Extreme Mapping:

Looking for water on the moon

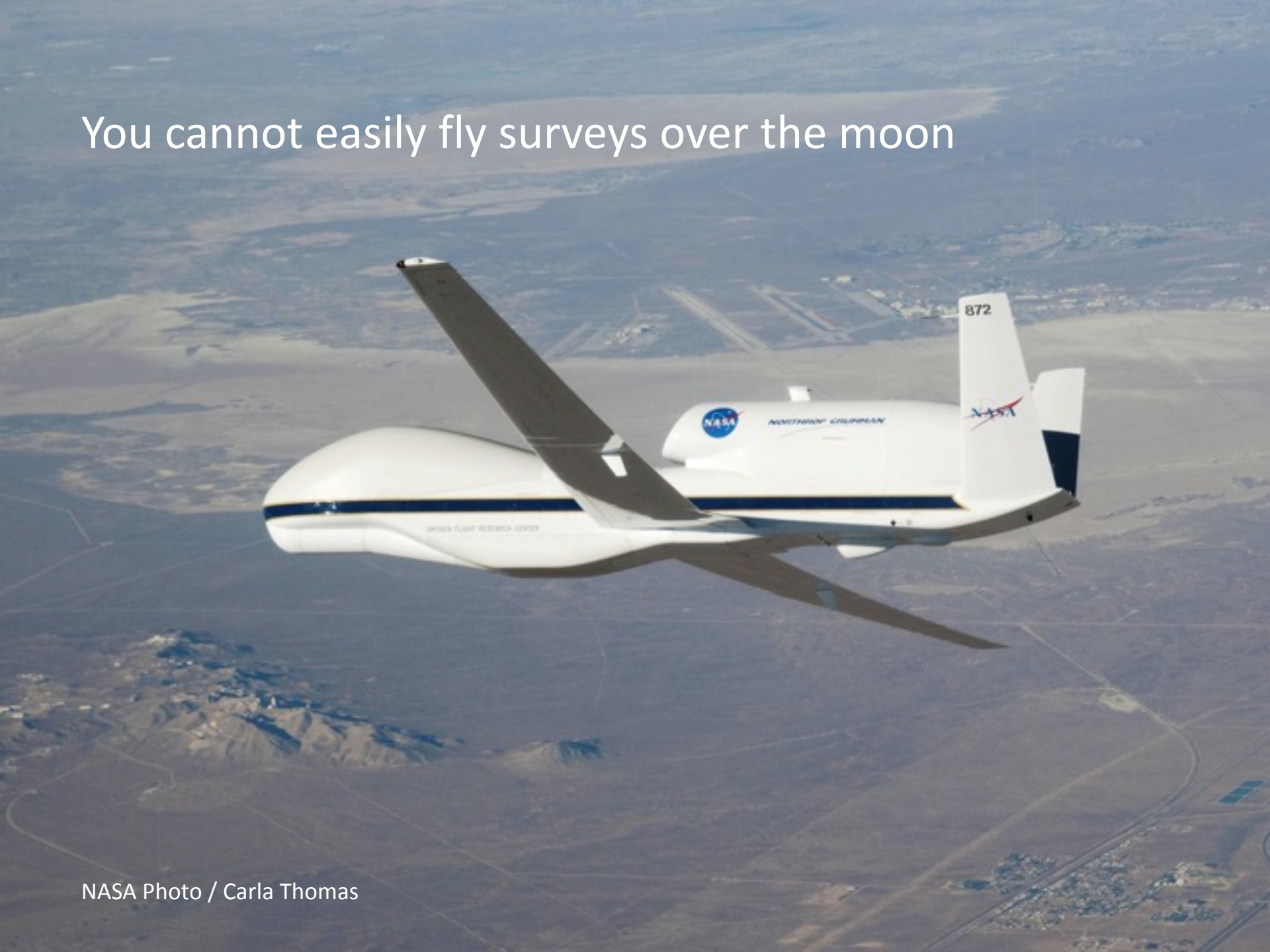
Tamar Cohen

SGT, Inc.
Intelligent Robotics Group
NASA Ames Research Center

What are the exploration challenges we face?

NASA / Bill Anders / Apollo 8

You cannot easily fly surveys over the moon



NASA Photo / Carla Thomas


Scientists prefer to go into the field.
Dr. Darlene Lim sampling basalt
Hawaii Volcanoes National Park
Photo by NASA / Kara Beaton


It is not often we have astronauts on Extra-Vehicular Activity (EVA)
Apollo 12 astronaut Charles Conrad Jr.

Why should we look for water on the moon?

NASA / Bill Anders / Apollo 8

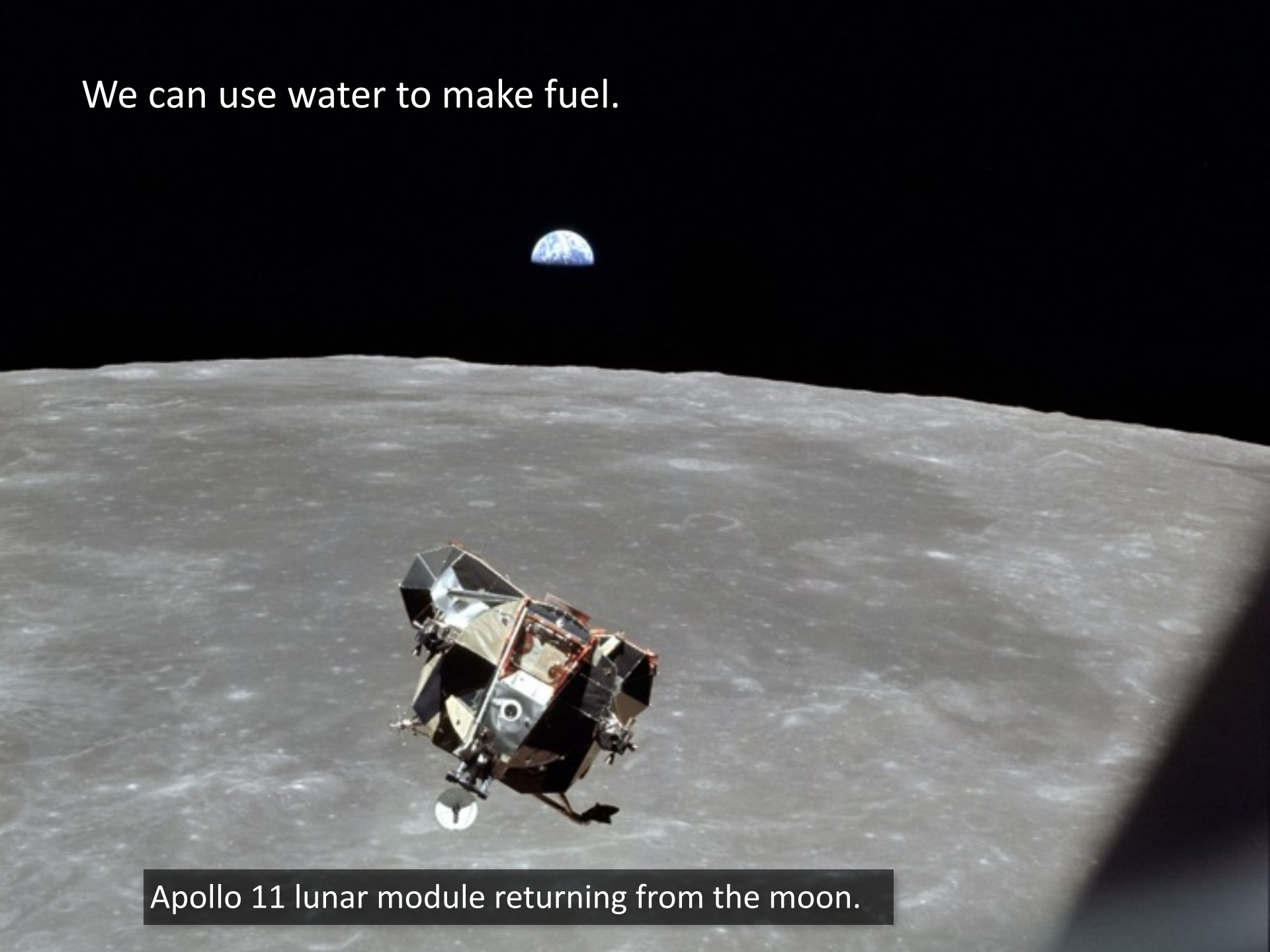

Human space exploration
People need to drink almost 2 liters of water per day
NASA Photo / Tracy Caldwell Dyson

Today it costs $450 to launch one kg.

Photo: Pat Corkery
United Launch Alliance


Yes, we recycle urine on the ISS
Water Recovery System

We can use water to make fuel.



Apollo 11 lunar module returning from the moon.

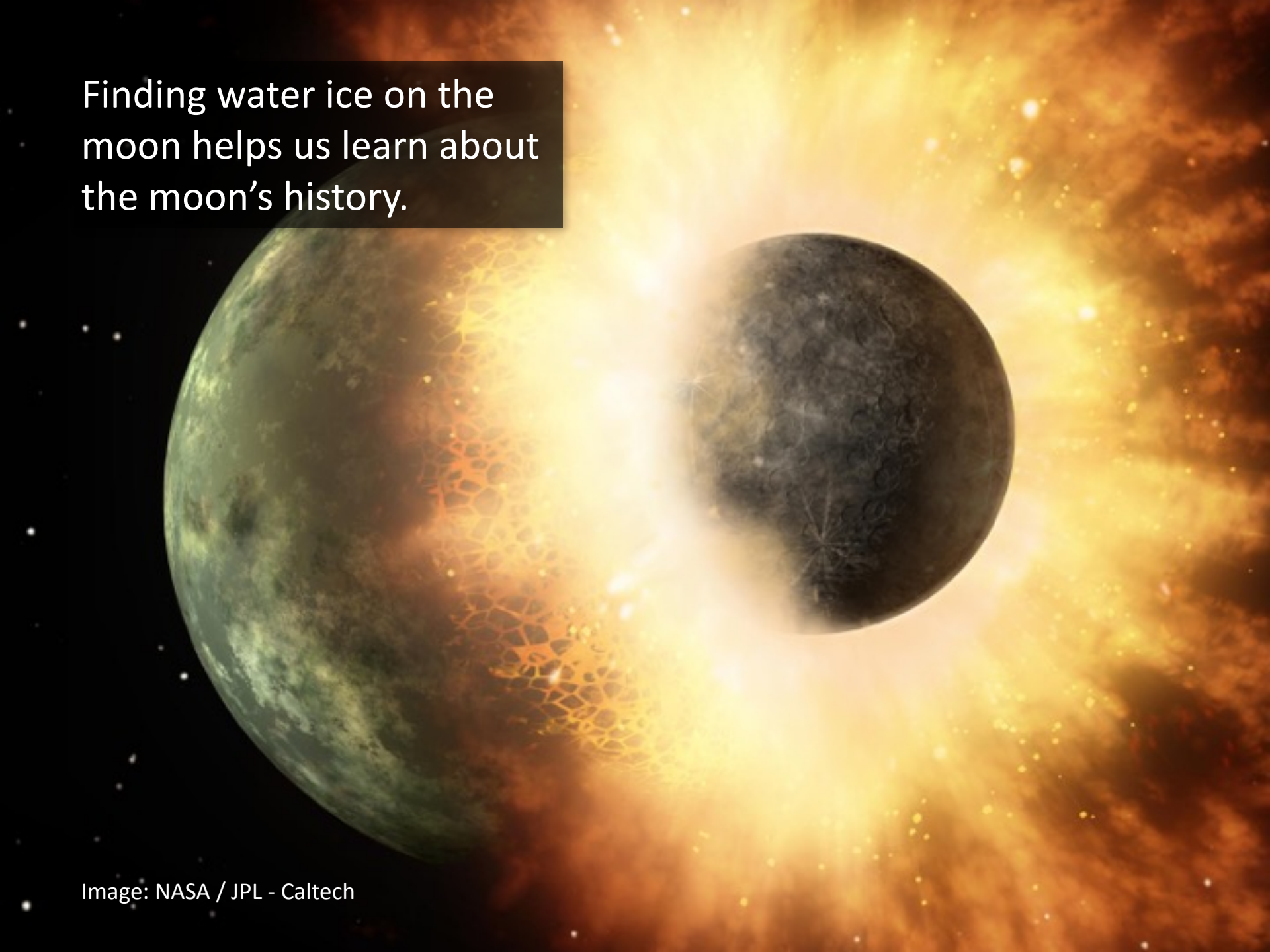


Image: NASA / JPL - Caltech

What do we already know?

NASA / Bill Anders / Apollo 8

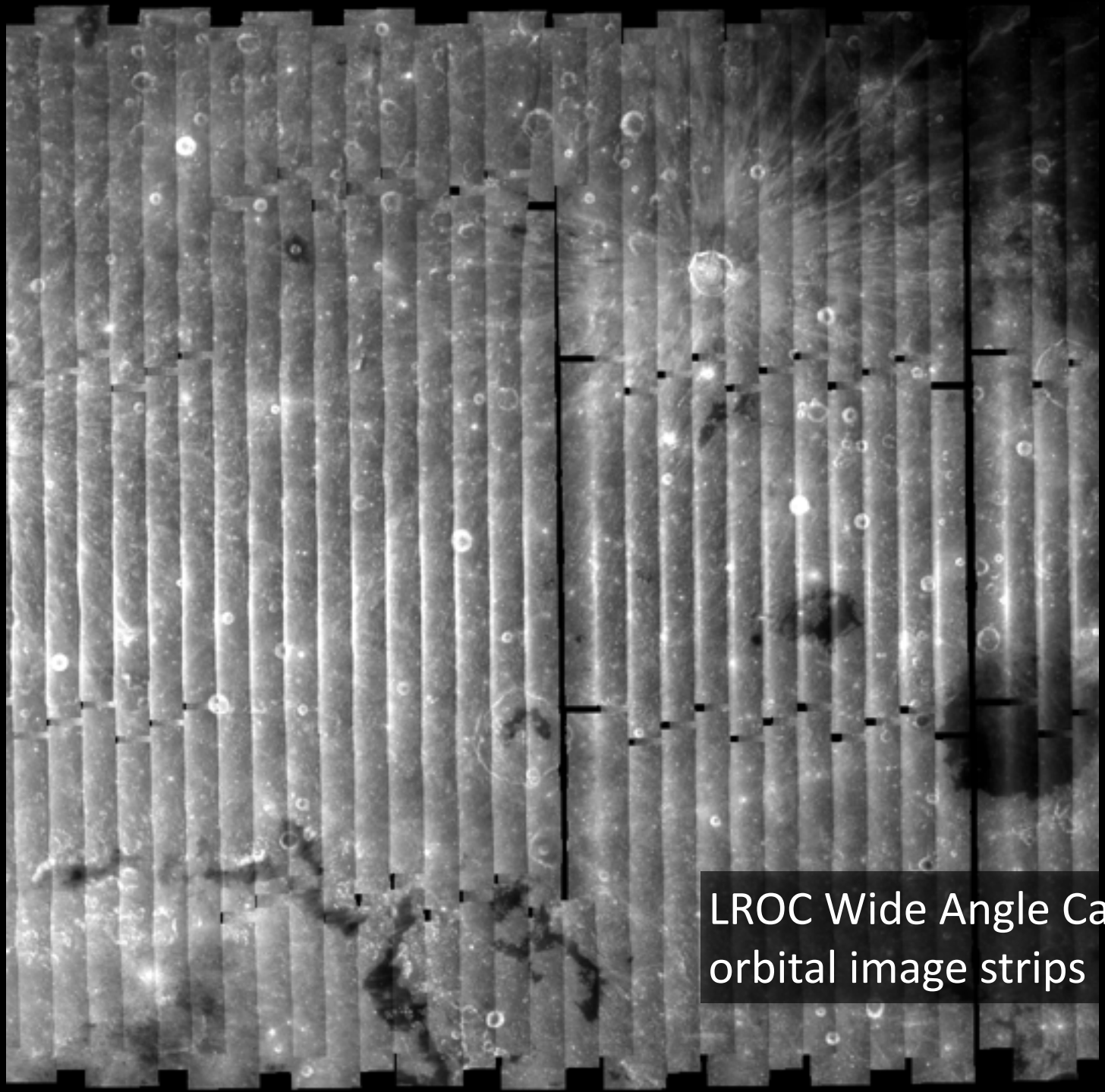
Moon facts:

384,400 km (238,900 mi)
from Earth

Temperatures from
123 °C (253 °F) to
-233 °C (-387 °F)

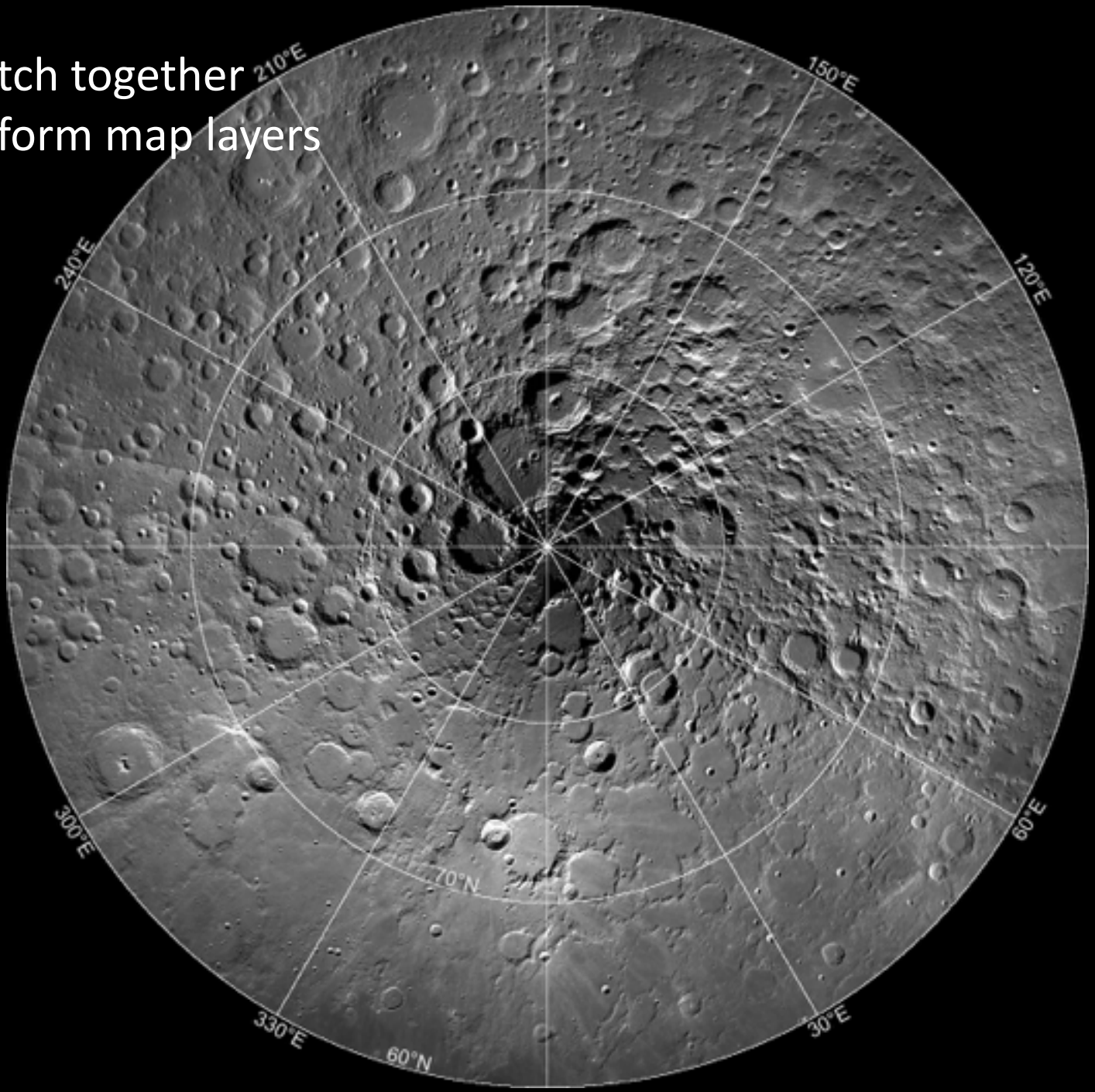
The same side of the moon is
always facing the earth.


