

National Aeronautics and  
Space Administration



# Robotic Missions: Trailblazing a Path for Humans

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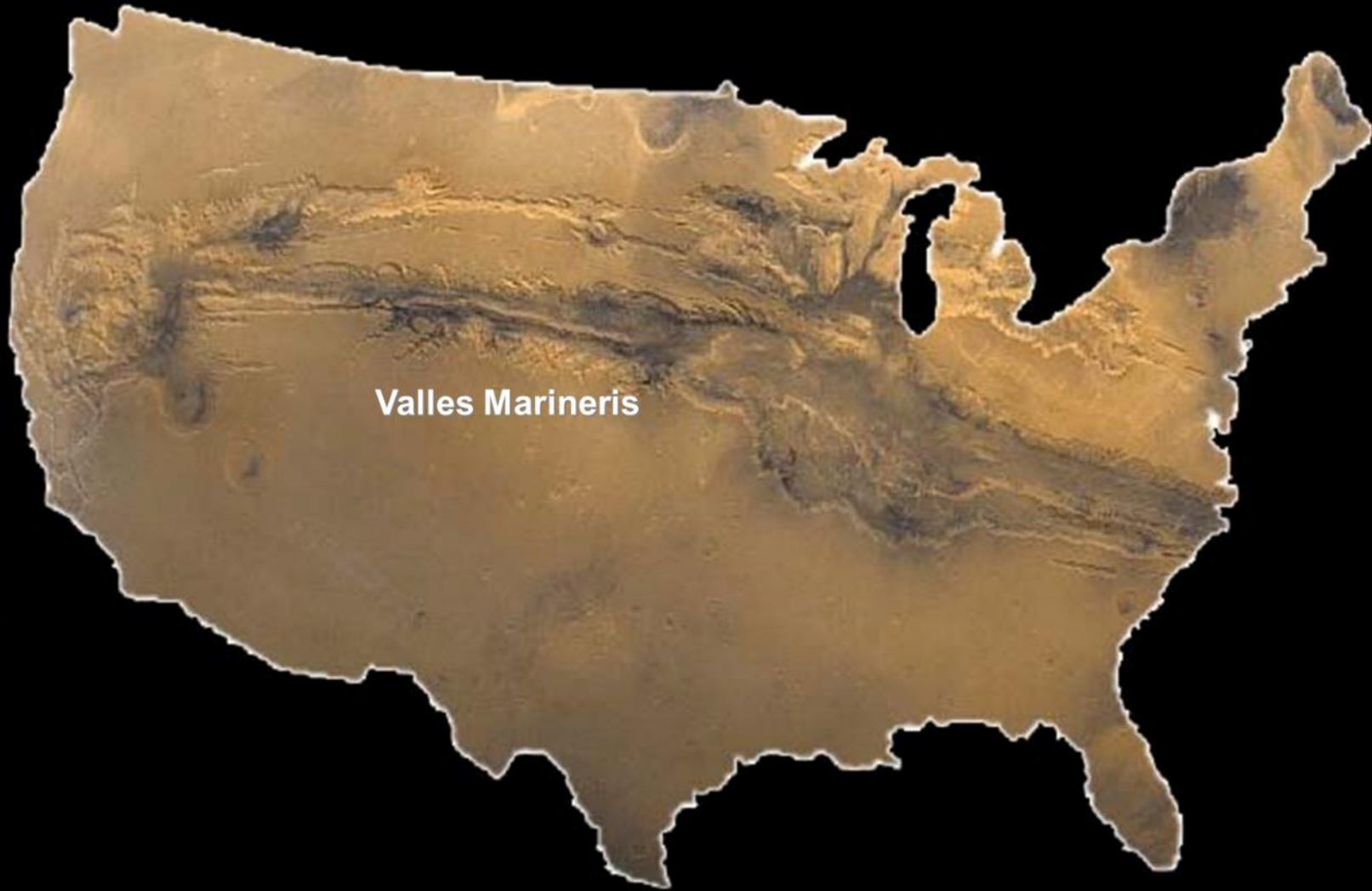
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# Everything is Bigger on Mars!



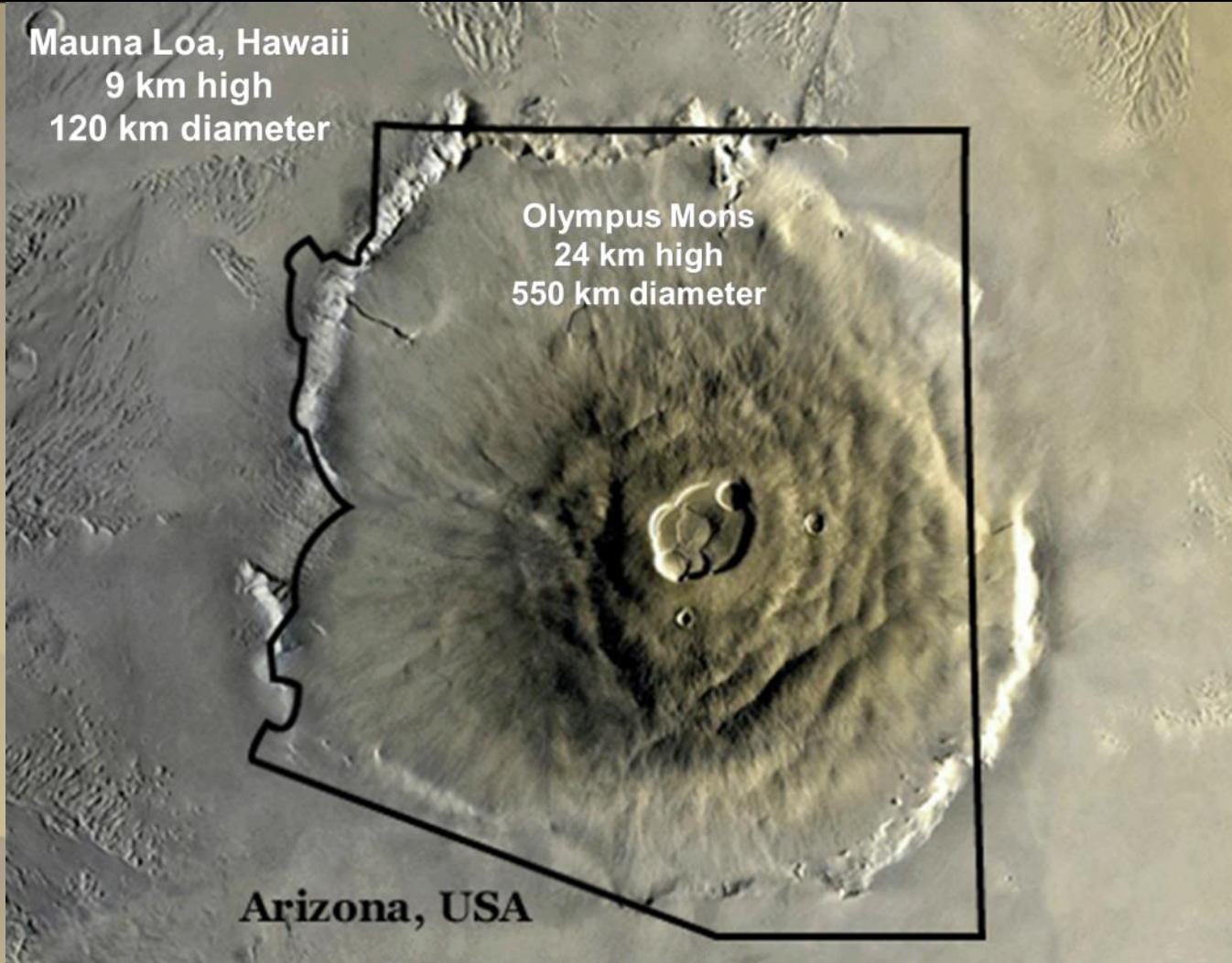
# Everything is Bigger on Mars!



