Differentiated Collisions and Their Effect on Terrestrial Planet Composition

David R. Rice and Jason H. Steffen
University of Nevada, Las Vegas

UNLV COLLEGE OF SCIENCES

Abstract

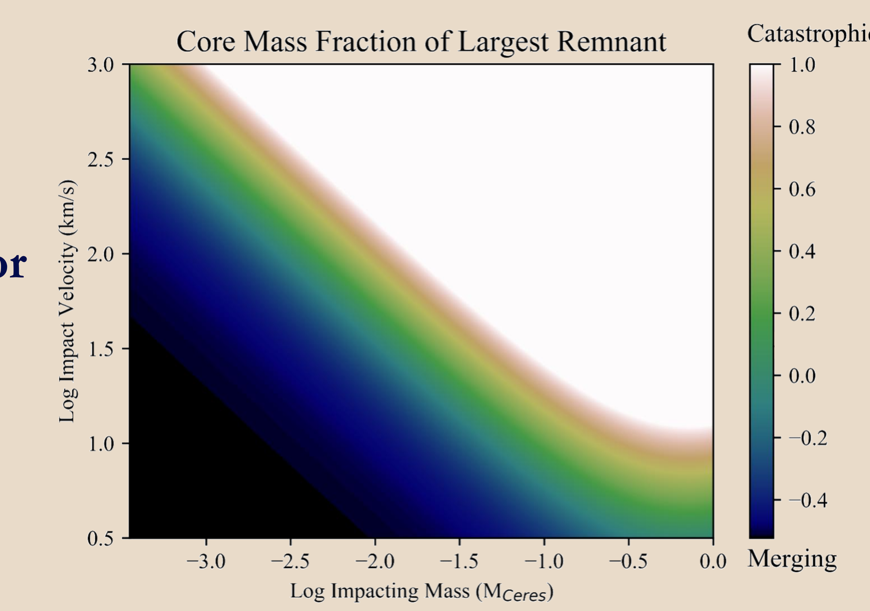
The inferred densities of observed exoplanets allow for a wide range of bulk compositions. Interior models based on density are dependent on the amount of mass a planet holds in its core. Throughout formation, the **core mass fraction (CMF)** of a planetary body evolves as differentiated planetesimals and planet embryos collide. The preferential erosion of mantle material during a collision has been evoked to explain Earth's non-chondritic composition and Mercury's interior structure. This effect can be tracked in planetesimal disk simulations by employing a mantle erosion model into N-body integrations with a collisional scheme. The CMF of each body can then be tracked throughout evolution. By making use of new dust condensation codes (M. Lee, UNLV), our model can be applied to a large variety of planetary systems. For our solar system, Carter et al. (2015) showed that the Grand Tack can create large variations in CMF. We plan to further delineate the relationship between dynamical "temperature" and variations in CMF.

Collisional Mantle Erosion

By conducting SPH calculations on the collision of two differentiated bodies, Marcus et al. 2009 showed that the CMF of the largest post-collisional remnant follows a power law with impact energy.

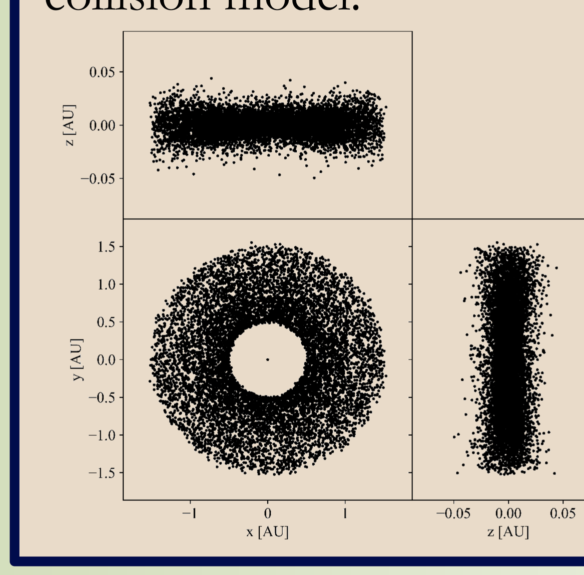
Between hit-and-run and catastrophic collisions, the bulk composition of a body can be changed by high energy impacts that preferentially strip mantle material.

