Into the Beyond: A Crewed Mission to a Near-Earth Object

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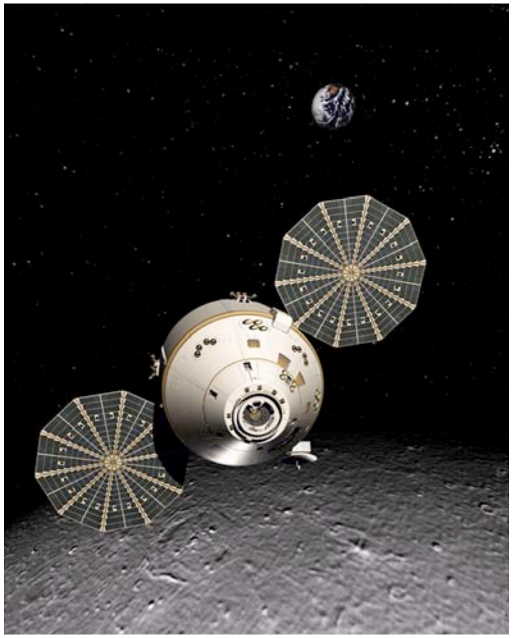
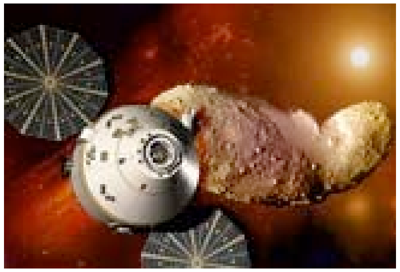


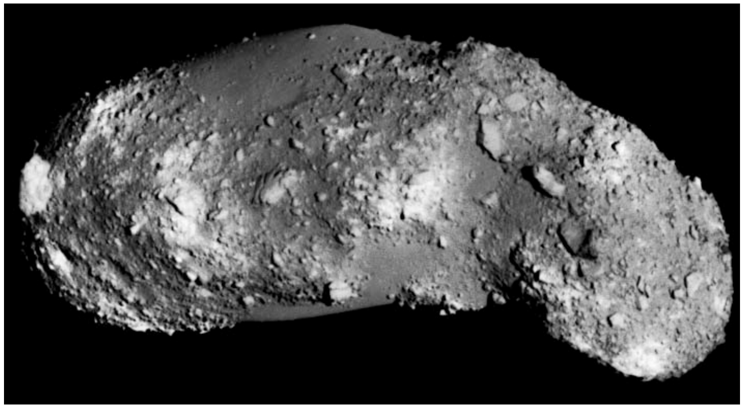


What is a NEO (Near Earth Object)?

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>

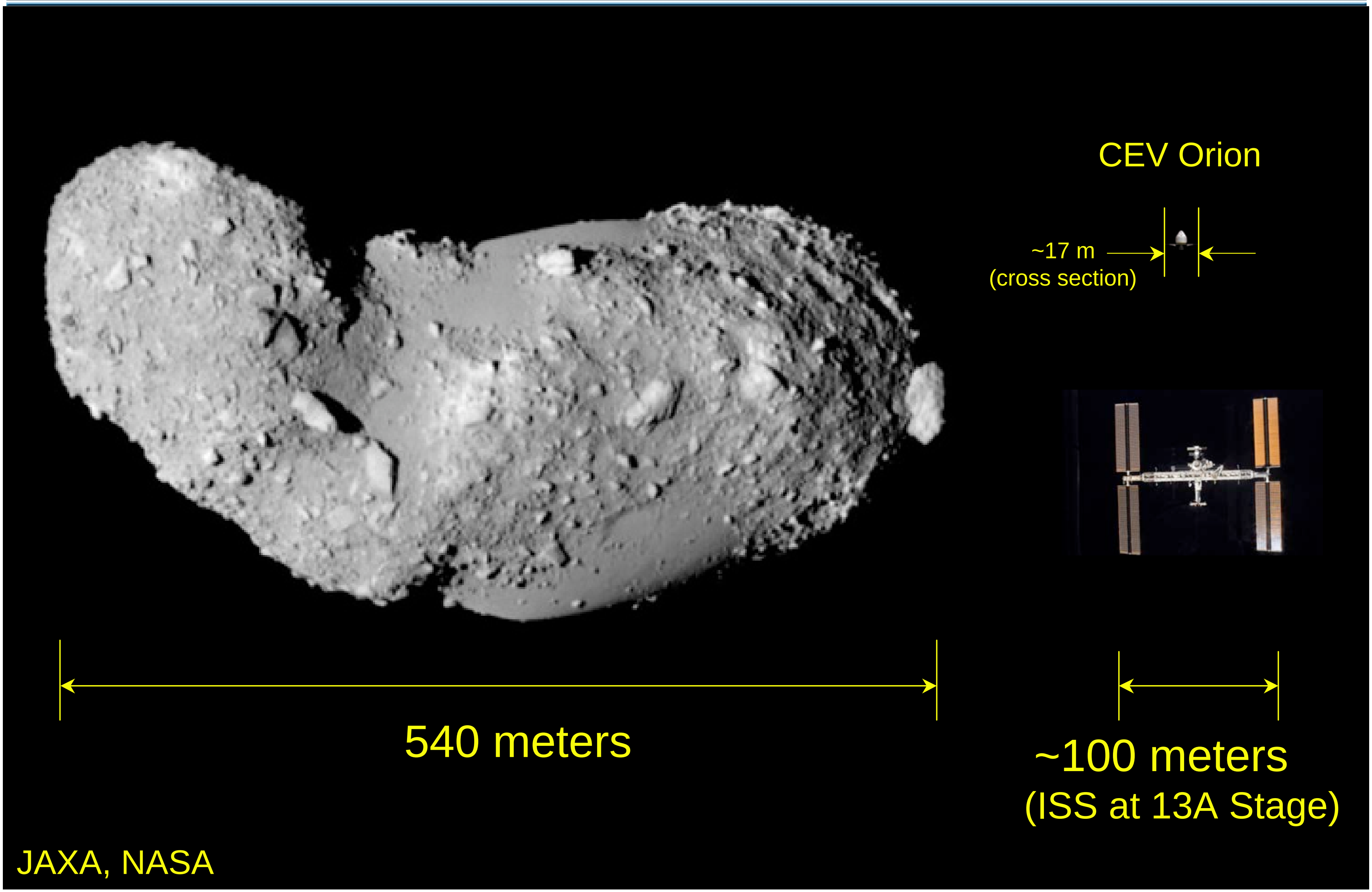
- Weak collection of talcum-powder sized silicate dust
- About 30% ices (mostly water) just below surface dust

