Target NEO: Forums Vested in Providing a Resilient NEO Accessibility Program for Human Exploration Beyond LEO

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Human Community Workshop on the
Global Exploration Roadmap (GER)
14 November 2011

Report/Summary Acknowledgments

- **Target NEO Workshop, Conferences & Final Report (2011):** Lindley Johnson (NASA-HQ); Cheryl Reed, Andy Cheng, Ken Hibbard, Andy Rivkin (JHU/APL); Rob Landis (NASA-ARC), Brent Barbee, Jim Garvin (NASA-GSFC); Paul Abell (NASA-JSC), Dan Adamo (NASA-JSC, ret.); Dan Mazanek (NASA-LaRC); Rich Dissly (Ball Aerospace) (Co-Chairs)

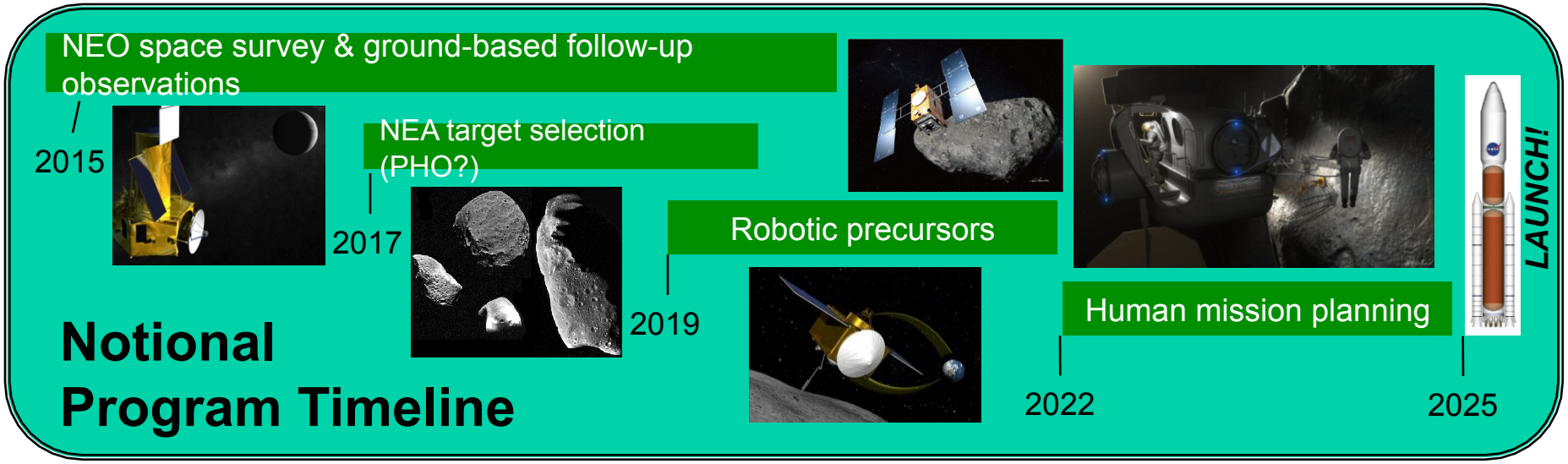
- **A Simplified, Low Risk Strategy for the Exploration of Near-Earth Objects, 62nd International Astronautical Congress (October 2011):** Rob Landis (NASA-WFF); Lindley Johnson, Bill Gerstenmaier* (NASA-HQ); Brent Barbee, Ron Mink, Jim Garvin, Piers Sellers (NASA-GSFC); Paul Abell, Susan Mauzy, Lee Graham (NASA-JSC); Dan Adamo (NASA-JSC, ret.); Dan Mazanek (NASA-LaRC); Cheryl Reed, Andy Cheng, Ken Hibbard, Andy Rivkin, Rob Gold (JHU/APL); Rich Dissly (Ball Aerospace); Tom Jones (IHMC), *presenter

- **NEA Users Team (NUT) LPSC Brief (2011):** Victoria Friedensen (NASA-HQ (Lead)

- **NASA Advisory Committee (NAC) Ad-Hoc Task Force on Planetary Defense (Final Report, October 2011)**: Tom Jones, Rusty Schweickart (Co-Chairs)

Key Results of the Collective Reports/Summaries

- **Necessity of completing the NEO survey first (space-based observations) to support sustainable human exploration to NEOs**
- **Need for continued operation of space- and ground-based assets for follow-up observations**
- **Required investigation of NEO candidate targets by robotic precursors**
- **Natural and important overlap between human operations, science, planetary defense, and resource utilization**



Overlap of NEO Focal Areas

Human Operations

Internal Structure (monolith vs. rubble pile)
Sub-surface properties
General mineral, chemical composition

Science

Internal Structure (monolith vs. rubble pile)
Sub-surface properties
Detailed mineral, chemical, isotopic composition

Intersection of all

Size (existence of binary/ternary)
Rotation rate and pole orientation
Gravitational field structure
Mass / Density estimates
Location (position prediction/orbit)
Surface morphology and properties

Internal Structure (monolith vs. rubble pile)
Sub-surface properties (-> Beta)
General mineral, chemical composition

Planetary Defense

Detailed mineral, chemical composition

Resource Utilization

Open Global Community NEO Workshop Final Technical Report Summary

Target NEO: Providing a Resilient NEO Accessibility Program for Human Exploration Beyond LEO

Held 22 February 2011
at George Washington University
Washington, D.C.

- Workshop Interim Report was provided during the LPSC on March 8, 2011

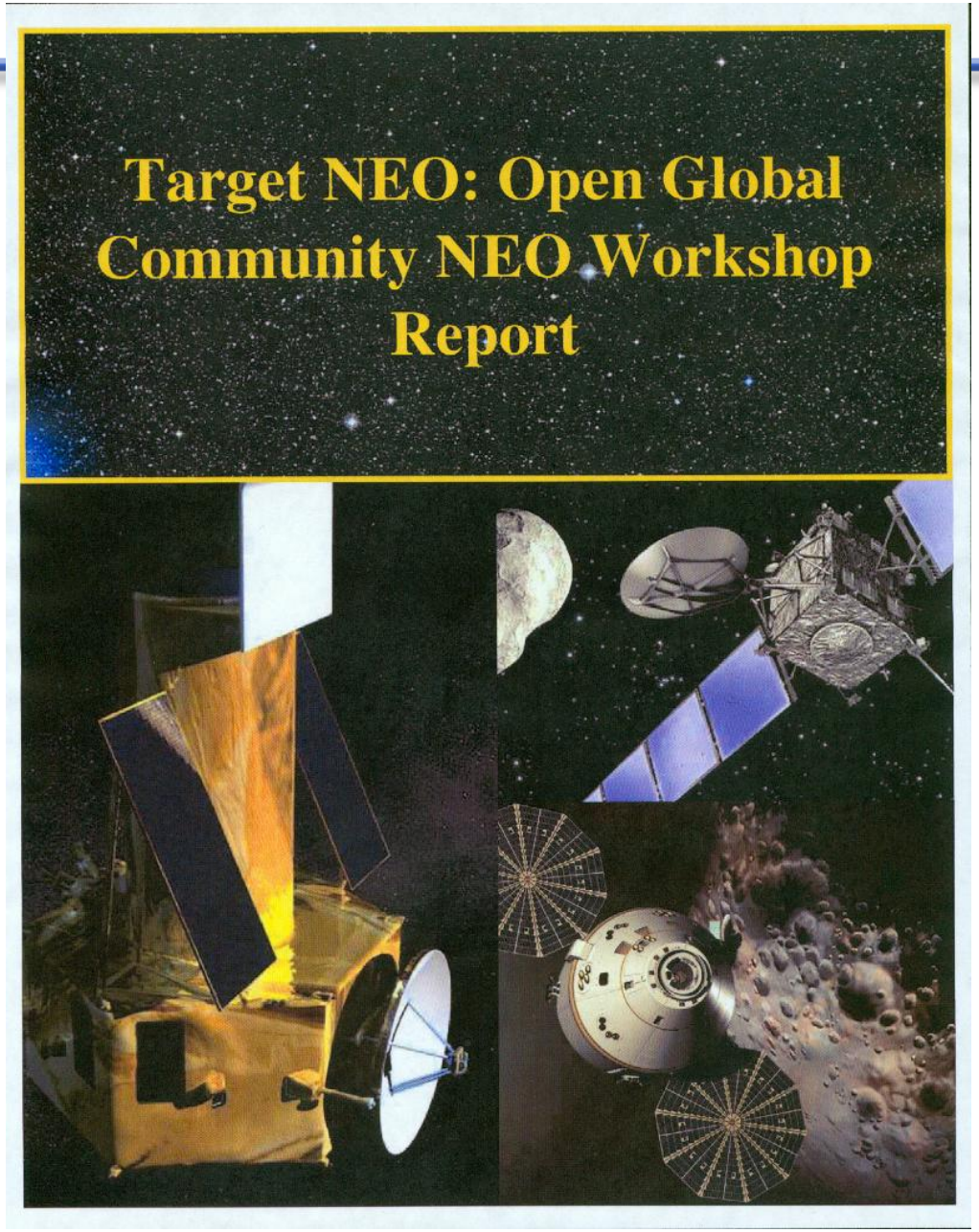
- Workshop Final Report was on-line for comment through 20 May 2011

- Additional comments were solicited during a companion international workshop that was held in conjunction with the PDC on 13 May 2011. An addendum to the final report will then be added to capture any additional discussion/input.

- Report was reviewed by NASA SBAG

- Final report was provided and briefed to key government stakeholders

- New Target NEO website: **http://targetneo.jhuapl.edu**



Summary of Recommendations (1)

- Ongoing ground-based surveys and data archives maintained by the NEO Program Office and the Minor Planet Center have provided a solid basis to build upon, but a more complete catalog of the NEO population is needed to define a robust and sustainable HSF exploration program.

- The sizes and heliocentric orbits of many known NEOs are so uncertain that they will be very difficult to find and observe for effective characterization to determine suitable targets. Follow-up observations are needed after NEO discoveries to obtain sufficiently accurate orbit determination to support HSF. Focused efforts with dedicated ground and space-based assets could greatly reduce unknowns about the NEO population within 10 years.

