Is Venus Concentrating Interplanetary Dust Toward Its Orbital Plane?

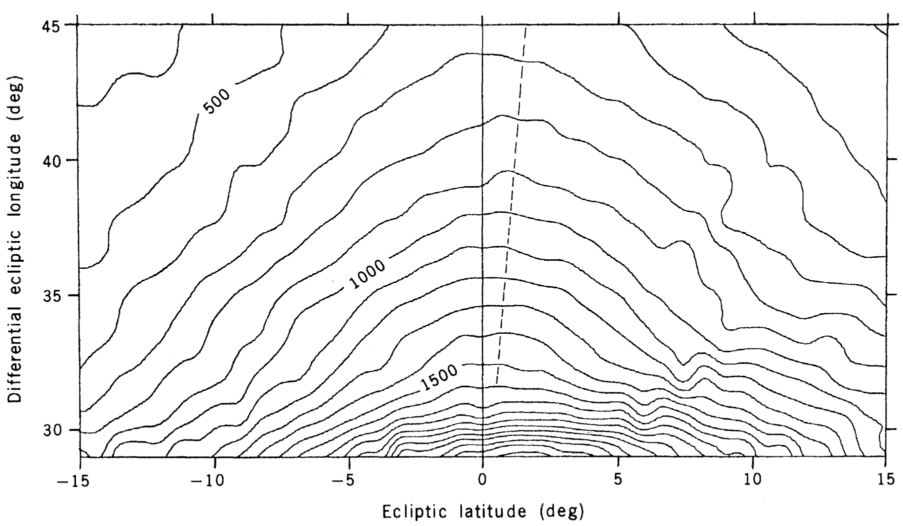
Abstract. *By use of observations of zodiacal light, the symmetry plane or plane of maximum density of interplanetary dust at elongations of 32° to 50° from the sun has been found to be closer to the orbital plane of Venus than to the invariable plane. This suggests that the plane of maximum density in this region is being gravitationally perturbed closer to the orbital plane of Venus.*

Interplanetary dust particles orbit the sun in a thin cloud that extends at least as far as Jupiter's orbit. Sunlight scattered by these particles is seen as a faint glow of light concentrated near the zodiac or ecliptic and increasing in brightness toward the sun; it is called zodiacal light. Observations of the zodiacal light contain information on such characteristics of the dust as spatial density distribution, particle size distribution, and chemical composition (*1*). The dynamics of the dust and hence the spatial density distribution remains one of the classical problems of solar system physics.

Since the dust is concentrated near the orbital planes of the planets, several questions arise concerning the effects of gravitational perturbations on the orbital elements and density distribution of the dust. Does Jupiter have the dominant role in changing the orbital elements of the dust, compared to the other planets? What is the magnitude of these perturbations and what are the associated time scales? How far is the gravitational sphere of influence of each of the planets? Does Mercury affect the dust distribution despite its small mass?

Answers to some of these questions can be found in observations of the zodiacal light, provided that these observations are carefully made and properly analyzed. The photometric axis or locus of points of maximum brightness of zodiacal light corresponds to the location of the plane of maximum dust density. It is generally assumed that the dust is symmetrical with respect to this plane. A number of investigators have analyzed such observations to deduce the position of the photometric axis of zodiacal light or, as it is often referred to, the symmetry plane of the interplanetary dust. Some of these investigations showed the symmetry plane to lie near the invariable plane of the solar system, while others suggested an association with the solar equatorial plane or the orbital planes of the inner planets (*2*, *3*). Association with the invariable plane suggests that the dust is affected gravitationally by the overall mass distribution and orbits of the planets. It also implies that Jupiter strongly affects the spatial distribution of all of the dust. In this report we present detailed observational evidence for the role of Venus in concentrating interplanetary dust toward its orbital plane and suggest that the individual inner planets, not the invariable plane, affect the location of dust between the sun and the asteroid belt. Thus, there may be a multiplicity of symmetry planes for the interplanetary dust; that is, the position of the symmetry plane may vary with distance from the sun.

