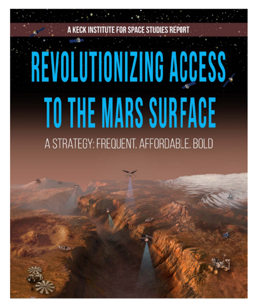
Revolutionizing Access to the Mars Surface: Key Technology Needs Identified from the Keck Institute for Space Studies (KISS) Report to Enable Low-Cost Missions to the Surface of Mars



Full report pdf here

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MOTIVATION

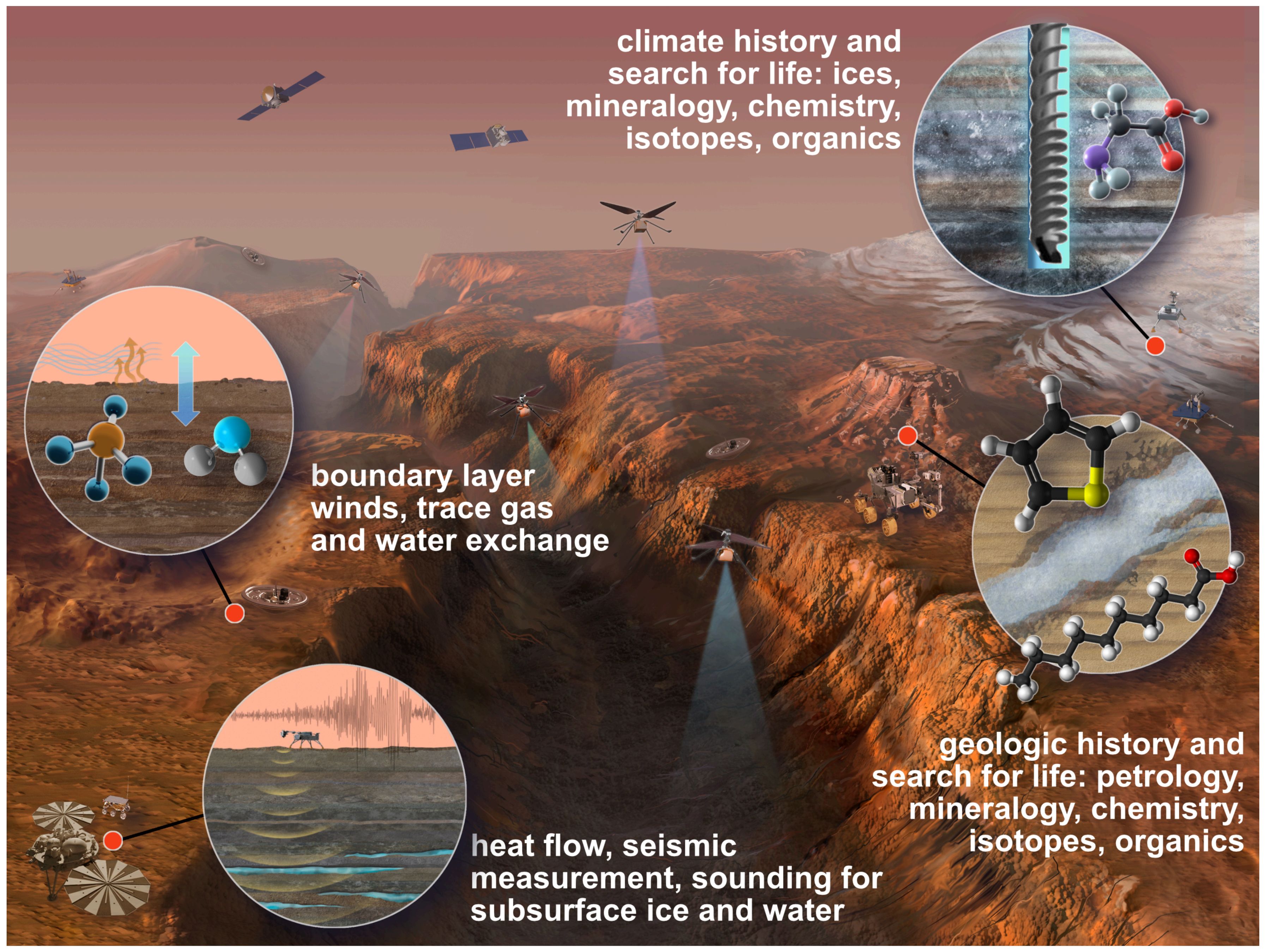
Crucial scientific measurements for understanding the Mars system require access to and interaction with the Mars surface.

As robotic sample return is underway and the U.S., Europe, China, India, and the UAE are all currently operating spacecraft at Mars, it is prime time to consider "what comes next?"

The next revolution in Mars science will come from a comprehensive exploration of the diversity that we already know exists at Mars.

