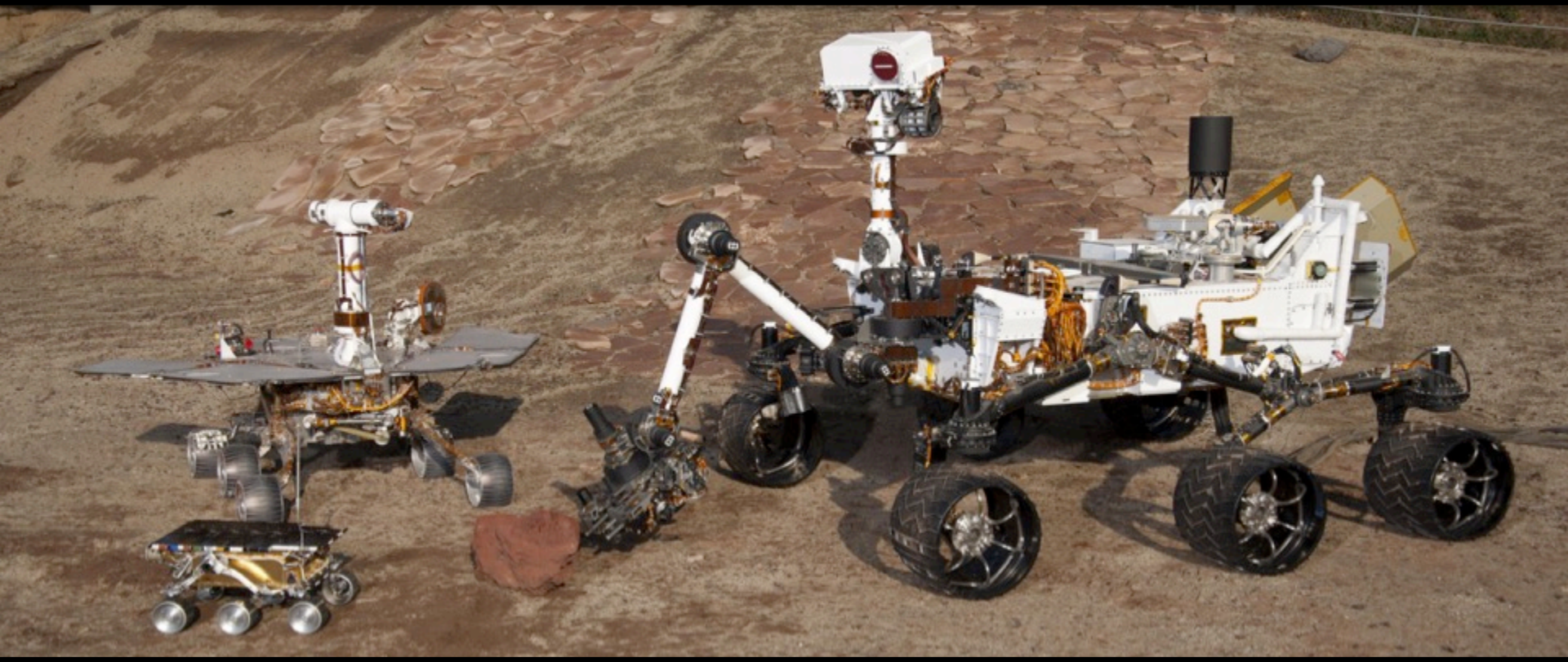
# Operating Mars Rovers

## *- This Is How We Roll -*



Colette Lohr – Jet Propulsion Laboratory, California Institute of Technology
USC Viterbi School of Engineering
W.V.T. Rusch Undergraduate Engineering Honors Colloquium, October 21, 2016
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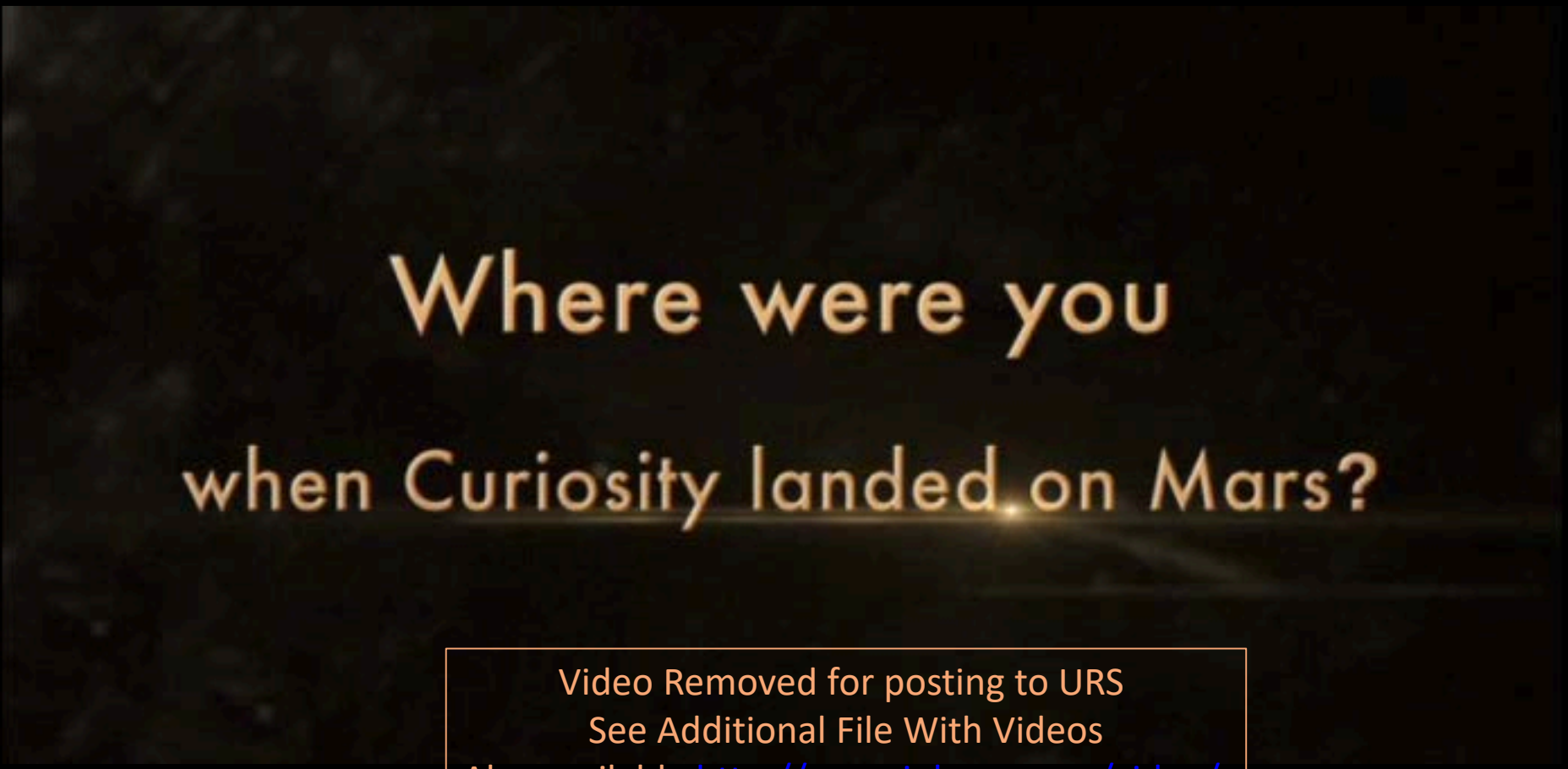
Jet Propulsion Laboratory
Burbank
Rose Bowl Stadium
37 min
23.2 miles
Glendale
Pasadena
Griffith Park
Adams Square
30 min
19.6 miles
28 min
17.7 miles
Pantages Theatre
Dodger Stadium
Los Angeles
STAPLES Center
City Terrace
University of Southern California
East Los Angeles

