CIRCE
Coordinated Ionospheric Reconstruction CubeSat Experiment

Tri-TIP Optical Calibration

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**Objective:** Provide space-based *tomographic* specification of $n_e$ vs altitude and orbit phase angle derived from ultraviolet (UV) observations of the ionosphere with different viewing angles from multiple CubeSats

- Two 6U CubeSats fly tandem (lead/trail)
  - 2 Tri-TIP / CubeSat (4 Total)
  - Coplanar orbit optimized for tomographic reconstruction
- NRL has heritage from the Tiny Ionospheric Photometer (TIP) on COSMIC & GROUP-C (ISS)
Tri-TIP – Viewing Geometry

- Lead
  - 16° down (limb)
  - 17° down (limb)
  - 45° down (wake)

- Trail
  - 45° down (ram)
  - 90° down (nadir)

Baseline separation
250 km

***Note this is a very sparse representation of the actual FOV for CIRCE
Dayglow spectrum filled with emission features (e.g. O, O$_2$, H, N$_2$, N)

Nightglow dominated by only a few species (O, H)

Target measurement is atomic oxygen O$_1$ 135.6 nm

Spectrum taken from UVLIM experiment

Data for figure from Budzien et al. [1994]
TIP used the Hamamatsu R10825 PMT
Tri-TIP uses the R13194 PMT

Example of a commercial FUV bandpass filter
**Excludes Lyman-α (121.6 nm)**
Tri-TIP – Red Leak Contamination

“Solar blind” PMTs see city lights! → Red Leak

Figure from Budzien et al. [2009]
Each Tri-TIP fits within 1U form factor

Tri-TIP optical layout

Parabolic Mirror
Deployed Mirror
Heated Filter
Dark count PMT
Beam Splitter
UV PMT
Shutter & Solenoid
Red-leak PMT

Figure from Dymond et al. [2017]
Tri-TIP – Optical Path

- Parabolic Mirror
- Heated Filter
- Beam Splitter
- UV PMT
- Red-leak PMT

[Mirror optional]

New to Tri-TIP

Heritage on TIP

May be used as 2nd UV PMT

Incoming Light
Ø SrF\textsubscript{2} filter substrate
- Cutoff at \textasciitilde128 nm (room temperature)
- Cutoff shifts > 131 nm when heated to 100°C
- Eliminates oxygen triplet at O\textsc{i} 130.4 nm

Target reduction is 0.5%

Figure from Stephan et al. [2018]
Two types of substrate:
1. Sapphire (Al$_2$O$_3$)
   - Red leak correction
   - Eliminates OI 135.6 nm
2. MgF$_2$
   - Limb sensor

Al+MgF$_2$ reflective coating uses polka-dot pattern to minimize geometric effects
Tri-TIP – Beam splitter characterization

Transmissivity and reflectivity tested as a function of wavelength

Substrate successfully eliminates OI 135.6 nm

Figure from Fritz et al. [2019]
Tri-TIP – Effective Passband

Full Spectrum

What a “Solar Blind” PMT measures

What TIP measured

What the Red Leak PMT will measure

Final Tri-TIP Result
Summary

Tri-TIP provides compact, high-sensitivity remote sensor in 1U package

- NRL has significant heritage through TIP and other UV remote sensors
- Limb sensor has potential to double observing capability
- Testing underway to characterize and match the UV and Red response of the Hamamatsu PMTs

CIRCE / Tri-TIP data will be analyzed using the VERT method

- CIRCE mission will be able to retrieve ionospheric structure
- Algorithms are tuned as information about observation scenario evolves

Launch expected to LEO as part of the Space Test Program
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Works Cited: