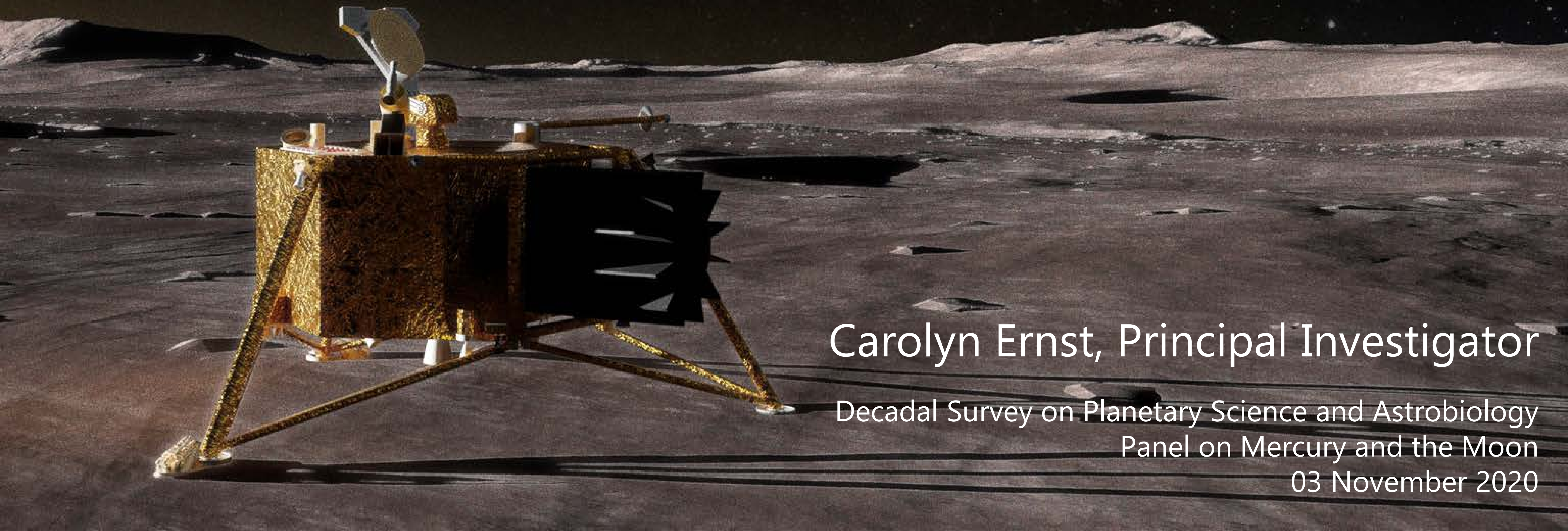
PLANETARY MISSION CONCEPT STUDY FOR THE 2023–2032 DECADAL SURVEY

Mercury Lander

Transformative science from the surface of the innermost planet

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY



Carolyn Ernst, Principal Investigator

Decadal Survey on Planetary Science and Astrobiology
Panel on Mercury and the Moon
03 November 2020

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Transformative science from the surface of the innermost planet

Science Team:

Carolyn Ernst, APL (PI); Nancy Chabot, APL (Deputy PI); Rachel Klima, APL (Project Scientist); Paul Byrne, NCSU; Steven Hauck, CWRU; Kathleen Vander Kaaden, Jacobs/JSC; Ron Vervack, APL; Sebastien Besse, ESA; David Blewett, APL; Brett Denevi, APL; Sander Goossens, UMBC; Stephen Indyk, Honeybee; Noam Izenberg, APL; Catherine Johnson, PSI; Lauren Jozwiak, APL; Haje Korth, APL; Ralph McNutt, APL; Scott Murchie, APL; Patrick Peplowski, APL; Jim Raines, University of Michigan; Elizabeth Rampe, JSC; Michelle Thompson, Purdue; Shoshana Weider, NASA HQ (NASA POC)

Engineering Team (APL):

Sanae Kubota (Lead); Gabe Rogers (Deputy Lead); Norman Adams; Justin Atchison; Dewey Barlow; Brian Bubnash; Stewart Bushman; Douglas Crowley; Jack Ercol; Derick Fuller; Daniel Gallagher; David Gibson; David Grant; Meagan Hahn; Gary Holtzman; Justin Kelman; Kathy Kha; Christopher Krupiarz; Donald Mackey; Deva Ponnusamy; Jackson Shannon; Benjamin Villac; Marcie Steerman; Gloria Crites; Christine Fink; Ben C. Smith; Matt Wallace

