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In-Flight Performance of the OCO-2 (Orbiting Carbon Observatory-2) Cryocooler

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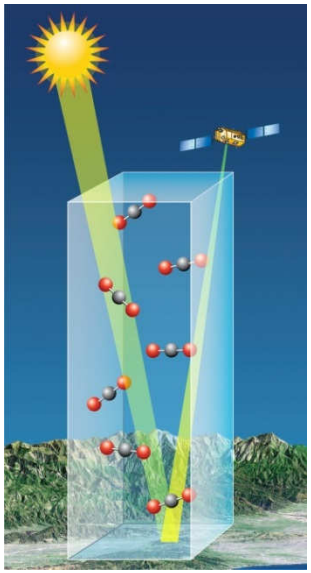
Topics

- Introduction to OCO-2
- Cryocooler System Overview
- In-Flight Performance
- Summary

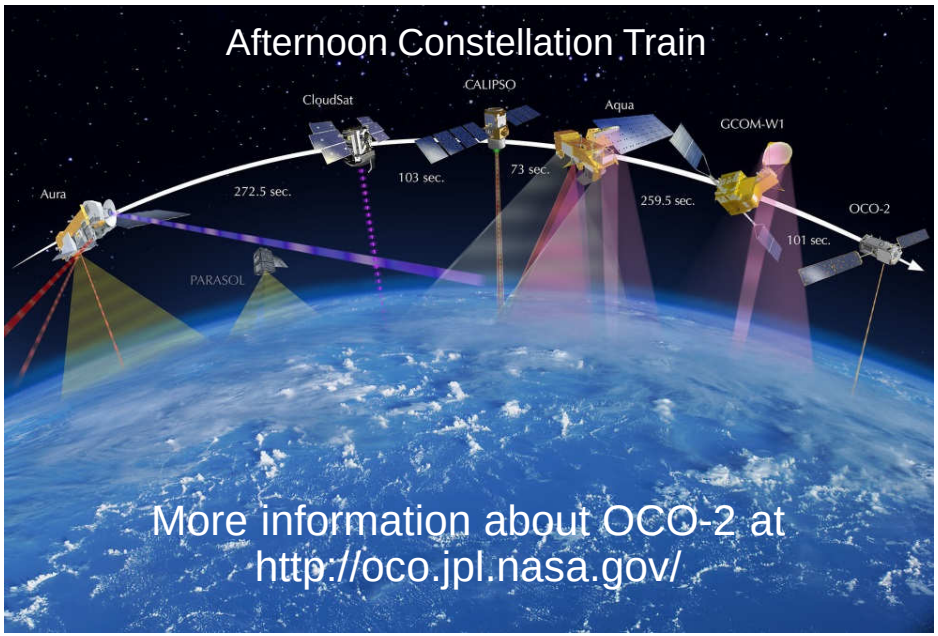
What is OCO-2?

- The Orbiting Carbon Observatory-2 (OCO-2) retrieves a global geographic distribution of carbon dioxide (CO_2) sources and sinks by measuring the intensity of sunlight reflected off the Earth's surface at specific wavelengths
- OCO-2 flies in front of the A-train, and carbon cycle science is facilitated by integrating OCO-2 observations with other instruments such as CO_2 retrievals from Atmospheric Infrared Sounder (AIRS) on Aqua and CO retrievals from Tropospheric Emission Spectrometer (TES) on Aura

