Draft

Technology Capabilities and Gaps Roadmap

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Presented to the Small Body Assessment Group (SBAG)

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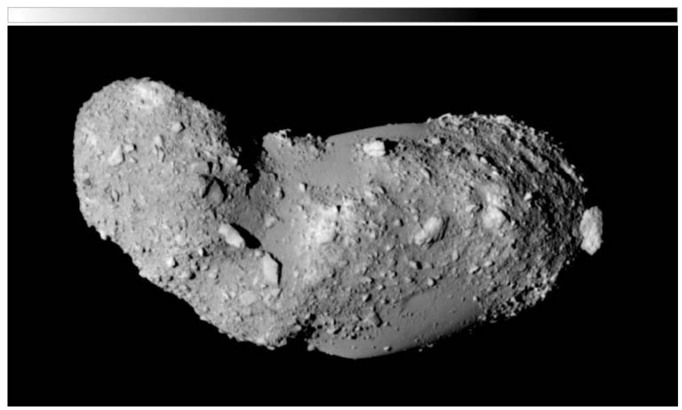
Introduction

This is to serve as an evolving technology development roadmap to allow maximum science return for mission class.

Though the diversity of the targets and missions are very broad, there is broad applicability for various missions / instruments.



Methodology

Originally planned to perform a detailed science traceability matrix for all technology requirements.

Top Level Measurement Objective	Specific Measurement Objective	Measurement	Instrument Type	Instrument Requirements	SOA	Technology Gap	Current TRL
Observe geologic state and composition of surface and infer past evolution and relative importance of surface processses	Create a spectral map of the surface	Spectral mapping of surface in the 1-5 micron range	IR Spectrometer	Range = 0.3 – 5 micron Relative radiance < 5%, spectral resolution = +/- 5nm at <5m per pixel	New Horizons - Ralph: 12 kg, 7 W, 10 Mbps 0.4-0.98, µ1.2 - 2.5 µ	Extend response to 5µ	5

➢ Enhancing Technologies: There is a desire to enhance existing capabilities for increased performance with lower risk, mass, power, and cost. While difficult to show technology gap, benefits of cross-cutting investments can be significant.

- Increased capability with reduced mass, power, and cost can be enabling.

➢ Enabling Technologies: Emphasis on enabling technologies or high science return beyond SOA capability if a new capability can be matured to acceptance.

- ➢ Background provided on SOA and what capability goals we wish to achieve
- ➢ Also provided (with all appropriate caveats) schedule and cost ROMs

➢ Prioritization based on science benefit over SOA alternative and the mission infusion / applicability expectation

Current Sections

- Power Systems
- Propulsion Systems
- Remote Sensing Instruments
- In-Situ Instruments
- Sample Return Technologies
- Communication Systems
- Ground Based Asset Technologies
- Support Tools and Capability
    - Simulants, Lab. Facilities, trajectory design, etc.
- Extreme Environments

Scope

- Depth of need description

  - Past roadmaps range from one sentence to a paragraph

  - Requested to limit document to 20 pages total.

  - Should we include the science rational in the technology roadmap or design reference missions and include that technology “pull” background information in the roadmap?

    - Science goal, how measurements translate into science discovery, instrument requirements, what the SOA capabilities are, gaps, potential solutions, expected degree of difficulty (cost/schedule) to advance.

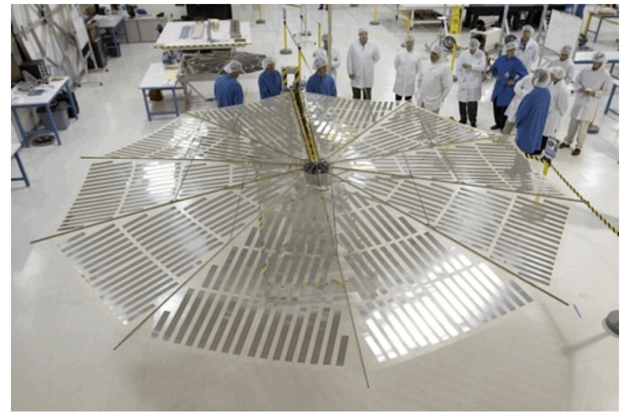
- Depth of potential solution descriptions

  - Want to avoid identifying a solution by only one institute over another

  - Want to avoid any specific instrument development

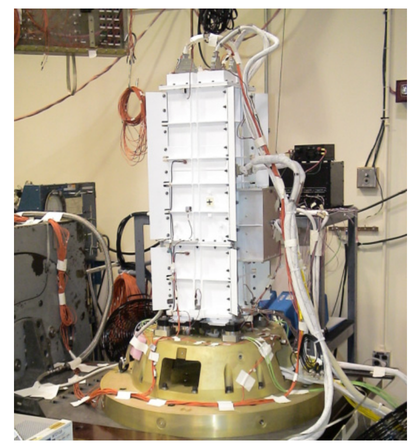
Power Systems

- Solar Power Systems



  - Nearly all missions use solar power
  -Today's SOA is 100 – 120 W/kg
  - Dawn ~82 W/kg
  - ST-8 goal was 175 W/kg
  - Orion expected to achieve 100 W/kg
  - **Recommend to mature solar array to true TRL-6 demonstrating 175 W/kg**

- Radioisotope power Systems



  - Any deep space mission will require RPS
  - Unsure if Discovery will allow RPS in the future
  - Trojan / Centaur only NF SB mission solicited (TBD)
  - We may have enough ^{238}Pu for two additional missions JEO without defined manned exploration program
  - Recommend ^{238}Pu production restart
  - **Recommend to improve RPS Alpha for long-term REP missions**

