Constellation Enabled Missions to NEOs

Paul Abell
Rob Landis
Dave Korsmeyer
and the NEO Mission
Study Team

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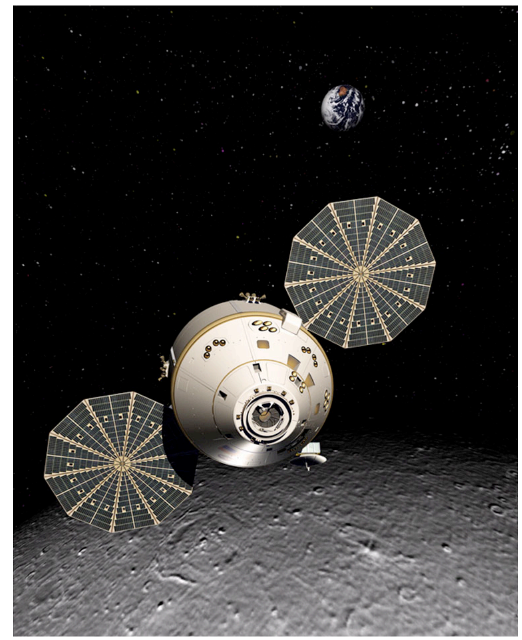
NEO Study Disclaimer

- ***This is only a Phase 1 technical feasibility study.***
- ***NASA has not endorsed this mission concept yet.***
- ***Work done to date is based on 4 ½ month effort.***

NEO Mission Study Team

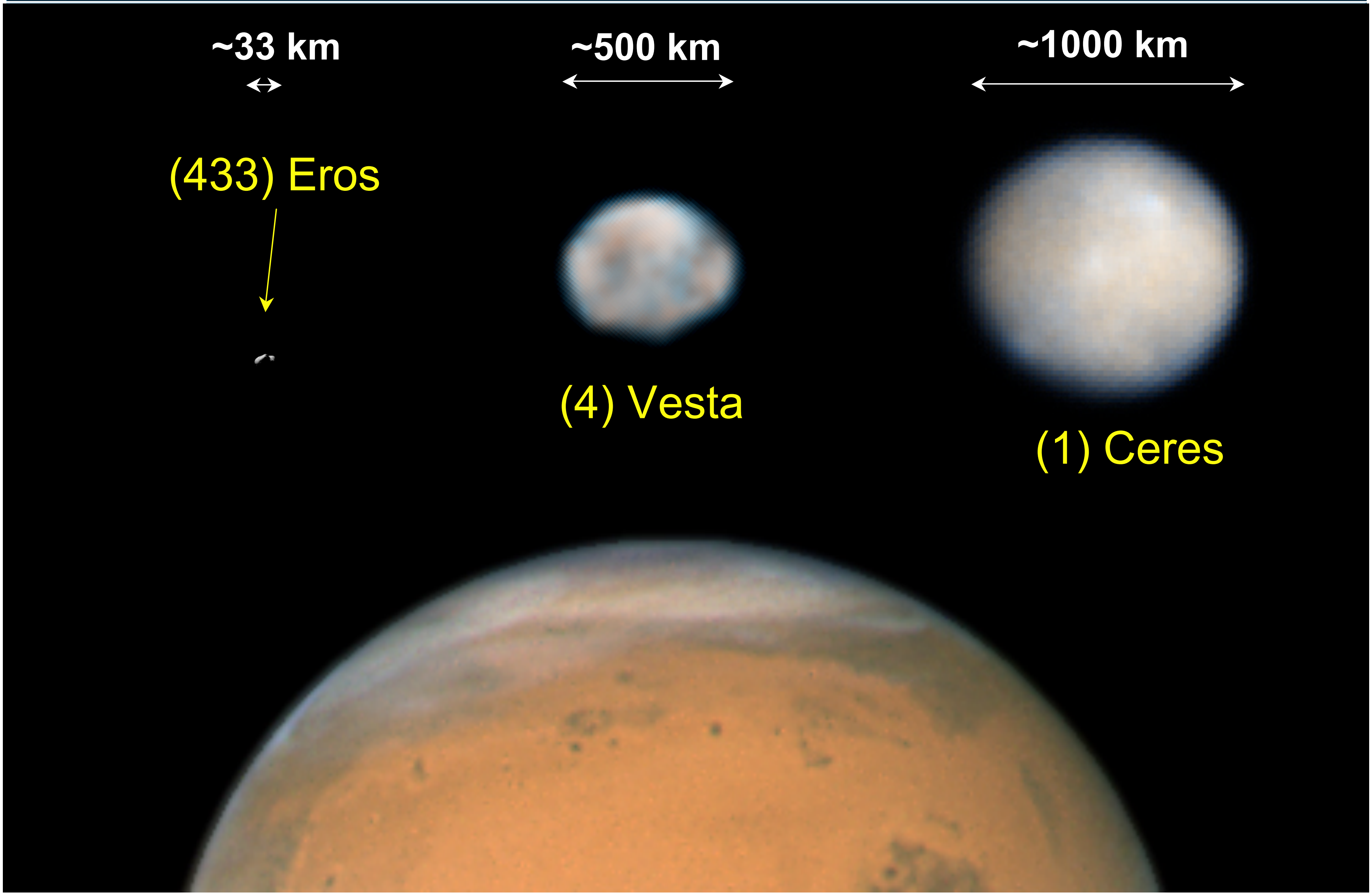
- Dave Korsmeyer, ARC, Study Lead
- Larry Lemke, ARC
- Andy Gonzales, ARC
- Dave Morrison, ARC
- Rob Landis, JSC
- Paul Abell, JSC/PSI
- Ed Lu, JSC (now at Google)
- Bob Gershman, JPL
- Tom Sweetser, JPL
- Bob Oberto, JPL
- Erick Sturm, JPL
- Min-Kun Chung, JPL
- Mark Wallace, JPL
- Chen-Wan Yen, JPL
- Lindley Johnson, NEO Program Scientist at NASA HQ
- Dan Adamo, Trajectory consultant
- Tom Jones, NAC member and consultant
- Bret Drake, JSC - CxP APO Sponsor

