EXPLORING ASTEROID INTERIORS: THE *DEEP INTERIOR* MISSION CONCEPT. E. Asphaug[1], M.J.S. Belton[2], A. Cangahuala[3], L. Keith[3], K. Klaasen[3], L. McFadden[4], G. Neumann[5], S.J. Ostro[3], R. Reinert[6], A. Safaeinili[3], D.J. Scheeres[7], and D.K. Yeomans[3] • [1]Earth Sciences Department and Center for Origin, Dynamics and Evolution of Planets, University of California, Santa Cruz, CA 95064 (asphaug@es.ucsc.edu), [2]Belton Space Exploration Initiatives, LLC, Tucson, AZ, [3]NASA Jet Propulsion Laboratory (JPL), Pasadena, CA, [4]Astronomy Dept., University of Maryland, [5]NASA Goddard Space Flight Center (GSFC), Goddard, MD, [6]Ball Aerospace and Technologies Corp., Boulder, CO, [7]Dept. Aerospace Engineering, U. Michican, Ann Arbor, MI

Summary: *Deep Interior* is a mission to determine the geophysical properties of near-Earth objects, including the first volumetric image of the interior of an asteroid. Radio reflection tomography will image the 3D distribution of complex dielectric properties within the ~1 km rendezvous target and hence map structural, density or compositional variations. Laser altimetry and visible imaging will provide high-resolution surface topography. Smart surface pods culminating in blast experiments, imaged by the high frame rate camera and scanned by lidar, will characterize active mechanical behavior and structure of surface materials, expose unweathered surface for NIR analysis, and may enable some characterization of bulk seismic response. Multiple flybys en route to this target will characterize a diversity of asteroids, probing their interiors with non-tomographic radar reflectance experiments.

Deep Interior is a natural follow-up to the NEAR-Shoemaker mission [1] and will provide essential guidance for future in situ asteroid and comet exploration. While our goal is to learn the interior geology of small bodies and how their surfaces behave, the resulting science will enable pragmatic technologies required of hazard mitigation and resource utilization.

Introduction: We are developing a single rendezvous, multiple-flyby mission to explore the global geology of representative (C and S type) asteroids. Detailed mission planning for the radio reflection tomography (RRT) and surface blast experiments, described below, recommends that our targets be previously imaged by groundbased radar. For this reason, and for trajectory optimization, our rendezvous target will be chosen from the radar-imaged subset [2] of the potentially hazardous Earth-crossing asteroids: objects of known size, shape, rotation state and spectral type, but whose interior and structural characteristics are almost entirely the subject of speculation [3,4].

Science Goals: Our principal goal is to provide definitive resolution to the modern confusion regarding asteroid interior structure. Seriously considered hypotheses range from monoliths to fractured solids to rubble piles to hollow bodies to compactable "puff balls" [3]. Radio reflection data acquired from orbit about a ~1 km asteroid can, given sufficiently precise *a posteriori* position knowledge, be inverted to yield volumetric images of complex permittivity comparable in many respects to a medical ultrasound image ~50-100 pixels across, depending on radar frequency. (Higher frequency yields higher resolution, but requires greater position accuracy and suffers greater attenuation with depth inside the asteroid.)

A 3D image of complex permittivity can discern the fabric of the interior and can tell us whether the interiors have been impact- or tidally-worked, whether body-wide fractures exist, and the overall interior configuration. Ideally a seismic investigation would also be involved. Under the NASA Discovery Mission cost cap, a true seismic plus radar experiment is prohibitive, and in our view radar comes first, as it is a very proven technology and can be operated entirely from orbit.

We also propose to assess structural and mechanical characteristics, and possibly to image body wave phenomena, with kg-scale explosion blast experiments on asteroids. From laboratory scaling, these are expected to yield craters ~10 to ~100 m diameter that will expose fresh surfaces for spectroscopic analysis, and reveal the physical behavior of a mechanically excited low gravity regolith. The experiments will quantify the effects of meteoroid bombardment (a close analogue process) and will characterize how regolith will respond (in terms of dust production and resultant opacity, or soil cohesion, etc.) on more ambitious future missions or mitigation attempts.

Investigations: These include radio reflection tomography (RRT), stereogrammetric color imaging, multispectral analysis of blast crater exposure, laser altimetry and mapping, lidar scans of evolving blast ejecta, and simple surface experimentation onboard 3-5 surface pods which terminate with high-energy blast experiments (see Scheeres *et al.*, "Asteroid Surface Science with Pods"). Asteroid science is so incomplete that one does not know, to within more than one order of magnitude, what diameter of crater to expect (a problem also of concern to the *Deep Impact* mission; see Schultz et al., LPSC 2002). Craters ~10 to 100 m are fairly certain to result from 1 kg of high energy explosive, unless the surface is bare rock (see Asphaug *et al.*, "Meteoroid Bombardment and Blast Experiments on Asteroids".)

