EUROPA ICE CLIPPER

Extracts From the Europa Ice Clipper Proposal to NASA

D. SCIENCE

D.1.1 Background

Europa is one of the most interesting objects in the solar system because underneath its surface of ice may be an ocean of liquid water. The existence of an ocean and the possibility that it may harbor life is a fundamental motivation in the exploration of Europa. It has been assumed that the outer solar system is beyond the reach of the Discovery Program and hence that any investigations that seeks to test for an Europan ocean would have to await more expensive and elaborate missions. However, we propose here a Discovery class mission that can reach Europa and return data that will provide an abundance of new information as to the nature of its surface and possible evidence for the presence of an ocean.

Europa, one of the four large satellites of Jupiter, has been known since Galileo first observed it in 1610. Its orbit is only 9.5 times the radius of Jupiter, making it, after Io, the second Galilean satellite from Jupiter. One of the most remarkable features of Europa is the smoothness of its surface. Voyager observations of features near the terminator on Europa indicated that relief is not more than a few hundred meters (Lucchitta and Soderblom 1982). The surface can broadly be divided into two basic units (Buratti and Golombek 1988): relatively light colored ice makes up the plains units while darker, redder material makes up the dark spots and bands that characterize the mottled terrain units. The clean ice on the surface of Europa has exceptionally high reflectivity --- as high as freshly fallen snow.

If Europa were in a perfectly circular, synchronous orbit it would experience negligible tidal heating from Jupiter. However, Europa, Io, and Ganymede are in a Laplace Resonance that forces non-zero eccentricities (Cassen et al. 1982). Physically, the energy dissipated by tidal forces in Europa comes from the orbital energy of the satellite and the rotational energy of Jupiter. This tidal heating together with the decay of radioactive elements and the release of energy from earlier periods represents the heat sources that are warming Europa's interior (eg. Squyres et al. 1983).

Europa's low density leads to the suggestion that there might be a significant layer of ice near its surface. Earth's moon, which is similar in size to Europa, and Io both have densities of about 3.5 g cm^{-3} compared to Europa's 3.0 g cm^{-3}. If Europa has differentiated into a rocky core of silicates with Io-like densities then this would imply a surface layer of water ice of over 100 km. If the heat flow is large enough, the lower layers of the ice would melt forming an ocean. If instead, Europa's interior is composed of hydrated silicates --- the water is distributed within the body --- then the surface shell may be relatively thin and completely frozen.

The notion of a subice ocean on Europa has been extensively discussed in the scientific literature for over 25 years (Lewis 1971, Fanale et al. 1977, Smith et al. 1979, Cassen et al. 1979, Squyres et al. 1983, Ross and Shubert 1987, Ojakangas and Stevenson 1989, McDonald et al. 1997) and in the popular literature as well (Clarke 1982). In addition, some models for the origins of life on Earth suggest a submarine origin at hydrothermal vents (Corliss et al. 1979) and others have invoked impact melting of a frozen ocean (Bada et al. 1994). Within this framework there have been speculations about life in an ocean on Europa (Reynolds et al. 1983). Unfortunately, the discussion of oceans on Europa, while rich in theory, has been devoid of any clear experimental tests. The question therefore arises: Are there direct tests that can be achieved in near-term low-cost missions that can indicate the presence of an ocean on Europa? We suggest that the surface of Europa may hold chemical and isotopic evidence of an ocean and that the Europa Ice Clipper is the near-term low cost mission to return this data.

The surface of Europa may hold clues to the presence of an ocean in several ways, all of which are related to the linear surface features. Squyres et al (1983) suggested that the mechanism responsible for the smooth surface of Europa was resurfacing by water ejected from an ocean through cracks in the ice (see also Crawford and Stevenson 1988). Lucchitta and Soderblom (1982) present several theories of how these lineations may have formed and the likelihood that these may be fissures through the ice. Transport of water to the surface of Europa through its lineations leads to speculation of the chromophores responsible for the darkening of the lineations. It is not unreasonable to assume that a soil-based silicate (Lucchitta and Soderblom 1982), or sulfoxide polymers (Hapke 1989) might be constituents, due to the rocky core of Europa and sulfur implantation from the Io plasma torus. Perhaps the most intriguing theories are that the chromophores are actually organic molecules (Cassen et al 1979; Squyres et al. 1983). A recent analysis (McDonald et al. 1997) concludes that simple molecular species such as CH_4 and NH_3 would not be stable on the surface, while hydrocarbons with at least four carbons, and possibly simple nitriles and aldehydes, would be stable as condensates. They conclude that if there is organic synthesis in a sub-surface ocean and the dark lineations on Europa do represent seepage vents of water from this ocean, then the lineations will retain a record of that organic chemistry. The likely species to be detected are the more complex organic macromolecules that would form in the interior ocean, such as polymerized hydrocarbons, aldehydes, and poly-HCN, and propagate to the surface through the fissures. Thus the surface materials may hold materials which are the direct result of ocean-based processes and have been carried to the surface through cracks. We propose to analyse and collect these materials.

The dark surface materials, possibly of ocean origin, and the "probable cause" warrants sending an investigative spacecraft to Europa. Our methods will investigate these materials during the encounter and transmit that data to Earth. This could then provide the basis for a more detailed, and expensive mission to characterize the ocean. We will also return samples to the Earth for analysis. Our approach here is predicated on the ability of terrestrial laboratories to analyse extremely small amounts of material --- a capability that will undoubtedly improve over the time of this project. Thus, our sample return strategy returns material amounts measured in the nanograms --- levels that are ample for measurement. The science conducted on the returned sample (isotope and elemental analysis at precisions adequate for cosmochemistry) can only be done with samples returned to sophisticated terrestrial laboratories and it is unlikely that even an expensive in situ missions can achieve these measurements at the desired precision.

The Europa Ice Clipper is a flyby mission. To obtain samples of the surface of Europa we will use an impact sampling method. As we approach Europa a 10 kg hollow copper sphere is released on a impact trajectory. The spacecraft then diverts to fly through the plume of surface material that is created by the impact. The ability to create a plume, predict its properties, and sample the particles in the plume while protecting the spacecraft are the basis for this mission design.

The current target site is at -75S, 66E in an area not imaged by Voyager and just recently seen by Galileo (see image on the Fact Sheet). The results of the main Galileo Europa encounter will arrive at Earth during the feasibility study of the Ice Clipper. We will tailor our target area based on these results.