So it Begins…

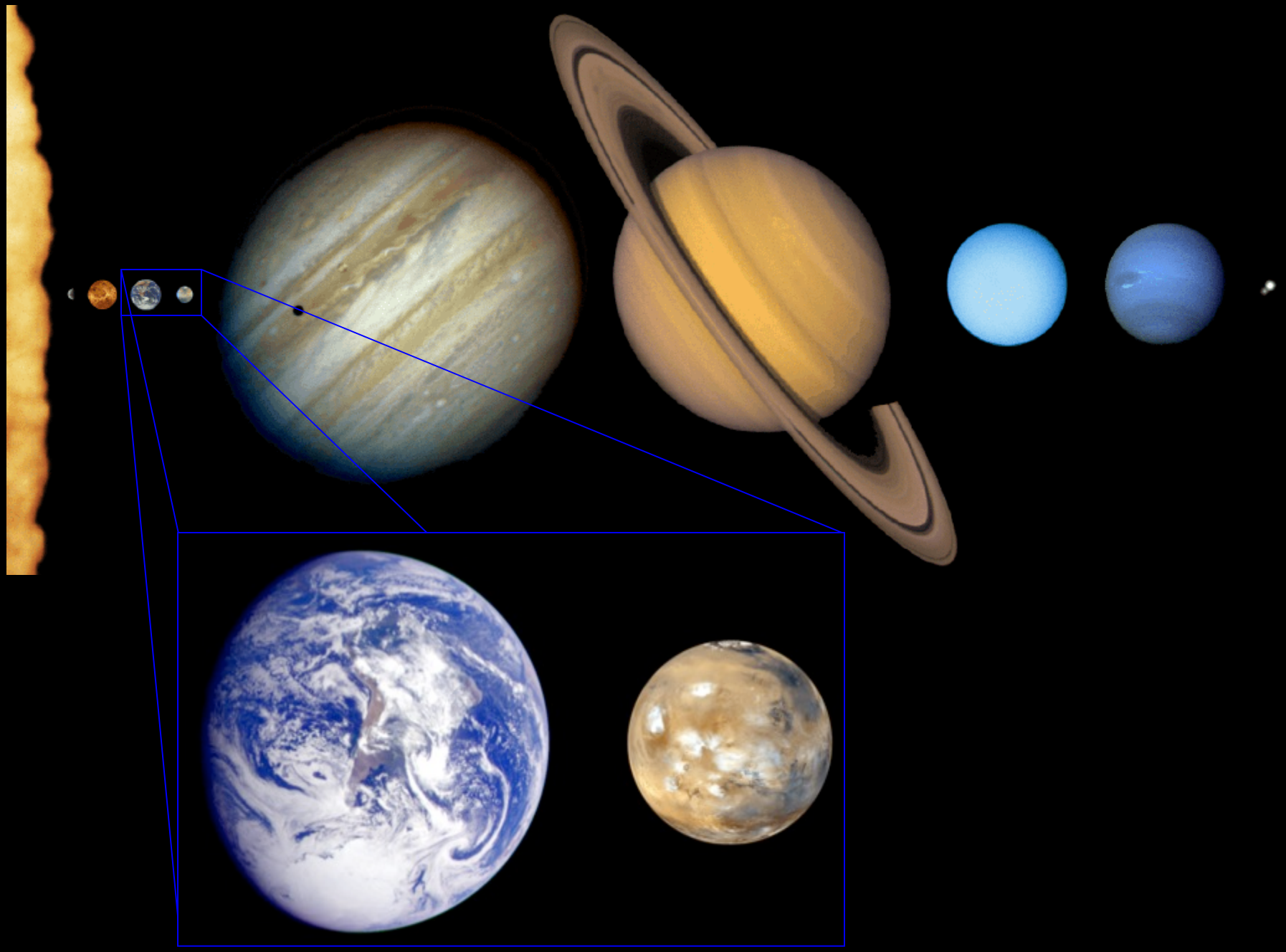



Video Removed for posting to URS
See Additional File With Videos
Also available http://www.jpl.nasa.gov/video/

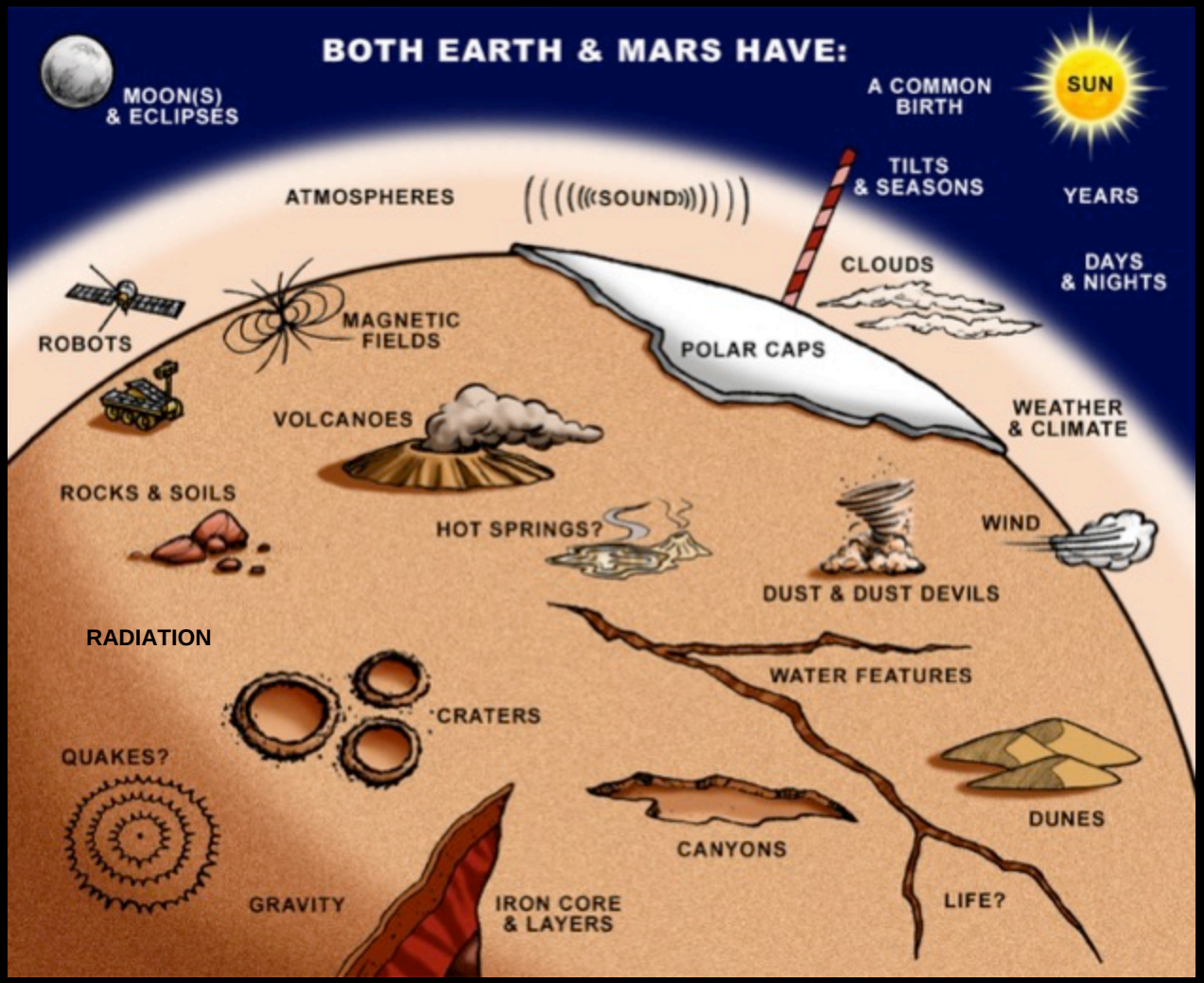
6 Wheels on Mars!!!
We Have a Mission!!!

Beyond Earth, Mars is one of the only places in the solar system where humans could one day live

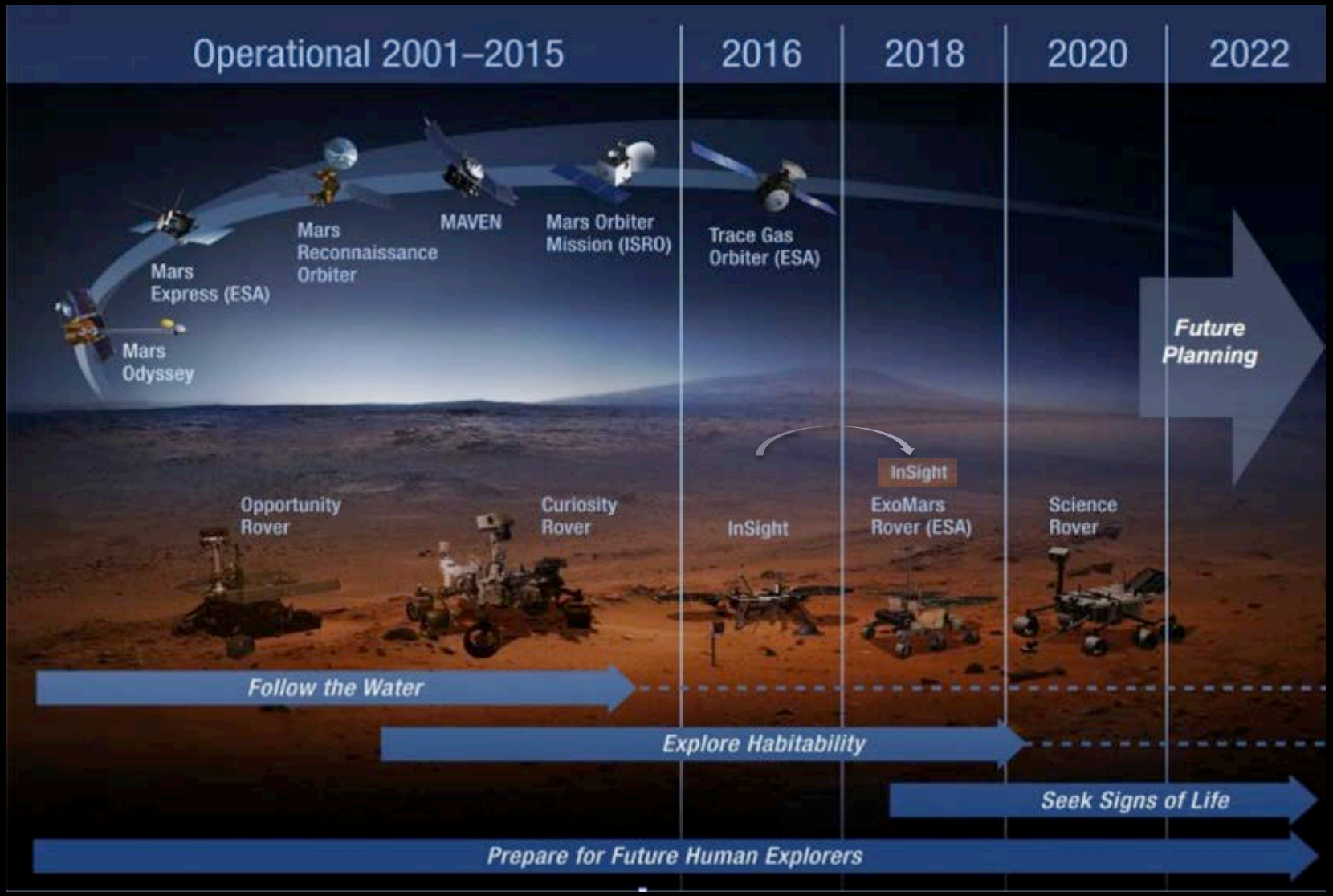
In size, Mars is about half the diameter of Earth



