EXPLORATIONS OF PSYCHE AND CALLISTO ENABLED BY ION PROPULSION. Daniel D. Wenkert[1], Damon F. Landau[1], Bruce G. Bills[1], and Linda T. Elkins-Tanton[2], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA (Daniel.Wenkert@jpl.nasa.gov), [2]Department of Terrestrial Magnetism, Carnegie Institution for Science, 5241 Broad Branch Road NW, Washington, DC 20015, USA.

Introduction: Recent developments in ion propulsion (specifically solar electric propulsion - SEP) have the potential for dramatically reducing the transportation cost of planetary missions. We examine two representative cases, where these new developments enable missions which, until recently, would have required resouces well beyond those allocated to the Discovery program. The two cases of interest address differentiation of asteroids and large icy satellites

Past Experience: Planetary missions are constrained by a variety of factors, including the mass of propellant needed to place the observatory at its destination. However, solar electric propulsion can greatly decrease the necessary mass, while providing comparable transit times to chemical propulsion. This technique has been demonstrated by the Deep Space 1 and Dawn missions. The former provided flybys of two objects, asteroid Braille and comet Borrelly. The latter went into orbit at Vesta and is now headed toward Ceres, which it will also orbit.

Deep Space 1 was launched in October 1998 with 81.5 kg of xenon propellant, and flew past Braille in July 1999 and Borrelly in September 2001. Dawn was launched in September 2007, with 425 kg of xenon propellant, and arrived at Vesta in July 2011. It spent over one year in orbit at Vesta, before leaving in September 2012 and heading to Ceres, which it will begin orbiting in 2015. In both cases, ion propulsion (SEP) successfully provided (and will provide) the thrust to achieve mission objectives.

We now present particulars of two missions to investigate differentiation of planetary bodies, which are made feasible by the advent of solar electric propulsion.

Psyche Orbiter Mission: The first mission we consider is an orbiter of the M-class asteroid Psyche, which would measure surface composition and internal structure. This mission is a walk back in time to one of the earliest periods of planetary accretion, when the first bodies were not only differentiating, but were being pulverized by collisions. It is also an exploration, by proxy, of the interiors of planets and satellites today: We cannot visit a metallic core any other way. What is the nature of the core-mantle boundary? Did this planetesimal's core solidify inward or outward, and did it produce a magnetic dynamo?

One key measurement to determine density structure is the precession of Psyche's pole, to determine the principal moments of inertia. To do this properly requires roughly a year of measurements in orbit at Psyche. Using the chemical and internal structure results, the goal is to help determine how the asteroid formed and where. For example, was it created by a giant impact into a differentiated asteroid, near its current orbit?

The baseline mission concept is a spacecraft using SEP with 15-kW solar array (at launch) launched by a Falcon 9 v1.1. The vehicle wet mass at launch is 1200 kg with 800 kg delivered to Psyche in 2.5 years. The vehicle carries 440 kg of xenon and 40 kg of hydrazine. The spacecraft's allocated dry mass is 700 kg including 35 kg of instruments. The trajectory is illustrated in Figure 1.

A threshold science instrument suite includes: magnetometers; cameras, a near-infared spectrometer; and a gamma ray/neutron spectrometer. Radio science at Psyche uses the Ka-band communication subsystem.

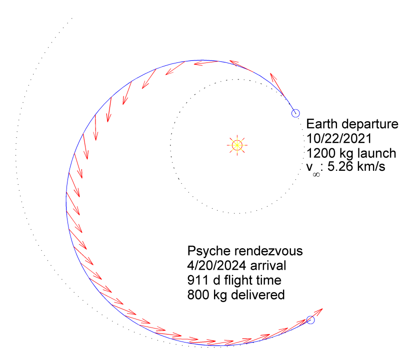

Figure 1. Example 2.5-year trajectory to Psyche

Comparable missions using chemical propulsion (bi-prop) are characterized by large post-launch delta-Vs and correspondingly large propellant masses. The smallest mass for a reasonable trajectory would use more than 2000 kg of propellant to deliver about 980 kg to Psyche in 6.5 years, with two Mars flybys, launching on an Atlas V 521.

Callisto Orbiter Mission: The second mission we consider is an orbiter of the icy satellite Callisto, which would measure internal structure. Current models suggest than Ganymede and Callisto have very different states of internal differentiation, despite their similar sizes. However, that inference is based on gravity observations and an assumption of hydrostatic equilibrium. A valid determination of the moment of inertia requires measurements of the low degree gravity field, and the spin pole precession rate. Those measurements will likely require roughly a year in orbit at Callisto.

Recent mission studies indicate that SEP combined with flybys of Callisto and Ganymede can capture 2000 kg into Jupiter orbit after launching on a Falcon 9, using about 650 kg of Xenon after a trip of 5 years [1]. See Figure 2. This trajectory can place 1700 kg into a 100 km altitude orbit at Callisto with a SEP system powered by a 30-kW solar array (at launch). The primary science mission would begin after another 3 years; the first half for a Jupiter tour to enable capture by Callisto (see Figure 3), and the second half to move into low circular orbit.

Delivery of a similar payload mass to Callsito orbit using a chemical propulsion system would require an Atlas 541 launch vehicle (instead of the Falcon 9) [2].

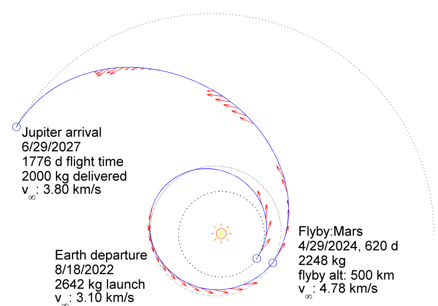

Figure 2. Example 5-year trajectory to Jupiter.

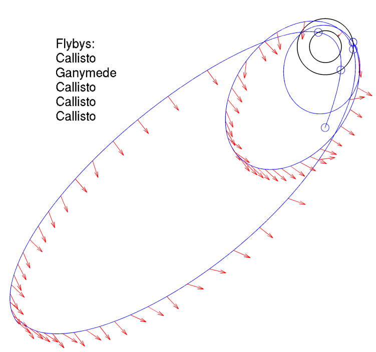

Figure 3. Example trajectory to set up Callisto capture.

The threshold science instrument suite includes: a magnetometer; a moderate-resolution camera, and a laser altimeter. Radio science at Callisto will use the Ka-band communication subsystem.

References: [1] Strange, N. et al. (2012) AIAA Paper 2012-4518. [2] Landau, D. (2010) AAS Paper 10-169.