Lunar Reconnaissance Orbiter (LRO)
gathers high resolution maps and data
NASA / Chris Meaney 2008

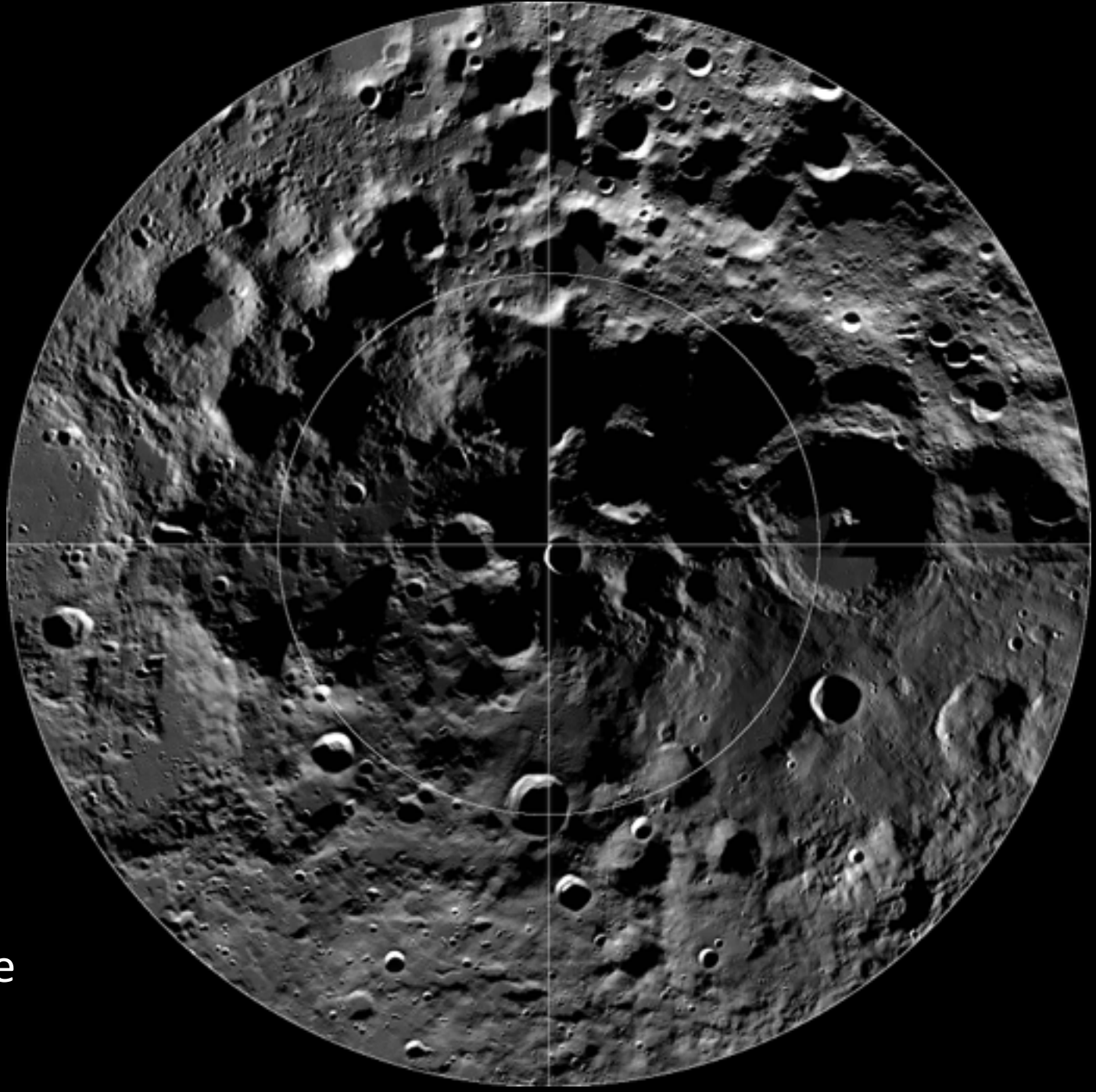

LROC Wide Angle Camera
orbital image strips

Nearside reflectance map
built of mosaic strips

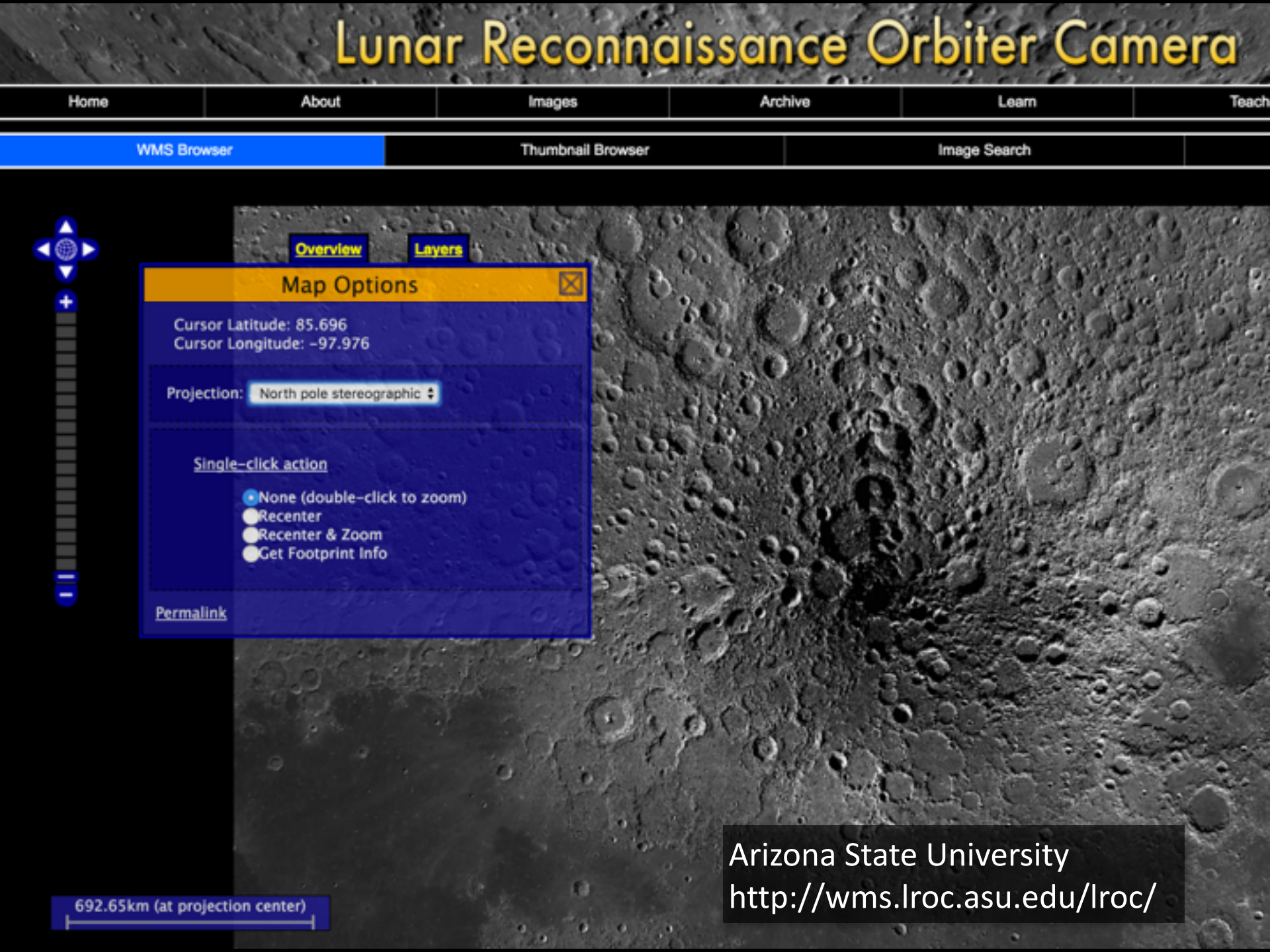
We can stitch together images to form map layers



Lunar
North Pole



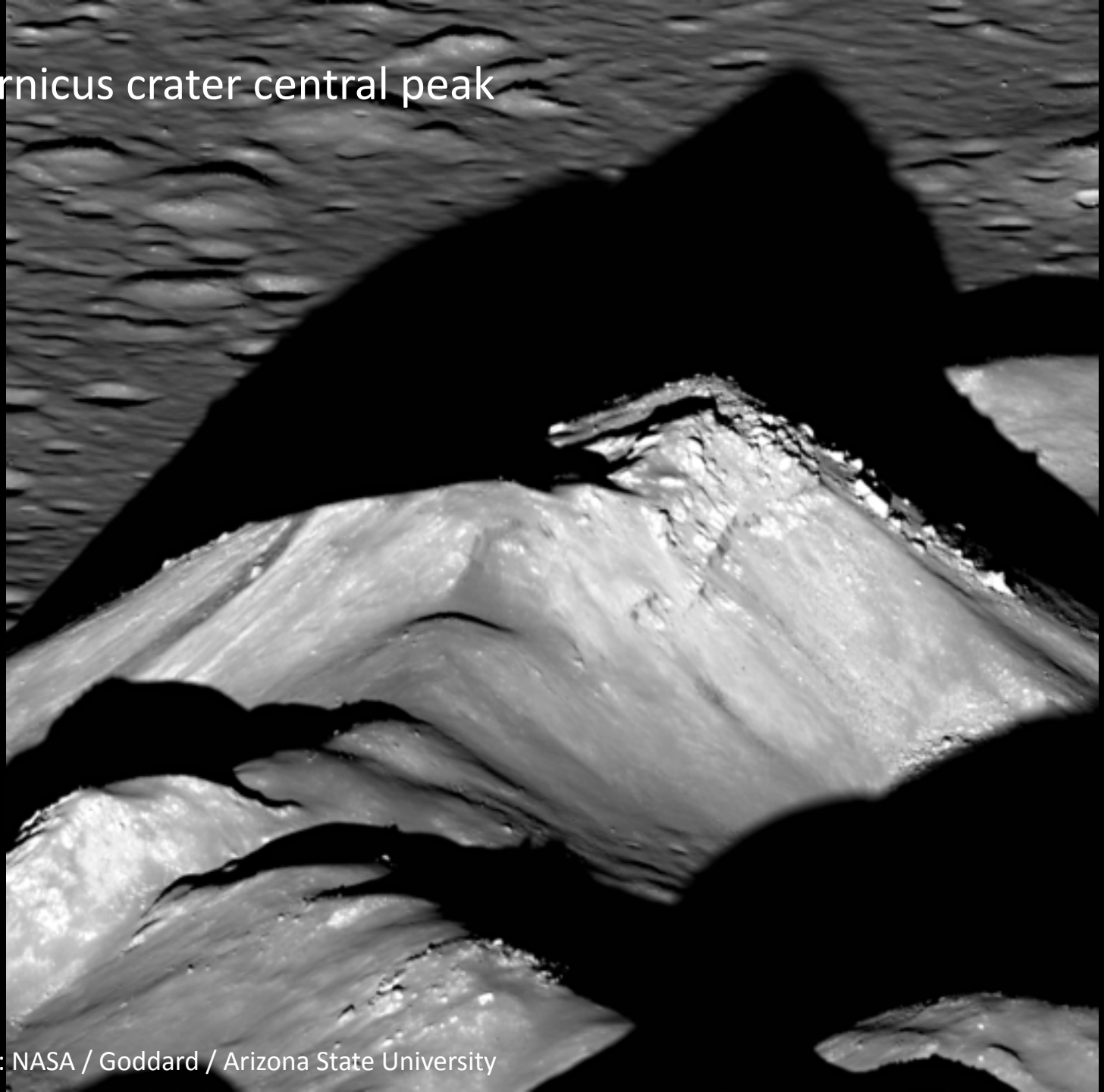
Lunar
South Pole


Lunar Reconnaissance Orbiter Camera
Home
About
Images
Archive
Learn
Teach
WMS Browser
Thumbnail Browser
Image Search
Overview
Layers
Map Options
Cursor Latitude: 85.696
Cursor Longitude: -97.976
Projection:
North pole stereographic
Single-click action
None (double-click to zoom)
Recenter
Recenter & Zoom
Get Footprint Info
Permalink
692.65km (at projection center)
Arizona State University
http://wms.lroc.asu.edu/lroc/

Floor and eastern wall of Antoniadi crater

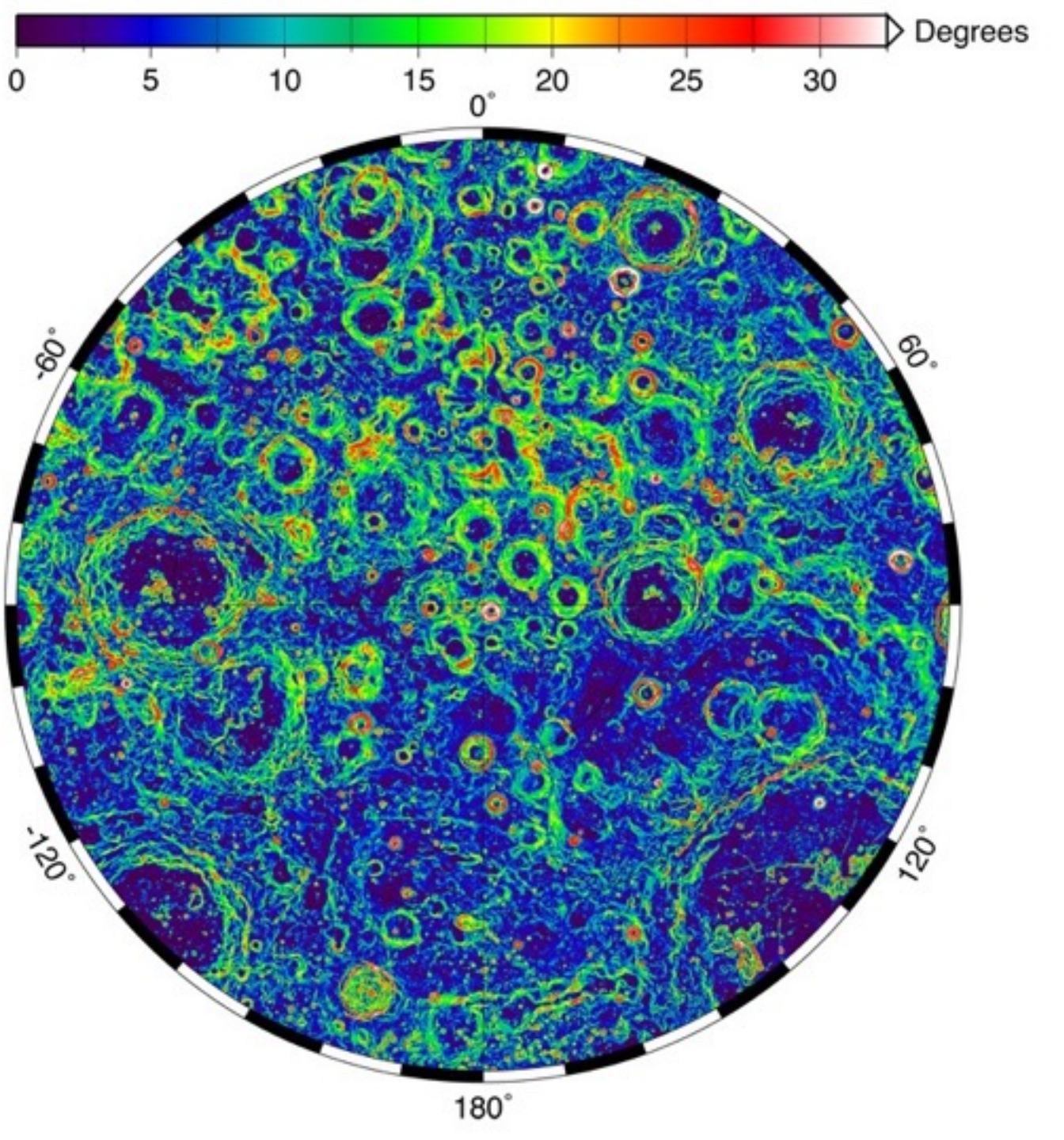
LRO Image: NASA / Goddard / Arizona State University

