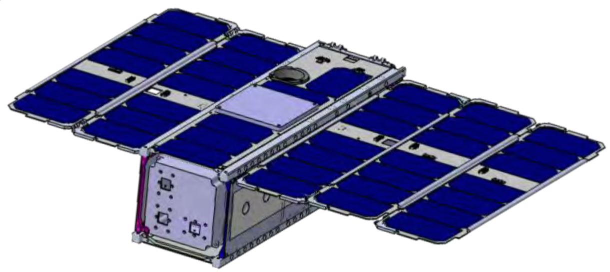
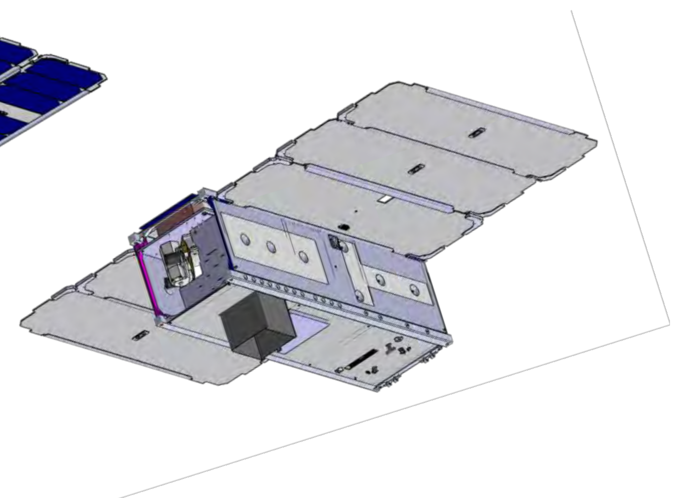
Space Environmental NanoSat Experiment (SENSE)





Alejandro Levi
Chief Engineer
Developmental Planning Directorate
USAF Space and Missile Systems Center

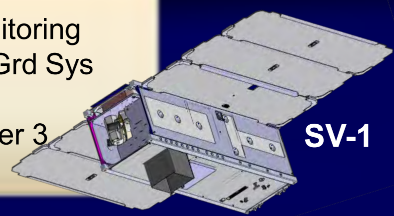
Overview

- SENSE Mission Overview
- Mission Organizations
- Space Vehicle Bus and Payloads
- Data Products and Users
- Timeline to Launch

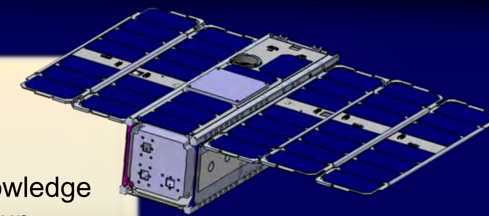
Space Environmental NanoSat Experiment (SENSE)

SENSE is a rapid-development pathfinder evaluating the cost-effectiveness and resiliency of CubeSat architectures for augmenting or performing operational missions. Additionally, SENSE is as a risk reduction and test bed for future SMC/IS WFOV efforts.

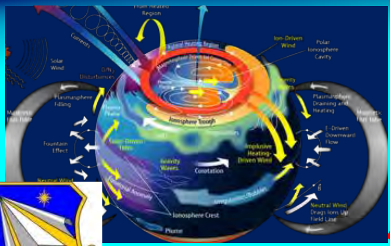
SENSE Overview:
- Mission: Space Environmental Monitoring
- Architecture: Two 3U CubeSats & Grd Sys
- Mission Life: 1yr
- Launch: Oct-Dec 2013, ORS Enabler 3
- Orbit: 500km Alt, 40.5° Incl



Bus Performance:
- Mass: 4kg
- Power: 10W Avg, 37W Peak
- ADCS: <0.5° pointing, <0.3° knowledge
- Data Rate: 1Mbps down, 4kbps up
- Encryption: AES256 Type II



GAIM Ionospheric Model



Sensors and Measurements:
1. CTECS: Electron Density (TEC), Scintillation
2. CTIP: Recombination of Oxygen Ions
3. WINCS: Temps & Composition of Ions & Neutrals
4. Dosimeter: Cumulative Radiation

Kirtland AFB, NM

Blossom Point, MD

AFSCN

Ground System:
- Sites: Manzano NM, Blossom Point MD, AFSCN
- Common Ground Architecture (CGA); lights-out operation
- Leave-behind asset for future missions

SENSE Organizations

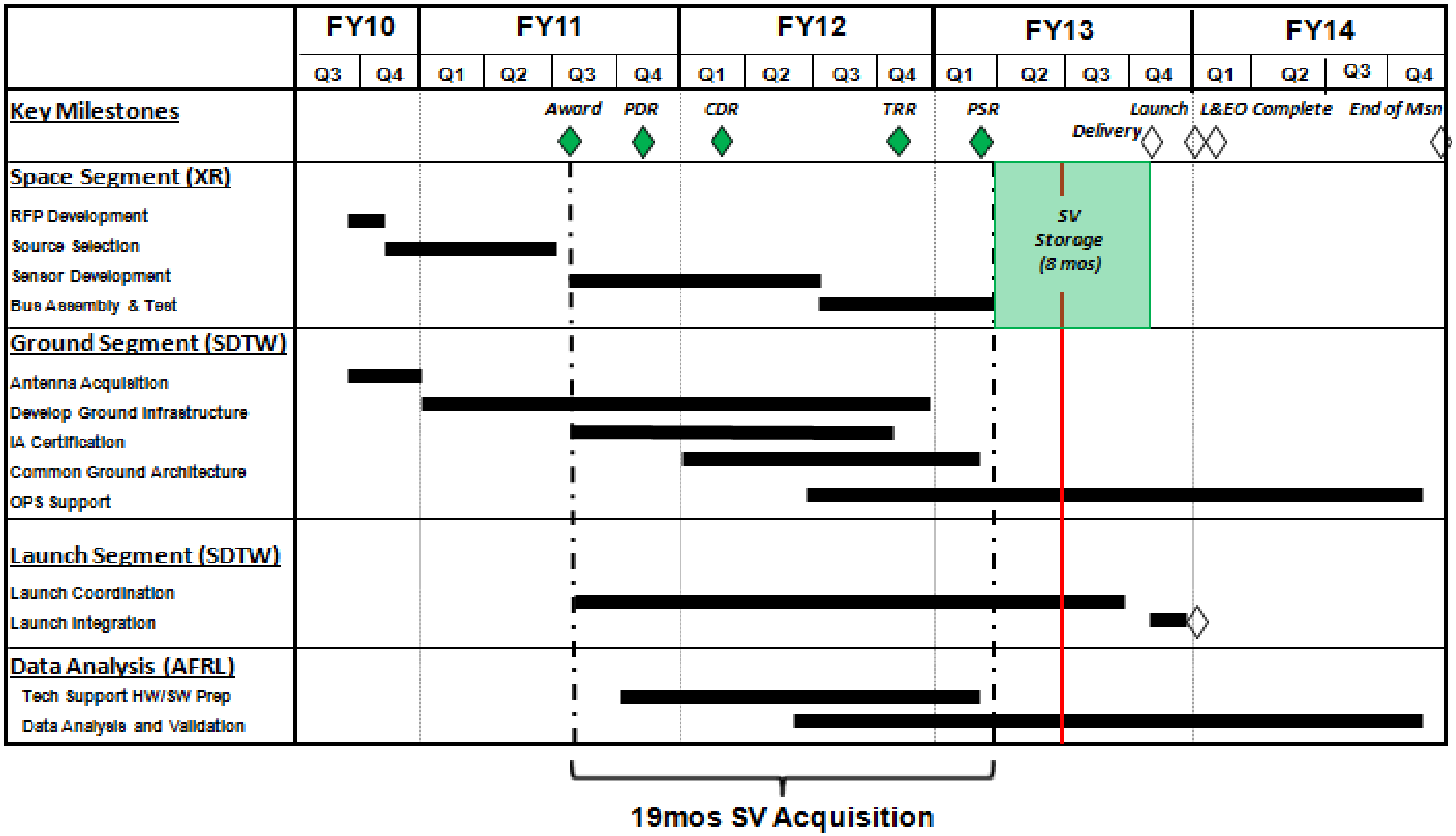
SENSE Demo Lead (SMC/XR)

