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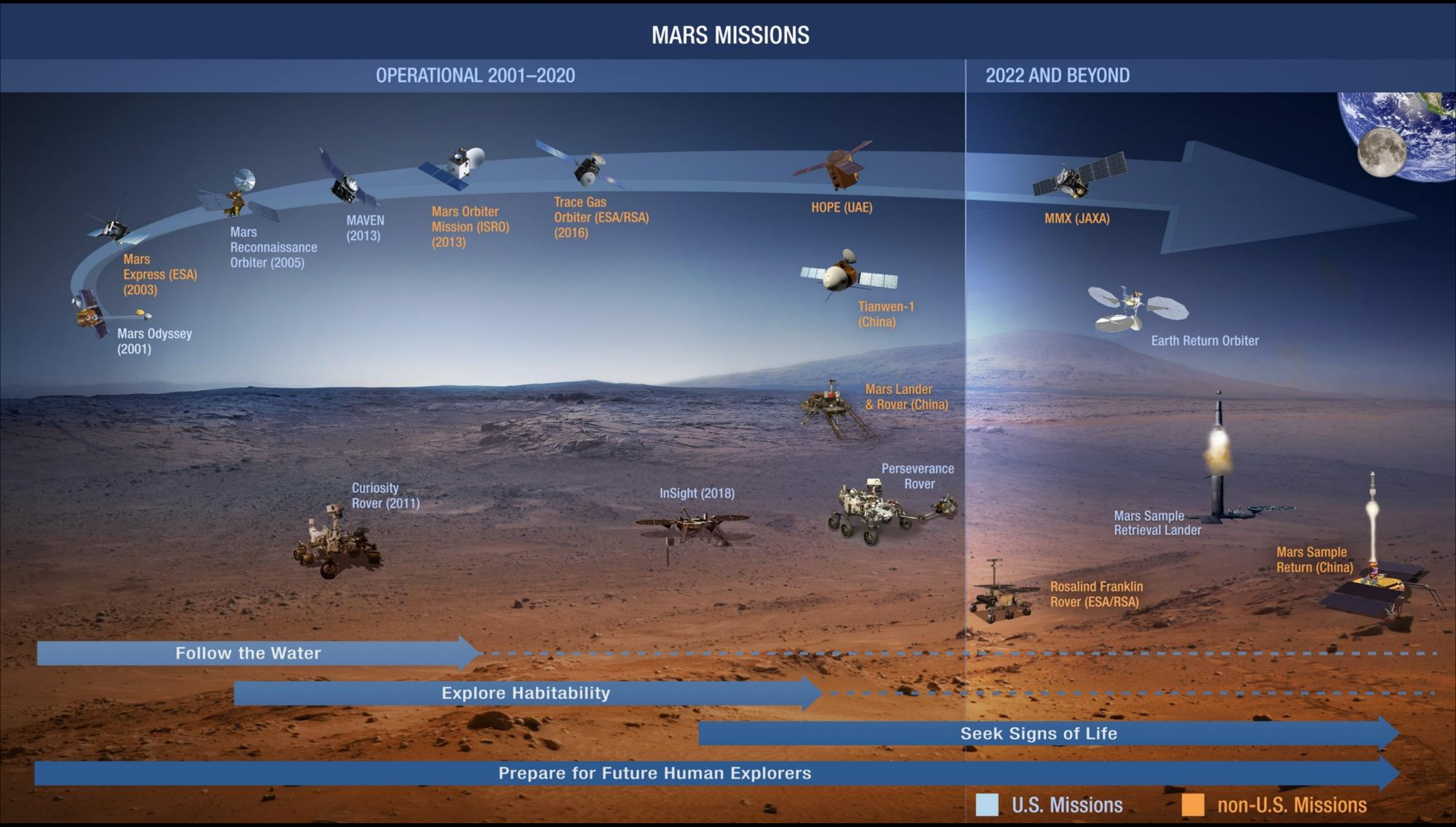
Mars Exploration & Mars Sample Return

