44th International Conference on
Environmental Systems

TEXAS TECH
UNIVERSITY

A Curious Year on Mars—Long-Term Thermal Trends for Mars Science Laboratory Rover's First Martian Year

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Purpose & Overview

Purpose: Discuss the completion of Curiosity's primary mission from a thermal perspective

Mission Overview

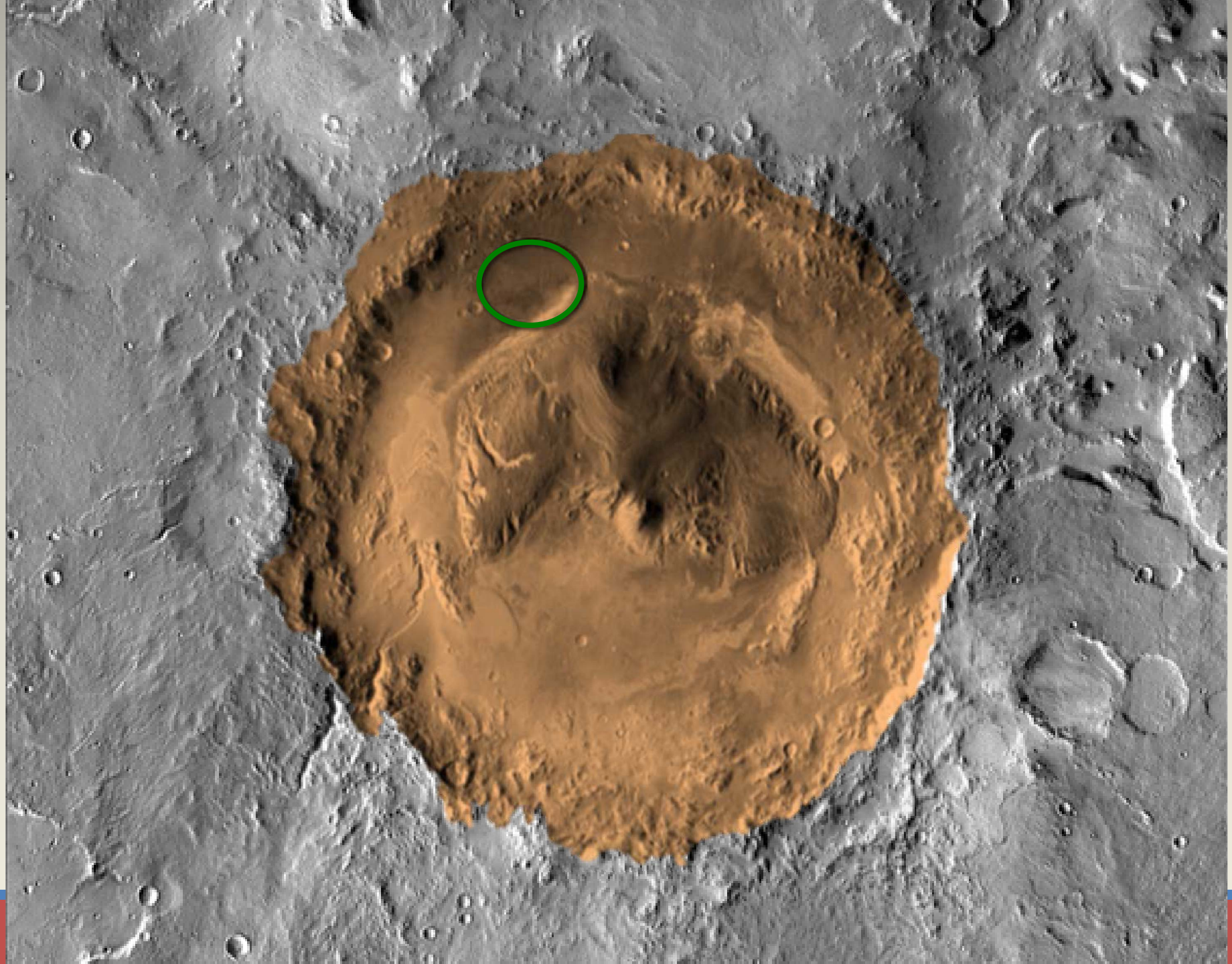
Mission Highlights

Thermal Trends—seasons, shadows, the highs and lows, and some curious behavior

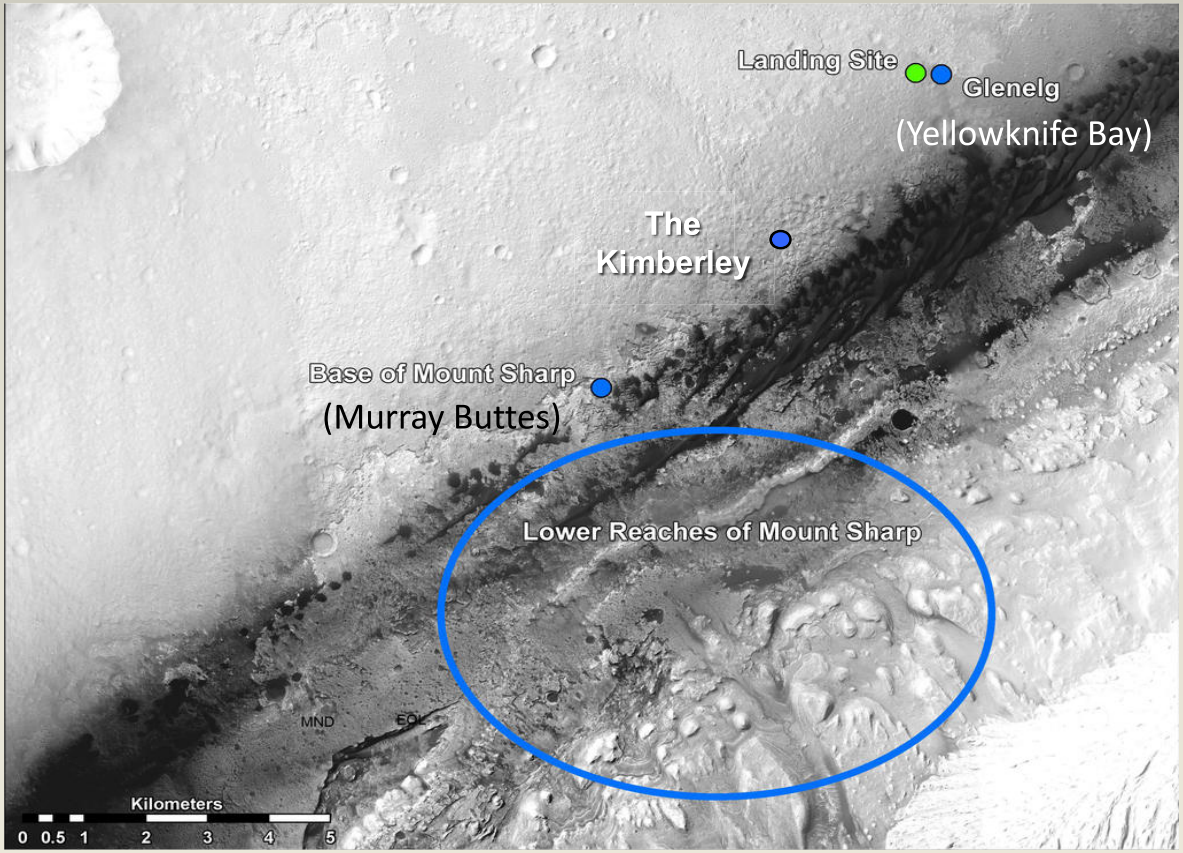
Thermal Challenges

- Helping drive the mission—helping drive further
- Protecting the rover from winter
- Assessing the thermal efficiency of the Rover
- Camera over heating

