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The Hera mission: multiple near-earth asteroid sample return

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Abstract

The NEAR mission was a spectacular rehearsal for one of the most exciting and scientifically rewarding missions of the next decade, sample return from near-Earth asteroids. A unique source of information about the early solar system, the formation of the planets, and the connection between stars and our Sun, are meteorites and asteroids. Yet, studies of both are hindered by a lack of unequivocal and detailed information linking the two. Meteorites are rock samples of unknown provenance. We have no information about the geological context of their source. They are also highly non-representative sampling of primitive solar system material because the terrestrial meteorite population is dominated by the ejecta of stochastic impacts and because the atmosphere filters out all but the toughest rocks. Without sample return, asteroids are not amenable to the depth and breadth of techniques available in the laboratory, yet the NEAR images indicate that there are many processes occurring on asteroids – or that could have occurred in the past – that we must understand if the meteorite data are ever to yield a clear image of early solar system processes. Technical developments of the last few years and the discovery of large numbers of NEAs mean that sample return is now within small mission capability. A team of about 20 scientists and engineers from all relevant subject fields are now assembling a mission called Hera. This paper reviews the mission as of fall 2002.

Keywords: Multiple asteroid sample return; The Hera mission; Near-earth asteroids

1. Introduction

The Hera mission is a proposed Discovery class mission that will visit three near-Earth asteroids, reconnoiter for at least two months, recover three samples from each asteroid, and return them to Earth. Preliminary descriptions of the mission have been presented at conferences, but this is the first publication (Fig. 1) (Sears et al., 2000a, 2002b, 2001e).

An important aspect of the Hera mission, is that we are seeking maximum community involvement. The mission is complex, with broad-ranging scientific implications, and only by maximizing community involvement will we fully exploit the opportunities provided. We seek community help before launch in characterizing and selecting the target asteroids, during flight in identifying sampling sites and finalizing asteroid selection, and after the mission examining the samples.

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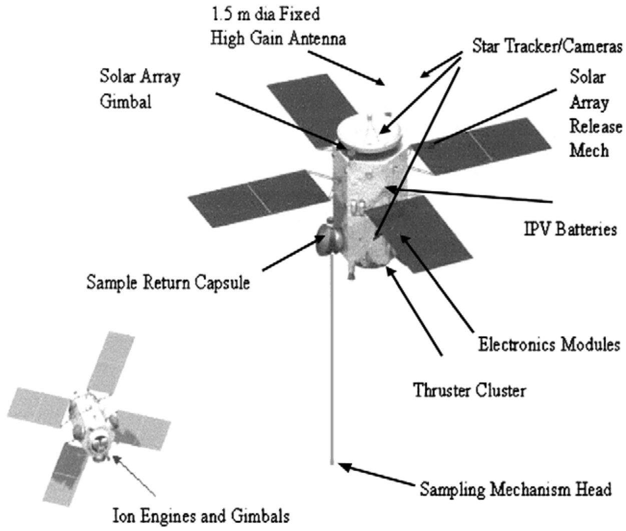

Fig. 1. The Hera spacecraft in a concept drawing by SpaceWorks (Jeff Preble) and according to mission design by Glenn research Center (Leon Gefert).

