Life on Mars? On Curiosity and Perseverance's Astrobiology Missions

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Contents

The Beginning of the Search for Martian Life

“Extraordinary claims require extraordinary evidence” – Carl Sagan

- Meteorite escaped from Mars 16 Mya due to Martian impact event
- Arrived on Earth 13,000 years ago
- Discovered in 1984 at the Allan Hills, Antarctica
- Composition resembled Martian atmosphere
- Much older than previously-discovered Martian meteorites

ALH84001: DISCOVERY

Evidence for Microbial Life on Mars: Fossilized Bacteria? | AMNH. American Museum of Natural History. (2000). Retrieved 17 March 2021, from https://www.amnh.org/learn-teach/curriculum-collections/cosmic-horizons-book/fossil-microbes-mars.

McKay, D., Gibson, E., Thomas-Keprta, K., Vali, H., Romanek, C., & Clemett, S. et al. (1996). Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001. Science, 273(5277), 924-930. https://doi.org/10.1126/science.273.5277.924

Evidence of Life? Or Just Headlines?

- Rock = orthopyroxenite
- Embedded Fe-rich carbonates
- 08/1996: *Science* research article by NASA researchers claimed there were 3 types of evidence of past Martian microbial life found in the carbonate minerals
- **Why are the carbonates important?**

ALH84001: CONTROVERSY

Catalog Page for PIA00290. Photojournal.jpl.nasa.gov. (1996). Retrieved 17 March 2021, from https://photojournal.jpl.nasa.gov/catalog/PIA00290.

Quick Background: Carbonates (CO_3^{2-}) form when water traps carbon dioxide (CO_2)

- Mars has too thin of an atmosphere today to support widespread carbonate formation
- Suggests that plentiful water and carbon dioxide (a thicker atmosphere) were present in a warm, wet environment
- Does not necessarily indicate that life existed on Mars!
  - To search for evidence of life, one needs evidence of habitability though

ALH84001: INFLECTION POINT

A Closer Look Leads to No Clear Conclusions

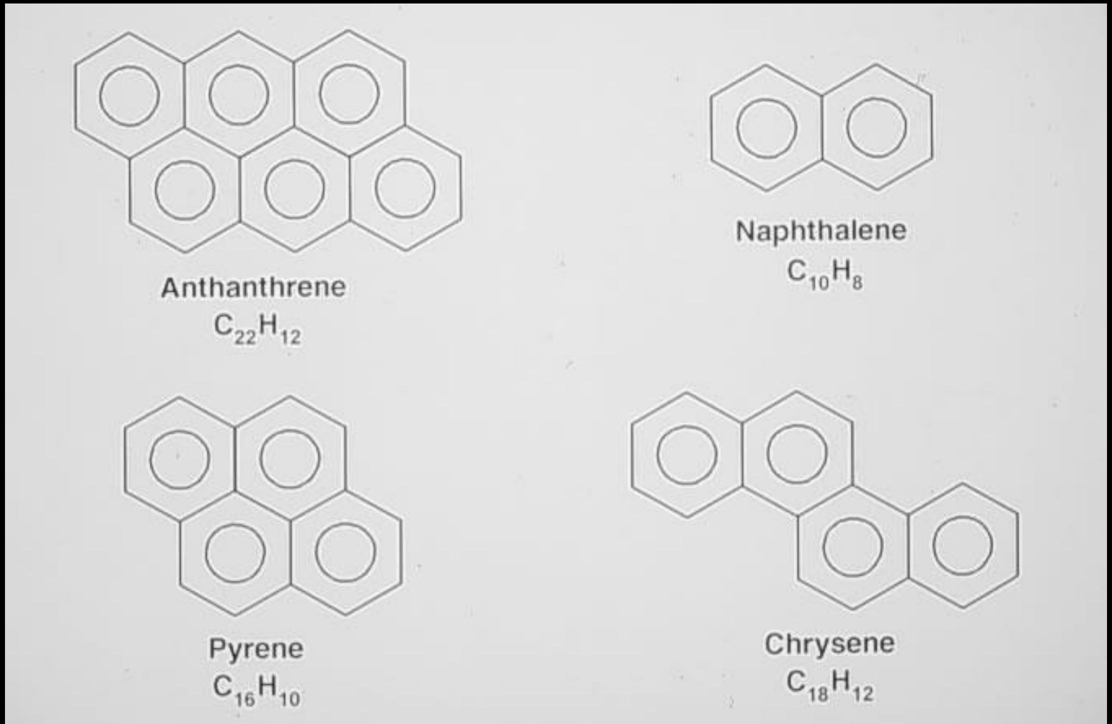
- Proposed evidence of life from the carbonates according to 1996 *Science* article:
    - 1. PAHs (polycyclic aromatic hydrocarbons)
    - 2. Bacteria-Like Structures
    - 3. Microscopic magnetite and iron sulfide

Choi, C. (2016). Mars Life? 20 Years Later, Debate Over Meteorite Continues. Space.com. Retrieved 17 March 2021, from https://www.space.com/33690-allen-hills-mars-meteorite-alien-life-20-years.html.

PAHs (polycyclic aromatic hydrocarbons)

- First organic molecules found on Martian samples
- Often associated with the decay and combustion of organisms
- But have found to be present in interstellar clouds

ALH84001: Evidence 1



Treiman, A. (2002). 25. Polycyclic Aromatic Hydrocarbons. Lpi.usra.edu. Retrieved 17 March 2021, from https://www.lpi.usra.edu/publications/slidesets/marslife/slide_25.html.

Electron Microscopy Reveals Bacteria-Like Fossil Structures

- Looks can be misleading
- Structures could have formed abiotically
- Dimensions are too small: tens of nanometers, ~10% of size of smallest Earth bacteria (e.g., *Mycoplasma, P. ubique*)
    - Machinery (e.g., ribosomes) for maintaining life likely would not fit

ALH84001: Evidence 2

If it looks like a bacterium, then it may not be a bacterium!