The depth and breadth of our scientific understanding have **generated a set of priority science questions that require measurements that are only achievable on the Martian surface by visiting multiple discrete locations** (Mars Architecture Strategy Working Group report, 2020), e.g.,

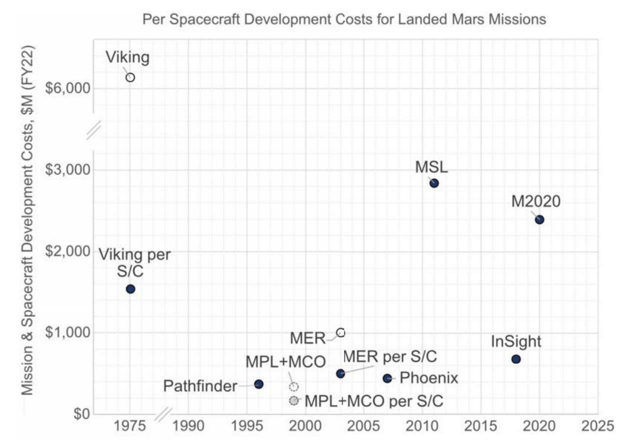
- Search for Life
- Search for Deep Water
- Understanding processes driving terrestrial planet evolution, recorded in the unique, 4-Gyr historical ice and rock record (isotopes, organics, chemistry, mineralogy)
- Understanding dynamic Mars (volatile exchange, surface boundary layer, seismicity) and prep for human exploration.



High priority scientific investigations require access to and interaction with the Mars surface in multiple locations across Mars

THE CHALLENGE

The technological challenge going forward is not simply to land payloads of various sizes on Mars—*this ability has been demonstrated*—***but to do so at an average per mission cost that enables multiple landings to answer the many scientific questions that require surface access at different locations***.



Spacecraft development costs for Mars missions to date with all costs converted to FY22 dollars. Original data compilation from the Planetary Society (2021) and references therein here scaled to common $FY22.

	Viking	Pathfinder	MER A/B	Phoenix	MSL	InSight	M2020
Diameter (m)	3.5	2.65	2.65	2.65	4.5	2.65	4.5
Entry Mass (kg)	930	584	840	602	3151	608	3440
Landed Mass (kg)	603	360	539	364	1541	358	1600
Traveled (km)	stationary	0.1	8 /45	stationary	29+	stationary	14+
Instrument Payload (kg)	91	8	9	59	84	50	59
Landing Altitude (km)	-3.5	-1.5	-1.3	-3.5	-4.4	-2.6	-2.5
Terminal Descent Approach	Retro Propulsion	Airbags	Airbags	Retro Propulsion	Skycrane	Retro Propulsion	Skycrane

Much mass delivered to Mars is for EDL (table adapted from Korzun et al., 2019; and landing press kits) with 15-30% for payload + science-enabling capabilities (sampling systems, mobility). Landed mass for MSL and M2020 includes skycrane mass.

- Per landed mission costs need to return to <<$1B/mission for many mission landed access
- Getting to Mars requires dedicated small-launch or piggyback with capable propulsion stages (harder than the Moon)
- Entry-Descent-Landing requires mass and sophisticated control systems (harder than the Moon)
- Telecom return can be a challenge (mitigated by NASA/ESA's network of orbiting satellites, allowing relay)

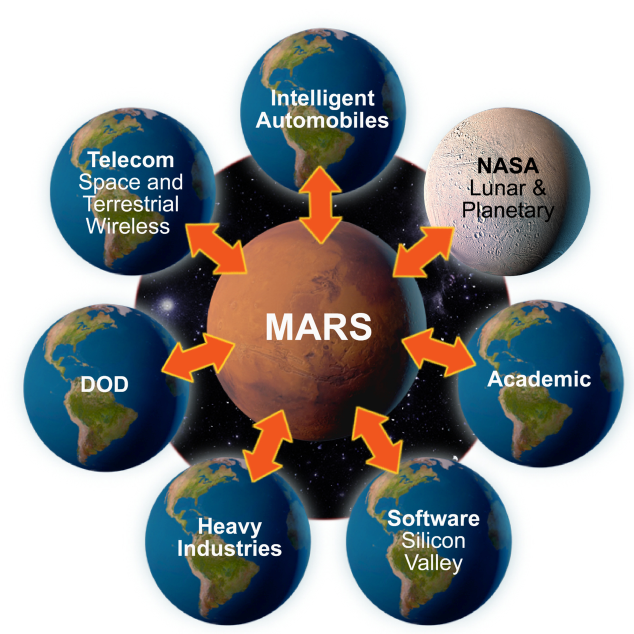
THE OPPORTUNITY

Matured science instruments and common system requirements allow capitalizing on broader trends in aerospace to enable low-cost surface access: new launch providers, lunar robotic system-level maturation, space-ready COTS technology, and a growing number of partners

- Recognized commonalities in desired mission platforms for science
- Decades of instrument miniaturization/maturation investment, enabling high quality science at lower mass points
- Commercial-off-the shelf components that are demonstrated space-ready
- Leveraging proven subsystem/system-level technologies for landed exploration generated for the Moon (e.g., CLPS)
- New launch opportunities at small-mass (multiple companies) and large-mass (upcoming Starship) and potentially lower cost
- New international, private, academic, and philanthropic stakeholders have capacity above traditional funding lines

