ATMOSPHERIC & SPACE TECHNOLOGY RESEARCH ASSOCIATES

SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

Scanning Imaging Photometer System (SIPS) Ionospheric Space Weather Sensor

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ASTRA LLC., Boulder, CO

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North Chelmsford, MA

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Scientific Solutions, Inc.
Spectroscopic Devices & Consulting

SRI International

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SCIENCE + TECHNOLOGY + APPLICATIONS // *Bringing it all together*

- Atmospheric & Space Technology Research Associates LLC
- Small business (Boulder, CO)
- Specializing in Solar-Terrestrial research/applications/products
- Current/recent customers:
  - AFRL
  - AFOSR
  - ONR
  - NRL
  - NASA
  - NSF
  - JHU-APL
  - Aerospace Corp.
  - Los Alamos National Laboratory
  - Various universities

❖ Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA: Space Weather Focus

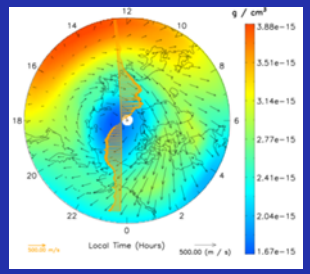
❖Science
❖ Technology
❖ Applications
Bringing It All Together

ASTRA

Modeling

Physics-Based Modeling (TIMEGCM)

Real-Time Specification of Ionosphere/ Thermosphere



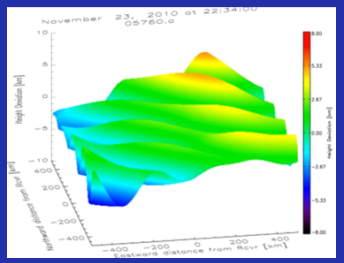
Data Assimilation

High-latitude Electrodynamics

Global Ionosphere

Thermospheric Neutral Density

Satellite Drag & Ballistic Coefficients



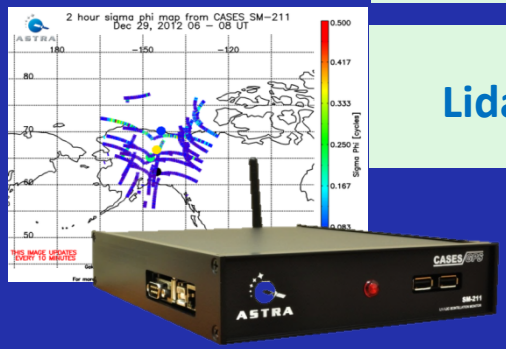
Data Services

Space Based Data

Ground Based Data

Forensic Space Weather Analysis

Spaceweather Phone Apps



Ground-based Instrument Development

GPS-based Space Weather Monitor

E-fields and Magnetometers

Low Power Ionospheric Sounder

HF TID Mapper

Lidar Systems

Space Systems

CubeSat Missions

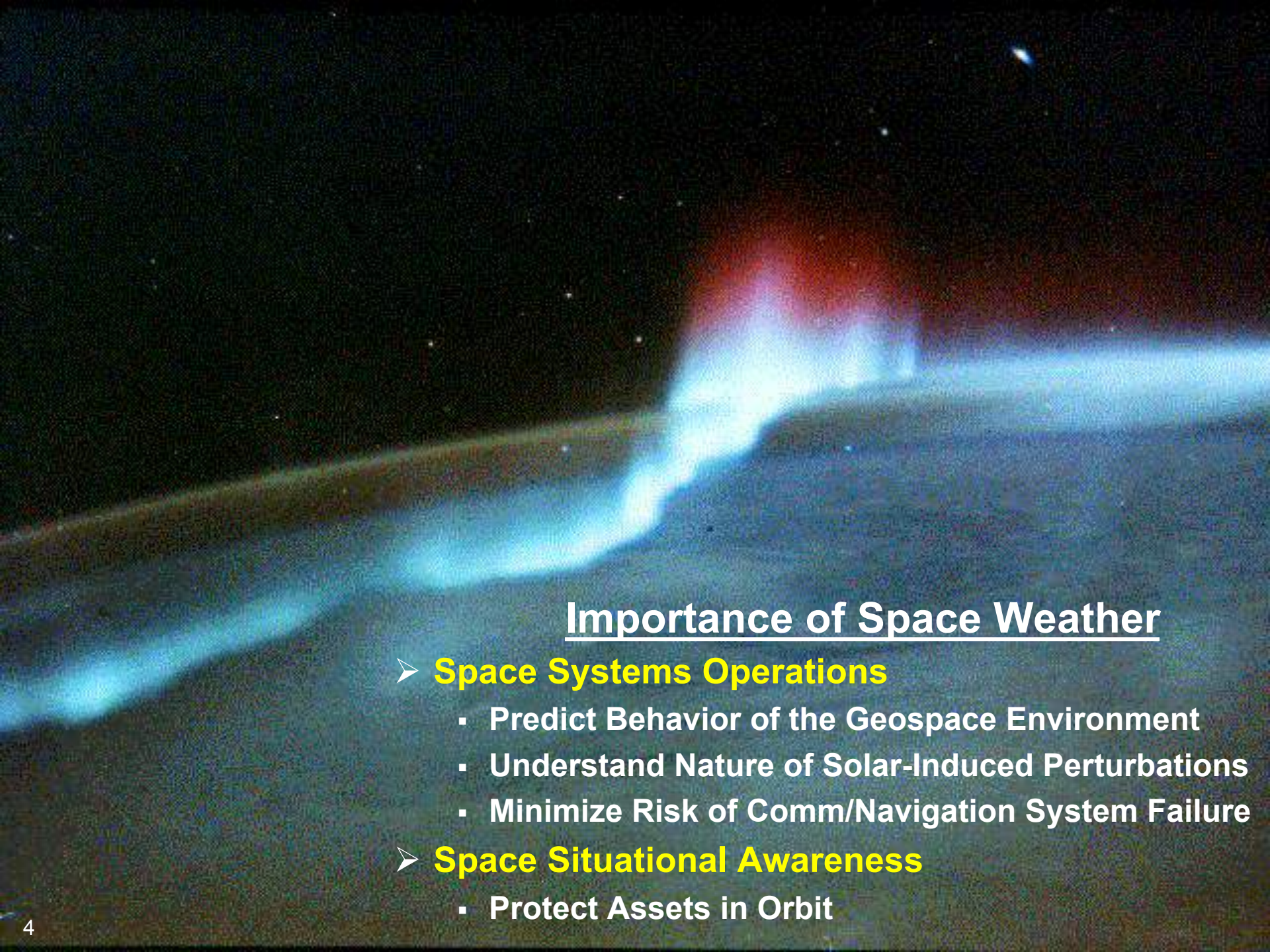
- NSF: DICE & LAICE
- AF: DIME, SIPS & TSS
- NASA: SORTIE & MiRaTa

Plug-N-Play Avionics

CubeSat Instruments

- Scanning UV Photometer
- E-field Double Probe
- RF Waves & Sounder
- Wind Profiler
- GPS-based Space Weather Monitor
- Magnetometer & Langmuir Probe

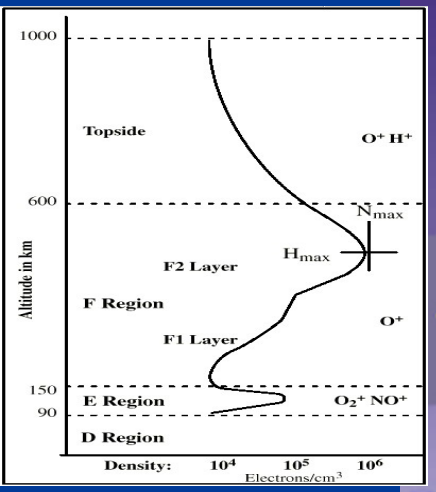
Hosted Payloads

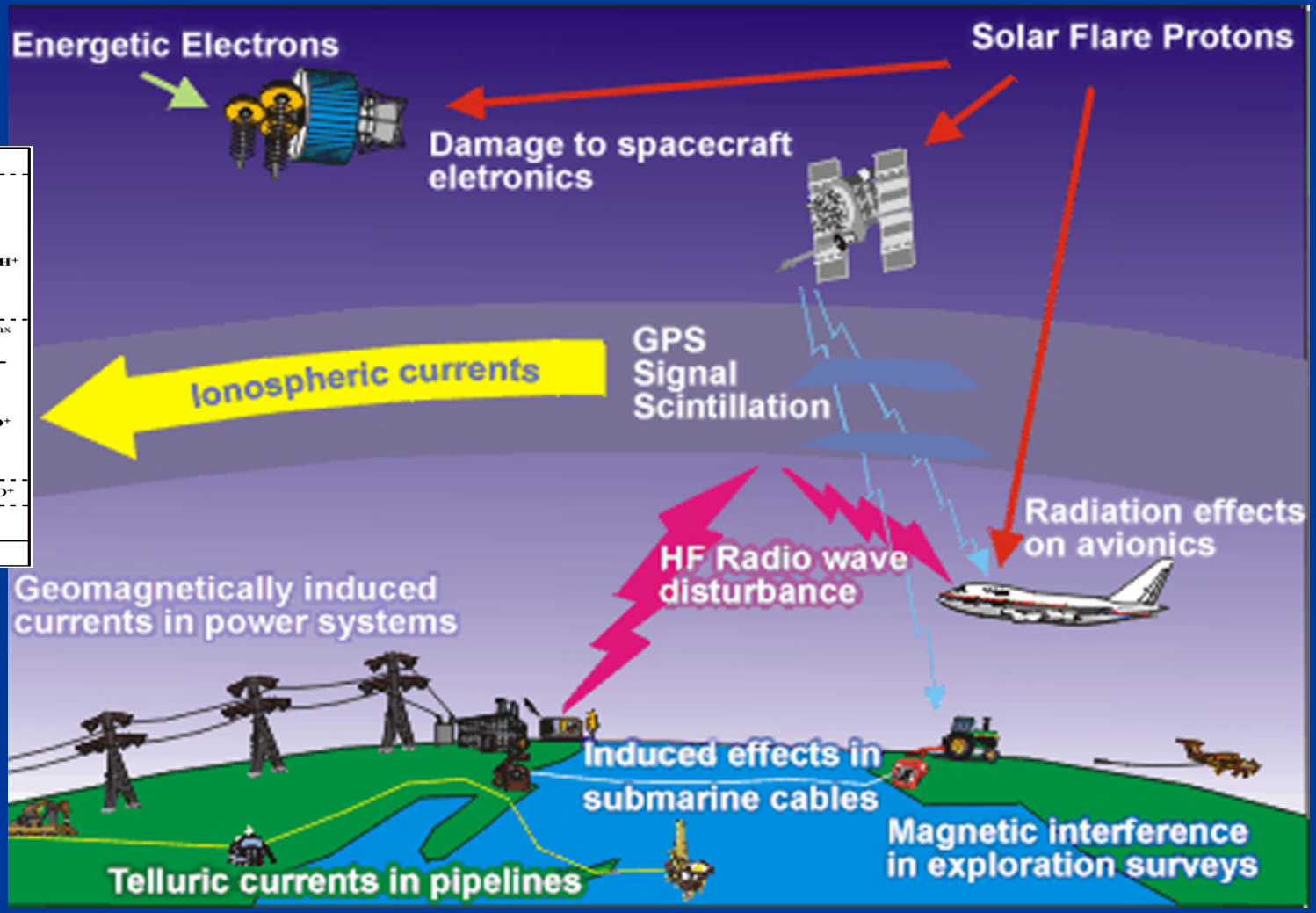


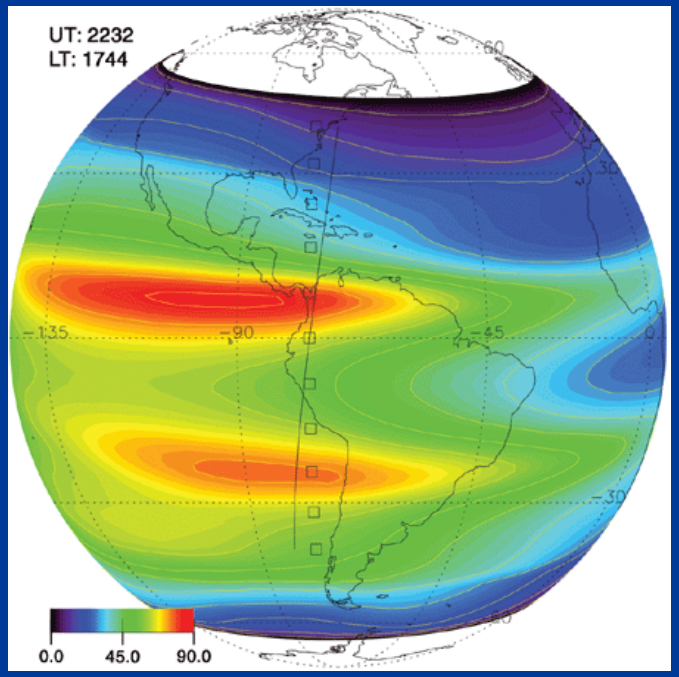
Importance of Space Weather

- **Space Systems Operations**
  - Predict Behavior of the Geospace Environment
  - Understand Nature of Solar-Induced Perturbations
  - Minimize Risk of Comm/Navigation System Failure
- **Space Situational Awareness**
  - Protect Assets in Orbit

