JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

All KC events will be approved for public using NASA Form 1676.

This synopsis provides information about the Knowledge Capture event below.

Topic: Human Exploration of Near-Earth Asteroids

Date: July 25, 2013 **Time:** 10:30-12:00 pm **Location:** JSC/B5S/R3102

DAA 1676 Form #: 29231

This is a link to all lecture material and video: \\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY13 Knowledge Capture\20130725 Abell_Human Exploration of Near-Earth Asteroids\For 1676 Review and Public Release

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

Assessment of Export Control Applicability:

This Knowledge Capture event has been reviewed by the EC5 Spacesuit Knowledge Capture Manager in collaboration with the author and is assessed to not contain any technical content that is export controlled. It is requested to be publicly released to the JSC Engineering Academy, as well as to CASI for distribution through NTRS or NA&SD (public or non-public) and with video through DVD request or YouTube viewing with download of any presentation material.

Presenter: Paul Abell

Synopsis: A major goal for NASA's human spaceflight program is to send astronauts to near-Earth asteroids (NEA) in the coming decades. Missions to NEAs would undoubtedly provide a great deal of technical and engineering data on spacecraft operations for future human space exploration while conducting in-depth scientific examinations of these primitive objects. However, before sending human explorers to NEAs, robotic investigations of these bodies would be required to maximize operational efficiency and reduce mission risk. These precursor missions to NEAs would fill crucial strategic knowledge gaps concerning their physical characteristics that are relevant for human exploration of these relatively unknown destinations. Dr. Paul Abell discussed some of the physical characteristics of NEOs that will be relevant for EVA considerations, reviewed the current data from previous NEA missions (e.g., Near-Earth Asteroid Rendezvous (NEAR) Shoemaker and Hayabusa), and discussed why future robotic and human missions to NEAs are important from space exploration and planetary defense perspectives.

Biography: Dr. Paul Abell is the lead scientist for Planetary Small Bodies assigned to the Astromaterials Research and Exploration Science Directorate at the NASA Johnson Space Center in Houston, Texas.

He received an artium baccalaureus in astronomy and physics from Colgate University, a master of science in space studies with a minor in geology from the University of North Dakota, and a doctor of philosophy (Ph.D.) in geology from Rensselaer Polytechnic Institute.

His main areas of interest are physical characterization of near-Earth objects (NEO) through ground-based and spacecraft observations, examination of NEOs for future robotic and human exploration, and identification of potential resources within the NEO population for future resource use. Abell has been studying potentially hazardous asteroids and NEOs for over 15 years. He was a telemetry officer for the Near-Earth Asteroid Rendezvous spacecraft Near-Infrared Spectrometer team and was a science team member on the Japan Aerospace Exploration Agency (JAXA) Hayabusa near-Earth asteroid sample-return mission. Abell was also a member of the Hayabusa contingency recovery team and participated in the successful recovery of the spacecraft‘s sample return capsule, which returned to Woomera, Australia in June 2010.

Since 2006, Abell has been a member of an internal NASA team that is examining the possibility of sending astronauts to NEOs for long duration human missions circa 2025 and is currently the lead committee member of the Small Bodies Assessment Group chartered with identifying Human Exploration Opportunities for NEOs. In 2009, he became a science team member of the Large Synoptic Survey Telescope (LSST) Solar System Collaboration tasked with identifying NEOs for future robotic and human space missions, and is also the science lead for NEO analog activities and operations of the NASA Extreme Environment Mission Operations (NEEMO) and Research and Technology Studies (RATS) projects. Asteroid 8139 (1980 UM1) is named Paulabell in recognition of Abell's contributions to NEO research and exploration studies.

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National Aeronautics and Space Administration

Human Exploration of Near-Earth Asteroids

Paul Abell

Astromaterials Research and Exploration Science

NASA Johnson Space Center

U.S. Spacesuit Knowledge Capture Series

Houston, Texas

July 25, 2013

Outline

- Recent Near-Earth Object (NEO) Events
- Basic Introduction to NEOs (Asteroids and Comets)
- Orbital Dynamics and Impact Threat
- Discovery Rate and Population Estimates
- Near-Earth Object (NEO) Characteristics (main focus on Asteroids)
- Robotic Spacecraft Missions to NEOs
- Rationale for Human Missions
- Conclusions

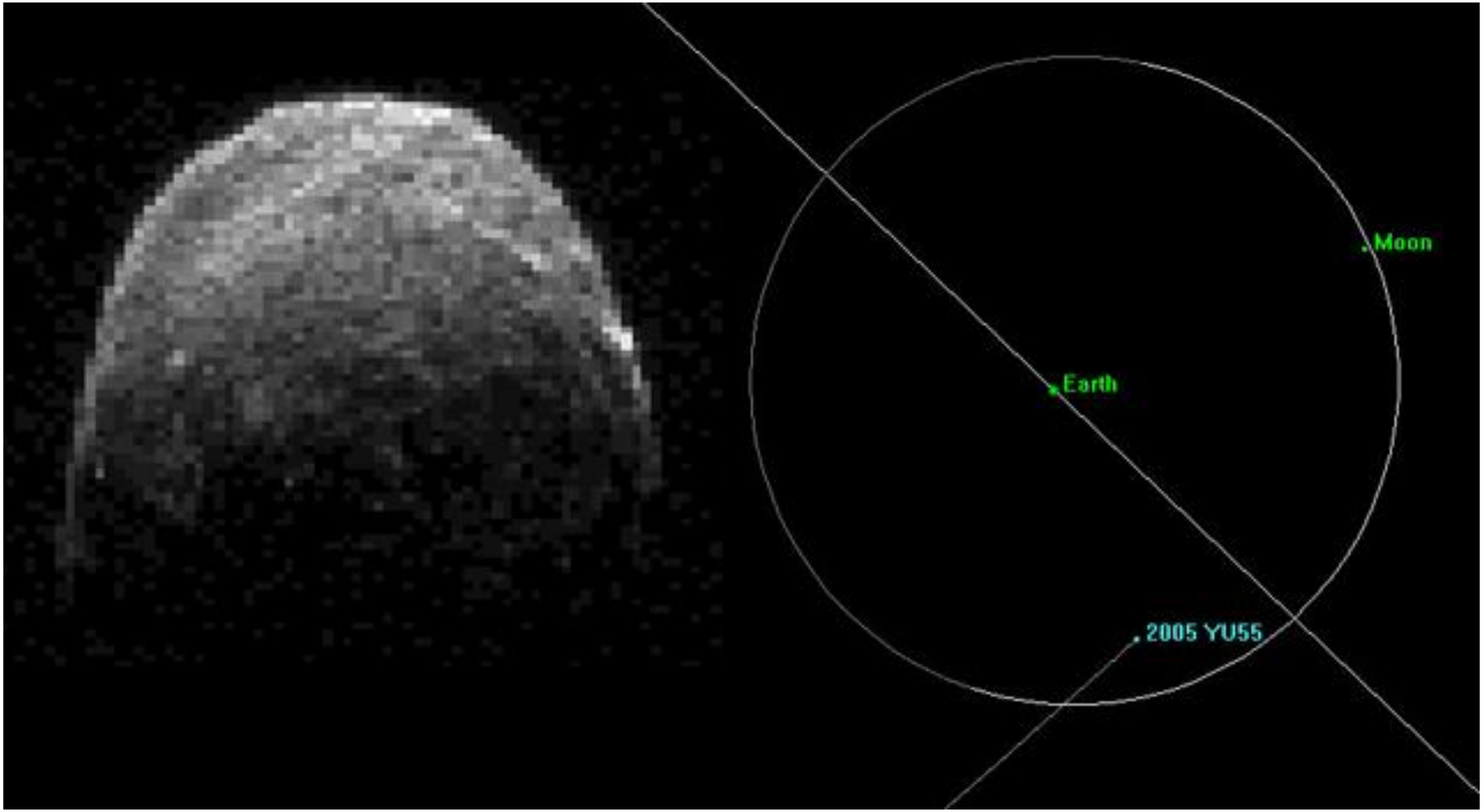
Recent NEO Events

- **2005 YU55 on Nov. 8, 2011**
  - ~360 ± 40 m diameter
  - Closest approach 0.85 lunar distance.
- **2012 EG5 on Apr. 1, 2012**
  - ~100 m diameter
  - Closest approach 0.6 lunar distance.
- **2012 DA14 on Feb. 15, 2013**
  - ~40 x 20 m diameter
  - Closest approach ~17,150 miles or ~27,600 km (well inside geostationary satellite ring)
- **Chelyabinsk Event on Feb. 15, 2013**
  - ~17 - 20 m diameter asteroid impacted at 18 km/s
  - ~440 kiloton airburst explosion
  - Largest event since Tunguska, Siberia (1908)

***Note these objects are not considered to be accessible from a human exploration perspective in the near term. Even though they come close to the Earth, the delta Vs, launch window constraints, and mission durations required for a round trip voyage make them less than ideal targets.**

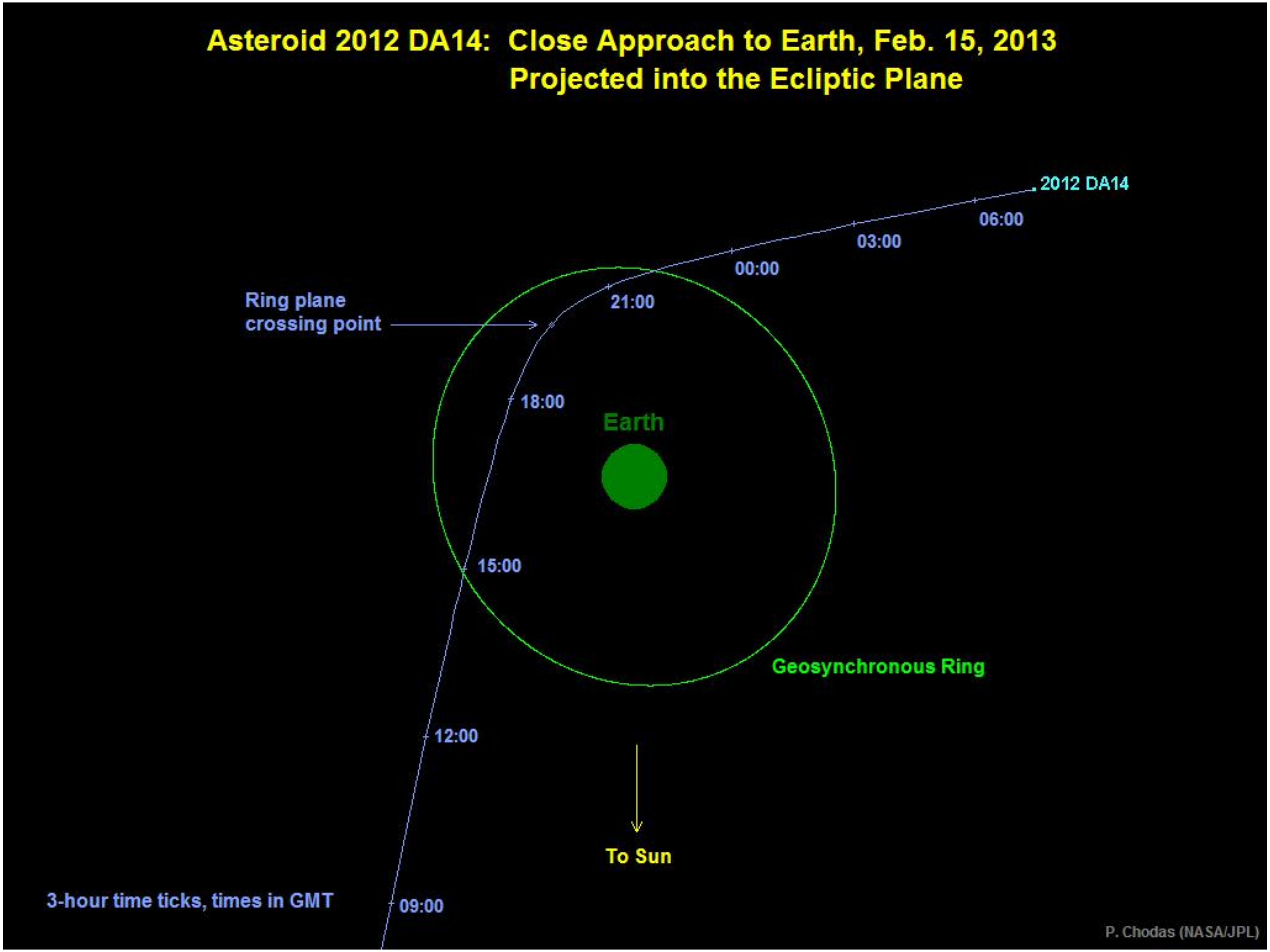
➢ **For updates see NASA Near-Earth object page (http://neo.jpl.nasa.gov)**

2005 YU55 (~360 m)



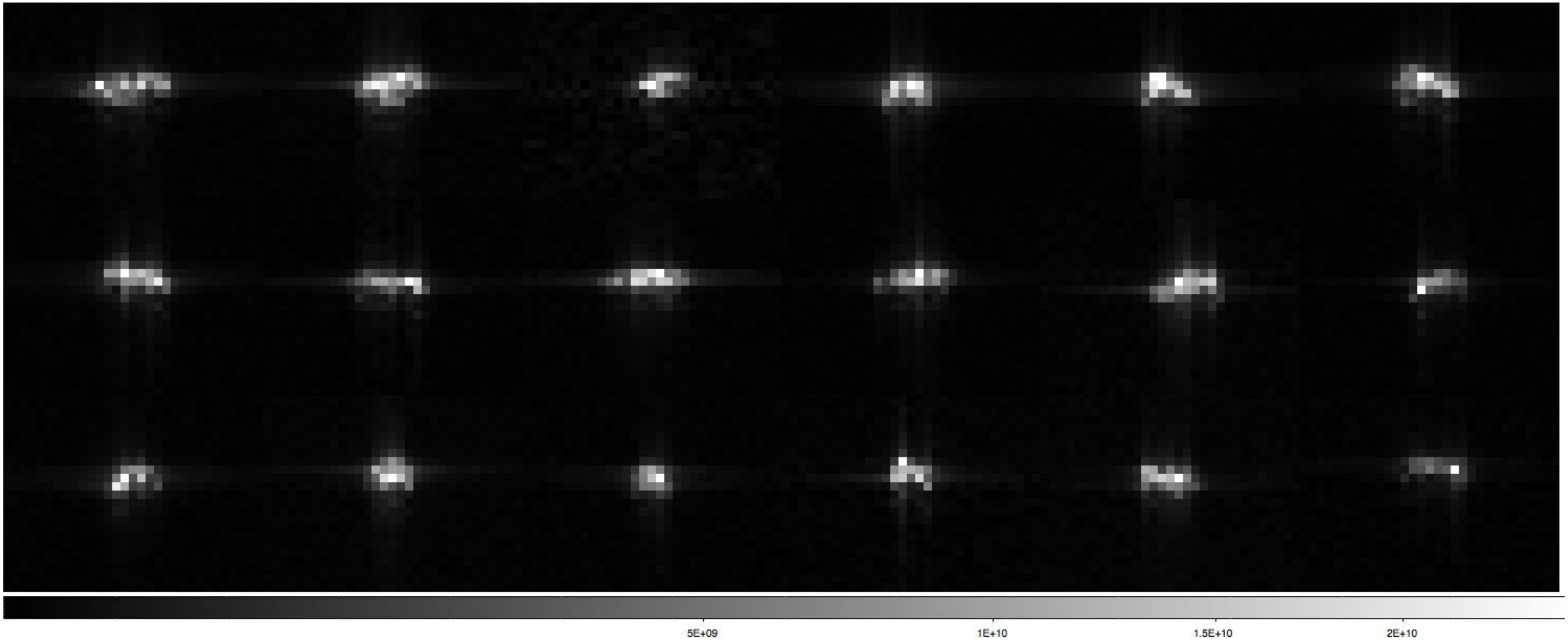
This radar image of asteroid 2005 YU55 was obtained on Nov. 7, 2011 when the space rock was at 3.6 lunar distances, which is about 860,000 miles, or 1.38 million kilometers, from Earth. **Closest approach was ~0.85 lunar distance**.

2012 DA14 (~40 x 20 m)



2012 DA14 (~40 x 20 m)

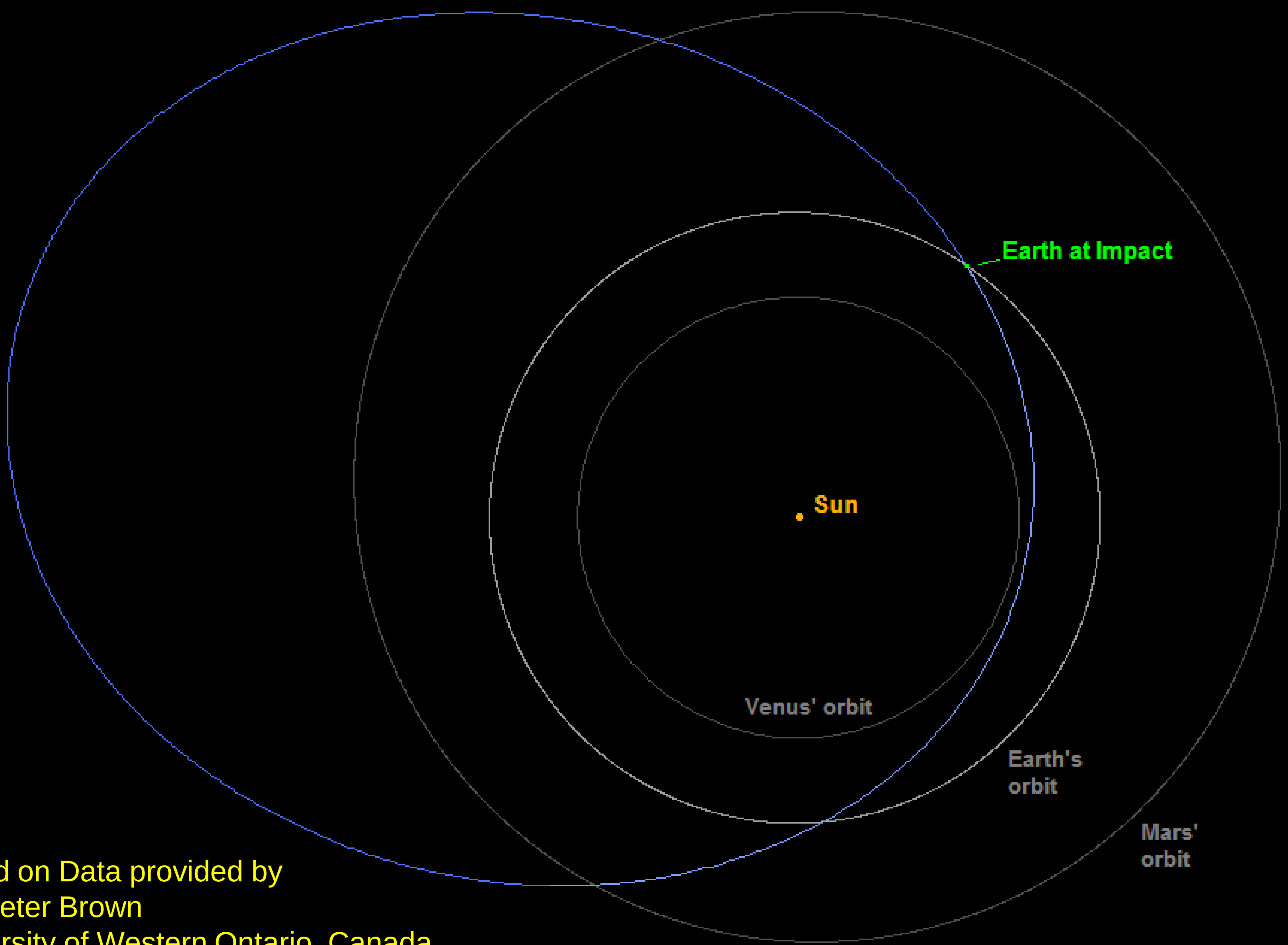
Images of 2012 DA14 spanning nearly 8 hours on Feb. 16. An elongated object is clearly revealed. Based on the changes the aspect ratio for this object is close to 2:1. Preliminary estimates the pole-on dimensions are roughly 40 x 20 meters.



A collage of the 2012 DA14 rotation obtained with a bistatic setup at Goldstone with DSS-14 transmitting and DSS-13 receiving: Feb 16, 00:46 – 08:31 UTC. The round-trip-time to 2012 DSS14 changed from ~0.85 s to ~2 s during observations. Each frame is 320 sec of data integration. One full rotation is about 7 hours.

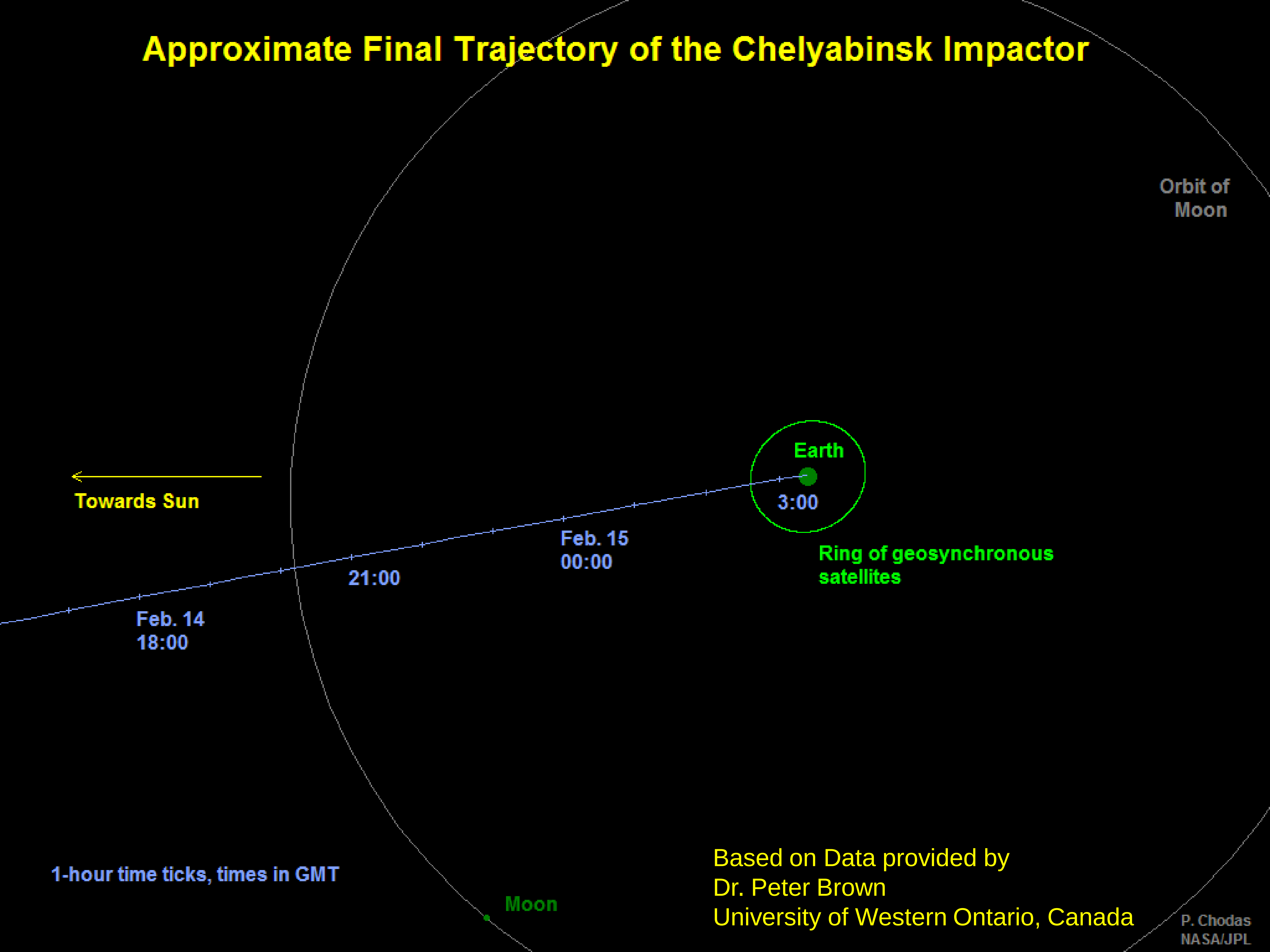
Chelyabinsk Impact Event

Estimated Orbit About the Sun of the Chelyabinsk Impactor

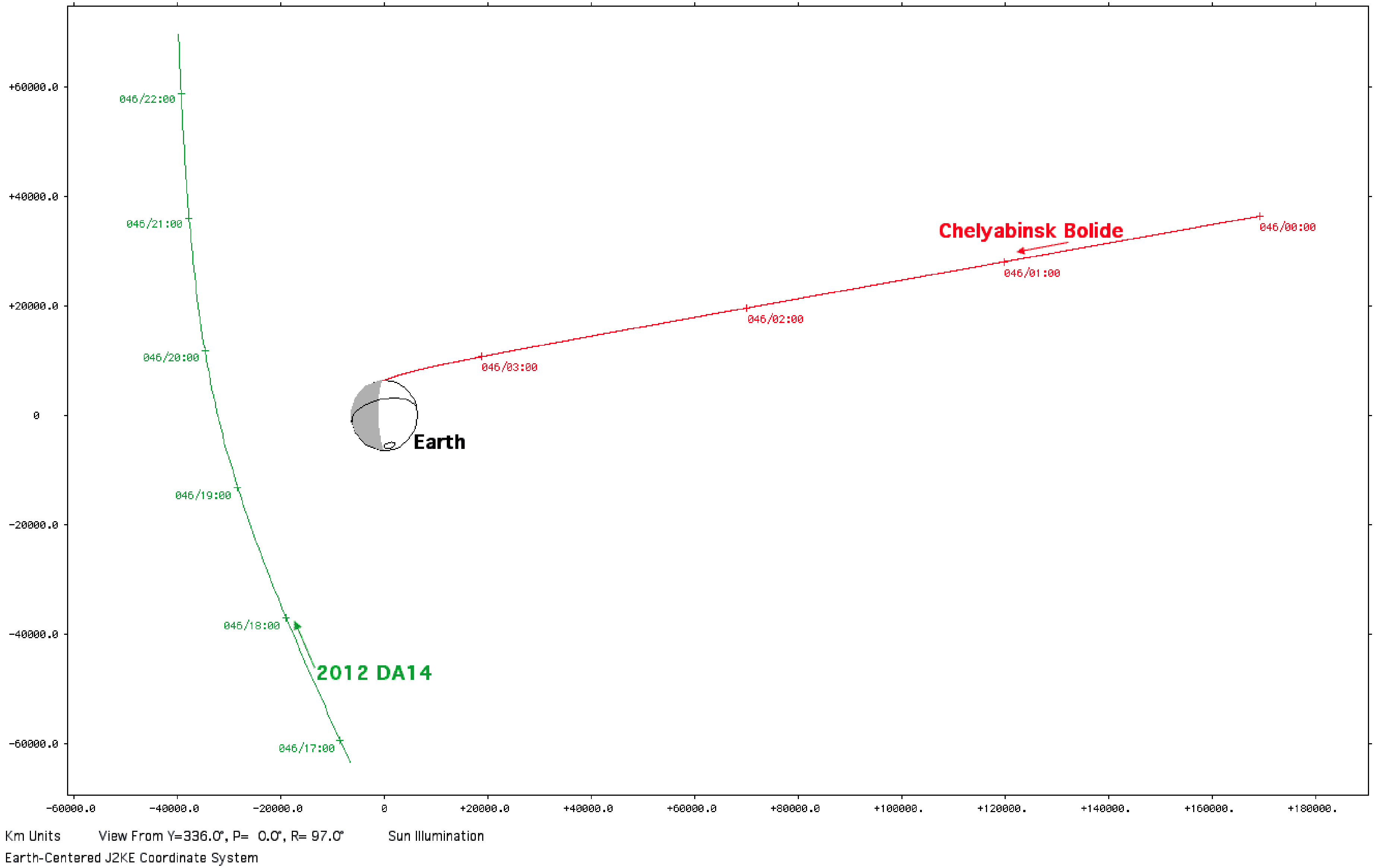


Based on Data provided by
Dr. Peter Brown
University of Western Ontario, Canada

P. Chodas (NASA/JPL)


Approximate Final Trajectory of the Chelyabinsk Impactor
Orbit of Moon
Earth
Towards Sun
3:00
Feb. 15
00:00
Ring of geosynchronous satellites
21:00
Feb. 14
18:00
Based on Data provided by
Dr. Peter Brown
University of Western Ontario, Canada
1-hour time ticks, times in GMT
Moon
P. Chodas
NASA/JPL

