BAOBAB (Big And Outrageously Bold Asteroid Belt) Project. L. A. McFadden[1] and C. A. Thomas[2], [1]J. A. Englander, [1]O. Ruesch, [3]S. Hosseini, [1]S. J. Goossens, [1]E. M. Mazarico, [4]N. Schmerr, [1]NASA-GSFC (Code 693, Greenbelt, MD 20771 and lucy.mcfadden@nasa.gov), [2]Planetary Science Institute (Tucson, AZ cristina.a.thomas@nasa.gov),[3] Jet Propulsion Lab, CalTech (Pasadena, CA), [4]Department of Geology, University of Maryland, College Park, MD 20742.

Introduction: One of the intriguing results of NASA's Dawn mission is the composition and structure of the Main Asteroid Belt's only known dwarf planet, Ceres [1]. It has a top layer of dehydrated clays and salts [2] and an icy-rocky mantle [3,4]. It is widely known that the asteroid belt failed to accrete as a planet by resonances between the Sun and Jupiter. About 20-30 asteroids >100 km diameter are probably differentiated protoplanets [5].

1) how many more and which ones are fragments of protoplanets?

2) How many and which ones are primordial rubble piles left over from condensation of the solar nebula?

3) How would we go about gaining better and more complete characterization of the mass, interior structure and composition of the Main Belt asteroid population?

4) What is the relationship between asteroids and ocean worlds?

Bulk parameters such as the mass, density, and porosity, are important to characterize the structure of any celestial body, and for asteroids in particular, they can shed light on the conditions in the early solar system. Asteroid density estimates exist but currently they are often based on assumed properties of taxonomic classes, or through astronomical survey data where interactions with asteroids are weak at best resulting in large measurement uncertainty. We only have direct density estimates from spacecraft encounters for a few asteroids at this time.

Knowledge of the asteroids is significant not only to understand their role in solar system workings, but also to assess their potential as space resources, as impact hazards on Earth, or even as harboring life forms. And for the distant future, we want to know if the idea put forth in a contest sponsored by *Physics Today*, to surface the asteroids into highly reflecting, polished surfaces and use them as a massively segmented mirror for astrophysical exploration [6], is feasible.

Science mission plan: Missions consisting of a mother ship with a fast, direct trajectory to the Main Belt that would visit 25 or more asteroids of different taxonomic type (surface composition), with a range of estimated mass, size, spin rate and internal structuresis envisioned. A mother ship would carry both daughter and tiny-tot ships with a range of payloads described below, and following trajectories designed to both fly by and orbit a number of asteroids within a decade or two. A process to determine how many targets are deemed necessary to characterize the main belt needs to be developed and target selection incorporating scientific return is necessary. In 2014, a contest to design trajectories for multi-spaceccraft exploration of the asteroid belt was carried out, so such a plan is feasible now, though with fewer targets than desired in the future [7].

Mother and/or daughter ships would both flyby and rendezvous with each target. They would fly by at a velocity high enough to propel a penetrator package into the surface and loft material into the asteroid's wake. Another spacecraft in a following trajectory would rendezvous later to sample the ejected gas and dust, survey the surface and site of the penetrator's impact and to drop a seismometer(s) onto the asteroids and receive data from them.

Mass and Interior Structure Determination. We envision a much more comprehensive survey of the asteroid belt than exists today, and anticipate developing different approached than currently approaches. Gravity today, can be determined through the tracking of a spacecraft perturbed by the gravity field of the object of interest using radio data. A spacecraft can be sent into orbit around the objects although this would require long missions at each object. An alternative to the long orbital missions required for gravity mapping through spacecraft tracking is launching multiple daughter spacecraft to one object, in a “swarm”-like fashion, generating multiple flybys in a short period, thus negating the need to spend long periods at one object. This would result in quick and precise estimates of the asteroid’s mass and its gravitational flattening which informs us about radial density profiles. With gradiometers small enough to fit on cube-sat type spacecraft, a highly accurate gravity map of each object can be obtained. From a dynamical viewpoint, we envision the long-term monitoring of small spacecraft in the asteroid belt perturbed by various different bodies, thus being able to deliver mass estimates for a range of asteroid types.

