

Rapid Acquisition and Return of Mercury Polar Ice Samples

University at Buffalo - The State University of New York

CRashworthiness for Aerospace Structures and Hybrids Laboratory (The CRASH Lab)

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AIAA Region I

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CRASH  **LAB**

CRashworthiness for Aerospace Structures and Hybrids Lab

Background

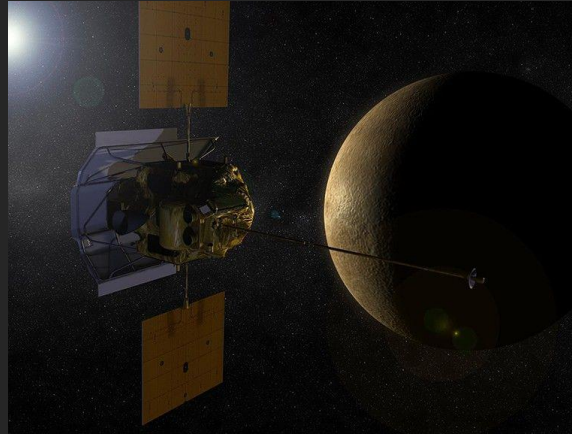
Mariner 10



- First spacecraft to visit Mercury
- Performed 3 flybys from 1974-1975
- Sent back photos of parts of Mercury's surface
- Lost contact in 1975

Source: NASA, "Mariner 10"

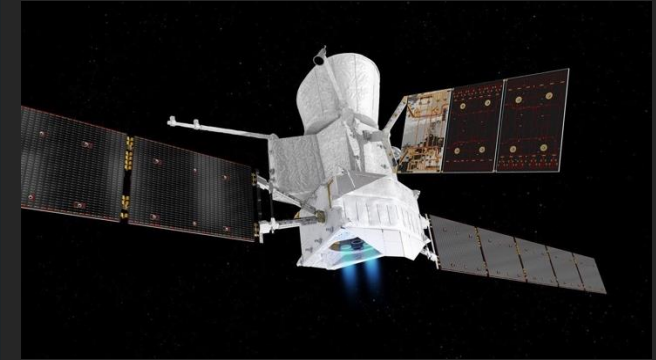
MESSENGER



- Launched in 2004, entered Mercury Orbit in 2011
- Collected large amounts of data
- Detected signs of water ice in polar craters
- Crashed into the surface at the end of its mission in 2015

Source: NASA, "MESSENGER"

BepiColombo



- Collaboration between ESA and JAXA
- Launched in 2018, due to enter Mercury orbit November 2026
- Plans to study surface in greater detail, including polar ice

Sources: NASA, "BepiColombo"

ESA, "BepiColombo – Investigating Mercury's mysteries"

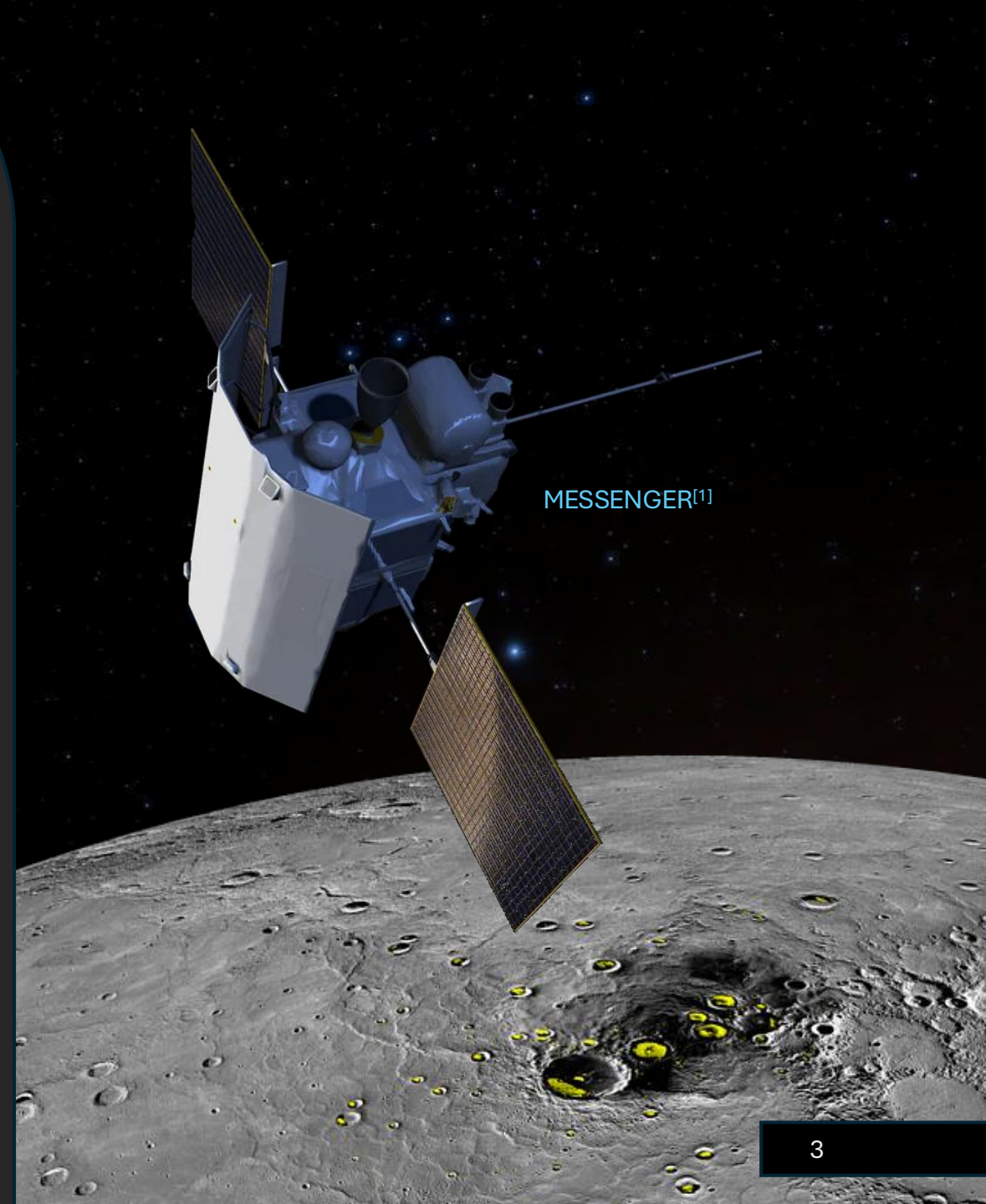
Motivation

- MESSENGER detected signs of water ice in permanently shaded craters near Mercury's north pole
- Formation process currently unknown
- Samples could hold information about Solar System's past
- No mission has yet landed on Mercury's surface

Figure 1: Potential detections of water ice (yellow)^[2]

[1] Image Source: NASA, "MESSENGER"

[2] Image Source: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington



Proposed Mission Goals

- Enter into a polar orbit around Mercury
- Land a vehicle in a permanently-shaded crater near the north pole
- Collect 1kg of water ice samples
- Launch samples into Mercury orbit and then back to Earth
- Carry out secondary science objectives on and around Mercury