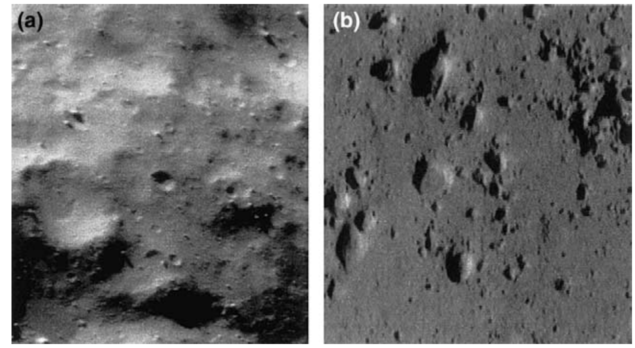

Fig. 2. (a) The surface of Eros as observed by the NEAR-Shoemaker spacecraft January 14, 2001, from an orbital altitude of 38 km showing features as small as 6 m and a field of view of ~1.1 km. Unlike the Moon's surface, which is dominated by craters, the surface of Eros is dominated by a blanket of regolith and boulders. Many of the low spots are extremely flat, and appear unfilled. (Image 0154882617). (b) NEAR-Shoemaker's image of asteroid 433 Eros taken from a range of 250 m. The image is 12 m across. The cluster of rocks at the upper right measures 1.4 m across. (Image 0157417133).

2. The value of returned samples

Why pay for expensive sample return missions when in situ analysis is so much cheaper and easier? This issue has been addressed many times in the literature (Brownlee et al., 1996; Sears, 1998a,b, 1999; Fujiwara et al., 2000; Sears et al., 2000b, 2001a,b,c; Burnett et al., 2003). Returned samples enable a much greater depth and breadth of data than can obtained by in situ methods. Elemental, mineralogical, and isotopic data of a quality that cannot be acquired by in situ methods can be obtained with returned samples. Certain studies require a level of sophistication that cannot be obtained by in situ methods and probably will not in the foreseeable future. Such studies as chronology, fingerprinting geochemical processes, minor and trace mineralogy, and detailed petrology, can be used to study the abundance and distribution of chondrules. Finally, samples can be stored pending new instruments and procedures. The returned samples have lasting value because new analytical techniques can be applied when they are developed.

3. The need for returned samples

Meteorites have yielded vast amounts of information, some of it relating to preplanetary processes, some relating to the process of accumulation, some relating to secondary alteration such as metamorphism, shock or the passage of aqueous fluids. However, there are still vast areas where our understanding is still far from complete. This is not surprising. Sears et al. (2002a) made the point that trying to understand the early solar system from meteorites was akin to trying to understand the geology of southern England from the pebbles on Dover beach without knowledge that they are altered wash products from narrow horizons in extensive chalk deposits.

We have now imaged several asteroids with robotic spacecrafts and have a good idea of the nature of the surface. Fig. 2 shows two images of Eros, one at 38 km and one at 250 m. The surface is highly diverse, but uniformly covered in regolith. Britt et al. (2001) used Eros for a case study of where samples would have been collected if the NEAR-Shoemaker spacecraft was equipped with sample return apparatus. Their suggestions were that we sample representative regolith, the ponds, bedrock and boulders, and transect a crater, sampling the crater floor, wall, and ejecta.

The second major argument for sample return can also use the pebble beach metaphor. In order to understand the geology of southern England we need chalk samples to date, to determine elemental and isotopic compositions, and perhaps even to find fossils. There are almost certainly new kinds of primitive material in the asteroid belt that is not reaching Earth, either because the stochastic processes required to bring it here have not been effective, or because it could not survive the rigors of the trip, especially passage through the Earth's atmosphere. We understand the mechanics of passage through the atmosphere and most of the material that makes up comets and asteroids would not survive. The material reaching Earth is a small tough residue of the material entering the atmosphere. The airbursts routinely monitored in the atmosphere by the defense forces are evidence for this, and so is our experience with recovered meteorites. The rarest meteorites are the most fragile, Tagish Lake and Revelstoke being examples.

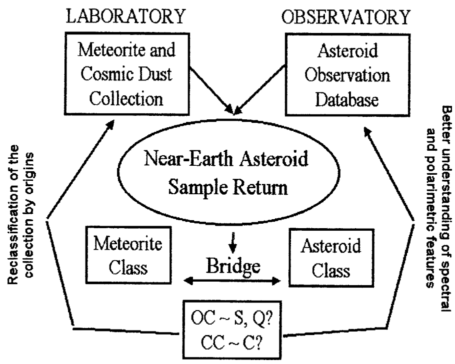

Fig. 3. The scientific rationale behind the Hera mission expressed as a logic flow chart. Only sample return from asteroids previously studied by remote observations and in situ/rendezvous measurements can bridge between the ground observations of minor bodies and laboratory analyses of meteoritic samples. (Courtesy Hajime Yano, ISAS).

