ISIS
Impactor for Surface and Interior Science

Steve Chesley & The ISIS Team
Small Bodies Assessment Group
July 11, 2013 Briefing
ISIS Mission Concept

- ISIS launches as a secondary payload with the InSight mission
  - Flight system based on ESPA minimizes any impact on InSight
- Five years after launch, ISIS impacts the asteroid Bennu while OSIRIS-REx is in a position to observe
  - Arrival is timed after OSIRIS REx has finished primary mission, during period of “quiescent” operations
- ISIS creates crater tens of meters in diameter
  - OSIRIS-REx images the impact from a safe vantage point
- After debris clears, image crater and collect spectra of pristine material exposed by impact
  - Measure asteroid delta-V due to impactor
ISIS would leverage two significant NASA investments to deliver Discovery-level science while providing a first-time demonstration of asteroid deflection at a fraction of the cost of a stand-alone mission.
ISIS/OSIRIS-REx Operations Concept

OSIRIS-REx Timeline

- **Acquisition**: 08-15-18
- **Rendezvous**: 10-15-18
- **Baseline Departure**: 07-17-19
- **Backup Departure**: 01-02-20
- **Stow Sample**: 01-03-20
- **Baseline Science Investigation**: 03-04-21
- **116 days**: 06-28-21

**ISIS Baseline Mission**

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch</td>
<td>04-Mar-2016</td>
</tr>
<tr>
<td>Mission Δ V</td>
<td>1.22 km/s</td>
</tr>
<tr>
<td>Arrival &amp; Impact</td>
<td>10-Mar-2021</td>
</tr>
<tr>
<td>Arrival Phase Angle</td>
<td>10°</td>
</tr>
<tr>
<td>Impact Velocity</td>
<td>14.9 km/s</td>
</tr>
<tr>
<td>Impact Mass</td>
<td>530 kg</td>
</tr>
<tr>
<td>Impact Energy</td>
<td>59 GJ (~14t TNT)</td>
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</table>

**OSIRIS-REx Activities**

1. Pre-impact characterization of asteroid ephemeris
2. Image impact from a safe location
3. Monitor ejecta as it dissipates
4. Crater reconnaissance
5. Radio science and global remapping
ISIS Flight System Overview

- System designed around flight-qualified ESPA
  - Imposes **no impact** on host SC/LV interface
- Modular Flight System
- Spacecraft Architecture emphasizes simplicity and reliability
  - No Crosslink
  - No Pyrotechnics
  - No Deployments
  - No Mechanisms
NEO Grand Challenge

- June 18 NASA Asteroid Initiative included the Grand Challenge to “find all asteroid threats to human populations and know what to do about them.”
- An intersection of Technology, Exploration and Science goals
- Specific program goals include: “Accelerating efforts to improve detection, characterization, and mitigation of potentially hazardous asteroids to help plan for the defense of our planet against the threat of catastrophic collisions”
ISIS Demonstrates Deflection Technology

- Demonstrate a capability to guide a spacecraft to a hypervelocity impact on a small asteroid
  - Relatively coarse terminal guidance (~1 km) demonstrated by Deep Impact. ISIS accuracy objective is 100 m with 99% confidence.

- Understand the deflection response of a small asteroid to a hypervelocity impact
  - Ability to even roughly predict response significantly eases deflection design
  - Demonstrate ability to “steer” an asteroid through an oblique impact

- The ability to launch a deflection mission on short notice (<29 months) is a key technological capability that will be proven by ISIS
  - Rapid development lessons learned white paper will be a mission deliverable
Recommendation: “If Congress chooses to fund mitigation research at an appropriately high level, the first priority for a space mission in the mitigation area is an experimental test of a kinetic impactor along with a characterization, monitoring, and verification system, such as the Don Quijote mission that was previously considered, but not funded, by the European Space Agency. This mission would produce the most significant advances in understanding and provide an ideal chance for international collaboration in a realistic mitigation scenario.”
Following each PDC, an international consensus white paper is developed:

- **Granada, Spain (2009)**
  - “Deflection-related testing should be included as part of science missions to asteroids and comets to increase information relevant to the mitigation process.”

- **Bucharest, Romania (2011)**
  - “Missions should be planned to demonstrate and validate the most promising deflection or disruption options.”

