Key Near-Earth Object Characteristics Measurements for Planetary Defense

Presented to the Apophis T-9 Years: Knowledge Opportunities for the Science of Planetary Defense

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Research Participants

- The planetary defense research efforts described herein result from ongoing collaboration between US government agencies, including:
  - NASA: GSFC, ARC
  - DOE / NNSA: LLNL, LANL, SNL
  - FEMA
  - USGS

Overview / Background (1/2)

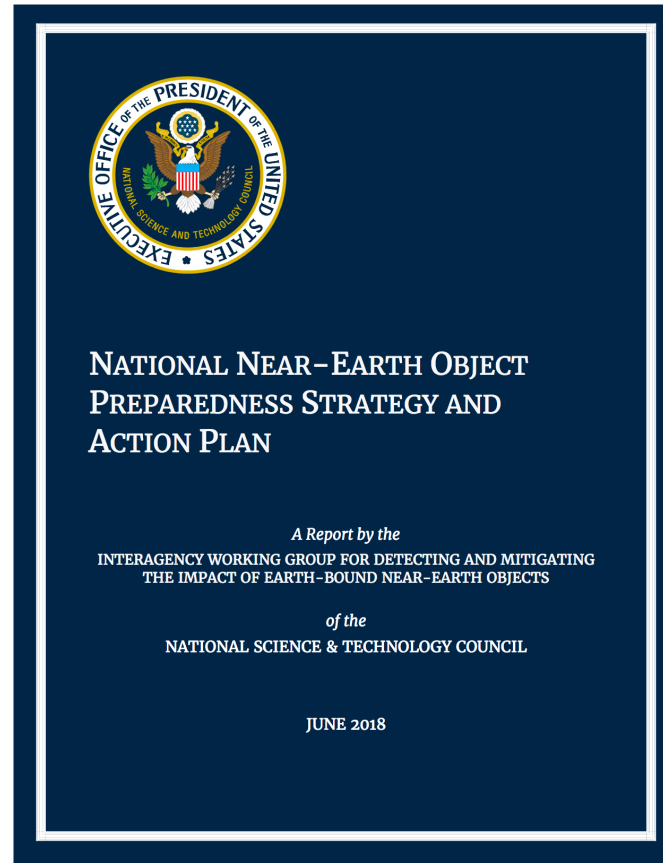
- Knowledge of the orbital and physical properties of a potentially hazardous near-Earth object (NEO), and the associated uncertainties, is essential to the planning and execution of Planetary Defense (PD) activities, including remote observations of and spacecraft reconnaissance missions to NEOs.
- There are presently uncertainties regarding which NEO properties are most important to know for PD purposes, how best to measure them, etc.
- Research and analysis efforts are currently underway, per the National Near-Earth Object Preparedness Strategy and Action Plan, to study this and other related problems.
- Herein is a summary of some current thoughts on these topics. Discussion and further inputs from the NEO community are invited.

Overview / Background (2/2)

- Uncertainties in key NEO properties, such as orbital state and mass, may be very large during the early stages of a potentially hazardous NEO scenario.
- Decisions on reconnaissance and mitigation missions may have to be made while details of the potential threat remain uncertain.
- In situ reconnaissance of the NEO via spacecraft may be the only means of reducing key uncertainties sufficiently in a timely manner.
  - This would enable mitigation to be carried out more effectively and reliably.

National NEO Preparedness Strategy & Action Plan

- PD priorities for NEO characterization in the context of an evolving potentially hazardous NEO scenario are important to multiple actions stated in our National NEO Action Plan.
- Understanding NEO characterization priorities for PD is necessary for completing some of the actions.


NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY AND ACTION PLAN

A Report by the
INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS

of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

JUNE 2018

https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf

NEO Characterization is Critical to Effective Planetary Defense

Notionally Prioritized High-Level NEO Characteristics To Inform Mitigation Options/Decisions (in order of decreasing notional priority):

- Orbit (i.e., heliocentric inertial orbital state (position and velocity vectors) at reference epoch(s))
  - **Precise orbit of NEO**
    - **Impact location** (sets requirements and/or informs minimum amount of deflection needed)
- Physical Properties
  - **Mass**: most important to know for a deflection/disruption attempt
  - **Binarity**: special considerations are required for deflecting/disrupting binary NEOs
  - **Shape**: with mass, we can then solve for bulk density
  - **Rotation:** may affect response to deflection/disruption attempt
  - **Strength**: influences NEO response to deflection/disruption attempt, cratering during Kinetic Impactor (KI) deflection, etc.
  - **Internal structure including porosity:** influences NEO response to deflection/disruption attempt, cratering during KI deflection, etc.
  - **Mineral composition**: particularly the iron fraction in the first few mm to cm of the NEO's surface (influences deflection/disruption method)
  - **Detailed surface topology**: relevant for predicting how the ejecta from a deflection attempt might influence the achieved deflection; may inform understanding of internal structure through boulder distribution analyses, regolith presence, etc.

