PLANETARY PERTURBATIONS: EFFECTS ON THE SHAPE OF A CLOUD OF DUST IN CIRCULAR HELIOCENTRIC ORBITS

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ABSTRACT. Synthetic infrared pictures are used to illustrate changes in the shape of portions of an interplanetary dust-cloud. The dust particles, in circular heliocentric orbits, are perturbed by radiation and corpuscular forces combined with gravitational disturbances by the major planets. Dust in the inner solar system and close to the ecliptic or the orbital plane of Venus is brought to a more narrow range of ecliptic latitudes. A dust-band evolves near and inside the orbit of Venus. The cloud's shape is less affected at high ecliptic latitudes.

1. INTRODUCTION

Derivations of the shape of the zodiacal cloud based on dynamical evolution are initial-value problems. Because the source remains unknown as well as the cloud's long-term steady state or transient nature, no statements can be made regarding the absolute shape of the interplanetary dust cloud. Instead, we address the problem of *changes* in the shape of a *portion* of the cloud as the dust spirals through the inner solar system. Conventional wisdom states that dust migrates through the solar system while losing angular momentum to drag forces. It is not yet established whether transfer of momentum from the planets may affect the rate significantly. The resulting uncertainty in magnitude of the perturbations has little effect on our qualitative results. Because orbital eccentricities are neglected, momentum transfer and, by implication, dynamical life-times of the dust are not addressed in this paper.

2. OBSERVATIONS

Observations show that the symmetry plane of the inner zodiacal cloud is close to the orbital plane of Venus (Misconi, 1980, and references therein). Leinert *et al.* (1980) concluded that this symmetry extends to 1 A.U., whereas most observations in this region favor a plane close to the invariable plane of the solar system (Misconi, 1980). The brightness plane of symmetry is close to the plane of maximum particle number densities except where shifted by the dust particles' light scattering characteristics, as in the Gegenschein (Misconi, 1981).

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3. MODEL CALCULATIONS

With model calculations we attempt to determine whether a change in the orientation of the plane of maximum dust density is expected from dynamical evolution alone and whether such an evolution would lead to other observable features that may help differentiate between evolutionary effects and artifacts of the initial conditions.

Dust distributed along a circular orbit about the sun is subject to permutations of nearly identical sets of perturbing forces. As long as the orbital changes are small enough to be treated as perturbations on a Keplerian orbit, the evolution may be described by a mean perturbation and a dispersion about the resulting mean orbit. The method to compute and integrate the compound perturbations by the planets Mercury through Saturn and solar radiative and corpuscular forces is described elsewhere (Gustafson, 1984). For computational efficiency, a radiation pressure efficiency 1 and ratio of radiation pressure to solar gravitation 0.5 is used throughout. The primary effect of decreasing this ratio is to increase the magnitude of integrated planetary perturbations.

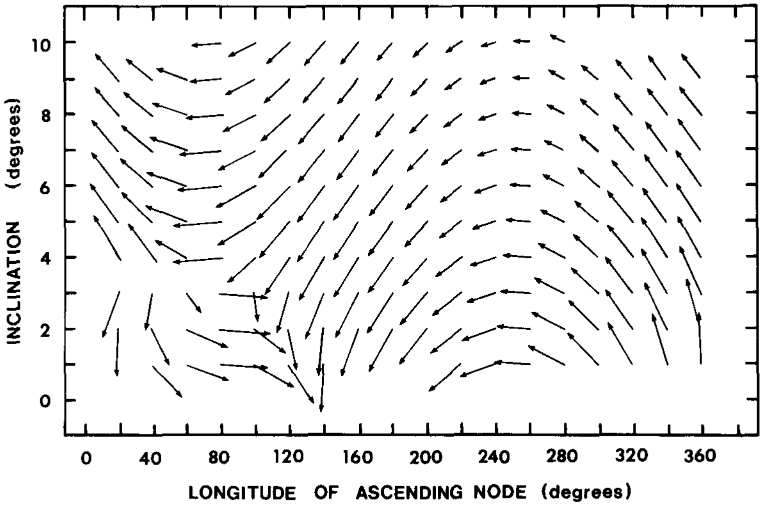

Figure 1. Arrows represent compound gravitational effects of the planets Mercury through Saturn on the orientation of 0.85 AU radius circular dust-orbits. The perturbations are averaged over a large number of orbits.

