Jet Propulsion Laboratory
California Institute of Technology

Mars Exploration Rover

Horizon Detection for Mars Surface Operations

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Overview

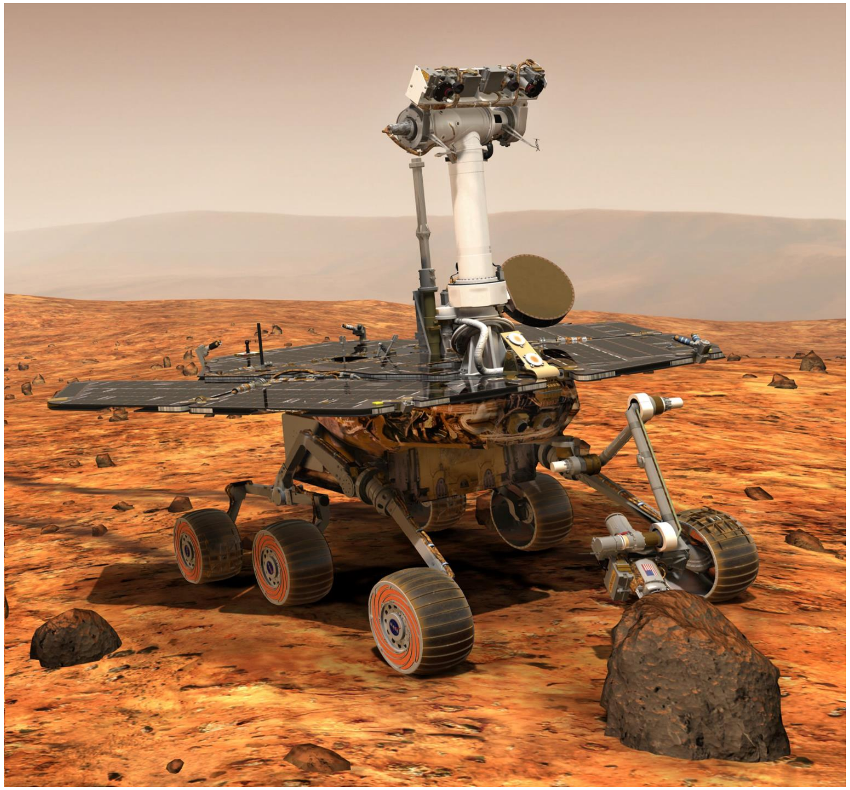
- Background and Motivation
- Solution
- Challenges
- Method
- Advantages and Disadvantages
- Current and Future Applications
- Recommendations
- Summary

BACKGROUND AND MOTIVATION

MER Overview

Mars Exploration Rovers: Two Identical Rovers

- Spirit
  - Launched on June 10, 2003
  - Landed on Mars Gusev Crater on January 3, 2004
  - Mission ended on May 25, 2011
- Opportunity
  - Launched July 7, 2003
  - Landed on Mars Meridiani Planum on January 24, 2004
  - Still ongoing into our 10th extended mission



Rover Instruments

- Engineering instruments: Front and Rear Hazard Avoidance Cameras, Navigation Cameras
- Science instruments: Panoramic Cameras (Pancam); Miniature Thermal Emission Spectrometer (Mini-TES); Mossbauaer Spectrometer (MB); Alpha Particle X-Ray Spectrometer (APXS); Magnets; Microscopic Imager (MI); Rock Abrasion Tool (RAT)

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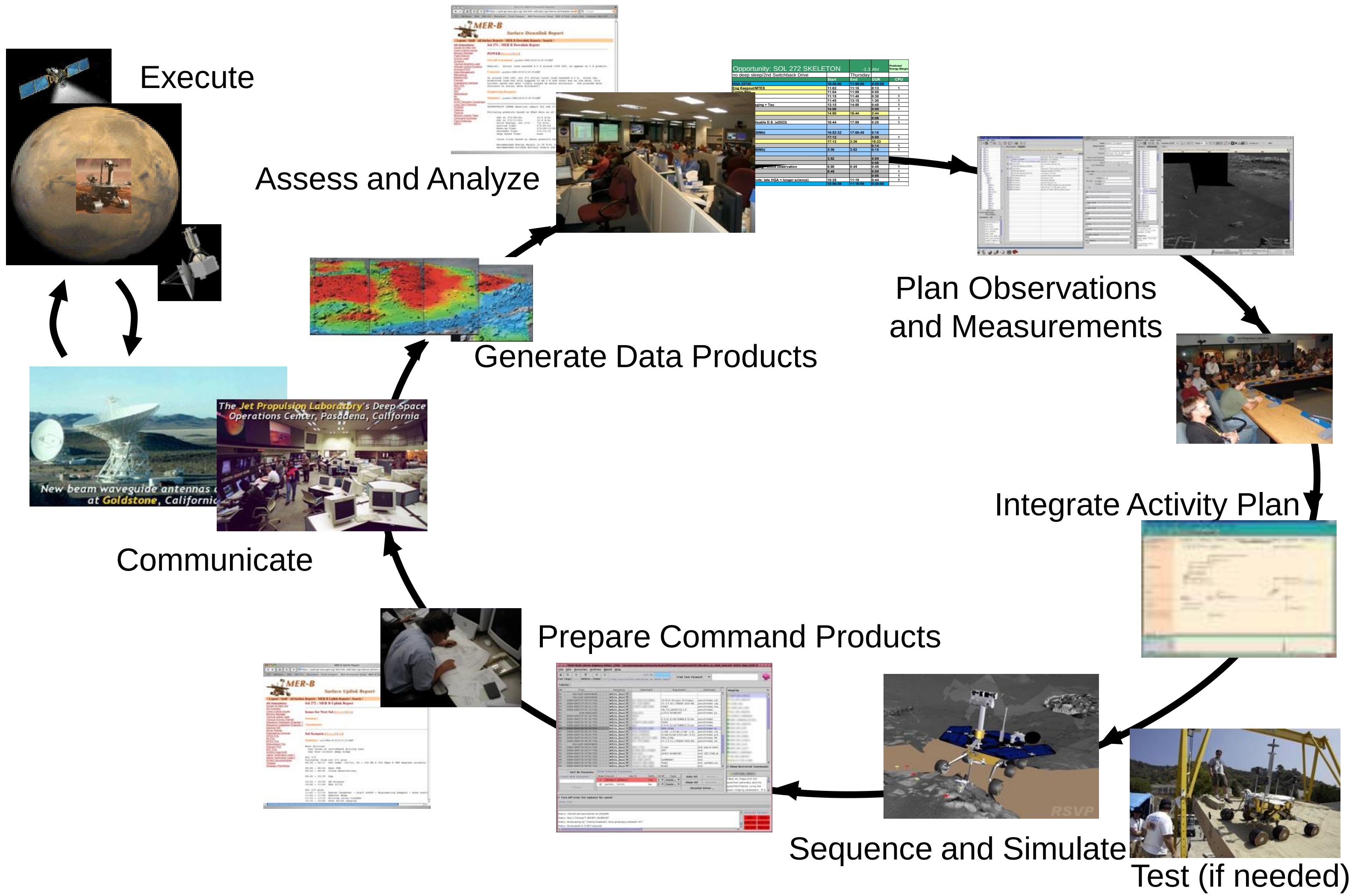
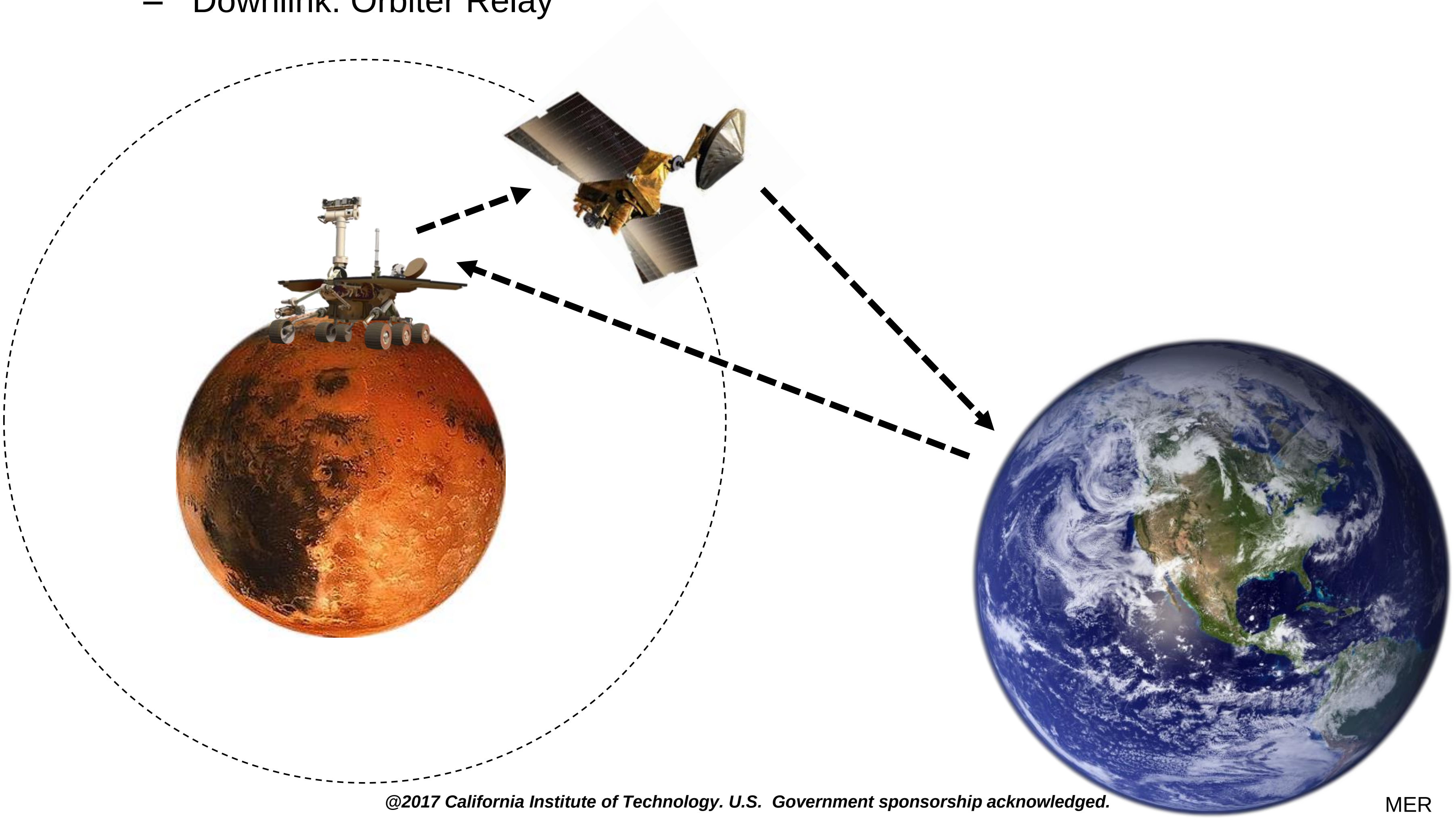
Mars Surface Operations

