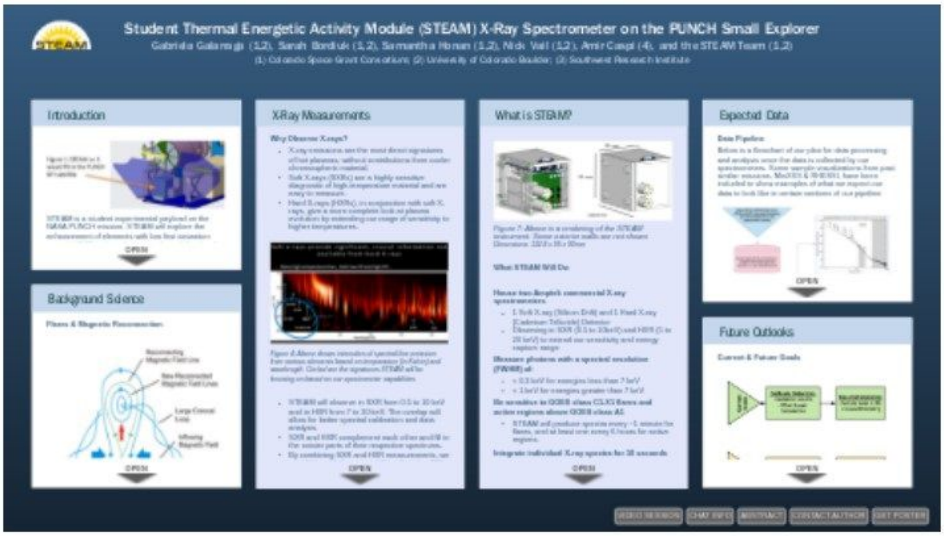
Student Thermal Energetic Activity Module (STEAM) X-Ray Spectrometer on the PUNCH Small Explorer



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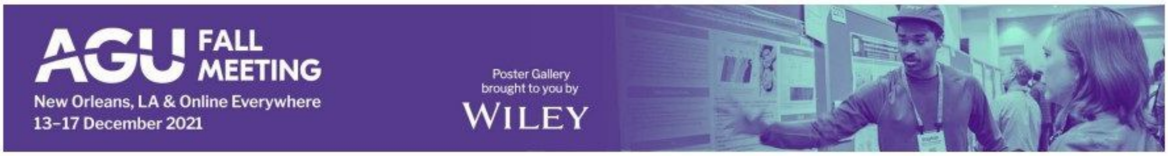
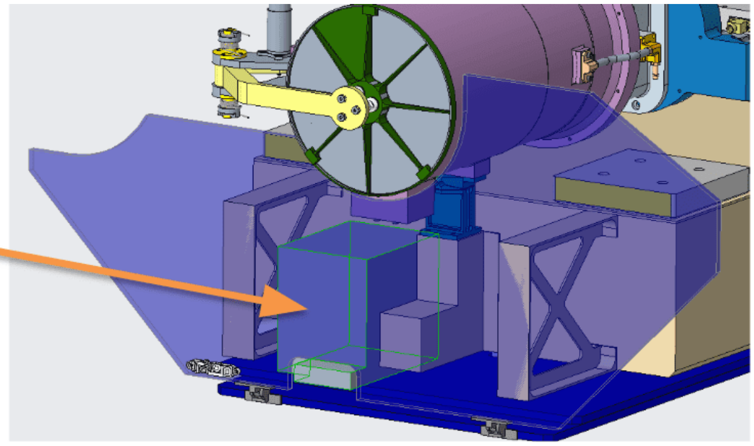
PRESENTED AT:



INTRODUCTION

Figure 1: STEAM as it would fit in the PUNCH NFI satellite



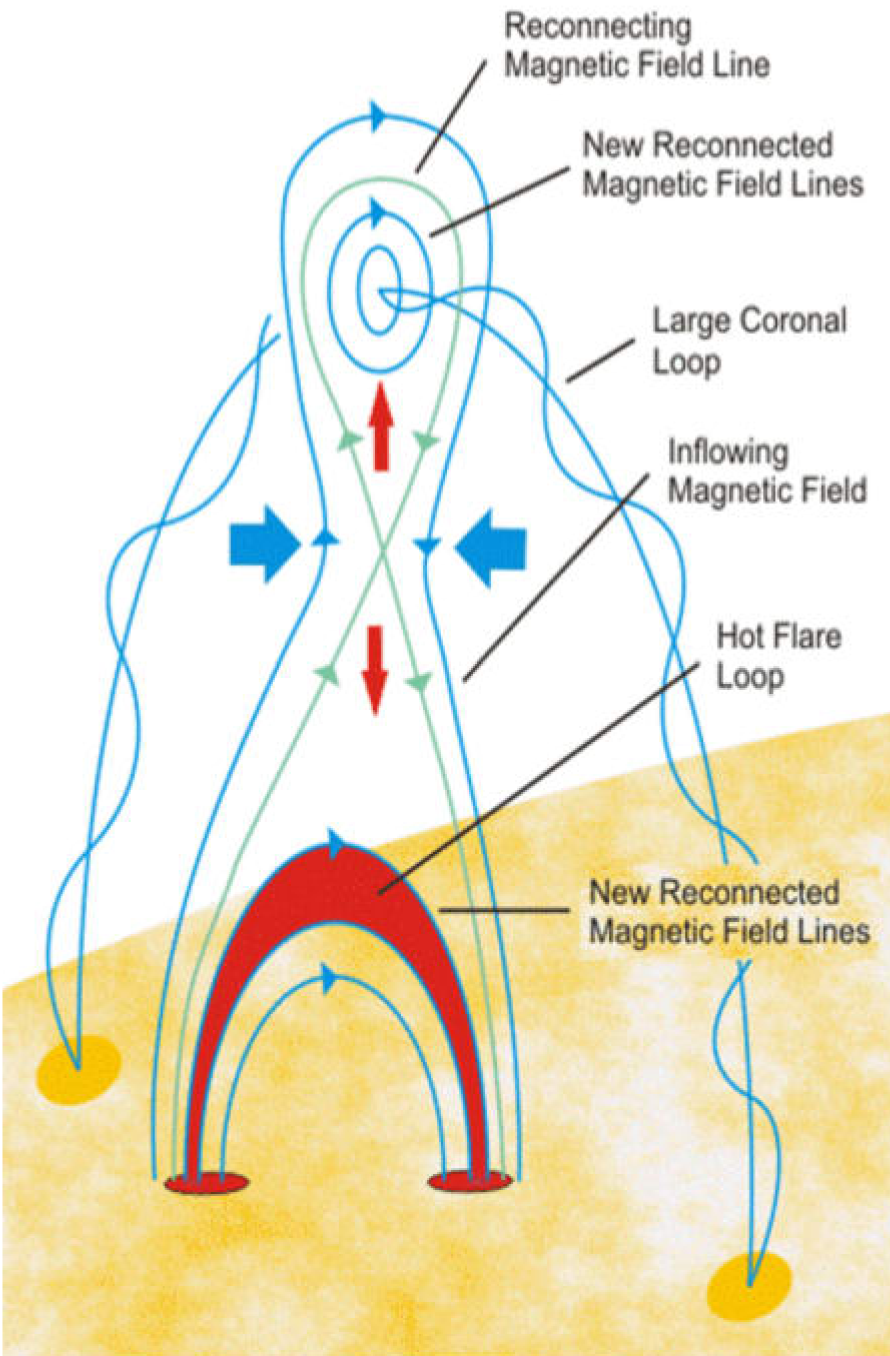
STEAM is a student experimental payload on the NASA PUNCH mission. STEAM will explore the enhancement of elements with low first ionization potential (FIP) in the solar corona through hard and soft X-ray spectroscopy to understand reconnection-based coronal heating mechanisms. STEAM observations will focus on flares and active regions. PUNCH launch with STEAM is scheduled in 2024.

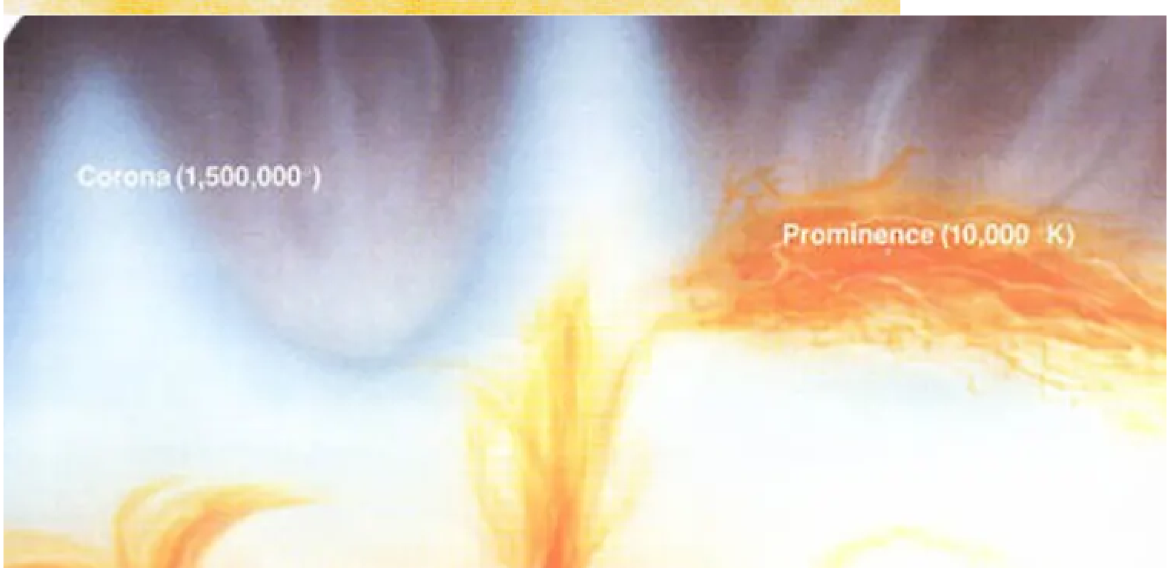
The Question: Why does the outermost layer of the Sun, the corona, reach millions of degrees, much hotter than the layers below?

