THE SYMMETRY PLANE OF THE ZODIACAL CLOUD NEAR 1 AU

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ABSTRACT

Analysis of zodiacal light observations from Mt. Haleakala, Hawaii show that the symmetry plane of the zodiacal cloud near 1 A.U. is close to the invariable plane of the solar system. Since the symmetry plane of the inner zodiacal cloud is close to the orbital plane of Venus (Misconi and Weinberg, 1978; Leinert *et al.*, 1979), we suggest that the symmetry plane changes inclination with heliocentric distance.

INTRODUCTION

The location in space of the plane of maximum dust density (symmetry plane) of the zodiacal cloud has important implications for the dynamics of solid particles in the solar system. These implications are related to questions such as the gravitational perturbations of the planets on the dust, the effects of solar magnetic forces, and the general dynamical history of dust ejected from comets. Helios 1 and 2 zodiacal light measurements near the region of 1 A.U. (Leinert *et al.*, 1979) find that the symmetry plane in this region has an inclination $i = 3 \pm 0.3°$ and ascending node $\Omega = 87 \pm 4°$, which is different from that of the invariable plane of the solar system ($i = 1.6°$, $\Omega = 107°$). At the same time, ground-based observations at Tenerife in the Canary Islands (Dumont and Sanchez, 1968) and satellite observations from the satellite D2A (Dumont and Levasseur-Regourd, 1978) find the symmetry plane close to the invariable plane near 1 A.U.

In the present study an attempt is made to obtain additional data on the location of the symmetry plane near the Earth's orbit using ground-based observations of the zodiacal light from Mt. Haleakala, Hawaii taken by Weinberg and Mann (1967).

THE OBSERVATIONS

Two nights of observations were found to be suitable for this purpose: the evenings of 23 and 24 February, 1968. These photoelectric

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 49–53.

observations were taken using a narrow band filter centered at 5300 Å (Weinberg and Mann, 1967). The photometer made almucantar scans of the evening zodiacal light cone in 5° steps of elevation from 10 to 45°.

Fig. 1 shows an isophote map of the zodiacal light brightness in ecliptic coordinates $(\lambda-\lambda_{\odot},\beta)$ on February 24, 1968. Details of the data reduction and the method of finding the photometric axis (dashed line) were given earlier (Weinberg, 1964; Misconi, 1976 and 1978). The displacement in ecliptic latitude of the photometric axis is found to be between 1 and 1.25° from the ecliptic plane. In Fig. 2, we show the displacements from the ecliptic plane of the observed plane (dashed line) of maximum brightness on two nights in February, 1968, at elongation angles 50-90° from the Sun. The predicted displacements of the invariable plane and the orbital plane of Venus, and the extension of the symmetry plane found by Misconi and Weinberg (1978) correspond to what would be observed if the dust that contributes most to the maximum brightness were in these planes (Misconi, 1977). It is clear that the observed "plane" departs from the symmetry plane of the inner zodiacal cloud and approaches the invariable plane near the Earth's orbit: we find that the inclination decreases from $i \simeq 2.7°$ at $\varepsilon \simeq 50°$ to $i \simeq 1.8$ to $2°$ at $\varepsilon \simeq 90°$.

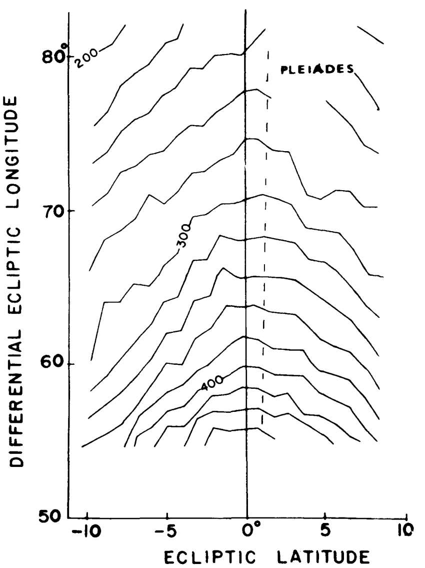

Fig. 1. Brightness contours for the evening zodiacal light on February 24, 1968 in ecliptic coordinates $(\lambda-\lambda_{\odot},\beta)$.