- **Flagstaff, Arizona (2013)**
  - Recommendations: “Verification of our ability to move an asteroid”
# Small Body Exploration SKGs

2012 SBAG reports details Strategic Knowledge Gaps for Human Exploration goals.

<table>
<thead>
<tr>
<th>SKG Theme</th>
<th>SKG Category</th>
<th>SKG Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>II. Understand how to work on or interact with the SB surface</td>
<td>II-C. SB surface mechanical properties</td>
<td>II-C-1. Macro-porosity of SB interior</td>
</tr>
<tr>
<td></td>
<td></td>
<td>II-C-2. (Critical) Geotechnical properties of SB surface materials</td>
</tr>
<tr>
<td></td>
<td>II-D. Mobility around and interaction with surface in microgravity conditions</td>
<td>II-D-1. (Critical) Anchoring for tethered activities</td>
</tr>
<tr>
<td>III. Understand the SB environment and its potential risk/benefit to crew, systems, and operational assets</td>
<td>III-A. The particulate environment in the proximity of Small Bodies</td>
<td>III-A-1. (Critical) Expected particulate environment due to impact ejecta</td>
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<tr>
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<td>III-A-2. Possible dust/gas emission via sublimation from volatile-rich objects</td>
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<td>III-A-4: (Critical) Possible particulate environment in the asteroid exosphere due to charged particle levitation following surface disturbances</td>
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<td>III-D. Local and global stability of small bodies</td>
<td>III-D-1: (Critical) Local structural stability based on remote</td>
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<tr>
<td></td>
<td></td>
<td>III-D-2: (Critical) Global structural stability based on remote measurements</td>
</tr>
<tr>
<td>IV. Understand the SB resource potential.</td>
<td>IV-A. NEO Resources</td>
<td>IV-A-2. Knowledge of how to excavate/collect NEO material to be processed</td>
</tr>
</tbody>
</table>
## SMD Solar System Exploration Roadmap

<table>
<thead>
<tr>
<th>Theme</th>
<th>Question</th>
<th>Investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Origin</strong></td>
<td><em>How did primitive bodies originate?</em></td>
<td>Study the processes that determine the original characteristics of bodies in the solar system</td>
</tr>
<tr>
<td><strong>II. Evolution</strong></td>
<td><em>How did primitive bodies come to their present state?</em></td>
<td>Determine how the processes that shape planetary bodies operate and interact</td>
</tr>
<tr>
<td><strong>V. Exploration</strong></td>
<td><em>How can these bodies affect us, for good or ill?</em></td>
<td>Determine the dynamics of bodies that may pose an impact hazard on Earth</td>
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<tr>
<td></td>
<td></td>
<td>Understand the impact process in different planetary settings</td>
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<tr>
<td></td>
<td></td>
<td>Characterize planetary resources that can sustain and protect human explorers</td>
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**ISIS addresses Major SSE Questions**
NRC 2011 Planetary Decadal Report
“Vision and Voyages for Planetary Science in the Decade 2013 – 2022”

• On prioritizing planetary missions: “The first and most important [criterion] was science return per dollar.”

• Questions on “formation, accretion and evolution” of primitive bodies:
  ▶ How do physical processes affect the evolution of small bodies?
  ▶ What are the geophysical properties of primitive bodies?
  ▶ What solar system bodies endanger Earth’s biosphere?
  ▶ How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?
Planetary Defense, Exploration & Science Benefits

ISIS delivers Discovery-level Science, closes Exploration SKGs and demonstrates NEO Deflection Technology, all for a small fraction of the cost of a Discovery mission.

- **What is the local response?**
  - Ejecta field properties
    - Creation of meteorite precursors
    - Ejecta blanket
    - Re-impacts
  - Crater morphology
  - Possible volatile release

- **What is the global response?**
  - Trajectory change ($\Delta V, \beta$)
  - Rotation change ($\Delta \omega, I_{zz}$)
  - Change in shape
  - Seismic activity
    - Internal structure
    - Material mobility
    - Particulate environment
  - Debris Environment

- **What are the geotechnical properties of the near-surface material?**
  - Strength
  - Cohesion
  - Porosity
  - Particle size distribution

- **What is the geology of the sub-surface?**
  - Stratigraphy
  - Structure
  - Composition
  - Mineralogy
  - Weathering

