Lindy Elkins-Tanton, P.I. (ASU)

Jim Bell, Deputy P.I. (ASU)

Presentation to NASA/SBAG

14th Meeting; Monrovia, CA

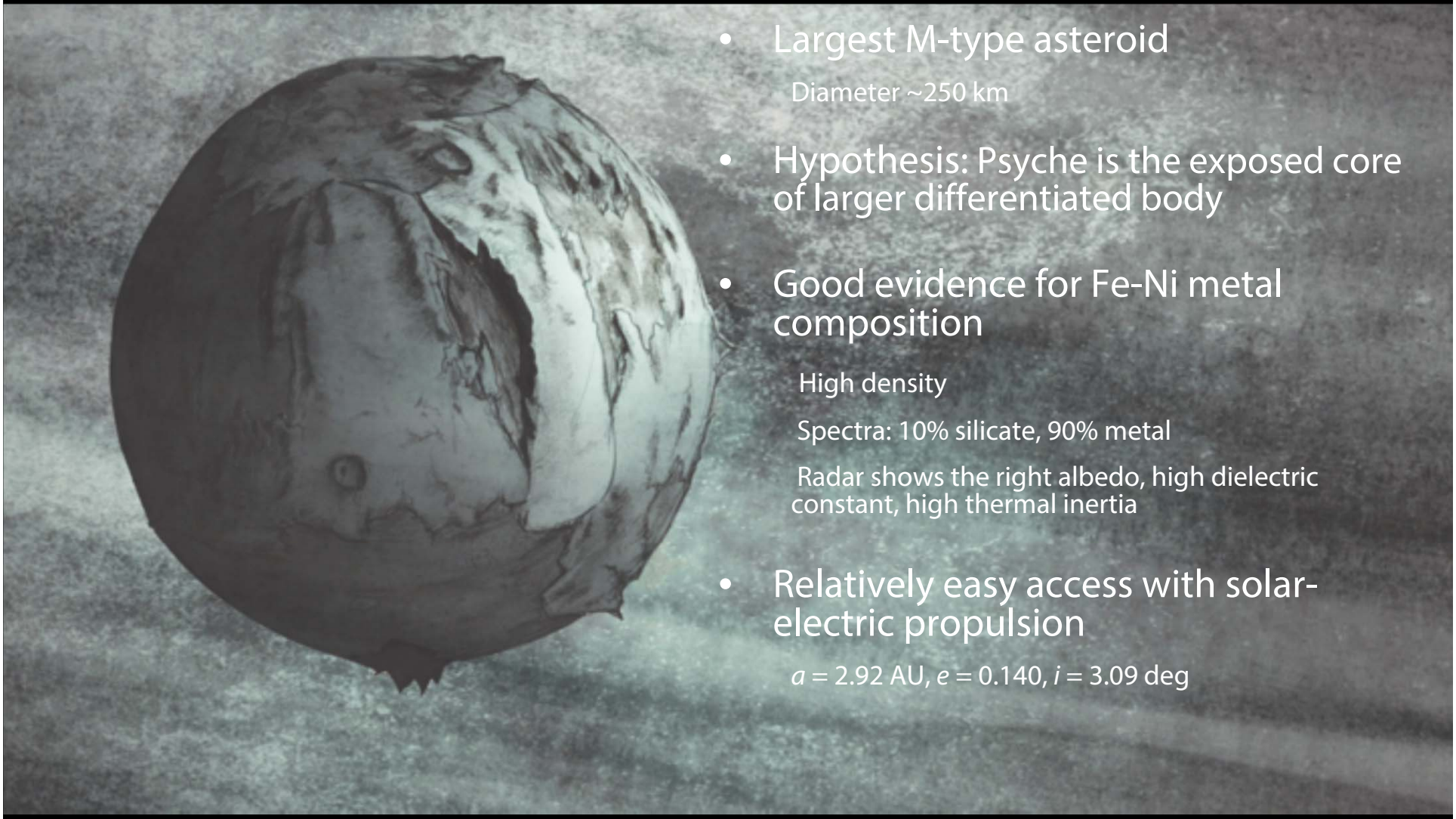
28 January 2016

Prepared for the National Aeronautics and Space Administration Science Mission Directorate; Submitted in response to AO NNH14ZDA014O

Dr. Linda Elkins-Tanton, Principal investigator, Arizona State University

Heather Clark, Associate Director of Research Administration, Authorized Organizational Representative

Why (16) Psyche?



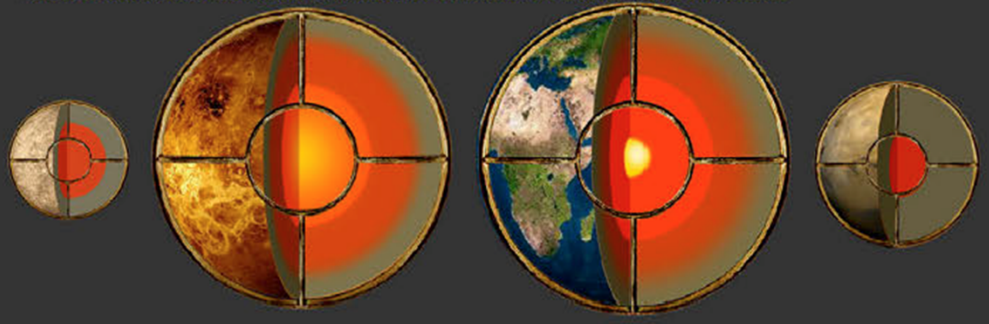
- Largest M-type asteroid
  - Diameter ~250 km
- Hypothesis: Psyche is the exposed core of larger differentiated body
- Good evidence for Fe-Ni metal composition
  - High density
  - Spectra: 10% silicate, 90% metal
  - Radar shows the right albedo, high dielectric constant, high thermal inertia
- Relatively easy access with solar-electric propulsion
  - a = 2.92 AU, e = 0.140, i = 3.09 deg

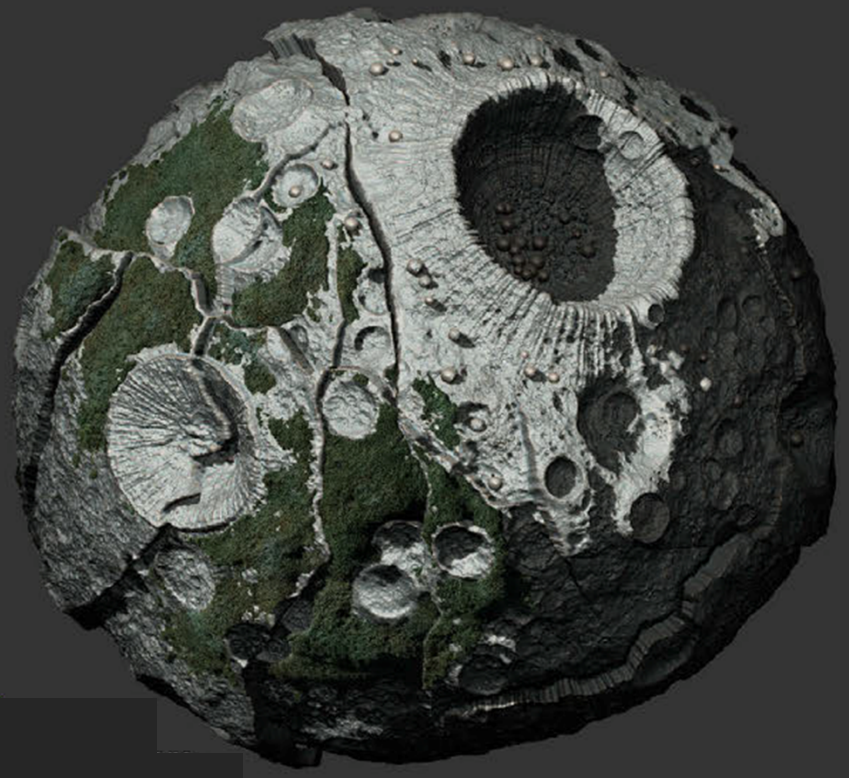
Image credit: Christopher Sullivan

PSYCHE

Journey to a metal world

The metal world Psyche is a unique window into the formation of planetary cores





SCIENCE GOALS

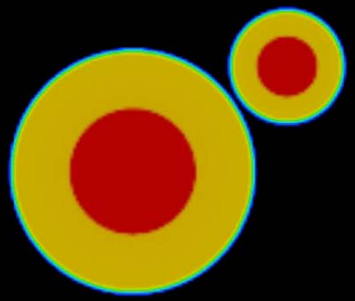
1. Understand a previously unexplored building block of planet formation: iron cores.
2. Look inside the terrestrial planets, including Earth, by directly examining the interior of a differentiated body, which otherwise could not be seen.
3. Explore a new type of world. For the first time, examine a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