Mauna Loa, Hawaii  
9 km high  
120 km diameter

Olympus Mons  
24 km high  
550 km diameter

Arizona, USA







# Global Dust Storms



## Mars • Global Dust Storm



June 26, 2001



September 4, 2001

**Hubble Space Telescope • WFPC2**

NASA, J. Bell (Cornell), M. Wolff (SSI), and the Hubble Heritage Team (STScI/AURA) • STScI-PRC01-31

# Recent Mars Robotic Missions

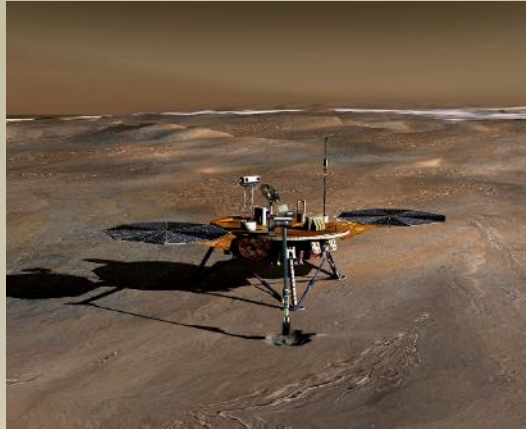


Spirit

Opportunity

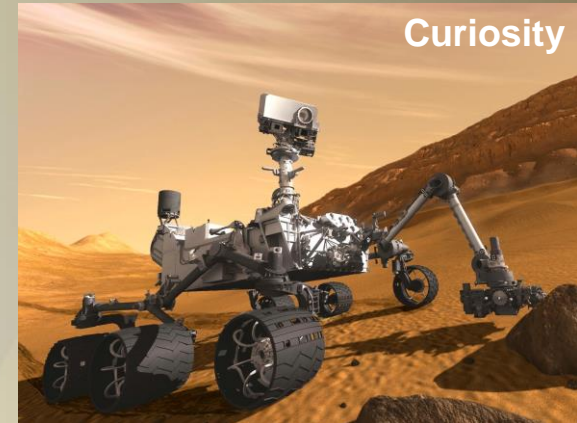