Copernicus crater central peak

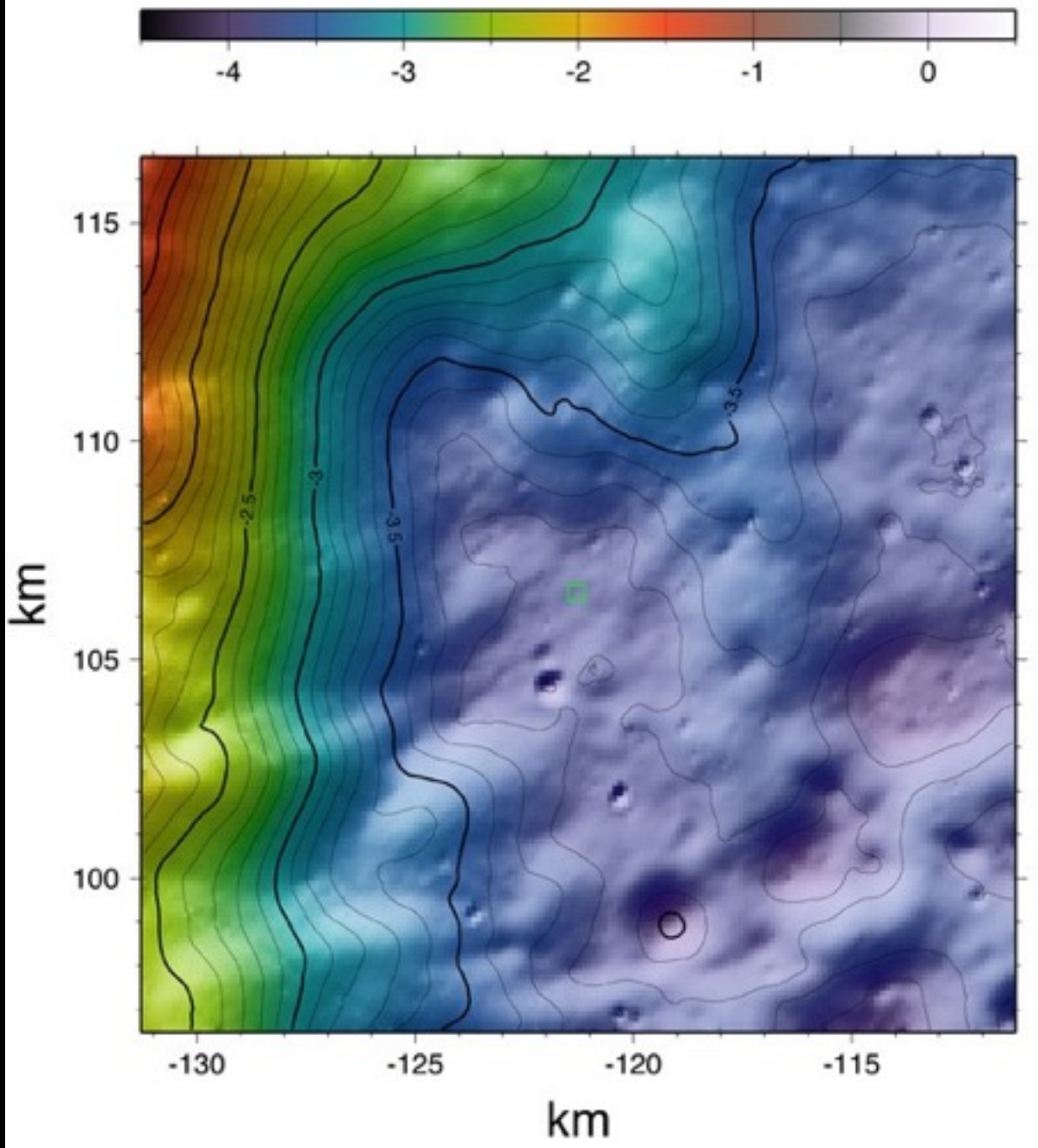


LRO Image: NASA / Goddard / Arizona State University

Slope map from LOLA

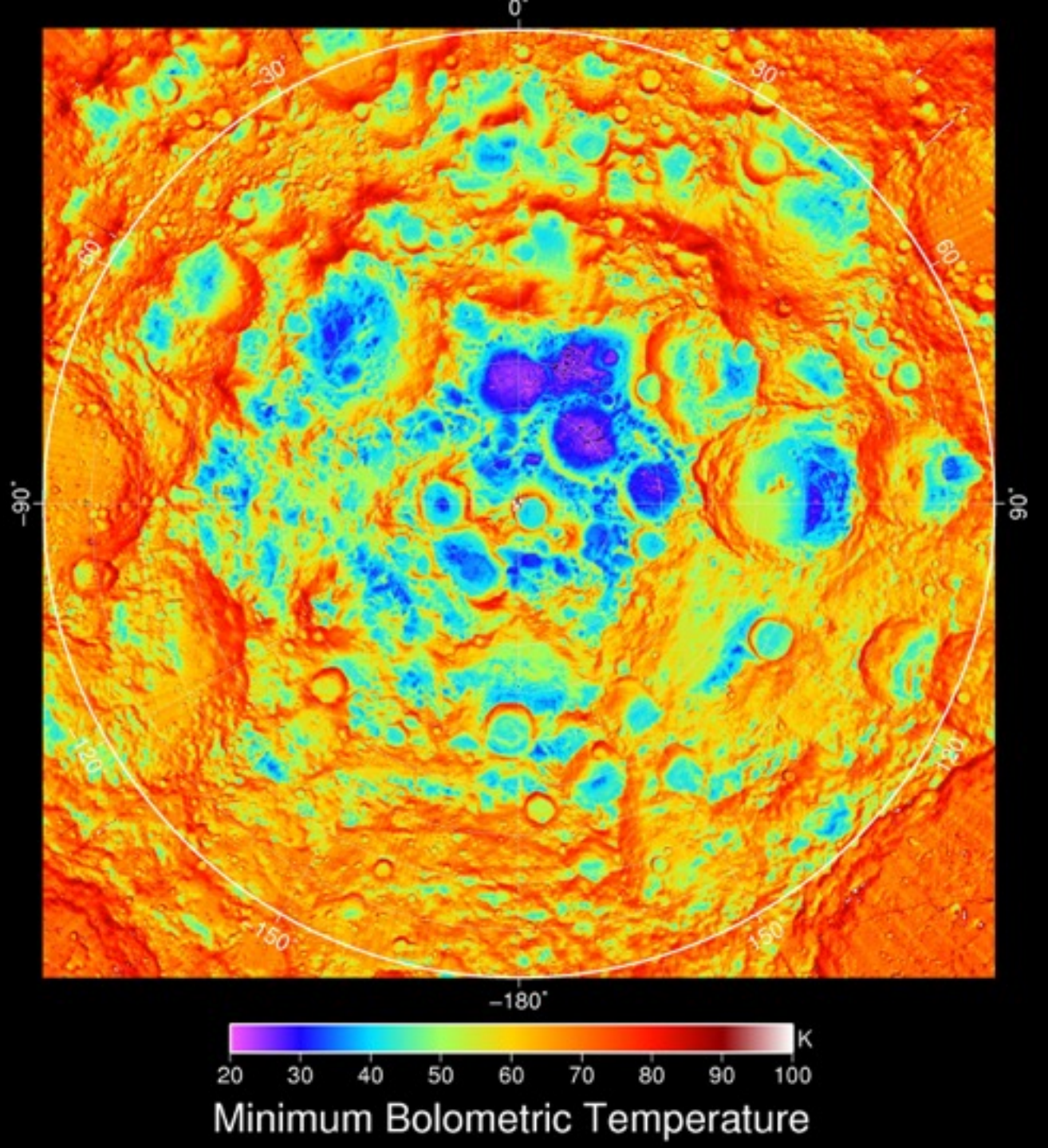


LRO's LOLA measures topography using lasers

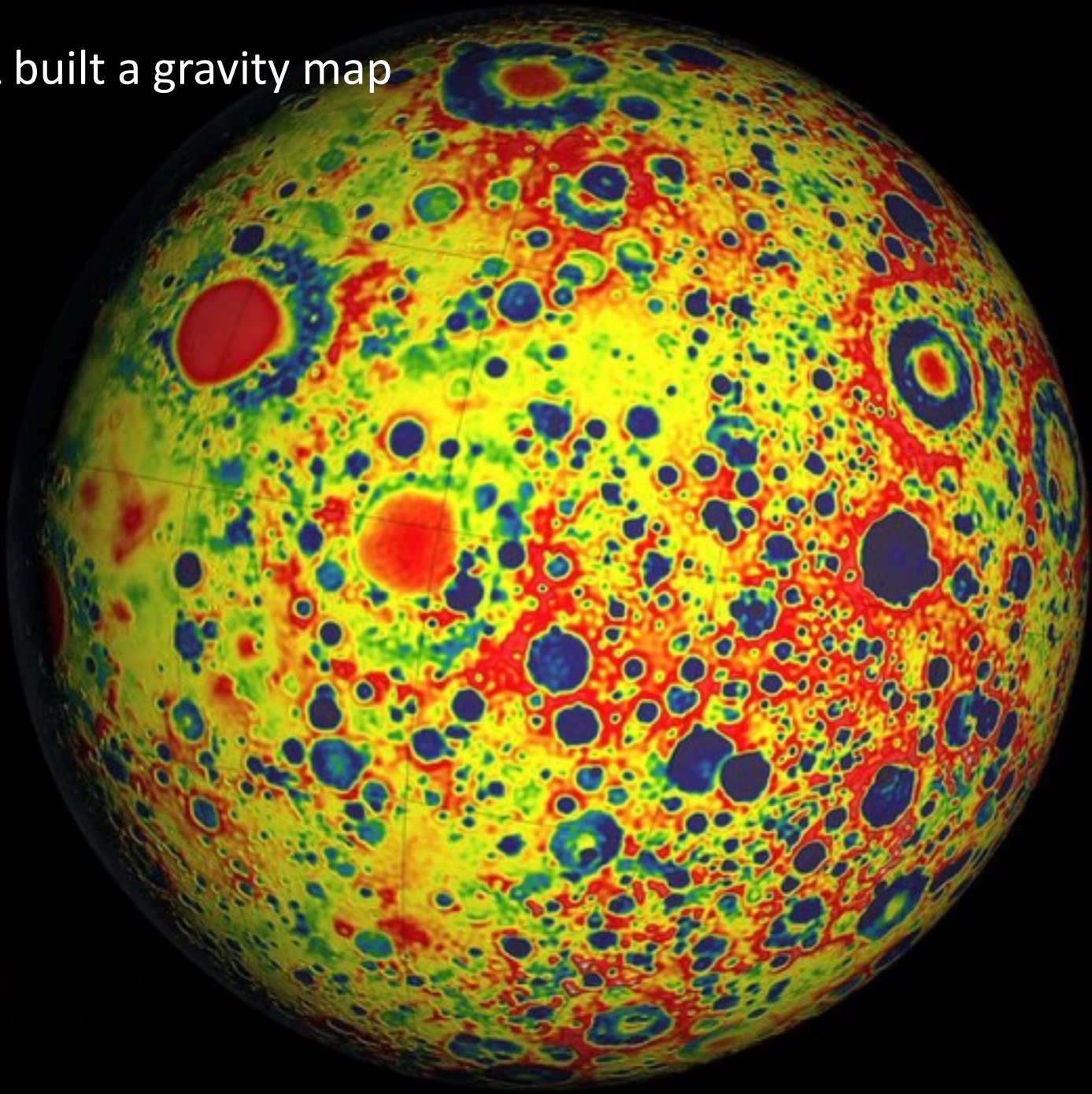


LOLA topography of LCROSS landing

LRO's DIVINER measures surface temperature



GRAIL built a gravity map

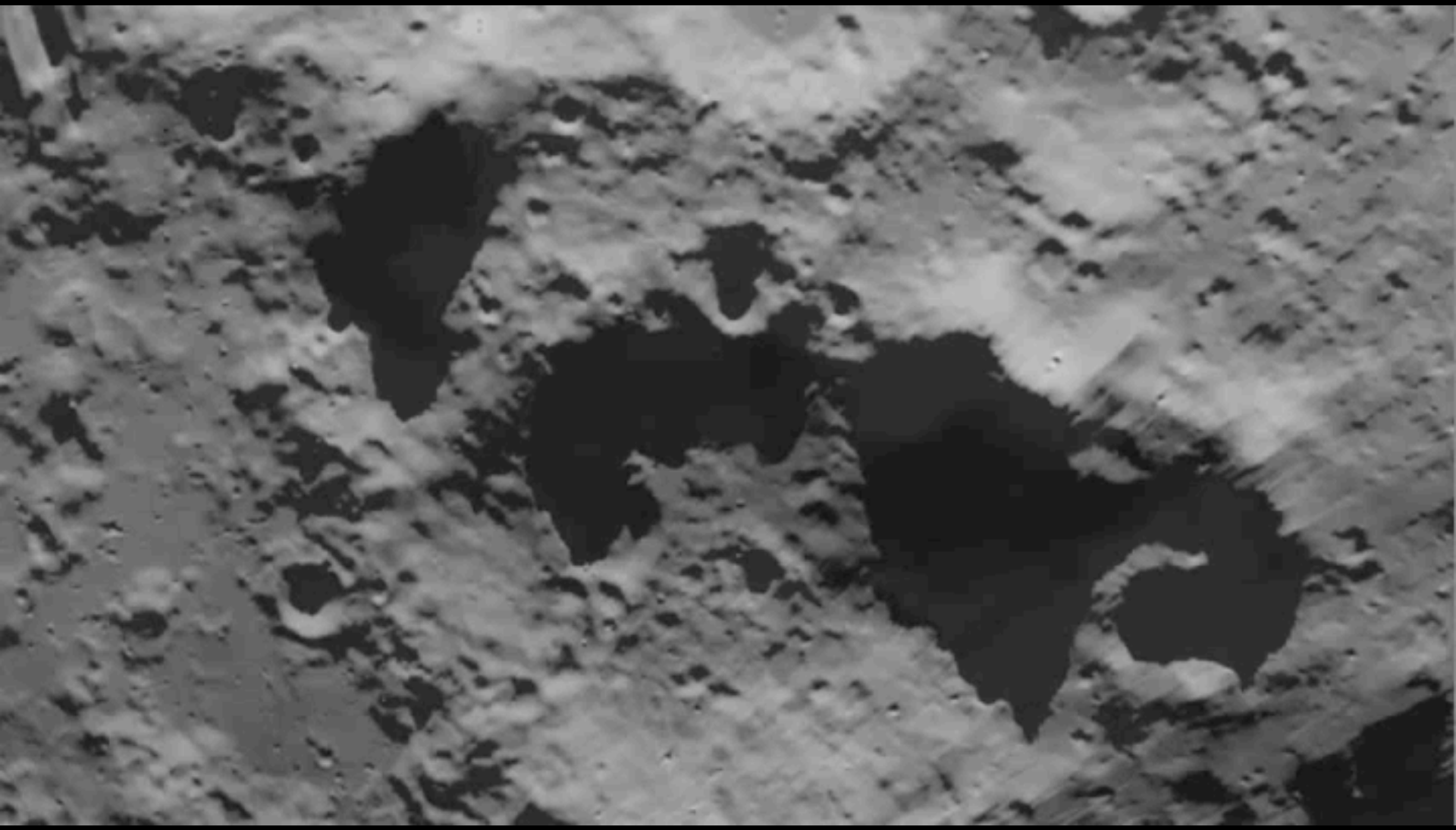


We know that there is water ice on the moon.

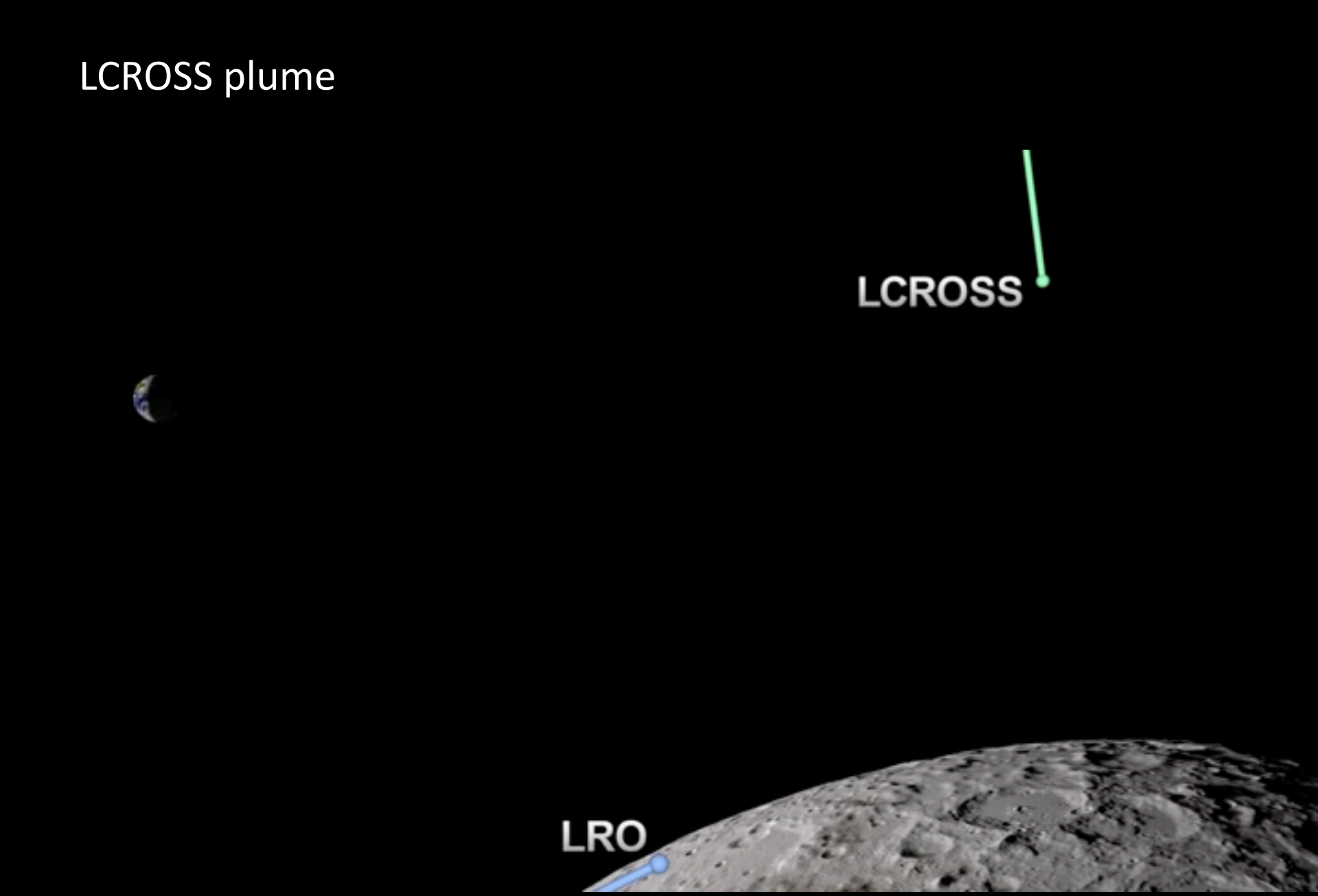
NASA / Bill Anders / Apollo 8

Lunar Crater Observation and Sensing Satellite (LCROSS) measured hydrogen on the moon

Simulation of LCROSS deployment

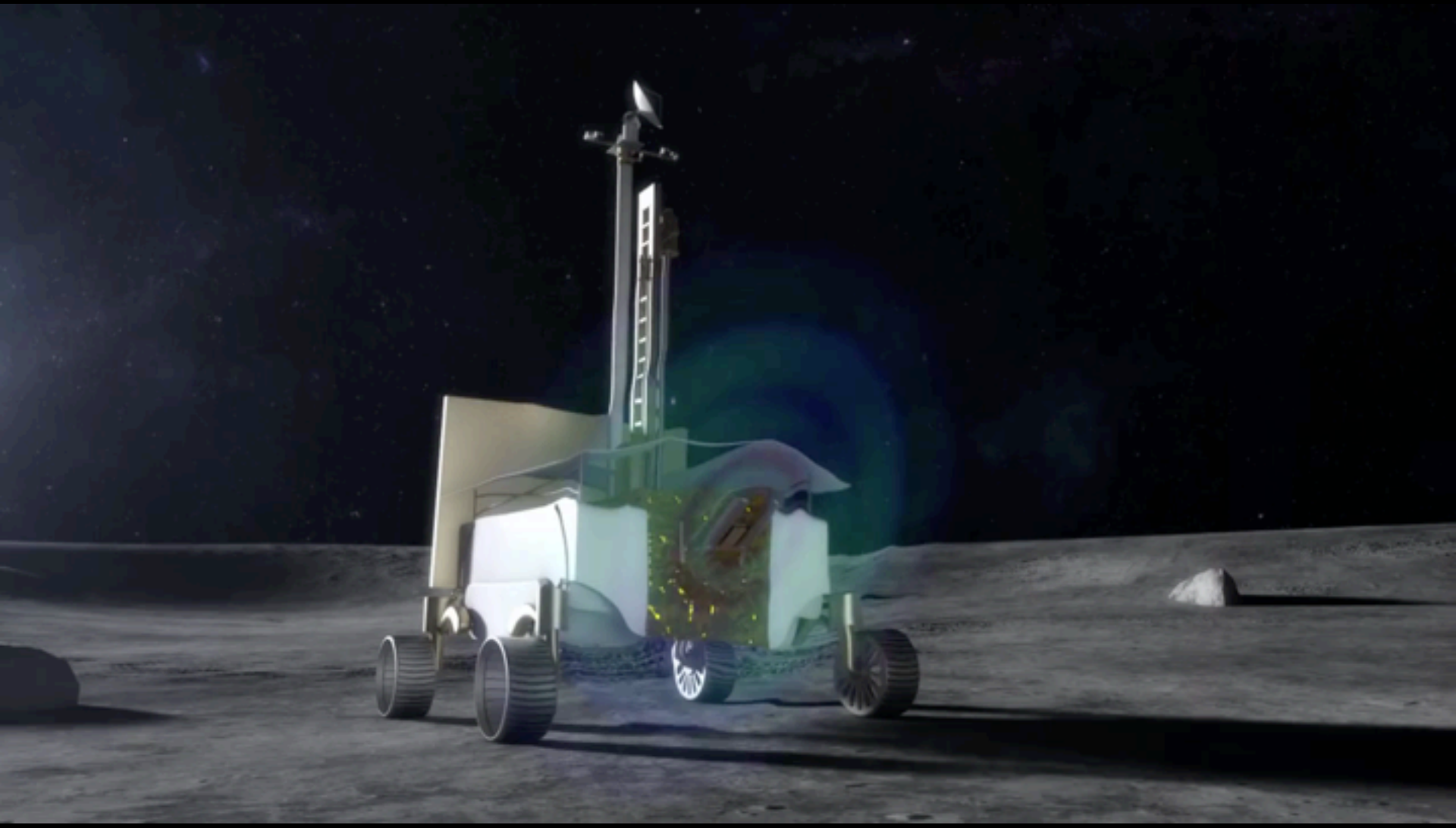


LCROSS plume

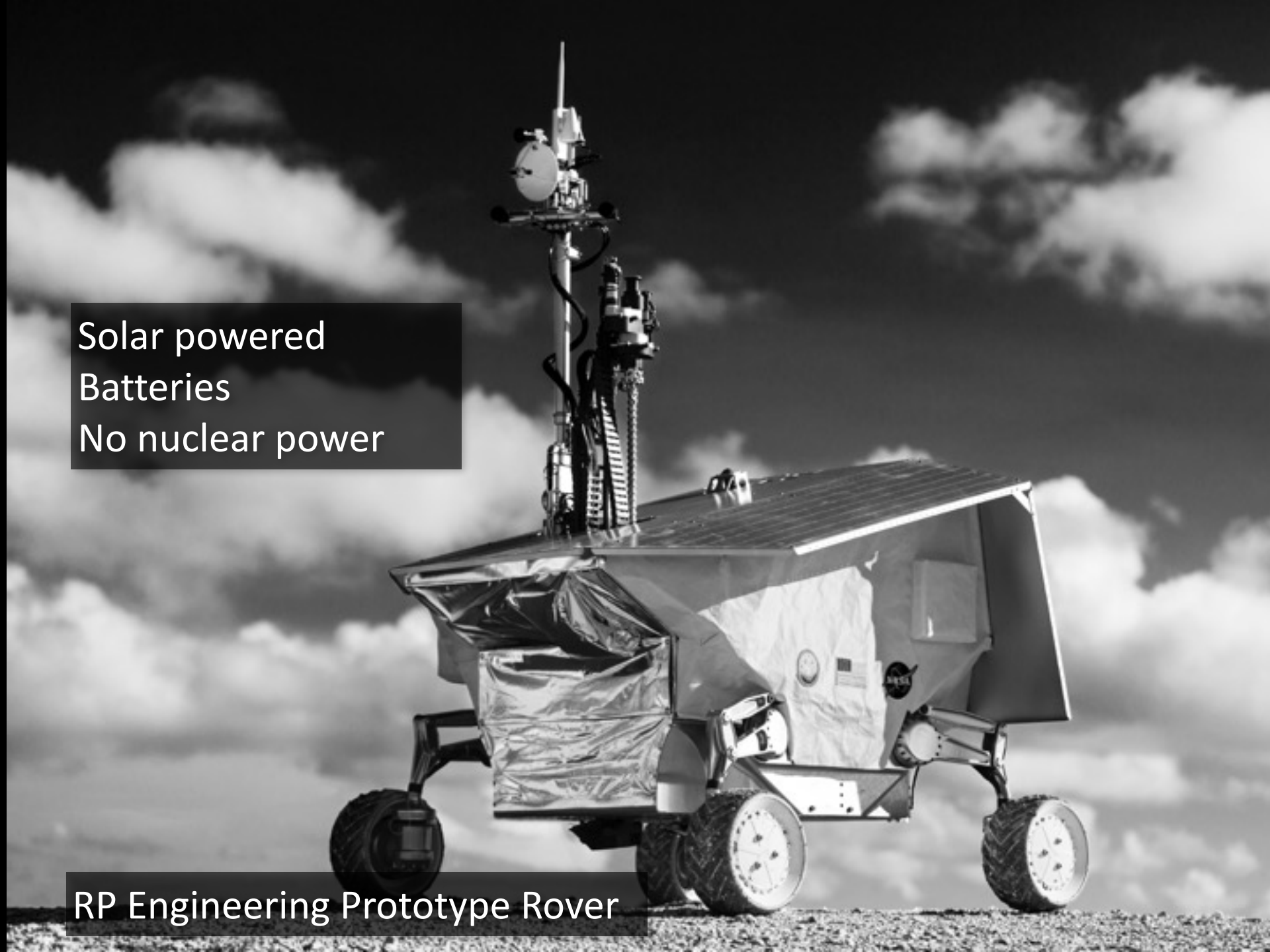


What is the proposed Resource Prospector Mission?