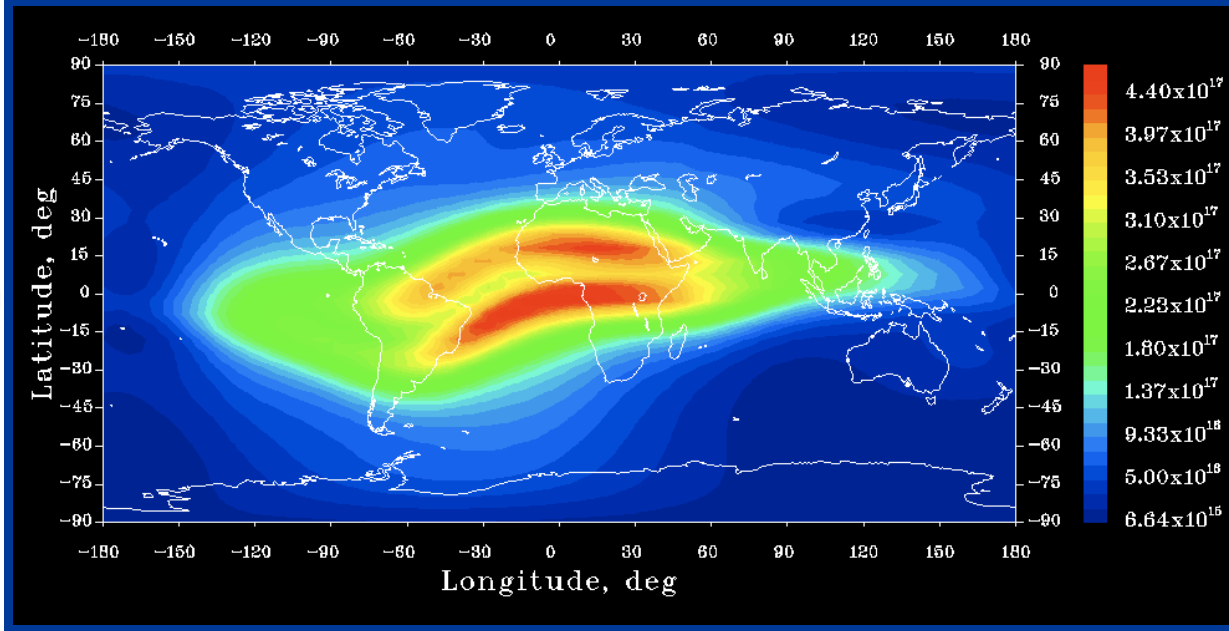
System performance limited by Ionospheric variability







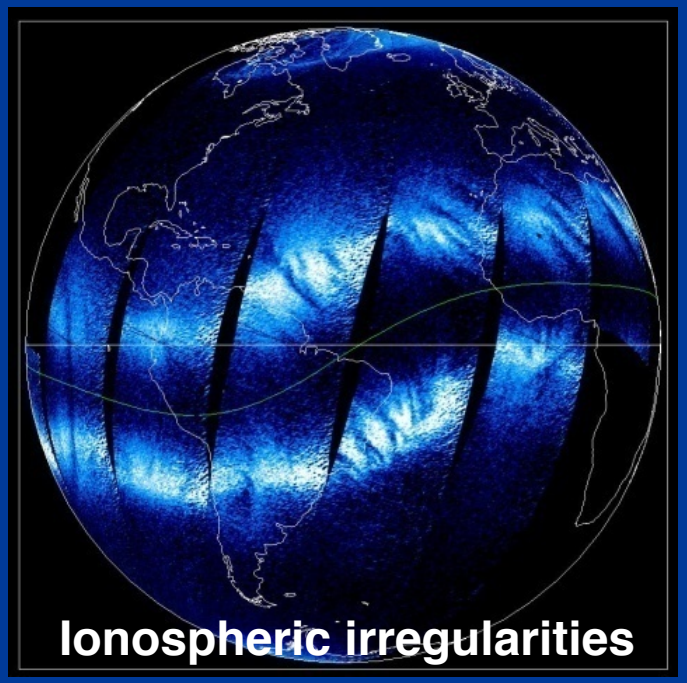
NRL SAMI3 Global TEC

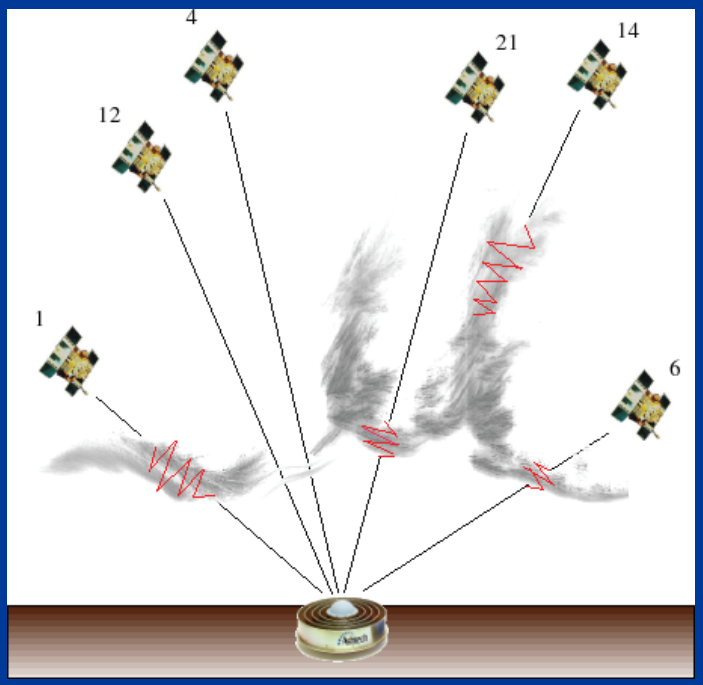


IRI Global TEC

- **Models of the ionosphere can reproduce the largest-scale average features**
- **Small scale structure is more difficult**
- **Small scale structure tends to affect systems**

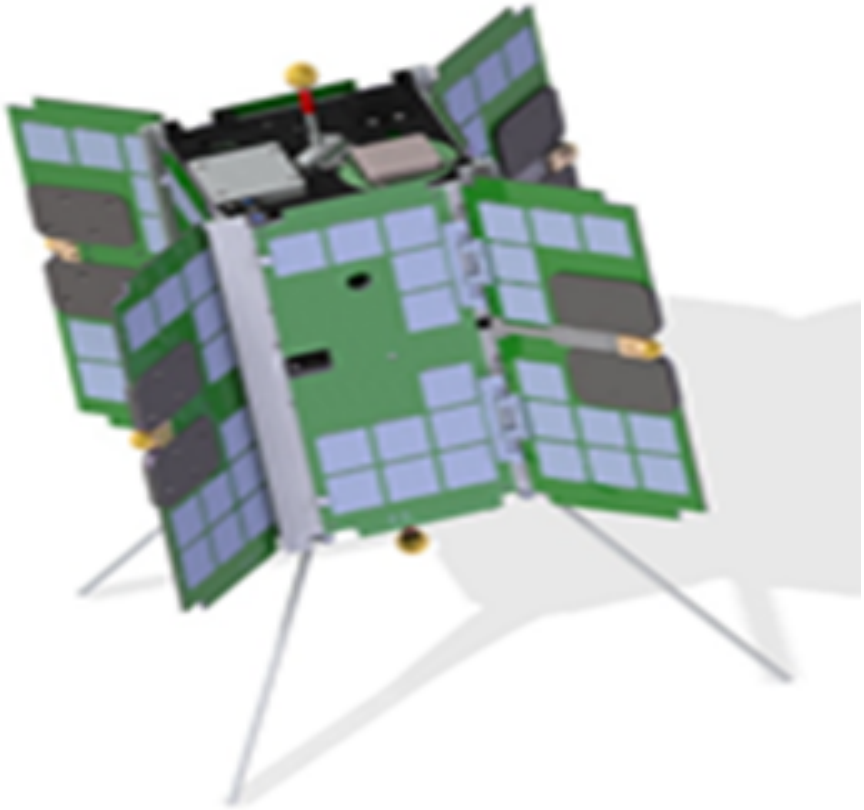
Small Scale Structure





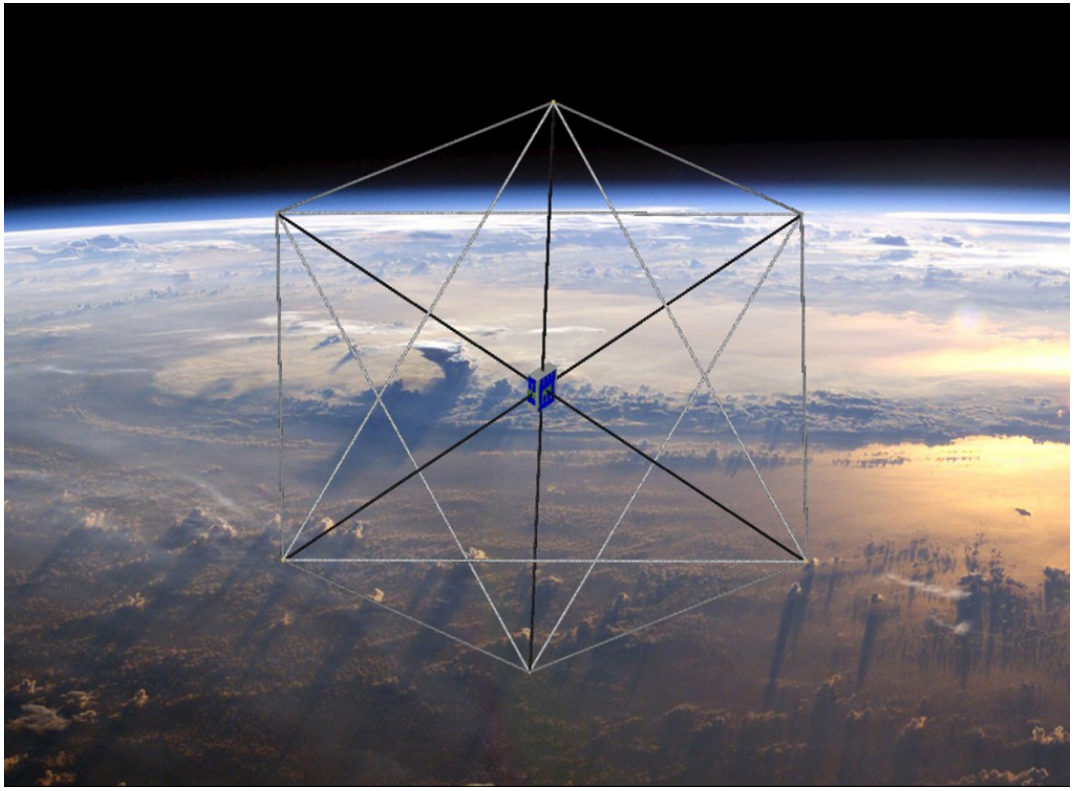
- Ionospheric irregularities remain one of the most important yet least understood phenomena in ionospheric science.
- Ionospheric space weather includes gradients and irregularities that affect trans-ionospheric radio wave propagation.

