1 ZODIACAL LIGHT

1.2 GROUNDBASED OBSERVATIONS

1.2.1 GROUND-BASED OBSERVATIONS OF THE ZODIACAL LIGHT

René DUMONT

Observatoire de Bordeaux
33270 FLOIRAC (France)

I. OBSERVATIONS AND THEIR DEGREE OF RELIABILITY

At the present time, when space experiments bring us more and more information of increasing quality, it might appear questionable whether ground-based zodiacal light observations are still of interest. Nevertheless, any detailed examination of the available data (see, for example, the review paper of Leinert 1975) shows that a considerable part of our present optical knowledge of interplanetary dust has been contributed by ground-based programmes. Moreover, new available parameters arising from space data, mainly in the field of heliocentric dependence of brightness, open new important abilities for a better interpretation of ground-based observations.

Shortcomings and advantages of ground-based compared to space zodiacal light observations

Airglow is the main drawback of ground-based data, and it has been in the past responsible for the lack of consistency of many ground-based results with each other and with space results, especially off the ecliptic. Most of the figures proposed before 1967 for off-ecliptic brightness and polarization degree are nowadays reckoned to be largely erroneous, viz. overestimated.

The difficulties of ground-based observations are even greater when we go from the blue-green range of the spectrum, either towards the red, where OH bands of the nightglow are increasingly disturbing, or towards the 0.3 - 0.4 μm range, where tropospheric corrections become large. A consequence is that colorimetric measurements from ground are scarce and not fully reliable. Extensions to IR and UV domains are practically impossible from ground.

As emphasized below, telluric disturbances to polarimetry from ground are more or less worrying according to the direction, and may become totally unacceptable near the horizon or the antisun.

Several doubtful results concerning z.l. intrinsic variations, especially short-timed ones, may be ascribed at least partially to these various sources of errors, particularly to airglow inhomogeneities and variations.

On the other hand, ground-based observations have in some cases no serious disadvantage compared to space experiments; on a few particular points they may even be credited for a true superiority. In the case of Fabry-Perot interferometry, disturbances coming from atmosphere are moderate, and in a space experiment the only major improvement expected would be a better coverage of small elongations. In the case of photopolarimetry, the advantages of space are much more obvious; still, ground-based data keep the best (up to now) with respect to the following rather important items:

1) better abilities to reduce the integrated starlight correction. The well-known uncertainty of this term can be lowered by a considerable ratio if the light-collector has a sufficient diameter, so that stars down to an advanced limit-magnitude can be excluded from the field by a visual and manual operation - typically irrelevant to spatial constraints.

2) the possibility of a very long time span of observation. Only a few space programmes have lasted a year or more, and many ones have lasted some days or even minutes, while ground-based programmes like those of Haleakala, of Pic-du-Midi and of Tenerife have been carried out for periods of 10 years or more. Now, problems about stability or evolution of the zodiacal cloud throughout a solar cycle obviously demand long programmes, with stable instrumentation.

3) ground-based observations cover the whole sky except small elongations, not only more or less restricted regions. Perhaps the most striking feature of our presently available collection of space results is its " mosaic " character: each concerns limited areas or lines, and the resulting density of the information remains rather patchy over the sky. This shortcoming will certainly be removed in the future, but to-day it contrasts highly with the bulk of homogeneous data obtained from ground over 90 percent of the celestial sphere.

Some remarks about the reliability of ground-based z.l. photometry and polarimetry

The various limitations to the accuracy of ground-based data arising from airglow and from tropospheric scattering largely depend upon wavelength, celestial direction and zenith distance, so that the situation cannot be summarized briefly.

The fact that this complexity has not always been borne in mind has sometimes resulted in excessive opinions, in both senses, with respect to the accuracy to be hoped - either a total suspicion of all ground-based results, or too much confidence in them. In order to clarify that problem, a rather extensive study of the accuracy has been attempted (Sánchez 1969; Dumont and Sánchez 1973, 1975a) and has led to the following conclusions:

a) in ground-based z.l. photometry, airglow is the main disturbance, except in the bright cones. All kinds of ways to minimize its intervention must be sought (lowest possible latitude and zenith distance; careful choice of the spectral range...) One such which we have adopted at Tenerife (Dumont 1965, 1967; Dumont and Sánchez 1975a) is to make use of the green oxygen line [OI] 5577 Å as a photometric indicator for the nightglow continuum variations, since a fair correlation appears most of the time between them. The existence of that correlation above all observatories remains controversial, but its usefulness in those ones where it is seldom failing, is beyond doubt. The accuracy provided by this refinement is of the order of ±10 percent in the cones down to ±25 percent in the dim off-ecliptic regions, but it remains possible to perform a reliable photometry up to the ecliptical pole.

b) ground-based z.l. polarimetry has, in addition, to take account of the false polarization originating in tropospheric transfers. The three celestial sources (z.l., airglow and stars) scattered along the line of sight introduce three parasitic totally polarized components j, which disturb the true

