Jet Propulsion Laboratory
California Institute of Technology

NASA, JPL, and Mars Exploration

Presented by Insoo Jun

Natural Space Environments Group
Jet Propulsion Laboratory, California Institute of Technology

June 15, 2017

Topics

- Introduction:
  - NASA
  - JPL
  - Natural Space Environments (NSE) Group
  - Myself

- Mars
  - Mars Exploration Program
  - Mars Science Laboratory
  - Mars 2020

NASA Vision Statements

Table 1: NASA's FY2017 Budget Request and Congressional Action (in $ millions, see notes below)

		FY 2017 Request (see table 2		Authorization			Appropriations		
Account	**2016 Approps**	**With Mandatory**	**Without Mandatory**	**House (note 2)**	**Senate**	**Final**	**House Cmte**	**Senate Cmte**	**Final**
Science	**5,589.4**	**5,600.5**	**5,302.5**				**5,597.0**	**5,395.0**	
Earth Science	*1,921.0*	[note 3] *2,032.2*	*1,972.2*				*1,690.0*	*1,984.0*	
Planetary Science	*1,631.0*	*1,518.7*	*1,390.7*				*1,846.0*	*1,355.9*	
Astrophysics	*730.6*	[note 3] *781.5*	*696.5*				*792.9*	[note 3] *807.0*	
JWST	*620.0*	*569.4*	*569.4*				*569.4*	*569.4*	
Heliophysics	*649.8*	*698.7*	*673.7*				*698.7*	*678.7*	
Education	[note 3] *37.0*	*note 3*	*N/A*				*N/A*	*note 3*	
Aeronautics	**640.0**	**790.4**	**634.5**				**712.0**	**601.0**	
Space Technology	**686.5**	**826.7**	**690.6**				**739.2**	**686.5**	
Exploration	**4,030.0**	**3,336.9**	**3,163.9**				**4,183.0**	**4,330.0**	
Expl Sys Dev	*3,680.0*	*2,859.5*	*2,686.5*				*3,779.0*	*3,934.0*	
(Orion)	*(1,270.0)*	*(1,119.8*	*N/A*				*(1,350.0)*	*(1,300.0)*	
(SLS)	*(2,000.0)*	*(1,310.3)*	*N/A*				*(2,000.0)*	*(2,150.0)*	
(Expl Ground Sys)	*(410.0)*	*(429.4)*	*N/A*				*(429.0)*	*(484.0)*	
Expl R&D	*350.0*	*477.4*	*477.4*				*404.0*	*396.0*	
Space Operations	**5,029.2**	**5,075.8**	**5,075.8**				**4,890.3**	**4,950.7**	
ISS	*not specified*	*1,430.7*	*N/A*				*not specified*	*not specified*	
Space Trans	*N/A*	*2,757.1*	*N/A*				*not specified*	*not specified*	
(Cmrcl Crew)	*(1,243.9)*	*(1,184.8)*	*N/A*				*not specified*	*(1,184.8)*	
(Crew and Cargo) [note 4]	*not specified*	*(1,572.8)*	*N/A*				*not specified*	[note 4] *(1,028.0)*	
Space & Flt Sprt	*not specified*	*887.4*	*N/A*				*not specified*	*not specified*	
Education	**115.0**	**100.1**	**100.1**				**115.0**	**108.0**	
Safety/Security/MS	**2,768.6**	**2,836.8**	**2,836.8**				**2,835.4**	**2,796.7**	
CECR	**388.9**	**419.8**	**419.8**				**398.0**	**400.0**	
Inspector General	**37.4**	**38.1**	**38.1**				**38.1**	**38.1**	
TOTAL	**19,285.0**	**19,025.1**	**18,262.1**				**19, 508.0**	**19,306.0**	

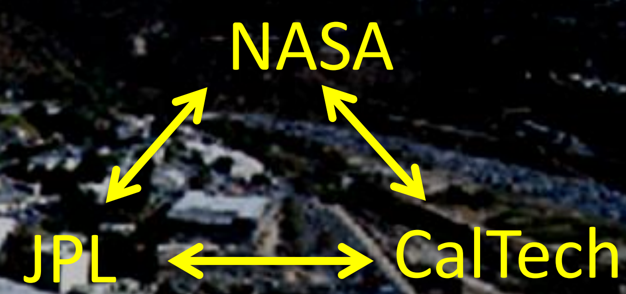
See notes on next page

4

NASA Centers

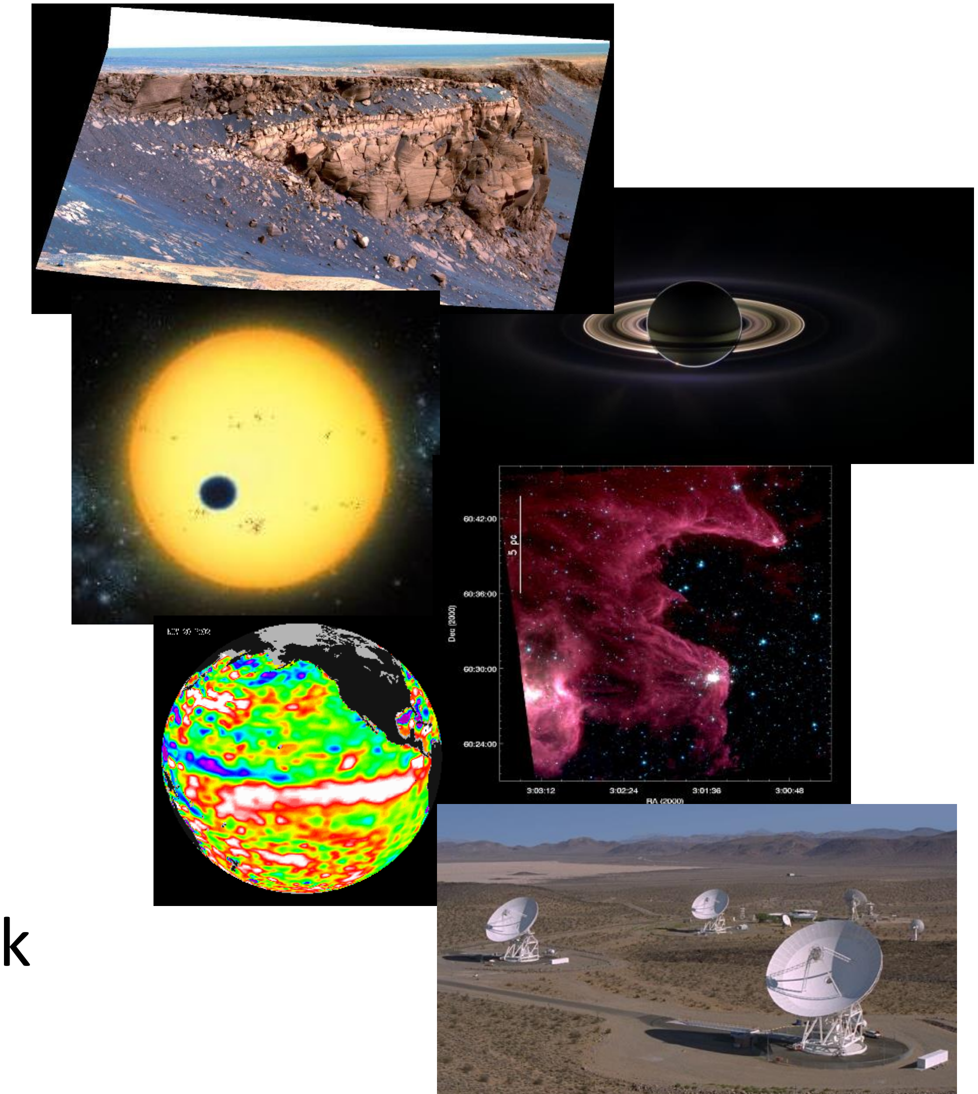
JPL is part of NASA and Caltech

- Federally (NASA)-owned “Federally-Funded Research and Development Center” (FFRDC)
- University (Caltech)-operated
- >$2 billion business base
- ~6,000 employees
- 177 acres (Includes 22 acres leased for parking)
- 139 buildings and 36 trailers
- 673,000 net square feet of office space
- 906,000 net square feet of non-office space (e.g., labs)



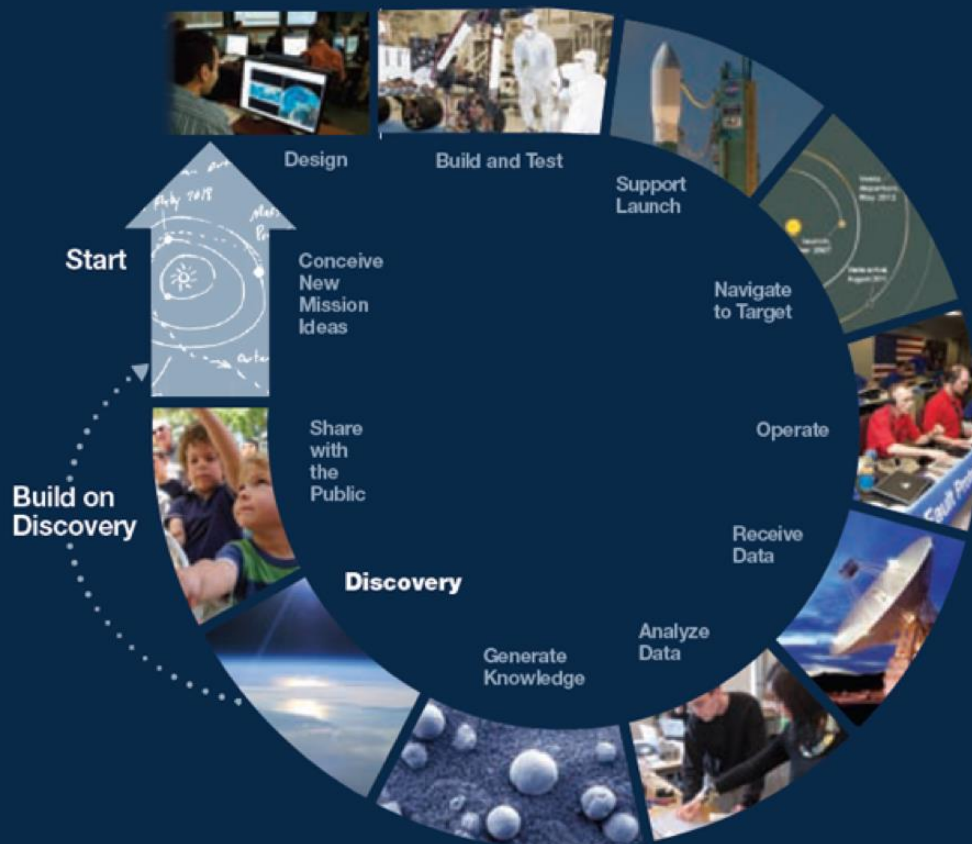
JPL's primary mission for NASA is robotic space exploration

- Mars
- Solar system
- Exoplanets
- Astrophysics
- Earth Science
- Interplanetary network



End-to-End Implementation

JPL's core competency is the end-to-end implementation of unprecedented robotic space missions. To sustain this skill, we develop and integrate some of the world's best capabilities in science, technology, and engineering on missions in all cost ranges. We do this by using our hands-on, experienced workforce and in partnership with other organizations.



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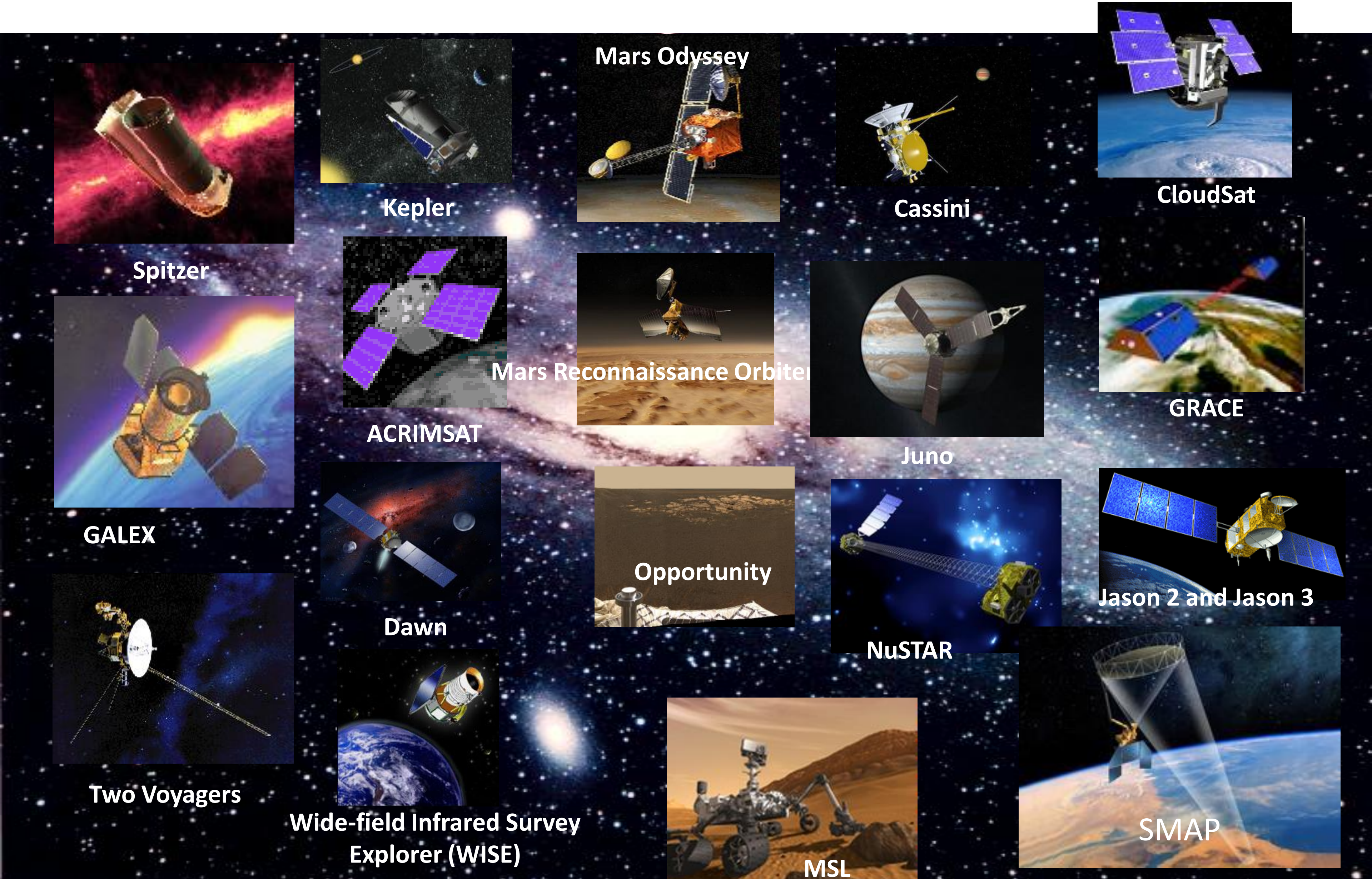
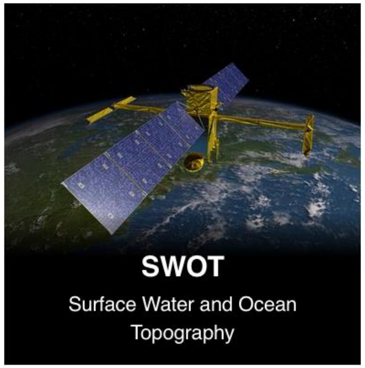
Comments and suggestions regarding this home page are welcome.
Please send them to the **Office of the Director**

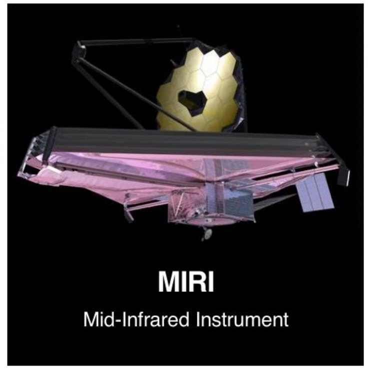
A Very Special Place.

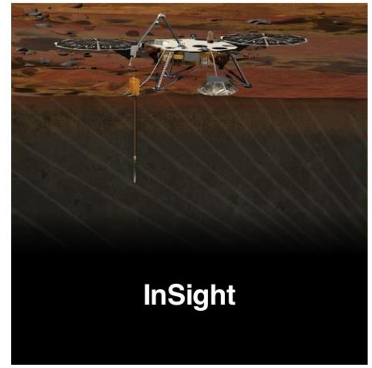
Thirty-nine spacecraft and instruments across the solar system (and beyond) – as of 2017

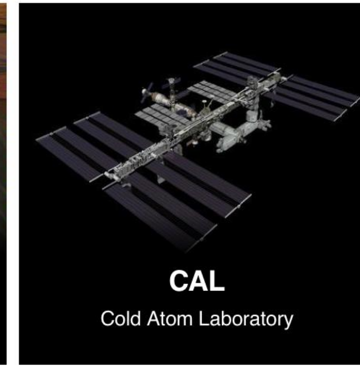


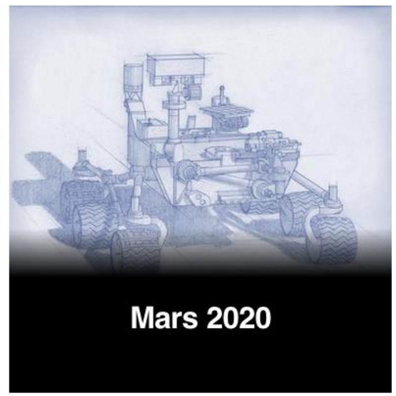
> 10 Future Missions (Planned)

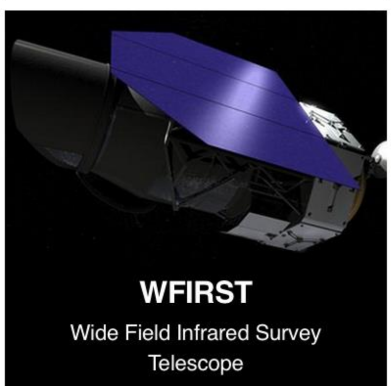












Pre-Decisional Information -- For Planning and Discussion Purposes Only

JPL's Natural Space Environment Group

- Supports all JPL flight missions for the space environments and effects area
  - Radiation (environment, shielding, charging, ….),
  - MMOD
  - Space weather
  - Atomic Oxygen, etc.