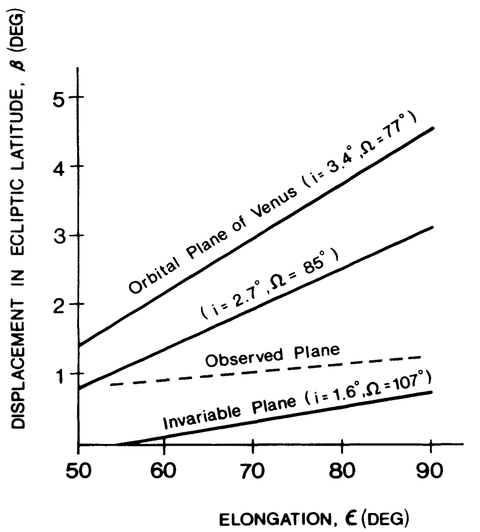

Fig. 2. Predicted displacements in ecliptic latitude (solid lines) of the orbital plane of Venus, extension of the symmetry plane of the inner zodiacal light (ε 32-50°) found by Misconi and Weinberg (1978), and the invariable plane, as a function of elongation angle. The observed symmetry plane in this region is shown by the dashed line.

At the same time, Leinert *et al.* (1979) found that a single inclination, $i = 3 \pm 0.3°$, applies over this entire range of elongation. As noted earlier, Dumont and Sanchez (1968) and Dumont and Levasseur-Regourd (1978) find the symmetry plane near 1 A.U. to be close to the invariable plane. Fig. 3 sketches the relative positions of the observed symmetry plane (dashed line) by Leinert *et al.* (1979), our observed symmetry "surface" as we prefer to call it (solid line), the invariable plane, the orbital plane of Venus, and the solar equatorial plane.

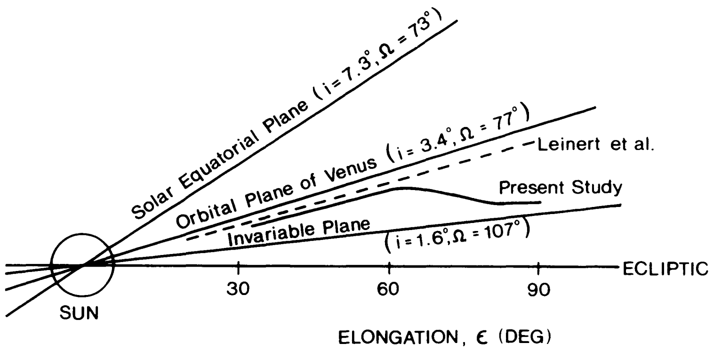

Fig. 3. A sketch of the relative inclinations from the ecliptic plane as a function of elongation: for the solar equatorial plane, the orbital plane of Venus and the invariable plane. Also shown is the position of the symmetry plane found by Leinert *et al.* (dashed line) and our combined results over this range of elongation.

DISCUSSION OF RESULTS

It is found that the symmetry plane of the zodiacal cloud at elongation angles 50-90° does not continue to be close to the orbital plane of Venus but rather departs from it and approaches the invariable plane. In view of this result one must re-evaluate the dynamical forces influencing the spatial distribution of the dust. If one considers the effects of the solar magnetic forces found by Grün and Morfill and reported in this symposium it would seem that the zodiacal cloud should have one symmetry plane decreasing smoothly in inclination with increasing heliocentric distance. Our result shows this tendency, but additional data are needed. Since the inclination of the inner part of the observed plane is 2.7° and the inclination of the solar equatorial plane is 7.3°, the solar magnetic forces have not yet achieved a symmetry to the solar equatorial plane. This fact raises questions about the lifetime of these effects and the origin of the dust in the inner region of the solar system.

It is not possible on an observational basis alone to distinguish between the gravitational effects of Venus and solar electromagnetic forces on the dust. This comes about from the fact that the solar equatorial plane and the orbital plane of Venus have almost the same ascending nodes ($\Omega = 73°$ and $\Omega = 77°$, respectively). Therefore, the question of what is influencing the dust distribution is still unanswered. A dynamical evaluation of the gravitational influence of the inner planets on the dust distribution is needed before one can discriminate between these effects.

