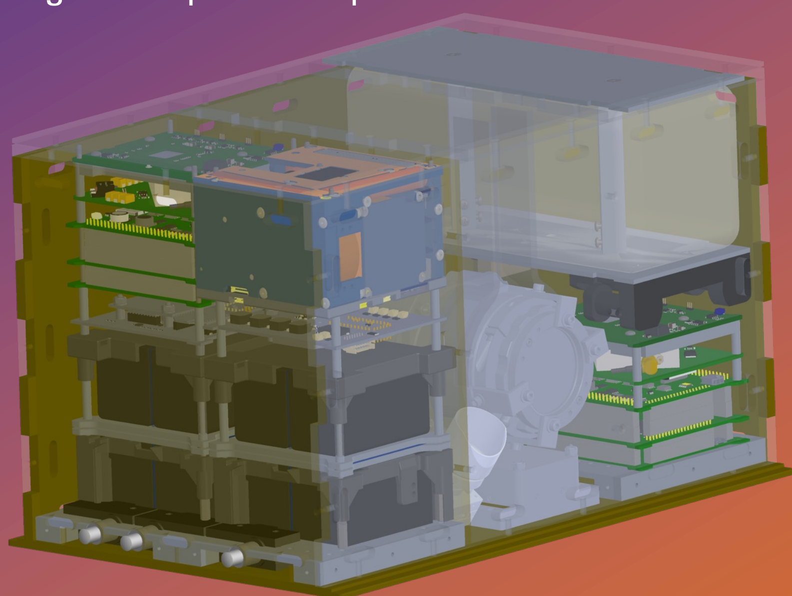
Implementation of a Cryogenic Optical Instrument in a 12U CubeSat:

THE DOPPLER WIND AND TEMPERATURE SENSOR (DWTS) FLIGHT EXPERIMENT

NOW The Nano Orbital Workshop

Rapid Flight Development Group



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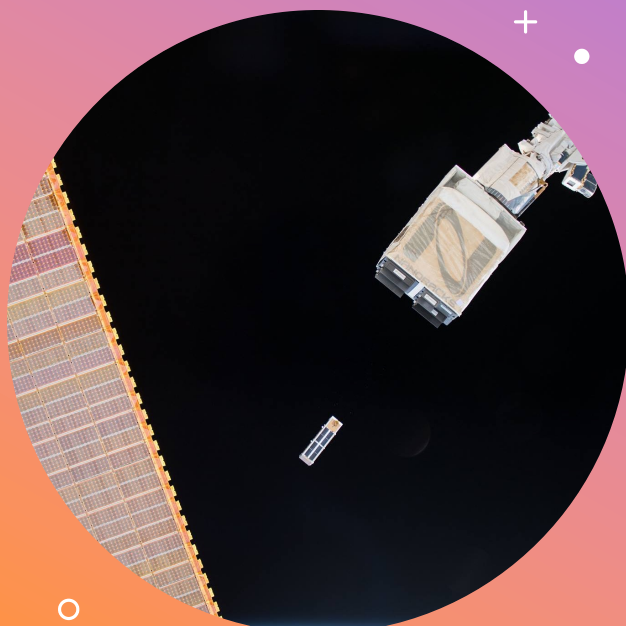
NASA SILICON VALLEY AMES RESEARCH CENTER

TechEdSat Rapid Spacecraft Development NASA Ames Research Center

CUBESAT DEVELOPERS WORKSHOP 2024

A CRYOGENIC OPTICAL INSTRUMENT IN A CUBESAT

OUTLINE



The Nano-Orbital Workshop TechEdSat Program

The Doppler Wind and Temperature Sounder (DWTS) Instrument

A Survey of Cryocooled Nanosatellite Experiments

TES DWTS Mission Design

Summary

Who we are:
Innovative flight project focused on rapid design & innovation

- 2-3 flights a year, low cost, ISS standards
- LEO, Lunar, & Mars exploration proposals
- Payload pathfinder(s) for new space launch providers (ISS, VO, Firefly)
- <u>100% In-house development, over 90% experiment success rate</u>
  - *Rapid development group for technology and people*

Key Innovations:
Communication

- Iridium SBD for quick command and control
- Custom 'Lunar' and 'Mars' S-Band SDR radios
- Satellite-internal mesh Wi-Fi network