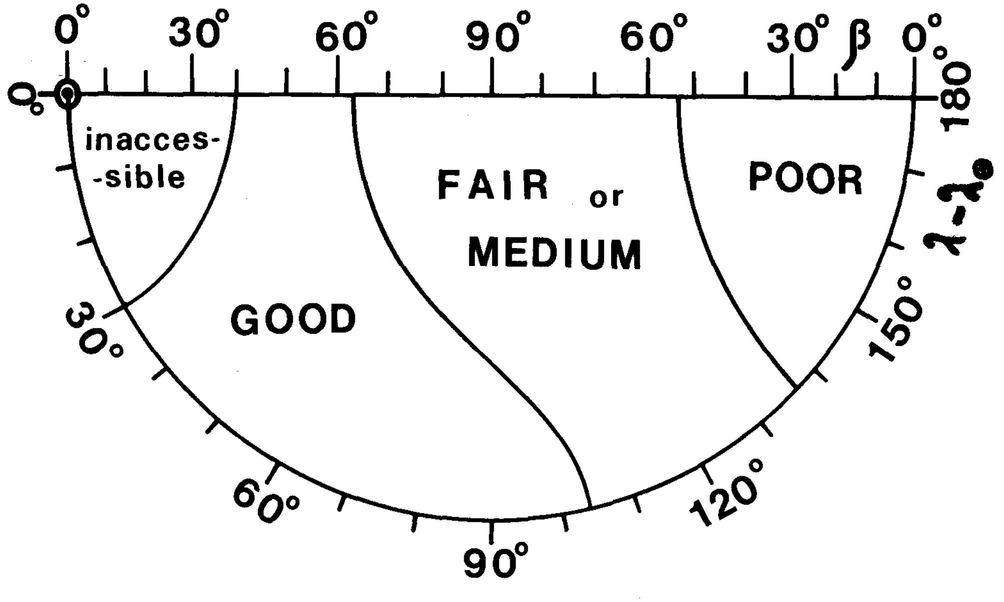

Fig. 1. Distribution over the sky in helioecliptic coordinates (with conservation of areas) of the expected reliability in ground-based polarimetry.

J component (J = PZ, where Z is the brightness and P the polarization degree of the z.l.). The resulting disturbance is of the order of 1 S_{10} near 30° zenith distance, up to 5 S_{10} near 70°; its effect is weak in the regions where J is strong, but it completely distorts the results when J is only a few S_{10}.

The sky may be divided into a few zones of different reliability for z.l. polarimetry (fig. 1). We see that an antisolar cap of about 45° radius is an area of very poor reliability from ground. This is the reason why, in my opinion, the problem of neutral points and slight negative polarization on the wings of the gegenschein is a typical aim for space experiments. Another consequence is the questionable credibility of some works (Bandermann and Wolstencroft 1974) which purport to show variations in gegenschein polarization, on the basis of observed J variations at levels of 1 S_{10} (see also Sparrow and Weinberg 1975). Despite these various difficulties in ground-based polarimetry, satisfying figures for the polarization degree P can be obtained over the major part of the sky.

The difficulties to compute the polarization degree P led several authors to restrict the problem to the determination of $J = PZ$. Obviously this quantity, although being disturbed by low-atmosphere scattering, is considerably safer to be computed from ground - and even from space - than P, since the bothers arising from the diluting sources (airglow and integrated starlight, whose brightnesses are uncertain but polarization is roughly negligible) are avoided as far as J alone is concerned. Unfortunately, J is a hybrid quantity, and its determination without any independent determination of Z and P - in other terms, the 2nd and 3d Stokes' parameters being known and the first unknown - remains a much less fundamental step towards the optical knowledge of the dust. Contrary to the opinion of Wolstencroft and Brandt (1972), I think that moderately accurate measurements of brightness Z and of polarization P are more useful than accurate data on the totally polarized component $J = PZ$, if interpretations in terms of dust distribution, size, optical properties, and nature, are the final purpose.

II. RESULTS AND INTERPRETATION:
OPTICAL PROPERTIES AND DISTRIBUTION OF THE GRAINS

The attempt in this section is to summarize the results and to extract which kind of information they contain about interplanetary dust, with emphasis on photopolarimetry over the whole sky.

Doppler-shifts measurements and the motion of the grains

The most evident conclusion arising from the recent works in this field (Reay and Ring 1968; James and Smeethe 1970; Hicks et al. 1974) is that almost all the grains move along prograde orbits. Obviously, much more information may be expected from the diagrams wavelength shift vs. elongation, especially, as pointed out by James (1969), about the size distribution of the grains.

Nevertheless, serious difficulties of interpretation seem to arise (in addition to the observational problems due to the weakness of the expected and observed Doppler-Shifts), and important discrepancies remain between the results, and if they are compared to the theoretical curves. The variety of the interpretations suggested to explain these discrepancies - a circumterrestrial component (Vanysek and Harwit 1970), eccentric orbits (Bandermann and Wolstencroft 1969) or interstellar dust streaming through the solar system (Hicks et al. 1974) - means that, up to now, unambiguous information can hardly be extracted from the available data in this field.

Photopolarimetric surveys of the ecliptic and the phase function of an elementary volume

It is obvious before any calculation that a lot of concealed information about the scattering functions of the grains and their distribution within the zodiacal cloud is contained in the surveys providing the brightness Z and the polarization degree P with a very wide coverage of the sky.

Measurements along the ecliptic are of special interest because of the rotational symmetry that we may ascribe to the zodiacal cloud, at least as an outline. The eccentricity of the earth's orbit, and the fact that the invariable plane of the solar system is more and more generally accepted to be the true symmetry plane, are able to introduce small seasonal effects, some of which are detected in Tenerife data (Dumont and Sánchez 1968), in Pic-du-Midi data (Robley 1973) and by the D2A satellite experiment (Levasseur and Blamont 1974). However, these seasonal changes are slight enough (a few percent) to ensure that observations in the ecliptic from the earth are practically equivalent with observations in the true symmetry plane and from 1 A.U. heliocentric distance exactly.

Considering that partial surveys of the ecliptic - some points, or a restricted range of a few tens degrees - are not so readily useful for interpretations as wide surveys on a considerable range of elongations are, only have been selected here the available data extending to at least 2/3 of the ecliptic (i.e. an elongation range $\Delta\epsilon \geqslant 120°$, since no significant east-west dissymmetries have been reported). It is noteworthy that, for brightness (fig. 2), only four published surveys satisfy this condition - three of them being ground-based and one from a balloon - and for polarization (fig. 3) only two surveys - both ground-based - presently offer this wide coverage.

Brightness along the ecliptic.

Fig. 2 shows two groups of curves; the upper pair gives from 35 to 110° elongation stronger values of Z than the lower pair by a nearly constant factor of 1.2. In the far zodiacal band, the four curves are more separated, the maximal discrepancy being almost a factor of 1.7. The elongation of the minimum ranges from 125 to 140°, and the ratio Z(antisun)/Z(minimum) ranges from 1.25 to 1.60. There is a fair agreement on the value of the derivative $dZ/d\epsilon$ at $\epsilon = 90°$, which is directly related to the scattering efficiency of a unit-volume of interplanetary space (Dumont 1972, 1973).

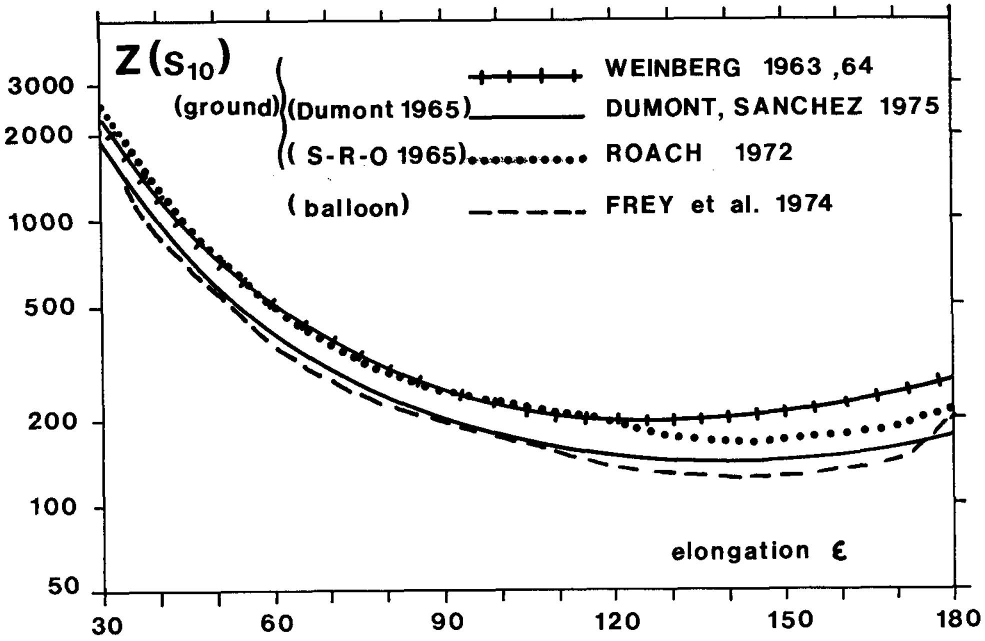

Fig. 2. Zodiacal light brightness along the ecliptic, according to the available surveys covering an elongation range $\Delta\varepsilon \geqslant 120°$.

Polarization along the ecliptic.

The only two available surveys of the whole ecliptic give the same general shape of curve (fig. 3). The maximum is 0.229 at $\varepsilon = 70°$ according to Weinberg 1964, and 0.177 at $\varepsilon = 62°$ according to Dumont and Sánchez 1975b (similar values already given in Dumont 1965). The greatest discrepancy is 6 percent polarization near $\varepsilon = 80°$. Both curves have a moderate slope at $\varepsilon = 30°$, suggesting that P remains rather high when the line of sight approaches the sun. This is in agreement with the photometric results obtained in the inner z.l. by the rocket experiment of Leinert et al. (1974).

Both in Z and in P these differences between Haleakala and Tenerife are rather important, and they exceed the minimal errors inherent to ground-based observations. However, they are not dramatic, and they probably do not prevent the extraction of conclusions in general agreement on dust properties and distribution.

The scattering phase function.

The possibility of deriving the phase function in arbitrary units, over the same range of scattering angle θ as the available observed range of elongation ε , has been emphasized by Dumont 1973 ; see also Leinert 1975, and Dumont (1976). The expression of the phase function for a unit-volume situated at 1 AU from the sun is,

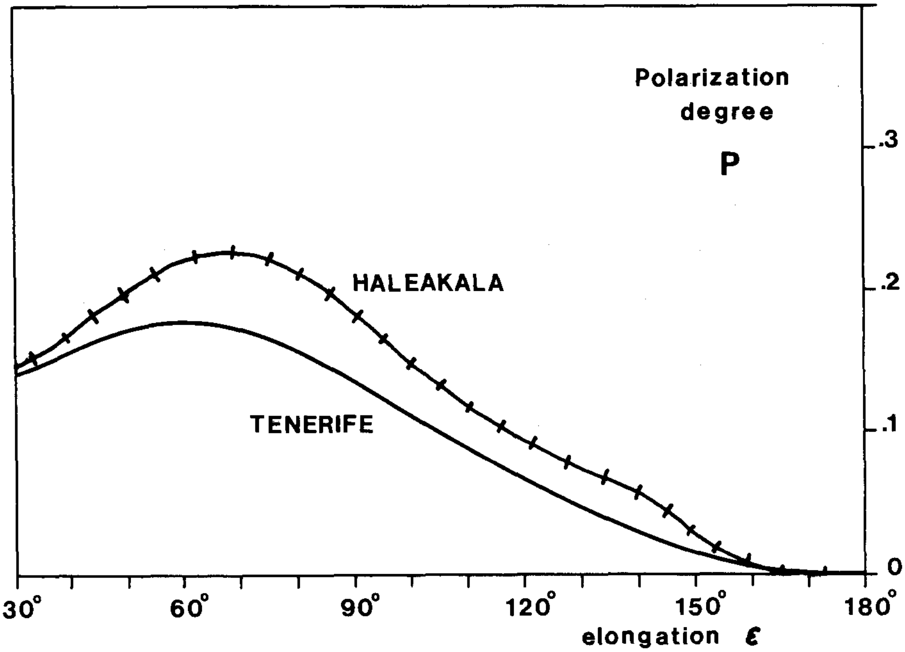

Fig. 3. Polarization degree of the zodiacal light along the ecliptic, according to the available surveys covering an elongation range $\Delta\varepsilon \gg 120°$.

after inversion of the brightness integral along the line of sight:

$$\sigma(\theta = \varepsilon) = -(1+n)\cos\varepsilon\, Z(\varepsilon) - \sin\varepsilon \frac{dZ}{d\varepsilon} \qquad (1)$$

if the space density in the symmetry plane of the zodiacal cloud (practically, in the ecliptic) is assumed to be proportional to r^{-n}, at least in the range of r the most efficient for producing the z.l. observable from ground ($0.5 < r < 2$ A.U.). The fact that the distribution law seems to be broken down to zero in the asteroidal belt cannot be seriously argued against the validity of this formula (Dumont, 1976).