- Is responsible for developing and maintaining the radiation environment models for planetary missions (Mars, Jupiter, Saturn, etc.)

- Is responsible for evaluating other radiation environment models available in the community (e.g., AP9/AE9, Solar proton models) and adopting for JPL missions

- Is the JPL lead for nuclear planetology
  - Gamma ray and neutron spectroscopy

What do I do ?

CURRENT (a few selected):

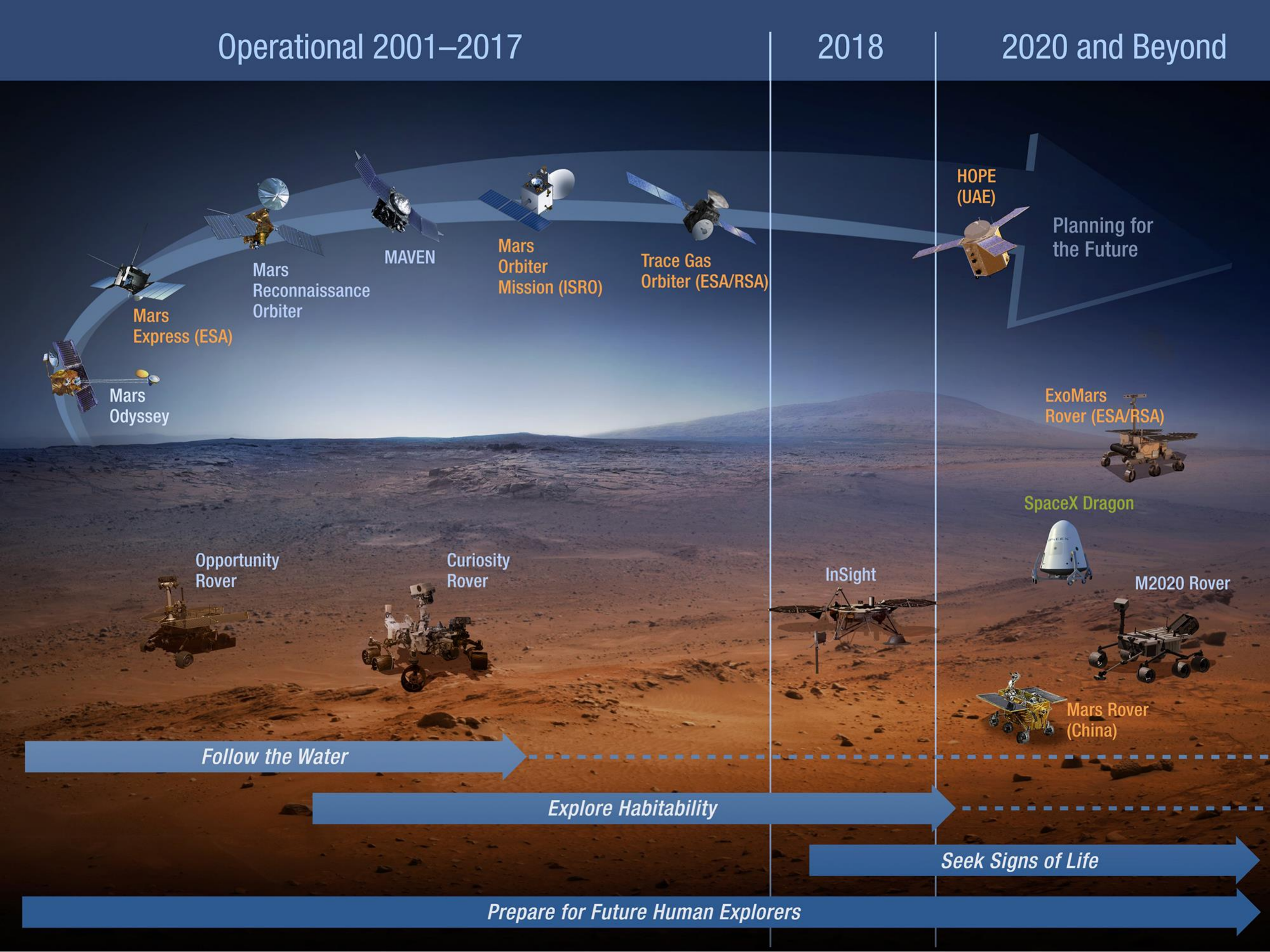
- Supervisor of the Natural Space Environment Group
- Science Team Member:
  - Mars Science Laboratory
  - Europa mission
  - Psyche mission
- JPL representing team member for:
  - NASA-wide Capability Leadership Team for Space Env.
  - Nation-wide Technical Discipline Team for Space Env.
- Teaches at UCLA
- Academic Advisor for two PhD students (SNU, MIT, and Texas A&M)

RECENT PAST:

- Study lead for JPL Black Box (Space Environment Monitor) Development
- PI and Task manager for Compact Reconfigurable Environment Assurance Monitor (CREAM)
- Committee member of The National Academies National Research Council (NRC)
- PIs for many R&TD (topics and initiative) and DRDF
- PIs for ROSES research grants
- NASA/ESA Jovian environment working group co-chair
- Juno IESD Tiger team lead

MARS


NASA'S JOURNEY TO
MARS



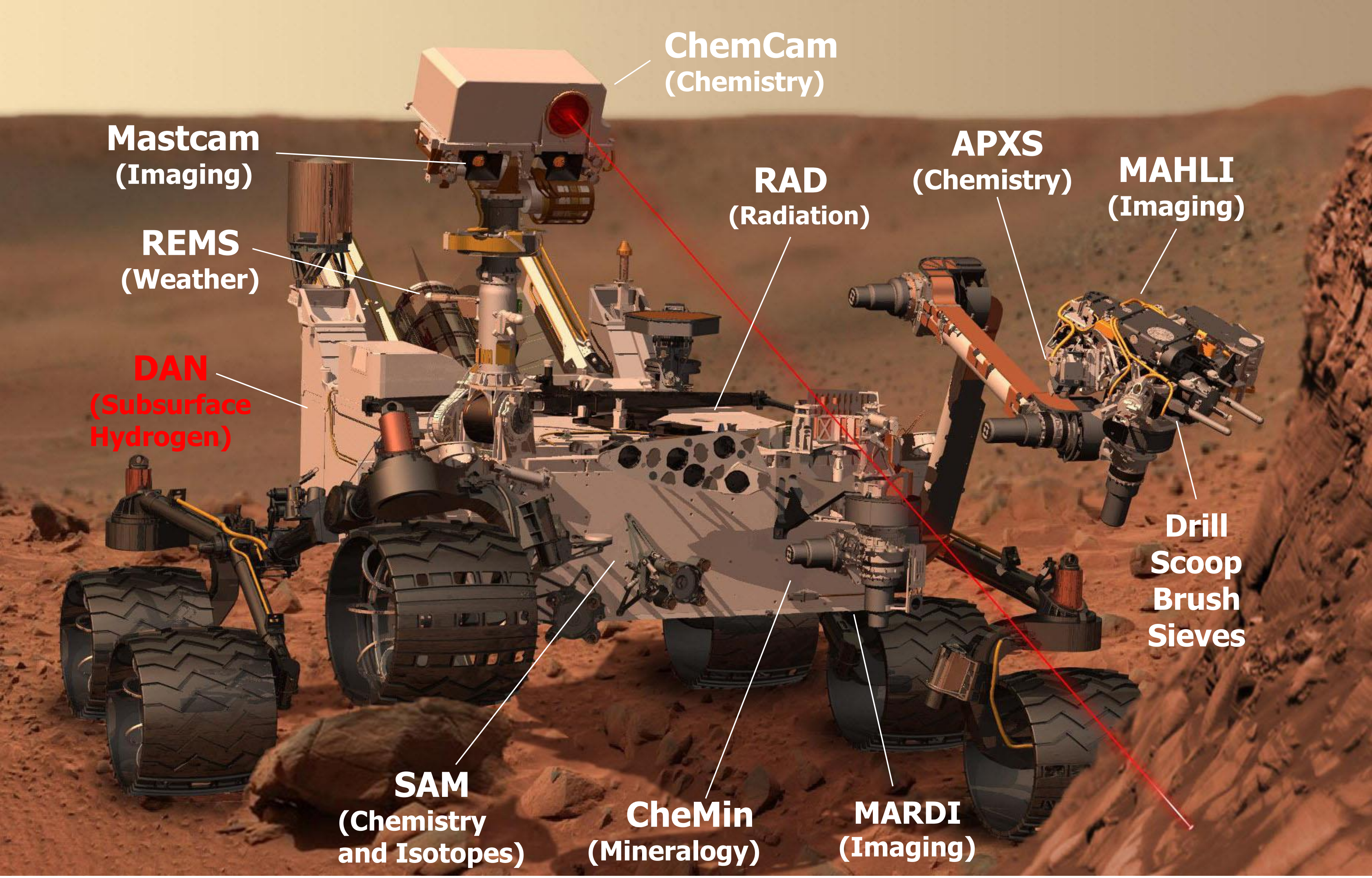
Operational 2001–2017
2018
2020 and Beyond
Mars Odyssey
Mars Express (ESA)
Mars Reconnaissance Orbiter
MAVEN
Mars Orbiter Mission (ISRO)
Trace Gas Orbiter (ESA/RSA)
HOPE (UAE)
Planning for the Future
ExoMars Rover (ESA/RSA)
SpaceX Dragon
Opportunity Rover
Curiosity Rover
InSight
M2020 Rover
Mars Rover (China)
Follow the Water
Explore Habitability
Seek Signs of Life
Prepare for Future Human Explorers

MARS SCIENCE LABORATORY (CURIOSITY)

Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

- **Biological potential**
- **Geology and geochemistry**
- **Water and weather**
- **Radiation hazards**

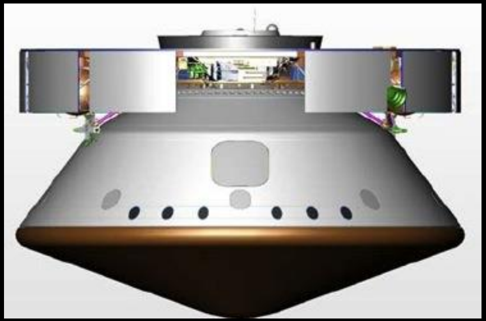
NASA/JPL-Caltech



CURIOSITY

Curiosity's Science Payload

Landing and Mobility

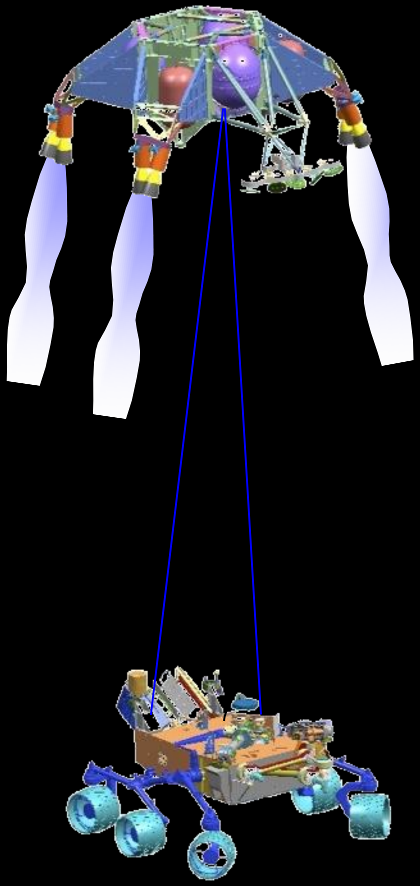


CRUISE/APPROACH

- 8-month cruise
- Arrived August 5th, 2012

ENTRY, DESCENT, LANDING

- Guided entry and powered "sky crane" descent
- 20×25-km landing ellipse
- Access to landing sites ±30° latitude, <0 km elevation
- 900 kg rover

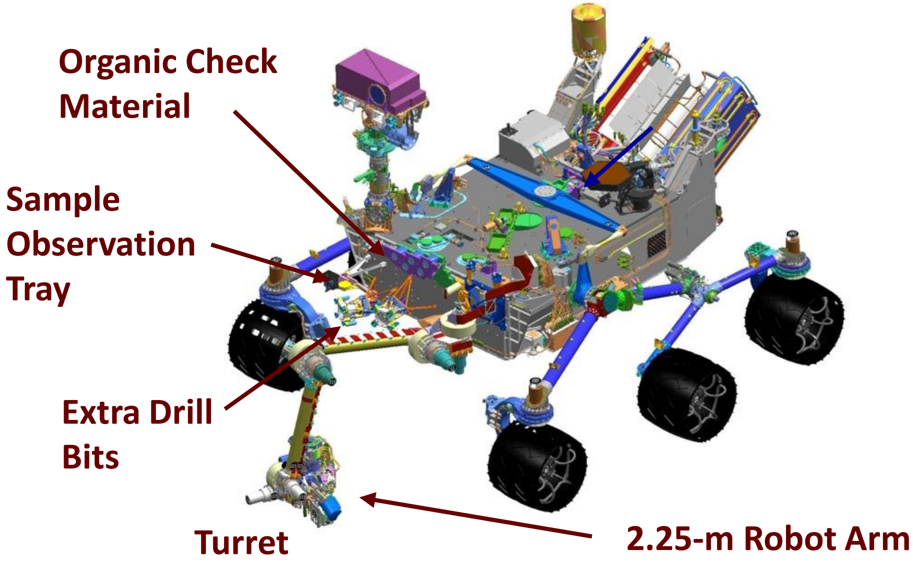


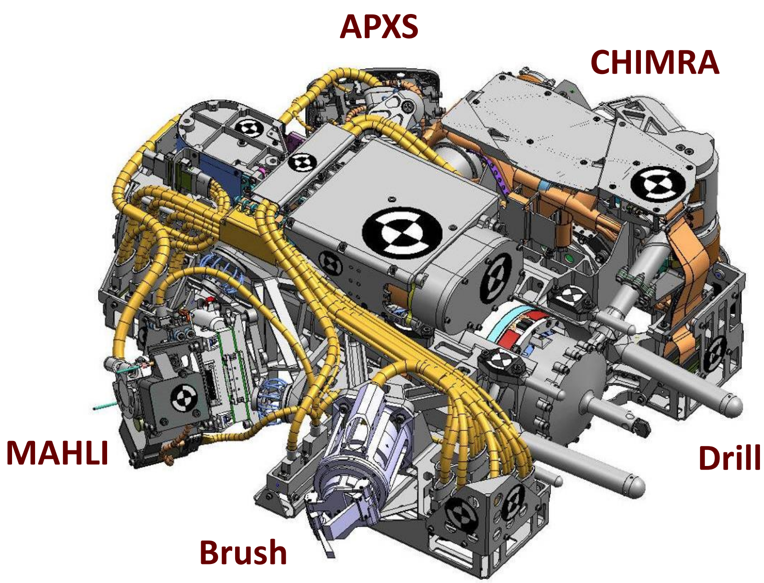
SURFACE MISSION

- Long-lived Plutonium power source
- Ability to drive out of landing ellipse, up 100 m per sol
- 84 kg of science payload
- Direct (uplink) and relayed (downlink) communication

LAUNCH

- Nov-2011
- Atlas V (541)





