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The Hera near-Earth asteroid sample return mission: science requirements of the sample collector

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Abstract

The Hera mission is a proposed Discovery class mission to collect three samples from each of three near-Earth asteroids. Returned samples would have information on geological context and possibly stratigraphy, would provide fresh regolith, and conceivably samples that would not naturally reach the Earth. During the development of a simple touch-and-go sample collector, questions arose concerning the nature of the samples to be collected, their maximum science return, and the simplest engineering designs. This article reports the results of a small workshop convened to discuss this topic. It is argued that the maximum science return for the Hera samples would be obtained if asteroids of different major spectral classes were visited, samples were disturbed as little as possible during collection, and samples from the very surface were obtained. Surface samples would have the utmost value in interpreting links between asteroids and meteorites, would yield maximum information in solar exposure, would avoid planetary protection concerns, and would produce material not reaching Earth as meteorites. At the same time, they would be simpler to sample than subsurface samples.

Keywords: Sample return mission; Hera; Science requirements of the sample collector; Near-earth asteroids

1. Introduction

The proposed Hera mission will rendezvous with three asteroids, remain in close proximity to each of them for up to a year, take three samples from each, and return them to Earth (Sears, 1999; Sears et al., 2000a; Sears et al., 2001d). The Decadal Survey considered sample return from near-Earth asteroid Eros, with a rover to select and collect the samples, a "high priority" mission for the New Frontiers (medium-sized class) program, but "deferred" the mission on the basis of cost and complexity (Space Studies Board, 2002). Hera is a much simpler mission that

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could fit into the Discovery (small-sized class) program, especially when costs are shared with an international partner. The mission visits asteroids much easier to reach than Eros and it does not involve complex and expensive landers or rovers. Instead, after performing a reconnaissance comparable to that performed by the NEAR spacecraft at Eros, it would swoop down at sites selected for their scientific interest, and collect ~100 g samples during a 1 to 2 s encounter with the surface.

During development of a touch-and-go sample collector, questions arose concerning the nature of the samples to be collected (Sears et al., 2002c). For a small Discovery class mission, the collector should be as simple as possible with a minimum of moving parts. Many sample collection devices have been proposed and have even flown on missions (Sears and Clark, 2000), these considerations might suggest that touch-and-go collectors should be carried on the first asteroid sample return missions. However, the design of the sample collector device might influence the nature of the material collected. So what type of simply collected material has the highest scientific potential? Should the samples come from the very surface or at depth and if at depth, how deep? Should they consist of just clasts or soil, or a mixture? Would just the magnetic material yield the science results being sought? Is it acceptable to grind samples during collection? Will it be necessary to store the samples at low temperatures during return, or keep them in gas-tight containers? This article reports the results of a half-day workshop preceding the Meteoritical Society meeting at Los Angeles during which many of these issues were discussed (Sears et al., 2002b). Invited participants were asked specifically to discuss the optimum samples that could be collected, given that the collector had to be as simple as possible. We discussed scientific value in order to settle on collector design, but the type of collector would affect the samples collected. Thus, this had to be an iterative process, involving juggling between science and engineering.

1.1. The science driving the mission

The science driving the Hera mission was summarized by one of the community panels of the NRC Decadal Survey (Sears et al., 2002a,d) and most of their arguments were adopted by the Primitive Bodies Panel in their contribution to the final report (Space Studies Board, 2002). There are many scientific justifications for sample return from near-Earth asteroids (Orgel et al., 1999; Sears, 1998a,b; Sears et al., 2000b, 2001a,b), but the most pertinent to the present discussion are the following.

1.1.1. Returned samples will have contextual information

Geologists are very familiar with the need for information about the geological context of the samples that they examine. In fact, it is crucial information. In the present case, returned samples will allow us to see how material varies with site. Material can be collected from a crater bottom, rim or from a transect across a crater, ejecta, material from the intercrater plains, or unusual structures (e.g., ponds) could be sampled. Having context information in addition to the wealth of data that will be obtained on the returned samples will be truly paradigm altering. An additional point is made in Fig. 1, which is that returned samples provide a linkage between meteorites and asteroids, and between remote observations of the same material in the laboratory.

1.1.2. Returned samples will contain new materials

It has been frequently observed that only mechanically strong meteoritic material can survive atmospheric passage and primitive (i.e., the most solar in composition and least altered by parent body processes) material tends to be mechanically weak. Thus, the atmosphere is filtering the most scientifically valuable samples of extraterrestrial material. Secondly, large fractions of material reaching Earth were involved in recent stochastic events suggesting that the numerical preponderance of meteorites falling to Earth are from relatively few asteroids. Thirdly, most asteroids are in dynamically unfavorable locations to yield fragments that would reach Earth. This is not to say that processes like the Yarkovsky effect are not sending a rich variety of material to Earth, but that the terrestrial flux is overwhelmed by atypical material that can reach the Earth's surface. Thus asteroid samples returned by Hera will almost certainly yield new types of material.

