# Deep Impact Mission

## Overview

The goal of the Deep Impact mission was to understand the physical and chemical properties of a comet as a function of depth below the surface. To reach this goal, Deep Impact reproduced the impact of a boulder onto a cometary nucleus at a hypervelocity speed, characteristic of collisions in the asteroid belt. The mission delivered an impactor spacecraft of approximately 360 kg onto the nucleus of 9P/Tempel 1 at a relative speed of 10.3 km/s. The kinetic energy of the impactor, about 19 gigajoules, produced a crater with a diameter between 100 and 250 meters in about 200 seconds (A’Hearn, et al. (2005), Schultz and Ernst (2005), Richardson, et al. (2005), and Busko, et al. (2007)). The impact was imaged by the three instruments on board the flyby spacecraft. The best estimate of the impact time was 4 July 2005 at 05:44:34 UTC at the flyby spacecraft (Earth-observed time 05:52:00 UTC). The phase angle on approach for both spacecraft was about 62.9 degrees.

Deep Impact consisted of two spacecraft launched together on 12 January 2005 at 18:47:08.57 UTC and which flew together until one day before impact on 4 July 2005. On July 3 at 05:59:58 UTC, the two spacecraft separated while on a course to impact comet Tempel 1. They immediately went into auto-navigation mode using an algorithm that ensured the impactor would hit an illuminated area of the nucleus and the flyby spacecraft would point to the same area for imaging the impact. The impactor observed the comet with a visible CCD (ITS) until several seconds before the impact. Shortly after separation, the flyby spacecraft performed a trajectory correction maneuver and passed approximately 500 km below the nucleus, as seen from the sun. The flyby spacecraft recorded the encounter and the impact with the High Resolution telescope’s visible CCD (HRIV) and infrared imaging spectrometer (HRII) as well as with the Medium Resolution telescope’s visible CCD (MRI). Initial results from the encounter were discussed by A’Hearn, et al. (2005a). Detailed results were presented later in volume 187 of Icarus (March 2007), dedicated specifically to Deep Impact.

The mission, science objectives, instrumentation, and expected results were described in a special edition of Space Science Reviews (SSR) dedicated to Deep Impact. See A’Hearn, et al. (2005b), Blume (2005), Mastrodemos, et al. (2005), Hampton, et al. (2005), Klaasen, et al. (2005), Belton, et al. (2005), Lisse, et al. (2005), Sunshine, et al. (2005), Richardson, et al. (2005), Schultz and Ernst (2005), Thomas, et al. (2005), Yeomans, et al. (2005), and McFadden, et al. (2005). These SSR papers are included in the Deep Impact and EPOXI documentation set, archived as PDS dataset DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V4.0.

The world-wide Earth-based observing campaign for the mission was described by Meech, et al. (2005) in the SSR edition. McFadden, et al. (2005) discussed the Education and Public Outreach component of the mission.

Calibration of Deep Impact instruments and the calibration pipeline were discussed in Klaasen, et al. (2008). A draft of this calibration paper is included in the Deep Impact and EPOXI documentation set, archived as PDS dataset DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V4.0.

### Known Clock Discrepancy

There is a known one- or two-second uncertainty in the time of the impact. Clock correlation packets indicated large drifts in the clocks on-board the flyby and impactor spacecraft due to thermal changes induced by trajectory correction maneuvers near encounter. The drifts resulted in a difference of several seconds between impact times based on data from the flyby and impactor spacecraft and ground-based data.

During January 2006 the project used available spacecraft data and advice from engineering personnel to correlate the flyby clock and Dynamical Barycentric Time (TDB) to within one or two seconds and the flyby and impactor clocks to one-half of a second. The project moved the estimated impact time forward by two seconds, from 05:44:36 UTC on 4 July 2005 as reported by A’Hearn, et al. (2005a) to 05:44:34.265 UTC at the flyby spacecraft and 05:44:34.200 UTC at the impactor spacecraft. The project also generated self-consistent SPICE CK kernels based on this analysis.

The improved kernels were included in the Deep Impact SPICE data set archived in the PDS. The timing discrepancy is discussed in the ‘Deep Impact Spacecraft Clock Correlation’ report included in the Deep Impact and EPOXI documentation set, archived as PDS dataset DI-C-HRII/HRIV/MRI/ITS-6-DOC-SET-V4.0.

## Mission Phases

Three primary phases are defined for the archive of flight-related data: thermal-vacuum ground calibrations (TV), cruise, and 9P encounter. A post-encounter phase is included below because the Deep Impact SPICE archive includes a SP-kernel providing the trajectory of the flyby spacecraft through 2009 and another providing the ephemeris of 9P/Tempel 1 through 2050.