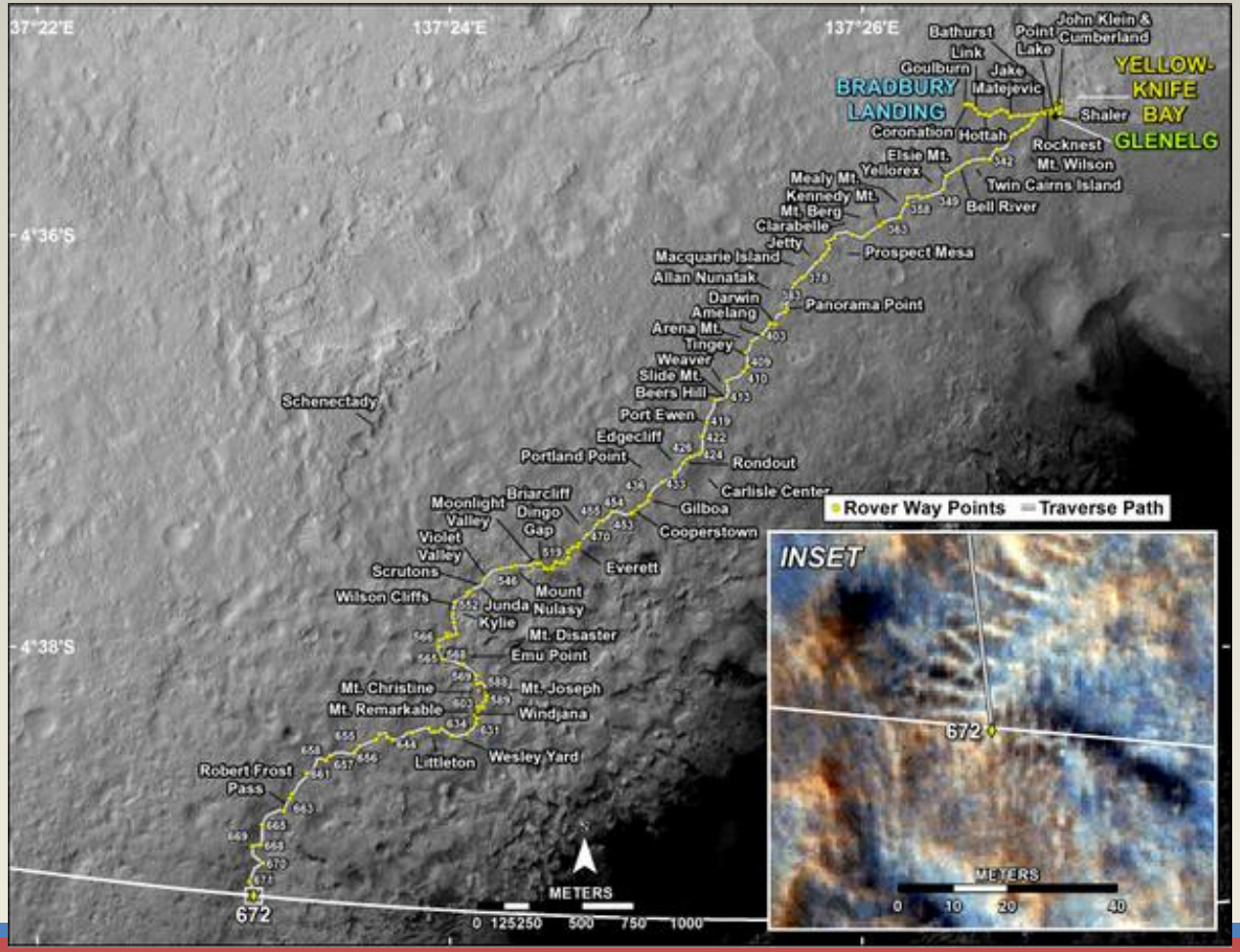
Extended Mission



Curiosity's Stomping Grounds

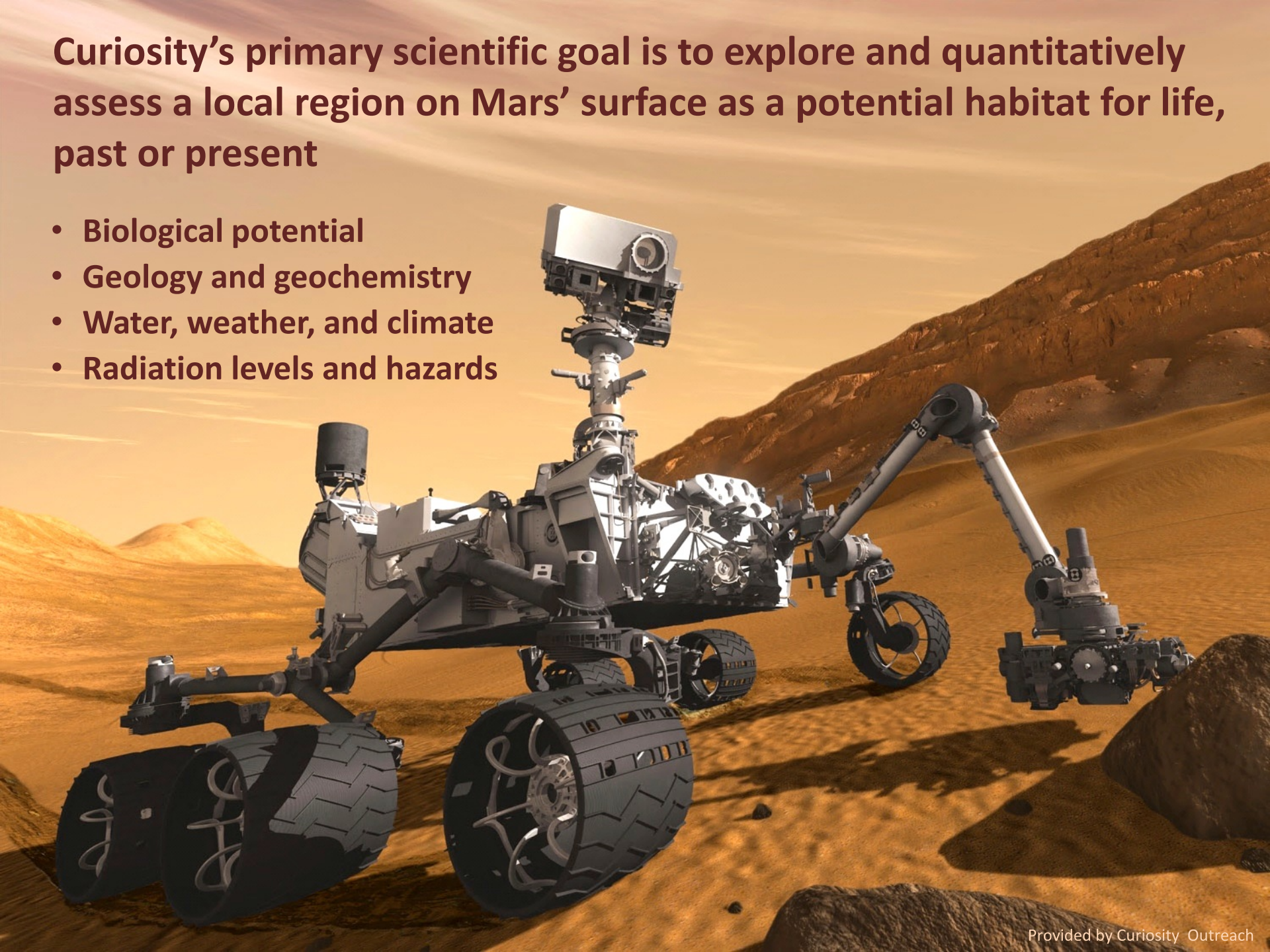


Traverse Out of the Ellipse



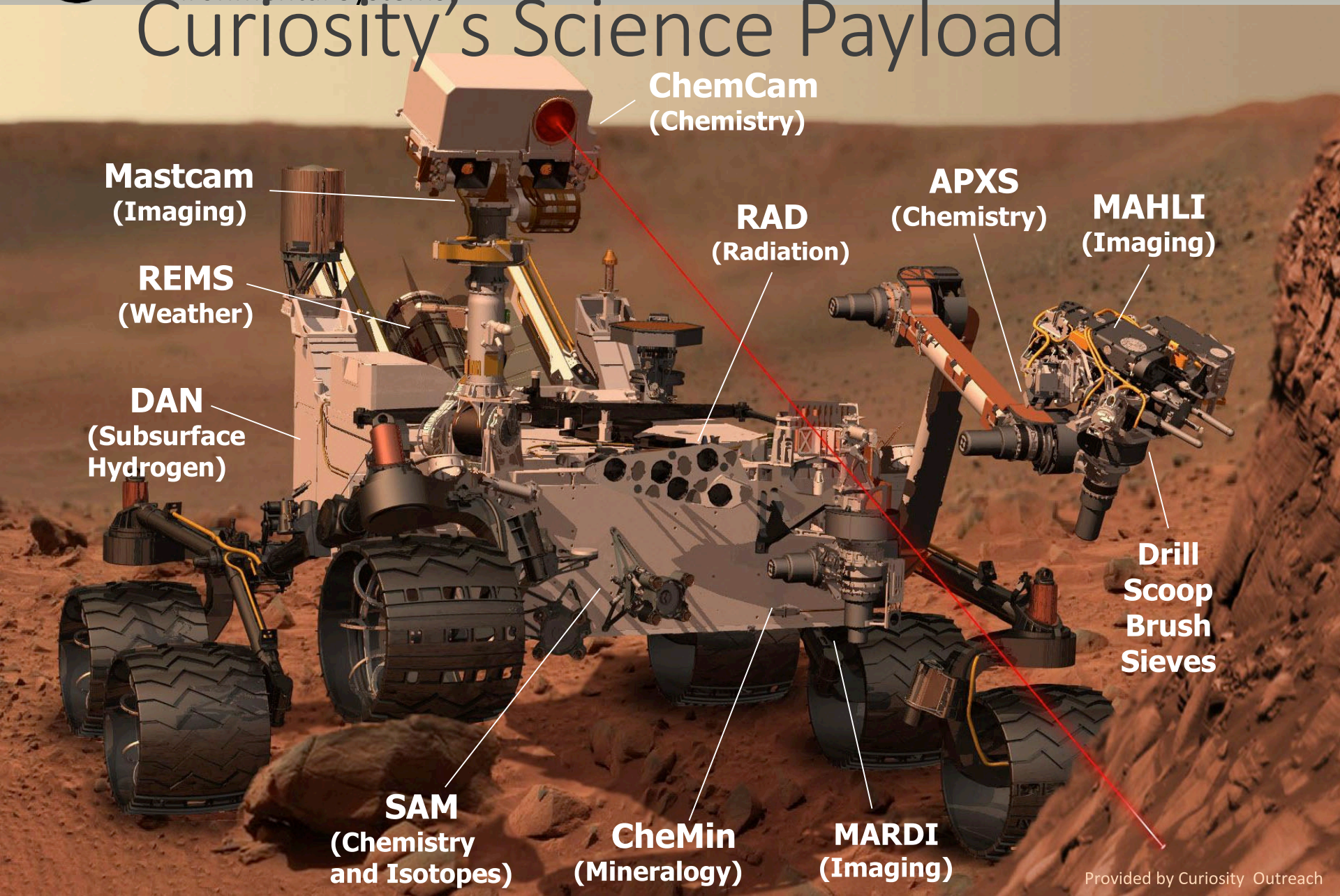
Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

- Biological potential
- Geology and geochemistry
- Water, weather, and climate
- Radiation levels and hazards

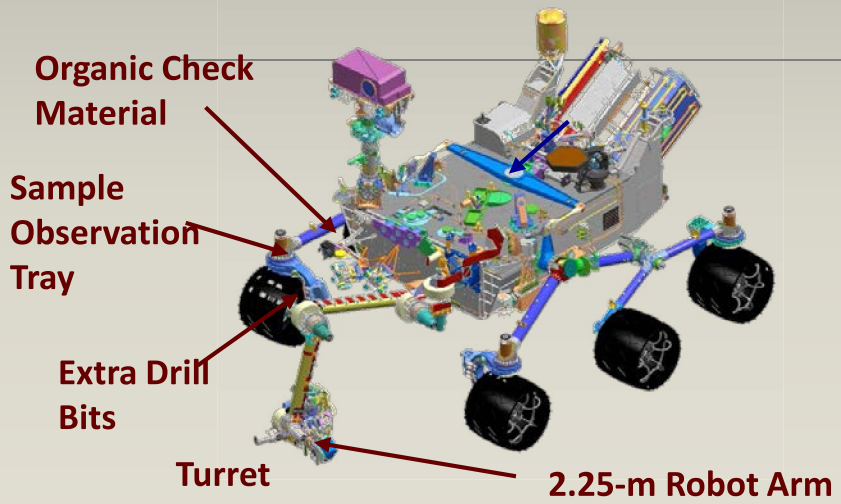


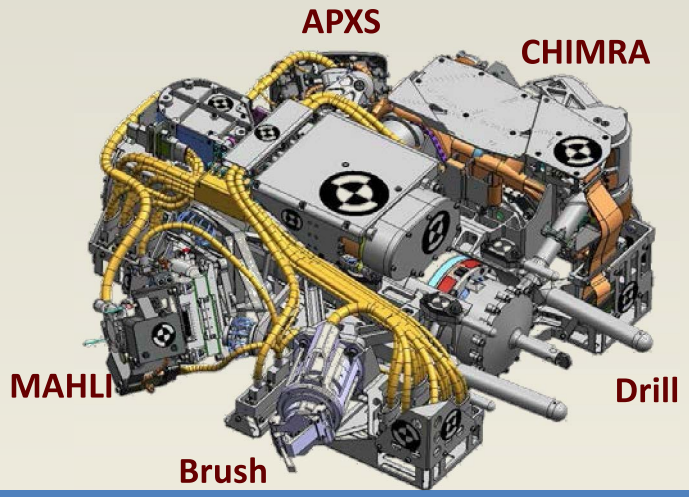
Provided by Curiosity Outreach

Curiosity's Science Payload



Curiosity's Sampling System





- Cleans rock surfaces with a brush
- Places and holds the APXS and MAHLI instruments
- Acquires samples of rock or soil with a powdering drill or scoop
- Sieves the samples (to 150 µm or 1 mm) and delivers them to instruments or an observation tray
- Exchanges spare drill bits

Highlights of Mission to Date

One complete Martian year Sol-669

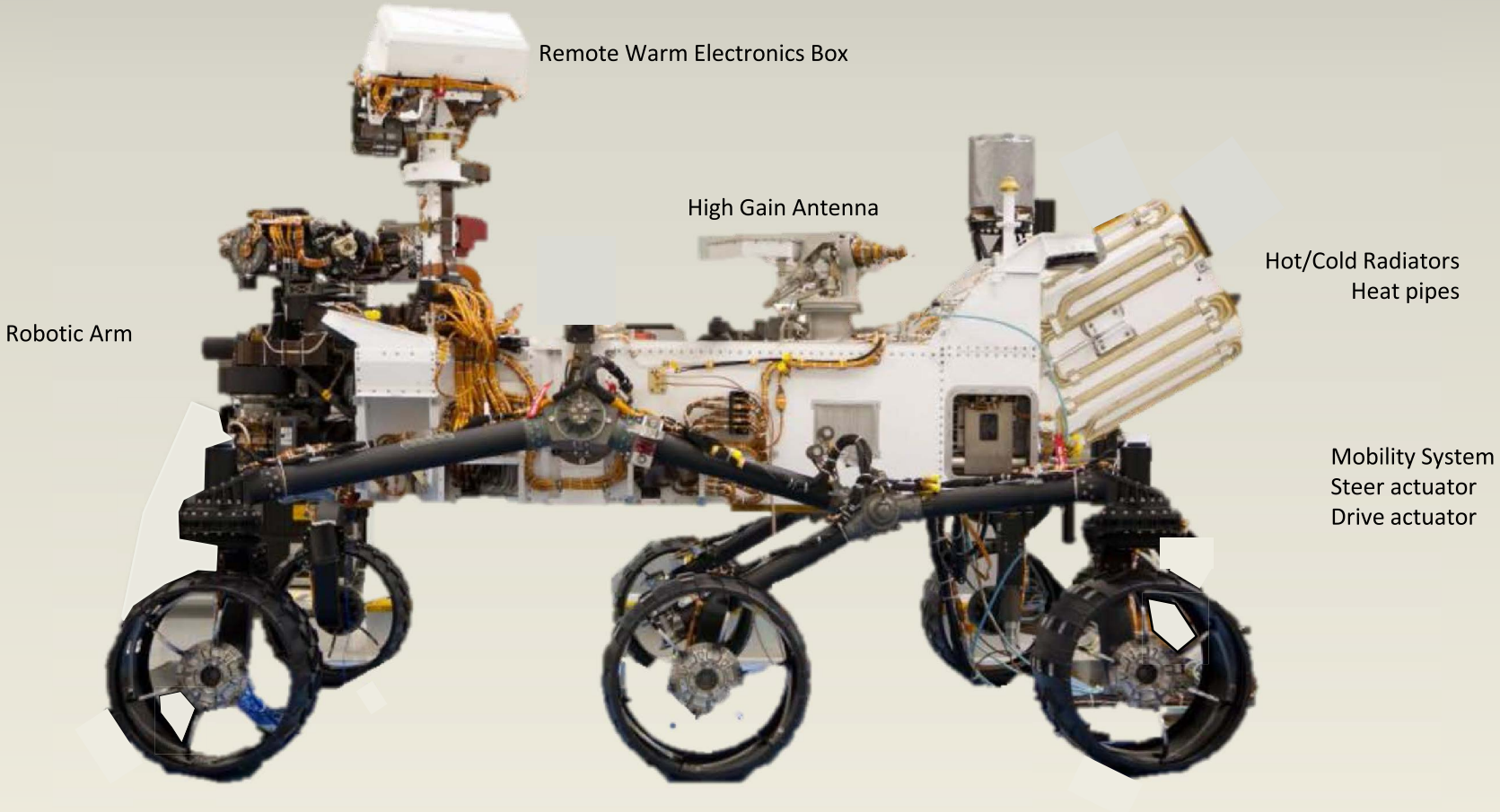
- Corresponding to Earth time of August 6, 2012 – June 23, 2014
- Traveled 8.3 Km (Sol 672), exited landing ellipse
  - Approximately 4 km SW to get to Murray Buttes, the entry point into the foothills of Mt. Sharp.

Discoveries:

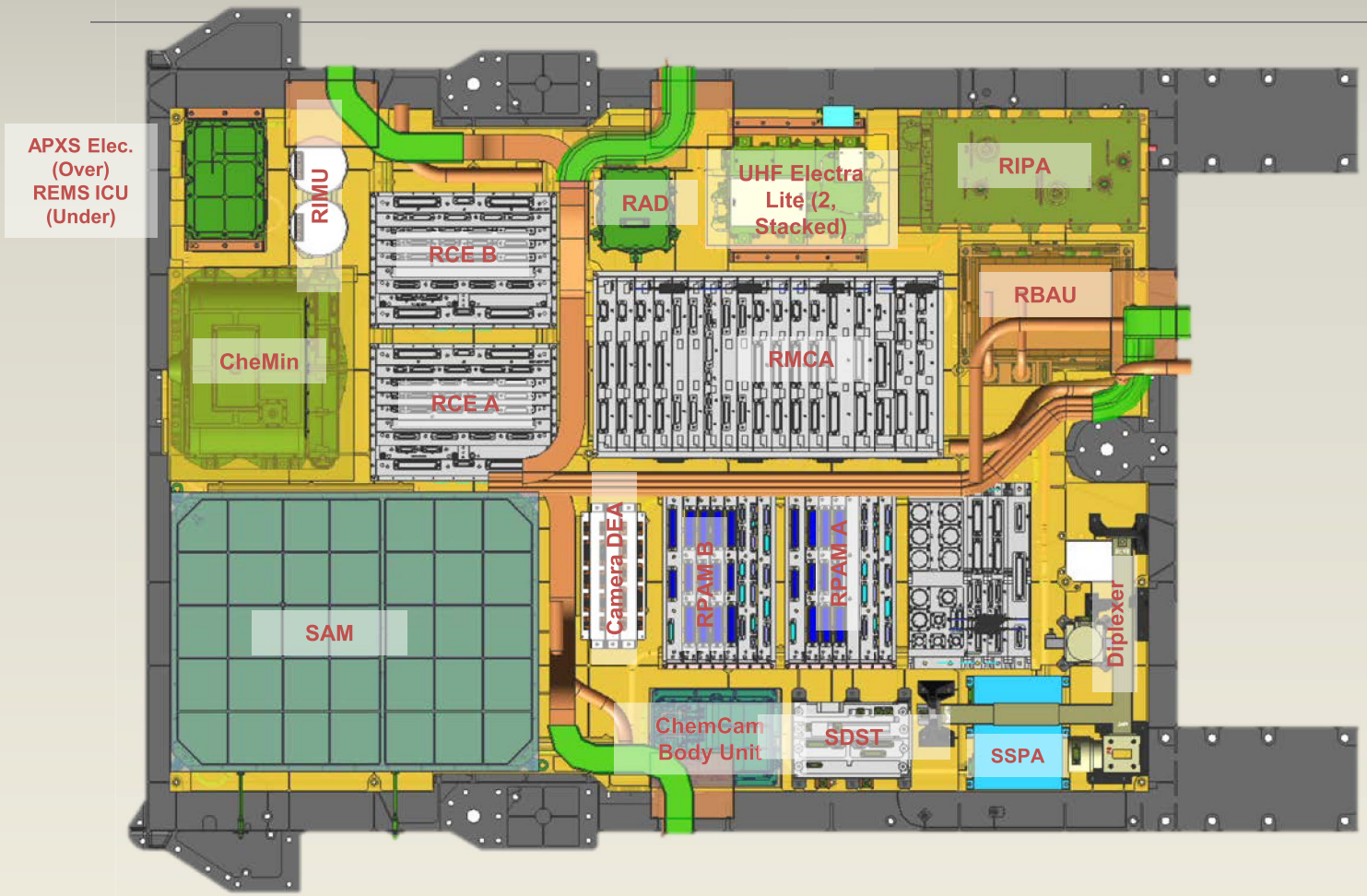
- Uncovered bedrock from Descent Engines
- Made the first drill hole on Mars, and found un-oxidized (not red) sediments
- Ancient river bed
  - Found round pebbles in a sand conglomerate that indicate water flow,
  - Onboard chemistry labs have detected clay and minerals that are consistent with flowing water and different from other portions of Gale Crater.


