



Development of the Thermospheric Winds Imager

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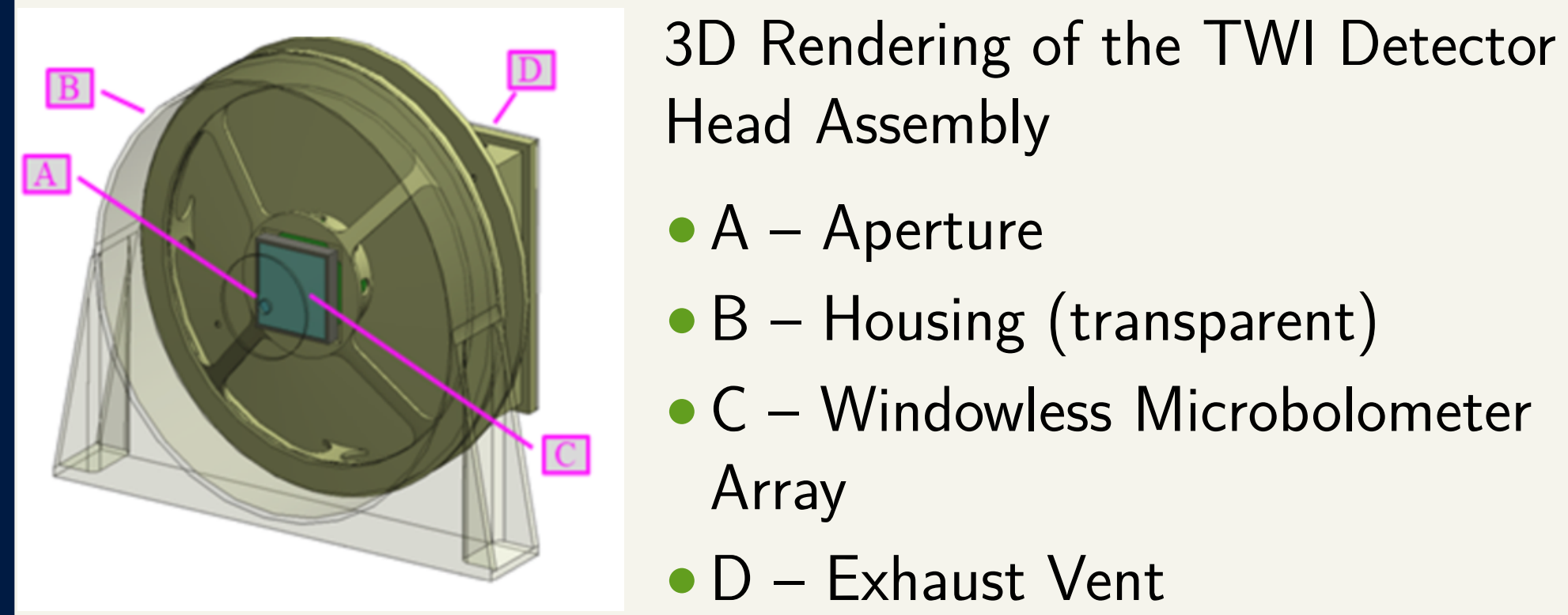


Introduction

Progress towards the successful characterization of atmospheric winds in Earth's thermosphere has been significantly hampered due to inadequate measurement techniques and modalities. To fulfill this need, the Thermospheric Winds Imager (TWI) has been developed. Characterizing the winds in this high-altitude region of the atmosphere is key to understanding the circulation and dynamics of this region.