Mars Exploration Rover

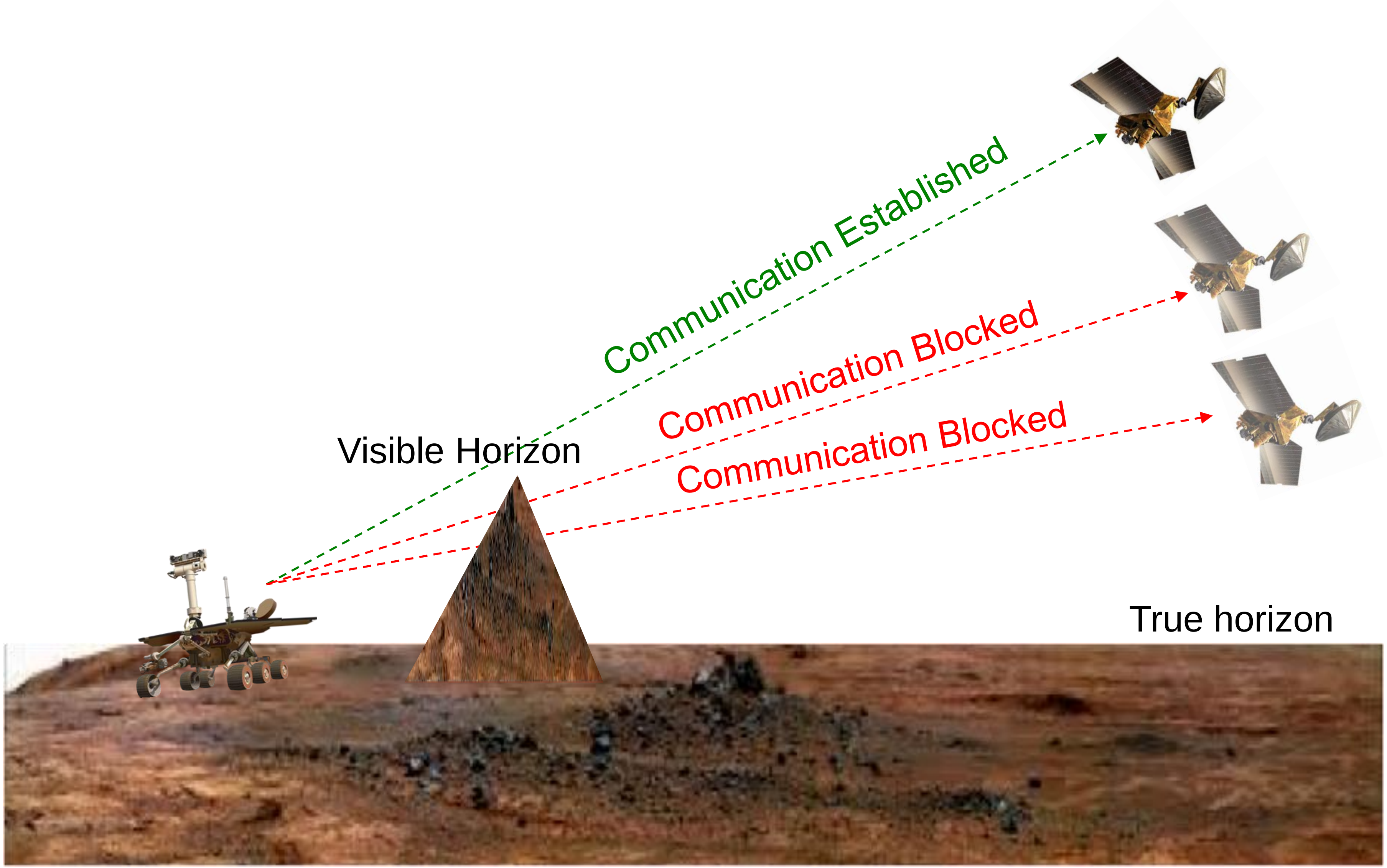


Mars Rover Communications

- Common communication paths with Mars Rovers
  - Uplink: Direct from Earth
  - Downlink: Orbiter Relay



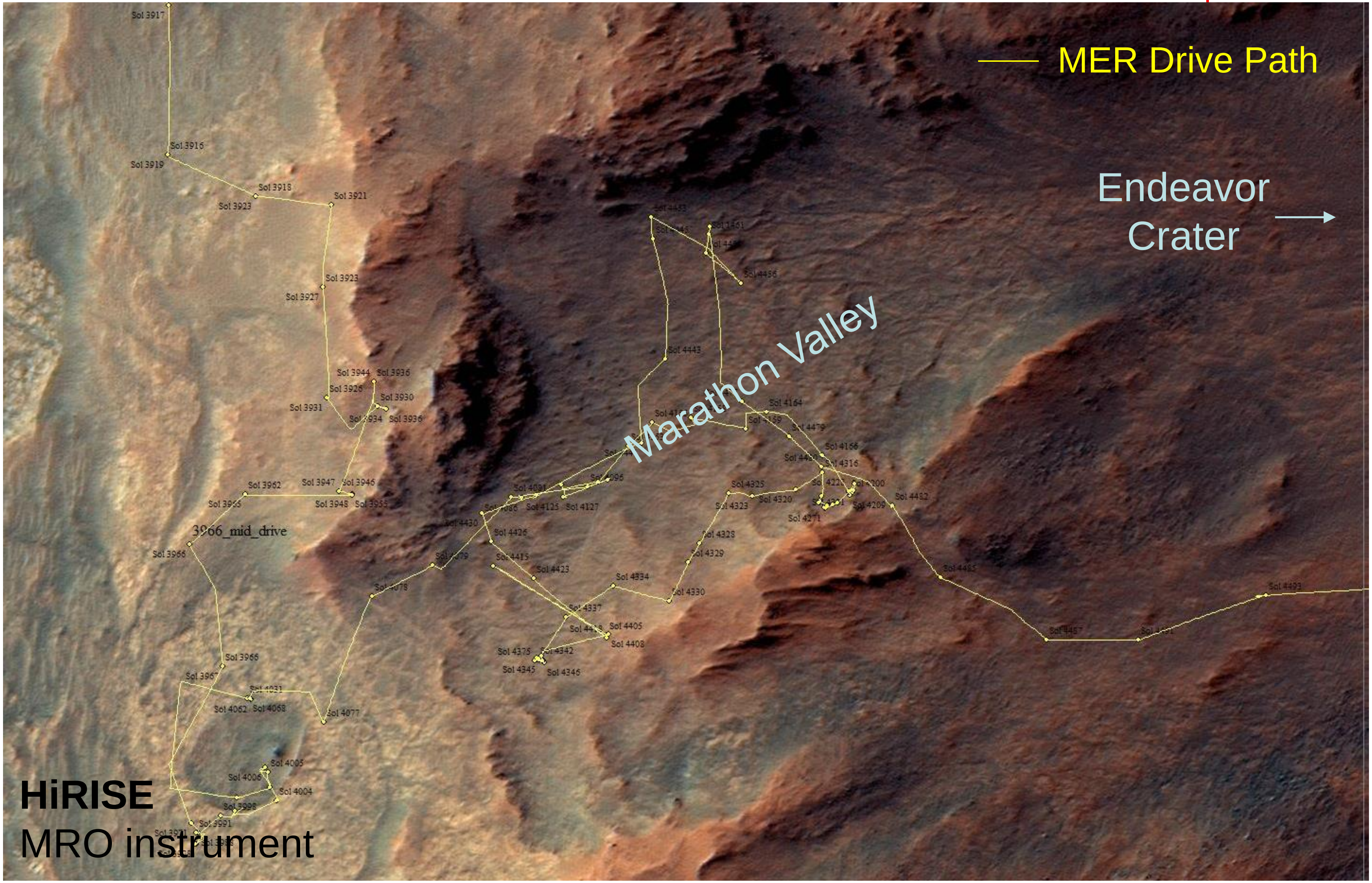
Mars Rover Communication



Motivation

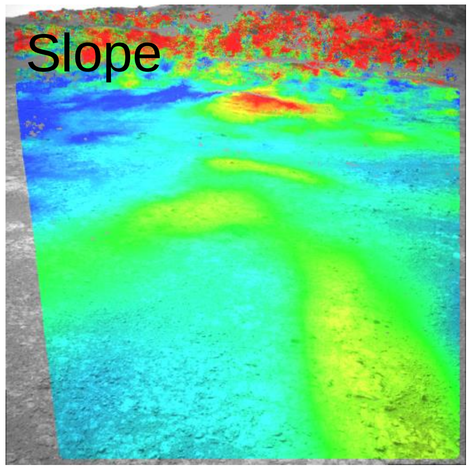
- Terrain occlusions have always been an issue with data volume transmission
- Due to aging rover hardware, MER no longer has Flash Memory and operates only using volatile memory (RAM)
- Data must be transmitted before rover shut downs, otherwise data is lost
- Downlink data volume predictions allow science team to anticipate how much data they can reasonably collect and receive
- Maximize the amount of science data return
- Especially important when planning critical observations before driving
  - If we do not accurately determine the amount of data that will be transmitted reliably to Earth, there is a risk we will lose that data and need to drive back to that location to re-capture those observations

