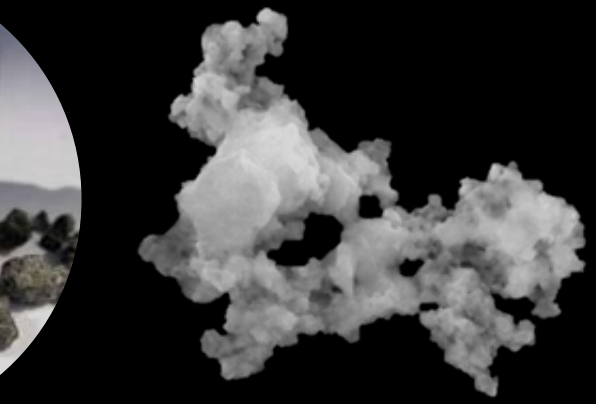
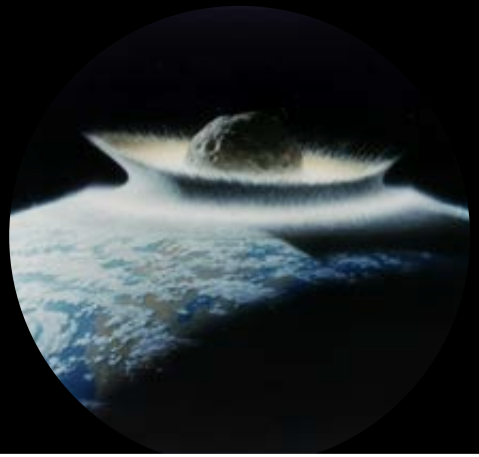



SBAG
SMALL BODIES ASSESSMENT GROUP

Bonnie J. Buratti, SBAG Steering Committee Chair
Jet Propulsion Laboratory, California Institute of Technology

November 13, 2020 Decadal Survey Small Bodies Panel
Virtual Meeting

www.lpi.usra.edu/sbag/

Summary of Talk

- Who we are and what we do
- Summary of Goals Document
- SBAG Findings that are important for the Decadal Survey
- What we did so far to support the Decadal Survey
  - Curated 5 white papers based on the “Big Questions” in the Goals Document
  - Distributed, analyzed, and made into a white paper a community small bodies questionnaire
- Planetary defense: highlights
- Mission priorities
- Human exploration
- Equity, Diversity and Inclusion (EDI) endorsements
- Technology

The Steering Committee

Present Steering Committee

Elena Adams (APL), Technology Lead
Maitrayee Bose (Arizona State Univ.)
Bonnie Buratti (NASA JPL/Caltech), Chair
Michael Busch (SETI Inst.) New
Terik Daly (APL), Early Career Secretary
Mike DiSanti (NASA Goddard)
Jessie Dotson (NASA Ames) Planetary Defense Lead
David Gerdes (U. of Michigan)
Mihaly Horanyi (UC Boulder) New
Stefanie Milam (NASA GSFC) New
William O'Hara (Sierra Nevada Corp.) Human Exploration Lead New
Jennifer Scully (NASA JPL/Caltech)

Members who rotated off in July:

Dan Adamo (independent consultant), Human Exploration Lead
Carolyn Ernst (APL)
Patrick Taylor (LPI)
Andy Rivkin (APL)
Tim Swindle (U. of Arizona), Past Chair

Steering Committee selects Chair and Steering Committee members from among nominations, applications. General membership open.

SBAG Representatives

Thomas Statler NASA Headquarters Liaison
Jake Bleacher Human Exploration and Operations Mission Directorate (HEOMD) Liaison
Paul Abell (JSC) HEOMD Observer

What does SBAG do?

