Instrumentation for Tomographic Studies of the Ionosphere

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Introduction

Purpose of this study:

• Explore the requirements of and technologies available for tomographic imaging (i.e. CAT scan) of the ionosphere through its airglow emissions

• Perform a trade study and conceptual design of an instrument suitable for tomographic measurements
Atomic Oxygen

\[ O^+ + e^- \rightarrow O + h\nu \]

Many spectral lines result:

- 911 Å EUV
- 1304 Å FUV
- 1356 Å FUV

- optically thin in upper atmosphere
- good for tomography
Science Application

- Ionosphere is visible in far ultra-violet
  - TIMED-GUVI
  - Equatorial Anomaly
  - Plasma Bubbles

- “Tomographic measurements” of airglow at 135.6nm could advance science

TIMED/GUVI 1356Å night side airglow measurements
The Ionosphere Affects Radio Communication
Tomographic measurements
Tomographic measurements
Tomographic measurements
Instrumentation Challenges

Main challenges to be considered with tomographic instrumentation:

• Signal Strength
• Mechanical constraints of a small satellite
• Spectral Selectivity / Isolation
Signal Strength

- Chapman layer specified by peak density
- Look direction – nadir @ 600km altitude
- Temperature = 1160K
- Recombination Rate
  - $7.3 \times 10^{-13}$ cm$^3$/s for 1356A
**Expected Fluctuations in Signal Strength**

### A_c
- **diameter**: 4 cm
- **area collector**: 12.5663706 cm²

### Omega_c
- **half angle (HFOV)**: 0.5 degrees
- **Projected solid angle**: 0.00023924 sr

### Photon Flux
- **Recombination Rate**: 7.30E-13 cm³/s
- **natural logarithm**: 2.71828183
- **k/mg (scale height part)**: 5670 cm/K
- **Temperature**: 1160 K
- **Electron Density**: 5.00E+05 cm⁻³
- **Intensity**:
  - 3.26E+06 q/s/cm²
  - 3.26286 R
- **flux (Rayleigh based)**: 0.00980939 × 10⁶ q/s
- **flux**: 9809.38669 q/s

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**Expected Intensity versus Look Direction Angles**

- **Angle Between Nadir and Look Direction (°)**
- **Rayleighs (R)**

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Conceptual Design - USUsat Constraints

Volume Constraint

Physical Dimensions Constraint

Nanosat Program constraint
Closed and Open Photometer Configurations
Photometer Layout
Motor and Detector

Direct drive torque motor
- Hollow bore allows for optic path through the motor, eliminating gearing.

Magnum Electron Multiplier (from Burle)
- Spiraltron Technology to reduce ion feedback noise
- On axis design
- Wide Dynamic Range
- Compact
Spectral Selectivity Challenges: 130.4nm Contamination
Spectral Selectivity

UVI-1356 Reflectors

Reflectance vs. Wavelength (nm)

UVI Photometer
Reflective Mirrors (4)
Photomultiplier Tube
Expected Signal for Conceptual Design

6 Layered Reflection Filters x ~78% = ~23% reflectivity

Mirror rotational frequency = 1Hz
Time sample = 2.8ms
Conceptual Design Summary

• Conceptual Design Features
  – Aperture size = 4cm with FOV = 1°
  – External Mirror Frequency = 1 Hz
  – Sample time (@ 1Hz) = 360°/1° samples/revolution = ~2.8 ms
  – Mirror reflectances = ~80% but total system reflectance= ~50%

• Expected signals from above features
  – ~10-10000 photons/sample at detector

• Ways to increase incident flux on detector
  – Fewer reflections
  – Increase mirror reflectances
  – Increase FOV
  – Reduce external mirror frequency

• Conclusion: Only signals close to the equatorial regions are strong enough to be measured on the TOROID instrument