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OSIRIS-REx Techniques Applied to Earth-Crossing Object Deflection

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Abstract

The threats to the Earth's population from objects that cross Earth orbit range from airbursts with localized damage to larger impacts with global consequences. The Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) spacecraft will arrive in 2018 at one of the most potentially Earth-hazardous asteroids known—near-Earth carbonaceous asteroid 101955 (1999 RQ36,) and return to Earth with a sample in 2023. Planetary defense against these Near-Earth Objects (NEOs) involves both detection and mitigation, where mitigations fall into three categories: civil defense warning, low-energy deflection, and high-energy deflection. Based on OSIRIS-REx mission design analysis, low-energy deflection missions require the tools and time to identify spacecraft hazards, know the gravity field to design mission-compatible stable orbits, and perform proximity operations. High-energy deflection with a kinetic-energy impactor requires tools to acquire the object and maneuver updates with on-board guided navigation. In addition to the low-energy deflection needs, high-energy deflection with explosives requires on-board guided navigation and tools to place an object in proximity to the NEO (standoff explosion), on the surface or into a crater formed by a kinetic-energy impactor mission. Each deflection mission also requires the means to verify the success of the deflection by measuring the change in the NEO's orbit and tracking fragments > 30-m in diameter. The OSIRIS-REx mission provides valuable insights into Planetary Defense spacecraft engineering and mission design in addition to performing its primary objective of collecting scientific data about the Solar System's most primitive objects.

1 Introduction

Near-Earth Objects (NEOs) pose a threat to the Earth's population when their orbits cross that of Earth's orbit. Effects range from air bursts with localized damage to larger impacts with global consequences [1-4]. The threat level for a given NEO depends on the probability, date, and energy of the impact [5]. Threat assessments rely on accurate and precise orbital information; however, our ability to predict the long-term orbital behavior of NEOs is imprecise. To improve the precision of our threat assessments, we need to refine our understanding of the small forces, specifically the Yarkovsky effect [6] that can affect an object's orbit. If we need to mitigate an asteroid impact, possible future attempts will involve deep-space spacecraft operations in close proximity to asteroids which have small gravitational fields. Greater insights into the characteristics of NEOs and operations around them will be obtained through in-situ observations and sample return from near-Earth carbonaceous asteroid 101955 (1999 RQ36) by the Origins Spectral Interpretation Resource Identification Security Regolith Explorer (OSIRIS-REx) mission. The scientific and engineering data collected will aid our understanding of NEOs, our threat assessment, and operational methods to deflect NEOs.

1999 RQ36 is, in itself, an important object of study, as it is classified as a Potentially Hazardous Asteroid (PHA), with an impact probability of greater than 1 in 1500 late in the next century [7]. Observations made by the OSIRIS-REx mission will provide important information useful in predicting the long-term ephemeris of RQ36 and should reduce the uncertainties associated with its status as a potential impactor. Study of RQ36 also addresses multiple NASA Solar System Exploration objectives. Among these are to obtain a greater understanding of the origin of the Solar System and the origin of life, as well as addressing asteroid sample return objectives of the NASA New Frontiers program and the National Research Council decadal survey [8,9]. The OSIRIS-REx mission will serve as a precursor to future NEO missions by developing specific operational techniques that potentially can be employed on a variety of planetary defense missions, and the mission's security-related science objectives of quantifying the non-gravitational forces that affect the dynamics of NEOs enable the prediction of a NEO orbit many decades into the future.

The OSIRIS-REx mission will collect vital scientific and engineering data to improve our threat assessment of NEOs and to document specific operational methods needed for planetary defense missions that will aim to detect and deflect Earth-crossing NEOs classified as PHA[2]. Herein, we examine the planetary defense applications of the OSIRIS-REx mission.