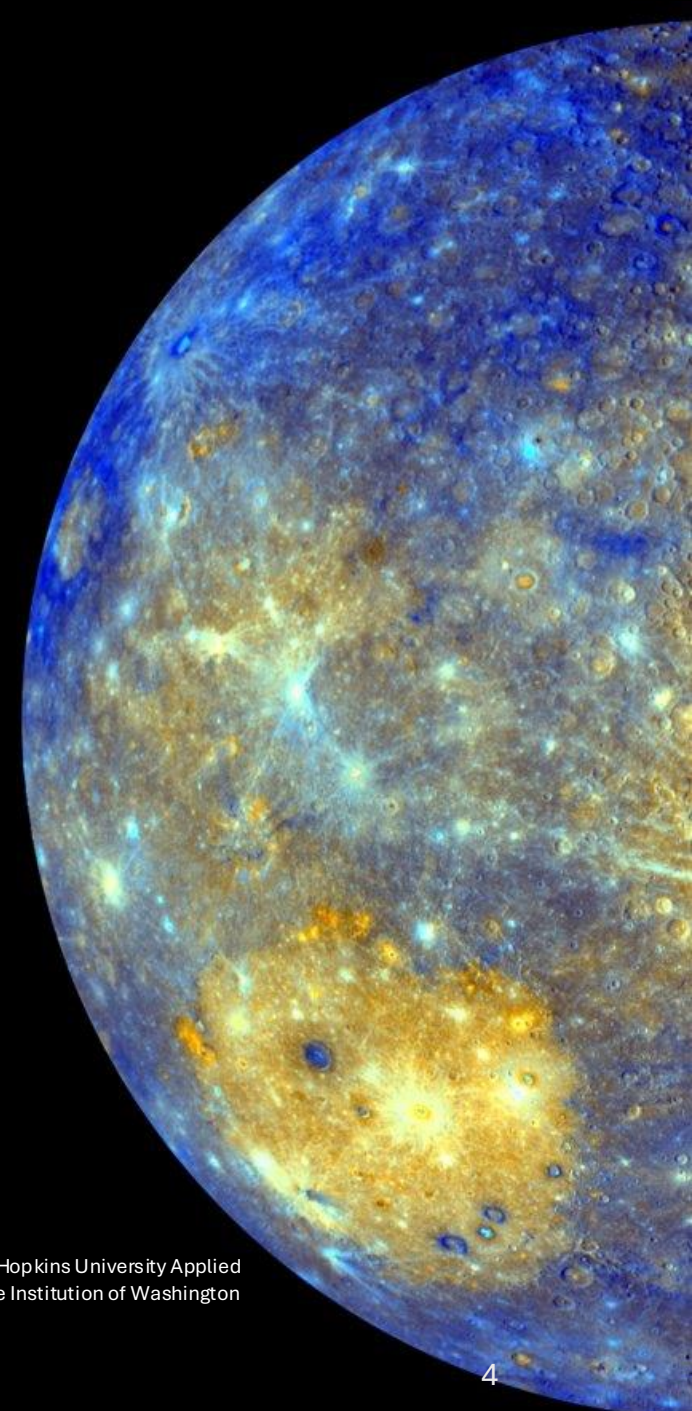
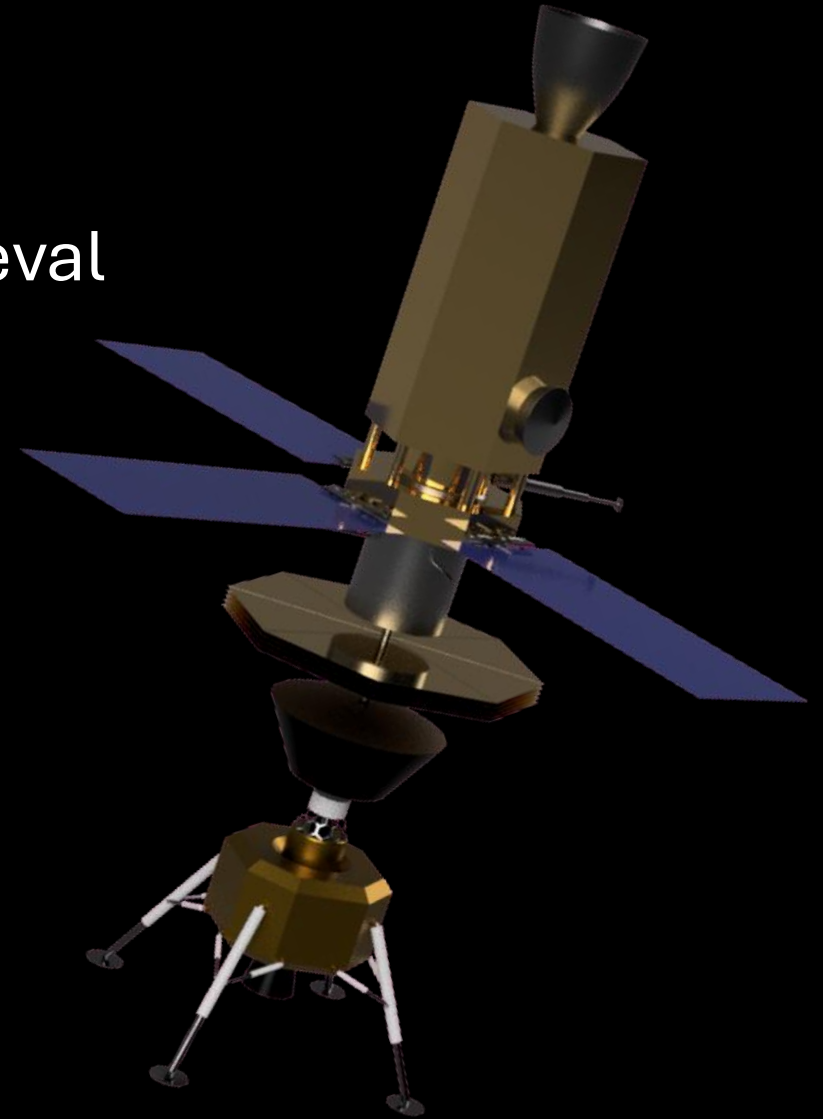


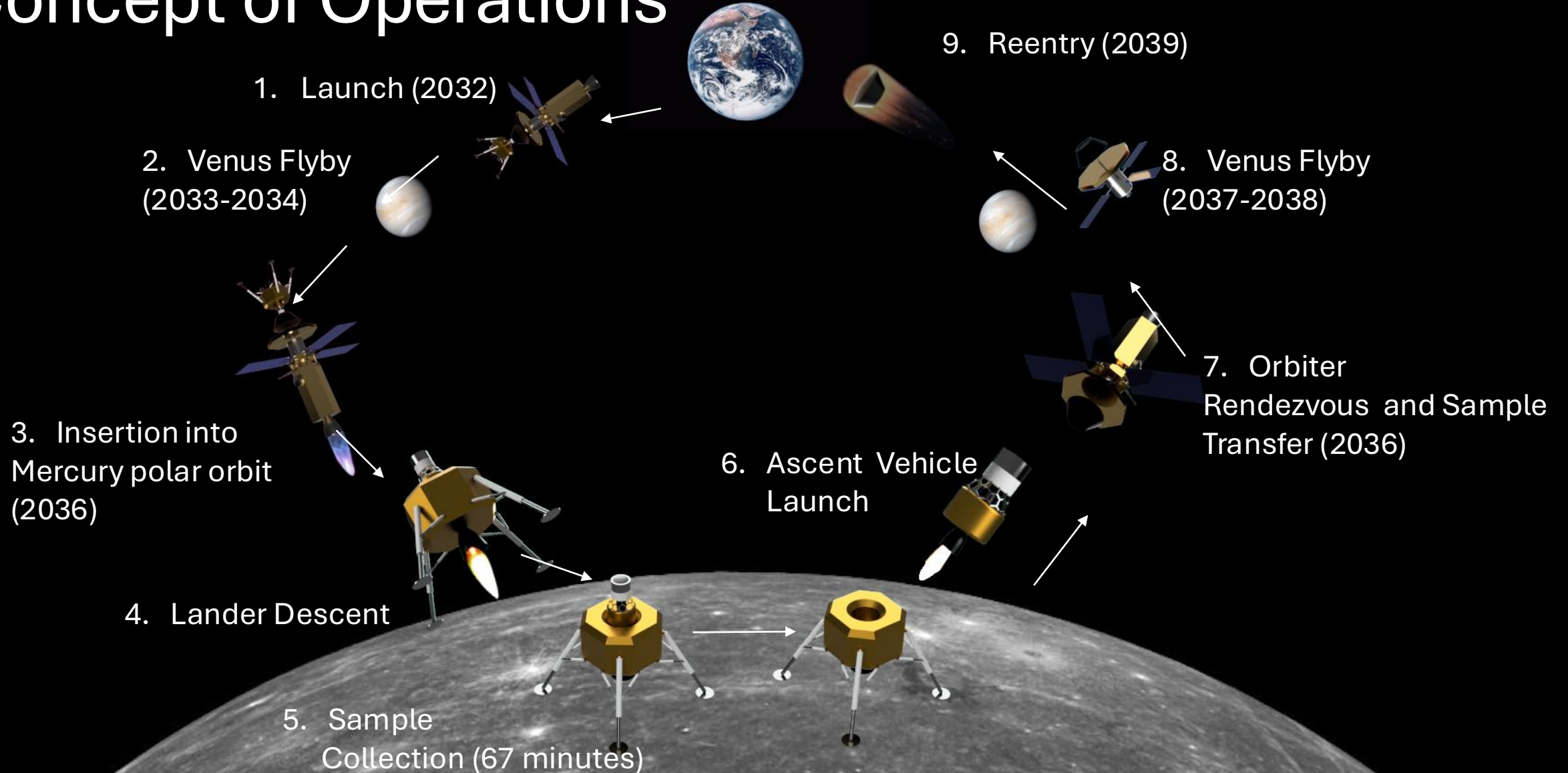
Image Source: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

HERMES Concept Overview

- **HERMES** – High-speed **E**xtraction and **R**etrieval of **M**ercury **E**xtraterrestrial **S**amples
- Mission consists of orbiter, lander, ascent vehicle, and return vehicle
- Sample collection and return in a single mission
- Just over 1 hour between lander touchdown and sample launch