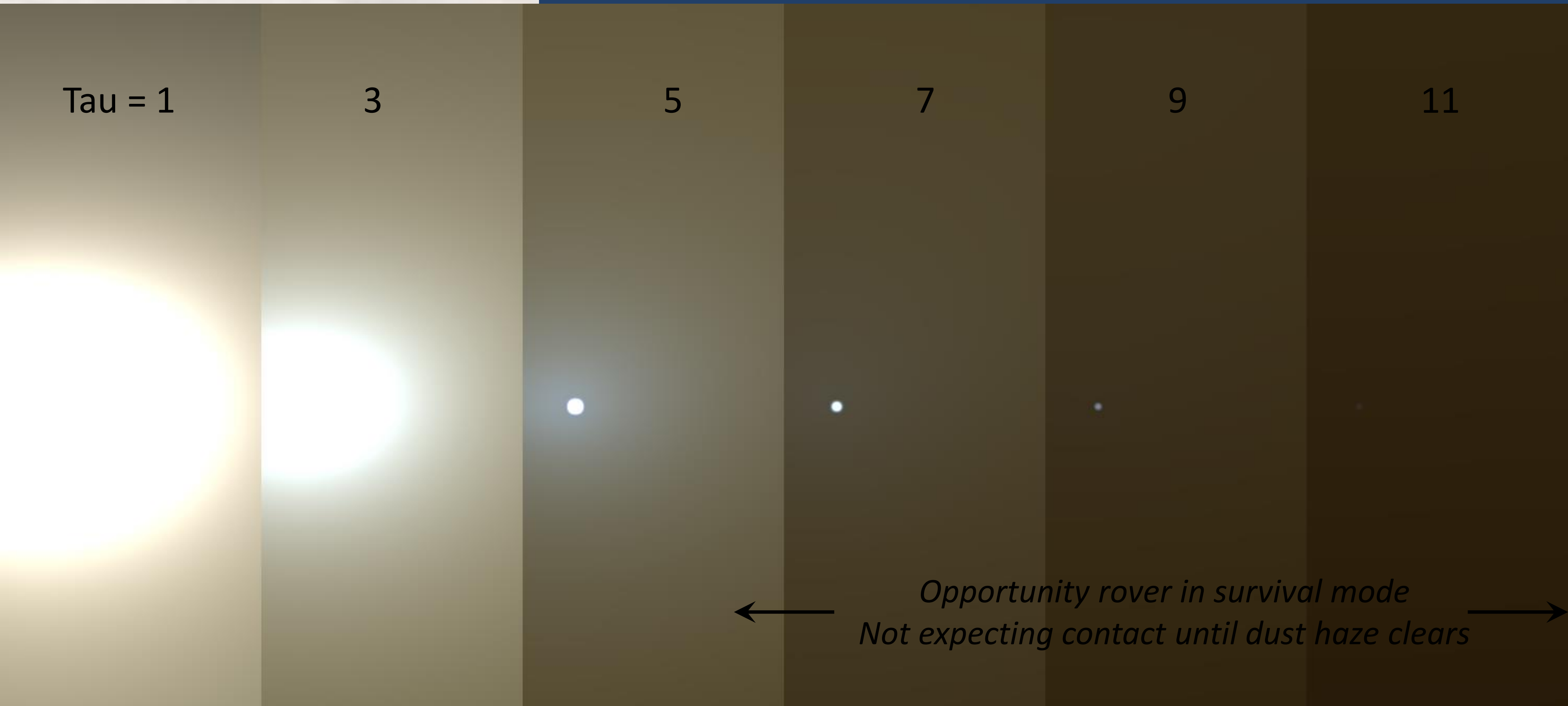
HEOC/SC
Jan 14, 2021

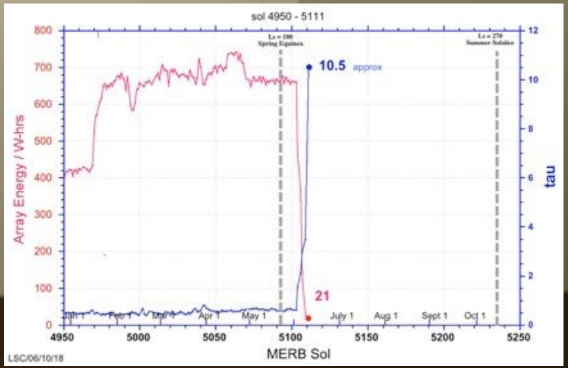

MARS MISSIONS
OPERATIONAL 2001–2020
2022 AND BEYOND
Mars Odyssey (2001)
Mars Express (ESA) (2003)
Mars Reconnaissance Orbiter (2005)
MAVEN (2013)
Mars Orbiter Mission (ISRO) (2013)
Trace Gas Orbiter (ESA/RSA) (2016)
HOPE (UAE)
MMX (JAXA)
Tianwen-1 (China)
Earth Return Orbiter
Mars Lander & Rover (China)
Curiosity Rover (2011)
InSight (2018)
Perseverance Rover
Mars Sample Retrieval Lander
Mars Sample Return (China)
Rosalind Franklin Rover (ESA/RSA)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers
U.S. Missions
non-U.S. Missions

Mars Exploration Program Analysis Group – Science Goals

Life	**I. Determine if Mars ever supported, or still supports, life.**	A. Search for evidence of life in environments that have a high potential for habitability and preservation of biosignatures. B. Assess the extent of abiotic organic chemical evolution.
Climate	**II. Understand the processes and history of climate on Mars.**	A. Characterize the state and controlling processes of the present-day climate of Mars under the current orbital configuration. B. Characterize the history and controlling processes of Mars' climate in the recent past, under different orbital configurations. C. Characterize Mars' ancient climate and underlying processes.
Geology	**III. Understand the origin and evolution of Mars as a geological system.**	A. Document the geologic record preserved in the crust and investigate the processes that have created and modified that record. B. Determine the structure, composition, and dynamics of the interior and how it has evolved. C. Determine the origin and geologic history of Mars' moons and implications for the evolution of Mars.
Human Exploration Source: MEPAG 2020	**IV. Prepare for Human Exploration.**	A. Human landing with acceptable cost, risk and performance. B. Human surface exploration and EVA with acceptable cost, risk and performance. C. In Situ Resource Utilization (ISRU) of atmosphere and/or water with acceptable cost, risk and performance. D. Biological contamination and planetary protection protocols with acceptable cost, risk and performance. E. Human missions to Phobos or Deimos with acceptable cost, risk and performance.