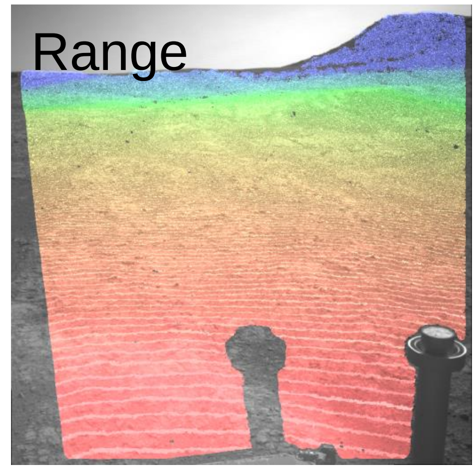
Driving in Marathon Valley

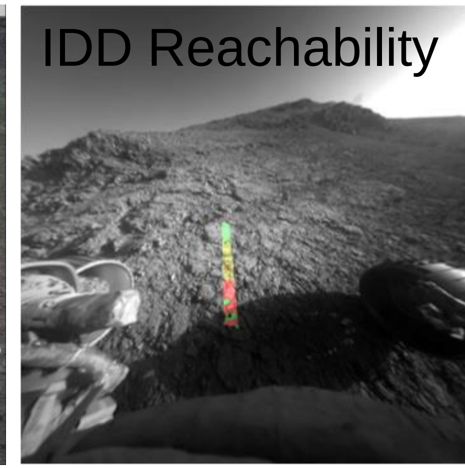


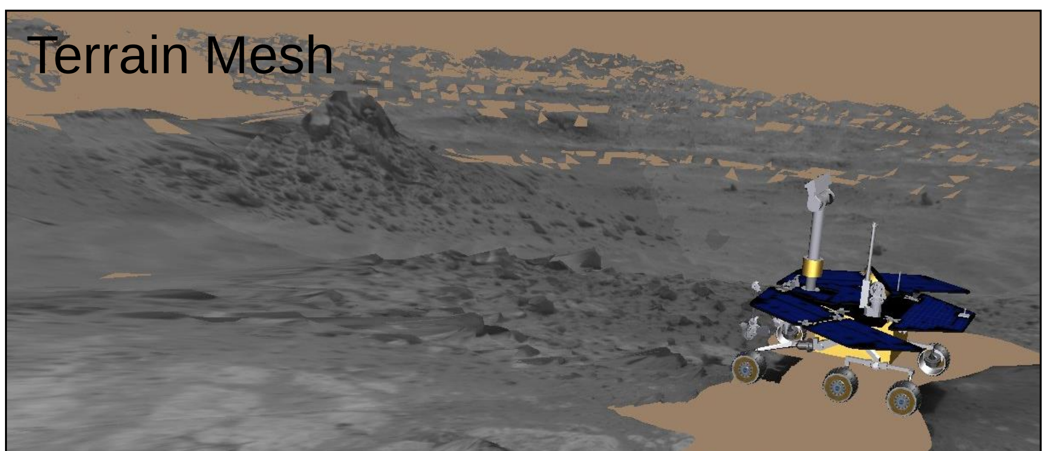
OPGS/MIPL

- OPGS: Operations Product Generation Subsystem
- MIPL: Multi-mission Image Processing Laboratory



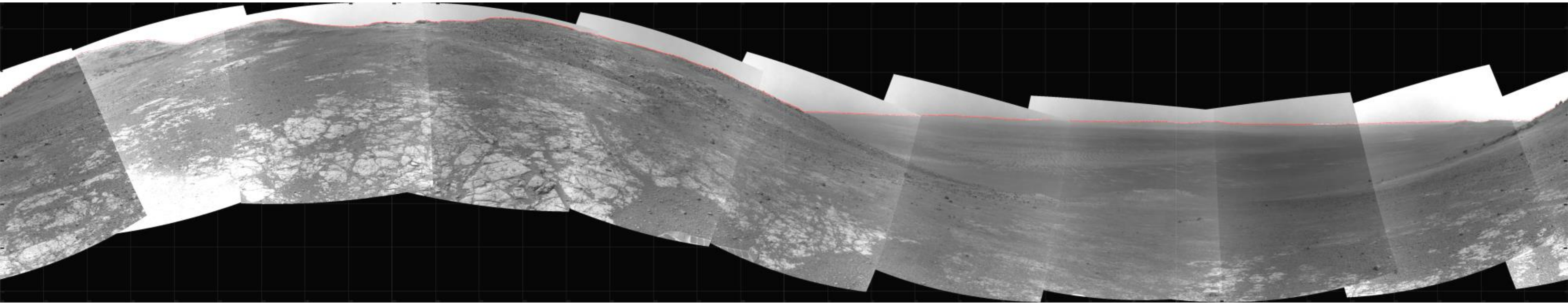


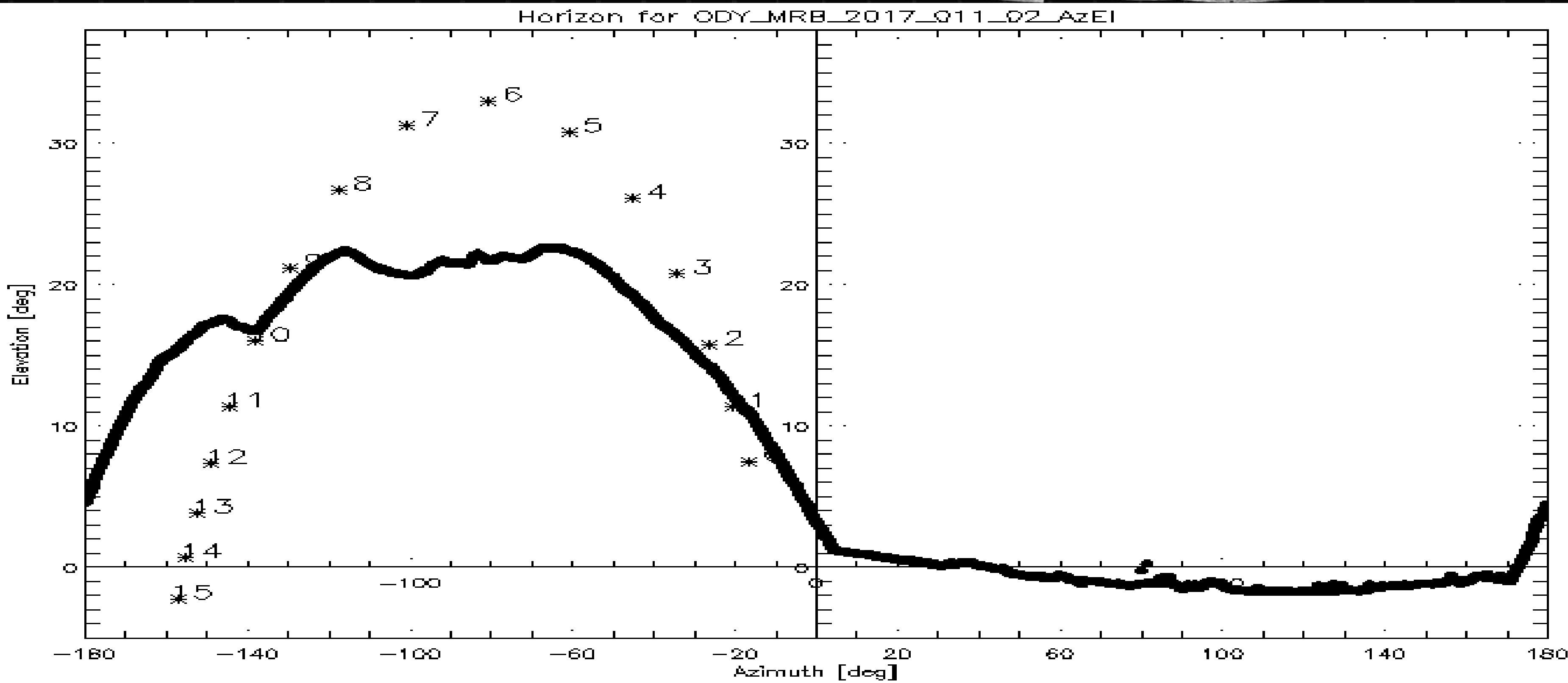




SOLUTION

Solution

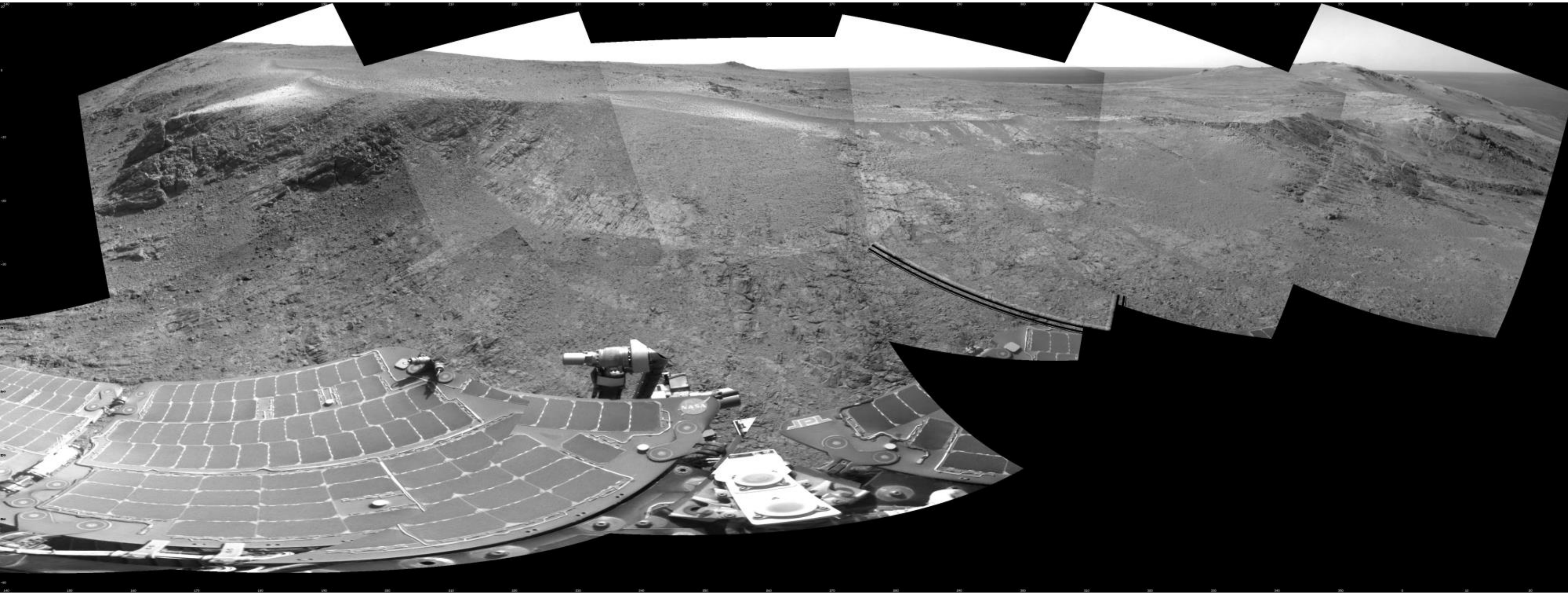



Horizon for ODY_MRB_2017_011_02_AzEl
Elevation [deg]
Azimuth [deg]
30
20
10
0
−180
−140
−100
−60
−20
20
60
100
140
180
0
2
3
4
5
6
7
8
11
12
13
14
15