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

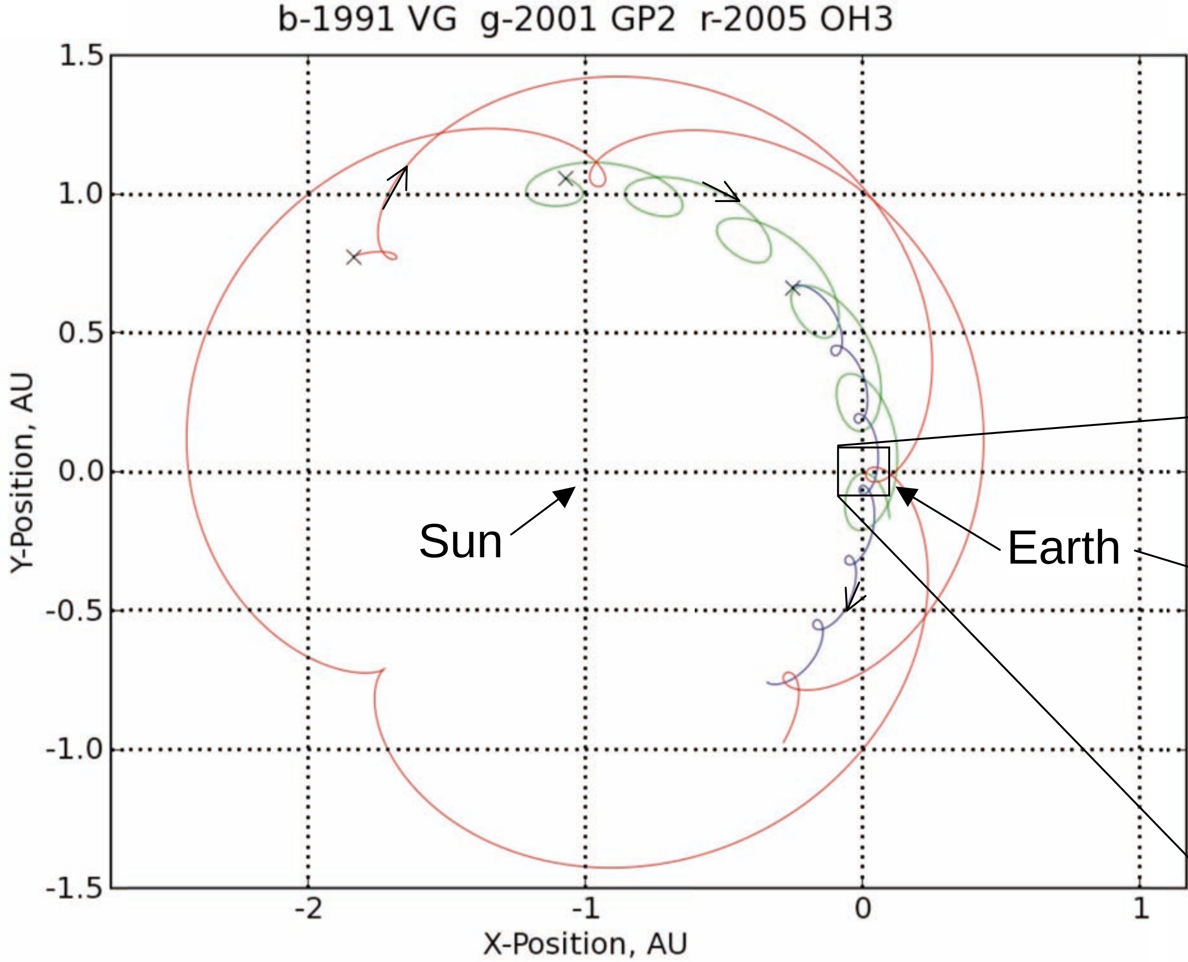
NEOs are <u>very diverse in makeup</u>

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

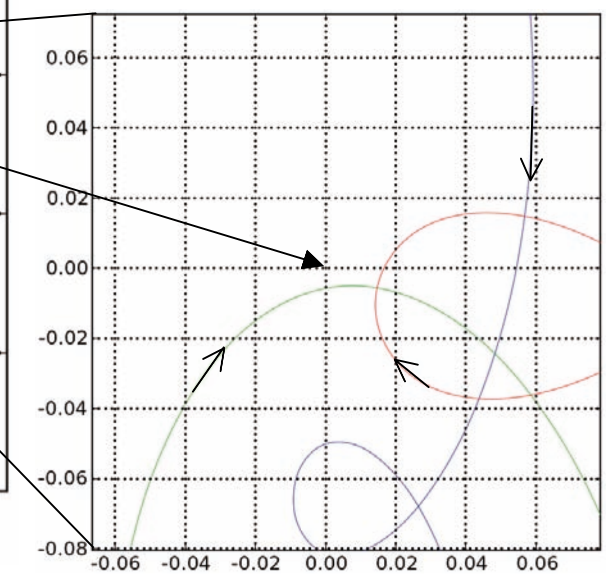
Asteroid Itokawa, ISS, and CEV Orion



Example NEO Trajectories



	1991 VG	2001 GP2	2005 OH3	
a	1.027	1.038	1.237	AU
e	0.04916	0.07397	0.1682	
i	1.446	1.279	4.791	deg
Q	1.077	1.115	1.445	AU
q	0.976	0.961	1.029	AU
Period	1.041	1.057	1.375	yr
Synodic P.	25.4	18.5	3.67	yr
Min Dia	4.4	8.8	13.3	m
Max Dia	11.4	22.8	34.4	m



NEOs plotted in a rotating frame where the Earth-Sun line is fixed in space. Objects with a > 1 move clockwise about this plot

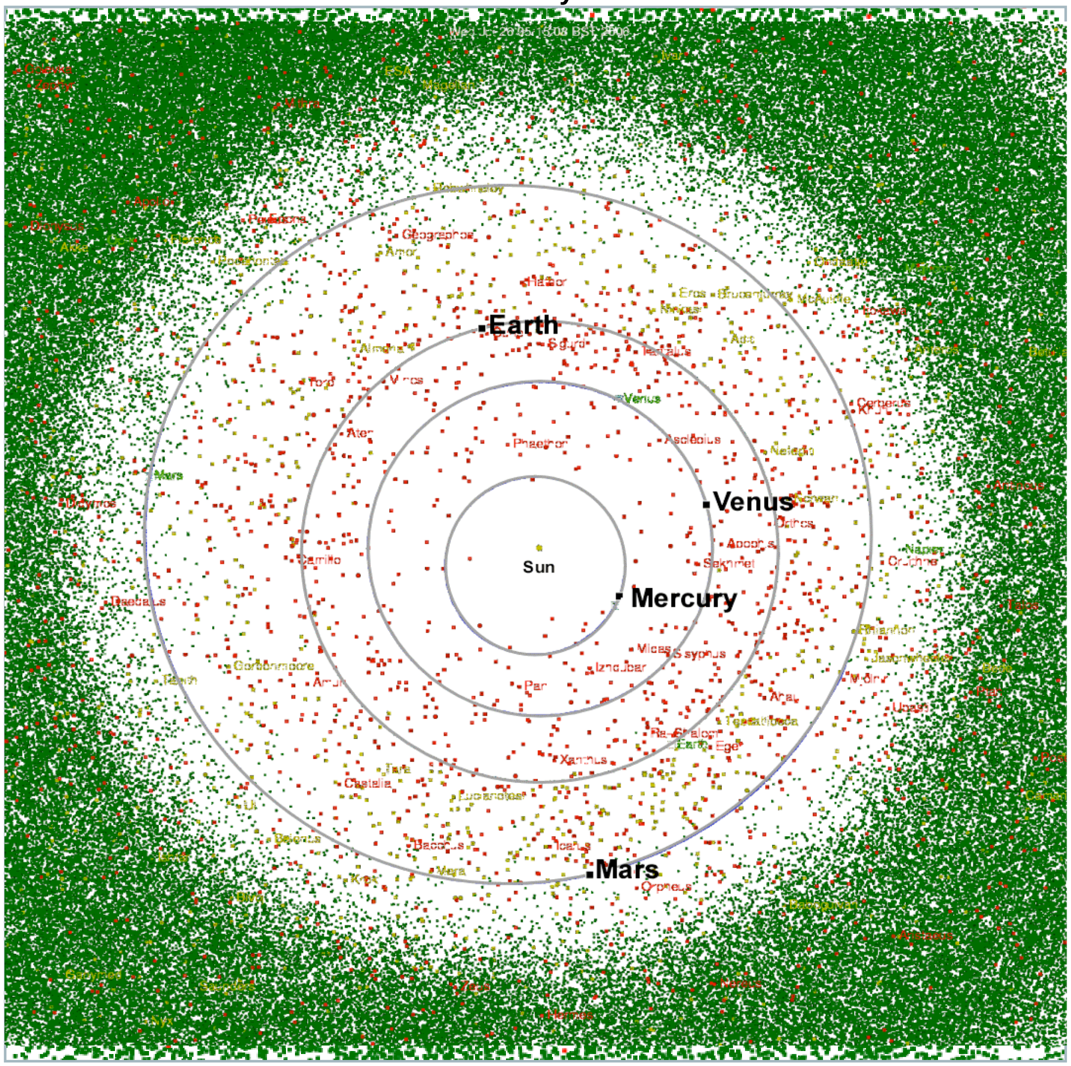
Known (current) NEO Population

2006

Earth Crossing (NEO)

Outside Earth's Orbit

The Inner Solar System in 2006

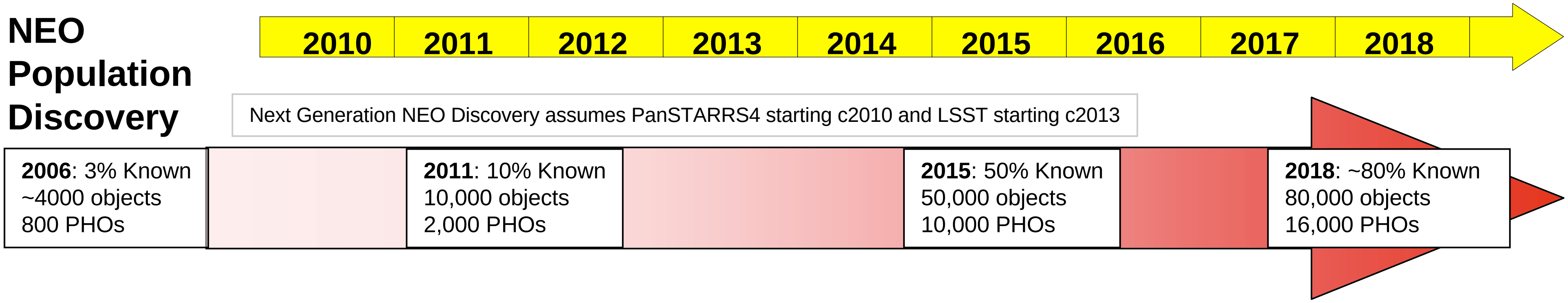


<u>Known</u>
- **340,000 minor planets**
- **~4500 NEOs**
- **~850 PHOs**

<u>Improved NEO Survey Will Likely Find</u>
- **100,000+ NEOs (> 140m)**
- **20,000+ PHOs**