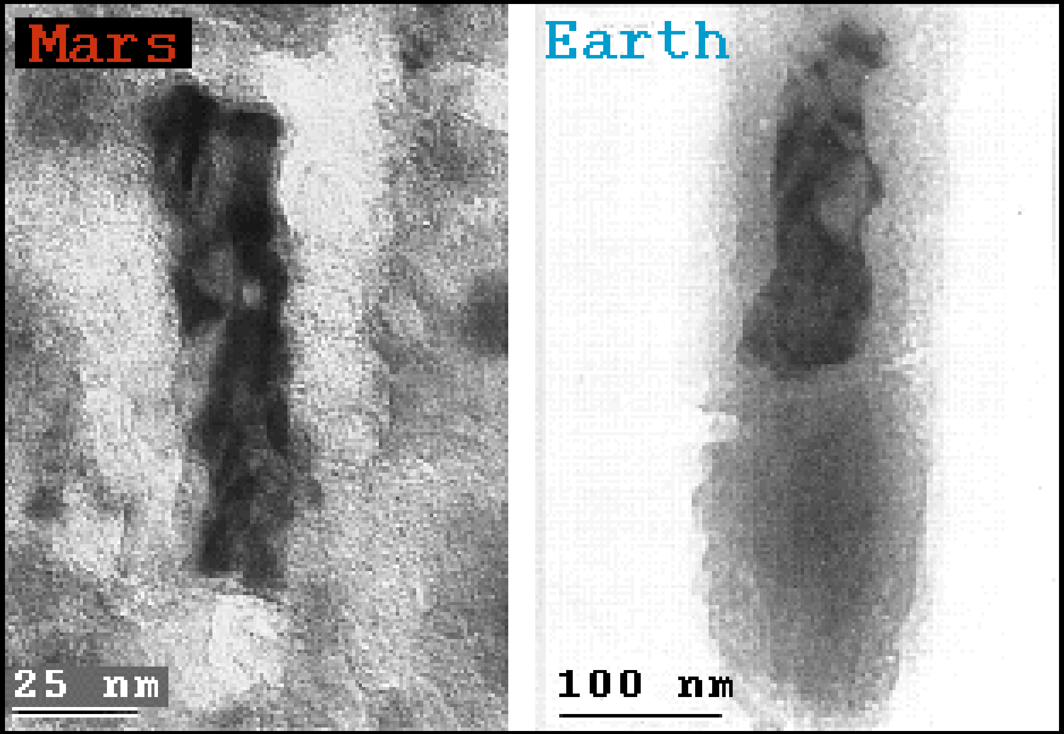
Choi, C. (2016). Mars Life? 20 Years Later, Debate Over Meteorite Continues. Space.com. Retrieved 17 March 2021, from https://www.space.com/33690-allen-hills-mars-meteorite-alien-life-20-years.html.

Staley, J. (1999). Bacteria, Their Smallest Representatives and Subcellular Structures, and the Purported Precambrian Fossil "Metallogenium". Ncbi.nlm.nih.gov. Retrieved 17 March 2021, from https://www.ncbi.nlm.nih.gov/books/NBK224752/.

Magnetite (Fe_3O_4) and Iron Sulfide (FeS)

- Usually are not present with carbonates except when iron-consuming bacteria undergo metabolism
- These biosignatures resemble chemically and structurally magnetosomes found in magnetotactic bacteria
    - Magnetosomes = built-in compass for suitable environments
    - Are also found in sequences

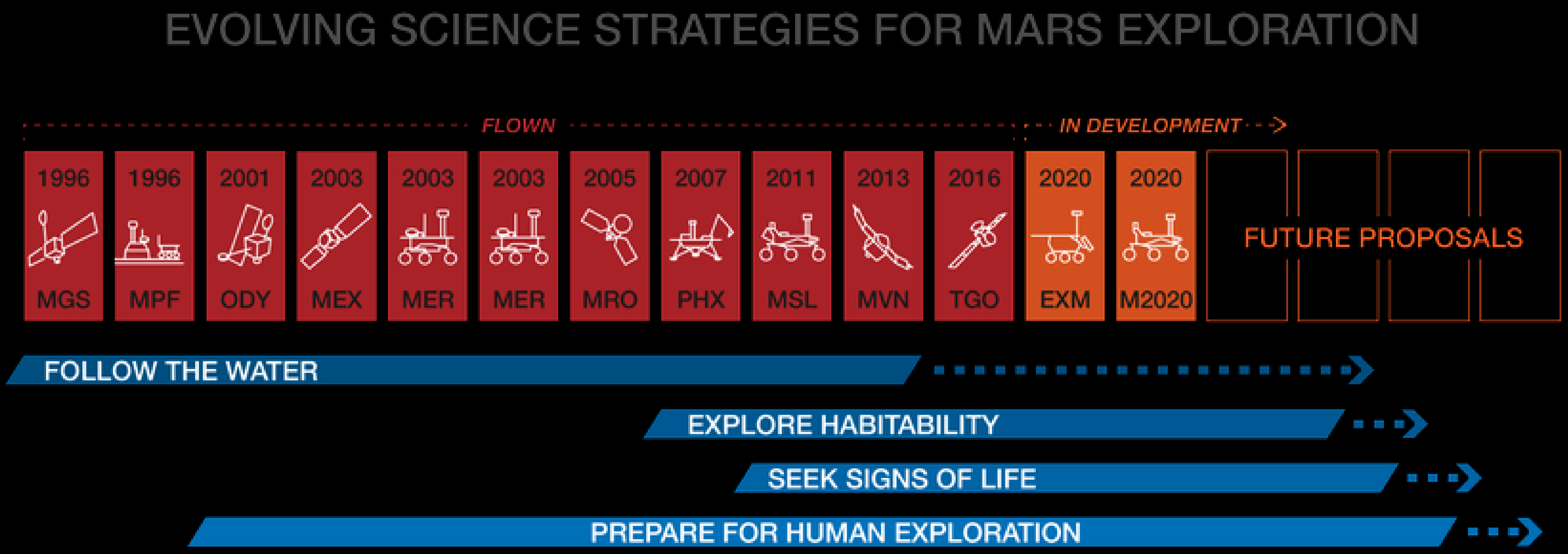
ALH84001: Evidence 3



Taylor, G. (1996). PSR Discoveries: Hot Idea: Life on Mars. Psrd.hawaii.edu. Retrieved 17 March 2021, from http://www.psrd.hawaii.edu/Oct96/PAH.html.

It has been >20 years ago that this 1996 *Science* research article was published. Do these hypotheses still stand, and what have we done and learned about potential life on Mars?