NASA/JPL-Caltech/MSSS
NASA/JPL-Caltech/MSSS

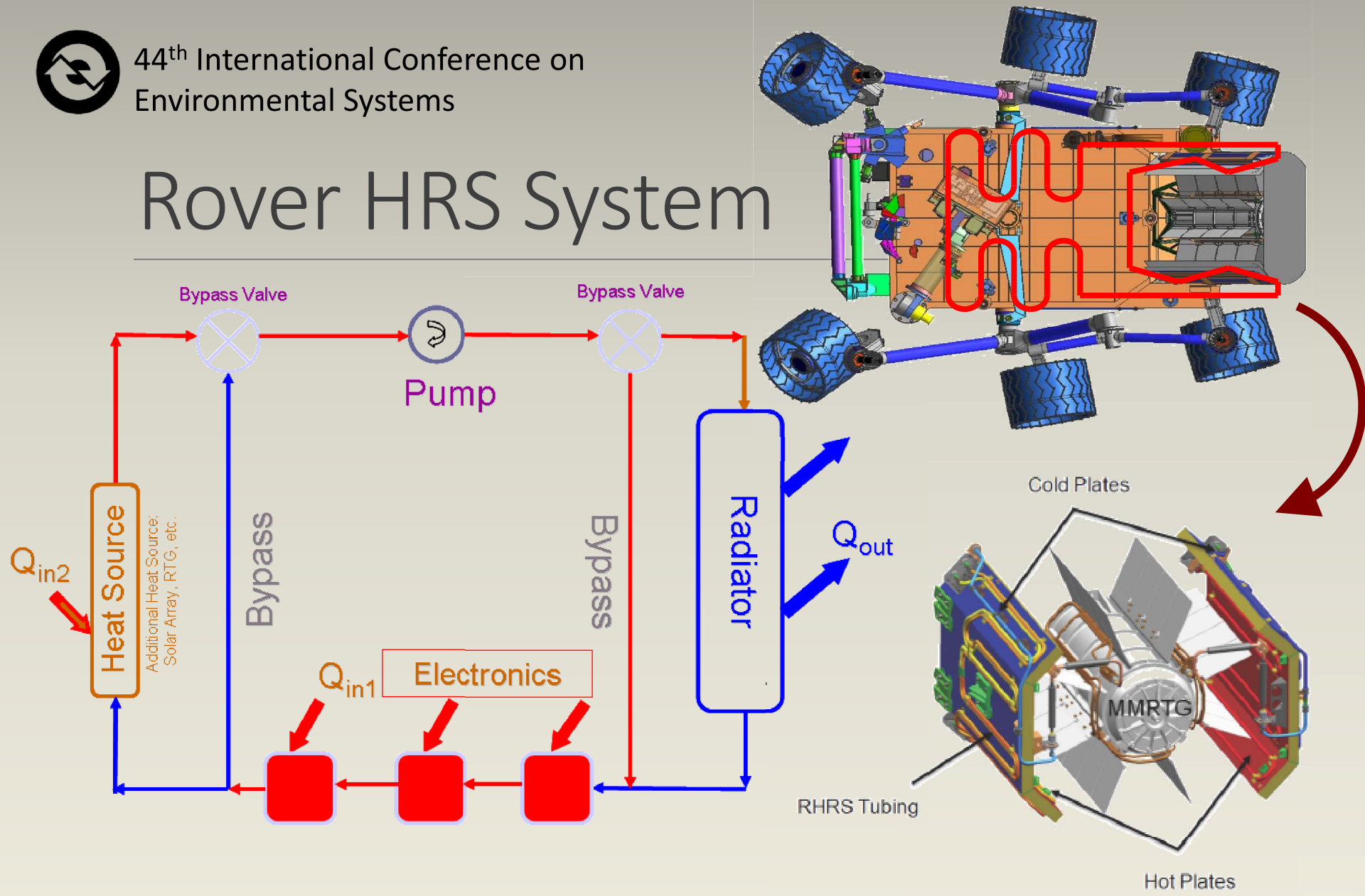
Curiosity's Engineering System



Curiosity's Engineering Subsystems

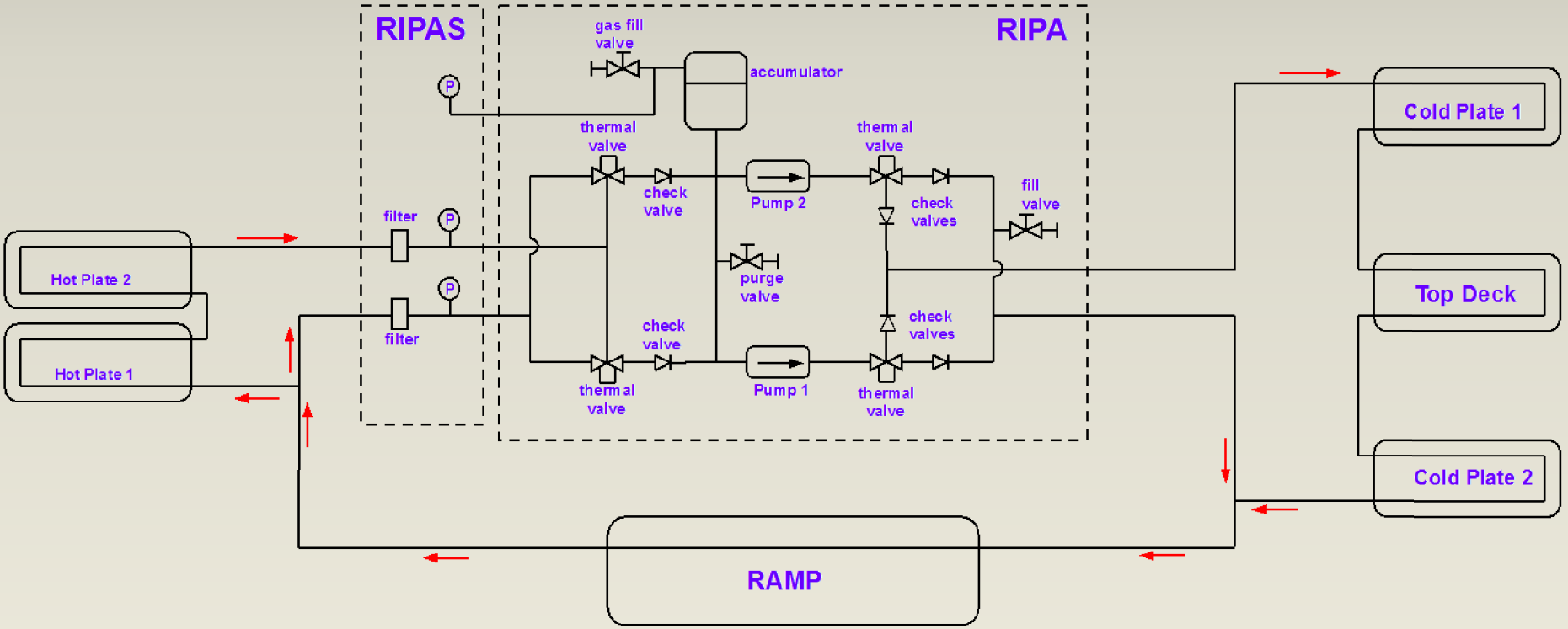


Rover HRS System



Images provided by Pradeep Bhanari

Rover HRS Flow Diagram



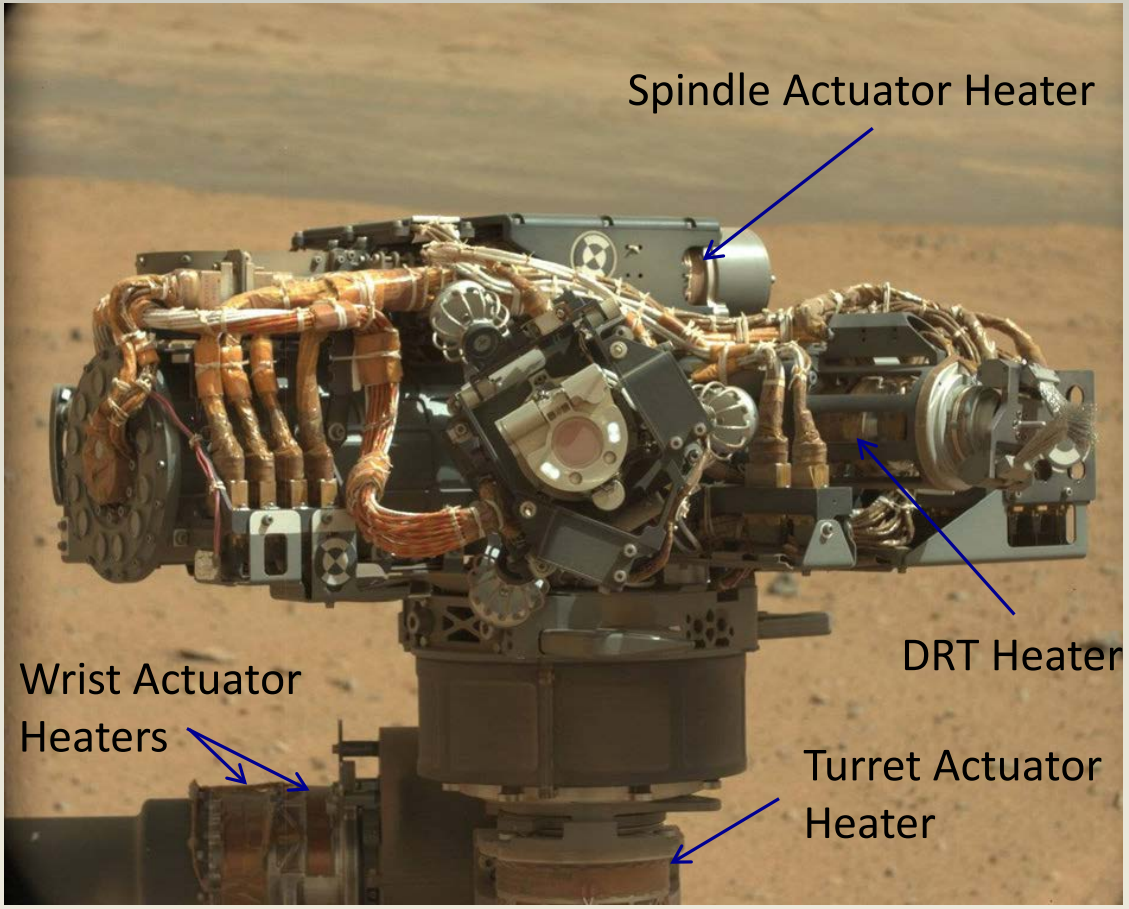
Warm-up & Survival Heating

Model derived ground commanded Heating

- There are 12 warm-up heater zones on the Rover
- **Outside -> Inside Heating**
- Prescriptions for these zones are sent up for a particular sol's activities.
- Time of Sol and Season drive the heater prescription
- Most zones have a "no-heat" window, and period during the Sol in which no-preheating is required for operations.

Thermostat Control

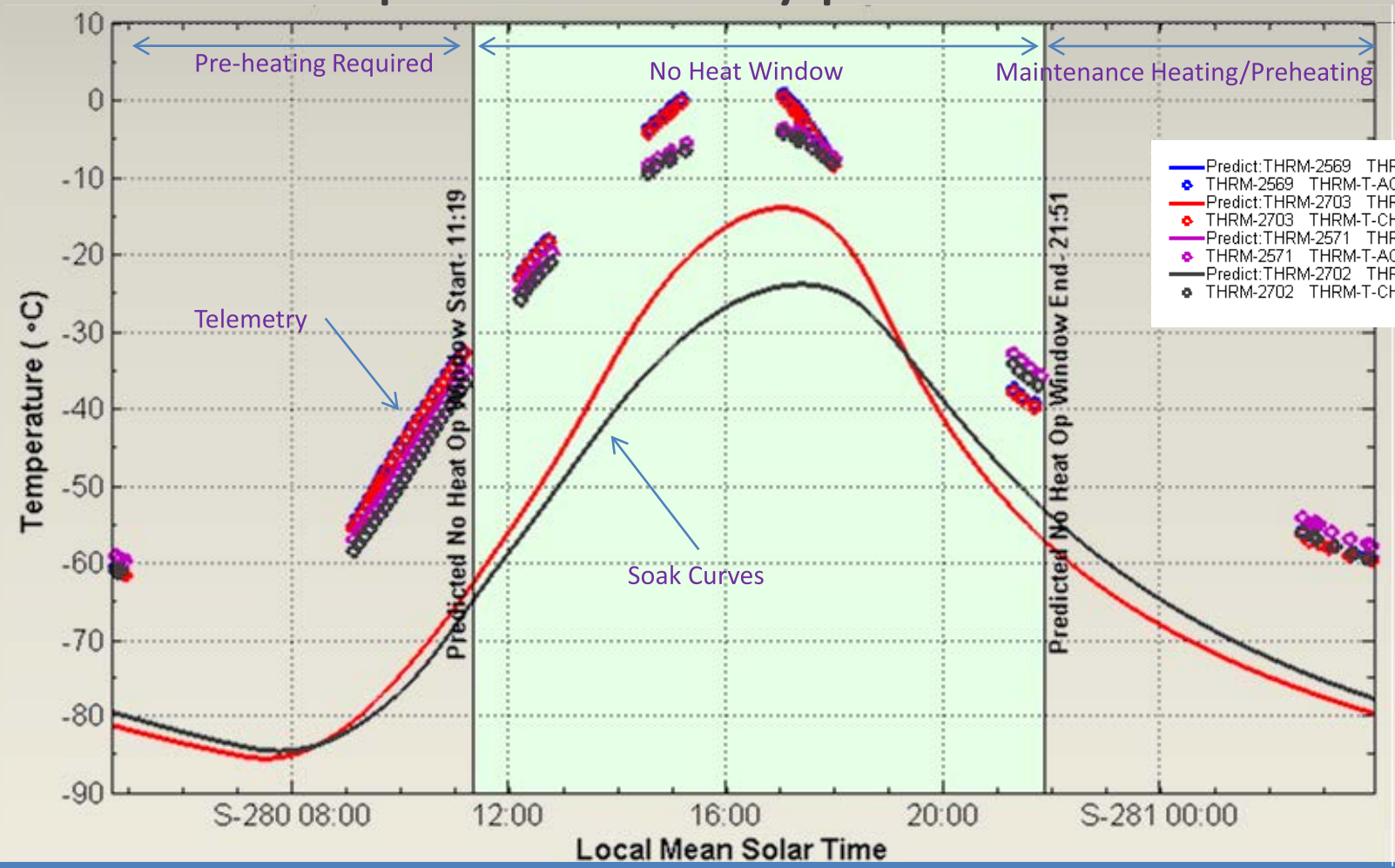
- The Rover also has 3 sets of survival heaters and 1 warm-up heater controlled by mechanical thermostat.
- These zones do not require ground determined heating.



