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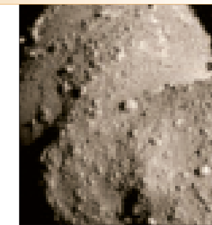


Finding NEOs: Stepping stones for human exploration

NASA'S ASTRONAUTS HOPE TO VISIT A nearby asteroid in the 2020s, but this November 8, near-Earth asteroid 2005 YU55 will come to us. In an unusually close flyby of Earth, the 400-m-wide, apparently carbonaceous body will pass within 0.85 lunar distances (330,000 km), enabling ground-based radars and telescopes to obtain high-quality topographical and compositional measurements.

This close encounter is serendipitous but hardly rare. On average, one 10-m object cruises past us within the Moon's orbit every day. But finding near-Earth objects (NEOs)—especially the ones that come closest to Earth—is a tough problem. Because they are typically both small and, in most parts of their orbits, distant from Earth, NEOs are often challenging for telescopes to see. Present ground-based observatories are just too limited in capability to find, on a practical time scale, the asteroids that we might target for robotic and human exploration .

Achieving NASA's 2025 asteroid exploration goal depends on a robust set of target objects, discovered early enough to design hardware and develop operations plans. (Dan Durda, SWRI)

Although more than 8,000 NEOs have been discovered by ground- and space-based searches, and more than a million sizable bodies make up the NEO population, we have barely begun to search for those asteroids that make the best human mission candidates. Last February's 'Target NEO' international asteroid workshop reported that today we know of just *one* object with the right size, orbit, and proximity to make a worthy exploration target.

To meet President Obama's 2025 asteroid mission goal, managers must identify enough 'accessible' asteroids to enable planners to develop NEO mission concepts well in advance. But finding enough sizable NEOs in accessible orbits is a daunting task. Using current ground-based techniques, we will not find enough mission-worthy candidates in time, said the Target NEO participants. The workshop experts recommended that NASA launch a space-based search telescope as its highest priority in pursuing the 2025 goal (see www.TargetNEO.org).

Why NEOs?

The president's 2010 decision to make an asteroid NASA's next human spaceflight goal came after his cancellation of the Moon-focused Constellation program. With the Moon out of the picture, nearby asteroids are the only celestial bodies within reach of NASA capabilities for the next couple of decades. Mars and its moons are just too far away for now, requiring round trips lasting at least 18-30 months. But some NEOs approach Earth so closely that missions lasting six months or less should be feasible.

Aside from attractive celestial mechanics, near-Earth asteroids hold out the promise of insights into planetary origins, water and other space resources, operations experience applicable to Mars, the civil engineering knowledge needed to divert a future Earth impactor, and the excitement of probing distant, alien worlds firsthand. With China openly hinting it will send taikonauts moonward by 2020, asteroid exploration can protect U.S. technological leadership and furnish the experience and resources necessary for the economic development of near-Earth space.

No matter how political sands shift in 2012, or what course our 'flexible path' in space takes, NEOs are likely experiential stepping stones to commercial opportunities in Earth-Moon space (water production, iron and nickel mining, strategic metals), and eventual human exploration of Mars.

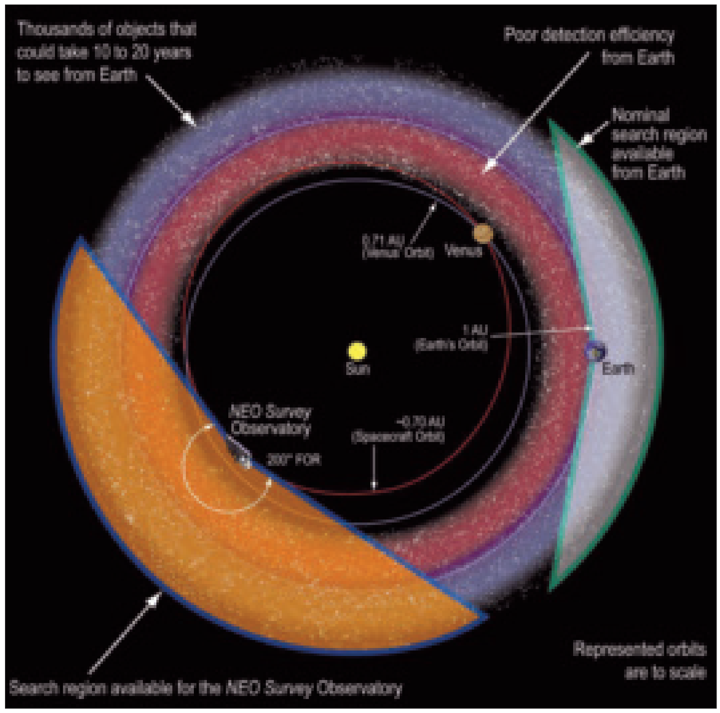
What is a 'good' target?

