Mars Exploration Program Analysis Group (MEPAG): Searching for life on Mars

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Why Search for Life on Mars?

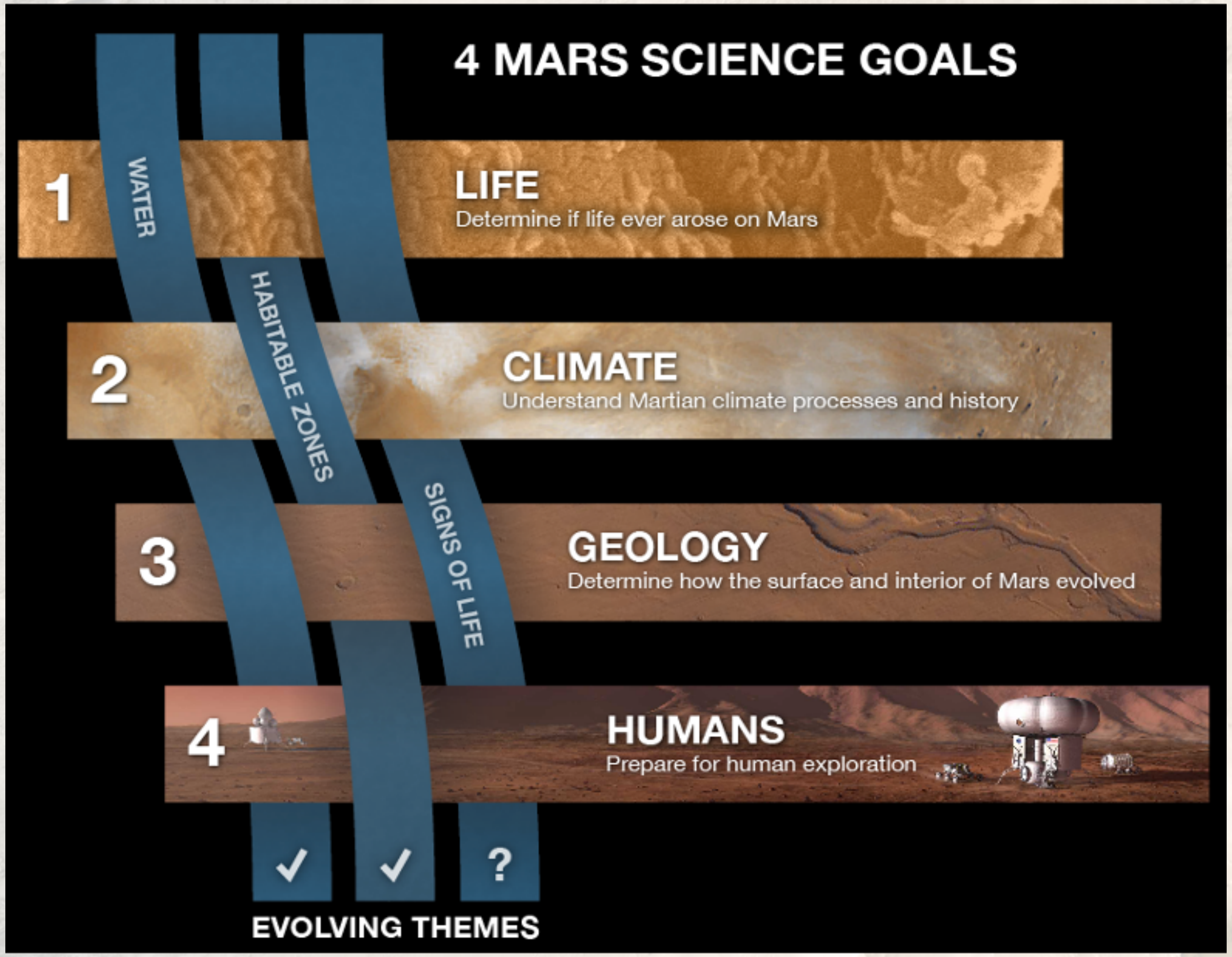
- Nearby terrestrial planet with longer geologic record than is preserved on Earth; offers greater insight into the earliest period of Solar System history and planetary formation

