2009 CUBESAT DEVELOPER'S CONFERENCE, SAN LUIS OBISPO, CA

Miniaturized Vacuum Ultraviolet Photometer

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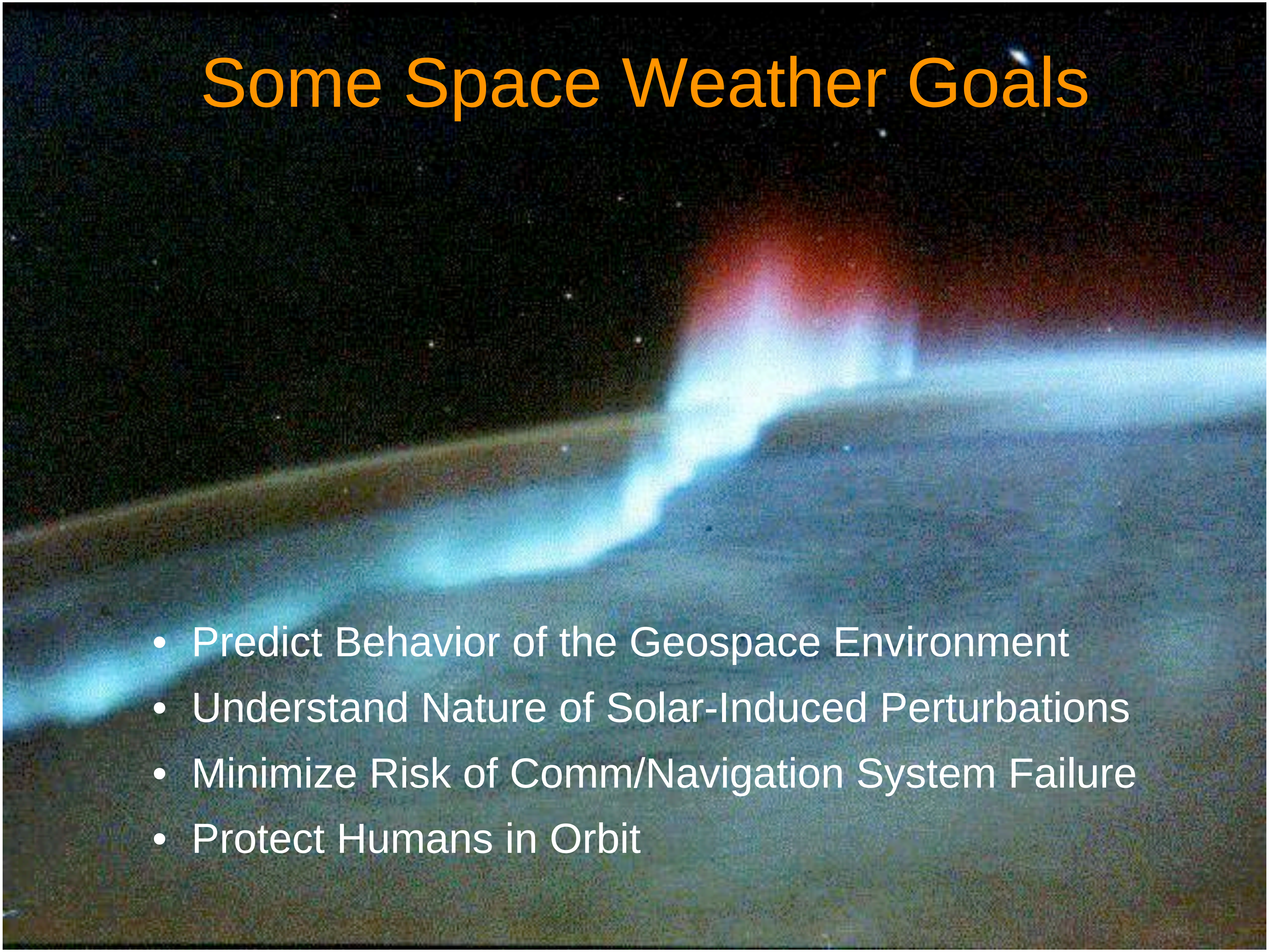
Scientific Solutions, Inc.
Spectroscopic Devices & Consulting