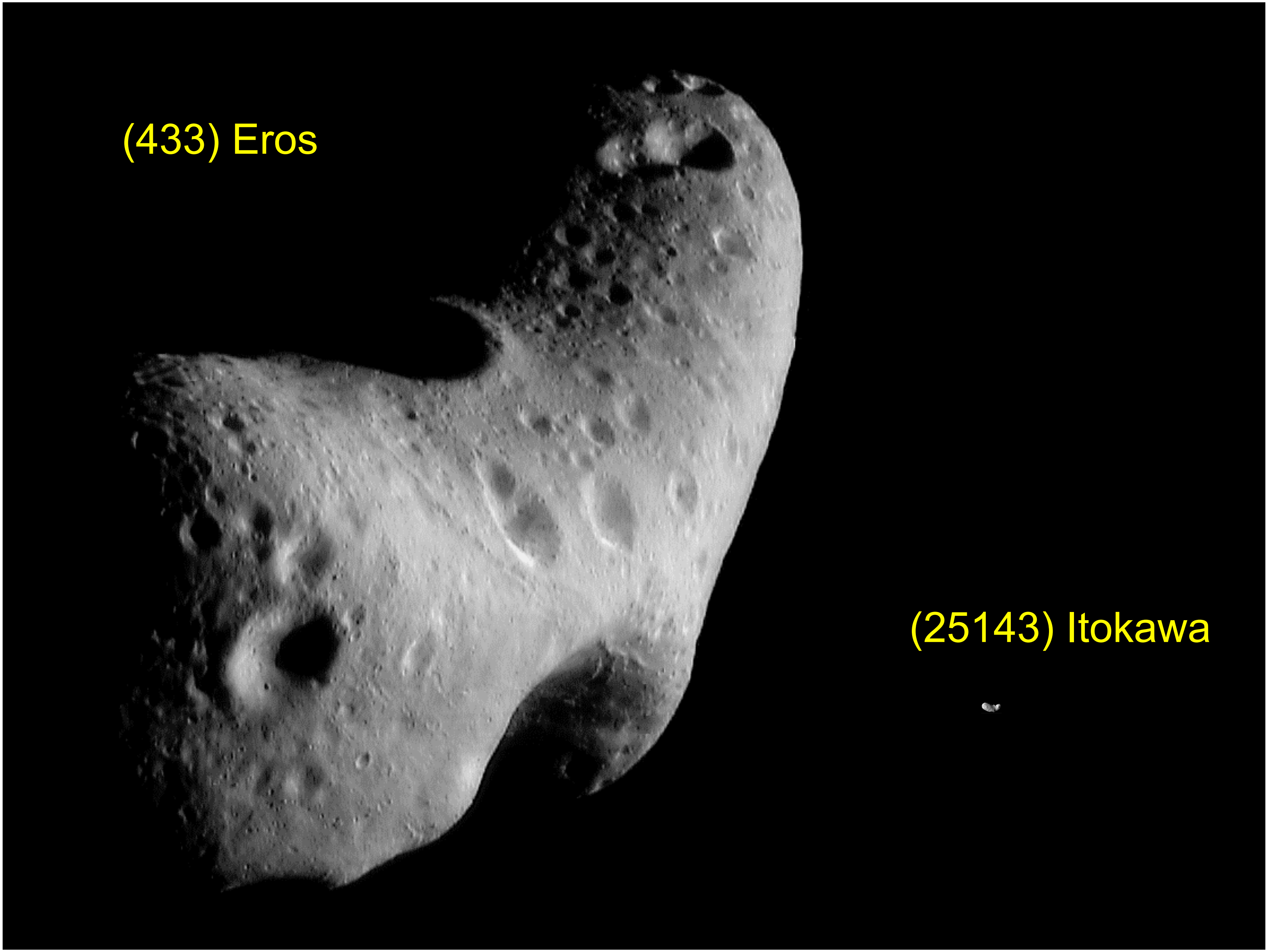


Past NEO Papers/Studies

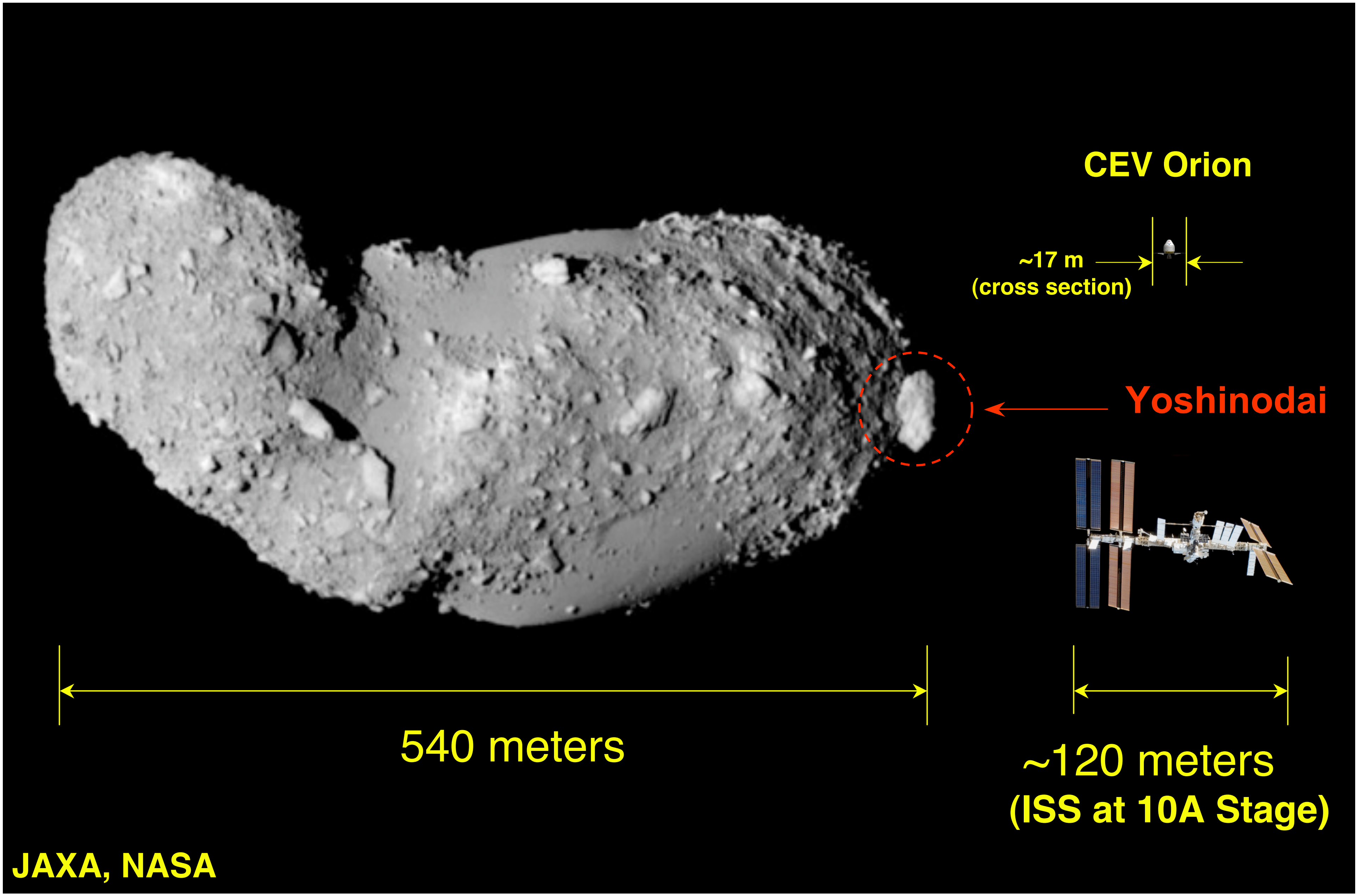
- **Eugene Smith (1966)** “A Manned Flyby Mission to Eros”, Northrop Space Labs Study.
- **Douglas Nash *et al*., (1989)** *Science Exploration Opportunities for Manned Missions to the Moon, Mars, Phobos and an Asteroid*, NASA Office of Exploration Doc No. Z-1.3-001/JPL Publication 89-29.
- **Donald Davis *et al*., (1990)** *The Role of Near-Earth Asteroids in the Space Exploration Initiative*, SAIC-90/1464, Study No. 1-12-232-S28.
- **Thomas Jones *et al*., (1994)** “Human Exploration of Near-Earth Asteroids”, *Earth Hazards Due to Comets and Asteroids*, University of Arizona Press, Tucson, Arizona, pp. 683-708.
- **Thomas Jones *et al*., (2002)** “The Next Giant Leap: Human Exploration and Utilization of Near-Earth Objects”, *The Future of Solar System Exploration 2003-2013 ASP Conference Series*, **272**:141-154.
- **Michael Griffin, Owen Garriott *et al*., (2004)** *Extending Human Presence into the Solar System: An Independent Study on the Proposed U.S. Space Exploration Policy.*
- **Daniel Mazanek *et al*., (2005)** “Near-Earth Object Crew Mission Concept Status”, NASA Internal Study.

Comparison of Various Asteroids (to scale)




(433) Eros
(25143) Itokawa

Asteroid Itokawa, ISS, and CEV Orion

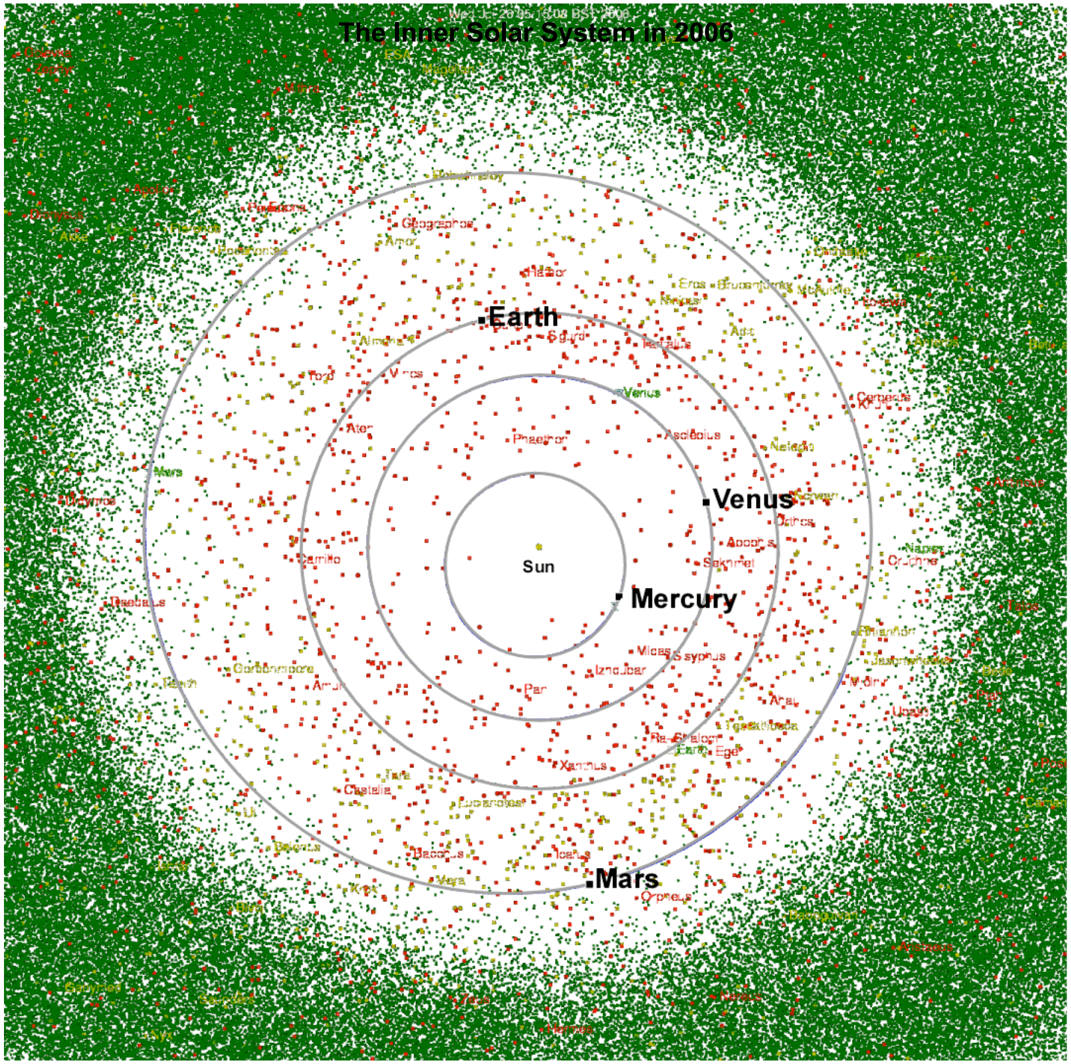


Discovery Rate of the NEO Population

2006

Earth Crossing

Outside Earth's Orbit



August 14, 2008
- **~418,000 Minor Planets**
- **5509 NEOs**
- **961 PHOs**

Improved NEO Survey Will Likely Find
- **100,000+ NEOs (>140 meters)**
- **20,000+ PHOs**

Images from: Scott Manley Armagh Observatory

CxP NEO Mission Feasibility Assessment

- No major changes to Constellation element performance specifications (i.e., no warp drive)

- Established 4 Mission Concepts
  - 2 initial concepts ("Bookends") based upon using the planned Cx launch system components.
  - At the Mid-term briefing 2 additional alternate launch concepts were added at CxPO request ("Mid-volumes")

- Determine mission length options and maximum total ΔV available from the Mission Concepts

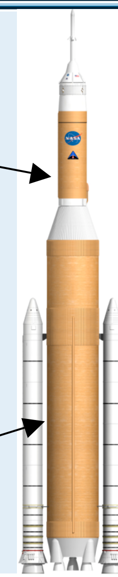
- Assess NEO catalog for targets that match the ΔV and mission length requirements for all the Mission Concepts

NEO Mission Launch Concepts

EELV
Used to
loft unmanned
Centaur Upper
Stage

ARES I
Used to loft
Orion and
Crew

LOWER BOOKEND
(DUAL LAUNCH)



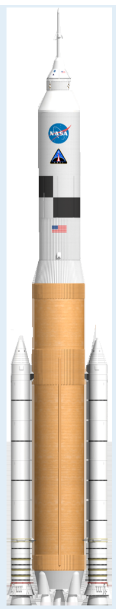
ARES I US

ARES V Core
+ Boosters

ARES IV
concept
used to
loft Orion

MID-VOLUME IV
(SINGLE LAUNCH)

*Mid Volume
concepts added by
CxP after the
MidTerm review



ARES V+
concept
used to
loft Orion

MID-VOLUME V
(SINGLE LAUNCH)

