

Mars Science Laboratory: Mission Overview & Some Challenges

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Jet Propulsion Laboratory
California Institute of Technology

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Government sponsorship acknowledge

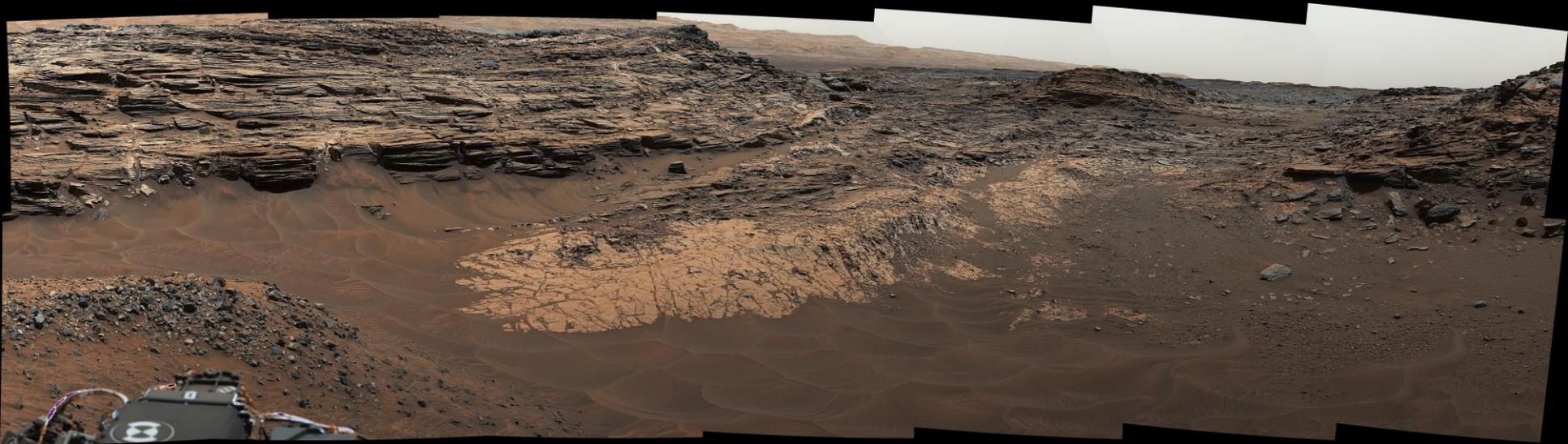


CURI  SITY

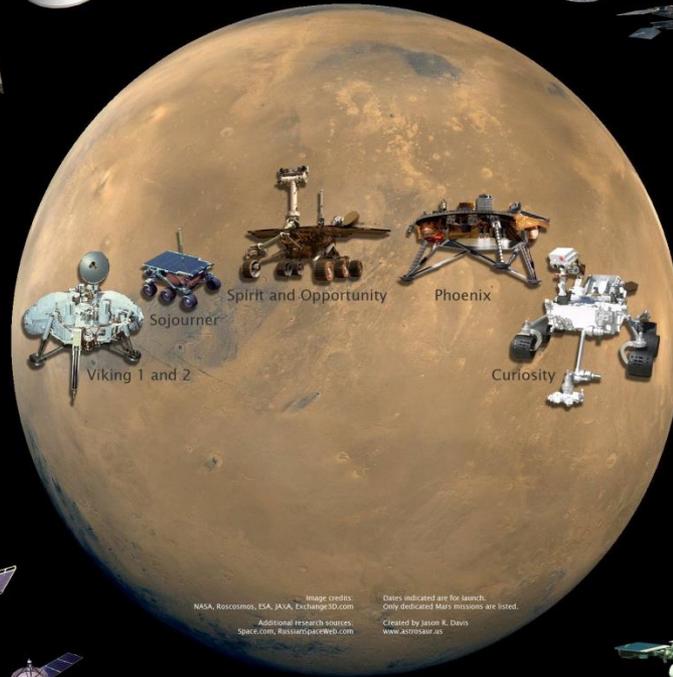
Acknowledgements

**There are nearly 500 scientists and
~200 engineers (and managers)
working on the Mars Science Laboratory mission...**

I am merely a messenger



Mars Exploration Family Portrait



40: Mars Science Laboratory Curiosity
November 26, 2011
Mission to Gale Crater

1, 2: MARS 1M No. 1 / MARS 1M No. 2
October 10 / October 14, 1960
Both destroyed during launch

3, 4, 5, 8: MARS 2MV-4 No. 1 / Mars 1 / Mars 2MV-3 No. 1 / Zond 2
October 24 / November 1 / November 4, 1962 / November 30, 1964
Broke up in Earth orbit / Radio failure en route / Stranded in Earth orbit / Radio failure en route

6, 7: Mariner 3 / Mariner 4
November 5 / November 28, 1964
Payload fairing failed to open / First flyby and picture return

9, 10: Mariner 6 / Mariner 7
February 25 / March 27, 1969
Both flew by, returned pictures

11, 12: Mars 1969 A / Mars 1969 B
March 27 / April 2, 1969
Both destroyed during launch

13, 17: Mariner 8 / Mariner 9
May 8 / May 30, 1971
Destroyed during launch / First probe to orbit Mars

14, 15, 16: Cosmos 419 / Mars 2 / Mars 3
May 10 / May 19 / May 28, 1971
Failed in Earth orbit / Lander crashed / Lander failed

18, 19, 20, 21: Mars 4 / Mars 5 / Mars 6 / Mars 7
July 21 / July 25 / August 5 / August 9, 1973
Missed planet / Orbed planet / Lander failed (6 and 7)

22, 23: Viking 1 / Viking 2
August 20 / September 9, 1975
Both landed on surface, returned data

24, 25: Phobos 1 / Phobos 2
July 7 / July 12, 1988
Lost communication en route / Lost communication near Phobos

26: Mars Observer
September 25, 1992
Lost communication near Mars

27: Mars Global Surveyor
November 7, 1996
Orbited and returned data

28: Mars 96
November 16, 1996
Destroyed during launch

29: Mars Pathfinder
December 4, 1996
Landed on surface, deployed Sojourner rover

30: Nozomi
July 4, 1998
Missed planet

31: Mars Climate Orbiter
December 11, 1998
Crashed due to imperial/metric unit mixup

32: Mars Polar Lander
January 3, 1999
Crashed on surface

33: Mars Odyssey
March 7, 2001
Orbiting Mars

34: Mars Express / Beagle 2 lander
June 2, 2003
Orbiting Mars, Beagle lost after separation

35, 36: Mars Exploration Rovers Spirit and Opportunity
June 10 / July 7, 2003
Both landed on surface, Opportunity still in operation

37: Mars Reconnaissance Orbiter
August 12, 2005
Orbiting Mars

38: Phoenix
August 4, 2007
Landed, dug for water

39: Phobos-Grunt
November 8, 2011
Stranded in Earth orbit

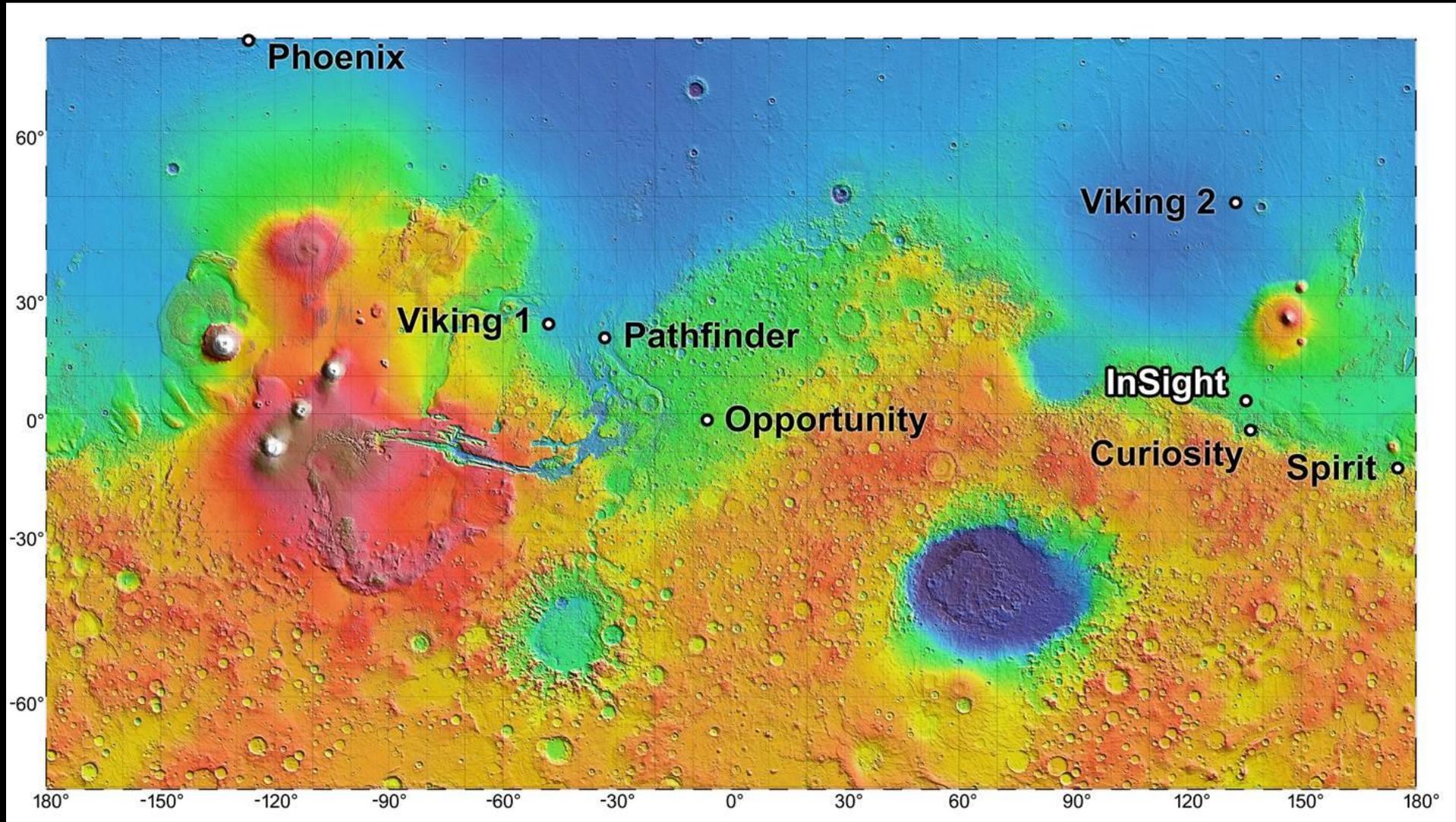
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www.astronaut.as

Mars Science Laboratory Primary Science Goal

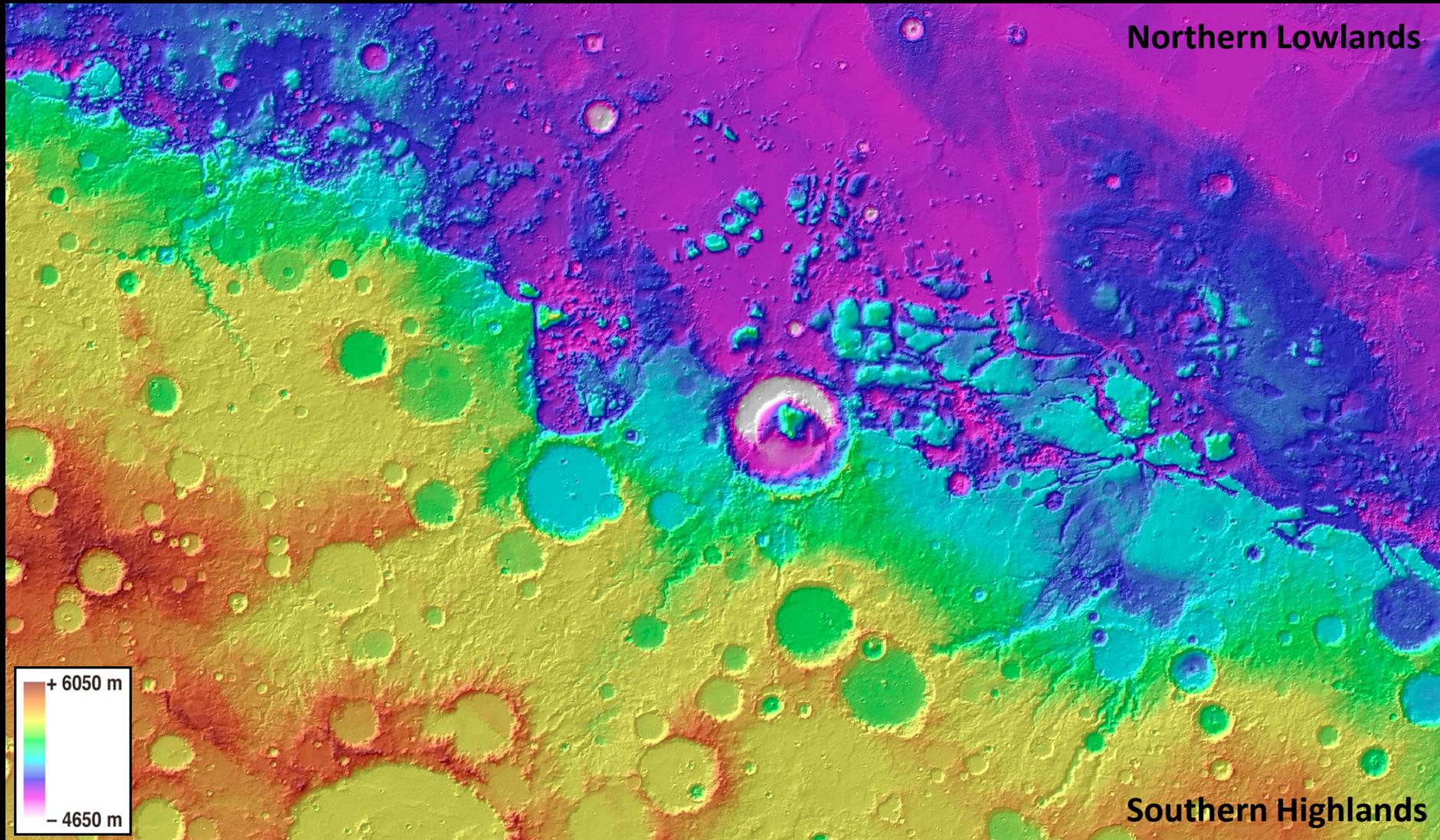
*to explore and quantitatively assess a local region on Mars' surface as a **potential habitat for life**, past or present*



NASA Landing Sites

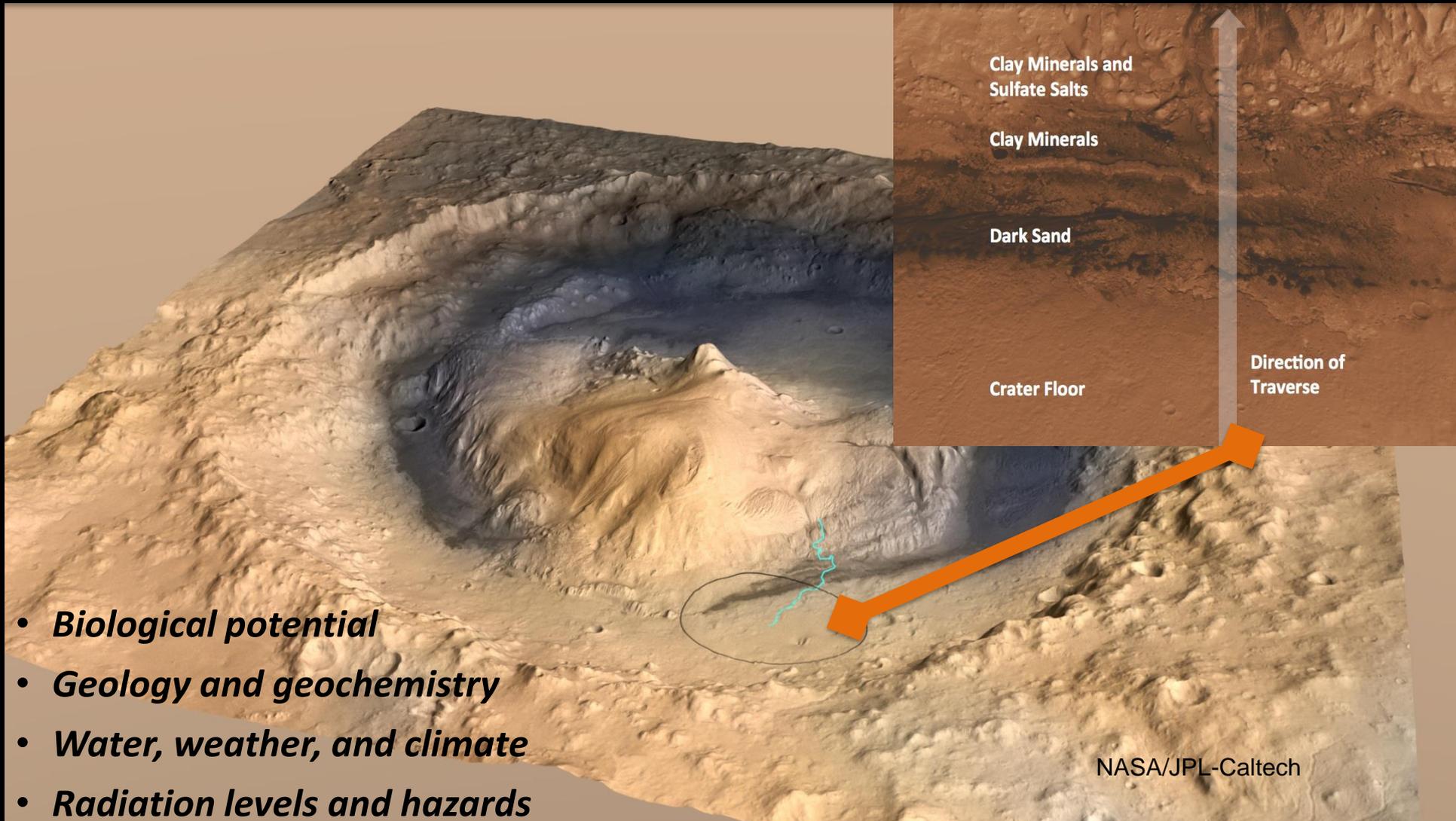


Why Gale Crater?



Mars Science Laboratory Primary Science Goal

*to explore and quantitatively assess a local region on Mars' surface as a **potential habitat for life**, past or present*



Clay Minerals and
Sulfate Salts

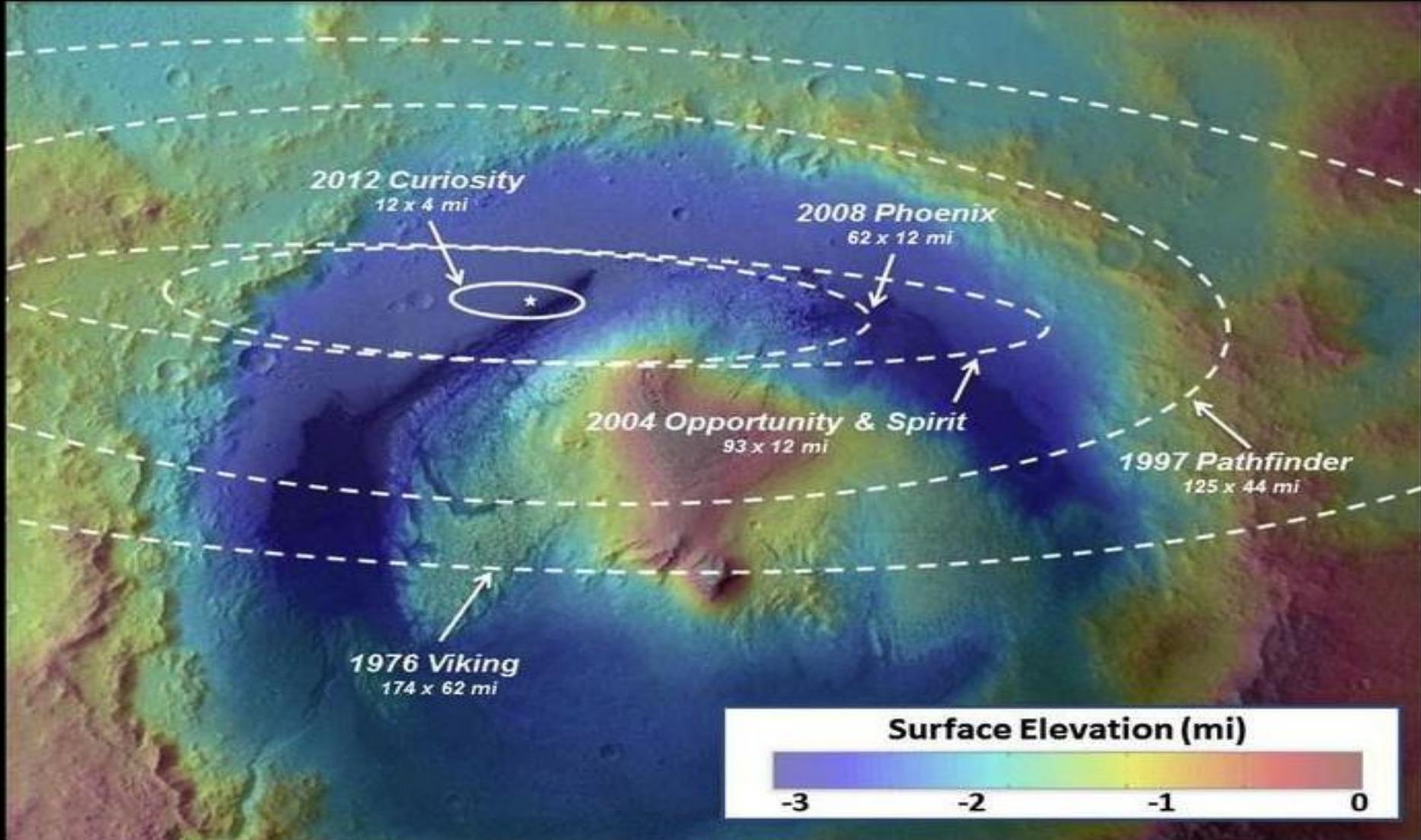
Clay Minerals

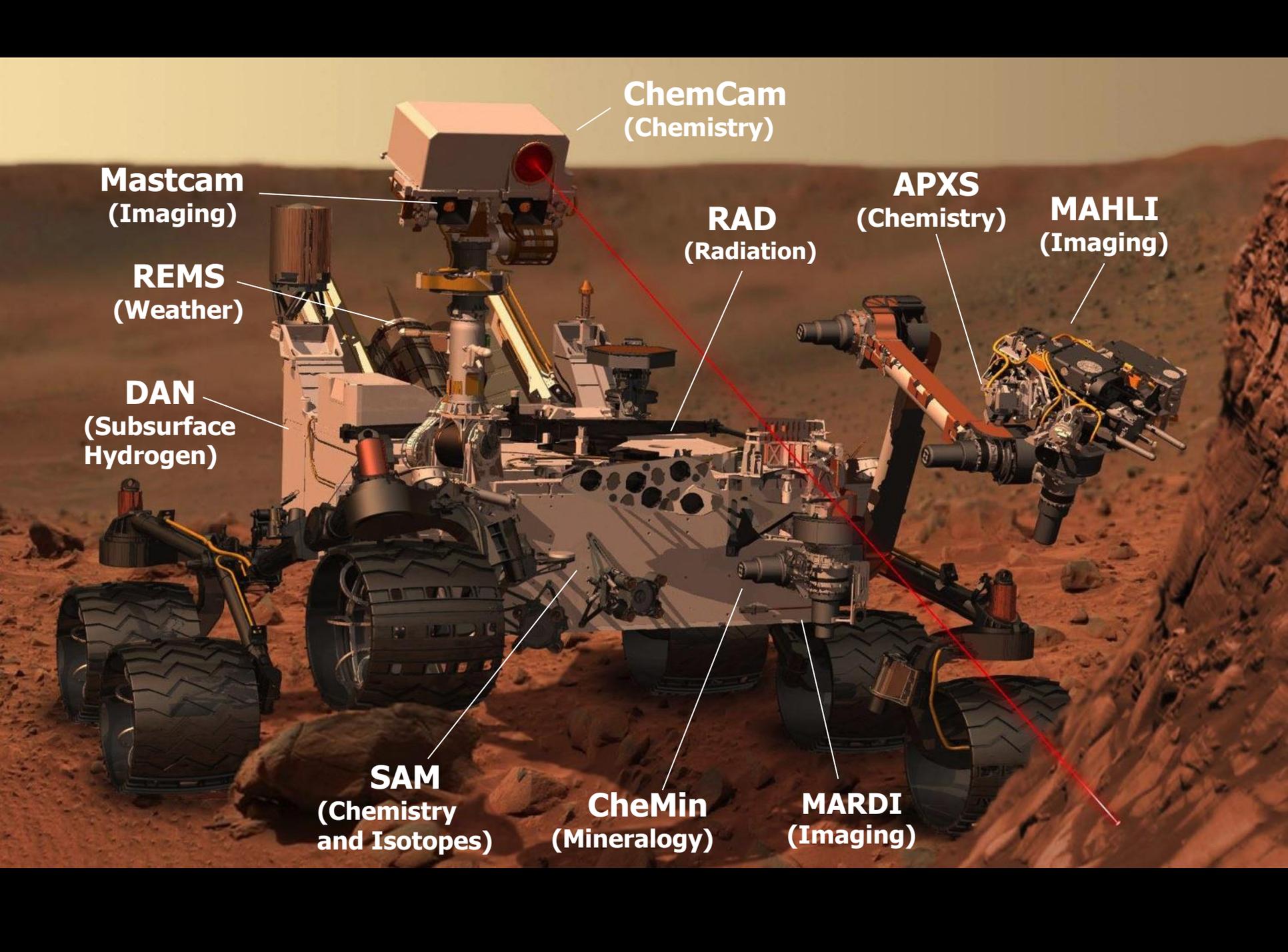
Dark Sand

Crater Floor

Direction of
Traverse

- ***Biological potential***
- ***Geology and geochemistry***
- ***Water, weather, and climate***
- ***Radiation levels and hazards***





ChemCam
(Chemistry)

Mastcam
(Imaging)

APXS
(Chemistry)

MAHLI
(Imaging)

REMS
(Weather)

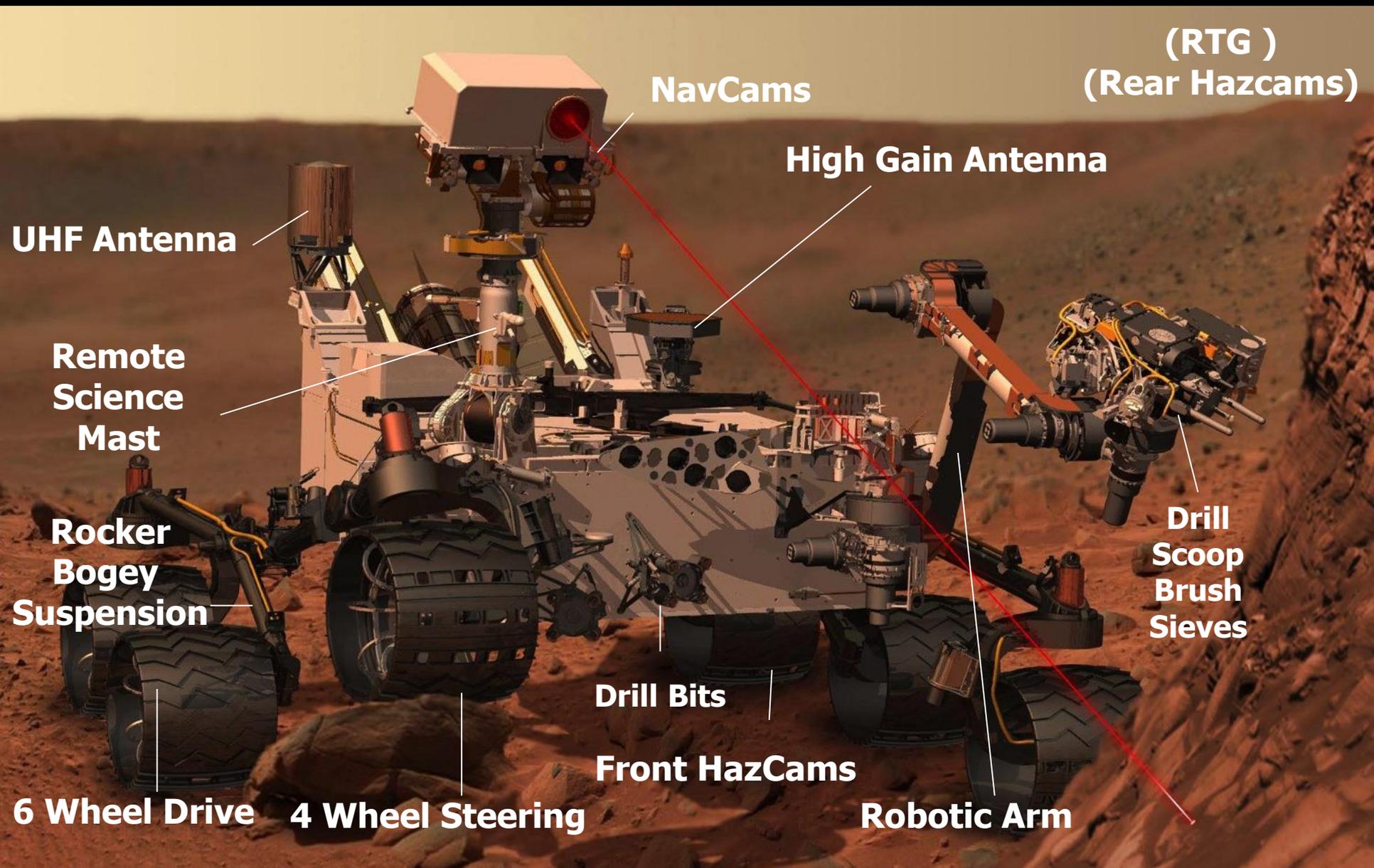
RAD
(Radiation)

DAN
(Subsurface
Hydrogen)

SAM
(Chemistry
and Isotopes)

CheMin
(Mineralogy)

MARDI
(Imaging)



(RTG)

(Rear Hazcams)

