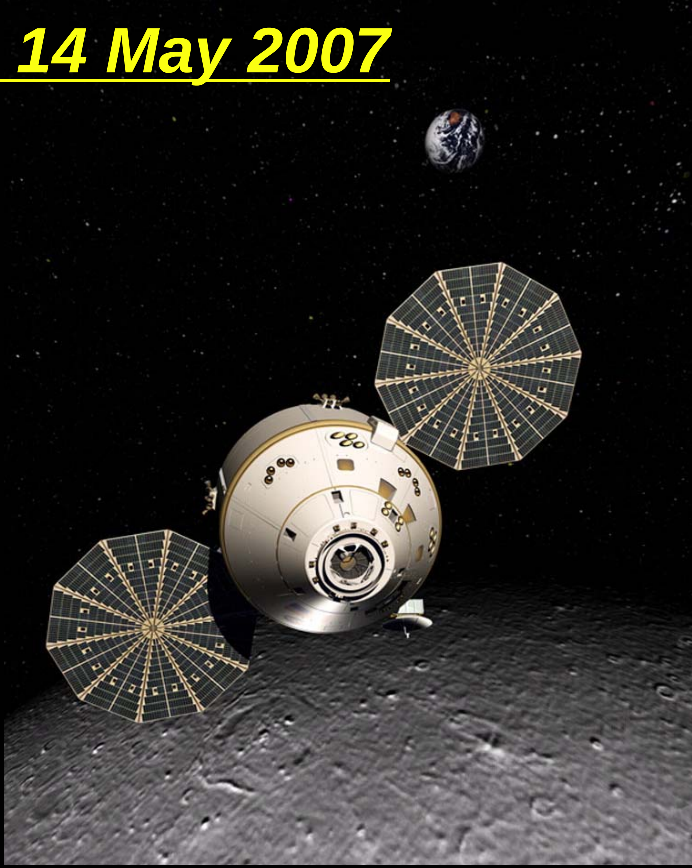
A Piloted Flight to a Near-Earth Object: A Feasibility Study

Goddard Engineering Colloquium – 14 May 2007

Rob Landis, NASA JSC
Dave Korsmeyer, NASA ARC
Paul Abell, NASA JSC
Dan Adamo, Consultant
Dave Morrison, NASA ARC
Ed Lu, NASA JSC
Larry Lemke, NASA ARC
Andy Gonzales, NASA ARC
Tom Jones, ASE
Bob Gershman, JPL
Ted Sweetser, JPL
Lindley Johnson, NASA Hq
Mike Hess, NASA JSC



Study Objective

Examine the flight hardware elements of the Constellation Program (CxP) and answer a fundamental question:

Can the Crew Exploration Vehicle (CEV - Orion spacecraft) and a combination of EELV(s), Ares launch vehicles be utilized for NEO missions?

Study Objective (con't)

Technical Feasibility study (~15 Sep 06 - 5 Feb 07)

Three (3) NASA Centers: Ames Research Center (ARC)
Johnson Space Center (JSC)
Jet Propulsion Laboratory (JPL)

---

1) Review of previous work and definition of mission objectives,
2) Identification/assessment of candidate NEOs (also science justification);
3) Assessment of performance characteristics of CxP elements;
4) Design of mission concepts and value added to CxP; and
5) Document the feasibility study results

Constraints:

- No change to existing planned CxP launch infrastructure.
- Minimal modifications for Block II Orion (i.e. SimBay instruments, 2-3 astronauts, etc.)

Overview

- Background
  - Definition
  - History and Discovery
  - 2005 Authorization Act
- Constellation (Cx) Hardware Options Studied
- NEOs for
  - Exploration
  - Resources
  - Planetary Defense

What is a NEO (Near Earth Object)?

What are NEOs?

- Near Earth Objects: Asteroids and Comets that are near, or cross, the Earth's orbit

Asteroids (~90% of NEO population)

- Most are shattered fragments of larger asteroids
- Ranging from loose rock piles to slabs of iron
- Many are Rubble rock piles - like Itokawa
- Shattered (but coherent) rock - like Eros
- Solid rock of varying strength (clays to lavas)
- 1/6 are binary objects

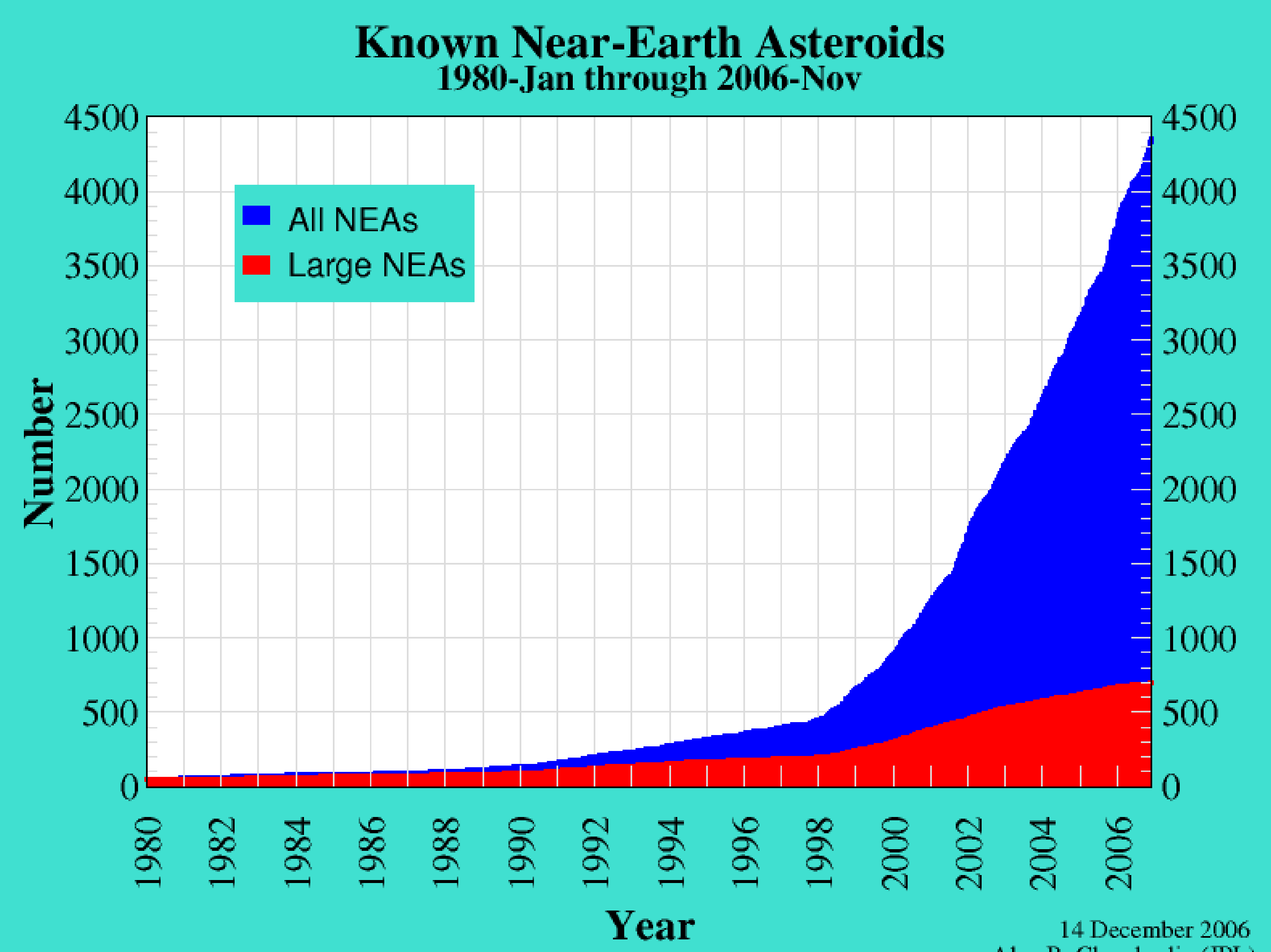
Comets (weak and very black icy dust balls) - <u>NOT targets for this study</u>

- Weak collection of talcum-powder sized silicate dust
- About 30% ices (mostly water) just below surface dust

NEO PHOs are Potentially Hazardous Objects (i.e. asteroids <0.05 AU of Earth)

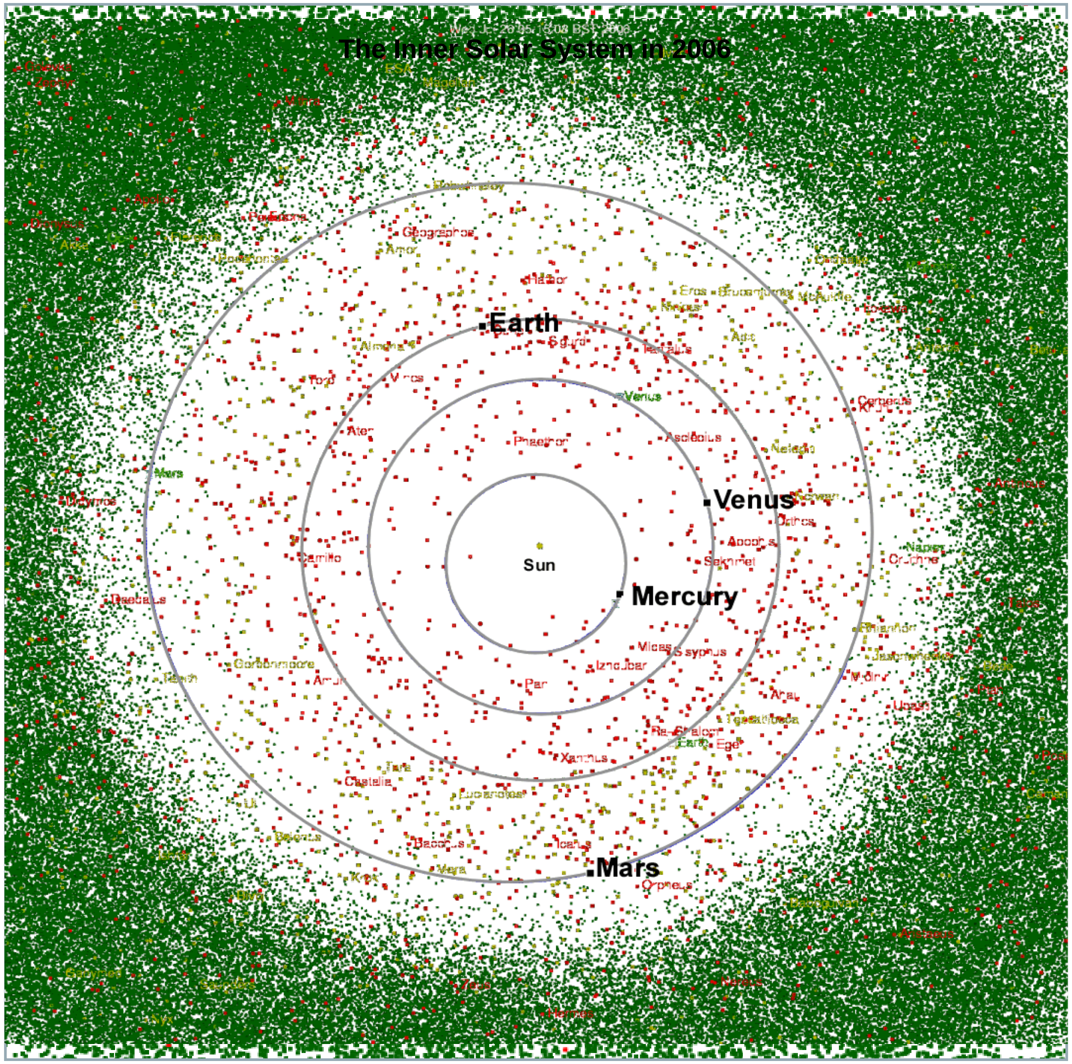
NEOs are <u>very diverse in makeup</u>

- Hard to characterize Asteroids solely with ground-based sensors
  - Some information available from radar, spectrometry
- Robotic analysis is required to fully characterize a NEO


Known Near-Earth Asteroids
1980-Jan through 2006-Nov
Number
Year
0
500
1000
1500
2000
2500
3000
3500
4000
4500
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
All NEAs
Large NEAs
14 December 2006

