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THE ISIS ASTEROID IMPACTOR MISSION CONCEPT: AN IMPACTOR FOR SURFACE AND INTERIOR SCIENCE. S. R. Chesley[1], J. O. Elliot[1], P. A. Abell[2], E. Asphaug[3], S. Bhaskaran[1], T. Lam[1], and D. S. Lauretta[4], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109; [2]NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058; [3]School of Earth and Space Exploration, Arizona State Univ., Tempe, AZ 85281; [4]Lunar and Planetary Lab., Univ. Arizona, 1415 N. 6th Ave., Tucson, AZ 85705

Introduction: The Impactor for Surface and Interior Science (ISIS) mission is a proposal for a kinetic asteroid impactor mission to (101955) Bennu, the target of NASA's OSIRIS-REx asteroid sample return mission. The two missions would be strong partners in this investigation, and thus the ISIS name is apt, given that Egyptian mythology tells us that Isis was the wife of Osiris. The ISIS mission concept calls for the ISIS spacecraft, an independent and autonomous smart impactor, to guide itself to a hyper-velocity impact with Bennu while the OSIRIS-REx spacecraft observes the collision. Later the OSIRIS-REx spacecraft would descend to reconnoiter the impact site and measure the momentum imparted to the asteroid through the impact, before departing on its journey back to Earth.

Mission Design: The ISIS mission plan starts with a launch in March 2016 as a secondary payload co-manifested with InSight, NASA's most recently selected Discovery mission. Six months later, the OSIRIS-REx spacecraft is scheduled for its launch, with a rendezvous at Bennu planned for Oct. 2018. The OSIRIS-REx team expects to collect its sample by July 2019, but there is schedule margin for a total of three sampling attempts, until early Jan. 2020. The window for the OSIRIS-REx injection back to Earth does not open until March 4, 2021, and so the OSIRIS-REx spacecraft would wait at least 14 months for its departure window to open. The baseline ISIS impact would be late in this period, on Feb. 10, 2021, about 4.5 months before the close of the OSIRIS-REx departure window in late June 2021. The baseline ISIS impact velocity would be 13.4 km/s.

Mission Operations: The ISIS concept of operations begins with the OSIRIS-REx spacecraft entering a radio science orbit around Bennu in order to establish the pre-impact asteroid ephemeris to very high precision. Well before the ISIS impact, OSIRIS-REx would move to a safe vantage point from which to observe the ISIS impact and view the ejecta cone as it expands over a period of several minutes. The spacecraft would also monitor for lofted debris at locations far from the impact to understand the shockwave propagation through the body. After the impact the ISIS science investigation includes three phases, each expected to last 15-20 days. In the first phase, OSIRIS-REx would monitor the debris generated by the impact until it has cleared enough to allow a safe start to the second phase, which consists of a low pass, or perhaps a few passes, over the impact area to obtain spectra and high-resolution imagery (1-2 cm/pixel) of the crater, as well as areas far from the impact site. The final stage in the ISIS science investigation calls for the OSIRIS-REx spacecraft to again enter a radio science orbit, perhaps a terminator orbit with radius 1-2 km, in order to facilitate the estimation of the asteroid deflection provided by the ISIS impact. The ISIS science investigation would be complete in 90 days with schedule margin, at which point OSIRIS-REx would be free to implement its Earth-return injection maneuver.

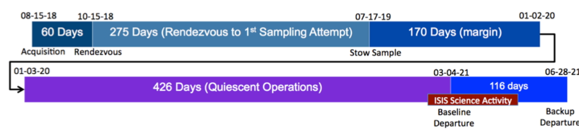

Figure 1. Timeline of OSIRIS-REx proximity operations with the 90-day ISIS operations period superimposed.

Mission Drivers: The ISIS mission would provide tremendous dividends across a wide range of planetary science disciplines, and meet significant objectives of human exploration and technology demonstration. Among the science drivers are the following investigations:

- The change in the asteroid's velocity from the impact (~0.2 mm/s) would be measureable through radio science observations with signal-to-noise ratios >10. This would reveal the momentum enhancement factor β, shedding light on the geotechnical properties of the interior and surface materials, as well as greatly informing any future asteroid impact deflection efforts.
- The cratering experiment would reveal the mechanical properties of the surface and subsurface material and the size distribution of the regolith material. The study of the ejected material would shed light on the meteorite formation process.
- The crater imaging would reveal the subsurface geology and constrain the crater formation process, while spectra of the pristine material from depth would provide added context for the OSIRIS-REx sample.
- The impact would induce seismic waves that travel through the body and reflect off boundaries. This would induce lower energy disturbances far from the impact site, providing a seismic experiment that may loft material, cause landslides and topple boulders. This part of the study would be facilitated by images showing the dynamic effects

of the impact, as well as through the comparison of pre- and post-impact high-resolution imagery.

- The particulate environment produced by a range of disturbances would be observed. Moreover, it is not unreasonable to expect that volatiles could be released, and these could be spectrally characterized.

Spacecraft Preliminary Design: The ISIS flight system design is constrained by a number of driving requirements. These include:

- Low cost and development risk
- Ability to develop complete flight and mission system on a very tight schedule
- Design which does not impact InSight primary payload
- Mass maximized for impact, but fitting within ~1000 kg available on InSight launch
- Navigation accuracy and agility to ensure targeting

These requirements have led to a simple free flying spacecraft design that is based on the space-qualified EELV Secondary Payload Adapter (ESPA). This further minimizes the cost and development risk of the flight system primary structure, and introduces no significant impact to InSight Launch Vehicle (LV) integration.

The preliminary design (shown in Figure 2) would allow the spacecraft to make maximum use of the loading capability of the ESPA ring to deliver an impactor with optimal mass at impact. In the ISIS configuration, all six payload-attachment positions on the ESPA ring are occupied by modules that remain attached to the ring throughout the mission. The modularity of the design and its use of ESPA standard interfaces greatly simplify development and integration while minimizing impact to the InSight LV process flow.

The ISIS design is based on the use of existing, flight-proven hardware to ensure the lowest cost and risk, as well as helping to accommodate the need for an expedited development schedule.

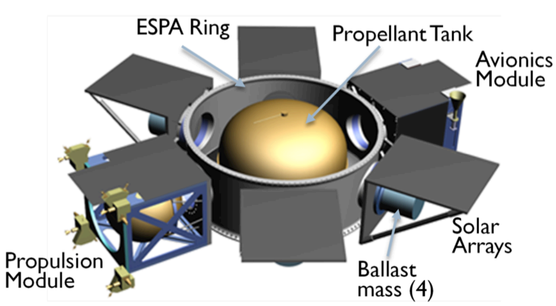

Figure 2. ISIS spacecraft configuration

Conclusion: The ISIS mission concept leverages NASA's investments in both the OSIRIS-REx mission and the InSight launch to provide Discovery-level science returns, address critical Strategic Knowledge Gaps for human exploration, and demonstrate asteroid impact mitigation technology, all for a small fraction of the cost of a Discovery mission. The New Frontiers-class observer spacecraft provides the ISIS mission with an impressive suite of instruments that are unlikely to be available if this mission is attempted later with a low-cost observer spacecraft. Given the low frequency of asteroid rendezvous missions, the fortunate convergence of the OSIRIS-REx schedule and the InSight launch represents an extraordinary but time-critical opportunity that will not be repeated soon.