- Affordable HSF mission opportunities, with sufficient lead time to launch them toward known NEO destinations, are few and far between if NEO surveys are confined to Earth's vicinity. Beyond the Moon, planetary launch windows are unforgiving.

- Given that only a few percent of the total NEO population accessible to HSF is known, a better return on investment is realized by a comprehensive NEO survey based in deep space, as opposed to a limited target tour.

- NEOs show a wide range of diversity in their physical characteristics. While some of this diversity is well-understood from existing data, further studies are required to help constrain the envelope of NEO physical characteristics that will drive development of HSF systems and operational concepts for future human exploration.

Summary of Recommendations (2)

- Characterization of candidate NEO targets should include information directly relevant for human exploration needs. While some of that information can be gleaned from Earth-based techniques (reflectance spectroscopy, radar experiments, lightcurve measurements, etc.), robotic precursor missions are required for some critical characterization details that can only be obtained *in situ* (response of surface to disturbance, debris hazards, geotechnical data, etc.).

- Duration of mission is the primary factor in HSF risk management and mission knowledge beyond six months is limited. This further constrains HSF target selection.

- Acute and long-term crew physiological effects from radiation (solar particle events and galactic cosmic rays and) and crew behavioral health are critical considerations for long-duration missions.

- A dedicated NEO survey will increase the number of HSF accessible targets by at least on order of magnitude. To this end, there already exist multiple, mature survey concepts with many of the cost estimates (i.e., the space-based solutions) within the Discovery mission class cost range.

- There are numerous, affordable space-based survey approaches. The existing survey concept capabilities and costs have had minimal intercomparison to date; they may not be using the same metrics and assumptions, especially in the area of required data processing. Panel recommends a formal intercomparison of capabilities and cost using a common set of assumptions on undiscovered target population parameters and completion metrics to objectively assess the range of survey options available.

International Liaison Workshop Conclusion

- **A workshop on the international coordination of NEO related activities was held in Bucharest, May 13, 2011, co-located with the IAA Planetary Defense Conference.**

- **The main objective of the workshop was to bring together the NEO communities interested in:**
  - Exploration (including precursor activities for human exploration)
  - Hazard Mitigation
  - Science
  - Commercial aspects (e.g., resource utilization)

- **It also served as the international extension of the US workshop held in February 2011**

- **Conclusion: Essential prerequisite for both mitigation and exploration is (in priority order)**

  1.) Comprehensive space-based survey (note that currently there are only 1 ± 1 possible targets for human exploration identified!) U.S. focus and best use of global expertise.

  2.) Characterization of (a variety of) asteroids (and comets).

  3.) Planning for the next step, i.e., a mitigation mission (which would also perform characterization). Recommended by the participants of the workshop to introduce a Mitigation Demonstration Mission (using spin off from Don Quixote study) into the ESA Space Situational Awareness (SSA) program. Possible coordination with other programs (e.g. Human Exploration should be further investigated.) **Connection to the Global Exploration Roadmap to be solidified**.

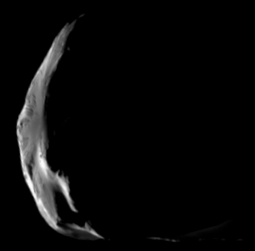
- **Summary: The participants of the workshop encourage an effort to introduce a Mitigation Demonstration Mission to the coming ESA Ministerial Conference, 2012.**

Final Conclusion

- "The NEO Workshop has provided substantial technical community review and conclusive peer support for a NEO Survey Mission as necessary to realize a future human exploration mission to a NEO in the 2025-2035 timeframe. Just as launch vehicles provide a critical need for access beyond LEO, a space-based NEO survey telescope should also be considered a strategic asset for NASA's human space flight exploration goals and objectives. Such a system is necessary to provide focused discovery and characterization of a more complete and robust target set relevant for future human NEO missions. This asset, working in conjunction with ground-based systems, will enable human exploration of deep space while significantly reducing budgetary, operational, and mission related risks.

- To provide a viable, robust target set, a space-based system should be commissioned on-orbit approximately a decade prior to the planned human flight to a NEO. A system of adequate operational life (at least 10 yrs) can be provided reliably, using full and open competition, for the approximate cost of a Discovery-class mission (~$500M). In addition, this affordable system could also satisfy the intent of the Congressional direction to NASA for Planetary Defense as outlined by the National Research Council (NRC) recent report Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies. Such a system will provide a significant return on investment for the US taxpayer by enabling future human space flight capability beyond LEO, learning about objects that could present a hazard to Earth, enhancing our understanding of the Solar System, and doing more exploration for less."

A Simplified, Low Risk Architecture for the Exploration of Near-Earth Objects



62nd International Astronautical Congress
Cape Town, South Africa
7 October 2011

Bill Gerstenmaier
NASA Headquarters

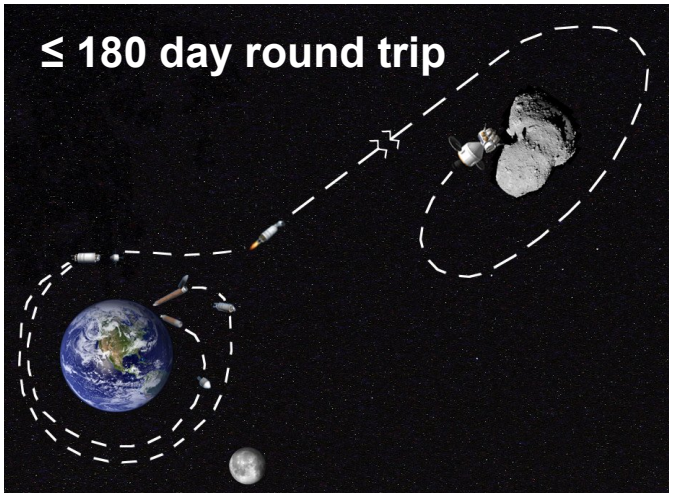
‘Accessible’ NEO List: Not Sufficient, Not Robust

- **Finding NEOs that permit affordable missions by 2025 requires a survey platform in space.**
  - Ground-based surveys will not detect them in time to plan a human mission because they are constrained to survey the night sky.
  - A space-based survey telescope will find these affordable targets, and represents a logical and cost-effective first step in human exploration of NEOs.

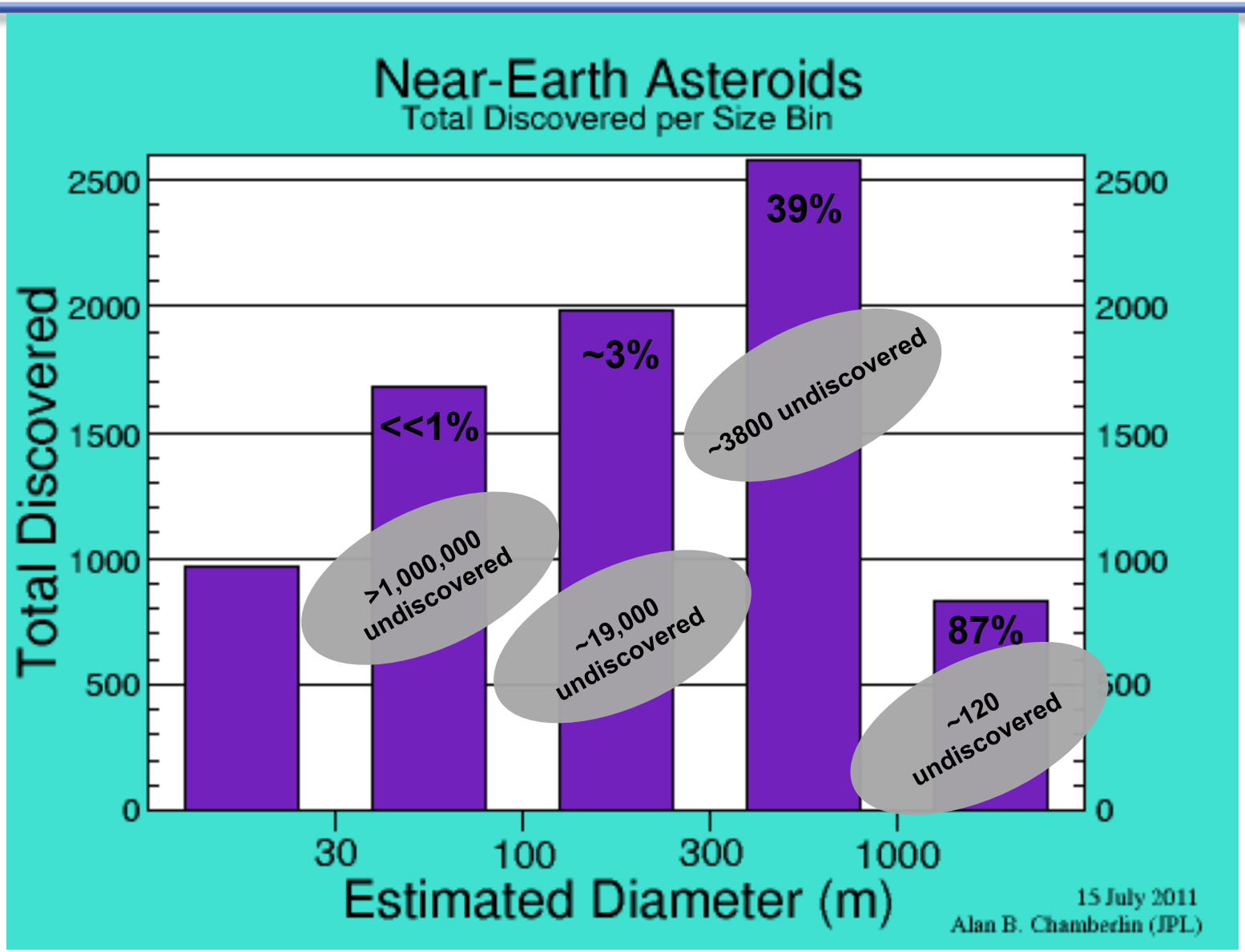
- **Accessing larger objects, or a wider range of small objects, requires**
  - > 1 year missions will be significantly longer than an ISS expedition
  - > 3 HLLV launches to use chemical propulsion (with added complexity for multiple rendezvous and dockings)
  - Reliable systems to support crew for such missions

