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Comet Collision Mission Finds Flying Snowbank

by Simon Mitton

On April 3, 1867, Ernst Tempel, a comet seeker at the Marseille Observatory in France, swept his telescope through the constellation Libra, where he spied a 9th magnitude fuzzy interloper that we know today as periodic comet 9P/ Tempel 1. This was to be his most important discovery, although he could not have foreseen the developments that would make the comet the subject of new Hot Paper #1, which describes the science outcomes of a collision engineered by NASA in which a metallic impactor with a mass of 364 kg was deliberately crashed into the comet.

Comets were formed from gas, ice, and dust about 4.5 x 10^9 years ago in the outer solar system, and their chemical composition reflects that of the primordial solar system. Each time a periodic comet makes a close approach to the Sun, volatile gases and dust are released from the surface to form the comet's

WHAT'S HOT IN PHYSICS

Rank	Paper	Citations This Period (Mar-Apr 07)	Rank Last Period (Jan-Feb 07)
1	M.F. A'Hearn, *et al.*, **"Deep Impact: Excavating comet Tempel 1,"** *Science*, 310(5746): 258-64, 14 October 2005. [14 U. S. and German institutions] *975NV	33	†
2	M.F. Skrutskie, *et al.*, **"The Two Micron All Sky Survey (2MASS),"** *Astronom. J.*, 131(2): 1163-83, February 2006. [11 U. S. institutions] *010RX	28	1
3	W. Ma, *et al.*, **"Thermally stable, efficient polymer solar cells with nanoscale control of the interpenetrating network morphology,"** *Adv. Funct. Materials*, 15 (10): 1617-22, October 2005. [U. Calif., Santa Barbara] *976VL	28	†
4	Y.-B. Zhang, *et al.*, **"Experimental observation of the quantum Hall effect and Berry's phase in graphene,"** *Nature*, 438 (7065): 201-4, 10 November 2005. [Columbia U., New York, NY] *982BV	27	2

tail that so delights the casual onlooker. Over time the surface composition changes: the evaporation of volatiles leaves behind a coating of dark silicate dust that reflects hardly any sunlight. The icy interior, however, preserves the original composition. The purpose of NASA's *Deep Impact mission* was to blast through the silicate crust and release pristine volatiles for spectroscopic analysis.

Deep Impact consisted of two spacecraft: the impactor itself, and a flyby mothership to observe the fireworks and relay the data. Almost all of the world's large observatories recorded the event on July 4, 2005, a level of activity unprecedented in the history of astronomy. Much of the science from the space mission was actually conducted on Earth's surface.

Close-up images of Tempel 1 obtained just before impact show signs of geological activity. Its surface shows many classical impact craters, as well as scarps and geological strata that hint at a layered interior.

Prior to the collision, comet researchers had not been sure what to expect. Perhaps the comet would be smashed to smithereens, or, maybe, the impactor would be swallowed up like a pole hitting quicksand. In the event, the

5	K.S. Novoselov, *et al.*, **"Two-dimensional gas of massless Dirac fermions in graphene,"** *Nature*, 438 (7065): 197-200, 10 November 2005. [U. Manchester, U.K.; Inst. Microelect. Tech., Chernogolovka, Russia; Radboud U., Nijmegen, Netherlands] *982BV	27	2
6	K. Adcox, *et al.* (the PHENIX Collaboration), **"Formation of dense partonic matter in relativistic nucleus-nucleus collisions at RHIC: Experimental evaluation by the PHENIX Collaboration,"** *Nucl. Phys. A*, 757(1-2): 184-283, 8 August 2005. [59 institutions worldwide] *943LF	26	†
7	J.R. Petta, *et al.*, **"Coherent manipulation of coupled electron spins in semiconductor quantum dots,"** *Science*, 309(5744): 2180-4, 30 September 2005. [Harvard U., Cambridge, MA; Weizmann Inst., Rehovot, Israel; U. Calif., Santa Barbara] *970NX	25	10
8	G. Li, *et al.*, **"High-efficiency solution processable polymer photovoltaic cells by self-organization of polymer blends,"** *Nature Materials*, 4(11): 864-8, November 2005. [U. Calif., Los Angeles; Natl. Renewable Energy Lab., Golden, CO] *979GS	25	†

impact surprised the experts: it blew out a huge cloud of microscopically small particles (1-100 μ m) that created a dense dust cloud shielding the impact crater from view. The quantity of dust expelled was of on the order of ~10^7 kg. This fine material is probably tens of meters deep.

After the dust had settled, scientists could clearly see that it was compositionally different from the normal surface. There were large increases in organics during and after the event. Emission features in the ejecta spectrum include H_2O, HCN, CO_2, as well as vibration mode signals from H_2CO (formaldehyde) and CH_3OH (methanol).

9	J. Adams, *et al.* (the STAR Collaboration), **"Experimental and theoretical challenges in the search for the quark-gluon plasma: The STAR Collaboration's critical assessment of the evidence from RHIC collisions,"** *Nucl. Phys. A*, 757(1-2): 103-83, 8 August 2005. [49 institutions worldwide] *943LF	23	†
10	J.K. Adelman-McCarthy, *et al.*, **"The Fourth Data Release of the Sloan Digital Sky Survey,"** *Astrophys. J. Suppl. Ser.*, 162(1): 38-48, January 2006. [61 institutions worldwide] *009RS	23	6

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By looking at the rate at which the ejecta cone expanded, principal investigator Michael A'Hearn (University of Maryland) and his colleagues conclude that the bulk density of the cometary nucleus is 0.6 g cm^{-3}, broadly similar to freshly fallen snow. This comet is decidedly fluffy: half of it is empty space rather than rock-hard ice. About two-thirds by mass is pure water ice.

Most comets, when approaching the Sun, undergo outbursts. By looking at these outbursts before and after impact, researchers have concluded that the natural and impact-induced outbursts are very similar, which means that a comet's tail is composed of material that originates below the surface.

For *Science Watch*, A'Hearn commented on the high citation rate of paper #1. "We are, of course, tremendously pleased that our results from *Deep Impact* have played such a big role in the research community. The main thrust of the mission was into the realm of totally unknown properties of comets, so the many new results have triggered a wide range of responses in the community, which is unusually diverse—embracing traditional astronomers, geologists and geophysicists, and even nuclear scientists with interest in craters. The fact that some of our early results seem to speak directly to the origin of comets 4.6 billion years ago means that many researchers are anxious to work with these results."

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