ENABLING RAPID RESPONSE MISSIONS TO NEAR-EARTH OBJECTS, LONG PERIOD COMETS, AND INTERSTELLAR OBJECTS: RESULTS OF A KECK INSTITUTE FOR SPACE STUDIES WORKSHOP

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SUMMARY

- 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 Workshop was held at W.M. Keck Institute of Space Studies in Oct '22 to examine rapid response missions
- Two possible architectures for rapid response missions are Ground Storage and In-Space Storage
- Technology challenges fall into two main areas - 1) rapid integration, testing, and launch; 2) navigation and data collection during hypervelocity flybys

MOTIVATION

Rapid response missions may enable deployment of dedicated spacecraft to newly identified targets (at right) that would otherwise not be possible via regular mission development timelines. Here we focus on architectures and technology gaps for NEO missions.

- 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.

- The recent National Academies Planetary and Astrobiology Decadal Survey 2023 – 2032 highlighted the need for a rapid response mission capability for planetary defense:

*"The highest priority planetary defense demonstration mission to follow DART and NEO Surveyor should be **a rapid-response, flyby reconnaissance mission targeted to a challenging NEO,** representative of the population (~50-to-100 m in diameter) of objects posing the highest probability of a destructive Earth impact. Such a mission should assess the capabilities and limitations of flyby characterization methods to better prepare for a short-warning-time NEO threat" [1].*

TARGETS

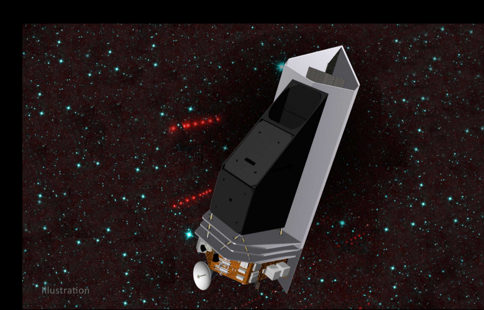
Over the last several years there has been growing recognition that detailed knowledge of specific classes of small bodies can only be attained through rapid response missions. Specifically, these classes consist of the following objects:

- **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. These primordial 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.

Twilight photo of Rubin Observatory taken in April 2021. Credit: Rubin Obs./NSF/AURA



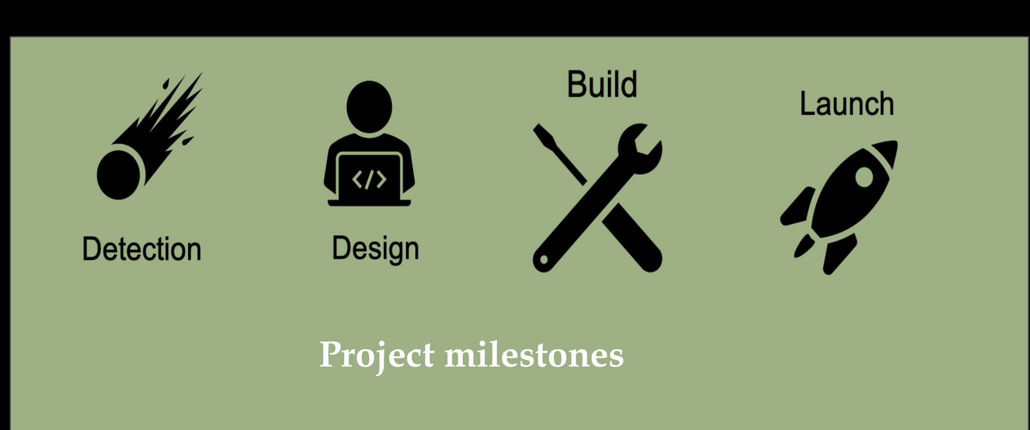
Credit: NASA-JPL/Caltech

One of the key factors for furthering knowledge of these small body populations are the emerging next-generation survey assets of the Vera Rubin Observatory (above, left) and NEO Surveyor spacecraft (above, right) which will come online in the coming decade.

These facilities will provide the data required to assess the population numbers in general and identify appropriate targets of opportunity which would enable NASA and the international community to quickly discover and respond to an emerging target or threatening object.