Demo Stakeholder: SMC

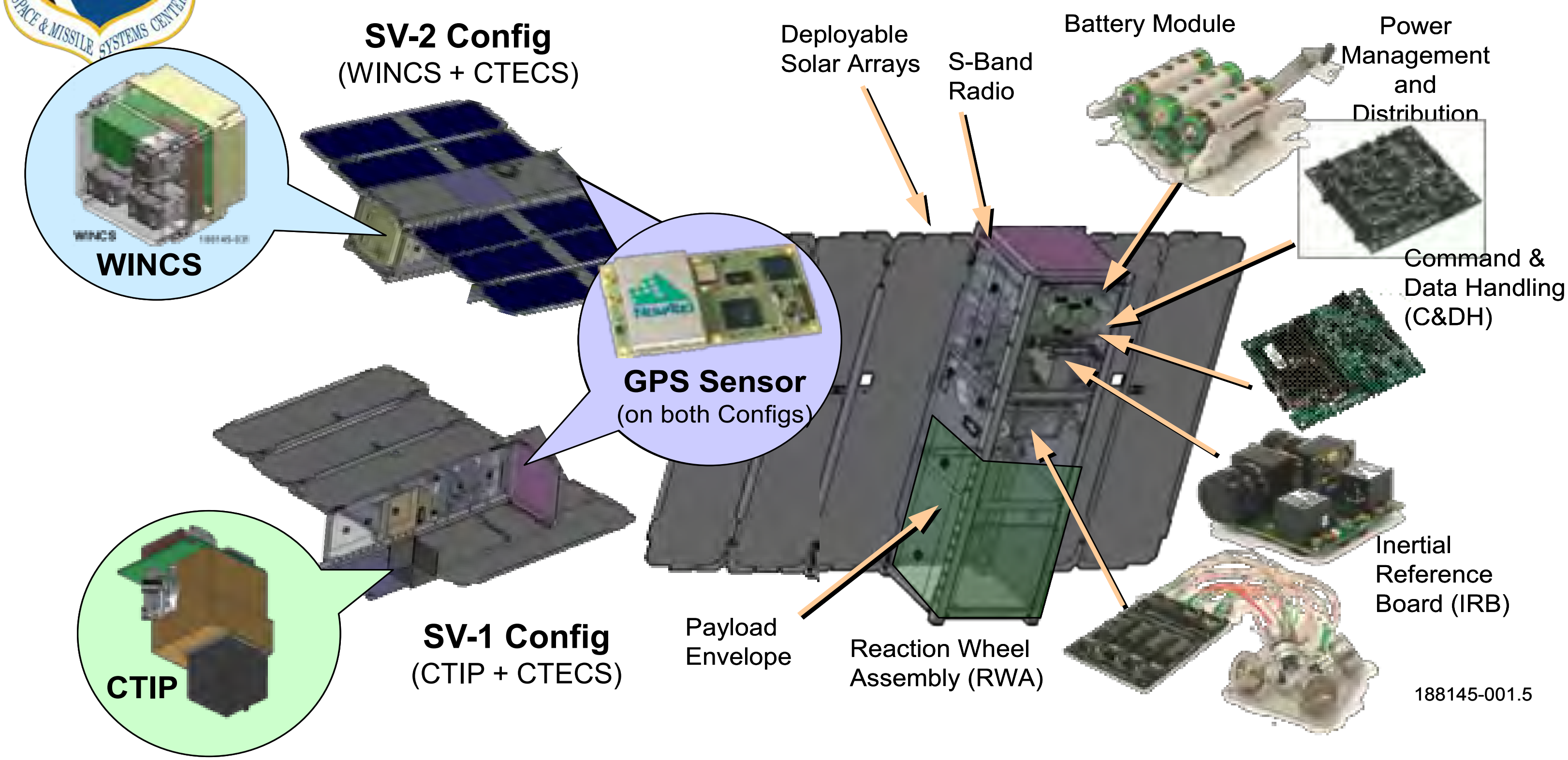
Demo Stakeholder: SMC/WM

- Space Segment (SMC/XRF)
- Launch Segment (SMC/SDD)
- Ground Segment (SMC/SDT)
- Data Analysis & Mission Validation (AFRL/RVB)

SENSE Schedule



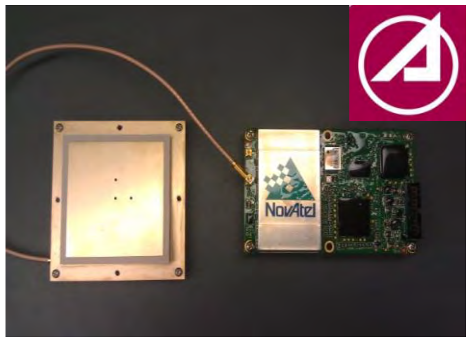
Space Vehicle Bus

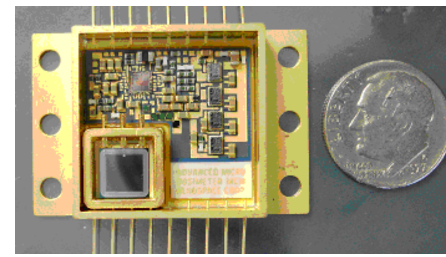


Highly Capable, Low Cost 3U Bus derived from NRO Colony II

- **Three axis stabilized**
  - **4 reaction wheels, 3 torque coils**
  - **2 star cameras, sun sensors, magnetometers, and GPS**
- **Dosimeter included into Bus design**
- **1 Mb/s downlink & 4 kb/s uplink S-Band transceiver w/ AES 256 Type II Encryption**
- **37W peak power, 10W average power**

Space Weather Sensors





CTIP (SRI)

Measures 135.6 nm UV nightglow giving ionospheric density variation and structure

CTECS (x2)

Measures amplitude and phase variations of occulting GPS signals giving ionospheric density and scintillation

WINCS (NRL)

Measures ram fluxes of ions and neutral particles giving local electric field, densities, neutral winds, and temperature

Microdosimeter

Provide radiation dosage for measurement and correlate exposure with system performance

JROCM 091-12 Space Weather Gaps Demonstrated in Form Factor

CTIP (SRI):
Cat A #4 Ionospheric Density

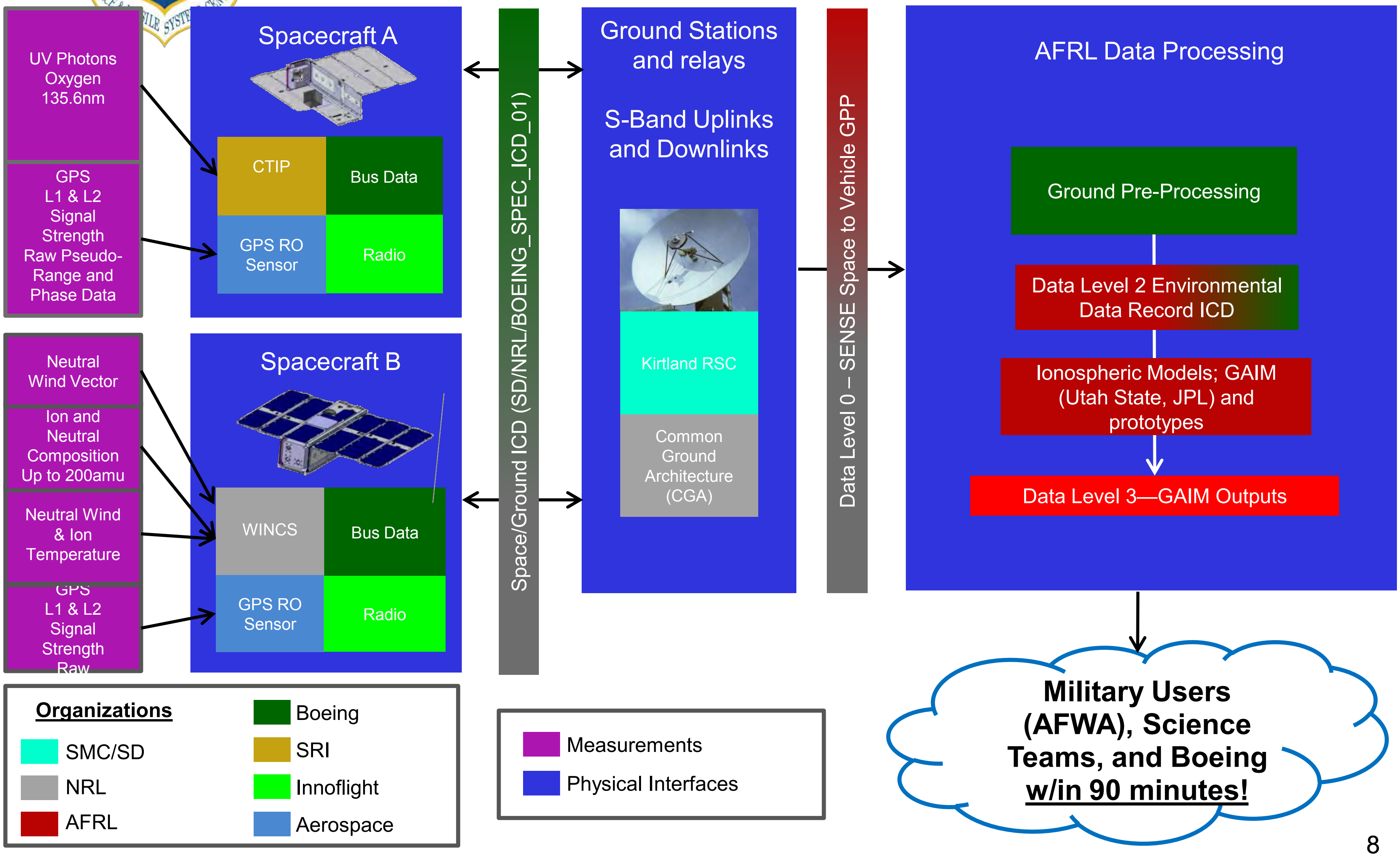
CTECS (x2):
Cat A #4 Ionospheric Density
Cat A #7 Ionospheric Scintillation (no troposphere)
Cat B #19 Trapped Electrons