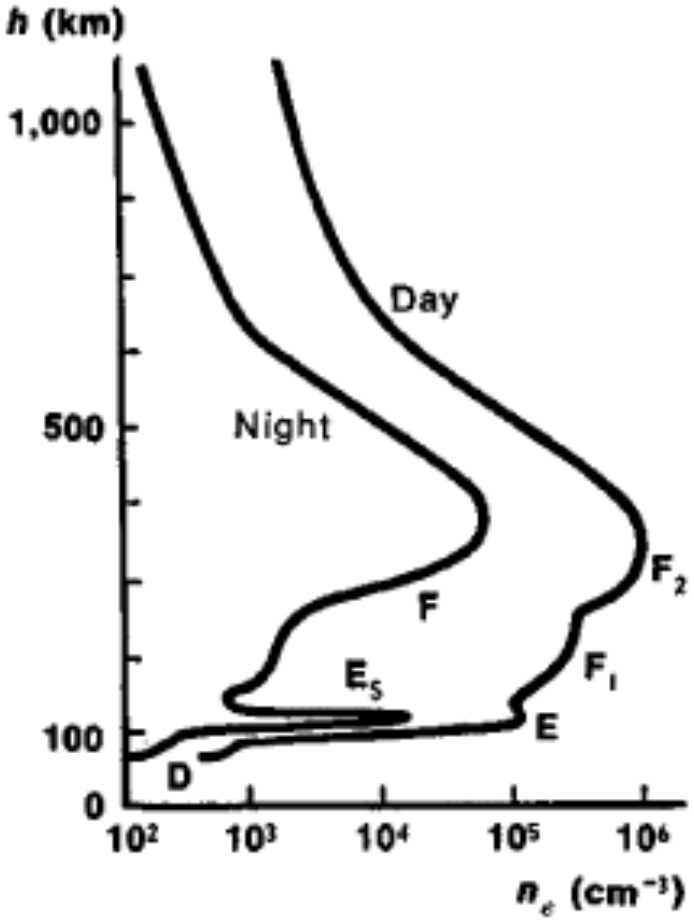
E-fields
Electron Density
Magnetic Field



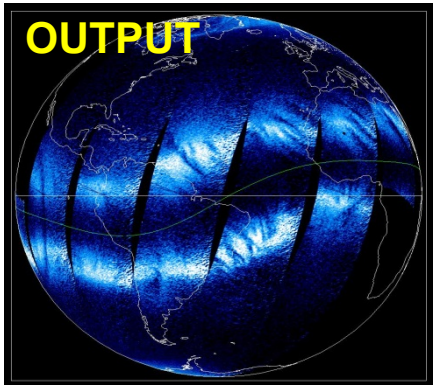
Topside Sounder Instrument

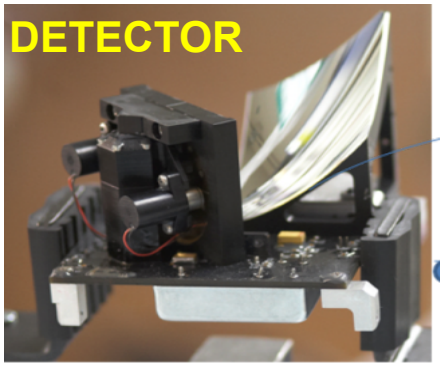
Uses HF Radio signals
Measures ionospheric electron density profile

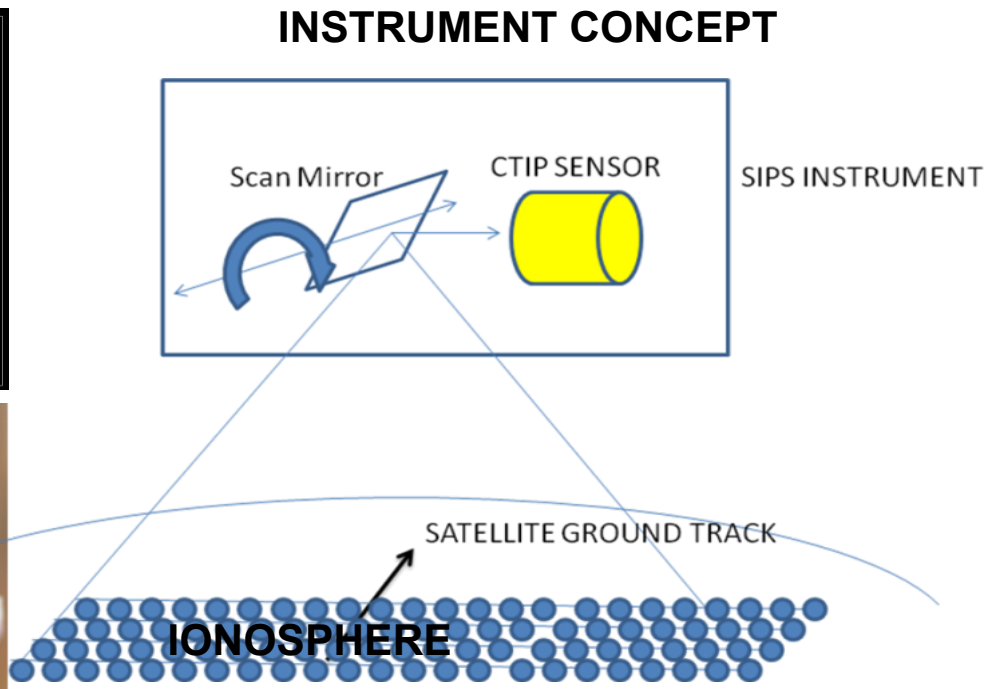




SIPS – UV Scanning Photometer



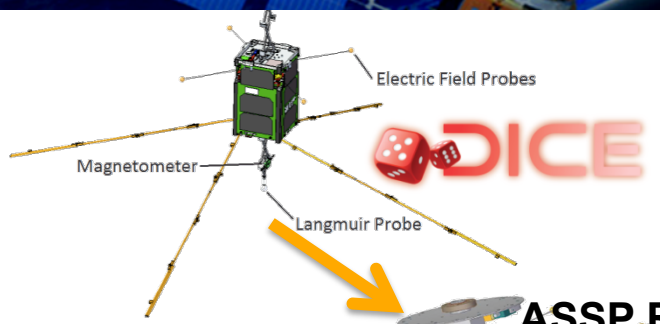




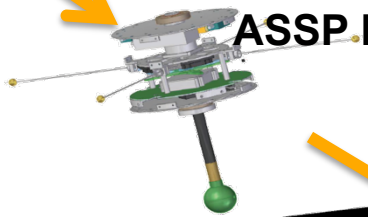
Small-Sat Constellations

❖Science
❖ Technology
❖ Applications
Bringing It All Together

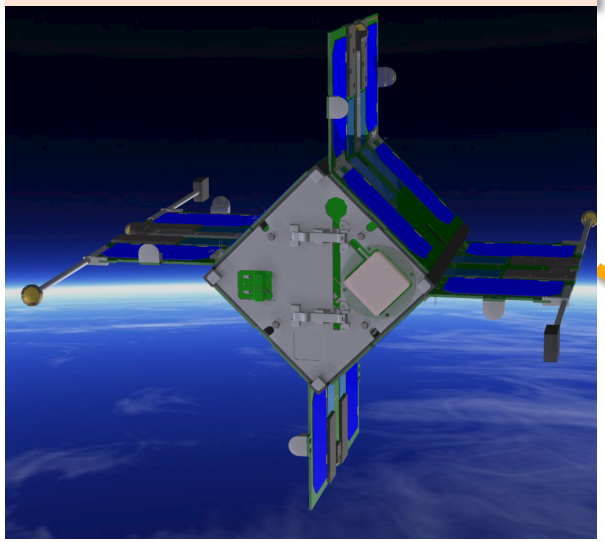
ASTRA



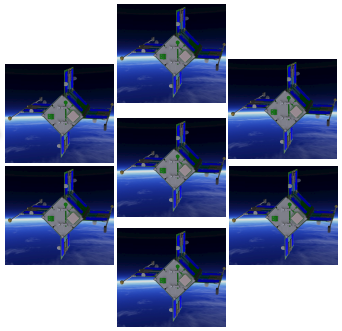
ASSP Rocket



DIMESat



Constellation



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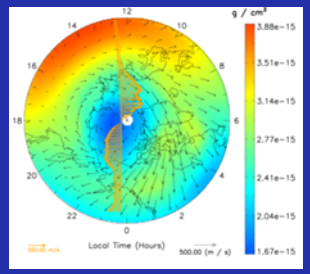

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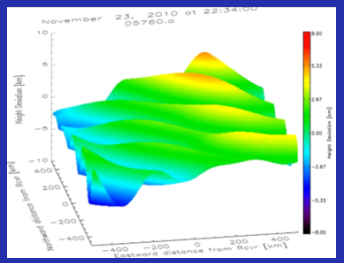

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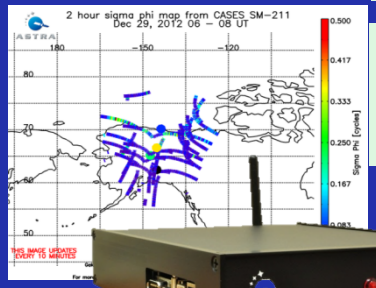

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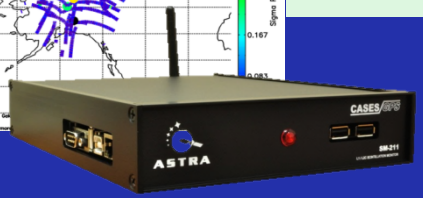

Space Systems

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- NSF: DICE & LAICE
- AF: DIME, SIPS & TSS
- NASA: SORTIE & MiRaTa

Plug-N-Play Avionics

CubeSat Instruments

- Scanning UV Photometer
- E-field Double Probe
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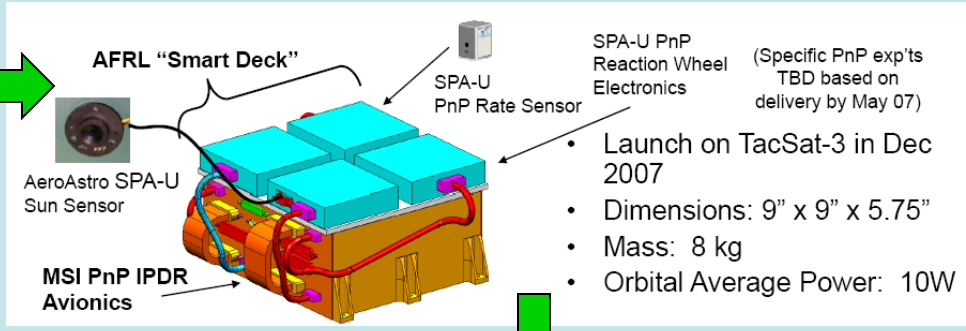
Once Upon a Time .....

Development of CubeSat Infrastructure: PnP Discipline

Demonstrations and tests

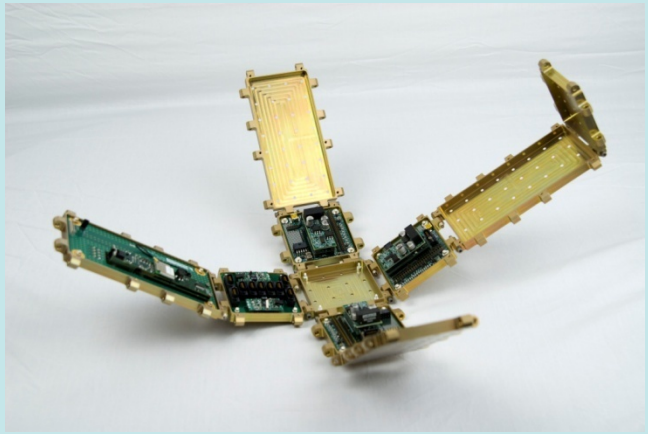
SPA-U radiation test board [*Lyke et al.*, 2005].