Density estimates not only require the mass of the object to be known, but also the volume. Imaging using the high definition imager can obtain such data, as can dedicated lidars on the daughter satellites. The characterization of the spin-state of the asteroids, from imaging and gravity data, would also further constrain models of the interior structure by having measurements of the moments of inertia.

The Payload: The desired instrument payload consists of the following instruments:

1) high definition imaging camera
2) space-qualified spatial heterodyne spectrometer
3) array of seismometers
4) penetrator package

The purpose of this payload and anticipated science return is described below.

High Definition imager. Detectors and cameras are constantly under development because visible and visual images are necessary for navigation, digital terrain modelling and volume measurements. As an added bonus, we get geological context and an important sense of being at the asteroid targets.

Spatial Heterodyne spectrometer. BAOBAB's spatial heterodyne spectrometer (SHS) will be an advanced design of a miniature, all-reflective two-beam cyclical spectrometer [8, 9]. SHS can observe targeted atomic and molecular gas spectral lines at high spectral resolution (R~50,000-150,000) without the need to couple to a large aperture telescope. It comprises a grating and reflective optics tailored to a target wavelength region (VIS to UV) with a solid-state array detector. With its high optical throughput (étendue) and wide field of view (FOV), it has very high sensitivity to weak or diffuse sources. These two characteristics, enable unique high sensitivity to specific spectral features such as global temporal observations of outgasing and global values of key isotopic ratios such as D/H, $^{3}He/^{4}He$, $^{14}N/^{15}N$, $^{12}C/^{13}C$, $^{16}O/^{18}O$.

Seismic Wave Capability. As noted by Bell et al. [10] in a numerical analysis to determine the minimum number of instruments required for a seismic network on an asteroid it is feasible to detect seismic waves from an impact source ranging in size from 0.1 to 100 kg onto a 250 m radius asteroid (Fig. 1 from [10]). The range of impact velocities in their study was 2 m/s to 5 km/s and results in eqivalent magnitudes of -7 to +1. For reference a hammer blow to a metal plate would result in magnitude -6 to -2, with the above parameters. A seismic experiment package on an asteroid has not yet flown. Yet in the next 30 years, their mass, energy and transmit- and receive- mechanisms are expected to enable resolutions greater than a single source would produce allowing determination of internal structure that would distinguish between protoplanetary and condensation-formed asteroids.

Penetrator Package. A penetrator package of 2050 would consist of accelerometers, heat probes, miniature cameras and hopefully a device for elemental analysis. The design would build on previous packages proposed for scientific exploration and hazard mitigation from small near-Earth asteroids. [eg. 11, 12, 13].

Note on the project's name: The Baobab tree is found in remote places on Earth (relative to where most of us live). It is a large tree with dense canopy and its trunk can hold up to 26,000 gallons of water to survive droughts. A baobab tree grew on asteroid B612 in Antoine de St. Exupery's Le Petit Prince. The tree represents the density and complexity of the content and nature of the Main Asteroid Belt and the hope that we can see into the interior of the tree.

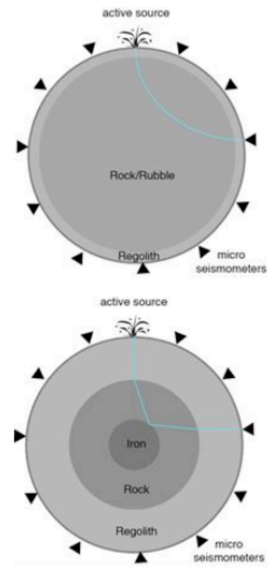

Figure 1. Simplified internal models of range of asteroid compositions used in this study. Seismic energy generated by an active source traverses interior and is recorded by seismometers on the asteroid surface. (upper panel) Homogeneous interior covered by thin layer of regolith. (lower panel) Differentiated model. from Bell et al. 2016 [10].

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