History of Known (current) NEO Population

2006



Earth Crossing

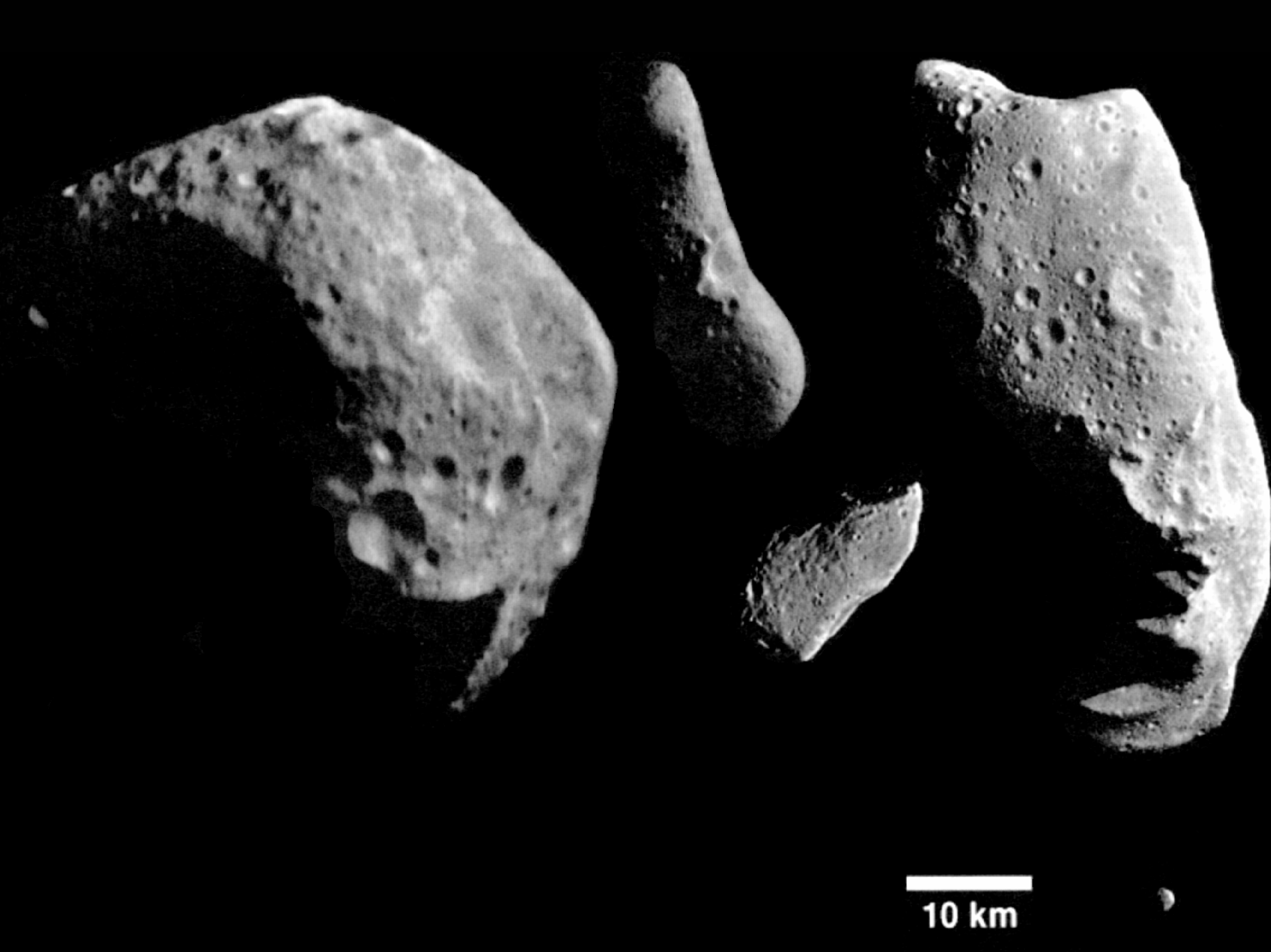
Outside Earth's Orbit

Known
- 340,000 minor planets
- ~4500 NEOs
- ~850 Potentially Hazardous Objects (PHOs)

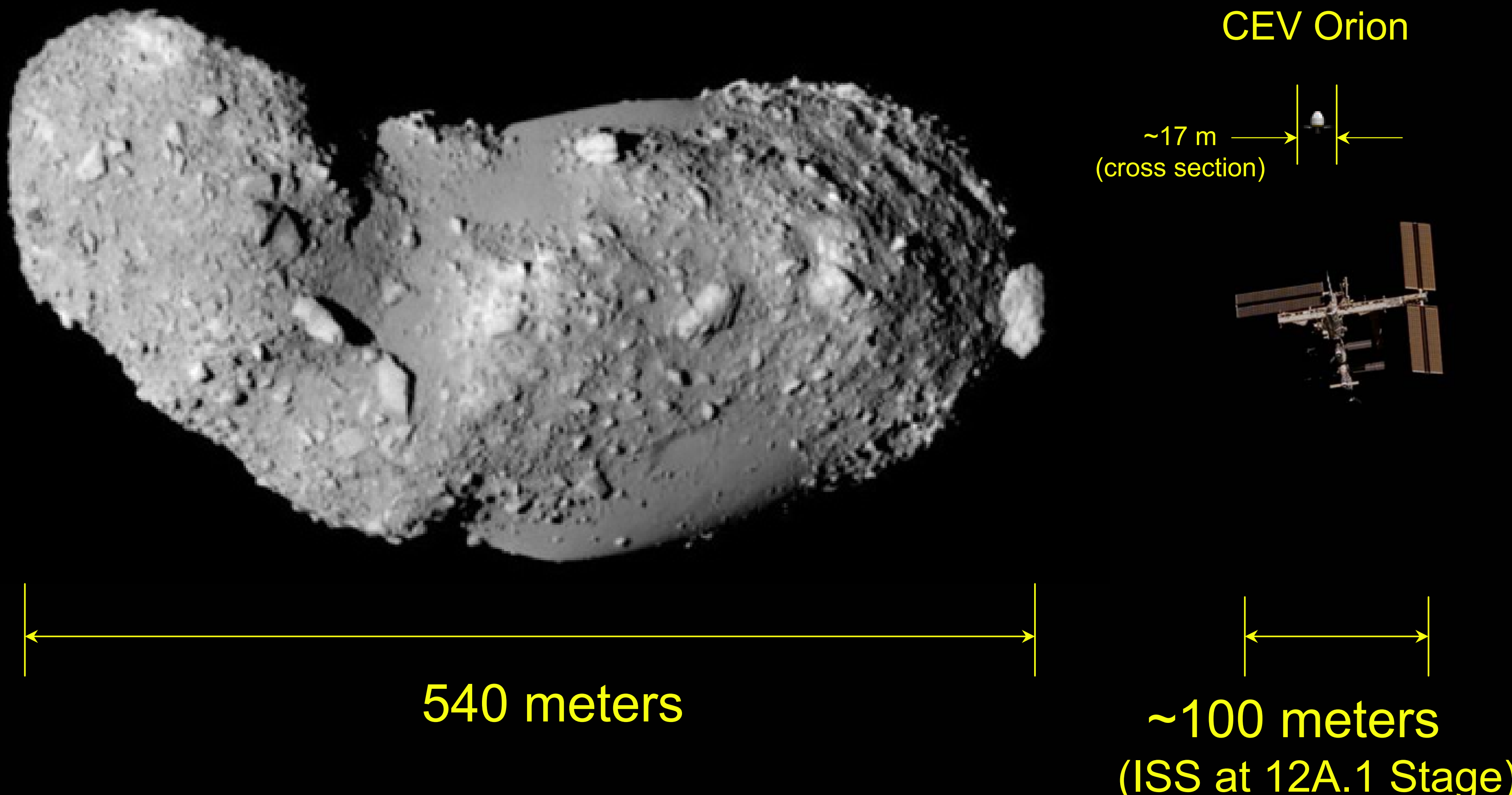
New Survey Will Likely Find
- 100,000+ NEOs (> 140m)
- 20,000+ PHOs

Scott Manley

Armagh Observatory


10 km

Asteroid Itokawa, ISS, and CEV Orion

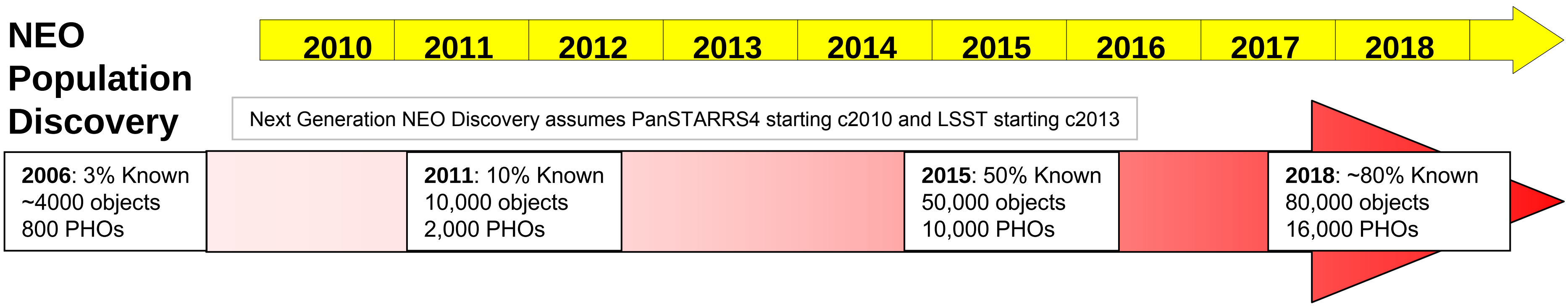


JAXA, NASA

NEO - Next Generation Search

- **NEO Next Gen Search (2008 – 2021) will be at 100 times the current discovery rate**
  - First month of PanSTARRS-4 operation (in 2010) is estimated to discover more asteroids than are currently known
  - ~500,000 new asteroids
  - ~100,000 near-Earth objects (D > 140m)
  - ~20,000 PHOs 140 m and larger by 2021
- **Many of NEOs PHOs could be possible candidates for piloted mission**
  - Viability depends phasing in orbit and on Δv to rendezvous

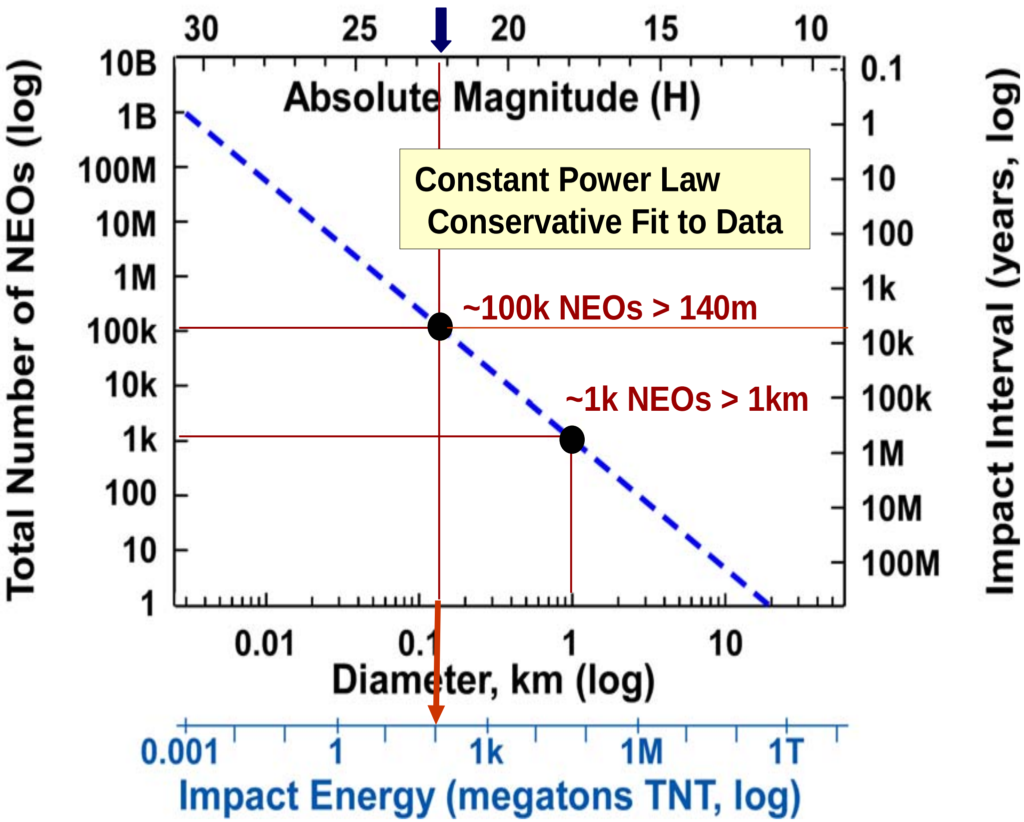
NEO Population Discoveries



- Current NEO Catalog shows few Target opportunities for a NEO Mission in 201x - 2030 timeframe however,
- NEO Next Generation Search will **increase target discovery ~40x**
- Crewed NEO Mission ‘Target of Opportunity’ may exist in the ~2015-2030 Timeframe
- Key to finding Mission Targets is putting NEO search assets to work ASAP
  - PanSTARRS4 – Complete to 300 m by 2020, Only ~10% complete to 30 m.
  - LSST – Complete to ~150 m by 2025, Only ~20% complete to 30 m.
  - Arecibo radar – Critical for characterization, funding in jeopardy
  - Space Based sensor – Not currently funded. Necessary if many possible targets are desired.