Spacecraft Avionics Experiments



[*Lyke*, 2008]

CubeFlow PnP Bench Kits



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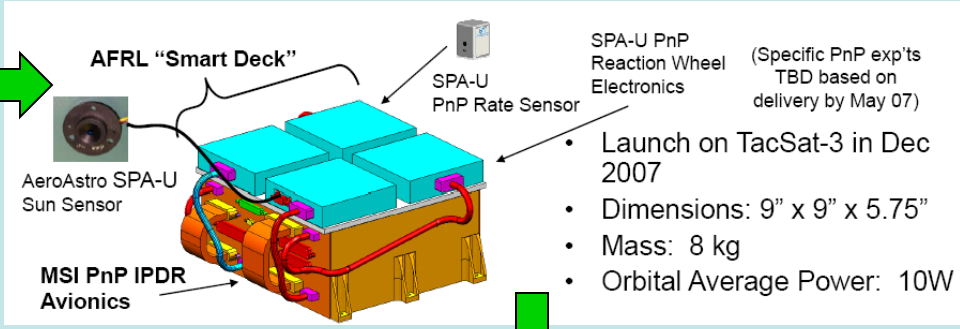

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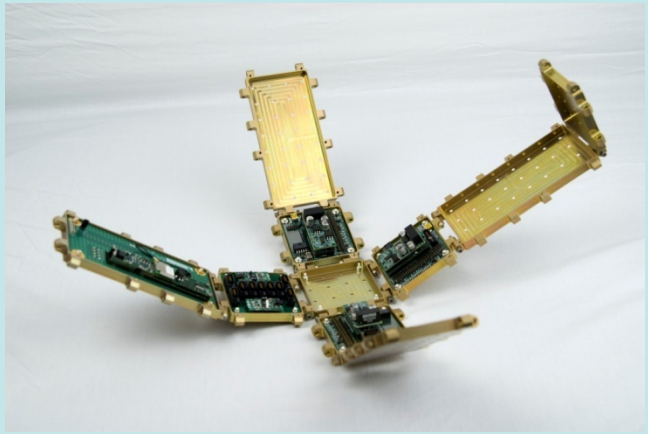
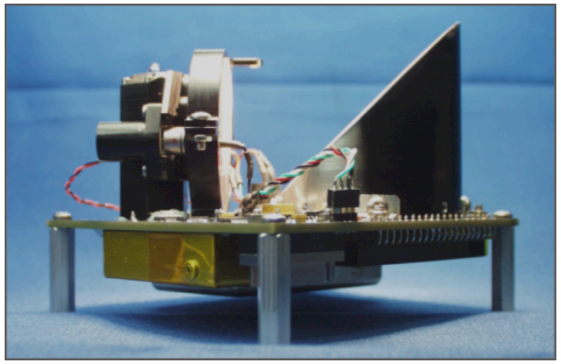
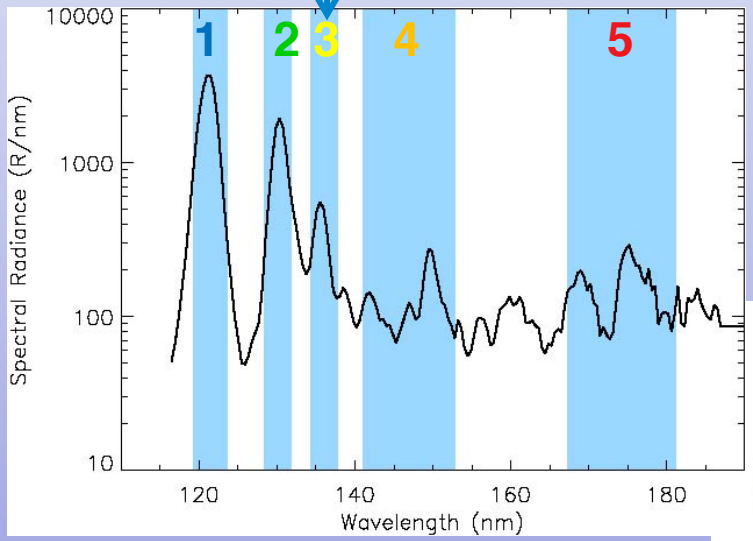


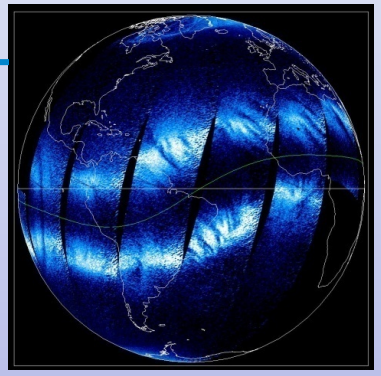
ASTRA space environment sensors

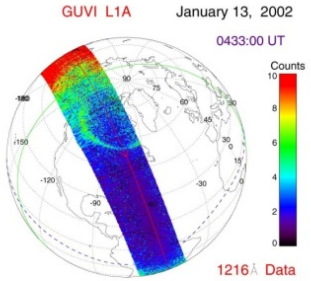


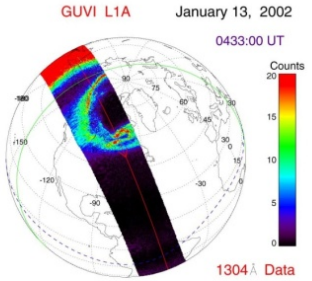
Ultra-Violet Remote Sensing of Ionosphere

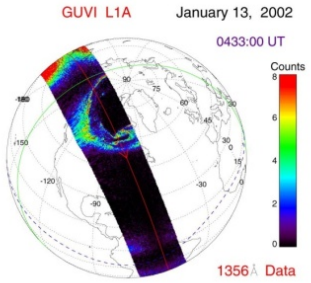
Hyperspectral Imagers (e.g. DMSP-SSUSI, NASA-GUVI)

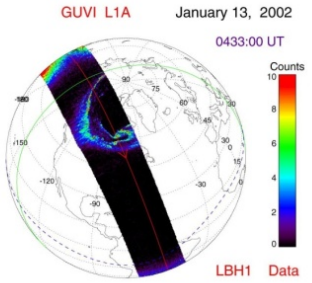


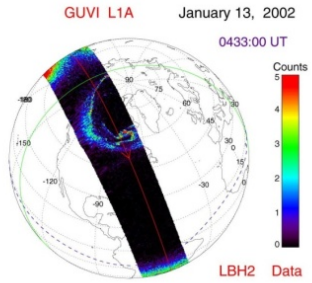








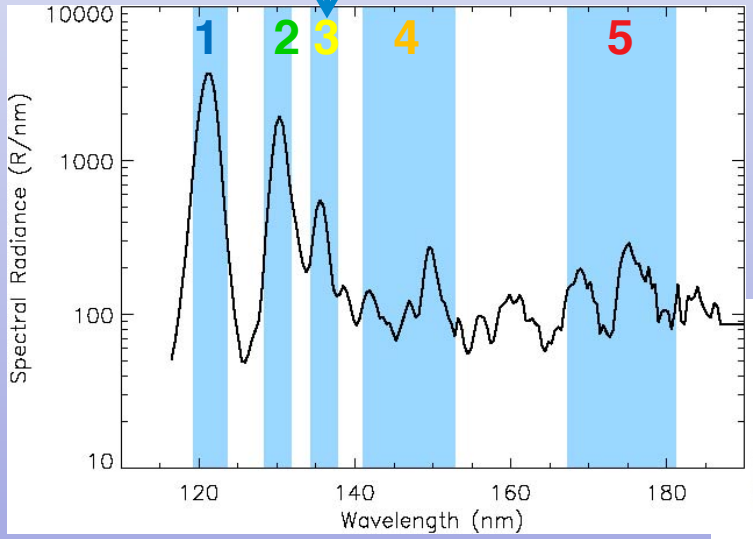


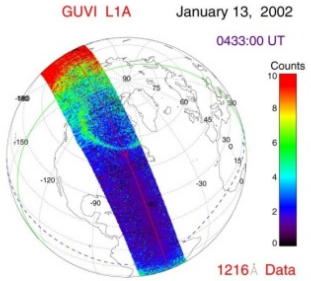


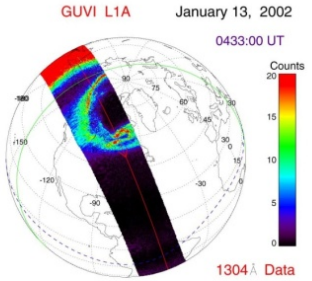
Ultra-Violet Remote Sensing of Ionosphere

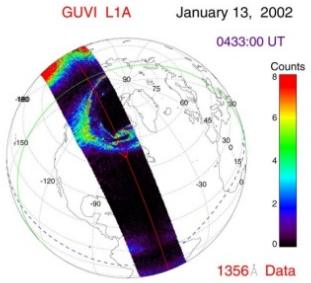
Hyperspectral Imagers (e.g. DMSP-SSUSI, NASA-GUVI)

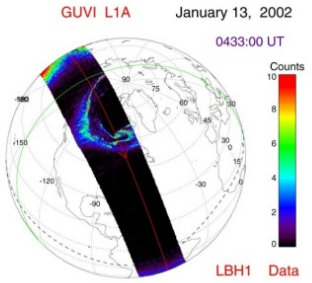
Photometers (e.g. TIPS, CTIP)

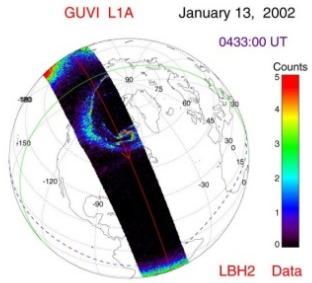












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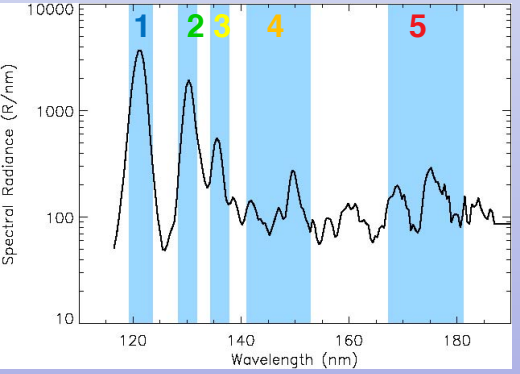
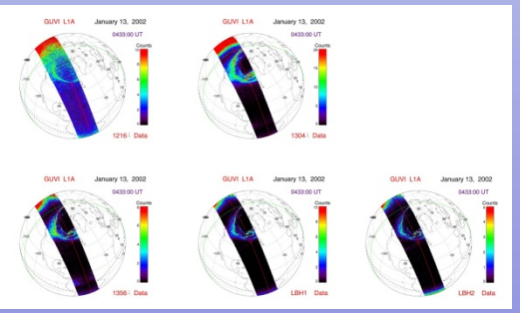
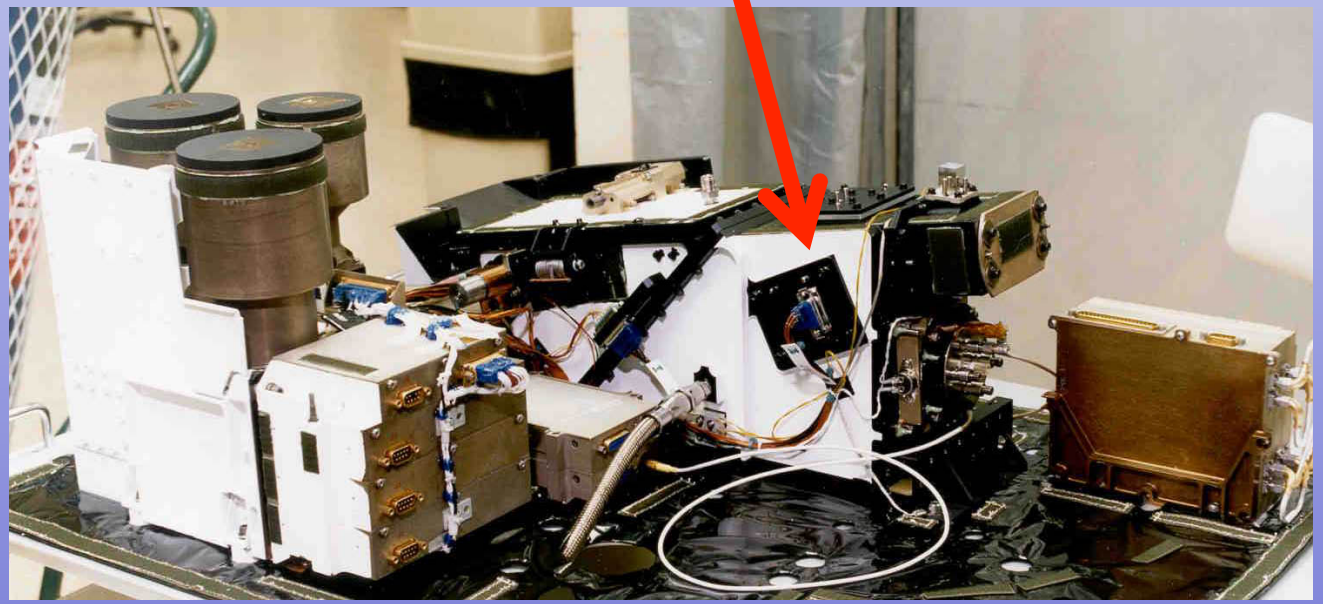


