SUBLIMATION IMPACT FOR THE TEMPORAL CHANGE OF ALBEDO DICHOTOMY ON IAPETUS.
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Introduction: Iapetus, Saturn's third largest moon, has a diameter of about 1436 km and synchronously orbits Saturn at an average distance of 3.6×10^6 km with a period of 79.3 Earth days. From a mean density of 1.08 g/cm^3 and spectral observations from spacecraft and ground telescopes, Iapetus has large volume fraction of H_2O ice. Remarkable characteristic of Iapetus is that there is an extreme albedo contrast between the leading (~ 4 %) and trailing hemispheres (~ 60 %) like a Yin-Yang symbol [1]. Composition of the dark material is still unknown, but mixture of tholin and some rocky materials has been suggested as a candidate material from some experimental works.

Although concrete origin of the albedo dichotomy is still unknown, two hypotheses have been proposed. The dark material may have originated from other satellites (i.e., outer moon Phoebe, which has very low albedo). Impact events cause ejection of the dark materials from the other satellites, and then Iapetus swept up. The fact that the material is on the leading hemisphere of Iapetus seems to support this theory. Moreover, spectral characteristics of the dark material on Iapetus are partially similar to that of material on Phoebe and Hyperion. Also, recent experimental work reported that the interplanetary material and cometary dust have some similarities to the Iapetus' dark material [2].

On the other hand, correspondence of the equatorial ridge and the dark region is pointed out. The ridge is almost exactly on the equator for about 1300 km and most of the ridge is located at the dark region. The dark materials were erupted from the ridge and deposited on the surface. However, whether the ridge spread to the bright region is uncertain because of the poor resolution of images by Cassini and Voyager spacecrafts. In addition, the energy source for the eruption of dark material that is denser than the bright water ice is highly questionable. Therefore, the origin for the albedo dichotomy on Iapetus is still controversial.

Key approach to clarify the origin of the dichotomy is to investigate the detail distribution of a dark material.

Icy sublimation and albedo change: Craters on Iapetus have a characteristic distribution of the dark material, that is, equator-facing wall and floor of several craters exhibit darker. This trend can be interpreted as it is because the pure bright ice has sublimed from the equator-facing wall where the insolation energy is larger, and the albedo has decreased. Cassini spacecraft has observed the surface temperature using mid-infrared wavelength, and the temperature on a dark region in daytime is about 130 K in maximum. The saturated vapor pressure of the H_2O ice in 130 K is about 1.2×10^{-10} Pas, thus the sublimation of the H_2O ice can be occurred if the atmospheric pressure of Iapetus has similar to or less than the pressure on the terrestrial Moon (10^{-12} hPa). Effect of the sublimation process to surface albedo and its morphology has been previously discussed for other icy satellites [3].

Another characteristic of the albedo dichotomy is the clarity of the edges of the dark region. If the dark material precipitated on the surface from external sources, distribution of the dark material should be more gradual. Therefore, the sublimation of bright ice and resultant albedo change must have an impact for current distribution of surface albedo on Iapetus. In other words, the volume fraction of dark material and ice in each region should have changed with time, and the albedo distribution when the dark material originally precipitated should have been different from the current state. It is important to note that the original distribution of the dark material on the surface is required to clarify the origin of the albedo dichotomy.

In this work, we evaluate the effect on icy sublimation and temporal change of surface albedo, and we try to reconstruct the original distribution the dark material on Iapetus.

Model: We assume the surface state that the dark material and bright ice is mixed uniformly with certain volume fraction. According to the position of Iapetus on its orbit around Saturn, the insolation energy on Iapetus' surface can be calculated and radiative equilibrium temperature and its surface distribution are derived by Stefan-Boltzmann's law. Based on the experimental data about the saturated vapor pressure of H_2O ice [4], we evaluate the sublimation rate of ice from the surface (inversely, the dark material remains there) using following equation:

$$V = e(T)\left(\frac{M_W}{2\pi RT}\right)^{1/2} \cdots (1),$$

which V is the sublimation rate of pure water ice [kg/m^3 sec], e(T) is the saturated vapor pressure of pure ice [Pa], M_W is the molar weight of H_2O (18.015×10^{-3} kg/mol), R is the gas constant [J/mol K], and T is the temperature [K]. Finally, we calculate the evolution of the distribution of surface albedo during 4.0 Gyr.

Results: Figure 2 shows the temporal change of surface albedo at Iapetus' apex with variations of initial albedo there. When the initial albedo is higher than ~0.5, the sublimation of ice hardly occurs and albedo changes only slightly during 4.0 Gyr. Meanwhile, when the albedo decreases near the value of ~0.4, the curve rapidly falls to near zero value. This means that the albedo decrease cause to increase the surface temperature, then the sublimation will be accelerated and the albedo decrease more. This positive feedback process induces such a rapidly changing of albedo. In other words, once the surface experienced the albedo feedback process, surface albedo would be extremely low, can not keep a moderate value. This trend is responsible for the clarity of edge of the dark region.

