A Response to the
Asteroid Initiative Request for Information

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Primary area that the response addresses: All.

Abstract: We comment here on all of the areas of the Asteroid Initiative Request for Information. In particular it appears that some type of precursor mission to a single asteroid or multiple asteroids will be required in order to properly characterize the target asteroid(s). Such a step will be necessary in order to sufficiently reduce the risk to any ARM, demonstration deflection mission, or human mission to an asteroid and greatly increase the science return and exploration and resource development potential of any such bodies. It is also necessary to do substantial and early instrument development, development of standards and methods for instrument calibration, and development of various standards, algorithms, software, and procedures, in order to accurately (with known levels of accuracy) and robustly determine fundamental parameters of any target asteroid, such as size, shape, density, and internal structure. Most of these issues have already been discussed in Archinal et al. (2012) – an extended abstract for the *International Workshop on Instrumentation for Planetary Missions*, Archinal et al. (2013) – an extended abstract for the *Planetary Defense Conference*, and Nefian et al. (2013) – a NASA TM publication and white paper from NASA Ames Research Center about the needs for small body mapping.

System concept: none

Development approach: none

Introduction

We are replying here to the NASA "Asteroid Initiative Request for Information", NASA Solicitation Number: NNH13ZCQ001L (http://prod.nais.nasa.gov/cgi-bin/eps/synopsis.cgi?acqid=156731). Our main point is that for any type of asteroid mission, -whether an asteroid return, mitigation, robotic, or human exploration mission – reconnaissance and characterization of the object will be required in order to minimize risk, assure the full value of the science or exploration return, and provide a reasonable assurance of mission success. We also see currently unmet needs for the development of new and more advanced remote sensing instruments, and perhaps even more importantly, algorithms and software to process the data from such instruments in order to provide the necessary measurements and mapping products for such missions, as well as robust estimates of the uncertainties of such information.

We have recently written about many of these issues, calling out the unmet needs for processing current and future planetary data sets (Archinal et al., 2012), the need to develop new algorithms, software tools, standards, and processing methods for collecting data at and mapping small bodies (Nefian et al., 2013) and in particular what type of close characterization of small bodies, particularly asteroids, will be required for mission support (Archinal et al., 2013).

In the remainder of this response we address the six areas of interest listed in the RFI.

We welcome any requests for clarification or additional information. With adequate funding, we can also help substantially with mission design, instrument design and calibration, development of calibration and standards requirements, processing algorithm and software development, and product generation and quality and accuracy evaluation.

1. Asteroid Observation

As we have already described (Archinal et al., 2013) any type of primary mission to an asteroid (e.g., asteroid capture, mitigation, or human missions) will require support in the form of close characterization of the target. This is necessary in order to minimize risk, assure the full value of any science or exploration return, and to achieve an acceptable assurance of mission success. In situ mapping, whether by a precursor mission or as the initial phase of the prime mission is the only way to adequately characterize the parameters listed in the RFI, and in particular the all-important size, shape, and density of the target body. Knowing those parameters and their uncertainties and keeping those uncertainties low (e.g. at the ~1 meter level for size and shape for a sample return mission) will be required for any successful mission to a small (e.g. few to 15 m sized) asteroid. Initial estimates of these types of parameters from telescopic observations (whether Earth or space based) may suffice to select possible objects for study, but an operational mission to such a target will require greater precision that can only be achieved by close-range observations from flyby, orbital, or station-keeping .

In addition to the need for this knowledge, as we have explained at the last two SBAG meetings (e.g. see the second portion of http://www.lpi.usra.edu/sbag/meetings/jul2013/presentations/Titus.pdf), there is also a critical need to do cartography planning and develop key technology to obtain such knowledge (i.e., there are "strategic knowledge gaps" in the parlance of Mike Wargo of HEOMD and the NASA "AG" groups). Critical gaps include determining the methods and accuracy of instrument calibration needed to support mapping at the accuracies needed for mission success; development of software and even fundamentally new algorithms for processing observations of highly irregular bodies, developing approaches for rigorous combination of disparate data (e.g., lidar, optical images, and radar) from multiple instruments and spacecraft, and vastly accelerated processing capabilities that can provide products to support decision making in real or near real time as opposed to the months to years for the current state of the art. There is also a recognized need for the development of some type of "tomographic" radar instrument, capable of doing tomographic measurements of the density and mass distribution of the target in order to reduce risk and assure mission success (again, for any type of small body mission), and we emphasize again that the development of new instrument types must be matched by the development of the processing capabilities needed in order to exploit the raw data. These and several other such needs are listed and described in much more detail in the three references, and in particular the NASA Ames white paper on small bodies (Nefian et al., 2013).