Two Unrelated Events

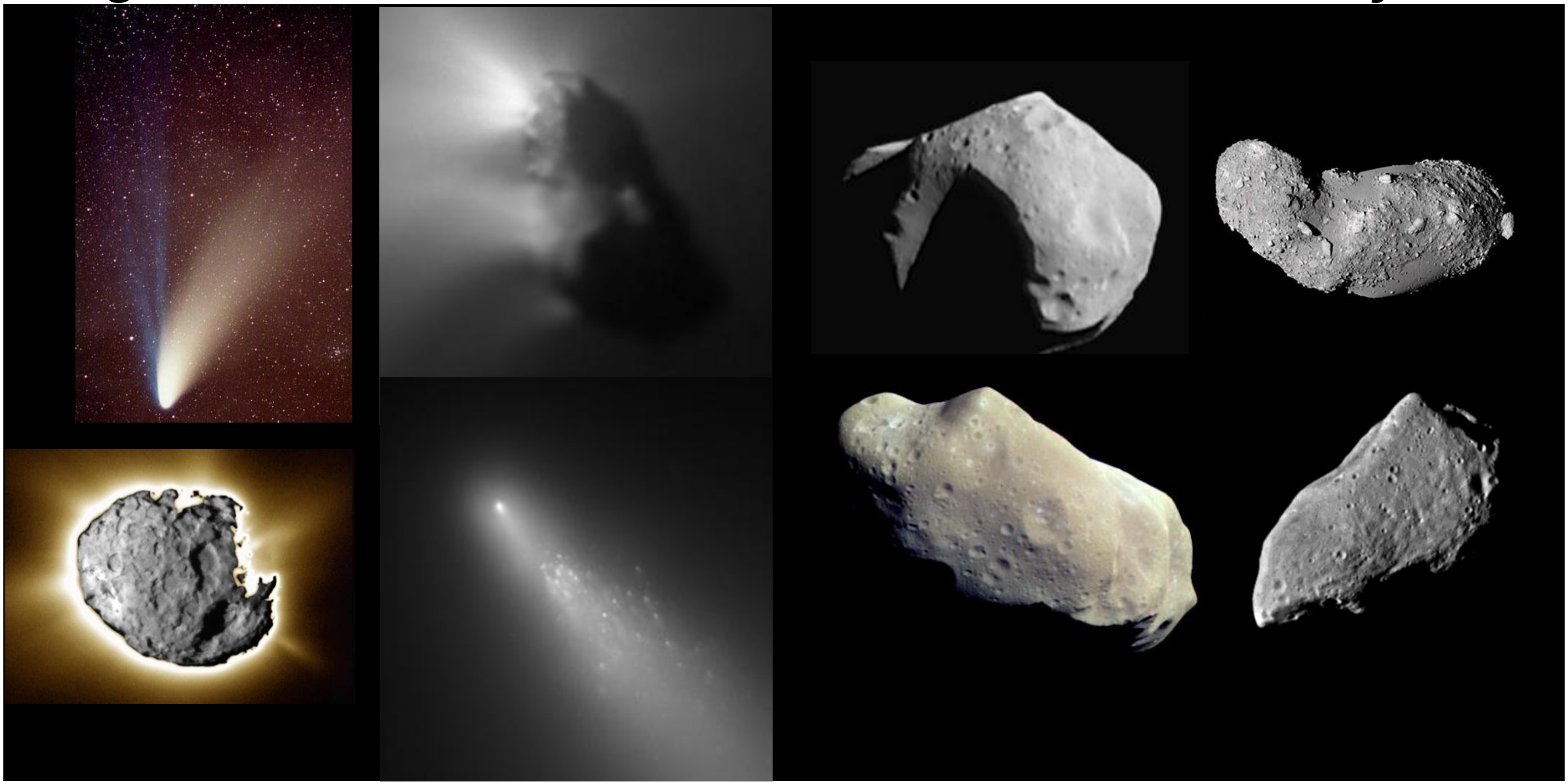


Similar Impact Events in Recent History

- **June 30, 1908 Tunguska, Siberia**
  - Equivalent 3 - 20 megatons of TNT
  - ~50 - 100 meters in diameter
  - Flattened trees over 2150 square km (830 square miles) from an airburst 6–10 km (4–6 miles) above Earth's surface
- **Feb. 15, 2013 Chelyabinsk, Russia**
  - Equivalent ~440 kiloton TNT from infrasound records
  - ~17 – 20 meters in diameter & mass of ~11,000 tonnes
- **Oct. 8, 2009 – Indonesia**
  - Equivalent ~50 kilotons TNT, over the ocean
  - ~6 – 10 meters in diameter
- **Feb. 12, 1947 - Sikhote-Alin, Soviet Union**
  - Equivalent ~10 kilotons TNT
  - Iron impactor -- much of this energy was deposited into the ground rather than at altitude

Comets   Asteroids

fragments left over from the formation of our solar system

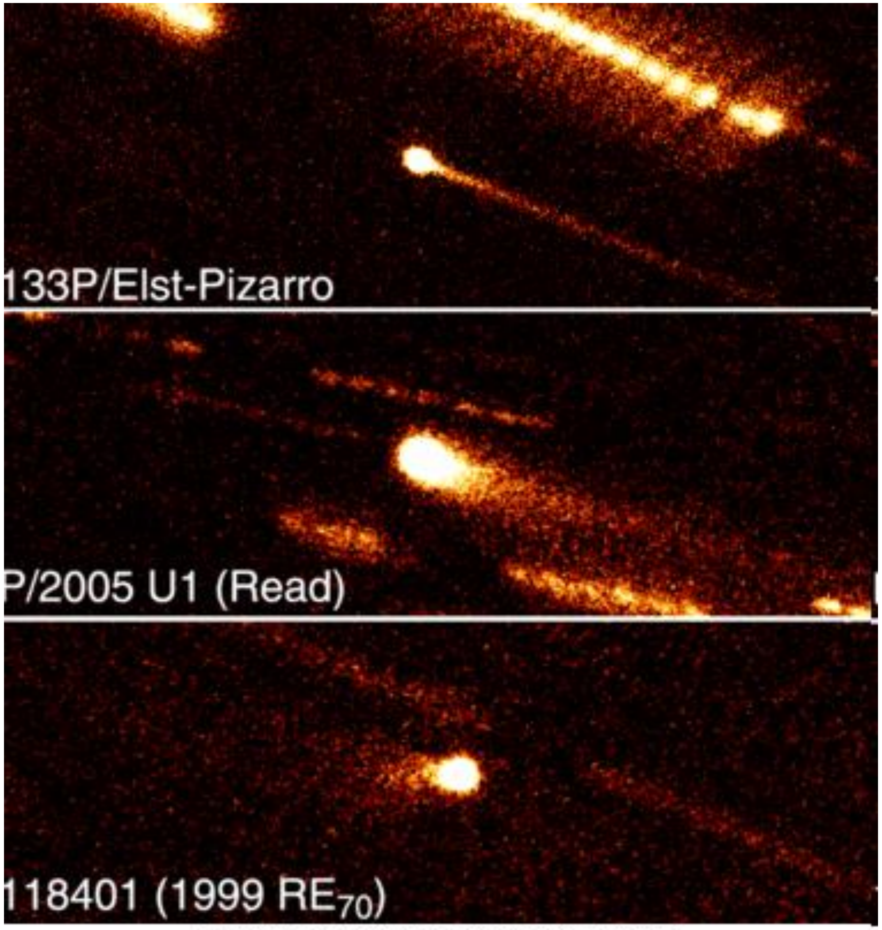


Comets contain volatiles in the form of ices and can produce visible atmospheres (coma)

Asteroids lack active ices and are essentially inert

However sometimes things are not that simple

Examples of dormant comets/active asteroids



(Images taken with the UH 2.2-meter telescope
by H. Hsieh and D. Jewitt, University of Hawaii.)

Small Body Diversity to Scale

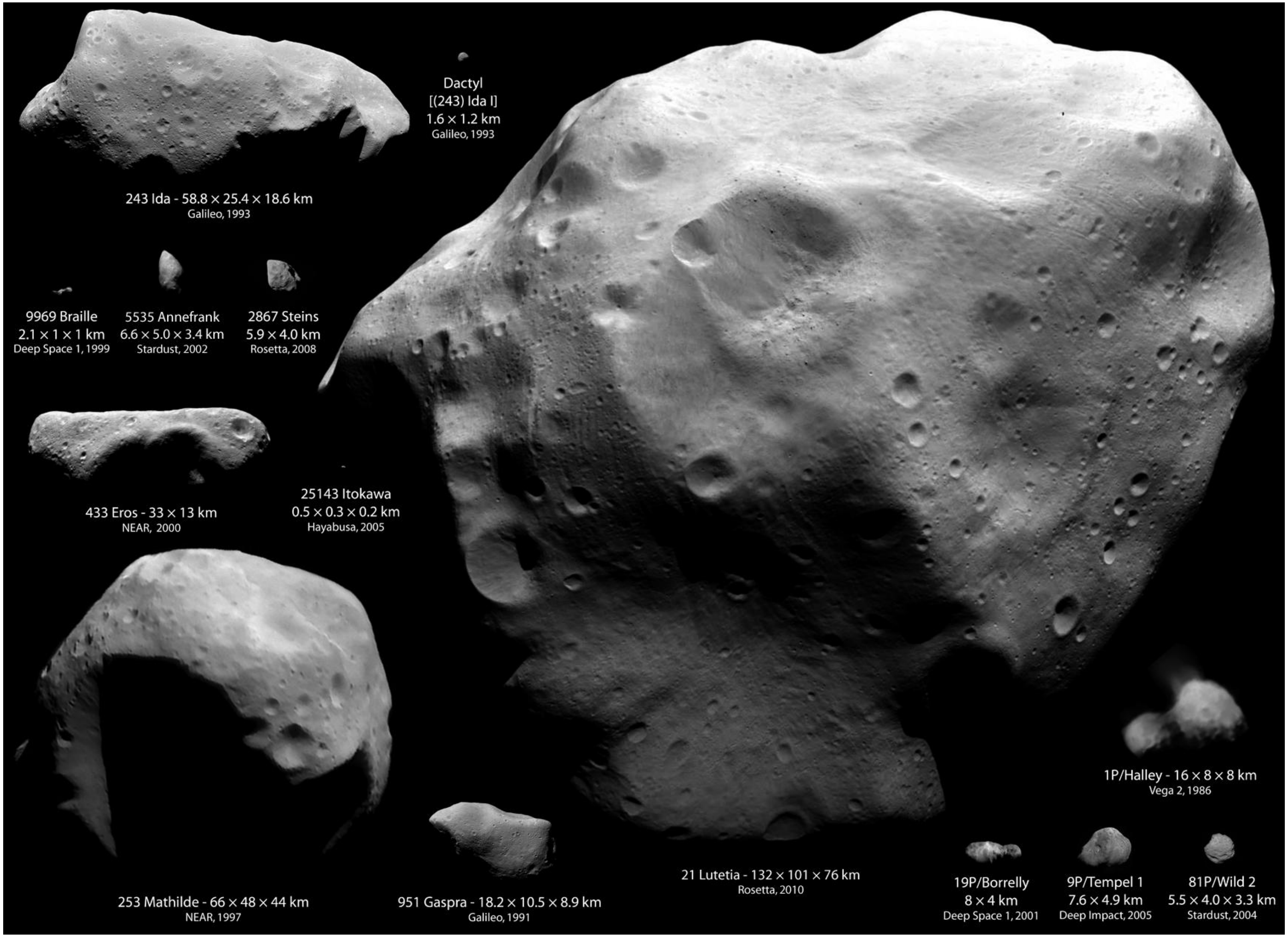


Image courtesy of The Planetary Society

Small Body Diversity to Scale

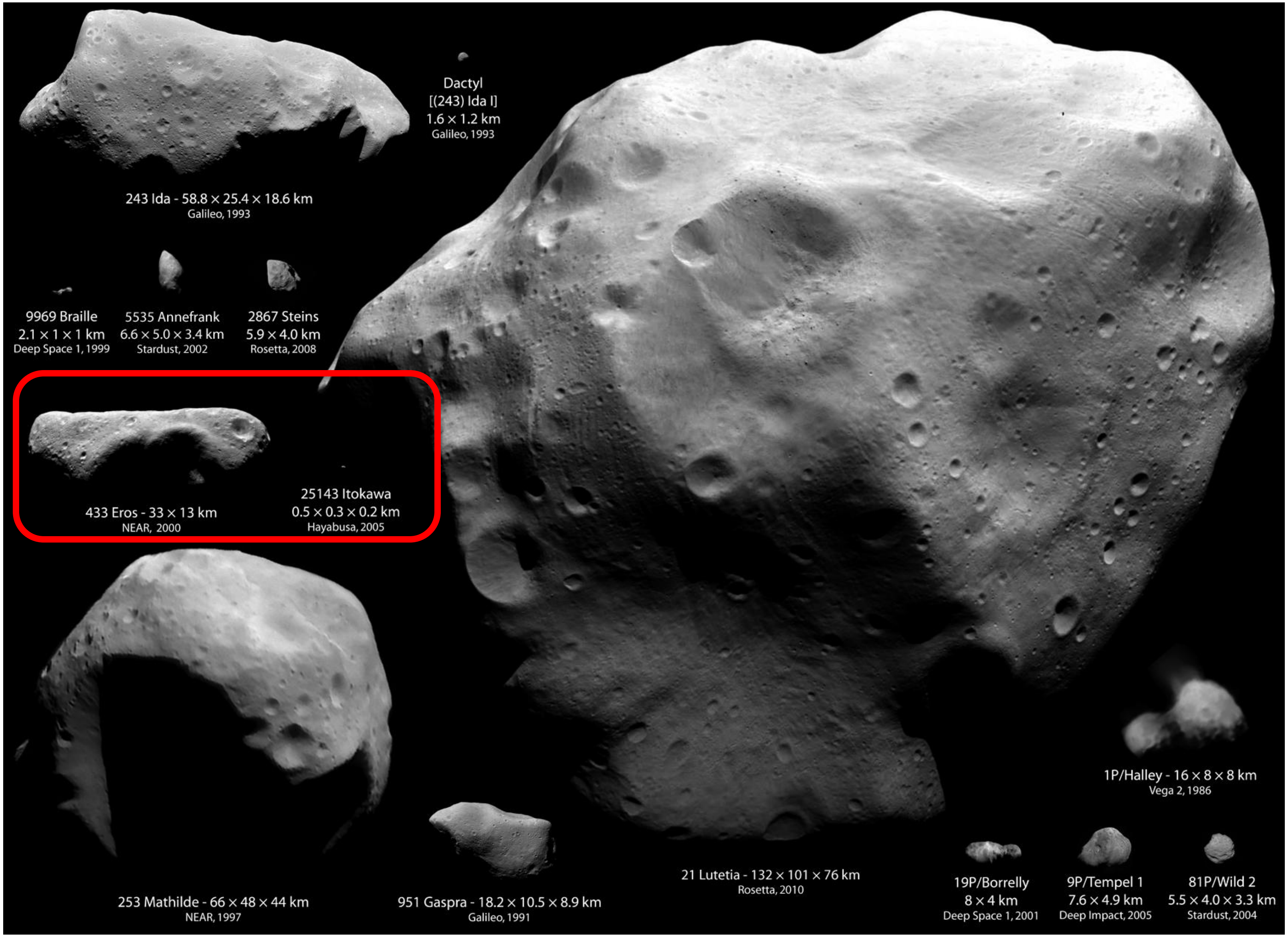


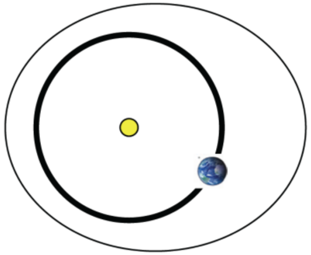
Image courtesy of The Planetary Society

NEO - Terminology

- "Near-Earth Objects (NEOs)"- any small body (comet or asteroid) passing within 1.3 Astronomical Unit (AU) of the Sun
  - 1 AU is the distance from Earth to Sun = ~150 million kilometers (km)
  - NEOs are predicted to pass within ~45 million km of Earth's orbit
  - Any small body passing between orbits of Venus to Mars
  - Dynamically "young" (~10 to 100 million year lifetime) population consisting of:
    - Near-Earth Asteroids (NEAs)
      - 90% originate from the main belt asteroid population
      - 10% are produced from cometary reservoirs (Kuiper Belt and Oort Cloud)
    - Near-Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      - 94 currently known
- "Potentially Hazardous Objects (PHOs)" – small body that has potential risk of impacting the Earth at some point in the future
  - NEOs passing within 0.05 AU of Earth's orbit
    - ~8 million km = ~20 times the distance to the Moon
  - ~20% of all NEOs discovered appear to be PHOs

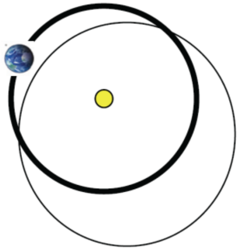
NEO – Orbital Classifications

- **Amors**
  Earth-approaching NEAs with orbits exterior to Earth's but interior to Mars'
  (named after asteroid 1221 Amor)



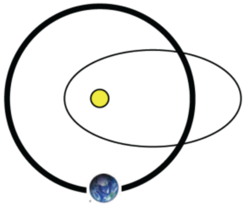
a > 1.0 AU
1.017 AU < q < 1.3 AU

- **Apollos**
  Earth-crossing NEAs with semi-major axes larger than Earth's
  (named after asteroid 1862 Apollo)



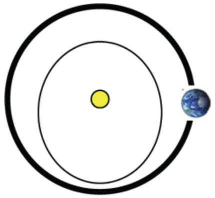
a > 1.0 AU
q < 1.017 AU

- **Atens**
  Earth-crossing NEAs with semi-major axes smaller than Earth's
  (named after asteroid 2062 Aten)



a < 1.0 AU
Q > 0.983 AU

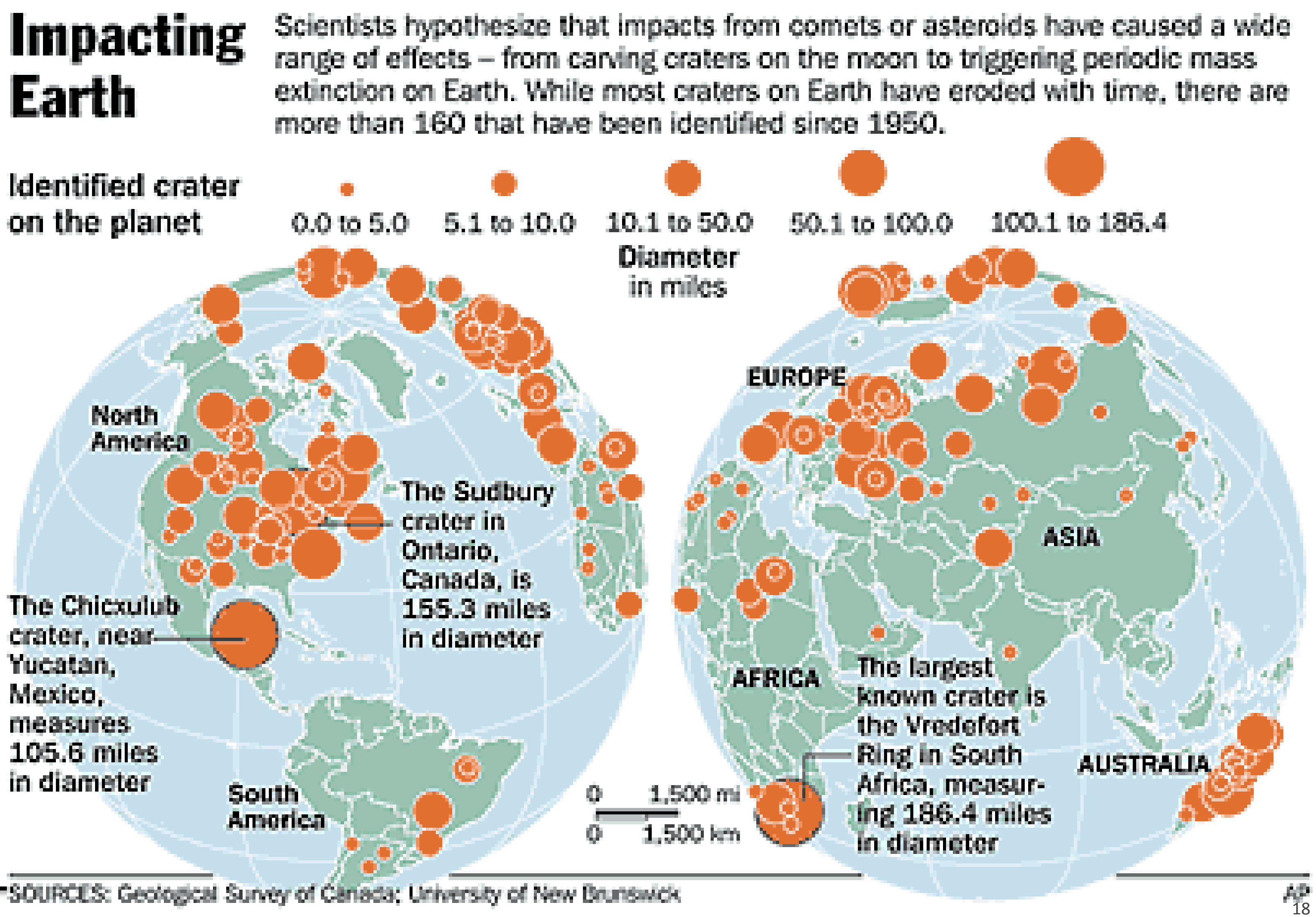
- **Atiras**
  NEAs whose orbits are contained entirely with the orbit of the Earth
  (named after asteroid 163693 Atira)



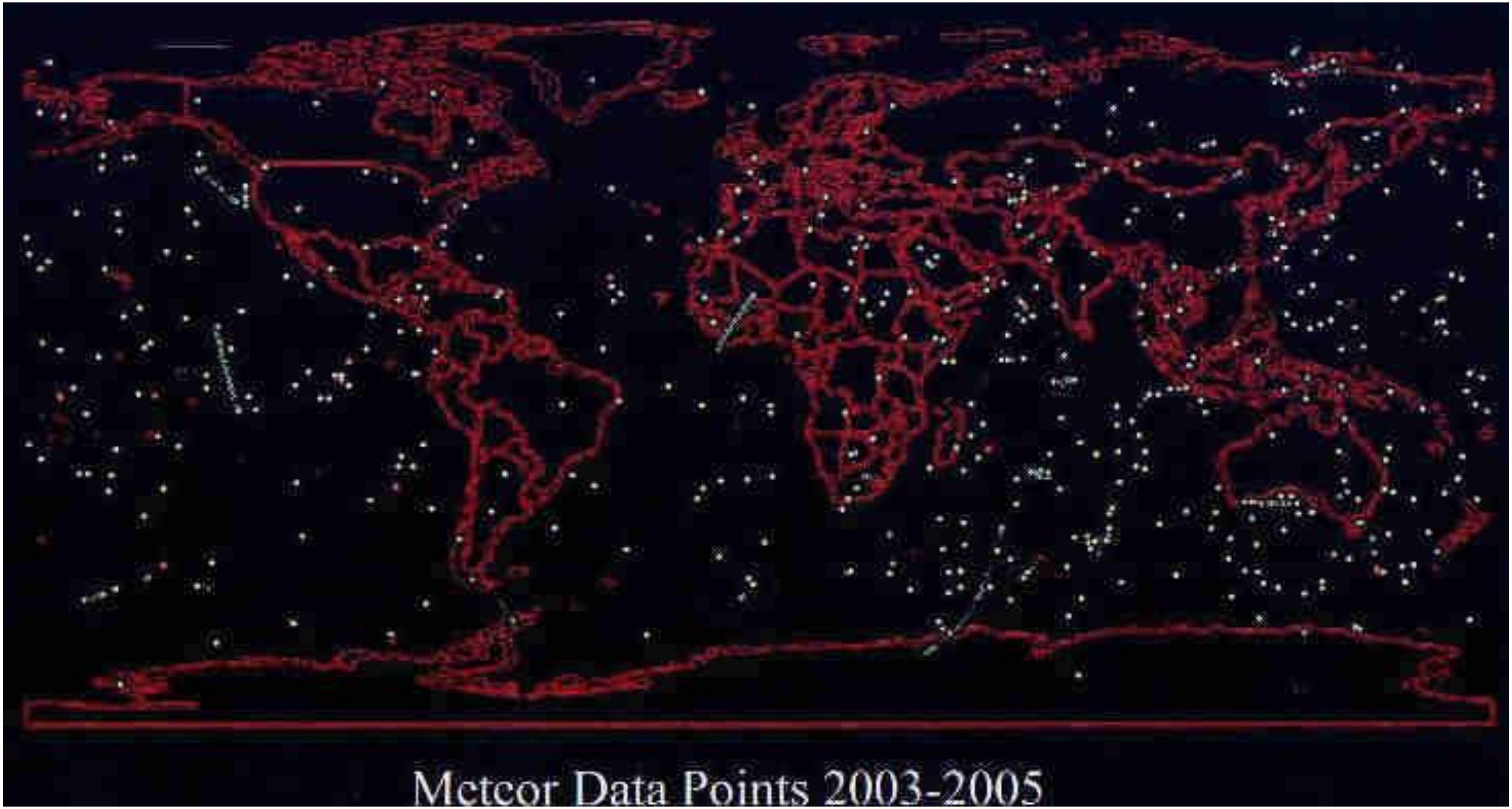
a < 1.0 AU
Q < 0.983 AU

(q = perihelion distance, Q = aphelion distance, and a = semi-major axis)

Earth's Cratered Past

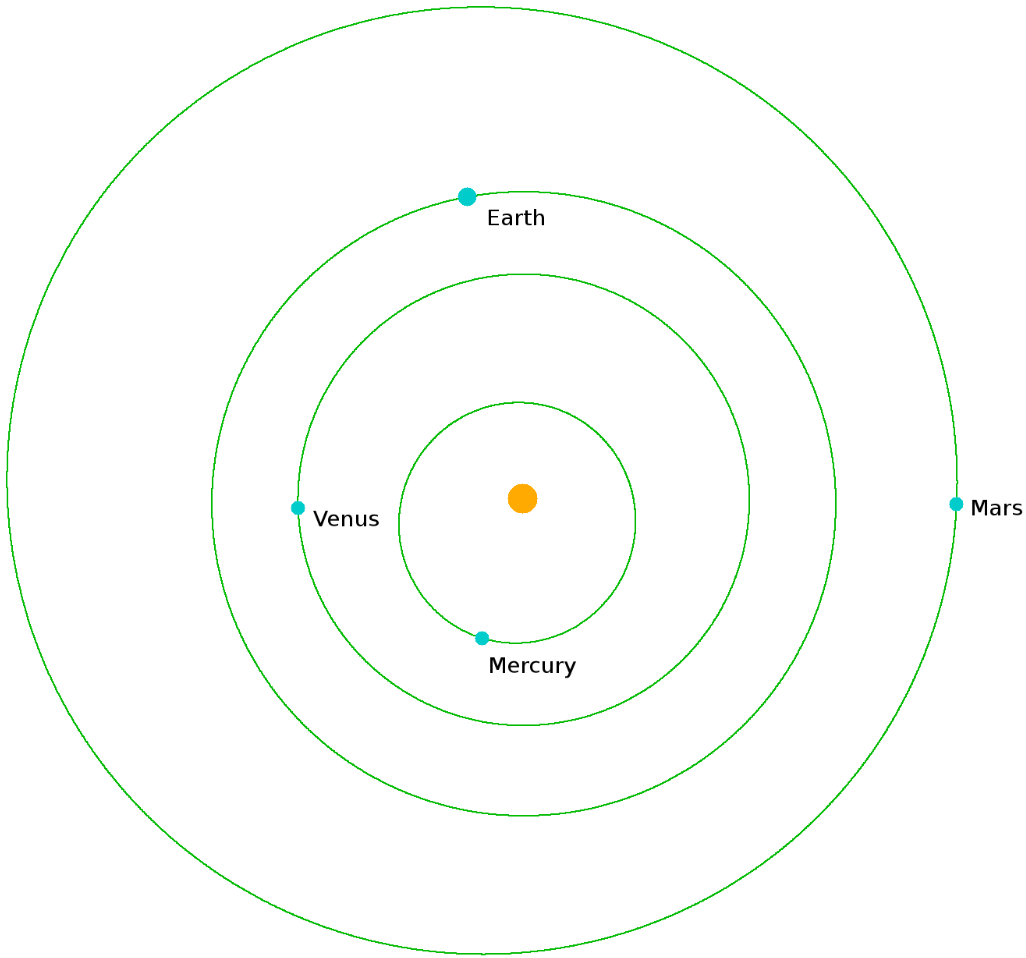


Small NEO Impacts to Earth (2003-2005)



U.S. early warning satellites detect flashes **in the upper atmosphere** that are **energy releases comparable to small nuclear detonations. We see about 30 such bursts per year** caused by the impacts of small asteroids probably about a few meters in diameter on the earth's atmosphere.