NavCams

High Gain Antenna

UHF Antenna

Remote
Science
Mast

Rocker
Bogey
Suspension

6 Wheel Drive

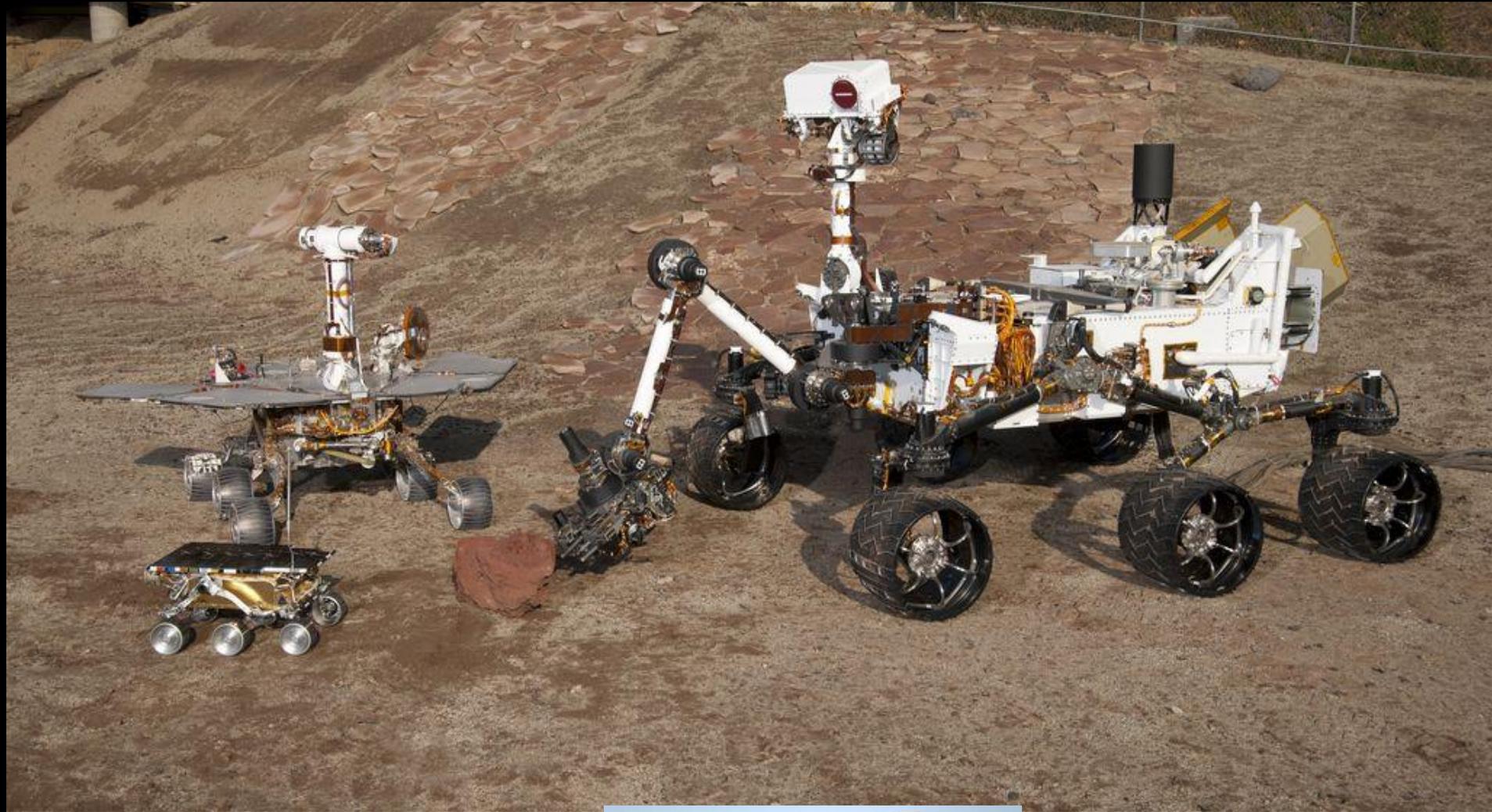
4 Wheel Steering

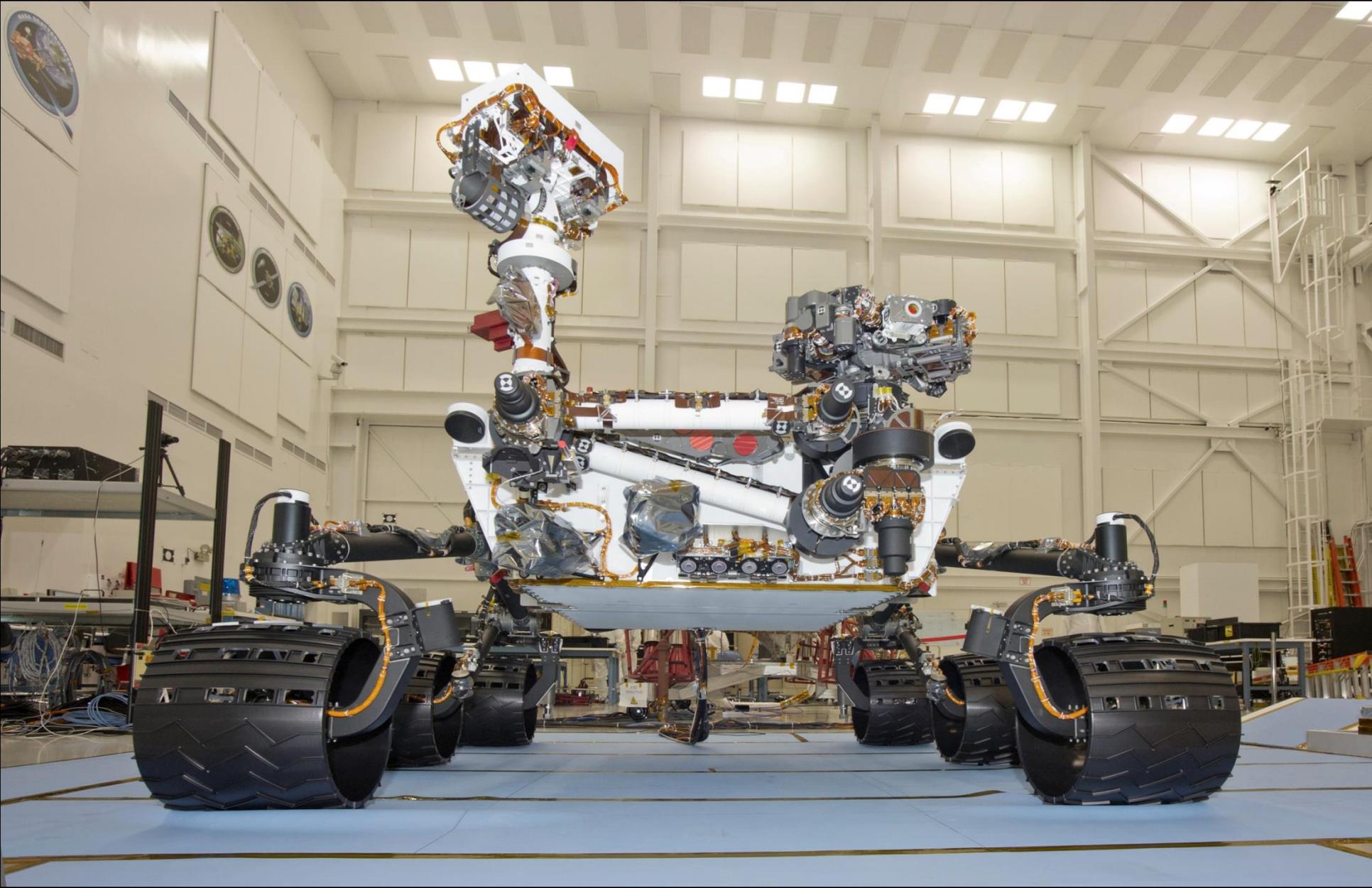
Drill Bits

Front HazCams

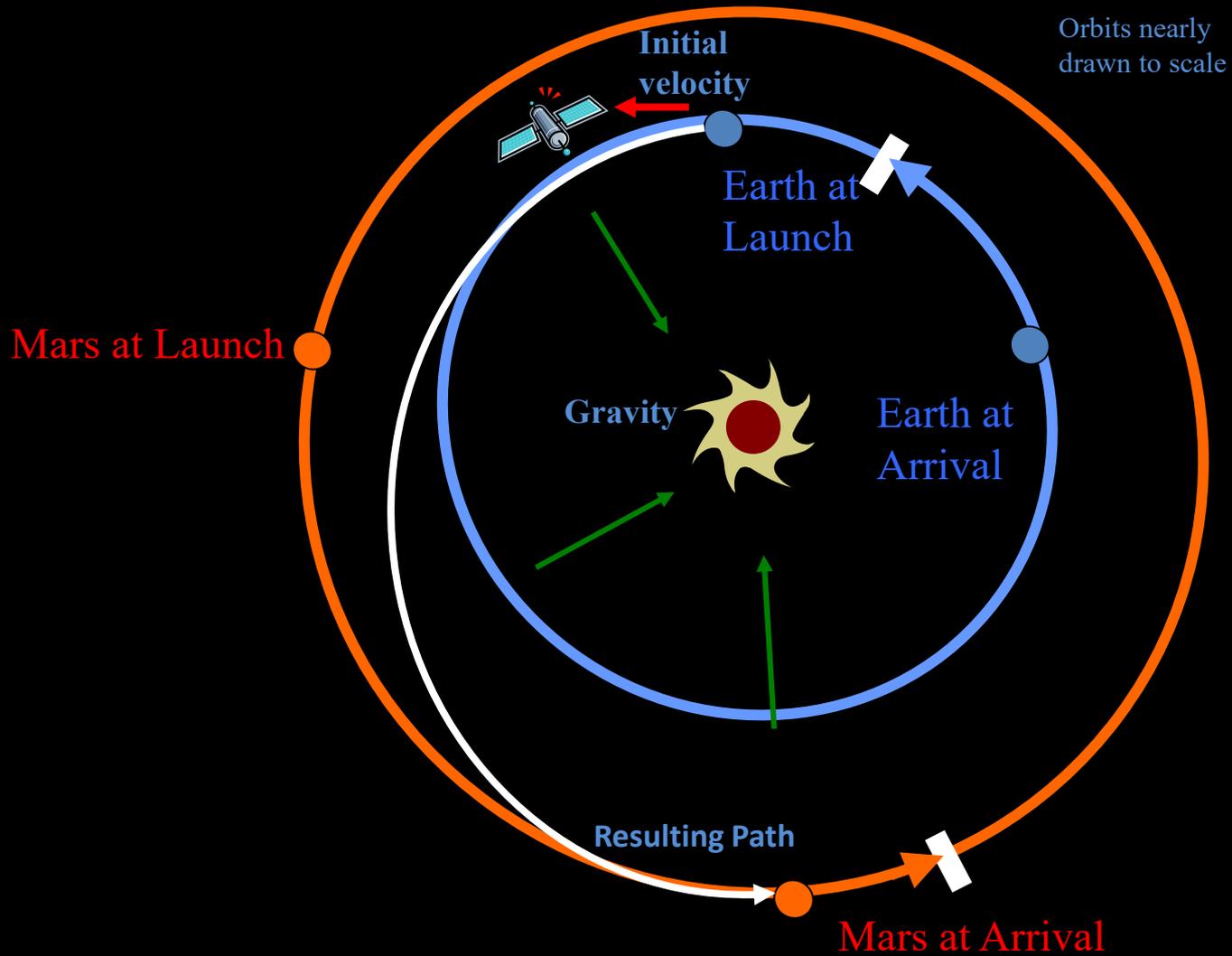
Robotic Arm

Drill
Scoop
Brush
Sieves

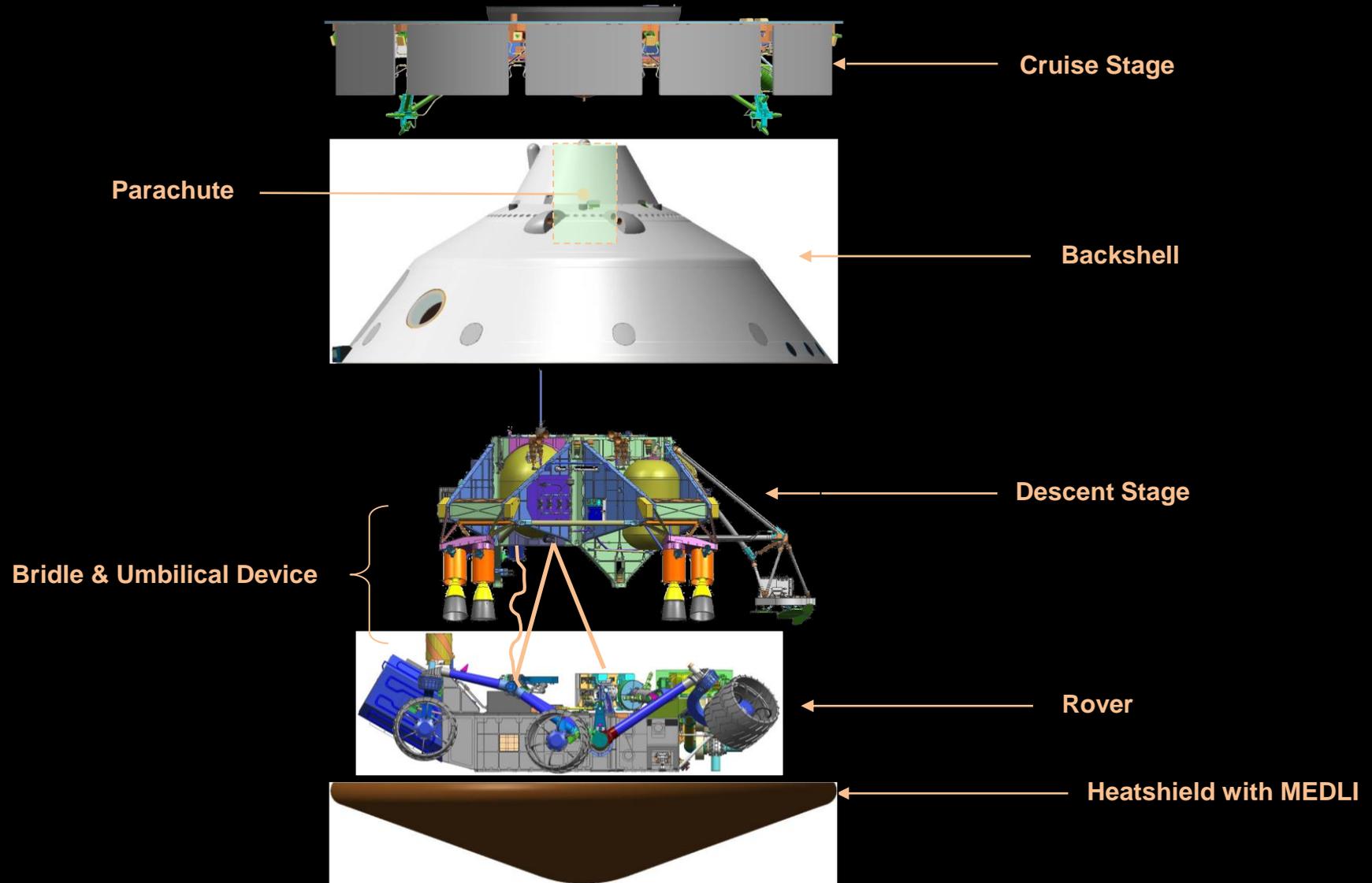




Flight Plan



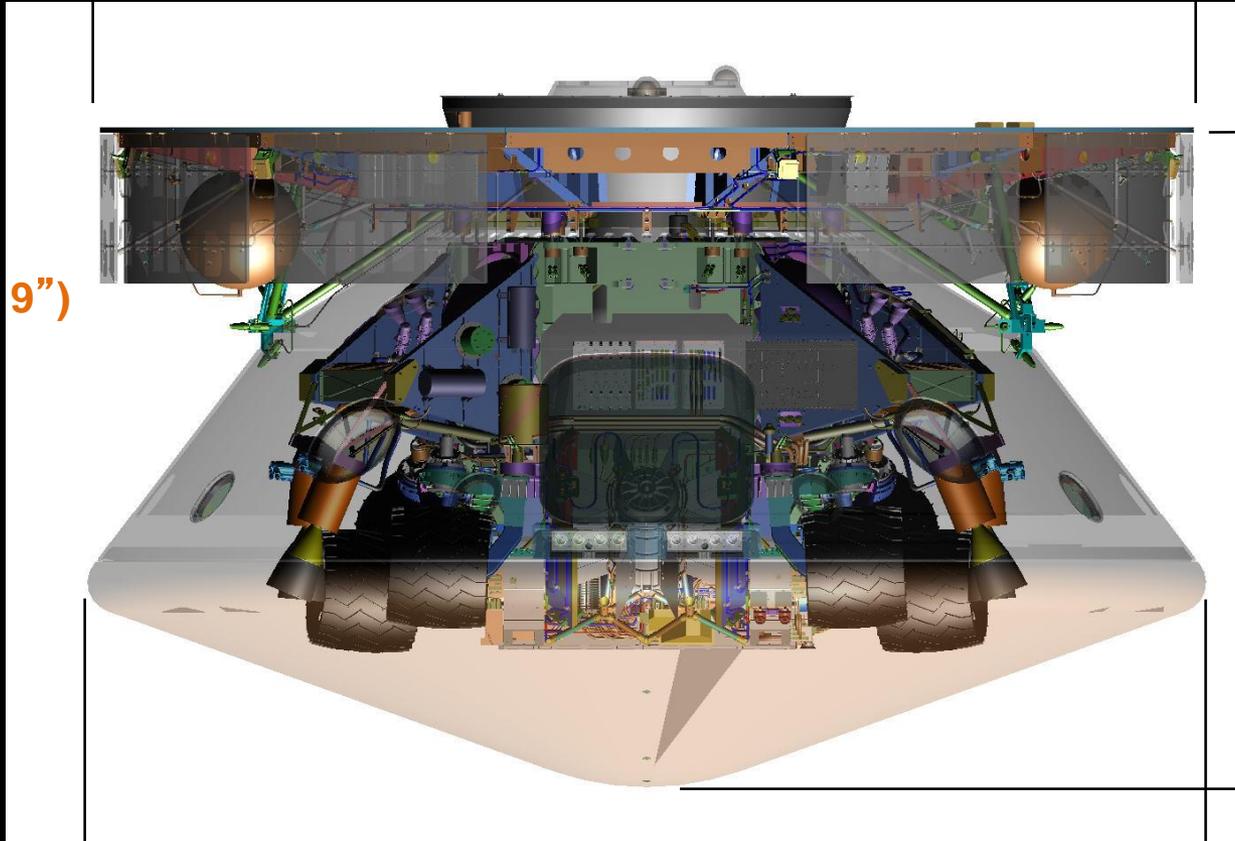
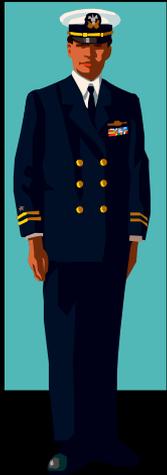
MSL Spacecraft Major Elements



Launch Configuration Dimensions

4400
mm

1750 mm (5' 9")



3690
mm

4500
mm



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Looked a bit like this

ESP_028401_1755
2012-08-17

Descent stage crash site

Backshell and parachute

Curiosity rover

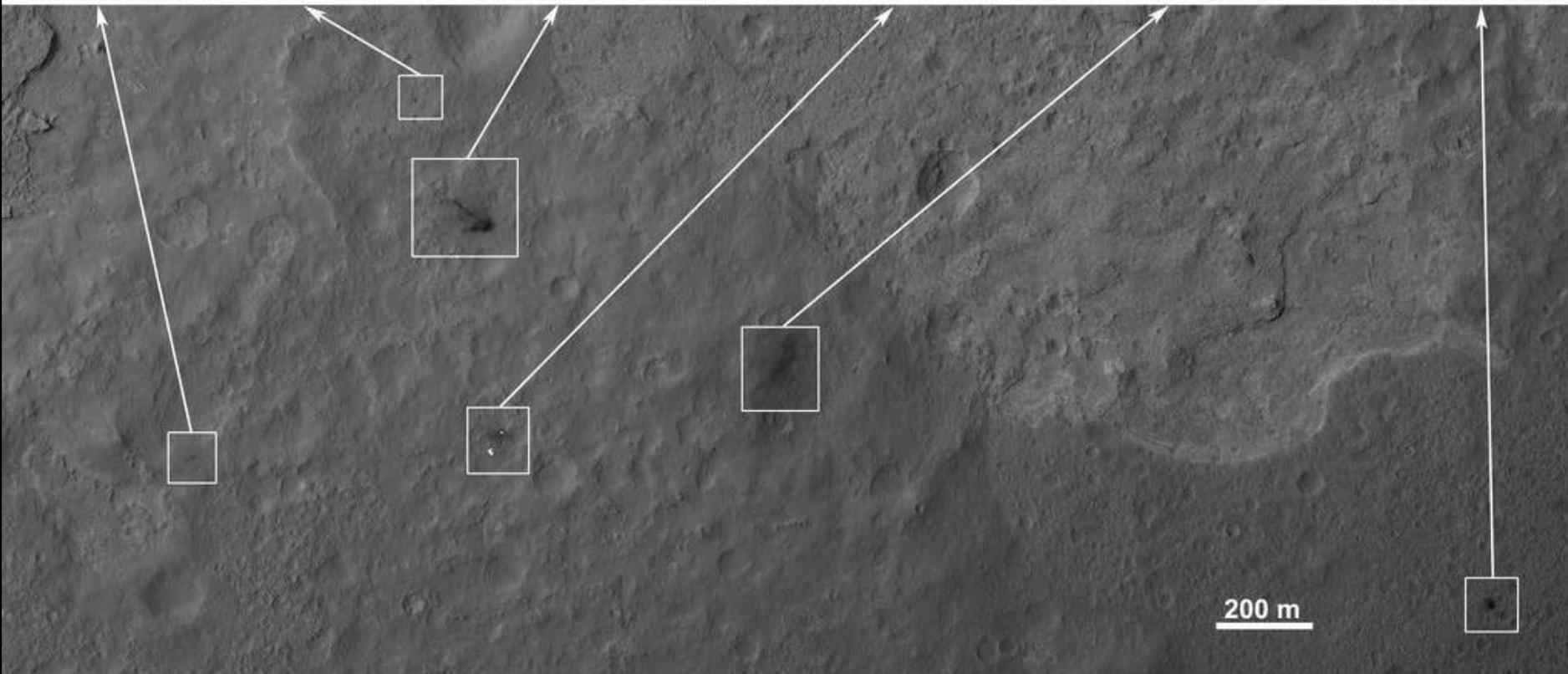
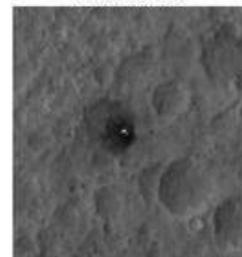
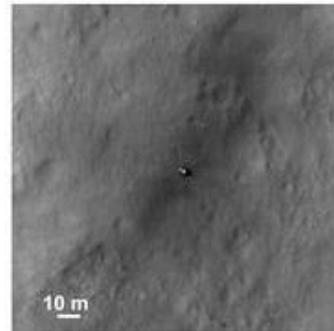
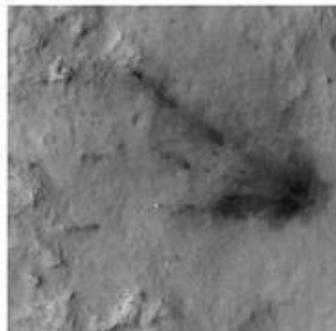
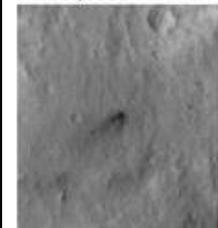
Heat shield