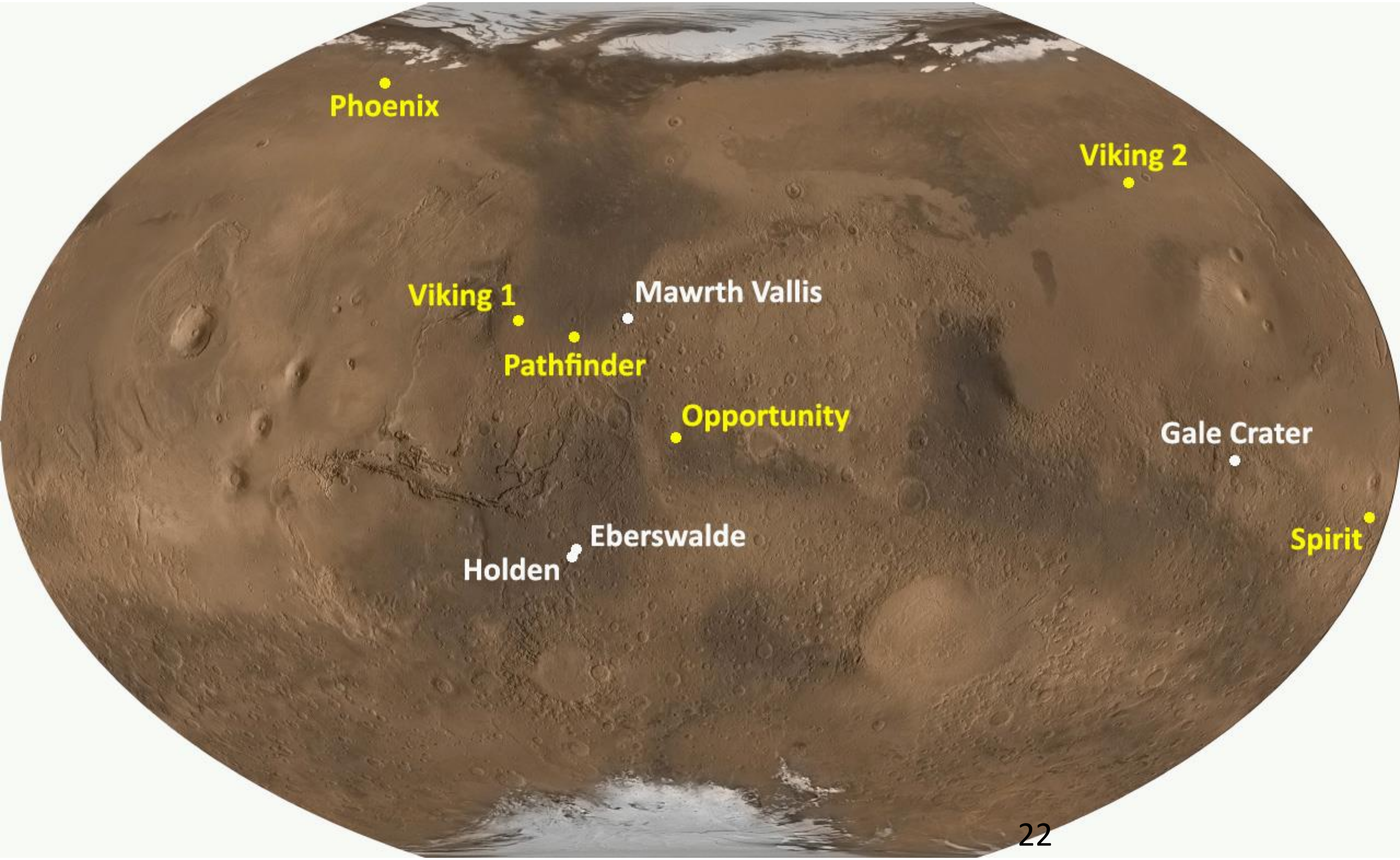
- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits

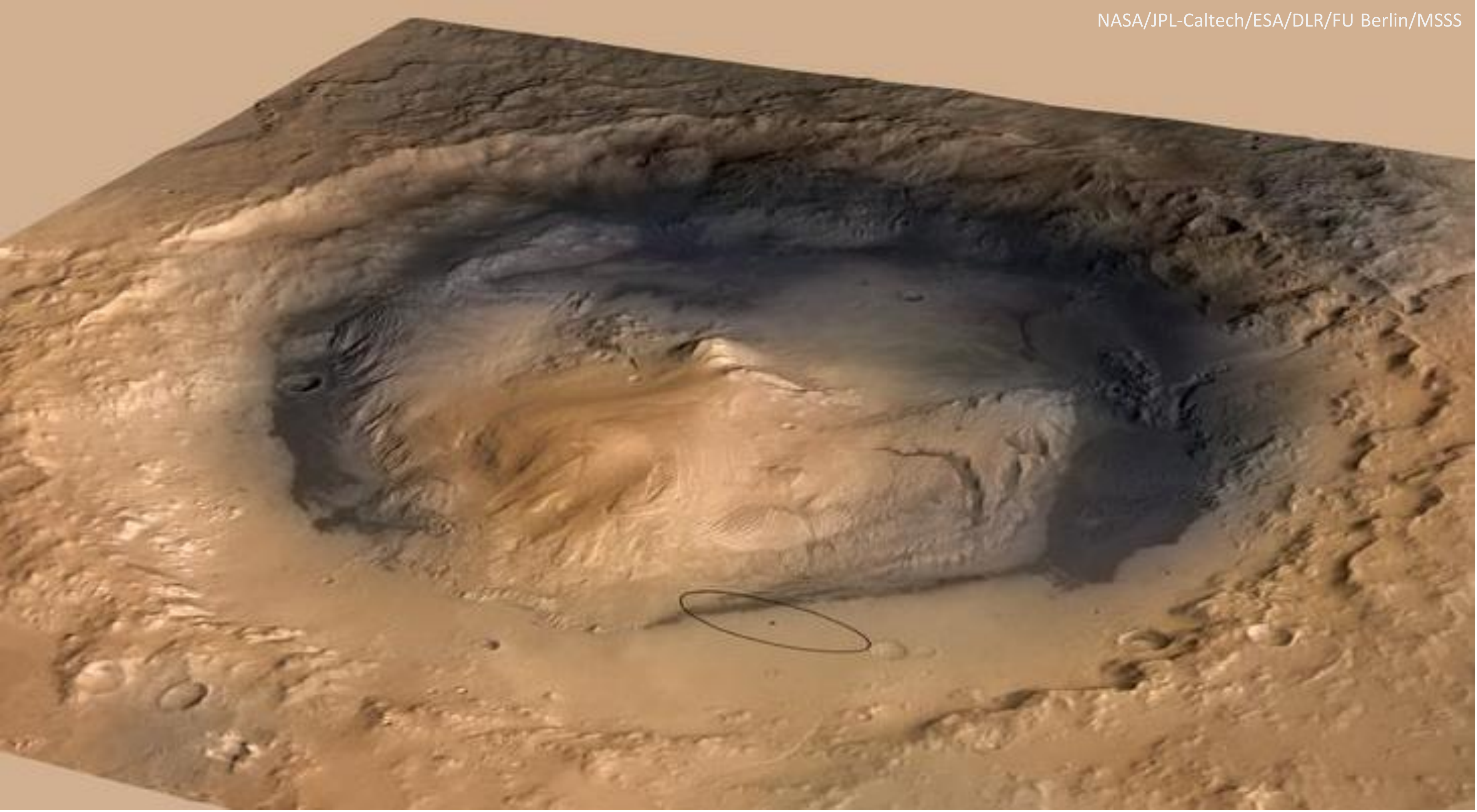
Curiosity’s Sampling System

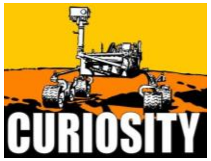
How do we get there?

Mars Landing Sites

(Previous Missions and MSL Final Candidates)







150-km Gale Crater contains a 5-km high mound of stratified rock. Strata in the lower section of the mound vary in mineralogy and texture, suggesting that they may have recorded environmental changes over time.

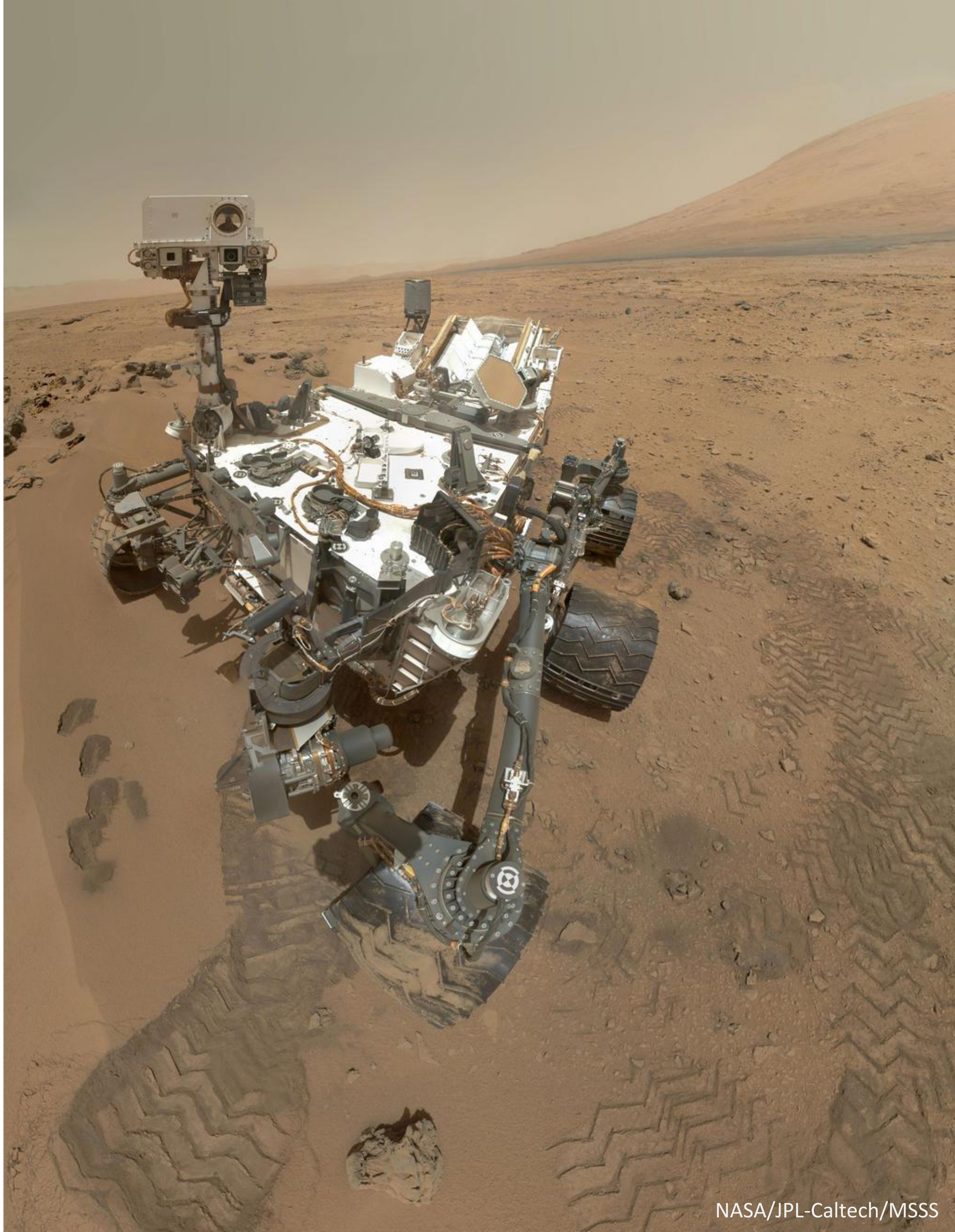
Kicking up dust just prior to landing

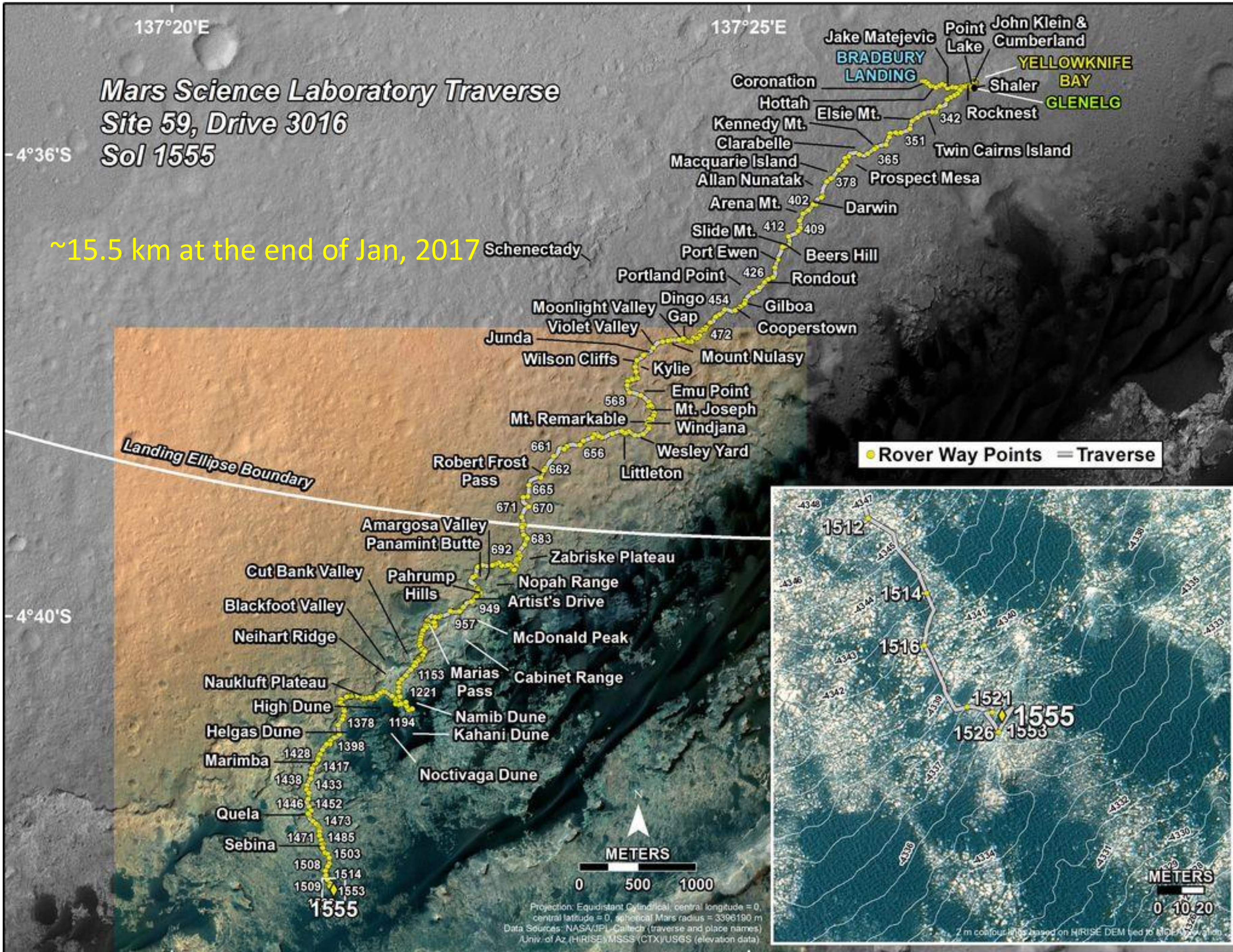
August 5, 2012: “Touchdown confirmed.”
“Time to see where our Curiosity will take us.”

Curiosity self-portrait at Rocknest

Assembled from 55 MAHLI images

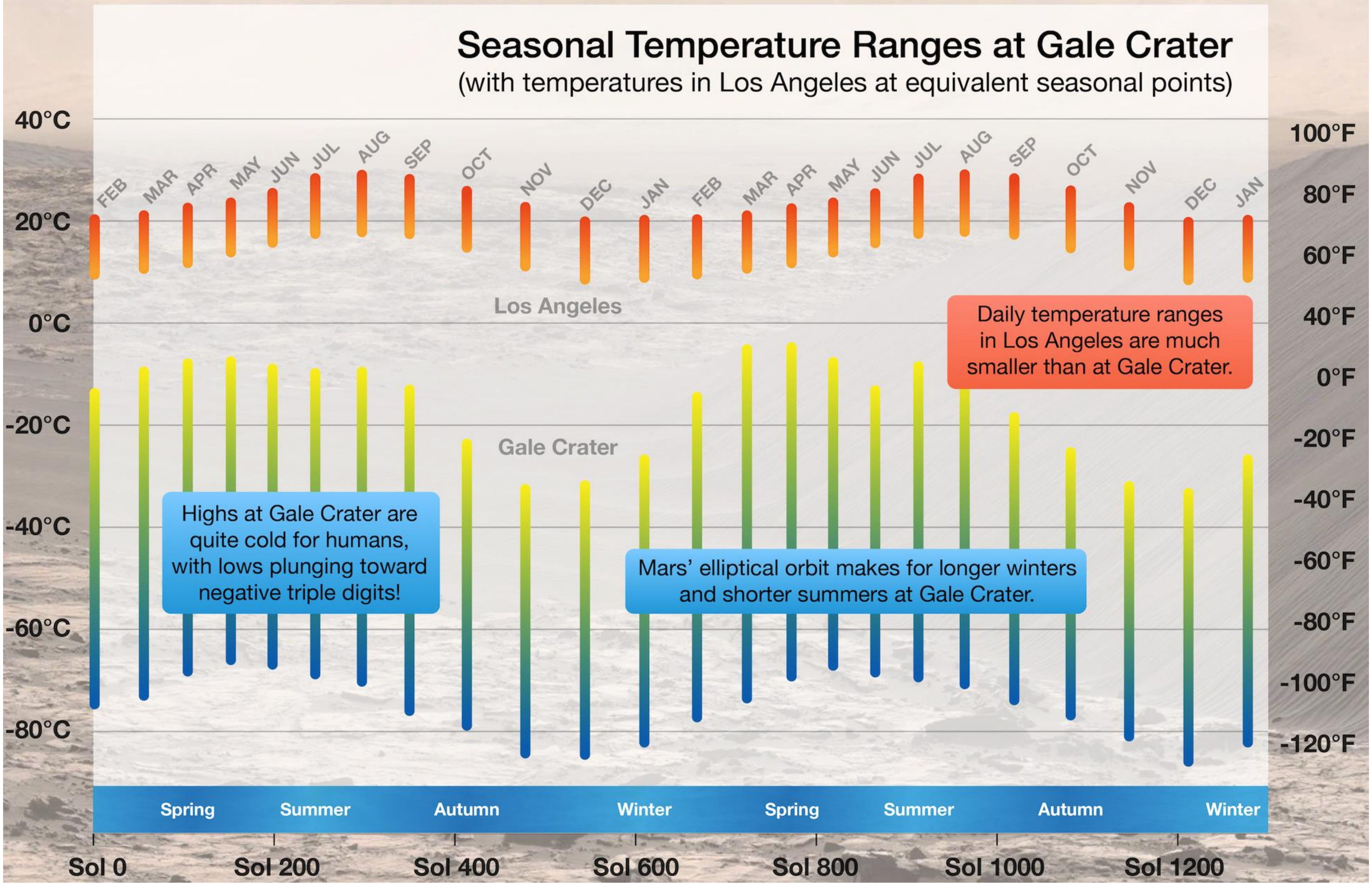
Shows four scoop trenches and wheel scuff