- OCO-2 was launched into orbit on July 2, 2014 from Vandenberg Air Force Base



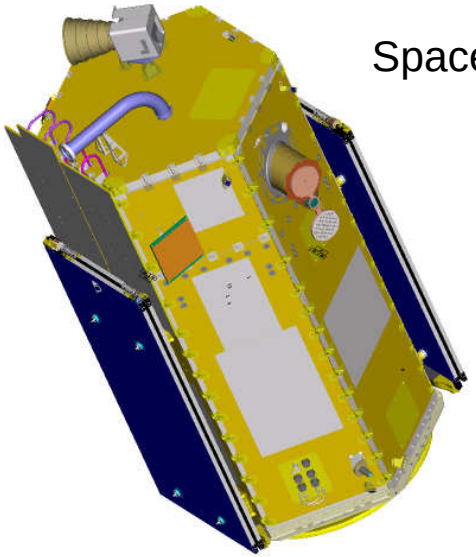
CO_2 column that OCO-2 sees

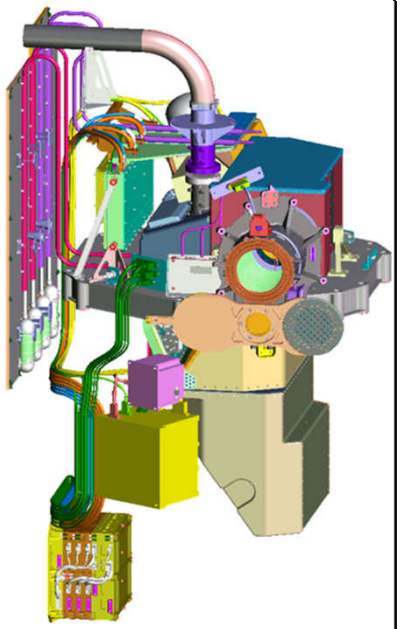


OCO-2 Instrument & Spacecraft

- Spacecraft Bus (LeoStar-2 provided by Orbital ATK)
  - Carries a single instrument
  - Bus made primarily of Al honeycomb panels that form hexagonal structure
  - Approximately 1 meter diameter and 2 meters tall
- Instrument (provided by JPL)
  - Measures gas concentrations at three wavelength bands (1.60 µm Weak CO_2, 2.06 µm Strong CO_2 and 0.76 µm O_2 A-Band), each specific to one of three high-resolution grating spectrometers
  - Measurements must be very accurate. To reduce thermally induced measurement errors, the three light detectors must remain at a cold and stable temperature.
  - A single cryocooler is used to keep the temperature of the three FPAs near 120 K.

Spacecraft (Orbital ATK)

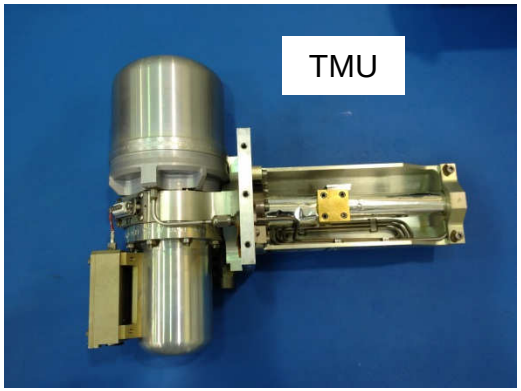


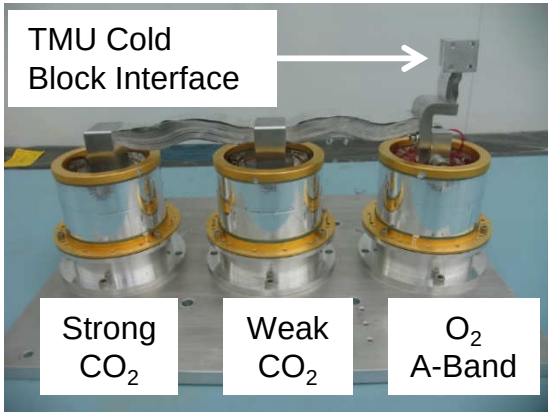


Instrument (JPL)