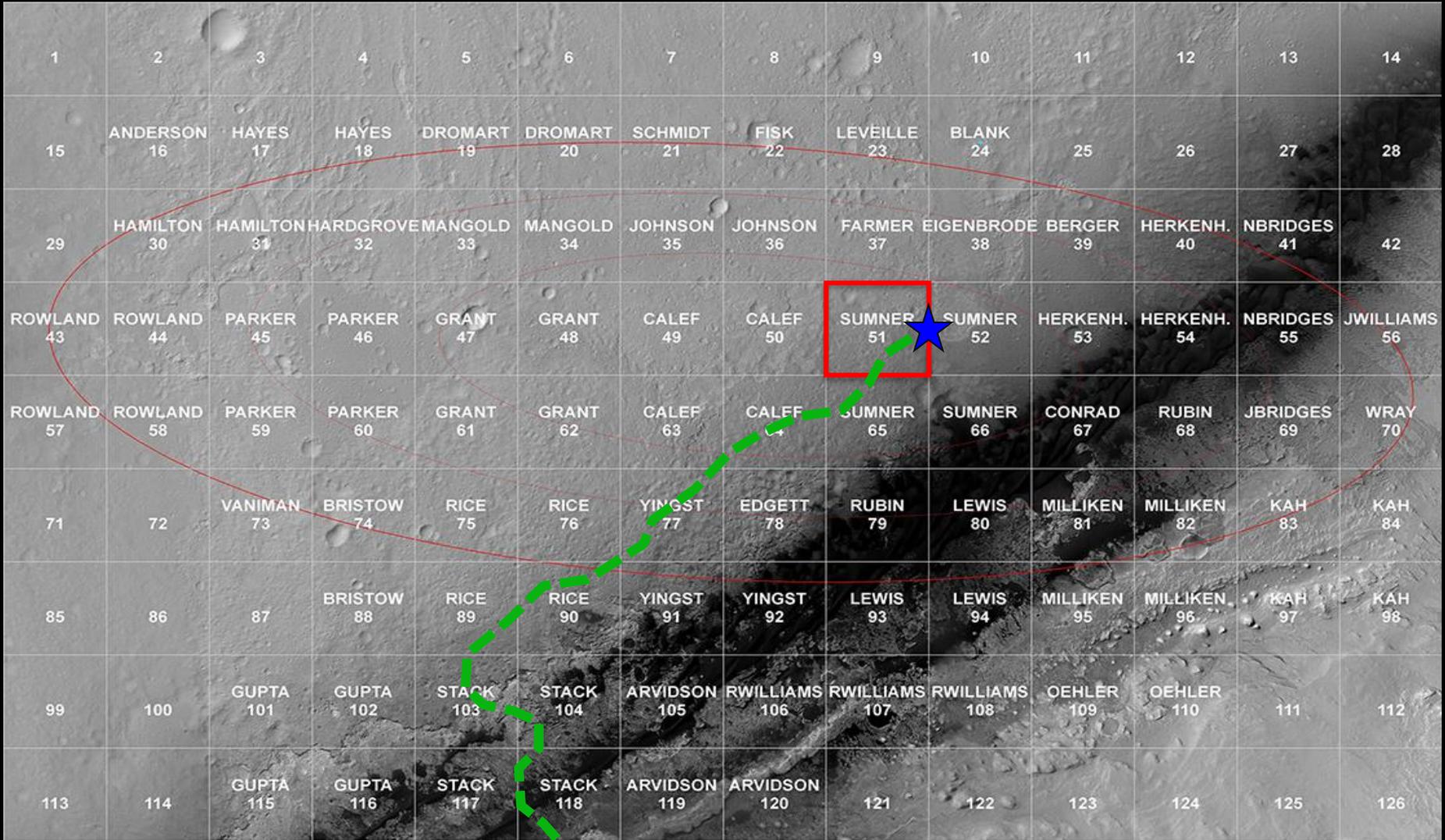
New spot with streak

2 new spots

10 m

200 m





**HUMMOCKY
PLAINS**

**BEDDED
FRACTURED UNIT**

**Bradbury
Landing**

Rocknest

**Yellowknife
Bay**

Rover Tracks

Curiosity

**CRATERED
UNIT**



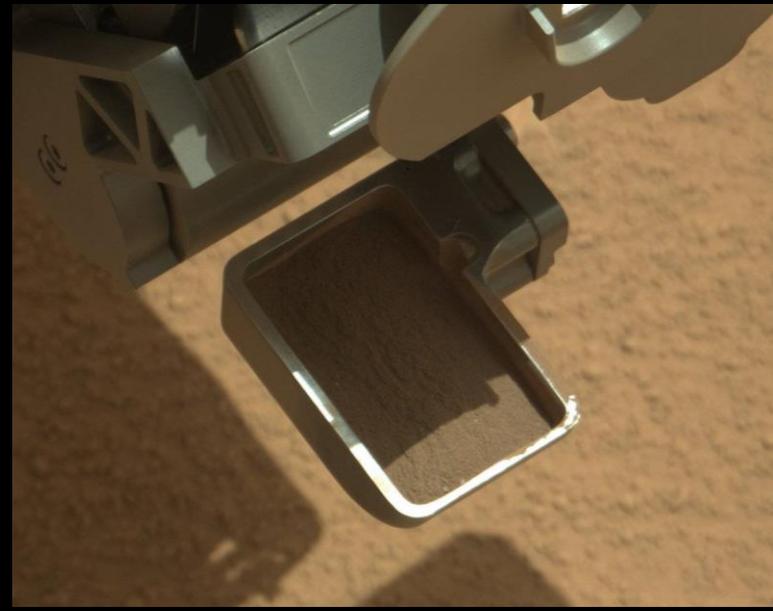




1 cm



NASA/JPL-Caltech/MSSS



Curiosity self-portrait at Rocknest

Assembled from 55
MAHLI images

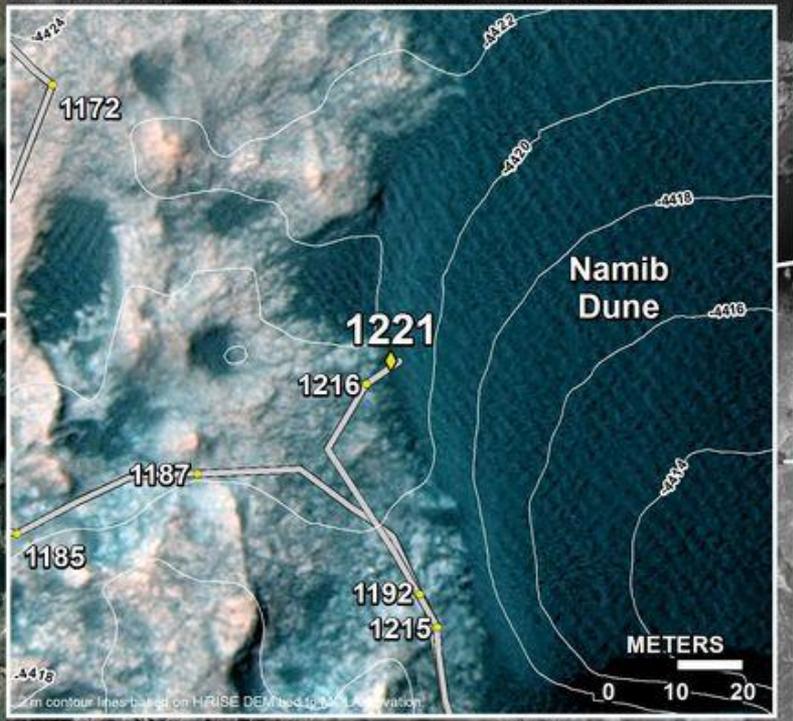
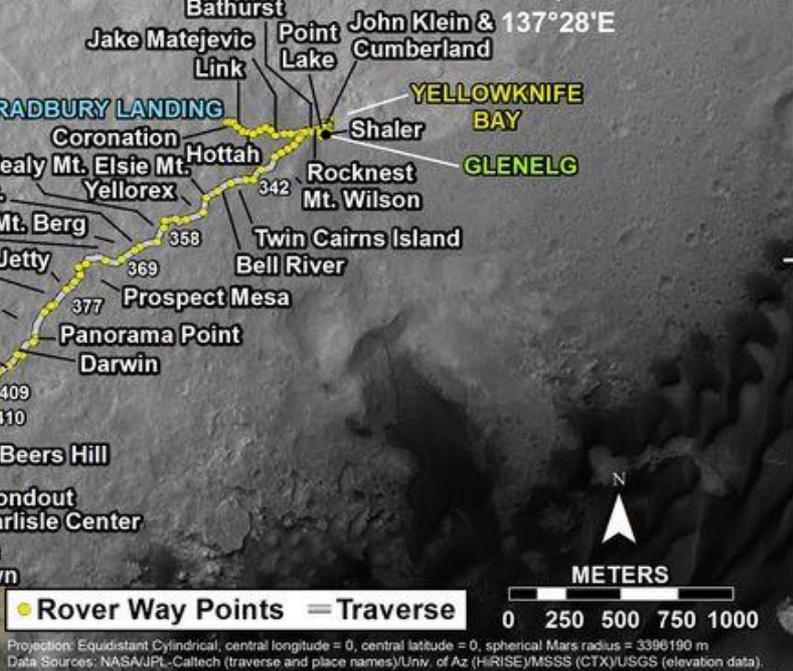
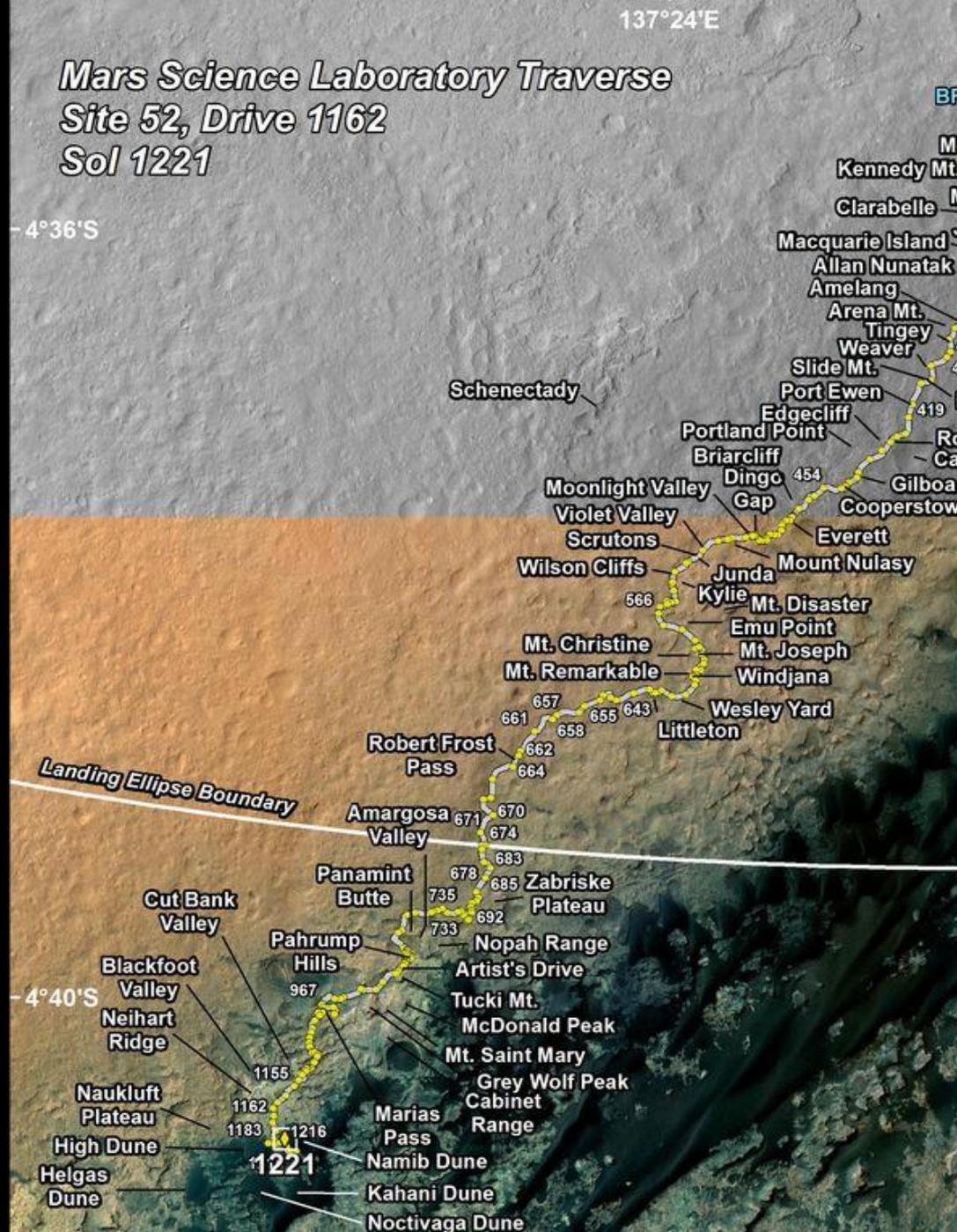


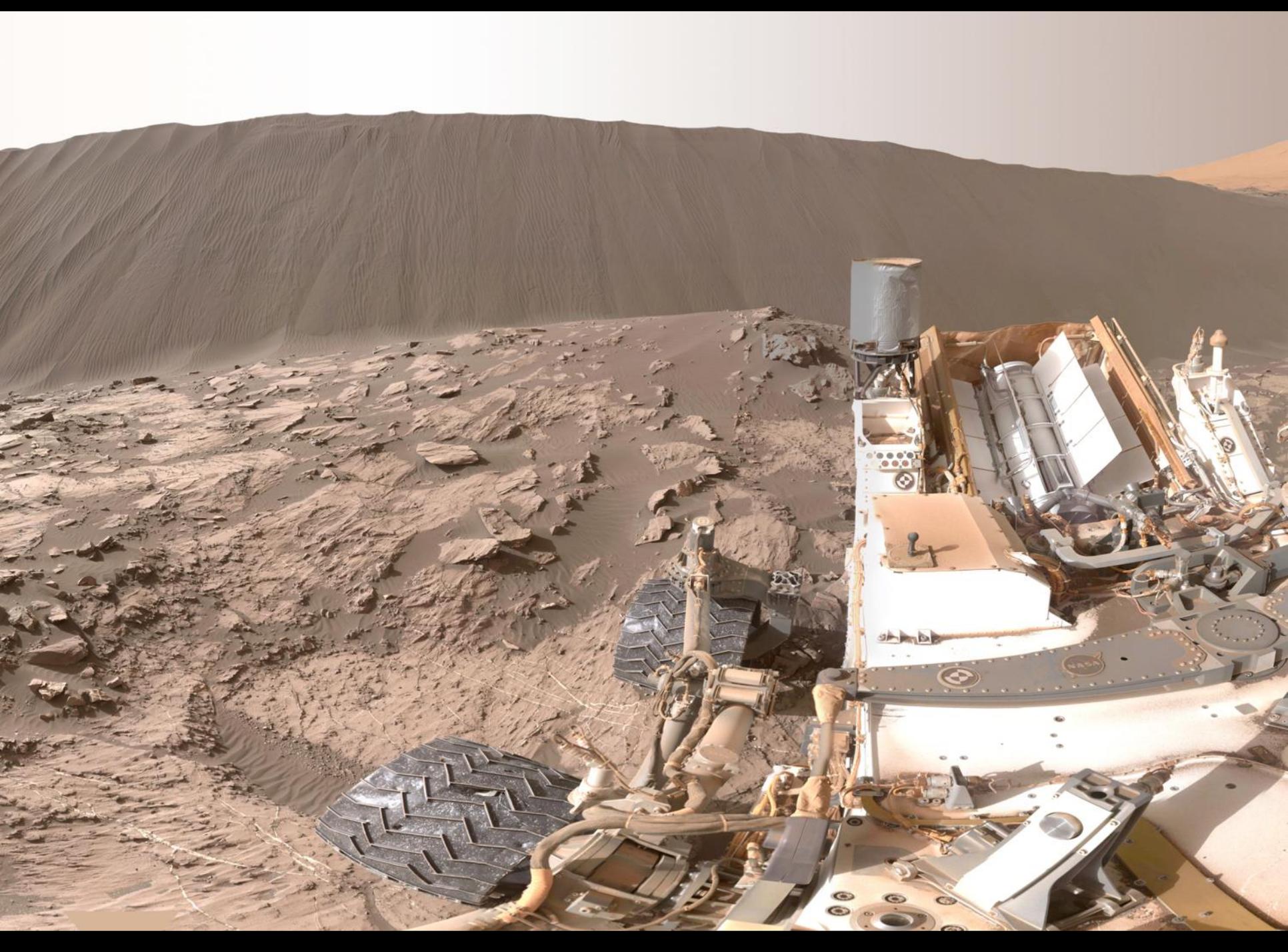
137°24'E

Mars Science Laboratory Traverse Site 52, Drive 1162 Sol 1221

-4°36'S

-4°40'S







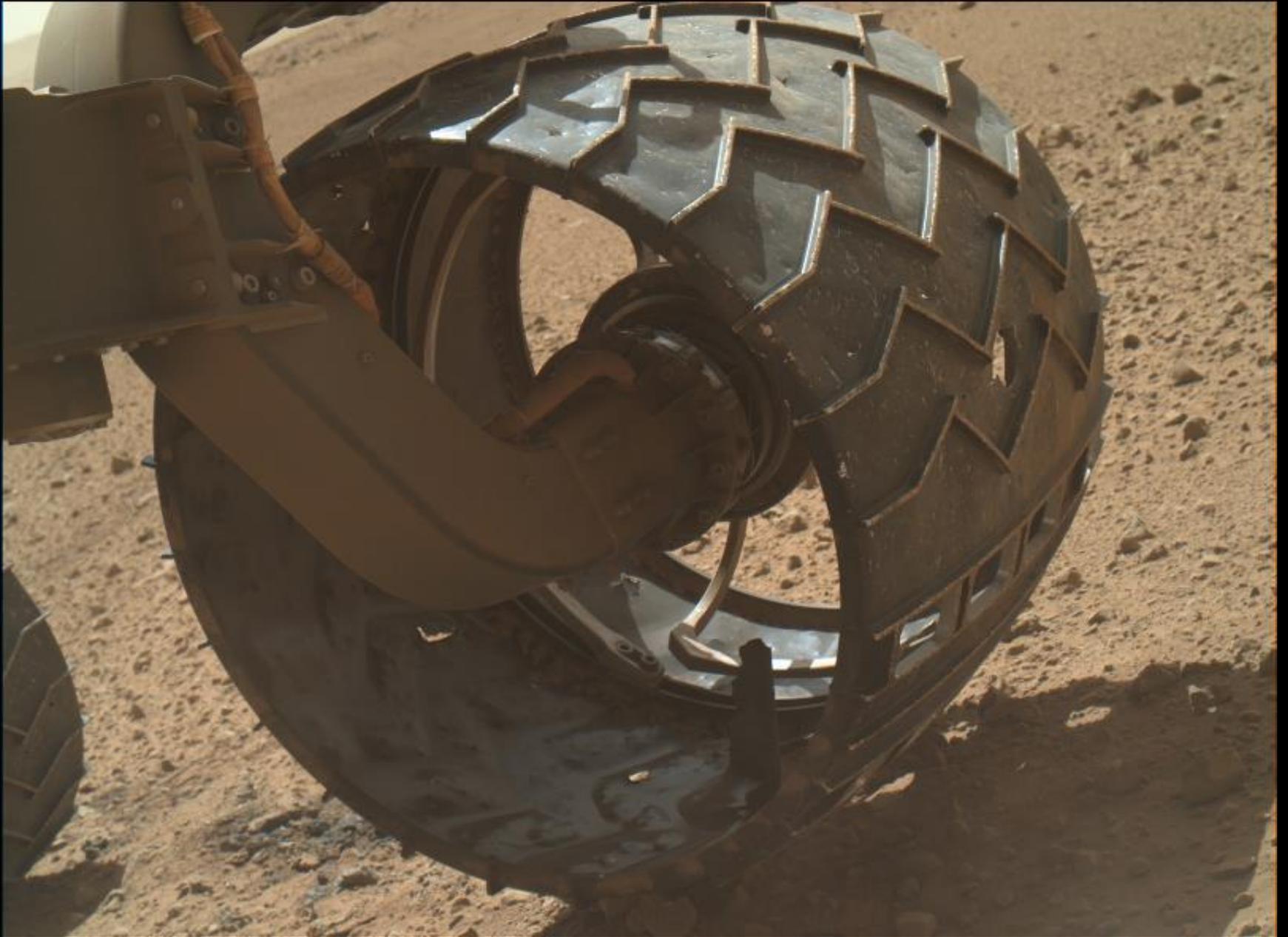
January 23, 2017



January 24, 2017

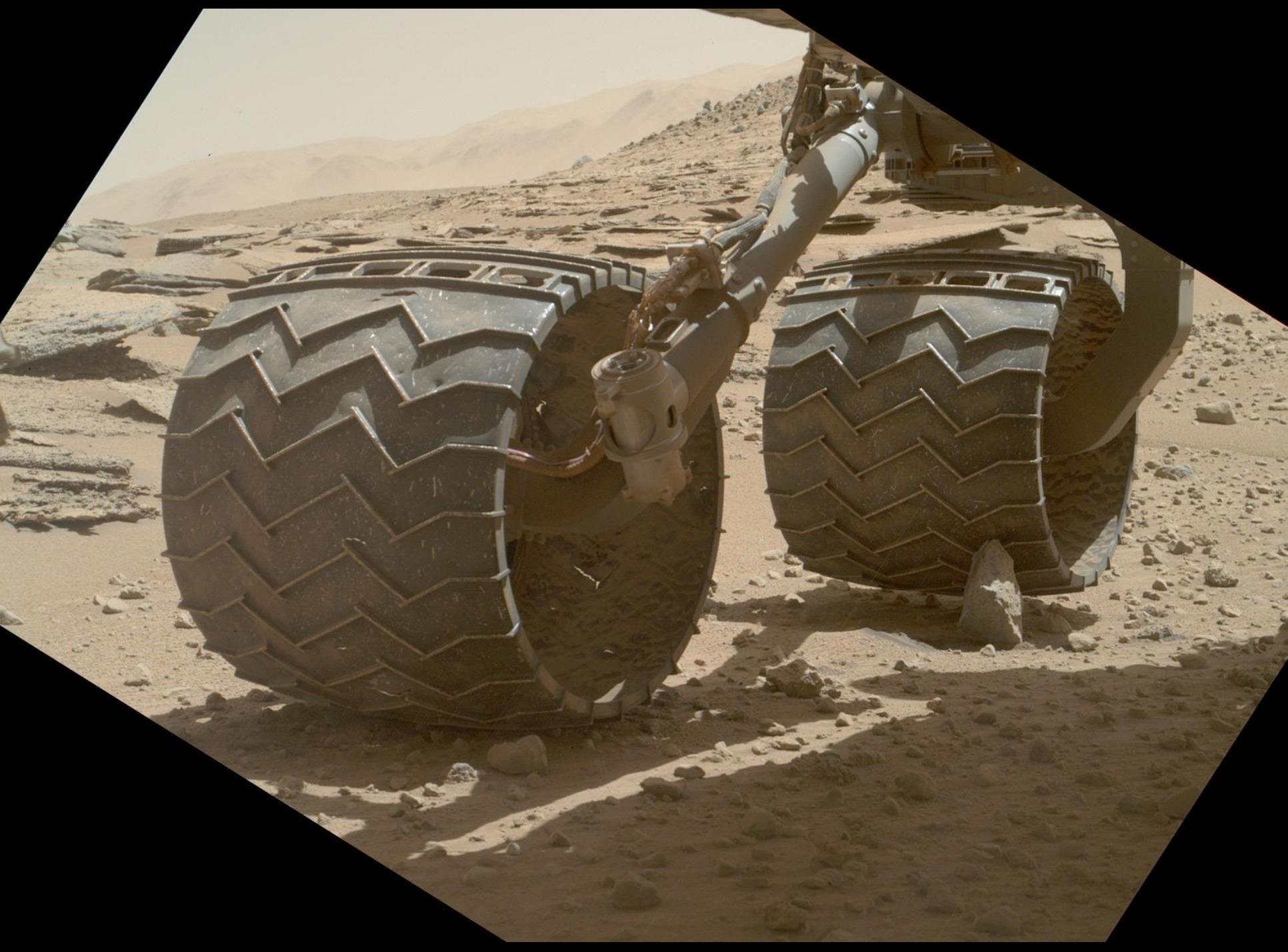






Sol 566

NASA/JPL-Caltech/MSSS





Front Wheel Driving Forward Over The “Impaler”





Wheel Leading
the Pivot

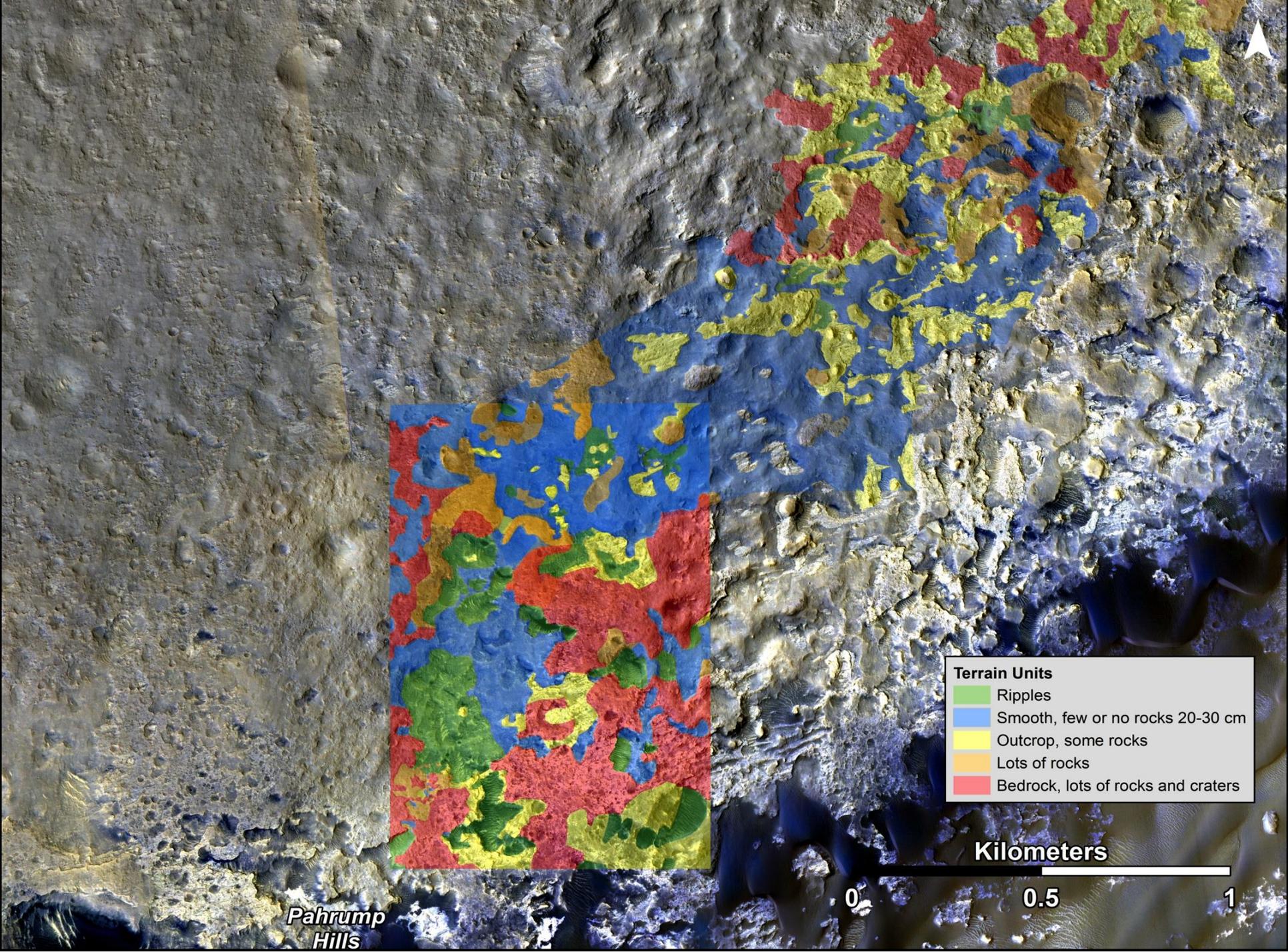
Wheel Trailing
the Pivot





Front Wheel Driving Backward Over The "Impaler"





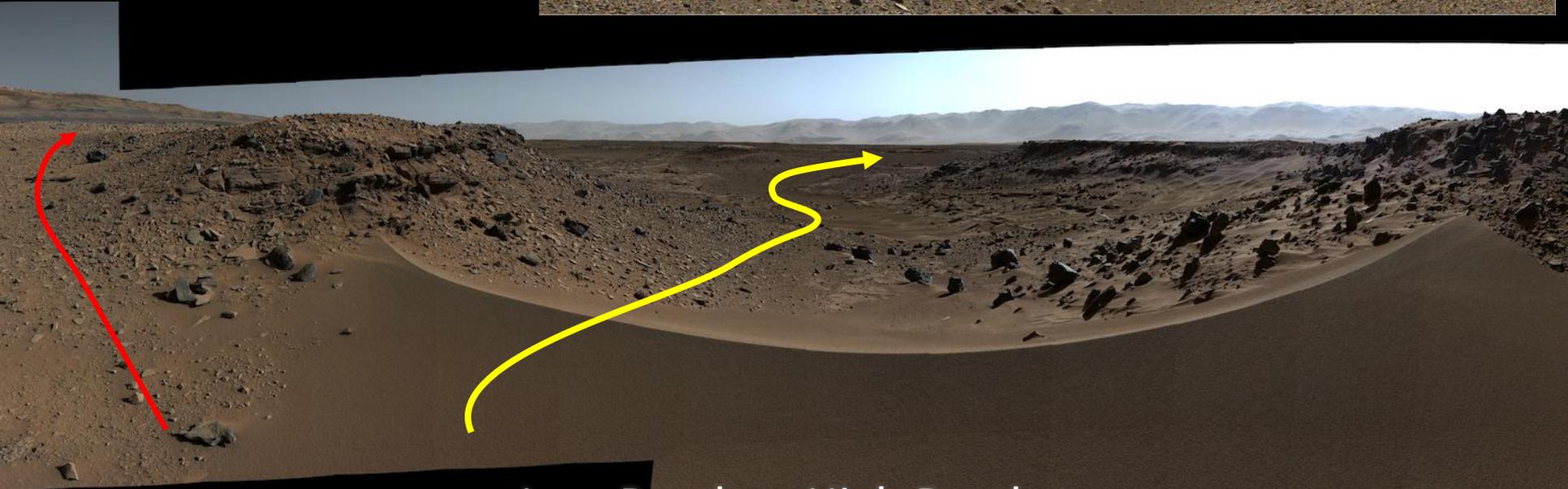
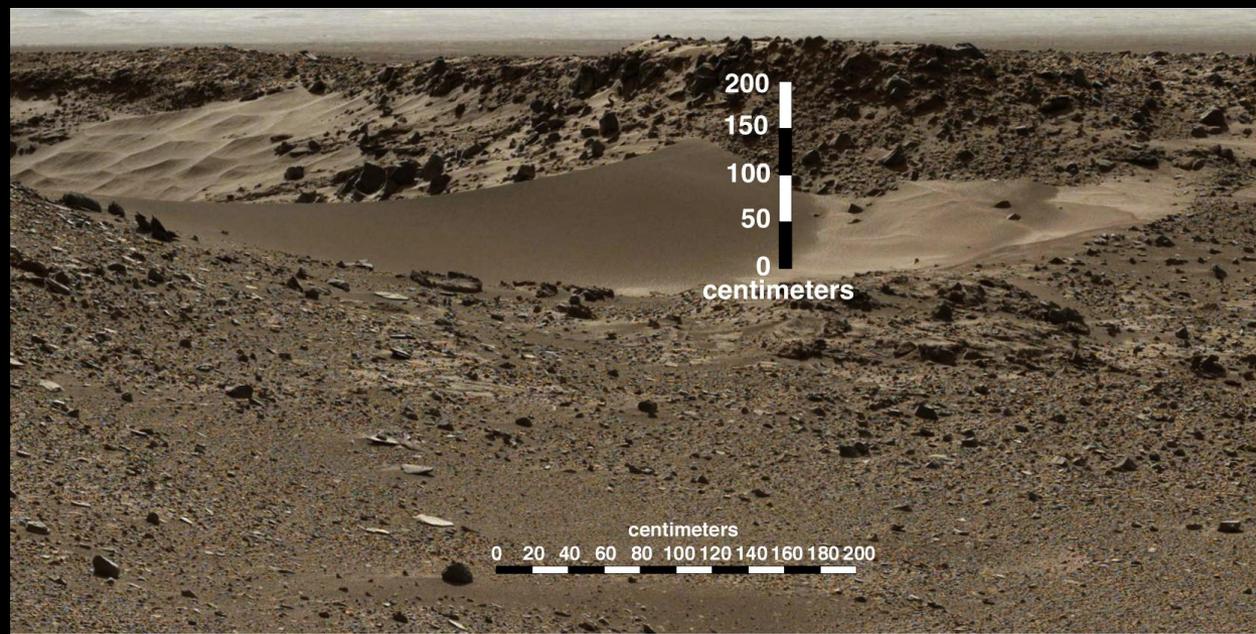
*Pahrump
Hills*

- Terrain Units**
- Ripples
 - Smooth, few or no rocks 20-30 cm
 - Outcrop, some rocks
 - Lots of rocks
 - Bedrock, lots of rocks and craters

