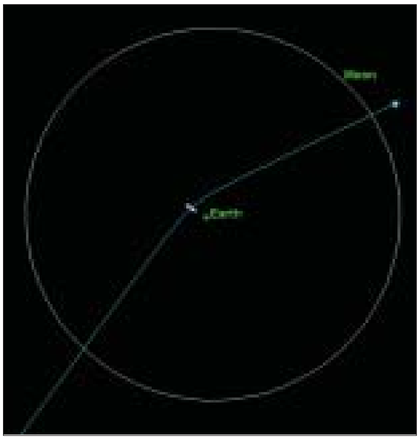
The View From Here

Stepping stones to Mars: The asteroid option

The U.S. and NASA are headed back to the Moon. By 2015, American astronauts should have the tools to enable them to reach the lunar surface, a thousand times farther from Earth than the International Space Station. After the Moon, the goal is Mars, an intriguing and complex world harboring frozen seas and, perhaps, traces of ancient life.

But the gulf looms large between us and Mars. From the Earth-Moon system, the distance is never less than about 56 million km (35 million mi.), nearly 150 times farther than the Moon. When the two planets lie on opposite sides of the Sun, they are nearly 380 million km (234 million mi.) apart. Robots blithely cruise between worlds, but NASA's new exploration initiative plans to bridge the startling distance with human explorers by 2030. The six-month one-way trip (with a mission duration of 2-3 years) will be a daunting test of human endurance.

The passage of asteroid 2004 MN4 by the Earth in 2029 will alter its subsequent trajectory and cause its position uncertainty region to expand rapidly as it moves away from Earth (that is, the line of white dots increases in extent). As a result, the asteroid's motion is much less predictable after the 2029 close Earth approach. Even so, the asteroid's uncertainty region is not large enough to extend to the Moon as it passes by, and so a lunar impact is not possible. Lance Benner (JPL), Mike Nolan (NAIC), Steve Ostro (JPL), and Jon Giorgini (JPL) provided the Arecibo radar data that made these updated results possible.



The NEA factor

The space between Earth and Mars is far from empty. Our planet orbits the Sun amid a swarm of small bodies known as near-Earth asteroids, or NEAs (short-period comets are a much smaller presence in the inner solar system). Hundreds of thousands of NEAs circle the Sun and approach Earth's orbit, but only a fraction of those are large enough to present an impact hazard to Earth. NASA estimates that about 1,100 are bigger than 1 km in diameter—with enough kinetic energy to threaten civilization. So far, under NASA's Spaceguard Survey, astronomers have charted the orbits of 762 such bodies.

Last year, a 300-m asteroid named 2004 MN4 caused a brief flurry of concern when orbital predictions showed it might strike Earth 24 years from now. Within a few days of Christmas, astronomers had additional observations in hand that ruled out an impact (which would be big enough to devastate Texas or the mid-Atlantic states, with the force of 10,000 megatons of TNT). But the object will still startle stargazers on April 13, 2029, when it misses Earth by just 40,000 km, about a tenth the distance to the Moon.

When we look up that evening to see 2004 MN4 sailing swiftly across the stars, we may view it as a breathtakingly close call. But if we plan well, the NEAs offer an opportunity—a chance to convert a peril to a potential resource. Such asteroids can be our stepping stones to Mars.

How asteroids fit the vision

Given the daunting challenges we must overcome to reach Mars, any approach that makes the journey easier, safer, and less expensive for human explorers should be considered. Our return to the Moon is driven in part by the possible presence of polar ice deposits, a resource that could provide an outpost with water, oxygen, and energetic propellants. At greater expense, we could also crack oxygen from the lunar regolith. These resources will eventually reduce the costs of supporting a lunar outpost, and provide surplus propellant for use in Earth-Moon space and beyond.

The president's suggestion in his vision announcement that the Moon's low surface gravity makes it an attractive place to assemble and launch Mars expeditions was probably a simple misunderstanding: The Moon's surface, at the bottom of a still-respectable gravity well, levies a heavy launch energy penalty on anything trying to leave. But there are nearby locations that do carry favorable gravitational "weight" as staging areas for Mars-bound spacecraft.