2 Background: OSIRIS-REx Mission

The OSIRIS-REx mission will travel to the carbonaceous near-Earth asteroid 1999 RQ36 [10]. The OSIRIS-REx mission objectives are to: 1) return and analyze a sample, 2) document the sample site, 3) measure the orbit deviations due to the Yarkovsky effect, 4) create maps of the asteroid for global physical, chemical, and mineralogical properties, and 5) compare the integrated asteroid properties to ground-based observations. To accomplish these objectives, the OSIRIS-REx mission will employ a spacecraft with fine thruster control and sample return hardware (designed and built by Lockheed Martin), precision tracking with the Deep Space Network, and a suite of remote sensing instruments. The suite of instruments includes three optical imagers (PolyCam, MapCam and SamCam) from University of Arizona, a laser altimeter (OLA) contributed by the Canadian Space Agency (designed and built by MacDonald, Dettwiler and Associates), a visible and IR spectrometer (OVIRS) from NASA/Goddard Space Flight Center, a thermal emission spectrometer (OTES) from Arizona State University, and an X-ray fluorescence spectrometer (REXIS), a student experiment jointly developed by MIT and Harvard University. The mission philosophy is to move closer to the asteroid in measured steps. This section focuses on the measured steps to encounter RQ36, which will provide critical data for Planetary Defense.

2.1 Approach

Approach phase will optically acquire RQ36, search for natural satellite hazards, and perform initial characterization of RQ36. PolyCam will optically acquire RQ36 and transmit images to refine the asteroid's ephemeris. MapCam will then search the 31 km-radius Hill Sphere for natural satellites around RQ36, and will characterize the object(s) to assess the hazard these objects pose. As the spacecraft approaches RQ36, OSIRIS-REx will collect progressively higher resolution images to construct a shape model and identify landmarks for navigation (Figure 1).

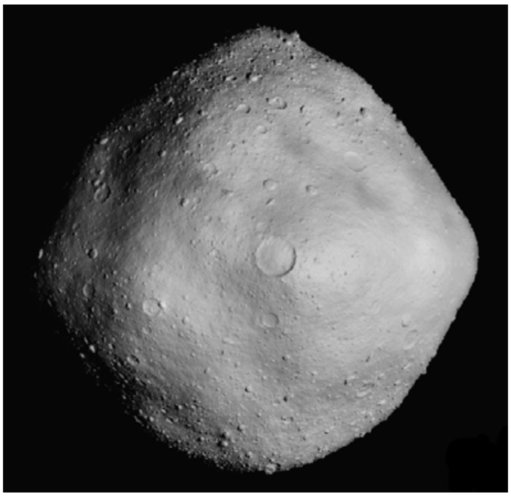

Figure 1. Simulated asteroid image—topography overlaid by Robert Gaskell of PSI on radar imagery of 1999 RQ36 [11]. Credit: NASA/GSFC/UA.

2.2 Survey

Survey phase will provide the first detailed measurement of RQ36's position and refine the size and rotation of RQ36 for the navigation plan. MapCam will search for small particle plumes that would indicate volatile outgassing, a potential spacecraft hazard [12]. Based on PolyCam, MapCam, OLA, OTES and OVIRS data, the science team will produce maps of RQ36's surface and identify potential sample sites. In parallel, the spacecraft team will acquire detailed gravity field data using Radio Science (radiometric ranging and Doppler tracking using the Deep Space Network), which will be used for proximity operations.

2.3 Sample Collection

OSIRIS-REx will touch the surface of RQ36 to collect a sample and then back away (Touch-and-Go (TAG)). Given the one-way light time of 15-20 minutes, the spacecraft team will require on-board guidance and navigation to perform the TAG operation. OSIRIS-REx will use range measurements to constrain the spacecraft position relative to RQ36 and then autonomously adjust the maneuvers to contact the surface in the sample site area. Sensing of surface contact by the spacecraft will trigger the activation of the sampling mechanism to collect regolith. The spacecraft will then back away from RQ36 at faster than the surface escape velocity of approximately 20cm/s. Once the OSIRIS-REx spacecraft is at a safe distance, the team will stow the sample in the Sample Return Capsule (SRC).

3 Planetary Defense Mission Needs and Applications

Planetary defense against a PHA requires detection followed by appropriate action. Detection involves the use of ground and space-based assets to detect the object, determine its orbit, and estimate its size. Following classification, a notice will be issued through established networks that include the Minor Planet Center, Jet Propulsion Lab, and NEODyS.

