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Combining dynamics, chemistry and isotopic properties. A holistic approach to Earth formation

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For a long time, the formation of the terrestrial planets was investigated with numerical simulations, aiming to reproduce the masses and orbits of the planets. Their characteristic distribution suggests that they formed from a ring of planetesimals [1,2,3]. But a wealth of additional constraints is provided by the chemistry of the bulk silicate Earth (BSE) and its isotopic properties, which can be compared to those of meteorites. Nucleosynthetic isotopic analyses support the ring model by showing that 95% of Earth's mass was accreted from inner solar system material [4,5]. But the chemical composition of the BSE implies the initial accretion of reduced materials, followed by more oxidized building blocks [6]. This cannot be explained in a simple ring model but requires the delivery of oxidized material to the ring towards the end of the disk phase. The Grand Tack model [7] was accomplishing this by invoking the migration of Jupiter through the asteroid belt [8], but this scenario is implausible in realistic, low-viscosity disks [9]. We will show a new dynamical possibility that is consistent with this framework. Supported by a disk-evolution model, we argue that the ring near 1 au was made of planetesimals as reduced as Aubrites or Enstatite chondrites but enriched in refractory elements and s-process isotopes. These planetesimals have been fully consumed by the growth of planetary embryos and therefore are absent in our meteorite collection. The material transported from the asteroid belt was akin to the parent bodies of non-carbonaceous iron meteorites, which have been shown to be volatile rich and oxidized [10,11].

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