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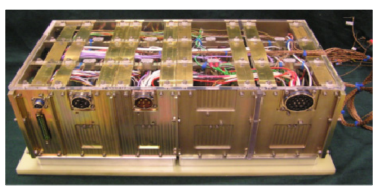
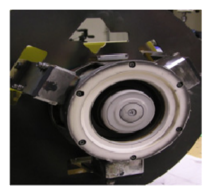
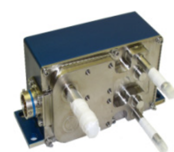
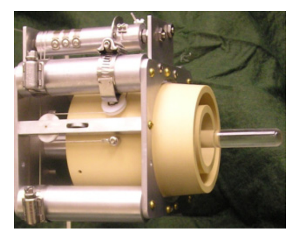
Propulsion Systems

- Chemical
  - The small body chemical propulsion missions can leverage existing capabilities
  - Advanced monoprops may have mission potential, but not sufficient for high priority small body technology investment; military investments ongoing
- Electric Propulsion
  - Electric propulsion is enabling for many and enhancing for most SB missions
  - Emphasis on low-cost higher voltage Hall system
  - Only institutional or SBIR PPU funding
  - **Recommend low-cost system development for next mission solicitation**

  - REP is enabling for several small body missions
    - Requires sustained developed for ~10 years
  - **Recommend investments in REP thruster technology for 2020+ mission**

Remote Sensing Instruments

- Variable Focus Distance Imager

  - Commercial advancements have made variable focus imagers a near-term technology if maturity can be advanced and a moving mechanism can be tested for long life in a relevant environment.

  - Recommend development (to TRL 6+) and significant testing of a variable focus distance imager with sub-cm resolution, mm scale desired.

  - To be used for global and spot (meter scale patch) measurements

- High Resolution Topography Instrument

  - **Recommended development of cm scale (both vertical and spatial) resolution topography instrument**

- Low-speed Dust Detector / Analyzer

  - Several opportunity to analyze dust during small body proximity operations; can be used in combination with projectiles

  - **Recommendation for low-speed dust analyzer for in-situ level science as a remote sensing capability**

In-Situ Instruments

- Seismic Science System

  - Seismic science is a high priority for asteroids, but no development opportunities exist for system level development and demonstration.

  - Seismic system demonstration requires development of sensors, packaging, deployment system, communication network, and integration system demonstration

  - Recommend seismic system development, demonstration, and strategy for infusion on PI class mission.

- In-situ Material Dating Instrument

  - Investment required for packaging an in-situ material dating instrument for PI-led class payload, should be used in combination with sampling for dating materials at various depths.

  - Recommend development of PI-led class payload for in-situ material dating instrument.

- Compositional Analyses Instruments

  - Compositional analyses in combination with spectral analyses can correlate asteroid groups to meteorite samples and ground based observations

  - Recommend development of compositional analyses instruments required for correlation

- Surface Manipulators

  - Small bodies lack a protective atmosphere. Micrometeorite and solar particle damage could have significantly altered the near-subsuface environment. Options range from rakes, penetrators, drills, etc.

  - Recommend development of surface manipulators to provide access to subsurface ~1cm? for in-situ analyses

Sample Return Technologies

Curation Analysis Planning Team for Extraterrestrial Materials (CAPTEM) Report from December 1, 2007:

- Solicited by the director of the PSD to analyze potential linkages between simple and complex sample return missions and identify those critical investments that would best reduce risk and cost for sample return missions over the next 20 years.
- Provided 7 Key findings:
  - SR is an important component in NASA's overall SSE strategy
  - The mitigation of cost and risk put a high priority on early technology development.
  - There are technology linkages with feed forward to increasingly complex sample return missions. Investing in developing and flying these technologies will increase the rate of success and lower the overall cost.
  - Linkages exist to non-SR such as terrain-relative navigation, for different styles of missions (flyby, touch-and-go, surface), such as hard landing EEV, linkages for collection, manipulation, storage, verification, etc., and linkages between robotic and human exploration.
  - High priority investments: Autonomous capailities, hard-landing and sample preservation in the EEV, inert collection materials, sample collection tools, sample handing, adaptable sample containment, etc.
  - There are many specific single body technologies (MAV, Cryo – Deep Ice Drill, etc.)
  - A Sample Return Technology Program would reduce the cost to individual missions to provide commonality, interfaces, coordinated investments for sample return missions, etc.

Sample Return Technologies

- Aside from flagship missions, sample return will be performed for small body targets. Significant development remain for sample site location, targeting, landing and anchoring if necessary, collection, verification, handling, encapsulation

- Technology requirements are based on three primary factors:

  1) Surface characteristics

  2) Time to take the sample

  3) Desired depth of the sample

- Technology gaps remain for nearly all areas of sample return technologies

  - Approximately 1/2 of the technology needs have a proposed solution at the concept stage

  - Nearly all lack sufficient maturity for low-risk infusion and required development remains

- The majority of on-going development in institutionally funded overlap, no integrated program for sample return technologies, no standard interfaces, etc.

SR: Flyby Sample Collection

➢ Flyby sample return missions have been successful with Stardust and Genesis.

➢ They offer the lowest science return for SR missions (limited sample discriminating), but also the lowest cost.

