Cryocooler/Thermal System Design and Performance on the HyTI-2 Flight Mission

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(defn. HyTI = Hyperspectral Thermal Imager)

Credit: https://www.hsfl.hawaii.edu/missions/hyti/

HyTI-2 Mission Overview

- NASA Earth Science Technology Office InVEST
- Program: Active Cooling for Multispectral Earth Sensors (ACMES)
- Instrument Objective: Hyperspectral measurement of land surface temperatures (LST)
- Approach: Push-broom Fabry–Pérot hyperspectral LWIR imager
  - 25 spectral bands in the 8–12 μm range
  - Ground sampling resolution at 45 m narrow-band
  - NEdT (noise equivalent variation in temperature) of less than 150 mK
- Orbit: Sun-synchronous LEO (550 km)
- Context: Gap-filler for OroraTech's Forest and Muon Space FireSat, and similar
  - Existing architectures provide persistence, but lack spatial and spectral resolution
  - HyTI-2: Surface emissivity retrieval, temperature-emissivity separation, and compositional mapping at Landsat-class radiometric performance with the revisit rate of a small satellite constellation

HyTI-2 Instrument Designed to be a Gap Filler in Fulfilling NASA's LST Measurement Objectives

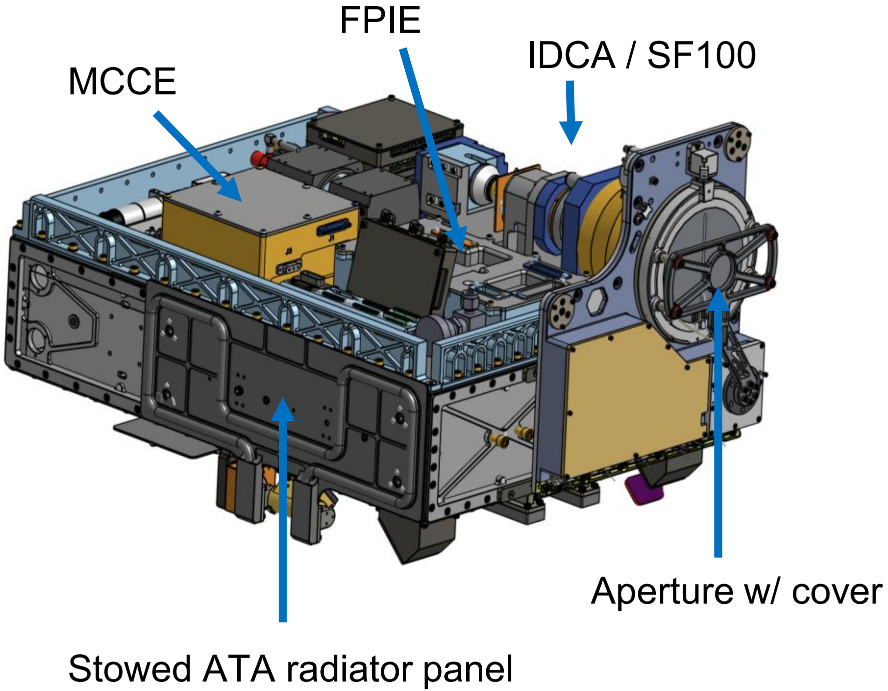
HyTI-2 System/Cryo/Thermal Requirements

Mission	GSD	LWIR Range	Detector	Bands	Platform
Landsat 9 TIRS-2	100 m	10.6–12.5 µm	QWIP; passive cooling	2	Large sat (~2,710 kg)
ECOSTRESS (ISS)	~70 m	8.0–12.5 µm	HgCdTe push-broom	5	ISS-hosted
OroraTech Forest	~200 m	8–14 µm	Uncooled microbolometer	1–2	3U–8U CubeSat
FireSat	~50 m	MWIR/LWIR	Cooled IR, AI onboard	6	Microsat (150–500 kg)
HyTI-1 (HSFL)	~60 m	8–12 µm	Fabry–Pérot, HOT-BIRD	~25	6U CubeSat
ACMES / HyTI-2	**45 m**	**8–12 µm**	**HOT-BIRD, Stirling cryo**	**25**	**Small sat (~70 kg)**
Blue Moon	~3 m	8–13 µm	uncooled micro-bolometer array (UMBA)	TBD	SmallSat 170 kg

