National Aeronautics and Space Administration

Human Expeditions to Near-Earth Asteroids: Implications for Exploration, Resource Utilization, Science, and Planetary Defence

Paul A. Abell
NASA Johnson Space Center, Houston, Texas

Dan Mazanek (NASA LaRC), Brent Barbee (NASA GSFC), Lindley Johnson (NASA HQ), Don Yeomans (JPL), Victoria Friedensen (NASA HQ), Rob Landis (NASA WFF), David Reeves (NASA LaRC), Dan Adamo (Consultant), Gerry Sanders (NASA JSC), and Ron Mink (NASA GSFC)

2013 IAA Planetary Defense Conference
High Country Conference Center
Flagstaff, Arizona
April 16, 2013

President Obama at Kennedy Space Center – April 15, 2010

"Early in the next decade, a set of crewed flights will test and prove the systems required for exploration beyond low Earth orbit. And by 2025, we expect new spacecraft designed for long journeys to allow us to begin the first-ever crewed missions beyond the Moon into deep space. So we'll start -- we'll start by sending astronauts to an asteroid for the first time in history. By the mid-2030s, I believe we can send humans to orbit Mars and return them safely to Earth. And a landing on Mars will follow. And I expect to be around to see it. "

Source: NASA

Background

- **NASA Focus Areas**
  - Extension of the International Space Station until at least 2020
  - Support for a commercial space transportation industry
  - Development of a Multi-purpose Crew Vehicle (MPCV) and heavy lift launch vehicle (SLS)
  - A “flexible path” approach to space exploration opening up vast opportunities including near-Earth asteroids (NEAs), the Moon, and Mars
  - New space technology investments to increase the capabilities beyond Low-Earth Orbit (LEO)

Near-Earth Asteroid (NEA) Mission Rationale and Benefits

- **Near-Earth Asteroids (NEAs) provide an intermediate destination for human missions between the Moon and Mars that, among other benefits, can reduce the risks for all deep-space exploration**
  - With *sufficient* propulsive capability, missions with durations of one year or less are feasible (e.g., several weeks or a few months)
  - Durations of a year or more are commensurate with the in-space transit segments for sending human missions to the Martian system
  - Provide vital operational experience and system development for deep-space missions to Mars and beyond

- **NEAs are remnants from the earliest stages of Solar System formation and contain some of the most primitive materials known**
  - Provide important scientific discoveries about the Solar System from additional planetary bodies, substantially different in origin, history, and composition from that of the Moon or Mars
  - Enable an understanding of the Earth-Moon system's impact history and insight into the evolution of life on Earth

Near-Earth Asteroid (NEA) Mission Rationale and Benefits

- **Some NEAs contain materials that may be relevant for future In Situ Resource Utilization (ISRU) initiatives (e.g., carbonaceous or metallic objects)**
  - Open access to resources vital to future exploration and economic activities in space by demonstrating extraction and utilization techniques for water, volatiles, and valuable metals
  - Use of extraterrestrial resources could enable exploration of destinations that would otherwise require massive amounts of material that would be prohibitive from a budgetary and/or operational perspective
- **Due to the nature of their orbit dynamics, NEAs that are viable human space flight targets are also the most likely objects to impact the Earth**
  - Provide opportunities to understand this population and "get" them before they "get" us (i.e., know your enemy)
  - Allow insights into the physical properties of NEAs and provide data to assist in the development and implementation of planetary defence technologies

Source: NASA/AMA, Inc.