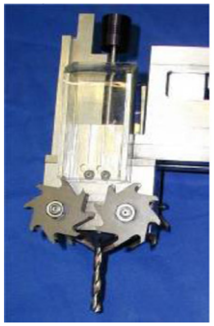
➢ If prioritized, the technology development required for flyby sample return missions would be on inert sample collection materials. This would reduce risk of achieving the science goals by reducing potential to alter the sample.

SR: Touch-and-Go

➢ Touch-and-Go sample returns are practical for small body missions with limited sample discrimination. The operations eliminate the need for costly and complex landing systems, eliminates the need for anchoring.

➢ **Recommend strategic investment in technologies needed to increase the number of potential samples collected, to isolate individual sample, to verify sample collected, ensure applicability for a wide range of surface characteristics, and reduce system risk.**

	Solution(s) Identified	Work Needed
Identifying landing/sampling site	✔	✔
Precision terrain-relative navigation	✔	✔
G&C sensors for landing/touch-and-go	✔	✔
G&C actuators for landing/touch-and-go	✔	
Propulsion for G&C actuators for landing/touch-and-go	✔	
Sampling mechanisms	✔	✔

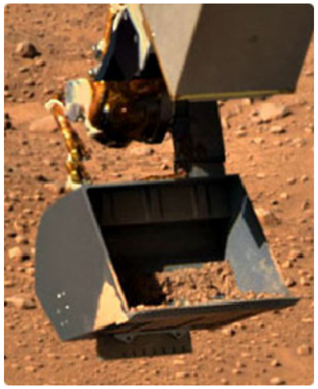


SR: Surface Collection

➢ Finite duration surface sampling allows for increased sample discrimination. Landed sampling also allows analysis of sample in-situ. Additional analysis and sample descrimination capabilities can quickly add to cost and risk.

➢ **Recommend strategic investment in autonomous operations and anchoring techniques and testing for small body surface collection.**

	Solution(s) Identified	Work Needed
Sampling mechanisms	✔	
Autonomous operations	✔	✔
Anchoring techniques		✔
In cometary materials	✔	✔
In asteroids		



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SR: Subsurface Collection

- Technologies gaps remain for vacuum rated low power drilling systems, down-hole sensors, health monitoring, autonomous operation, thermal challenges, preventing the loss of volatiles, and multi-string systems for various depths and material properties.
- The largest gaps remain for uncontaminated unaltered cryogenic nucleus sample collection.
- **Recommend strategic investments for autonomous and redundant drilling / coring technologies and testing.**

	Solution(s) Identified	Work Needed
Subsurface Sampling	✔	✔
Subsurface core sample	✔	✔
Maintain stratigraphy		✔
Drill or Worm Technology	✔	✔
cm depth	✔	✔
< 2m depth	✔	✔
> 2m depth	✔	✔
> 20m depth (Nucleus Sample)	✔	✔

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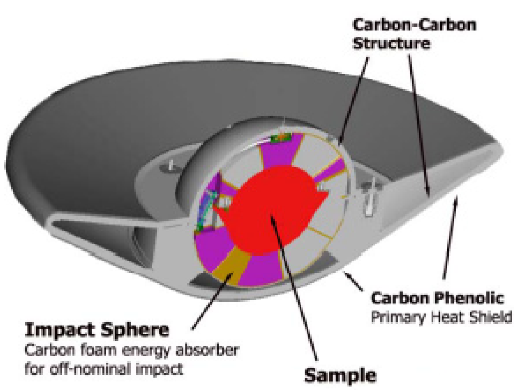
SR: Earth Entry Vehicle

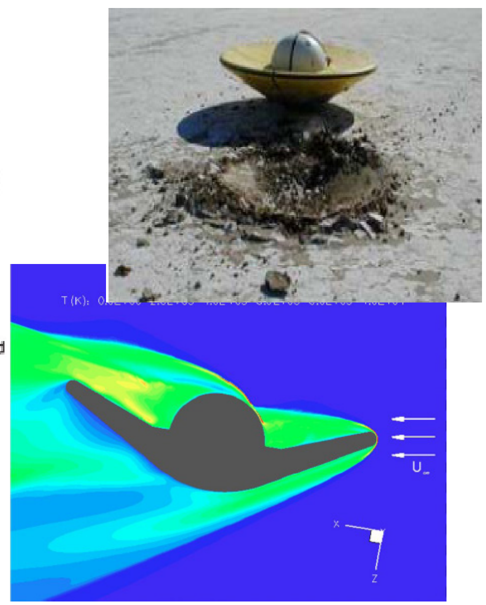
➢ NASA is currently investing in design, analysis, and modeling for a Multi-Mission Earth Entry Vehicle (MMEEV) applicable to MSR and small body sample return missions. Existing systems are limited and not build-to-print.

➢ **Recommend development of an EEV with multi-mission commonality.**

➢ **Recommend the EEV leverages the MSR investments to ensure the EEV remains applicable to small body sample return missions.**

➢ **Recommend a source of carbon phenolic is qualified for available on small body sample return missions.**





	Solution(s) Identified	Work Needed
General Vehicle Development	✔	✔
Aerodynamics stability	✔	✔
Thermal Protection System (TPS)	✔	✔
Impact Protection System	✔	✔
Dust mitigation / vehicle sterilization	✔	✔
Micrometeoroid protection	✔	✔
Sample reception	✔	✔
Environmental control within return capsule	✔	✔
Maintain sample cryogenic	?	✔
Prevent contamination (hermetic seal)	?	✔
Capture volatiles		✔
Sublimation, water chemical reactions		✔
Core sample in compression	?	✔
Environment control during Earth landing	✔	✔
Maintain sample cryogenic		✔
Prevent contamination (hermetic seal)	?	✔
Core sample in compression	?	✔
Transfer of sample to curation facility	✔	✔
Maintain sample cryogenic	✔	✔
Prevent contamination (hermetic seal)	✔	✔
Core sample in compression	✔	✔