1.2. Importance of regolith as a science objective and mission constraint

Participants at the workshop repeatedly stressed the importance of regolith in connection with both under-

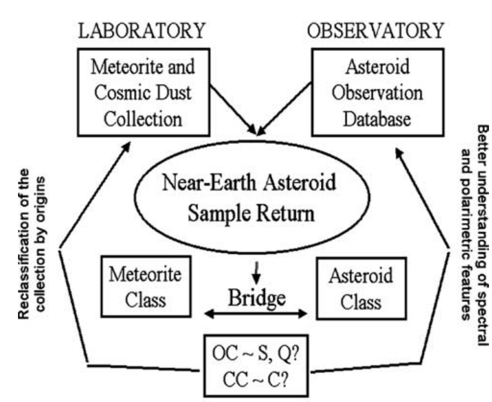

Fig. 1. The scientific rationale behind the Hera mission expressed as a logic flow chart. Only sample return from asteroids previously studied by remote observations and in situ/rendezvous measurements can bridge between the ground observations of minor bodies and laboratory analyses of meteoritic samples. (Courtesy Hajime Yano, ISAS.)

standing surface processes on asteroids and understanding the link between meteorites and asteroids. Regolith samples of the moon were remarkably successful in identifying the major global rock types and the global geology because the components could be geochemically and petrologically identified. Samples of the regolith were essential in determining solar-surface interactions (such as solar wind implantation and charged particle track production) and surface exposure histories for macroscopic clasts. They were also essential in characterizing the space environment, such as the micrometeorite flux, and the nature of space weathering on the Moon. Finally, but most importantly, it is the surface of the regolith (top few cm) that is actually observed by astronomers and it is for this material that we need "ground truth".

It is clear from the observations of asteroid by Galileo and NEAR that the Hera mission should plan for diversity. While some regions are representative of the whole asteroid some are not. Some regions of Eros could be considered as "intercrater plains" and probably typical, but others such as the "ponds", or inside linear structures or ejecta blankets, are not (Chapman, 1996; Veverka et al., 2001; Robinson et al., 2002). It is also clear that we should not expect lunar-like regolith and that on the meter-scale there are major differences between the Moon and Eros. For example, at the scale of the spacecraft-sampling site, structures with positive relief dominate the surface features on Eros while it is craters that dominate the scene on the Moon.

Probably the most critical lesson learned about the surface of asteroids from past missions is that we should expect unconsolidated surface. Every asteroid visited appears to be covered by a regolith whose depth probably varies from meters to kilometers. This obviously has major implications for the nature of the collector, the nature of the samples collected, and for our ability to do the scientific research that we require.

1.3. What is required in the way of samples?

The criterion used by the Hera team for the sample mass to be returned is that every scientist in the sample analysis community should be able to obtain samples. Only in this way can we be assured that the full depth and breadth of available laboratory techniques will be brought to bear on the samples and only in this way will the full value of these samples be applied to addressing the major science goals. So what is the required mass?

There are several ways to address this question. First, we can ask what masses are required to determine the major physical properties of the samples like density, porosity, and mechanical strength. These are the sorts of properties that are needed in order to understand the geophysical properties and internal structures of asteroids. Second, we can consider the considerable amount of effort that was spent in the 1960s and 1970s determining the minimum mass required for an accurate determination of bulk compositions of chondrites. An often-quoted mass was about 10 g (Wasson, 1974). If several laboratories are to independently make such determinations, then the required sample masses will be several tens of grams. Third, we can ask how much mass is required to determine the major structural components in a statistically significant way. For example, what are the mineral and phase proportions and what are the chondrule and metal grain size distributions? For many years, these parameters have long been considered crucial in understanding meteorites. Such considerations lead to the requirement that each sample must be $\sim$100 g.

The philosophy behind the Hera mission is in contrast to that of recent discussions of the amount that can be learned from microgram samples. It is certainly true that when microgram samples are all that are available, incredible amounts can be learned from nano-scale techniques. But this is not the same as saying that a full range of investigation does not require $\sim$100 g. First, many techniques still require gram-sized samples because their detection limits are high. Most chronometry methods require gram-sized samples and chronology is essential information in understanding the genesis of any rock. Second, many phenomena require centimeter-sized samples so that the property being measured can be observed. Bulk compositions, chondrule and metal grain size distributions are in this category, as are the majority of petrographic observations.