CHALLENGES

Horizon Detection Challenges

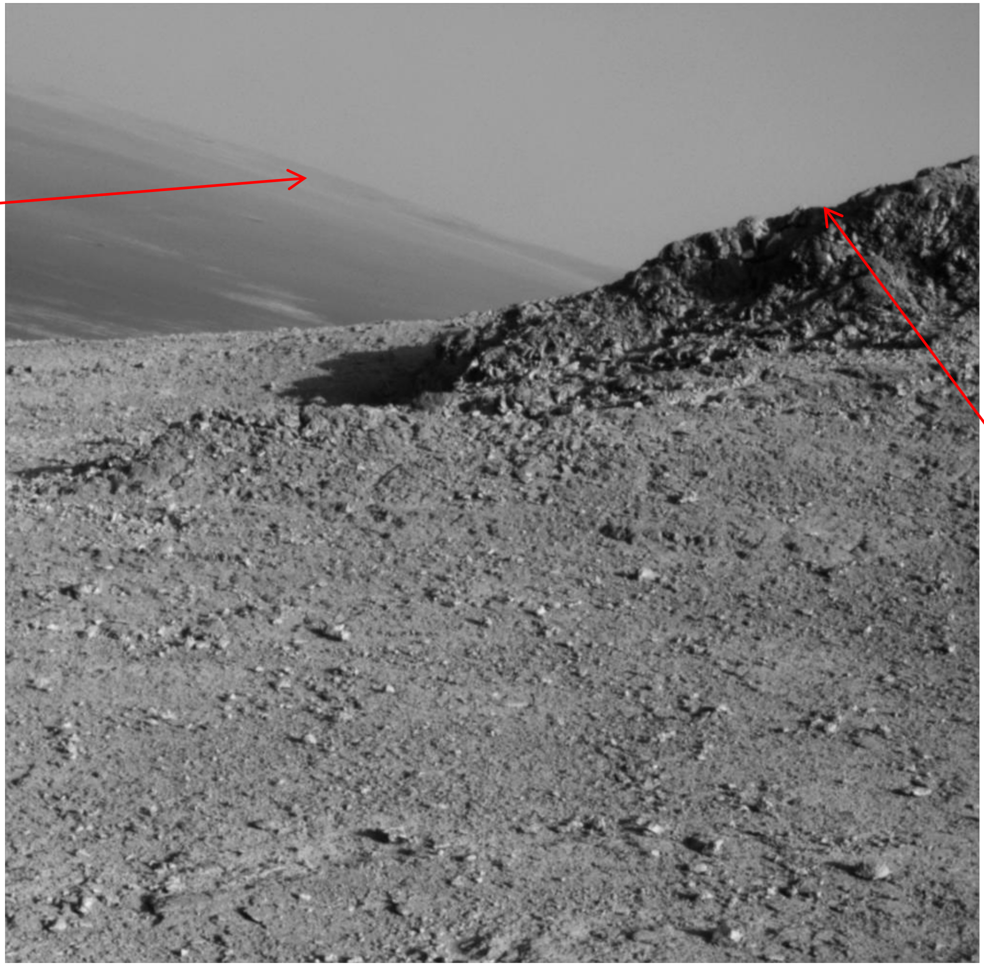
- Images contain vignetting effects
- Various image compressions
- Intensity levels of the sky can be similar to intensity levels of the terrain
- Images do not always contain horizon



MER Horizon Image

Weak Horizon

Visible horizon far from rover's position, where intensity levels of the sky are similar to the intensity levels of the terrain



Opportunity navigation camera image taken on sol 4096

Strong Horizon

Visible horizon close to rover's position, where intensity of the sky are much less than the terrain

METHOD

Horizon Detection Solution

Step 1: Reduce Noise

Step 2: Compute gradient images

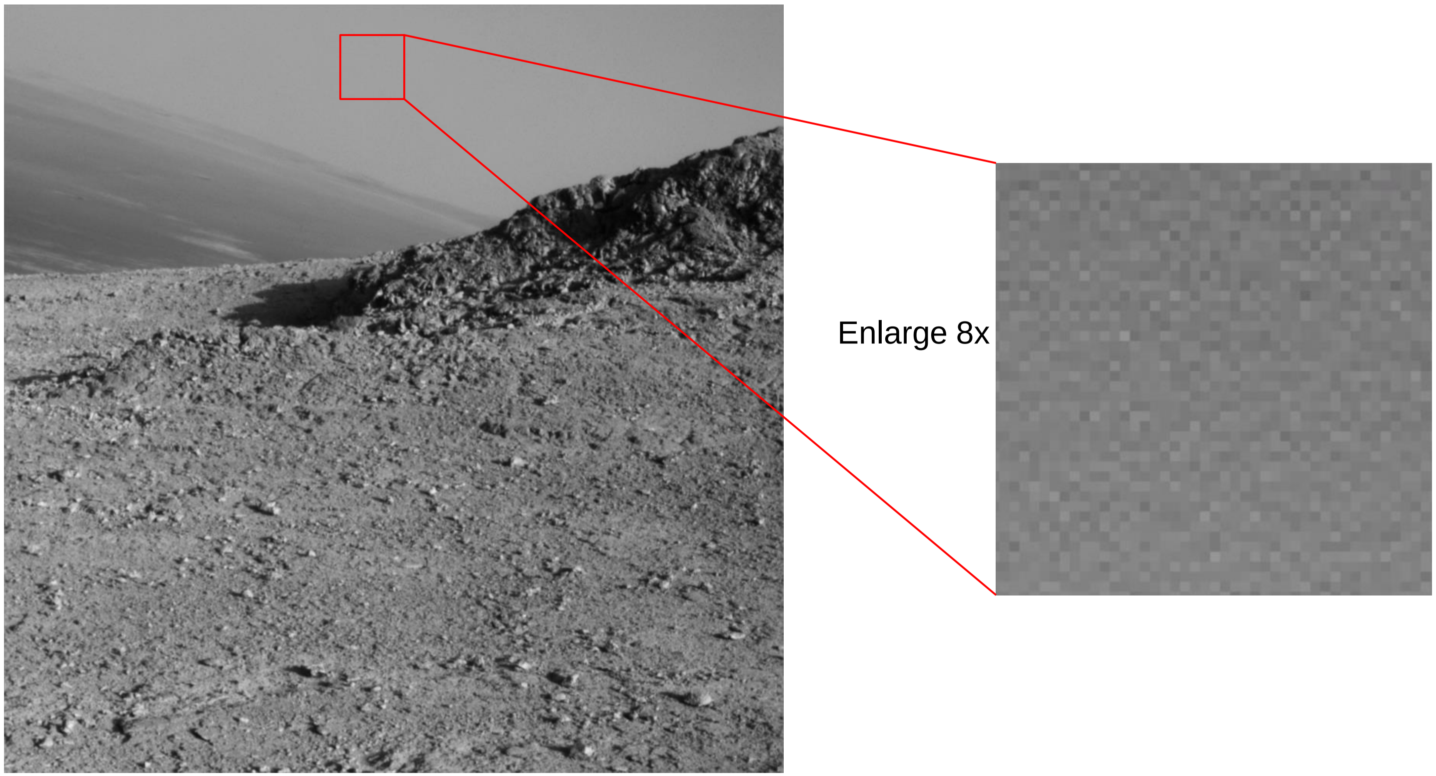
Step 3: Detect strong horizon

Step 4: Detect outliers and weak horizon

Step 5: Remove outliers

Step 1: Reduce Noise

- Apply median filter to blend noise
- Kernel size of median filter can be adjusted by the user



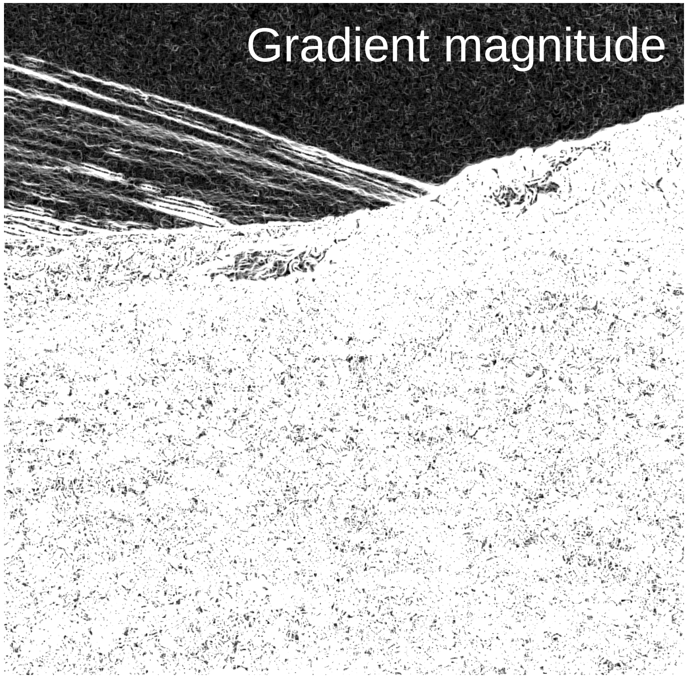
Step 2: Compute Gradient Images

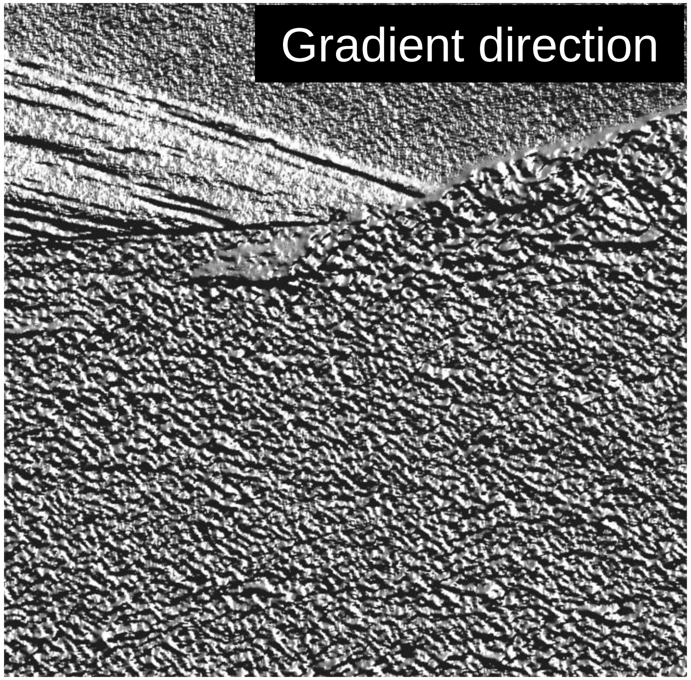
Horizontal gradient: $G_x = SobelHorizontalKernel \otimes Images$

