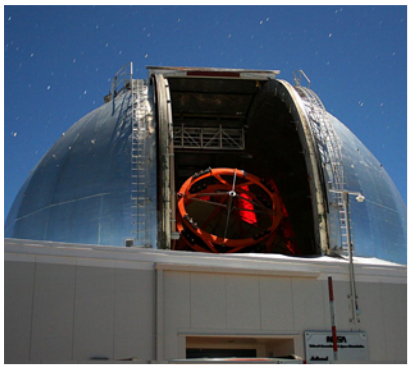
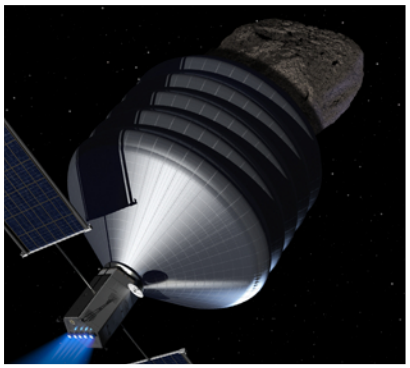
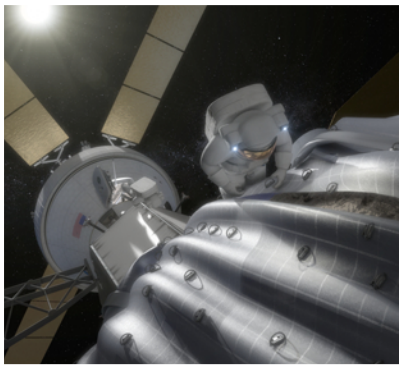
National Aeronautics and Space Administration

ASTEROID INITIATIVE

Ideas Synthesis Workshop

Final Report

January 2014

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Executive Summary

NASA's Asteroid Initiative consists of two separate but related activities: the Asteroid Redirect Mission (ARM), and the Asteroid Grand Challenge (AGC). NASA is developing concepts for the ARM, which would use a robotic spacecraft to capture a small near-Earth asteroid (7 to 10 meters), or remove a boulder (1 to 10 meters) from the surface of a larger asteroid, and redirect it into a stable orbit around the moon. Astronauts launched aboard the Orion spacecraft would rendezvous with the captured asteroid material in lunar orbit, and collect samples for return to Earth.

The AGC is seeking the best ideas to find all asteroid threats to human populations, and to accelerate the work that NASA is already doing for planetary defense. The Asteroid Initiative will leverage and integrate NASA's activities in human exploration, space technology, and space science to advance the technologies and capabilities needed for future human and robotic exploration, to enable the first human mission to interact with asteroid material, and to accelerate efforts to detect, track, characterize, and mitigate the threat of potentially hazardous asteroids.

On June 18, 2013, NASA issued a Request for Information (RFI) to gather innovative ideas that NASA will use to plan the Asteroid Initiative (Ref. 1). The RFI was open to individuals, companies, universities, government agencies, and international organizations. The RFI closed on July 18, 2013, and 402 responses were received from 16 countries. Approximately 40% of the responses were from the general public. All responses were evaluated for relevance, impact, maturity, and affordability, and 96 of the most promising ideas were selected for presentation at the Asteroid Initiative Ideas Synthesis Workshop.

The purpose of the workshop was to further examine and foster a broad discussion of the most promising ideas gathered via the RFI, and to identify and synthesize ideas that could help inform NASA's planning of the Asteroid Redirect Mission and Asteroid Grand Challenge. The workshop participants also made recommendations for further studies and next steps.

The workshop was held in two parts at the Lunar and Planetary Institute. The first part took place on September 30 before the government shutdown, and about 150 people attended. The workshop resumed on November 20-22, and about 120 people attended the second part. Over 2,000 people were able to participate virtually. The workshop sessions included presentations and discussion in the following areas:

- Asteroid Observation
- Asteroid Redirection Systems
- Asteroid Deflection Demonstrations
- Asteroid Capture Systems
- Crew Systems for Asteroid Exploration

- Partnerships and Participatory Engagement
- Crowdsourcing and Citizen Science (Grand Challenge)
- Next Generation Engagement (Grand Challenge)

The Asteroid Observation area discussed concepts for augmenting and accelerating ground and space-based capabilities for detecting all near-Earth asteroids, determining their orbits, and characterizing their shape, rotation rate, mass, and composition as accurately as possible. This information is needed to identify candidate targets for the Asteroid Redirect Mission, as well as to expand our knowledge of the population of potentially hazardous asteroids for planetary defense. The main recommendations from the workshop were to encourage international participation by working through the United Nations, assist amateur astronomers in contributing to asteroid detection and characterization efforts, use surplus observational time on U. S. space surveillance systems, encourage commercial partnerships for asteroid precursor missions using small spacecraft, and include grants to detect and characterize small asteroids in NASA's annual space science solicitations.

The Asteroid Redirection Systems area discussed concepts for robotic spacecraft systems such as solar electric propulsion and integrated sensing systems to enable asteroid rendezvous, proximity operations, in-space characterization, and redirection into cis-lunar space. This session also discussed alternate concepts for the ARM such as removing a boulder from the surface of a large asteroid, and leveraging dual use technology for satellite servicing. The main recommendations from this session were to establish a concise set of mission objectives and figures of merit, perform assessments of the various technology options for enhancing the mission, focus risk reduction activities on the highest priority technologies needed to enable the mission concept, conduct further studies of integrated sensing systems that can support multiple mission phases, improve coordination with the small body science community, and establish an approach for involving commercial partners.

The Asteroid Deflection Demonstrations area discussed concepts for deflecting the trajectory of a larger asteroid (100 meters or larger) using the ARM robotic spacecraft to prepare for planetary defense. The main recommendations from this session were to conduct further studies of the enhanced gravity tractor using mass augmentation, ion beam deflection, and post-mission kinetic impactor deflection concepts; demonstrate robotic spacecraft mechanisms such as surface samplers, excavators, and anchors to support planetary defense efforts; and test some of the hardware and operational concepts needed for nuclear detonation approaches. Additional demonstrations, such as a kinetic impactor, solar collector, or use of in situ materials for a mass driver or propulsion, could be important to addressing the AGC, but would require additional funding or cost sharing arrangements.