- **Affordable …**
  - Two HLLV launches
  - < 180-day round trip (or less)
  - Re-entry ~11.8 km/s

- **Hence, the currently known NEO target set severely constrains program flexibility and lowers its resiliency to budget challenges.**



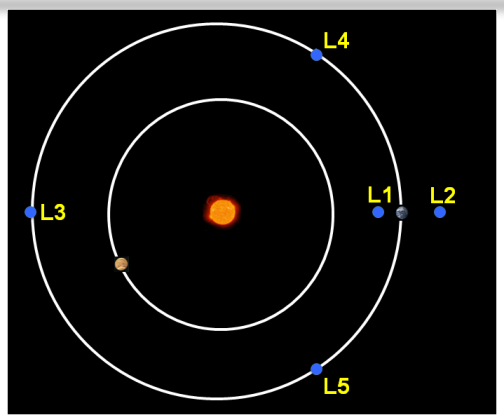
NEA Discoveries; Estimated Completeness of Survey

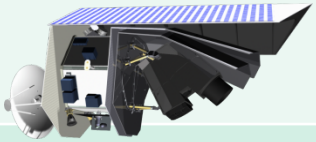
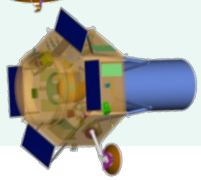


Note: these tallies of NEOs are based on visible light, Earth-based surveys. These estimates will change significantly with a space-based IR survey.

Various NEO Survey Telescope Concepts

- **A NEO survey telescope will discover highly accessible NEO targets suitable for human exploration in a timely manner.**
  - Optimized for detection of objects in Earth-like orbits within two years of launch
  - Launch ready in 4 to 5 years with low risk
- **<u>The survey will include follow-up of all detected objects, *plus characterization (size, rotation rate) of selected objects*</u>.**



Study	Description	Survey Type	Picture	Cost
NEOCam/JPL	•Sun-Earth L1 orbit •Mid-IR •50cm aperture	Sweet Spot		< $500 M (excluding launch)
NEOStar/BATC	•Trailing Venus orbit •Mid-IR •50cm aperture	Opposition		< $500 M (excluding launch)
NEST – L2/APL	•Sun-Earth L2 orbit •Visible •90cm aperture	Sweet Spot		< $500 M (excluding launch)
NEST - Venus/ APL	•Trailing Venus orbit •Mid-IR •90cm aperture	Opposition		< $500 M (excluding launch)

Follow Up Ground-Based Observations of Accessible NEOs for Piloted Missions

The planetary radars of the Goldstone 70-m or the Arecibo 300-m (not shown) can significantly improve our knowledge of NEOs (NASA/JPL).

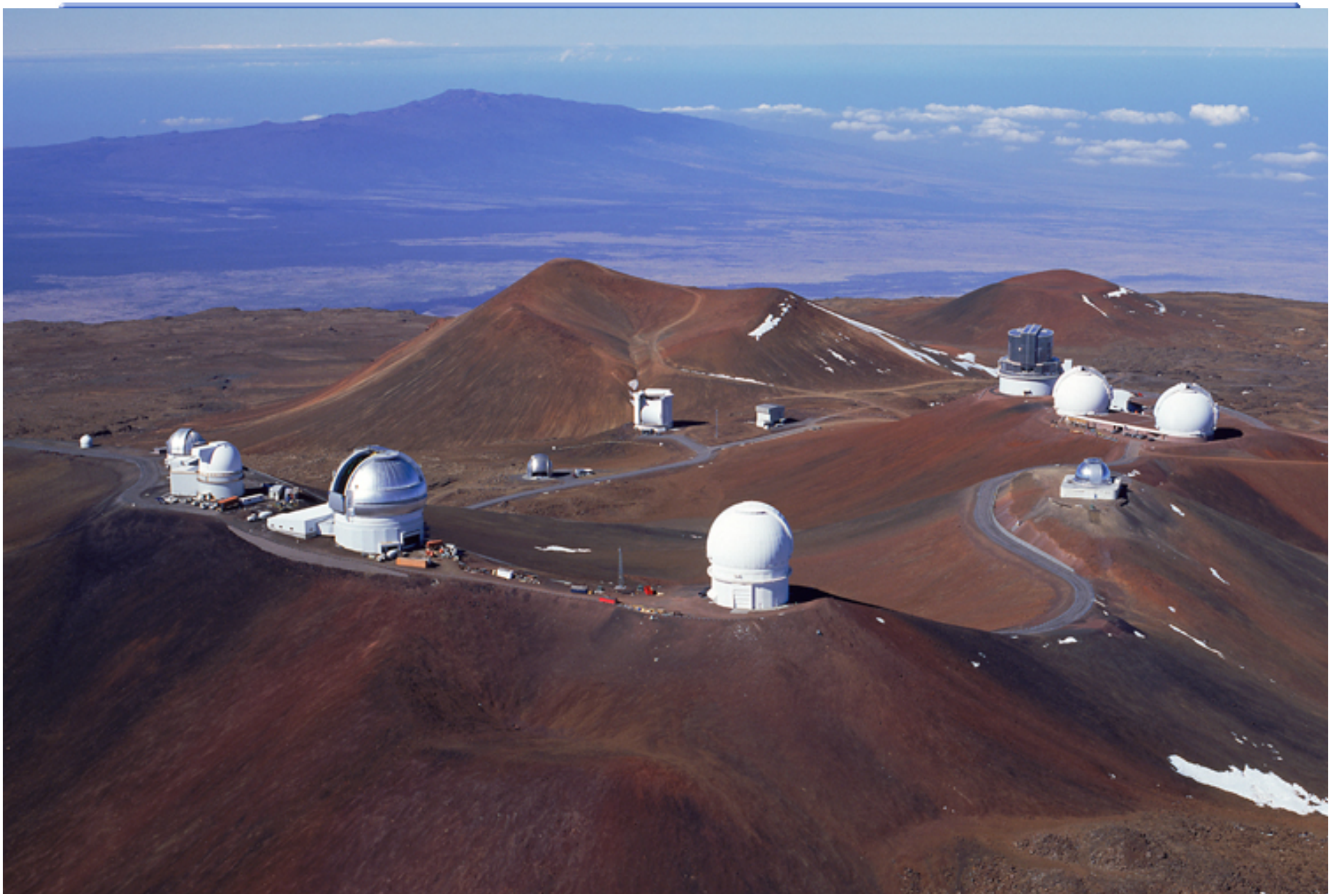
Radar

Spatially resolve NEOs with ~ 4-m resolution (depending on proximity of passage near the Earth):
Greatly exceeds ground- & space-based optical telescope (i.e., *HST*); 3-D shapes, sizes, surface features, spin states, surface roughness and density, regolith, constrain composition; gravity environment

Identify binary and ternary objects:
orbital parameters, masses and bulk densities, orbital dynamics, constrain bulk porosity. Probably too dangerous for first crewed missions.

Improve orbital knowledge:
Very precise and able to dramatically reduce uncertainties for newly-discovered NEOs to which robotic & piloted missions might be mounted. (Radar results yield predictive motion for centuries; prevents NEOs from being 'lost.')

Follow Up Ground-Based Observations of Accessible NEOs for Piloted Missions - Optical



Robotic Precursor Mission Objectives

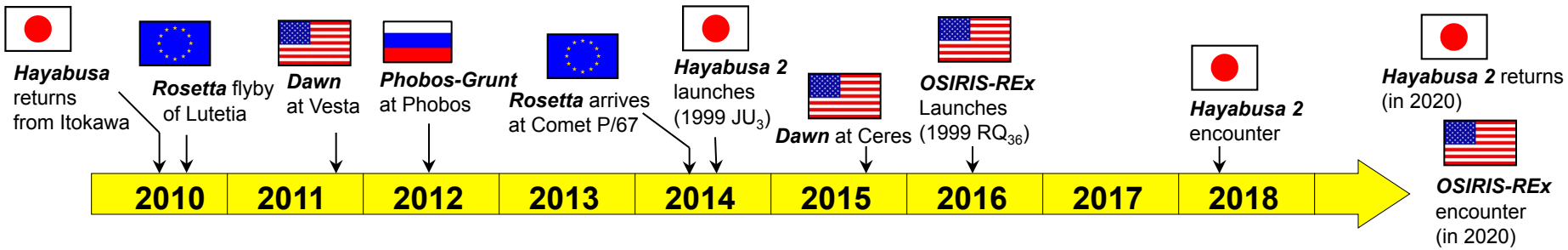
- **Prior to sending a piloted mission to a NEO, additional characterization of the target is required. Fill the knowledge gap.**

- **Obtain basic reconnaissance; make preliminary determination of NEO target characteristics:**
  - Surface morphology and properties
  - Rotation rate & pole orientation
  - Potential hazards to crew
  - Mass/density estimates
  - Gravitational field structure
  - General mineral composition

  All to assess surface for future activities to be conducted for the piloted mission

  and its assets (e.g., crew and payload) → maximize mission safety & efficiency.

Leverage Primitive Body Rendezvous Robotic Missions



- ***NEAR*** (USA), rendezvoused with (433) Eros on 14 Feb 2000.
- ***Hayabusa*** (Japan), arrived at (25143) Itokawa on 12 Sep 2005.
- ***Dawn*** (USA), arrived at (4) Vesta Aug 2011 and later to (1) Ceres in 2015.
- ***Hayabusa 2*** (Japan), slated for launch in 2014 to C-type NEO (1999 JU_3).
- ***Rosetta*** (ESA), flyby of (2867) Steins on 5 Sep 2008 and (21) Lutetia on 10 Jul 2010, and arrives at Comet P67/Churyumov-Gerasimenko in 2014.
- ***OSIRIS-REx*** (USA), sample return from B-type NEO (1999 RQ_{36}) in 2023.
- ***Phobos-Grunt*** (Russia), sample return from Phobos in 2014.