Mars Exploration Rovers

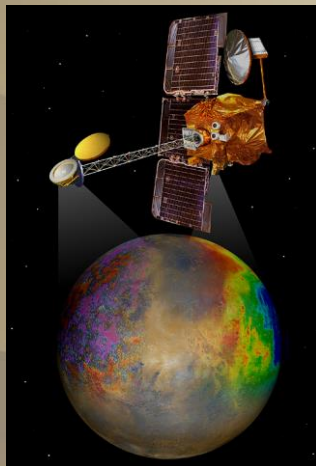


Mars Phoenix

Curiosity



Mars Science Laboratory



Mars Odyssey

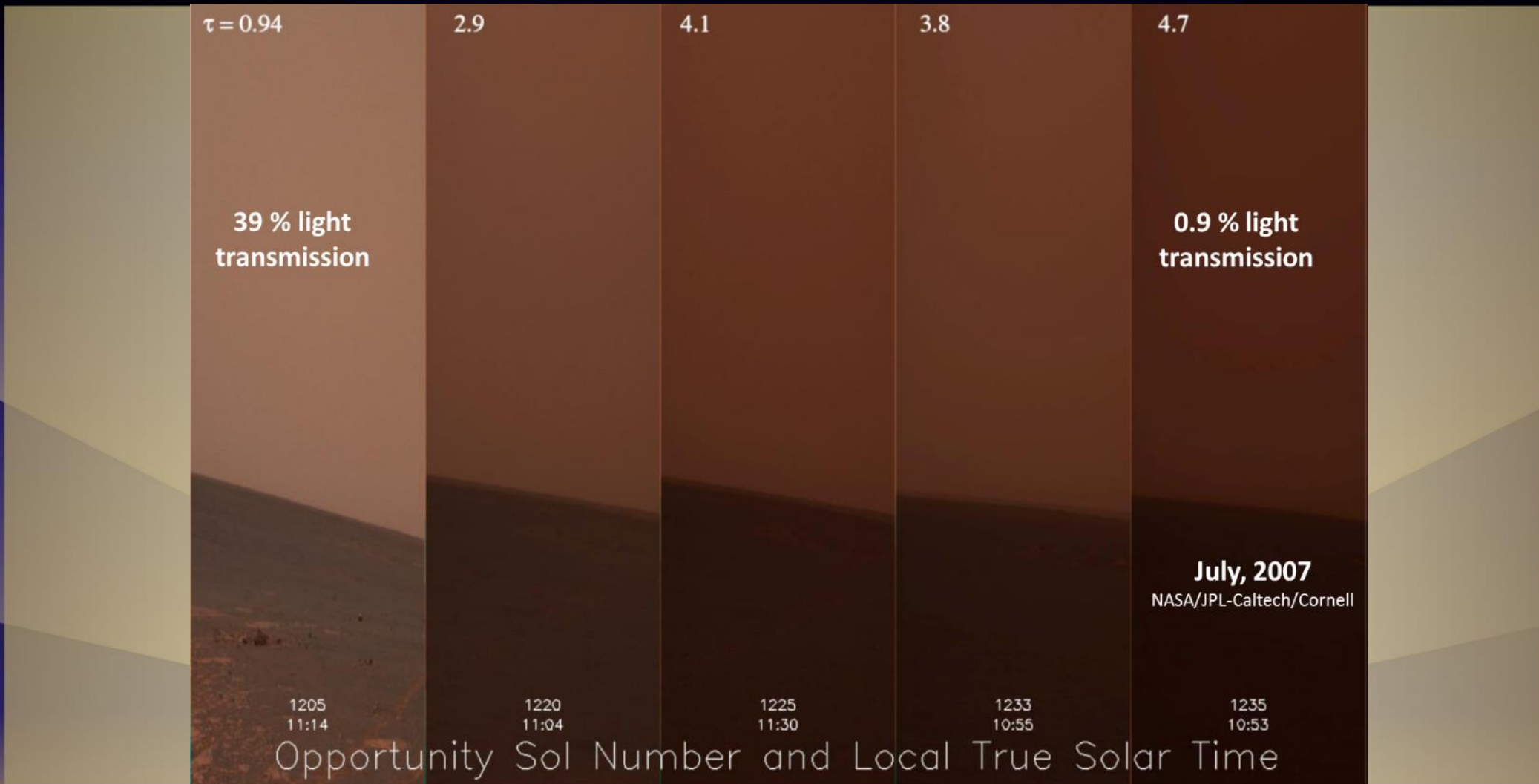


Mars Express



Mars Reconnaissance Orbiter

# Dust Storm at the Opportunity Landing Site



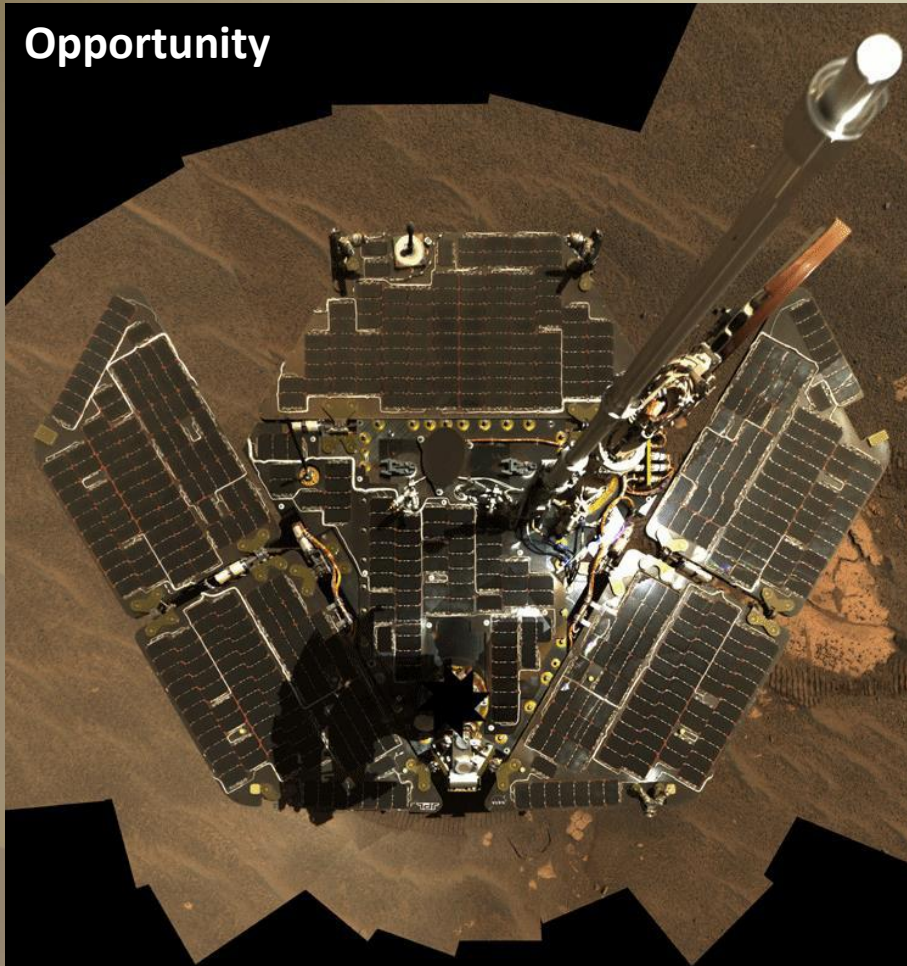


# Dust Accumulation on Spacecraft

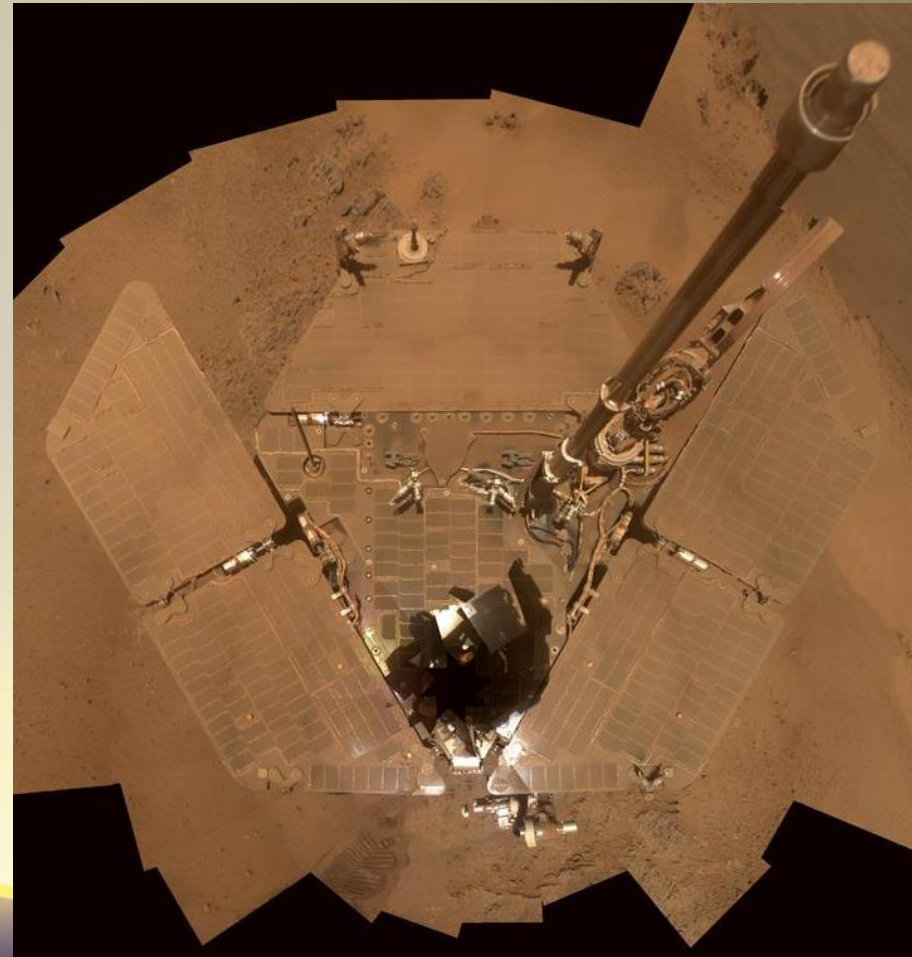


NASA/JPL-Caltech/Cornell

Opportunity



Sol 332 (December 2004)



Sol 2814 (December 2011)

