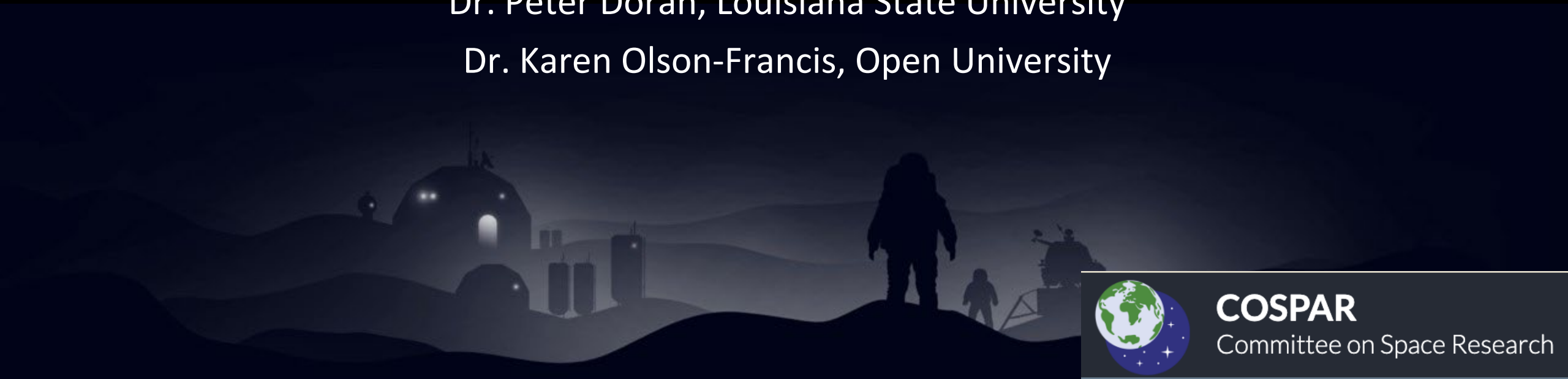
COSPAR Work on Limits of Life and Performance/Probability-Based Assessment

Dr. Peter Doran, Louisiana State University

Dr. Karen Olson-Francis, Open University



COSPAR
Committee on Space Research

Limits of Life (LoL)

- Initial work on current limits of life was to set boundaries for Special Regions on Mars

- Concept developed qualitatively by COSPAR and adopted in PP policy in 2002

- Idea was to have simple indices for habitability (with regards to Earth life) that could be modeled and/or measured from space

- To date, focus has been on limits for replication

Evolution of Special Regions limits of life

NRC PREVCOM 2006 – All of Mars is Special

Study	Low T record (°C)	Low T limit with buff (°C)	Low Aw record	Low Aw limit with buff
MEPAG SR-SAG (Beaty et al. 2006)	-15	-20	0.62	0.5
COSPAR Colloquium (Kminek et al. 2010)	-15	-25	0.61	0.5
MEPAG SR-SAG2 (Rummel et al. 2014)	-18	-23	0.605	0.5
Rev. of SR-SAG2 Report (NASEM, ESF, ESA 2015)	-18	-25	0.605	0.5
COSPAR Panel on PP Colloquium (Hipkin & Kminek 2015)	-18	-28	0.605	0.5

Since 2015, the Aw record has become 0.585 (Stevensen et al. 2017). New theoretical Aw lower limit for anabolic activity of 0.540 (Paris et al., 2023)

EXPERTS INVOLVED IN DEVELOPMENT OF SPECIAL REGIONS CONCEPTS

Alexandre Anesio
Ron Atlas
Victor Baker
Corien Bakermans
Nadine Barlow
John Baross
David Beaty
Penelope Boston
William Boynton
Karen Buxbaum
Sherry Cady
Michael Carr
Vincent Chevrier
Benton Clark
Steven Clifford
Charles Cockell
Cathy Conley
Alfonse Davila
A. Debus
J-P de Vera
Jody Deming
Peter Doran
Christine Foreman
Raina V. Gough
John Hallsworth
Steven Hancock
Ernst Hauber
Michael Hecht
Jen Heldmann
J. Helbert
James Head
Victoria Hipkin
Gerda Horneck
Thomas Kieft
G. Klingelhoefer
Gerhard Kminek
Michael Mellon
Chris McKay
Eric McDonald
Alfred McEwen
Jill A. Mikucki
Gian Ori
Chris Omelon
David Paige
J. Parnell
David Pearce
Ronald Peterson
Nilton Rennó
Petra Rettberg
Eric Roden
John Rummel
Gary Ruvkun
Mark Saunders
D. Schulze-Makuch
Birgit Sattler
B. Sherwood Lollar
Mitch Sogin
Perry Stabekis
E. Stackebrandt
Andrew Steele
Andy Spry
Kenneth Tanaka
J. Vago
Donna Viola
Michel Viso
Mary Voytek
Francis Westall
L. Wells
James J. Wray
Dirk Wagner