D.1.2 Science Goals and Objectives

Science Goals and Objectives

The overall science goal for the Europa Ice Clipper is to sample the surface of Europa to understand the processes that shape it and to look for evidence of a subsurface ocean. In addition we will address questions at to the formation of Europa and the source of water for the Galilean satillites. We are proposing the following specific science objectives.

To explore for the presence of an ocean we will:

-- determine of the structural properties of the surface ice.

-- determine the presence of light organics (eg., CO_2, and C_2, C_3, C_4 compounds), volatile inorganics (eg. NH_3), and soluble salts in the surface ice.

-- analyze organic and/or mineral phases in the surface ice.

To understand the formation of Europa and the source of water we will:

-- measure the D/H and the oxygen isotopes of the surface ice in returned samples.

-- return to Earth samples of the refractory components of the surface ice.

Structure: The structural properties of the surface ice on Europa could provide clues to the presence of an ocean. A fluffy snow-like surface could be the result of precipitation from vapor clouds ejected through cracks in the ice shell. Alternatively the direct condensation of water vapor (essentially vacuum condensation) onto the surface could result in a compact hard surface. The nature of the plume generated by the impactor will depend on the strength and cohesiveness of the surface. For a nominal 10 kg impactor mass and an impact velocity of 10 km/s the amount of ejected mass is a sensitive function of the strength of the surface. For compact ice the ejected mass is estimated to be about 4800 kg while for loose material in which gravity is the determinate of ejection the mass could be as high as 2.5×10^5 kg for material with the consistency of sand. Even more extreme, light fluffy surfaces like the ice of C/SL9 would result in the ejection of about 107 kg. Crater sizes and depths vary with the radius of the impactor; for our impactor, we expect a crater radius of order 10 meters. Thus, a very sensitive measure of Europa's crustal strength (to depths of 10 m or so) will be available from imaging the impact - generated plume. An estimate of the total ejecta mass will be possible from images of the impact plume.

Organics: A potential key signature of an ocean is the presence of complex organics in the surface ice. These organics may be the result of biological or abiological processes in the ocean. Abiotic processes that could produce organics include: synthesis in deep hydrothermal vents, cosmic ray synthesis and even photochemistry in the water. Irradiation on the ice surface may also produce and alter organics and this factor must be considered in the analysis. Nonetheless, as we discussed above, if organics are produced in an ocean then the signature of this process could be recognizable in the distribution of organics seen in the ice. The organics in the plume particles will be measured with a time-of-flight mass spectrometer after particles impact on a metal foil.

Volatile Species: The presence of light organics and volatile inorganics in the surface ice of Europa could be compelling evidence of an active source of these materials related to a subice ocean. McDonald et al. (1996) argue that there are no mechanisms for the direct production of light organics and over geologically short timescales they would migrate out of the surface ice and be lost to space. Even clathrate formations --- potential sources of CH_4 and CO_2 -- - would be unstable at the surface due to the low pressures. We note however that the impact itself may cause the production of light organics from refractory organics on the surface. If the impact-induced source can be corrected, then detection of these volatile organics could be a strong indication of an ocean and very recent activity.

Soluble salts: Progressive freezing of liquid water exposed to the surface will concentrate soluble salts. These would be incorporated into the ice surface as discrete particles that could be recognized as such in the particle analyzer by their relative concentrations and types of cations and anions. The ratios of these elements could be indicative of water solubility and hence provide further evidence of an ocean, and one that deposits material on the surface.

Isotopes: The deuterium to hydrogen ratio and the oxygen isotopes will be measured in water molecules returned to Earth. These measurements will address questions related to the major sources of volatiles in the solar system. From studies of the D/H ratio in the outer solar system and comets it is clear that there are variations in the D/H in major solar system reservoirs. The protosolar value is about $8x10^{-4}$, the Galileo result form Jupiter is about $6x10^{-4}$. In general the large planets in the outer solar system have D/H results that are consistent (within error bars) with the protosolar value. By contrast, standard mean ocean water on Earth is about 10 times the protosolar level and the comet Hally results gives a D/H that is about twice the terrestrial value. Comet Semarkona also give a D/H that is larger than terrestrial. For Europa the key question is the source of its H ; does it come from the Jovian subnebula and would therefore reflect the Jovian value -- close to the presolar value? Or does the water on Europa reflect accretion from a cometary source and the associated much higher value of D/H? To address these question we will measure the D/H on Europa to within 20% of it's expected range (between 10^{-4} and 10^{-5}). The isotopes of oxygen will also provide information on the source processes and formation of Europa. Here the central comparison is with the meteorites. To differentiate a Europa isotopic ratio from values characterizing, for example the Eucrites, requires a precision of 1 per mil in the $_{17}O$ and $_{18}O$ determinations.

Refractory Species: Samples returned from Europa will include particles composing the refractory component of the surface material. It is likely that this will include both silicates and kerogen-like organics. Laboratory analysis of the solid organics could allow for discrimination between sources in an ocean interior to Europa and production by irradiation on the ice surface. Elemental and mineralogical analysis of the silicate particles should provide considerable information on the nature of Europa's interior and possibly about the planetary nebula form which the galilean satellites formed. Meteoritic infall and interplanetary dust particles (IDP) provide an additional source of surface material. It concentration with respect to ice and to material from within Europa provides information on the relative timescale of the various processes that deposit material on the surface. Meteoritic and IDPs can be distinuished from Europa-derived particles by the elemental composition.

D.2. Baseline Mission:

The baseline mission that achieves the science objectives discussed above is as follows. The spacecraft, essentially a modified version of Stardust, is launched in Nov 2000 on a Delta 7925 launcher. After a two year Earth gravity assist followed by a flight as far as 6.4 AU from the sun, the Ice Clipper reaches Europa in 2008. The favorable alignment of velocity vectors allows the Ice Clipper to fly by Europa at a relative velocity of 10 km/s, 50 km above the surface.

Before the Ice Clipper moves over Europa it has released, using a gentle spring system, a small inert mass onto a collision course with the satellite. The spacecraft does a small course correction to avoid the same fate and instead of hitting Europa it flys through the ejecta plume created by the impact mass. During the flyby, the camera on board the Ice Clipper photographs the surface of Europa and the ejecta plume. Because of Europa's low escape velocity, the spacecraft's relative velocity is the most significant factor as the spacecraft moves through the plume collecting particles and gas. The images from the camera will be used to determine the location of the impact site on Europa as well as to characterize the plume dynamics. This will include: some images over time of the ejecta plume and the particle size of the ejecta. This information, in turn, will be used to constrain models of the surface properties. Thus, the impact and the resulting plume, is not only a convenient sampling device it is also an investigation into the structural properties of the ice surface. The concept of impact sampling of airless bodies was considered for the Comet Rondezvous Asteroid Flyby mission in the early '80s and was suggested as a way of sampling Mercury's polar icecaps by J.V. Post in 1993.