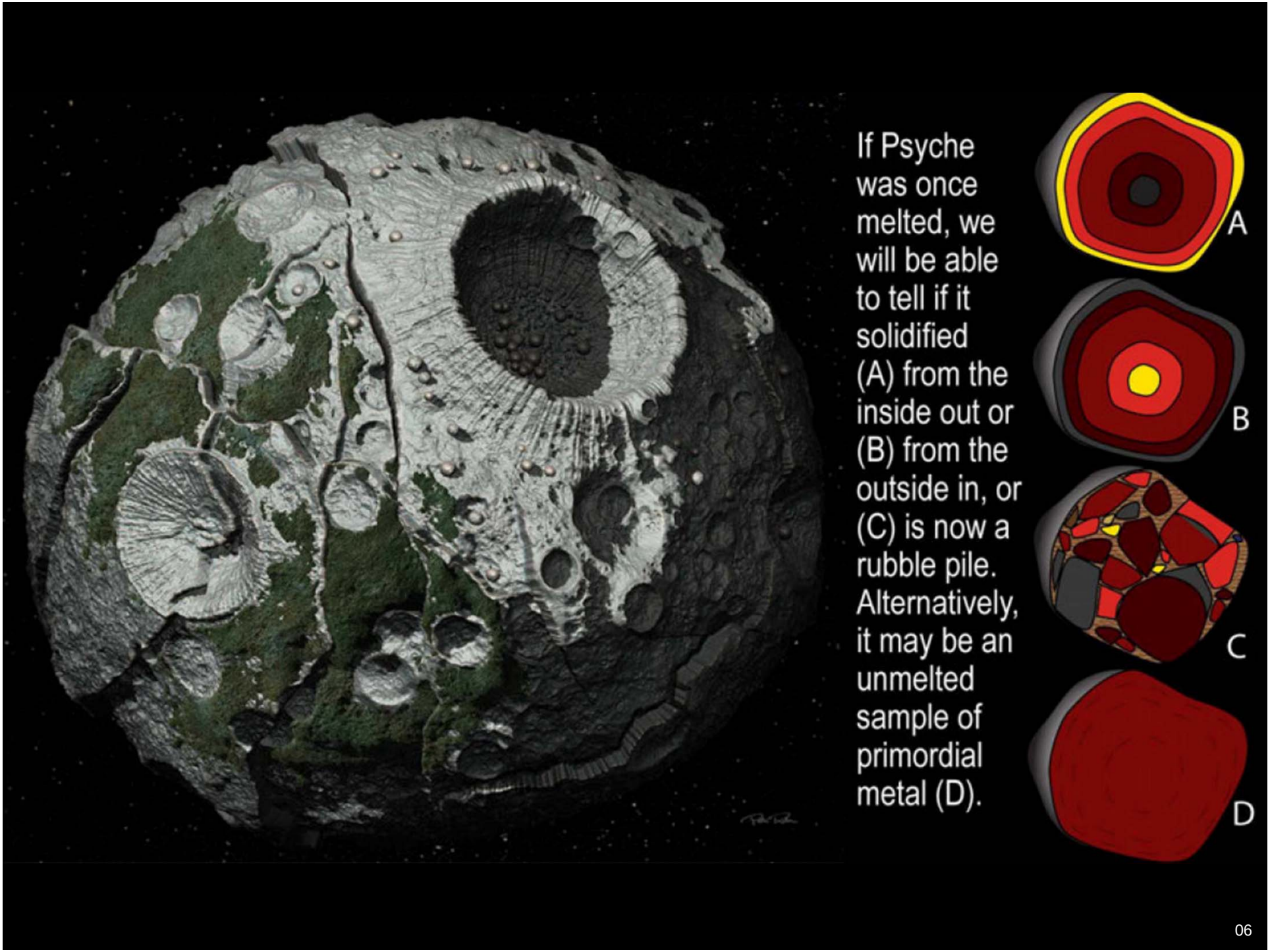
Psyche is most likely a survivor of violent hit-and-run collisions that stripped away the outer layers of a protoplanet.

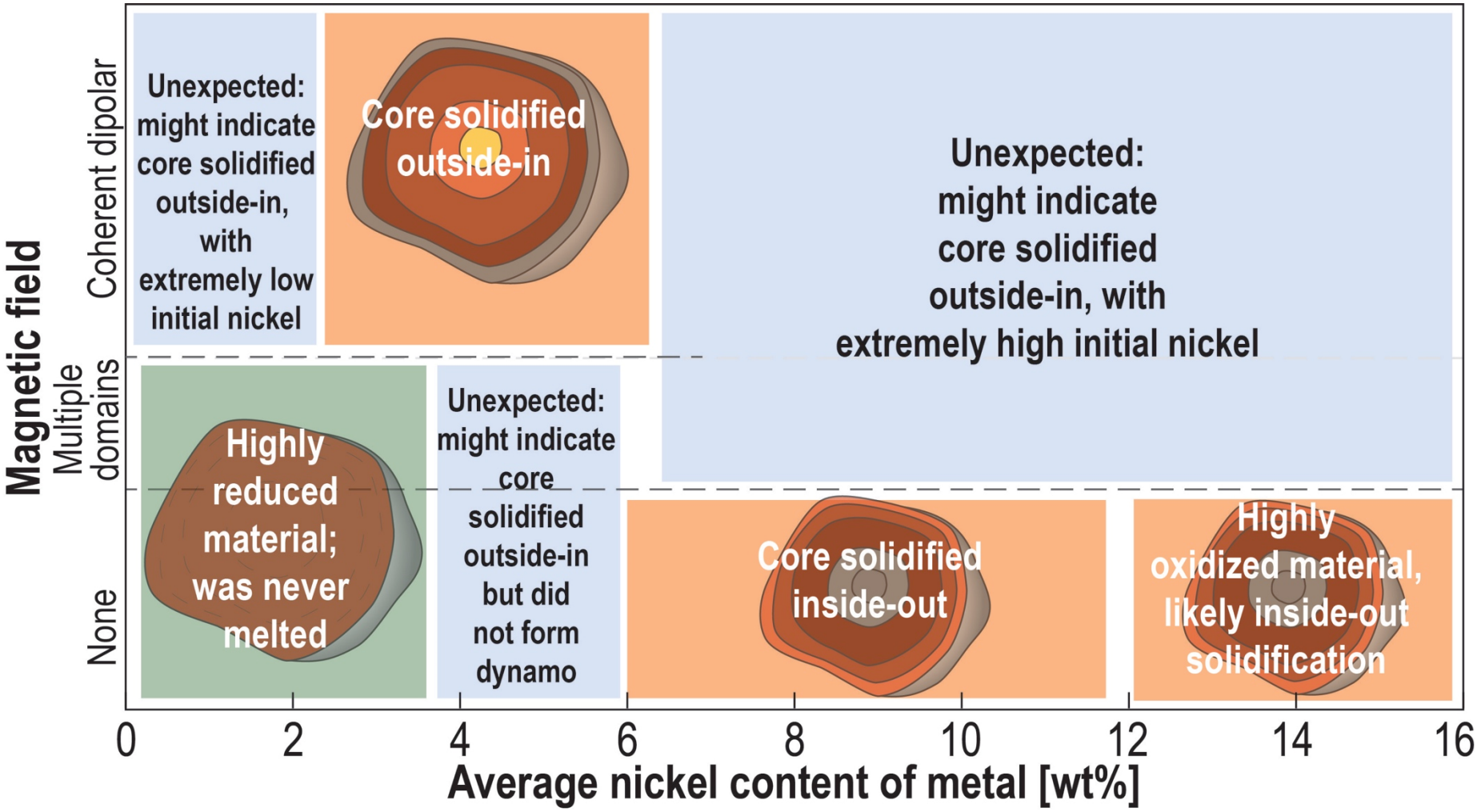
Objective A: Determine whether Psyche is a core, or if it is unmelted material.

