NEOCAM

Near Earth Object Chemical Analysis Mission

Bridging the Gulf between Telescopic Observations and the Chemical and Mineralogical Compositions of Asteroids

Or

Diogenes A: Diagnostic Observation of the Geology of Near Earth Spectrally-classified Asteroids

I. The Next Logical Step in Understanding Asteroids

What do we currently know about asteroids?

Studies of meteorites have yielded a wealth of scientific information based on highly detailed chemical and isotopic studies possible only in sophisticated terrestrial laboratories. Telescopic studies have revealed an enormous (> 10^5) number of physical objects ranging in size from a few tens of meters to several hundred kilometers, orbiting not only in the traditional asteroid belt between Mars and Jupiter but also throughout the inner solar system. Many of the largest asteroids are classed into taxonomic groups based on their observed spectral properties and are designated as C, D, X, S or V types (as well as a wide range in sub-types). These objects are certainly the sources for the meteorites in our laboratories, but which asteroids are the sources for which meteorites?

Spectral classes are nominally correlated to the chemical composition and physical characteristics of the asteroid itself based on studies of the spectral changes induced in meteorites due to exposure to a simulated space environment. While laboratory studies have produced some notable successes (e.g. the identification of the asteroid Vesta as the source of the H, E and D meteorite classes), it is unlikely that we have samples of each asteroidal spectral type in our meteorite collection. The correlation of spectral type and composition for many objects will therefore remain uncertain until we can return samples of specific asteroid types to Earth for analyses. The best candidates for sample return are asteroids that already come close to the Earth.

Asteroids in orbit near 1 A.U. have been classified into three groups (Aten, Apollo & Amor) based on their orbital characteristics. These Near Earth Objects (NEOs) contain representatives of virtually all spectral types and sub-types of the asteroid population identified to date. Because of their close proximity to Earth, NEOs are prime targets for asteroid missions such as the NEAR-Shoemaker NASA Discovery Mission to Eros and the Japanese Hyabusa Mission to Itokawa. Also due to their close proximity to Earth, NEOs constitute the most likely set of celestial objects that will impact us in the relatively near future. Indeed, nearly 1000 of these asteroids are classified as potentially hazardous objects whose orbits come within 0.05 A.U. of the orbit of the Earth. Understanding the chemical composition and physical characteristics of this population of asteroids could be essential if the need ever arises to avoid a collision with one. On a more practical note, understanding the composition and physical characteristics of these bodies could also provide an important resource base for use in the future exploration of the solar system.

Nearly 60,000 asteroids were discovered in 2007: just over 1% of these asteroids were NEOs. We cannot possibly send spacecraft to all such bodies, either for in situ analyses or for sample return. It is unlikely that we can significantly improve our understanding of these asteroids based on meteoritic studies. Telescopic observation and spectral classification of the asteroid population is the only practical means of cataloging such a large and diverse set of objects. Unfortunately, although our current classification scheme can successfully bin objects based on their spectral properties, detailed interpretation of this spectral information in terms of their chemical composition or structural integrity is based more on faith and inference than on actual measurements of the properties of asteroids of specific types.

How can we improve our knowledge of the asteroid population?

We propose to measure the chemical composition of representative members of each major asteroid class, and as many of the sub-classes as possible, in order to put the current spectral classification system onto a strong analytical foundation. In particular, we will map the surface of each asteroid from 400nm to 4000nm at 10 meter spatial resolution in order to compare the spectral signatures of typical asteroid surfaces with the much lower resolution measurements made from ground-based or space-based instruments (e.g. Spitzer). Such maps will be used to choose appropriate locations for in situ measurements. If possible, we will also use Ground Penetrating Radar and Radio Sounding techniques to determine the interior structure of each asteroid we encounter.