Parameter	Requirement	Measured	Notes
FPA operating temp.	~65–67 K	~65–67 K ✓	AIM SF100 IDCA; target 67 K
Cryocooler input power (nominal)	< 40 W	< 30 W	Measured with MCCE after camera integration
Cold tip heat load	< 0.8 W	< 0.8 W ✓	FPA + parasitics
Payload thermal dissipation	> 100 W sustained	> 105 W (ATA design)	ATA-enabled; ±5°C stability
Duty cycle	> 50% (target)	~Near-continuous (ATA)	vs. ~2% without active cooling

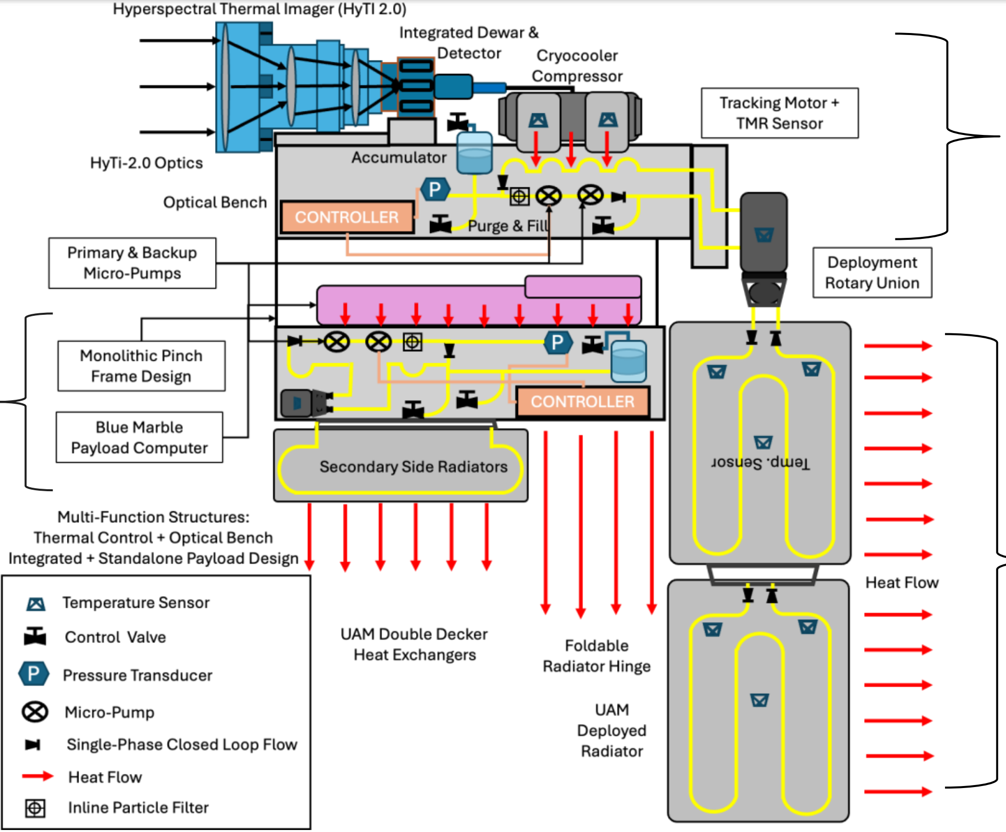
Instrument Overview

- Fore optics with passive temperature compensation
- Fabry–Pérot etalon interferometer
- HOT-BIRD (Higher Operating Temperature Barrier Infrared Detector) focal plane array (FPA)
- Blue Marble Space (BMS) Space Edge Processor (SEP)
- Cryocooler System
    - AIM SF100 Cryocooler w/ “Space Housing,” i.e., housing built with large flat heat rejection surfaces for conduction cooling
    - Customized Creare/WCS MCCE
- Heat Rejection System – Active Thermal Architecture (ATA)
    - Dual pumped loops to enable >50% duty cycle



Active Thermal Architecture (Arcfield)

Loop #2: BMS Spaced Edge Processor (SEP) - Typical electronics control range, i.e., tight regulation not required



Loop #1: IDCA

- SF100
- MCCE
- Saaz FPIE (focal plane interface electronics)
- Tight regulation: +/- 2.5ºC

