THE MULTI-ASTEROID ENCOUNTER TOUR WITH IMAGING AND SPECTROSCOPY (MANTIS): MISSION DESIGN AND PROSPECTS FOR IN SITU SAMPLE ANALYSIS.

A. S. Rivkin[1], B. A. Cohen[2], O. Barnouin[1], C. M. Ernst[1], N. L. Chabot[1], B. W. Denevi[1], B. T. Greenhagen[1], R. L. Klima[1], M. Perry[1], Z. Sternovsky[3], J. R. Szalay[4], and the MANTIS Science Team. [1]Applied Physics Laboratory, Johns Hopkins University, Laurel MD 20723, [2]NASA Goddard Space Flight Center, Greenbelt MD 20771, [3]LASP, University of Colorado, Boulder CO 80303, [4]Princeton University, Princeton, NJ 08544.

Introduction: While the overwhelming numbers of small bodies may make the prospects of visiting a representative sample of asteroids seem daunting, recent work suggests that the vast majority of objects in the asteroid belt may be derived from a small number of 100-km-scale parent bodies, which then collisionally evolved to created today's population. A flyby tour of near-Earth and main-belt asteroids is an effective means of quickly sampling many members of this original population of objects, providing discovery science on a large number of small worlds in the inner solar system and also returning data that is complementary and contextual to past, present, and future missions. Focusing on family members makes it possible to effectively visit the objects responsible for most of the impactors in the inner solar system and the meteorites that fall to Earth. The Multi-Asteroid eNcounter Tour with Imaging and Spectroscopy (MANTIS) mission would explore the diversity of asteroids to understand our solar system's past history, its present processes, and future opportunities and hazards.

The MANTIS tour includes 14 unexplored asteroids, including an intact planetesimal, a Mars Trojan asteroid, a low-albedo multiple-asteroid system, and members of 8 collisional families. MANTIS would revolutionize our understanding of asteroids through its state-of-the-art payload of complementary instruments: A powerful infrared imaging spectrometer and narrow angle camera, both with recent flight heritage, a capable mid-IR imager, and an innovative dust analyzer operating during and between asteroid encounters. MANTIS would obtain datasets at each target that could be readily intercompared with one another, effectively doubling the current sample of asteroids visited by spacecraft. Here we discuss how the MANTIS mission could sample the cloud of µm-scale particles shed by asteroids, effectively "microsamples", to provide direct links to known meteorite groups without returning the samples to terrestrial laboratories [1].

Asteroid dust clouds as microsample sources: Particle clouds around asteroids provide a rich and thus-far unexplored opportunity to understand the origin and evolution of airless bodies in the solar system. While comet-like activity appears to be important for some objects, impacts act on all objects to eject material. This ejecta, both neutral and charged, becomes part of the environment, either as bound or unbound particles, around all airless bodies [2]. The tenuous dust cloud is maintained by the continual bombardment of the surfaces by fast, interplanetary micrometeoroids. Such ejecta clouds were detected and characterized in situ by the Galileo mission during flybys of the icy moons of Jupiter (Europa, Ganymede, and Callisto), and also around the Moon by the LADEE mission [3-9].

We modeled micrometeorite-derived ejecta clouds near main-belt asteroids, building upon an existing model for the dust distribution around asteroids near 1 au [10]. The abundance of microsamples is a function of the parent body radius, heliocentric distance, and altitude above the surface. A spacecraft coming within a body radius of the surface of larger asteroids would encounter thousands of these particles.