Psyche may be the result of a hit-and-run collision(s) early in solar system history, which stripped its mantle and restarted its core dynamo.

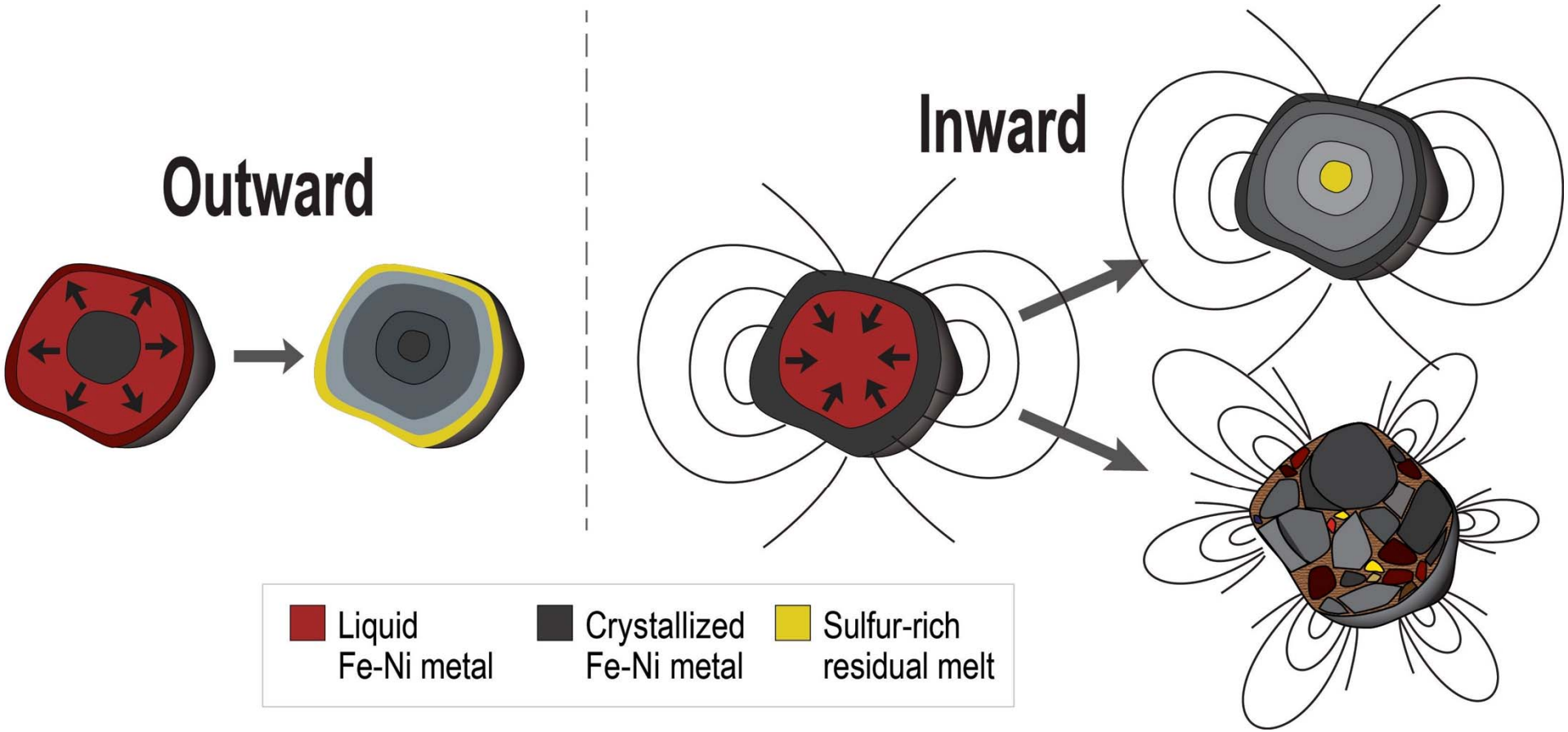
Jutzi and Asphaug (unpublished), shows a Vesta-sized asteroid in a 10:1 mass ratio collision, at $V_{imp} = 2*V_{esc}$

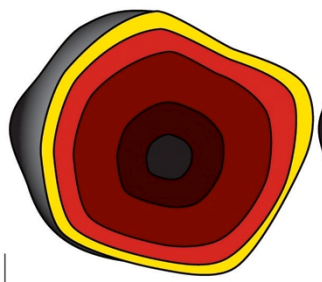
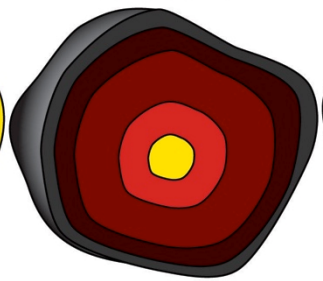
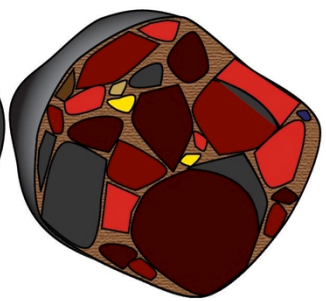
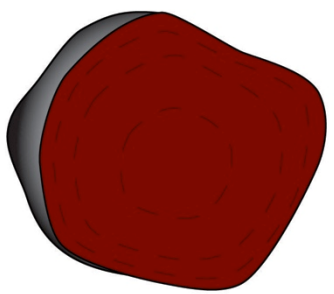



If Psyche was once melted, we will be able to tell if it solidified (A) from the inside out or (B) from the outside in, or (C) is now a rubble pile. Alternatively, it may be an unmelted sample of primordial metal (D).
A
B
C
D

