ASTEROID (16) PSYCHE: THE SCIENCE OF VISITING A METAL WORLD. L.T. Elkins-Tanton[1], E. Asphaug[2], J. Bell[2], D. Bercovici[3], B.G. Bills[4], R.P. Binzel[5], W.F. Bottke[6], J. Goldsten[7], R. Jaumann[8], I. Jun[4], D.J. Lawrence[7], S. Marchi[6], D. Oh[4], R. Park[4], P.N. Peplowski[7], C.A. Polanskey[4], T.H. Prettyman[10], C.A. Raymond[4], C.T. Russell[11], B.P. Weiss[5], D.D. Wenkert[4], M. Wieczorek[9], M.T. Zuber[5], [1]School of Earth and Space Exploration, Arizona State University, 781 Terrace Rd., Tempe AZ 85287, ltelkins@asu.edu, [2]ASU, [3]Yale, [4]JPL, [5]MIT, [6]SwRI, [7]APL, [8]DLR, [9]IPGP, [10]PSI, [11]UCLA.

We describe a Discovery-class mission, selected for a Step 2 concept study, to investigate an exposed metal planetary core. Our target is the large asteroid Psyche (~240 x 185 x 145 km) that orbits at 3 AU. It is made almost entirely of Fe-Ni metal, as indicated by:

- High radar albedo of 0.42 [1]
- Thermal inertia of ~120 J m^{-2} $S^{-0.5}$ K^{-1} [2] (Ceres, Pallas, Vesta, Lutetia are all 5 to 30 J m^{-2} $S^{-0.5}$ K^{-1})
- Density estimates of 6,980 ± 580 kg m^{-3} [3], 6,490 ± 2,940 kg m^{-3} [4, 5], and 7,600 ± 3,000 kg m^{-3} [6].

A 0.9 µm absorption feature suggests 10% of Psyche's surface is high-magnesian orthopyroxene [7].

Psyche may be:

- A larger planetesimal's exposed core, once molten, that solidified either inside-out or outside-in, and is now either intact or now broken into a rubble pile;
- Not a core, but instead highly reduced, primordial metal-rich materials that accreted, but never melted.

Fig 1: *Discovery-class investigation of Psyche. The mission plan includes solar electric cruise, arrival at Psyche in 2026, and 12 months of science operations.*

Hit-and-run collisions could create Psyche: Despite living on this planet and being able to study it more closely than any other, we continue to revise our models of Earth's core, in part because we cannot see or measure the core directly. Psyche offers a unique window into the violent history of collisions and accretion that created the planets and their cores.

Meteorite geochronology reveals that metal cores formed within the first half million years [8]. Meteorites also reveal that many differentiated bodies, including iron meteorite parent bodies, produced magnetic dynamos [9-11]. High-energy impacts were ubiquitous in the early solar system, so cores likely formed and reformed repeatedly.

Models show that there were many destructive "hit and run" impacts that could strip the silicate mantle from differentiated bodies, leaving an exposed metal core. This is the leading hypothesis for Psyche's formation (Fig. 1). Psyche is the only asteroid that will yield substantial information about metal cores (other metallic asteroids are far smaller and not roughly spherical).

The Psyche investigation has three broad goals:

1. Understand a previously unexplored building block of planet formation: iron cores.
2. Look inside the terrestrial planets, including Earth, by directly examining the interior of a differentiated body, which otherwise could not be seen.
3. Explore a new type of world. For the first time, examine a world made not of rock, ice, or gas, but of metal.

Psyche mission objectives

A. Determine whether Psyche is a core, or if it is unmelted material.

B. Determine the relative ages of regions of its surface.

C. Determine whether small metal bodies incorporate the same light elements as are expected in the Earth's high-pressure core.

D. Determine whether Psyche was formed under conditions more oxidizing or more reducing than Earth's core.

E. Characterize Psyche's topography.

We will meet these objectives by examining Psyche with three high heritage instruments and radio science:

1. Multispectral imagers (MSL Mastcam heritage) with clear and seven color filters provide surface geology, composition, and topographic information [12].
2. A gamma-ray and neutron spectrometer (MESSENGER heritage) determines the elemental composition for key elements (e.g., Fe, Ni, Si, and K) as well as compositional heterogeneity across Psyche's surface [13, 14].
3. Dual fluxgate magnetometers characterize the magnetic field [15].
4. Radio science will map Psyche's gravity field using the X-band telecomm system.