Discovery Rate of NEO Population

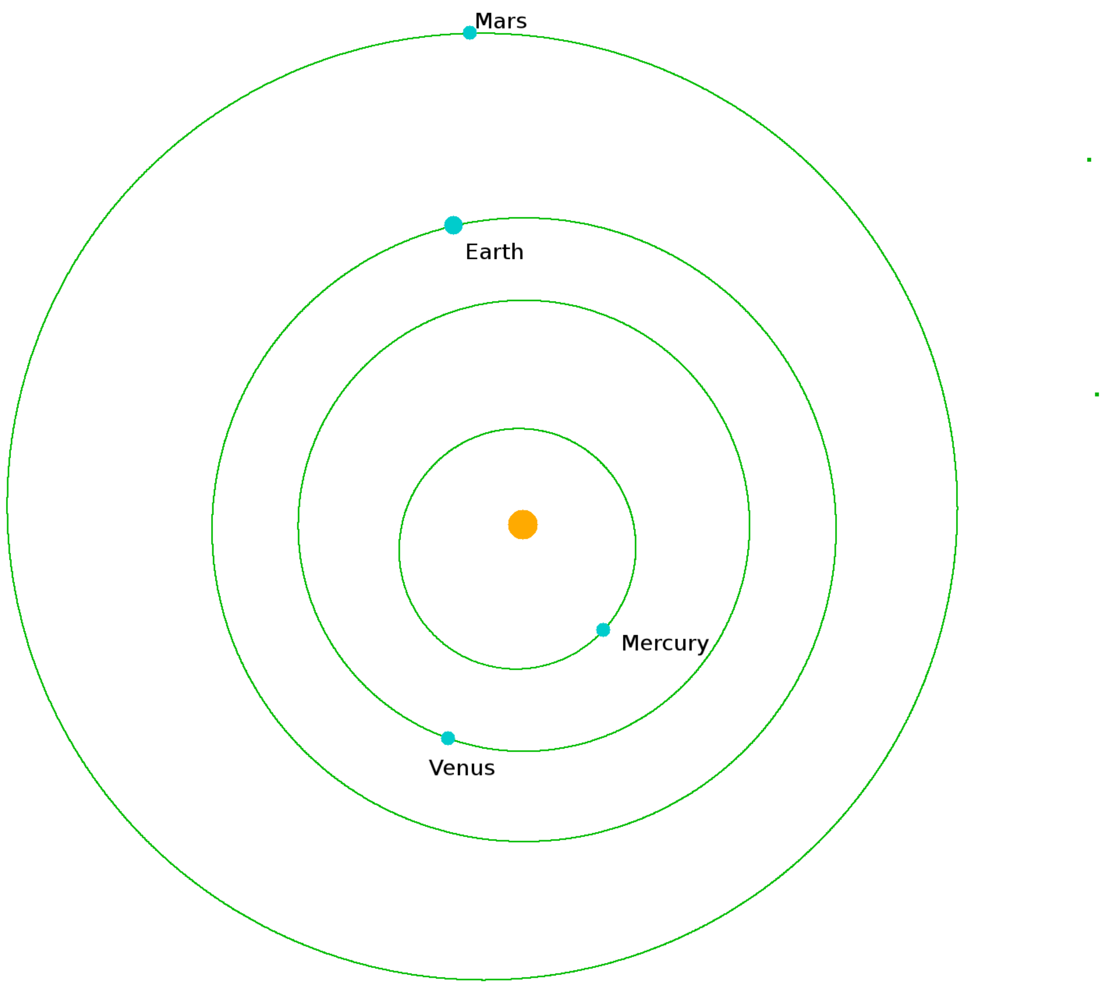


1800

no known asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population



1850

10 asteroids known and named

Legend:

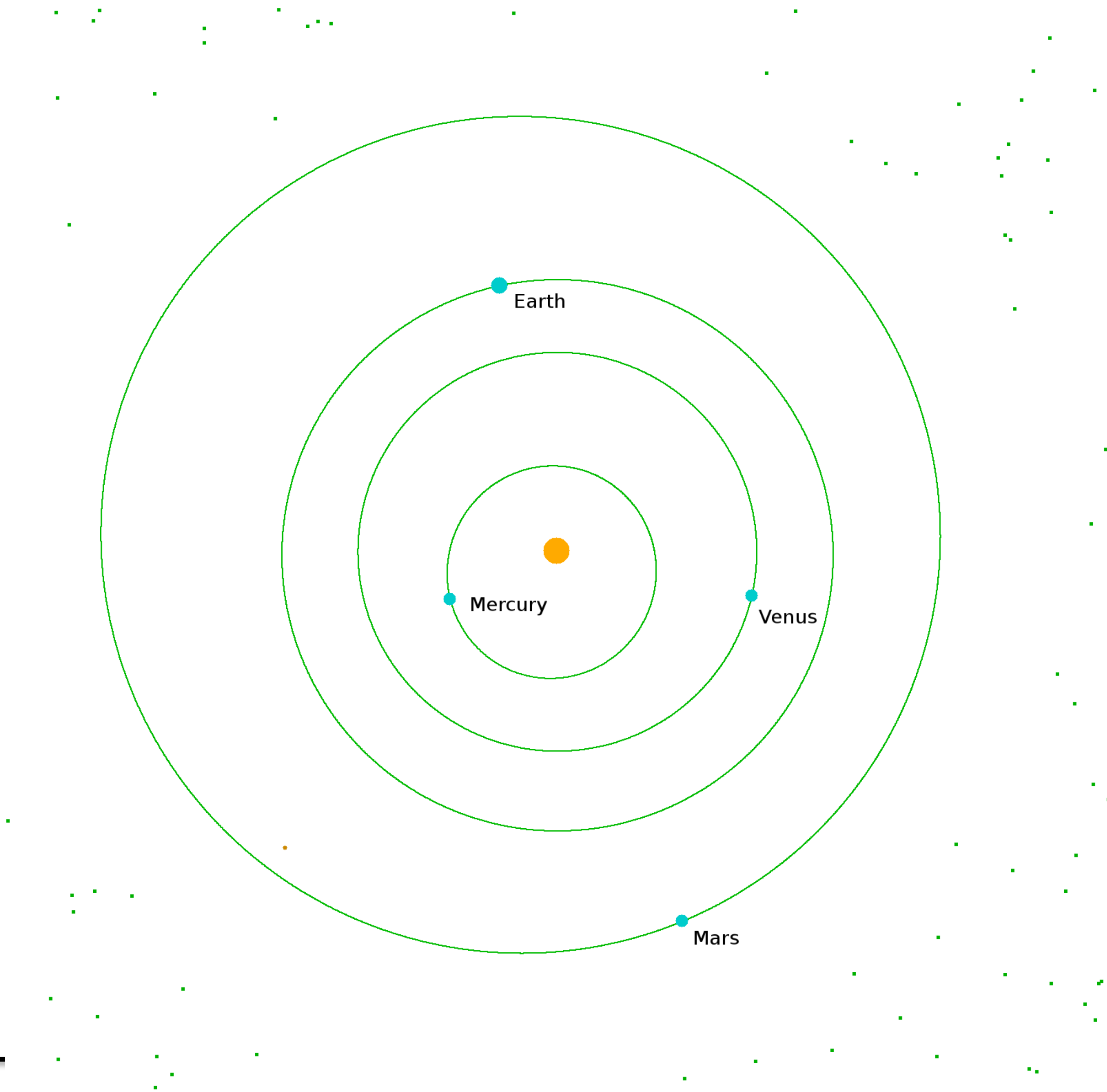
- Green dots represent objects which do not approach the Earth at present *e.g.* Main Belt asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population

1900

hundreds of known objects in the main belt, some even inside the orbit of Mars

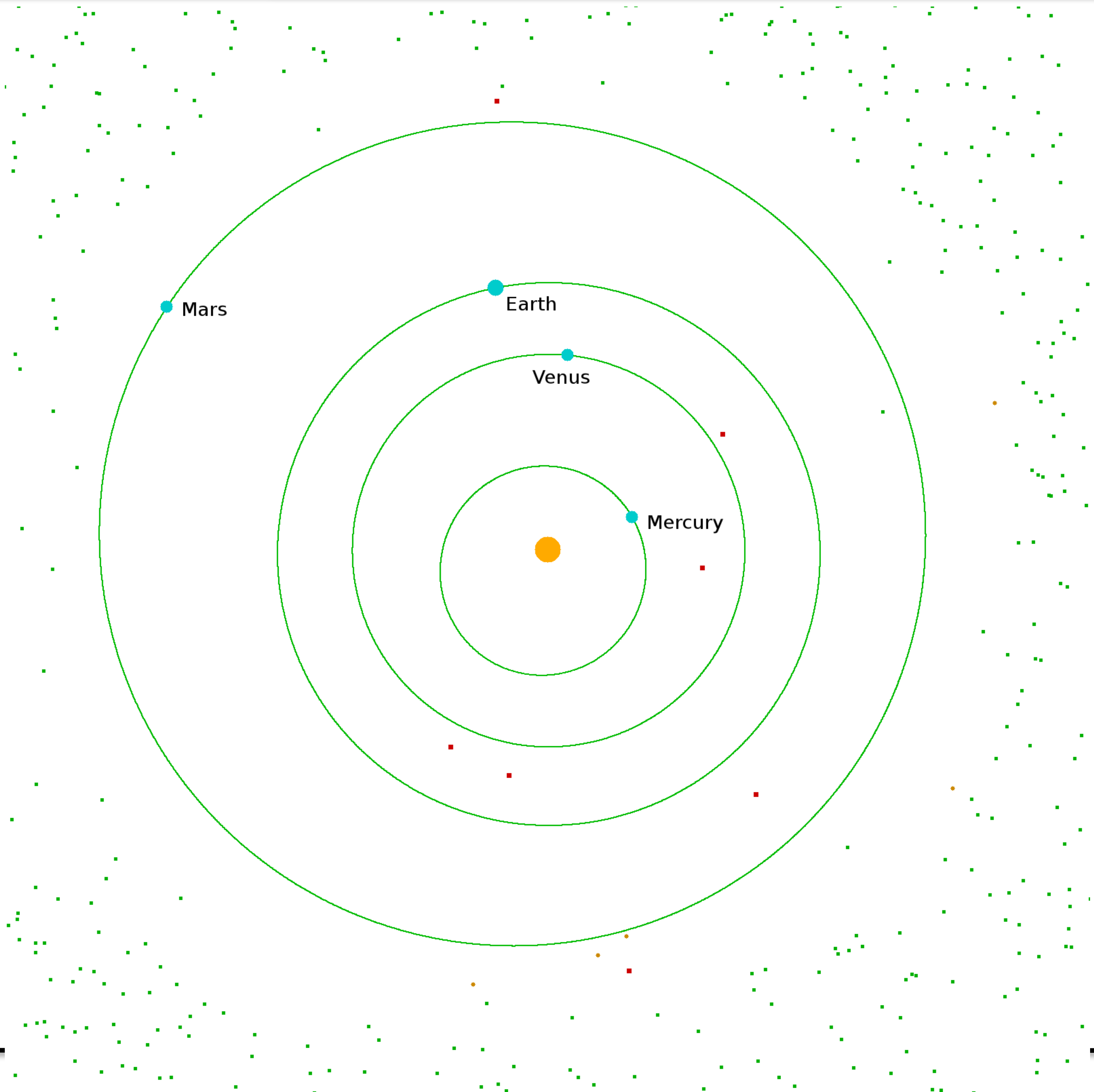


Legend:

- Green dots represent objects which do not approach the Earth at present *e.g.* Main Belt asteroids
- Yellow dots represent objects which approach the Earth but do not cross its orbit *e.g.* Amor asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population



1950

almost 2000 known objects with a handful of Earth crossing

Legend:

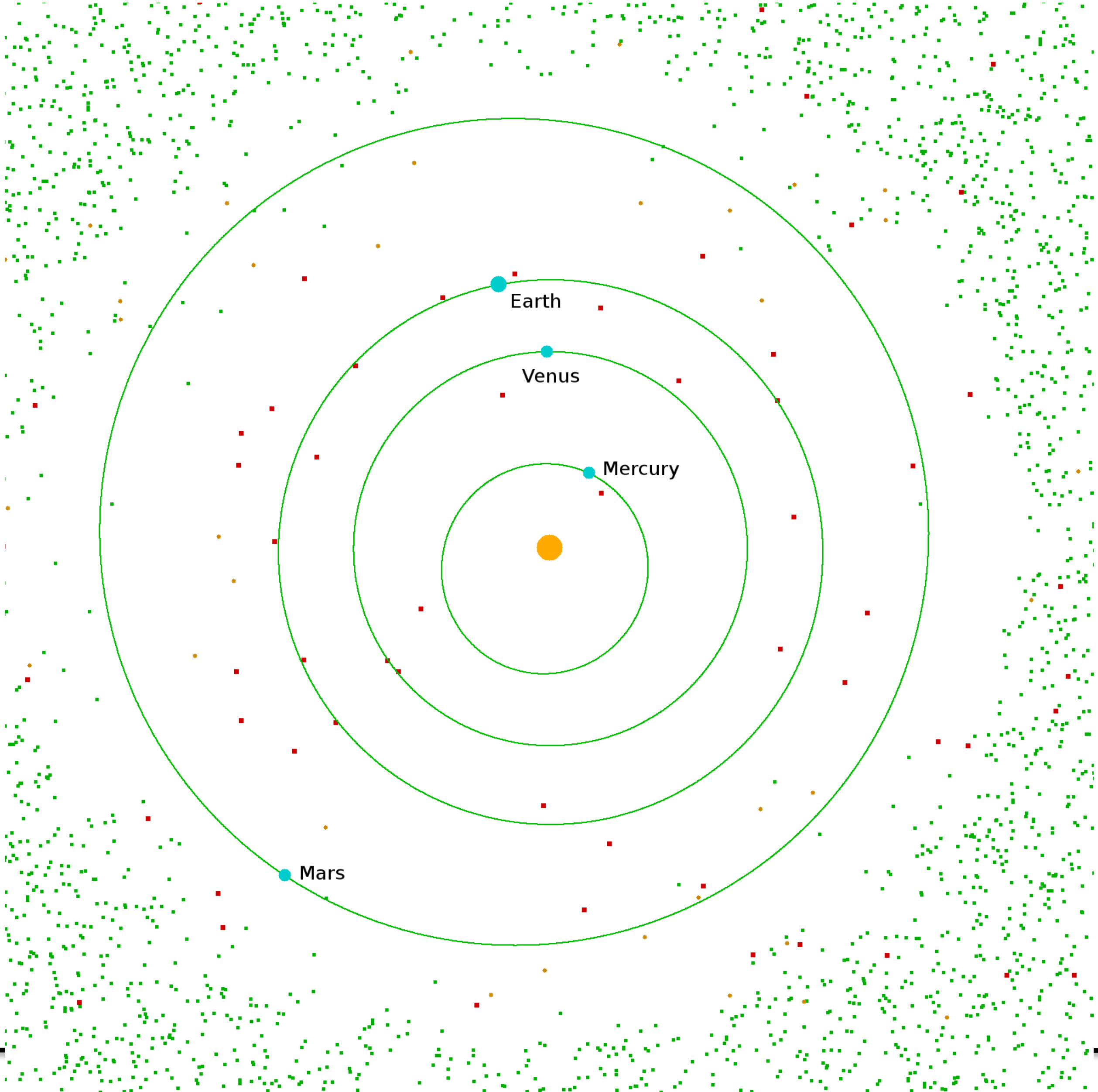
•Green dots represent objects which do not approach the Earth at present *e.g.* Main Belt asteroids

•Yellow dots represent objects which approach the Earth but do not cross its orbit *e.g.* Amor asteroids

•Red dots represent objects which cross the Earth's orbit *e.g.* Aten and Apollo asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population



1990

over 9,000 known objects

Legend:

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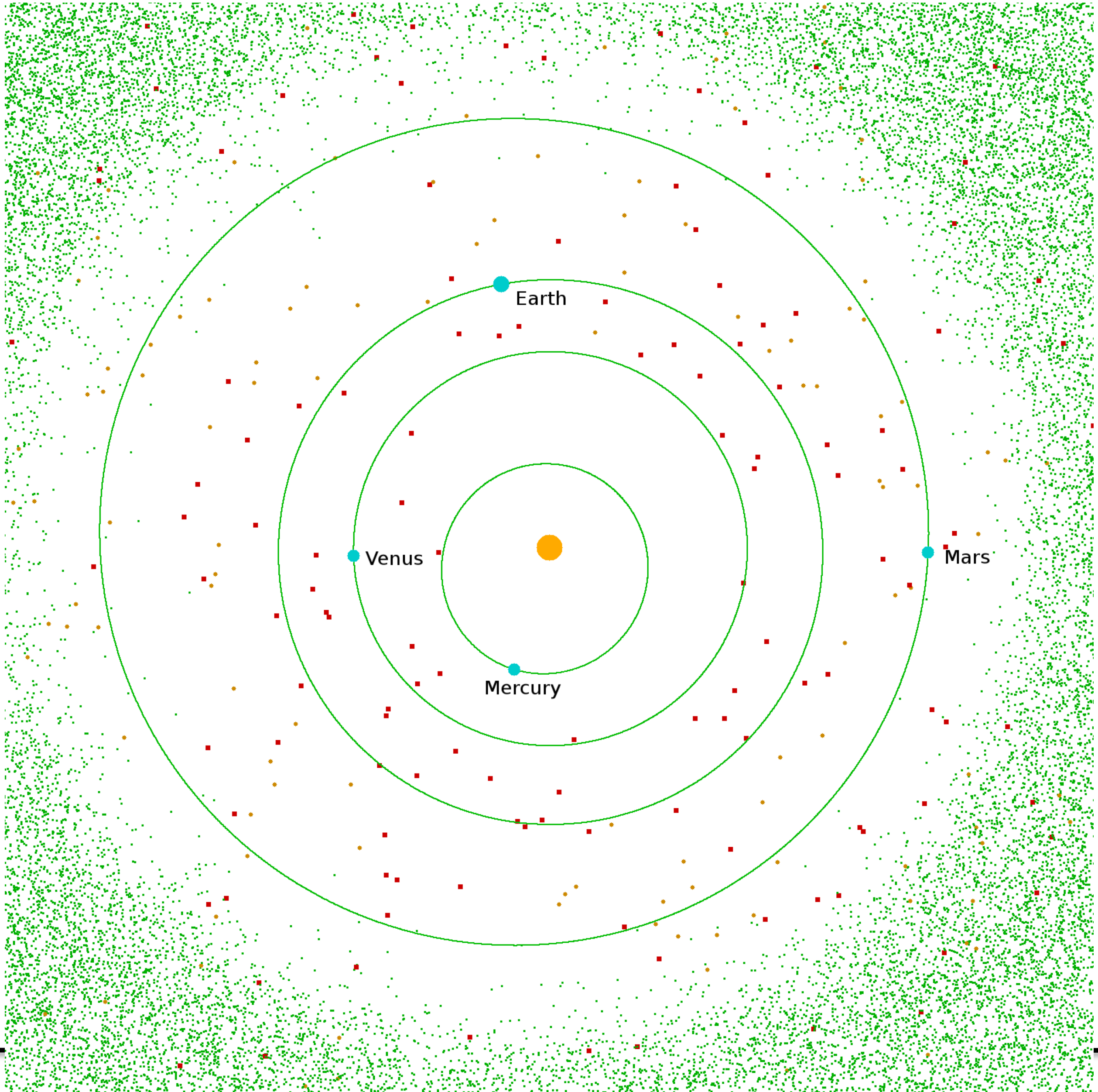
- Red dots represent objects which cross the Earth's orbit *e.g.* Aten and Apollo asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population



2000

automated search brings the total to 86,374

Legend:

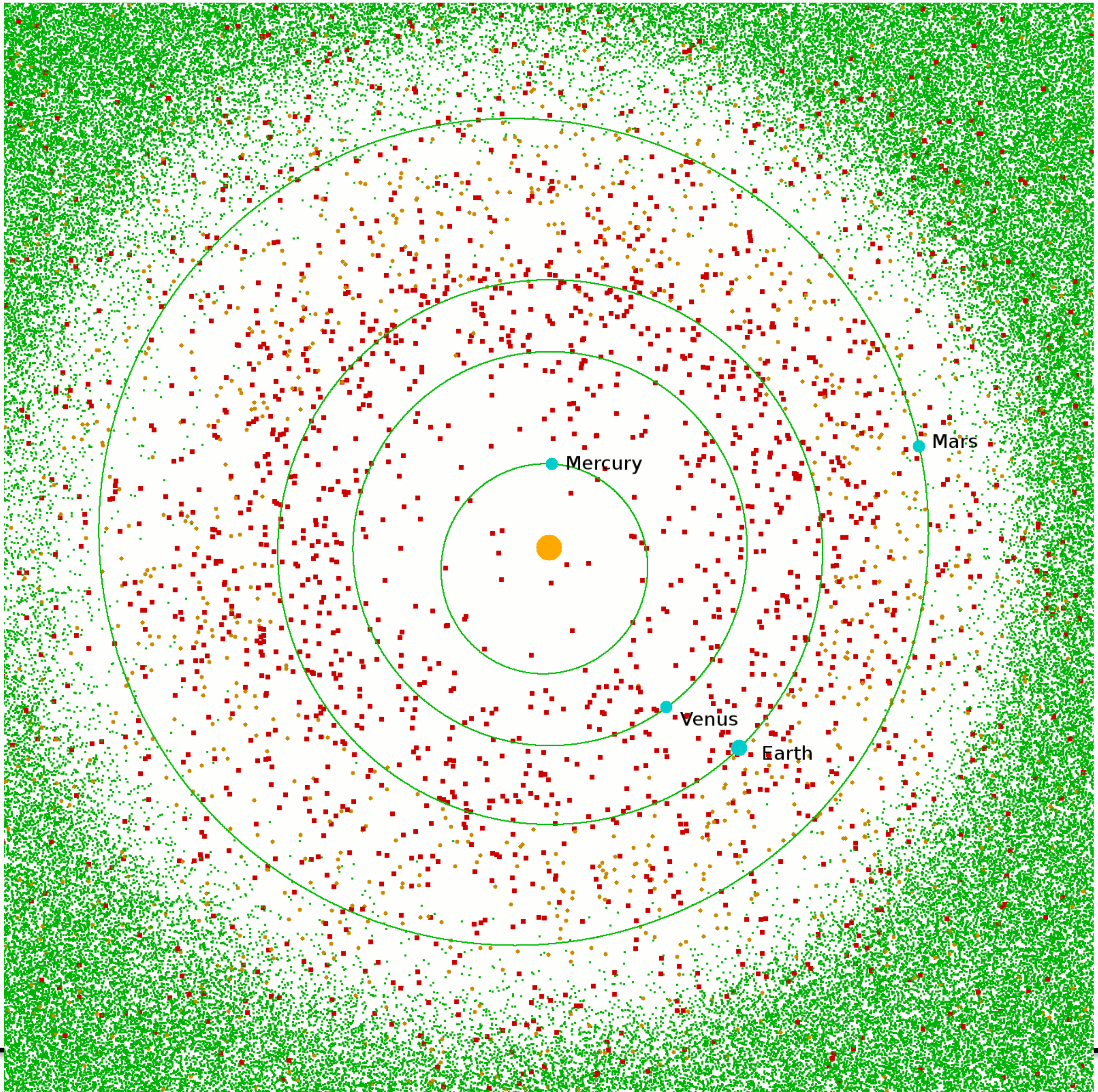
•Green dots represent objects which do not approach the Earth at present *e.g.* Main Belt asteroids

•Yellow dots represent objects which approach the Earth but do not cross its orbit *e.g.* Amor asteroids

•Red dots represent objects which cross the Earth's orbit *e.g.* Aten and Apollo asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population



2007 August

379,084 known objects ranging from a few meters up to the dwarf planet Ceres

Legend:

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•Red dots represent objects which cross the Earth's orbit *e.g.* Aten and Apollo asteroids

Images from Armagh Observatory

Discovery Rate of NEO Population

Legend:

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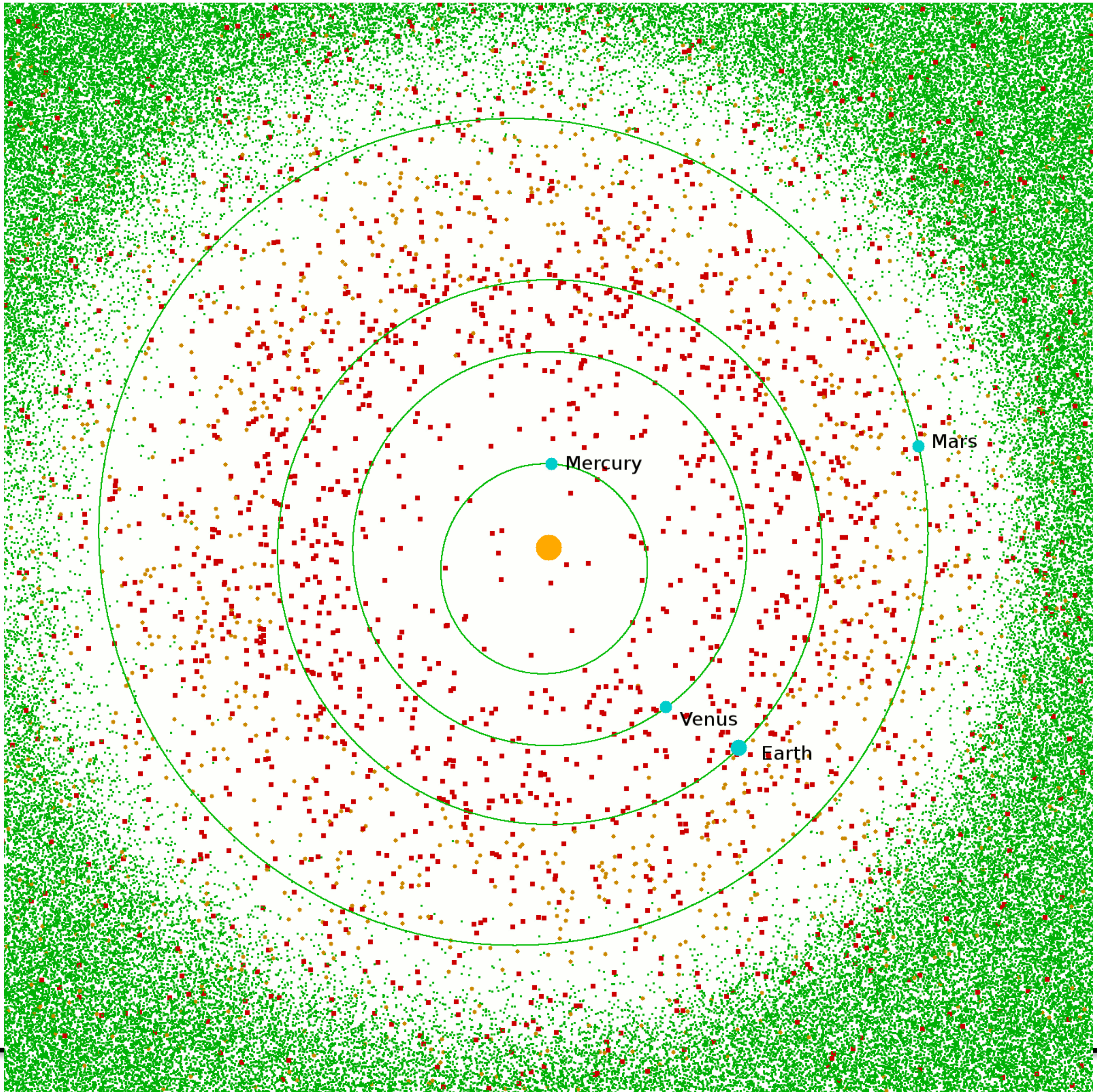