We perceived a clear consensus during the NEO2 and SBAG meetings held the week of 7/8/12 that any "asteroid return" mission absolutely must achieve the objective of capturing an asteroid in order to be considered a successful and useful mission. (Similar statements have also been made in many places in the popular press.) The rationale, stated by NASA officials, that a mission that merely demonstrates an advanced ion drive and solar array could be considered fully successful simply does not make sense to us or to many others. It appears unlikely that the American public, and indeed the planetary science and NASA community, would accept the expense of a few billion dollars to only achieve only that goal, particularly when actually capturing the asteroid and allowing a later human mission to it are the publically stated goals (and for that matter with "return" even included in the current name) of such a mission. Flying an asteroid retrieval mission (ARM) without prior close characterization runs the serious risk that the target will turn out to be too large, too irregular in shape, or too massive to be returned. A poorly characterized target could even turn out be a spent rocket booster, as many of the currently considered objects likely are. In either of those cases the mission would be widely considered completely unsuccessful, no matter what its formal mission success criteria might be. And of course such an outcome would preclude any human mission to such an object as well, thus resulting in that mission being considered unsuccessful, even before it is undertaken. Therefore detailed reconnaissance, most likely by a precursor mission, is absolutely necessary in order to reduce the risk of such a failure to acceptable levels.

As an alternative to a stand-alone mission, obviously the ARM itself could be fitted with the types of sensors needed for target characterization and could evaluate the asteroid upon arrival in the vicinity. The disadvantage of this approach is that provision must be made for the ARM spacecraft to continue to one or multiple further targets in order to find one that meets the requirements of the mission. This would probably take longer than for a separate smaller, simpler, and lower cost precursor mission to be designed, built, and flown, and locate such a target independently. Such a mission could be well underway before an ARM was even launched, or at least while it was initially enroute and during a period where new target selection for the ARM could be done.

NASA should also consider performing a multi-asteroid rendezvous, reconnaissance, and characterization mission. Such a mission would be of tremendous value whether an ARM was to be done or not. Such a mission could – a described above – be a precursor to an ARM, but could also provide for the demonstration of the advanced ion drive and solar power collection technology just as well as an ARM. However, it would avoid the cost and risk of an unsuccessful asteroid capture mission (and the development of the capture technology, which would be used for little else, including mitigation (deflection) missions to what would be much larger objects). Such a mission would provide a fantastic science return, tremendous world-wide public interest, and detailed characterization of many asteroids. The knowledge gained would be invaluable for planning for any future asteroid missions, whether for ARM, a mitigation (deflection) demonstration, robotic in situ operations, or future human missions, and for providing extensive ground truth information about many types of asteroids. Such knowledge will be essential in sufficiently reducing the risk of failure or even loss of life in the case of human missions. One could argue that such a mission would result in the delay of any ARM and the corresponding human mission to any captured asteroid, but since some such mission is necessary at least to the initial target body, any such delay would only result in a much higher assurance of eventual mission success. It is also possible that an ARM and a human mission to a captured asteroid could be by passed entirely because such a multi-asteroid mission would provide greatly increased assurance that a suitable target for a much more desirable human mission to an NEO in its natural environment. This is clearly the type of mission as envisioned by President Obama that would truly provide us a start on the deep space experience required for a trip to Mars. The science return from such a multiple object mission would be nearly unimaginable and could prove as the Rosetta stone for understanding the solar system, its early history, and the early history of the Earth. Such an understanding would also be critical for the exploitation of such bodies for their resources, whether by NASA for exploration (for oxygen, fuel, and construction materials) or by private enterprise for commercial use. The understanding that such a mission would provide could be the critical step in allowing for the expansion of the human economic sphere into space.