3.1 NEO Detection

To date, the success of the hazard identification process has depended primarily on detecting, tracking and then properly classifying the object from ground-based observations. The primary detection systems include the Catalina Sky Survey, Lincoln Near-Earth Asteroid Research, and the Pan-STARRS surveys [2]. Ground-based detection systems are limited by atmospheric conditions, confusion with background stars, and visible light interference (solar, lunar, and human generated), and observing geometry. NEO detection from space-based surveys has been demonstrated and shows great promise (NEOWISE, NEOSAT). To date, over 90% of the NEOs with a >1-km diameter [15] and over 9,700 total NEOs [16] have been discovered. However, current detection methods are limited in their ability to identify potential threats from the > 1,000,000 asteroids of > 30-m diameter [2]. As seen with the Chelyabinsk Event on February 15, 2013, an airburst of an object estimated at 17m in diameter injured over 1,000 people [3].

Each detected object is characterized with visible light observations to estimate the object's size range. If a sufficiently close pass is made during the discovery or subsequent apparitions, other parameters (shape, spin and composition) can be obtained using radar and/or spectroscopic observations. [2,17]. A threat assessment is then performed to establish a potential hazard to Earth based on the object's size, the minimum orbit intersection distance (MOID) of ≤ 0.05 AU (approximately 7.5 million km), and the prediction uncertainty with the MOID. The Palmero scale [5] has been most useful to specialists in establishing observational priorities of these threats. For a PHA with a high threat assessment, mitigation may take the form of a simple warning or the mounting of a hazard mitigation mission.

3.2 NEO Hazard Mitigation

A NEO threat may be mitigated by deflecting or dispersing the Near-Earth object to minimize the mass intercepting the Earth [2,4]. A mitigation mission may only require a small velocity change of 0.1 cm/s to 1 cm/s (a nudge) in the object, if performed years to decades in advance of a potential impact. If an object is detected less than a year before impact, mitigation approaches are limited to civil defense or a large velocity change from 10 cm/s to 1000 cm/s. The success of these shorter-duration missions may be limited for a number of reasons (launch vehicle capacity of several metric tons to deep-space, inadequate characterization, analysis). For this reason, mitigation approaches fall into three categories: Civil defense/ warning, low-energy deflection, and high-energy deflection (Table 1). The OSIRIS-REx mission will provide important data to inform a possible PHA mitigation. The OSIRIS-REx mission architecture will provide specific details and knowledge about the operations and tools that will be needed to conduct the different mitigation approaches as discussed in the following section.

Table 1. Knowledge Needs for PHA Mitigation Missions

	Detection	**Low-Energy Deflection**	**High-Energy Deflection**
Object Location (Ephemeris)	X	X	X
Small Force Effects: (Solar Pressure, Yarkovsky)	X	X	X
Hazards (Natural Satellites around Object, Volatiles)		X	X
Size, Mass, Shape, and Rotation State	X	X	X
Mass Distribution		X	X
Gravity Model for Stable Orbits		X	X
Object Interior Composition			X

3.2.1 Civil Defense/ NEO Warning

Impact threats remain from NEOs that range from 30 m to the few remaining undetected objects over a kilometer in diameter, with the smaller diameter asteroids being much more numerous and harder to detect. As many of these NEO threats remain undetected, the National Research Council has made a finding that airbursts from smaller objects (30-50m) represent the most likely near-term threat, and that a search program for these objects is highly desirable [2]. For detected NEO threats, the United Nations has recommended an international asteroid warning network to improve the existing communication [13,14]. This warning is needed to both save lives from a NEO impact and to prevent misinformation on the source of the impact or air burst that could be misinterpreted as a state-sponsored hostile act.

The threat-level with NEO warnings and potential civil defense action depends on understanding the size, track and composition of the object. NEO composition is estimated based on integrated observations as described in Section 3.1. OSIRIS-REx will provide data to compare the integrated asteroid properties and *in-situ* asteroid observations to ground-based observations. This information will improve our ability to determine composition from only ground-based observations; this in-turn will improve the threat-level assessment with NEO warnings.

3.2.2 Low-Energy Deflection

Small forces gradually change the trajectory of NEOs over time. These small forces include solar pressure, anisotropic thermal emission from the object (Yarkovsky effect), and multi-body gravitational effects. Low-Energy deflection could be accomplished by manipulating these small forces or applying an external small force over the course of a few years to decades.