Under study . . .

***Marco Polo-R* (ESA)** target is 1996 FG_3, binary C-type. if selected, would launch in 2020-2022. Marco Polo-R is currently under an assessment study as a part of ESA's Cosmic Visions Program.

HSF - Robotic Precursor Mission Objectives

- **Aid in the navigation of the Orion spacecraft stack to the target NEO.**

- **Provide additional data coverage during Orion-NEO 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 the crew's departure.**
  - Measure momentum transfer from possible kinetic energy/explosive experiment
  - Image crater excavation processes/results (*e.g.,* internal composition)
  - Provide precise orbital measurements over relatively long time periods (*e.g,,* Yarkovsky and YORP effects)

- **Relay data from science equipment left behind by the crew.**
  - Seismic stations, excavation/engineering equipment, resource extraction etc.
  - Radio beacon to help track NEO long after crew departure for precise tracking

Conclusions

- **Space-based NEO Survey is required first (as there is no robust target list of human-accessible NEOs)**
- **In order to find human exploration targets, an NEO survey telescope in an orbit interior to that of the Earth (optimized in the IR) is the most beneficial option**
  - ~400 potential targets within the first two years of observing (based on preliminary NEOWISE results)
  - Such a new target list, with well-defined NEO orbits, will be robust for piloted missions (i.e., 'robust' meaning a few launch opportunities in a given year)
  - List shared with international community and transformed into a matrix of mission opportunities
  - Will provide foundational solar system science on NEOs, the Main Belt, and even the outer solar system (Jovian Trojans, TNOs, Kuiper Belt, comets, etc.)
  - Informs planetary defense (for detection and tracking of all PHOs)
- **Continued follow-up space- and ground-based observations are necessary**
- **Uncertainty in physical properties on candidate NEOs candidates limits the number of mission opportunities → requiring a robotic precursor**
- **Current robotic missions are science-driven and provide critical knowledge and mission operations experience for future human missions – leverage these**
- **Piloted NEO missions will provide an excellent test bed into interplanetary space!**

National Aeronautics and Space Administration

Exploration's NEA User Team (NUT) Precursor Requirements

Presentation to LPSC

8 March 2011

NEA User Team

Victoria Friedensen, Lead

Advanced Capabilities Division
Exploration Systems Mission Directorate

Identifying Knowledge Gaps

- **Constraints translated to gaps in knowledge**
  - Required knowledge to increase mission success and crew safety
    - The information required to qualify a destination as suitable for human visitation
  - Recommended knowledge to inform systems and mission design, increase crew efficiency
    - The information recommended to provide engineering boundary conditions, minimize logistics, and maximize mission planning
- **The Outcome:**
  - The required knowledge will be used to choose between possible destinations
  - Precursor data is required before destination selection can occur
  - The recommended knowledge will be used to inform architecture and systems engineering decisions
  - Precursor data is desired to maximize planning

NEA Exploration: Need to Knows

Required

- Exact location
- System Type
- Spin Mode
- Activity/Debris Field
- Mechanical Stability
- Gravitational Field

Recommended

- Mineralogical/Chemical composition
- Regolith mechanics/ geotechnical properties
- Electrostatics/ plasma field
- Radiation assessment
- Thermal properties

Conclusion

- **Recommendation:** To inform destination selection and to maximize safety and efficiency of the crew, the *same information for each NEA is required*. To inform systems design and mission planning, *basic information about potential destinations is needed*.

- **Rationale:** To maximize programmatic flexibility *identical data sets from multiple NEAs* would be the basis for selecting primary and backup destinations
  - Providing multiple launch windows (consecutive weeks/ months) to shorten on-orbit dwell time
  - Ensuring equivalent mission durations (to ease logistics and margins)
  - Enabling similar mission ‘portfolios’ (the exploration and science goals would be similar for each primary/secondary destination identified).

NASA Associate Administrator
October 18, 2011

Final Report: NAC Ad-Hoc Task Force on Planetary Defense

Co-Chairs
Dr. Tom Jones
Mr. Rusty Schweickart

Synergies from Planetary Defense (1 of 2)

- **NASA NEO activity is "3-D": exploration, science, planetary defense (PD)**
  - **Minor incremental cost to "other" space missions can yield large increase in PD knowledge**
  - **Example: Science mission can demonstrate prox ops algorithms for PD, human exploration**
  - **Example: NEO's interior structure, physical properties, and stability of surface materials (for human exploration) aids PD planning**

Synergies from Planetary Defense (2 of 2)

- **Time is a 4th dimension of NEO research**
  - **Early integration of PD results in faster maturity of technology**
  - **Eliminates cost of duplicate flight missions**

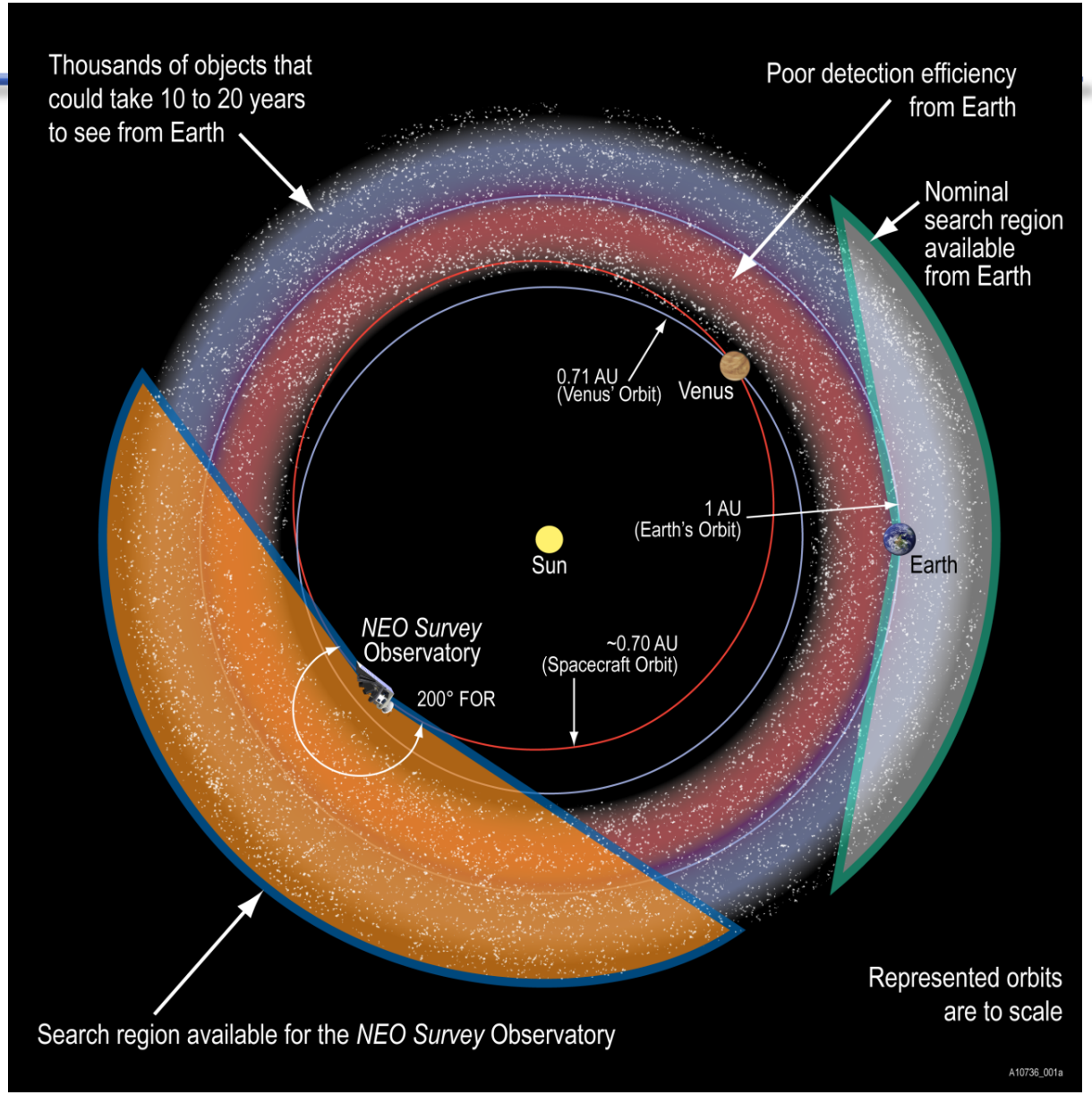
- **Integrating PD into science and human exploration missions increases overall knowledge return**
  - **Meets needs of managers, policy makers, scientists, public**

Investigate the Nature of the Impact Threat

To guide development of effective impact mitigation techniques, NASA should complete the target inventory and acquire a better understanding of NEO characteristics by using existing and new science and exploration research capabilities, including ground-based observations, impact experiments, computer simulations, and *in situ* asteroid investigation. Specifically, by…..

.. A space- and ground based NEO search survey:

Showing orbit geometry when Earth and the spacecraft are on approximately opposite sides of the sun. Earth-based telescopes will detect some NEOs that the space-based telescope will miss during the NEO perihelion passage. The resulting completeness will be better than with any single telescope.



Recommendations

1. **Organize for Effective Action on Planetary Defense**
2. **Acquire Essential Search, Track, and Warning Capabilities – Space Situational Awareness**
3. **Investigate the Nature of the Impact Threat**
4. **Prepare to Respond to Impact Threats**
5. **Lead U.S. Planetary Defense Efforts in National and International Forums**

Understand and determine HSF's future role in Planetary Defense…

In closing, expert forums recommend …..