Kilometers

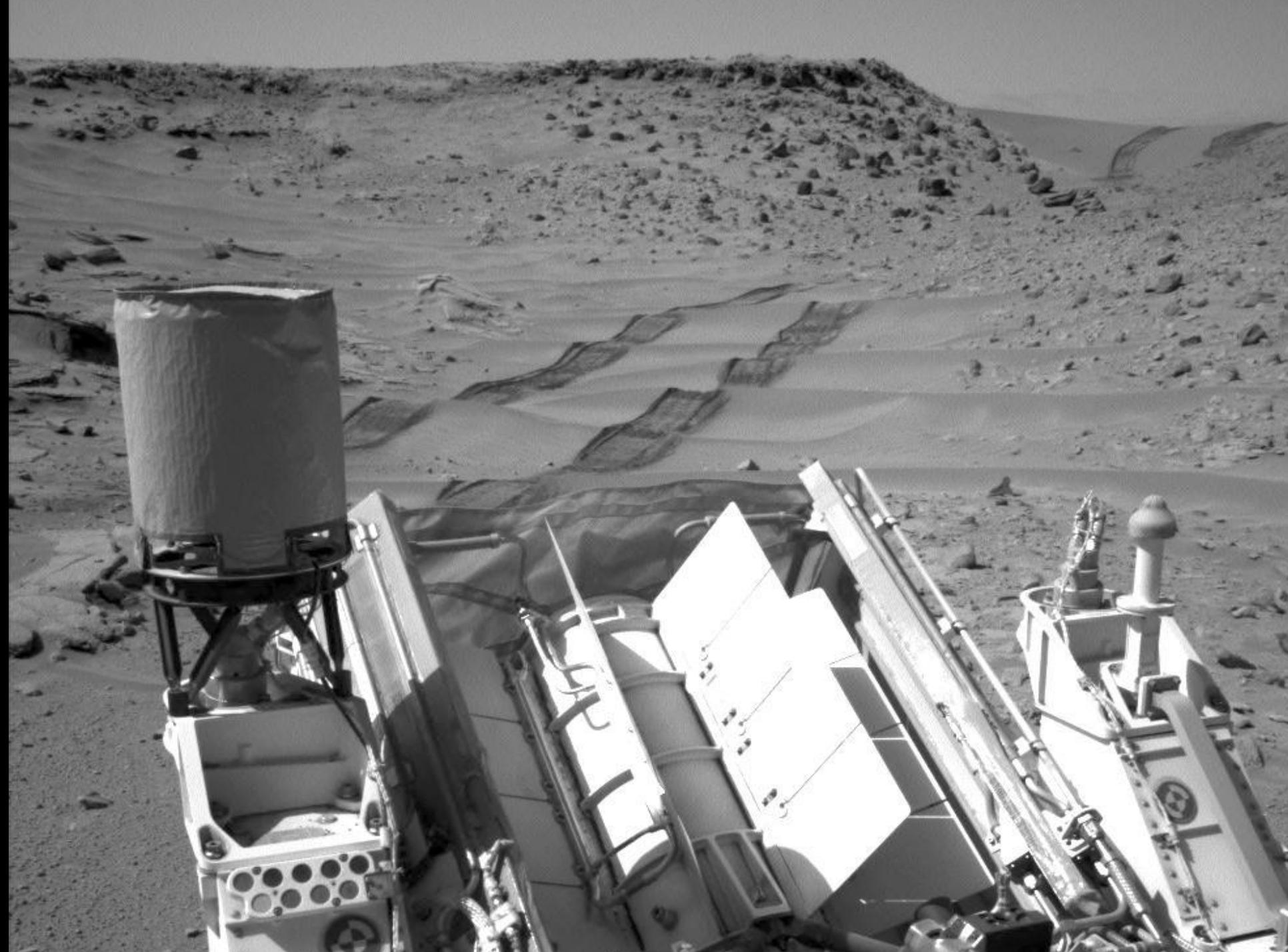
0 0.5 1

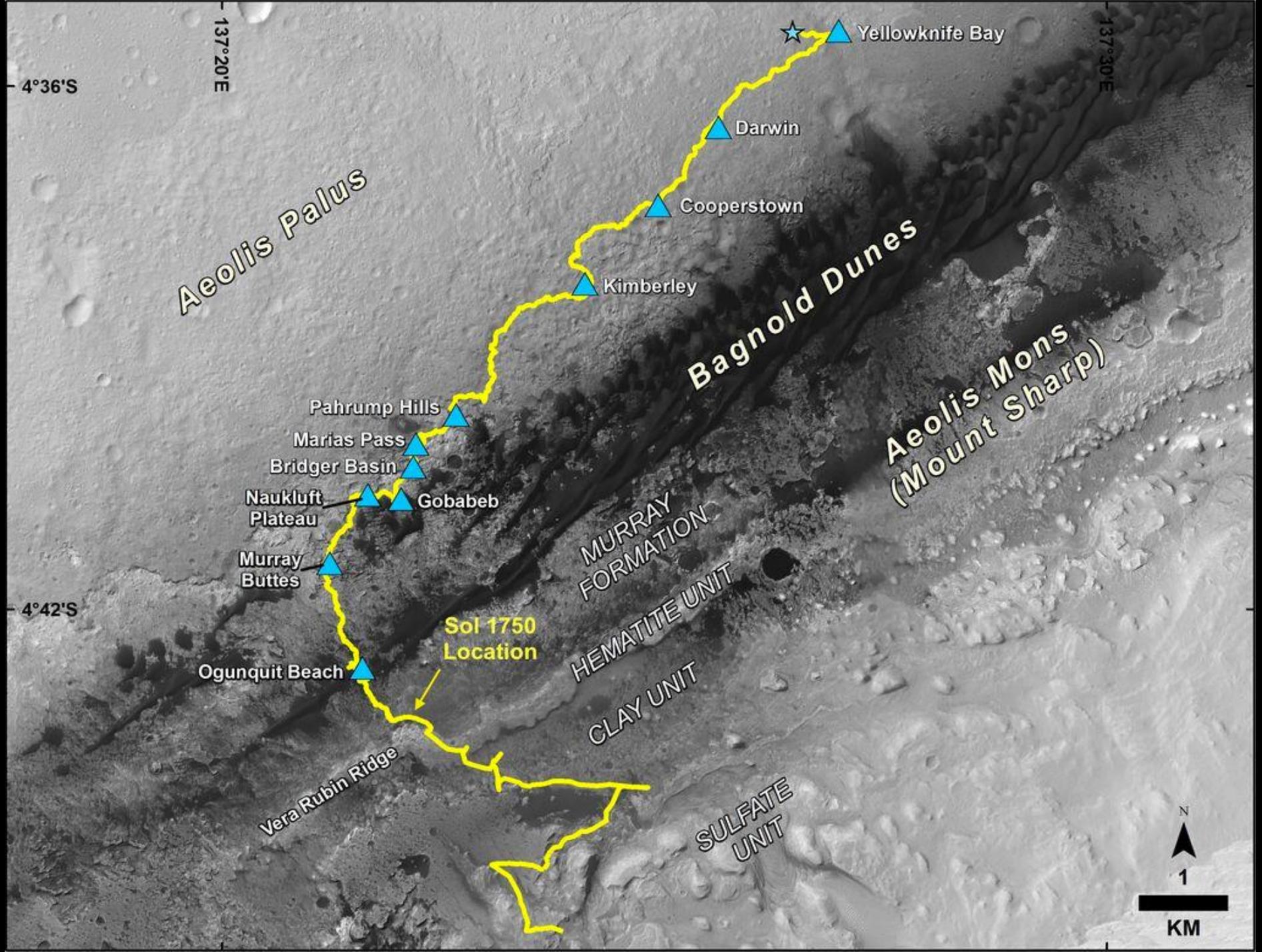
Sol 533-535: Dingo Gap

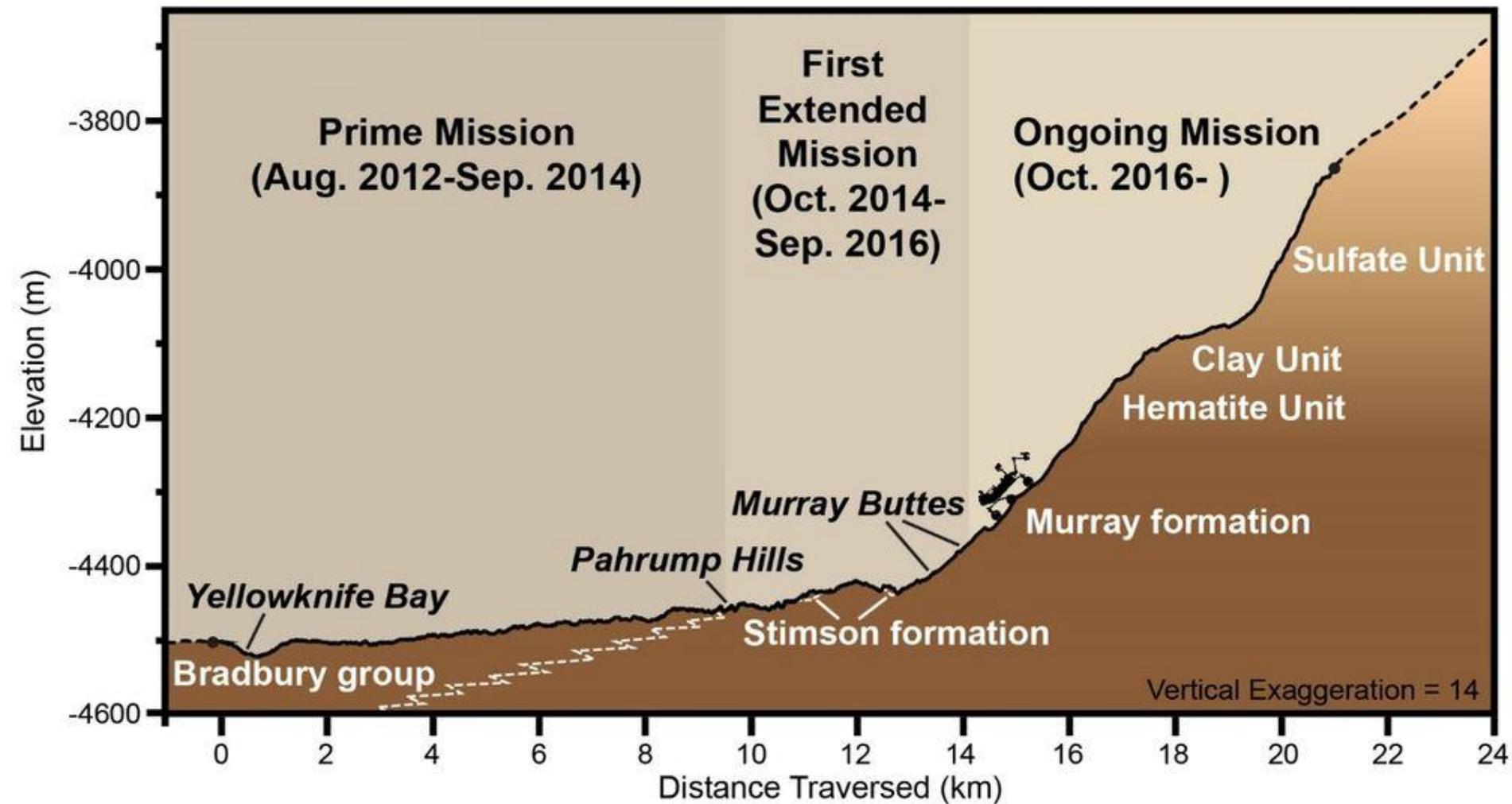


Low Road vs. High Road





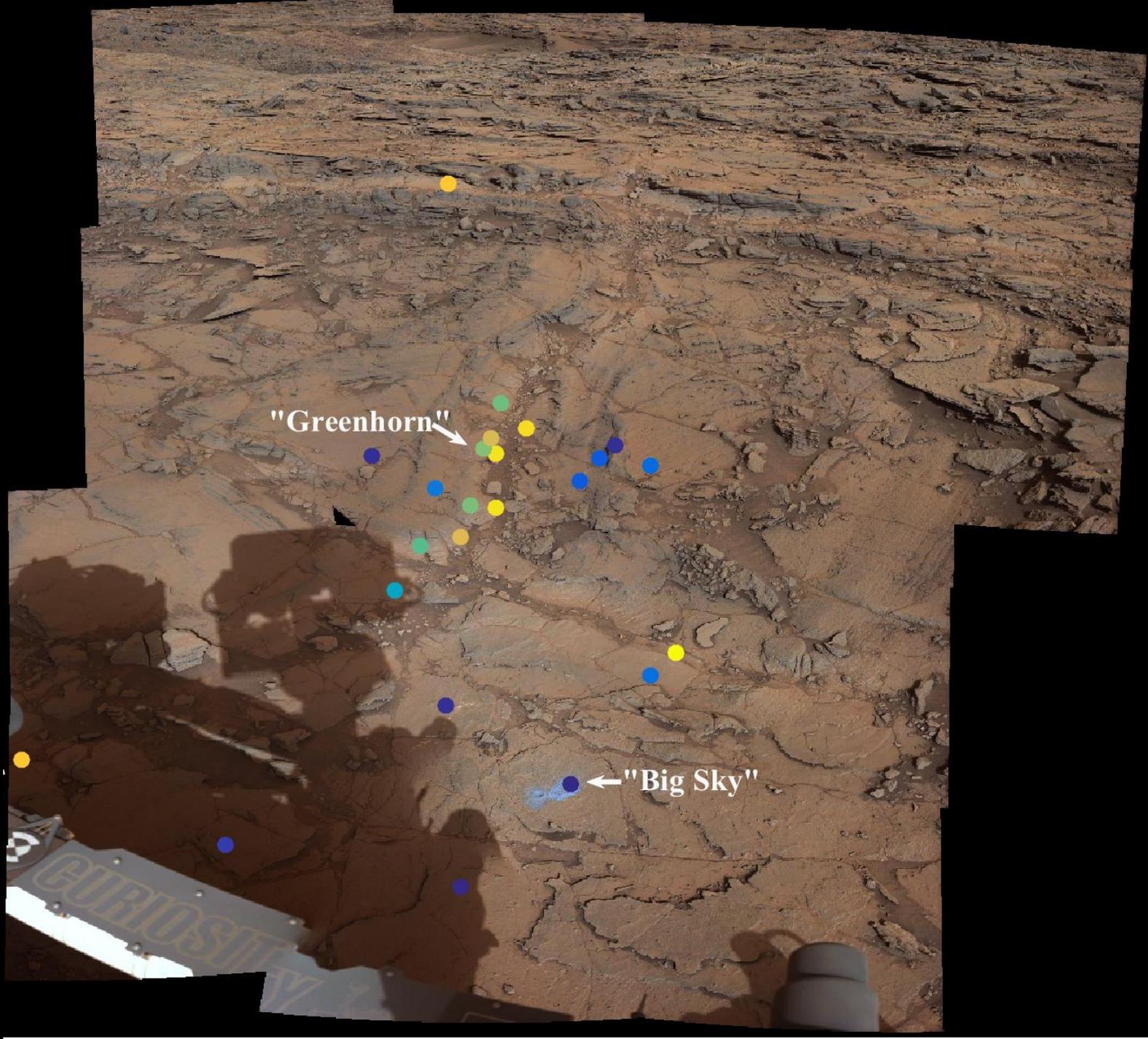




Entrance to 'Murray Buttes'



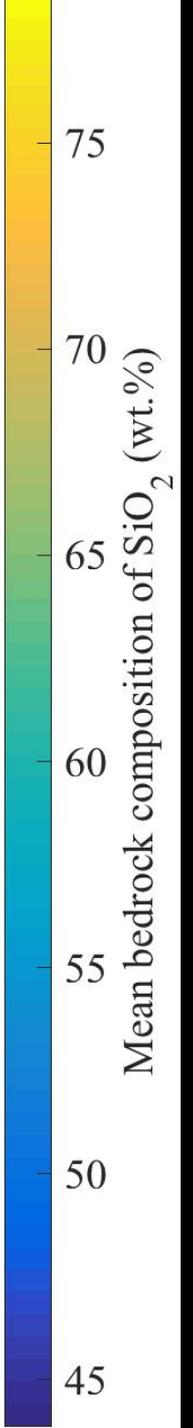
NASA/JPL - CalTech/MSSS/James Sorenson



"Greenhorn"

"Big Sky"

