Measuring Pitch Angle Distributions of Superthermal Electrons Using Coded Aperture Imaging

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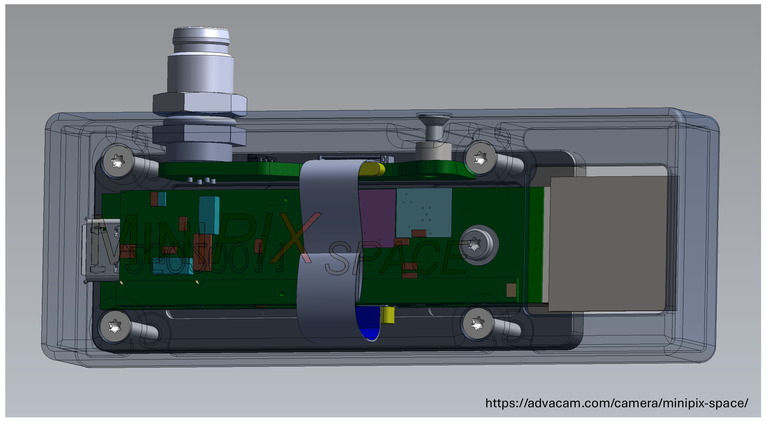
Motivation

- Understanding space weather and magnetic reconnection requires improved heliospheric & geospace magnetic field mapping.
- High-resolution **pitch angle measurements** of **superthermal electrons** can be used to validate magnetic field modeling and theory.
- Traditional **electrostatic analyzers** are often too **bulky, heavy, and limited** in angular resolution for deployment on resource-constrained platforms like small sats, which would be cost beneficial for constellation missions.

Instrument Design



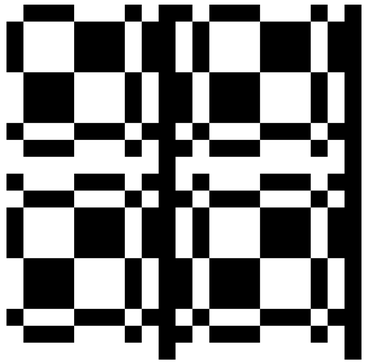
- We are developing a compact, low-mass particle detector utilizing a **coded aperture mask** and a **MiniPIX SPACE sensor** to achieve high-resolution pitch angle measurements.
- A custom **instrument housing** is currently in development to protect the internal electronics, precisely mount the mask, and strictly **collimate the field of view** to ensure no unmodulated particles bypass the mask to strike the detector.

Hardware and Data Integration

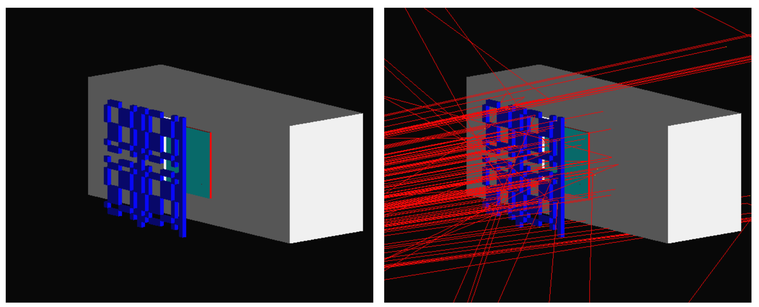
- Signal extraction from the **high-vacuum plasma chamber** is achieved via a custom wiring system utilizing outgassing-resistant materials for insulation.
- The detector physically communicates via serial UART connection. A dedicated custom circuit is being designed to translate this signal to a standard USB format for control using a computer.
- Device control and data logging are managed via the MiniPIX UART Interface (MUI), a lightweight C99 software library that utilizes a **Low-Level Communication Protocol (LLCP)** to parse incoming telemetry.

Coded Aperture Imaging

- A 2x2 mosaic of a **Modified Uniformly Redundant Array** (MURA) coded aperture mask was chosen
- The 2x2 mosaic guarantees that a complete, cyclically shifted version of the base pattern is always projected onto the detector plane, regardless of the electron incidence angle, enabling the **MLEM deconvolution**.



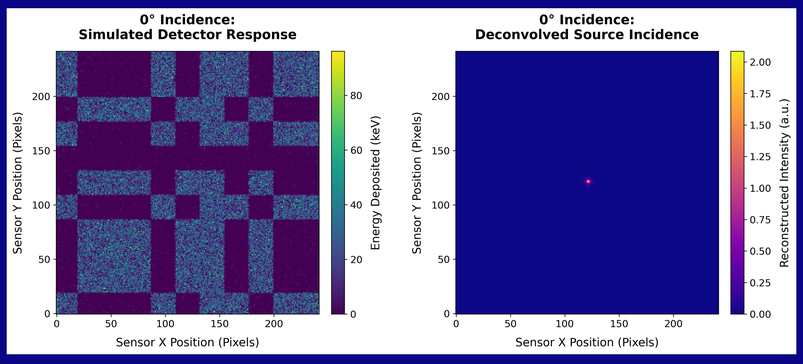
Simulation Setup

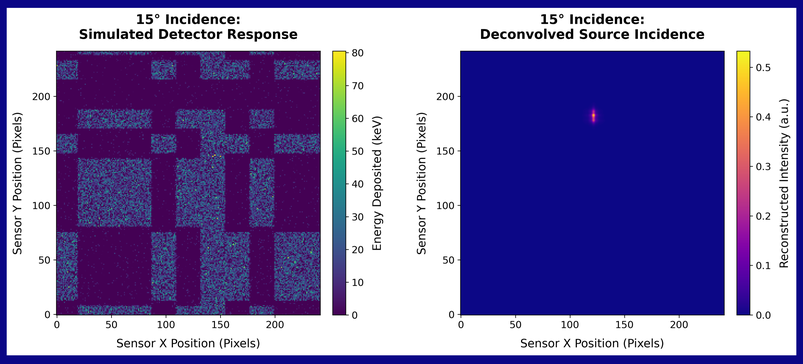


- **Geant4** was utilized to model the detector's physical geometry, particle interactions, and internal energy deposition.
- A **virtual electron source** was directed at the coded aperture mask at varying incidence angles to validate the internal tracking of superthermal electrons.
- To fully project the mask's pattern onto the detector plane, 1 million 10 keV electrons were fired at the instrument.

Preliminary Results

- Simulated hit data was processed using an **MLEM** (Maximum Likelihood Expectation Maximization) **reconstruction algorithm.**
- The algorithm **successfully deconvolved** the TimePIX detector response, accurately retrieving the **original source incidence angles** and validating the instrument's angular resolution capabilities.





Future Work

- Finalize assembly of the physical instrument and integrate the TimePIX sensor with the custom housing.
- Conduct **empirical validation testing** within a plasma vacuum chamber using a controlled electron source gun.
- Compare physical detector performance against Geant4 models to refine the data reconstruction pipelines for future flight software.

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Reid, R. A. (2024). *Novel high-angular resolution imaging techniques for energetic electron pitch angle observations* (Order No. 31330641). Retrieved from https://login.lp.hscl.ufl.edu/login?url=https://www.proquest.com/dissertations-theses/novel-high-angular-resolution-imaging-techniques/docview/3100711377/se-2