Dust Storm

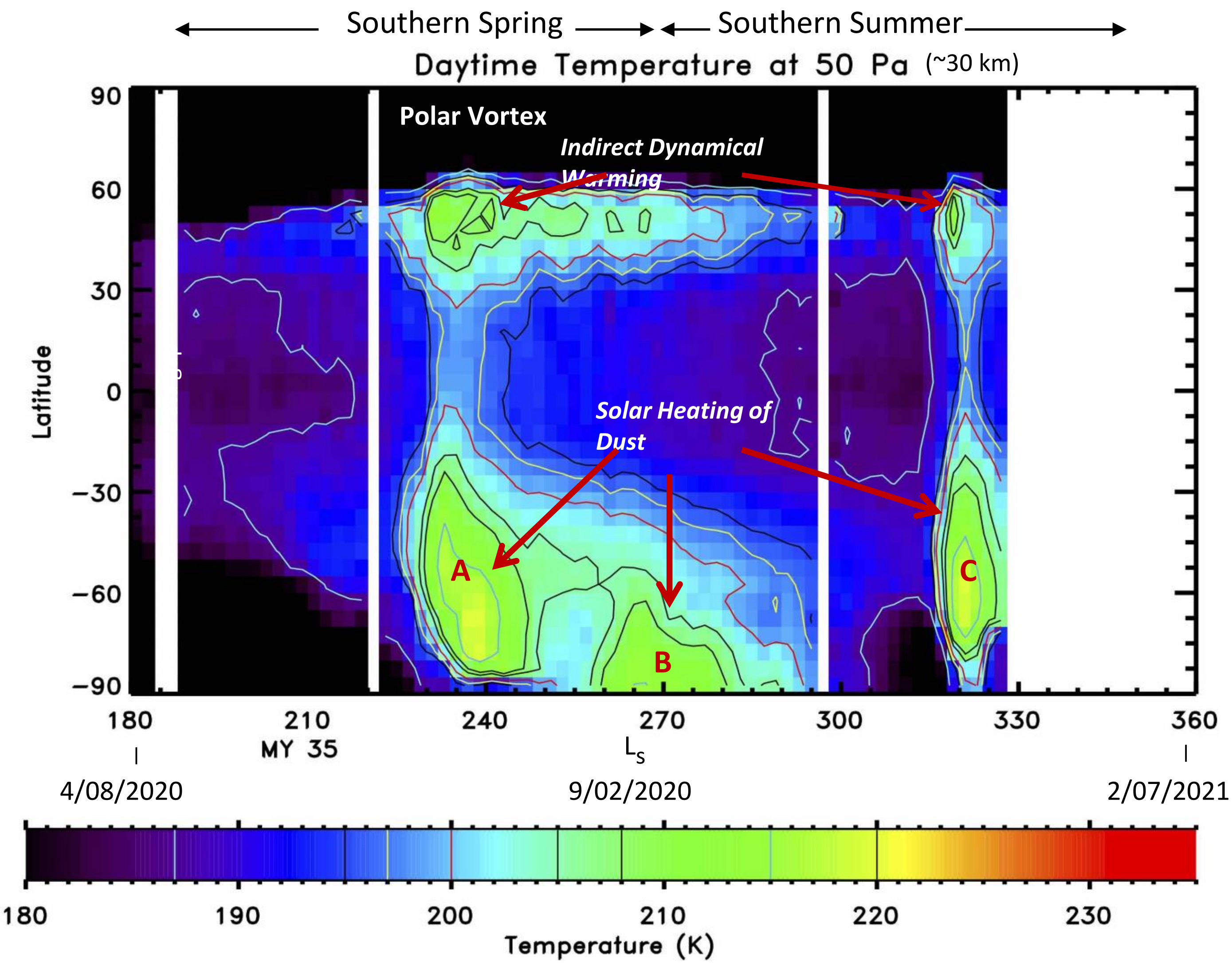




Mid-day skylight at Opportunity as simulated by M. Lemmon from measurements ***MER / JPL / NASA***

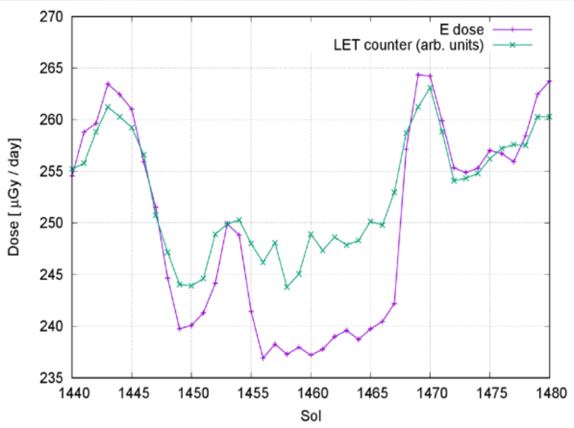
Mars Year 35 Great Dust Storm Season

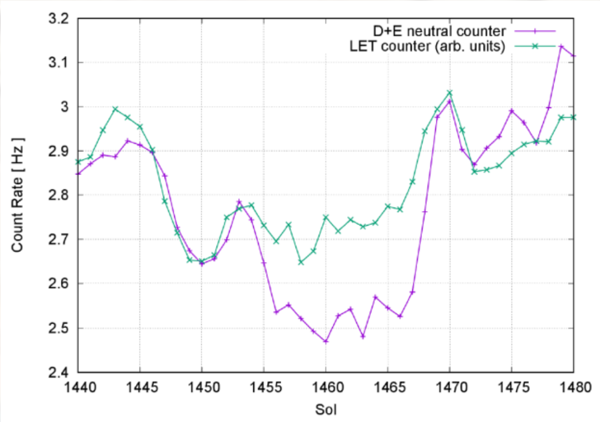
MRO MCS / JPL-Caltech / JPL / NASA



Regolith Shielding of the Radiation Environment on Mars: Murray Butte

Total Dose Rate - Curiosity's RAD measured a 4% drop in dose rate, the Butte blocked ~ 21% of the sky in RAD's FOV. Assuming the shielding effect comes from the main part of the Butte, we extrapolate that ~ 8% of the radiation is coming from within <20° of the horizon.