From IAU Minor Planet Center

July 24, 2013

>620,000 objects

10052 NEOs

(776 Atens, 5423 Apollos)

1414 PHAs

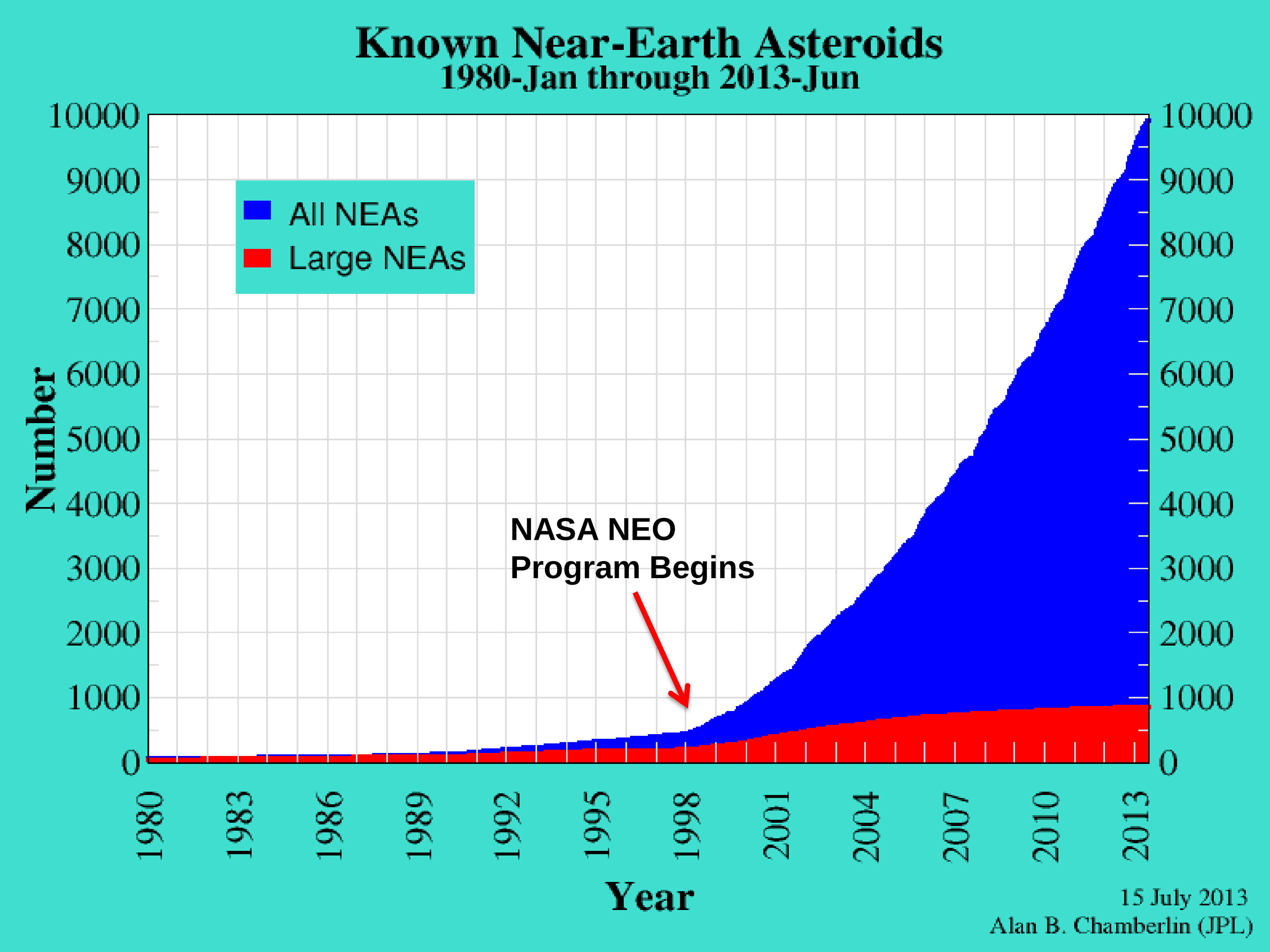
NEO Population

20,000+ NEOs diameters ≥ 140 m

300,000+ NEOs diameters ≥ 50 m

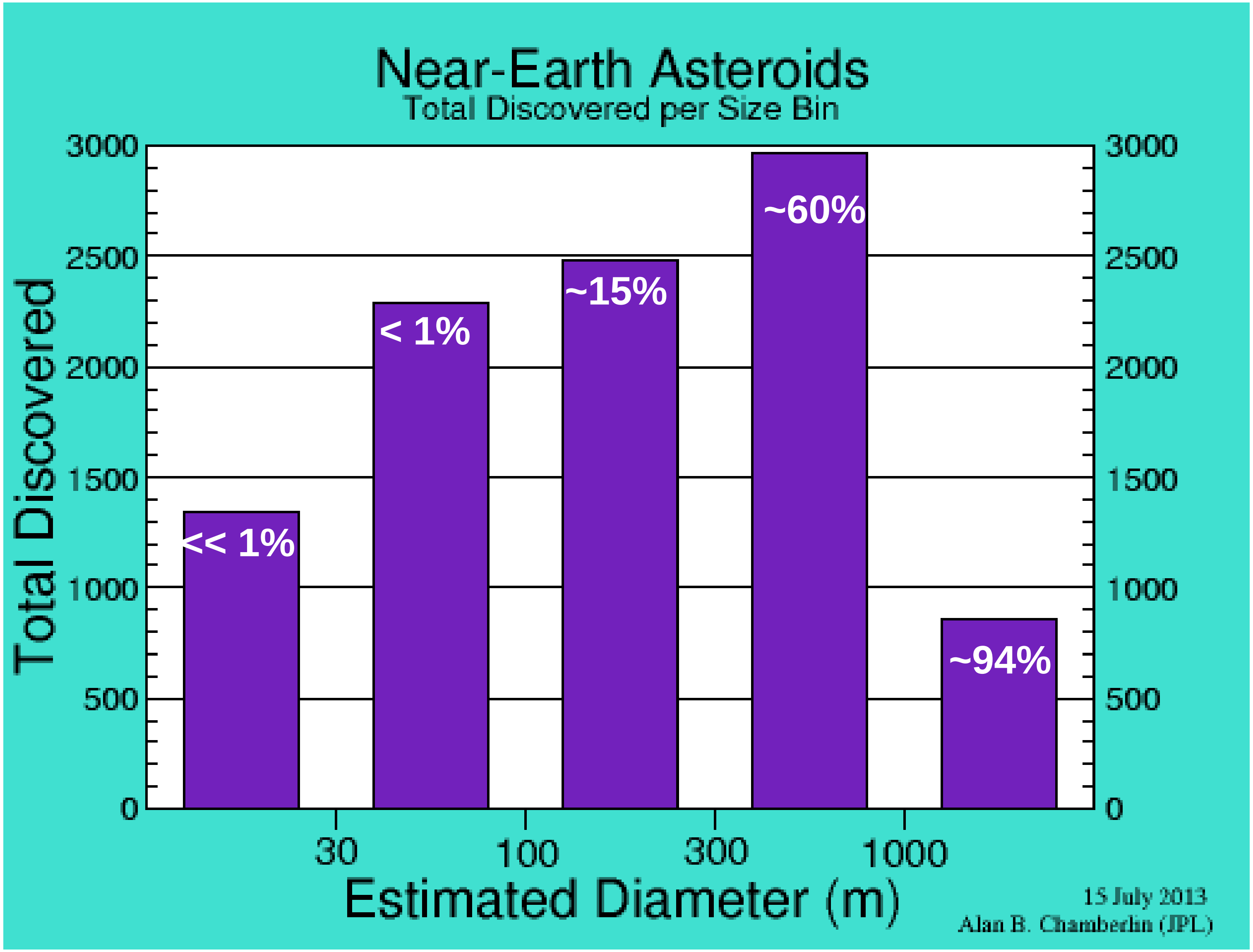
Millions of NEOs diameters ≥ 15 m

Images from Armagh Observatory



Known Near-Earth Asteroids
1980-Jan through 2013-Jun
Number
Year
All NEAs
Large NEAs
NASA NEO
Program Begins
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
15 July 2013
Alan B. Chamberlin (JPL)

Known Near-Earth Asteroids vs. Size with Percent of Estimated Completeness



Data on NEOs and other Small Bodies

- **What we know about asteroids and comets comes from several sources, which all support each other:**
  - **Meteorites and Dust Particles**
    - Biased by what reaches us dynamically and what can get through our atmosphere
  - **Telescope Optical & Radar observations**
    - Biased in terms of brightness (size, distance, and albedo)
    - ~ 94% of all NEOs larger than 1 km are known
    - However, only < 1% percent down to 50 m have been detected
  - **Theory and Modeling**
    - Binary formation and crater studies inform theories on NEO internal structures
  - **Spacecraft Missions**
    - Such as NEAR Shoemaker and Hayabusa

Compositional Diversity of Asteroids

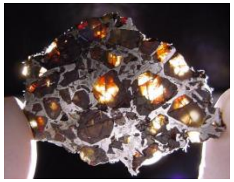
- **Asteroids represent a diverse group - these objects are the remnants of our early Solar System (some are water rich - up to 20% by weight)**

- **Asteroids have been divided into many taxonomic classes**
  - Color, albedo, and major spectral features
  - <u>**Many classes and variations within classes**</u>: A-G, I, K, M, P-V, X (100+ parent bodies)

- **C-types (carbonaceous)**
  - Blue colors, flat/feature spectra similar to carbonaceous chondrite meteorites
  - Lower albedos (0.03 – 0.09)

- **S-types (silicate-rich)**
  - Reddish colors and spectra similar to stony-iron meteorites and consist mainly of iron- and magnesium-silicates
  - Higher albedos (0.10 – 0.35)

- **Many Others**
  - Basaltic (lava rock), Iron-nickel (like the iron-nickel meteorites), Enstatite (iron-free silicates), mixtures of ice-rock, rock-metal compositions, *etc*.
  - Wide range of albedos (0.02 – 0.55)



Internal Structure of Asteroids

- **There are 3 basic kinds of internal structures for asteroids**

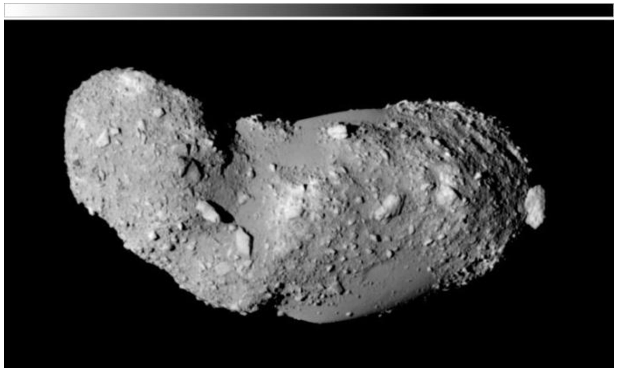
- **Intact Monolith**
  - A solid body
  - Has low porosity
  - It may have some impact craters
  - A good example is 6489 Golevka

2867 Steins

6489 Golevka

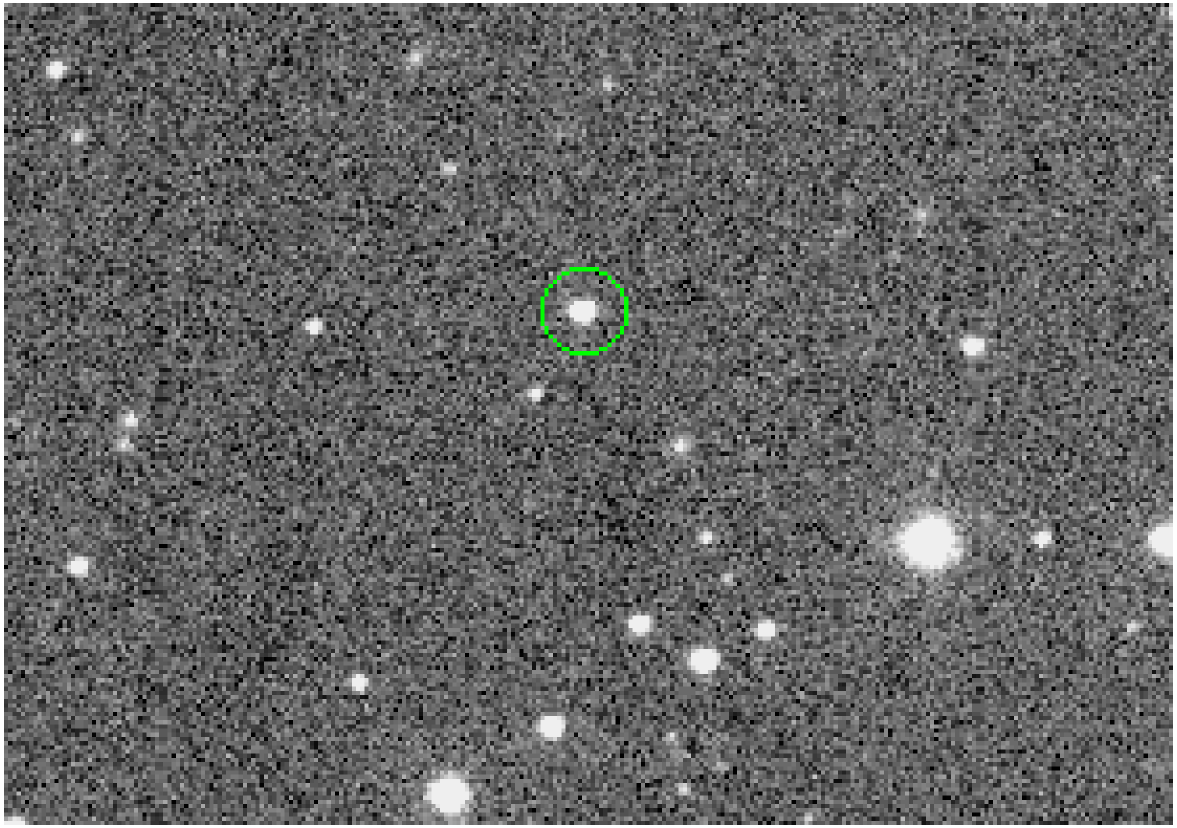
- **Coherent, but heavily fractured**
  - Mostly intact coherent body
  - Has some degree of porosity
  - Usually have large and extensive fractures
  - A good example is 2867 Steins

25143 Itokawa

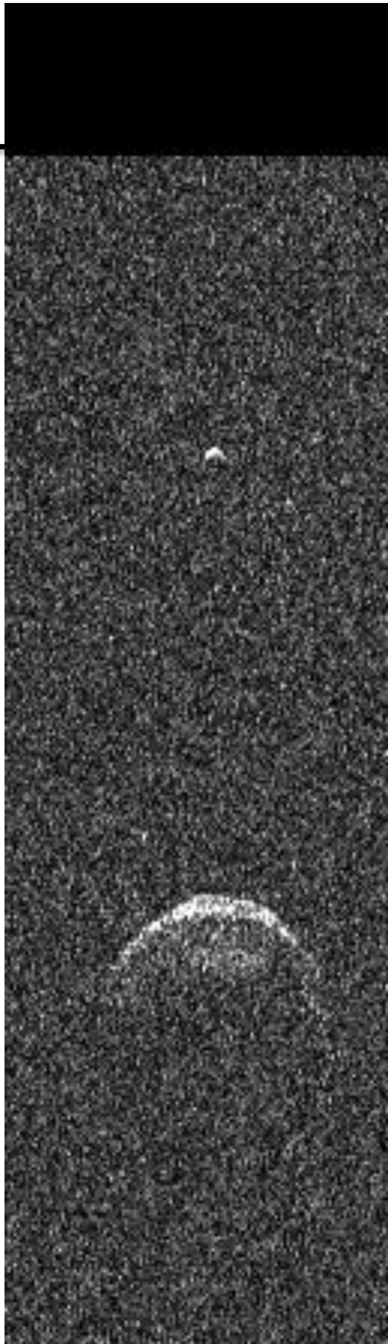


- **Rubble Pile**
  - Contain significant empty space (voids)
  - Has high porosity
  - Formed from disrupted asteroid materials
  - A good example is 25143 Itokawa

Optical Image of a Near-Earth Object



Radar Image and Model of an NEO

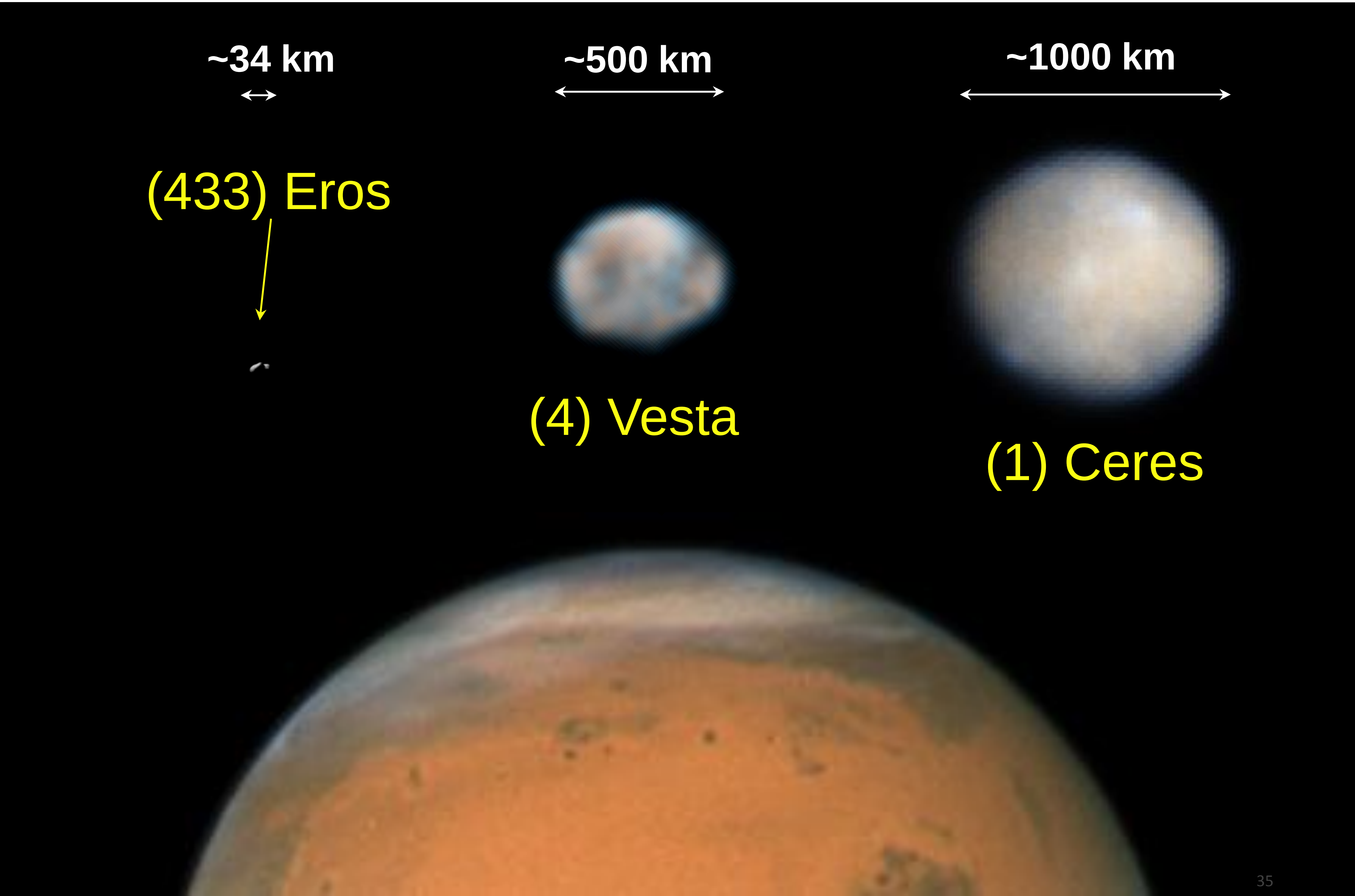


Radar Study of Shape, Size, Motion & Mass of 1999 KW_4

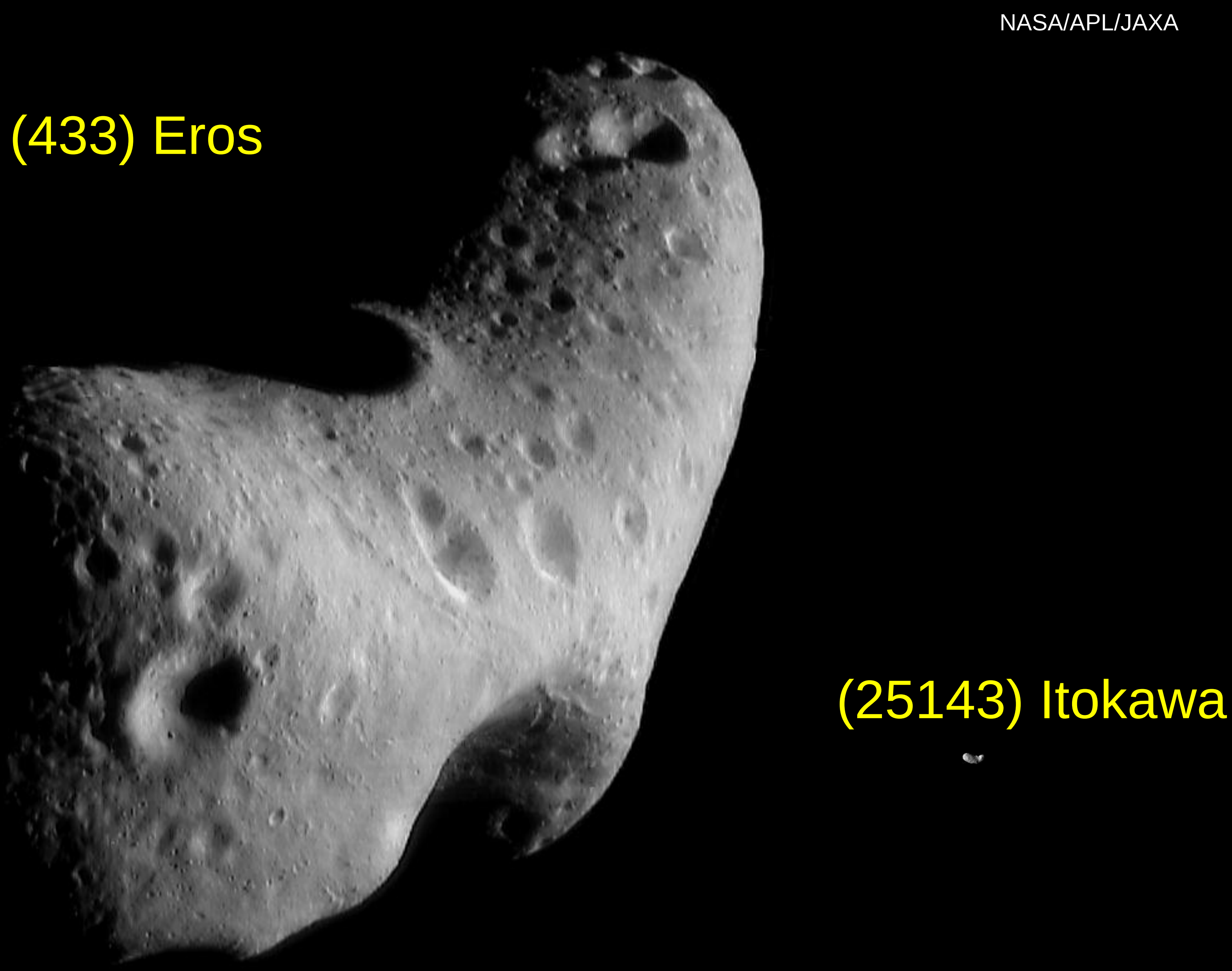
70-m Goldstone Antenna

305-m Arecibo Observatory

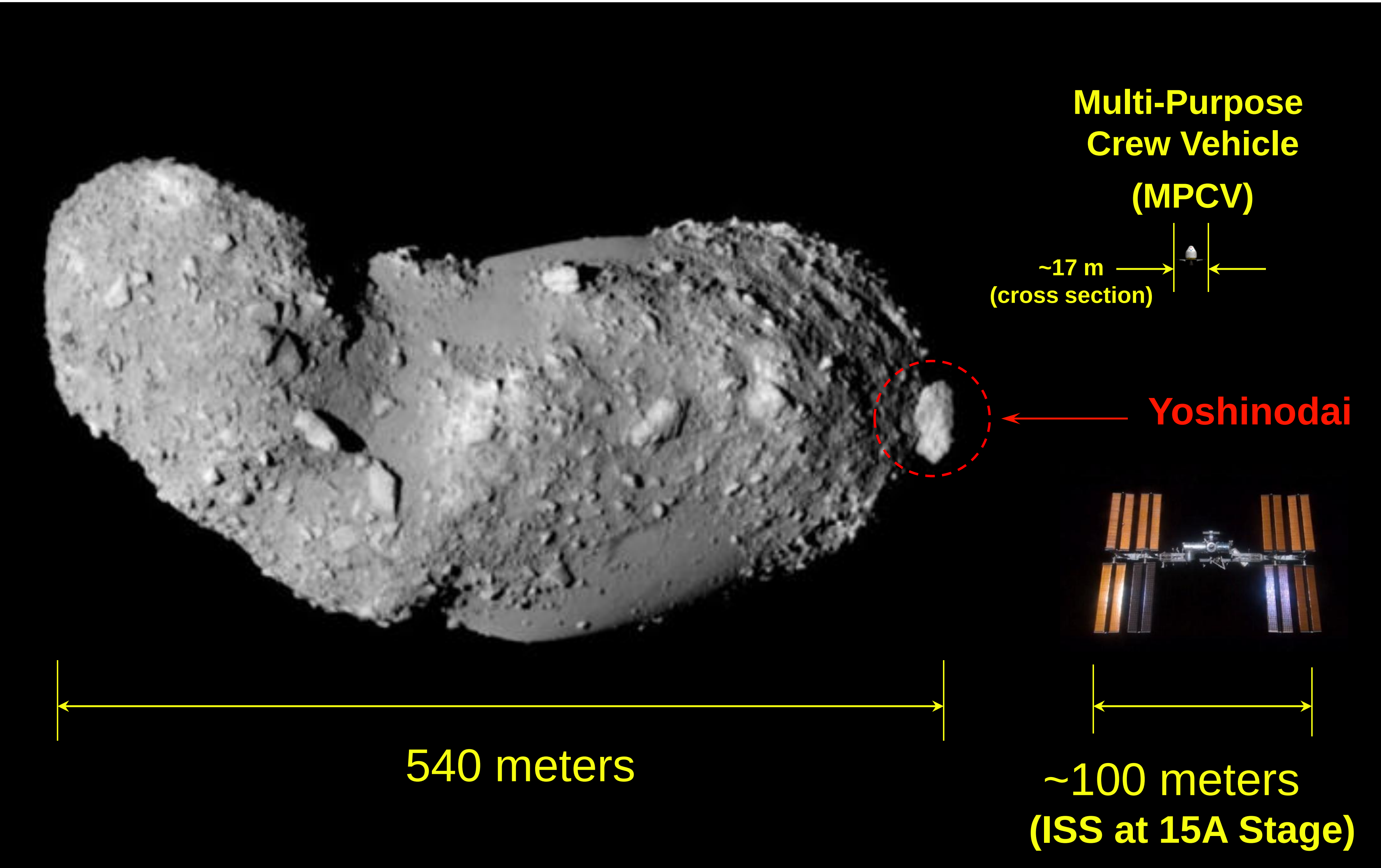
Comparison of Various Asteroids (to scale)



