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Stormy outlook for weather satellites

A conversation with Sean O'Keefe

New thrust for solar electric propulsion

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Delivering on a promise to Columbia's explorers

In the skies today we saw destruction and tragedy. Yet farther than we can see, there is comfort and hope. In the words of the prophet Isaiah, "Lift your eyes and look to the heavens. Who created all these? He who brings out the starry hosts one by one and calls them each by name."

Mankind is led into the darkness beyond our world by the inspiration of discovery and the longing to understand. Our journey into space will go on.

—President George W. Bush, February 1, 2003

On the day shuttle Columbia's crew perished returning from a U.S. scientific expedition to space, President Bush comforted the astronauts' grieving families, and vowed that "the cause in which they died will continue." Ten years later, the crew of Columbia would not recognize the nation's space program. Today, few Americans know where we are bound in space, when we will get there, or why we are going. Many think that with the shuttles gone, our nation's space program has effectively ended.

True, four or five Americans visit and work aboard the international space station each year. But we won't reach the ISS again with crewed commercial rockets until 2015 at the earliest. NASA's heavy-lift ride to orbit, the Space Launch System (SLS), will not make its first test flight until 2017. The deep-space Orion craft it will carry will not transport a crew until after 2020. Astronauts are no closer to deep space than they were a decade ago.

Three years ago, President Obama directed NASA to mount a piloted asteroid expedition by 2025. At its current pace, the agency will not have the necessary knowledge or hardware to execute such a mission by that target date. What NASA desperately needs is consensus on near-term goals for clear progress toward deep space *in this decade*. They must be practical, carry an affordable price tag, and yet demonstrate real movement toward exciting, ambitious exploration in the 2020s. We can reverse our decline in space with a fresh commitment to near-term action.

How are we doing?

Declining budgets and White House-congressional wrangling over space policy have hindered NASA's progress toward the asteroid expedition goal. An enabling, dedicated search program to find attractive near-Earth asteroid (NEA) targets has yet to materialize. Orion and the SLS, even if ready by 2020, will not have the endurance and performance to reach nearby asteroids, which typically require round-trip times of six months or more. A practical NEA expedition will also need a small habitat for consumables and extra living space. The vehicle will require augmented propulsion and solar power systems, and its crew will need new spacesuits as well as mobility and anchoring gear for NEA surface exploration.

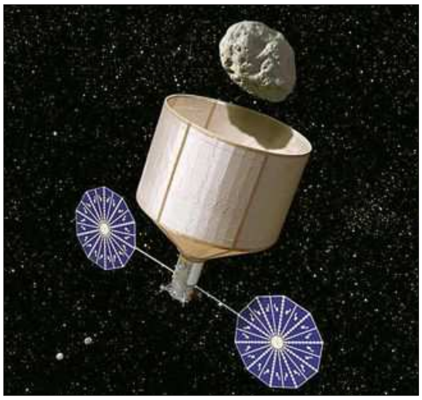
Inflatables like the Bigelow Expandable Space Module, after testing at ISS, may serve as deep-space habitats for sorties throughout translunar space, and on piloted near-Earth asteroid expeditions. Image courtesy Bigelow Aerospace.

There are a few positive signs. NASA and the B612 Foundation signed a Space Act agreement to support the latter's privately funded deep-space Sentinel NEA search telescope. But B612 has just begun to raise the estimated $400 million for Sentinel. Although designed primarily for planetary defense, the telescope will also provide NASA with a sizeable catalog of candidate asteroid targets.

The agency announced a $17.8-million agreement in January with Bigelow Aerospace to explore the feasibility of attaching the firm's inflatable module to the ISS. The Bigelow expandable activity module, or BEAM, would expand the station's storage and habitation space, and is one candidate for providing deep-space Orion crews with more elbow room.

New ideas

As the government's discretionary budget declines, NASA managers fear that continued lack of action on beyond-LEO exploration could lead to cancellation of the entire deep-space effort. Anxious to avoid a repeat of Constellation's sorry denouement, the



ARM, evaluated by the Keck Institute for Space Studies, could place about 500 tons of ancient, resource-rich asteroidal material in translunar space. ARM would be a robotic component of NASA's prospective plans for establishing astronaut explorers in translunar space in the 2020s. The 7-m asteroid could serve, in addition to the Moon, as a major focus for astronaut activity on sorties near the Earth-Moon L2 point. Credit: Keck Institute for Space Studies.

agency is said to be seeking near-term steps it can take to advance its human spaceflight timetable.

Reports surfaced late last year that NASA would propose to the White House creation of a deep-space outpost near the Earth-Moon L2 Lagrange point. Although official plans depend on the president's 2014 budget proposal (delayed until this month), the bare outline discussed by NASA observers centers on a crew-tended 'line shack,' comprising a habitat, docking port, and propulsion module, delivered to EM L2 by the SLS. Orion crews would visit the outpost for several weeks at a time, engaging in remote sensing, radio astronomy, and telerobotic operation of rovers on the lunar far side. Hardware, consumables, and propellant could be built and delivered by international partners or commercial launch services.

