MSL Stacked Spacecraft – Final Rotation

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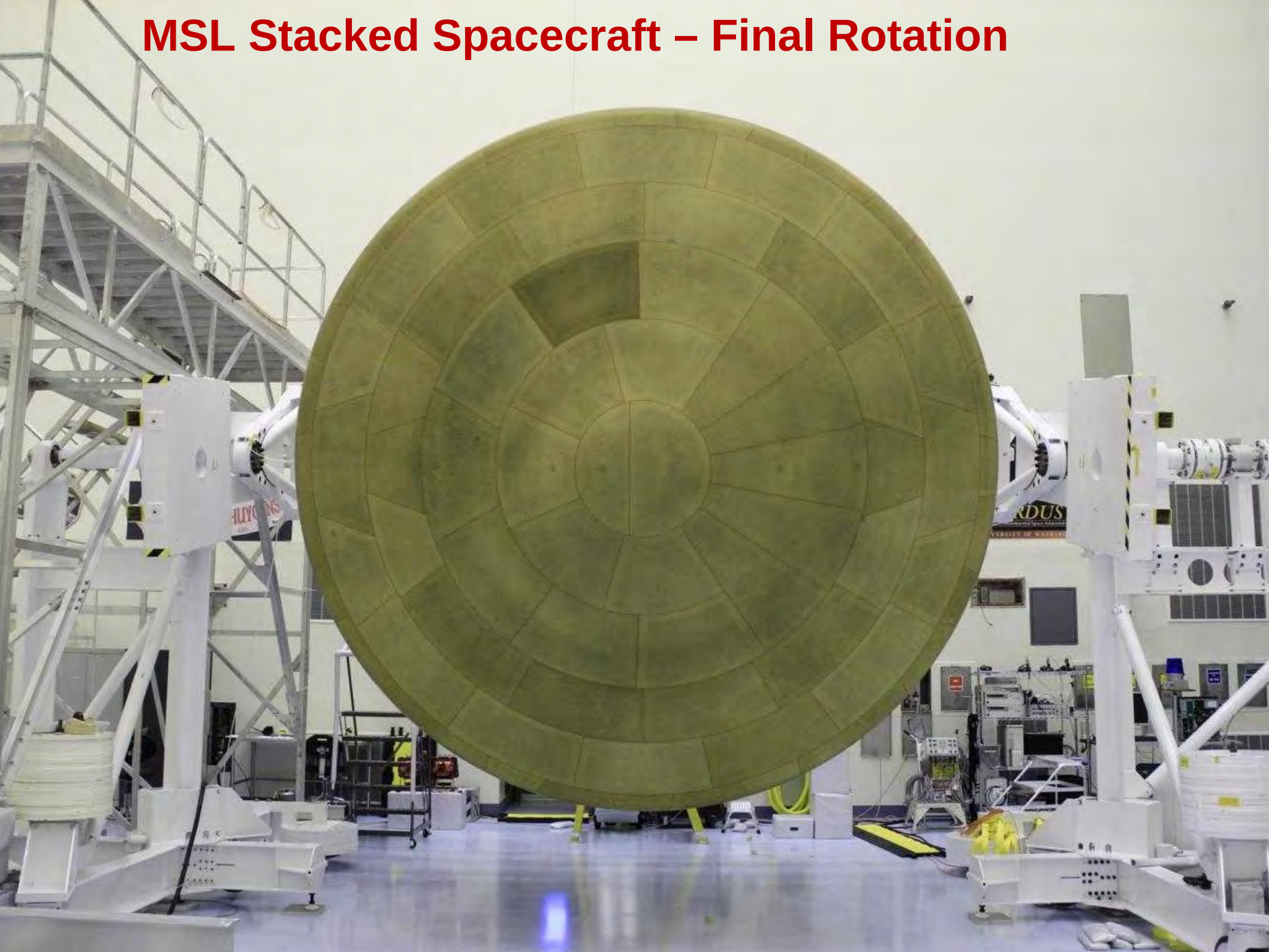
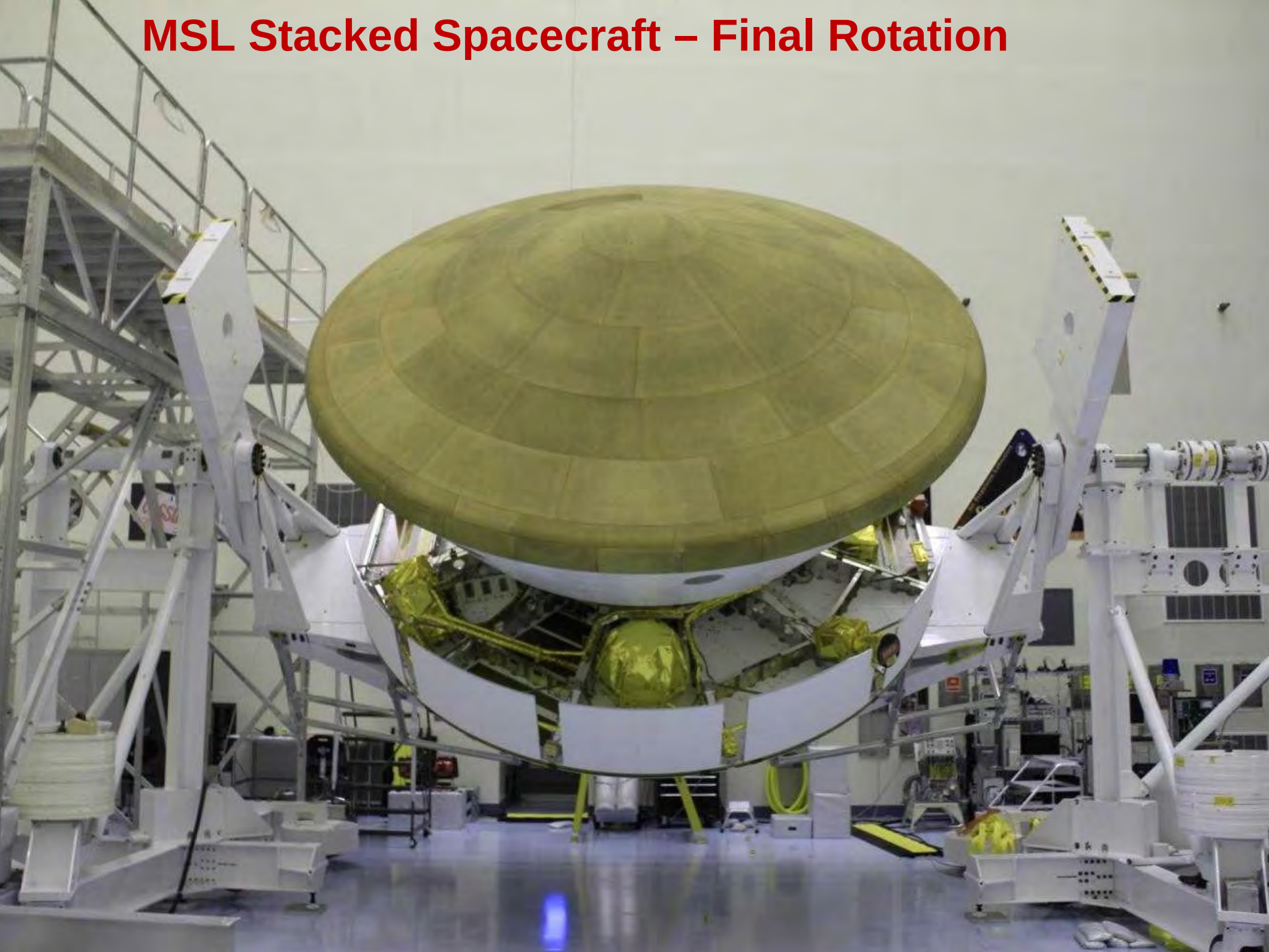
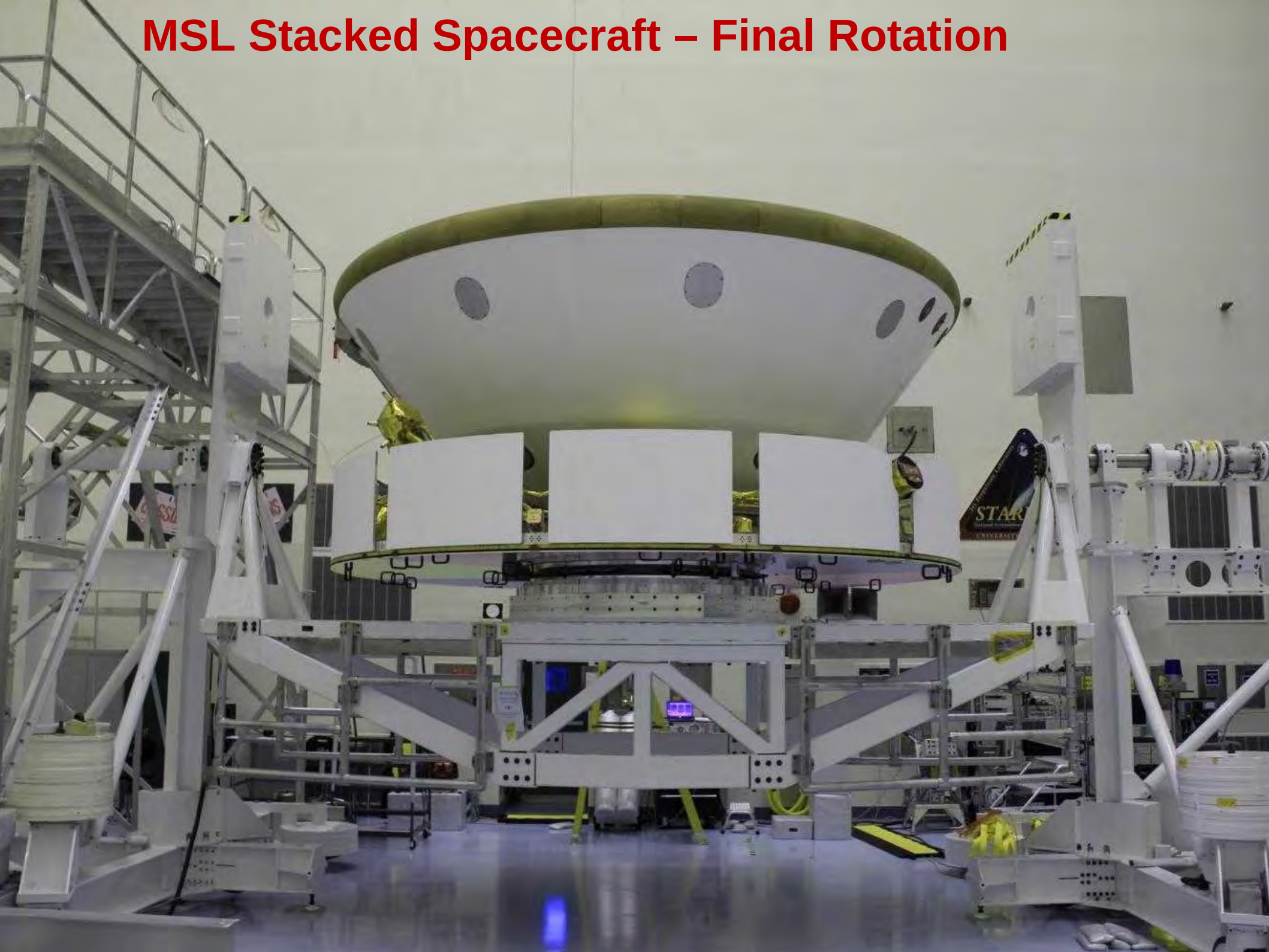


