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The demise of Comet 85P/Boethin, the first EPOXI mission target

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ABSTRACT

Comet 85P/Boethin was selected as the original comet target for the *Deep Impact* extended mission, *EPOXI*. Because this comet had been only observed at two apparitions in 1975 and 1986 and consequently had a large ephemeris error, an early intense recovery effort similar to that of 1P/Halley was undertaken beginning in 2005 using the ESO Very Large Telescopes (VLTs) in a distant comet program. These were challenging observations because of the low galactic latitude, and an error ellipse (the line of variations) that was larger than the CCD FOV, and the comet was not seen. Dedicated recovery observing time was awarded on the Subaru telescope in April and May 2006, and June 2007, in addition to time on the VLT and Canada–France–Hawaii telescopes during July–August 2007 with wide field mosaics and mosaicing techniques. The limiting *V* magnitudes from these observing runs ranged between 25.7 and 27.3 and again the comet was not seen in the individual nights. A new image processing technique was developed to stack images over extended runs and runs after distorting them to account for dilations and rotations in the line of variations using modifications of the world coordinate system. A candidate at $V \sim 27.3$ was found in the CFHT data along the LOV, 2.5′ west of the nominal ephemeris position. The *EPOXI* mission was unwilling to re-target the spacecraft without a confirmation. Additional time was secured using the Spitzer Space Telescope, the Gemini South 8-m telescope, the Clay and Baade (Magellan 6.5 m), CTIO 4 m, and SOAR 4 m telescopes during 2007 September and October A composite image made by stacking the new data showed no plausible candidate nucleus to a limiting magnitude of $V = 28.5$, corresponding to a nucleus radius between 0.1 and 0.2 km (assuming an albedo of 0.04). The comet was declared lost, presumably having disintegrated. Searches in the WISE data set revealed no debris trail, but no constraints on the possible time of disruption can be made. NASA approved the trajectory correction maneuver to go to Comet 103P/Hartley 2 on 2007 November 1. Many observers searched for the comet as it came to its December 2008 perihelion, but no trace of the nucleus was found.

Based on observations collected at the Very Large Telescope, Chile, in part on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan, in part using data gathered with the 6.5 m Magellan Telescopes located at Las Campanas Observatory, Chile, in part on

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observations obtained with MegaPrime/MegaCam, a joint project of CFHT and CEA/DAPNIA, at the Canada–France–Hawaii Telescope (CFHT) which is operated by the National Research Council (NRC) of Canada, the Institut National des Science de l'Univers of the Centre National de la Recherche Scientifique (CNRS) of France, and the University of Hawaii, in part using data collected at the Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatory, which are operated by the Association for Research in Astronomy, under contract with the National Science Foundation, and in part on observations obtained at the Southern Astrophysical Research (SOAR) telescope, which is a joint project of the Ministério da Ciência, Tecnologia, e Inovação (MCTI) da República Federativa do Brasil, the U.S. National Optical Astronomy Observatory (NOAO), the University of North Carolina at Chapel Hill (UNC), and Michigan State University (MSU). This work is also based in part on observations taken with the Spitzer Space Telescope, which is operated by JPL/Caltech under a contract with NASA.

1. Introduction

1.1. The Deep Impact extended mission

On July 4, 2005 the *Deep Impact* spacecraft delivered a 364-kg impactor to the nucleus of Comet 9P/Tempel 1 at 10.2 km s^{-1}, taking optical imaging and near-IR spectral data, before, during and after the impact. The mission has yielded new insights into comets and their origins (A'Hearn et al., 2005; Meech et al., 2005a,b). The surface of the comet was seen to have many different types of terrains, differing in gross morphology, photometric properties and composition. Combined with previous encounters, the comet flybys have shown that comet nuclei are very diverse. *Deep Impact* images showed that the very low density nucleus had low albedo, low thermal inertia surface materials and that the activity was controlled from the subsurface with little surface expression of ice (Fernández et al., 2003; Richardson and Melosh, 2006; Sunshine et al., 2006; Richardson et al., 2007; Li et al., 2007; Groussin et al., 2007). This has important implications for formation and evolution of icy bodies and prospects for pristine sample return (Belton et al., 2007). On this basis, coupled with adequate fuel reserves, on 2005 July 24 NASA authorized a spacecraft maneuver that would bring the flyby spacecraft back to the Earth's neighborhood in early 2008 in preparation for an extended mission to fly by another comet. The goal of the extended mission would be to explore the diversity of comets.