Asteroid (4) Vesta to Scale

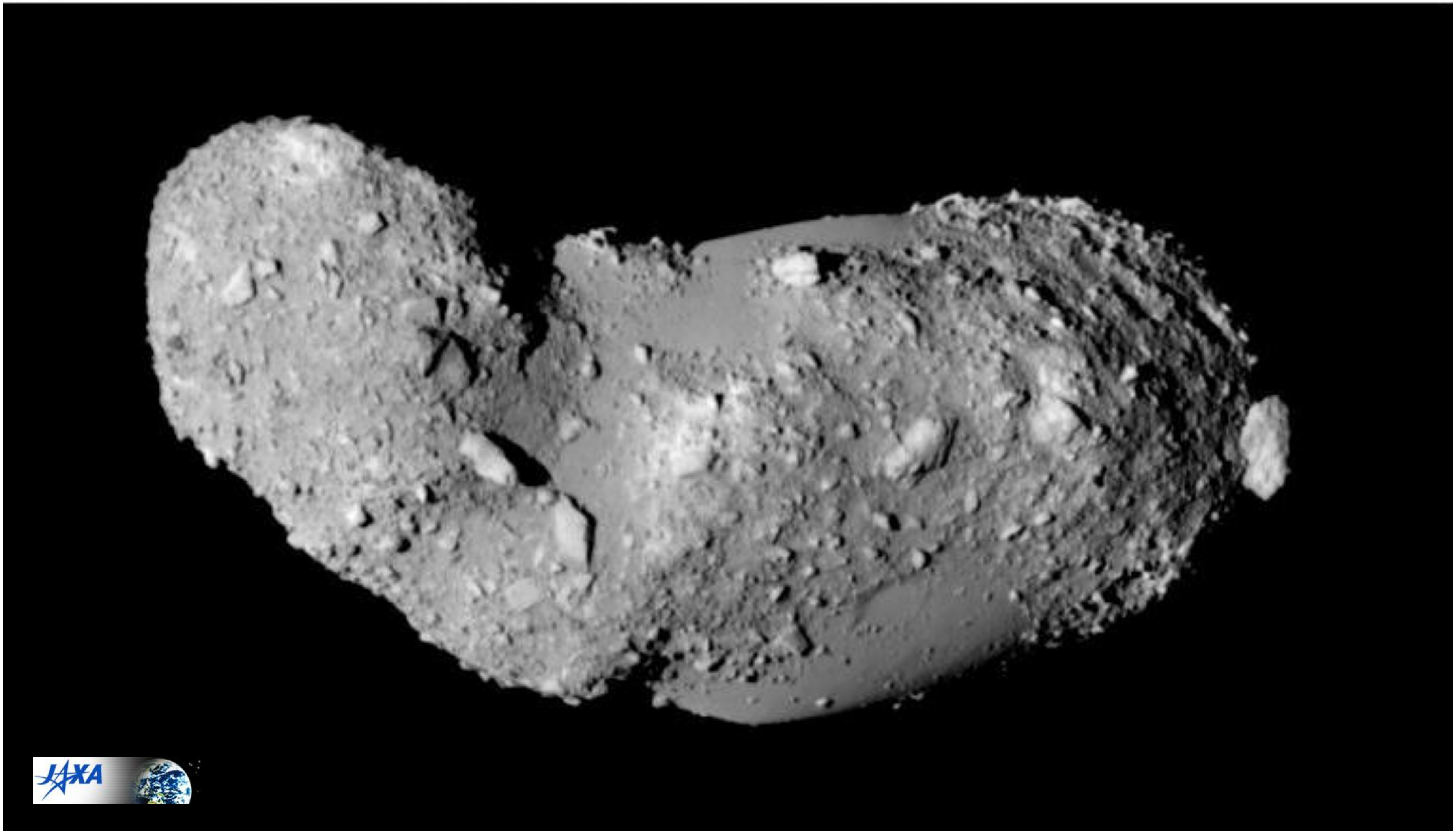

NASA/APL/JAXA
(433) Eros
(25143) Itokawa

Asteroid Itokawa, ISS, and MPCV



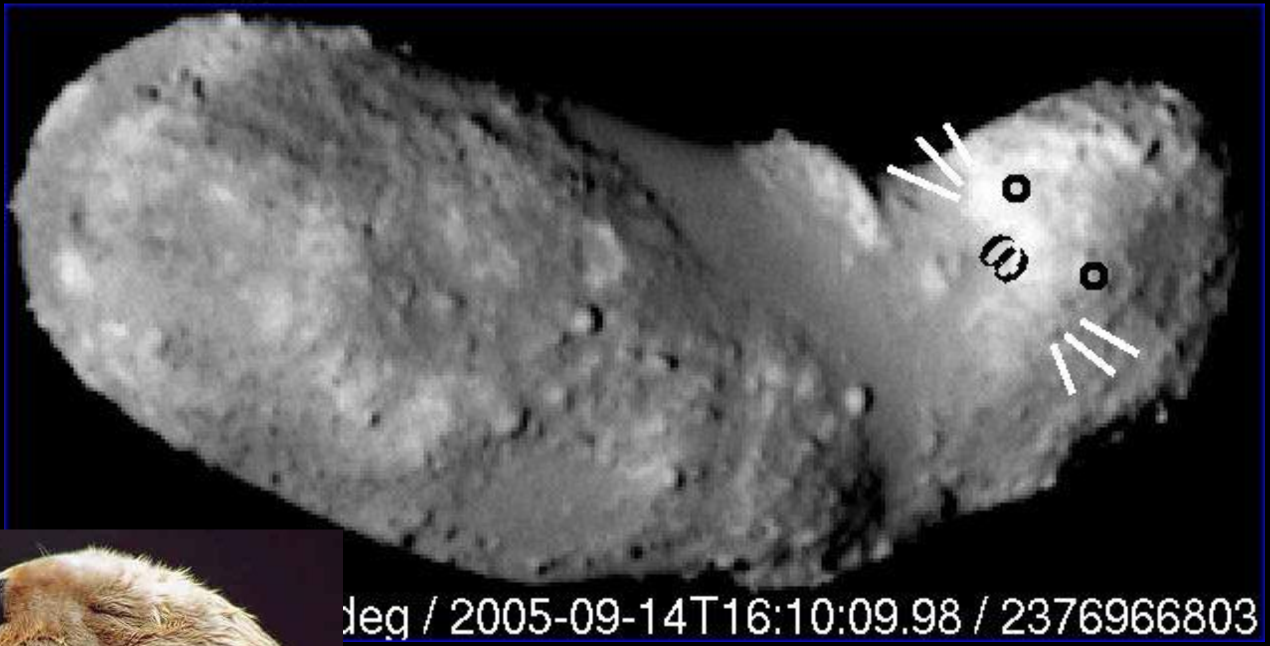
JAXA, NASA

Asteroid (25143) Itokawa



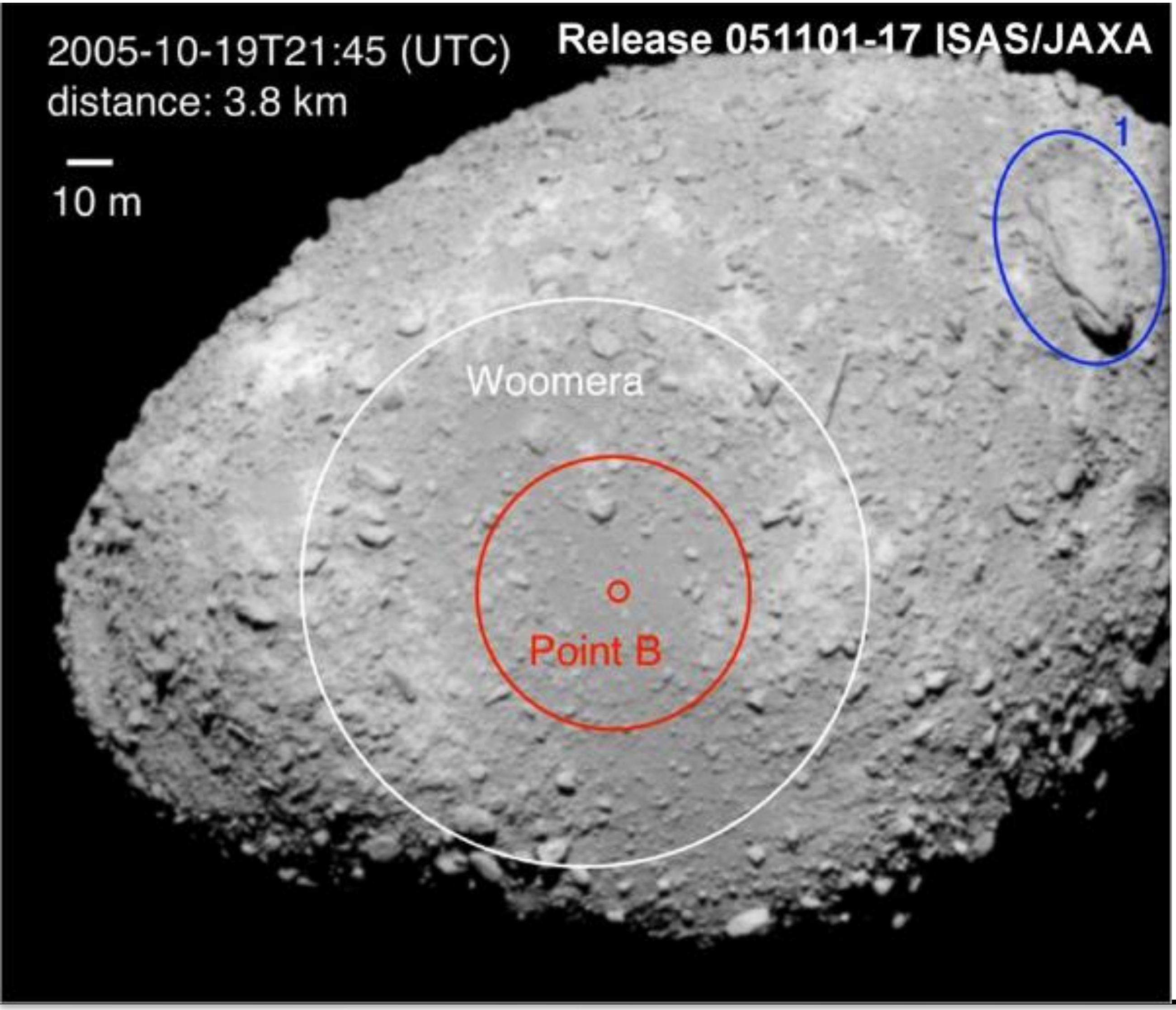
Itokawa and the Golden Gate Bridge

Vegetable, Animal, or Mineral?



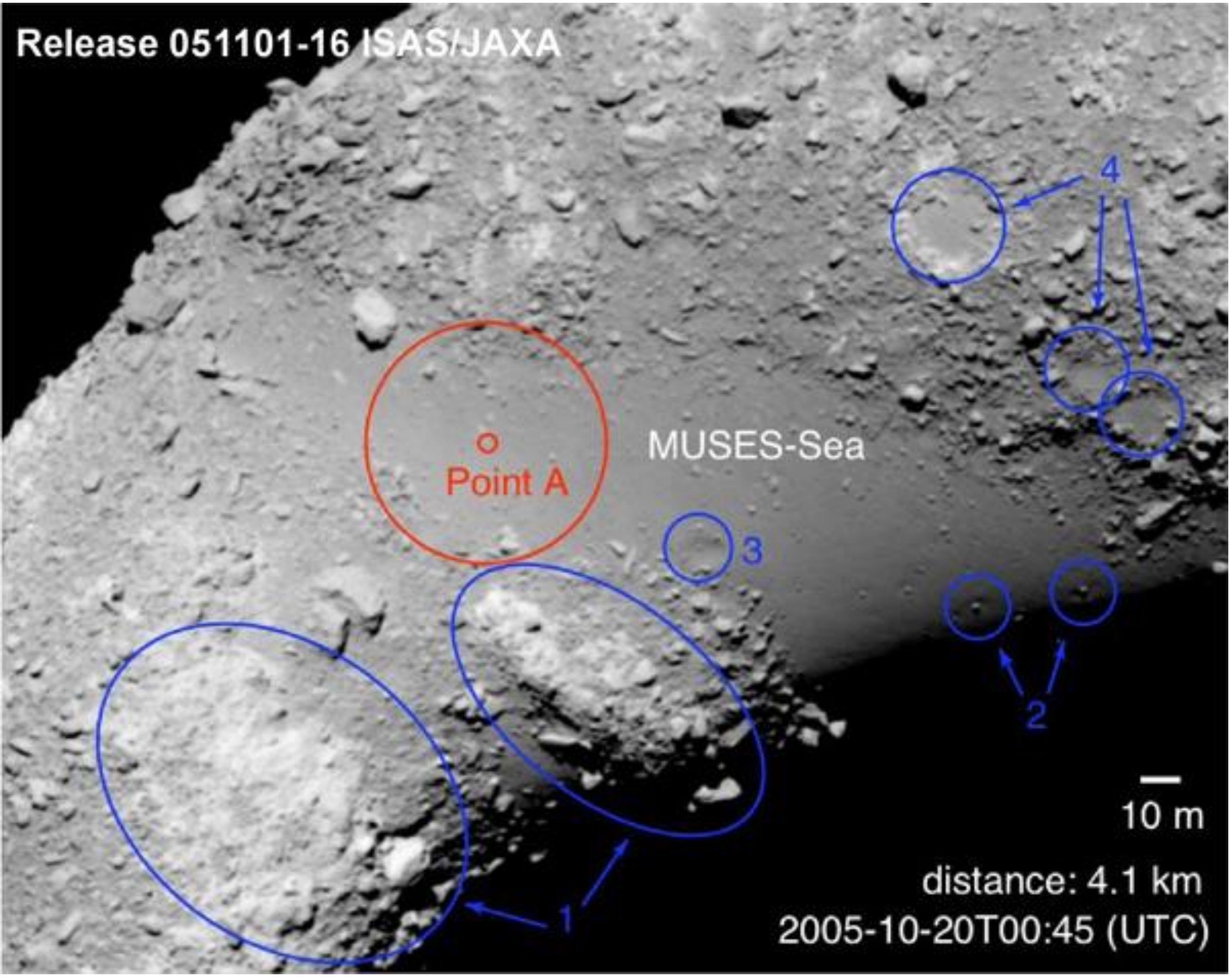
Sea Otter!

Touch Down Site Candidate B: Little Woomera



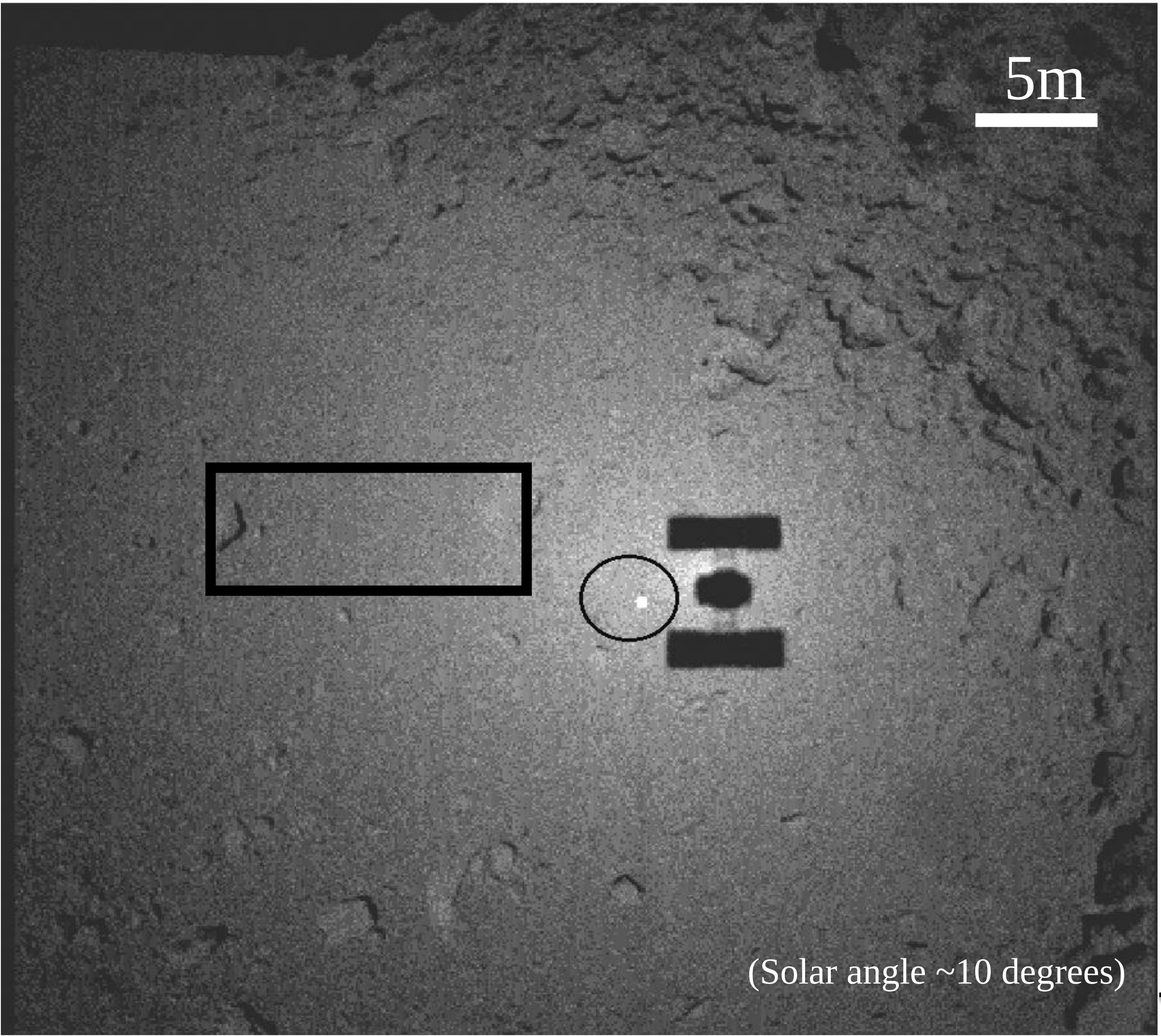
- ➢ This area was selected as one possible landing site.
- ➢ Subsequent high resolution images showed that this area still held too many meter-sized boulders.

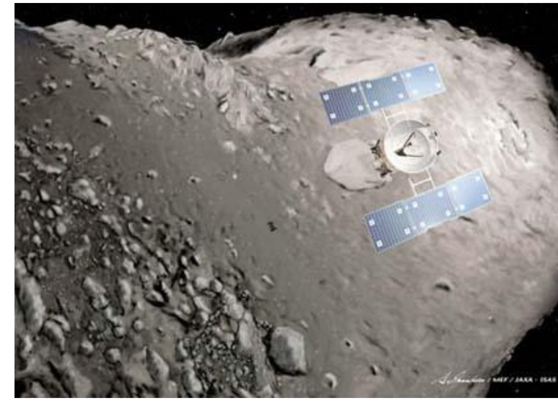
Touch Down Site Candidate A: Muses Sea

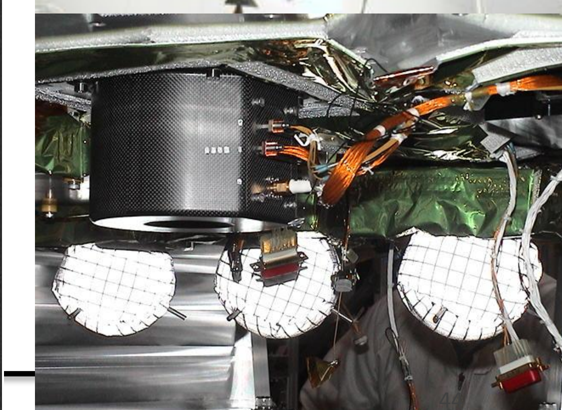


- The largest smooth terrain located between the "Head" and "Body" of the Otter.
- ~60 m across at its widest point.

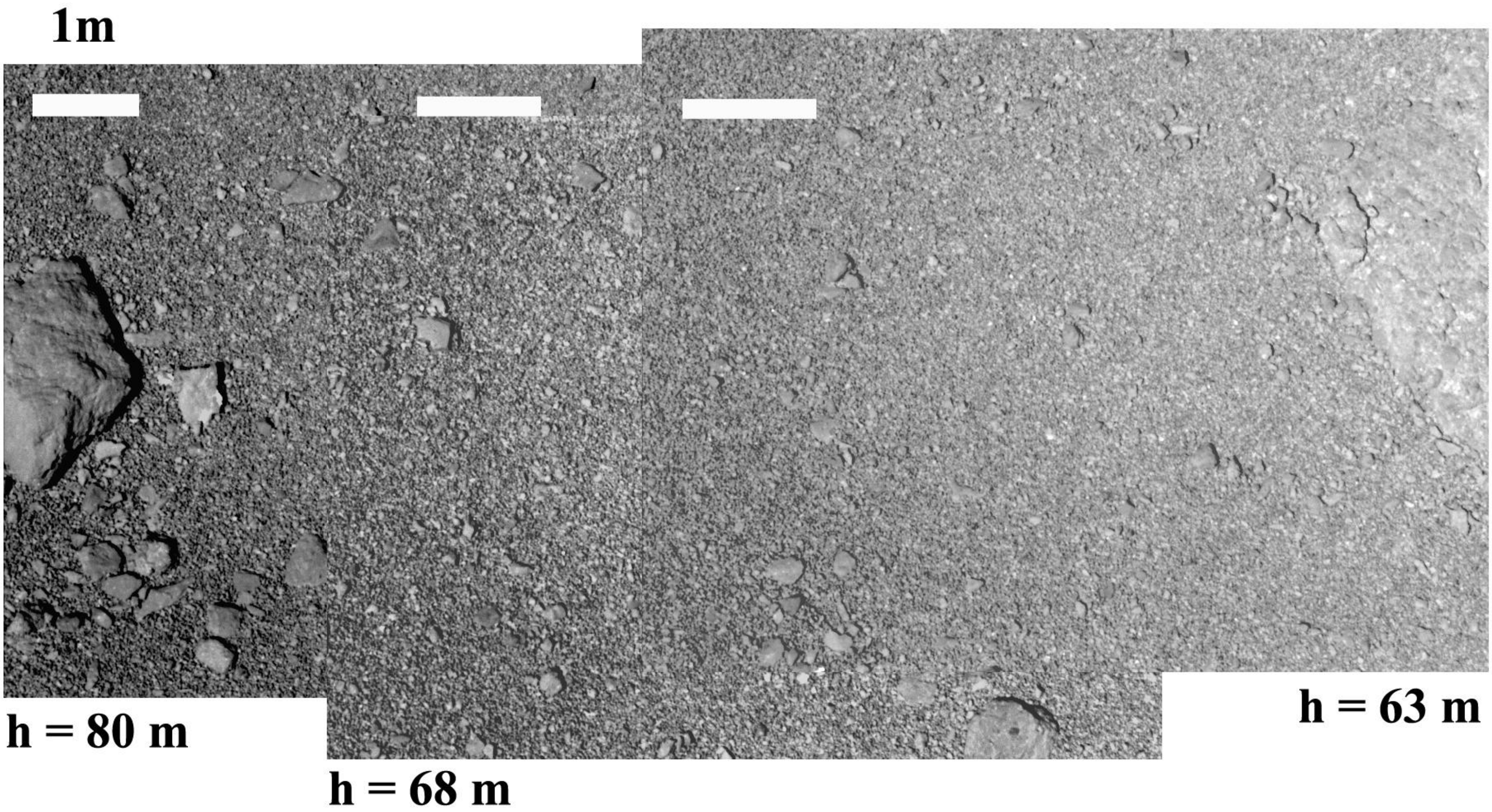
Touch Down Site Approach







Surface Terrains on Itokawa - Smooth



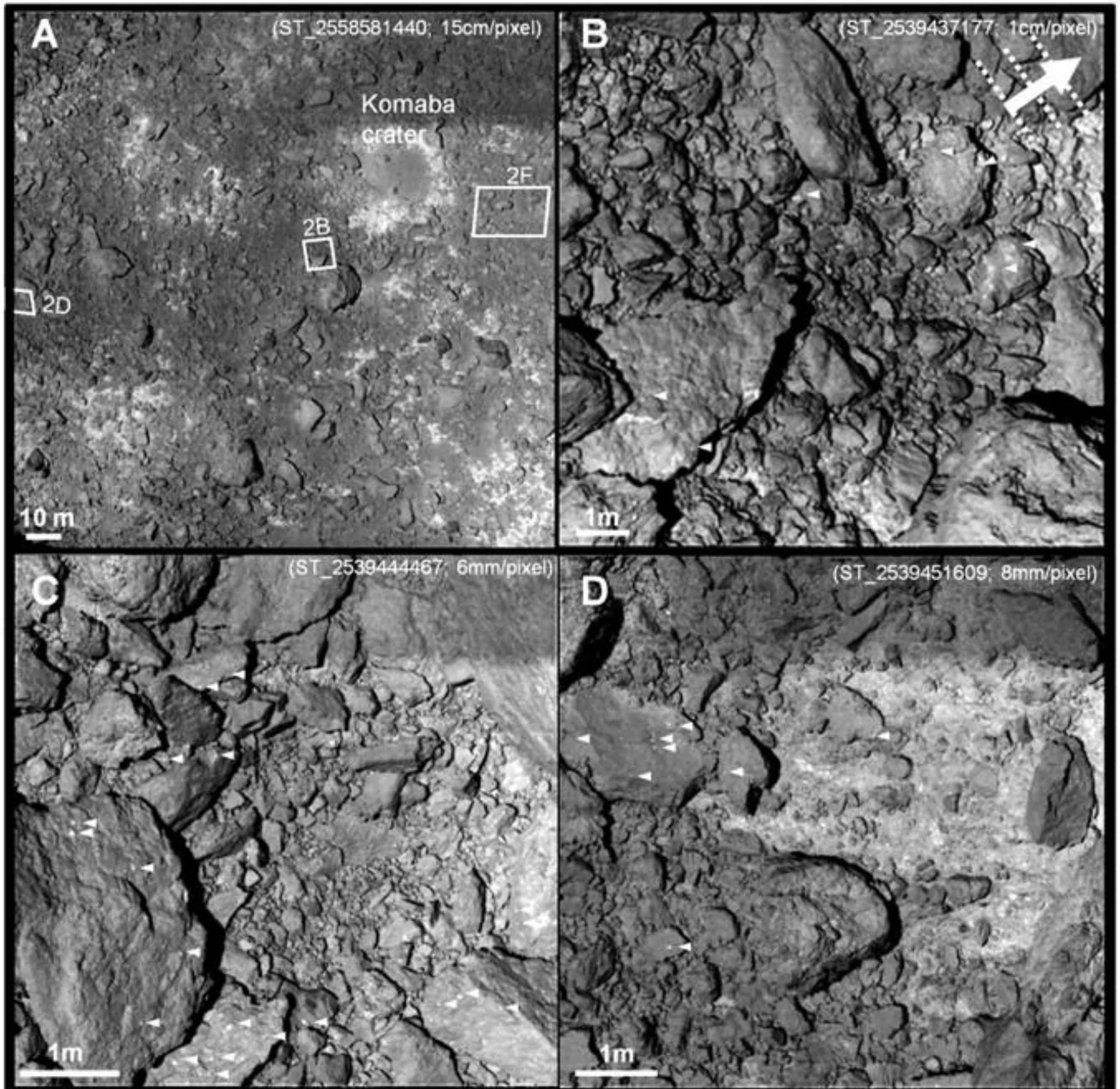
- Spatial Resolution: 6~8 mm/pixel

Smooth Terrains on S-type Asteroids: Eros Pond and Muses Sea

In the Middle of Muses Sea
(During the TD1 descent)

Surface Terrains on Itokawa - Rough

Surface Terrains on Itokawa - Rough



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? Or altered Itokawa material?

NEO Exploration Considerations

Selection of Viable NEOs for Human Exploration

- Dynamical considerations with respect to exploration systems
- Orbit location, mission duration, number of launches, launch windows, delta V, *etc*.

