OSIRIS-REX: THE JOURNEY TO ASTEROID BENNU AND BACK

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1811-5209/17/0212-$0.00 DOI: 10.2113/gselements.13.3.212

In May 2011, NASA selected the *Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer* (*OSIRIS-REx*) asteroid sample return mission as the third of its New Frontiers program missions. The previous, yet ongoing, two New Frontiers missions are *New Horizons*—which explored Pluto during a flyby in July 2015 and is on its way for a flyby of Kuiper Belt object 2014 MU69 on 1 January 2019—and *Juno*—an orbiting mission that is studying the origin, evolution, and internal structure of Jupiter. The *OSIRIS-REx* spacecraft departed for near-Earth asteroid (101955) Bennu aboard a United Launch Alliance Atlas V 411 evolved expendable launch vehicle at 7:05 p.m. eastern daylight time (EDT) on 8 September 2016 for a seven-year journey to return samples from Bennu. Bennu is an Earth-crossing asteroid that has an orbital semi-major axis of 1.1264 AU, which is greater than that of the Earth, but a perihelion distance of 0.89689 AU, less than the Earth's aphelion distance.

OSIRIS-REx is led by the University of Arizona (USA) in partnership with Lockheed Martin Space Systems (USA), the NASA Goddard Spaceflight Center (USA), the Canadian Space Agency, Arizona State University (USA), KinetX Aerospace (USA), the Massachusetts Institute of Technology (USA), and NASA's Johnson Space Center (USA). Science team participation involves researchers from the United States, Canada, France, Japan, the United Kingdom, Spain, Italy, and the Czech Republic.

The spacecraft (Fig. 1) is currently on an outbound cruise trajectory that will result in a rendezvous with Bennu in August 2018 (Fig. 2). The science instruments on the spacecraft will survey Bennu to measure its physical, geological, and chemical properties, and the team will use these data to select a site on the surface to collect at least 60 g of asteroid regolith. The team will also analyze the remote-sensing data to perform a detailed study of the sample site for context, assess Bennu's resource potential, refine estimates of its impact probability with Earth, and provide ground-truth data for the extensive astronomical data set collected on this asteroid. The spacecraft will leave Bennu in 2021 and return the sample to the Utah Test and Training Range on 24 September 2023.

Figure 1 The *OSIRIS-REx* spacecraft launched aboard a ULA Atlas V 411 rocket on 8 September 2016 from Cape Canaveral Air Force Station, Florida (United Launch Alliance) (USA).

Asteroids are geological remnants from the early Solar System. The prime objective of the *OSIRIS-REx* mission is to return pristine carbonaceous regolith from Bennu to understand both the role that primitive asteroids may have played in the origin of life on Earth and how they served as one of the fundamental "building blocks" of planet formation (Lauretta et al. 2015).

The mission has several secondary science objectives. One of the great values of sample return lies in the knowledge of sample context. The mission will provide an extensive global data set of Bennu along with thorough documentation of the sample site. Surface processes that affect the origin of the sample, and which act across the asteroid, will be investigated at unprecedented resolutions. The mission team will also study

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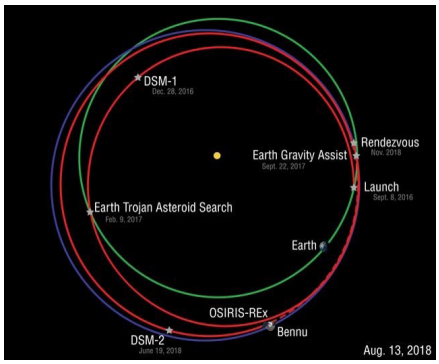

Figure 2 Orbit diagram of the *OSIRIS-REx* spacecraft from launch to asteroid arrival, as of the beginning of Approach Phase on 13 August 2018. Included are the spacecraft's positions during Deep Space Maneuver 1 (DSM-1), the Earth Trojan Asteroid Search, the Earth Gravity Assist, Deep Space Maneuver 2 (DSM-2), and the November 2018 rendezvous with asteroid Bennu itself.

the Yarkovsky effect (the effect of thermal emission on the trajectory of a small, rotating celestial object), improving our ability to predict the long-term orbital trajectory of objects like Bennu, whose orbits cross the path of the Earth. This work can help better predict Bennu's future trajectory and determine whether an impact is a likely outcome within the next several hundred years. In addition, near-Earth asteroids (NEAs) harbor resources such as water and organic molecules that can support future missions of Solar System exploration. *OSIRIS-REx* will assess the resource potential of Bennu and extrapolate this knowledge to other accessible NEAs. Finally, the *OSIRIS-REx* mission will provide ground-truth data for the extensive telescopic observations of Bennu, permitting an assessment of the fidelity of these astronomical techniques for asteroid characterization.

The above investigations are codified into five science objectives.

- **Objective 1**—Return and analyze a sample of pristine carbonaceous asteroid regolith in an amount sufficient to study the nature, history, and distribution of its constituent minerals and organic material.
- **Objective 2**—Map the global properties, chemistry, and mineralogy of a primitive carbonaceous asteroid to characterize its geologic and dynamic history and to provide context for the returned samples.
- **Objective 3**—Provide sample context by documenting the regolith at the sampling site in situ at scales down to the subcentimeter.
- **Objective 4**—Understand the interaction between asteroid thermal properties and orbital dynamics by measuring the Yarkovsky effect on a potentially hazardous asteroid and constraining the asteroid properties that contribute to this effect.
- **Objective 5**—Improve asteroid astronomy by characterizing the astronomical properties of a primitive carbonaceous asteroid to allow for direct comparison with ground-based telescopic data of the entire asteroid population.

The *OSIRIS-REx* mission will return samples that present critical links among often disparate studies of asteroids, meteorites, and Solar System formation. The returned samples will furnish important insight into the formation and dynamical evolution of the Solar System and the links between a known asteroid body and meteoritic samples. The measured properties of asteroid regolith will provide important clues on the energy balance of the surface, and the influence this has on the orbital and rotational evolution of Bennu. *OSIRIS-REx*, together with other small-body missions and telescopic observations, will contribute fundamental insights into asteroids and their past and present roles in planetary systems. The returned samples will be curated at NASA's Johnson Space Center. Samples will be available to any qualified researcher worldwide.

REFERENCE

Lauretta DS and 28 coauthors (2015) The OSIRIS-REx target asteroid (101955) Bennu: Constraints on its physical, geological, and dynamical nature from astronomical observations. Meteoritics and Planetary Science 50: 834-849