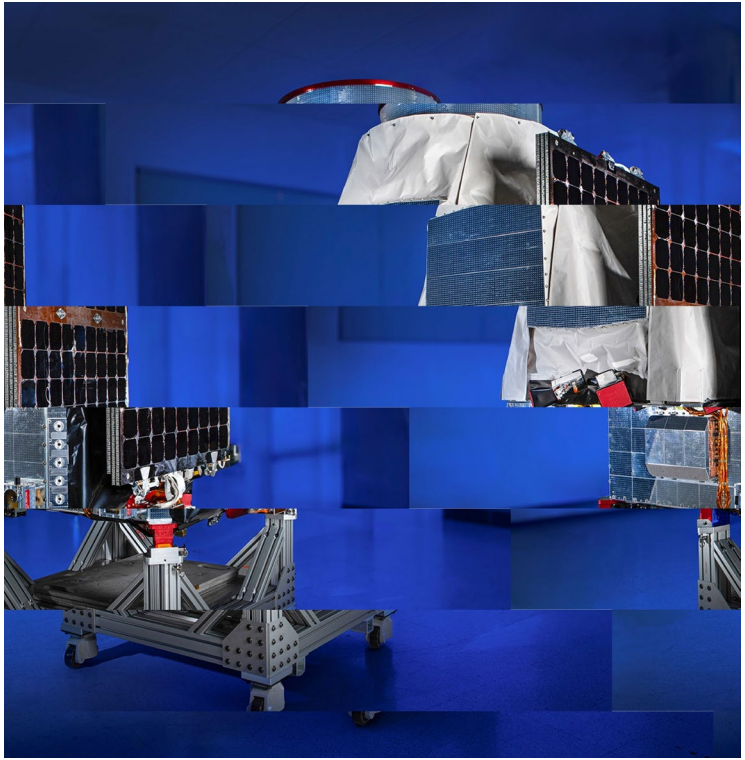
Cryocooler System Design and Performance for the Pandora Flight Mission

C.S. Kirkconnell, West Coast Solutions (WCS)
J.M. Baxter, WCS
N.A. Hudson, WCS
R.W. Kaszeta, Creare
J. T. Greenhalgh, Creare
J. Karburn, Lawrence Livermore (LLNL)



Credit: https://science.nasa.gov/mission/pandora/ [NASA/BCT]

