JOURNEY TO A METAL WORLD: CONCEPT FOR A DISCOVERY MISSION TO PSYCHE.
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Visiting an iron core: We propose to visit the exposed iron core of a protoplanet by sending a mission [1] to (16) Psyche, by far the largest exposed iron metal body in the asteroid belt. At Psyche we will explore, for the first time ever, a world made not of rock or ice, but of iron (Fig. 1).

This mission would be a journey back in time to one of the earliest periods of planetary accretion, when the first bodies were not only differentiating, but were being pulverized, shredded, and accreted by collisions. It is also an exploration, by proxy, of the interiors of terrestrial planets and satellites today: we cannot visit a metallic core any other way.

For all of these reasons, coupled with the relative accessibility to low-cost rendezvous and orbit, Psyche is a superb target for a Discovery-class mission that would characterize its geology, shape, elemental composition, magnetic field, and mass distribution.

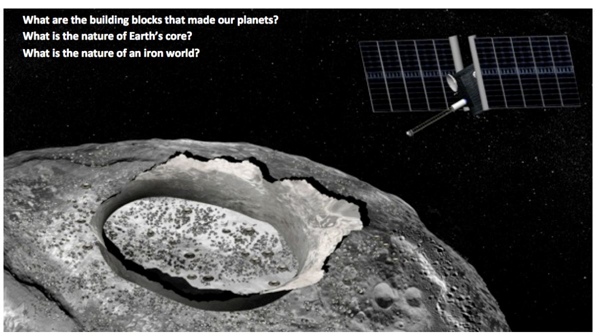

Figure 1: *Artist's conception of an orbiter around (16) Psyche. Impacts into metal will likely differ from those into silicates or ice; here frozen ejecta flaps are envisioned, though we cannot know what will be found at Psyche. Abundant compressional scarps are expected because of the high contraction of iron when it freezes. (JPL/Corby Waste)*

What is Psyche? Psyche's bulk density is consistent with an exposed iron core. Based on density, spectra, and radar surface properties, it appears to be a world not of ice or silicate rock, but predominantly of iron [2-7]. Planetesimals that formed earlier than about 1.5 to 2 Ma after the first solids in the solar system had sufficient heat from short-lived radionuclides to differentiate into a metallic core and a silicate mantle.

The most widely-accepted proposal for creating an almost naked core is that one or more massive collisions stripped this body of its silicate crust and mantle (Fig. 2). The most plausible scenario for mantle stripping is hit-and-run collisions with other planetesimals [8, 9].

The surviving metal core may have been molten before stripping, and may also have been melted by the impacts that stripped it or by later impacts. A melted core may produce a core dynamo and attendant magnetic field as it cools.

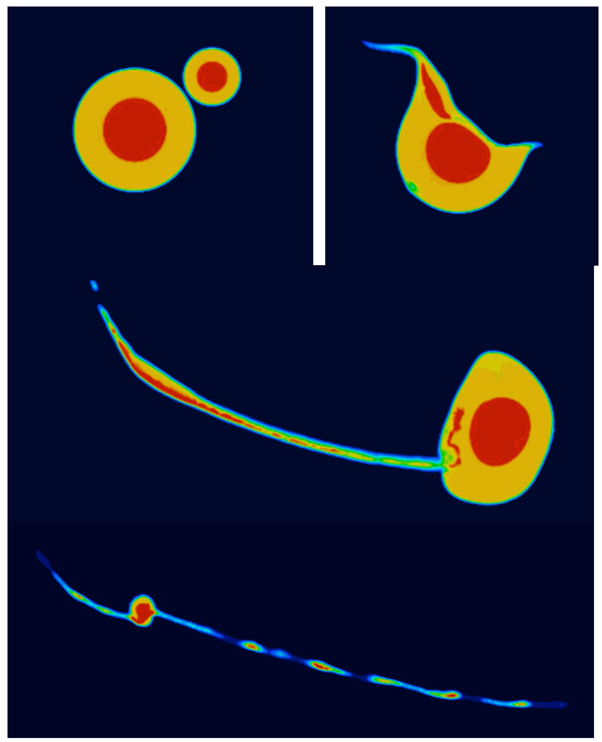

Figure 2: *Four frames in a time sequence from a hit-and-run simulation by Jutzi and Asphaug (unpublished), shows a Vesta-sized asteroid in a 10:1 mass ratio collision. In the final frame a highly iron-rich analog to Psyche is formed. In this simulation,* $V_{imp} = 2*V_{esc}$.

How do metallic cores solidify? Iron meteorite compositions indicate that protoplanet cores in some cases crystallized from the inside out (like the Earth's core), and in others from the outside in [10-12] (Fig. 3). A body stripped of its mantle is most likely to cool from the outside in.

We expect to be able to determine how this body solidified:

- Only crystallization from the outside in would produce material below its Curie point during the period of dynamo action and thus capable of becoming magnetized.

- Fractional solidification creates a compositional signature that may be detectable [13].
- During solidification, light elements that prefer the liquid phase are excluded from growing metal crystals and enriched in the remaining liquid. Thus a body that solidified from the outside in would likely have a low-density inner core that might be detected in the moment of inertia factor.