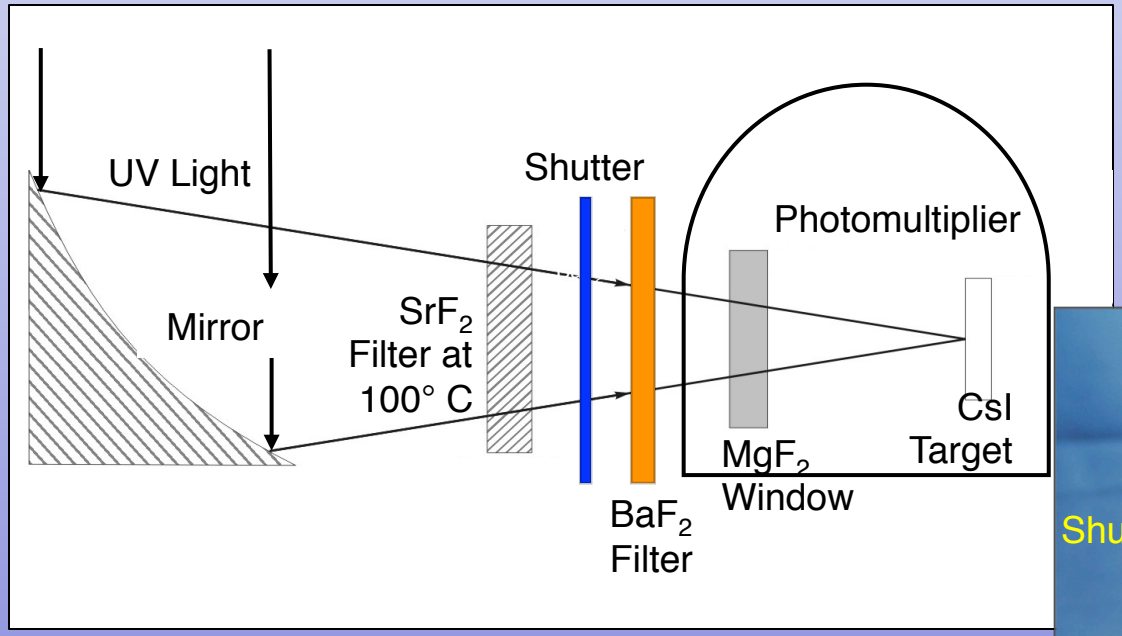


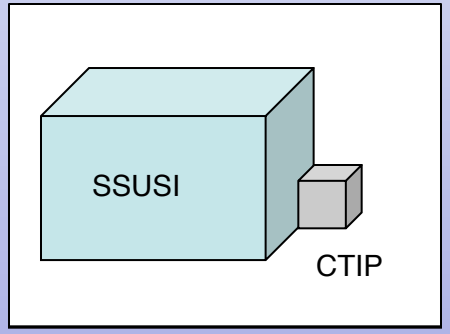
DMSP-SSUSI
17” × 12” × 12”
25 Kg
25 W
$10 Million

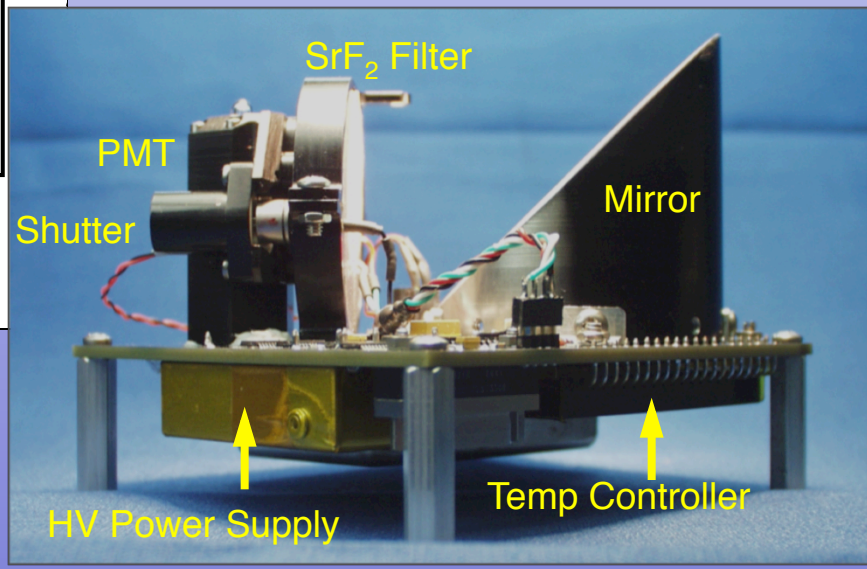


UV Photometer Development

NRL-TIPS, SRI-CTIP







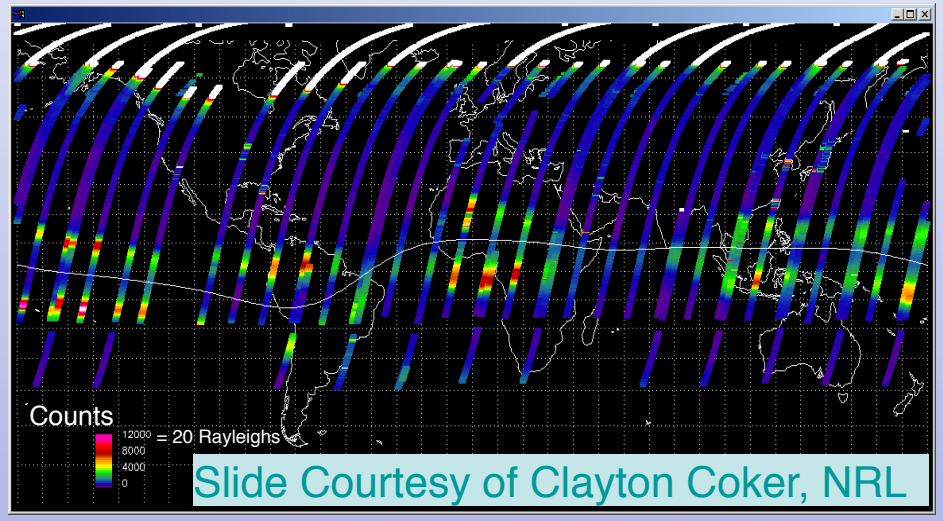
CTIP Optical Elements

requirements of the CTIP and TIPS instruments

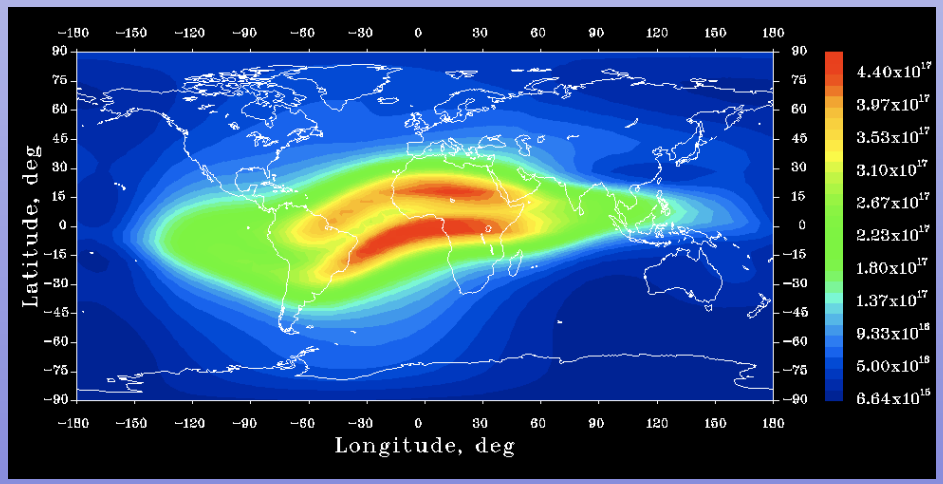
Parameter	CTIP	TIPS
Responsivity	> 300 counts/R-s	> 300 counts/R-s
Field of View	3.8°	3.8°
Average Power	2 W	7.6 W
Shutter In-rush	2.6 W X 0.1 s	< 2.4 W
HV In-rush	6.4 W X 0.3 s	< 2.4 W
Volume	1500 cm3 (1.5 U)	3000 cm3
Weight	< 800 g	2300 g

Single Pixel Photometer Provides Under-Sampled View of the Ionosphere

TIPS 135.6-nm
2100 LT at equator
14 Sep 2006

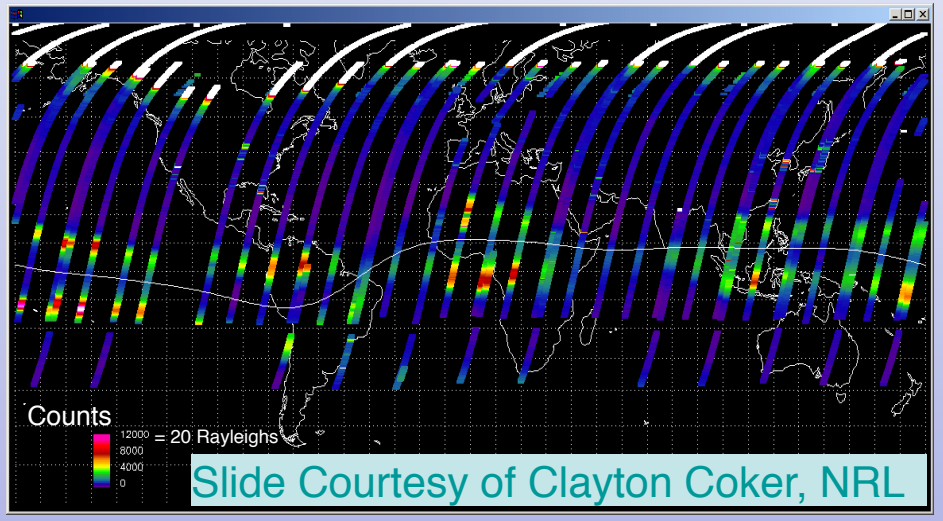


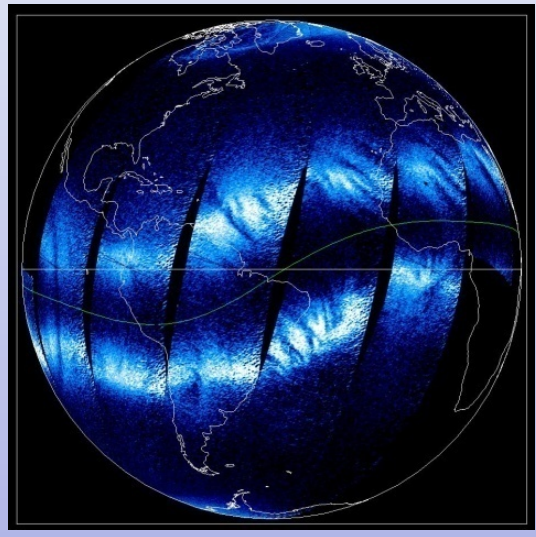
Model Prediction



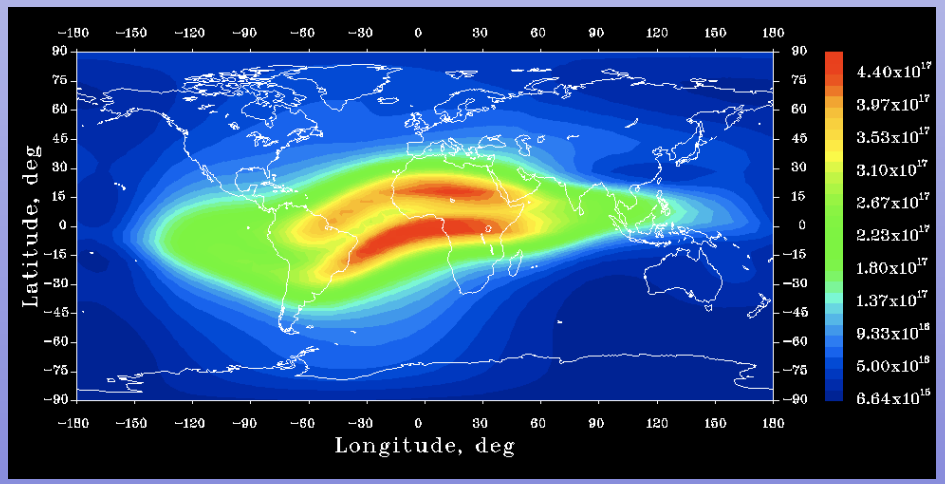
Single Pixel Photometer Provides Under-Sampled View of the Ionosphere