SR: Recovery, Transfer, and Curation

- It is quite likely that the MSR mission will drive the requirements for SR recovery, transfer, and curation capabilities.
- **Recommend studies to define clear planetary protection requirements for all classes of small body sample return missions.**

SR: Cryogenic Sample Return

- The cryogenic nucleus sample return has been listed as a high priority science mission in the last three SSE exploration updates.
- There are numerous technologies required for a cryogenic nuclear sample return, many below TRL 3.
- Technologies are required for cryogenic sampling, handling, encapsulation, hermit sealing, environmental control throughout the process, transit to earth, EDL at Earth, recovery and curation, and for cryogenic analysis capabilities.
- **Recommend detailed Cryogenic Nuclear Sample Return study for detailed sampling, handling, storage, etc. requirements with concept studies for supporting technology solutions.**
    - **Completed APL Led Study for Decadal Survey**
- **Recommend investments in low TRL technologies required for the CNSR mission including cryogenic sampling, handling, and encapsulation, water confirmation, deep ice drilling, long duration cryo-coolers, etc.**

SR: Technology Development Integration

(Is this appropriate?)

- **Recommend integrated strategic investments are made for SR technologies.**

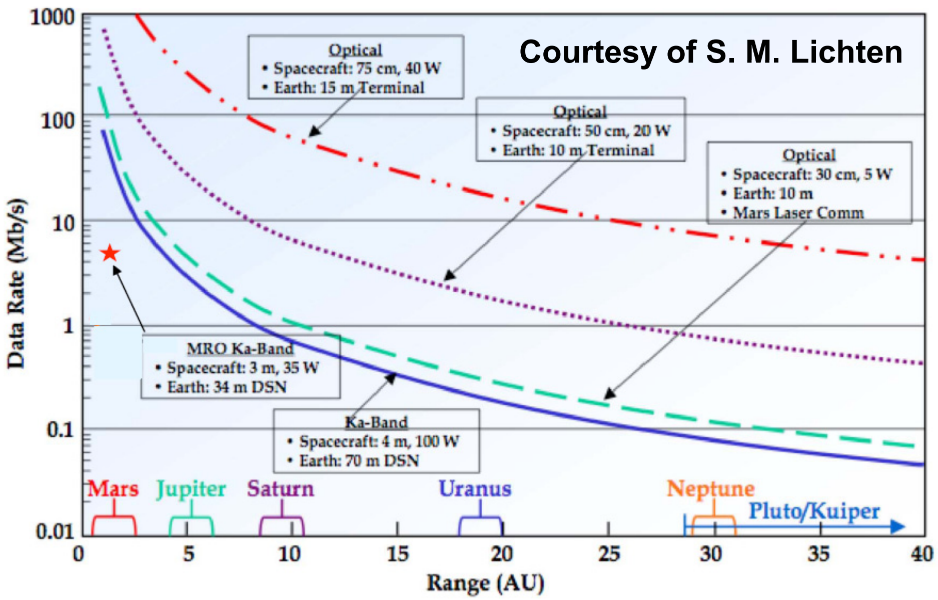
  - Defined interfaces or coordinated solicitations for broadly applicable technologies.

  - All NASA funded technologies should be available to all institutions.

    - Need to ensure all feed forward technologies are available to all.

Communication Systems

- Small body targets range significantly in distance from the Earth
  - Includes the farthest science targets in the solar system
- Small body missions can also have unique navigation requirements
- Missions are currently mandated to use Ka band
- Anticipated data volume and distance will likely require optical communication
  - **On August 22nd GSFC was selected for a optical com. flight demonstration**



NASA has recently developed technology roadmaps, including TA05 – Communication and Navigation Systems. The roadmap address the small body community needs.

Recommend Small Body Community endorse the OCT Communication and Navigation Roadmap.

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Ground Based Observatories

- Ground based observatories can offer significant contributions to small body science
  - Survey capabilities; dramatically extend inventory
  - Characterization when possible

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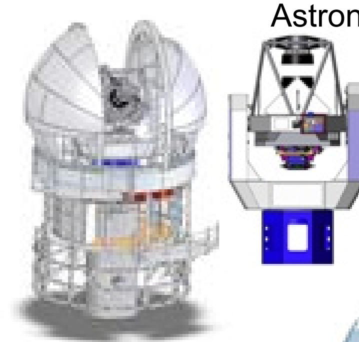


Ground based observatories offer large payoff, but dedicated time for small body science is limited. Less than 4% of NEOs characterized by radar despite value.

Recommend continued advocacy in ground based asset development and increased dedicated time for small body science.