One such location is the Lagrange point called Sun-Earth L2, on the Earth-Sun line 1.5 million km beyond our own planet. Because of its gravitational stability, trajectory experts have long cited "SEL-2" as a useful spacecraft basing node; it is well positioned for both operation of large space observatories and efficient escape trajectories from the Earth-Moon system.

But of course at SEL-2, there is no "there" there. By traveling a bit farther, we can reach many NEAs, which offer both resources and an energetically attractive path for shipping them back to near-Earth space. Fifteen years ago, John Lewis, a planetary scientist at the University of Arizona, pointed out how a well-chosen NEA, with its small size and Earth-grazing orbit, makes departure for Earth about as easy as a space maneuver can be. At asteroid 4660 Nereus, for example, a given payload can leave the surface and return to Earth with a velocity change (delta-V) of only 60 m/sec^{-1} (just 134 mph). By contrast, Lewis noted, the return delta-V from the Moon is about 3,000 m/sec^{-1}.

We will have a wide choice of attractive asteroid targets. There are about

300,000 NEAs greater than 100 m in diameter (a 100-m NEA has a mass of roughly 1 million metric tons). A launch opportunity from Earth to a specific NEA occurs about every 2-4 years; thus, if we knew the orbits of 100,000 NEAs, we could expect a launch window to open about every 15 min.

The lure of water

A round trip to one of the best-situated NEAs requires less delta-V than a one-way trip to the lunar surface. But why should we make asteroids part of our vision for exploration?

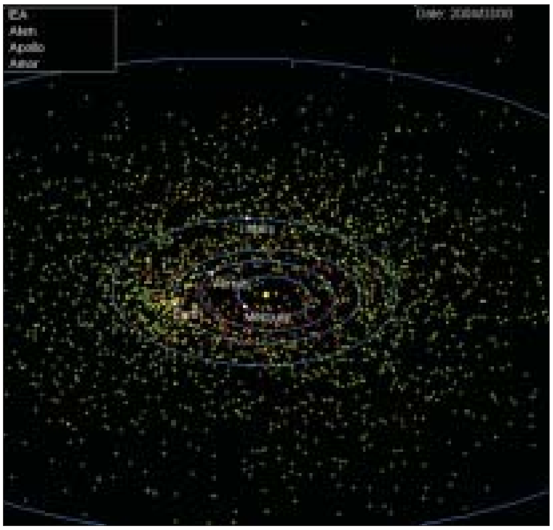
The first reason is resources. The NEA population may be the most attractive and practical source of shielding, propellants, metals, and refractory elements available to our exploration efforts. As Lewis and his colleagues noted in 1993, NEAs might provide life-support fluids for maintaining a lunar base, propellants for our Mars expeditions, or the building materials for large space structures like solar power satellites.

We know the water is out there, on the Moon or the asteroids, but locating it is the rub. If the Moon's reputed polar ice deposits prove illusory or impractical to exploit, we should turn to the plentiful NEA population. So far, we have found water in the surface minerals of only a single NEA. But some carbonaceous chondrite meteorites in our collections consist of minerals containing as much as 10% water by weight. If we can find the near-Earth asteroids that produced these "wet" meteorites, we can begin to extract this resource in quantity.

Extinct comet nuclei should comprise yet another segment of the NEA population, but it will take in-situ investigations to see if icy cores might be hidden under their dark, dusty surfaces.

Confirmation of accessible asteroidal water awaits detailed spectroscopic studies of the different compositional classes of NEAs. These studies will be followed by robotic survey and sampling missions to the most promising targets. As recent near-misses by a veritable barrage of NEAs illustrate, water-bearing objects are probably sweeping through near-Earth space continuously. It's as if we had discovered a water main at the edge of our front yard: Why should we drill a 100-ft-deep well near the porch when we can reach out a little farther and tap into a ready supply?