Discovery and Remote Characterization of NEOs

- Ground-based assets
  - Existing NEO search telescopes (*e.g*., Catalina Sky Survey , LINEAR, Spacewatch, *etc*.)
  - New NEO search telescopes being developed (*e.g.,* Pan-STARRS and LSST)
  - Visible and Infrared telescopes for characterization (e.g.. NASA IRTF, Keck, NGT, *etc.*)
  - Planetary radar telescopes for characterization (*e.g.,* Arecibo and Goldstone)
- Space-based assets
  - Most accessible NEOs are in Earth-like orbits (*i.e*., difficult to observe from Earth)

In Situ Characterization of NEOs

- Robotic Precursors for detailed physical characterization
  - Wide range of compositions and internal structures
  - Reduces mission risk, aids in planning for proximity operations/surface interactions by astronauts, and enables better science return

Human Missions to NEOs

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
- No communication delay issues for command and control

Sample Return

- Several ~10s to 100s 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)

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

NEO Environments

- **It is very important to have knowledge of the NEO environment and potential hazards for target selection and mission operations planning**

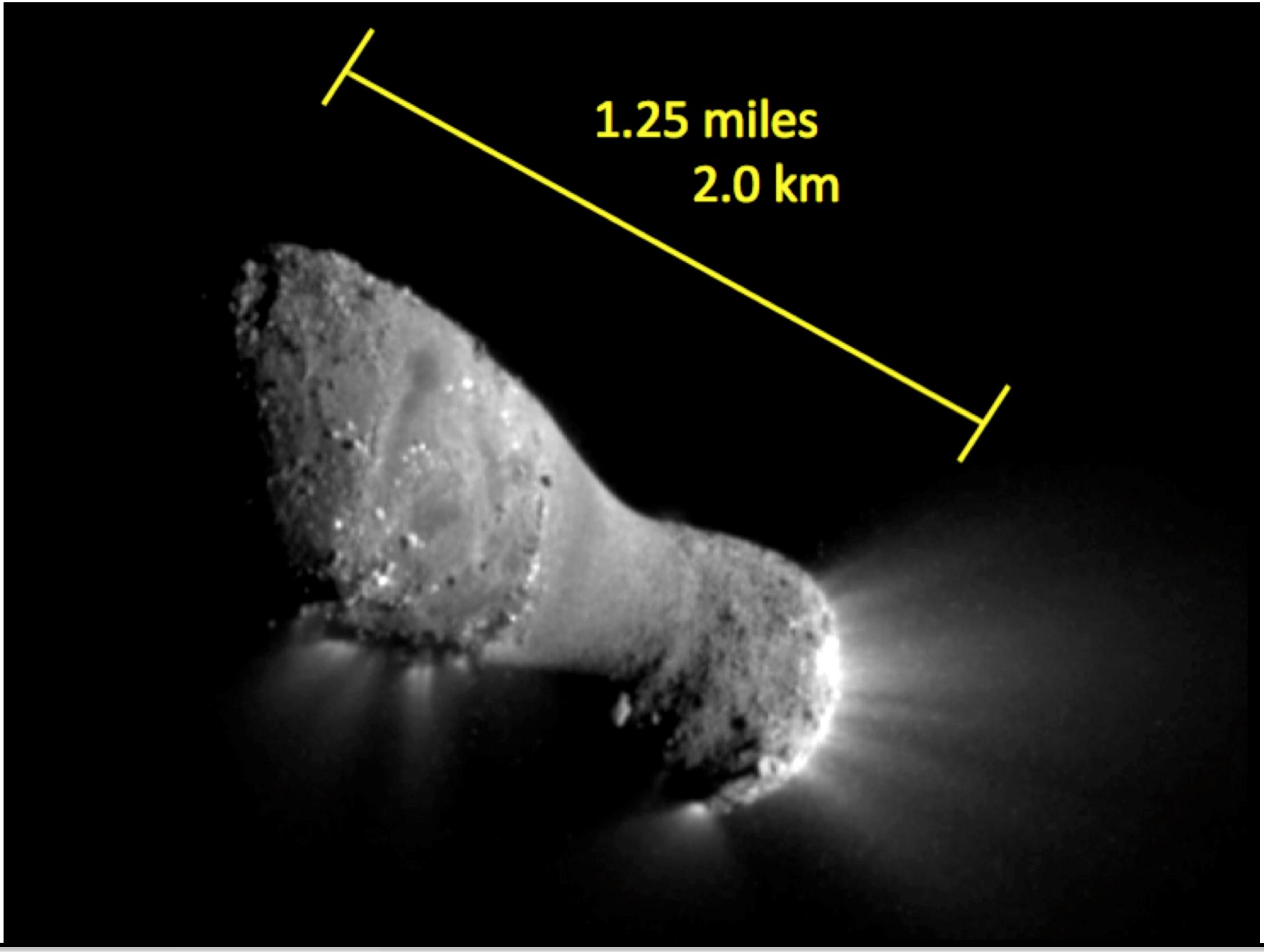
- **Understanding the radiation environment at the NEO and during transit to/from the destination is critical for crew health and safety**

- **Companion bodies**
  - Ground-based data suggest that 1 of 6 NEOs are binary systems
  - Ternary systems have also been observed (2 systems so far)

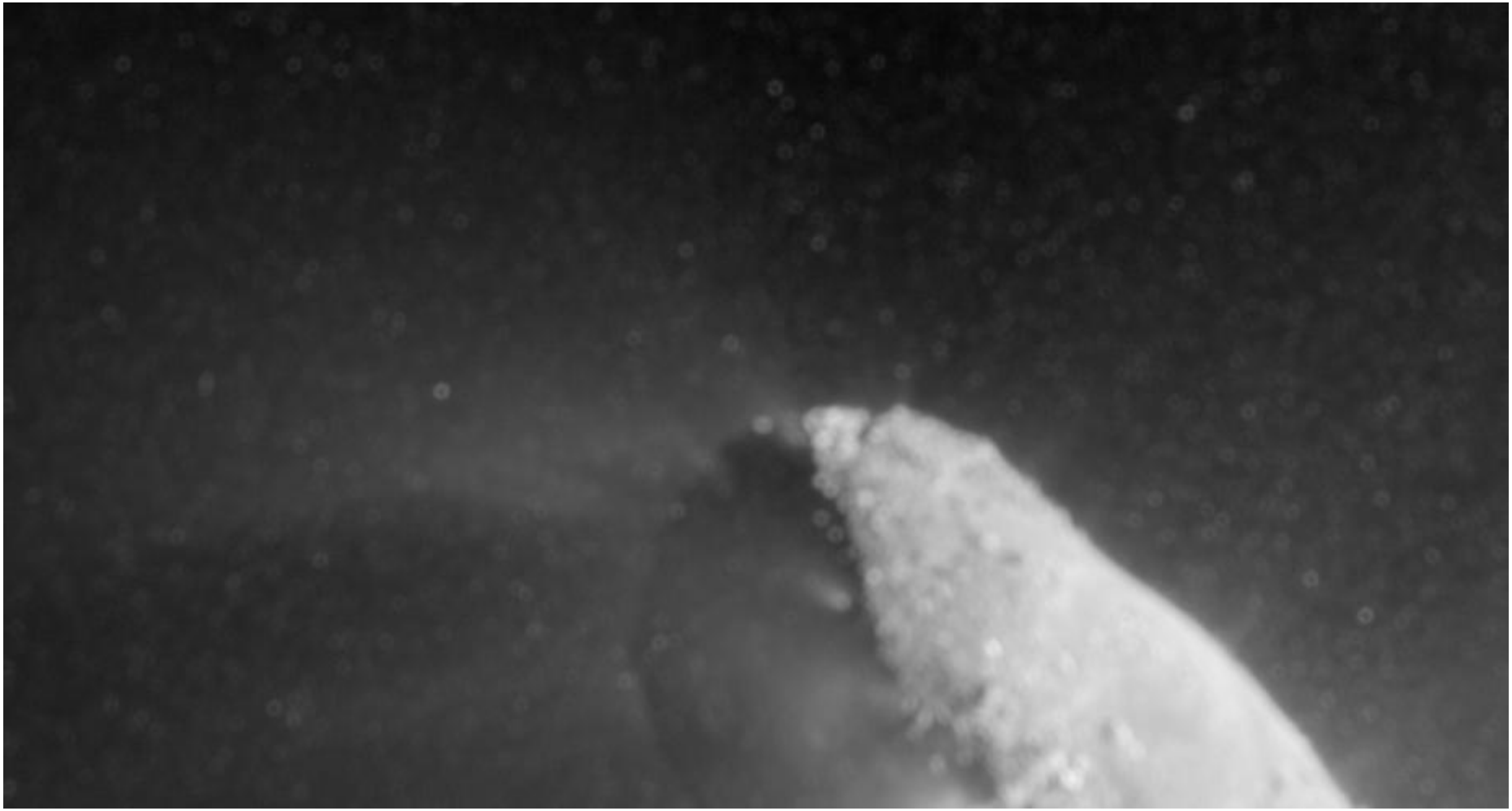
- **Particle environment**
  - Unclear how the particle size distribution can vary for specific objects
  - Potential for dust/debris levitation with extended orbital lifetimes

- **Active surfaces and volatiles**
  - Ground-based data suggests that at least 5-10% of NEOs may be extinct/dormant comets

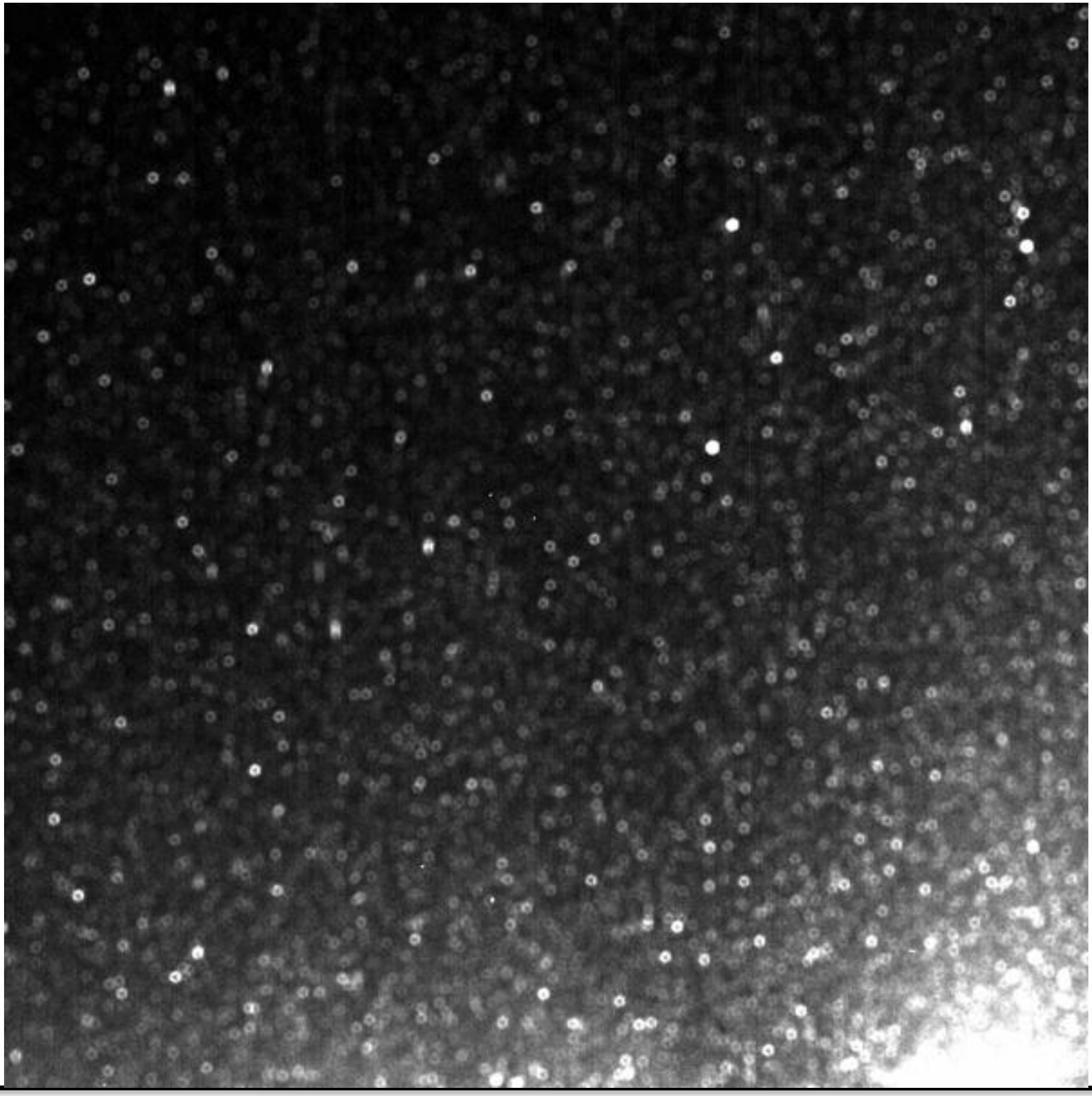
Comet Hartley 2 from EPOXI



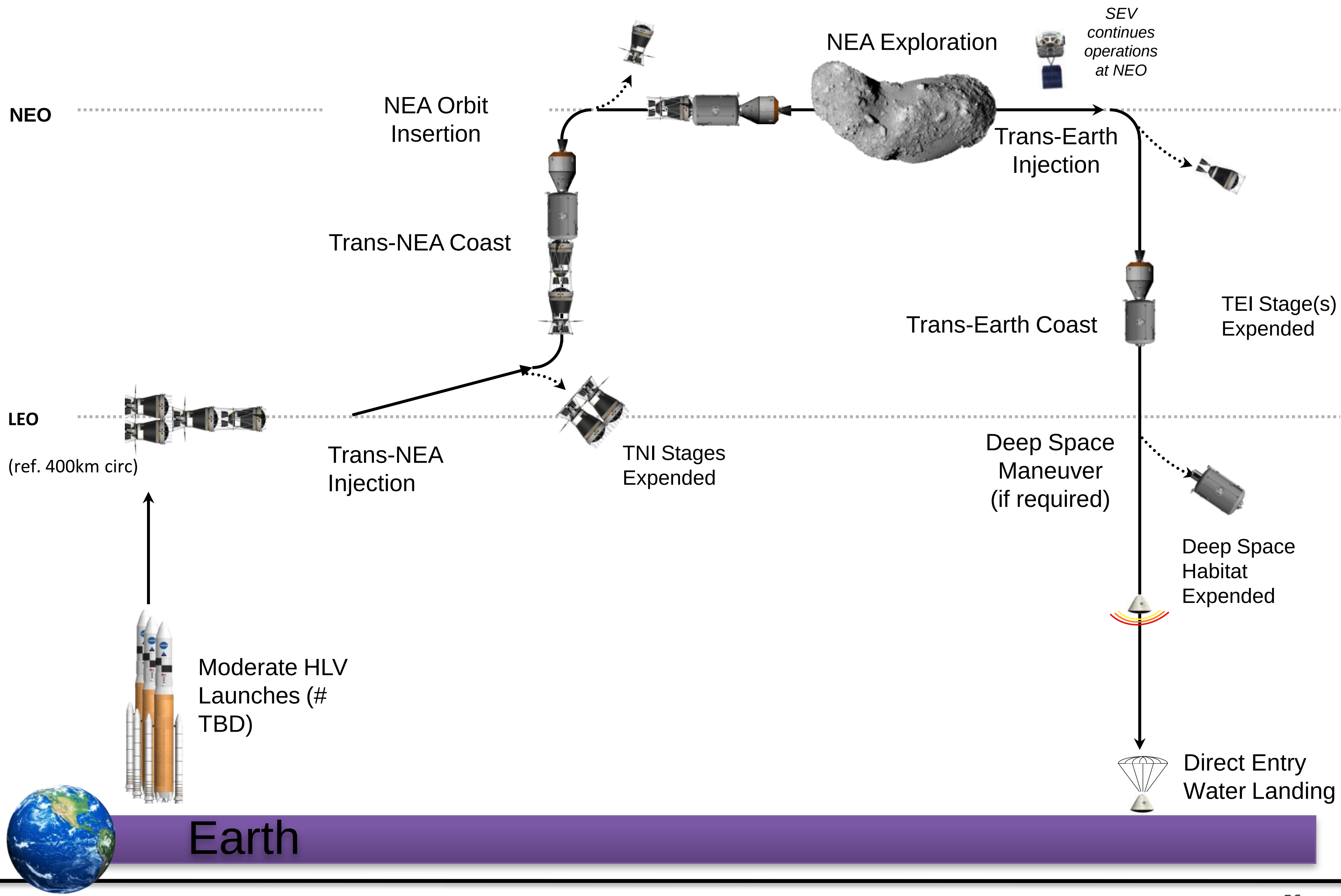
Comet Hartley 2 – “Snow” Storm



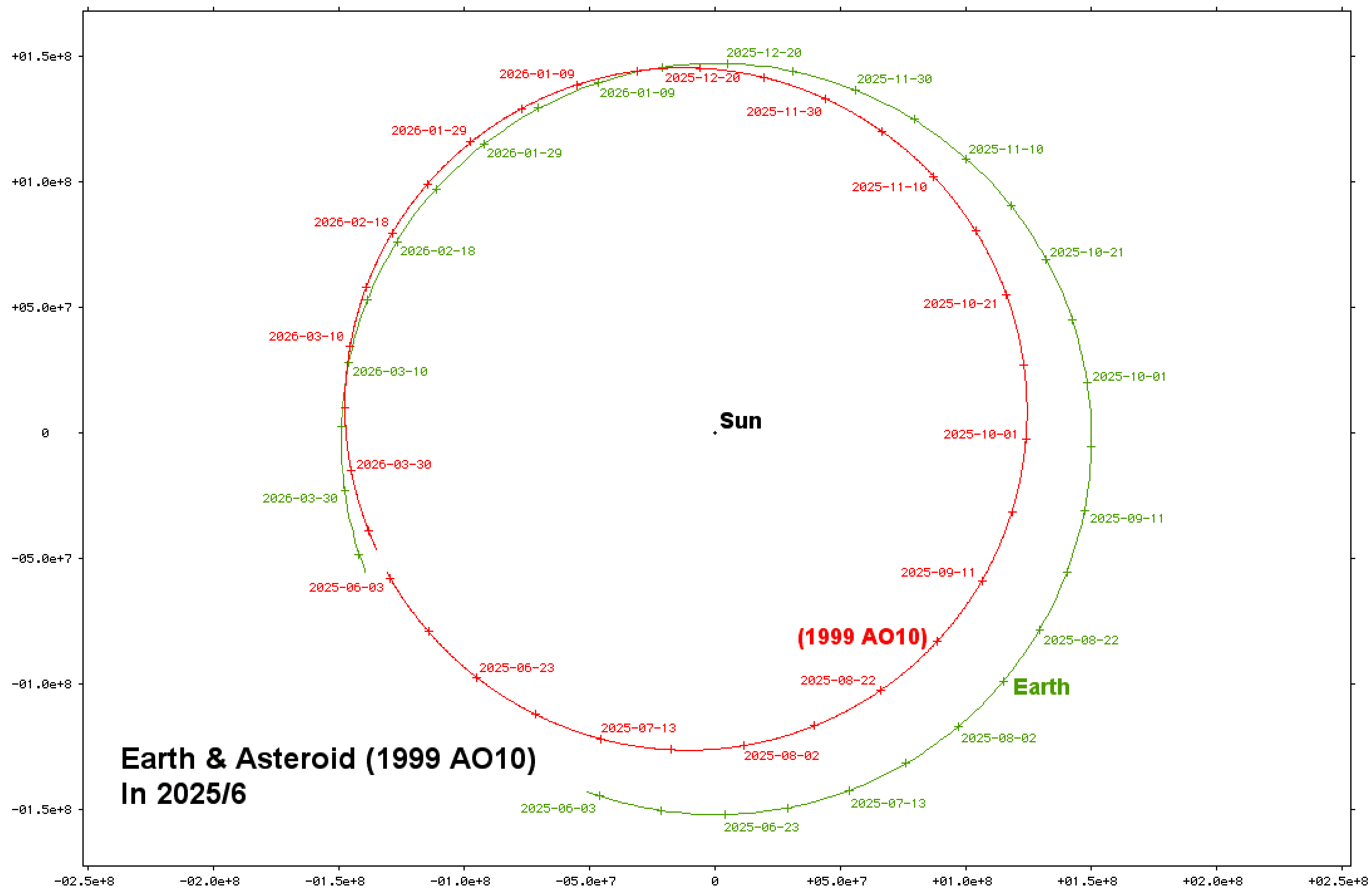
Comet Hartley 2 – "Snow" Storm



Sample Design Reference Mission

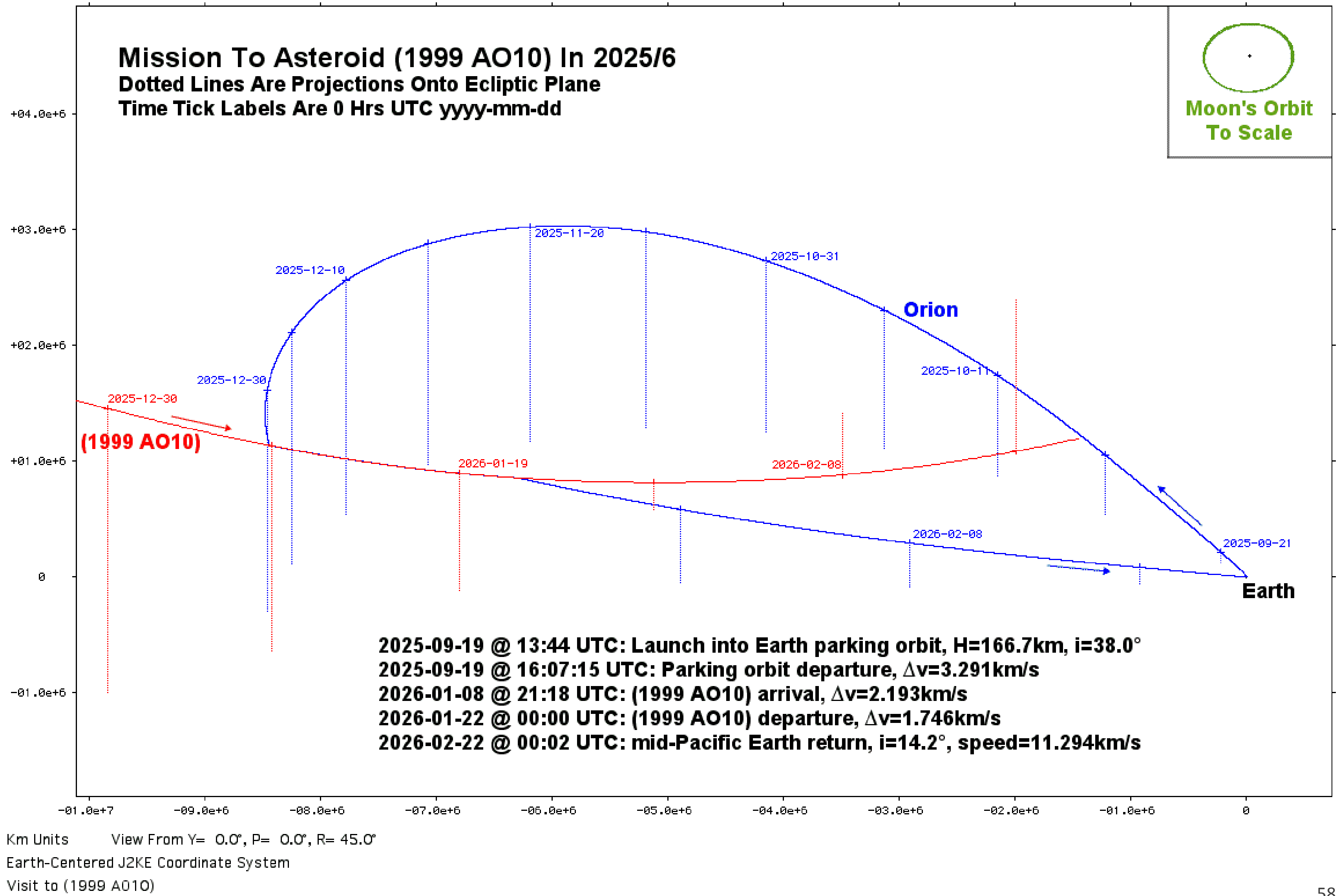


150-Day Mission to 1999 AO_{10} Heliocentric Trajectory Plot



Km Units View From Y= 0.0°, P= 0.0°, R= 0.0°
Sun-Centered J2KE Coordinate System
Visit to (1999 AO10)

150-Day Mission to 1999 AO_{10} Earth-fixed Trajectory Plot




A Few 'Take Away' Thoughts…
- NEOs for Exploration
- NEOs for Science
- NEOs for Resources
- NEOs for Planetary Defence

Back Up Slides

Recent and Current Activities

- **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

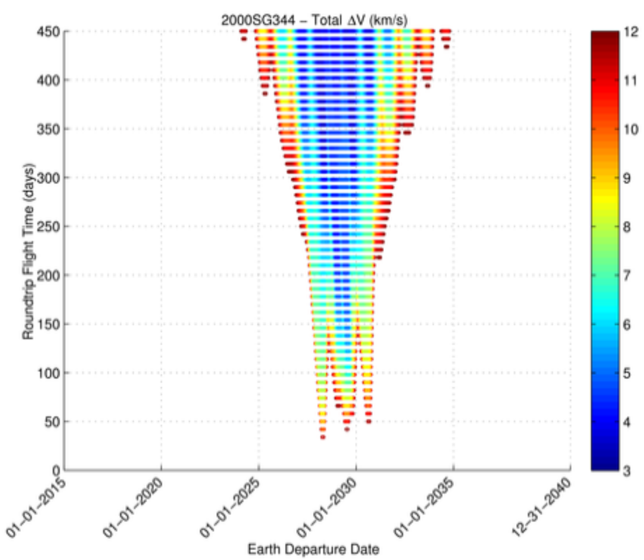
Mission Trajectories Table

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.

