Summary of the 2009 September 9 to 11 Meeting of the Primitive Bodies Panel of the 2010 Planetary Science Decadal Survey

Washington, DC

Michael Busch

Introduction

The Primitive Bodies Panel of the Planetary Science Decadal Survey met from 2009 September 9 to 2009 September 11, one of the series of meetings organized for the Survey by the Space Studies Board of the National Research Council (NRC). The panel met to discuss primitive bodies and receive instructions from the Survey's Steering Committee, and heard presentations of the status of various space missions, summaries of white papers related to primitive bodies, and the mission planning options available to the Survey.

This report was prepared by a graduate student observer and captures the topics discussed, but does not represent the specific views of any individual. It reflects the status of the panel's work as of the end of the meeting, and does not include any later decisions. The open and closed sessions have been reported separately. A list of acronyms is provided as an appendix.

Open Session

Wednesday, September 9, 10:15 AM – 6:00 PM

The open sessions of the meeting were accessible to the public via webcast and teleconference, and archives of the webcasts are available through the Planetary Science Decadal Survey website.

Decadal Survey Overview
Steven Squyres, Cornell University, Chair of the Steering Committee

This is the second Planetary Science Decadal Survey, and was requested by NASA at the end of 2008. The NRC organized the Steering Group in the first half of 2009, and the first panel meetings are taking place during the third quarter. The peak period of activity for all of the panels will be the fourth quarter of 2009 and the first quarter of 2010; the final report of the survey must be completed by the middle of 2010.

The Survey is organized into a Steering Committee and five panels, covering the Inner Planets, Mars, the Outer Planets, Satellites, and Primitive Bodies. In contrast to the previous Survey, astrobiology is not separate, but has been integrated into the other panels. The panels should draw from the reports of their predecessors. In particular: what questions are still interesting, what have been answered, and what has changed?

The goal is for the planetary science community to rally behind the Survey's report, and the panels must establish a consensus view of the community. There should be the greatest possible amount of outreach and community interaction. The primary form of community involvement has been the white papers, but the Steering Committee has also organized Town Hall meetings at major conferences (DPS, AGU, LPSC) and is coordinating with other groups that have overlapping interests (e.g. the Astronomy 2010 Decadal Survey). Panels and panel members are encouraged to organize their own outreach events.

White papers must have been submitted by September 15, between 150 and 200 were expected. All authors are eligible, except for NASA headquarters staff, Steering Committee members, and the Chairs of the panels.

The Survey has been asked to evaluate candidate spacecraft missions for NASA to fly in the coming decade. The panels include members expert in engineering, project management, and cost estimating, to produce a technically feasible and reliably costed portfolio of missions. NASA has provided approximately 5 million dollars in funding for a mission design studies, and the NRC will procure independent cost estimates. Each panel will prepare a list of missions they would like studied for cost and technical maturity and provide it to the Steering Committee, who will organize the design studies and use the independent cost estimates to establish a list of missions that can be flown without the cost cap. Each mission study must include at least one panel member to inform the design team of the science goals of the mission; and studies should be requested as early as possible – large studies, in particular, must be reported by January 2010. There are no restrictions on the types of missions that may be studied. Missions that exceed reasonable budget limits can be suggested if there is a compelling case for international collaboration and funding.

Ultimately, the Survey must make recommendations for science programs that fit in the cost cap for all of planetary exploration, rather than each subpanel. Recommendations for NSF funding should be considered as a subsection of the Survey's report. While NASA dominates planetary science funding, the report cannot focus only on the missions: it must include technology development, research and analysis, ongoing missions, and what to do when missions creep out of the cost box. Technology development includes funding for projects in the decade after next, and may well be comparable to mission costs. Mission studies can include infrastructure studies as well – there are no strict rules.

<u>Lessons Learned from the 2003 Decadal Survey</u>
Dale Cruikshank

The first Planetary Science Decadal Survey took place in 1993, and was somewhat more narrowly focused than this second iteration: the panels focused on missions and did not include curation and research and analysis recommendations. The previous primitive bodies panel agreed on two goals: "Building Blocks of the Solar System" and "Organic Matter in the Solar System" and assembled categories of science questions relating to each. They then recommended missions to address those questions.

In particular, the first Survey recommended several New Frontiers-class missions: a flyby of Pluto/Charon and other Kuiper Belt objects; sample return from comets and near-Earth asteroids; and extensive surveys of primitive bodies. As well, they recommended a flagship-scale mission: cryogenic comet sample return. While most of the other recommendations have been followed in one form or another, this remains of unknown cost and technical feasibility.