2. Asteroid Redirection Systems

Many of our comments above are also applicable to topics 2 b and 2 c. Our primary point is once again that if a precursor mission is not made to the asteroid in question, the ARM itself must be capable of close characterization of the asteroid, and capable of moving on to additional targets if the initial target is examined and cannot be captured or returned to the Earth-Moon system, e.g. due to its size, shape, or mass. Under this heading we will expand somewhat on the nature of the sensors needed for characterization of asteroid targets; the conclusions apply equally to the various classes of mission being supported. Clearly a stereo imaging capability (either near real-time with two cameras, or less preferably with a single camera doing repeat imaging) would be required to obtain the basic parameters of the asteroid, although an integrated scanning or flash lidar system (integrated in the sense of being calibrated and having related boresights, and also in the sense of having algorithms and software to jointly process the data from both instruments), would provide additional robustness to the determination of such parameters and a reduction in their uncertainties. A framing camera – rather than a push broom camera – would be critical for this application so that spacecraft jitter would not affect the derivation of the final size and shape information. A multi- or hyper-spectral imaging system would also be needed in order to characterize the asteroid for composition and resources. As also noted above, tomographic radar would be desirable in order to map the internal structure and density of the asteroid. Such a system would ideally incorporate both a radar transmitter deposited on the surface or perhaps left in an orbit / station-keeping position, and a separate receiver (presumably on the main spacecraft) in some type of orbit or station keeping position that allows the volume of the asteroid to be swept out.

It is also appropriate to point out that we (the USGS Astrogeology Science Center) have the expertise needed to help design and calibrate such sensors (including development of the standards and procedures needed for calibration) in order to be able to derive necessary parameters and robust accuracy estimates for them, develop data processing algorithms and software, and do data processing, parameter estimation, map product generation, distribution, and archiving. No matter who does the work, much development of algorithms, software, and procedures will be necessary, as described and recommended in detail in the NASA Ames white paper (Nefian et al., 2013) but also described in the other two references (Archinal et al., 2012; 2013).

3. Asteroid Deflection Demonstration

Here again, it is important to recognize (as described in our paper (Archinal et al., 2013)) the need to do a close reconnaissance of any asteroid that is the target of a mitigation mission, whether as a demonstration or actual operational mission. All of the types of missions cited here would benefit – and might not otherwise be realistically possible – from such a reconnaissance. It is also likely that such a reconnaissance would be beneficial – if not critical from a results analysis perspective – after any deflection operation occurred in order to measure and quantify the effect on the object.

Sub-bullet c) here includes the "use of ARV instrumentation for investigations useful to planetary defense (e.g. sub-surface penetrating imaging)". As indicated above, radar tomography may be extremely useful in determining the interior structure and density variations of a given asteroid but will require the development of novel data analysis and display capabilities as well as instrumentation.

4. Asteroid Capture Systems

As pointed out in the RFI, "Asteroid composition, internal structure, and physical integrity will likely be unknown until after rendezvous and capture." Taken at face value, this is a recipe for mission failure. Once again, the target body to be captured *must* be characterized adequately in advance, either by a precursor mission or as an initial phase of the prime mission.

5. Crew systems for Asteroid Exploration

We do not wish to comment here on specific hardware that would be used by a human crew in the exploration of an asteroid. However it is critical to note that such a crew will require either real-time or very near real-time (e.g., overnight processing turnaround) mapping capabilities. Both Archinal et al. (2013) and Nefian et al. (2013) point out this need. Such a capability will be a requirement for visiting any object not previously mapped or that has undergone changes (due to mitigation or capture efforts). There will also be a critical need for remote sensing hardware and software tools so that the crew and any robotic assistants will be able to use mapping and gravity field data to safely navigate between their crewed vehicle(s) and the target, and on the surface of the asteroid.

6. Partnerships and Participatory Engagement

We comment here on several of the sub-headings of this topic.

b) What organizations are potential partners, and how can we involve a broad community?