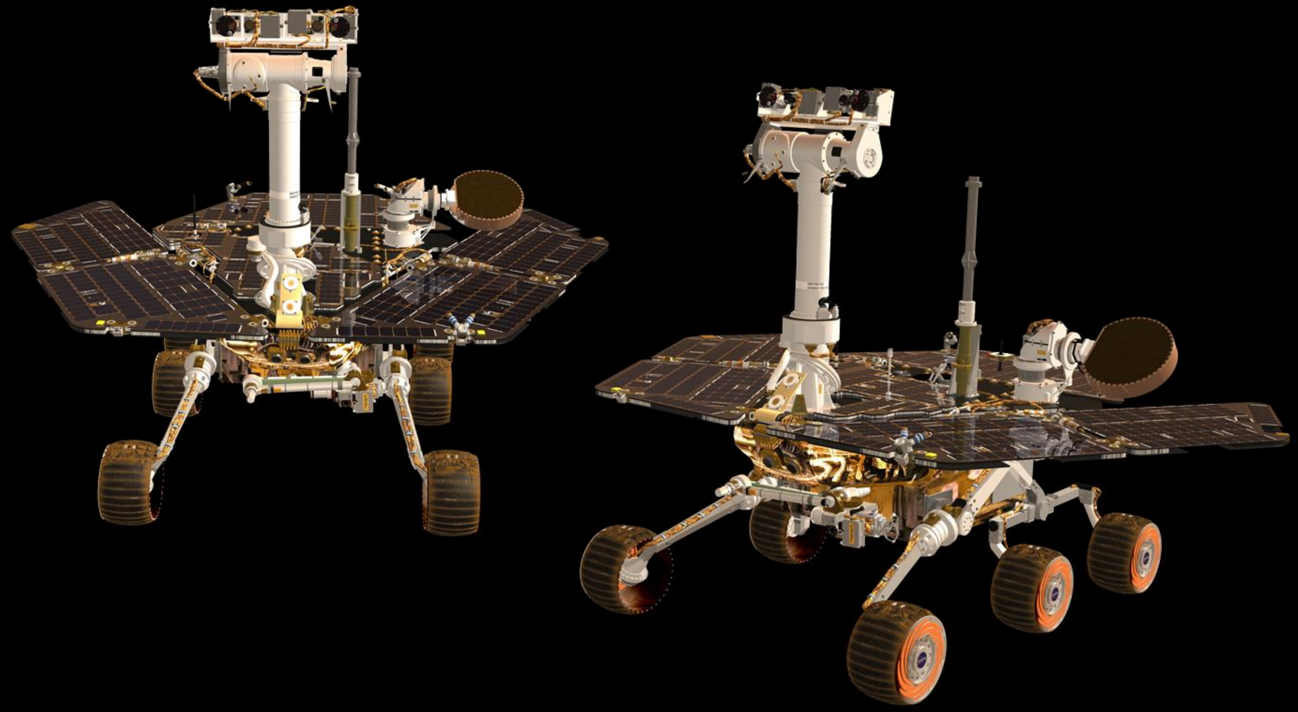
Brief History of Mars Exploration



- Program Missions Overview. Mars.nasa.gov. (2016). Retrieved 17 March 2021, from https://mars.nasa.gov/programmissions/overview/.

Past Rovers: Sojourner, Spirit, and Opportunity

- Sojourner (1997)
- Spirit (2004-2011)
- Opportunity (2004-2019)



Mars Exploration Rovers Overview. Retrieved 17 March 2021, from https://mars.nasa.gov/mer/mission/overview/.

Spirit and Opportunity: The Rime of the (Very) Ancient Mariner

- Twin Geologists
- Characterize climate and geology of Mars
- Water existed on Martian surface until 4 bya
- Find evidence of ancient habitability, the environmental conditions needed for life
  - Spirit
    - Pure silica – found in steam vents and springs
    - Carbonate-rich rocks – indicative of warm and wet climate
  - Opportunity
    - Hematite spheres - formed from the reaction of dissolved iron with oxygen (from water)
    - Jarosite - forms in acidic water
    - Crossbeds/Ripples - indicative of flowing water, wet sediments

"Shoemaker's Patio" - Opportunity

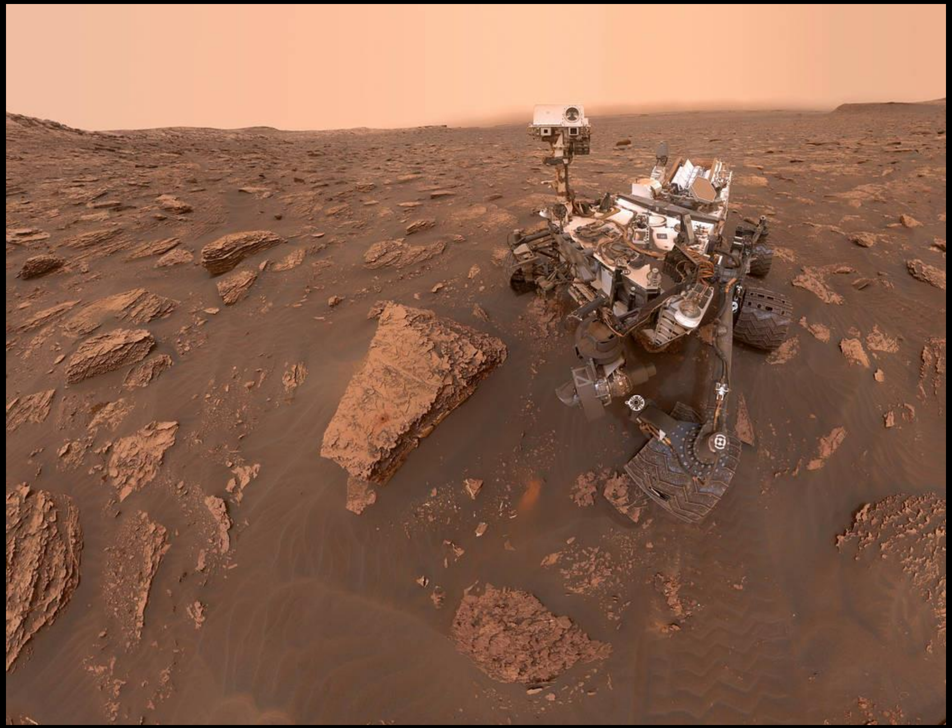
Science Results. Mars.nasa.gov. (2004). Retrieved 18 March 2021, from https://mars.nasa.gov/mer/mission/science/results/.

Curiosity and Perseverance’s Astrobiology Missions

Relevant Instruments for Biosignatures Detection & Other Astrobiology Objectives

Curiosity	**Perseverance**
Spectrometers:	**Spectrometers:**
CheMin (Chemical and Mineralogy instrument)	SHERLOC (Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals)
SAM (Sample Analysis at Mars)	PIXL (Planetary Instrument for X-ray Lithochemistry)
	For Supporting Future Exploration:
	MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment)

Spectrometer = Instrument that measures the spectrum (EM radiation) of a sample, helping identify the composition of said sample



Curiosity (2012-present)

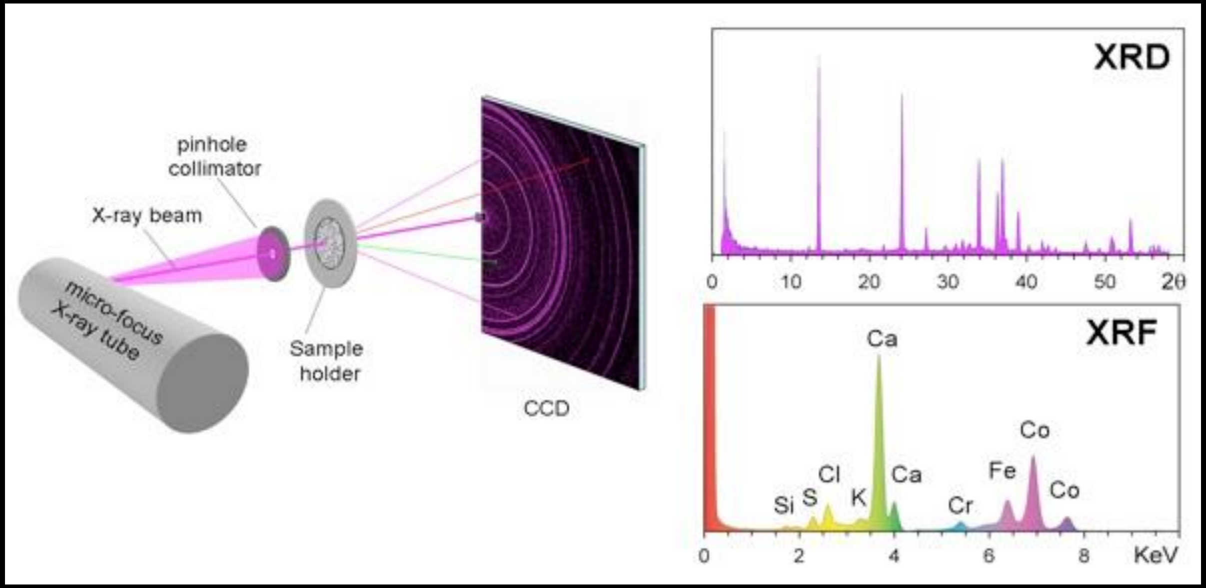
Mars Science Laboratory (MSL)

https://www.nasa.gov/image-feature/curiosity-celebrates-8-years-on-the-red-planet

