth mentioning is the presence, in spectra of the first class, of a band at 6.8 micron as seen in the spectra of some protostars and probably due to a carbonate mineral.

The impressive development of analysis techniques benefits equally to the renewal of deep-sea spherules studies, a field which have been absent from the interplanetary dust conferences for about a decade. Several criteria are proposed to test their origin such as the ^{26}Al/^{10}Be ratio, the chemical and isotopic compositions, the cosmic ray exposure age, the density of the internal metal globules. While Raisbeck et al. conclude for a cometary origin, Parkin favors their formation as splash ejecta in asteroidal collisions. Of importance is the ability of cosmic exposure ages to provide the first experimental checks of theoretical lifetimes of micrometeoroids in space.

The harmonious parallel development of both experimental and theoretical studies of the optical properties of irregular and rough dust grains is also one of the main achievements of these past years in our field. We have therefore available good laboratory measurements, especially from the Bochum group, and a variety of models (which are in fact complementary) cooperating in an improved understanding of the light scattering by non-spherical rough grains such as the negative branch of polarization resulting from preferential geometrical blocking of reflected rays. Likewise, efforts are being pursued to extract local optical properties of interplanetary dust grains from zodiacal light data especially by Dumont who has been fighting for years to retrieve non model dependent information which may be viewed as offering "absolute calibration" points for any model. Although, the out-of-ecliptic optical probing of the zodiacal cloud will not be possible, Giese et al. have shown that a clever analysis of available data can indeed help to confirm or reject three dimensional distribution models of interplanetary dust.

Combining all these results lead to an improved understanding of the main features of the zodiacal light. They (including the IRAS data) converge to a low albedo, of the order of a few percents. The increased flux model proposed by Grün et al. considerably eases the compatibility with zodiacal light data (especially, in view of the low albedo) but

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still, the contribution of submicronic grains is non-negligible as shown by Lamy and Perrin and probably required to explain the slight reddening of the zodiacal light down to 2000 Å. The question of the heliocentric variation of the spatial density of grains ($r^{-\nu}$) must remain opened as the result $\nu = 1.3$ derived from the Helios zodiacal light experiment is not compatible with the observed brightness of the inner zodiacal light and F-corona as noted by Leinert and Hong. It may be argued that part of the $r^{-1.3}$ variation can be attributed to the variation of the out-of-ecliptic "thickness" of the zodiacal cloud since the Helios photometers were pointing away from the ecliptic. Furthermore, the Helios impact experiment reveals that the "ecliptic" flux tends to level off near 0.5 AU. It is also likely that ν is not a constant, but a function of heliocentric distance. As an alternative view and if a bimodal population is considered, each population may have its own ν such as $\nu = 1$ for large grains and $\nu = 2$ for small grains. Taking into account the scattering efficiency of both populations, one could well produce an apparent, intermediate ν such as $\nu = 1.3$.

This, by no means, precludes investigating constraints on the dynamics of interplanetary grains to produce $\nu > 1$ (the Poynting-Robertson effect alone would result in $\nu = 1$). Three mechanism recently proposed were discussed and compared in a very enlighting way by Leinert. Catastrophic collisions of larger meteoritic particles indeed appear to be the most natural process and Grün et al. studied the collisional balance of the "meteoritic complex" and found that the population of "zodiacal light" particles is not presently in equilibrium.

The dynamics of grains larger than a few microns is essentially controlled by solar gravitational and radiation forces and gravitational disturbances by the major planets. When applicable, it can be studied by perturbation theory and Dermott et al. presented a thorough application to the case of the IRAS dust bands to predict longitudinal variations in their brightness and in their latitude so as to discriminate between cometary and asteroidal origins. Gustafson proposed a method to calculate and integrate the perturbations on ensembles of particles of low eccentricity and showed that dust close to the orbital plane of Venus is flattened while a dust band is created. The general case is investigated by Burkhardt who numerically integrated the equations of motion of test particles in three-dimensions, all planets from Mercury to Jupiter being included; although this kind of approach is always limited by the number of test particles preventing a global view, it does show some interesting behaviours not predicted by the planar treatment. Electromagnetic forces may become important for submicronic grains. Applying the quasi-linear theory, Barge et al. convincingly proved that only the low frequency fluctuations associated with the sector structure of the interplanetary magnetic field must be considered and that, introducing the cyclic variables associated with the three constants of the unperturbed motion, allows to obtain a simple diffusion equation. The diffusion, which has a resonant behaviour, mainly affects the inclination.

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The general problem of connecting the interplanetary dust distribution with the dust dynamics and dust sources and sinks was addressed by Fahr and Ripken. The problem may be rigorously formulated in terms of the Boltzmann kinetic equation (or a Fokker-Planck equation when stochastic interactions are considered). In the case of loss-free motion and circular orbits, these authors could obtain an explicit solution for the intensity distribution function. They also explained how the dust dynamics can be traced by measuring the velocity distribution function of hydrogen and helium atoms which desorb from the grains surface and how it will be applied to a forthcoming rocket experiment.

Progress in the calculation of the charge of interplanetary dust grains were mainly achieved on both theoretical and experimental fronts by a french consortium. In particular, the effect of surface roughness on the charging process was investigated by Lafon and Millet. Such efforts, which are somehow parallel to those in the optical domain, must be further developped and backed by laboratory experiments which are not too difficult in principle. The case of energetic particles penetrating dust grains was examined by Rössler and Eich while Ibadov looked at the possibility of X-ray emission in dusty comets coming from a high-temperature plasma generated by collisions between cometary and interplanetary grains.

Looking in retrospect to past conferences in our field has led me to refrain from drawing definitive conclusions. The panel and I have pointed out directions where immediate or near-future progress can be achieved, domains of potential and promising results, studies and (space) experiments which are needed. In my opinion, the continuous vitality of our field and its perpetual renewal stems from the variety of techniques of probing the zodiacal dust cloud, each one involving in turn its part of observational, laboratory and theoretical studies. It is essential that this type of interdisciplinary approach be pursued to assure continuous progress in our understanding of the properties and interactions of interplanetary dust. The potential access to primitive interstellar matter offered by collected interplanetary grains and the recent observation of "zodiacal" dust cloud around stars will probably led us to expand our horizons and to cast a new light on our interplanetary medium.

Writing this "summary and conclusion" was the most demanding task of all of the organization of this colloquium. But it was also the most interesting and rewarding and I am most thankful to R. Giese for having asked me to do it.

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