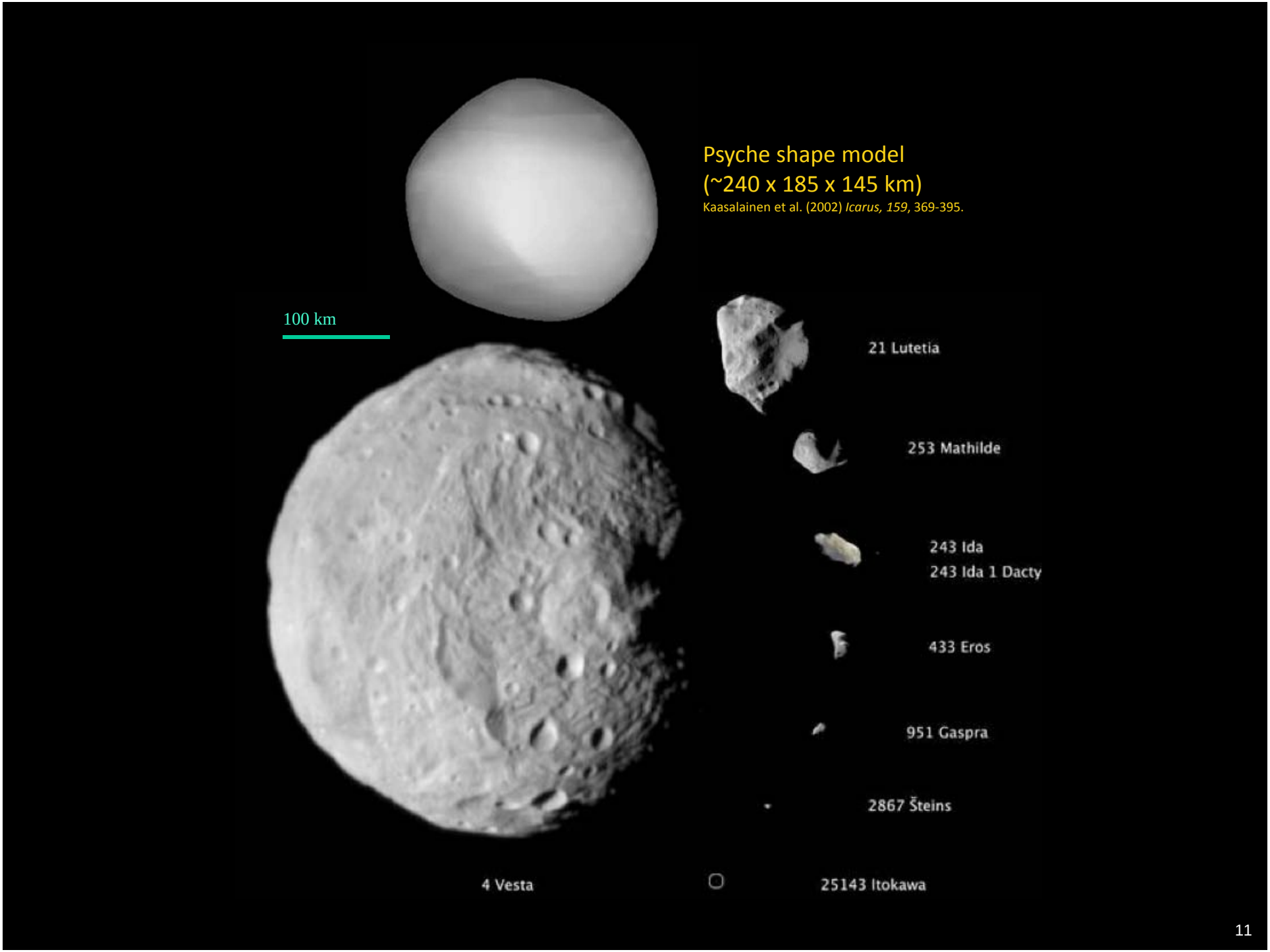


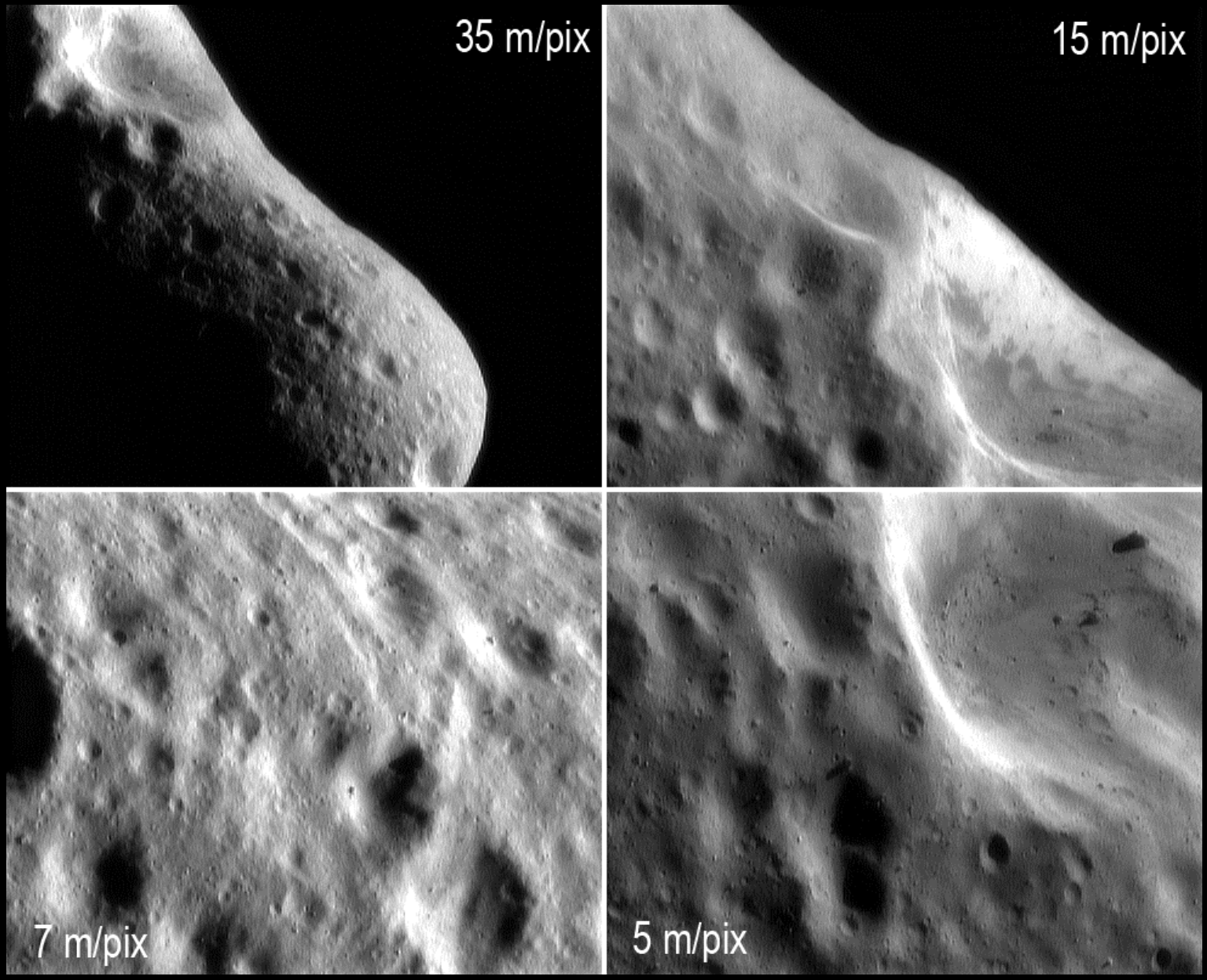
from Elkins-Tanton *et al.,* LPSC 2016


Outward
Inward
Liquid
Fe-Ni metal
Crystallized
Fe-Ni metal
Sulfur-rich
residual melt

	Core of a differentiated planetesimal			Accretion of highly reduced primordial metal
	Largely intact core, solidified inside out	Largely intact core, solidified outside in	Later broken up into rubble pile	
				
FeS (troilite) and silicates	patchy on surface	patchy on surface	patchy on surface	homogeneously dispersed on surface at fine scale
Ni content of surface	~6–12 wt%	~2–6 wt%	hetero-geneous	≤ 4 wt%
Magnetic field	None	Coherent dipolar	Multiple domains or none	Multiple domains or none

Objective B: Determine the relative ages of Psyche's surface regions.

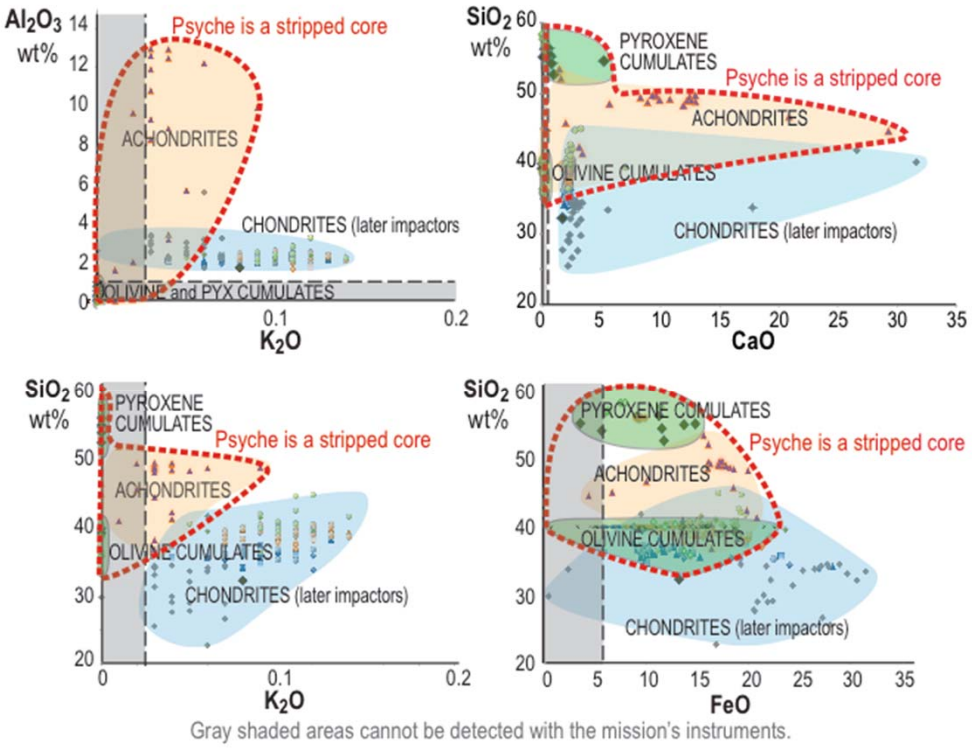

Psyche shape model
(~240 x 185 x 145 km)
Kaasalainen et al. (2002) *Icarus, 159*, 369-395.
100 km
21 Lutetia
253 Mathilde
243 Ida
243 Ida 1 Dacty
433 Eros
951 Gaspra
2867 Šteins
4 Vesta
25143 Itokawa