Background

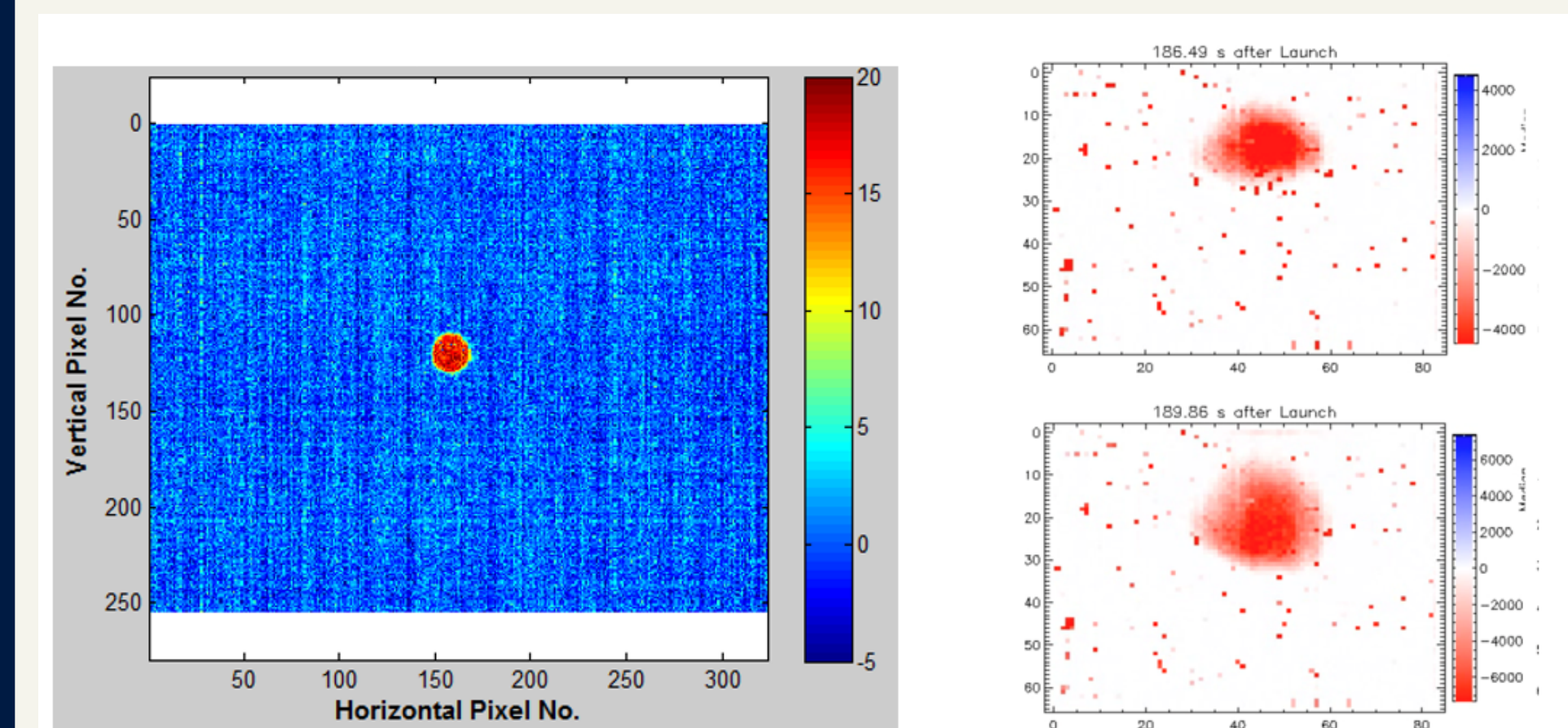
- The TWI leverages the small footprint and energy sensitivity of a commercial-grade thermal camera to transiently measure the particle energy during the data acquisition of a sounding rocket mission.
- The TWI has the unique advantage of being a relatively low-cost imaging system that can be deployed on a sounding rocket payload, or similar platform, with relative ease.



Previous Flight Data & Testing

Left: Sample testing image from the TWI observing an impinging SF₆ molecular beam

Right: TWI captures from the Auroral Jets mission



TWI Theory

The TWI is limited by the minimum detectable heat flux incident on a single pixel. Assuming the following parameters, the instrument detects a temperature change via impinging thermal radiation. Using a first-order thermal expansion of radiated power, we estimate detectability limits based on the Stefan-Boltzmann law.