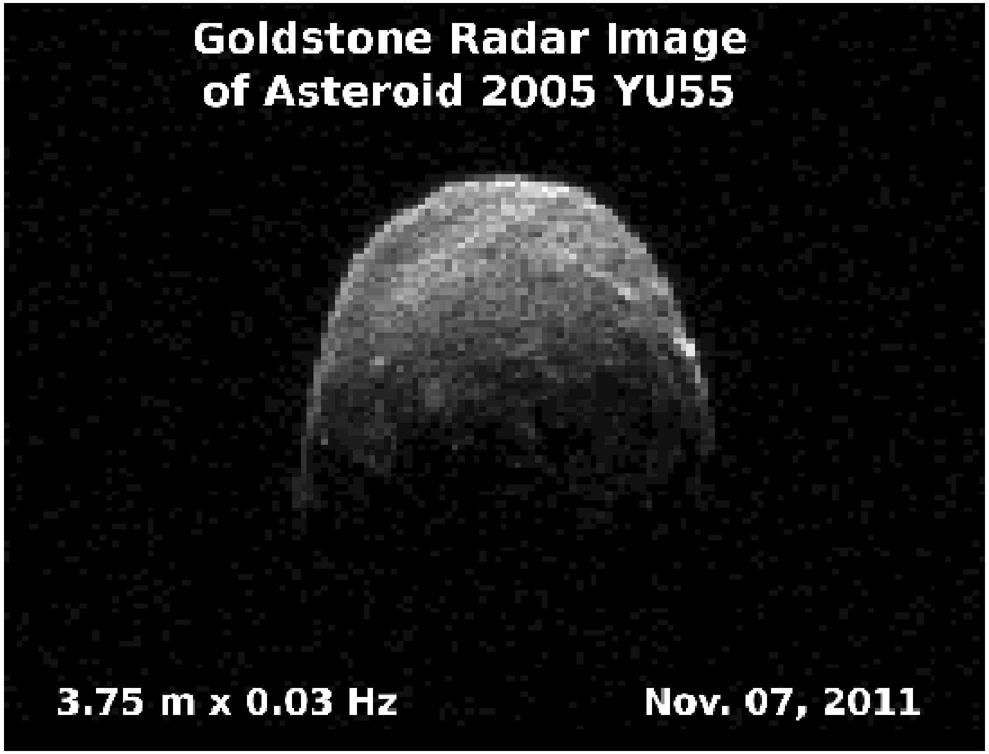
Total Mission delta-V as a Function of Departure Date and Mission Duration



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



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 (Itokawa)

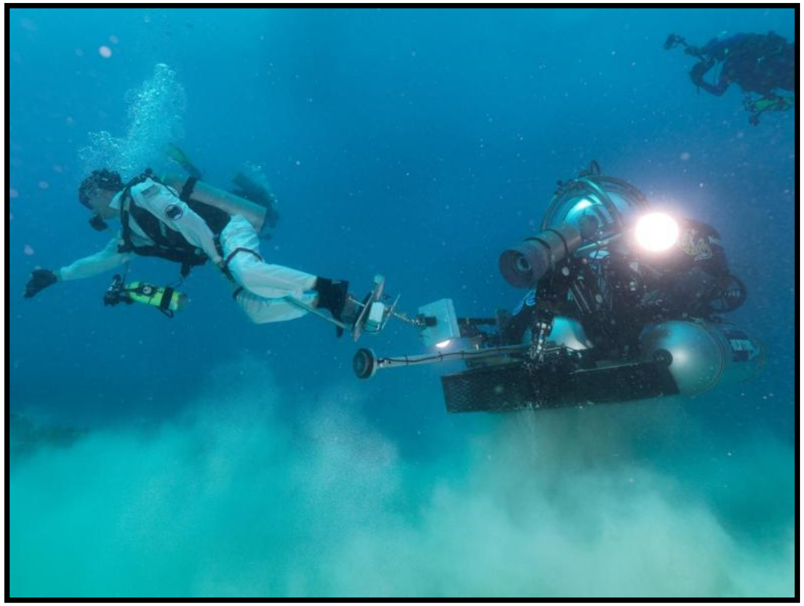
View of Itokawa from the forward windows of the Multi-Mission Space Exploration Vehicle (MMSEV)

Mock up of the MMSEV on an air-bearing floor to simulate micro-gravity conditions

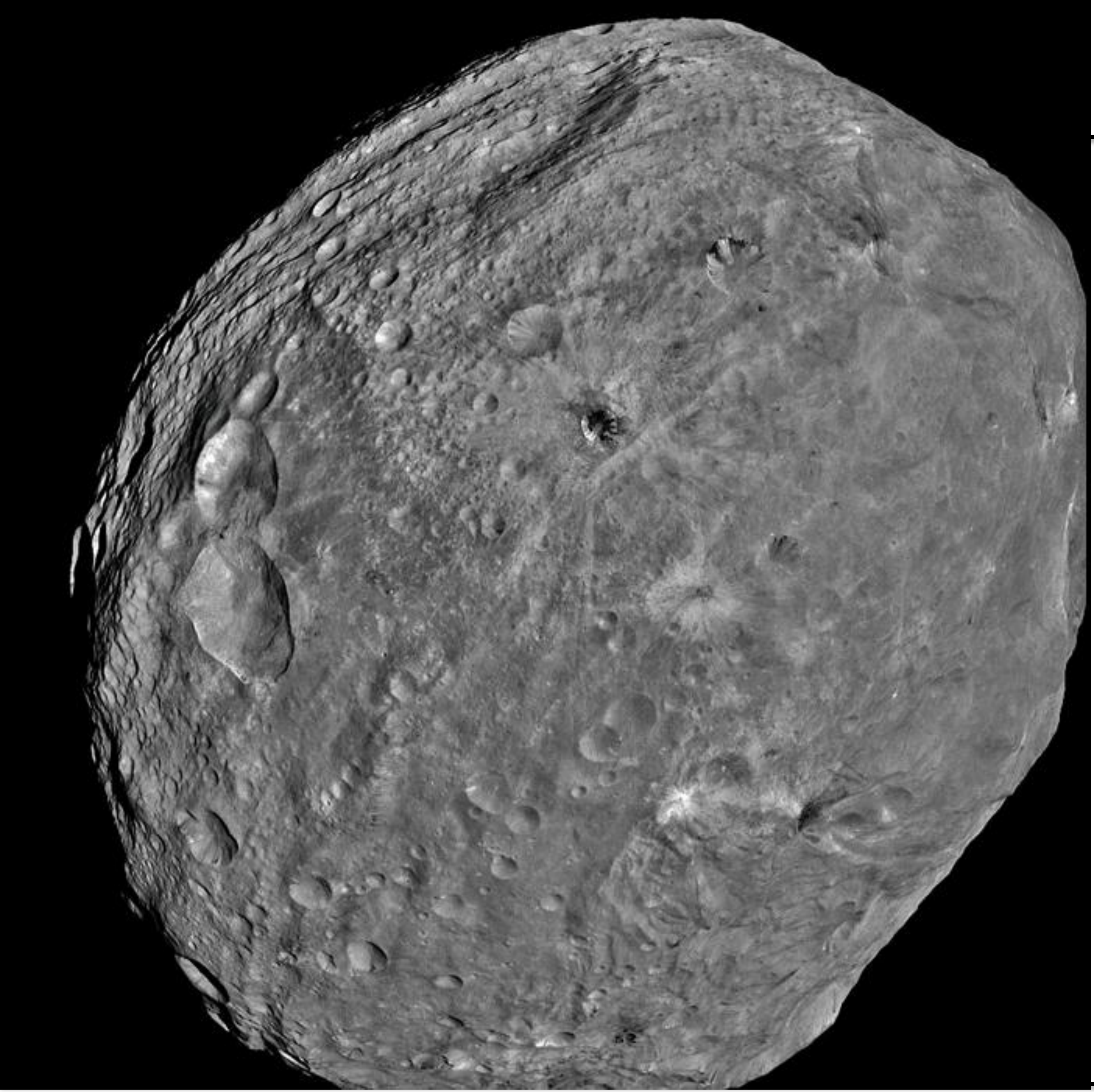
Recent and Current Activities

- **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

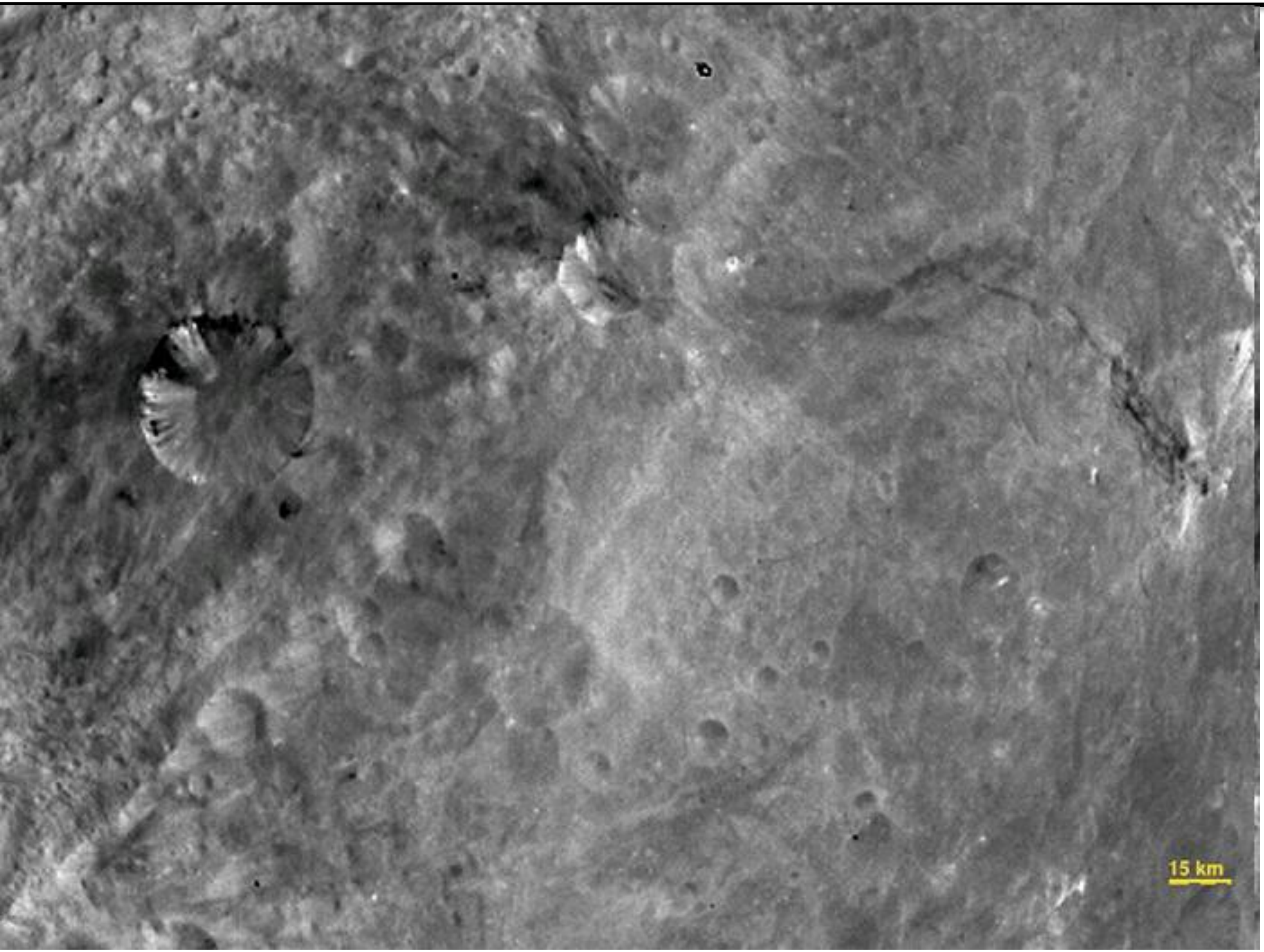


Dawn at (4) Vesta

Image taken at a distance of 3200 miles (5200 km) from Vesta

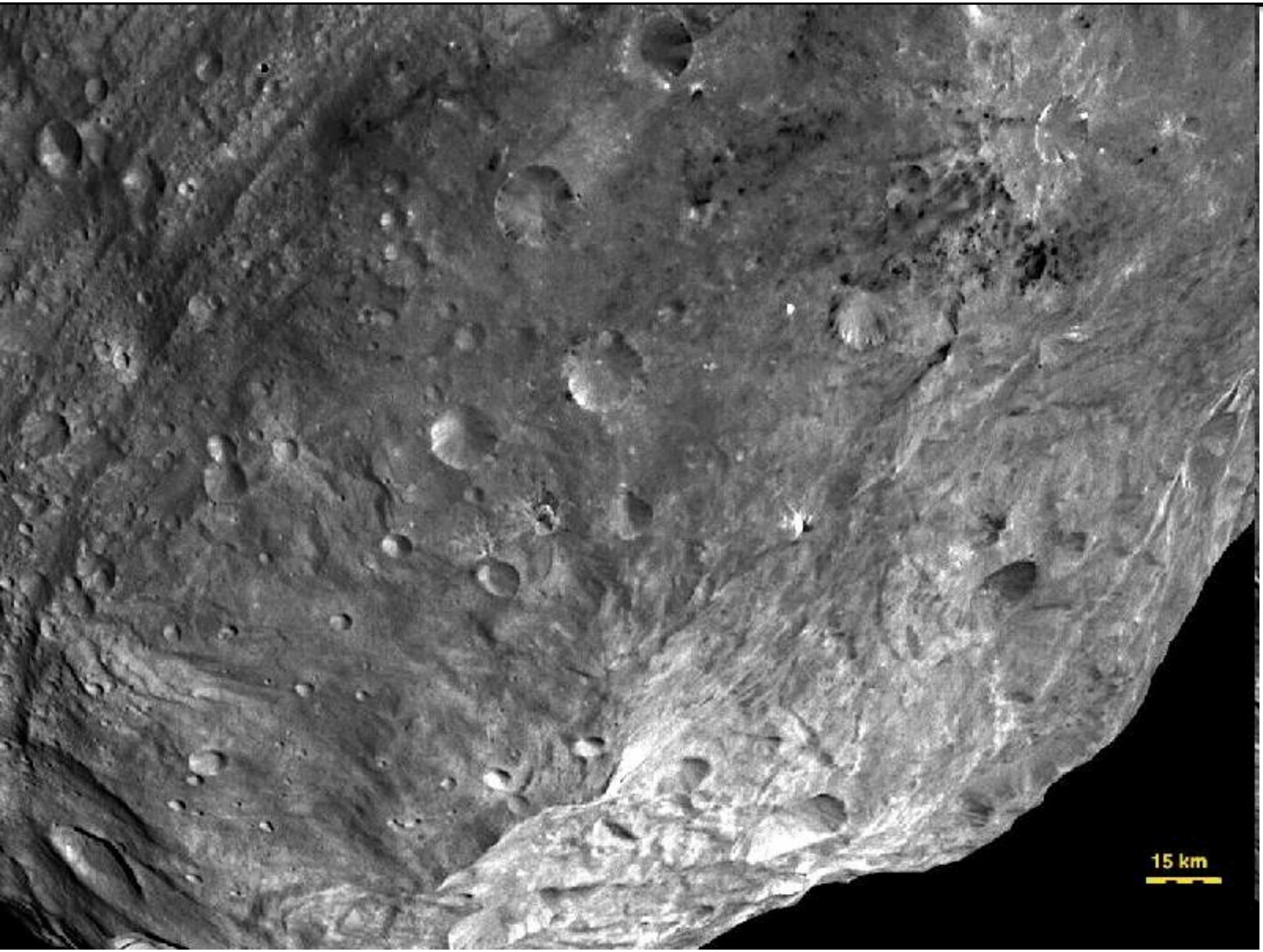
NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Dawn at (4) Vesta



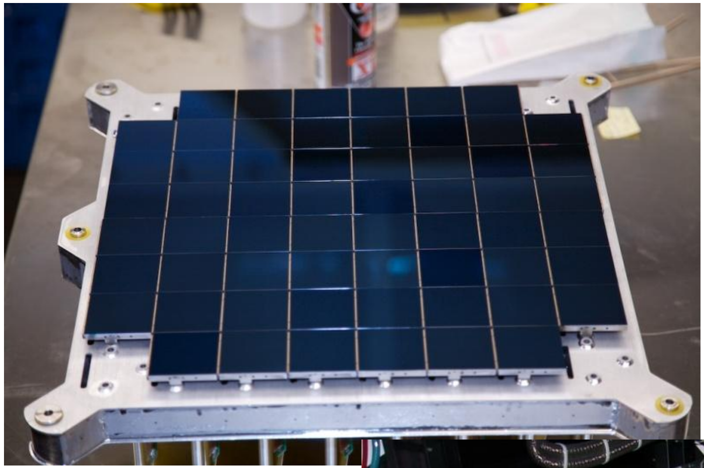
NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Dawn at (4) Vesta

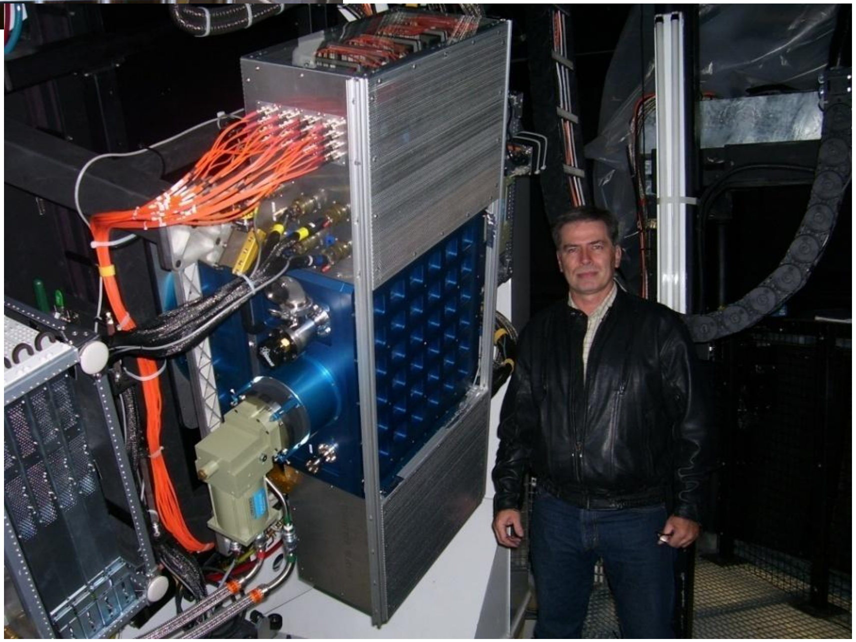


NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Panoramic Survey Telescope and Rapid Response System (PanSTARRS)

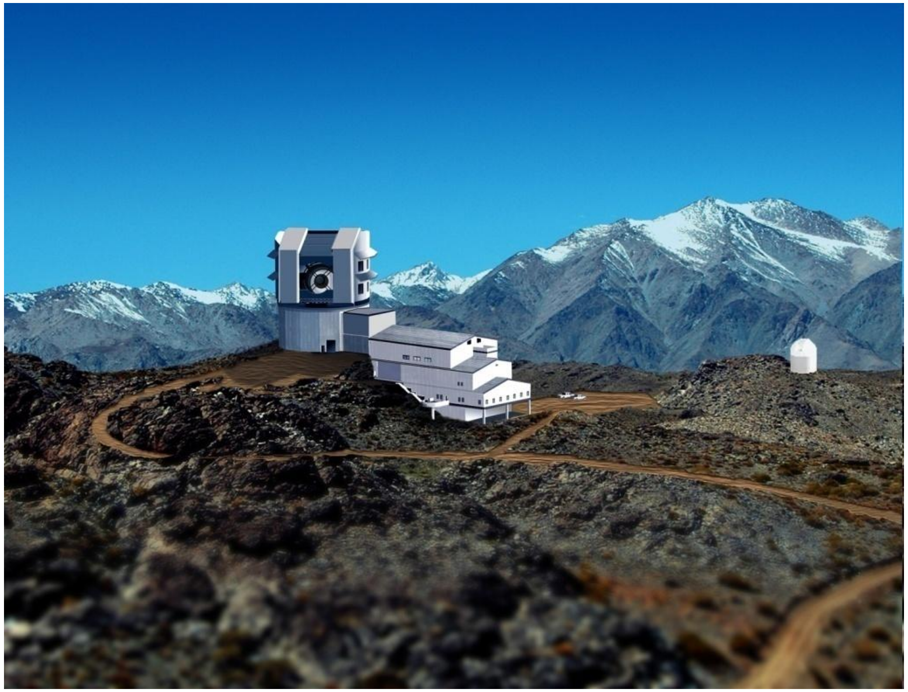


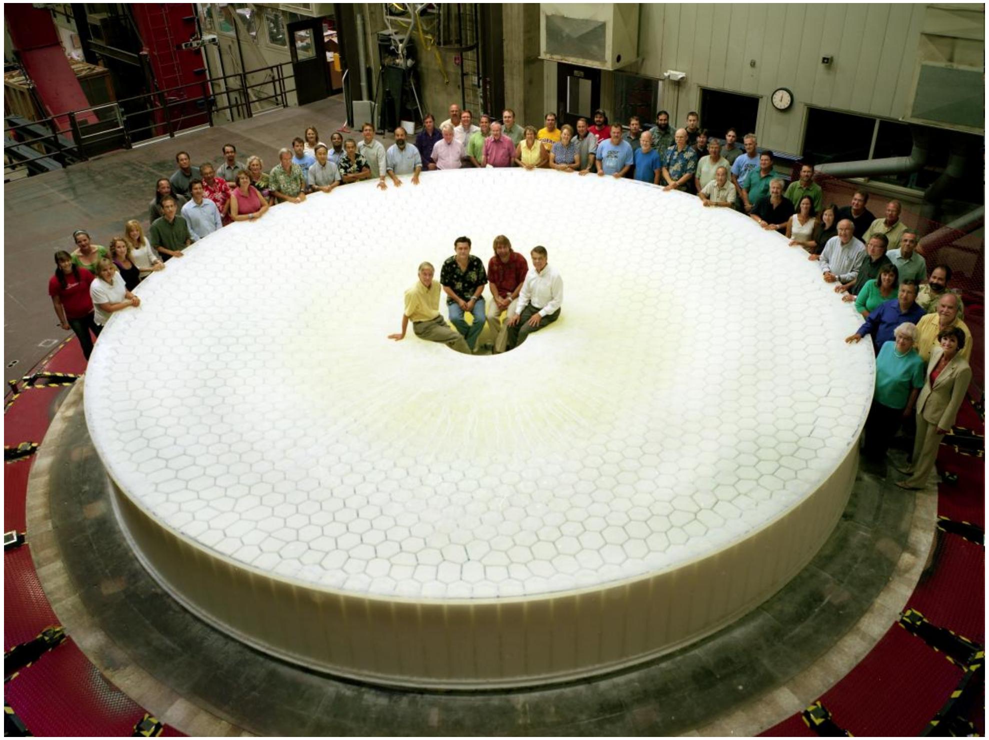
USAF Research Labs
R&D Project
PS-1
1.8 meter telescope
1.4 giga-pixel camera
Haleakala,Hawai'i



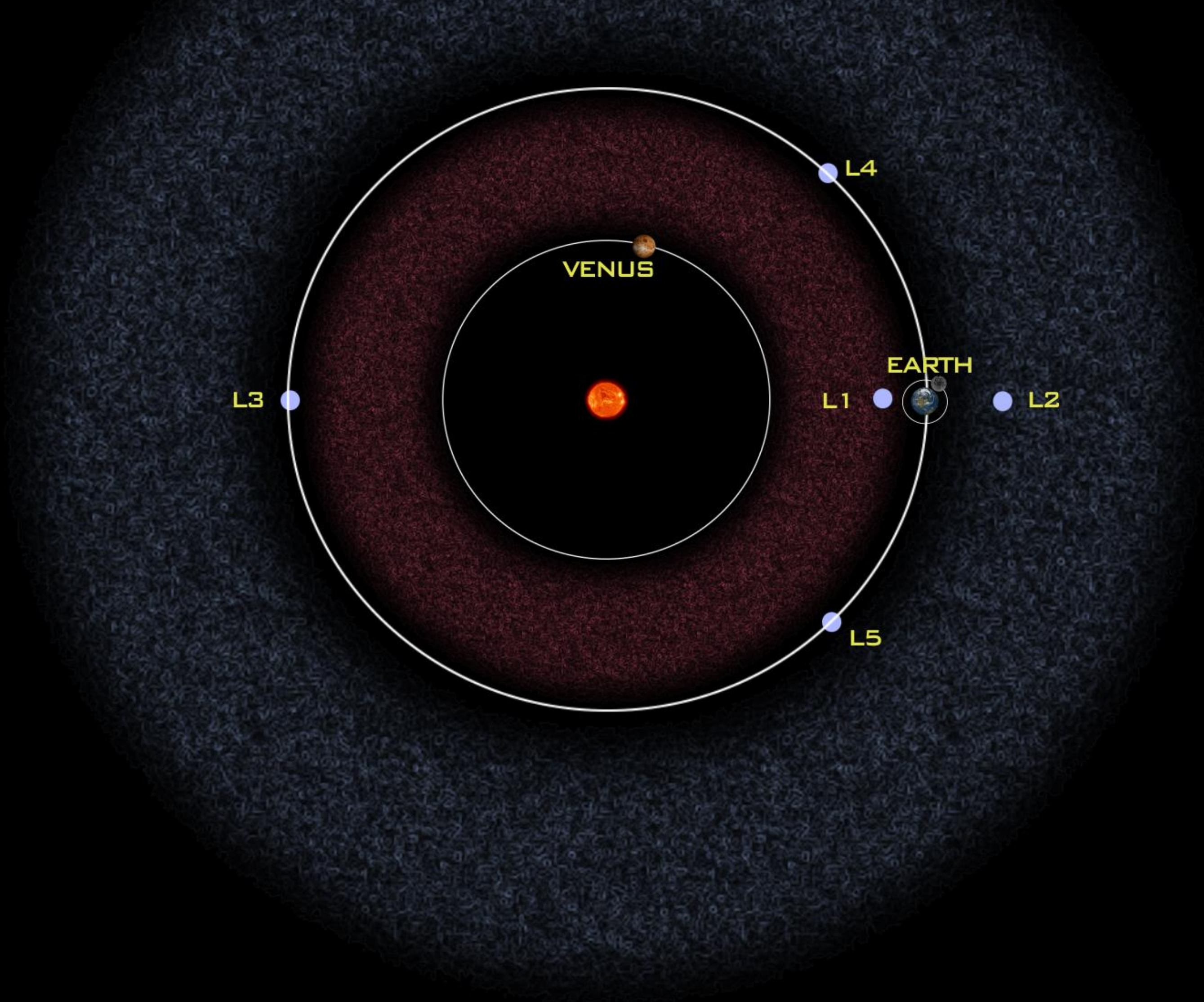
Large Synoptic Survey Telescope (LSST)

National Science Foundation
LSST
8.4 meter telescope
3.2 giga-pixel camera
Cerro Pachon, Chile