Frequency of NEOs by Size (or Magnitude)

Alan W. Harris (Space Science Institute), Edward Bowell (Lowell Observatory)



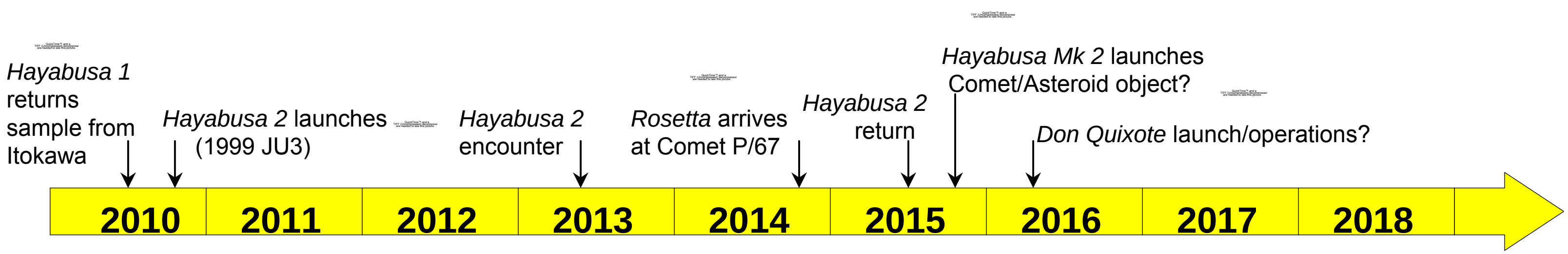
Survey Parameters

- ~21% of NEOs are potentially hazardous
- Survey to find ~18,000 PHOs 140 m and larger
- Will find many other minor planets and smaller threats
- Data system must be sized for 2 million observations of up to 500,000 objects
- Discovery of ~15 PHOs per day will generate a peak of 2-3 warnings per week

Discovery rate implies a large number of Manned NEO Mission opportunities

NEO Precursor Missions

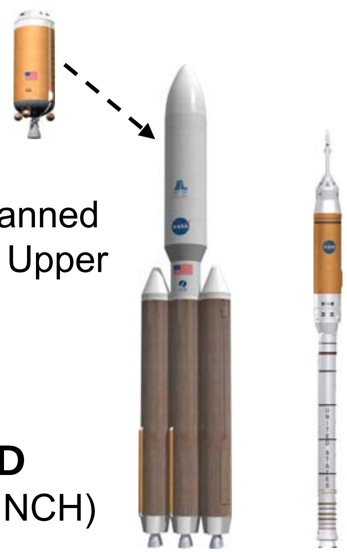
Planned Robotic Missions to NEOs



- ***NEAR*** (USA), Rendezvoused with 433 Eros on Feb. 14, 2000.
- ***Hayabusa*** (Japan), arrived at NEO Itokawa on Sept. 12, 2005.
- ***Hayabusa 2*** (Japan), is planned for launch in 2010 to C-type NEO (1999 JU3).
- ***Hayabusa Mk 2*** (Japan), is planned for launch to an extinct comet in 2015.
- ***Don Quixote*** (ESA), is a planned mission to launch between 2013 and 2017 to a TDB target NEO.
- ***Osiris*** (USA), is a Discovery-class mission in Pre-phase A for a possible launch in 2011 to C-type NEO (1999 RQ36).

- Prior to a Crewed Mission to a NEO, additional characterization of the Target Asteroid is required for mission planning and crew safety (e.g., Ranger and Surveyor).
  - NEOs greatly vary in size and composition (1/6 are binary objects)
  - Rotation rates and make-up will significantly impact proximity operations

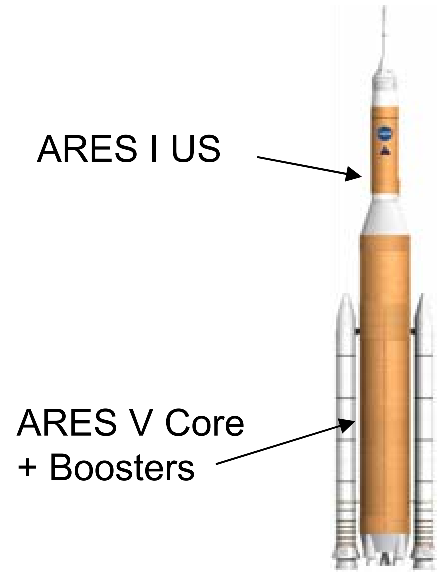
NEO Mission Launch Concepts



EELV
Used to loft unmanned Centaur Upper Stage

ARES I
Used to loft Orion and Crew

LOWER BOOKEND
(DUAL LAUNCH)



ARES IV
used to loft Orion

MID-VOLUME IV
(SINGLE LAUNCH)

ARES V
used to loft Orion

MID-VOLUME V
(SINGLE LAUNCH)

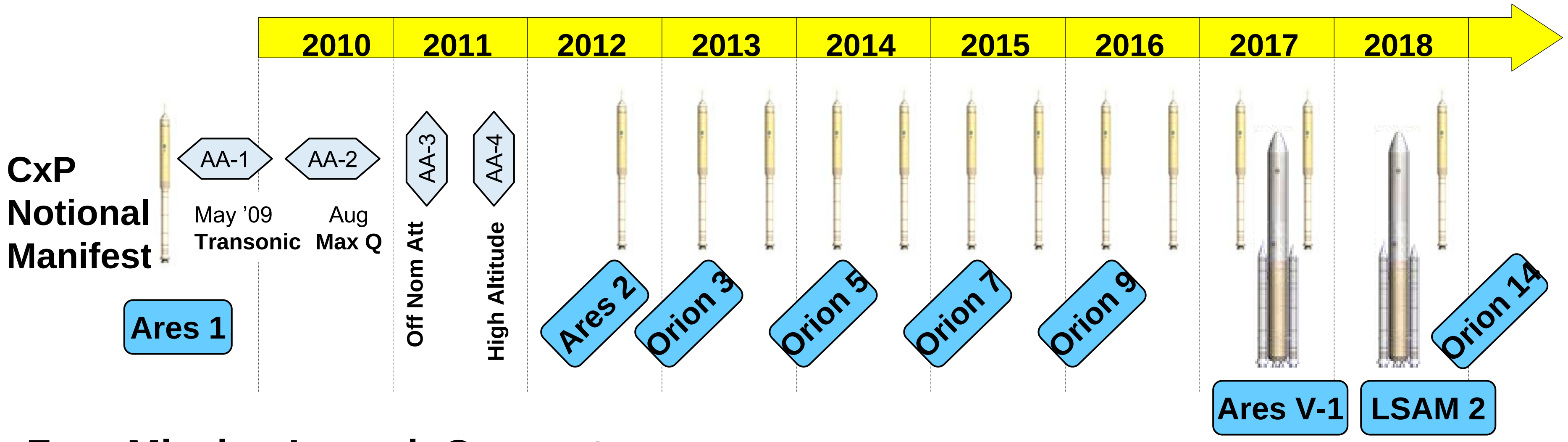
ARES V
Used to loft EDS + LSAM

ARES I
Used to loft Orion

UPPER BOOKEND
(DUAL LAUNCH)

Vehicles are not to scale.

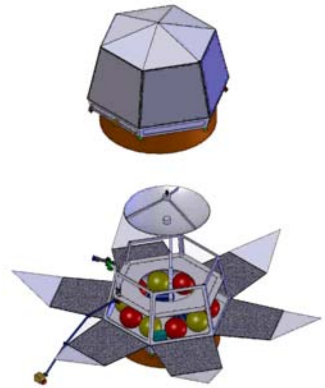
NEO Mission Launch Concepts



Four Mission Launch Concepts:

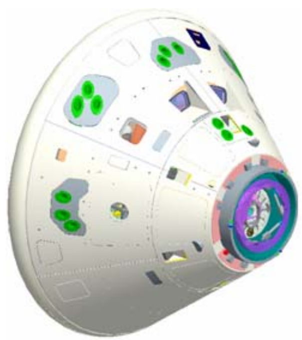
- Lower Bookend: Earliest possible concept (2013+)
  - Dual Launch: Orion Block II on CLV/Ares I, and Centaur upper stage on an EELV
- Upper Bookend: Most like a lunar mission (2017+)
  - Dual Launch: Orion Block II on CLV/Ares I, and LSAM prototype on Ares V and earth departure stage (EDS)
- Mid Volume (two versions): Alternate launch concepts at CxPO request
  - a) Single launch: Orion Block II on Ares IV
    - (Where Ares IV = Ares V core / boosters with CLV/Ares I upper stage)
  - b) Single launch, Orion Block II on Ares V and EDS upper stage

