RAPID RESPONSE MISSIONS TO NEAR-EARTH OBJECTS, INTERSTELLAR OBJECTS, AND LONG-PERIOD COMETS. Paul A. Abell[1], Benjamin P. S. Donitz[2], Julie C. Castillo-Rogez[2], James F. Bell, III[3], Michael E. Brown[4], Karen Meech[5], Joseph Lazio[2], Carol A. Raymond[2], and Darryl Z. Seligman[6], [1]NASA Johnson Space Center, Houston, TX (paul.a.abell@nasa.gov), [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, [3]Arizona State University, Tempe, AZ, [4]California Institute of Technology, Pasadena, CA, [5]Institute for Astronomy, Honolulu, HI, [6]Cornell University, Ithaca, NY.

Introduction: Over the last several years there has been growing recognition that detailed knowledge of certain classes of small bodies can only be attained through rapid response missions. For example, the development of rapid response mission capabilities has recently been driven by the discovery of the first two interstellar objects (ISOs) [1,2], the desire for *in-situ* data of long-period comets (LPCs), and the realization that the next damaging Earth-impact event will likely be from a relatively small, but still hazardous near-Earth object (NEO) [3]. Moreover, one of the primary recommendations from the recent National Academies Planetary Science and Astrobiology Decadal Survey supports a rapid reconnaissance planetary defense demonstration mission [4]. In addition, NASA's Science Mission Directorate concurs with the Decadal Survey recommendation, and states that development of such a capability could also enhance opportunities for the study of ISOs and LPCs [5]. Knowledge of all three of these small body populations will ultimately increase in the upcoming years as the next-generation survey systems Vera Rubin Observatory [6] and NEO Surveyor [7] come online. These systems will provide the data required to assess these populations and identify appropriate targets of opportunity which would enable NASA and the international community to quickly respond to an emerging target such as a NEO, ISO, or LPC.

Rapid response missions can enable deployment of dedicated spacecraft to newly identified targets that would otherwise not be possible via regular mission development timelines. For example, 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, to determine the potential magnitude of the impact hazard, and to ascertain whether subsequent mitigation missions to deflect or disrupt the NEO are warranted. Rapid response missions could also enable science-focused missions to fascinating 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. Although some of the requirements for rapid response missions to NEOs, LPCs, or ISOs may differ, there are broad similarities in the context of quickly deploying a spacecraft to a newly discovered target.

In October 2022, subject matter experts from around the world gathered at the California Institute of Technology Keck Institute for Space Studies (KISS) for a one-week workshop to address the challenges and opportunities for developing rapid response mission capabilities. Participants from NASA, ESA, JAXA, academia, and industry met and identified overlapping architectural drivers, constraints, and synergies that could help enable development and deployment of a rapid response mission during the next decade.

Science Goals and Objectives: The capabilities discussed here respond to three different classes of targets, each with their own goals and objectives. The goal of rapid characterization of a NEO is to determine the asteroid's orbit, mass, and relevant physical characteristics to inform potential mitigation mission strategies. If a NEO >50 meters in diameter were identified to have a >1% likelihood of impacting the Earth with at short warning time (e.g., a few years to a decade), it would be an international priority to characterize the target to the maximum extent possible as quickly as possible [8]. Note that this goal is not explicitly for science, but the measurement techniques for planetary defense knowledge are commensurate with *in-situ* scientific observations of a NEO.

ISOs and LPCs, meanwhile, are important targets for planetary science. The lack of context, small sample size, and unknown target origin makes it challenging to make inferences on generic solar system formation without a more in-depth population study. ISOs do remain, however, of paramount interest to the science community and the general public as key exploration targets because they provide information about the early stages of planet building in other star systems. ISOs therefore occupy a unique niche between astrophysics and planetary science.

LPCs, and in particular dynamically new comets, are extremely valuable tracers of solar system formation. The volatiles that have been locked within these comets since the formation of the early solar system act as fossil records that are exposed upon close passage to the Sun. The science goal of a dedicated LPC rapid response mission would be to constrain the conditions of the protoplanetary disk and to better understand the diversity amongst comets by characterizing their chemistry and morphology [9].

Mission Architecture/Platform: The KISS workshop identified two primary mission architectures to address rapid response capabilities. In the first architecture, several spacecraft would be mostly pre-built and stored until a target is identified, after one or more could be rapidly integrated onto a launch vehicle and directly injected on an intercept trajectory. In the second architecture, a single or small constellation of spacecraft already deployed would be ready to respond to a new target. The spacecraft would be placed in orbit(s) to maximize accessibility to a new target and would use a combination of on-board propellant and Earth gravity assists to inject into the intercept trajectory. The loitering spacecraft could perform heliophysics or other observations from an Earth-like heliocentric orbit while they wait for a target of opportunity. If no targets are identified during their operational lifetime, they would still have the capability to visit scientifically compelling NEOs as alternate targets.

For both architectures, the spacecraft would perform a fast flyby of a target, possibly at extremely high velocities (≥30 km/s). For active targets, like comets, the flight system might require a Whipple shield to protect the vehicle from high-velocity dust impacts. In the ground storage architecture, the fight system could be modified before launch to include a dust shield and in the constellation architecture, a fraction of the spacecraft could include dust shields.

Expected Measurements: In all cases, typical data acquired could consist of visible and thermal IR images with multiple filters to characterize shape, rotation, volume, limited compositional information, and surface morphology. Additional payloads to enhance the science return could include a small near-IR point spectrometer and/or small deployable spacecraft or gravity probes to help determine/constrain the target mass [10]. The ground-stored spacecraft could include an optional hypervelocity dust spectrometer and gas mass spectrometers to determine bulk composition of active objects. In general, the ground-stored system would rely on modularity to be applicable to a variety of targets while the space-stored system would make use of a fixed payload suite to characterize NEOs, and possibly an opportunistic low-activity ISO or LPC target.

Conclusions: The KISS workshop recommended a new initiative for rapid response, primarily focused on planetary defense, but with an opportunity to apply lessons learned from the planetary defense rapid response demonstration to an ISO or LPC target of scientific opportunity. The initiative would consist of regularly procured spacecraft from commercial vendors to be deployed as a fleet, stored either on the ground or in space and ready to respond within only a few months.

These spacecraft, primarily focused on NEO-reconnaissance, could provide preliminary insight into an ISO or LPC but would not provide the same science return as a dedicated Discovery mission. With increased modularity for the ground-stored system, payloads more appropriate for a cometary flyby could be integrated, including a dust shield which may be necessary for any close flyby of an active target. It would be more difficult to re-purpose a space-based system to visit a LPC if it were designed for an asteroid-like target. The space-based system could also perform a population study of non-threatening NEOs to better inform the diversity and key characteristics of those types of targets.

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