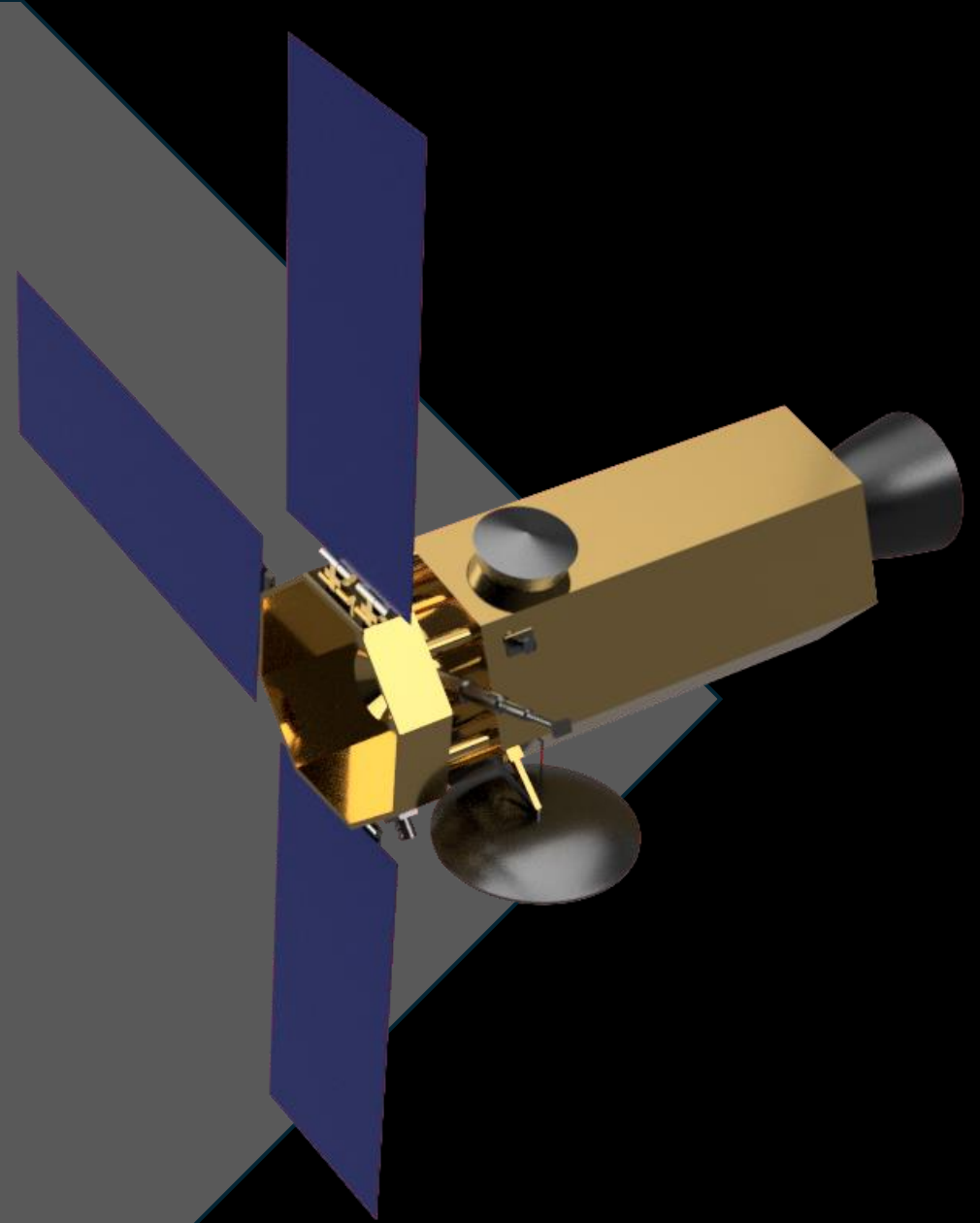
Concept of Operations



MISSION COMPONENTS

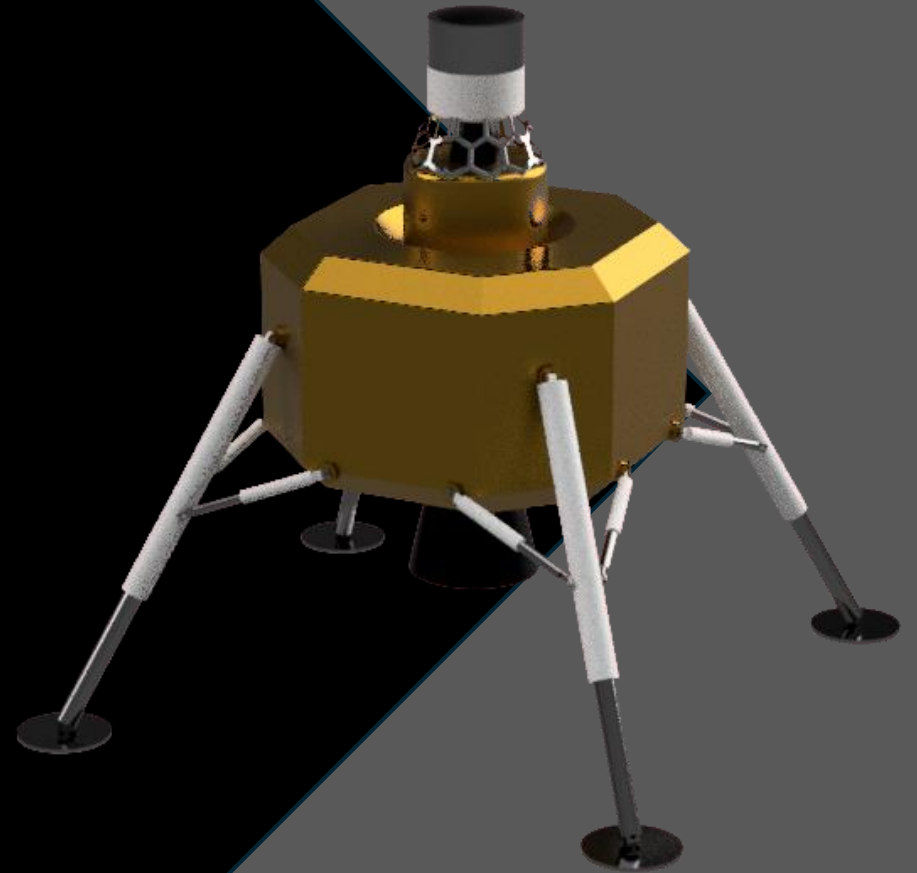
Orbiter

- Main propulsion module for transit to Mercury
- Manages communications with Earth via the Deep Space Network
- Relays data and commands between Earth and Mercury surface
- Carries secondary science instruments for study of Mercury and the Sun



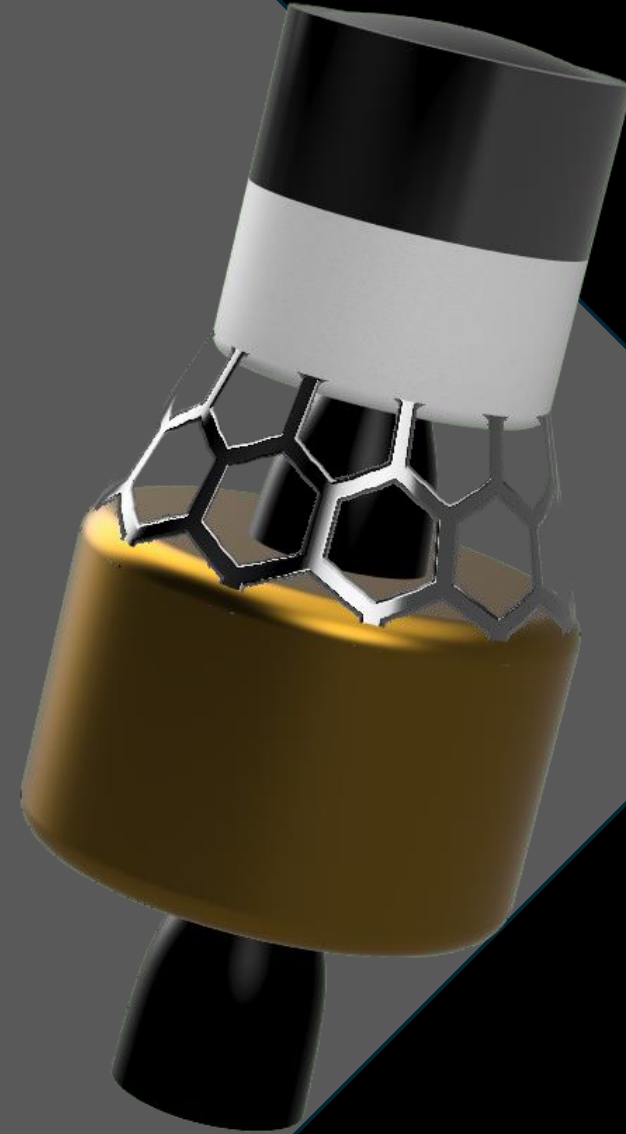
Lander

- Descends from Mercury orbit to touch down safely in target crater
- Houses robotic arm, drill, and launch systems for ascent vehicle
- Carries out objectives entirely using battery power
- Carries secondary science payloads to study Mercury surface