NASA would use such a mobile outpost to gain deep-space experience in advance of NEA missions planned for the later 2020s. In addition, EM L2 would provide a gravitationally advantageous jumping-off point for other destinations beyond the Moon. Expeditions could follow to the EM L1 point (between Earth and Moon), Sun-Earth L2 (about a million miles beyond Earth), and eventual voyages to nearby NEAs and the lunar surface.

A major criticism of a translunar outpost is that proposed activities there do not justify the expense and risk of astronaut visits. NASA must identify some challenging mission in translunar space to engage its crews and bridge the decade or more before NEA or lunar expeditions can begin. Current policy rules out the Moon's surface, so NASA is now examining another target to fill the vacuum: astronaut visits to a small, roughly 500-ton asteroid returned to a safe high orbit around the Moon or EM L2.

Asteroid retrieval mission

NASA Administrator Charlie Bolden told a National Research Council committee in mid-December 2012 that meeting the president's 2025 asteroid goal does not necessarily mean astronauts must travel a great distance. Observers took this to mean that Bolden's team was considering the merits of a robotic asteroid retrieval mission (ARM), proposed nearly a year ago by the Keck Institute for Space Studies (this author was a study team member and wrote about the concept in *Aerospace America*. See "Snaring a piece of the sky," May 2012, page 18).

The Murchison CM2 carbonaceous chondrite meteorite, recovered after it fell in Australia in September 1969, represents the type of asteroid material of high value to science and industrial use of space resources. Murchison contains 12% water, 22% iron, aromatic hydrocarbons, and amino acids; an asteroid of similar composition would make an attractive target for sampling and retrieval. Courtesy Chip Clark, Smithsonian Institution.

The ARM concept proposes that a solar electric spacecraft capture and transport a 7-m-diam., 500-ton NEA back to translunar space for astronaut exploration. Orion crews aboard the L2-based translunar vehicle would visit the NEA repeatedly, returning valuable information for science, planetary defense, and the future use of space resources. The returned NEA would anchor NASA's translunar science and commercial activities for a decade, until the U.S. is ready for voyages to larger NEAs, Phobos, Deimos, and Mars.

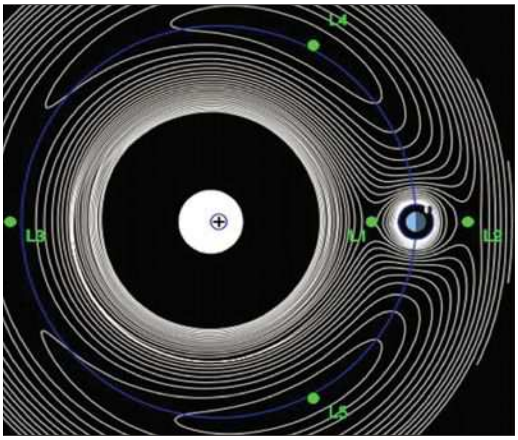
The asteroid retrieval concept is a timely one for the agency's human spaceflight program. NEA search telescope technology has improved and soon will enable NASA to discover and characterize small NEAs as they make close approaches to Earth. Solar electric propulsion technology has also matured—a 40-kW, xenon-fueled system is now capable of transporting a 500-ton asteroid into a high, safe lunar orbit. Finally, NASA plans to have astronauts reaching translunar space in the mid-2020s, at just the right time to explore, dissect, and exploit hundreds of tons of ancient asteroid material, rich in volatiles, metals, and organic compounds.

Recent presentations to NASA and the European space community by the KISS study leaders have outlined how an ARM mission would unfold. First, a low-cost, ground-based search program would identify about five suitable small asteroids annually. From that set, NASA would select a 7-m, 500-ton NEA with spectral properties like those of volatile-rich, carbonaceous chondrite meteorites. An Atlas V-551 booster would launch an 18-ton capture spacecraft into LEO. Deploying a pair of 10-m solar arrays, the vehicle would use five Hall-effect ion thrusters to begin an upward spiral, taking roughly two years to escape Earth completely.

The ARM craft would take about two more years to reach the target asteroid. During a three-month survey period, spacecraft sensors would examine the spin state, shape, and composition of the asteroid. Using hydrazine reaction jets to match the NEA's rotation rate (much like the Pan Am shuttle closing on the 'big wheel' station in *2001: A Space Odyssey*), the craft would deploy a rib-and-fabric capture mechanism whose maw is wide enough to engulf the object.

The spacecraft would then maneuver to pass the extended bag over the object. Closing shut like the legs of a spider, retracting limbs would restrain the asteroid within the fabric envelope and position it against a thrust ring. Using just 300 kg of RCS fuel to despin the 500-ton mass, the craft would then reactivate its ion thrusters to begin the long transit to the Earth-Moon system.