# Dust Devils on Mars



NASA/JPL-Caltech



## Dust Devils



## In Gusev Crater

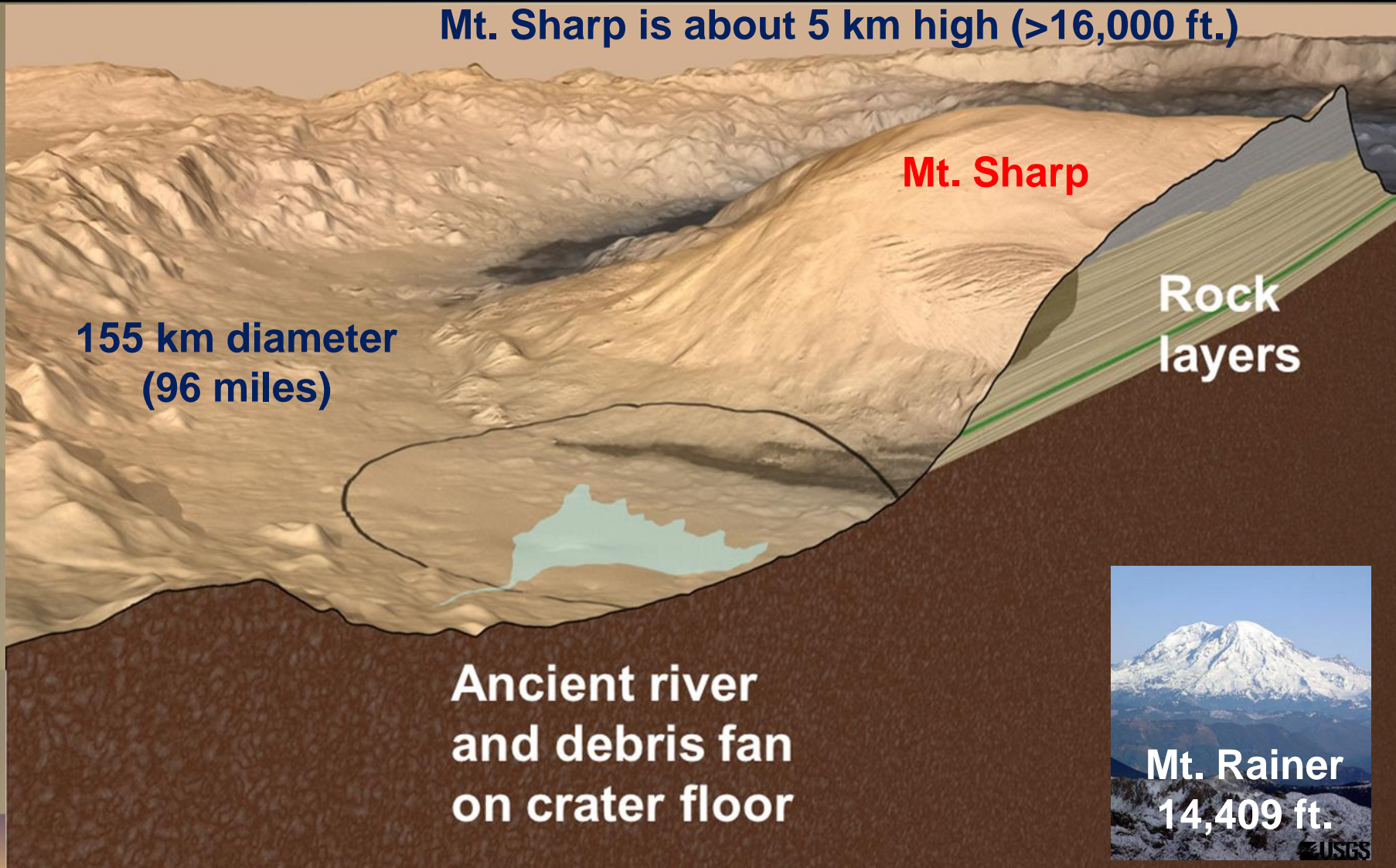




# Curiosity in Gale Crater



Mt. Sharp is about 5 km high (>16,000 ft.)



155 km diameter  
(96 miles)

Mt. Sharp

Rock  
layers

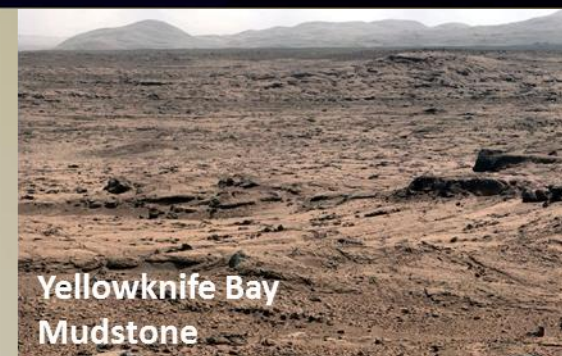
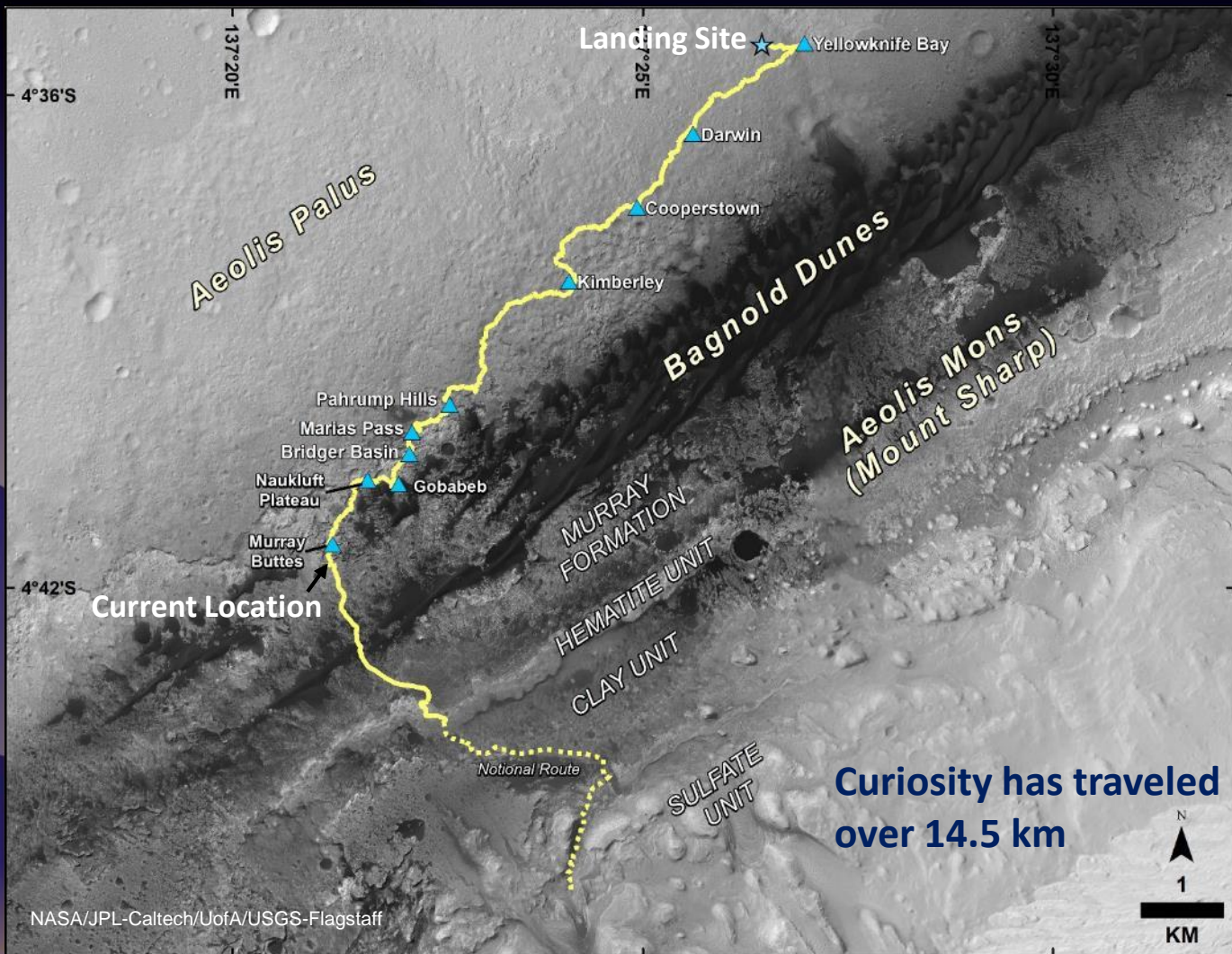
Ancient river  
and debris fan  
on crater floor