Mission Science Objective	Small, hard fixed lander (≥ 5-kg science payload)	Soft fixed lander (≥20-kg science and enabling payload)	Aerial mobile (~3–5-kg science payload)	Medium mobile (≥20-kg science and enabling payload)	Large mobile (≥100-kg science and enabling payload)
Surface-atmosphere boundary layer interactions (incl. trace gas measurements)	✓	✓	✓	✓	✓
Geophysics (subsurface ice/water w/ resistivity, GPR, Seismo, magnetism)	✓	✓	✓	✓	✓
Polar Layer Deposit climate record determination		✓	✓	✓	✓
Mid-latitude ice sampling for characterization		✓		✓	✓
Geology Field Explorer for characterizing ancient habitable environments, environmental change			✓	✓	✓
Geochronology for Martian and solar system chronology				✓	✓

A common set of platforms enables multiple diverse science investigations



Mars pulls technology from—and can push technology to—other sectors. Future Mars missions can draw on technology developments from a wide range of sponsors and markets, enabling enhanced capabilities as well as reducing development and recurring costs.

KEY REQUIRED TECHNOLOGIES

Low-cost Mars surface missions are enabled by two types of technological advancements: (1) maturation and development in key areas to enable fundamentally new capabilities and (2) adaptation and application of existing commercial state-of-the-art to bring needed capabilities at lower cost

<u>New Tech Maturity: Improving the State-of-the-Art</u>

What aspects need TRL-raising?

- **Transit systems to Mars** (prop systems, architectures)
- **Innovative Entry-Descent-Landing (EDL)** (at small size and largest size)
  e.g., rough lander (high-g) EDL and accompanying instrument and electronics packaging
  e.g., large mass delivery systems

<u>Lowering Cost: Adapting & Applying the State-of-the-Art</u>

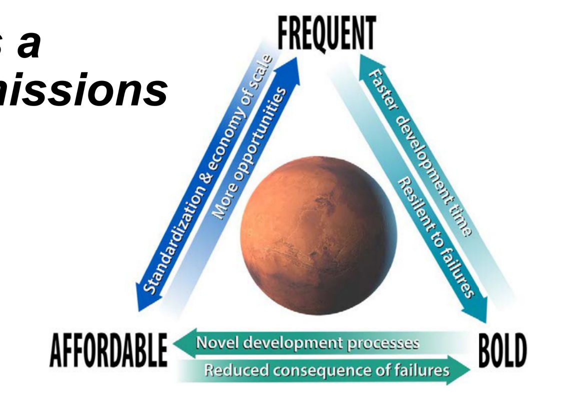
What aspects of CubeSat/SmallSat/CLPS designs can be used close to 'as-is' for Mars missions?

- **Commercial electronics and batteries**: system-level approaches in Mars atmosphere/gravity/radiation (e.g., single component failure redundancy; see Ingenuity Snapdragon).
  note: environments in some categories less challenging than the Moon
- **Telecom:** Mars orbiters with high bandwidth Direct-To-Earth (more power, higher gain than Moon) + proximity links between landed missions and orbiter (similar requirements at Mars and Moon)
- **Software and avionics** in semi-autonomous mode with long time delays
- **Mobility systems,** roving and aerial (adapt lunar rovers, terrestrial UAVs)
- **EDL-related sensors**: IMUs, radar, lidar, terrain-relative nav, hazard avoidance

PROGRAMMATIC CONSIDERATIONS

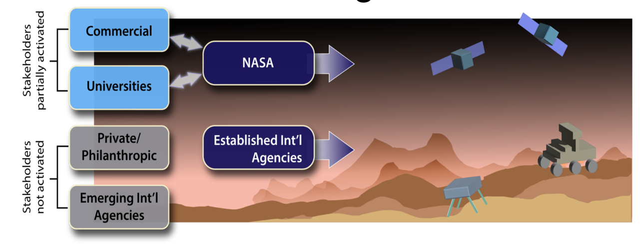
Enabling low-cost missions requires a programmatic approach across multiple missions

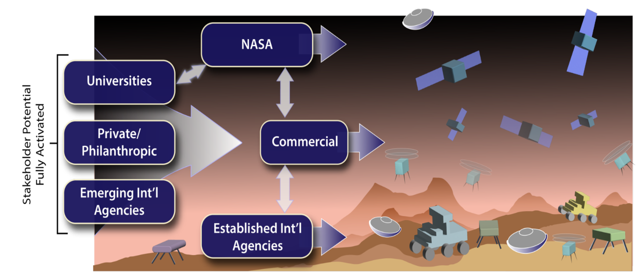
- Engage stakeholders to identify where priority mission activities align with current commercial interests and near-term technical capabilities
- Devise instrument development plans consistent with early opportunities (small orbiters, hard landers) as well as future mission types
- Determine near-term investments to enable longer-term program needs for mission types
- Create agreements, partnering with multiple entities to develop, deliver, or provide services for Mars landed missions
- Develop costing databases and models for Class-D builds and multi-builds



Frequent-Affordable-Bold (FAB): higher cadences allow more risk-tolerant approaches thereby lowering costs

Planning for multiple landed missions allows for development of increasingly sophisticated common platform capabilities over time





A service model for some Mars missions activates more stakeholders, "growing the pie"

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