The mean change in orientation of 0.85 AU radius circular dust orbits is shown in Figure 1. The orientations are defined by the inclination i and the longitude Ω of the ascending node relative to the ecliptic of 1950. Dust in orbits whose inclination exceeds that of any of the planets', shows a recession of the longitude of the nodes when the perturbations are averaged over many orbits. For lower inclinations there is slower recession near some nodes or even an *advance* of the line of nodes. When integrated over time to simulate the evolution of a portion of a dust cloud, zones of concentration and depletion develop in plots of i versus Ω. Evolutions from orbits of four degrees inclination at

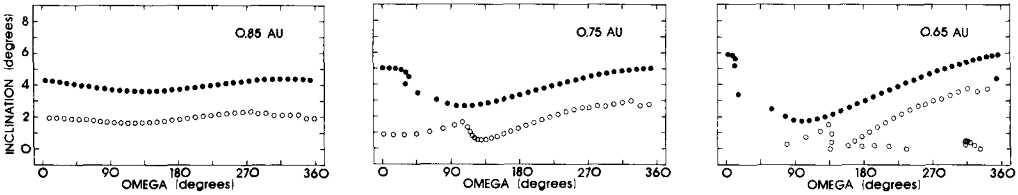

Figure 2. Evolution of the orientation of circular dust-orbits initialized at 1.25 AU with four degree inclination (dots) or two degree inclination (circles).

1.25 AU (dots in Figure 2) and two degrees inclination (circles) are representative of medium and low inclination orbits respectively. At 0.85 AU a waviness begins to develop. The cloud essentially maintains its shape while shifting orientation. Figure 1 shows rapid recession of the nodes near the orbit of Venus at medium inclinations followed by a region of inclination increase and low precession rate. A crest-like structure results in Figure 2 and appears as a dust-band in a simulation

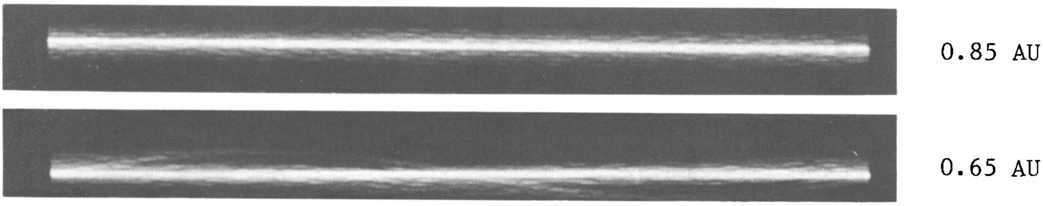

Figure 3. A computer simulation of a portion of a dust-cloud as seen in infrared light by an observer at the Sun. The cloud's shape at 1.25 AU is modeled on the distribution of radio-meteor's orbital elements up to six degrees inclination. The cloud is depicted at 0.85 AU and 0.65 AU from the Sun.

of a portion of a cloud depicted in Figure 3. At lower inclinations, the nodes near Venus are advancing and meet the receding ascending nodes near 100 degrees longitude. With decreasing inclinations this neutral point tends toward higher longitudes. The emerging regions of high density in orbital parameter-space also correspond to decreasing inclinations. This leads to the flattening of regions of the cloud that are below the orbit of Venus (Figure 4). Evolution from the set of four degree inclination orbits indicate a less dramatic overall narrowing of that portion of the cloud.

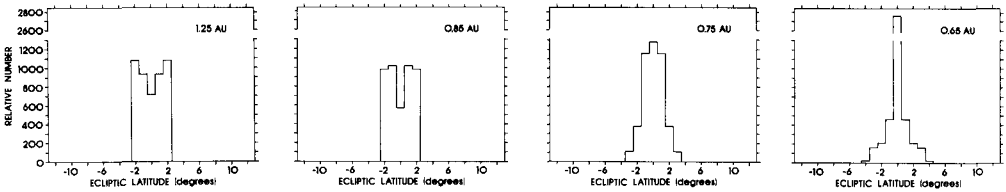

Figure 4. Evolution of the distribution of particle number densities in ecliptic latitude from two degree inclination orbits at 1.25 AU.

4. CONCLUSIONS

Dynamical effects on the shape of a cloud of dust in the inner solar system are essentially separable into effects on three regions - a flatted part close to the ecliptic or to the orbital plane of Venus, creation of a dust-band, and a small change in orientation of high latitude portions of the cloud. As a "signature" of planetary perturbations, the presence of the dust-band may help to discriminate evolutionary effects from remnants of the initial conditions.

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6. REFERENCES

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