

The Ricor K508 Cryocooler Operational Experience on Mars

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Topics

Mars Science Laboratory

- **Overview of Mars Environments**
- **Description of the CheMin Instrument and Cooler**
- **Description of the Thermal Model and the Integrated CheMin Instrument Testing**
- **CheMin Mission Operations**
- **First CheMin Analysis Results**
- **Summary**



Rover Family Portrait at JPL's Mars Yard

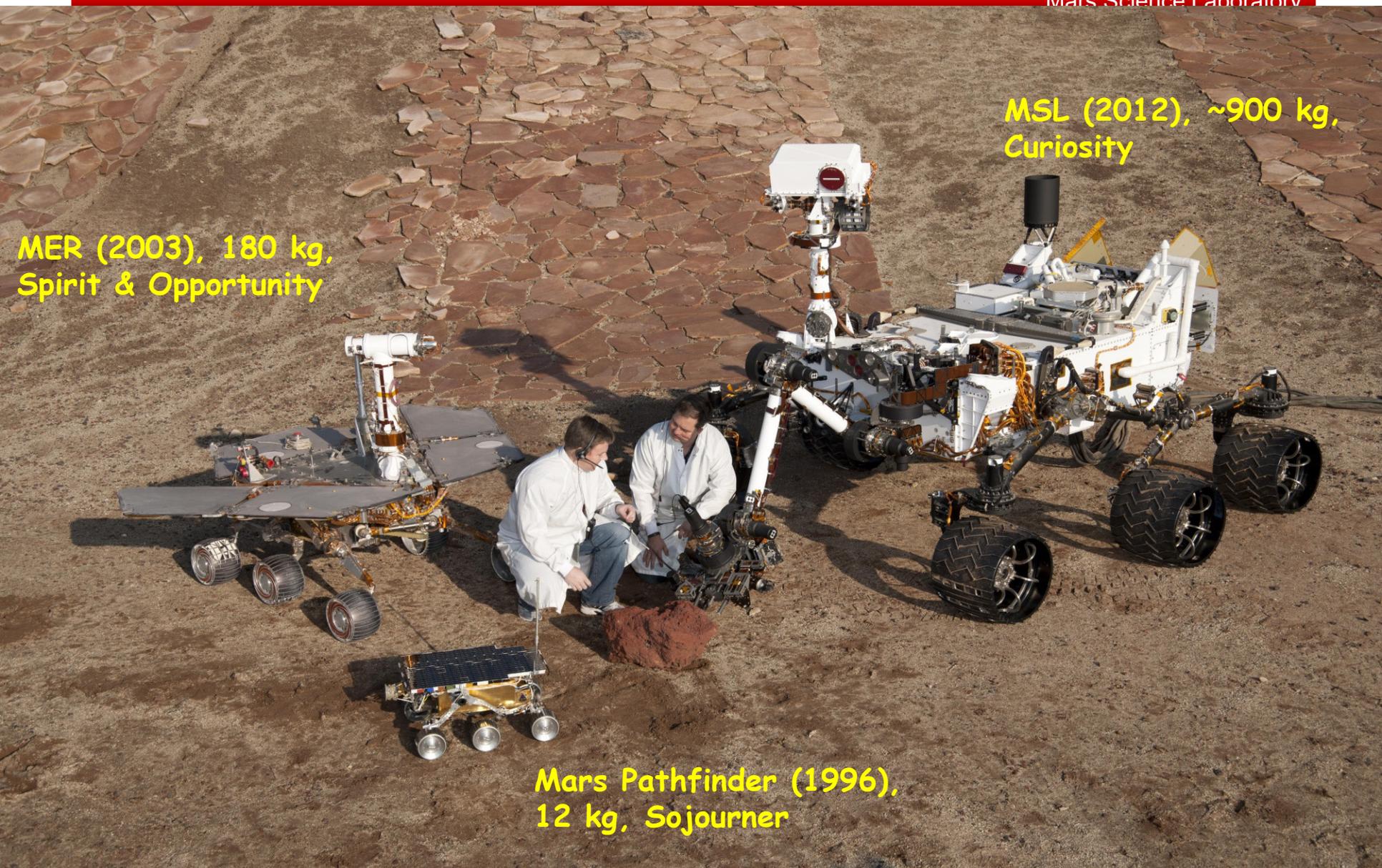


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MSL (2012), ~900 kg,
Curiosity

MER (2003), 180 kg,
Spirit & Opportunity

Mars Pathfinder (1996),
12 kg, Sojourner





Mars Rover Instrument Suite

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- MSL is powered and thermally controlled by an RTG capable of 110W power and generates ~2000W of waste heat used to keep Rover internals above 0°C
- MSL carries a suite of 10 science instruments

Cameras

- Mast Camera (Mastcam)
- Mars Hand Lens Imager (MAHLI)
- Mars Descent Imager (MAARDI)

Spectrometers

- Alpha Particle X-Ray Spectrometer (APXS)
- Chemistry & Camera (ChemCam)
- Chemistry & Mineralogy X-Ray Diffraction/X-Ray Fluorescence Instrument (CheMin)
- Sample Analysis at Mars (SAM)

