Rapid isotopic evolution of the protoplanetary disk and the building blocks of the Earth-Moon system

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Although many scenarios have been proposed for the origin of the Earth-Moon system, they fail to account for the identical isotopic composition of the Earth and the Moon for refractory elements despite the large nucleosynthetic variability observed between bulk Solar System reservoirs. A potential solution to this conundrum is the proposal of a isotopic homogeneous inner disk region from which proto-Earth and the Moon-forming impactor accreted [1]. However, the assumption of a constant disk isotopic composition at any given heliocentric distance throughout the accretion history of terrestrial planets requires limited mass transfer across the inner disk, which is difficult to reconcile with the early dynamics of the protoplanetary disk. Indeed, the bulk of the disk mass is accreted from the envelope, thermally-processed and recycled over short timescales relative to the formation history of the Earth and Moon system.

Chondrules are the main constituent of chondrite meteorites and their sheer abundance suggest that they may have promoted the growth of planetary objects. For example, gas-drag assisted accretion of chondrules is a viable mechanism to grow terrestrial planets and gas giant cores during the lifetime of the protoplanetary disk [2]. Chondrules are thus suitable tracers of the chemical and isotopic evolution of the protoplanetary disk and, hence, the material precursor to terrestrial planets. We present new mass-independent ^{48}Ca isotopic compositions of Pb-Pb dated individual chondrules from various chondrites. Combined with the ^{48}Ca isotope signatures for asteroids and planets, our data allows us to track the chemical and isotopic evolution of the inner protoplanetary disk region throughtout its lifetime. We show that the bulk isotopic composition of the protoplanetary disk rapidely evolved from a ^{48}Ca-depleted to a terrestrial-like composition within 5 Myr. This allows us to define a chronology for the growth of the terrestrial planets and the formation of their precursor material, which is linked to the final mass of the planetary bodies. Our results indicate that the isotopic similarity between the proto-Earth and the Moon-forming impactor is a natural consequence of the bulk isotopic evolution of the inner protoplanetary disk and does not require *ad hoc* scenarios.

[1] Dauphas *et al*., 2014, *EPSL* **407**, 96–108 [2] Johansen *et al*., 2015, *Sci. Adv*. **1,** e1500109