CURIOSITY



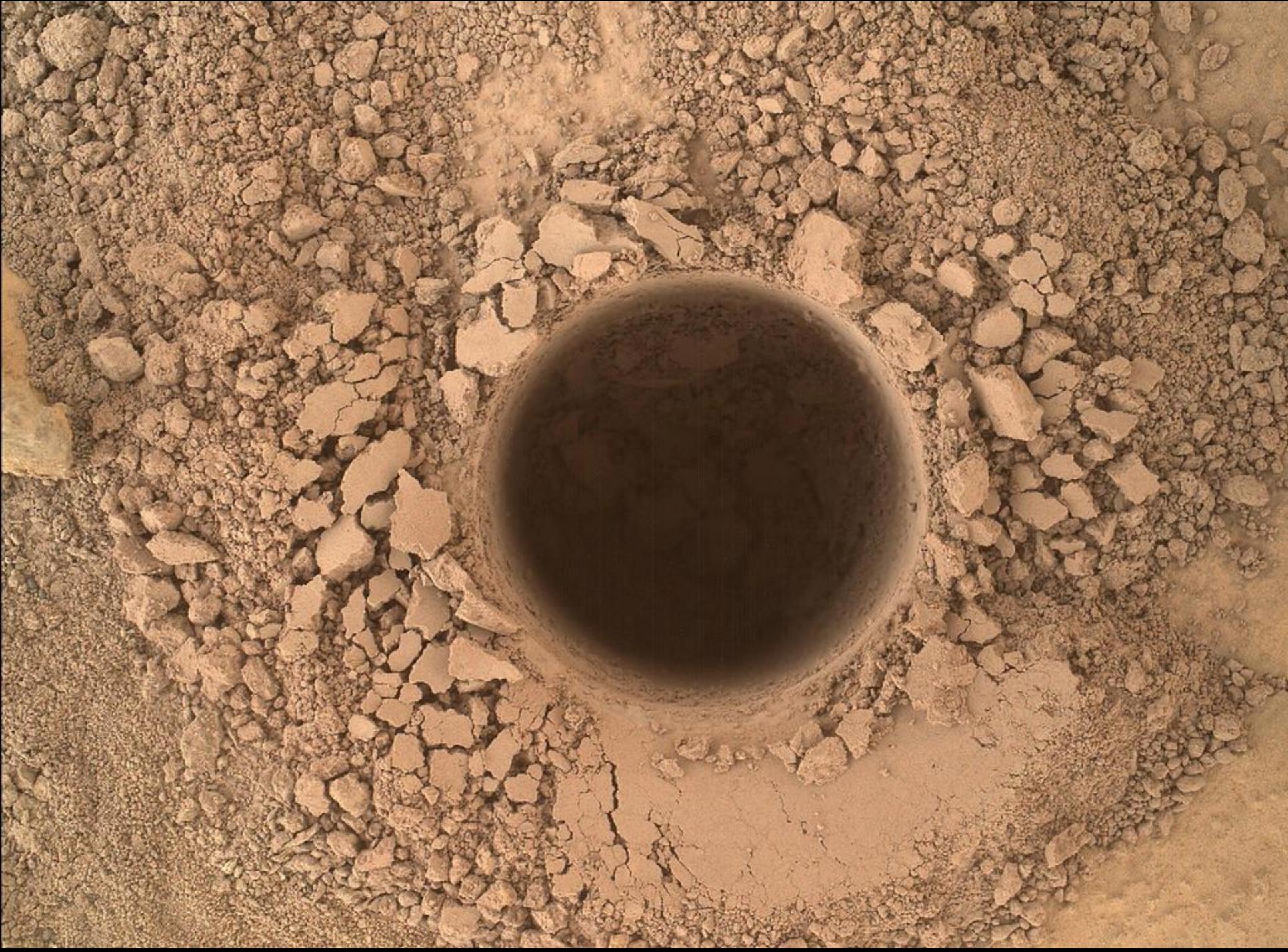


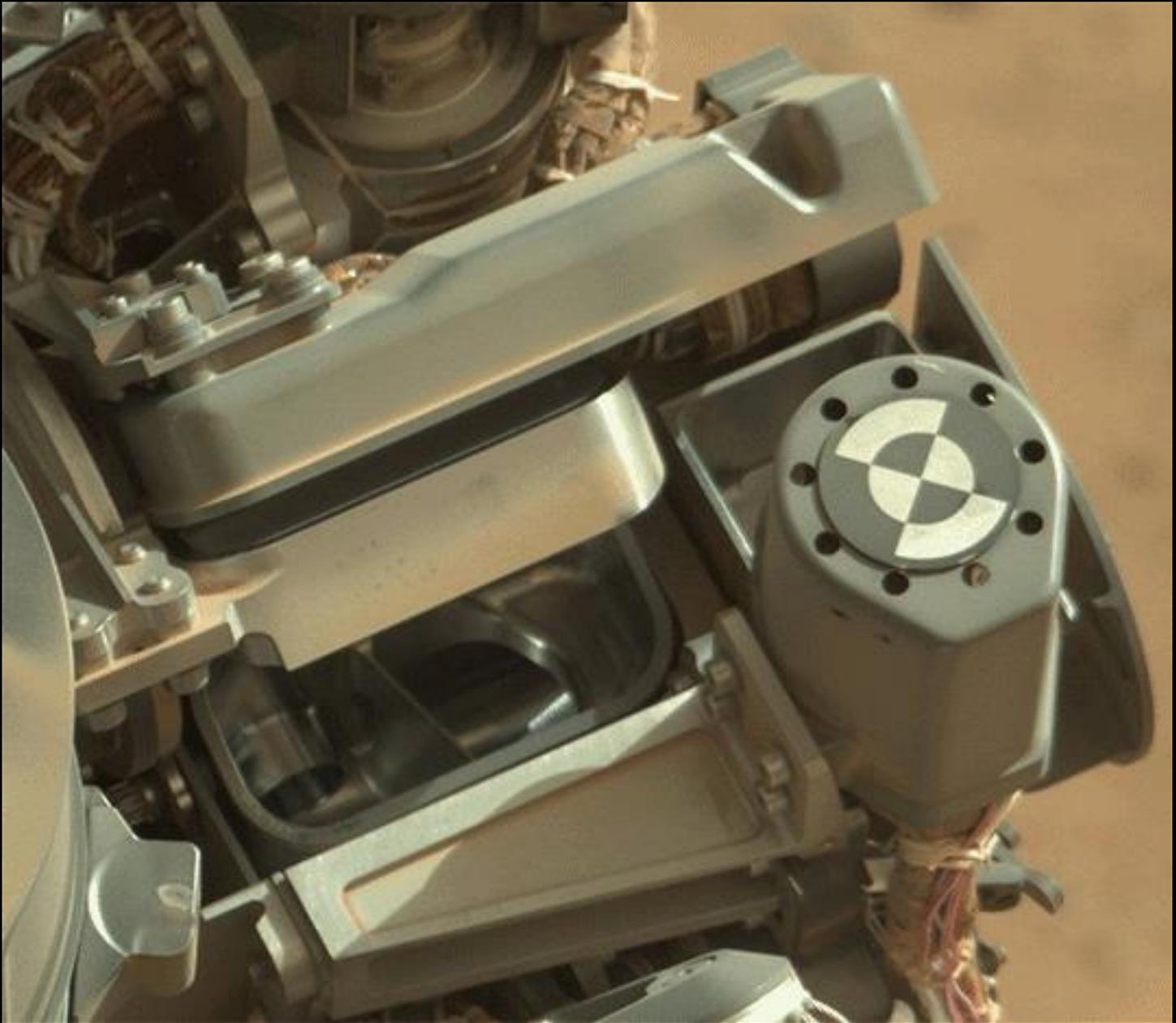
NASA/JPL-Caltech/U. Guelph

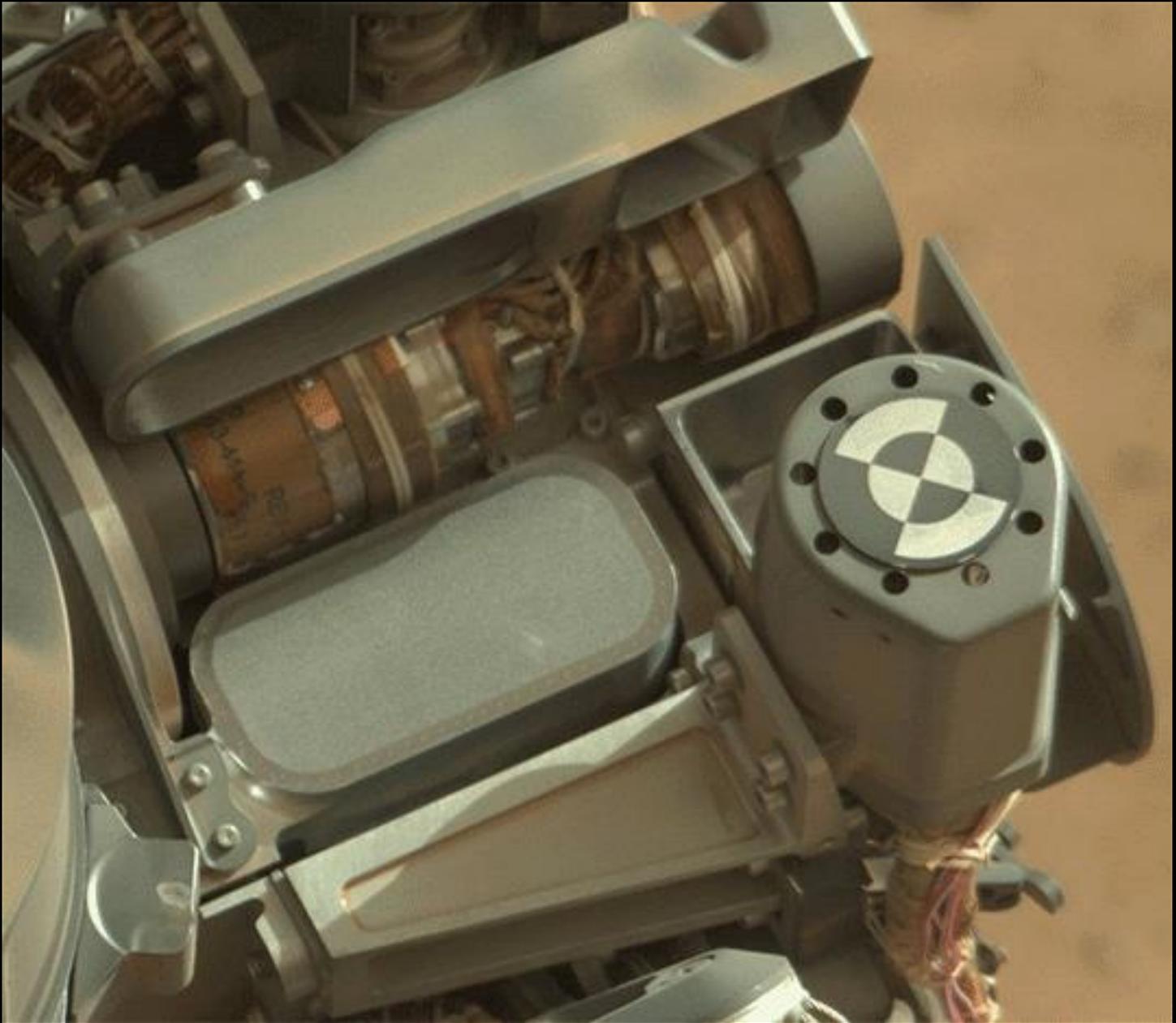
NASA/JPL-Caltech/MSSS

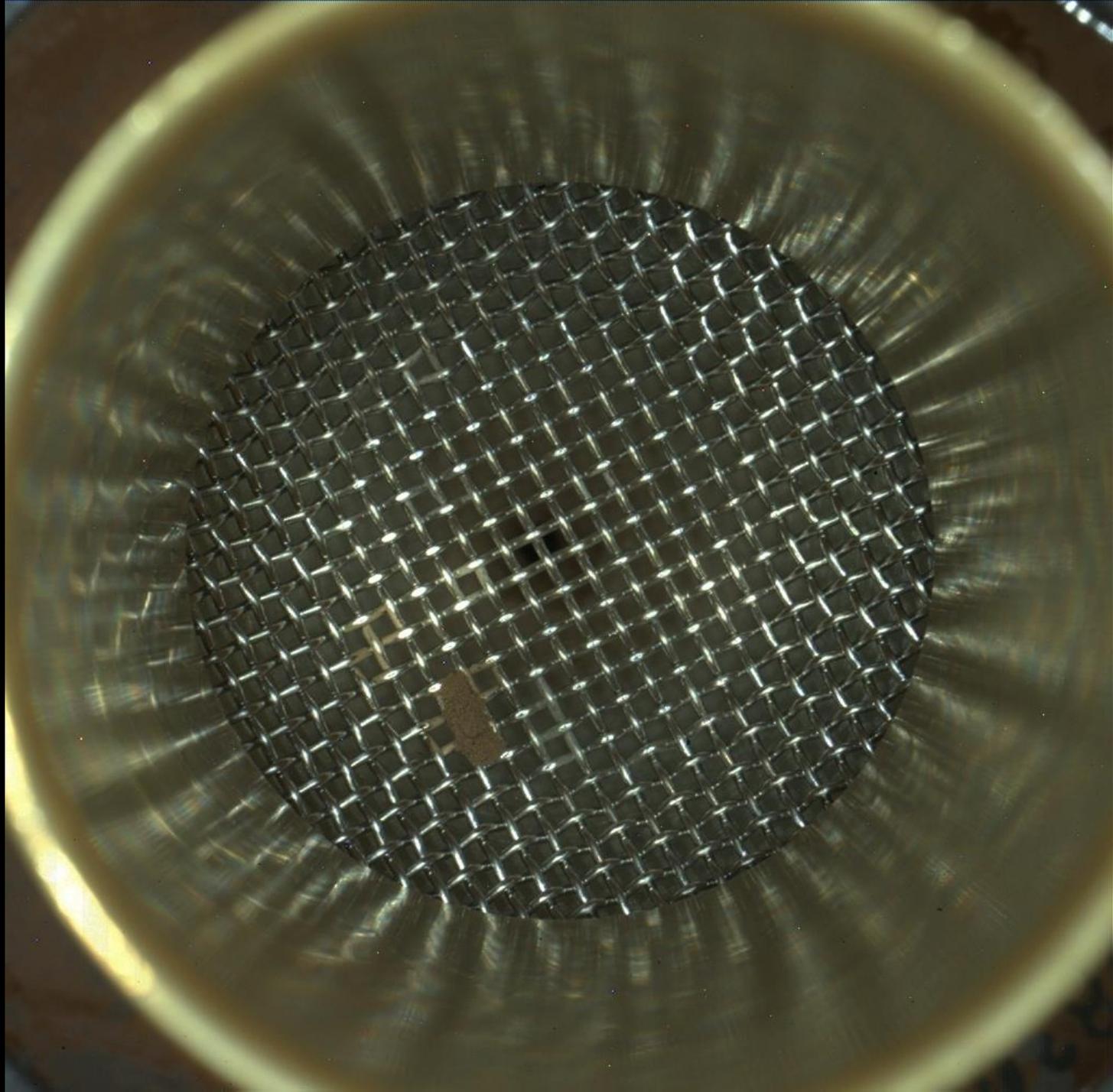


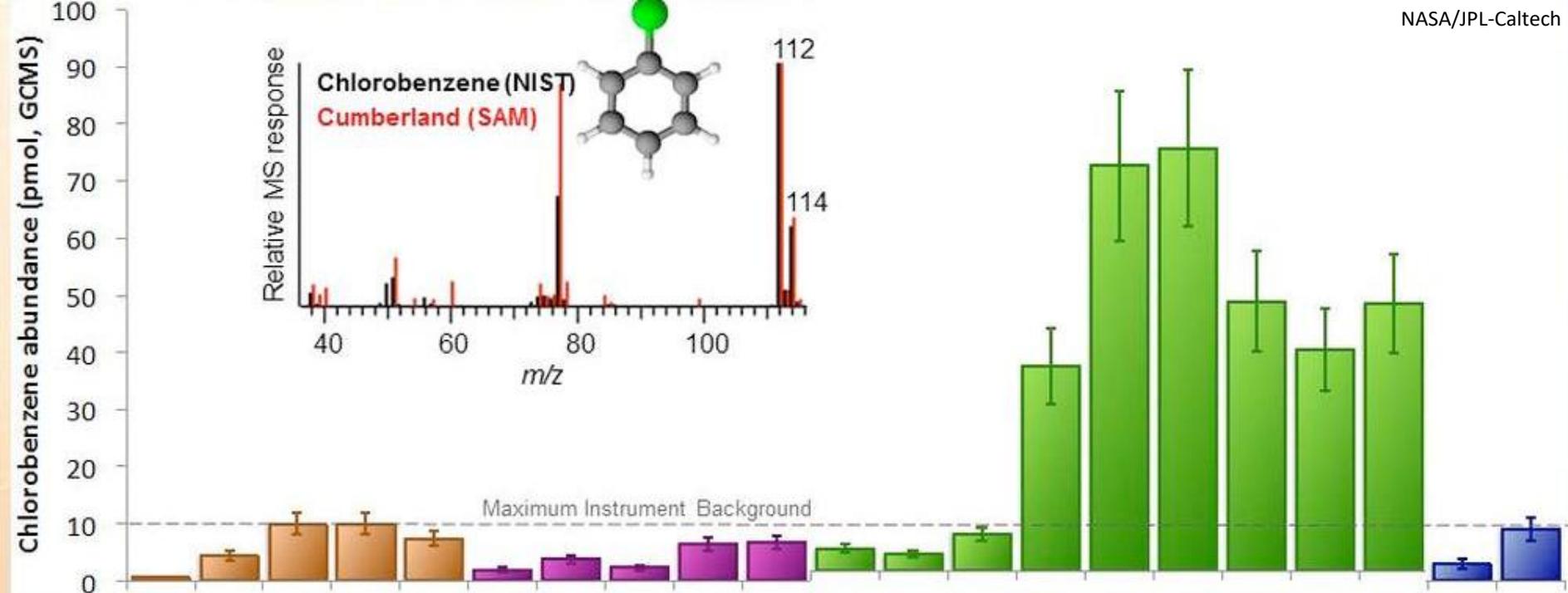








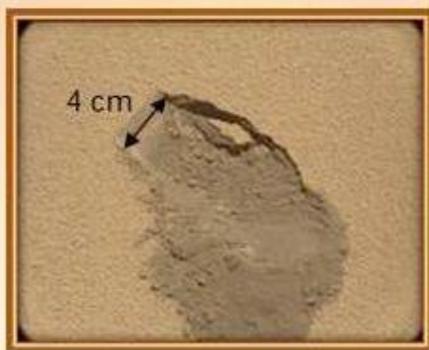




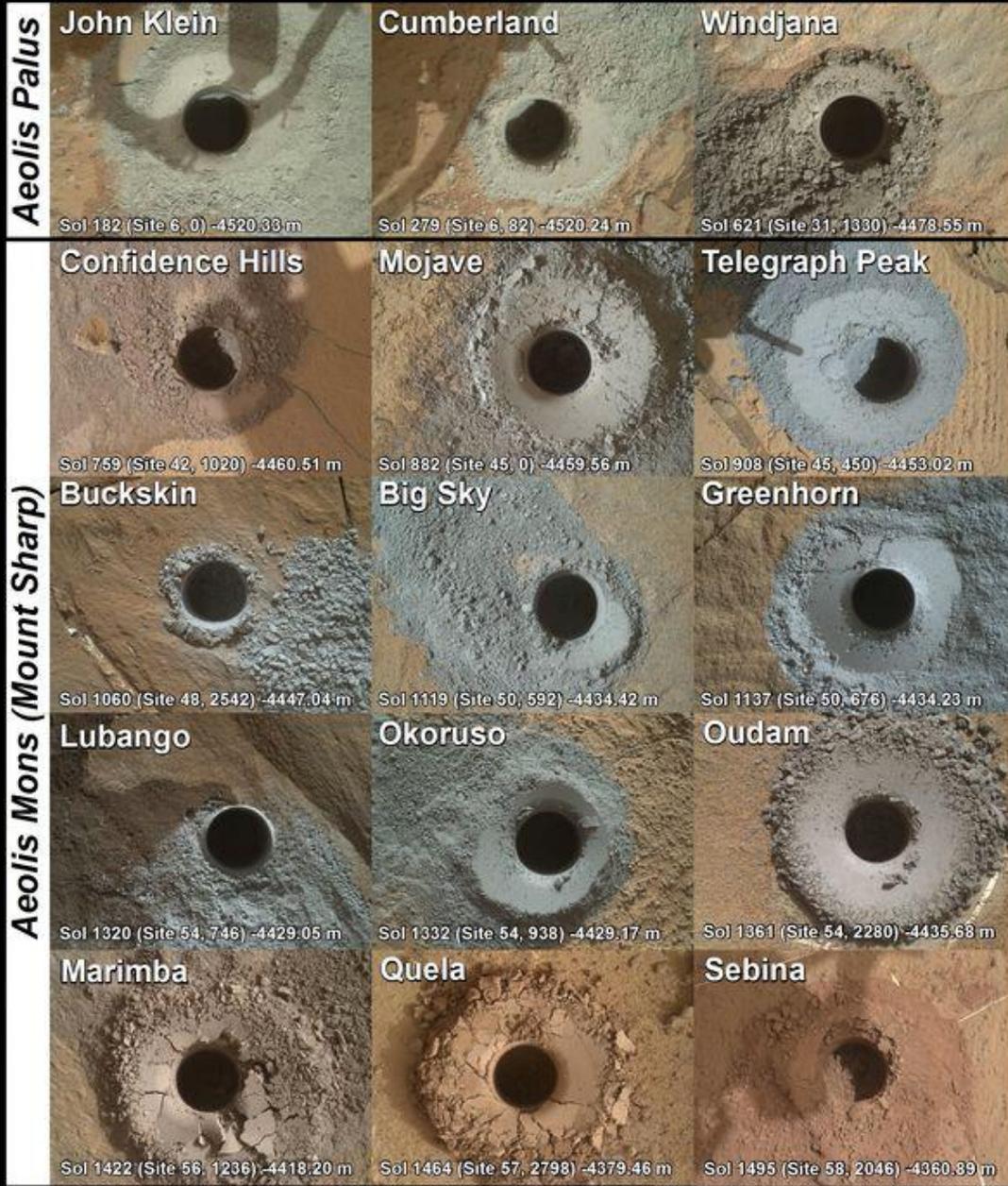
ROCKNEST

JOHN KLEIN

CUMBERLAND

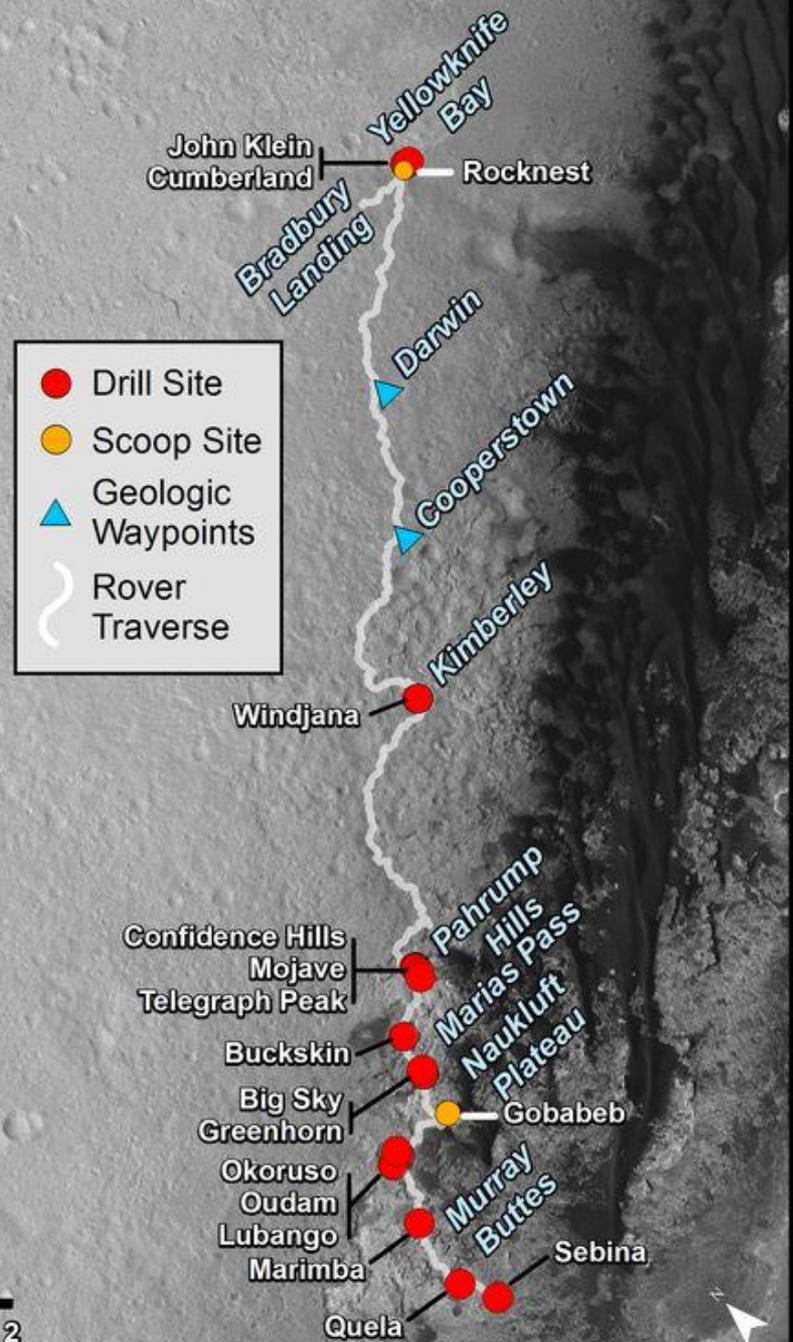
CONFIDENCE
HILLS

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



Drill hole diameter = ~1.6 cm.

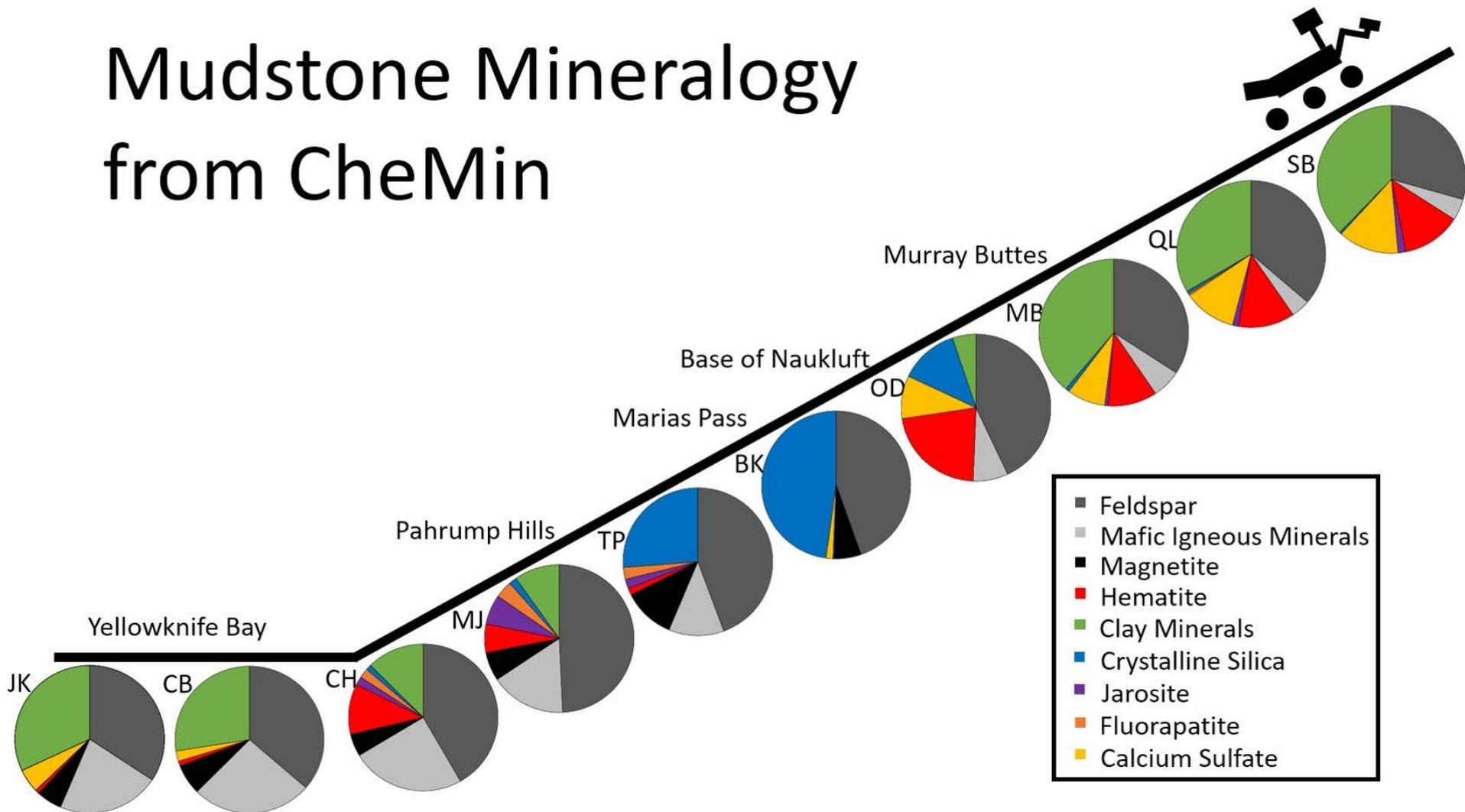
DRILL SITES AT GALE CRATER



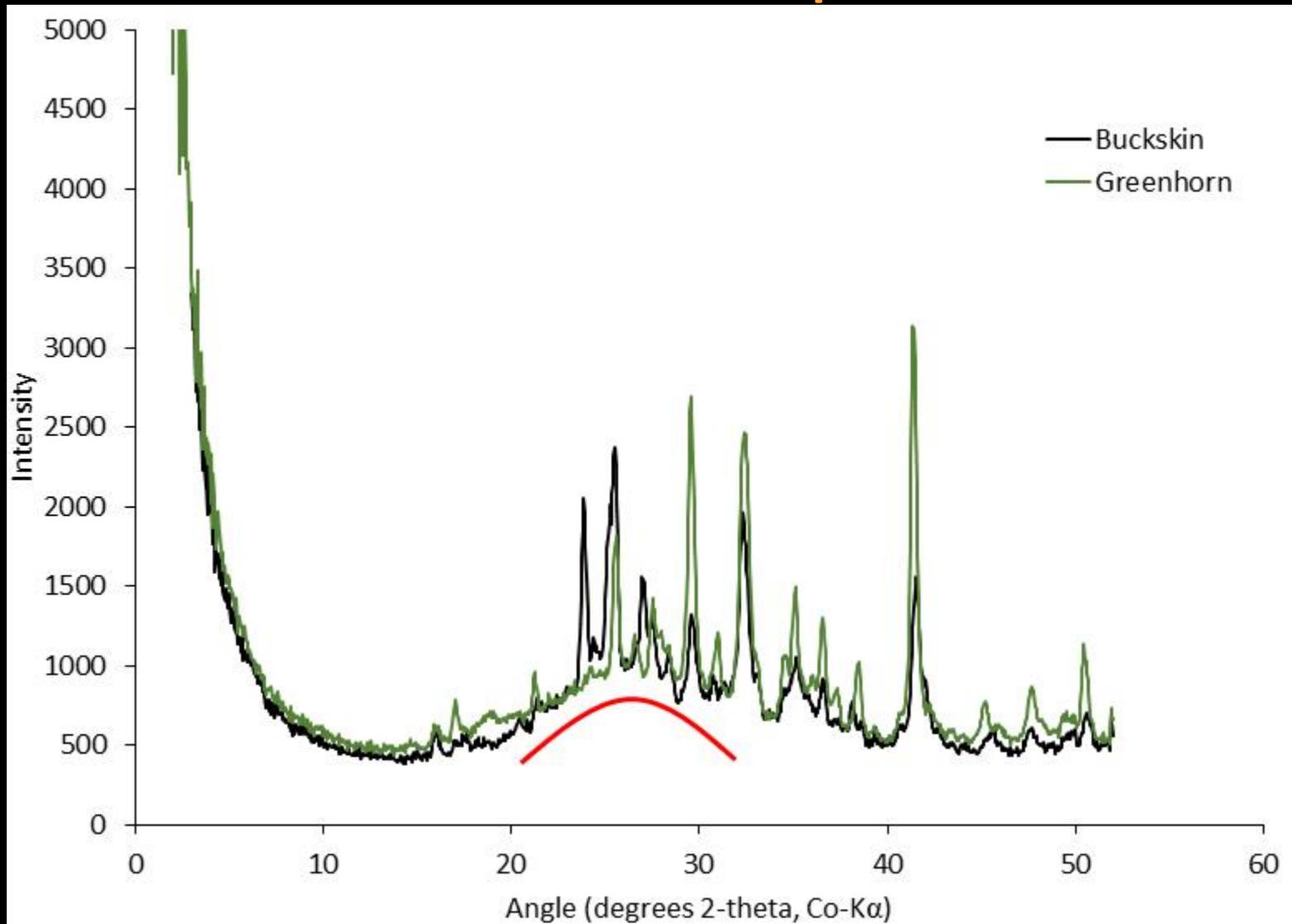
Map Produced by NASA/JPL-Caltech, 2016
MAHLI and basemap images courtesy
NASA/JPL-Caltech/MSSS/UofA/USGS-Flagstaff



Mudstone Mineralogy from CheMin



It contains Opal!



Follow Along With Curiosity!

Twitter: @MarsCuriosity
@Facebook: MarsCuriosity

Mars Exploration Program
<http://mars.jpl.nasa.gov>

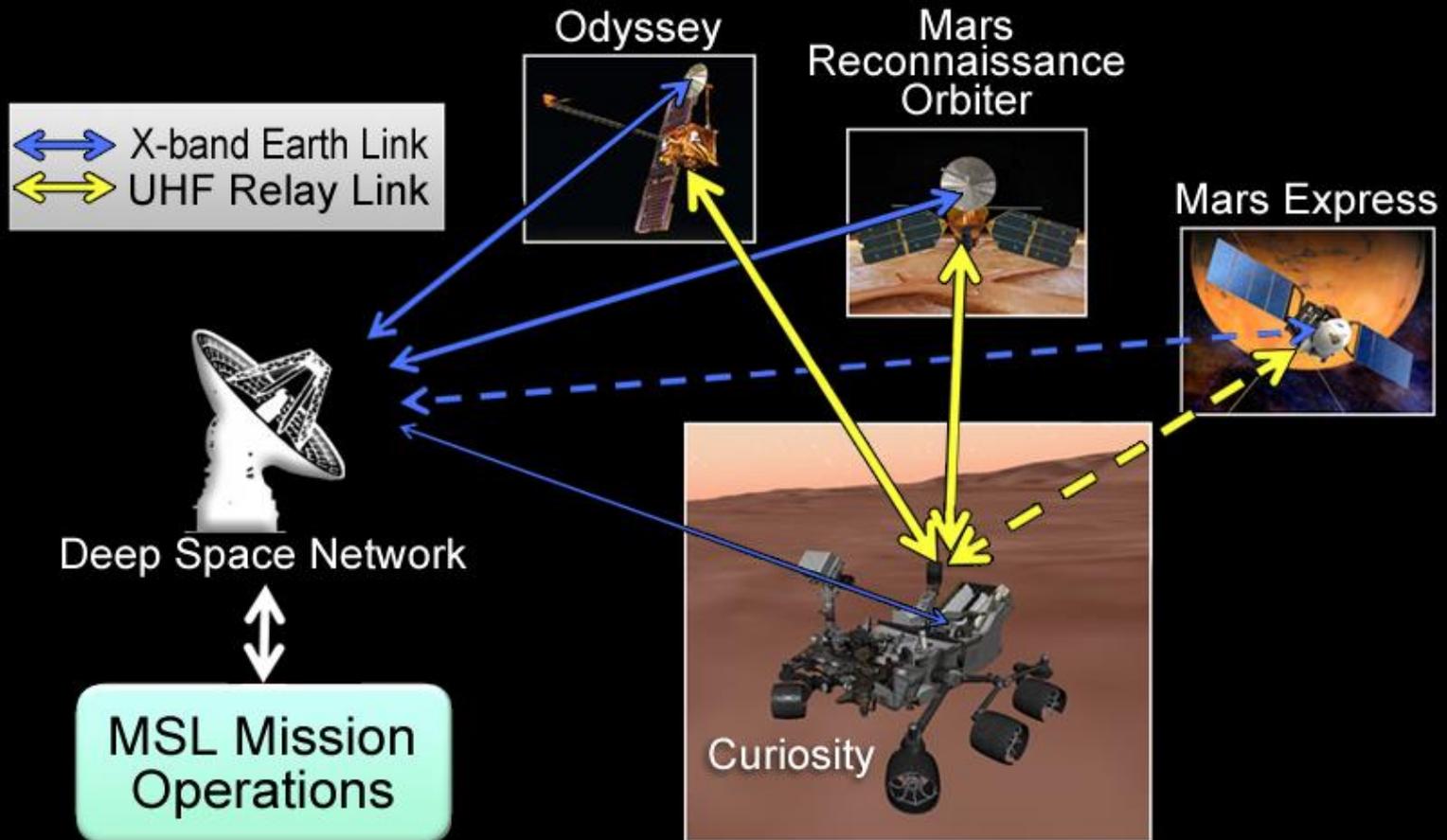


Backup Slides

Logan's Run

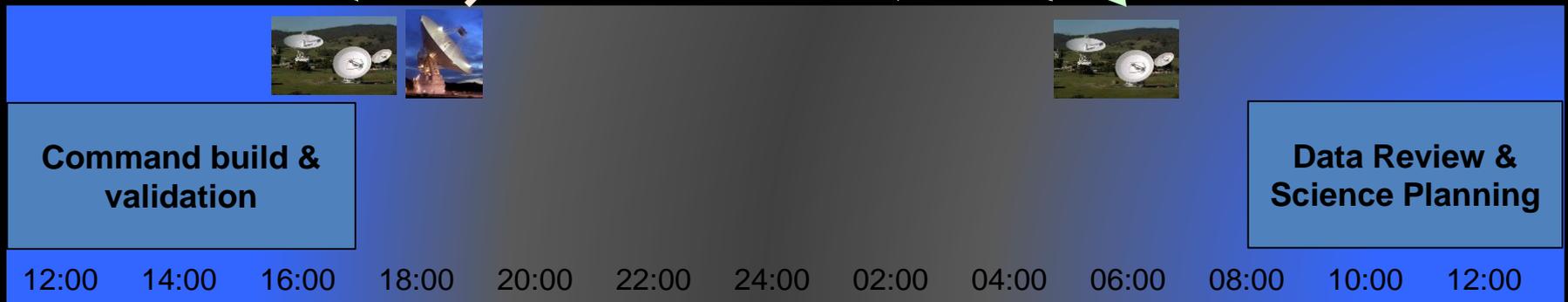


Rover Communications



Surface Operations Approach

Mars Day: Rover Schedule



Earth Day: Flight Team Schedule

Aeolis Mons
(Mount Sharp)

Salsberry Peak

Whale Rock

Gilbert Peak

Chinle

Alexander Hills

Book Cliffs

Comb Ridge

Pink Cliffs

Confidence Hills

Mid-Drive Observation
Longer Stop





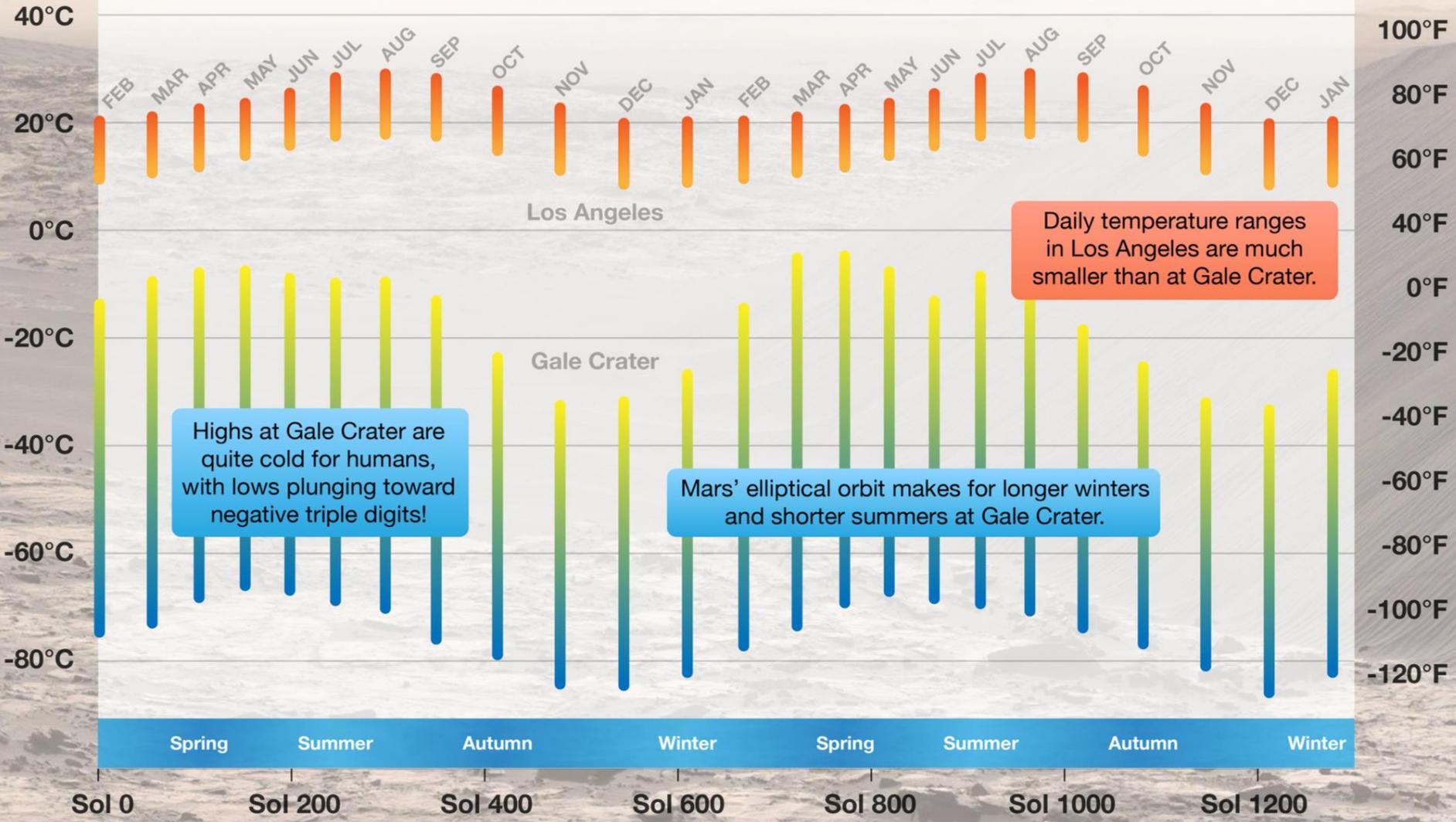


centimeters
0 1 2 3 4 5 6 7 8 9 10

Measurements of Mars' Atmosphere and Environment

Seasonal Temperature Ranges at Gale Crater

(with temperatures in Los Angeles at equivalent seasonal points)

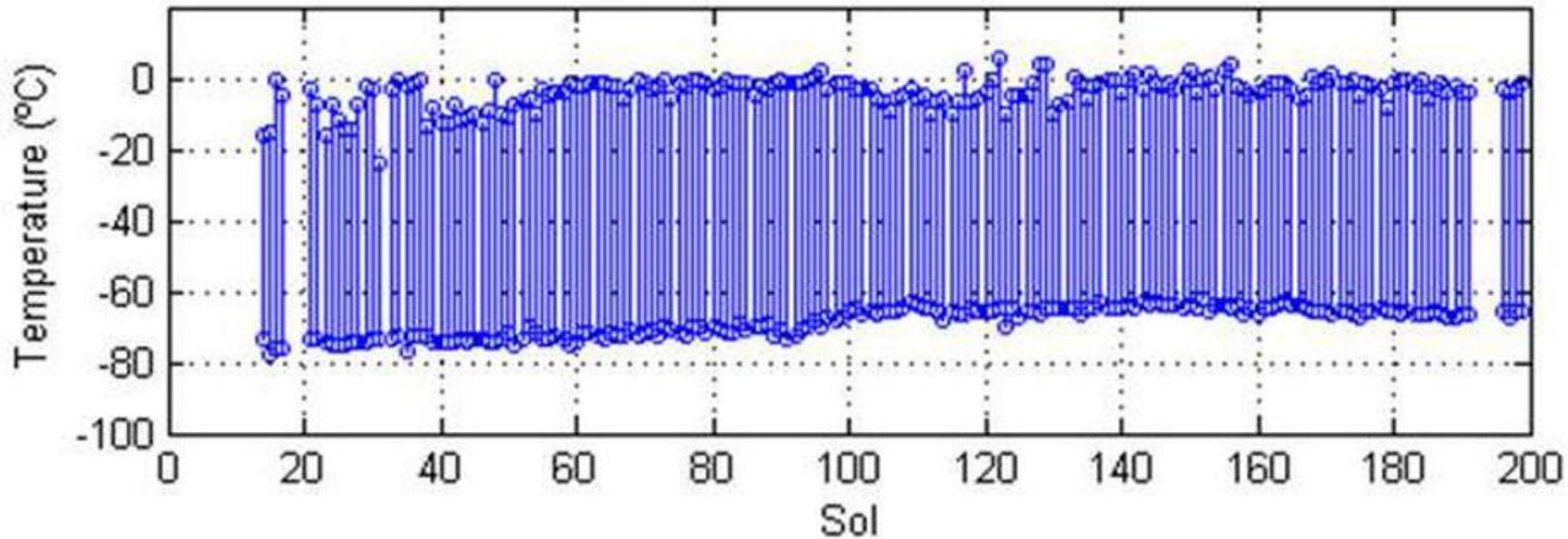


Highs at Gale Crater are quite cold for humans, with lows plunging toward negative triple digits!

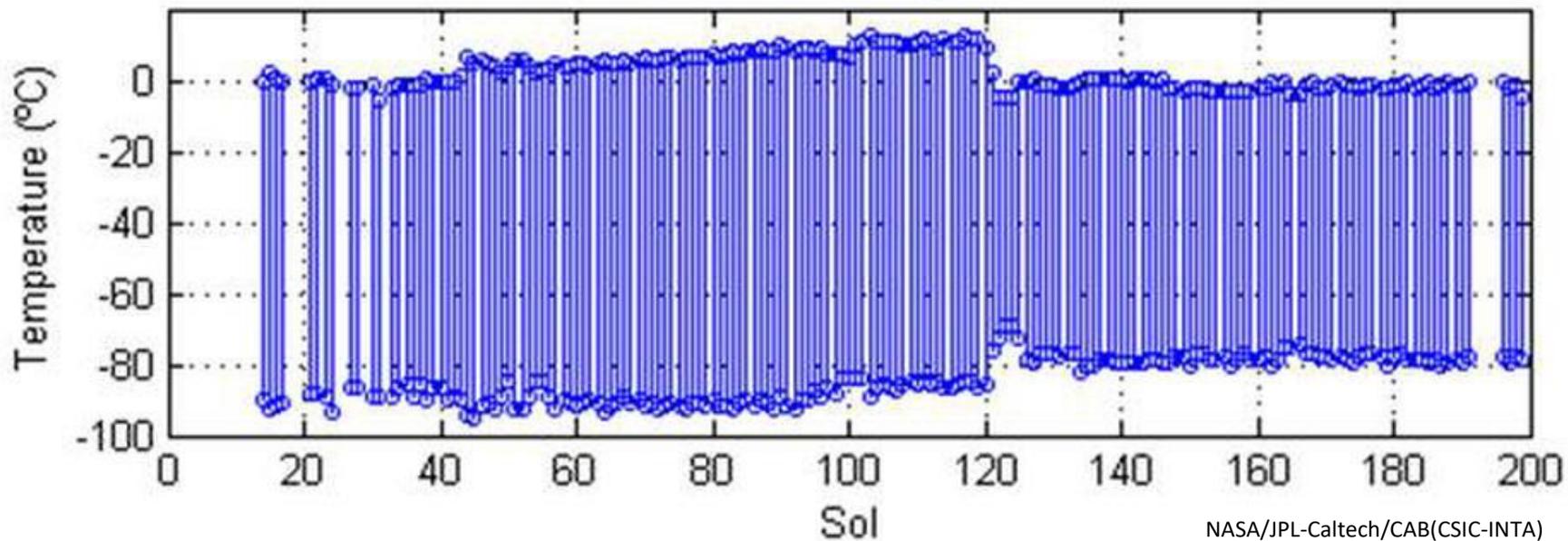
Mars' elliptical orbit makes for longer winters and shorter summers at Gale Crater.

Daily temperature ranges in Los Angeles are much smaller than at Gale Crater.