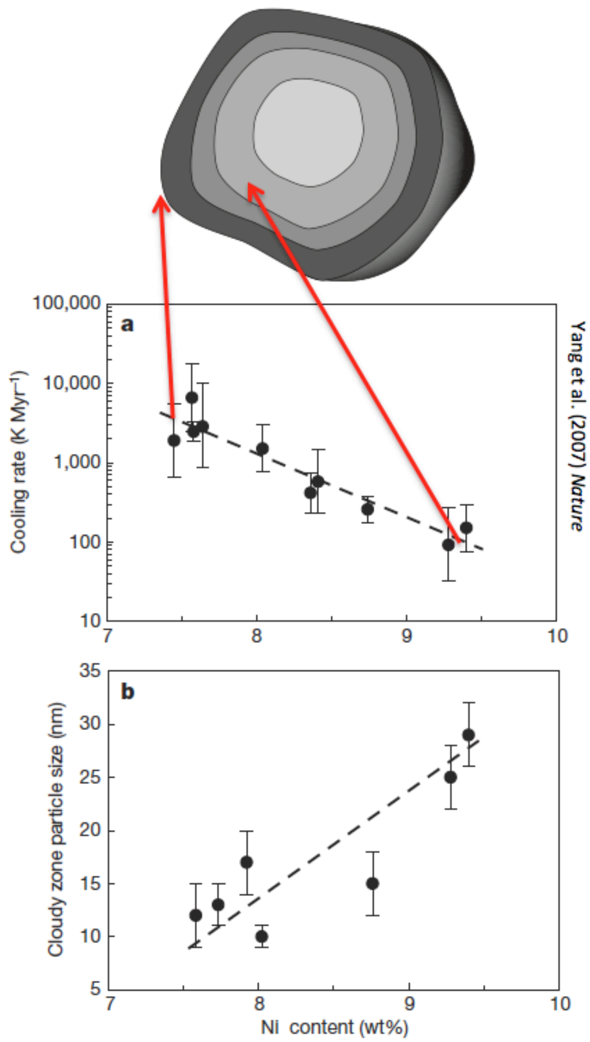

Figure 3: *Iron meteorites contain ~4 to ~60 mass% nickel. Nickel increases in the solid as fractional solidification of an iron-nickel liquid proceeds. Thus, a body that has fractionally solidified from the outside in would have relatively low nickel on its surface, and high nickel in its interior. We expect a range of nickel contents on Psyche, created by fractional solidification. Psyche may be the parent body of the IVA iron meteorite family [13, 14], in which case its Ni fraction will be ~7 - 12 mass% of the metal.*

Fundamental advances in understanding planetary formation and interiors: The science questions this mission will address are:

1. Is Psyche the stripped core of a differentiated planetesimal, or was it formed as an iron-rich body?
   - What were the building blocks of planets?
   - Did planetesimals that formed close to the Sun have very different bulk compositions?
2. If Psyche was stripped of its mantle, when and how did that occur?
3. If Psyche was once molten, did it solidify from the inside out, or the outside in?
4. Did Psyche produce a magnetic dynamo as it cooled?
5. What are the major alloying elements that coexist in the iron metal of the core?
6. What are the key characteristics of the geologic surface and global topography?
   - This is a new field: geology of metal objects.
   - Does Psyche look radically different from known stony and icy bodies?
7. How do craters on a metal body differ from those in rock or ice?

Accomplishing the Goals of the Decadal Survey: This proposal is well aligned with priorities from the Decadal Survey, *Vision and Voyages*, which specifically promotes a mission like this one (p. 104): "Orbital/rendezvous missions to selected comets or asteroids of high scientific interest—While Dawn's exploration of 4 Vesta represents a first spacecraft study of a differentiated asteroid, a logical follow-on would be an orbital mission to explore an M-class asteroid with high radar reflectivity that could reasonably be the stripped core of a differentiated asteroid. Differentiation was a fundamental process in shaping many asteroids and all terrestrial planets, and direct exploration of a core could greatly enhance understanding of this process."

References: [1] Elkins-Tanton, L. T., et al. (2013) LCPM-10 abstract. [2] Matter, A. (2013) *Icarus*, 226, 419. [3] Shepard, M. K. (2008) *Icarus*, 195, 184. [4] Magri, C. (1999) *Icarus*, 140, 379. [5] Kuzmanoski, M. and A. Koračević (2002) *Astron. Astrophys.*, 395, L17. [6] Baer, J. (2011) *Astronom. J.*, 141, 1. [7] Lupishko, D. F. (2006) *Solar Sys. Res.*, 40, 214. [8] Asphaug, E. (2006) *Nature*, 439, 155. [9] Asphaug, E. (2010) *Chemie der Erde*, 70, 199. [10] Fricker, P. E. (1970) *Geochem. Cosmochim. Acta*, 34, 475. [11] Goldstein, J. I. (2009) *Chemie der Erde*, 69, 293. [12] Williams, H. (2006) *EPSL*, 250, 486. [13] Yang, J. (2007) *Nature*, 446, 888. [14] Yang, J. (2008) *Geochim. Cosmochim. Acta*, 72, 3043.