Radiation Detectors

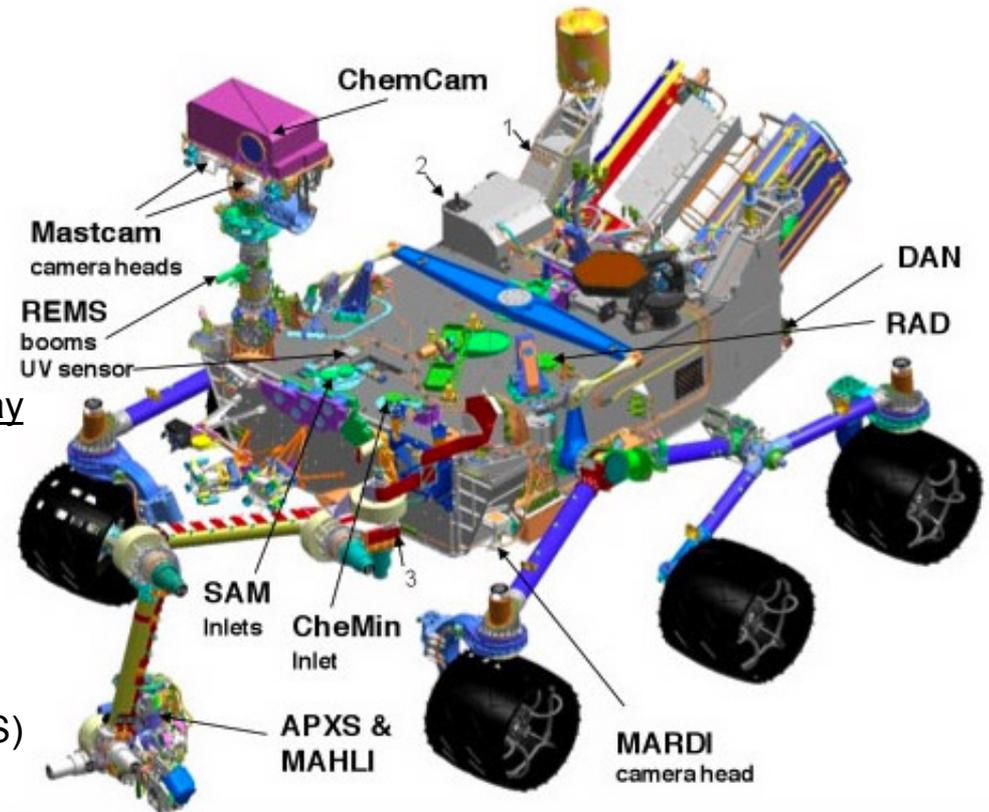
- Radiation Assessment Detector (RAD)
- Dynamic Albedo of Neutrons (DAN)

Environmental Sensors

- Rover Environmental Monitoring Station (REMS)

Atmospheric Sensors

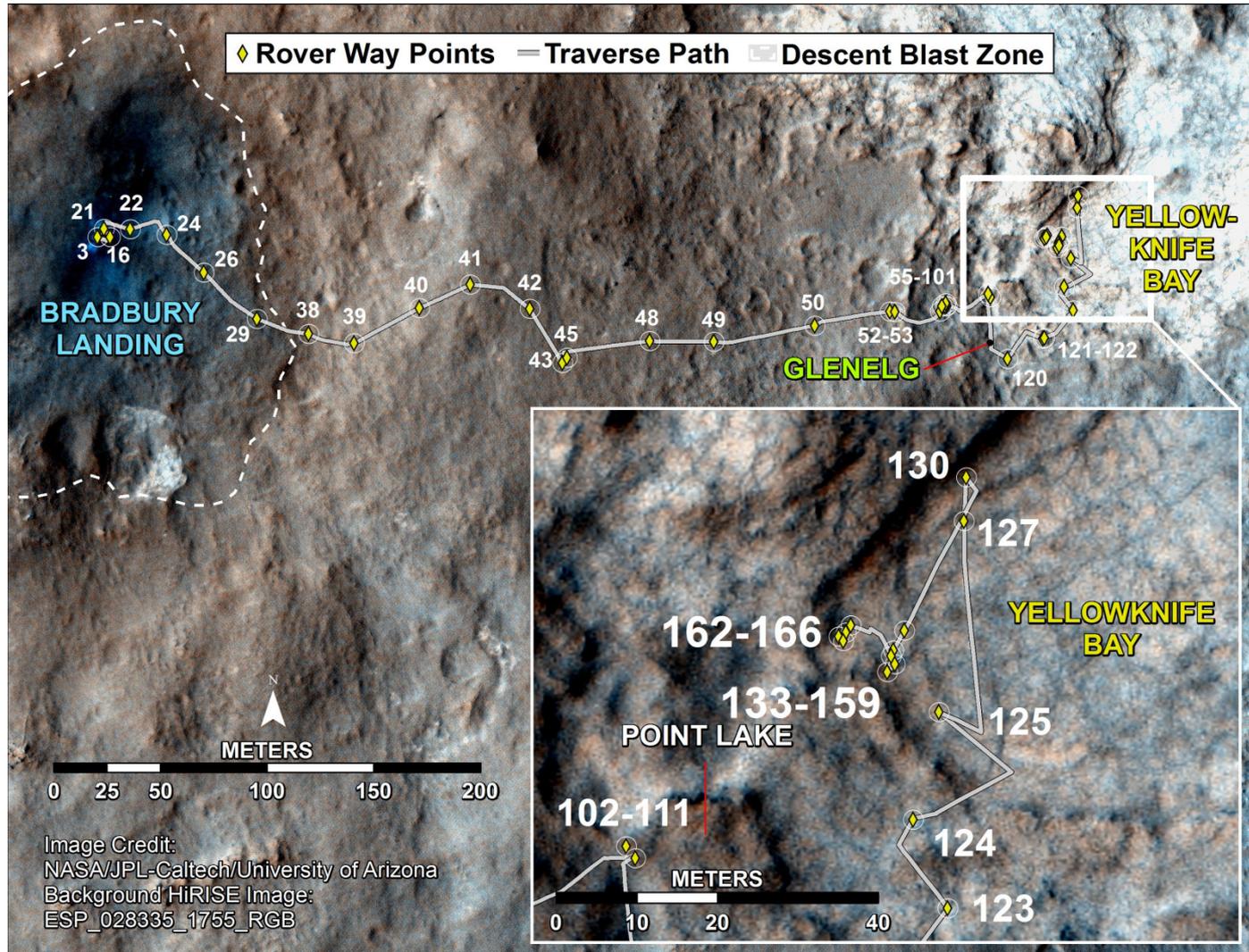
- MSL Entry Descent and Landing Instrument (MEDLI)





The MSL Travelogue through Sol 166

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Mars Environment

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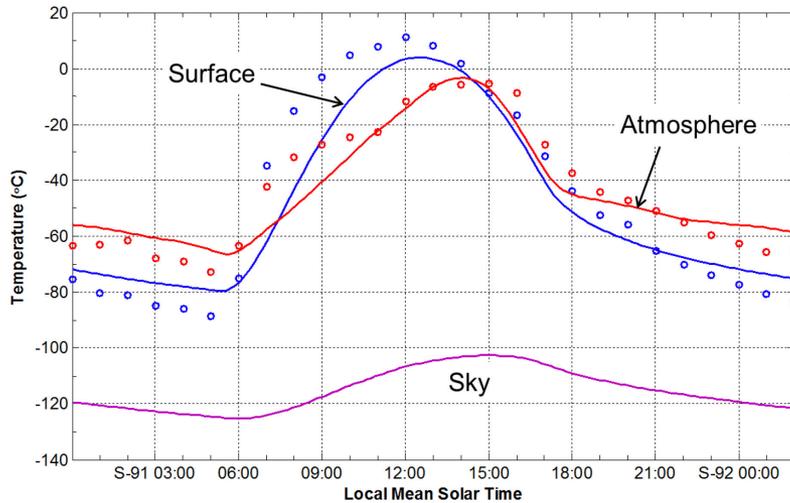
- **Mars atmospheric composition**
 - 95% CO₂, with N₂ and Ar making up the bulk of the rest
 - CO₂ nominal pressure is 7 torr, but variable between 2-12 torr
 - Water vapor pressure is nominally 0.004 torr, but can increase to 0.020 torr depending on season and location
- **Surface temperature range -130°C to +50°C**
- **Sustained winds as high as 15 m/s (32 mph, 54 km/hr)**
 - Wind chill can drive rover internal temperatures colder by another 30°C
- **Mars gravity 3.72 m/s² (0.38 earth's gravity)**



