Mars Program

Power Systems for Future Mars Missions

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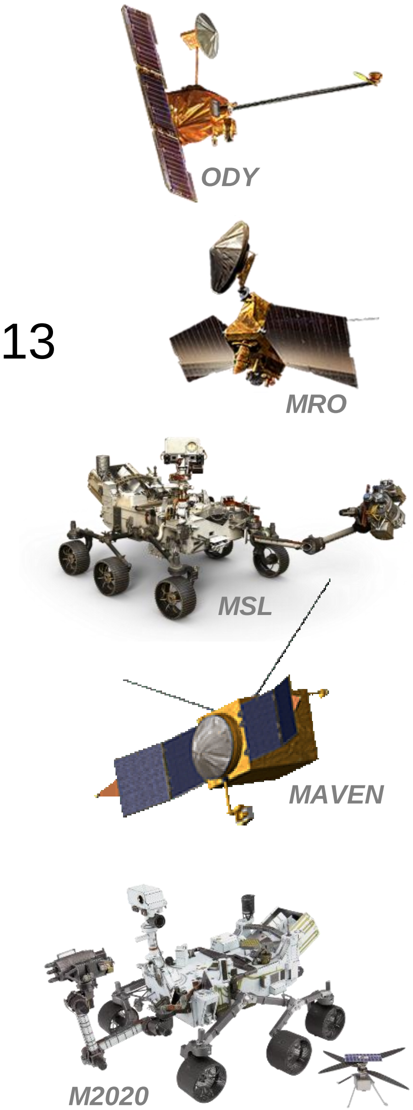
The Aerospace Corporation

Currently Operating Mars Missions

Mars Program

- Mars Odyssey - 2001
- Mars Reconnaissance Orbiter - 2005
- Mars Science Laboratory (Curiosity) - 2011
- Mars Atmosphere and Volatile EvolutioN (MAVEN) - 2013
- Mars 2020 (Perseverance and Ingenuity) - 2020
- Non-U.S. missions
  - ESA: Mars Express (2003)
  - ESA: Trace Gas Orbiter (2016)
  - UAE: Hope orbiter (2020)
  - China: Tianwen 1 orbiter (2020)