Peaks of Higher Intensity Form at Constructive Interference ($n\lambda = 2d\sin\theta$) – Top Graph

CheMin

- X-ray **diffraction** and fluorescence spectrometer
- Identifies and measures types of Martian minerals (collected as powdered samples)
- Microfocus cobalt X-ray source & tube
- Charge Coupled Device (CCD) detectors – convert photons into electric charge
    - Photons detected were diffracted or fluoresced off the sample's electrons
- Produces 2-D X-ray diffraction ring patterns & energy-dispersive X-ray histogram
- Data is processed by Rietveld refinement = **Compound** Analysis

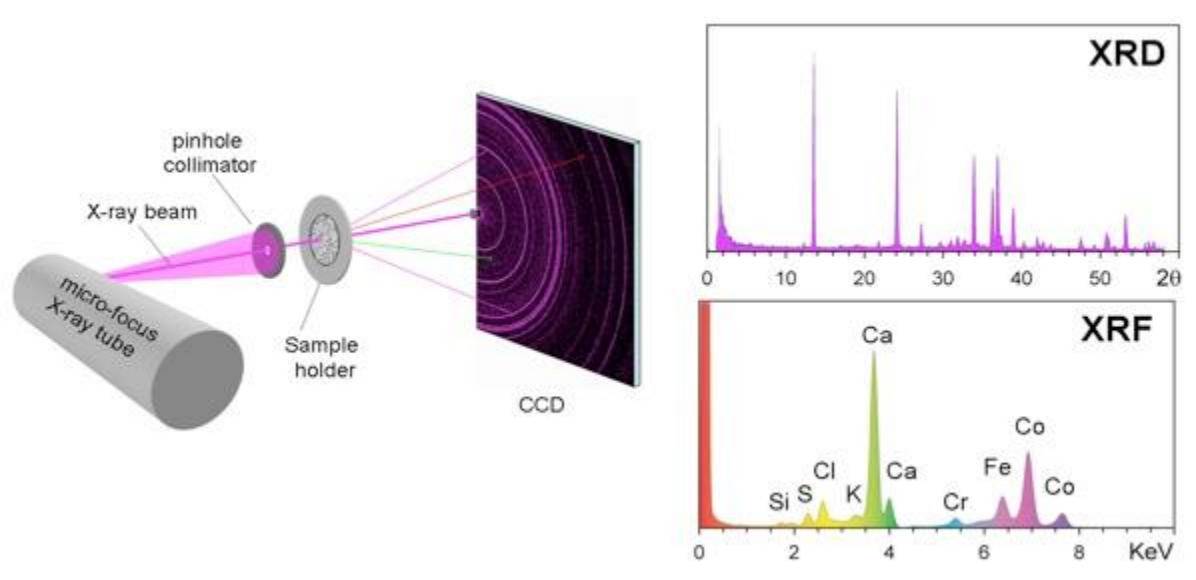


CheMin for Scientists | Instruments – NASA's Mars Exploration Program. NASA's Mars Exploration Program. Retrieved 18 March 2021, from https://mars.nasa.gov/msl/spacecraft/instruments/chemin/for-scientists.

CheMin (cont.)

- X-ray diffraction and **fluorescence** spectrometer
- X-ray bombardment leads to dislodgement of inner shell electrons and replacement by outer shell electrons, releasing energy as secondary emissions
- Amount of energy released identifies **Elemental Composition** of sample

X-ray fluorescence forms a histogram comparing count of photons and photon energy – Bottom Graph

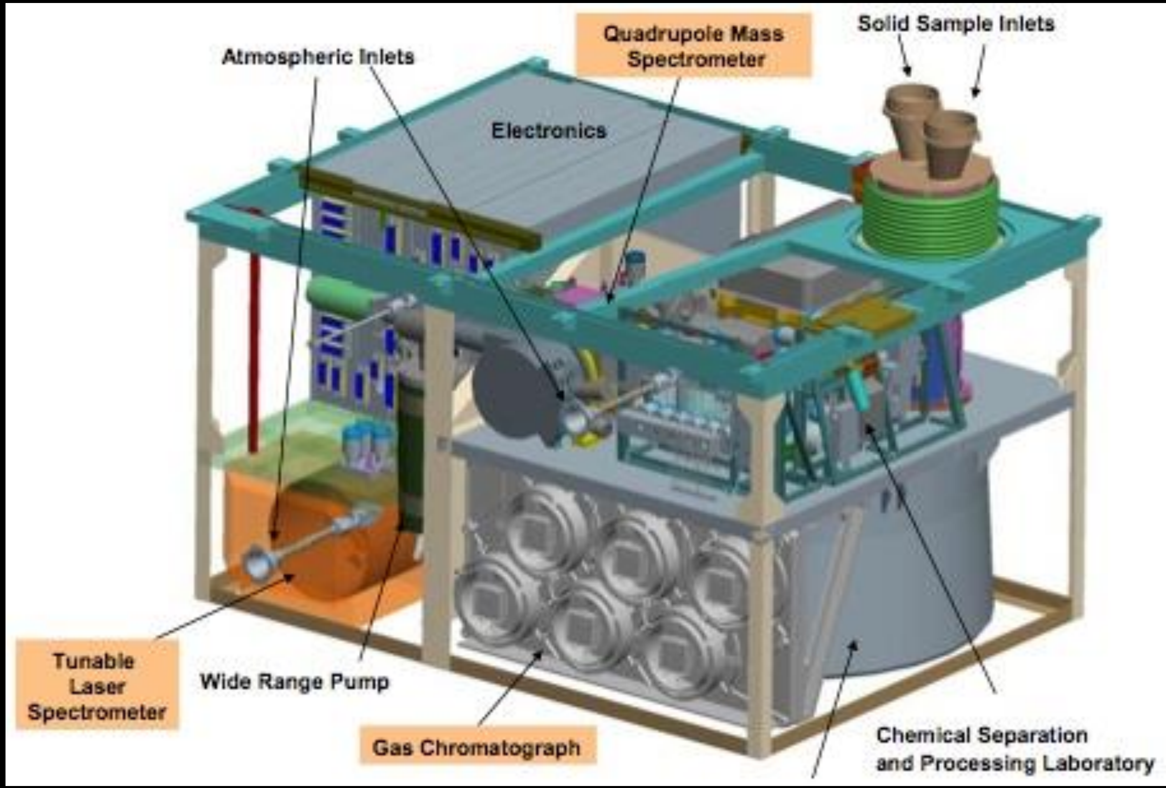


CheMin for Scientists | Instruments – NASA's Mars Exploration Program. NASA's Mars Exploration Program. Retrieved 18 March 2021, from https://mars.nasa.gov/msl/spacecraft/instruments/chemin/for-scientists.