Very different values of n have been suggested in various models, but the plausible range is presently much more restricted. Most of the preliminary results of Pioneer 10 (optical data) are in favour of $n \cong 1$ (Hanner and Weinberg 1973a 1973b; Soberman et al. 1974). Still, according to the weak residual brightness due to the z.l. at $r = 2.4$ A.U. reported by Hanner et al. (1974), n could be > 1, perhaps of the order of 1.5.

Introducing high values of n (of the order of 2 or even 1.6) in eq. (1) leads, on the basis of our knowledge of Z along the ecliptic, to negative and therefore meaningless values of σ . Values > 1.5 being eliminated by these considerations, and values < 1 conflicting with Pioneer 10's results, I suggest that $n = 1.2 \pm 0.3$ is presently the best evaluation of this parameter (see footnote).

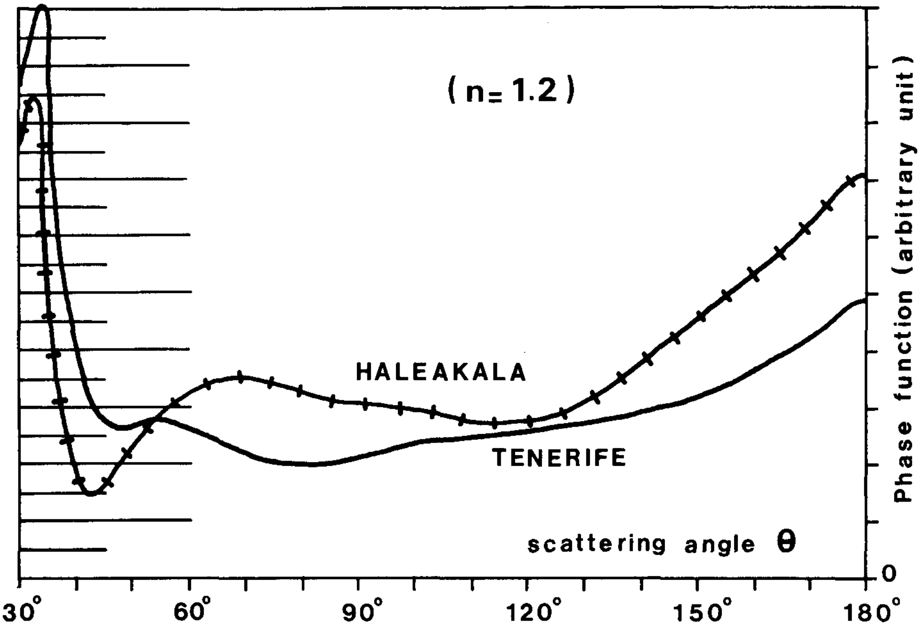

Fig. 4. The phase function of interplanetary dust, as resulting from eq. (1) and from Haleakala and Tenerife photometric surveys. A space density $\sim r^{-1.2}$ in the ecliptic is assumed. The left side is poorly reliable.

Fig. 4 shows the phase functions obtained when supplying eq. (1) with the Z(ε) data of Haleakala (Weinberg 1964) and of Tenerife (Dumont 1965; Dumont and Sánchez 1975b), assuming $n = 1.2$. We must notice that the accuracy of the method is decreasing with decreasing θ , due to the fact that the two terms of eq. (1)'s right hand side increase rapidly, with absolute values of the same order and opposite signs. The peaks near $\theta = 33°$, although conspicuous in both curves, must therefore be considered with caution. Rightward of $\theta \cong 50°$ the reliability becomes fair, and both curves show a rough isotropy from 50 to 130° and they climb in the backscattering domain.

These curves are rather sensitive to the value of n adopted, but not enough

---

- The evolution with heliocentric distance of the brightnesses observed by Helios between 1 and 0.3 A.U., as reported by Link et al. (1976) is in favour of $n = 1.3$, therefore in very good agreement with the above conclusion.

to lose their conspicuous trend to isotropy for medium values of θ, as far as values of n in the range 1.0 – 1.5 are assumed (see Dumont and Sánchez 1975b, fig. 3). The variations of σ from $\theta = 50°$ to $\theta = 130°$ are probably within a factor of 2, and this conflicts with many theoretical scattering functions which show variations by a factor of 5 to 10 in the quoted range of scattering angle.