SRI International

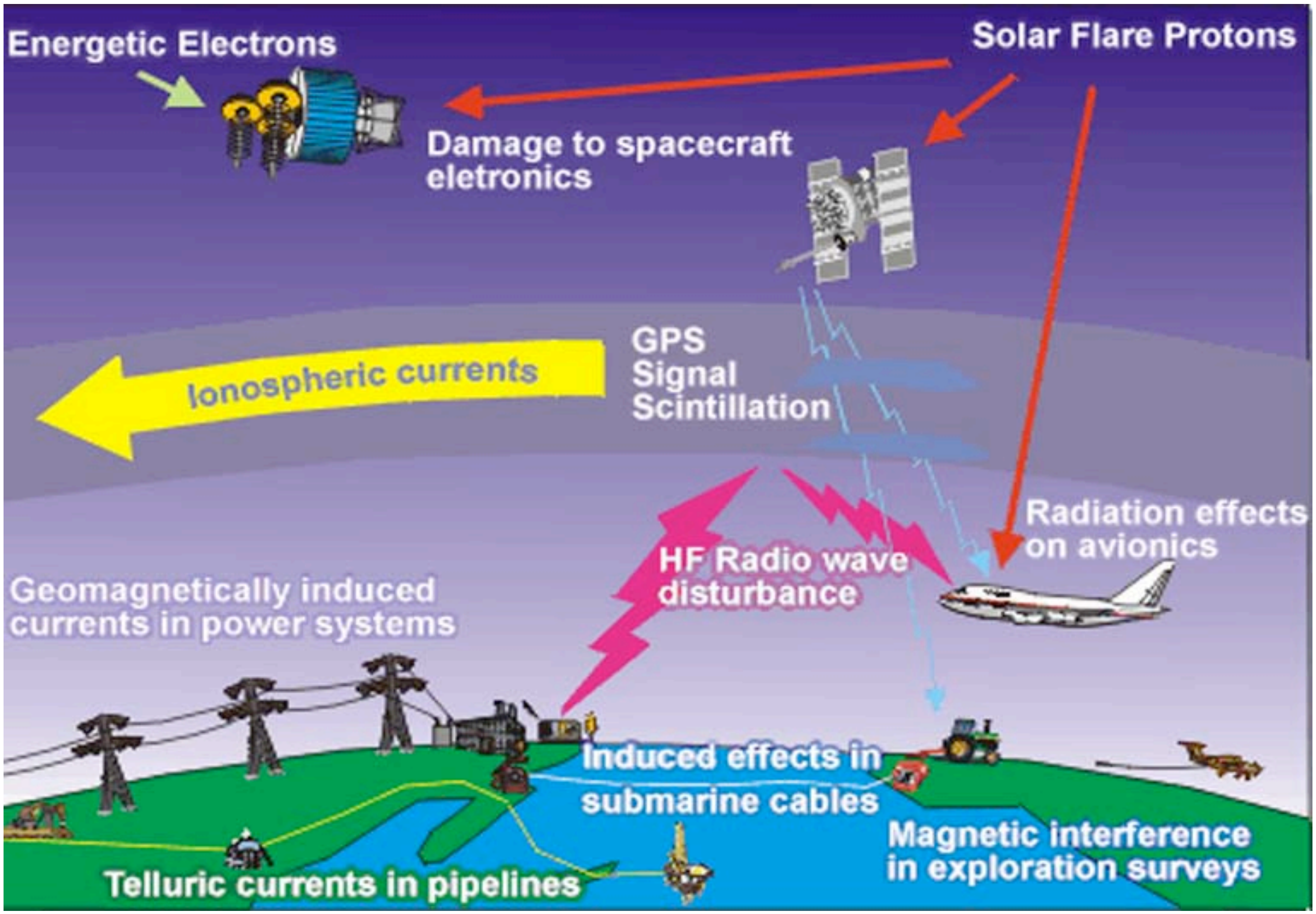
ASTRA

Some Space Weather Goals

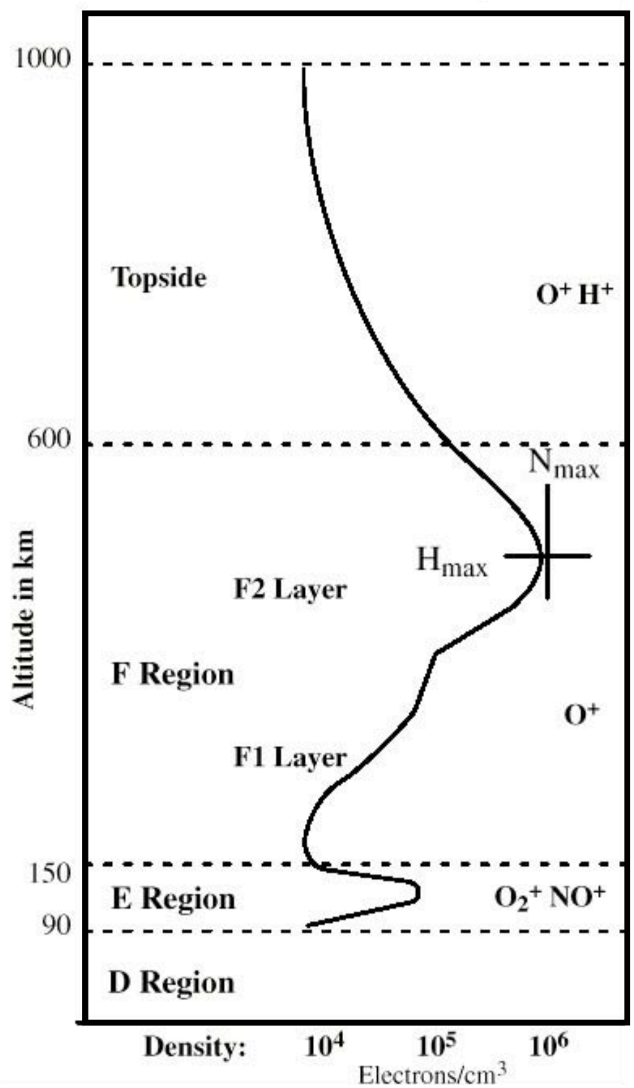


- Predict Behavior of the Geospace Environment
- Understand Nature of Solar-Induced Perturbations
- Minimize Risk of Comm/Navigation System Failure
- Protect Humans in Orbit

Comm/Nav System Performance Limited by Ionospheric Variability

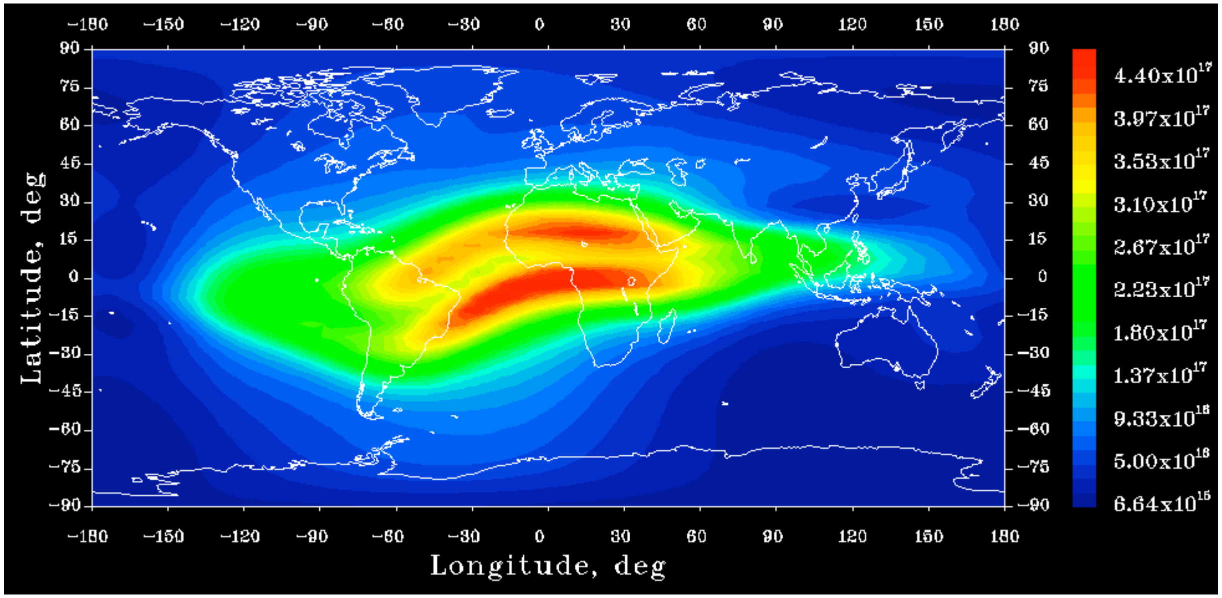


What is the Vertical Structure of the Ionosphere?

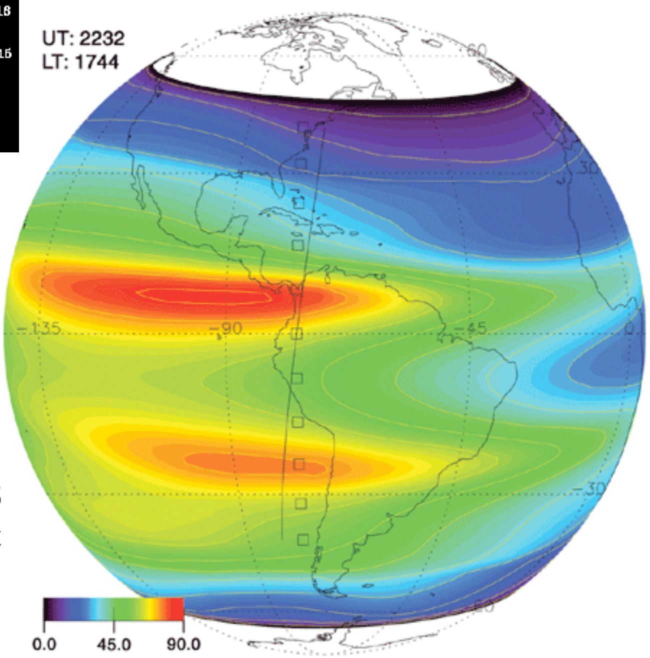


- Layers discovered by RF techniques
- E-region (O2+ and NO+)
  - Produced by solar X-rays and hard auroral bombardment (high latitude)
  - Lost by fast chemical destruction
- F-region (O+)
  - Produced by solar photoionization and soft auroral bombardment
  - Lost by slow chemical recombination

First-principle Models of the Ionosphere Can Reproduce Only the Largest-scale Average Features