NEO Characterization for PD

- Characterization may be required via both remote observations and in-space / in situ spacecraft reconnaissance (recon)
- Responds to actions called for in the National Near-Earth Object Preparedness Strategy and Action Plan
- Requires rapid-response NEO recon capabilities to enable high-fidelity estimates of mass, size, composition etc.
  - Alert the NEO observing community, to obtain observations as early as possible
  - Confirm the extent of the potential hazard as early as possible
  - Enable effective mitigation planning and spacecraft launch preparation as early as possible (making decisions earlier opens up more response options)
- Enables sufficiently accurate modeling of NEO impact consequences as soon as possible to inform:
  - Assessment of potential consequences, including uncertainties
  - In-space reconnaissance (recon) decision-making
  - Mitigation (deflection/disruption) decision-making
  - Cost/benefit analysis for in-space mitigation options vs. “accepting” the impact
  - Civil defense planning (emergency/disaster response planning, expectations for lives/infrastructure that could be affected, etc.)
- Model outcomes for in-space mitigation attempts (deflection/disruption), including uncertainties
- Perform trade studies, execute decision-making processes, design the overall response to NEO scenario
  - If/when to conduct various operations, including recon, in-space mitigation, civil defense, etc.

Flyby vs. Rendezvous (1/2)

- More data about the NEO can be gathered via a rendezvous mission than a flyby mission.
  - Flyby missions only speed by the NEO at some distance, and at a high relative velocity; this limits the types, quantities, and perspectives of gathered data.
  - Under those conditions, the mass of an NEO (of the size category relevant to planetary defense) cannot be estimated by tracking the flyby spacecraft.
    - It is possible when flying by very large objects (e.g., asteroids tens of km in size or more, mostly in the main asteroid belt), but those are not relevant here.
- Thus, flyby missions represent a stressing case from the perspective of NEO reconnaissance for planetary defense purposes.
- However, flyby missions may tend to be more responsive than rendezvous missions because:
  - there are usually more launch opportunities for flyby missions than for rendezvous missions;
  - a flyby spacecraft usually requires less propellant mass;
  - a flyby spacecraft may be simpler, smaller, and easier to launch (all else being equal) than a rendezvous spacecraft.
- Thus, we are motivated to learn the capabilities and limitations of flyby missions
  - **To what extent can a flyby reconnaissance mission service the needs of PD?**

Flyby vs. Rendezvous (2/2)

Y+ = Yes, Excellent Y = Yes, Good P = Partial N = No

Capability	Flyby Reconnaissance	Rendezvous Reconnaissance
Improve NEO Orbit Estimate	Y	Y+
Reduce Uncertainties in NEO Earth Impact Probability	Y	Y+
Reduce Uncertainties in NEO Earth Impact Location	Y	Y+
Estimate NEO Mass	P	Y
Observe NEO Shape	P	Y+
Estimate NEO Size	P	Y+
Estimate NEO Rotation State	P	Y+
Observe NEO Composition and Other Details	P	Y+
Carry Along NEO Deflection Mechanism	Y	Y
Continue Monitoring NEO After Deflection Attempt	N	Y