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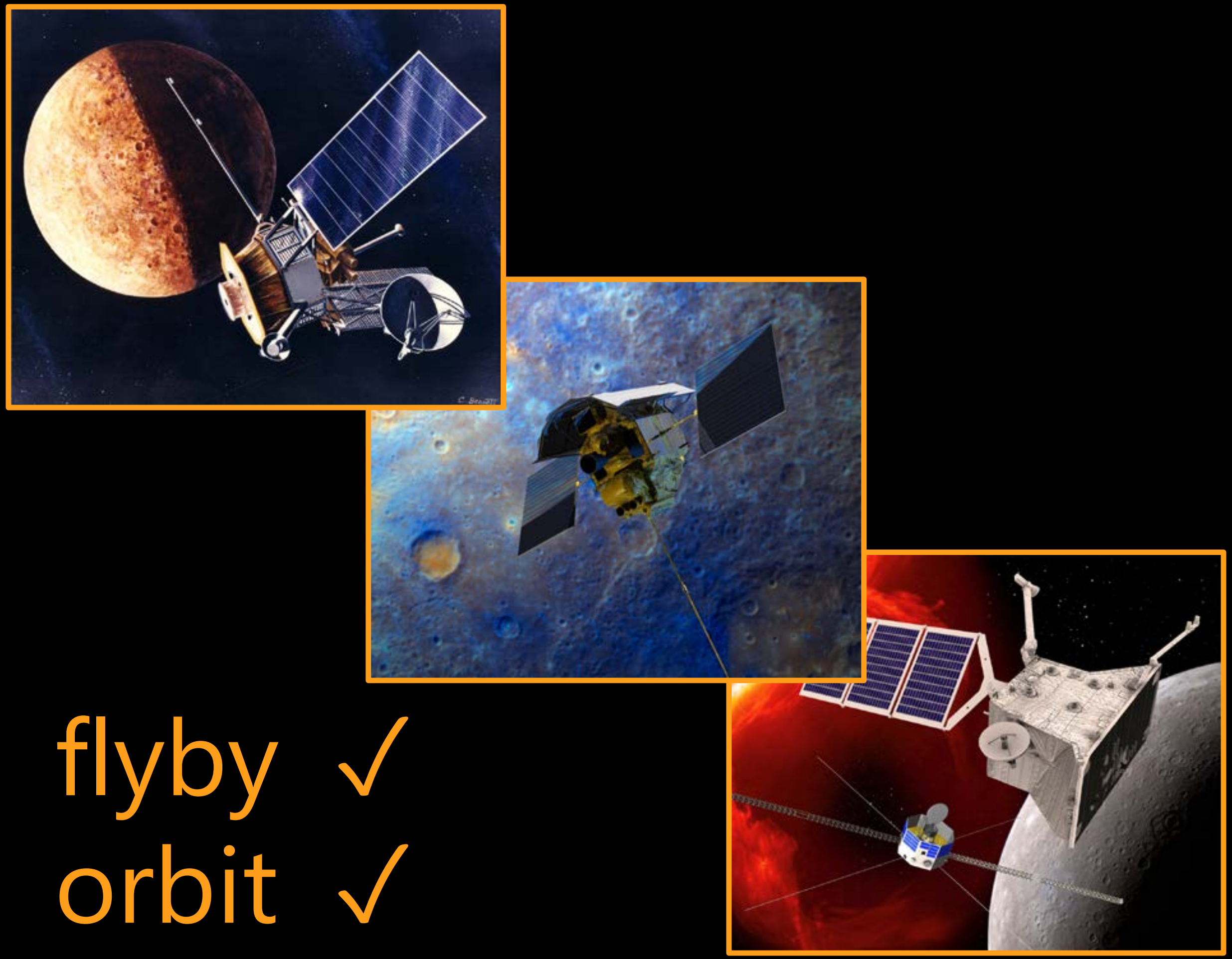
Spacecraft Reconnaissance of Mercury



flyby ✓
orbit ✓
land __

- **Previous Decadal Study**
  - Limited lander concept study completed in 2010
  - Concluded too challenging and expensive for New Frontiers in the last decade

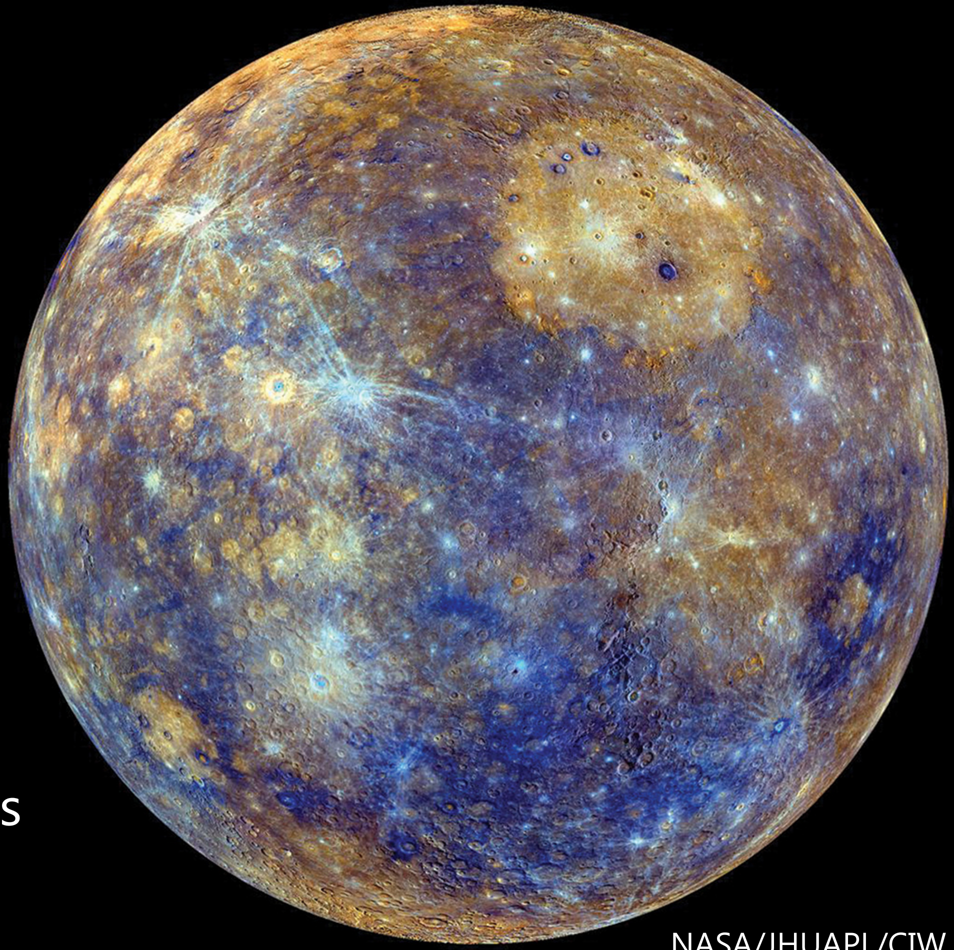
- **Significant advances in the last decade make it important to perform a new study for a new decade**
  - MESSENGER orbital observations
  - Technology and capability advances
  - Changes to NF costing

Why Land on Mercury?