These were particularly primitive meteorites that deposited small amounts of material on the surface of the Earth, but they created enormous commotion in the atmosphere as they disintegrated.

4. The multiplying effect

The immediate value of near-Earth asteroid samples will be enormous, but their ultimate value will be far greater. This is because 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. In short, there is a multiplying effect. We have attempted to summarize this argument in Fig. 3.

5. The decade of sample return

Solar system exploration is about to enter a decade of sample return. The Stardust mission is collecting interstellar dust en route to comet Wild and when it arrives it will collect cometary dust for return to Earth. The Genesis spacecraft is currently orbiting at the first Lagrange point where it is collecting solar wind for return to Earth. The Japanese MUSES-C spacecraft is due for launch in March 2003 towards asteroid 1998 SF36 where it will collect about a gram of surface material for return to Earth. There is a new Astromaterials Branch at the Johnson Space Center and returned samples are to be the main thrust of a reinvigorated Lunar and Planetary Institute in Houston. Finally, the NASA planning documents, the missions and technology roadmap, and the Space Science Enterprise Goals all underline the scientific value of sample return and now the NRC Decadal Study describes it as a scientific priority (Sears et al., 2002a; Space Studies Board, 2002).

6. The mission is timely

Technologically, near-Earth sample return is timely with the success of NEAR-Shoemaker, which achieved most of the objectives of a near-Earth sample return mission, including repeated maneuvering. Deep Space 1 demonstrated the reliability of solar electric propulsion that will be needed for Hera. The extraordinary rate of discovery of NEAs means that targets are numerous and energetically favorable. There are currently about 30 NEAs easier to get to than the Moon. Finally, the selection of the Dawn mission, with three NSTAR thrusters and a mission-duration of nine years demonstrates the confidence of NASA in solar electric propulsion for long duration deep space missions.

7. The mission concept

The overall mission design, which is to select three near-Earth asteroids that can be visited on a single mission and return samples to the Earth. In our original (Sears et al., 2000a), the asteroids were 1999-AO10, 2000-AG6 and 1998-UQ. This particular mission would be launched in January 2006 and return 4.5 years later. The spacecraft would be launched on a Delta 2925-10, with nine strap-on solid fueled boosters and a 10' fairing. The solar arrays would provide 6 kW of electricity at 1 AU. Since the spacecraft stays within about 40% of 1 AU, the arrays are operating near maximum efficiency most of the mission. These arrays would power three solar electric propulsion (SEP) thrusters of the type carried on Deep Space 1 of which only two would be thrusting at any one time. Thus there is a one-thruster redundancy. Monopropellant hydrazine thrusters will be used for proximity operations, where the power from the SEP thrusters is too weak, and have an allocation of 20 kg of propellant for each thruster. The mass of the entire spacecraft is about 800 kg, of which about 600 kg is Xe fuel for the thrusters.

Since our original work, we have identified about 40 trajectories that would take the spacecraft to three asteroids and return it to Earth within the capabilities of Delta II launch vehicle and three solar electric propulsion units. The 20 asteroids that occur most frequently in these calculations are listed in Table 1. A strategy for the mission might be to identify the, say, four most likely and scientifically interesting targets and then keep the array of possible trajectories a variable during mission development.