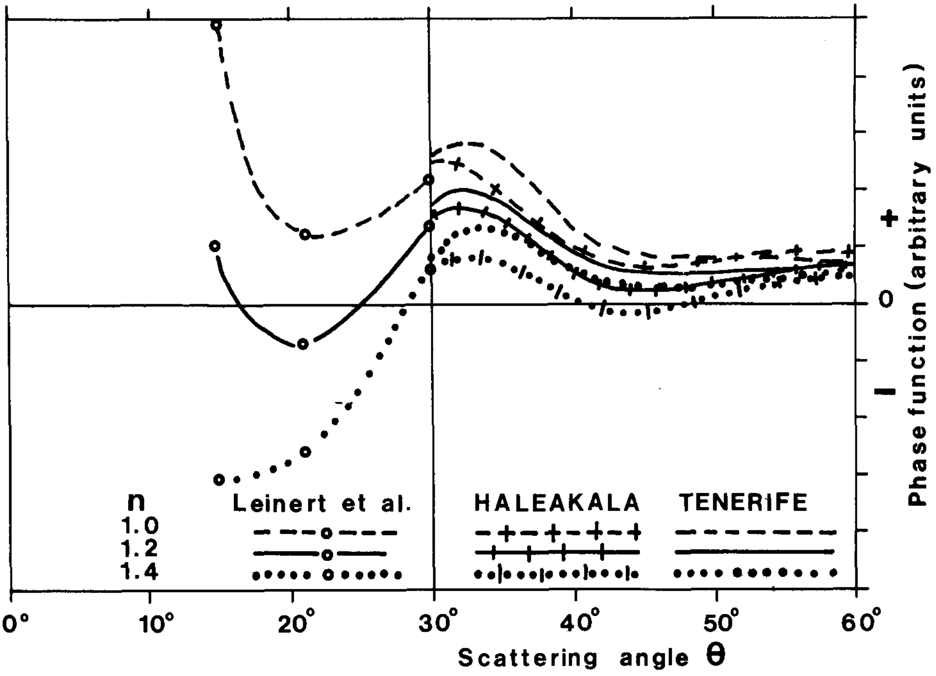

Fig. 5. Forward scattering range of the phase function of interplanetary dust, as resulting from eq.(1). A density law ∼ r^{-n} (n = 1.0; 1.2; 1.4) is assumed in the ecliptic. Classical z.l. ground-based surveys rightwards of $\theta = 30°$; inner z.l. rocket results leftwards of that scattering angle. The level of accuracy given by eq. (1) decreases rapidly when $\theta \rightarrow$ zero.

Fig. 5 concentrates on the forward-scattering range ($\theta < 60°$). Even if we keep in mind the lower level of accuracy achieved when θ decreases, we may notice the good junction of the ground-based curves with those derived from the rocket data of Leinert et al. (1974) at the elongations 15, 21 and 30°. We see that:

- high values of n also conflict with the latter observations;

- the general trend to isotropy extends to the inner z.l. if values of n in the range 1.0 – 1.2 are assumed (waves of moderate amplitude, such as the slight negative range of σ around $\theta = 20°$ for n = 1.2, must of course be disregarded, since in this domain only the general appearance of the curves remains significant).

Indeed, the variations of σ seem to be within a factor of 5 in the $20^\circ < \theta < 180^\circ$ range. Such a flatness can agree with few of the scattering functions reported by Wickramasinghe (1973) for Mie particles, or by Giese (1970, 1971, 1974) for elaborate mixtures of homogeneous or mantle-core particles: most of these curves exhibit a much stronger forward scattering. Some agreement may perhaps be sought with absorbing particles, for which the ratio $\sigma_{max}/\sigma_{min}$ is generally of the order of 10 in the $20^\circ < \theta < 180^\circ$ range, but can be as low as 2 or 3. On the other hand, the curves of figs 4 and 5 seem very hard to reconcile with dielectric particles, for which the same ratio is between 20 and 200 or more.

Polarized components of the phase function.

On the assumption that the vibration plane of the scattered light does not deviate from the plane perpendicular to the scattering plane (or, if some negative polarization occurs, from the scattering plane itself), eq. (1) can be duplicated

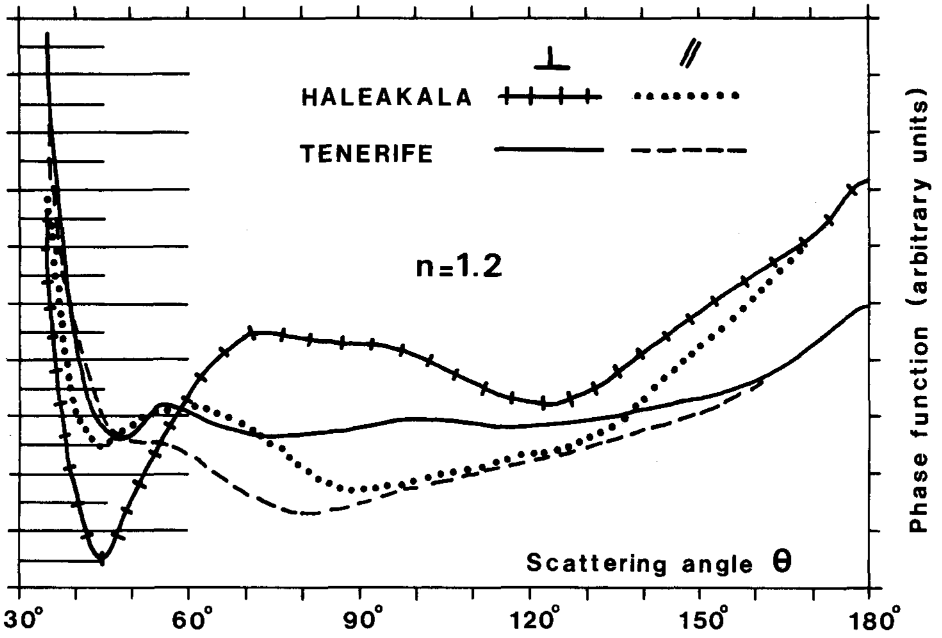

Fig. 6. Polarized components (electric vector perpendicular to: ⊥ , and lying in: // , the scattering plane) of the phase function of interplanetary dust, given by a duplication of eq. (1). A density law $\sim r^{-1.2}$ is assumed in the ecliptic. The left side is poorly reliable.

for the two components of the scattered light, corresponding to the Fresnel or electric vector perpendicular to (1), or lying in (2), the scattering plane.

Fig. 6 shows, for Haleakala and for Tenerife data, the polarized components of the phase function. The trend to isotropic scattering is especially conspicuous upon the component 1 for Tenerife results, since no variations greater than 10 percent of the mean value occur between $\theta = 44°$ and $\theta = 142°$. The component 2 has a minimum at a level of about half the mean level of the component 1. The backscattering efficiency is higher than the mean scattering efficiency for the first component by a factor of 1.7 (Tenerife) or 1.9 (Haleakala). In the left (poorly reliable) side, some negative polarization appears, but it is probably not genuine.