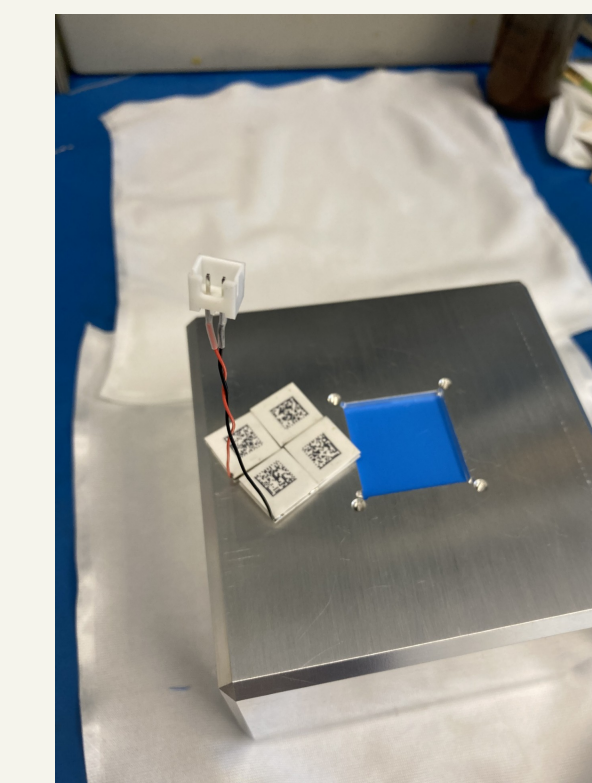
$$\Delta P = \frac{dP}{dT} \cdot \Delta T = 4\epsilon\sigma T^3 \Delta T$$

$$\Delta E = \Delta P \cdot A \cdot t \approx 3.05 \times 10^{-12} \text{ J}$$

$$q_{\min} = 4\epsilon\sigma T^3 \Delta T \approx 0.183 \frac{\text{W}}{\text{m}^2}$$

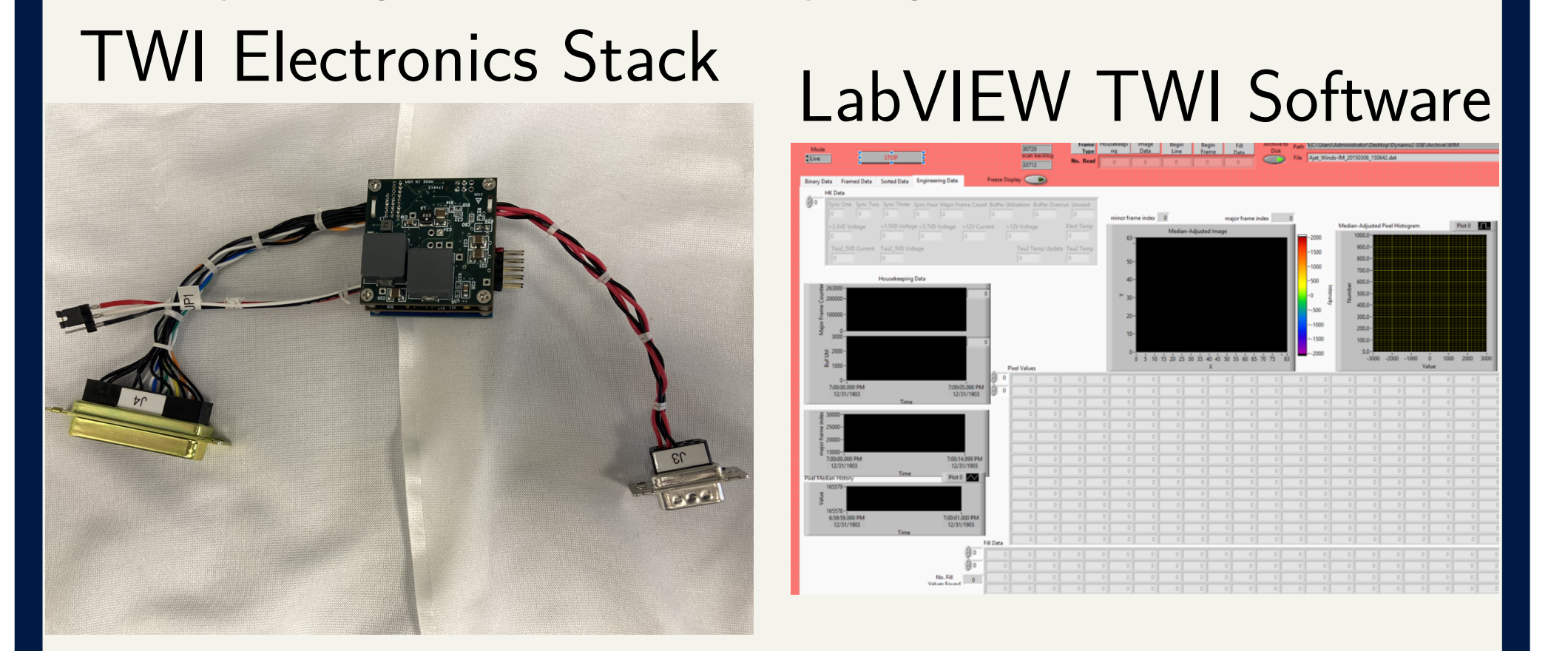
As a result of the impinging energy, much of the sensor's reading is the camera's internal heat. This prompted the need for an active cooling system to be integrated into the electronics stack.