Since the last Survey, there have been profound advances in understanding almost all primitive bodies. Even so, the old recommendations on surveys of near-Earth asteroids and the outer solar system remain valid. Despite NASA's general aversion to ground-based telescopes, this survey should endorse LSST and other ground based surveys as the best way to survey the Kuiper Belt, understand the processes at work in the outer asteroid belt and Centaur population, and complete the near-Earth asteroid survey goals. NASA will continue to fund the IRTF, but radar astronomy as well as other ground-based observing is still being passed to the NSF.

There were three particular lessons for the panel: there must not be even the appearance of conflicts-of-interest; science questions should be clearly organized into themes and overall goals; and missions should be sorted in priority.

<u>Charge to the Decadal Survey</u>
James Green & Lindley Johnson, NASA Headquarters

The results of the Decadal Survey will be shared between NASA and the NSF, and must be an integrated view of all of planetary science; including the interaction with human exploration, research & analysis, and technology development. The Survey's report must recommend a portfolio of programs that fit within the known fiscal year 2011 budget, and consider options with for additional funding sources.

Headquarters has assigned contact points: people to be at each panel meeting, responsible for satisfying panel requests for information and facilitating mission concept design students. Lindely Johson has this job for the primitive bodies panel.

The panels will recommend mission concepts that provide compelling science and could be launched within the next decade. To insure reliable cost estimates, these concepts will be studied by one or more design centers and these studies evaluated by an independent cost estimator. The Steering Committee must approve all studies and will ensure that each study follows a uniform set of guidelines, and each study will have a science advocate assigned to it from among the panel members.

Missions that are and are not covered by this Decadal Survey

Currently active planetary missions and those in final Phase-A construction are not under the range of this Survey. These include:

Lunar missions: LCROSS/LRO is active; Artemis in 2011; GRAIL in 2012; LADEE in 2013.

Mars missions: Odyssey, MRO, Mars Express, and MER are active; MSL in 2011; Maven in 2013.
All others: Messenger, Venus Express, Deep Impact & Stardust extended, Rosetta, Dawn, Hayabusa, Cassini, and New Horizons are active; Juno in 2012.

The WISE mission, although primarily astronomical, has some application to primitive bodies. The mission's data processing has been changed to obtain asteroid infrared brightnesses and discover a limited by significant number of near-Earth objects, using an adaptation of the Pan-STARRS moving object pipeline. WISE launches in December 2009, with the survey starting the January and running six to nine months.

Any missions beyond these are in the range of the Survey. Currently, an outer planet flagship mission to launch in 2020, a new Discovery mission to launch by 2016, and the third New Frontiers mission are explicitly budgeted.

Technology Development

Two major new technologies will be available to missions in the next decade. First, the Advanced Space Radioisotope Generator (ASRG) is a Sterling-cycle RTG providing six times the power per unit mass of plutonium-238 than the previous generation. Two flight units will be available in 2014, in addition to that allocated to MSL. Second, laser communication outperforms radio in terms of mass, power, and data rate. This will be used by the LADEE mission, with two to four mobile receiving stations and burst transmissions to avoid clouds. There have been cutbacks to technology development for Mars to fund MSL.

Ground-based Facilities and Programs

This panel will be more focused on ground-based science than the others, so NASA's position on ground-based facilities must be clear: they are only in support of spacecraft missions. Near-Earth object discovery is the odd one out, since NASA is mandated to support the discovery of NEOs. That said, unless additional funds are provided by Congress to support the second NEO discovery mandate (90% completeness of 140 m by 2020), NASA has no plans to fund LSST or another large survey program.

Any and all sample returned from missions will be preserved and handled by the curators at NASA Johnson, who are already handling the samples from Stardust and Genesis.

<u>NSF's Support for the Planetary Sciences</u>
Vernon Pankonin, NSF

The Survey covers all of planetary science, and while the NSF's primary support is to ground-based astronomy through observatories and individual investigator grants, the planetary-related programs in the geological and atmospheric sciences will listen to its recommendations.

Currently, 27% of NSF astronomy funding is for individual grants while 54% goes to facilities. They wish to provide more funding to individual grants, which may mean decreasing funding to some observatories. In particular, Arecibo and the NAIC are being considered for budget cuts. The NRC is currently running an asteroid discovery panel, which should yield a decision on Arecibo's future.

The NSF encourages the Survey, particularly Steering Committee and the survey recommendations of this panel, to coordinate with the astronomy decadal, so that the overlapping areas in recommending ground-based facilities will reflect the consensus of both communities. For example, work relating to extrasolar planets has been placed under Astro2010, but will also be relevant to the Outer Planets panel. For this panel, the LSST project is the most relevant, as it promises a thorough census of the solar system.

