POSSIBLE EXOGENOUS MATERIAL ON ASTEROID APOPHIS. H. Campins[1], R. Cantelas[1], M. Popescu[2,3], E. Tatsumi[2,3], J. de León[2,3], J. Licandro[2,3], J. L. Rizos[2,3], D. DellaGiustina[4] and H. Kaplan[5].
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Introduction: It is possible that exogenous material will be detectable on asteroid Apophis; the likelihood of such a detection has increased based on several recent observations. Here, we review this topic and consider the implications of detecting exogenous material on Apophis.

Related Studies: The Almahata Sitta meteorites produced from the breakup of 2008 TC3 were highly unusual, as the stones contained various different meteorite types [1]. At the time this was as considered an anomaly, but new data from the OSIRIS-REx and Hayabusa2 missions suggest that mixed material in the asteroid belt may be more common than previously thought.

Xenoliths, foreign fragments unrelated to its host stone, have been found in various types of meteorites, the most relevant to this discussion being HED (Howardites, Eucrites and Diogenites) achondrites and ordinary chondrites, with a majority of xenolithic material in these meteorites being carbonaceous in origin [2, 3]. These xenoliths have been studied for some time, but it wasn't until recently that foreign material was also found on asteroids. Data from the Dawn mission confirmed that the carbonaceous xenoliths found in HED meteorites were related to the dark material found on the surface of asteroid (4) Vesta [4, 5]. On near-Earth asteroids (NEAs) (101955) Bennu and (162173) Ryugu, the OSIRIS-REx and Hayabusa2 spacecraft have both discovered V-type and S-type material respectively [6, 7, 8]. Due to the primitive nature of these asteroids it is highly unlikely that these unique fragments could have formed on them and are likely exogenous [e.g., 6, 7].

In 2029, the close approach to Earth of NEA (99942) Apophis will provide the unusual opportunity to obtain detailed Earth-based and space-based observations. Such observations could reveal something similar to what was observed on asteroid Vesta: exogenous carbonaceous material on a silicate surface. Apophis, an Sq-type asteroid likely delivered to its near-Earth orbit from the ν_6 resonance, is associated with LL chondrites. This group contains the Krymka meteorite which has been found to have carbonaceous xenoliths. The 2029 encounter will enhance our ability to study this phenomenon, which can have implications for the formation of rubble pile asteroids and the collisional histories of themselves and their parent bodies.

On Bennu, exogenous material was first identified from its high albedo and unique visible colors, and the V-type composition was confirmed spectroscopically. The surface of Bennu is homogenously dark (mean geometric albedo of 4.4%), consistent with carbonaceous chondrites, with the exception of a small fraction of much brighter spots [6, 7]. The calculated absolute reflectance of mixed basaltic and carbonaceous material explained the albedo of bright spots on Bennu, while their distinct spectra matched closely that of Vesta and other asteroids in its family, confirming that these spots were V-type [6, 7, 9]. On Ryugu, there was a similar approach to categorize bright spots in contrast to a nearly homogenous dark surface; spectra were taken of these bright spots, which revealed that a fraction were likely S-type [8, 10].

The same methodology can be used in reverse on Apophis. The geometric albedo for Apophis is estimated to be 0.25±0.11 [11] and for C-types in between 0.03 and 0.10, meaning carbonaceous material should appear as dark spots contrasted on a bright surface.

Survivability of Projectiles: The high mean collisional velocity in the asteroid belt (~5 km/s) [12], had been used as an argument against exogenous material on asteroids; however, observations clearly show they survived impact on Bennu, Ryugu and Vesta [5, 6, 7, 8]. Modeling is underway to explore how material from an impactor can contribute to a rubble pile asteroid after the disruption of its parent body [12].

Implications: The presence and amount of exogenous material on Apophis can have significant implications for studying the collisional histories and formation of NEA's and asteroids in the main belt. If carbonaceous impactors can survive on the surface, the amount of carbonaceous material could constrain the time Apophis spent in the inner asteroid belt before being scattered by the ν_6 resonance, with higher amounts implying more time spent in the inner belt.

This can be combined with cosmic-ray exposure ages in an attempt to link specific meteorites to Apophis.

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