New observations of the zodiacal light are scheduled from Mt. Haleakala at $\varepsilon = 50\text{-}180°$ to provide more information on the symmetry plane in these regions.

We thank D. Beeson and Tani Engel for assistance. Supported by NASA grant NSG 7093 and by Air Force Office of Scientific Research Contract F 49620-78-C-0013.

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DISCUSSION

Grün: Electromagnetic effects (Grün and Morfill, this volume) perfectly account for your observed variation of the zodiacal light symmetry plane with solar distance, i.e., the increase of inclination toward the Sun. In particular, the observed longitude of the ascending node outside the Earth's orbit supports the importance of the solar equator and contradicts the gravitational influence of Venus on dust particles outside the Earth's orbit.
Misconi: Electromagnetic effects are certainly one source affecting the symmetry plane of the zodiacal cloud. From these effects one would expect a smooth decrease in the inclination of the symmetry plane away from the Sun, whereas our observations show an irregular decrease in inclination. We agree that the fact that the symmetry plane is near the orbital plane of Venus does not necessarily mean that the dust is perturbed gravitationally by Venus. But, unless the lack of a gravitational effect by Venus is shown through a treatment using perturbation techniques - which to our knowledge has not been done - gravitational effects along with electromagnetic effects should continue to be considered as potential forces affecting the symmetry plane. Our observations find the symmetry plane near the orbital plane of Venus only at heliocentric distances between 0.5 and 0.8 AU, not outside the Earth's orbit.

Roach: How does Dr. Tanabe's measurement of the inclination near the Gegenschein compare with measurements out to Earth?
Misconi: Dr. Tanabe's results show that the symmetry plane outside the Earth's orbit decreases in inclination to a value of 0.5° and an ascending node close to that of the orbital plane of Venus; i.e., a general decrease in the inclination away from the Sun. Dr. Tanabe also suggests that the combined masses of the Earth and Venus are affecting dust outside the Earth's orbit.

Burns: A calculation has recently been completed (Burns, J.A., Hamill, P., Cuzzi, J.N. and Durisen, R.: 1979, Astron. J. in press) that might pertain to the question of gravitational perturbation of the symmetry plane. We studied analytically the out-of-plane perturbations of a particle in Saturns's ring as affected by an inclined satellite of Saturn and the planet's oblateness. We found that the ring particles suffered short - period oscillations of amplitude $(m_{part}/M)(a/a_{part})^3$ $a(\sin i_{part})$ as the particle passed under the perturbing satellite. The long- period perturbations were smaller than this but of the same form, and amounted to a smooth precession about the Laplace plane which lies between the perturber's orbital plane and the planet's equatorial plane. The Laplace plane moved closer and closer to the perturber's plane as the particle was further away from the planet; the plane was warped. Many satellite perturbers were not studied but I would expect that the plane of symmetry of Saturn's ring would be due to the global perturbation of all satellites with only small local effects due to individual satellites.
Misconi: It would be interesting to see similar calculations done for Venus.

Cook: The exchange which we have just heard appears to neglect the averaging effect of integrating along the line-of-sight. If we start with symmetry about the solar equator close to the Sun and end with the Gegenschein necessarily being close to the ecliptic at the other end, we must have local latitudes of symmetry which correspond to a steady decrease of the apparent inclination of the plane of symmetry as we move away from the Sun. If, in addition, the local Laplace plane plays a role, then the pattern will show a wavy structure - an effect which is probably beyond the reach of observations.

Leinert: Plotting the predicted ecliptic latitude of the point of maximum zodiacal light brightness makes it appear as if a determination of the plane of symmetry in the F-corona was not possible. This is misleading. The problem can be avoided by plotting the inclination angle instead of ecliptic latitude. Also it might be useful to check by model calculations whether the approximation used is still good at very small and very large elongations.
Misconi: Use of the inclination angle is a better measure of the maximum brightness but not of the photometric axis in the F-corona. We believe that information on the symmetry plane can best be obtained by scanning perpendicular to the ecliptic plane and by finding the displacement of the photometric axis in ecliptic latitude. Our method of prediction is also reliable at small and large elongations.