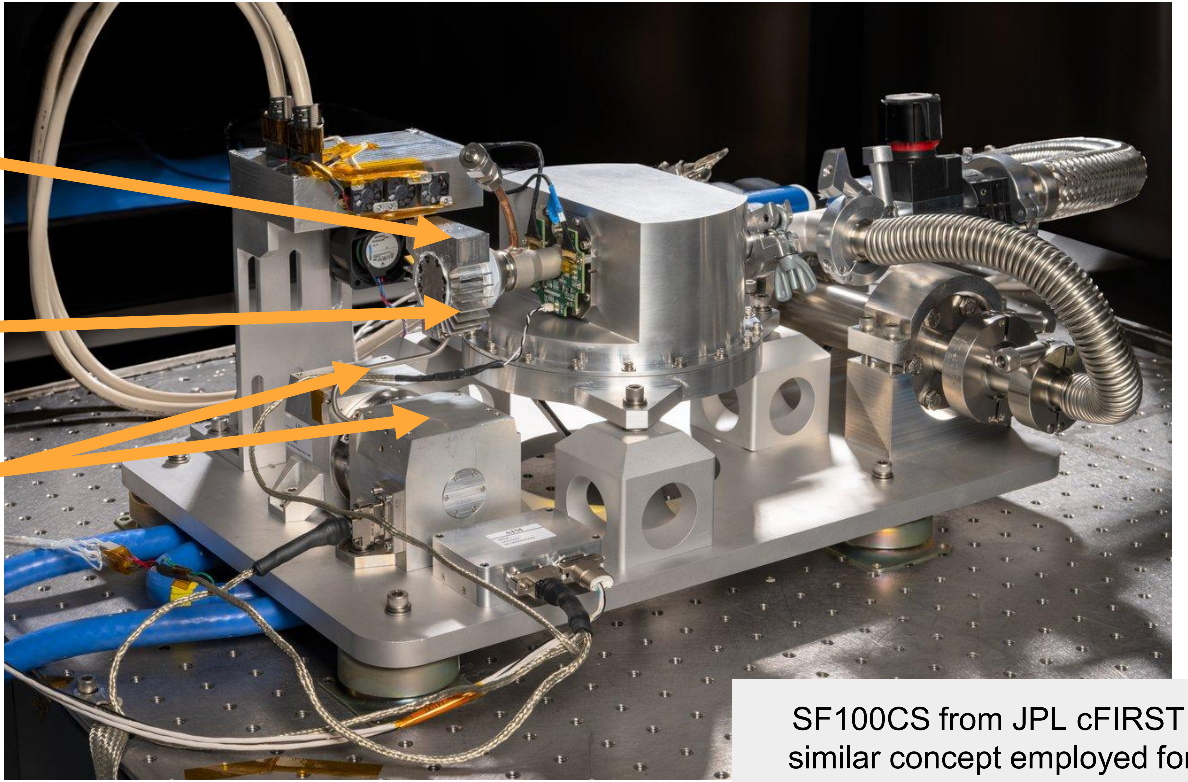
On-orbit duty cycle w/o ATA ~ 2%, with ATA >50%