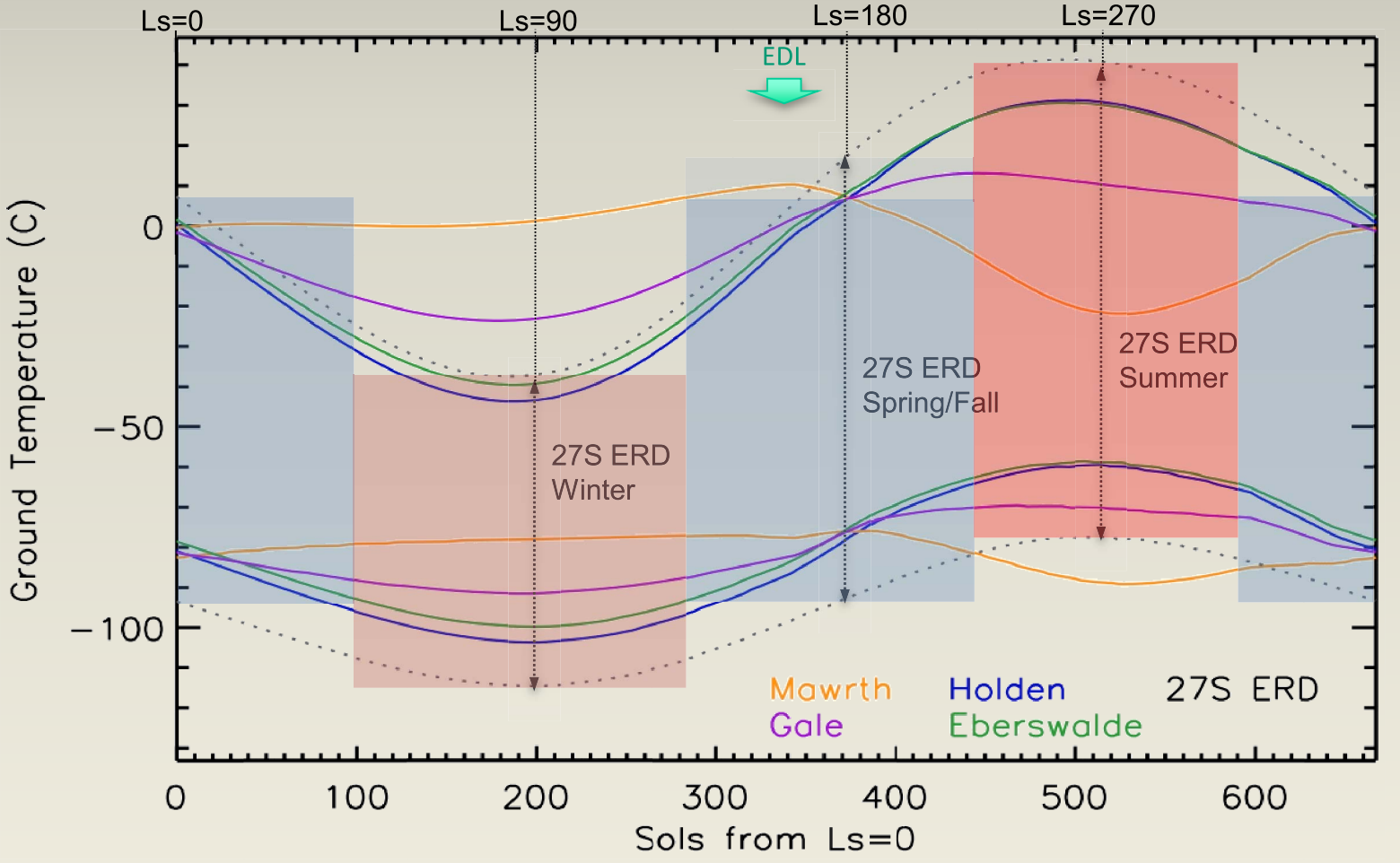
Trends & Performance

LONG THERMAL SEASONAL TRENDS AND SYSTEM PERFORMANCE

Example of a Typical Sol

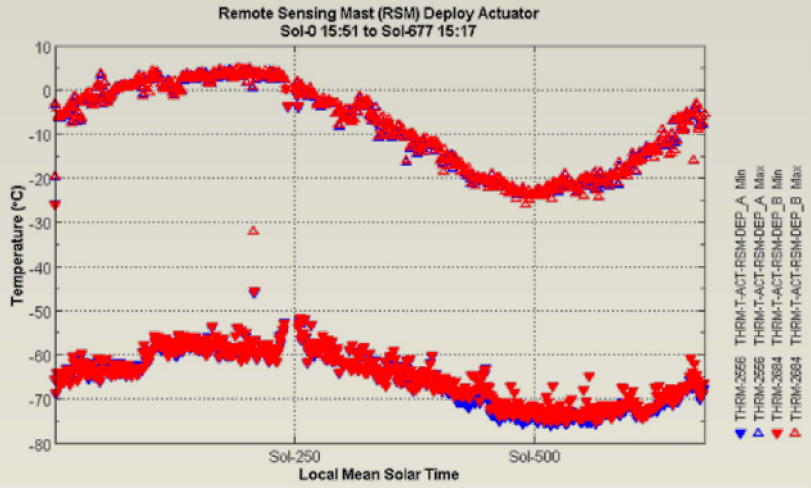


Modeled Ground Temperature For Gale Crater



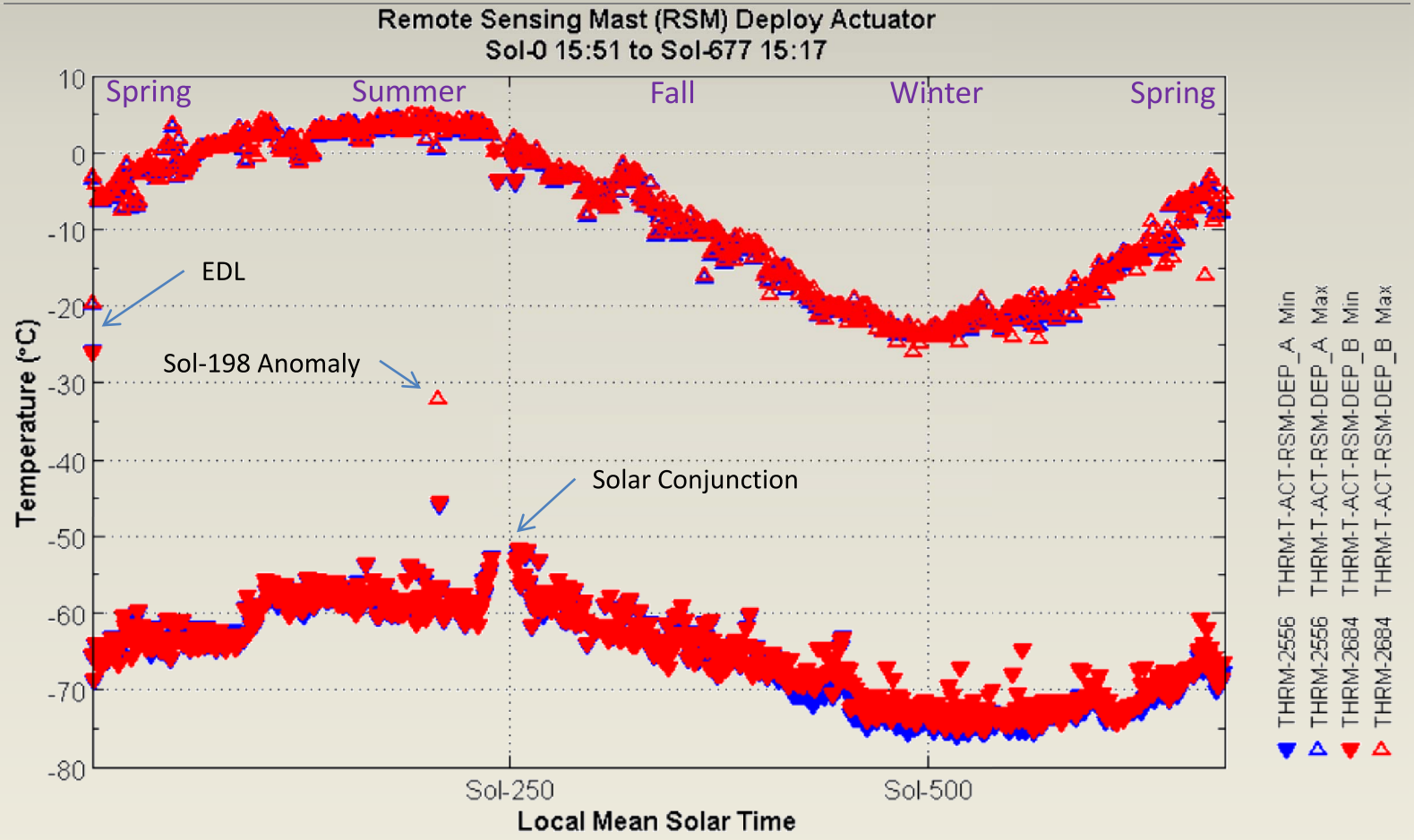
Long Term Seasonal Trends

Complete seasonal change evident in plots.

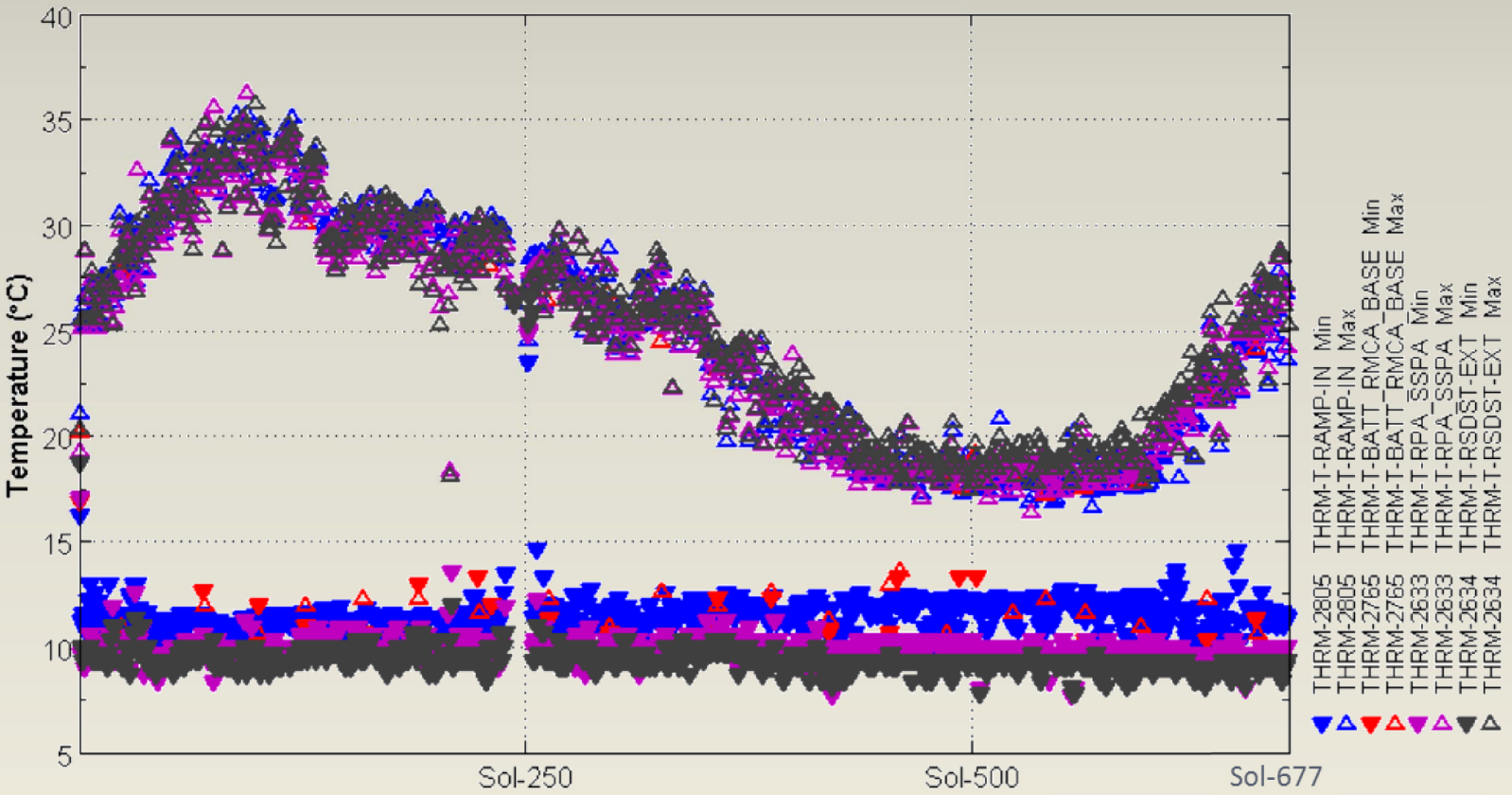


Sol	Ls	Season
0	151	Early Spring
55	180	Spring Equinox
197	270	Summer Solstice
350	0	Fall Equinox
544	90	Winter Solstice