WINCS (NRL):
Cat A #11 LEO Energetic Charged Particle Characterization
Cat B #22 Neutral Density
Cat B #44 Neutral Temperature

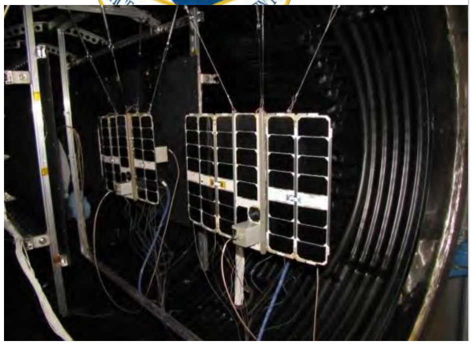
Microdosimeter:
Cat A #11 LEO Energetic Charged Particle Characterization (partial)

*While not hosting a payload SENSE makes a strong case for Cat A #12 Electric Field in NanoSat form factor

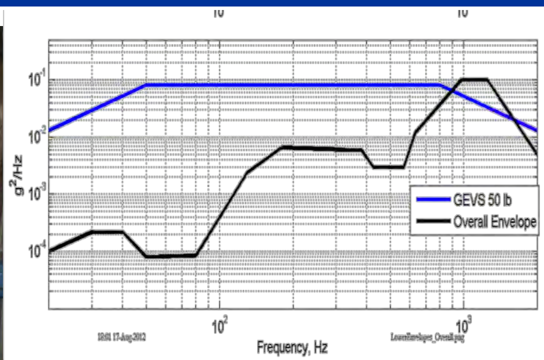
SENSE Data Flow



Timeline to Launch



SENSE entering T-VAC



ORS Enabler III launch levels

CGA End-to-End test

Antenna Testing

SV Delivery at Kirtland, AFB

Minotaur 1 launch from Wallops, VA

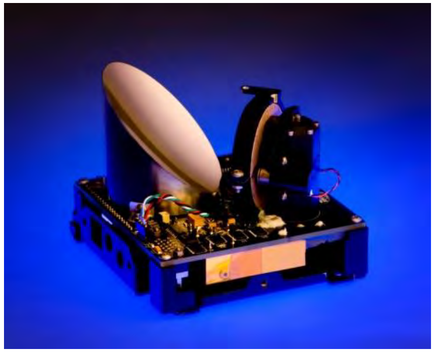
Aug '12	EM & FMs Fabricated	✔
Sep '12	SV Flight Software Complete	✔
Oct '12	CGA Build 3 (Grnd S/W) Delivered	✔
Oct '12	EMs & FMs T-Vac	✔
Nov '12	EMs & FMs Vibe Test	✔
Nov '12	Space-Ground Compatibility Test	✔
Dec '12	Pre-Ship Review & SV Delivery	✔
Feb-Apr '13	Operator Training	☐
Jun-Sep '13	Ground Rehearsals	☐
Aug-Sep '13	SV Integration	☐
Oct-Dec '13	Launch	▼

Summary

1. **SENSE is SMC's premier rapid development effort which will demonstrate the capability of CubeSats to perform space missions in an affordable and resilient manner.**
   - **Acquired under SMC acquisition strategy for all space vehicles**

2. **The first AF CubeSat mission with the potential to become operational.**
   - **Delivers three first generation miniature sensors; WINCS, CTIP, CTECS.**
   - **Meets 2 of 12 Space Weather Gaps**

3. **A distributed ground architecture with leave-behind capability to fly the next minimally-manned satellite mission.**



CTIP

CTECS

WINCS

Points of Contact

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- **Mr. Alejandro Levi, SMC/XR Chief Engineer**
  - **Office: (310) 653-9344**
  - **Email: alejandro.levi.1@us.af.mil**

SUPPLEMENTARY SLIDES

CubeSats & P-PODs Defined

- **Cal Poly CubeSat Design Specification developed by academia nearly 1 decade ago to enable access to space for low-budget space experiments**
  - **1U CubeSat standardized as a 10cm cube of 1.3kg mass**
  - **3U CubeSat extends length to 34 cm and 4.0 kg mass**
- **Poly-Picosatellite Orbital Deployer (P-POD) encapsulates the CubeSat(s) during launch and deploys the CubeSat(s) on orbit**
- **A key SENSE objective is to evaluate the 3U form factor's potential as a viable option for future operational mission architectures**

CubeSat Integration into P-POD

3U P-POD

On-Orbit Operations

- **SENSE Operations will be conducted from the RSC at Kirtland AFB**
  - **SENSE operations team consists of fourteen 62/63-coded Lieutenants from SMC/SD, SMC/XR, and SMC/IS**
    - Senior oversight provided by DO for SMC/SDTO, Lt Col Michael Todd
    - Lt Col Todd is a 13S satellite operator with 15yrs rated experience
    - Additional operational support available from LinQuest and 13S operators assigned to SMC/SD
  - **All SENSE operators will complete a 10 lesson training course and will participate in a 1wk mission exercise and a 1wk mission rehearsal**
    - All operators must complete the SENSE Master Task List (MTL):
      - A 152-item training checklist requiring students to demonstrate proficiency in all aspects of SENSE satellite operations
      - MTL has been approved by Lt Col Todd at SMC/SD
  - **SENSE operational procedures, to include procedures for off-nominal and emergency situations, are modeled after TacSat-3 and must be reviewed and approved by SMC/SDTO leadership**

Command and Data Handling

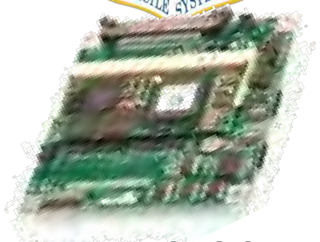
Element	Performance		Notes	Heritage
Command and Data Handling (C&DH)	Mass	67.5 g		CSTB1, CSTB3, C2B
	Power	0.97 W (max)	0.33 W (idle mode)	
	Processor	PXA270	520 MHz	
	RAM	128 MB		
	FLASH	64 MB		
	Data Storage	2 x 2 GB	2GB effective data storage	

TLM Item Storage	SV Config A (CTIP, CTECS, Dosimeter)	SV Config B (WINCS, CTECS, Dosimeter)
WINCS	176.3	
CTIP		6.4
CTECS	340.5	340.5
Dosimeter	0.3	0.3
Bus	89.8	89.8
Total Storage Rate	**606.6 kB/min**	**436.7 kB/min**
Total Data 2 Days	1747 MB	1258
Total Storage Capability	2000 MB	2000 MB
Data Storage Margin	**14%**	**59%**
CTECS GPS Data based on 50hz RO sampling in eclipse, 1hz PVT		

Features

- **Ferroelectric RAM (FRAM) used to system state and mission critical data**
  - **Approximately 1.5MB in redundant banks of 768MB each**
  - **Scheduler sequences are stored on non-volatile FRAM written redundantly with triple voting**
- **High density bulk storage uses industrial grade micro-SD type memory used in redundant configuration**
  - **Two 2GB industrial grade cards**

S-Band Transceiver



Spacecraft C&DH (EPIC Board)

Ribbon Cable

UART Data Xmt/Rcv

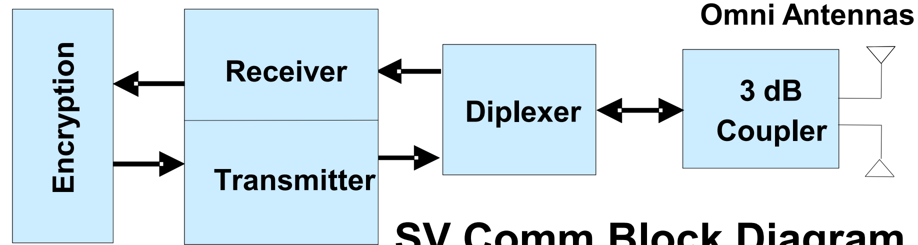
Flow Control

UART CMDs

I/F Board (TBR)