Exo-Brake

- Precision deorbit and reentry
- Space debris mitigation via EoM disposal

AI/ML Testbed

- Neuromorphic processing, cognitive communication, and health monitoring

THE NOW TECHEDSAT TEAM

Support:
<u>Ames Research Center</u>
Glenn Research Center
Goddard Space Flight Center
Air Force Research Laboratory
NASA STMD
NASA SST Program
NASA CSLI Program

University Partners:
San Jose State University
University of Minnesota
University of Idaho

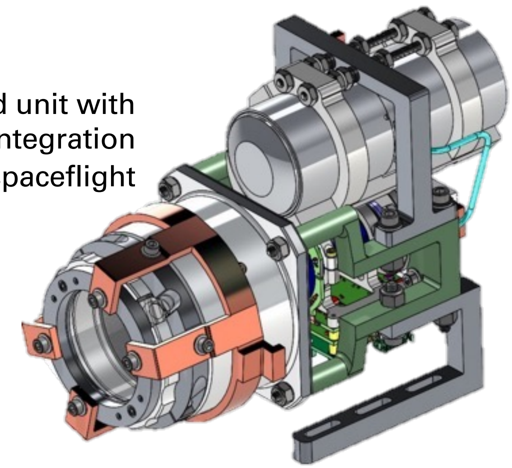
THE DWTS INSTRUMENT

Cryocooled Short-Wave Infrared Camera (SWIR), ESA flight heritage
MFG: AIM Infrarot-Module GmbH

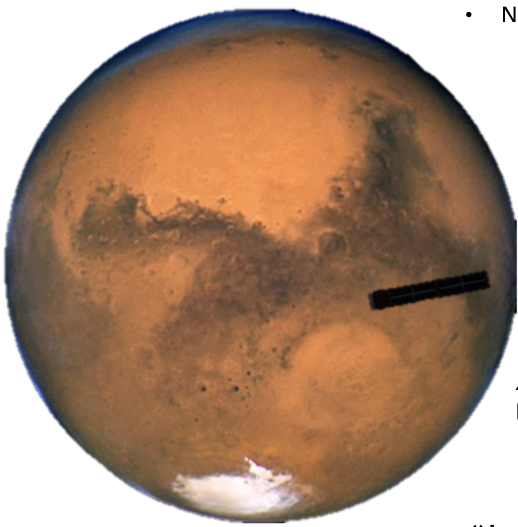
640x512px 12b 120Hz, 80K, Mil-COTS SWIR Imager
(Image: AIM)

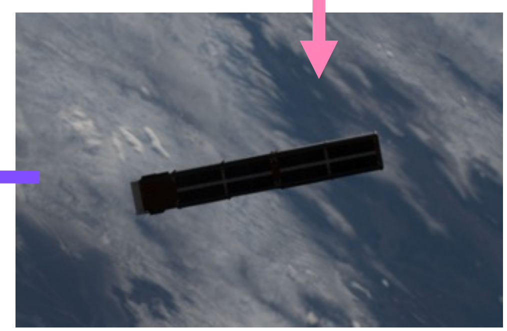
- Added gas cells for DSGF (Doppler Scanning with Gas Filter)
- GATS NO-gas filter and mechanical assembly
  - DWTS-A with single aperture/filter (NO)
  - DWTS-B with triple aperture/filter (add N_2O, NO_2)
- Non-standard bandpass filter swap on sensor (AIM)

GATS* customized unit with custom integration hardware for spaceflight



GATS Thermal & Mechanical Isolation Frame with Gas 'lens' Assembly
DWTS-A: IMPROVED FLIGHT INTERFACE
(Image: GATS)





Gas Filter Swap

***Aeolus* DWTS for Mars**
Use of O_3 regenerative gas cell

*L. Gordley/GATS is the DWTS innovator

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Doppler modulated gas correlation approach is used to measure:

- Cross-Track(CT) Winds – 200km spatial resolution
- Along-Track(AT) Winds – 10km spatial resolution
- Kinetic Temperature