NASA/JPL-Caltech/MSSS



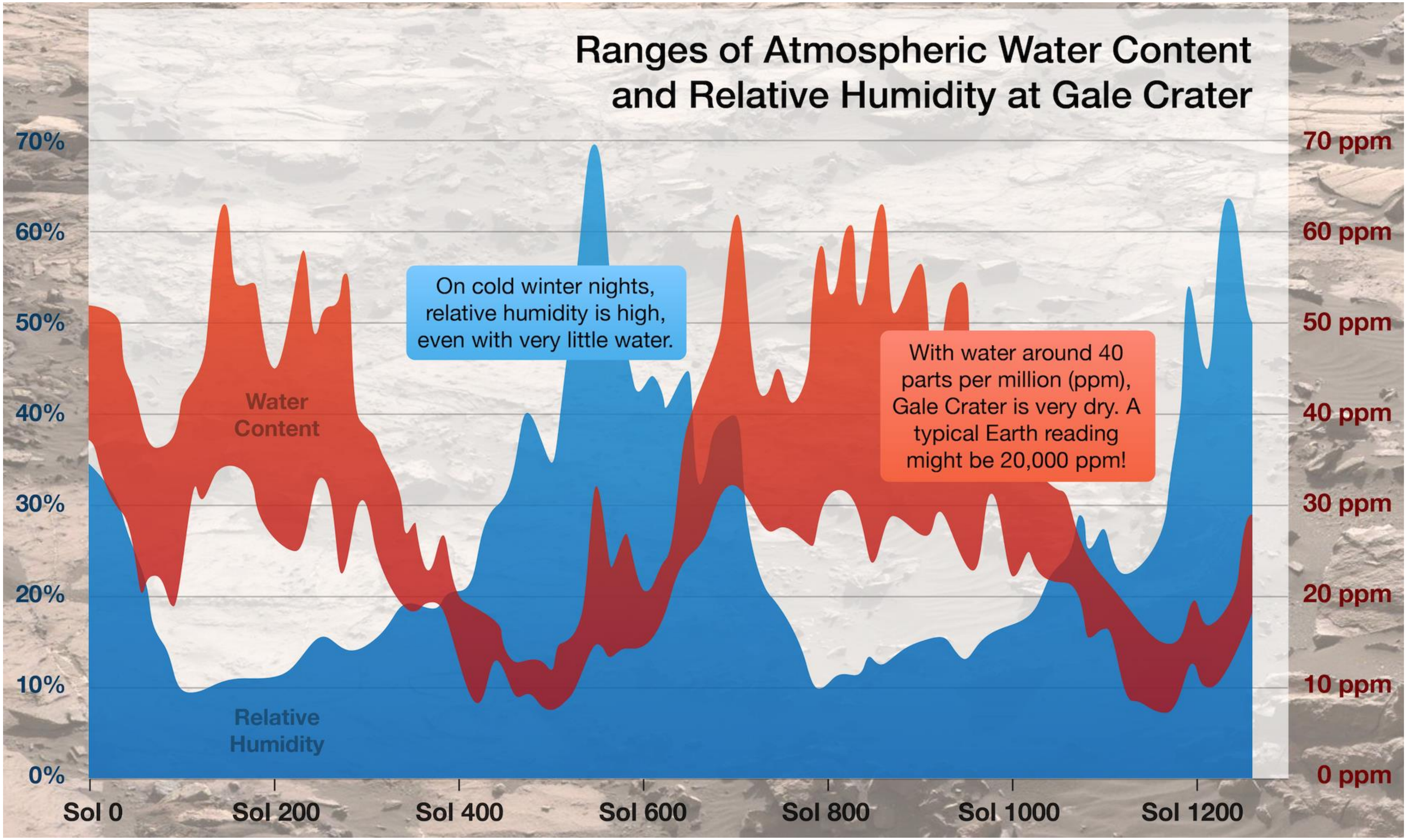
Mars Science Laboratory Traverse
Site 59, Drive 3016
Sol 1555
~15.5 km at the end of Jan, 2017
137°20'E
137°25'E
4°36'S
4°40'S
BRADBURY LANDING
YELLOWKNIFE BAY
GLENELG
Jake Matejevic
Point Lake
John Klein & Cumberland
Shaler
Rocknest
Coronation
Hottah
Elsie Mt.
Kennedy Mt.
Clarabelle
Twin Cairns Island
Macquarie Island
Allan Nunatak
Prospect Mesa
Arena Mt.
Darwin
Slide Mt.
Port Ewen
Beers Hill
Portland Point
Rondout
Schenectady
Dingo Gap
Gilboa
Moonlight Valley
Violet Valley
Cooperstown
Junda
Mount Nulasy
Wilson Cliffs
Kylie
Emu Point
Mt. Joseph
Mt. Remarkable
Windjana
Wesley Yard
Littleton
Robert Frost Pass
Landing Ellipse Boundary
Amargosa Valley
Panamint Butte
Zabriske Plateau
Cut Bank Valley
Pahrump Hills
Nopah Range
Artist's Drive
Blackfoot Valley
McDonald Peak
Neihart Ridge
Marias Pass
Cabinet Range
Naukluft Plateau
High Dune
Namib Dune
Kahani Dune
Helgas Dune
Noctivaga Dune
Marimba
Quela
Sebina
1555
Rover Way Points
Traverse
METERS
0 500 1000
1512
1514
1516
1521
1526
1553
1555
METERS
0 10 20

Measurements of Mars' Atmosphere and Environment

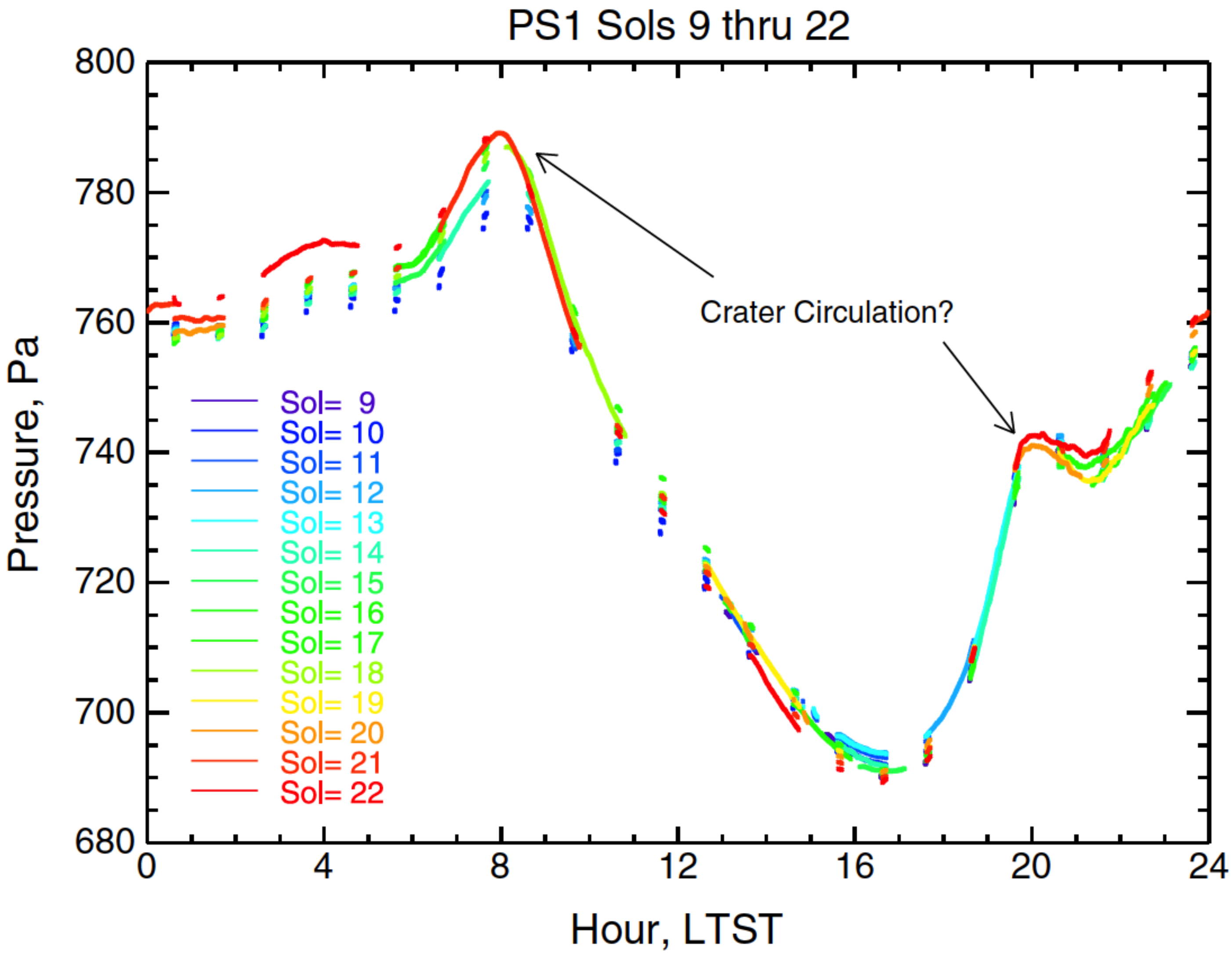


NASA/JPL-Caltech/CAB(CSIC-INTA)

Curiosity's Rover Environmental Monitoring Station is taking weather readings 24 × 7



Air in Gale Crater is much drier than on Earth, but relative humidity rises on cold winter nights



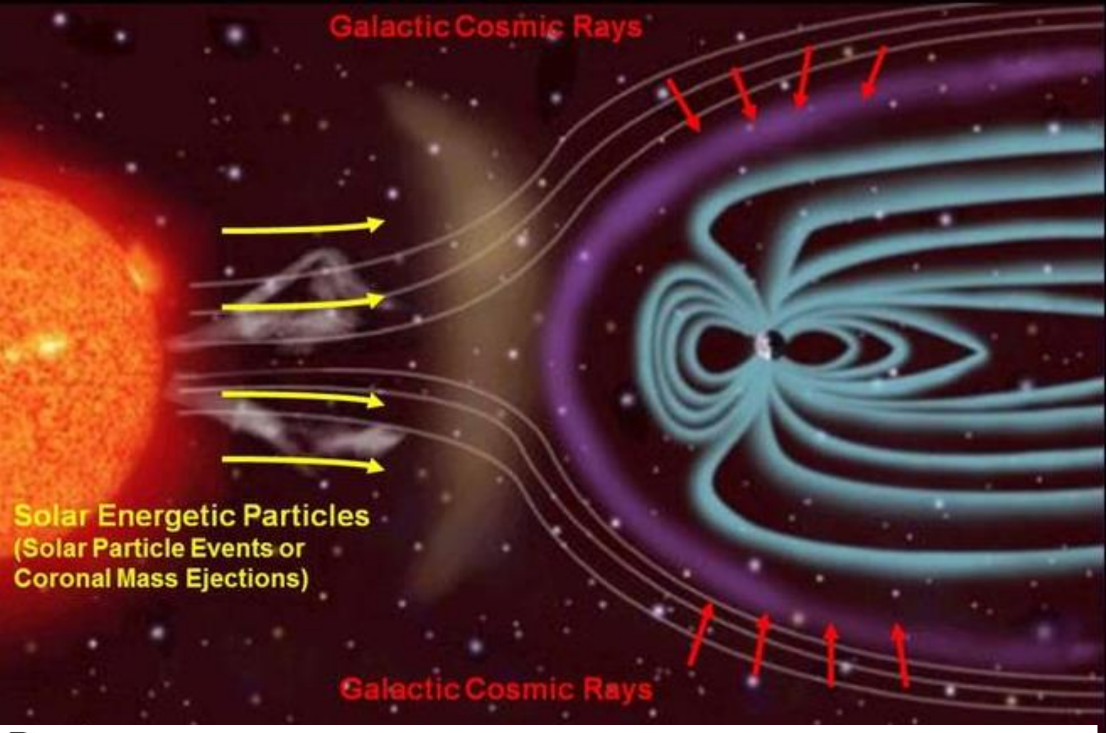
REMS takes hourly measurements with occasional 1-Hz extended sessions

Daytime convective vortices are present, but no dust devils have been observed

Diurnal thermal tides (left) are amplified and modified by the crater topography

The CO_2 pressure cycle at Gale also has components due to elevation and planetary circulations

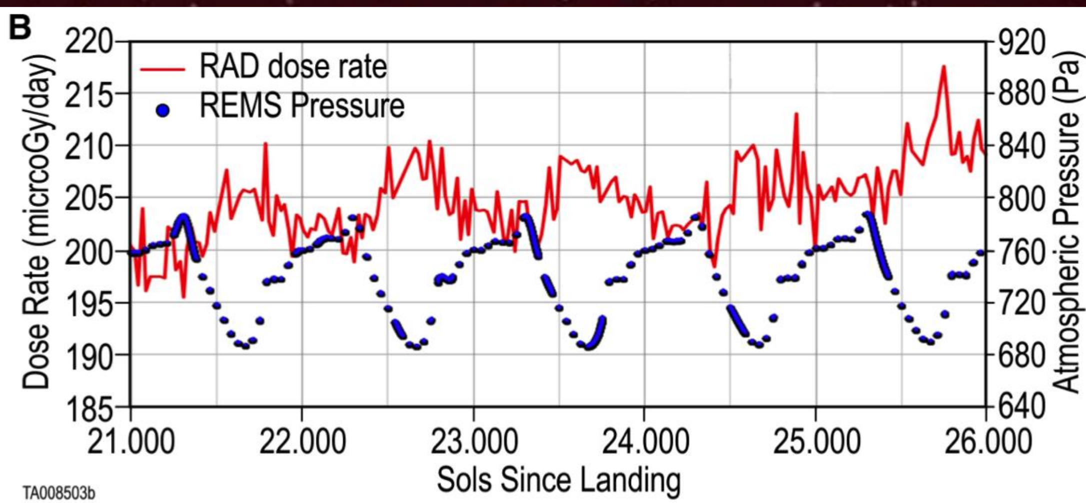
REMS pressure measurements reveal local, regional, and planetary-scale phenomena

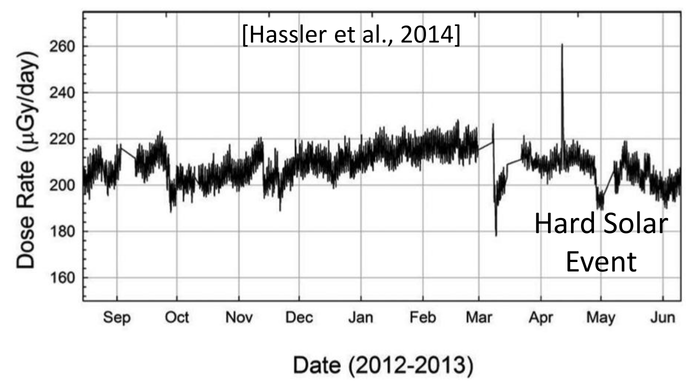


The RAD instrument measured the radiation flux from both galactic cosmic rays and solar energetic particles, in cruise and at Mars' surface

***If shielded similarly to the RAD instrument*, a crewed mission would receive ~1 Sievert of exposure in a round trip to Mars with 500 sols on the surface**

