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# MODELING OF THE ORBITAL EVOLUTION OF VAPORIZING DUST PARTICLES NEAR THE SUN

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The Poynting-Robertson (P-R) effect (Robertson, 1937, Wyatt and Whipple, 1950), assisted by a pseudo P-R effect due to the sputtering (Whipple, 1955, 1967), is known to cause small dust particles in interplanetary space to spiral toward the sun. Evaporation from the surface of such particles thus increases progressively with time and their size is being reduced accordingly. When the rate of evaporation is no longer negligibly low, it induces on the particle a measurable dynamical effect, which is associated with the implied variations in the magnitude of solar radiation pressure relative to solar attraction. By gradually reducing solar attraction, the particle evaporation tends to increase the orbit dimensions, thus acting against P-R. The P-R inward spiraling, far exceeding the dynamical effect from evaporation at larger heliocentric distances, slows gradually down as the particle approaches the sun, and virtually ceases when the critical distance is reached, where the two forces approximately balance each other. Then, typically, the perihelion distance stabilizes, while the eccentricity starts increasing very rapidly until the particle is swept out of the solar system. This, in brief, is the orbital evolution of a vaporizing particle in the absence of other potentially important but rather poorly known processes, such as particle collisions, rotational bursting, electric charging and interactions with the solar wind and with the interplanetary magnetic field.

If we assume that the particle is rapidly rotating, spherical in shape, of a uniform density $\rho$, and that most of the solar energy it absorbs is spent on reradiation, the linear vaporization rate of the particle $\dot{a}$ is given, in the first approximation, by

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$$\dot{a} = (A/\rho)\ \exp[B(1-r^{\frac{1}{2}})],$$

where A is the normalized (to 1 AU from the sun) vaporization flux from the particle (mass per unit surface area per unit of time), r is the heliocentric distance (in AU), $B = 1.81\ L\ (\varepsilon/\kappa)^{\frac{1}{4}}$, L is the latent heat of vaporization (in kcal $\text{mole}^{-1}$), $\kappa$ is the absorptivity of the particle's surface for solar radiation and $\varepsilon$ its emissivity for reradiation. In the following the expression $L\ (\varepsilon/\kappa)^{\frac{1}{4}}$ will be termed the effective latent heat of vaporization.

The calculations based on this model of particle evaporation indicate that a particle, whose pre-evaporation orbit was circular, is expelled from the solar system on a hyperbolic orbit as soon as radiation pressure attains about 0.8 of solar attraction. The expulsion limit, however, is lower for elongated pre-evaporation orbits; it amounts, for example, only to 0.5 - 0.6 of solar attraction for the pre-evaporation eccentricity of 0.2. Nevertheless, purely dielectric particles, some of which may never be subject to radiation pressure exceeding 0.5 of solar gravity, could perhaps, under certain circumstances, vaporize off completely near the sun. However, this possibility is not here pursued further, as it is considered rather untypical.

In order to determine quantitatively the relation between the initial (pre-evaporation) and final (at expulsion) physical and dynamical characteristics of the vaporizing particles, we computed a total of 64 runs, varying the initial particle size and density, the effective latent heat of vaporization and the normalized vaporization flux, the scattering efficiency for radiation pressure and the eccentricity of the initial orbit. We arrived at the following basic conclusions.

The final particle size is on the order of magnitude of 0.1 micron. It is essentially independent of the initial particle size, the effective latent heat of vaporization and the normalized vaporization flux. It is directly proportional to the scattering efficiency for radiation pressure, inversely proportional to the particle density and it increases with increasing eccentricity of the initial orbit.

The perihelion distance of the final orbit varies in inverse proportion to an approximately 2.2 power of the effective latent heat, from less than 0.1 AU above 70 kcal $\text{mole}^{-1}$ to more than 1 AU below 25 kcal $\text{mole}^{-1}$, and it decreases with decreasing normalized vaporization flux.

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It is, however, virtually independent of the initial particle size, its density and the scattering efficiency, and only slightly dependent on the initial eccentricity.

The heliocentric velocity at expulsion can lie anywhere between the parabolic limit and a maximum hyperbolic velocity, which is determined by the final perihelion distance, the two vaporization constants, the scattering efficiency, the particle density and the final particle size. However, since the particles are strongly affected by radiation pressure, their velocity of escape from the solar system and the maximum hyperbolic velocity are, at 1 AU from the sun, typically less than 20 and 30 km $s^{-1}$, respectively. The velocities are somewhat higher than indicated for more eccentric initial orbits and for materials of the effective latent heat of vaporization exceeding 100 kcal $mole^{-1}$.

The maximum intercept velocity at expulsion, i.e., the maximum velocity of an expelled particle relative to the earth at the encounter, increases with increasing effective latent heat of vaporization, but attains no more than 40 km $s^{-1}$ at 100 kcal $mole^{-1}$.

The maximum intercept angle at expulsion, i.e., the maximum angle toward the sun subtended by the direction from which the particle intercepts the earth and by the earth's apex direction, also increases with increasing effective latent heat, reaching about 50° at 100 kcal $mole^{-1}$.

Finally, the expulsion lifetime of a vaporizing particle, measured by the span of time from the onset of appreciable evaporation to expulsion, decreases from some 1000 years at the effective latent heat of 30 kcal $mole^{-1}$ to about 10 years at 100 kcal $mole^{-1}$. The lifetime increases somewhat with the initial particle size and the particle density.

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