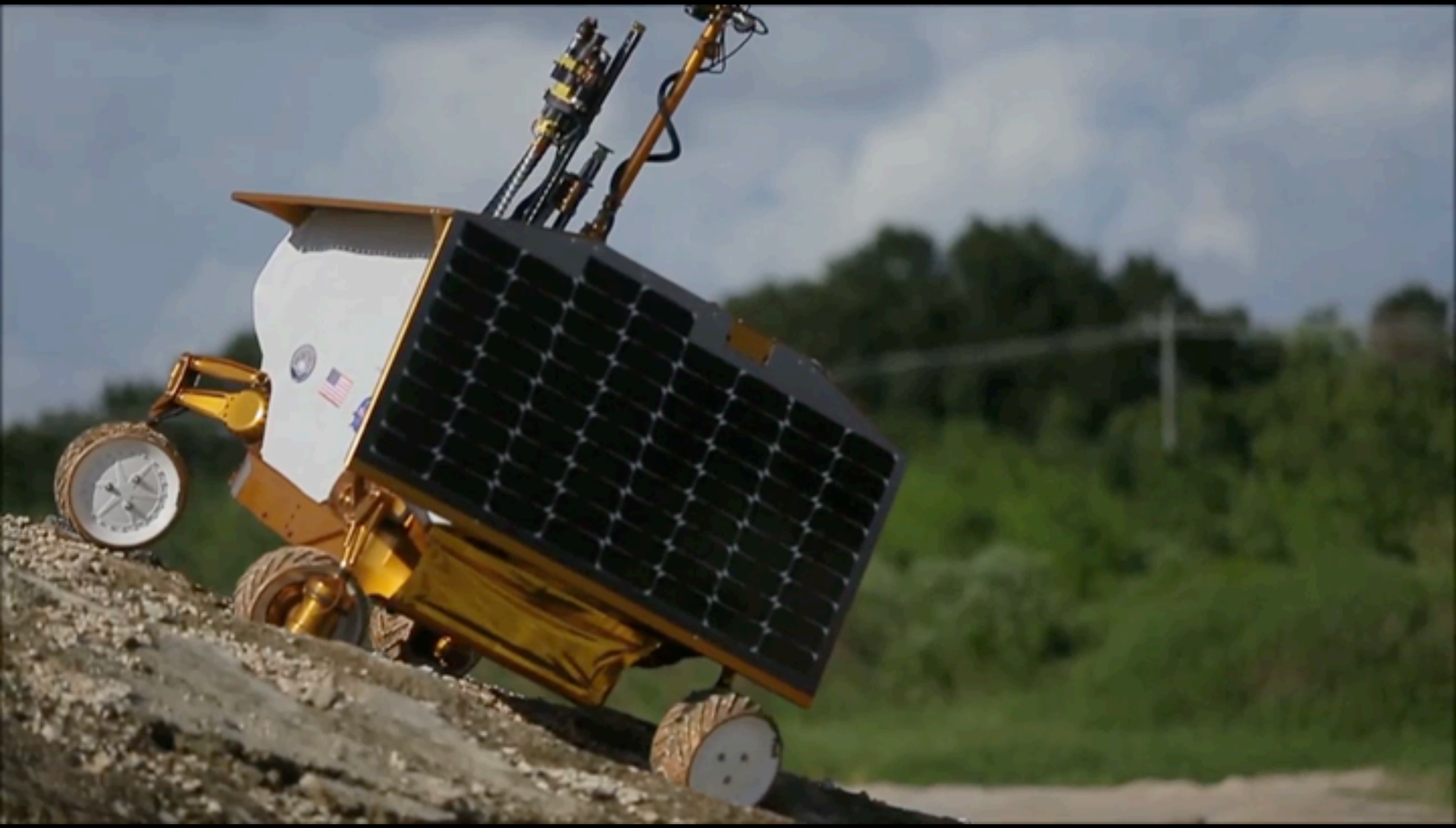
NASA / Bill Anders / Apollo 8




Resource Prospector
NASA
RP Engineering
Prototype
Rover


Solar powered
Batteries
No nuclear power
RP Engineering Prototype Rover

RP Engineering Prototype Rover in action

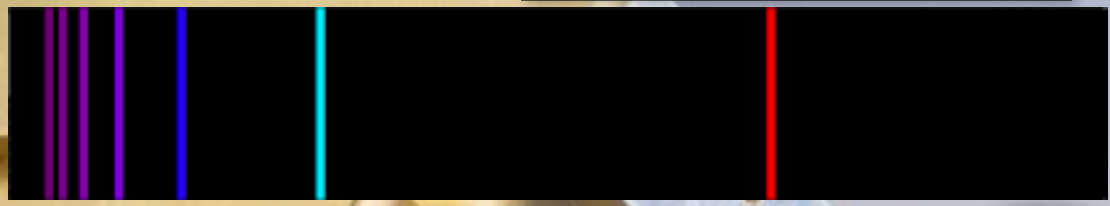


How do the instruments work to detect water?

NASA / Bill Anders / Apollo 8

Near Infrared Volatile Spectrometer System
NIRVSS

Hydrogen spectrum

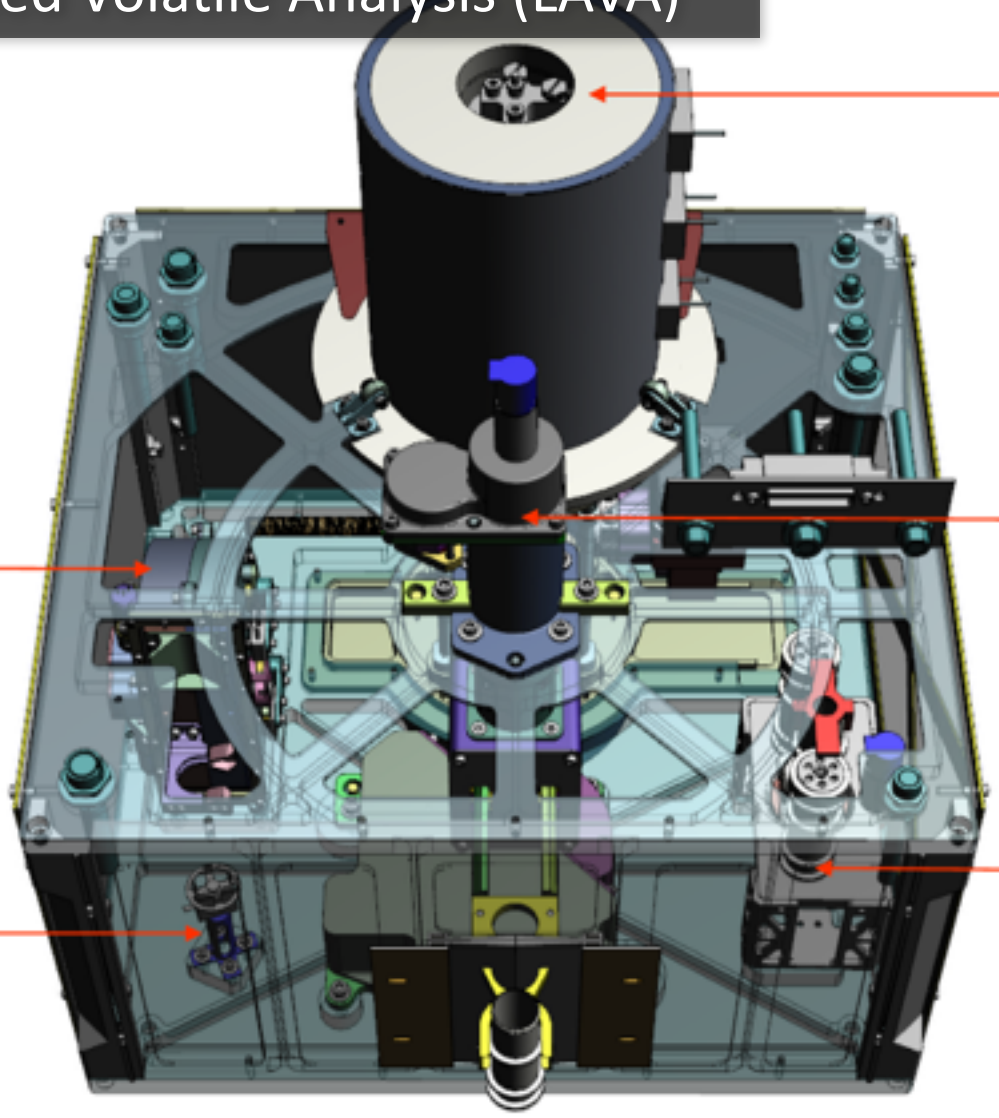


Detects surface elements

Neutron Spectrometer System
NSS

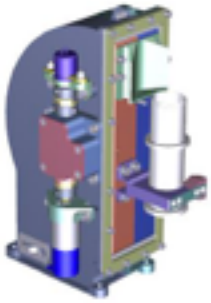
Detects subsurface elements

Oxygen and Volatile Extraction Node (OVEN) & Lunar Advanced Volatile Analysis (LAVA)



REACTOR STATION
Elevates/Seals/Heats
Regolith Samples

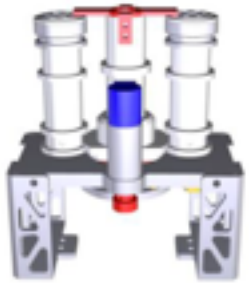
REMOVAL STATION
Discards Regolith Samples



ARM
Rotates/Elevates/Extends
Crucibles

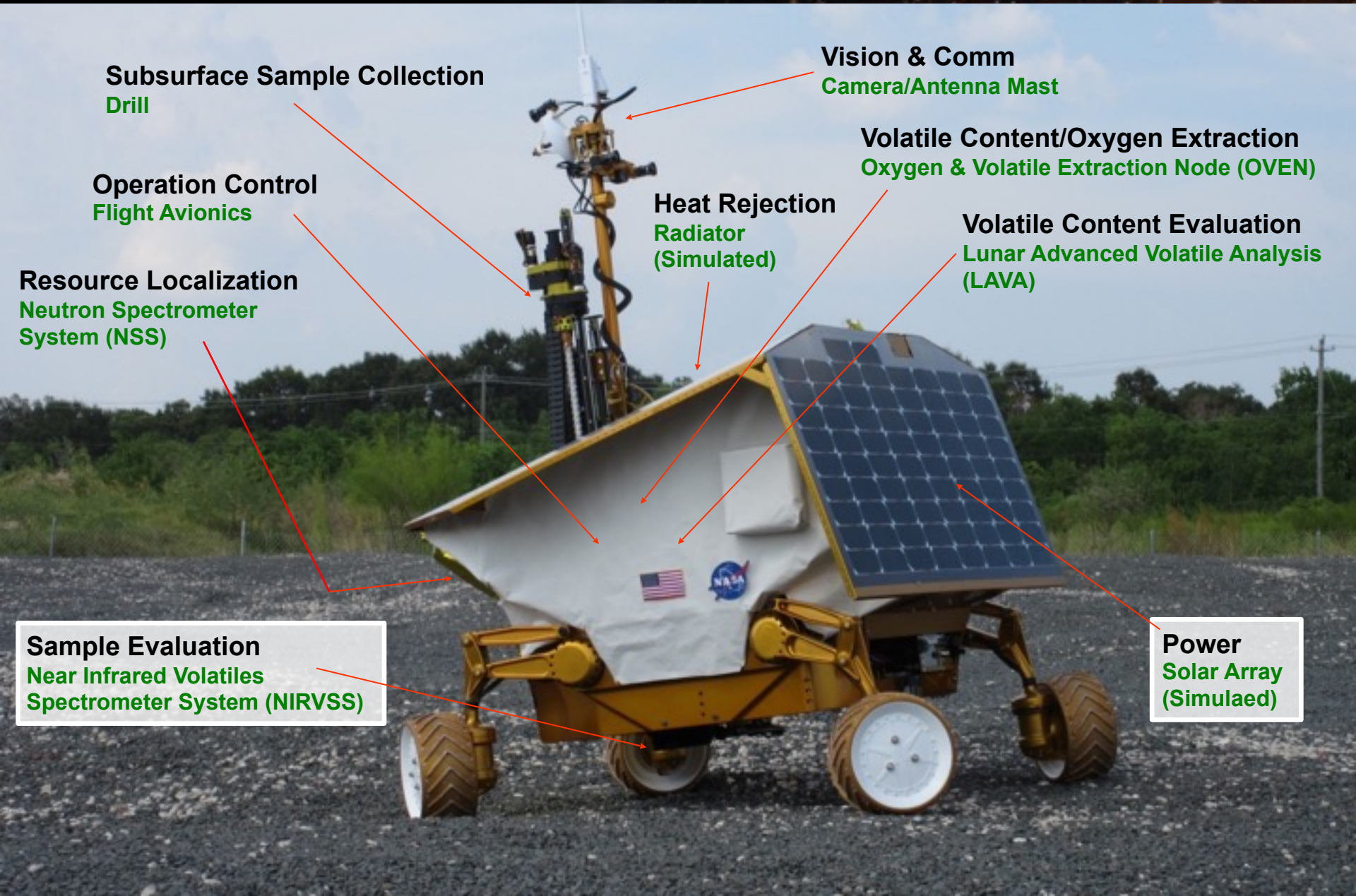
WEIGH STATION
Weighs Regolith Samples

STORAGE STATION
Stores 2 Crucibles



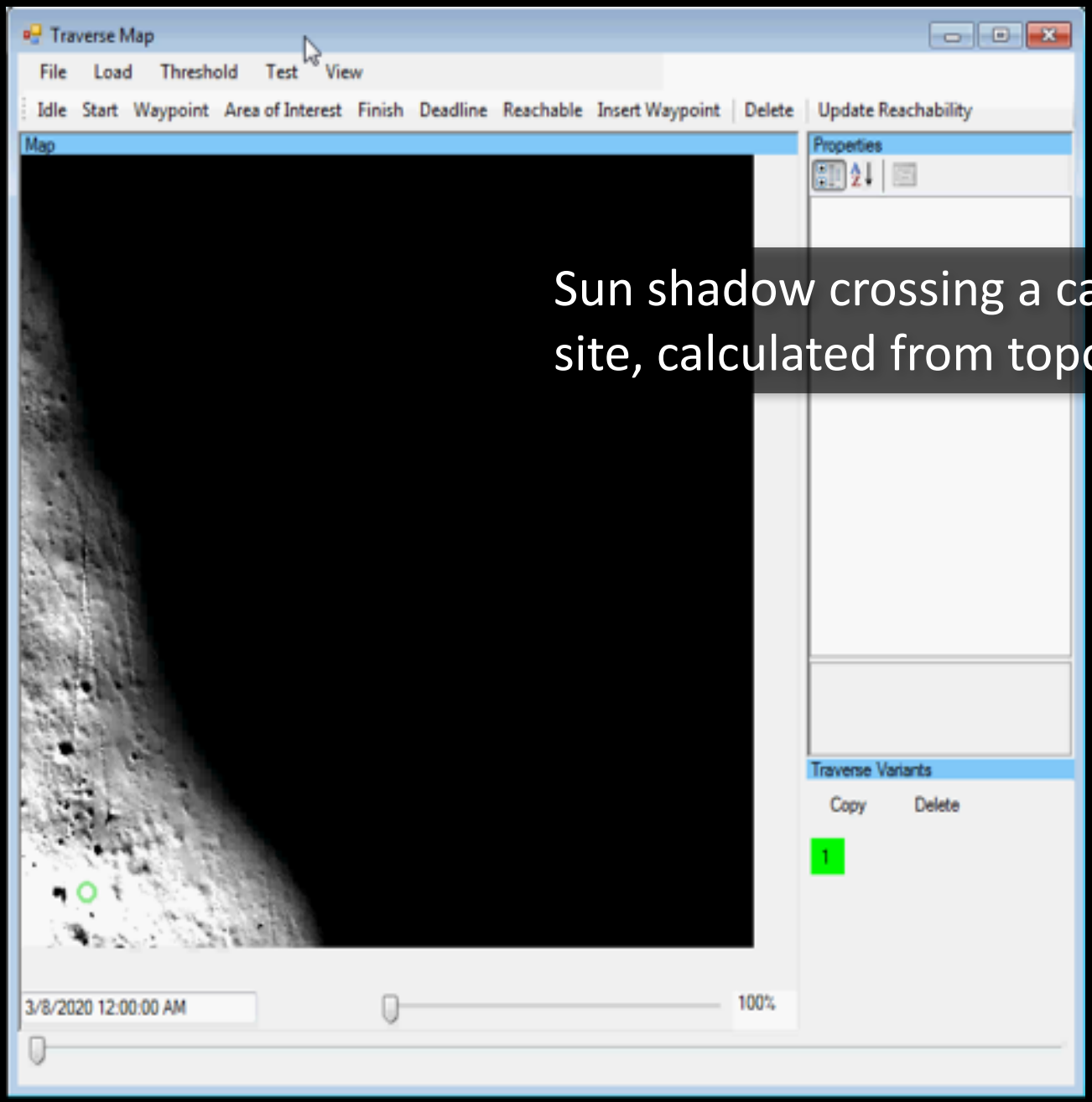
REGOLITH SAMPLE INLET
Drill Interface

RP Engineering Prototype Rover



How do we plan where to send the rover?