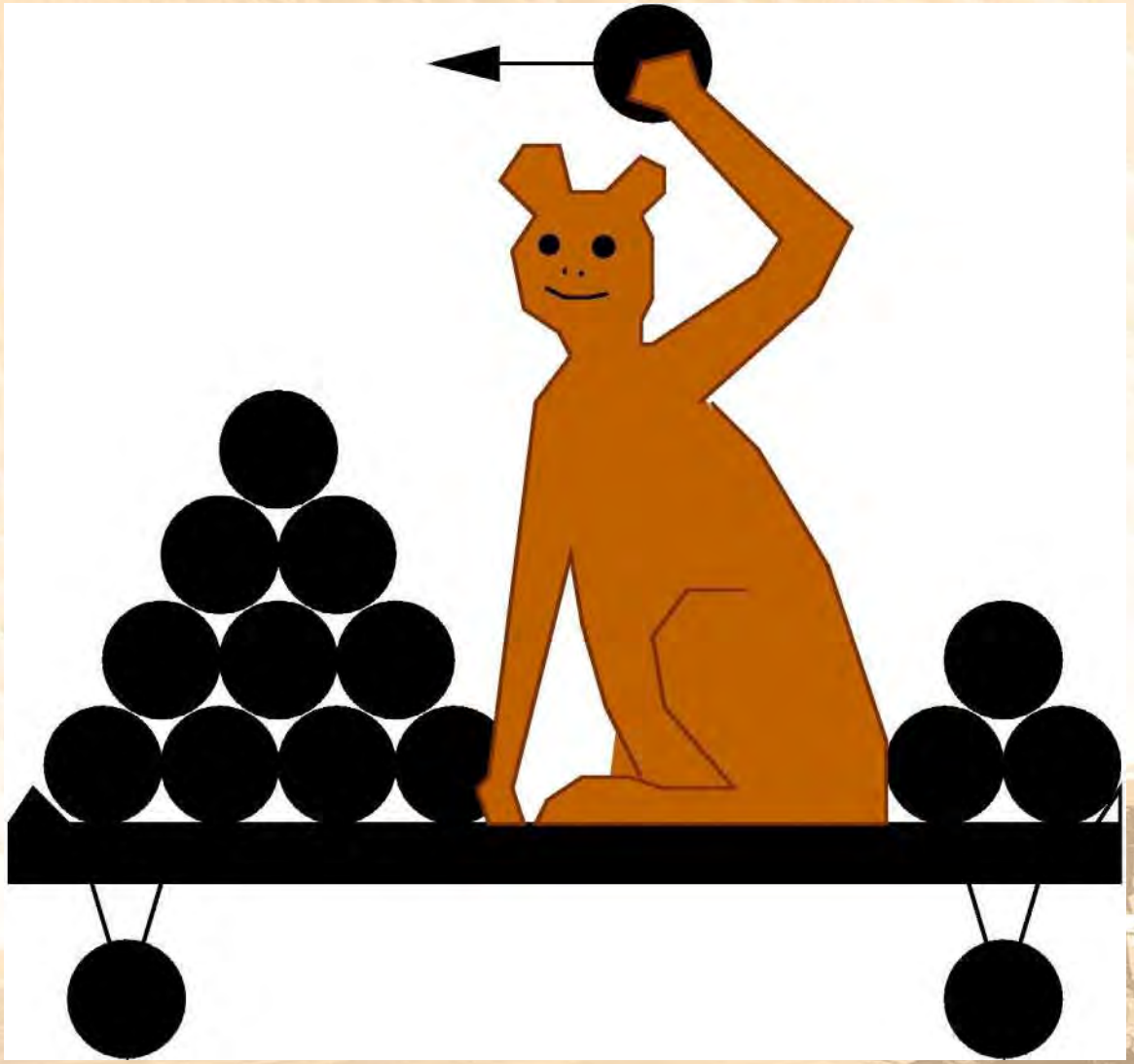
MSL Stacked Spacecraft – Final Rotation



MSL Stacked Spacecraft – Final Rotation

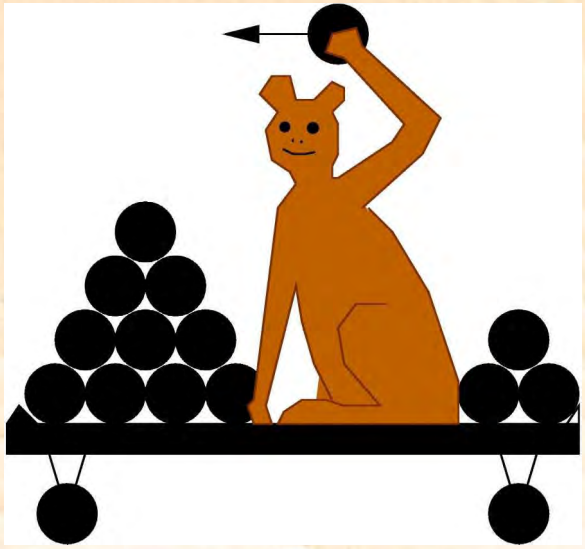


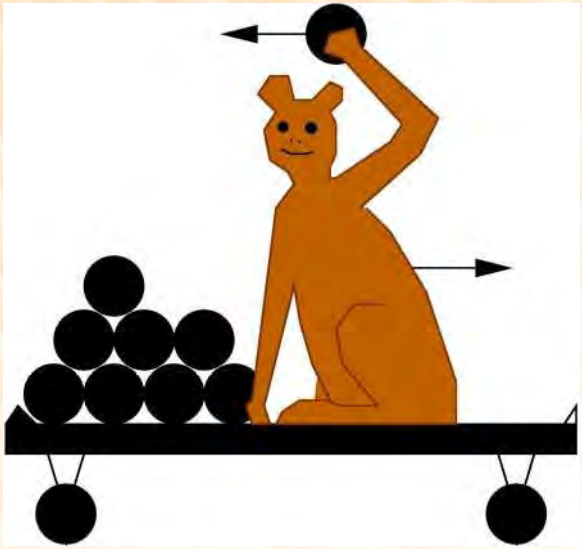
How does a rocket work?

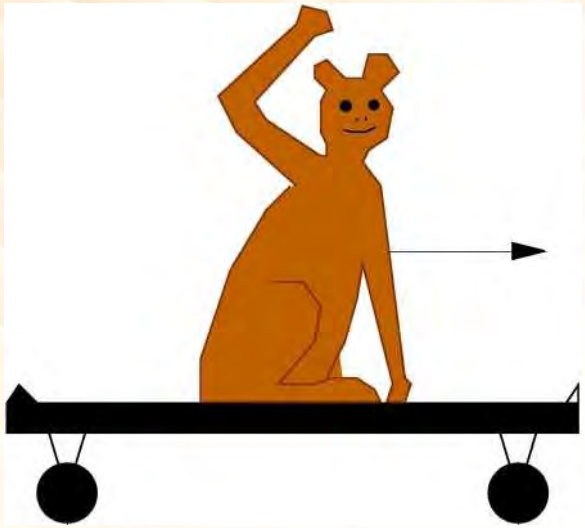


How does a rocket work?

The rocket accelerates …

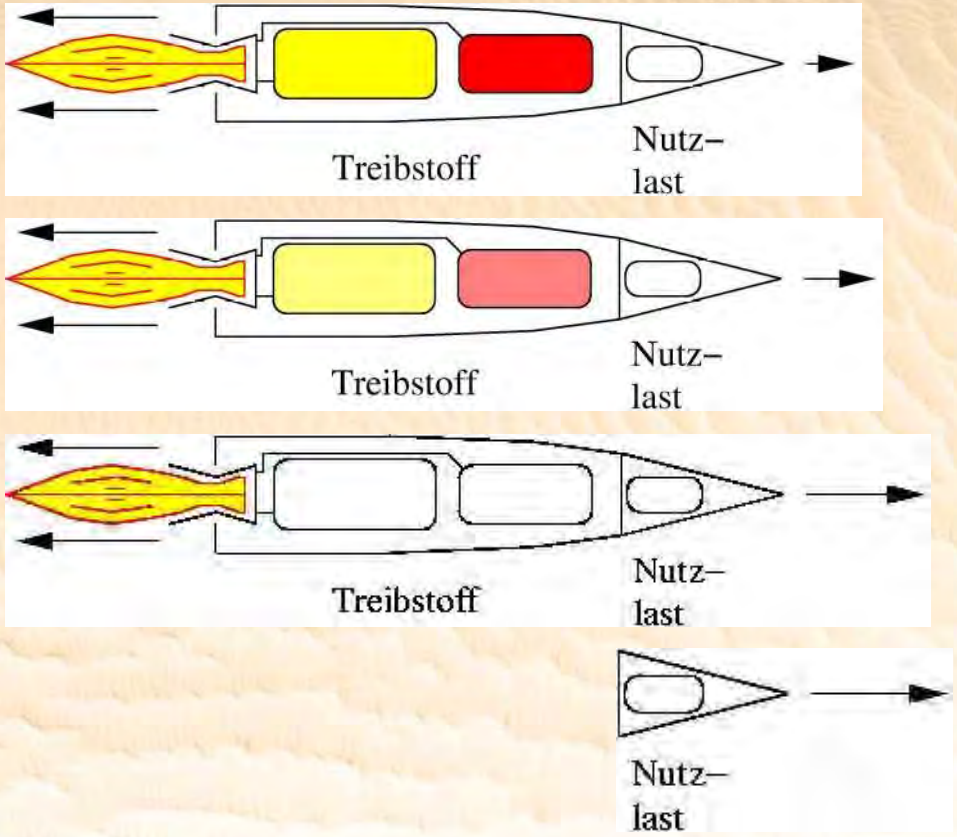






… also because it gets lighter!

How does a rocket work?



The rocket accelerates because of momentum conservation!