We obviously consider ourselves, the USGS Astrogeology Science Center, as a potential partner in these efforts. This year is the 50th anniversary of what was then the USGS Branch of Astrogeology being set up by the USGS and NASA to help plan the Apollo missions, including training of astronauts and lunar mapping. The mission of Astrogeology was expanded to doing other planetary science and mapping work in the 1970's to the present. We remain the premier organization in the world regarding the development of planetary mapping algorithms, software, standards, mapping products, and planetary geologic mapping. We stand ready to help with such work for asteroids. We have already done extensive work on mapping small bodies and development of standards for such work. However, we currently have no funding in this area (aside from some to develop some specific instrument geometric camera models) and would need to be regularly and fully funded to further assist in the planning and development of remote sensing and mapping technologies for small body missions in general (as recommended in the various references) and for any given mission or instrument in particular. As to involving "a broad community", we are aware of and often collaborate with others who have some limited capabilities for this type of mapping work, both nationally and internationally, and can help in identifying possible further partners for such work and the further development of such capabilities.

e) What do we need to know with more certainty to expand planetary defense capabilities?

As just mentioned this is discussed at length in the references, particularly our Planetary Defense Conference paper (Archinal et al., 2013) and the NASA Ames white paper (Nefian et al, 2013). Among many others, there are needs to build and properly calibrate instruments, develop algorithms and software for data processing including for quick turnaround, and to devise validated methods of accuracy estimation for both size/shape/rotation parameters and the map products based on them. The latter type of validation is particularly necessary for the use of combined stereo and photoclinometry methods, which are currently in operational use (e.g. MESSENGER) and planned for use in future missions (e.g. OSIRIS-REx), despite the fact that they have never been rigorously tested and serious questions remain about their accuracy.

f) What other applications may result from investments in technologies to support the Asteroid Initiative"?

The algorithms, software tools (including calibration and uncertainties estimates and fusion of disparate data sets such as lidar and images) that must be developed in order to carry out an asteroid mission could also be applied to existing and future planetary datasets, revolutionizing the science return from many past and current missions. This applies not only to small bodies but will also be relevant to missions and bodies throughout the solar system (i.e. for the Moon, Mars and its moons, Mercury, the outer planet satellites, and Pluto). The same mapping tools will also be critical for preparation for geologic and resource mapping of NEOs and other asteroids in order to begin to estimate the commercial value of their mineral resources. Evaluation of such mineral resources on the Earth is one of the primary functions of the USGS, and the same role and methodologies can readily be extended throughout the solar system.

g) How do you see the Asteroid Initiative Contributing to our nation's future role in space?

Rather than try to comment on this question broadly, we address the specific types of applications already discussed here. As just indicated, the initiative will require the improvement and further development of algorithms, tools, and procedures to do planetary mapping and exploration work, thus benefiting all lunar and planetary exploration and science, as well as eventually benefiting the development of planetary resources for operational or commercial uses. If properly funded, such an initiative can also help with improving international cooperation, with collaborations on this type of mapping and exploration work, and various synergies leveraging and amplifying work now being done independently by different groups.

References:

Copies of these documents can be provided upon request or can be downloaded from the given web and ftp sites.

Brent A. Archinal, Randolph L. Kirk, Lazlo P. Keszthelyi, Lisa R. Gaddis, and Mark R. Rosiek (2012). "Can (and Will) the Data be Processed? Technology Development to Address Science Questions," International Workshop on Instrumentation for Planetary Missions (IPM-2012), Greenbelt, Maryland, October 10-12. Abstract no. 1151. Available as http://www.lpi.usra.edu/meetings/ipm2012/pdf/1151.pdf.

Brent Archinal, Randolph Kirk, Ken Edmundson, Mark Rosiek, Lisa Gaddis, Ara Nefian, Terry Fong, Ross Beyer, and Julie Bellerose (2013). "The Need for NEO Close Mapping and Characterization," in *2013 IAA Planetary Defense Conference*, 15-19 April, Flagstaff, AZ, in press. A copy of this is temporarily available at ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/barchinal/PDC2013/Archinal-mapping-paper-PDC2013_v3.pdf. A copy of the poster presentation itself is available as ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/barchinal/PDC2013/Archinal-mapping-poster-PDC2013_v0.pdf.

Ara V. Nefian, Julie Bellerose, Ross A. Beyer, Brent Archinal, Laurence Edwards, Pascal Lee, Anthony Colaprete, and Terry Fong (2013). "Human and Robotic Mission to Small Bodies: Mapping, Planning and Exploration - A Study for the Advanced Exploration Systems (AES) Joint Robotic Precursor Activities (JRPA) Project". NASA/TM–2013–216538, White Paper, July. A copy of this is temporarily available as ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/barchinal/SmallBodiesWhitePaper.pdf.