- Seeks broad planetary science community input on small bodies and missions to small bodies.
- SBAG TOR (updated this year) includes in SBAG's charter human and robotic exploration, fundamental research and analysis, resource utilization, and planetary defense; and lists all of the following as being in SBAG's bag: Main Belt Asteroids, Comets, Near-Earth Objects, Meteoroids, Interplanetary Dust and Meteors, Trojans (of all the planets), Centaurs, Trans-Neptunian Objects (TNOs), Dwarf Planets, small planetary satellites (including Phobos, Deimos, and the irregular satellites of the Giant Planets), and Meteorites and returned samples from any of these objects
- Holds open meetings twice each year for community participation. **Decadal white paper workshops were held at the last two meetings.**
- Maintains a Goals Document.
- Makes findings: community-based concerns and issues and transmits them to NASA; many are relevant to the Decadal Survey

The SBAG goals document

https://www.lpi.usra.edu/sbag/goals/

- New goals document posted February 2020
- New document preserves the three goals listed on the right.
- Technology and human exploration sections are included
- In situ resource utilization (ISRU) section will be updated in the next goals document
- All goals will be addressed by the Decadal Survey

Goal 1: Small Bodies, Big Science.

Investigate the Solar System's formation & evolution & advance our knowledge about the early Solar System conditions necessary for the origin of life through research & exploration uniquely enabled by small bodies.

Goal 2: Defend Planet Earth.

Understand the population of small bodies that may impact our planet & develop ways to defend the Earth against any potential hazards.

Goal 3: Enable Human Exploration.

Advance our knowledge of potential destinations for human exploration within the small body population & develop an understanding of the physical properties of these objects that would enable a sustainable human presence beyond the Earth-Moon system.

Highlights of of 2019-2020 findings that are relevant to the Decadal Survey

(**Full text and NASA response at https://www.lpi.usra.edu/sbag/findings/**) **Repeated SBAG findings** (orange is just for easier reading)

June 2020:

- SBAG urges NASA to include Ceres as an "Ocean World" when considering missions to that category of Solar System bodies, including the upcoming New Frontiers round if applicable.
- SBAG encourages NASA to develop a process that would permit US scientists to participate in missions led by non-US space exploration agencies (e.g., ESA, JAXA, CSA, etc.), including during the early stages of these missions [US Participating Scientist Programs supported in June 2019 finding]
- The SBAG community reaffirms its awareness of the unique observational capabilities supplied by planetary radar and urges NASA to apply continued effort toward achieving at least one operational planetary radar facility at all times and particularly at scheduled high-priority observation events. [Note: currently there is no radar capability at Arecibo due to the August 10th broken cable event; the observatory would be offline at least through March 2021 (the next approach Apophis will be observable only with Goldstone for radar).]

Highlights of of 2019-2020 findings that are relevant to the Decadal Survey

(Full text and NASA response at https://www.lpi.usra.edu/sbag/findings/)

January 2020:

- SBAG endorses the recommendations of the recent report on *Strategic Investments in Instrumentation and Facilities for Extraterrestrial Sample Curation and Analysis* from the National Academies of Sciences, Engineering, and Medicine. SBAG endorses the recommendations of the report in full, including an increase in investments to maintain and renew planetary equipment with the introduction of new capabilities, to sustain technical staff over the long term, and to train the next generation workforce. [Also mentioned in January 2019 Findings]
- SBAG encourages NASA to support preparatory work dedicated to maximizing planetary science from both ground-based and space-based assets. There is great near-term potential for small-body science with LSST [Vera C. Rubin Observatory], and longer-term prospects with TMT, GMT, WFIRST, and other facilities. . [Also mentioned in January 2019 Findings, with encouragement of tools and workshops]
- SBAG reiterates its support for the NEOCam asteroid survey mission [now NEOSurveyor], which could provide a major contribution towards the fulfillment of the George E. Brown congressional goal of discovering 90% of the near-Earth asteroid population larger than 140 meters in size, while characterizing the diameters of a significant fraction of that NEA population. [Also mentioned in June&January 2019 findings]
- SBAG endorses NASA's efforts to improve diversity in mission teams and to encourage the demographics of the planetary science field to more closely resemble the demographics of the nation at large.

Highlights of of 2019-2020 findings that are relevant to the Decadal Survey

(Full text and NASA response at https://www.lpi.usra.edu/sbag/findings/)

June 2019:

- SBAG supports continued Center for Near Earth Object Studies (CNEOS) Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) processing and associated public webpage postings. This effort provides a database of near-Earth asteroid (NEA) targets and mission profiles relevant to human roundtrips from Earth
- SBAG supports continued Center for Near Earth Object Studies (CNEOS) Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) processing and associated public webpage postings. This effort provides a database of near-Earth asteroid (NEA) targets and mission profiles relevant to human roundtrips from Earth
- SBAG expresses its enthusiastic support for ESA's Hera mission, which will significantly advance the goals of planetary defense.
- SBAG urges the National Academies to select a Planetary Decadal Survey Committee that reflects the demographic makeup of the planetary science community. [January 2019 encouraged diversity on teams and selections]

January 2019 key findings all reiterated later.