Picture from: Scott Manley. Armagh Observatory

NEO Population Discoveries



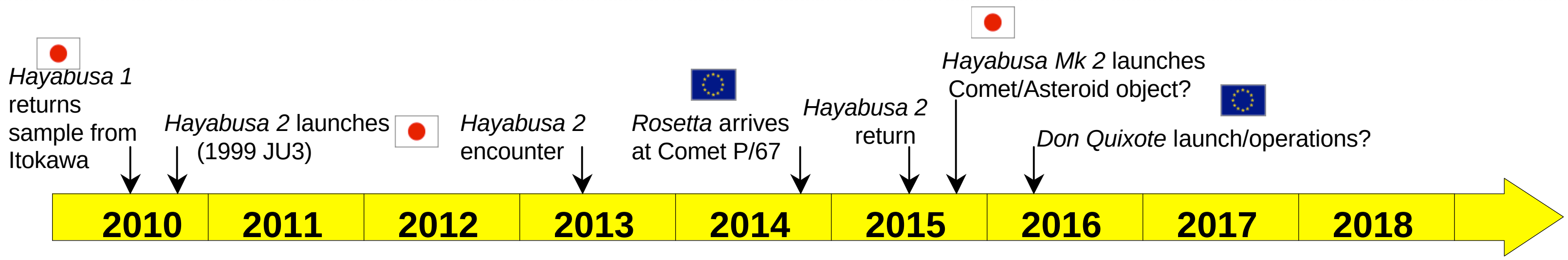
- Current NEO Catalog shows few (12) Target opportunities for a NEO Mission in 201x - 2030 timeframe however,
- NEO Next Generation Search would **increase target discovery ~40x**
- Crewed NEO Mission 'Target of Opportunity' may exist in the ~2015-2030 Timeframe

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 question
- Space Based sensor – Not currently funded, needed if most possible targets are desired.

NEO Precursor Missions

Planned Robotic Missions to NEOs



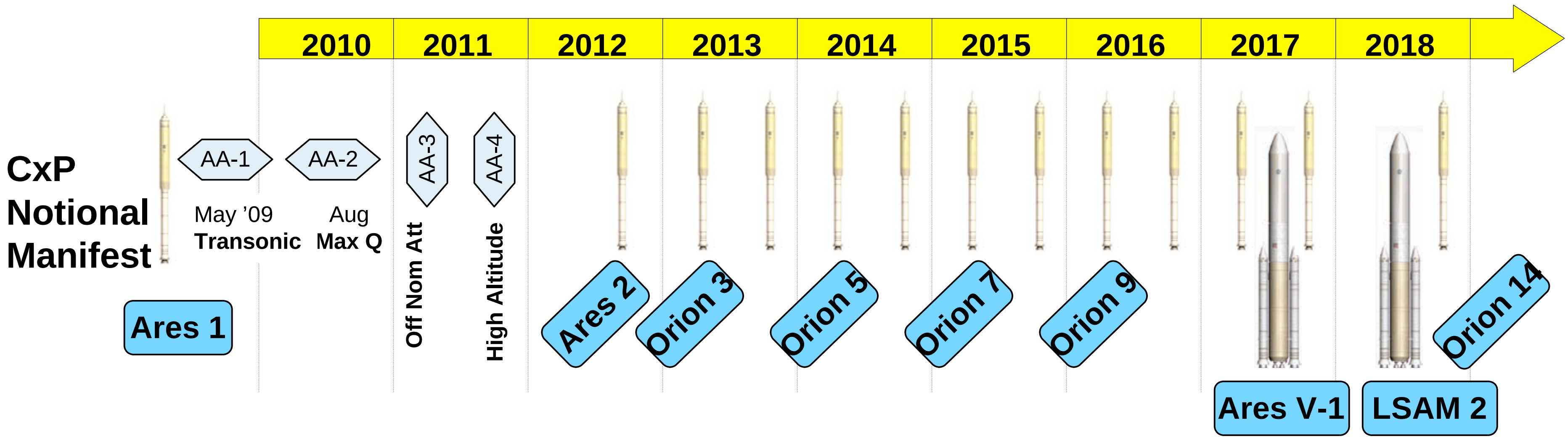
- ***NEAR*** (USA), Rendezvoused with 433 Eros on Feb. 14, 2000.
- ***Hayabusa*** (Japan), arrived at NEO Itokawa on Sept. 12, 2005.
- ***Hayabusa 2*** (Japan), is planned for launch in 2010 to C-type NEO (1999 JU3).
- ***Hayabusa Mk 2*** (Japan), is planned for launch to an extinct comet in 2015.
- ***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 so a Precursor robotic mission is required.
  - NEOs greatly vary in size and composition (1/6 are binary objects)
  - Rotation rates and make-up will significantly impact proximity operations

Precursor NEO Mission Objectives

- Obtain basic reconnaissance to assess potential hazards that may pose a risk to both vehicle and crew.
- Preliminary determination of NEO target's surface morphology, gravitational field structure, rotation rate, pole orientation, mass/density estimates, and general mineral composition.
- Assess potential terrains for planning future proximity operations and sample collection by the CEV and its assets (crew/payload).
- Aid in Orion spacecraft navigation to the NEO by deploying transponder to surface, or by station keeping.