OCO-2 Cryo/Thermal System

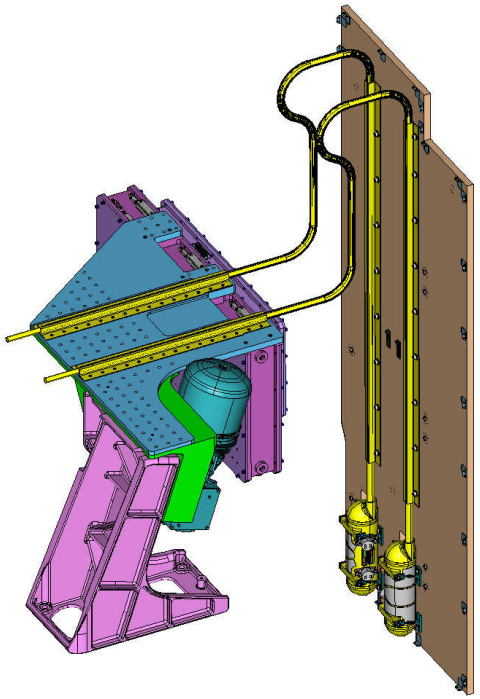
- Thermal Mechanical Unit (TMU)
  - NGAS High Efficiency Cryocooler (HEC)
  - Single stage linear pulse tube cooler maintains cold head temperature at ~110 K
  - Cryocooler maximum drive limit is set to 50% (~ **48** W compressor power) due to spacecraft power limitations
- Cryocooler Control Electronics (CCE)
  - NGAS Advanced Cryocooler Electronics (ACE)
- Cryogenic Subsystem (CSS)
  - Developed by Utah State University Space Dynamics Laboratory (SDL)
  - Interface between the three focal plane arrays (FPAs) and the TMU
  - Thermal isolates each FPA from instrument optical bench
  - Flexible aluminum foil thermal link connects each FPA to the TMU
  - Cryocooler BOM heat load is ~ 3 W at 110 K
  - With TMU cold block controlled to ~110 K, the CSS maintains the three FPAs at ~120 K

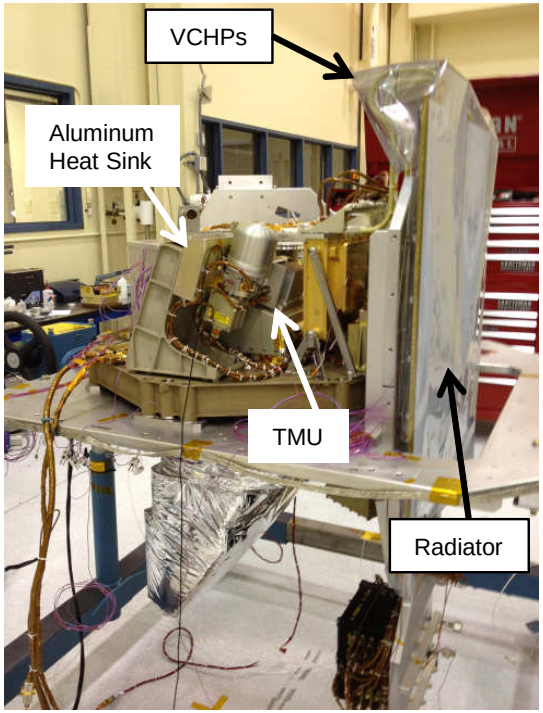




OCO-2 Instrument Heat Rejection System

- Cryocooler Heat Rejection System (HRS) uses variable conductance heat pipes (VCHPs) to transport waste heat from the cryocooler to a space-viewing radiator
- CCE is directly mounted to a spacecraft radiator viewing Earth

