

# Hydrated minerals and/or water ice on Jupiter's inner satellite Amalthea

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## [Abstract]

Amalthea, one of the inner small satellites of Jupiter, has been considered to have formed by accretion from the proto-Jovian subnebula because of its uninclined, circular orbit. Since the inner region of the subnebula was hot, Amalthea should consist of refractory, high-density materials (Prinn & Fegley 1981). However, recent gravity analysis of the Galileo spacecraft flyby of Amalthea indicates unexpectedly low bulk density (Johnson & Anderson 2003), which is inconsistent with the subnebula origin and alternatively suggests that Amalthea is a captured asteroid. Here we report spectroscopic evidence of the origin of Amalthea. The spectrum in the near-infrared wavelength implies that the surface of Amalthea consists of a mixture of high-temperature products and hydrated minerals and/or water ice. This suggests that water played an important role even in inner satellite. We consider that Amalthea is not a captured asteroid but that it formed in the hot region of the subnebula and subsequently suffered a bombardment of icy bodies such as planetesimals or comets.

## [Observations and Results]

We have measured reflectance spectra of Amalthea in 1.0-4.2  $\mu\text{m}$  spectral range (Fig. 1) with IRCS on Subaru Telescope. The reflectance was calculated at J, H, K and L'-band using photometric data and in the 2.9-4.2  $\mu\text{m}$  wavelength range using a flux calibrated spectrum. The leading side is 1.25(+0.10) times brighter than the trailing side in K-band, which is also consistent with Galileo's result of 1.26 (Simonelli et al. 2000).

The reflectance spectrum of Amalthea is unusual. It shows two distinct features: one is the steep, red continuum slope in 1.0-2.5  $\mu\text{m}$  with broad absorption features at 1.0 and 1.8  $\mu\text{m}$ , the other is the deep, broad absorption near 3.0  $\mu\text{m}$ . No other solar system object shows these two spectral features clearly on the same object.

In the wavelength range from 1.0 to 2.5  $\mu\text{m}$  the spectrum closely matches a S-type asteroid 433 Eros (Clark 2001) (Fig. 2). However, almost all S-type asteroids do not show the 3- $\mu\text{m}$  feature.

The depth of the 3- $\mu\text{m}$  absorption feature of Amalthea is 52(+12) %, which is one of the deepest absorption features among the asteroids and carbonaceous chondrites. The 3- $\mu\text{m}$  feature indicates the possible presence of hydrated minerals. The Tagish Lake meteorite, a proposed analogue for D-type asteroids (Hiroi et al. 2001, RELAB), shows a 3- $\mu\text{m}$  feature in the spectrum, but does not show the 1.0 and 1.8  $\mu\text{m}$  absorption. Another interpretation of the 3- $\mu\text{m}$  feature is water ice absorption. The spectrum of icy satellite Callisto (Brown et al. 2003) matches Amalthea in 3.2-4.1  $\mu\text{m}$ .

## [Origin of Amalthea]

Since there is no other object with a spectrum similar to Amalthea, a simple captured scenario is not plausible.

Models of the formation of the Jovian system suggest that if Amalthea has formed in its present location, the temperature around Amalthea is about 1000 K. It is too high to condense hydrated minerals. Thus the simple in situ formation scenario cannot explain the observed 3- $\mu\text{m}$  feature.

The two spectral features, the 3- $\mu\text{m}$  feature and the silicate features, are incompatible in origin, and must originate from separate events. The spectrum of 'Kilauea soil'(RELAB), a terrestrial volcanic soil that consists of iron oxides and altered silicate, closely matches Amalthea, which suggests the Amalthea's spectrum can be interpreted as a result of aqueous alteration of high temperature products.

We consider the formation of Amalthea to have taken place in two stages. First, Amalthea formed near its current orbit in a high temperature environment. Second, it suffered bombardments of icy planetesimals or comets, forming the hydrated minerals or adding water ice. The low bulk density of Amalthea (0.86 g/cm<sup>3</sup>) is consistent with the presence of hydrated minerals and/or water ice. The angular shape of Amalthea suggests a heavy bombardment history, supporting our two-stage scenario.