- MESSENGER revealed Mercury's highly chemically reduced and unexpectedly volatile-rich composition
    - Unique among the terrestrial planets
    - Unlike any predictions of previously proposed hypotheses of the planet's origin

- *In situ* measurements from the surface are needed to:
    - Understand Mercury's unique mineralogy and geochemistry;
    - Constrain the massive core's structure;
    - Measure its active and ancient magnetic fields at the surface;
    - Investigate the processes that alter its surface and produce its exosphere;
    - Provide ground-truth for remote datasets.

- As an end-member of terrestrial planet formation, Mercury holds unique clues about the original distribution of elements in the earliest stages of the solar system and how planets (and exoplanets) form and evolve in close proximity to their host stars.



NASA/JHUAPL/CIW

Science Goals

- **Goal 1 (geochemistry):** Investigate the highly chemically reduced, unexpectedly volatile-rich mineralogy and chemistry of Mercury's surface, to understand the earliest evolution of this end-member of rocky planet formation.
- **Goal 2 (geophysics):** Investigate Mercury's interior structure and magnetic field, to unravel the planet's differentiation and evolutionary history and to understand the magnetic field at the surface.
- **Goal 3 (space environment):** Investigate the active processes that produce Mercury's exosphere and alter its regolith, to understand planetary processes on rocky airless bodies, including the Moon.
- **Goal 4 (geology):** Characterize the landing site, to understand the processes that have shaped its evolution, to place the *in situ* measurements in context, and to enable ground truth for global interpretations of Mercury.

Study Philosophies

- There is no shortage of transformative science that can be done by the first landed mission to the innermost planet. Consequently, two overarching philosophies were adopted for this concept study:
  - **Investigate a comprehensive, scientifically robust payload spanning the wide-ranging science measurements that could be made in situ on Mercury's surface.**
    - Coverage of all four goals in fairly equal detail
    - Inclusion of a large number of instruments to provide a more valuable resource for the science community when planning a landed mission to Mercury in the future
  - **Prioritize landing safely on Mercury.**
    - Focus resources on this fundamental challenge, without which landed science is not possible
    - Considered only payload implementations that leveraged previous development efforts; the first landed measurements on the surface of Mercury are so fundamental that they can be made by current existing instrumentation
- The only absolute requirement to achieve ground-breaking science from a Mercury Lander is to perform *in situ* measurements on the surface of Mercury.

Study Flexibility

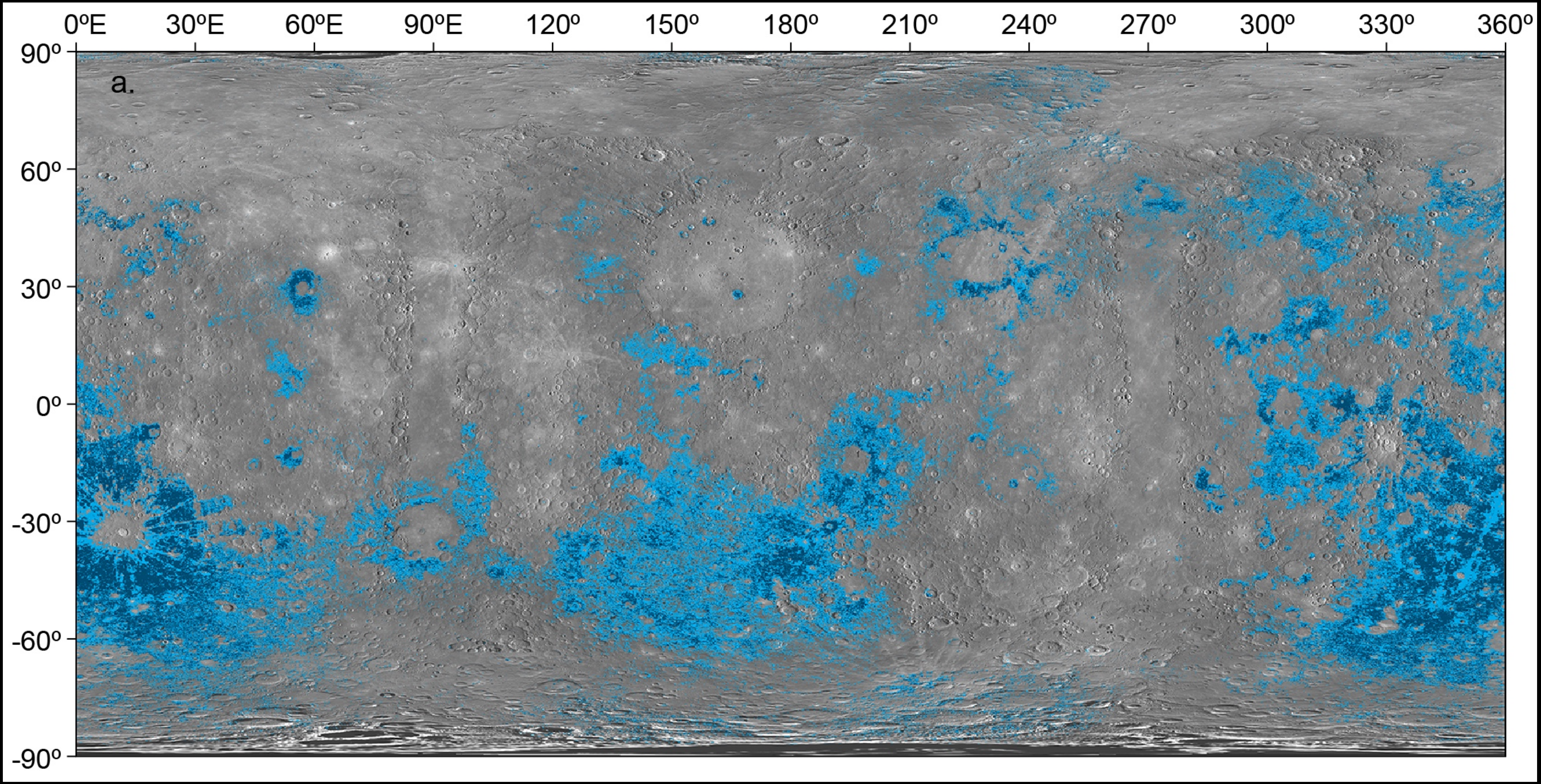
- There are compelling scientific cases to be made for a wide range of landing locations.
  - The overarching science goals remain the same regardless of the ultimate landing site choice (specifics of Goal 1 would necessarily be adapted for a polar deposit lander).
  - The measurements made by the first landed mission to Mercury will be foundational and transformative, answering high-priority outstanding science questions for Mercury from any location.