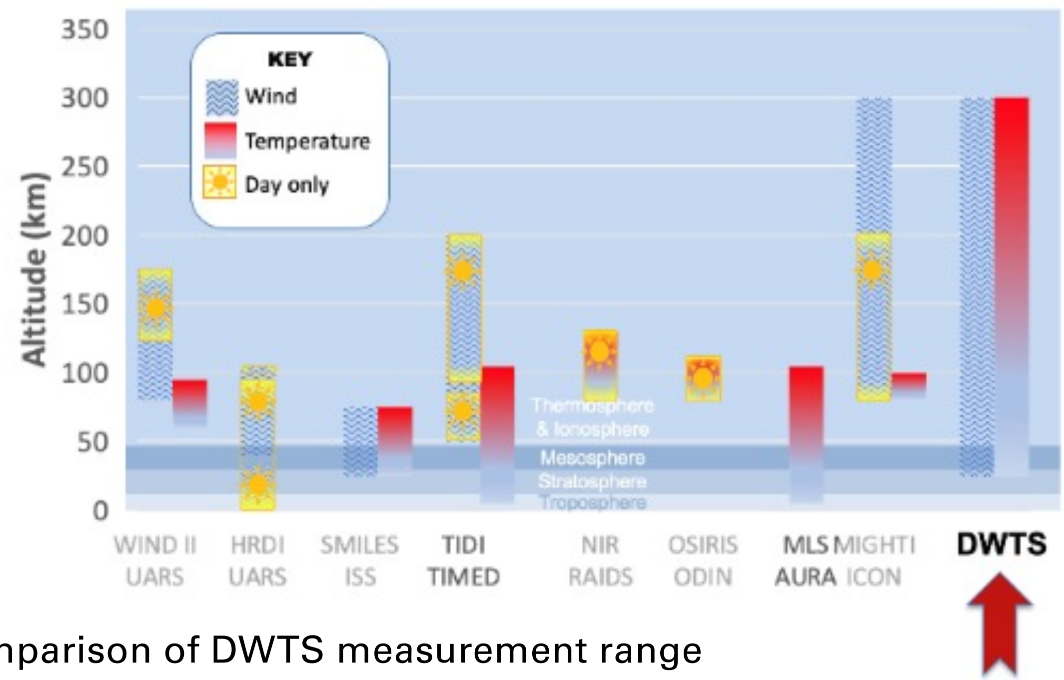
(Cross-Track and Along-Track Winds: 2km Vertical Resolution)

Altitude Coverage:

- Technology Demonstration Mission:
    - 25-50km & 85-250km

- 3x Aperture Mission: 25-250km
    - 1x NO
    - 1x N_20
    - 1x $^{13}CO_2$

<u>No time-of-day imaging dependency</u>



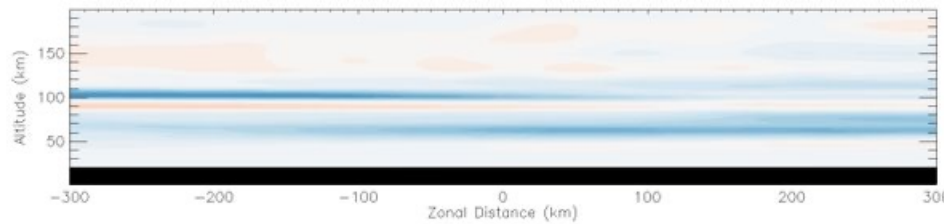
Comparison of DWTS measurement range with other weather observation platforms.

The DWTS measurement technique will allow improved atmospheric measurement for enhanced weather prediction, fine structure, climate change effects observation

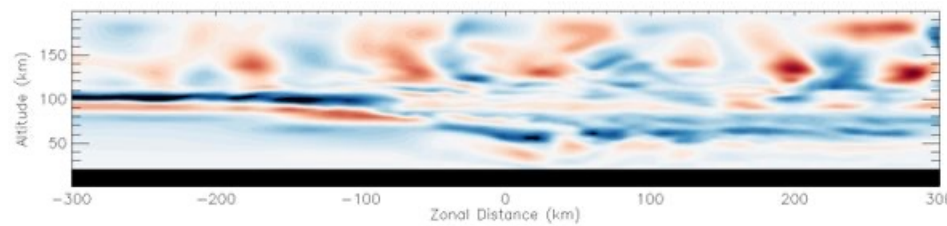
Cloud formations caused by gravity waves

Wind Field Observable by <u>Current</u> Technology
(altitude limitations not depicted)