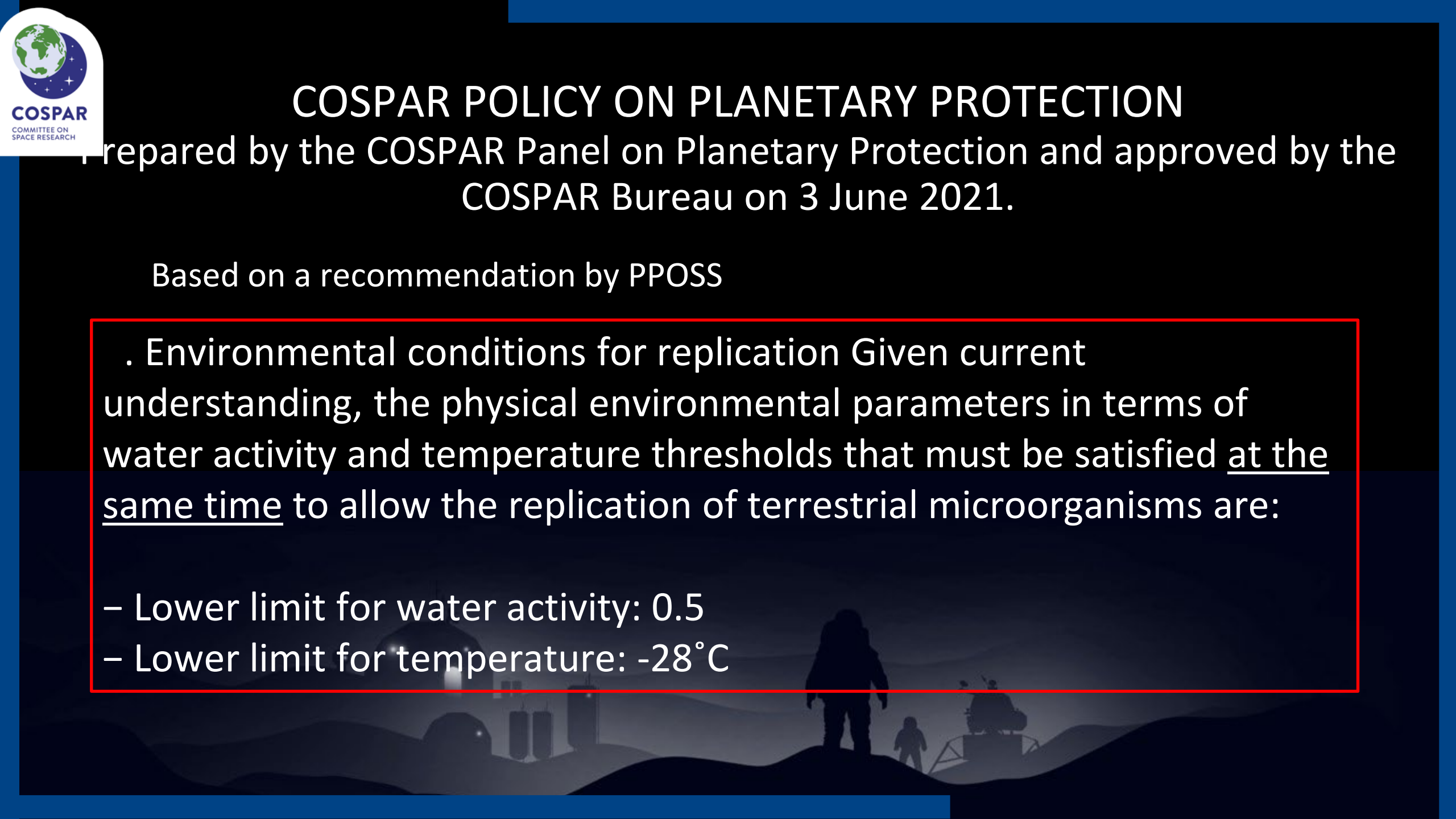
COSPAR POLICY ON PLANETARY PROTECTION

Prepared by the COSPAR Panel on Planetary Protection and approved by the COSPAR Bureau on 3 June 2021.