While a single-rendezvous mission as described can be delivered for under the NASA Discovery cost cap, international participation in this area is particularly desirable, given the potential global significance of NEOs and the fact that for a comparatively modest additional cost one could add true seismology (by adding an anchored station) and visit multiple rendezvous targets with diverse characteristics in the vicinity of Earth.

REFERENCES: [1] Veverka, J. et al. 2002. NEAR at Eros. *Icarus* **155**, 1-2. • [2] Ostro, S.J. et al. 2002. Asteroid radar astronomy at the dawn of the new millennium. *LPSC* 33 • [3] Asphaug, E., Ryan, E.V, and Zuber, M.T. 2002. Asteroid Interiors. In *Asteroids III*, UA Press. • [4] Weissman, Asphaug and Lowry 2004. Structure and density of cometary nuclei. In *Comets II*, UA Press, in press.

SUMMARY: **A rendezvous mission to assess the structural diversity of near-Earth asteroids, providing the first 3D image of their interiors with radio reflection tomography (RRT) to a volumetric resolution of ~20 m, and determining surface mechanical properties with a set of surface probes that each carry an explosive charge to produce an artificial ~10-100 m crater. Crater formation will be imaged with a fast frame rate imager on the spacecraft, and the fresh crater floor will be analyzed with a NIR spectrometer.**

• SCIENCE DETERMINATIONS:

Deep Interior. Decameter-wavelength (HF) RRT to determine internal variations of complex permittivity at spatial resolutions approaching 20 m. Determine deep interior structure: inclusions or voids, fracture geometries, and compositional or structural boundaries.
Subsurface. Meter-wavelength (VHF) RRT to determine shallow interior characteristics: depth of regolith, existence and nature of mantle, geology beneath and around craters, and subsurface expressions of surface geology.
Surface material properties. Set of small, self-righting probes that will image the surface at sub-cm resolution and directly measure regolith mechanical properties with internal accelerometers. The probes also carry a remotely activated explosive charge that will produce a few meter-scale crater. Crater formation and ejecta dynamics will be recorded @ 8 frame/sec, 10 cm/pixel, from the spacecraft to enable simple and direct laboratory constraints on material density, cohesion and porosity.
Dust. Look for dust lofted by surface waves propagating from the explosions, to constrain elastic properties and attenuation. Observe longer-term dynamics and optical properties of dust "atmosphere" generated by human-induced activity.
Topography and Geodesy. Map the surface topography by stereogrammetric imaging with 1 m/pixel spatial resolution, supplemented by laser altimetry to ±1 m, to determine detailed shape, volume, and spin state. Compare with radar sounding to learn how internal structure is manifested on the imaged surfaces of asteroids and comets.
Mass and Density. Determine total mass and lower moments of the internal mass distribution by mapping the exterior gravitational field. Look for mass concentrations. From shape and gravity, determine density distribution within each body.
Surface microphysics and composition. Map the color, albedo, and scattering properties of the surface over sunlit regions with high resolution color imaging, complemented by an NIR spectrometer.
Diversity. Assess the diversity of the interior structures in two classes of near-Earth objects.

• MISSION CHARACTERISTICS:

Mission Concept. Primary rendezvous target will be a 1km-class asteroid that has been imaged by ground-based radar to predetermine size, shape, and spin state. Second rendezvous target (if achievable for under the cost cap) and flyby targets will be chosen to maximize the diversity of studied objects
Mission Mode. 60-day rendezvous at each NEO; mapping, then radio tomography, and finally deployment of surface probes
Probable Launch Date. 2008.
Mission Flexibility: Pre-launch ground-based NEO discoveries and recoveries to optimize asteroid target selection..

• SPACECRAFT INSTRUMENTS:

Radar Reflection Tomography. 5 and 50 Mhz global 3-D image reconstruction for rendezvous targets.
High resolution imager. 1-m/pixel, color stereogrammetric imaging of rendezvous target surface and 10cm/pixel sub-frame imaging of crater formation with 8 frames/sec.
NIR Spectrometer. 0.8-3 μm narrow FOV point spectrometer, co-boresighted with imager.
Laser Altimeter. +/-1m range resolution for shape reconstruction

• CANDIDATE SURFACE POD INSTRUMENTS:

Low Resolution Imagers. 360° imaging with sub-cm near-field spatial resolution of surface.
Accelerometers. 3-axis measurement of probe deceleration upon free fall impact with surface.
Cratering charge. 1kg of PETN will create 10-100 m diameter crater in 1e-5 G.
Langmuir probe. Measures electrostatic potential field of asteroid surface