STANFORD ENGINEERING

Space: The Final Frontier for AI?

A Case Study of Mars Rovers

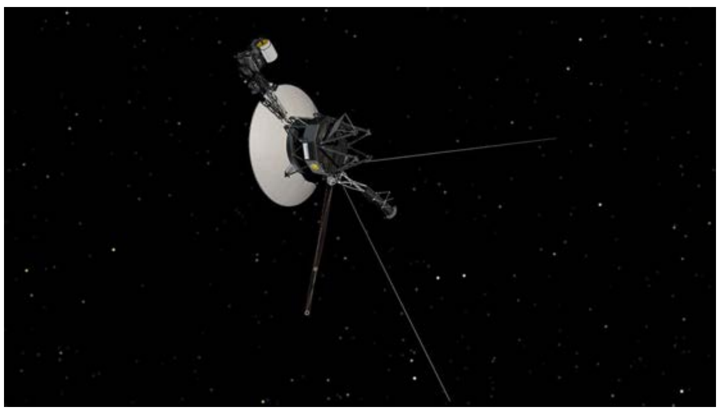
Prof. G. Scott Hubbard,
Department of Aeronautics and Astronautics
Stanford University
Former Director NASA Ames and NASA's first "Mars Czar"

Trusted AI Challenge

October 14, 2020

Special Issues of Space Exploration for Planning and Operations

- Communications: signal travel time
- Unpredictable/unstructured environment
- Radiation damage
- No ability to recall/redesign/fix hardware (exception Hubble Space Telescope)