Table 1
Target asteroids and data relevant to the Hera mission (Sears et al., 2001d; Binzel et al., 2001, 2004)

Name	N[a]	Class	Size (m)	H	Rotn (h)	Obs[b]
1993-BX3	16	–	190–420	21	20.463	>10y
2000-EA14	16	–	190–440	20.9	–	May 06
1989-UO	13	B	500–1100	19	7.733	Oct 03
(4660)-Nereus	12	XE	700–1500	18.2	–	Jun 04
1998-KY26	11	CO	<40	25.5	0.178	>10 y
(3361)-Orpheus	10	Q or V	500–1100	19	3.58	Oct 05
1998-VD32	9	–	100–240	22.2	–	Jul 07
2000-AG6	9	–	20–50	25.3	0.076	>10 y
1998-SF36	8	S(IV)	360	19.2	–	Jan 04
(10302)-1989-ML	5	X	370–840	19.5	–	Jan 06
2000-AF205	5	–	150–330	21.5	–	>10 y
1997-UR	3	–	70–160	23	–	>10 y
(4581)-Asclepius	3	–	250–560	20.4	–	>10 y
1993-PC	3	–	700–1500	18.3	–	–
1996-FG3	2	C	600–1400	18.4	–	Apr 09
2000-AH205	2	S_k	90–220	22.4	59 ± 16.1	Jun 09
1999-AO10	2	–	50–110	23.9	–	>10 y
(6239)-Minos	1	–	800–1800	17.9	–	Jan 04
1998-HL3	1	–	300–670	20	–	Apr 04
2000-CH59	1	–	390–880	19.4	–	Jan 04

[a] N is the number of instances when the asteroid appears in 40 independent trajectories involving visits to three asteroids.
[b] Opportunity for next observation.

8. The target asteroids

The only asteroid candidates for a mission are the asteroids for which classifications are known and this limits discussion to eight of the asteroids in Table 1. Even so this is an interesting list. We have two S asteroids, a C asteroid, a B asteroid and two X asteroids (Gaffy et al., 1993). The best known example of a B asteroid, like 1989-UO in our list, is the second largest asteroid, Pallas. B asteroids are related to C asteroids and their surface is probably composed of metamorphosed clay and opaque minerals. The S(IV) asteroid class is the S subclass most closely resembling ordinary chondrites. The S(IV) asteroid 1998-SF36 is the MUSES-C target. Binzel et al. (2001) suggested that this object is a reddened ordinary chondrite. The asteroid 2000-AH205 is S_k class. These asteroids may represent a low pyroxene type of chondrite. As one of the two major asteroid classes, perhaps related to the very important CI and CM chondrites that are rare on Earth, it seems essential that we include a C asteroid like 1996-FG3. C asteroids are thought to have clays, carbon and organics on their surfaces. They are good candidates for new types of material because their rareness on Earth is probably related to their fragility. The X asteroids have poorly understood featureless spectra and it is not clear what their scientific ranking should be. Samples would probably not help us understand the asteroid–meteorite link, but such asteroids might be the best source of new materials. Asteroid Orpheus is either Q or V class. The Q class is a rare asteroid class whose spectra closely resemble those of ordinary chondrites, while the V class is sometimes referred to as vestalets (basaltic material probably originating on Vesta). This class uncertainty could easily be resolved by ground based observations extended to near infrared wavelengths.

9. Mission constraints on sample collection

Detailed mission design is going to require knowledge of the physical properties of the asteroid, and the simplest designs will be obtained if the asteroids are similar in physical properties. In order of importance the properties are: whether the asteroid is binary, its size, its spin rate, its type, its shape, and its spin state (Sears et al., 2001d).

10. Honeybee sample collector

The first collector examined by the Hera team is a device designed by Honeybee Robotics for the Hummingbee comet sampling mission of Glen Carle (Fig. 4(left)). The sample collector consists of counter-rotating cutters that eject the samples into container located behind the cutters. The whole assembling is attached to a boom that retracts into the spacecraft. Once retracted, the sample collector drops the samples into a container in a carousel. The Honeybee collector has a technical readiness of 3–4.