- The coronal heating mechanism is not fully understood, but there are leading theories.

BACKGROUND SCIENCE

Flares & Magnetic Reconnection


Reconnecting
Magnetic Field Line
New Reconnected
Magnetic Field Lines
Large Coronal
Loop
Inflowing
Magnetic Field
Hot Flare
Loop
New Reconnected
Magnetic Field Lines


Corona (1,500,000)
Prominence (10,000 K)

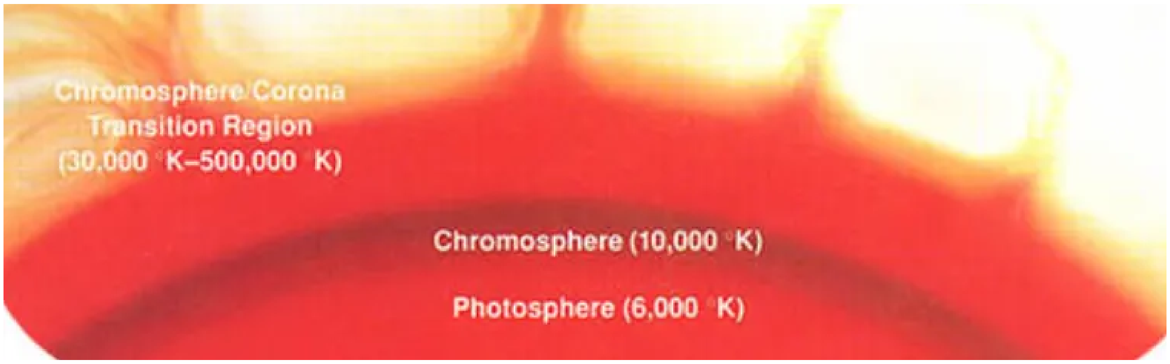


Figure 2: (Left) Cartoon schematic of magnetic reconnection in a flare. Credit: NASA (Right) Diagram of outer layers of the Sun, with the corresponding temperature. Note high coronal temperatures. Credit: NASA

A Theory: Coronal plasma is heated through energy release from magnetic reconnection during flares and nanoflares (very small, very frequent flare-like events).

- Magnetic reconnection: oppositely oriented magnetic field lines cancel out and release stored energy
- The reconnection changes the overall magnetic field configuration as the field falls to a lower energy state
- This results in a rapid release of energy in the form of flares and nanoflares.

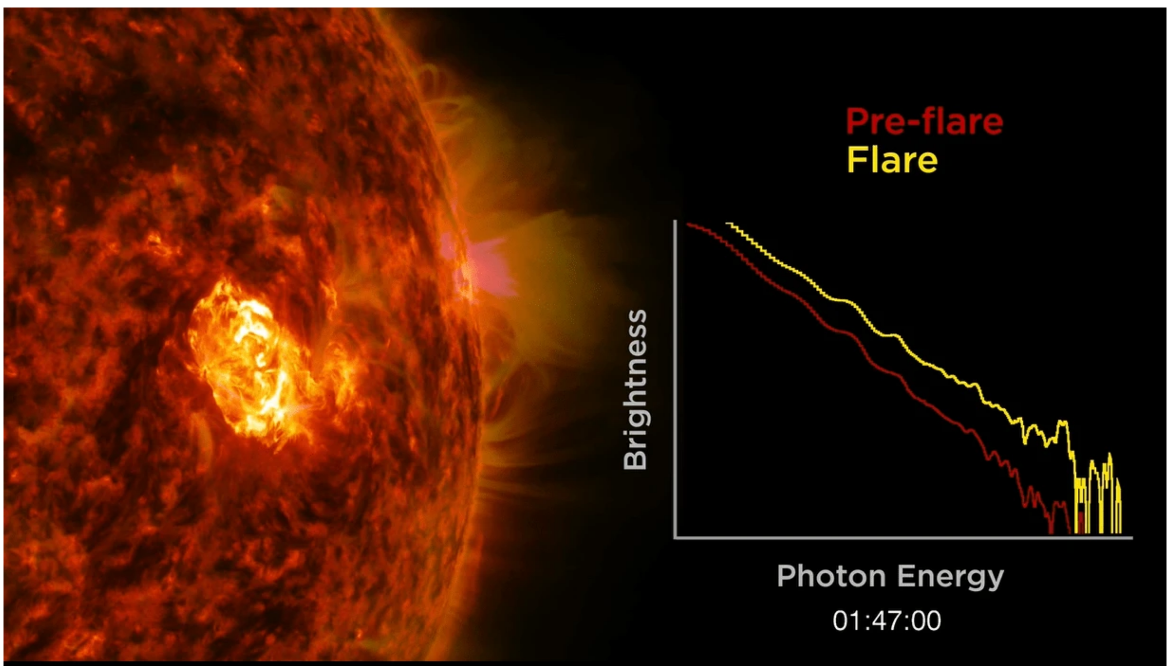


Figure 3: Snapshot of MinXSS soft X-ray spectra during a solar flare. Credit: MinXSS & NASA