<u>Small Bodies' Community Goals and Priorities</u>
Mark Sykes, Planetary Science Institute

The NASA Small Bodies Assessment Group (SBAG) is an independent community-based forum designed to provide science input for planning the exploration of small bodies throughout the solar system, potentially including human exploration. SBAG divided primitive bodies into NEOs, asteroids, comets, dwarf planets, Centaurs, small satellites, and dust and organized meeting and an online forum to aid in writing "community white papers" – overview papers with a large number of coauthors to represent the views of the community. These papers include, but are not limited to:

> *Near Earth Objects (Nolan et al.)*
> Composition, physical properties and evolution of NEOs; their specific source regions and sinks; and how NEOs can be used as resources for human exploration. The mission priority here is sample return.
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> *Main Belt and Trojan Asteroids (Britt et al.)*
> Composition gradient of the asteroid belt, which fragments originate from which parent bodies, support and development of ground-based telescopes, studies of asteroid families and meteors. The mission priority here is again sample return, but this is lead by flyby or rendezvous missions to the Trojans or a main belt comet, since sample return is far more expensive.
>
> *Comets (Weaver et al.)*
> Solar system formation, role of volatiles, detailed composition and structure. The emphasis is still on sample return, either from the surface or near subsurface. Cryogenic sample return is the long-term goal, as recommended in the previous survey.

<u>Asteroid Science Goals</u>
Faith Vilas, Erik Asphaug

In the previous Survey, the only specific mentions of asteroids were Trojans and the impact hazard, with a large new ground-based survey project recommended as the way to resolve the latter. No spacecraft missions to asteroids were directly recommended. While we have lagged on finishing the survey telescopes, we have exceeded the recommendations with the

Dawn mission and the US involvement on Hayabusa and Rosetta. We have a lot more data, and many new questions, particularly with respect to the role of asteroids in understanding the formation of the solar system.

Advances in the last decade

Our understanding of asteroids, particularly the near-Earth population, has fundamentally changed since the last Survey. We now know that most asteroids are unconsolidated rubble piles fractured by collisions, and that radiation pressure dramatically affects their orbits, spin states, and shapes. In particular, the NEO "life cycle" of radiation spinning up objects until they fragment, then either recombine or separate completely, explains the large number of binary near-Earth asteroids discovered in the past decade. A similar process occurs in the main belt, with collisions dominating radiation. Rubble-pile asteroids have little tensile strength, which changes their response to collisions. Some asteroids are solid metal or rock, others are 60% empty space, and all have complex surface features from microgravity geology.

There is dramatic diversity in mineralogy and geochemistry among asteroids, from space weathering of the surface to the bulk composition. The Jupiter Trojans are very low density and some objects in the outer main belt show cometary activity, implying that both are largely volatiles or ice. Closer in there are objects dominated by metal, silicates, or carbonaceous material. The near-Earth asteroids are young disrupted shards of larger objects, and may not have internal structure or variations in chemical alteration, but the largest main-belt objects do.

The increased discovery rate of asteroids means that we are effectively mitigating the Earth-impact hazard, with the side effect of locating many objects that have a significant probability of impact when first discovered but are then determined to pose no risk. Given the current generation of surveys and rapid reduction and reporting of data, we can now discover small objects before they impact the Earth, as demonstrated by the case of 2008 TC3. Such cases confirm our spectral identification of objects, but are not a substitute for sample return from selected objects, especially of materials that are destroyed in meteorites.

Current science goals

Spacecraft missions to asteroids are essential if we want to understand them as physical objects, particularly to understand the physical processes active in microgravity environments. There is no such thing as a 'typical' asteroid, given the diversity of the population is size, composition, and internal structure, so missions to many different objects would be desirable. Likewise, sample return is essential to understand the composition of particular objects; but more importantly; to understand the compositional differences between asteroids and the meteorite collection. Rubble-pile asteroids may not have any consistent composition variations, but the largest objects will.

Ground-based exploration of asteroids; from discovery to photometry, spectroscopy, and radar; remains essential. It provides the information to define the questions to answer with space missions and provides context for their results. Since the last study, NASA has a new mandate: to discover 90% of NEOs larger than 140 m by 2020. This goal cannot be met without LSST or a comparable facility, which will require investment in data handling, processing, and storage as well as in hardware. Over the next decade, we will understand more about the very diverse population of asteroids, but we must be able to accommodate the processing of that data.

Missions recommended by the community

There are at least two white papers advocating a space-based survey telescope to locate all the remaining hazardous NEOs. However, the cost of these missions is likely to exceed that of a comparable ground-based survey, which would provide a great deal of other science (both planetary and astronomical) in addition.