- Geologic features and mineralogy indicative of a once more Earth-like environment with a thicker atmosphere

- The surface of Mars is readily accessible and traversable, environment is less extreme than other planetary bodies — long duration, ongoing exploration

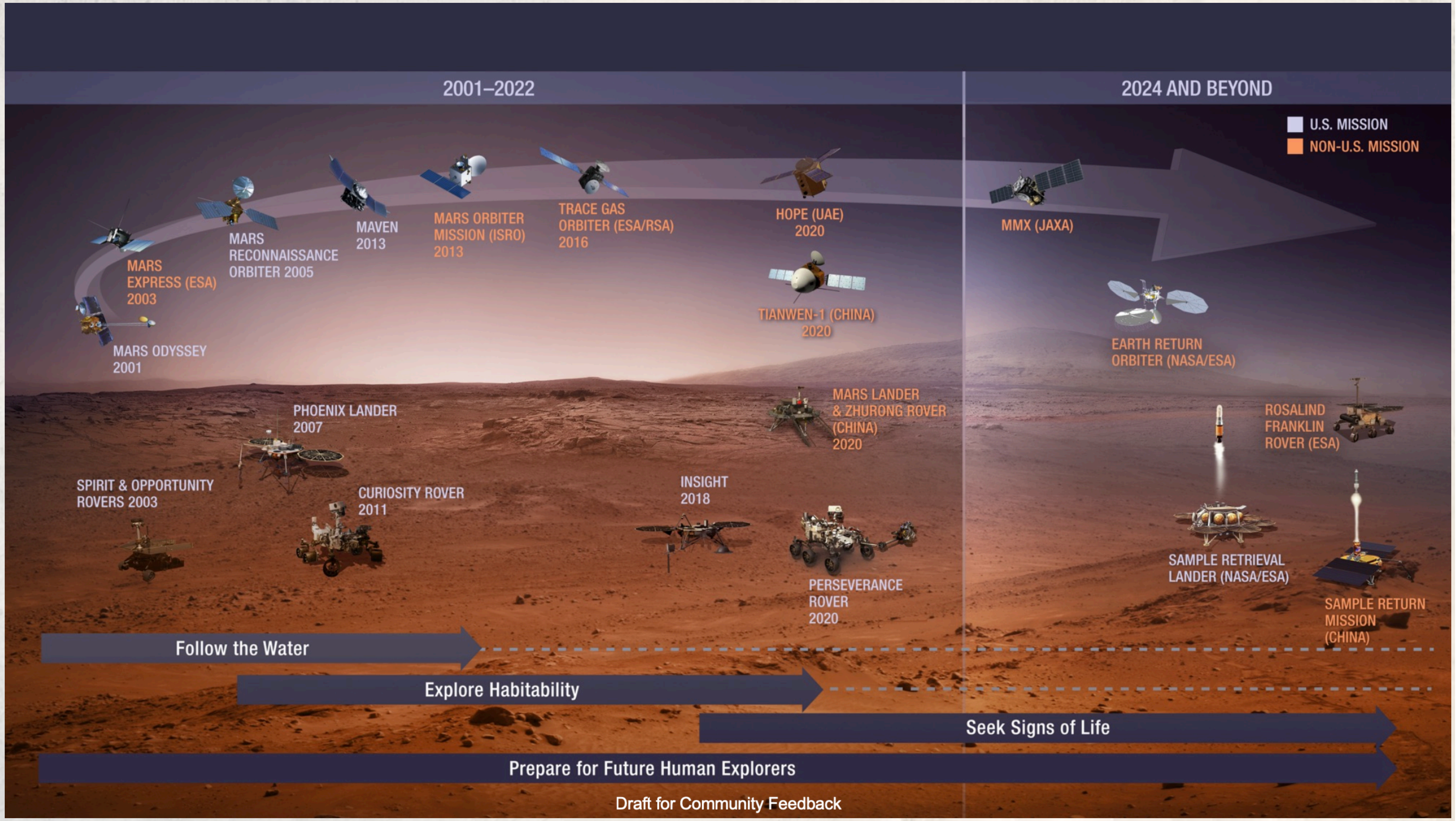
Exploration of Mars — Science Goals

- Thematic studies (water, habitable zones, signs of life) are interwoven with high level objectives > sub-objectives > investigations
    - Life: Determine if life ever arose on Mars
    - Climate: Understand Martian climate processes and history
    - Geology: Determine how the surface and interior of Mars evolved
- All of these complement human exploration