Based on a recommendation by PPOSS

. Environmental conditions for replication Given current understanding, the physical environmental parameters in terms of water activity and temperature thresholds that must be satisfied at the same time to allow the replication of terrestrial microorganisms are:

– Lower limit for water activity: 0.5
– Lower limit for temperature: -28˚C



COSPAR POLICY ON PLANETARY PROTECTION

Prepared by the COSPAR Panel on Planetary Protection and approved by the COSPAR Bureau on 7 November 2025.

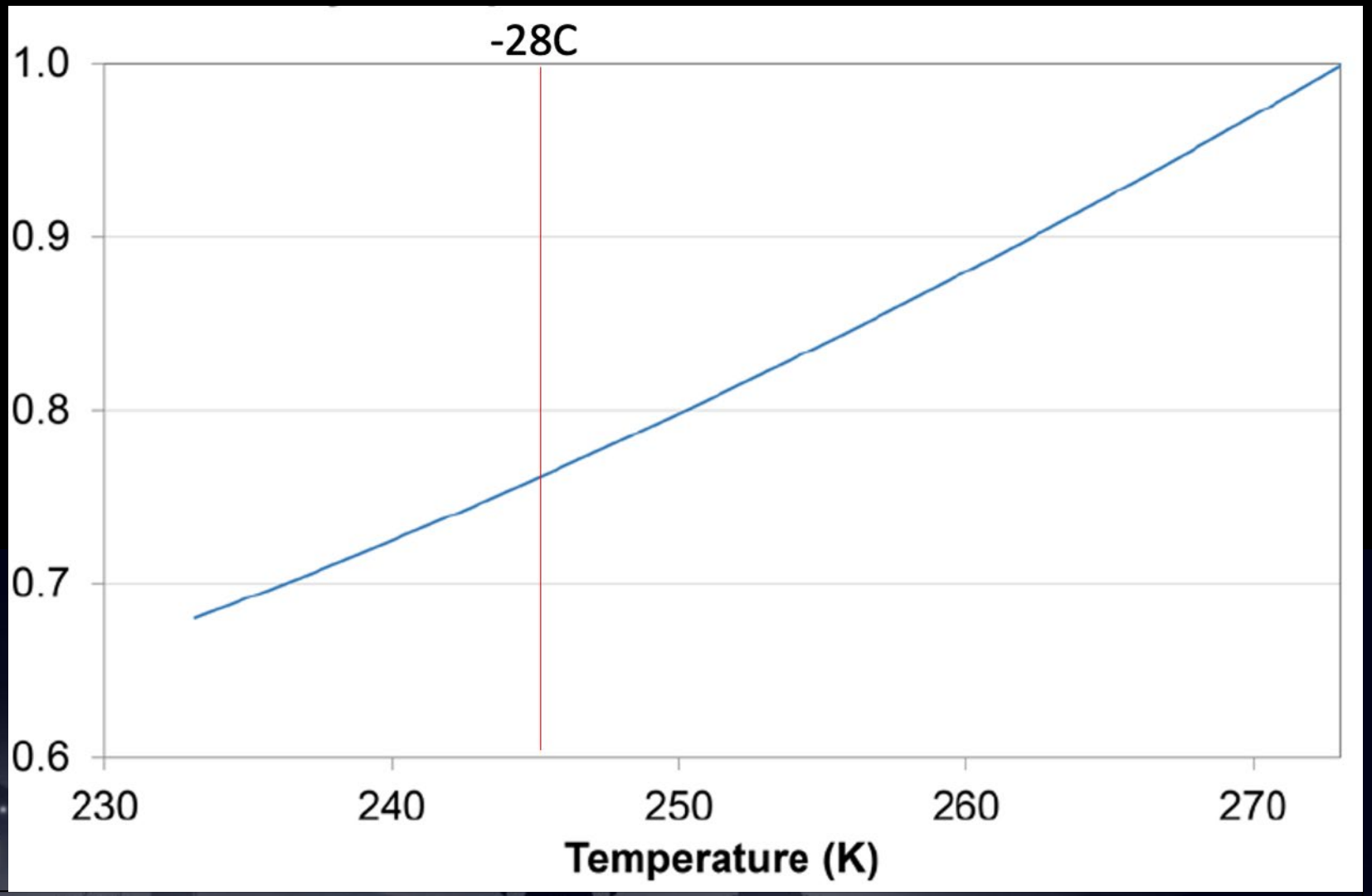
4.2. Environmental Conditions for Replication Given current understanding, the limiting physical environmental parameters in terms of water activity and temperature thresholds that should be satisfied at the same time to allow the replication of terrestrial microorganisms are [Rummel et al. 2014, Kminek et al. 2016 and Doran et al. 2024]:

- Lower limit of water activity (LLAw): 0.5
- Lower limit of temperature (LLT): -28°C

Both of these limits include margins below the reported limits of terrestrial biology [Rummel et al. 2014, Kminek et al. 2016].

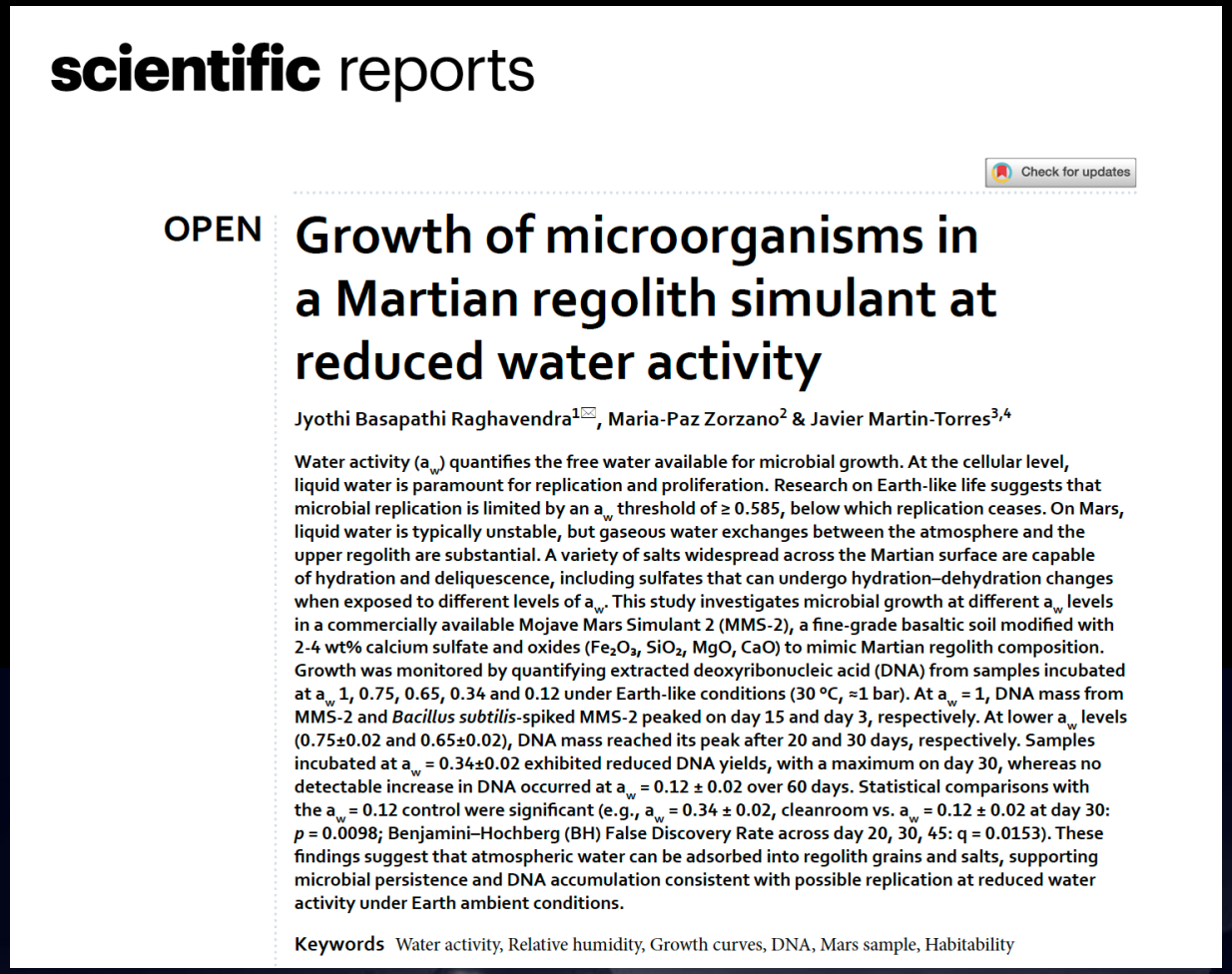
Application to Icy Worlds in new 2026 Policy – just LLT