TIPS 135.6-nm
2100 LT at equator
14 Sep 2006

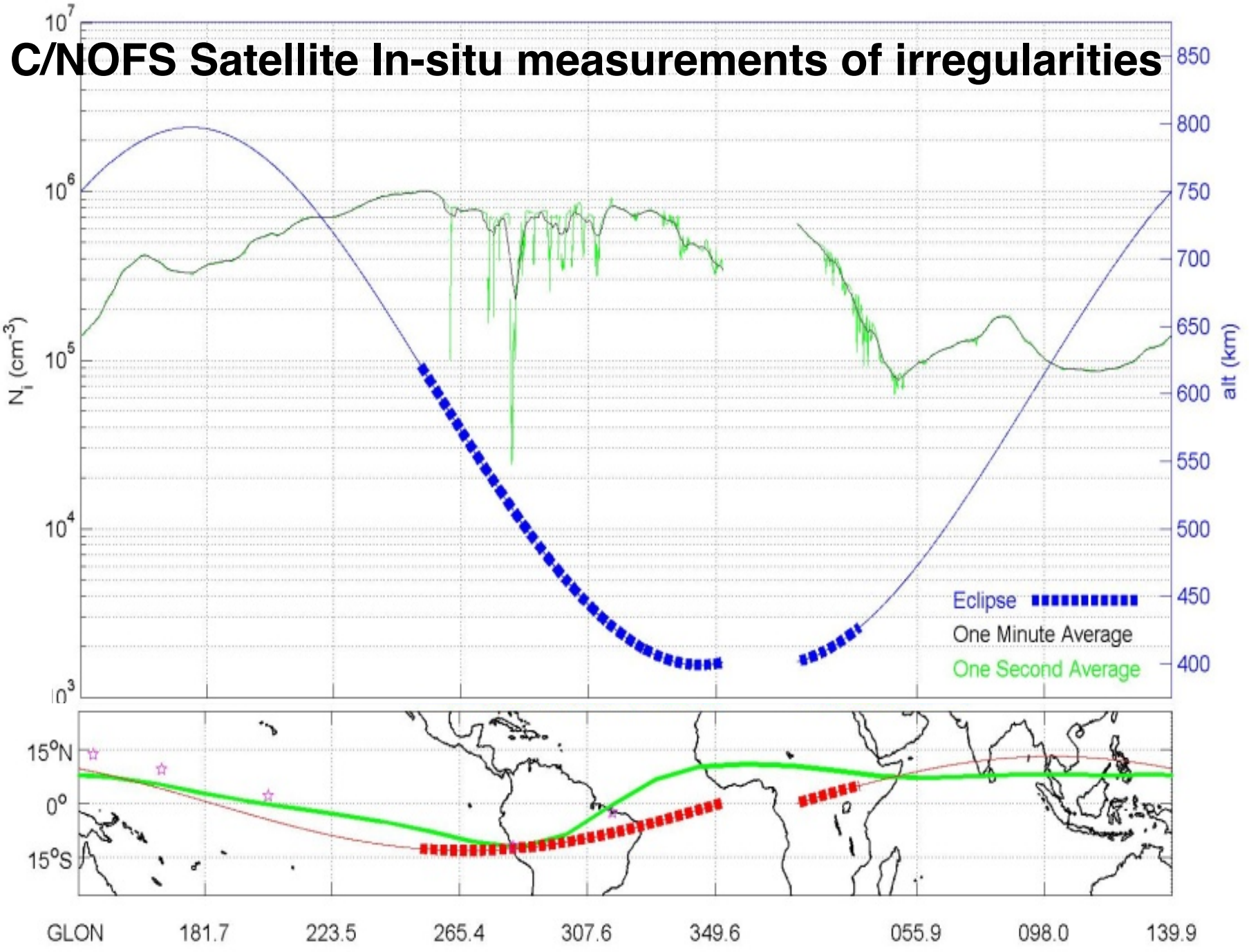




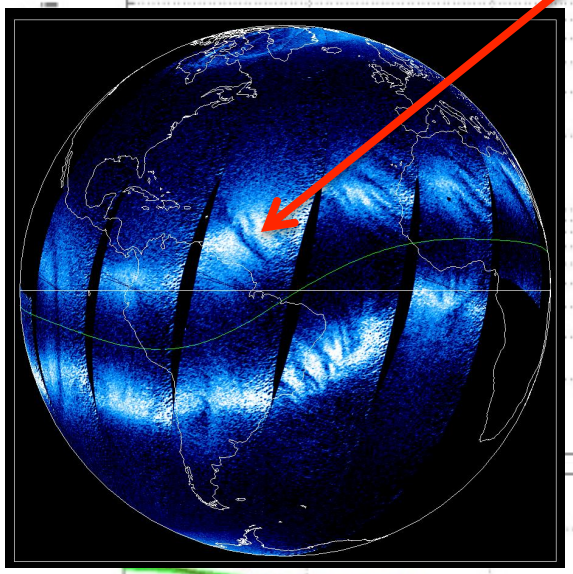
Model Prediction



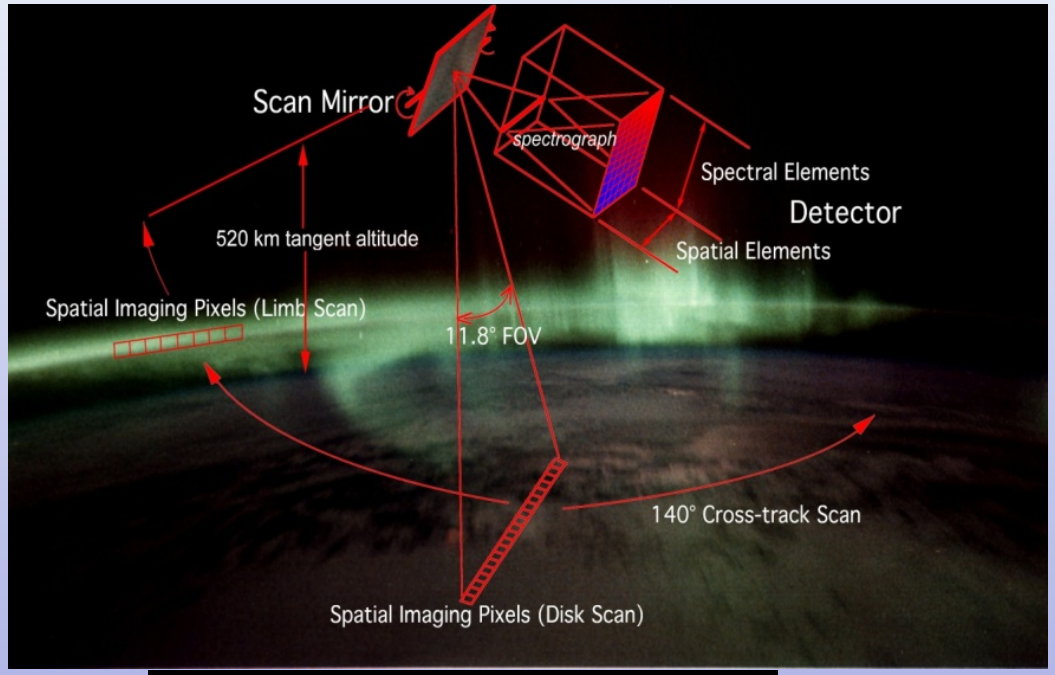
C/NOFS Satellite In-situ measurements of irregularities

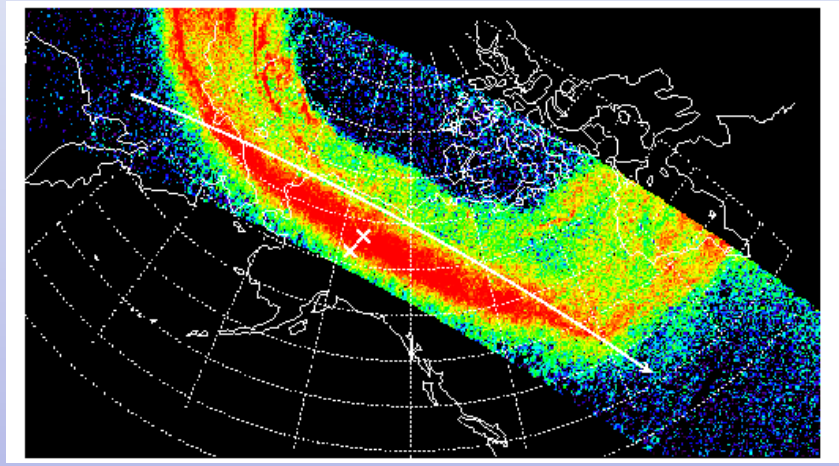


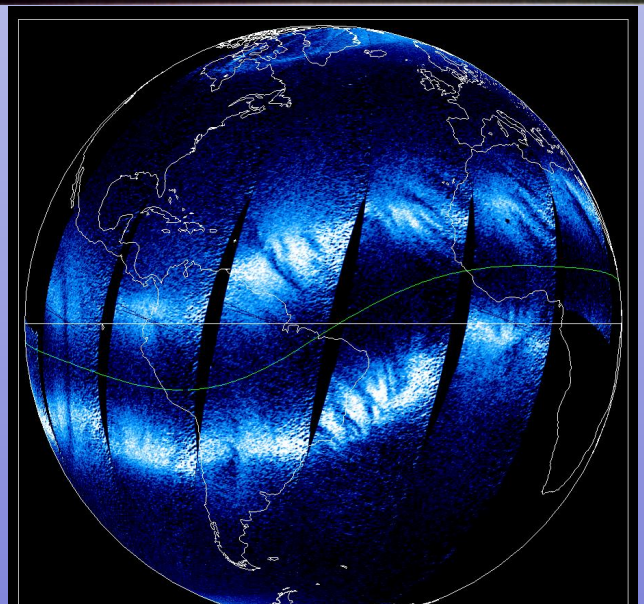
C/NOFS Satellite In-situ measurements of irregularities



GUVI/SSUSI Used a Scan Mirror





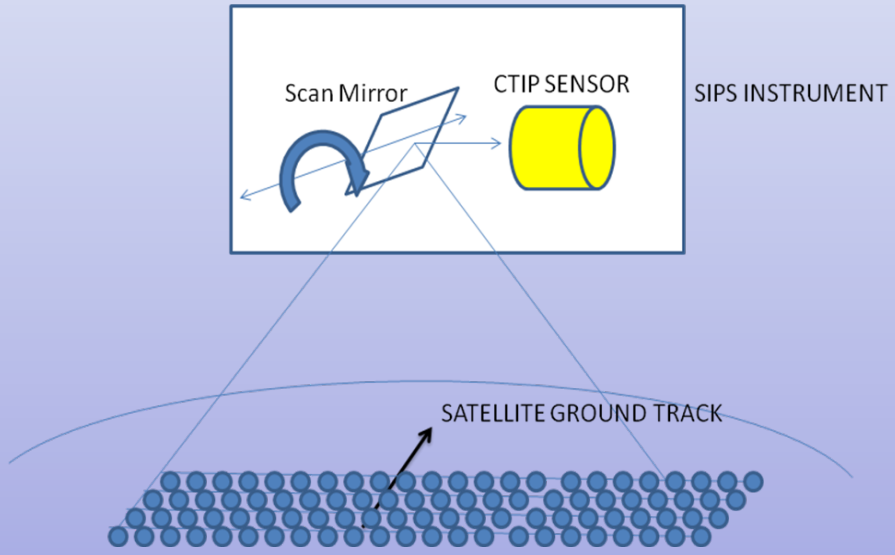


Proposed Instrument Evolution

TIP → CTIP → SIPS

Scanning Imaging Photometer System (SIPS)