Mt. Rainer  
14,409 ft.



# Curiosity's Journey

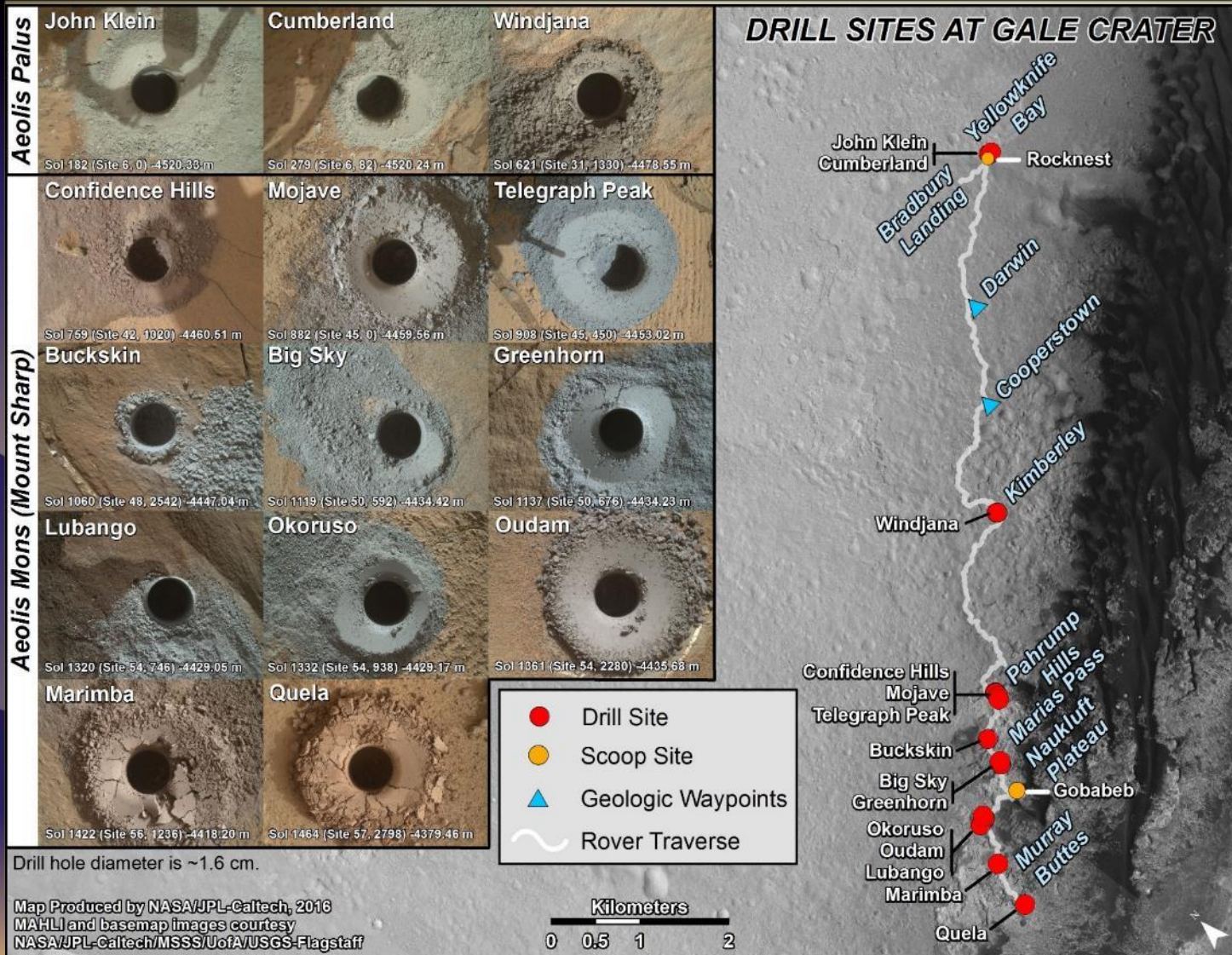


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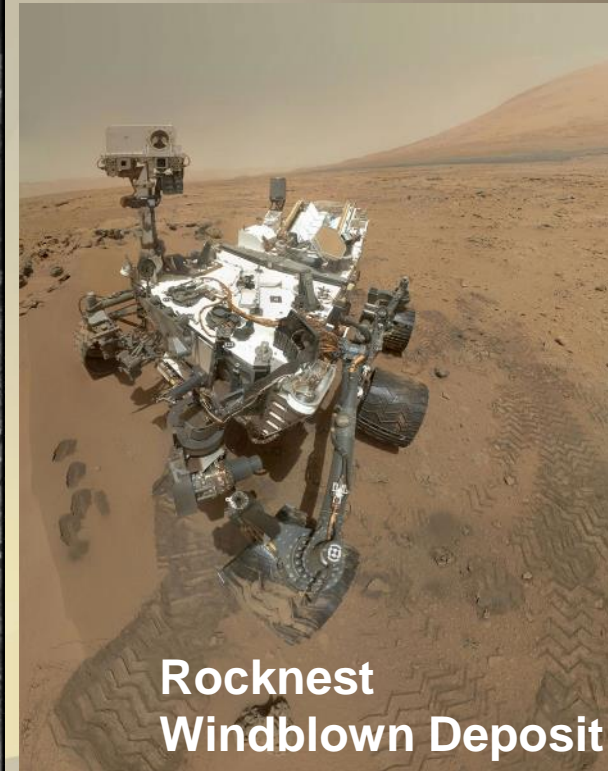