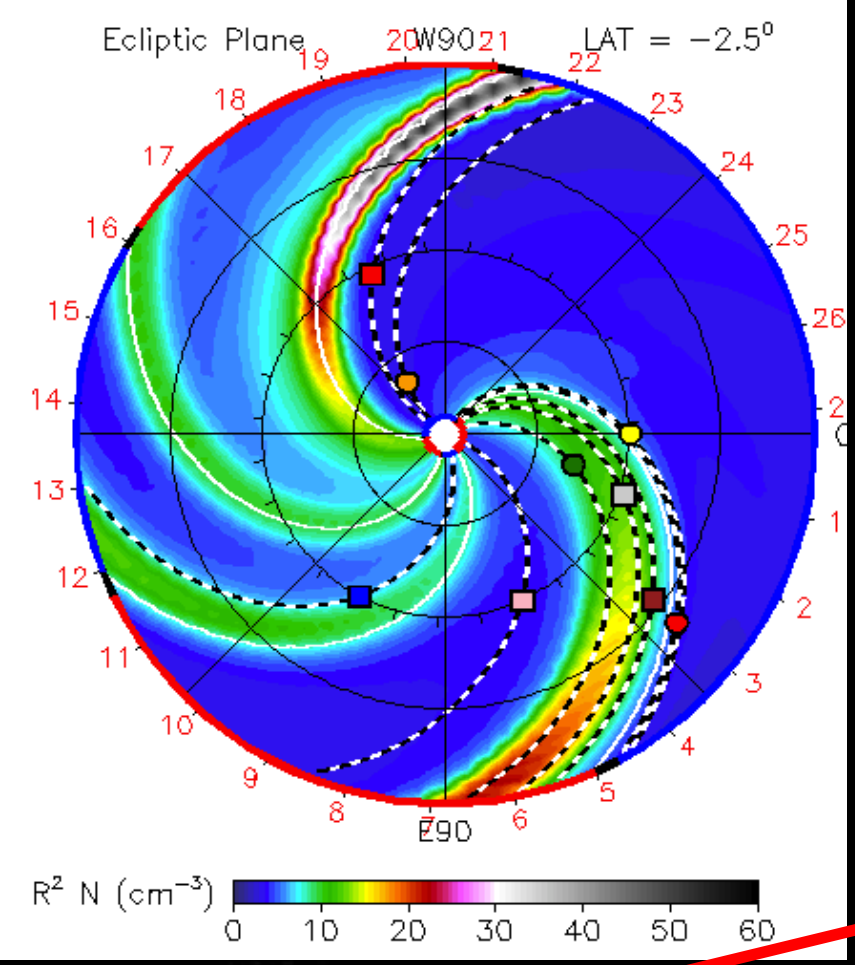
$$m(t) = m_0 - \dot{m}t$$

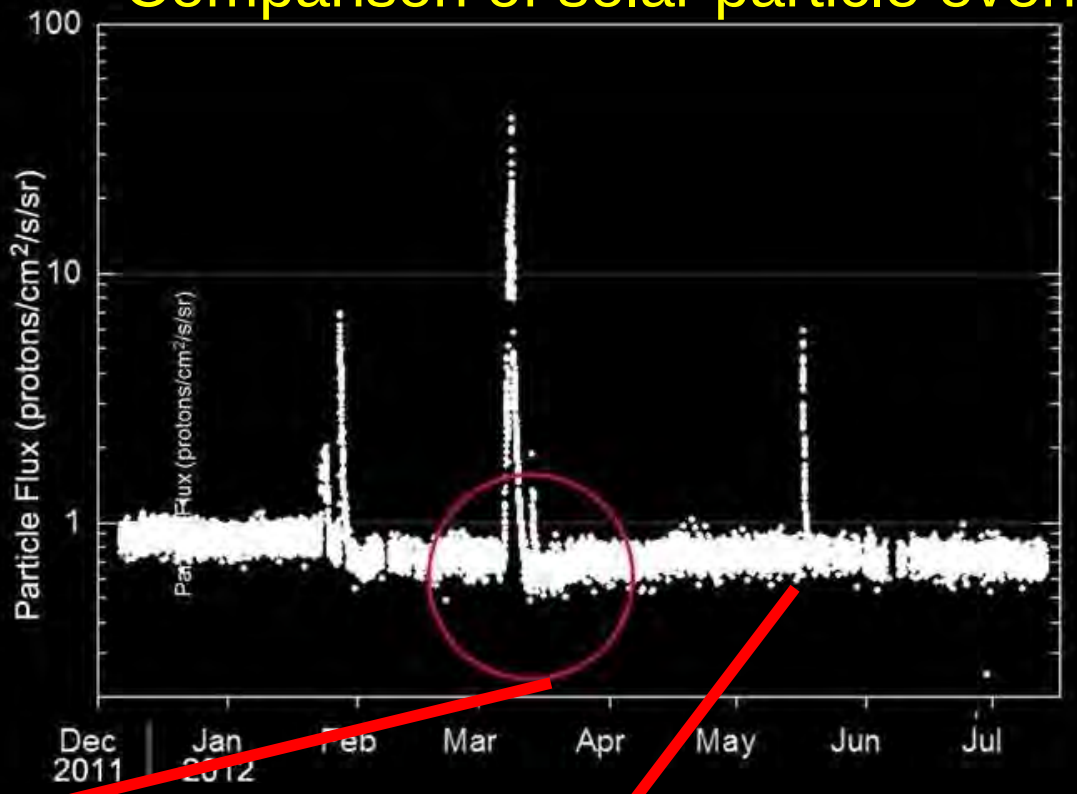
$$\begin{aligned}
(m_0 - \dot{m}t)\,a(t) &= \dot{m}v_0 - (m_0 - \dot{m}t)\,g \\
\ddot{x}(t) = a(t) &= \frac{\dot{m}}{(m_0 - \dot{m}t)}v_0 - g \\
\dot{x}(t) = v(t) = \int \mathrm{d}t'\ddot{x}(t') &= \int_0^t \mathrm{d}t' \left(\frac{\dot{m}}{(m_0 - \dot{m}t')}v_0 - g\right) \\
v(t) &= v_0 \int_0^t \mathrm{d}t' \frac{\dot{m}}{(m_0 - \dot{m}t')} - gt \\
v(t) &= v_0 \ln\left(\frac{m_0}{m_0 - \dot{m}t}\right) - gt
\end{aligned}$$

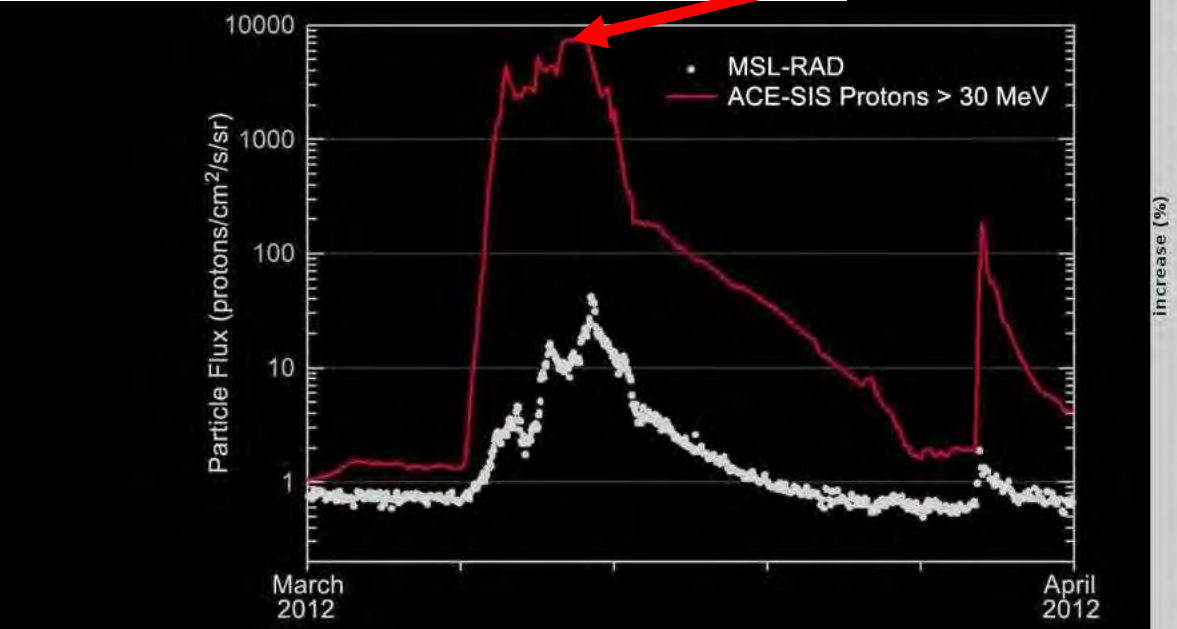
The rocket equation (Ziolkowsky, 1903)

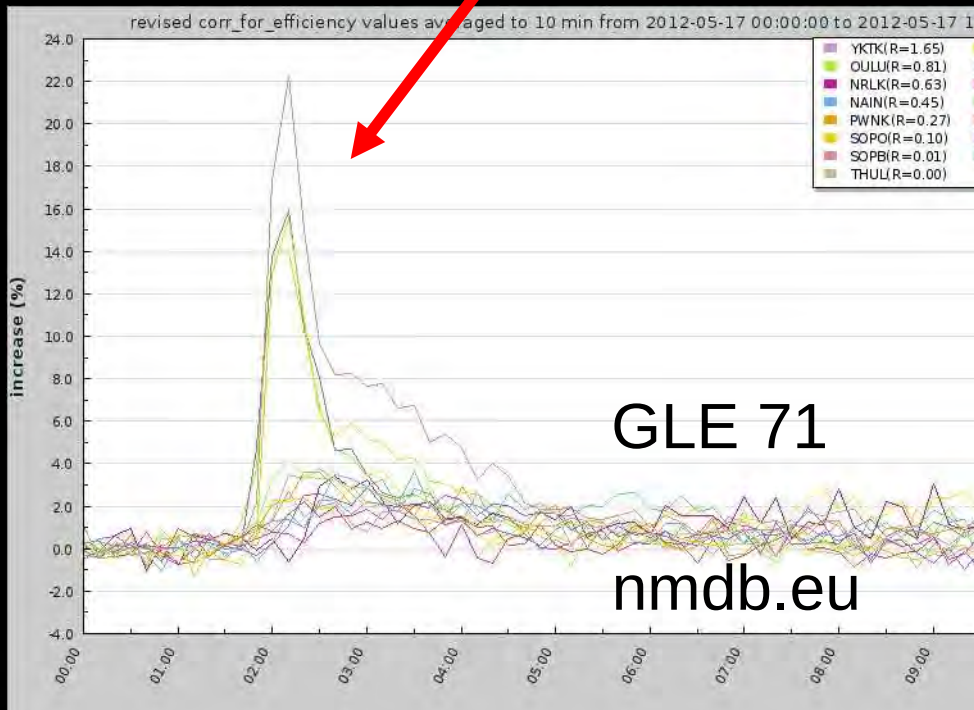
$$v(t) = v_0 \ln\left(\frac{m_0}{m_0 - \dot{m}t}\right) - gt$$