Decadal Survey, summary of SBAG actions

- SBAG curated five broadly supported white papers based on five “Big Questions” (next viewgraph, which in turn were based on our Goals Document.
- The January 2020 meeting included a workshop in which the community signed up for individual papers that covered the major small body targets.
- Specific mission white papers or technology white papers were not organized by SBAG
- SBAG sent out a questionnaire to the community on science and mission priorities that was turned into a white paper.
- SBAG endorsed several Diversity, Inclusivity and Equity papers, and other workforce or climate papers. MAPSIT White Paper was also endorsed

Big questions for the Decadal Survey (based on Goals Document) that formed the basis of five SBAG-intiated White Papers

- What do small bodies tell us about the formation of the Solar System and the conditions in the early solar nebula?
- What does the distribution, composition, and sizes of small bodies tell us about the evolution of the Solar System, including its dynamical history, cratering processes, and the influx of volatiles and organics into the inner Solar System?
- Do sustainable habitable environments exist on any of the small bodies?
- What are the main geological processes that determined the evolution and current state of the small bodies and are they similar to those on larger bodies?
- What threat do Near-Earth Objects pose to civilization and life on Earth, and how can we quantify and mitigate that threat?

Summary of white papers, cont.'d (see https://www.lpi.usra.edu/decadal/sbag/)

Main White Papers Based on Scientifc Goals	Relevant Targets	Lead Author
What do small bodies tell us about the formation of the Solar System and the conditions in the early solar nebula?	KBOs; Small satellites; Comets; Asteroids; Interstellar bodies	Bjorn Davidsson (JPL)
The Evolution of Small Body Populations: from Planet Migration to Thermal Drift Forces What does the distribution, composition, and sizes of small bodies tell us about the evolution of the Solar System, including its dynamical history, cratering processes, and the influx of volatiles and organics into the inner Solar System?	All	Bill Bottke (SWRI), JJ Kavelaars (Dominion Astrophysical Observatory)
Do sustainable habitable environments exist on any of the small bodies?	Ceres; large KBOs	Julie Castillo-Rogez (JPL)
What are the main geological processes that determined the evolution and current state of the small bodies and are they similar to those on larger bodies?	All	Carol Raymond (JPL)
The Future of Planetary Defense in the Era of Advanced Surveys. What threat do Near-Earth Objects pose to civilization and life on Earth, and how can we quantify and mitigate that threat?	NEOs	Amy Mainzer (LPL)

Most of the other small body white papers, including ones on Main Belt asteroids, comets, dust, KBOs, interstellar objects, Centaurs, Pluto, and small moons, are also listed and linked at the above web site. Many were encouraged by SBAG during the January 2020 workshop. Copies of the submitted white papers are on the Academy website: https://www.nationalacademies.org/our-work/planetary-science-and-astrobiology-decadal-survey-2023-2032

The Questionnaire

Mark Sykes commissioned a SBAG-led questionnaire for the previous Survey. The questions covered missions and research priorities. The questions were updated by the current SBAG Steering Committee and distributed to the community. The results were submitted as a white paper.

Summary: SBAG surveyed the small bodies community for input to the Planetary Decadal Report. Seventeen questions on science and mission priorities were answered by 121 respondents. The highest priority scientific issues for small bodies were population identification and physical/compositional characterization; understanding the characteristics and evolution of individual objects; determination of the early conditions in the Solar System; and completion of the catalogue of PHAs. The highest priority flagship mission was a comet sample return followed by a Pluto orbiter/KBO mission. A comet sample return was also the highest priority New Frontiers mission, followed by a Ceres lander and a Main Belt multiple asteroid mission. Emphasis was also placed on the importance of ground-based and Earth orbiting telescopes (including radar), laboratory studies, and theory. The group also advocated preserving research funding over missions in the event of budget pressures.