Example imaging resolution on 433 Eros

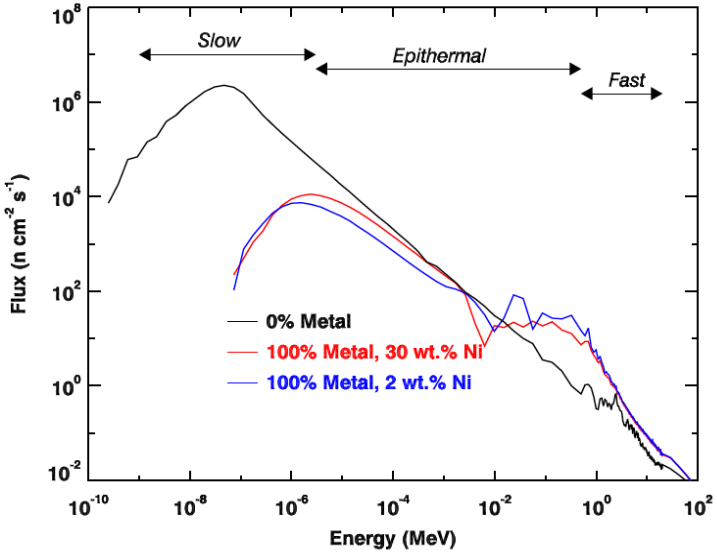
NEAR-Shoemaker mission
NASA/APL/Cornell

Objective C: Determine whether small metal bodies incorporate the same light elements as are expected in the Earth's high-pressure core.
(Si, K, S)

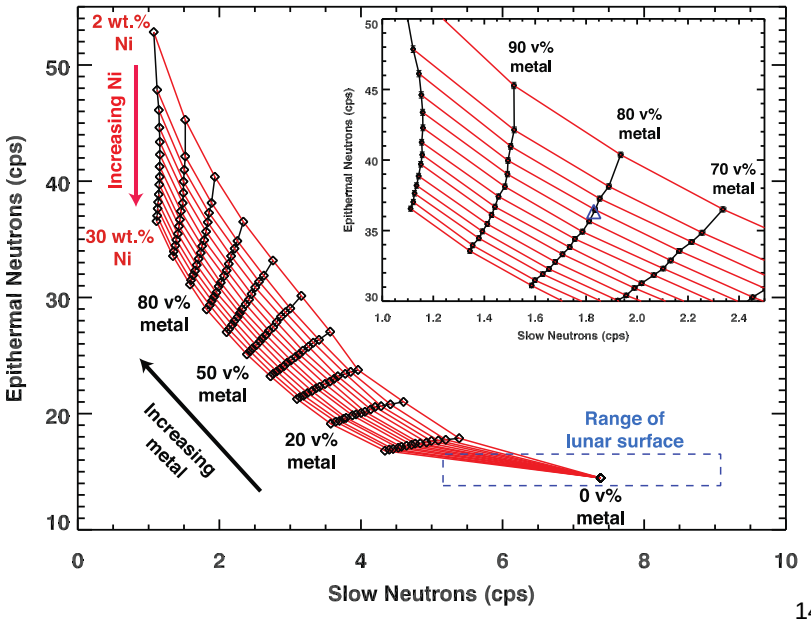


Gray shaded areas cannot be detected with the mission's instruments.

Is Psyche a core, or unmelted primitive material? Bulk major element compositions can discriminate among possible types of silicates. Achondritic or cumulate compositions likely indicate Psyche is a stripped core; chondritic compositions could be from later impactors.

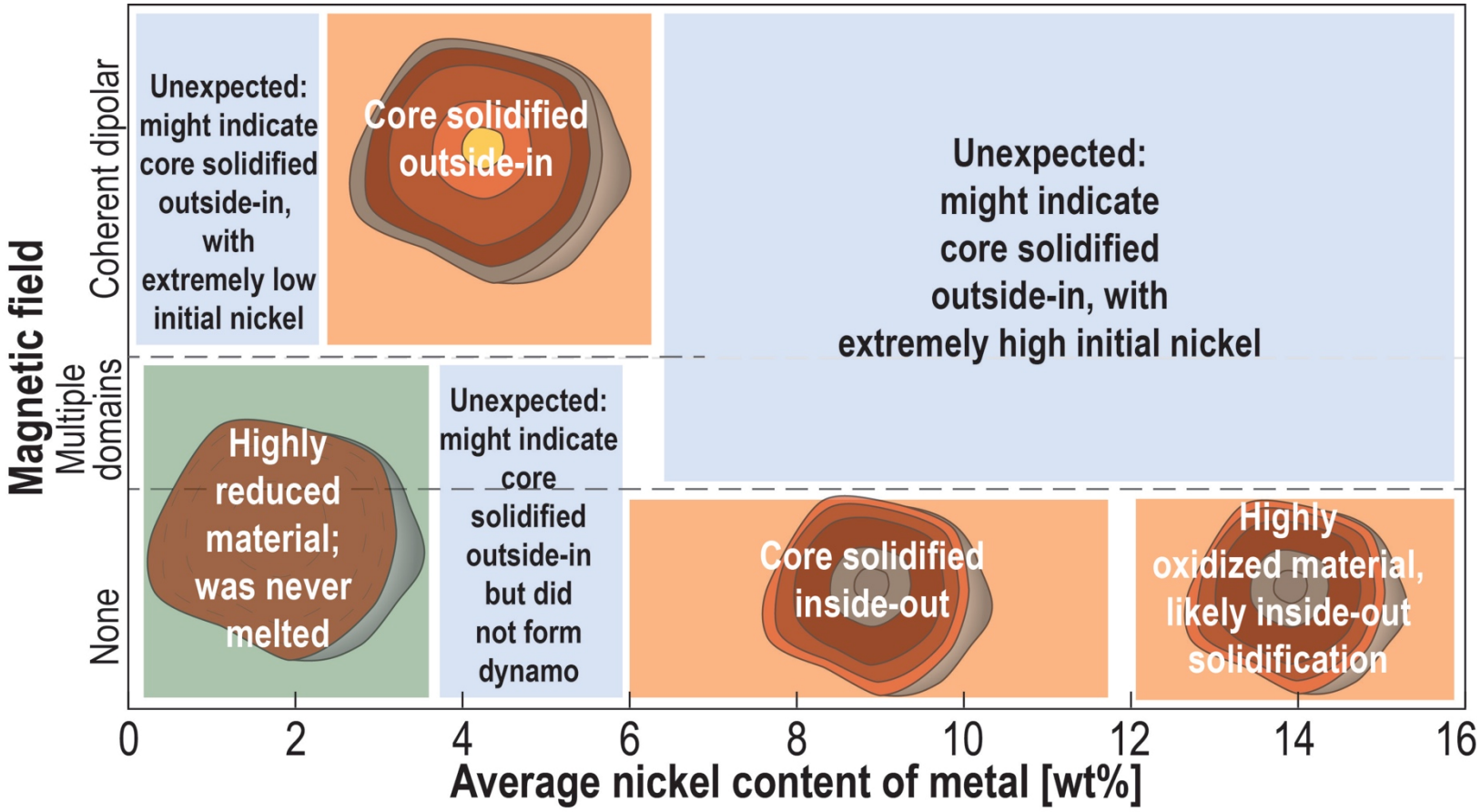


Metal Neutrons. Modeled neutron flux spectra for a possible Psyche surface compositions, ranging from provinces containing no metal (black) to 100% metal (red and blue). High (30 wt.%, red) and low (2 wt.%, blue) Ni concentrations within the high-metal case are shown. Figure from Lawrence *et al.*, LPSC 2016.