Support Technologies / Capabilities

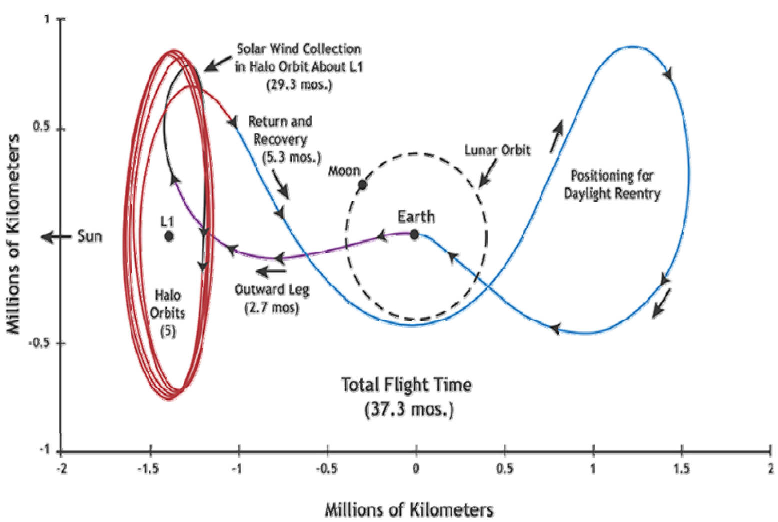
➢Support Technologies / Capabilities

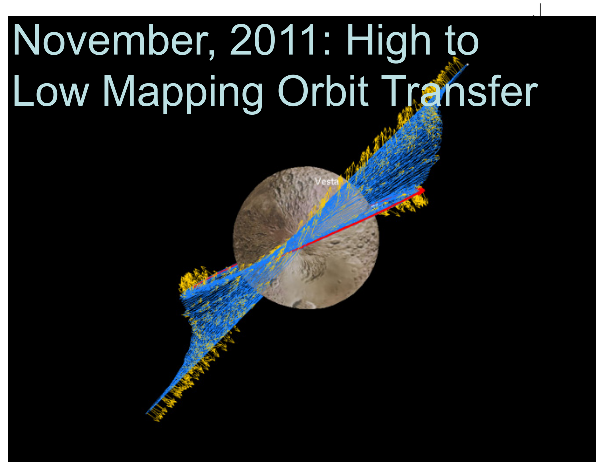
- Simulants for asteroids and comets can be used for system testing and risk reduction. Validate functionality of handling, sampling, anchoring, etc.

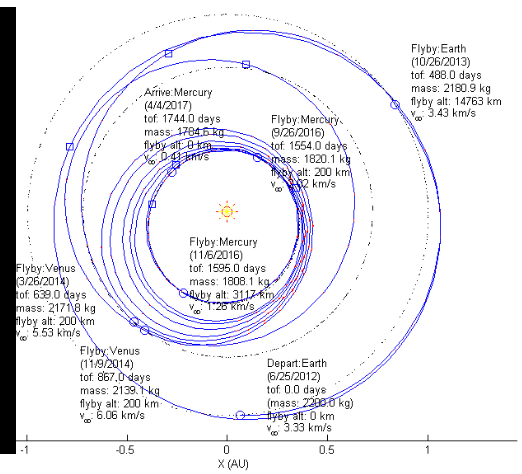
Recommend development and characterization of a suite of simulants for small bodies.

- Mission / Spacecraft Design Tools are critical to small body missions. Missions often require proximity operations in complex gravity fields and many leverage low-thrust trajectories.

Recommend investment in mission design tools including small body dynamics tools.