NASA / Bill Anders / Apollo 8



Sun shadow crossing a candidate site, calculated from topography

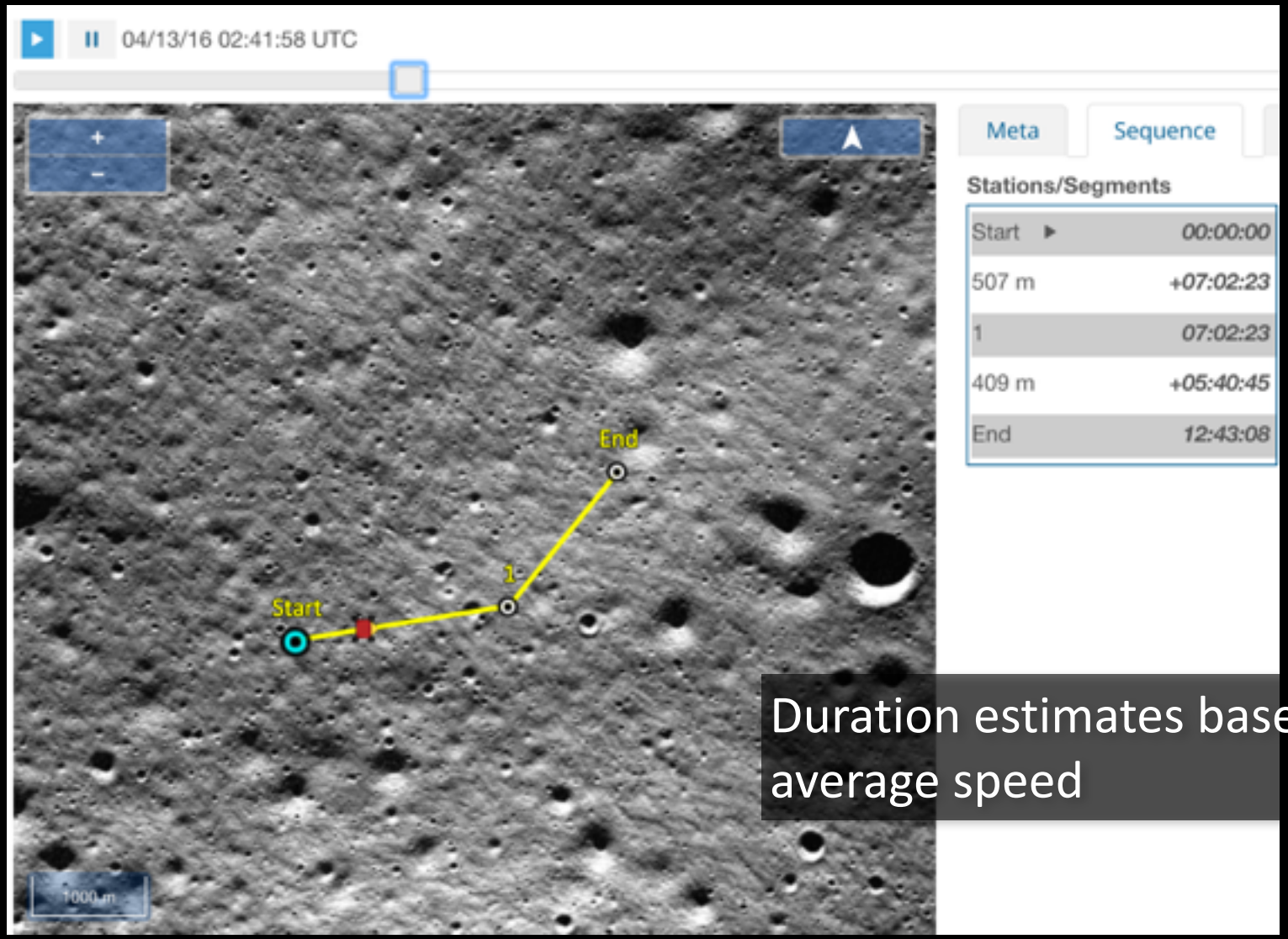
NASA/ Mark Shirley | Images: Andy McGovern / APL

Build map layers and mark up maps

Multi-temporal illumination map of the lunar south pole

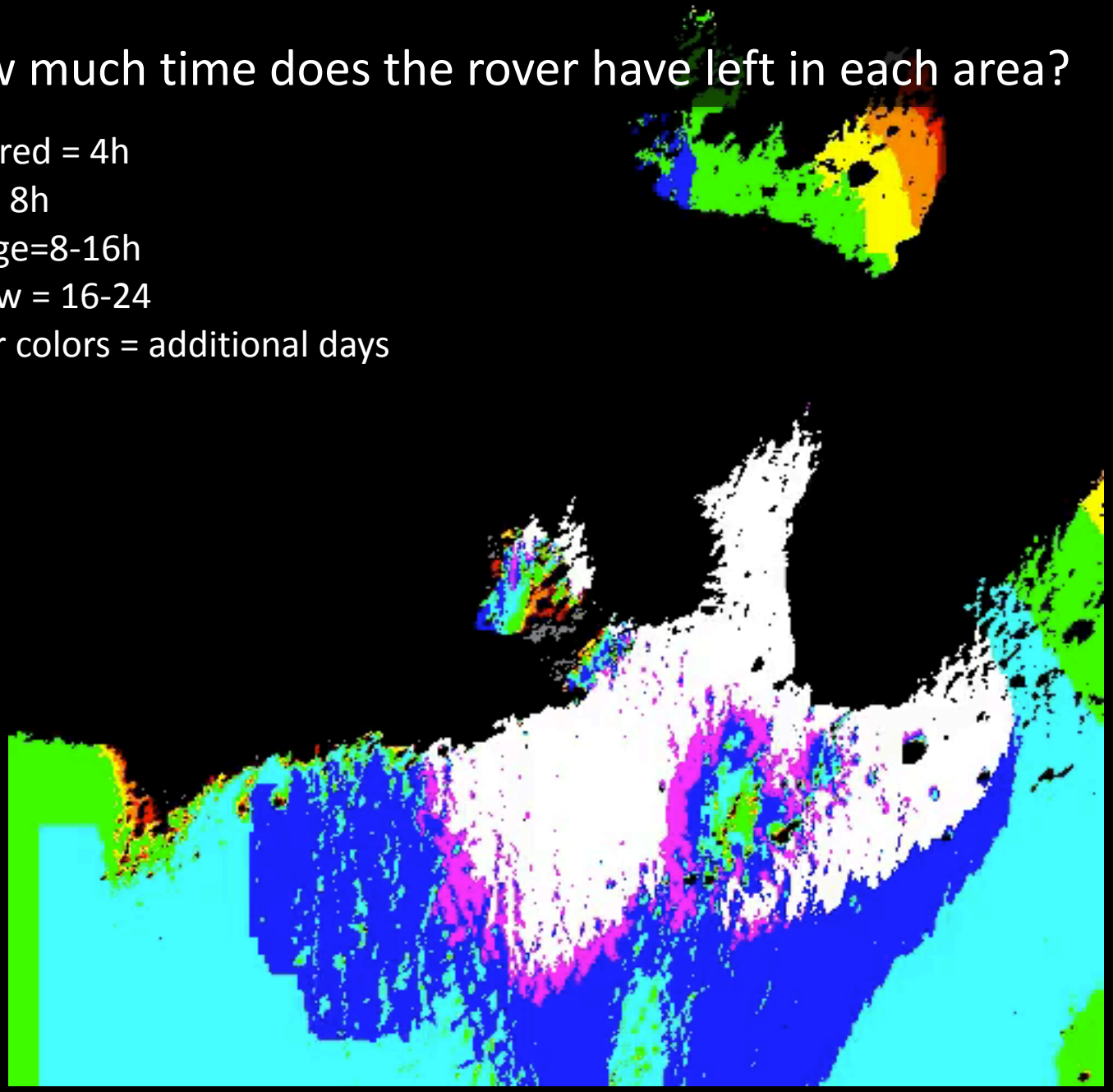
NASA/GSFC/Arizona State University

Create simple sequential route plans in xGDS on OpenLayers 3 (Exploration Ground Data Systems)



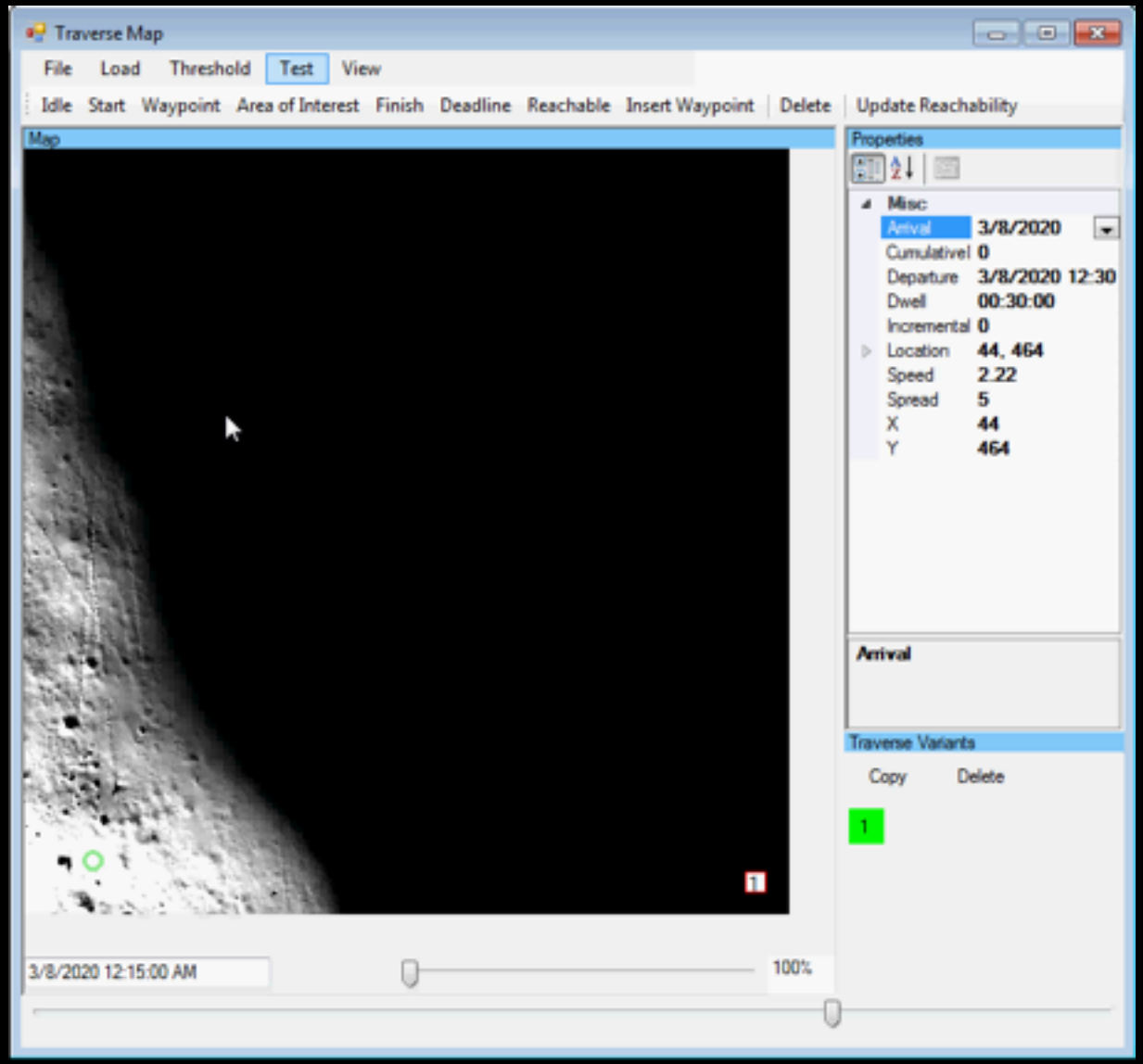
How much time does the rover have left in each area?

dark red = 4h
red = 8h
orange=8-16h
yellow = 16-24
other colors = additional days

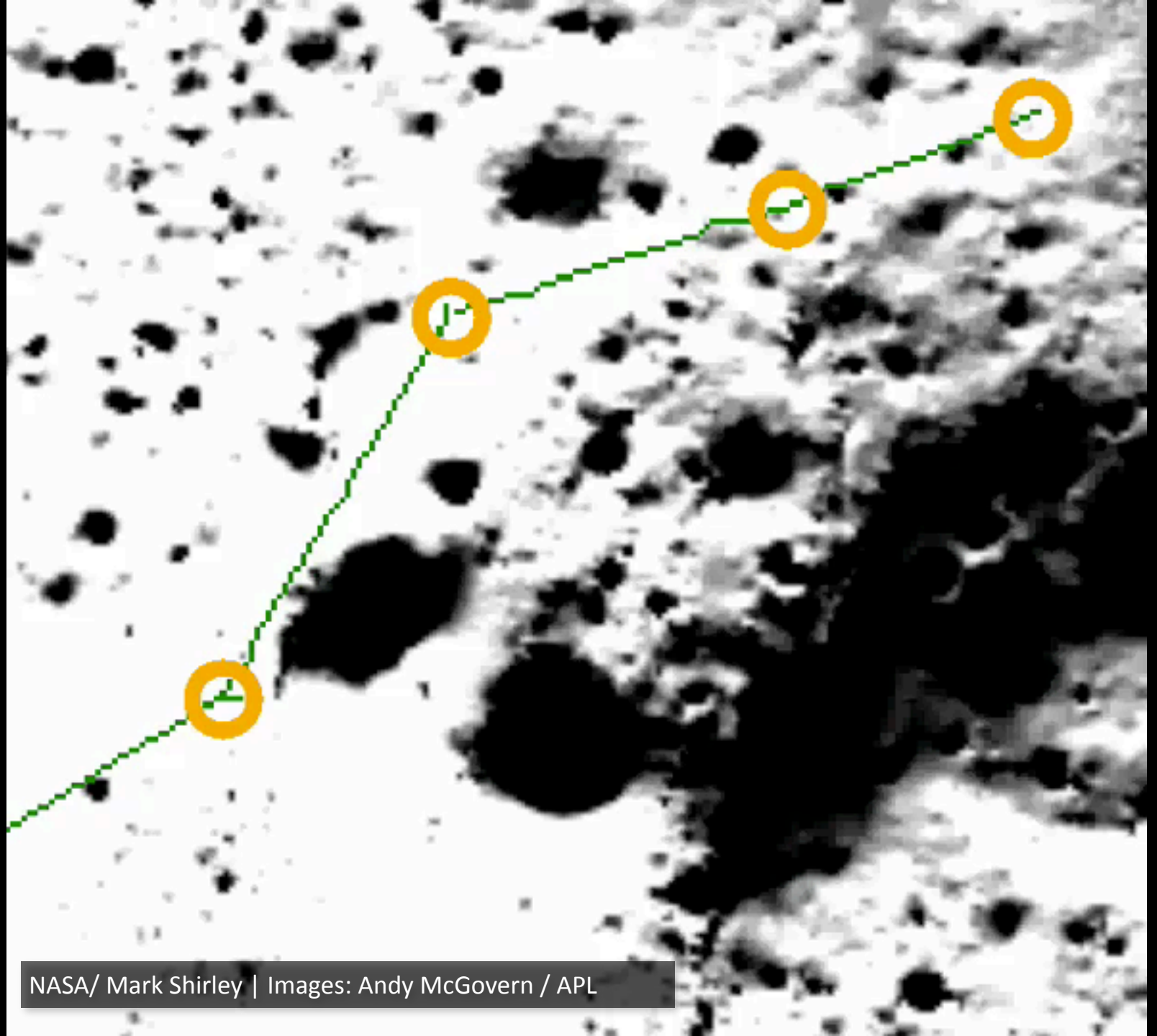


NASA/ Matthew Deans | Images: Andy McGovern / APL

Prototype planner: can the rover follow the proposed route?

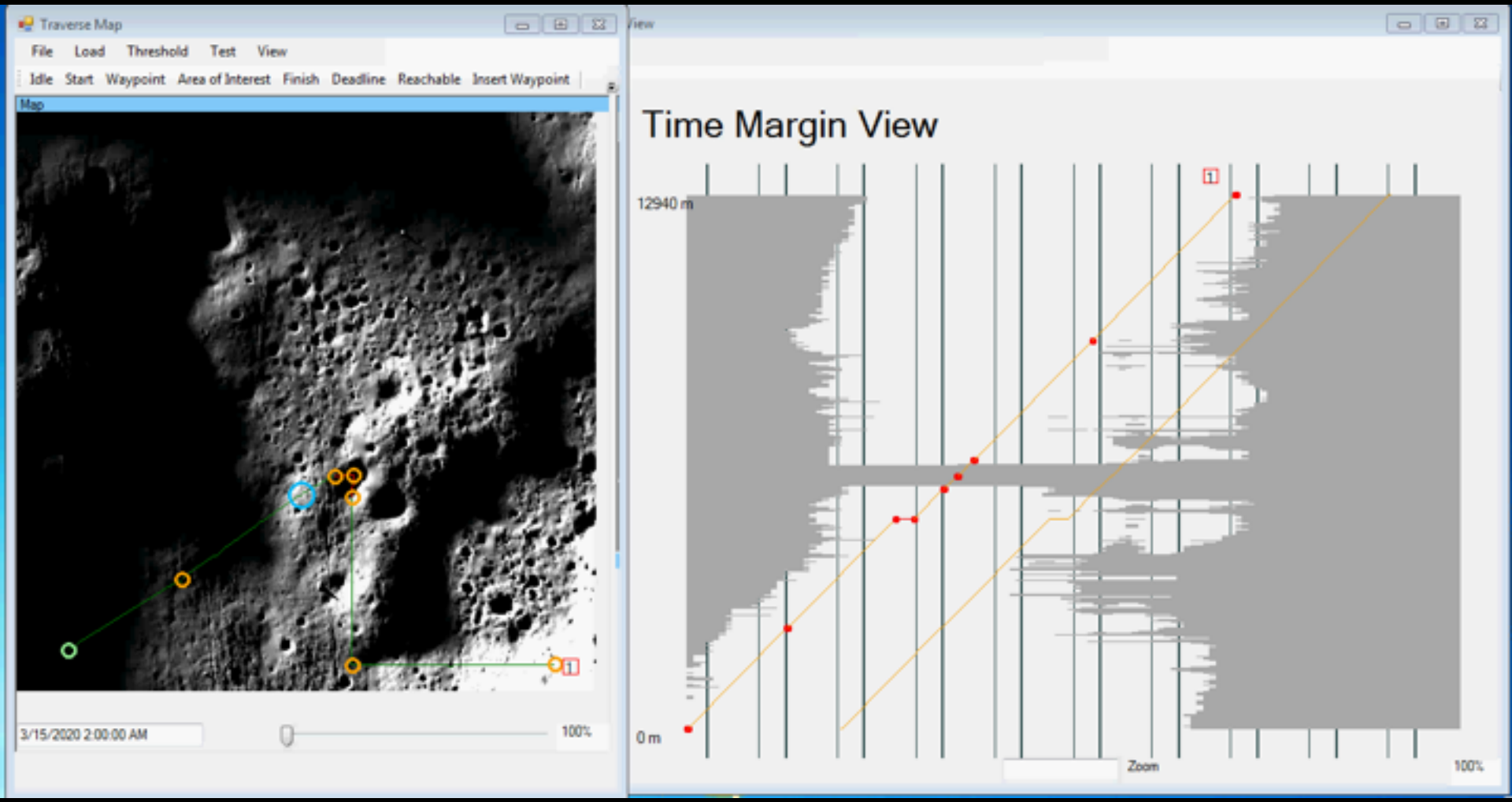


NASA/ Mark Shirley | Images: Andy McGovern / APL



NASA/ Mark Shirley | Images: Andy McGovern / APL

Prototype planner: How much margin is there at each point?



NASA/ Mark Shirley | Images: Andy McGovern / APL

How do we communicate with a rover on the moon?