SF100CS Cryocooler - cFIRST

Flat surface on expander heat sink for conductive cooling

Remaining finned heat sink facilitates ground testing

Large flats on compressor housing for conductive cooling



SF100CS from JPL cFIRST shown; similar concept employed for HyTI-2

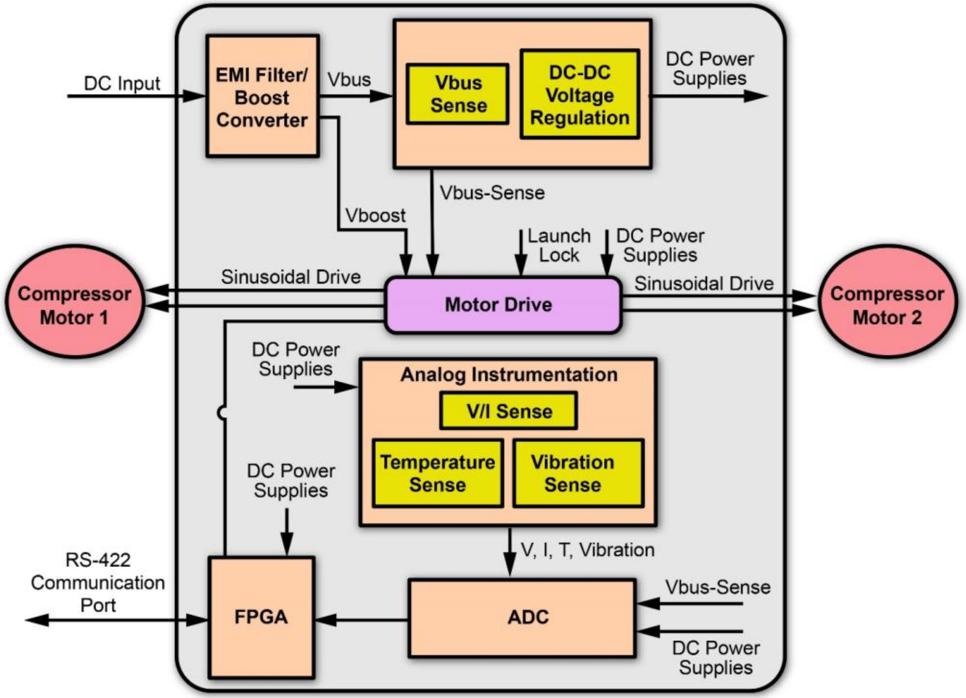
Cryocooler Electronics Approach

- HyTI-2 CCE a follow on / upgrade to HyTI CCE (ref. ***Cryocoolers 21***)
- Primary upgrades:
    - Support higher power SF100 cryocooler (vs. SF070 used on HyTI)
    - Add an enclosure (vs. PCBAs mounted directly to the CubeSat facets)
    - Implement active vibration cancellation
- Design Approach
    - MCCE-HP1 electrical design as starting point
    - HyTI (and ARCSTONE)-like low voltage boost converter for 15V +/- 1V bus
    - Aggressive repackaging
        - HP1: 6.4" x 6.0" x 3.5"
        - HyTI-2: 5.0" x 4.9" x 2.3"

Product	MCCE-C3E	MCCE-C3EPT	MCCE-TS1	MCCE-TS2	MCCE-HP1	MCCE-HP1+
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 CCE


DC Input
EMI Filter/ Boost Converter
Vbus
Vbus Sense
DC-DC Voltage Regulation
DC Power Supplies
Vbus-Sense
Vboost
Launch Lock
DC Power Supplies
Sinusoidal Drive
Compressor Motor 1
Motor Drive
Sinusoidal Drive
Compressor Motor 2
DC Power Supplies
Analog Instrumentation
V/I Sense
Temperature Sense
Vibration Sense
DC Power Supplies
V, I, T, Vibration
RS-422 Communication Port
FPGA
ADC
Vbus-Sense
DC Power Supplies