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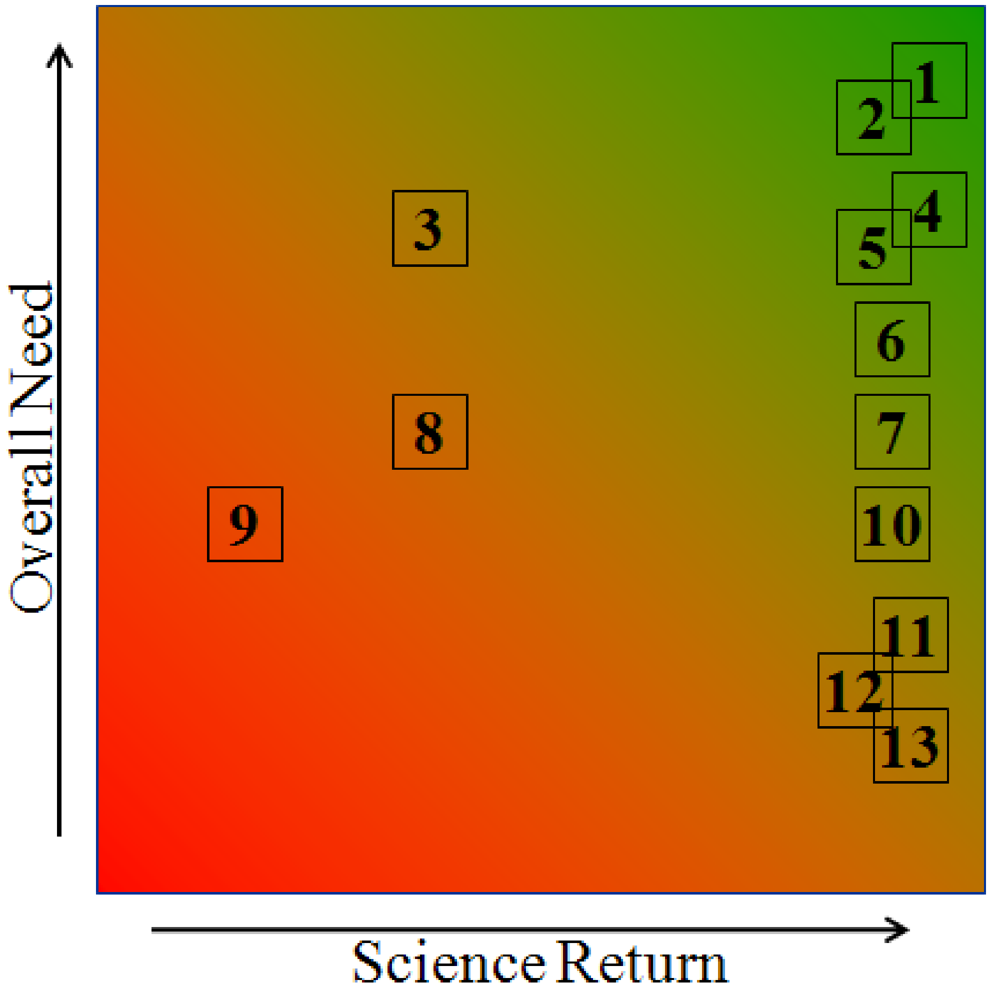
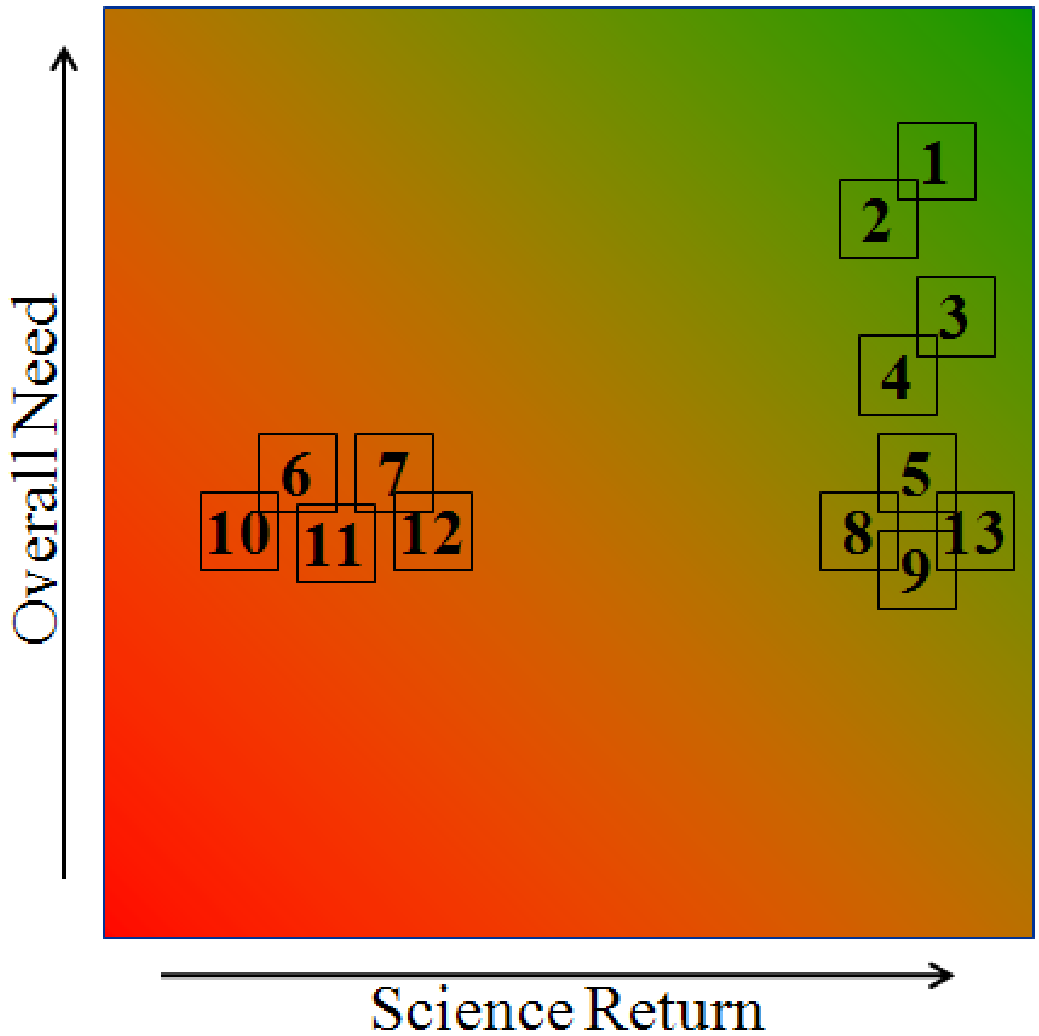
Prioritization – Non-SR