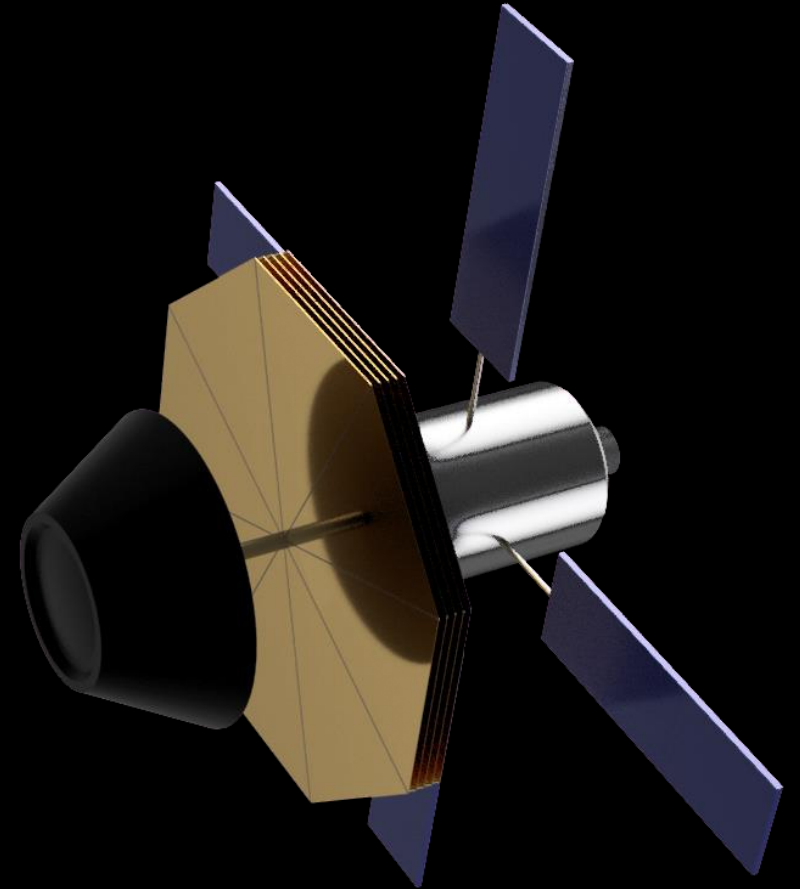
Ascent Vehicle

- Delivers samples from surface to orbiter
- Must remain as light as possible
- Efficient form-factor, only consisting of rocket, sample storage, and docking hardware



Earth Return Vehicle

- Provides shielding and propulsion for return to Earth
- Solar panels provide power to cryocooler
- Kapton sunshield protects capsule from solar radiation
- After final deorbit burn, capsule detaches and re-enters atmosphere to be collected by scientists



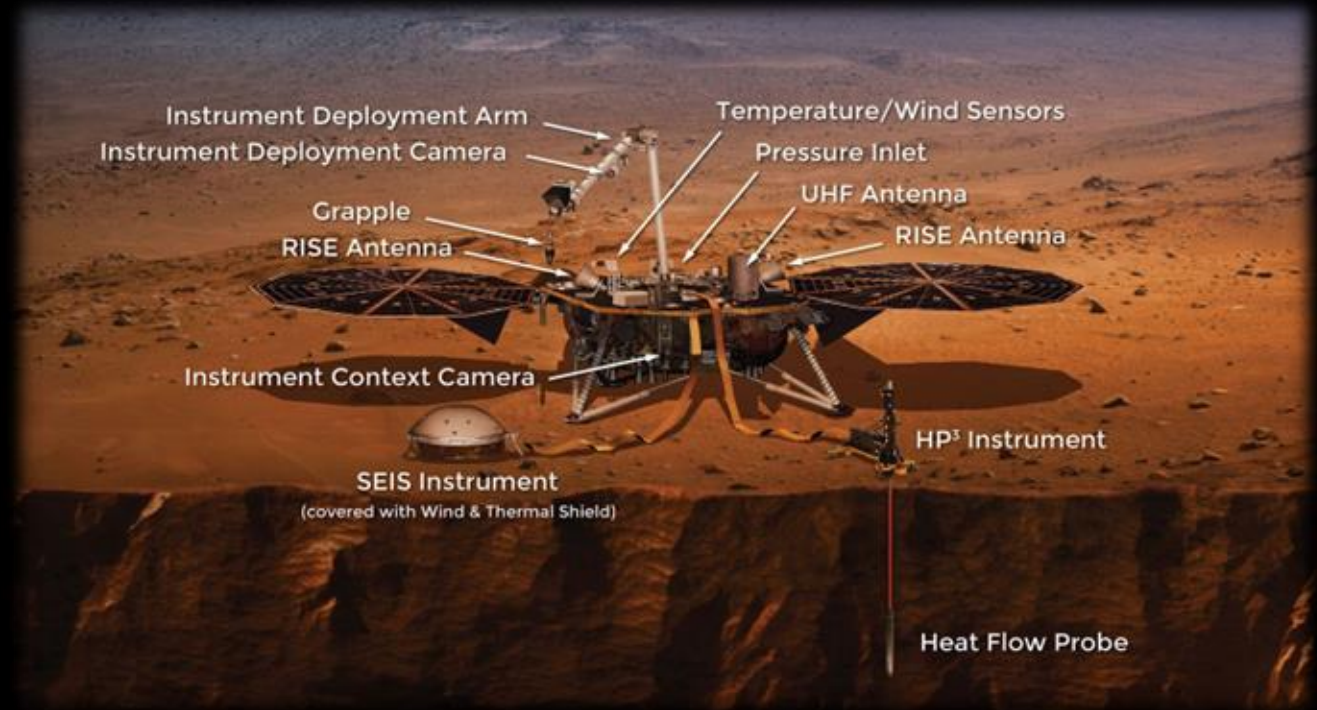
Secondary Scientific Instrumentation

Orbiter:

- Spectrometer
- Magnetometer
- Imaging cameras

Lander:

- Seismometer
- Thermal probe
- Magnetometer
- LIDAR



"InSight Lander Science Instruments" - Source: NASA Science

Journey to Mercury

- Orbiter will commence journey once Earth is aligned with Venus
- Multiple planetary flybys will be performed to conserve fuel
- Single flyby of Earth
- Once approaching Venus 2 flybys are performed
- HERMES will change perihelion of orbit to a distance of Mercury's distance to the sun