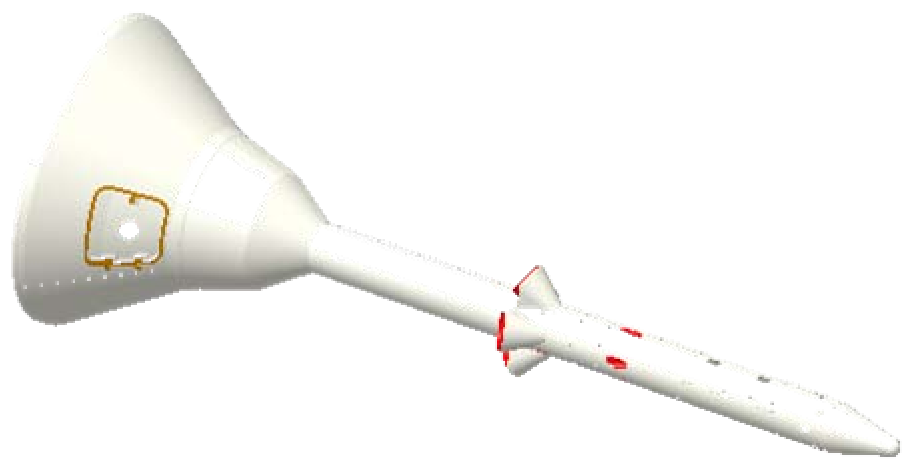
NEO CEV Components Overview



EO Telerobotic System,

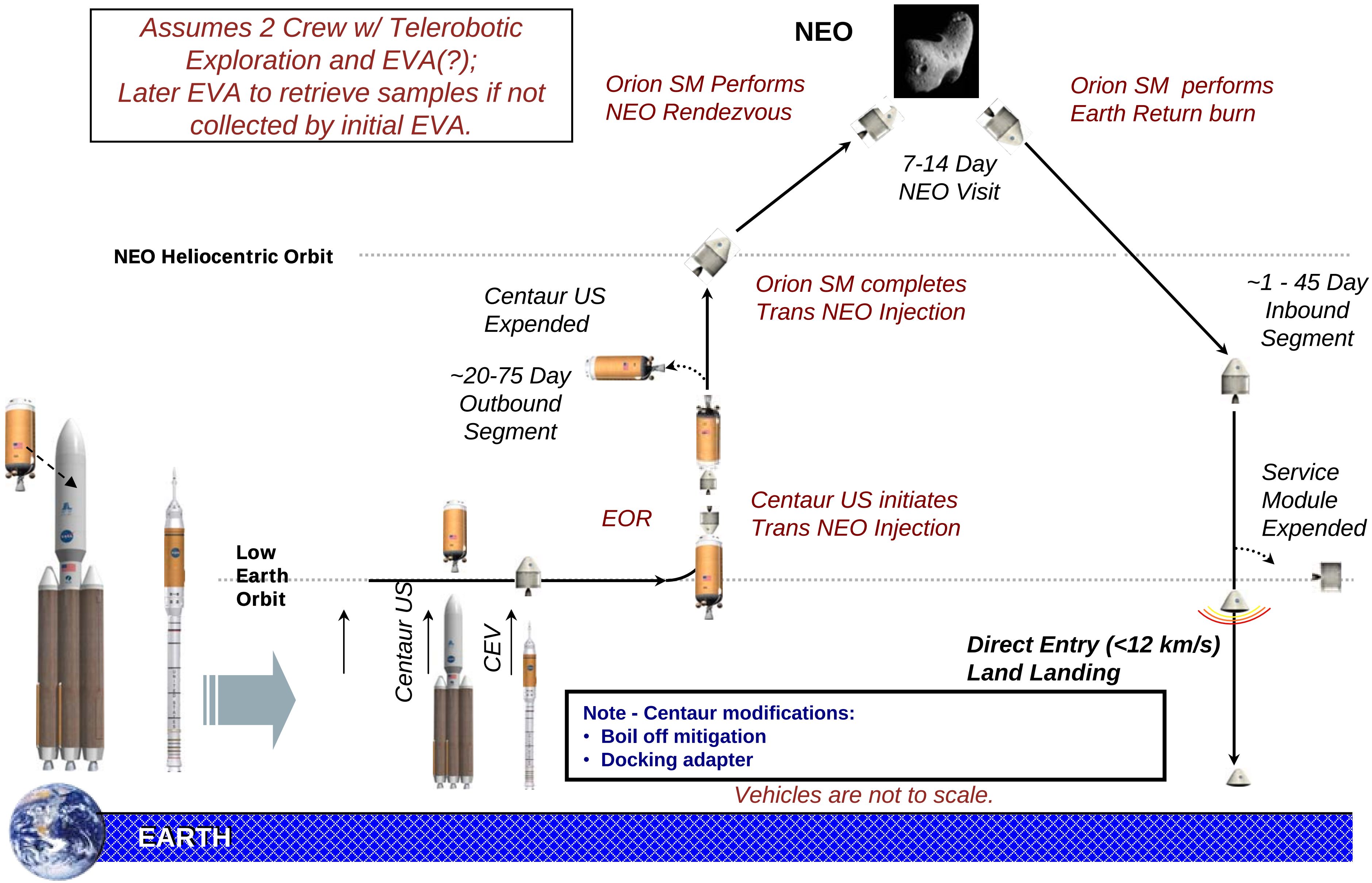
- launched in place of LIDS adapter under the Party Hat





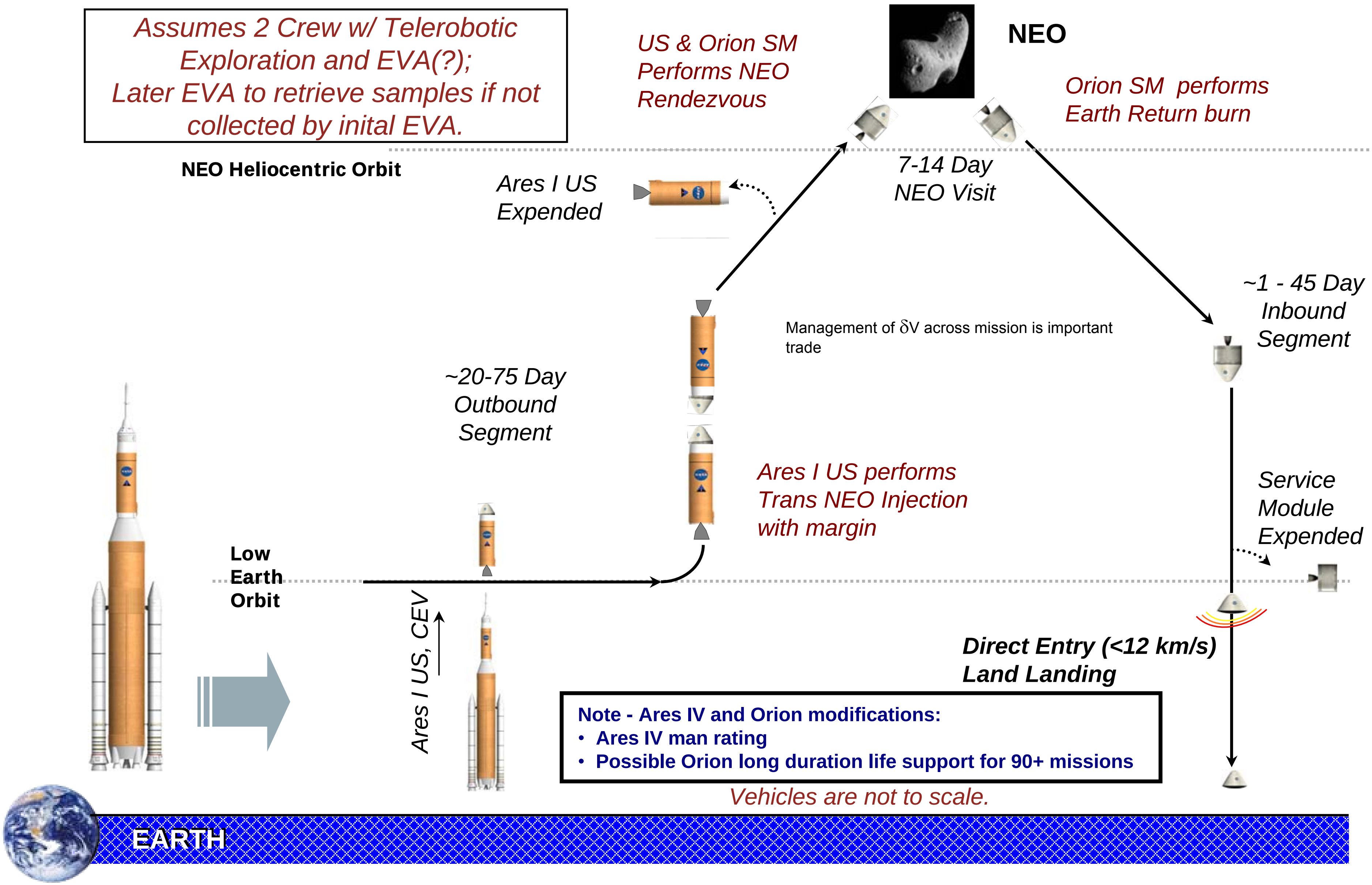
"Lower Bookend" Near-Earth Object (NEO) Crewed Mission

Centaur upper stage / Orion SM provides Earth Departure, NEO Arrival, and Earth Return ΔV



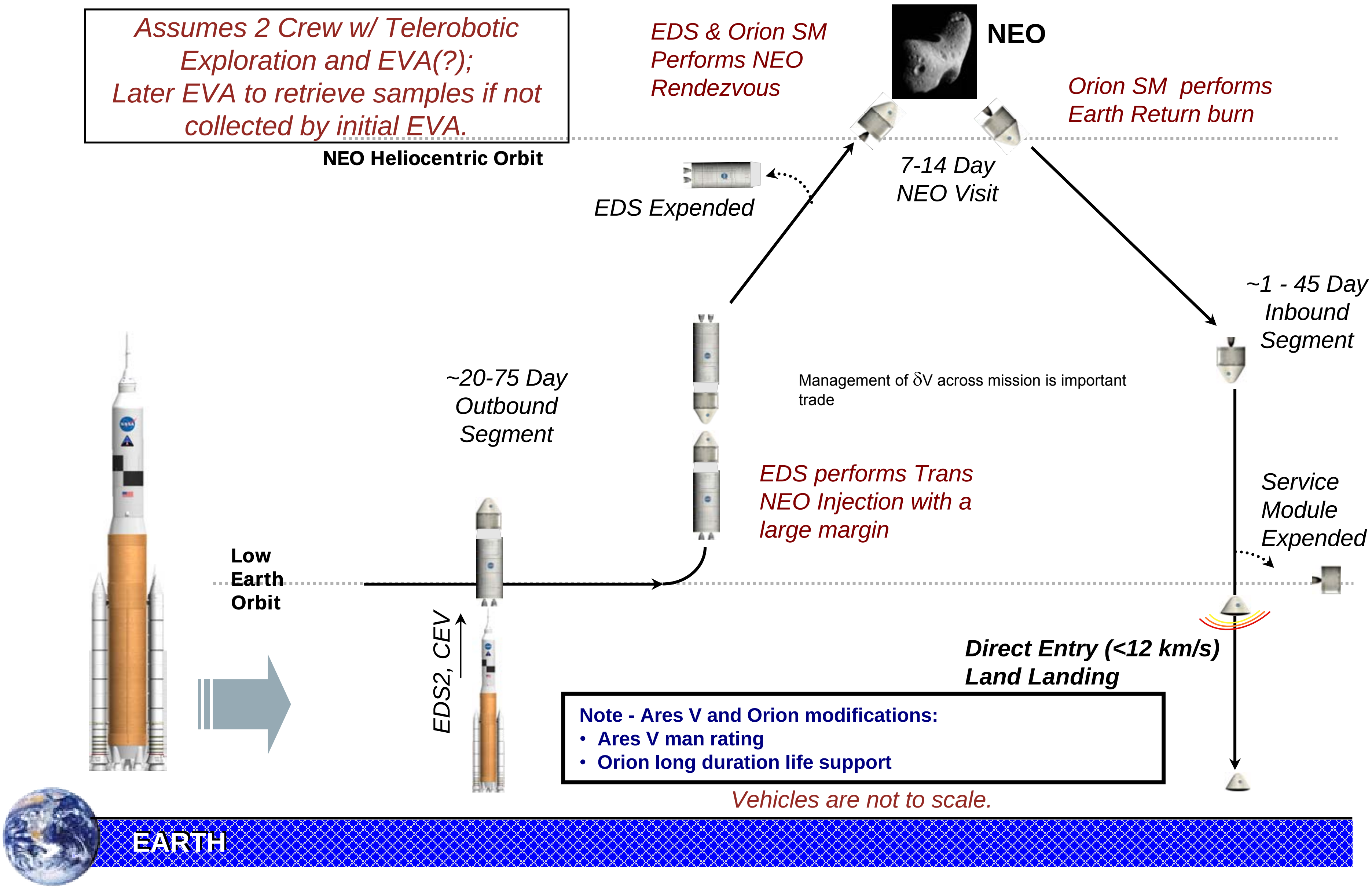
“Mid Volume IV” Near-Earth Object (NEO) Crewed Mission - Ares IV

Ares I Upper Stage / Orion SM provides Earth Departure, NEO Arrival, and Earth Return ΔV