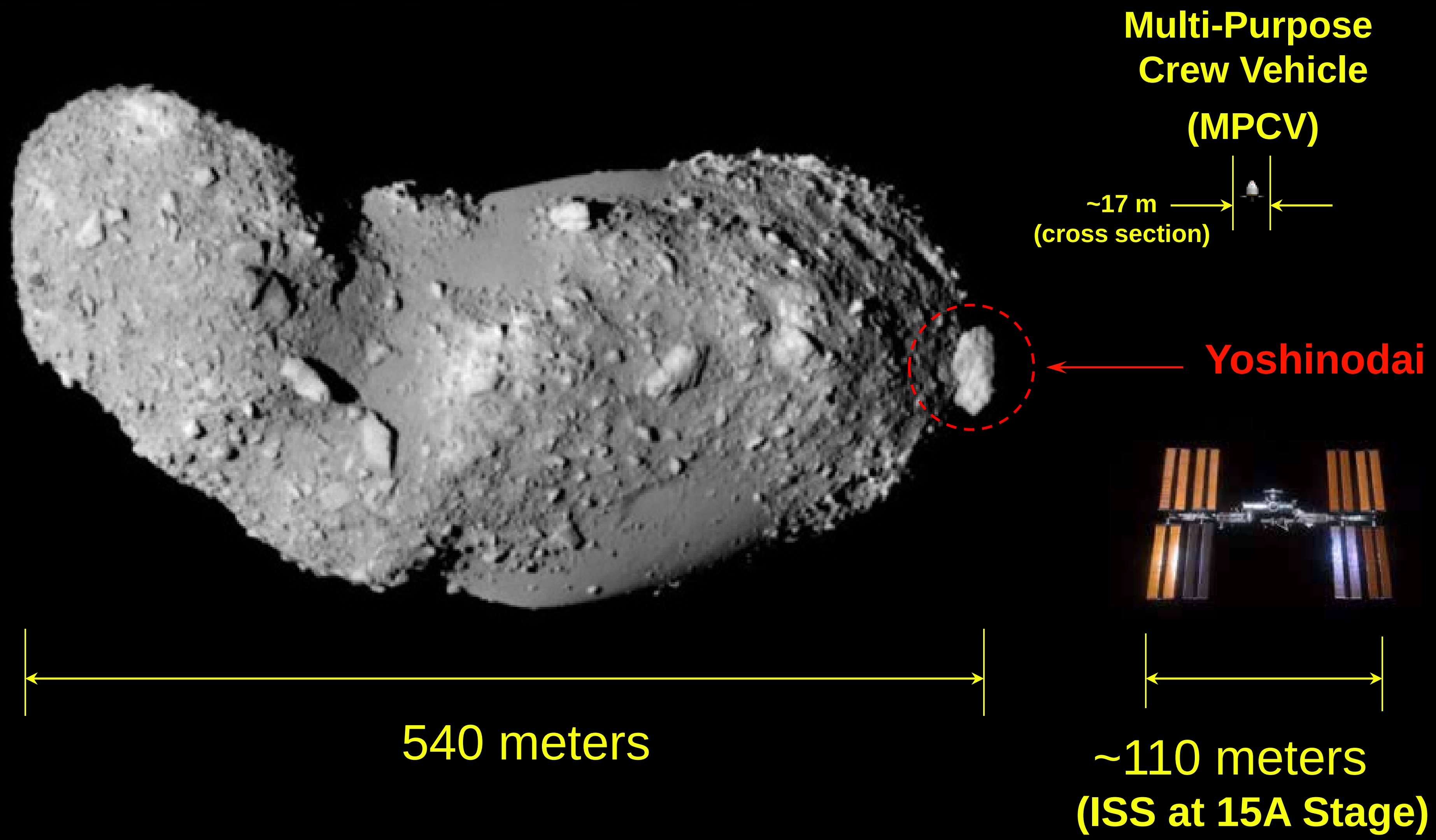
Near-Earth Asteroid (NEA) Mission Rationale and Benefits

- **Opportunities exist for commonality/extensibility with the systems and elements needed for missions to the Moon, Mars, and other destinations**
  - Multi-purpose Crew Vehicle (MPCV)
  - Space Launch System (SLS)
  - Deep Space Habitat (DSH)
  - Multi-Mission Space Exploration Vehicle (MMSEV) (i.e., excursion vehicle)

- **Foster international, commercial, and academic cooperation for both robotic precursor and human missions**
  - JAXA, ESA, Roscomos, CSA, and other exploration agencies
  - Space X, Planetary Resources, Deep Space Industries, Bigelow Aerospace, etc.
  - Scientific and Engineering academic communities

Source: NASA/AMA, Inc.

