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The Deep Impact Project

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The Deep Impact Project Team

Abstract. The Deep Impact mission aims at understanding the third dimension of a cometary nucleus, the physical and chemical properties as a function of depth below the surface. General wisdom holds that comets, because they are small and spend most of their lives far from the sun, hold primordial ices in their interiors. However, it is universally agreed that the surface layers have evolved, whether from cosmic rays while residing in the Oort cloud or from solar heating during previous perihelion passages. Clearly, in order to interpret surface observations and outgassing, we must understand how the surface layers differ from the interior. Deep Impact is the first mission to carry out a macroscopic experiment on a planetary body since the Apollo program dropped a lunar module on the moon and measured the seismic response.

1. The Mission

Deep Impact consists of two spacecraft, launched together on 30 Dec 2004 And flying together until one day before impact on 4 July 2005. On 3 July the two spacecraft separate very gently and are both on course to impact Comet 9P/Tempel 1 at 10.2 km/s, approaching at phase angle 63°. The impactor, with dry mass 360 kg, immediately goes into auto-navigation mode ensuring that it will impact the comet in an illuminated area. Images from the Impactor Targeting Sensor (ITS) are analyzed on board for navigation and transmitted to the flyby spacecraft, which transmits the images to Earth in its regular telemetry. The ITS is not expected to survive the dust in the coma unscathed, serious damage to the primary mirror being expected at some time within the last minute before impact, long after all auto-navigation has ceased. If the camera on the impactor continues to take images until impact, it will provide a series of images analogous to the series taken by the Ranger spacecraft impacting on the moon, the last having a resolution of order 20 cm.

Meanwhile, when impactor and flyby have separated by $\sim$ 100 m, the flyby spacecraft decelerates by $\sim$ 100 m/s and diverts by $\sim$ 6 m/s. This allows the flyby to pass 500 km below the nucleus (as seen from the sun) and provides a window of 850 sec between impact and closest approach. The flyby has a Medium Resolution Instrument (MRI) for imaging and a High Resolution Instrtument (HRI) that uses a dichroic beamsplitter to provide both optical imaging and also $1 - 5$ μm spectroscopy. The instruments are body-mounted, the spacecraft rotating to follow the comet as it flies by. Since the largest uncertainty in the position of the comet relative to the spacecraft is the down-range distance, the flyby spacecraft measures its rotation to estimate the distance to the comet and thus predict the time of impact. This time is transmitted to the impactor and is used on both impactor and flyby to optimize the data-taking sequences.

From impact until 50 seconds before closest approach (14 min after impact), the spacecraft takes all the crucial data, including high-speed imaging and spectroscopy of the impact event itself, images of the nucleus at various resolutions and in all filters, infrared spectral maps of both the nucleus, and the innermost coma. The last images will be taken at a range of 700 km, about 50 seconds before closest approach, and the high-resolution images at this point will have a spatial scale of 1.4 meters per pixel (the point spread function is near 2 pixels).

By the time the flyby spacecraft has reached 500 km before closest approach, it has rotated 45°and the slew rate is too fast to accurately track the comet. The flyby spacecraft freezes at this position, which is designed to optimize the protection of the spacecraft and instruments from dust damage at closest approach. When the spacecraft has safely transited the inner coma, it turns again and views the other side of the nucleus.

2. The Expected Phenomena

The goal of Deep Impact is to understand the physical and chemical properties of the near-surface layers of a cometary nucleus. This enables study of the differences in composition and structure with depth and thus of the evolution of surface layers due to heating at previous perihelion passages. However, we know so little about the physical structure of the surface layers that cratering experts have a wide range of mutually inconsistent predictions based on different assumptions about which physical processes will matter. Our own team thinks that local gravity will control the formation of the late stages of the crater, i.e., that material will continue to flow out of the crater until it gets to material moving so slowly that it can not reach the rim of the crater before falling back. Other experts favor ultimate control by compression of weak (but not totally strengthless) material, while yet others predict that the strength of porous ice will control the formation of the crater. This range of physical processes, coupled with the uncertainty in key parameters such as the value of local gravity, lead to predictions for the crater diameter ranging from > 200 m down to < 10 m, our favored prediction being somewhat larger than 100m in diameter and 25 to 30m deep. The personal opinion of the PI is that the three concepts above are given in order of decreasing probability. Other predictions of the phenomenology include suggestions that the impactor will just bury itself very deeply in the nucleus (implying very low density for the nucleus), breaking a piece off the nucleus, shattering the nucleus into many pieces, and even passing all the way through the nucleus. These are also in decreasing order of probability, in the PI's personal opinion, with the most likely of these (burial of the impactor) being at least as likely as strength-dominated cratering. This wide range of possible outcomes is the primary reason that such a conceptually simple experiment as Deep Impact is an important one.

There are many other aspects to the phenomenology as well. For example, many of predictions imply an initial, very bright flash, with the strength or even the existence of the flash depending on details of the cometary structure. The true, cratering predictions (the first three above) coincide with three very different morphologies for the ejecta cone. Given that the surface of the comet is thought to be mostly inactive, the impactor will likely land in an inactive area and thus a plausible outcome is that the crater will become a new, active area. This new active area may lead to long-lasting outgassing in a jet over days, weeks or even months after the impact.

Using our prediction of crater volume and timescale, we crudely estimate, with many caveats, the the impact will eject into the coma as much material in 4 minutes as is released in a month of ambient cometary activity. If it is ejected as grains with a size distribution similar to that of ambient dust, the comet could easily become visible to the naked eye from Earth within minutes.

3. Spacecraft Instrumentation & Earth-based Observations

Although small by the standards of NASA's Great Observatories, HRI will be the largest telescope/camera ever flown on an interplanetary mission, with 2 μrad/pix. The IR spectrometer is aimed at studying the spectral reflectivity of the nucleus and dust, the thermal emission of the nucleus and dust, and the emission bands of the most abundant volatiles, H_2O, CO, and CO_2. It uses a 2-prism design for high throughput and elimination of order overlap. The very non-linear resolving power ($R = \lambda/\delta\lambda$) varies from 750 at 1.05 μm through a minimum of about 220 near 2.5 μm and back up to 400 at 4.8 μm. The filters on HRI are aimed at spectral reflectivity maps. At the time of the last images before flyby, the nucleus will be significantly larger than the field of view of HRI. The MRI has a 5$\times$ larger scale and 5$\times$ larger field of view to include the entire nucleus at the end of pre-flyby imaging. MRI includes a subset of the HRI filters and narrower-band filters to isolate emission bands and continuum. The Impactor Targeting System (ITS) is identical to MRI except that the filter wheel is omitted.

The impact will take place on 4 July 2005, at an adjustable time in the Period 06:00-06:30 UT, when the comet is at $(\alpha, \delta) = (13\text{h}38\text{m}, -9.6^\circ)$, near the star Spica. The impact will be observable high in the sky after end of nautical twilight from Hawaii and New Zealand and lower in the sky in total darkness from southwestern US and Baja California. It will be observable in daylight from Australasia. Since phenomena related to the impact are expected to continue for at least several days, Earth-based observations are desired with nearly continuous coverage from several days before impact through weeks after perihelion. The uncertainty in the predicted phenomenology emphasizes the need for observations of all possible types and at all possible wavelengths.

Further details of the mission are at http://deepimpact.umd.edu. A web page for collaborating observers will be linked in the last quarter of 2003, providing background information for observers to assist in planning observations. and allowing data entry regarding observing programs to enable individual observers to best complement other observations that are being made. We acknowledge support from NASA and from a large team of people.