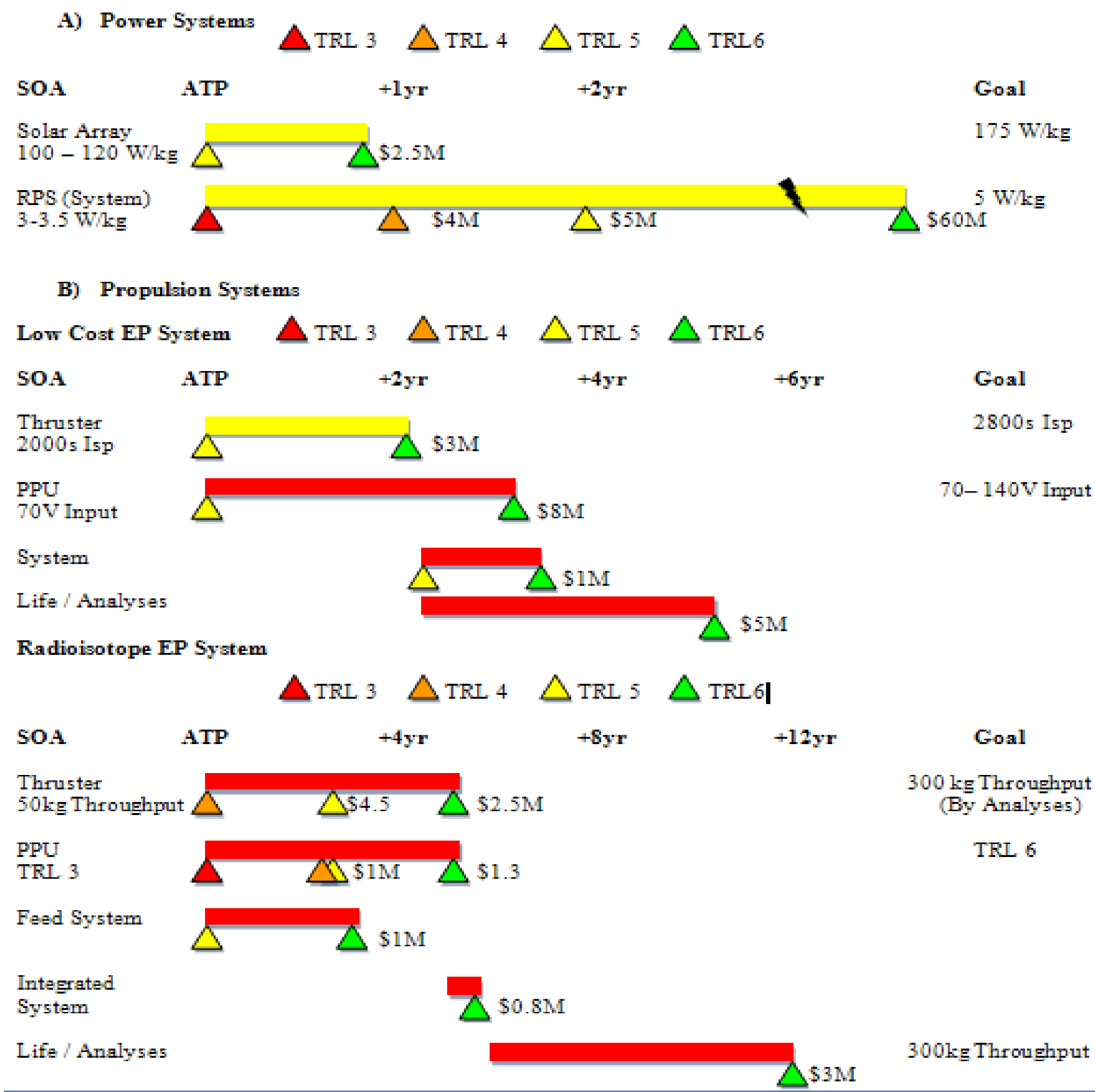
1) Variable Focus Distance Imager
2) High Res. Topography Instrument
3) Demonstrate high W/kg Array
4) Low-Cost EP System
5) Compositional Analyses Instrument
6) REP System
7) In-situ material dating
8) Surface Manipulators
9) Low Speed Dust Analyzer
10) Seismic System Demonstration
11) Pu^{238} Restart
12) Larger ASRG Unit
13) Extreme Cold Mechanisms/Electronics

Prioritization - SR



1) Autonomous Operations
2) Drill / Worm Technologies
3) Subsurface Samplers / Cores
4) Cryogenic Sampler
5) Touch-and-Go Samplers
6) Terrain-relative Navigation
7) G&C Sensors for Lander / T-and-G
8) Comet Anchoring
9) Asteroid Anchoring
10) Sample Verification
11) In-Situ Sample Handling
12) Multi-Mission Entry Vehicle
13) Surface Samplers