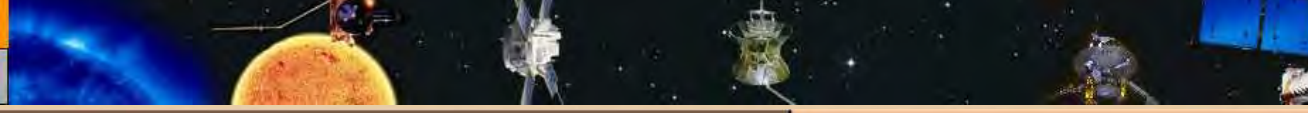
Comparison of solar particle events

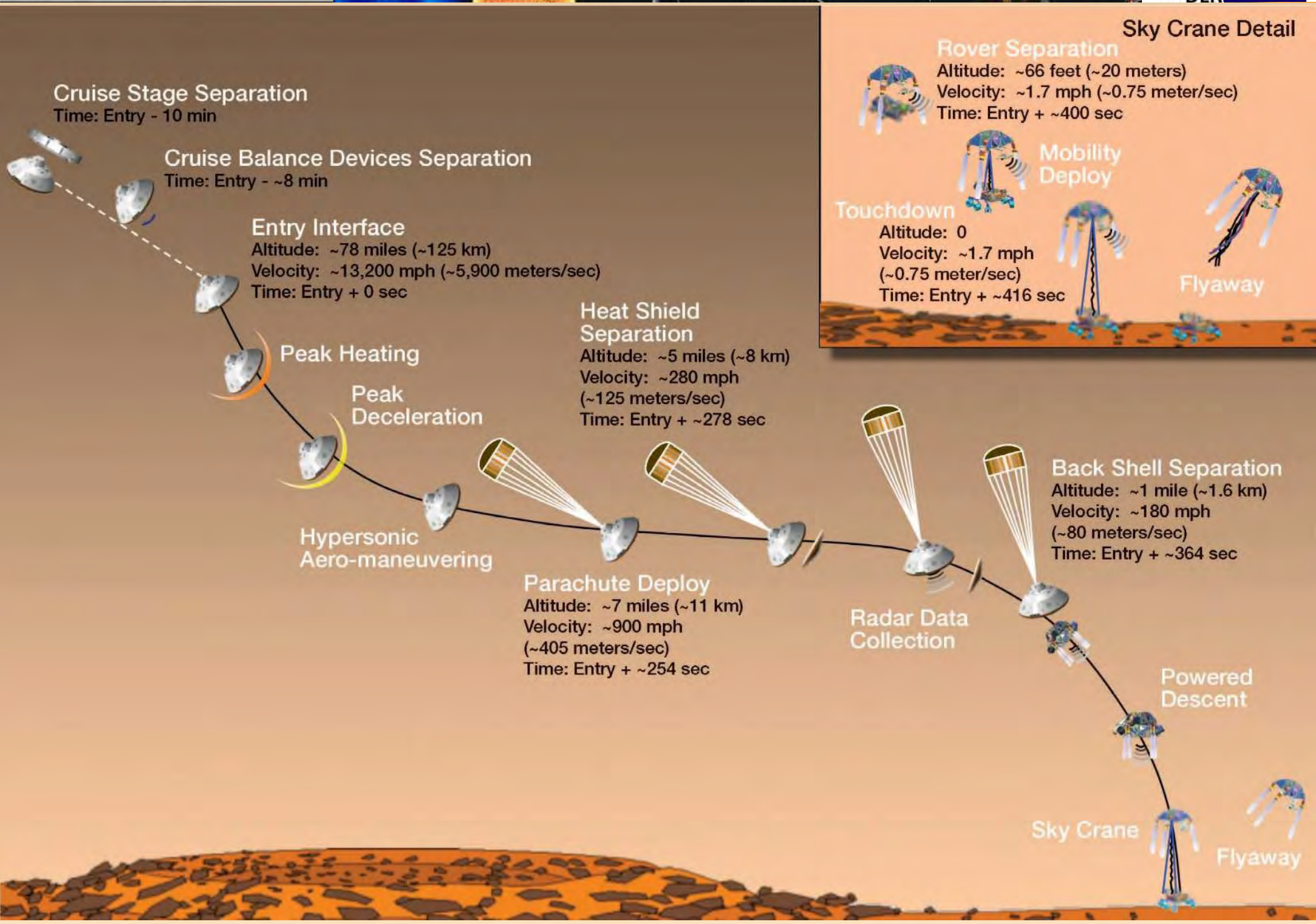




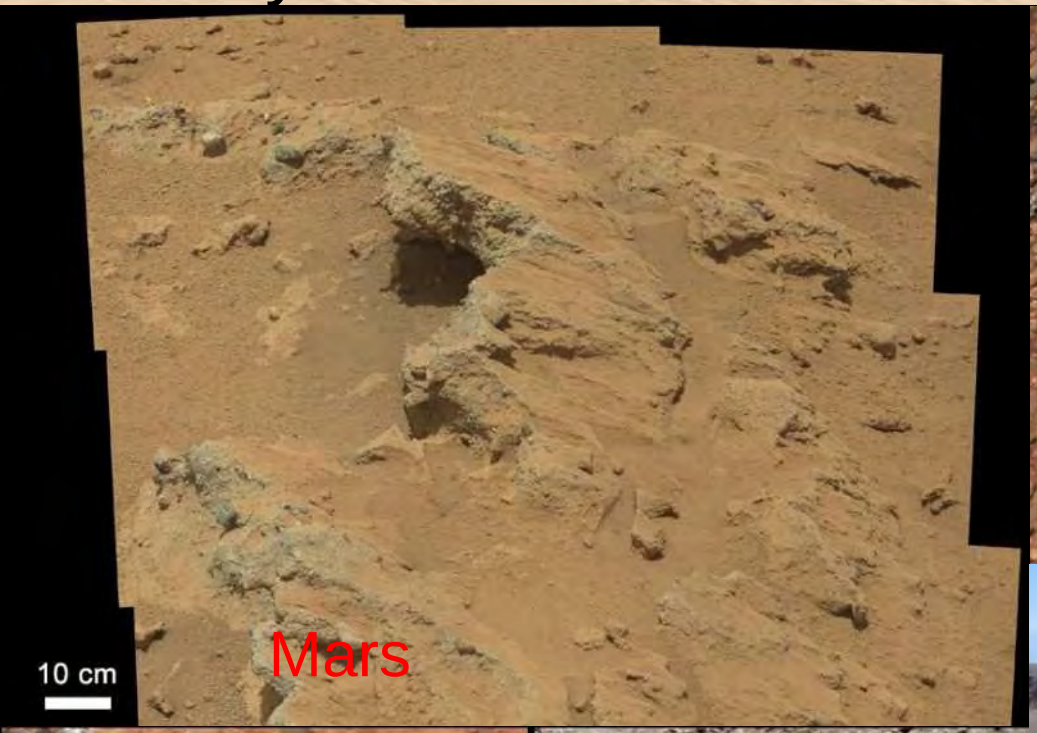




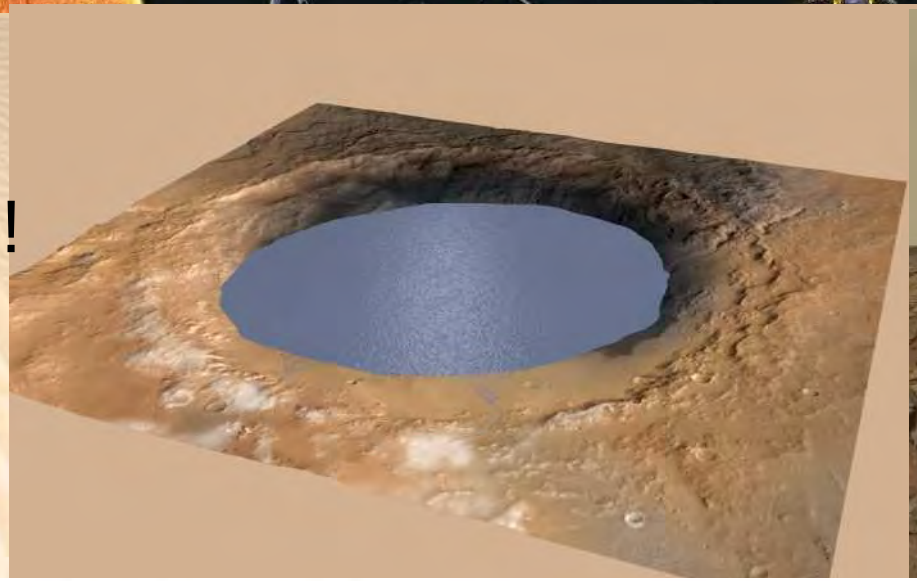


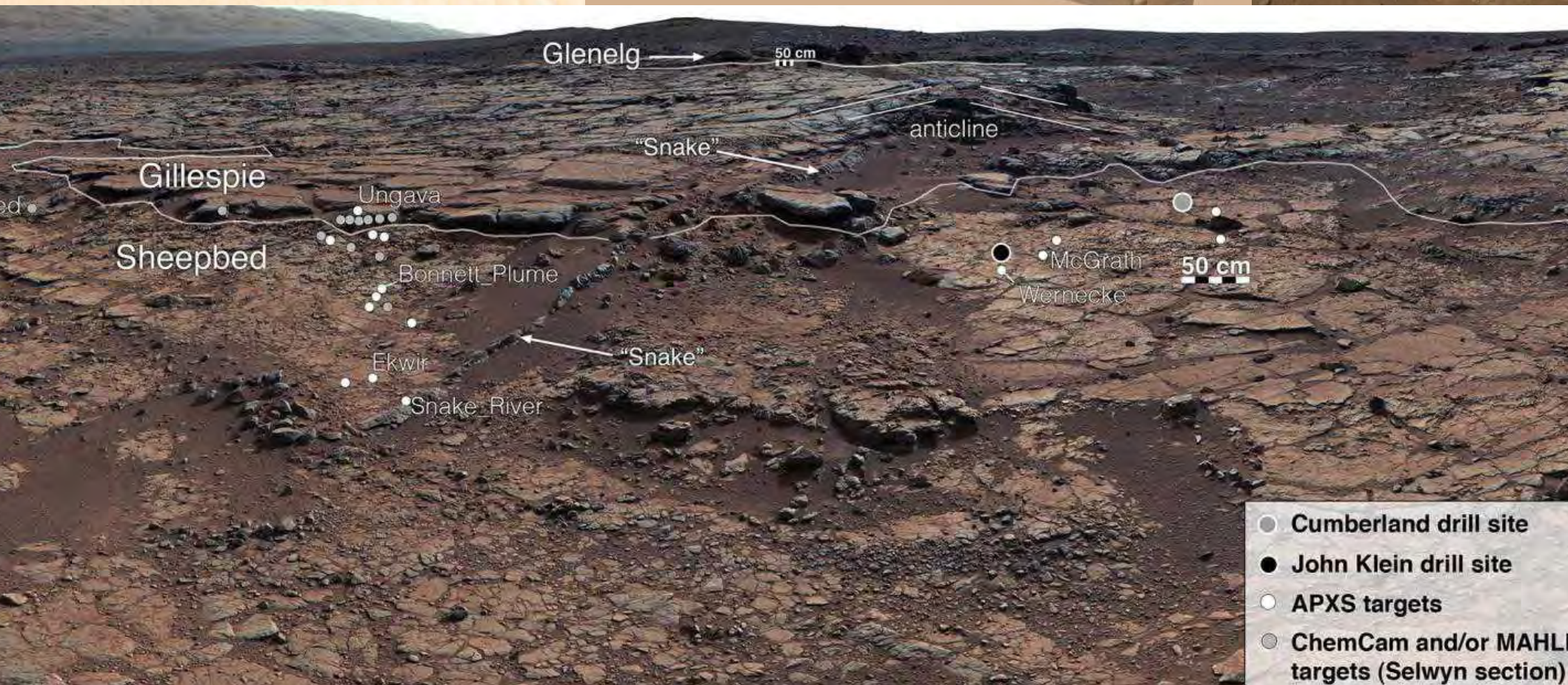

Cruise Stage Separation
Time: Entry - 10 min
Cruise Balance Devices Separation
Time: Entry - ~8 min
Entry Interface
Altitude: ~78 miles (~125 km)
Velocity: ~13,200 mph (~5,900 meters/sec)
Time: Entry + 0 sec
Peak Heating
Peak Deceleration
Heat Shield Separation
Altitude: ~5 miles (~8 km)
Velocity: ~280 mph
(~125 meters/sec)
Time: Entry + ~278 sec
Hypersonic Aero-maneuvering
Parachute Deploy
Altitude: ~7 miles (~11 km)
Velocity: ~900 mph
(~405 meters/sec)
Time: Entry + ~254 sec
Radar Data Collection
Back Shell Separation
Altitude: ~1 mile (~1.6 km)
Velocity: ~180 mph
(~80 meters/sec)
Time: Entry + ~364 sec
Powered Descent
Sky Crane
Flyaway
Sky Crane Detail
Rover Separation
Altitude: ~66 feet (~20 meters)
Velocity: ~1.7 mph (~0.75 meter/sec)
Time: Entry + ~400 sec
Mobility Deploy
Touchdown
Altitude: 0
Velocity: ~1.7 mph
(~0.75 meter/sec)
Time: Entry + ~416 sec
Flyaway

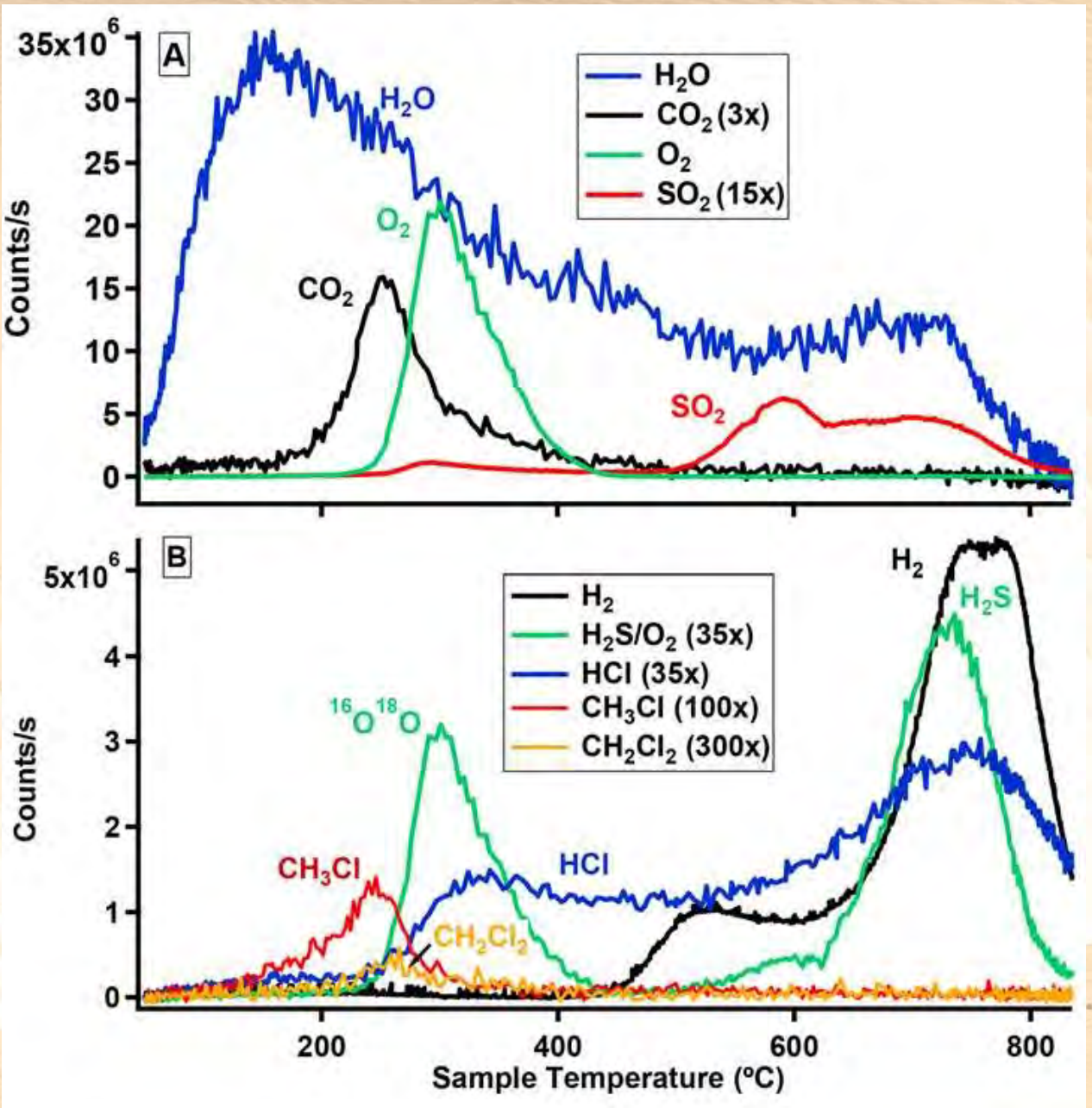
Curiosity landed in the remnants of an ancient river bed...