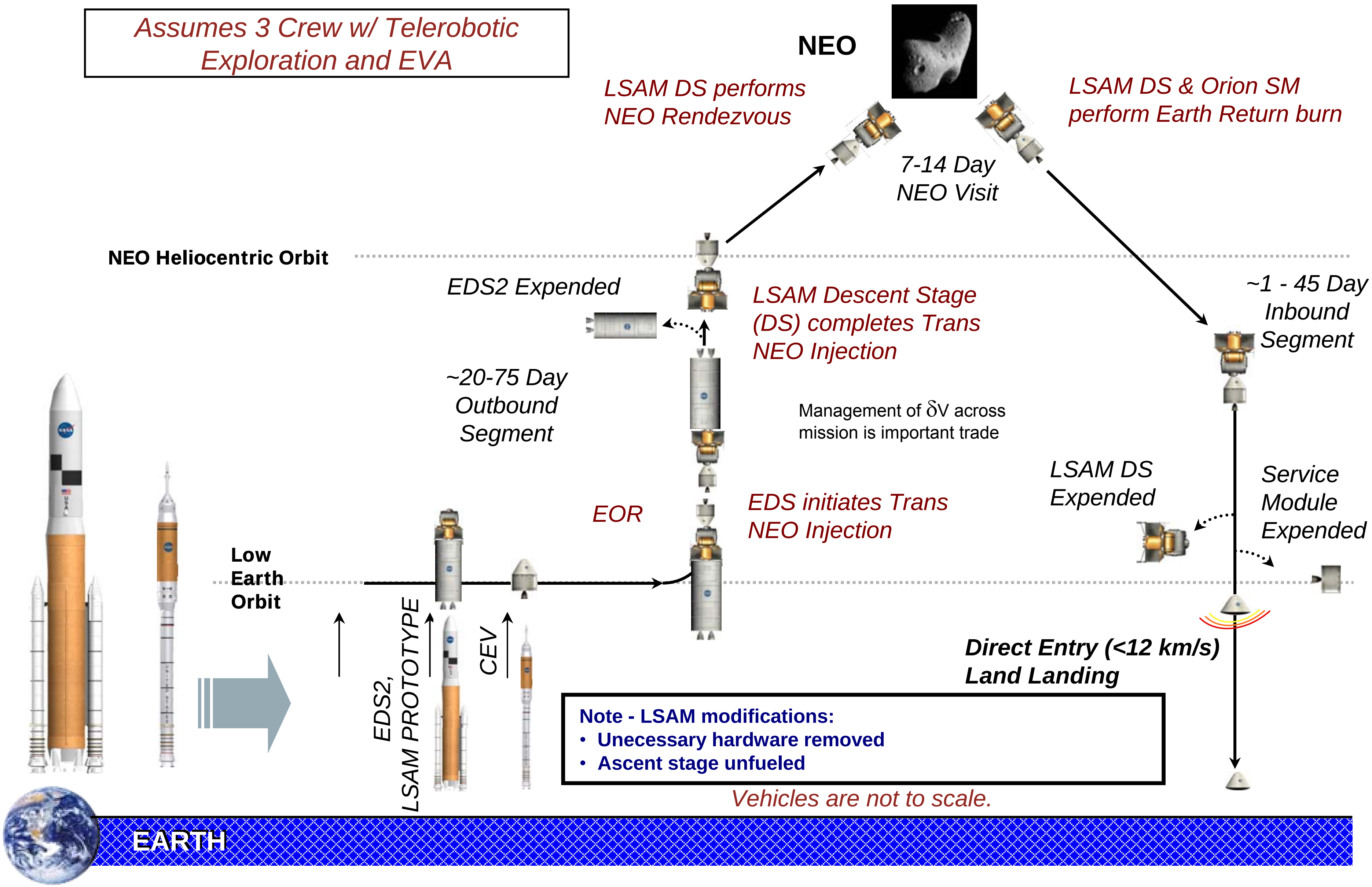
“Mid Volume V” Near-Earth Object (NEO) Crewed Mission - Ares V

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



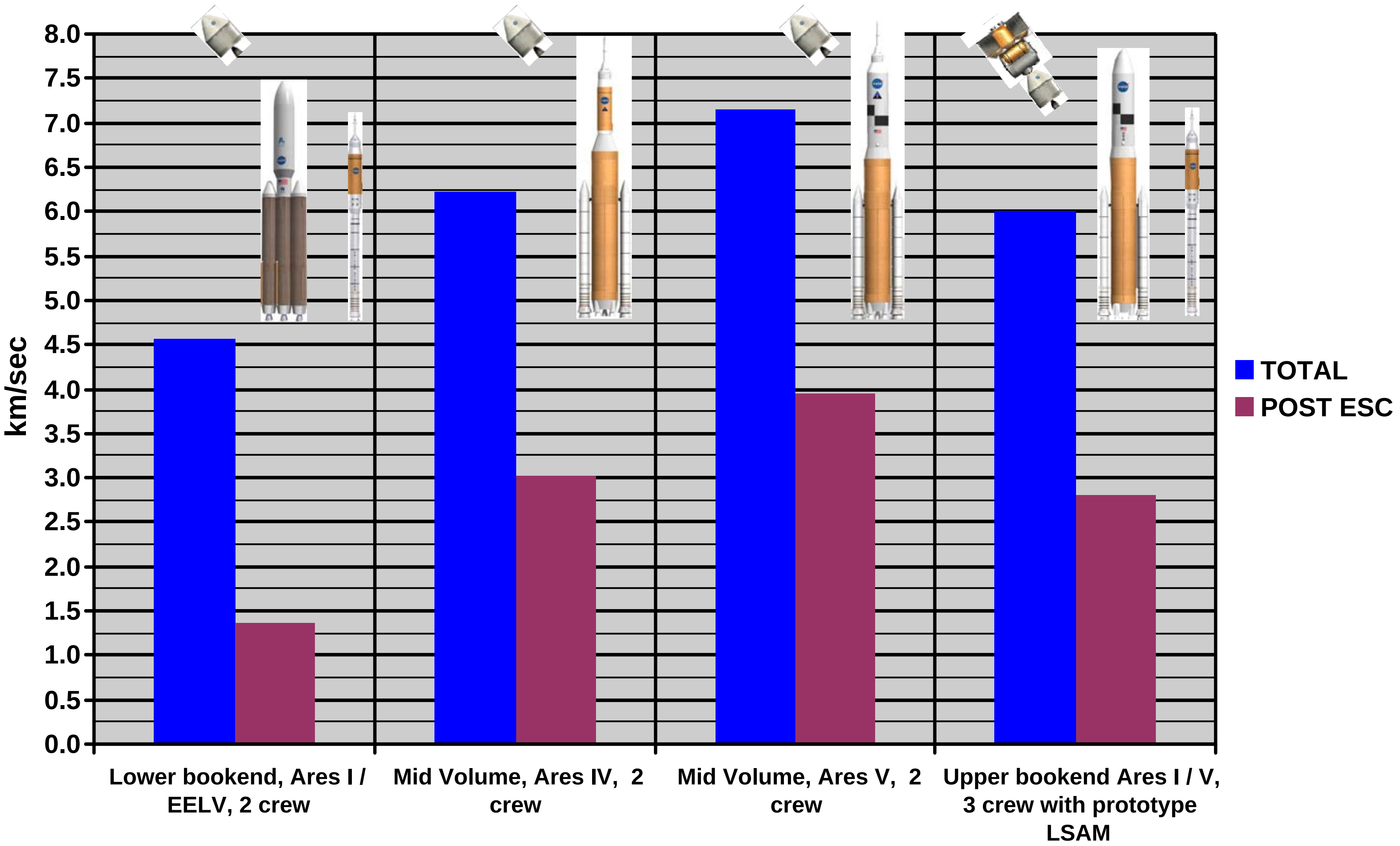
"Upper Bookend" Near-Earth Object (NEO) Crewed Mission

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



ΔV Rack and Stack for Options Studied

Application of ΔV across mission is an important trade



NEO Database and Trajectory Analysis

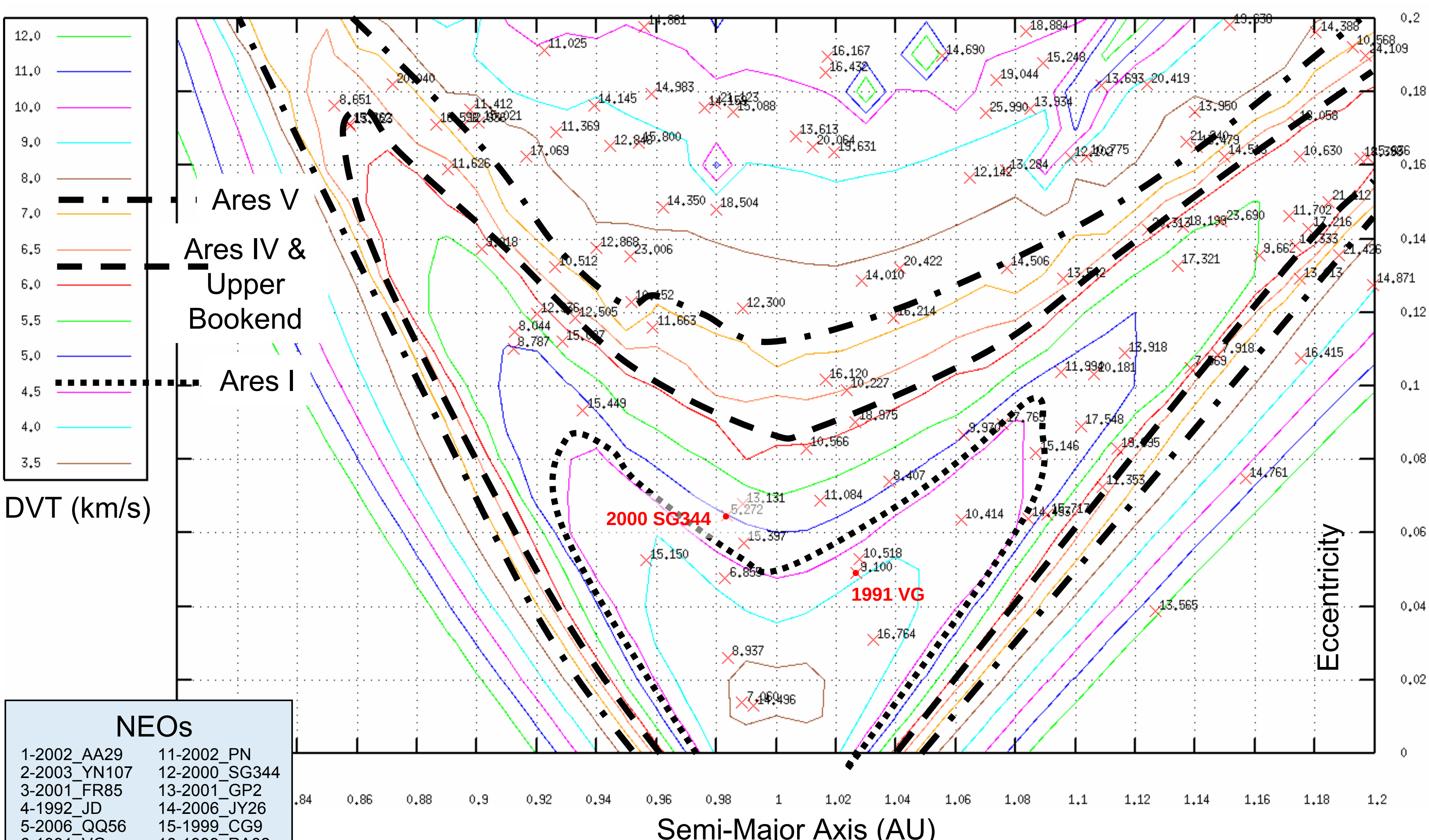
- **Which NEOs are good targets of opportunity?**
  - Earth-like orbits with low eccentricity and inclination
  - Earth close approaches during our time frame (2015 - 2030) (aka PHOs)
- **Team assessed NEO targets from existing NEO (HORIZONS) database**
  - 1228 NEOs filtered by semi-major axis (a), eccentricity (e), and inclination (i)
    - 0.5AU < a < 1.5AU; e < 0.5; i < 3º
    - Only 71 (6%) have i < 2 º and 237 (19%) < 5 deg
      - Each degree of inclination requires 0.5 km/s to be added to the post-escape ΔV for a mission
  - Assessed the best 80 NEOs

- **Identified the ΔV to match NEO orbits and Created "Lambshank" ΔV contour plots**
  - ΔV contours show the minimum possible post-escape, and total mission ΔV to a NEO with a given semi-major axis a and eccentricity e.
  - Idealized a close approach to Earth (neglected NEO's position in the orbit)
  - 14-day stay time assumed.
  - Results for 90-day mission (also ran 120, 150, 180-day options)

Selecting the Target NEO

- **Overlaid the known NEO catalog on Lambshank plots**
  - Finds the possible NEO opportunities based upon the orbital elements
  - Allows quick assessment of new NEOs as opportunities as they are found
  - Doesn't capture all the highly elliptical or earth-transit NEOs but those are much fewer
  - Current NEO Database had no known candidate targets in 2014 - 2030
  - Looked for candidate missions in an expanded database ~40x in time, 2014-2214
- **One existing NEO (2000 SG344) in database met the ΔV and orbital position requirements**
  - Low inclination (0.11)
  - Best relative orbital position (mean anomaly) occurs in 2069 (however, other passes come during 2026, 2028 apparitions - possibly reachable with mid- and hi-bookend missions)
- **We used the 2069 launch to 2000 SG344 for our detailed mission concept analysis.**

90-Day Mission Set: NEO Target Opportunities vs Total ΔV from LEO, 2006 Current population