Mars Rover Environment for Gale Crater

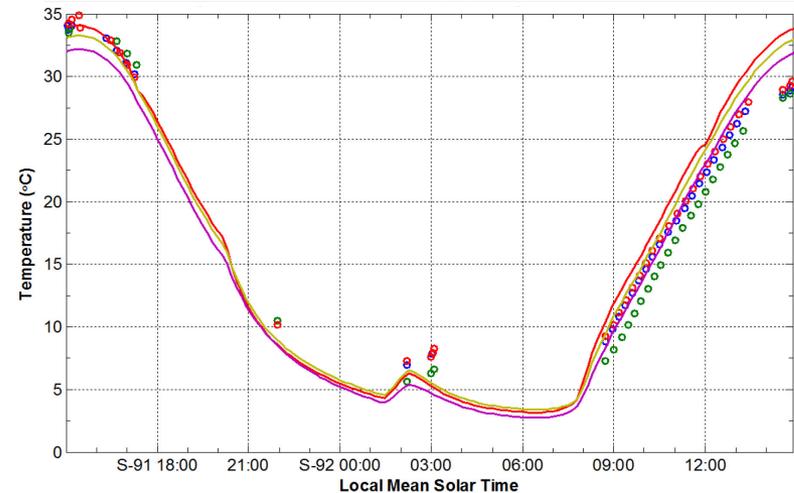
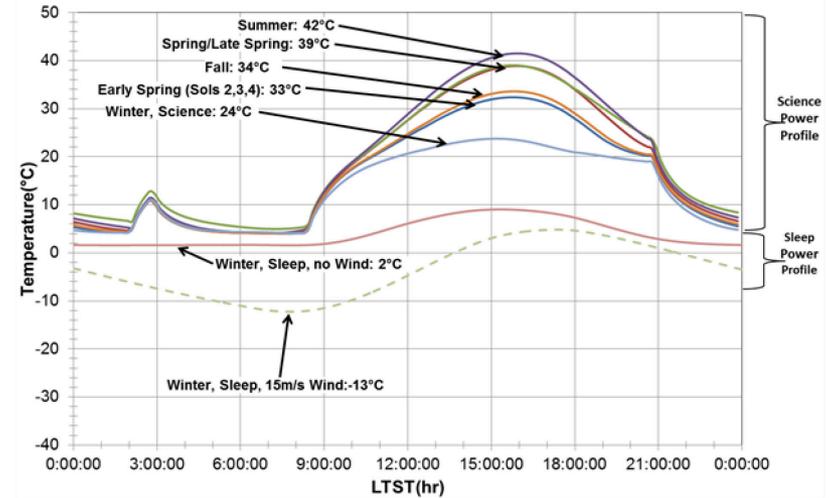
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Predicted & measured Mars temperatures for Sol 91



Predicted and measured CheMin/RAMP interface temperature for Sols 91-92

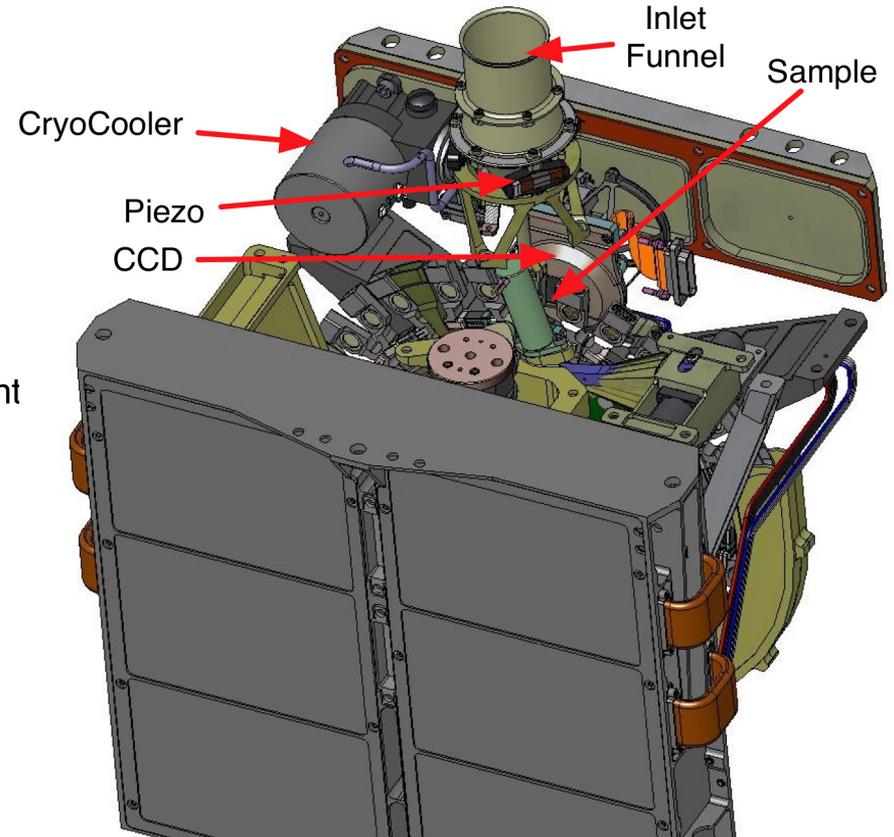
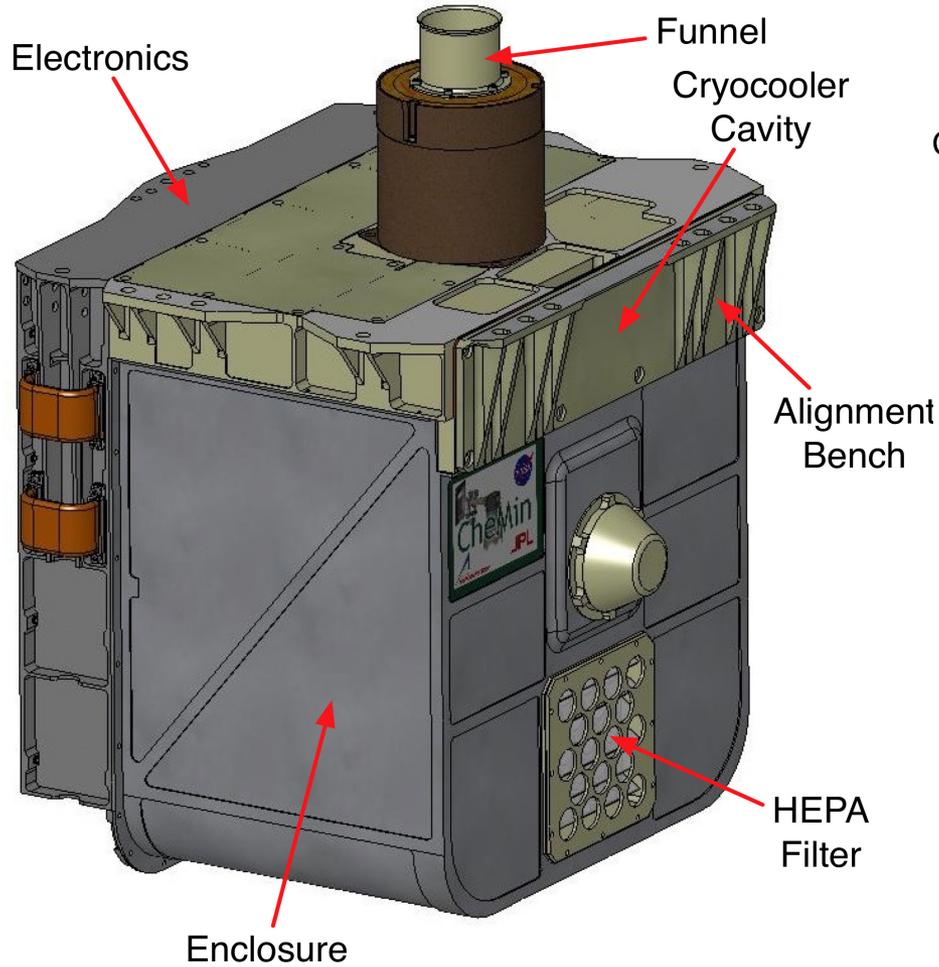
Predicted diurnal RAMP temperature, by season Assumes 40% dust coverage of top deck