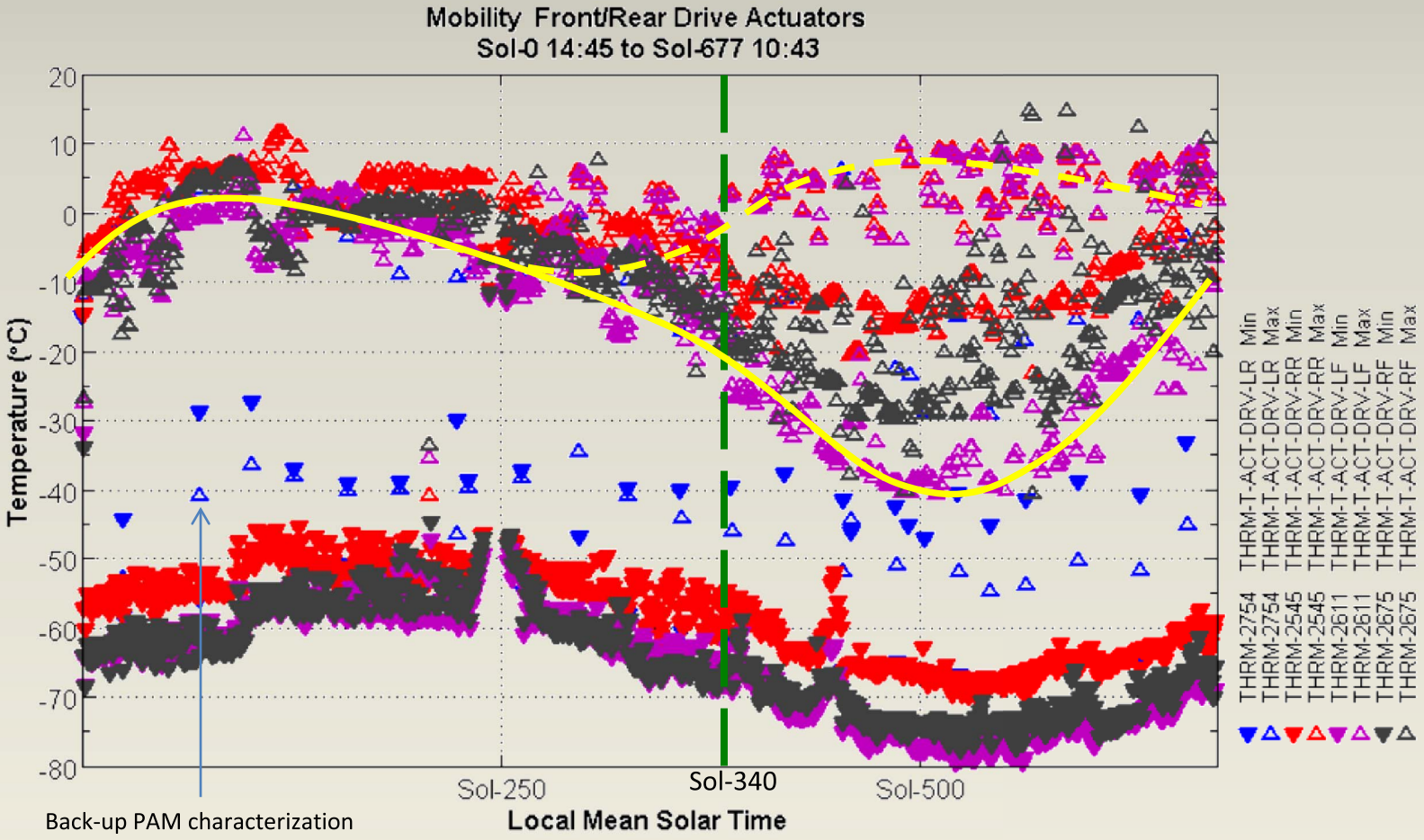
Seasonal Variation RSM Deploy Actuator



Long-Term Min/Max Temperature Trending of the RAMP near the HRS Inlet



Mobility Long Term Trending



Back-up PAM characterization
Approximately every 30-sols

Coldest & Hottest

Deployed arm configuration repeatedly causes our coldest temperature -95.2°C

The RTG and SAM instrument's oven internally drives to the hottest temperatures

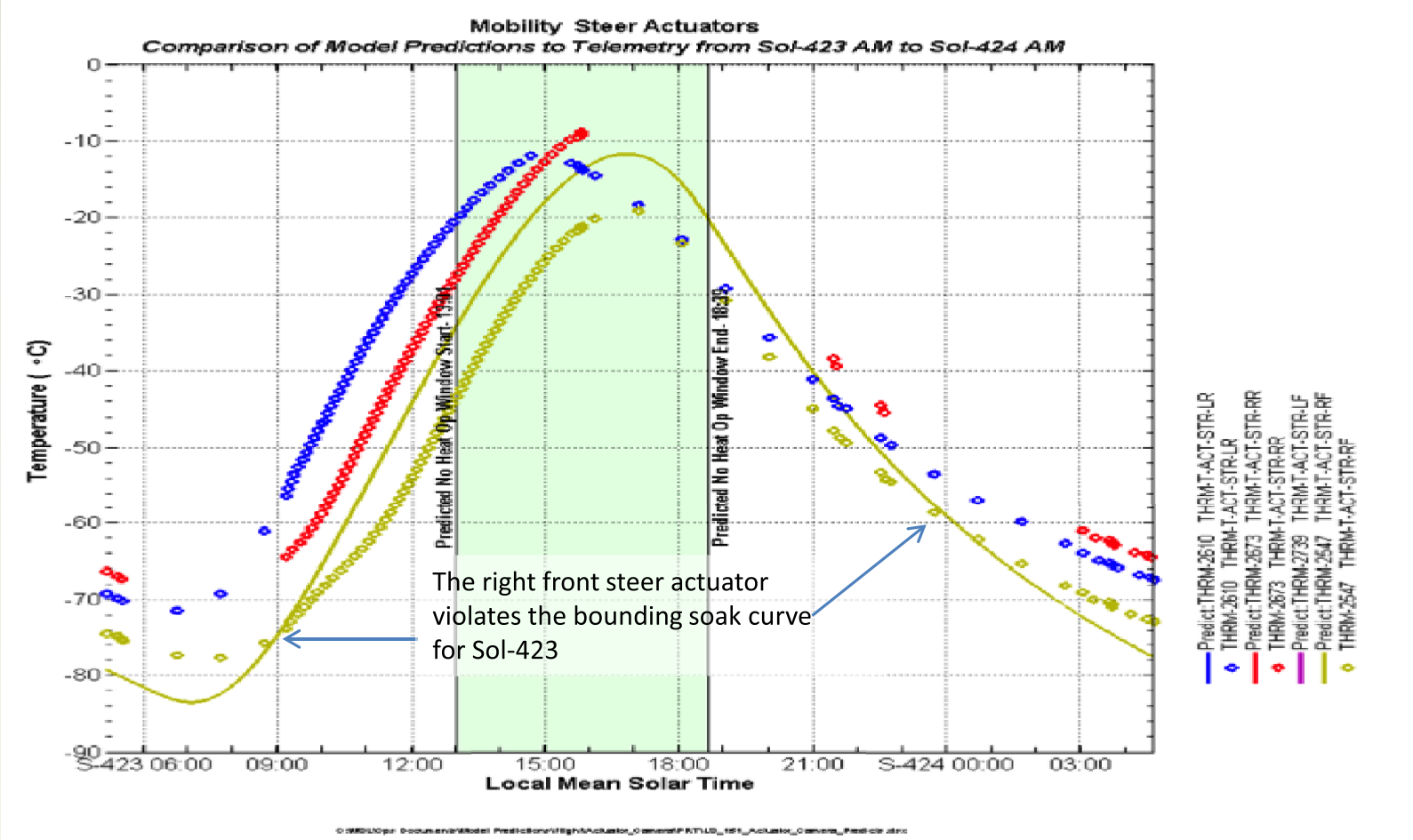
Winter & Spring Heater Tables

As Curiosity entered Martian fall, the thermal team watched for telemetry violations of the bounding soak temperatures.

The plan was to swap from the Ls-151 (landing) tables to the Ls-90 (winter) tables.

- The going in plan did not looks so palatable to mission planners once we were there.
- A comparison of the change in the no-heat windows follows

151 Soak Curve Violation



Comparison of No-Heat Windows

Sol Number : 300

Subsys	Ls151		
	Start_LMST	End_LMST	Duration
RA	12:59	22:10	**9:11**
CHIMRA	11:19	21:51	**10:31**
Drill	N/A	N/A	**0:00**
DRT	10:10	21:13	**11:03**
Inlet Covers	9:53	23:27	**13:34**
HGA	8:25	0:44	**16:19**
RSM	12:07	22:01	**9:54**
RSM Deploy	11:21	23:05	**11:43**
Mobility	13:13	19:17	**6:04**
MAHLI	10:31	19:02	**8:31**
MastCam	11:42	19:05	**7:22**
Frt HazCam	10:03	22:36	**12:32**
Rear HazCam	7:14	4:08	**20:54**
NavCam	10:40	21:02	**10:22**
MARDI	10:52	19:31	**8:38**

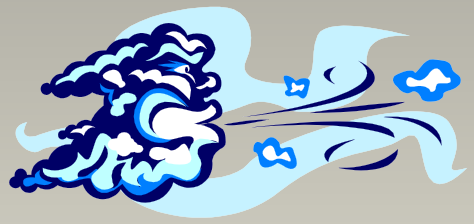
Sol Number : 300

Subsys	Ls90 Winter		
	Start_LMST	End_LMST	Duration
RA	15:52	19:57	**4:05**
CHIMRA	14:31	19:27	**4:56**
Drill	N/A	N/A	**0:00**
DRT	15:09	19:05	**3:56**
Inlet Covers	11:42	19:33	**7:51**
HGA	10:36	21:20	**10:44**
RSM	15:06	19:14	**4:08**
RSM Deploy	15:37	19:17	**3:40**
Mobility	15:32	18:41	**3:09**
MAHLI	13:26	18:15	**4:49**
MastCam	N/A	N/A	**0:00**
Frt HazCam	11:21	19:54	**8:33**
Rear HazCam	9:32	23:38	**14:06**
NavCam	15:34	18:17	**2:43**
MARDI	13:48	18:44	**4:56**

Duration Differences

Subsystem	Change in duration
RA	5:06
CHIMRA	5:35
Drill	0:00
DRT	7:07
Inlet Covers	5:43
HGA	5:35
RSM	5:46
RSM Deploy	8:03
Mobility	2:55
MAHLI	3:42
MastCam	7:22
Frt HazCam	3:59
Rear HazCam	6:48
NavCam	7:39
MARDI	3:42

Winter Violations



By Sol-423, we saw some subsystems dip below the Ls-90 soak curves, indicating that the bounding model wasn't precisely bounding the subsystem.

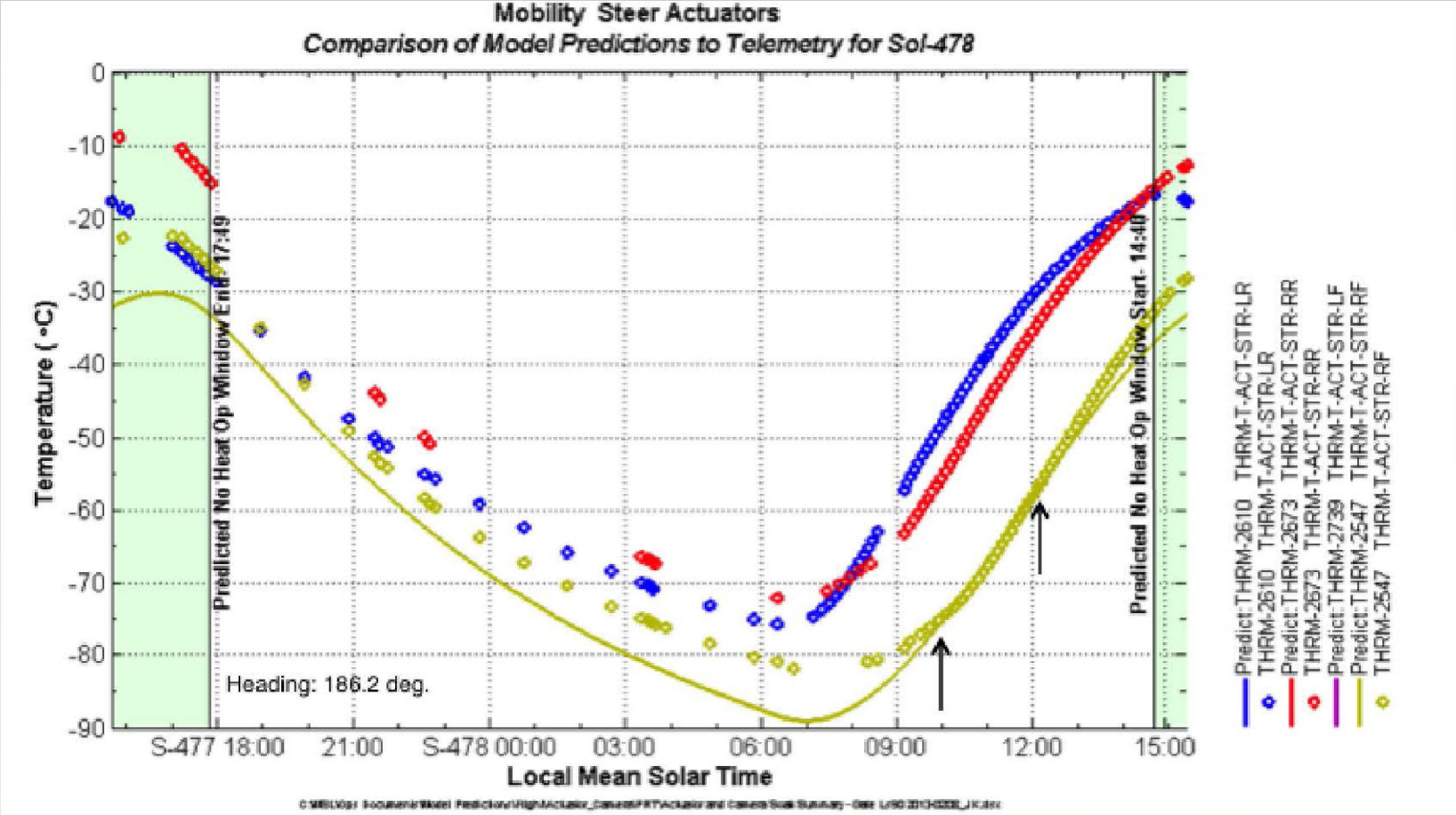
This required the generation of custom heating prescriptions based on:

Recent time of violation

Predicted temperatures

New Heating Duration

Winter Soak Curve Violation

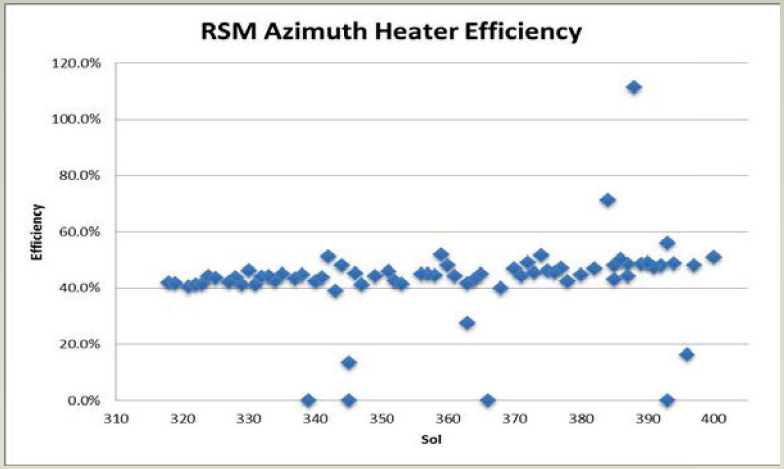


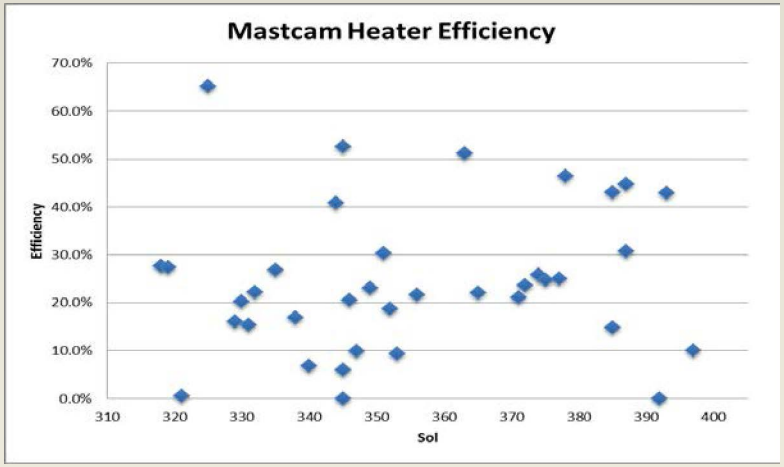
Heater System Performance: Hybrid Heating

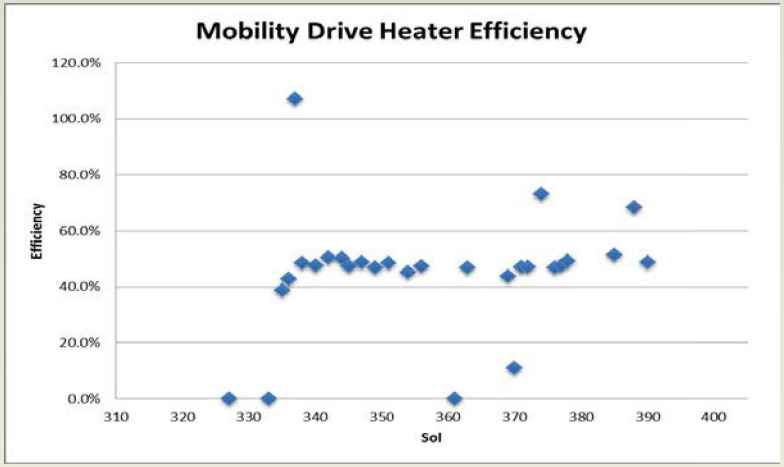
Comparison of planned duration versus actual time to target temperature.