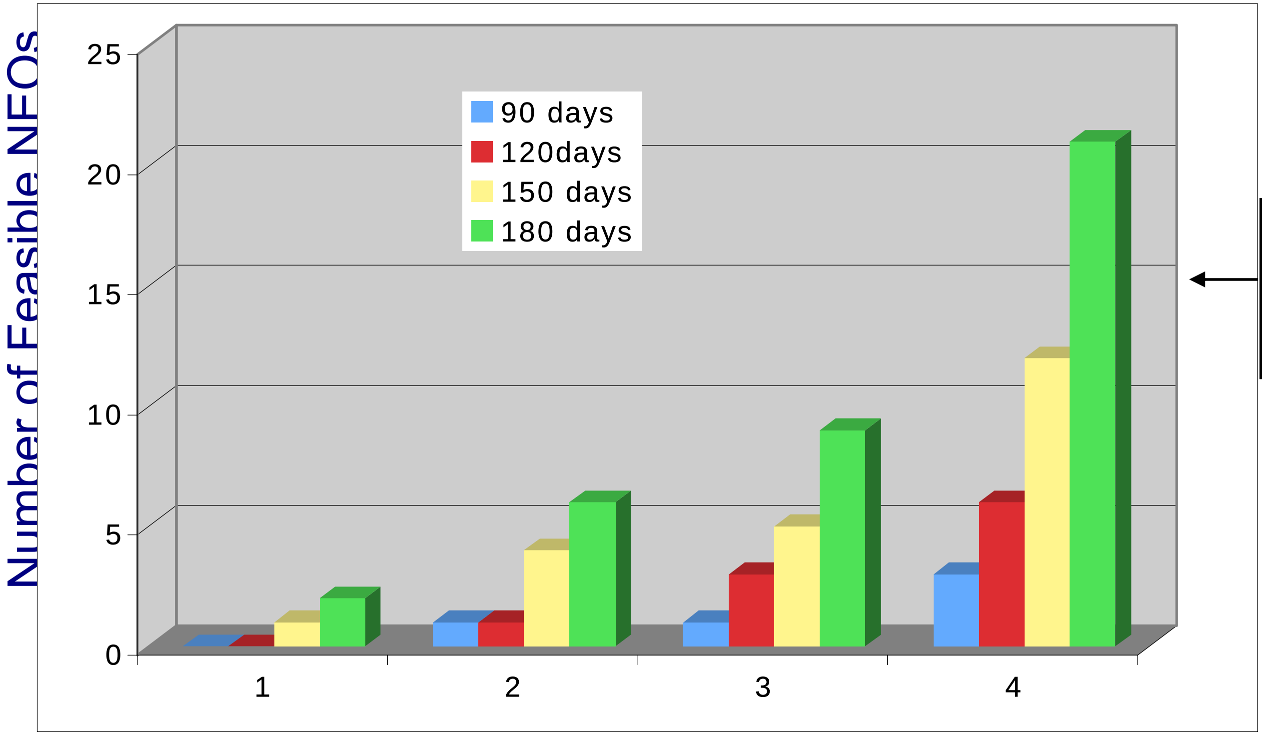
NEOs

1-2002_AA29	11-2002_PN
2-2003_YN107	12-2000_SG344
3-2001_FR85	13-2001_GP2
4-1992_JD	14-2006_JY26
5-2006_QQ56	15-1999_CG9
6-1991_VG	16-1999_RA32
7-2001_ED18	17-2006_BZ147
8-2006_DQ14	18-2002_LW
9-2003_EM1	19-2001_QJ142
10-2005_CN61	20-1999_SO5

All asteroids in Horizon catalogue with I<3-deg are overlaid on the plots, showing best ΔVT for 2014-2100 time frame.

Mission Length impacts on NEO targets

Current database: Feasible NEOs 2014-2100



•NEO Size range: 10-120m

•Mean 30m

Mission Concepts

1 Lower Bookend: Ares 1 + EELV

2 Upper Bookend: Ares V/LSAM with boil-off control

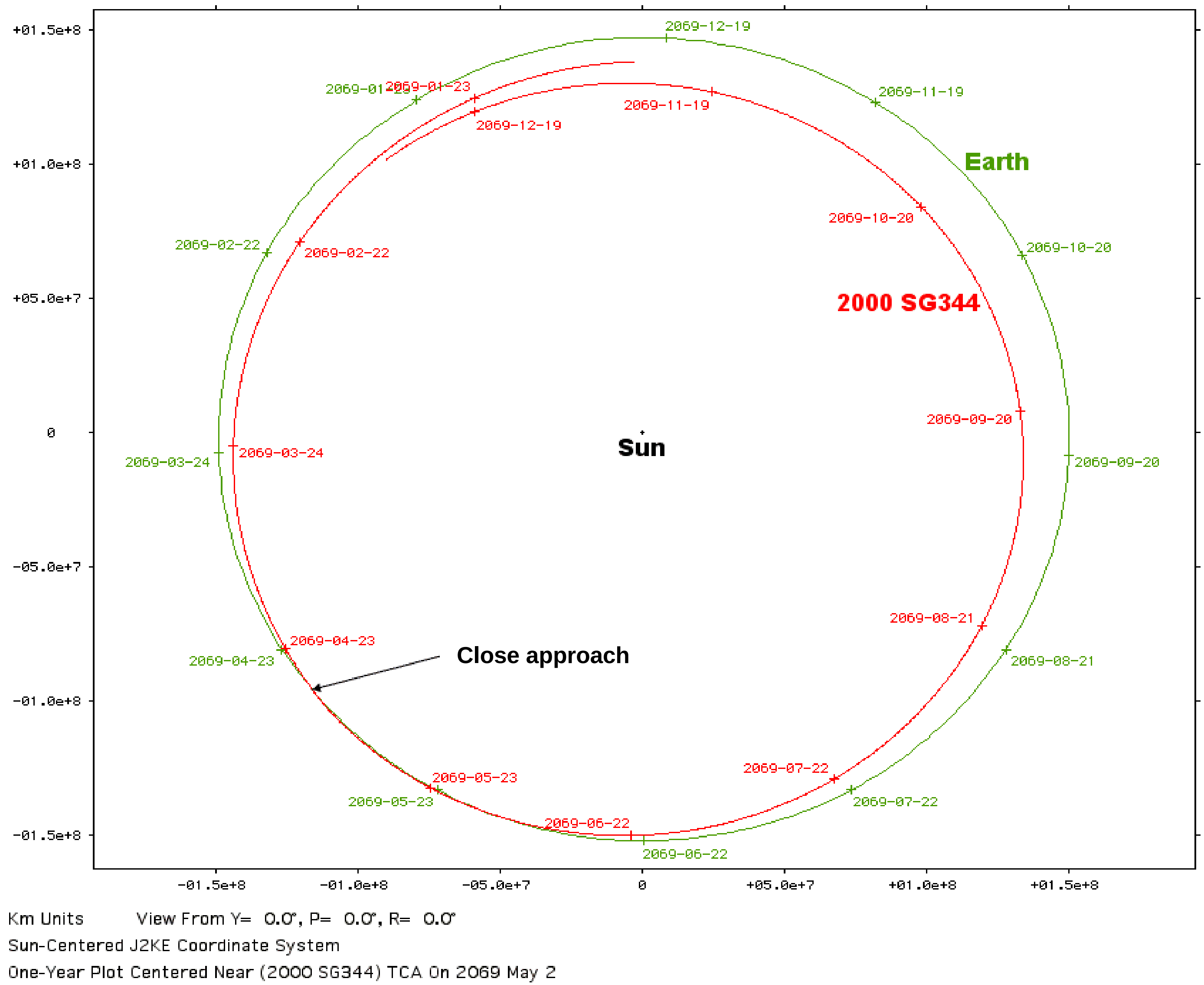
3 Ares IV with boil-off control

4 Ares V with boil-off control

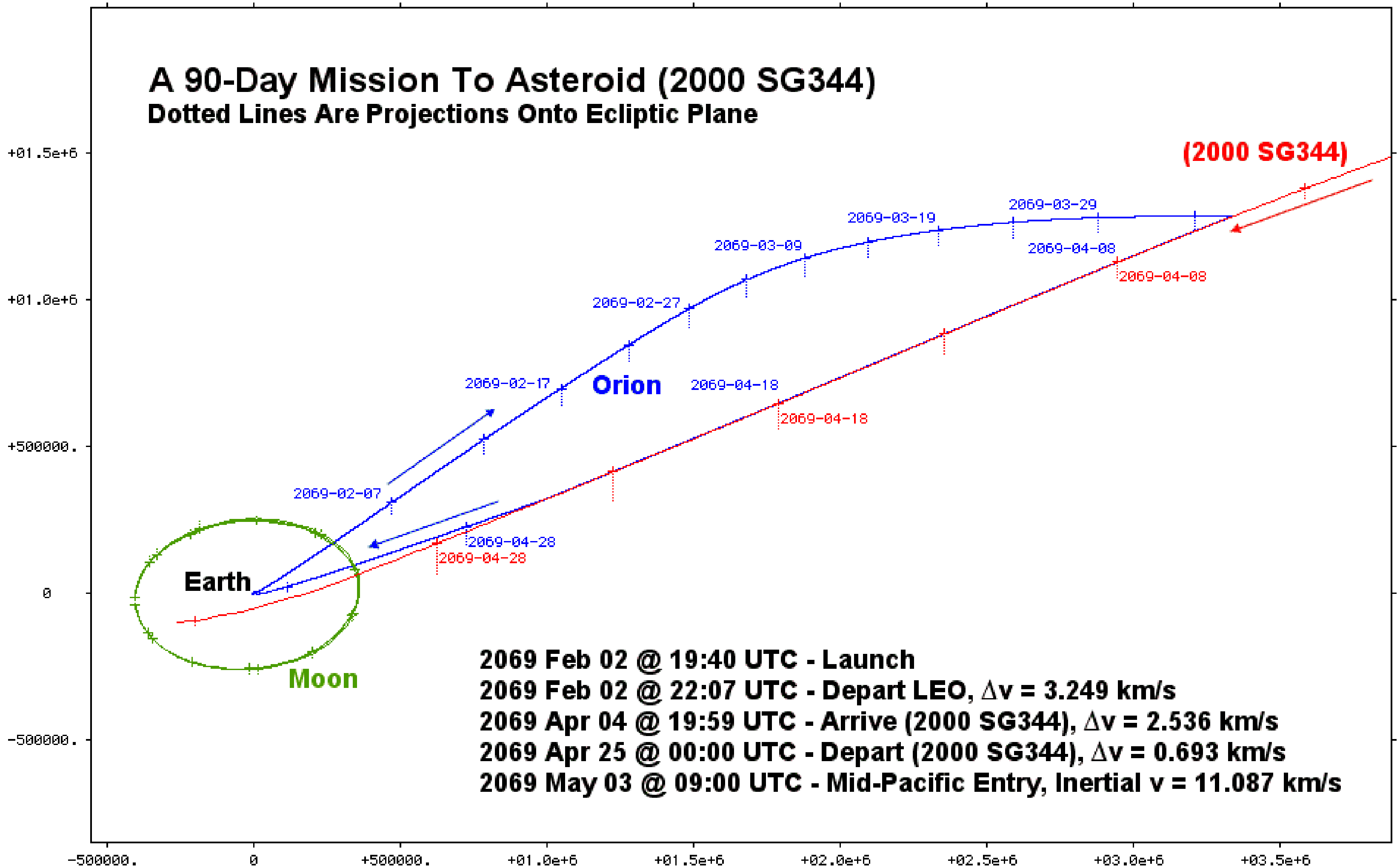
A More Capable Launch System provides greater access to NEO targets

- **Increased ΔV and trip time**

Lower Bookend (Ares I + EELV upper stage)
90-Day Mission to 2000 SG344
Heliocentric Trajectory Plot for Mission



Lower Bookend (Ares I + EELV upper stage)
90-Day Mission to 2000 SG344
Earth-fixed Trajectory Plot for Mission



Km Units View From Y= 0.2°, P= 0.0°, R= 45.0°

Earth-Centered J2KE Coordinate System

Inbound visit to (2000 SG344): Earth parking orbit segment

Summary Findings for Lower Bookend Mission Analysis

- **In general, mission ΔV can be reduced by**
  - Longer mission duration
  - Shorter stay times (second order)
  - Lunar gravity assist (second order)
- **Mission length approaching 180 days impacts ΔV**
  - Can reduce amount of post-escape ΔV to deal with NEO inclination
  - Mission timing can put inclination change ΔV into launch and reentry
- **NEO Launch Windows**
  - Two ~equal launch opportunities to NEOs - each several days long
  - Launch period can be extended by launching into a high elliptical phasing orbit around Earth
  - Can minimize van Allen radiation exposure if the phasing orbit period matching the time from launch to escape
- **A NEO must be in the right place in its orbit at the right time to have a really close approach to Earth, thus allowing a low-ΔV fast mission**