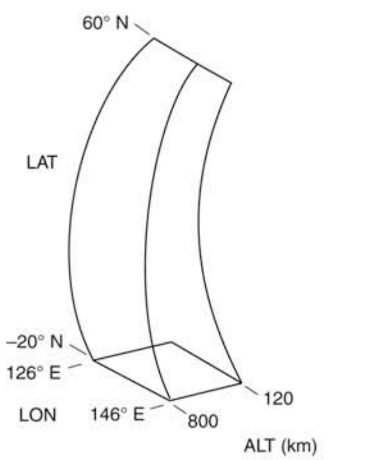


IRI Global TEC

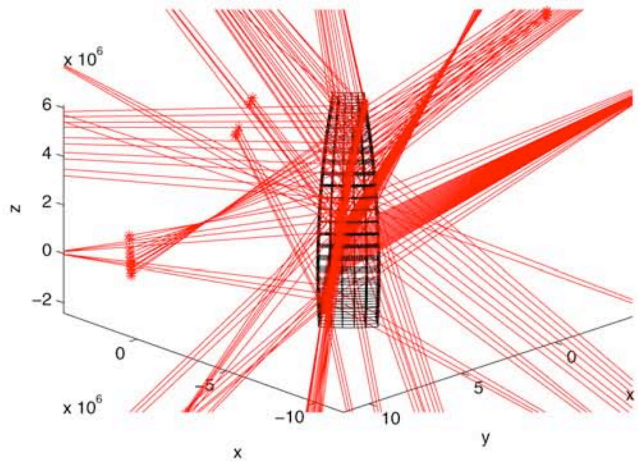


NRL SAMI3
Global TEC

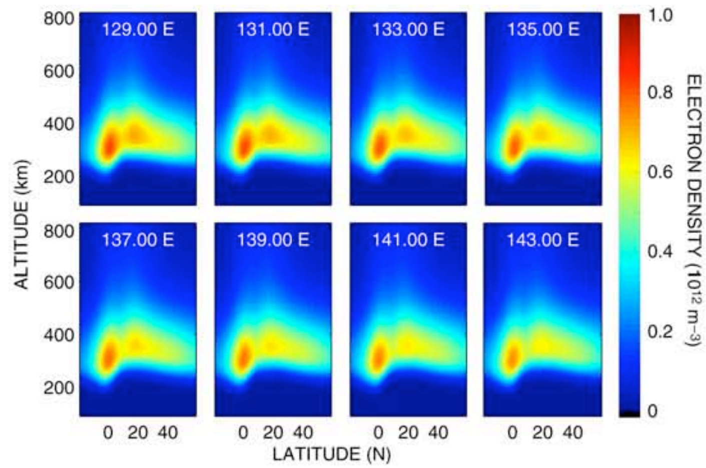
Assimilative Models Can Reproduce Fine Structure but Are Typically Data-Starved



Simulation Geometry

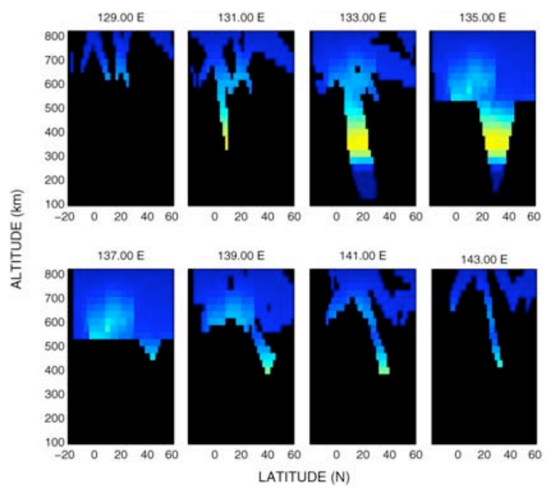


Raypaths for Single Satellite

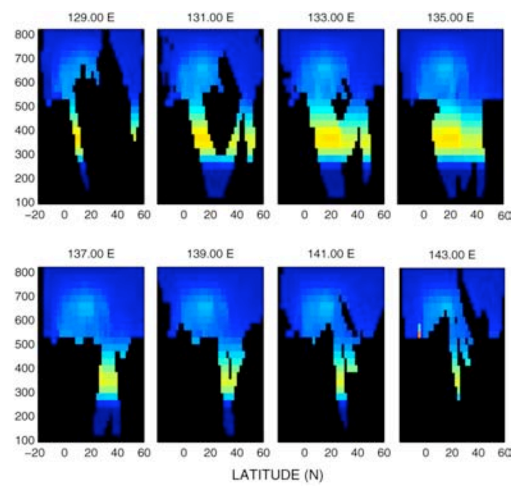


IRI Baseline, 28 July 2003, 1300 UT

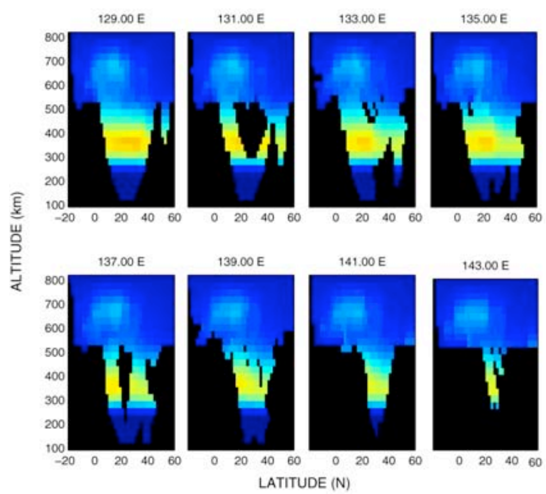
A Small Fleet of Ionospheric Specification Probes Can Significantly Improve Regional Model Convergence



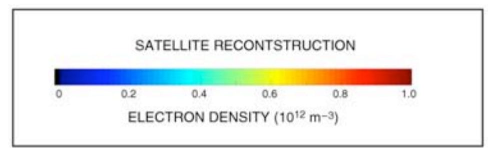
Single Satellite Reconstruction

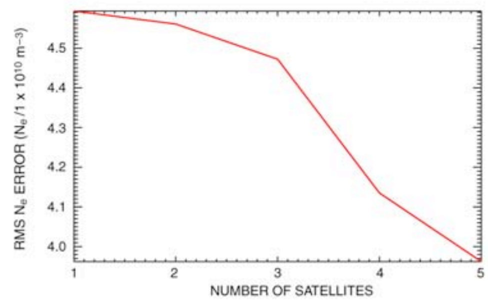


Three-Satellite Reconstruction



Five-Satellite Reconstruction





N_e Error Performance

How to Measure Ionospheric Density?

Ground-based

- Incoherent Scatter Radar (expensive)

Ground- or Space-based

- Total Reflection Sounders (partial profile only)
- Faraday Rotation Polarimeters (e.g. beacons)
- Two-Frequency Propagation Delay Receivers (e.g., GPS)

Space-based

- Monochromatic Imagers and Photometers

Which Method is Best for CubeSats?

- Beacon and GPS receivers are bistatic and require arrays of ground-based TX or RX nodes, or favorable satellite occultation geometries, respectively.

- UV Photometers measure airglow from naturally occurring ionospheric recombination without need for special geometries.

How does a UV Photometer Gauge Ionospheric Density?

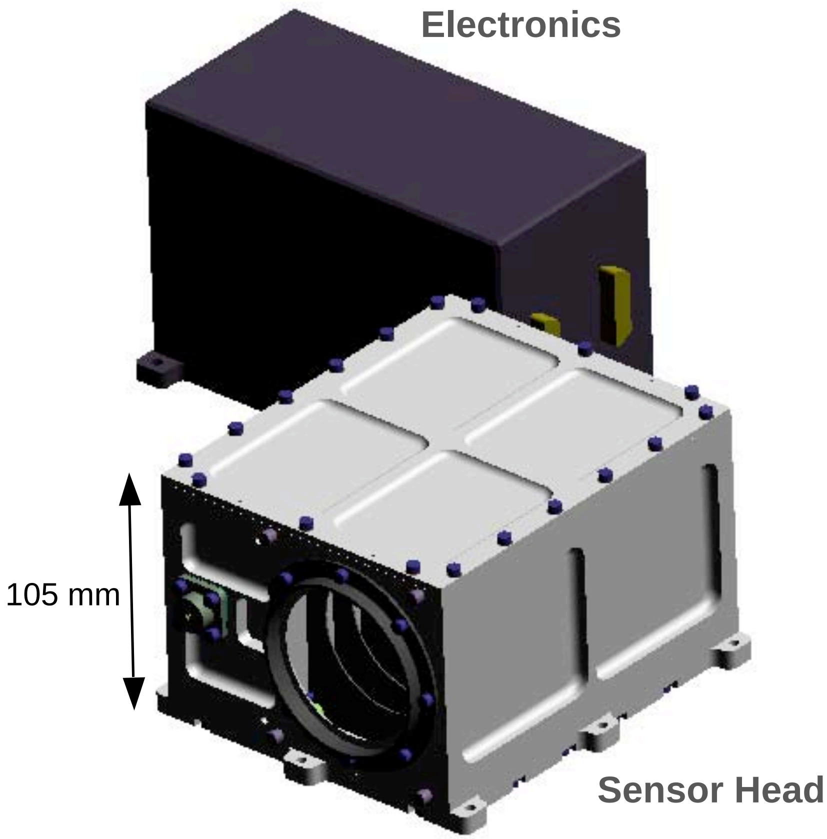
- Atomic Oxygen ions constitute the primary ionospheric species in the F-region