ARES V
Used to
loft EDS
+ LSAM

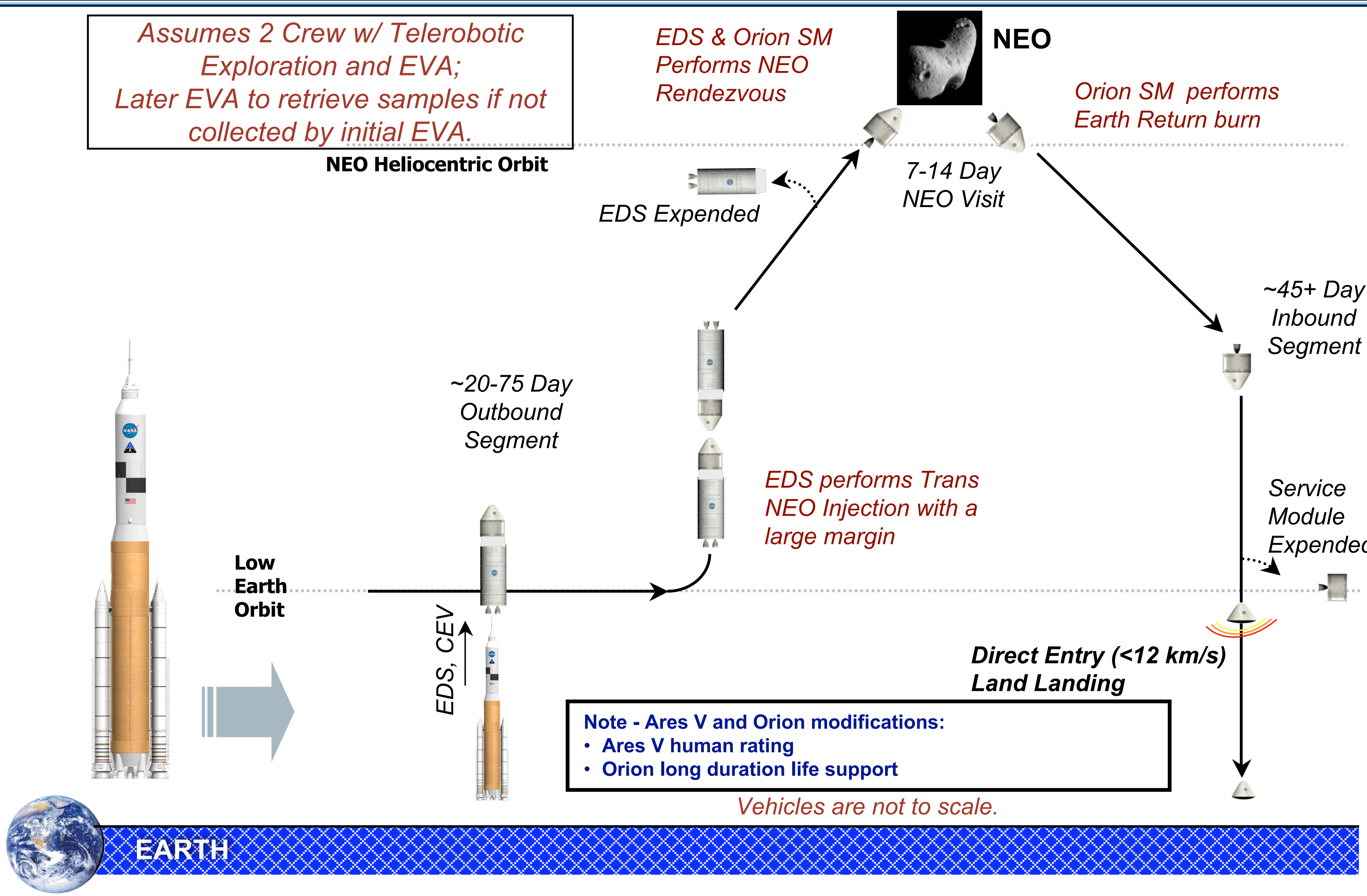
ARES I
Used to
loft Orion

UPPER BOOKEND
(DUAL LAUNCH)

Vehicles are not to scale.

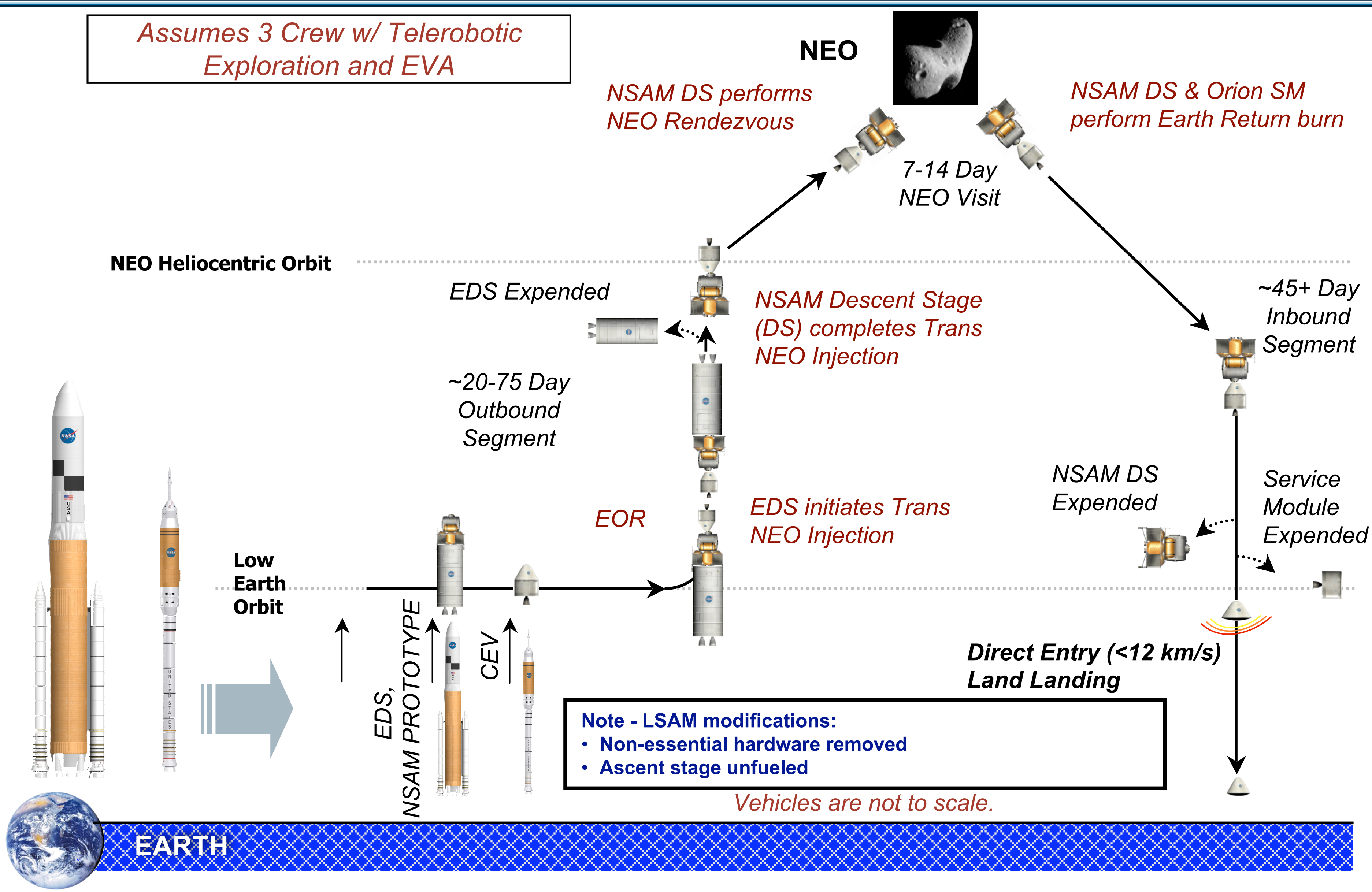
"Mid Volume V+" Near-Earth Object (NEO) Crewed Mission - Ares V

EDS / Orion SM provides Earth Departure, NEO Arrival, and Earth Return ΔV



"Upper Bookend" Near-Earth Object (NEO) Crewed Mission

EDS / NSAM / Orion SM provides Earth Departure, NEO Arrival, and Earth Return ΔV



NEO Database and Trajectory Analysis

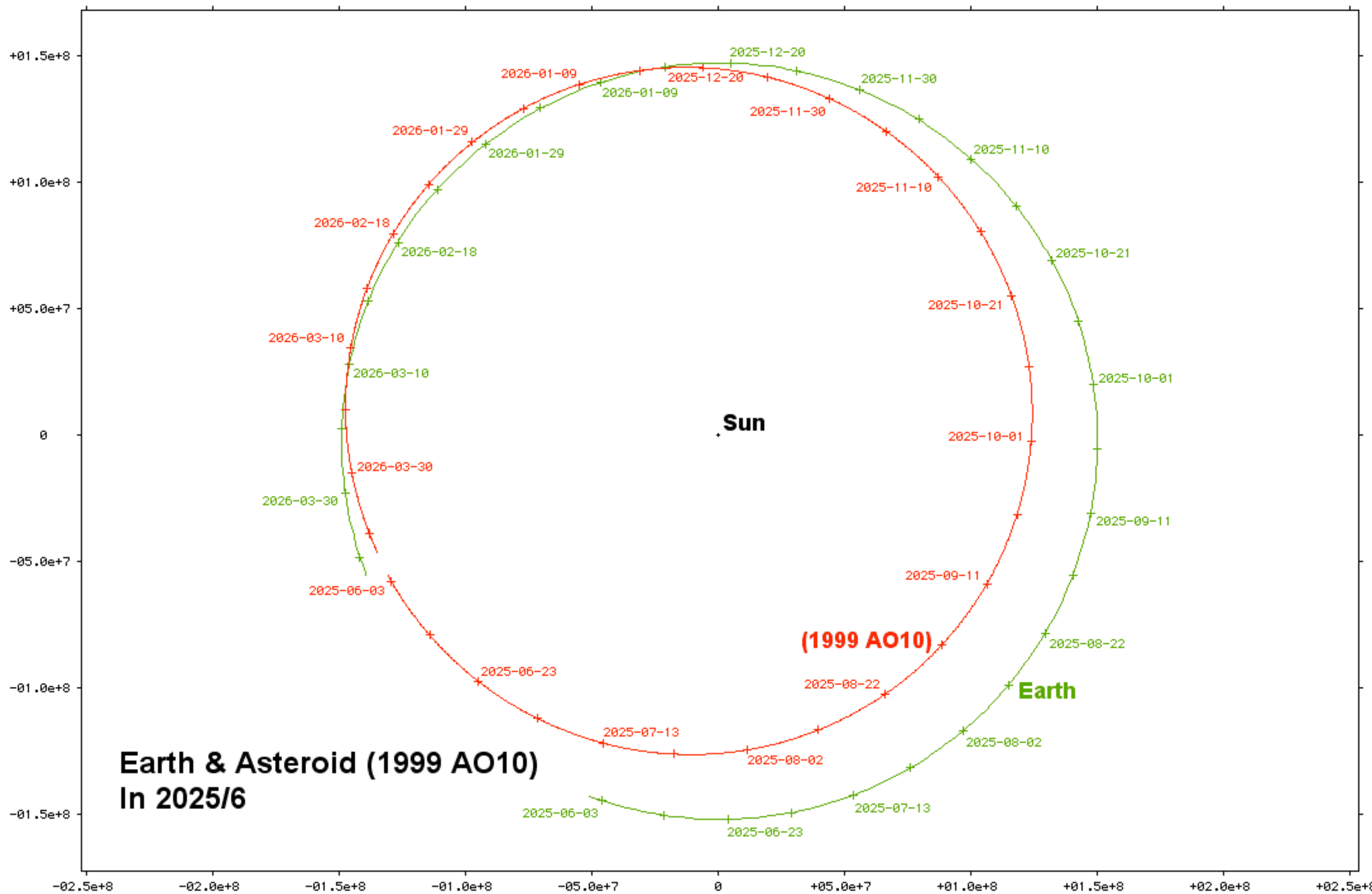
- **Which NEOs are good targets of opportunity?**
  - **Earth-like orbits with low eccentricity and inclination**
  - **Earth close approaches during our time frame (2020 - 2035) (aka PHOs)**