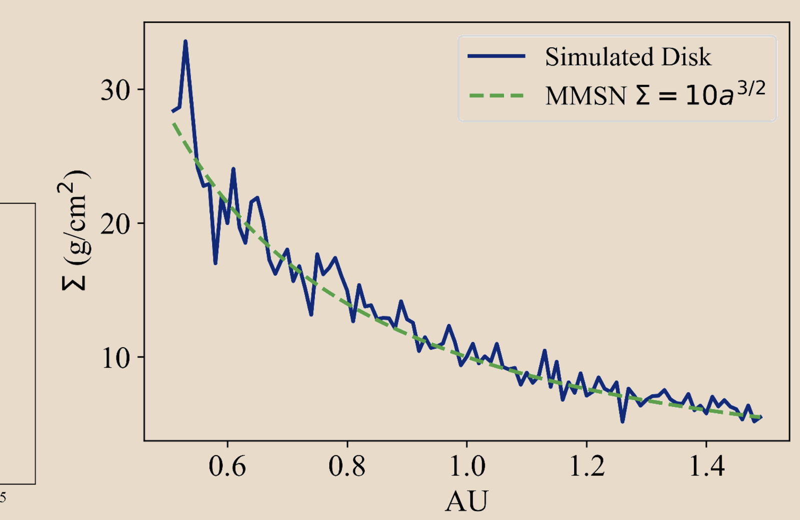
***Right:* Final CMF of the largest remnant for an impactor hitting a Ceres-mass target which has 30% core.**



Planetesimal Disk Simulations

- 10,000 bodies of following $\Sigma = \Sigma_1 a^{-3/2}$ with radii of a few 100 km (approx. Ceres sized).
- For our initial study, all bodies have equal-mass and equal starting CMF.
- Bodies are inflated by an expansion factor which results in lower collision times effectively speeding up the simulation by f^2.
- Simulated in Mercury6 with the Leinhardt & Stewart (2012) collision model.





Ternary Diagram

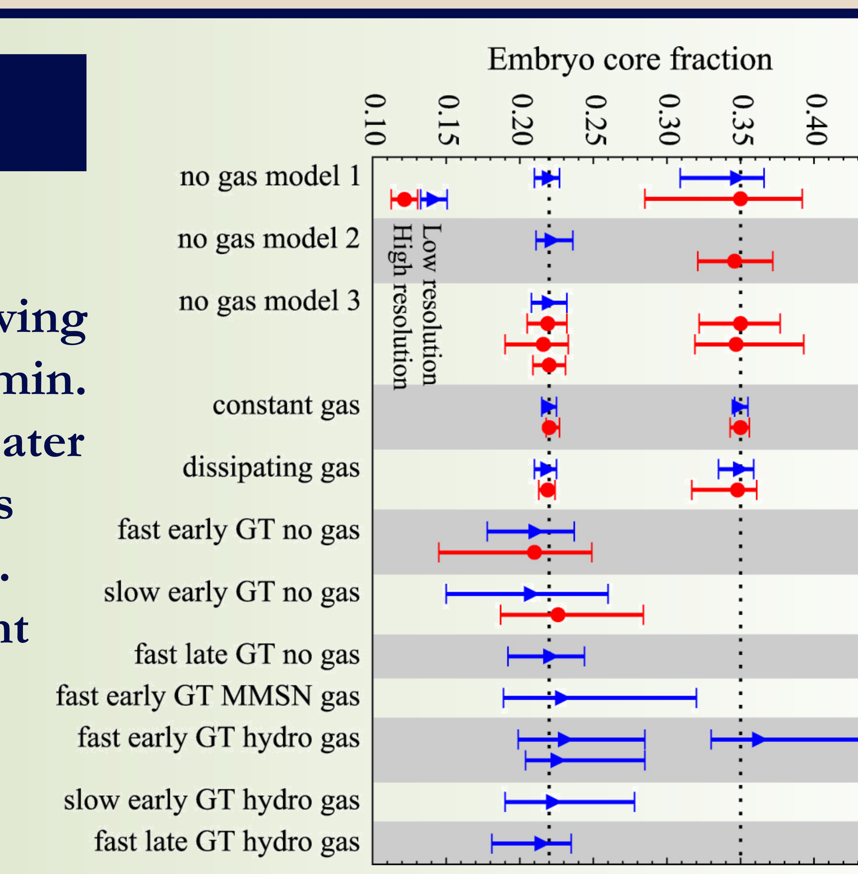
Exoplanet observations show that similar planets may have a range of densities. The composition of a planet with a known density is degenerate with the amount of mass in the iron-core and in the ice layer. We wish to constrain the typical size of an exoplanet core through dynamical studies.