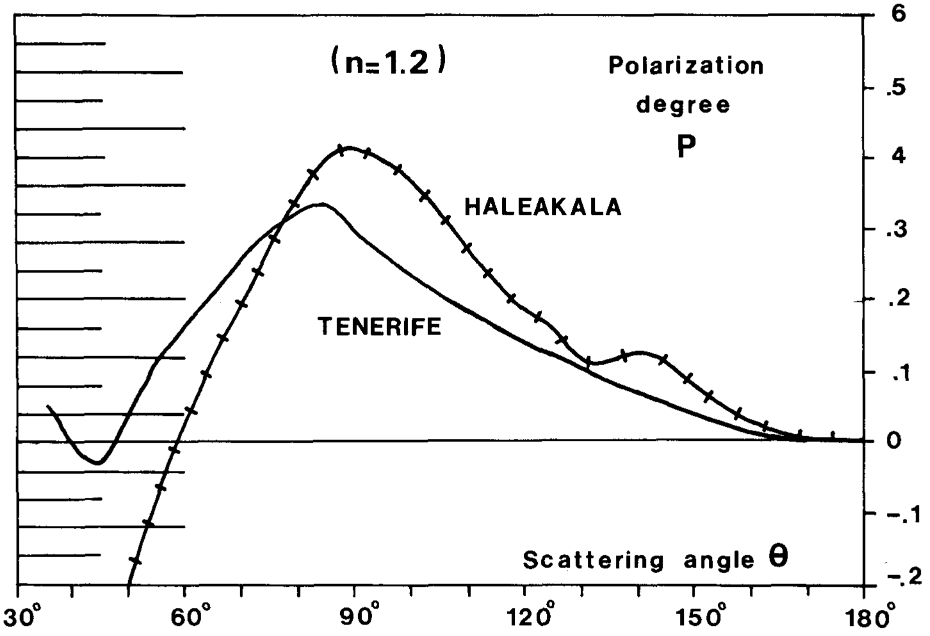

Fig. 7. The polarization curve of interplanetary dust (polarization degree vs. scattering angle θ) obtained by a duplication of eq. (1) and assumption of a density law $\sim r^{-1.2}$ in the ecliptic. The left side is poorly reliable.

The polarization degree of the scattered sunlight, $\mathcal{P} = (\sigma_1 - \sigma_2)/(\sigma_1 + \sigma_2)$ is given by fig. 7, still under the assumption that n = 1.2. Contrary to the photometric curves, the polarization curve is weakly sensitive to the value of n adopted. This is due to the fact (Dumont 1972, 1973) that two points are rigorously independent of n ; they are $\theta = 90°$ and $\theta = \varepsilon_M$, i.e. the elongation of the maximum of observed polarization P (60 to 70°); in the latter case, we have $\mathcal{P}$ = P. As far as the polarization curve is expected to be symmetrical with respect to θ = 90°, these two points are more or less sufficient to determine the whole curve, so that the curves really obtained for very different values of n (see Dumont and Sánchez 1975b, fig. 5) will not differ a great deal from the curve corresponding to n = 1.2. The maximum of the true local polarization $\mathcal{P}$ (0.41 at θ = 88° from Haleakala data; 0.33 at θ = 82° from Tenerife data) is stronger than the corresponding maximum of P observed in the z.l. by almost a factor of 2.

Off-ecliptic photopolarimetry
and the oblateness of the zodiacal cloud

Rather few data are available in the field of photometry and/or polarimetry over large off-ecliptic sky areas. Photometric data are given by Roach (1972) on the whole sky; by Dumont (1965) on 90 percent of the sky; by Frey et al. (1974) (balloon) on 80 percent of the sky. All other data, from ground or space, are of fragmentary nature with respect to the coverage of the sky. Concerning off-ecliptic z.l. polarimetry, Tenerife results (Dumont 1965; Dumont and Sánchez 1966; Sánchez 1967) are the only extended ones.

For the simplicity of the presentation and discussion, we shall concentrate here on the circle sun-ecliptic pole-antisun, which cuts the zodiacal cloud practically along a meridian plane. This circle provides the largest differences in the observations, compared to the ecliptic.

Off-ecliptic brightness.

Fig. 8 gives the brightness from 15° to 180° elongation (= angular distance to the sun), according to Roach's compilation (1972), and from 40° to 180°, according to Tenerife results (Dumont 1965; Dumont and Sánchez 1973; the provisional values for a paper in preparation about off-ecliptic results are also taken into account). Also plotted are the rocket data at 15, 21 and 30° elongation of Leinert et al. (1974).

The minimum, which is at the ecliptical pole according to Roach 1972, is significantly lower in Tenerife results, and it is shifted by 20° towards the antisun ($\lambda-\lambda_{\odot}$ = 180°, β = 70°). Let us recall that several space determinations of Z at the ecliptic pole agree on 50 - 60 S_{10}, i.e. slightly less than the brightness found at Tenerife (65 S_{10}). The latter figure leads to 0.32 for the ratio Z (90, 90)/Z (90, 0), frequently used in zodiacal cloud models and theoretical works.

Comparisons with an ellipsoidal model of the zodiacal cloud.