S- Band Radio

Omni Antennas



SV Comm Block Diagram

9-12.6VDC unregulated

Power (PMAD Board)

Electrical & Data Interfaces

- **9V-12.6V DC power**
- **RS-422**
- **FTSH-110-01-L-DV-K**
- **Our approach would be to distribute the crypto, TX, RX across the available pins to minimize copper losses**
- **Assessing 2 UART interfaces with Flow control from Transceiver**
  - **Command & Data paths**
  - **Requires new I/F board on SC side or design change to Transceiver**

SV Mass Summaries

Final Total Measured:

- **SV-1 (CTIP): 3.402 kg**
- **SV-2 (WINCS): 3.524 kg**

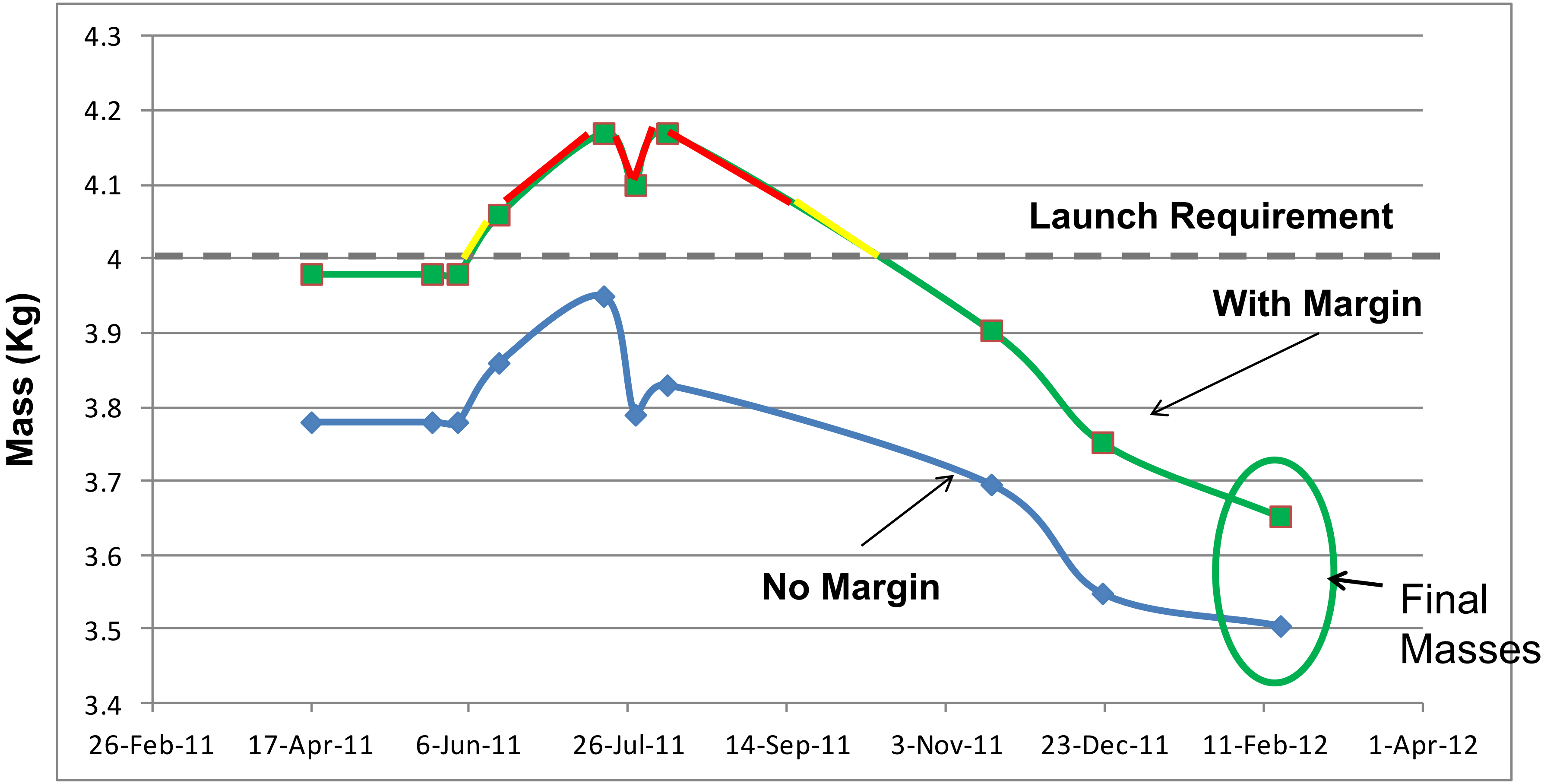
CTIP + GPS CTECS Configuration

Subsystem	Mass w/ Margin	Margin	Mass w/o margin
Command and Data Handling	70	3.0%	68
Attitude Determination, Control, and Navigation	620	3.0%	602
Telemetry, Tracking, and Command	579	4.5%	554
Electrical Power System	1026	3.9%	987
Structures and Mechanical	246	3.0%	239
Thermal Control	335	10.1%	305
Harness/Cabling	64	7.2%	60
Spacecraft BUS TOTAL	**2939**	4.5%	**2814**
Payload	600	16.5%	515
SV TOTAL	**3540**	**6.3%**	**3329**
Launch Margin	**460**	**11.5%**	
SV Margin including uncertainty	**4000**	**16.8%**	**3329**

