Ice sublimation of dust particles and their detection in the outer solar system

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Abstract

The flux of interplanetary dust, which supposedly originates from Edgeworth-Kuiper belt, has been measured in situ by instruments on board Voyager and Pioneer spacecraft. The measured flux shows a nearly flat radial profile at 10–50 AU for Voyager and at 5–15 AU for Pioneer. Because the orbital evolution of dust particles controlled by radiation forces results in the flux that is inversely proportional to distance from the sun, dust particles detected by spacecraft would suffer from other dynamical effects. We calculate the model fluxes on the spacecraft taking into account the orbital evolution of dust particles by ice sublimation as well as the radiation forces. Our results show that the radial profile of the model flux becomes relatively flat at the edge of the sublimation zone, where ice substantially sublimes. The expected location of a flat radial profile, which depends on the detection threshold of instruments, is 20–50 AU for Voyager and 5–15 AU for Pioneer. Because our model fluxes agree with the measured ones, we conclude that the flat radial profile of the dust flux derived from in-situ dust impacts may be caused by ice sublimation.

EKB dust

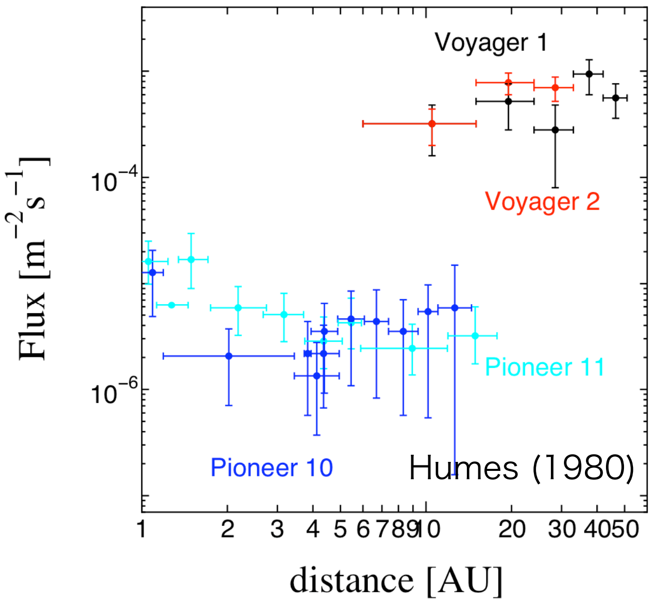
- Edgewoth-Kuiper belt objects (EKBOs) are the least processed icy bodies that are located in the Edgeworth-Kuiper belt (EKB) currently at 30–50 AU from the sun.
- EKBOs are thought to produce dust particles through mutual collisions between EKBOs and/or erosion of EKBO surfaces by impacts of interstellar dust streaming into the solar system (Stern 1996,Yamamoto and Mukai 1998).
- EKB dust particles in bound orbits around the sun drift inward by the P-R effect.
- Remote observations, instruments on board spacecraft have identified impacts of dust particles on the spacecraft beyond the Jupiter's orbit (Humes 1980, Gurnett et al. 1997).

The measured flux of dust

- These constraints would give new insights into the physical properties of EKB dust particles and the collisional process of EKBO surfaces.

- The flux measured by Voyager is 2–3 order of magnitude higher than that by Pioneer 10 and 11. This may give a constraint of the size distribution of dust particles drifting from EKB because the spacecraft have different detection size threshold.

Gurnett et al. (1997)



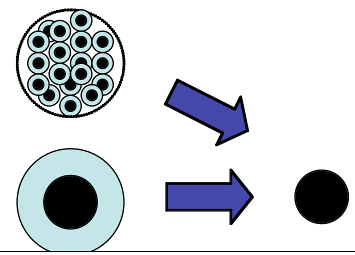
- The radial profiles of the fluxes are flat at 20–50 AU for Voyager 1/2 and 5–15 AU for Pioneer 10/11. The flux of dust particles controlled by radiation force is inversely proportional to the heliocentric distance. Therefore, the flat profile suggest that dust particles are affected by other dynamical effects.