… and drove on into the remnants of an ancient lake on Mars!

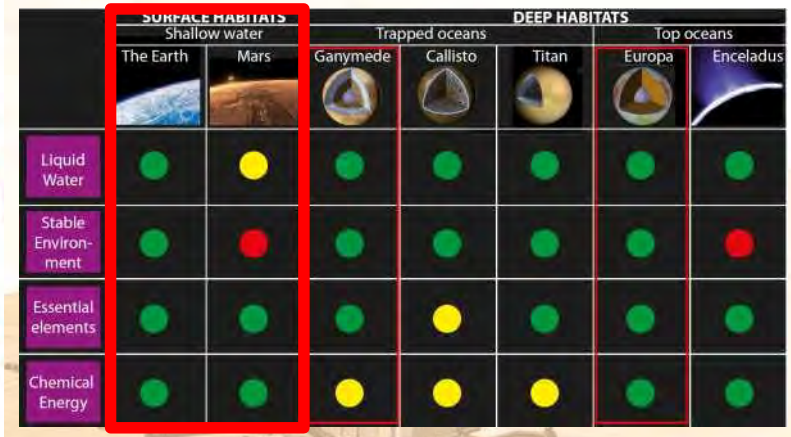






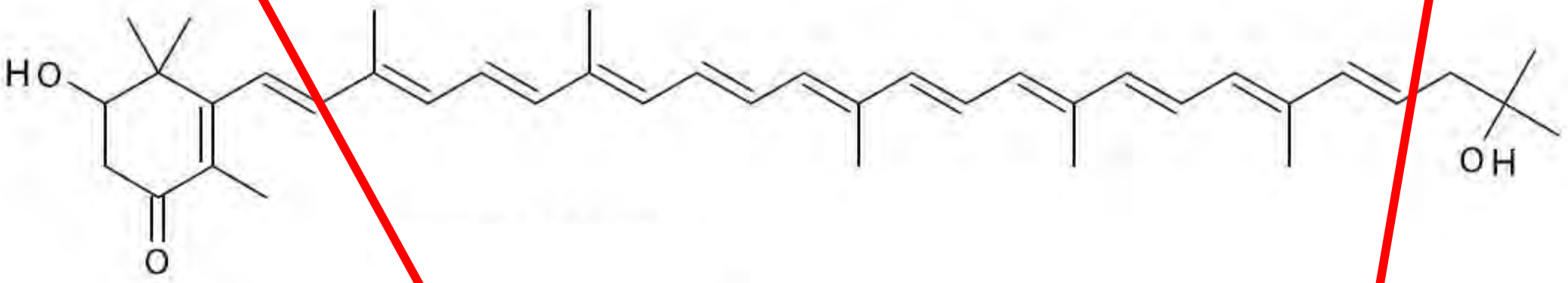
(Ming et al., Science, 2013)

Measurements show that the drilled mudstone contains carbon, nitrogen, oxygen and sulfur. Living organisms need these elements!



Radiation breaks molecular bonds

Remnants combine with free radicals...



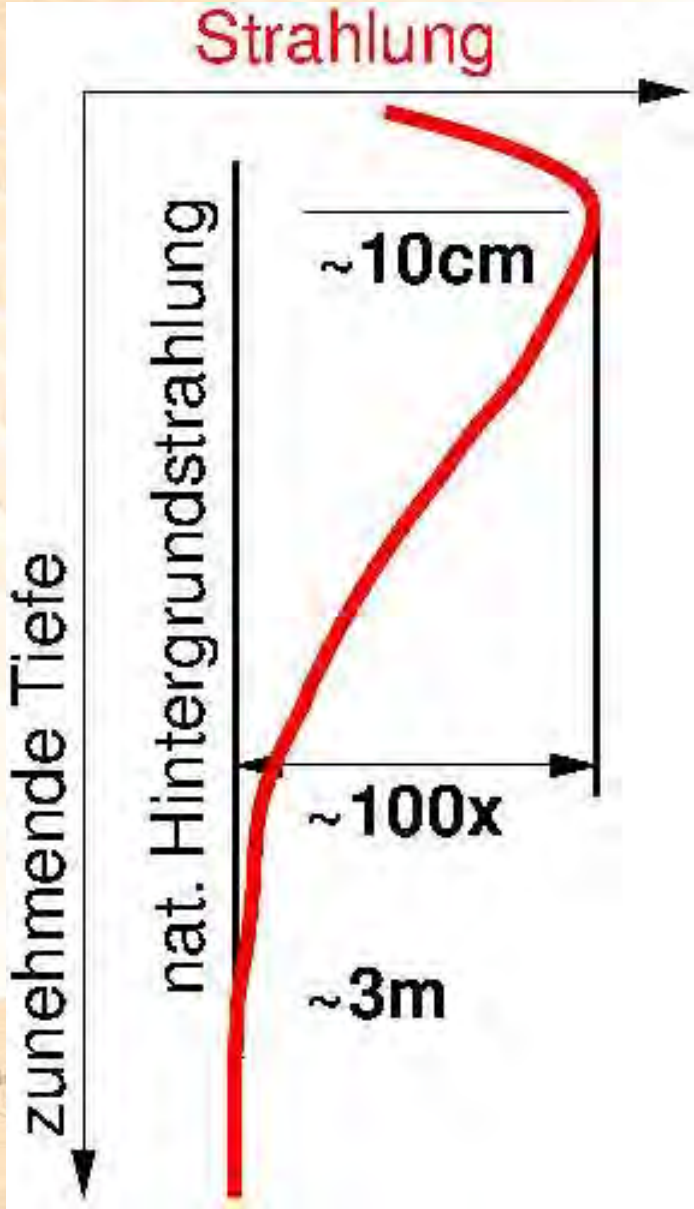
Result: Large organic molecules get smaller and smaller (if there is no repair mechanism)

How long do large organic molecules survive?

Previous models: 50 – 150 mGy/y
RAD measurements: 76 mGy/y

999 of 1000 organic molecules at a depth of 4-5 cm are destroyed within 650 million years.

… and after 3.7 billion years … ?



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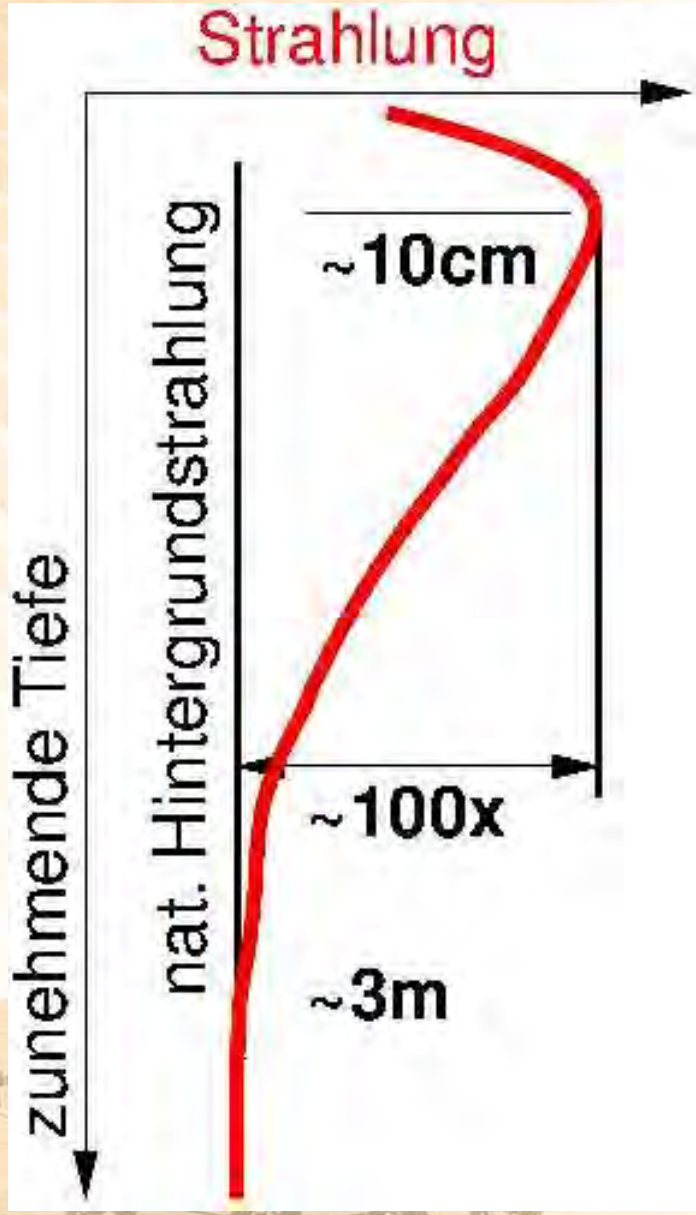
… and after 3.7 billion years … ?

$$\left(10^{-3}\right)^{3.7/0.65} \approx 10^{-17}$$



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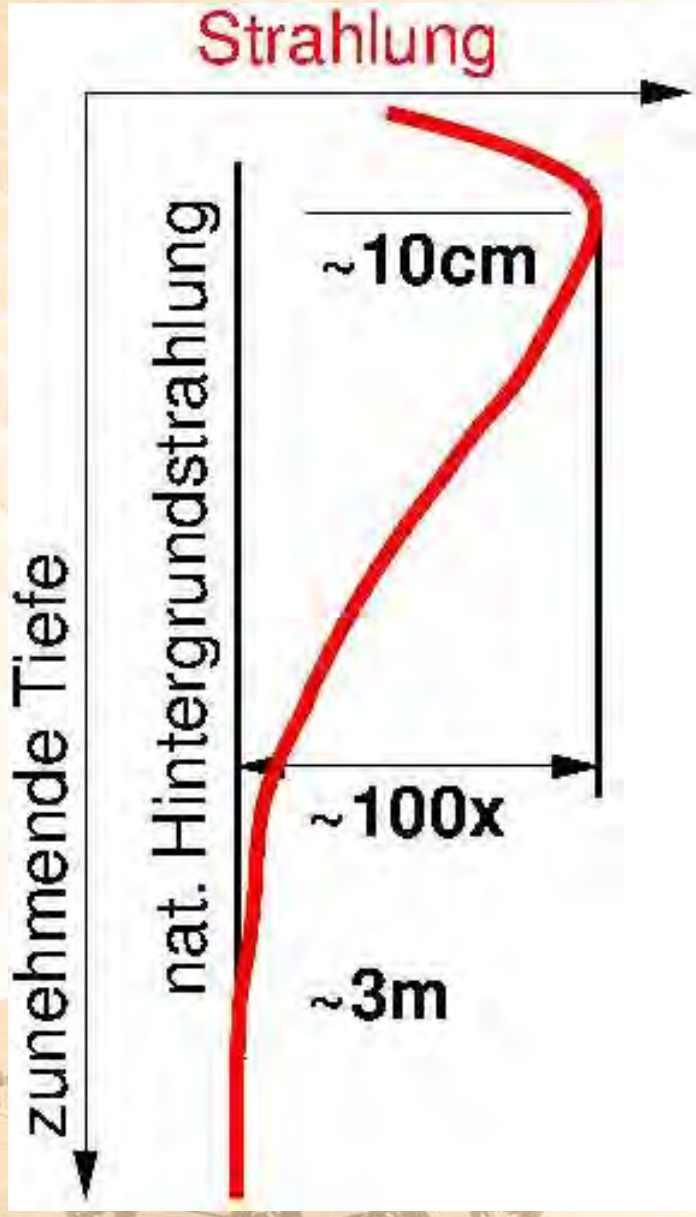
How deep do you need to drill?



