NUCLEOSYNTHETIC VARIATIONS GENERATED BY SIZE AND DENSITY DRIVEN SORTING OF DUST IN PROTOPLANETARY DISK.

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Introduction: Various isotopic systems studied in meteorites bear testimony of a nucleosynthetic heterogeneity in solar system bodies. As a first order observation, some systems show an isotopic dichotomy between objects formed in the inner solar system (Non-carbonaceous chondrite (NC) reservoir) and those formed further out (carbonaceous chondrites (CC) reservoir) [e.g., 1,2]. These heterogeneities stem from presolar grains generated in different stellar environments before they were delivered to our solar system. However, how these presolar grains were originally distributed in the solar protoplanetary disk, and to which extent they were subsequently transported, concentrated, and processed in different locations, remains unclear. It has been suggested that the formation of Jupiter's core may explain the observed separation of the two reservoirs defined by NC and CC chondrites – being located inside and outside of Jupiter's orbit, respectively [e.g., 2]. Large planets carve a gap in the disc, depleting the surrounding orbital region of both gas and dust. The resulting pressure maxima that form on either side of the gap act as dust traps and prevent most of the dust from moving between the inner and outer disc. Hydrodynamical simulations can track the dynamical evolution of the presolar grains, i.e. the dust, in which the isotopic signatures are incapsulated. Here, we apply smoothed particle hydrodynamics (SPH) simulations to assess, whether we can replicate the isotopic anomalies observed in solar system bodies via the interaction between the dust grains and the background gas disk assuming an initially homogeneous distribution throughout the disk relative to the silicate grains with average solar system composition.

Methods: We use the SPH code PHANTOM [4] to perform 3D gas and dust simulations of protoplanetary discs to evaluate how the back-reaction of pebble-sized grains (~mm) affects the (sub-)micron grain population with and without a Jupiter-mass planet carving a gap in the disc at different radii. We use the MULTIGRAIN algorithm [5] to simultaneously simulate a total of 17 dust phases comprised of ten `silicate' phases (size: 0.1 microns - 1 cm; density: 3 g/cm$^3$), four `silicon-carbide' (SiC) phases (size: 0.25 - 4.225 microns; density: 3.16 g/cm^3), and three `oxide' phases (size: 0.1 - 0.6 microns; density: 3.93 g/cm^3). Simulations containing only one of these phases were also conducted to assess the effects of back-reaction. We determine the abundances of the silicate grains with a standard power-law grain-size distribution of slope -3.5 (e.g. [6]). The abundances for the silicon carbide and oxide phases come from generalised extreme value distributions that fit the catalogued abundances from meteoritic studies [7,8]. Abundances, element concentrations and isotopic compositions were estimated from presolar grain data. There are large uncertainties associated with these parameters. We used them to attribute different anomalous isotopic tracers to the oxides (supernova produced isotopes, e.g., ^{54}Cr) and SiC (*s*-process isotopes, e.g., Zr) populations to assess whether variations in intrinsic grain density, grain-size distribution, and/or back-reaction from larger grains in the disc can generate differences in the local concentrations of presolar grains and thus their tracers.

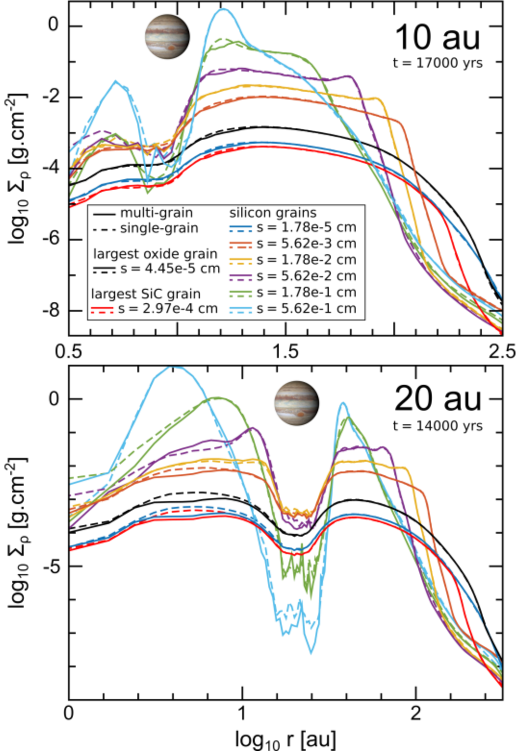

Figure 1: Radial surface densities of oxides, SiC, and solar system silicates in single- and multi-grain simulations for a planet at 10 au (top panel) and 20 au (bottom panel). Single-grain simulation results are shown as dashed lines and those from multi-grain simulations as continuous lines.

Isotopic variations can be inferred from mass balance equations (Fig. 2).