# Samples Delivered to Instruments



- 14 Drilled Samples
- 2 Scooped Samples

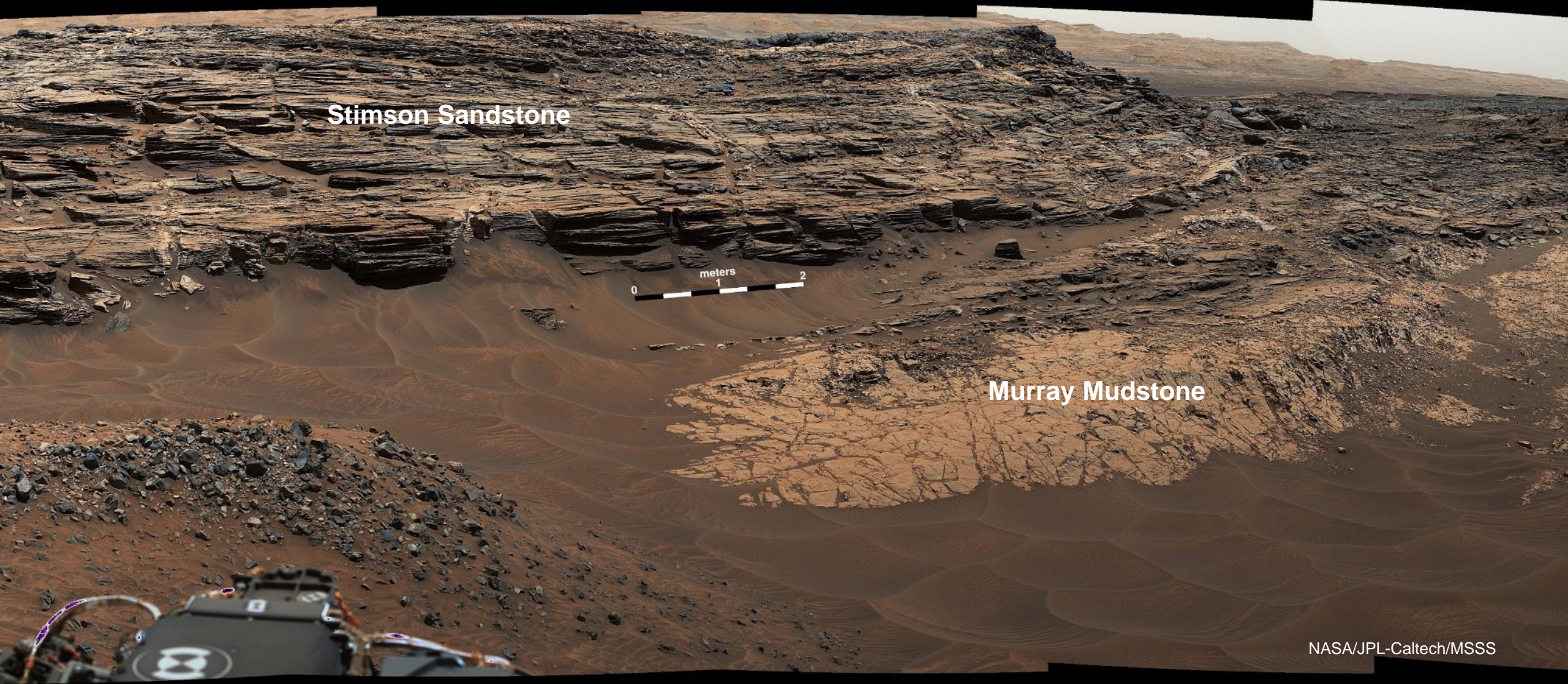


Rocknest  
Windblown Deposit

NASA/JPL-Caltech/MSSS



# Sandstone overlying Mudstone



Stimson Sandstone

0 1 2  
meters

Murray Mudstone



# Mudstone Mineralogy



Cumberland

Confidence Hills

Debye X-ray  
diffraction rings

Iron Oxide

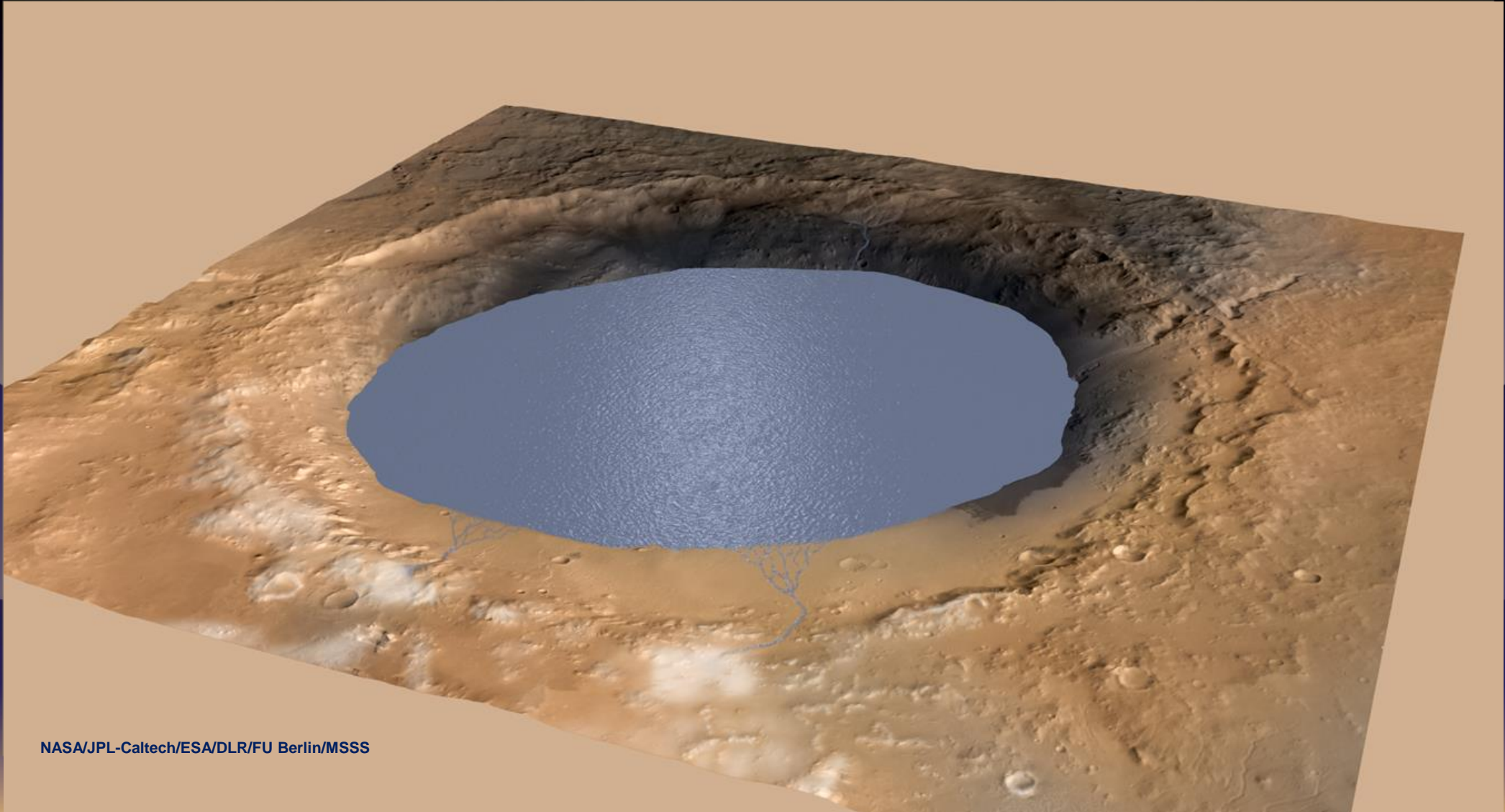
Clay Mineral

- Clay Minerals
- Iron oxides
  - Hematite (oxidized)
  - Magnetite (reduced)
- Sulfates
