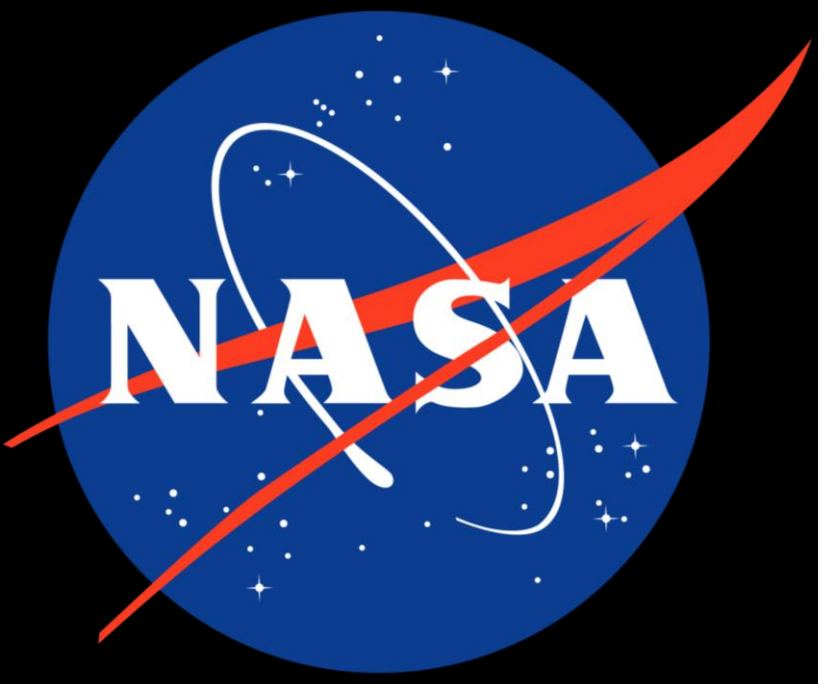




Capabilities for Long-Duration Landers On Mercury

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