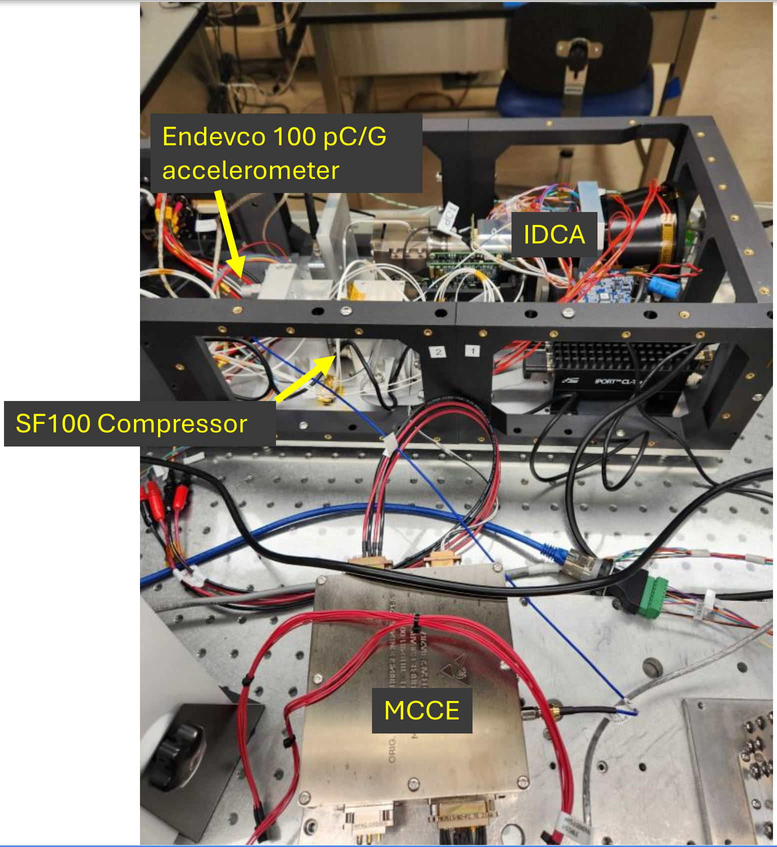

Mass = 1.76 kg

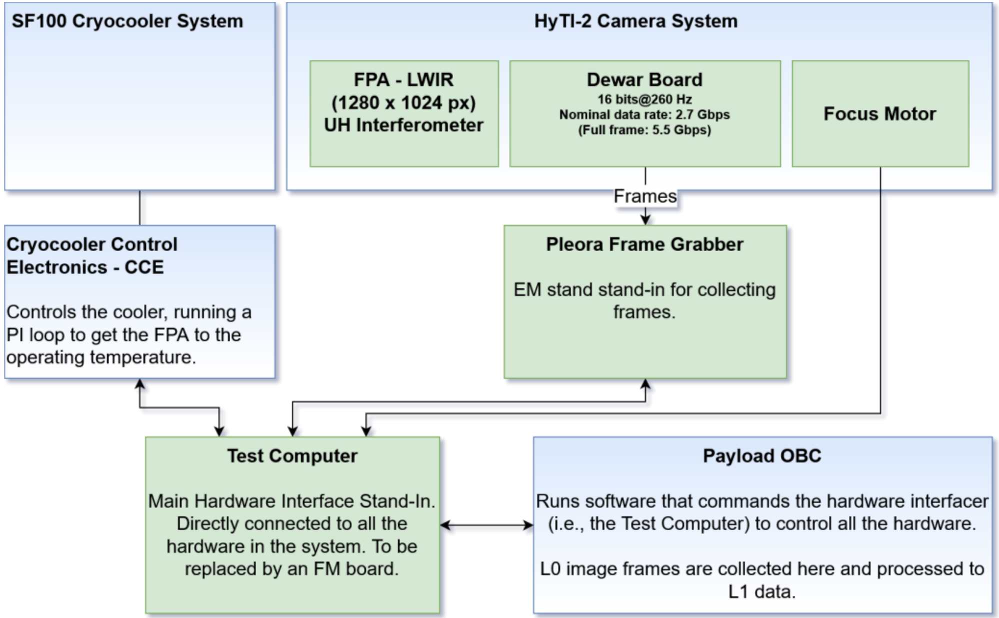
Pre-Ship Testing at Creare

Full Acceptance Testing:

- Standard production screening tests
- Standard production performance tests
- Sine sweep vibration tests
- Random vibration tests
  - 6.8 Grms; 0.04 G^2/Hz from 80 to 500 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 75% total throughput efficiency
  - Low input bus voltage (15V vs. typical 28V) increases losses in the ripple filter / boost converter circuit
  - Low impedance SF100 increases losses in the motor drive and output EMI filter

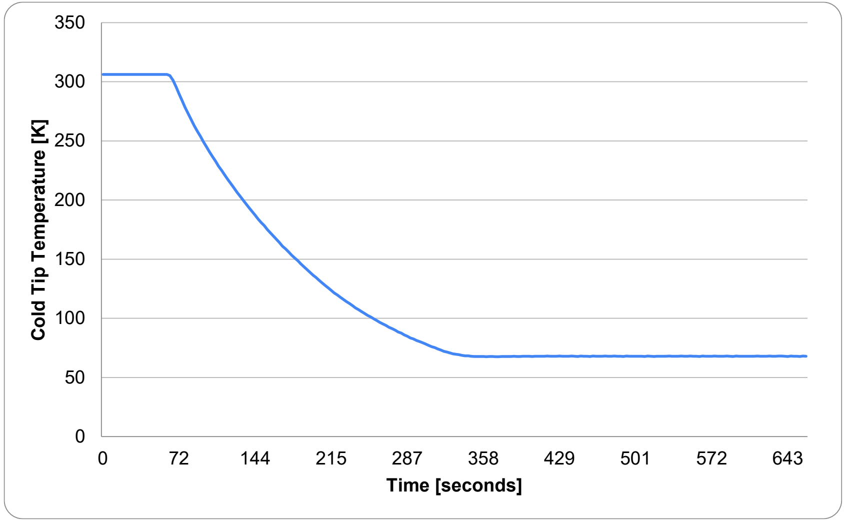
Integrated Testing at HSFL - Configuration