This relates to a second point. If $\sim$100 g of regolith from a given site is required for analysis and that regolith typically consists of a mixture of fine-grained material and clasts, what is the smallest sized clast that yields scientifically meaningful information? Guided by our experiences with lunar petrography we suggest that we would aim to include 1–2 cm sized clasts in our returned samples; this also being the size of petrographic thin sections used for microscopic examination. The importance of petrographic observations also means that we need to avoid grinding the sample, and that the collector retains the particle size distributions of the original material.

For the Hera mission, we have made the decision that this will be a highly focused sample return mission. No scientific measurements will be made on the mission that are not absolutely required in order to achieve sample return. An observation in this category is that we closely monitor the site before, during and after collection. The primary purpose is to insure that material is collected and to determine whether the sample is ready to be loaded into the sample return capsule, or whether the spacecraft should return to the surface for another collection attempt. However, these observations will also provide scientifically valuable data on the nature of the surface and the ballistic properties of surface materials.

Given the kinds of measurements we will need to make on returned samples, it is a given that there are certain conditions that must be met by the collection procedure. It is important that the collection process does not change:

- Composition; molecular, elemental, or isotopic
- Physical properties; density, porosity, mechanical strength
- Mineral and phase proportions, including the metal-silicate ratio, etc.
- Particle size distribution

1.4. The necessity for reconnaissance

The Decadal Survey emphasized the need for detailed reconnaissance of the target asteroid prior to sample return and for this reason it is assumed that the first near-Earth asteroid sample return mission would be to Eros which has already been documented by NEAR. In one year of reconnaissance the NEAR spacecraft returned 160,000 images of the asteroid. Britt et al. (2001) used the NEAR images of Eros as a case study. On the assumption that Hera, rather than NEAR-Shoemaker, had been placed into orbit around Eros, where would we take samples? They suggested:

- Representative regolith
- Ponds
- Bedrock and boulders
- Crater transect; floor, wall, ejecta

Of course this list may be different for other asteroids. The Hera mission will spend about 100 days in orbit about each asteroid before it descends to take samples so that it will be able to perform a detailed reconnaissance prior to collecting samples. It will also obtain spectroscopic and altimetry information so that a site selection team can make the final judgements as to where samples can be collected.

1.5. Which asteroids?

The science-return from three asteroids would be orders-of-magnitude greater than from just one asteroid. Asteroids are numerous and compositionally diverse and far more will be learned from seeing how analogous processes occur on different bodies than extrapolating from the studies of one body. To truly access this diversity requires that the Hera mission return samples from three asteroids of different and contrasting taxonomic classes. Since the Muses-C mission will obtain samples of an S (IV) class asteroid, perhaps Hera could sample C, S (VII), P or D asteroids. The National Research Council considers the P, D, and F asteroids as possible sources of biological materials that could be dangerous to Earth, but it might be argued that the space environment will have sterilized surface samples.

1.6. Engineering constraints on asteroid selection

Engineering constraints will make it necessary to avoid asteroids that are smaller than 200 m because they tend to have high spin rates and are more likely than large asteroids to be regolith-free. Sampling bedrock is more difficult than sampling regolith requiring a device such as a drill to free a sample for collection. Close proximity operations during sample collection are also very challenging with a fast moving irregularly shaped asteroid.

The physical properties of the asteroids provide important constraints on the asteroids that can be sampled (Sears et al., 2001c). Size, shape, spin rate, spin state, orientation of angular momentum, and whether the asteroid is binary, are all important in deciding the strategy for close proximity operations. It is possible to design a mission to satisfy most of the expected conditions, but a mission that could deal with different situations at each asteroid would be very sophisticated. Realistically, the mission has to be designed so that the same close proximity operations can be used at each asteroid. This means knowing the physical properties of the three target asteroids before the mission design is finalized.

2. Summary

The main conclusions of our workshop were as follows:

- The asteroids should be characterized (at least approximately) from ground-based observations before mission design so that the same procedures can be used at all three asteroids.
- The target asteroids should be the subject of ~100 days reconnaissance before sampling. During this period of reconnaissance, the surfaces can be imaged and spectra obtained so that a site selection committee of scientists and engineers can select sampling sites.
- The mission should visit three asteroids of contrasting taxonomic type, taking three samples per asteroid from scientifically interesting geological contexts.
- The surface should be imaged before, during, and after sample collection, and it should be possible to image the surface and the sample collector to monitor the collection procedure, document geological context, and obtain ballistics information of material on disturbed material.
- About 100 g of sample should be collected per site. This is the minimal mass required to provide every qualified researcher with a sample. This is also the mass required to obtain certain fundamental kinds

of scientific data such as mineral and phase proportions and chondrule and metal grain size distributions.
- The samples collected should be surface (regolith) samples because such samples provide an unambiguous link between the returned samples and astronomical data, because they record a history of solar interactions and tend to sample most of the major geological units.
- The sample collection procedure should cause no alteration of composition or the physical properties of the samples and should preserve clasts of at least one-centimeter in size.

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