Neutral particle dose rate – The drop in neutral particle count rates of ~ 7.5% Using these data, we find that **~35% of the neutrals RAD measures are albedo particles coming from the ground and surrounding rocks** (S. Loeffler, et al.)

RAD Murray Butte and tilt angle measurements provide the first in-situ proof of concept for using environment as natural shelter!

First Sample Return from Another Planet

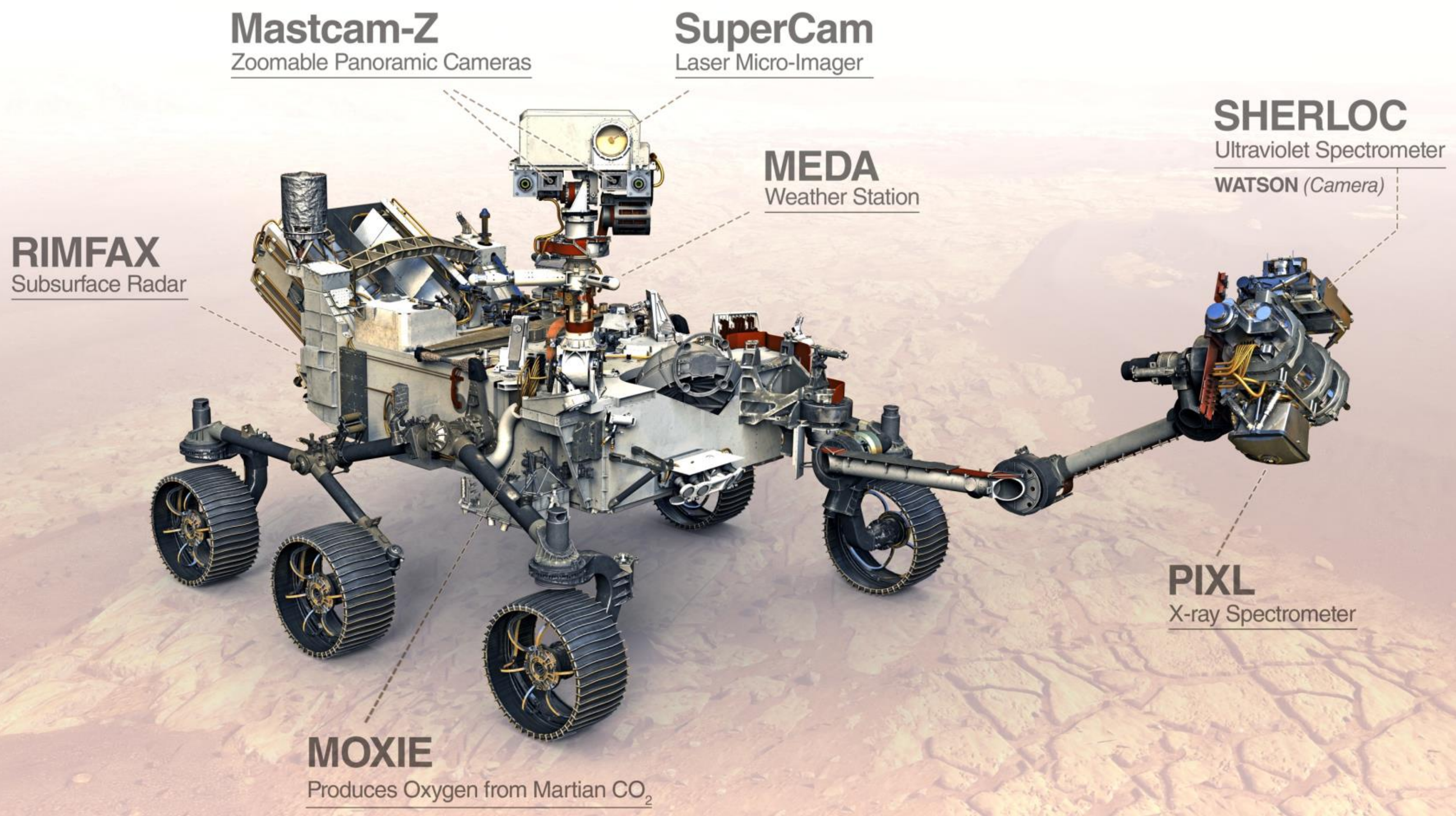
Mars Sample Return

A priority since 1980 and of two National Academy Decadal Surveys
A first-step “round-trip” in advance of humans to Mars

The oldest known life on Earth existed ~3.5 billion years ago, a time when Mars was habitable. Today,

<<1% of the Earth’s surface is 3 billion years or older
>50% of the Mars’ surface is 3 billion years or older

The first billion years and life’s beginning in the Solar System:
The record is on Mars


Mastcam-Z
Zoomable Panoramic Cameras
SuperCam
Laser Micro-Imager
SHERLOC
Ultraviolet Spectrometer
WATSON (Camera)
MEDA
Weather Station
RIMFAX
Subsurface Radar
PIXL
X-ray Spectrometer
MOXIE
Produces Oxygen from Martian CO_2

Mars 2020 Mission Objectives

HABITABILITY AND BIOSIGNATURES

- Assess habitability of ancient environment
- Seek evidence of past life
- Select sampling locations with high biosignature preservation

GEOLOGIC EXPLORATION

- Explore an ancient environment on Mars
- Understand processes of formation and alteration

PREPARE A RETURNABLE CACHE

- Capability to collect ~40 samples and blanks
- Include geologic diversity
- Deposit samples on the surface for possible return