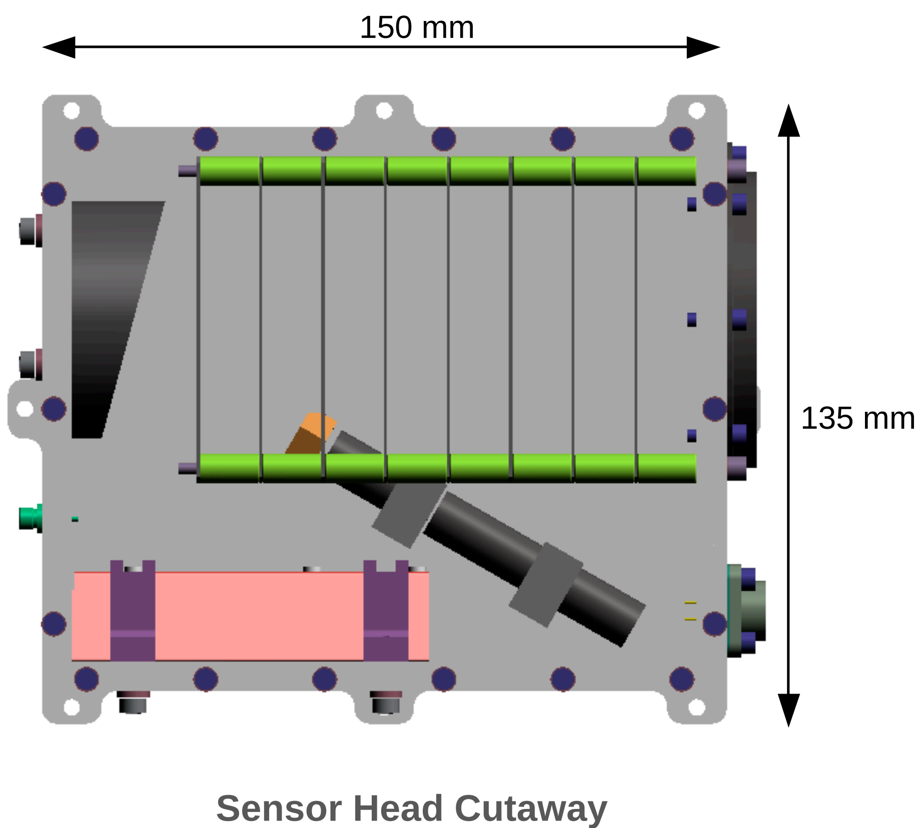
- In the nighttime F-region ionosphere, 135.6 nm photons are emitted spontaneously from the recombination of atomic oxygen ions,

$$O^+ + e^- \rightarrow O\,(5P) + h\nu_{135.6}$$

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

Flight Heritage: NRL 135.6 nm "Tiny" Ionospheric Photometer System (TIPS) on COSMIC Satellite





$3000\ cm^3$ and 7.6 W Orbit Average

Challenges in Evolving TIPS into CubeSat TIP (CTIP)

- Thermal Management
  - How to heat the required SrF_2 blocking filter to 100° C in a CubeSat with 2 – 3 W maximum payload power?
- Optical Efficiency
  - How to mimic the TIPS mirror in a 1.5U form factor?
- Miniaturization
  - How to shrink the electronics functions?
- EMI
  - How to overcome potential noise between the –1 kV switching power supply and the high-gain PMT preamplifier?