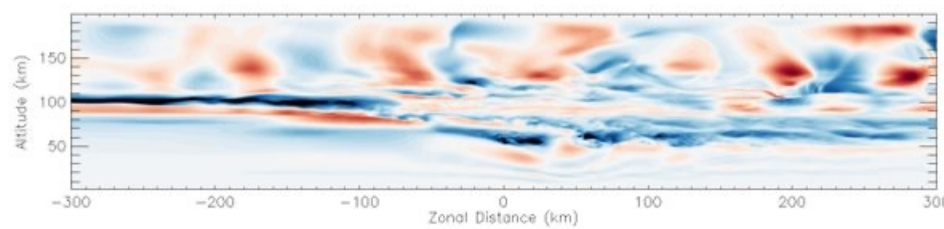
+



<u>DWTS</u> Sensor Capability (model)



<u>Actual</u> Wind Field (model)



Improved Resolution(Image: GATS)

COMPARABLE CRYOCOOLED NANO-SAT MISSIONS

Mission	TechEdSat-DWTS	HyTi	Lunar IceCube	ARCSTONE
Spacecraft Size	12U	6U	6U	6U
Spacecraft Mass	15kg	--	14kg	--
ILC Date	January 2024	December 2023	November 2022	Spring 2025
Orbit	550km, Sun Sync	400km, 51° inc.	100x5000km, 90° Lunar	550km, Sun Sync
Bus Power	80W	40W	120W	-
Instrument	DWTS	HyTi	BIRCHES	ARCSTONE
Instrument Volume	4U	3.5U	2.5U	4U
Instrument Type	**IR Radiometer**	**IR Hyperspectral Interferometer**	**Miniaturized IR Spectrometer**	**Hyperspectral Spectrometer for Lunar Measurements**
Cryocooler Type	**AIM SF070**	**AIM SF070**	**AIM SX030**	**AIM SF070**
Cryocooler Controller	AIM DCE100	Creare MCCE-TS	IRIS Technology LCCE	AIM DCE100
Nominal Required Power	38W	45W	40W	27W Cooldown 10.58W Measurement
Thermal Control Method	Passive Radiators	Heat Sink – Graphite Flex Straps	--	Passive heat rejection to the spacecraft body
Maximum Heat Rejection Temperature	**40° C**	**40° C**	**55° C**	**71° C**
Instrument Cooling Requirement	**<80K FPA**	**<68K FPA**	**<115K Detector/FPA**	**<140K FPA**

TES-DWTS MISSION DESIGN

TES missions will test critical supporting subsystems (power, command and control, data-handling) as well as DWTS instrument functionality on-orbit

- Instrument **requires** orbital velocities to verify Doppler Modulated Gas Correlation (DMGC) technique

Technology demonstration mission is designed to decouple instrument/subsystem calibration and testing from the high continuous power and large data throughput requirements of a dedicated science mission

- Deployable solar arrays avoided; operations simplified in favor of opportunistic downlinking of smaller data product
- Rapid, low-cost increment in flight series

Mission Objectives	Technology Demonstration Mission	Full Science Mission
Gather continuous IR frames with Earth limb in 20˚ FOV	Two minutes of continuous data	One orbit period of continuous data
Synthesize resultant data to retrieve wind and temperature data	Data reduction to a single downlink	Data reduction from all acquired data
Validate/Calibrate resulting wind and temperature measurements with independent source **e.g., Course measurements from existing satellite or sounding rocket direct measurement**	Data acquisition between 20-50 km and 85-250 km	Data from multiple science regions between 17-200km with multiple gas filters (NO, N2O, NO2)

