

National Aeronautics and
Space Administration



EXPLORE SCIENCE

**The Search for Life and
Habitable Worlds at NASA –
Past, Present, and Future**

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8th Interstellar Symposium, Montreal, Canada

July 11, 2023

Introduction

I am an astrobiologist.

I am a NASA scientist.

I am a first-generation college graduate.

I am a child of Appalachia (West Virginia).

I am a mother to small children.

I am a public servant.

I am a lover of science fiction.

I am a board gamer.

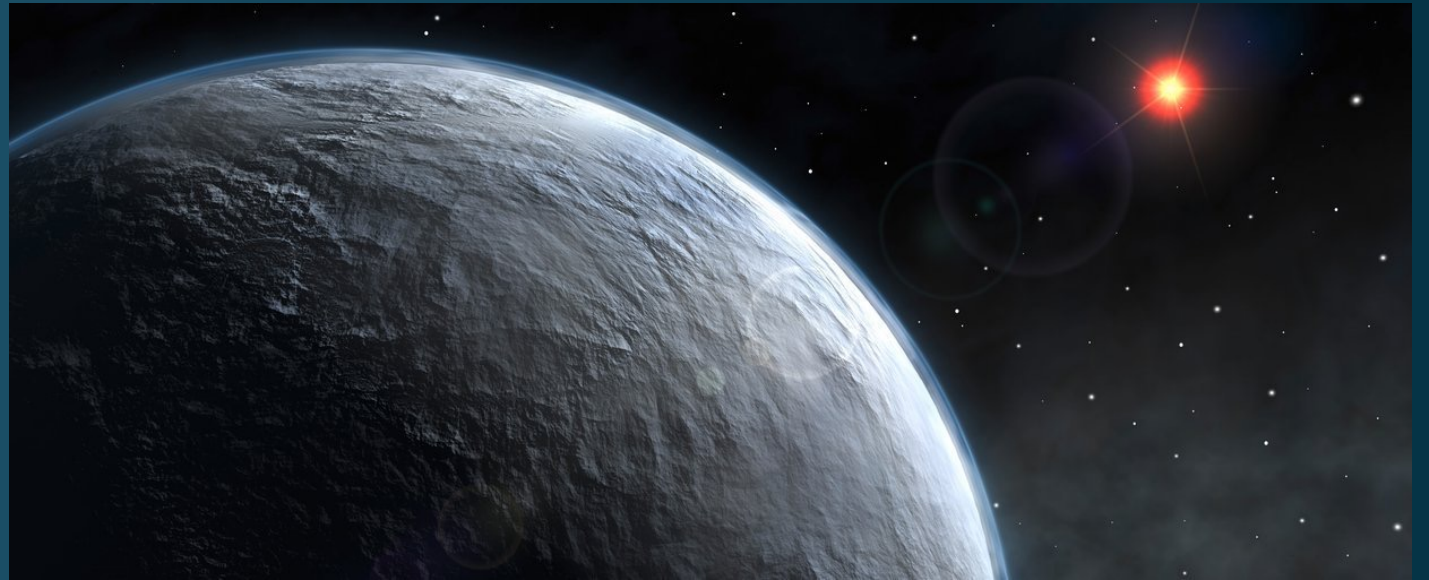


Astrobiology at NASA

(1963-present)

Interdisciplinary study of life in the context of the Universe, focusing on three fundamental questions:

1. How does life begin and evolve?
2. Does life exist elsewhere in the Universe?
3. What is the future for life on Earth and beyond?



Astrobiology at NASA



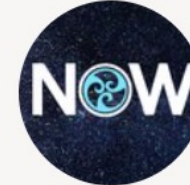
NASA Research
Coordination Networks



The Nexus for Exoplanet
System Science



Network for Life
Detection



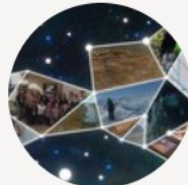
Network for Ocean
Worlds



LIFE: Early Cells to
Multicellularity



Prebiotic Chemistry and
Early Earth Environments



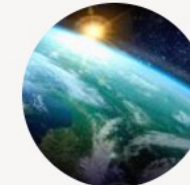
Interdisciplinary
Consortia for
Astrobiology Research
(ICAR)



Exobiology



Habitable Worlds



Emerging Worlds



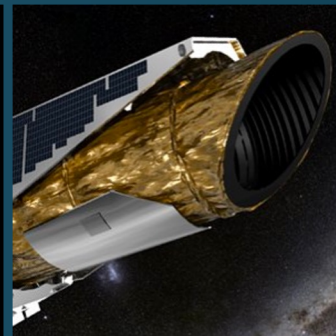
Instrument Development
Programs PICASSO &
MatisSE



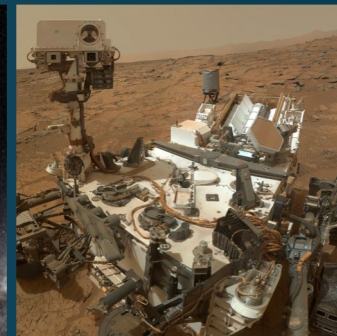
Planetary Protection
Research



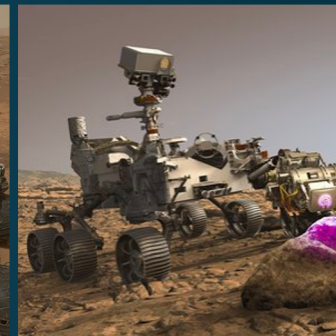
Viking 1 & 2
(1976)



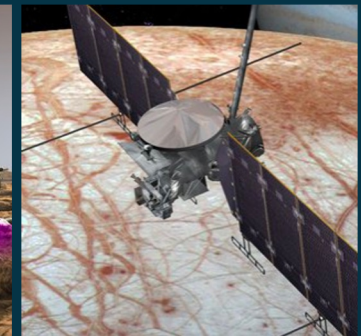
Kepler
(2009)



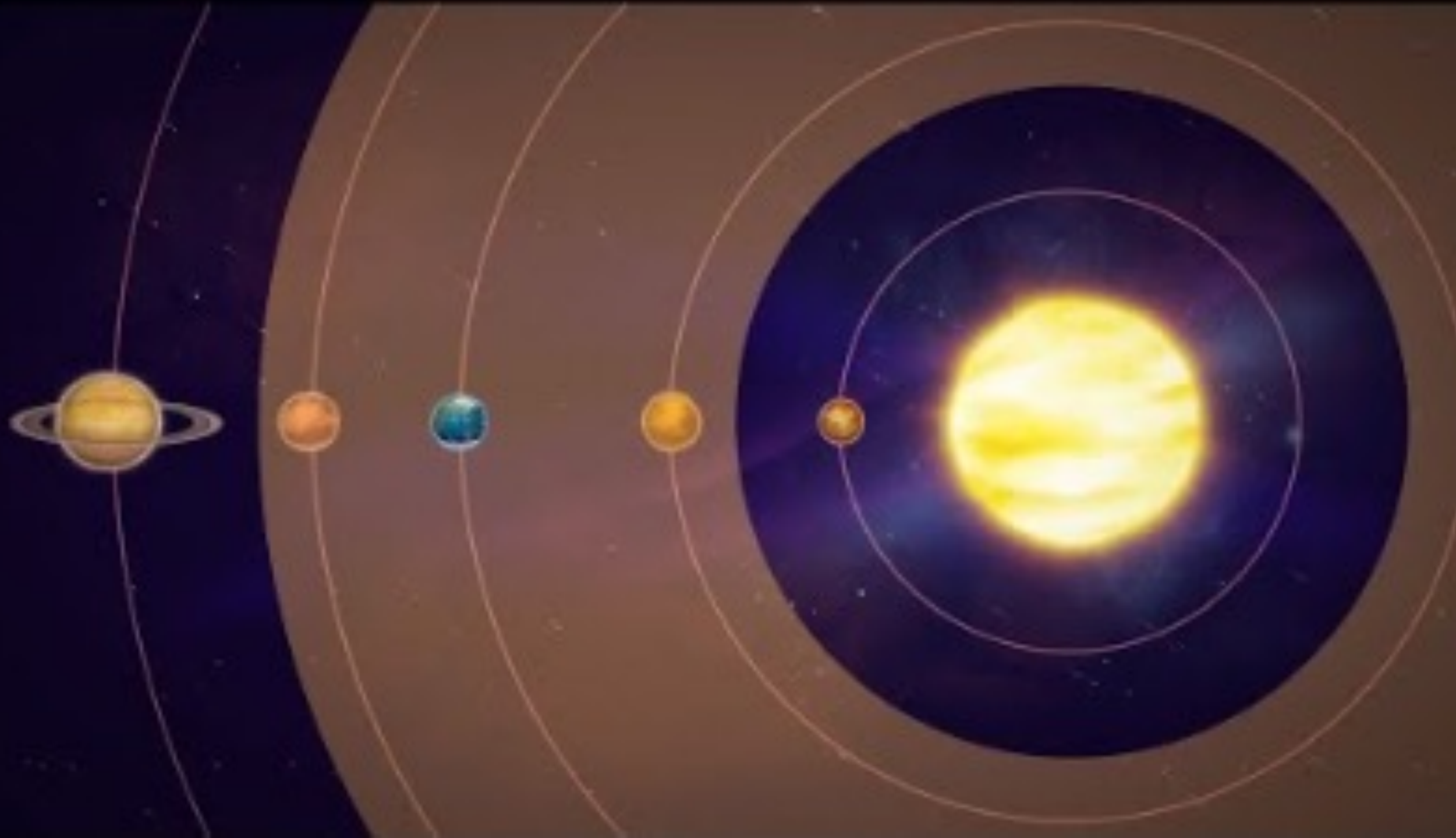
Curiosity
(2012)



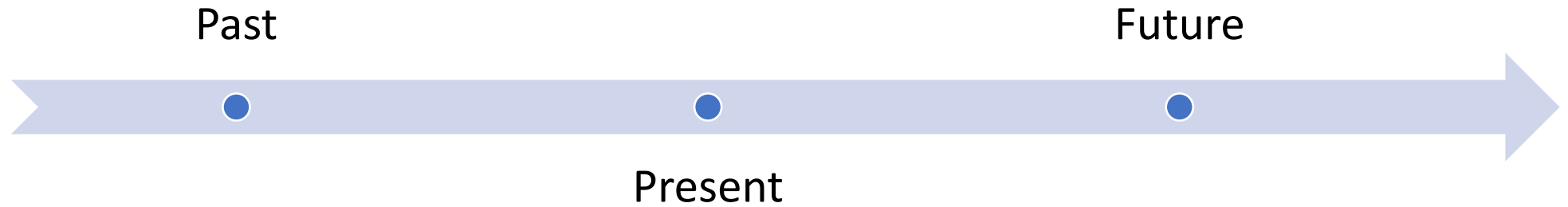
Perseverance
(2021)



Europa Clipper
(planned 2024)