The Coronal Plasma: STEAM will study X-ray emissions from the hot coronal plasma to search for signatures of magnetic reconnection-based heating by measuring the abundances of key low FIP elements

- Emissions lines of low FIP (<10eV) elements (K, Na, Al, Ca, Mg, Fe, Si) are typically prominent above the thermal continuum.
- Their abundances are typically enhanced by a factor of ~4 in the corona over chromospheric abundances
- Abundances allow STEAM to infer the origin of heated plasma for flares and active regions (AR), as the enhancement hints at whether the plasma comes from the corona itself, the chromosphere, or some mixture of origin

X-RAY MEASUREMENTS

Why Observe X-rays?

- X-ray emissions are the most direct signatures of hot plasmas, without contributions from cooler chromospheric material.
- Soft X-rays (SXRs) are a highly sensitive diagnostic of high-temperature material and are easy to measure.
- Hard X-rays (HXRs), in conjunction with soft X-rays, give a more complete look at plasma evolution by extending our range of sensitivity to higher temperatures.

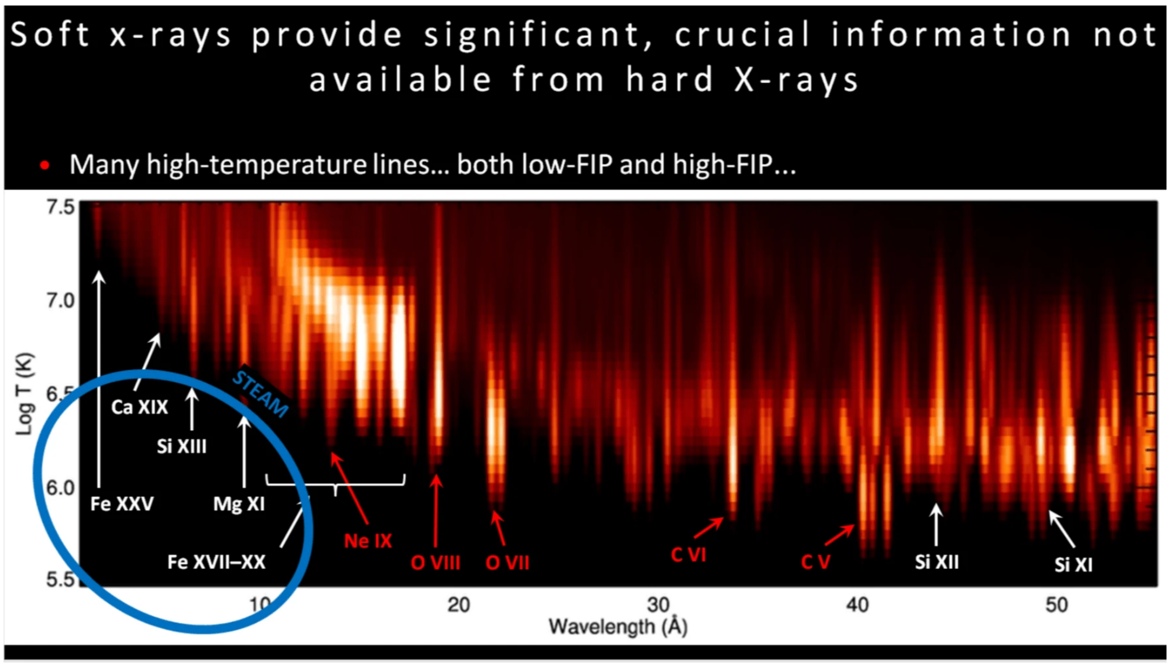


Figure 4: Above shows intensities of spectral line emission from various elements based on temperature (in Kelvin) and wavelength. Circled are the signatures STEAM will be focusing on based on our spectrometer capabilities

- STEAM will observe in SXR from 0.5 to 10 keV and in HXR from 7 to 30 keV. The overlap will allow for better spectral calibration and data analysis.
- SXR and HXR complement each other and fill in the noisier parts of their respective spectrums.
- By combining SXR and HXR measurements, we can distinguish key spectral lines from low FIP elements as well as the thermal continuum from the solar corona.