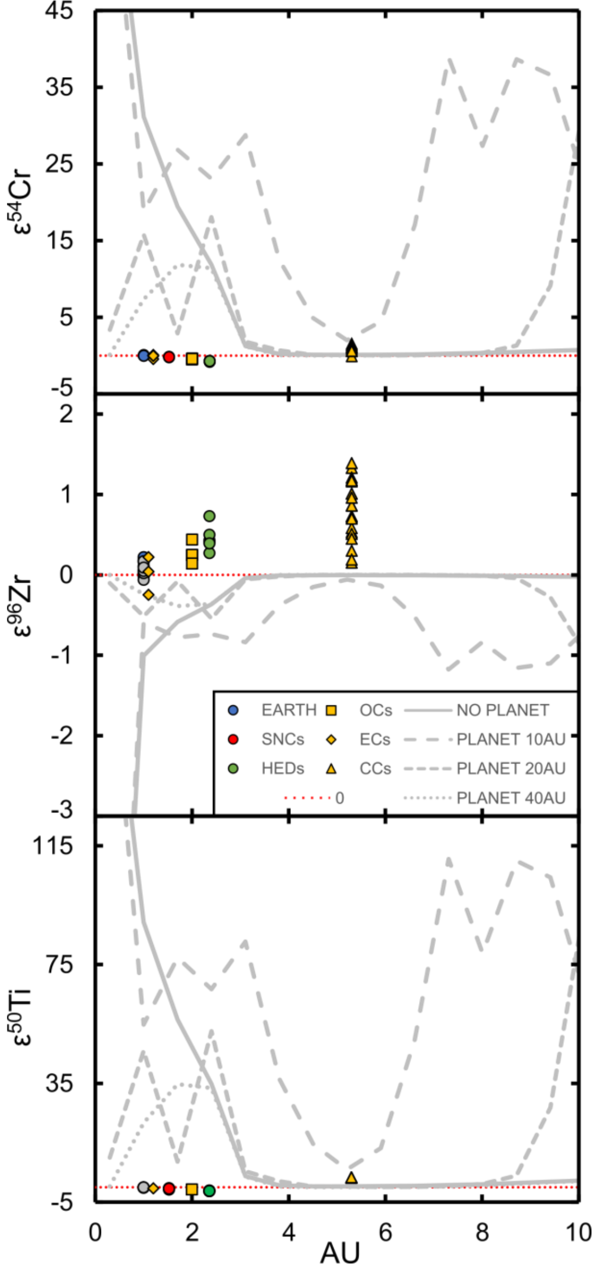

Figure 2: Estimations of isotopic ratios obtained from mass balance calculations using surface densities of grain phases (grey curves). Where available, values for Earth, Moon, SNC & HED meteorites, as well as chondrites are given for reference [9,10,11]. The ε^{54}Cr and ε^{96}Zr signatures are assumed to be carried by oxides and SiC, respectively; ε^{50}Ti by both SiC and oxide grains. Epsilon is the deviation from the terrestrial ratios in parts per 10^{-4}. The Earth is assumed to reflect the average solar system compositions, which is not necessarily correct.

Results & Discussion: Strong density variations occur around the planet (Fig. 1), resulting in a region of low densities directly around the planet and regions of higher densities inside and outside of its orbit. Larger grains are particularly affected. Little deviation is observed between single- and multi-grain simulations (Fig. 1), and only for the largest silicate grains, which implies that back reactions do not significantly affect grain sorting.

Within the first 10 au, the produced heterogeneities in ε^{54}Cr and ε^{50}Ti are larger than those measured in planets and meteorites from asteroidal bodies by one and two orders of magnitude, respectively (Fig. 2). The range of ε^{96}Zr values is comparable. The positive values of ε^{96}Zr are not matched by the curves. This is the result of assuming that solar system silicates have the same composition as the Earth, while SiC data shows negative ε^{96}Zr. Allowing a more positive ε^{96}Zr value than of the Earth for average solar system material, would lead to a better fit of model curves and meteorite data.

The presence of a planet and the pressure bumps that form on both sides of the gap can create changes in grain densities, particularly affecting the larger silicate grains. This modifies the abundances of silicates relative to SiC, oxides and as such the isotopic ratios (Fig. 2). Hence, solar system silicates are the controlling phase of the isotopic anomalies due to their larger grain sizes and thus their increased susceptibility to grain sorting. Considering the uncertainties in the presolar grain data and caveats with the SPH simulations, it is not surprising that solar system values were not fully achieved. However, our results show that size- and density-sorting generates differences in concentrations of presolar grains that could create isotopic heterogeneities in the order of those observed in solar system bodies.

Acknowledgments: This work has been carried out within the framework of the NCCR PlanetS supported by the Swiss National Science Foundation.

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