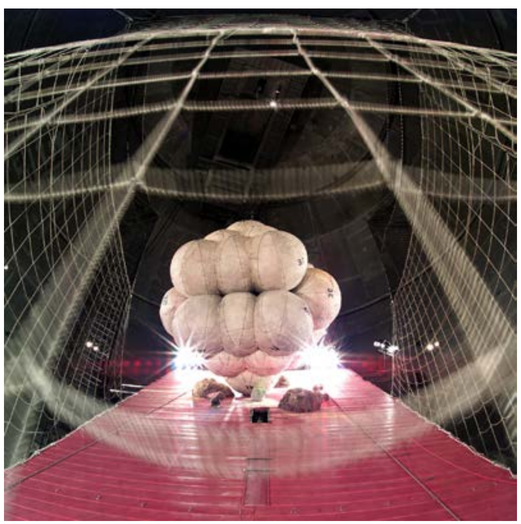


Voyager 1 light travel time is 20 hours – 1 way

Mars Reconnaissance Orbiter light travel time averages 12.5 minutes – 1 way

Special Issues of Space Exploration for Development

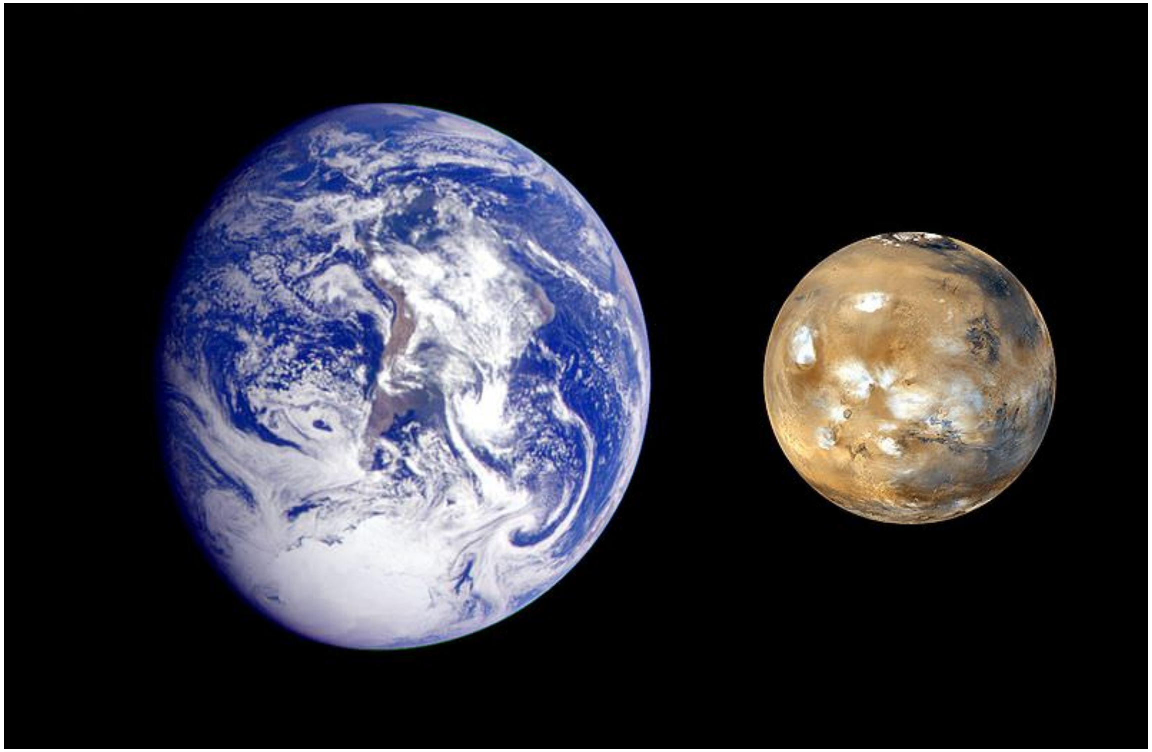
- For space systems hardware design and initial software, the rule is “Test as you fly, fly as you test.”
  - Deviations from this rule have resulted in failures
- Judgement calls for full and minimum success criteria usually enveloped by test
- Software upgrades and uploads allowed once system is safe on orbit or on the surface



Air bag landing system for MER Rovers tested extensively

Curiosity “sky crane” tested and modeled thoroughly

A Few Basic Mars Facts and Figures



Mars is about ½ the diameter of Earth

Mars has about 1/3 the gravity of Earth

The atmospheric pressure of Mars is about 1% that of Earth (like Earth at 100,000 feet) and it is mostly CO_2

The launch window to go from Earth to Mars is only 20 days every ~2 years (26 months)

STANFORD ENGINEERING

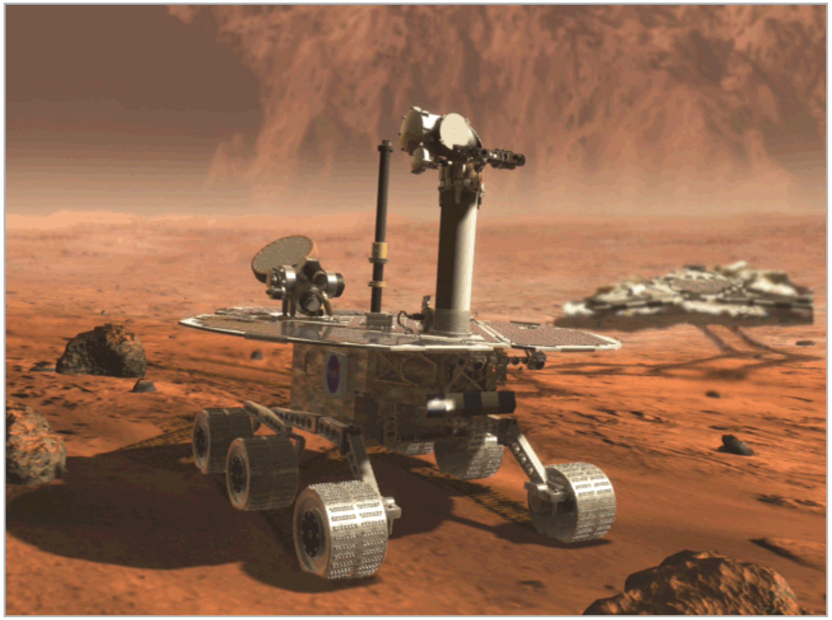
Mars Rover Family Tree

- Mars Pathfinder rover (Sojourner): 1997; 12.5 kg
- Mars Exploration Rovers (Spirit and Opportunity) 2004-2018; 185 kg
- Mars Science Lab (Curiosity) 2012 – date; 1000 kg

2003 Twin Mars Exploration Rovers

Science Goals:

- **Learn about the climate on Mars and scout for regions where mineralogical evidence of water has been found.**
- **Determine the geologic record of the landing site, what the planet's conditions were like when the Martian rocks and soils were formed and help us learn about ancient water reservoirs.**



Spirit:

Launch: June 10, 2003, 1:58 EDT

Landing: January 3, 2004 PST

Opportunity:

Launch: July 7, 2003, 11:18 EDT

Landing : January 24, 2004 PST

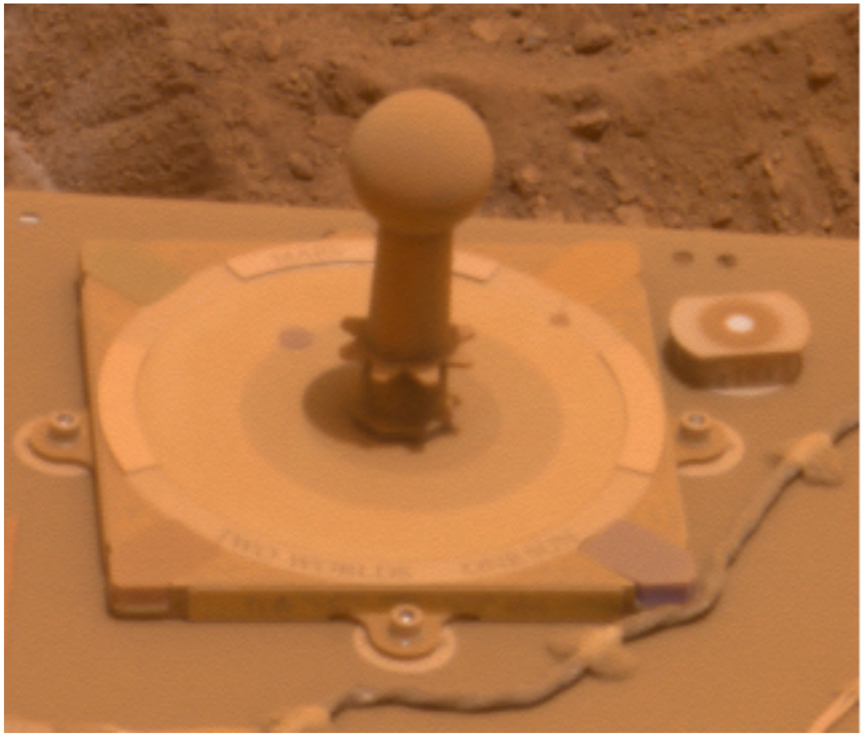
Spirit lasted 7 years

Opportunity survived 14 years

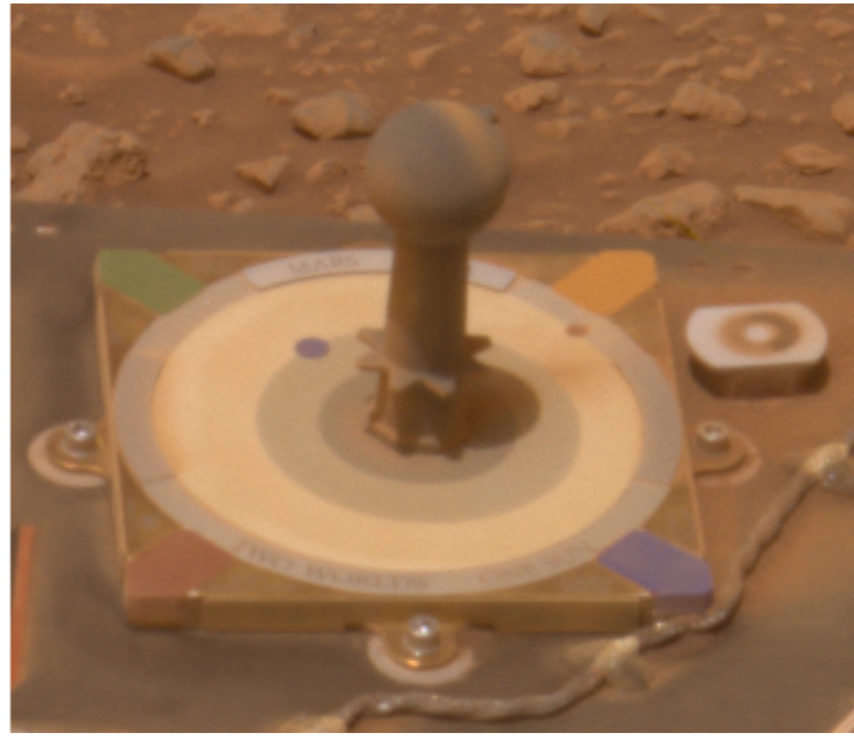
STANFORD ENGINEERING

~14 years??? How???

Dust Devils Clean the Rovers!



