WHERE DID CERES ACCRETE? William B. McKinnon, Department of Earth and Planetary Sciences and the McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130 (mckinnon@wustl.edu).

Introduction: Ceres is an unusual asteroid. Comprising ~1/3 of the total mass of the present asteroid belt, it resides deep in the Main belt at a semimajor axis of 2.77 AU, at the center of the broad distribution of C type asteroids [1]. But it is not a C-type as usually considered. It is likely a differentiated dwarf planet, whose ice-rich composition indicates a kinship with bodies farther out in the solar system [2]. Here I explore Ceres' place of origin, either in situ in the asteroid belt, farther out among the giant planets, or even in the primordial transneptunian belt. As the next target of the *Dawn* mission, I also address whether any of these formation scenarios can be tested.

Density and Composition: Ceres is now classified as a dwarf planet (one in rotational hydrostatic equilibrium), with a mean radius ~470 km and density ~2.2 g cm^{-3} [3]. It thus joins an elite group of outer solar system bodies, the largest KBOs: Triton, 2.061 ± 0.007 g cm^{-3}; Eris, 2.52 ± 0.05 g cm^{-3}, and the Pluto-Charon binary, 1.94 ± 0.09 g cm^{-3} [4,5]. These densities are quite different from those of Ganymede, Callisto, and Titan, when self-compression is accounted for. When interpreted in terms of rock/water-ice ratio, Ceres' density implies a ≈75/25 mix, arguably a signature of accretion in the outer solar system [e.g., 6].

The iciness of Ceres contrasts with the much smaller water contents of carbonaceous meteorites. Zolotov has [7] argued that such iciness is unnecessary as long as there is a sufficient combination of internal porosity, highly hydrated and oxidized ($fO_2 >$ HM) minerals, and organic matter. These are necessary because the grain density of carbonaceous rock is not that low [7-9]; the grain density of Tagish Lake (e.g.) is 2.84 g cm^{-3} [10]. Castillo-Rogez [12] showed, however, that even modest radiogenic heating should drive dehydration of the most water-rich phases in the low-density model of [7]; accompanying diagenesis would allow exhalation of free water and eliminate porosity [12].

Birth In Situ: In terms of mass, Ceres is an outlier in the Main belt [13], which could indicate nascent runaway growth/protoplanet status. Its icy nature could be consistent with temporal evolution of the nebular snow-line across the asteroidal zone [14]. Icy planetesimals from further out could also contribute to Ceres' makeup, but after Jupiter forms, accretional efficiency will be low due to higher impact speeds.

Inter-Planet Disk Origin: Perhaps the most radical elaboration of the Nice model [e.g., 15] to date is the "grand tack," in which Jupiter and Saturn undergo a two-stage, inward-then-outward, migration [16]. In models where Jupiter reverses migration direction at 1.5 AU, the primordial asteroid belt is simply emptied, but then repopulated with bodies from both the inner and outer solar system. At Ceres' distance the majority of icy, outer solar system bodies derive from between the giant planets (out to ~8 AU in the initial compact configuration). The new belt is also a dynamically hot belt, and (if it lasts) requires e and i reshuffling during the Nice-model LHB [16].

Transneptunian Refugee: In 2008, I proposed that Ceres was dynamically scattered inwards during a Nice-model like reorganization of the outer solar system, and implanted in a more massive, primordial asteroid belt, where it ~circularized due to dynamical friction and remains today [17]. The dynamical justification stems from modeling that showed that KBOs/comets could have been embedded in large numbers into the jovian Trojan clouds and the outer asteroid belt (>2.6 AU) [18]. In Levison et al. [18], large KBOs are not considered; the comet distribution is truncated at 180-km diameter, and the large (bright) end of the size-frequency distribution follows a very steep power-law slope (q = 6.5 differential). If, rather, the bright end followed the more canonical distribution for the Trojans (q = 5.5) or even the cold classical KBOs (q = 5.1) [19], the probability of injecting a "Ceres" would approximately unity. The probability of retaining a "Ceres" would, however, be reduced by dynamical (but not collisional) erosion of the asteroid belt over 3.8 b.y. (by perhaps a factor of 2–3 [18]). What is not obvious is how to reconcile the much shallower slope of the *hot* population of the Kuiper belt with the steep distribution of large jovian Trojans [19].

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