Technology Recommendations to Support:

Goals and Objectives for the Exploration and Investigation of the Solar System's Small Bodies

Small Bodies Assessment Group (SBAG)

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Executive Summary

This document lists technologies that would contribute substantially to the success of small bodies missions representative of those expected to achieve the goals and objectives described in the 2019 SBAG goals document. The representative missions span destination targets from near-Earth to the Kuiper Belt, encompass science, planetary defense, and human exploration goals, and include all mission types from flybys to sample return. These technologies of high interest to the small bodies community span the following NASA Technical Areas: Propulsion; Power and Energy Storage; Surface Systems; Communications; Information Technology and Data Processing; Ground Systems; Thermal Management Systems; and Science Instruments and Sensors.

Introduction

The Small Bodies Assessment Group (SBAG) was established by NASA in 2008 and is composed of members with knowledge and expertise of small bodies throughout the Solar System. Membership in SBAG is open to all interested individuals of the interdisciplinary small bodies' community. The term "small bodies" refers to a wide-ranging, highly diverse, and numerous set of Solar System objects, including near-Earth objects, main belt asteroids, the Martian moons, comets, Trojan asteroids, irregular moons of the outer planets, centaurs, Kuiper belt objects, other trans-Neptunian objects, dwarf planets, dust throughout the Solar System, and meteorites and other samples of such bodies. The SBAG Goals Document[1] captures the high-priority objectives and unique exploration opportunities related to the Solar System's small bodies.

This document describes the SBAG's recommendations for technology investments needed to meet the overarching goals and objectives of future missions to small bodies. These recommendations are based on prior work done by the SBAG to prioritize technology needs and an assessment of capabilities that will be needed for likely future missions. To assess these capabilities, SBAG determined representative missions for destinations including near Earth asteroids, main belt asteroids, comets, Centaurs, and Kuiper Belt Objects. These missions collectively address each of the goals identified by SBAG: science, planetary defense, in-situ resource utilization and human exploration strategic knowledge gaps. Finally, the representative missions encompass the major mission types: flyby, orbit, landing/rendezvous, sample return, small body deflection, and space-based telescopes. These missions are consistent with the goals and objectives described in the SBAG Goals Document.

Rather than provide an encyclopedic listing of all technologies that would be beneficial for these future missions, we instead cite what we consider to be those few that will have the most impact for each mission class, specific for small body missions. Notably absent from our list is a broad listing of spacecraft bus technologies. It is axiomatic that reductions in mass, volume, and cost, and improvements in the reliability of any subsystem will provide benefits to any mission, including those of interest to the small body community.

Technology Assessment

In 2016 the SBAG assessed all of the technologies described in NASA's 2015 Technology Roadmaps[2] with respect to their relevance to the SBAG goals and objectives, and applicability to mission classes ranging from SmallSats to Flagships. They then employed the Strategic Prioritization and Planning (SP2)[3] quality functional deployment process to provide prioritized technology listings based on weights given to each goal, objective, and mission class. The SP2 method was used separately for general technologies and for instruments.

The results of this process are provided in the 2016 SBAG Technology Goals Document, hereafter referred to as the 2016 report.[4] The highest-priority spacecraft technologies for the baseline case of equal weighting for science and human exploration and all mission classes are technologies for: optical communication, solar arrays, star trackers, navigation, batteries, Hall-effect thrusters, proximity operations, electrospray propulsion, and algorithmic frameworks to support rapid exploration. If science missions are weighted higher than missions in support of human exploration, then the top twelve technologies are the same but in different order. Furthermore, the top ten to twenty technologies generally remain the same regardless of the prioritization placed on the overall objectives. Technologies below the top ten can change significantly based on weightings assigned to the mission class. For example, technologies that improve packaging and cost score higher for small missions.

Similarly, instrument priorities included those needed for both science and missions to support human exploration. The recommendations from the 2016 report include advanced detectors for survey missions, landing proximity sensors, a long-wave infrared camera identified for human exploration mission needs, cosmic dust acquisition, orbital radar, deep drilling, lander payload, drill-embedded instruments, small satellite instruments, and seismometer instrument technologies.

Technology Context

To put the studied spacecraft technologies and instruments into context, we selected a set of missions representative of those that would be needed to achieve the goals described in the SBAG Goals and Objectives document. The breadth of destinations, goals, and types that these missions must span is shown in Table 1.