The most direct and simple assumption for the zodiacal cloud is an ellipsoidal (oblate) shape. The model we wish to propose (Dumont and Sánchez, to be published) has the following parameters:

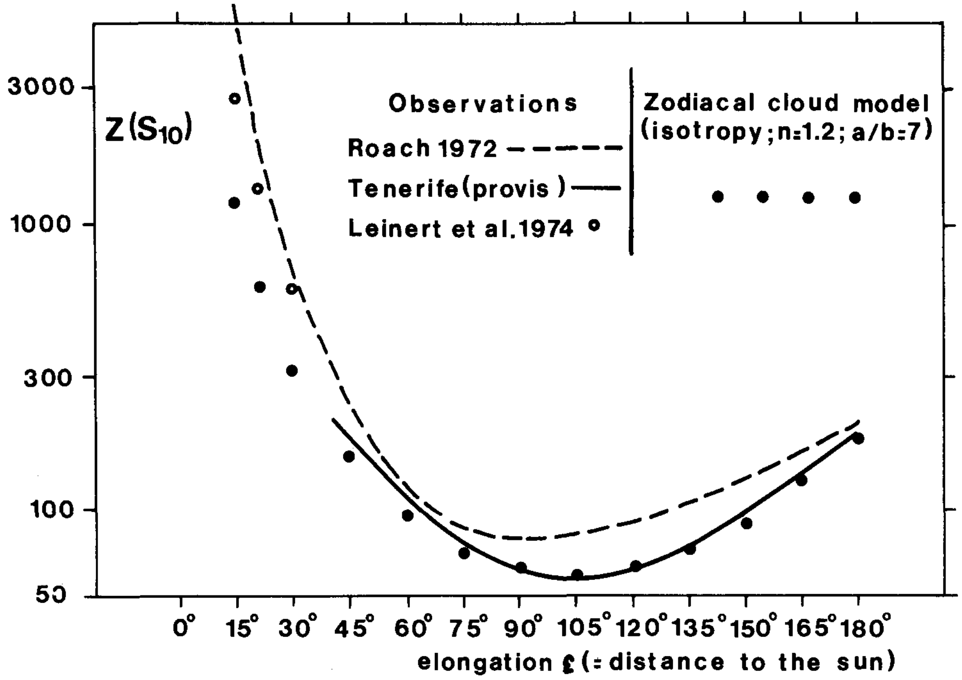

Fig. 8. Off-ecliptic z.l. brightness (in the plane sun-ecliptic pole-antisun) and comparison with the ellipsoidal model of the zodiacal cloud proposed in the text.

a) in the symmetry plane, the run of the space density is $r^{-1.2}$.

b) the dust has the same optical properties outside as inside the ecliptic, i.e. the phase function $\sigma(\theta)$ found in the ecliptic (fig. 4), its polarized components (fig. 6), and its polarization curve (fig. 7) are valid in all directions. Within $\theta = 45°$, viz. where σ is poorly known, we have assumed an isotropy.

c) the isodense surfaces are ellipsoids, with a ratio of oblateness a/b, to be determined by the observations.

Brightness Z and polarization P in each direction are easily computed for such a model by integrating along the line of sight the local values $\mathcal{J}(\theta)$ (= intensity scattered under the scattering angle θ by a unit volume of space) and $\mathcal{P}(\theta)$ (= polarization degree of the scattered light).

The value a/b = 7 has been chosen for the oblateness ratio, since it fits the observed ratio Z(90, 90)/Z(90, 0).

On fig. 8, also appear the theoretical values of Z corresponding to our model. Although the rocket data for the inner z.l. fit better Roach's values than our model, it can be seen that this model is in very satisfying agreement with all Z values obtained at Tenerife; especially, it reproduces the shift of the minimum towards the antisun by a score of degrees.

Off-ecliptic polarization.

Similar agreement arises between our observational data and the above model, with respect to the polarization degree P. Fig. 9 shows the theoretical and obser-

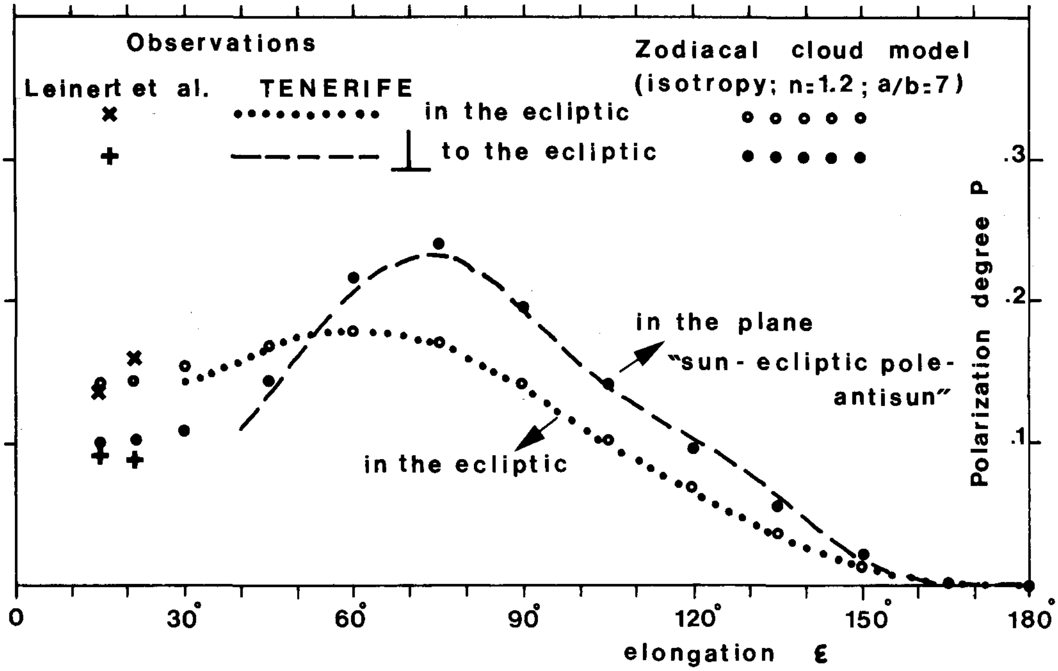

Fig. 9. Off-ecliptic polarization of the z.l. (in the plane sun-ecliptic pole-antisun) compared to the results along the ecliptic. Also plotted are the polarization degrees given for both planes by the ellipsoidal model of the zodiacal cloud proposed in the text (note the good agreement of the model with Tenerife data and with inner z.l. rocket data).

ved P values along the plane sun-ecliptic pole-antisun, compared to the same values along the ecliptic. Our results along the former plane are still provisional, awaiting a thorough reduction of all observations made since 1964. Near the elongation $\varepsilon = 50°$ the polarization degree is the same (0.17) at all inclinations; P is stronger off the ecliptic than along it for greater elongations, weaker for smaller elongations. Part of this result was already implied in the oblate isopolarimetric curves given in the antisolar hemisphere by the former Tenerife results (Dumont 1965, fig. VII-5). A similar trend is reported in the same region by the preliminary results of Skylab in its study of low light level phenomena (Weinberg and Hahn 1975).