Search for Life and Habitable Worlds



Viking
Kepler

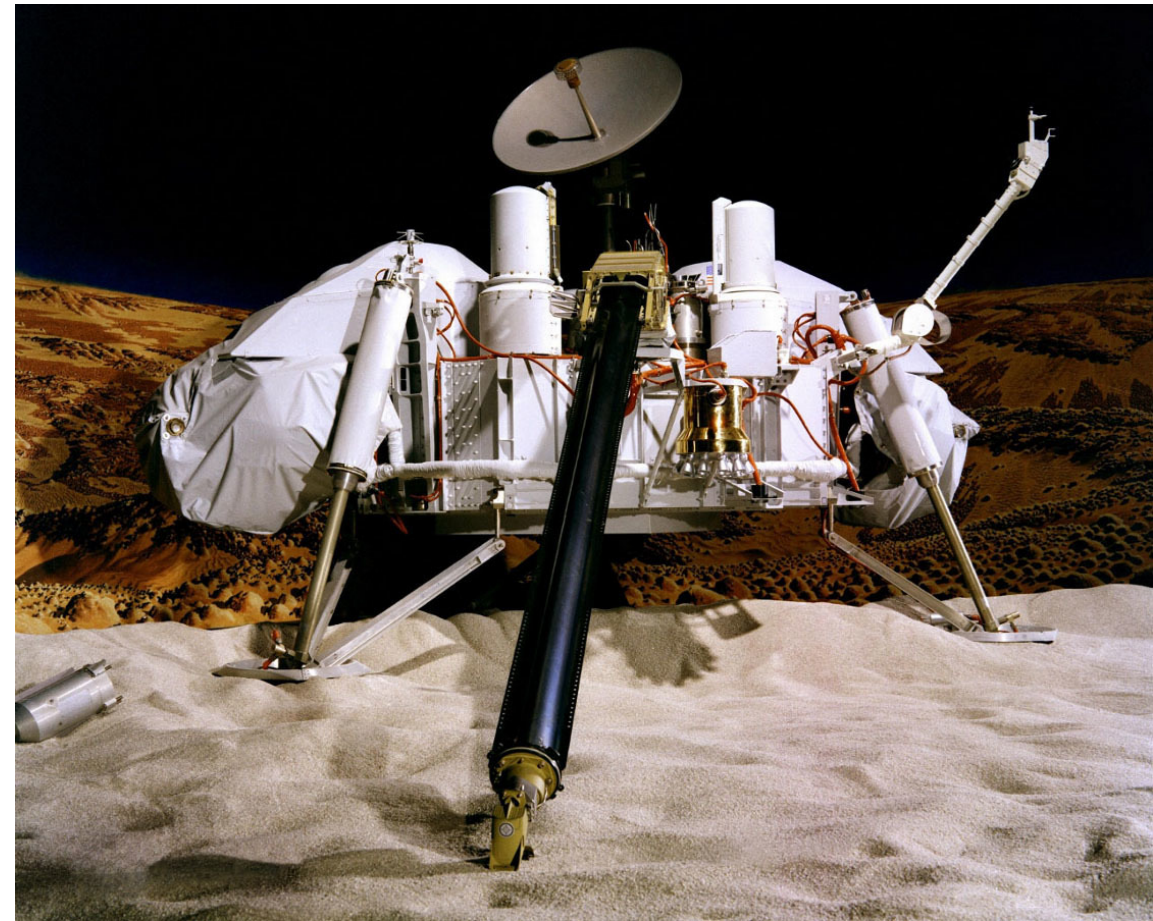
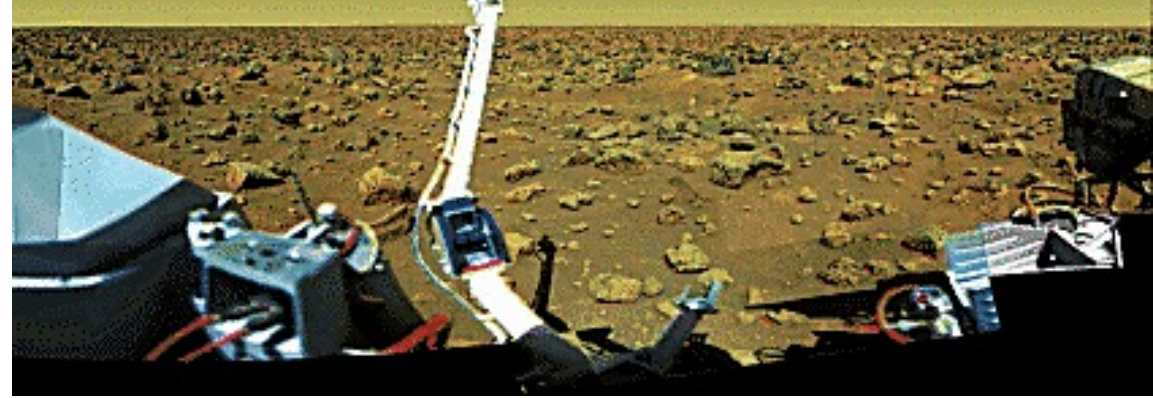
Astrobiology Research

Technology Development

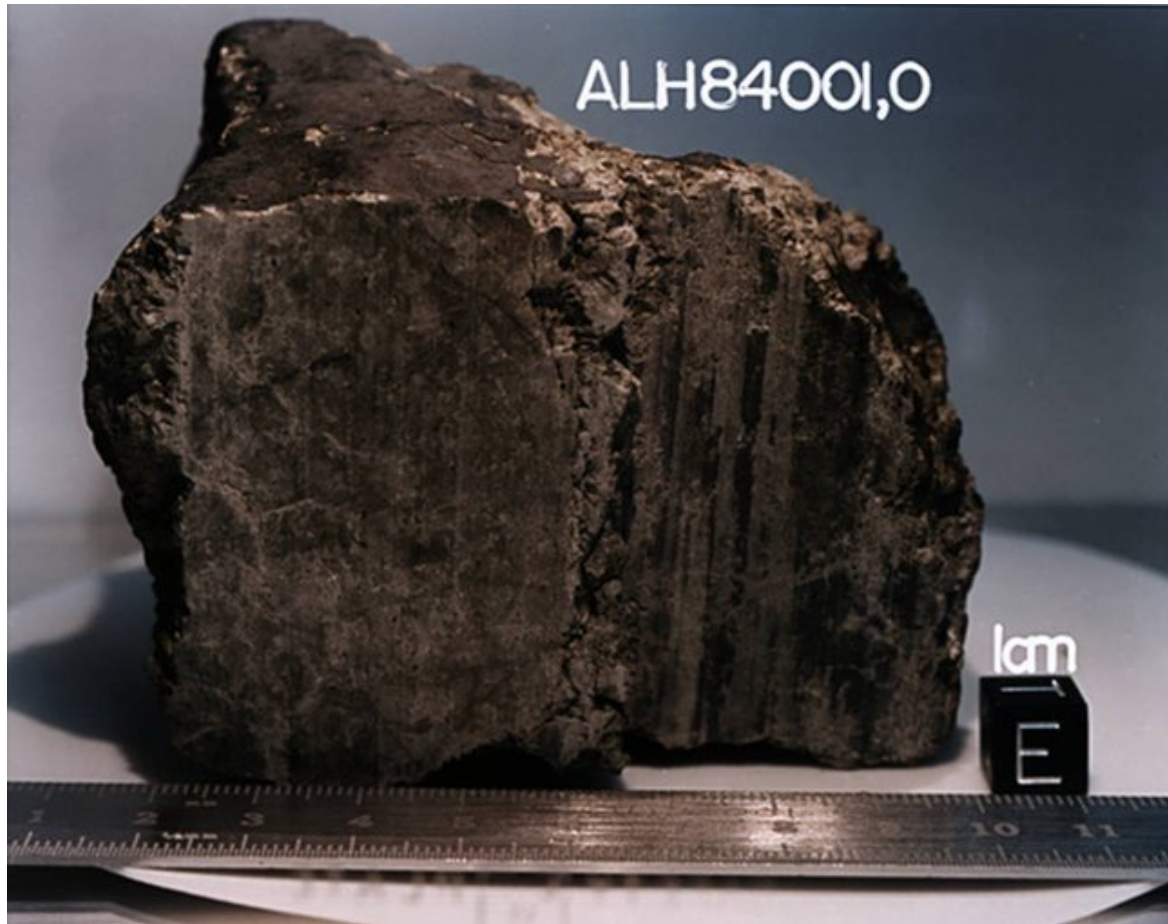
DO
ALIENS
EXIST ?

Viking 1 & 2

- first mission to reach the martian surface
- first to search for evidence of life on Mars
- two landers conducted three biology experiments designed to look for possible signs of life on the surface
- results taught scientists a great deal about how little we knew about life on Earth and how to detect it
- experiments prompted by a 2008 surprise result from NASA's Phoenix Mars Lander suggest that soil examined by NASA's Viking Mars landers in 1976 may have contained carbon-based chemical building blocks of life



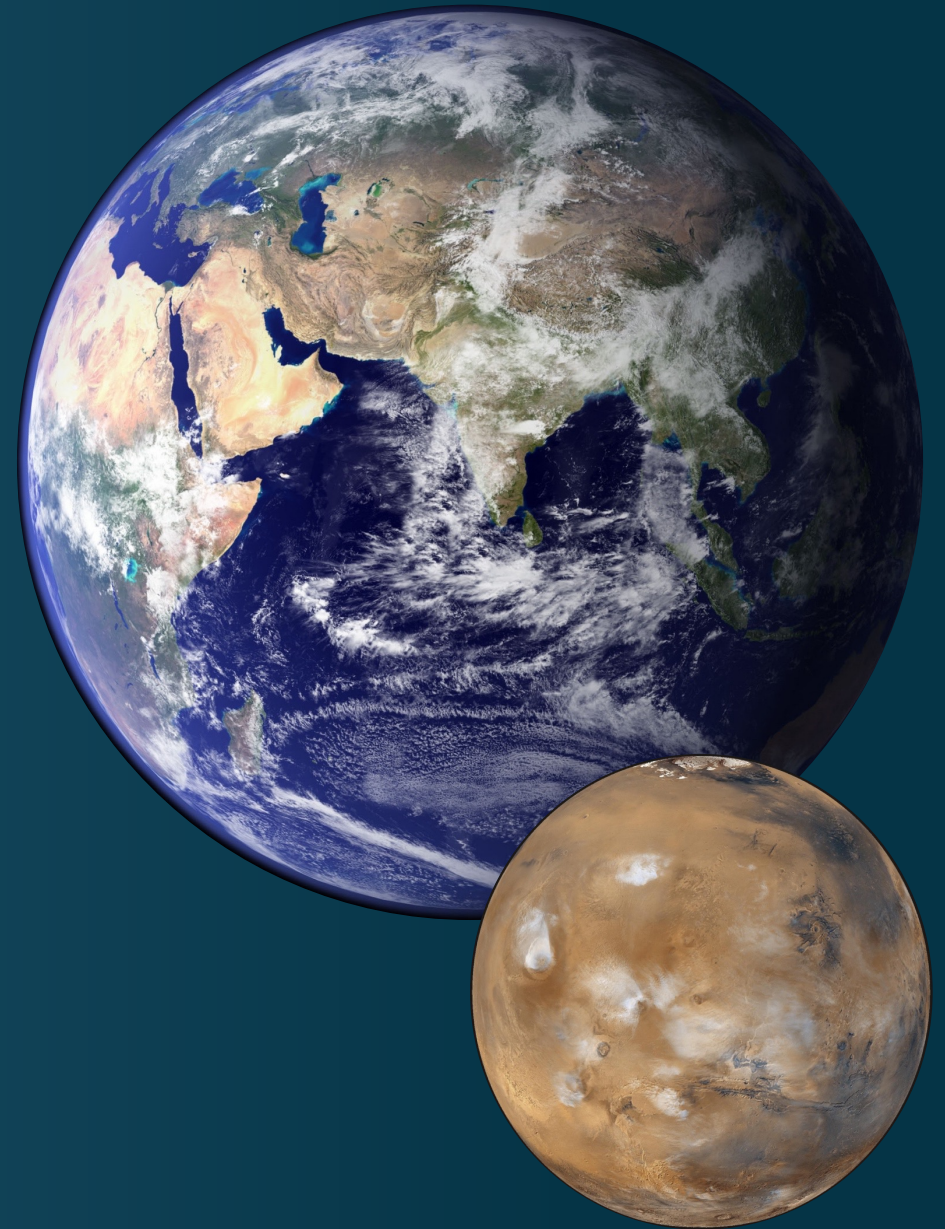
Allen Hills Meteorite ALH84001



Headlines in 1996 told of a NASA research team, led by David McKay, that had found six indicators of past life in a meteorite from Mars. The famous ALH84001 meteorite, uncovered in the Allan Hills region of Antarctica in 1984, was presented as containing clear signs that microbial life once existed on Mars. There were even images of what was interpreted to be the fossil remains of a bacterium-like life form.

What can we learn about searching for life, by studying the Earth?

1. Life is tough (extremophiles)
2. Life is tenacious (long survival times)
3. When conditions get tough, life moves inside the rocks!
4. Life is metabolically diverse (it eats anything, it breathes anything!!)



Kepler

Planets outnumber stars.
Small planets are common.
Planets are diverse.
Solar systems are diverse too!