- **Team assessed NEO targets from the existing NEO (JPL HORIZONS) database in 2006.**

- **Identified the ΔV required to match to NEO orbits.**
  - **14-day stay time assumed**
  - **Analyzed 90-day mission length (also ran 120, 150, and 180-day options)**

- **9 NEOs within the current database could be targets in 2020 – 2035.**
  - **Best suited to 150 and 180 day missions**

Mid-Volume (Ares V+ Single Launch)
150-Day Mission to 1999 AO_{10}
Heliocentric Trajectory Plot for Mission

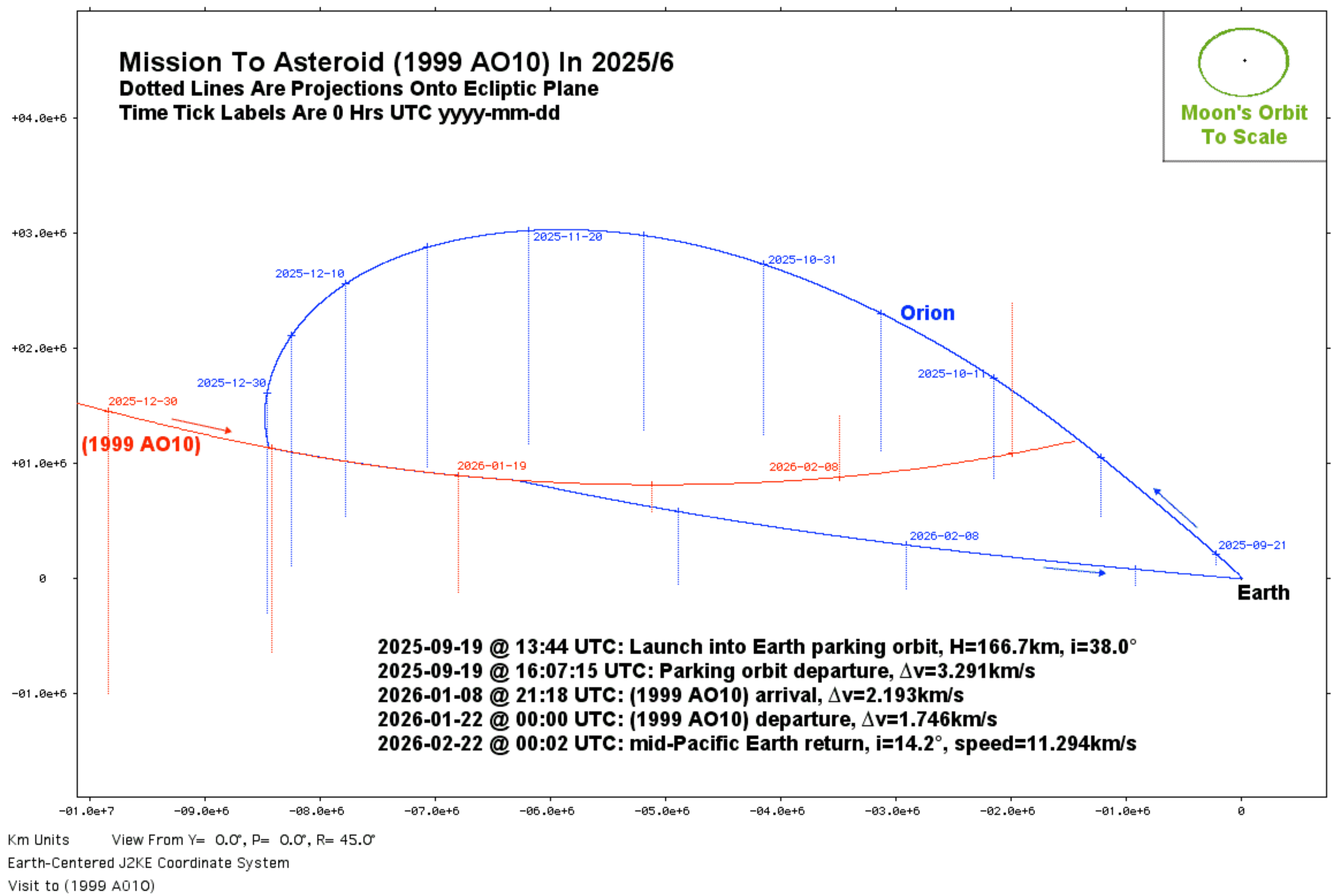


Km Units View From Y= 0.0°, P= 0.0°, R= 0.0°

Sun-Centered J2KE Coordinate System

Visit to (1999 AO10)

Mid-Volume (Ares V+ Single Launch)
150-Day Mission to 1999 AO_{10}
Earth-fixed Trajectory Plot for Mission



Value of Human Exploration of NEOs

- Exploration
- Science
- General Public

Value of Human Exploration of NEOs

➢ Why NEOs for Exploration?

- Expand human capability to operate beyond Earth orbit
- Assess resource potential of NEOs for exploration and commercial use (*e.g., in situ* resource utilization)
- Gain operational experience performing complex tasks with crew, robots, and spacecraft under microgravity conditions
- Assess the psychology of crew autonomy; ground/crew interactions at 10 – 20 second round-trip time delays for deep space operations
- Help identify more efficient/cost-effective deep space exploration architectures

Value of Human Exploration of NEOs (2)

- **Why NEOs for Science?**

  - Sample return, sample return, sample return
  - Ground truth for data for terrestrial meteorites/dust collections and telescopic/spacecraft investigations of asteroids and comets
  - Small body samples key to models of solar system formation and evolution
  - Obtain ultra pristine samples for sensitive laboratory analyses
  - Study the internal structure of NEOs to refine impact physics models

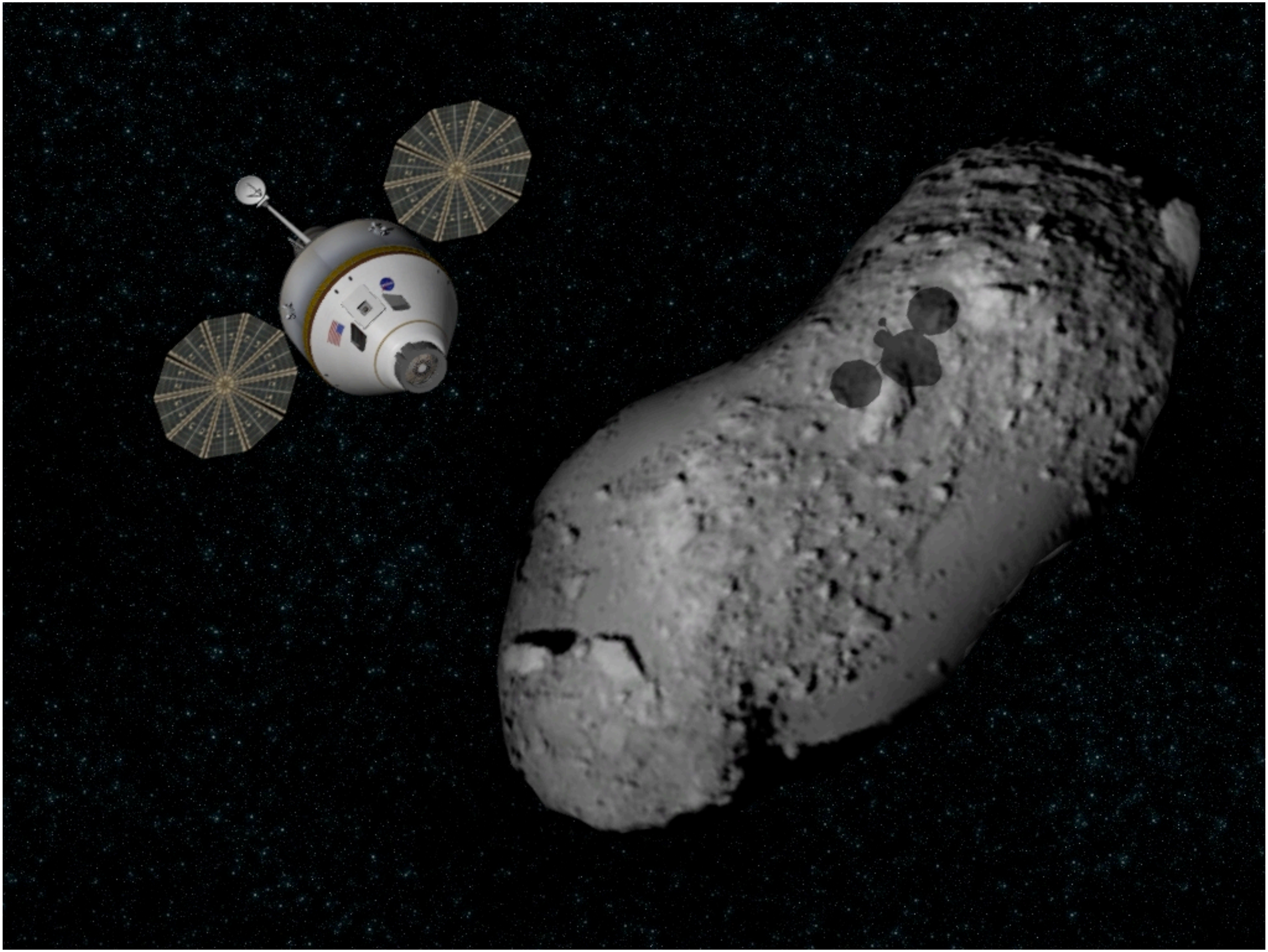
Value of Human Exploration of NEOs (3)

➢ Why NEOs for the General Public?