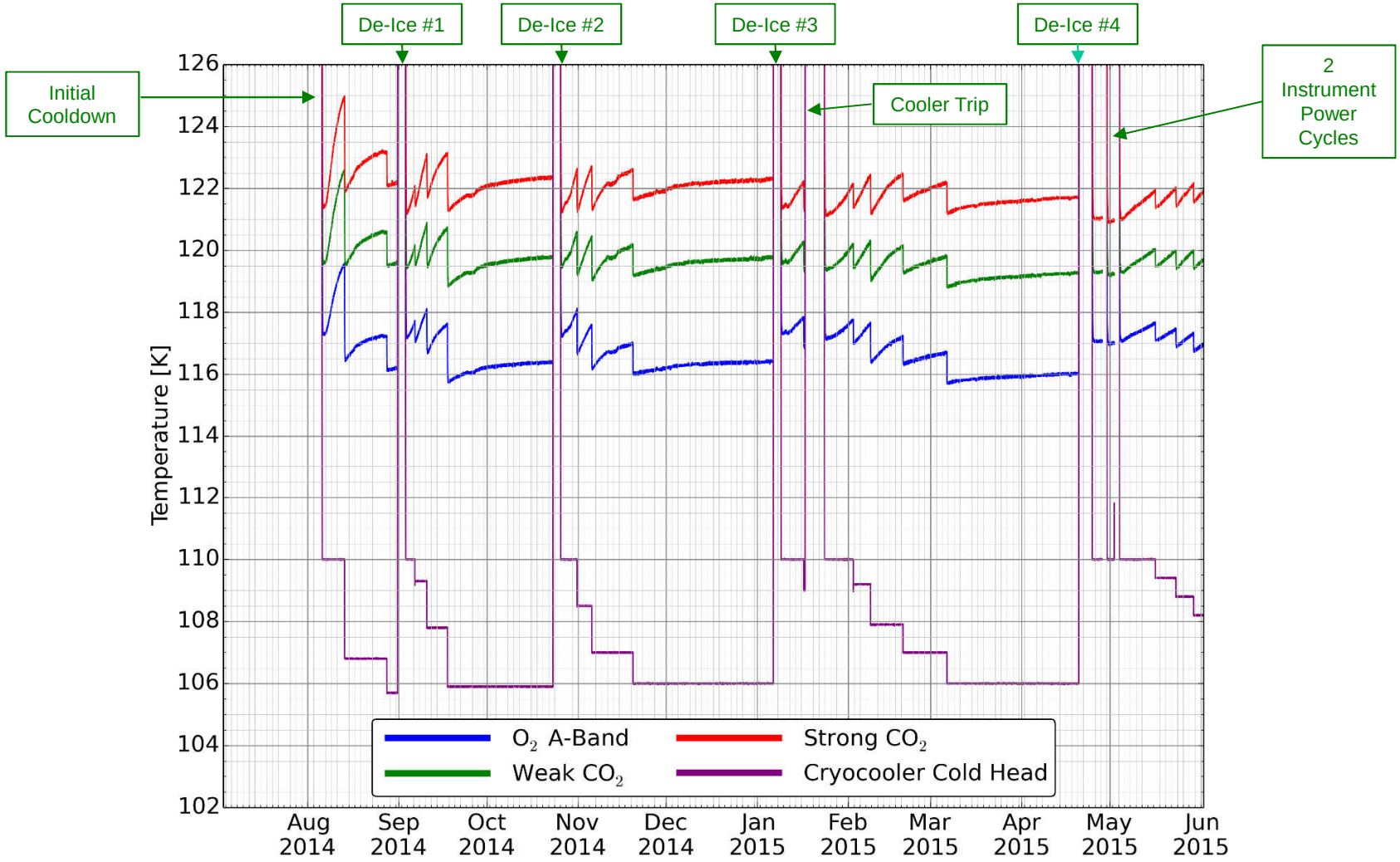




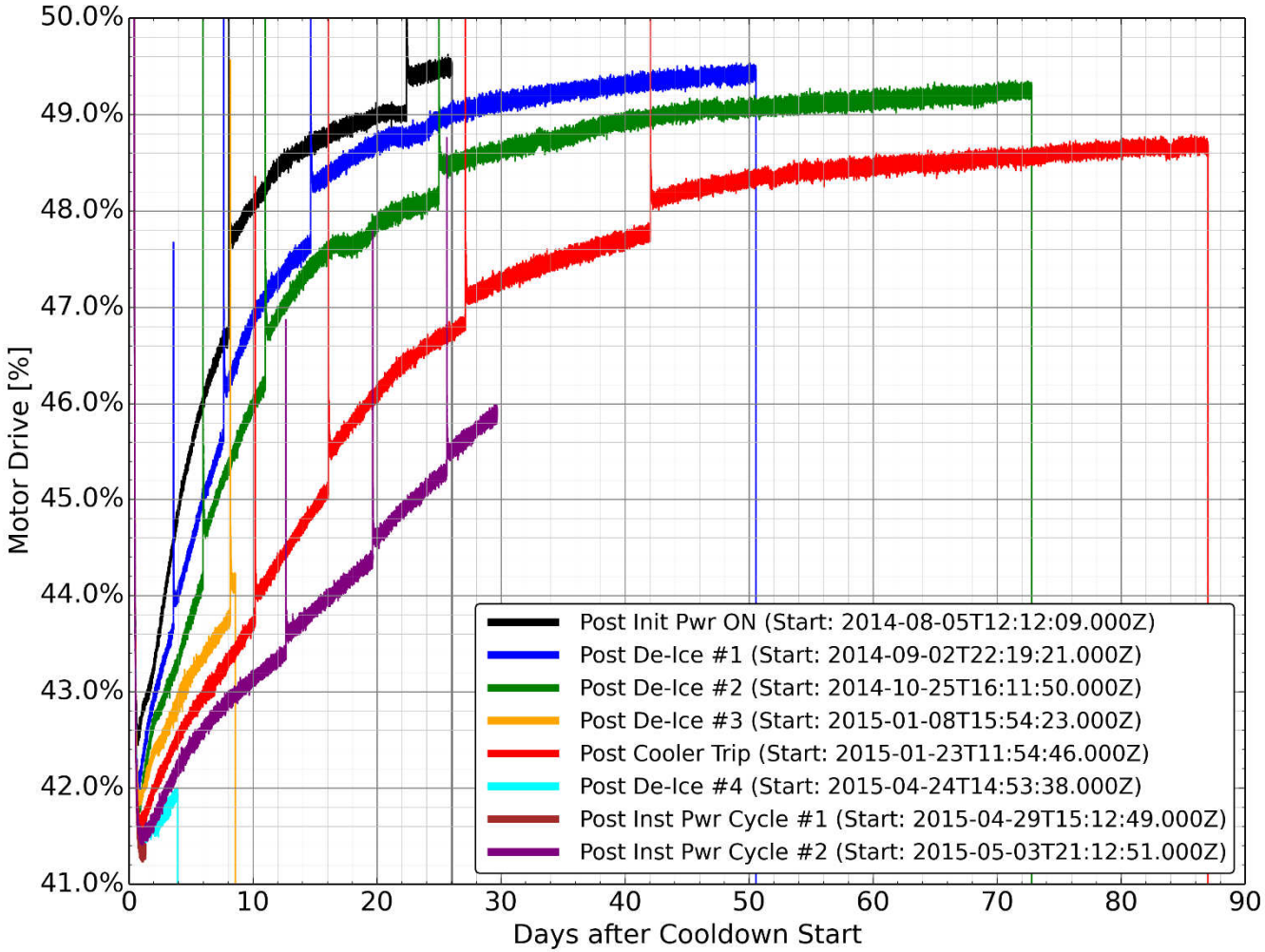
In-Flight History of Events

Day	Date	Event
1	7/2/2014	Launch; spacecraft powered ON; survival heaters ON
2	7/3/2014	Instrument powered ON; FPA decontamination heaters ON to raise detectors to ~300 K
5	7/6/2014	CCE powered ON
34	8/4/2014	FPA decontamination heater OFF after 32 days of outgassing
35	8/5/2014	Cryocooler powered ON
61-63	8/31/2014 - 9/2/2014	Cryocooler OFF; De-Ice Cycle #1 because approaching 50% cryocooler motor drive limit
114-116	10/23/2014 - 10/25/2014	Cryocooler OFF; De-Ice Cycle #2 because approaching 50% cryocooler motor drive limit
189-191	1/6/2015 - 1/8/2015	Cryocooler OFF; De-Ice Cycle #3 due to gain degradation in the O_2 FPA
200-206	1/17/2015 – 1/23/2015	Cryocooler OFF; De-Ice Cycle #3.1 due to cryocooler accelerometer overload over-limit. After confirmation of low risk, cryocooler returned to “ON” condition with same fault threshold settings.
293-297	4/20/2015 - 4/24/2015	Cryocooler OFF; De-Ice Cycle #4 due to gain degradation in the O_2 FPA
301-302	4/28/2015 – 4/29/2015	Cryocooler OFF; De-Ice Cycle #4.1 due to need to perform Instrument power cycle to fix error in the observatory absolute time sequence used to command OCO-2 autonomously
305-306	5/2/2015 – 5/3/2015	Cryocooler OFF; De-Ice Cycle #4.2 due to need to perform Instrument power cycle to fix error when powering down during the previous instrument power cycle
335	6/1/2015	Latest operating data prior to publication, no faults of any kind have occurred since day 306, and no de-icing has been required thus far