ice sublimation

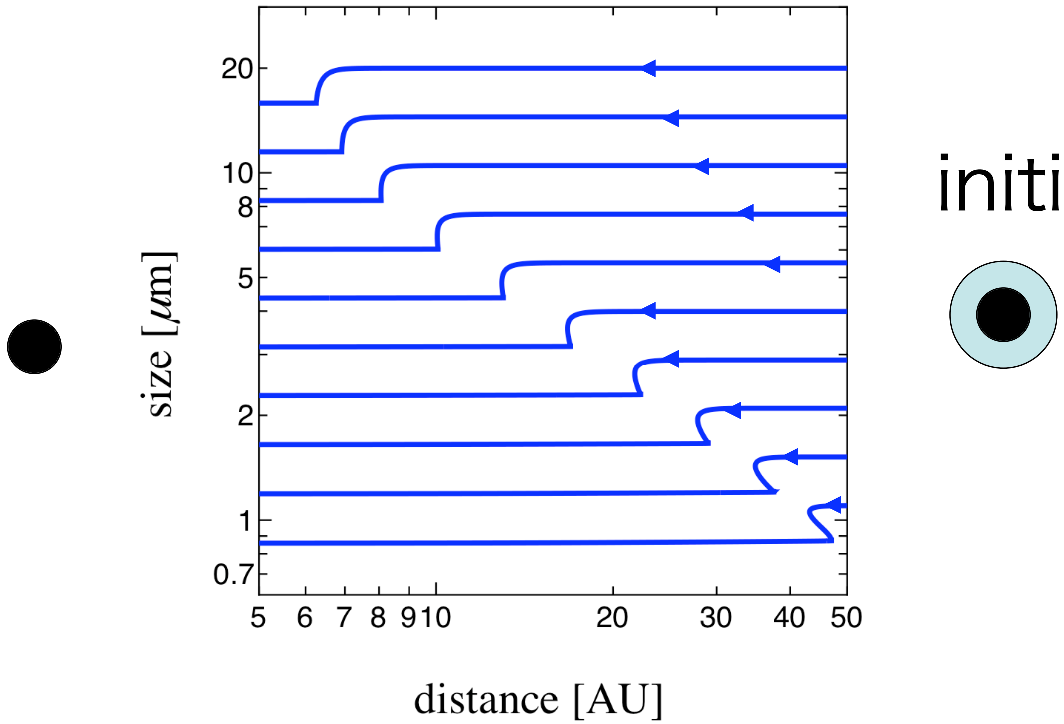
- It is natural to expect that EKB dust particles are mainly composed of ices together with refractory carbonaceous materials.
- If such icy dust particles drift inward by the P-R effect, ice component in the dust particles actively sublimes when their temperatures become about 100 K (Kobayashi et al. 2008).
- For small dust, active sublimation occurs at 20–40 AU, while large icy dust particles sublime inside. That is because smaller dust has lower emissivity in the dust size we concerned. The locations of flat profiles in the measured fluxes may be explained by the difference in the threshold sizes, because the locations coincide with heliocentric distances where dust particles of the threshold size actively sublime.
- We propose ice sublimation to explain the flat profile in the fluxes measured by the spacecraft.

Model

- We assume that dust particles produced in EKB have spherical shape and a power-law size distribution with the power index $-p$ in the radius range from $1.1\mu m$ to $20\mu m$.
- Each spherical particle consists of a pure H_2O ice mantle and an organic refractory core with the volume fraction γ (core radius $\propto \gamma^{1/3}$).
- When the temperatures of the particles exceed 100 K, the ice component of the particles starts to sublimate and their inward drifts almost stop at the sublimation zone because of an increase in β (Kobayashi et al. 2008).
- After complete sublimation of the ice component, the remnant particles consisting only of the refractory component resume to drift inward by the P-R effect.



orbital and size evolution

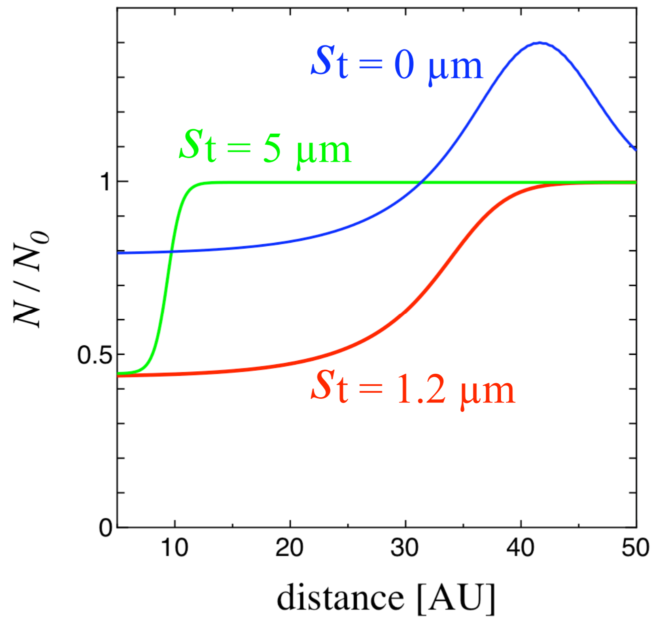


Icy particles actively sublime at T ~ 100 K

Small dust sublimes prior to large dust because the emissivity of small dust is low (Kobayashi et al. 2008).

detection threshold

- We numerically calculate the surface number density $N(s_t, r)$ of EKB dust particles larger than the threshold radius s_t, based on the method described in Kobayashi et al. (2008).
- The enhancement is seen as a hump around 40 AU in the model flux without the size threshold. The pile-up occurs for only small particles because their β is large (Kobayashi et al. 2008).
- The number of dust particles larger than the threshold decreases during ice sublimation, resulting in the surface number density becomes smaller than that without sublimation.