Prototype CTIP Optical Elements

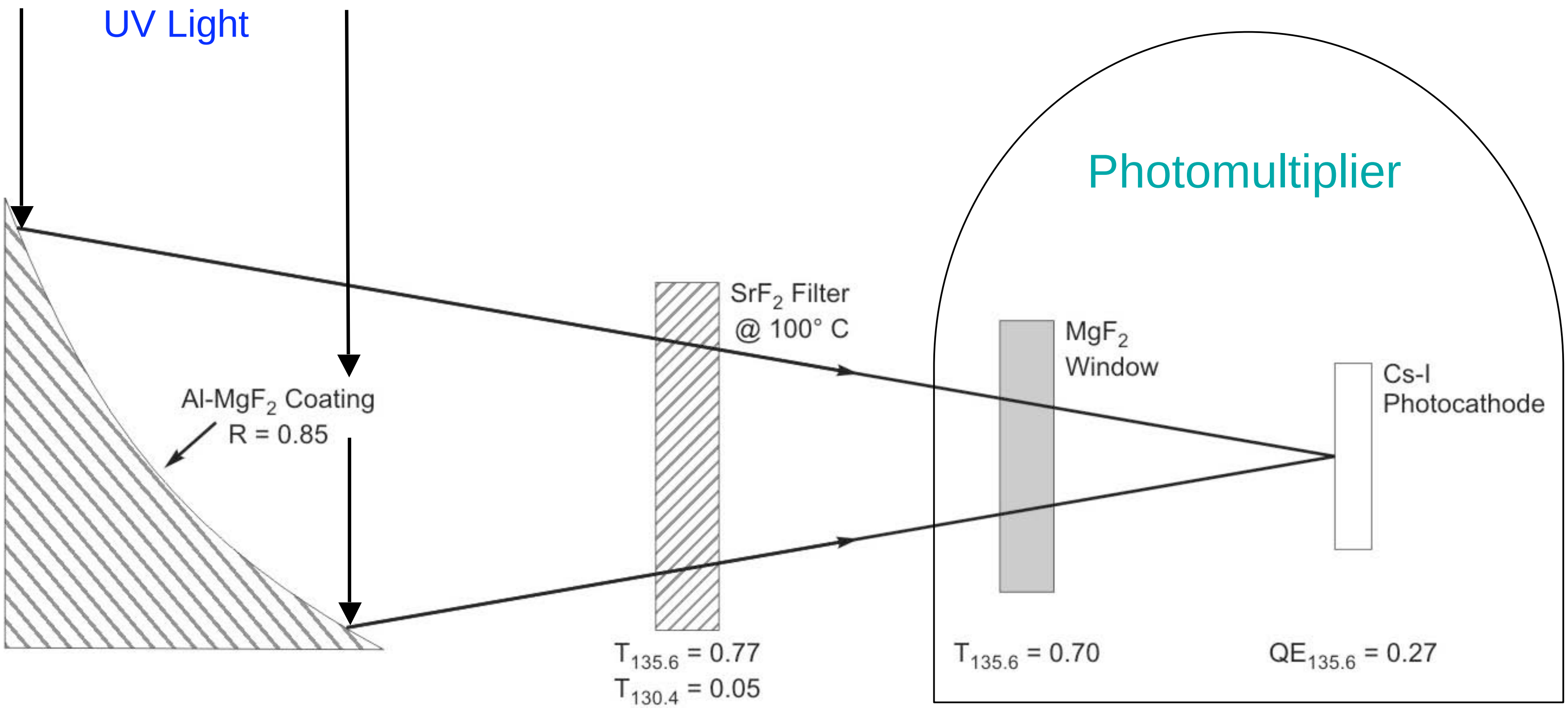
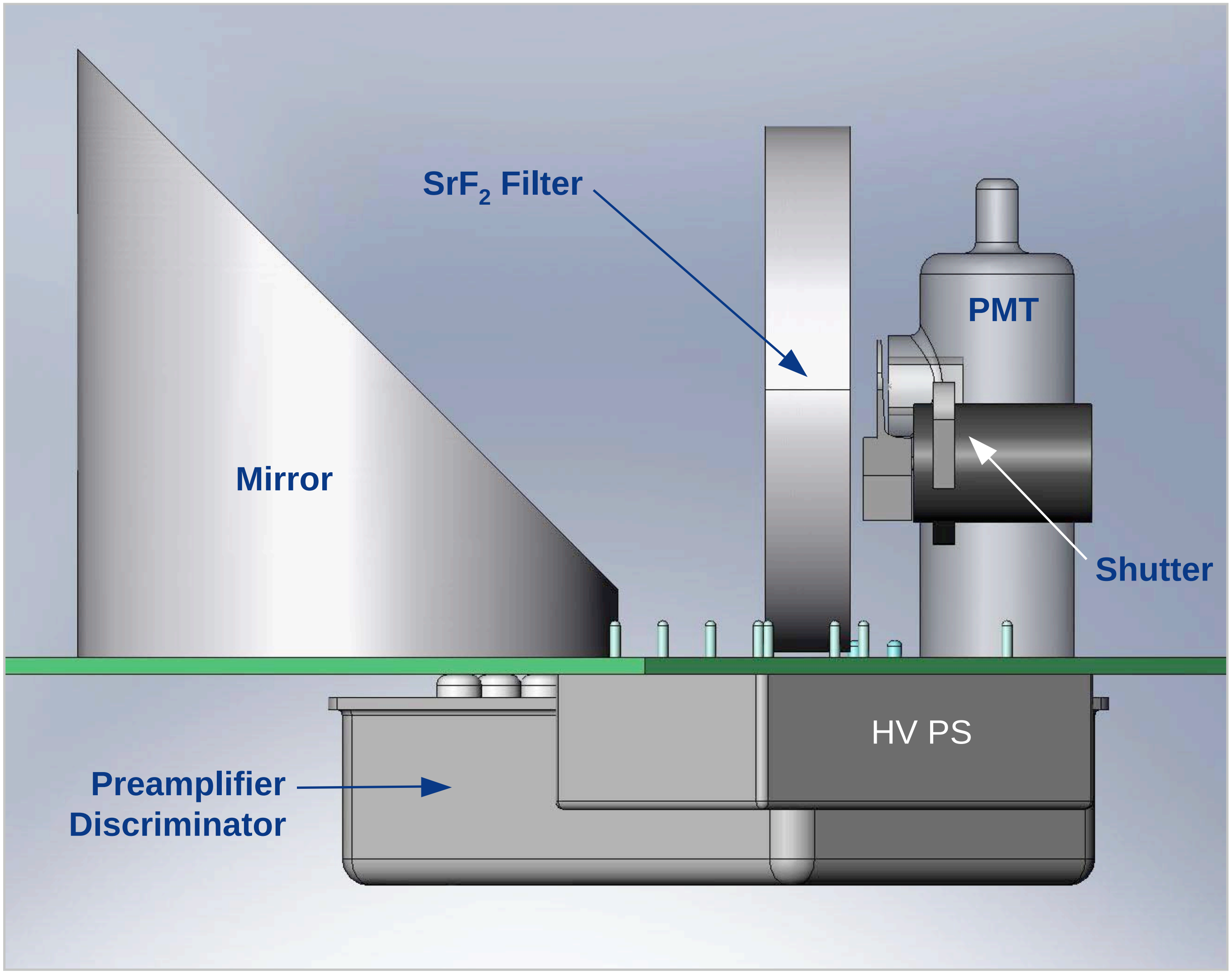
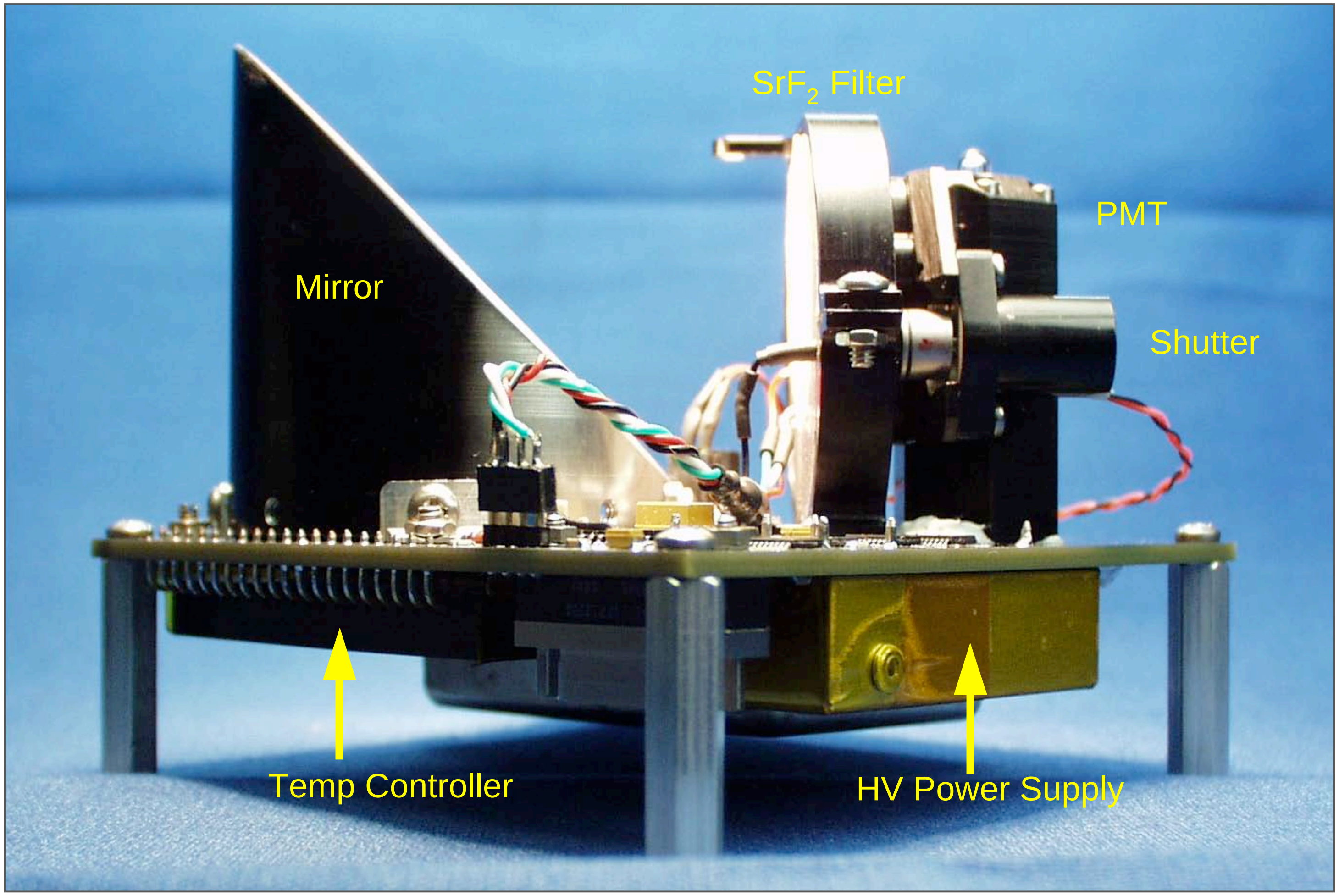


Figure 3 UV Optical Chain

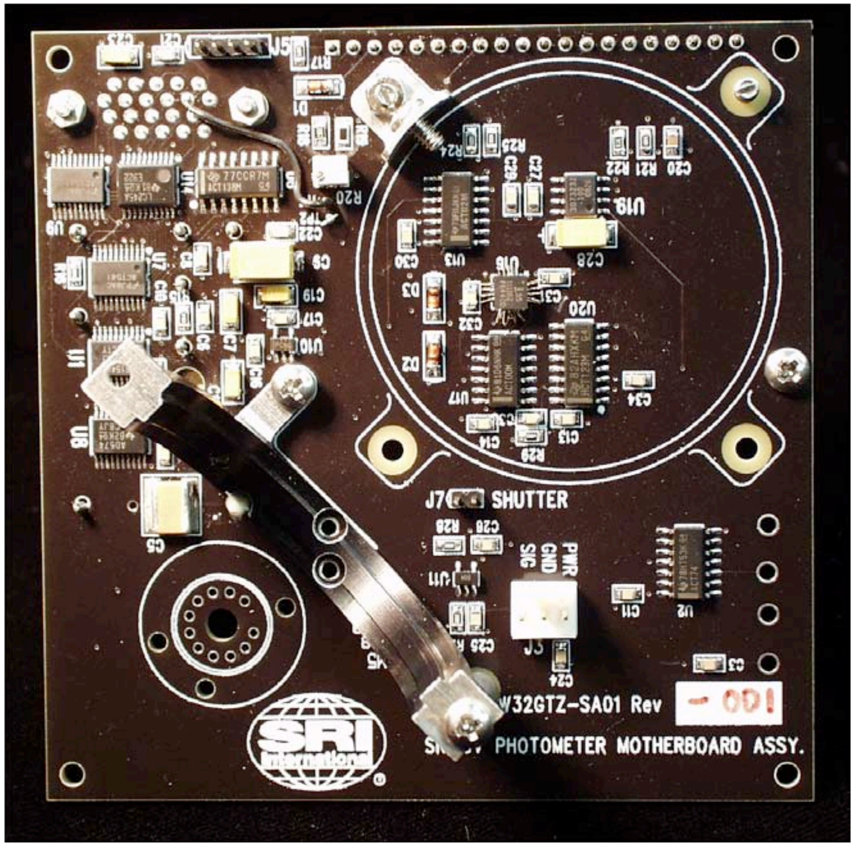
CTIP Attached All Optics and Electronics on a Common PCB