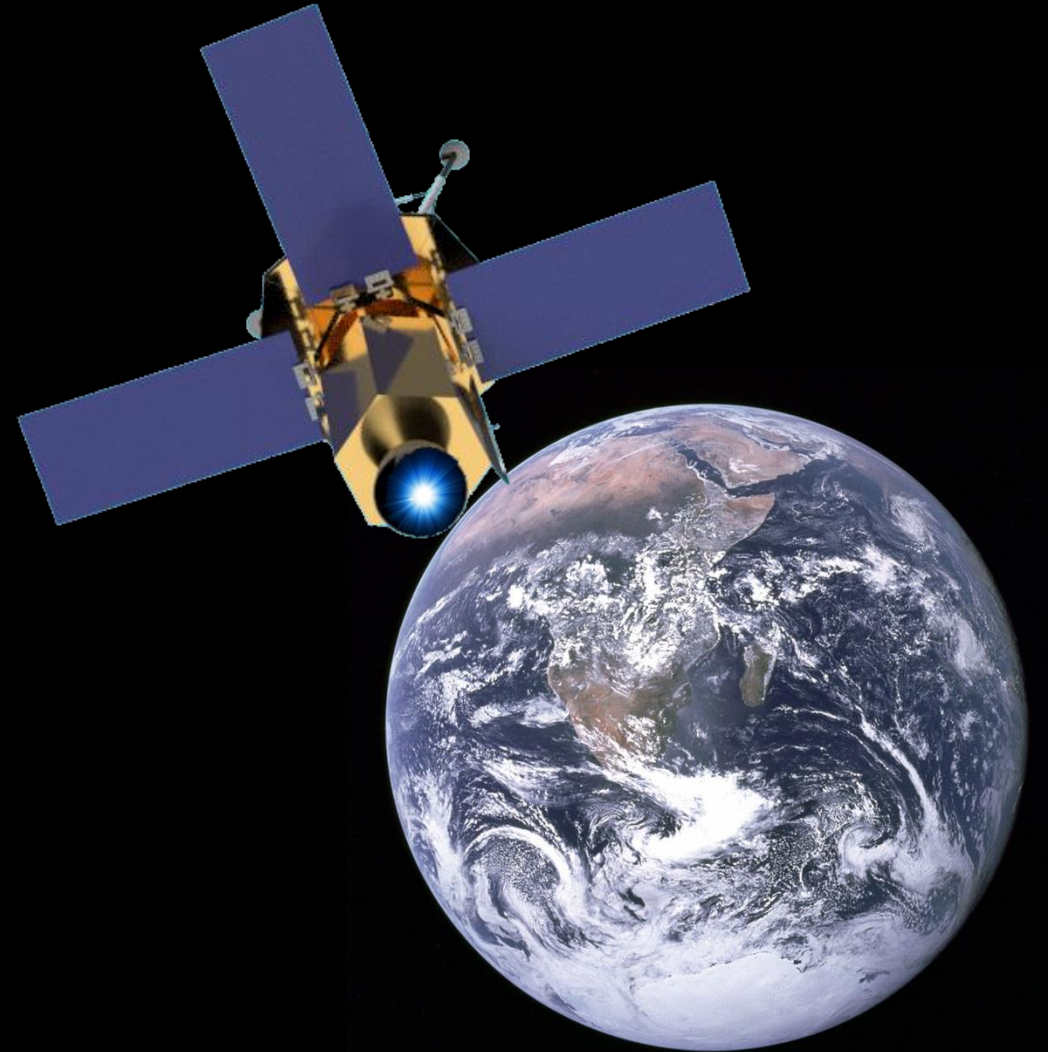


Image Source: NASA, "The Blue Marble"

Mercury Orbit

- HERMES will do 2 flybys around Mercury to lower the speed upon arrival
- Parking orbit will be 480km above north pole where descent and ascent will release and connect
- 2.3 hour orbital period
- Sample collection will occur within 1 orbit



Image Source: NASA, "Mercury as Mariner 10 Speeds Away"

Planetary Conditions

- No solar power inside crater, battery only
- Surface: $-100\text{ }^{\circ}\text{C}$ (shaded) to $430\text{ }^{\circ}\text{C}$ (sunlit)
- Unknown terrain, permanently-shaded craters have not yet been explored
- High radiation environment due to proximity to Sun

Image Source: NASA, "A Teachable Moment You Can See! The Transit of Mercury"

Descent

2.996 km/s powered descent, no atmosphere to assist

2.3-hour orbital window , miss it and wait another full orbit

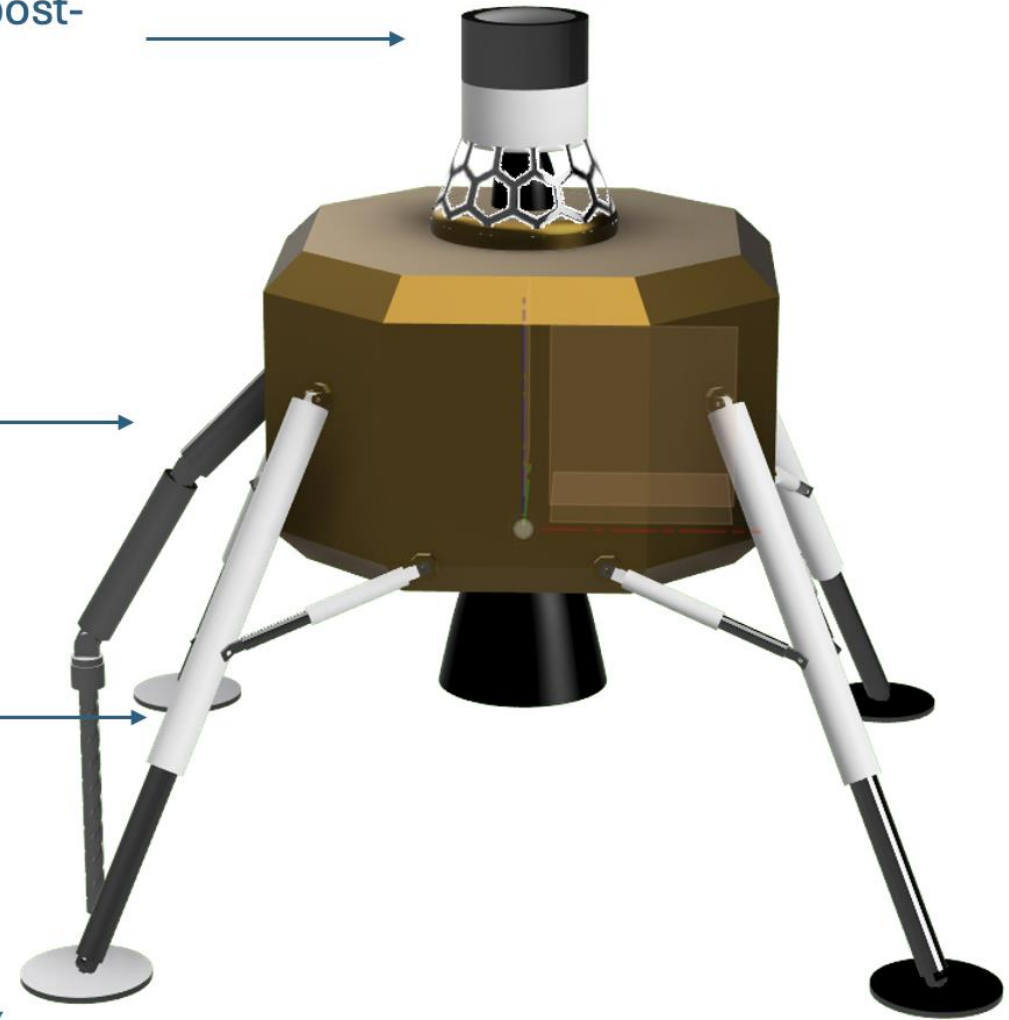
$g = 3.7 \text{ m/s}^2$ (38% Earth)