Vertical gradient: $G_y = SobelVerticalKernel \otimes Images$

Gradient magnitude: $Gradient_{magnitude} = \sqrt{{G_x}^2 + {G_y}^2}$

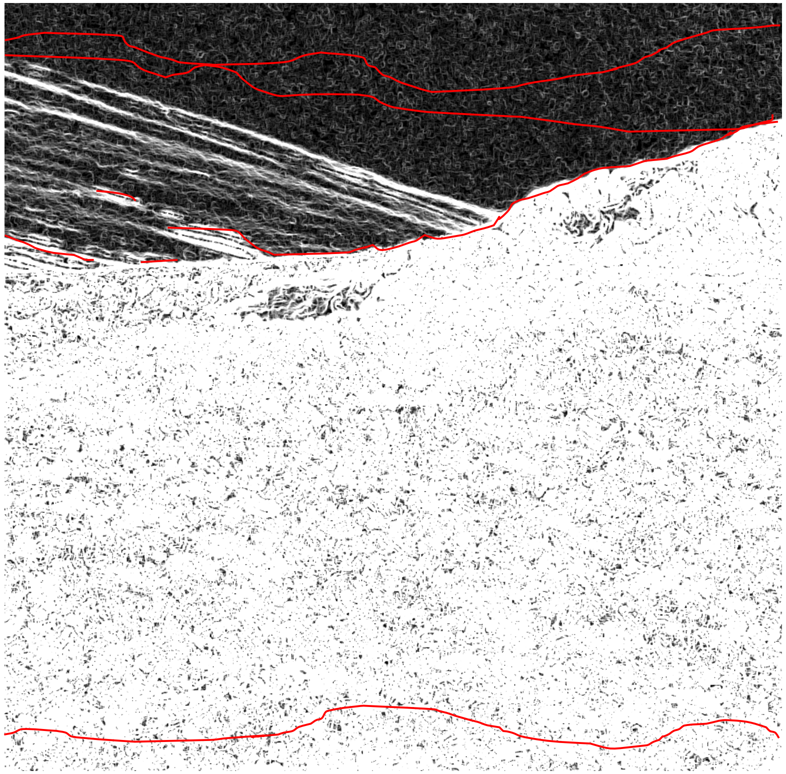
Gradient direction: $Gradient_{directional} = \tan^{-1}\frac{G_y}{G_x}$



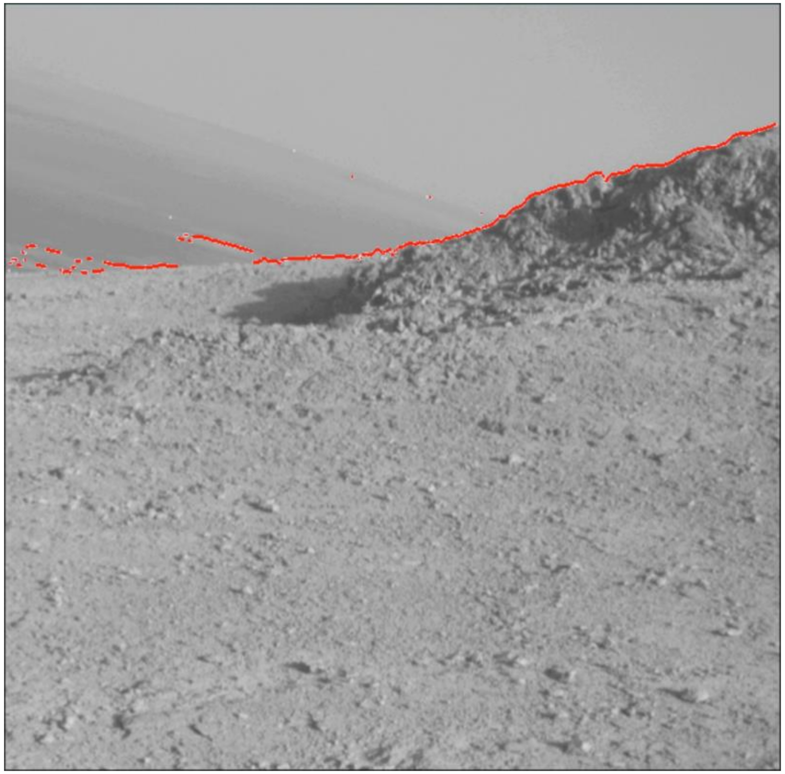


Step 3: Detect Strong Horizon

- Find maximum difference between sky and ground region in gradient magnitude image