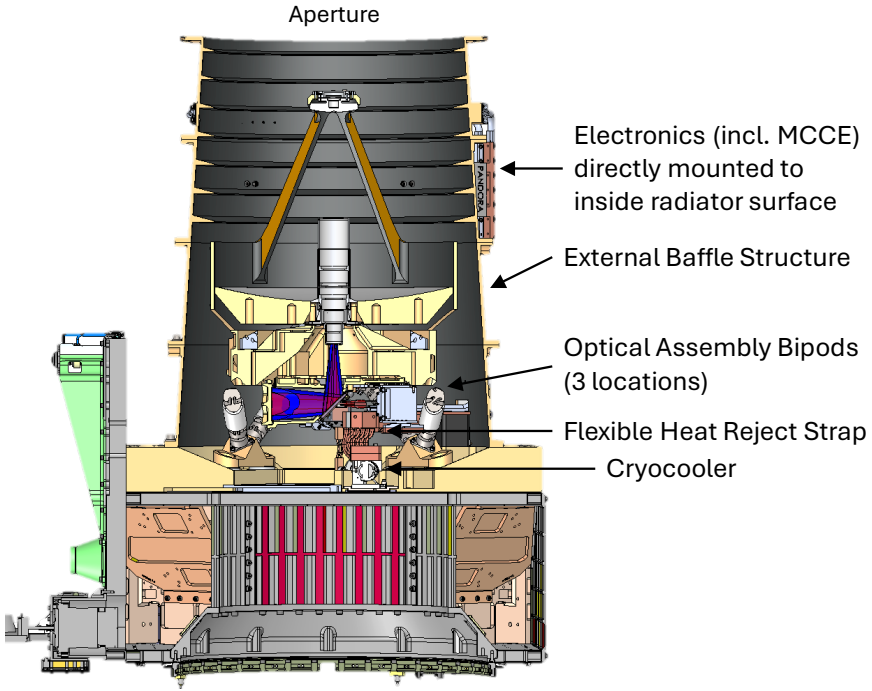
Pandora Mission Overview

- NASA Astrophysics Pioneers Program
- Purpose: Exoplanet atmospheric characterization
- Approach: Simultaneous, long-baseline visible photometry and near-infrared (NIR) spectroscopy – transit spectroscopy
- Orbit: Sun-synchronous LEO (600 km)
- Context: Alternate platform vs. James Web Space Telescope (JWST)
  - JWST oversubscribed
  - Pandora: 20 exoplanets across >10 transits, > 12 hour continuous data

Pandora providing an alternate platform for exoplanet atmospheric characterization at a substantially lower price point

Spaccraft / Instrument Overview

- Blue Canyon Technologies (BCT) Saturn-class bus
- ESPA-Grande secondary payload form factor
  - 325 kg
  - 500 W
- Optical Payload
  - 45-cm, aluminum Cassegrain telescope
  - Two detector channels fed by dichroic beamsplitter
    - Visible Detector Assembly (VISDA): 380 – 750 nm
    - Near-Infrared Detector Assembly (NIRDA): 850 – 1620 nm
      - Utilizes spare JWST Teledyne H2RG
      - **Enabled by Cryocooler Subsystem including Creare/WCS CCE**



Pandora Cryocooler System Requirements

Parameter	Value
Cold tip set point	120 K
Total subsystem input power (cooler + CCE)	55 W (45 W cooler, 10 W CCE)
Heat-reject interface temperature range	−20 °C to +40 °C
Pointing stability (telescope imaging reference frame)	3 arcsec / 60 s RMS
Mission duration / duty cycle	1 year / 100% (nominal)
Redundancy	Single string
TRL at selection	6