Cost and Schedule ROMs



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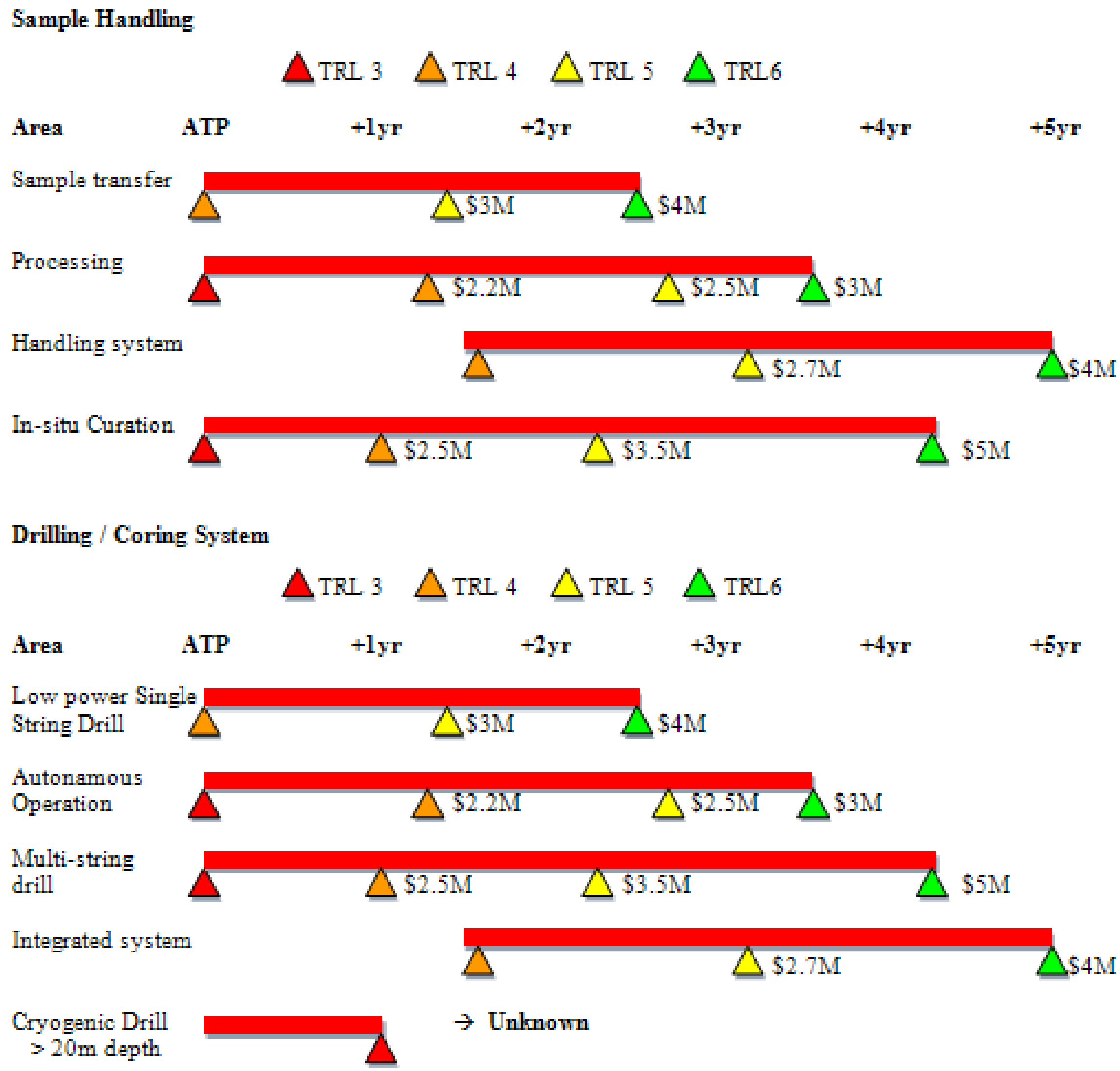
Cost and Schedule ROMs Cont.



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Technology Infusion

- TMC educational / familiarization opportunities
- Limited opportunity for advancement from PIDDP, ASTID to flight
- Limited opportunity for infusion of complex systems, e.g. a deployable seismic science network may not be cost viable in discovery, not allowed in NF
- Several institutional / proprietary investments (inefficient)
- NASA directly funded investments
  - Assuming SR technologies will be funded by SMD, NASA will be developing sampling mechanisms, handling mechanisms, in-situ analyses techniques, sample verification techniques, encapsulation, hermetic sealing, and Earth-Entry Vehicle subsystems
  - **Unless all directed to a single organization, recommend these technologies must have defined interfaces where appropriate**
  - Investments should be available to all institutions

One of the strengths is also a weakness for SBAG, a lot of quality science can be achieved on smaller class (Discovery and New Frontiers) missions. Unfortunately, this limits the opportunity for dedicated technology funding analogous to the Mars Technology Program. Also, new technology has been difficult to infuse with the current risk tolerance for Discovery class missions.

NASA recently selected missions for technology development:

Whipple (Survey of deep space small bodies)

Prime (Chemical composition of a comet)

NEOCam (Survey of NEOs)

All Small Body Missions!

Previous Roadmaps - Status

➢ This document is consistent with previous decadal study recommendations and technology roadmapping efforts

- SSE Survey initiated in 2001 recommended: ”Key Enabling Technologies for Primitive Body Exploration” as drilling on small bodies to depths on the order of a meter, cryogenic sample preservation and handling including subsurface collection, transfer, encapsulation, and return from Earth where the sample is never exposed to temperatures exceeding 150K, and in-situ age determination and compositional analyses.

- SSE Roadmap for SMD 2007 – 2016: Solar array technology for 175 W/kg, addressing the shortage of ^{238}Pu and developing an Advanced Stirling Radioisotope Generator, affordable solar electric propulsion system for use by Discovery missions, cryogenic sample return technologies, sample acquisition and preparation technologies, small body anchoring, subsurface access, high heat flux entry return TPS, etc.

Decadal Survey

- Decadal survey devoted a chapter to technology development

General:
1) Cross-cutting investments to reduce mass and power
2) Advanced communication systems
3) Mature power and propulsion systems
4) New and improved sensors, instruments, and sampling systems
5) Mission and trajectory design tools

Specific:
- Mature the ASRG and UltraFlex Solar Array
- Cryogenic sampling technology (icy subsurface sampling, preservation below 125k, water percentage penetration, etc.)
- Penetrator systems with seismic network and composition
-SEP and REP (for 2022+ mission)
- USOs, laser comm., dust analyzer, advanced spectrometers, etc.

Baseline Roadmap Summary

- This is the baseline and request for feedback for recommendations
- SBAG Roadmap is consistent with SSE survey and roadmap, CAPTEM report, OCT technology roadmaps, and current decadal survey recommendations
- Needs include: A variable focus imager

  high resolution topographer

  Improved solar array alpha

  Low-cost electric propulsion option

  Advanced communication systems

Higher TRL investments for instruments for: in-situ compositional analysis, in-situ material dating instruments, seismic science system demonstrations, improved alpha radioisotope power systems and fuel availability, extreme cold electronics and mechanisms, and a myriad of sample return technologies.

Cryogenic sample return and REP technologies for 2022+ missions.

Instruments have large opportunity for infusion.

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