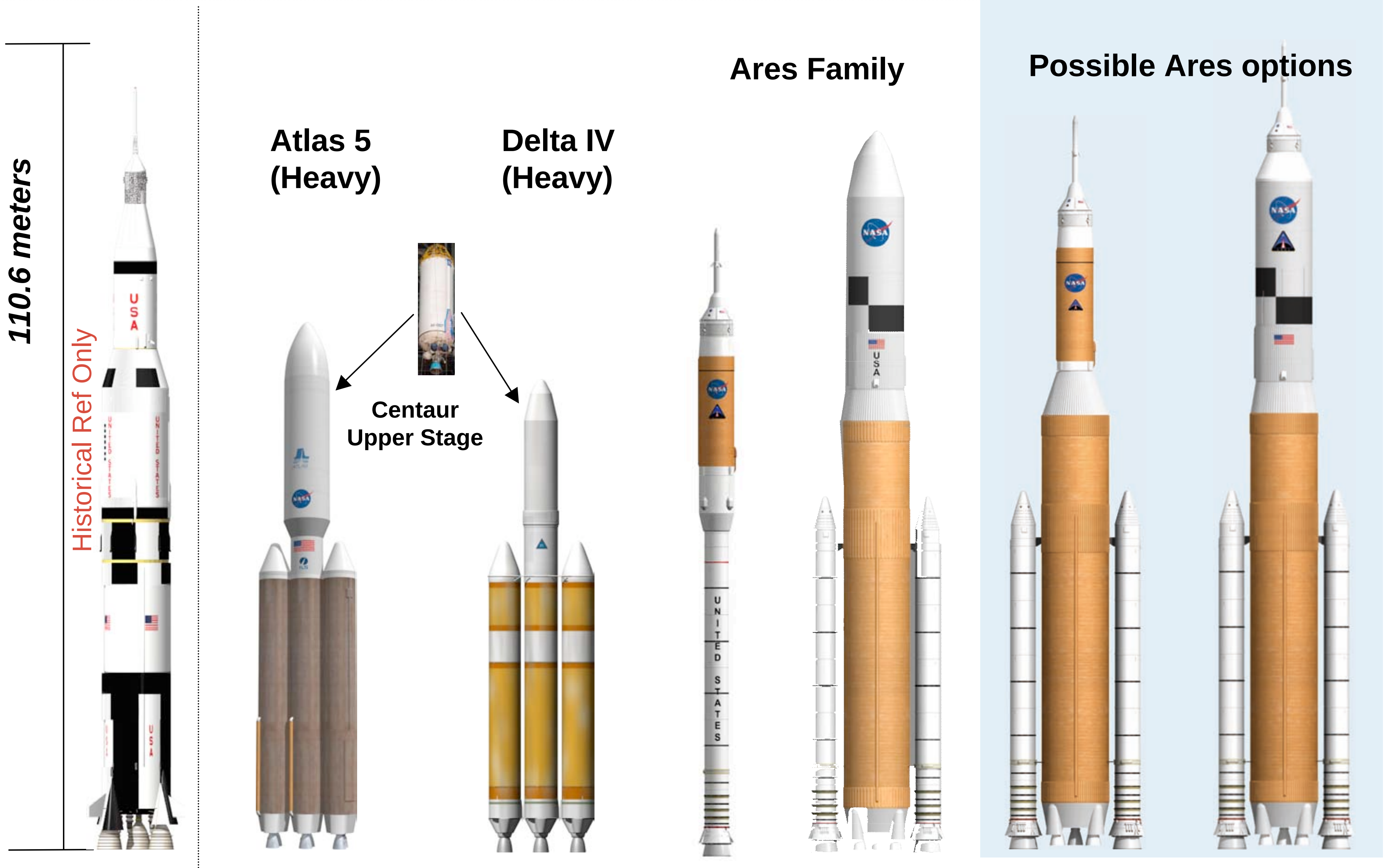
NEO Mission Launch Concepts



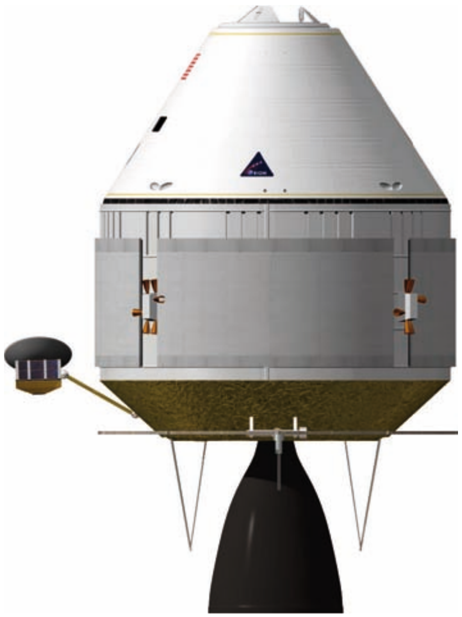
Mission Launch Concepts:

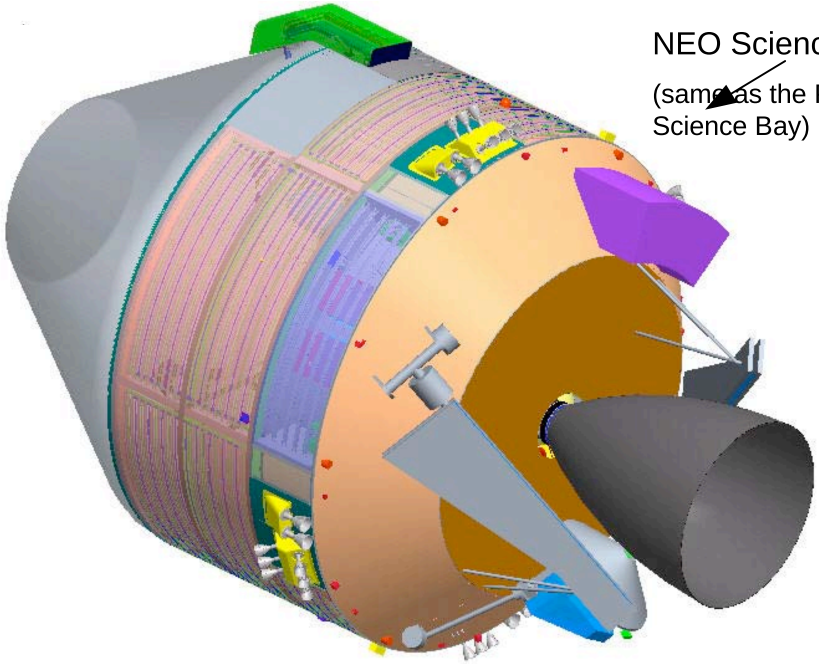
1. Earliest possible concept (2013+) aka "Lower Bookend"
    - Orion (Block II) on an Ares I, and
    - Centaur upper stage on an EELV
2. Most like a lunar mission (2017+) aka "Upper Bookend"
    - Orion (Block II) on an Ares I, and
    - Lunar Module on Ares V with an Earth Departure Stage (EDS)

Possible Launch Vehicles for NEO Missions



NEO Orion Configuration Overview

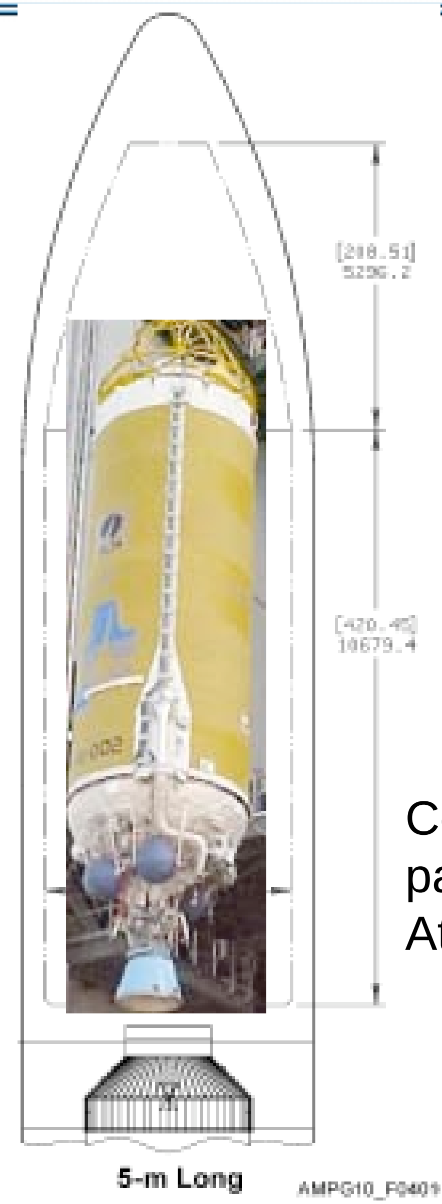




The Orion's ∂V capability post-LEO escape is ~1.7 km/sec.

EELV for Launch of Earth Escape Stage

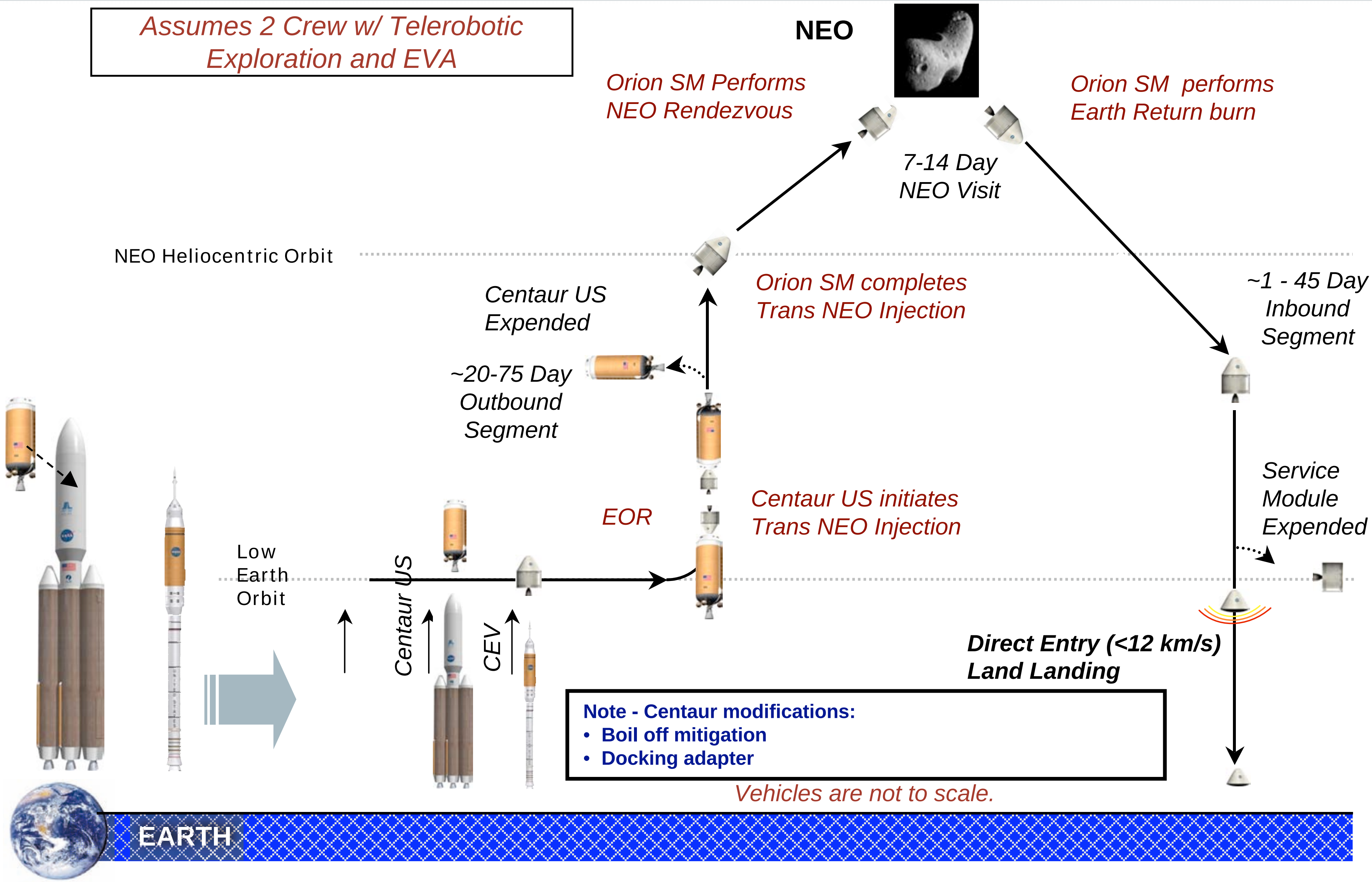
- Atlas V Heavy Lift Vehicle
  - “Maximum” capability to 100x100 nmi: 64.9 klb
  - Centaur wet mass: 50.6 klb
  - Launch vehicle margin: 22%
- Delta IV Heavy has marginal capability for orbiting a fully loaded Centaur.
- Both launch vehicle lines have more capable versions on the drawing board.