Before



After

But Sometimes the Dust is a Global Storm

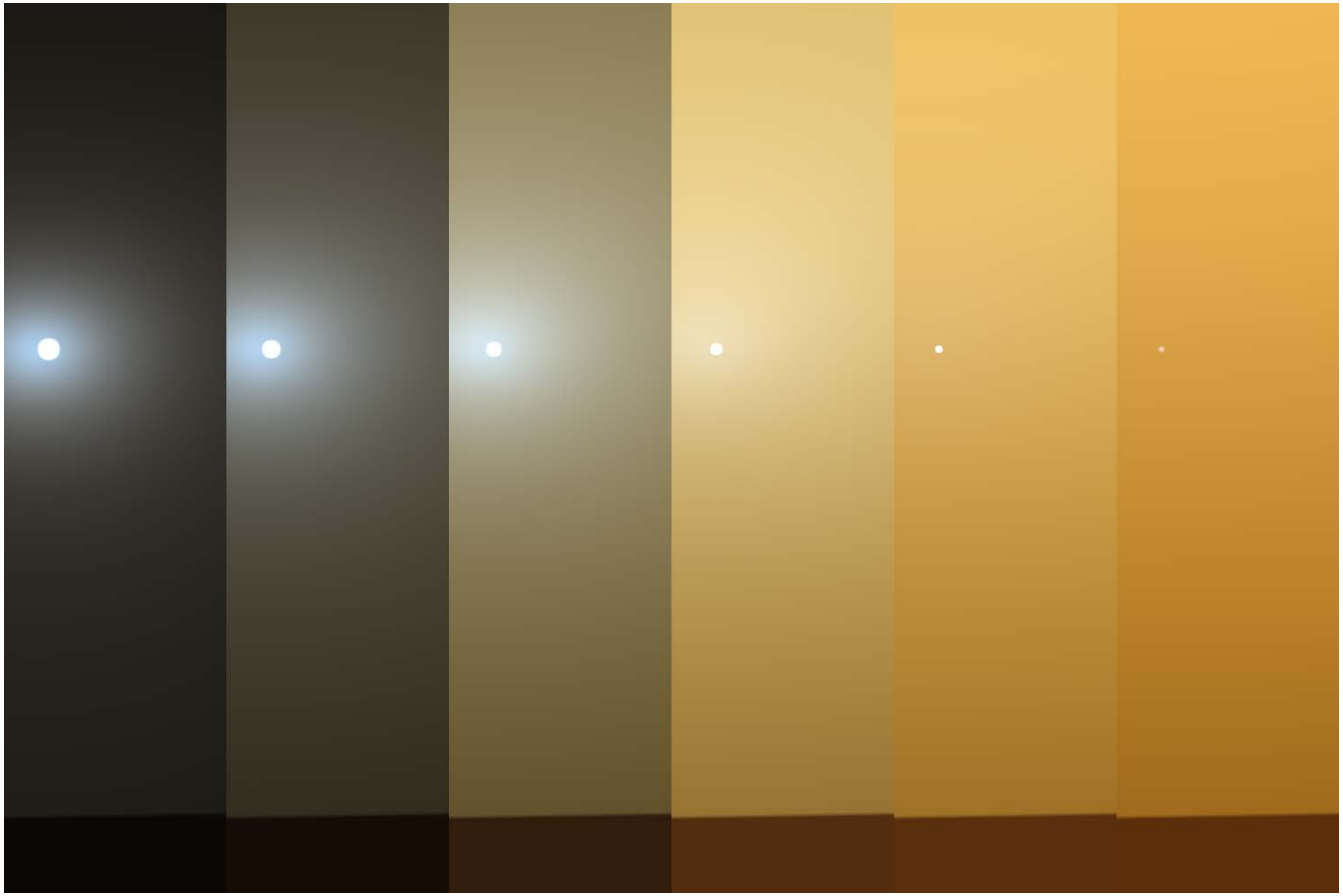
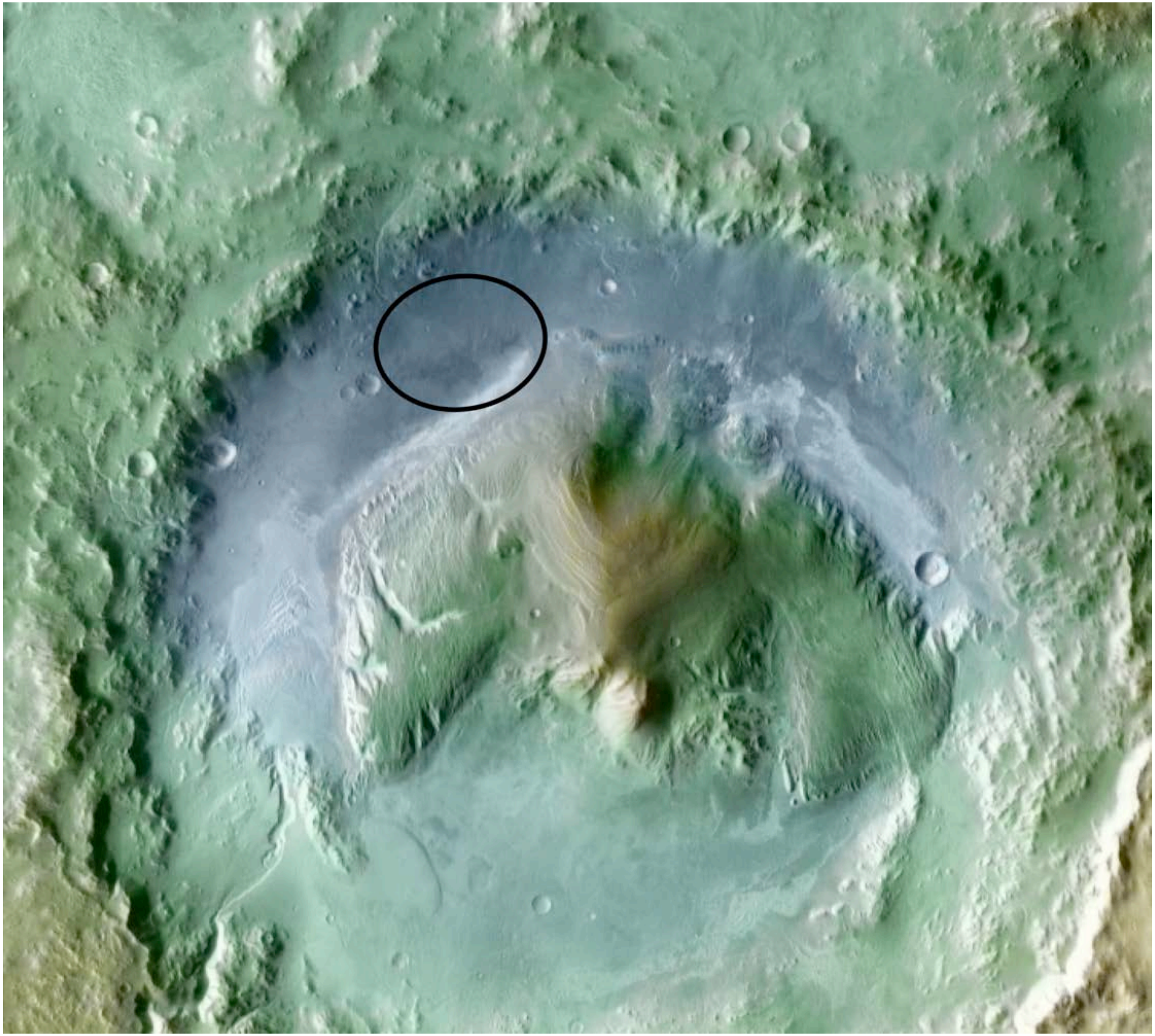