In ice, A_w is well above the limit when temperature is at -28C, so we can focus on just temperature as limiting



Sippola and Taskinen 2018, Activity of Supercooled Water on the Ice Curve and Other Thermodynamic Properties of Liquid Water up to the Boiling Point at Standard Pressure. Journal of Chemical & Engineering

COSPAR PPP has been monitoring the literature



scientific reports

Check for updates

OPEN

Growth of microorganisms in a Martian regolith simulant at reduced water activity

Jyothi Basapathi Raghavendra[1]✉, Maria-Paz Zorzano[2] & Javier Martin-Torres[3,4]

Water activity (a_w) quantifies the free water available for microbial growth. At the cellular level, liquid water is paramount for replication and proliferation. Research on Earth-like life suggests that microbial replication is limited by an a_w threshold of ≥ 0.585, below which replication ceases. On Mars, liquid water is typically unstable, but gaseous water exchanges between the atmosphere and the upper regolith are substantial. A variety of salts widespread across the Martian surface are capable of hydration and deliquescence, including sulfates that can undergo hydration–dehydration changes when exposed to different levels of a_w. This study investigates microbial growth at different a_w levels in a commercially available Mojave Mars Simulant 2 (MMS-2), a fine-grade basaltic soil modified with 2-4 wt% calcium sulfate and oxides (Fe_2O_3, SiO_2, MgO, CaO) to mimic Martian regolith composition. Growth was monitored by quantifying extracted deoxyribonucleic acid (DNA) from samples incubated at a_w 1, 0.75, 0.65, 0.34 and 0.12 under Earth-like conditions (30 °C, ≈1 bar). At a_w = 1, DNA mass from MMS-2 and *Bacillus subtilis*-spiked MMS-2 peaked on day 15 and day 3, respectively. At lower a_w levels (0.75±0.02 and 0.65±0.02), DNA mass reached its peak after 20 and 30 days, respectively. Samples incubated at a_w = 0.34±0.02 exhibited reduced DNA yields, with a maximum on day 30, whereas no detectable increase in DNA occurred at a_w = 0.12 ± 0.02 over 60 days. Statistical comparisons with the a_w = 0.12 control were significant (e.g., a_w = 0.34 ± 0.02, cleanroom vs. a_w = 0.12 ± 0.02 at day 30: p = 0.0098; Benjamini–Hochberg (BH) False Discovery Rate across day 20, 30, 45: q = 0.0153). These findings suggest that atmospheric water can be adsorbed into regolith grains and salts, supporting microbial persistence and DNA accumulation consistent with possible replication at reduced water activity under Earth ambient conditions.

Keywords Water activity, Relative humidity, Growth curves, DNA, Mars sample, Habitability

- Indigenous microorganisms in MMS-2 Martian regolith simulant showed DNA accumulation consistent with possible replication down to a water activity of 0.34 (or below)

- The authors note that on present-day Mars, sufficient water activity and sufficient temperature never co-occur

Raghavendra, J.B., Zorzano, M. & Martin-Torres, J. Growth of microorganisms in a Martian regolith simulant at reduced water activity. *Sci Rep* **16**, 7499 (2026). https://doi.org/10.1038/s41598-026-35595-2

