Scoping It Out Technical Report

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When developing a space mission, the first step is deciding on a clear scientific problem and then designing methods that are realistic to investigate it with engineering limitations in mind. In the case of exploring Mars, the possible presence of liquid water beneath the south polar ice cap is a heavily discussed, unanswered question. Orbital radar observations have demonstrated detection of unusually bright reflections below the surface. However, these observations have not yet been confirmed through directly investigating the surface (Lalich et al., 2022). The Polar Brine Seep Investigation mission is designed to explore this question and address this gap by deploying a robotic lander that is capable of studying subsurface ice and potential brine layers. This report outlines the mission need, scientific questions, landing site selection, operational concept, stakeholders, constraints, and overall mission purpose.

Mission Needs and Goals

A robotic mission is needed because orbital data cannot alone decide whether the detected reflections truly represent liquid brines. It also cannot measure their chemical composition or stability in the long-term. Therefore, direct subsurface analysis is very much needed to confirm these findings. The mission is guided by three primary scientific questions.

The first question asks whether stable hypersaline brines currently exist beneath the south polar layered deposits. This question supports the Mars Exploration Program goals of determining whether life ever arose on Mars. The concept of liquid water is considered to be essential for life there to exist, and on Earth, brine environments are known to support extremophilic organisms (Bailey, 2019). By confirming the presence of stable liquid reservoirs, currently astrobiological models would be heavily influenced.

The second focuses on the chemical and thermal properties of detected brines. This supports the goal of characterizing the climate of Mars. The formation of brines depends on various conditions like salt concentration, pressure conditions, and temperature gradients. All of these are tied to the long-term climate evolution of the planet and measuring these properties can

help refine models of Martian volatile cycling (Starinsky & Katz, 2003).

The third question considers whether subsurface brines could serve as a usable water resource for future human missions. This directly supports the goal of preparing for human exploration. The determination of there being accessible water resources would greatly contribute to a lowering of mass requirements for crewed missions and improve long-duration mission sustainability (Avery, 2024).

Mission Subject

The Polar Brine Seep Investigation looks into the layers of ice and soil beneath the south polar surface of Mars. It especially studies areas where liquid brine might exist. This process would start with ground-penetrating radar scanning beneath the surface to find differences in material that could indicate trapped liquid. Once a promising location is identified, a cryogenic drill will dig up to five meters into the ground and collect sealed core samples. Temperature of the drill must be carefully controlled during this process in order to make sure that any ice or brine does not evaporate or change state in the thin Martian atmosphere.

After the samples are collected, onboard instruments will analyze them. For example, a gas chromatograph-mass spectrometer will look for organic molecules, while a Raman spectrometer will figure out the types of minerals and salts that are present. Thermal sensors will also be used to measure how temperature changes beneath the surface to determine whether or not conditions are stable enough for liquid brine to exist (Davis, 2025). Therefore, by using both radar imaging and chemical testing, the mission will be able to gather information about what is physically there alongside what it is made of.

Stakeholders

The main stakeholders for this mission include NASA’s Mars Exploration Program alongside planetary scientists, astrobiologists, and engineers involved in future human mission planning. Scientists will use the collected data to improve climate models and further evaluate the habitation potential of modern Mars. Engineers will be able to assess if subsurface water