3.2.2.1. Thermo-optical Manipulation

Solar pressure and thermal emission could be manipulated by changing the object's thermo-optical properties. One option is to expose unweathered material with known properties (e.g., a few centimeters below the surface) through surface explosions or thruster interactions. A second option is to coat the surface with a material (e.g., highly reflective crystals) which requires depositing a coating in a low-gravity environment. Full coverage of an object is logistically prohibitive due to the consumables, time (months/years) for surface exposure, and the kilo-tons of mass for coatings. (For example, a 1-cm coating of a 30-m diameter spherical object requires launching and dispersing 10,000 kg of material assuming a density of 1-g/cm^3). Therefore, only a portion of the object may be feasibly changed. As asteroid surface properties are changed through close encounters with Earth, bombardment or other regolith mixing processes [18], the effectiveness of this mitigation approach may degrade over the centuries needed to deflect an object [2], unless the surface modification is repeated. To optimally apply thermo-optical manipulation, the mission requires knowledge of the object's surface properties, rotation rate, spin axes, and mass; these values are inputs to the deflection modeling with solar pressure and Yarkovsky effects to determine the required thermo-optical change (surface area and albedo) for a given body (Table 1). OSIRIS-REx will provide operational knowledge on proximity operations and surface contact for surface manipulation, precise data on asteroid thermo-optical properties, and asteroid deviations due to Yarkovsky effect with these properties, which is critical for understanding the effectiveness of the mitigation option (Table 2).

Table 2. OSIRIS-REx Techniques Applicable to PHA Mitigation Missions

OSIRIS- Techniques	**Low-Energy Deflection**	**High-Energy Deflection**			
	Ion-beam, gravity tractor	*Standoff Explosion*	*Kinetic-energy impactor*	*Subsurface Explosion*	*Surface Explosion, Mass driver*
Acquire Object	X	X	X[b]	X	X
Detect Natural Satellites	X	X	X[a]	X	X
Establish Size/Shape/ Rotation State	X	X	X[a]	X	X
Establish Gravity Model	X	X	X[a]	X	X
Maintain Long-Term Stable Orbit	X	-	X[a]	X	X
Position Relative to the Surface	X[b]	X[b]	X[a,b]	X[b]	X[b]
Maintain Position Relative to Surface	X[b,c]	-	-	-	-
Contact the Surface	-	-	X[b]	X[b]	X[b]
Determine Asteroid / Fragment Ephemeris	X	X	X	X	X

Note: a) required to operate an observer spacecraft, b) closed-loop control, and c) operate for a time period of weeks to years

3.2.2.2. Direct "Push" or "Pull"

Gravitational effects may also be exploited by changing the effective mass interacting with the Sun and combined with a direct "push" or "pull" of the object. A thrusting spacecraft (gravity-tractor) may use a force less than the gravitational force of the object to change the NEO velocity over months to years with a magnitude slightly larger than the Yarkovsky effect [2,4,19]. As an example, a gravity-tractor deflection of a 30-m diameter spherical iron asteroid would require the thrusting spacecraft to expel approximately 500 kg of propellant for a velocity change of 1 cm/s based on the ideal rocket equation $\Delta V = v_e \ln(m_0/m_1)$, where dV = change in velocity, v_e is the effective exhaust velocity of 2262 cm/s, m_0 is the initial mass of propellant plus asteroid mass, and m_1 is the final mass of only the asteroid. The optimal distance for the spacecraft maximizes gravitational force while minimizing thruster plume impingement on the object which would reduce thrust effectiveness. (Note: This simplified example ignores the significant non-ideal propellant usage for control and system losses.) The range to the surface for a gravity-tractor will be tens of meters to two times the NEO radius, depending on the spacecraft mass. As an alternative, an ion-beam or other force could "push" the object [20]. The optimal distance would have the ion-beam fully intercept the surface while minimizing the gravitational pull; with a 15-degree half-cone, the range to the surface would be three times the radius of a spherical NEO. For these "push" or "pull" approaches, the most effective approach is to apply the force in the NEO velocity direction as opposed to a radial or orbit-normal direction, so these missions require knowledge and tools to maintain a precise location relative to the asteroid to be maintained over years. A spacecraft in close proximity to the NEO requires knowledge of the existing hazards (natural satellites in the Hill Sphere or volatiles), induced hazards from spacecraft influence on the body, thermo-optical properties of the object for natural force modeling, and gravitational field with respect to a catalogue of landmarks for active control [21].