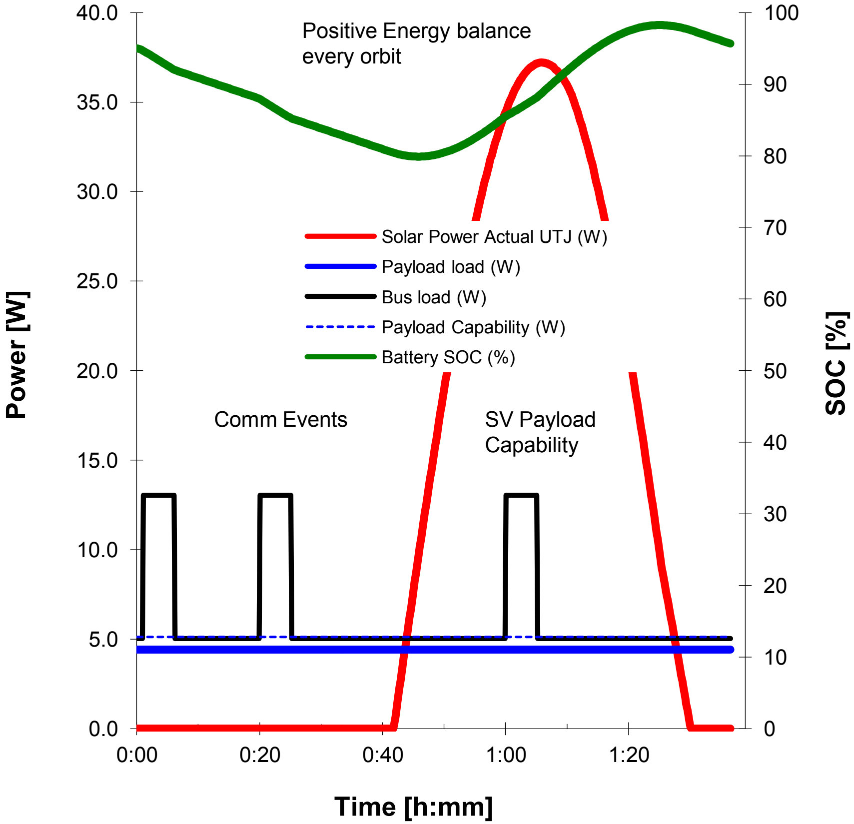
WINCS + GPS CTECS Configuration

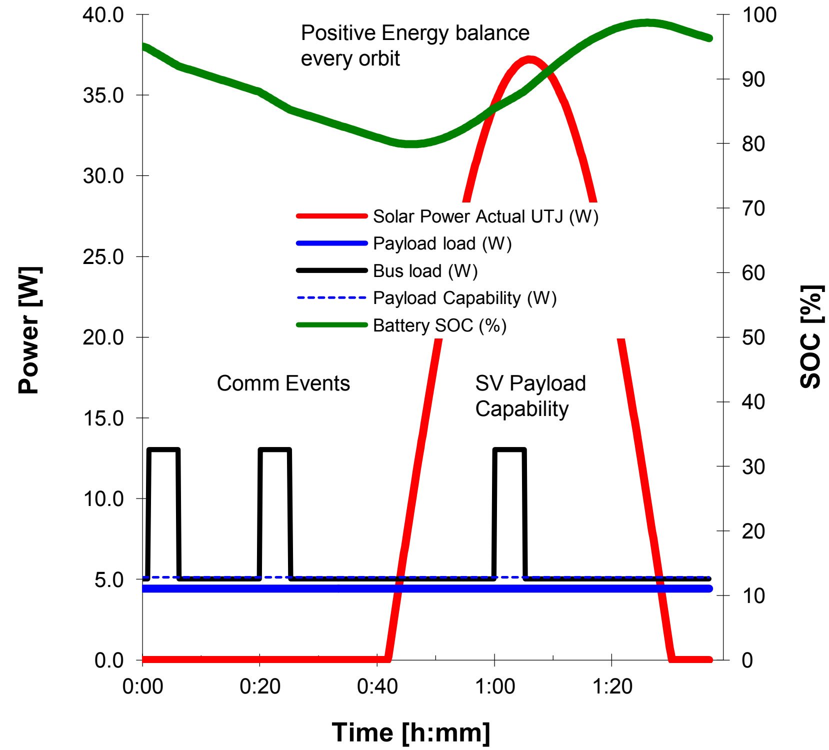
Subsystem	Mass w/ Margin	Margin	Mass w/o margin
Command and Data Handling	70	3.0%	68
Attitude Determination, Control, and Navigation	620	3.0%	602
Telemetry, Tracking, and Command	579	4.5%	554
Electrical Power System	1026	3.9%	987
Structures and Mechanical	246	3.0%	239
Thermal Control	335	10.1%	305
Harness/Cabling	64	7.2%	60
Spacecraft BUS TOTAL	**2939**	4.5%	**2814**
Payload	713	3.2%	691
SV TOTAL	**3653**	**4.2%**	**3505**
Launch Margin	**347**	**8.7%**	
SV Margin including uncertainty	**4000**	**12.4%**	**3505**

Space Vehicle Mass (Worst Case SV #2)



Positive Energy Balance





- SV has the ability to transmit 15 min/orbit
- Enables latency requirements satisfaction for SEM mission

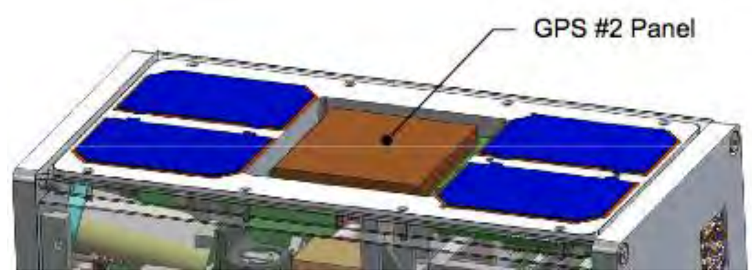
CTECS- Radio Occultation Sensor

- **CTECS is a GPS occultation sensor**
  - Primary data product: line-of-sight TEC to all GPS satellites in view for ingest into ionospheric models
  - Secondary data product: L-band scintillation observations
- **Antenna is dual patch**
  - 1557 MHz and 1227 MHz
  - A Low-Noise-Amplifier (LNA) is placed between antenna and receiver
- **L1, L2, L2c signal tracking capability**

Measures:

1. Delay of signal between SENSE and the GPS transmitter to extract Total Electron Count in the atmosphere
2. Atmospheric Scintillation

NovAtel OEMV-2 receiver



AutoCad drawing of CTECS custom dual patch antenna embedded in the MTV satellite panel.

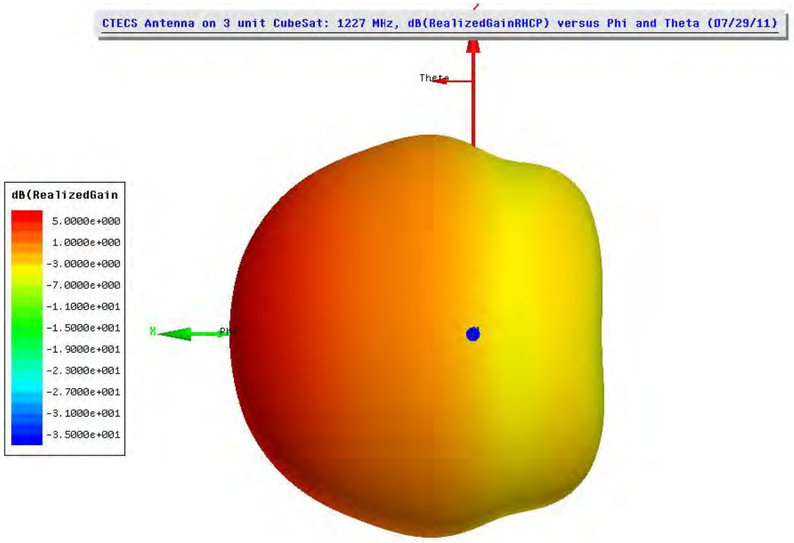
NovAtel Receiver

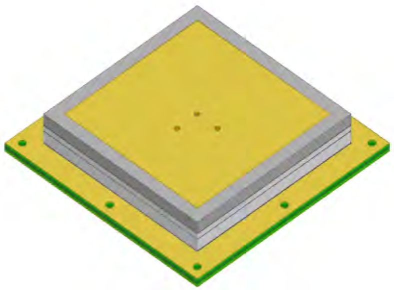
- 14 channel receiver (track 14 GPS satellites L1/L2 simultaneously)
- Allows user-specified software
- Provides position and timing information.
- Simplified structural analysis planned to determined frequency and mode behavior of COTS board.

Parameter	Value
Size	60 mm x 100 mm x 11.4 mm + connectors
Mass	56 g
Voltage	+3.3 VDC (+5%/-3%)
Allowable Input Voltage Ripple	100 mV p-p (max.)
In-rush Current	22 A for 30 μs
Power	1.2 W
Data Rate	Approx 240-280 kbps during occultation

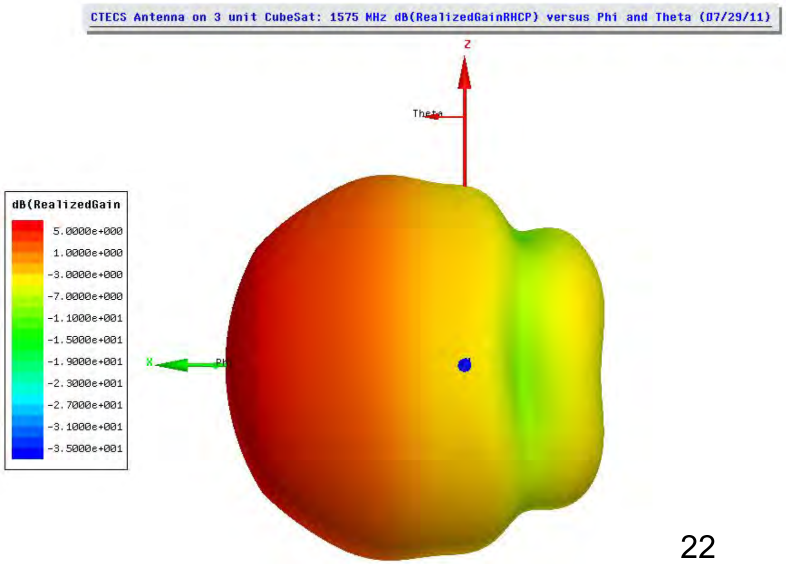
Aerospace Corporation Custom Antenna

- **Design based on PSSC-2 CTECS antenna with minor modifications**
  - **1U side placement on s/c**
  - **LNA circuit surface mounted to back of antenna**





CAD model of the CTECS antenna viewed from the top.