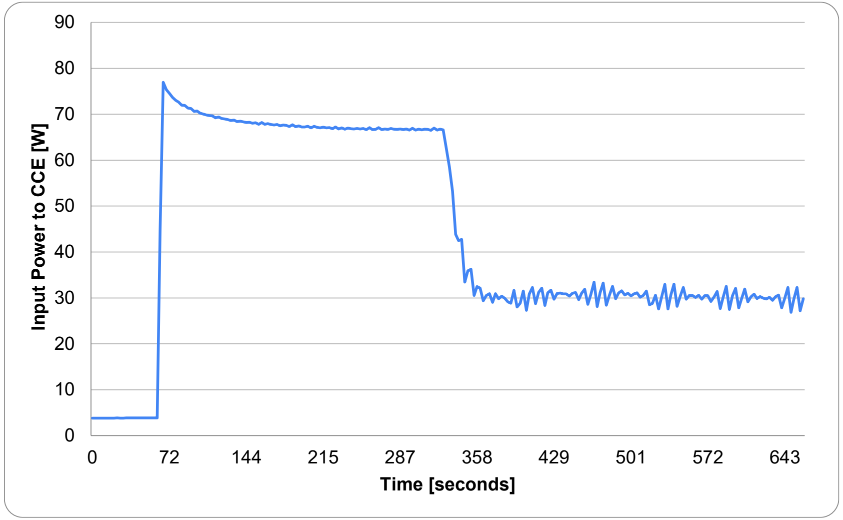


Initial testing has focused on thermal performance. Vibration control to be tuned and characterized at the next level of integration.

Typical Cool Down Curves – Initial Testing



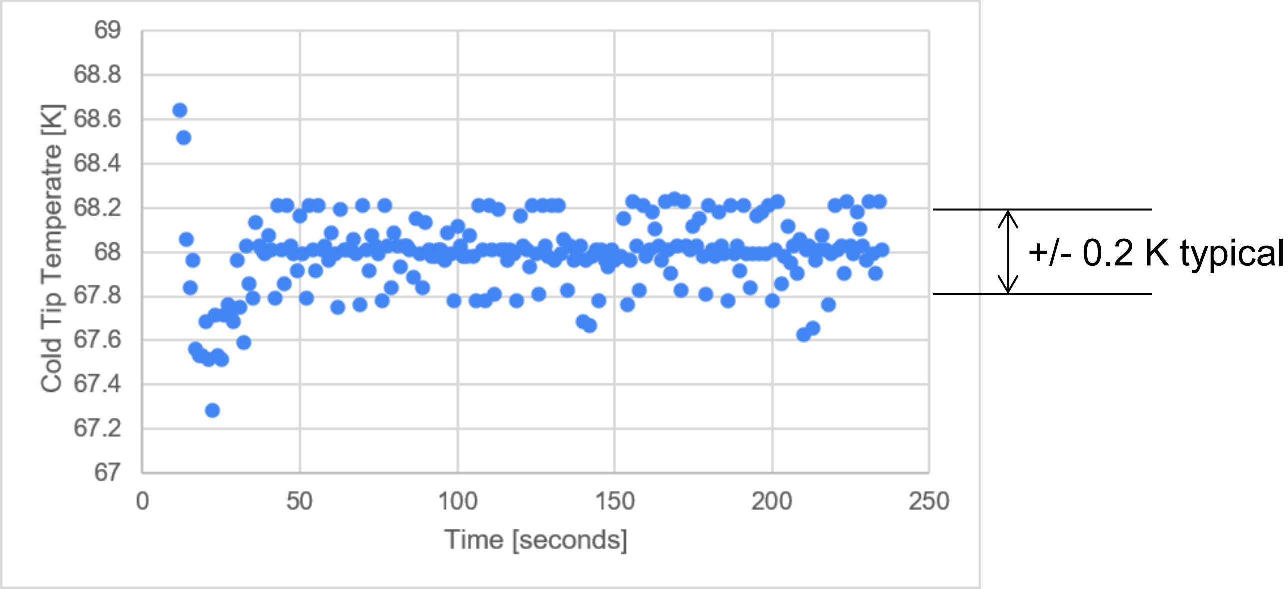
Controlled cool down from ambient to 68K in ~ 6 minutes



