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Rapid seeding, core segregation, and volatile loss of planetesimal belts isolated in space and time

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Abstract

Multiple recent observations from astronomical surveys and geochemical studies are in tension with our current theoretical understanding of the accretion process. Radiometric dating suggests that rocky protoplanet accretion was long underway after 1–2 Myr after CAIs [1], which is supported by evidence for rapid dust coagulation during the earliest, embedded disk phases of young protostars [2]. In contrast, planetesimal formation from, e.g., the streaming instability, requires elevated solid densities, which typically necessitates major redistribution of dust mass during the class II disk stage [3]. Furthermore, overcoming the earliest accretion stages before a potential onset of effective pebble accretion may be too slow to satisfy geochemical constraints on early core segregation in the non-carbonaceous meteorite reservoir [4, 5].

Here, we suggest that an early planetesimal burst during the disk infall stage [6] can overcome some of these challenges. We combine models of dust coagulation and planetesimal formation [6] with their subsequent thermochemical evolution to show that such early-formed, water-rich planetesimals rapidly dehydrate due to ^{26}Al heating [7] and undergo efficient metal-silicate separation due to the build-up of internal magma oceans [8] during the first $\approx$ 1 Myr after CAI formation, consistent with geochemically-inferred segregation ages [4, 5]. Furthermore, a second planetesimal burst from dust pile-up at a later inwards-moving snowline during the class II stage displays characteristics representative of the carbonaceous chondrite meteorite reservoir, including the build-up of cores between $\approx$ 2–3 Myr after CAIs, again consistent with geochemical constraints [4, 5].

Such a two-step process may rapidly seed and facilitate the accretion of the terrestrial planets prior to the gas and ice giants, and may alleviate the tension between the inferred water inheritance during Earth's main accretion phase [9] and the rapid water incorporation of embryos nucleated beyond the snowline [7].

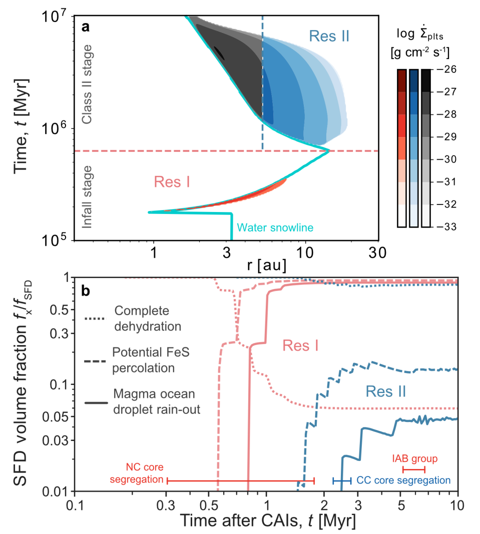

Figure 1: (a) Change in planetesimal surface density per time, reservoir definition. (b) Chemical evolution of planetesimal reservoirs for a Gaussian-like size-frequency distribution (SFD) centered on a radius of 100 km. NC and CC core segregation ages from [4, 5].

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