Compact Tiny Ionospheric Photometer (CTIP)

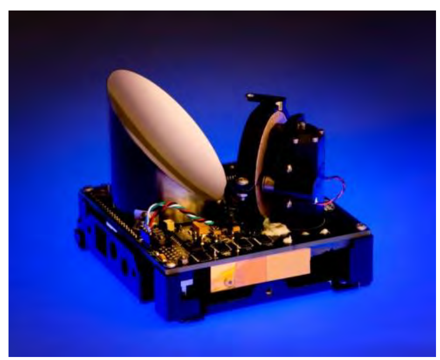
Objective: Gather data to characterize the ionosphere through the natural decay rate as seen in recombination of O^+ ions and electrons

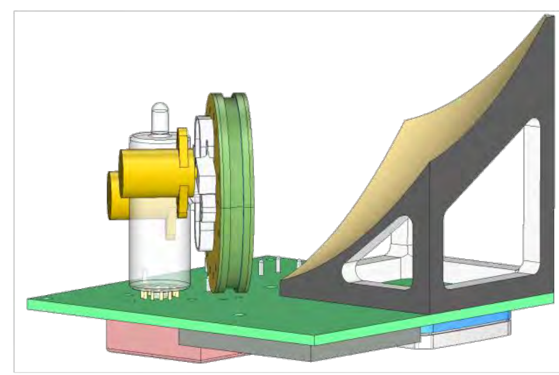
- **Atomic Oxygen ions constitute the primary ionospheric species in the F-region**
- **In the night-time F-region ionosphere**
  - 135.6 nm photons are emitted spontaneously
  - from the recombination of atomic oxygen ions
  - $O^+ + e^- \rightarrow O\ (5P) + h\nu_{135.6}$

- **O^+ and e- are in equal number and 135.6 nm emission is proportional to the path integral of $[O^+]$ squared**

Measures:

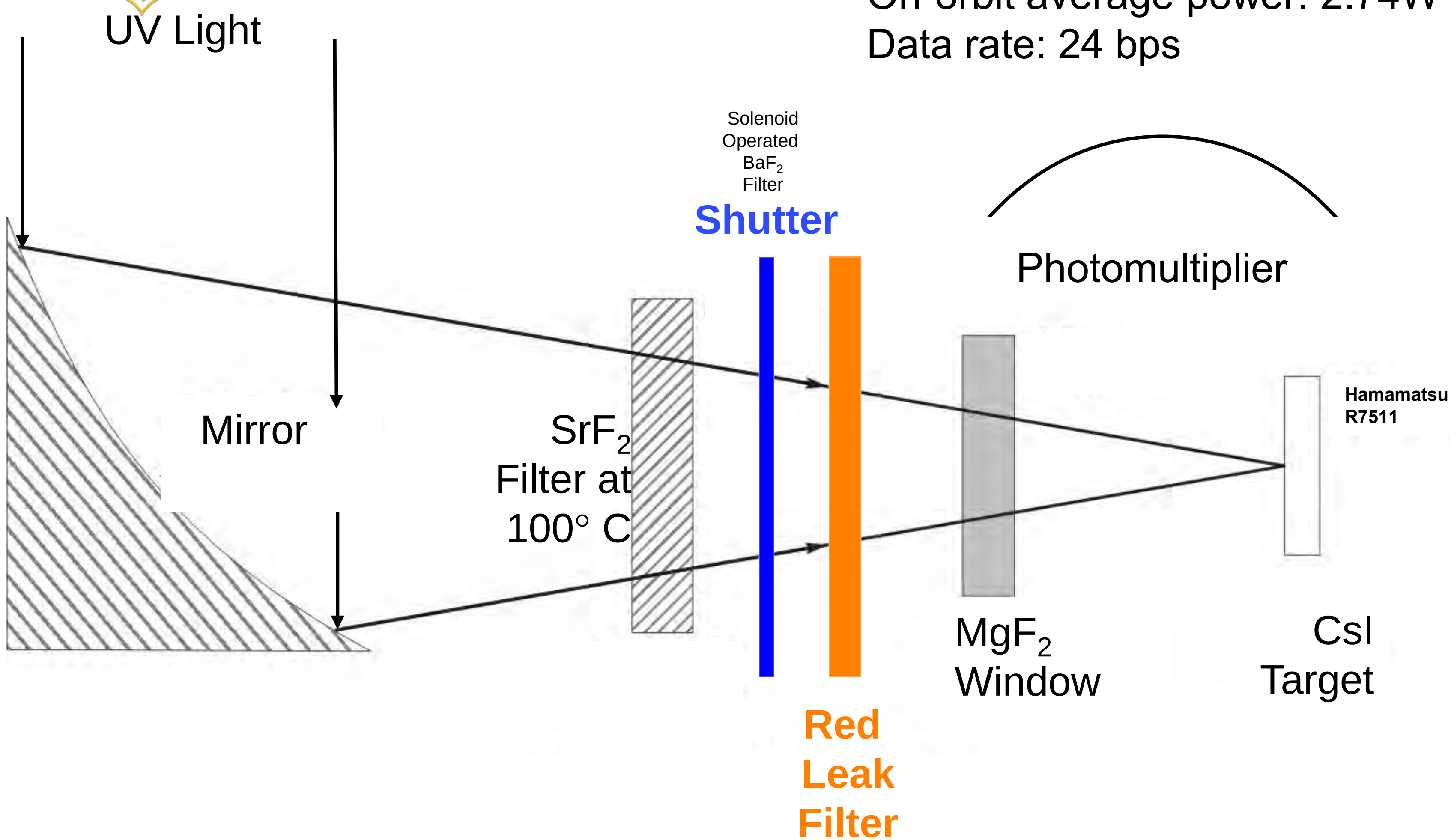
1. Ultraviolet Airglow at 135.6 nm





CTIP Design

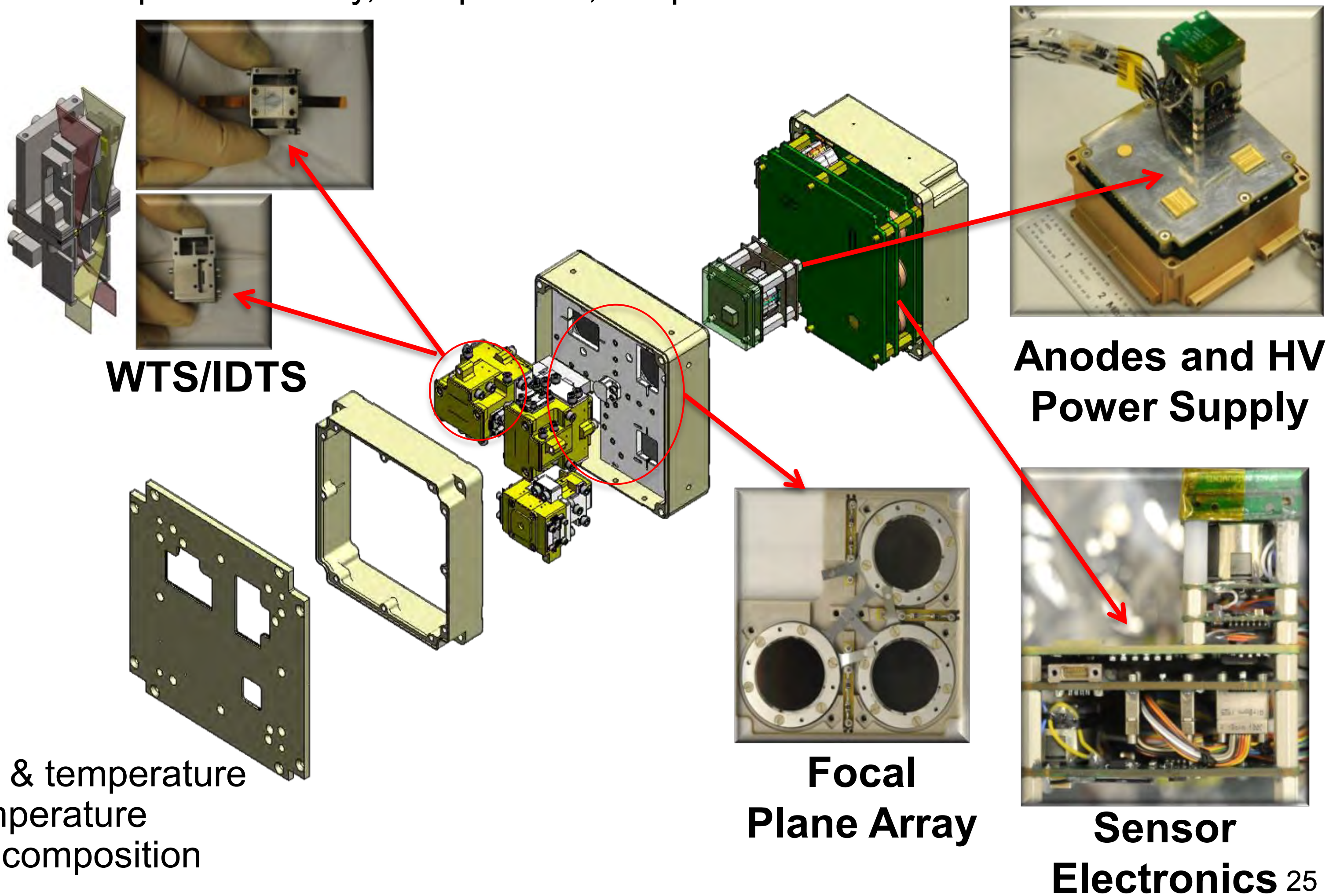
On-orbit average power: 2.74W
Data rate: 24 bps



CTIP optics based on heritage COSMIC TIP design

Winds Ions Neutrals Composition Suite (WINCS)

Objective: Acquire simultaneous co-located, in-situ measurements of atmospheric density, composition, temperature and winds.