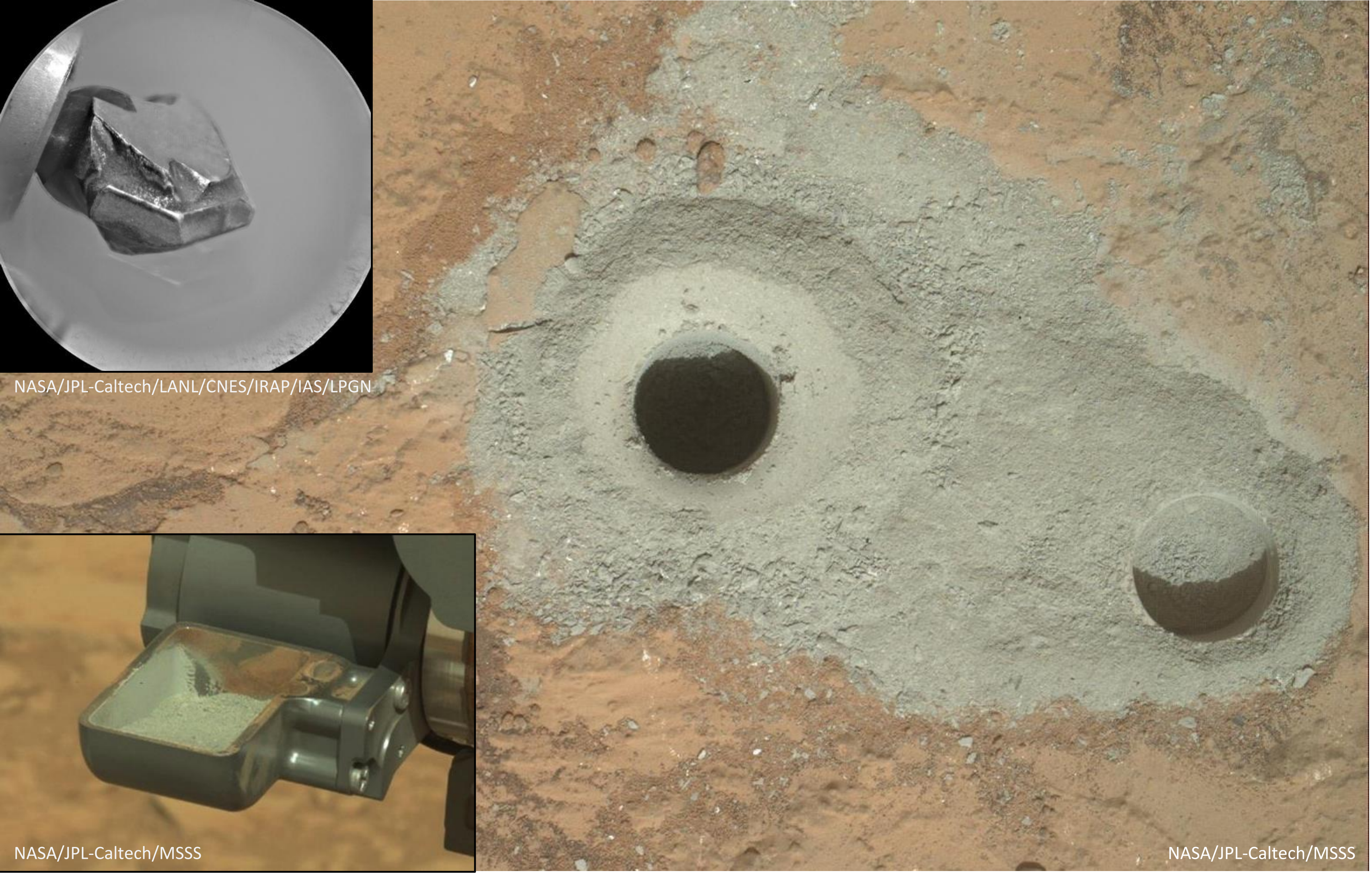
1 Sievert is currently the maximum lifetime dose for astronauts





Curiosity's Radiation Assessment Detector measures high-energy radiation

Arm deployed at Yellowknife Bay



CURIOSITY

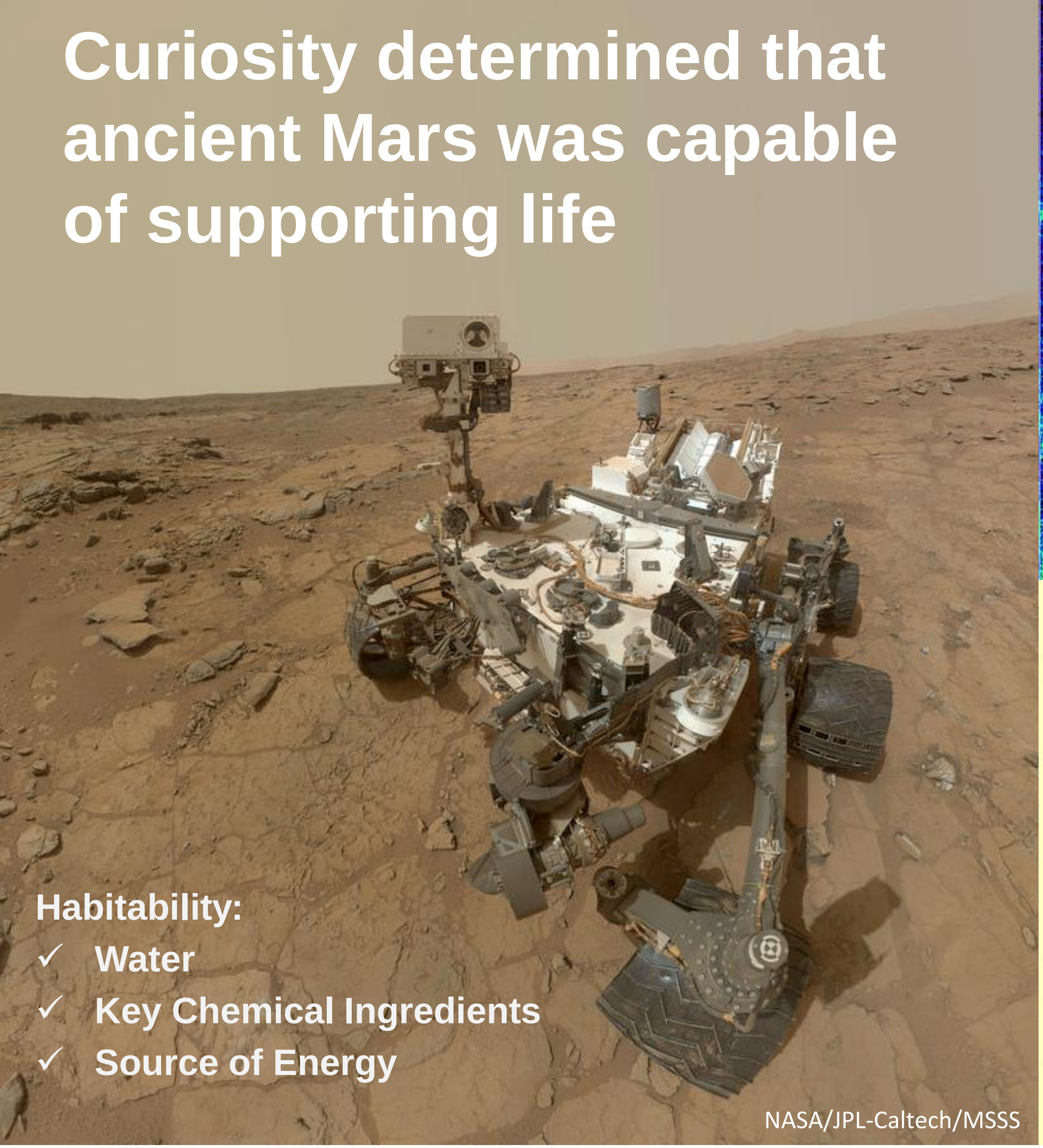
Curiosity’s 1.6-cm drill bit, drill and test holes, and scoop full of acquired sample

NASA/JPL-Caltech/
U. Guelph

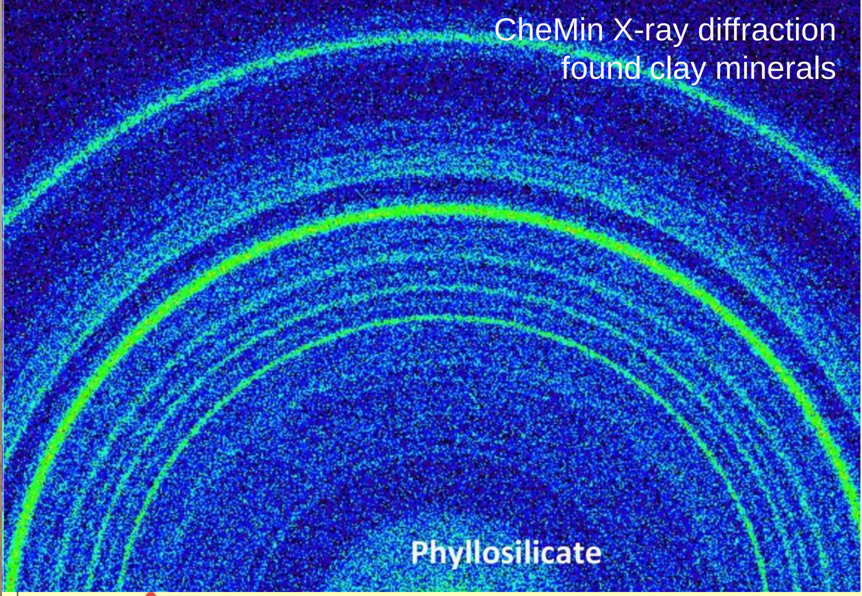
NASA/JPL-Caltech/MSSS

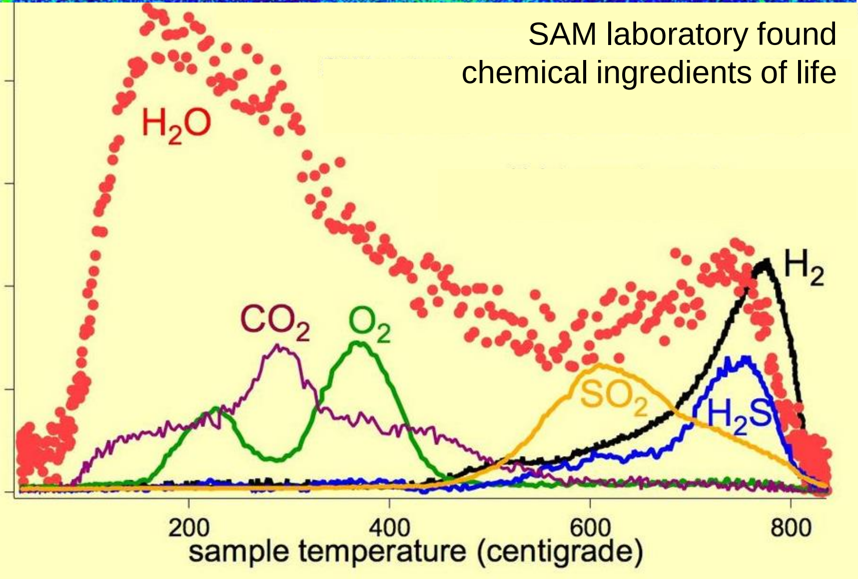
US dime-sized drill hole with light-toned veins and ChemCam profile

Curiosity determined that ancient Mars was capable of supporting life



Habitability:
- ✓ Water
- ✓ Key Chemical Ingredients
- ✓ Source of Energy



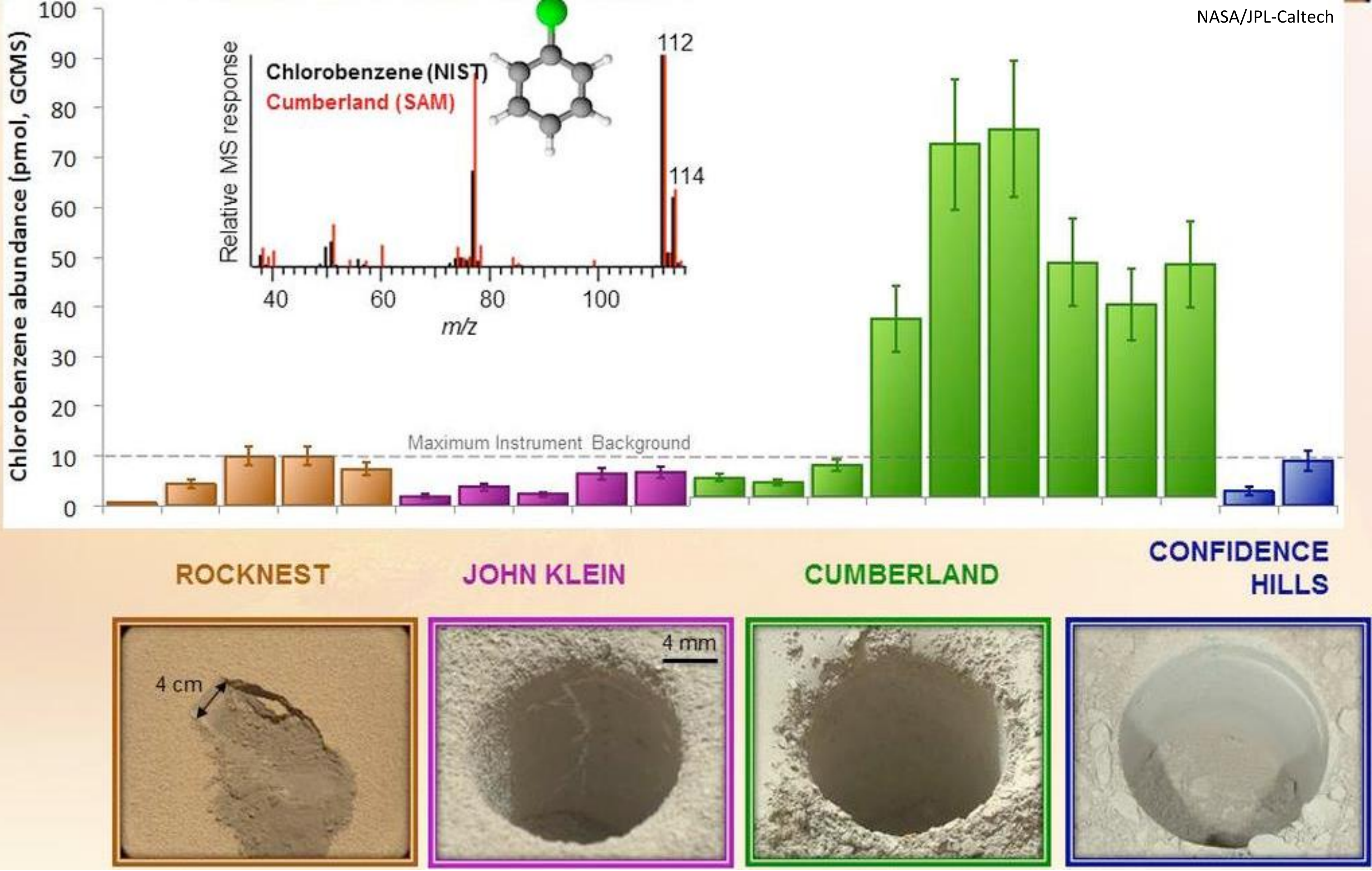


At Yellowknife Bay, Curiosity found an ancient lake, the key chemical ingredients required by life (such as carbon, nitrates, and sulfur), and chemical energy usable for microbial metabolism

An Ancient Habitable Environment at Yellowknife Bay

- The regional geology and fine-grained rock suggest that the John Klein site was at the end of an ancient river system or within an intermittently wet lake bed
- The mineralogy indicates sustained interaction with liquid water that was not too acidic or alkaline, and low salinity. Furthermore, conditions were not strongly oxidizing.
- Key chemical ingredients for life are present, such as carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur
- The presence of minerals in various states of oxidation would provide a source of energy for primitive organisms

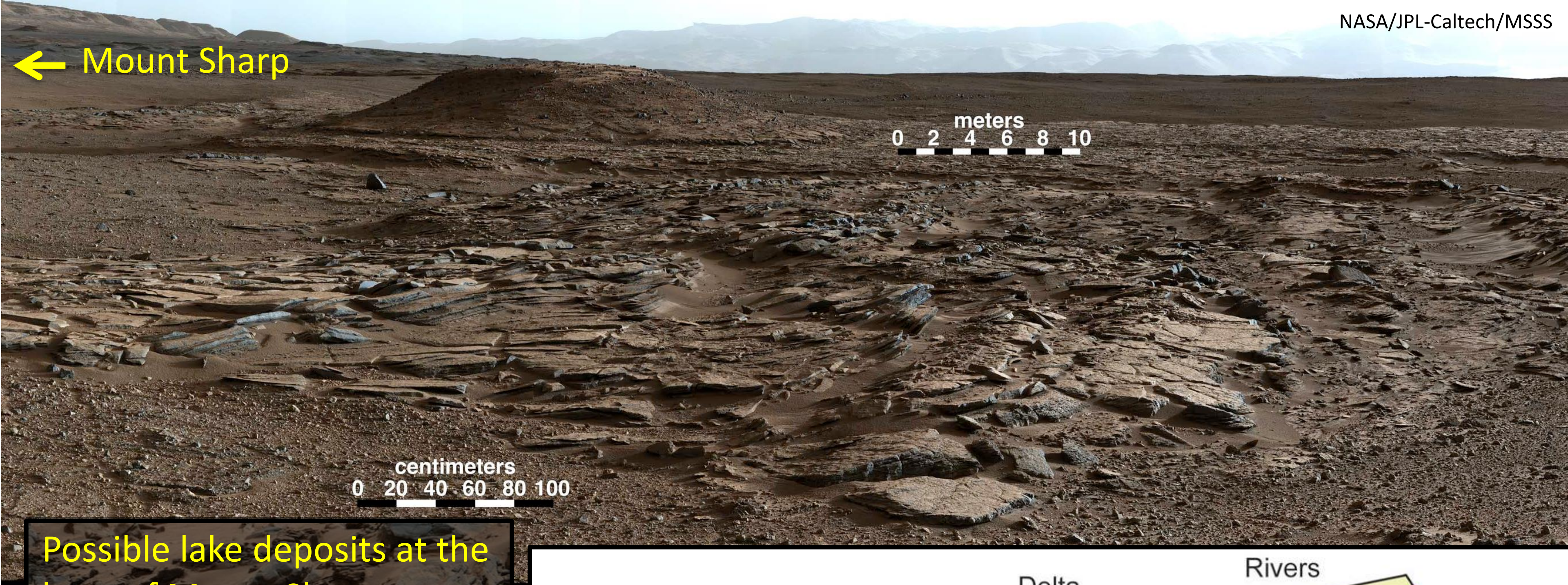
NASA/JPL-Caltech/MSSS

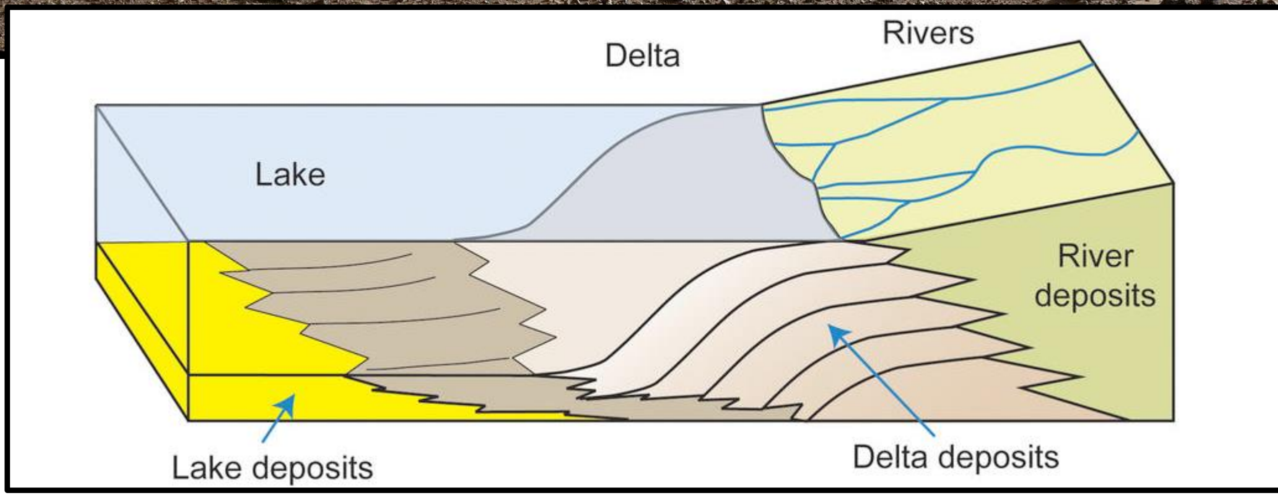


The organic chemical chlorobenzene was detected in the Cumberland drilled sample. The chlorine likely is derived from perchlorate in the sedimentary rock.