Sensitivity to Ni. Modeled count rates for slow and epithermal neutrons for a range of metal to pyroxene fractions (vol.%, black) and concentration of Ni in the metal (wt.%, red). Count rates for 8 wt.% Ni and 80 vol.% metal shown as blue triangle in inset; statistical errors for mapping are the size of the black data symbols.
Figure from Lawrence *et al.*, LPSC 2016.

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



More reducing...

More oxidizing...

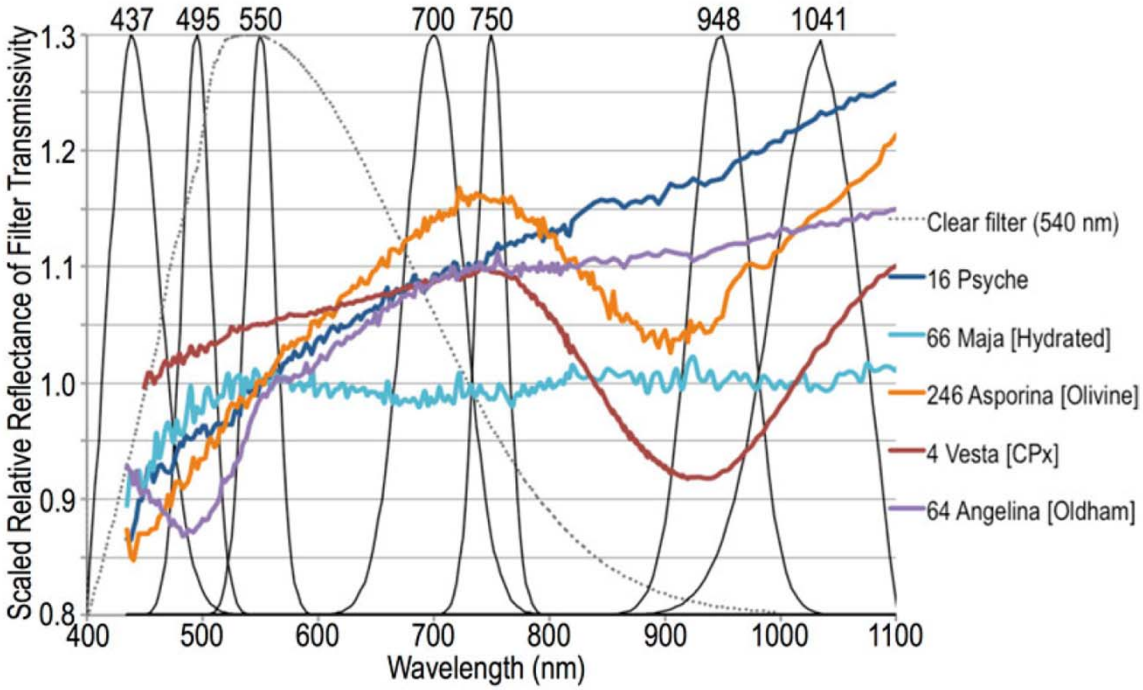
from Elkins-Tanton *et al.,* LPSC 2016

Table 1. Psyche Multispectral Imager Filters		
Band[a]	*λ (nm)*	*Science Objective*
Clear	540 ± 280	Unfiltered CCD for OpNav, topography, and geologic characterization
B	437±50	Asteroid classification and blue component of true color
o	495±25	Search for evidence of oldhamite
v	550±25	Oldhamite continuum and green component of true color
w	700±50	Typical peak reflectance continuum and red component of true color
0.75	750±25	Search for evidence of low-Ca pyroxene
p	948±50	Search for evidence of higher Ca pyroxene band and characterize weak Psyche Earth-based spectral feature
z	1041±90	Search for evidence of olivine

[a]Eight Color Asteroid Survey filter designations [3].