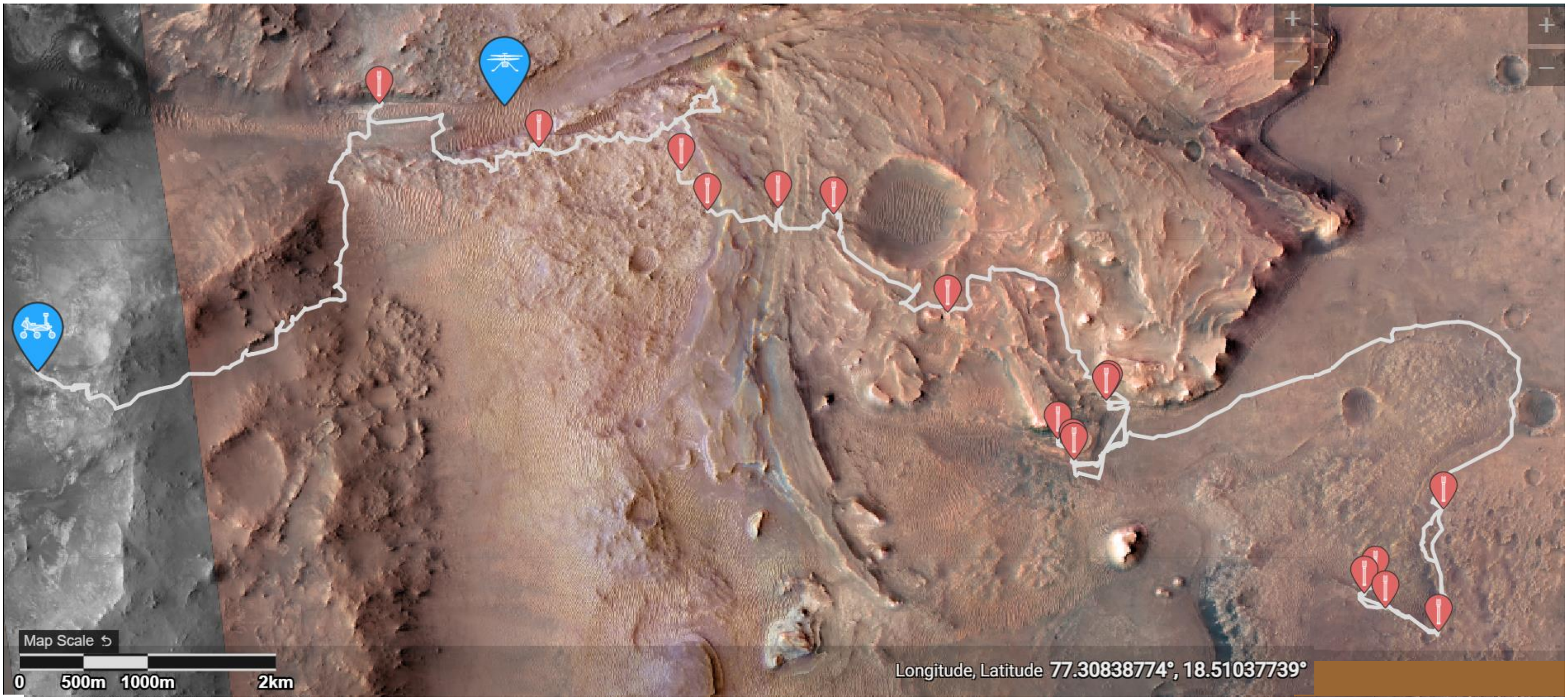


Pre-decisional information – For planning and discussion purposes only. Approved for public release.

Mars 2020 Mission Progress

Mars Program

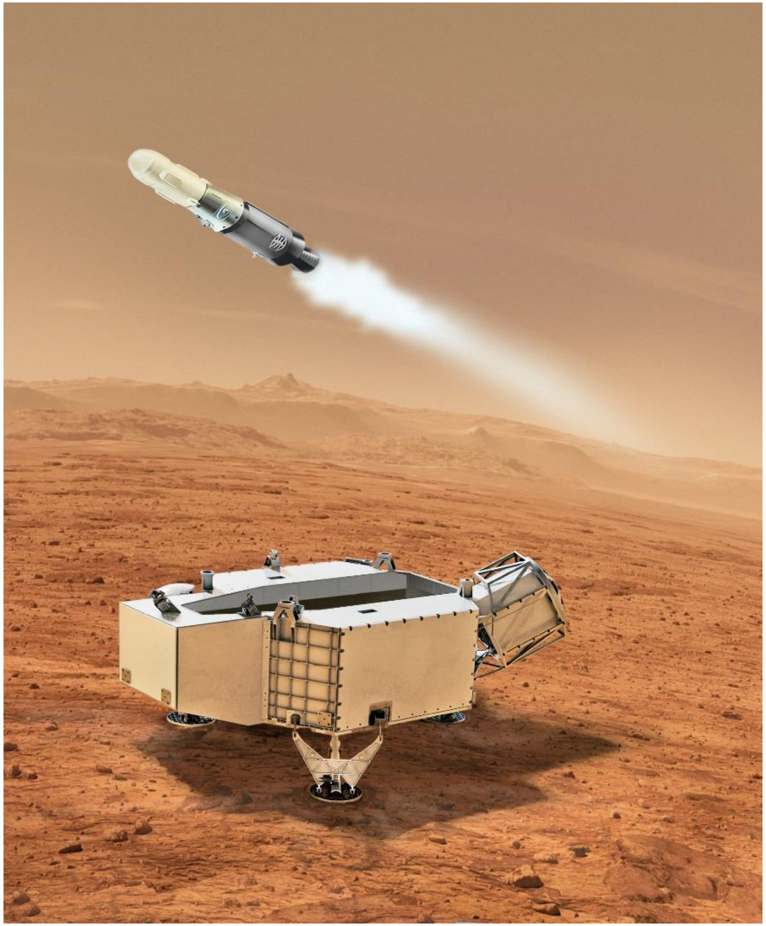
- As of April 3, the Perseverance Rover has traveled ~35.5 km and collected 18 rock core samples and 1 regolith sample
- The Ingenuity Helicopter flew ~17 km in 72 flights



Mars Sample Return Status

Mars Program

- The Perseverance rover continues to collect scientifically valuable core samples for return to Earth
- A new smaller MAV design is under development
- JPL is developing a heritage sky crane approach for a Sample Retrieval Lander (SRL)
- Industry studies are looking at alternatives for a large lander
- ESA continues development of the Earth Return Orbiter to bring samples from Mars orbit to Earth



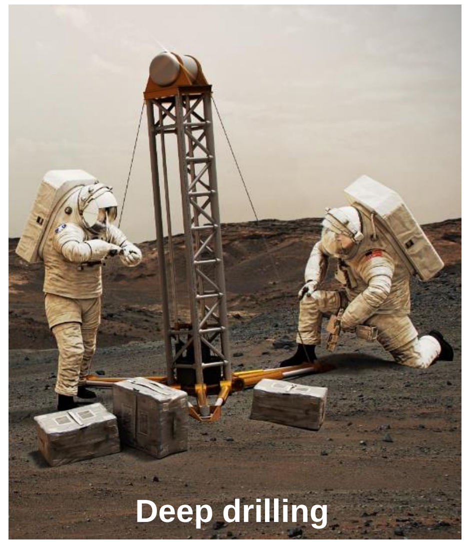
The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This status is being made available for information purposes only.