Way Forward (1)

- **Plan for a Agency-wide NEO survey mission to be initiated in the 2012-2013 timeframe, beginning with a Phase A study. As there are numerous concepts that could do the task, this effort and the mission should be competed.**

- **The NEO survey telescope should be the top precursor priority for a human mission to a NEO, but most importantly will be a key infrastructure asset which serves the HSF, planetary defense, and science communities at large. Such an asset can be of benefit to SMD, ESMD, and SOMD interests.**

- **Coordinate with other space exploration agencies interested in NEOs from the standpoint of Human exploration, planetary defense, science, and commercial interest. Note that some agencies have missions in early planning stages, but are not yet finalized (e.g., Marco Polo-R)**

Way Forward (2)

- **Leverage ongoing NEO programs and planned missions for mutual benefit in terms of data exchange (e.g., ESA's SSA program, JAXA's Hayabusa 2, Russia's Phobos Grunt, CSA's NEOSSAT, etc.)**

- **Coordinate with ESA and other space agencies on a potential planetary defense mitigation demonstration mission. Note that this has been suggested as a top priority for ESA as it is seen as their contribution to the NEO hazard issue.**

- **Engage and task assessment/working groups such as the Small Bodies Assessment Group (SBAG) and the International Primitive Body Exploration Working Group (IPEWG) for ongoing input on NEO related activities.**

Key Results of the Collective Reports/Summaries

- **Necessity of completing the NEO survey first (space-based observations) to support sustainable human exploration to NEOs**
- **Need for continued operation of space- and ground-based assets for follow-up observations**
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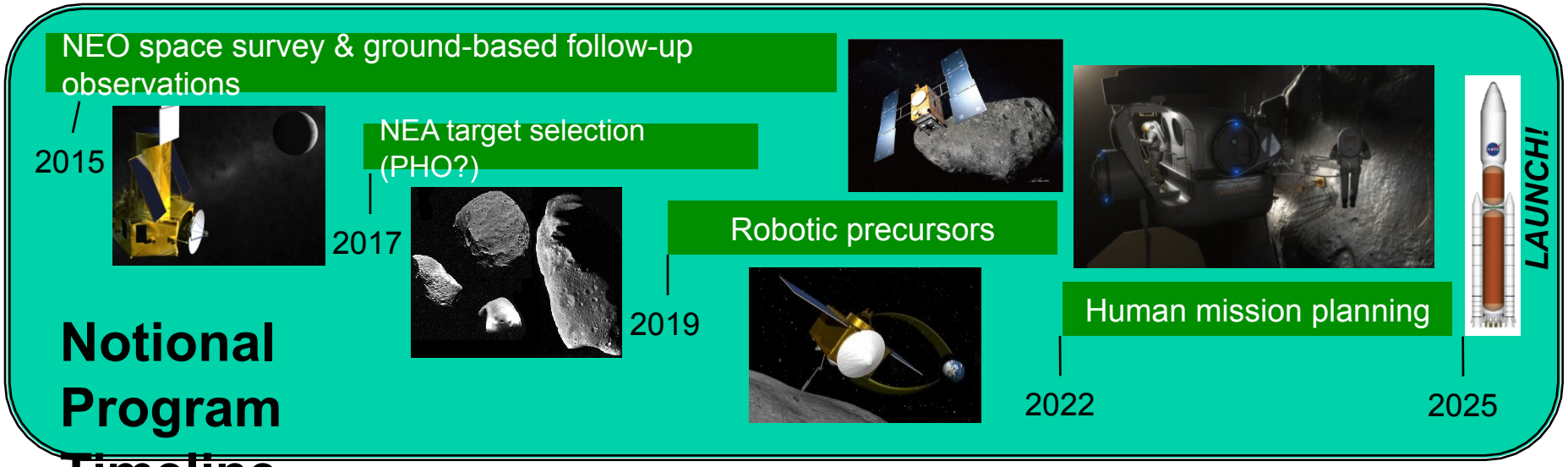
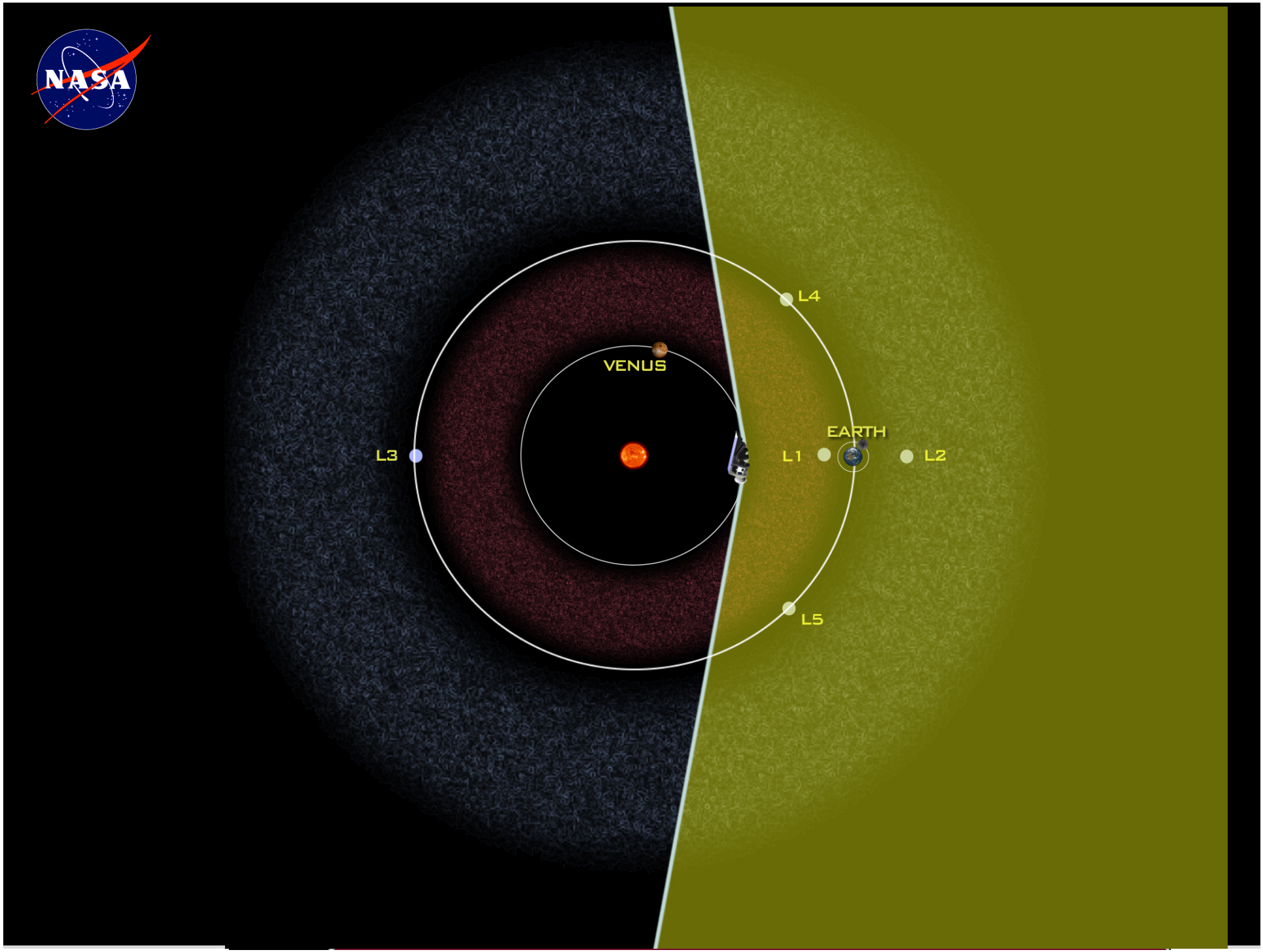


Notional Program Timeline

Back-up


L4
VENUS
EARTH
L3
L1
L2
L5

Relatively Accessible NEO Targets

- The Near-Earth Object (NEO) Human Space Flight (HSF) Accessible Targets Study (NHATS) (pronounced "gnats") was inaugurated by NASA in late 2010.

- The objective of the study is to identify all NEOs (in particular, NEAs) that offer at least one round-trip trajectory solution in compliance with a purposely permissive set of trajectory filter parameters, including:
  - Earth departure between 2015/01/01 and 2040/12/31
  - Total mission $\Delta v \leq 12$ km/s
  - Mission duration ≤ 450 days

- 765 of the 7665 NEAs known during early 2011 passed this filter; the top 25, ranked by the number of NHATS-compliant solutions they offer, are tabulated here

The top 25 accessible NEOs ranked according to *n*, a tally of NHATS-compliant mission solutions associated with each NEO. Maximum estimated diameter d must exceed 30 m for each NEO listed.

Rank	Designation	*n*	*d* (m)
1	2000 SG_{344}	3,302,638	29 - 66
2	2006 BZ_{147}	1,674,416	22 - 49
3	2001 FR_{85}	1,618,888	33 - 75
4	2010 UJ	1,082,350	15 - 34
5	2009 HE_{60}	970,582	20 - 44
6	2007 YF	791,134	30 - 66
7	2010 JK_1	773,964	35 - 78
8	2004 VJ_1	679,319	37 - 83
9	2009 YF	663,423	31 - 69
10	1993 HD	656,700	20 - 44
11	2001 QJ_{142}	638,089	55 - 123
12	2006 FH_{36}	630,084	69 - 155
13	2009 HC	555,180	30 - 66
14	2011 AA_{37}	546,096	74 - 165
15	1999 CG_9	541,015	24 - 53
16	2007 UY_1	537,599	71 - 158
17	2005 QP_{11}	491,888	14 - 31
18	2009 OS_5	478,949	51 - 115
19	2009 DB_{43}	477,581	14 - 30
20	2001 CQ_{36}	473,574	77 - 171
21	2004 JN1	465,681	54 - 121
22	1999 AO_{10}	462,650	45 - 101
23	2003 SM_{84}	445,022	76 - 169
24	2009 CV	434,988	37 - 84
25	2009 TP	433,374	52 - 117