Constant voltage output, nearly constant power to CCE after initial cooling

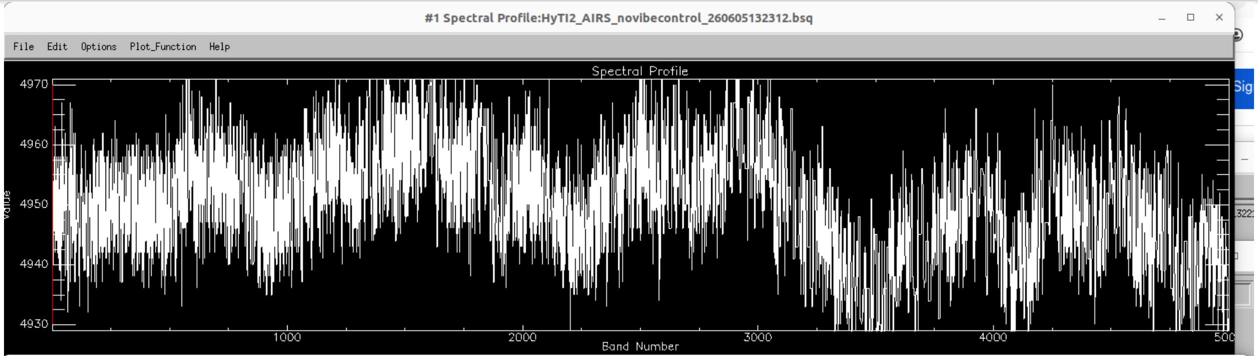
Power drops to ~ 30W(DC) once setpoint is reached

Temperature Stability

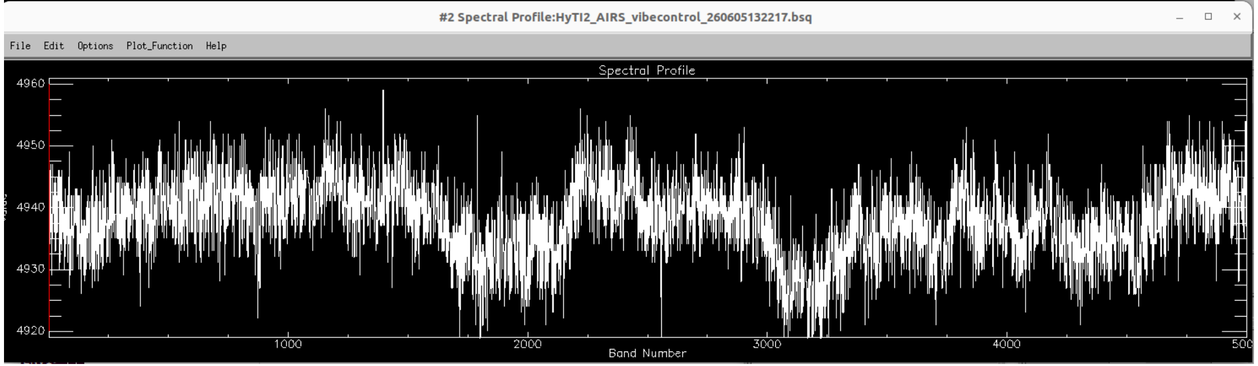


Compliant performance achieved with very minimal temperature control loop tuning

Very Initial Vibration Control



Digital noise in a single pixel over 5000 fames (~40 seconds) – no vibe control



Same pixel and operating case – with vibe control, on benchtop, very minimal tuning

Approximately 50% Noise Reduction Achieved with Minimal Tuning in Non-Ideal Setup

Conclusion

- HyTI-2 will demonstrate on-orbit hyperspectral imaging capability with unique, combined spectral and spatial resolution capabilities
- Cryocooler System
  - SF100 w/ “Space Housing”
  - CCE: Creare/WCS MCCE-HP1 adaptation for minimal volume
- Modified MCCE-HP1 is full featured (inrush limiting, active ripple filter, launch lock, vibe control)
- Initial integrated thermal testing indicates cryocooler system compliance (30W required vs. >80W capability)
- Very initial vibration control testing promising
- HyTI-2 on track to launch in 2027