Dust particles as microsamples: Compositional analysis of dust particles encountered by spacecraft has

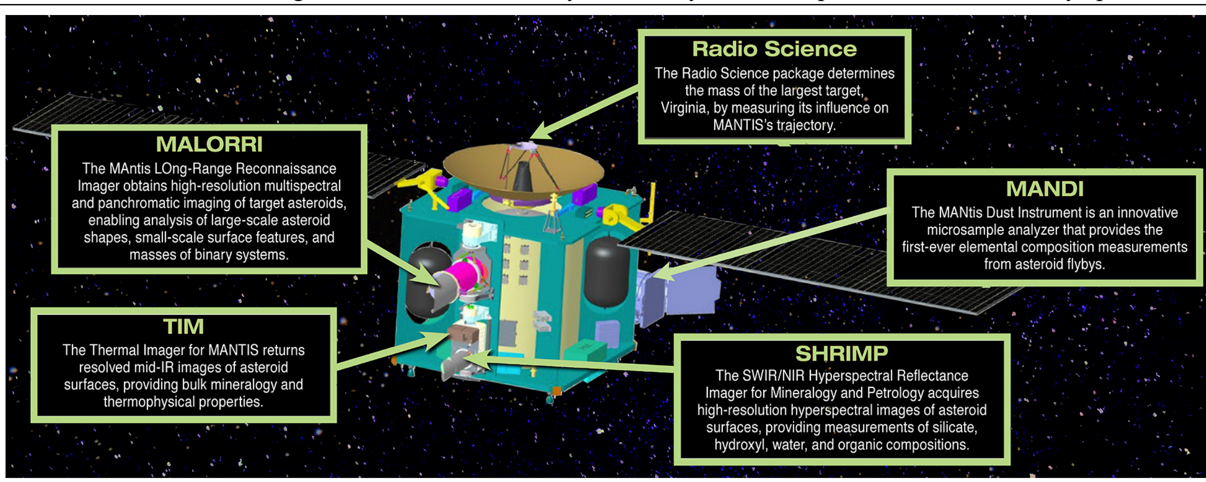

Fig. 1: The MANTIS spacecraft would be a robust and simple bus carrying a high-heritage instrument suite that would enable rendezvous-quality science during flybys.

been successfully conducted using dust detector instruments coupled with an impact-ionization mass spectrometer. Planetary, interplanetary, and interstellar dust grains have been analyzed in situ by dust instruments onboard spacecraft such as Vega-1 and Vega-2, Giotto, Helios 1, Stardust, and Cassini [11-15]. Individual particles' origin as planetary or interplanetary is determined from its impact speed and direction. The interpretation of impact mass spectra in terms of elemental ratios and mineralogy is aided by laboratory calibration measurements and remotely sensed data.

Despite the wide diversity of meteorites and the complexities of their compositions, major mineralogy and silicate Fe/Mg ratios are generally sufficient to distinguish major groups of meteorites from each other [16], given a sufficient number of particle analyses (Fig. 2). Using only this basic mineralogy, the measurement precision of each analysis need only be sufficient to recognize it as a silicate, metal, oxide, or sulfide, which is well within the capabilities of current instrumentation. We also evaluated the number of particles that would need to be analyzed to accurately link it to a specific class of meteorites using a combination of a Monte Carlo method of generating sample sets and a multidimensional nearest-neighbor matching algorithm. Several hundreds of microsamples derived from the meteorite bulk composition, if randomly ejected and encountered, would readily accomplish the goal of linking mineral abundance and composition with known meteorite types. Constraints on parent body types may additionally be inferred by examining the dispersion of compositions, detecting diagnostic phases (e.g., hydrated silicates, carbonates, organic molecules, and silicate compositions unique to specific meteorite groups, such as oldhamite or fassaite), and combining microsample analysis with the other MANTIS measurements, such as spectroscopy, significantly reducing the necessary number of microsamples.