TES-n Core Stack

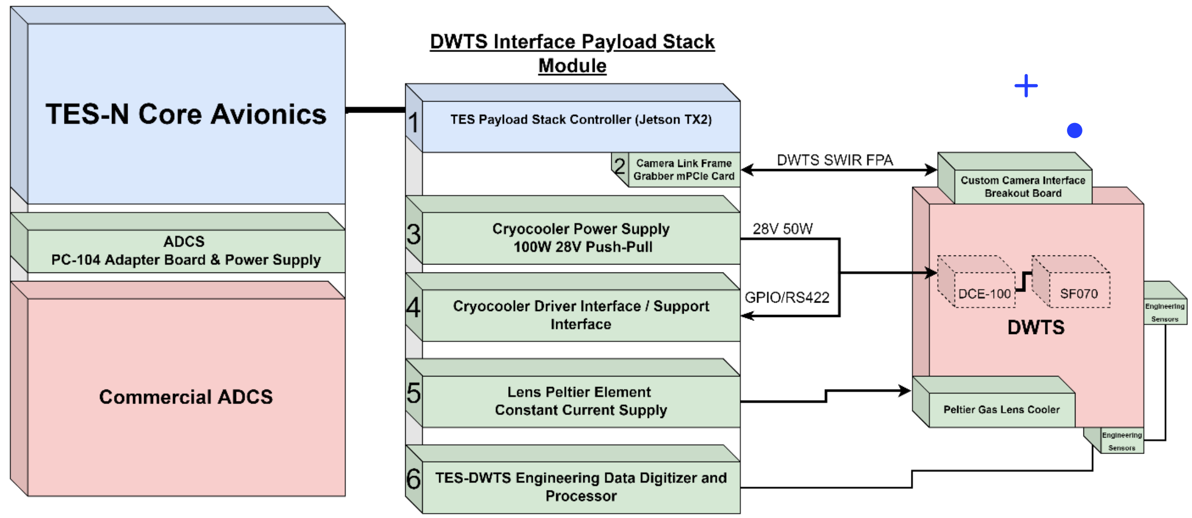
- 150-300W-hr capacity
- L-band cmd/control
- S-band downlink
  - UIS/GRC

DWTS Interface Stack

- Data/image processing
- 5/28V power
- Data transfer

DWTS Instrument

- 40-50W during operation
- Various cmd/control modes
- Thermal control systems

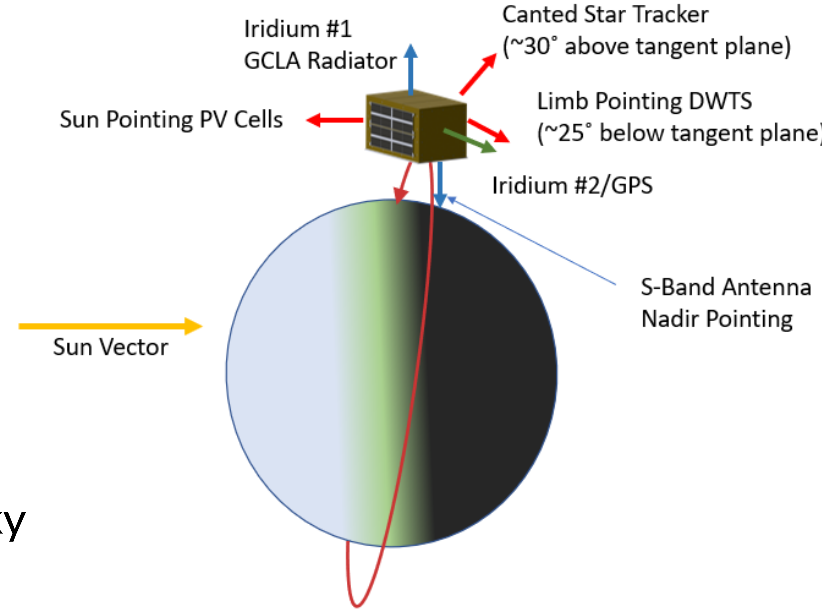


DWTS payload interface with TES-n bus architecture

DWTS Instrument
- <1˚ Pointing Error, <1 arcmin pointing knowledge
- Imaging mode: Orthogonal to flight velocity vector

ADCS
- Star tracker required to attain <1 arcmin pointing knowledge
  - Must maintain well-exposed view of star field