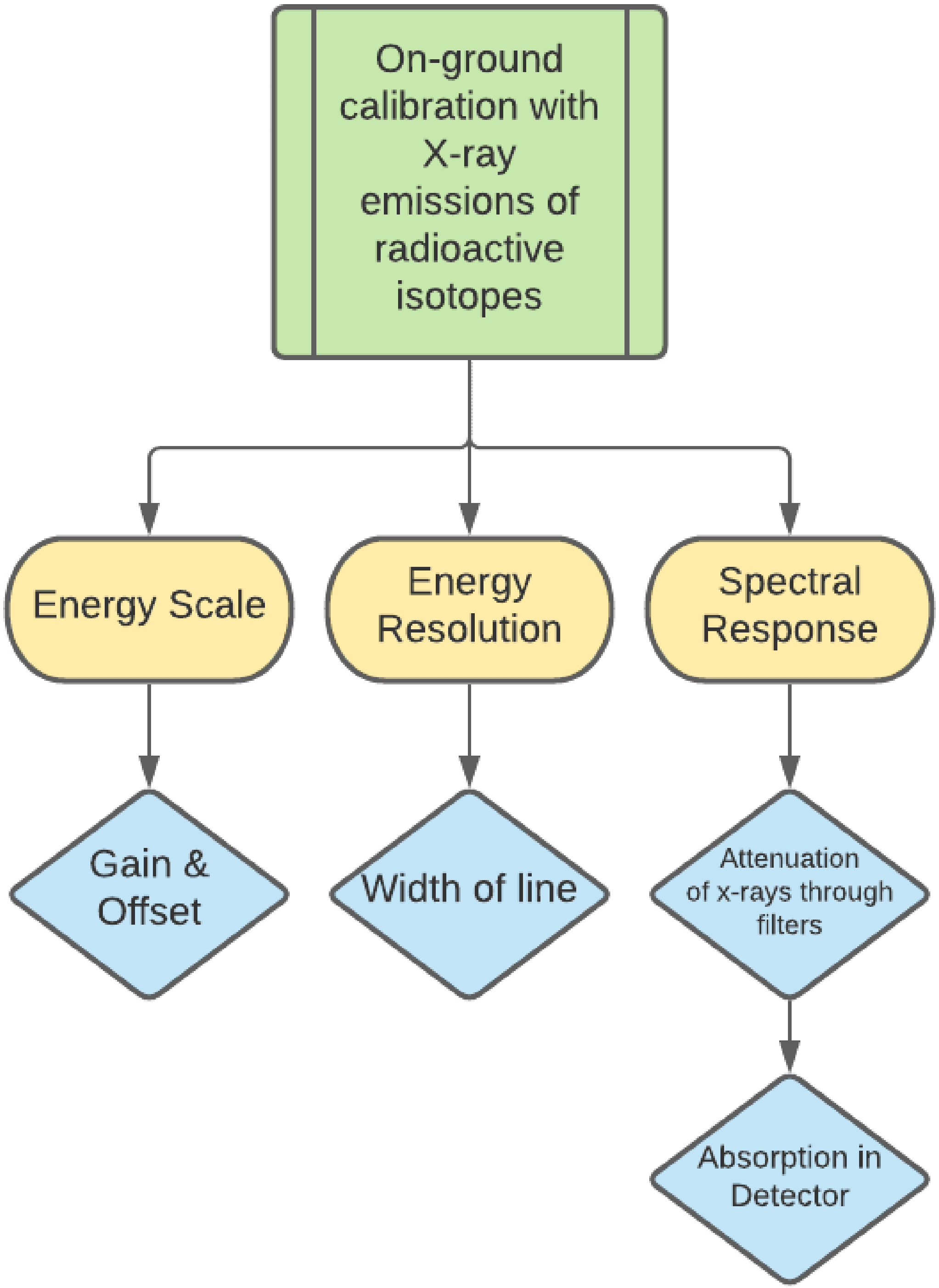
How Will STEAM Observe X-rays?

- Each detector (SXR and HXR) will measure individual incident photons and their energies
- Photons are assigned into their appropriate bins based on their energies.
- Each integration period provides a histogram spectrum of detected photons
- These histograms can be summed to improve statistics

[VIDEO] https://res.cloudinary.com/amuze-interactive/video/upload/vc_auto/v1638311379/agu-fm2021/4D-7B-77-99-AE-D7-36-2A-74-34-43-26-8F-04-A7-4B/Video/media3_fmbcch.mp4

Figure 5: individual histograms from 10-second integrations (red) can be summed to create a spectrum (white)

Spectrometer Calibration Process



Field of View & Cosmic Background X-ray Radiation

STEAM has taken into account estimated values for expected cosmic background radiations within our instrument sensitives and compared them against sample Active Regions and Flare activity data. It was clear upon our analysis that the background X-ray radiation would not interfere with our scope within a 10-degree field of view. This has allowed for more flexibility in design collaboration with NIFI.

WHAT IS STEAM?