An excellent agreement arises between the polarization degrees given by our model in the inner z.l. and those found along circles of 15 and 21° radii around the sun by the rocket experiment of Leinert et al. (1974). Our model predicts that the polarization degree P remains rather high when the line of sight approaches the sun ($\varepsilon \longrightarrow$ zero), with a limit nearly equal to P ($\varepsilon = 90°$), viz. about 0.15, and a plain geometrical explanation of this fact can be found (Dumont and Sánchez 1975b). Perhaps the most convincing test of validity for the model is that it reproduces very well the change of sign for the difference of polarization degree between the two planes, near 50° elongation.

CONCLUSION

A considerable part of the observed photopolarimetric features of the zodiacal light appear to be simultaneously fitted by a rather simple model, the outlines of which are:

- an ellipsoidal dust cloud, flattened in a ratio of about 7;
- a space density decreasing with heliocentric distance slightly steeper than 1/r;
- a scattering phase function and polarization curve exhibiting a quasi-isotropy for the normal component (except some backscattering excess, and a possible but not proven enhancement near $\theta = 30°$), with a loss of 50 percent at right angle (or somewhat before) for the parallel-component.

On the basis of the phase functions obtained (figs. 4 to 7), the field remains open to determine which mixtures of grains (size spectrum, refractive and absorptive indices, nature) are candidates to be the interplanetary " dust " producing the zodiacal light.

REFERENCES

Bandermann L.W., Wolstencroft R.D. 1969, Nature, 221, 251.

Bandermann L.W., Wolstencroft R.D. 1974, Nature 252, 215.

Dumont R. 1965 (thesis), Ann. Astrophys. 28, 265.

Dumont R. 1967, in " The zodiacal light and the interplanetary medium ", Honolulu Symposium, ed. J.L. Weinberg, NASA Sp-150, 63.

Dumont R. 1972, C.R. Acad. Sci. Paris 275 B-765.

Dumont R. 1973, Planet. Space Sci. 21, 2149.

Dumont, R. 1976, this Volume.

Dumont, R., Sânchez, F. 1966, Ann. Astrophys. 29, 113.

Dumont R., Sánchez F. 1968, Ann. Astrophys. 31, 293.

Dumont R., Sánchez F. 1973, Astron. & Astrophys. 22, 321.

Dumont R., Sánchez F. 1975a, Astron. & Astrophys. 38, 397.

Dumont R., Sánchez F. 1975b, Astron. & Astrophys. 38, 405.

Frey A., Hofmann W., Lemke D., Thum C. 1974, Astron. & Astrophys. 36, 447.

Giese R.H. 1970, " Tabellen von Mie-Streufunktionen I " (Max Planck Institut, München, MPI-PAE extraterr. 40).

Giese R.H. 1971, " Tabellen von Mie-Streufunktionen II " (Max Planck Institut, München, MPI-PAE extraterr. 58).

Giese R.H., Schwehm G., Zerull R. 1974, " Grundlagenuntersuchungen zur Interpretation extraterrestrischer Zodiakallichtmessungen und Lichtstreuung von Staubpartikeln verschiedener Formen ", Bochum, BMFT-FB W 74-10.

Hanner M.S., Weinberg J.L. 1973a, Sky & Telesc. 45, 217.

Hanner M.S., Weinberg J.L. 1973b, paper C 3.8 presented at XVI. COSPAR Meeting, Konstanz, Germany.

Hanner M.S., Weinberg J.L., DeShields L.M., Green B.A., Toller G.N. 1974, J. Geophys. Res. 79, 3671.

Hicks T.R., May B.H., Reay N.K. 1974, Mon. Not. Roy. Astron. Soc. 166, 439.

James M.F. 1969, Mon. Not. Roy. Astron. Soc. 142, 45.

James M.F., Smeethe M.J. 1970, Nature 227, 588.

Leinert C. 1975, " Zodiacal Light - a measure of the interplanetary environment " Space Sci. Rev. (in press).

Leinert C., Link H., Pitz E. 1974, Astron. & Astrophys. 30, 411.

Link, H., Leinert, C., Pitz, E. and Salm, N. 1976, this Volume.

Levasseur A-C., Blamont J.E. 1974, paper IIIC-1.5 presented at XVII. COSPAR Meeting, Sao Paulo, Brazil.

Reay N.K., Ring J. 1968, Nature 219, 710.

Roach F.E. 1972, Astronom. J. 77, 887.

Robley R. 1973, Ann. Geophys. 29, 321.

Sánchez F. 1967, in " The zodiacal light and the interplanetary medium ", Honolulu Symposium, ed. J.L. Weinberg, NASA Sp-150, 71.

Sánchez F. 1969 (thesis) Urania 269-270.

Soberman R.K., Neste L.S., Lichtenfeld K. 1974, J. Geophys. Res. 79, 3685.

Sparrow J.G., Weinberg J.L. 1975, Astron. & Astrophys. (in press).

Vanysek V., Harwit M. 1970, Nature 225, 1231.

Weinberg J.L. 1963 (thesis), Univ. of Colorado.

Weinberg J.L. 1964, Ann. Astrophys. 27, 718.

Weinberg J.L., Hahn R.C. 1975, " Multicolor photometry of low light level phenomena from Skylab " (proc. AIAA/AGU Conference on scientific experiments of Skylab, Huntsville, Alabama, in press).

Wickramasinghe N.C. 1973, " Light scattering functions for small particles ", ed. Hilger, London.

Wolstencroft R.D., Brandt J.C. 1972, " Planets, stars and Nebulae studied with photopolarimetry " (Tucson Symposium, ed. T. Gehrels), 768.