Armagh Observatory offers this map of the solar system, displaying the orbits of the terrestrial planets and the estimated position of thousands of known asteroids. There are over 300 known objects on Earth-crossing orbits. Terrestrial planets are shown in cyan or white squares, and their orbits are represented by the blue ellipses around the Sun (the yellow dot at center). Small green points mark the location of asteroids that are not approaching close to the Earth right now; yellow objects are Earth-approaching asteroids; and red boxes mark the location of the Apollo and Aten asteroids. These cross the Earth's orbit and are the most directly identifiable astronomical threat for the near future. It is estimated that there are perhaps 100,000-1 million undiscovered asteroids on similar Earth-crossing orbits.



Learning by doing

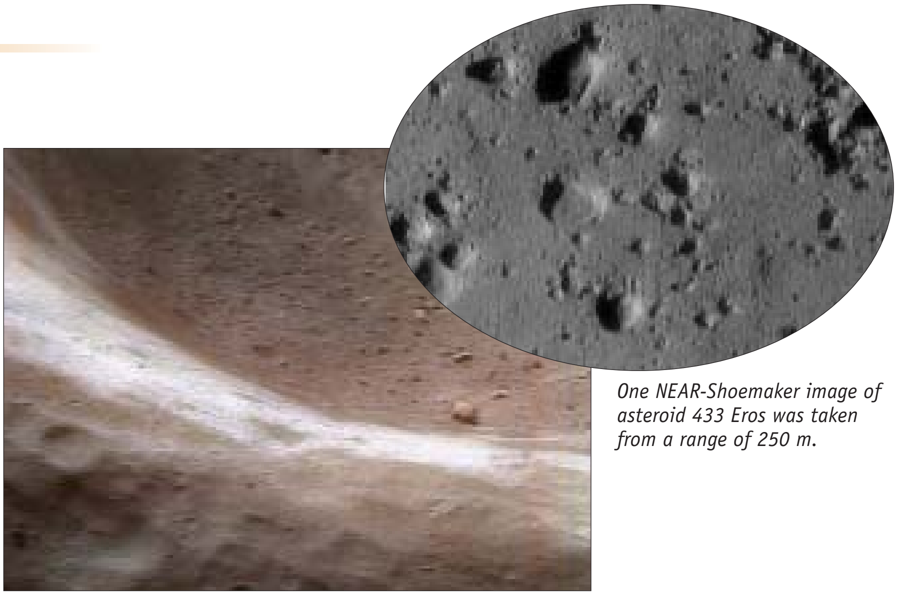
The second reason to incorporate NEAs into our exploration plans is our need for deep space experience. The Moon, just a few days away, is a good place to stretch our legs beyond LEO. But lunar operations are a far cry from a multiyear Mars expedition—propulsion, communications, life support, reliability, and autonomous operations requirements will be far more demanding. Russian cosmonaut Sergei Krikalev, now commanding Expedition 11 aboard the ISS, joined me in a 1995 paper to point out that NEA missions are an ideal intermediate step between lunar operations and the challenges of interplanetary flight.

253 Mathilde (59 x 47 km) is a dark asteroid imaged by the NEAR-Shoemaker spacecraft in June 1997. Fragments of main-belt asteroids like this one may carry water into orbits favorable to robotic and human resource exploitation.

Since then, mission planners have identified candidate round-trip asteroid missions that are less than 6 months in duration. Such mission profiles offer 2-3 weeks for surface operations on the asteroid, and the required delta-Vs are comparable to a lunar surface round trip. The astronauts would remain within about 0.1 AU of Earth—about 15 million km—and in case of a serious emergency could abort directly to Earth.

Such a shakedown mission could check out the major elements of the Mars expedition hardware—propulsion, life support, communications, field exploration gear, and autonomous command and control. The complex and expensive Mars lander would not be required.

If high-caliber scientific exploration is a prime motivator for our human spaceflight effort, then robotic and eventually human expeditions to the varied near-Earth asteroids would bring in a rich harvest of new data. The Moon and Mars are



One NEAR-Shoemaker image of asteroid 433 Eros was taken from a range of 250 m.