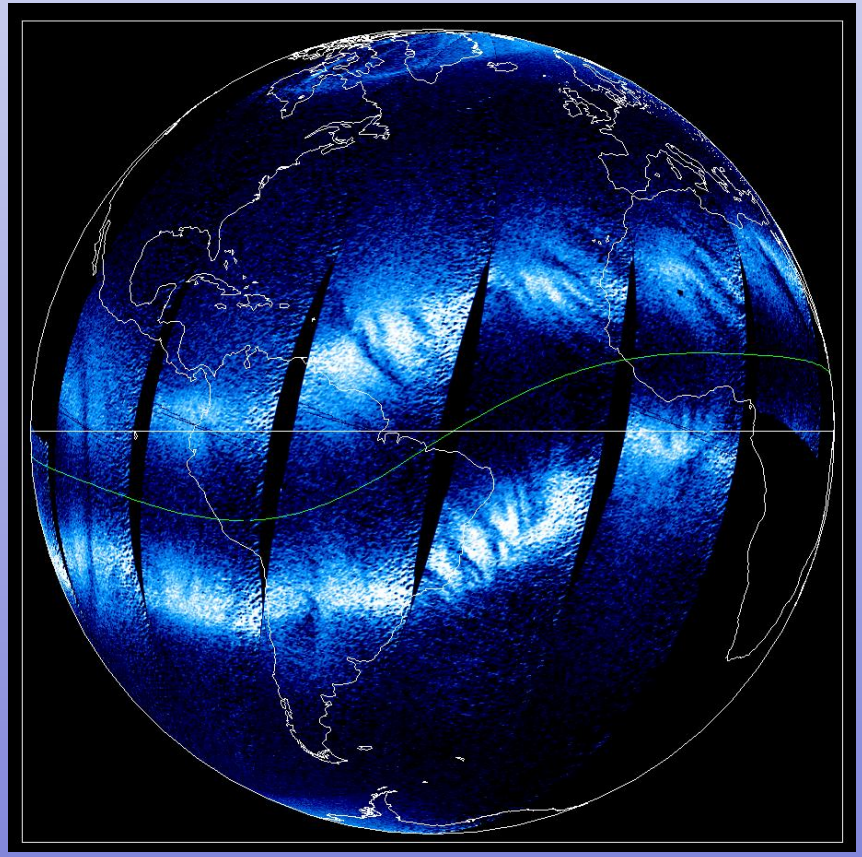
Scan-enabled CTIP Sensor



- Scan geometry for SIPS. The viewing geometry for SIPS is similar to that used for SSUSI.
- The scan mirror sweeps the FOV of the CTIP sensor side-to-side perpendicular to the satellite motion building up a raster scanned image of the 135.6 nm airglow from the ionosphere.

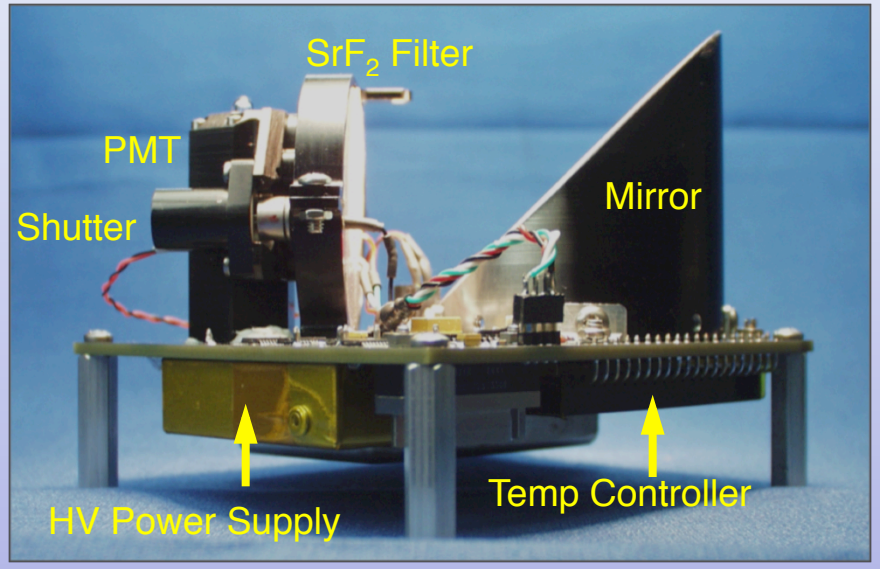
Utilizes Scan Mechanism…..

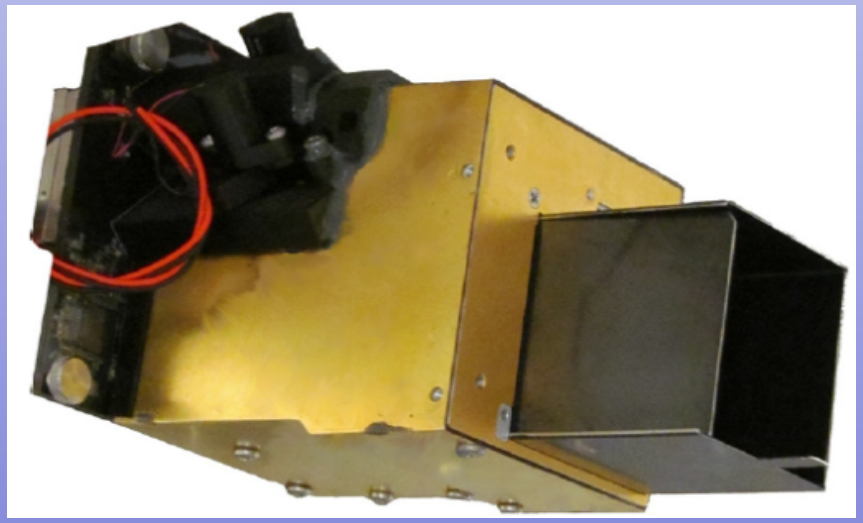
….. to produce images



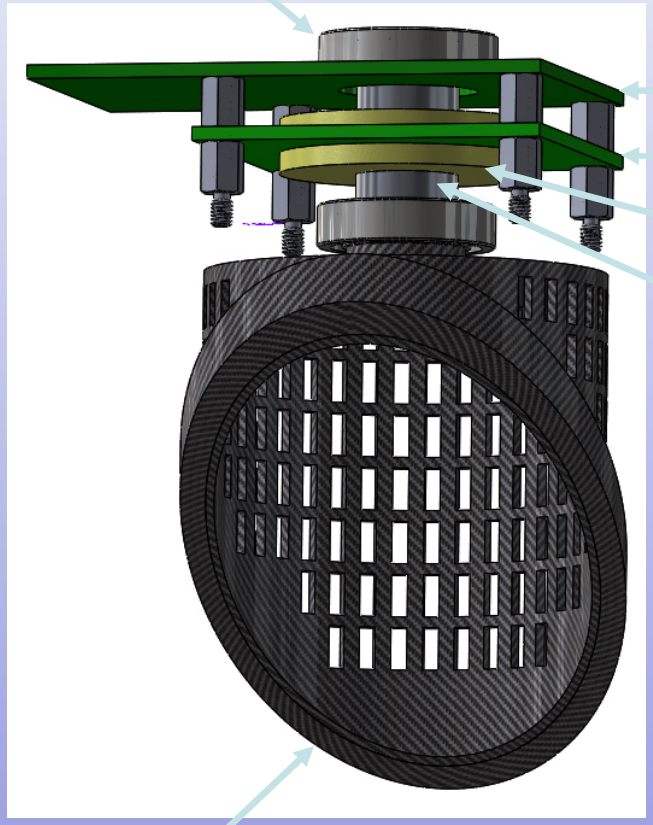
CTIP

- Detects photons at **135.6-nm**
- Current plan is to use EDU from the SENSE mission (GFE)
- Power supply needs to be replaced on this EDU unit to meet responsivity requirement for potential test flight





Scan Mirror Overview



Alignment of SMA to CTIP

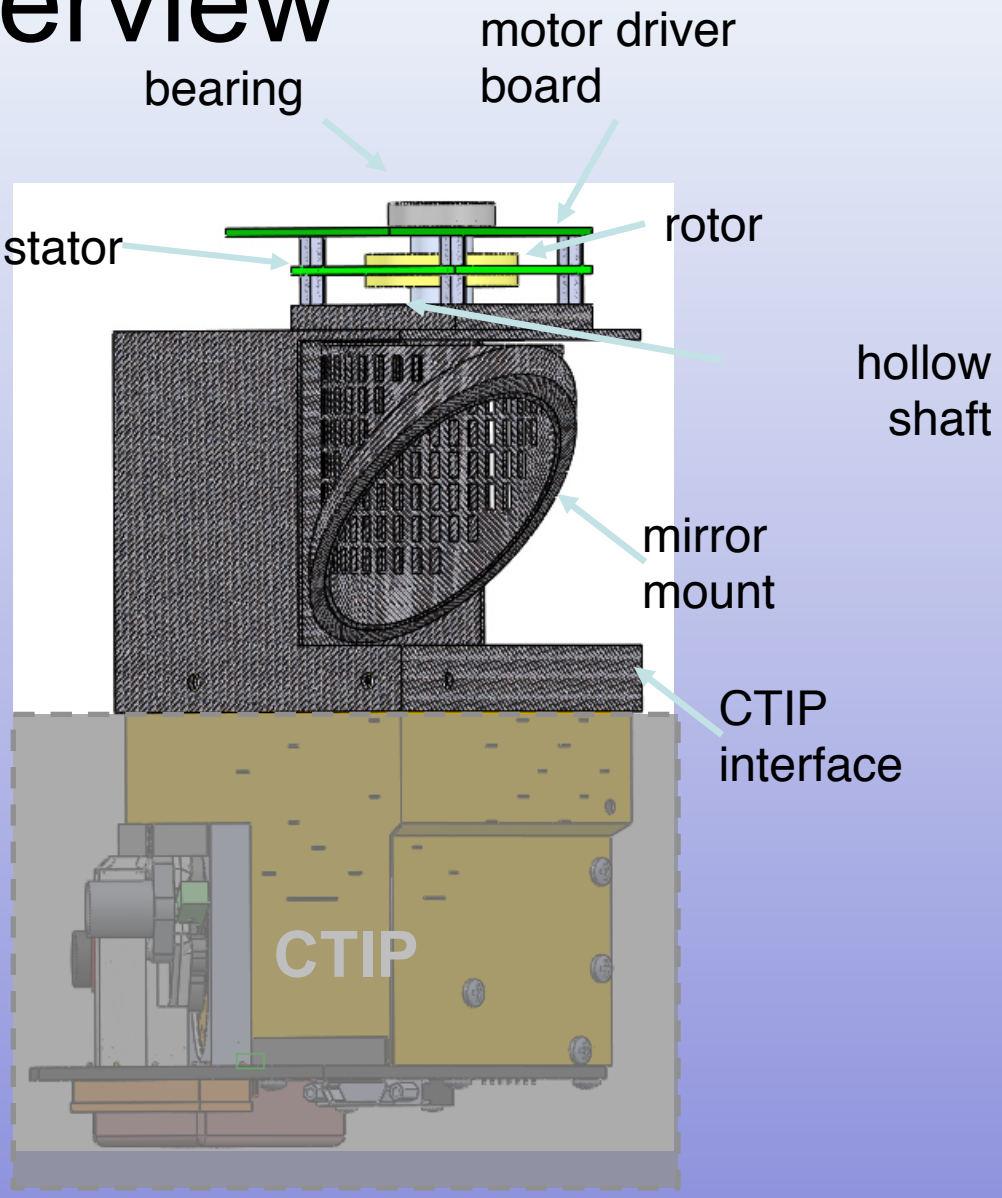
- Two bearings and hollow shaft maintain optical axis perpendicular to rotation axis
- Tip tilt adjustment when mounting motor assembly to optical bench