For New Frontiers-class missions, the white papers include proposals for: rendezvous with a Jupiter Trojan or a main-belt comet; a tour of many main belt objects as a follow-on to Dawn; and landing and sample return from several near-Earth objects. For smaller, Discovery-cost missions: rendezvous with a binary near-Earth asteroid. Should the human spaceflight program include missions to near-Earth objects as an alternative to lunar missions, the target objects should be studied in detail beforehand to maximize the science return.

Asteroid sample return missions require technological development depending on the details of the mission. Hayabusa has demonstrated a touch-and-go landing. However, moving about the surface of an asteroid under microgravity is difficult to design for, particularly on objects with dust-rich surfaces, and these problems must be solved before, e.g., landing a rover.

Comet Science Goals
Jessica Sunshine, Donald Brownlee

Determining the science goals for comets is slightly complicated by the definition of what a comet is. The current working definition is “volatile rich objects pushed in from the outer solar system”. This does not include objects that formed in the main belt or were placed there during the last stages of planet formation by a migration process such as predicted in the Nice Model. That said, there are comets on near-Earth and main-belt orbits.

Advances in the last decade

The last Survey focused on comets as probes of solar system formation and as sources of organic material. Over the past decade, we have come to more primarily study comets as unique physical objects as well. As with the asteroids, comets are a hugely diverse population. We understand this thanks to the flybys of comets Borrelly, Wild-2, and Temple-1 and their dramatic structural differences from comet Halley and from each other. On Temple-1, there are large-scale layers and preserved impact craters, and different regions rich in different ices.

There are some common properties. Ground- and space-based infrared measurements have provided size, albedo, and thermal inertia information for many comets. Comets generally are porous, fluffy, aggregates of sub-micron particles and thus conduct heat poorly. However, their albedos vary by up to a factor of ten, and the relative abundances of different volatile species (e.g. water and CO_2 ice) likewise are highly variable. We also understand that comets incorporate material from both the inner and outer parts of the protoplanetary disc, as a result of Stardust's return of cometary dust grains.

Current science goals

To understand the surface processes on and internal structure of comets; how jetting occurs, how old their surfaces are, how layering like that on Temple 1 is produced; we must study the changes in a particular comet over time. The Stardust-NEXT extended mission will provide a first step by flying by Temple 1 and observing the changes since Deep Impact. The Rosetta mission, by remaining in orbit around a comet for a least a year, will provide truly detailed information.

Comets obviously played some role in planetary accretion, be it providing volatiles to the inner planets or producing the Late Heavy Bombardment when their orbits were perturbed by the migration of the outer planets. However, to trace what material came from cometary reservoirs, we need isotopic and trace element measurements. In particular, the isotopic ratios of H, C, N, and O would help us to understand if comets provided a significant fraction of the organic and volatile material on Earth. Rosetta will measure these ratios for the surface material of one comet, but it is very much a first step.

Ground-based observations are essential to complete the census of comets, particularly those with large perihelion – the main-belt comets and cometary activity among the Centaurs; to identify physical and compositional differences between different comet populations; and again to provide context for spacecraft. The results of observations must also be studied extensively with modeling; to understand cometary migration, orbital evolution, and how comets accreted from smaller planetismals.

Missions recommended by the community

Sample return from a comet nucleus is the priority for future missions – Rosetta will provide information on the surface morphology and evolution from aphelion to perihelion, and sample the surface, but in situ analysis can only tell so much. The white papers favor either sampling the non-volatile material from the surface or a cryogenic mission to bring back the ices, depending on the size of mission that can be flown.

Thursday, September 10, 10, 08:30 – 5:30 PM

<u>Meteorite Science Goals</u>
Timothy McCoy, Mark Sephton

The meteorite community is largely detached from spacecraft missions. This will change as samples are returned to Earth and can be analyzed with the same set of laboratory tools. Chemically, "primitive" is a hard-to-define word, and it is more useful to consider objects as more or less altered in their composition during their formation and since then. For sample return, the meteorite community is most interested in samples of objects not represented in the current collection.

Recent advances

Meteoritics advances directly with the development of new analysis techniques and the availability of new samples. Some meteorites have been traced to the crusts of oxidized differentiated asteroids due improvements in spectroscopy and having more samples to work with. The development of short-lived radio isotopes (Al-26 and Fe-60) as clocks showed that planetesimals formed rapidly, and that the Sun formed in a massive star forming region. Ion microprobes have located presolar grains inside of cosmic dust, giving us information on that environment. Isotopic techniques to establish the origin and alteration history of samples have been developed to a high level for geological applications, and can be readily applied to meteorites.

