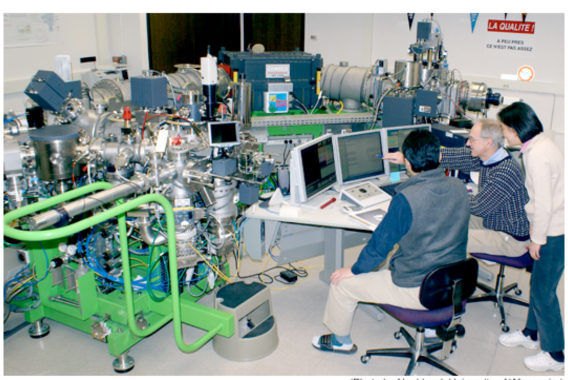
SAMPLING THE SOLAR SYSTEM: THE NEXT LEVEL OF UNDERSTANDING. A.H. Treiman, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058. treiman@lpi.usra.edu.

Introduction: With the success of the Dawn and New Horizons missions, NASA has completed its first-cut inventory of the major bodies in the solar system. The next level of understanding of the solar system will come from detailed analyses of its materials. For most materials, sample return to Earth will be essential, permitting use of massive, power-hungry, and delicate instrumentation. Some sample return missions have succeeded, others are in flight, and NASA should formally encourage many sample returns in its long-term plans [1,2]. NASA should also encourage collection of larger (kilogram-size) and temperature-sensitive (e.g., ice) samples, and develop curation and analysis capabilities for them here on Earth.

Importance of Sample Science: Study of the solar system through samples, its physical materials, is crucial for understanding its origins, the origins of life, and the extension of human presence beyond Earth. Knowledge from samples has completely reshaped our understanding of the solar system, its history, and events before and beyond it (e.g., [3-5]). Sample science is complementary to remote sensing and in-situ studies (e.g., orbiters and rovers). Remote sensing allows the Apollo lunar samples to be placed in a geologic context and relative chronology, and the samples provide calibration for remote spectral observations.

Rationale for Sample Return: The value of extraterrestrial samples on Earth is well documented (e.g., [3,6]). Returned samples can be prepared for analysis in various ways (e.g., FIB sections, mineral separates) and be analyzed in instruments that could not conceivably be sent off Earth (constrained by power, mass, and delicacy), Fig. 1. Samples, properly curated, are "gifts that keeps on giving" [6], in that they can be studied into the future with increasingly precise instruments and in response to new discoveries and new hypotheses. As proof, consider how re-analyses of Apollo lunar samples has completely overturned of our thinking about lunar volatiles (e.g., [7,8]).



(Photo by Neal Lord, University of Wisconsin.)

Figure 1. A modern laboratory instrument: Cameca 1280 SIMS (secondary ion mass spectrometer). University of Wisconsin SIMS lab, Drs. J. Valley and N. Kita at right (for scale, ~ 1.5 m tall)

Rationale for Large Samples: Recent sample returns have been of tiny particles, ranging from individual solar wind atoms (Genesis mission) to ~200 µm grains (Stardust, Hayabusa). Small samples permit important science (e.g., [3-5]) but cannot address other crucial objectives. (1) Such small samples may not be representative of planetologically significant masses (Fig. 2); e.g., a volcanic glass bead could represent a magma composition, but a single mineral grain would not. (2) Small samples may not show multiple mineral grains and their intergranular relationships (i.e., textures) that permit one to unravel the formation conditions and histories of the grains. (3) Small samples may not be massive enough for specific analysis, e.g., a radiometric W-Hf isochron age.