Scan Mirror Overview

- Carbon fiber mirror mount
- Piezoelectric Motor
- PIC controller
- Optical Encoder
- 400 position control resolution
- Custom bearing assembly
- Optical bench made out of single piece of carbon fiber material for stability

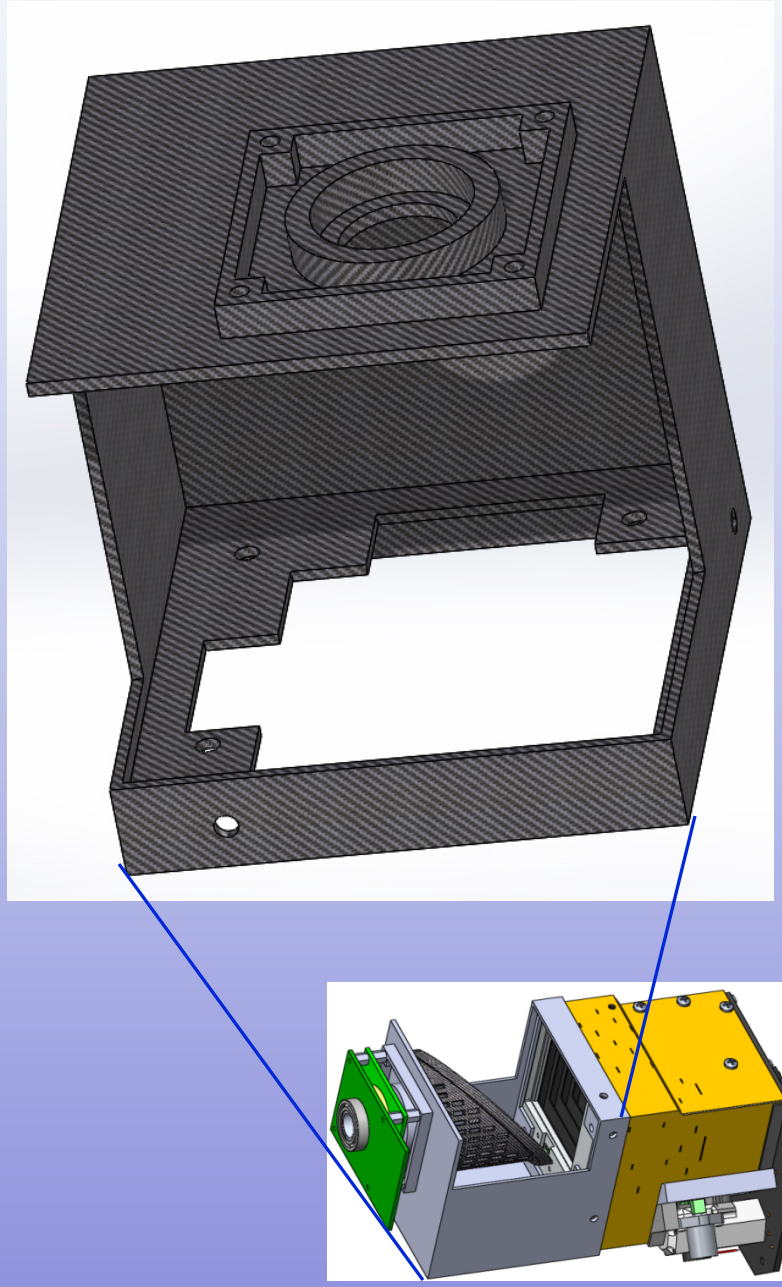
- SMA Mass: 200g
- Power Consumption: 2W
- MOI of moving parts is <1% that of a 6U spacecraft

- **Shake& Bake August 2015**



Optical Bench

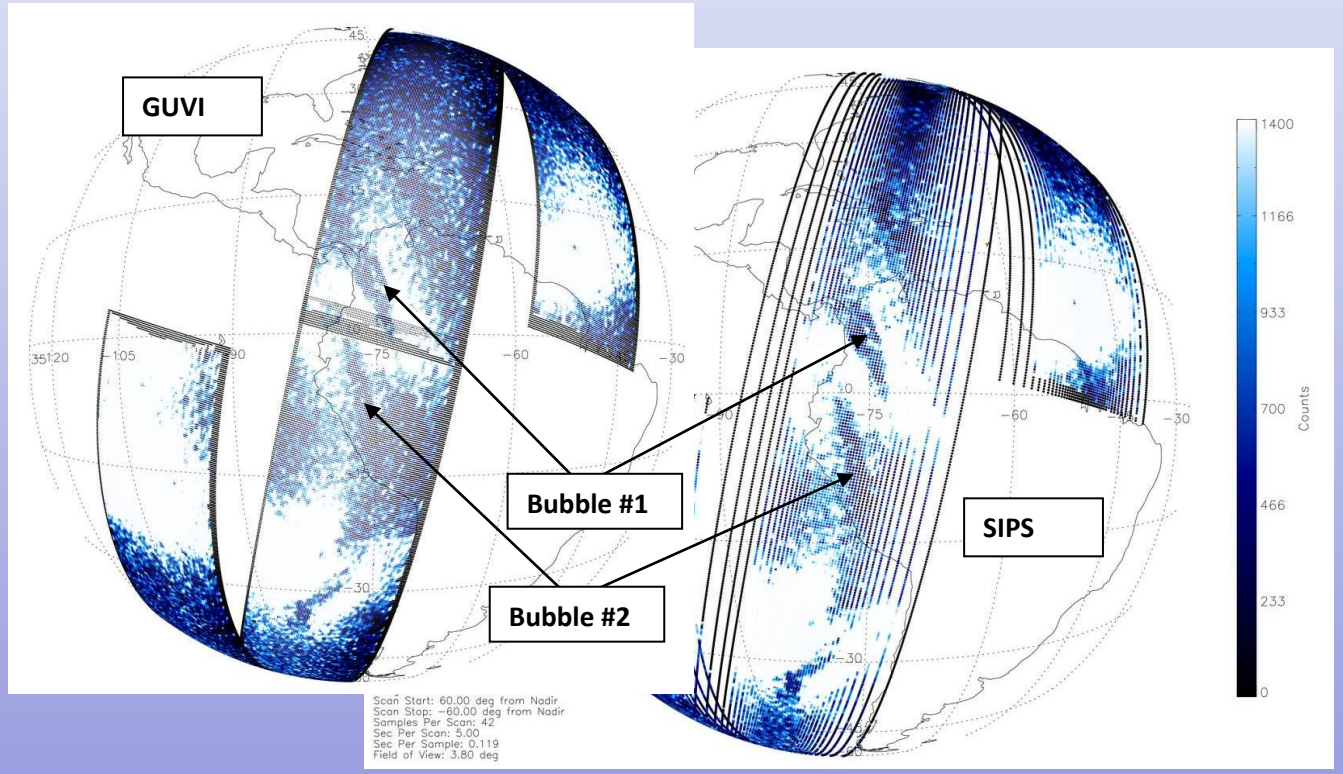
- 3-D printed using WindformXT 2.0 carbon fiber
- Mates with both CTIP and motor
- Largest CTE along rotation axis
- Rigid structure
- Monolithic construction (one piece)
  - Best practice at SSI
  - Reduces alignment uncertainties
- Conductivity can be tailored by manufacturer
- Static cantilever deflection of windformXT with mirror assembly mounted is $<10^{-2}$mm



SIPS Performance

Table 1.10 SUMMARY OF SSUSI/GUVI AND SIPS INSTRUMENT CHARACTERISTICS		
Parameter	**SSUSI/GUVI**	**SIPS**
Wavelength range/Bandpass	115 nm to 180 nm	135.6 ± 3.0 nm
Wavelength resolution	better than 2 nm across full range, 160 resolution elements	Equal to BandPass
Field of view	11.8 deg x 0.8 deg, line of 16 resolution elements	3.8 deg cone
Angular pixel dimension	0.74 deg x 0.8 deg instantaneous single element field – three slits are available as well as a closed position (0.8, 0.4, and 0.2 deg width)	3.8 deg instantaneous
Mirror scanning	140 degree full angle cross-track in 0.4 degree steps	120 degree full angle cross-track in 3.8 degree steps
Field of Regard (FOR)	140 x 11.84 deg	120 x 3.8 degree
Spectral channels (binning)	HI 121.6 nm, OI 130.4 nm, OI 135.6 nm, N_2 LBH_{short} 140 – 150 nm, N_2 LBH_{long} 165 – 180 nm	OI 135.6 nm
Aperture	2.5 cm x 2 cm; 5 cm^2	5.08 cm dia
Integrating time	0.11 seconds	0.11 seconds
Quantum Efficiency	>10 % at 130 nm	0.27 at 135.6 nm
Dynamic range	>200,000 counts/second maximum	>200,000 counts/second maximum
Physical dimensions	73 cm x 33 cm footprint; 30 cm height	150 cm2 footprint, height 10 cm CTIP without scan mirror

SIPS Images will have Higher SNR than SSUSI



Left panel is the GUVI image from combining two nightside passes on Day 86, 2003. Right panel is the corresponding count per sample for the SIPS instrument at an altitude of 850 km. Two ionospheric bubbles are evident in both images as depletions in the brightness that extend across the magnetic equator.

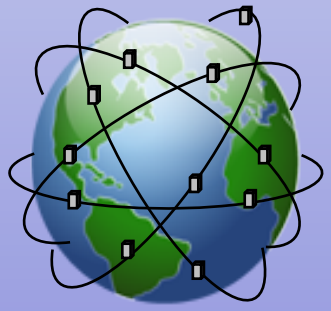
Summary

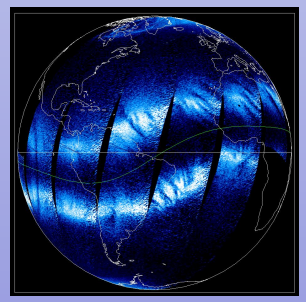
- Detector (TRL-9)
- Scan Mirror (TRL-4)

- SRI built the detector for SENSE mission
- Expecting CTIP detector as GFE from SMC

- SIPS is a technology demonstration and risk reduction mission for future constellation flights
- SIPS will prove the technology by imaging bubble formation regions to aid in specification and forecast of ionospheric irregularities and their effects
- Data from a future SIPS constellation would be complementary to data from ASTRA's DIME and Topside efforts supported by AFRL:
  - all three would provide a robust and low-cost constellation
  - Each meets critical IORD requirements and augments current DMSP observations

Measures	Images ultraviolet emissions from nightside ionosphere and aurora; estimates of TEC and aurora; identifies presence, location, size, drift, evolution of plasma bubbles and aurora
Utility	Present-time topology and evolution of ionospheric structures, including bubbles and aurora. Reduces SWaP and cost by factor of 10 vs DMSP
IORD-II	TEC, scintillation





Disaggregated Space Weather Network of Complementary "Sensor Sats"

- Robust to various conditions
- 100% effective and subject to graceful degradation

FUV Spectral Region Exhibits the Signatures of Space Weather in the Upper Atmosphere

- FUV spectral features were identified and interpreted during 30 years of rocket and spacecraft missions.

	1	2	3	4	5
	HI (121.6 nm)	**OI (130.4 nm)**	**OI (135.6 nm)**	**N_2 (LBHs)**	**N_2 (LBHl)**
Dayside Limb	H profiles and escape rate[1]	Amount of O_2 absorption[1]	O altitude profile	Amount of O_2 as seen in absorption	N_2, Temperature
Dayside Disk	Column H	Amount of O_2 absorption[1]	Used with LBHs to form O/N_2	N_2, Solar EUV	Solar EUV
Nightside Limb	H profile and escape rate	Ion/ENA precipitation	EDP HmF2 NmF2 T_{plasma}	Ion/ENA precipitation characteristic energy	Ion/ENA precipitation characteristic energy
Nightside Disk	Geocorna and Ion/ENA precipitation	Ion/ENA precipitation	$\int n_e^2 ds$ (line of sight) and $\int n_e dz$ (vertical TEC) Ion/ENA precipitation Ionospheric bubbles	Ion/ENA precipitation	Ion/ENA precipitation
Auroral Zone	Region of proton precipitation	Auroral Boundary and amount of column O_2 present[1]	Region of electron and (possibly) proton precipitation	Used with LBHl to form Eo and the ionization rate and conductance information	Measure of the effective precipitating flux, used with LBHl to form Eo and the ionization rate and conductance information