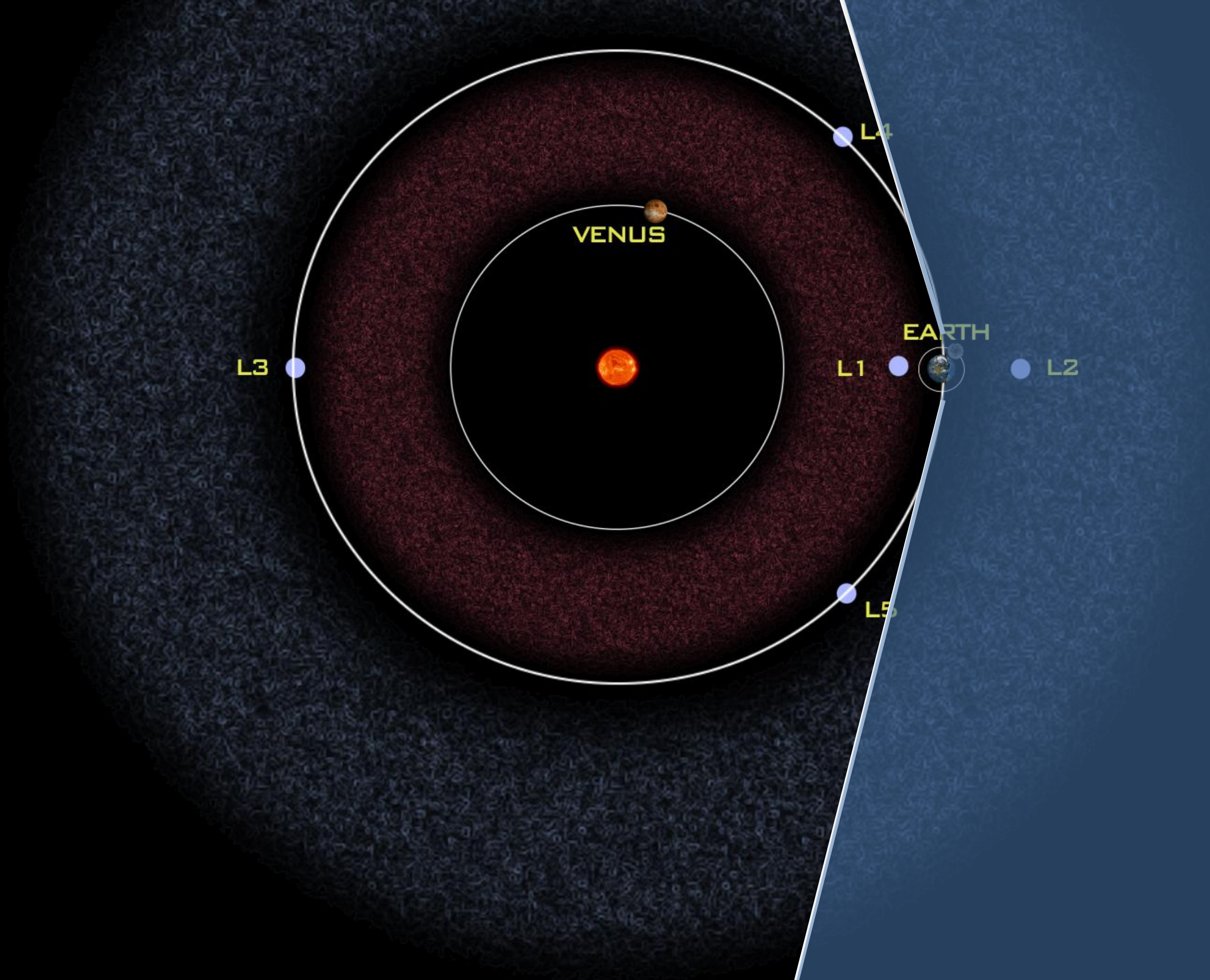




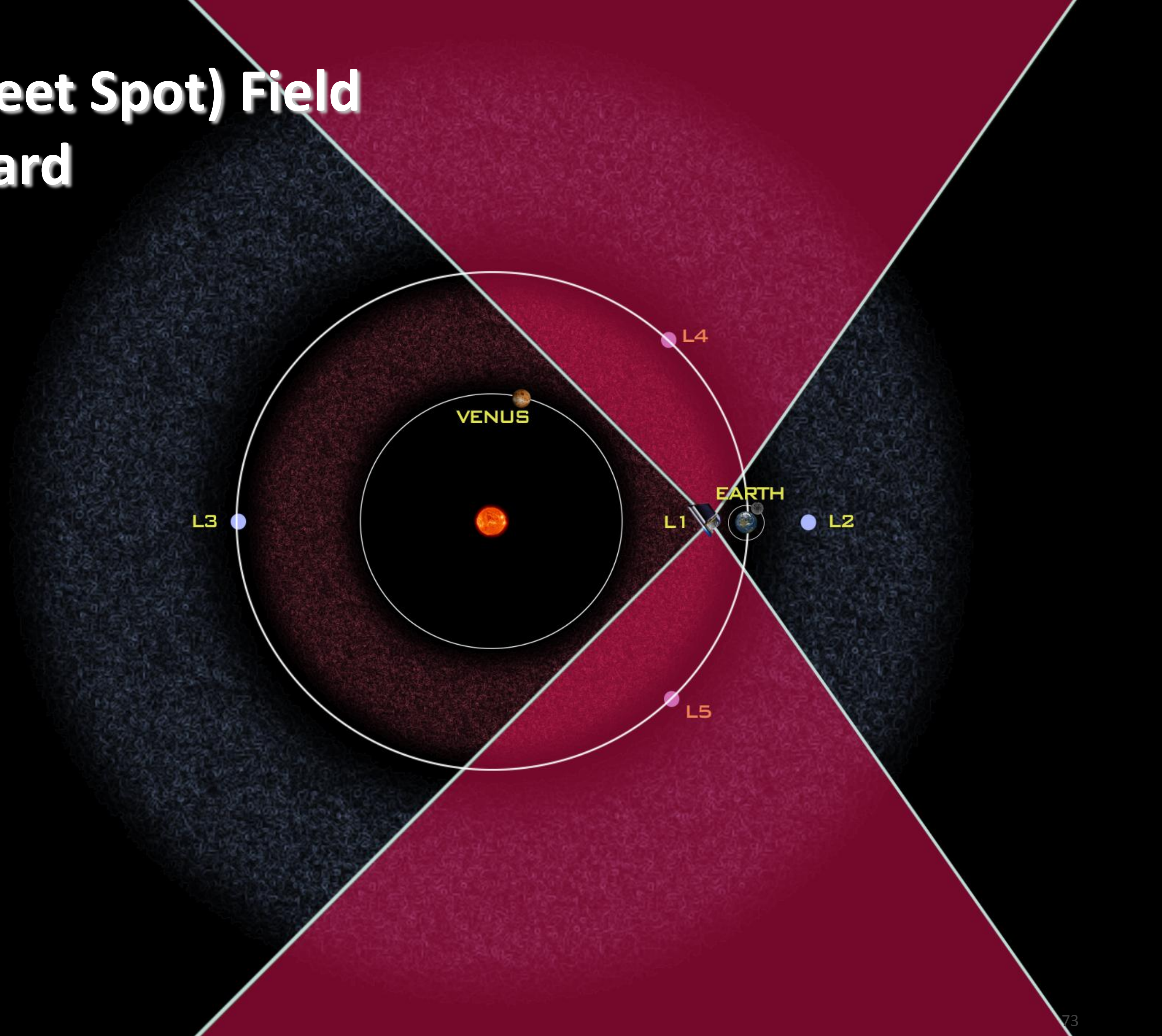
Orbits of Earth & Venus about the Sun with Lagrange points



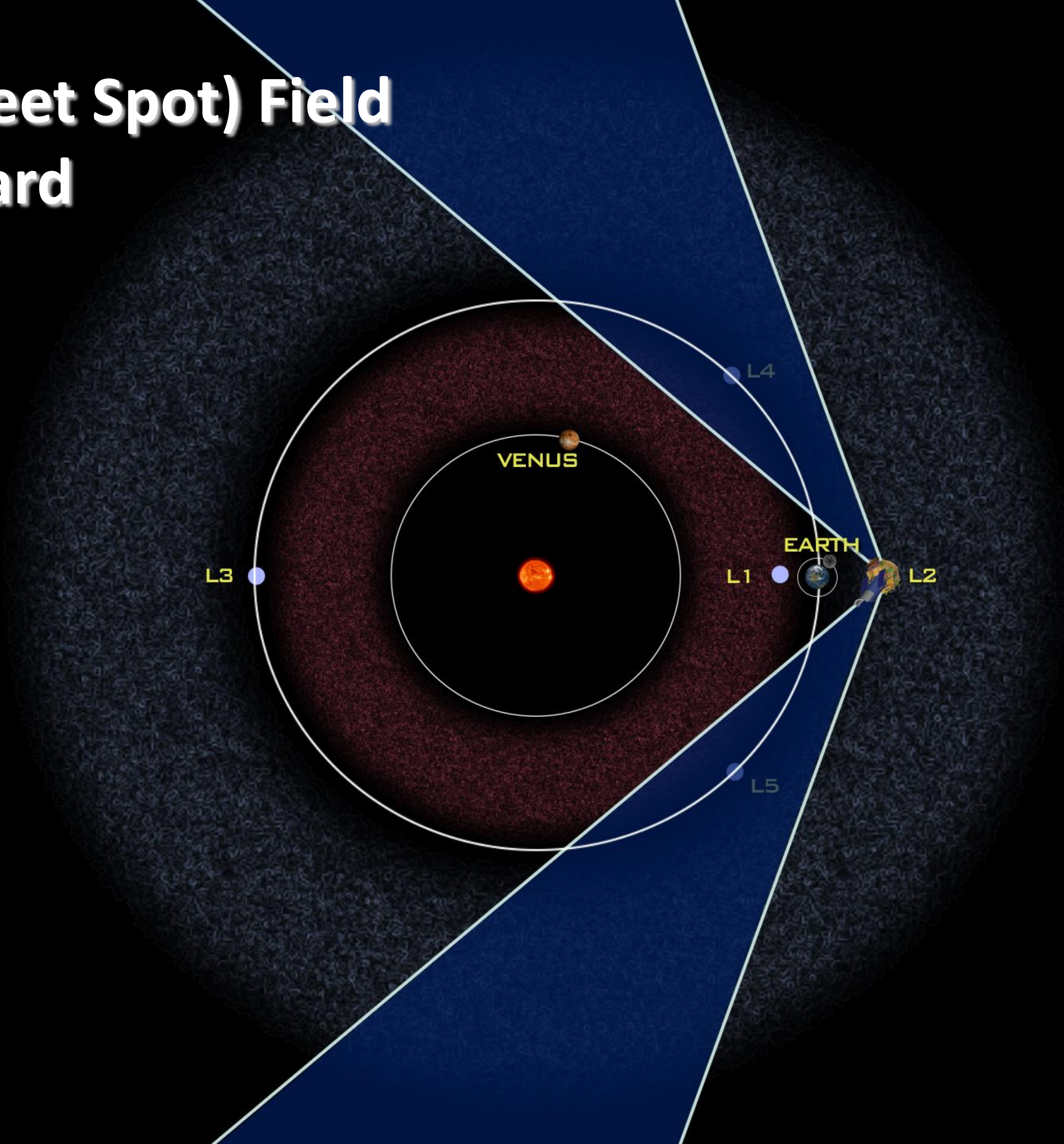
Nominal Search Region of Ground-Based Assets



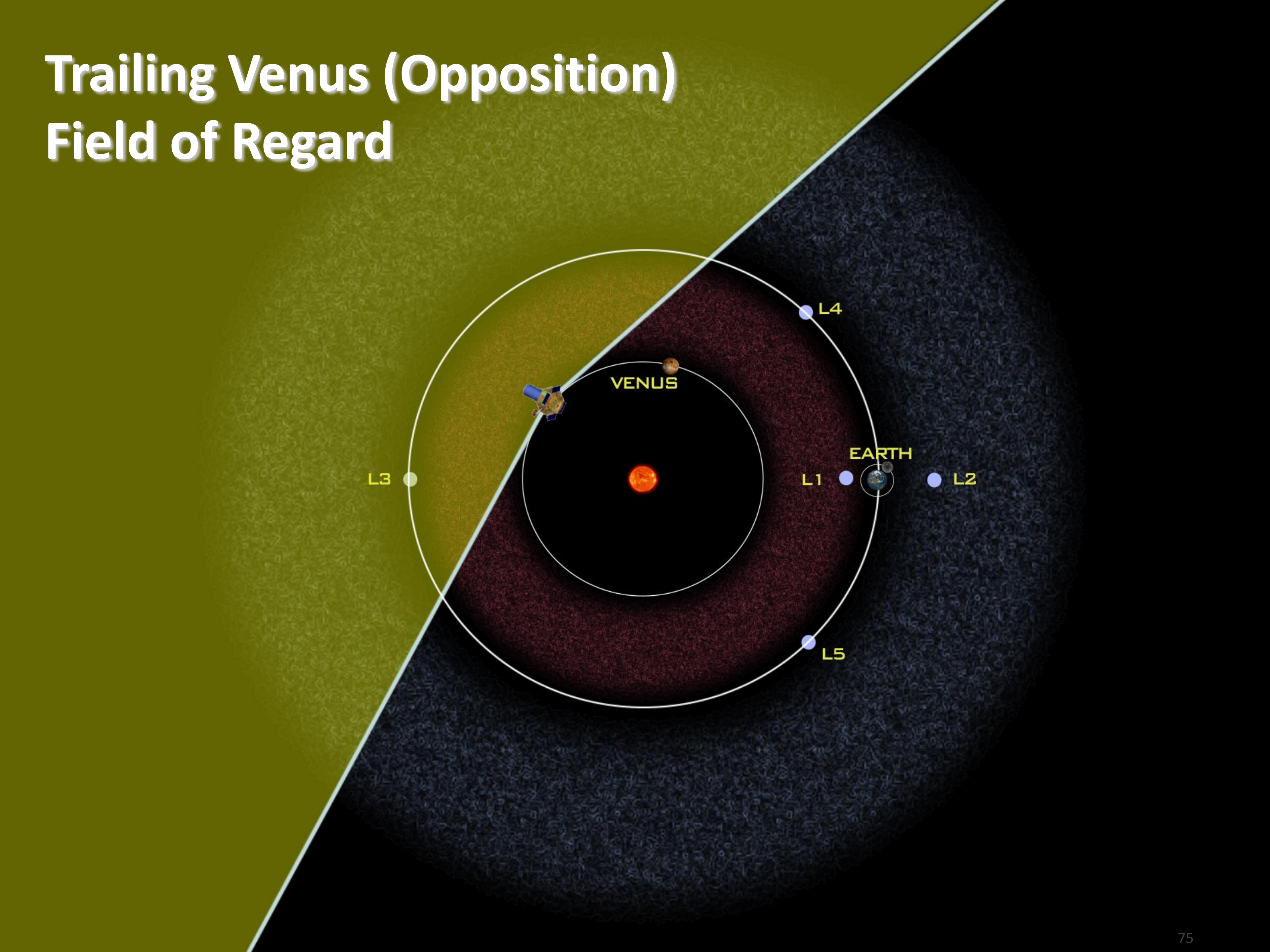
L1 (Sweet Spot) Field of Regard

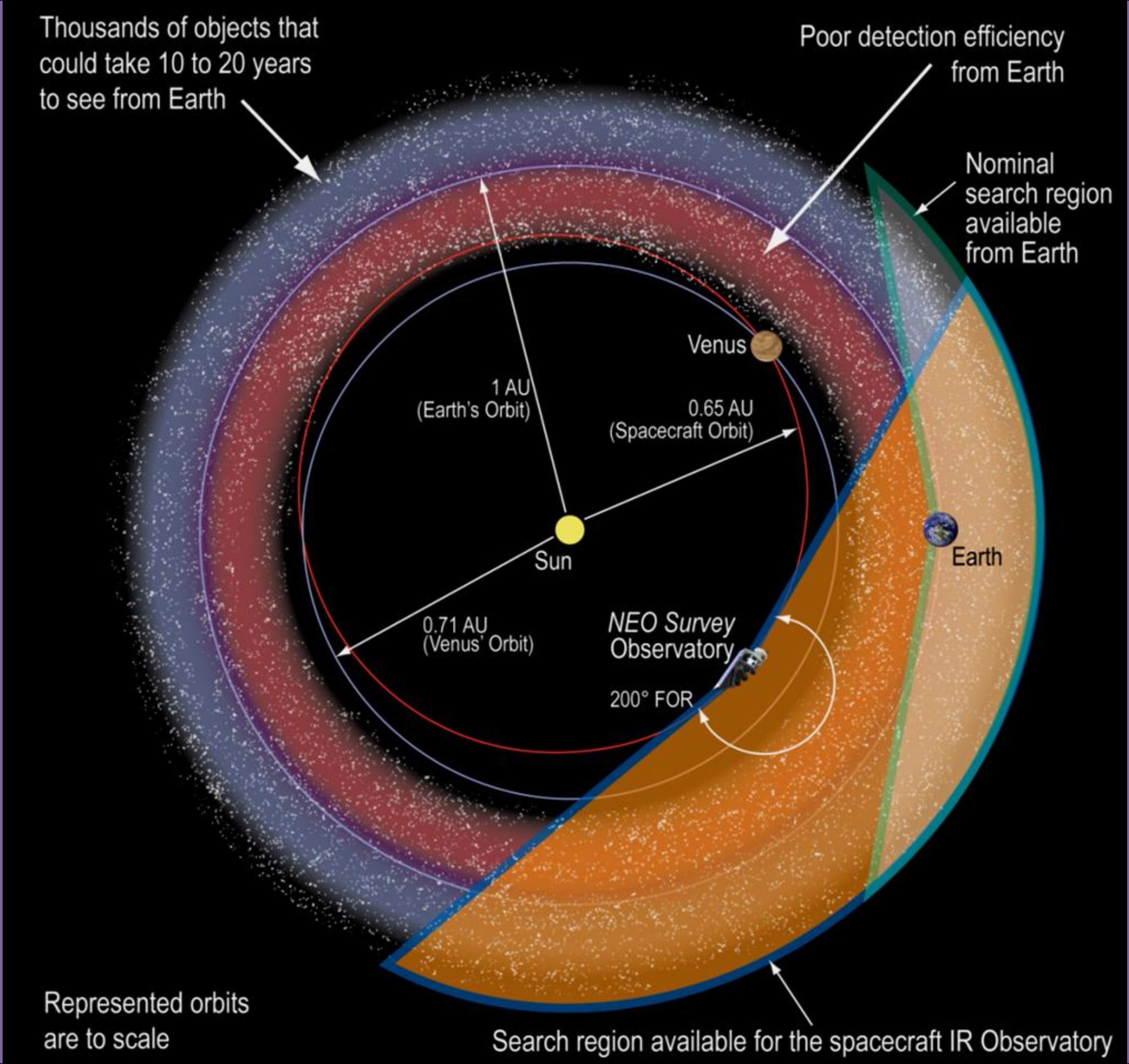


L2 (Sweet Spot) Field of Regard



Trailing Venus (Opposition) Field of Regard




Thousands of objects that could take 10 to 20 years to see from Earth
Poor detection efficiency from Earth
Nominal search region available from Earth
Venus
1 AU (Earth's Orbit)
0.65 AU (Spacecraft Orbit)
Sun
Earth
0.71 AU (Venus' Orbit)
NEO Survey Observatory
200° FOR
Represented orbits are to scale
Search region available for the spacecraft IR Observatory

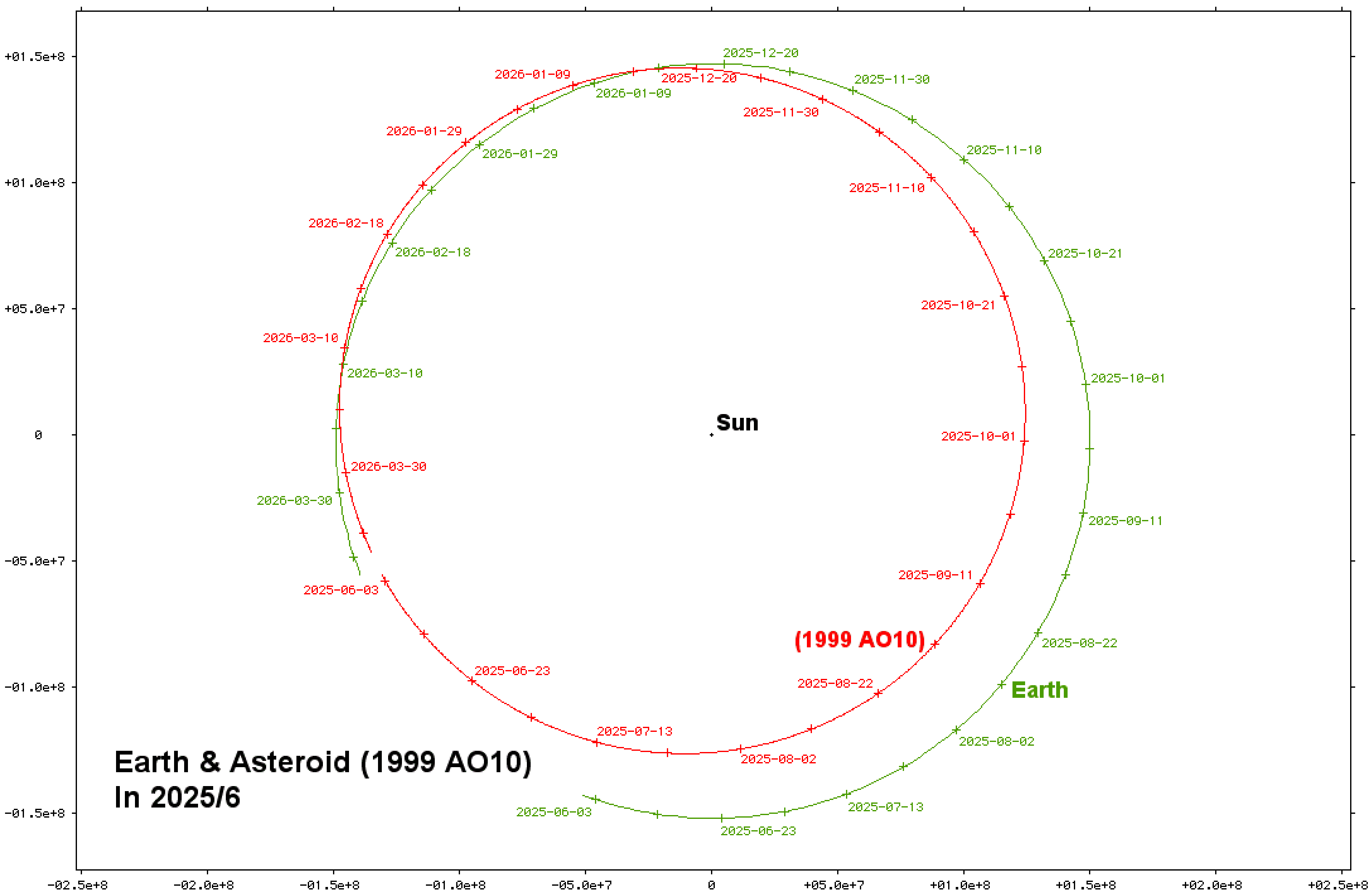
The Need for Prior NEO Characterization

- **Prior to sending a piloted mission to a NEO, additional characterization of the target is <u>required.</u>**
  - Orbit refinement
  - Ground-based characterization (radar, lightcurve, spectra, etc.)
  - *In situ* physical characterization (internal structure, mechanical properties, etc.)

- **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

150-Day Mission to 1999 AO_{10} Heliocentric Trajectory Plot

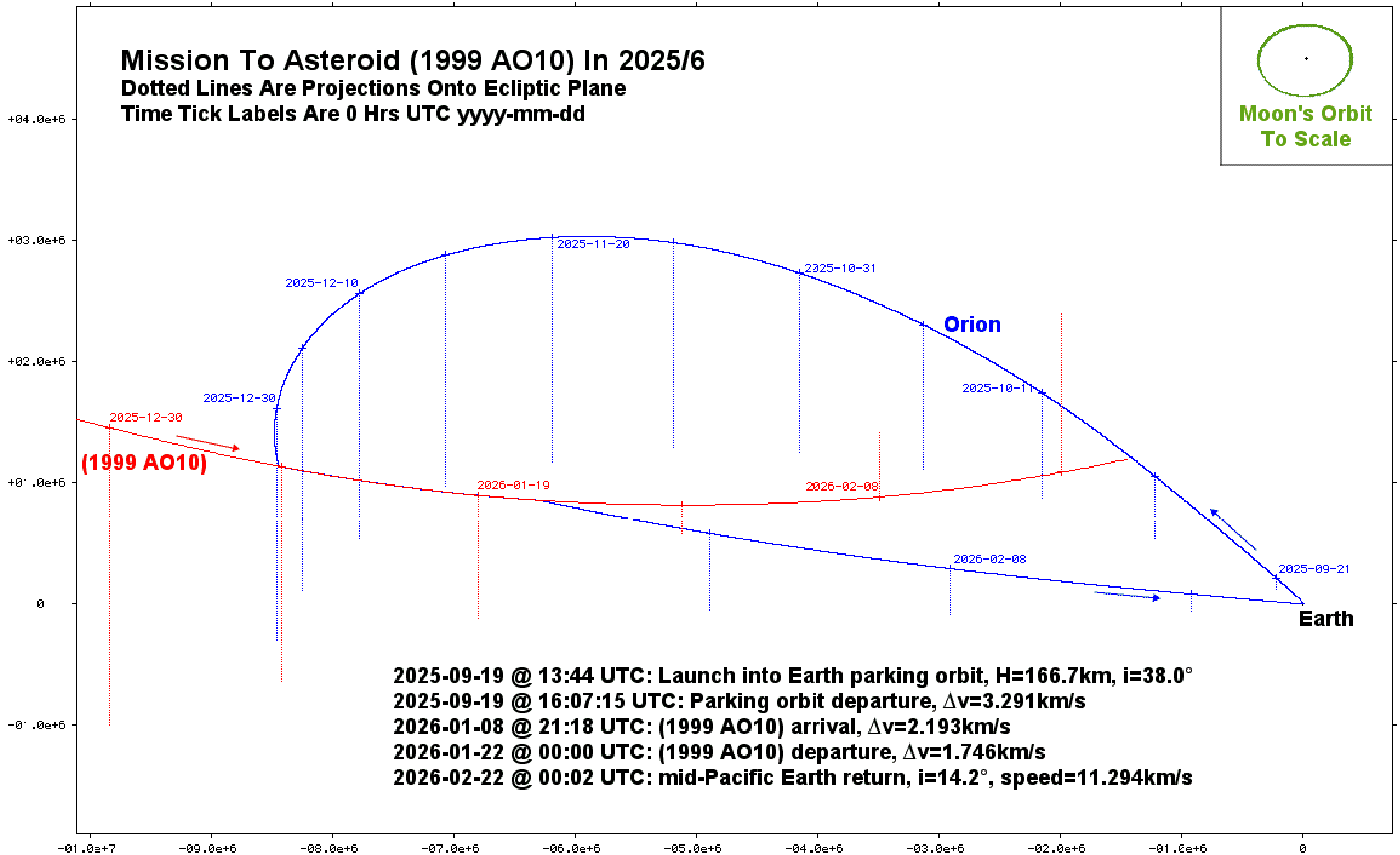


Km Units View From Y= 0.0°, P= 0.0°, R= 0.0°

Sun-Centered J2KE Coordinate System

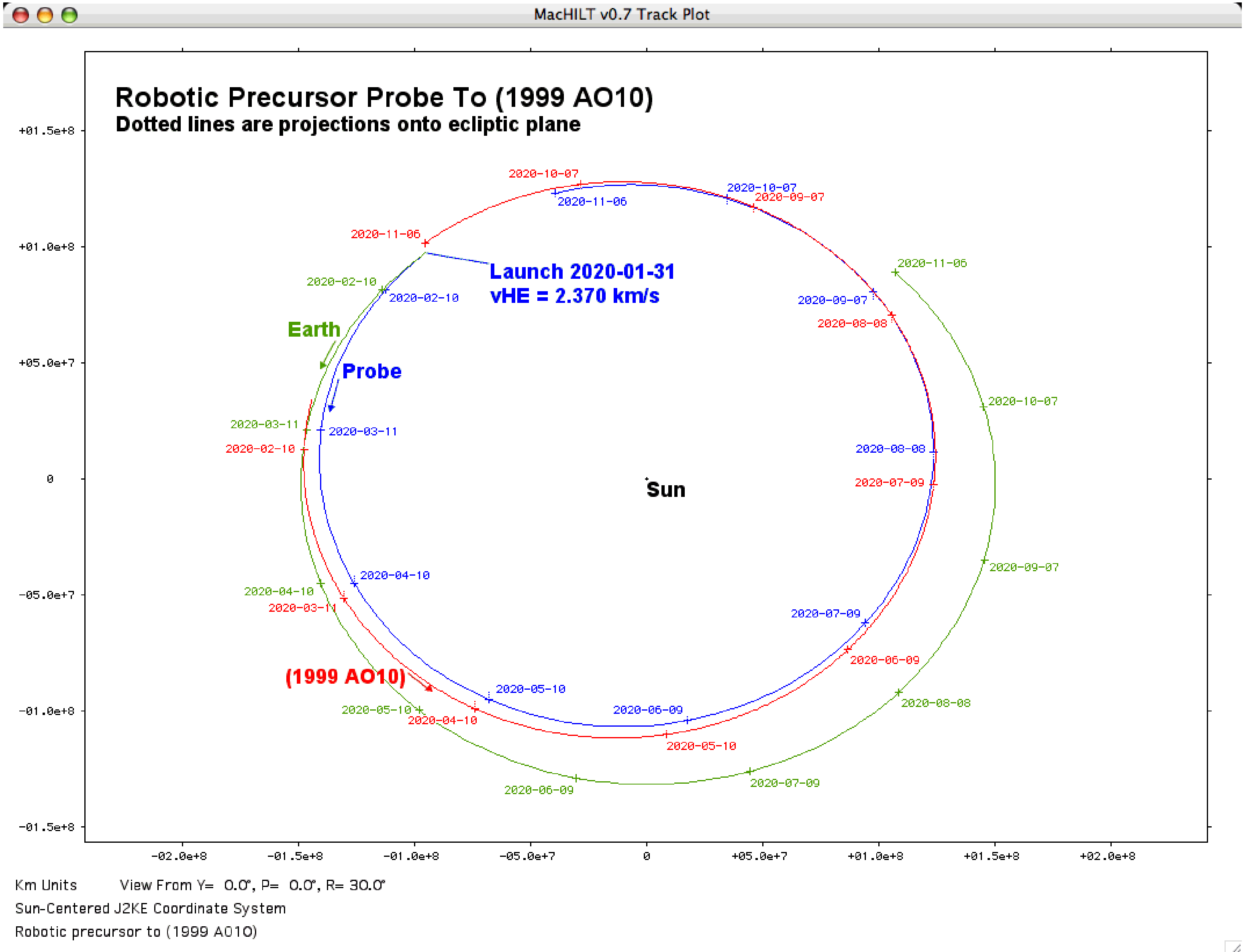
Visit to (1999 AO10)

150-Day Mission to 1999 AO_{10} Earth-fixed Trajectory Plot



Km Units View From Y= 0.0°, P= 0.0°, R= 45.0°
Earth-Centered J2KE Coordinate System
Visit to (1999 AO10)

Robotic Precursor to 1999 AO_{10} Launch on Jan. 31, 2020



Robotic Precursor to 1999 AO_{10} Arrival on May 11, 2022