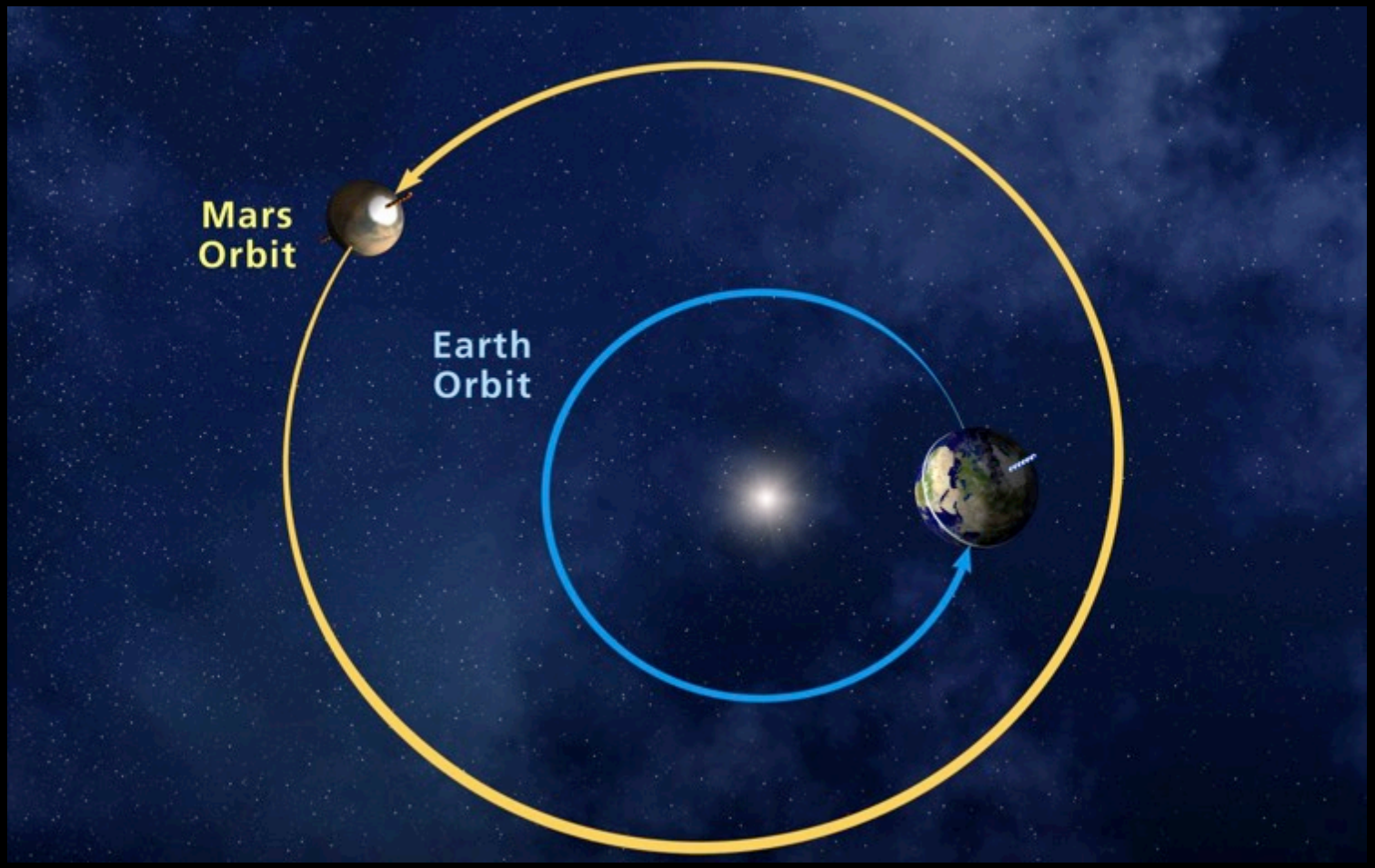
# Scientists and engineers from all over the world have discovered many environmental and other similarities between Earth and Mars