- Performs unprecedented deep space voyage experience with dramatic perspectives of Earth-Moon system and views of the CEV at a new world
- Puts humans demonstrably on the way to Mars while producing exciting new science
- Gain an understanding of physical characteristics of NEOs, which will be useful for mitigating a possible impact threat in the future

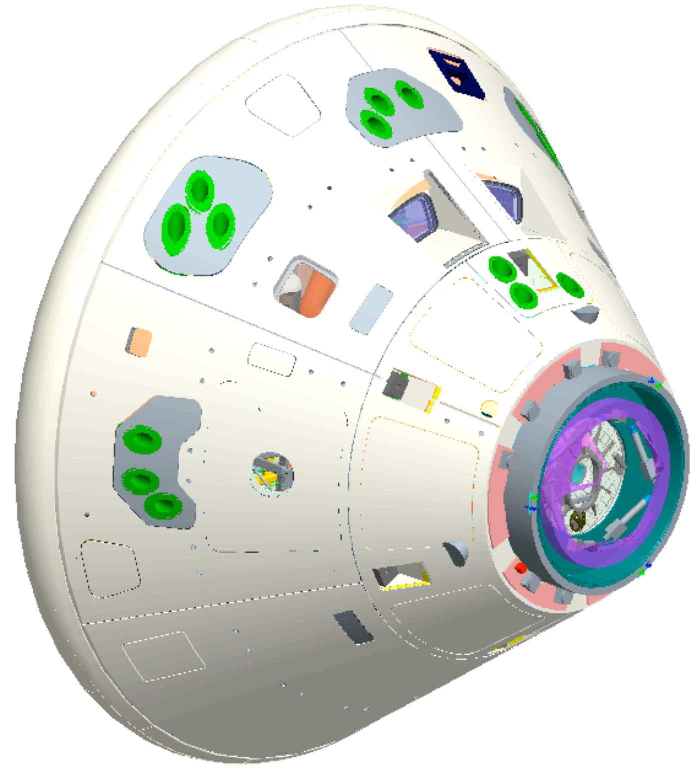
Summary of Study Results

- **Can we do it? Yes!**
  - Constellation program elements (Ares & Orion) are capable of supporting a 2 or 3 crew mission to a NEO.
- **Benefits of the Next Generation NEO Survey**
  - NEO Next Generation Search will increase target discovery ~40x
  - Several more NEO Targets of Opportunity may exist in the desired 2020 - 2035 timeframe
- **In depth Phase 2 follow-on mission analysis needed**
  - More details on applicable innovative technologies (*e.g.*,inflatables)
- **More analysis of potential Mars mission benefits**



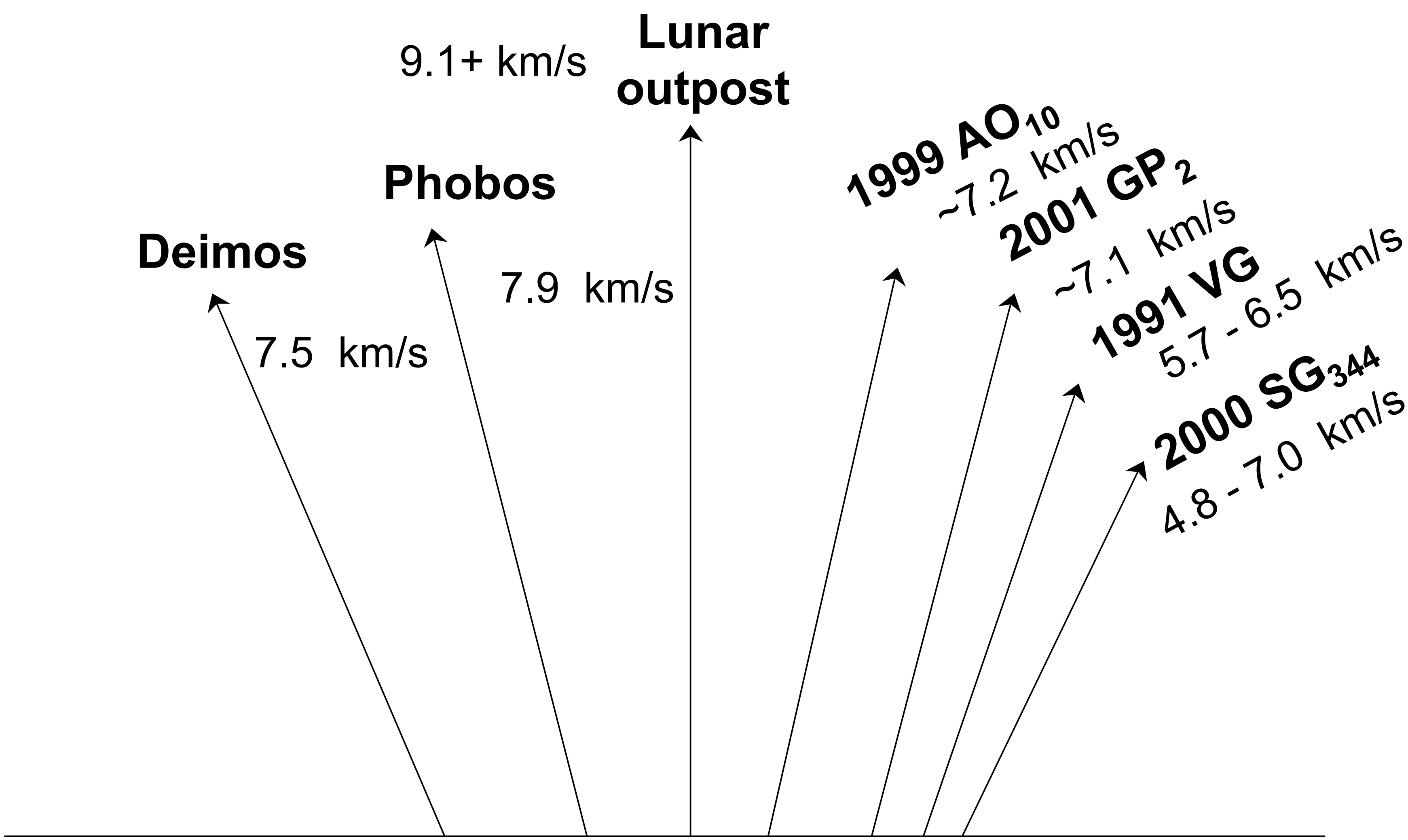
BACKUP

Orion Modifications for a NEO Mission



- No changes to telecommunication system
  - OK out to 6+ million km from Earth
- No modifications to power requirements
  - CEV will never be far from 1 AU
- Reduced crew size
  - Crew of 2 (or 3)
- Removed extra seats and spacesuits
- Increased storage capacity of Crew Module
  - More food and trash/waste stowage
- Increased capacity of the Crew Module's and Service Module's Environment Control and Life Support Systems (ECLSS)
  - Added a moisture collector
  - Added extra consumables for extended mission

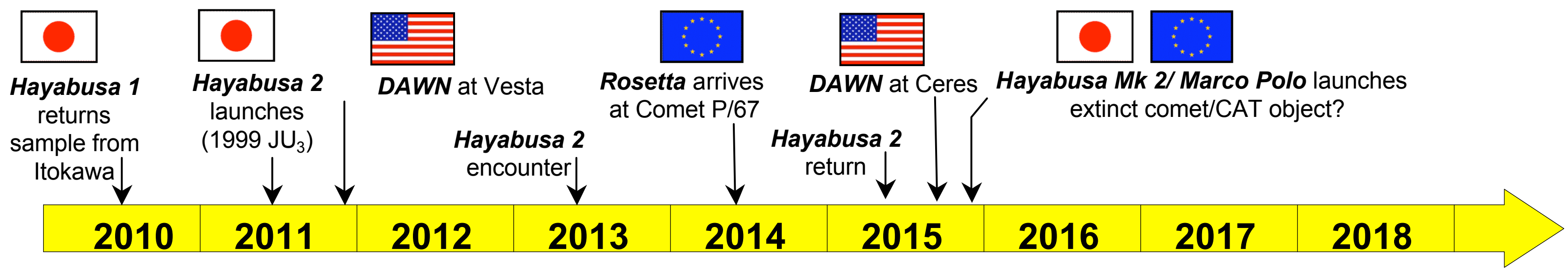
Δv_{tot} Comparisons for Lunar Surface, Phobos, Deimos, and a few NEOs



for NEOs Δv depends on phasing of orbit and when mission is launched.

Primitive Body Robotic Missions

Robotic Missions to Primitive Bodies



- ***NEAR*** (USA), rendezvoused with (433) Eros on Feb. 14, 2000.
- ***Hayabusa*** (Japan), arrived at (25143) Itokawa on Sept. 12, 2005.
- ***Dawn*** (USA), launched Sept. 27, 2007 to (4) Vesta and (1) Ceres.
- ***Hayabusa 2*** (Japan), is planned for launch in 2011 to C-type NEO (1999 JU_3).
- **Rosetta** (ESA), flyby of (2867) Steins on Sept. 5, 2008 and (21) Lutetia on July 10, 2010, and arrives at Comet P67/Churyumov-Gerasimenko in 2014.
- ***Hayabusa Mk 2/ Marco Polo*** (Japan/ESA), is planned for launch to an extinct comet/CAT in 2015.