Ascent vehicle launches post-collection

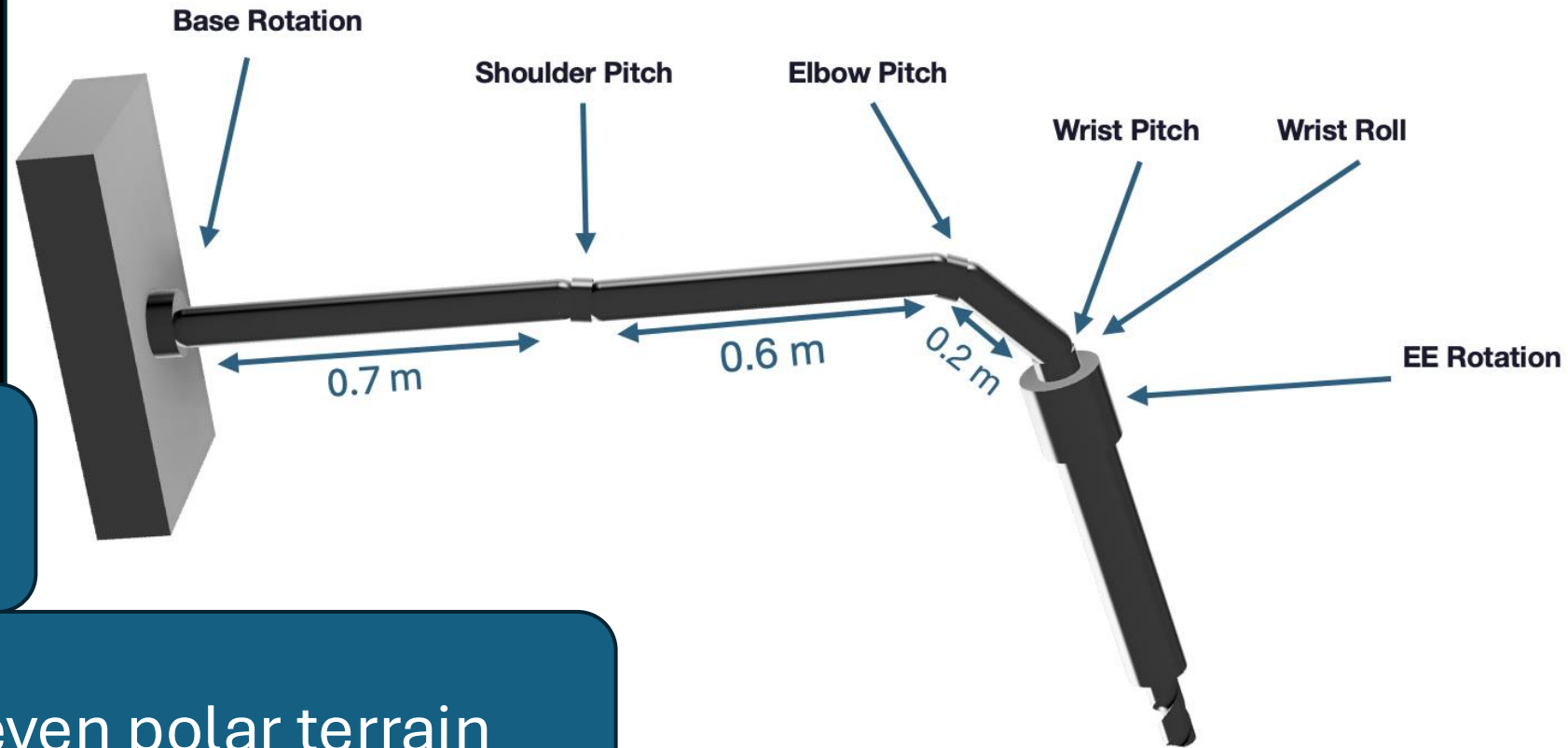
Robotic Arm

Retro thruster - 2.996 km/s descent ΔV

Shock-absorbing legs



Robotic Arm



6-DOF 1.5 m reach

Wrist roll axis for uneven polar terrain

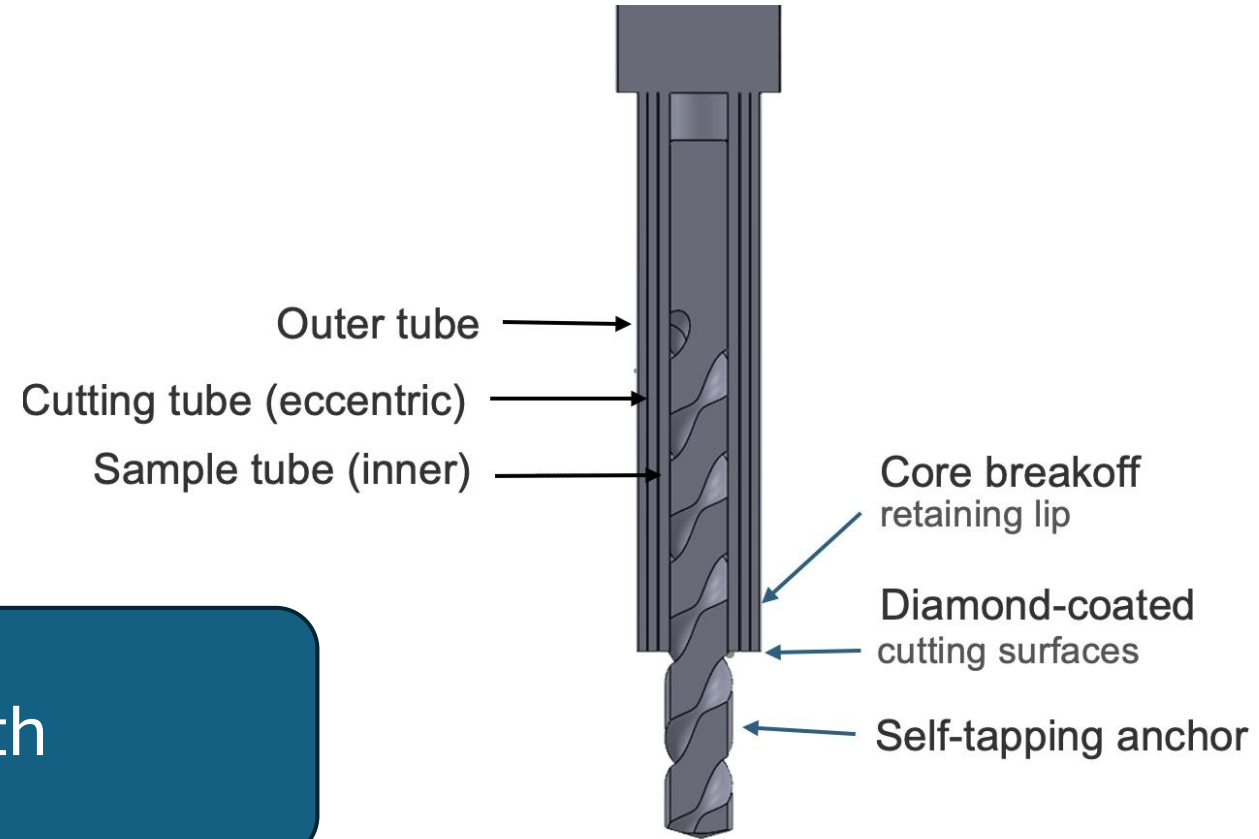
Derived from Perseverance-class heritage