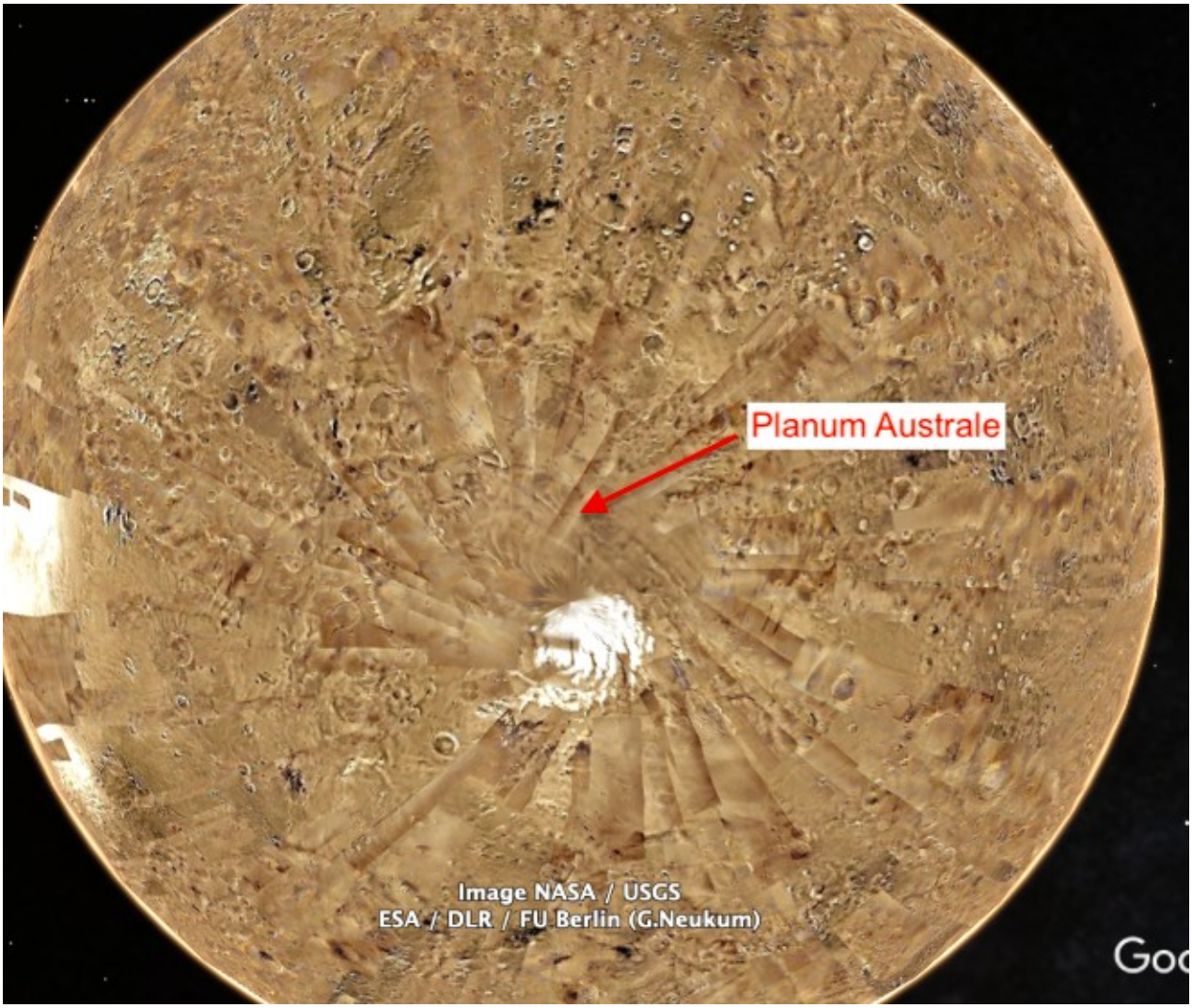
could support resource utilization systems in Mars for future missions. Other stakeholders include international research organizations and educational institutes that benefit from expanded Mars data. The mission also contributes to the interest of the public by advancing autonomous robotics and cryogenic drilling technologies (Bowman, 2023).

Landing Site

The selected landing site is Planum Australe, which is located about 83°S latitude and 193°E longitude. Planum Australe contains thick layered deposits of water ice interbedded with dust and seasonal carbon dioxide frost. Within its region, orbital radar data has identified strong subsurface reflections that may indicate the presence of liquid brines (Malin et al., 2026). The layered structure also maintains and preserves a long-term record of Martian climate, which can be similarly compared to polar ice cores on Earth. Even though the site presents some engineering challenges because of the extreme cold and seasonal frost accumulation, the high scientific value of it makes it the most appropriate landing location for this mission.

Figure 1

Image of Planum Australe (Eduterre, 2015)



Operational Concepts

Mission Duration

The Polar Brine Seep Investigation mission is designed to operate for one year following landing. This duration allows for adequate time to complete subsurface radar mapping, multiple drilling operations, and detailed chemical analysis of collected samples. It would also open the door to the observation of seasonal changes in the south polar region. A shorter mission duration than this could possibly limit the number of drilling attempts and reduce the reliability of the collected data. On the other hand, a longer mission duration than that would increase exposure to extreme cold, mechanical wear, and radiation (Atkinson, 2024).