Synthesis and Expected Outcomes If our magnetometer detects a coherent dipolar field, then Psyche had a core magnetic dynamo and solidified outside-in, allowing the cold solid exterior to record the magnetic field [16]. We would then expect to find Ni content of ~4 wt% (or slightly lower if diluted with other material), consistent with the first solidifying metal in a fractionating core. Nickel of 6–12 wt% indicates the surface was the last material to solidify and thus the core solidified inside-out. We would expect no remanent magnetic field, since there would have been no cool surface material to record the field while the dynamo was working (Fig. 2).

If we find very low nickel content, and no coherent magnetic field, then we may arrive at perhaps the most exciting hypothesis: Psyche never melted, but consists of highly reduced, primordial metal. This hypothesis would be further supported by the discovery of no mantle silicates, but instead reduced silicates mixed on a small scale throughout the surface. The likeliest place for such material to exist is closest to the Sun in the early disk, where temperatures are very hot (reducing) and light elements are volatilized away, leaving heavy elements and metals. This outcome would support the hypothesis of Bottke et al. [17], that such bodies were injected into the asteroid belt from the innermost solar system. This kind of migration has been little considered.

If we find a coherent dipolar magnetic field and either higher or lower average surface nickel content, then we have found something unexpected based on existing models for small core formation.

If we discover that Psyche has a magnetic field, then we will have detected in situ magnetization at an asteroid for the first time. The increasing evidence that some planetesimals had magnetic dynamos requires that they had convecting metallic cores, but our understanding of the ways they solidify makes modeling their dynamos difficult. If Psyche was a core and solidified from the outside inward, it is an analog for Mercury's and Ganymede's cores in the present day, which may be solidifying this way [18]. This unexpected process could be observed on Psyche as can never be done on Mercury. Solidification inside out, in contrast, parallels the Earth's core.

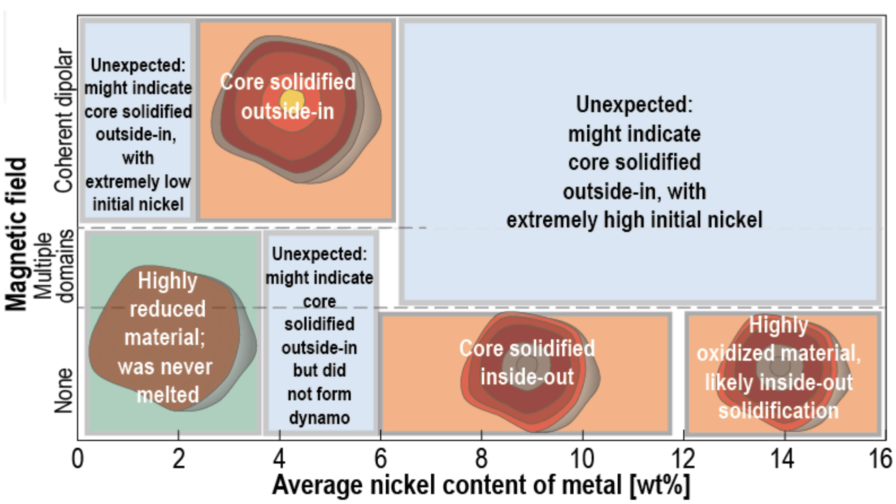

Fig. 2. *Instrument measurements allow hypothesis discrimination. Ni content and magnetic field shows the utility of having multiple instruments addressing the same hypotheses. Ni below 4 wt% is not detectable by our instruments, but we will use magnetic field measurements, silicate domain size, and oxidation state to discriminate between the two low-Ni models.*

[1] Shepard et al. (2010) *Icarus*, 208, 221. [2] Matter et al. (2013) *Icarus*, 226, 419. [3] Kuzmanoski & Koračević (2002) *Astron. & Astrophys.*, 395, L17. [4] Baer et al. (2011) *Astronom. J*, 141, 1. [5] Lupishko (2006) *Solar Sys. Res.*, 40, 214. [6] Shepard et al. (2008) *Icarus*, 195, 184. [7] Hardersen et al. (2005) *Icarus*, 175, 141. [8] Scherstén, et al. (2006) *EPSL*, 241, 530. [9] Tarduno et al. (2012) *Science*, 338, 939. [10] Elkins Tanton et al. (2011) *EPSL*, 305, 1. [11] Bryson et al. AGU abstract (2015). [12] Bell et al., this LPSC (2016). [13] Peplowski et al., this LPSC (2016). [14] Lawrence et al., this LPSC (2016). [15] Weiss et al., this LPSC (2016). [16] Scheinberg et al., this LPSC (2016). [17] Bottke et al. (2006) *Nature*, 439, 821. [18] Hauck et al. (2013) *JGR*, 118, 1204.