Triple-Tube Coring Drill

~67 min max drilling time

Cores at 10, 50, and 100 cm depth

Rotary-percussive diamond-coated cutting surfaces

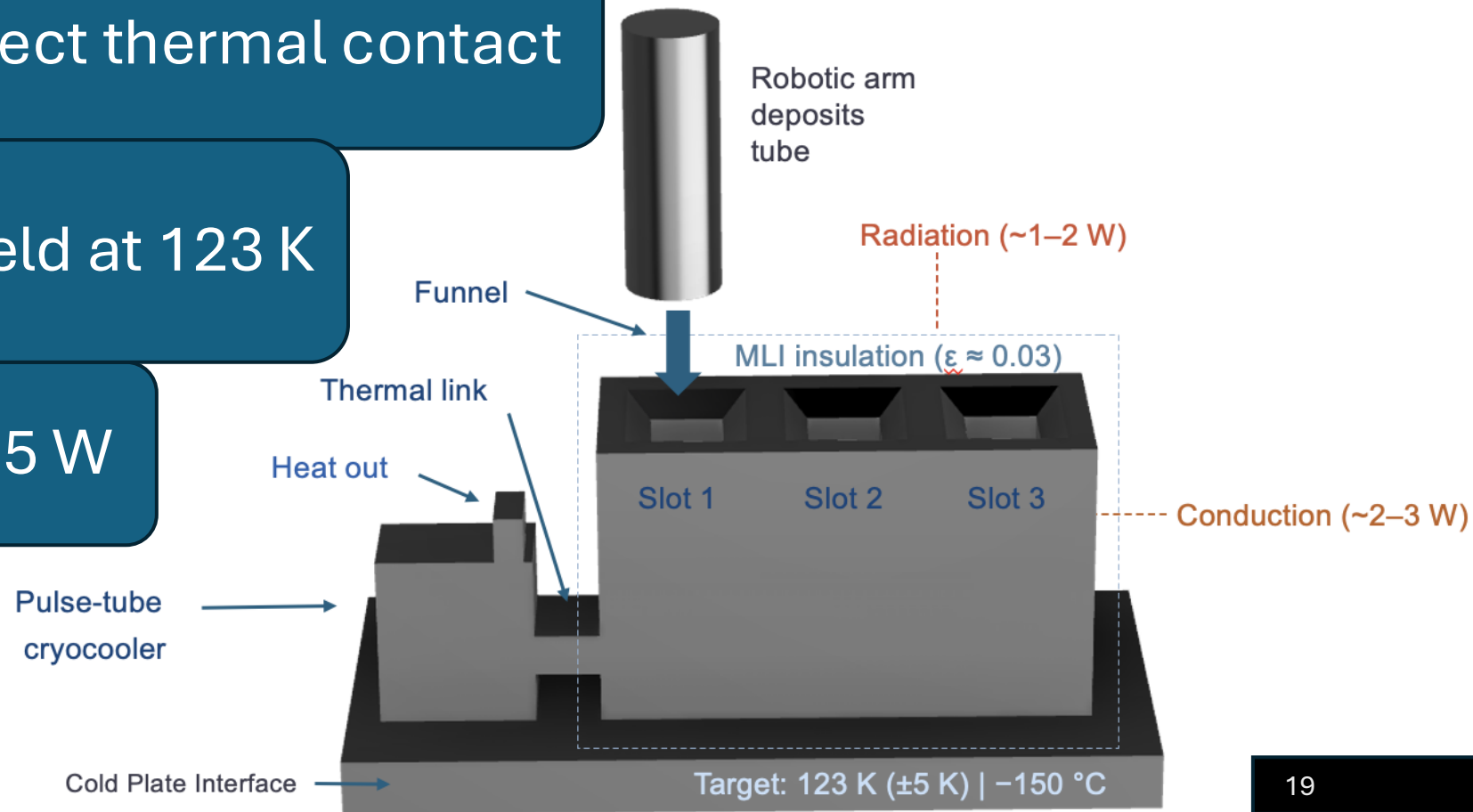


Cryogenic Storage Rack

3-slot aluminum rack direct thermal contact

Pulse-tube cryocooler held at 123 K

Peak cooling load ~10–15 W



Mercury Ascent Vehicle (MAV) Interface

Short-wide configuration arm reaches cryo-rack directly

Two-stage solid rocket | 700 kg GLOM | $I_{sp} = 262$ s

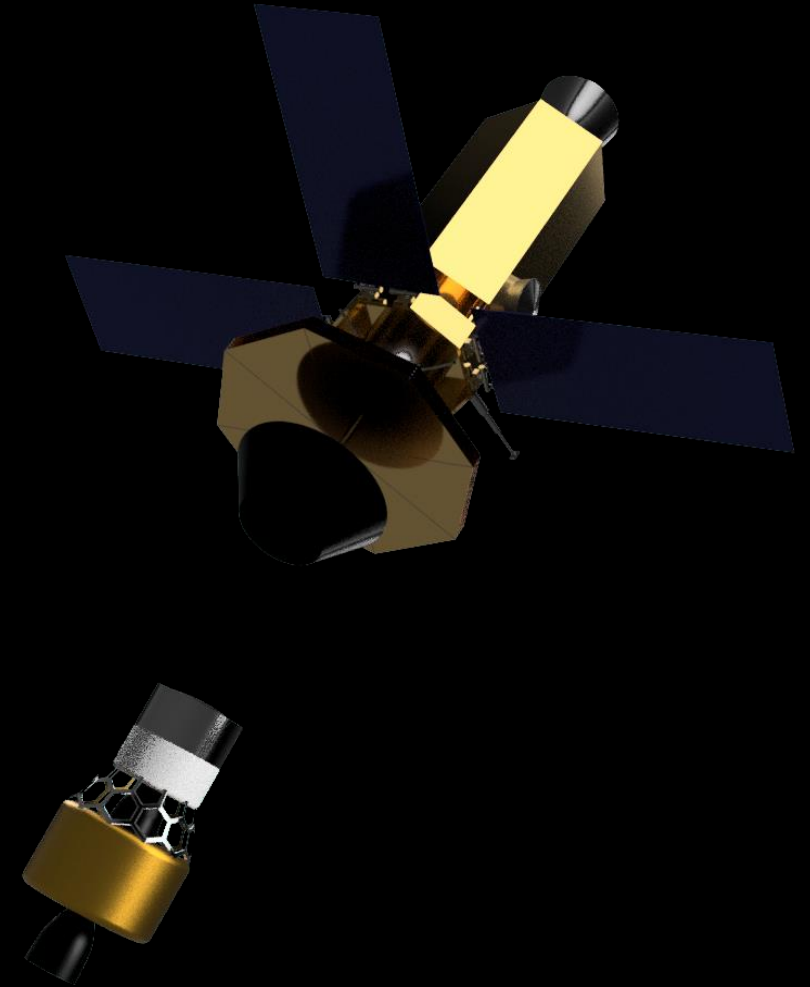
Cryo section separates at orbit, stays with orbiter

4.72 km/s ΔV to 480 km polar orbit



Ascent & Sample Transfer

- Ascent vehicle will land on Mercury with lander
- Once samples are collected, they will be secured in ascents cryogenic containment system
- Ascent vehicle launches and reach a velocity of 4.717km/s to rendezvous with orbiter using LiDAR
- Samples are secured in return vehicle to ensure preservation and prevent solar radiation and heat from Earth reentry



Return

- Earth return vehicle will preserve samples in cryocooler while in transit
- Multi-layered Kapton sun shield will prevent excessive solar heating
- Includes propulsion module to perform maneuvers and generate power for cryocooler and subsystems using solar panels
- Performs capture and deorbit burns once reaching Earth
- Capsule will use proven phenolic impregnated carbon ablative heat shield for reentry
- Descent controlled with parachutes

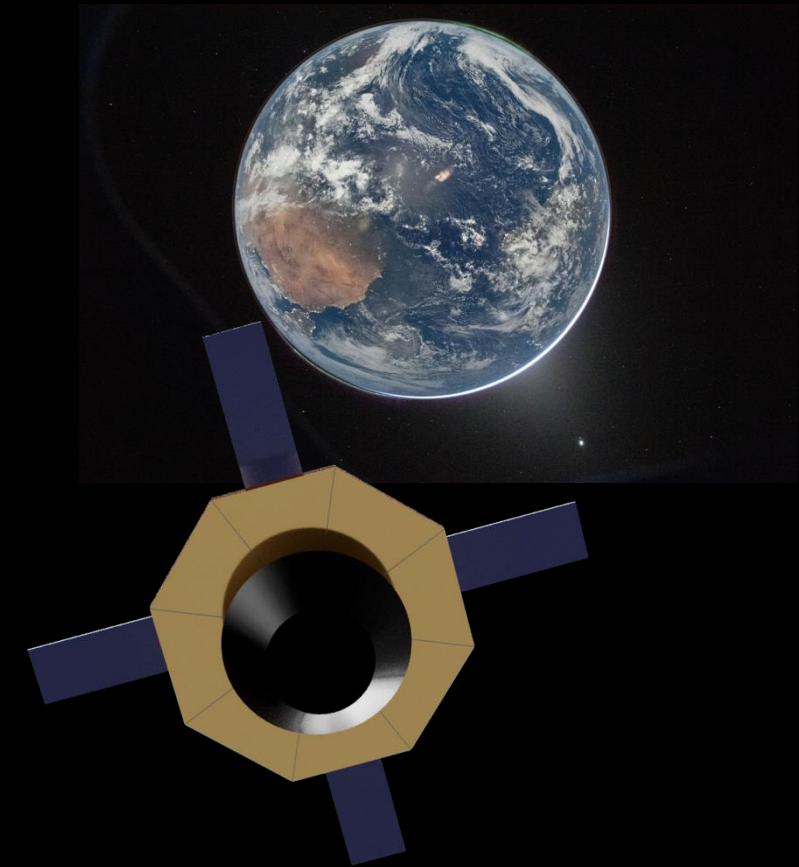
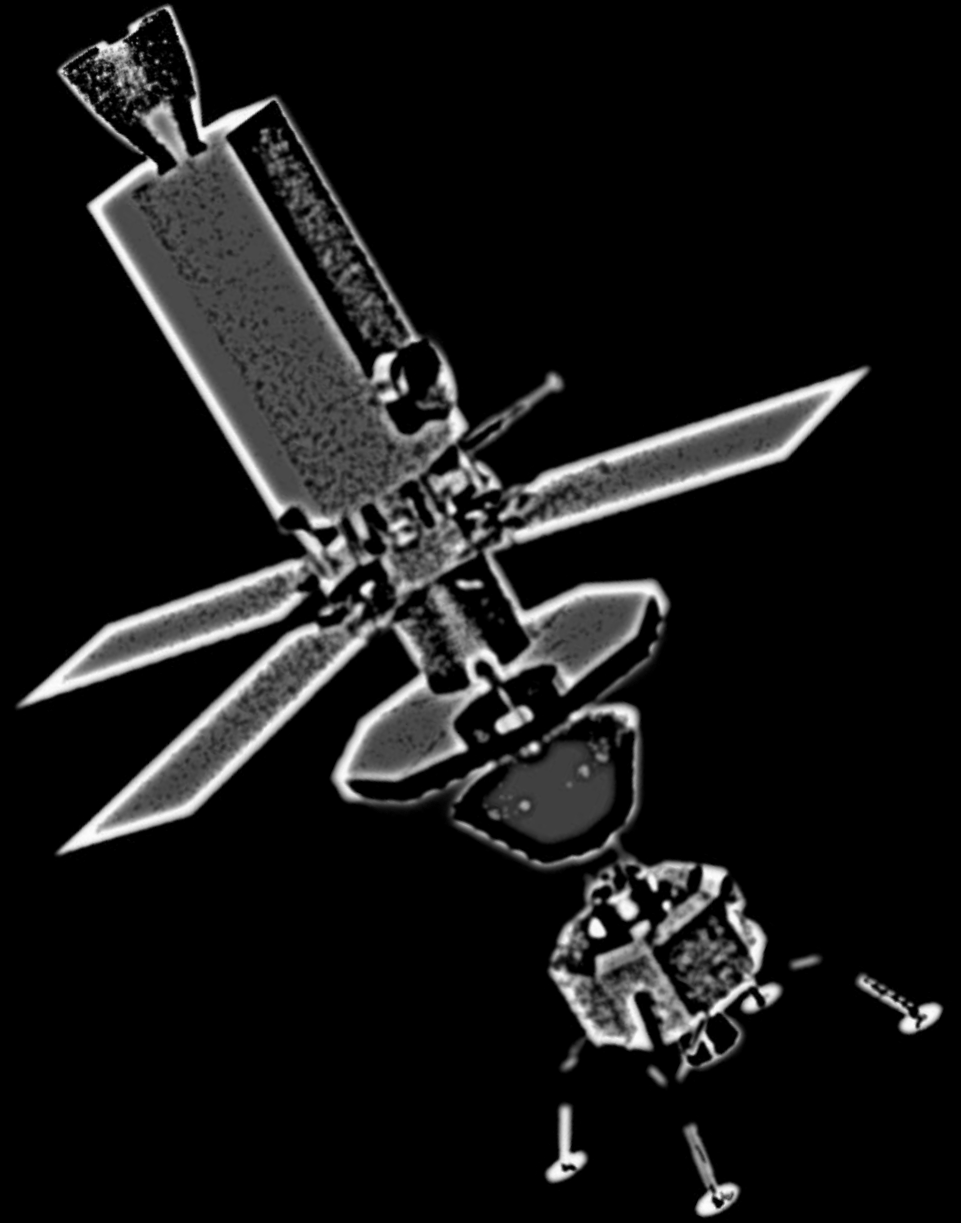