We will deploy a small lander to measure the composition of the thin surface layer responsible for the spectral signature we use to classify the object using x-ray spectroscopy stimulated by an electron gun. We will measure the composition of a one meter cubic volume below the surface of the lander using pulsed neutron, gamma ray spectroscopy. We will also determine the nature of volatiles released by a progressively heated probe using a GCMS (Gas Chromatograph Mass Spectrometer). Once all measurements at one site are completed, the lander will hop to another site of interest and will perform an identical suite of measurements. The lander will also serve as a mobile receiver for the Radio Sounding experiment. When the chemistry of each unique spectral site has been determined, and we have obtained as much information on the interior structure of the asteroid as is practical, the lander will return to the carrier spacecraft and the pair will use Solar Electric Propulsion (SEP) to move to the next NEO in our target sequence.

At least 10 separate asteroids will be targeted for exploration. Each will be thoroughly mapped from orbit, or while flying in formation, as appropriate. We plan to analyze at least three surface sites on each target with in situ instruments, and will use each landing site as a base for interior measurements using radio sounding techniques. We will plan to spend six months at each rendezvous, though complex asteroids may require more time to achieve our measurement goals and simple bodies could easily require less.

To more efficiently use our spacecraft resources and because of the flexibility provided both by SEP and by the very large number of NEOs, we plan to retarget our mission as we go. In other words, if we encounter a body that displays a very homogeneous surface and appears to be a uniform block of material, we may not need to do a large number of measurements at different sites. Such bodies might require only a 3-month mapping and analysis phase. Rather than waste three months waiting for a launch window to our next target we can calculate a new trajectory either to the next asteroid in our original sequence, to a completely new and interesting target, or to an asteroid that we had planned to visit later in the mission. Similarly, if we encounter a very complex asteroid that requires more than 6 months of analyses to understand the relationship between its chemical properties and spectral class, we can take the time needed to do a proper analysis of each different spectral component that we observe without fear of jeopardizing our mission objectives. We will simply retarget the spacecraft to another interesting asteroid once our analyses are finished. We may be able to visit our original target later in the mission or we might choose to visit another asteroid of similar spectral type instead.

Our primary mission objective is to obtain the ground truth required to transform the present asteroid spectral classification system into a definitive measurement of the physical and chemical properties of the target. This will permit us to geologically characterize any asteroid with confidence based upon a few hours (or days) of remote sensing data. It will also identify the measurements that prove to be the most diagnostic in revealing both the chemical and physical properties of an unknown small body in space with a specific spectral signature. In order to keep the mission lifetime reasonable (less than 20 years) we will restrict our targets to the NEO population. In order to unravel as many of the important factors that control the spectral signature of a given asteroid type as possible, we may choose to target more than one representative asteroid of a given type, especially if our initial target, upon close examination, proves to be a highly complex object. Finally, in order to ensure confidence in and to provide validation for our in situ measurements, we will attempt to target one or more of the several prime targets for asteroid sample return missions such as RQ36 or JU3.

What do we propose to measure?

We will carry out a series of interleaved investigations for at least one representative asteroid for each major spectral class. These will include: measurement of the spectral properties, surface chemistry and bulk mineralogy; measurement of the volatile content, with special emphasis on the distribution of water and organic molecules throughout the body; measurement of the mass and mass distribution within the target; construction of maps of the surface of each target asteroid at a variety of wavelengths with sufficient spatial resolution to distinguish significant geological features such as craters, fissures and lithologic units necessary to decipher the geologic history of the asteroid.

These investigations will allow us to understand the relationship between the bulk chemistry of the target and the surface chemistry (resulting from the space weathering of the underlying material) responsible for the observed spectral signature of each asteroid class. We can also infer the geologic and dynamic history of each asteroid we visit and the processes responsible for the current state of each individual target. In combination with telescopic observations of the asteroid population, our measurements will enable us to address the following questions posed in the NOSSE Report:

Foundation Building

- How do colors and albedos of small bodies relate to their compositions and histories of alteration by various processes since their origin?
- What are the processes by which organic material forms on the surfaces of icy and other primitive bodies in the current epoch?
- What is the thermal and aqueous alteration history of the parent bodies of the organic-rich primitive meteorites?

Pivotal

- What processes modify the surfaces of all categories of building blocks?
- Did organic matter from comets and meteorites provide the feedstock for the origin of life on Earth?

Paradigm-Altering

- What are the compositions and origins of the organic and volatile materials in primitive bodies?
- How is organic matter distributed throughout the solar system?