CheMin Instrument

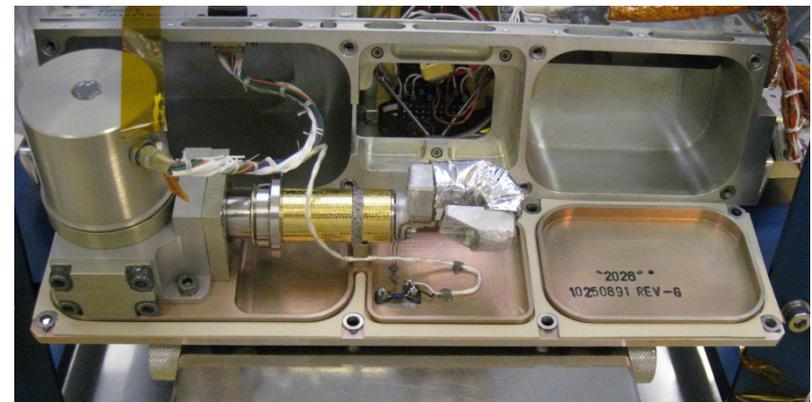
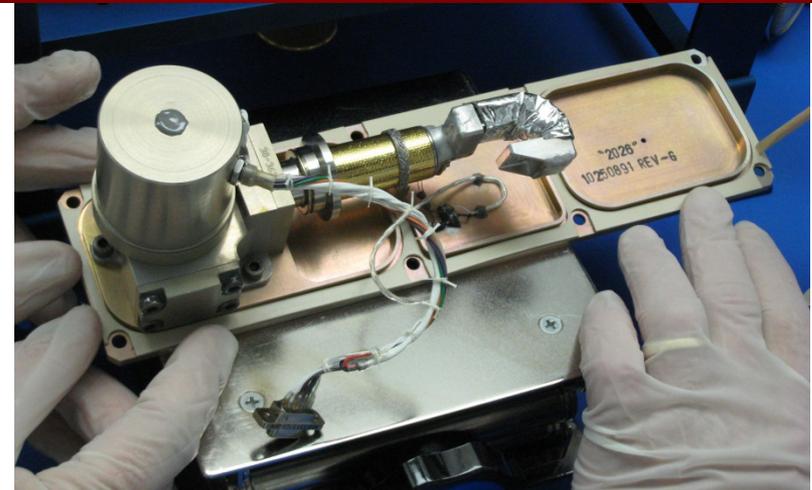
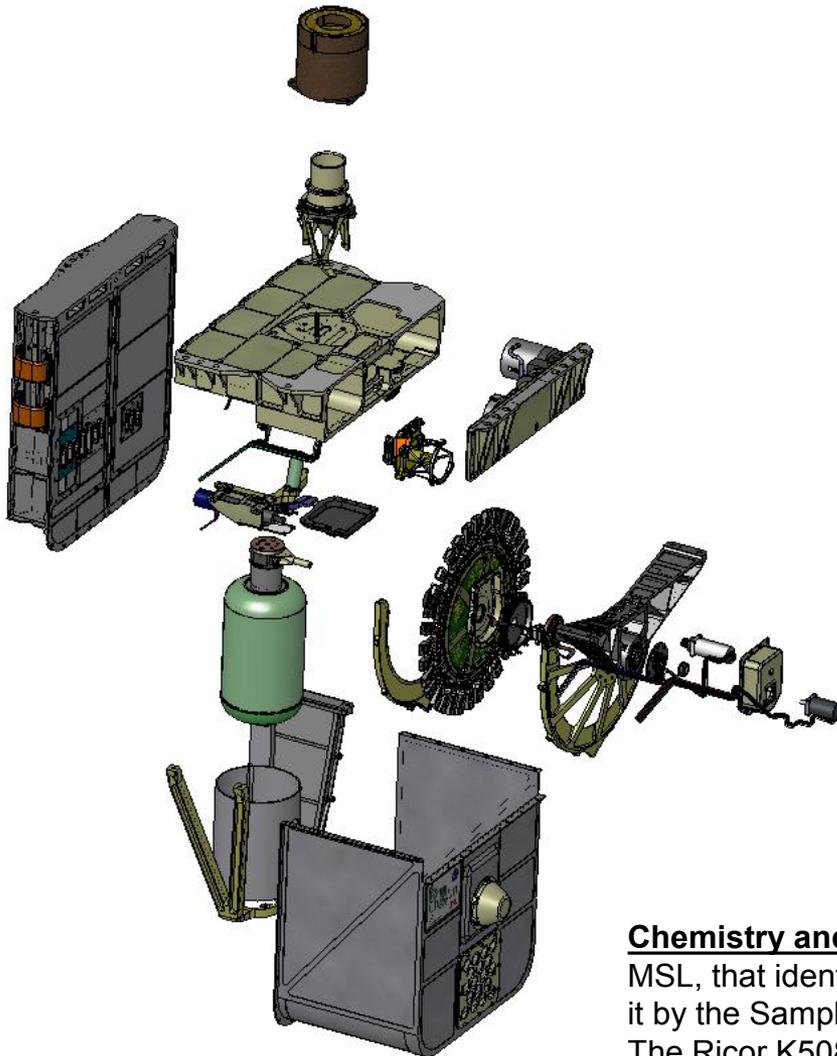
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CheMin Ricor K508 Cryocooler

