2018 Workshop on Autonomy for Future NASA Science Missions

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Small-Body
Design Reference Mission (DRM)

Issa Nesnas and Tim Swindle

Small-Body DRM Participants

Name	Affiliation
Sarjoun Skaff	Founder /CTO **Basso Nova**
Shyam Bhaskaran	Supervisor, Outer Planet Navigation Group, **JPL/Caltech**
Julie Castillo (remotely)	Research Scientist, **JPL/Caltech**
Michelle Chen	Software Systems, **JHU/APL**
David Gump	Former CEO, **Deep Space Industries**
Issa Nesnas	Robotics/Autonomy Technologist, AS-SCLT, **JPL/Caltech**
Lute Maleki	Senior Distinguished Engineer, **Cruise Automation**
Jay McMahon	Assistant Professor, **University of Colorado**, Boulder
Carolyn Mercer	Manager, Planetary Exploration Science Technology Office, **NASA**
Harry Partridge	Chief Technologist, **NASA ARC**
Marco Pavone	Assistant Professor, **Stanford University**
Andrew Rivkin	Principal Professional Staff, **JHU/APL**
Timothy Swindle	Director, Lunar and Planetary Laboratory, **University of Arizona**
Bob Touchton	Chief Autonomy Scientist, **Leidos Advanced Solutions Group**
Felix Gervits	Graduate Student Researcher, **Tufts University**

Scope, Drivers and Platforms

Scope:

- Missions to small bodied: *comets*, *near-Earth objects* (NEOs), *main-belt asteroids*, and *other bodies*
- Emphasis on bodies closer to Earth

Small-body Drivers:

- Science objectives *
- Planetary defense *
- Resources utilization *
- Human exploration

Platforms

- Fly-by spacecraft and orbiters
- Landers
- Surface or near-surface mobile platforms
- Below-surface access and sampling systems
- Others?

Questions to Ponder

Communicating Desirements

- What would scientists like to see in the near term and long term?
- What would engineers like to know from scientists to make their work more relevant and applicable?
- What would industrial partners like to know from scientists and engineers at NASA?

Capability Advances:

- ***Current:*** What would *current activities in autonomy* enable for near-term missions?
- ***Incremental:*** What science/capabilities could be achieved with *incremental advances* in autonomy that are not being pursued today or not being considered by scientists?
- ***Revolutionary:*** What science/capabilities could be achieved with *revolutionary advances* in autonomy?