The low velocity of the impactor on Europa ensures that the material in the plume is primarily unmelted particles. These particles are sampled by the JEPA (Jupiter Europa Particle Analyser) time-of-flight mass spectrometer. The particles disintegrate as they impact on a silver target plate at the entrance of the instrument and the ions are measured by time-of-flight spectroscopy. This instrument is essentially a duplicate of the CIDA (Comet and Interstellar Dust Analyzer) instrument that is being flown on Stardust. The main objective of the instrument is to detect the presence of organics, volatile inorganics, and water-soluble salts present in the water ice. As discussed above these may be direct indicators of ocean water reaching to the surface.

A primary objective of the Europa Ice Clipper will be to return a sample of the refractory material in the surface of Europa to the Earth for detailed analysis. As the spacecraft moves through the ejecta plume the Aerogel Collectors (AC) --- similar in design to those used on Stardust --- will be exposed and collect particles. It is not expected that water and other volatiles will be retained in these collectors. However, the silicate materials and refractory organics will be preserved for transport back to Earth.

A second collector is also deployed during flyby, the Active Volatiles Collector (AVC). This collector is composed of substrates made of sapphire wafers onto which a low-Z metal film is deposited during encounter of the volatile plume. Encounter velocity is too low to capture volatiles by implantation, but they can be effectively trapped by co-deposition. Using this approach we will capture water vapor in sufficient quantitates to allow for the measurement of the D/H and oxygen isotopes after return to Earth. A third collector, the Particle Capture Collector (PCC) will directly collect particles that penetrate a thin aluminum membrane. By sealing the collector volume immediately following the flyby, this material, including released volatiles, is returned to Earth also for isotopic and elemental analyses.

After the flyby and collection phase the spacecraft returns to Earth. Compared to many Discovery missions, little propellent is required because the trajectory to Jupiter is a free return. The total mission Delta V is 1054 m/s. The spacecraft is solar powered with batteries for use during the encounter and begins to transmit the images and data from the particle analysis instrument on its long flight home. The vehicle reaches Earth in 2012 for a direct entry of it's Sample Return Capsule (SRG) with a V_{inf} of 9 km/s. The return procedures are similar to those for Stardust. The aerogel and other collectors are transported to the JSC curatorial facility for analysis and archiving.

D.3. Science Floor Mission

Only one instrument can be descoped from the Baseline Mission before the science floor is reached. This is either the PC or the AVC. These two collectors both are designed to return water samples to Earth. Although complimentary, the performance floor science objectives can be met with one or the other of these instruments. Thus, the science floor includes both the in-situ and sample return components of the science, as shown in Table 1. As discussed in section I, our strategy for dealing with cost uncertainty is not based on descoping instruments. Instead we carry a significant reserve.

D.4. Science Implementation

In this section we describe in more detail how the selected instruments and mission design address the science goals listed above. Table 2 summarizes the measurement strategy for the two principle classes of objectives for this mission; the ocean and the formation of Europa.

Table 2. Principle Measurement Strategy

Science Objective	Measurement	Instrument
Is there an Ocean?	Organics, volatile inorganics, salts in surface materials	JEPA
	Hi-res. images	Camera
Formation, location and mechanism of Europa	D/H and Oxygen Isotopes of water, trace refractories	Sample returned to Earth by AC , AVC, and PC.

D.4.1 Impactor and Plume Dynamics

The centerpiece of the Europa Ice Clipper concept is the controlled impact on the surface and the resulting production of a plume of surface material which can be analysed and sampled. Because of the importance of this aspect of the mission we devote considerable detail to the description of our analysis of the plume formation and time evolution (see pullout number 2). Currently this analysis is based on existing laboratory data for cratering in sand, basalt and ice. Because the ice cratering data is limited, we have begun some small scale experimental studies of impacts into ice. More extensive simulations will then be conducted as part of the feasibility study. These studies will be conducted at Caltech and at Ames in the Vertical Gun facility. Our current designs are based on theoretical extrapolation of the available laboratory data.

To demonstrate the viability of ejecta collection from Europa by the Ice Clipper spacecraft, model calculations of ejecta dynamics and collection have been performed. An overview and results of the calculations are presented here; a detailed description of the calculations are given in the pullout at the end of Section D. The calculations assume a 10 kg projectile released by the spacecraft. The impact velocity is approximately the flyby velocity of Ice Clipper, assumed to be 10.6 km/s. Ejecta is collected as the spacecraft passes through the ejecta plume. Total collected ejecta is computed along the spacecraft trajectory discussed in section F. For this trajectory the impact angle is ~ 20 degrees with respect to horizontal. Because the porosity of Europa's surface is not known, calculations are presented for both gravity and strength- dominated cratering. A cohesive layer of water ice would crater in the strength regime, whereas a fluffy ice or a loose regolith may be gravity controlled. Specifically, cratering in wet sand, dry sand, and crystalline ice are considered. Abundant laboratory data exists for ejecta excavation in wet and dry sand, and provides a good proxy for gravity-controlled cratering. Strength- controlled cratering was represented by ice impact data. Estimates were also made of the ejecta particle size distribution, but limited data exists for impact ejecta distributions from ice targets. The effect of atmospheric drag on fines, and the total amount of Europa atmosphere sampled by the spacecraft, are also calculated.

Cratering scaling laws for wet and dry sand (Schmidt and Housen (1987) are used to determine the total mass of ejecta and crater dimensions. The total ejecta mass is 2.4×10^4 and 2.5×10^5 kg for dry sand and wet sand, respectively. For a non-porous surface, such as annealed ice, cratering is in the strength- regime, and the total ejecta mass depends on the tensile strength of the target material. Using a scaling law derived for cratering in ice targets (Lange and Ahrens 1987), and for a surface ice with a tensile strength of 200 bars (Europan surface ice could be significantly weaker), the total ejecta mass computed is 2.6×10^4 kg. Assuming a half-oblate spheroid crater with a depth-to-diameter ratio of 0.2 (Ahrens and Harris 1994), the crater diameter is 17 m (wet sand), 7.4 m (dry sand), and 6.2 m (ice, strength 200 bars). Thus, a sensitive measure of Europa's crustal strength will be available from imaging of the impact crater.