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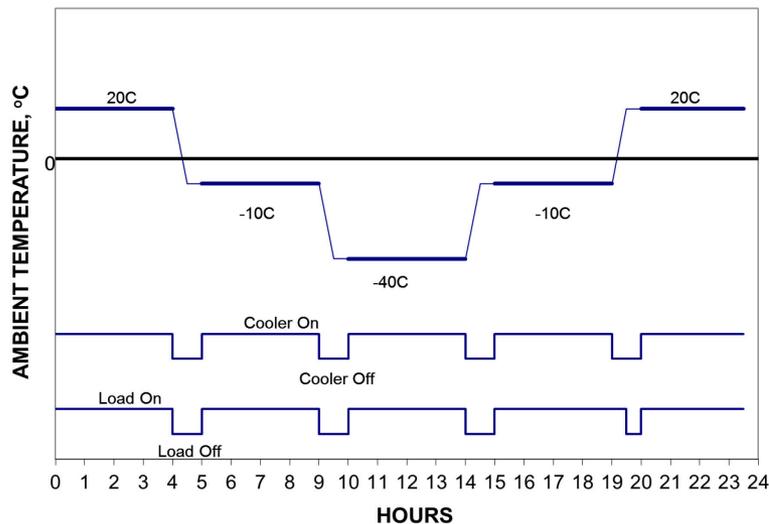
Chemistry and Mineralogy (CheMin): CheMin is a mineralogy instrument, onboard MSL, that identifies and quantifies the minerals present in rocks and soil delivered to it by the Sample Acquisition, Sample Processing and Handling (SA/SPaH) system. The Ricor K508 rotary cooler provides cooling to CCD at ~210K with a lifetime requirement of 1600hrs for surface operations.



Cryocooler Life Test Results

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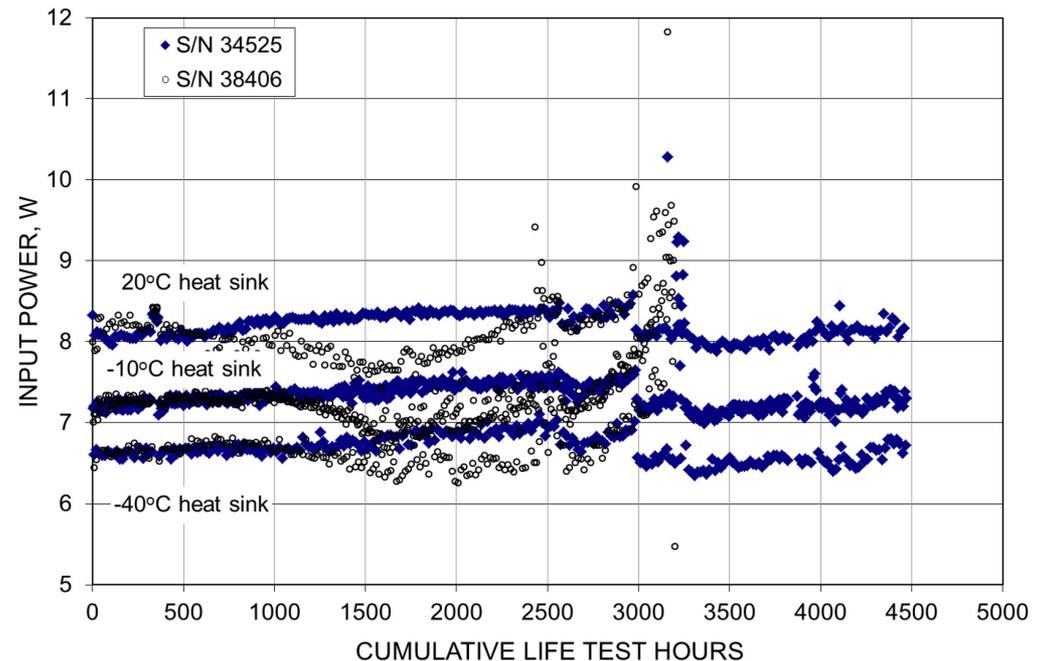
Life Test Temperature/Power Profile:
1.5 W applied load when powered;
4hrs on; 1 hr off during temp transition



Cum Characterization test + life test:

s/n 34806 mechanical failure after
3584 hrs operation; 847 pwr cycles

s/n 34525 still operating w/ no
degradation when life test stopped
4742 hrs operation; 1173 pwr cycles