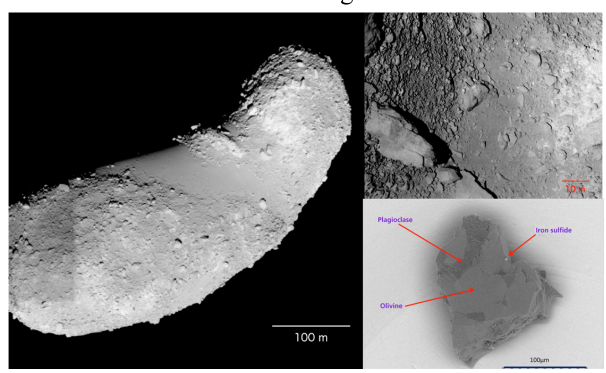


Figure 2. Asteroid Itokawa. Left is whole object, ~ 525 m long; note variety of boulders and fines on surface. Right above, closeup showing range of textures and fragments at meter scales. Right below, backscattered electron image of a large particle of Itokawa regolith, returned by Hayabusa spacecraft. All images from JAXA.

Long-Term Strategy: In the long term, NASA should encourage returns of material samples from all classes of objects across the solar system. This program should begin with the simplest missions, building from current successful architectures outward to larger samples and to more difficult logistics and curation needs. Hayabusa, Hayabusa II, and Osiris REX have (will) sample several sorts of asteroids without ice, but many more spectral/compositional types are known (including the martian moons Phobos and Deimos). Stardust sampled one comet, but many different types are known. Lunar sample returns should also be early, and build on known architectures. Later sample returns would include volatile-rich targets (asteroids, comets), distant high Δv objects (moons of outer planets, KBOs), and those with special logistical issues.

Moon, Involatile Asteroids, Comet Material, Phobos, Deimos. Samples have been returned from volatile-poor (not icy) small bodies (by Apollo, Luna, Hayabusa, Stardust) and others returns are in progress (Hayabusa 2, Osiris REX). Most such bodies are in the inner solar system, allowing relatively rapid and low Δv access. Lunar sample return has been discussed at length (e.g., [3]), and many important lunar targets remain unsampled [9]. The asteroids include a huge diversity of spectral types [10,11], and each may represent a different sort of solid (e.g., like a meteorite type [12]). Comets come in a wide range of types also, at least from their volatile constituents [13,14]. Phobos and Deimos are strong targets for sample returns (e.g., [15-17]), and could possibly preserve Martian ejecta [18]

Icy Asteroids & Comets. Returns of icy materials should be enabled next. Their samples will provide crucial evidence about the sources, processing and distribution of volatiles in the solar system, and the foundation for the emergence of life. Ices are characteristic of comets 'dead comets' in the asteroid-belt, and also of larger indigenous asteroids [19].

Sample returns of solar system ices will require mechanisms of cryogenic transfer to Earth, and cold curation procedures and facilities on Earth. Cryogenic curation is under study [20], but perhaps not ready yet.

Outer Solar System. Proposals have been floated for sample returns from the outer solar system, like from Enceladus, Europa and KBOs (e.g., [21-24]). These are technically challenging, and must follow establishment of cryogenic curation practices (see above). Such missions also require large Δv's, especially to bodies orbiting close to giant planets (e.g., Europa). Planetary protection could be a major issue for many such bodies [21,25,26].

Mars, Venus and Mercury: Technical Challenges. The terrestrial planets (except Earth) present unique challenges for sample return. Mars sample return has been studied unto death for ~40 years [27], and planning for the Mars 2020 Rover includes caching of samples for eventual return. Planetary protection is a major issue, and will require development of spacecraft and earth-based infrastructure [25], some of which in planning [28,29]. Venus sample return, though proposed [30,31], would need to penetrate its thick atmosphere, and possibly conduct surface operations at its ambient conditions. Mercury sample return [32] could be similar in concept to lunar return, but the Δv needed to traverse to Mercury, land there [33], and return to Earth is huge.

Summary: Returned samples of solar system objects will provide crucial data on the constitution, variety, and history of the solar system. Returned samples will provide data that cannot be obtained by conceivable robotic instrumentation, increase the value of remote observations by providing ground truths, and (properly curated) allow for testing of new hypotheses by ever-more-capable instruments. Sample returns from across the solar system should be among NASA's long-term goals, and can be achieved in a logical sequence of activities, building on its current successes.

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