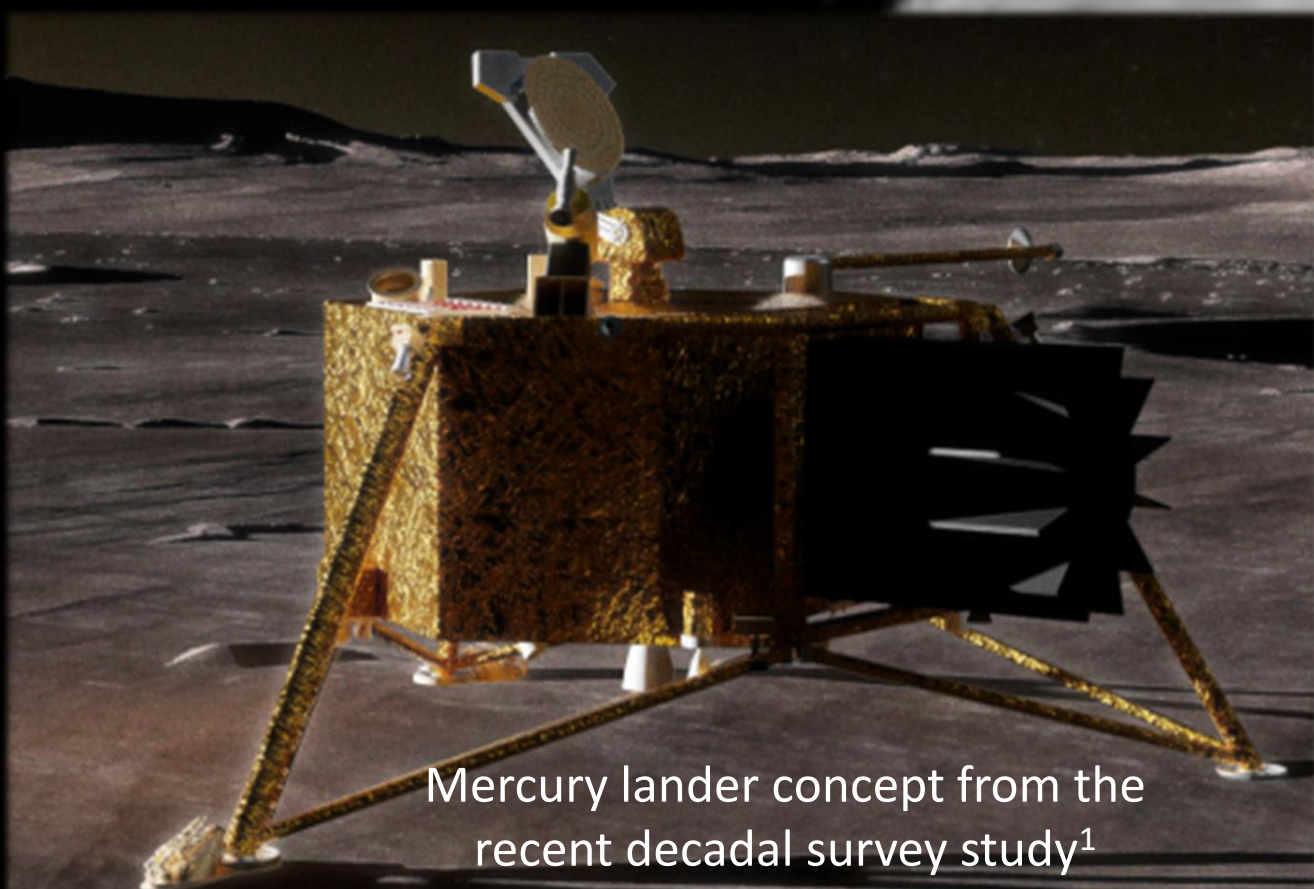
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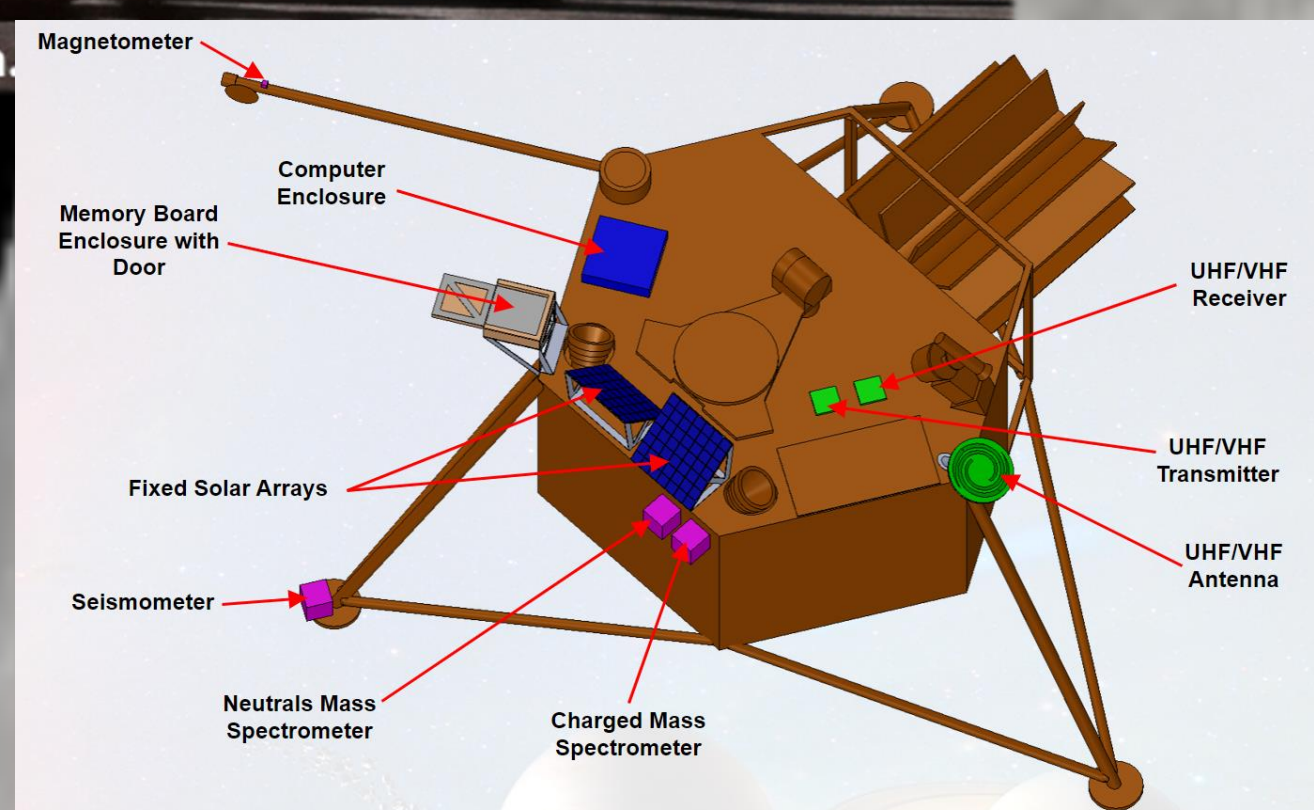
Introduction