The Asteroid Capture Systems area discussed concepts for systems to capture and de-spin a small asteroid (10 meters or smaller). The main recommendations from this session were to conduct trade studies between deployable booms and inflatable structures for the reference capture system concept, investigate alternate ways to de-tumble the asteroid

prior to capture such as using tethers for momentum transfer, and study ways to make the robotic spacecraft more robust against the de-tumble event such as using retractable solar arrays.

The Crew Systems for Asteroid Exploration area discussed concepts for extra-vehicular activity (EVA) systems, such as space suits, tools, and translation aids that will allow astronauts to explore the surface of a captured asteroid, prospect for resources, and collect samples. This session also discussed the extensibility of ARM systems and capabilities to future human exploration missions. The main recommendations from this session were to study concepts for an exploration augmentation module to enable extended duration missions in cis-lunar space and extensibility to Mars missions; investigate self-anchoring drills, electrodynamic dust shields, and telescoping booms for EVA; and continue to evaluate EVA suits, tools, and operational concepts in the Johnson Space Center's Neutral Buoyancy Laboratory.

The Partnerships and Participatory Engagement area discussed ideas and innovative methods to broaden participation in the asteroid initiative, such as crowd sourcing, prizes and challenges, citizen science, and public-private partnerships. For the Asteroid Redirect Mission, the main recommendations from this session were to consider Cooperative Research and Development Agreements (CRADAs), milestone-based contractual approaches, data buys, and incentive prizes; learn what motivates industry partners; establish clear mission objectives; and develop technology roadmaps so industry can focus their resources on gaps. For the Grand Challenge, the main recommendations were to consider forums for engaging the public in two-way policy conversations; build momentum through the use of smaller technology demos; and learn from the natural disaster response community about planning and messaging.

Two additional sessions were held on topics pertaining to the AGC: Crowdsourcing and Citizen Science, and Next Generation Engagement. These sessions discussed using online crowdsourcing to improve machine learning and the accuracy of asteroid detection by observatories, engaging citizen scientists globally in follow-up observations such as light and phase curve measurements, integrating citizen science activities into the work of large ground-based surveys, leveraging gaming and data visualization to engage the public, using videos to create more compelling storytelling and information about potentially hazardous asteroids, and using prizes to incentivize technology development.

Follow-on activities will include developing plans to incorporate workshop recommendations into current study efforts, keeping the external community engaged through periodic updates on mission and Grand Challenge status, providing opportunities for industry to participate in system and mission concept studies, providing opportunities for the public to contribute meaningfully to the scientific and technical work of the AGC, and continuing collaboration with the asteroid community.

NASA's Asteroid Initiative

NASA's Asteroid Initiative consists of two separate but related activities: the Asteroid Redirect Mission (ARM), and the Asteroid Grand Challenge (AGC). NASA is developing concepts for the Asteroid Redirect Mission (ARM), which would use a robotic spacecraft to capture a small (7 to 10 meters) near-Earth asteroid, or remove a piece (1 to 10 meter boulder) from the surface of a larger asteroid and redirect it into a stable orbit around the moon. Astronauts launched aboard the Orion spacecraft would rendezvous with the captured asteroid material in lunar orbit, and collect samples for return to Earth.

The AGC is seeking the best ideas to find all asteroid threats to human populations, and to accelerate the work that NASA is already doing for planetary defense. The Asteroid Initiative will leverage and integrate NASA's activities in human exploration, space technology, and space science to advance the technologies and capabilities needed for future human and robotic exploration, to enable the first human mission to interact with asteroid material, and to accelerate efforts to detect, track, characterize, and mitigate the threat of potentially hazardous asteroids.

Three study teams have been developing initial concepts for the ARM. Teams led by JPL and LaRC are defining concepts for the robotic segment of the mission, which include redirecting an entire small near-Earth asteroid, or retrieving a boulder from the surface of a larger asteroid, respectively. Another team led by JSC is defining the human segment. The Science Mission Directorate (SMD) is enhancing its existing Near-Earth Objects Observation Program to identify candidate targets for the ARM. The Space Technology Mission Directorate (STMD) is developing a high-power solar electric propulsion system for the robotic spacecraft that will rendezvous with the target asteroid and redirect it into lunar orbit. The Human Exploration and Operations Mission Directorate (HEOMD) is developing and testing a short duration space suit that astronauts could use to explore the captured asteroid material.

The AGC planning process is being led by NASA's Office of the Chief Technologist in close coordination with the appropriate offices in HEOMD, SMD, and STMD.

Request for Information Process

A Request for Information (RFI) was formulated to gather ideas that could help NASA refine the objectives of the Asteroid Initiative and initial ARM concepts, to explore alternative mission concepts, and to broaden participation in the mission and planetary defense (Ref. 1). The Asteroid Initiative RFI was released on June 18, 2013. Information was requested in six main areas:

1. **Asteroid Observation**: Concepts to augment and accelerate current efforts to detect and characterize all near-Earth asteroids, and to identify candidate targets for the ARM.
2. **Asteroid Redirection Systems**: Robotic spacecraft systems such as solar electric propulsion and integrated sensing systems to enable rendezvous, proximity operations, in-space characterization, and redirection of an asteroid into cis-lunar space.
3. **Asteroid Deflection Demonstrations**: Concepts for deflecting the trajectory of a large asteroid (> 100 meters) using the ARM robotic spacecraft to prepare for planetary defense.
4. **Asteroid Capture Systems**: Concepts for deployable and inflatable systems to capture and de-spin a small asteroid between 5 and 13 meters in diameter, and weighing up to 1,000 metric tons.
5. **Crew Systems for Asteroid Exploration**: Concepts for EVA suits, tools, and translation aids that will allow astronauts to explore the surface of a captured asteroid, prospect for resources, and collect samples.
6. **Partnerships and Participatory Engagement:** Ideas and innovative methods to broaden participation in the Asteroid Initiative.

The RFI was open to individuals and all types of organizations, including companies, universities, NASA Centers, other government agencies, and international organizations. The RFI closed on July 18, 2013, and 402 responses were received.