Asteroid Itokawa, ISS, and MPCV



JAXA, NASA

Itokawa and the Golden Gate Bridge

NEA Target Identification and Remote Characterization

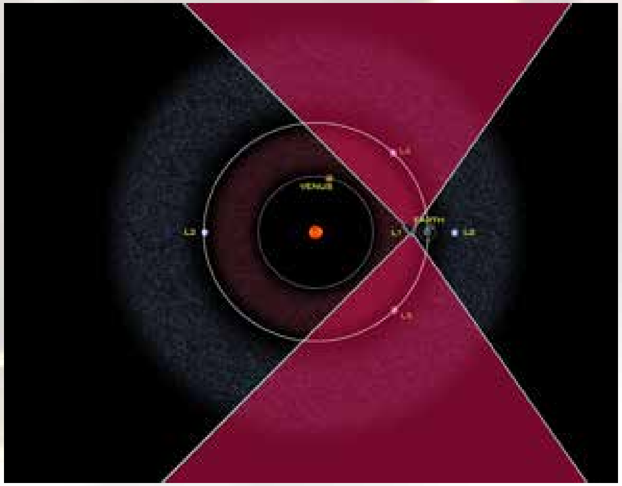
- **In order to be selected as a viable target for near–future Human exploration (2025 - 2040), a NEA should be within reach of attainable and realistic exploration capabilities**
  - Dynamical considerations need to be made with respect to potential exploration system's capabilities
  - Key parameters for this analysis are orbit location, mission duration, number of launches, length of launch windows, number of launch opportunities, and delta V
  - The most accessible NEAs have very Earth-like orbits and can have continuous departure windows that can last many months and repeat for several years
  - However, they are difficult to detect via ground-based observations

- **Missions to currently known objects requires crew exposure to long mission durations and development of advanced propulsion and re-entry technologies**
  - Thus, basing a target set on the known NEA population severely constrains program flexibility and lowers its resiliency to budget challenges
  - Increase of mission, programmatic, and budgetary risk

NEA Target Identification and Remote Characterization

- **Fortunately the deployment of a space-based survey telescope can significantly improve this situation**

- **This system would be a <u>Foundational Asset</u>**
  - Only a fraction of the NEA population has been discovered
  - Several of these undiscovered NEAs may be viable as destinations for Human missions
  - A space-based survey will be able to refine orbit and perform some remote characterization of NEAs (e.g., albedo, size, etc.)
  - NEOWISE results have proven invaluable
  - NASA has funded IR sensor development with the NEOCAM Discovery proposal
  - NASA has a space act agreement with the B612 foundation for space-based NEA survey



NEA Target Identification and Remote Characterization

- **Identification of a sufficient number of accessible & desirable NEAs is an important consideration for enabling future human missions – <u>therefore, a robust target list is critical</u>**
  - An example of desirable NEA characteristics are provided in the table below
  - Filtering based on desired values reduces the number of targets

Target Characteristic	Desired Value
Total Mission Duration	<< 1 year
DV (from LEO)	< ~5 km/s
Size	> 30 m
Departure Window	Weeks+, not days
Rotation Period	> 2 hrs
Orbital Condition Code	0 (desired)
Asteroid Type	Understood

- **Prior to conducting <u>either</u> robotic and human missions, securing the NEA's orbit and obtaining remote characterization are critical for cost-effective target selection**
  - Hence the need for additional ground-based and space-based observations
  - Identification of targets well in advance of human mission launch possibilities (or impact threats)

NEA Target *In Situ* Characterization

- **Prior to sending a piloted mission to a NEA, additional *in situ* characterization of the target is <u>required</u>**
  - Obtain basic reconnaissance to assess potential hazards that may pose a risk to both vehicle and crew (e.g., *Ranger, Lunar Orbiter, Surveyor, LRO* have done for the Moon)
  - Some NEAs may have physical characteristics that would make them unsuitable as targets for early human exploration
- **Precursor missions would also assess the NEA for future activities to be conducted by the crew and their assets to maximize mission efficiency**
  - Proximity operations (spacecraft, robotic assets, crew on EVA)
  - Surface activities (scientific and engineering investigations)
  - Touchdown site identification, surface/subsurface characterization, and sample collection

NEA Target *In Situ* Characterization

- Build on lessons learned from other small body missions
- Strong overlap with Science and Planetary Defence
- Past, current, and future mission examples
  - NEAR Shoemaker
  - Hayabusa
  - Rosetta
  - Hayabusa 2
  - OSIRIS REx
  - Marco Polo-R
  - AIDA
  - ISIS

- **NASA Near-Earth Objects Human Space Flight Accessible Targets Study (NHATS) http://neo.jpl.nasa.gov/nhats/**
  - Online tool that identifies potential HSF targets and lists future potential observing opportunities that is continually updated
  - See Brent Barbee's presentation (PDC13-04-13)