To determine the mass of ejecta collected by the spacecraft, the mass and velocity distributions of the ejecta at the flyby altitude of the spacecraft are required. Based on the semi-empirical expressions of Housen et al. (1983) and Holsapple (1993), the cumulative mass of ejecta with velocity > v has been calculated for cratering in the gravity and strength regimes. For the spacecraft trajectory considered here, ejecta originating with v > 0.5 km/s is capable of reaching the spacecraft altitude. The total mass of ejecta moving at v > 0.5 km/s is 510 kg (wet sand), 25 kg (dry sand), and 120 kg (ice, 200 bars). The actual ejecta mass collected is computed by integrating the ejecta mass distribution along the spacecraft trajectory. For a hemispherical ejecta cloud, and a collection area of 0.1 m^2, the collected ejecta mass is 0.2 micrograms (ug) (wet sand), .01 ug (dry sand), and 0.08 ug (ice, 200 bars). The bulk of the ejecta is collected over a period of ~ 10^2 seconds, about 500 seconds after projectile impact. To refine our modeling results, light-gas gun experiments with ice targets are underway to provide direct data on total ejecta mass excavated and the mass and velocity distribution of ice ejecta particles.

An estimate of the distribution of particle sizes in the collected ejecta is made following the formalism of O'Keefe and Ahrens (1985) in which the cumulative mass distribution function of ejecta particles with mass > m and velocity v has the same functional form as the distribution function for ejecta fragments in an ejecta blanket. Via this formalism the number flux of particles collected as a function of particle size is computed (see pullout at end of Section D). For ice targets, calculations of this type are quite uncertain; even the minimum ejecta particle size for ice targets is unknown. Data from planned laboratory impact experiments into ice will greatly alleviate this uncertainty.

From the formalism of O'Keefe and Ahrens (1985), an assessment of the collision hazard of Ice Clipper with larger ejecta particles can be made. The largest particles capable of reaching the spacecraft have diameters of 0.52 cm (wet sand), 0.17 cm (dry sand), and 4.9 cm (ice). In a worst-case scenario (all ejecta mass is in particles ~ 0.1 to 1.0 cm in diameter), the probability of collision with a 10 m^2 spacecraft is ~0.01. Thus, spacecraft shielding against particles ~1 cm is required.

Based on these calculations we determine that the 0.1 m^2 area of the particle analyser (JEPA) will collect over 5,000 particles of size about 1 um (radius) over the course of the fly through. Collected ice ejecta may be in particles larger than 1 micron. Similarly the 0.01 m^2 area of the particle collector (PC) will collect 0.3 nanograms of water, and the AVC will collect ?? molecules m^{-2} of water vapor. Given the shield configuration discussed in Section F, we estimate that the probability of an impact serious enough to endanger the spacecraft is less than .01 (see above paragraph).

D.4.2 Camera Science Implementation

A crucial part of this activity will be Ice Clipper imaging system. It will have two main operational functions: (a) conduct optical navigation (opnav) exercises that will allow the close-in 50 km approach to Europa, and (b) provide geo-located data that will allow pinpointing of the actual impact site. In addition to and complementing the operational requirements are a variety of related science goals that will depend on the imaging system for their attainment. In general these are: (a) outbound and inbound stellar imaging for opnav, and for limb occultations to determine Europa's radius; (b) whole body imaging to accurately determine the optical figure of Europa at pixel scales of order 1-3 km, and thus substantively contribute to the discussion as to whether Europa possesses an ocean under an icy crust; (c) impact process imaging to attempt to capture the actual impact crater and to gauge the important parameters associated with the products of impacts (e.g., surface properties/site location/sample identification, ejecta plume characteristics, ejecta blanket characteristics) ; and (d) geomorphic imaging to address the actual formative processes of the surface as reflected in the surface textures related to bright interlinea areas and the lineaments themselves. All aspects of the imaging system will be geared to answer the primary question posed by this mission: does Europa possess an ocean under the ice, and are the ice - coloration materials ocean-derived products (salts, organics, etc)?

Optical Navigation will be essential for the Europa Ice Clipper. With precise optical navigation it will be possible to maneuver to achieve a 50 km Europa flyby distance.

Imaging of Impact Event and Site will be an important aspect of the planned mission, and will depend on imaging sequence timing and on adequate sensitivity of the detector. Seeing the impact event -- both the impact flash and the initial stages of ejecta plume formation -- will be important not only from the aspect of probing the mechanical and chemical properties of Europa's upper crust, but could be of great benefit in locating the site of the impact. This is particularly important, given that the small scale morphology and structure of the Europan surface is unknown below a pixel scale of 300 m/line pair. A posteriori determination of the impact site should be possible given the combination of wide-angle (low spatial resolution) and narrow angle (high spatial resolution) camera designs that we are implementing. Fresh bowl-shaped craters are rare at larger scales on Europa (Malin and Pieri, 1986) and resurfacing processes appear to soften and remove crater rim morphologies down to km scales. Thus, a new 100 m diameter crater with a fresh, rough, bright ejecta blanket will be clearly identified at the imaging resolutions of order 1 m, that will be possible during the impact site flyover from 137 km range, and that the relatively low planned sun angle (10-20 deg above the horizon) will aid in the detection of small scale topography, such as fresh crater rims. The challenge will be in targeting the impact site within the FOV of the NAC.

Imaging of Surface Materials will provide information at a spatial scale not accessible to either the Voyager or Galileo spacecraft. Maximum pixel scale at 50 km closest approach will be 0.5 m, yielding a "rule of thumb" isolated feature resolution of about 1.5 m, and a FOV of about 500 meters. This is about 10 times better than the maximum resolution expected from Galileo. This high resolution, narrow-angle data approximates terrestrial metric airphoto resolution, and will be comparable to Mars Global Surveyor highest- resoluion orbital data at Mars. Closest approach to the impact site will occur at 137 km with pixels only a little more than 1.2 m. Orbital data at these pixel scales can literally be used like airphotos for geological mapping on the Earth. Surface textures and discrete morphological features are easily accessible, and the geomorphic process signatures, prominent at scales of 1 - 10 m on the Earth and Mars, will be visible. Clearly, of particular interest will be any features diagnostic of ice floes, ice tectonism, or ice volcanism. With the several dozen Narrow/Wide-Angle nested and mosaic images planned for the flyby and close approach phases of Ice Clipper, a comprehensive sampling of the smallest scale Europan geomorphic features and processes should provide otherwise unattainable information on the nature of the formation, and composition, of the icy crust.