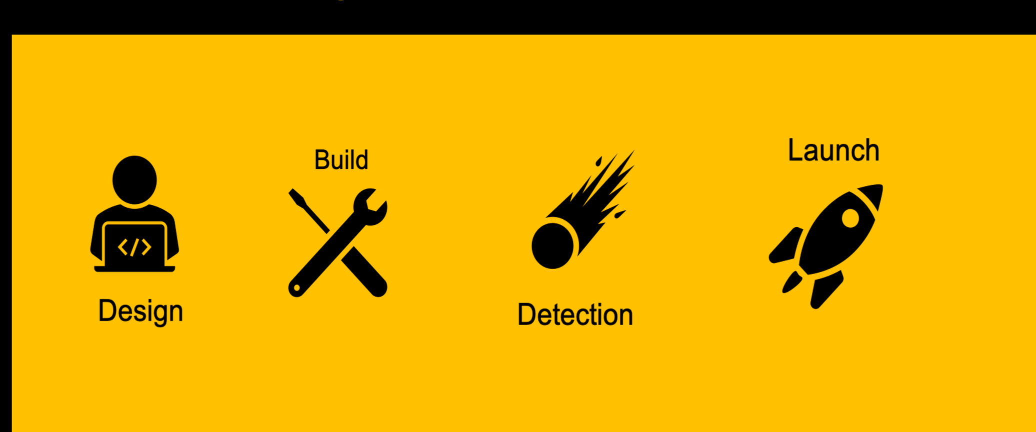
RAPID REPONSE MISSION ARCHITECTURES

Traditional paradigm for missions – target must be identified well in advance and often relies on a regular cadence of announcements of opportunity (AOs)

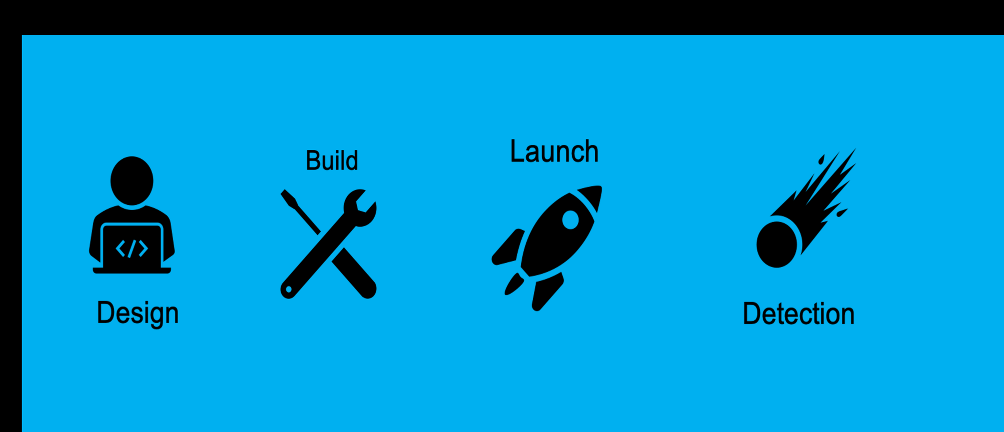


New rapid response paradigm – strategies that allow flexibility in target selection and mission deployment

Ground Storage – Build – Launch on detection



In Space Storage – Parking Orbit – Launch then loiter



TECHNOLOGY GAPS: CHALLENGES AND OPPORTUNITIES

For NEO targets, the main technical challenges are rapid implementation, integration, testing, and launch.

Plug and Play:

Technologies that would enable rapid payload interfacing, such as universal adapters, could enable the flight system to make small modifications to the payload suite without a significant change to the overall vehicle or instrument design.

Modularity:

Modular propellant tanks, communication systems, and power systems, to optimize the spacecraft for an individual target and flyby geometry, maximizing potential payload mass and probability of having sufficient launch energy to encounter the target without sacrificing response time.

Rapid Testing:

Periodic 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 would enhance reliability and readiness.

Autonomy:

AutoNav and onboard science planning allow precise navigation to, and optimized examination of a target without ground in the loop. Technologies required include miniaturized deep space autonomous clocks, capable processors and advanced algorithms, compatible with small spacecraft platforms.

RAPID RESPONSE ARCHITECTURES: PROS AND CONS

Architecture	Pros	Cons	Applicability
Ground Storage	• S/C in controlled environment • Ready for deployment • Variety of mission classes • Can aim for specific target	• Needs rapid, dedicated launch • Additional time required for regulatory tasks (e.g. FCC licensing)	• Wide range of missions • Target detected with enough time to set up launch
In Space Storage	• S/C operational; ready for deployment • Variety of mission classes • Bonus science possible while in orbit	• S/C cannot be tailored to target *(you get what you get…)* • Standby duration driven by cost and S/C aging • Less energy left to reach target	• Wide range of missions • The larger the propulsion system, the broader the pool of targets

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References: [1] Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023 – 2032, The National Academies (2022) Chapter 18, Page 21. .https://nap.nationalacademies.org/catalog/26522/origins-worlds-and-life-a-decadal-strategy-for-planetary-science