Gravity tractor and ion-beam options place the spacecraft at a range from the surface from tens of meters to three times the radius of the NEO. These approaches face four challenges during the years to decades of operation: 1) interference from natural satellites, 2) active control to maintain a precise location relative to the rotating object(s) for years, 3) on-board guidance and navigation to perform proximity operations given one-way light times on the order of tens of minutes. and 4) reliable, long-duration operation of thrusters or ion-beam devices [2]. The spacecraft may intersect with natural satellites or liberated material within the Hill Sphere over the years of operation, so the spacecraft will need to be designed to tolerate this environment or actively monitor the environment (potentially by an observer spacecraft) and perform avoidance maneuvers. To identify the initial asteroid environment and monitor hazards, OSIRIS-REx (Section 2.1, Approach phase) will provide the tools to map the satellites' orbits and establish the gravitational model to predict future orbital states of natural satellites.

OSIRIS-REx will inform the operations and provide tools to perform active control in proximity to a NEO. Prior to positioning the spacecraft for deflection, the mitigation mission will need to compile a catalogue of the landmarks to determine relative position and a gravitational field model as inputs to the on-board closed-loop control system; these data are attainable with the OSIRIS-REx platform through Radio Science observations and global optical mapping (Section 2.2). The OSIRIS-REx mission will also provide the tools to position the spacecraft at 0.5 to 3 NEO radii from the surface (Section 2.3, Sample Collection maneuvers). To maintain this position, the mission could mature the OSIRIS-REx on-board navigation system for a single event into a surface-relative navigation technique, which continuously processes sensor input and adjusts thrust with a closed-loop control.

Overall, low-energy deflection missions require the tools and time to identify hazards, understand the orbit deviations due to small forces, know the gravity model to design and maintain a stable position, and perform proximity operations with on-board guidance, navigation and control.

3.2.3 High-Energy Deflection

Mitigation approaches may also involve the use of a higher-energy event to change velocity of a NEO. High-energy deflection options include a kinetic-energy impact (as demonstrated by the Deep Impact mission), a standoff explosion in proximity to the body, surface explosion, subsurface explosion, or a mass driver [4,22]. The high-energy deflection mission's goal is to deflect the object from an Earth intercept trajectory, or at least fragment the object, to reduce the coherent mass that would encounter the Earth.

3.2.3.1. Kinetic-Energy Impactor

A kinetic-energy impactor would intersect a NEO at >10 km/s to deflect the object and potentially break or scatter the object mass along its orbital path. (Note: This approach is not practical for objects with a diameter >1 km [2,4].) As NEOs range from comets to loose rubble-pile asteroids (e.g., RQ36) to solid iron bodies, the effectiveness of this mitigation will depend on the object composition and the spacecraft's ability to strike the critical target location (e.g., center of mass or a critical mass concentration). A successful intercept requires the ability to target the object's trajectory en route at 10 km/s to 30 km/s, knowledge of natural satellites above a critical mass orbiting the object (which could interfere with the spacecraft), and knowledge of mass concentrations relative to its size, shape, and rotation state.

If the mission employed an optical imager equivalent to PolyCam, the PHA would be acquired at approximately 100,000 km about 0.9 hr to 2.8 hrs prior to impact and >1-m natural satellites surveyed at 1000 km to 1200 km about 33 seconds to 100 seconds prior to impact. With seconds to a few hours to transmit and process the data, there is insufficient time to transmit and process observation data with ground-in-the-loop. (Note: For a 100,000 km range and a relative approach speed of 1 km/s, a 28-hr period is insufficient to acquire the object, transmit the data, design the maneuver on the ground, and execute the maneuver.) To mitigate the risk of loss of mission, an observer spacecraft should perform observations to study the object months to years before intercept for natural satellites and to create a high-fidelity track for the intercept. An observer spacecraft with the OSIRIS-REx tool set could identify the natural satellites, provide extremely accurate ephemeris of the PHA, and categorize the mass concentrations with high-fidelity shape, rotation state, and gravity models to select an optimal target impact site on the PHA. If needed, the impactor could mature the OSIRIS-REx on-board guidance to perform the final correction maneuvers from acquisition data. OSIRIS-REx (as an observer spacecraft) also provides the capability to observe the high-energy interaction from a safe standoff distance to verify the deflection, determine the NEO's orbit after the deflection attempt to verify its success, and possibly determine the orbits of dispersed fragments.