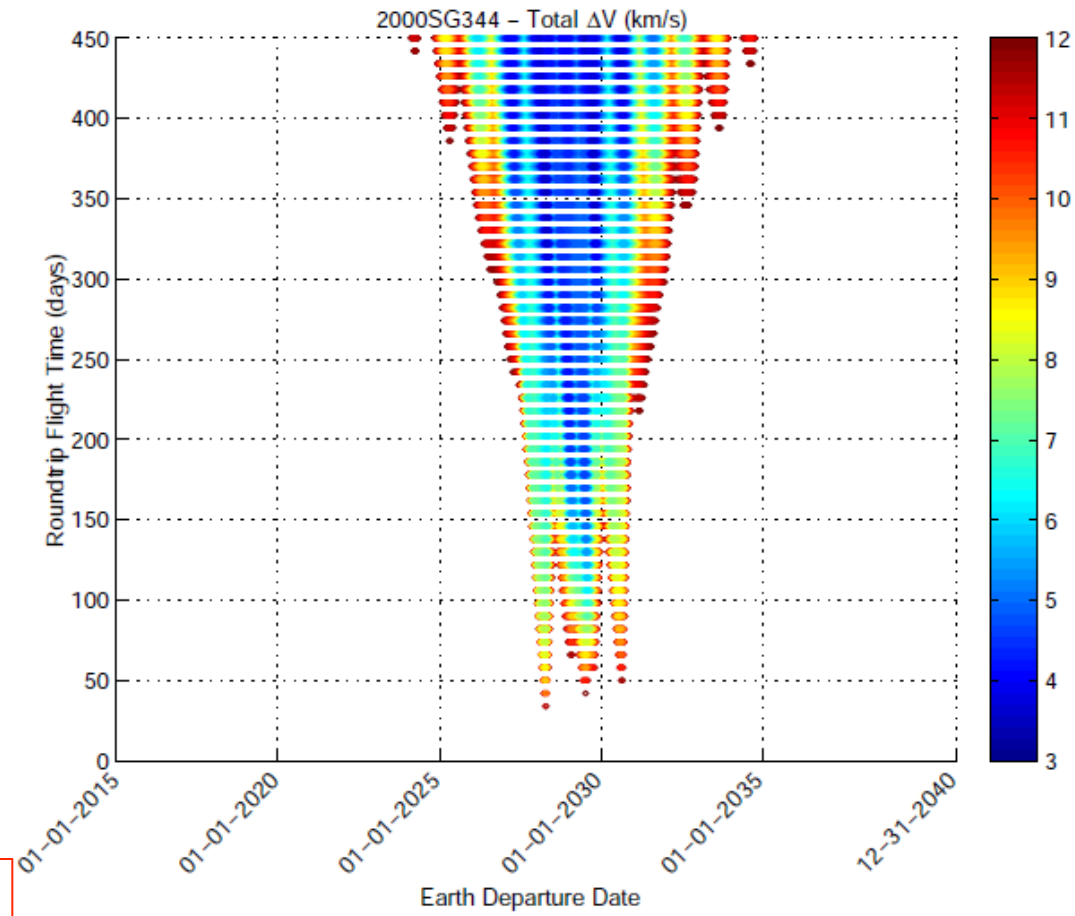
Relatively Accessible NEO Targets

- Future HSF capability is undefined, and NHATS results are pre-decisional in terms of selecting actual targets for future HSF missions

- When a more realistic set of trajectory filter parameters is applied, only 3 NEAs barely pass
  - Earth departure between 2025 and 2030
  - Total mission $\Delta v \leq 5.0$ km/s
  - Mission duration ≤ 180 days

- None of the 3 NEAs are large in size, and 2 of them are likely too small to justify HSF missions
  - 2000 SG_{344} (up to 66 m diameter)
  - 2007 XB_{23} (up to 23 m diameter)
  - 2006 RH_{120} (up to 7 m diameter)

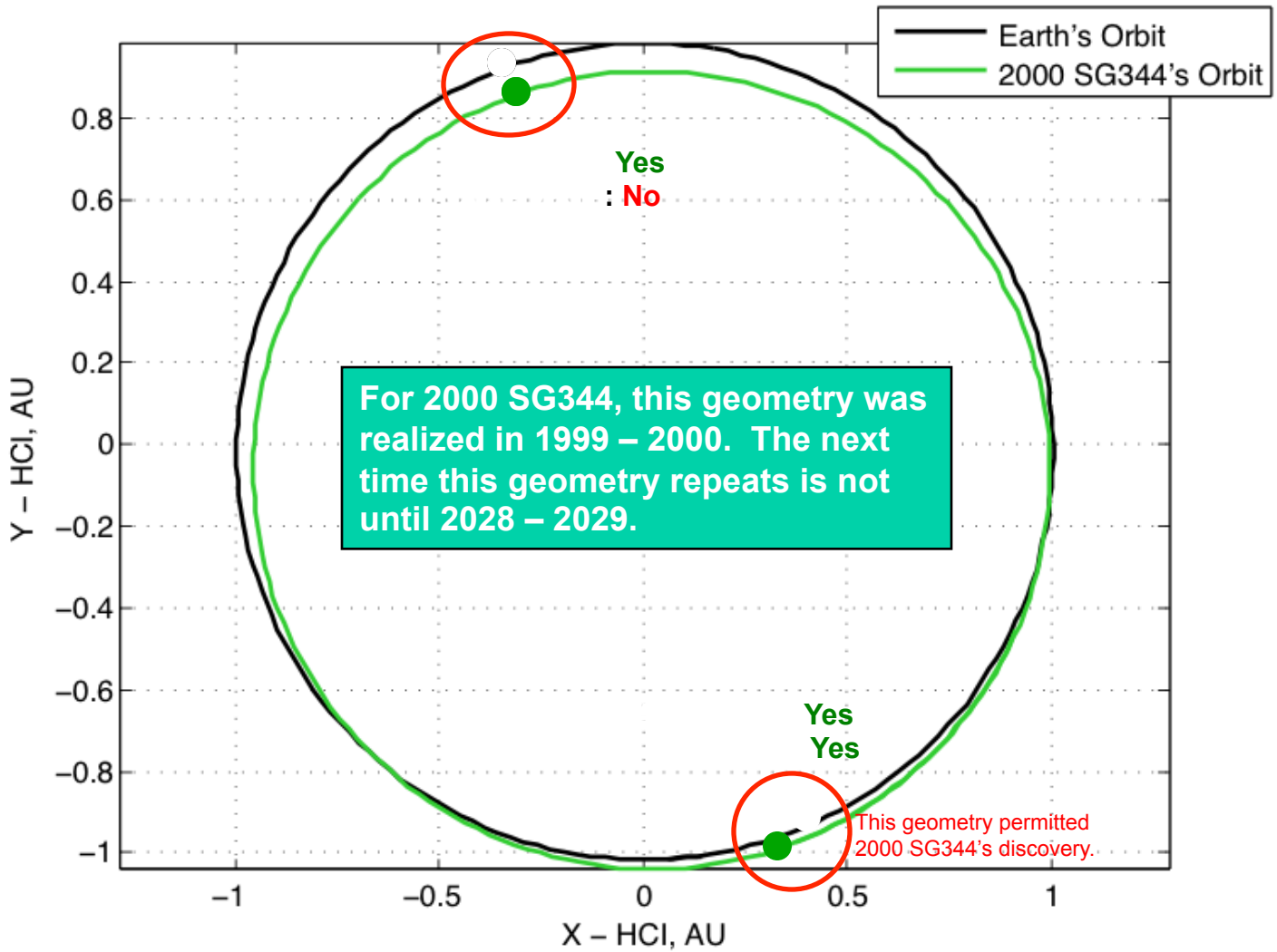
- **The lack of viable human destination targets clarifies the need to discover highly accessible NEOs within the next several years if any HSF missions to NEOs are to be planned for and executed within the 2025 - 2030 time frame.**



Pork chop plot of the *n* = 3,302,638 NHATS-compliant mission solutions pertaining to 2000 SG_{344}.

Importance of Viewing Geometry

- **An asteroid's close encounter with Earth (< ~0.1 AU) enables both its ground-based discovery (when it's in the dark night sky) and human mission viability.**

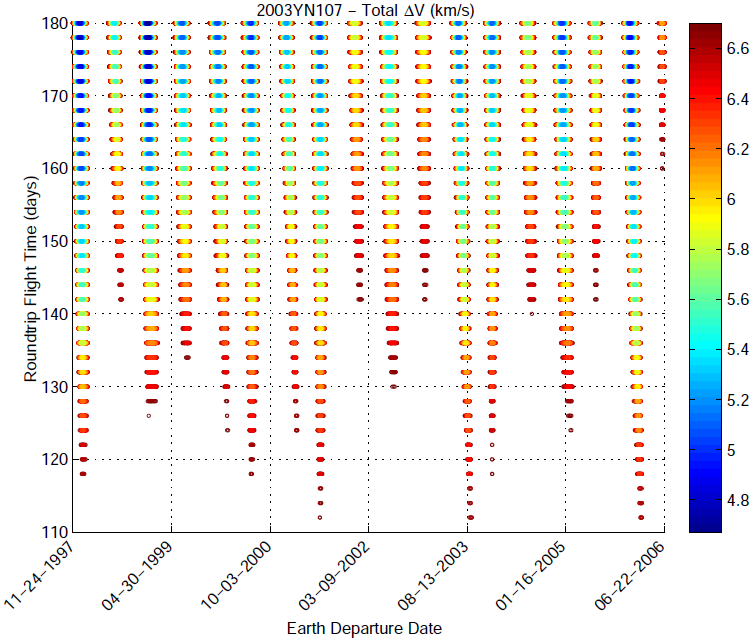


Previously Discovered NEOs as Existence Proofs

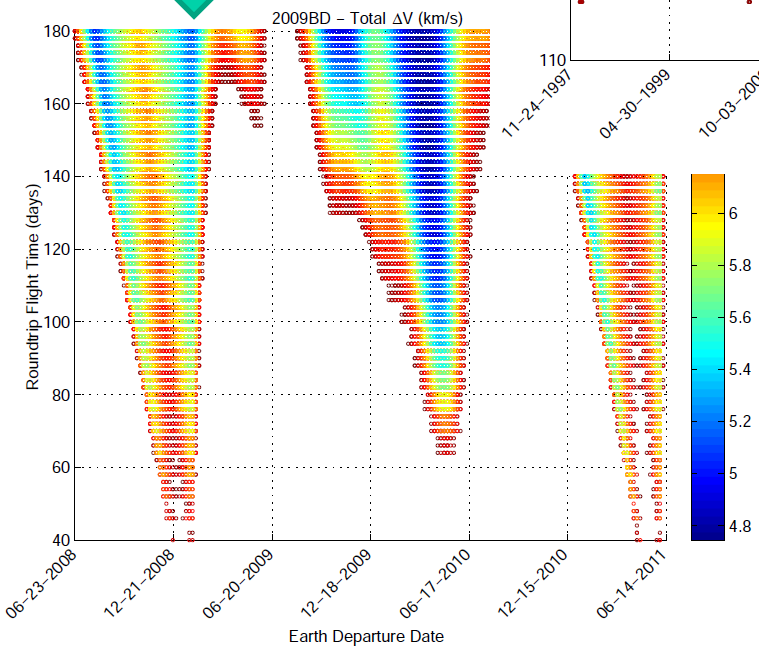
- **Many more targets may exist within the undiscovered NEO population.**