Centaur as a payload for Atlas V HLV

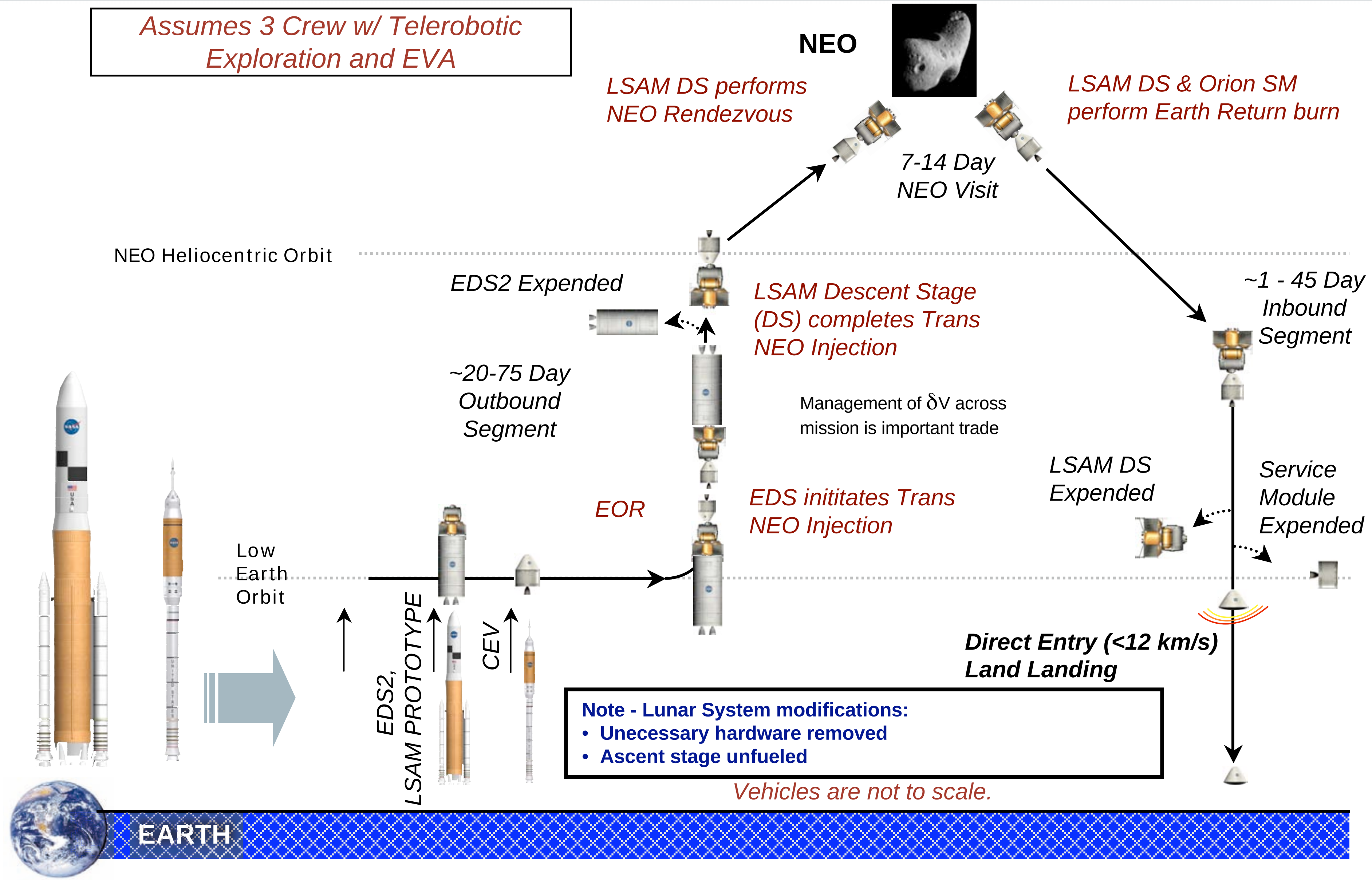
“Lower Bookend” Near-Earth Object (NEO) Crewed Mission