The Genesis and Stardust missions have demonstrated sample return, providing more material for laboratory analysis. The Stardust samples in particular have changed our understanding of transport and mixing in the solar nebula: it did not discover presolar grains, but grains from the inner part of the disc.

Current science goals

Chemical composition provides a proxy for the history of objects; for example, the delivery of volatiles to the early Earth and the collisional history of the asteroid belt. If we focus on organic compounds, there is a great deal of interest in the interaction between organic molecules and mineral surface, and the goal is to see the sequence of chemical evolution from the compounds present in the solar nebula, be that on a high-temperature carbonaceous materials on asteroids or cryogenic icy compounds on a comet. It is already clear that chemical evolution is very heterogeneous, even on individual objects, but remote observations cannot give the exact information required to understand the relative order and absolute chronology of chemical alteration.

Meteorites and samples returned from space must have both appropriate laboratories and curatorial facilities waiting for them, to prevent contamination and preserve them for later studies. Genesis and Stardust provide a basis for handling sample returns, but older meteorite, dust, and lunar rock collections must also be appropriately maintained.

To obtain samples not represented in the meteorite collection will require significant technological advancements, particularly for cryogenic samples or if the samples are to be studied extensively in situ before returning them to Earth. For example, there is currently no reliable way to obtain the age of a sample without bringing it back to the lab.

Missions suggested by the community

All of the mission concepts derived from meteoritics are focused on sample return or in situ composition analysis. Dawn is the prototype for the latter, since Vesta is inferred to be the source of the HED meteorites. Unless reliable dating can be obtained in situ, sample return is massively favored, especially of types of material not in the current meteorite collection or sampling a sequence of chemically different materials on the same object.

<u>**Kuiper Belt Science Goals**</u>
Michael Brown, Marc Buie

Our knowledge of the Kuiper Belt has grown dramatically since the last Survey, largely because of the limited starting point. A decade ago, a very small number of KBOs were known and, other than Pluto/Charon, the main priority was the existence and extent of the belt. The questions from the last Survey reflect this: “are there Pluto-sized and larger bodies beyond Neptune?” – and many of them have been answered (for this question, very much yes).

Advances in the last decade

The greatest advance in our knowledge of the Kuiper Belt has been the large number of objects discovered by ground-based surveys – currently over 1300. Beyond this, we now understand KBOs as physical bodies. Early simulations of the formation of Pluto/Charon predicted that there should be a large number of small satellites around large KBOs. The surveys have now discovered the largest objects, and three out of four have satellites, all of which are small except for Charon. We now know that Pluto has two small satellites, as well.

The largest Kuiper Belt objects are physically and chemically diverse. Eris has a surface of nearly pure methane and nitrogen ice; Makemake has large amounts of methane and ethane without a significant amount of nitrogen; and Haumea contains only water ice and is the parent body of a collisional family of water-rich objects as the result a collision that left it spinning nearly at breakup velocity. All of the large objects are much denser than the small ones, implying that they are differentiated and some are almost entirely rock. Some small (several hundred kilometer) objects have density less than 1, implying high porosity.

The dynamical structure of the Kuiper Belt is explained by the outward migration of Neptune during the early history of the solar system. In the Nice model and other formulations of planetary migration; some objects are captured into resonance, others scattered onto high eccentricity and inclination, and only a few remain in the ‘classical’ Kuiper Belt with low eccentricity and inclination. There are some anomalies. There are significantly more classical KBOs than predicted by current migration models. The object Sedna has a very high eccentricity and a perihelion too high to be explained by scattering from Neptune. It may represent an inner population of the Oort Cloud.

Current science goals

KBOs can be considered as test particles recording the dynamical history of the outer solar system, the birth environment of the sun, and their own accretional and collisional history. The key to a better dynamical understanding of the Kuiper Belt and inner Oort Cloud will be to discover more objects, through a survey.

In addition, KBOs are unique worlds in their own right, and there is a developing field of icy planetology; including radiation chemistry, collisional physics, atmospheric studies, and models of internal activity. This will continue to be driven by spectroscopic and photometric observations and laboratory work, until New Horizons flies by Pluto and its moons and provides on-site information.

Missions suggested by the community

Studies of the Kuiper Belt will continue to be dominated by ground-based telescopes for at least the next decade. Discovery of smaller objects requires a survey comparable to LSST. Photometry and spectroscopy require more collecting area than can be flown in space, and ground-based submillimeter arrays such as ALMA can outperform spacebased infrared measurements. These projects are heavily promoted for astronomy by Astro2010, but should be considered here as well. NASA is encouraged to continue to fund the IRTF and Keck, and to consider partnering with the NSF to fund LSST's operating costs. LSST is comparable in cost to a Discovery mission, and will likely have much greater scientific impact.