### THERMAL-VACUUM GROUND CALIBRATIONS (TV1-TV5)

Data acquired during ground-based thermal-vacuum tests TV1 through TV4 were archived in the PDS. The science team used these data for pre-flight calibration analysis. TV5 data were not used for science calibrations but may be archived at a future data.

TV# Instruments Tested Test Period

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TV1 HRII 2002 June-July

TV2 HRII, HRIV 2002 August-September

TV3 ITS 2003 January

TV4 HRII, HRIV, MRI 2003 February-March

TV5 HRII, HRIV, MRI, ITS 2004 June-July

### CRUISE

Mission Phase Start Time : 2005-01-12 (DOY 012)

Mission Phase Stop Time : 2005-04-30 (DOY 120, Impact-65 days)

The cruise phase began at the lift-off of the launch vehicle. This phase included checkout of the HRII, HRIV, and MRI instruments in the second and third days after launch. Science calibrations began shortly after checkout, then were performed approximately once every month. The best sets of data for science calibrations were acquired in April, May, and June 2005 and during the post-impact calibration in July. Calibration targets included the Moon, Earth, stars, nebulae, and galactic clusters. Comet 9P/Tempel 1 was not imaged for scientific purposes during this phase. Details of the cruise calibrations were discussed in the ‘Deep Impact Instrument Calibration’ paper by Klaasen, et al. (2008).

### 9P ENCOUNTER

Mission Phase Start Time : 2005-05-01 (DOY 121, Impact-64 days)

Mission Phase Stop Time : 2005-07-13 (DOY 194, Impact+9 days)

Scientific data acquisition of comet 9P/Tempel 1 began and ended during this phase. On the approach to the comet, the objectives were to determine the size of the nucleus, map the albedo, and spectral variations of the surface, determine the rotational state of the nucleus, and monitor the activity of the nucleus. Other objectives included identifying large-scale structure in the coma, mapping the evolution of the inner coma over a full rotation period, and searching for satellites to constrain the mass of the nucleus (none were found). Also, science calibrations were performed in early May and June. During approach, the HRII, HRIV, and MRI instruments began acquiring data once every day, then every four hours from 7 May through 30 June. On 1 July, the sampling rate changed to every two hours. About 24 hours before impact, data were acquired every hour until about 3 July 20:00 UT, nine hours before impact. Then, data were acquired every 30 minutes until ten minutes before impact when the instruments began continuously imaging the comet.

During approach, the phase angle of the nucleus (sun-comet-spacecraft) increased by about 0.5 degree/day, beginning at 28 degrees and reaching 60 degrees at impact minus seven days. About three days from impact the HRIV instrument spatially resolved the nucleus. The HRII and MRI instruments did not resolve the nucleus until the day before impact. Due to pointing errors, the HRII instrument was not imaging the comet until 20 June.

Twenty-four hours before the scheduled impact, the flyby craft released the impactor at a distance of about 864,000 km from the comet. The ITS instrument began acquiring data, and the impactor spacecraft transmitted the data over a S-band link to the flyby spacecraft. About 18 hours before impact, a small set of calibration data (darks and internal stimulator frames) were acquired for each instrument. The pixel scales of the four instruments as a function of time before impact were:

Pixel Scale (meters/pixel)

Time ITS HRIV MRI HRII

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I-20 hr 7415 1480 7430 7350

I-1 hr 370 90 460 450

I-2 s 0.1 17 87 87

The last ITS image was taken at 05:44:29 UT (at the impactor), about 5 seconds before impact, with an estimated pixel scale of 0.5 meters/pixel.

During the impact event, the instruments on the flyby craft continuously recorded the development of the crater and start of the ejecta flow. At impact+804 seconds (05:57:58 UT), the flyby space craft entered shield mode (SM) where the shields were pointed in the direction of the spacecraft’s velocity vector to protect the instruments from dust impacts during closest approach to the comet. During the impact event, pixel scales of the instruments were:

Pixel Scale (meters/pixel)