Parameter	Symbol	Value
Pixel Area	A	$2.89 \times 10^{-10} \text{ m}^2$
Pixel Thickness	d	10^{-7} m
Min ΔT	ΔT_{\min}	30 mK
Emissivity	ϵ	1
Stefan-Boltzmann	σ	$5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$



Future Work

The feasibility of the TWI for success during rocket flight has been validated; the electronic infrastructure must now be updated to properly output data during flight. Communication with the ground support equipment is vital for proper data output and syncing with telemetry signals.

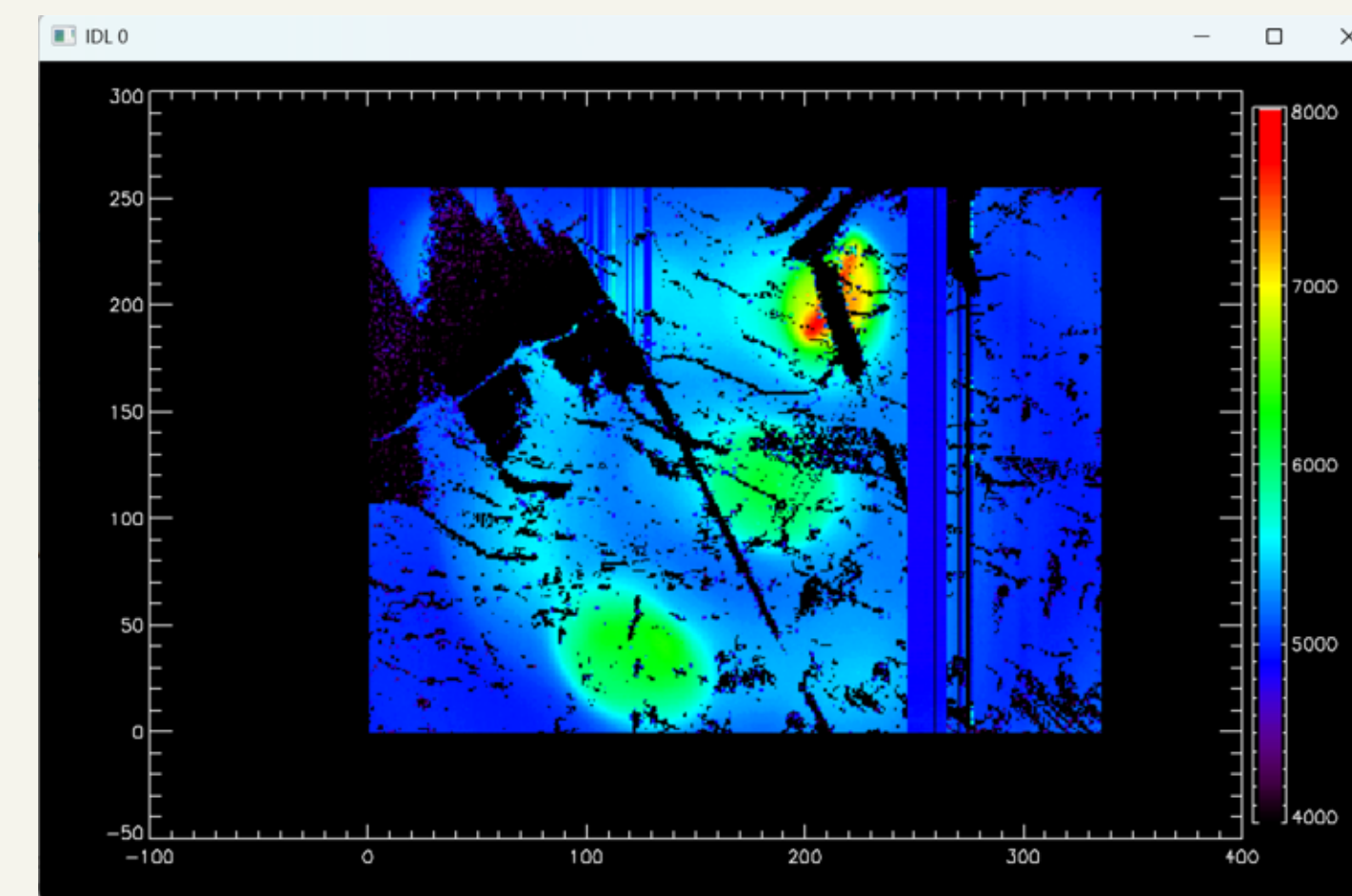


Laboratory Testing

Ion Gauge in Chamber

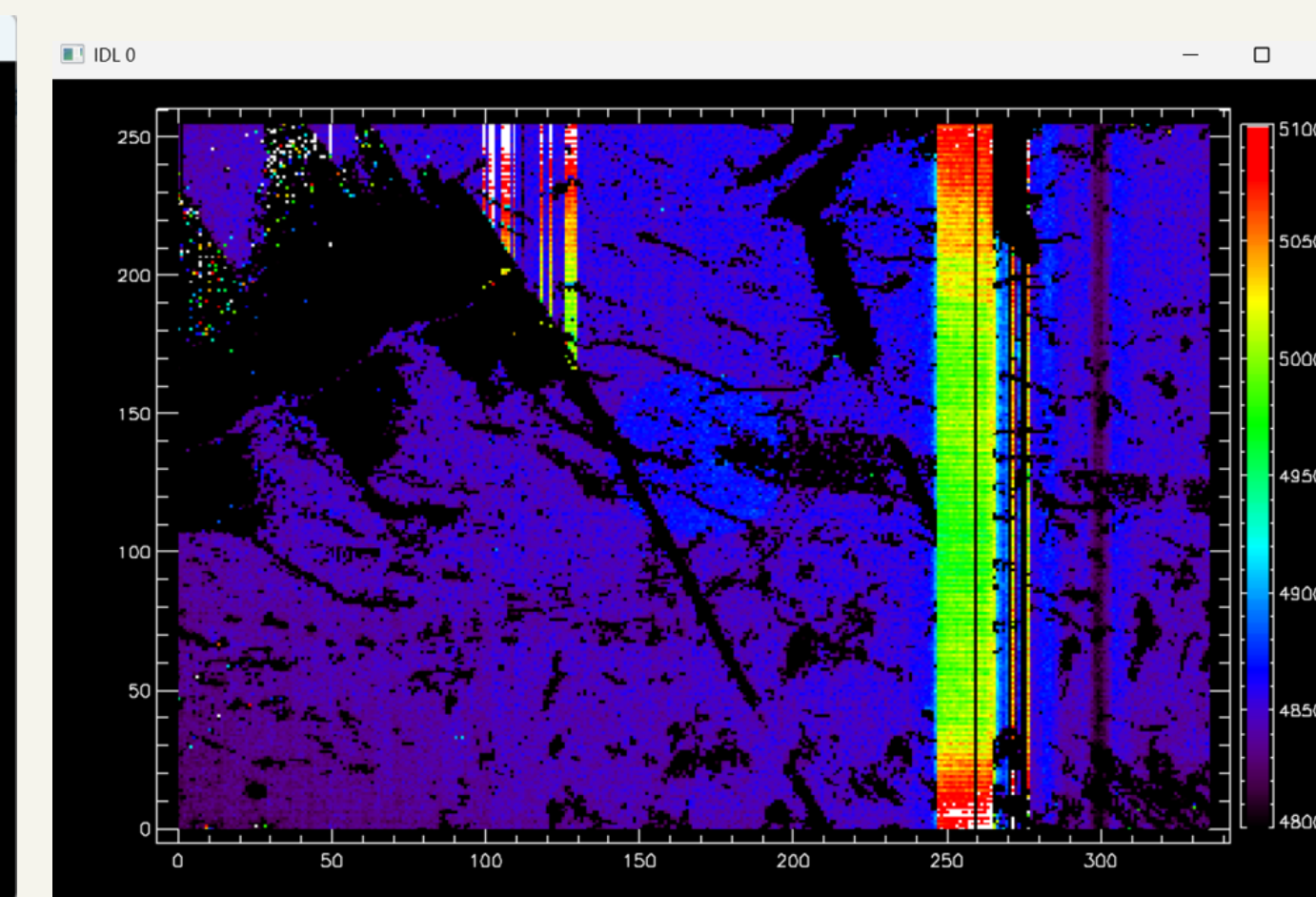


Output Image of Ion Gauge