NASA's Mars Exploration Program (MEP)

- Strategic series of flight missions for characterizing Mars and ultimately seeking signs of life
- Orbiters for global reconnaissance, landers and rovers for *in situ* measurements over varying spatial scales
- Given the importance of water to life as we understand it, the ever-increasing evidence for liquid water at/near the surface of Mars today and throughout history is a major indicator of habitability



Draft Future Plan for Mars Exploration, 2023-2043; Ianson, E. and MEP Planning Team, 2023

Habitable Environments and Dynamic Habitability

- Habitability is the ability of a planet to develop and sustain life — Earth is our benchmark, but that benchmark is biased by our understanding of life as it developed on Earth in the Solar System
    - A habitable environment is, therefore, an environment that was or is conducive to sustaining life (can be surface or subsurface)
    - Needs: water, source(s) of energy, ability to form complex organic molecules
- Dynamic habitability is a continuum transitioning through time from, for example, inhabitable to uninhabitable as the planet and its environment in the Solar System evolve over time
    - For example: shut down of Mars' interior dynamo leads to loss of magnetic field, which in turn leads to loss of atmosphere and climate change

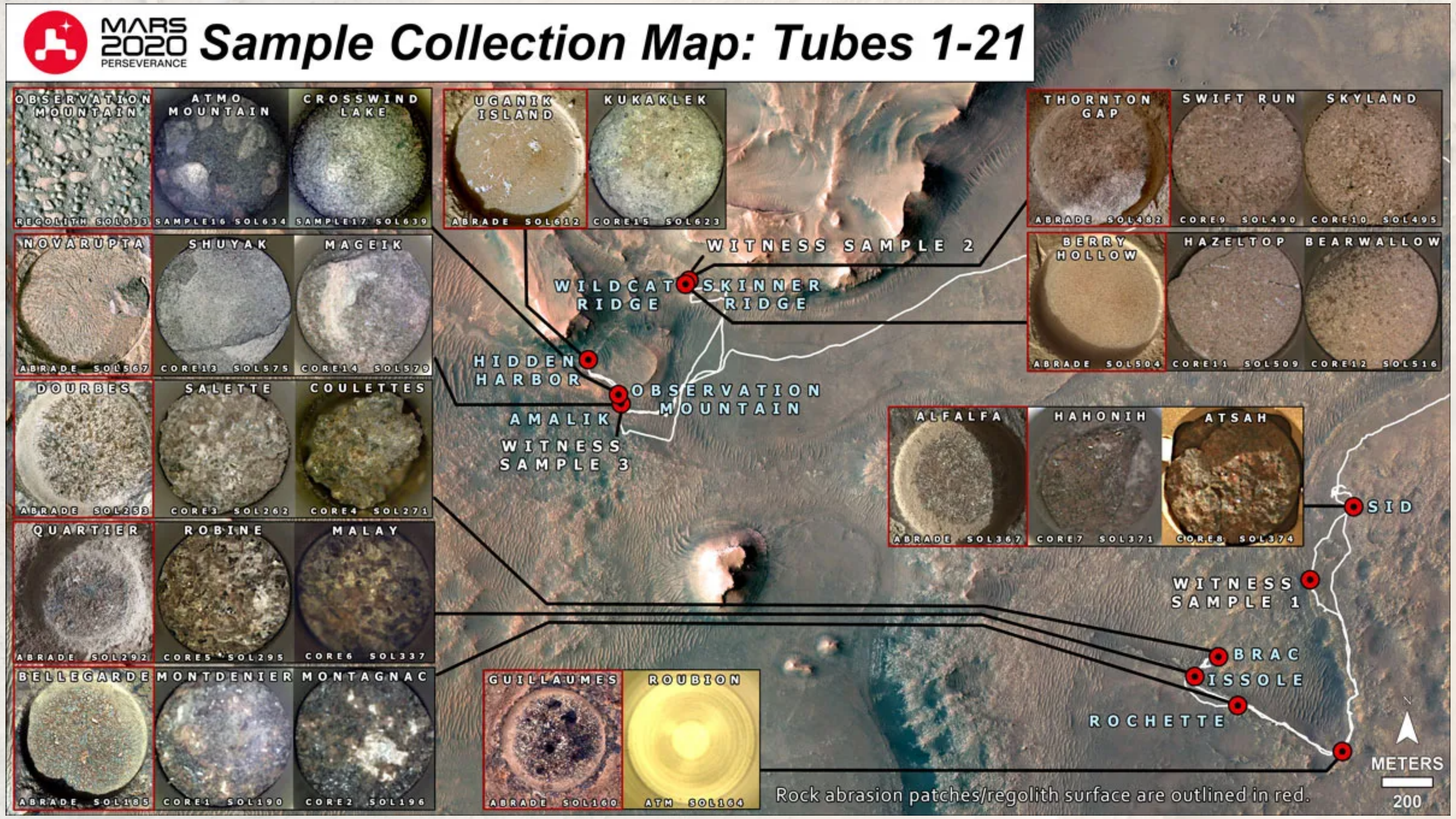
Searching for Signs of Ancient Life via Returned Samples of Mars

