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DUST EMISSION FROM COMET KOHOUTEK (1973f) AT LARGE DISTANCES FROM THE SUN

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Abstract

During a period of 60 days around the time when the HEOS 2 satellite penetrated the orbital plane of Comet Kohoutek (1973f) the micrometeoroid experiment on board registered an excessive particle flux. These particles are identified with those originated in Comet Kohoutek. Orbit calculations show that their emission occurred outside 3.8 AU from the sun. The ratio of the force of radiation pressure to that of gravity of these particles was determined to $\beta = 1 \pm 0.1$, their mass has been measured from the satellite data (10^{-13} g to 10^{-11} g). The velocity and the rate of dust particles emitted from the comet is studied on the basis of the theory of dust comets formulated by Finson and Probstein. An emission rate of appr. 1.2×10^{18} particles per second in the size range corresponding to $0.9 \leq \beta < 1.1$ and an emission velocity of appr. 0.5 km/sec match best the observed data.

From optical observations of the shape and occurrence of the anti-tail of Comet Kohoutek (1973f) Sekanina (1974) concluded that appreciable dust production took place as far as 4 AU from the sun. These grains found in the anti-tail are in the order of 0.1 to 1 mm in size. The presence of particles with diameters in the order of 1 μm has been shown in the coma and tail of Comet Kohoutek by infrared observations (Ney, 1974 and Noguchi et al., 1974). This paper discusses some consequences of in situ measurements of dust particles from Comet Kohoutek reported by Hoffmann et al. (1975b) which give evidence for emission of micron sized particles at heliocentric distances of approx. 4 AU from the sun.

During a period of 60 days around the time when the HEOS 2 satellite penetrated the orbital plane of Comet Kohoutek in June 1974, an excessive flux of particles in the velocity range of 15 to 20 km/sec and mass range of 10^{-13} to 10^{-11} g was registered. The average rate of these particles measured during preceding years was 1 to 2 particles in the same time interval compared with 7 particles in 1974. The chance for such an accidental clustering is less than 0.01;

https://doi.org/10.1017/S0252921100051940 Published online by Cambridge University Press

therefore, an additional source for these particles is required. Nazarova and Rybakov (1975) also reported an enhancement of the dust particle flux detected by the Luna-22 space probe which occurred in the same period as observed by HEOS 2. The measured properties of the particles detected by HEOS 2 are:

- ecliptic longitude of detection by HEOS 2: 235° - 295°
- apparent radiant: cone of 60° half angle around earth apex
- mass range: 10^{-13} g - 10^{-11} g
- speed range: 15 km/sec - 20 km/sec.

The moon and the upper atmosphere of the earth as source for the particles (Hoffmann et al., 1975a) are ruled out because the sensor was looking away from these objects most of the time when it recorded the impacts. Particles from meteor showers which are observed during the months of May through August have apparent radiants which do not fit the radiants of the registered particles. Additionally in 1973 during a similar period no such flux increase was detected; therefore, shower meteors cannot supply these particles. As the nodes of all comets (apart from Comet Kohoutek) observed in 1973 and 1974 do not fit the required interval of ecliptic longitudes or have perihelion distances outside 1 AU, they cannot supply these particles either. Only particles from Comet Kohoutek meet all requirements set by the measurements. A simple orbit consideration already shows that dust particles released from the comet at a distance of approx. 4 AU come very close to the earth at the time when it passes the line of nodes if their β (ratio of radiation pressure over gravity) is close to 1. These particles would have a speed relative to the earth of approx. 20 km/sec and an apparent radiant 40° away from the earth apex, which is well within the field of view of the sensor.

Orbit calculations for dust particles, taking into account an initial release velocity v_i, show that particles with $0.9 \leq \beta < 1.1$ and release distances outside approx. 3.8 AU can reach the satellite at its passage through the comet's orbit. From the magnitude of the time interval during which the particles were recorded, Hoffmann et al. (1975b) concluded that the initial velocity was in the order of several 100 m/sec. Only micron sized particles can be accelerated to such a high speed by the outstreaming gas from the comet at large heliocentric distances (Delsemme and Miller, 1971). Therefore, an emission of these particles from the comet inside millimeter sized "dirty-ice" grains and subsequent evaporation of the large grains, as suggested by Sekanina (1974 and 1975a), must be ruled out for the particles detected by HEOS 2. In the following it is assumed that the particles have not changed in size during their flight path.