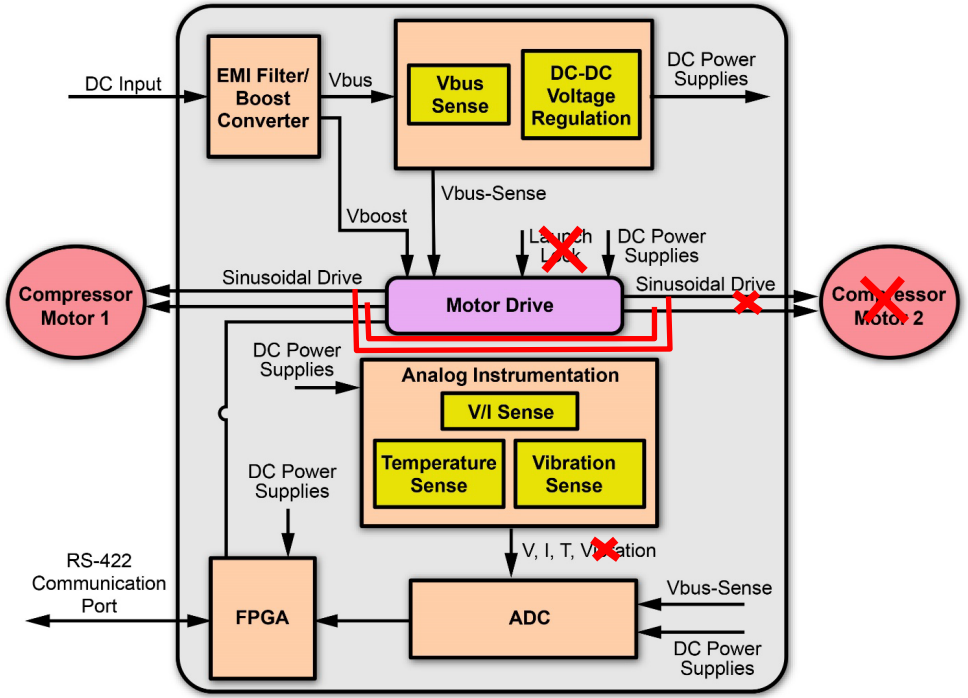
Cryocooler Electronics Approach

- Linear drive, Stirling-class cryocooler
- CCE: Adaptation of standard MCCE-TS product
  - MCCE-TS1 – 80W class CCE
- MCCE was a late program selection, necessitated a 6-month delivery time
  - Typical lead time 10-14 months
  - Aggressive schedule met by leveraging a high TRL/MRL unit, i.e., mature design and spare components and subassemblies from the ongoing CCE production line
- Active vibration control not required due to optomechanical design, enabling simplification, which in turn helped enable schedule closure

Product	MCCE-C3E	MCCE-C3EPT	MCCE-TS1	MCCE-TS2	MCCE-HPI	MCCE-HPI+
Drive Configuration	Single	Single	Dual	Dual*	Dual*	Dual*
Max Output Power (W)	30	50	80	80	160	160
Mass Range for 0.1 - 0.3" Thick Chassis	0.39 - 0.50	0.56 - 1.2	1.2 - 1.9	1.4 - 2.9	1.7 - 3.0	3.2 - 4.7
Ripple Filter	Passive	Active/Boost	Passive	Passive	Active/Boost	Active/Boost
Comms	RS-422	RS-422	RS-422	RS-422	RS-422	RS-422
Protocol	SLIP	SLIP	SLIP	SLIP	SLIP	SLIP
Vibe Control	No	No	No	3 Harmonics	3 Harmonics	5+ Harmonics
Inrush Limiting	Yes	Yes	Yes	Yes	Yes	Yes
Overcurrent (Output)	No	Yes	No	No	No	No
Clock Sync	No	Yes	No	No	No	No
EEE Parts Min TID (kRad(Si))	30	30	30	30	30	100
TRL	6	6	9	9	8	5
TRL 6 Date	2024	2025	2022	2023	2026	TBD

* Configurable as either two identical drives (e.g., dual-opposed motors) or as one high power and one low power drive (e.g., compressor motor plus balancer motor)

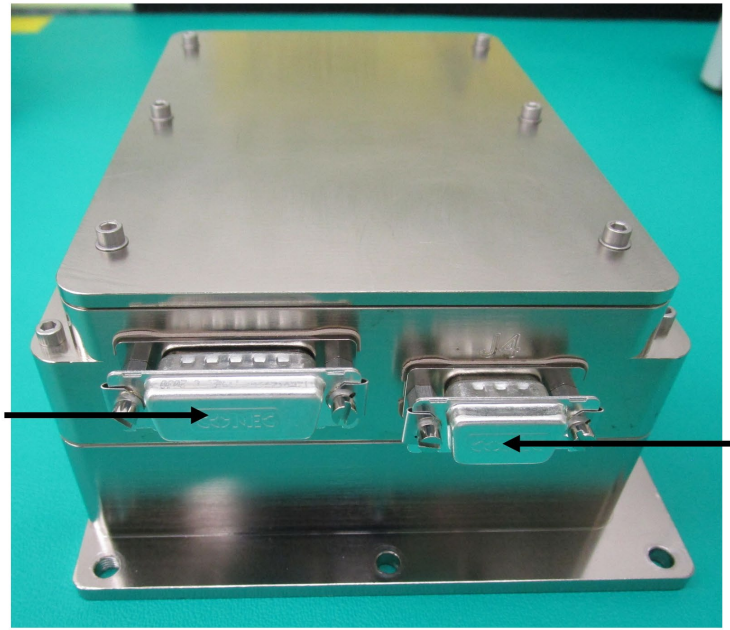
HyTI-2 vs. “Standard” MCCE



Manufacturing Approach

- MCCE-TS1 Auxiliary Board, comprised primarily of the input ripple filter and inrush limiting circuit, was used as is
- MCCE-TS2 Main Board modified as follows
- Removed launch locks
- Wired motor drives together (single output)
- Optimized the cold tip telemetry to provide improved (30 mK) resolution on one of the two cold tip PRT) channels
- Updated firmware to adapt the controls to the above hardware changes
- Custom enclosure