NASA / Bill Anders / Apollo 8


We communicate with the
Deep Space Network (DSN)
Goldstone Antenna

DSN covers the whole planet

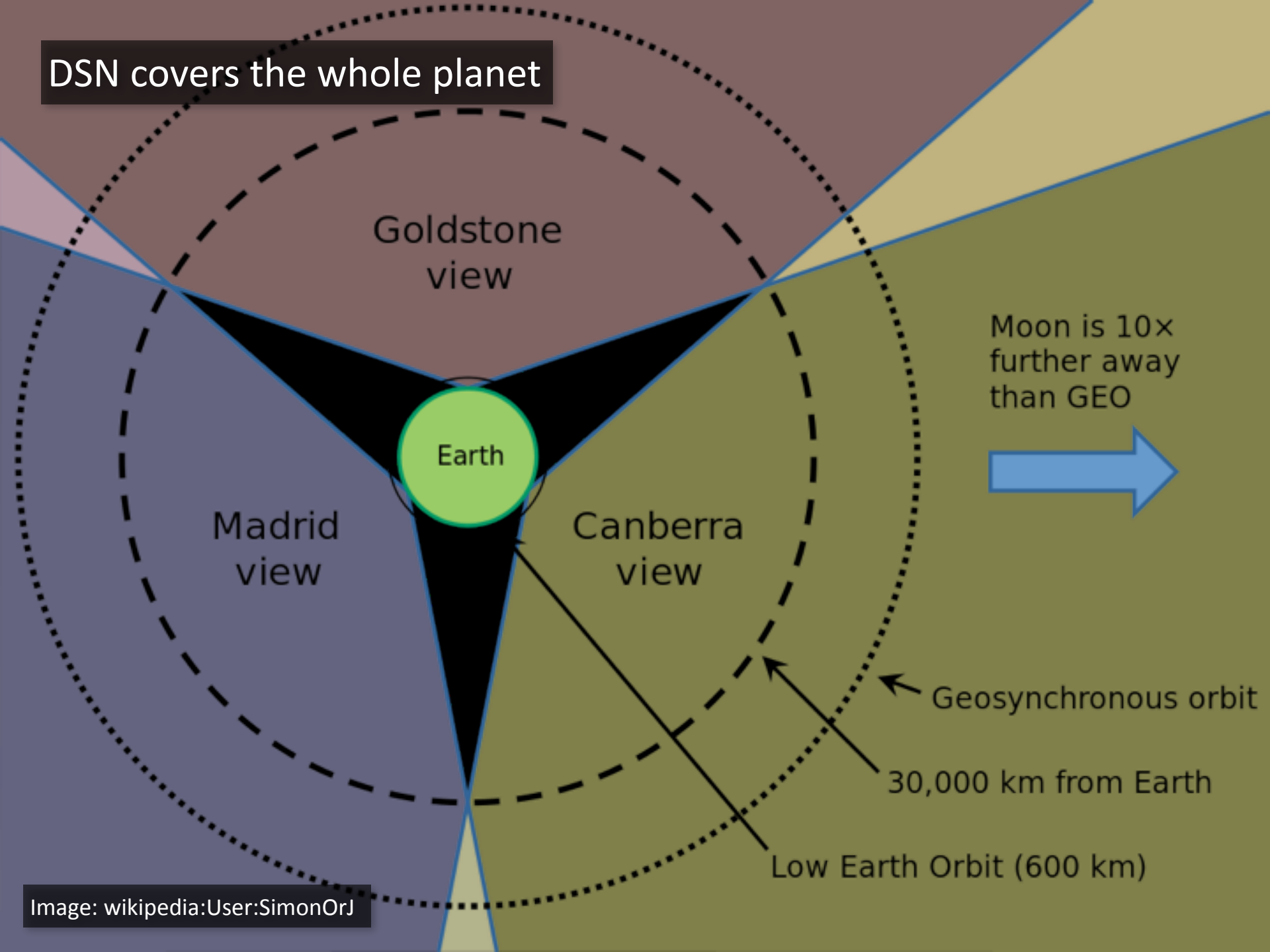


Image: wikipedia:User:SimonOrJ

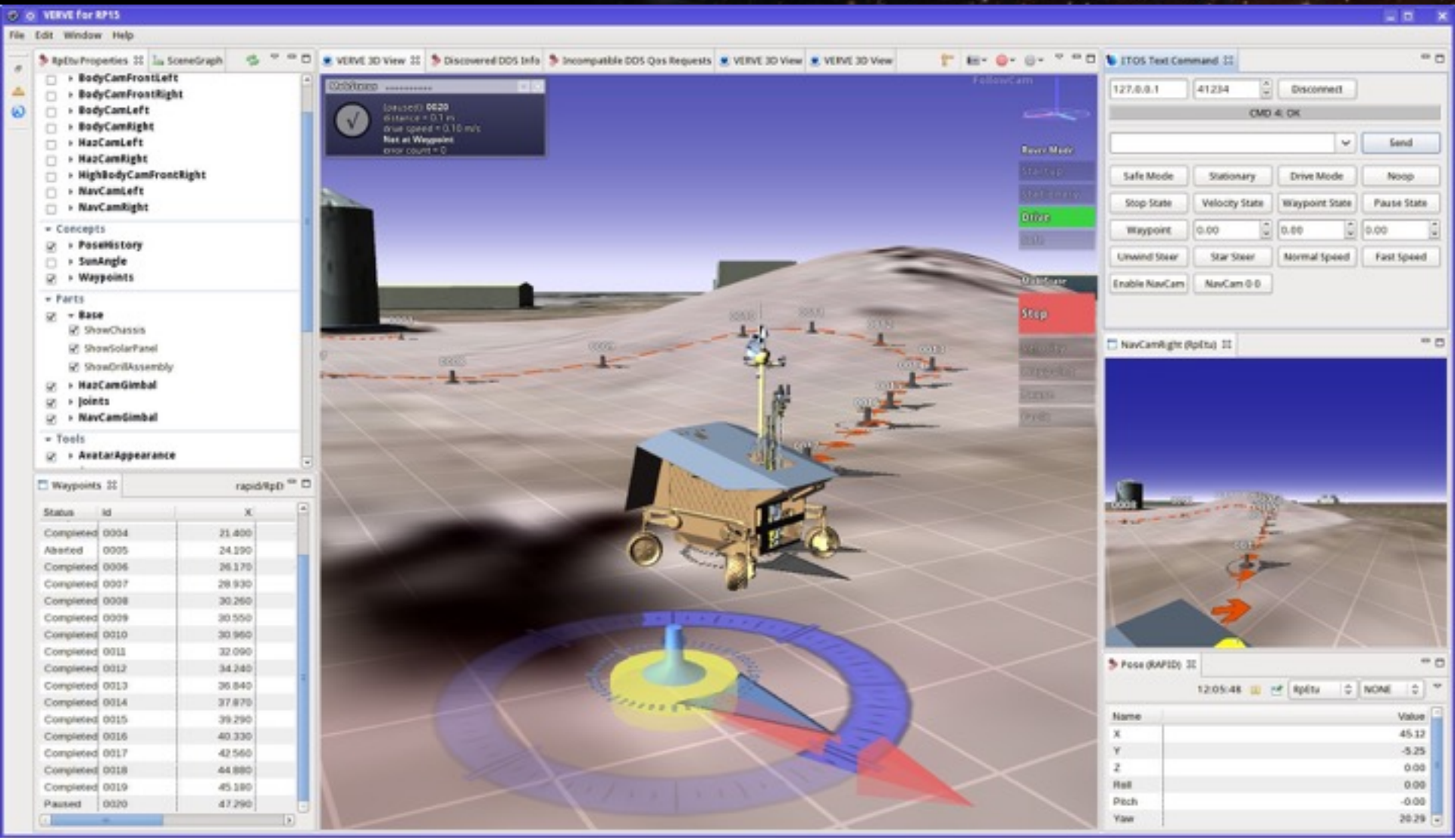
It can take 2 minutes to communicate one way between the Earth and the Moon over the DSN.

Image: ESA

How do we remotely operate a rover on the moon?

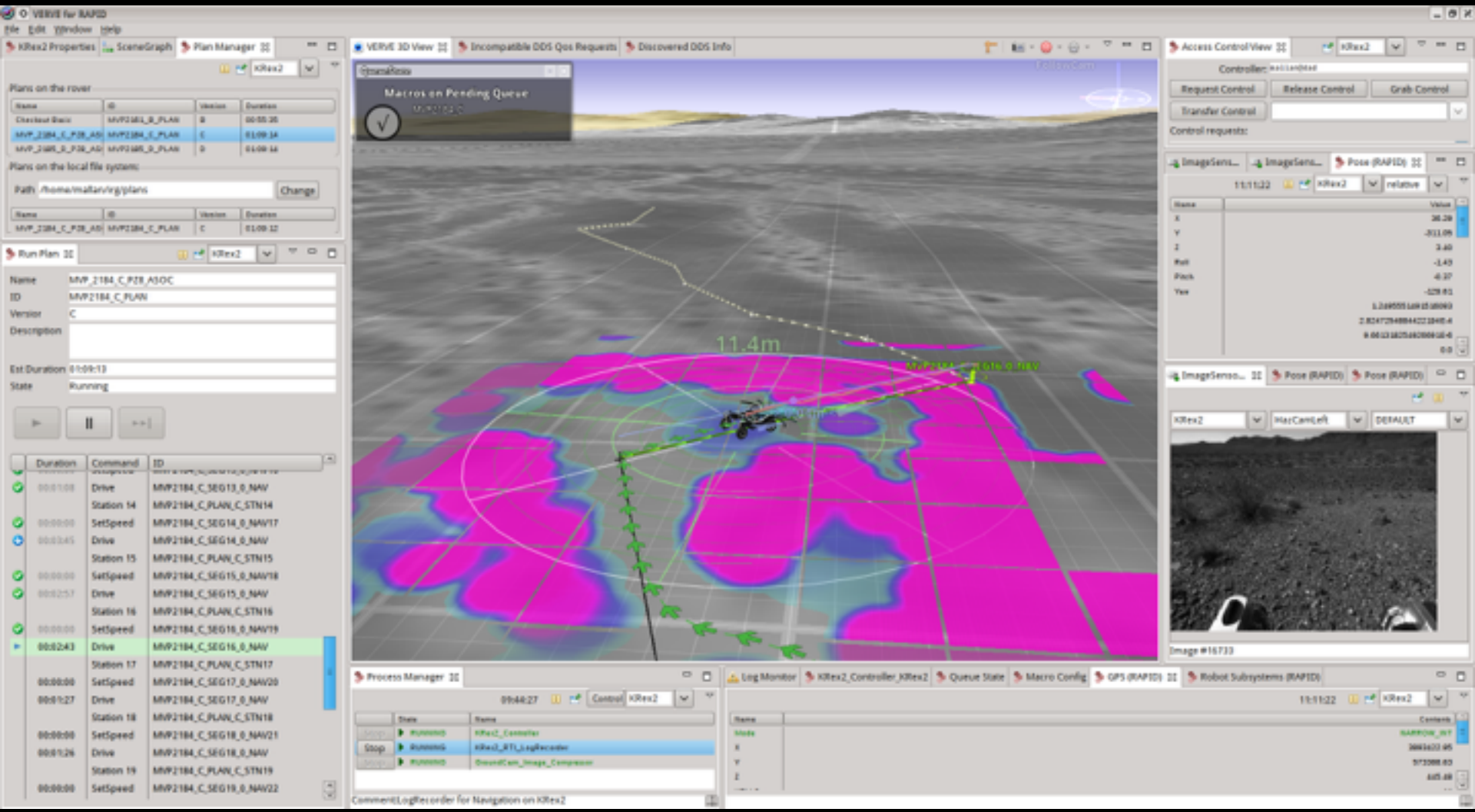
NASA / Bill Anders / Apollo 8

Rover Operator Interface (VERVE)



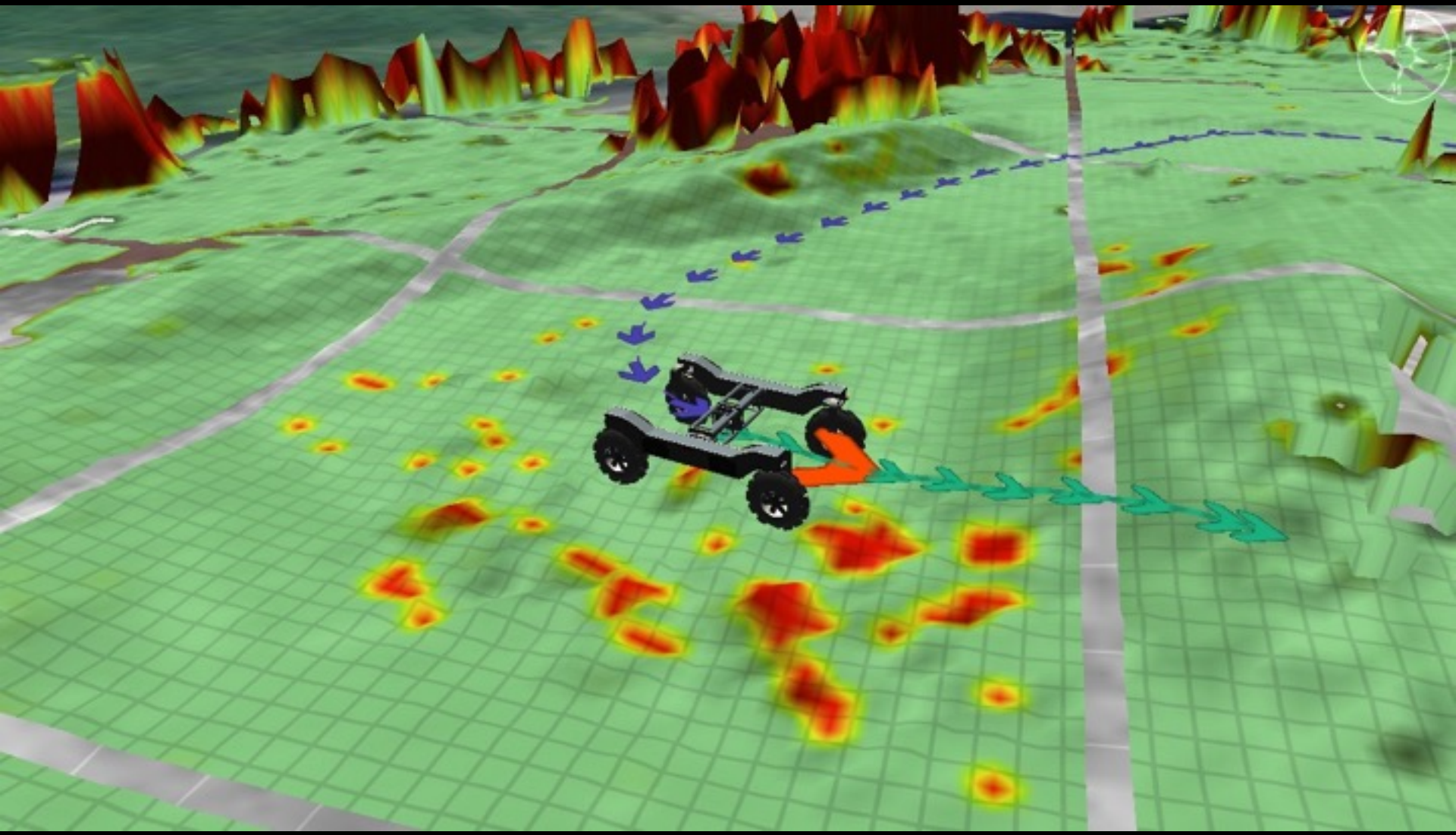
NASA/ Mark Allan

In VERVE, we customize tabular views to show diagnostics

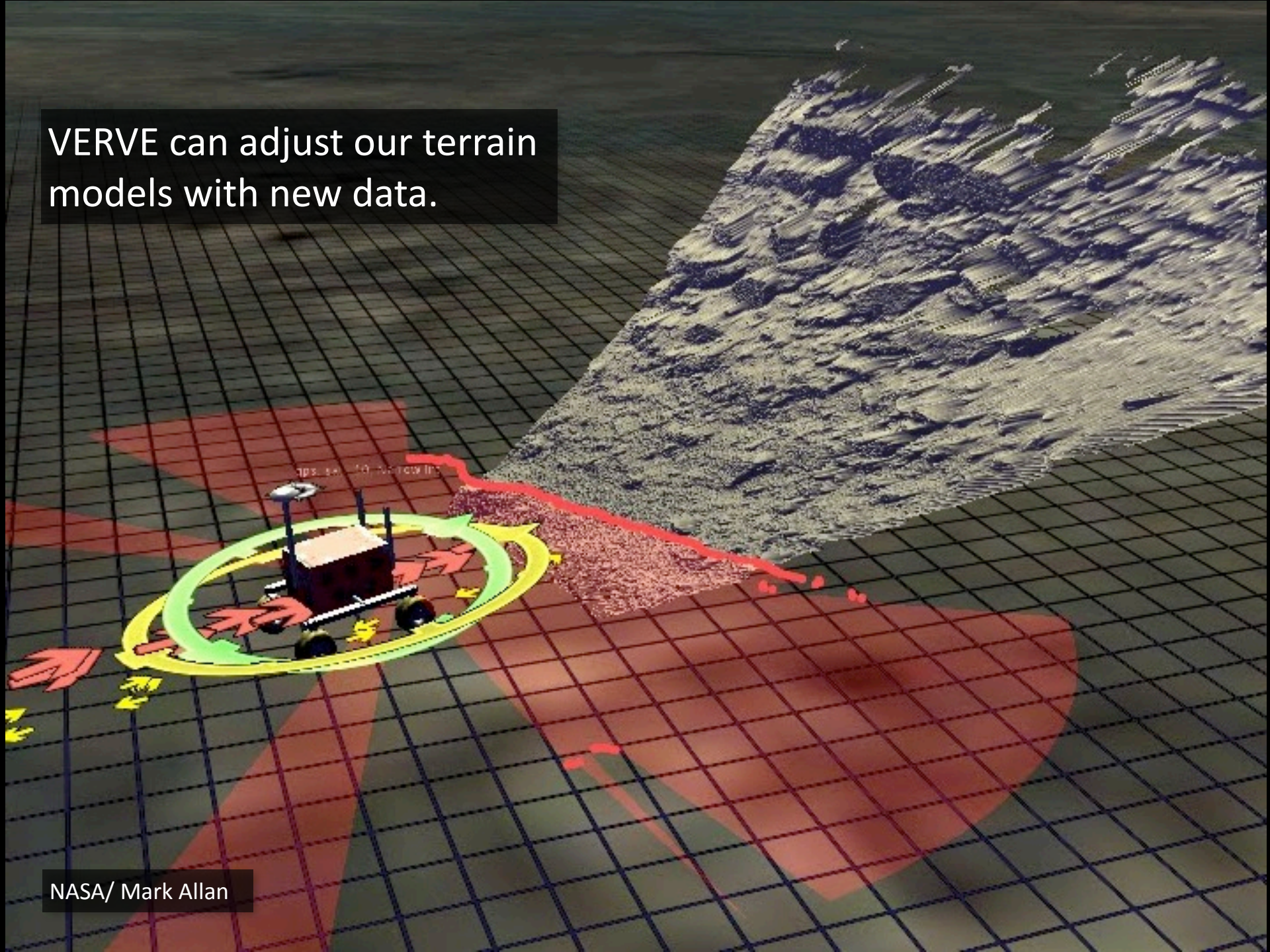


NASA/ Mark Allan

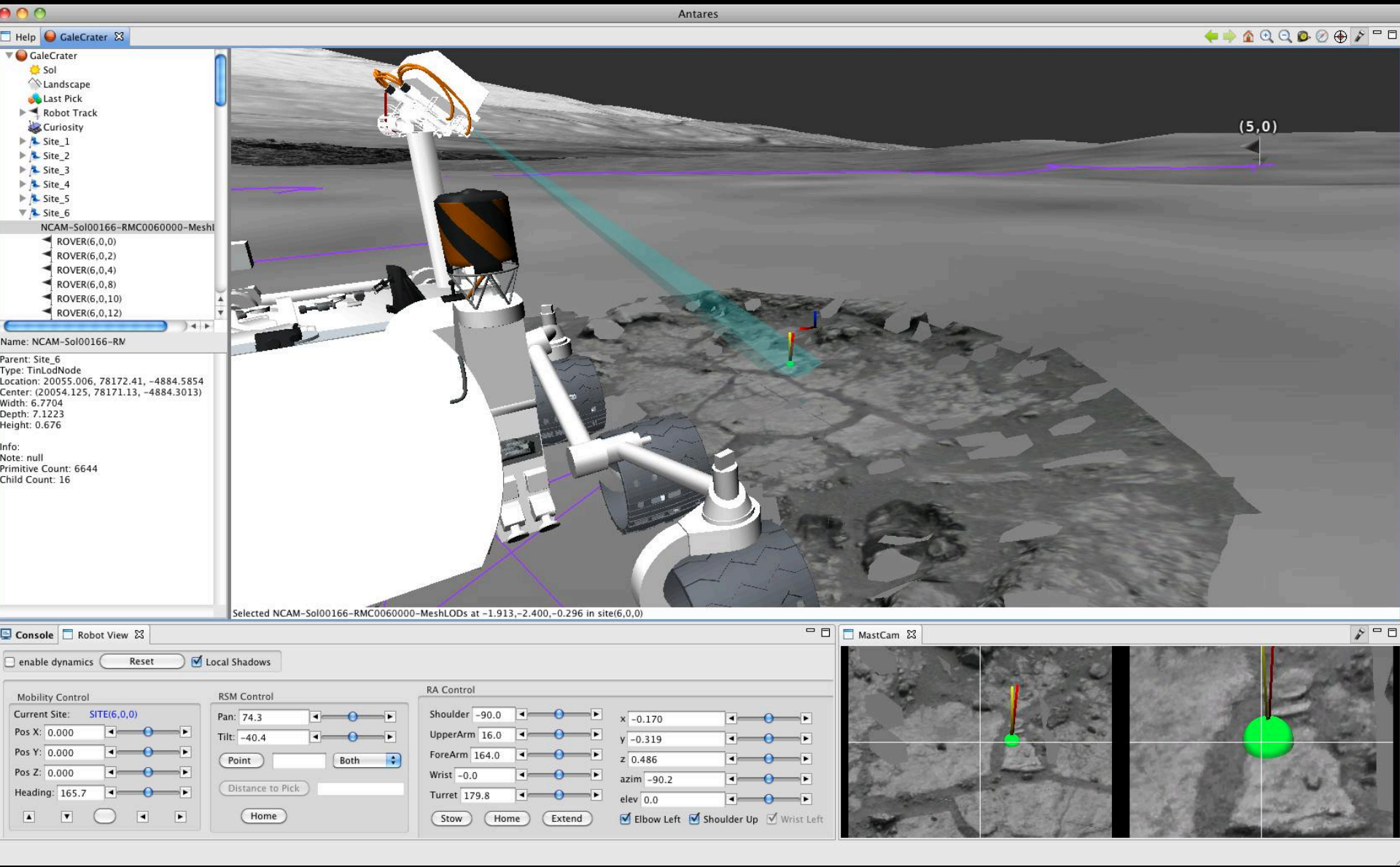
VERVE shows 3D terrain with overlays for rover operators.