Thermal Management
- Passive lens cooling radiator: Maintain view of dark sky

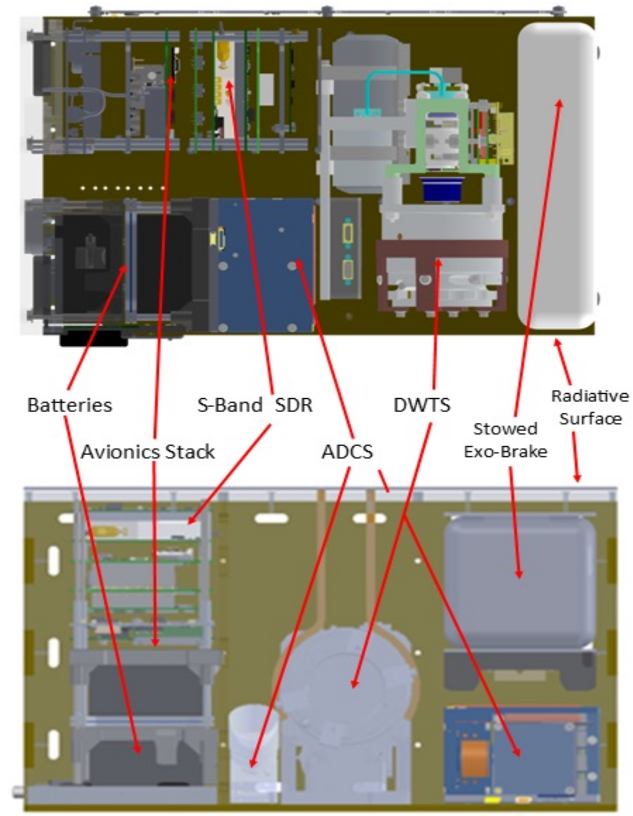


Pointing constraints for solar, communication, and DWTS (not to scale)

High inclination, terminator orbits accommodate these constraints well.

- DWTS occupies ~2U of volume
  - Technology demonstration for intermittent imaging (minimal power) appears feasible in both 6U and 12U form factors
- Scalable battery capacity eliminates need for deployable solar arrays, minimizing complexity
- Cryocooler compressor located at center of mass to minimize attitude perturbations
- Deployable Exo-Brake drag device for end-of mission disposal

6U Side View



12U Side View

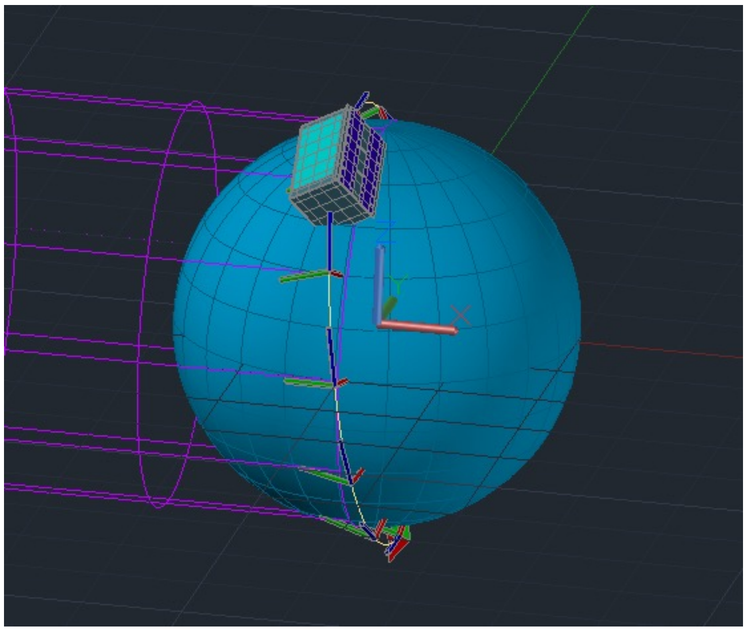
- Focal Plane Array cooling achieved with forementioned SF070 Cryocooler

- Optics require stable cooling to <200K
    - **Tech Demo to employ passive, radiative cooling to maintain lens temperature**

    - Requires 2Ux3U body-mounted radiator

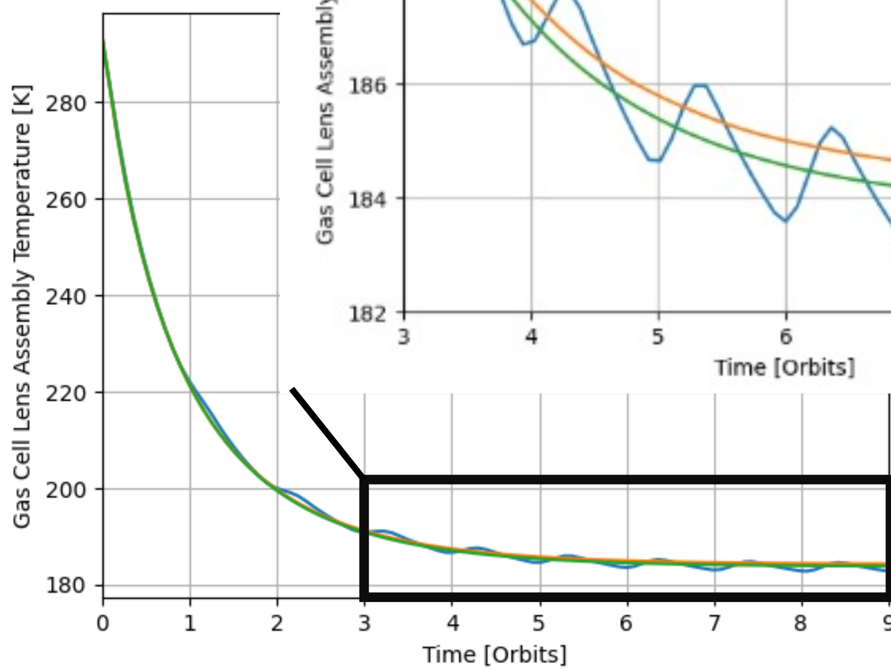
    - Steady-state illumination and operational limb-pointing compliment the use of passive radiator

