Workshop Summary and Next Steps

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Motivation

NASA Asteroid Initiative had prompted much community discussion on the science value and technical challenges involved

Workshop was a community-driven effort to ensure that the technical viewpoints of experts in fields pertinent to robotic and human NEO exploration were provided and documented. Technical, not a policy discussion

Key questions to address:

- What are the technical challenges involved and what new capabilities are needed for the newly proposed Asteroid Retrieval Mission (ARM)?

- What technical information is still needed?

- Are there any alternative approaches?

Scope

Sessions Topics Included:

- Update to Flexible Path Architecture (Asteroid First)
- The Small (<10 meters) NEA Population
- Finding Small NEAs: Current Capabilities and Gaps
- Small NEA Mission Design Challenges
- Technical Value of ARM - Panel Discussion

Plus substantial time for questions and comments

Session 1: Update to Flexible Path Vision

- *Overview of NASA’s New Asteroid Initiative* (Bill Gerstenmaier, NASA HQ, AA HEOMD)
- *NRC Human Exploration Study Update* (Michael Maloney, SSB)
- *Global Exploration Roadmap Update, ISECG Perspective* (Kathy Laurini, NASA HQ)

Co-chairs: Doug Stetson (Independent) and Cheryl Reed (APL)

Session 1 Summary

Gerstenmaier:

- ARM capability driven towards an ultimate Mars destination. Leverages existing technology investments
- 2016 final target selection, goal for 2017 launch to enable Mars mission in 2030's
- Will likely need to build the spacecraft prior to a target selection. This would likely drive a spacecraft overdesign to support multiple mission scenarios.
- The differences of the missions are so extreme (free-space target, boulder on a rubble-pile), it is acknowledged that a decision needs to be made "soon" as to which mission scenario will be pursued.
- Potential for higher costs, including a need for a larger, more costly LV given the inability to optimize to a point design.
- Key questions:
  - What is process by which these mission and spacecraft requirements will be developed? Note of extreme caution: Well-known that a lack of clear and specified requirements is the top culprit for driving-up (uncontrollable) mission cost.
  - Need to define mission success criteria. Doubtful that not bringing an asteroid back would be seen as an acceptable success criteria.
  - Need to define a realistic cost cap (which establishes a cost uncertainty range) and schedule.

Session 1 Summary (cont'd)

Maloney:

- An overview of studies by NRC/NAS to assess human exploration over last few decades was provided. A current study focuses on future relevance and focus of human space (what it should and should not be). But report card on the progress of the program against the study's expectations is not done (vs. what is done for missions in SMD).

Laurini:

- An overview of the Global Exploration Roadmap (GER) update was provided, and how ARM could fit into this architecture in an international cooperation construct. Noted that international collaboration and contribution is key to a robust and sustained human exploration program.
- Discussion of specific international cooperation on ARM has not yet occurred, however, it is likely that any contribution would come from existing partner efforts due to the highly compressed ARM implementation schedule.

Session 2: The Small (<10 meters) NEA Population

- *Population Estimates of Small NEAs* (Al Harris, More Data!)
- *Small NEA Characteristics* (Andy Rivkin, APL)
- *Modeling Capabilities and Uncertainties* (Bill Bottke, SwRI)
- *Estimated ARM Candidate Target Population and Projected Discovery rate of ARM Candidates* (Paul Chodas, JPL)

Co-chairs: Mark Sykes & Dan Britt

Session 2 Summary

ARM Target Characteristics (Chodas)

- Orbit: $V_{infinity}$ relative to Earth < 2 km/s desired, <2.6 km/s required.
- Orbit: Natural return to Earth. Orbit-to-orbit distance (MOID) < 0.03 au, Natural return to Earth in early 2020s (2020-2026) (ie, close approach within 0.3 au)
- Mass: <1,000 metric tons (upper bound varies according to $V_{infinity}$)
- Rotation State: Spin period > 0.5 min. Upper bound on angular momentum: ~$1x10^6$ kg-m^2/s. Non-Principal-Axis rotation can be accommodated
- Size and Aspect Ratio: 4 m < mean diameter < 10 m (roughly, 27 < H < 31). Upper limit on max dimension: ~15 m. Aspect ratio < 2:1
- Spectral Class: Known Type (C-type with hydrated minerals desired)

Session 2 Summary (cont'd)

Projected Discovery Rate of ARM Candidates (Chodas)

- The ARM candidate discovery rate will almost certainly increase due to enhancements to existing surveys and new surveys coming online.
- Current detection of targets meeting ARM dynamical and magnitude constraints is ~2.8/year. Expanding existing and new ground-based facilities may double this.
- With at least another 3-4 years to accumulate ARM candidate discoveries, at least ~15 more ARM candidates are expected to be discovered; favorable mission design trajectories should be available for at least half of these.