SAM

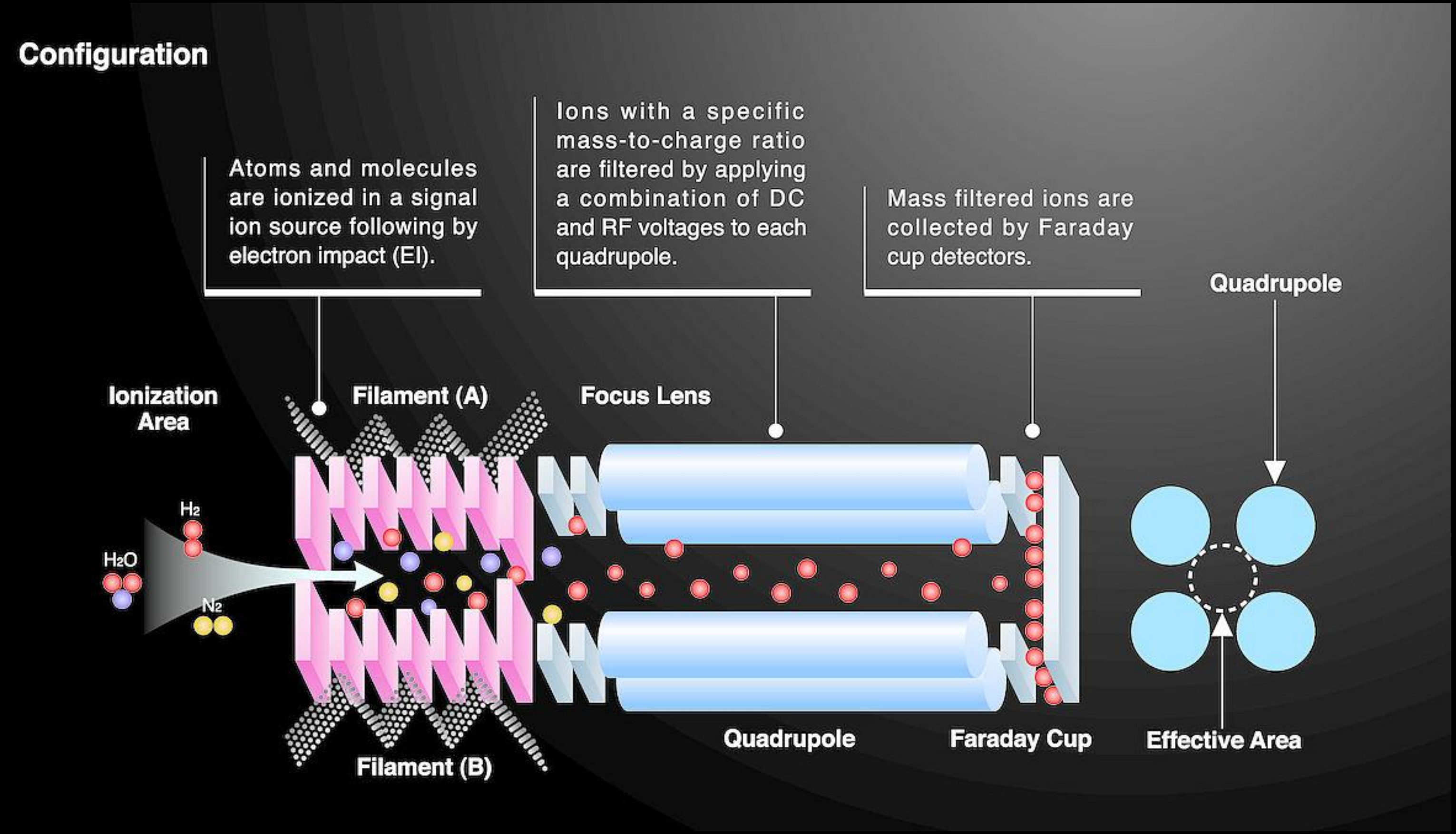
- Gas Chromatograph, Mass Spectrometer, and Tunable Laser Spectrometer
- Identifies potential biosignatures
- Mass spectrometer identifies & measures organic compounds & elements (N, H, S, O, etc.)
    - Measure mass-charge ratio of molecules → determine molecular weight
        - Create gas-phase ions
        - Separate ions according to mass-charge ratio (based off trajectory stability in electrical fields)
        - Determine number of ions of each mass-charge (m/z) ratio
- Gas chromatograph separates gases into components
- Laser spectrometer measures abundance of isotopes of C, H, and O in gases like water vapor

SAM is composed of 3 instruments that work together

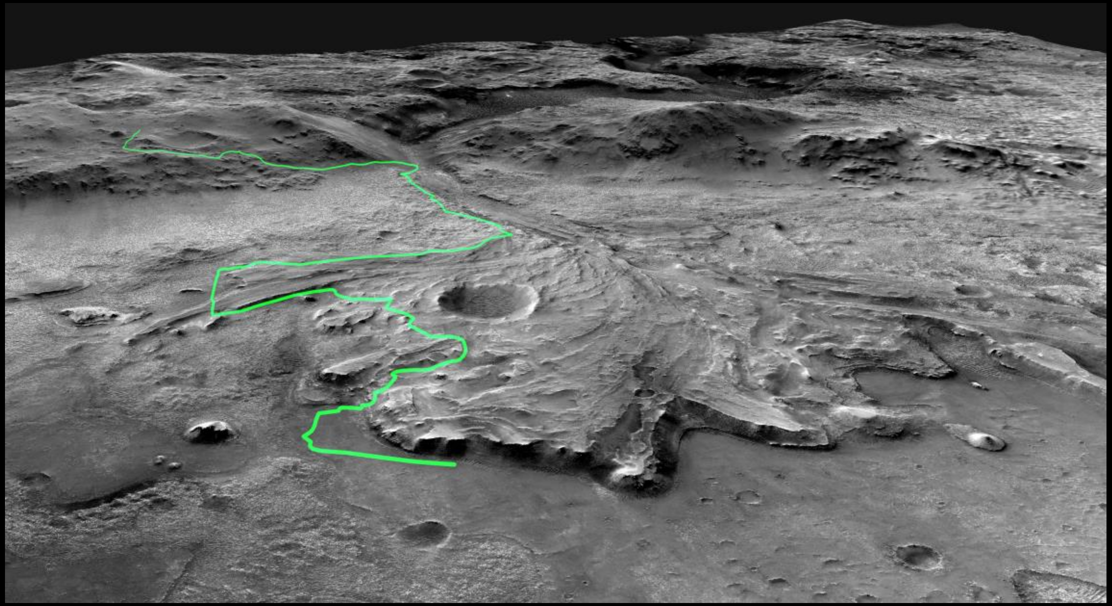


SAM for Scientists | Instruments – NASA's Mars Exploration Program. NASA's Mars Exploration Program. Retrieved 18 March 2021, from https://mars.nasa.gov/msl/spacecraft/instruments/sam/for-scientists.

SAM – Quadrupole Mass Spectrometry



Quadrupole Mass Spectrometry. Horiba.com. Retrieved 18 March 2021, from https://www.horiba.com/en_en/technology/measurement-and-control-techniques/mass-spectrometry/quadrupole-mass-spectrometry/.