# Robotic Mars Missions

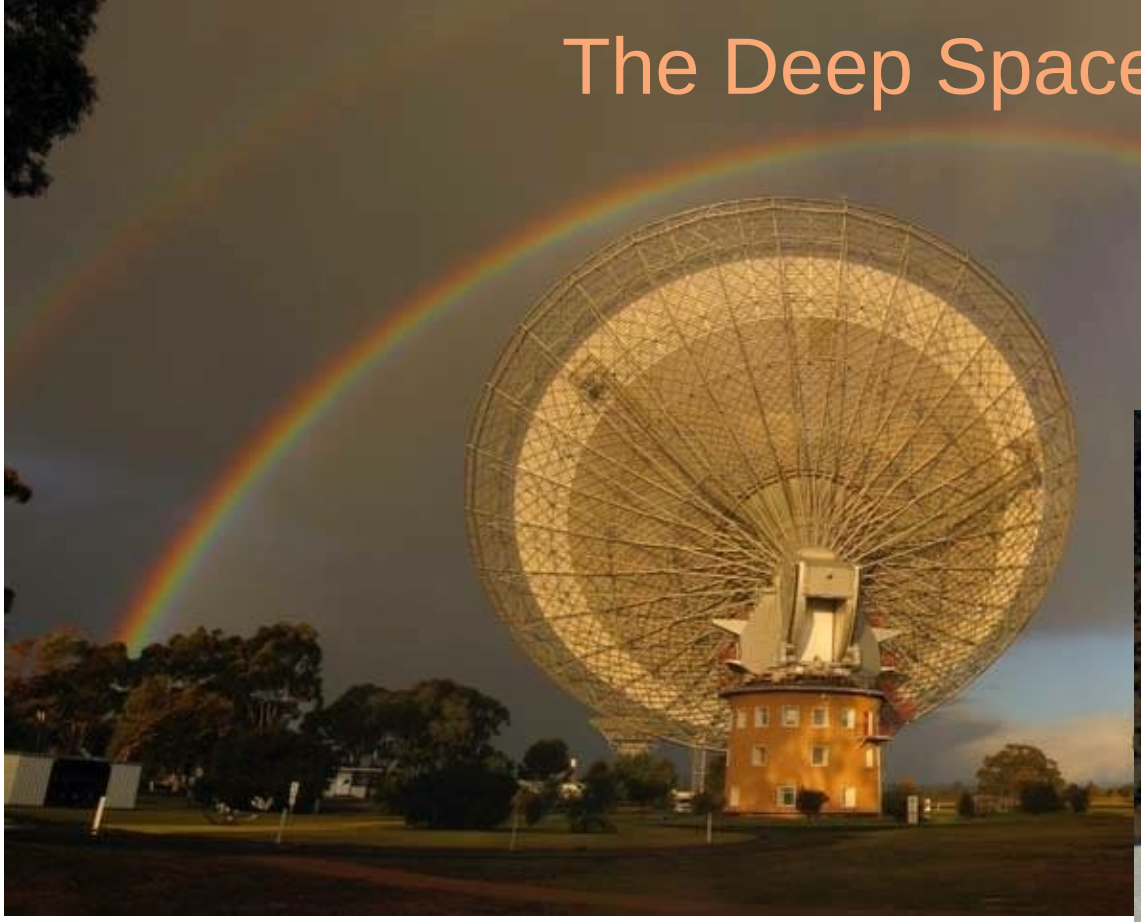


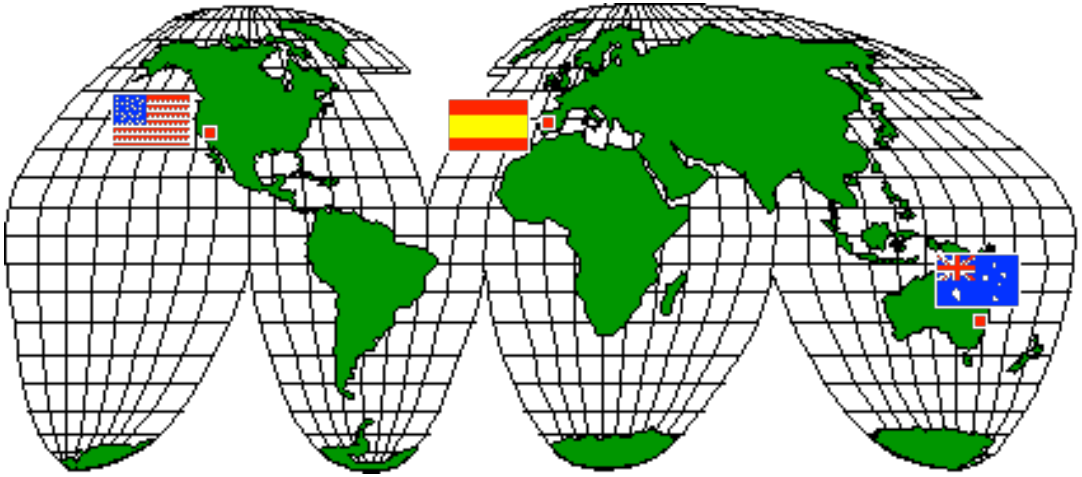
# Because of the distance between Earth and Mars, we can't drive a rover in real time



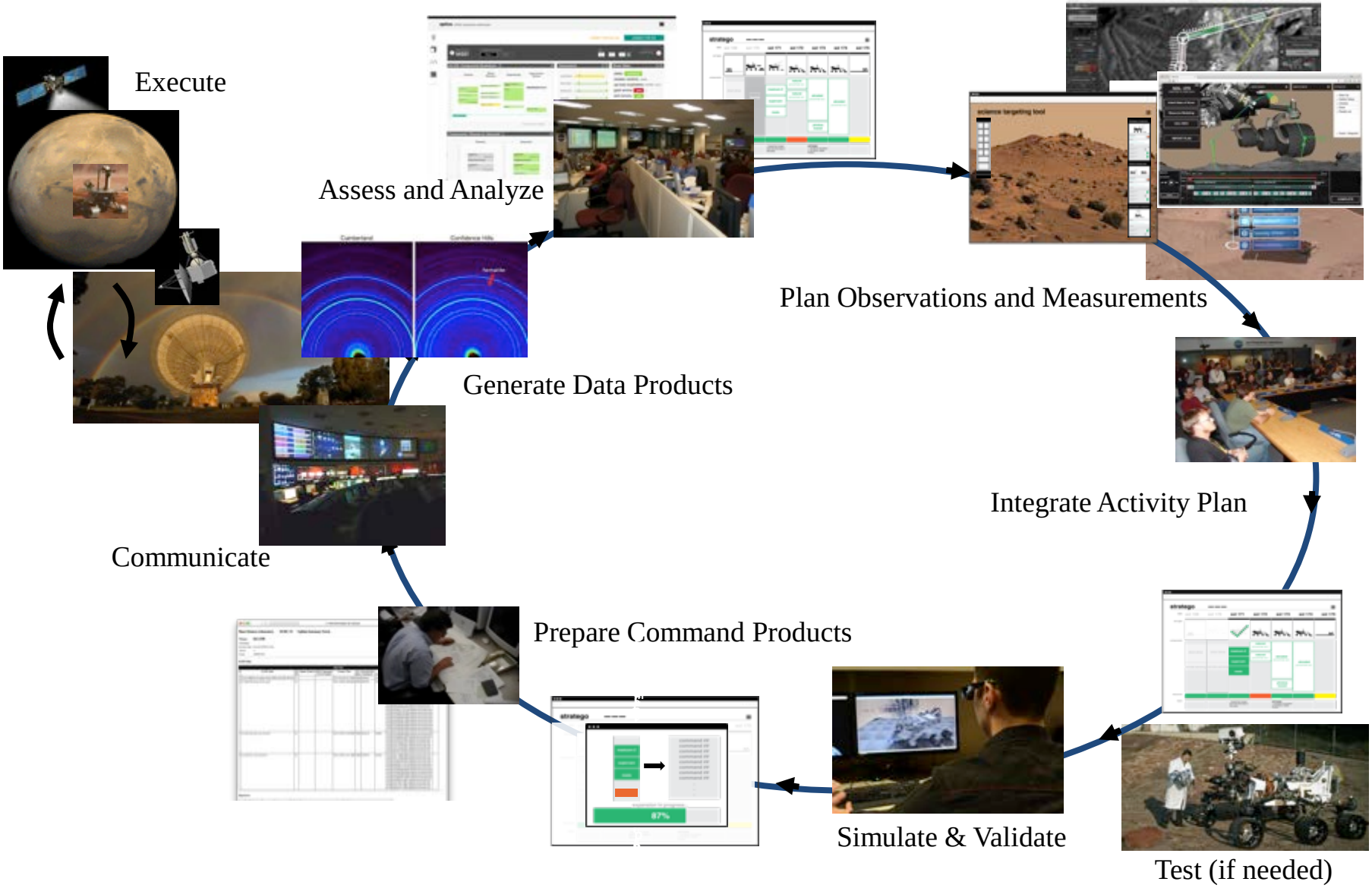

It takes between 4 and 22 minutes each way for a signal to travel between the two planets

# The Deep Space Network





# High Level Mars Surface Ops Cycle



# Every morning on Mars, the rover receives one set of commands for the whole day…

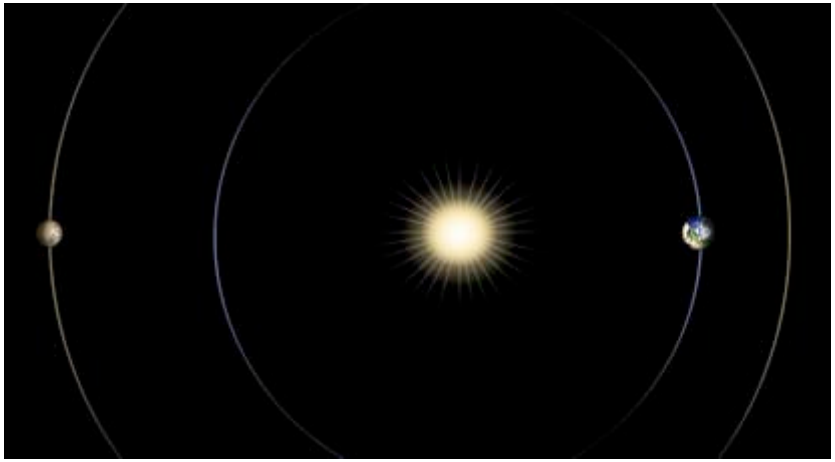
Curiosity's activities for the Sol could include driving, analyzing rock samples, even taking selfies!