One example of results for the long-time change of albedo distribution is shown in Figure 3. Initially, it is assumed that dark materials accumulated on the concentric pattern around the apex, which implies that synchronously rotating Iapetus swept the dark material existed around the Iapetus' orbit. Initial albedo is set to be 0.1 at the apex, and 0.7 at the antapex. After 4.0 Gyr, the resultant surface albedo has mainly three notable points. First, the albedo in the leading hemisphere has significantly decreased to near the lower bound value. Second, albedo distribution has been elongated along the equator. Third, the edge of the low albedo region became clear. Putting together above results, resultant distribution of surface albedo is very similar to the current state. Therefore, it can be concluded that the sublimation of ice greatly influences present albedo distribution on Iapetus.

References: [1] Hendrix et al. (2008) *Icarus,193*, 344–351. [2] Cruikshank D. et al. (2008) *Icarus,193*, 334–343. [3] Spencer, J.R. (1987) *Icarus*, *69*, 297–313. [4] Andreas E. (2007) *Icarus, 186*, 24–30.

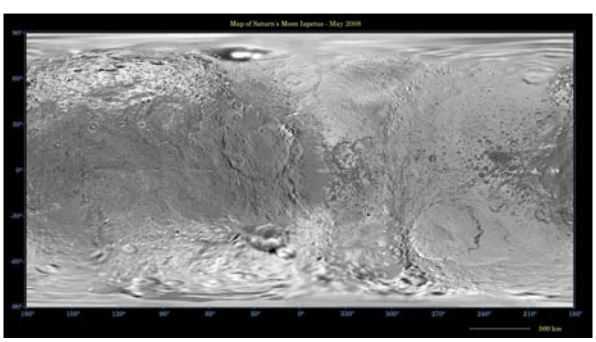

Figure 1: Global map of Iapetus (PIA11116: http://Saturn.jpl.nasa.gov/photos)

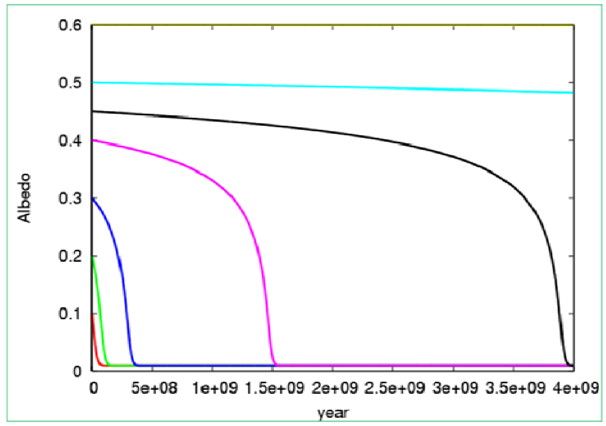

Figure 2: Temporal change of the surface (at Iapetus' apex) albedo with various initial values. Assumed albedo of dark material and bright ice are 0.01 and 1.0, respectively.

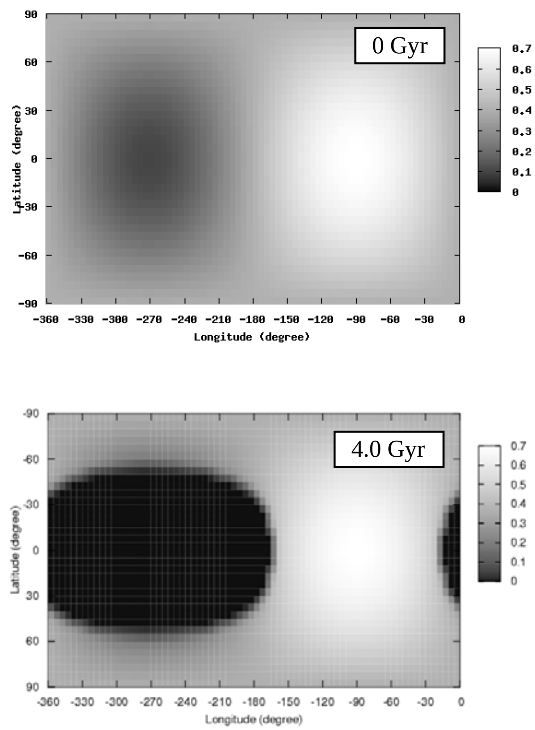

Figure 3: Long-time change of albedo distribution. Upper panel: Initially, it is assumed that dark materials accumulated on the concentric pattern changing gradually around the apex to antapex. Lower panel: After 4.0 Gyr, albedo distribution has been elongated along the equator, and the edge of the low albedo region became clear.