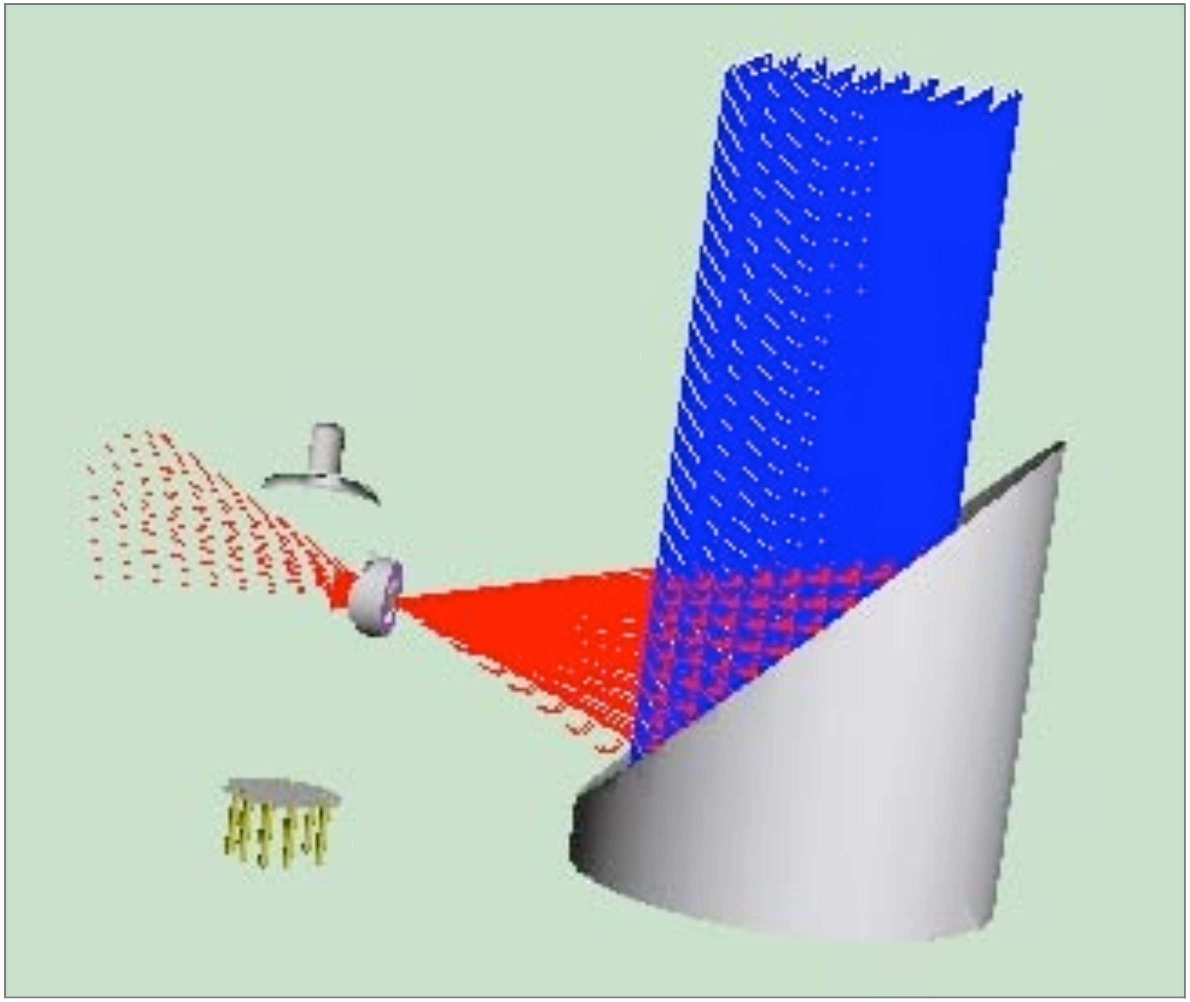
Prototype CTIP Motherboard



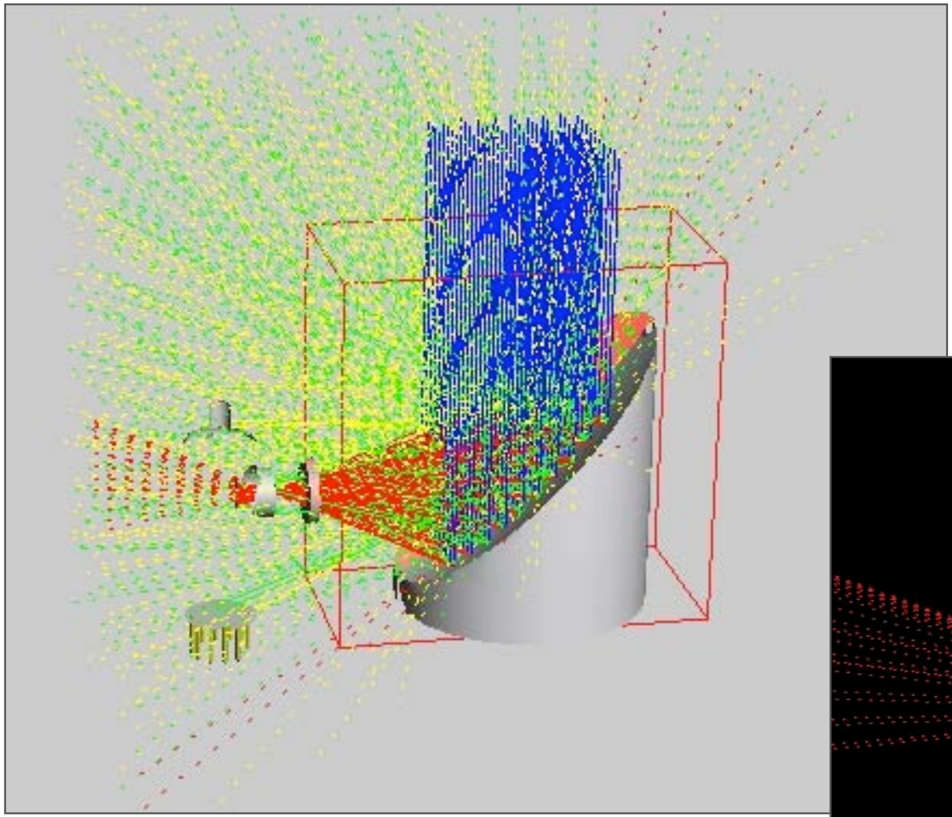
CTIP Motherboard Prototype Electronics

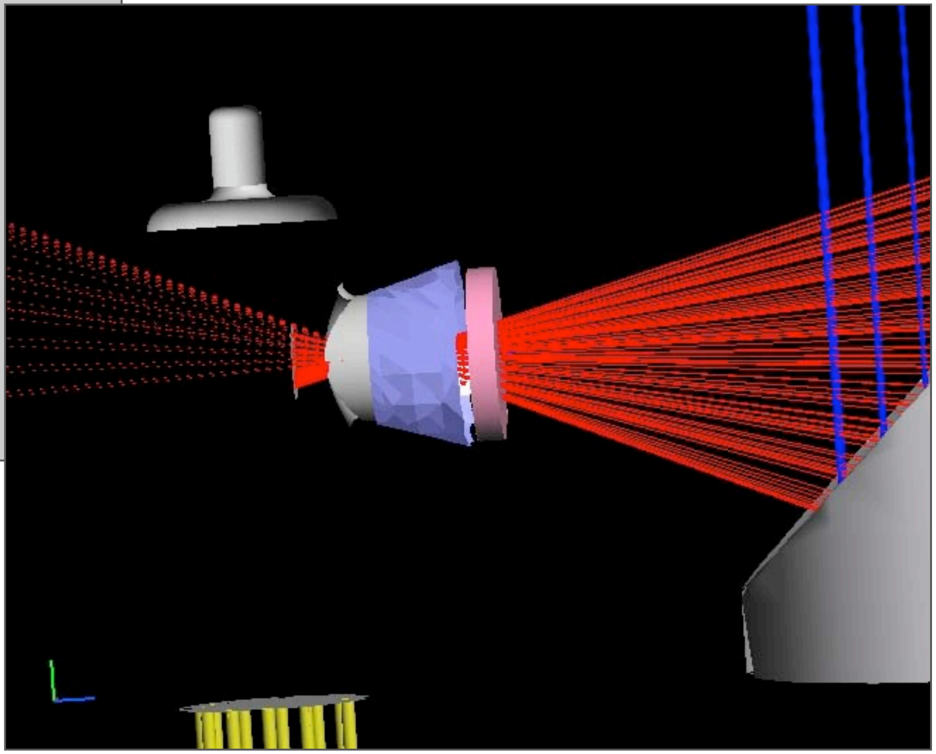


Optical Ray Trace Model: Mirror and PMT

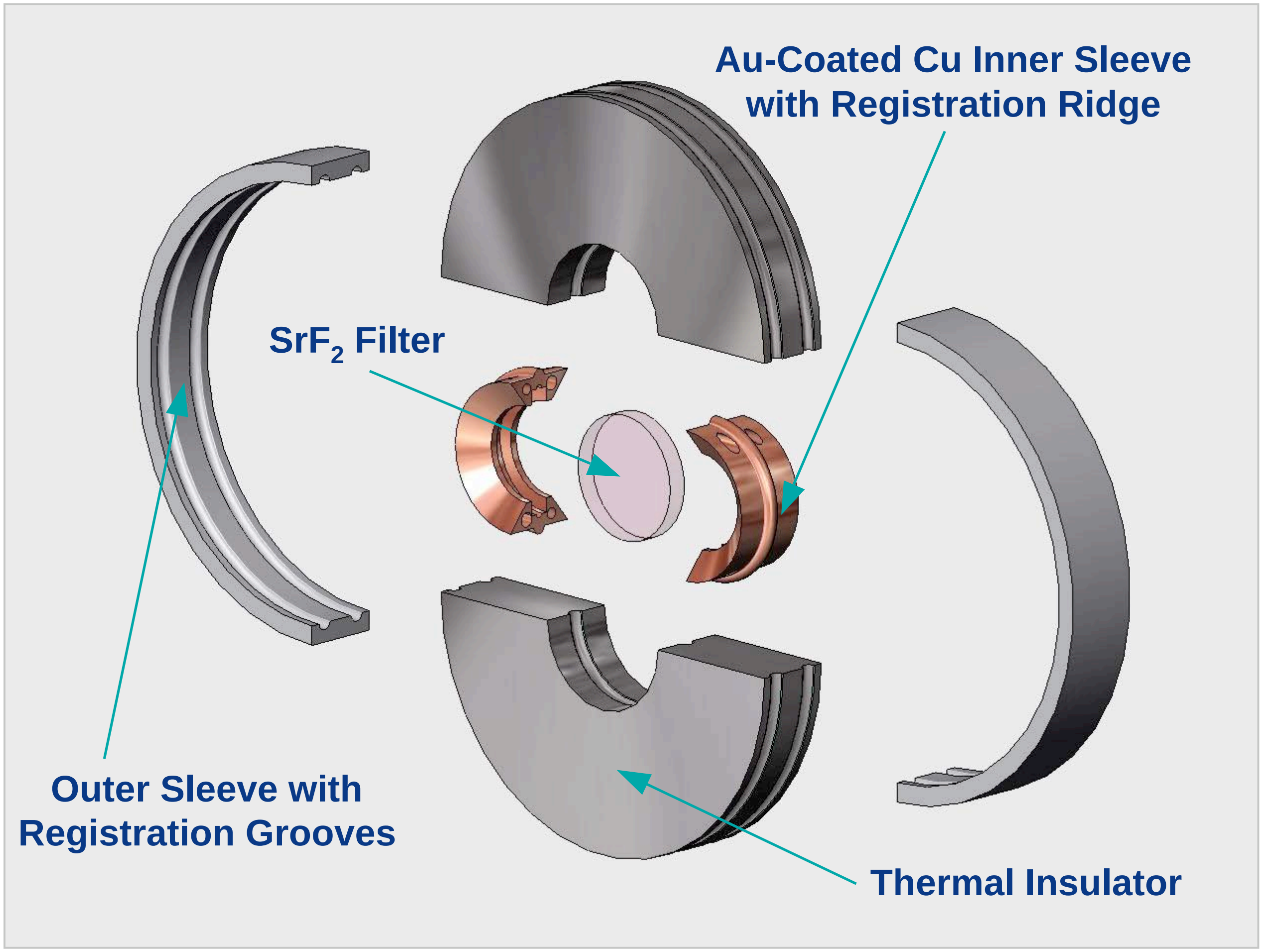


Optical Ray Trace Model: Scattered Light and Baffle

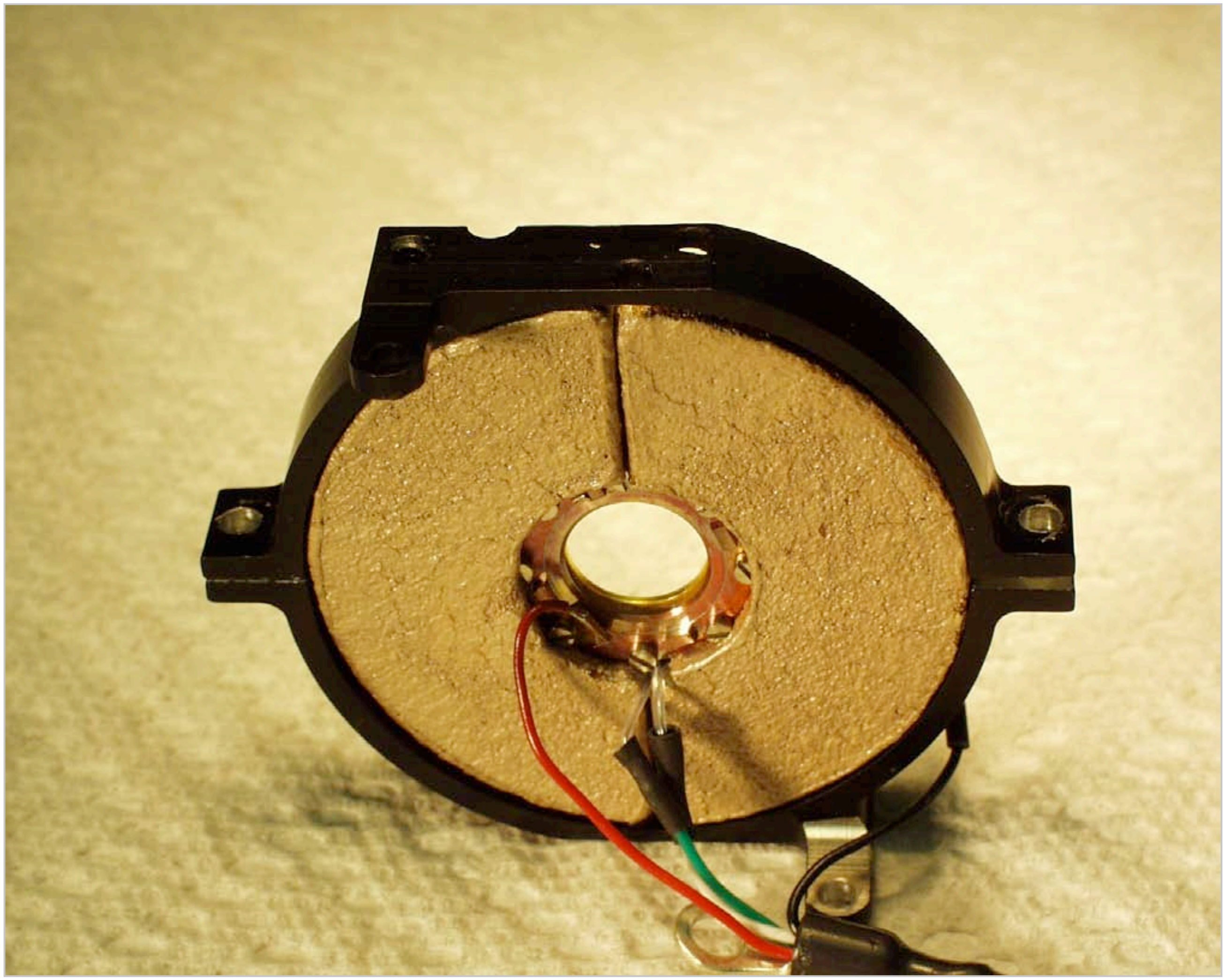




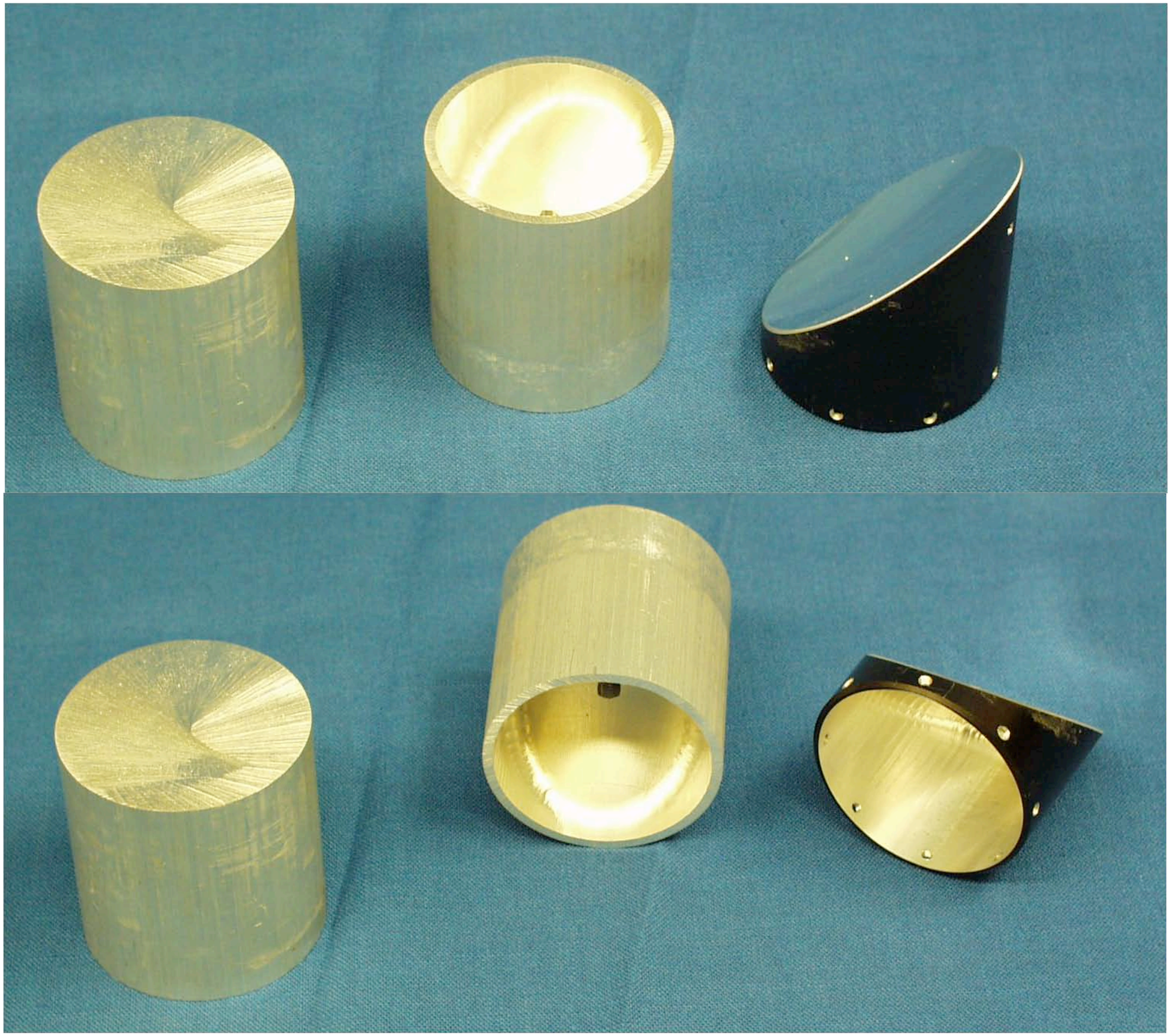
Heated SrF_2 Filter Holder Design



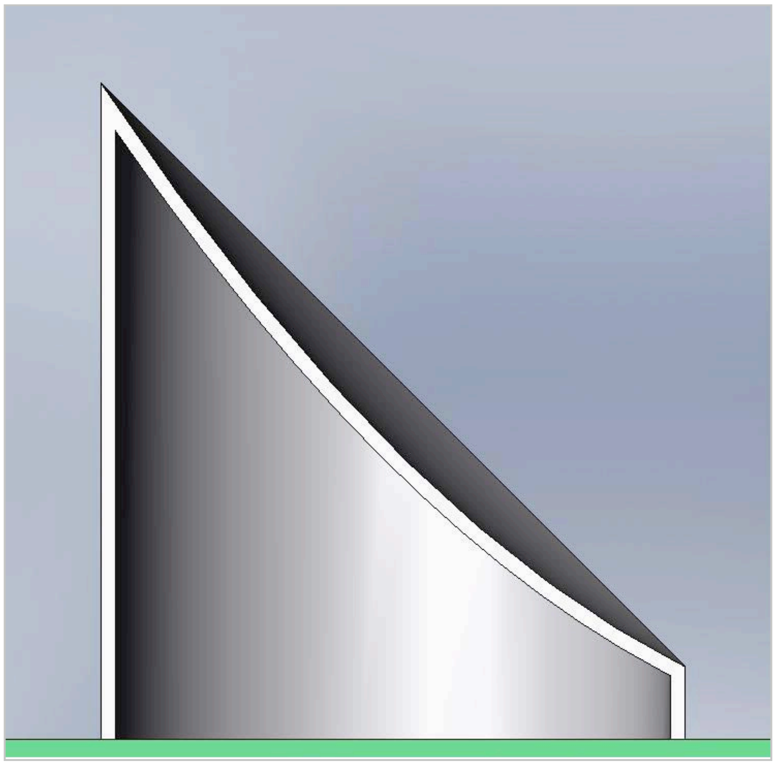
Heated SrF_2 Filter Holder Prototype