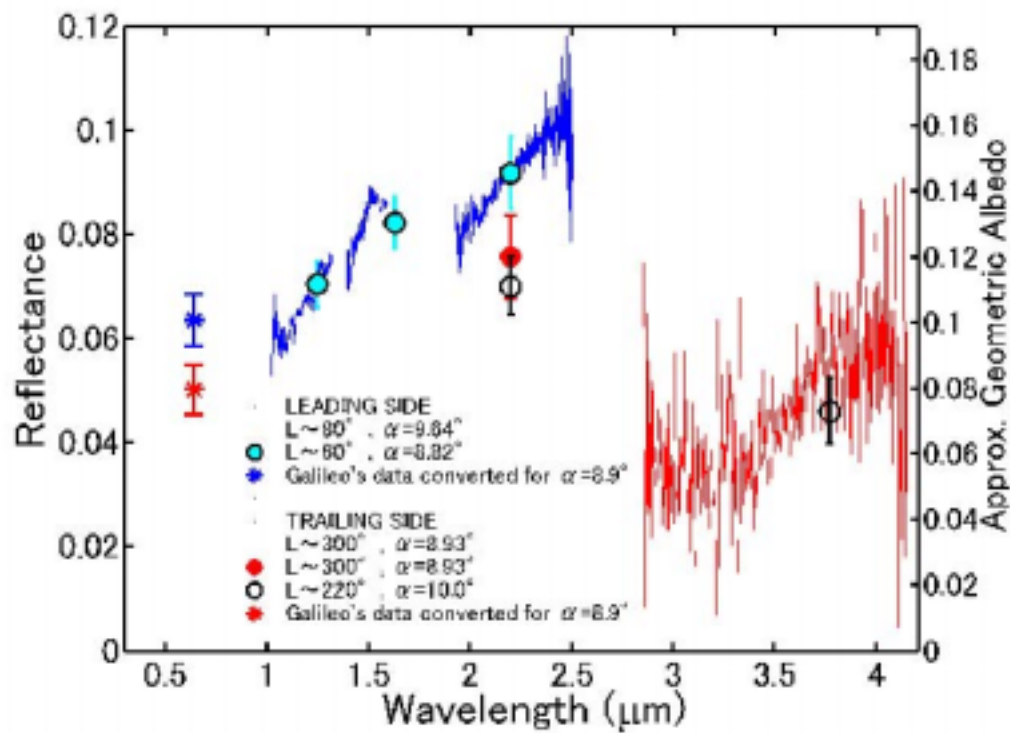


Fig. 1 Reflectance spectra of Amalthea

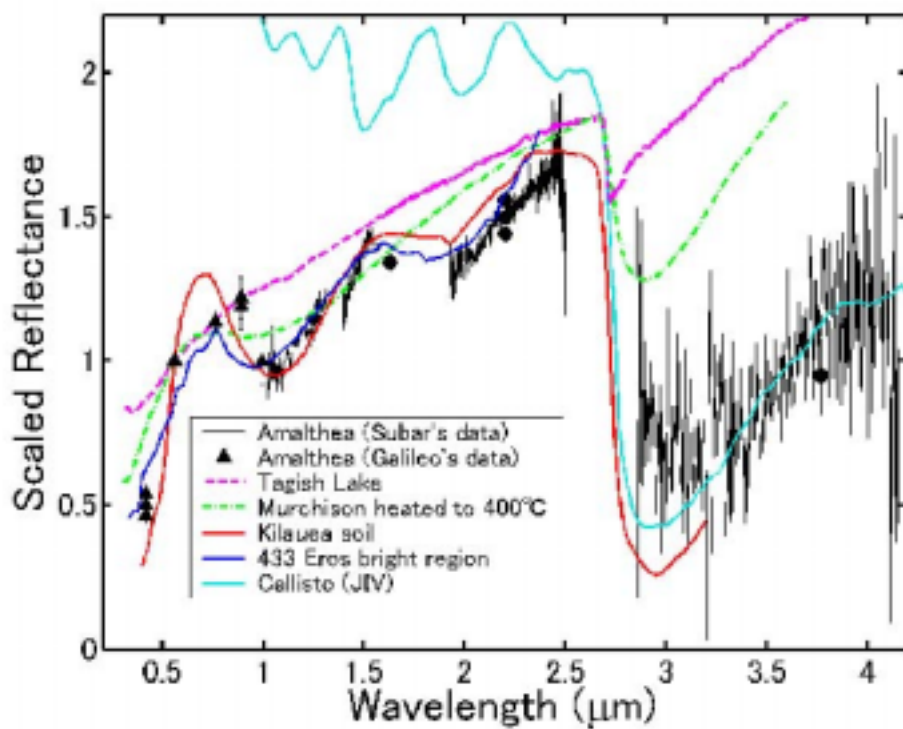


Fig. 2 Comparison with several objects and materials.