In-Flight Performance – Cold Head & FPAs

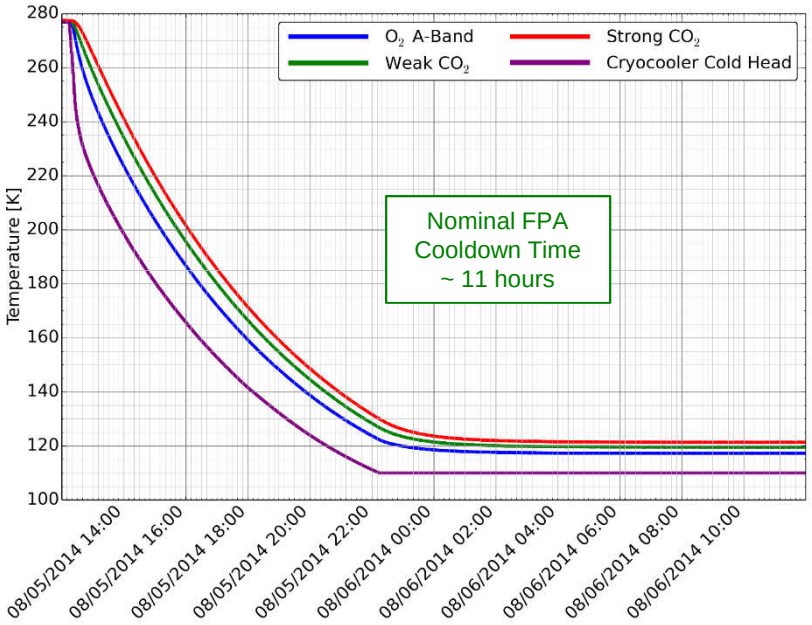


In-Flight Performance – Motor Drive Comparison

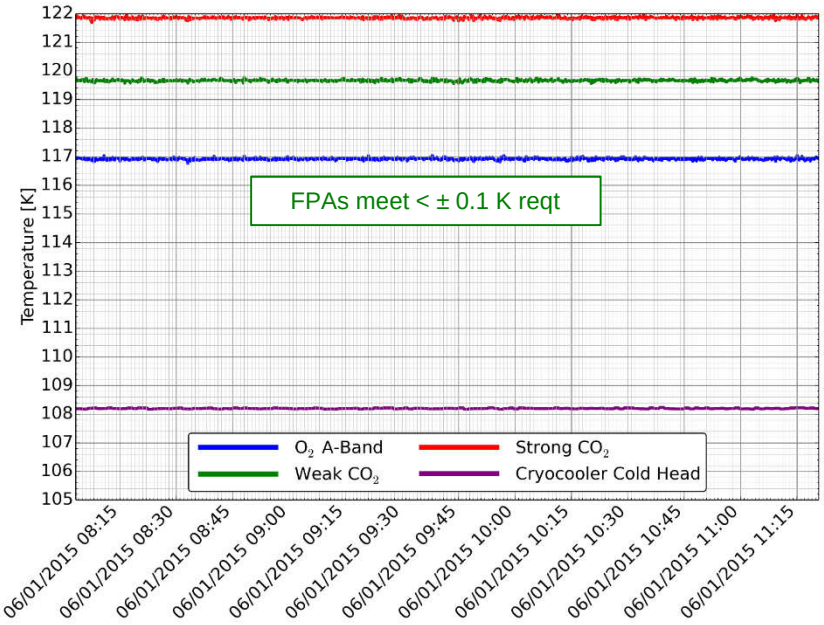


In-Flight Performance (cont.)