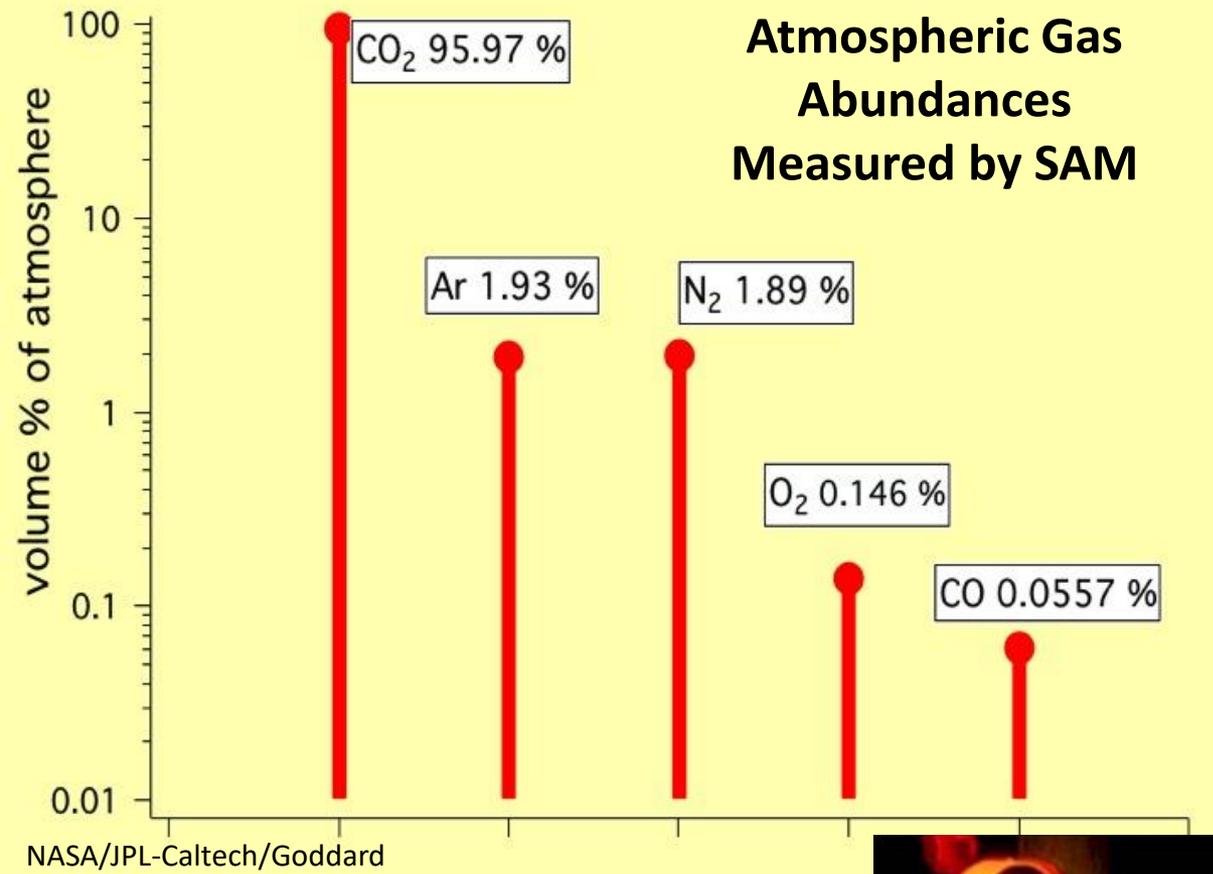
REMS Air Temp. Sensor. Daily max. and min. variations



REMS Ground Temp. Sensor. Daily max. and min. variations



Atmospheric Gas Abundances Measured by SAM



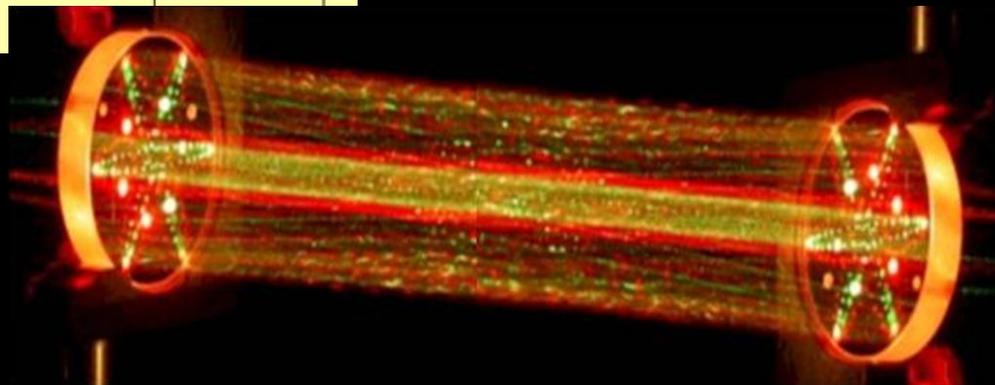
SAM found that argon, rather than nitrogen is the second most abundant gas

SAM also found that Mars' atmosphere is enriched in the heavy versions of isotopes, indicating massive atmospheric loss to space

$$\delta^{13}\text{C} = 46 \pm 4 \text{ per mil}$$

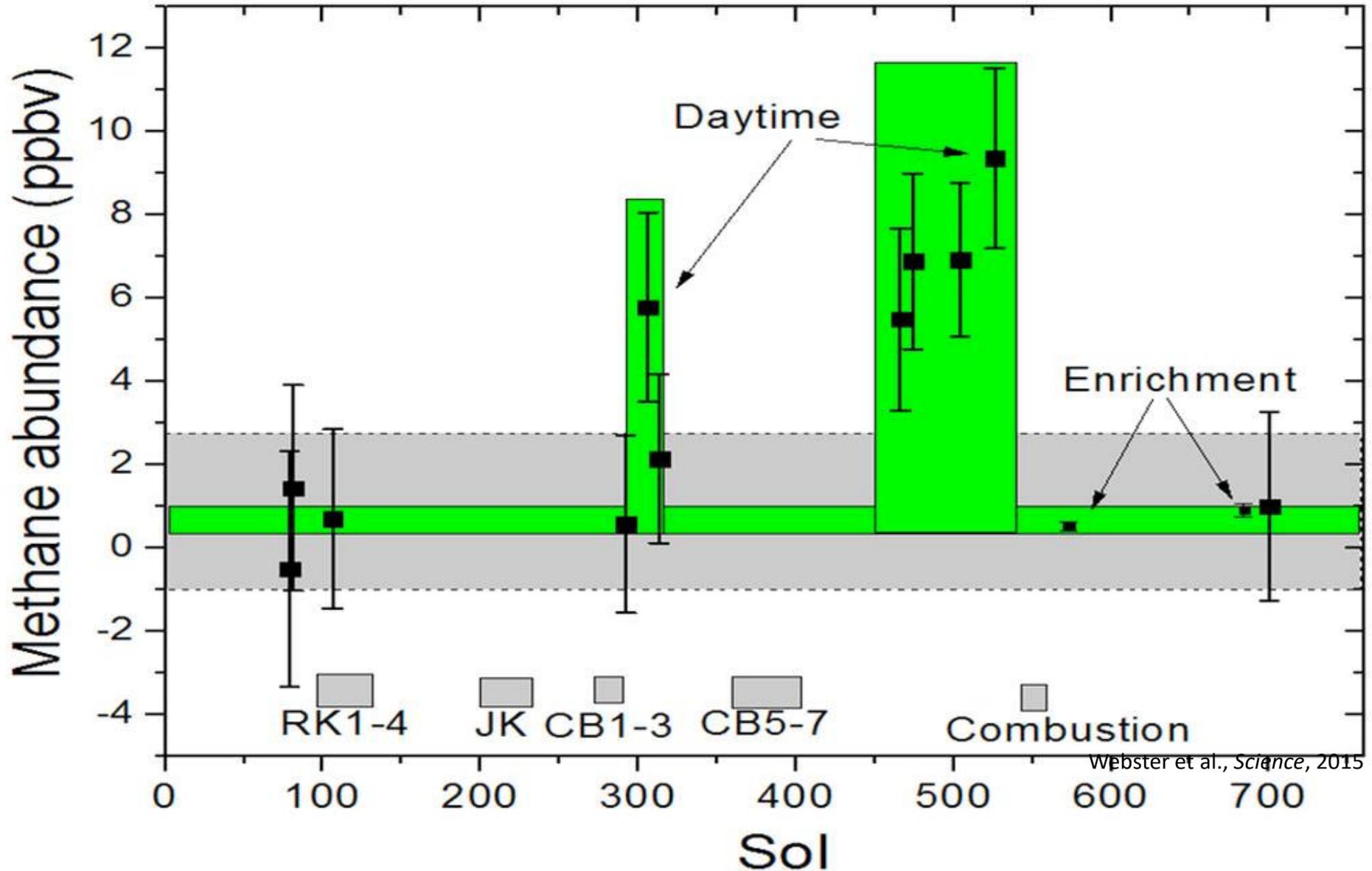
$$\delta\text{D} = 4950 \pm 1080 \text{ per mil}$$

$$^{40}\text{Ar}/^{36}\text{Ar} = 1900 \pm 300$$

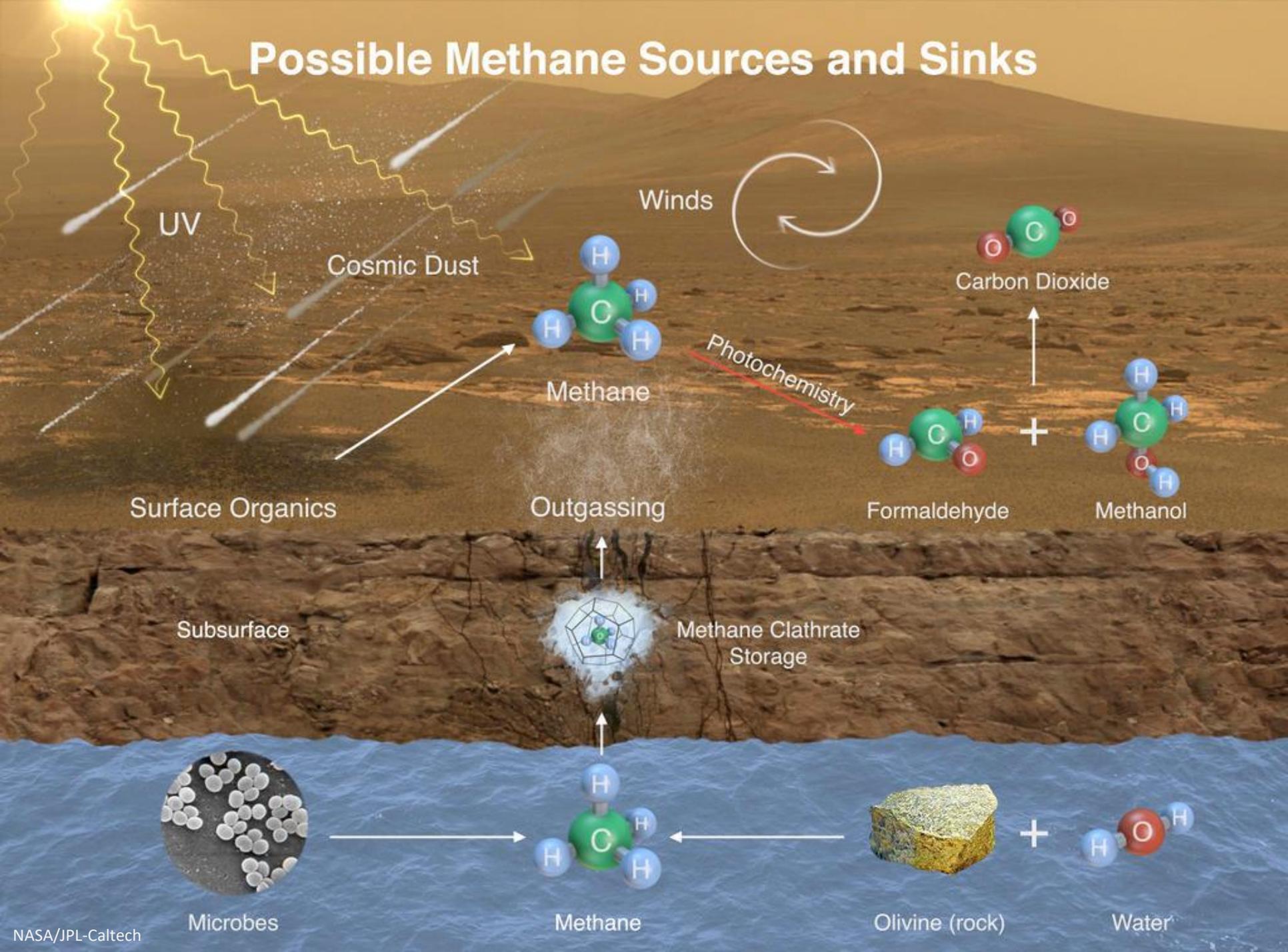


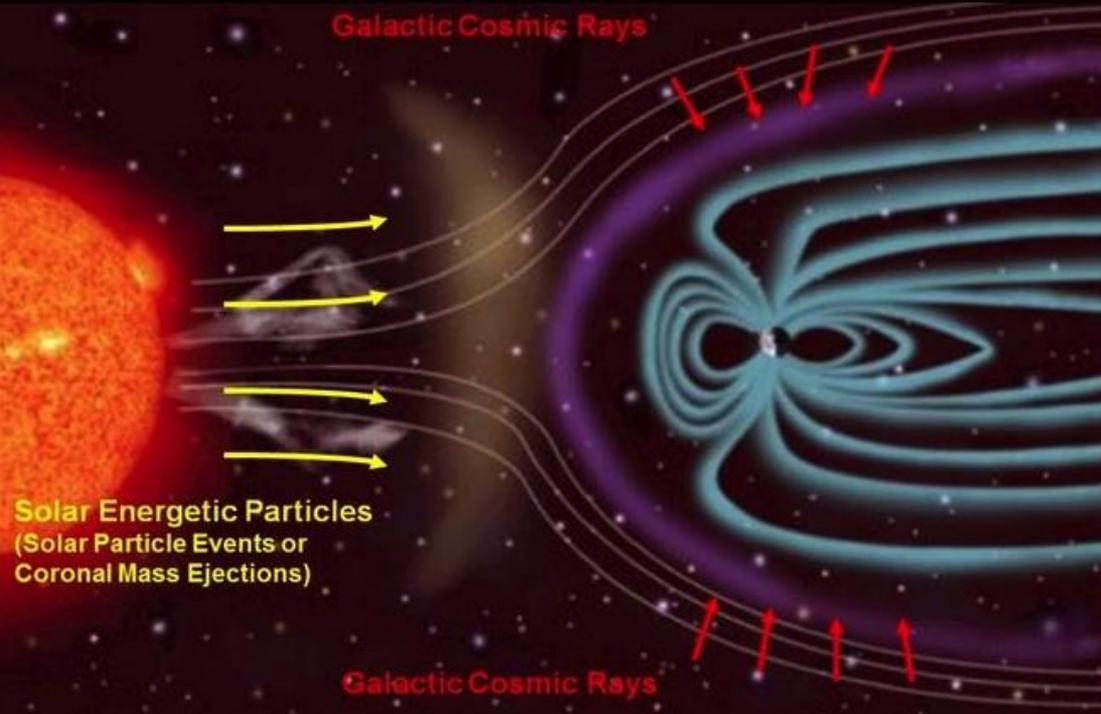
The SAM Tunable Laser Spectrometer and Mass Spectrometer measure atmospheric composition

Methane variation in Atmosphere



Possible Methane Sources and Sinks

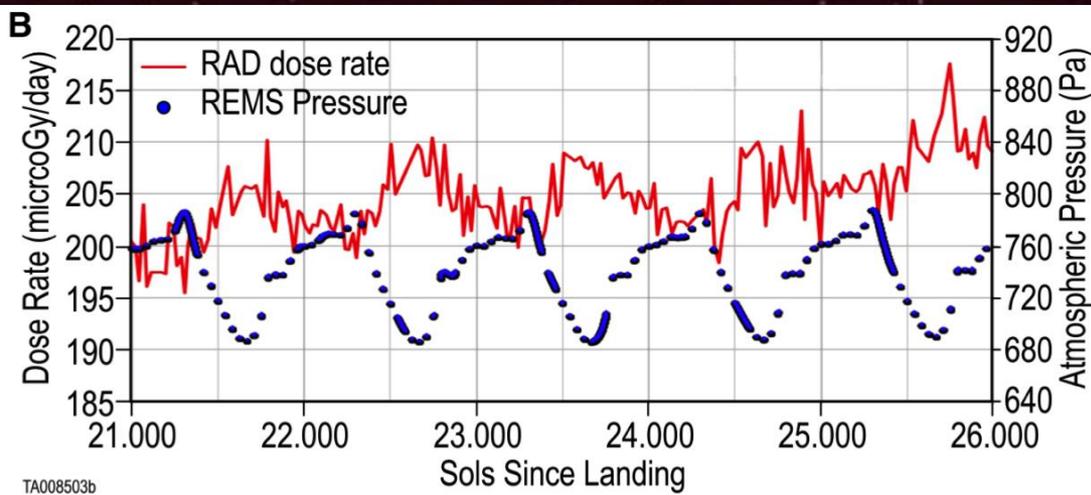




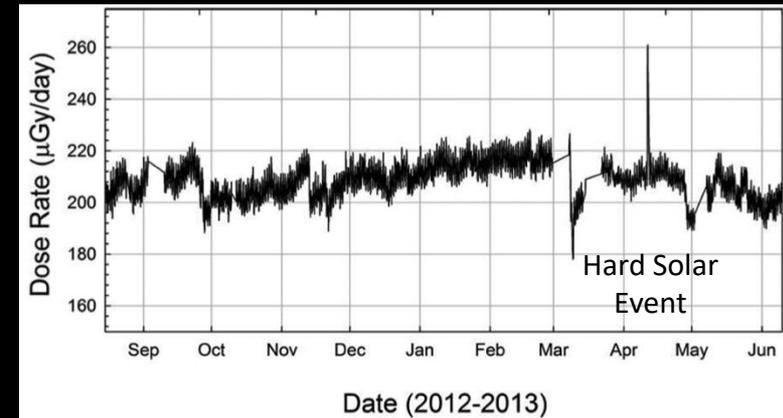
The RAD instrument measured the radiation flux from both galactic cosmic rays and solar energetic particles, in cruise and at Mars' surface

The surface dose rate is about half that measured in cruise

A crewed mission would receive ~1 Sievert of exposure in a trip to Mars with 500 sols on the surface



[Hassler et al., 2014]



Curiosity's Radiation Assessment Detector measures high-energy radiation

Exploration of Yellowknife Bay

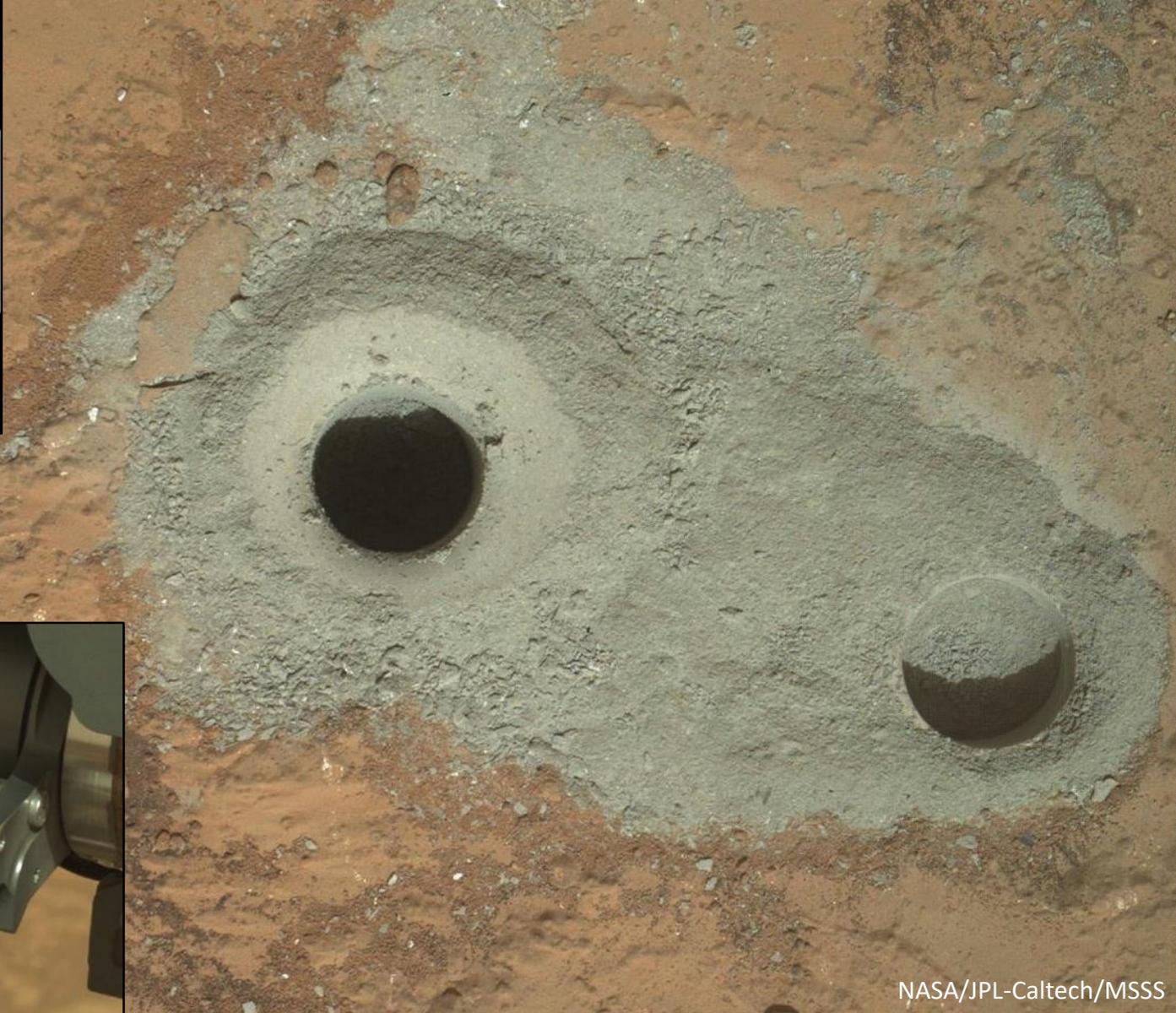


NASA/JPL-Caltech/D. Bouic

Arm deployed at John Klein



NASA/JPL-
Caltech/LANL/CNES/IRAP/IAS/LPGN



NASA/JPL-Caltech/MSSS



NASA/JPL-Caltech/MSSS

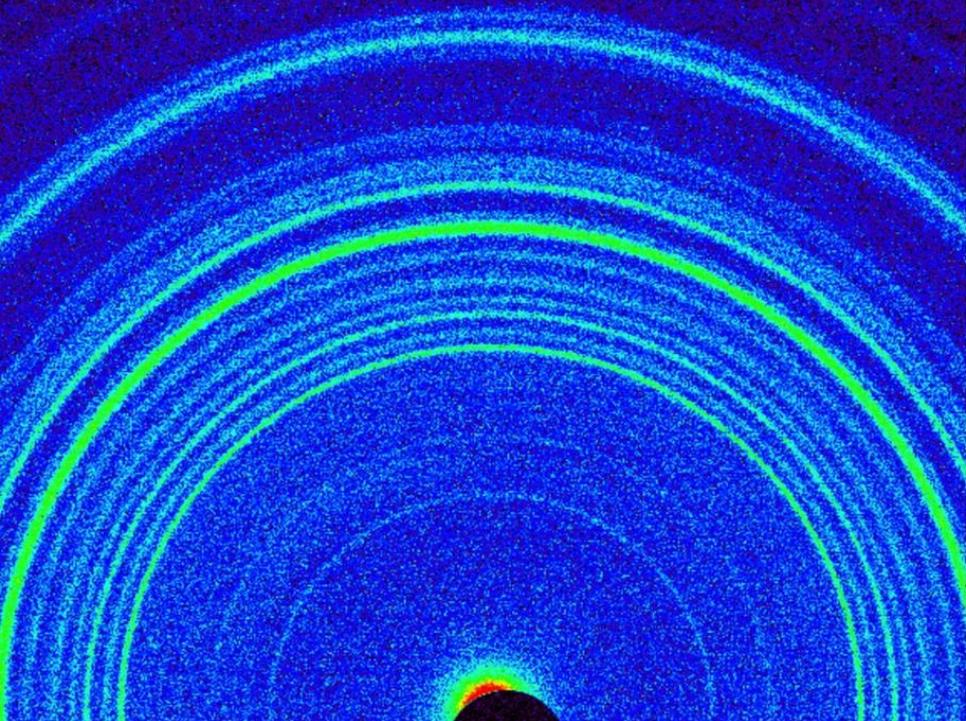
Curiosity's 1.6-cm drill bit, Full & Partial depth holes, and scoop full of acquired sample



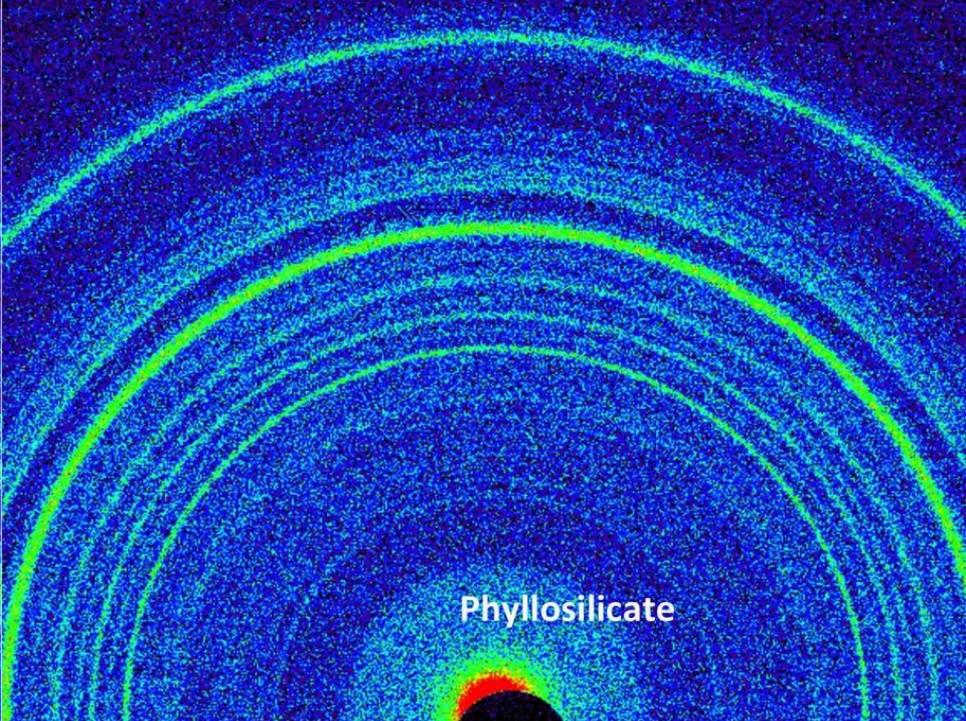
NASA/JPL-Caltech/MSSS

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

Rocknest sand shadow



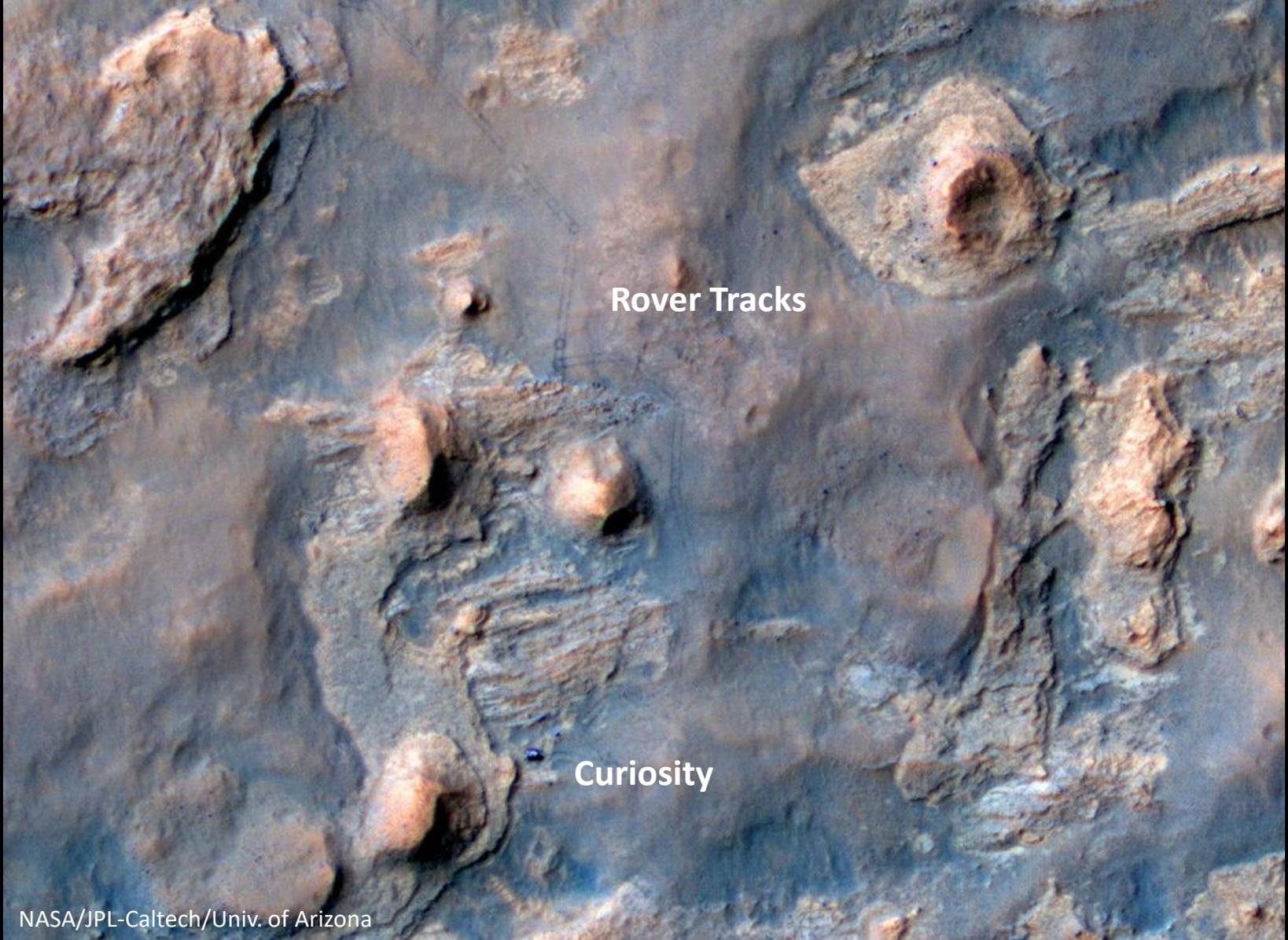
John Klein drill powder



Phyllosilicate

NASA/JPL-Caltech/Ames

The Sheepbed mudstone contains ~ 20% clay minerals that formed in place. The bulk composition is similar to that of unaltered basaltic materials.