NASA/ Mark Allan

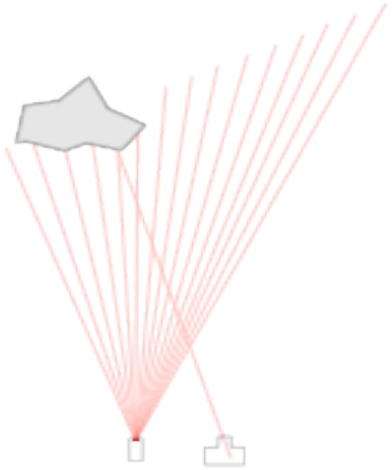

VERVE can adjust our terrain models with new data.
NASA/ Mark Allan

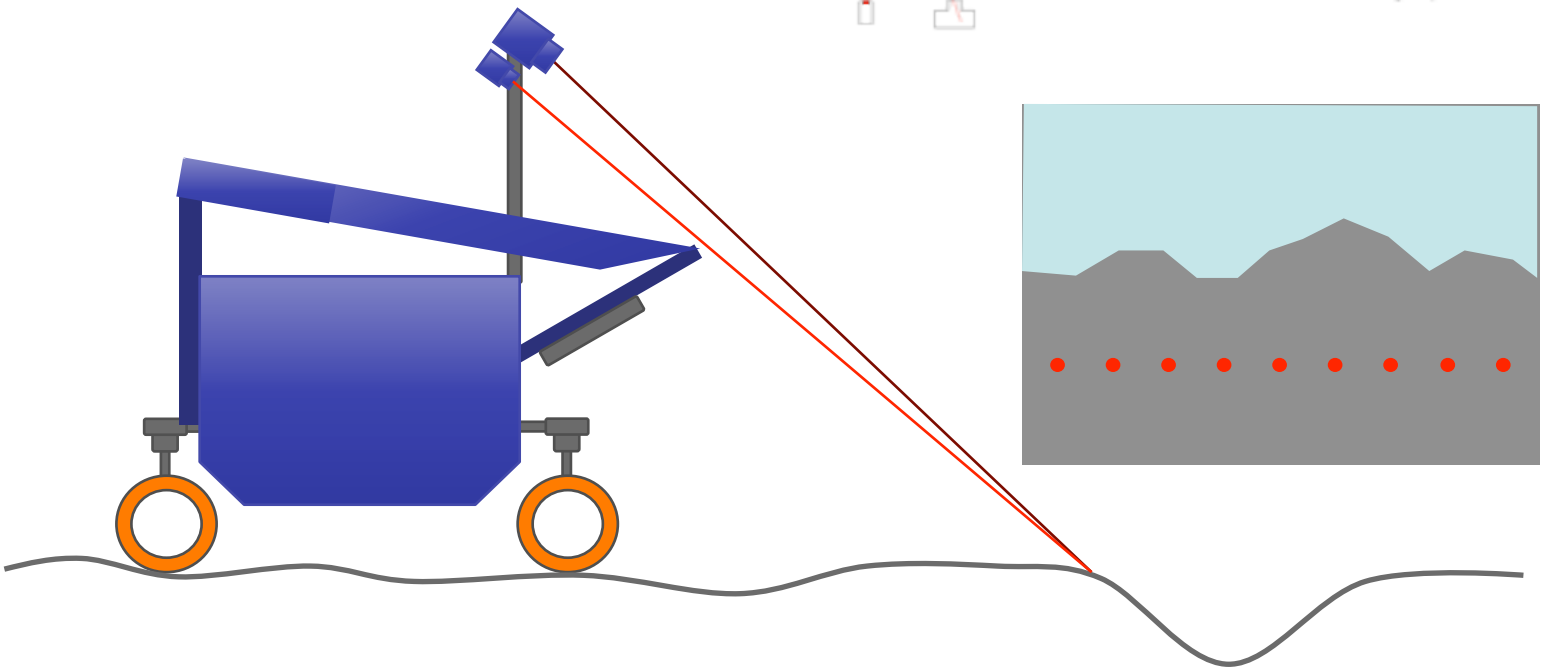
2011 Mars Science Laboratory (MSL) & Antares for Curiosity

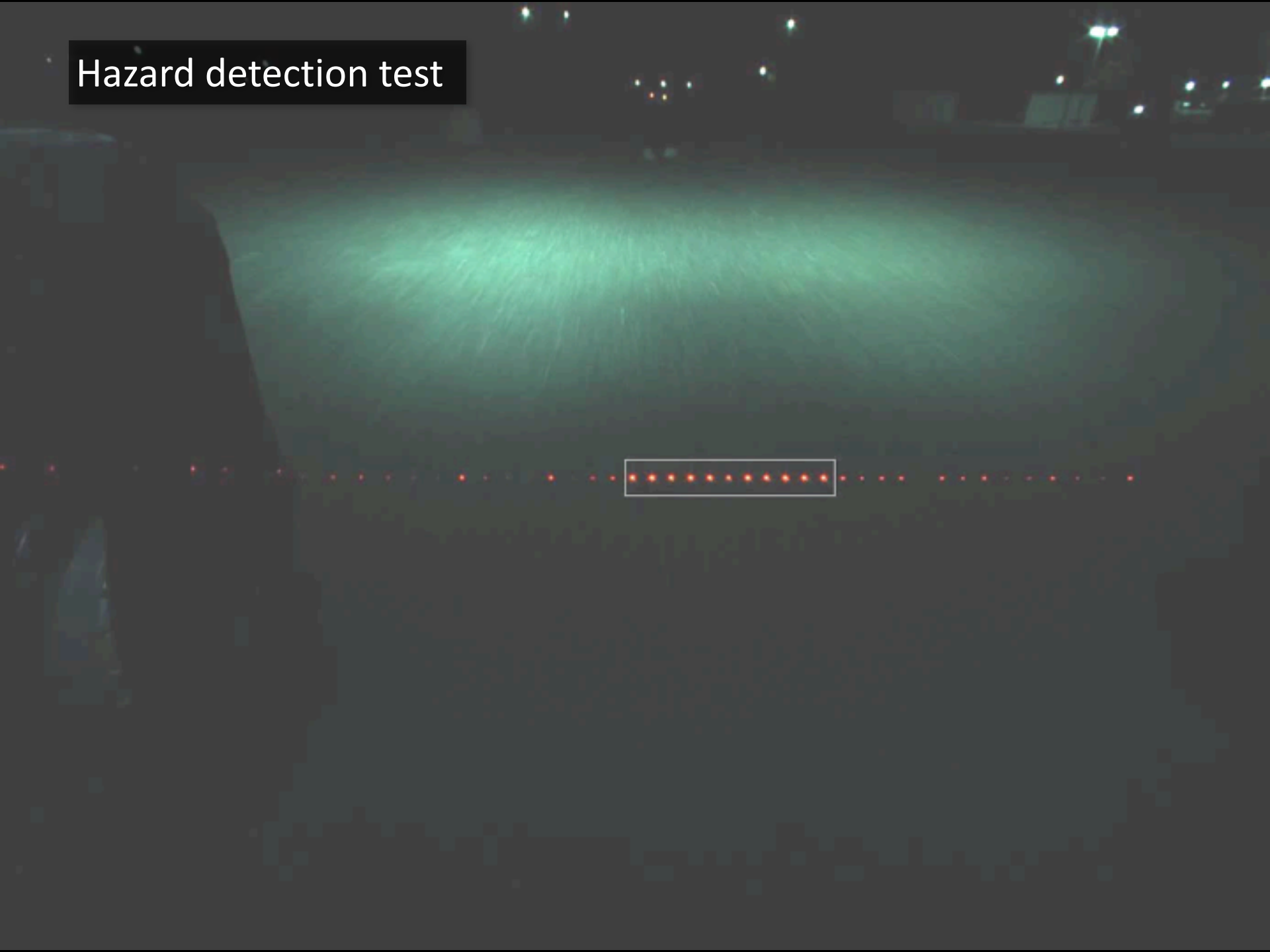


NASA/ Laurence Edwards

Hazard Detection with lasers






Hazard detection test

How do we prepare for a lunar mission?

NASA / Bill Anders / Apollo 8

We practice at our facilities.

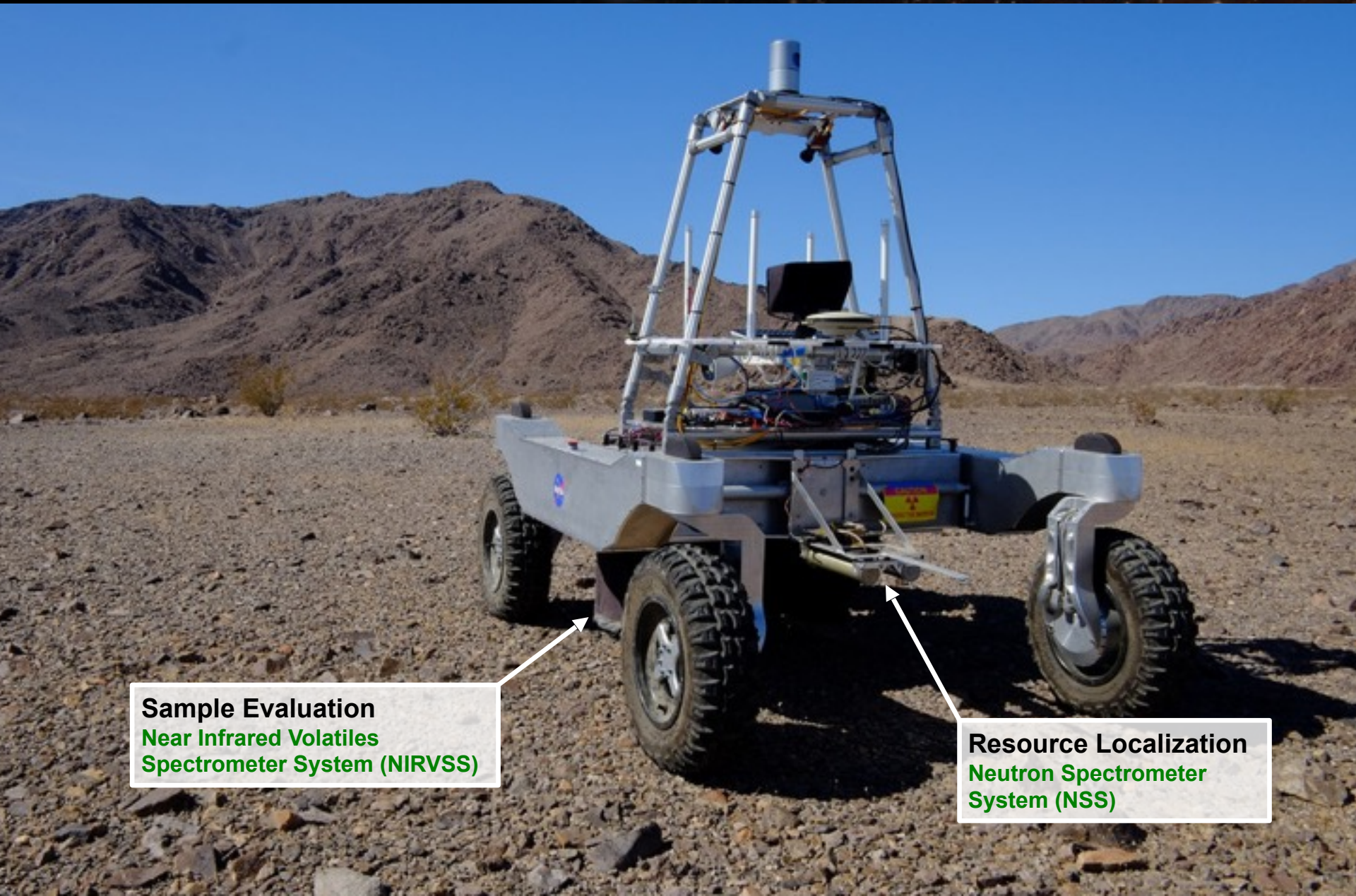
NASA ARC Mission Control driving RP15 rover at NASA JSC, August 2015

NASA JSC Rock Yard from the rover (left) stereo camera

NASA KSC Payload Control


We practice in the field with “Analog Missions”
Mojave Volatile Prospector (MVP) 2014
KRex2 rover with RESOLVE instruments

Prospecting Payload on K-REX Rover



Making sure we will find water


MVP sampling

Mojave Volatiles Prospector

How do scientists work with the rover?

NASA / Bill Anders / Apollo 8


The science team for MVP works in the back room at NASA Ames
NASA
Ames Research Center

Exploration Ground Data Systems (xGDS) for rapid remote science

Label	Note	Still	Video
sponge	area of barrel sponges		Full Video Compressed Video
sponge	space sponges		Full Video Compressed Video
other	completed first pass		Full Video Compressed Video
other	going in reverse		Full Video Compressed Video
other	start moving to waypoint		Full Video Compressed Video

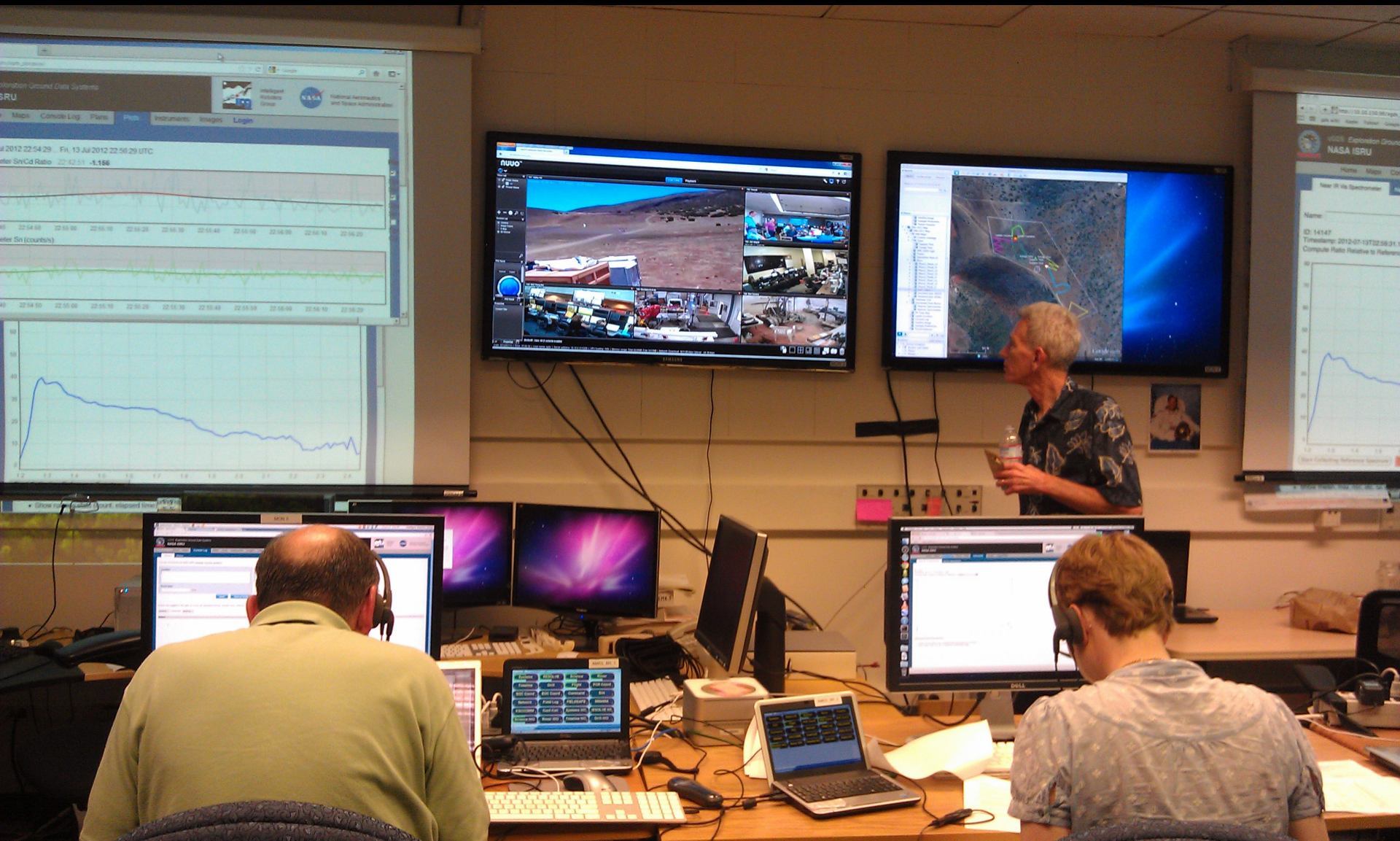
Plan

Monitor & Archive

Explore

Pre-Mission | **During Mission** | **Post-Mission**

Scientists can customize their own views of the data.



Each person in the back room has a particular job.

Scientists must also monitor the rover.