Planetary Defense: Highlights from the Goals Document (More Details in the Backup)

- Identify and track potentially hazardous objects.
- Characterize the properties of near-Earth objects to advance our understanding both of the threats posed to our planet and of how Earth impacts may be prevented in the future.
- Develop and maintain rigorous models to assess the risk to Earth from the wide-ranging potential impact conditions.
- Develop robust mitigation approaches to address potential impactor threats. Main ones are: Kinetic Impactor (KI; DART is testbed), Nuclear Explosive Device (NED), Gravity Tractor (GT), and Ion-Beam Deflection (SBAG, 2020).
- Establish coordination and civil defense strategies and procedures to enable emergency response and recovery actions.

Mission priorities

The Goals Document lists missions by targets and does not prioritize. SBAG did not curate mission white papers. Information from the SBAG questionnaire was incorporated to present this (imperfect) consensus

Discovery:

- Diverse objects; especially those not represented in the meteorite collection

New Frontiers:

- Comet surface sample return (mentioned in Goals Document and first priority on SBAG questionnaire)
- KBO tour (in Goals Document)
- Ceres Lander (not in Goals Document, but its place as an ocean world with astrobiological potential has ascended since the document was published).
- Main Belt Tour mentioned in SBAG questionnaire; it is an "upscope" of the Discovery concept of capturing a diversity of objects.
- Trojan tour: in Goals Document but not as compelling because of *Lucy*

Flagship:

- Cryogenic comet sample return (#1 in the SBAG questionnaire and mentioned in the Goals Document)
- Pluto orbiter plus KBO tour (not mentioned in Goals Document, but it is an "upscope" of the KBO tour)
- SBAG strongly supports the investigation of small bodies (Mars moons, outer irregular moons of the gas and ice giants; Centaur flyby enroute) as an integral part of a Flagship mission

Targets for New Frontiers (or not?)

SBAG is homing in on the following consensus, which is quoted from an email exchange among the committee:

“Have the Decadal recommend a set of targets *and* recommend a time frame (< 10 years) on which NASA should ask for a reassessment. These proposals are a huge investment and when the prioritization is left entirely up to the review panel the results are often swayed by the perspective of the handful of panelists. The community (and science) definitely benefit from a prioritization that involves a larger fraction of the community.” – Jessie Dotson

There is already in place a mid-term review of NASA's progress with respect to the Decadal Survey goals and objectives. Perhaps it is reasonable to have a review of the target priorities by NAS prior to a release of a new NF Mission AO.

Human Exploration: NEOs and moons of Mars

Because NEOS are the most accessible targets (see backup), and Phobos and Deimos are stepping stones - essentially space stations - to Mars Exploration, small bodies are important for human exploration. The Goals Document says to:

Advance our knowledge of potential destinations for human exploration within the small body population and develop an understanding of the physical properties of these objects that would enable a sustainable human presence beyond the Earth-Moon system.

- *Discover and characterize Near-Earth Object Human Space Flight Accessible Targets (NHATs; composition; dynamical and mechanical properties)*
- *Understand how to work on or interact with the surfaces of small bodies*
- *Understand the small body environment and its potential risk/benefit to crew systems, and operational assets*
- *Evaluate and utilize small body resources relevant to human exploration*

EDI Endorsements

A pan-AG group (Equity, Diversity Inclusion Working Group – EDIWOG) curated several white papers that we endorsed (below). SBAG is concerned there is no EDI Panel for the Decadal

Title	Lead author
Who is missing in Planetary Science?: A Demographics study of the planetary science workforce	Ed Rivera-Valentin
Who is missing in Planetary Science?: Recommendations to increase the number of Black and Latinx scientists	Julie Rathbun
Ensuring a safe and equitable workspace: The importance and feasibility of a Code of Conduct	Serina Diniega
Breaking Down Barriers: Accessibility in Planetary Science	Jen Piatek
Lessons learned from the ASTRO Decadal Survey White Papers	Christina Richey
LGBTQ+ in Planetary Science	Kathleen Vander Kaaden
Recommendations from the CSWA Survey on Workplace Climate	Christina Richey
The Preventing Harassment in Science Workshop: Summary and Recommendations of Best Practices for Planetary Science and Astrobiology	Kristen Bennett
Building Safer And More Inclusive Field Experiences In Support Of Planetary Science	Jacob Richardson