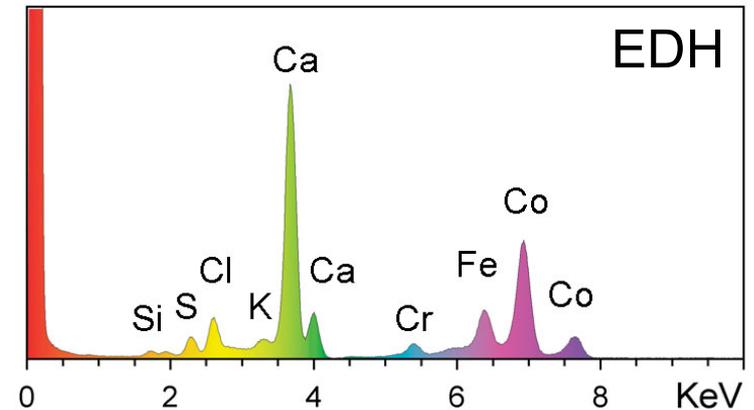
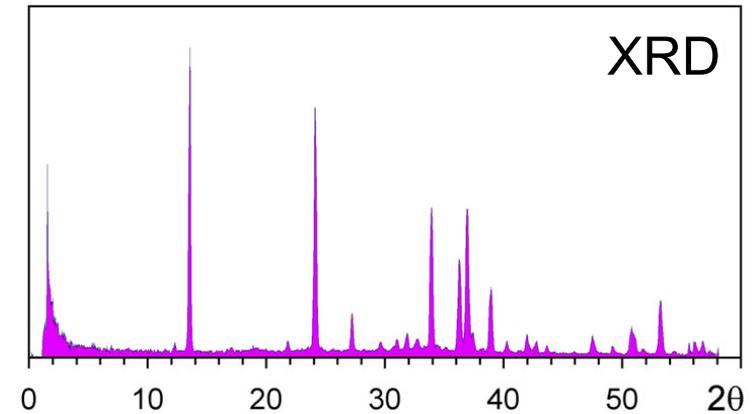
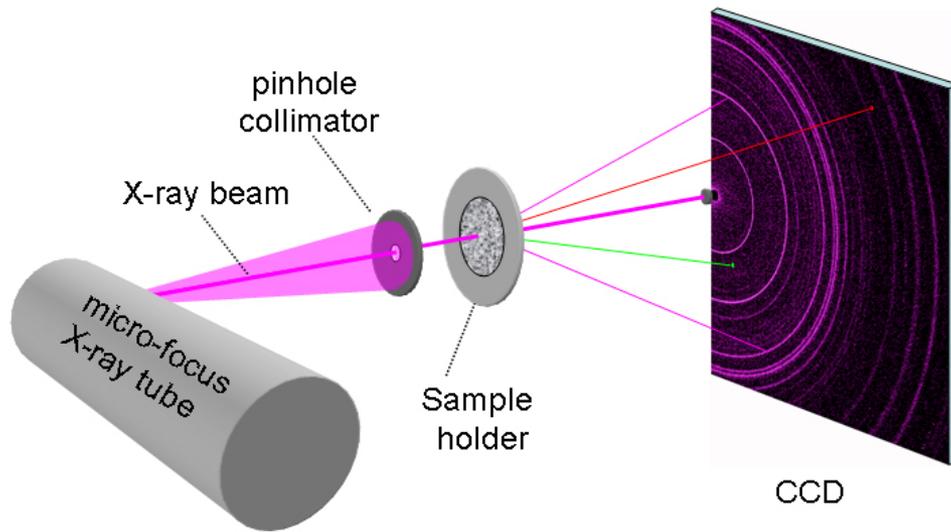




CheMin Measurement Description

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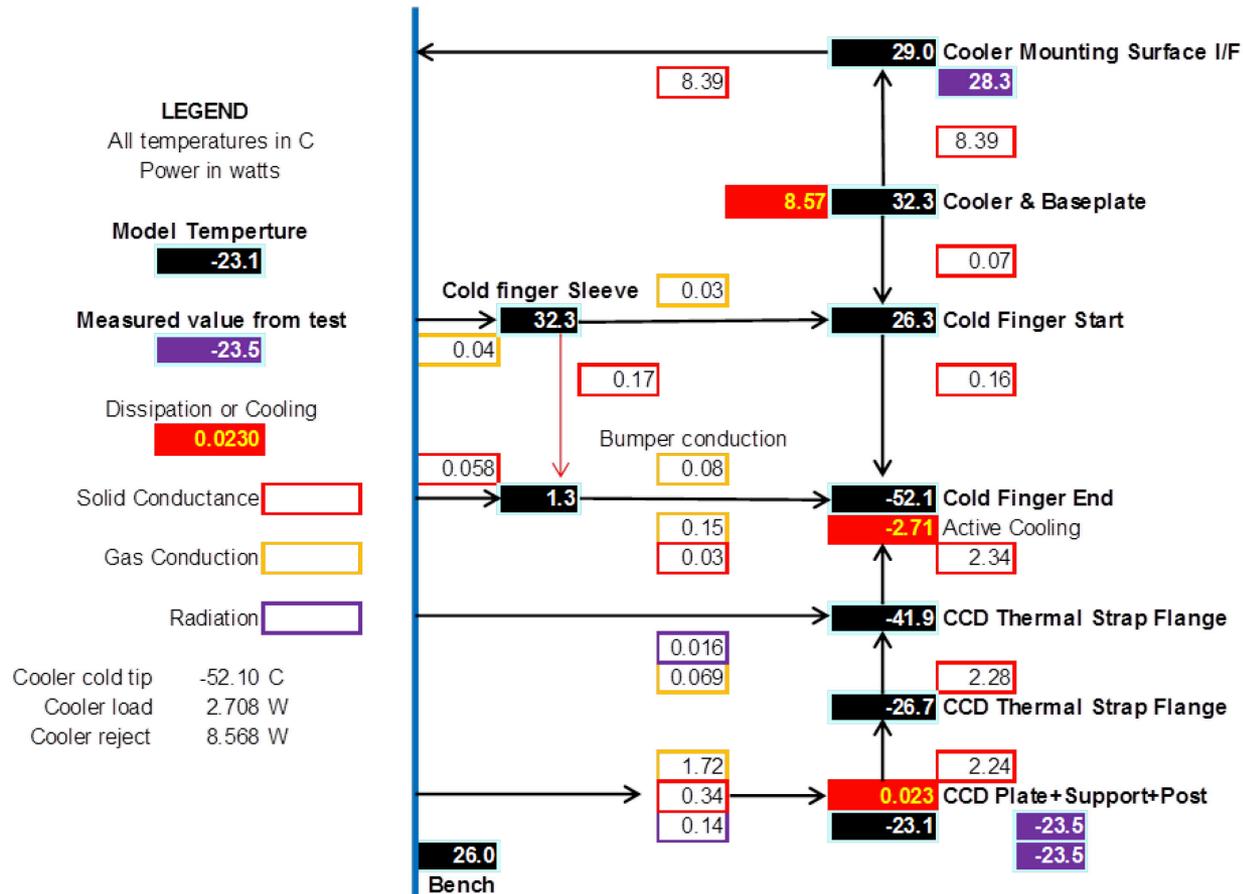
A single detector measures energy, position and intensity of the X-rays emanating from the sample