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How deep do you need to drill?

Exomars: 2 meters

How long do large organic molecules survive?

Previous models: 50 – 150 mGy/y
RAD measurements: 76 mGy/y

999 of 1000 organic molecules at a depth of 4-5 cm are destroyed within 650 million years.

How deep do you need to drill?

Exomars: 2 meters

MSL/RAD: 4-5 cm!

How long do large organic molecules survive?

Previous models: 50 – 150 mGy/y
RAD measurements: 76 mGy/y

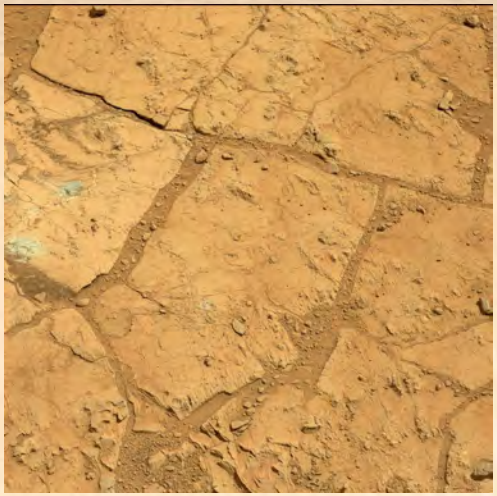
999 of 1000 organic molecules at a depth of 4-5 cm are destroyed within 650 million years.

How deep do you need to drill?

Exomars: 2 meters

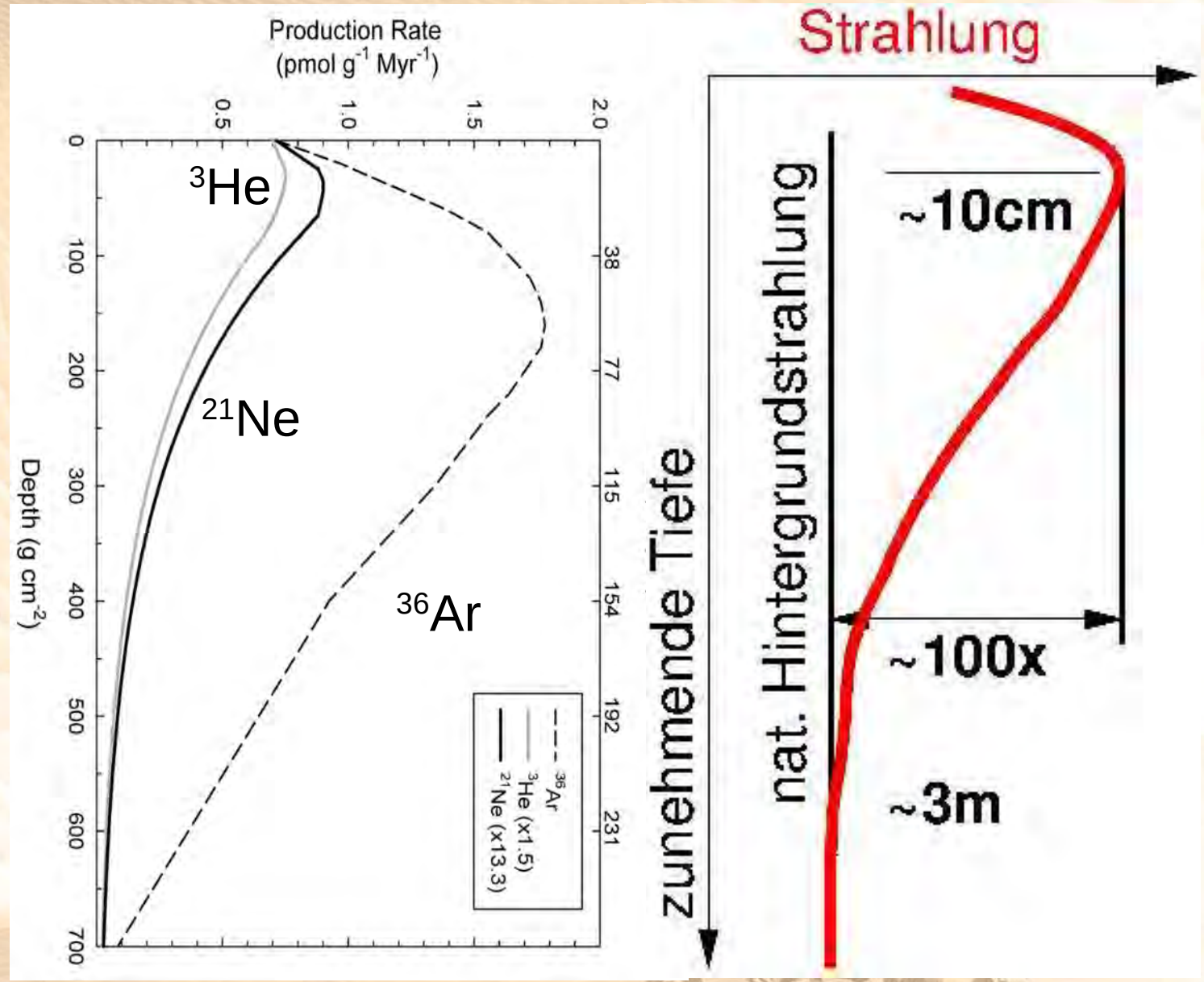
MSL/RAD: 4-5 cm!

==> Half the molecules survive 65 million years!

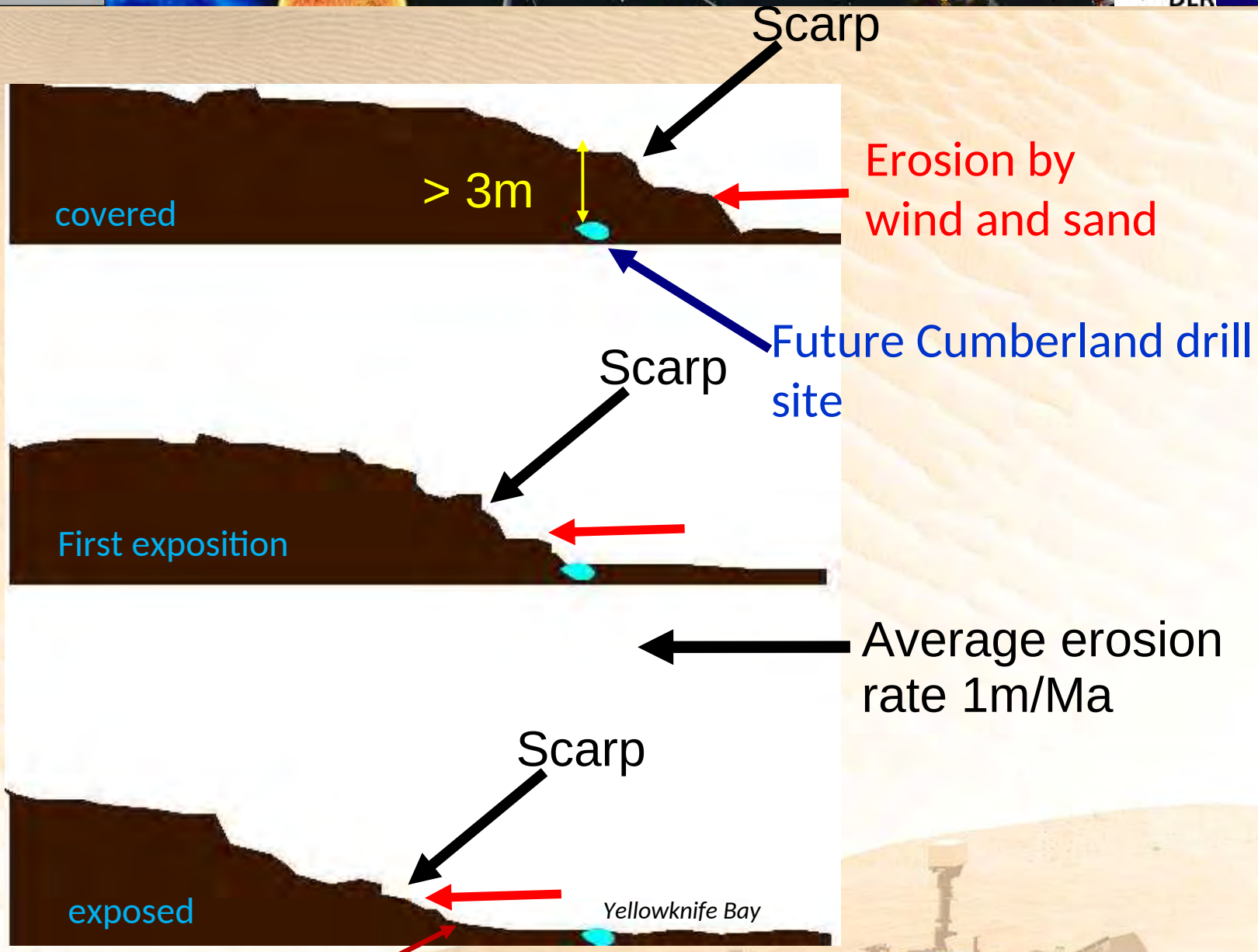


Determine exposure age from the abundances of cosmogenic nuclei.

MSL found Cumberland to be 80 ± 30 Myrs old.