After a 2- to 6-year voyage, the craft would combine a lunar gravity assist and solar-electric power to achieve a high lunar orbit. This 'distant retrograde orbit' is stable against loss of control for a century or more; even then, orbital perturbations could only culminate in a lunar impact. Another layer of safety stems from the carbonaceous asteroid's small size and low physical strength, like that of dried clay: An errant 7-m asteroid would break up harmlessly in Earth's atmosphere. (Only NEAs larger than 30-40 m can survive atmospheric entry to cause damage.)



Lagrange Points in the Earth-Moon system: L2 (at right) provides direct viewing of the lunar farside about 60,000 km beyond the Moon's orbit. Credit: SpudisLunarResources.com.

A valuable grab bag

A number of valuable benefits would be returned with the captured asteroid. First, NASA would position in translunar space a new destination that *requires* astronaut presence for full exploration and exploitation. Coordinated EVA and robotic activity will be necessary to unwrap, examine, and dissect the boulder-sized asteroid.

Second, for about $2.5 billion (the cost of the Curiosity rover mission), NASA obtains near-term operational experience for astronauts working around and with a small asteroid, its physical surface, its mineralogy. This experience is a valuable bridge to later, deep-space sorties to larger, more challenging and distant NEA targets, or the Martian moons.

Finally, the capture, transportation, examination, and dissection of a small NEA provides valuable knowledge about the structure and makeup of NEAs, and is in fact a deflection demonstration—insurance against a future rogue asteroid headed for Earth impact. Although solar electric propulsion is not the only option for deflection, actually moving a small NEA builds solid confidence in our ability to prevent a future catastrophe.

Commercial opportunity

'Commercial' is the current NASA watchword, and putting astronauts in close contact with 500 tons of asteroidal material opens a new and exciting economic frontier. If similar to volatile-rich carbonaceous chondrites, the raw materials could jump-start an entire industry to harvest resources such as water, metals, shielding material, and industrial chemicals. Orion crews could return multiple samples, of many kilograms each, for analysis and process development on Earth and in free fall at the ISS.

Provided with regular access to the asteroid, international partners and private companies (like asteroid mining startups Planetary Resources and just-announced Deep Space Industries) could test anchoring, sampling, and extraction techniques. A simple solar collector could deliver enough heat to drive water gently from the hydrated silicates typical of these asteroids; a 7-m object could easily contain 100 tons of H_2O. At current launch prices, that water would cost about $5 billion to deliver to LEO, and much more to the Moon's vicinity. Eventually, NASA and its partners could turn over the processing of this and other asteroidal material to private firms; the first customer would be NASA itself, buying oxygen and hydrogen propellant for use in translunar space.

There are plenty of such asteroids to go around. The NEA population contains an estimated 100 million objects 10 m in diameter or larger. If they can be tapped for a profit, rocket propellants from these NEAs could lower the cost of deep space and lunar surface access, expanding scientific exploration and opening an industrial frontier using space-derived raw materials and abundant solar energy.

Small but near-term steps

If NASA hopes to gain approval to send astronauts beyond the Moon around 2020, it should take a series of small, near-term steps to assure they will find plenty to do when they get there. First, the agency should spend a few million dollars annually to fund existing and new off-the-shelf telescopes in the search for small asteroids suitable for capture.

Completing the asteroid retrieval mission itself and delivering the goods would take about a dozen years if the effort were initiated now. NASA could quickly begin to test ARM sensors, mechanisms, and propulsion systems. At the ISS, the agency could check out grappling tools, new space suits, and resource processors. As the ARM unfolds in the latter half of this decade, NASA could step up its testing of Orion and heavy lifters to gain access to translunar space.

As the ARM craft begins its return with asteroid in tow, international and commercial partners would join NASA to establish a mobile EM L2 outpost by

This concept for a translunar vehicle (TLV), capable of moving among the Earth-Moon Lagrange points and lunar orbit, would support periodic astronaut sorties beyond the lunar far side. Visiting Orion crews would engage in lunar scientific exploration, and perhaps examine and exploit a captured asteroid in high lunar orbit. Courtesy NASA.

the early 2020s. The consortium would develop small robotic craft designed to examine, sample, and process NEA materials. Astronauts on their regular visits could step in to help those ships along when necessary.

The translunar vehicle, based at L2, and the NEA retrieval mission are synergistic efforts. Each enhances the return from the other. Although the 500-ton NEA (about the mass of the ISS) would be delivered robotically, only astronauts could fully exploit the scientific and economic potential of this unique resource in translunar space. At the same time, asteroid retrieval would supply astronauts with a decade of engrossing, challenging, and high-payoff activities beyond the Moon. Crews will encounter many unknowns in unraveling the history and potential of these strange space boulders, but grappling with such challenges is the surest way to build confidence in our ability to explore and exploit Earth-Moon space.

Planned wisely, the conjunction of robotic and human activities near EM L2 can fuel further exploration of the lunar surface, larger, more distant asteroids, and the Mars system. Instead of suffering stagnation and incremental loss of its leadership in space, the U.S. can embark now on a fascinating and inviting journey to and beyond the Moon. How better to fulfill the vow we made a decade ago to Columbia's crew?

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