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Drivers

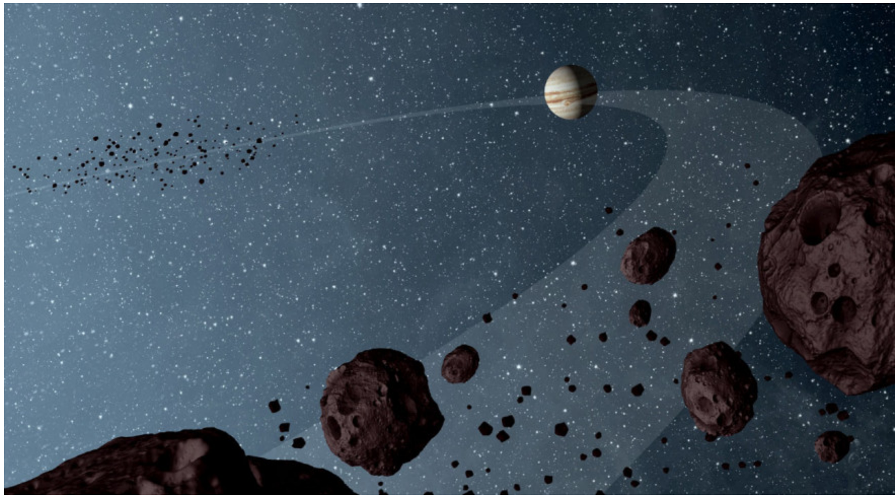
Science

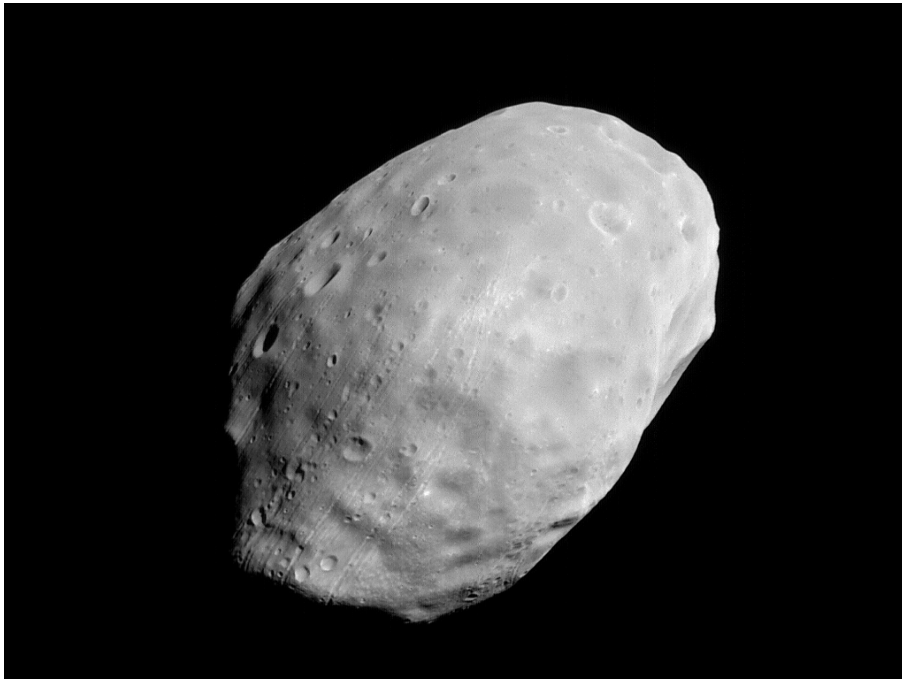
- **Origins** (what is where, composition)
- **Precursors of life** (composition with emphasis on water detection)
- **Evolution** (current processes, composition, geotech)

Planetary Defense

- **Assessing threat** (what is where, mass, geotech)
- **Mitigation** (geotech)

ISRU (what is where, composition, geotech)





Science Drivers

- **What is where?**
  - Size depends on specific needs (meters to kilometers)
  - Larger bodies like Pluto and Ceres are similar and covered in ocean worlds
  - Focusing on smaller bodies where there is enough gravity (~ meters to 10s's kms) (10^{-6}g – 10^{-3} g)
  - Diversity
- **Composition**
  - Volatiles like water (type example) stands out
  - Astrobiology, formation, resources (most valuable, least complex to extract).
- **Geotechnical properties**
  - Little known

How?

- **What is where?**
  - **5-10 year (current tech):** space-based IR coupled with one large ground based. Lagrange and sun orbiting
  - **Beyond:** coarser observations driving finer observations using multiple assets (incl. wide baseline)
- **Composition**
  - **Revolutionize:**   multi-asteroid flyby mission (use autonomy to reduce ops cost)
  - Composition needs surface contact: isotopic ratios (origins), solar system (origins).
- **Geotechnical properties**
  - 50 m asteroid, rumble pile? Rock? May figure out from orbit, send signal through it? Philae – orbiting case was not sufficient.
  - Benefits of going to the surface: seismic measurements (processes). GPR on surface -

Enabling – cannot do without Autonomy

- Interactions near (~50 m) on or into surface (low-gravity, surface roughness, dynamic)
  - Final descent phase
  - Understanding the surface properties for both science and engineering purposes
  - To manage a robotic mechanism to achieve mobility and interacting
- Handling environment
  - Dynamic conditions on comets due to outgassing can perturb or image platform (meter size blocks of ice coming off the small body Hartley)
- Access
  - Multiple and specific destinations within specific timeframes (dense vs. sparse, targeted vs. sampling, time for measurements, coupling with surface and seismic measurements)
  - Designated targets of < 25 m (cannot from do from ground)
- Manipulation
  - Resolving sample properties for collection (grain size)
  - Anchoring or holding on to the surface based on instantaneous local conditions
- Sampling: operate near a vent on comet – sampling from a vent
- ISRU
  - Exploration - likely 1-2 m below (need anchoring)
  - If resource extraction requires extensive
- Planetary defense: requires first understanding composition, geotech, and mitigation all deal with interaction with a largely unknown surface