Centaur US / 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

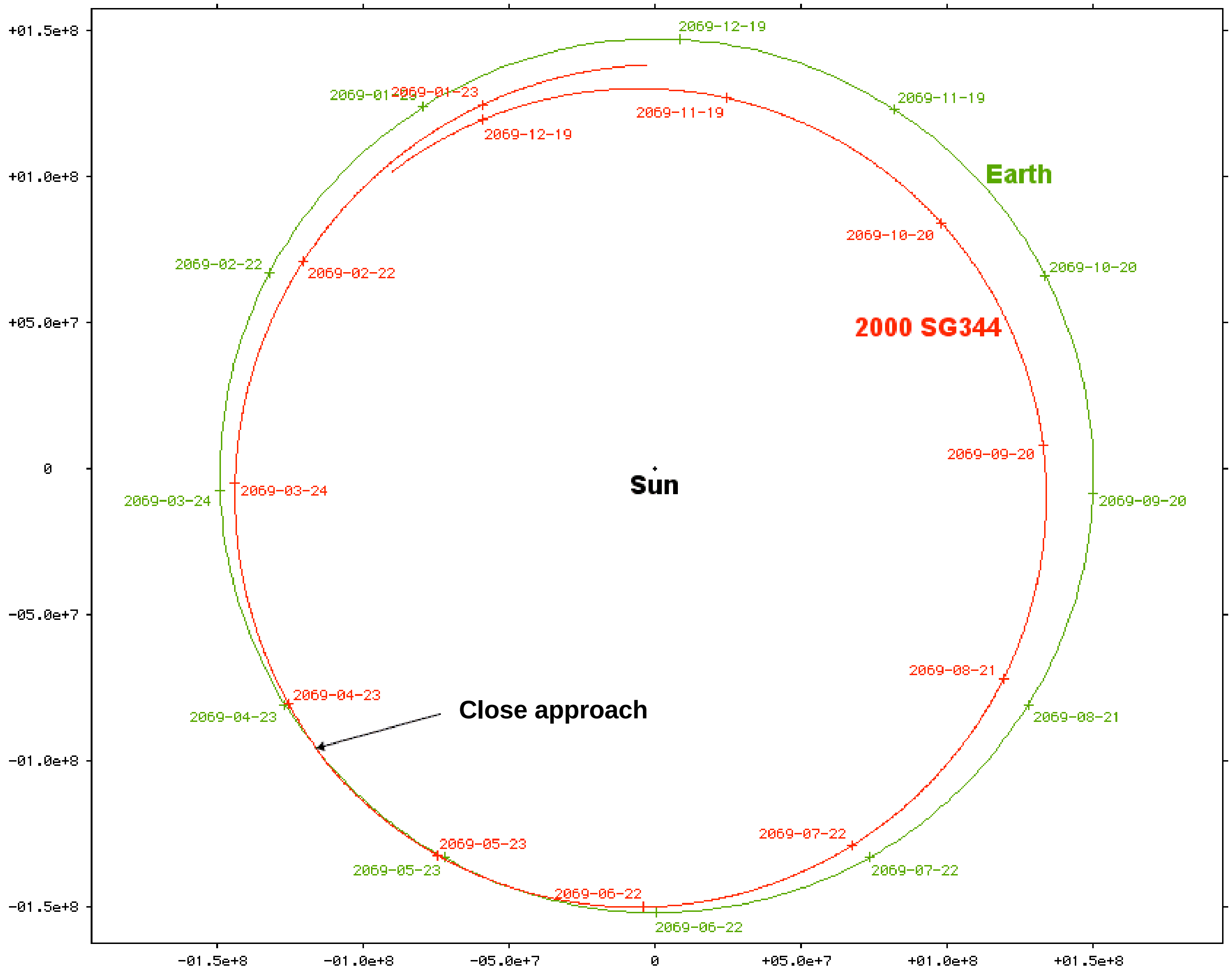


NEO Database and Trajectory Analysis

- **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, eccentricity, and inclination
    - 0.5AU < a < 1.5AU; e < 0.5; I < 3º
    - Only 71 (6%) have inclination < 2 deg 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 84 NEOs
- **An existing NEO (2000 SG344) in database met the ΔV and orbital position requirements**
  - Low inclination (0.11)
  - Best relative orbital position (mean anomaly) to Earth occurs in 2069
- **As an example, we used the close approach date of 2000 SG344 for our detailed mission trajectory analysis.**

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

Heliocentric Trajectory Plot for Mission

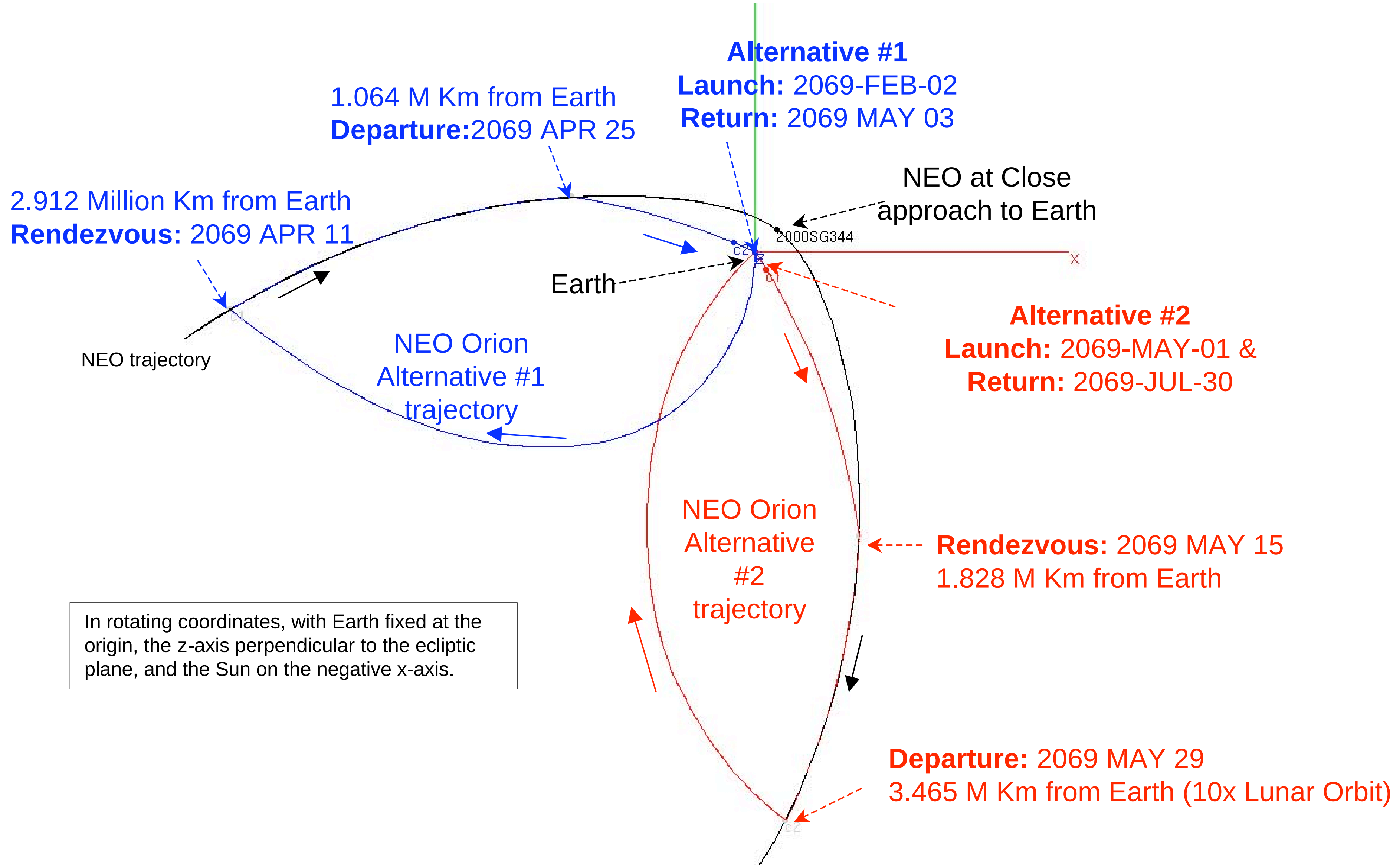


Km Units View From Y= 0.0°, P= 0.0°, R= 0.0°

Sun-Centered J2KE Coordinate System

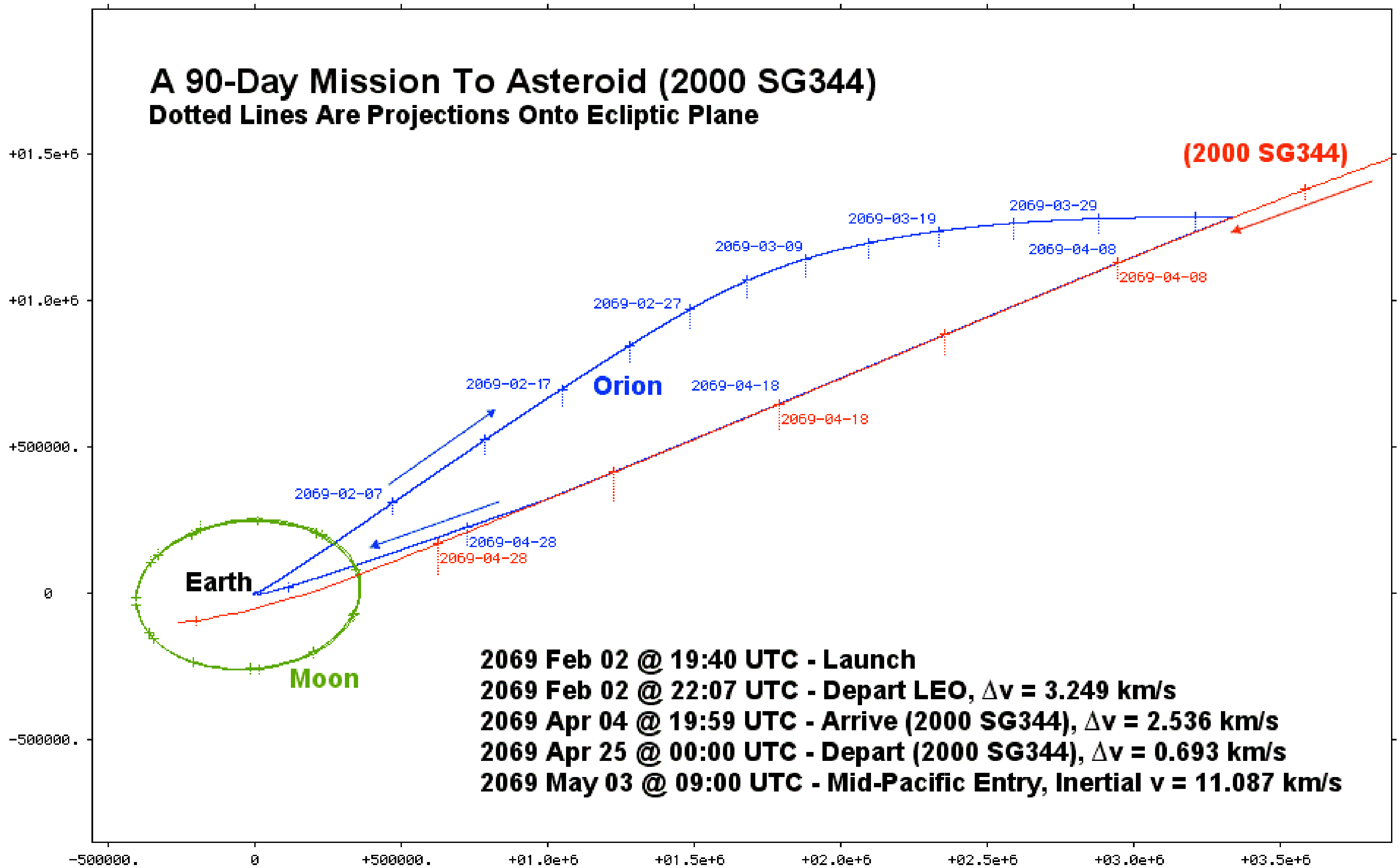
One-Year Plot Centered Near (2000 SG344) TCA On 2069 May 2