  - Calcium sulfates (neutral?)
  - Iron sulfates (acidic)
- X-ray amorphous materials





# Ancient Lake in Gale Crater



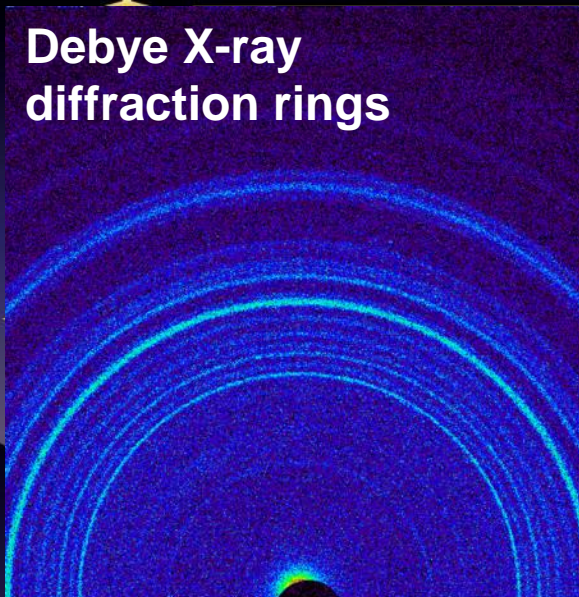
NASA/JPL-Caltech/ESA/DLR/FU Berlin/MSSS



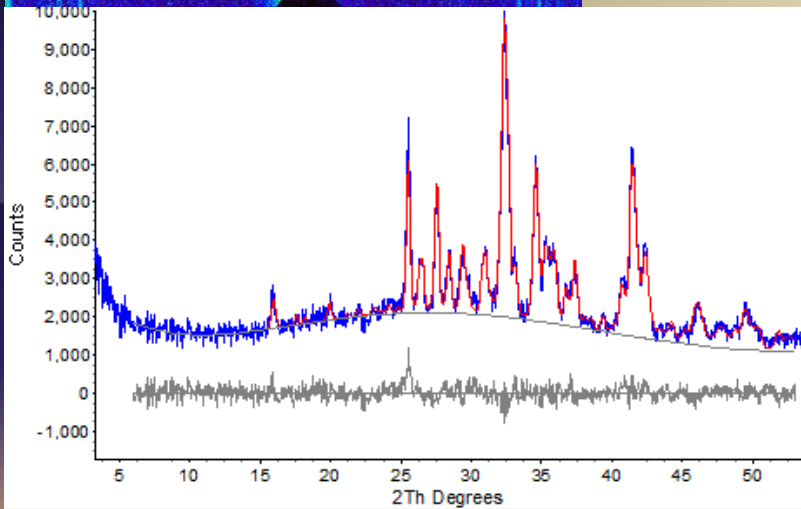
# Windblown Deposit Mineralogy/Chemistry



## Debye X-ray diffraction rings

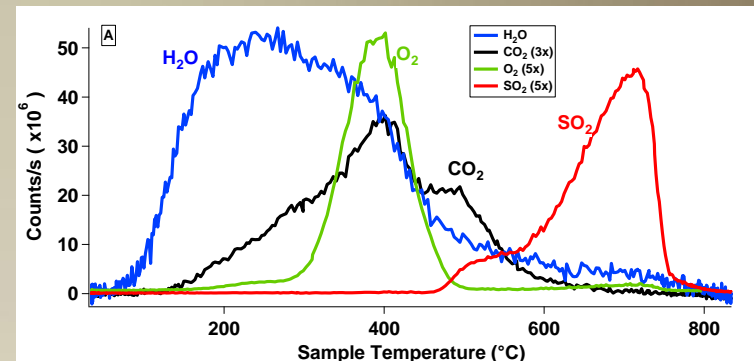


- Basalt minerals
  - Feldspars
  - Olivine
  - Pyroxene
  - Magnetite
- Minor phases
  - Hematite (Fe-oxide)
  - Calcium sulfate
- X-ray amorphous materials