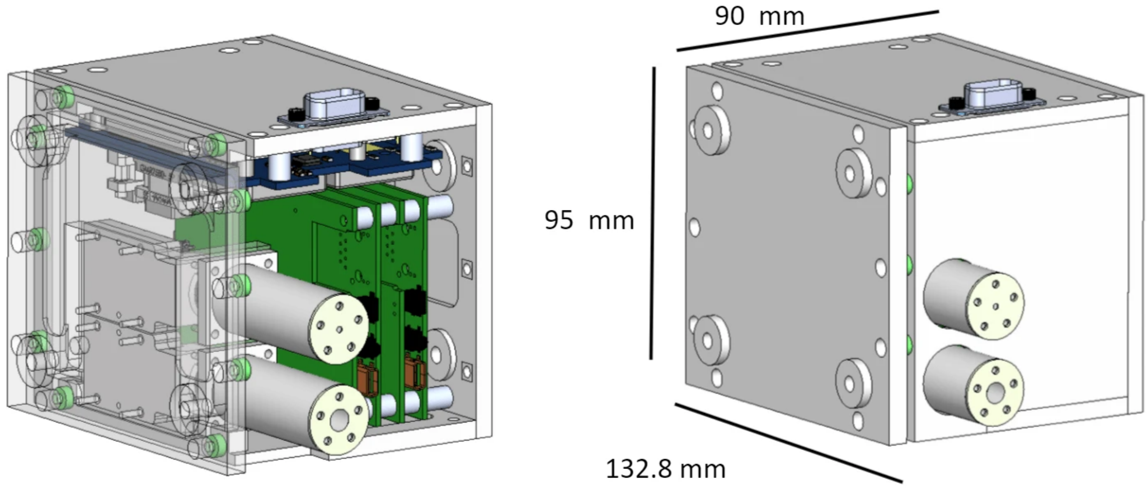


Figure 7: Above is a rendering of the STEAM instrument. Some exterior walls are not shown
Dimensions: 132.8 x 95 x 90mm

What STEAM Will Do:

House two Amptek commercial X-ray spectrometers

- 1 Soft X-ray (Silicon Drift) and 1 Hard X-ray (Cadmium Telluride) Detector
- Observing in SXR (0.5 to 10keV) and HXR (5 to 20 keV) to extend our sensitivity and energy capture range

Measure photons with a spectral resolution (FWHM) of:

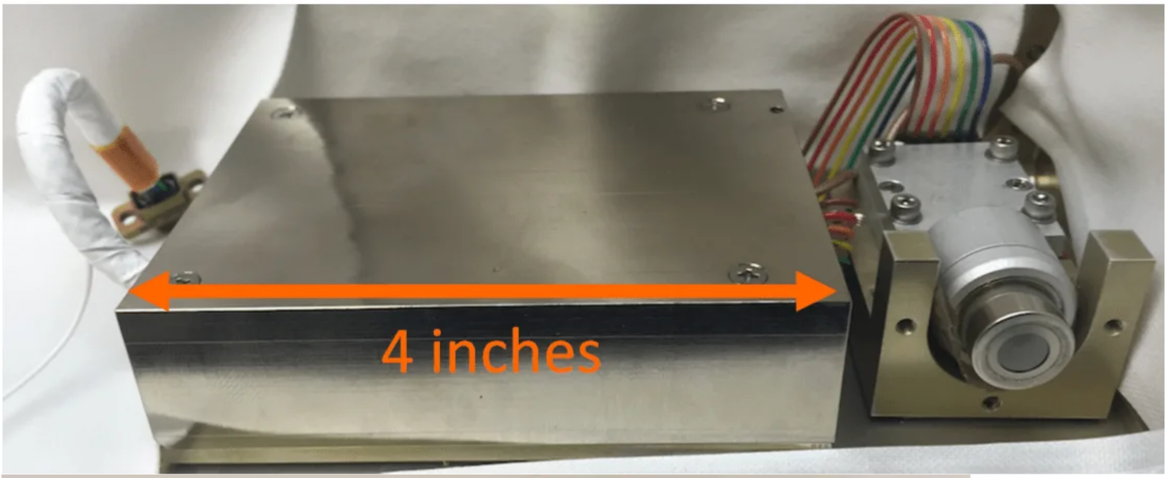
- < 0.3 keV for energies less than 7 keV
- < 1 keV for energies greater than 7 keV

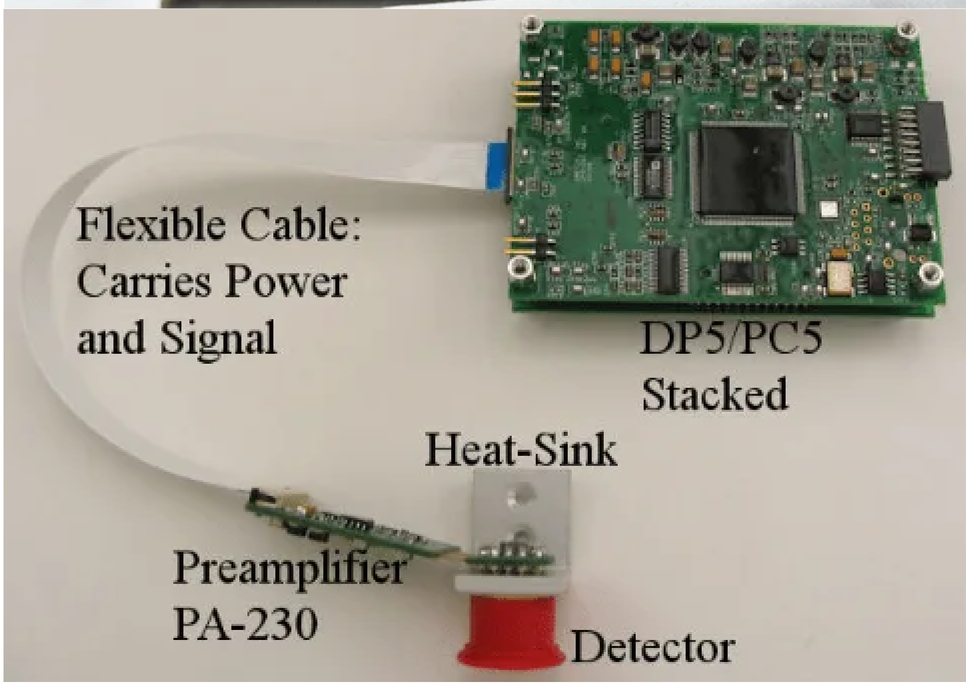
Be sensitive to GOES class C1-X1 flares and active regions above GOES class A1