# The rover carries out the activities and then sends data to the orbiters, which relay it to Earth

It takes less energy and a smaller antenna to send data 200 miles (322 km) up to an orbiter, rather than millions of miles to Earth

# Unique Operational Experiences of Planetary and Deep Space Missions

- Communication restrictions
  - Delayed knowledge of spacecraft state
  - Limited data volume return
  - Long light-time - It can take 10-20 minutes or longer to receive a transmission from Mars, depending on the current distance between Earth and Mars
  - Impacts of orbital mechanics - Solar conjunction impacts our ability to communicate with our spacecraft at Mars for about 2 weeks every 2 Earth years
  - The Deep Space Network is a limited resource – Multiple missions in contention

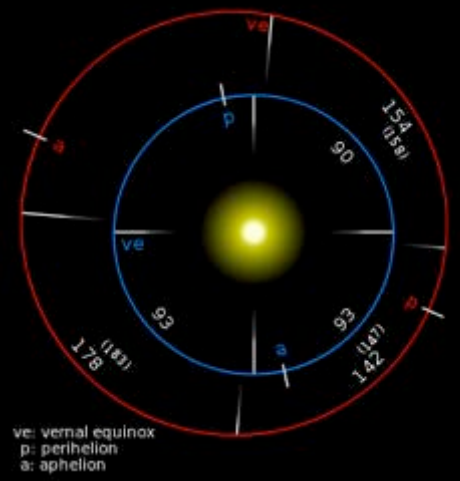


- Onboard automation
  - Execution of pre-planned command sequences
  - Response to anomalies (Fault Protection)

- Missions are scientifically unique, requiring science and engineering goals to be negotiated regularly
- Utilization of Relay Assets at Mars
- Working Mars Time

# What Time Is It?

- Due to the Mars orbit and rotation, days are measured differently there than they are on Earth
- One solar day on Mars, called a “Sol," is about 40 minutes longer than an Earth day
- Terms to live by:
  - Yesterday = YesterSol
  - Today = ToSol
  - Tomorrow = Solorrow
  - Martial Holiday = Soliday



# Why Work Mars Time?

- Provides maximum number of work hours between afternoon downlink and morning uplink
- Key spacecraft and ground events are tightly coordinated
  - Tosol's afternoon downlink triggers uplink planning process which must complete in time for solorrow's uplink
  - Spacecraft and ground activities happen at a consistent time on the Mars clock
- Personnel have clear understanding of when spacecraft events will occur
  - Easy to know what's happening on Mars right now

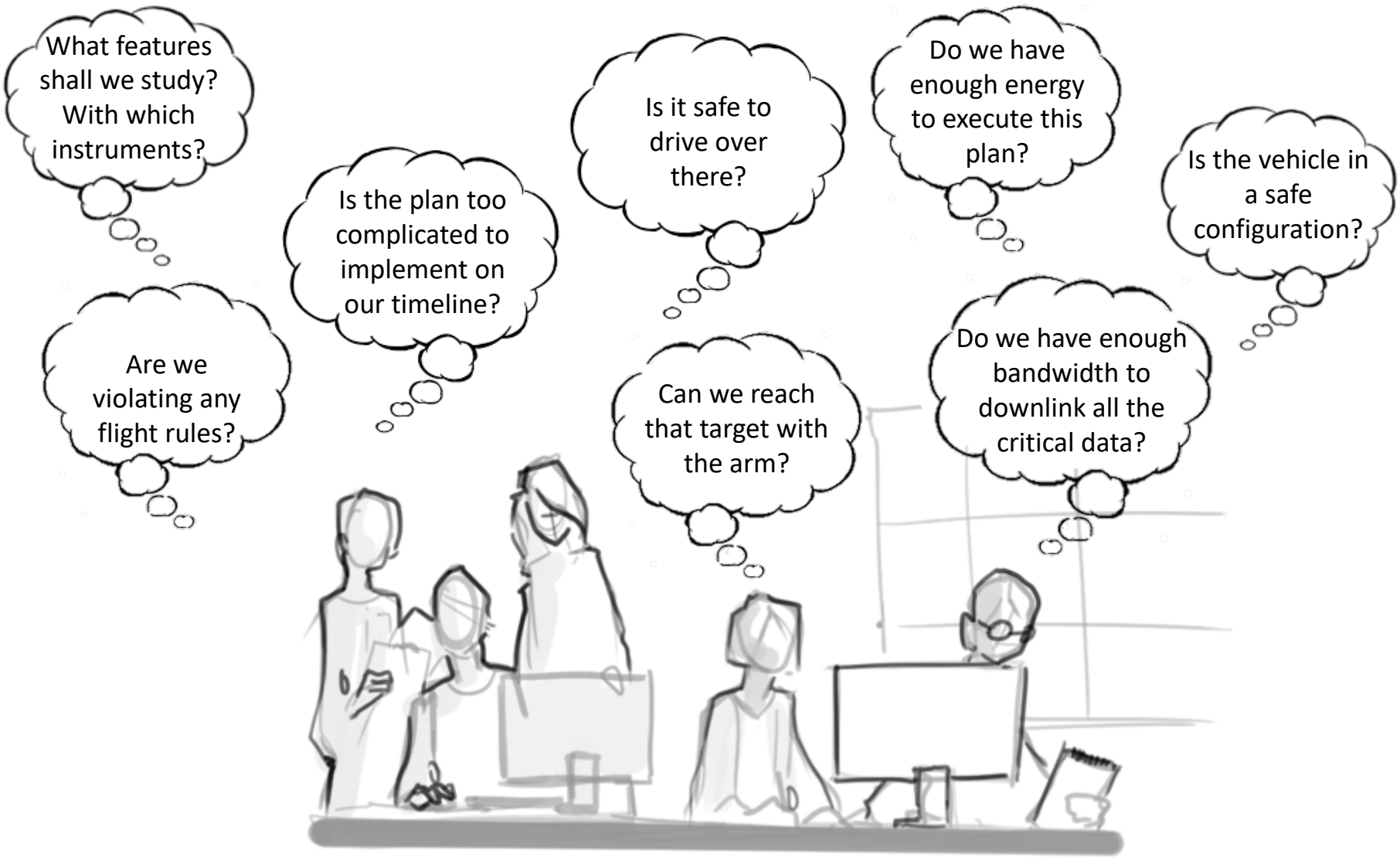
# Why Not Work Mars Time?

- Working Mars time is incredibly disruptive of team members' personal lives
- Easily leads to fatigue-related symptoms
- “Breakfast at 3pm, biking at 3am and bedtime at noon”
- Who are those people (and critters) living in my house making noise when I’m trying to sleep?

# Challenges of Earth Time

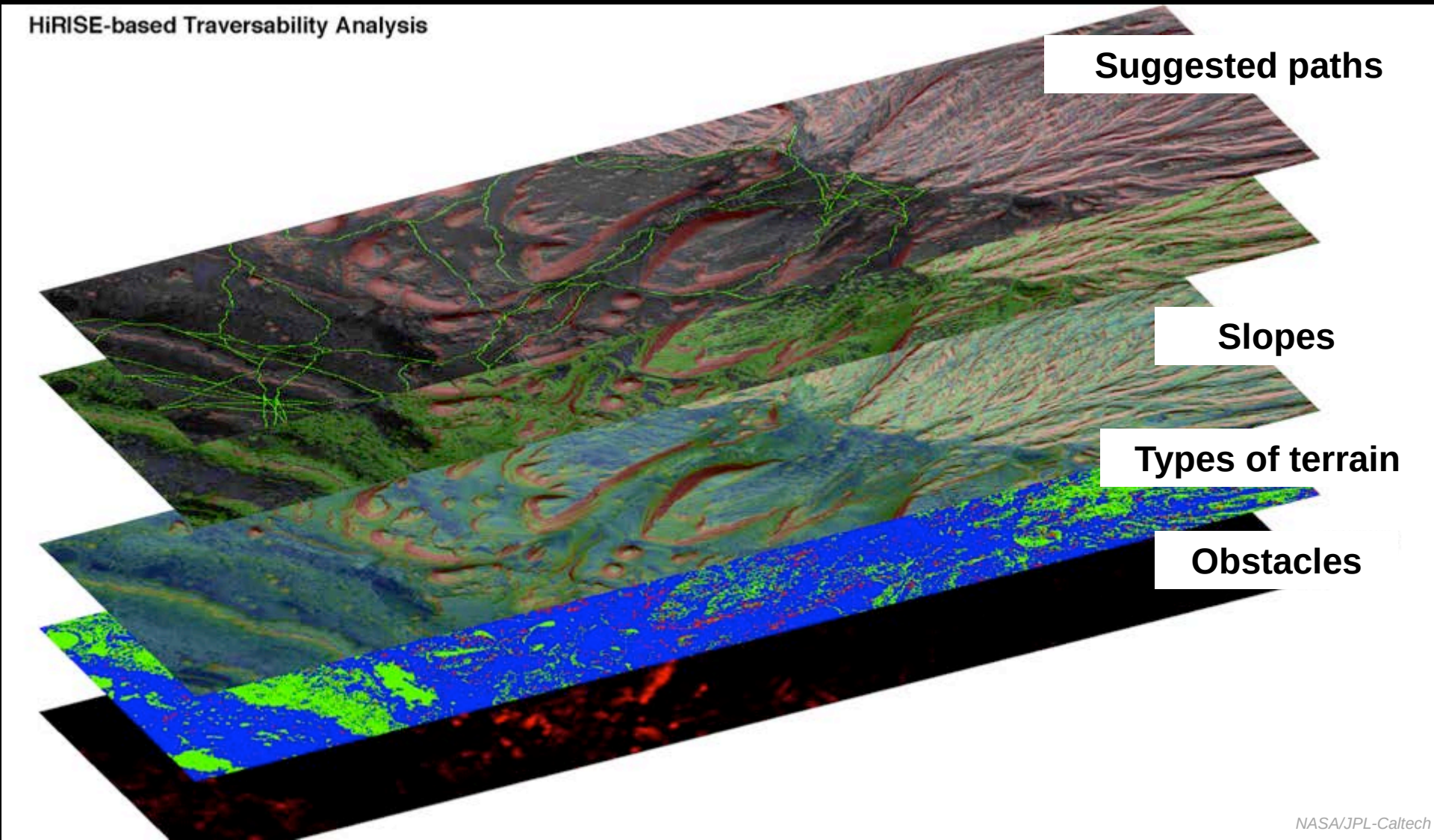
- Working on Earth Time
  - Logistics complexity in staffing and scheduling Earth time ops for Mars-clock mission is greater than managing Mars-time schedule
  - "Earth-time" schedule still has walking of shifts (earliest start 7 am; latest end 10 pm)
  - Spacecraft and ground operation activities are often only loosely synchronized
    - Downlink/uplink may occur off-shift
    - Exceptions occur when downlink drifts into Earth-day shift or when uplink must occur early in Earth day shift
  - Easy to lose lock on what's happening on Mars
  - Use of alternating "restricted" and "un-restricted" sols to enable planning based on stale data
    - Required when downlink occurs too late in Earth-day to support Earth-time schedule
    - Preclude key state changes (i.e., rover motion or instrument placement) on restricted sols so uplink team may rely on telemetry from the prior un-restricted sol to plan the next un-restricted sol