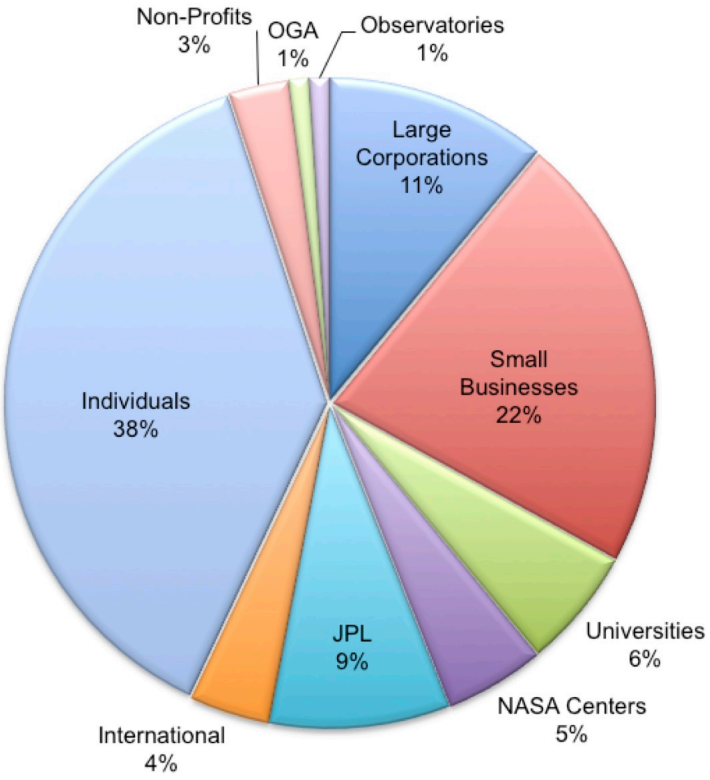

Figure 1: Responses by type of organization

A breakdown of the responses by type of organization is shown in Figure 1. The RFI triggered high public interest. Individuals submitted 38% of the responses, which was the largest segment. Small businesses were the second largest segment with 22% of the responses. There were 14 responses from international organizations.

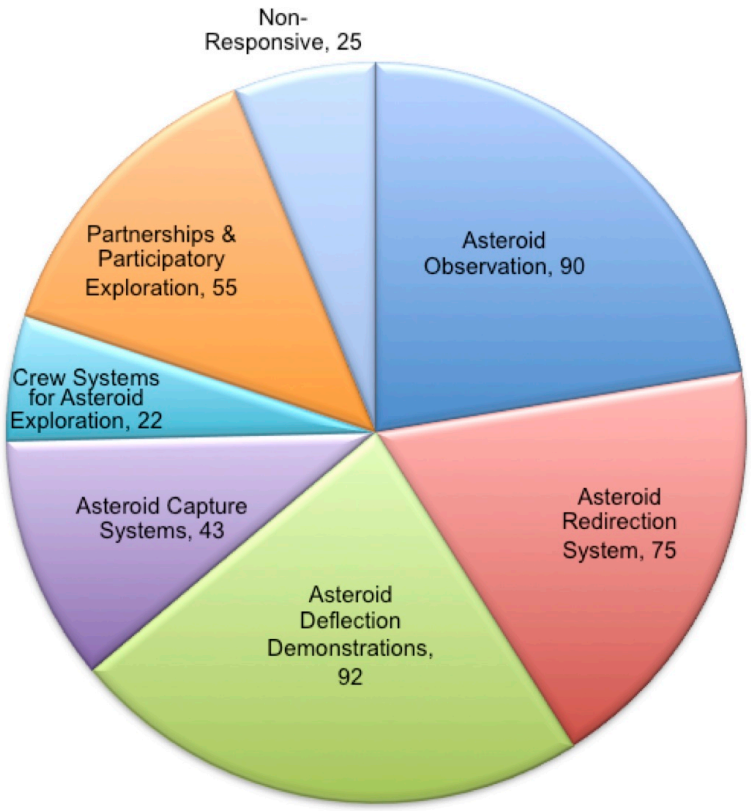

Figure 2: Responses by RFI Area

The break down of responses by RFI area is shown in Figure 2. Asteroid Deflection Demonstrations and Asteroid Observations received the largest number, with 92 and 90 responses respectively. Crew Systems for Asteroid Exploration received the fewest number with 22 responses. There were 25 submissions that did not address any of the areas in the RFI and these were not evaluated.

A team of NASA reviewers evaluated the RFI responses in each area according to the following criteria:

- Factor 1: Relevance to RFI objectives. Does the response demonstrate a clear understanding of the objectives outlined in the RFI? Does it address one of the six main areas?

- Factor 2: Impact. Does the idea have the potential to make a major impact in ensuring mission success, accelerating asteroid observations, improving system performance, reducing risk, etc? Is the idea innovative? Is the idea feasible?

- Factor 3: Maturity. Is the concept or technology sufficiently mature that it can be incorporated into mission plans? Does the response outline a development approach?

- Factor 4: Affordability. Does the concept or technology have the potential to significantly improve mission affordability?

For each evaluation factor (Relevance, Impact, Maturity, Affordability), the RFI responses were rated as:

3 = High
2 = Moderate
1 = Low

All evaluation factors had equal weight. Each response was evaluated by at least three reviewers. Based on the composite ratings for the evaluation factors, the reviewers assigned an overall score to each response that indicated NASA's interest in the idea, and in having follow-up discussions with the respondent:

5 = Definitely consider
4 = Possibly consider
3 = Borderline
2 = Likely reject
1 = Definitely reject

The evaluation process identified 96 highly-rated responses, and the respondents were invited to present their ideas at a public workshop. Abstracts for each invited presentation are archived online (Ref. 2).

Asteroid Initiative Ideas Synthesis Workshop

The purpose of the public workshop was to further examine and foster a broad discussion of the 96 most promising ideas gathered via the RFI, and to identify and synthesize ideas that could help inform NASA's planning of the Asteroid Redirect Mission and Grand Challenge. The workshop participants also made recommendations for further studies and next steps.