Example Mission Type:
Lower Bookend (Ares I + EELV upper stage)
90-Day Mission to 2000 SG344



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

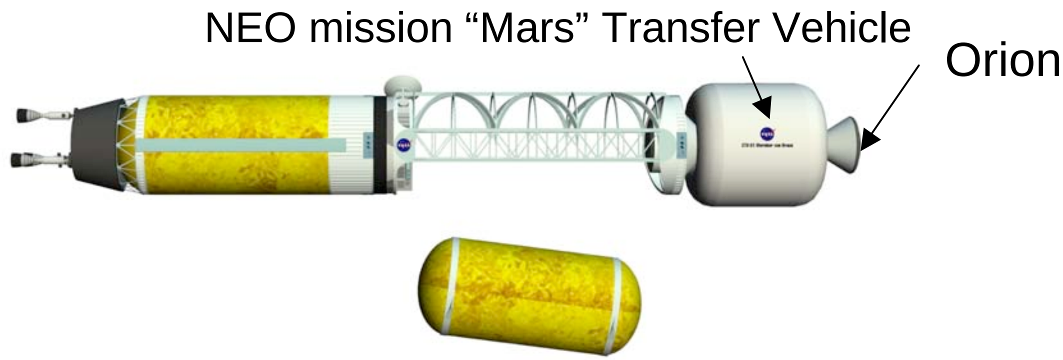
Inbound visit to (2000 SG344): Earth parking orbit segment

Benefits from NEO Mission

Why a Crewed NEO Mission?

- Verify new NASA infrastructure's flexibility, adaptability, and potential beyond the Lunar case.
- Dual launch pad operational experience.
- A NEO mission will reduce some Technical 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 systems to support full Mission planning, command, and control
- Validate Orion Earth Return from interplanetary trajectories

Mars Technology Validation via NEOs



NEO mission allows early checkout and validation of critical technologies for Mars Transfer Vehicle.

No Mars Lander systems are required

Crew travels to NEOs in prototype Mars transfer vehicles.

Longer NEO missions are Mars-like, in terms of deepspace, time and system performance

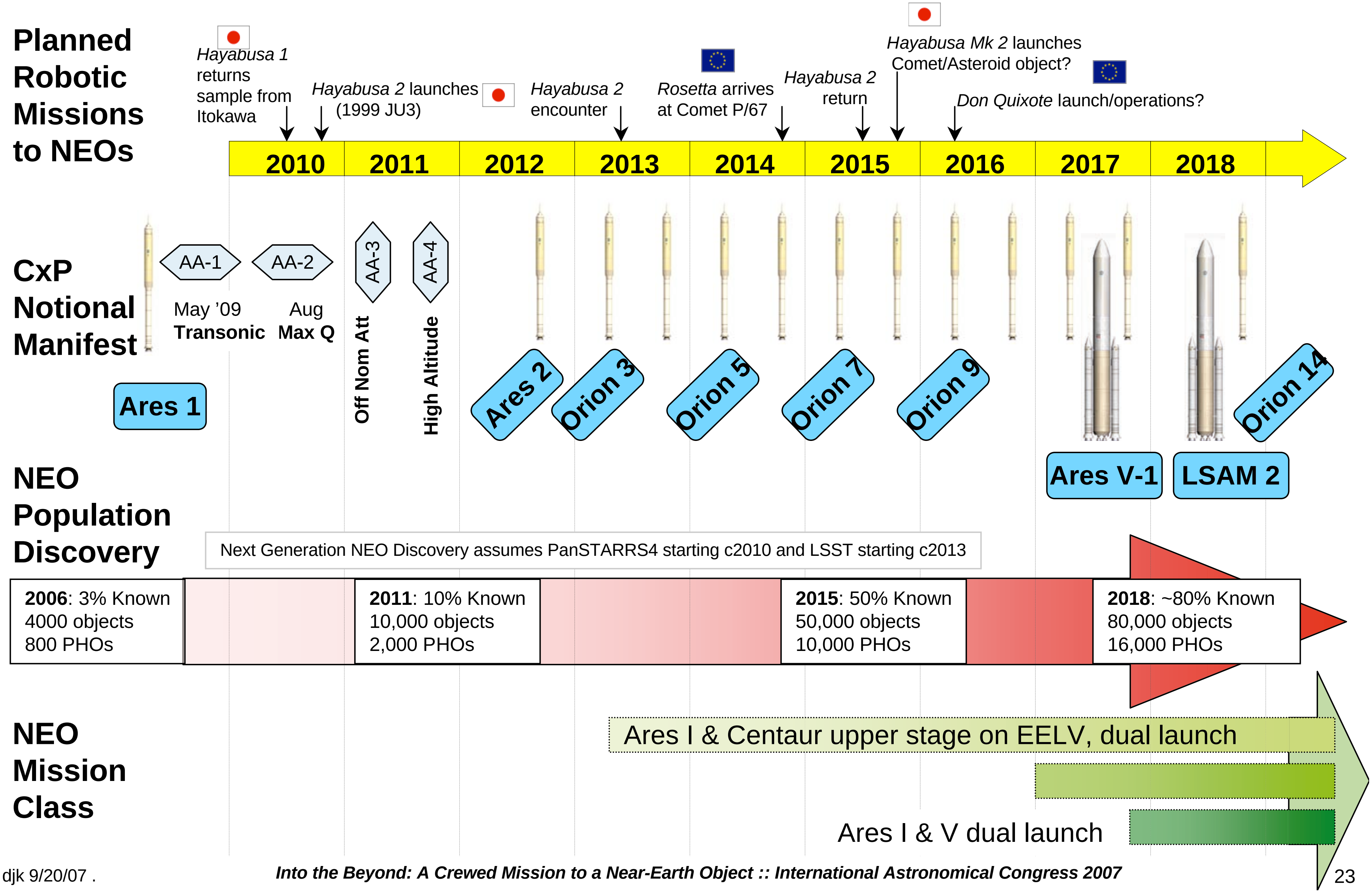
– Test of potential Mars crew vehicles

NEO Mission Engineering Benefits

CONSTELLATION

- Identification of mining and mechanical engineering methods to extract material for *in situ* resource utilization.
- Identification of techniques and materials that showed promise in attaching equipment under micro-gravity regimes that could be researched in more detail for subsequent spacecraft missions.
- Gain operational experience in performing complex tasks with crew, robots, and spacecraft under microgravity conditions at/near the surface of a NEO
- Risk reduction for future designs of Martian exploration missions and equipment. Help identify more efficient and cost-effective deep space exploration architectures.