# Some Typical Rover Operations Concerns



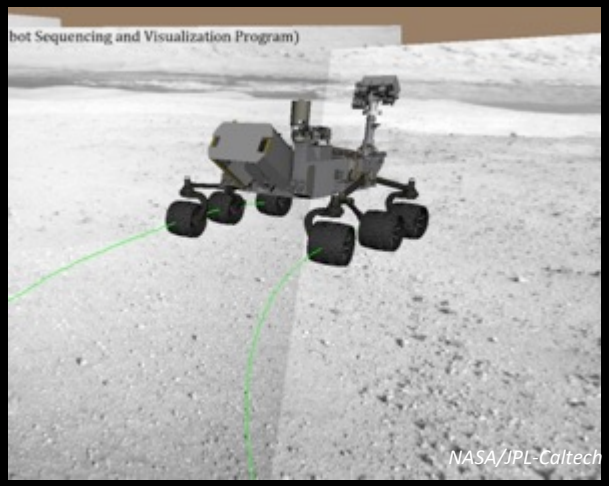
# Some Typical Rover Operations Concerns

# Data from the Mars Reconnaissance Orbiter helps "see" several kilometers ahead, allowing for long term planning



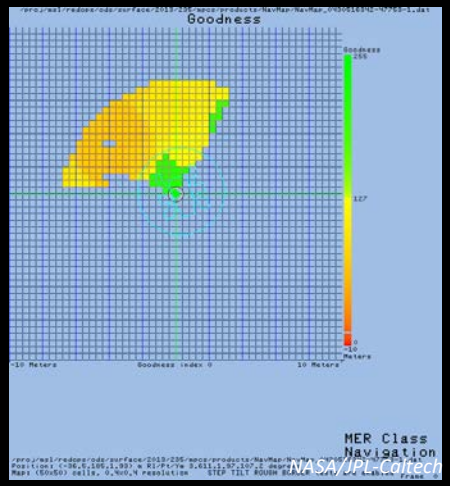

NASA/JPL-Caltech

# Engineers use several methods to drive the rovers, depending on terrain, how far they can see, and science goals



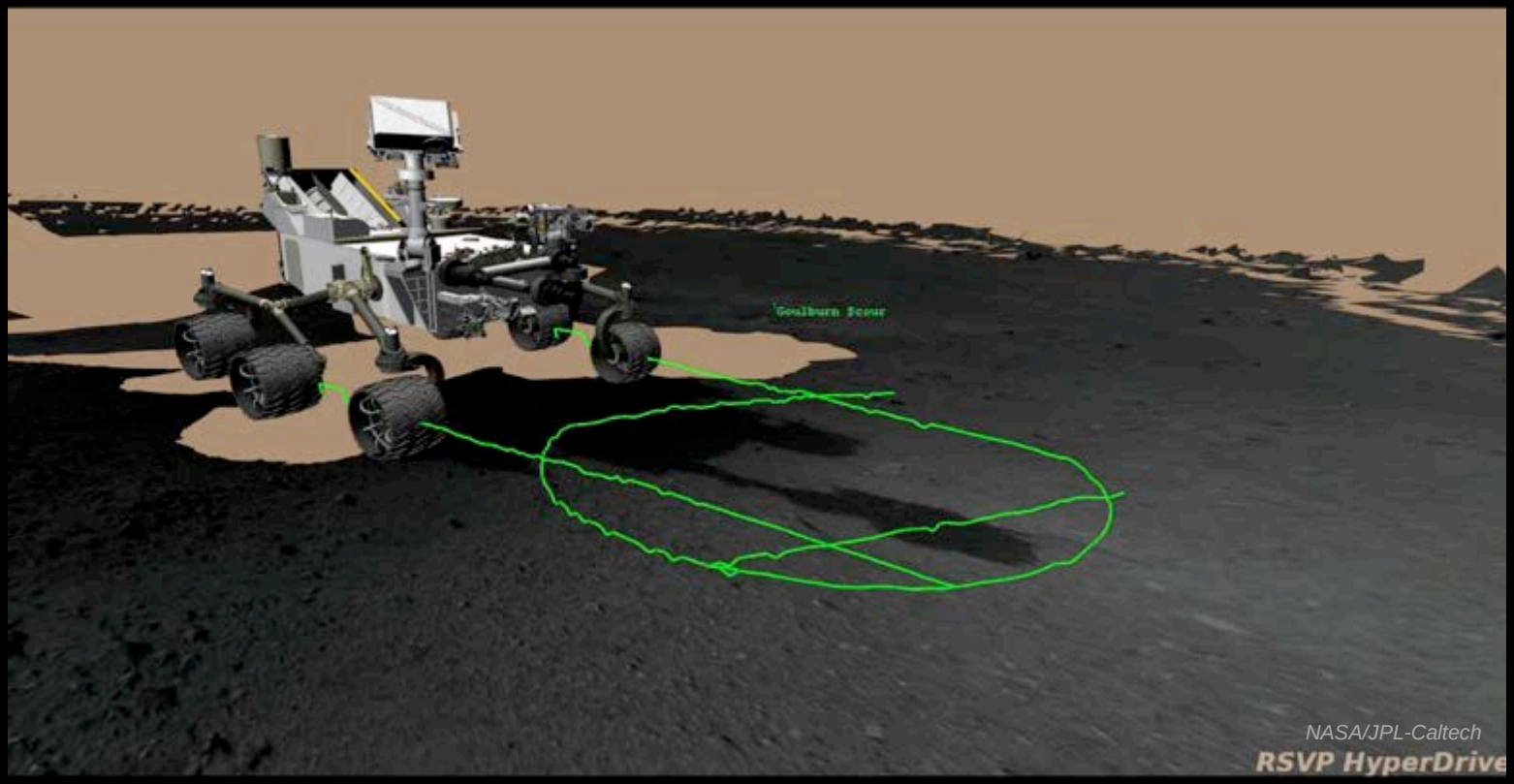

Directed driving

Visual odometry



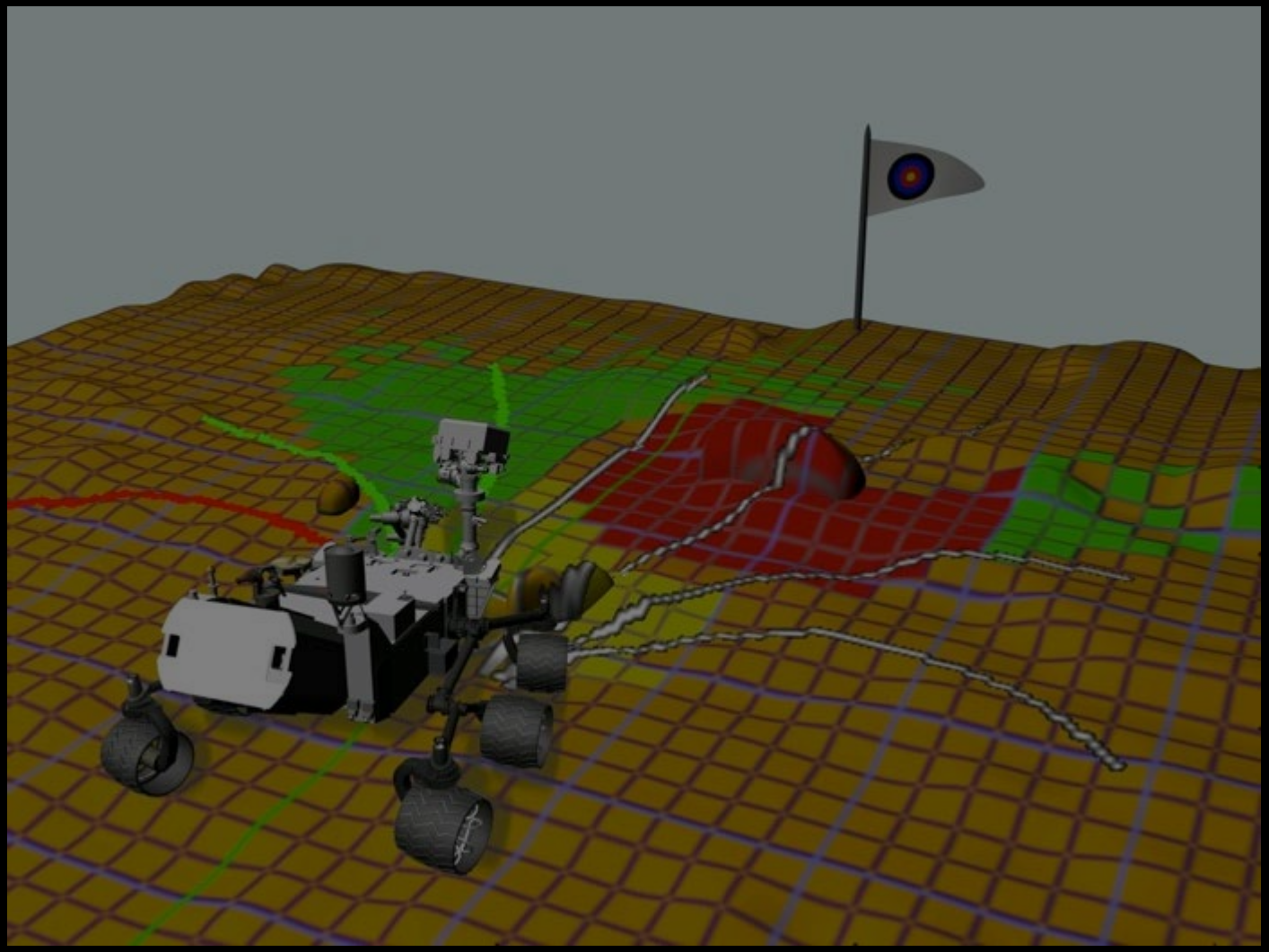

Auto-navigation

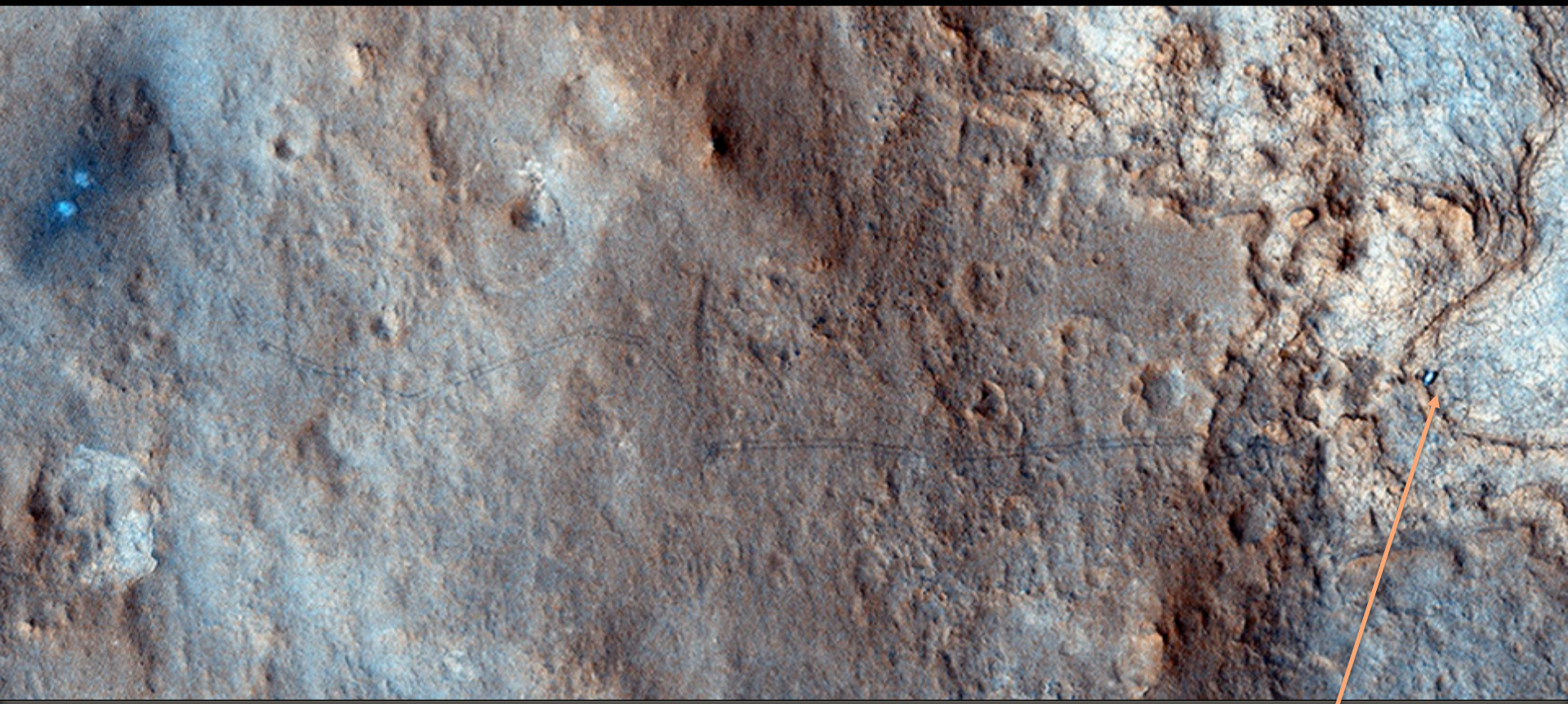
For “directed driving,” drivers command the rover to move a certain distance over ground that they know is safe




This is the fastest way to drive, because no predictive hazard processing is done, but distance is limited by what people can see. Curiosity will *always* stop the drive if needed!