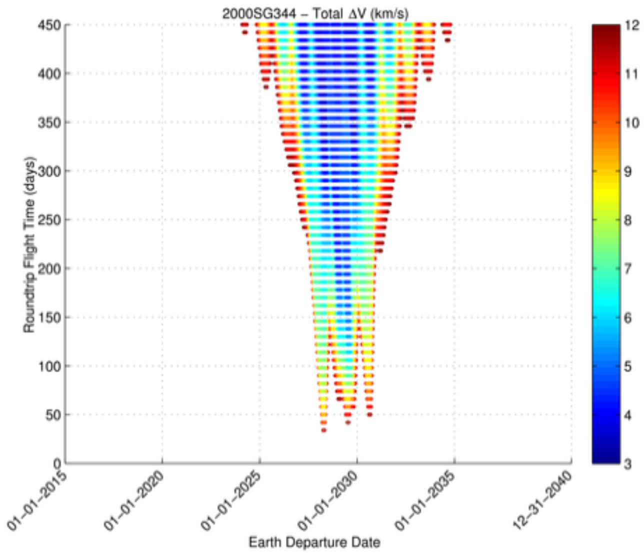
Mission Trajectories Table

Column headings described below

(2000 SG344)	Min. delta-V Parameters	Min. Duration Parameters
Total Mission delta-V (km/s)	**3.556**	5.973
Total Mission Duration (d)	354	**114**
Outbound Flight Time (d)	145	49
Stay Time (d)	8	8
Inbound Flight Time (d)	201	57
Launch date (YYYY-MM-DD)	2028-04-22	2029-07-22
C_3 (km^2/s^2)	1.737	3.009
Departure $V_{infinity}$ (km/s)	1.318	1.735
Earth Departure dV (km/s)	3.256	3.314
dV to Arrive at NEA (km/s)	0.113	1.067
dV to Depart NEA (km/s)	0.187	1.592
Earth return dV (km/s)	0.000	0.000
Entry Speed (km/s)	11.133	11.214
Depature Declination (deg)	-8.950	-22.493
Return Declination (deg)	-5.933	22.663
NHATS Trajectory Solution ID	890465	2046652

These data were computed on 2012-01-06 using the latest available orbital parameters.

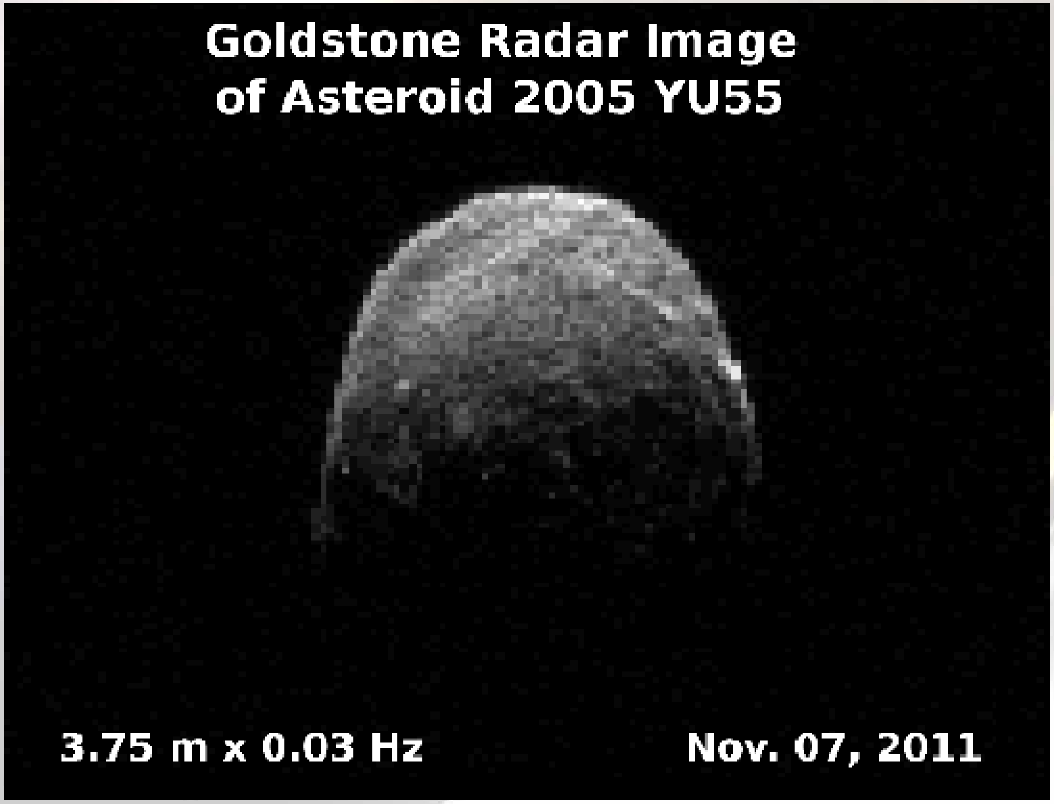
Total Mission delta-V as a Function of Departure Date and Mission Duration



The plot above shows total mission delta-V as a function of Earth departure date and total round-trip flight time (mission duration). It summarizes the many potential mission scenarios by plotting, for each case, the total round-trip delta-V values (color-coded) required for each launch date and round trip flight time considered. Note that these trajectories span a range of possible stay times at the NEA.