Perseverance (2021-present)

Mars 2020

https://mars.nasa.gov/resources/25538/angle-on-jezero-crater-illustration/

SHERLOC

- Deep UV resonance Raman and **fluorescence spectrometer**
- Detect potential biosignatures, minerals, organic molecules
- Smaller wavelength (248.6 nm) deep UV laser creates better resolution
- Assisted by WATSON, a color camera
- Two spectral phenomena- Raman scattering and **native fluorescence**
- Native fluorescence: fluorescing organic sample absorbs incident photon and re-emits at greater wavelength from ~270 nm to visible (difference in wavelengths → electron transitions → identify trace organics)

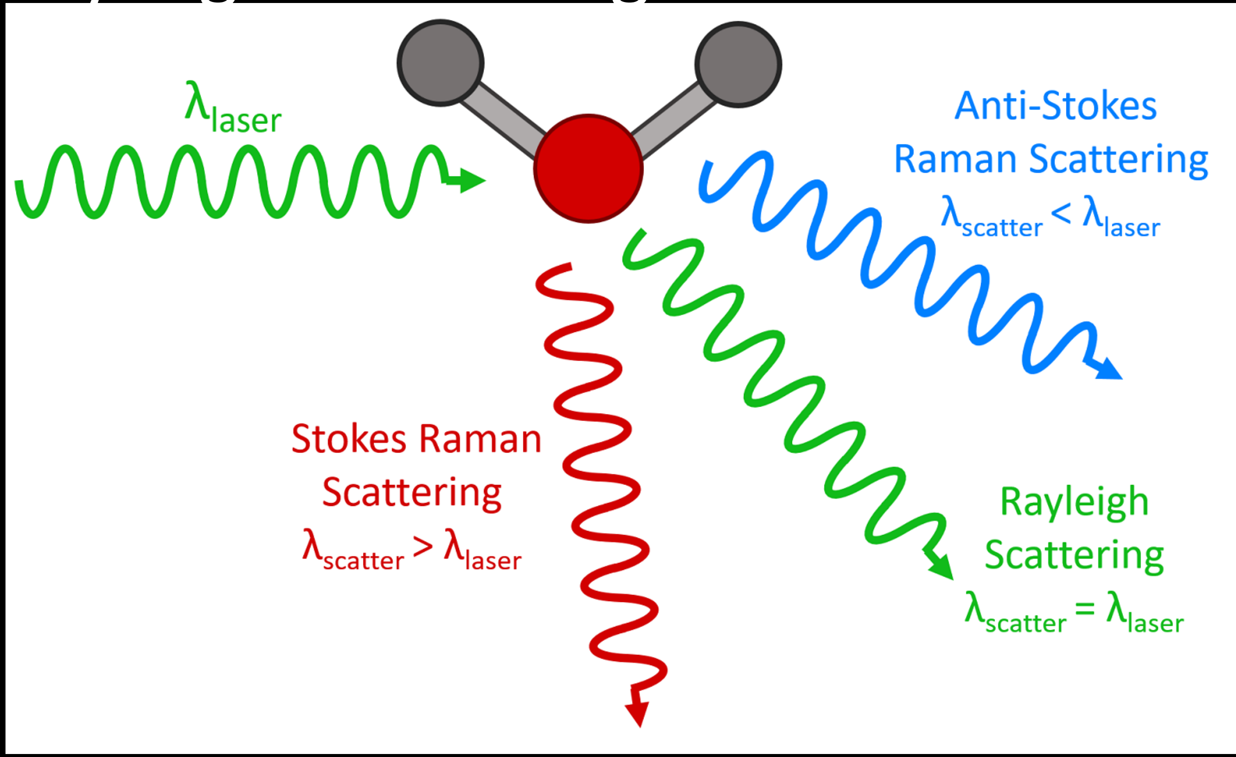
The Interior of SHERLOC, which is located on the rover’s robotic arm

SHERLOC for Scientists (Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals). Retrieved 18 March 2021, from https://mars.nasa.gov/mars2020/spacecraft/instruments/sherloc/for-scientists.

Stokes Raman Scattering is much rarer yet more important than Rayleigh Scattering

SHERLOC

- Deep UV resonance **Raman** and fluorescence spectrometer
- Two spectral phenomena: **Raman scattering** and native fluorescence
- Raman scattering: light energy is transferred to molecular bond vibrations, wavelength of incident and emitted photon changes accordingly, can identify structure and types of bonds within the sample
- Note E = hv & hc/λ, where v = frequency, c = speed of light, λ = wavelength, E = energy, and h = Planck's constant

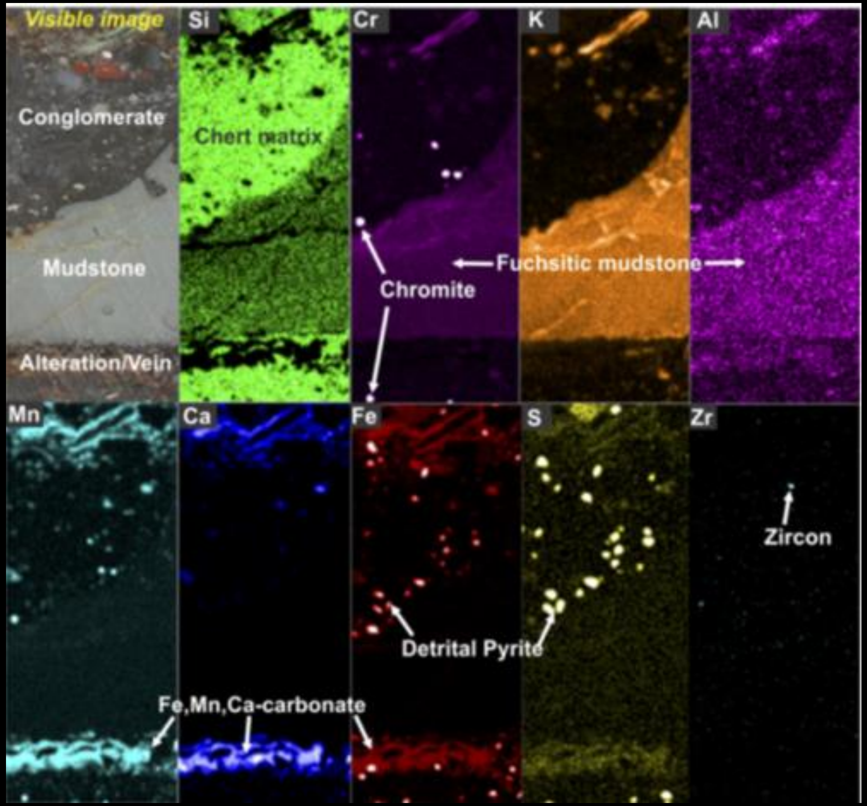


What is Raman Spectroscopy? | Raman Spectroscopy Principle. Edinburgh Instruments. Retrieved 18 March 2021, from https://www.edinst.com/blog/what-is-raman-spectroscopy/.

PIXL

- X-ray spectrometer
- Determines chemical composition of rocks
- Akin to Curiosity's CheMin, but has better resolution, sensitivity, data return rate, can detect more elements, etc.