- STEAM will produce spectra every ~1 minute for flares, and at least one every 6 hours for active regions.

Integrate individual X-ray spectra for 10 seconds

- Provides adequate subsamples to mitigate data loss due to interference.

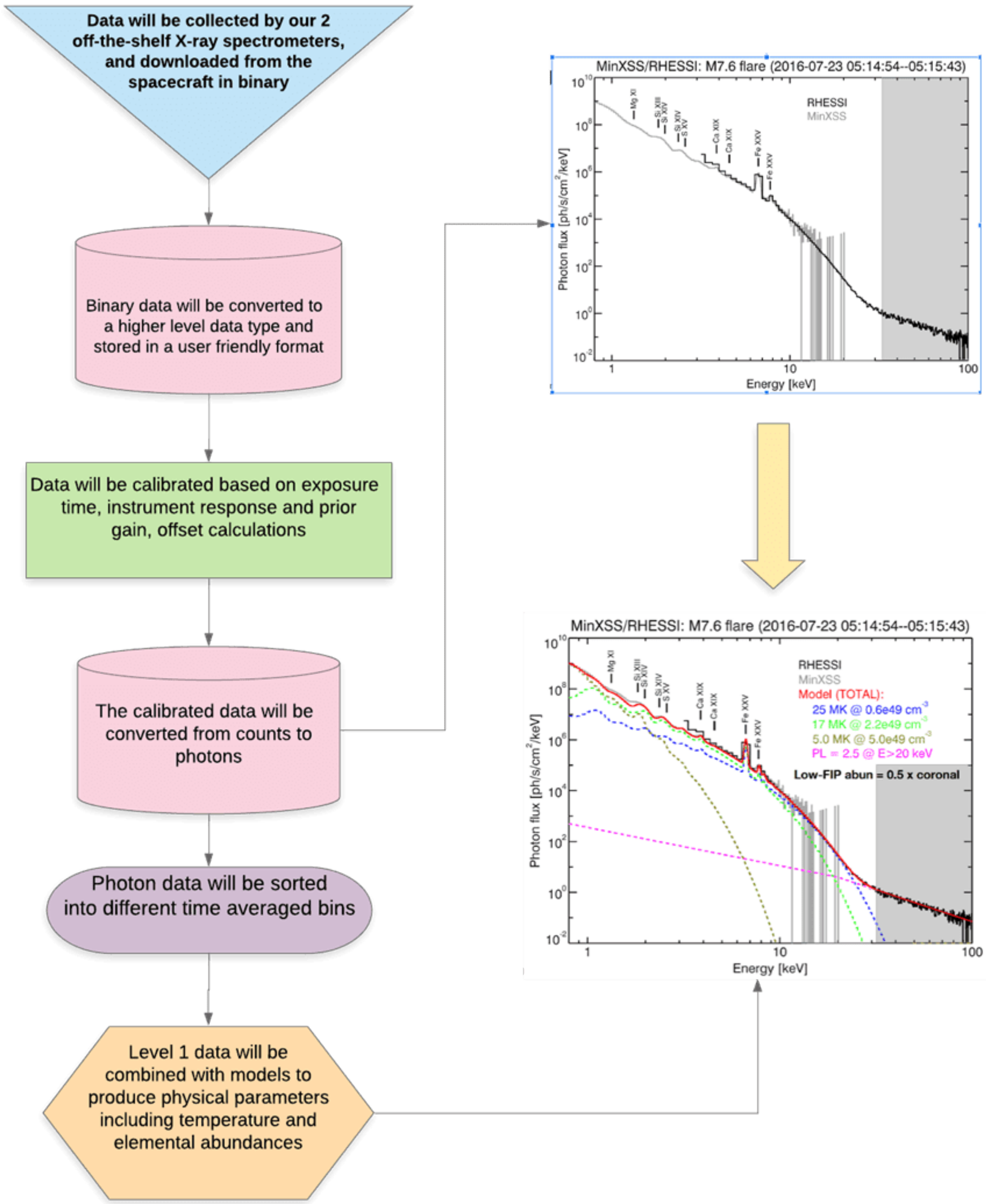

4 inches


Flexible Cable:
Carries Power
and Signal
DP5/PC5
Stacked
Heat-Sink
Preamplifier
PA-230
Detector