Precursor Mission Objectives

- **Prior to sending a piloted mission to a NEO, additional 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* and *Surveyor*).
  - Binary systems, rapid rotators, active surfaces, *etc*.
  - Non-benign surface morphologies

- **Assess surface for future activities to be conducted by the CEV and its assets (*e.g.,* crew and payload) → maximize mission efficiency.**
  - proximity operations
  - surface operations
  - sample collection

Precursor Mission Objectives (2)

- **Preliminary determination of NEO target characteristics.**
  - Surface morphology and properties (*e.g.,* boulders vs. pebbles)
  - Gravitational field structure
  - Rotation rate and pole orientation
  - Mass/density estimates
  - General mineral composition

- **Aid in the navigation of the CEV to the target NEO.**

- **Provide additional data coverage during CEV operations.**
  - Obtain images of interactions of the crew and other assets at the NEO
  - Supplemental examination of the NEO with additional sensors

- **Monitor the NEO over time after CEV departure.**
  - Measure momentum transfer from kinetic/explosive experiment
  - Image crater excavation processes/results (*e.g.,* internal composition)
  - Provide precise orbital measurements over relatively long time periods

- **Relay data from science equipment left behind by the CEV.**
  - Seismic stations, excavation/engineering equipment, resource extraction *etc.*

Precursor Mission Instruments

- **High resolution optical camera system**
  - Surface identification, navigation, characterization, and optical mapping
- **LIDAR (Laser Imaging Detection and Ranging)**
  - Topographical mapping, gravitational field survey, and shape modeling
- **Visible and near-IR spectrometer**
  - General compositional investigation
- **Small lander package**
  - APXS, micrometeorite counter, dust collector, solar wind/particle collector, imager, radiometer, *etc.*

CEV Mission Objectives

- **Sample Return**
  - Several ~10 to 100 kg from the surface
  - Collected in geological context from different locations by astronaut EVAs
  - Collection of different or unusual samples from the surface (*e.g.,* black boulders on Itokawa)

- **Investigate NEO interior characteristics**
  - Determination of internal structure (size scale & distribution of components)
  - Measurement of density and macroporosity of the NEO

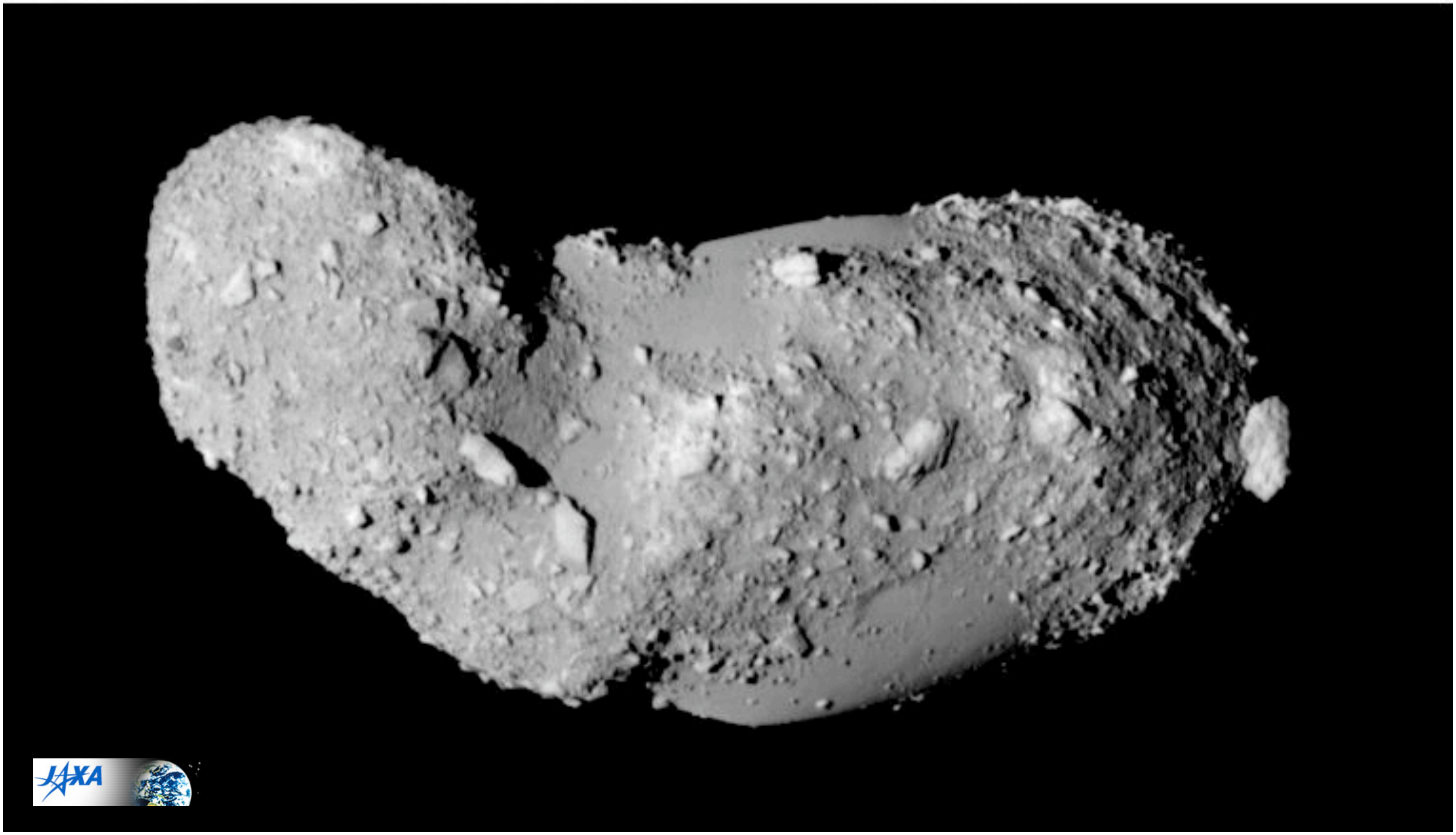
- **Test/Attach payloads to surface for operation and subsequent retrieval**
  - Microgravity regime
  - Possible rubble pile nature with high porosity

- **Emplace and operate a resource extraction device**
  - ISRU applications for water production or metal extraction
  - Demonstrate capability even in token quantities

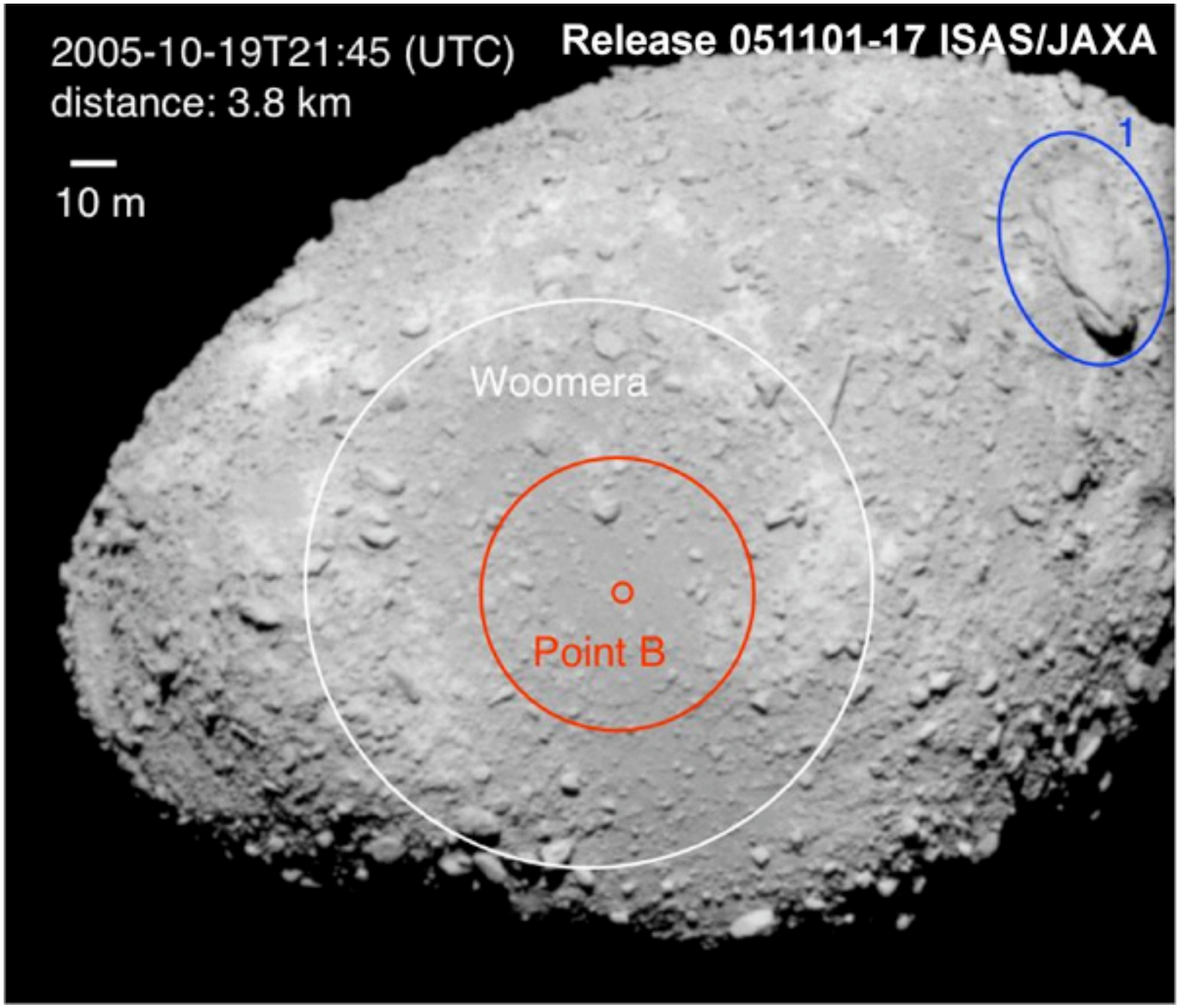
CEV Mission Instruments

- **Teleoperated robotic rover**
  - Multiple trips to/from surface
  - Supplemental collection from other/difficult to reach areas on the NEO
  - Collection of ultra-pristine samples
- **Multi-wavelength radar system**
  - Radar tomography of the NEO to obtain internal structure
- **Small instrument packages for precision deployment by the crew**
  - Deployed by crew during EVA or by the robotic rover system
  - Science payloads, engineering structures, EVA equipment, *etc*.
- **Human crew**
  - Have the adaptability and ingenuity to deal with complex issues in real time
  - Direct interaction with the surface via a variety of methods