- The return of samples from Mars has been a top priority in all three Planetary Science Decadal Surveys
  - Detailed characterization of, e.g., isotopic, elemental, molecular, and mineralogical composition in laboratories on Earth yields information on environmental chemistry and conditions through time and as a function of Mars' evolution
  - Return of samples permits the application of the greatest number of scientific instruments to the search for signatures of ancient life and understand why they may or may not be present
- Recognition that to achieve maximum scientific return, samples must be carefully selected (not a grab bag) utilizing knowledge obtained from MEP missions

"OWL", 2023

Mars Sample Return (MSR) Mission

- A multiple mission approach to returning scientifically selected samples to Earth for detailed study
    - Mars 2020 rover *Perseverance* has now collected 24 samples of atmosphere, multiple types of rock, regolith/dust for Earth return
- Jezero Crater contains record of a variety of ancient environments that may preserve signs of *ancient* life

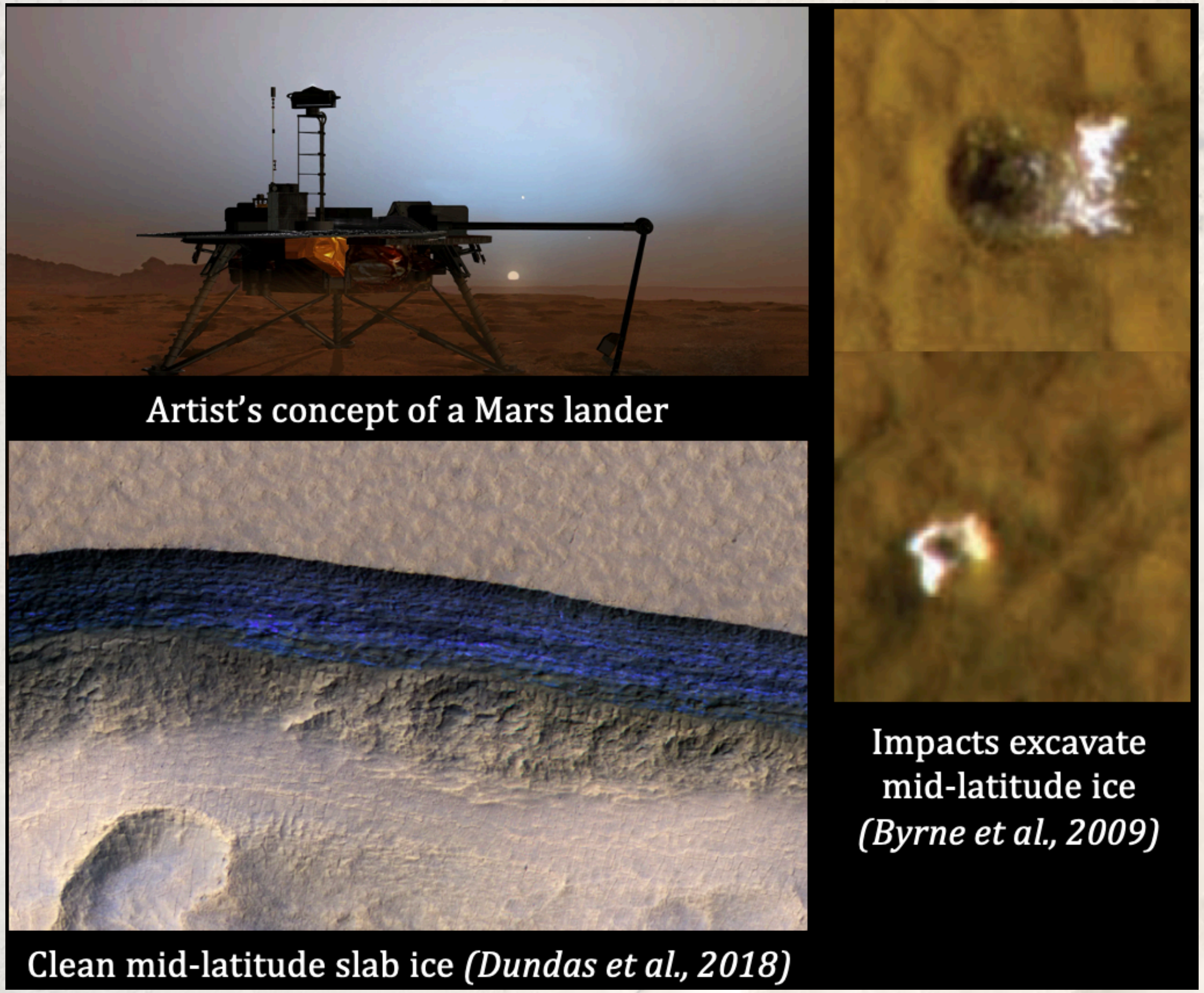


Searching for Signs of Extant Life

- Planetary Science and Astrobiology Decadal Survey (OWL) prioritized a medium-class mission to Mars aimed at searching for signs of extant life *in situ* in an environment that may be *currently* habitable

- Mission concept called Mars Life Explorer (MLE) would seek extant life and assess modern habitability through examination of low-latitude, icy terrain via a lander with drilling capability

  - Characterize organics, trace gases, and isotopes at a fidelity suitable for biosignature detection; assess ice stability and the question of modern liquid water via chemical, thermophysical, and atmospheric measurements [NASEM, 2022]