We should also be in an excellent position to address the following questions posed by the Primitive Bodies Panel:

- Where in the solar system are the primitive bodies found, and what range of sizes, compositions, and other physical characteristics do they represent?

- What processes led to the formation of these objects?
- Since their formation, what processes have altered the primitive bodies?
- What is the composition, origin, and primordial distribution of solid organic matter in the solar system?
- What is its present-day distribution?
- What processes can be identified that create, destroy, and modify solid organic matter in the solar nebula, in the epoch of the faint early Sun, and in the current solar system?

II. Mission Implementation Roles and Responsibilities

GSFC will provide the Instrument Platform and the Lander. GSFC will manage the mission, provide systems engineering, Quality Control and instrument integration. GSFC scientists will provide most of the scientific instruments (NIR, FIR, GSMS, PNGRAND, EBXRS, Radio Sounding). GSFC will lead the Navigation Team.

Boeing will provide the Carrier Spacecraft in the form of a modified 702A Bus (used successfully for the past 15 years as the bus for communications satellites. Boeing will also provide the Automated Rendezvous and Docking system to be incorporated into the Lander based on the Orbital Express system successfully deployed and tested in Earth Orbit.

Emergent Technologies will provide the Ground System and real time NEO Targeting options.

NASA Glenn will provide NeXT Engines for the Carrier Spacecraft as well as the Advanced Stirling-cycle Radio-isotopic Generator (ASRG) that will serve as the primary power system for the Lander. Although the Lander will also be equipped with small body mounted solar panels as well as internal batteries, the ASRG will greatly increase the flexibility of the Lander to explore dark or shadowed sites.

University of Arizona may provide the camera system, EPO and liaison with OSIRIS REx.

A foreign partner will be invited to provide a Ground Penetrating Radar system. At the moment the preferred provider is the Italian Space Agency. (The GPR system may be redundant with a truly flexible Radio Sounding system. However, the GPR does not require a receiver system on the asteroid surface while the radio sounding system may be available at little cost due to slight modifications to the communications systems already planned for the Carrier and Lander spacecraft.)

III. Highly Notional Costs

$75M	Modified 702A Bus including NeXT Engines (provided as a combination of a Fixed Cost contract for the 702A Bus together with a Cost plus Incentive Award Fee for the modifications such as the installation of NeXT engines, etc.). This is the key cost control measure controlling the potential for making a Discovery Cost Cap.
$50M	Instruments for Carrier (includes I&T): Camera, Vis-NIR, Far-IR, Radio Sounder, GPR
$50M	Lander Spacecraft (built in house at GSFC). This is also a crucial cost control item.
$50M	Instruments for Lander (includes I&T): PNGRAND, EBXRF, GCMS, Camera?
$25M	ATLO
$75M	Operations – assumed to be using the GSFC communications network at White Sands and ground support equipment installed at GSFC.
$50M	Science Team Support for a 10 year mission.

IV. Possible Cost Reductions

Minimum Instrument Suite for Baseline Mission

The baseline mission requires measurement of the surface and bulk composition of asteroids of the major spectral classes: A Lander is absolutely required. The analytical instruments that the Lander carries could be scaled back somewhat to include a Pulsed Neutron Gamma Ray system without a neutron detector, an e-beam excited x-ray detector and a simple Mass Spectrometer rather than a more complex GCMS, though the heated probe is still required. We assume that the Lander will have a radio receiver on board as standard equipment.

Most major cost reductions could come from the instrument complement on the Carrier. While we need a Vis-NIR spectrometer and a simple camera system to map the asteroid's surface: we do not need a Far-IR spectrometer with moving parts. We could make the FIR measurements required to measure the thermal inertia of the surface using a simple cooled photometric system, possibly at multiple wavelengths if an array detector is used. Similarly, we do not need the GPR or a separate multi-frequency Radio Sounder. It is possible that the communications system already planned for the carrier could be used for this purpose given the relatively small size (10 –

100 km) of most target asteroids. Foreign contributions could increase our capability in certain areas but are not essential.