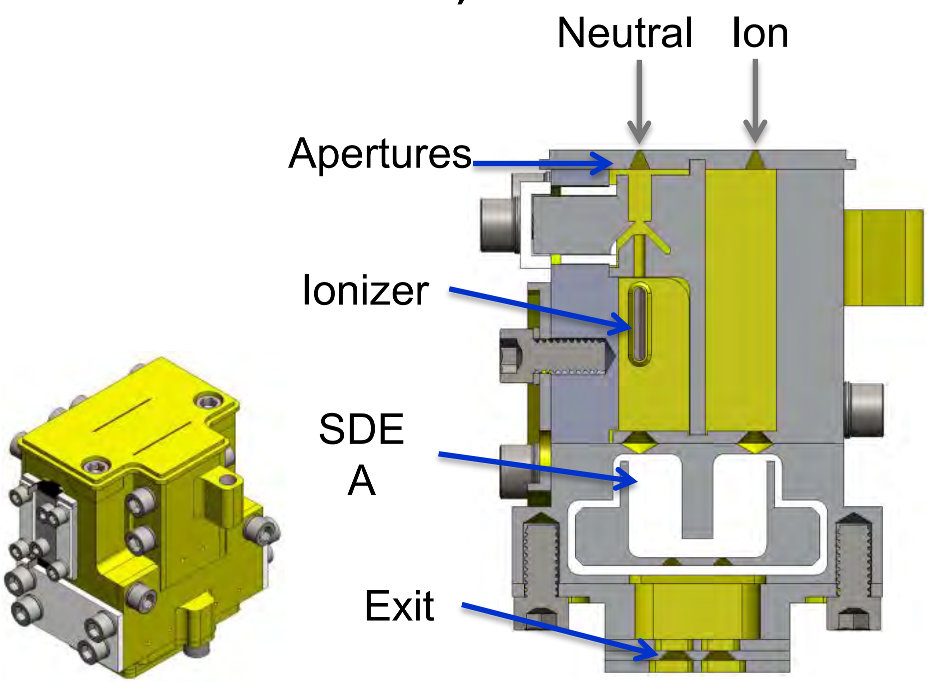


Measures:

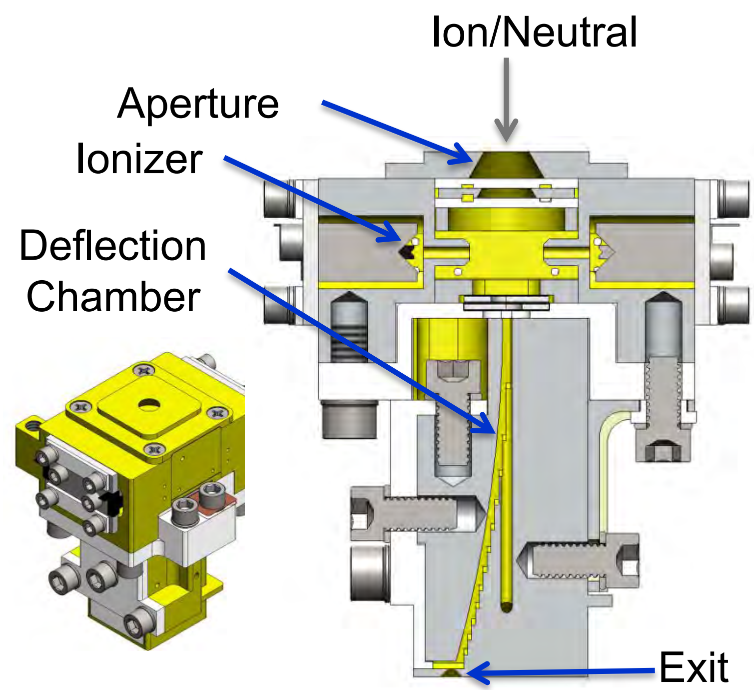
1. Neutral winds & temperature
2. Ion-drift & temperature
3. Ion & Neutral composition

WINCS Theory of Operation

- **WTS/IDTS: Ionize incident air stream to measure the angular distribution at many angles simultaneously while scanning energy in time**
- **IMS/NMS: Time of Flight mass spectroscopy**
- **Calibration: via extended ion source on the ground (rotate source/sensor to simulate winds)**



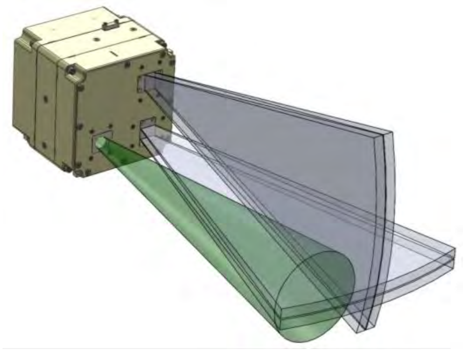
WTS/IDTS



GEMS: IMS/NMS

WINCS
Requirements vs. Performance

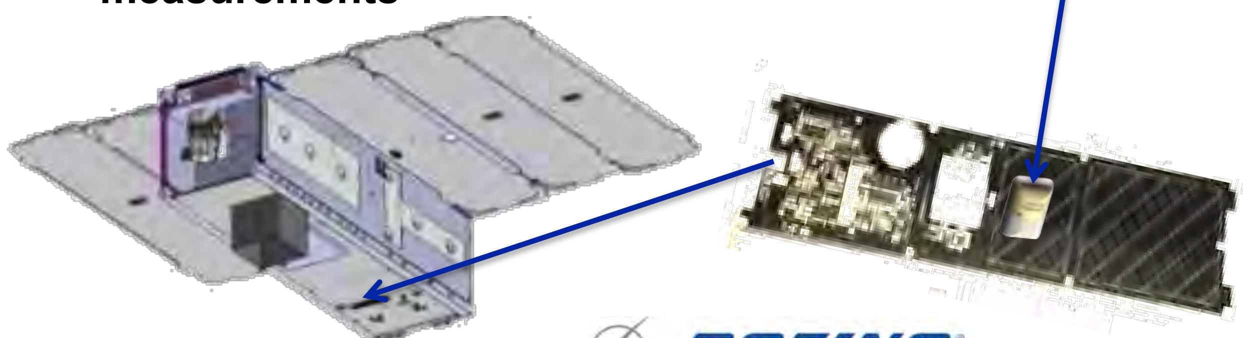
Parameter	Units	Requirement	Designed Performance
Mass	kg	< 1	0.745
Average Power	Watt	< 2.25	2.165
Nominal Data Rate	kbps	< 25	22.672
Data Storage	Gbytes	N/A	2
Field of View	Degrees	45	45 (± 22.5)
Humidity*	%	0 - 90	30 - 80
Operating Temperature	Degrees C	-20 to 50	-20 to 50
Survival Temperature	Degrees C	-34 to 71	-34 to 71
Pointing Knowledge	Degrees	<0.1 (<0.03 desired)	<0.1 (<0.03 desired)



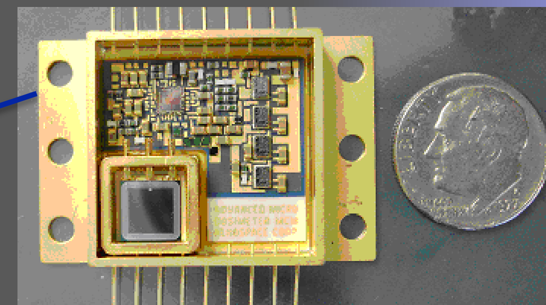
Teledyne Micro-Dosimeter

Objective: Provide radiation dosage for measurement and to correlate system performance with exposure

- **First compact microcircuit that provides a repeatable measurement of radiation dose and dose rate over a wide range of energies**
- **Enables routine monitoring of spacecraft radiation environment**
- **Custom microchip in a small footprint package for low weight and power**
- **Correlates environmental models and ray-tracing analyses with real in-flight measurements**



Teledyne Microdosimeter



<u>Technical Specifications</u>

- 14 uRad Dose resolution
- Survivability to 40 kRad
- Class K space qualified
- Mechanical dimensions: 3.6 cm x 2.5 cm x 0.1 cm
- 20 grams
- 10 mA , 13 Vdc to 40 Vdc
- 3 DC linear outputs
- 1 Pseudo Log
- 100 kRad total count
- Test Input bypasses silicon detector for circuitry detection
- Volatile count retention
- Updates every 30 seconds

Mission Data Products (TPMs)