NEO Human Mission Opportunities



Summary

Can we do it? Yes

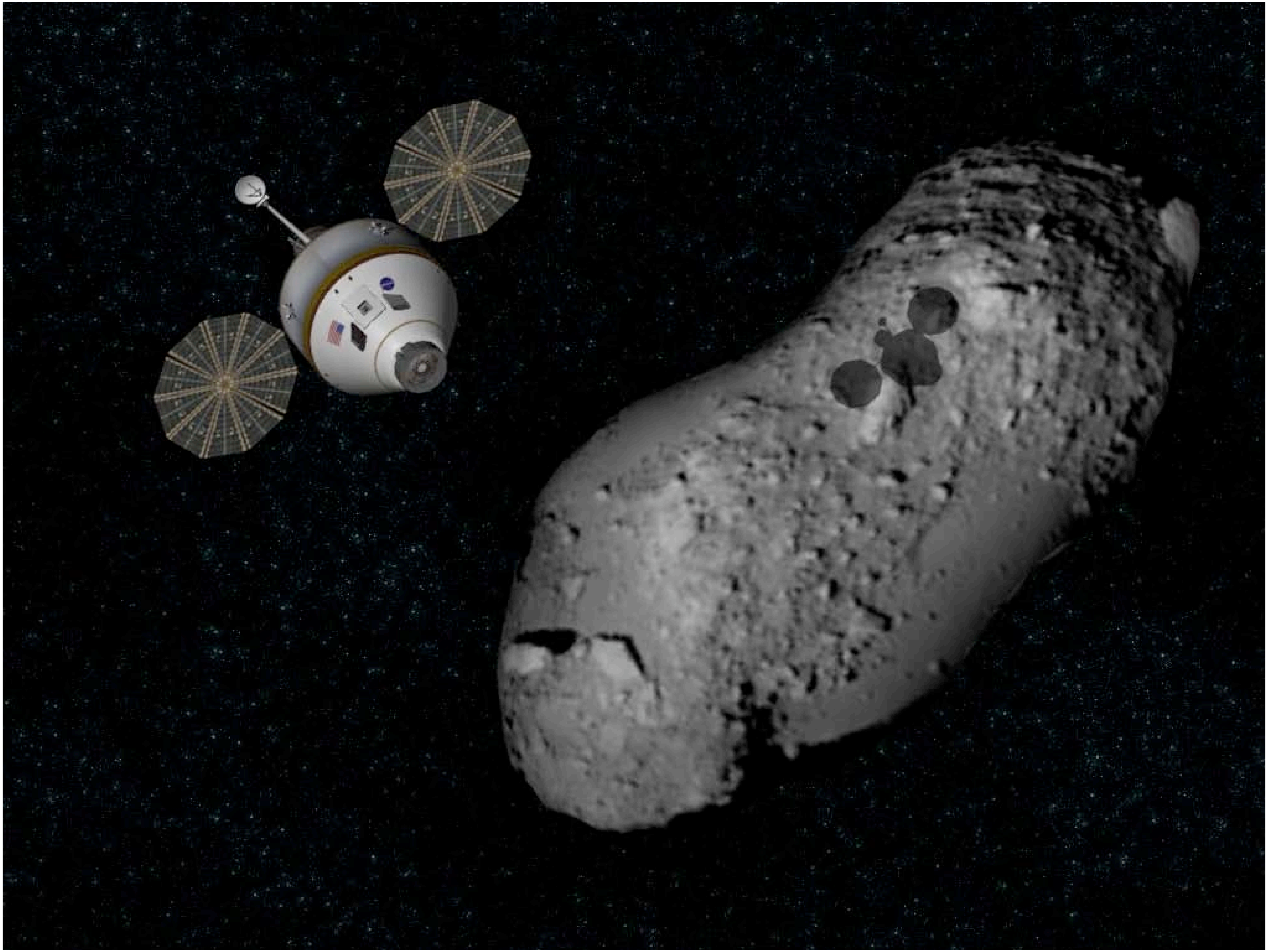
- NASA's new launch and spacecraft system (Ares & Orion) are capable of supporting a 2 or 3 crew Mission to a NEO.

Do we have a good NEO target now? No, not Yet

- Ideally need the Next Generation NEO Survey
  - NEO Catalog currently shows few opportunities for a Mission in 201x - 2020,
  - NEO Next Generation Search will increase target discovery ~40x
  - NEO Target of Opportunity may exist in the desired 2015 - 2030 Timeframe

NEOs are excellent targets for Human Explorations

- Begin the exploration of the inner solar system and better understand its formation
- Validate key operations and technologies "near" the Earth-Moon system



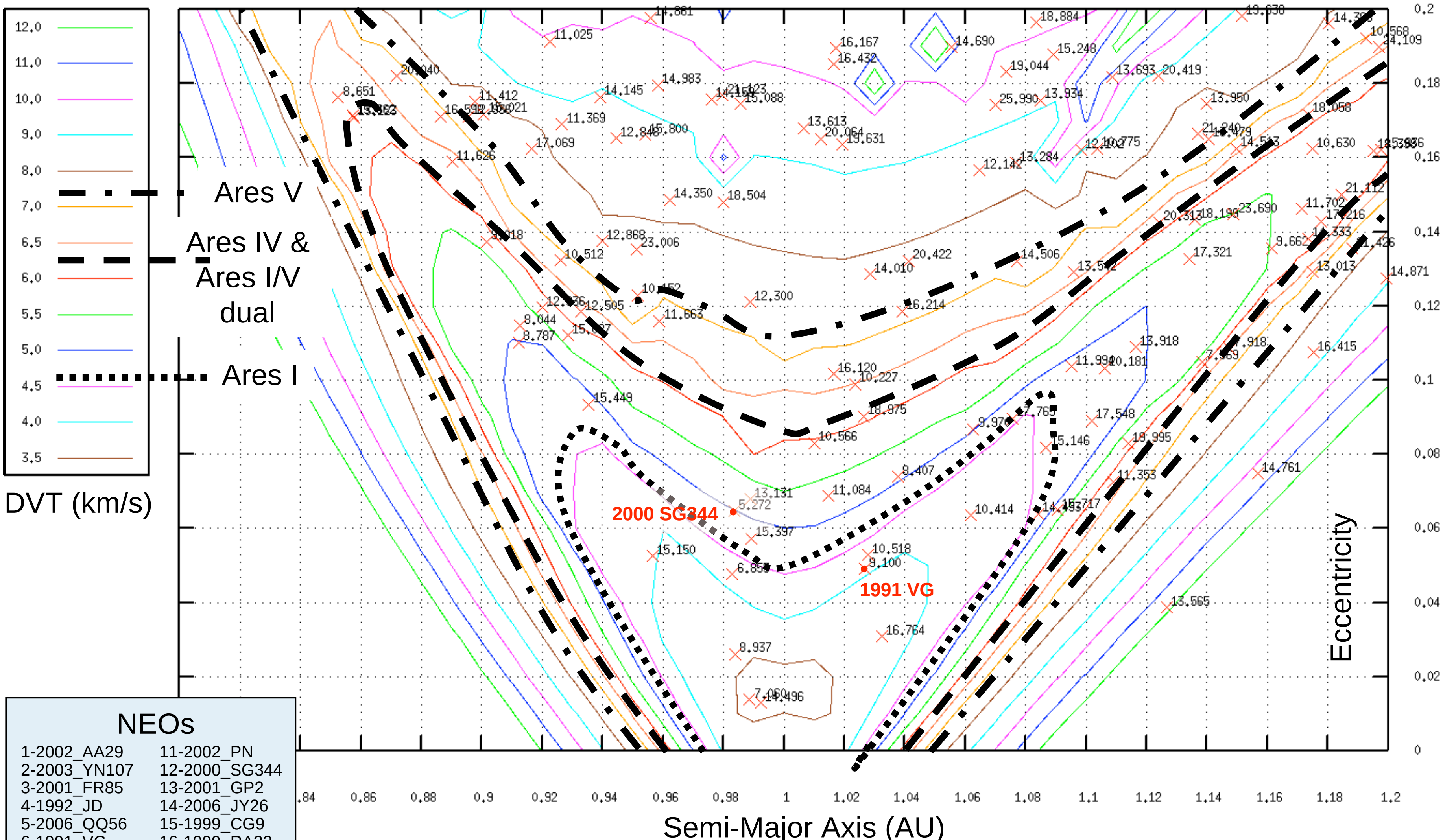
BACKUP

Selecting a Target NEO

- **Identified the ∂V to match NEO orbits and Created "Lambshank" ∂V contour plots**
  - ∂V contours show the minimum possible post-escape, and total mission ∂V 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.
  - Tried for a 90-day mission (also ran 120, 150, 180-day options)

- **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 candidate targets for Lower Bookend in 201x - 2030
  - Looked for earliest candidate missions in an expanded database ~40x in time, 2014-2214

90-Day Mission Set: NEO Target Opportunities vs Total ∂V from LEO, Known 2006 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.

Summary Findings for NEO Mission Trajectory Analysis

- **In general, mission ∂V can be reduced by**
  - Longer mission duration (150 and 180 trips are best)
  - Shorter stay times (second order)
  - Lunar gravity assist (second order)
- **Mission length approaching 180 days impacts ∂V**
  - Can reduce amount of post-escape ∂V to deal with NEO inclination
  - Mission timing can put inclination change ∂V 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-∂V fast mission**