Time HRIV MRI HRII

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I+1 s 17 86 86

I+24 s 17 84 84

I+470 s 7.8 38 39

I+802 s 1.4 7 7

SM Entry n/a n/a 6.7

The HRIV and MRI instruments stopped imaging immediately before shield mode. HRII continued (smeared) spectral imaging for about 50 seconds into shield mode. The flyby spacecraft remained in shield mode for about 24 minutes, through closest approach and until the dust-impact hazard zone had been passed. To exit shield mode, the spacecraft performed an attitude maneuver over several minutes, flipping over and pointing its instruments back toward the nucleus. Once in lookback attitude, the HRIV instrument continued to image the impact site for another 12 hours. The MRI and HRII instruments continued to monitor the comet for 60 hours, until 6 July 18:17 UT. During lookback imaging, the pixel scales of the instruments were:

Pixel Scale (meters/pixel)

Time HRIV MRI HRII Comments

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I+44 m 37 n/a 183 4 Jul 06:28:53 UT, first HRIV

and HRII after SM exit

I+48 m 42 210 199 4 Jul 06:32:41 UT, first MRI

after SM exit

I+134 m 146 737 756 4 Jul 07:58 (SM Entry+ 2 h)

I+734 m 880 4406 4422 5 Jul 17:58 (SM Entry+12 h)

I+24.24 h n/a 8810 8826 5 Jul 05:58 (SM Entry+24 h)

I+36.24 h n/a 13214 13230 5 Jul 17:58 (SM Entry+36 h)

I+48.24 h n/a 17618 17635 6 Jul 05:58 (SM Entry+48 h)

I+60.24 h n/a 21950 21968 6 Jul 17:58 (SM Entry+60 h)

At impact, data determined to be less critical were stored in the buffer memory of the two processors (A and B) on the flyby spacecraft. During lookback, the flyby craft transmitted these stored data back to Earth. Due to a planning oversight, the memory of processor B was not cleared of data before lookback began. This caused some lookback images to never be recorded. The last science calibration started about two days after impact and continued to 13 July, which concluded the scientific activities of the mission.

Steve Wissler from mission operations at JPL provided the actual UTC times for several key events at the flyby and impactor spacecraft (s/c):

Flyby Spacecraft Event Actual UTC at s/c

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Last TCM before impactor release 2005-07-02 23:59:58.3

Impactor battery activated 2005-07-03 04:57:59.4

Impactor release 2005-07-03 05:59:58.3

Flyby s/c divert maneuver 2005-07-03 06:11:58.3

Flyby enters shield mode 2005-07-04 05:57:58.3

Closest approach (planned) 2005-07-04 05:58:58

Flyby s/c turns for look back imaging 2005-07-04 06:24:37.2

The mission operations also provided the actual UTC times for several events at the impactor spacecraft:

Impactor Spacecraft Event Actual UTC at s/c

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Auto-navigation system begins imaging 2005-07-04 03:44:37.7

1st TCM (burn center) 2005-07-04 04:13:57.7

2nd TCM (burn center) 2005-07-04 05:09:05.8

3rd TCM (burn center) 2005-07-04 05:32:06.8

### 9P POST-ENCOUNTER CRUISE

Mission Phase Start Time : 2005-07-13 (DOY 194, Impact+9 days)

Mission Phase Stop Time : 2009

In the Deep Impact SPICE archive, the SP-kernel providing the trajectory of the flyby spacecraft extends through 2009, and the SP-kernel providing the ephemeris of Tempel 1 extends through 2050. There are no data from the science instruments for this phase.

Since the flyby spacecraft and its instruments survived the encounter with Tempel 1, a trajectory correction maneuver was performed on 20 July 2005 to put the spacecraft into an orbit for Earth return in late 2007, favoring an extended mission. On 9 August 2005, the flyby craft was put into sleep mode. On 10 February 2006, an aliveness test was performed on the spacecraft. The results of the wake-up and pointing activities indicated it was healthy for an extended mission.

## Mission Data

The following mission-related data are archived at the PDS:

* Pre-launch, thermal-vac calibration (HRII, HRIV, MRI, ITS)
* Raw science and calibration imaging from flight (HRII, HRIV, MRI, and ITS)
* Reduced science imaging from flight in physical units of radiance (uncleaned and cleaned) for HRII, HRIV, MRI, and ITS and cleaned I-over-F data for HRIV, MRI, and ITS.
* Raw and reduced navigation images from flight (HRIV, MRI, ITS)
* Radio science data from flight
* SPICE data, including 5-Hz telemetry from the Attitude Determination and Control System (ADCS) as a CK kernel
* Higher-level products, including a shape model and surface temperature maps for Tempel 1.
* Select data from the Earth-based observing campaign

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## Note on Authorship

This mission overview was originally paraphrased from A’Hearn, et al. (2005b) with permission from the Deep Impact project, then revised throughout the mission by the archive team.