SMALL, DENSE, AND ISOLATED: GROWING BETTER MERCURY ANALOGS WITH IN-SITU ACCRETION AND CATACLYSMIC INSTABILITIES. M. S. Clement[1] and J. E. Chambers[1], [1]Carnegie Institution for Science, Earth & Planets Laboratory, Washington DC, USA (mclement@carnegiescience.edu)

Introduction: Mercury's enigmatic origin continues to puzzle dynamical models more than that of any of the solar system's planets Mercury analogs of appropriate mass and sufficient radial offset from Venus are extremely rare within the terrestrial planet formation literature [1,2,3]. In practicality, this is simply a result of the initial conditions chosen by such studies; specifically, the truncation the inner terrestrial disk outside of Mercury's modern orbit and the incorporation of unrealistically massive planet embryos. However, Mercury's depleted inventory of volatiles and large core seem to suggest that it formed in a different manner than the other terrestrial worlds [4]. While Mercury's high bulk density has been interpreted to hint that much of its silicate-rich mantle material was eroded in a massive impact [5,6], the various proposed collisional scenarios are highly improbable from a dynamical standpoint [1]. Therefore, it is imperative for dynamical models to explore all possible avenues for Mercury's genesis. In general, there are two types of viable explanations for Mercury's large iron core: "orderly" scenarios where the planet accretes directly from planetesimals already possessing enriched Fe/Si ratios, and "chaotic" hypotheses where the young Mercury's once-thicker mantle is violently stripped in an energetic giant impact.

Orderly Solutions: Several compelling explanations for early iron-enrichment of the enstatite chondrite precursors to the Mercury-forming planetesimals have been proposed. While detailed models combining analytical disk chemistry relationships and dynamical simulations are required to validate the feasibility of such a scenario, the photophoretic effect [7], magnetic aggregation [8] and the concentration of carbon-rich interplanetary dust particles near the disk midplane in the Mercury-forming region [9] are all promising mechanisms for favorably transforming the chemistry of solids in the inner disk. Unfortunately, dynamical models [2,3] studying local accretion with an additional component of planetesimals extending from ~0.2 au to Venus' modern orbit overwhelming find that the resulting Mercury analogs grow too large and too close to Venus. We present new simulations (see Figure 1 for an example) that build on this scenario, and test various mass surface density profiles for a *mass-depleted* region of planet-forming material inside of ~0.7 au (an extrapolation of similar studies investigating Mars' formation with local mass depletion: [10]). We find this genesis avenue for Mercury to be plausible for a specific subset of disk parameters, and plan to fully validate its likelihood within the larger context of planet formation and dynamical evolution [e.g.: 1,10] in the solar system in future work.

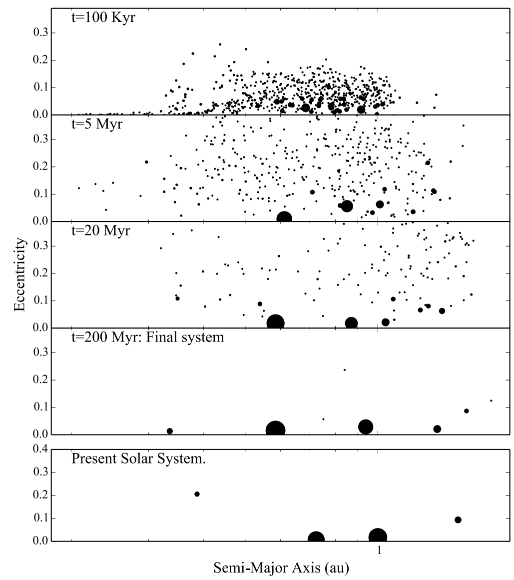

Figure 1: *Time evolution of an example simulation where Mercury accretes from a mass-depleted inner extension of the terrestrial-forming disk. The size of each point is scaled to the object's mass. The final terrestrial planets in the simulation have masses of 0.083, 1.12, 0.62 and 0.15* $M_\oplus$*, respectively.*

Chaotic Solutions: While the collisional geometries required in a scenario [6] where Mercury's mantle is eroded in a single massive impact are quite improbable occurrences in conventional models of terrestrial planet formation [1,2,10], it is also possible that a prolonged series of less-energetic erosive collisions [11] were responsible for accomplishing the same net result. Moreover, tightly packed systems of short-period exo-planets with orbits smaller than Mercury's have been shown to be unstable over Gyr-timescales [12]. We report results from similar models investigating systems of large planet embryos interior to Venus. Due to the proximity of the strong ν_5 secular resonance with Jupiter's perihelia precession, these chains of proto-planets are relatively easily destabilized and undergo a series of mantle-depleting collisions through which Mercury is left behind as the lone survivor (an example of a successful evolutionary sequence is plotted in

Figure 2). A consequence of these events is some amount of material delivery to the other planets, and thus fully validating this hypothesis in the future will require a detailed study of its effects on Earth and Venus.

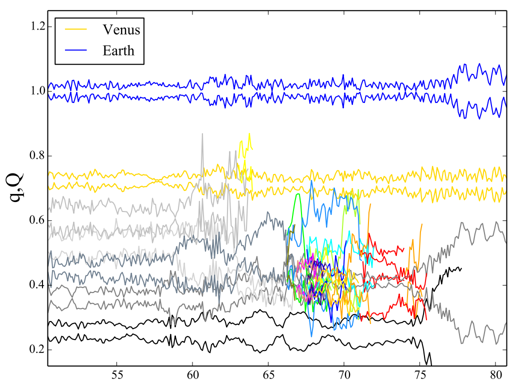

Figure 2: *Time evolution of the perihelia and aphelia of Mercury-forming embryos in a simulation where Mercury forms as the sole survivor of a primordial generation of short-period proto-planets that are cataclysmically destroyed by an orbital instability. The initial proto-planets are plotted in shades of grey, while collisional fragments produced throughout the instability are plotted in various bright colors.*

Results and Conclusions: While our simulations represent a step forward in terms of the ability of dynamical studies of terrestrial planet formation to simultaneously reconcile Mercury's mass, orbit and composition, the precise solar system result remains somewhat of an outlier within the spectrum of numerically generated outcomes. Nevertheless, our results are promising in terms of their consistent ability to generate Mercury-Venus pairs, and several of our simulations generate remarkably accurate inner solar system analogs. In particular, in both scenarios we find that a total mass of ~0.25-0.5 $M_{\oplus}$ of material with $a <$ 0.7 au (either in planet forming material for an orderly origin; or in the form of quasi-stable proto-planets for a delayed, chaotic genesis) is particularly successful at simultaneously reconciling Mercury's particular mass and radial separation from the other terrestrial worlds.

Finally, we note that Mercury's proximity to the ν_5 resonance should not be neglected as a possible explanation for the planets' peculiarity. Indeed, our preliminary work indicates that an interaction between proto-Mercury and the resonance during the epoch of giant planet migration [13] cannot be ruled out as a possible source of the planets' modern dynamical isolation from Venus. In spite of all efforts made, we conclude that Mercury's curious origin remains, perhaps, the largest outstanding problem for terrestrial planet formation models to resolve.

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