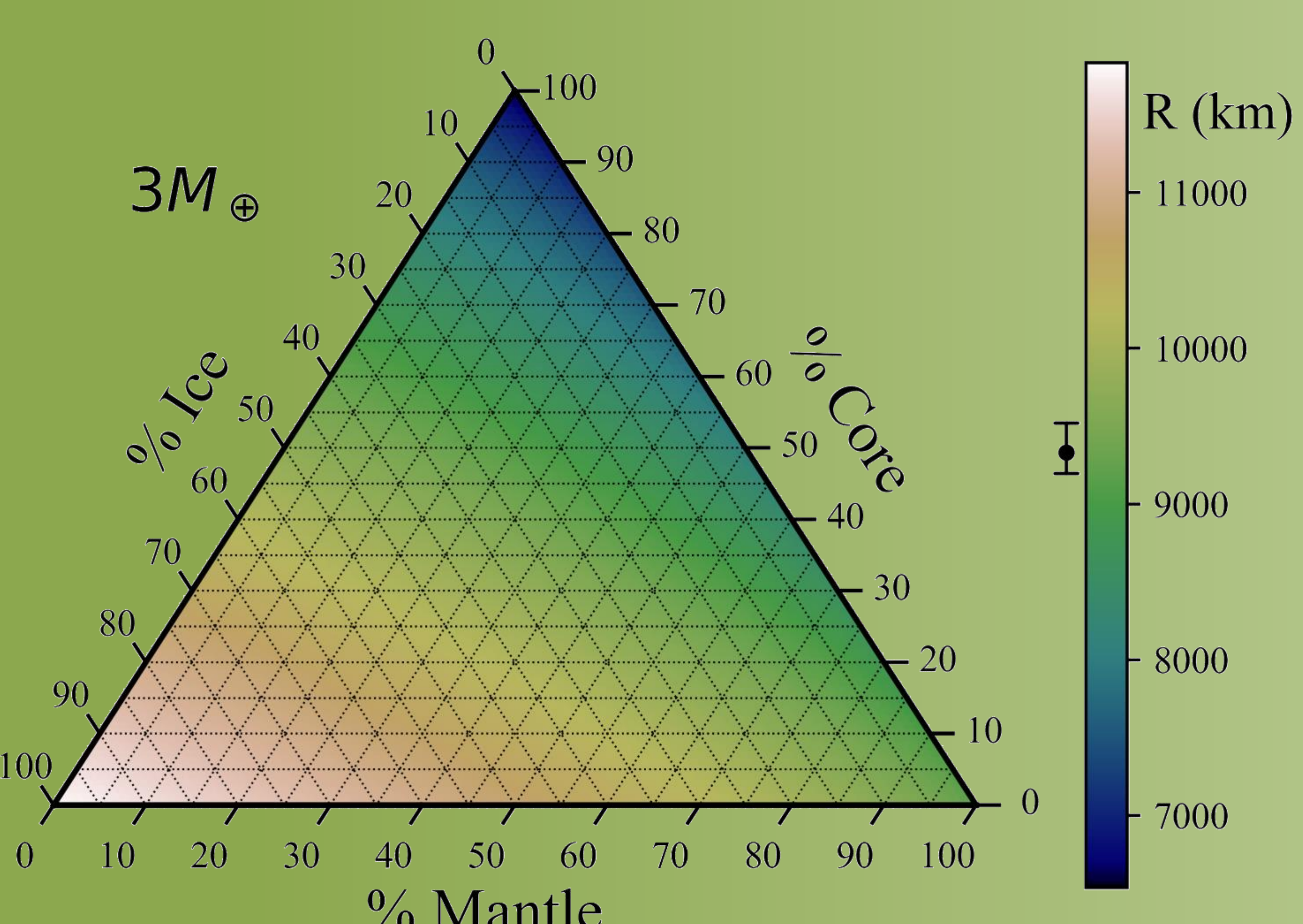
A **ternary diagram (below)** is a useful way to plot three variables that add to a constant. Use the tick marks as directional guides to read the radius with corresponding percentage of mass.

Carter et al. 2015

- Previous study on a disk of differentiated planetesimals with collisions and mantle erosion.
- Final planetary embryos grown from uniformly differentiated planetesimals can have a larger or smaller CMF than initial.
- A dynamically hot system, such as a system with a Grand Tack, will have a larger range in the final CMF of the embryos than a calm disk, since more high-velocity collisions occur.
- Erosive collisions are sufficient to explain the difference between the Earth and the chondrites (Fe/Mg ≈2.1 vs. ≈1.92).

***Right:* Figure from Carter et al. 2015 showing the max., mean, and min. CMF for embryos greater than two lunar masses across all simulations. Dashed lines represent the initial CMF of all bodies in the given simulation.**





***Left:* Shown is the radius of a three Earth mass planet with the corresponding ratio of core to mantle to ice. Radius calculated using the planet structure code, UNLVPlanet (C. Huang, UNLV).**

Error bar shows the radius of Kepler-10 b which has a mass of 3.33 ± 0.49 $M_\oplus$ and a radius of 1.47 +0.03/-0.02 $R_\oplus$.
From exoplanet.eu

Summary

- Inferring composition from a mass-radius relationship depends on the fraction of mass in differentiated layers.
- Mantle erosion from differentiated collisions has been shown to be influential in our solar system.
- We propose that by relating the range of CMF to formation history we can constrain the probable interiors of exoplanets.

References

Carter P. J., Leinhardt Z. M., Elliott T., Walter M. J., Stewart S. T., 2015, ApJ, 813, 72.
Leinhardt Z. M., Stewart S. T., 2012, APJ, 745, 79.
Marcus R. A., Stewart S. T., Sasselov D., Hernquist L., 2009, ApJ, 700, L118.
Mercury6 (Chambers 1999): http://www.arm.ac.uk/ jec/home.html

Produced and presented by David R. Rice. Contact: David.Rice@unlv.edu