- The science payload chosen for this study is just one possible configuration that could accomplish the high-priority science goals
  - Alternate payload implementations could be designed to return equally compelling science measurements.
  - A future Mercury Lander mission should take advantage of technology advancements.
  - It may be advantageous to reduce the payload or to consider foreign contributions.

Key Trades

	Trade Space, Result	Rationale
Cruise Propulsion	Chemical vs **SEP**	Propellant savings
	Aerojet XR5 vs Qinetiq T6 vs **NEXT-C**	Thrust requirements, propellant savings
MOI / Orbit Propulsion	**Chemical** vs SEP	Long duration for SEP implementation, impacts to solar array thermal management and cell degradation
Braking Burn Propulsion	Bipropellant vs **SRM**	Mass savings, load path efficiency
Lander Propulsion	Monopropellant vs **Bipropellant**	Mass savings
Landing Area Risk Reduction	Targeted imaging orbits vs **opportunistic imaging**	Thermal constraints in lower orbits
Vehicle Stages	3 vs **4**	Propellant savings through jettison of stages prior to large burns

Where to Land?



Klima et al. (2018)

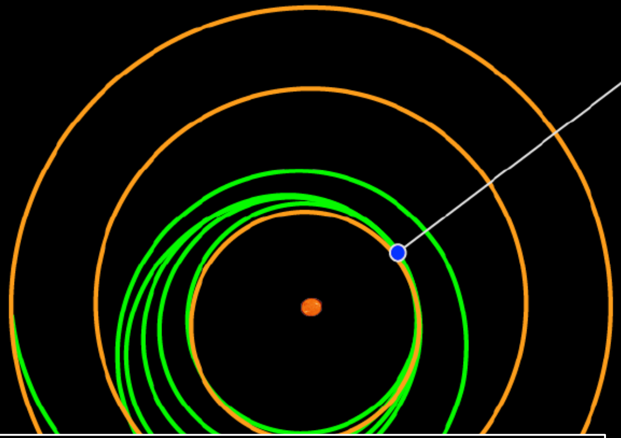
Mission Timeline

Launch: March 2035 on an expendable Falcon Heavy

Landing: April 12, 2045

Cruise Phase

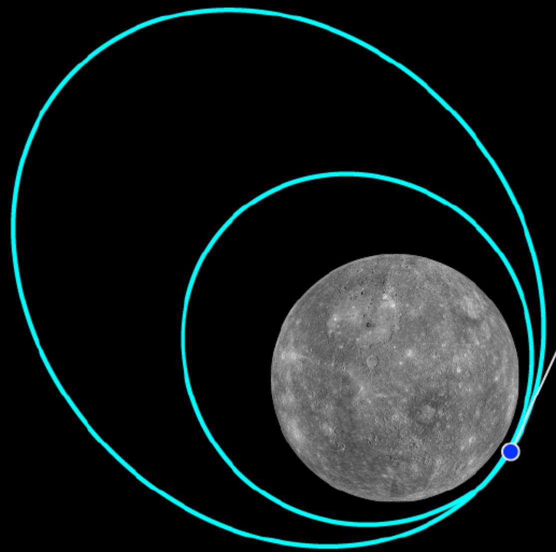
10 Year solar electric propulsion cruise



- Earth flyby – March 2036
  (back-up launch opportunity)
- Venus flyby 1: June 2036
- Venus flyby 2: March 2038
- Mercury flyby 1: May 2038
- Mercury flyby 2: Feb 2039
- Mercury flyby 3: Jan 2040
- Mercury flyby 4: Jan 2041
- Mercury flyby 5: June 2042

Orbital Phase

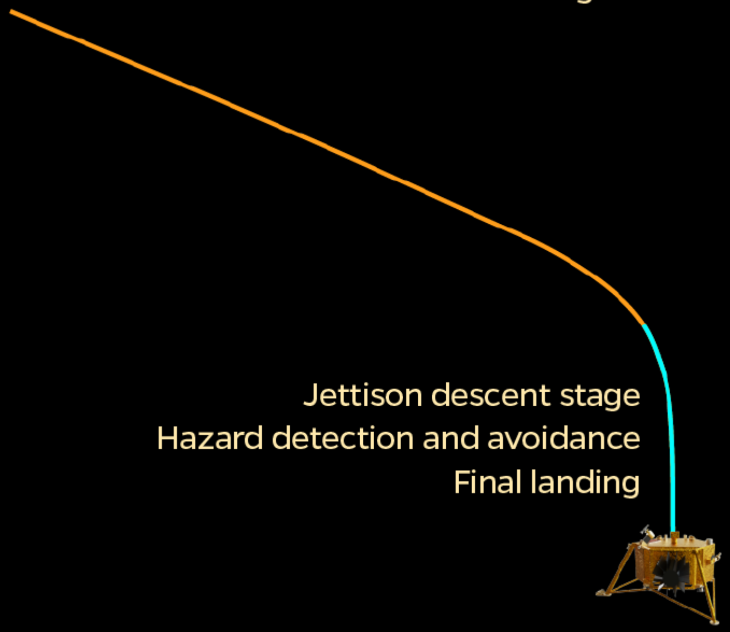
Jettison cruise stage
Mercury orbit insertion
2.5 Months in 100 x 6000 km orbit