Recent and Current Activities

- **Advanced Exploration Systems (AES) Goldstone Radar Project**
  - Enhanced Goldstone capability to observe NEAs at higher spatial resolutions (~4 m)
  - Obtain information on NEA surface properties relevant for Human exploration considerations (Human Exploration and Operations Mission Directorate funded)
  - See Lance Benner's presentation (PDC13-03-08)



Recent and Current Activities

- **NASA Desert Research and Technology Studies (DRATS)**
  - Mission analogue for NEA simulations in 2011 and 2012 at NASA JSC
  - Combination of vehicle mock ups, virtual reality, and simulated low-g EVA via the Active Reduced Gravity Offload System (ARGOS)
  - Simulate science and engineering operations at a NEA

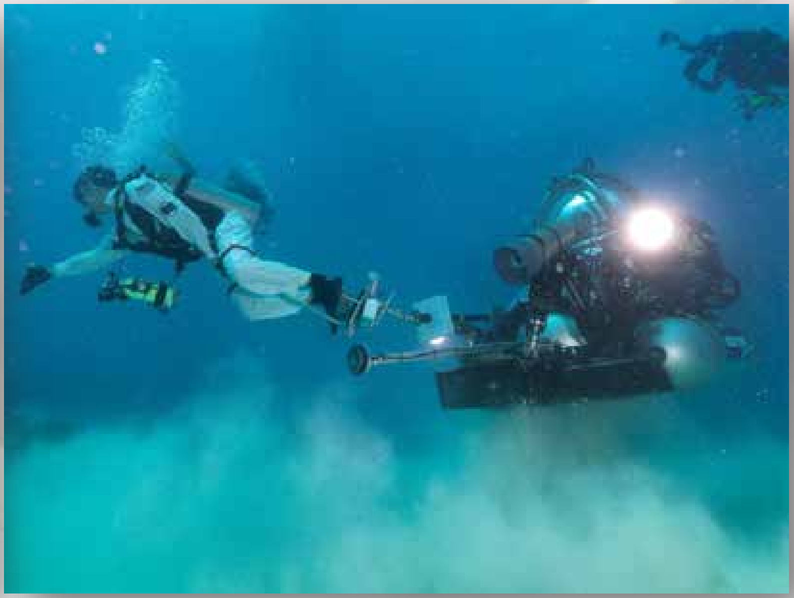
Test subject on simulated EVA via the ARGOS system

Mock up of the Space Exploration Vehicle (SEV)

Recent and Current Activities

- **NASA Extreme Environment Mission Operations (NEEMO)**
  - Mission analogue for NEA operations at the National Undersea Research Center Aquarius Base located 3.5 miles off of Key Largo, Florida 62 feet (18.9 m) under the sea.
  - NEEMO 15 conducted in October 2011, NEEMO 16 conducted in June 2012
  - Simulate science and EVA operations in neutrally buoyant environment with communication delay times of 50 seconds (0.1 AU)

Aquanauts testing EVA equipment during simulated NEA exercise



Simulated EVA with crew and SEV using aquanaut and submersible

Recent and Current Activities

- **Solar System Exploration Research Virtual Institute (SSERVI)**
  - Cooperative Agreement Notice released January 10, 2013
  - Opportunities for multi-institutional team based proposals (including international partners) – Deadline of April, 10, 2013
  - "Broadly based research program addressing basic and applied scientific questions fundamental to understanding the nature of the Moon, Near-Earth Asteroids (NEAs), the Martian moons Phobos and Deimos, and the near space environments of these target bodies, to enable human exploration of these destinations."
  - Funded by NASA Science Mission Directorate (SMD) and NASA Human Exploration and Operations Mission Directorate (HEOMD)

Source: NASA/AMA, Inc.

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A Few ‘Take Away’ Thoughts…
- NEAs for Exploration
- NEAs for Science
- NEAs for Resources
- NEAs for Planetary Defence