Asteroid (25143) Itokawa

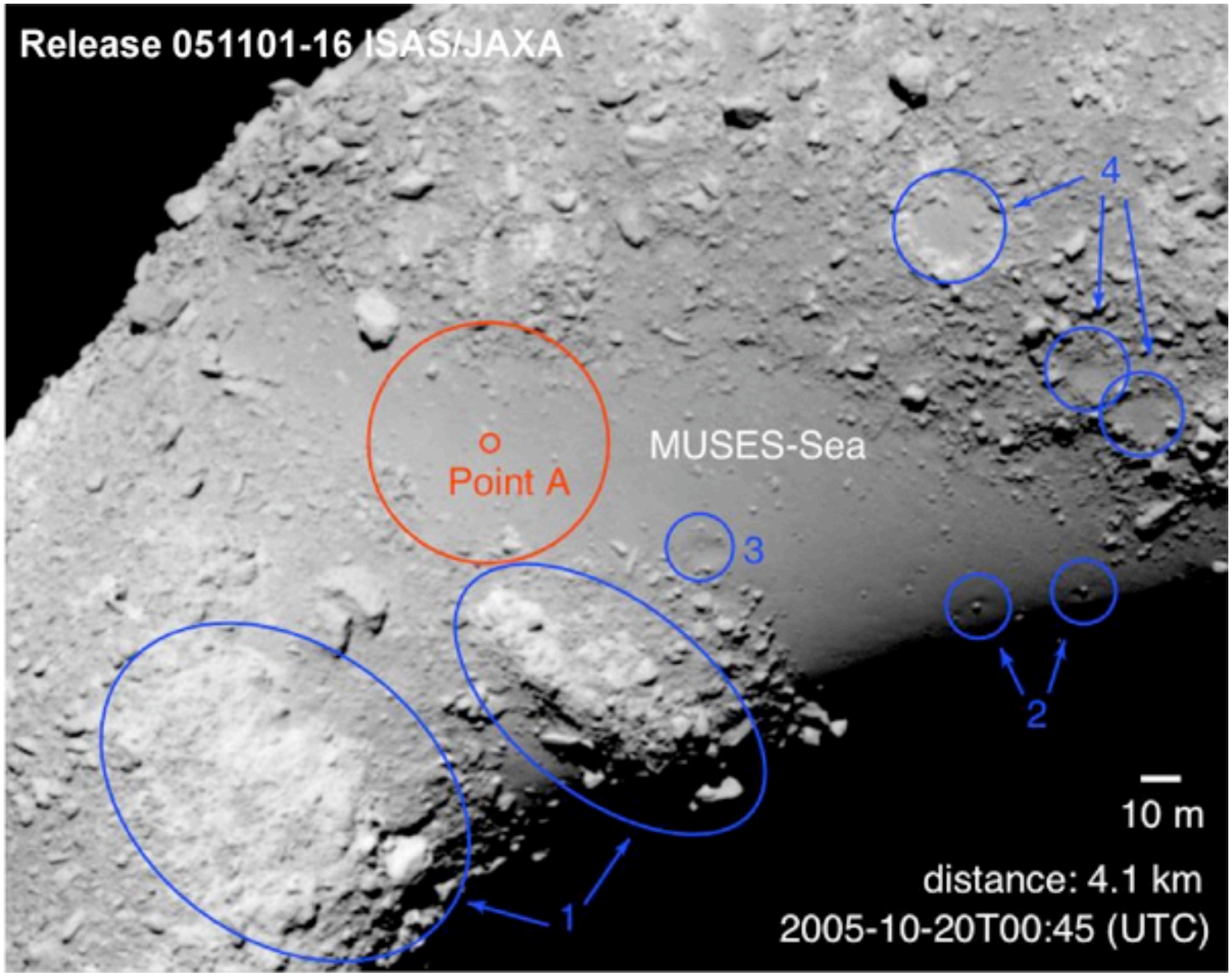


Touch Down Site Candidate B: Little Woomera



- This area was selected as one possible landing site.
- Subsequent high resolution images showed that this area still held too many meter-sized boulders.

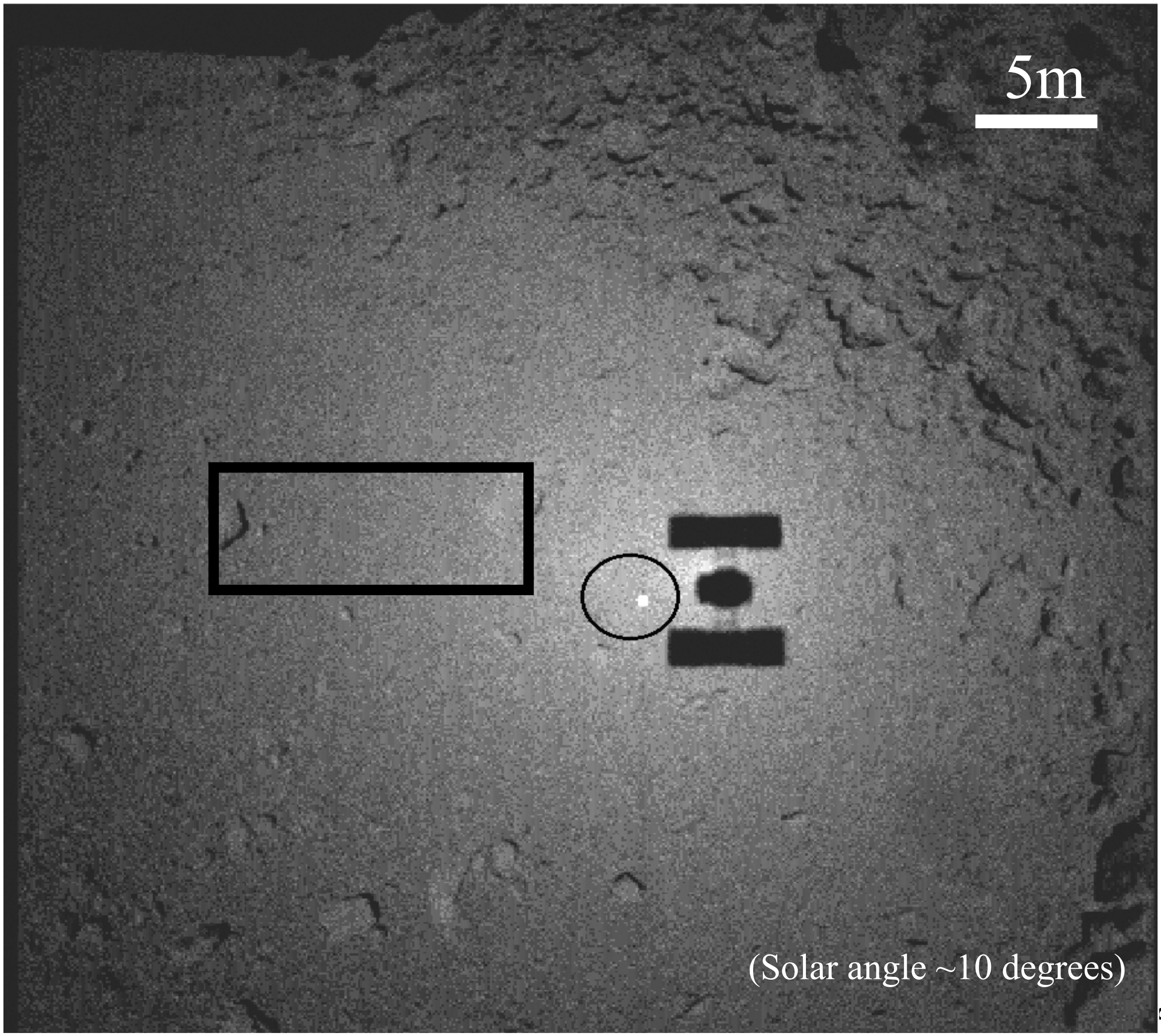
Touch Down Site Candidate A: Muses Sea

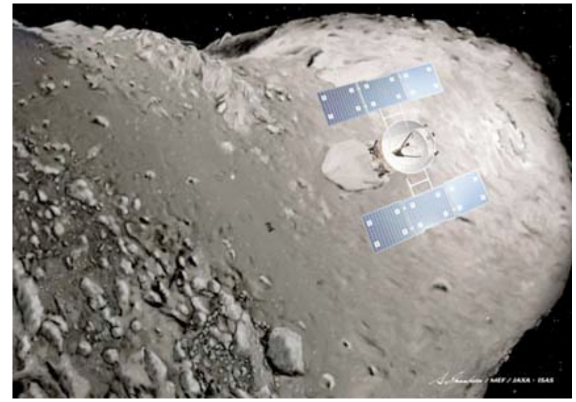


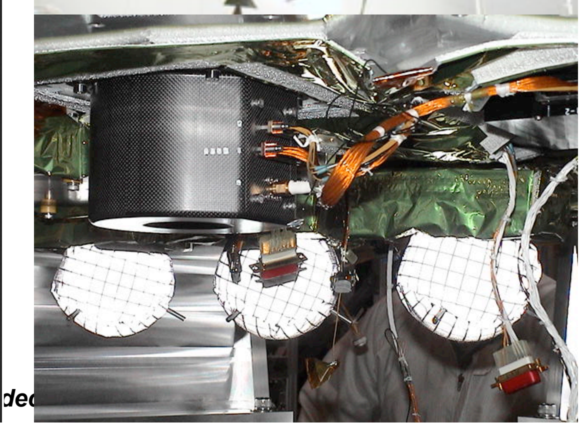
- The largest smooth terrain located between the "Head" and "Body" of the Otter.
- ~60 m across at its widest point.