# Human drivers *and* Curiosity depend on 3D image analysis to find the safest path





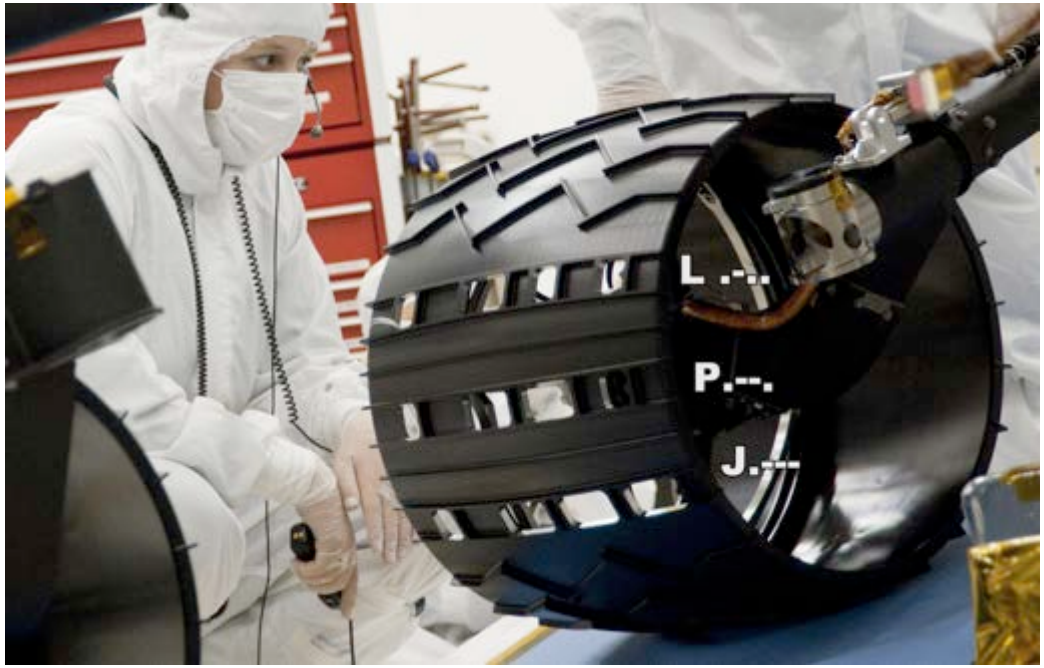

During the initial phases of Curiosity's mission, the terrain was smooth, the science was amazing, and life was good

# What’s Wrong With This Picture?

# What Happens When Things Go Wrong?

- Mars is a challenging environment, and Mars Rovers are complex – We do get thrown some curve balls!
- First, we work to make sure the vehicle is in a safe, stable configuration
- Next, we search for root-cause
  - Can involve performing diagnostics, trying to replicate the problem here on Earth, conferring with subject matter experts
- Finally, we fix the problem, or establish operational work-arounds