The impact site, of course, will merit special attention. Since it will be fresh, it will stand out in comparison to any other impact or endogenic geomorphic feature. Its ejecta blanket could show contrasting reversed layering, if the substrate itself is layered, and crater walls could reveal stratigraphic layering, which would undoubtedly yield valuable insights into the substrate and surface formation processes.

The characteristics of the plume and its dissipation timescales would provide important information on the mechanical properties of the Europan surface. While the smallest size fraction of the plume will tend to be grey spectrally, it is to be expected that the larger particles could show some spectral contrast, thus yielding information about the composition of the upper crust of Europa. And, even though the phase angle "parameter-space" observations will have a relatively modest angular excursion, there will be information on the particle size-frequency distribution embedded within these data.

Optical determination of the figure of Europa will also be possible using full disc images of the planet combined with partial limb-fits. The currently specified (see below) Cassini-derived telescope system with its 1024 x 1024 pixel array will allow us only approximately 3.1 km pixels when Europa fills the FOV of the Wide-Angle camera, with comparable pixel scale available from the Narrow-Angle camera at the point where its FOV is filled by Europa. During the feasibility study we will consider a larger (e.g., 3400x3400) CCD array on the Wide Angle camera, thus yielding much wider FOV, and at better determination of whole planet diameter, with a view toward more accurate radii values, for determining whether Europa possesses a hydrostatic figure, and thus possibly a liquid-water sub-ice ocean. Limb fitting routines can also be employed to fit limb segments, in the absence of a full disc image. On approach, Europa will exhibit a 120-130 degree phase angle, yielding a crescent Europa (we will impact into the sun-facing side just beyond the terminator). Nevertheless, our calculations show it will be possible to view the "unlit" side of Europa in reflected light from Jupiter in order to capture a full disc image.

Stellar occultations, if they can be identified and observed, will be useful to characterize (in a limited sense) the limb topography, but may possibly be useful to probe the lowermost (near surface) structure of Europa's tenuous oxygen atmosphere. In addition, since the limb of Europa will be overexposed for opnav purposes, images of such phenomena may be significant in detecting geyser plumes, similar to the Voyager-Io plume discoveries.

Finally, near-limb topography, as derived from the whole-disc images may indicate the presence of gravitationally uncompensated continental-sized terrain, but there is at present no topographic information to suggest this.

The NAC (Narrow Angle Camera) telescope design is derived from the space- qualified optics developed by Optical Corporation of America (OCA) Applied Optics Division for Lawrence Livermore National Laboratory. They were flown successfully on Clementine Mission for geological survey of the Moon. The high resolution telescope is low in mass and uses low-outgassing materials qualified for space usage. The optical designs use thermally compensating element cell designs for stability over wide temperature ranges necessary in remote sensing space applications. The NAC telescope uses a lightweight beryllium mirror and structure. The block diagram illustrates both the wide angle camera, WAC (150 mm focal length), and the NAC. Mass has been allocated to shield the CCD from the radiation environment that it will accumulate through the mission. The 1024 x 1024 12 micron pixel array CCDs will be provided by JPL. These CCDs were developed for the Cassini Camera, derived from the Galileo design, which is currently operational in the Jovian environment.

The camera design uses radiation tolerant electronic parts and shields those known to be radiation sensitive to a 10 krad total dose level. The radiation effects would be seen only as radiation noise in individual frames and quasi- permanent radiation damage to the CCDs know as "dark spikes". The CCDs on the Ice Clipper Cameras will have up to 0.5 to 1 cm of tantalum around the focal plane. The S/C spends much less time in the Jovian radiation environment than the Galileo S/C. The filter, primary and secondary mirror of the telescope will also shield the CCDs from the electron flux coming directly into the telescope aperture (the angular direction not shielded by the tantalum). We plan to store the CCDs at temperatures between -20° to +32° C for annealing and then to run them at about -20° C. The warm storage temperature will anneal out any dark spikes and the cool operating temperature will suppress the dark level and obtain optimium noise performance of ~10 electrons.

D.4.3. Jupiter Europa Particle Analyzer (JEPA)

In addition to the Camera, the principle instrument for in situ analysis will be the JEPA (Jupiter and Europa Particle Analyzer). JEPA will be a virtually identical instrument to CIDA (Cometary and Interstellar Dust Analyzer) which is being flown on the Stardust mission, and which is derived in turn, from the PIA (Particle Impact Analyzer) flown successfully on the Giotto spacecraft mission to Halley's comet.

As the spacecraft flies through the impact generated plume, particles in the plume hit the silver target of the JEPA instrument (as shown in the pullout). Upon impact the particles are vaporized and partly ionized. The resulting ions in the impact plasma are extracted by electrostatic fields for injection into a time-of-flight mass spectrometer. This technique was demonstrated on the Halley Flyby missions, with three different TOF-MS instruments of this type, one each on the Giotto (ESA) mission and the two Vega (Russian) spacecraft. JEPA and CIDA are improved versions of the Giotto/Vega versions of the instruments, with mass range now covering 1 to 330 Daltons. In addition, all data will be complete spectra, with no need for the highly lossy data compaction that was necessary for the Halley flybys. Mass resolution for this TOF-MS is 150 or better, using a transient recorder method with 10 ns sampling increments.

A complete compositional analysis of elemental composition of the particles is obtained, and because of the much lower flyby speeds than for Halley's comet (70 km/s), it is expected that much more information will be preserved, generating considerable data on molecular constituents, including the organic materials that may be present.

Our model of the plume density shows that the number of particles larger than 2 um in diameter impacting the JEPA target will nominally be 5,000 over the course of the fly through. Since the JEPA spectrum sweep is completed in 72.66 us, the instrument can accommodate particle impact event rates of several thousand per second. JEPA is sensitive to much smaller particles, 10- 16 g (less than 0.1 um), for which the event rates could be extremely high. A similar problem occurs for the Stardust mission. Using the same built-in adaptive technique for reducing the effective target area via electrostatic biasing, the JEPA instrument will prevent spectral overlaps if high event rates are encountered. The only limitation on data taking will be the storage capacity of the on-board mass memory. Baselining for the time being the Stardust memory size (1 Gbit total), the allocation for JEPA is 100 Mbits. This is adequate to store up to 15,000 particle spectra, with simple lossless data compression. The total number of events from pooling the three Halley missions was considerably less than this amount, and the number of lossless spectra obtained was less than 1% of this amount. Thus, we expect to acquire a wealth of in-flight compositional data on the particulates, which should also provide an excellent statistical base from which to ascertain the microscale compositional heterogeneity of the area sampled. For example, mineral or organic components may not be uniformly dispersed throughout the material volume sampled.

