Stardust New Exploration of Tempel 1 (Stardust-NExT) Mission Summary

# Mission overview

Stardust-NExT was an extended mission that used the Stardust (SDU) spacecraft to effect a flyby of comet 9P/Tempel 1 at 178 km on 15 February, 2011 (40 days post perihelion) and obtain high-resolution images of the coma and nucleus, as well as measurements of the composition, size distribution and flux of dust emitted into the coma. The SDU spacecraft had been launched in 1999 and had already flown by comet 81P/Wild 2 in January 2004 as part of the prime Stardust mission (Brownlee, et al. 2003; Semenov, et al. 2004a; Ryno, et al. 2004; and Semenov, et al. 2008).

The 2005 impact by the Deep Impact (DI) mission on 9P/Tempel 1 excavated ejecta with an optical depth such that the cameras on the DI flyby spacecraft could not image the surface in the impact area. Therefore, the size of and character of the crater that had been excavated could not be determined (A’Hearn, et al. 2005a; A’Hearn, et al. 2005b) by the DI mission.

Mission activities included a plan to update knowledge of the rotational phase of the comet sufficiently well to view significant portions of the hemisphere studied by Deep Impact in 2005 and imaging the crater excavated by the impactor (Belton, et al. 2011; Meech, et al. 2011).

Stardust-NExT was a low-cost, low-risk mission to complete and expand the investigation of comet Tempel 1 initiated by Deep Impact, and for the first time assess the changes in the surface of a comet between two successive perihelion passages. It provided important new data that may be used to assess how Jupiter family comets (JFCs) evolve and how they were formed 4.6 billion years ago.

The investigation of comets addresses each of the three strategic objectives for solar system exploration enunciated in NASA's Space Science Enterprise Strategy (SSES) 2003 (Weiler, et al. 2003):

* To learn how the solar system originated and evolved to its current state.
* To understand how life begins and determine the characteristics of the solar system that led to the origin of life.
* To catalog and understand the potential impact hazard to Earth from space.

Stardust-NExT contributed significantly to the first and last of these objectives. Stardust-NExT was designed to obtain essential new data, capitalize on the discoveries of earlier missions to determine how cometary nuclei were constructed at the birth of the solar system, and increase our understanding of how they have evolved since then.

The investigations on the Stardust-NExT mission included:

* Cometary coma and nucleus imaging (Navigation Camera a.k.a. NAVCAM; Newburn, at al. 2003)
* Comet particle composition measurements (Cometary and Interstellar Dust Analyzer a.k.a. CIDA; Kissel, et al. 2003)
* Dust flux measurements (Dust Flux Monitor Instrument a.k.a. DFMI, Tuzzolino, et al. 2003)

The Sample Return Capsule (SRC) had been returned to Earth in 2006 and was no longer part of the in-flight spacecraft (Farnham and Semenov 2006.

# Mission phases

Based on NAVCAM activities, and particle instruments' general inactivity before and after the Tempel 1 encounter, there were four logical mission phases for Stardust-NExT: CRUISE; APPROACH; ENCOUNTER; DEPARTURE.

***N.B.*** *Because of differences in sensing range between the imaging and particle instruments, these logical mission phases correspond only approximately to instrument-specific operational data collection periods or subphases as defined in instrument data catalogs for the Stardust-NExT data sets.*

*For the particle instruments, CIDA and DFMI, there are only two phases: CRUISE and ENCOUNTER. APPROACH and DEPARTURE, as defined here, are combined and considered to be CRUISE.*

*For the NAVCAM, operational mission subphases were defined as CO (CHECKOUT), C5 and C6 (CRUISE 5 and 6), and TE (TEMPEL ENCOUNTER), and those two-letter acronyms were used in the NAVCAM PRODUCT\_IDs and FILE\_NAMEs. C6 was not intentional but was added when the NAVCAM image count was reset during C5, temporarily causing problems in the ground data system. An earlier mission phase, C4 (CRUISE 4) was defined but no NAVCAM data were taken during that phase. Details of these two-letter NAVCAM 'subphase' designations have been provided in the NAVCAM data set.*

## Cruise

Mission Phase Start Date : 2007-01-17 (2004-02-12 for CIDA)

Mission Phase Stop Date : 2010-12-16

Spacecraft Operations Type : CRUISE

Target Names : CALIBRATION

INTERSTELLAR PARTICLES

NON SCIENCE

Performed instrument checkout and calibration activities: All instruments were in CRUISE configuration when turned on: NAVCAM and DFMI were off except for calibrations; CIDA was on nearly continuously. Minimal science data were taken except for CIDA. NAVCAM activities included characterization of photometric (stars), geometric (star clusters), bias and dark (shutter closed), and post-decontamination (post-bake) behaviors. Navigation maneuvers were performed including Tempel 1 time of arrival adjustment in February 2010 to maximize the probability of optimizing imaging of both previously seen and unseen comet surface including the DI crater.