Initial Cooldown

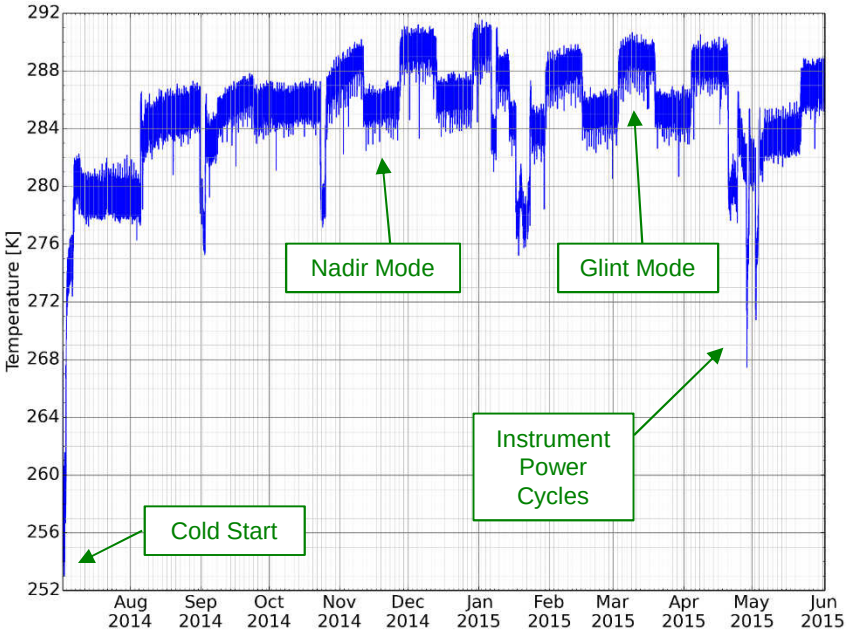


Temperature Stability

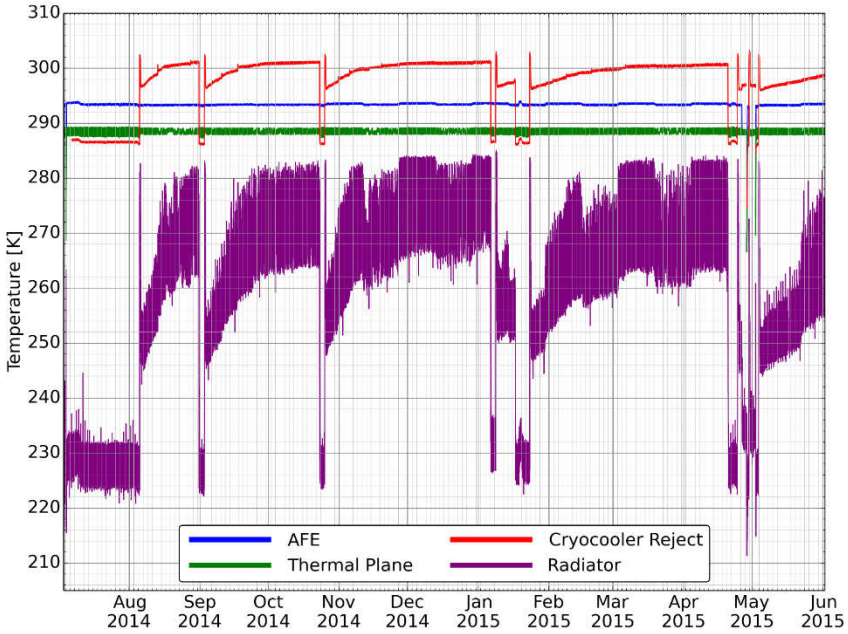


In-Flight Performance (cont.)

Cryocooler Control Electronics (CCE)



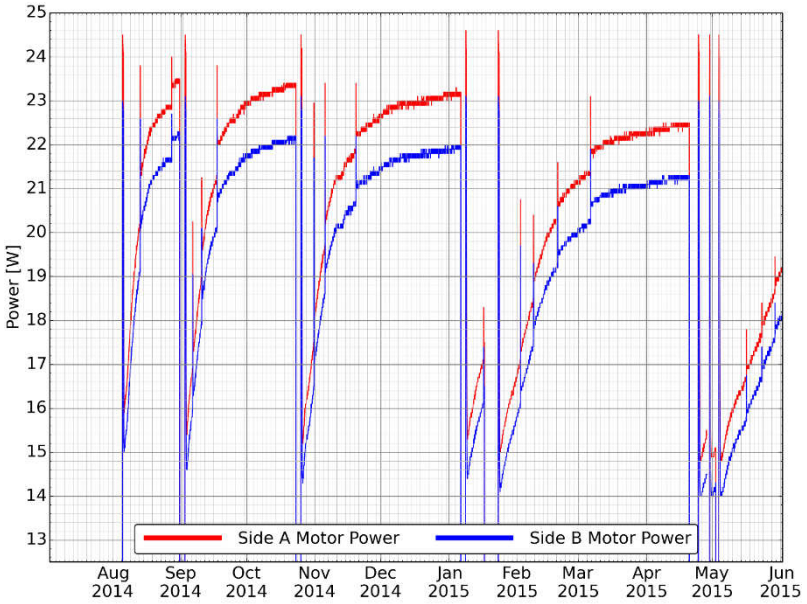
Cryocooler Heat Rejection System (HRS)