- Mercury surface assets will be exposed to extreme thermal swings over a Mercury day (-180 C to +430 C).
- Dayside operations, in particular, are challenging from a thermal control and power perspective.
- Consequently, the latest planetary decadal survey process included a Mercury lander concept that only operated during the night⁽¹⁾.
- Recent technology advancements in high and low temperature systems may enable new science over the entire Mercury day.

Ref 1: Mercury Decadal Survey report at https://science.nasa.gov/wp-content/uploads/2023/05/MercuryLander_2020PMCS_Final_v2_Tagged.pdf



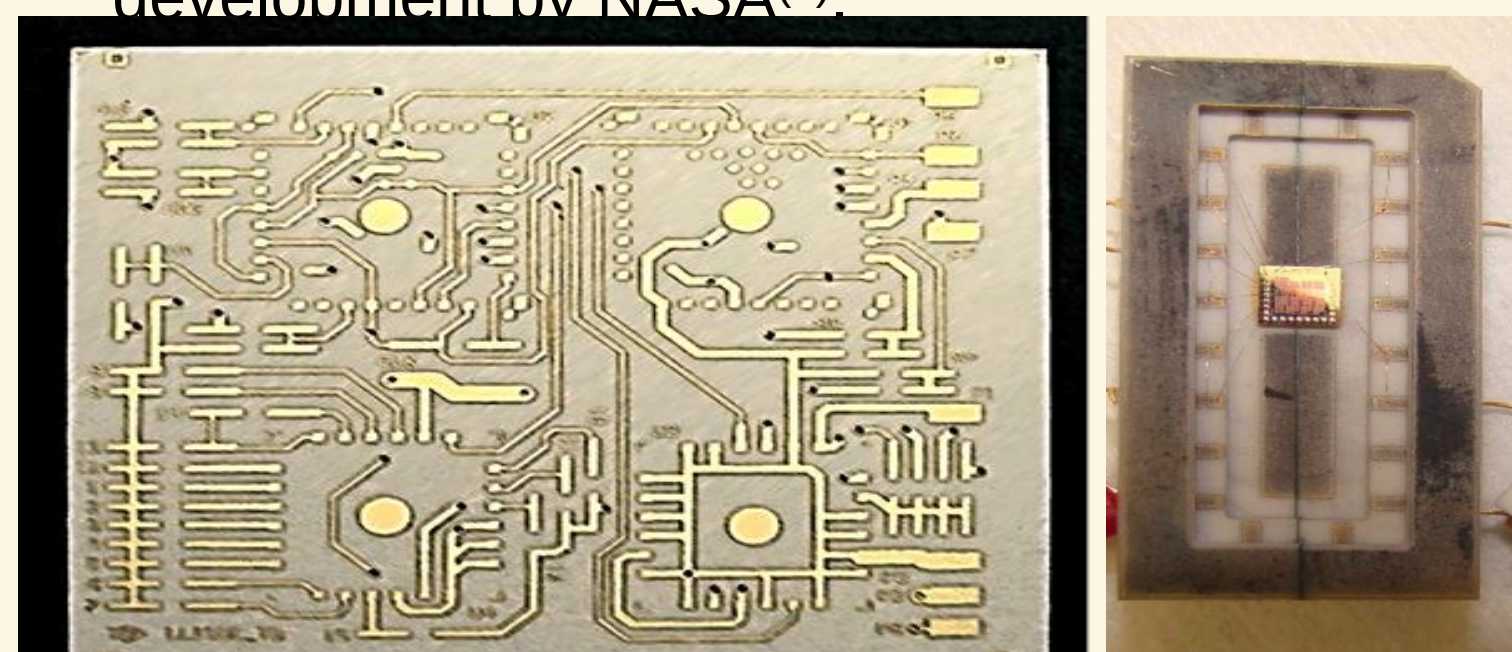
Mercury lander concept from the recent decadal survey study¹



