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Reconstructing Earth's accretion through time

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Nucleosynthetic isotope anomalies can be used to identify the building material of Earth, and to assess to what extent Earth grew by accreting material from different regions of the protoplanetary disk [1,2]. In particular, these anomalies show that the disk can be subdivided into the non-carbonaceous (NC) and carbonaceous (CC) reservoirs [3]. The isotopic composition of the bulk silicate Earth (BSE) relative to the NC-CC dichotomy likely provides information on the amount of inner and outer solar system material accreted by Earth. However, prior studies reached disparate conclusions about the amount of CC material in Earth [2,4], and whether this material was added early [1] or late [5]. Here we show that the calculated CC fraction in Earth increases systematically with increasing siderophile character of an element. As the BSE's isotopic compositions for siderophile elements only record later accretion stages [1], this correlation demonstrates that Earth accreted CC material predominantly during the waning stages of its growth. We used the formalism of [1] and an element's metal-silicate partition coefficient to estimate which part of Earth's accretion is recorded in the isotopic composition of a given element, and fitted the results to accretion curves with varying NC-CC proportions. Our results show that the first ~95% of accretion were dominated by NC material with an on average enstatite chondrite-like isotopic composition, followed by accretion of ~4% CC material. The final ~1% were added after cessation of core formation as a late veneer, which again had an enstatite chondrite-like isotopic composition. The late-stage accretion of ~4% CC material is consistent with the timing of the Moon-forming impact, suggesting that this impactor may have delivered much of the CC material to Earth. A CC origin of the Moon-forming impactor is consistent with the larger CC fraction in Earth compared to Mars, and with the BSE's chemical composition, but may be dynamically implausible.

References: [1] Dauphas N. 2017, Nature 541. [2] Burkhardt C. et al. 2021, Science Adv. 7. [3] Warren P. 2011, Earth Planet Sci. Lett. 311. [4] Schiller M. et al. 2018, Nature 555. [5] Budde et al. 2019, Nature Astron. 3.