

# Late Accretion of large Dark Asteroids and Their Implantation into the Outer Main Belt

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Dark (geometric albedo  $< 0.09$ ) asteroids are genetically linked to carbonaceous chondrites. Most of these asteroids are located in the mid-outer main belt ( $2.5 < a < 4.0$  AU) and thought to be remnants of the primary accretion of the first solar system planetesimals. Here we present new near-infrared (NIR:  $\sim 0.5\text{--}4.0$   $\mu\text{m}$ ) reflectance spectra of dark and large (diameter  $> 100$  km) asteroids measured at NASA Infrared Telescope Facility (IRTF). We place the astronomical observations of these large dark asteroids in the context of the thermal evolution and dynamical models and provide new interpretations for the origin and evolution of these asteroids. The astronomical observations together with thermal evolution and dynamical modeling show late accretion and implantation to a confined heliocentric region ( $\sim 3.0 < a < 3.4$  AU) for these large dark asteroids, in agreement with the dynamical predictions. Average densities of large and dark asteroids suggest highly porous interiors and, consequently, relatively late accretion at a time of 1.5-3.5 Myr relative to the formation of calcium-aluminum-rich inclusions with maximum interior temperatures of  $< 900$  K. This work demonstrates that the derived accretion times of large dark asteroids do not correlate in any way with their current semimajor axes. Large and dark asteroids were likely implanted from more distant regions of the solar system during the giant planet's dynamical instability. The discovery of dark large asteroids that are smaller than Ceres near its orbital vicinity suggests that this dwarf planet is not unique in the main belt and its surface composition is not driven by its very large size.