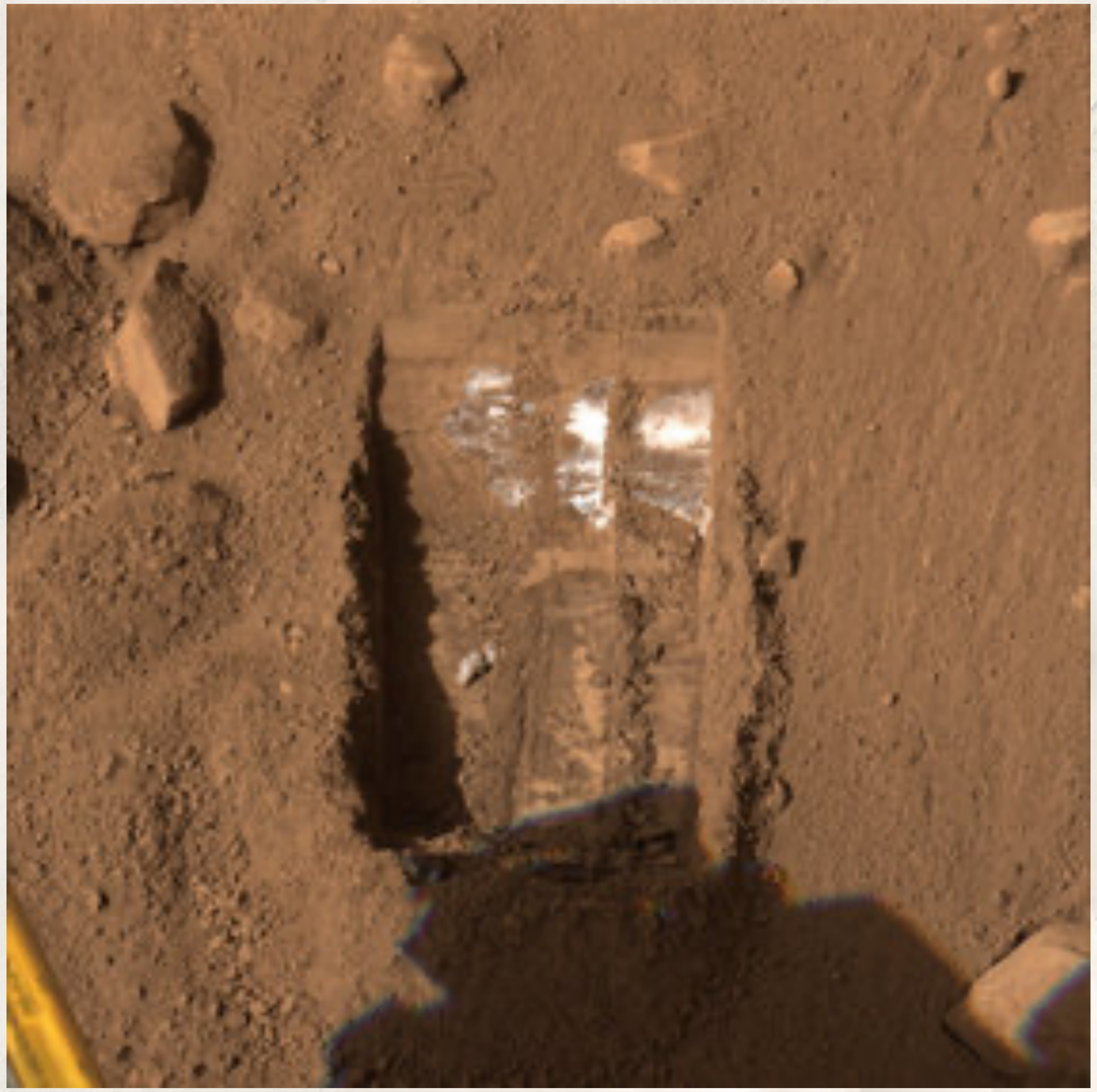
Artist's concept of a Mars lander

Clean mid-latitude slab ice *(Dundas et al., 2018)*

Impacts excavate mid-latitude ice *(Byrne et al., 2009)*

Search for Life Mission (SFL) Based on MLE Concept

- Identify and quantify organics, trace gases, and isotopes at a fidelity suitable for biosignature detection
- Evaluate ice habitability and the question of modern liquid water via analysis of elemental chemistry, salts, conductivity, and ice thermophysical properties
- Long-term atmospheric measurements (1 Mars year) to document seasonal stability of the ice deposits
- MEPAG is formulating a Science Analysis Group (SFL-SAG) to evaluate science, technology gaps, landing regions



Mars Phoenix lander exposes frozen water
(NASA/JPL/University of Arizona/Texas A&M University)

Mars-Exoplanet Research Linkages and the Search for Habitable Environments and Life

