WHAT CAN THE Hf–W SYSTEM TELL US ABOUT THE MECHANISM AND TIMING OF EARTH’S CORE FORMATION? R. A. Fischer¹, F. Nimmo², and D. P. O’Brien¹, ¹Harvard University, ²University of California Santa Cruz, ³Lunar and Planetary Institute.

Introduction: The Hf–W isotopic system is one of the most widely used geochemical tools for dating Earth’s core formation [e.g., 1]. $^{182}$Hf decays into $^{182}$W with a half-life of 8.9 Ma [e.g., 2]. During core formation, moderately siderophile W is mostly sequestered into the core. If lithophile $^{182}$Hf is alive during core formation, it will remain in the mantle and decay into $^{182}$W, creating an excess of $^{182}$W relative to other W isotopes. Previous studies show that the Hf–W system is also sensitive to the siderophility of W and the degree of metal–silicate equilibration [e.g., 3–5]. Here we use Hf–W modeling to investigate the core formation process. Relative to previous Hf–W models, we introduce several novel concepts. First, the partitioning behavior of W varies with temperature ($T$), oxygen fugacity ($f_{O_2}$), and composition ($X$) as the Earth grows. Second, a large number of accretion simulations are used, to illustrate how stochastic variability in growth history affects the Hf–W system. Finally, we incorporate a full core formation model, so Earth’s mantle composition provides additional constraints.

Methods: Growth histories for 73 Earth analogues are taken from 100 $N$-body simulations [6], fifty with Jupiter and Saturn on initially circular orbits (CJS) as predicted by the Nice model and fifty with Jupiter and Saturn on their current, eccentric orbits (EJS). We are currently undertaking calculations using 16 Grand Tack simulations [7].

The output of these simulations is combined with a core differentiation model [8], in which bodies undergo $P$-$T$-dependent metal–silicate equilibration with each impact. Many major, minor, and trace elements are tracked, and $f_{O_2}$ is evolved self-consistently [9]. W partitioning as a function of $P$-$T$-$f_{O_2}$-$X$ is based on [10]. Between impacts, radiogenic $^{182}$W is produced in the mantle, and with each impact, the $^{182}$W abundance is modified by a core formation event. Adjustable parameters include the equilibration depth ($P$-$T$), amounts of metal and silicate equilibrating, thermal profile, and initial $f_{O_2}$.

Results and Discussion: In the first few 10s of Ma, the tungsten anomalies ($\varepsilon^{182}$W) reach a few hundred due to the very siderophile behavior of W at low $P$-$T$ and Earth-like $f_{O_2}$, an effect not seen in previous studies that used a constant W partition coefficient. The degree of equilibration cannot be varied in isolation, because doing so affects other aspects of planetary chemistry (e.g., mantle W abundance) [8]; here a compensating change in equilibration depth is used to maintain an Earth-like mantle composition. Reducing the degree of equilibration increases the final tungsten anomaly [e.g., 11] (Figure). For whole mantle equilibration, Earth’s anomaly is best matched with the fraction of equilibrating metal $k = 0.4$, in agreement with previous studies [12–13]. Matches are also achieved for $k = 0.55$ and equilibration with $5x$ the impactor’s silicate mass, or $k = 1$ and $3x$ the impactor’s silicate mass, or some intermediate combination (Figure).

These $N$-body simulations produce Moon-formation ages (last giant impact times) of 10–175 Ma. Later final impacts require less equilibration to match Earth’s tungsten anomaly. For whole mantle equilibration, final impacts at ~50 Ma require $k = 0.4–0.55$; those at >150 Ma require $k = 0.25–0.4$. For the right combination of model parameters, nearly all Earth analogues can have the observed anomaly regardless of formation timescale. Requiring a small late veneer generally excludes last impact dates of <65 Ma [6, 14]. At these later times, matching Earth’s anomaly requires $k = 0.2–0.55$ regardless of equilibrating silicate mass, implying equilibration depths of 0.5–0.7x the core–mantle boundary pressure. There are strong tradeoffs between $k$, equilibrating silicate mass, depth, and timing of core formation, underscoriing the importance of understanding the physical processes that control metal–silicate equilibration.