The workshop sessions covered the six RFI areas:

1. Asteroid Observation
2. Asteroid Redirection Systems
3. Asteroid Deflection Demonstrations
4. Asteroid Capture Systems
5. Crew Systems for Asteroid Exploration

6. Partnerships and Participatory Engagement

Two additional sessions were held to gather inputs on the Asteroid Grand Challenge from the external community:

- Crowdsourcing and Citizen Science
- Next Generation Engagement

The participants in these two sessions were not selected through the RFI evaluation process, but were invited based on their experience with similar public engagement activities.

The participants in these two sessions were also selected through the RFI evaluation process. These sessions sought to dive more deeply into two particular areas of interest to the AGC.

The Asteroid Initiative Ideas Synthesis Workshop was held at the Lunar and Planetary Institute in Houston, Texas. The workshop was originally scheduled for September 30-October 2, 2013, but it was interrupted by the government shutdown after the first day was completed on September 30. Approximately 150 people attended the first day. In the opening plenary session, NASA speakers described the Asteroid Initiative and presented overviews of the studies performed by JPL and JSC to develop initial concepts for the ARM. The Asteroid Observation and Asteroid Redirection Systems sessions were also completed on the first day.

The workshop resumed on November 20-22, 2013, and about 120 people attended the second part in which the remaining sessions were completed. Over 2,000 people were able to participate virtually in both parts.

A NASA lead and co-lead facilitated the discussion in each session. The session leads are listed in Appendix H. The NASA facilitators are involved in the ARM and Grand Challenge study teams to ensure that the workshop recommendations are considered in future plans. The following sections describe the topics discussed and main recommendations from each session.

Asteroid Observation

The Asteroid Observation area discussed concepts for augmenting and accelerating ground and space-based capabilities for detecting all near-Earth asteroids, determining their orbits, and characterizing their shape, rotation rate, mass, and composition as accurately as possible. This information is needed to identify candidate targets for the ARM.

There were 90 RFI responses in the Asteroid Observation area, and 17 were invited for presentation at the workshop. NASA was already aware of many of the highly-rated ideas through its current NEO Observation Program activities, so it was decided to invite respondents who were proposing new ideas that NASA was not familiar with to the

workshop. The presentations in this session are listed in Appendix A. The specific topics discussed included:
- Small ground-based telescopes
- Software solutions for mining sky survey databases
- Radar/Ladar systems
- Space-based observations and small satellites

Recommendations
- Encourage international participation through the United Nations Committee on the the Peaceful Uses of Outer Space (UNCOPUOS) member states.
- Assist amateur astronomers in learning astrometric and photometric skills, procuring low-cost hardware and software, and interfacing with Minor Planet Center and professional community.
- Repurpose existing U. S. assets by using surplus capabilities from the Space Surveillance Network and the National Science Foundation (NSF).
- Encourage partnerships for characterization such as space-based precursor and "ride-along" small spacecraft.
- Include detection and characterization of small asteroids relevant to ARM in annual Science Mission Directorate research opportunities such as ROSES or SALMON.

Asteroid Redirection Systems

The Asteroid Redirection Systems area discussed concepts for robotic spacecraft systems such as solar electric propulsion and integrated sensing systems to enable asteroid rendezvous, proximity operations, in-space characterization, and redirection into cis-lunar space. This session also discussed alternate concepts for the ARM such as removing a boulder from the surface of a large asteroid, and leveraging dual use technology for satellite servicing.

There were 75 RFI responses in the Asteroid Redirection Systems area, and 14 were invited for presentation at the workshop. The presentations in this session are listed in Appendix B. The specific topics discussed included:
- Vehicle Systems
- Sensing Systems and Algorithms
- Mission Enhancements
- Extensibility
- Alternate Mission Scenarios/Concept of Operations
- Different Business Strategies

Recommendations
- Establish a concise set of mission objectives and figures of merit, including extensibility, sustainability, and commercialization considerations.
- Perform an assessment of the various mission enhancement options, including technology push vs. using low-risk mature technologies.

- Focus risk reduction activities so that they are consistent with the mission concept approach and commercial utility of technology development.
- Conduct follow-on studies of integrated sensing systems that can support multiple mission phases and broader NASA exploration needs.
- Improve coordination with the small body science community.
- Establish an approach for addressing business case and partnership opportunities.

Asteroid Deflection Demonstrations

The Asteroid Deflection Demonstrations area discussed concepts for deflecting the trajectory of a larger asteroid (>100 meters) using the Asteroid Redirect Vehicle to prepare for planetary defense.

There were 92 RFI responses in the Asteroid Deflection Demonstrations area, and 13 were invited for presentation at the workshop. The presentations in this session are listed in Appendix C. The specific topics discussed included:

- Deflection demos with little or no additional costs (use Asteroid Redirect Vehicle assets)
- Deflection demos with additional costs (e.g., kinetic impact, solar collector, micro-satellites, etc.)
- Demonstration of devices that are applicable to future planetary defense approaches, but are not based on the ARM robotic mission concept.

Recommendations

- Conduct further studies of the enhanced gravity tractor using mass augmentation, ion beam deflection, and post-mission kinetic impactor deflection concepts using the Asteroid Redirect Vehicle with or without the returned mass to compare costs, effectiveness, and applicability to ARM.
- If budget permits, consider demonstrating other deflection concepts that do not affect the Asteroid Redirect Vehicle to support planetary defense efforts:
  - Robotic spacecraft mechanisms (anchoring, excavation, surface samplers, etc.).
  - Possible testing of some of the hardware and operational concepts needed for nuclear detonation approaches.
- Many demonstrations, such as a kinetic impactor, solar collector, or use of in situ materials for a mass driver or propulsion, could be important to addressing the Grand Challenge.
  - These concepts should be analyzed in more detail given the wide range of ideas and uncertainty in how or if they could be accommodated on the ARM robotic mission.
  - These ideas could be pursued under the ARM robotic mission if additional funding is available or cost sharing can be provided.

Asteroid Capture Systems

The Asteroid Capture Systems area discussed concepts for systems to capture and de-spin a small asteroid.