- OWL Decadal Survey identifies exoplanets as having cross-cutting linkages to questions of origins, worlds and processes, and life and habitability; both what we can infer about, and what we can learn from, exoplanetary systems — below are taken from that report and many involve understanding through time
  - **Evolution of (our) protoplanetary disk:** measuring abundances and isotopic compositions of noble gases and other key elements (e.g., H, C, O, N, and S) aids understanding of radial compositional gradients in disks and resulting compositional diversity between planets (Mars orbital/in situ analysis, sample return)
  - **Evolution of inner Solar System:** measurements of noble gas abundances and isotope ratios, and stable isotope ratios in the atmosphere of Mars inform how conditions in the disk control planetary composition and distribution of volatiles that are critical to the evolution of life (sample return from Mars)
  - **Impact events**: history of impact events at Mars contributes to understanding of volatile delivery and removal, especially during planet formation and early evolution (Mars orbital geologic mapping, absolute geochronology from returned samples, geochemistry of returned samples)

Mars-Exoplanet Research Linkages and the Search for Habitable Environments and Life

- **Solid body compositions and magnetism:** measurements of Mars' bulk composition and crustal magnetism differ from Earth's — how might exoplanet compositions and magnetism vary with location in their solar systems? (orbital mapping of Mars crustal magnetism, seismic mapping of interior, chemistry/mineralogy of returned samples)

- **Solid body evolution:** understand, through time, processes such as solidification of magma oceans; solid-state mantle convection; thermally and chemically driven dynamics in metallic cores; and dynamos generated in liquid metals and silicates (modeling and theoretical research).

- **Atmospheres:** Measure noble gas abundance and isotopic fractionation at Mars to aid determination of past mass and composition; identify characteristics of Martian atmosphere that could be observable on exoplanets, including potentially biogenic gases such as methane (orbital, landed, and returned sample data)

Mars-Exoplanet Research Linkages and the Search for Habitable Environments and Life

- Atmospheres: Determine the properties of the atmospheres of terrestrial planets (i.e., Earth, Venus, and Mars) that would be observable on exoplanets to build a foundation for atmospheric characterization of analogue exoplanets through coordinating in situ/remote sensing measurements and theoretical studies of wind velocities, radiative balance, cloud dynamics, and atmospheric compositing as function of orbital phase, local time, and solar conditions.

- Remotely observable properties (e.g., spectral indications of habitability and biosignatures): characterize for Earth-like planets across varied planet ages, and environmental and stellar conditions through theoretical modeling and laboratory studies that emulate possible exoplanet conditions, informed by remote sensing…

- Habitability: Improve exoplanet habitability predictions for cold, low-mass planets by determining the key factors that made Mars habitable 3–4 Ga, via a combination of in situ geological and atmospheric analysis and sample return, orbital observations, and climate modeling.

Mars-Exoplanet Research Linkages and the Search for Habitable Environments and Life

- **Habitability**: Determine the environmental requirements of life on Earth to inform the limits of habitability on exoplanets through field and laboratory investigations, and studies of "extreme" forms of Earthly organisms (equally applicable to Mars).
- **Habitability**: Determine the presence or absence of atmospheres on potentially habitable rocky exoplanets…, and via comparisons to solar system planets
- **Search for Life**: Study methods to discriminate past and present false positive biosignatures on solar system bodies (e.g., abiotic O_2 on Venus and Mars) from true biosignatures to inform false positive discrimination methods for exoplanets through in situ, remote sensing, theoretical/modeling studies, analog field research, and laboratory studies that characterize remotely observable properties of these features.

Mars-Exoplanet Research Linkages and the Search for Habitable Environments and Life

- **Search for Life:** Devise metrics and frameworks to establish confidence in interpretation of biosignatures in the solar system and exoplanetary systems, informed by a synthesis of relevant in situ, remote sensing, theoretical modeling, field, and laboratory data.
- **Analogues**: Observations of solar system planets and moons through transit spectroscopy and direct-imaging as analogs to exoplanet observations.

- In our solar system, Mars is closest to Earth in terms of the accessible geologic record and evidence for habitable environments on a terrestrial planet; use it to better understand our inner solar system's formation and evolution, its ability to develop and support life (or not), and how we might identify a more complete range of conditions that are conducive to habitability/life on exoplanets
- Conversely, exoplanet studies have the potential to inform our understanding of our own solar system and its evolution, and to what degree it (and terrestrial planets) are "typical", which is particularly interesting with respect to the search for life