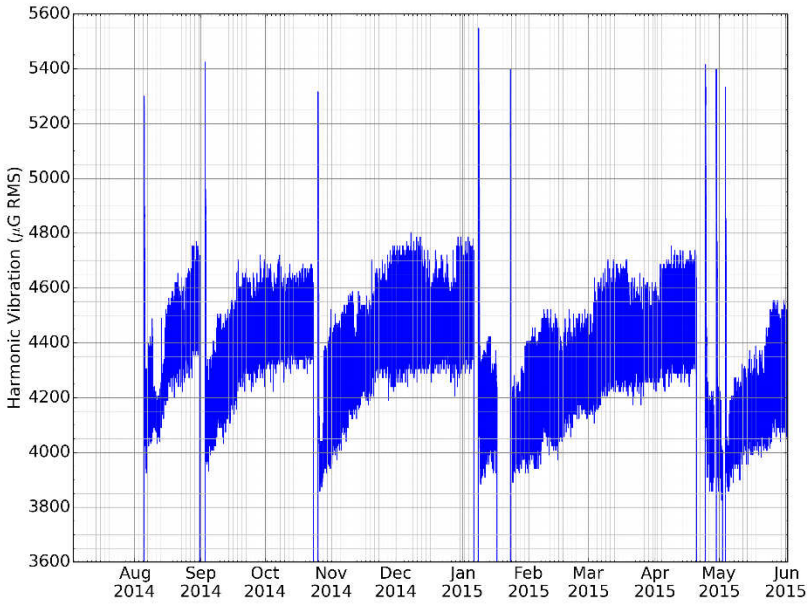
Cooler Reject varies by ~0.6 K p-p
Radiator varies by ~ 20 K p-p

In-Flight Performance (cont.)

Cryocooler Power



Cryocooler Vibration (RSS of 16 harmonics)



Cryocooler Accelerometer Overload Trip

- The trip event occurred on 1/17/2015, resulting in the CCE switching to Standby mode and powering off the cryocooler
  - The anomaly was similar to events experienced during ground testing where the cause of the fault was attributed to external sources (e.g., vibrating chiller lines and/or optical GSE movement above the chamber)
- In the interest of returning the instrument back to science mode, JPL and NGAS determined that the cryocooler was operating within specification and that there was no risk to powering back ON the cryocooler on 1/23/2015 with the same fault threshold setting
  - Root cause and corrective action still remained open for investigation; risk remained open for trip re-occurrence
- Accel Overload Detector is intended to protect the compressor against over-stroking
  - Does not differentiate between internal cooler vibration and external vibration
  - Can be false alarmed by external mechanical noise
- Root Cause: Could not be identified (appeared to be a false alarm)
  - There were no unique instrument or spacecraft activities at the time of trip; space environment was not abnormal
  - All cryocooler telemetry prior to the event shows nominal operation
  - RSS of all 16 harmonics at time of trip was 4.1 mG RMS
- The CCE provides several layers of protection against over-stroke
  - Asynchronous, time-domain over-vibration detection set to 47 mG (accel overload detector)
  - Synchronous, frequency-domain over-vibration detection set to 28 mG (individual harmonic level)
  - Motor over-current detection set to 2.0 A
  - Drive limit set to 50%
- Corrective Action: Disabled the accelerometer overload detector on 5/3/2015 to eliminate the risk of false alarms and very low risk due to other layers of protection in place
  - Investigation closed; no faults of any kind have occurred since 5/3/2015

Summary

- The heat rejection system for the cryocooler and CCE have performed well, maintaining the compressor and CCE near 300 K and 285 K, respectively
- The NGAS HEC cooler has operated wonderfully and demonstrated excellent in-flight thermal performance to date
- Ice contamination rate on detectors and cooler cryogenic surfaces has decreased over time such that de-icing cycles are now only performed once every ~ 4 months
- The exceptional performance of the cryocooler system has enabled OCO-2 to meet its science objectives and is expected to continue for the remainder of the 2 year mission