Analysis of Kepler's discoveries concluded that 20 to 50 percent of the stars visible in the night sky are likely to have small, possibly rocky, planets similar in size to Earth, and located within the habitable zone of their parent stars

Discovered more than 2600 planets around other stars



Credit: Aaron Gronstal

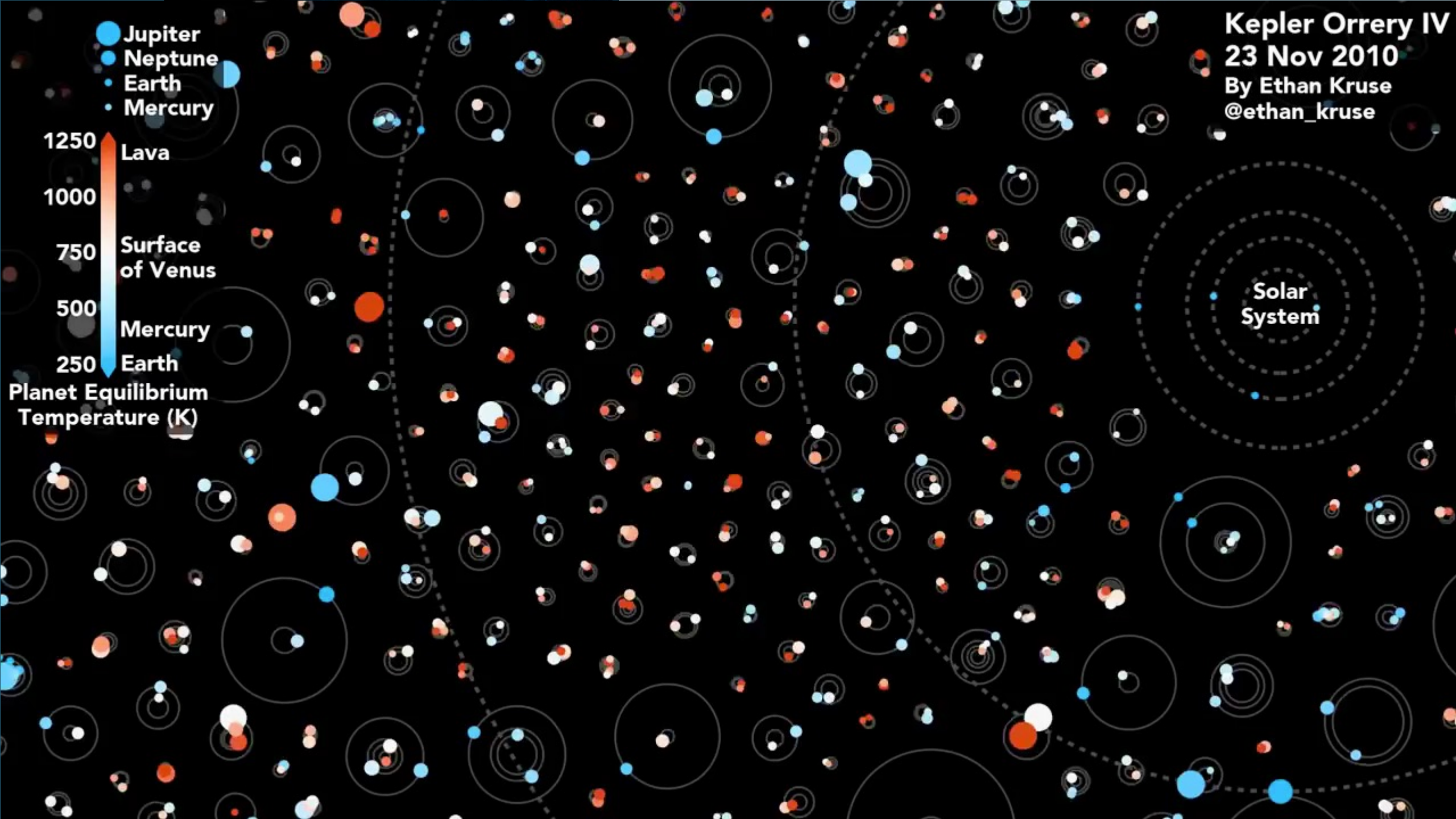


Kepler Orrery IV

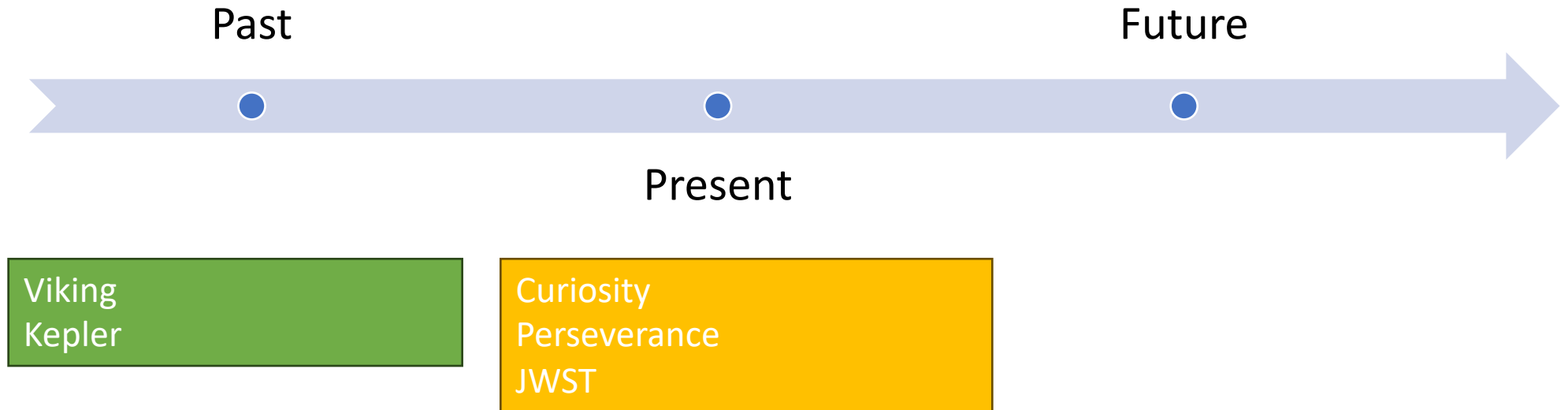
23 Nov 2010

By Ethan Kruse

@ethan_kruse



Search for Life and Habitable Worlds



Astrobiology Research

Technology Development



IS THERE
LIFE ON
MARS?

Mars Science Laboratory (MSL) Curiosity

Curiosity is headed toward the upper Gediz Vallis ridge, a landform that may record the most recent episode of liquid water on Mount Sharp

Driven over 30 kilometers and gained over 700 vertical meters on Mount Sharp

All ten instruments continue to return high-value scientific measurements

Completed its 38th successful drill-based sampling campaign in May at Ubajara, marking 44 sampling campaigns overall.

Years in the making, a major software update installed in April enables Curiosity to drive faster and reduce wear and tear on its wheels - just two of about 180 software changes implemented



NASA's Curiosity Mars rover will drive faster and reduce wear on its wheels thanks to two of the new capabilities included with a major software update that was completed on April 7. Seen here is the rover's view of a hill nicknamed "Bolívar," with Gale Crater's vast floor in the upper right.
Credits: NASA/JPL-Caltech/MSSS

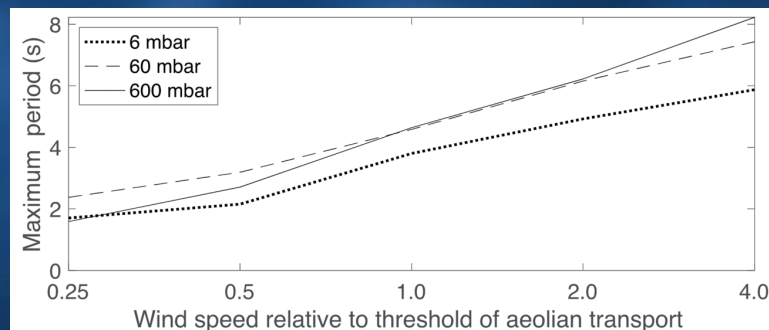
Curiosity: Ancient Winds and Waves on Mars



Structures on “Square Top” could have formed by wave ripples near a lake shore.

Possible wave ripples preserved in rocks examined by the Curiosity rover reveal there may have been times when an ancient lake within Gale crater was not covered by ice.

- There has been debate as to if the lakes that existed in Gale crater were covered by ice or not; absence of ice would indicate a past warmer climate.
- A recent study highlighted three rocks that have ripple structures which could have been created in the shallow part of an ice-free lake with wind-driven waves at its surface.
- Most of the lake rocks seen by Curiosity lack wave ripples, suggesting most sediment was deposited further from the shore, or when the lake was deeper, smaller, or in periods when it was covered in ice.
- The wave ripples imply that there were times when the ancient climate was warm enough, and the ancient atmosphere was thick enough, to allow water to neither freeze nor rapidly evaporate.



Modeling shows that even in a thin atmosphere, winds would have been strong enough to form waves that would produce ripples on the lake floor near shore.

Mars2020

Perseverance Odometer: 19.3 km*
Rover samples: 9 rock, 1 regolith,
2 witness

Ingenuity Log: 51 flights, 11.7 km,
waiting to conform flight 52*

* As of June 13, 2023



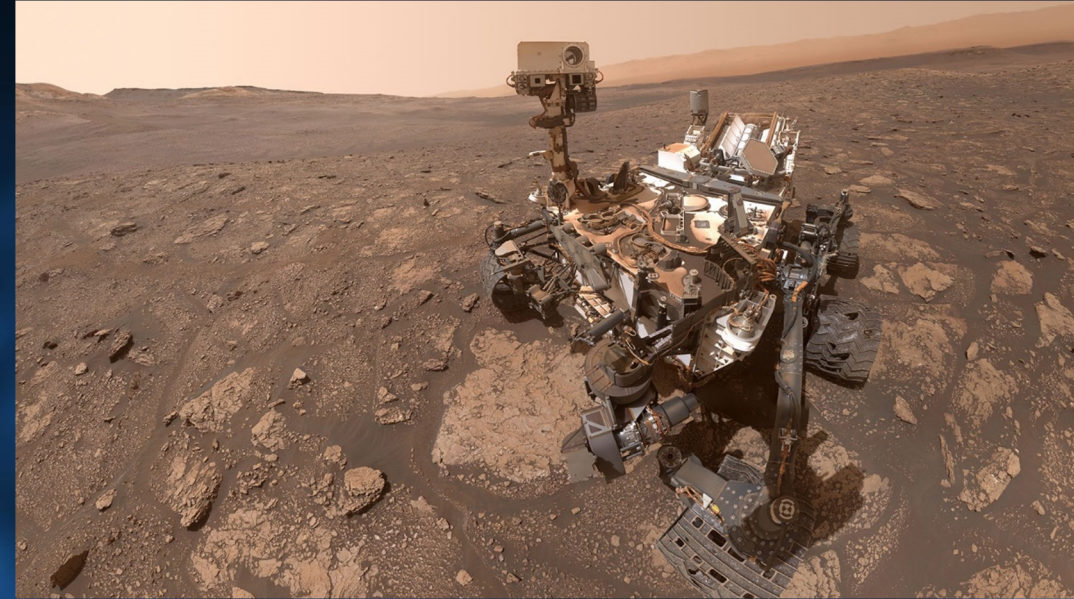
Front Hazcam from Sol 821 (Emerald Lake) Credits: NASA/JPL-Caltech/MSSS

- Perseverance explored the 'Onahu' outcrop for over the past 3 weeks after abrading 'Ouzel Falls' indicated interesting conglomerates (crumbly) but worth sampling attempt
- Conglomerate core from Emerald Lake acquired, working on sample processing now
- Ingenuity connectivity to Perseverance limited at current location; flight 52 data (April 25th) not relayed to the rover until Perseverance moves closer to the Ingenuity landing site
- After completing the Upper Fan science campaign, Perseverance will move toward the 'margin unit', the carbonate-bearing rocks located along the inner rim of Jezero

Life on Mars: Are we digging deep enough?

Amino acids can be created by life and by non-biological chemistry and finding certain amino acids on Mars would be considered a potential sign of ancient martian life.

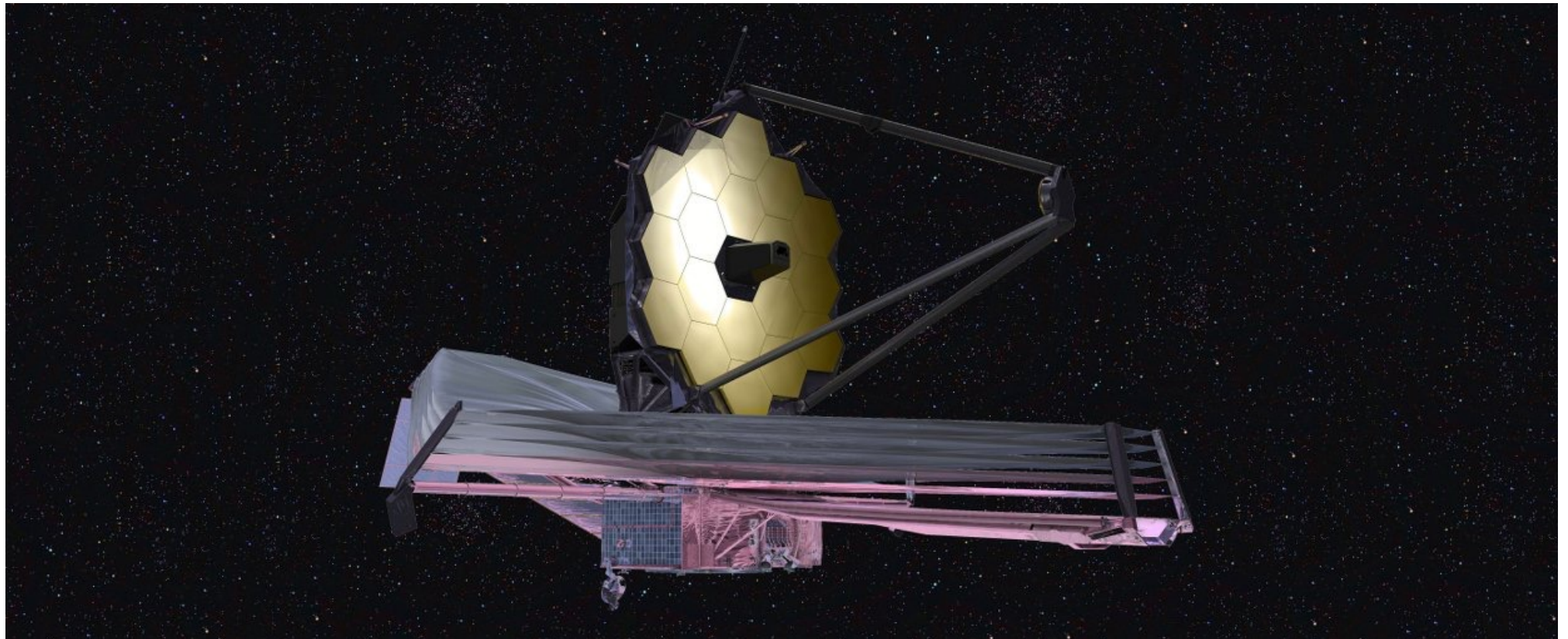
- To test the resilience of some amino acids on Mars surface, research scientists mixed several types of amino acids in simulated martian soil and sealed the samples in test tubes. Some samples were kept at room temperature, while others were chilled to -55 °C. The samples were blasted with gamma radiation, simulating 800 million years of radiation exposure in the martian surface rocks.
- Results suggest that amino acids are destroyed by cosmic rays in the martian surface rocks and regolith at much faster rates than previously thought.
- At the depths that current Mars rover missions drill to, amino acids could be completely destroyed over relatively short geologic timescales, indicating some potential challenges for the search of ancient amino acids and other possible organic biosignatures in the top 2 m of the martian surface.