Ground-based observations of the eve-



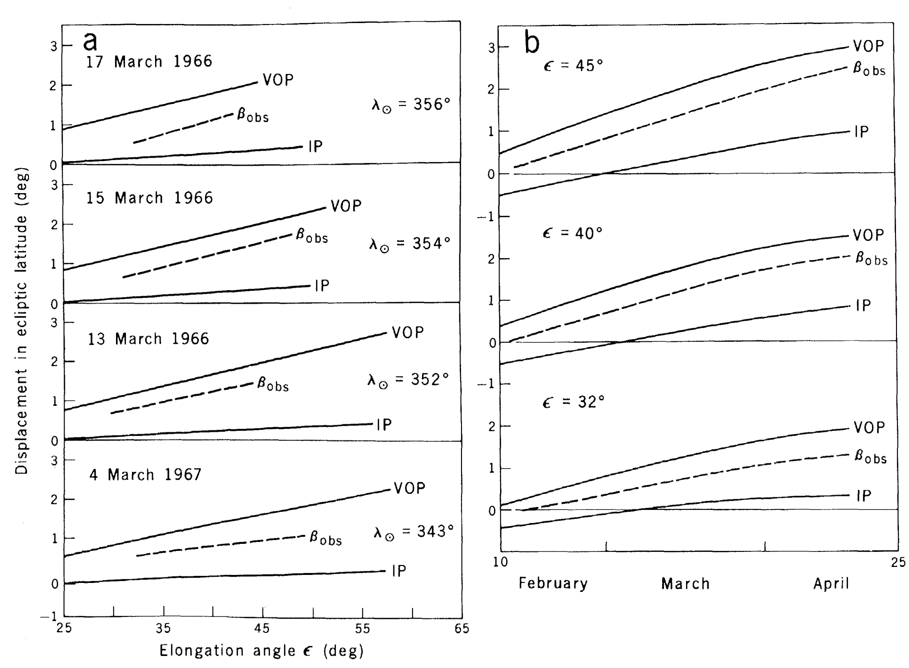


Fig. 1 (top). Contour map of the evening zodiacal light brightness derived from photoelectric observations at Mount Haleakala, Hawaii, on 17 March 1966 at 5080 Å. The brightness contours are shown every 100 S_{10} (V) units [1 S_{10} (V) is the brightness equivalent to one 10th visual magnitude solar (G2 V) star per square degree = 1.261×10^{-9} erg cm^{-2} sec^{-1} $sterad^{-1}$ $Å^{-1}$] as a function of ecliptic latitude β and differential ecliptic longitude $\lambda - \lambda_\odot$. The solid vertical line corresponds to the plane of the ecliptic; the dashed line is the observed photometric axis. Fig. 2 (bottom). (a) Observed (β_{obs}) and predicted displacements from the ecliptic of the plane of maximum brightness on four nights in March 1966 and March 1967. The solid lines correspond to the positions that would be observed if the dust that contributed most to the maximum brightness were located in the orbital plane of Venus (*VOP*) or the invariable plane (*IP*). (b) Displacements of these planes as a function of day of year.

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ning zodiacal light obtained by one of us (J.L.W.) at 3052 m on Mount Haleakala, Hawaii, on 16 nights in February, March, and April 1966 and March 1967 (*4*) were used to determine the symmetry plane at elongations, ϵ, of 32° to 50° from the sun. Details of the data reduction were given earlier (*5*). Figure 1 shows an example of zodiacal light brightness contours in ecliptic coordinates after discrete starlight, background starlight, and airglow continuum emission are subtracted out and corrections are made for atmospheric extinction and scattering. The photometric axis (dashed line) was located by a least-squares fit to the contour peaks. The position of each peak was obtained by connecting the midpoints between intersections of the contour with lines at 1° intervals of differential ecliptic longitude. The position is relatively insensitive to the method used; that is, the position corresponding to the actual contour peak was generally the same as the position obtained from the midpoints of that contour.

