PROBABILITY OF THE EARTH AND THE MOON HAVING SIMILAR MANTLE TUNGSTEN ISOTOPIC COMPOSITION IN VARIOUS N-BODY ACCRETION SIMULATIONS. N. G. Zube[1], R. A. Fischer[2], F. Nimmo[1], S. A. Jacobson[3], [1]Department of Earth and Planetary Sciences, University of California Santa Cruz (1156 High St., Santa Cruz, CA 95064, USA, nzube@ucsc.edu, fnimmo@es.ucsc.edu), [2]Harvard University (20 Oxford St., Cambridge, MA 02138, USA, rebeccafischer@g.harvard.edu), [3]Michigan State University (228 Farm Ln., Rm 207, East Lansing, MI 48824, USA, seth@msu.edu).

Introduction: A giant impact of the proto-Earth and a planetary embryo is thought to result in the formation of the Moon, but the details of this collision are still being debated. Models of formation must now explain the observed near-identical isotopic compositions between many elements in the Earth and the Moon [1]. Canonical models of the impact predict that the Moon was mostly formed of material from the impactor ("Theia") [2]. For this scenario to be consistent with Earth-Moon isotopic similarities both bodies must not only be formed of isotopically homogeneous inner disk material (shown to be unlikely in [3]), but also must experience a growth evolution such that time-dependent isotopic systems influenced by core and mantle re-equilibration (such as Hf-W) produce a near-identical result for the Earth and the Moon. We wish to evaluate the probability in late-stage accretion simulations that an Earth and a Moon formed from the impactor Theia will follow the observed isotopic similarity in tungsten between the two bodies [1].

The decay of lithophile ^{182}Hf into siderophile ^{182}W with a half-life of 9 My provides constraints on the timescales of planetary core formation and accretion. Classical accretion scenarios have produced planets with tungsten isotopic values like those measured presently on the Earth [4,5,6]. In Grand Tack accretion simulations [7,8] terrestrial planet formation occurs more rapidly, and reproducing the observed tungsten isotopic anomaly for Earth's mantle requires nearly complete equilibration between impactor core and target mantle [9]. To evaluate the likelihood that a moon composed of Theia material can have a similar tungsten composition to the Earth, we will evolve differentiated Earths and Moons in classical and Grand Tack simulations through time to the present and compare final ^{182}W.

Methods: We model Hf-W evolution for growing planets in 100 N-body simulations in the Classical scenario and 141 N-body simulations in the Grand Tack scenario. Partition coefficients are assumed constant throughout a model run and are set by the present-day inferred mantle Hf and W concentrations. During collisions, the re-equilibration of elements between the core and mantle is calculated following [10] for classical and [5] for Grand Tack. For each set of models, we vary the equilibration factor *k* during collisions—the fraction of impactor core that experiences re-equilibration with the entire target mantle—in steps ranging from none, 0.0 (cores merging) to complete equilibration, 1.0. The last giant impact (LGI) is modeled assuming the canonical scenario where the Moon is built from mostly impactor mantle (no mixing with Earth material) [2]. Pre-impact isotopic values for the Earth and Theia are compared.

Discussion: For classical N-Body accretion, we find that cases with lower equilibration factor ($k < 0.7$) were most frequently able to approximate the observed W measurements for Earth and Mars (Fig. 1) [5,6,10]. Conversely, Grand Tack scenarios were most successful replicating Earth W measurements with an equilibration factor $k > 0.7$ [9]. The necessity of high equilibration for Grand Tack models is explained by the faster accretion timescales compared to classical scenarios.

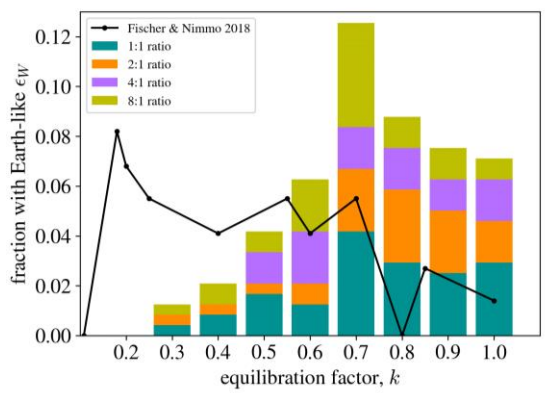

Fig 1. Fraction of total Earth-like bodies that match the pre-late veneer terrestrial tungsten anomaly (ε_W = 2.2 ± 0.15), divided among groups with varying initial embryo:planetesimal mass ratio, for Grand Tack scenarios [9]. The solid line shows results from Classical accretion scenarios in [10] with varying partition coefficients.

For model moons made entirely of mantle material from Earth's last giant impactor (Theia), the probability of an Earth-Moon pair achieving a ^{182}W anomaly difference $|\Delta\varepsilon_W| < 0.15$ when the model Earth ε_W value resembles the measured value is ~4% across all classical simulations (Fig. 2) [11]. Similarly, this values is ~1% across all Grand Tack simulations (Fig. 3).

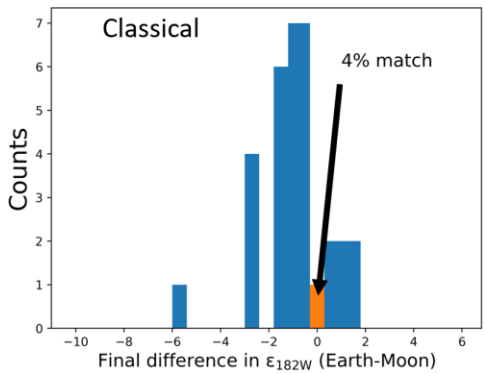

Fig. 2. For classical accretion, counts of ε_W difference in Earth-Theia pairs for cases when the model Earth matches the measured value, $\varepsilon_W = 2.2 \pm 0.15$ (this value strips out the effect of the subsequent late veneer [12]).

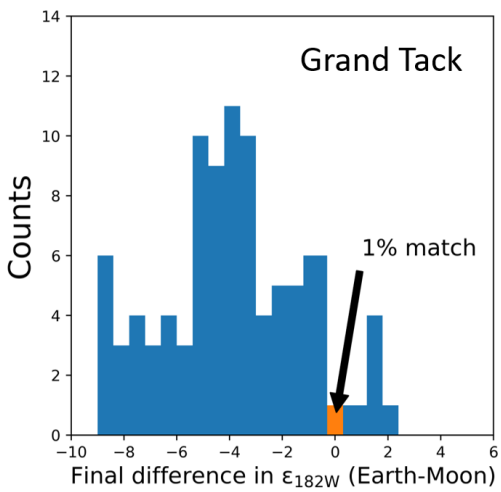

Fig. 3. Same as Fig. 2, but for Grand Tack simulations.

A comparison of final time-evolved moons and Earths will also be presented. In these sets of models, *both* post-LGI bodies experience differentiation and core formation, and ^{182}Hf decay is evolved to the present for the moon. The low likelihood (~1%) of Earth-Moon ε_W similarity in the LGI model for both Grand Tack and Classical accretion indicates that a scenario where the Moon isotopically equilibrated with the Earth's mantle after the impact [1] may be required to explain the measured values.

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