Fraction of dynamic/magnitude ARM candidates that meet size/mass requirements is not known.
Question about small number of Pan-STARRS ARM target detections (3) to which models are constrained.

Session 2 Summary (cont'd)

ARM Population Uncertainties and Options (Bottke)

- Most Asteroid Redirect Mission (ARM) Candidates, objects on very Earth-like orbits, are from the main asteroid belt (Bottke).
- There are probably many thousands to many tens of thousands of ARM Candidates.
- Our existing NEO models, developed for large NEOs, may break down for small NEOs.
- Estimates suggest our NEO models may be missing as much as a factor of 8-10 of the ARM Candidate population. Possible explanation (Harris): Possible sources of ultra-low v_∞ NEAs are Lunar ejecta (most), space debris (some), Main-belt asteroids (almost none), Mars ejecta (almost none).
- Minimoons are NEOs that have been temporarily captured in the Earth-Moon system. We argue they provide superior targets for future human missions.
- A minimoon mission may allow NASA astronauts to reach an NEO by 2025 at lower cost and risk than other prospective missions.

Session 2 Summary (cont'd)

Uncertainties of Potential ARM Target Physical Characteristics

- Albedo uncertainties for a given brightness lead to factor of ~3 uncertainty in size → factor of ~25-30 in mass. Albedo/size measurements are imperative. (Rivkin)
- Range of likely-seeming porosities from zero (*if* monolith) to 50% (if like larger asteroids, high end of TC3 estimate) → Densities from ~1 g/cm^3 - ~3 g/cm^3 → another factor of 3 in mass (*irreducible prior to S/C visit?*). (Rivkin)
- Great uncertainty in understanding overall population composition because of (unconstrained?) fraction of low albedo X-complex asteroids. Expect >~5% of NEOs to have hydrated minerals. (Rivkin)
- Rotation rates likely < 5 minutes (Rivkin). Many small objects are tumblers (Harris).
- Regolith cohesion can result in a 10m rubble rapidly rotating < 0.5 RPM with >mm grains on the surface (Scheeres & Sanchez).

Session 2 Summary (cont'd)

Uncertainties of Potential ARM Target Physical Characteristics

- In choosing a very low v_∞ target, you need to have very good physical characterization of the object if you want to be sure you aren't bringing a piece of the moon back to its home, or even an old rocket body. (Harris)

- Size/mass determinations are essential as it can easily push a dynamic/ magnitude compliant candidate beyond the ARM target requirement range.

- Is it possible to adequately characterize all potential ARM targets in the time period after their discovery?

- A rapidly rotating cohesive rubble pile may represent a source of risk against interacting with the surface (intentionally or unintentionally).

Session 3 - Finding Small NEAs Current Capabilities and Gaps

- *Tutorial on Process of Finding Small NEAs* (Tim Spahr, MPC)
- *Follow-up Characterization Needs and Issues* (Lance Benner, JPL)
- *Existing and Near-Term Ground-Based Capabilities and Gaps* (Steve Larson, U of Arizona)
- *Discovery Process for Finding ARM Targets Using PS2 and Atlas* (Eva Schunova, U of Hawaii)
- *Existing and Near-Term Space-Based Capabilities and Gaps* (Amy Mainzer, JPL)

Co-chairs: Paul Abell & Rich Dissly

Session 3 Summary

- In the short time frame needed for ARRM, ground based assets offer the best opportunity to increase the viable target set
  - Several ground based assets are being upgraded/developed in time to increase the number of possible targets for ARM : CSS, PS2, and ATLAS are all likely to detect multiple objects/year in the ARRM size range
- Current and near-term space-based assets are better suited to follow-up characterization (IR obs) rather than detection of a large number of small objects
- Very limited time for follow up (few days for optical/IR, radar) – but low ΔV objects may offer a longer characterization window
- Size uncertainty by visible observations alone can be a factor of 2-3. This propagates into a much larger uncertainty in target volume, mass. IR or radar follow-up critical to reducing this uncertainty

Session 3 Summary (cont'd)

- Follow-up by ground based assets is very important to close an orbit in the short time available for small targets; most very faint objects currently "lost"
- Many follow-up limitations are organizational rather than technical
  - Clearing house for follow-up observations at time of discovery, more rapid radiation clearance recommended as key improvements
- Simple upgrades and continued support to both Goldstone and Arecibo are important to support this as a NEA characterization asset
- Determining if a NEA has few meter-class boulders on the surface cannot be done remotely by IR, and limited with radar observations
- Detection of new, small objects by amateurs highly unlikely; the low-hanging fruit has been found.
  - But skilled amateurs still very important for follow-up, characterization of already discovered targets.