There were 43 RFI responses in the Asteroid Capture Systems area, and 11 were invited for presentation at the workshop. The presentations in this session are listed in Appendix D. The specific topics discussed included:
- Tether concepts
- Inflatable concepts
- Deployable structures and robotic concepts

Recommendations
- Conduct trade between deployable booms and inflatable beams with respect to the reference capture system concept.
- Investigate cost effective ways to de-tumble the asteroid prior to capture to make it a more cooperative target, such as using tethers for momentum transfer.
- Study ways to make the spacecraft more robust against the de-tumble event, such as using retractable solar arrays.

Crew Systems for Asteroid Exploration

The Crew Systems for Asteroid Exploration area discussed concepts for extra-vehicular activity (EVA) systems, such as space suits, tools, and translation aids that will allow astronauts to explore the surface of a captured asteroid, prospect for resources, and collect samples. This session also discussed the extensibility of ARM systems and capabilities to future human exploration missions.

There were 22 RFI responses in the Crew Systems for Asteroid Exploration area, and 13 were invited for presentation at the workshop. The presentations in this session are listed in Appendix E. The specific topics discussed included:
- Extensibility for exploration
- Anchoring techniques
- Translation and EVA tools

Recommendations
- Study concepts for an Exploration Augmentation Module to enable extended duration missions in cis-lunar space and extensibility to Mars missions.
- Investigate self-anchoring drills, electrodynamic dust shields, and telescoping booms for EVA.
- Continue to evaluate EVA suits, tools, and operational concepts in Neutral Buoyancy Laboratory tests.

Partnerships and Participatory Engagement

The Partnerships and Participatory Engagement area discussed ideas and innovative methods to broaden participation in the Asteroid Initiative, such as crowd sourcing, prizes and challenges, citizen science, and public-private partnerships.

There were 55 RFI responses in the Partnerships and Participatory Engagement area, and 12 were invited for presentation at the workshop. The presentations in this session are listed in Appendix F. The specific topics discussed included:
- Examples of successful partnerships.
- Ideas for Asteroid Initiative partnership models and financial incentives for success.
- Challenges smaller companies can have when trying to work with NASA.
- Engagement examples.

Recommendations: Asteroid Redirect Mission
- Consider CRADAs as they have been successful in the past.
- Consider milestone-base contractual approaches similar to COTS and ILDD.
- Consider data buys or incentive prizes for acquisition of asteroid data/information.
- Learn what motivates industry partners and understand the different phases of the mining business to inform mission design and architecture.
- Establish clear mission objectives, stick to them, and define what roles participants will play so industry can organize properly.
- Develop specific technology roadmaps so industry and universities can focus their energy on gaps.

Recommendations: Grand Challenge
- Consider forums for engaging the public in two-way policy conversations.
- Build momentum through the use of smaller demos that can culminate in larger demos to leverage the shared progress.
- Explore conversations about risk and learn from the natural disaster response community.

Grand Challenge Sessions

The Crowdsourcing and Citizen Science session discussed ideas and innovative methods to broaden meaningful contributions by the global public in the Asteroid Grand Challenge. Eight respondents to the RFI were invited for presentation at the workshop. The presentations in this session are listed in Appendix G. The specific topics discussed included:
- Examples of successful citizen science projects for asteroid observations.
- Ideas for how amateurs and small observatories internationally might contribute to the Grand Challenge.
- Barriers to citizen science involvement in asteroid observation.
- Ideas for how crowdsourcing might be leveraged for detection, monitoring, and data analysis.

The Next Generation Engagement session discussed ideas and innovative methods to broaden participation in and knowledge of the Asteroid Grand Challenge. Four respondents to the RFI were invited for presentation at the workshop. The presentations in this session are listed in Appendix G. The specific topics discussed included:

- Examples of how data visualizations and video can strengthen understanding in science and technical topic areas.
- Ideas for how NASA could leverage existing, popular education and outreach activities to increase attention on the Asteroid Initiative.

Detailed notes and ideas from these sessions can be found on the Grand Challenge's public wiki (Ref. 3).

Next Steps

The RFI process gathered a rich set of innovative ideas from diverse perspectives in industry, universities, NASA Centers, and international partners. Follow-on activities will include developing plans to incorporate workshop recommendations into current study efforts, keeping the external community engaged through periodic updates on the Asteroid Redirect Mission and Grand Challenge status, providing opportunities for industry to participate in system and mission concept studies, involving the public in the scientific and technical work of the Grand Challenge, and continuing collaboration with the asteroid community. The next public forum is planned in the spring of 2014.

References

1. "Request for Information for NASA's Asteroid Initiative," Solicitation Number NNH13ZCQ001L, June 18, 2013, https://prod.nais.nasa.gov/cgibin/eps/synopsis.cgi?acqid=156731

2. Asteroid Initiative Ideas Synthesis Workshop, http://www.nasa.gov/asteroidworkshop

3. Asteroid Grand Challenge Wiki, http://agcnotes.wikispaces.com.

Acronyms

AGC	Asteroid Grand Challenge
ARM	Asteroid Redirect Mission
COTS	Commercial Orbital Transportation Services
CRADA	Cooperative Research and Development Agreement
EVA	Extra-Vehicular Activity
HEOMD	Human Exploration and Operations Mission Directorate
ILDD	Innovative Lunar Demonstrations Data
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
LaRC	Langley Research Center
NEA	Near-Earth Asteroid
NEOWISE	Near Earth Object Wide-field Infrared Survey Explorer
RFI	Request for Information
ROSES	Research Opportunities in Space and Earth Sciences
SALMON	Stand Alone Missions of Opportunity Notice
SMD	Science Mission Directorate
STMD	Space Technology Mission Directorate
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space

Appendix A: Asteroid Observation Presentations

DAY 1 – MONDAY, SEPTEMBER 30
Asteroid Observation | Lecture Hall | #FindAsteroids
Lindley Johnson & Paul Abell