The image output matches the geometry of the ionization gauge, suggesting working detector.

Molecular Beam



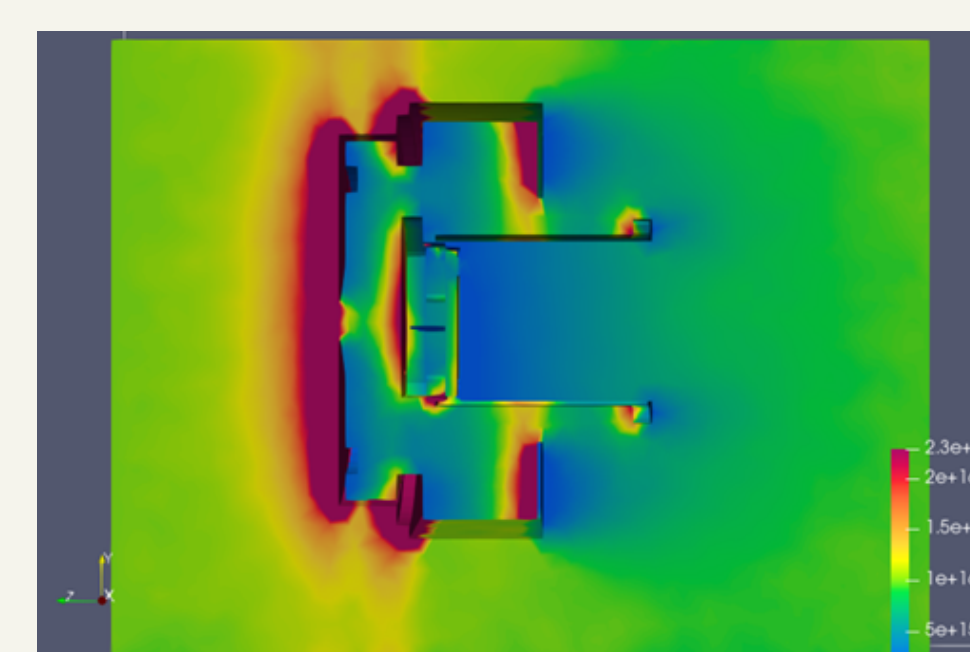
The center is observing higher counts than background, striations present are dead pixels.

CFD Simulations

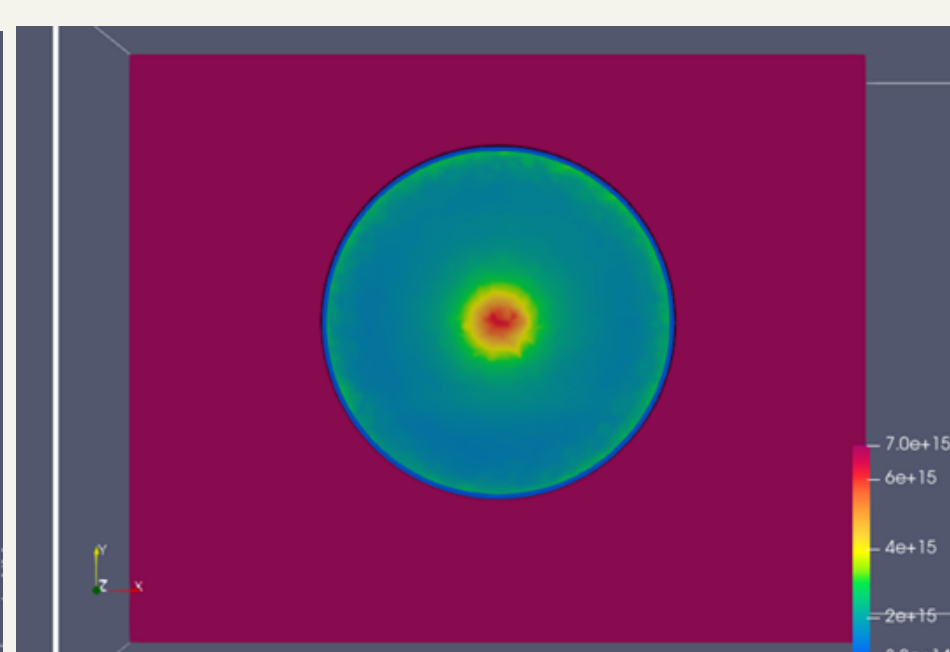
The CFD simulations model particle flow and thermal interaction within the detector geometry.