Figure 2a shows the displacements from the ecliptic of the observed planes of maximum brightness on four representative nights in March 1966 and March 1967. The predicted displacements for the invariable plane and for the orbital plane of Venus correspond to what would be observed if the dust that contributes most to the maximum brightness were in these planes (*3*). Figure 2b shows the positions of the same three planes as a function of day of year for three different elongations. By the method used in (*3*), the mean inclination and ascending node of the planes of maximum brightness observed on 16 nights are found to be $i = 2.7° \pm 0.3°$ and $\Omega = 85° \pm 5°$, respectively. For comparison, $i = 3.4°$ and $\Omega \simeq 78°$ for the orbital plane of Venus and $i = 1.6°$ and $\Omega = 107°$ for the invariable plane. These results show beyond doubt that the observed photometric axis of the inner zodiacal light lies closer to the orbital plane of Venus than to the invariable plane.

Interplanetary dust must eventually spiral into the sun by the action of solar radiation (Poynting-Robertson) drag (*6*). During the Poynting-Robertson lifetime, gravitational perturbations by the planets on the dust near their orbital planes may bring the orbital elements of the dust closer to those of the planets' orbital planes. This effect depends primarily on the mass of the planet and on the orbital inclination and eccentricity of the dust (*7*). If the dust particles are in circular orbits, the chances for planet-particle encounters are increased (*8*). Although small in magnitude, this effect could be appreciable over expected time scales of thousands of years. We suggest that Venus is in the process of concentrating nearby dust toward its orbital plane.

The observational results reported here, which were obtained in the limited elongation range 32° to 50°, indicate that the dynamic influence of Venus on the dust extends to 0.2 A.U. inside and perhaps to the same amount outside its orbit. This was found by calculating the distance between the line of sight at $\epsilon = 32°$ and the tangent to the orbital path of Venus at the point where the brightness contribution along the line of sight is 50 percent (*3*). More information on the extent of Venus' influence could be obtained from analyses of similar observations at $\epsilon < 32°$ and at $50° < \epsilon \leqslant 80°$; suitable observations are not now available. These data could provide information on average inclination and average eccentricity, which are directly related to the source and evolution of the interplanetary dust.

Similar gravitational effects can be expected for Jupiter, Earth, Mars, and perhaps Mercury. Observations are needed at $\epsilon < 32°$ from space (especially for Mercury) and at $50° < \epsilon \leqslant 180°$ from the ground or from space to verify the presence of these effects. In a recent analysis of zodiacal light observations at ϵ from 110° to 140° from Skylab and from Mount Haleakala, the photometric axis was found to lie between the ecliptic and the orbital plane of Mars (*9*). Whether Mercury has an appreciable influence on the dust despite its small mass (0.053 of Earth's mass) remains to be seen. The inclinations of the solar equatorial plane, the orbital plane of Mercury, and the orbital plane of Venus are 7.3°, 7.0°, and 3.4°, respectively. Therefore, it should be possible to separate the effects of Mercury from those of Venus. Possible effects of the solar equatorial plane and the orbital plane of Mercury can be separated by using the difference in their ascending nodes ($\Omega = 49°$ and 73°, respectively).

Future studies should examine the dynamics of gravitational perturbations that might lead to the concentration of dust toward the orbital planes of the planets. They should include the question raised by Whipple (*10*) of whether the planets can concentrate dust from Comet Encke toward their orbital planes in spite of the high inclination (12°) of Encke's orbit. Finally, additional ground-based observations of the zodiacal light should be made to determine the position of the photometric axis at $\epsilon > 50°$ and $\epsilon < 32°$.

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Initiation of Light Adaptation in Barnacle Photoreceptors

Abstract. *Intracellular recordings were used to measure the action spectrum of light adaptation in barnacle photoreceptors. The action spectrum closely resembles the absorption spectrum of rhodopsin (λ_{max} at 530 nanometers) and is clearly different from that of metarhodopsin (λ_{max} at 495 nanometers). These results suggest that absorption of light by rhodopsin initiates both excitation and light adaptation. The previously reported antagonistic process initiated by metarhodopsin does not appear to play a role at moderate light intensities.*

Photoreceptors exhibit two principal light-dependent processes, excitation and light adaptation. Excitation is the process by which light brings about a change in transmembrane potential; light adaptation is the process by which light lowers the cell's sensitivity (the amount of voltage change per incident photon). Absorption of light by the cell's visual pigment or pigments initiates both excitation and light adaptation, but it is unclear whether a single pigment initiates both processes or whether cells contain two visual pigments (or pigment states),