Definition

Rapid Response Mission: Conducting a mission to a recently discovered, non-recurring object or high interest/consequence event. If no timely action is taken, future assessment, investigation, and exploration of the object is not possible.

Targets

Over the last several years there has been growing recognition that detailed knowledge of specific classes of small bodies can only be attained through rapid response missions. Specifically, these classes consist of the following objects:

- **Interstellar Objects (ISOs)**: Active or inactive objects that originate outside the solar system and are traveling on hyperbolic trajectories (e.g., 1I/‘Oumuamua and 2I/Borisov).
- **Long Period Comets (LPCs)**: Comets with periods of >200 years, as opposed to short period comets (like Halley’s Comet). These foundational objects are generally extremely active and contain volatiles from the early formation of the solar system (e.g., C/2022 E3 (ZTF)).
- **Near-Earth Objects (NEOs)**: Near-Earth asteroids (or comets) that pose a significant impact hazard to Earth and have short warning times.

Rapid Response & the Decadal Survey

More recently one of the primary recommendations from the National Academies Planetary and Astrobiology Decadal Survey 2023 – 2032 highlighted the need for developing a rapid response mission capability for planetary defense.

The capability to conduct a rapid response mission allows Earth defense asset providers to achieve their mission capability for planetary defense.

It is important to note that in addition to ISO and ISO survey assets, ISO and ISO survey assets could be a significant source of new ideas. In 2022, the NASA 90-day Initial Response to the Decadal Survey (August 2022) indicated:

- **NASA concurs with this recommendation and recognizes that the ability to determine the key characteristics of an imminently dangerous NEO quickly and accurately may be critical to the success of any future mitigation efforts. Moreover, developing a rapid-response capability may significantly enhance Planetary Science opportunities for the study of long-period comets and interstellar objects, which are unpredictable targets of opportunity.**

Importance of New Survey Assets

One of the key factors for furthering knowledge of these small body populations is emerging near-Earth object (NEO) surveys that are capable of identifying new NEOs with sufficient properties to be used as targets for missions. The rapid response mission capability facilitates the gathering of useful information when the NEO is still far enough from Earth to allow for reasonable planning time. In addition, the rapid response capability may enable the development of novel technologies and methods to better prepare for a shorter-warning-time NEO threat.

Rapid Response Mission Capabilities

- **Rapid response missions may enable deployment of dedicated spacecraft to newly identified targets that would otherwise not be possible via regular mission development timelines.**
- **Development of rapid response mission capabilities could be necessary to characterize a recently discovered NEO that may pose a near-term threat to Earth. Such in situ characterization is necessary to adequately assess the physical characteristics of the NEO, determine the potential magnitude of the impact hazard, and ascertain whether a subsequent mitigation mission(s) to deflect or disrupt the NEO is warranted.**
- **Rapid response would enable planetary science missions to fascinate objects such as LPCs and ISOs that are typically challenging to investigate via in-situ spacecraft. Data from these objects could revolutionize understanding of early solar system formation and evolution.**

Science Goals and Objectives

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Rapid Response Architectures

- **New alternatives based on rapid response paradigm — allows for flexibility in target selection and mission deployment**