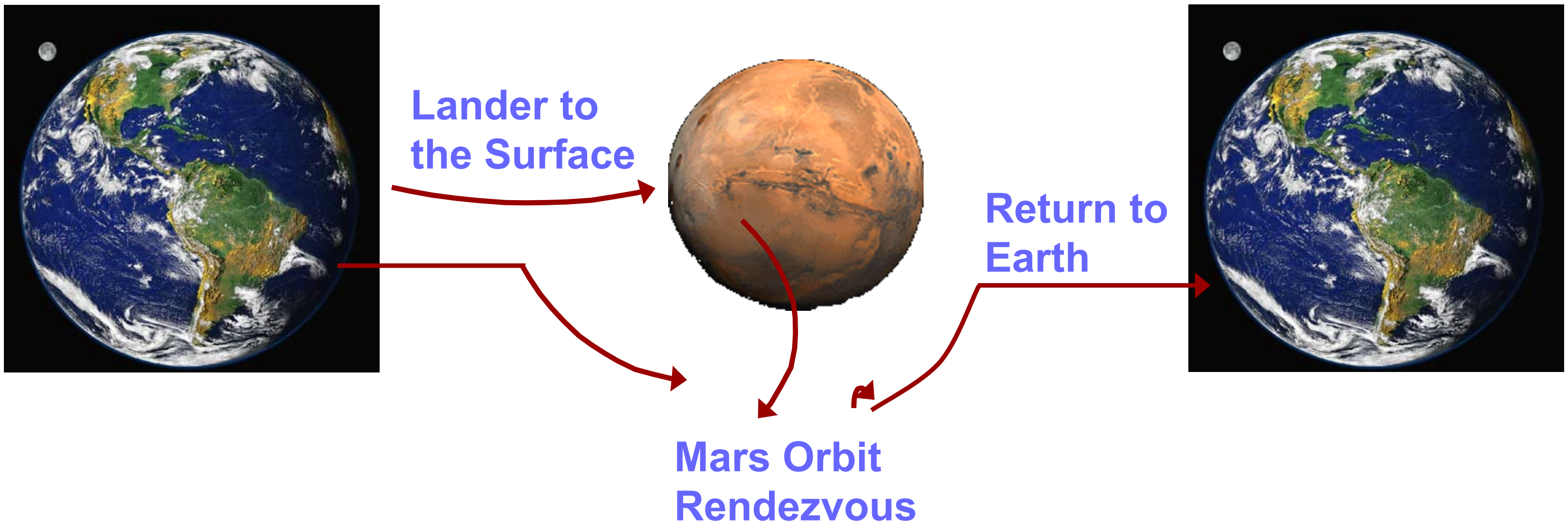
Illustration of sun/sky appearance at Opportunity site: Rover lost contact June, 2018. Declared dead Feb 2019.