The extended mission would seek to investigate the range of cometary topography, activity, physical processes and chemistry. While there was a viable trajectory to return to 9P/Tempel 1 at the next perihelion passage in January 2011, a return to the comet was deemed too risky because of the long flight time, a long period with the spacecraft behind the Sun as viewed from Earth, the large geocentric distance (Δ = 2.3 AU) at encounter, and insufficient fuel reserves. Thus, Comets 85P/Boethin and 103P/Hartley 2 were the only viable targets for a possible extended mission given the remaining fuel in the spacecraft. 103P/Hartley 2 was known to have a small very active nucleus (i.e. very different from the other comets seen in flybys and thus possibly very hazardous), but 85P/Boethin had better encounter conditions, allowing for a lower phase angle of approach and near-continuous communication with Earth during the flyby. A 103P/Hartley 2 2010 mission would involve a longer (more costly) trajectory, and thus the team selected Comet 85P/Boethin as the optimum target for an encounter in 2008 December, with Comet 103P/Hartley 2 as a back up.

At the time of target selection there was little opportunity to observe 85P/Boethin because the comet moved into solar conjunction in late August 2005. The subsequent observing windows included: 2006 February–August, 2007 February–August and continuously from 2008 March through a planned 05 December encounter (at r = 1.159 AU, Δ = 0.890 AU, and phase angle α = 55.6°, with a flyby speed of 10.25 km s^{-1}). The maneuver to reach the comet at encounter was to be carried out at the Earth flyby in late 2007. In order to minimize fuel usage for later retargeting, it was important to know the target's ephemeris well in advance of the Earth flyby. Thus a recovery by mid-2007 was essential for preserving a substantial fuel margin for the encounter. Doing the maneuver correction after the Earth flyby would be prohibitive (see Fig. 1). Because of the comet's orbital history, observing circumstances and likely nucleus brightness, this required a more intensive recovery effort than was conducted for Comet 1P/Halley prior to the 1986 Giotto encounter (Jewitt et al., 1982), requiring a large telescope with a wide field of view. An early recovery would also allow observers to fully characterize the nucleus well in advance of the encounter, increasing the likelihood of mission success and good scientific return.

We report on our nucleus recovery efforts, starting as a modest effort at large r, and becoming a massive campaign pulling together many people inside and outside of the planetary community. The comet was not recovered and has likely disintegrated. The mission was redirected to the backup target but in the process we developed new powerful techniques for faint moving object searches in crowded regions.

1.2. Orbital history

On January 4, 1975, one day prior to its perihelion passage, short period Comet 85P/Boethin was discovered by Reverend Leo

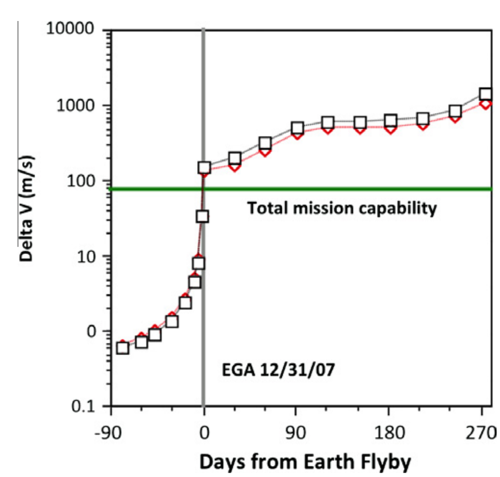

Fig. 1. The ΔV (proportional to fuel) required to correct the spacecraft trajectory to reach Comet 85P/Boethin as a function of time from the Earth flyby (EGA, shown by the vertical gray line) in late 2007. The two curves are generated from two comet Boethin ephemerides representing the range of possible dispersions in the comet along-track position (black squares = comet arrives at perihelion earlier than the red diamond curve). After EGA, the amount of fuel required to change the spacecraft trajectory exceeded the available fuel onboard the spacecraft (the total mission capability of ~75 m/s is shown as the horizontal green line). Figure from K. Williams (private communication). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)