Pandora CCE – Modified MCCE-TS1

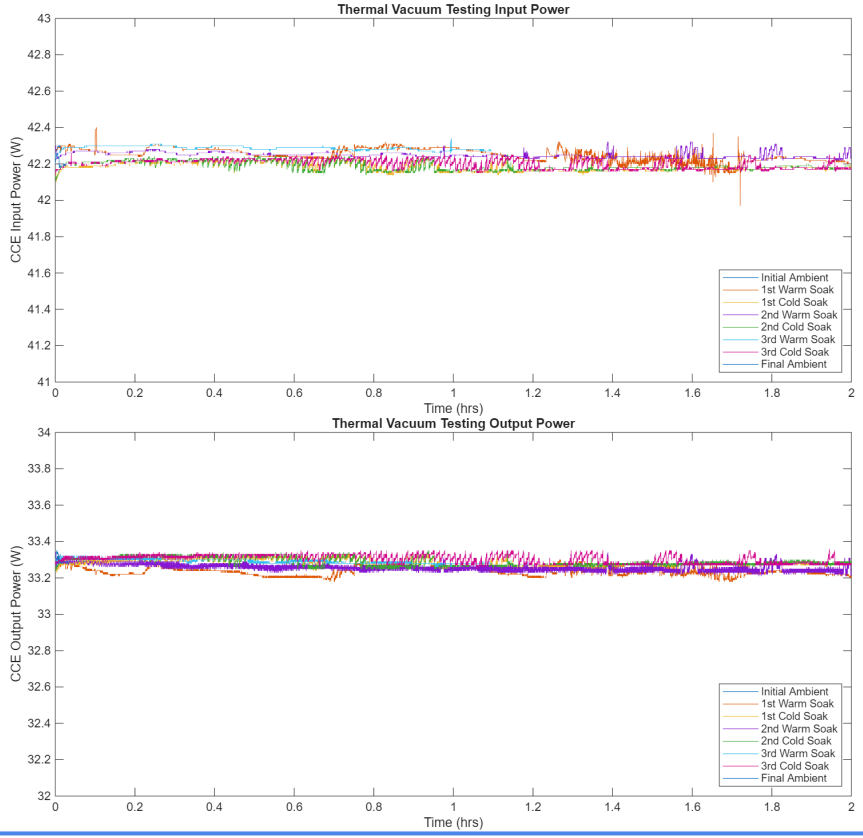


- 6.75” x 5.1” x 3.0”
- Mass = 1.85 kg
- Telemetry and Output Power connectors shown
- Input Power and Communications on opposite face (not visible)