Given a next-generation survey and ground-based physical observations, the next priority is for flybys of objects other than Pluto. When Kuiper Belt missions beyond New Horizons are launched, they will draw heavily on new technologies: the ASRG, improved communications, designs for higher autonomy and lower mass and power, and perhaps nuclear electric propulsion. Options for new missions include flying clones of New Horizons to other objects, even before it arrives at Pluto, and a new mission to Neptune/Triton, to see what changes there have been since Voyager 2.

<u>Rosetta Status Report</u>
Rita Schulz, European Space Agency

Previous missions to comets (Giotto, Deep Space 1, Stardust, and Deep Impact) have been limited by the size of the spacecraft and by being flyby missions. There have been few in-situ measurements of composition, and those only sampled the gas and dust coma (of Halley and Wild-2). This is the motivation for Rosetta: an orbiter and a surface lander. The mission cost is 1 billion euros.

Rosetta's science objectives are to understand the origin and evolution of comets by global characterization of the nucleus of comet Churyumov-Gerasimneko, and its dynamic properties, surface morphology and composition. In particular, Rosetta will study the development of cometary activity and changes in the surface layers and coma from aphelion through perihelion and further if possible.

During cruise, the spacecraft flies by Earth, Mars, and the main belt asteroids Lutetia and Steins. The orbiter's instruments have been successfully tested in the flybys of Earth, and Mars, and have provided intriguing information on the composition of Steins. The Lutetia flyby will take place in July 2010. Rosetta will arrive at Churyumov-Gerasimneko in May 2014, when the comet is 4.5 AU from the Sun. The lander will be deployed November 2014, and perihelion occurs in August 2015. The lander will be placed in a quiet region of the surface and the orbiter's orbital radius will be increased to avoid flying through active jets too often.

The orbiter has a scientific payload of 180 kg, distributed between 11 instruments; and the lander 27 kg distributed between 10 instruments.

The orbiter's instruments include:

- Dust impact analyzer
- VIRTUS – visible and infrared thermal imaging spectrometer
- OSIRIS – optical, infrared, and spectral imager
- ALICE – ultraviolet spectrometer
- CONSERT – radar tomography of the nucleus using the lander as a receiver/reflector
- MIDAS – atomic force microscopy of captured dust grains
- Ion mass analyzer – measure masses of ionized dust grains
- Ion and neutral mass spectrometer
- Microwave and plasma instrumentation
- Radio science – to obtain the comet's mass

On the lander:

- Imager
- Alpha particle X-ray spectrometer
- Material properties and seismic measurements
- Magnetic sensors
- CONSERT receiver/reflector.
- Drill and sampling device – to obtain samples at the surface and down to 20-cm depth.
- Mass spectrometer & gas chromatograph to analyze samples. The samples will be baked and the gases analyzed to obtain the isotopic ratios of H,C,N,O in different ices and the abundances of organic compounds up to 1000 amu.

EPOXI Status Report

Michael A'Hearn, University of Maryland

EPOXI is the extended mission for Deep Impact and consists of EPOCh (continuous monitoring of transiting exoplanet host stars) and DIXI, a flyby of Comet Hartley 2 in November 2010. EPOCh does not relate directly to primitive bodies, and has not yet seen any additional planets in the systems under surveillance, although it has achieved photon-limited precision.

DIXI's goal is to probe cometary diversity: the differences between previously visited comets are so extreme that to understand how comets work, we must visit more to understand what is common and what is obviously aberrant. The Deep Impact flyby spacecraft carries medium and high resolution cameras and a near-IR spectrometer and will reach Hartley 2 in November 2010.

Hartley 2 is much smaller than Tempel 1, but is more active in ejecting both dust and gas. The encounter will take place when the comet is 1.06 AU from the Sun and 0.16 AU from the Earth, so there will be an unprecedented opportunity to map the inner structure of the coma and the release of species of gas other than water in concert with ground-based observations.

This extended mission is a demonstration of the continued utility of Discovery- and New Frontiers-class missions. See also the Stardust-NEXT status report by Joseph Veverka.

Hayabusa Status Report
Donald Yeomans, Jet Propulsion Laboratory

Hayabusa is a joint JAXA/NASA mission. It carried an optical camera, near infrared spectrometer, laser ranger, X-ray spectrometer, sample collector, and a lander to the near-Earth asteroid Itokawa.