Mission Elements

Launch Vehicle

The spacecraft will launch during the 2028 Earth-Mars transfer window using a heavy-lift launch vehicle. This window is chosen because Earth and Mars are properly aligned, which reduces the amount of fuel needed to reach Mars. The rocket must also be strong enough to carry the lander, drilling equipment, and scientific instruments, heating systems, and communication hardware safely into space without damage during launch (Malin et al., 2026).

Entry, Descent, and Landing (EDL)

After a cruise phase lasting about seven months, the spacecraft will enter the Martian atmosphere. The entry sequences will begin with a heat shield to protect the spacecraft from atmospheric heating. After that, a supersonic parachute will be deployed to slow the descent, and then a powered descent system will take over to guide the lander to the selected site. Terrain-relative navigation will make sure that the landing is accurate within the south polar region (Carney, 2025).

Lander System

After landing, a commissioning phase lasting about 30 sols will occur. During this time, the lander will perform system health checks while also stabilizing internal temperatures and calibrating scientific instruments. Due to the extreme cold the mission happens in, thermal regulation systems will operate continuously to ensure that the instruments remain functional. Power will be supplied by a radioisotope thermoelectric generator, which provides steady energy even with limited sunlight at this high altitude (Garcia, 2026). The lander remains stationary rather than mobile like a rover, reducing mechanical complexity and allowing for full focus on a specific landing site.

Scientific Payload

The scientific payload includes ground-penetrating radar, a cryogenic drill, a gas chromatograph-mass spectrometer, a Raman spectrometer, and thermal sensors. The radar will

identify subsurface layers that may contain liquid brine, while the drill will extract core samples from depths up to five meters. The collected samples will then be analyzed to determine mineral composition, salt concentration, and the possible presence of organic molecules. Temperature measurements beneath the surface will help assess whether conditions are stable enough for liquid brine to persist (Davis, 2025).

Communication

Communication between Mars and Earth will occur through existing Mars orbital relay satellites. The lander will store collected data onboard and transmit it during scheduled communication windows. Due to the signal delays ranging from four to twenty-four minutes, the lander will operate mainly in autonomous mode (Tomaswick, 2023). Ground control teams will monitor spacecraft health, review transmitted data, and update the mission sequences as needed.

Timeline and Milestones

The mission timeline follows a clear sequence from launch to surface operations and extended science. Each stage builds on the success of the previous phase, and several events are considered to be critical to the overall success of the mission.

Stage 1 - Launch. The spacecraft departs Earth during the 2028 Earth-Mars transfer window. This timing is chosen because Earth and Mars are aligned in a way that reduces travel time and fuel use. A successful launch is the first major milestone of the mission.

Stage 2 - Cruise. The spacecraft travels to Mars for about seven months. During this time, small adjustments are made to keep it on the correct path. Engineers also check systems to make sure everything is working properly before arrival.

Stage 3 - EDL. When the spacecraft reaches Mars, it enters the atmosphere protected by a heat shield. A parachute slows it down, and a powered landing system helps guide it safely to the surface at Planum Australe.

Stage 4 - Surface Commissioning. After landing, the spacecraft spends about 30

Martian days checking its instruments and stabilizing internal temperatures. Communication with Earth is established, and all systems are prepared for science operations.

Stage 5 - Subsurface Exploration and Analysis. Radar scans help identify the best places to drill. The drill collects samples from below the surface. Onboard instruments study the samples to determine their mineral content, salt levels, and possible signs of organic material. Data is sent back to Earth for further study.

Stage 6 - Extended Operations. If the spacecraft remains in good condition, it may continue drilling and collecting environmental data. Seasonal changes in temperature and surface conditions may also be monitored.

Step 7 - Mission Closeout. When power levels decrease or environmental conditions become too harsh, typically near the end of the planned one-year surface mission, the spacecraft will complete its final transmission to Earth. The mission will formally be over once systems can no longer operate safely. Even though the lander will stay on Mars, the collected data will continue to be analyzed by scientists years after mission completion.