The Planetary Defense aspects of a deflection experiment will generate significant public interest.
<table>
<thead>
<tr>
<th>Impact Mission Phase</th>
<th>Science Investigation</th>
<th>Observation</th>
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<tbody>
<tr>
<td>Pre-Impact</td>
<td>Preliminary Radio Science</td>
<td>Imaging, Radio</td>
</tr>
<tr>
<td></td>
<td>Set asteroid ephemeris and rotational baseline prior to impact</td>
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<tr>
<td>Impact</td>
<td>Ejecta Field</td>
<td>Imaging, Spectra</td>
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<tr>
<td></td>
<td>Morphology, optical and spectral properties of ejecta plume</td>
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<td>Lofted Material</td>
<td>Imaging</td>
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<td>Surface excitation from seismic wave</td>
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<tr>
<td>Debris Clearing (~30 days)</td>
<td>Ejecta Evolution</td>
<td>Imaging</td>
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<td>Population size distribution vs. time</td>
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<td></td>
<td>Dynamics of longer lived orbits</td>
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<tr>
<td></td>
<td>Re-impacts and associated effects</td>
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<tr>
<td>Low-phase Flyover (~10 days)</td>
<td>Crater Reconnaissance</td>
<td>Imaging, Spectra, Altimetry</td>
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<td></td>
<td>Crater size, morphology, stratigraphy, structure. Spectral changes, local topography, transported volume, thermal inertia</td>
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<tr>
<td>Terminator Orbit (~70 days)</td>
<td>Radio Science</td>
<td>Imaging, Radio</td>
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<td></td>
<td>Orbital and rotational change with respect to pre-impact baseline</td>
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<tr>
<td></td>
<td>Surface Re-mapping</td>
<td>Imaging, Spectra, Altimetry</td>
</tr>
<tr>
<td></td>
<td>Global surface variation: topography, geology, spectra, thermal inertia</td>
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**Science Analyses**

- **Surface Characteristics:** Strength, cohesion, porosity, size distribution
- **Subsurface Geology:** Stratigraphy, spectra, structure
- **Interior Structure:** Seismic Wave Speed, Energy Dissipation
- **Momentum Enhancement:** Deflection Efficiency ($\beta$)
ISIS Impact Modeling

Preliminary SPH results (M. Jutzi & E. Asphaug):
• $\beta = 1.37 \pm 0.06$
• Crater diam. 15-20 m

Scaling law predictions (K. Holsapple):
• $\beta = 1.2-1.5$
• Crater diam. 10-40
• Depth similar to diameter
K. Housen has conducted high-speed gun experiment into OSIRIS-REx regolith simulant provided.

Scaling to ISIS/Bennu leads to:
- $\beta = 1.2 - 1.3$
- Crater diameter $\sim 40m$
  - Upper bound $110m$
At impact OREx is well clear of possible ejecta zone and moving away. Asteroid rotation keeps crater visible for ~2.5 hours.
Particle Evolution

Sun direction
Debris Clearing

- Detailed study of debris clearing time not yet complete
- What we know is that the far field (outside ~5 km) is cleared by 30 days
- A few objects remain in tighter orbits, but estimating number density and associated hazard suffers from low number statistics
- Ongoing study seeks to quantify the hazard associated with terminator orbit
  - How many objects per cubic km
  - Associated collision hazard
  - Collision damage at ~20 cm/s
- In operations, OSIRIS-REx spacecraft would be able to stand off on sun line and track any remaining objects
Measuring Beta

The momentum enhancement from ejecta is a central question. The $\Delta V$ from the ejecta can be estimated with uncertainty

$$\sigma_\beta = \sigma_{\Delta V} / \Delta V_{sc}$$

The ISIS mission will measure $\beta$ with uncertainty <0.1
The InSight launch date provides a critical constraint on the ISIS schedule

NASA-funded 3-month pre-phase A study now underway

- Will achieve high concept maturity crucial to support short development schedule
- Leading to a late FY2013 Decision Point

ISIS development schedule assumes ~30 month Phase A-D

- Requires Oct 2013 start to make Mar 2016 InSight launch
Conclusions

- ISIS is a low-cost mission that addresses NASA strategic goals and provides Discovery-class science returns across a wide range of small body science disciplines.
  - The mission leverages NASA’s investment in the OSIRIS-REx mission and takes full advantage of the New Frontiers-class instrumentation on the observer spacecraft.
  - Co-manifesting with InSight further improves the cost-effectiveness.
- NEAR-Shoemaker is NASA’s only NEA rendezvous mission so far. The second will be OSIRIS-REx, twenty years later.
  - The convergence of OSIRIS-REx schedule and Insight launch opportunity is an extraordinary alignment that will not be repeated again soon.
  - ISIS represents a once-in-a-generation opportunity to fly a low-cost asteroid cratering experiment.