A theory developed by Finson and Probstein (1968a and b) was applied in order to compare the number of particles observed with the dust emission rate, the initial speed distribution and the size distribution of dust particles released from the comet. Finson and Probstein assume that dust particles are continuously expelled from a cometary nucleus by evaporating gases, and that the subsequent motion of the particles is controlled only by solar gravity and solar radiation pressure. Instead of the diameter d of dust-particles it is convenient to use their radiation pressure ratio as a measure of their size:

$$\beta \sim 1/d$$

The number of particles emitted in the time t to t + dt with sizes in the range β to $\beta + d\beta$ is given by

$$\dot{N}_d\ (t)\ dt\ h(\beta)\ d\beta$$

where $\dot{N}_d$ (t) is the dust emission rate in particles per second and h (β) is the corresponding size distribution function. After emission this group of particles forms a spherical shell which expands with the speed v_i which is a function of the particles' size and time

$$v_i = v_i\ (\beta,\ t).$$

If one denotes the time from emission t_e to the time of observation t_o with τ:

$$\tau = t_o - t_e$$

the shell has a radius of $v_i\tau$. The number of particles seen by the satellite experiment while penetrating this shell is given

$$\frac{\dot{N}_d\ h(\beta)\ d\beta\ d\tau}{4\ \pi(v_i\,\tau\,)^2} \qquad \frac{dA}{dA_\perp} \quad p\ (\delta)$$

where dA is the differential surface area of the shell, $dA_\perp$ is the projection of dA on a plane perpendicular to the flight direction of the satellite and p (δ) is the sensitivity of the micrometeoroid detector for particles coming from an apparent direction with respect to the sensor axis, indicated by the angle δ (Hoffmann et al., 1975a).

Integrating numerically over all such spheres of different τ and β values the impact rate on the micrometeoroid detector is found. Since only a small range of sizes $0.9 \leqslant \beta < 1.1$ can reach the detector, the size distribution is taken to be constant

$$h(\beta) = \text{const. for } 0.9 \leqslant \beta < 1.1$$

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Fig. 1 shows the calculated impact rate as a function of observation time t_o for a set of different initial conditions. The dust emission rate $\dot{N}_d$ is kept constant over the time of consideration, whereas the emission speed v_i is varied from 100 m/sec to 700 m/sec. At 100 m/sec the expected impact rate should peak during a narrow time interval around the earth's passage through the line of nodes. At higher emission speed the enhancement of the impact rate becomes broader and more flat during the time of observation. For comparison the actual observation dates of the particles are indicated at the bottom of the figure. An emission speed of 500 $\pm$ 200 m/sec best fits the observed data.

In Fig. 2 the effect of dust emission rate and initial velocity varying in time is examined. The variation of both functions with the heliocentric distance r, which is equivalent to a time variation, does not change the rate profile very much. This is due to the fact that more than 50 % of the observable particles are released within a narrow distance interval of 3.8 AU $\leq$ r $<$ 4.4 AU.

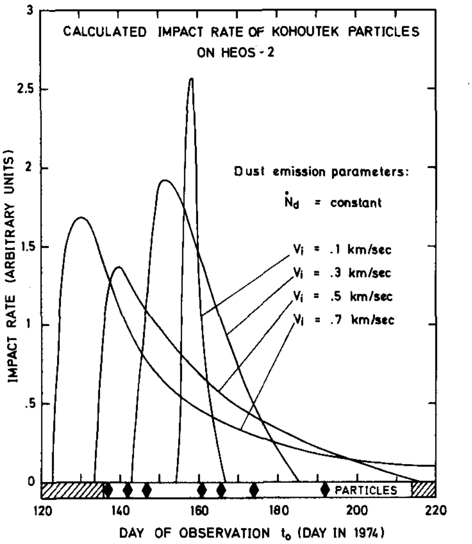

Fig. 1: Calculated impact rate for constant emission rate $\dot{N}_d$ and constant emission speed v_i compared with measured particles.

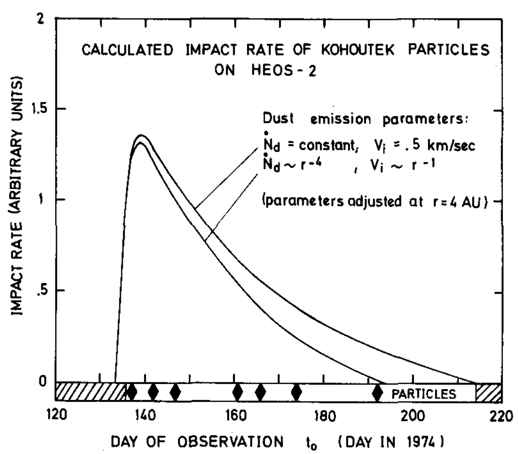

Fig. 2: Effect of varying dust emission rate $\dot{N}_d$ and varying emission speed v_i on the impact rate.

The absolute dust emission rate $\dot{N}_d$ is obtained by integrating the calculated impact rate over the observation time t_o and comparing it with the number of particles observed. A dust emission rate of $\dot{N}_d = 1.2 \times 10^{18}$ particles per second is found to account for the particles detected by HEOS 2. Taking a mass of 10^{-13} to 10^{-11} g per particle, a dust emission of 0.1 to 10 tons per second is estimated. This mass was released by the comet in the form of particles in the size range corresponding to $0.9 \leq \beta < 1.1$.

Due to the large uncertainty of the mass determination no information can be gained on the particles' material composition or density by a comparison of the observed values for ß and mass (Sekanina, 1975b). However, ice, as a material of the registered particles, must be excluded because of the long flight time between emission from the comet and detection by the satellite.

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