Benefits

- **Scalability:** reaching multiple destinations at multiple times
  - Concerns: cost (CubeSats still cost too much, comm challenges)
  - Could possibly be enabled by advanced SmallSats at reduced cost
  - Autonomy would enable reaching multiple asteroids at affordable cost
- **Agility:** rapid way to get to a different asteroid

Futuristic Scenario (2040+)

Scenario: centralized mother platform launch and forget multiple daughter satellites to explore the diversity of small bodies, to identify and reach/study potential targets of interest (e.g. opportunistic interstellar object, hazardous objects) to reach, collect samples and return to centralized platforms (Gateway) for analysis, extract resources, or divert.

Key Capabilities

- Management and coordination of multiple assets on ground or in-space at centralized platform to survey, monitor, characterize and identify targets
- Autonomous mission design and navigation
- Autonomous characterization
- Safe approach and landing on surface
- Precision targeting
- Autonomous surface operation (mobility and measurements)
- S/C resource and health management
- In situ science (onboard data analysis and decision making)
- Manipulation of blocks
- Refueling using in situ resources
- Return to Centralized Platform
- Refueling at Centralized Platform (Gateway)

Possible Realistic DRM - 2030

- **Scenario:** an affordable SmallSat mission to LEO, with a high-level goal of finding an asteroid, cruising to, approaching, landing on body, precisely accessing at least one target on surface, sampling, analyzing and sending publication back* ***all autonomously***
- **Key capabilities/technologies**
  - Autonomous identification of asteroid based on intent
  - Autonomous mission design and navigation
  - Autonomous cruise, approach and safe landing
  - Autonomous characterization
  - Precision targeting
  - Autonomous surface operation (mobility and measurements)
  - S/C resource and health management
  - *In situ* science (onboard data analysis and decision making)

How to engage industry

- Define crisp engineering challenges to present to industry to attract partnership
- Scour DoD activities that have government rights and offer them to proposing community
- Assess applicability of automotive computing, sensing reliability **standards** and **capabilities** for human-rated Avs to potentially facilitate interoperability of relevant components: sensing, computation, software, etc.

Connecting to other DRMs

Small bodies:

- Have science, planetary defense, and ISRU drivers
- Are accessible, diverse and plentiful: only 15% observed
- Embody challenges that are cross-cutting with other DRMs
  - Unknown topography for body mapping
  - Extremely rugged surfaces (Europa, Enceladus)
  - Dynamic interaction (Venus, Titan, liquid bodies, etc.)
  - Lower-cost for approach and landing
  - More forgiving (impact with surface less harmful)
  - Accessible via SmallSats
  - Unknown surface properties
- Offer mission of opportunity (inter-stellar visitors)

Autonomous capabilities would pave the way to more remote and expensive missions

Backup Slides

Implementation Roadmap

- How would autonomy help with different types of requirements for target bodies?
- What are the steps in developing autonomy technologies to enable such missions?
- What would *enable* or *prevent* the infusion of such technologies?
- What are the key elements of a small-body DRM?
- Are there *technical* reasons why the DRM we define would not be possible today?

Outcome and Deliverables

Targeted Outcome

- Leverage collective knowledge and expertise to draft a DRM
- Follow up after workshop to complete the DRM

Perhaps a more modest outcome from the face-to-face could be identifying the three to four elements of autonomy that would be most useful to enable one or more of the small-body drivers.

Science Mission Directorate Expectations

- A Small-body DRM enabled by autonomy: new or better science, reduced risk, or new opportunities in planetary defense or resource extraction
- Specific strategic recommendations to NASA on autonomy/AI investments (both programmatic and technical)

Deliverables to SMD

- PowerPoint presentation to workshop attendees on Day 2 (15 minutes)
- Completed DRM framework
- White paper for the next AGU or AAS
- Briefing to SMD upper management at NASA Headquarters by DRM leads (in 6 months)