## Approach

Mission Phase Start Date : 2010-12-17

Mission Phase Stop Date : 2011-02-13

Spacecraft Operations Type : CRUISE

Target Names : 9P/TEMPEL 1 (1867 G1)

CALIBRATION

INTERSTELLAR PARTICLES

NON SCIENCE

Performed NAVCAM imaging of coma for science and navigation starting sixty days before Encounter (E-60d) closest approach through two days before encounter. All instruments were in cruise configuration when turned on. CIDA was off. DFMI was off except for calibration. NAVCAM coma observations started with eight-image sets every 2-6 days, increasing later to up to ~100 images per day, interrupted only for calibration and decontamination. Significant scattered light was observed for most of these images, due to the spacecraft attitude and mirror angle used, which prevented coma detection. The coma was first detected in summed images at E-28d when the sequences were modified to use a spacecraft attitude which minimized scattered light. Approach phase ended with a two-day standdown of instrument operations to prepare for ENCOUNTER phase (below). Because of the standdown, there is a discontinuity (gap) between the APPROACH stop date and the ENCOUNTER start date.

## Encounter

Mission Phase Start Date : 2011-02-15

Time of Closest Approach : 2011-02-15T04:39:10

Mission Phase Stop Date : 2011-02-15

Spacecraft Operations Type : ENCOUNTER

Target Names : 9P/TEMPEL 1 (1867 G1)

NON SCIENCE

Performed close-up science measurements of comet 9P/Tempel 1 on 15 February, 2011; all instruments were in encounter configuration when turned on. NAVCAM took seventy-two high-spatial resolution brightness-compressed images over T +/- ~4minutes; four of these were coma observations for which the comet nucleus was intentionally overexposed. CIDA was on continuously. DFMI was on for T +/- ~20 minutes. Auto-navigation software performed flawlessly and kept the bulk of the comet nucleus in all NAVCAM images. Before and after the encounter, the spacecraft was in two-day standdowns of instrument operations to downlink data. Because of the standdowns, there are discontinuities (gaps) between the APPROACH stop date and the ENCOUNTER start date, and between the ENCOUNTER stop date and the DEPARTURE start date.

## Departure

Mission Phase Start Date : 2011-02-17

Mission Phase Stop Date : 2011-02-25

Spacecraft Operations Type : CRUISE

Target Names : 9P/TEMPEL 1 (1867 G1)

CALIBRATION

INTERSTELLAR PARTICLES

NON SCIENCE

Performed NAVCAM imaging of coma for science, similar to APPROACH phase above. All instruments were in cruise configuration when turned on. CIDA was off. DFMI was off except for a final calibration. NAVCAM imaging was stopped at E+10d after the coma was determined to be too faint for further scientific utility. Remaining spacecraft fuel was burned to exhaustion on 26 March in a final maneuver to allow validation and/or calibration of fuel estimation techniques used on this and other missions. The Stardust spacecraft was left in a safe orbit (it will not come near Earth for the foreseeable future) and will boot to a safe configuration in the event the solar panels supply power to the processing unit.

# References

A'Hearn, M.F., M.J.S. Belton, W.A. Delamere, J. Kissel, K.P. Klaasen, L.A. McFadden, K.J. Meech, H.J. Melosh, P.H. Schultz, J.M. Sunshine, P.C. Thomas, J. Veverka, D.K. Yeomans, M.W. Baca, I. Busko, C.J. Crockett, S.M. Collins, M. Desnoyer, C.A. Eberhardy, C.M. Ernst, T.L. Farnham, L. Feaga, O. Groussin, D. Hampton, S.I. Ipatov, J.-Y. Li, D. Lindler, C.M. Lisse, N. Mastrodemos, W.M. Owen, J.E. Richardson, D.D. Wellnitz, and R.L. White, Deep Impact: Excavating Comet Tempel 1, Science, 310, 258-264, 2005a, doi:10.1126/science.

A'Hearn, M.F., M.J.S. Belton, A. Delamere, and W.H. Blume, Deep Impact: A Large-Scale Active Experiment on a Cometary Nucleus, Space Science Reviews, 117, 1-21, 2005b, doi:10.1007/s11214-005-3387-3.