Mercury lander concept highlighting high-temperature elements

Electronics and Comm Capabilities

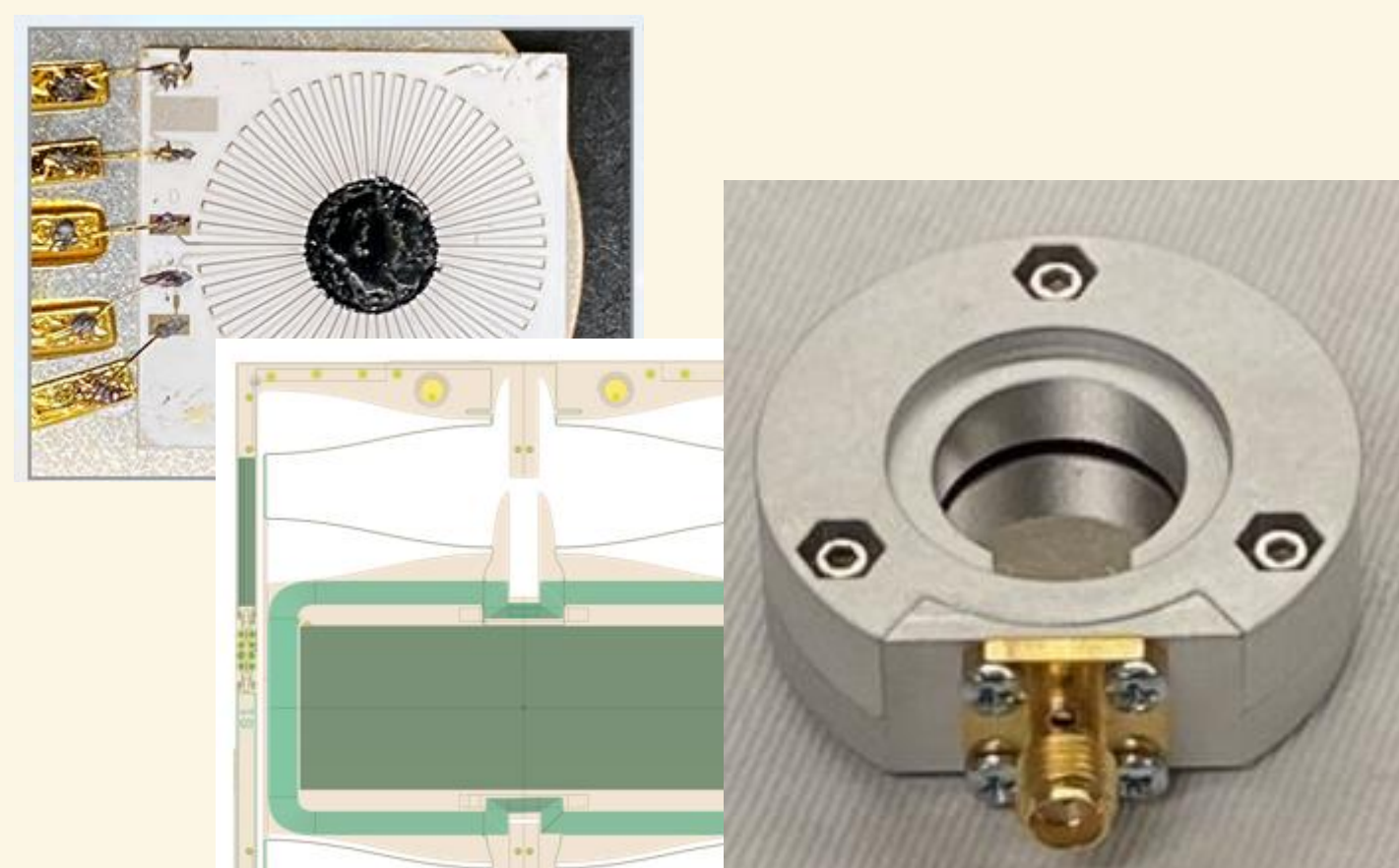
- High-temperature Electronics (IC and passive components are in development.
- NASA's Long-Lived Insitu Solar System Explorer (LLISSE) project increased performance, complexity and maturity of electronics by orders of magnitude in recent years⁽⁴⁾.
- Currently fabricating the 12th generation of high-temperature Junction Field Effect Transistor devices. This generation will be capable of executing simple surface lander operations.
- Bipolar Junction Transistor (BJT) devices have also been successfully fabricated. These provide capability for power switching and high frequency operations.
- Low power high-temperature memory is in development by NASA⁽²⁾.