Itokawa is a contact binary asteroid with dimensions 535 x 294 x 209 m, much smaller than any other asteroid visited by a spacecraft. It rotates retrograde about its short axis, with a period of 12 hours, has a bulk density of 1.9 and an optical albedo of 0.25 to 0.3. Its composition is closest to the L or LL chondrites. There are very few obvious impact craters, and most of the surface is covered by rough angular blocks, suggesting that Itokawa is a rubble pile. The average slope of the surface is quite low, but smooth areas occupy gravitational lows.

Hayabusa arrived at Itokawa in September 2005. The lander was released on November 12, but a control failure placed it onto a trajectory that missed the asteroid. On November 20 and 26, the spacecraft landed on Itokawa to collect samples from the 'MUSES-Sea' – large smooth area covered in primarily cm-scale particles. There is no verification that the sampling pellets fired or kicked material into the sample container, but the capsule is being returned to Earth on that assumption. Both the capsule and the spacecraft will re-enter Earth's atmosphere on 2010 June 13, with the capsule to land near Woomera, Australia. This is the first attempt to return samples from an asteroid.

Dawn Status Report
Harry McSween

The Dawn spacecraft is flying to Vesta and Ceres, the two largest main belt asteroids. In contrast to smaller objects, they are differentiated and represent a later stage of planet formation. Dawn could only be flown on a Discovery-class budget by using ion engines and a very large solar array. Over the course of the 8-year mission, the engines will be on for over five years and the spacecraft will accumulate over twice the delta-v of any other mission.

Dawn will reach Vesta orbit in September 2011, and remain there through May 2012 according to the baseline mission schedule. Dawn's instruments and their science objectives at Vesta are:

- Framing Camera (from Germany): map the surface of Vesta in 8 filters with 100-m spatial resolution to examine the geology and cratering history. Imaging will also determine the topography of the object to 10-m with 100-m resolution.
- Visible and Infrared Spectrometer (from Italy): obtain mineralogical information over 65% of the surface, with 800-m resolution, with more detailed observations of areas of interest.

- Gamma Ray and Neutron Detector: map elemental abundances and global-scale variations.
- Radio Science: map the gravity field to 90-km resolution to determine the internal structure.

Vesta is the presumed source of the HED meteorites, and these were used to calibrate the instruments.

Dawn's science objectives at Ceres are similar to those at Vesta, despite the great differences between the two objects. According to the baseline mission, Dawn will arrive at Ceres in August 2014 and remain there. The baseline mission can be changed, depending on community support. The solar array is producing more power than predicted, and this can permit Dawn to travel faster, and be at Vesta from August 2011 until August 2012 without changing the arrival at Ceres. Alternatively, departure for Ceres could be delayed by up to six months and Dawn would complete a full map of Vesta without shadowing. NASA would need to approve additional funds for these extended missions.

Stardust-NEXT Status Report
Joseph Veverka

Stardust-NEXT is a mission of opportunity, using the Stardust carrier spacecraft, which was diverted after releasing its sample container carrying dust from the coma of Wild-2. Stardust carries a camera and dust flux monitor and analyzer and will now flyby Tempel 1 at a distance of 200 km on 2011 February 14. The goals are: observe the crater produced by the Deep Impact impactor at ~10-m resolution to understand crater formation, document any changes to the surface over the intervening years, and extend mapping and study of surface features, particularly the global layering and composition variations observed by Deep Impact. The comet's activity will be monitored on approach and departure, both with the camera and with the dust instruments.

The spacecraft is performing well. However, to ensure that the Deep Impact crater is illuminated and observable during the flyby, we require ground-based observations to refine our knowledge of Tempel 1's spin state.

Mission Studies and Technical Assistance
Robert E. Gold, Applied Physics Laboratory
Michael J. Amato, Goddard Space Flight Center
Kim Reh, Chet Borden, Keith Warfield, Jet Propulsion Laboratory

The mission design studies described by James Green and Lindley Johnson will be conducted by one or more of three mission planning groups: the Applied Physics Laboratory (APL) Concurrent Engineering Lab, the Goddard Space Flight Center (GSFC) Integrated Design Center, and Jet Propulsion Laboratory (JPL)'s Rapid Mission Architecture and Team-X. Their presentations had considerable overlap, and have been combined here.

All three groups are staffed by engineers with flight project experience, and have long histories of designing missions that have later been flown and of evaluating mission concepts, including many for the Astronomy Decadal Survey. Each group draws from extensive databases and knowledge of previously flown and well-developed hardware, and mission operations. In the past, the cost estimates from mission planning have been accurate to ~30% for small missions, but flagship-class projects have had a tendency to overrun.