A reasonable target for astronaut exploration should have certain attractive characteristics. First, it should be large and complex enough to occupy the skills of astronaut explorers for at least a couple of weeks during the course of a multimonth journey. Thus a target NEO should be larger than, say, 30 m in diameter; a 100-m object would be a truly imposing presence, weighing in at about 1 million metric tons.

Second, the asteroid should offer a low-delta-V mission opportunity from Earth during the 2020s—'low-delta-V' means the round-trip mission should be less than the 9 km/sec of velocity change required for a lunar surface round trip.

Third, for crew health reasons (particularly radiation exposure), the mission should take no more than six months round trip.

Fourth, the target asteroid should enable in-situ demonstrations of various water- and metal-extraction processes. C-type asteroids are rich in carbon, organics, nitrogen, phosphorus, sulfur, and in some cases water; they would get my vote for a first astronaut visit. C-types can be selected via spectroscopic characterization, using Earth- or space-based telescopes. Eventually, astronaut expeditions should explore a representative spectrum of asteroid compositional types (perhaps about a half dozen) to give us a good sense of the range of asteroid mineralogical and physical properties.



A space-based NEO search takes advantage of orbital geometry. Earth-based telescopes are limited to Earth's night sky, but a sensor in an interior, Venus-like orbit will detect NEOs that will take decades to find from Earth. Complementary Earth- and space-based sensors will rapidly find both hazardous NEOs and the best targets for human exploration. (Ball Aerospace, NASA)

Finally, initial missions should avoid asteroids with chaotic or rapid rotation rates (less than a couple of hours), those circled by a natural satellite, or those surrounded by orbiting debris. Mission risk will be high enough without adding those hazards.

An impoverished catalog

Do any known near-Earth asteroids meet those criteria? NASA has been searching for NEOs larger than 1 km across for 15 years, and has found about 87% of the statistically predicted population. An impact from one of these could cause global disaster due to dust-induced cooling and subsequent agricultural failure.

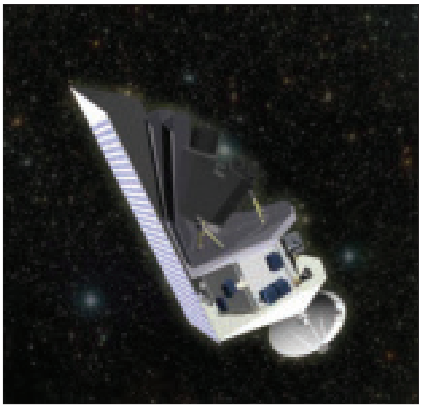
A byproduct of this Spaceguard Survey has been the discovery of many smaller NEOs, down to the size of pickup trucks (such as 2008 TC3, which struck Earth 19 hr after its October 2008 discovery). The current near-Earth asteroid tally is above 8,000, with discoveries accelerating as more sensitive search telescopes come online (see www.neo.jpl.gov).

Asteroids are best detected from the ground at opposition, when they are close to a line between Sun and Earth, with their full diameter illuminated by sunlight. Of course, an asteroid must be visible from Earth's night side to be seen by a ground-based telescope; nearby asteroids in the daytime sky are completely invisible to us. To find those objects from the ground, their orbits must carry them beyond Earth so they can be detected at opposition. Those asteroids—like the Atens, which spend most of their time in orbits interior to Earth's—are nearly impossible to detect from the ground, even with sensitive facilities like PanSTARRS and the planned Large Synoptic Survey Telescope. A good discussion is in the National Research Council's report, *Defending Planet Earth* [http://www.nap.edu/catalog.php?record_id=12842 #toc].