NASA's Curiosity Mars rover took this selfie at a location nicknamed "Mary Anning" after a 19th century English paleontologist. Curiosity snagged three samples of drilled rock at this site on its way out of the Glen Torridon region, which scientists believe was a site where ancient conditions would have been favorable to supporting life, if it ever was present. Credits: NASA/JPL-Caltech/MSSS

James Webb Space Telescope (JWST)

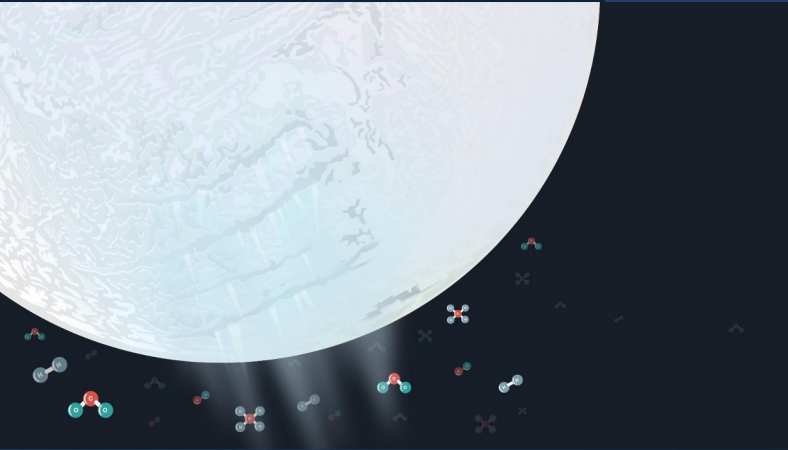
Data from Webb will be used to study the formation and evolution of habitable worlds, and will be invaluable in understanding processes that have shaped habitability in our own solar system. Webb is capable of making detailed observations that might one day allow astrobiologists to identify signatures of life on Earth-like planets beyond our Solar System.



Atmosphere Exchange & Signs of Life

A recent study aimed to answer the question: Could the exchange of chemicals between two exoplanets be mistaken for signs of life when observing one of them?

- The team of researchers modeled exoplanet atmospheres and simulated how they would look when observed with the James Webb Space Telescope (JWST) or next-generation space telescopes.
- Researchers specifically simulated cases where oxygen atoms entered the top of the atmosphere, as this process is observed on Titan and could potentially lead to the accumulation of oxygen and ozone - potential biosignatures - in the atmosphere.
- Results showed that methane could survive this oxygen influx, but that oxygen and ozone could not build up to detectable levels. Thus, if a rocky planet is seeded with water or oxygen from external sources, **it is unlikely that this could be mistaken for signs of life when observing with JWST and next-generation space telescopes.**



Saturn's moon Enceladus with cryovolcano plumes spewing organic compounds out into space. Image credit: NASA/JPL-Caltech

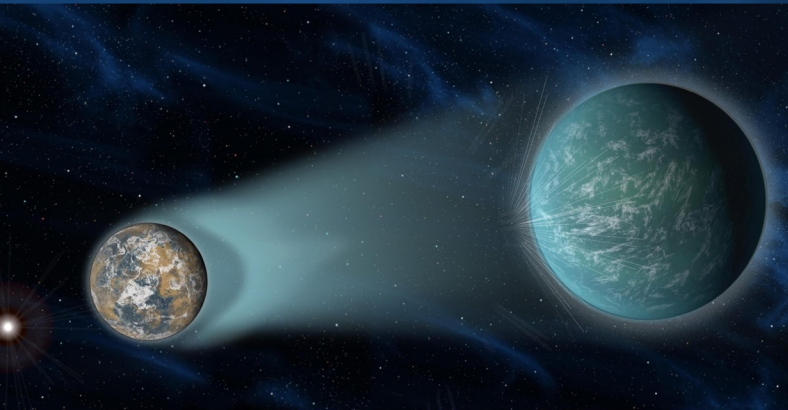
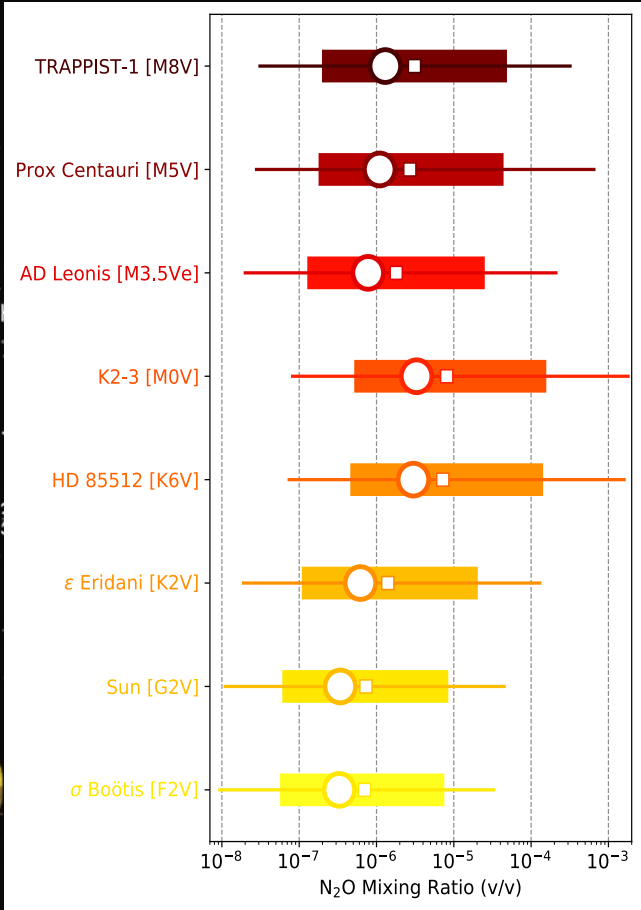


Illustration of TRAPPIST-1 d losing its atmosphere due to stellar activity and raining down onto TRAPPIST-1 e. Image credit: NASA/GSFC Jay Friedlander.

N_2O as a Biosignature for Exoplanets



Predicted accumulation of N_2O on Earth-like planets orbiting FGKM stars with surface fluxes of $0.0\text{--}100 \text{ Tmol yr}^{-1}$

N_2O , a product of biological nitrogen metabolism, could accumulate to detectable abundances on terrestrial exoplanets, making it a potential indicator for the presence of life beyond Earth.

- Biogenic gases in the atmosphere of distant exoplanets are a promising approach for inferring the presence of life. The most reliable gases to consider remains an area of active debate.
- This study predicted N_2O concentrations over a range of atmospheric oxygen levels, host star spectral types, and N_2O surface fluxes using linked series of biogeochemical and photochemical models. Results showed plausibly detectable levels of N_2O productivity on an exoplanet like TRAPPIST-1e.
- The James Webb Space Telescope and future exoplanet observatories could be used for future N_2O observations of Earth-like planets orbiting K dwarf stars.

Ladder of Life detection

Neveu et al. (2018),
Astrobiology

CRITERIA		EXPLANATION	EXAMPLES / NOTES
	Sensitive	Signal for feature of life selectively quantified above instrumental limit of quantitation, within response time and dynamic range	Encompasses all quantitative measures of instrumental performance (Armbruster & Pry 2008)
	WHY? Avoid false negatives TEST Positive controls		
	Contamination-free	Signal for feature of life not selectively detected (below instrumental LoD) in abiotic samples	"Below LoD" implies signal indistinguishable from noise given instrument sensitivity and stability (Armbruster & Pry 2008)
	WHY? Avoid false positives TEST #1 Neg. controls		
	TEST #2 Blanks	Distinguish indigenous signals from contamination signals arising from:	• Hardware • Other samples (cross-contamination)
	Repeatable	$N \geq 3$ measurements is the typical burden of proof in microbiology and chemistry, also depends on other factors (Table 2)	N measurements per sample, for as many samples as needed to capture the heterogeneity of the setting
	WHY? Avoid fluke TEST $\geq$ Triplicate		
	Detectable	Physical, chemical, or geological conditions in the sample's current environment do not prevent the measurement from being made	• Reaction of organics with oxidant upon heating • Ionization suppression by salts • Some antibody methods in "sticky" briny liquid
	WHY? Avoid false negatives TEST Positive controls		
	Survivable	Physical, chemical, or geological conditions in the suite of environments encountered by the sample between its synthesis and its measurement have not destroyed targeted signs of life	• Photo-destruction of biosignature gases • Radiolysis of organics • Racemization
	WHY? Avoid false negatives TEST $T_{\text{residence}} > N \cdot T_{\text{degradation}}$		Test from Hoehler (2017); $N \sim 1$ to a few units
	Reliable	Propensity to be produced by life and distinguished from abiotic backgrounds from any of the environments encountered by the sample between its synthesis and its measurement	$\frac{[\text{bio}]}{[\text{bio}] + [\text{abio}]} > \text{instrument precision}$
	WHY? Avoid false positives TEST Measure $[\text{bio}] \neq [\text{abio}]$		
	Compatible	The feature must not be excessively different from what is known of life on Earth (specificity vs. genericity). Limits can be pushed within bounds.	• Organic molecules, carbon-based (this would include e.g. proposed "arseno-DNA" (Wolfe-Simon et al., 2011)). • Temperature not too high. Prions survive combustion at 600°C (Brown et al. 2004).
	WHY? Consistent with what we know of life TEST Within bounds of NRC (2007)		
	Last-resort hypothesis	The measurement, either alone or taken together with sufficient complementary measurements, precludes an abiotic origin with sufficiently little ambiguity.	Not just an appeal to authority (Sagan et al., 1993), as this criterion has been informally adopted by the astrobiology community as a standard.
	WHY? Precludes abiotic origin TEST Decision rules (Table 3)		