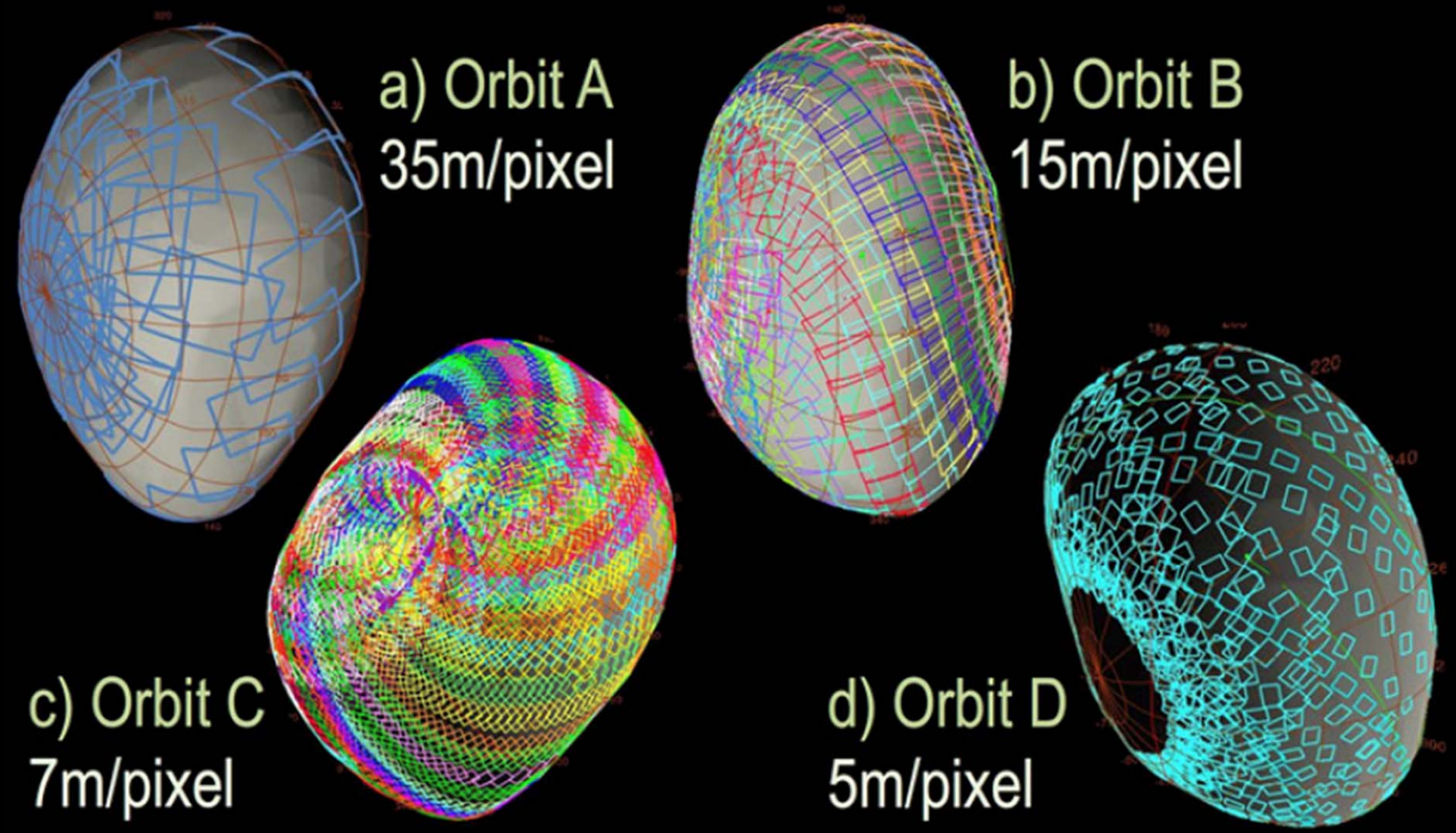
from Bell *et al.,* LPSC 2016

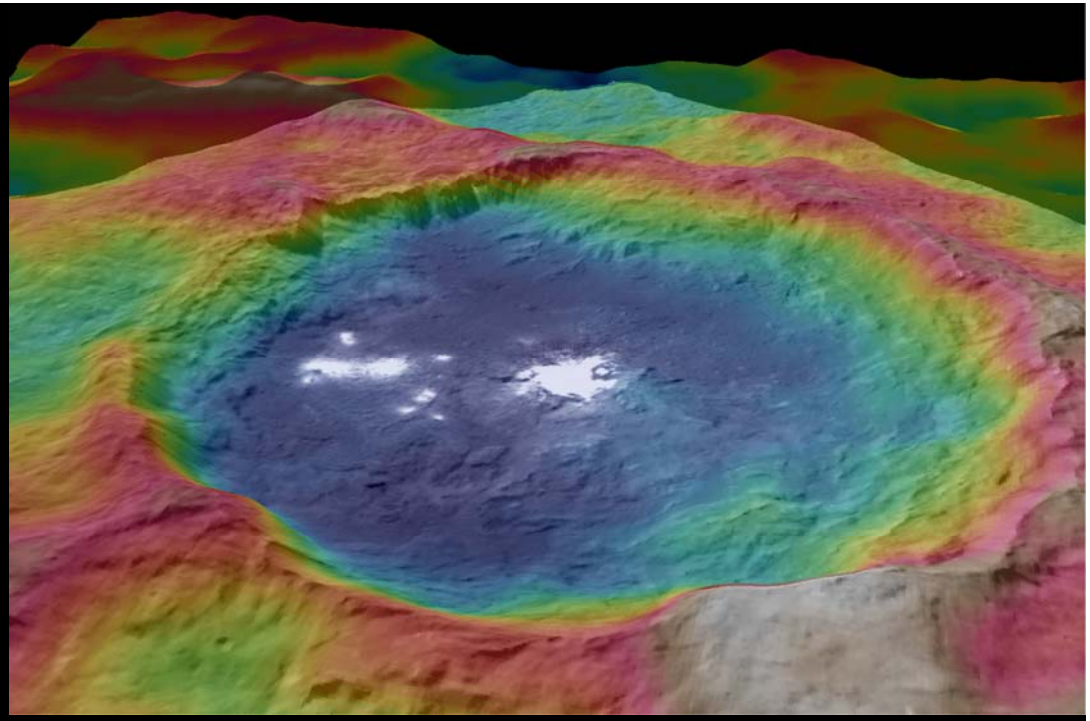
Psyche Multispectral Imaging



The composition of any coexisting sulfides [oldhamites, that is, (Fe, Mg, Ca)S] also indicate redox condition. FeS is formed over a range of oxidation conditions, while MgS or CaS require very reducing conditions (IW-3 or lower).

Objective E: Characterize Psyche's topography.


a) Orbit A
35m/pixel
b) Orbit B
15m/pixel
c) Orbit C
7m/pixel
d) Orbit D
5m/pixel

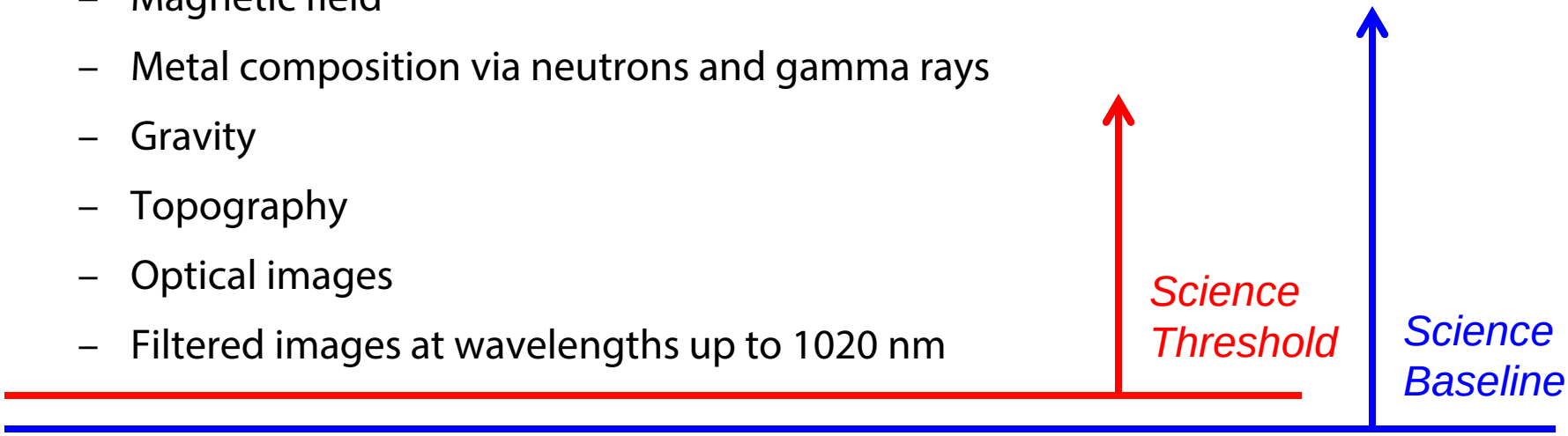


Ceres (top) and Vesta (bottom)

Dawn mission
NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

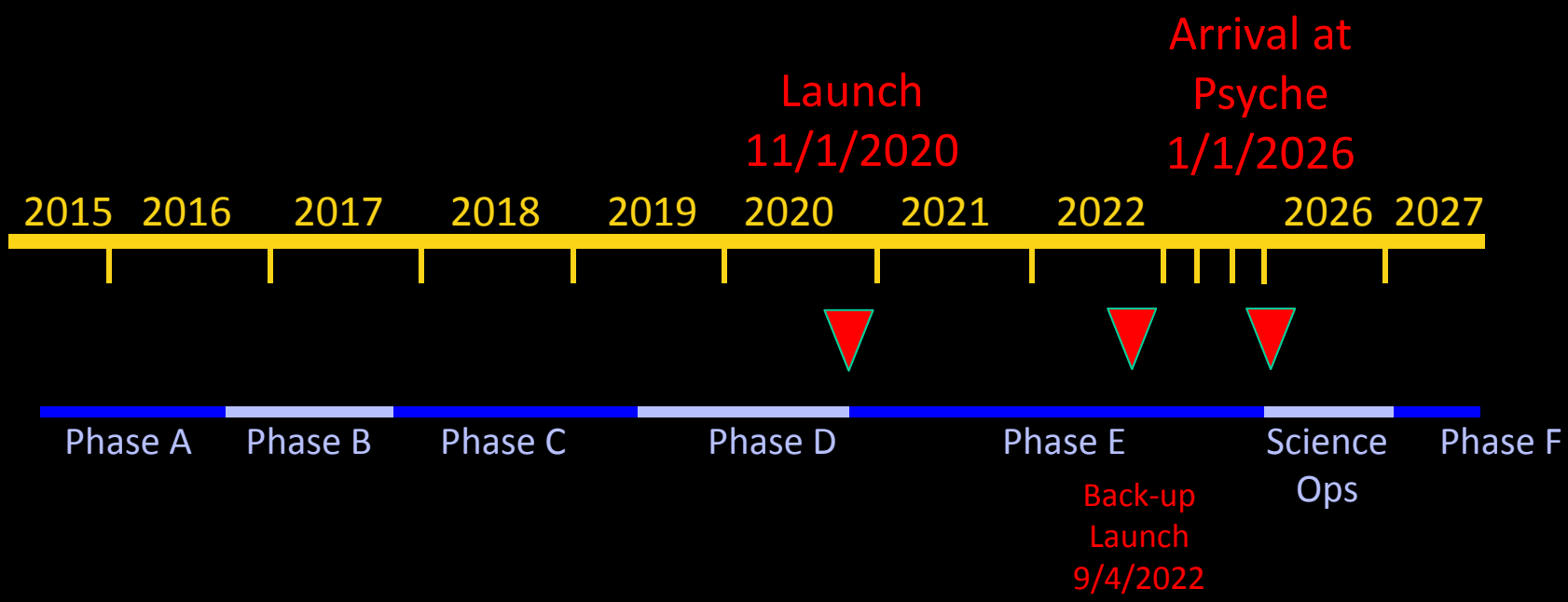
Required Measurements to meet Psyche Science Objectives:

- Magnetic field
- Metal composition via neutrons and gamma rays
- Gravity
- Topography
- Optical images
- Filtered images at wavelengths up to 1020 nm



We are targeting the simplest mission that produces transformational science. We have no additional science beyond the threshold.

Nominal Psyche Mission Timeline...



Nominal Psyche Orbital Plan...