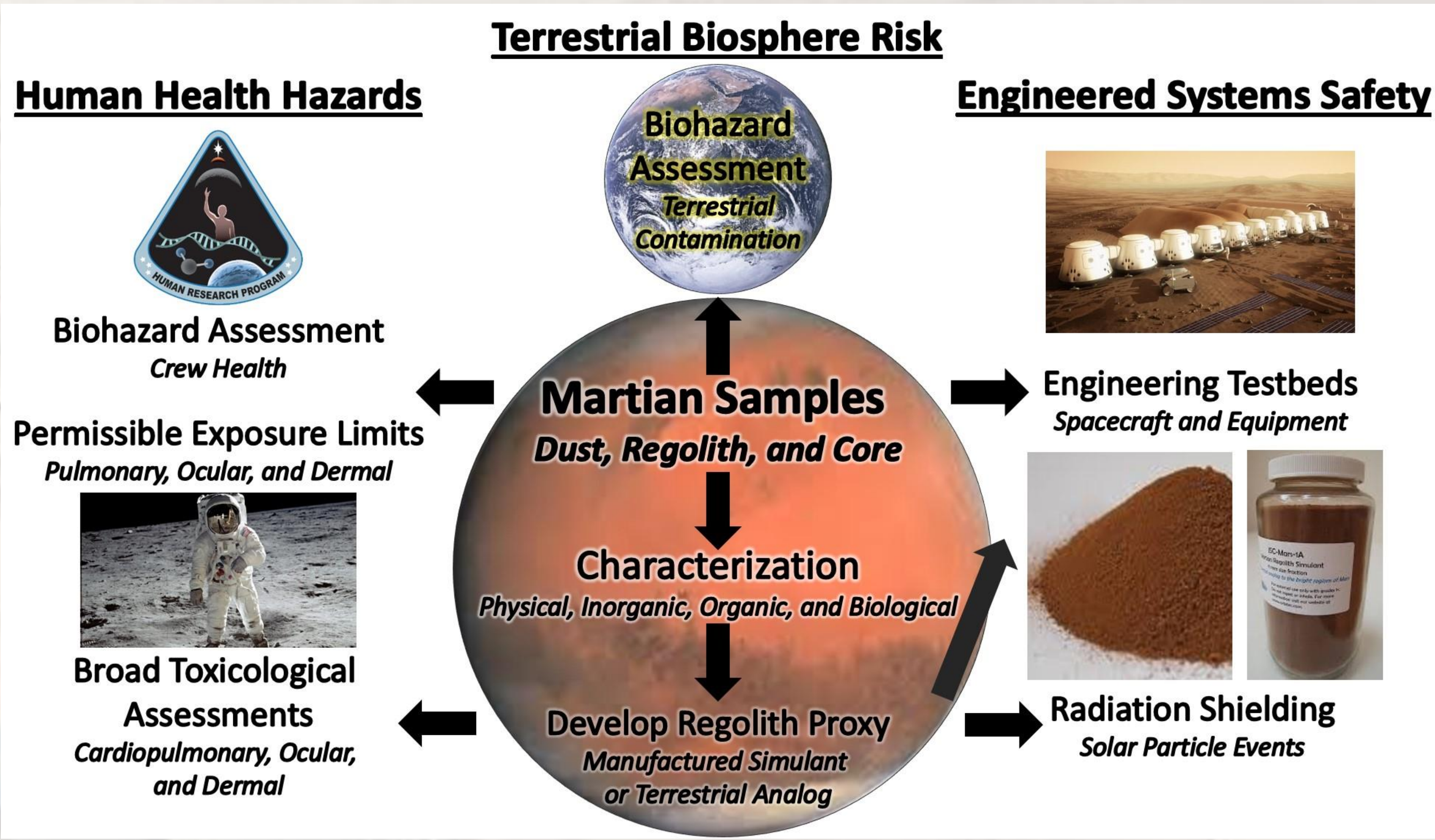
PREPARE FOR HUMAN EXPLORATION

- Measure temperature, humidity, wind, and dust environment
- Demonstrate In Situ Resource Utilization converting atmospheric CO_2 to O_2

Hazards to Future Martian Exploration
iMOST Objective 6

Mars Program

- Three primary gaps in our knowledge about potential environmental hazards that could be addressed via the analysis of returned martian samples.



MARS *Ice Mapper*

SCIENCE & RECONNAISSANCE QUESTIONS ADDRESSED

SCIENCE

MARTIAN HYDROSPHERE/ENVIRONMENT

FOLLOW THE WATER: What does subsurface water-ice reveal about the possibility of life and the identification of potential "special regions"?

What geologic features lie under all of the dust and dirt on Mars?

What do they reveal about the volcanic, fluvial, impact, & other processes in Mars' history?

What can we learn about Mars's climate from seasonal water ice/atmospheric exchanges?

RECON

WATER ICE RESOURCES

How much near-surface water-ice exists?

How thick/deep are the deposits?

Can robot-assisted human explorers core and sample them for high-value surface science investigations?

TERRAIN

How much regolith is on top of water-ice resources?

What is the distribution of materials (e.g. bedrock vs. regolith)?

How porous is the soil at prospective landing sites?

How rough is the terrain?