EXPECTED DATA

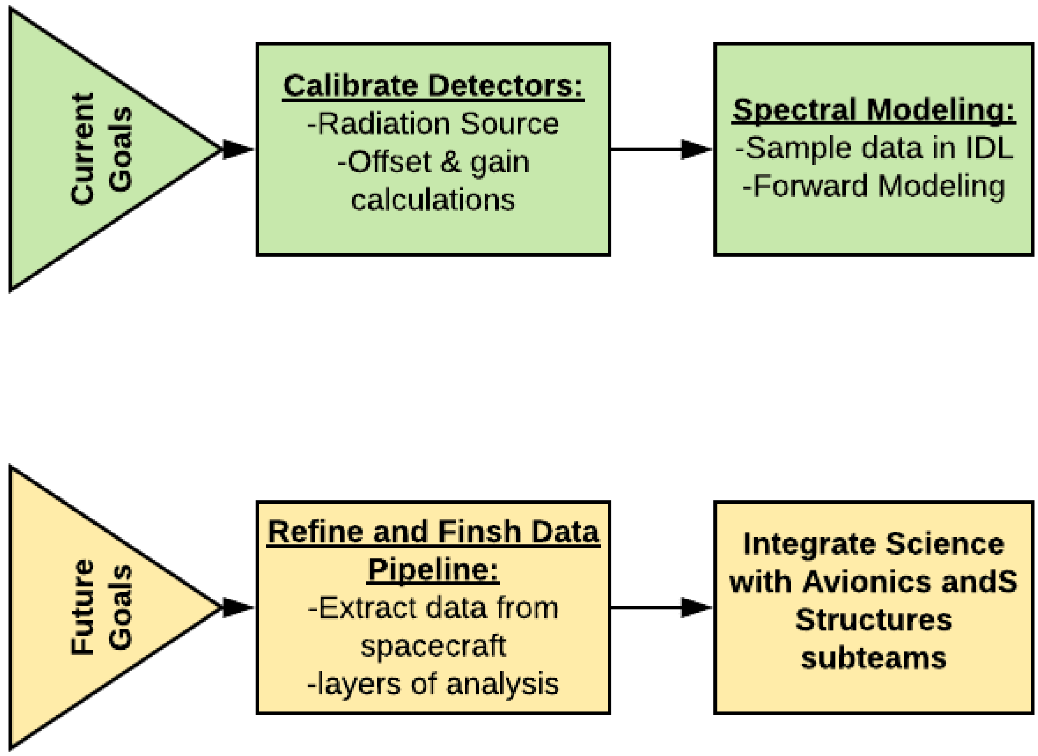
Data Pipeline

Below is a flowchart of our plan for data processing and analysis once the data is collected by our spectrometers. Some sample visualizations from past similar missions, MinXSS & RHESSI, have been included to show examples of what we expect our data to look like in certain sections of our pipeline.



FUTURE OUTLOOKS

Current & Future Goals



- Above is a visualization of our current and future goals with STEAM. We will be focusing on understanding and planning for calibration of both spectrometers and practicing our analysis with sample data pre-launch.
- The Science subteams will eventually integrate with Avionics and Structures subteams and a final calibration will be performed before launch once STEAM is fully assembled.
- Once STEAM has launched, we will be ready to collect and analyze data sent from STEAM through the spacecraft.

ABSTRACT

The Student Thermal Energetic Activity Module (STEAM) will explore how solar coronal plasmas are heated in flares and active regions by measuring the abundances of elements with low first ionization potential (FIP) using soft (0.5-10 keV) and hard (5-30 keV) X-rays to distinguish signatures of reconnection-based coronal heating mechanisms.

Typically, coronal abundances of low-FIP elements (e.g. Mg, Si, Fe, Ca) are enhanced by a factor of 4 above chromospheric values. Measuring the abundances of low FIP elements for various ions of these elements at different temperatures provides insight into the coronal or chromospheric origins of the heated plasma. X-ray emissions, including spectral lines and continuum, provide the most direct signatures of hot coronal plasma.

A combination of hard and soft X-ray spectrometers will be used to measure incident photons and their energies within solar active regions. STEAM will utilize forward modeling with bremsstrahlung and atomic emission databases to fit physical parameters such as temperature and elemental abundance to observed spectral data. These elemental abundances allow STEAM to infer the origin of plasma for flares and active regions.

STEAM is a student payload hosted on one of the PUNCH Small Explorer spacecraft with an expected launch in late 2023 and 2-year prime mission. STEAM’s spectral observations of solar flares and active regions in soft and hard X-rays during the rising phase and maximum of solar cycle 25 will measure a wide range of activity to help constrain potential coronal heating mechanisms. STEAM is in the preliminary design phase and completing critical trade studies. We will present the STEAM science motivation, design, current progress, and future outlook.