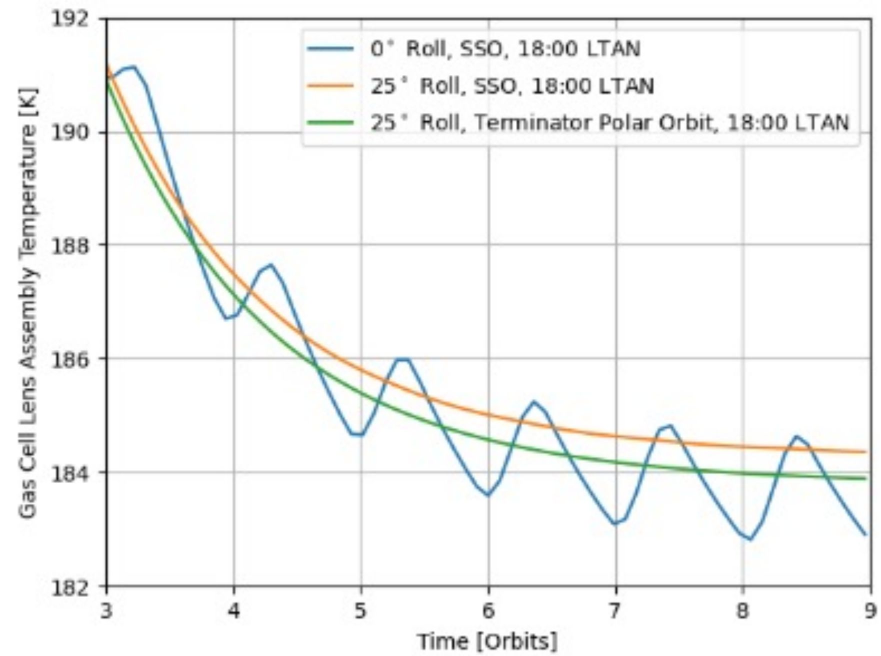
Trait	Attribute
IDCA Cold End Operating Temperature	80K
Gas Cell Lens Operating Temperature	150-200K, stable over measurement duration
IDCA Hot End Max. Temperature	313K
IDCA Transient (Cool Down) Heat Dissipation	37.7W
IDCA Steady State Heat Dissipation	16.2W
Gas Cell Lens Assembly Heat Dissipation	<1W



Orbit and attitude configuration for thermal analysis. 557 km Dusk SSO shown with instrument rolled 25° towards the limb. Lens radiator shown in turquoise.

Simulated gas cell lens assembly temperature





SUMMARY

1. TES-n/NOW is developing payloads advancing various pertinent nano-sat subsystems. These include:
   Advanced COM, AI/ML (BrainStack), innovative power systems (150-300W-hr), cryocooler/optic systems, de-orbit devices (Exo-brake)

2. The use of a tactical cryocooler combined with an IR imager enables a variety of science missions in the nano-sat (6-12U) format

3. The DWTS may be an important future atmospheric sensor
   - Improved sensitivity in the temperature and wind velocity profile from 25-250km

4. Aeolus-Earth / TES16-17 will be the initial flight tests for validation/evolution

5. Aeolus-Mars mission using a different gas cell combination (O_3, CO/CO_2) will also enable greatly improved Martian wind/atmospheric predictions (GCMs)

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TechEdSat Missions

DWTS SmallSat '23 Paper

TechEdSat Website

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