This large dynamic range capability of the JEPA instrument will also allow us to respond to changes in the expected particle concentration due to improved models, experimental simulations, or further data from Europa itself.

The JEPA instrument has the capability to analyze either positive or negative ions from a given particle event, but not simultaneously. It takes up to 30 seconds to switch from one mode to the other. Because the fly through time is short, it will not be possible to repeatedly switch modes in the instrument. Our strategy will be to set the mode for positive ions during cruise, to use both modes in the Jupiter zone prior to Europa encounter, and then for negative ions at the plume encounter. These strategies are related to the fact that the Halley data and the Stardust interstellar data are with positive ion extraction. However, for Europa both modes are desired. Our approach will be to set the instrument for the pre-determined optimum setting, and once 2,000 particles have been successfully detected and analyzed, it will automatically switchover to the oppositely charged ions. This assures that the switch, with its associated downtime, is not done prior to collection of a significant data set.

We expect that the particles analyzed will consist primarily of water ice but with measurable levels of organic and mineral components. The JEPA instrument will thus return the following information:

- overall elemental composition of all components
- characterization of the organic component
- characterization of the mineralogy of the dust particles
- range of elemental ratios
- light element abundance relative to CI Chondrites
- light carbon and other major isotopic anomalies

The concept of the dust-impact time-of-flight mass-spectrometer has proven its capabilities during the flyby missions to Comet p/Halley in 1986. The PUMA 1 and 2 and PIA dust impact mass spectrometers on board Vega1 and 2 and Giotto respectively provided several thousand mass spectra of individual dust particles released by the comet. In the meantime extensive data analysis and data interpretation has taken place. The consistency and the variety of the results obtained and published by various groups proves the versatility of this kind of instrument. In addition, the development of the instruments and the in situ measurements have lead to an improvement of the understanding of ion formation during particle impact, with continuing improvements (Hornung and Kissel, 1994). This better understanding together with earlier work like by Krueger and Kissel (1984) ensures that data obtained at different impact velocities can easily be compared. The Ice Clipper trajectory provides an opportunity to measure also at lower impact speeds (as compared to Halley), which as found by Knabe and Krueger (1982) provides a higher share of molecular ions in the mass spectrum of the individual particles. The major elements measured at comet Halley were: H C N O Mg Al Si S Ca Fe; the minor elements measured were: B Li Na P (Cl) K Ti Cr Mn Co Ni Cu; and the elements whose presence were only inferred were: V Zn Ga Ge Se Br Sr Y. Detection of mineral components was clearly successful at Halley (Brownlee and Kissel, 1989), and characterization of organic components was likewise successful, including the determination of CHON particles and subclasses of organic constituents (Clark et al., 1987). With the improvements in mass resolution and full spectral readout, it is to be expected that the JEPA instrument will be able to further improve upon the Halley measurement capabilities.

D.4.4. Dust Flux Montior (DFM)

To characterize the total mass of particles in the plume the Europa Ice Clipper will carry of copy of the Stardust Dust Flux Monitor. This instrument senses the momentum of impact for each dust particle using small vibro-acoustic sensors.

D.4.5. Aerogel Collector for Europa (ACE)

A primary goal of the Ice Clipper mission is to collect Europa surface ejecta and return this to Earth for detailed analysis. The returned samples will be investigated by our team as well as the global community of researchers at laboratories capable of analyzing extraterrestrial materials at extremely small levels of sample.

The samples will be collected during a 10 km/s flyby of Europa using aerogel collectors identical to those deployed in the Stardust mission. At this relatively low flyby speed, ejecta particles in the 1 to 100 um size range will be captured by impact into ultra-low density aerogel. (See figure on pullout). Particle collection at this speed has been extensively demonstrated in laboratory simulations and Shuttle flights [Tsou 1993] and is central to the Stardust mission. It has been shown that the dust collection can be done with acceptable levels of sample alteration. The most important result of the study of the returned samples --- and probably only achievable with returned samples --- will be detailed analyses of the elemental, isotopic, mineralogical, chemical, and biogenic properties of the refractory material in the surface of Europa.

Laboratory investigation of the returned samples with instruments including electron microscopes, ion microprobes, atomic force microscopes, synchrotron microprobes, and laser probe mass spectrometers will provide an extraordinary opportunity to examine Europa samples at the highest possible level of detail. Advances in microanalytical instrumentation now provide unprecedented capabilities for analysis on the micron and submicron level, extending to atomic scale for imaging.

D.4.6. Particle Collector (PC)

The Particle Collector consists of a small box comprising several cells of the collecting plate area with a total area of 25 cm^2. (See figure on pullout). The box is capped with a thin metal film. As particles impact on the film they penetrate leaving microscopic holes. After entering the box particles will largely vaporize as they impact the far wall of the collection chamber. The small holes represent a negligible leak and the vapor is essentially trapped for the duration of the encounter. After encounter a metal lid with a low temperature Indium Gallium metal seal is thermally activated to emplace a metal - to - metal seal preventing any further loss of gas.

The expected mass in particles intercepted by the spacecraft is computed to be over 0.01 ug m^{-2} (see figure on pullout), or for a 10 cm radius collector. Since the mean particle size is expected to be 1 um, this implies capture of about 70 particles. To determine the loss rate of gas in the collection box during the encounter we assume that the entrance film receives 100 punctures of 1 um radius. The pressure of 0.3 nanograms of mass in the 0.5 liter volume is ~10- 13 atms (for an intial gas temperature of 500 K) and the mean free path is of vastly larger than the size of the container. Thus leakage from the collector will occur only when molecules chance to impact the puncture sites. The loss rate is therefore the hole area divided by the total container area multiplied by the collision rate with the walls. Due to the extremely small area insignificant leakage occurs over the timescale of the encounter (the timescale to deplete by a factor of e is about 14 hours and the encounter lasts only 10 minutes). After encounter the container is closed with the metal lid and sealed with the low current solder system for return to Earth.