3.2.3.2. Standoff Explosion

A standoff nuclear explosion ablates the surface material, which removes mass from the surface and pushes the object [4, 22, 24]. The mitigation effectiveness depends on the density, elemental composition, and the intersection of the expanding sphere from the explosion with the surface of a PHA which may be spherical or irregularly shaped. For a spherical NEO, the optimal range is 0.4 times the radius of the NEO based on the subtended angle [4]. Range may be increased with a larger mass explosive or decreased for smaller mass explosive, until the effectiveness mirrors a surface explosion. A spacecraft in close proximity to the NEO requires knowledge of the existing hazards (natural satellites in the Hill Sphere or volatiles) and knowledge of the shape, rotation state, and gravitational field to accurately position the spacecraft.

The range for a standoff explosion depends on the object shape and required explosion efficiency. For spherical NEO, the range is 0.4 times the radius; recent studies have used similar distance (0.44 radius for 60-m above a 270-m diameter object) [24]. Prior to positioning the spacecraft for deflection, the mission could leverage the OSIRIS-REx toolset to create a shape model and a gravitational model. These data are attainable with the OSIRIS-REx platform through Radio Science observations and global optical and LIDAR mapping (Section 2.2, Survey Phase). Based on the OSIRIS-REx mission design, a long-term stable orbit is not expected at a range of 0.4 radii to enable ground-based tracking, so a ranging instrument such as a LIDAR, radar, or optical altimeter, combined with on-board functionality, is required. OSIRIS-REx approaches for on-board guidance (Sample Collection phase) would provide the necessary data to reach the optimal distance, to arm the device, and to initiate the mitigation at the appropriate range. OSIRIS-REx (as an observer spacecraft) also provides the capability to observe the high-energy interaction from a safe standoff distance, determine the NEO's orbit after the deflection attempt to verify its success, and determine the orbits of dispersed fragments, which may number from a few small objects for a small change in velocity to numerous objects from a dispersal event [24]. Re-measuring the NEO's shape and rotation state after the deflection attempt is also essential to predict potential future Earth impacts.

It should be noted that because of restrictions found in Article IV of the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies,* it is presumed the use of a nuclear device would require prior international coordination [25].

3.2.3.3. Surface Explosion and Mass Drivers

Surface explosions and mass driver options eject material from the surface at faster than escape velocity to push the object while dispersing material [4].The effectiveness of this approach depends on the accurate ejecta release (vector and timing) to "push" the object in a consistent direction and to disperse the material. These options require knowledge of the asteroid's shape, rotation state, and gravity field, precision navigation to the asteroid, hazard identification, proximity operations, and then sustained contact with the surface of an object with low gravity. In addition to the capabilities for a standoff explosion, OSIRIS-REx mission will provide the tools to reach multiple locations on a NEO and deliver one or more packages with precise navigation. Soft regolith beds could be identified from flyovers, and the package would release a few centimeters into the subsurface. For stony objects, the package would require an anchoring feature or detonation upon contact. OSIRIS-REx will provide the capabilities to contact the surface and then return to monitor the mitigation approach as an observer spacecraft (Section 3.2.3.2).

3.2.3.4. Subsurface Explosion

Subsurface explosives have 100 times the effect as a surface explosion [23]; the goal of this approach is to disperse the object. The challenge is to place an explosion in the object's interior [4]. A potential solution is to use a kinetic-energy impactor to create a crater and then place the nuclear explosion into the crater, which could be accomplished with one or two spacecraft [23]. A successful intercept and detonation requires the ability to target the object's trajectory en route, knowledge of the natural satellites (which could interfere with the lead or follower spacecraft), and knowledge of mass concentrations relative to its size, shape, and rotation state.