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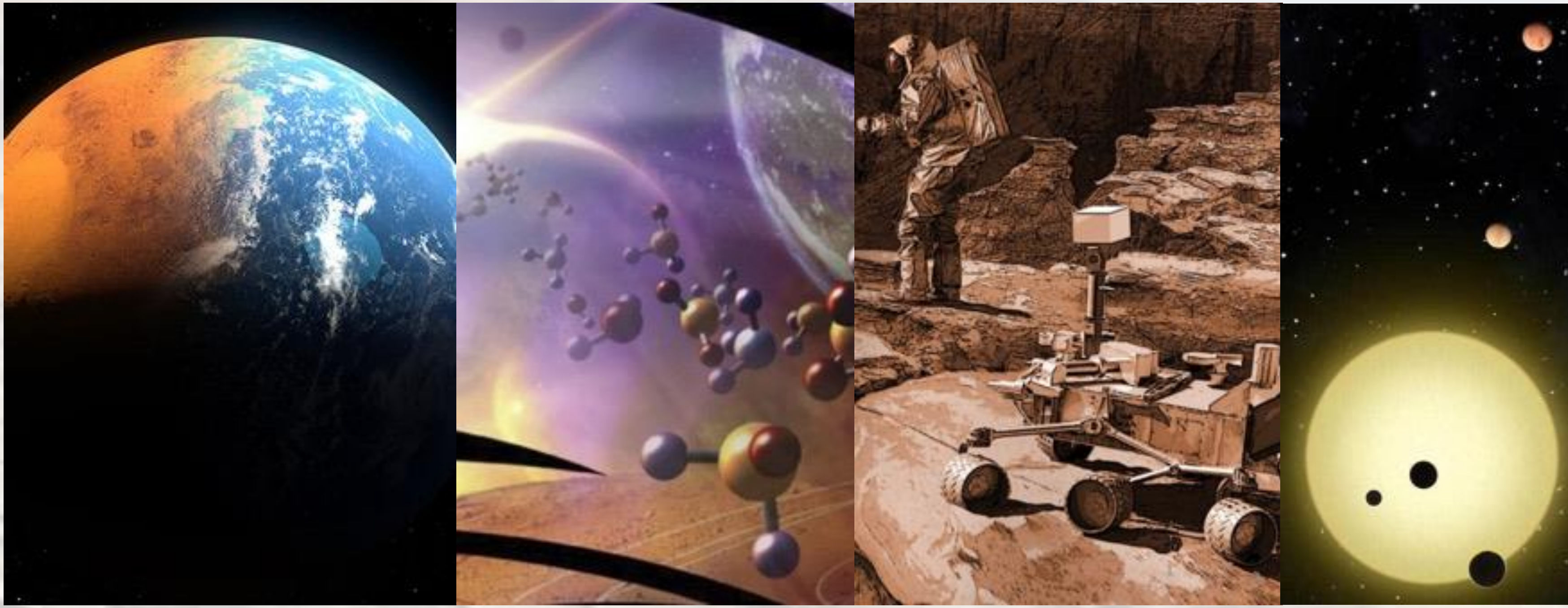
Mars, The Nearest Habitable World –
A Comprehensive Program for Future Mars Exploration



Mars Architecture Strategy Working Group (MASWG)*

Reading the Martian record:

- *Potential for life*
- *Mars' habitability and changing climate*
- *The first billion years of planetary evolution*
- *Using Mars to understand exoplanet evolution*
- *Mars as a destination for human exploration*

*https://mepag.jpl.nasa.gov/reports/MASWG%20NASA%20Final%20Report%202020.pdf

Mission Arc Brief Descriptions

- Diverse Ancient Environments & Habitability
  - Explore diversity of ancient Mars, following up on the thousands of possible sites, to understand early planetary evolution and the nature, timing and geochemistry of environments, habitability, and/or biological potential of Mars.
- Subsurface Structure, Composition & Possible Life
  - The subsurface of Mars is largely unexplored and yet its structure and composition holds many clues to the early evolution of Mars. Further, it could be the refuge of an early Martian biosphere.
- Ice: Geologically Recent Climate Change
  - Understand Martian ice ages in terms of the distribution and stratification of ice as it was emplaced/removed over the last hundred million years, both in the polar regions and at lower latitudes.
- Atmospheric Processes and Climate Variability
  - Record variability of the current climate from hours to decades and the processes of transport and photochemistry, Sun-Mars interactions, exchange of water, dust, CO_2 and trace gases.

Mars Is A Compelling Target For Both Science And Exploration In Addition To Sample Return

Mars has a uniquely accessible archive of the long-term evolution of a habitable planet. *The well-exposed and preserved 4-billion-year record of physical and chemical planetary processes is unique in the solar system because of its preservation, accessibility, and importance to understanding planetary habitability. This record includes planetary formation, impact bombardment, interior and crustal processes, atmospheric and climate evolution, and potentially the origin and evolution of life on another planet.*

- **A compelling destination for human exploration and science-exploration synergism.** After the Moon, Mars is the next-most accessible destination for humans. Future human exploration and science investigations at Mars are complementary activities that can leverage advancements from each other. New science investigations (such as understanding the dust cycle and the formation of low-latitude ice deposits) support planning of human exploration activities. In turn, the arrival of humans at Mars will dramatically enhance our ability to achieve big-picture science objectives.