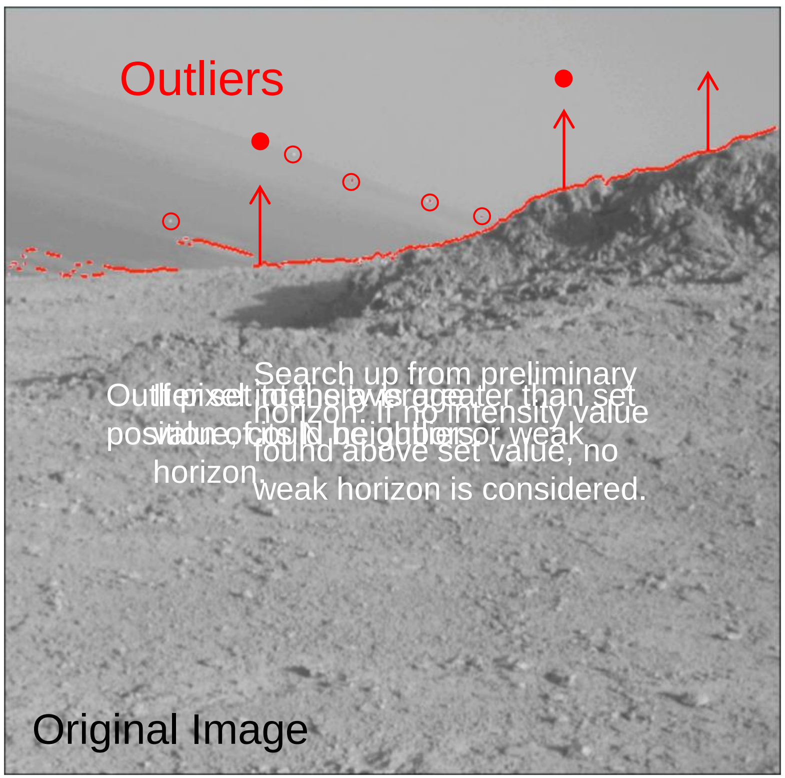
Gradient Magnitude Image

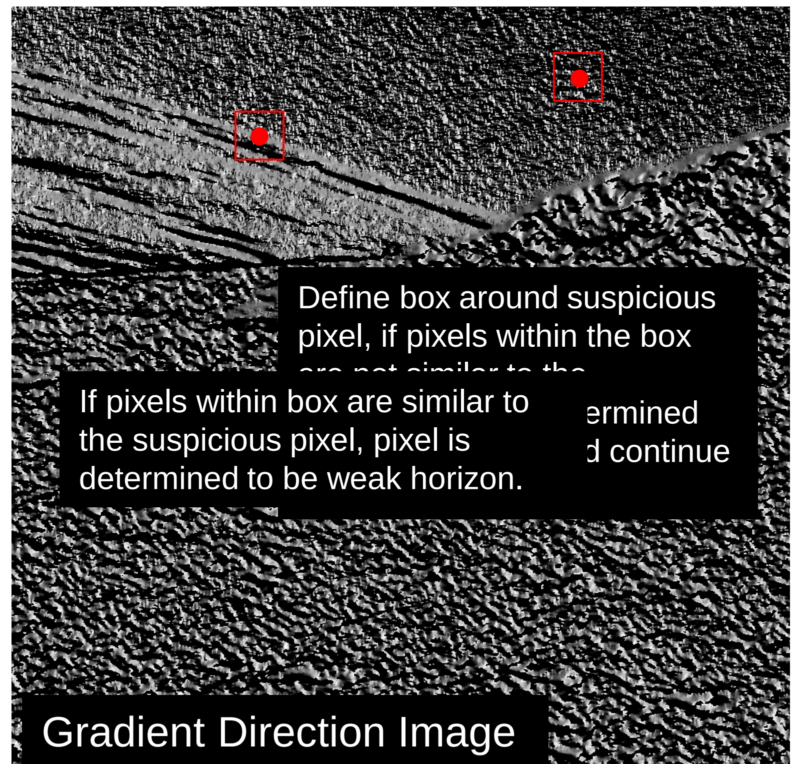


Original Image

Step 4: Detect Outliers and Weak Horizon

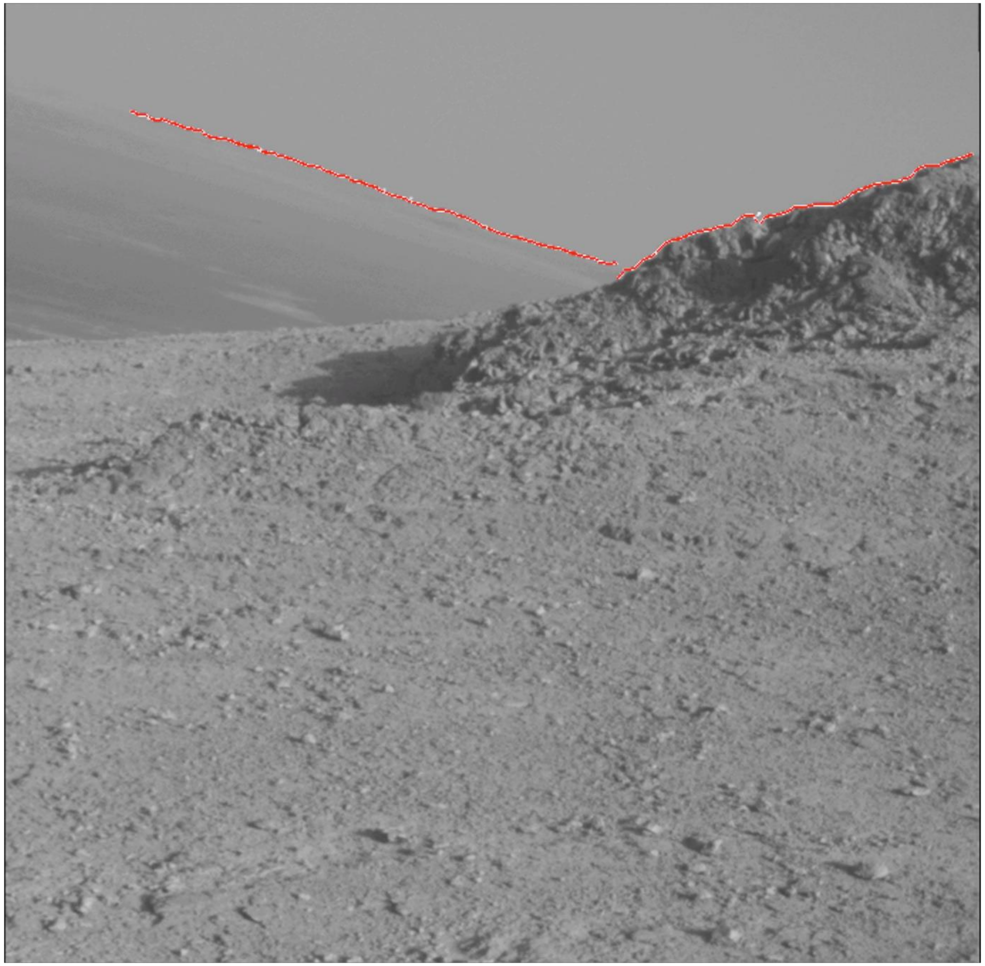
- Apply filter to set outliers' position to the position of its neighbors
- In each column of preliminary horizon profile, search upwards to find weak horizon
  - Often preliminary horizon profile contains outliers and false horizon
- Repeat until there is no outlier or weak horizon found, or exceeds maximum iterations (defined by user)





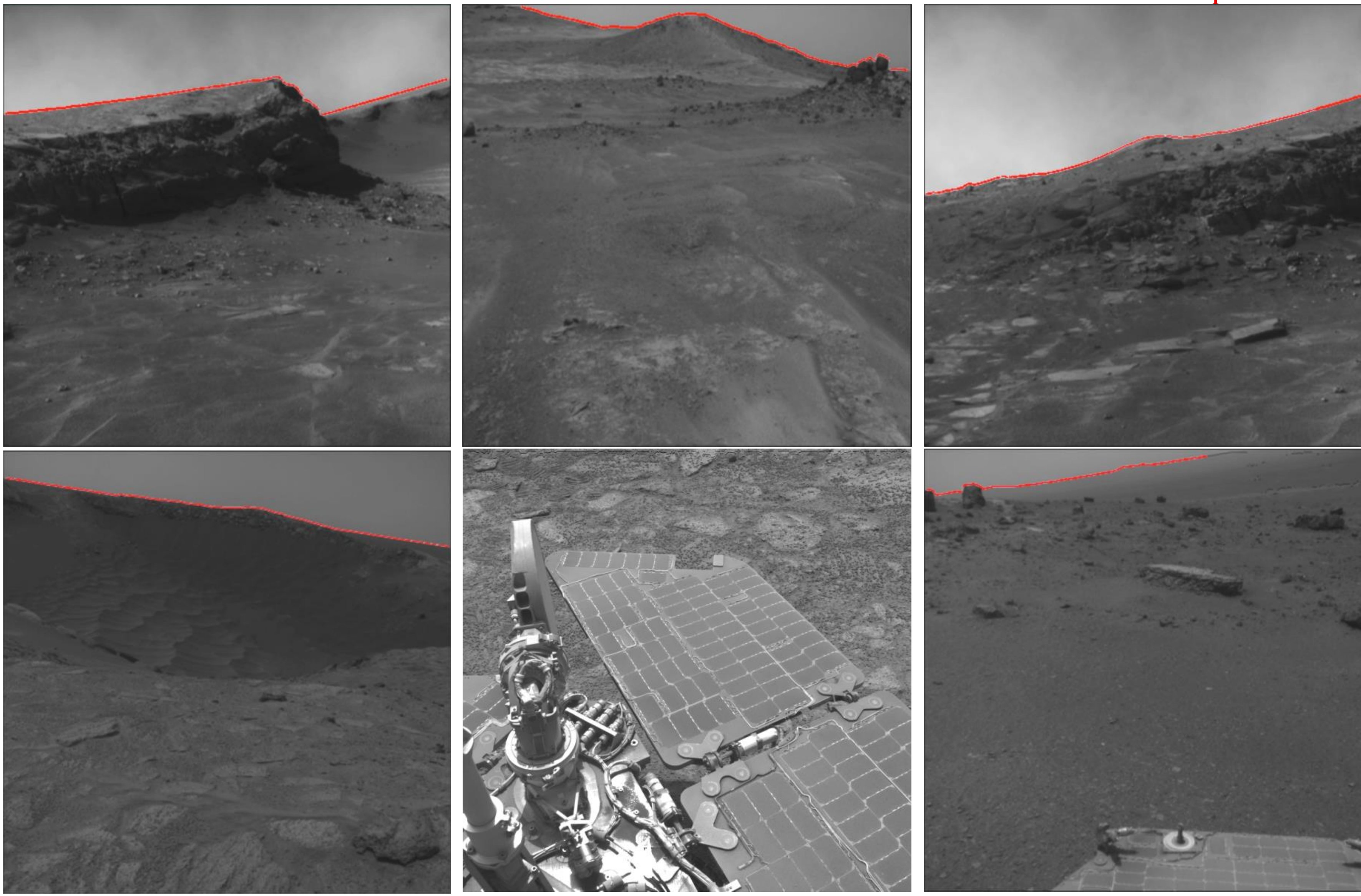
Step 5: Remove Outliers

- Remove outliers detected in previous step that were not determined as weak horizon

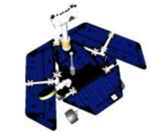


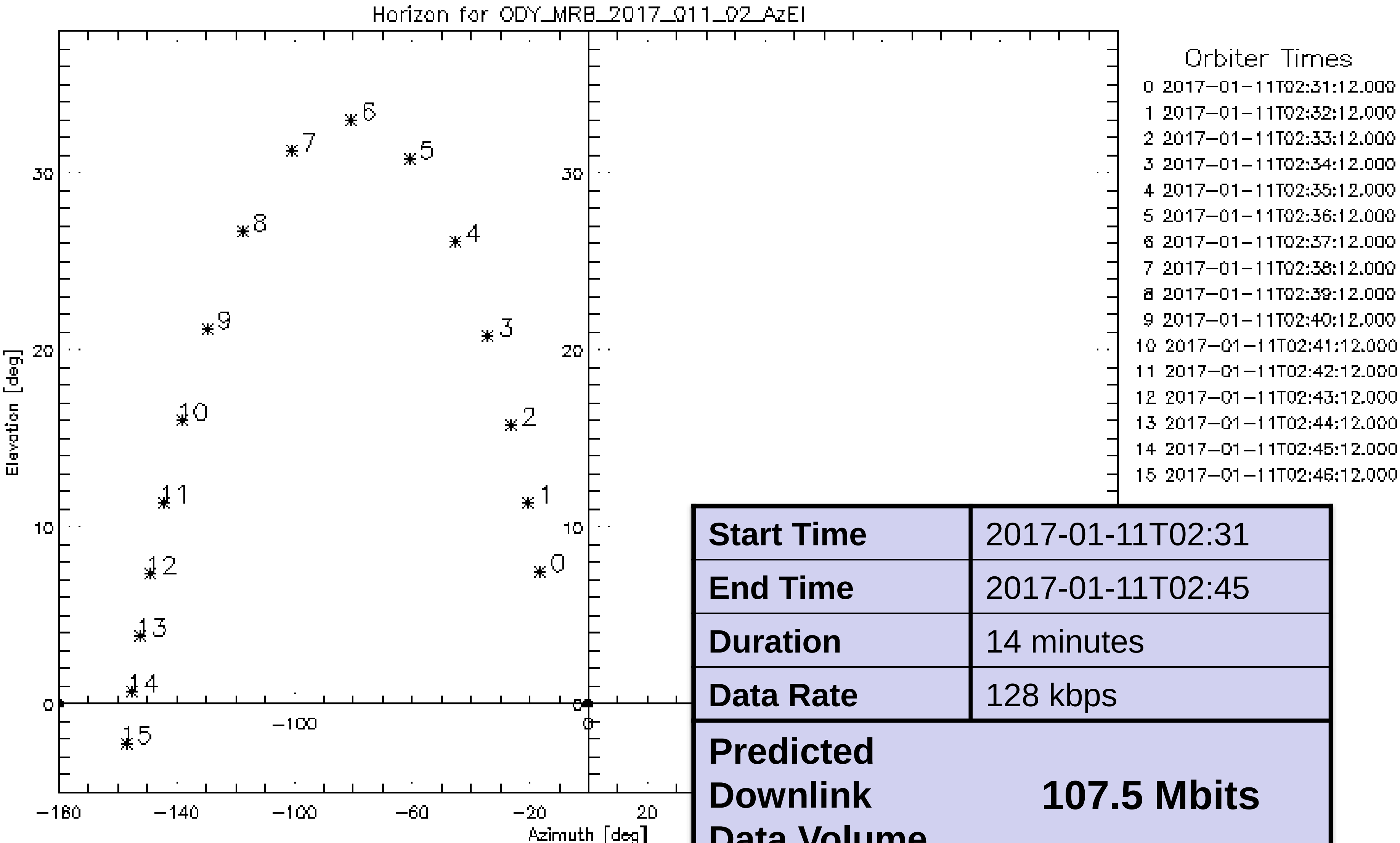
RESULTS

Results



Downlink Predictions without Horizon Detection





Start Time	2017-01-11T02:31
End Time	2017-01-11T02:45
Duration	14 minutes
Data Rate	128 kbps
Predicted Downlink Data Volume	**107.5 Mbits**