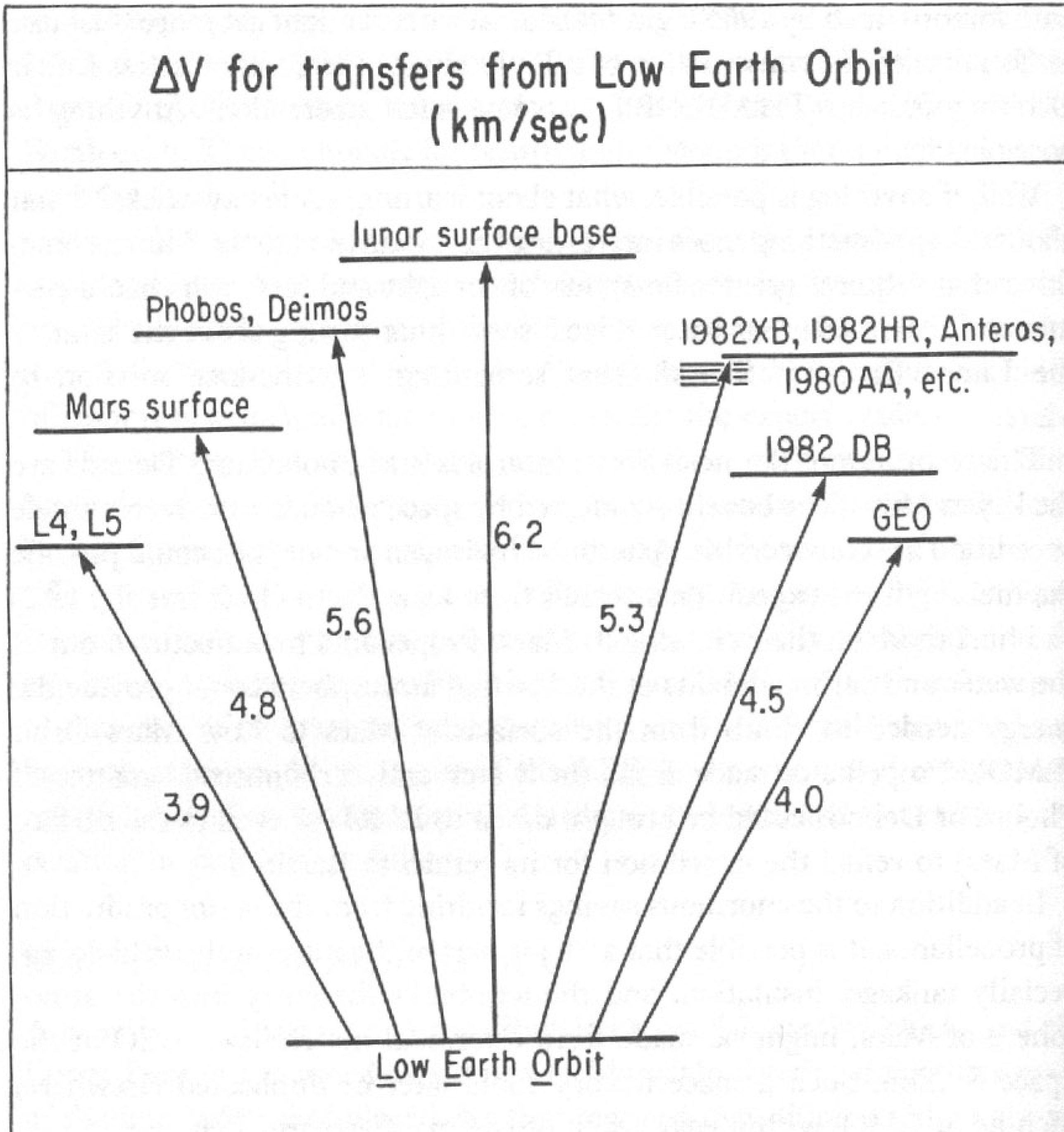
CxP Benefits from NEO Mission

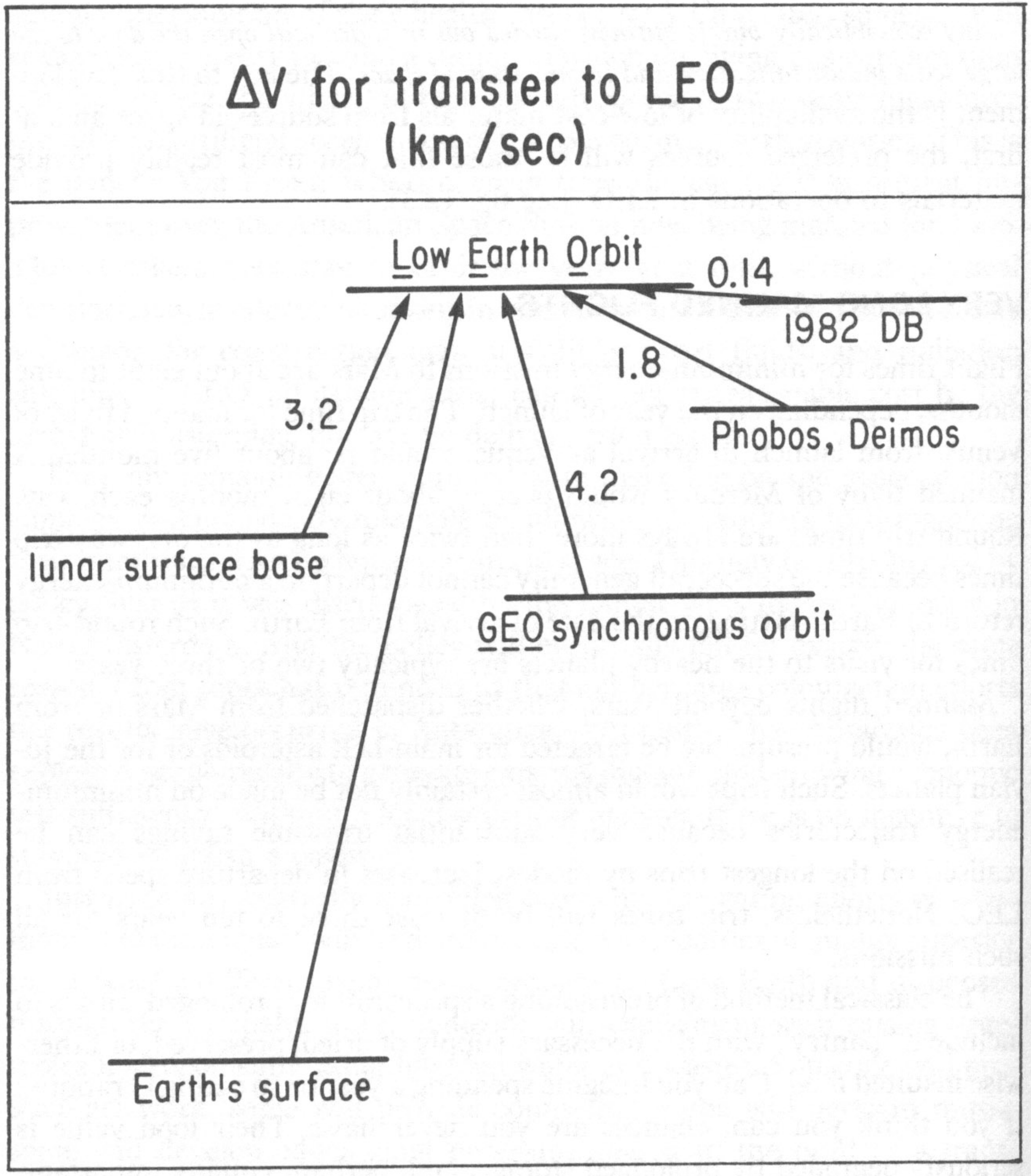
Why NEOs for a Constellation Enabled Mission?

- Verify Constellation infrastructure's flexibility, adaptability, and potential beyond the Lunar case.
- Dual launch pad operational experience.
  - Lower Bookend Mission can use 1 KSC Pad (Ares 1) and 1 Canaveral Pad (EELV)
- A NEO mission may reduce some CxP Risks and add value to the Lunar and Mars Mission sets.
  - e.g. a bridge between Lunar and Mars expeditions
  - Deep-space opportunity prior to or overlapping with Lunar operations
  - Sustain programmatic momentum
- Deep Space Operational Experience
  - Semi-autonomous Crew Operations (10-20 seconds Communication time delay)
  - Need for on-board avionics and software to support full Mission planning, command, and control
- Crewed Sample Return exercise prior to Mars
- Orion Earth Return from interplanetary trajectories

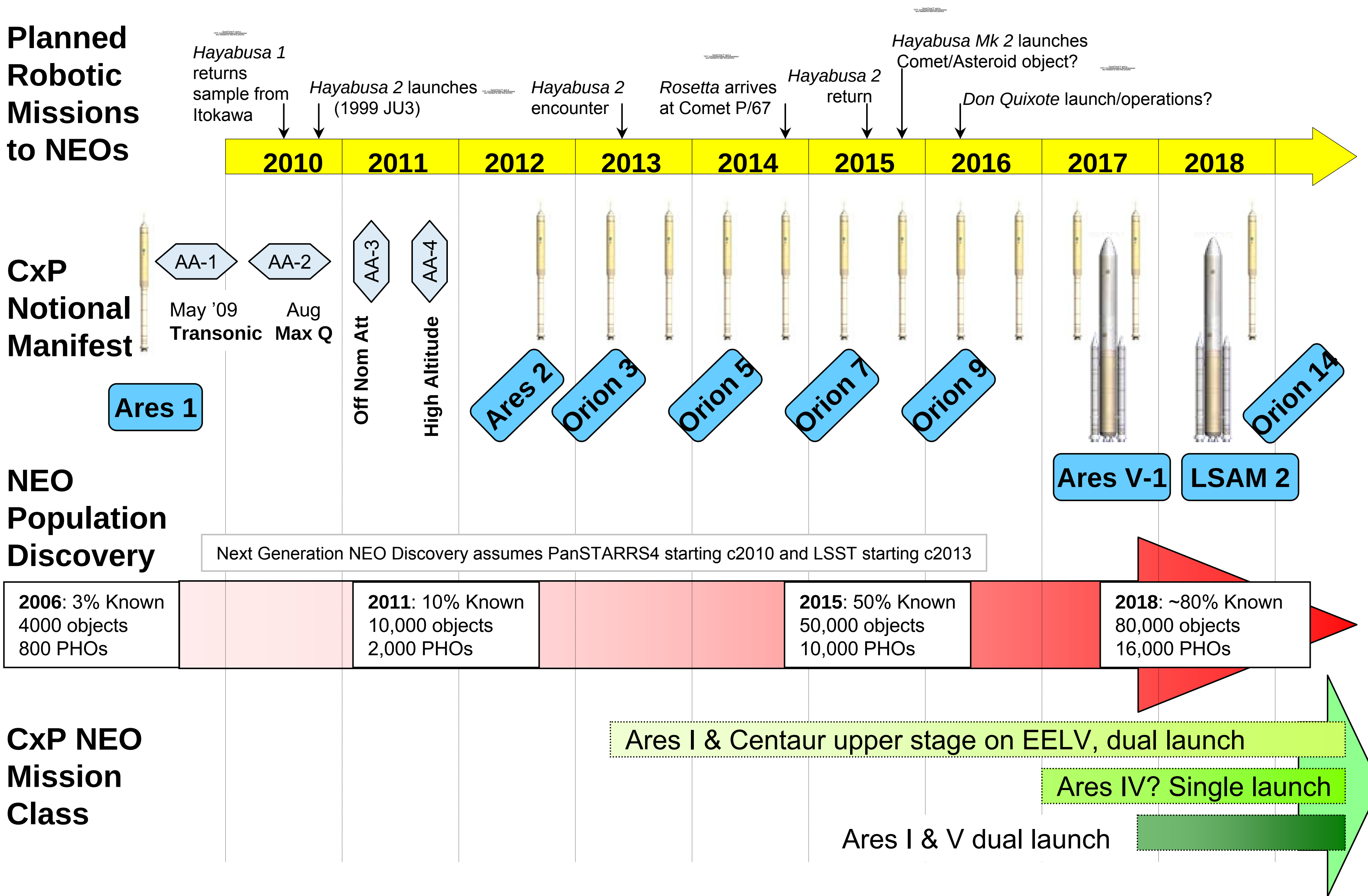
Value of Human Exploration of NEOs

- **Why NEOs for Exploration?**
  - Expand human capability to operate beyond Earth orbit
  - Verify physiological impacts outside the earth's magnetosphere and in the interplanetary radiation environment
  - Assess the psychology of crew autonomy; ground/crew interactions at 20-30 sec delay for deep space operations
  - Assess resource potential of NEOs for exploration and commercial use
  - A logically elegant cycle: quantify and track NEOs > assess for impact threat > select an accessible target > visit and conduct operations around asteroids > while learning to deal with threat, exploit NEO resources in future exploration efforts.