Mars Exploration Program Future Plan

Mars Program

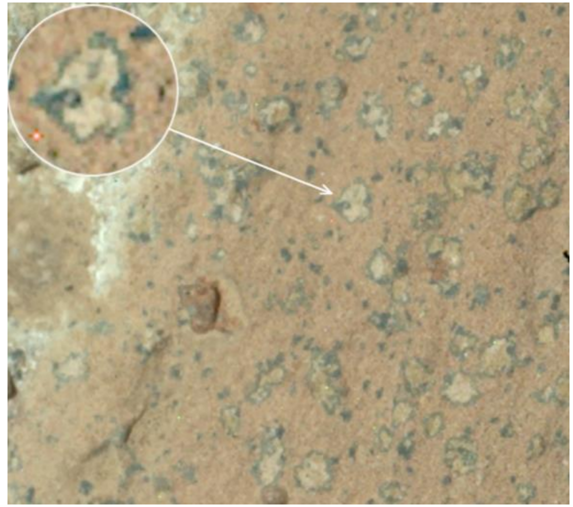
- MEP has released a Future Plan that incorporates inputs from across the planetary science community, Mars science community, and engineering and technology communities: https://science.nasa.gov/planetary-science/programs/mars-exploration/future-of-mars-plan/
- Looking forward, we plan to implement a sustainable portfolio of missions that
  - Address our critical and aging infrastructure for data relay, high resolution surface imaging, and many other capabilities
  - Take advantage of the expanding space business environment
  - Help prepare for human exploration of Mars
- Part of the future effort needs to be developing new technologies, and power generation and storage are key technologies


Science helicopter

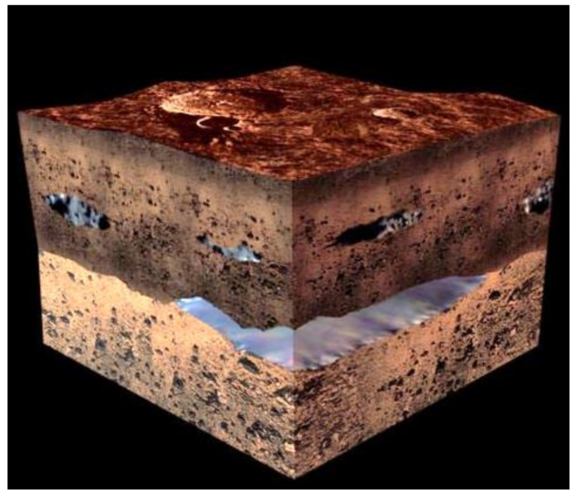

Deep drilling

Mars Future Plan Science Themes

- Explore the Potential for Martian Life
  - Advance the search for past and present microbial life and habitable environments through time
- Support Human Exploration of Mars
  - Collect science that is synergistic with the objectives for human exploration of Mars
- Revealing Mars as a Dynamic Planetary System
  - Understand the dynamic geological and climatological processes on Mars to illuminate the evolution of the Martian system, our home planet Earth, our solar system, and distant planets around other stars



“Cheyava Falls” leopard spots



Sub-surface ice and water

Potential Future Mars Opportunities

Mars Program

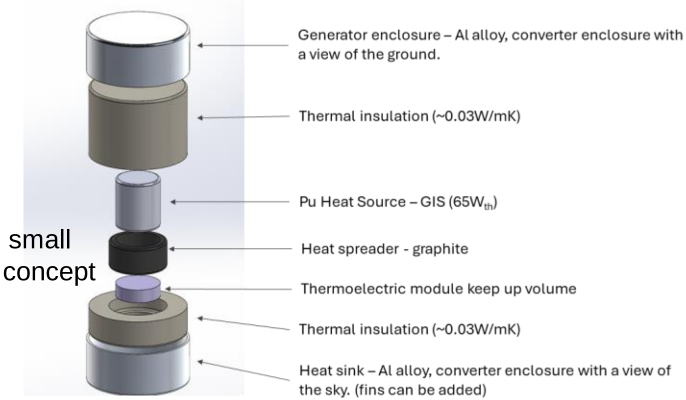
- The goal is to establish a regular cadence of science-driven, lower-cost mission opportunities