Image Source: NASA / Reid Weissman, "Hello, World"

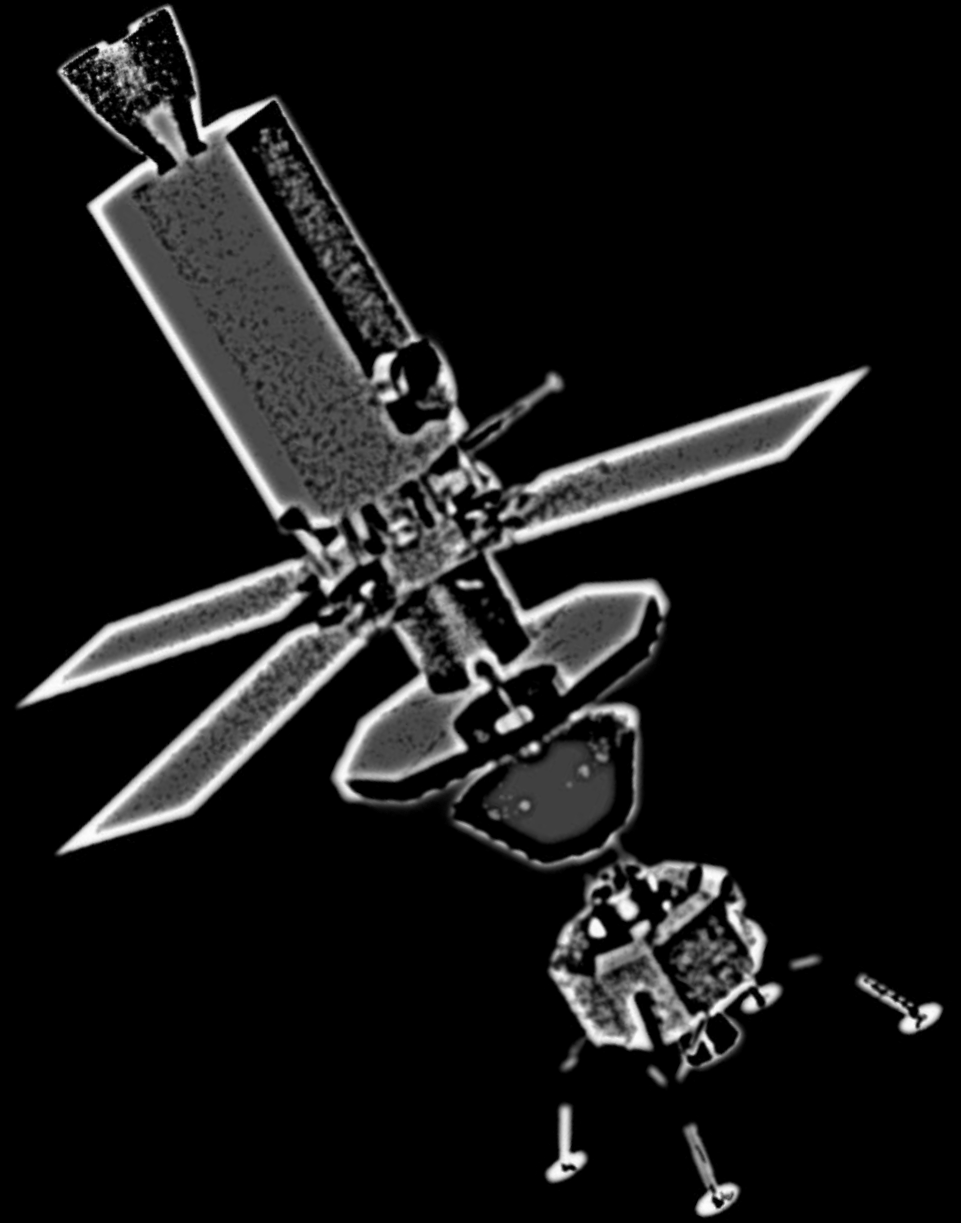
Conclusion

- The HERMES platform promises to be a versatile and highly capable system
- Mercury surface landing, sample collection and preservation will occur in one mission reducing mission cost
- Instrumentation will gather data on Mercury for further scientific understanding



Contributions

- Offers a first close-up look at the surface of Mercury
- Highly adaptable concept could be altered to perform sample return missions from other bodies
- First single mission planetary sample return



Acknowledgments

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Questions?

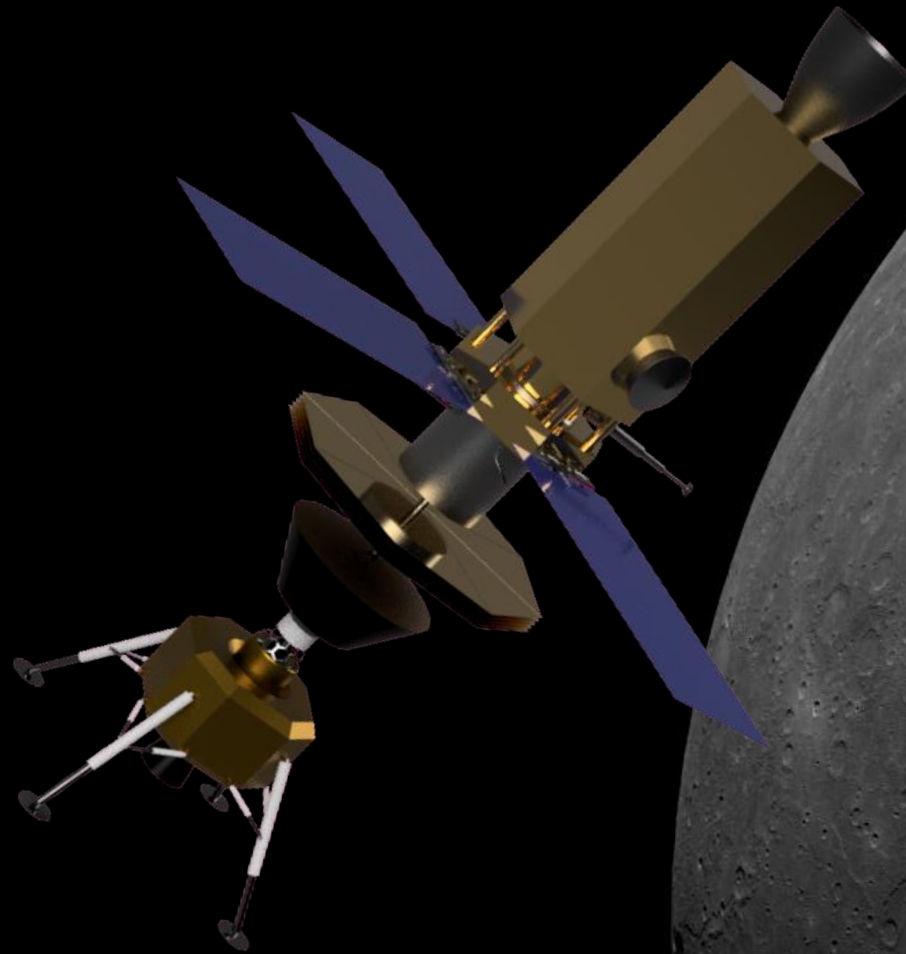


Image Source: NASA, "Mercury Facts"

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