N_0 is the surface number density at 50 AU

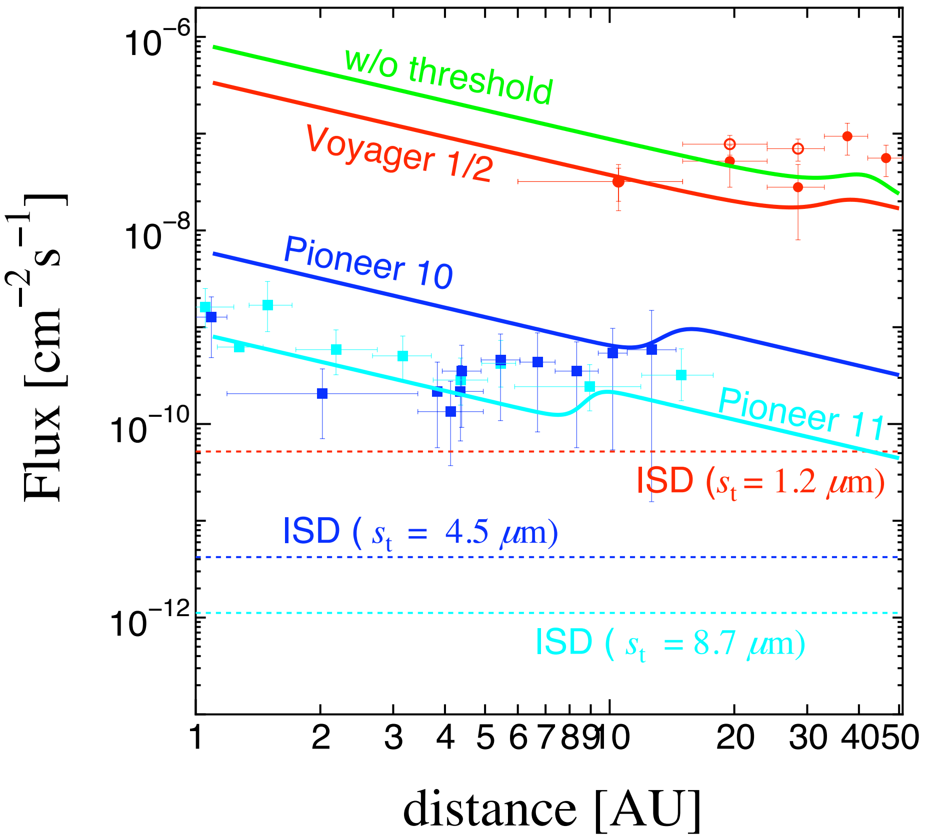
the measured flux

$$F(r, s_{\mathrm{t}}) = \frac{N(s_{\mathrm{t}}, r)}{2r\bar{i}} v_{\mathrm{r}}$$

the dust production rate in EKB

$$\dot{M}_{\mathrm{dust}} = 1 \times 10^6 \,\mathrm{g\,s^{-1}}$$

and
the size-distribution power-low index $-p = 5$.



the model flux is consistent with the measured flux.

Discussion

gravitational scattering

- Because Pioneer 10/11 detected dust particles larger than Voyager 1/2 , the model flux with the Pioneer's threshold decreases by planetary gravitational perturbations (Landgraf et al. 2002).

- Considering that the model flux with Voyager threshold are reduced by 5 % for the gravitational scattering of Neptune and that those with Pioneer threshold are by 80 % for the scattering of Jupiter and Saturn, the model fluxes reproduced the measured fluxes for p = 3.5–4.

the index is consistent with that in a steady state of the collision cascade.

Discussion

Future space missions

- The Student Dust Counter (SDC) on board New Horizons has the threshold radius of $s_t = 0.8\mu m$ (Horanyi et al. 2007).
- The threshold radius is smaller than the blown-out radius corresponding to $\beta = 0.5$.
- We estimate the flux measured by SDC to be 3×10^{-8} cm^{-2} s^{-1} in the EKB region.
- SDC might detect an enhancement of the flux at 30–40 AU as a result of ice sublimation from the smallest icy particles.