1. **Ground Storage — Partial or Complete Build — Launch on detection**

2. **In Space Storage – Parking Orbit – Launch then later**

Rapid Response architectures: Pro and Cons

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<tr>
<th>Architecture</th>
<th>Pros</th>
<th>Cons</th>
<th>Applicability</th>
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| Ground Storage | - Low risk of launch failure <br>- Ability to store spacecraft in space<br>- Low risk of loss of spacecraft due to launch failure | - Long range of_missions and limited by launch vehicle capabilities<br>- Spacecraft undergoes long period of storage and aging <br>- No benefit to mission performance from in-space storage<br>- Spacecraft can undergo in-flight storage if needed | - Earth/moon <br>- Mars <br>- All NEO missions <br>- ISOs <br>- LPCs <br>- NEA <br>- Other NEOs with high consequence or threat <br>- Near-Sun orbit objects with scientific interest or potential planetary defense interest <br>- Interstellar objects with scientific interest or potential planetary defense interest |<br>| In Space Storage | - Can store spacecraft in space<br>- Spacecraft undergoes long period of storage and aging<br>- Spacecraft can undergo in-flight storage if needed<br>- Spacecraft can be launched without requiring a dedicated launch vehicle<br>- Spacecraft can be launched after a period of storage | - Long range of missions and limited by launch vehicle capabilities<br>- Spacecraft undergoes long period of storage and aging<br>- No benefit to mission performance from in-space storage<br>- Spacecraft can undergo in-flight storage if needed | - Earth/moon<br>- Mars<br>- All NEO missions<br>- ISOs<br>- LPCs<br>- NEA<br>- Other NEOs with high consequence or threat<br>- Near-Sun orbit objects with scientific interest or potential planetary defense interest<br>- Interstellar objects with scientific interest or potential planetary defense interest |<br>

References


[2] (NASA 90-day Initial Response to the Decadal Survey (August 2022))

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Technology Gaps: Challenges and Opportunities

The technical challenges fall primarily into two categories:

1. Challenges for rapid implementation, integration, testing, and launch and,
2. Challenges related to hypervelocity flybys of small targets and/or active bodies (i.e., comets).

Rapid response missions may enable the deployment of dedicated spacecraft to newly identified targets that would otherwise not be possible via regular mission development timelines. Rapid response missions may enable the deployment of dedicated spacecraft to newly identified targets that would otherwise not be possible via regular mission development timelines.

- **Rapid implementation, integration, testing, and launch require new technologies and practices. Technologies that would enable rapid data interfacing, such as universal adapters, could enable the flight system to make small modifications to the payload suite without a significant change to the external vehicle or spacecraft design.**

- **Further modeling, the modularpropulsion tanks, communication systems, and power systems of modularity could significantly optimize the spacecraft design for an individual target and flyby geometry, minimizing the potential payload mass and probability of having sufficient launch energy to encounter the target without sacrificing response time. Modularity might also increase the ability to encounter an ISO or OPC farther than 1 Au.**

Rapid testing might require regular maintenance of ground-stored spacecraft, rapid battery integration and test, and a suite of flight system checkouts that could be performed within several weeks of notification of target identification. On-going Department of Defense activities needed to need launch vehicle integration provides a useful template for how something similar might be achieved with NASA.

Hypervelocity flyby drive the need for instruments that can operate in more extreme conditions, new autonomy software that can effectively sample material in situ and meet the spectral resolution required for origin science (e.g., volatile detection). Shielded probe that can withstand meter-size gravel particles at speeds of 70 km/s would also be needed to explore the surface of an asteroid. A target that has undergone long-term storage would have undergone surface degradation and may be unrecognizable as a framework for managing a high velocity target without ground in the loop. At such high velocities, it is insufficient time for the ground to calculate a required trajectory correction maneuver and update the command for the spacecraft. In this case, autonomous operations like autonomous control and navigation can propagate at a rate faster than the ground can control, risking a failed flyby.

Technologies required for precise autonomous navigation include miniature deep space autonomous systems, advanced Astrobotics algorithms, and algorithms that can identify the nucleus for rapid response missions. In all cases, the technology should be compatible with small spacecraft systems.

The Ten Second Review

- Rapid response missions are valuable for interstellar objects, long-period comets and near-Earth objects.
- The Decadal Survey and NASA are supportive of rapid response missions.
- A W.M. Keck Institute of Space Studies was held in October 2022 to examine rapid response missions.
- Two possible architectures for rapid response missions are Ground Storage and In Space Storage.
- Technology challenges to rapid response missions include: rapid integration, testing, and launch, hypervelocity data collection during hypervelocity flybys.