INSTRUMENTAL CRITERIA

CONTEXTUAL CRITERIA

	RUNG	FEATURE	MEASUREMENT	TARGET	LIKELIHOOD	INSTRUMENTAL CRITERIA			CONTEXTUAL CRITERIA				
						Quantifiable Detectability	Contamination-free Likelihood of false positive	Repeatable	Detectable Detectability	Survivable Likelihood of false negative	Reliable Ambiguity of feature	Compatible Specificity to Earth life	Last-resort Ambiguity of interpretation
LIFE	Darwinian evolution	 Changes in inheritable traits in response to selective pressures	Not practical under mission constraints	• In situ • Sample return	No	-	-		-	N/A (extant)	-	-	-
	Growth & Reproduction	 Concurrent life stages or identifiable reproductive form, motility	Cell(-like?) structures in multiple stages	• In situ • Sample return	Low	Hard	Low		Med (don't identify stages, timing off, sample size low)	High?	Ambiguous. What is a cell? What morphological differences exist?	Earth	Med / High
	Metabolism	 Major element or isotope fractionations indicative of metabolism	Deviation from abiotic fractionation controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Low / Med	Easy	High		Medium	High	Hinges on understanding of context	Earth?	Low
		 Response to substrate addition	Waste output (compound, heat)	• In situ • Sample return	Low / Med	Easy	Low		High	N/A (extant)	Hinges on understanding of context	Earth	Medium
		 Co-located reductant and oxidant	Deviation from abiotic distribution controlled by thermodynamic equilibrium and/or kinetics	• Remote sensing • In situ • Sample return	Med / High	Med (linked to specificity of instrument)	Low / Med	Number of replicates depends on:	Med / High	High	Mixed reactions, large inventory of chemistries	Generic	Low / Med
	Molecules & Structures Conferring Function	 Polymers that support information storage and transfer for terran life (DNA, RNA)	Abundance	• In situ • Sample return	Low	Hard (instrument specificity must be high); RNA hard to measure on Earth	DNA: high; RNA: low (reactive)		Low (technology limited, only terran); RNA highly reactive	Low (hydrolysis in water)	Reliable	Earth	Negligible
		 Structural preferences in organic molecules (non-random and enhancing function)	Polymer with repeating charge	• In situ • Sample return	Low / Med	Need a lot of material and overprinting must be discernable	Low		Med / High	Low (hydrolysis in water, diagenesis)	How much preference needed to detect?	Generic	Low
		 Enantiomeric excess > 20% in multiple amino acid types	Enantiomeric excess > 20% in multiple amino acid types	• In situ • Sample return	High	How much excess necessary?	Low		Low	Medium	Mixed sample both processes present	Generic	Low
		 Pigments as evidence of non-random chemistries (e.g. specific pathways)	Spectral feature and/or color, otherwise see "structural preferences"	• Remote sensing • In situ • Sample return	Low / Med	Easy (fluorescence)	Low		Low (limitation of what we are looking for)	Low (diagenesis)	How to define pigment as we don't know it?	Earth (can one abstract?)	Very low
		 Organics not found abiotically (e.g. hopanes, ATP, histidine)	Presence	• In situ • Sample return	Medium	Easy if enough material	Low	• Value and cost of information.	High	High	Low	Earth?	High
SUSPICIOUS BIOMATERIALS	Potential biomolecule components	 Complex organics (e.g. nucleic acid oligomers, peptides, PAH)	Presence	• Remote sensing (PAH) • In situ • Sample return	High	Easy if enough material	Low		High	Medium	Abiotic production known	Generic	Med / High
		 Monomeric units of biopolymers (nucleobases, amino acids, lipids for compartmentalization)	Presence	• Remote sensing • In situ • Sample return	Med / High	Limit of detection, need a lot of material	High		High	Med (diagenesis)	Abiotic pathways known	Generic	Medium
		 Distribution of metals e.g. V in oil or Fe, Ni, Mo/W, Co, S, Se, P	Presence	• In situ • Sample return	Medium	Easy except background issue	Low		High	High	Background known	Generic	Medium
	Potential metabolic byproducts	 Patterns of complexity (organics)	Deviation from equilibrium (P(Poisson distribution of pathway complexity) < 0.01?) or abiotic kinetic distribution	• In situ • Sample return	High	Background issue, material limited	Low		High	Medium?	Limited documentation of abiotic vs. biotic differences	Generic	Medium
	Biofabrics	 Textures	Biologically mediated morphologies, preferably with co-located composition	• In situ • Sample return	Medium	Medium	Low		Medium	High?	Highly ambiguous	Earth	High
Habitability		Liquid water, building blocks, energy source, gradients		Redox, temperature, pH, energy, disequilibria									

Ladder of Life Detection

Neveu et al. (2018),
Astrobiology

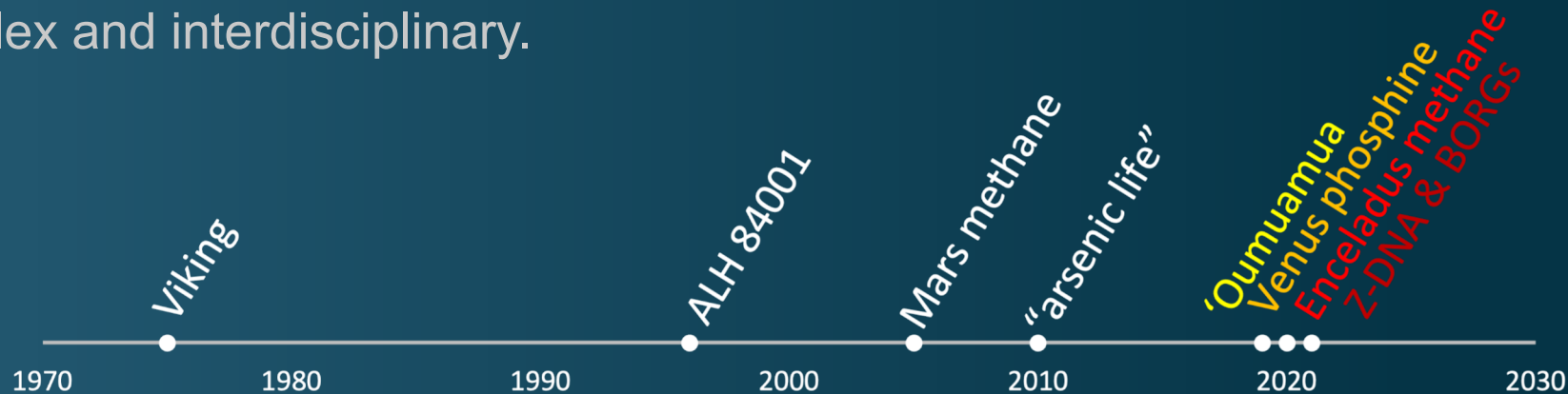
The need for biosignature standards of evidence

The detection of extraterrestrial life, in our Solar System and beyond will likely be neither instantaneous, nor unambiguous---and is a high stakes scientific achievement with high public interest.

Extraterrestrial life detection is an explicit goal for planetary science and astronomy research/missions.

There needs to be an effective way to convey the multi-step, continuum process that is life detection, which may span missions and multiple measurement techniques (See Green et al., 2021; “Call for a framework for reporting evidence for life beyond Earth”)

With increasing claims of possible life detection, it is timely to discuss as a community the *best process* for evaluating and supporting discoveries, and how to report and convey information on a topic that is inherently complex and interdisciplinary.



The Biosignature Assessment

Question 1: Have you detected an authentic signal?

Question 2: Have you adequately identified the signal?

Question 3: Are there abiotic sources for your detection?

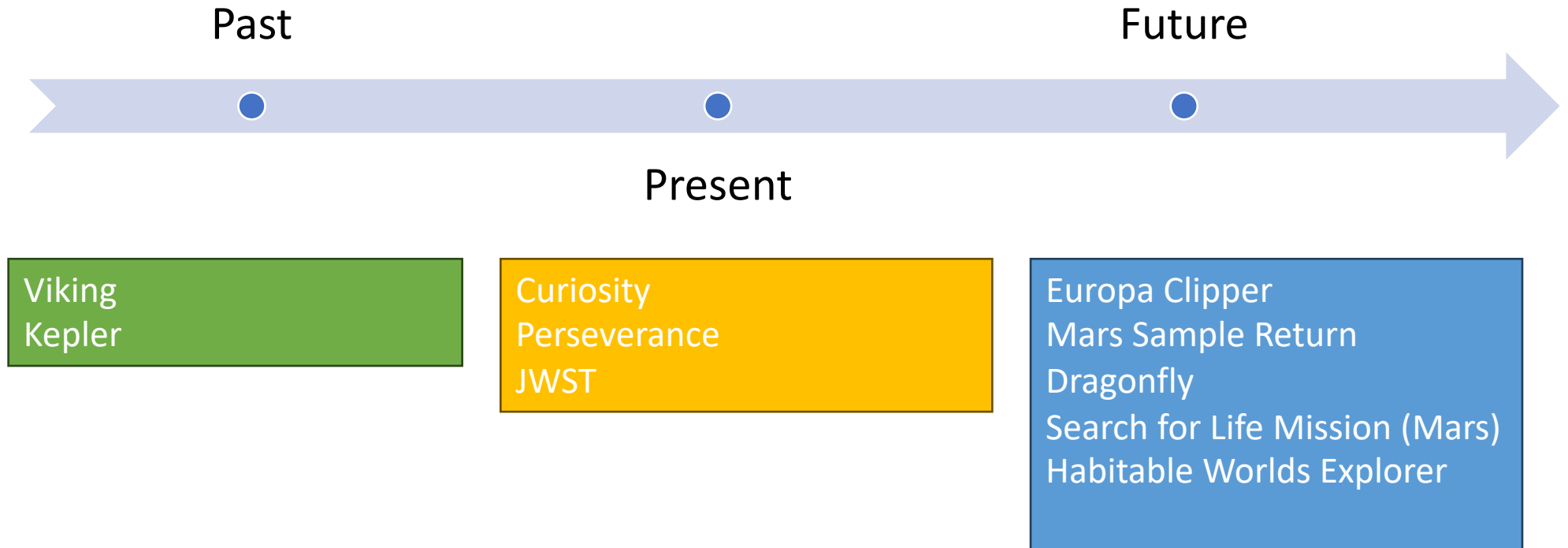
Question 4: Is it likely that life would produce this expression in this environment?

Question 5: Are there independent lines of evidence to support a biological (or non-biological) explanation?

Ultimately need assessment of standards of *confidence/certainty* for each step (future workshop)

A workshop goal was assessing and *challenging* the framework with a range of examples.

Search for Life and Habitable Worlds



Astrobiology Research

Technology Development

Planetary Environments are Diverse

The unaltered surfaces of most planets are cold, and by being cold, are dry

Mars

Europa

Titan

Enceladus

Interior environments may be more similar to Earth:

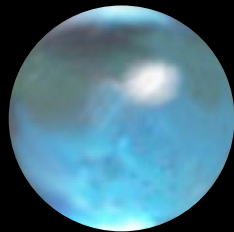
- possible subsurface oceans, both hot and cold
- subsurface rock, similar (?) to inhabited Earth rocks

Exploration of Ocean Worlds



Shown to scale

Exploration of Ocean Worlds



Earth

**30x Earth's
water volume!**

Ice-covered moons

New Frontiers: Dragonfly

Dragonfly is a rotorcraft lander to explore prebiotic chemistry and habitability at dozens of sites on Saturn's moon Titan

Dragonfly takes advantage of Titan's unique organic laboratory to understand how far chemistry can progress in environments that provide key ingredients for life

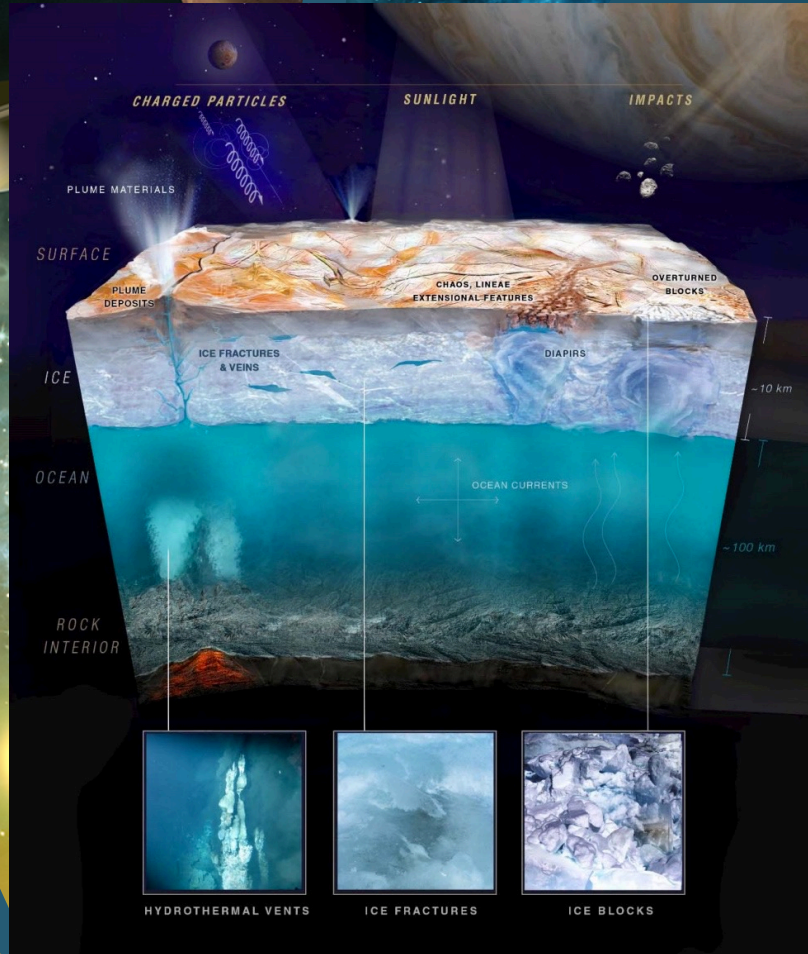
Aerial mobility provides access to Titan's diverse materials in different geologic settings, tens to hundreds of kilometers apart