Time	Topic	SPEAKER
1:30 p.m.	Session Introduction	LINDLEY JOHNSON* NASA Headquarters
1:35 p.m.	Substantially increase the number of amateur astronomers looking for asteroids by developing low-cost equipment	PHIL BEFFREY
1:45 p.m.	Using amateur astronomers for follow-up observations from Southern Hemisphere.	DOUGLAS WALKER University of Canterbury
1:55 p.m.	Involve small private observatories in asteroid observations; Need more telescopes looking for asteroids in Southern Hemisphere	RAY PICKARD* Bathurst Observatory Research Facility, Australia
2:05 p.m.	Leverage existing 1.1-m commercial telescope	GARY MATTHEWS Exelis
2:15 p.m.	Leverage Boeing expertise developing space surveillance sensors for the Air Force	JOHN LAMBERT The Boeing Company
2:25 p.m.	Break	
2:35 p.m.	Web portal for aggregating, disseminating, and standardizing observations	JEFFREY MITCHELL* StormBourne, LLC
2:45 p.m.	Developing algorithms for automatic detection of asteroids. Interested in cooperation to determine asteroid orbits	VADYM SAVANEVYCH* Kharkiv National University (Ukraine)
2:55 p.m.	Development of a high-performance, information theory-based data mining tool for asteroid threat determination	ORLEY LINDGREN* Entropy Limited
3:05 p.m.	Leverage algorithms developed for Missile Defense Agency for automated NEA detection	CLINTON CLARK ExoAnalytic Solutions
3:15 p.m.	FreeFlyer software for asteroid observation and mission design	SARA CASE a.i. solutions, inc.
3:25 p.m.	Geometric Nonlinear Signal Processing algorithm to enhance range performance of NASA radars for tracking asteroids	TOM BURLESON Reisz Engineers
3:35 p.m.	Break	
3:45 p.m.	Laser radar for characterization and orbit determination of NEOs	JANE LUU* MIT Lincoln Lab
3:55 p.m.	Measuring the size of NEAs with coherent Doppler ladar	BIJAN NEMATI NASA Jet Propulsion Lab
4:05 p.m.	Use star tracker from existing satellite missions to measure light variation due to rotation of asteroid	STEPHAN KLENE
4:15 p.m.	Leveraging Planetary Resource's network of Arkyd 100 space telescopes to be launched in 2015	CHRIS LEWICKI Planetary Resources
4:25 p.m.	Cubesat swarm with IR sensors and onboard data processing	DAVID RABANUS* SpaceAppsChile
4:35 p.m.	Scouting missions are required to characterize potential asteroid targets	RICK TUMLINSON Deep Space Industries
4:45 p.m.	Discussion and Synthesis	
5:30 p.m.	End of Observation Session	

*Virtual Presenter

Appendix B: Asteroid Redirection System Presentations

DAY 1 – MONDAY, SEPTEMBER 30
Asteroid Redirection Systems | Berkner Room | #MoveAsteroid
Jim Reuter & Steve Sandford

TIME	TOPIC	SPEAKER
1:30 p.m.	Session Introduction	JIM REUTER NASA Marshall Space Flight Center
1:40 p.m.	Asteroid Retrieval Alternatives from the KISS Study	JOHN BROPHY NASA Jet Propulsion Lab
1:55 p.m.	Proposed Development Solutions for Asteroid Redirection Systems	SIMONA FERRARIS* Thales Alenia Space Italy
2:10 p.m.	Asteroid Redirect Vehicle with Solar Electric Propulsion and Robotic Manipulator	ADAM MAHER Space Systems Loral
2:20 p.m.	Alternative Mission Concepts and Summary of GSFC Technologies and Facilities Relevant to ARM	BENJAMIN REED NASA Goddard Space Flight Center
2:30 p.m.	Leveraging Heritage Spacecraft Platforms and Subsystems to Reduce ARM Execution Risk	MIKE ELSPERMAN Boeing MANNY LEINZ Boeing
2:45 p.m.	Asteroid Redirect Systems - Integrated Sensing Systems Asteroid Redirect Systems - Solar Electric Propulsion System Concepts	JOHN RINGELBERG Lockheed Martin JOHN RINGELBERG Lockheed Martin
3:00 p.m.	Enabling Technologies for Asteroid Redirection Systems	KIEL DAVIS Honeybee Robotics
3:10 p.m.	Integrated Sensing Systems to Support Asteroid Rendezvous, Proximity Operations, Characterization, and Capture	STEVEN WARWICK Northrop Grumman
3:20 p.m.	Integrated Sensing Systems for Asteroid Missions	RICHARD DISSLY Ball Aerospace
3:30 p.m.	In-situ Radar for Asteroid Characterization and Altimetry	MARK HAYNES NASA Jet Propulsion Lab
3:40 p.m.	Integrated Sensor Systems and Applications of Satellite Servicing Technology to ARM	PAUL FULFORD MDA Canada
3:50 p.m.	Refinements of the Asteroid Redirect Mission Concept to Maximize Scientific and Commercial Value	DAVID GUMP Deep Space Industries
4:00 p.m.	Earth's Minimoons: New Prospective Targets for Human Exploration Minimoons: Discovery and Retrieval Missions	BILL BOTTKE Southwest Research Institute ROBERT JEDICKE University of Hawaii
4:15 p.m.	Discussion and Synthesis	OPEN DISCUSSION
5:30 p.m.	End of Asteroid Redirection Session	