- Confirms fluid flow through instrument
- Identifies heat flux regions and impacts of cross-track winds
- Validates fluid properly impinging upon sensor, suggesting observable signal

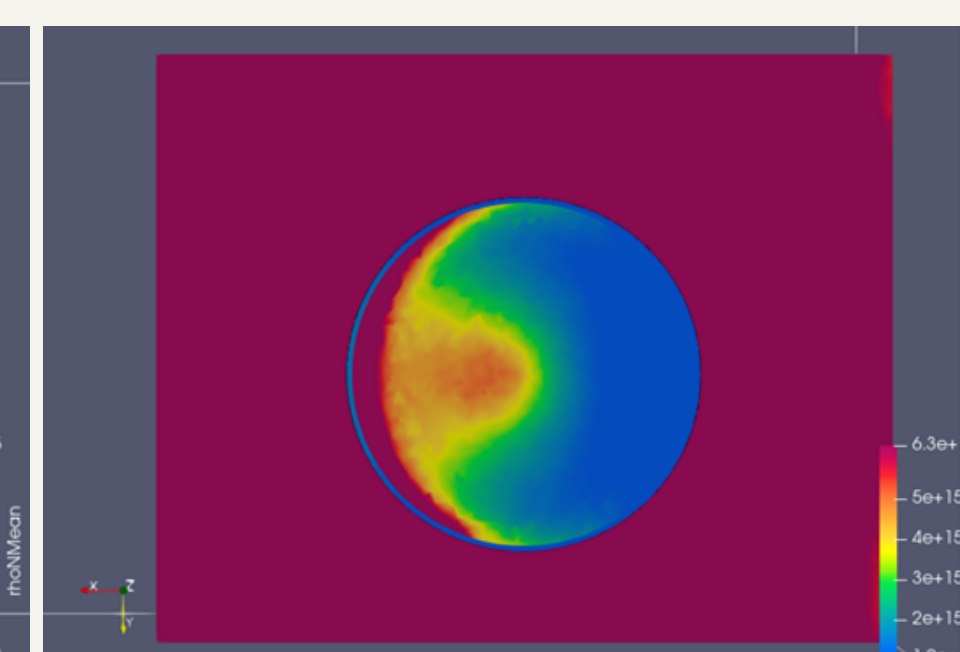
Cross-Section



In-Track Winds



Cross-Track Winds



Conclusions

The TWI is a technically capable instrument that can characterize the gas dynamics of the Earth's upper atmosphere, though currently in need of infrastructure updates to succeed on its next flight. The mechanical modifications for the RENU3 mission were sufficient; however, its electrical interface with the GSE requires further study.

Acknowledgements

I would like to thank all members of the Experimental Research Group, Space Science Assembly Lab and Machine Shop, Hamel Center for Undergraduate Research, and the Department of Physics and Astronomy for continued support of this project.

Grant Acknowledgment: This work was supported by NASA Grant 80NSSC21K0972 for the Rocket Experiment for Neutral Upwelling (RENU) 3.

References

- [1] G. A. Bird. *Molecular Gas Dynamics and the Direct Simulation of Gas Flows.*
- [2] J. H. Clemmons, B. B. Brady, J. L. Hall, and T. J. Curtiss. Windowless microbolometer array, 2017.

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