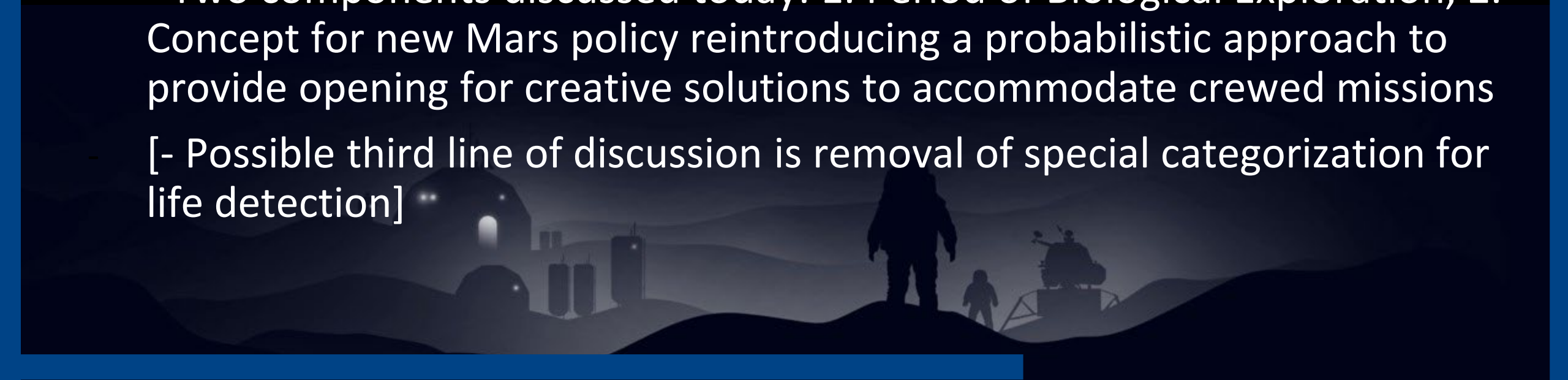
Potential Changes to Mars Policy

- First discussed at our January PPP meeting, much discussion about potential changes to Mars policy

- Everything discussed here is very much work in progress and still being discussed – not PPP consensus (yet)

- Two components discussed today: 1. Period of Biological Exploration, 2. Concept for new Mars policy reintroducing a probabilistic approach to provide opening for creative solutions to accommodate crewed missions

[- Possible third line of discussion is removal of special categorization for life detection]



Period of Biological Exploration (PBE)

Definitions vary, but current COSPAR Policy states: “The period in which contamination sensitivities are considered a driving importance to preserve the native state of a planetary body for initial biological exploration“

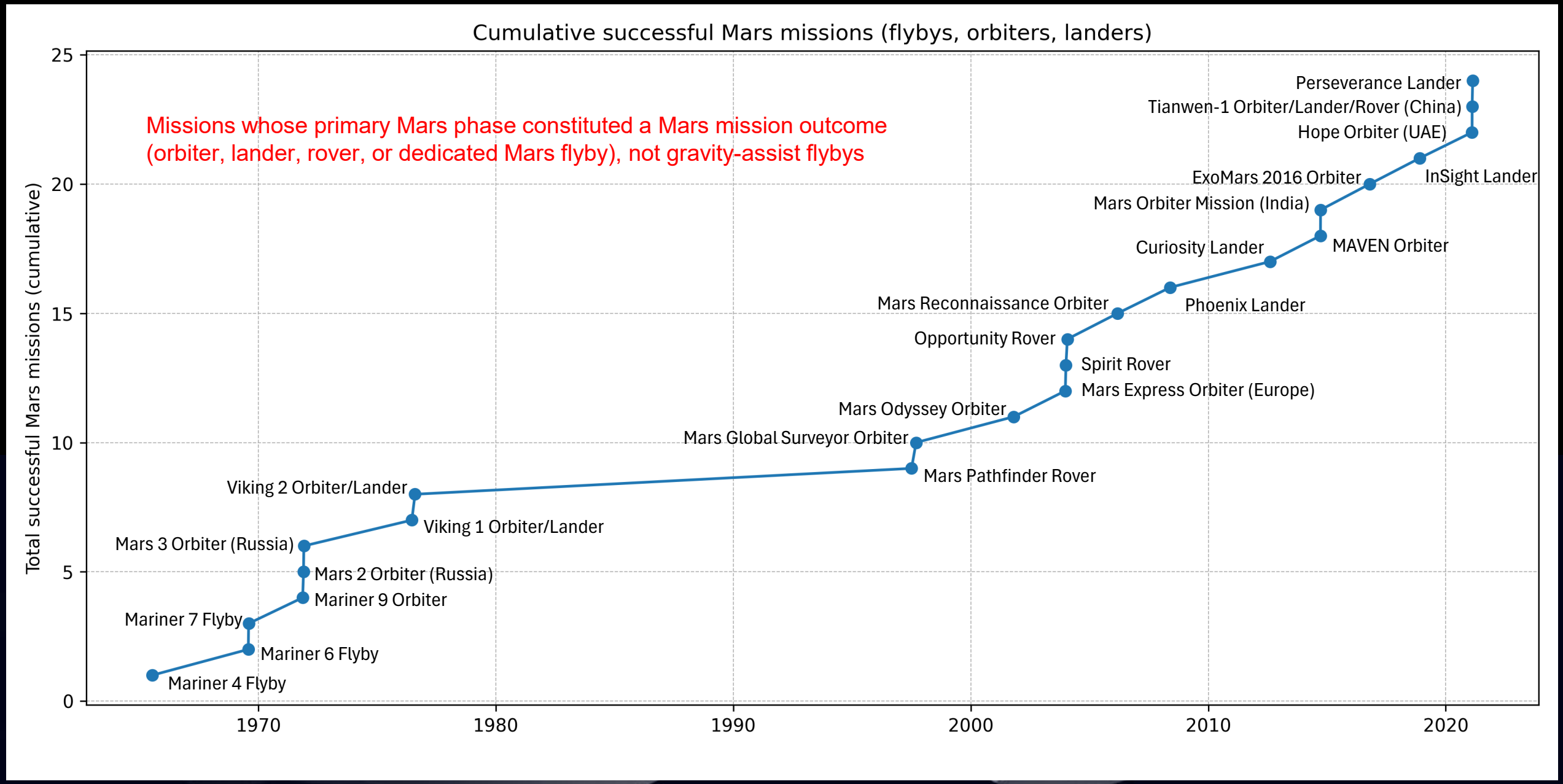
- PBE is set by projected frequency of missions
- In the early 60’s PBE was 20 years given thinking we would have **100 missions** to Mars within that period
- Later Mars was shifted to a “rolling” 50 year PBE
- Icy Worlds now a fixed 1000 year PBE