*Virtual Presenter

Appendix C: Asteroid Deflection Demonstration Presentations

DAY 2 – THURSDAY, NOVEMBER 21

Asteroid Deflection Demonstrations | Hess Room | #ProtectPlanet

Dan Mazanek & Pat Troutman

TIME	TOPIC	SPEAKER
1:30 p.m.	Session Introduction	DAN MAZANEK NASA Langley Research Center
1:40 p.m.	Concepts for Asteroid Trajectory Deflecting Using an ARV	DAVID SMITH* The Boeing Company
1:55 p.m.	Low-risk, High-heritage Approach for Asteroid Deflection/Capture Implementation	HOWARD ELLER Northrop Grumman
2:10 p.m.	Affordable Spacecraft with Capabilities to Enable Multiple Deflection Schemes	ANDY TURNER Space Systems/Loral
2:25 p.m.	ARV-based Kinetic impactor and Multiple ARV Gravity Tractors for Orbit Modification	BONG WIE Iowa State University
2:40 p.m.	Asteroid Repositioning for Planetary Defense	GEOFFREY LANDIS* NASA Glenn Research Center
2:55 p.m.	Gravity Tractoring with Local Mass Augmentation	TIM MCELRATH NASA Jet Propulsion Laboratory
3:10 p.m.	Mass Augmented Gravity Tractor	JOSH HOPKINS Lockheed Martin
3:25 p.m.	Push-Me/Pull-You Asteroid Deflection Demonstration	JOHN BROPHY NASA Jet Propulsion Lab
3:40 p.m.	Break	
3:50 p.m.	Multiple Independent, Small Vehicles for De-tumble and Redirection	SCOTT SEVCIK Prospect Dynamics
4:05 p.m.	Utilization of Surface Material for Asteroidal Deflection	ROB MUELLER NASA Kennedy Space Center
4:20 p.m.	The Solar Collector Option for Maneuvering Near Earth Asteroids	ROB ADAMS NASA Marshall Spaceflight Center
4:35 p.m.	The ISIS Mission: An Impactor for Surface and Interior Science	STEVEN CHESLEY NASA Jet Propulsion Lab
4:50 p.m.	Impactor and other Deployable Devices for Planetary Defense Demonstration	JONATHAN WROBEL* Honeybee Robotics
5:05 p.m.	Initial Discussion and Synthesis	
5:25 p.m.	Summary – End of Deflection Session	

*Virtual Presenter

Appendix D: Asteroid Capture Systems Presentations

DAY 2 – THURSDAY, NOVEMBER 21

Asteroid Capture Systems | Berkner Room | #CatchAsteroid

Jasen Raboin & Andre Sylvester

TIME	TOPIC	SPEAKER
8:00 a.m.	Session Introduction	JASEN RABOIN NASA Johnson Space Center
8:05 a.m.	Background on Asteroid Capture Mission	BRIAN WILCOX NASA Jet Propulsion Laboratory
8:15 a.m.	Asteroid research and modeling to improve understanding of small asteroid properties	DANIEL SCHEERES Univ. Colorado Boulder
8:30 a.m.	Anchoring system, lasso snare capture system	ERIK MUMM* Honeybee Robotics
8:45 a.m.	Two concepts for deployable capture bag using integral ribs or expanding hoops and telescoping booms	KENNETH STEELE ATK Space Systems
9:00 a.m.	Extendable/Retractable Boom Capture System	SCOTT BELBIN NASA Langley Research Center
9:15 a.m.	Use under-actuated linkages for robotic grasping of asteroid	PAUL FULFORD MDA Canada
9:30 a.m.	Assessment of alternative capture system concepts	CARLOS ENRIQUEZ Boeing
9:45 a.m.	Momentum exchange tether to de-spin asteroid	HAROLD GERRISH NASA Marshall Space Flight Center
10:00 a.m.	Nanosat deploys net to capture asteroid, then deploys multi-kilometer long tether to de-spin asteroid	JEFF SLOSTAD Tethers Unlimited
10:15 a.m.	Airbeam inflatable tubes deploy capture bag	ALLEN LOWRY Airborne Systems
10:30 a.m.	Asteroid redirection vehicle with solar electric propulsion and AstroMesh-based capture mechanism	HOWARD ELLER Northop Grumman
10:45 a.m.	Group Discussion	
11:55 a.m.	Summary – End of Capture Systems Session	ANDRE SYLVESTER NASA Johnson Space Center

*Virtual Presenter

Appendix E: Crew Systems for Asteroid Exploration Presentations

DAY 2 – THURSDAY, NOVEMBER 21

Asteroid Crew Systems | Lecture Hall | #AsteroidCrew

Steve Stich & Mark McDonald

TIME	TOPIC	SPEAKER
1:30 p.m.	Session Introduction	STEVE STICH NASA Johnson Space Center
1:35 p.m.	Asteroid Exploration Module with airlock and docking ports to augment Orion capabilities	MICHAEL RAFTERY Boeing
1:51 p.m.	Orion mission kit consisting of pantry module and robotic arm. Collaborating with MDA	DOUGLAS ROSS Lockheed Martin
2:07 p.m.	Anchoring, sample acquisition, and ISRU approaches for asteroids	JONATHAN WROBEL* Honeybee Robotics
2:14 p.m.	Anchoring and sample collection devices	JONATHAN WROBEL* Honeybee Robotics
2:23 p.m.	Self-anchoring microgravity drill for use by crew to sample asteroid	AARON PARNESS NASA Jet Propulsion Laboratory
2:30 p.m.	Mobile robot with microspline anchors	AARON PARNESS NASA Jet Propulsion Laboratory
2:39 p.m.	Robotic manipulators, EVA tools, and human-robotic collaborative systems	PAUL FULFORD MDA Canada
2:50 p.m.	Free-flying camera for asteroid inspection; tether system to anchor crew; space utility vehicle for EVA	DAVE AKIN* University of Maryland
3:01 p.m.	Electrodynamic dust shield, pneumatic regolith rake, percussive excavation shovel	ROB MUELLER NASA Kennedy Space Center
3:12 p.m.	Telescoping booms for astronaut translation and EVA tools	DOYLE TOWLES ATK Space Systems
3:23 p.m.	ARV with robotic manipulators can be used to berth spacecraft with Orion and assist the crew during EVA	JOHN LYMER Space Systems/Loral
3:34 p.m.	Oceaneering has expertise in developing EVA suits and tools	FRANK EICHSTADT Oceaneering Space Systems
3:45 p.m.	EVA systems, robotic systems, and simulation and training	BENJAMIN REED NASA Goddard Space Flight Center
3:56 p.m.	Break	
Discussion Facilitated by Steve Stich		
4:10 p.m.	Extensibility	
4:30 p.m.	Anchor Technique Trades	
4:44 p.m.	Translation and EVA Tool Trades	
5:04 p.m.	Additional Mass Delivery for Utilization	
5:18 p.m.	Panel Observations/Forward Work	
5:28 p.m.	Summary – End of Crew Systems Session	STEVE STICH NASA Johnson Space Center