Current Matrix of Prioritized NEO Properties for PD Recon / Characterization

	NEO Properties (in ascending order of notional priority for planetary defense analysis)	Measureable via Remote Observations	Measureable During Flyby	Measureable During Rendezvous	Measureable via Deep Space Network (DSN) Radiometric Tracking of Spacecraft	Spacecraft Instruments		
						Visible Camera	IR Camera	Neutron Spectrometer
1	Heliocentric Orbit State	Y-	Y	Y	Y	Y	Y	
2	Mass	N	p	Y	Y	Y	Y	
3	Binarity	p	Y	Y		Y	Y	
4	Body bounding sphere	p-	p	Y		Y	Y	
5	Best-fit triaxial ellipsoid	p-	p	Y		Y	Y	
6	Target point on asteroid surface	N	p	Y		Y	Y	
7	Topography	N	p	Y		Y	Y	
8	Surface roughness within 2-sigma targeting error around surface target point	N	N	Y		Y	Y	
9	Rotational State	Y-	p	Y		Y	Y	
10	Bulk cohesion	Y-	p	Y		Y	Y	
11	Compressive strength	N	N	Y		Y	Y	Y
12	Tensile strength	N	N	Y		Y	Y	
13	Shear strength	N	N	Y		Y	Y	
14	Bulk porosity	N	N	Y	Y	Y	Y	Y
15	Gravity field (masscons)	N	N	Y	Y	Y	Y	
16	Composition	p-	p	Y		Y	Y	Y
17	Volatile inventory and location	N	N	Y				Y

Legend	Y: Yes, usually best quality, usually sufficient.	Y-: Yes, but not necessarily best quality / sufficient	p: partial, may be incomplete / inaccurate / uncertain.	p-: partial, of less quality than "p".	N: No; asteroid property cannot be characterized.

- This matrix describes direct measurements; inferences from combined information is treated separately
- Prioritization of NEO properties?
- Other NEO properties to measure?
- Appropriate instruments?
- Other instruments / techniques?
  - Technology road-mapping
- How might the matrix change for different PD scenarios?
  - E.g., 3, 5, 10, 15-year warning for an asteroid on a NEA-family orbit, vs. incoming hyperbolic comet, vs. …

Required Accuracies / Tolerable Uncertainties in NEO Properties Knowledge for PD Purposes: TBD

		Desired/required accuracies/precisions w/ caveats					
	NEO Properties (in ascending order of notional priority for planetary defense analysis)	***For Earth Impact Probability / Impact Location Calculations***	***Impact Consequence Modeling / Impact Risk Modeling***	***For Mission / Trajectory Design***	***For Kinetic Impactor Modeling***	***For Nuclear Deflection Modeling***	***For Nuclear Disruption Modeling***
1	Heliocentric Orbit State						
2	Mass						
3	Binarity						
4	Body bounding sphere						
5	Best-fit triaxial ellipsoid						
6	Target point on asteroid surface						
7	Topography						
8	Surface roughness within 2-sigma targeting error around surface target point						
9	Rotational State						
10	Bulk cohesion						
11	Compressive strength						
12	Tensile strength						
13	Shear strength						
14	Bulk porosity						
15	Gravity field (masscons)						
16	Composition						
17	Volatile inventory and location						

?

(And, variations across different incoming NEO scenarios …?)

- What computational modeling sensitivity studies are required to understand accuracy requirements?
- What NEO properties have most leverage over scenario properties / outcomes?
- Prioritization? … i.e., where/how should uncertainty be reduced first / most aggressively?
- How might this matrix change for different PD scenarios, as mentioned previously?
- Forthcoming risk-informed mission design process analyses---along with aforementioned sensitivity studies---will help answer these questions, and more …

Questions?

Appendices

National Plan Actions Relevant to PD NEO Characterization Priorities (1/2)

- **Action 1.2:** Identify technology and data processing capabilities and opportunities in existing and new telescope programs to enhance characterization of NEO composition and dynamical and physical properties.
- **Action 1.4:** Establish and exercise a process for rapid characterization of a potentially hazardous NEO.
- **Action 2.2:** Ascertain what information each participating organization requires on what timeframe, identify gaps, and develop recommendations for modeling improvements.
- **Action 2.5:** Assess the sensitivities of these models to uncertainties in NEO dynamical and physical properties.

National Plan Actions Relevant to PD NEO Characterization Priorities (2/2)

- **Action 3.1:** Assess technologies and concepts for rapid-response NEO reconnaissance missions.
- **Action 3.3:** Create plans for the development, testing, and implementation of NEO reconnaissance mission systems.
- **Action 5.2:** Establish a procedure and timeline for conducting a threat assessment upon detection of a potential NEO impact, and for updating the threat assessment based on improved data.
- **Action 5.6:** Establish a procedure and timeline for conducting a risk/benefit analysis for space-based mitigation mission options following a NEO threat assessment.
- **Action 5.7:** Develop benchmarks for determining when to recommend NEO reconnaissance, deflection, and disruption missions.