Table 1. Technology Applications for Small Body Missions

Destinations

- Near – Near Earth Asteroids
- Medium – Main Belt Asteroids and Comets, Phobos and Deimos
- Far – Centaurs, Kuiper Belt Objects

Goals

- Science
- Planetary Defense
- Enabling Human Exploration
    - In situ resource utilization (ISRU)
    - Strategic knowledge gaps (SKG) for human exploration

Mission Types

- Flyby – reconnaissance and limited characterization
- Orbit – detailed characterization
- Land – surface characterization, ISRU
- Sample Return – detailed characterization on Earth
- Space-based telescopes – surveys
- Asteroid deflection – planetary defense

The missions we selected as representative are shown in Table 2, including an indication of which destination, goal, and mission type is covered by each.

Table 2. Representative Missions for Technology Assessment

Near Earth

- Near Earth Asteroid (NEA) orbiter (Science, ISRU, SKG, Planetary Defense)
- NEA rendezvous/lander (Science, ISRU, SKG, Planetary Defense)
- NEA sample return (Science, ISRU, SKG)
- NEA deflector (Planetary Defense)
- Space-based telescope for Near Earth Object (NEO) survey (Science, ISRU, Planetary Defense)

Medium Distance from Earth

- Phobos/Deimos orbiter (Science, ISRU, SKG)
- Ceres lander (Science)
- Cryogenic comet sample return (Science)
- Main belt asteroid flyby tour (Science)

Far from Earth

- KBO flyby (Science)
- Pluto lander (Science)
- Multi-flyby Centaur tour (Science)

Spacecraft Technologies

We assessed the technologies studied in the 2016 report and determined which were enabling or critically important for the missions listed in Table 2. In addition, we added technologies not included in the 2016 report for the multi-flyby Centaur tour and NEA deflector missions. These missions were not included in the assessment done by SBAG in 2016. The mapping of these technologies to the missions is shown in Table 3.

Table 3. Spacecraft Technologies Needed for Representative Small Body Missions

Near Earth

- NEA orbiter – autonomous proximity operations and navigation, high performance computing
- NEA rendezvous/lander – same as orbiters, plus anchoring, surface mobility systems, dust mitigation, and retractable solar arrays
- NEA sample return – same as landers, plus sampling hardware
- NEA deflector – kinetic impactors, laser tractor beam, nuclear impulsors
- NEO survey – small spacecraft propulsion, communications, and power

Medium Distance from Earth

- Phobos/Deimos orbiter – small spacecraft propulsion, power, and communications

- Ceres lander – planetary protection, and same as landers (above)
- Cryogenic comet sample return – sampling hardware, cold containment, curation, autonomy, batteries
- Main belt asteroid flyby tour – small spacecraft navigation, propulsion, power, and communications

Far from Earth

- KBO flyby – communications, power, fault detection isolation and recovery
- Pluto lander – planetary protection, cold electronics, and same as landers (above)
- Multi-flyby Centaur tour – radioisotope electric propulsion, long-lived spacecraft subsystems

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In addition, an in-space SmallSat deployer would help survey multiple near-Earth or main belt asteroids: long cruise on a deployer, alone or with the mothership, with the deployer carrying communications and propulsion and power for the SmallSat(s).

A short description of the key performance characteristics of these technologies are described below, grouped according to the taxonomy (technical areas) used in the NASA Technology Roadmap. General objectives, rather than quantitative goals, are listed because the timeframe for these recommendations is meant to cover the entire span of the next decade. Note that planetary protection technology, while needed for landers on Pluto and Ceres, is not included here because it is expected that the requirements for small body missions will not exceed those for expected missions to Europa or Mars, and so this technology will be developed by the time the small body missions occur.

TA-2 Propulsion Technology

- Radioisotope electric propulsion (REP) – entire system needs to be designed and built; long life operation will be the driving requirement.
- SmallSat propulsion: electric – long life (high throughput) operation will be required to enable several thousand km/s of delta-V for small spacecraft.

TA-3 Power and Energy Storage Technology

- Power for distant destinations – low-intensity low-temperature solar arrays with intrinsically high solar cell conversion efficiency (not screened for) and radiation damage resistance.
- Power for proximity operations – retractable solar arrays.
- Power for SmallSats – highly compactable solar arrays to minimize stowed volume, generating several hundred watts of electrical power.
- Energy storage – ultra-low temperature batteries to minimize heat transfer to sample return systems.

TA-4 Surface Systems

- Anchoring and mobility systems for very low-gravity, and in some cases dusty, surface operations.
- Sampling hardware for autonomous collection of uncontaminated cryogenic nucleus sample. Examples include pre-lander impactors and deep drills (>20 m) with associated cryogenic sample transfer mechanisms.