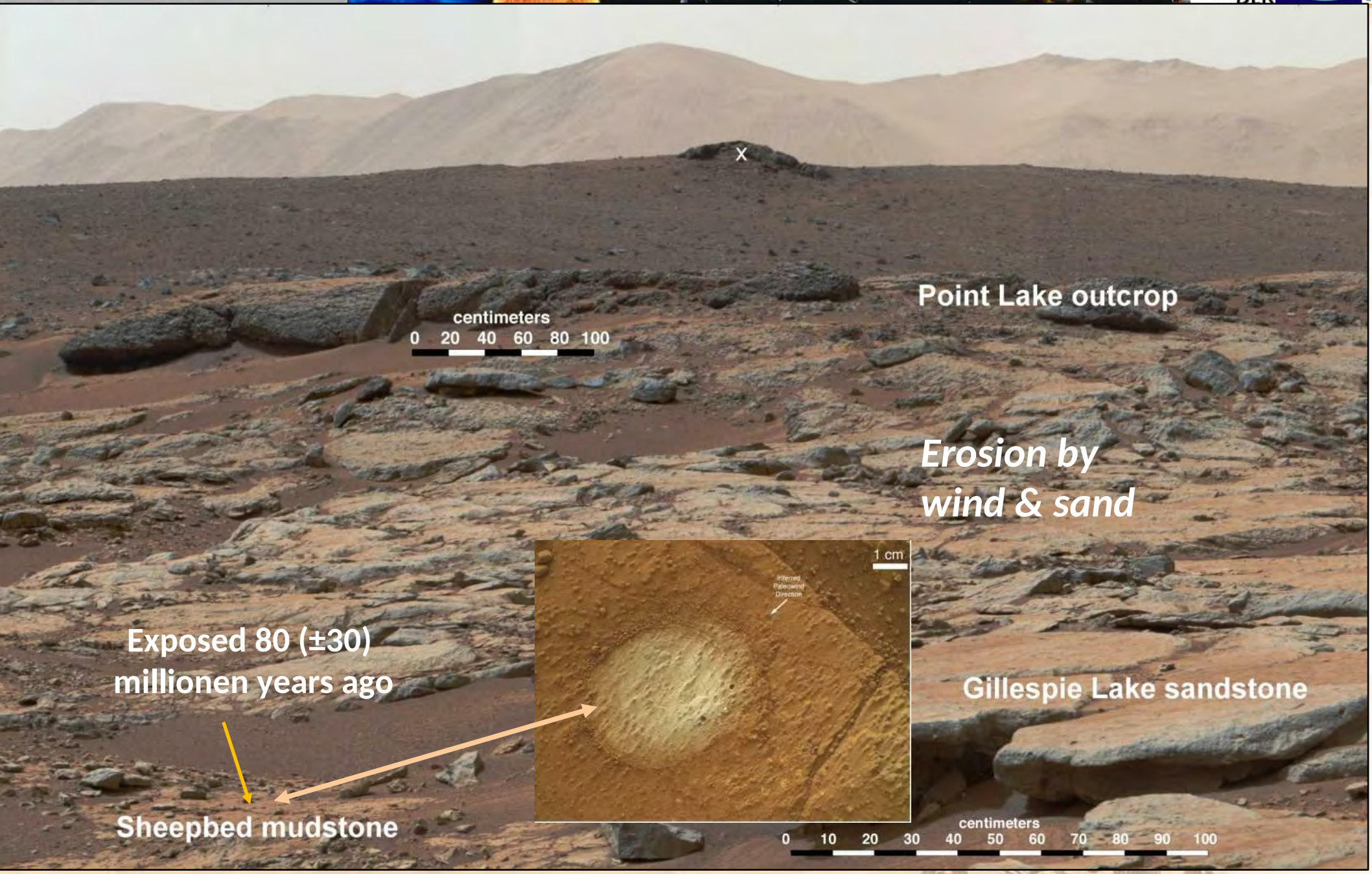


(Farley et al., Science, 2013)

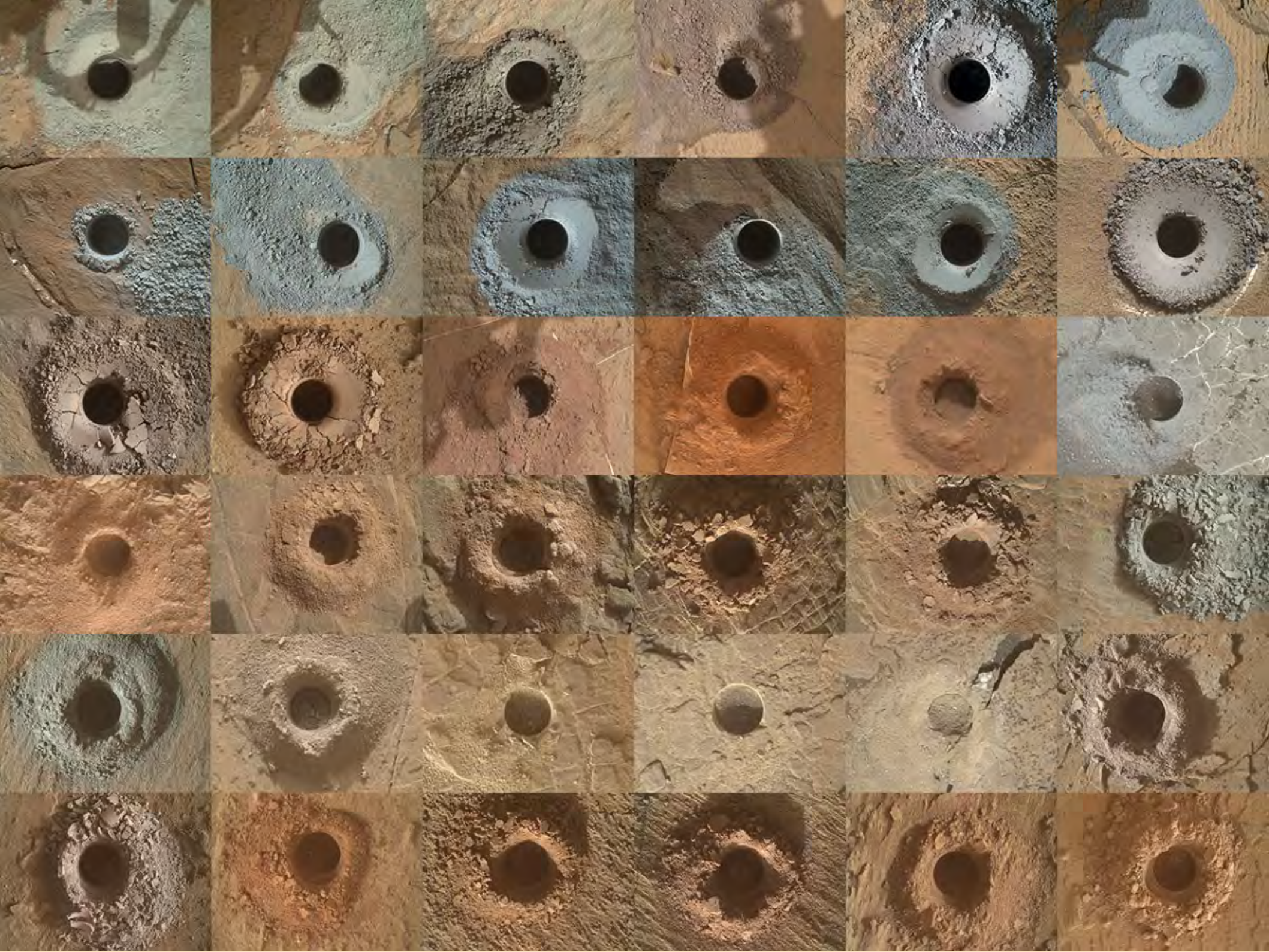


(Farley et al., 2013)

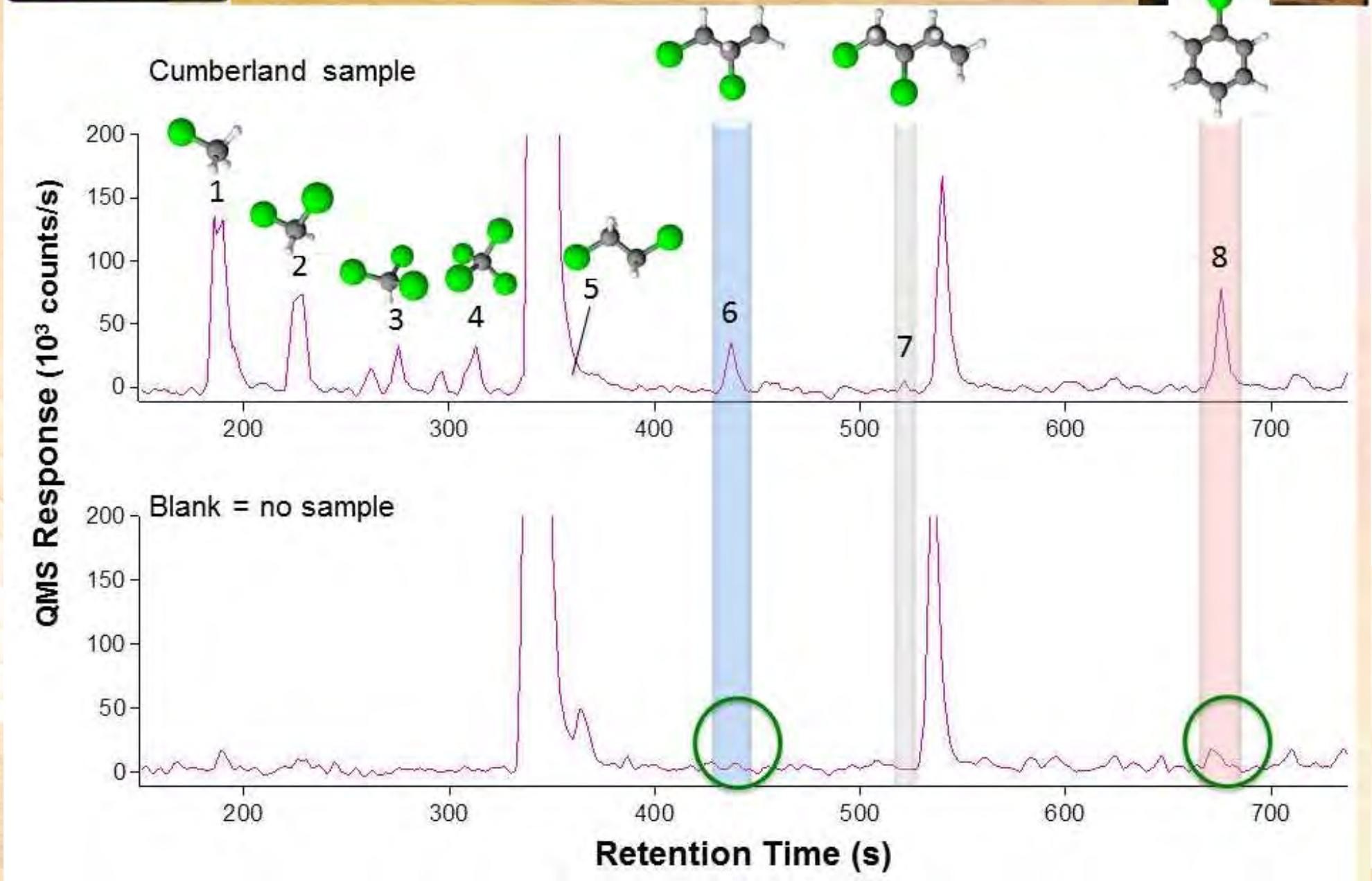
Layer with shortest exposition



(Farley et al., Science, 2013)