Scientists take geolocated notes within xGDS

David Lees 10/21/15 17:20:46 HST

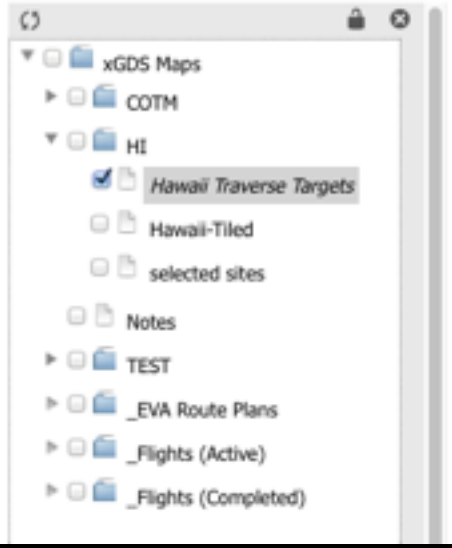
Edit Info | Add Note

Notes

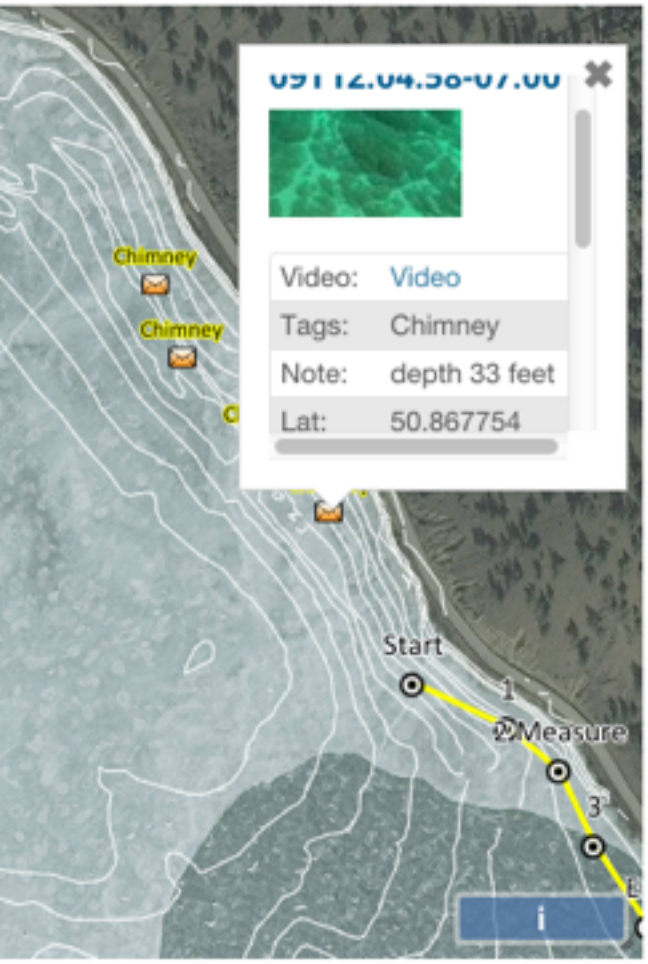
Shannon takes a pXRF reading

geology x

Save



Scientists can search for data within xGDS and use it for planning



Meta | Sequence | Layers | Search | Tools | Links

Search for: Note Start

author			
content			
flight			
label	Chimney		
Depth		up to	
New Depth		up to	

Search | Save Search

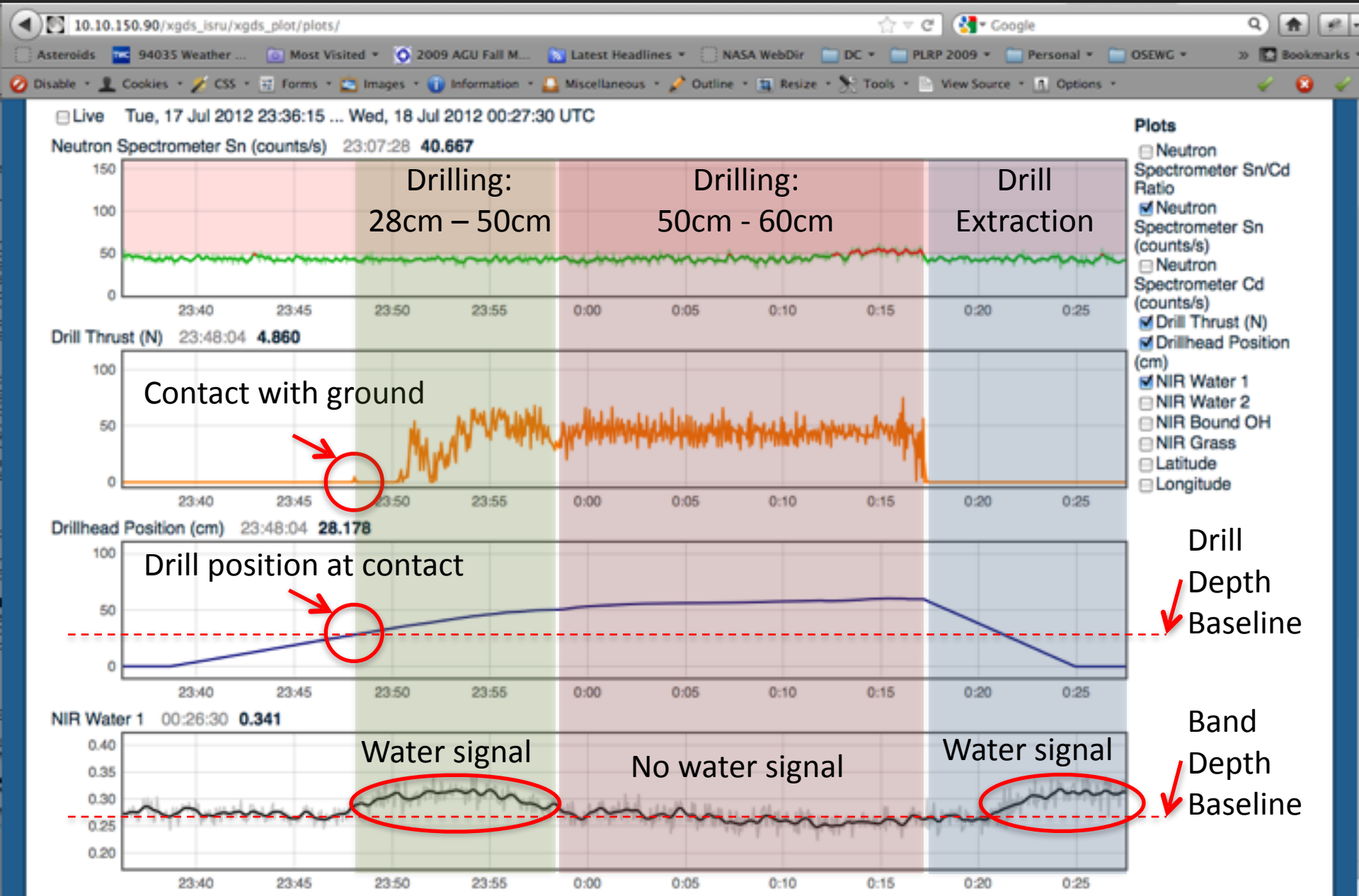
Display All Search:

flight	event_time	author	tags	content
	06T16:24:54-07:00	Cohen		artichoke like.
20090706B	2009-07-06T15:43:27-07:00	Lisa Leoni	Chimney	observed chimneys, recording, checked nnovia says not recording
20090708C	2009-07-08T17:13:59-07:00	Lisa Leoni	Chimney	tall skinny chimneys.

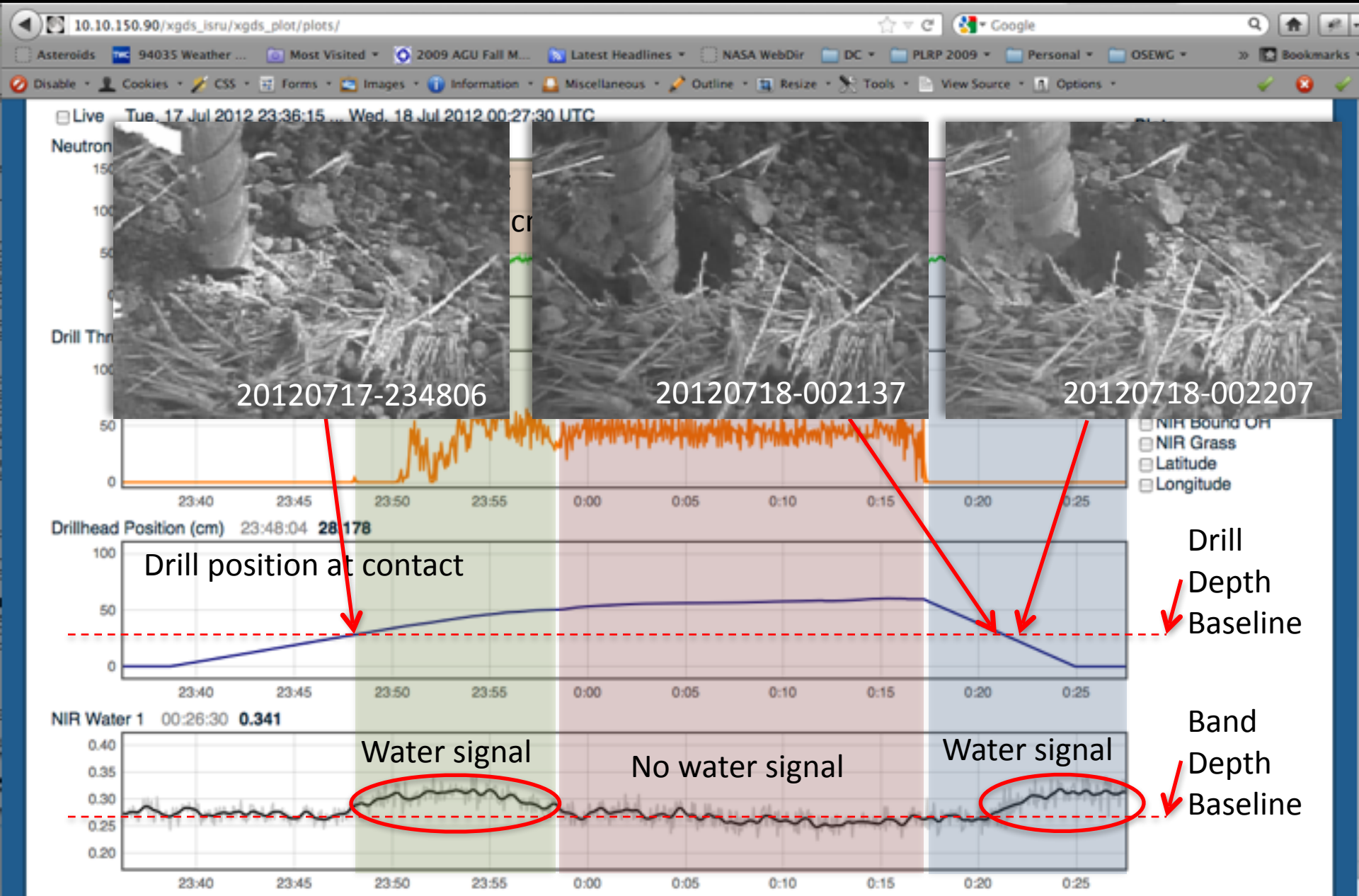
Scientists can monitor rover position, tracks, notes and other events in xGDS.

xGDS aggregates plot data

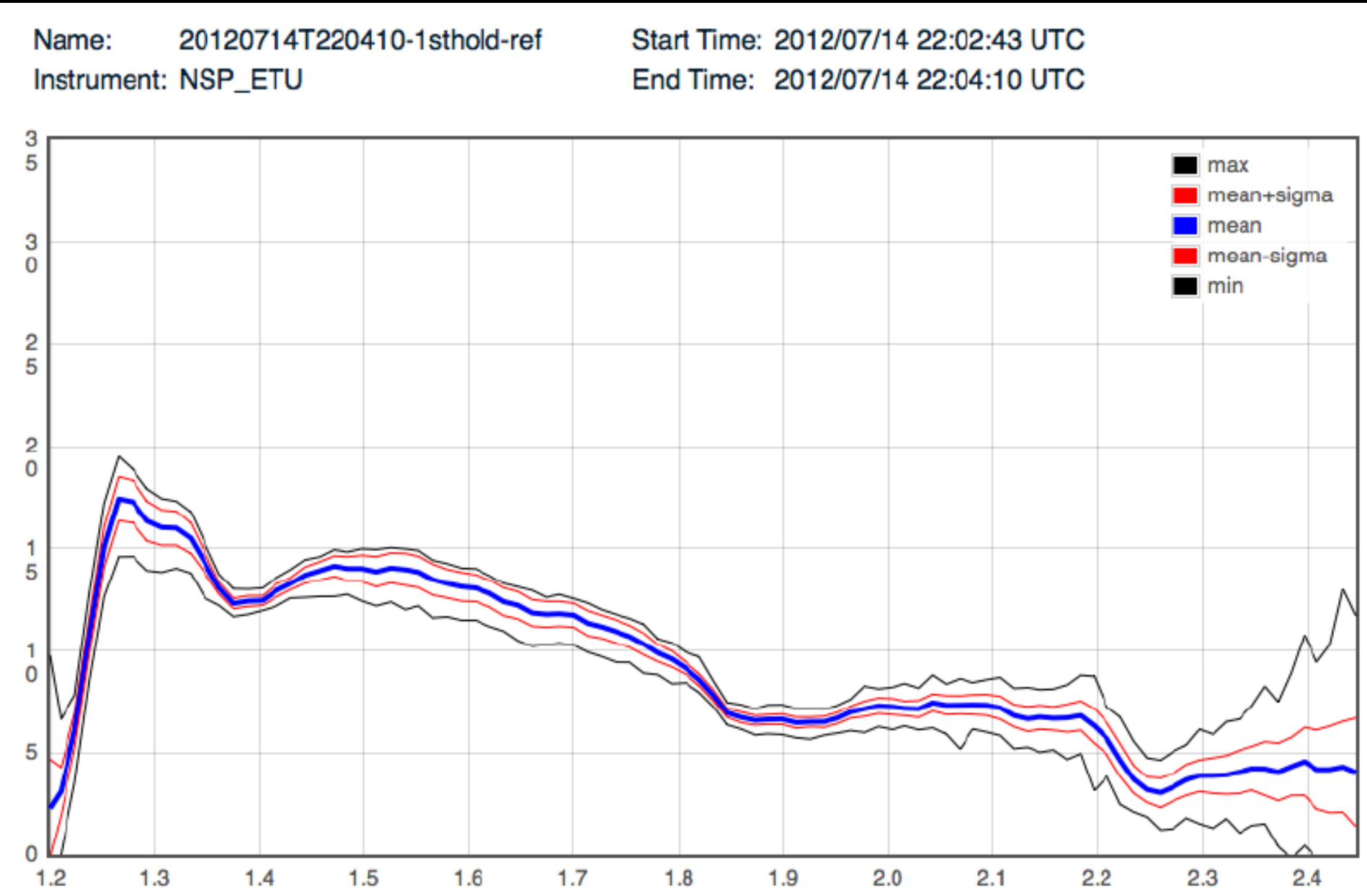
*



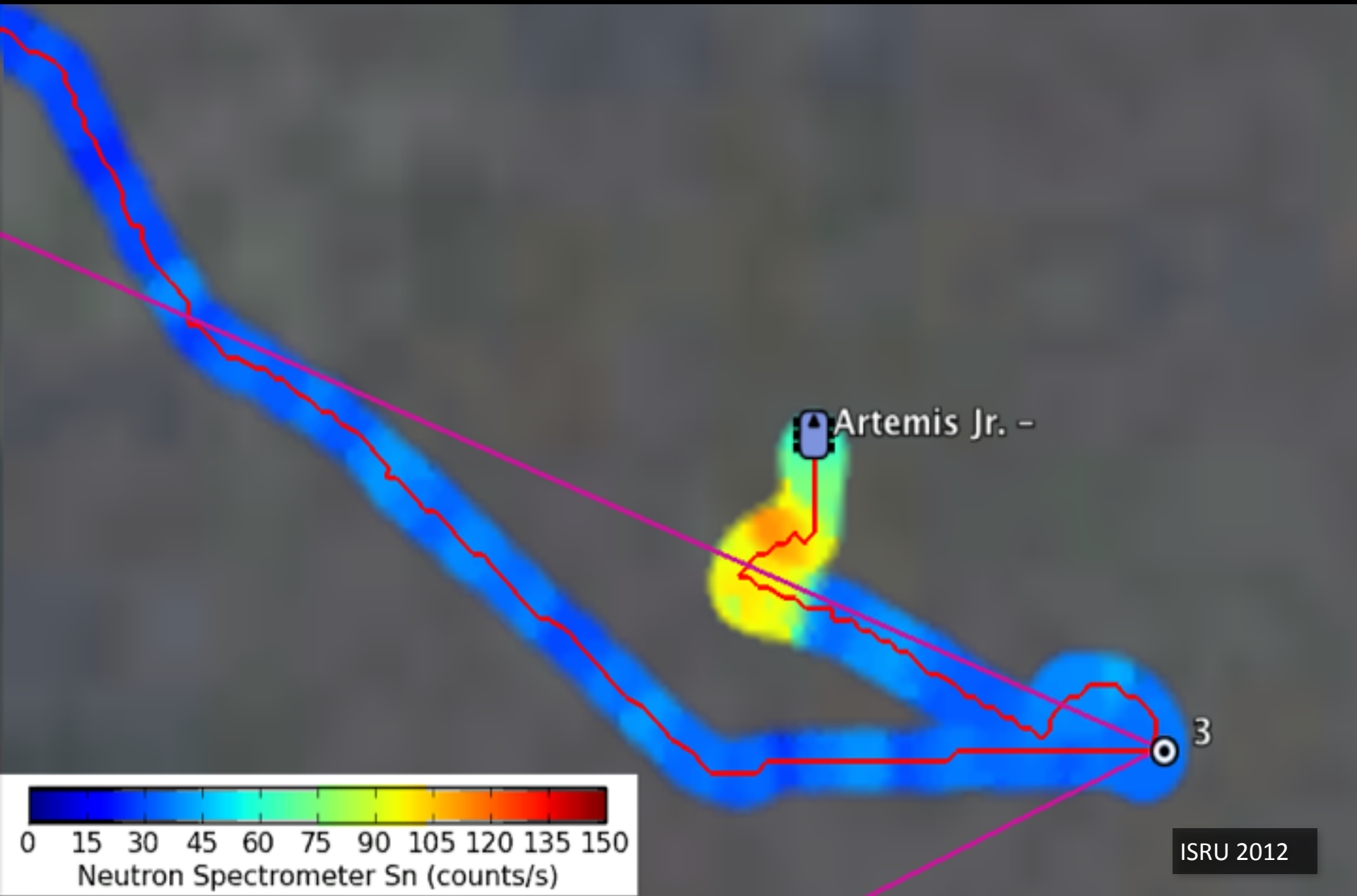
Plots correlated with images

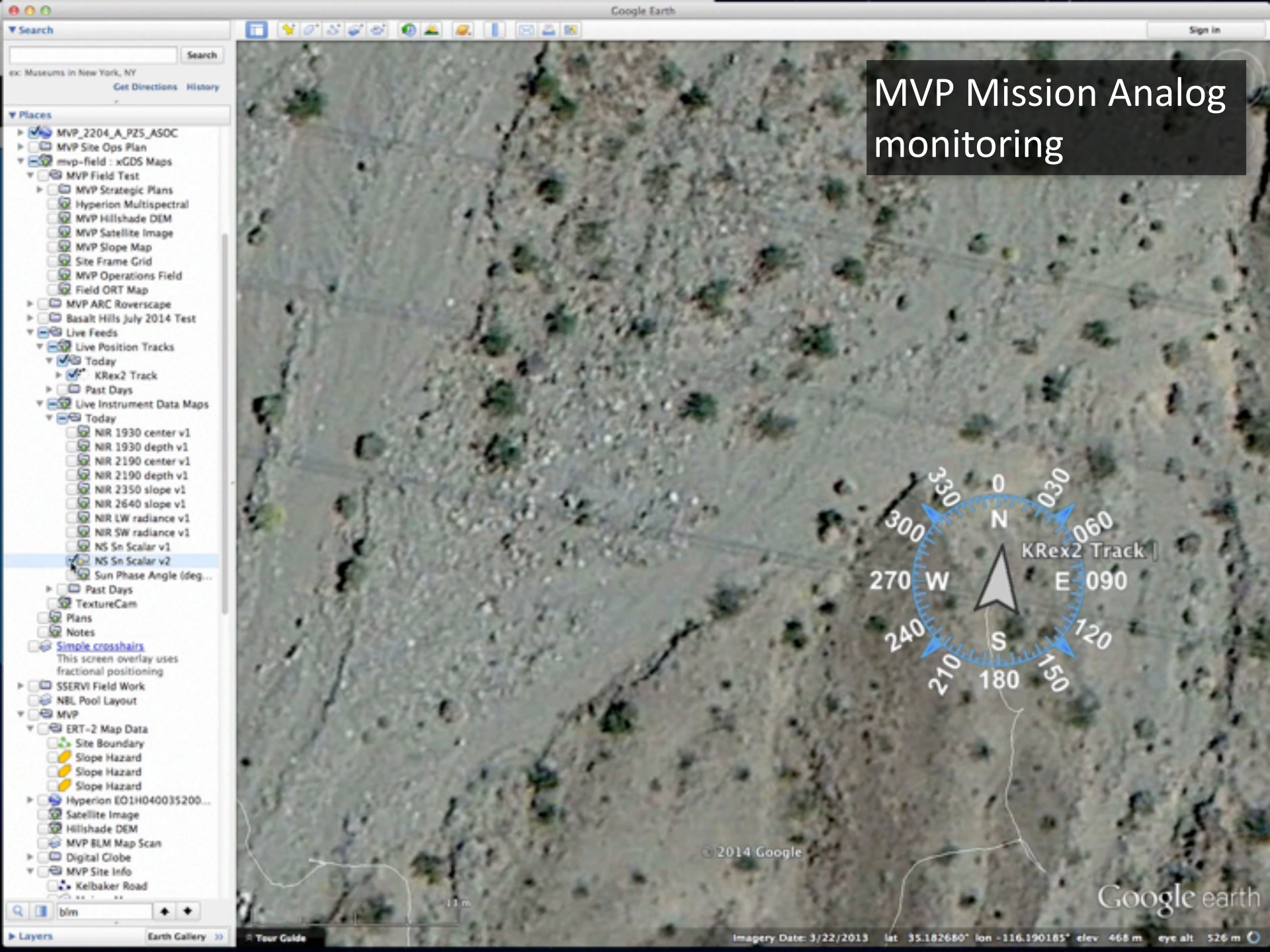


xGDS can compare instrument readings with reference spectra



xGDS can aggregate instrument readings into heat maps




MVP Mission Analog monitoring
Google Earth
Search
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Slope Hazard
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KRex2 Track
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What will this mission accomplish?

NASA / Bill Anders / Apollo 8

We will have expanded human knowledge about the moon.

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