Off-Axis Parabolic Mirror Fabrication Steps



Hollow Mirror to Reduce Mass and to Liberate PCB Real Estate



Functional Test Sequence

NO.	DESCRIPTION	REQUIRED ELEMENTS
1	Initial Thermal Function	Complete
2	Initial Red-Leak	Complete
3	Mirror Distortion Test	Complete
4	Thermal Prototype Validation	Complete
5	PMT & Solenoid Function	Complete
6	Red-Leak Function	Complete
7	UV Detection @ 123.5 nm	Complete
8	Sun Detector Function	Daughterboard Design & Fab
9	UV & Red-Leak Calibration	Multiple PMTs, Vis Standard Source, and VUV monochromator
10	Full Photometric Calibration	UV Block Filter, Flight Baffle, and VUV monochromator

Prototype Performance

Parameter	CTIP	TIPS
Sensitivity	> 500 counts/R-s	> 500 counts/R-s
Field of View	3.8°	3.8°
Average Power	2.3 W	7.6 W
Shutter In-rush	2.6 W [1]	NA
HV In-rush	6.4 W [2]	NA
Volume	1500 cm^3	3000 cm^3
Weight	< 800 g	2300 g

1 100 ms pulse
2 300 ms pulse

Future Testing Goals

- Vibration and shock
- EMI per Mil-STD 461
- LEO proton lifetime exposure
- Full VUV calibration

Concept of Operations

- Nadir Oriented Mission
- Orbit Plane Spinner