Pre-Ship Testing at Creare

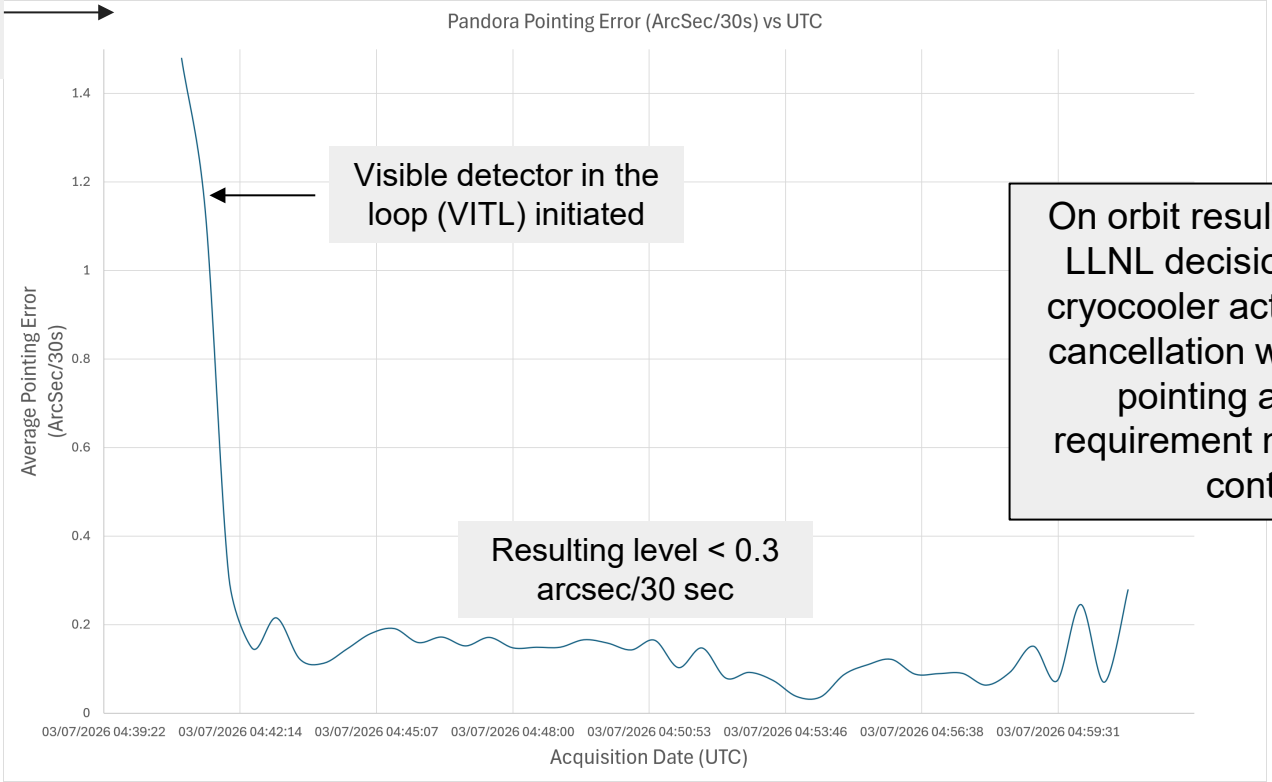
Abbreviated Acceptance Testing:

- Standard production screening tests
- Standard production performance tests
- Sine sweep vibration tests
- Random vibration tests
  - 7.8 Grms (GEVS Acceptance); 0.05 G^2/Hz from 50 to 800 Hz
  - 60-seconds per axis, 3 axes
  - Compliance verified with pre- and post-tests
- Thermal vacuum tests
  - Three cold operational soaks: 2 hours @ -20 degC
  - Three hot operational soaks: 2 hours @ +50 degC
  - Compliance verified with pre- and post-tests
  - Essentially imperceptible difference between cases
- Measured 79% total throughput efficiency lower than typical (~85%)
  - Reflective of operation at only ~ ½ CCE capacity