Launching in 2027

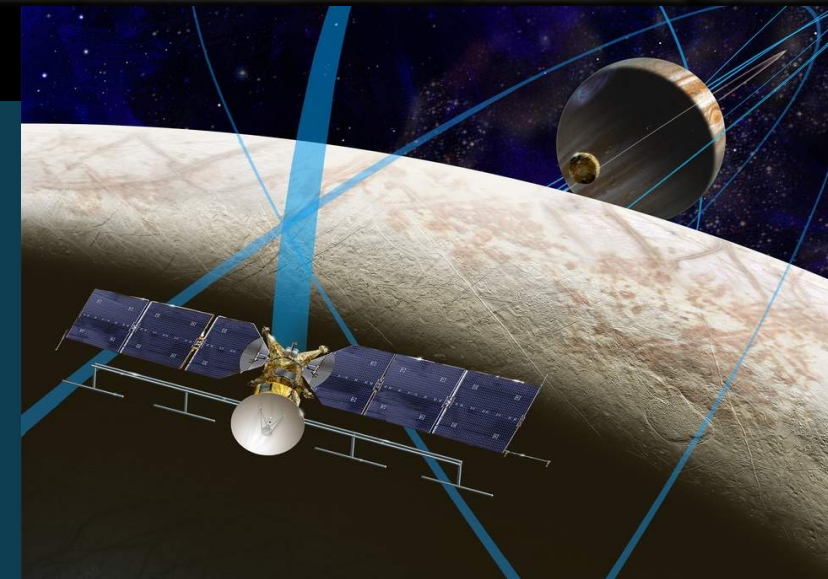
Landing in 2034



Europa Clipper



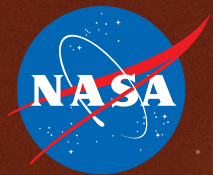
A primary objective of the Europa Clipper mission is to determine the thickness of the Europa's icy shell and to search for subsurface lakes similar to those beneath Antarctica's ice sheet. T



Set to Launch in October 2024

We are creatures of constant awe





National Aeronautics and
Space Administration

Eric E. Ianson
Director, Mars Exploration Program
Science Mission Directorate, NASA Headquarters

EXPLORING MARS TOGETHER

DRAFT Plan for a Sustainable Future for Science at Mars

2023 – 2043



MEP Planning Team

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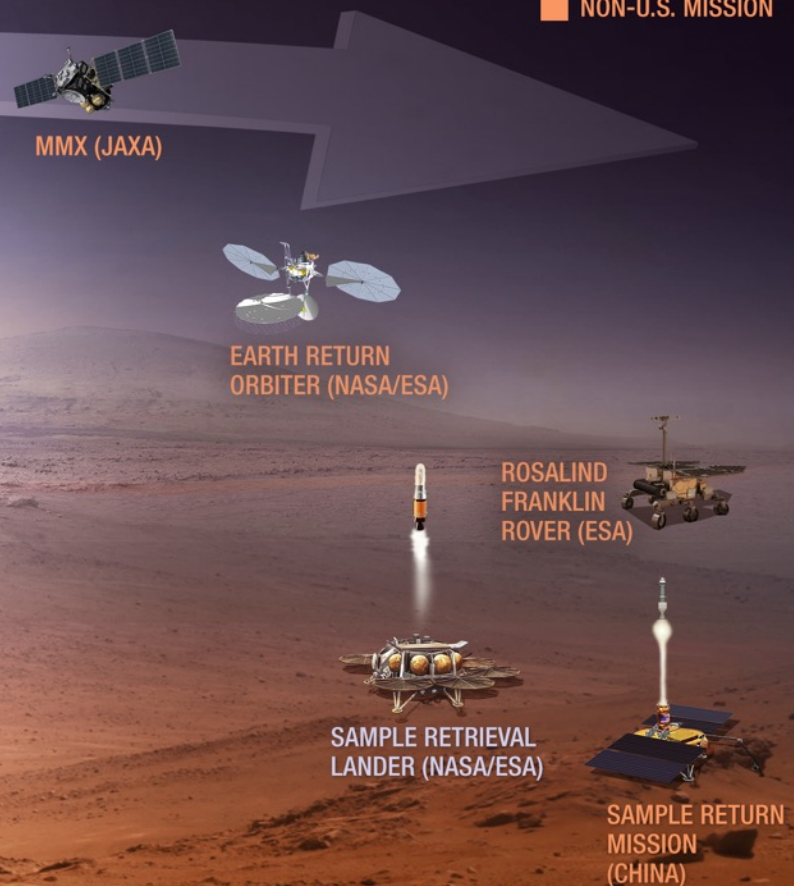
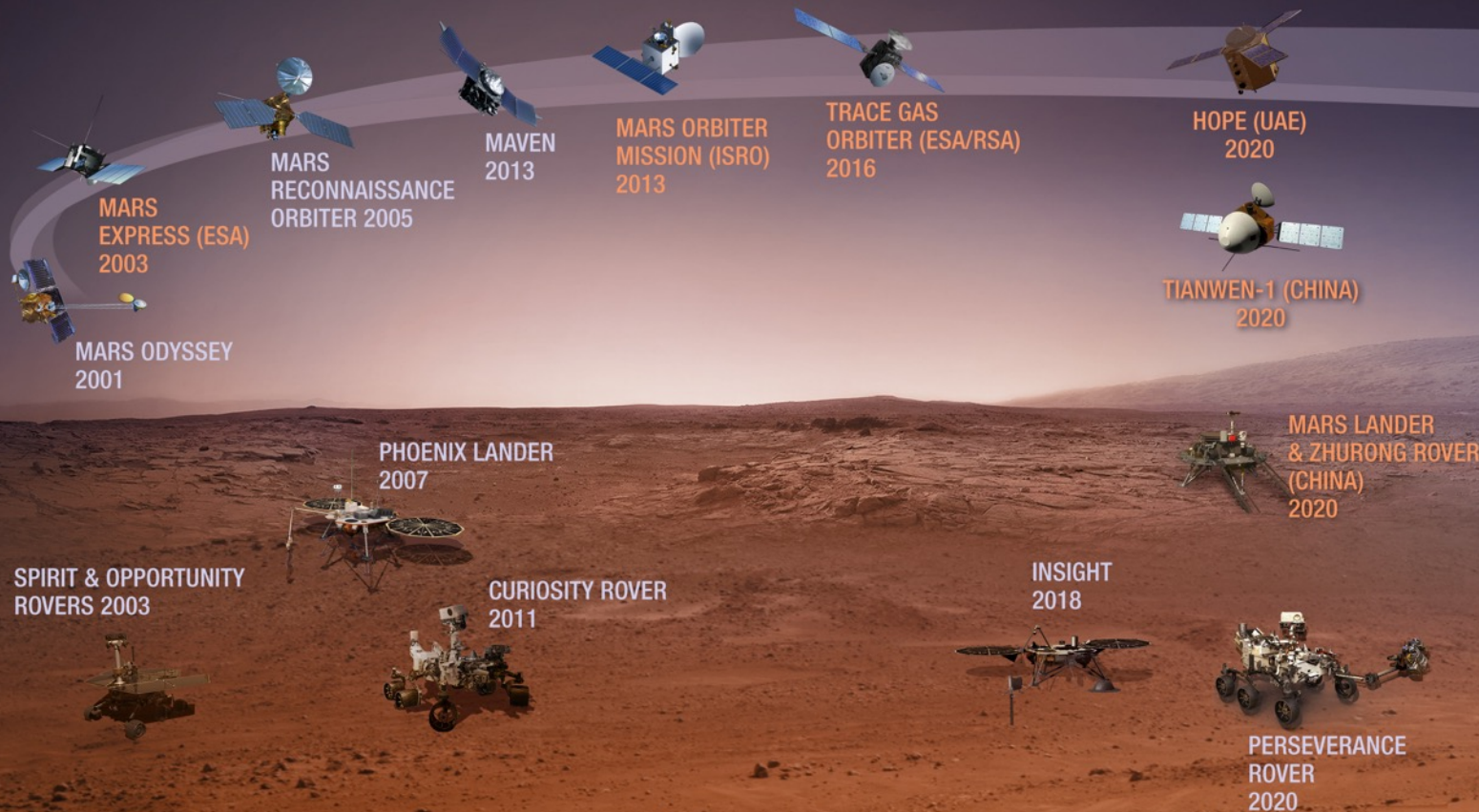
^{††}Science Mission Directorate, NASA Headquarters

Draft for Community Feedback

2001–2022

2024 AND BEYOND

■ U.S. MISSION
■ NON-U.S. MISSION



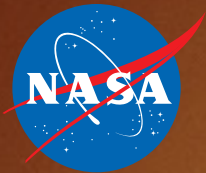
Follow the Water

Explore Habitability

Seek Signs of Life

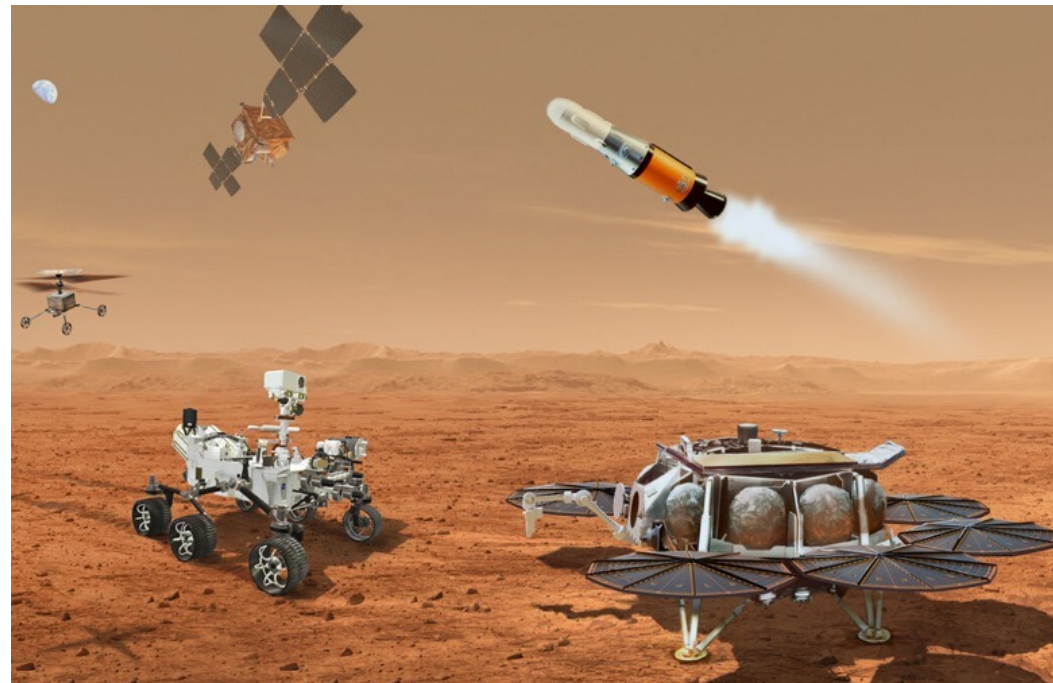
Prepare for Future Human Explorers

Draft for Community Feedback



Mars Sample Return within the Context of the Mars Exploration Program

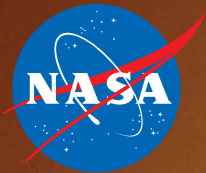
- Mars Sample Return (MSR)* represents the culmination of the community's highest Mars Exploration priority over the last two decades, as cited in the past three Decadal Surveys.
- MEP has responsibilities on both ends of the MSR campaign:
 - Collecting samples with Mars rover *Perseverance*
 - Curating them at the future Sample Receiving facility.



Artist's Concepts

- While MSR would achieve decadal-class science enabled by the past two decades of MEP exploration, MEP is planning for the next two decades of equally profound scientific investigations with a new strategic paradigm designed to send lower-cost, high-science-value missions and payloads to Mars at a higher frequency.

*The decision to implement Mars Sample Return will not be finalized until NASA's completion of the National Environmental Policy Act (NEPA) process. This presentation is being made available for information purposes only.



EXECUTIVE SUMMARY

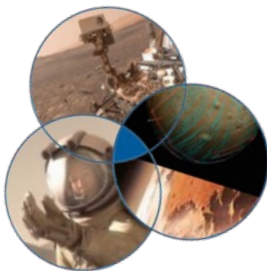
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EXPLORING
MARS
TOGETHER
2023 - 2043

EXPLORING MARS TOGETHER: MEP FUTURE PLAN, 2023 - 2043

KEY TAKEAWAYS

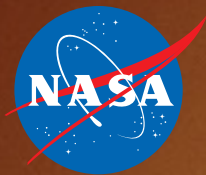
Mars continues to pose key questions that call for a coordinated program of scientific exploration – three community-responsive science themes for 2023-2043 will guide MEP activities:



- Explore the Potential for Martian Life
- Support Human Exploration of Mars
- Discover Dynamic Mars

Emerging capabilities enable a new era of competitive missions, strengthened infrastructure, transportation opportunities, advanced technologies, and inclusive exploration – MEP will:

- Expand opportunities through frequent, small, low-cost missions to produce impactful science
- Build, strengthen, and maintain critical infrastructure
- Reduce the cost of access to Mars through partnerships, low-cost launch vehicle providers, and new delivery systems
- Develop technologies to enable new capabilities for exploring Mars
- Make exploration more accessible and inclusive to the broader community



High-Level Co-Equal Program Science Themes, 2023 - 2043

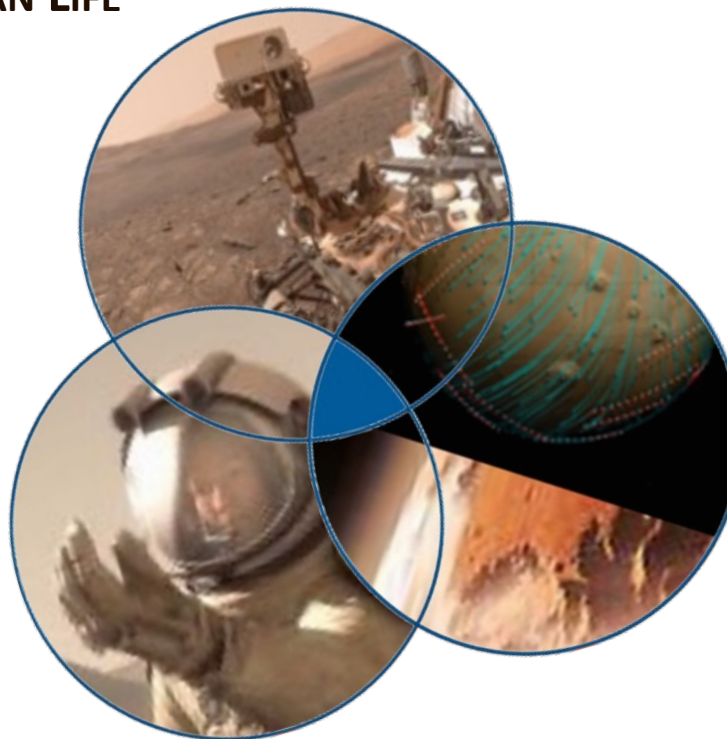
Driven by science, MEP will focus its systemic approach on the following science themes, **which draw upon the MEPAG** goals of life, climate, geology and preparation for human exploration.