Constraints

There are various constraints that shape the design of this mission. For example, temperatures near the south pole can drop below -120°C. Due to this, the spacecraft must have strong heating systems to keep its instruments working. Because sunlight is limited at high altitudes, solar panels would not provide enough power, meaning the mission must rely on radioisotope power sources for steady energy. Communication between Earth and Mars is also delayed, so the spacecraft must operate mostly on its own without manual control. Planetary protection rules require strict contamination prevention since liquid water may exist in the region. Other limits include how much mass the rocket can carry, overall budget restrictions, and the risks of landing on icy terrain (Atkinson, 2024).

Conclusion

The Polar Brine Seep Investigation mission is designed to determine whether subsurface

liquid brines exist beneath the south polar layered deposits of Mars. By combining radar mapping, cryogenic drilling, and chemical analysis, the mission supports key Mars Exploration Program goals related to life detection, climate history, and preparation for human exploration. Furthermore, confirming stable brines would improve understanding of the habitability of modern Mars and potential water resources. With equal importance, the mission shows the value of clear scope designation, focusing on a specific and achievable objective that directly supports future crewed missions. If accessible brines are confirmed, they could contribute to life support and fuel production systems, which could reduce risk and uncertainty for future long-duration human exploration.

Scope Summary

- **Need**: Verify existence and properties of subsurface polar brines.
- **Goal**: Determine modern habitability potential and assess ISRU viability.
- **Objective**: Drill and analyze subsurface polar deposits at Planum Australe.
- **Mission**: Deploy a robotic polar lander with cryogenic drilling capability.
- **Operational Concept**: Launch during the 2028 Earth-Mars transfer window, complete cruise to Mars, perform entry, descent, and landing at Planum Australe, conduct subsurface radar mapping and drilling operations, analyze collected samples onboard, and transmit scientific data to Earth through orbital relay systems.
- **Assumptions**: Radar detections are accurate; RTG power available; required technology and funding are available.
- **Constraints**: Mission must align with the 2028 launch window; systems must withstand extreme south polar temperatures below -120°C; mass limits must be met for launch; operations must comply with planetary protection requirements due to possible liquid water presence; communication delays require autonomous operation.

References

Atkinson, N. (2024, July 12). *Challenges Facing the Human Exploration of Mars.* The Planetary Society. https://www.planetary.org/articles/challenges-facing-the-human-exploration-of-mars

Avery, M. (2024, November 18). *Mars Exploration Science Goals*. NASA.gov. https://science.nasa.gov/planetary-science/programs/mars-exploration/science-goals/

Bailey, R. (2019). *Extremophiles - Extreme Organisms*. ThoughtCo. https://www.thoughtco.com/extremophiles-extreme-organisms-373905

Bowman, A. (2023, July 26). *Stakeholder Expectations Definition*. NASA.gov. https://www.nasa.gov/reference/4-1-stakeholder-expectations-definition/

Carney, S. (2025, January 25). *How We Land on Mars*. NASA.gov. https://science.nasa.gov/planetary-science/programs/mars-exploration/mission-timeline/how-we-land-on-mars/

Davis, P. (2025, April 7). *Science Instruments*. NASA.gov. https://science.nasa.gov/mission/mars-exploration-rovers-spirit-and-opportunity/science-instruments/

Eduterre. (2015). *Situation Planum Australe* [Photograph]. Access Platform. https://eduterre.ens-lyon.fr/ressources/par-theme/geologie-et-hommes/comparaison-terre-et-mars/situation-planum-australe/image_view_fullscreen

Garcia, S. (2026, January 22). *Landers*. NASA.gov. https://www.nasa.gov/reference/jsc-landers/

Lalich, D. E., Hayes, A. G., & Poggiali, V. (2022). Explaining Bright Radar Reflections Below The South Pole of Mars Without Liquid Water. *Nature Astronomy, 6(10)*, 1142–1146. https://doi.org/10.1038/s41550-022-01775-z

Malin, M. C., Belton, M. J., Carr, M. H. (2026, February 15). *Mars*. Encyclopedia Britannica. https://www.britannica.com/place/Mars-planet

Starinsky, A., & Katz, A. (2003). The formation of natural cryogenic brines. *Geochimica et Cosmochimica Acta*, *67*(8), 1475–1484. https://doi.org/10.1016/s0016-7037(02)01295-4

Tomaswick, A. (2023, March 7). *Are There Better Ways to Communicate with Mars?*. Universe Today. https://www.universetoday.com/articles/are-there-better-ways-to-communicate-with-mars