Various Period of Biological Exploration Definitions

“The length of time over which a solar system body needs to be protected from contamination in order to permit unimpaired biological study” (NASEM 2018, Review and Assessment of Planetary Protection Policy Development Processes)

“A period referred to as either a defined number of years or the time to completion of a series of robotic missions to, or experiments on, Mars, during which strict planetary protection practices must be followed to protect the planet for the conduct of scientific investigations, including the search for life” (NRC 2006 Preventing the Forward Contamination of Mars)

“The period of time (decades to centuries) during which a solar system body is explored for signs of the origin of life and the history of prebiotic chemistry based on current scientific understanding consistent with current COSPAR policy and guidelines.“ NASA 2022 IMPLEMENTING PLANETARY PROTECTION REQUIREMENTS FOR SPACE FLIGHT NASA-STD-8719.27


Cumulative successful Mars missions (flybys, orbiters, landers)
Missions whose primary Mars phase constituted a Mars mission outcome
(orbiter, lander, rover, or dedicated Mars flyby), not gravity-assist flybys
Total successful Mars missions (cumulative)
0
5
10
15
20
25
1970
1980
1990
2000
2010
2020
Perseverance Lander
Tianwen-1 Orbiter/Lander/Rover (China)
Hope Orbiter (UAE)
InSight Lander
ExoMars 2016 Orbiter
Mars Orbiter Mission (India)
MAVEN Orbiter
Curiosity Lander
Phoenix Lander
Mars Reconnaissance Orbiter
Opportunity Rover
Spirit Rover
Mars Express Orbiter (Europe)
Mars Odyssey Orbiter
Mars Global Surveyor Orbiter
Mars Pathfinder Rover
Viking 2 Orbiter/Lander
Viking 1 Orbiter/Lander
Mars 3 Orbiter (Russia)
Mars 2 Orbiter (Russia)
Mariner 9 Orbiter
Mariner 7 Flyby
Mariner 6 Flyby
Mariner 4 Flyby

Missions to Mars

PBE initially set for Mars to cover 100 missions

- Over 60 missions have attempted to go to Mars
- About 24 have made it to the vicinity of Mars (includes successful flybys, orbiters that entered Mars orbit, and landers/rovers that touched down).
- 4 unintentional impacts
- Only 10 successful soft landings on Mars

We are far from the 100 mission intent of the initial PBE no matter how you look at it.

Is there a need to review/revise the current 50 year PBE for Mars?