

LARGE PRIMITIVE ASTEROIDS: THERMAL AND DYNAMICAL CONTEXT. D. Takir¹, W. Neumann², S.N. Raymond³, J.P. Emery⁴, ¹Jacobs, NASA Johnson Space Center, Houston (driss.takir@nasa.gov), TX 77058, USA, ²German Aerospace Center, Institute of Planetary Research, Berlin, Germany, ³Laboratoire d'Astrophysique de Bordeaux, Bordeaux, France, ⁴Northern Arizona University, Flagstaff, AZ 86011, USA.

Introduction: Primitive asteroids, most of which are located in the outer belt and Jupiter's Trojan clouds, provide information related to the origin and evolution of the solar system and the conditions in which the solar nebula was formed. These asteroids are widely thought to be the origin of the least-altered carbonaceous chondrite that allow us to put crucial constraints on the current dynamical and thermal theories of the formation and evolution of the early solar system. The nature of surface composition of large and low-albedo asteroids, like (1) Ceres, (10) Hygiea and (52) Europa, is still under intense debate and different interpretations have been put forth to explain the absorption features in these objects (e.g., [1, 2, 3, 4, 5, 6]). Laboratory and spectroscopic experiments on meteorites that represent all nine carbonaceous chondrite types also found no spectral matches for these large asteroids (e.g., [7]). Previous studies of asteroid Ceres (the largest primitive asteroid in the solar system) have been conducted to constrain and estimate its surface composition (e.g., [2, 5]). Using linear mixing, [2] found hydroxide brucite, serpentines, and carbonates, to be consistent with Ceres' ground-based spectra. [5] estimated the surface composition of Ceres and found evidence of widespread NH₃-phyllosilicates across its surface using best-fit solutions to Dawn's NIR spectra. The presence of NH₃-phyllosilicates implies that material from the outer solar system was incorporated into large primitive asteroids, either during their formation at great heliocentric distance or by incorporation of material transported into the Main Belt region. Here we present new large and primitive asteroids that share the same spectral similarities with the largest asteroid in the solar system, Ceres. We also present the context of these new observations in terms of their thermal and dynamical evolution.

Large Primitive Asteroids: Dynamical and Thermal Context:

Orbital Distribution of Large Primitive Asteroids: Constraining the mineralogy and surface composition of large primitive asteroids will place crucial constraints on existing dynamical and thermal theories of the formation of the early solar system. We identified several additional asteroids in the Europa-like group in addition to asteroids Europa, Euphrosyne, and Patientia, that were identified in [8] using NASA IRTF telescope (e.g., **Figure 1**). These new asteroids along with the already-observed Ceres- and Europa-like group

members are localized in the $2.8 < a < 3.4$ AU region and characterized by larger sizes, showing an interesting orbital distribution (**Figure 2**). Ceres-like and Europa-like groups, which include the largest asteroids in the solar system, show an interesting orbital distribution. These groups are located in the $2.6 < a < 3.6$ AU region that contains the snow-line. The snow-line's location may have been drifted inwards due to the disk's cooling and evolution [9, 10]. Recent dynamical models [11, 12] suggested that a substantial fraction of primitive asteroids originated between or beyond the giant planets ($a > 5$ AU), where water ice would have been stable, and then implanted in the outer Main Belt region because of the giant planets' growth.

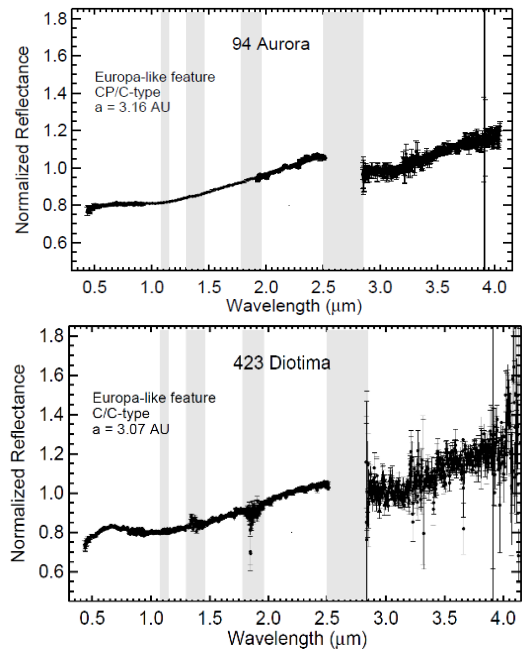


Figure 1. Two asteroids, 94 Aurora and 423 Diotima, showing spectra similar to asteroids (1) Ceres and (52) Europa.