At all three groups, mission planning follows a similar progression. A series of preparatory meetings specifies the goals and limits of the design. It is are followed by half- or full-day sessions in an integrated design environment, with a team of up to 20 engineers working with each other and the science advocates for the mission to establish a design. Following this, a final report is written up specifying the design. The report includes: mission architecture, conceptual design broken down by sub-system, notional payload, technology assessment, and a development and flight schedule; at a level of detail sufficient to capture the design rational and results for clear reference long after the study. These reports will be provided to the independent cost estimator for the Survey.

There are three basic levels of design study, which can be separated out by the study cost and the level of detail although the names for each differ between the planning groups. At a minimum, any study requires a basic description of the mission: the target object; if the spacecraft is a flyby, an orbiter, or a lander; the required measurements and priorities for the mission objectives; and the target mission type and cost cap. The more information that is available, both in terms of requirements and previous design work, the better the results.

"Mission Feasibility Studies (APL) / "Rapid Mission Archiecture" (JPL)

These cost a few times 10k USD and assess the ability to get to the destination, and the landed mass and the launch capability required, very roughly. At JPL, the emphasis is on understanding the trade space of possible designs, to advance the "Concept Maturity Level" of the mission far enough that more detailed studies can converge on a preliminary design. The cost can approach 100k if there are areas where the risk and cost uncertainty are high and a large number of designs have to be considered. These studies involve a small team and are completed within about 3 weeks.

"Preliminary Concept Evaluation" (APL) / "Rapid Basic Trades and Approaches" (GSFC) / "Team-X Study" (JPL)

With a typical cost of 100k, these studies are designed to establish a practical design suitable for reliable independent cost estimates. They take 3-4 weeks, with a week of integrated sessions with a team of about 20. The design will include a trajectory, a strawman structure and configuration for the spacecraft, resource and cost estimates, risk analysis, a schedule, and in some cases a list of the required equipment. All three groups expect that this will be the most common design study requested by the Survey.

"Full Conceptual Design" (APL) / "Basic Mission Study" (GSFC) / "In-Depth Study" (JPL)

This is the most in-depth design study, designed to produce a product suitable, for example, for a first-round Discovery Proposal, and to address missions with high technical risk and high science return. They cost >500k and last approximately three months. The product is like that from a preliminary design, but more detailed, and there should be greater involvement from the science advocates.

After reviewing these options, the panel decided to locate previous, but not too dated, mission studies and request updated costs or in-depth studies only as necessary. The science advocates should take initiative in selecting particularly compelling missions, and understanding if they require particular technologies (e.g. the ASRG for deep space missions or cryogenic sample handling for a comet mission).

General Discussion and Wrap-up

Some minor administration and a confirmation of the current requests by the panel for information from NASA: information on the WISE near-Earth asteroid program, common standards for the design studies, and funding and history of new applicants to the R&A programs.

Appendix: Acronym Definitions

AGU	American Geophysical Union
ALMA	Atacama Large Millimeter Array
APL	Applied Physics Laboratory at Johns Hopkins University
Astro2010	Astronomy and Astrophysics 2010 Decadal Survey
ASRG	Advanced Space Radioisotope Generator
DPS	Division for Planetary Sciences of the American Astronomical Society
EPOXI	Deep Impact extended mission: EPOCh extrasolar planet observations, DIXI Deep Impact Extended flyby of comet Hartley 2.
GRAIL	Gravity Recovery And Interior Laboratory: spacecraft to measure the Moon's detailed gravity field.
GSFC	Goddard Space Flight Center
HED	Howardite, Eucrite, & Diogenite meteorites, presumed from the asteroid Vesta.
IRFT	Infrared Telescope Facility
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JWST	James Webb Space Telescope
KBO	Kuiper Belt Object
LADEE	Lunar Atmosphere and Dust Environment Explorer
LCROSS	Lunar Crater Observation and Sensing Satellite
LPSC	Lunar and Planetary Science Conference
LRO	Lunar Reconnaissance Orbiter
LSST	Large Synoptic Survey Telescope
MER	Mars Exploration Rovers
MRO	Mars Reconnaissance Orbiter
MSL	Mars Science Laboratory
NAIC	National Astronomy and Ionosphere Center – operators of Arecibo Observatory
NEO	Near-Earth Object

NASA	National Aeronautics and Space Administration
NRC	National Research Council
NSF	National Science Foundation
Pan-STARRS	Panoramic Survey Telescope And Rapid Response System
R&A	Research and Analysis programs, distinct from missions or observatory funding.
RTG	Radioisotope Thermal Generator
SBAG	Small Bodies Assessment Group
WISE	Wide-Field Infrared Survey Explorer