Belton, M.J.S., Meech, K.J., Chesley, S., Pittichova, J., Carcich, B., Drahus, M., Harris, A., Gillam, S., Veverka, J., Mastrodemos, N., Owen, W., A'Hearn, M.F., Bagnulo, S., Bai, J., Barrera, L., Bastien, F., Bauer, J.M., Bedient, J., Bhatt, B.C., Boehnhardt, H., Brosch, N., Buie, M., Candia, P., Chen, W.-P., Chiang, P., Choi, Y.-J., Cochran, A., Crockett, C.J., Duddy, S., Farnham, T., Fernandez, Y.R., Gutierrez, P., Hainaut, O.R., Hampton, D., Herrmann, K.A., Hsieh, H., Kadooka, M.A., Kaluna, H., Keane, J., Kim, M.-J., Klaasen, K., Kleyna, J., Krisciunas, K., Lara, L.M., Lauer, T.R., Li, J.-Y., Licandro, J., Lisse, C.M., Lowry, S.C., McFadden, L., Moskovitz, N., Mueller, B., Polishook, D., Raja, N.S., Riesen, T., Sahu, D.K., Samarasinha, N., Sarid, G., Sekiguchi, T., Sonnett, S., Suntzeff, N.B., Taylor, B.W., Thomas, P., Tozzi, G.P., Vasundhara, R., Vincent, J.-B., Wasserman, L.H., Webster-Schultz, B., Yang, B., Zenn, T., Zhao, H., Stardust-NExT, Deep Impact, and the accelerating spin of 9P/Tempel 1, Icarus, Volume 213, Issue 1, May 2011, Pages 345-368, doi:10.1016/j.icarus.2011.01.006

Brownlee, D. E., P. Tsou, J. D. Anderson, M. S. Hanner, R. L. Newburn, Z. Sekanina, B. C. Clark, F. Horz, M. E. Zolensky, J. Kissel, J. A. M. McDonnell, S. A. Sandford, and A. J. Tuzzolino, Stardust: Comet and interstellar dust sample return mission, J. Geophys. Res., 108, (E10), 8111, 2003

Farnham, T.L., Semenov, B., STARDUST DUST COLLECTOR GEOMETRY, SDU-C-SRC-6-GEOMETRY-V1.0, NASA Planetary Data System, 2006.

Kissel, J., A. Glasmachers, E. Grun, H. Henkel, H. Hofner, G. Haerendel, H. von Hoener, K. Hornung, E. K. Jessberger, F. R. Krueger, D. Mohlmann, J. M. Greenberg, Y. Langevin, J. Silen, D. Brownlee, B. C. Clark, M. S. Hanner, F. Hoerz, S. Sandford, Z. Sekanina, P. Tsou, N. G. Utterback, M. E. Zolensky, and C. Heiss, Cometary and Interstellar Dust Analyzer for comet Wild 2, J. Geophys. Res., 108, (E10), 8114, 2003

Meech, K.J., Pittichova, J., Yang, B., Zenn, A., Belton, M.J.S., A'Hearn, M.F., Bagnulo, S., Bai, J., Barrera, L., Bauer, J.M., Bedient, J., Bhatt, B.C., Boehnhardt, H., Brosch, N., Buie, M., Candia, P., Chen, W.-P., Chesley, S., Chiang, P., Choi, Y.-J. et al., 2011. Deep Impact, Stardust-NExT and the Behavior of Comet 9P/Tempel 1 From 1997-2010, Icarus, in press.

Newburn Jr., R. L., S. Bhaskaran, T. C. Duxbury, G. Fraschetti, T. Radey, and M. Schwochert, Stardust Imaging Camera, J. Geophys. Res., 108, (E10), 8116, 2003

Ryno, J., B.V. Semenov, J. Kissel, J. Silen, and C.H. Acton, STARDUST CIDA DATA, SDU-C/D-CIDA-1-EDF/HK-V1.0, NASA Planetary Data System, 2004.

Semenov, B.V., A.J. Tuzzolino, J.A.M. McDonnell, H.W. Taylor, and C.H. Acton, STARDUST DFMI WILD 2 ENCOUNTER EDR DATA, SDU-C-DFMI-2-EDR-WILD2-V1.0, NASA Planetary Data System, 2004a.

Semenov, B.V., R.L. Newburn, H.W. Taylor, C. Hash, and C.H. Acton, T.L. Farnham, STARDUST NAVCAM IMAGES OF WILD 2, SDU-C-NAVCAM-2-EDR-WILD2-V2.0, NASA Planetary Data System, 2008b.

Tuzzolino, A. J., T. E. Economou, R. B. McKibben, J. A. Simpson, J. A. M. McDonnell, M. J. Burchell, B. A. M. Vaughan, P. Tsou, M. S. Hanner, B. C. Clark, and D. E. Brownlee, Dust Flux Monitor Instrument for the Stardust mission to comet Wild 2, J. Geophys. Res., 108, (E10), 8115, 2003

Weiler, E.J., 2003 Space Science Enterprise Strategy, National Aeronautics and Space Administration, 01 October, 2003. http://spacescience.nasa.gov/admin/pubs/strategy/2003/SpSciEntStrat(low).pdf