LOW-COST MISSIONS	MEDIUM-CLASS MISSIONS	MISSIONS OF OPPORTUNITY
Enable broad, competed scientific investigations that address community-defined questions and encourage incremental development of networks.	Enable targeted or discovery-responsive scientific missions that address strategic, highest priority decadal class themes.	Open greater access to Mars for more participants by expanding lower-cost flight opportunities.
• Competed Small Missions • \$100M - \$300M level • Single instrument or small complement of instruments • Intent to select missions for every Mars launch opportunity • May select multiple smaller missions per launch opportunity • Draws on experience from COTS/CLPS programs	• Broad Science Investigations • More complex instrument suites, competitively selected or partner contributed • New technologies in sample acquisition, mobility, autonomy • Considering competition at either the mission or instrument level • Scalable to significant discoveries	• Competed Payloads • Potentially competed or directed • Could be science or infrastructure focused • Flown on international or commercial missions

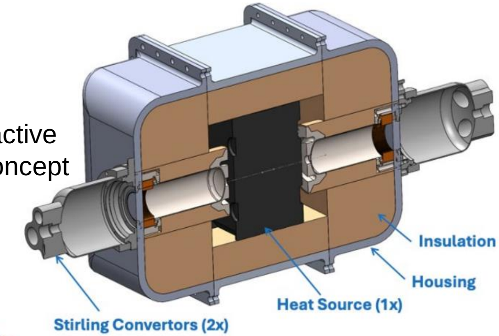
New Technologies Currently in Development

Mars Program

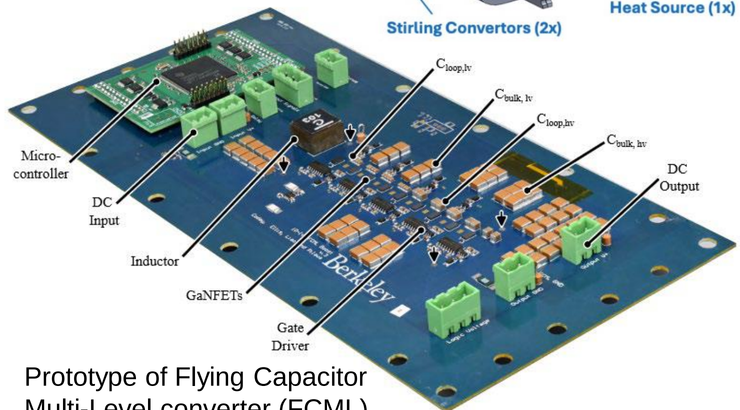
- Helicopter rotors to carry multi-kg payloads
- Advanced wheeled and legged surface mobility
- Subsurface drilling technology
- Low-cost Entry, Descent, and Landing (EDL) for small landers
- Advanced telecom subsystems
- Advanced orbital instruments
- Advanced power systems
  - Small RTGs in sub-Watt to 3W range for small landers
  - Dynamic RPS in 50-70W range for small landers or rovers
  - Helicopter power systems to support take-off mass of 30-40 kg