High-temp board ready for addition of devices and packaged IC. Electronics and IC have been tested for thousands of hours at 500 C.

Instruments and Sensors

- Various high-temperature instruments & sensors have been developed to work at Venus temperatures (>450 C) and are at varying readiness levels, TRL 3 to 5+.
 - Mercury oriented science payload (e.g. charged particle and neutral detectors, magnetometer) is not as mature.
- Development of a seismometer that will function on both the day and night sides of Mercury is under way. Expected to be at between TRL-4 and 5 in 2025.
- Depending on complexity of the lander and capabilities of the power and thermal control system, other more traditional lander instruments may also be feasible.



Various sensors and instruments have been in development that would be suitable for Mercury dayside science.

Major Science Goals

Understand active processes at the surface of Mercury involved in producing the exosphere and altering surficial materials.

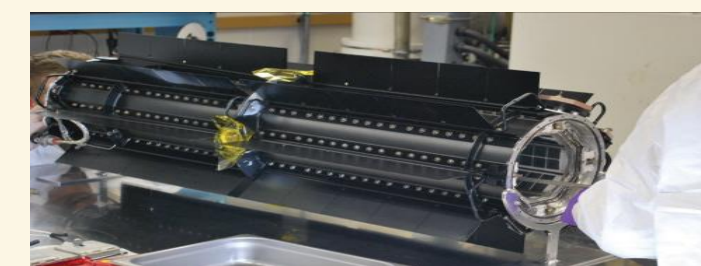
- Characterize the near-surface neutral exosphere and its surface interactions.
- Determine the fluxes of inbound and outbound low-energy charged particles with the surface.

Understand Mercury's interior including its structure, tectonic activity, and the operation of the magnetic field.

- Characterize the seismic activity associated with the cooling planet and tidal deformations.
- Determine the structure of the interior, including the state and size of the core.
- Investigate the behavior of the magnetic field at the surface and the interactions between the external and internal fields, as well as those recorded and produced in the crust and mantle.

Power System

- The recent Mercury decadal survey study incorporated a radioisotope power system (RPS)¹.
- A study is planned to assess what, if any, changes are required the Next Generation Radioisotope Thermoelectric Generator power system, assumed in the study, to allow it to operate over multiple Mercury days and years.
- High temperature solar arrays are in development⁽²⁾ which could be used to power small loads and charge high temperature batteries which in turn could support night-side lander operations.
- High-temperature batteries have been developed for Venus and could directly be applied on Mercury for dayside instrument operations.
- In summary, there are several feasible approaches to powering Mercury day and night side lander operations and combining these may allow for creative engineering solutions to maximize science returned.



NextGen RTG assumed by recent Mercury lander decadal study report (1), (3).



1/3 scale batteries that function at temperatures up to 500 C delivered to GRC for testing by Advanced Thermal Batteries, Inc.