Relative Scale on Itokawa

Touch Down Site Approach

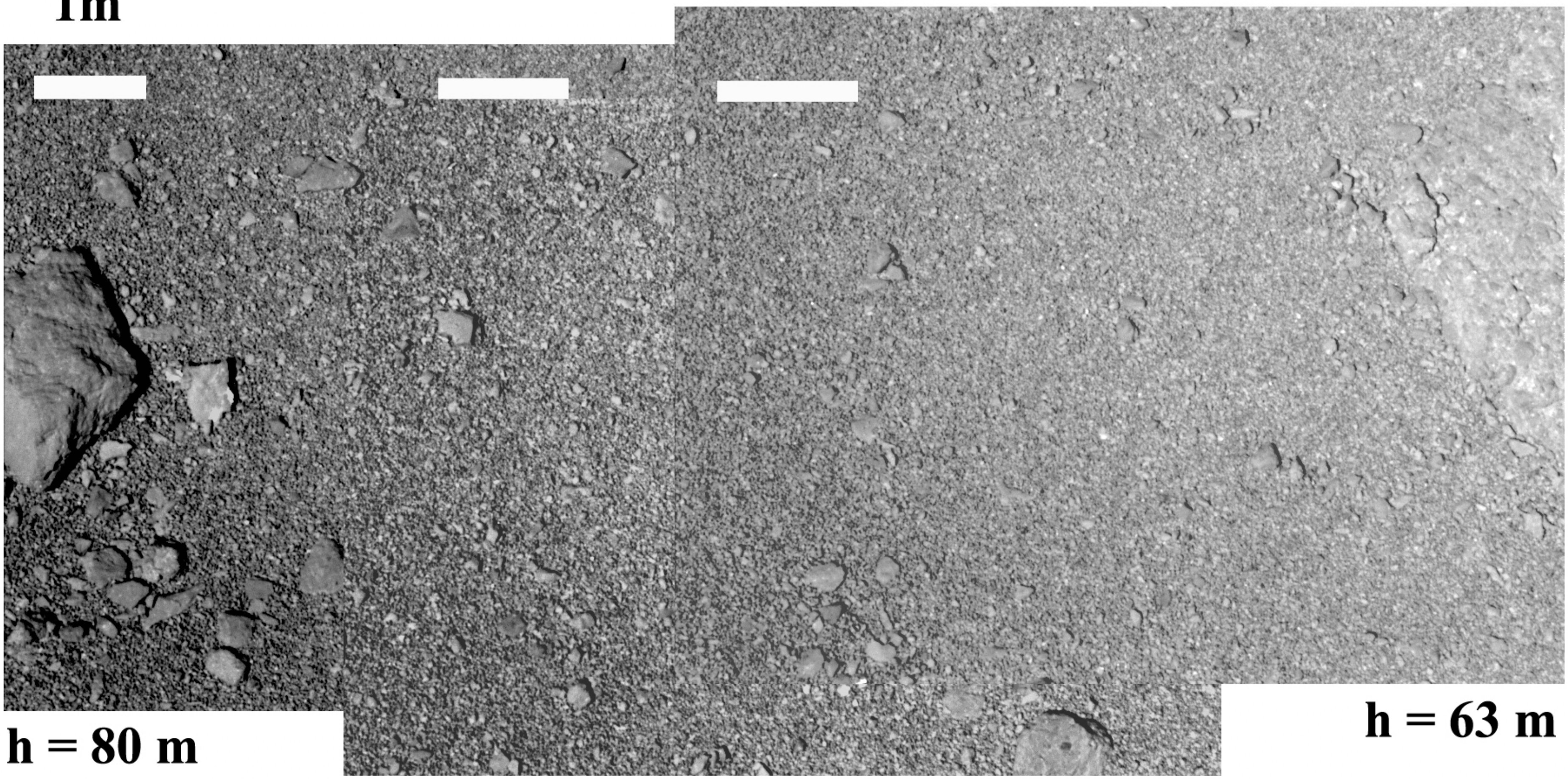






Touch Down Site Close-Up

1m



h = 80 m

h = 68 m

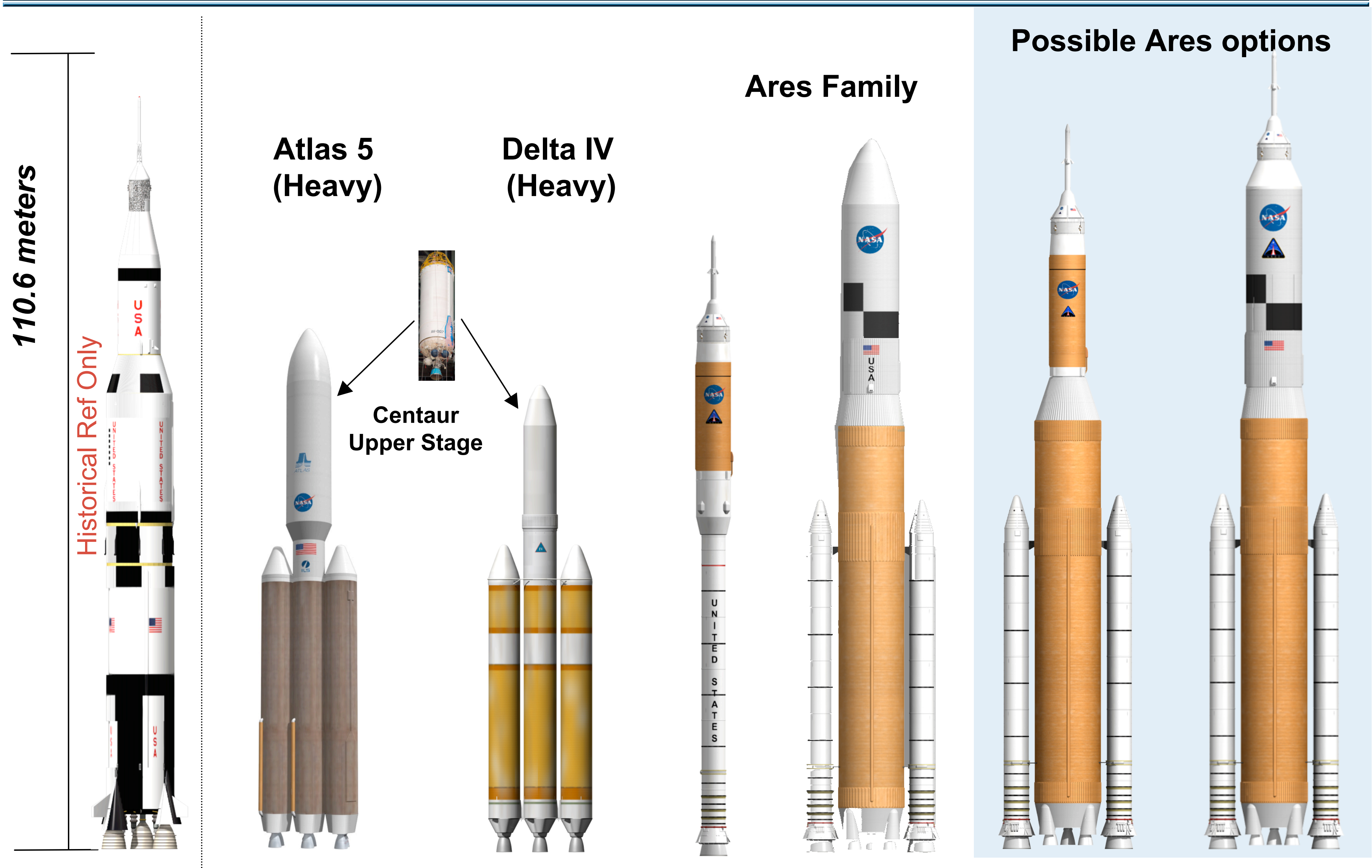
h = 63 m

- Spatial Resolution: 6~8 mm/pixel (cf. NEAR: 12 mm/pixel)

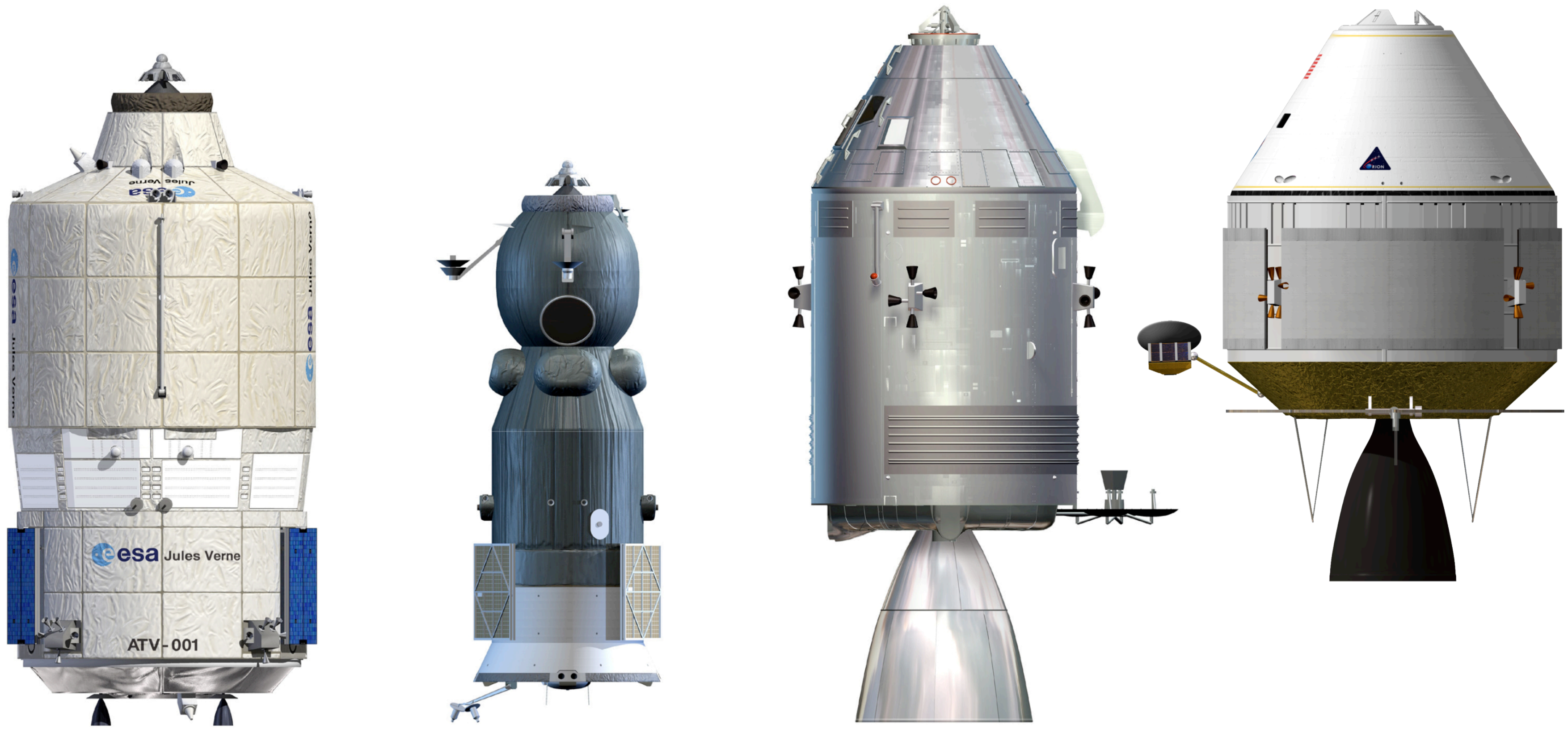
Black Boulders on Itokawa

- Several large black boulders have been imaged on the surface of Itokawa.
- Largest of these is located on the "Head" of Itokawa.
- Possible material from another object.

Possible Launch Vehicles for NEO Missions



Comparison of ATV, Progress, Apollo, and CEV



ATV Progress Apollo Orion