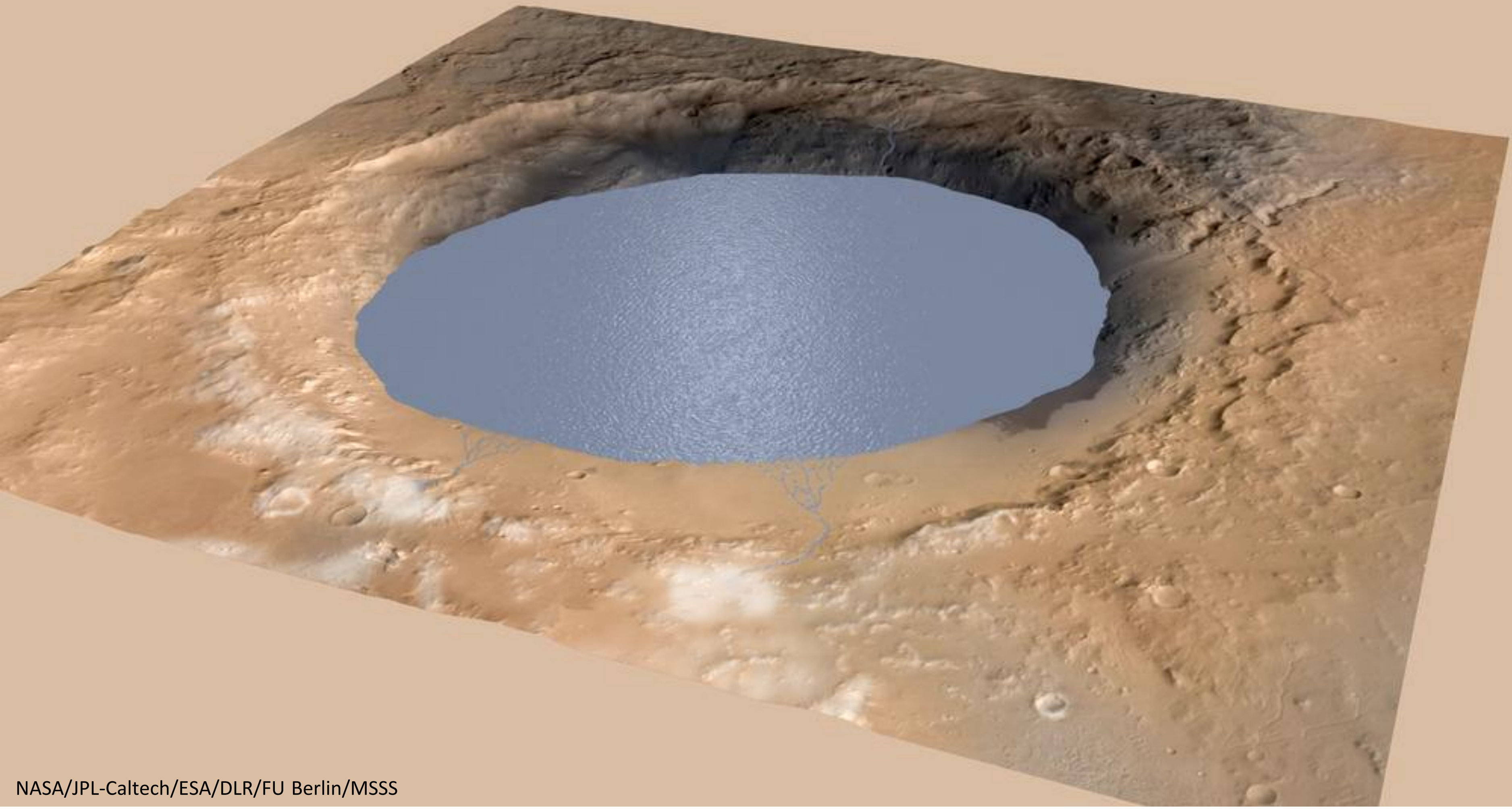
Notes on Organics

- This is the first-ever detection of a martian organic chemical.
- It took many analyses of rocks and soils, as well as additional analyses of blanks and calibration standards on Mars and on Earth, in order to verify this discovery.
- SAM detected simple hydrocarbon molecules in which some of the hydrogen was replaced with chlorine. This could have happened on Mars, or within the instrument, through reaction with perchlorate compounds that are known to be widespread on Mars.
- Simple organic molecules do not require biology for their formation. However, they are building blocks of life. More importantly, we now can study what environments preserve organics on Mars' surface, increasing our ability to search for other life-related materials.



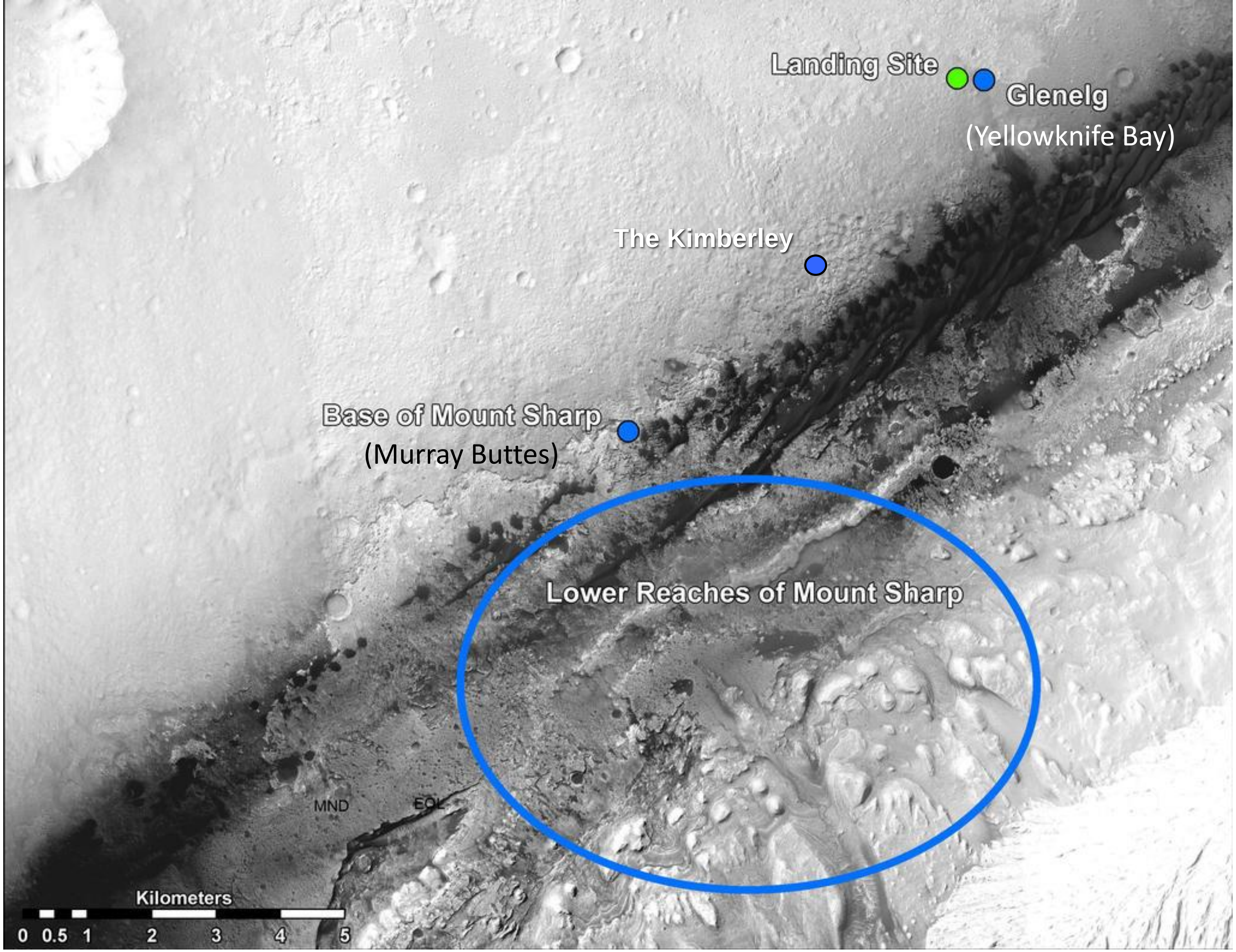


Curiosity discovered southward-tilted sandstone beds on Gale Crater's plains that indicate water-driven transport of sediment, building lower Mount Sharp from lake deposits



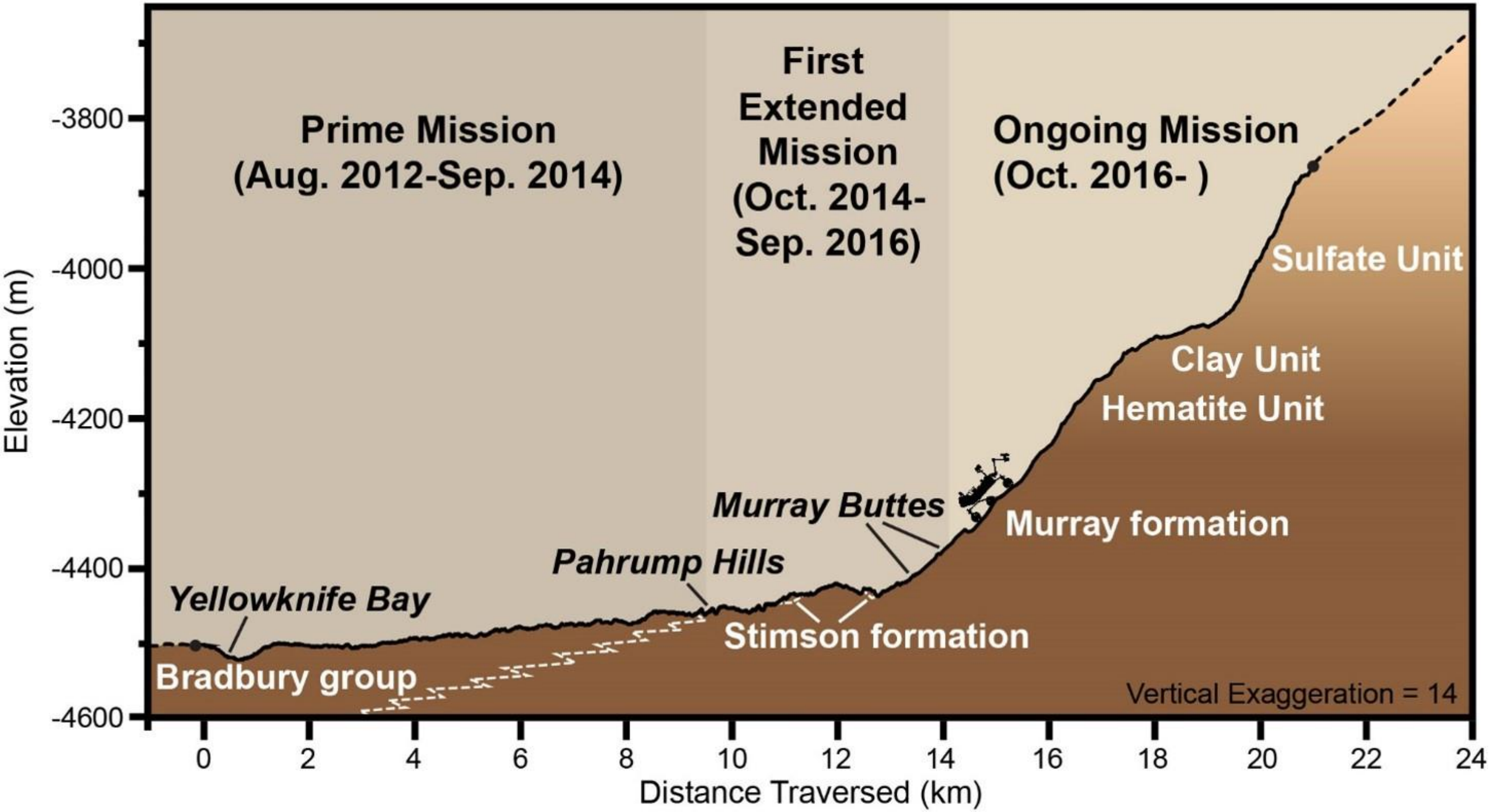
NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS

An illustration of lake partially filling Gale Crater. If such a lake existed for millions of years, it would have required a more humid climate and active hydrological cycle.

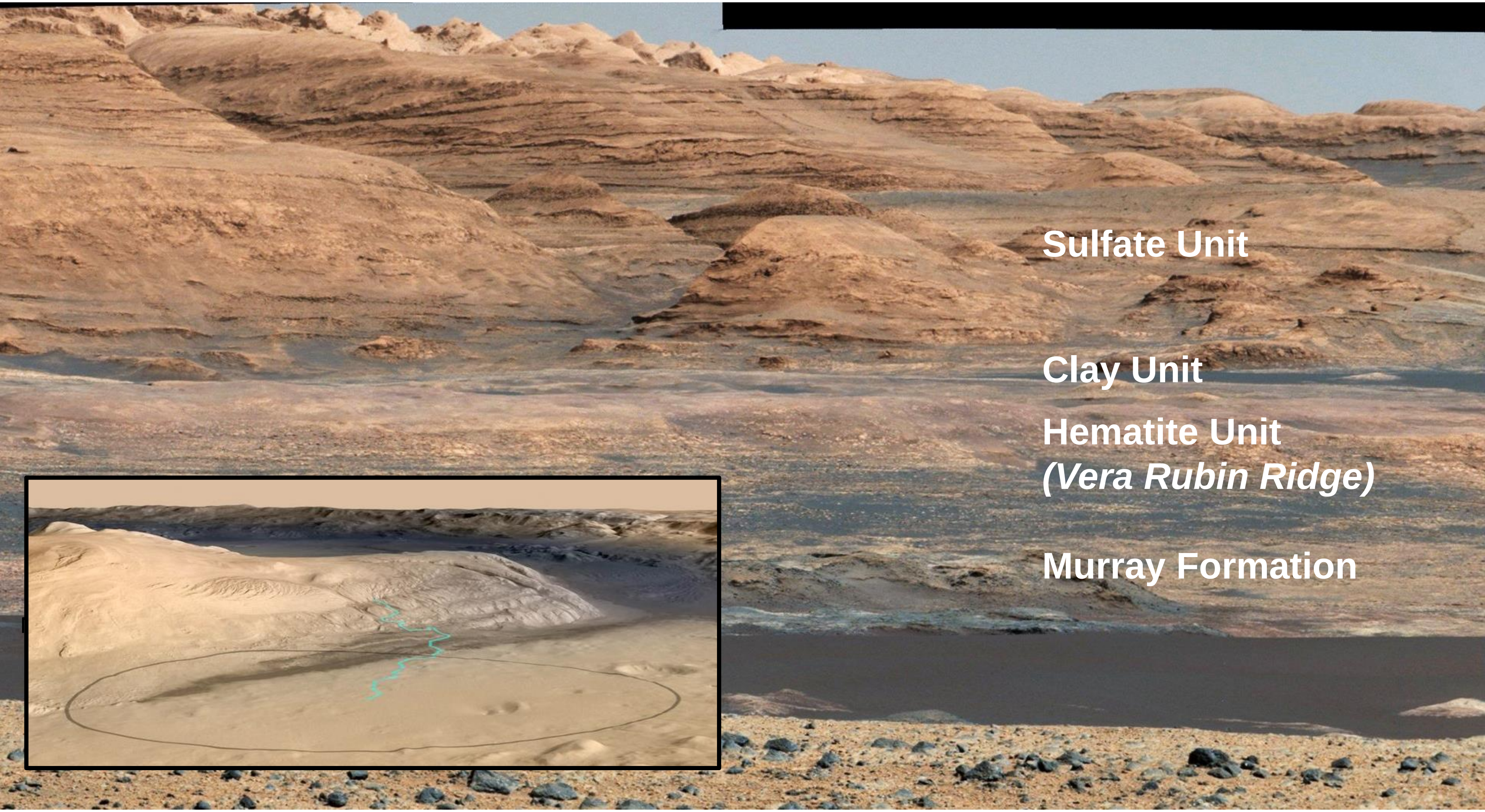


NASA/JPL-Caltech/Univ. of Arizona

Curiosity's ultimate goal is to explore the lower reaches of the 5-km high Mount Sharp