EXPLORE THE POTENTIAL FOR MARTIAN LIFE

Advance the search for past and present microbial life and habitable environments through time, while developing approaches that protect both Mars and Earth.

SUPPORT HUMAN EXPLORATION OF MARS

Make observations that are synergistic with the objectives for human exploration of Mars and prepare for the science that humans will do once there.



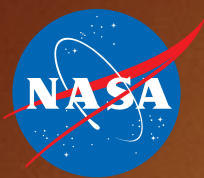
DISCOVER DYNAMIC MARS

Understand the dynamic geological and climatological processes on Mars to illuminate the evolution of the Martian system, our home planet Earth, our solar system, and distant planets around other stars.

SECTION 2
SCIENCE
THEMES

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EXPLORING
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TOGETHER
2023 - 2043



SCIENCE THEME 1

Explore the Potential for Martian Life

Search for evidence of past or present life on Mars in potentially habitable environments and establish how the Martian environment and habitability co-evolved over time.

1.1 Search for Biosignatures, Past & Present

Determine whether the Martian geologic record has biosignatures and identify areas most likely to capture preserved biosignatures based on what is known about past and current habitability at Mars.

1.2 Understand Temporal and Geographic Patterns of Habitability

Leverage Mars' unique ancient geologic record to understand the extent of habitability and its temporal evolution, the existence of any present-day, subsurface habitable environments (including ice), and how habitable environments on Mars and Earth may have diverged.

1.2.1 Physical Access to the Subsurface

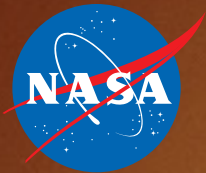
Advance investigations related to subsurface and ice science and access to the ice-rich subsurface as a major programmatic focus, building on water- and habitability-related scientific discoveries of the previous two decades.

1.3 Examine Samples from MSR to Understand Martian Geological & Biological Processes

Study returned samples to understand organic chemistry processes on Mars, what the samples reveal on global, regional and temporal scales, the nature of any biosignatures, and the relationship between Mars' geological and potential biological history.

Planetary protection principles are key across our presence at Mars and upon return to Earth with samples and astronauts, especially as it relates to our search for life.

A focus on potential "special regions" (natural or spacecraft-induced) and the environmental characterization of candidate landing/exploration sites is important to mitigate risks for future human explorers and/or to their astrobiological research.



SECTION 3
INITIATIVES
FOR THE
NEXT TWO
DECADES

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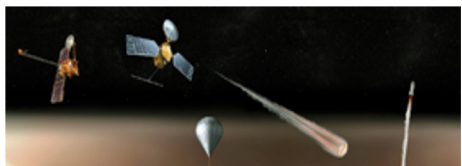
EXPLORING
MARS
TOGETHER
2023 - 2043

Program Initiatives for the Future of MEP



INITIATIVE 1

EXPAND OPPORTUNITIES TO EXPLORE MARS THROUGH COMPETED, LOWER-COST, MORE FREQUENT FLIGHT OPPORTUNITIES



INITIATIVE 2

STRENGTHEN AND BROADEN INFRASTRUCTURE AT MARS TO ENABLE A DIVERSE SET OF MISSIONS & NEW OPPORTUNITIES FOR PARTNERSHIPS



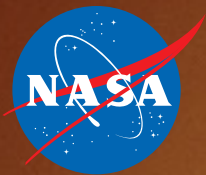
INITIATIVE 3

INVEST IN KEY TECHNOLOGIES TO ENABLE EXPANDED ACCESS TO, AND SCIENTIFIC UNDERSTANDING OF, MARS

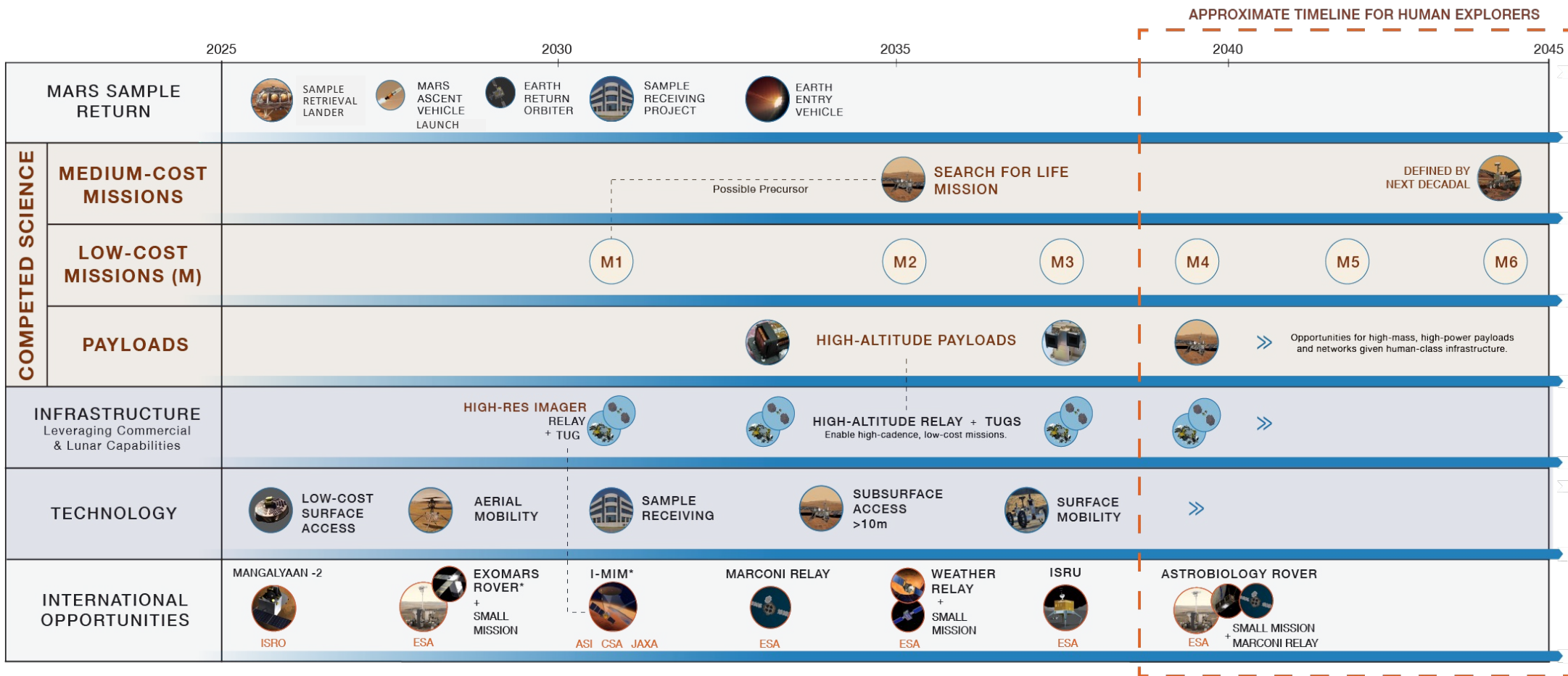


INITIATIVE 4

ENABLE PARTICIPATION IN MARS EXPLORATION FOR ALL COMMUNITIES



Aspirational MEP Timeline



* Launch Dates Fixed

This timeline should be considered hypothetical.

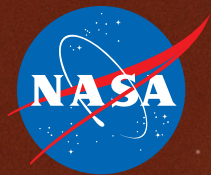
There is flexibility to adjust the phasing of activities if and when funding becomes available to begin implementation and to respond to discovery.

Draft for Community Feedback

SECTION 4
Aspirational
Program
Timeline

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MARS
TOGETHER
2023 - 2043



National Aeronautics and
Space Administration

We welcome your feedback!