Another serious problem in finding asteroids with low-delta-V trajectories is orbital phasing. The most accessible NEOs have orbits much like Earth's, with semimajor axis close to 1 AU, and low eccentricity and inclination. Such an object exhibits long intervals between successive close Earth encounters, when it is 'in tandem' with Earth. That encounter is when a small asteroid is most likely to be discovered, and when a piloted mission is most feasible, but its Earth-like orbit means it will be a long time—a decade or more—before the asteroid is again close by. For example, one favorable candidate, 2000 SG344, was found in 2000, but its next favorable observation and piloted mission phasing will not recur until around 2028 or 2029.

The long intervals between Earth encounters,

NASA's newly selected OSIRIS-REx mission will sample C-type NEO 1999 RQ36, and return tens of grams of the organic and possibly water-rich asteroid to Earth in 2023.



The Near-Earth Object Survey spacecraft proposed by Ball Aerospace would prowl for hazardous NEOs and astronaut targets from a Venus-like orbit.

along with factors such as cloudy weather and confinement to searching only Earth's night sky, mean that for ground-based telescopes, many of the best asteroid targets may be discovered far too late for missions in the 2020s. In fact, we would have to discover them before 2015, a decade before their next Earth encounters in the mid-2020s. The stark conclusion from the Target NEO workshop was that ground-based surveys simply will not provide those discoveries in time.

Taking the search to space

Up to now, we've found most NEOs by waiting for them to come to us, in the clear night sky, relatively close to Earth. Target NEO presenters stated that at the present rate of discovery, only a few *tens* of accessible NEOs larger than 30 m in diameter will be found by 2025. That's too few to provide managers with an attractive set of targets and timely launch options. The only solution is to remove the geometrical blinders limiting our searches. We must find a 'mountaintop' for our observatory somewhere off the planet.

The ideal location is one that will enable us to get at those NEOs that orbit mainly in Earth's daytime sky, and to get more frequent opportunities to observe those objects in attractive, Earth-like orbits. An orbit closer to the Sun, like that of Venus, for example, gives us two advantages: First, a telescope there can look outward and see all those asteroids lost in the glare of our daytime sky; and second, it will circle the Sun in seven months, significantly faster than asteroids in Earth-like orbits. Like a race car on an inside track, the telescope will overtake those NEOs and shorten the interval between detection opportunities. The Venus-like orbit telescope will find more asteroids, and do it much faster, than observatories on the ground.

An infrared detector is best for finding NEOs. Relatively close to the Sun, they have equilibrium temperatures of 170-300 K, and glow brighter in emitted thermal wavelengths than in reflected visible light. The survey spacecraft design would feature passive cooling and perhaps an active 'chiller' to keep the IR detector at optimum performance.

A Ball Aerospace analysis showed that an infrared space telescope with an aperture of 0.5 m would find 90% of 140-m and larger asteroids in just over eight years, along with many smaller ones. The same spacecraft, derived from the successful Spitzer and Kepler designs, would find 80% of the astronaut-accessible NEOs larger than 60 m within two years of launch.

In May, NASA chose a similar IR telescope concept, called NEOCam, for technology development funding. As proposed by a JPL team led by Amy Mainzer, NEOCam would operate at Sun-Earth L1, a million miles sunward of Earth. Although this 0.5-m telescope would not have the inside track advantage of a Venus-like orbit, it would still find many asteroids in interior orbits by searching as close as 40 deg to the Sun, catching NEOs as they overtake Earth. Mainzer predicts that in 10 years of operation, NEOCam would find 90% of all objects larger than 140 m in diameter, fulfilling the goal of the George E. Brown planetary defense survey ordered by the Congress in 2005.

Timing is everything

Regardless of the particular spacecraft and sensor chosen, it is important to begin the search as soon as possible. The Target NEO report recommended we orbit a NEO survey telescope at least a decade before any human NEO expedition. If it starts the survey by 2015, then by the early 2020s NASA could tap a very large catalog of NEOs: There are an estimated 1 million objects 30 m and larger in the near-Earth population. Finding a significant number of these (even a 30-m NEO packs the kinetic energy of a Tunguska-sized, 3-5-megaton TNT explosion) will help us identify and track thousands of hazardous asteroids and give NASA's managers hundreds of suitable mission candidates.