For subsurface explosion with a leader-follower spacecraft, OSIRIS-REx will provide the capabilities to track the object en route. The proposed Hypervelocity Asteroid Intercept Vehicle (HAIV) solution [23] has two risks to successful detonation: 1) The explosive not arming and firing in the small time (milliseconds) before striking the surface excavated by the kinetic-energy impactor, and 2) the explosive not detonating due to interference from a natural satellite or crater debris with the follower spacecraft. The proposed solution may benefit by separating the explosive package from the kinetic-energy impactor. An OSIRIS-REx platform could map the object, identify any new natural satellites produced by the impact, establish the new shape and rotation state, place the package interior to the impact crater with on-board guidance, and then provide real-time observation of the mission effectiveness from a safe standoff distance as an observer spacecraft (Section 3.2.3.2).

4 Conclusion

NEO planetary defense missions will benefit from the formulation of and information returned from, the OSIRIS-REx mission. OSIRIS-REx will prove mission design approaches and gather needed scientific and engineering data from design phases through 2023 return and beyond. The mission architecture provides insights into future missions to PHAs and the demonstration of on-board guidance and navigation of the spacecraft, which is critical for deep-space spacecraft operations in close proximity to asteroids with small gravitational fields. To precisely contact a surface, it takes time to characterize and establish the spacecraft’s proximity to the asteroid. Overall, the OSIRIS-REx data are applicable to near-term NEO detection systems and longer-term PHA mitigation missions.

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The OSIRIS-REx spacecraft draws from a strong heritage of Lockheed Martinâ€™s previous planetary spacecraft, while incorporating innovative technologies that make this sample return mission possible. When you look at OSIRIS-REx, its structures and subsystems can be traced back to MAVEN, Juno and Mars Reconnaissance Orbiter.Â OSIRIS-REx has a suite of instruments to thoroughly measure and map the asteroid, including visible-light cameras, infrared spectrometers, an x-ray spectrometer and active-scanning LIDAR. These tools will provide incredibly detailed information about Bennu. Spacecraft StatsÂ This is the second fastest man-made object to return to Earth as the Lockheed Martin-built Stardust capsule came back to Earth at 28,185 mph. Photo Gallery: Flickr. OSIRIS-REx is an acronym for "Origins, Spectral Interpretation, Resource Identification, Security-Regolith Explorer." The goal of the mission â€“ collect a sample weighing at least 2.1 ounces (59.5 grams) from near-Earth asteroid 101955 Bennu (formerly known as 1999 RQ36) and then bring the sample to Earth. The mission, developed by scientists at the University of Arizona, will give us more information about how the early solar system formed and about how life began.Â The spacecraft also carries three other sets of thrustersâ€”the attitude control system (ACS), the main engine (ME), and low thrust reaction engine assembly (LTR) thrustersâ€”thus providing significant redundancy for maneuvers. On Dec. The OSIRIS-REx spacecraft will travel to a near-Earth carbonaceous asteroid (101955) Bennu, study it in detail, and bring back a sample (at least 60 grams or...Â Not only will the spacecraft navigate to the surface using innovative navigation techniques, but it could also collect the largest sample since the Apollo missions. https://nasa.gov/osiris-rex Video credit: NASA's Goddard Space Flight Center James Tralie (ADNET): Lead Producer Lead Editor Animator Narrator Aaron E. Lepsch (ADNET): Technical Support Walt Feimer (KBRwyle): Animator. OSIRIS-REx II OSIRIS-REx II was a 2012 mission concept to replicate the original spacecraî€¹ for a double mission, with the second vehicle collecting samples from the two moons of Mars, Phobos and Deimos. It was stated that this mission would be both the quickest and least expensive way to get samples from the moons.[44][45]. Gallery. OSIRIS-REx imaged OSIRIS-REx's ï¬rst Super-resolution view. the Earth-Moon images of target of asteroid Bennu system during an asteroid Bennu from from OSIRIS-REx on engineering test in August 2018 October 29, 2018 January 2018. from a distance of 205 miles (33 OSIRI S-REx Techniques Applied to Earth-Crossing Object Deflection. R Mink. Recommended publications.Â The first three missions will be described. The Comet Rendezvous Asteroid Flyby mission has a February 1993 launch to comet Tempel 2. The Cassini mission has a May 1995 launch to Saturn and Titan. The third mission is a Comet Nucleus Sample Return launch [Show full abstract] in 1998.