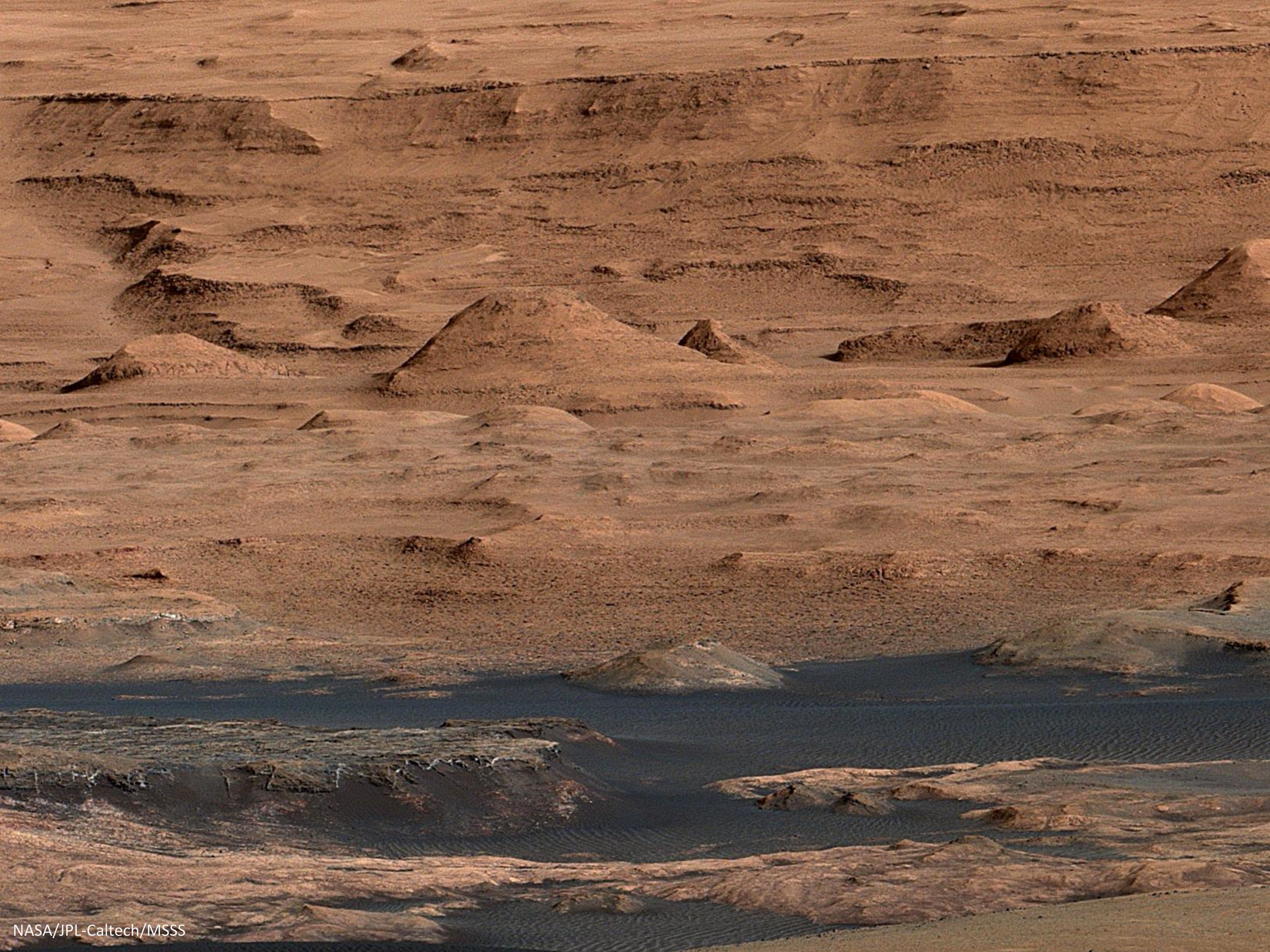


Curiosity is more steeply climbing Mount Sharp in the second two-year extension of its mission



NASA/JPL-Caltech/MSSS

Curiosity's Extended Mission will explore Mt. Sharp, with an emphasis on understanding the subset of habitable environments that preserve organic carbon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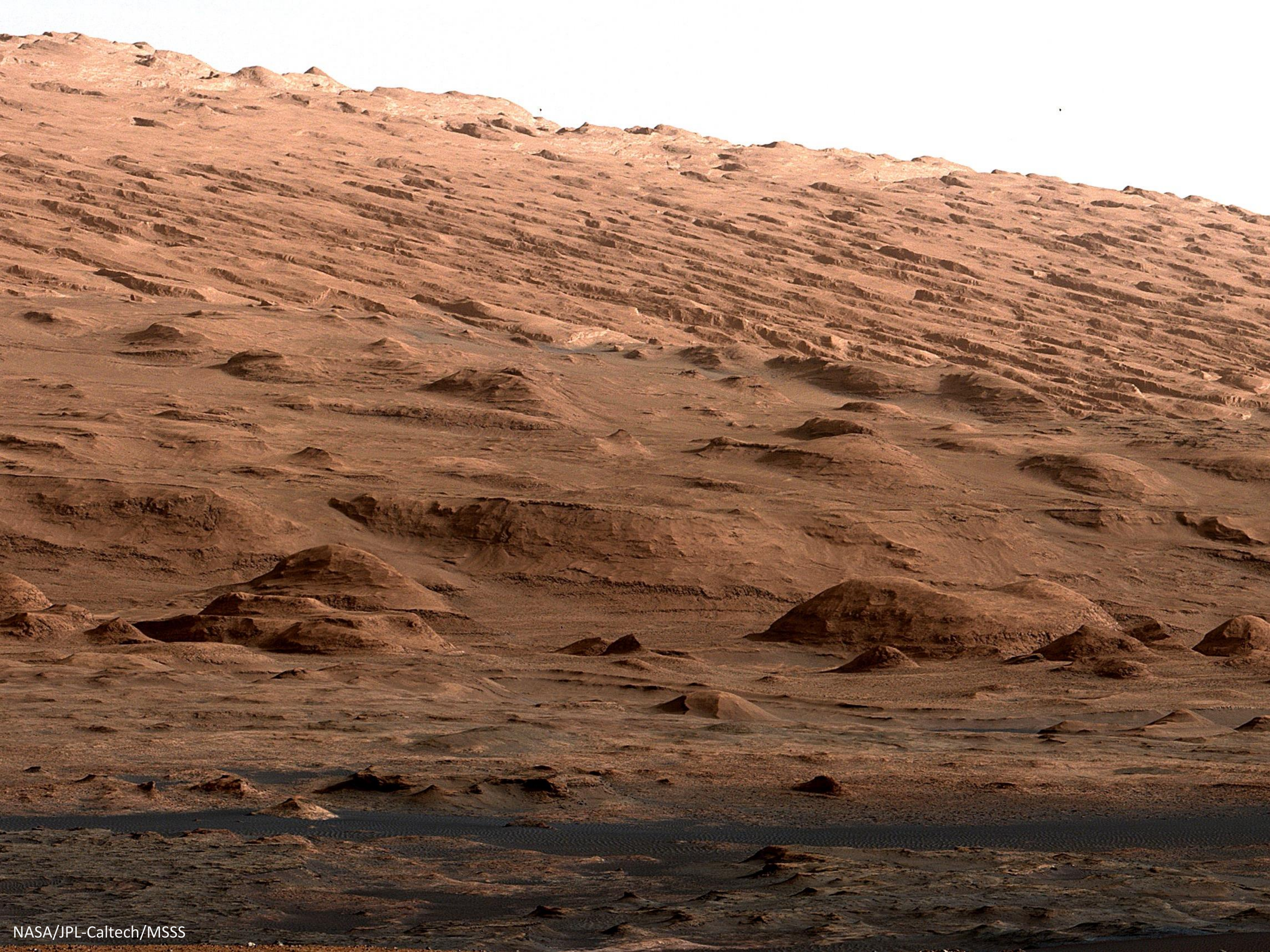
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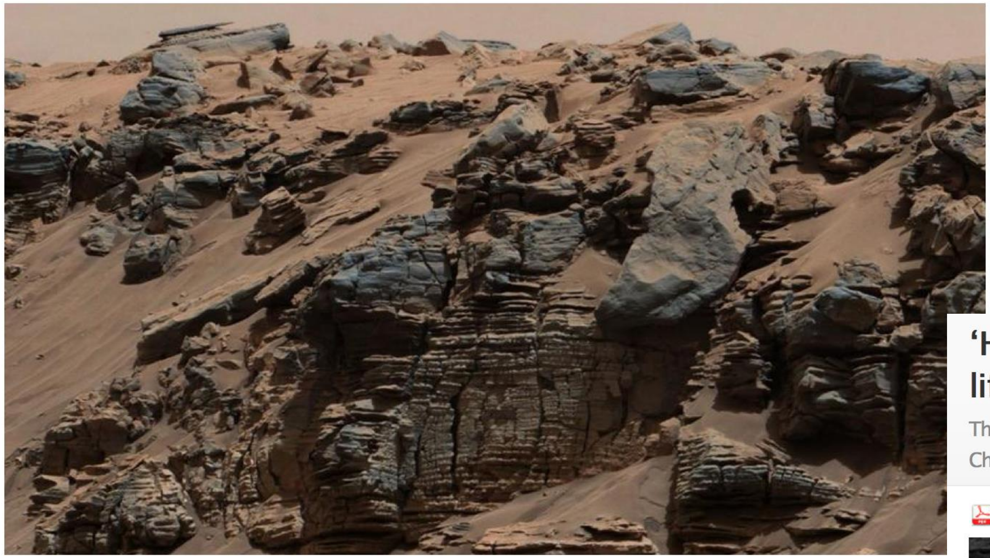
An ancient lake on Mars could have supported a variety of microbial life



This evenly layered Martian rock, photographed by the Curiosity rover's mast camera, shows a pattern typical of a lake-floor sedimentary deposit not far fron where flowing water entered a lake. (NASA/JPL-Caltech/MSSS)

By Amina Khan
Contact Reporter

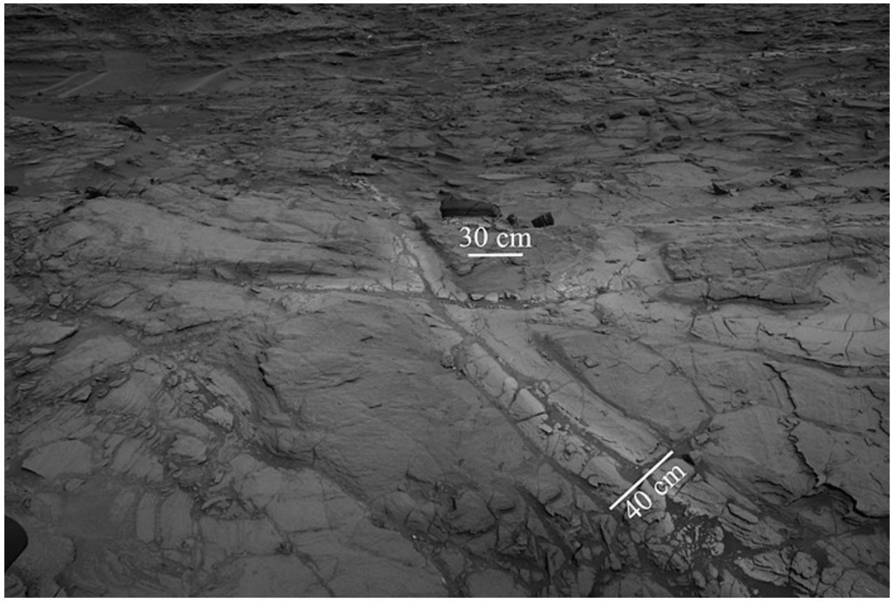
JUNE 6, 2017, 11:15 AM

'Halos' discovered on Mars widen time frame for potential life

The halos were analyzed by the rover's science payload, including the laser-shooting Chemistry and Camera (ChemCam) instrument.

8

May 30, 2017

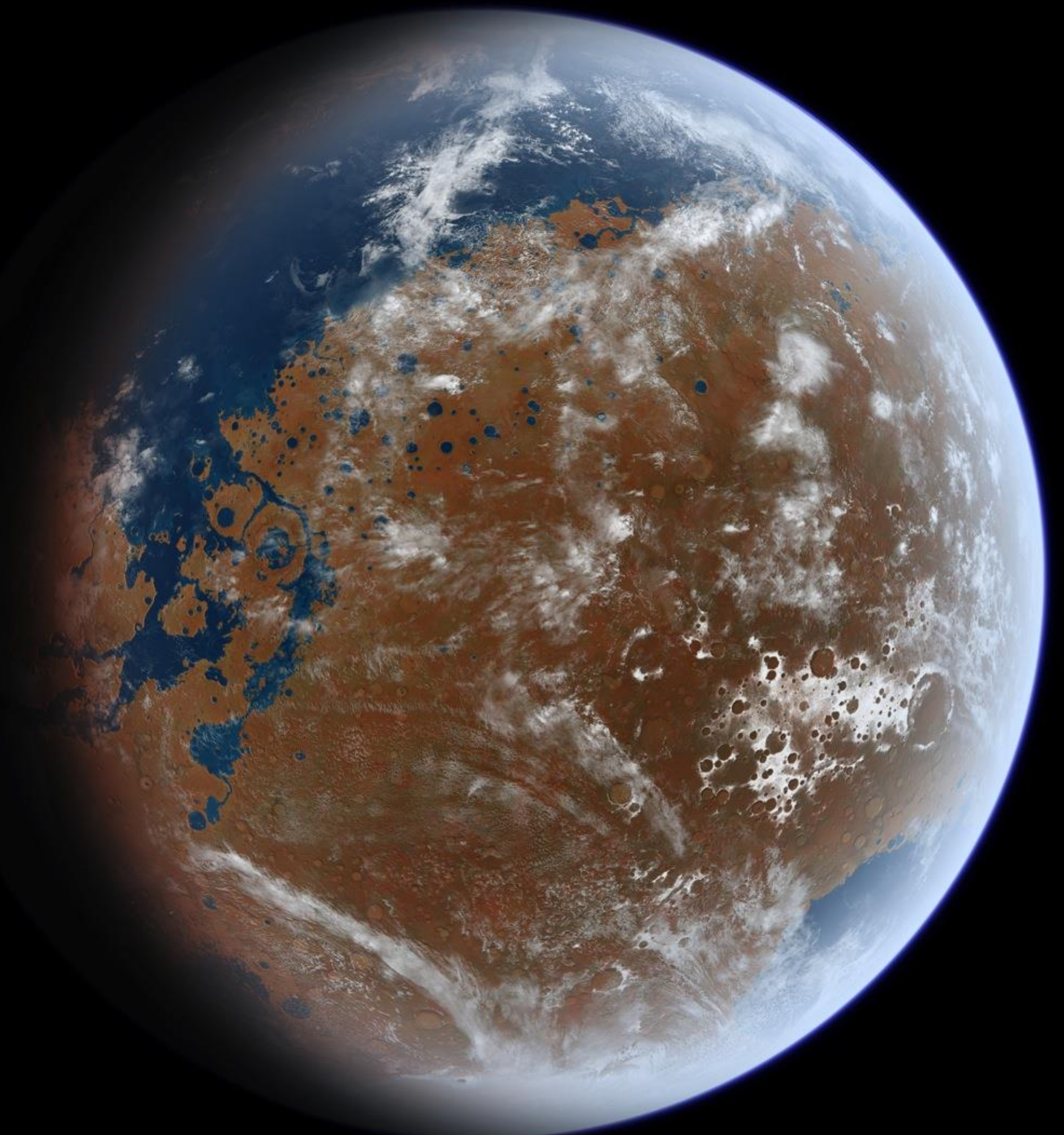


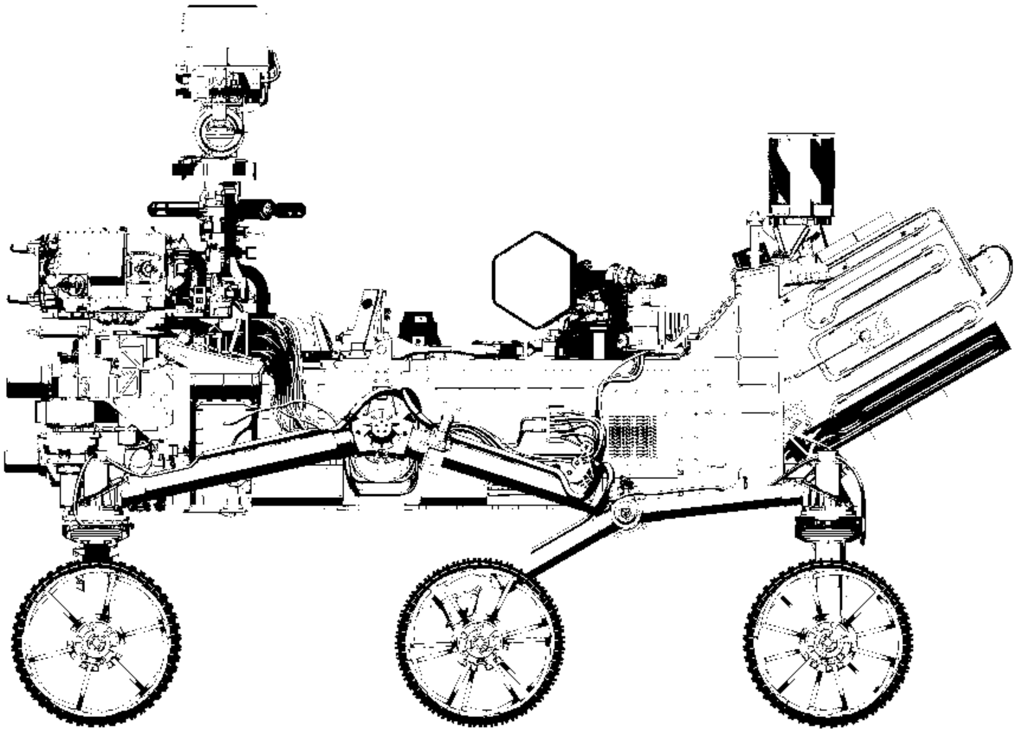
A mosaic of images from the navigation cameras on the NASA Curiosity rover shows "halos" of lighter-toned bedrock around fractures. These halos comprise high concentrations of silica and indicate that liquid groundwater flowed through the rocks in Gale crater longer than previously believed. (CREDIT: NASA/JPL-Caltech)

Mars exploration results are strong evidence that <u>early Mars was warm and wet</u>.