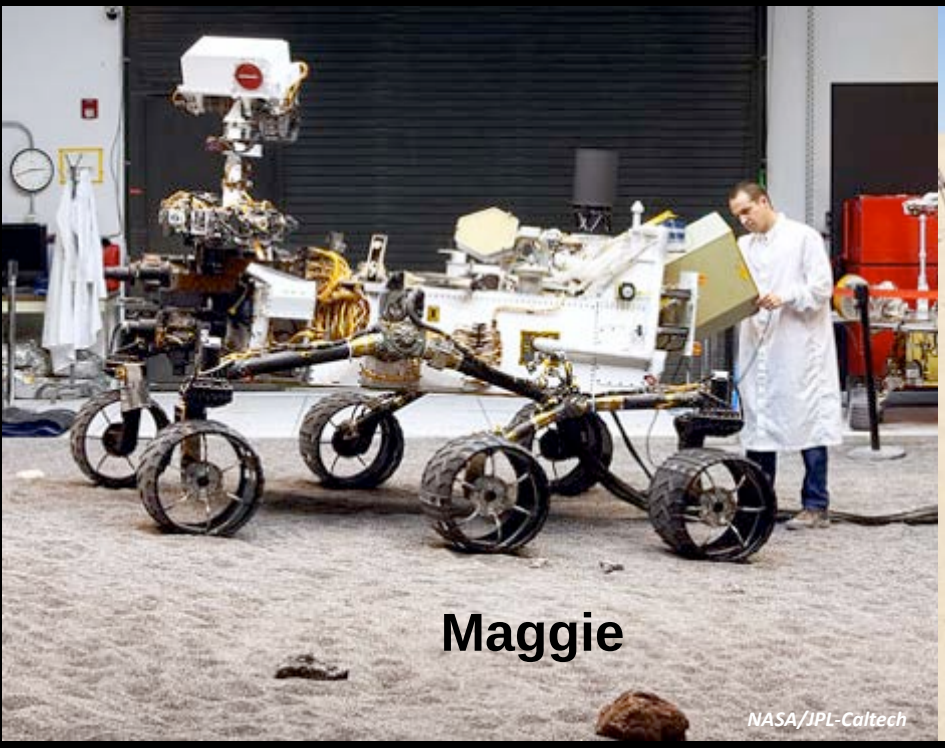
# Start With The Facts – What Do We Know?




- Curiosity's Wheels are machined from a single piece of aluminum
- The Skin of the wheels is 0.75mm or 10 sheets of paper thick
- Recall that Curiosity landed on her wheels
  - The wheels were deployed while the rover was suspended from the bridle underneath the descent stage
  - Keeping wheel mass as light as possible was important to reduce forces on the mobility system during deployment

# So What Happened?

# There are two rovers at JPL that are used to train human drivers in all those methods



"Maggie" has the same mobility, cameras, computers and robotic arm as Curiosity. "Scarecrow" weighs on Earth the same as Curiosity on Mars

See Additional File With Videos

(Wheel Test 1 & 2)

# Wheel Trailing the Pivot

# Wheel Leading the Pivot

# Test The Hypothesis

# Why Didn't We Anticipate This Problem?

- Curiosity was designed to withstand landing on the wheels
- Curiosity's wheels were designed to account for the problems we encountered with the Spirit and Opportunity Rovers, including sand traps (which Curiosity handles far better than the MER rovers), flat bedrock, and a wide variety of randomly distributed rock types
- We did *not* account for the rocks to be cemented into the ground as we found at Gale Crater
  - This was not observed at either the Spirit or Opportunity landing sites
  - Simply – Mars surprised us!

# Preserving Wheel Life Going Forward

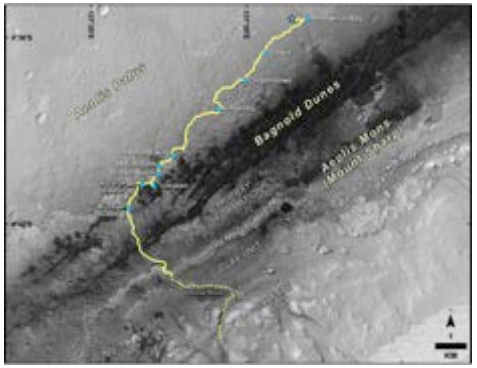
- There are a number of things we can do to preserve wheel life on Curiosity
  - Drive over benign terrain as much as possible
    - The science and engineering teams work together to classify hazardous terrain
  - Drive backwards when this isn't possible

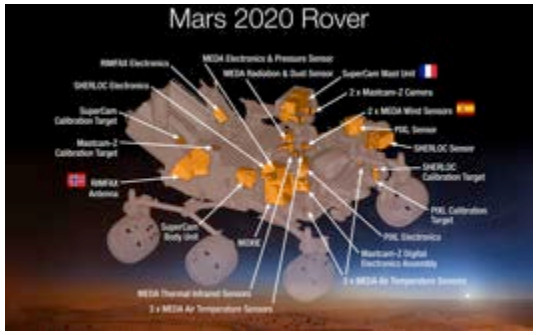
# Mars Rovers at a Glance

- Opportunity is just shy of 13 years (!) of operation on the Martian Surface

- Curiosity has started it's second extended mission

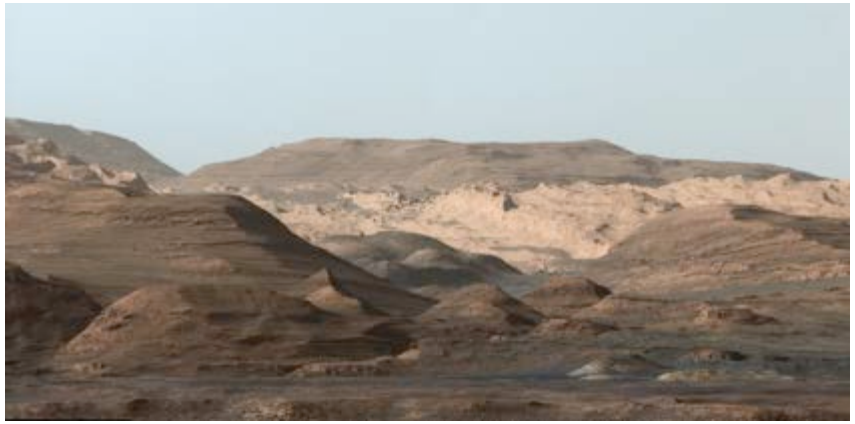
- Mars 2020 is approaching Critical Design Review in February 2017, Assembly begins early 2018

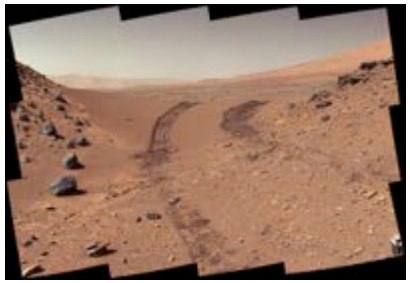


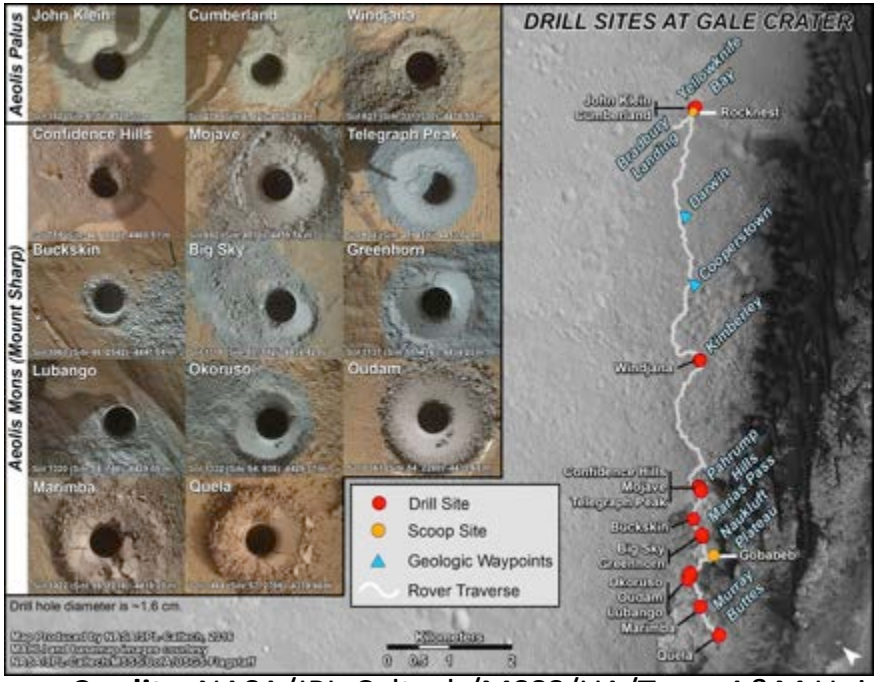



# Curiosity Images

http://mars.jpl.nasa.gov/msl





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