D.4.7. Active Volatiles Collector (AVC)

One of the key science goals for the Europa Ice Clipper Baseline Mission is the return of water from Europa for D/H and oxygen isotope analysis. These isotopic analyses will provide information on the sources of water in the Galilean satellites and the conditions in the jovian sub-nebulae. Water collection will be accomplished by the Active Volatiles Collector (AVC). In addition, if the heavier noble gases (Ar, Kr and Xe), and possibly Ne, are present in the ice on Europa at approximately solar concentrations then they also will be captured in sufficient abundance in the AVC to be carefully studied. Elemental concentrations and isotopic compositions of these noble gases can then be obtained. Noble gases, because of their low natural abundances, simple chemistry and multiple isotopes, have proven to be quite useful in developing our understanding of the early evolution of the solar system, the energetic particle environment of the early sun, the evolution of planetary atmospheres and, for the case of Europa, could provide further information on the source of the volatiles for the Galilean satellites.

Collection of volatiles is a challenge on the Ice Clipper, because the low encounter velocity with the Europa plume (8-10 km/s) is too slow for capture by implantation and gases held in absorption beds would not survive the return trip and entry at Earth. Our AVC method is based on a simple lightweight and low-power method of actively capturing cometary volatiles by the co-deposition of low-Z metal (Al or Mg) onto a sapphire substrate. As volatile molecules impact the substrate, some of them are held at the surface or near-surface for times much longer than the (10-13 s) collision time. and are covered up by the continuously deposited metal film before they are lost. Storage of the volatiles in the metal films is permanent until the film is removed. A schematic of the instrument is shown in the figure on the pullout. Upon return to the Earth, the metal films are easily removed by laser volatilization, releasing the entrapped volatiles for analysis by well - proven techniques.

The metal films are inherently clean since only local volatiles during encounter (when the metal film is deposited) are captured. This will be dominated by the Europa plume as the spacecraft will have been well degassed prior to encounter.

The Active Volatiles Collector will capture Europa volatiles in a thin metal film deposited during encounter. The metal film protects the volatiles from post-encounter contamination in the spacecraft, entry and terrestrial environments. After sample return, the thin metal film can be removed by a single laser pulse, liberating the contained volatiles for analysis. Some analyses, such as spectral absorption, can be done through the film on parts of the collector where thinner films are deposited without altering the sample.

Most of the returned material (75%) will be deposited in the JSC curatorial facility for use by other investigators. The volatiles in the metal films could be analyzed in many ways by a variety of techniques. Examples of the techniques that could be used on these samples include: (i) detection of volatile molecular species by UV and IR spectroscopy (absorption and fluorescence), (ii) measurement of isotope ratios for the more abundant species like H and O, and the heavy noble gases and (iii) laser desorption noble gas and 2-step organic mass spectrometry, as well as the more conventional static mass spectrometry. The stability of the metal films ensure that the samples will remain available for analysis for future generations of analytical techniques.

The most desirable metal for coating is magnesium, as it requires only a few watts of electrical power for the few minutes of actual metal deposition during plume encounter. In recent laboratory simulations we have demonstrated a capture efficiency of approximately 0.3% (for 14 eV krypton).

In support of volatiles collection in the outer solar system a breadboard of the Active Volatiles Collector has been constructed and tested for the collection of noble gases. Most of the elemental comparisons were made using aluminum as the co-evaporated metal, since Al films are known to capture with a nearly 100% efficiency at solar wind energies (1000 eV/amu) and tenaciously retain the captured gases. We have detected no sample loss after 8 years of storage in air of noble gas implants in Al films. In experiments with this breadboard, capture efficiencies for Ar (at 7.5 eV), Kr (at 14 eV), and Xe (at 24 eV) ranged between 0.1% and 1%. The thickness of the metal film used in the simulation runs was 200 nm at a deposition of 4 nm/s.

Mass discrimination for krypton and xenon has been measured on a suite of six different samples, co-implanted under different conditions and with different metals (Al, Mg and Zn). There appears to be an approximately 2%/amu mass discrimination independent of the experimental conditions. The capture efficiencies and the mass discrimination are experimental parameters that will be exhaustively determined in a matrix of normal (and abnormal) conditions prior to the mission. Initial studies show these to be well-behaved over a variety of conditions. As discussed below, if the Active Volatiles Collector encounters a plume from Europa of about 1016 H_2O molecules cm^{-2}, ample water will be collected for D/H and oxygen isotope measurements using SIMS. Assuming solar ratios, we should have sufficient collection of Ar, Kr and Xe for conventional mass spectrometry: (about 10^{11}, 10^{9}, and 10^{9}, impacting per cm^2, respectively). With the capture efficiencies given above, 1 cm^2 of recovered collector will yield about 3 million Xe and Kr atoms and 30 million Ar atoms, well within current state-of-the-art mass spectrometry, where typical blanks for Kr and Xe are 10,000 atoms. If the column densities of volatiles is very much lower than this, or if the active volatiles collector should fail part way through the encounter, resonance ionization techniques can be used that have sensitivities significantly greater than conventional mass spectrometry.

In addition to the noble gases, which we have used in the simulations thus far, and represent the "worst case" capture candidates, the whole suite of volatiles expected from Europa should be captured and returned for laboratory analysis. For instance, water should be captured with high efficiency and with a H column density of more than $10^{16}/cm^2$, a capture efficiency of only 1 percent will make the D/H ratio a possible measurement.

The plume model discussed above suggests that the total column mass of water vapor intercepted by the spacecraft is ?? molecules/cm^2, adequate for the AVC. Power to evaporate the Mg, uniformly coating the wires, comes from a power-regulated DC-to-DC converter. This converter takes 28 V DC from the spacecraft bus and converts it to a 3 VDC, regulated by the total power supplied to the evaporator wire. Power required will less than 10 watts for less than 10 minutes. The weight of the total unit is 350 grams.

The key science goal for the Active Volatiles Collector is the collection of sufficient water vapor to allow for the determination of the D/H and O isotopes. We propose to do this analysis by Secondary Ion Mass Spectroscopy (SIMS) on a fraction (1/8) of the returned sample.

Current detection limit by SIMS is ~200 ppba for O in pure synthetic materials (such as semiconductors). This does not include the problems due to surface contamination, which must be eliminated in other ways.