Aqueous minerals, high silica deposits, long-lived lakes in Gale Crater would be possible only with an active hydrological cycle and other bodies of water.

Mars was habitable, could have been inhabited, may be today, and could be in the future.





MARS 2020

Mars 2020 Becoming Publicly Visible

Jet Propulsion Laboratory
California Institute of Technology

NEXT STOP, MARS

The best way to look for life on Mars is to bring back rocks from the red planet. Now NASA is gambling $2.4 billion on a high-risk mission to do it.

BY ALEXANDRA WITZE

Adam Steltzner rose to engineering stardom in 2012, when NASA's Curiosity rover plummeted to a perfect landing on Mars, thanks to a daring, fiery manoeuvre designed by his team. Now, all Steltzner wants to talk about is how to clean.

The object of his sanitary obsession is a dark-grey metallic tube about the size of his hand. It sits on a workbench inside a warehouse-like building at the Jet Propulsion Laboratory (JPL) in Pasadena, California, where Steltzner works as chief engineer for NASA's next Mars rover. He needs the tube to be one of the cleanest objects ever created so that the rover can complete its mission.

As early as July 2020, the 1-tonne, 6-wheeled vehicle will blast off from Florida, carrying 43 such tubes on a 7-month trip to the red planet. Once it arrives, the rover will drive across the Martian surface and fill each tube with dirt, rock or air. Then it will seal the tubes, place them on the ground, and wait — for years, or possibly decades — for another spacecraft to retrieve them and fly them back to Earth. It will be humanity's first attempt to bring back part of the red planet.

If all goes to plan, these will become the most precious extraterrestrial samples ever recovered. Tucked inside one of those metallic tubes could be evidence of life beyond Earth in the form of a microorganism, biominerals or organic molecules.

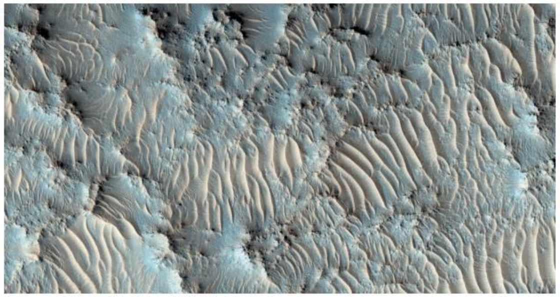
Which is why Steltzner and his team have to be very, very clean. Just one Earth cell or specks of other contaminants would ruin any chance of unambiguously detecting a Martian microbe. So the project team is trying to design a robotic sampling system that will keep things spotless. "We are going to be more serious about cleanliness than anyone's been before," Steltzner says, shaking the tube as if to knock errant microbes off it. "We're just going to engineer this shit."

The stakes could not be higher. NASA is gambling $2.4 billion and the future of its Mars exploration programme on the 2020 rover. If it gathers a pristine set of rock samples that eventually return to Earth, they will shape the course of Solar System science. If it fails — and Mars is notorious as a graveyard for space missions — the agency will have to relinquish a dream it has had for decades.

In conference rooms, laboratories and

PATRICK FALLON FOR NATURE

NEWS IN FOCUS



Jezero crater, one of the possible landing sites picked, is the location of an ancient lake.

PLANETARY SCIENCE

NASA narrows sites for rock-harvesting Mars rover

Plans advance for the first-ever sample return from the red planet.

BY ALEXANDRA WITZE

The future of NASA's Mars programme is taking shape. The agency has narrowed down — from eight to three — the list of potential landing sites for its 2020 rover, which will scoop up Martian rock and soil in the hope of one day returning samples to Earth.

NASA shortlisted the sites on 10 February, at the end of a three-day workshop in Monrovia, California to hash out where the spacecraft will go. The final decision, due a year or two before launch, will be one of the most momentous in Mars exploration. The rocks that the Mars 2020 rover collects are likely to dictate the scientific questions that will be tested for decades to come.

"What if this is the only set of samples that we ever return from a known place on Mars?" asks Briony Horgan, a planetary scientist at Purdue University in West Lafayette, Indiana. Until now, the only Mars rocks that researchers have studied are meteorites, which reach Earth stripped of their original geological context.

The three landing sites still in contention include Jezero crater, which was once home to an ancient Martian lake and could preserve the remains of microbial life, if that ever existed on Mars. "You've got a large river bringing water and sediment into a very large lake, comparable to Lake Tahoe," says Timothy Goudge, a planetary scientist at the University of Texas at Austin. Jezero scored highest in a community vote of scientists attending the workshop.

Other possible targets are Northeast Syrtis (NE Syrtis), where hot waters once circulated through the crust and could have supported life, and Columbia Hills, the area explored for years by NASA's Spirit rover.

Unlike Jezero and NE Syrtis, Columbia ▸

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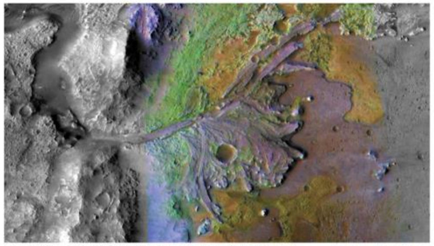

A deltalike fan in Jezero crater shows where water would have flowed into the lake-filled crater, transporting clay minerals and, possibly, organic molecules. NASA/JPL/JHUAPL/MSSS/Brown University

Jezero crater most popular scientific target on Mars for NASA's 2020 rover

By Paul Voosen | Feb. 10, 2017, 4:45 PM

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PLANETARY SCIENCES | Project Update

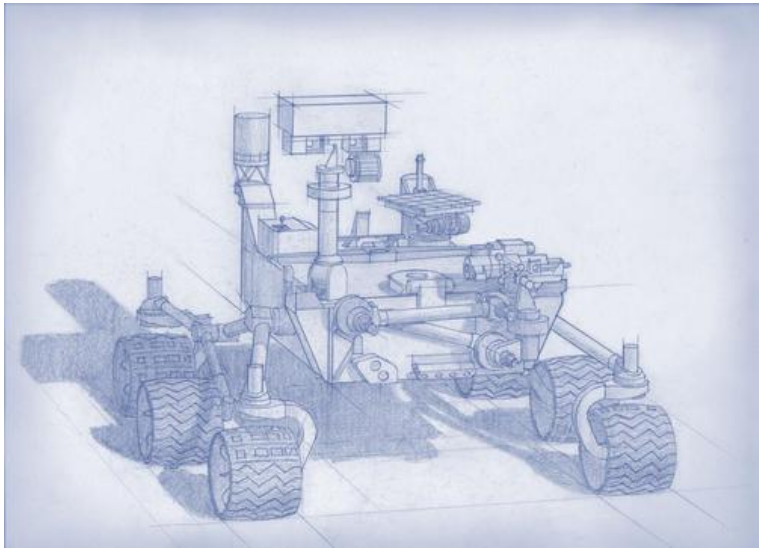
Seeking Signs of Life and More: NASA's Mars 2020 Mission

The next Mars rover will be able to land near rugged terrain, giving scientists access to diverse landscapes. It will also cache core samples, a first step in the quest to return samples to Earth.

Project Overview

Salient Features

- *Category: 1*
- *Risk Class: A-tailored*
- *Directed, JPL in-house implementation*
- *High heritage MSL design*
- *Modifications only as necessary to accommodate new payload and Sampling / Caching System (SCS)*
- *Planetary Protection Category V per Program direction*



Science (https://mars.nasa.gov/mars2020/mission/science/objectives/)

- *Characterize the processes that formed and modified the geologic record within a field exploration area on Mars selected for evidence of an astrobiologically-relevant ancient environment and geologic diversity.*
- *Perform the following astrobiologically relevant investigations on the geologic materials at the landing site:*
  1. *Determine the habitability of an ancient environment.*
  2. *For ancient environments interpreted to have been habitable, search for materials with high biosignature preservation potential.*
  3. *Search for potential evidence of past life using the observations regarding habitability and preservation as a guide.*
- Assemble rigorously documented and returnable cached samples for possible future return to Earth.
- *Contribute to the preparation for human exploration of Mars by making significant progress towards filling at least one major Strategic Knowledge Gap (SKG).*

Mission Overview

LAUNCH

- Atlas V 541 vehicle
- Launch Readiness Date: July 2020
- Launch window: July/August 2020

CRUISE/APPROACH

- ~7 month cruise
- Arrive Feb 2021

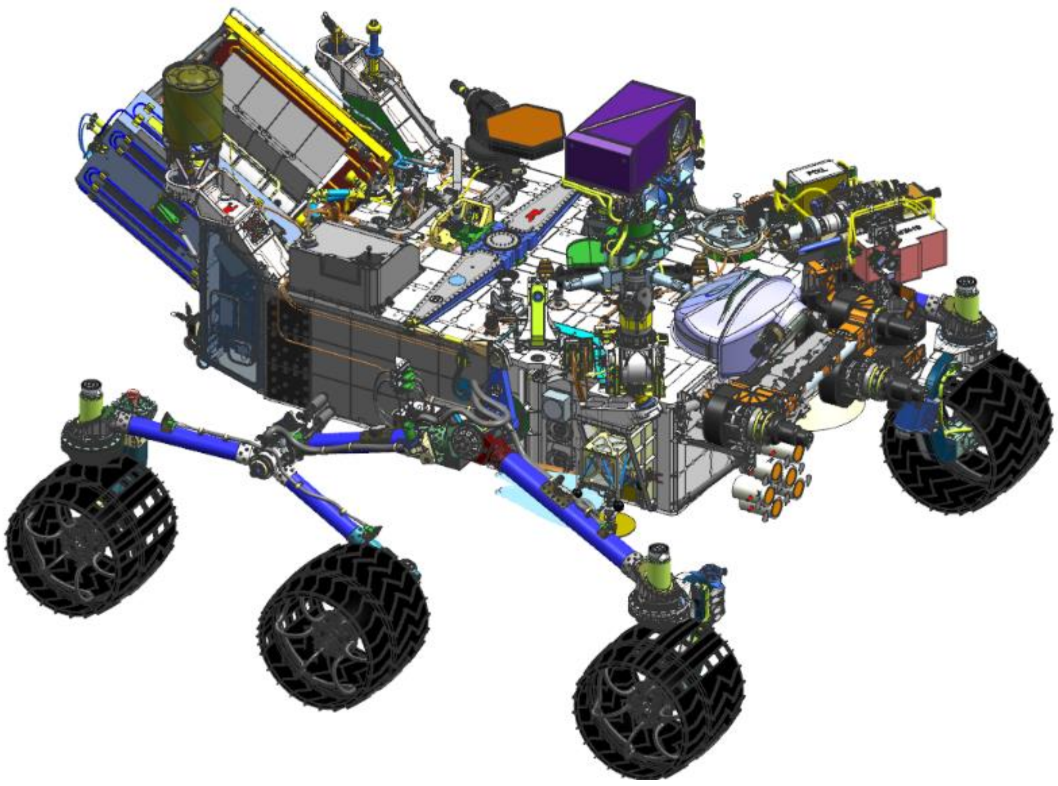
ENTRY, DESCENT & LANDING

- MSL EDL system (+ Range Trigger and Terrain Relative Navigation): guided entry and powered descent/Sky Crane
- 16 x 14 km landing ellipse (range trigger baselined)
- Access to landing sites ±30° latitude, ≤ -0.5 km elevation
- Curiosity-class Rover

SURFACE MISSION

- 20 km traverse distance capability
- Enhanced surface productivity
- Qualified to 1.5 Martian year lifetime
- Seeking signs of past life
- Returnable cache of samples
- Prepare for human exploration of Mars

Mars 2020 Rover Concept



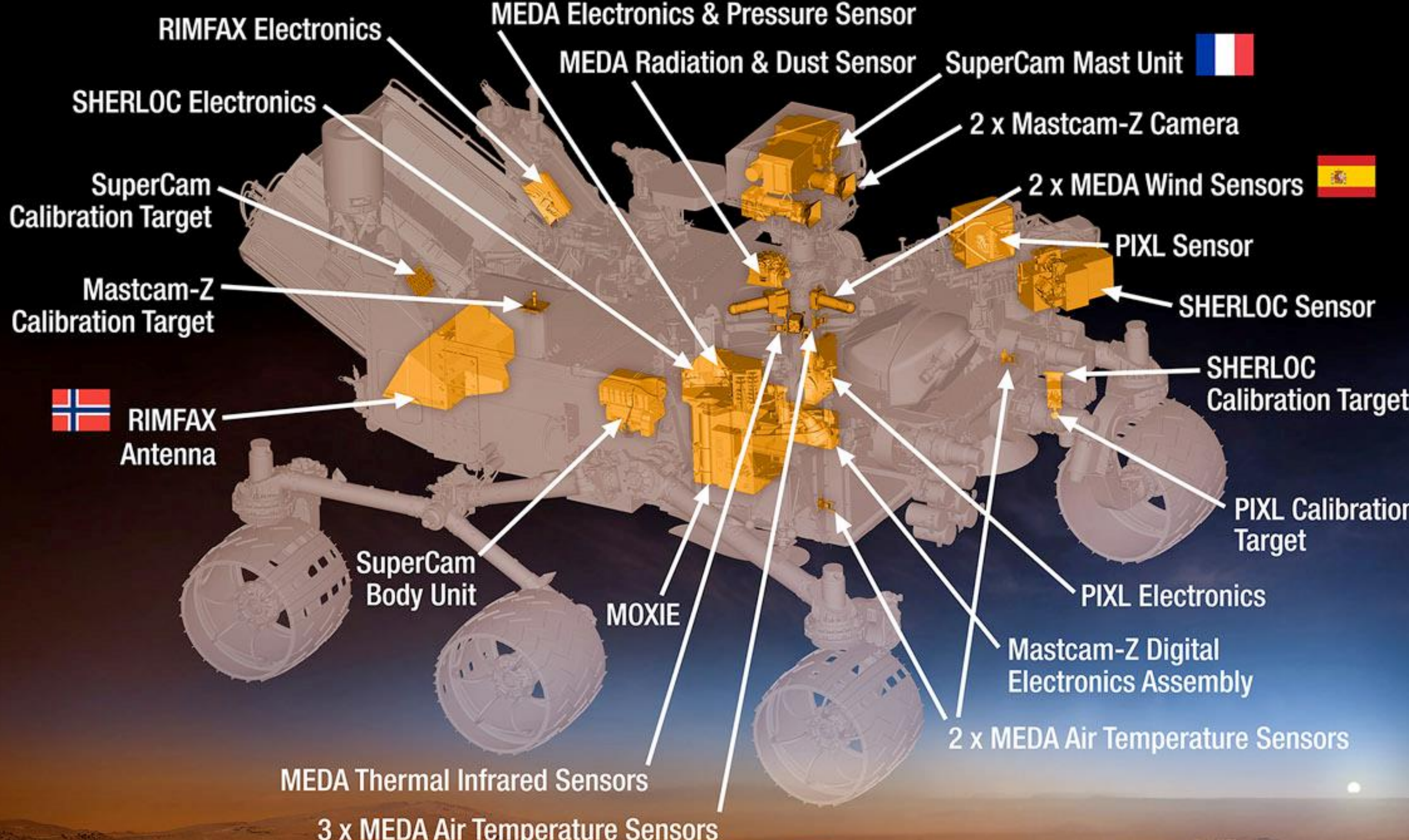
Stays the Same as MSL

- Avionics
- Power
- GN&C
- Telecom
- Thermal
- Mobility

Changed

- New Science Instrument Suite
- New Sampling Caching System
- Modified Chassis
- Modified Rover Harness
- Modified Surface FSW
- Modified Rover Motor Controller
- Modified Wheels

Mars 2020 Rover



https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA19672

THANK YOU!

QUESTIONS?