TA-5 Communication Technology

- Higher data rates are needed to communicate to and from the long distances associated with Kuiper Belt Objects to accommodate the expected increase in data volume and also for small spacecraft. Examples of technologies that could provide this capability include deployable reflectors and high power solid state amplifiers. Optical communication technology was identified as a high priority in the 2016 report, and is being demonstrated on the Psyche mission.

TA-11 Information Technology and Processing

- High performance, radiation tolerant computer hardware to enable real-time navigation and proximity operations around small bodies
- On-board autonomous data processing to reduce the data transmitted to Earth by orders of magnitude.
- Autonomous fault detection, isolation, and recovery of all major spacecraft subsystems.
- Low temperature electronics (active and passive) for Pluto lander, and for cryogenic sample return systems.

TA-13 Ground and Launch Systems

- Cryogenic sample curation down to temperatures that will maintain the native state of samples.

TA-14 Thermal Management Systems

- Low temperature containment systems for cryogenic sample return
- Thermal management to transport heat from interior of small spacecraft

Unclassified by the current TA taxonomy

- Kinetic impactors, laser tractor beam, and/or nuclear impulsors designed to alter the trajectories of near-Earth asteroids.

Instrument Technologies

We assessed the instruments studied in the 2016 report and determined which were enabling or critically important for the missions listed in Table 2, and removed those instruments that have been recently developed and/or selected for flight. These instruments are listed in Table 4. All of them are categorized under TA-8 Science Instruments, Observatories, and Sensor Systems.

Table 4. Instrument Technologies Needed for Representative Small Body Missions

Telescope Technologies –

- Low-noise infrared/visible detectors for near-Earth asteroid survey
- Cosmic dust sample acquisition technology

Small Instruments for Landers and SmallSats –

- Gamma ray instrument for landers
- Mass spectrometer electronics and detector systems that consume less power and have lower mass and smaller volumes
- Seismometers
- Passive or no-cooling infrared cameras (e.g., photon efficient imaging)

Material Sampling/Processing and Instrumented Drills

- Drill embedded physical instruments (e.g., resistivity, thermal, shear)
- Deep drill / coring technologies for small body surfaces (e.g., low-strength regolith)
- Drill embedded chemical instruments: LIBS, neutron spectrometer
- Front ends specific to small body surface properties (e.g., low-strength regolith)
- Fluid process control technologies

Orbital Instruments

- Longwave infrared (LWIR) camera
- Sub-millimeter heterodyne radiometer
- Flexible orbital radar for subsurface sounding and software for radar data analysis

Sensors for In Situ Operations

- Landing proximity
- Rugged lasers

ISRU-Specific Technologies

- Geotechnical instruments for ISRU (e.g., penetrometers, shear gauges, compaction)
- ISRU regolith flow instruments

Summary

This document lists technologies that would contribute substantially to the success of the small bodies missions representative of those expected to achieve the goals and objectives described in the 2019 SBAG goals document. The representative missions span destination targets from near-Earth to the Kuiper Belt, encompass science, planetary defense, and human exploration goals, and include all mission types from flybys to sample return.

The technologies listed here, and the descriptions of needed performance characteristics, are based on the findings described in the 2016 SBAG Technology Goals Document, updated to address these representative missions. This body of work is supported by a Strategic Prioritization and Planning (SP2) quality functional deployment process that assessed hundreds of technologies with respect to their relevance to the SBAG goals and objectives, and applicability to mission classes ranging from SmallSats to Flagships.

The technologies are grouped according to their applicability for the representative missions, and also according to NASA's Technology Roadmap technical areas. Descriptions of needed technology performance characteristics are purposefully left at a high level rather than specifying quantitative targets. This is because our expectation is that this document will be used to guide broad technology investments for over ten years, and necessarily those quantitative goals will change as technology improvements are realized.

References

[1] SBAG (2020), Goals and Objectives for the Exploration and Investigation of the Solar System's Small Bodies. ver. 2.0.2020, 44 p., at http://www.lpi.usra.edu/sbag/goals/

[2] 2015 OCT Tech Roadmap

[3] Kirby, M. R., "An Approach for Strategic Planning of Future Technology Portfolios," Georgia Institute of Technology, Atlanta, GA.

[4] SBAG (2016), Goals and Objectives for the Exploration and Investigation of the Solar System's Small Bodies. ver. 1.2.2016, 41 p, at http://www.lpi.usra.edu/sbag/goals/