Session 4 - Small NEA Mission Design Challenges

- *End-to-End Mission Design Trajectory Optimization* (Damon Landau, JPL)
- *Proximity Operations and Characterization/Nav/Control* (Steve Broschart, JPL)
- *Docking, Grappling, Capture, Control, and Alternative Approaches* (Carlos Roithmayr, LaRC)
- *Maintaining a Safe, Stable, and Human Accessible Parking Orbit* (Dave Folta, GSFC)
- Defining Key Technology Requirements (John Dankanich, MSFC)

Co-chairs: Brent Barbee & Steve Chesley

Session 4 Summary

- Mission Design (Landau)
  - Given a suitable target, it appears feasible to rendezvous with and return an entire near-Earth asteroid using technology that is or can be available in this decade.
    - 6 years, 8 t of propellant, & 40 kW SEP system can return a 500 t asteroid to Earth/Moon capture orbit
- Proximity Ops (Broschart)
  - Solar radiation pressure (SRP) would dominate the dynamics during most ARM phases
    - A station-keeping strategy more practical than orbiting
  - Operations require a careful balance of OD/maneuver turnover time and execution errors
    - Autonomy can be used to minimize turnover time, which allows for larger maneuver/model errors
- Capture (Roithmayr)
  - Capture/despin of principal axis rotators appears feasible
  - Hovering at low latitudes appears impractical for fast rotators (suggesting that matching rates with a fast tumbler is also infeasible)
- Parking Orbit (Folta)
  - Distant Retrograde Orbits provide suitable stability without station-keeping
  - Dynamical Systems Theory and associated flight experience should be leveraged
  - Human accessibility of DRO is comparable to other alternatives, e.g., Lagrange point orbits
- Driving Technology (Dankanich)
  - Key technology development needs: Propulsion, Power, ProxOps, Capture Mechanism
  - Mission requirements not fully formulated making technological targets poorly defined
  - Unclear if these technologies can be “ready” in time for 2018 launch

Session 4 Summary (cont'd)

Issues from Q&A Discussion

- Tumbling rotation requires careful study: flexible structure dynamics, shearing inside capture mechanism
- Target mass uncertainty creates challenges/risks
- Boulder vs. Asteroid trade
- Xenon production question will be asked often
- Schedule is aggressive in terms of technology and target set
- Should ARRM get a pass on standard TRL and development oversight applied to other missions?
- Quantify value to ARM of
  - Enlarging the pool of suitable targets to afford more flexibility
  - Small robotic precursor to close characterization risks

Session 5 - Technical Value of ARM, Panel Discussion

Panel

- Gentry Lee, JPL
- Doug Cooke, AA NASA (Retired)
- Tom Jones (FIHMC, former astronaut)
- Jim Bell (ASU)

Co-chairs: Dan Mazanek (LaRC) & Faith Vilas (PSI)

Session 5 Summary

Key points from remarks

- Many benefits, but lack of mission definition is a significant risk
  - Define range of acceptable target characteristics and mission parameters
  - Schedule is too aggressive when coupled with funding uncertainties
- ARM has the potential to be a unifying, cohesive endeavor across NASA directorates
- Possibly the only near-term “planetary surface” destination
  - Use experience gained to reduce design uncertainties for future human missions and gain more crew autonomy
  - Progresses human skills and experience in deep space
  - Opportunity to demonstrate NASA competence and risk management within tight budget times
- Space resources
  - Breaks the paradigm of relying completely on resources brought from Earth
  - Promotes commercial and international partnerships

Session 5 Summary (cont'd)

Additional issues from Q&A/Discussion

- ARM is exciting, but in these austere times, what is our opportunity threshold cost? Depends in part on where the money is coming from – needs to come from HEOMD.
- Cost compared to OSIRIS-REx (60 grams vs. many, many tons). Need to have a reasonable schedule or costs of mission will become excessive (2019 earliest with proper funding).
- Public perception is that this mission is much more than technology demonstration mission
  - NASA needs to set bold goals for itself and reasonable success criteria
  - Relevant also for general public especially in terms Mars exploration
- Is the ARM concept worth the risk to astronauts? Consensus of panelists was "yes."
- Duration of crewed visit to returned asteroid is not on the same order as a Mars mission, but stretches Orion capability and Deep Space Habitat shake out and advances fault protection for this mission given that no quick return is available. ISS missions significantly helps with the long duration.

Next Steps

- Written report out within ~1 month
  - Open for inputs
  - Will have draft available for comment on website
- Briefings at DPS, other (GER 2?)

More Info

- Website : **http://targetneo.jhuapl.edu**
- All talks will be uploaded by end of week
- Can always send in comments through gmail: (TargetNEO2@gmail.com) or talk to any of the co-chairs