Thermal modeling and evolution of primitive asteroids: Primitive water-rich asteroids are thought to be originally composed of mixtures of anhydrous materials and water ice that was later melted by heating sources such as the decay of ²⁶Al, reacting with anhydrous materials to form H₂O/OH-rich minerals. Calculations of the evolution of the temperature and structure of icy planetesimals were performed using a 1D finite differences thermal evolution model [13, 14] for ²⁶Al-heated planetesimals. In particular, thermally ac-

tivated compaction due to hot pressing of bodies with an initially unconsolidated porous structure is included. An ice-rich initial composition that leads to a material dominated by phyllosilicates upon aqueous alteration (with 25 vol% H₂O and a rock fraction that contains 85 vol% phyllosilicates and 15 vol% olivine upon aqueous alteration, similar to CI and CM chondrites) was assumed. A typical initial porosity of 40% [15] is reduced following the change of the strain rate that is calculated as Voigt approximation from the strain rates of components [16]. Material properties (thermal conductivity, density, heat capacity, etc.) correspond to the composition assumed and are adjusted with temperature and porosity. Melting of the water ice as well as water-rock separation are included [14]. Both short- and long-lived radionuclides are considered as heat sources. **Figure 3** shows the maximum temperature calculated as a function of radius and accretion time. A variety of internal structures is obtained, ranging from primordial (no melting of water ice) over partially melted or partially differentiated (melting of water ice, hydration, formation of a rocky core and water ocean below an undifferentiated layer) to completely differentiated ones (rocky core, water mantle, Enceladus-like case).

The heating and differentiation of planetesimals is determined by the availability of ²⁶Al, i.e., by the accretion time t_0 relative to the formation of the calcium-aluminum-rich inclusions (CAIs), such that maximum temperatures and structures vary strongly for $t_0 < 6$ Myr rel. to CAIs. However, for a later accretion only the size of the body determines its maximum temperature and structure due to the nearly constant heating by long-lived radionuclides. Average densities of Ceres- and Europa-like group members imply highly porous interiors and, consequently, relatively late accretion at $t_0 > 3$ Myr rel. to CAIs with a maximum temperature of < 600 K (**Figure 3**).

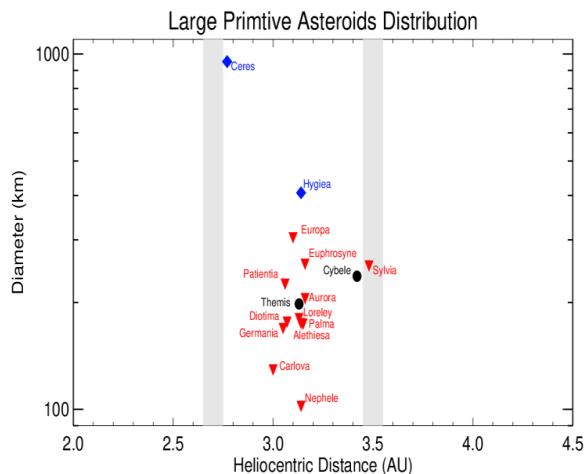


Figure 2. Orbital distribution of large primitive asteroids. The blue diamonds represent Ceres-like group. The red triangles represent Europa-like group. The black dots show asteroids (24) Themis (Rivkin and Emery 2010; Campins et al. 2010) and (65) Cybele (Licandro et al. (2011)). The 3- μ m feature on these two asteroids was interpreted as a H₂O frost feature.

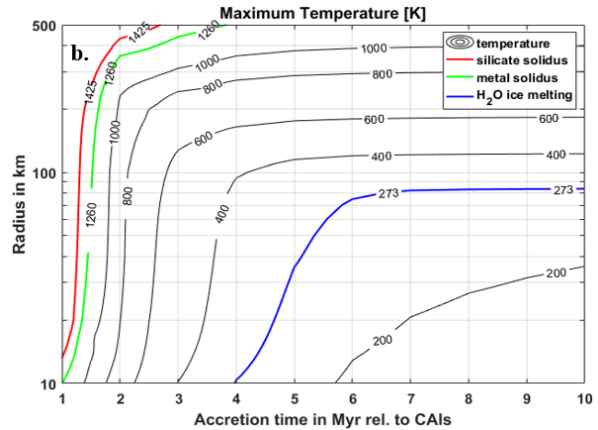


Figure 3. Maximum temperature for icy planetesimals as a function of the accretion time rel. to CAIs and of the radius.

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