Initial small RTG concept



Small active RPS concept

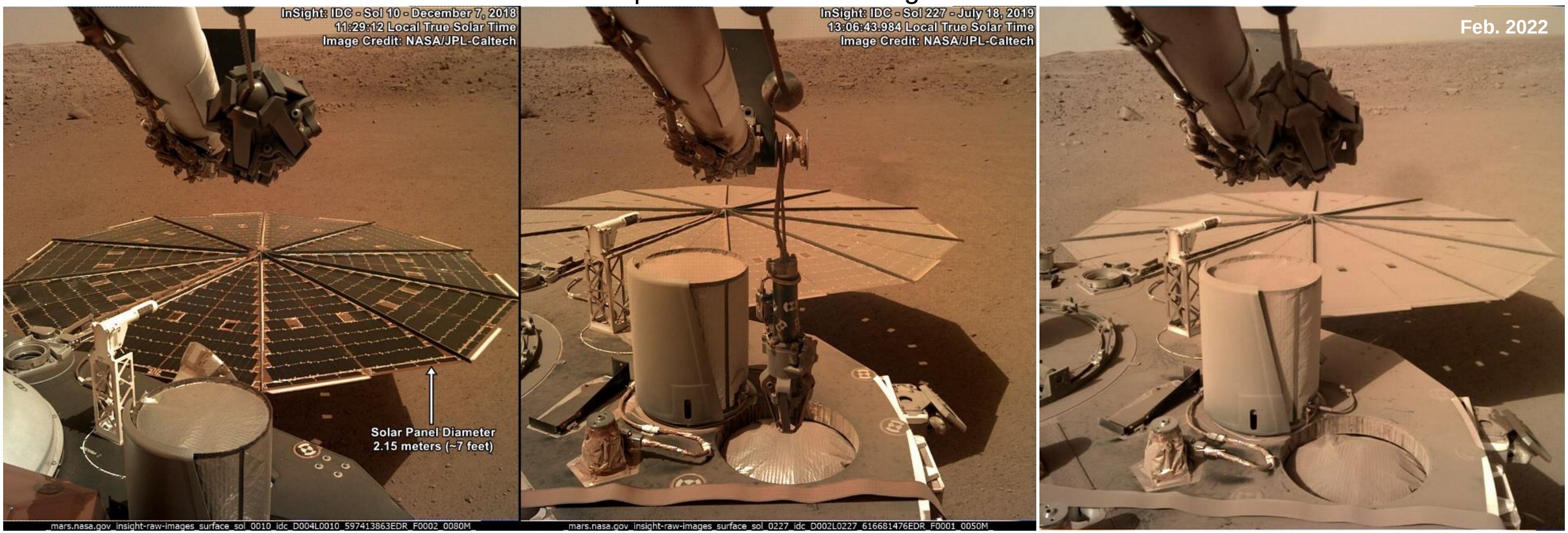


Prototype of Flying Capacitor Multi-Level converter (FCML)

Power Challenges for Mars

- Solar array dust deposition
  - Spirit and Opportunity had wind cleaning events intrinsic to their locations
    - Opportunity survived for 14 Earth years
  - InSight was not so fortunate
- Limited power, high cost, and limited availability of RTGs
- Surviving the cold Martian nights (RHUs can help)

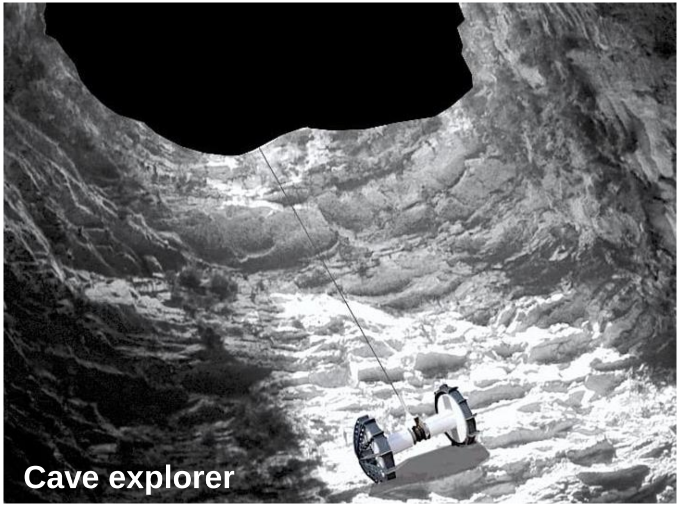
Dust deposition on Mars InSight lander



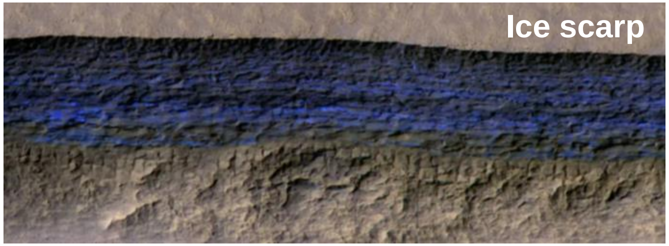
Power Needs for Future Missions

Mars Program

- More efficient solar arrays
  - Helicopters are severely limited by size and mass constraints
  - Dust cleaning capability is needed
- More efficient batteries
  - Mass and volume for helicopters is severely constrained
  - Surviving low nighttime temperatures is critical
- Lower cost and more available radioisotope power options
  - Needed for rovers, cave explorers, and polar missions
  - Surface network missions need long life through dust storms, darkness, and winter conditions
  - Lower power radioisotope systems might be acceptable


Cave explorer


Cliff explorer


Ice scarp


Sinkhole

Closing Thoughts

- Future Mars mission concepts have significant power challenges
  - Innovative new ideas are welcome from industry and elsewhere
- New systems and technologies need to be developed and qualified (e.g. solar array cleaning)
- Keep looking at alternative options for radioisotope power
  - Sr 90, Am 241, or other lower cost heat sources
  - More efficient conversion technologies (e.g. dynamic systems)
  - Providing a range of options from low to high power