Some of the SAM Data

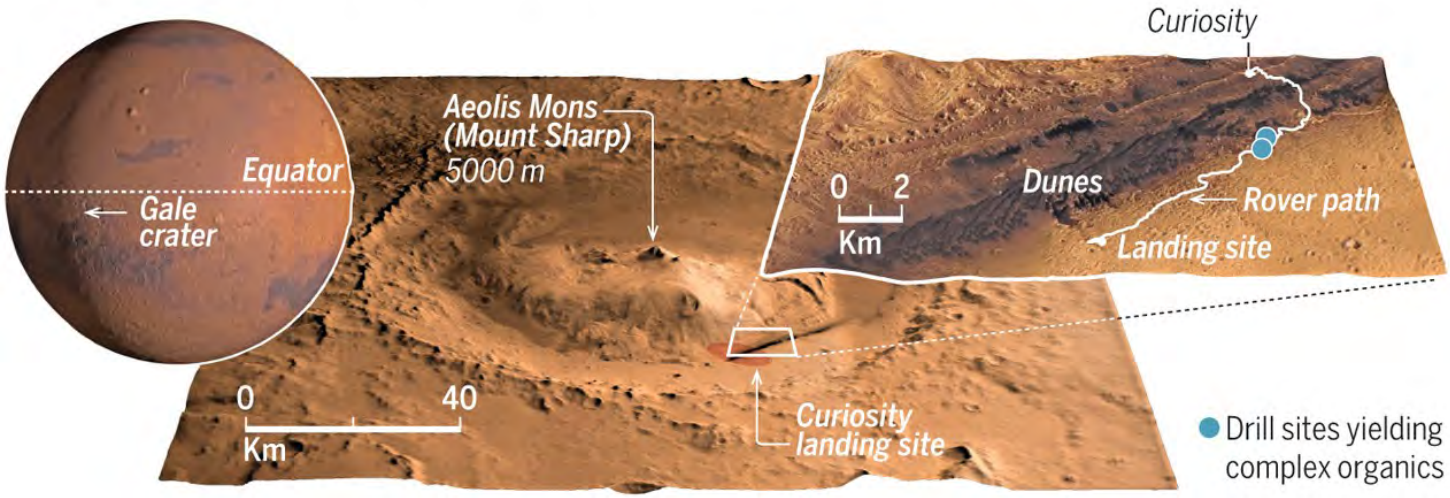


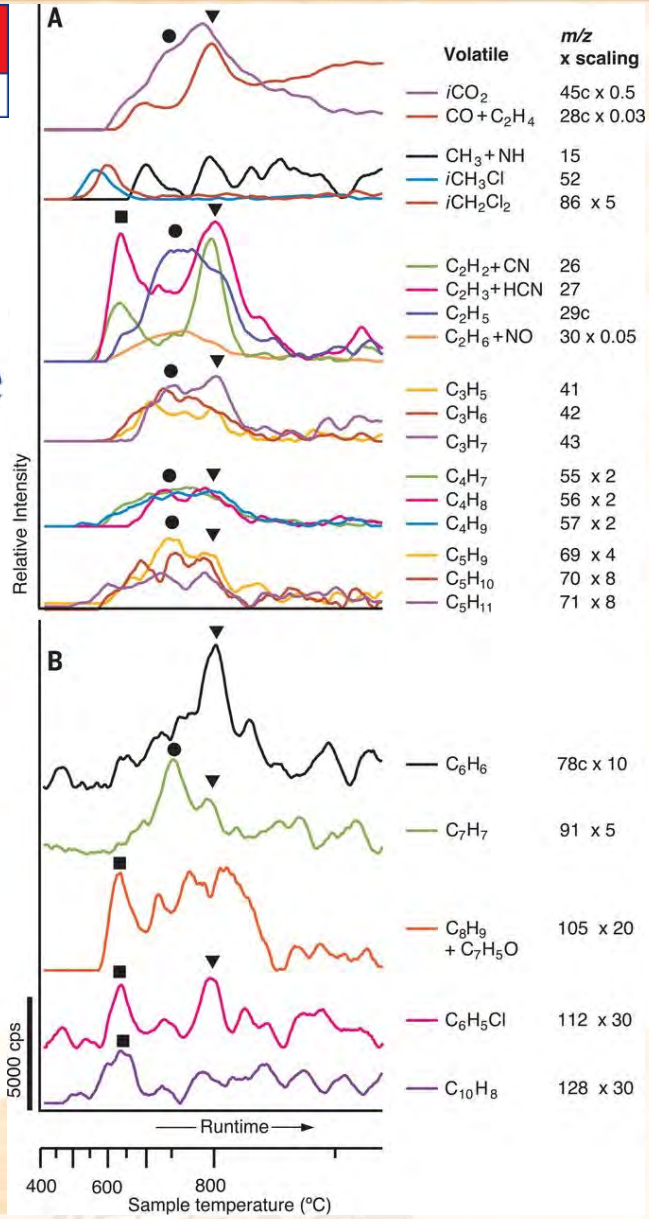
PLANETARY SCIENCE

Science
AAAS

NASA Curiosity rover hits organic pay dirt on Mars

Carbon molecules in rocks from ancient lakebed resemble kerogen, a "goopy" fossil fuel building block on Earth





Organic matter preserved in 3-billion-year-old mudstones at Gale crater, Mars

Eigenbrode et al. Science 2018;360:1096

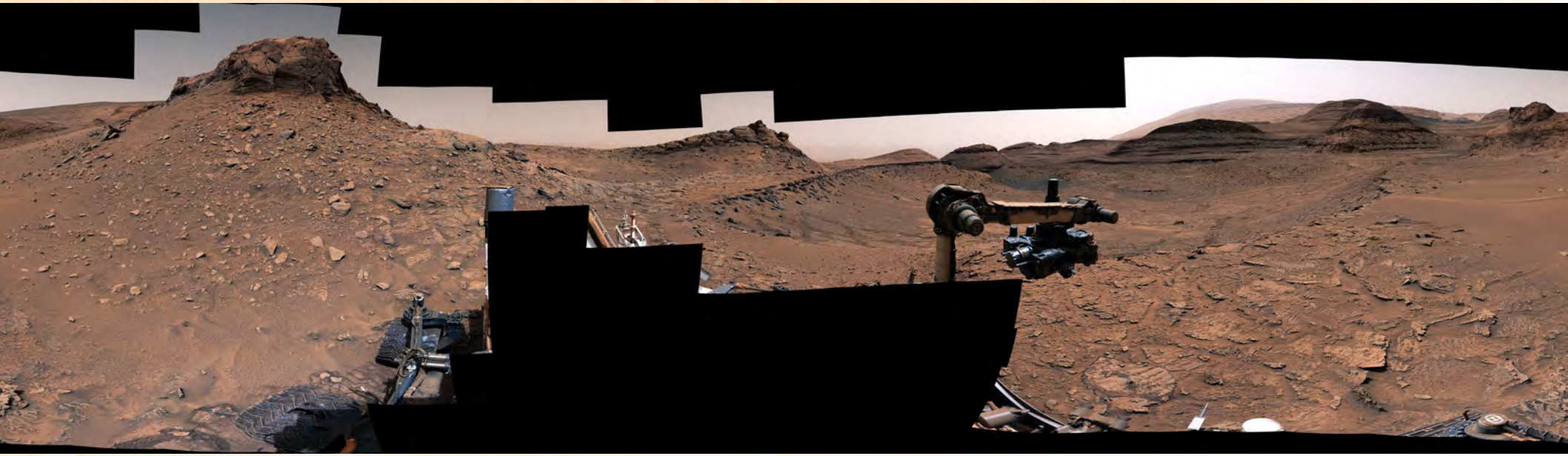
C A U Institute of Experimental and Applied Physics
Extraterrestrial Physics

DLR
SwRI

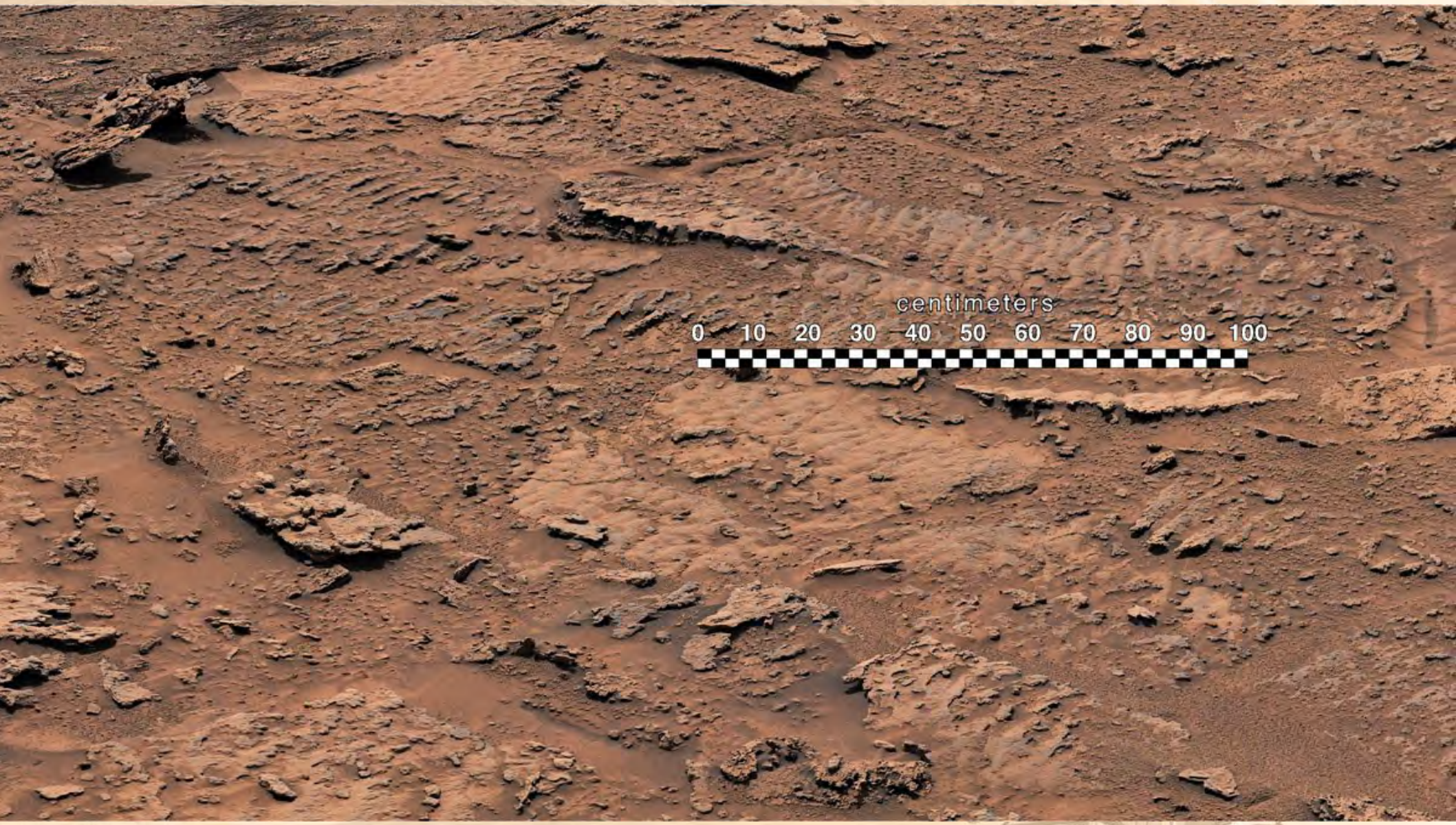
Yellowknife Bay
Bradbury Landing
Darwin
Cooperstown
Aeolis Palus
Kimberley
A'
Bagnold Dunes
Pahrump Hills
Marias Pass
Bridger Basin
Naukluft Plateau
Gobabeb
Murray Buttes
Ogunquit Beach
Vera Rubin Ridge
Greenheugh Pediment
Aeolis Mons (Mount Sharp)
1000m
2km


Greenheugh
Pediment
Aeoli
(Mount
500m

Curiosity discovers remnants of a lake much later in the history of Mars than expected.



https://mars.nasa.gov/resources/27294/curiositys-360-degree-view-of-marker-band-valley/?site=ms


centimeters
0 10 20 30 40 50 60 70 80 90 100

Mission Overview and Scientific Contributions from the Mars Science Laboratory Curiosity Rover After Eight Years of Surface Operations

Ashwin R. Vasavada[1]

Abstract

NASA's Mars Science Laboratory mission, with its Curiosity rover, has been exploring Gale crater (5.4° S, 137.8° E) since 2012 with the goal of assessing the potential of Mars to support life. The mission has compiled compelling evidence that the crater basin accumulated sediment transported by marginal rivers into lakes that likely persisted for millions of years approximately 3.6 Ga ago in the early Hesperian. Geochemical and mineralogical assessments indicate that environmental conditions within this timeframe would have been suitable for sustaining life, if it ever were present. Fluids simultaneously circulated in the subsurface and likely existed through the dry phases of lake bed exposure and aeolian deposition, conceivably creating a continuously habitable subsurface environment that persisted to less than 3 Ga in the early Amazonian. A diversity of organic molecules has been preserved, though degraded, with evidence for more complex precursors. Solid samples show highly variable isotopic abundances of sulfur, chlorine, and carbon. In situ studies of mod-

Space Science Reviews (2022) 218:14
https://doi.org/10.1007/s11214-022-00882-7

Summary and thanks

- Landing site (Gale crater) is important
- Landing was extremely challenging
- MSL explores Mars (past habitability)
- MSL is a mobile laboratory (versatile payload)
- Mars was habitable billions of years ago
- Germany part of this exciting mission (RAD)

Thanks to:
Colleagues at IEAP
and

Supported by:
Federal Ministry of Economics and Technology
on the basis of a decision by the German Bundestag

DLR

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Christian-Albrechts-Universität zu Kiel