Some systems show great variability.

Others show a consistent performance







Heater Efficiency

Heating is based on bounding conditions, not on daily weather prediction.

- Therefore most Sols the heater duration and target temperature are more conservative than the conditions might otherwise warrant.

Seasonal, orientation, and terrain influences along with the ground heater table in service influence some subsystems more than others.

For the subsystems that are predictably over estimated, Thermal is giving back some of the power in a ‘fudge factor’.

HRS System Performance

The RAMP has never dipped below 4C

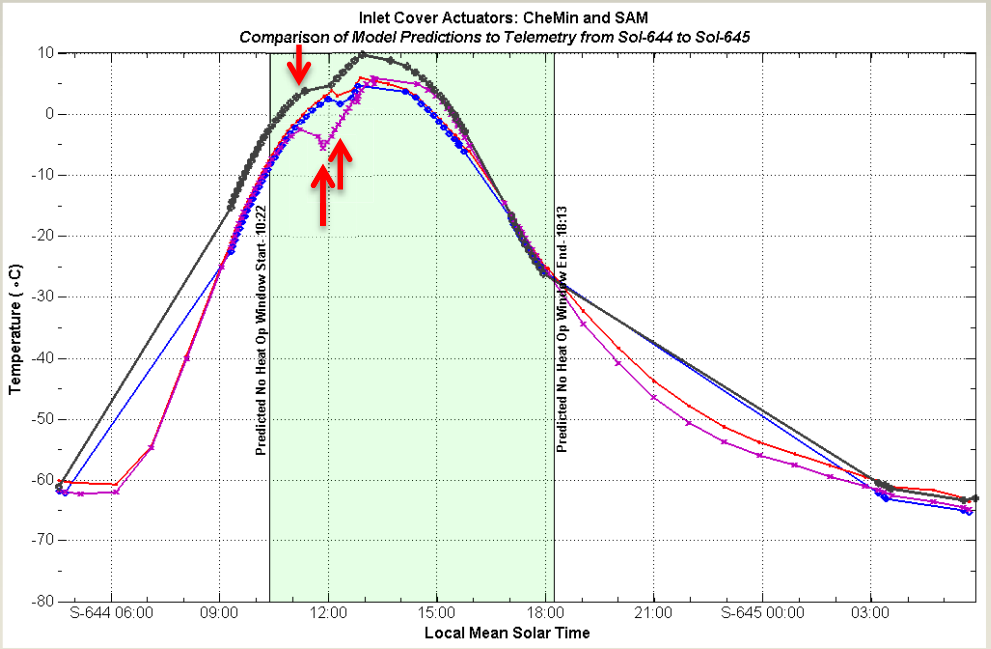
- The minimum temperature variation at any given point on the RAMP has varied by less than 5C
- The maximum difference between minimum temperatures has been less than 4.5 C.
- Maximum temperatures along the RAMP have varried from +12 to a maximum max of +37 C.
- The RAMP mounted survival heaters and warm-up heaters controlled by thermostats have not been required, and may never turn on, as predicted by the thermal system architect Keith Novak in his previous paper to ICES.

This is a factor of Curiosity's equatorial location (compared to $\pm$ 35^{o} Longitude requirement) in addition to the excellent design and workmanship of the HRS system.

Other Curious Telemetry Features

Shadowing

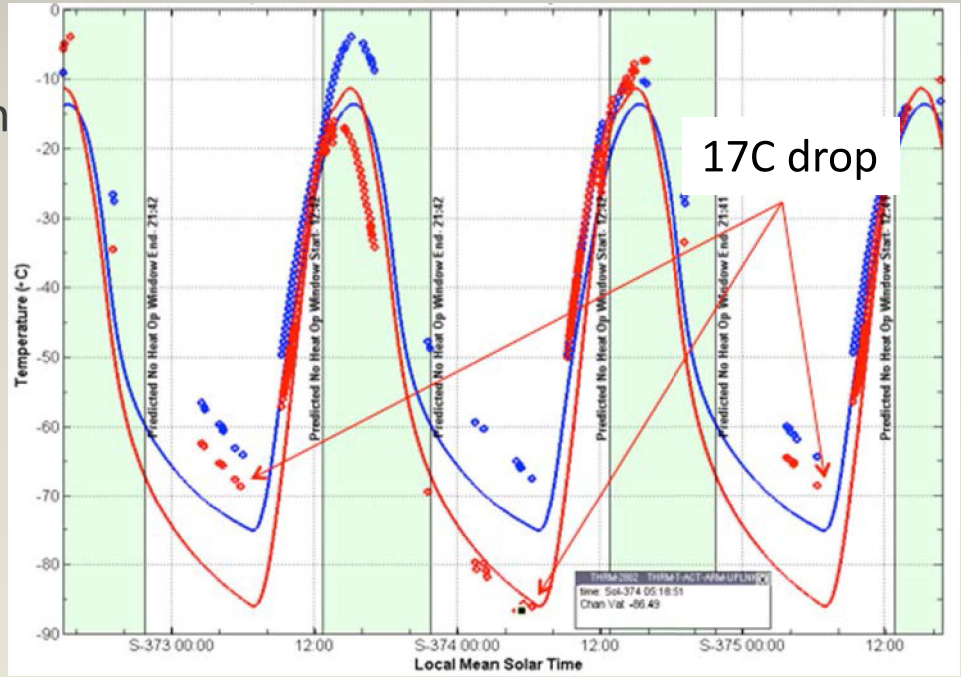
Do to self-shadowing, we've noted significant temperature drops as the sun angle changes



Orientation & Configuration Effects

There have been 17C drops from one Sol the next simple due to a change in the rover orientation or configuration (arm-stowed or deployed)

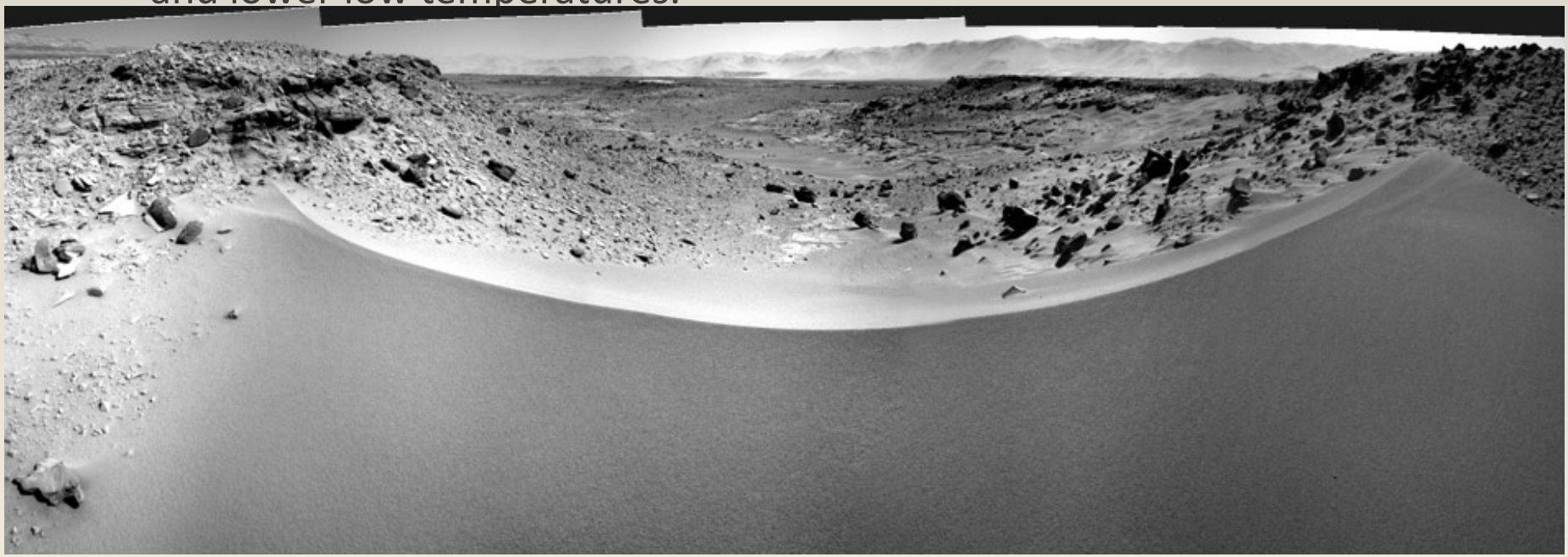
Turning the Rover's overnight orientatino can have similar dramatic changes in temperatures.

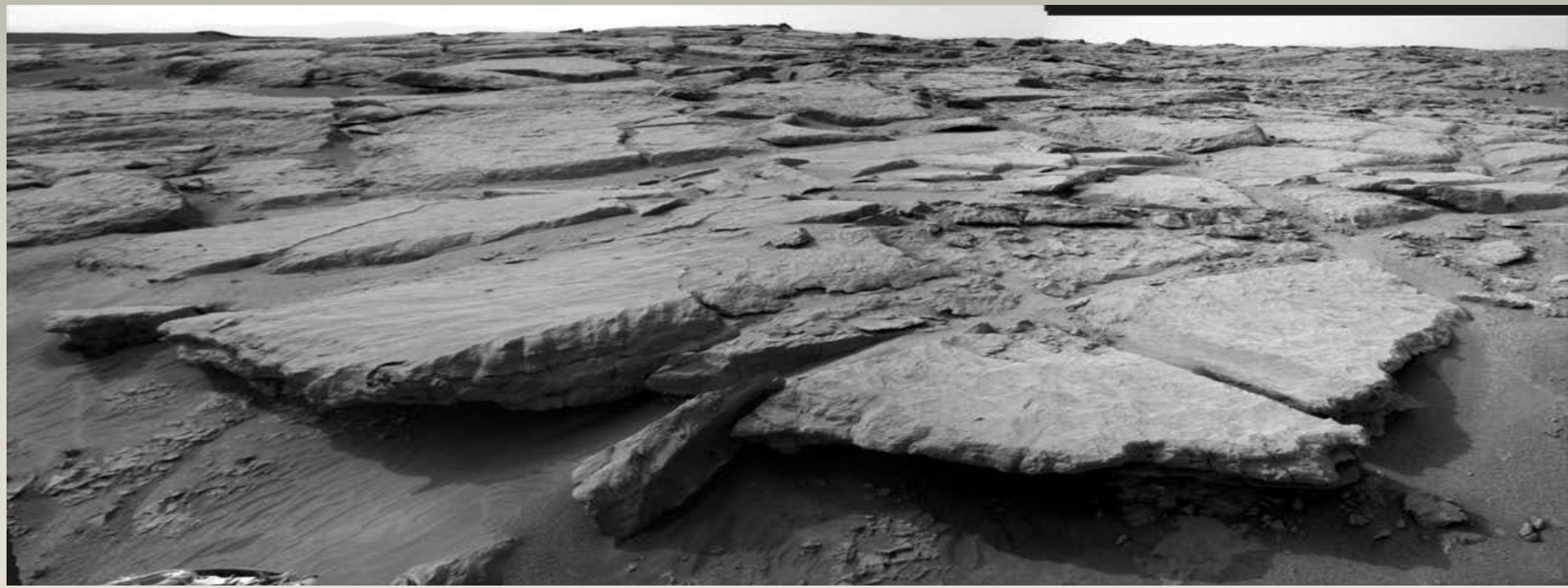


Terrain

The thermal inertia of the local terrain can also cause a noticeable change in the sol-to-sol temperature telemetry.

Sandy terrain, with low thermal inertia, is associated with higher high and lower low temperatures.