Downlink Predictions with Horizon Detection

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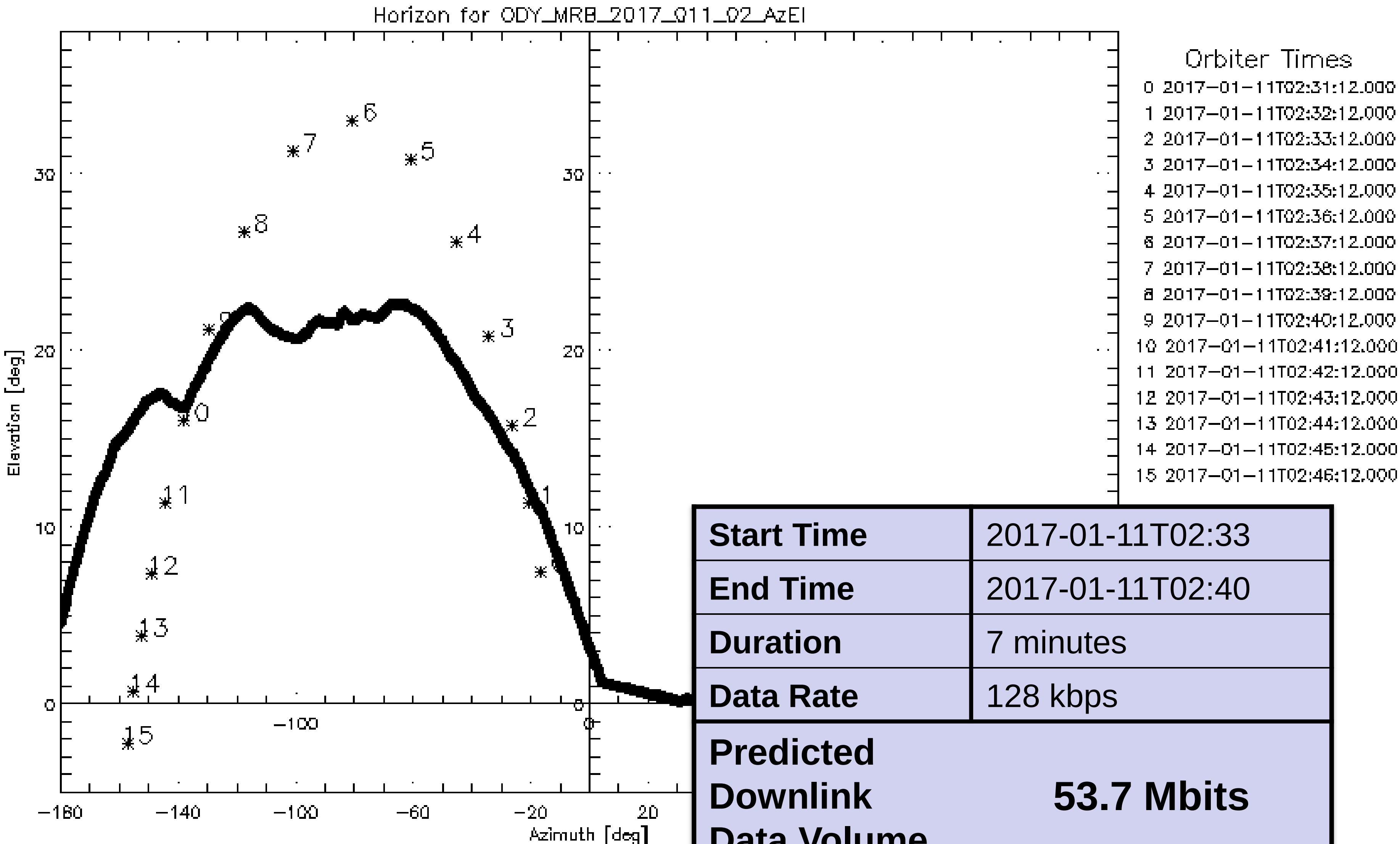
Mars Exploration Rover



Start Time	2017-01-11T02:33
End Time	2017-01-11T02:40
Duration	7 minutes
Data Rate	128 kbps
Predicted Downlink Data Volume	**53.7 Mbits**

CONCLUSIONS

Advantages and Disadvantages

- Advantages
  - More accurately predict downlink data volumes
  - Parameters can be adjusted to work for variety of images

- Disadvantages
  - Cannot be 100% automated because default parameters do not always accurately find horizon and parameters may need to be adjusted
  - Driving will adjust the rover’s visible horizon and images used for horizon detection only exist at our current or previous positions

Current and Future Applications

- Current Applications
  - Downlink data volume predications for MER
  - Use horizon detection to find when the rover is in direct sunlight to generate power predictions for MER
  - In development for downlink data volume predictions on MSL

- Future Applications
  - Rover on-board horizon detection for downlink data volume predictions
  - Mask out sky region to reduce computational complexity in generating data products

Conclusions

- With horizon detection, the Opportunity team can more accurately plan the amount of data volume that can be collected each plan

- Horizon detection has reduced the amount of data captured and subsequently lost due to inaccurate downlink data volume predictions and RAM memory mode operations

Sol 4332 Navcam

Acknowledgements

- Amy Chen
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- Zareh Gorjian
- Stirling Algermissen
- Mike Seibert
- Benjamin Mellman
- Padma Varanasi

Questions & Answers

BACKUP SLIDES

MER Mission

- Twin rovers: Spirit and Opportunity
- Mission Goal – each rover to drive up to 40 meters in a single day, for a total of 1 kilometer.
- Spirit
  - Launched on June 10, 2003
  - Landed on Mars Gusev Crater on January 3, 2004
  - Mission ended on May 25, 2011
- Opportunity
  - Launched July 7, 2003
  - Landed on Mars Meridiani Planum on January 24, 2004
  - Still ongoing into our 10^{th} extended mission
- Each rover carries the same numbers of engineering and science instruments
  - Engineering instruments: Front and Rear Hazard Avoidance Cameras, Navigation Cameras
  - Science instruments: Panoramic Cameras (Pancam); Miniature Thermal Emission Spectrometer (Mini-TES); Mossbauaer Spectrometer (MB); Alpha Particle X-Ray Spectrometer (APXS); Magnets; Microscopic Imager (MI); Rock Abrasion Tool (RAT)

Science Objectives

The scientific objectives of the Mars Exploration Rover mission are to:

•Search for and characterize a variety of rocks and soils that hold clues to past water activity. In particular, samples sought will include those that have minerals deposited by water-related processes such as precipitation, evaporation, sedimentary cementation, or hydrothermal activity.

•Determine the distribution and composition of minerals, rocks, and soils surrounding the landing sites.

•Determine what geologic processes have shaped the local terrain and influenced the chemistry. Such processes could include water or wind erosion, sedimentation, hydrothermal mechanisms, volcanism, and cratering.

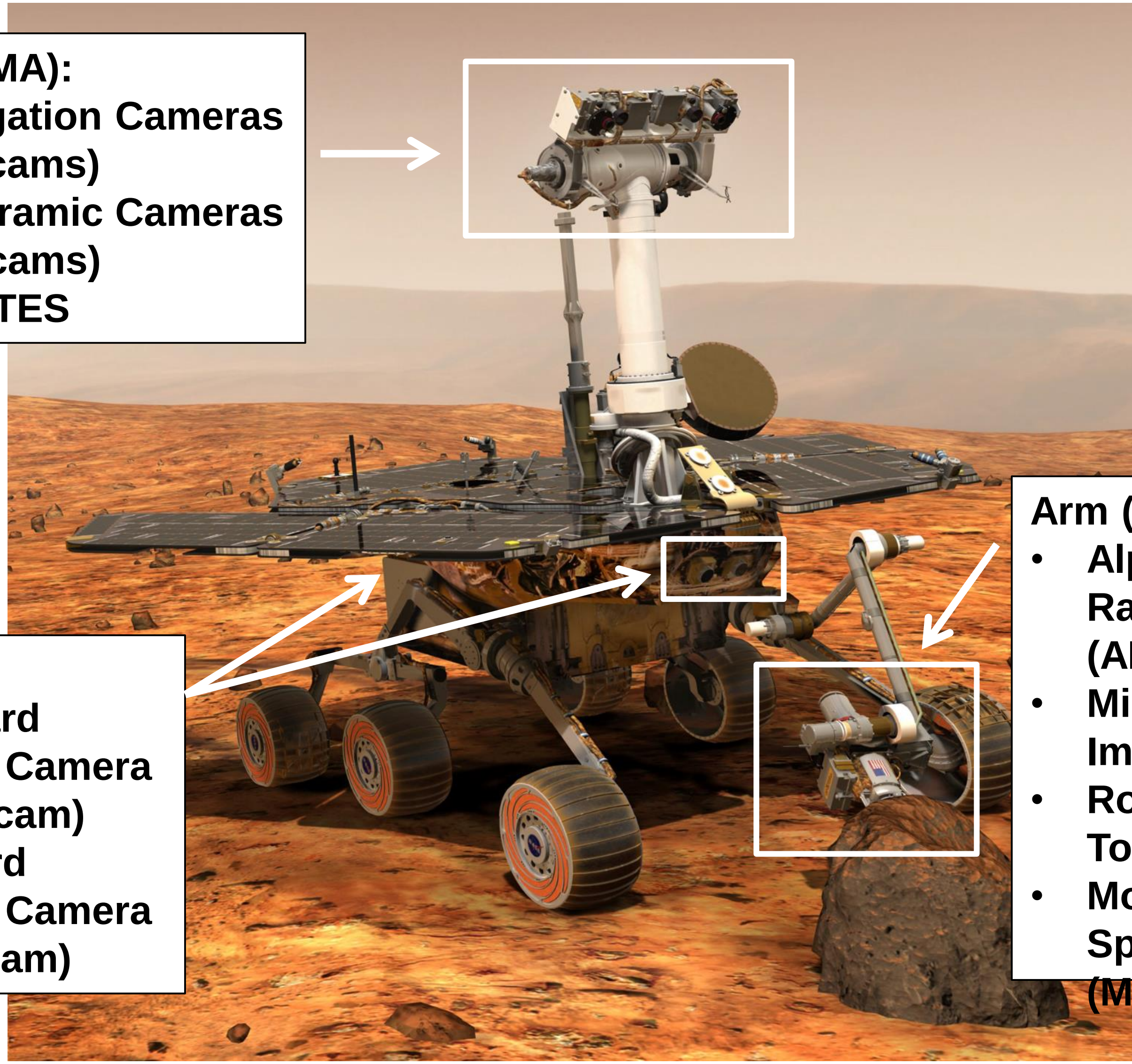
•Perform "ground truth" -- calibration and validation -- of surface observations made by Mars orbiter instruments. This will help determine the accuracy and effectiveness of various instruments that survey Martian geology from orbit.