Simplified Thermal Model

Assumes 7-torr Argon atmosphere, 26°C RAMP temperature





CheMin Integration & Test

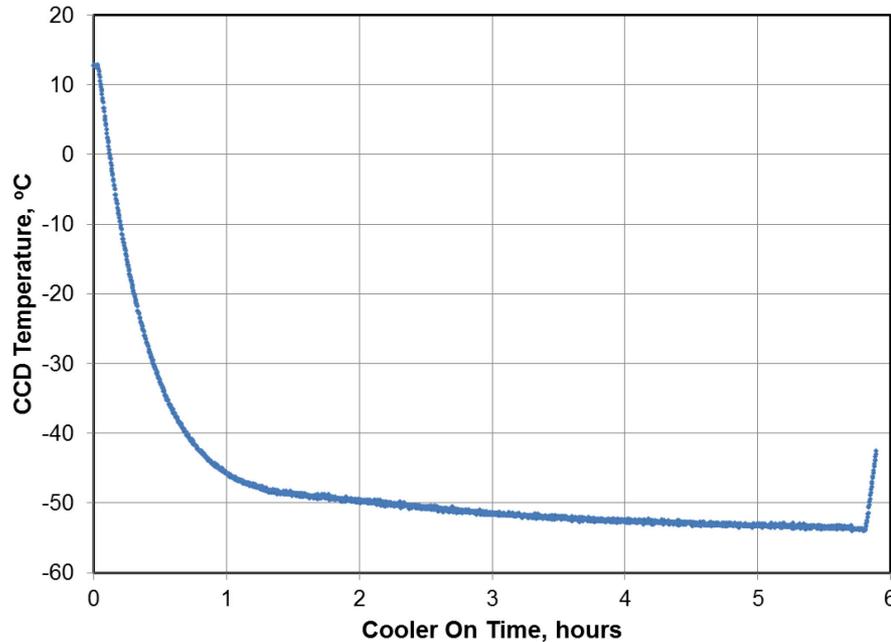
- **Significant time spent in Instrument-level thermal tests**
 - 3 testing periods over a 17 month span, 41 days total
 - Tests in vacuum showed CCD could be cooled to -100°C , or to -60°C for all RAMP (reject) temperatures (-40°C to $+26^{\circ}\text{C}$)
 - Operated in 7-torr Argon to simulate Mars CO_2 atmosphere; CO_2 could not be used or would condense on LN_2 plumbing lines
 - Demonstrated need for modified coldfinger bumper tube design (resulted in 6°C CCD temperature drop)
 - Demonstrated strong tie between RAMP temperature and CCD temperature (as expected)
 - CCD cools to 52°C below RAMP temperature in 7-torr Argon (measured)
 - CCD cools to 58°C below RAMP temperature in 7-torr CO_2 (predicted)
 - Achievable CCD temperature indicates a cooler coldtip load of 2.6W



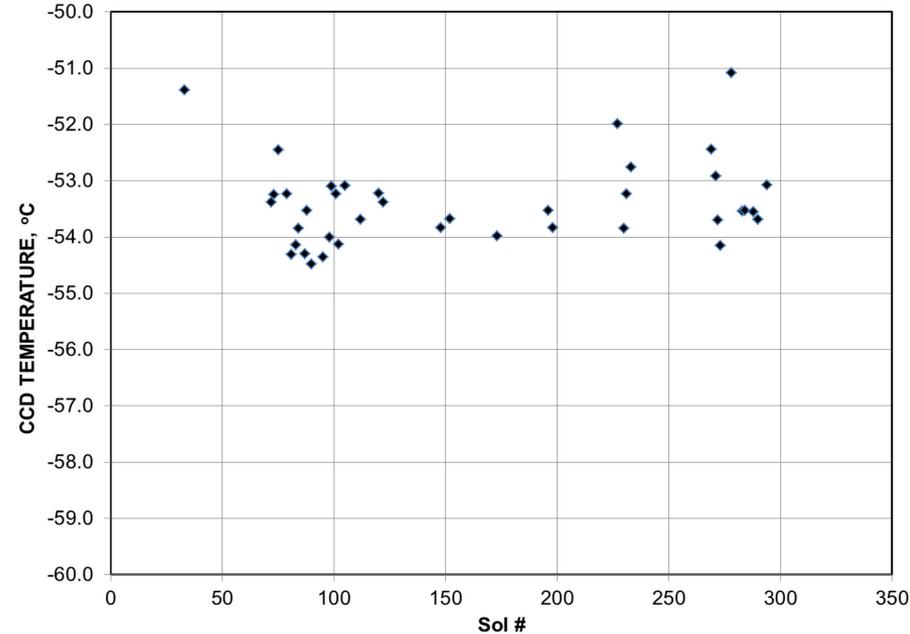
Mission Phase Cryocooler Operation

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CCD temperature during nominal analysis period



Final CCD temperature reached for each analysis period; RAMP temperature ~9°C by end of analysis