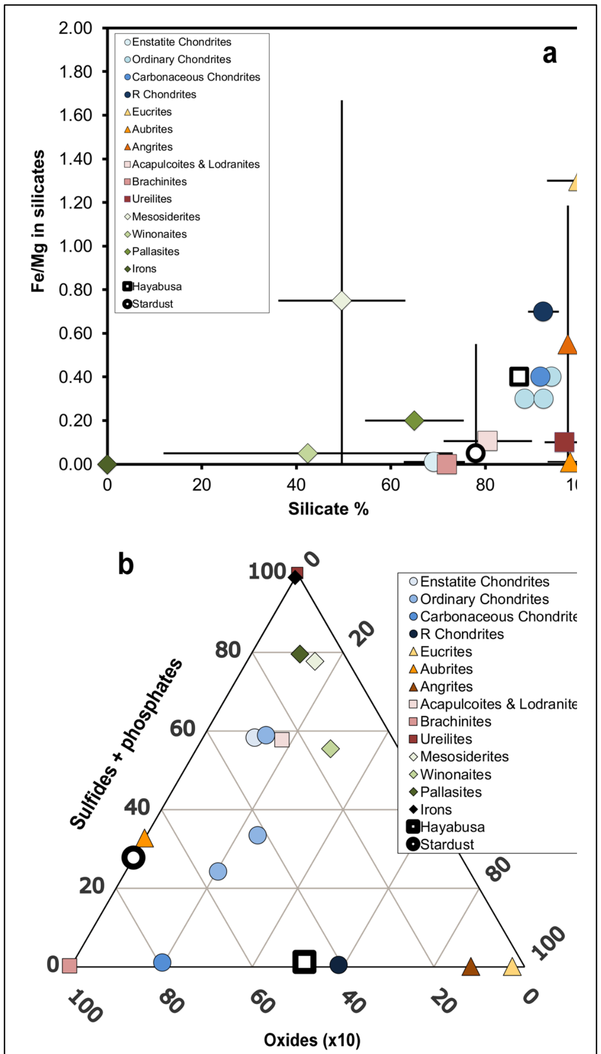

Figure 2. Meteorite groups plotted as simple combinations of a) silicate abundance and Fe/Mg ratio in the silicate fraction (unequilibrated meteorites have large ranges in Fe/Mg ratios); and b) sulfides + phosphates, oxides, and FeNi metal.

Summary: The MANTIS mission addresses many of NASA's highest priorities as laid out in its 2014 Science Plan and provides additional benefit to the Planetary Defense and Human Exploration communities via a low-risk, cost-effective tour of the near-Earth region and inner asteroid belt. Given the compositional diversity of asteroids, and their distribution in space, it is implausible to consider returning samples from each one to establish their origin. Our modeling shows that hundreds of samples shed from a parent body could be collected and analyzed at relevant speeds during flybys of individual asteroids, depending on the mission design, and that these numbers are sufficient to robustly link dust samples to known meteorite classes.

References: [1] Cohen, B.A., et al. (2019) Met Planet Sci 54, 2046-2066. [2] Szalay, J.R. and M. Horányi (2016) Icarus 275, 221-231. [3] Horanyi, M., et al. (2015) Nature 522, 324–326. [4] Krivov, A.V., et al. (2003) Planet Space Sci 51, 251-269. [5] Krüger, H., et al. (1999) Nature 399, 558–560. [6] Krüger, H., et al. (2000) Planet Space Sci 48, 1457–1471. [7] Sremčević, M., et al. (2005) Planet Space Sci 53, 625-641. [8] Sremčević, M., et al. (2003) Planet Space Sci 51, 455-471. [9] Szalay, J.R. and M. Horányi (2015) Geophys. Res. Lett. 42, 5141-5146. [10] Szalay, J.R. and M. Horányi (2016) Geophys. Res. Lett. 43, 4893-4898. [11] Dikov, Y.P., et al. (1989) Advances in Space Research 9, 253-258. [12] Kissel, J.I. (1986) ESA Special Publication ESA SP-1077, 67-83. [13] Altobelli, N., et al. (2006) Astronomy & Astrophysics 448, 243-252. [14] Grün, E., et al. (1980) Planet Space Sci 28, 333-349. [15] Srama, R., et al., The Cassini cosmic dust analyzer, in The Cassini-Huygens Mission. 2004, Springer. p. 465-518. [16] Rubin, A.E. (1997) Met Planet Sci 32, 231-247.