Send comments/questions to: **HQ-MEP@mail.nasa.gov**

Feedback requested by April 30, 2023

Eric E. Ianson
Director, Mars Exploration Program

EXPLORING MARS TOGETHER

DRAFT Plan for a Sustainable Future for Science at Mars

2023 – 2043

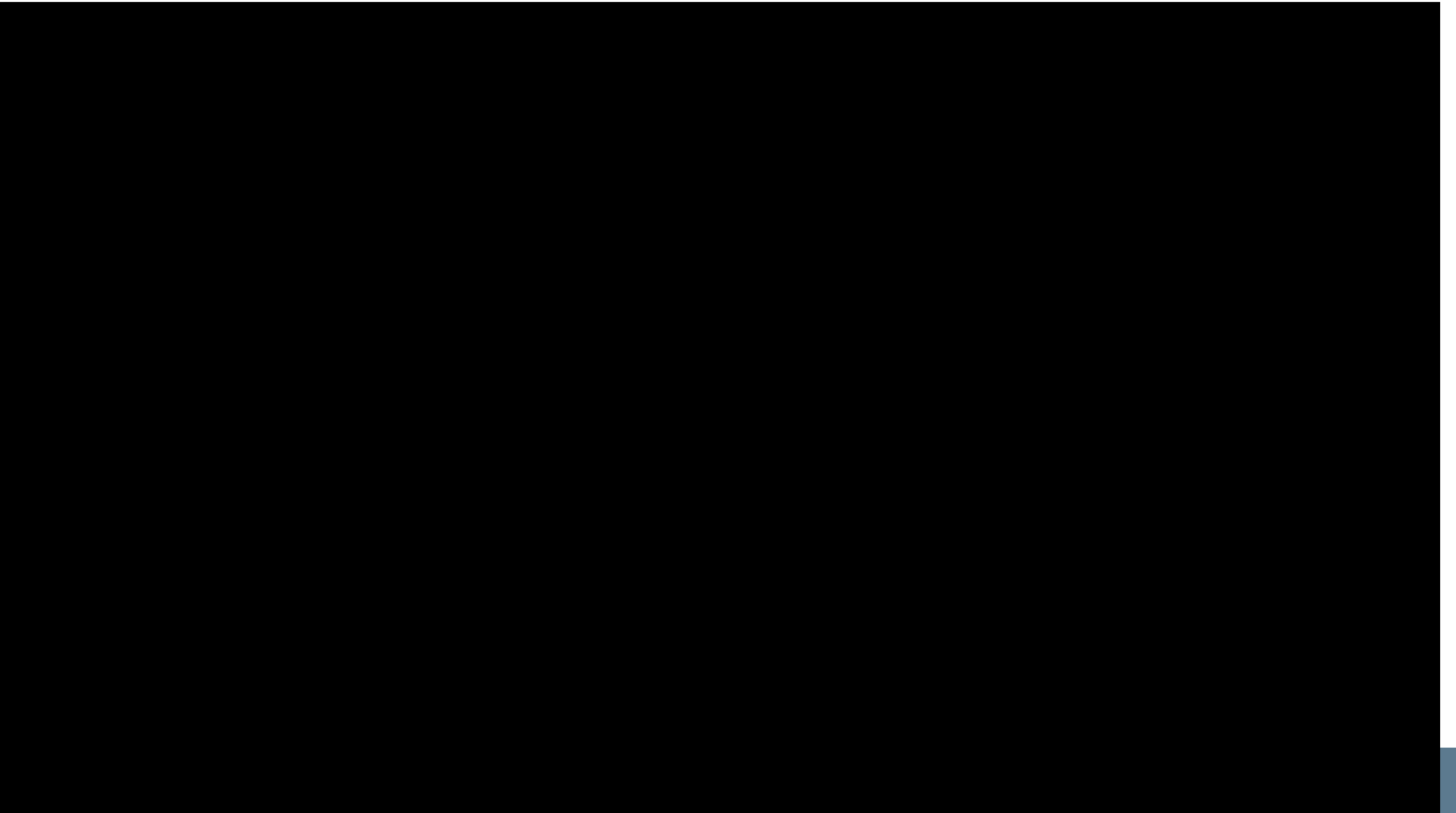
Draft for Community Feedback

MEP Planning Team

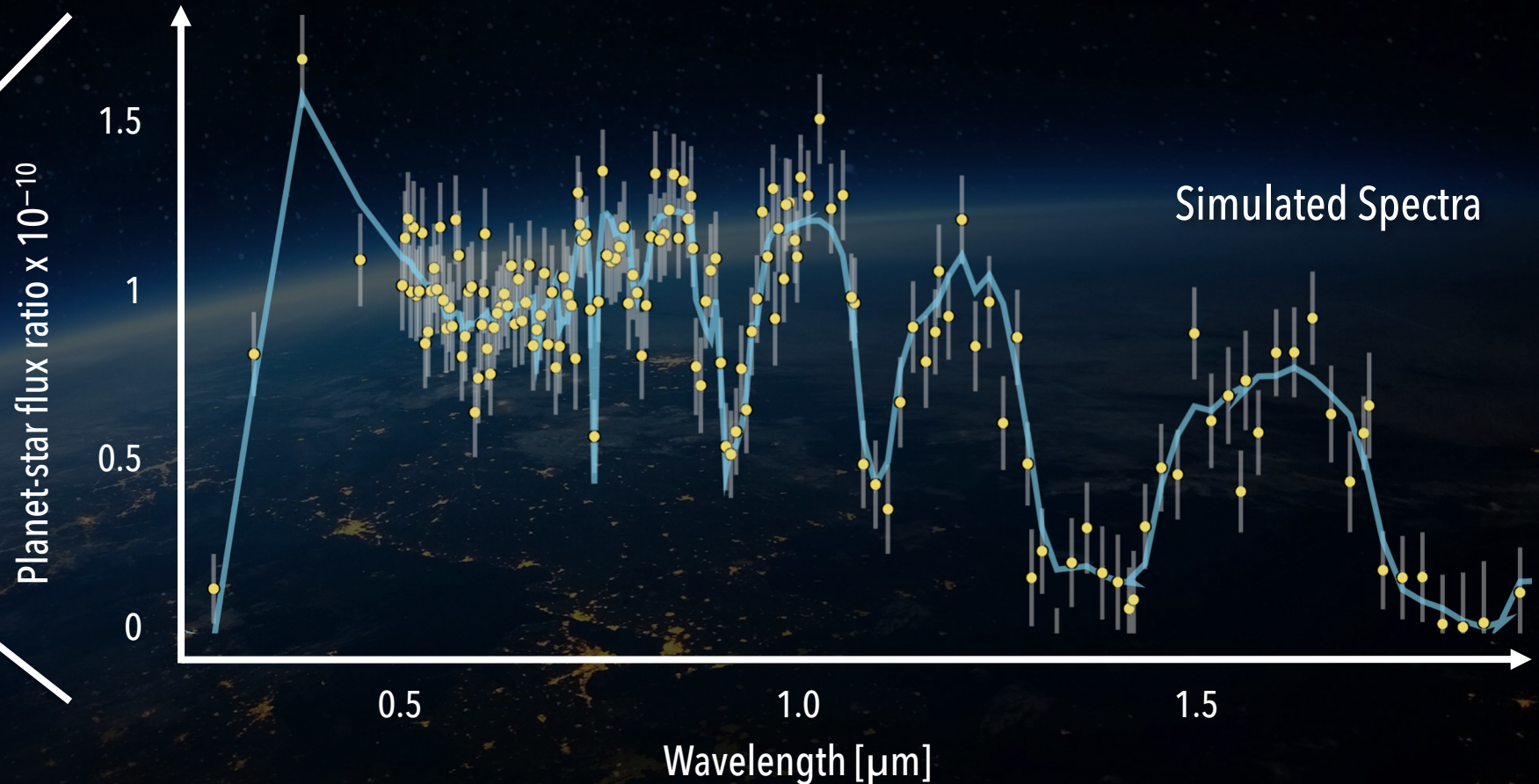
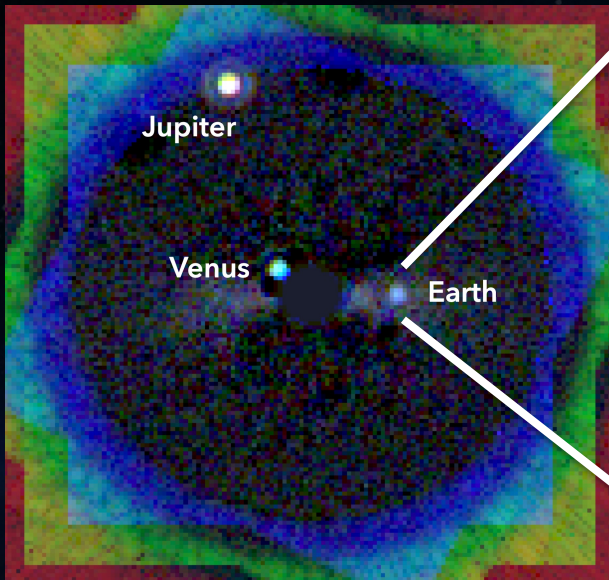
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S. Hulme
D. Lavery
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*Co-Leads

Habitable Worlds Observatory

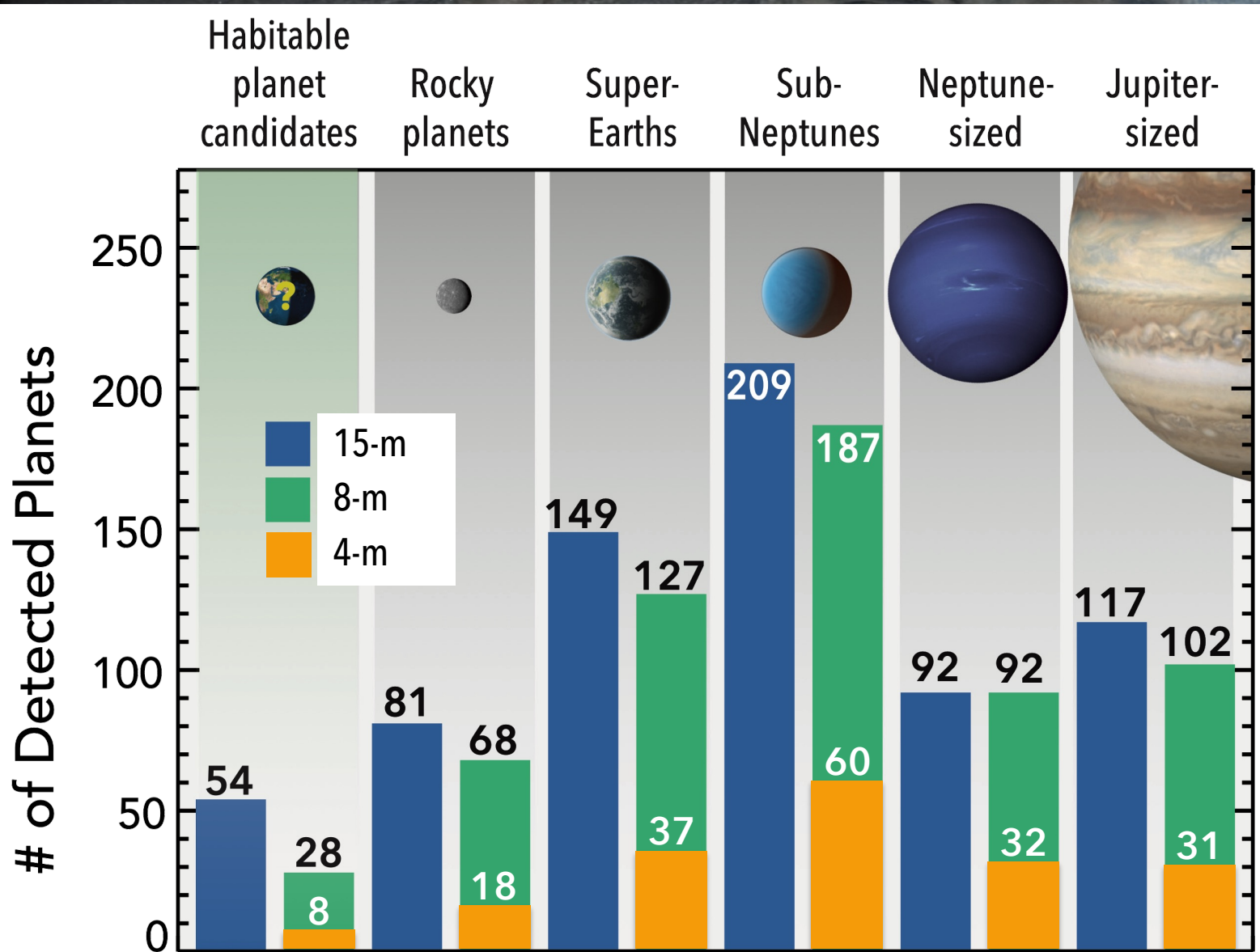


SEARCHING FOR LIFE OUTSIDE THE SOLAR SYSTEM



Analyze light directly reflected by the planet, with little or no starlight mixed in

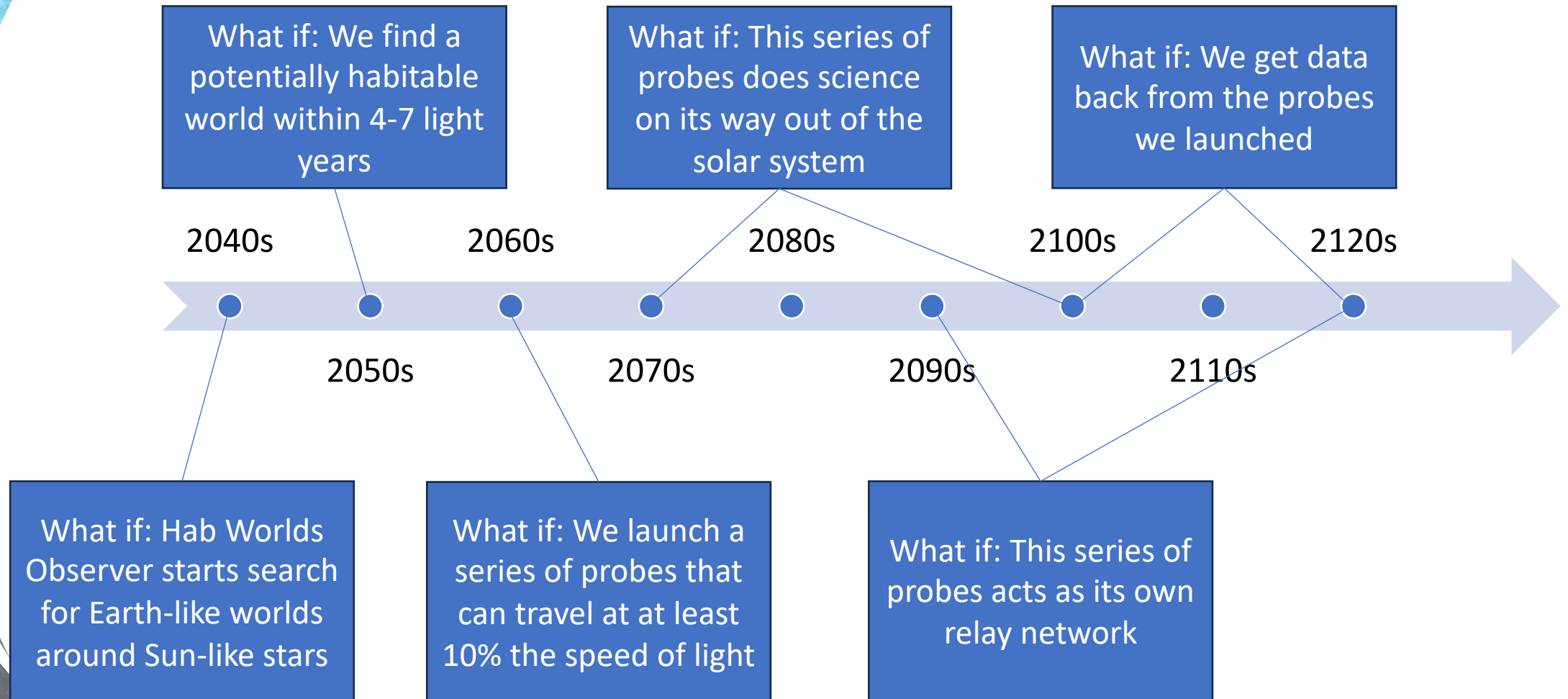
EXPLORING THE DIVERSE RANGE OF EXOPLANETS



HWO can reveal what these exotic worlds are really like

Search for Life and Habitable Worlds

...what's possible?



Any Questions ?