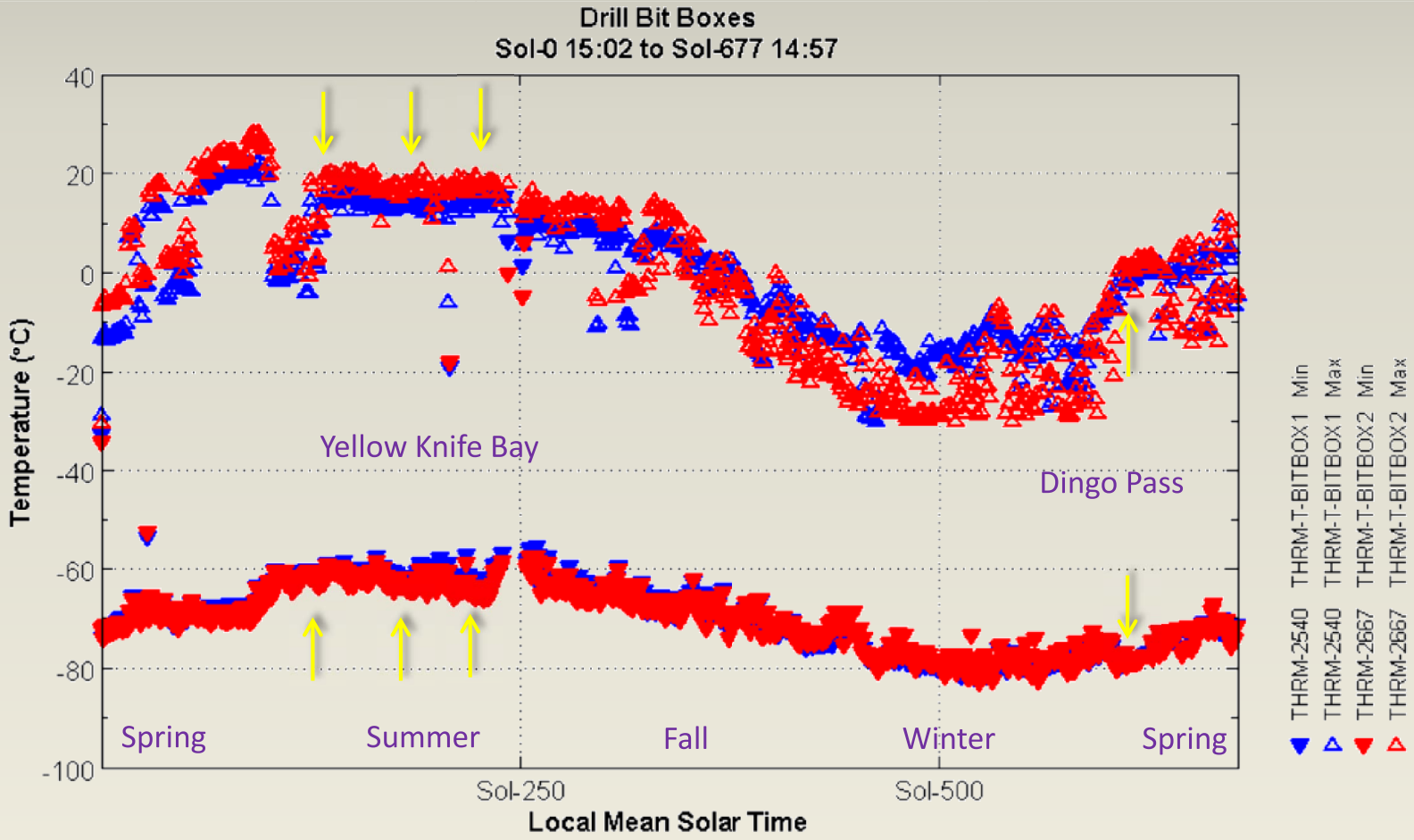




Rockier terrain, with a higher thermal inertia, diminishes the high and low temperatures.

The following long term trending plot shows this feature in the telemetry.