Gale Crater Landing for Curiosity

Required much greater precision



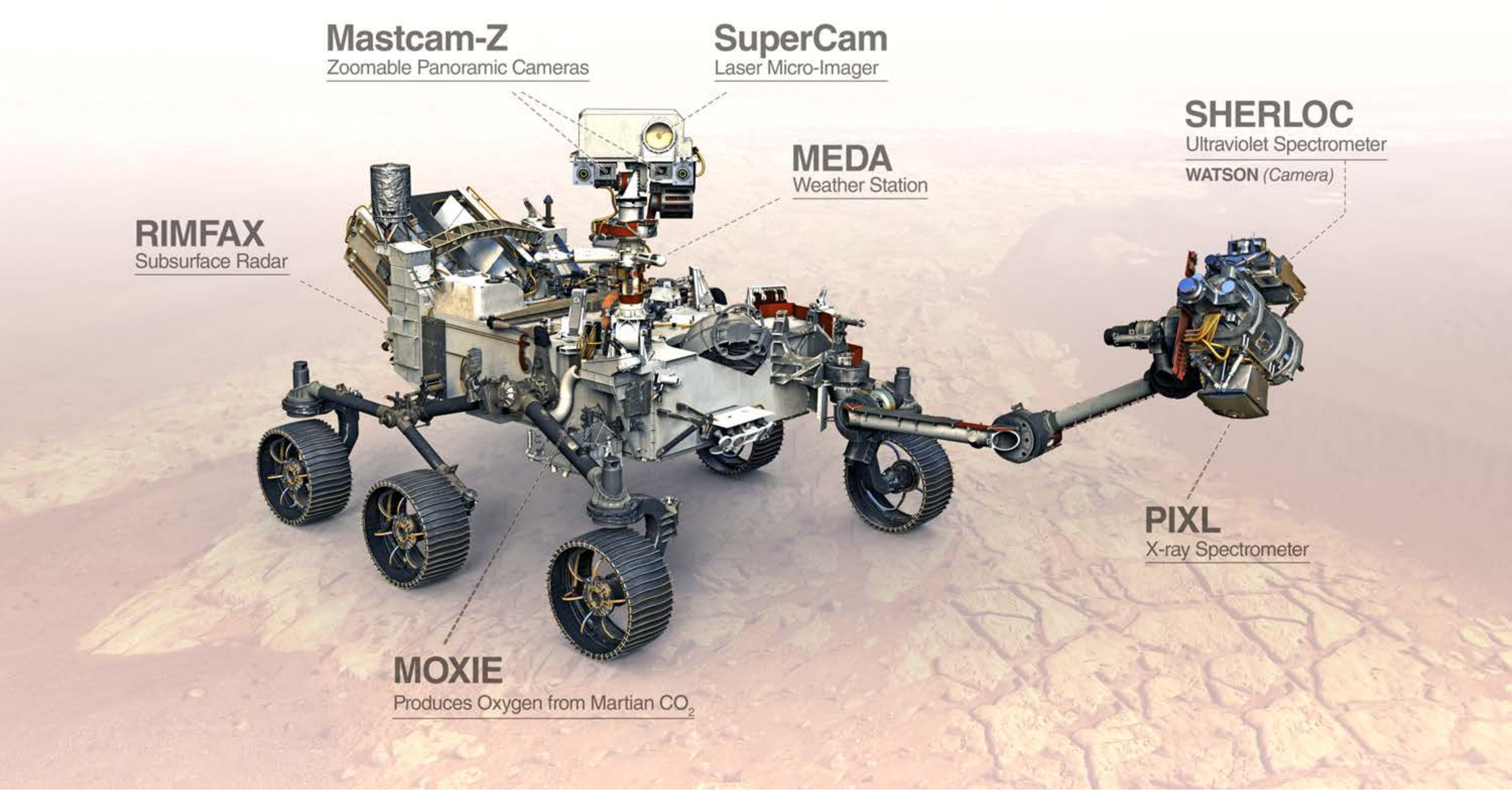
Next Step
Mars Sample Return



<u>Why:</u>

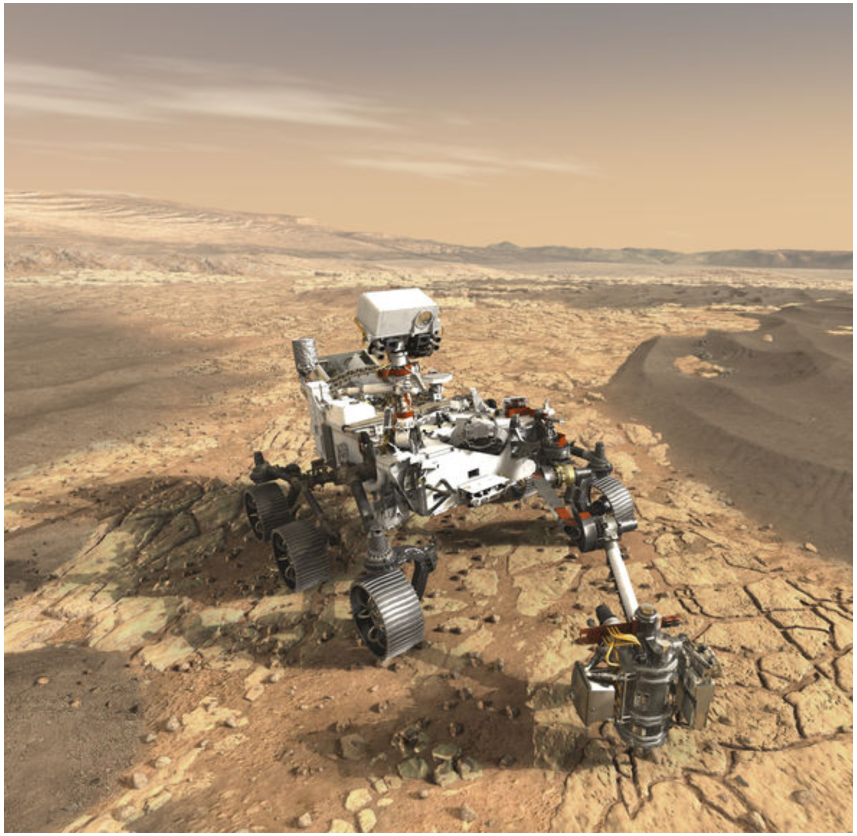
- Next logical step – most science return for the investment
- Samples can be analyzed by multiple labs
- Investigations by 100's of researchers
- Advanced instrument utilized that is too large, complex or recent for space hardware
- Alternate measurement routes can be followed

First Step: Perseverance
In Situ Science and Sample Collection



Using Self-Driving Vehicle Technology on Mars: Perseverance

- Process: capabilities tested on Earth, then tested during extended mission phases before baselined for more "routine" use.
- "AutoNav" (autonomous rover driving) was first used as a tech demo on the MER rovers, then used (occasionally) for Curiosity
- Planned for greater use with Perseverance.



Also: A Helicopter Named Ingenuity

Status of Autonomous Systems and Potential for AI*

- For flight (whether aero or space), NASA projects still rely on the results of V&V to have confidence in the expected performance of software.
  - "Trust" is still tightly coupled to: (1) how the requirements for software are written and (2) what methods are used to confirm that the requirements are met
  - Generally includes both nominal and off nominal cases.
- Commercial terrestrial systems can be different
  - Within the autonomous vehicle (self-driving car) world, the primary focus is compliance to standards, since that is what needed for certification.
- The UL 4600 standard was released last year and is the first standard for evaluating the safety of autonomous products. This includes dealing with AI technology (e.g., deep learning) and helping to ensure that vehicles are safe even in off-nominal situations and with equipment failure.