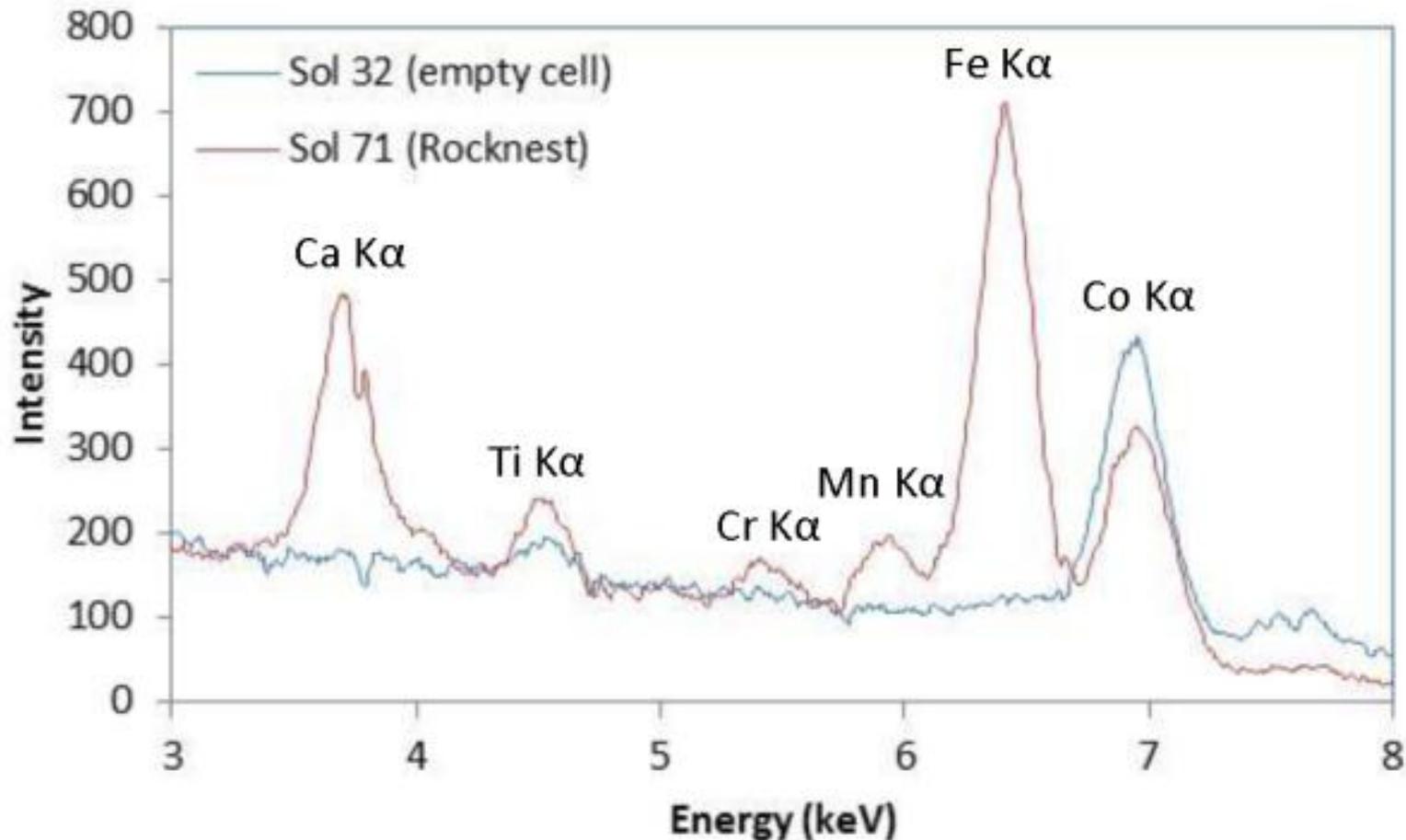
By Sol 300, cooler had accumulated 39 cooldowns and 180 hrs of operation



CheMin Analysis Results

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X-Ray fluorescence picks up elemental constituents for atomic numbers 14 (silicon) and greater; shown below is result from Rocknest soil sample scoop 5

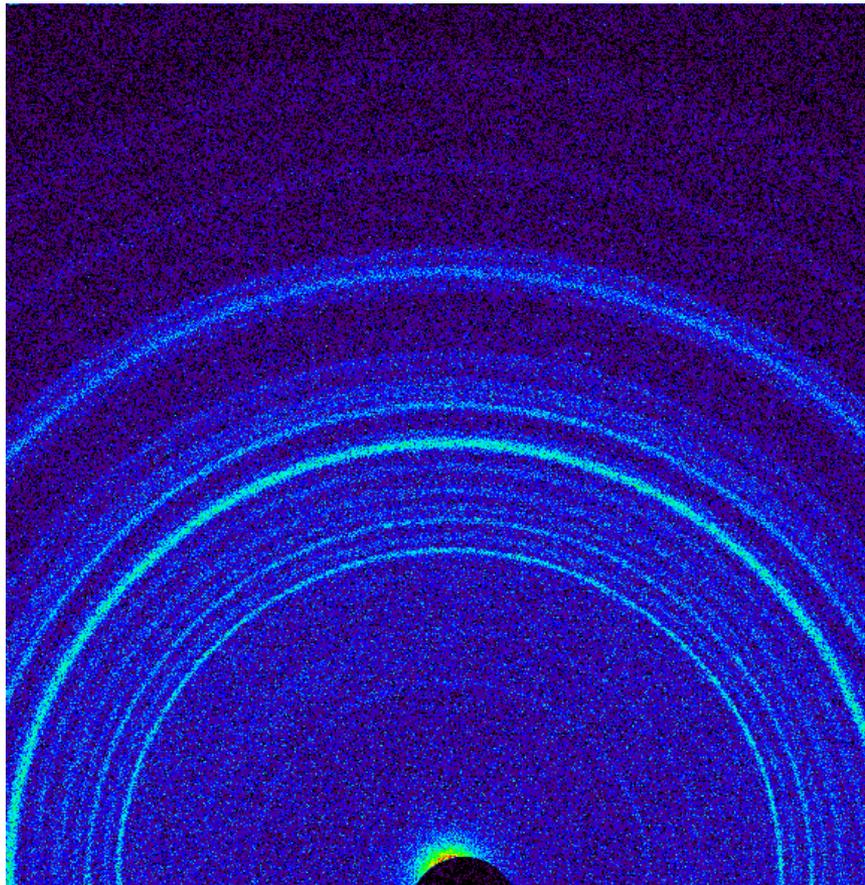




CheMin Analysis Results

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X-Ray Diffraction results from Rocknest sample shows soil sample was wind driven, with little previous water activity



Crystalline components (amorphous-free) of the Rocknest sample

Mineral	Weight %	2 α
Andesine (~An50)	42.9%	3.4%
Forsterite (~Fo58)	20.5%	2.6%
Augite	16.7%	3.5%
Pigeonite	11.4%	3.9%
Sanidine	2.1%	1.9%
Magnetite	1.8%	1.1%
Quartz	1.7%	0.7%
Anhydrite	1.4%	0.9%
Hematite	0.8%	1.1%
Ilmenite	0.7%	1.2%



Summary

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- Ricor K508 cryocooler able to consistently cool the CCD to -53°C
- By Sol #300 the cooler has experienced 39 cooldowns and 180 hours of operation
- MSL/CheMin is first opportunity to measure X-Ray diffraction on a non-earth location
- The first published X-Ray diffraction and X-Ray fluorescence data of soil samples from Rocknest have been published
- CheMin in process of analyzing 3rd sample; second sample analyzed but not yet published
- Although CCD temperature not as cold as hoped, with extra analysis time the X-Ray diffraction and X-Ray fluorescence results have been able to determine the mineralogy and mineral abundances as expected