Technology

SBAG did not curate a technology white paper. However, the Goals Document and the SBAG Questionnaire have a lot to say. Here is a summary of the most key technologies from the Questionnaire:

Unique to small bodies

There are four pages on the website. Answers include RTGs, robotics/autonomous systems for spacecraft, including for small NEO flybys; improved power systems; landers; magetometry; advanced solar electric propulsion; large-area imaging detectors that provide high sensitivity and low noise at ambient temperature, e. g. graphene-monolayer-based sensors; reusable launch vehicles; cubesats including ridealongs; Spatial Heterodyne Spectrometers (SHS); volatile sample return preservation and curation, long-duration (15 years) spaceflight parts qualification; in situ instrumentation for asteroid flyby missions; further development of asteroid impact deflection technologies; smaller, lighter, and lower power-consumption; cryogenic sample return; multiband lidar; surface contact characterization of mechanical properties; contamination control - including low-outgassing materials for all types of components; more compact, less expensive mass spectrometers; next generation neutron spectrometers; observatory facilities capable of detecting asteroid outgassing; drilling and storage on icy surfaces, applicable to both comets and ocean worlds; AI to preprocess data before transmitting to the Earth; Small-sats, including constellations; instruments for geophysical investigation; instrument miniaturization; deployable radar architecture; detection and deflection infrastructure on land and in space to provide earliest possible detection of PHOs and launch-ready capability to deflect objects of any size with little warning; lidar; surface instruments for use in microgravity: sample collection, drilling; sample sealing/containment and hermetic seal validation in space; high-end computing; inflatable components (that can be made rigid); laser instrumentation, AFM, microprobes, microscopes, vacuum chamber technology; in situ instruments that can do more analysis at the target.

Summary and future

- Next Meeting: January 26-27, 2021, virtual
- SBAG Findings are based on broad community input, represent the consensus of the community, and pinpoint persistent problems that need attention at the highest levels.
- SBAG Decadal White Paper work
  - Oversaw a collection of Decadal White Papers that represent broad science questions and community input.
  - Distributed and analyzed a questionnaire on research and mission priorities that was produced as a white paper.
  - “Supervised” (lightly) target papers, but not mission papers or technology
  - The Steering Committee endorsed some of the Decadal papers on Diversity, Inclusion, and Equity, and workforce and climate issues.
  - Prepared to assist the Decadal Small Bodies Committee in any way we are asked.

Backup

- More information on Planetary Defense (from Goals Document)
- Human Exploration of NEOs

Identify and track potentially hazardous objects

- Maintain and improve ground-and space-based surveying capabilities.

Several studies (Stokes et al. 2003; National Research Council, 2010, Stokes et al. 2017) have recommended that a space-based infrared survey be conducted in concert with a large-aperture ground-based survey: such a combination could complete the survey of objects larger than140 meters well before 2030, as well as increasing the total number of known NEOs of smaller sizes by more than an order of magnitude.

- Maintain and improve the process for rapid identification of imminent impactors, to enable wide-ranging characterization of these bodies prior to and after impact.

To accelerate the identification of imminent impactors, an automated system has been implemented by NASA's Jet Propulsion Laboratory (https://cneos.jpl.nasa.gov/scout/) to provide a continually updated online assessment of impact possibilities for objects on the Minor Planet Center NEO Confirmation Page (NEOCP). The system also automatically sends notification messages to follow-up observers for possible imminent impactors.

Physical Characterization

- Maintain a robust program of ground-based – including radar – and space-based assets to characterize the sizes, albedo, composition, and dynamical state of NEOs
- Place high priority on in situ measurements through sample returns, including a New Frontiers class mission

Develop and maintain rigorous models to assess the risk to Earth

- Understand the effects and potential damage from an atmospheric airburst or surface impact event
- Develop, maintain, and exercise risk assessment tools that are capable of near-real-time risk and damage assessment to support decision makers in the event of an imminent impact threat. Over the last fe

These tools combine entry, impact, and hazard models to provide near-real-time risk updates (impact probability, expected impact corridor, expected range of damage, etc.) as knowledge of the approaching object improves. As models of hazards (airburst, impact, tsunami, global effects, etc.) improve, they are incorporated into these models