*Virtual Presenter

Appendix F: Partnerships and Participatory Engagement Presentations

DAY 2 – THURSDAY, NOVEMBER 21

Partnerships & Participatory Engagement | Lecture Hall | #asteroidPartners

Jason Kessler & Jenn Gustetic

TIME	TOPIC	SPEAKER
8:00 a.m.	Session Introduction	JASON KESSLER NASA Headquarters
8:10 a.m.	Asteroid Initiative Unique Opportunities	MICHAEL O'HARA Aerojet Rocketdyne
8:20 a.m.	Restore Satellite Servicing Partnership Approach	BO NAASZ NASA Goddard Space Flight Center
8:30 a.m.	Sunjammer Technology Demonstration Mission	CHARLES CHAFER Space Services Holdings, Inc.
8:40 a.m.	Questions	
8:55 a.m.	Break	
9:05 a.m.	Robotic Precursor Partnership	CHRIS LEWICKI* Planetary Resources
9:15 a.m.	Comprehensive Demonstration Plan	SCOTT SEVCIK Prospect Dynamics
9:25 a.m.	Commercial Asteroid Development Initiative	DAVID GUMP Deep Space Industries
9:35 a.m.	Robotic Mission Support	ERIK MUMM* Honeybee Robotics
9:45 a.m.	Questions	
10:00 a.m.	Break	
10:10 a.m.	Expert and Citizen Assessment of Science and Technology (ECAST)	DAVID GUSTON* Arizona State University
10:20 a.m.	Learning from Natural Hazards and Communication Research	MARGARET RACE* SETI Institute
10:30 a.m.	Partnership to Develop an Asteroid Deflection Capability	JOE LEPORE Spacedesign Corporation
10:40 a.m.	A Program Based on This Initiative	TONY FREEMAN* NASA Jet Propulsion Laboratory
10:50 a.m.	Canadian Space Agency	JEAN-CLAUDE PIEDBOEUF Canadian Space Agency
11:00 a.m.	Questions	
11:15 a.m.	Group Discussion	
11:55 a.m.	Summary – End of Partnerships & Participatory Engagement Session	

*Virtual Presenter

Appendix G: Grand Challenge Presentations

DAY 2 – THURSDAY, NOVEMBER 21

Grand Challenge – Crowd Sourcing & Citizen Science | Berkner Room | #asteroidGC
Jenn Gustetic & Jason Kessler

TIME	TOPIC	SPEAKER
1:30 p.m.	Session Introduction	JENN GUSTETIC NASA Headquarters
1:40 p.m.	Spacewatch FMO and OSIRIS-REx "Target Asteroids!" Citizen Science Programs	CARL HERGENROTHER University of Arizona
2:00 p.m.	Large Synoptic Survey Telescope Project	TIM AXELROD* Large Synoptic Survey Telescope Corp.
2:20 p.m.	Contributions from Small Observatories to Asteroid Grand Challenge (Webcast)	RAY PICKARD* Bathurst Observatory Research Facility, Australia
2:30 p.m.	Amateur Involvement in Asteroid Observation	PETER BERRETT*
2:50 p.m.	Citizen Science and the Minor Planet Center	JOSE LUIS GALACHE* IAU Minor Planet Center
3:10 p.m.	A Crowdsourced Solution for Detection and Monitoring of NEA	PAUL COX* Slooh LLC
3:30 p.m.	Crowdsourced Asteroid Data Analyses and Algorithm Development	CHRIS LEWICKI* Planetary Resources
3:50 p.m.	Asteroid Citizen Science and TopCoder Global Crowdsourcing	ANDY LAMORA* TopCoder, Inc.
4:10 p.m.	Break	
4:25 p.m.	Discussion and Synthesis	
5:20 p.m.	Summary – End of Crowd Sourcing Session	

*Virtual Presenter

DAY 3 – FRIDAY, NOVEMBER 22

Grand Challenge – Next Generation Engagement | Lecture Hall | #asteroidGC

Jason Kessler & Jenn Gustetic

TIME	TOPIC	SPEAKER
8:00 a.m.	Session Introduction	JASON KESSLER NASA Headquarters
8:10 a.m.	Multiple Channel Engagement Model	KEVIN BERRY* Lifeboat Foundation
8:20 a.m.	Eyes on the Solar System and Asteroid Watch Enhancements	DAVID DELGADO NASA Jet Propulsion Lab
8:30 a.m.	XPRIZE Incentivized Prize Competition	ALEX HALL* X-Prize Foundation
8:40 a.m.	Asteroid Observation and Mission Simulation Automated Movie Production	ERIC DE JONG NASA Jet Propulsion Lab
8:50 a.m.	Questions	
9:05 a.m.	Break	
9:15 a.m.	Discussion	
9: 55 a.m.	Summary – End of Next Generation Engagement Session	

*Virtual Presenter

Appendix H: Workshop Session Leads

1. **Asteroid Observation:**
   Lindley Johnson, NASA Headquarters (Lead)
   lindley.johnson@nasa.gov

   Paul Abell, NASA Johnson Space Center (Co-Lead)
   paul.a.abell@nasa.gov

2. **Asteroid Redirection Systems:**
   Jim Reuter, NASA Marshall Space Flight Center (Lead)
   jim.l.reuter@nasa.gov

   Steve Sandford, NASA Langley Research Center (Co-Lead)
   stephen.p.sandford@nasa.gov

3. **Asteroid Deflection Demonstrations:**
   Dan Mazanek, NASA Langley Research Center (Lead)
   daniel.d.mazanek@nasa.gov

   Pat Troutman, NASA Langley Research Center (Co-Lead)
   patrick.a.troutman@nasa.gov

4. **Asteroid Capture Systems:**
   Jasen Raboin, NASA Johnson Space Center (Lead)
   jasen.a.raboin@nasa.gov

   Andre Sylvester, NASA Johnson Space Center (Co-Lead)
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5. **Crew Systems for Asteroid Exploration:**
   Steve Stich, NASA Johnson Space Center (Lead)
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   Mark McDonald, NASA Johnson Space Center (Co-Lead)
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6. **Partnerships and Participatory Engagement:**
   Jason Kessler, NASA Headquarters (Lead)
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   Jenn Gustetic, NASA Headquarters (Co-Lead)
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