Tests were performed in the laboratory and on the NASA KC-135 microgravity facility (Fig. 4(right)) (Sears et al., 2002c). During laboratory tests, 10 out of

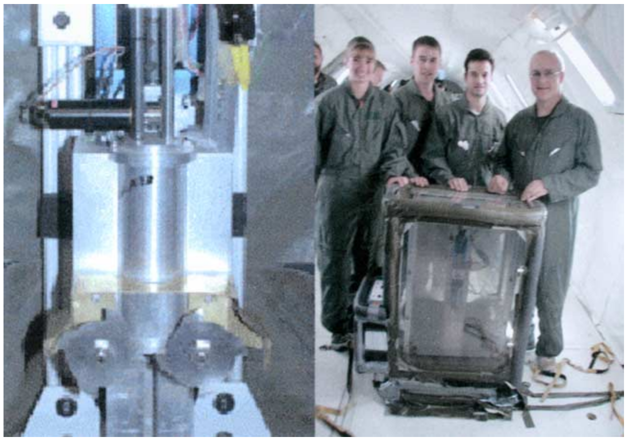

Fig. 4. (Left) The head of the Honeybee sample collector. The collector consists of two counter-rotation cutters that throw samples into a containment vessel with a closing door. (Right) The collector test fixture on board the NASA KC-135 microgravity test facility. With experimenters Melissa Franzen (University of Arkansas), Paul Bartlett (Honeybee Robotics), John DiPalma and Jeff Preble (both SpaceWorks).

12 attempts to pick up gravel were successful and the amount of material collected was satisfactory. Sand and gravel mixtures could also be collected in reasonable amounts but the sand-to-gravel ratio was not reproducible because of the small size of the collector relative to the centimeter-sized gravel. In the laboratory the collector was also able to pick up satisfactory amounts of sand and sand–iron filings mixture, and the reproducibility of the sand-to-iron filings mixtures was excellent. Unfortunately, tests under microgravity were not as satisfactory. The biggest difficulty was that as soon as the cutters touched the surface, the surface would usually move away. When material was thrown into the collector cavity it would often swirl around and leave the collector. The result was that gravel could be collected, although at lower efficiency than on the ground, and small amounts of concrete could be collected. Virtually all of the attempts to collect sand and sand–iron filing mixtures failed.

We conclude from these tests that a better collector would be one that fixed the surface so that it could not move away from the collector and one which did not rely on unconstrained movement on the surface material into the collector. A sample collector proposed by SpaceWorks that overcomes these problems is the sticky footpad (Fig. 5). This consists of three banks of hinged arms long enough when fully extended to keep the spacecraft able to tumble without touching the asteroid surface. At the end of each arm is a circular footpad containing adhesive that actually touches down. After visiting the asteroid, the arm folds back into place and the pad is put into one of three sample return containers.

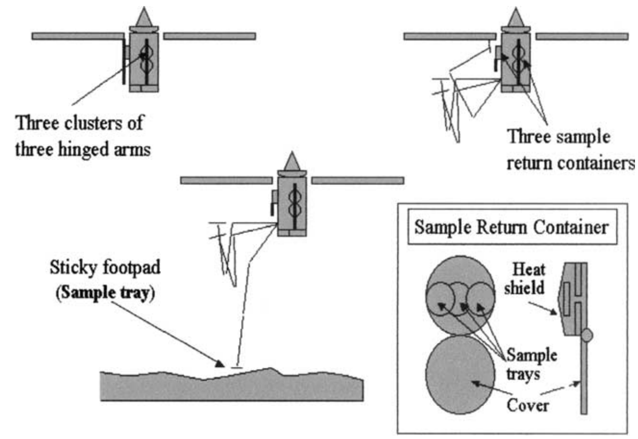

Fig. 5. The SpaceWorks sticky footpad collector. Three sets of 3 arms are associated with sample return containers. Each has a 30 cm diameter tray containing adhesive which is momentarily touched onto the asteroid surface. After collection, the sample tray is place inside the sample return container.

11. Earth return

The Hera spacecraft will bring the sample return capsules back to Earth and jettison them into the Earth's atmosphere to return using parachutes and a landing, as Stardust, retrieval in mid-air, as Genesis, or a landing with direct return, relying on an aeroshell for the entire descent.

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