Terrain Effects on Temperatures



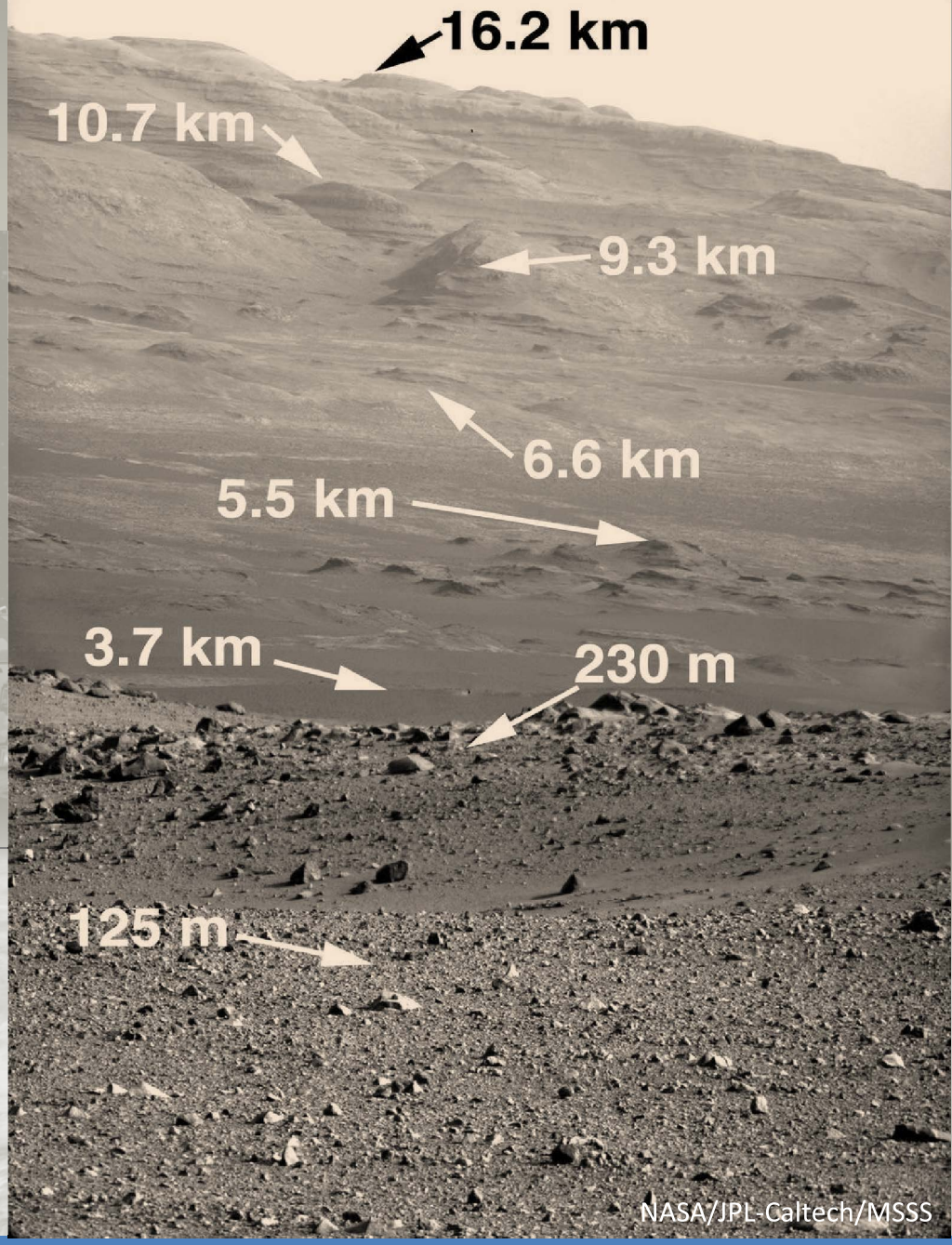
Dust Accumulation

SOL 84

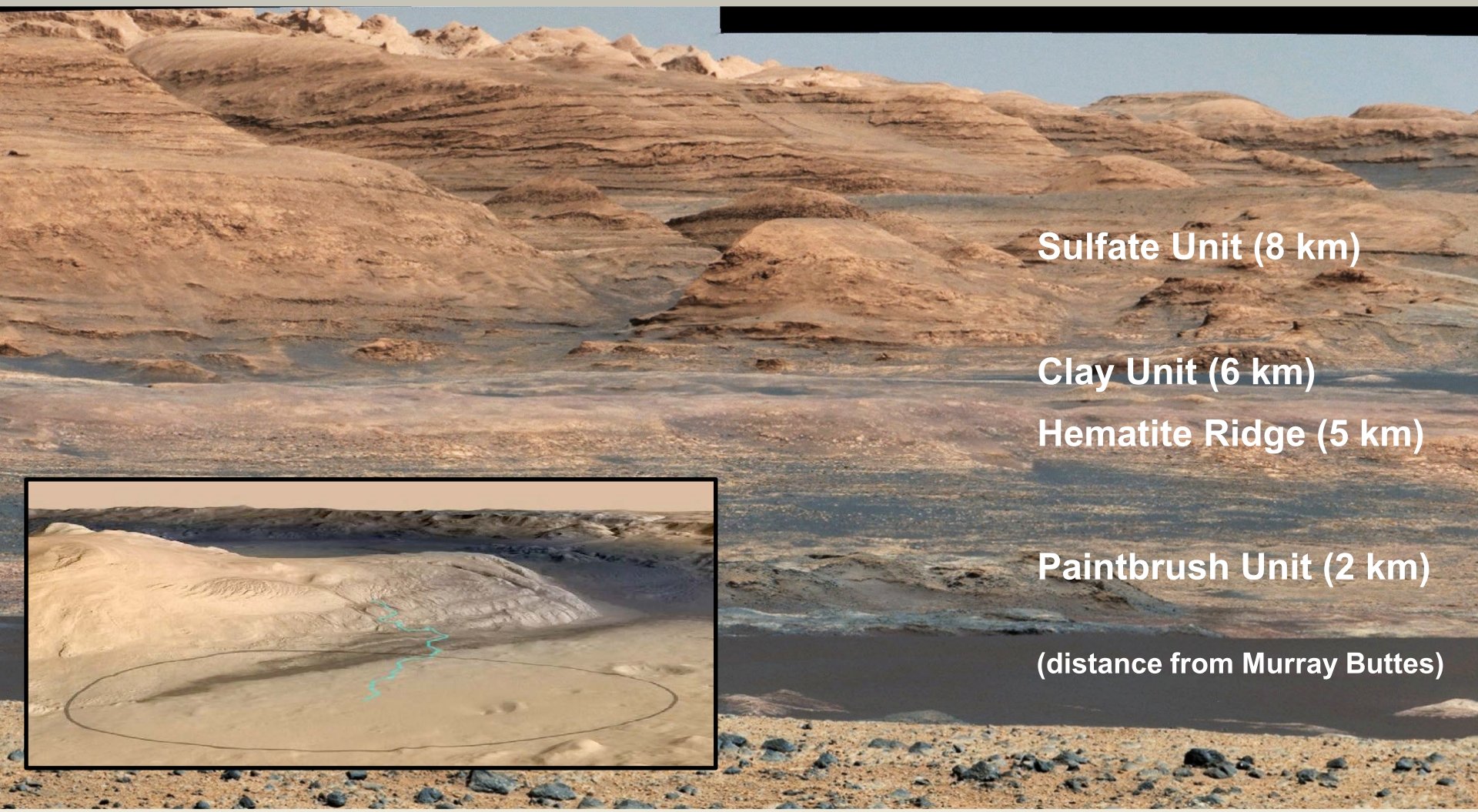
SOL 613

Looking Ahead

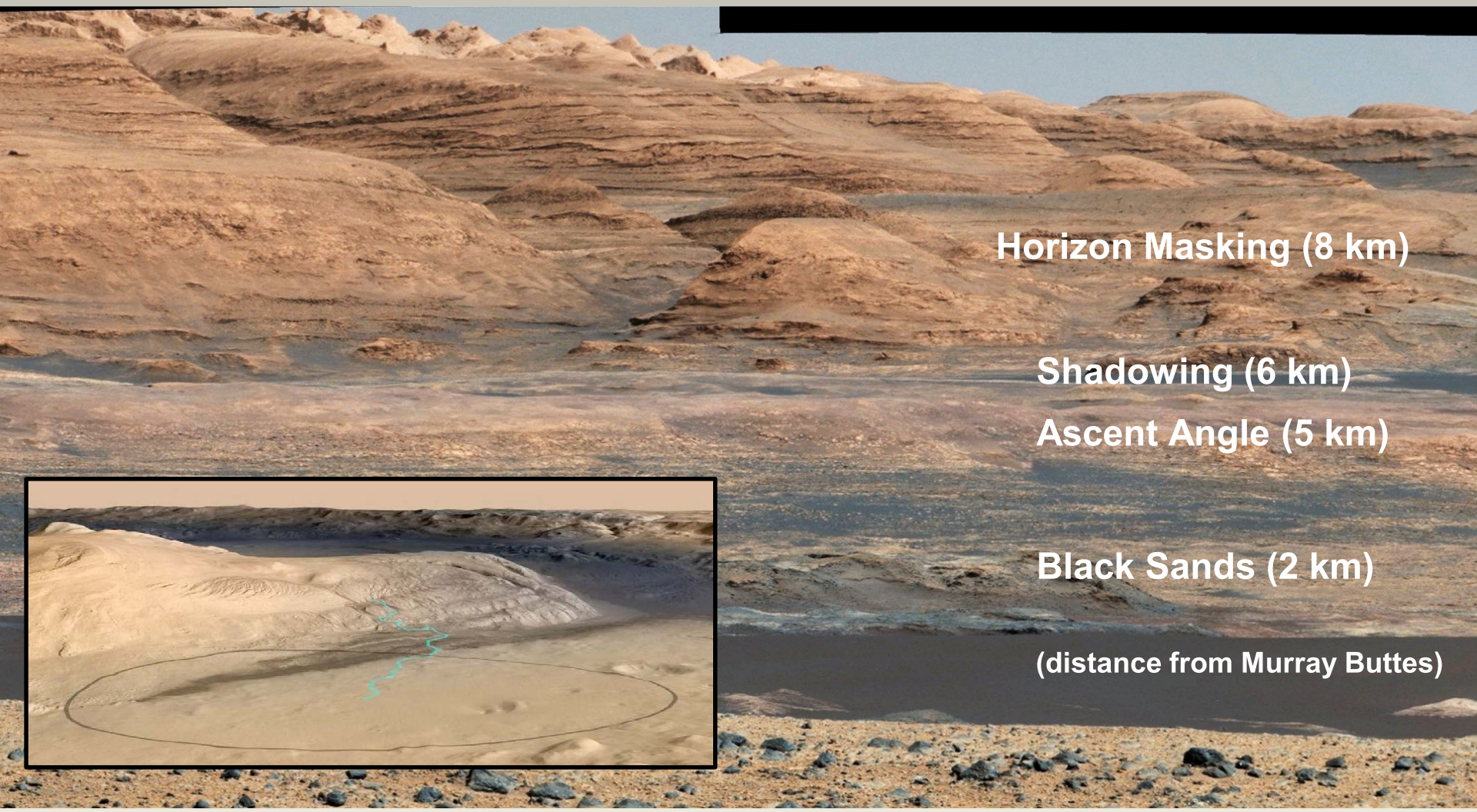
PLANS & TOOLS FOR THE EXTENDED MISSION



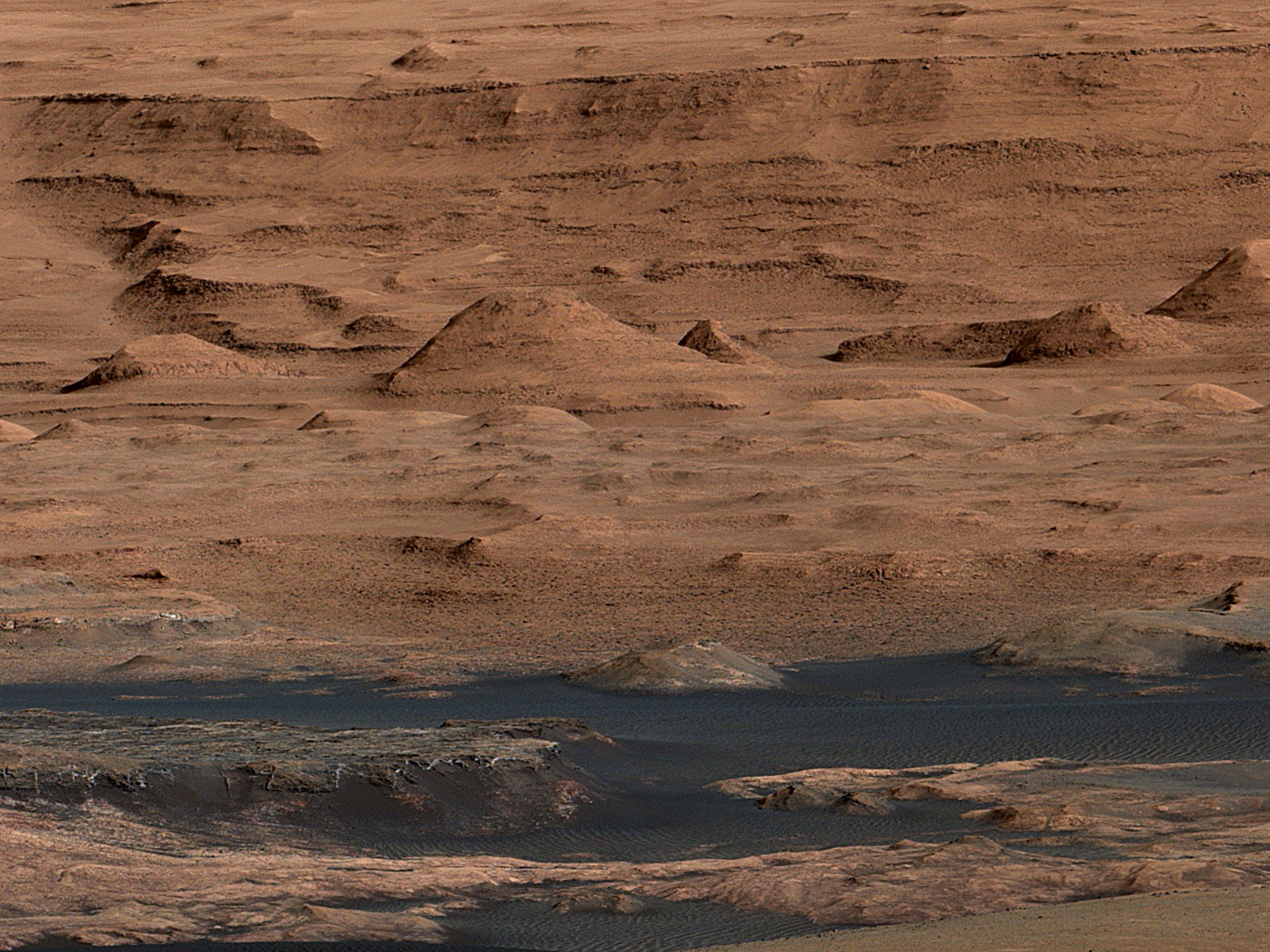
Curiosity's Extended Mission



From a Thermal Perspective



Destination



Plans for Mission

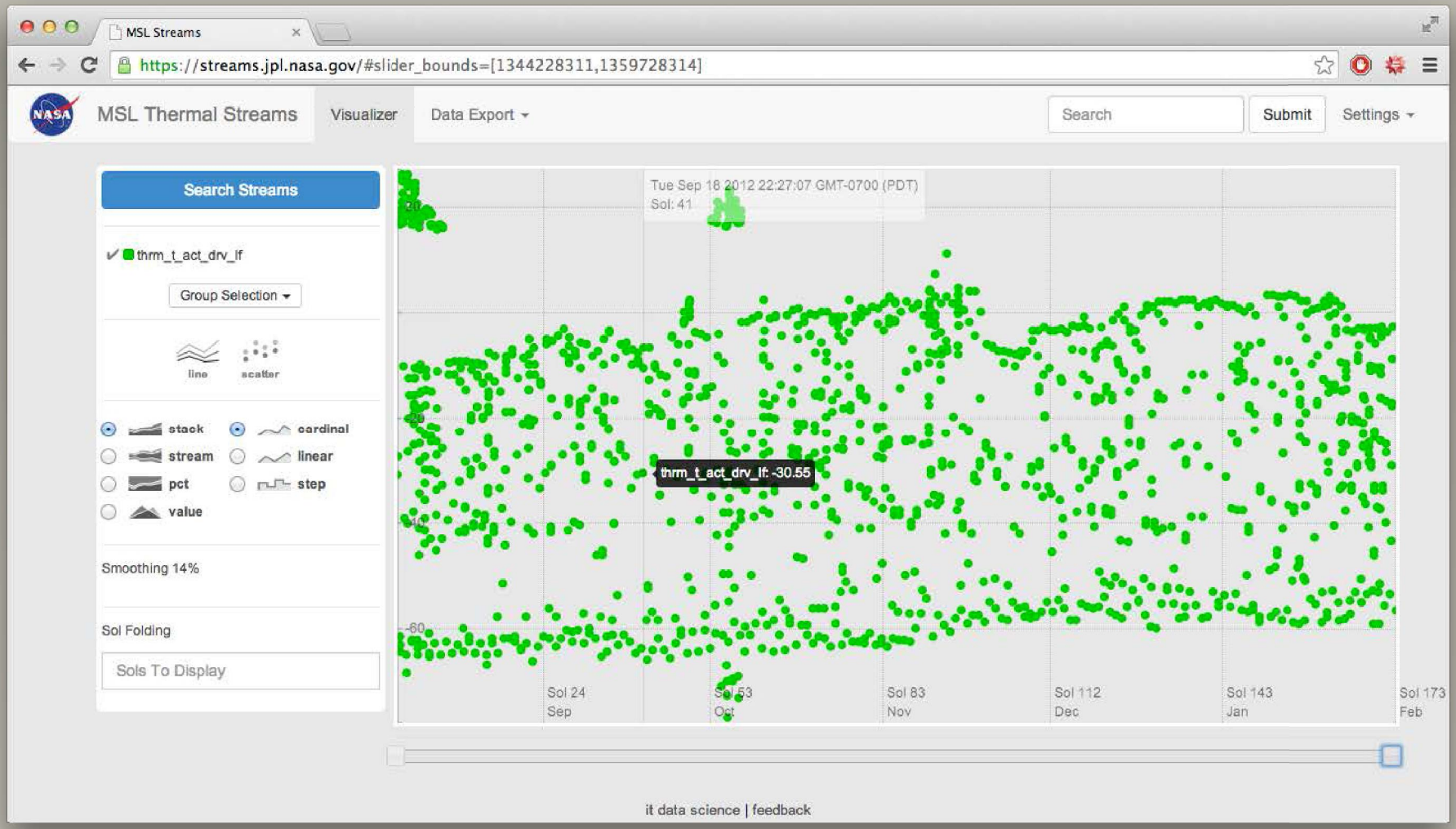
The primary MSL mission was 1-years on Mars, which was completed the final week of June.

Many of our tools and reporting method are geared toward the first 100-Sols on Mars.

- Daily downlink analysis is posted to Sol-specific wiki pages.
- Supporting documentation is in PDF, XLS, and PPT formats.
- Yesterday's plan is compared to the downlink as run on the following Sol

We're building tools to assist in:

- Long-term trend comparison
- Capture all the use-cases (planned events versus actual) on a single page
- Pushing our data into the cloud based computing that quickly allows trending and daily downlink analysis.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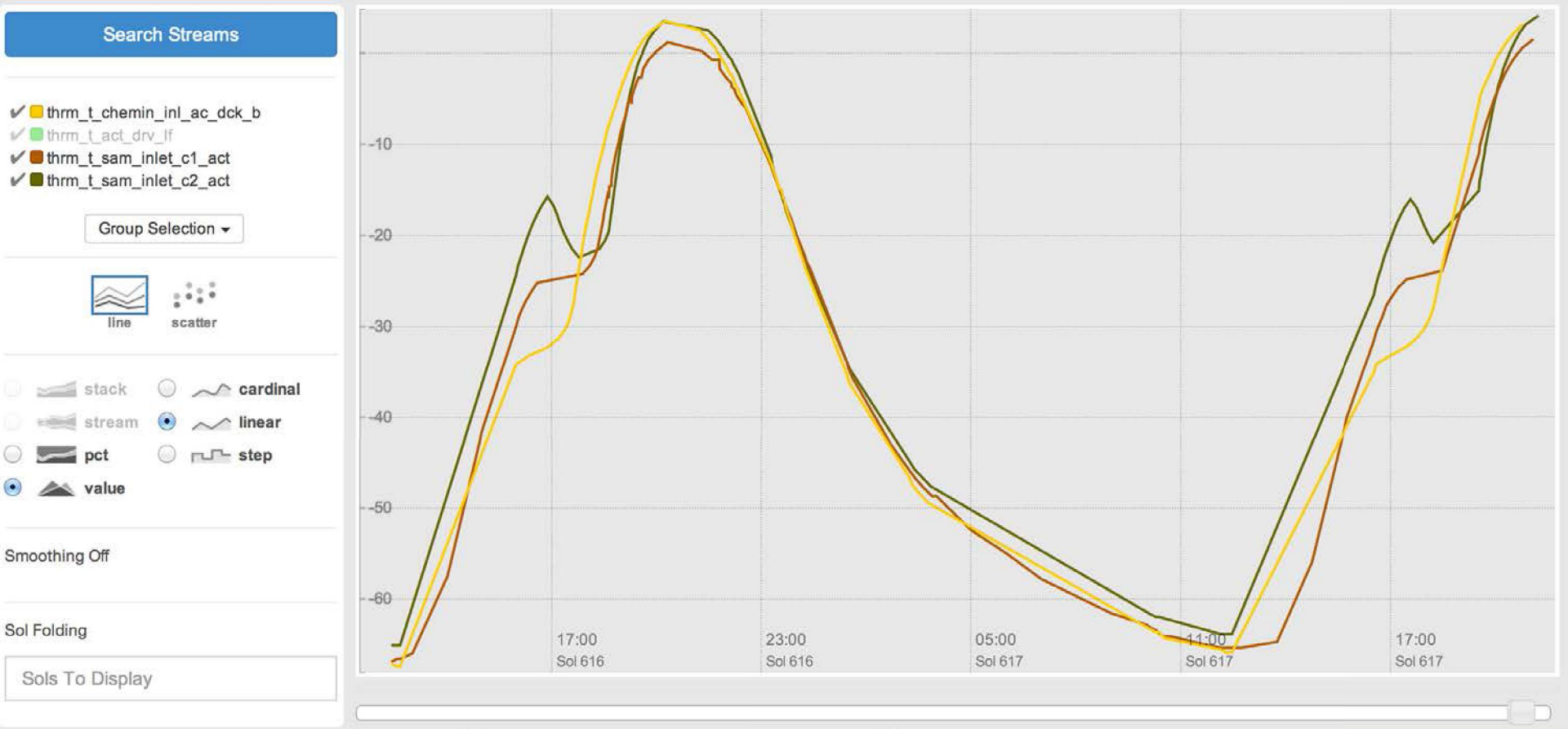
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thrm_t_act_drv_lf
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Group Selection
line
scatter
stack
stream
pct
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Smoothing Off
Sol Folding
Sols To Display
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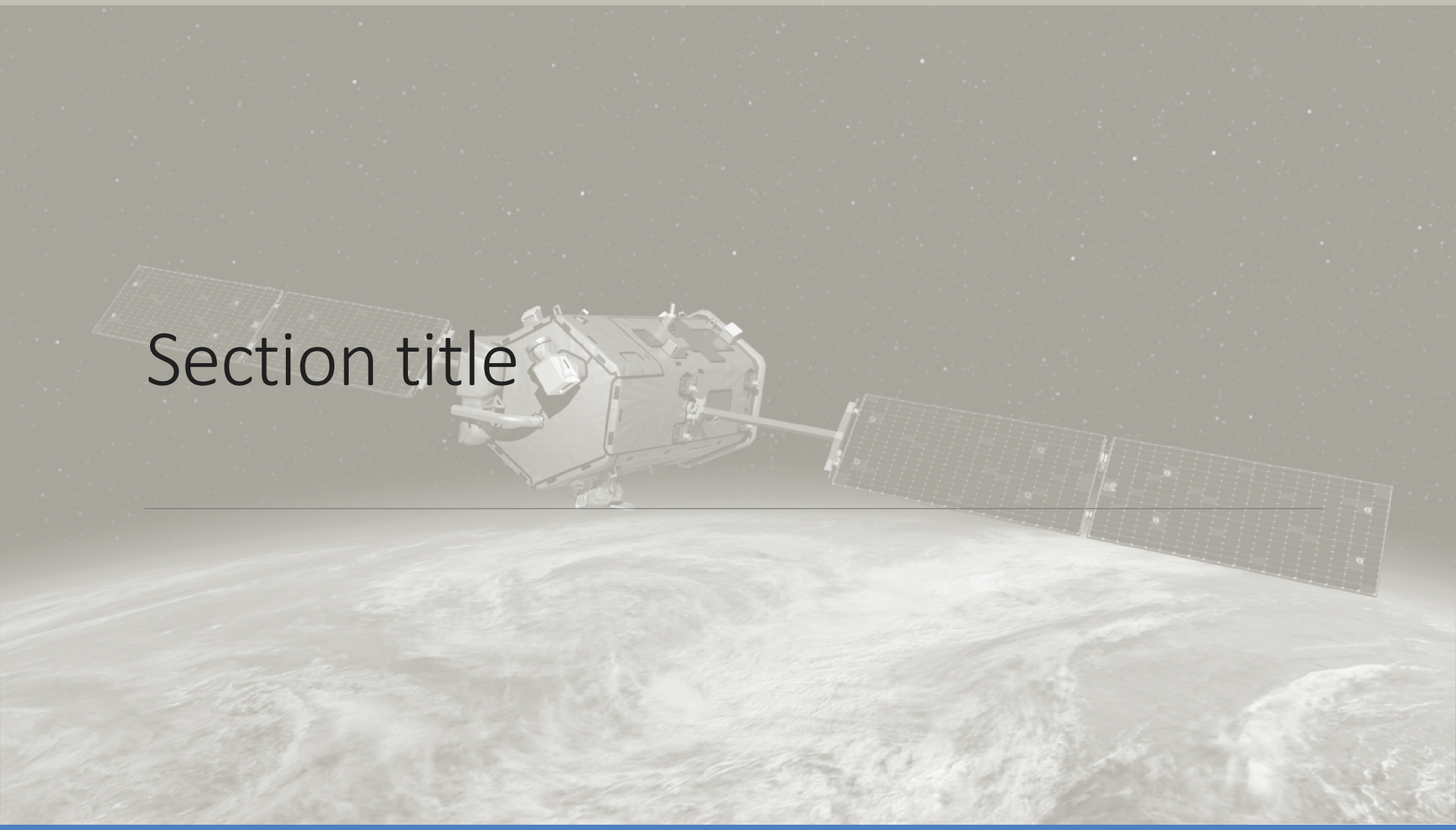

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