Goals Document, p. 31

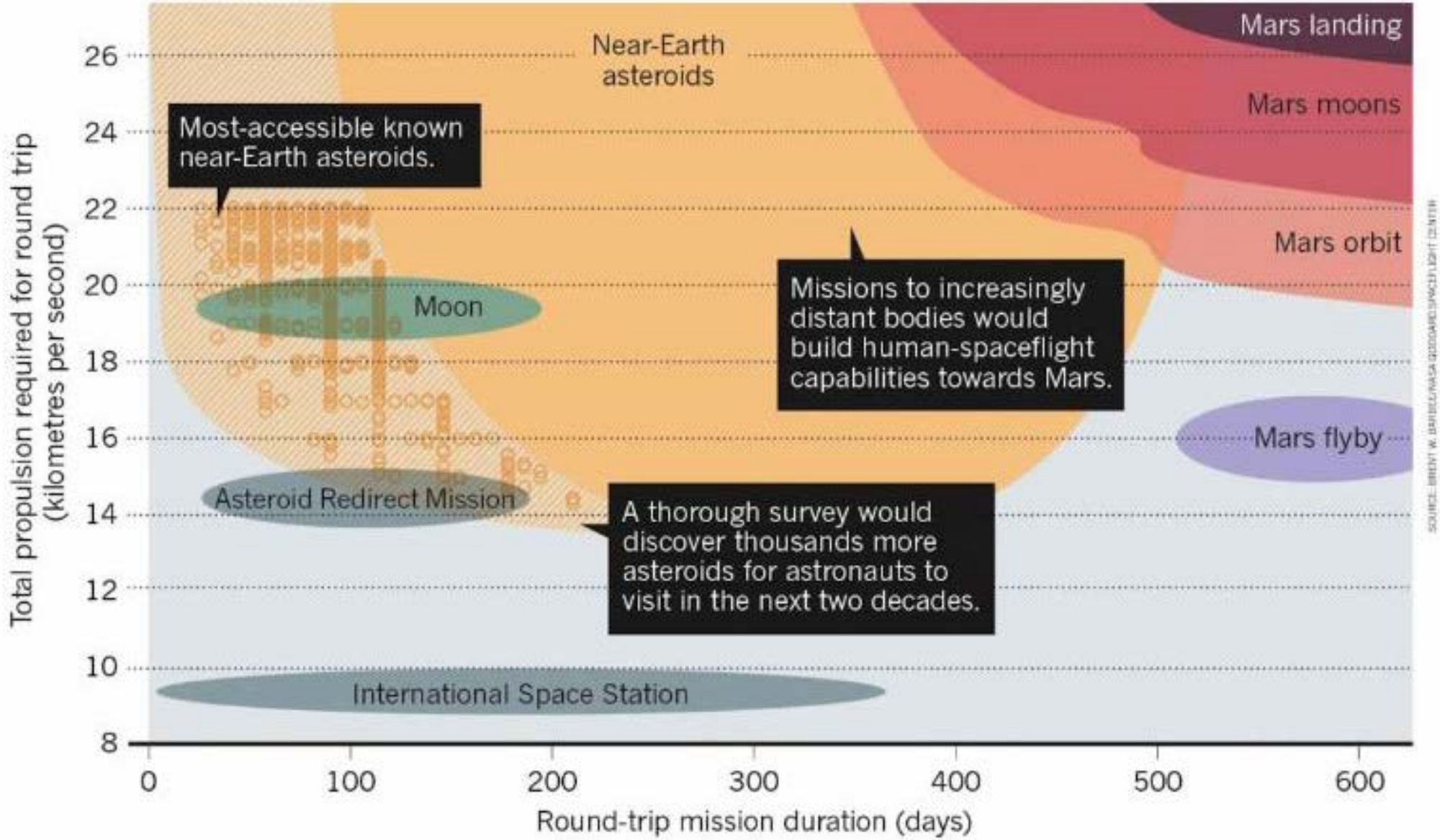

Figure 3.1. *A mission to a near-Earth object can require less propulsion and a shorter mission duration than a human mission to any other celestial target. Less than 1% of the estimated population of most accessible NEOs are currently known (yellow circles), but a dedicated space-based survey (filling in the yellow-hatched region) would reveal abundant NEO stepping-stone opportunities as a gateway for interplanetary exploration.*