The survey would cost about $500 million, roughly the cost of one NASA Discovery-class planetary mission. The results would not only enable astronaut mission planning, but would also furnish vital data for planetary defense, and for a scientific understanding of the raw ingredients of terrestrial planetary formation. The bottom line is that a timely NEO survey telescope is as important for human spaceflight goals and objectives as a heavy-lift booster, or NASA's projected multipurpose crew vehicle. We need it to find a robust target set for NEO exploration, and to reduce budgetary, operational, and mission-related risks.

Next steps for NEOs

With a space-based NEO telescope spitting out a flood of new asteroid discoveries, NASA could hit a series of milestones, culminating a decade later in its first astronaut expeditions. Follow-up ground observations or repeat glimpses from the space observatory would refine the orbits of attractive NEOs. Those with the most favorable orbits could be characterized in terms

Asteroid 2005 YU55 (seen in a 2010 radar image) will pass within the Moon's orbit on November 8. Goldstone and Arecibo radar observations should image surface details as small as 7.5 m, and create a shape model with 4-m accuracy.

of diameter, albedo, spectral class, estimated mineral composition, rotation rate, and the presence of companions (about 16% of known NEOs are binary objects). Several precursor missions could then explore the best candidates, making detailed measurements of topography, composition, physical properties, and operations hazards.

Attempts to meet such asteroid exploration milestones by 2025 must build steadily on progress from previous efforts. The entire process starts with approval and execution of the space-based NEO search. The Target NEO report recommended to NASA that it immediately begin a Phase A survey mission study to identify feasible instrument concepts, then compete the mission for early development and launch.

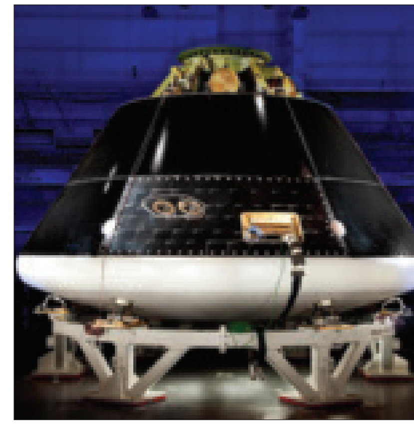
Agency leadership in this area would almost certainly see an international collaborative response from JAXA, the Canadian Space Agency, ESA, and others via proposed scientific and planetary defense asteroid missions such as Hayabusa II, NEOSSat (near-Earth object surveillance satellite), and Don Quixote.

Search synergy

NASA's own experts, including the NASA Advisory Council's 2010 ad hoc Task Force on Planetary Defense [http://www.nasa.gov/pdf/490945main_10-10_TFPD.pdf], cited the space-based survey as a top priority. The Target NEO report calls it the key to serious asteroid exploration. Rarely does one NASA project promise such enabling, cross-cutting results, delivering synergistic benefits to NASA's efforts in human exploration, planetary defense, science, and space resources, all for the price of a single planetary probe.

Limited funding and NASA's own organizational barriers have hurt the search. Traditionally, asteroid research has been sponsored by the Science Mission Directorate (SMD); however, its planetary exploration budget is already fully committed.

In late May the SMD selected the OSIRIS-REx (origins-spectral interpretation-resource identification-security-



Astronauts on future asteroid expeditions may use the NASA multipurpose crew vehicle, which is currently in ground testing at Lockheed Martin's Denver facility, to return them to Earth from a multimonth NEO mission. A NEO-capable spacecraft will require habitation and propulsion modules as well as a reentry vehicle. (Lockheed Martin.)

regolith explorer) NEO sample return as its next New Frontiers-class (around $800 million) mission; SMD on its own is unlikely to follow with another NEO-centered mission.

The Exploration Systems Mission Directorate (ESMD) has had no success in funding a line of robotic precursor missions. Planetary defense from rogue asteroids has yet to win NASA priority; the agency spends only about $6 million annually on ground-based NEO surveys and research. Yet early NEO detection via space-based search is the necessary precursor to developing any future asteroid deflection capability.

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As NASA looks for ways to build momentum toward its declared 2025 human spaceflight goal, the agency would do well to start with an affordable NEO survey mission that pays dividends in such a wide-ranging array of space activities. Getting that survey off the ground will be the surest sign that NASA, the White House, and Congress are committed to deep space exploration. The target for the first astronaut expedition to a NEO won't be discovered until we get serious about looking for it.

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