One year of operations at Psyche

Approach: (100 days)

- Optical navigation and instrument calibration, hazard assessment
- Psyche spin axis and rotation period determination

Orbit A: Characterization: 40 days (29 orbits, 7 mapping cycles)

- Nadir mapping for preliminary shape determination, gravity science, and global color mapping

Orbit B: Topography: 42 days (90 orbits, 5 mapping cycles)

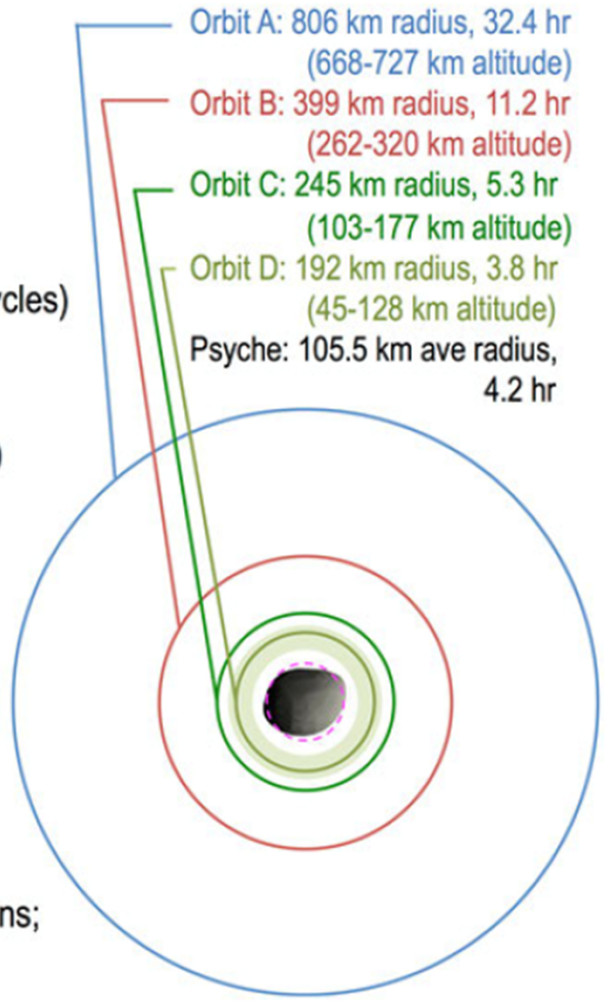
- Nadir and 4 off-nadir imaging cycles for topography
- Global color maps, gravity science, and preliminary magnetic field characterization

Orbit C: Integrated Science: 70 days (317 orbits, 4 cycles)

- Gravity science, magnetic field mapping, crater age determination, bulk composition from gamma ray spectrometer, and preliminary neutron mapping

Orbit D: Elemental Mapping: 70 days (442 orbits)

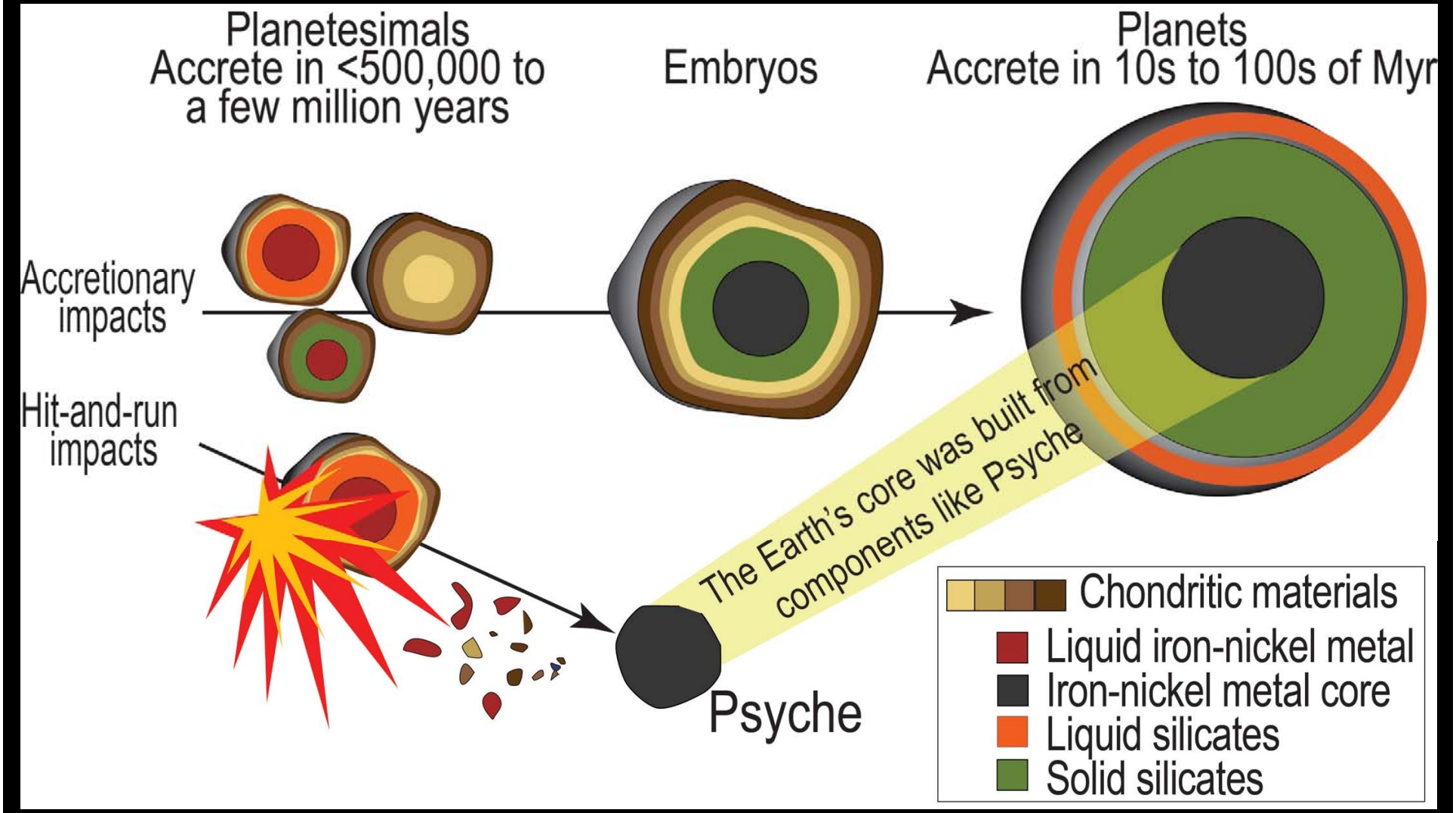
- Map elemental composition with gamma rays and neutrons; improved imaging, gravity, and magnetic field mapping



The Awesome Psyche Team

- **Principle Investigator:** Lindy Elkins-Tanton (ASU)
- **Deputy PI**: Jim Bell (ASU)
- **Project Scientist:** Carol Polanskey (JPL)
- **Project Managers**: Henry Stone and Bob Mase (JPL)
- **Project Systems Engineer:** David Oh (JPL)

- **Science Team**
  - Erik Asphaug (ASU)
  - David Bercovici (Yale)
  - Bruce Bills (JPL)
  - Rick Binzel (MIT)
  - Bill Bottke (SWRI)
  - Ralf Jaumann (DLR)
  - Insoo Jun (JPL)
  - David Lawrence (APL)
  - Simone Marchi (SWRI)
  - Tim McCoy (Smithsonian Museum)
  - Ryan Park (JPL)
  - Patrick Peplowski (APL)
  - Tom Prettyman (PSI)
  - Carol Raymond (JPL)
  - Ben Weiss (MIT)
  - Daniel Wenkert (JPL)
  - Mark Wieczorek (IPGP)
  - Maria Zuber (MIT)


Planetesimals
Accrete in <500,000 to
a few million years
Embryos
Planets
Accrete in 10s to 100s of Myr
Accretionary
impacts
Hit-and-run
impacts
The Earth's core was built from
components like Psyche
Psyche
Chondritic materials
Liquid iron-nickel metal
Iron-nickel metal core
Liquid silicates
Solid silicates


The Awesome
Psyche Mission
Asteroid: Peter Rubin/Caltech-JPL
Spacecraft: SSL