- MOI: Jan 2045
- Apoherm lowering: March 30, 2045
  (2 Weeks in 100 x 2000 km orbit)

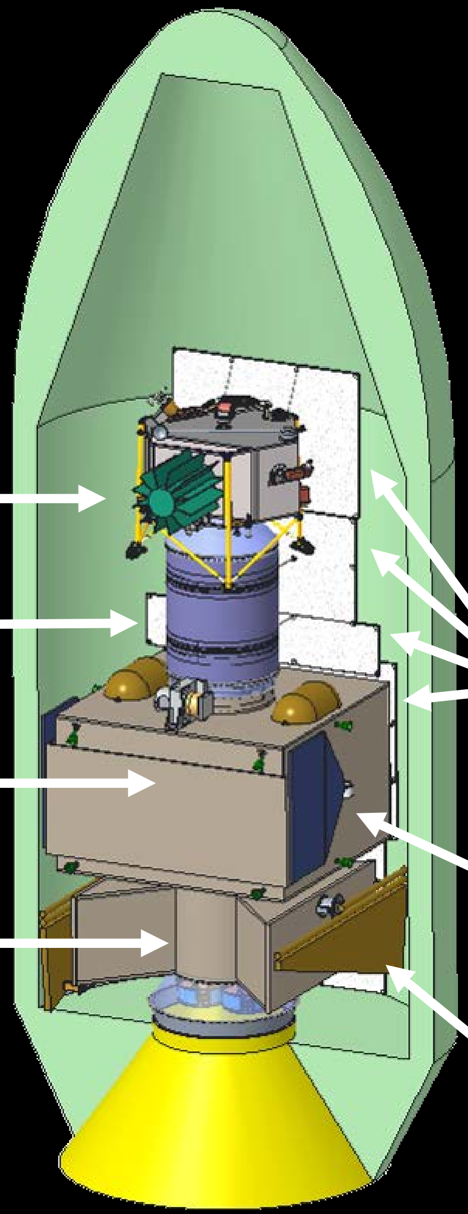
Descent Phase

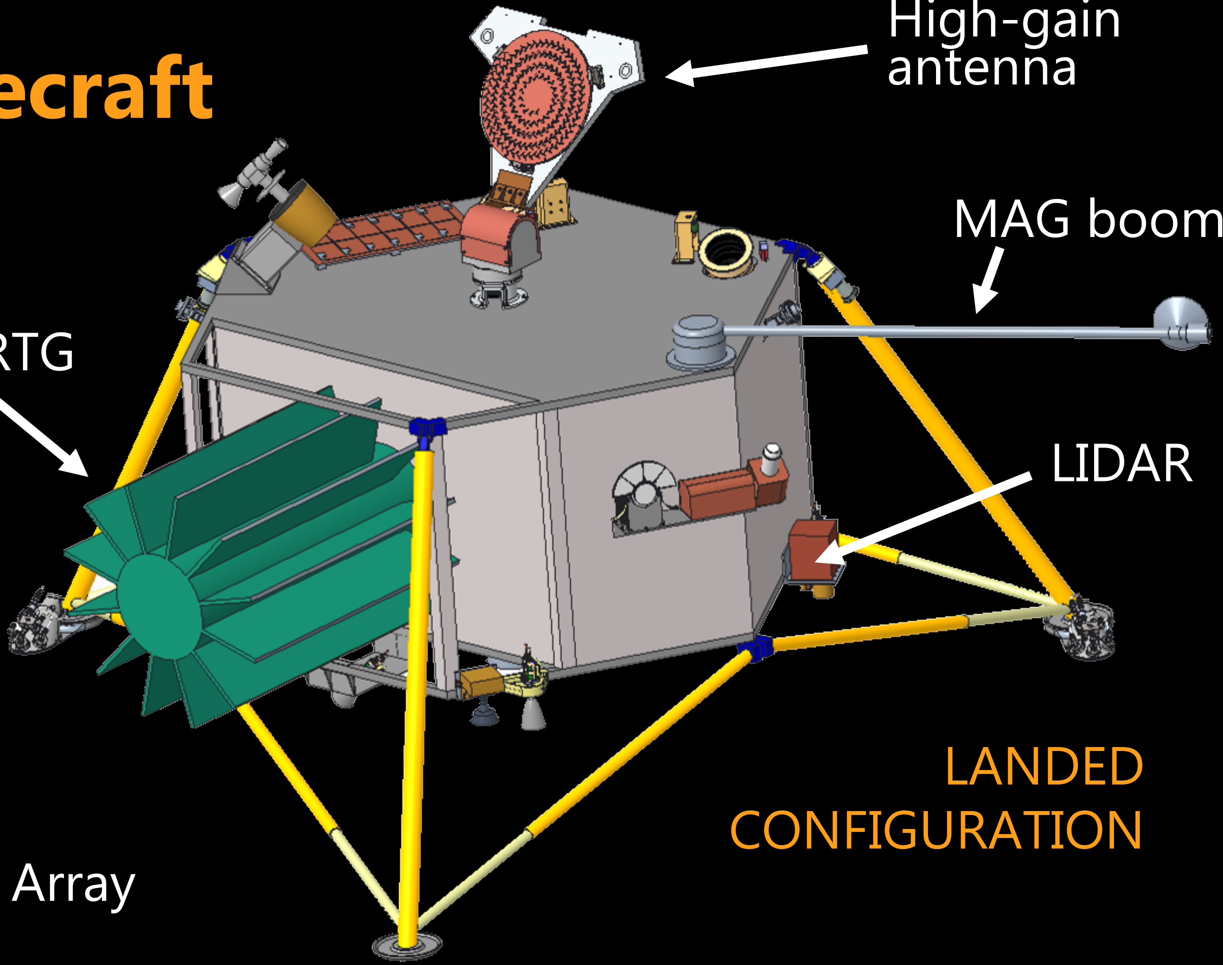
Jettison orbital stage
Initiate braking burn