Curiosity at the Kimberley, where four rock types typical of Gale's plains come together



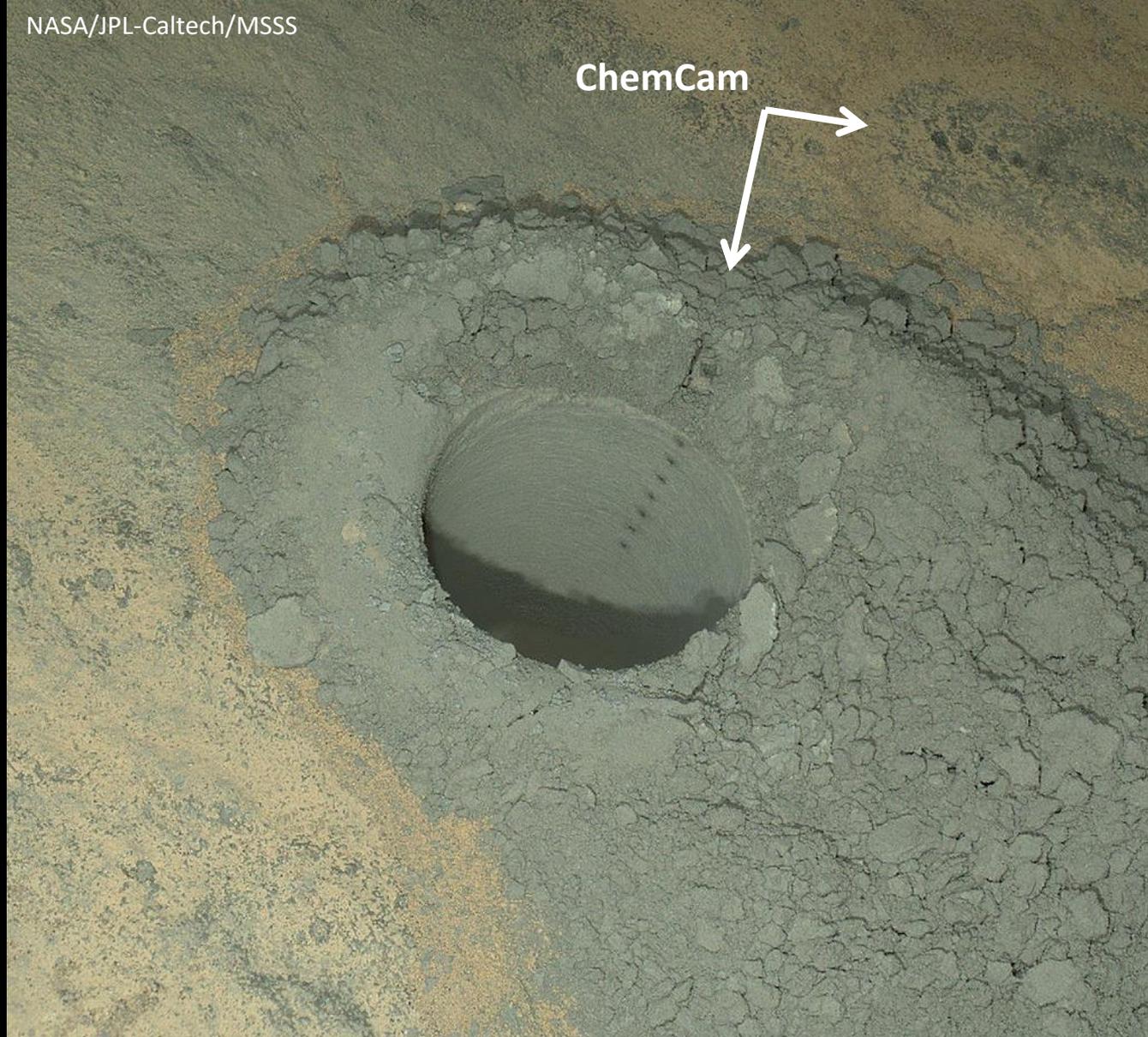
Full Drill

Mini-Drill

“Stephen” target cleaned
and analyzed by ChemCam

NASA/JPL-Caltech/MSSS

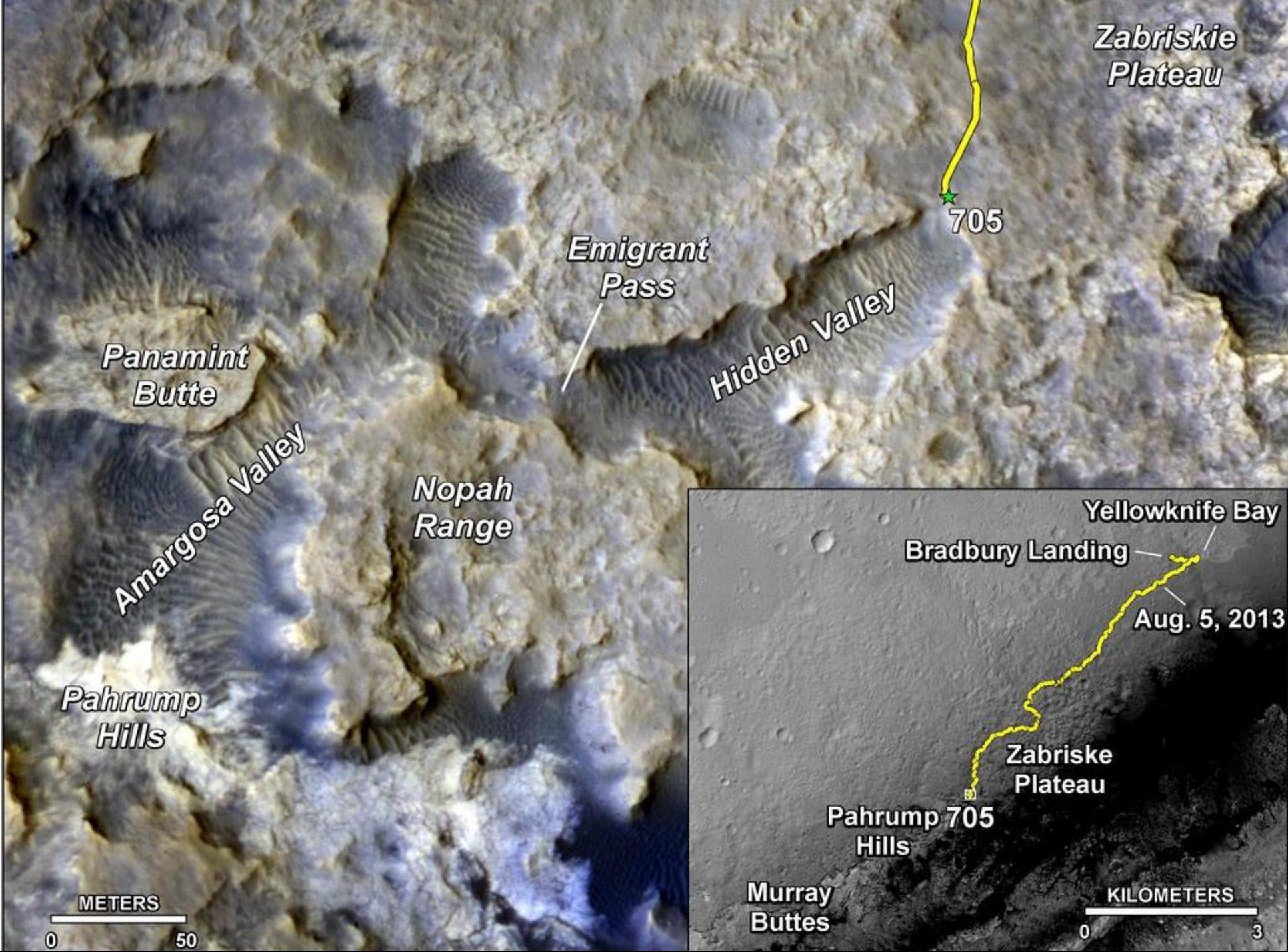
**Windjana fluvial sandstone drill target at the
Kimberley, showing drilling-induced slumping**

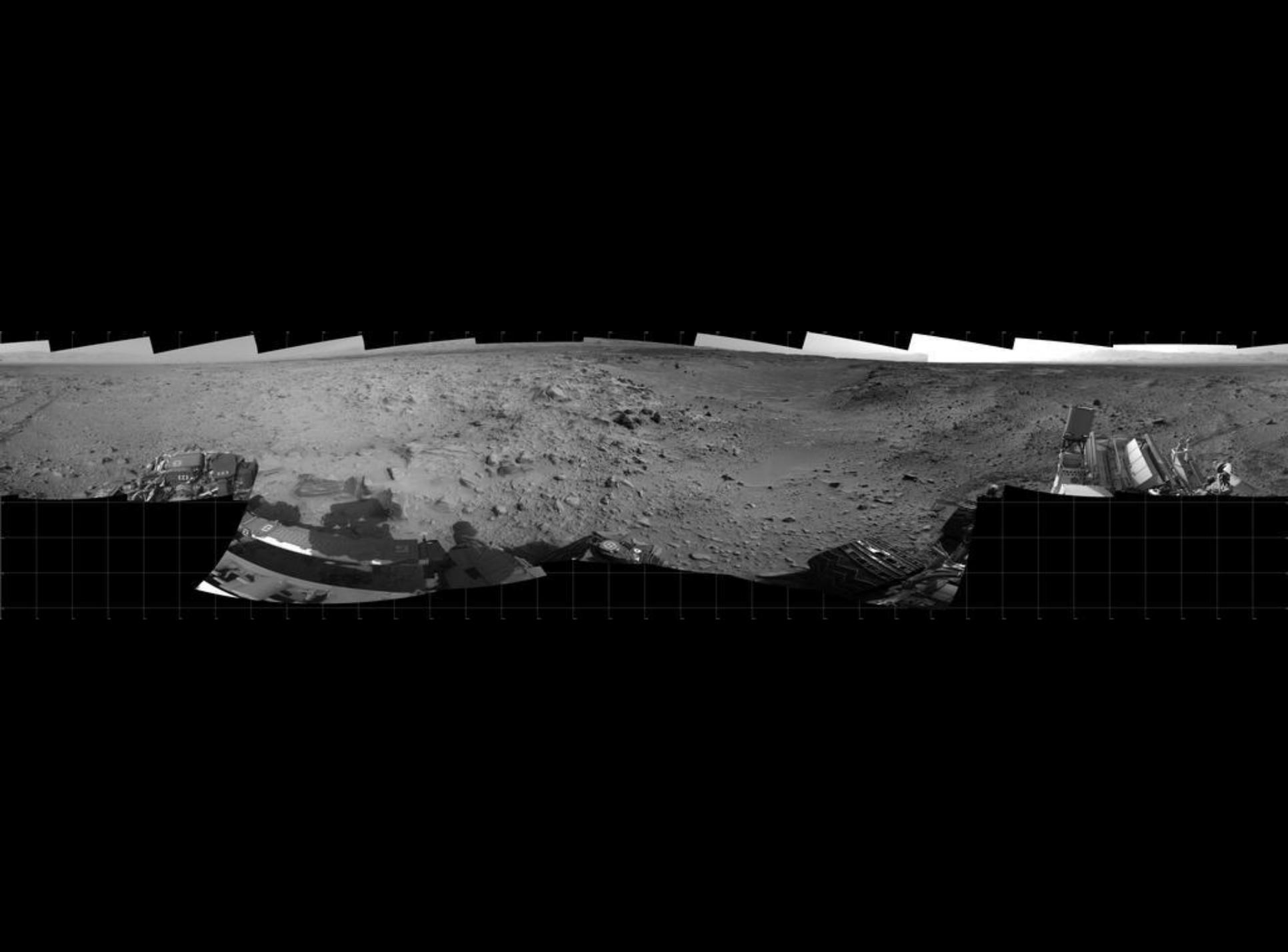


ChemCam

Nighttime image of Windjana drill hole illuminated by MAHLI LEDs and showing ChemCam spots





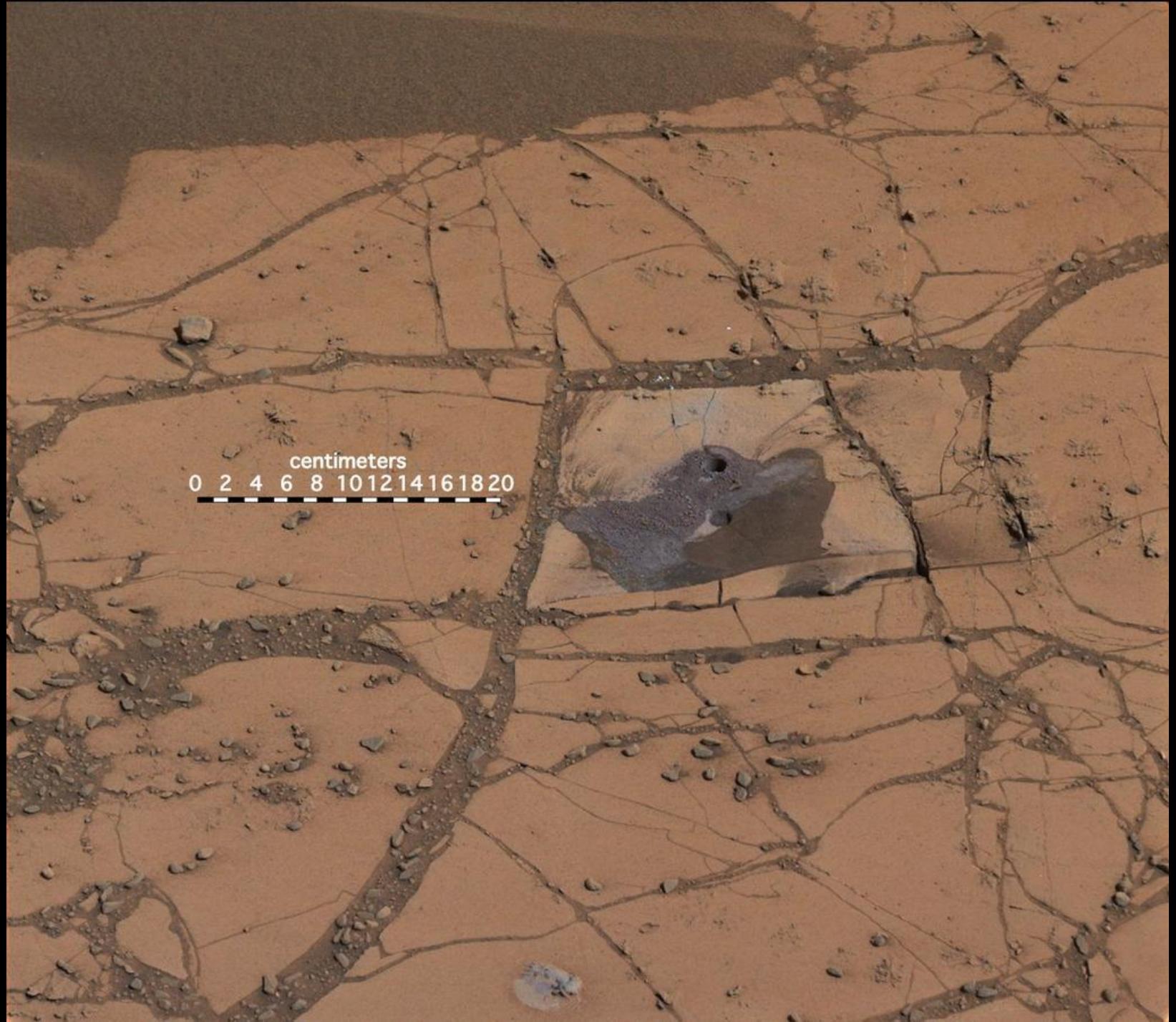


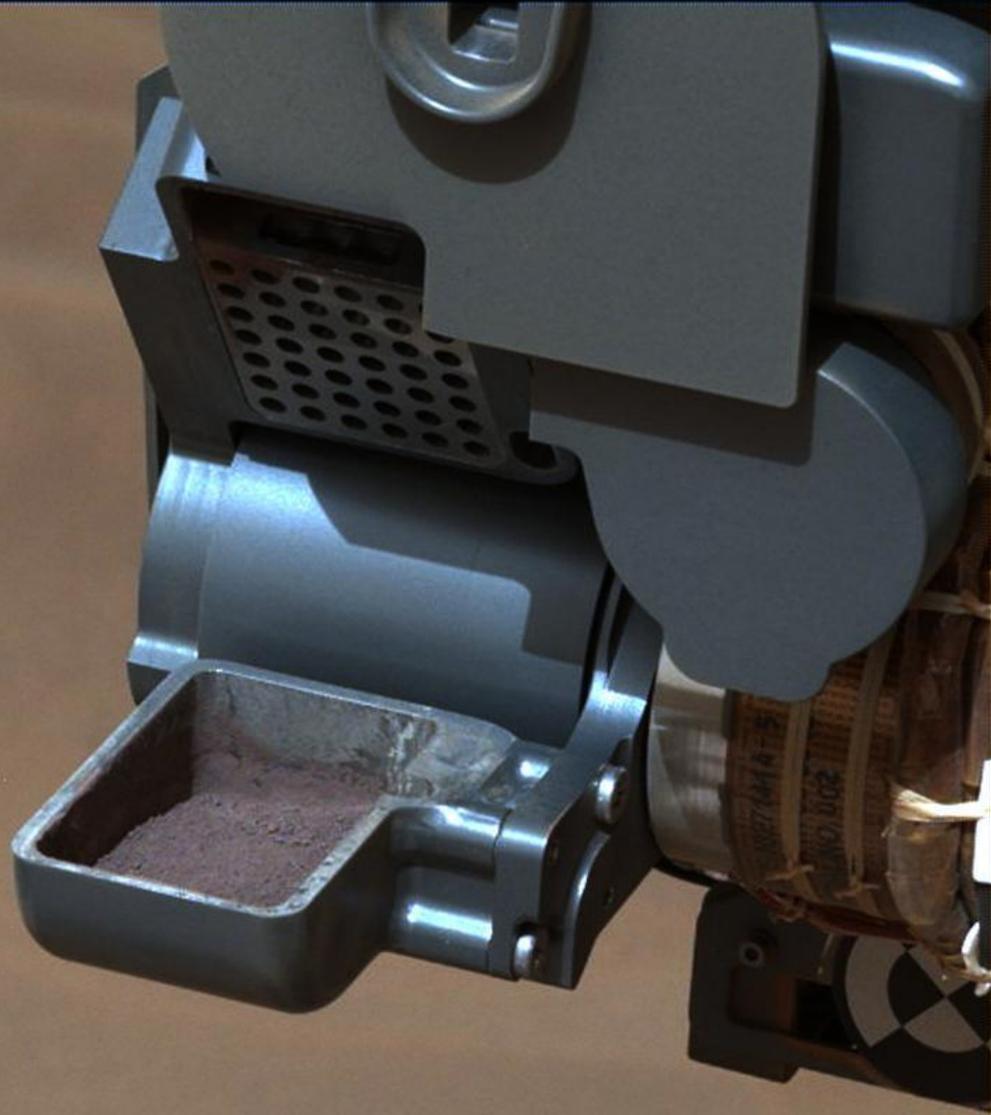


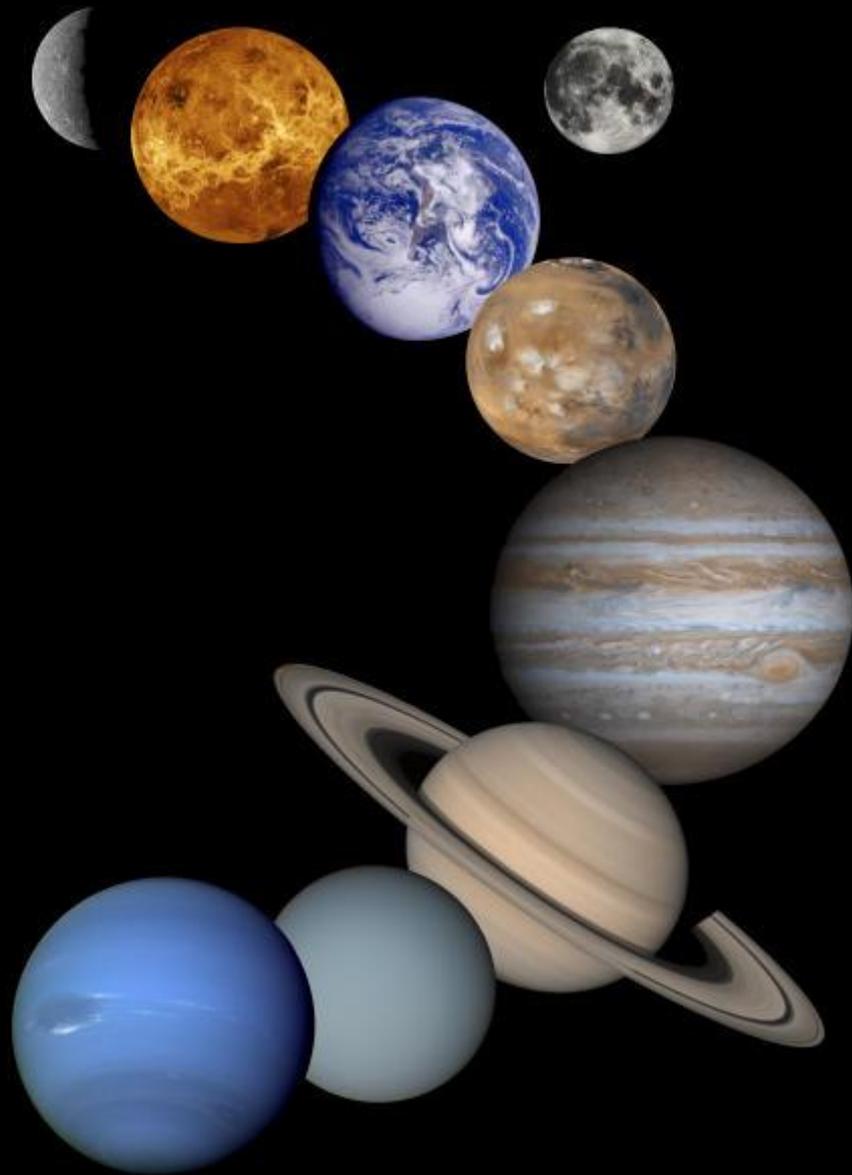


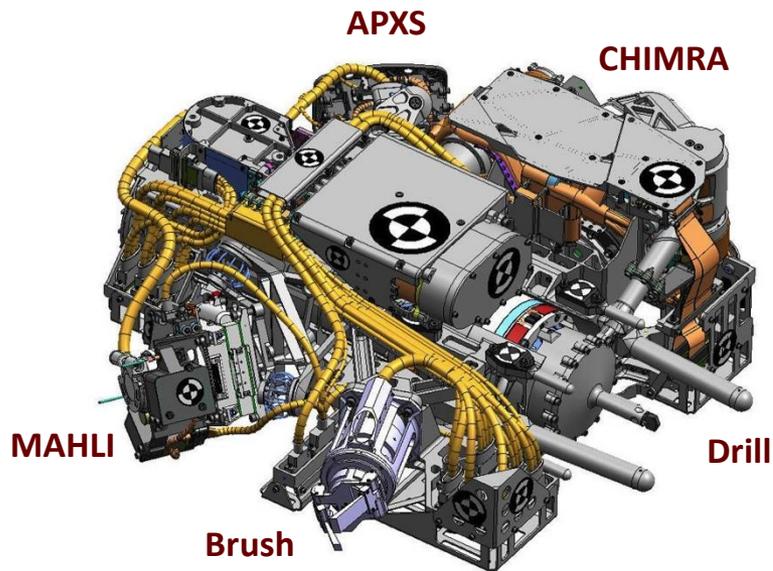
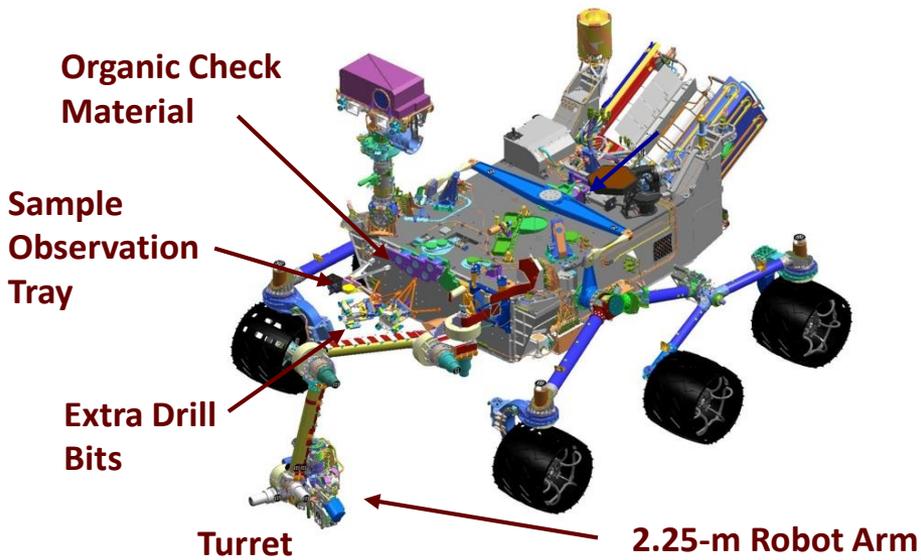


centimeters
0 2 4 6 8 10 12 14 16 18 20



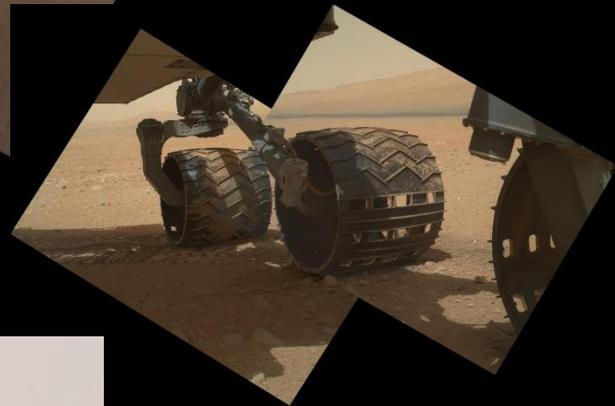
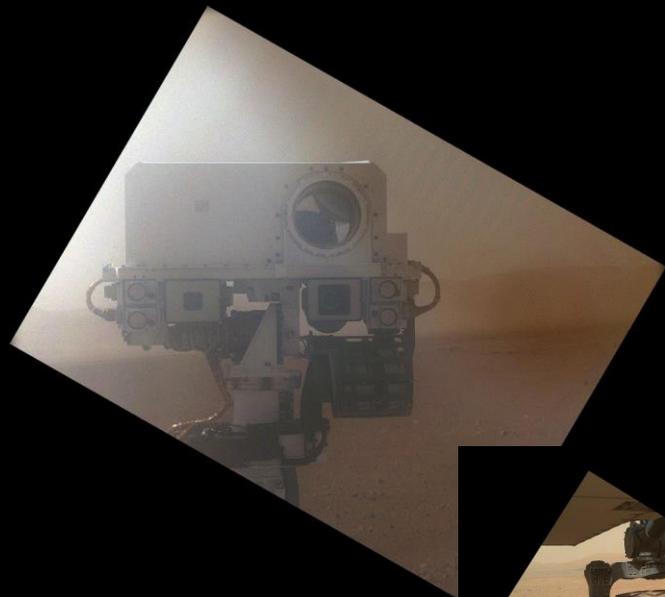




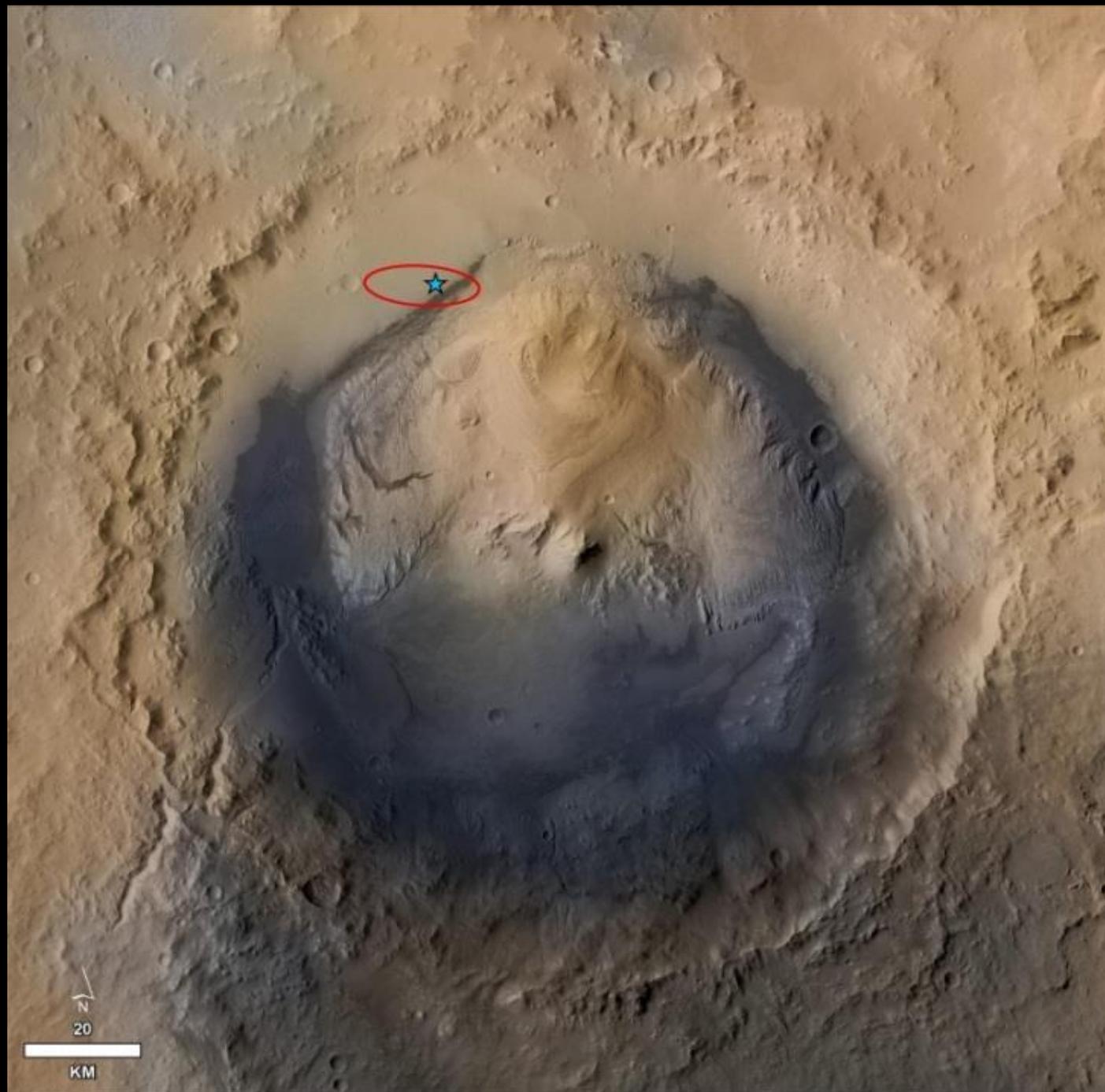


- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 μm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits

Curiosity's Sampling System







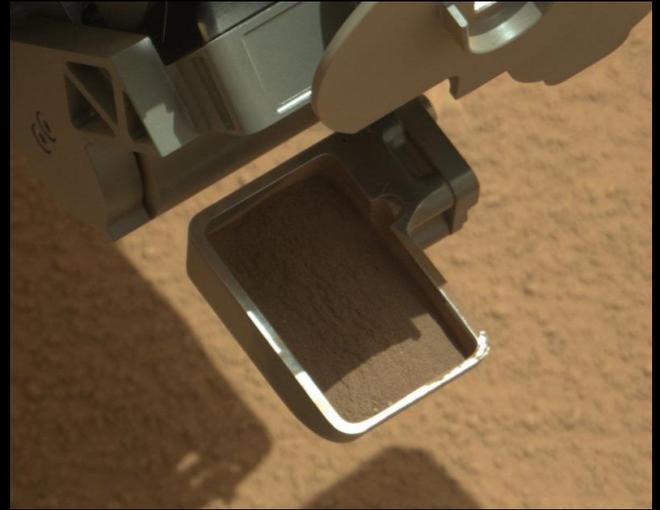


CURIOSITY AT JOHN KLEIN OUTCROP

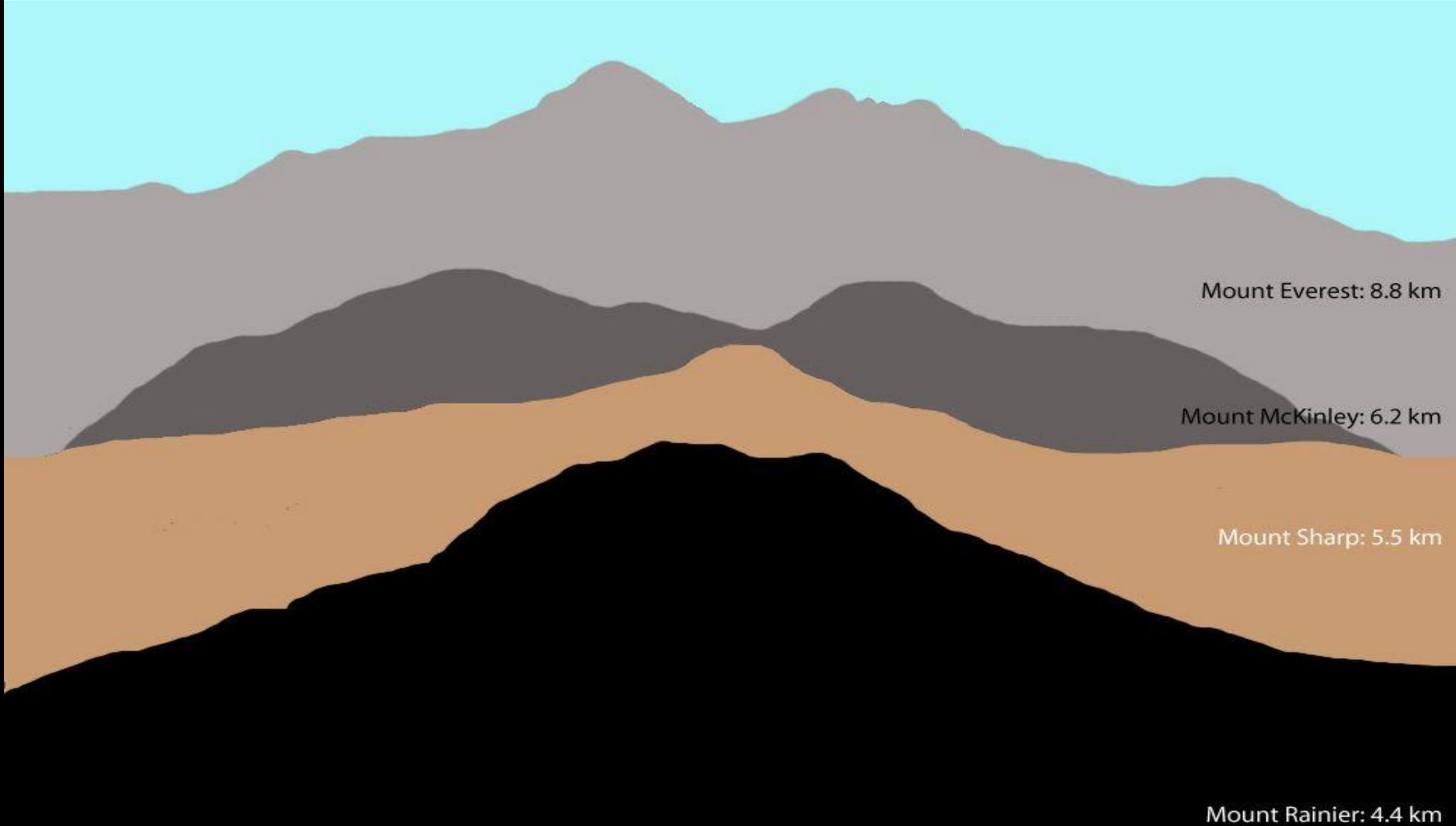
SOL 169

CREDIT: NASA/JPL-CALTECH/KEN KREMER/MARCO DI LORENZO

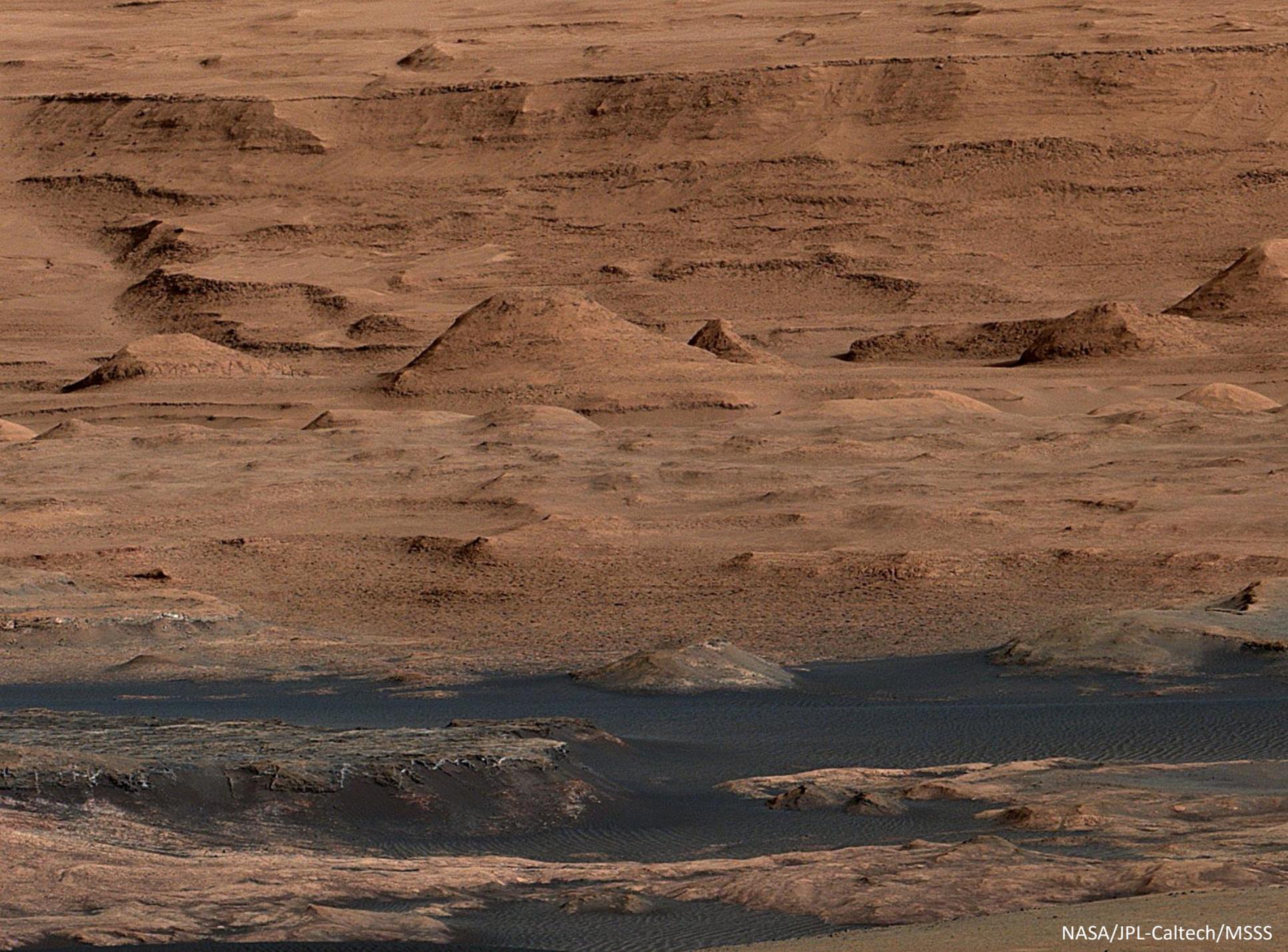




Why Gale Crater?



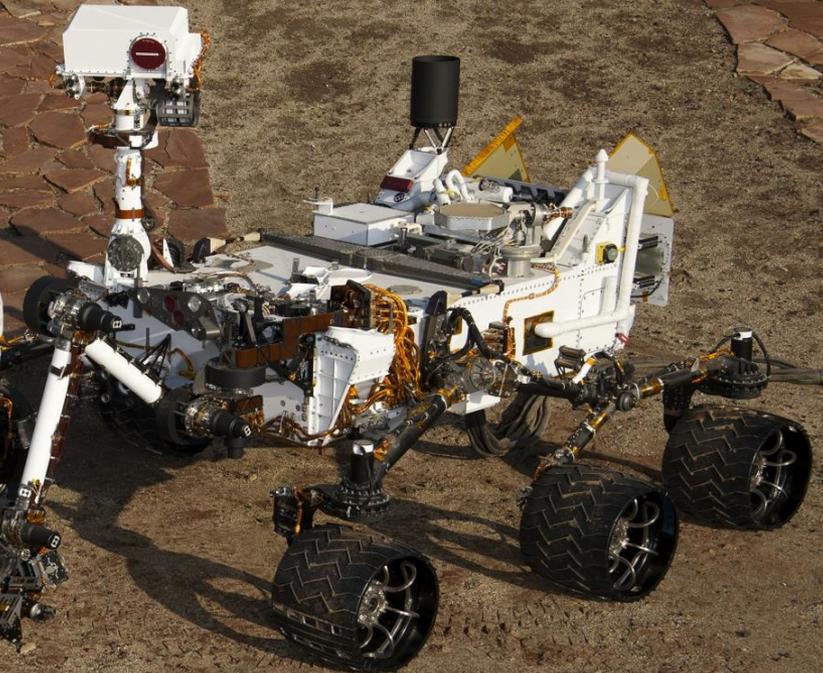
More than 5 km of strata are preserved in the central mound



Rover Family Portrait

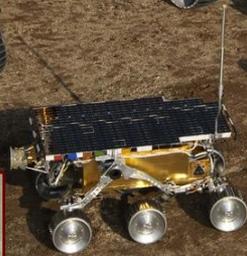
MER: Spirit & Opportunity

Height: 1.5 m (4.9 ft)
Width: 2.3 m (7.5 ft)
Length: 1.6 m (5.2 ft)
Weight: 185 kg (407.8 lbs)



MPF: Sojourner

Height: 30 cm (11.8 in)
Width: 48 cm (19 in)
Length: 65 cm (2.1 ft)
Weight: 10.6 kg (23.4 lbs)



MSL: Curiosity

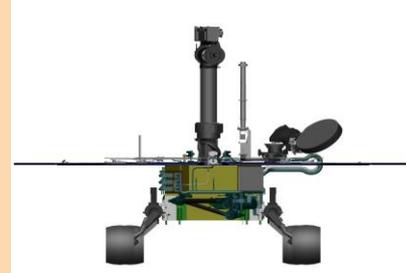
Height: 2.2 m (7.2 ft)
Width: 2.8 m (9.2 ft)
Length: 3 m (9.8ft)
Weight: 889 kg (1960 lbs)



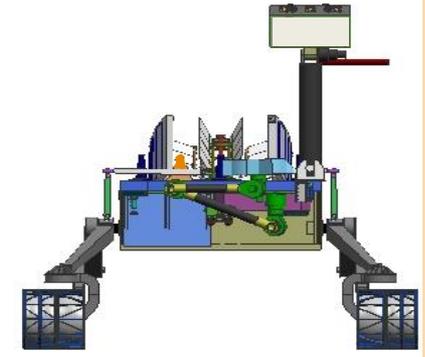
Rover Comparison



**Mini
Cooper**



**MER
Spirit/Opportunity**



**MSL
Curiosity**

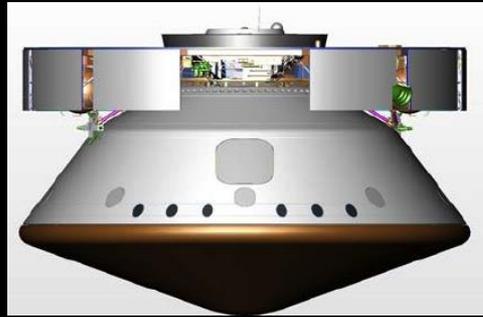
<i>Mass (kg) Launch /Entry/Rover</i>	587-664	1077 / 841 / 185	4050 / 3460 / 889
<i>Mass (lbs) Launch /Entry/Rover</i>	1294-1463	2374 / 1854 / 408	8929 / 7628 / 1960
<i>Payload Mass</i>	Not Included	5 kg / 11 lbs	72 kg
<i>Height m/ft</i>	1.3 m / 4.4 ft	1.5m / 4.9 ft	2.2 m / 7.2 ft
<i>Width</i>	1.4 m / 4.6 ft	2.3 m / 7.5 ft	2.8 m / 9.2 ft
<i>Length</i>	3 m / 10 ft	1.6m / 5.2 ft	3m / 9.8 ft
<i>Ground Clearance</i>	0.14 m / 5.7 in	0.3 m / ~11.8 in	0.66 m / 25 in
<i>Data Return / Sol</i>	Not Included	100 – 200 Mbits	40 – 250 Mbits

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.



Sol 200

Mission Overview



CRUISE/APPROACH

- 9-month cruise
- Arrive August 5, 2012

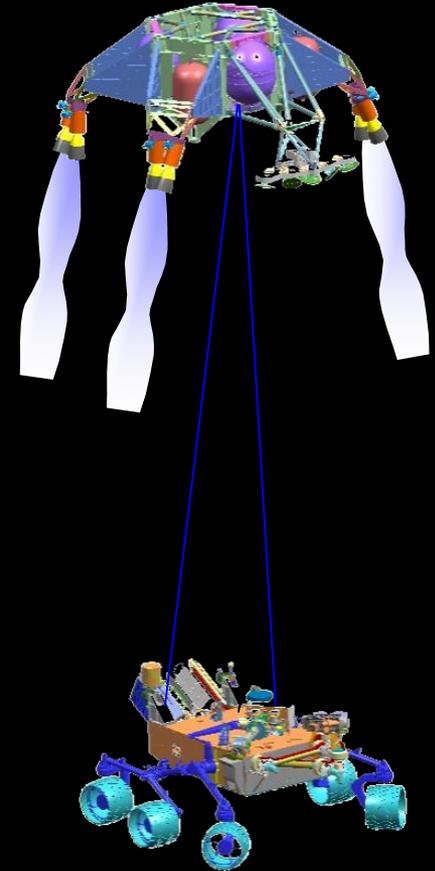
LAUNCH

- November 26, 2011
- Atlas V (541)



ENTRY, DESCENT, LANDING

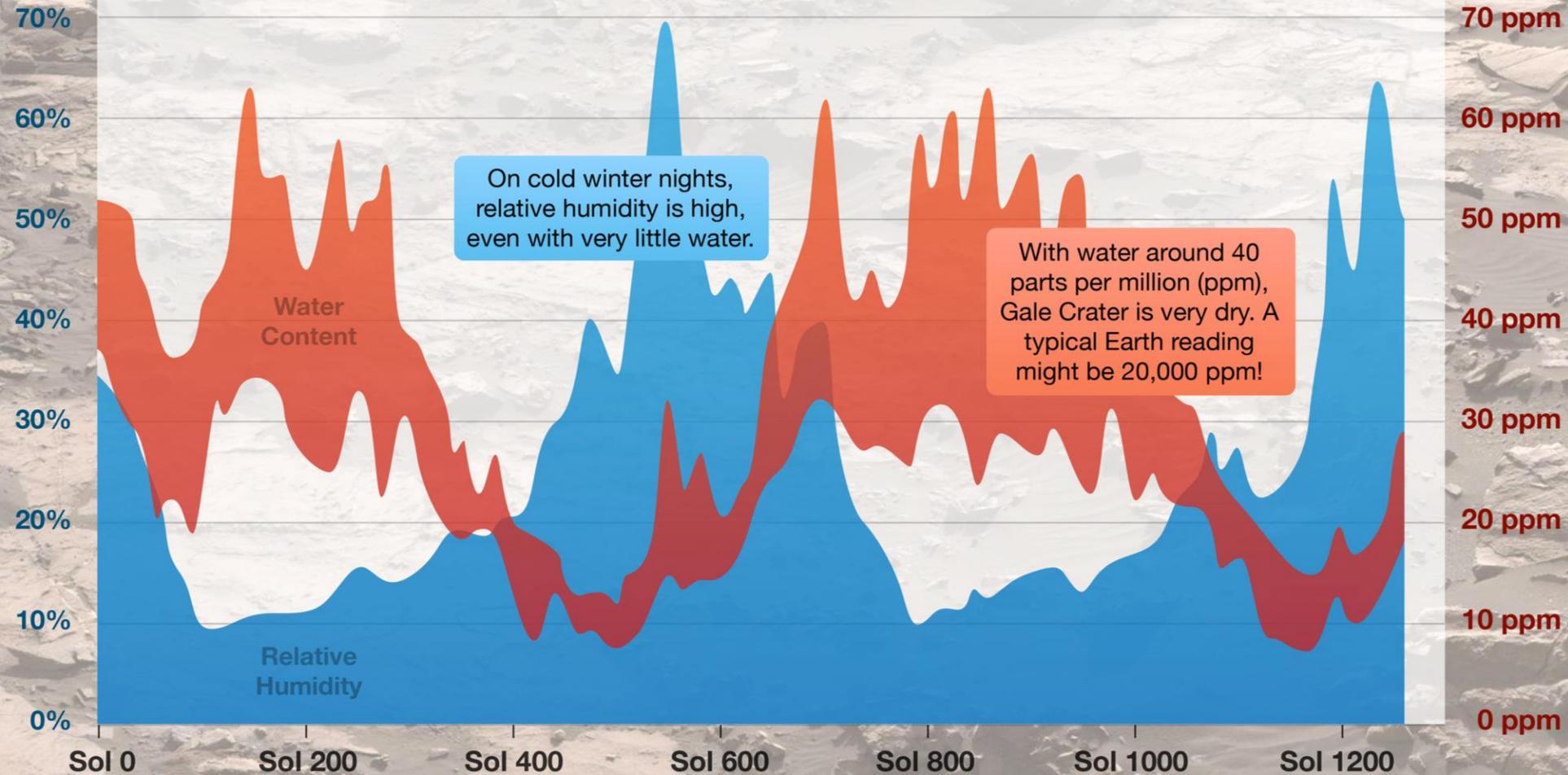
- Guided entry and powered “sky crane” descent
- 20 × 25-km landing ellipse
- Access to landing sites $\pm 30^\circ$ latitude, < 0 km elevation



SURFACE MISSION

- Prime mission is one Mars year (669sols/687 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- 72 kg of science payload
- Direct (uplink) and relayed (downlink) communication

Ranges of Atmospheric Water Content and Relative Humidity at Gale Crater



On cold winter nights, relative humidity is high, even with very little water.

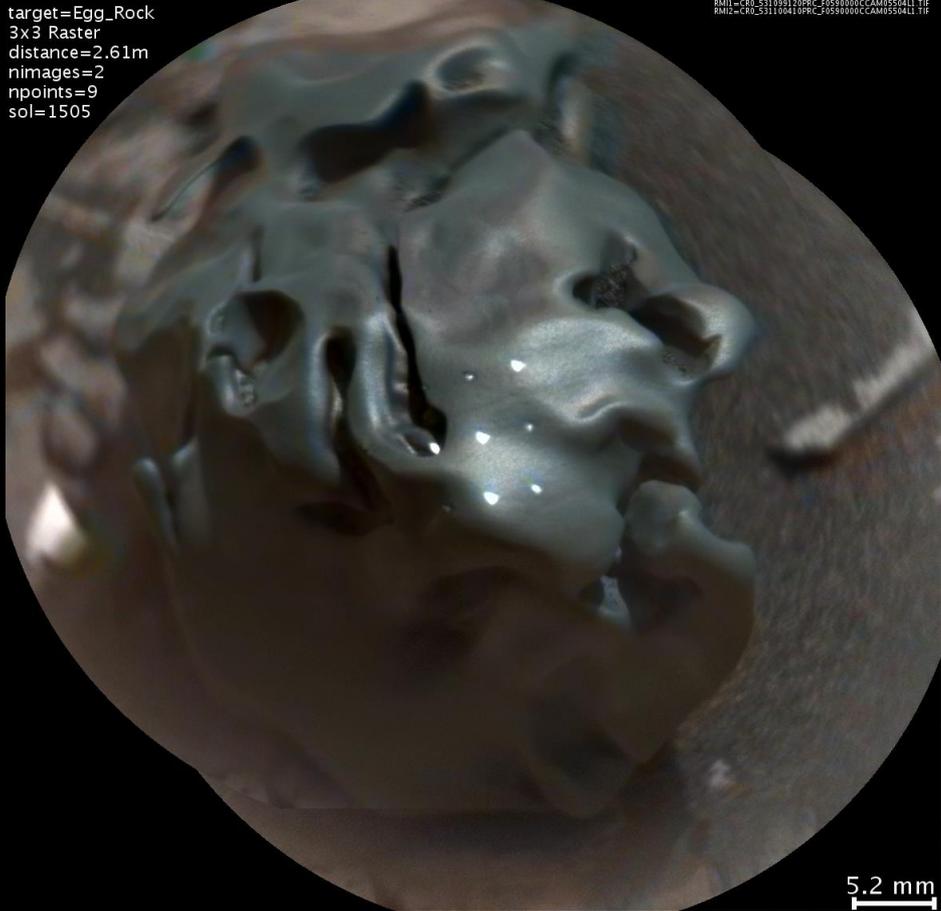
With water around 40 parts per million (ppm), Gale Crater is very dry. A typical Earth reading might be 20,000 ppm!



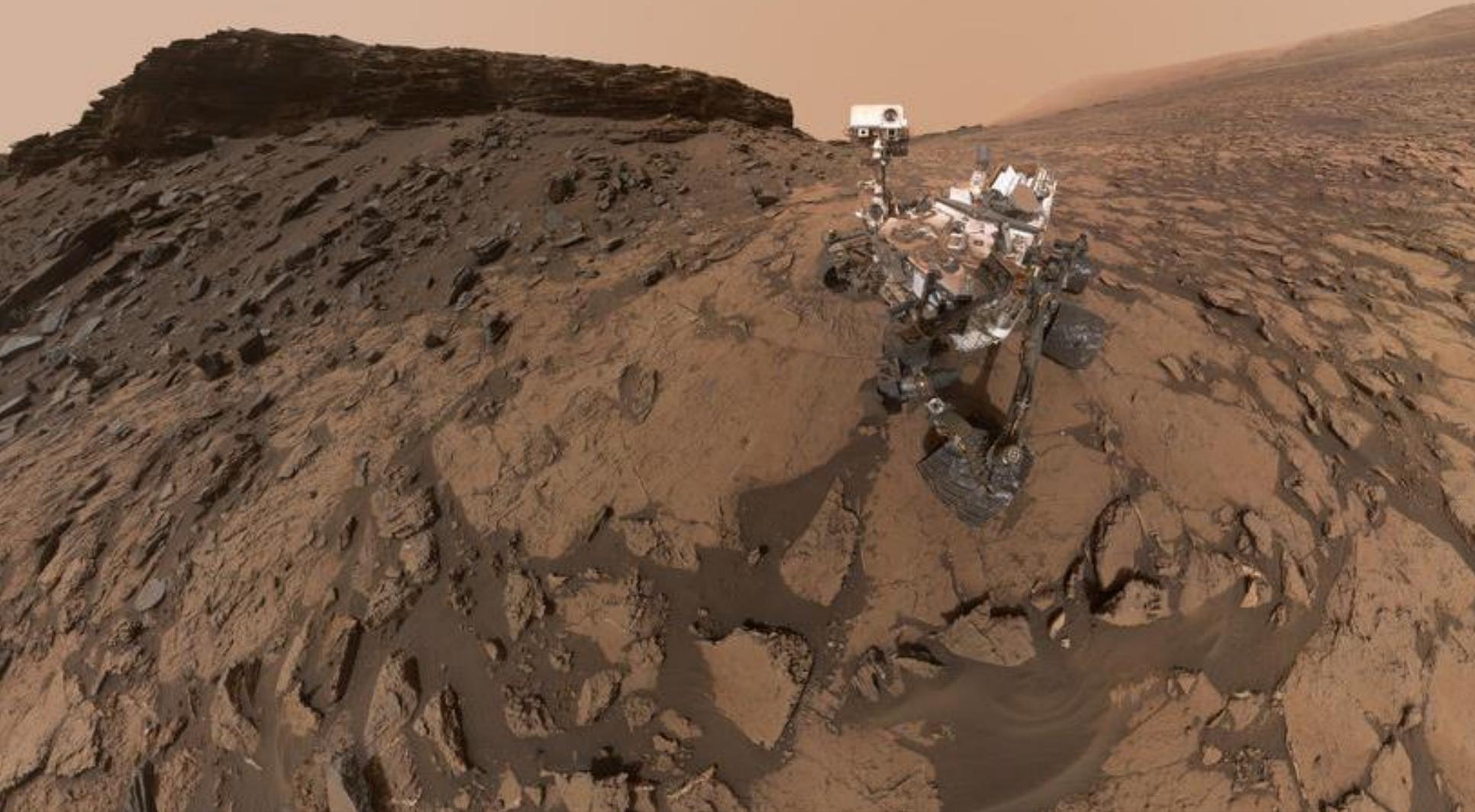
target=Egg_Rock
3x3 Raster
distance=2.61m
nimages=2
npoints=9
sol=1505

RMI-CR0-531199410PRC-10880000CCAM050411.TIF

Nov 2016



Sept. 17, 2016





Plan, Model, and Build the Commands



MSLICE - Red MSA - Command Dictionary: R10_5_7_20120628_05

Sequence Proj: sol00069_tap_end_of_sol-69-70 [READ_ONLY]

sol00069_tap_end_of_sol-69-70 [READ_ONLY]

seqProj

- fileloads
- fileloads1 [A]
- SAM Files
- SeqwRML.rml
- sam_02052.0001a.AS_tl
- sam_01058.0001a.ENG
- sam_00000.0001a.CLN
- mcam00350.0000b.sco
- mcam00349.0000b.sco
- mcam00318.0000a.sco
- mcam00130.0000a.N20
- sss_00013.0000b.end_s
- sam_11070.0001a.EIM
- mstr00062.0000c [Prev]
- sol00048_Jap
- sol00052_SAM_fragment_tfs_c
- sol00061_SSS_Scoop_Throwav
- sol00063_sam_ega_blank
- sol00064_SSS_Scoop_Throwav
- sol00069_tap_end_of_sol
- sol00070_tap_skeleton_STG

LST

- wakeup_aware
- Shutdown_BeAsleep
- Master
- Sol_69_AM_HGA_DFE
- HGA Beep
- Descooped Activities (Unsched)
- Engineering Keepout
- CleanUp
- DAN_On_Passive
- REMS_UploadST_GetData_bar
- Science Block
- MARGIN
- CleanUp
- Arm Submaster
- RHzaz hot pixel monitor
- Arm Backbone
- RHzaz hot pixel monitor
- REMS_Sensor_Maintenance_S
- MARGIN
- CleanUp
- MARGIN - 2 min
- ODY_MSL_2012_290_02
- Decisional_Marker
- MARGIN - 5 min
- DAN_Power_Off
- MARGIN
- CleanUp
- REMS_GetData_backbone
- ODY_MSL_2012_290_03
- ODY_MSL_2012_290_04
- REMS_GetData_backbone
- RSM Heating (Sol 70)

Timeline Table

61:5:104 ML_40290

61:5:104 ML_40290

mstr00062.0000c [ACCEPTED]

```
1  ALL # Deactivate all sec
2  62M10:50:00
3  "eng_00080" NOABORT # HGA Beep
4  62M11:05:00
5  "sub_00000" NOABORT # Engineering Keep
6  #
7  62M11:25:00
8  # Begin Cleanup
9  ALL # Cleanup
10 10(sec) # 62M11:25:10 (WAIT_FOR end t
11 # End Cleanup
12 "sub_00062" NOABORT # MCAM, NCAM, CCAM
13 62M12:20:00
14 "rems13022" NOABORT # REMS_UploadST_Ge
15 #
16 62M12:52:52
17 # Begin Cleanup of sub_00062
18 ALL # Cleanup
19 "ccom15000" NOABORT # Cleanup ChemCam
20 480(sec) # 62M13:00:41 (WAIT_FOR end t
21 "mcam00092" NOABORT # Cleanup Mastcam
22 120(sec) # 62M13:02:39 (WAIT_FOR end t
23 "mcam00093" NOABORT # Cleanup Mastcam
24 120(sec) # 62M13:04:36 (WAIT_FOR end t
25 ALL # Cleanup
26 "c1np00000" NOABORT # Stop imaging, St
27 125(sec) # 62M13:06:40 (WAIT_FOR end
28 # End Cleanup
29 62M14:41:06 # Shutdown at
30 # Resume at 62M14:41:06
31 "sub_01062" NOABORT # MCAM, NCAM, CCAM
32 #
33 62M15:24:16
34 # Begin Cleanup of sub_01062
35 ALL # Cleanup
36 "ccom15000" NOABORT # Cleanup ChemCam
37 480(sec) # 62M15:32:05 (WAIT_FOR end t
38 "mcam00092" NOABORT # Cleanup Mastcam
39 120(sec) # 62M15:34:03 (WAIT_FOR end t
40 "mcam00093" NOABORT # Cleanup Mastcam
41 120(sec) # 62M15:36:01 (WAIT_FOR end t
42 ALL # Cleanup
```

RML 'Seqv

Activity Dictio
Command Dictio
Spacecraft Id
Version

Last Edit
Time 2
User Id a
Application N
Host d

Sequence Problems (124) Search Console
4 errors, 120 warnings, 0 others (Filter matched 100 of 124 items)



JPL Curiosity



MINI Cooper S