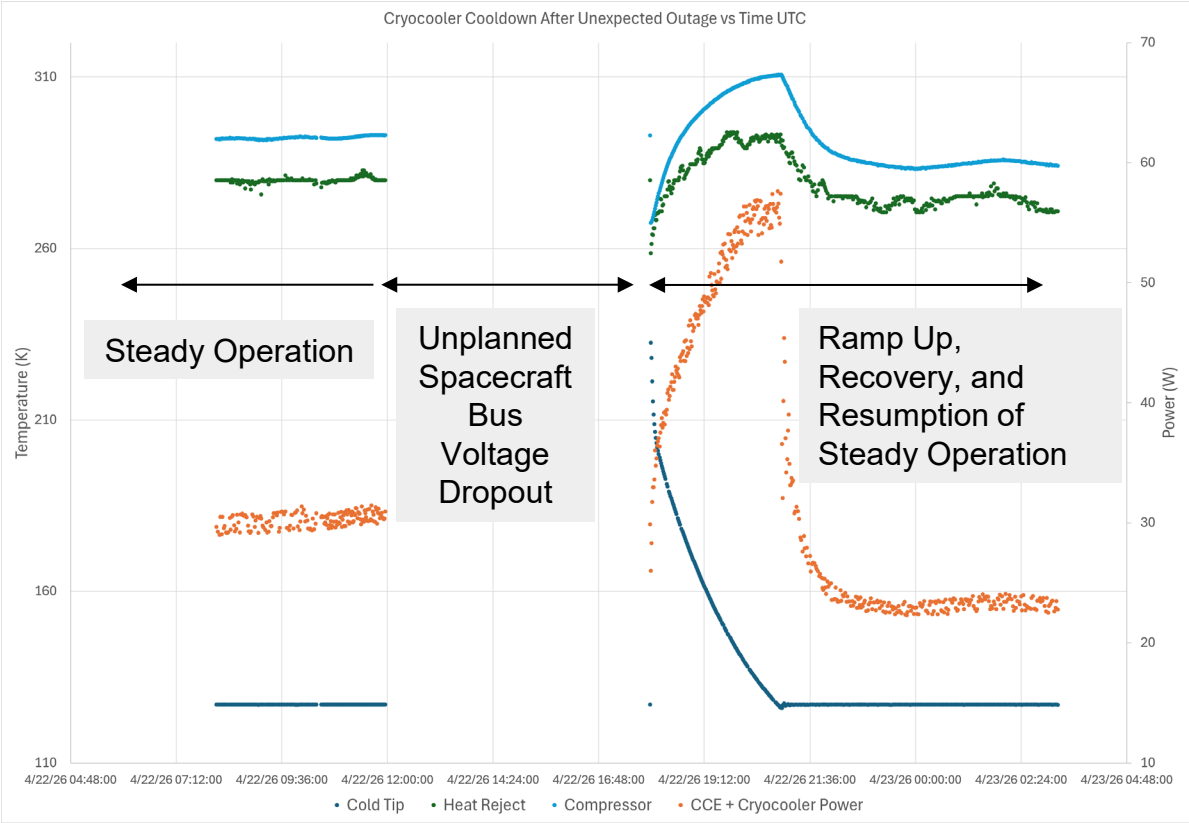
On-Orbit Performance: Pointing Accuracy

Requirement:
1.5 arcsec/30 sec

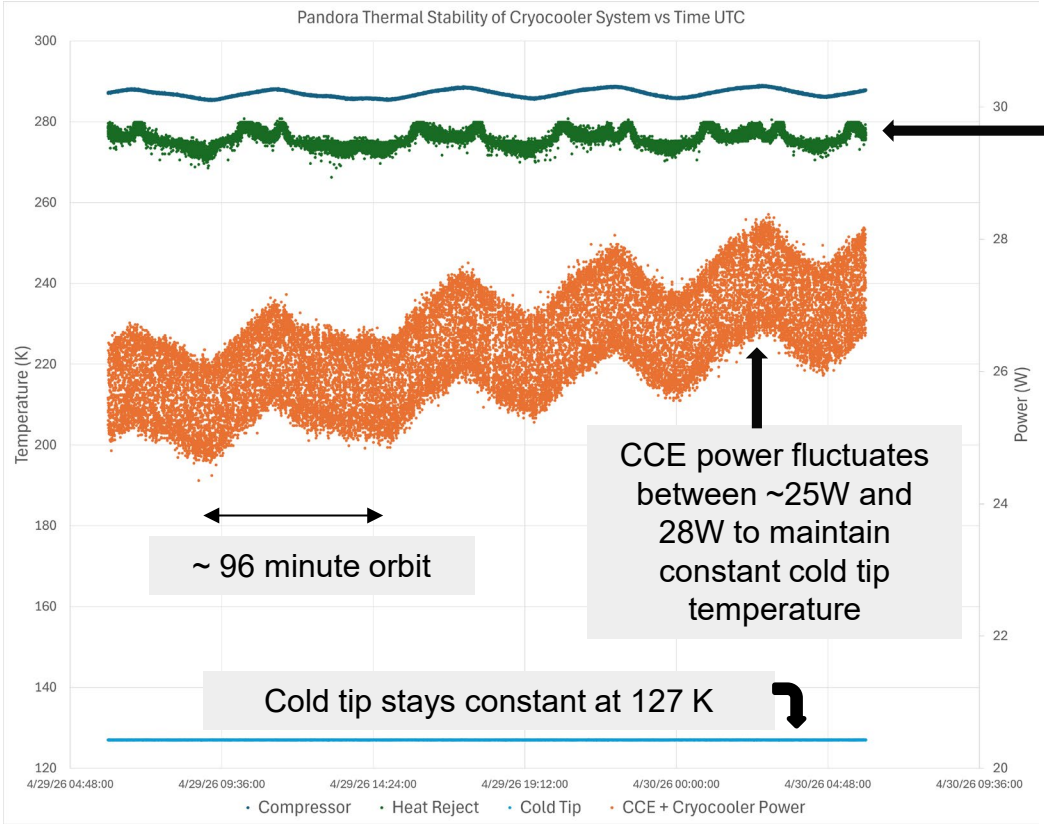


On orbit results prove that LLNL decision to forego cryocooler active vibration cancellation was correct – pointing accuracy requirement met w/o vibe control

On-Orbit Cryo System Auto-recovery

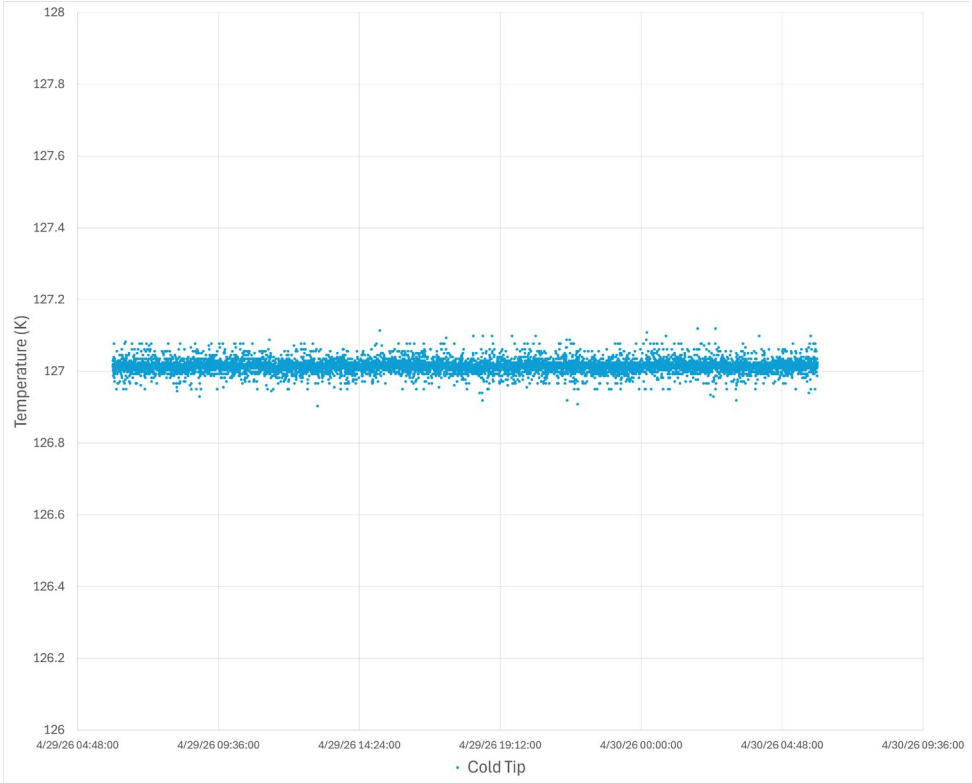


Cryo System Prototypical Orbital Fluctuations



Modest orbital fluctuations in heat reject and associated compressor temperature

Very Stable On-Orbit Cold Tip Temperature



60-second-averaged rolling standard deviation is 5.2 mK – a factor of two within the 10 mK/60 second requirement

Conclusion

- Creare and WCS successfully adapted a high-TRL MCCE design to meet aggressive technical and schedule challenges for Pandora
- Cryocooler System is performing in full compliance with mission requirements
- On-orbit performance of the Pandora instrument is outstanding, generating valuable science products