- Landing: April 12, 2045

Spacecraft

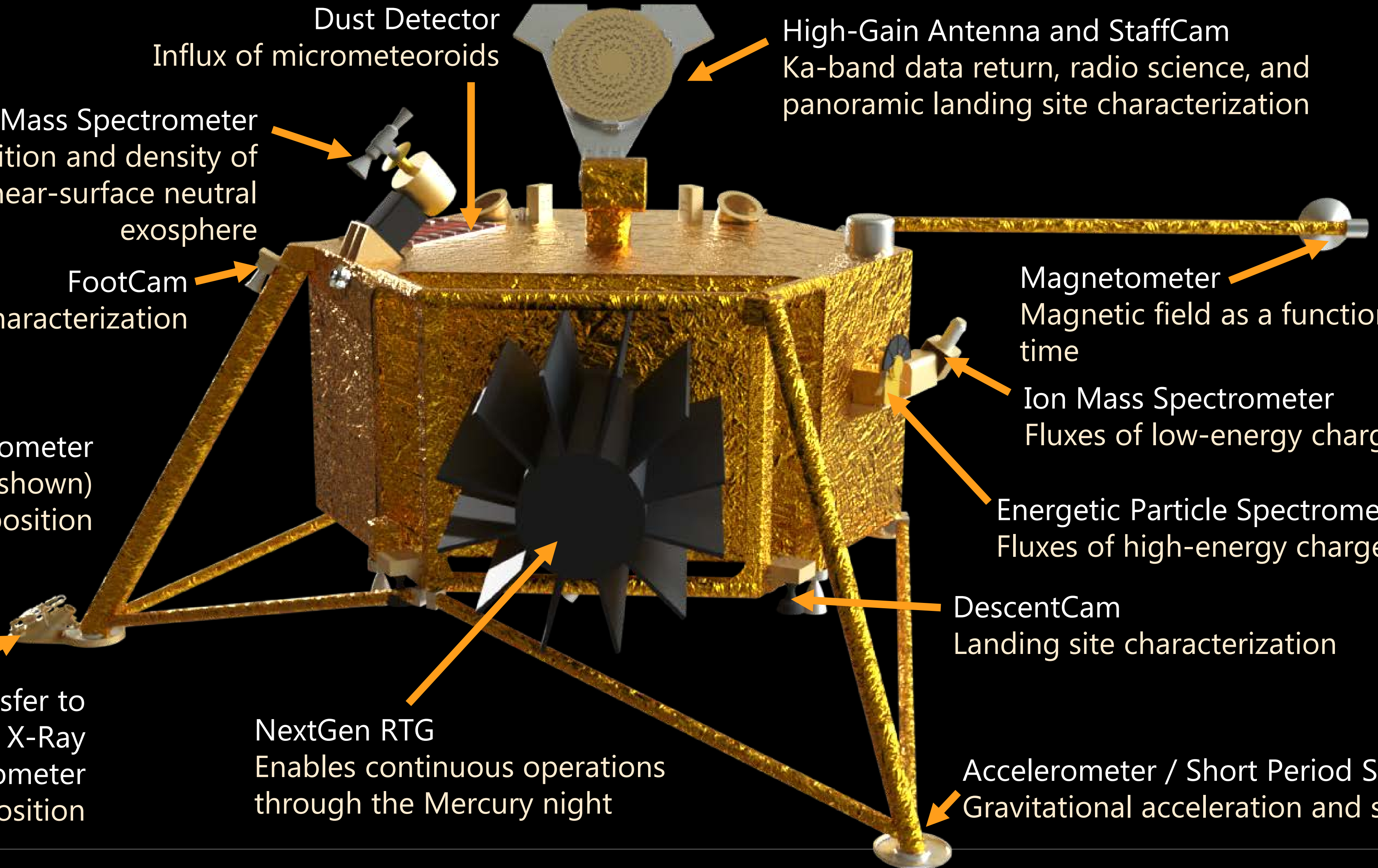




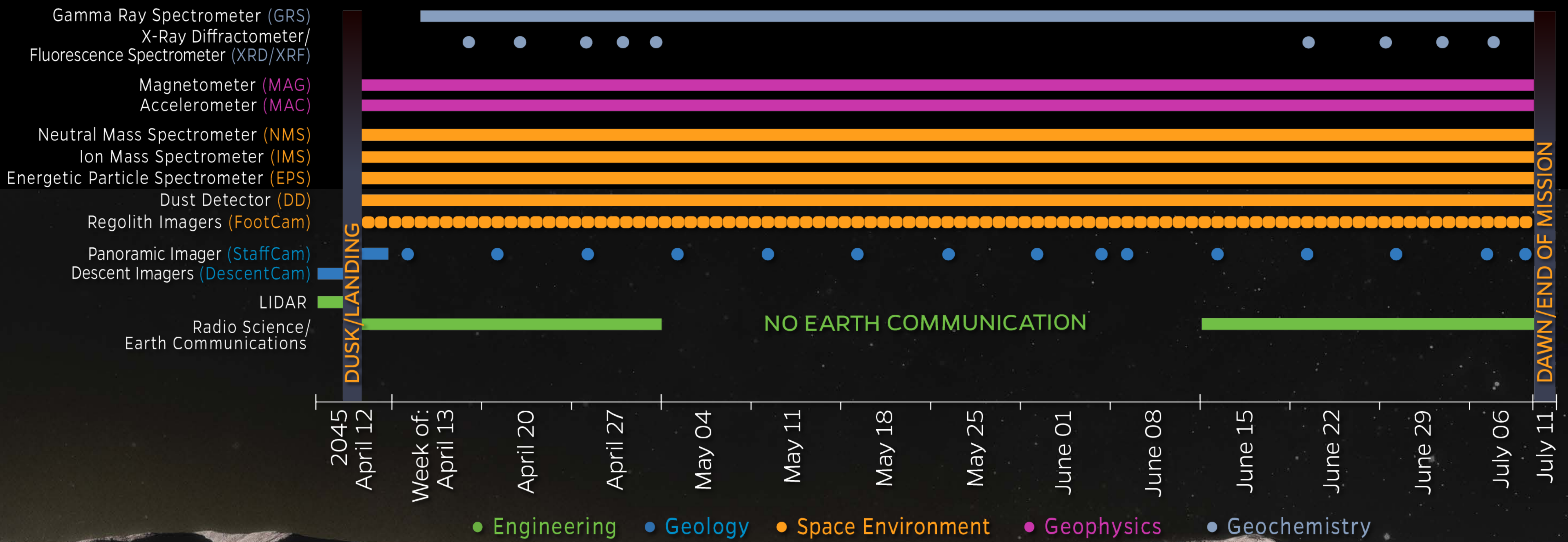
Four-stage flight system:

- Cruise Stage
- Orbital Stage
- Descent Stage
- Lander

Lander and Payload



One Full Mercury Year of Surface Operations

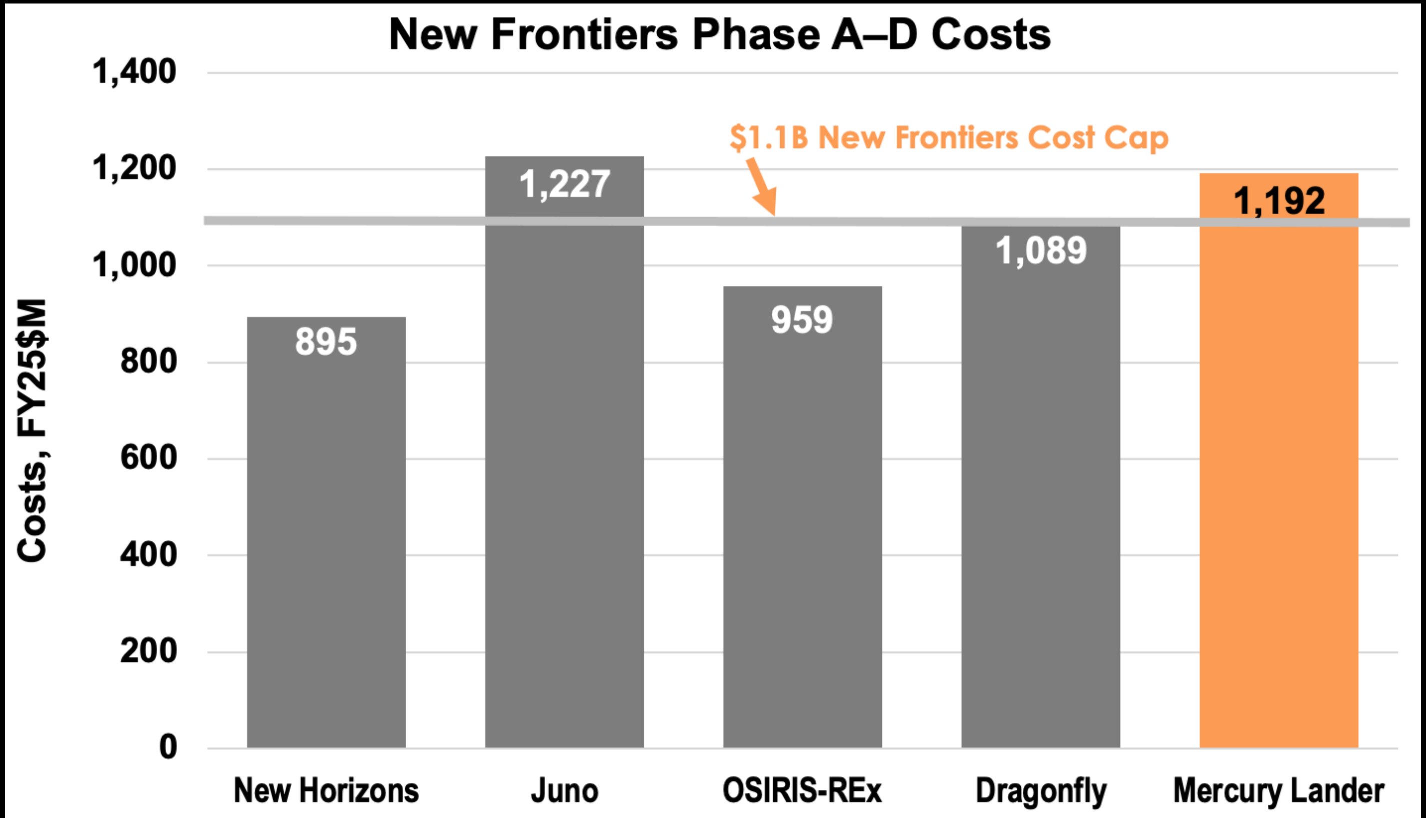


	NMS	IMS	EPS	DD	GRS	XRD/XRF#	MAG	MAC	StaffCam	FootCam	DescentCam	TOTAL
Surface Ops Description	Cont*	Cont*	Cont*	Cont*	Cont	Specific Collection Times	Cont*	Cont*	Specific Collection Times	Daily	Descent Only	
Total Data Volume Downlinked (MB)	228	1138	228	228	484	93	1422	4619**	773	1138	469	10,820

* Continuous except for during XRD/XRF analyses
\# Includes XRD/XRF and PlanetVac data
** Only difference between data acquired and data downlinked; MAC acquires 7111 MB of data.