PIXL can identify elements and fine-scale geological features

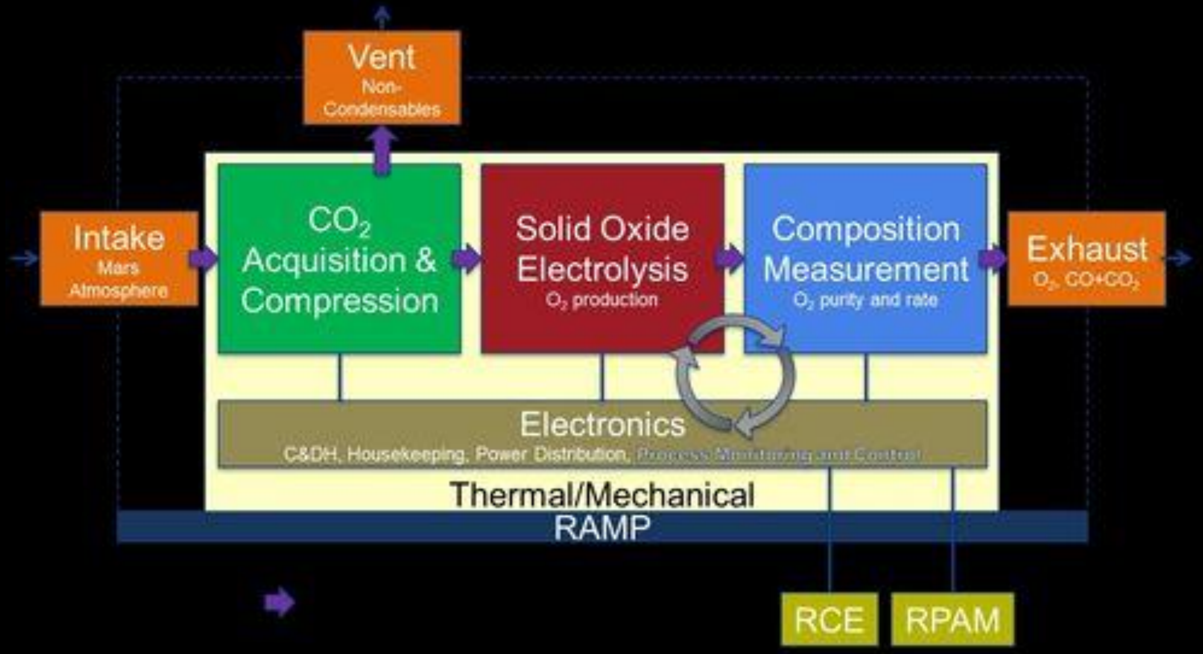


PIXL for Scientists (Planetary Instrument for X-ray Lithochemistry). Retrieved 18 March 2021, from https://mars.nasa.gov/mars2020/spacecraft/instruments/pixl/for-scientists.

MOXIE

- Produce oxygen from CO_2 - rich Martian atmosphere
- If successful, can apply on a larger scale for rocket fuel production and human use
- Carbon dioxide is electrolyzed when a voltage is applied to it over a cathode: $CO_2 + 2e^- \rightarrow CO + O^-$
- After CO is removed, the oxygen ion undergoes oxidation at the anode: $CO_2 + O^- \rightarrow O + 2e^-$
- 2 O's then combine to form diatomic oxygen O_2

MOXIE will produce up to 10 g of oxygen per hour, while it will release CO as exhaust



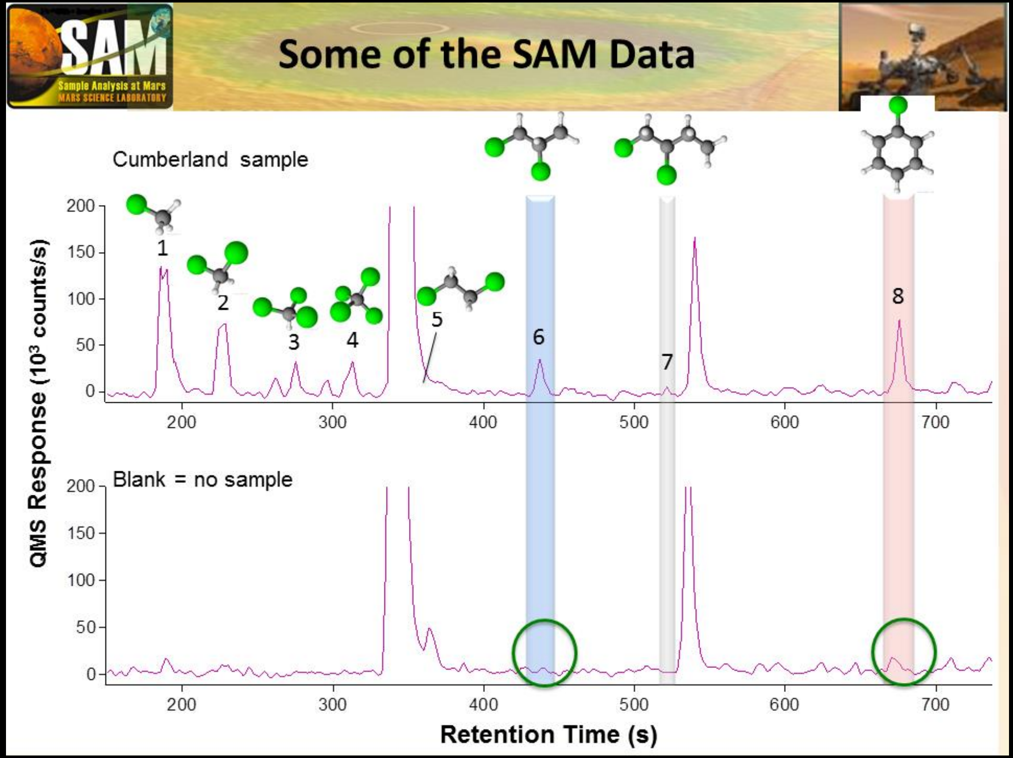
MOXIE for Scientists (Mars Oxygen ISRU Experiment). Retrieved 18 March 2021, from https://mars.nasa.gov/mars2020/spacecraft/instruments/moxie/for-scientists.

Findings

Curiosity’s Major Astrobiology Discoveries

- First confirmed detection of Martian organic compounds (building blocks of life) found on Mars’ surface
  - Mudstone Bedrock sample = “Cumberland”
  - Significant difference between rock sample and blank’s chemical compositions
  - Axes: Thousands of counts/second in mass spectrometer (y) and retention time (x)
  - Gray spheres = carbon atoms, green spheres = chlorine, bare sticks from carbon atoms = hydrogen atoms
  - Organics detected include chlorobenzene (8), chloromethane (1), or carbon tetrachloride (4)

These organic molecules may have originated from Mars itself or from meteorites

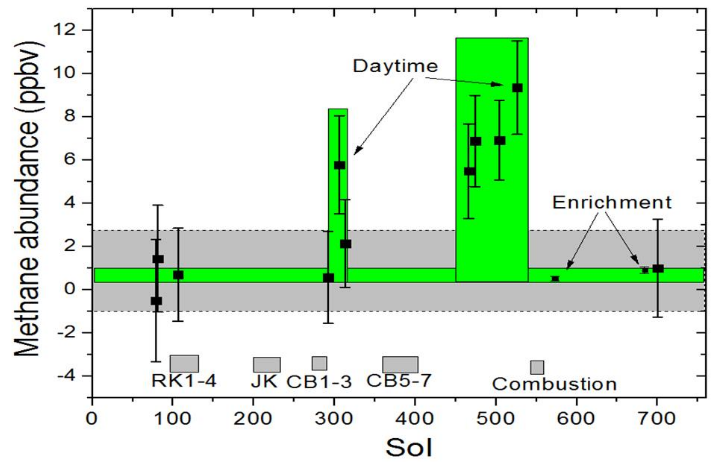


Data from Detection of Organics in a Rock on Mars – NASA’s Mars Exploration Program. NASA’s Mars Exploration Program. (2014). Retrieved 18 March 2021, from https://mars.nasa.gov/resources/6892/data-from-detection-of-organics-in-a-rock-on-mars/?site=msl.