If we can measure and correct for background with 10% accuracy, with no more than a 0.5% background correction we can achieve 0.5 per mil overall uncertainty due to background. This translates into collecting 40 ppma oxygen in the near-surface layers of the target (at the top 2 um). If we have a unit square centimeter of target this represents collecting about 5×10^{14} atoms of O (or molecules of water, since this may be the only source of oxygen). With a useful yield of 1 per mil by SIMS this gives enough detected $_{17}O$ ions to achieve a statistical precision of order 0.1 per mil. With the background correction and other sources of instrumental uncertainty, it could still be possible to achieve an overall precision of 1 per mil (or maybe slightly better) in both del-$_{17}O$ and del-$_{18}O$ by analyzing an entire cm^2 of collector (laborious, but achievable). One per mil provides an acceptable level of precision and useful results from the oxygen isotopes. It may be possible to reach 0.5 per mil with technology available in the near future, but in any case it would require about 5 times more collected sample. Note that the best current measurements on rocks (where O abundance is not a problem) can only achieve 0.5 per mil with extraordinary effort, (i.e., it is not at all routine to get to this precision level and it cannot always be achieved even with unlimited sample).

The SIMS measurements will require instrumental development well beyond the current state of the art, but most of these advancements are in the planning stages. The major issues are (1) a working, high mass resolution multicollector instrument capable of simultaneous measurements of all 3 oxygen isotopes (this is critical), (2) an UHV vacuum system with about factor of 10 improvement over existing commercial machines (< 10-10 Torr range required), and (3) some method for removal of surficial oxygen aside from sputtering (laser desorption) in vacuum prior to analysis. The first point is under development at CAMECA and UCLA (co-I: McKeegan) will receive a multicollector sometime next year. The second issue is reasonably straightforward and will be supported as part of this project. The third issue is not yet seriously addressed and a plan for its resolution will be developed during the feasibility study.

D.5. Data Analysis and Archiving

The Europa Ice Clipper will generate data in two discrete phases; the encounter and the sample return. Data from the encounter will be collected during the brief period between the release of the impactor and when the spacecraft exits the plume. The encounter data directly addresses the question of an ocean on Europa and will therefore have the most potential in terms of education and outreach activities as well as the most interest for the planning of future missions to further investigate the ocean. Thus its return and timely release is essential. Due to power limitations on the data transmission the return of data will take considerable time. Depending on the availability of 70 m or quad-arrayed 34 m receiving antennas, the entire encounter dataset will require 2 to 6 months to transmit to Earth. To minimize the delay for the return of key data we will prioritize the data return stream. This data will consist of three parts: trajectory data, images, and JEPA data. The trajectory and JEPA data will be sent in their entirety in the first set of data as these represent minor data burdens compared to the images. The closest encounter images of the surface of Europa and the images of the formation and maximal extent of the plume will also be among the first data set to be returned as will highly compressed version of most other images. After receipt at the Earth we propose to have a summary publication and release of calibrated data over the PDS system within 60 days. All initial images and subsequent images as they are received they will be released immediately over the internet. All images will be achieved on the PDS system in final and calibrated form within 90 days of their receipt at Earth.

The returned sample will consist of three parts: the aerogel collector (AC), the particle capture collector (PCC), and the active volatiles collector (AVC). All of these will be transferred to the JSC curatorial facility where 75% of the material of each sample will be made available for outside use as deemed appropriate by NASA. For the analyses outlined in this proposal we will reserve 1/4 of the sample. We anticipate that only 1/8 of the sample will be necessary for our analyses and will maintain the other 1/8 as reserve.

D.6. Science and Mission Teams

The Europa Ice Clipper Team will consist of the PI, the project manager (to be selected by JPL), the industrial representative, and co-investigators. Each of the principle participants has well-defined roles as described below. During the feasibility phase of this investigation an oversight committee composed of the PI, and a senior representative from JPL (C. Elachi) and the industrial partner (N. Hinners) may change the composition of the team as needed to achieve the mission objectives.

Chris McKay, NASA Ames (PI); will be involved with, and have fundamental responsibility for, all aspects of the mission. He will be especially involved in the education and outreach activities.

Henry Harris, JPL (PM), will be involved in the impactor development and the educational and public outreach. He has been the proposal manager and the JPL point of contact. He, or his JPL appointed replacement, will be responsible for the mission implementation at JPL.

Ben Clark, Lockheed-Martin (Ind. Rep., Co-I), will be the representative for the Lockheed Martin portion of the proposal. In addition, as an accomplished planetary scientist, he will play a "deputy-PI" role in the overall science analysis and coordinate the science instruments.

Tom Ahrens, Cal Tech, will be responsible for the development of the model of the impact, associated experiments, and the analysis of the plume results.

Jim Lyons, Cal Tech, will be involved in the plume analysis and the organic analysis.

Dave Pieri, JPL, will be the head of the imaging team.

G. Edward Danielson, Cal Tech, will be responsible for the design and production of the camera.

Jochen Kissel, Max-Planck Inst. Kernphysik, will be responsible for the dust analysis instrument. This instrument will be build in the US (at JPL or at a suitable firm) under the direction and guidance Jochen Kissel. He will oversee its operation in flight, and data analysis.

Huy Tran, NASA Ames, will be responsible for the entry analysis and will work with LMA in the heat shield design.

Kevin D. McKeegan, UCLA, will be responsible for the analysis of D/H and O isotopes on the returned sample.

Norbert Thonnard, University of Tennessee, will be jointly responsible for the development and construction of the Active Volatiles Collector.

Charles M. Hohenberg, Washington University, will be jointly responsible for the development and construction of the Active Volatiles.

Maureen Bell, Cornell University, will be part of the imaging team and will also be responsible for surface analysis.

Peter Tsou, JPL, will be responsible for the aerogel collector.

David Bender, JPL, will be responsible for mission scenarios and trajectories.

Ted Sweetser, JPL, will be responsible for navigation and trajectories through the impact plume.

Jeff Bada, UCSD, will be part of the surface analysis and returned sample team. He will contribute to the analysis of the organics.

Steve Squyres, Cornell University, will be part of the imaging team, and will participate in the site selection for the impact site.

Carl Sagan, Cornell University, will be involved in the educational and public outreach and will be part of the surface analysis and imaging teams.

James Cutts, JPL, will participate in the overall mission design and technology integration. He will also be involved in the impact targeting, and image analysis and interpretation.

Mahadeva Sinha, JPL, will be the the JPL representative for the instrument integration.

Fraser Fanale, University of Hawaii, will assist in the design of the sampling devices.

Torrence Johnson, JPL, will be a member of the imaging team.

Gene Shoemaker, USGS, will be a member of the imaging team.