On June 14, 2000, NEAR-Shoemaker trained its camera on Eros' 5.3-km-diam crater to measure the properties of regolith inside the asteroid's craters. In this false-color view, taken from an altitude of 50 km, redder hues represent rock and regolith that have been altered chemically by exposure to the solar wind and small impacts. Bluer hues represent fresher, less-altered rock and regolith, such as the bright patches that have been less affected by "space weathering." In that process, during micrometeorite impacts, rock reacts with minuscule amounts of trapped solar wind and is chemically changed. Most of the large boulders have been just as affected as the regolith, suggesting either that the rocks are relatively old, or that they are "dirty" from an adhering film of regolith particles.

examples of two very different planetary bodies whose materials have been highly processed by impact, volcanism, tectonics, and weathering. Asteroids represent a third and very different class of planetary materials.

We know from meteorites that asteroidal matter dates to the earliest era of solar system history. Some of it has changed little since the dispersal of the solar nebula. The NEA parent bodies never grew large enough or stayed hot long enough to reprocess most of their original constituents; asteroids thus preserve the ancient raw materials of planetary formation. As we gain experience and resources at these bodies, we will also sample the very stuff from which Earth—and we humans—were formed.

Sustaining momentum

Another reason we should put NEAs on our path to Mars is to sustain the momentum of this new vision—a scientific, technical, and cooperative effort of unprecedented ambition. We might be back on the Moon within a decade. But following our lunar return there will necessarily be a long interval when we consolidate our gains and build our experience for the leap to Mars. During this phase, lasting a decade or more under the plan proposed by the president and NASA, we will find it difficult to marshal the political will and steady funding to press on.

Asteroid missions give us a way to keep moving forward on a third spiral of capability beyond LEO and the Moon. Venturing to an NEA is a dramatic way to show sustained progress, prove new flight hardware, and return new science and resources while preparing for Mars. Five years after establishing ourselves on the Moon, we could be ready for our first foray to an asteroid. Such an expedition, where astronauts will see the Earth dwindle to Carl Sagan's "pale blue dot," will inject excitement and fresh success into a complex program continually in need of political buttressing.

Taking care of home

Finally, it seems to me that our learning to grapple with the nearest asteroids has a common sense appeal—to put it simply, it's "homeland security." With as many as 300,000 potential catastrophes lurking near Earth's orbit, learning how to operate around and on an NEA seems prudent public policy.

Apollo 9 astronaut Rusty Schweickart and his fellow organizers of the B612 Foundation have called for NASA to mount a demonstration mission by 2015 to measurably alter the orbit of an NEA. He argues that this task is a better first use of NASA's Prometheus nuclear technologies than the extremely challenging Jupiter Icy Moons Orbiter expedition.

The asteroid demonstration, which requires the use of nuclear electric propulsion and a decent understanding of the physical characteristics of such bodies, will put our deep space know-how to use in a practical test that might one day save our civilization, should a rogue NEA out there have our name on it.

Natural next steps

I confess to having a soft spot for asteroids: They were the subject of my doctoral dissertation, and as a rookie astronaut I carried a tiny piece of water-rich meteorite—an NEA fragment—into space aboard the shuttle Endeavour. A favorite memory from my 2001 work aboard the space station was the moment when capcom Gerhard Thiele called me during my second spacewalk with a thrilling announcement: The NEAR-Shoemaker spacecraft had just soft-landed on asteroid 433 Eros. Our shuttle and station crews were the closest human explorers to that historic event, the first machine from Earth to touch the ancient surface of an NEA. I shivered with excitement even as the Sun warmed the thick layers of my space suit. "I hope it won't be too long before we're spacewalking on an asteroid like Eros," I radioed Gerhard in Mission Control.

If in the next several decades we discover a cousin of 2004 MN4 that has Earth in its cross-hairs, we'll need all the operations and technical experience we can get. NASA should expand its ground-based observations of the NEA population, searching for subkilometer objects both to rule out future impacts and identify attractive mission targets. It should begin a fresh campaign of robotic missions to "local" asteroids, with increasingly sophisticated mission goals and capabilities.

Our spacecraft should sample selected asteroids, take their physical measure, and demonstrate an ability to alter their course in space and time. As our knowledge increases, we should make these resource-laden chunks of rock into the cornerstones of our plans for operating across the solar system. When that long journey at last begins, the near-Earth asteroids will enable us to reach neighboring worlds—and make it affordable to stay there.

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