SENSE = GPS RO + WINCS + CTIP

Environmental Data Record (EDR)	Parameter	Requirements		Current Value at DR			
		Threshold	Objective	CTECS	WINCS	CTIP	SENSE
Electron density profile	Horizontal cell size	50 km	10 km	Variable	8 km	15 km	8 km
Electron density profile	Vert Cell Size	10 km	3 km	6 km	N/A	10 km	2 km
Electron density profile	Vert coverage	90 km to Sat Alt	90 km to 1600 km	90 km to Sat Alt	N/A	90 km to Sat Alt	90 km to Sat Alt
Electron density profile	Range Ne	2.5E4 to 1E7 e/cm^3	1E4 to 1E7 e/cm^3	2E4 to 1E7 e/cm^3	1E3 – 1E7/cm^3	2E4 to 1.4E8	1E4 to 1E7 e/cm^3
Electron density profile	Range VTEC	3 to 200 TECU	1 to 200 TECU	3 to 200 TECU	N/A	3 to 19000 TECU	1 to 19000 TECU
Electron density profile	Sigma Ne	Greater of 1E5 /cm^3 or 30%	Greater of 1E4 /cm^3 or 5%	Variable[1]	10%	± 9%	< 20%
Electron density profile	Sigma TEC	Greater of 3 TECU or 30%	Greater of 1 TECU or 30%	Greater of 3 TECU or 35%	N/A	3 TECU	Greater of 1 TECU or 20%
Electron density profile	Sigma H_mF_2	20 km	5 km	20 km	N/A	N/A	10 km
Electron density profile	Sigma N_mF_2	20%	10%	30%	N/A	N/A	15%
Electron density profile	Sigma N_mE	20%	5%	100%	N/A	N/A	20%
Electron density profile	Latency	90 minutes	15 mintues	15 mintues	N/A	15 minutes	15 mintues
Scintillation	Horizontal Cell Size	100 km	25 km	500-2000 km	N/A	N/A	15 km
Scintillation	Amp. index (S4)	0.1 to 0.5	0.1 to 1.5	0.1 to 1.5	N/A	N/A	0.1 to 1.5
Scintillation	Phase Index (σ_φ)	0.1 to 20 rad	0.1 to 20 rad	0.1 to 20 rad	N/A	N/A	0.1 to 20 rad
Scintillation	Uncertainty S4	0.1	0.1	0.1	N/A	N/A	0.1
Scintillation	Uncertainty σ_φ	0.1 rad	0.1 rad	0.1 rad	N/A	N/A	0.1 rad
Scintillation	Latency	90 minutes	15 mintues	15 mintues	N/A	N/A	15 mintues
Ions	Ion species	none	O_2^+, NO^+, O^+, H^+, He^+	N/A	O_2^+, NO^+, O^+, H^+, He^+	N/A	O_2^+, NO^+, O^+, H^+, He^+
Ions	Composition discrimination	none	5% of Ne	N/A	5 % of Ne	N/A	5% of Ne
Ions	Drift velocity	none	Objective	N/A	+/- 2000 m/s	N/A	+/- 2000 m/s
Ions	Density	none	Objective	N/A	1E3 – 1E7/cm^3	N/A	1E3 – 1E7/cm^3
Ions	Density fluctuations	none	Objective	N/A	1E3 – 1E7/cm^3	N/A	1E3 – 1E7/cm^3
Ions	Energy	none	Objective	N/A	0 to 20 ev	N/A	0 to 20 ev
Ions	Temperature	none	Objective	N/A	1000 K to 4000 K	N/A	1000 K to 4000 K
Electric Field	Electric field	none	Objective	N/A	0 to 150 mV/m	N/A	0 to 150 mV/m
Neutrals	Wind speed	none	Objective	N/A	+/- 2000 m/s	N/A	+/- 2000 m/s
Neutrals	Density	none	Objective	N/A	1E3 to 1E10 /cm^3	N/A	1E3 to 1E10 /cm^3
Neutrals	Temperature	none	Objective	N/A	1000 K to 4000 K	N/A	1000 K to 4000 K

1. 100% E layer, 50% F layer bottom side, 30% F layer near peak, 15% topside

SEM Matrix

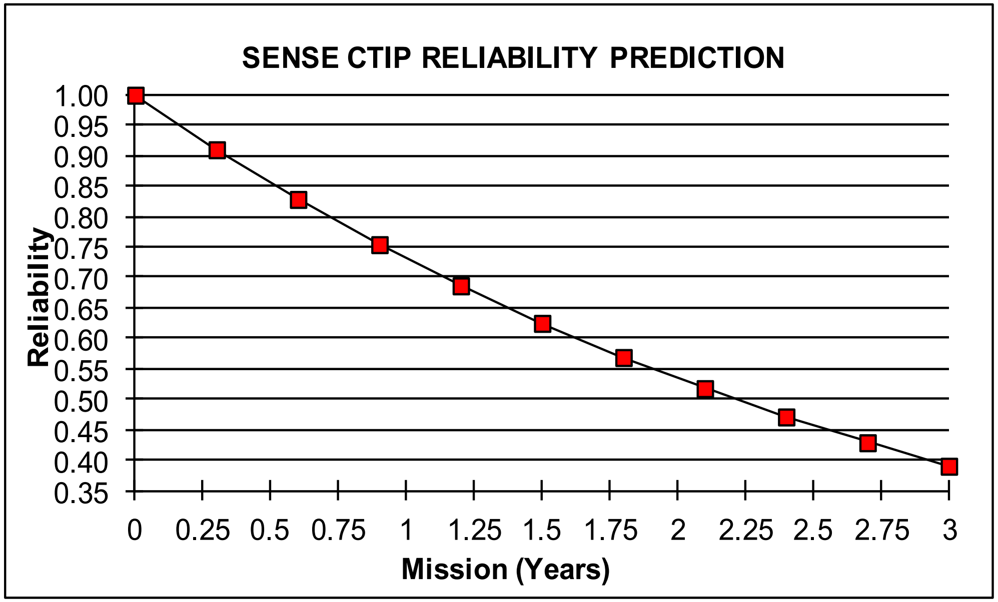
Space Environment Measurement Matrix					
Measurement	DMSP Polar Orbit Fixed LT	C/NOFS Equatorial Orbit All LT	SENSE Instruments All LT	SENSE + Ground Processing	DMSP, C/NOFS, SENSE
Auroral Particles	G	N / A	N / A	N / A	G
Auroral Energy Deposition	G	N / A	N / A	N / A	G
Auroral Imagery	G	N / A	N / A	N / A	G
Auroral Boundary	G	N / A	N / A	N / A	G
Energetic Ions	Y - L	N / A	N / A	N / A	Y
Medium Energy Particles	G	N / A	N / A	N / A	G
High-Lat Ionospheric Scintillation	Y - A	N / A	N / A	N / A	G
Low-Lat Ionospheric Scintillation	Y - OA	G	Y - O	G	G
High-Lat *In Situ* Electric Field	G	N / A	N / A	N / A	G
Low-Lat *In Situ* Electric Field	Y - O	G	Y - OT	G	G
High-Lat Electron Density Profile	Y - A	N / A	N / A	N / A	Y
Mid-Lat Electron Density Profile	Y - OA	N / A	G	G	G
Low-Lat Electron Density Profile	Y - OA	G	Y - O	G	G
Neutral Density Profile	R	Y - AT	Y - AT	G	G
In Situ Neutral Winds	R	Y - AT	Y - AT	Y	Y
High-Lat Geomagnetic Field	G	N / A	N / A	N / A	G
Low-Lat Geomagnetic Field	Y - O	G	R	R	G
In Situ Plasma Temperature	G	G	Y - T	Y	G
In Situ Plasma Fluctuations	G	G	R	R	G

G	Good measure of parameter
Y	Measurement made, but with limitation(s)
R	No measurements made to address this parameter
N / A	Does not apply in specified orbit

O	Sub-optimal orbital inclination
A	Orbit altitude
T	Technology – instrument has limited or unproven capability for this parameter
L	Instrument covers a limited range of the parameter

Reliability Modeling (CTIP)

- CTIP vehicle reliability is estimated to be 0.7312 at 1 year.
  - 5 Bus Drivers are:
    - USB Radio (0.950)
    - IRB (0.954)
    - PMAD (0.969)
    - RWA controller (0.975)
    - +Y Body panel (0.980)
  - Payload Driver
    - CTIP (0.960)



Reliability Modeling (WINCS)

- **WINCS vehicle reliability is estimated to be 0.7304 at 1 year.**
  - **5 Bus Drivers are:**
    - **USB Radio (0.950)**
    - **IRB (0.954)**
    - **PMAD (0.969)**
    - **RWA controller (0.975)**
    - **+Y Body panel (0.980)**
  - **Payload Driver**
    - **WINCS (0.954)**