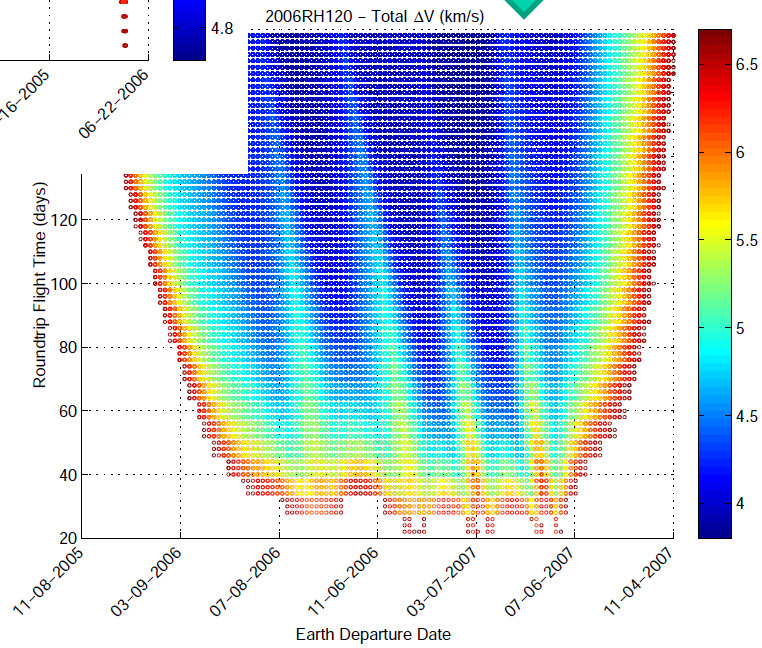
Multiple mission opportunities spanning several years

~9 years
~3 years



More than a year of continuous mission opportunities with short mission duration (< 150 days) and very low ΔV (< 5km/s).





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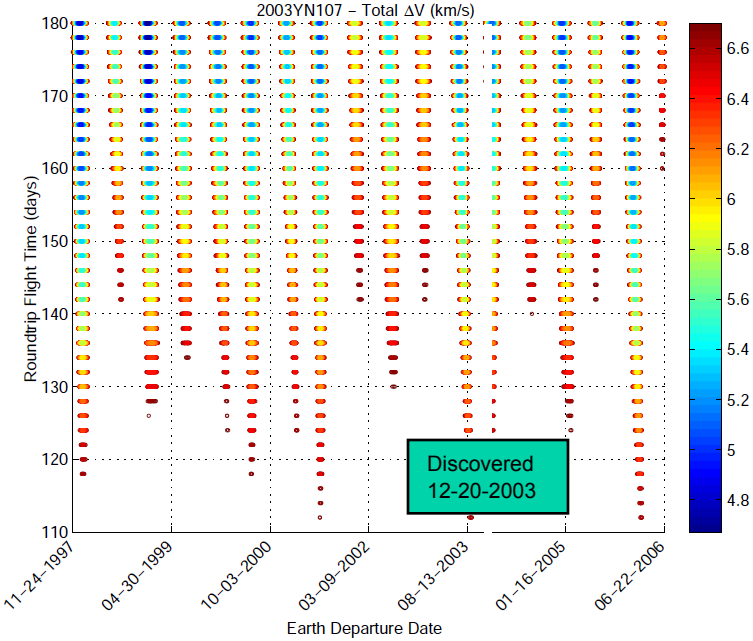
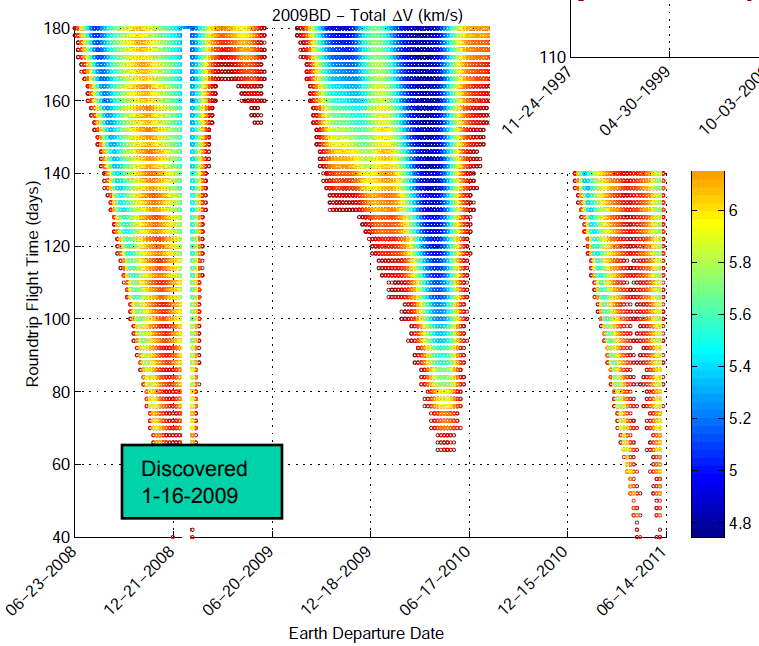
Discovery of NEOs and Mission Planning

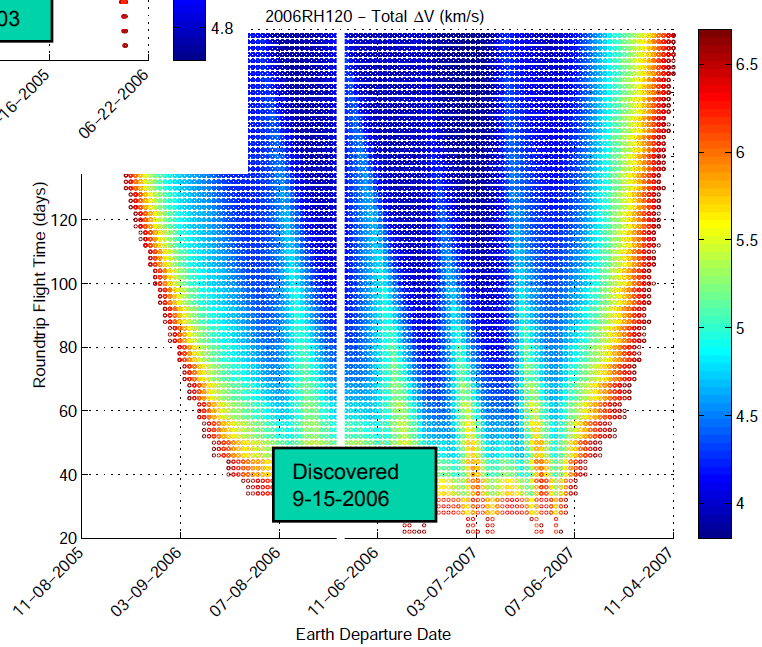
- **Timing of NEO discoveries will be crucial for adequate mission planning.**

Relying on discovering the NEOs during their tandem phase with Earth is too late for effective mission planning.