Baseline Plan:
10.8 GB total data

Cost



- Phase A–D mission cost estimate (50% unencumbered reserves, excluding the launch vehicle) with the 11-instrument payload is $1.2 B (FY25$).

- Compares favorably with past NF missions, and cost cap prescribed in the NF4 AO (~$1.1B FY25$).

Ground-breaking science that can only be addressed by *in situ* surface measurements on the innermost planet…

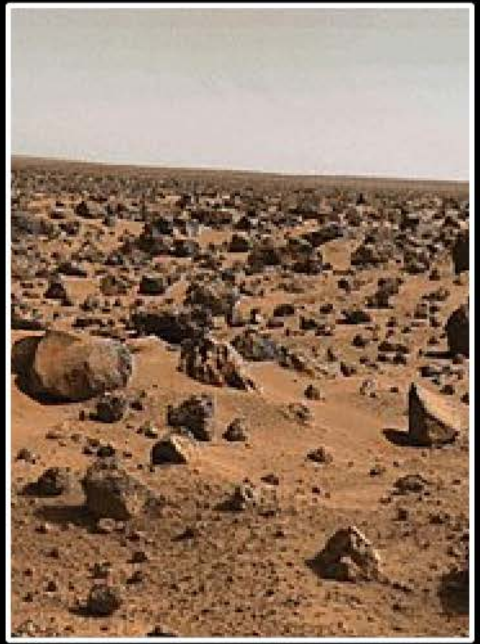
Mercury

Venus

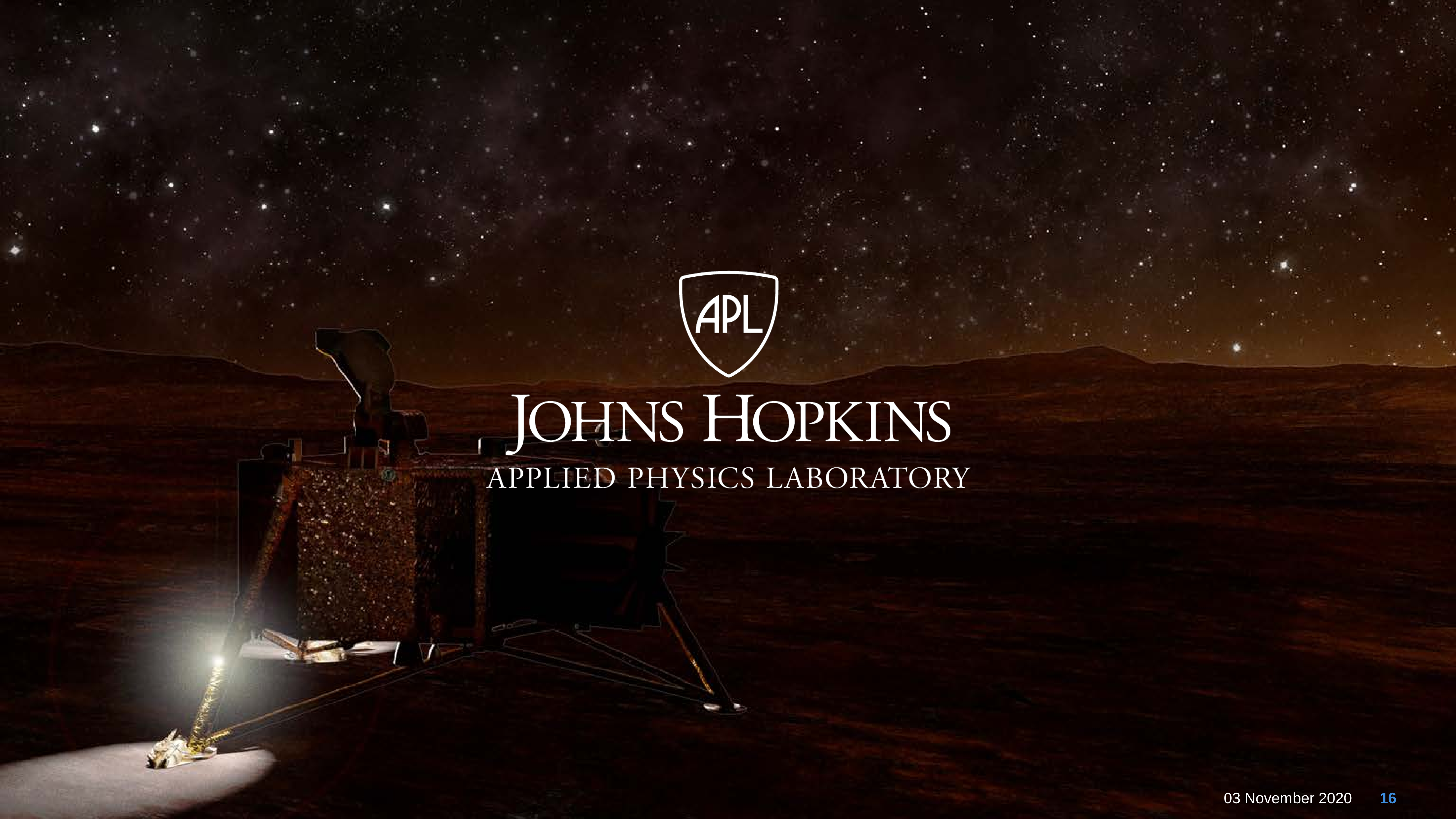
Earth

Moon

Mars



…is feasible and compelling for a New Frontiers-class mission in the next decade!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