ΔV for transfers from Low Earth Orbit
(km/sec)
lunar surface base
Phobos, Deimos
1982XB, 1982HR, Anteros,
1980AA, etc.
Mars surface
1982 DB
L4, L5
GEO
6.2
5.6
5.3
4.8
4.5
3.9
4.0
Low Earth Orbit

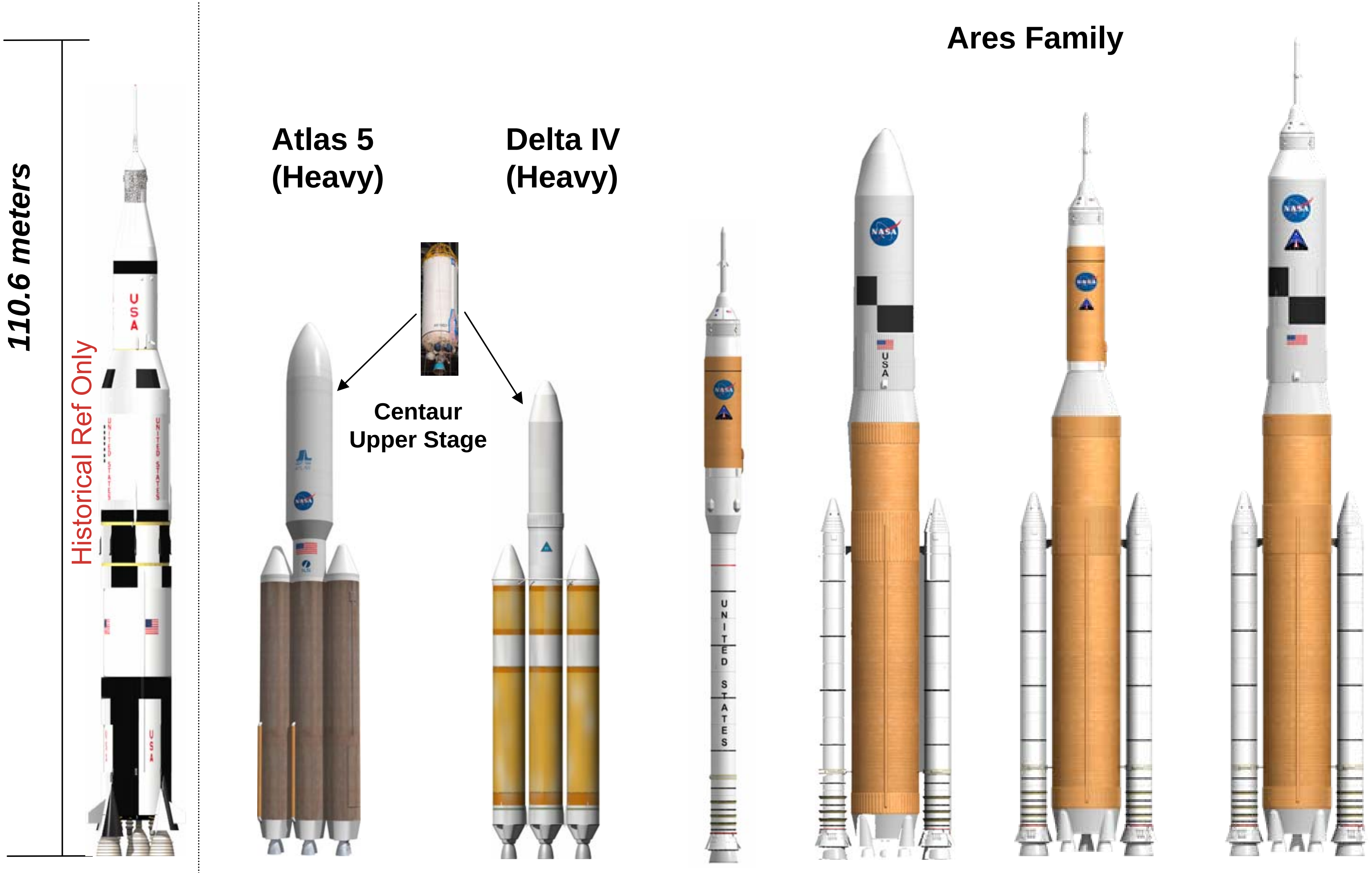

ΔV for transfer to LEO
(km/sec)
Low Earth Orbit
0.14
1982 DB
1.8
Phobos, Deimos
3.2
4.2
lunar surface base
GEO synchronous orbit
Earth's surface

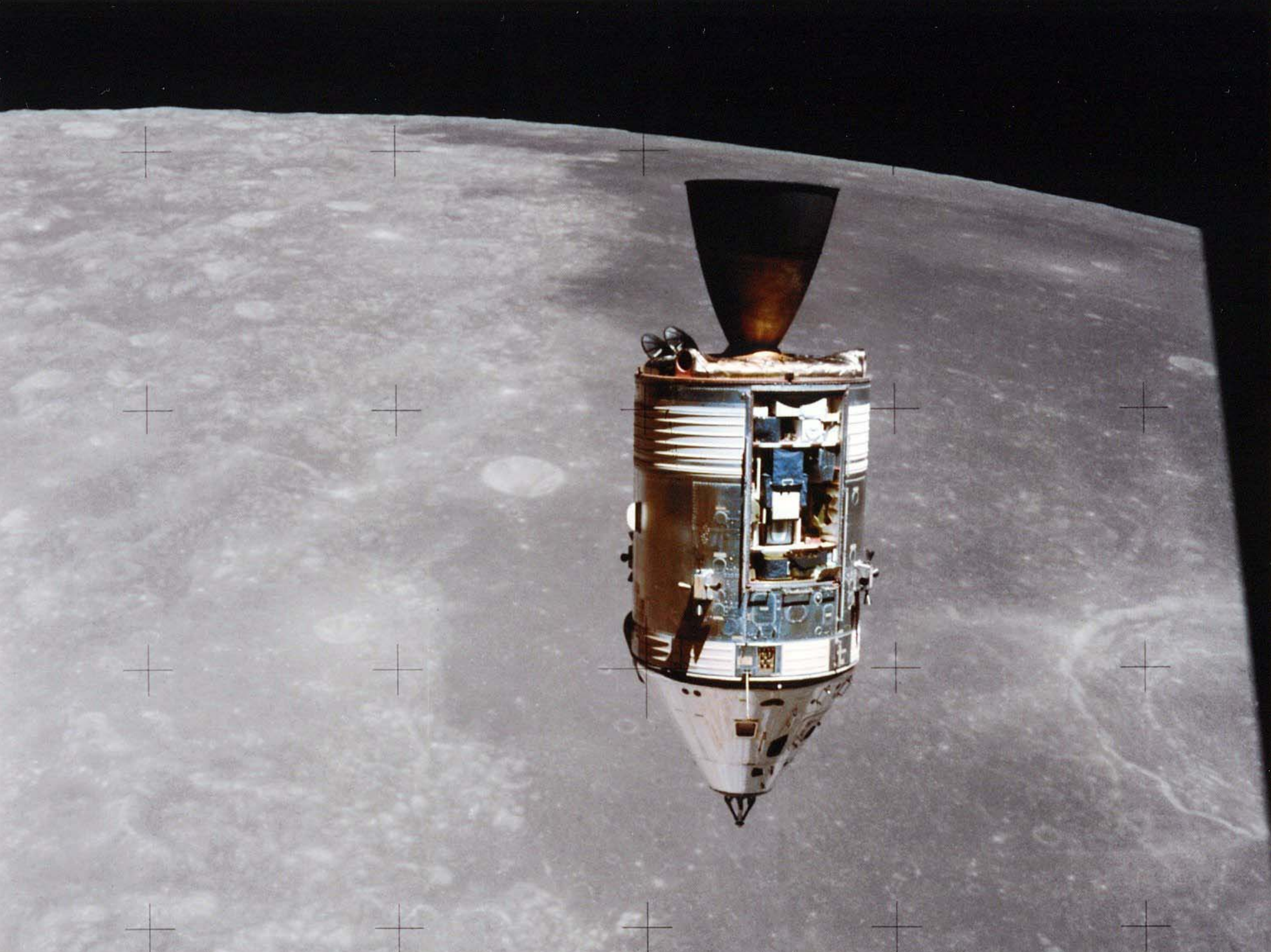
NEO Human Mission Opportunities



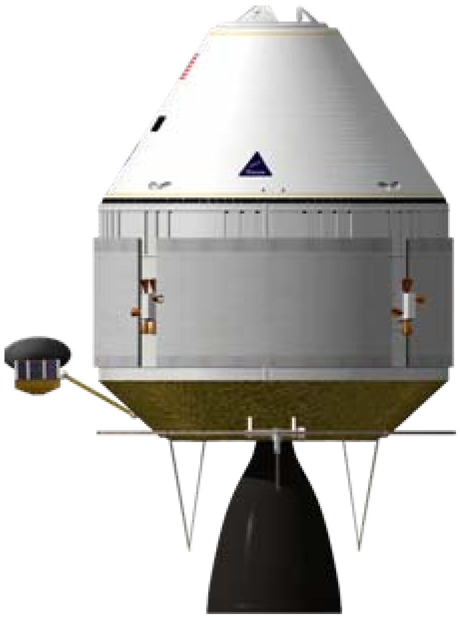
Back up materials

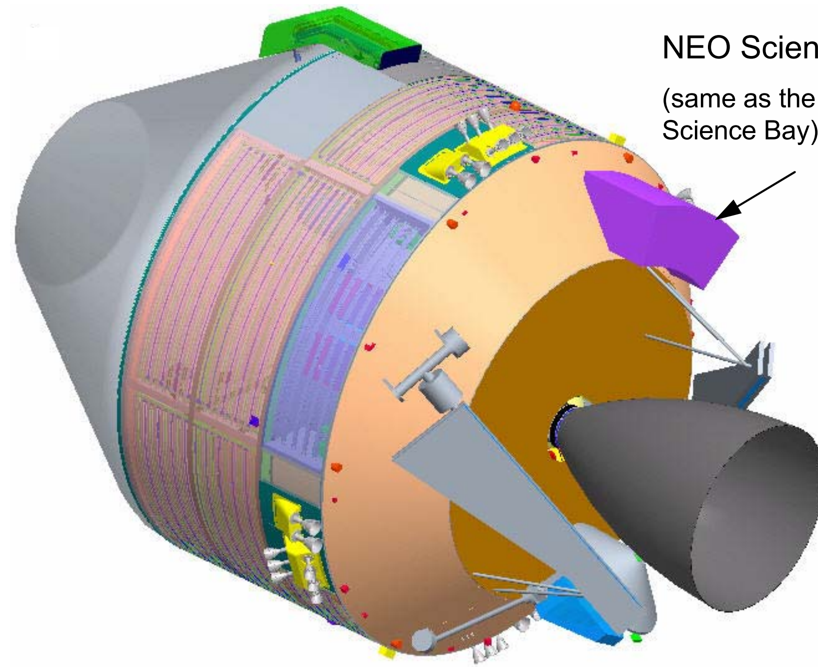
Possible Launch Vehicles for NEO Missions





NEO Orion Configuration Overview





The Orion's ΔV capability post-LEO docking is 1.68 km/sec.

• This assumes that the LIDS mechanism (or similar mass) is left attached to the upper stage

• Similar figures used for mid volume and upper bookend cases, except ΔV in upper bookend case is ~ 0.7 km.sec with LSAM attached