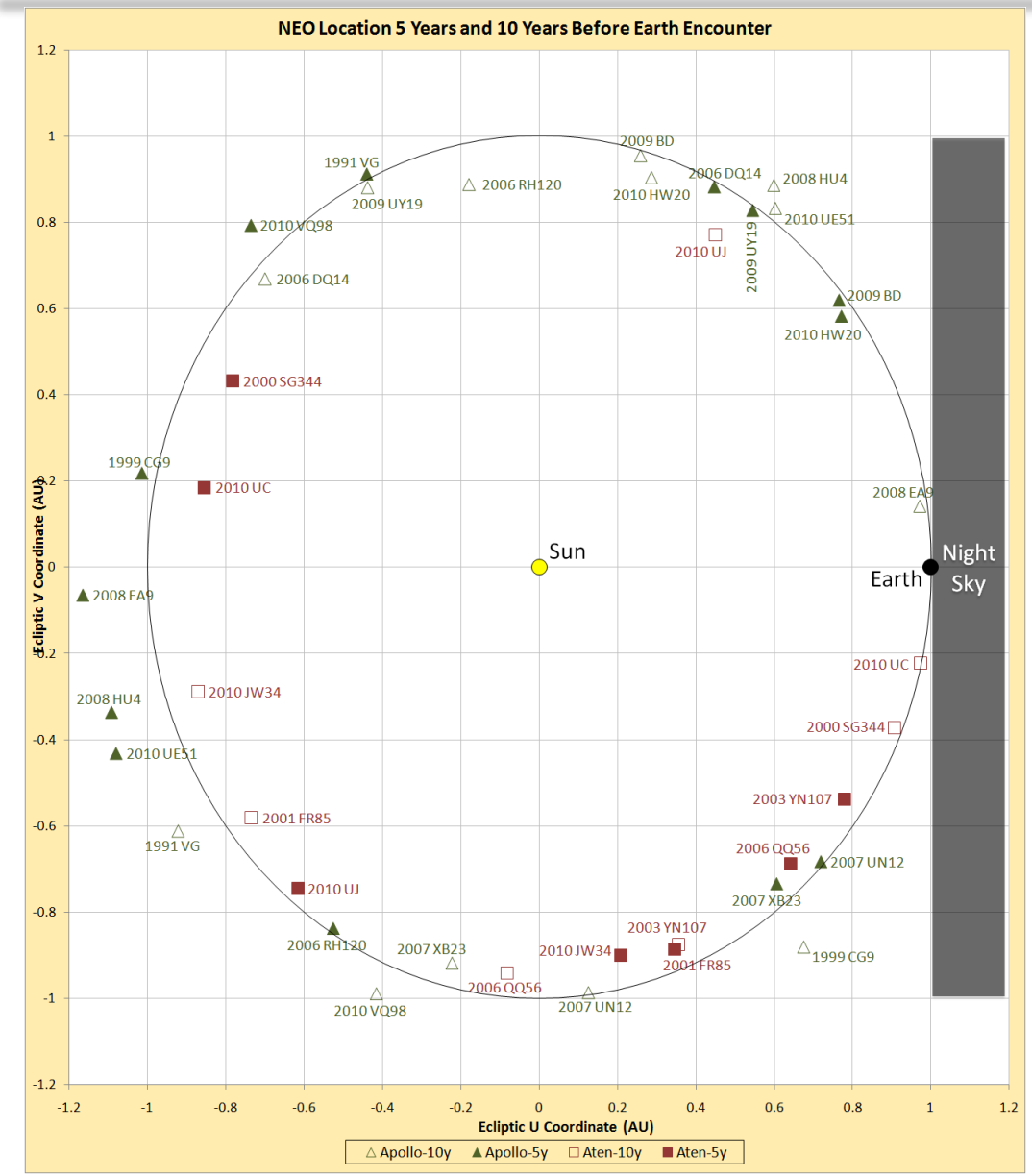


Ground-based surveys will not provide enough time for effective mission planning because of their constraint to observe in the dark night sky.





Where and When to Search for NEOs?



- **Where: Daytime Sky**
- **When: 2015 - 2020**

The plot at the left shows the position of each of the 20 NEOs 10 years before (open symbols) and 5 years before (closed symbols) the onset of its tandem period.

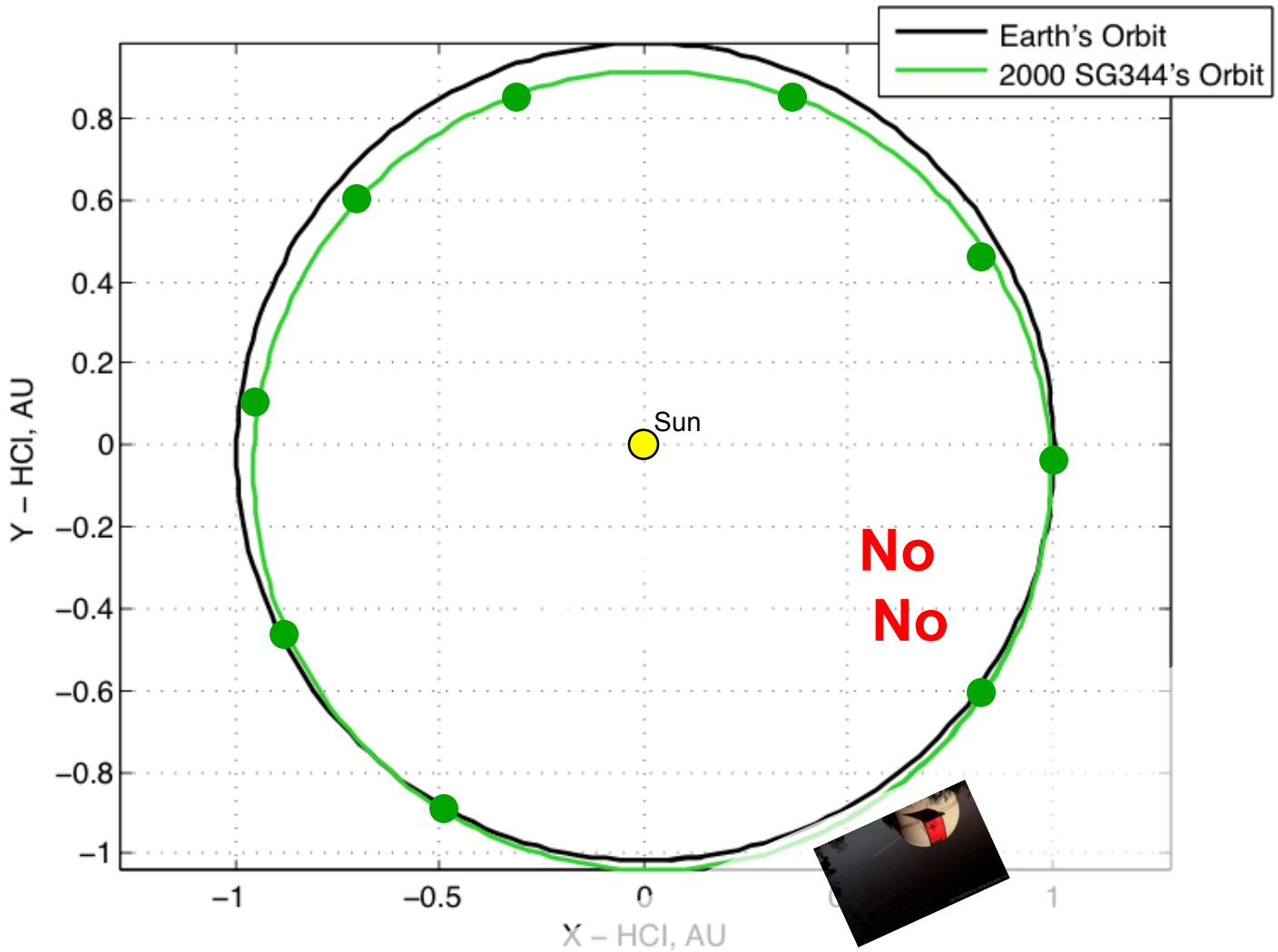
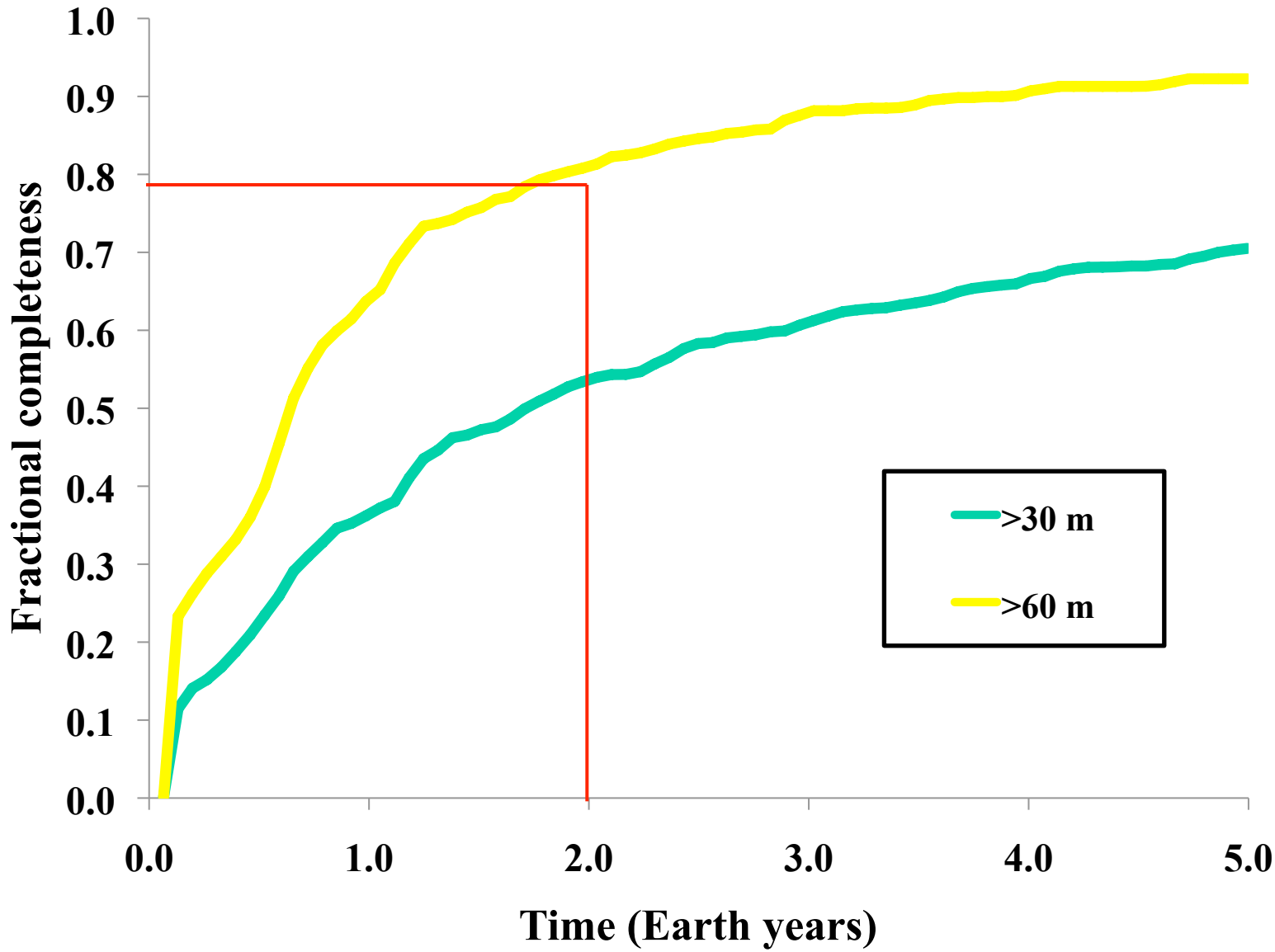
The Earth's dark night sky – the region of space in which current ground-based NEO survey telescopes are searching – is shown at the right of the plot.

Note that *none* of these objects appear in the dark night sky at 10 and 5 years prior to their discovery periods.

CONCLUSION: For missions in 2025 – 2030, **a platform in space is needed to find the most affordable targets in a timely manner.**

Importance of Viewing Geometry

- **And in the intervening ~28 years…**



Completeness on Human Exploration targets: IR space telescope only