•Search for iron-containing minerals, identify and quantify relative amounts of specific mineral types that contain water or were formed in water, such as iron-bearing carbonates.

•Characterize the mineralogy and textures of rocks and soils and determine the processes that created them.

•Search for geological clues to the environmental conditions that existed when liquid water was present. Assess whether those environments were conducive to life.

MER Instruments

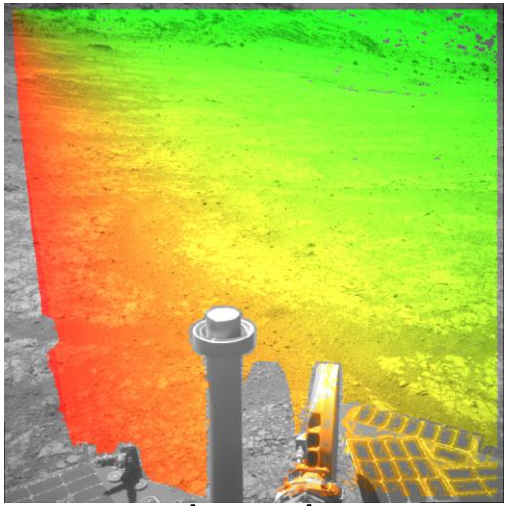


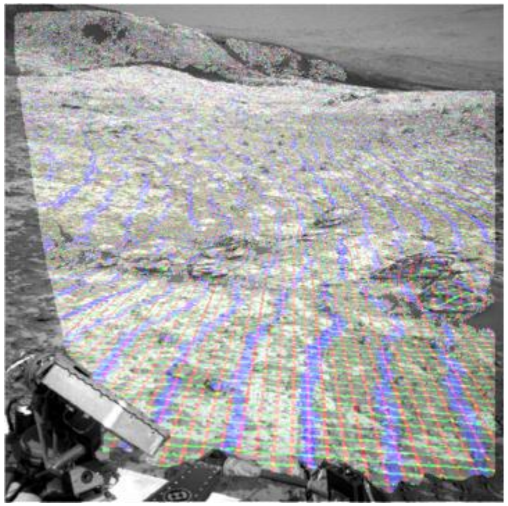
Mast (PMA):
- Navigation Cameras (Navcams)
- Panoramic Cameras (Pancams)
- Mini-TES

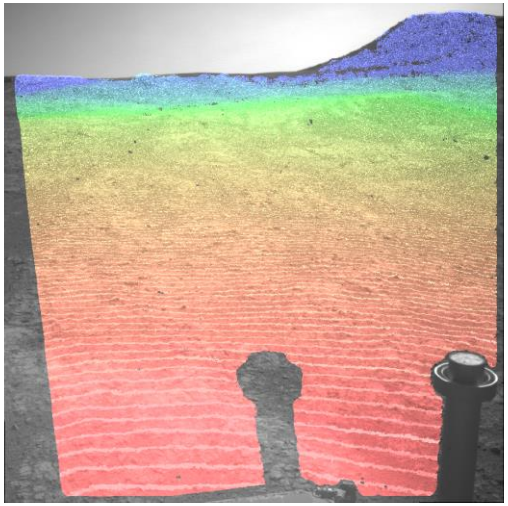
Body:
- Front Hazard Avoidance Camera (Front Hazcam)
- Rear Hazard Avoidance Camera (Rear Hazcam)

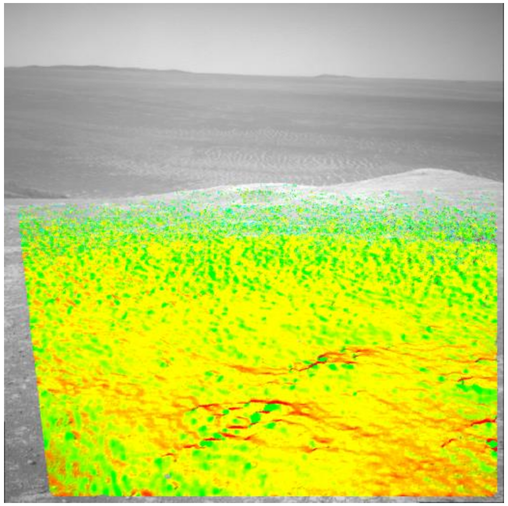
Arm (IDD):
- Alpha Particle X-Ray Spectrometer (APXS)
- Microscopic Imager (MI)
- Rock Abrasion Tool (RAT)
- Mossbauer Spectrometer (MB)

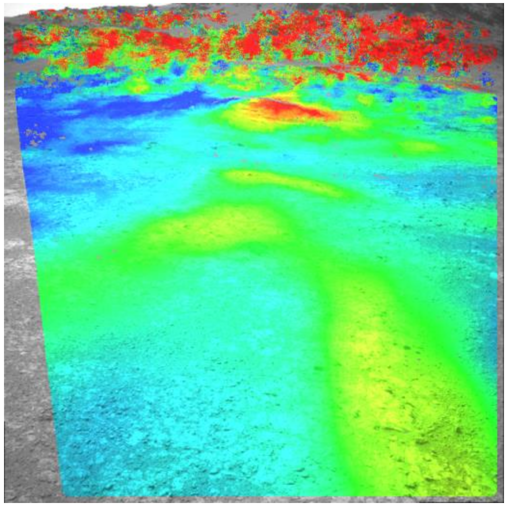
RDR Products

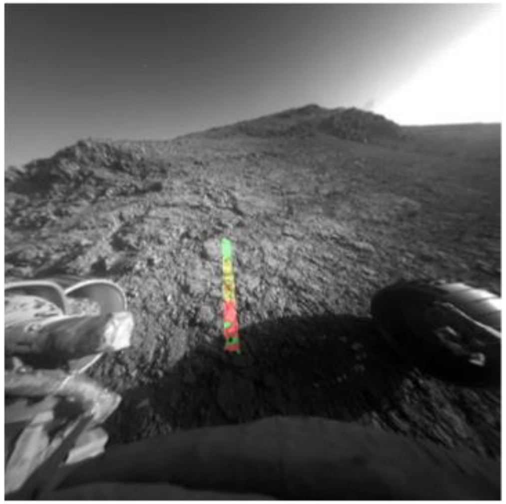

Disparity


XYZ

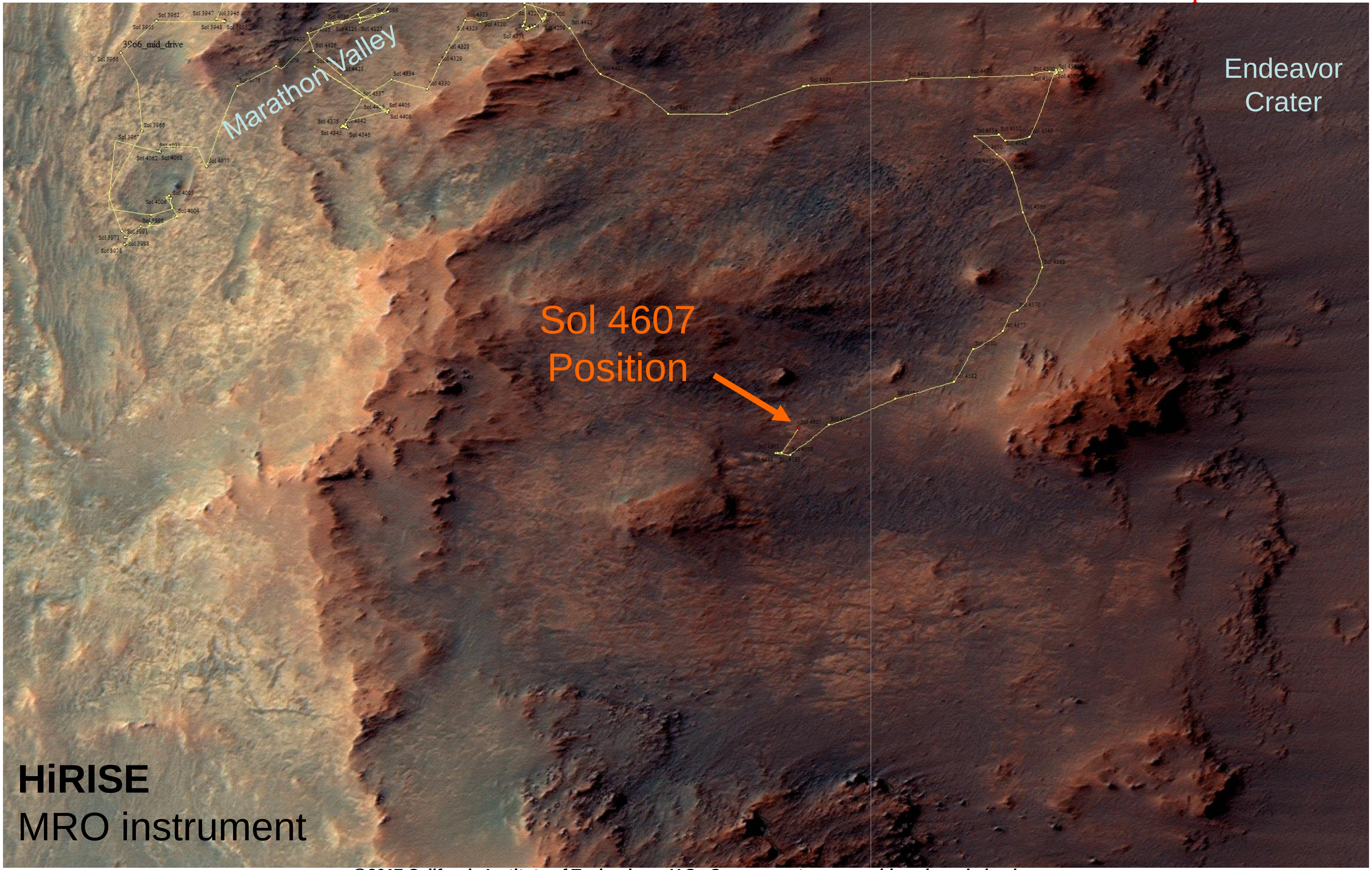

Range


Surface Normal


Slope


IDD Reachability

Solution


Marathon Valley
Endeavor Crater
Sol 4607 Position
HiRISE
MRO instrument

References

- 3D Vision Processing for the MER and MSL Mars Rover Missions. Bob Deen.
- MER MIPL Products as Used by Rover Planners. Hallie Gengl.
- MER Operations Support Multi-Instrument Processing Laboratory. Doug Alexander and Bob Deen.