Can commercial systems experience be adapted for space?

* Credit: T. Fong, NASA Ames

AUTOMATED VEHICLES SYMPOSIUM
DRIVEN BY AUVSI & TRB
July 27 - 30, 2020
A Full Virtual Event

Prof. Philip Koopman

Key Ideas: UL 4600 Safety Standard for Autonomous Vehicles

AVS / July 2020

Carnegie Mellon University

@PhilKoopman

EDGE CASE RESEARCH

Goal Based Approach

- Traditional safety standards are prescriptive
  - "Here is how to do safety" (process, work products)
    - ISO 26262, ISO/PAS 21448, IEC 61508, MIL-STD 882, etc.
- UL 4600 is goal based
  - "Here is what a safety case should address"
    - Do NOT prescribe any particular engineering approach
      - Use other safety standards within the safety case context
  - Standard for how to assess a safety case
    - Minimum coverage requirement (what goes in the safety case?)
    - Properties of a well-formed safety case
    - Objective assessment criteria

Future Applications and Pathways for Greater Autonomy

- NASA is conducting significant R&D for autonomous management (vehicle operations and IVA caretaking) of Gateway (the mini-space station in cis-lunar orbit).
- Deployment approach, particularly for the Gateway "Vehicle Systems Manager" (VSM) is to incrementally increase operational scope.
- VSM initially used to autonomously manage a very limited set of functions, then will incrementally allowed to do more based on operational experience.
- In my opinion, if an operational envelope with “watchdogs” can be established, AI may be incorporated within that envelope.

Artist’s concept of the Gateway