Ref 2: <https://www1.grc.nasa.gov/space/pesto/investment-areas/hottech/>
Ref 3: <https://science.nasa.gov/wp-content/uploads/2024/02/nf%E2%80%93932022%E2%80%939311%E2%80%939328%E2%80%9393hq-next-gen-factsheet-508.pdf>

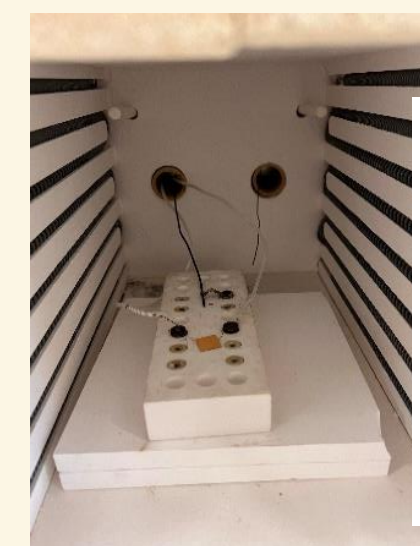
Concept of Operations

- The instruments and sub-systems that are required for day side operations are assumed to be attached and delivered as a part of the Mercury lander concept developed by the decadal survey study.
- Sub-systems critical for day side operations will all be built using high-temperature components and devices and will continue to operate.
- After the initial night mission concludes the high-temp systems will continue to operate and collect science.
- The orbiter will relay lander data to the Earth through an orbiter. After deployment of the lander, the carrier/orbiter will transition to an elliptical orbit to maximize contact times with the lander and Earth.
- Mission duration will be determined by science objectives but a minimum of one Mercury day is assumed.

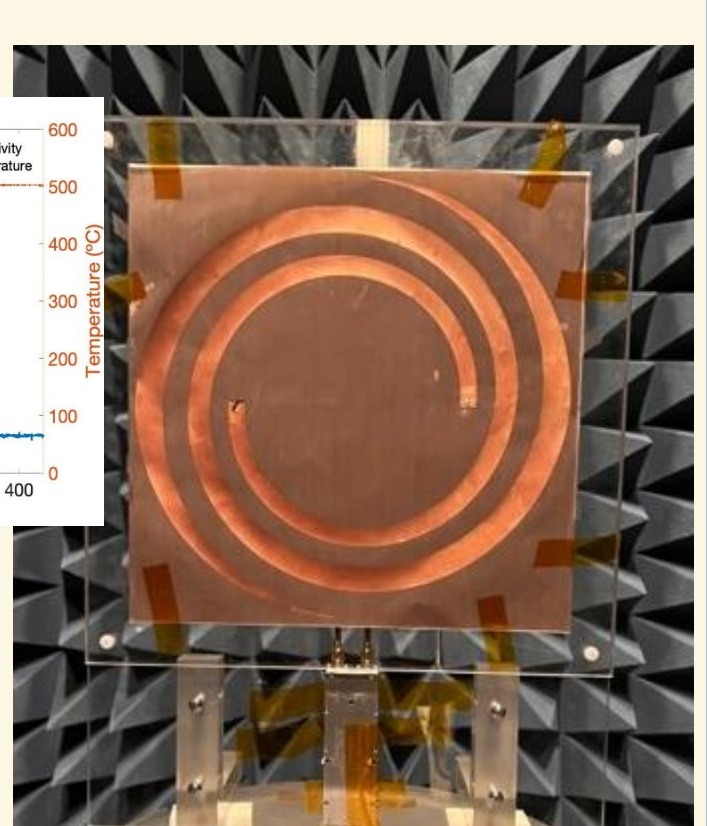


Communication System

- Recent BJT development progress is significant and will reduce risk and enhance science returned.
- Circuits utilizing high-temperature devices have been designed and tested via simulations. Testing with actual devices will occur when devices are through fabrication process.
- Antenna and other component materials with appropriate properties at temperature and manufacturability at scales needed have been selected and tested.
- Long duration landers will return more data by using a Mercury orbiter as a relay to Earth than direct lander-to-Earth transmission.



Oven testing and stability of high temperature antenna material



Testing a potential antenna design

Conclusions and Acknowledgments

- Advances in lander sub-systems are enabling them to operating in extreme hot and cold environments, including the surface of Mercury.
- Advances made for Venus landers are also applicable to Mercury. These can be leveraged to return new and more science from a Mercury lander.
- Hardware exists for all sub-systems and various levels of testing have been completed at Mercury relevant temperatures.
- Science enabling and enhancing instrument developments have also been funded. (E.g. Seismometer, Radiance). More instrument development needed to complete a desired Mercury payload suite.

The resources for exploring how the technologies advances can apply to Mercury have been provided by NASA's Glenn Research Center.