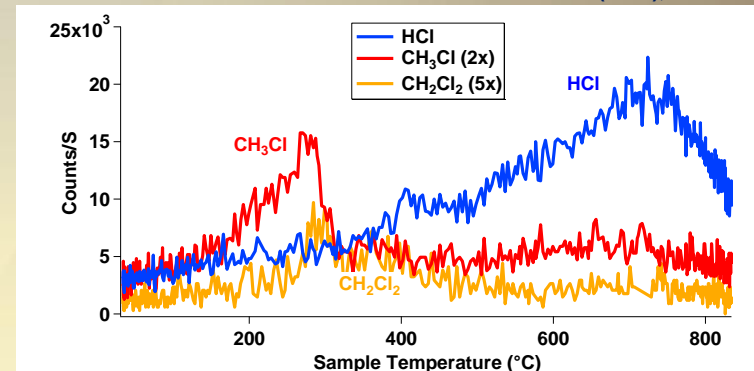


Bish et al. (2013), *Science*

## Evolved Gas Analysis

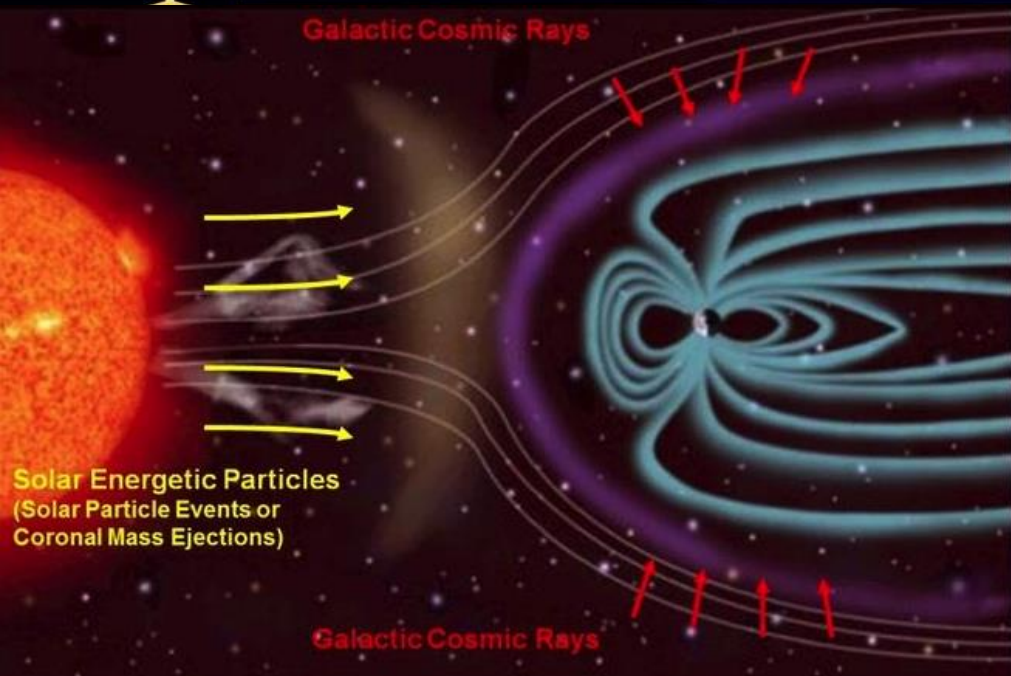


Leshin et al. (2013), *Science*



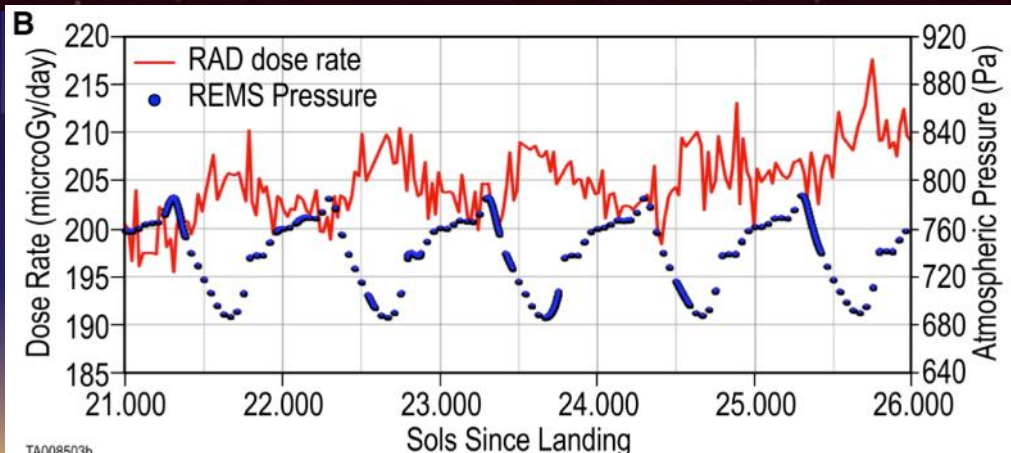
- 2-3 wt. % water release
- Oxygen, hydrochloric acid, and chlorinated hydrocarbon releases from decomposition of perchlorate salts

# Radiation Environment on Mars

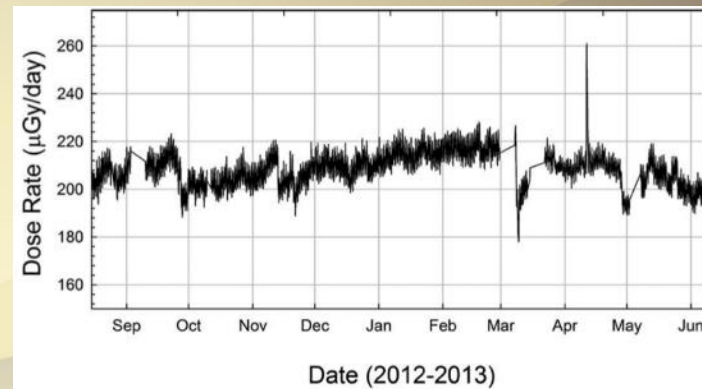


## Radiation Assessment Detector (RAD)

- RAD measured the radiation flux from galactic cosmic rays and solar energetic particles, in cruise and at Mars' surface
- The surface dose rate is about half that measured in cruise
- ~1000 millisievert of exposure on a trip to Mars with 500 sols on the surface (only about 75 millisievert dose during 6 months on ISS; 2-3 millisievert/year on Earth)

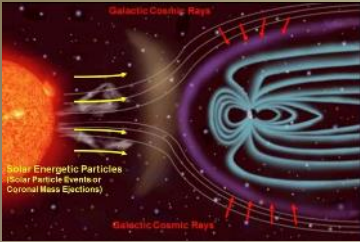


Hessler et al. (2014), *Science*

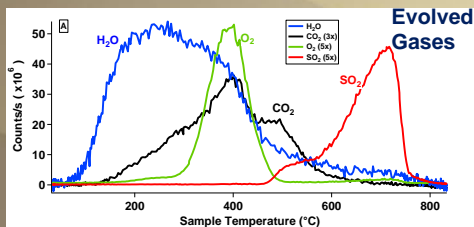




# Technology Challenges/Benefits For Humans



NASA/JPL-Caltech/Cornell



Leshin et al. (2013), *Science*

- Radiation WILL be an issue (but not a “show stopper”)
  - Shielding (what materials should we use for shielding?)
  - Minimize exposure
- Martian dust must be addressed
  - Toxicology – e.g., perchlorates
  - Tribology – effects on seals, joints, airlocks, etc.
  - Minimize dust in living spaces and suits
- Extraction of resources (In Situ Resource Utilization)
  - Water extraction for propulsion, life support, etc.
    - Regolith, minerals with high water content, ice?
  - CO<sub>2</sub> atmosphere extraction and O<sub>2</sub> production
  - Other resources?

# Can We Grow Plants in Martian Regolith?



Can Plants  
**GROW**  
with  
MARS SOIL?

Essential Plant Nutrients

Macronutrients	Micronutrients
✓ Oxygen (O)	✓ Iron (Fe)
✓ Carbon (C)	✓ Manganese (Mn)
✓ Hydrogen (H)	✓ Zinc (Zn)
✓ Nitrogen (N)	✓ Copper (Cu)
✓ Potassium (K)	✓ Molybdenum (Mo)
✓ Phosphorus (P)	✓ Boron (B)
✓ Calcium (Ca)	✓ Chlorine (Cl)
✓ Magnesium (Mg)	
✓ Sulfur (S)	

✓ = detected on Mars soil, or in Martian meteorites

#JOURNEYTOMARS

- **Regolith (“Soil”)** contains all essential plant growth nutrients.
  - **N** present but will likely have to fertilize.
  - **Others?**
- **Perchlorates** may be an issue collecting in plant tissue.
- **Other salts? Other issues?**
- **As an agronomist by training – I think we CAN grow plants in Martian “soil.”**