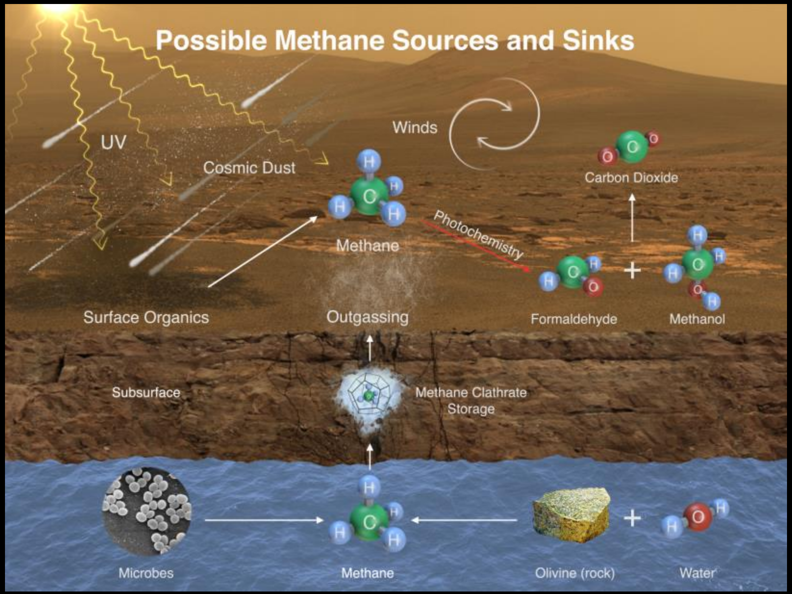
Curiosity's Major Astrobiology Discoveries

- Detection of Sharp Increase in Atmospheric Methane Levels
    - Axes: Martian days (x) versus methane concentration (y)
    - Sharply rose by tenfold at Gale Crater (before and after < 1 ppbv, spike = 7 ppbv)
    - Demonstrates that planet still has active organic chemistry
    - TLS may be used to detect natural gas leaks on Earth

These findings were detected by the Tunable Laser Spectrometer



Proposed Methane sources and sinks incorporate biotic and abiotic possibilities

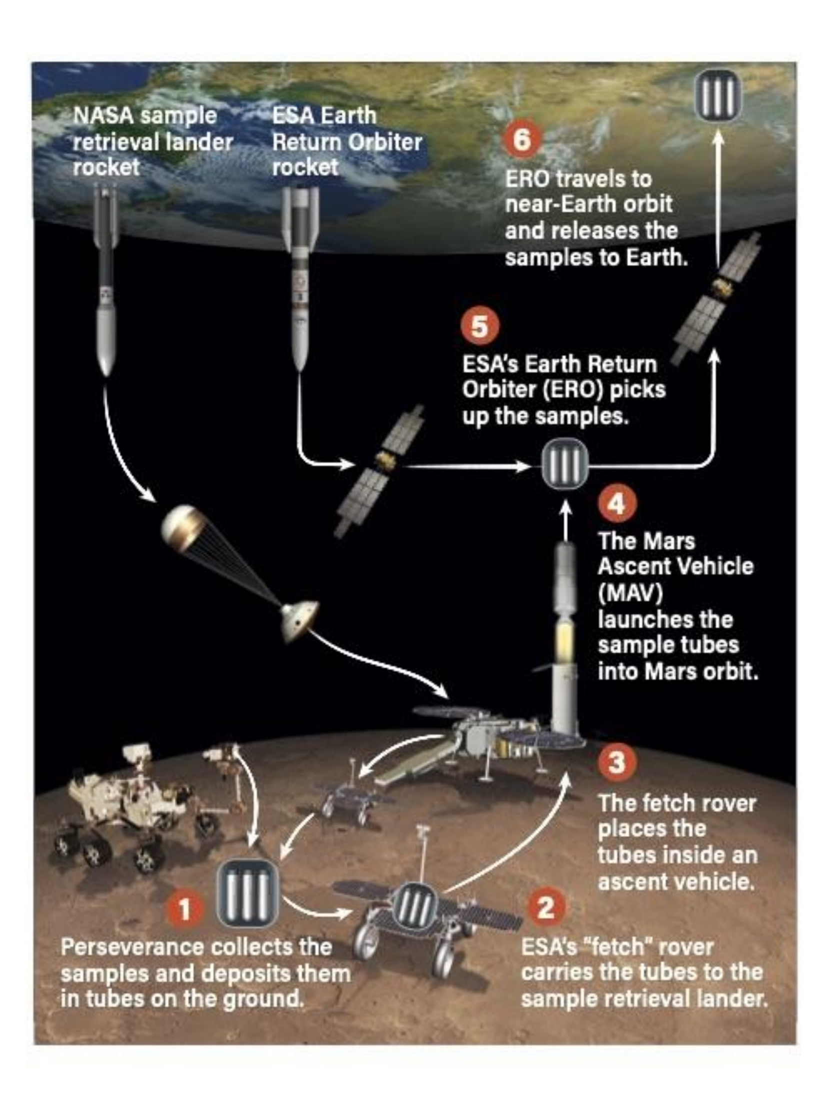


Methane Measurements by NASA's Curiosity in Mars' Gale Crater – NASA's Mars Exploration Program. NASA's Mars Exploration Program. (2014). Retrieved 18 March 2021, from https://mars.nasa.gov/resources/6890/methane-measurements-by-nasas-curiosity-in-mars-gale-crater/?site=msl.
Possible Methane Sources and Sinks – NASA's Mars Exploration Program. NASA's Mars Exploration Program. (2014). Retrieved 18 March 2021, from https://mars.nasa.gov/resources/6891/possible-methane-sources-and-sinks/?site=msl.

Future Work

Perseverance's Surface Operations

- Find, analyze, and collect promising samples using its cutting-edge instruments
- Carry the samples
- Deposit the samples for future collection
    - Collection effort will likely be joint effort between ESA and NASA
        - Rosalind Franklin rover set to launch in 2022
    - Will undergo even more detailed analysis on Earth (e.g., to be able to see cells, if they exist)
    - Human exploration



Bell, J. (2021). Mars Madness: Perseverance rover is about to begin its mission. Astronomy.com. Retrieved 19 March 2021, from https://astronomy.com/magazine/news/2021/02/mars-madness-perseverance-rover-is-about-to-begin-its-mission.

Discussion and Questions

Feel free to speak up or use the chat!

Discussion Questions

- Do you believe humans should explore Mars? Settle it? Why or why not? Does your answer change if it is discovered that there is still life on Mars?
- If life is found on Mars, would humanity change? If so, how?
- What do the rovers' names Curiosity and Perseverance mean to you?
- What opportunities and challenges (ethical, medical, scientific, technological, political) do you foresee in future exploration, settlement, and/or commerce in space?
- Why do you think people have always been interested in the cosmos?

Questions?

Thank You!