

Using Machine Learning to Measure Temperatures of Solar Eruptions

Situation

Solar flares are eruptions in the Sun's atmosphere creating hot gas with temperatures up to ~50 million degrees Celsius. Such hot sources emit strong X-ray radiation. By measuring these X-rays, the temperature of the flare can be retrieved.

Over the past decade, FHNW has developed and built the X-ray telescope STIX onboard ESA's solar Orbiter mission (see [1] and Figure 1). STIX, which can be considered as a "flare thermometer" operating at temperatures above 10 million degrees Celsius, has observed over 80'000 solar flares since 2021.

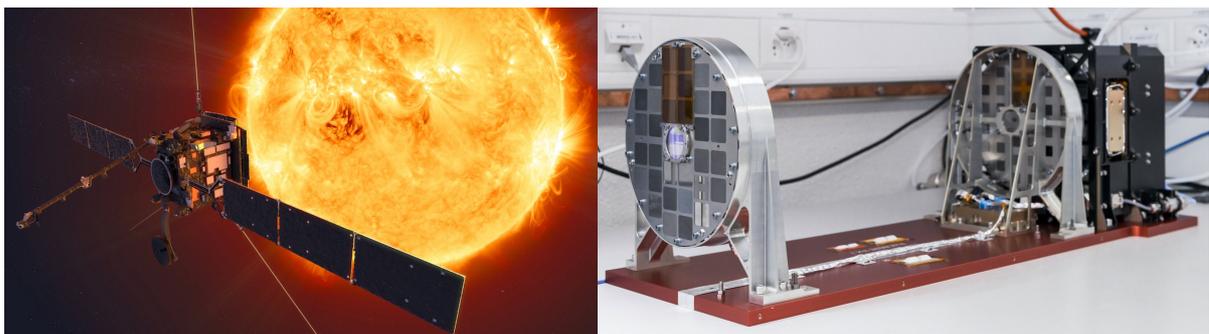


Figure 1. Left panel: the Solar Orbiter spacecraft [1]. Right panel: the STIX instrument [2].

We generally use fitting of spectral STIX data to derive flare temperatures. This is a slow and manual process based on a 20-year-old software package, which we intend to replace by a Machine Learning (ML) approach. There are existing python routines to derive the X-ray spectrum for a given flare temperature [3]. Hence, we are able to create a dataset of simulated STIX flare observations and corresponding temperatures, which will be used to train an ML model to predict the flare temperature from STIX data. The resulting model will be applied to the STIX database to derive flare temperatures as a function of time (see Figure 2).

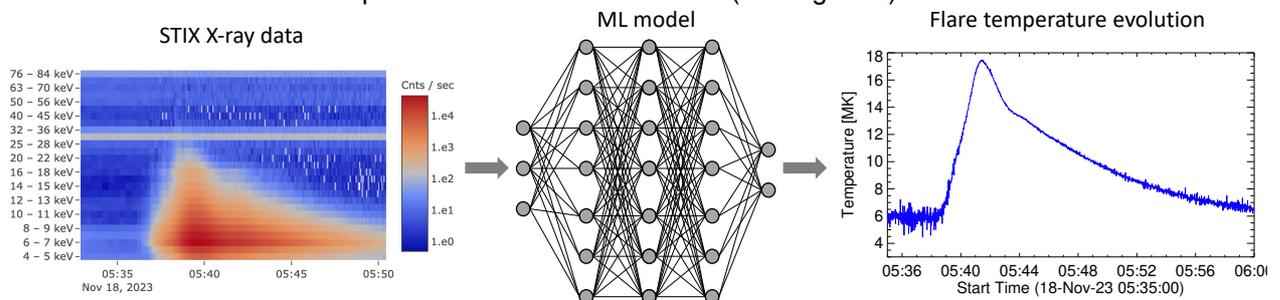


Figure 2. Scheme of the proposed project: an ML model is trained to predict the time evolution of the flare temperature from STIX X-ray data.

Goals / Methodology / Tasks

We will train an ML model on a dataset of simulated STIX X-ray data and corresponding flare temperatures. The model will be subsequently applied to the entire STIX data archive to predict the flare temperature as a function of time for each recorded event. High level data products will be created and delivered to ESA.

Required Skills

Prior knowledge in ML is desired. No prior knowledge of the physics of the Sun is required, however, enthusiasm for space related topics is highly desired.

Tasks for the Master Student

We foresee the following project phases.

P7: Existing Python routines are available to derive the X-ray spectrum for a given flare temperature [3]. Using these tools, we will generate a dataset of simulated STIX flare observations paired with their corresponding temperatures. This dataset will be used for training a machine learning model to predict the flare temperature from STIX data. The model's performance will be evaluated on a separate simulated test set.

P8: We will construct an appropriate set of STIX data from the raw measurements provided by the instrument, which are stored as FITS files [4] on the STIX Data Center [5]. Our ML model will be evaluated on this dataset of experimental observations, and its predictions will be compared to the results of the fitting procedure currently in use. If the model proves insufficiently robust to systematic errors present in real STIX data, we will refine the simulation procedure developed in P7 to incorporate both statistical and systematic uncertainties, and retrain the model accordingly. Finally, the trained model will be integrated into the STIX data pipeline [6] to support the generation of high-level data products for delivery to ESA.

P9: Solar activity is monitored by space weather missions, which often operate under strict limitations on data transmission to Earth. In such contexts, performing onboard data processing is highly advantageous, as it reduces the need to transmit large volumes of raw data. For instance, estimating the flare temperature directly onboard would eliminate the need to downlink extensive datasets for ground-based analysis.

The final objective of this master's thesis is to determine the most efficient approach for onboard flare temperature estimation. This may include techniques such as model quantization, building upon methods previously developed and implemented in [7].

Full/Parttime: Full time study
 Part time study

Location:

The STIX team at FHNW is in Windisch in room 5.2C03.

Advisor:

Prof. Säm Krucker, Dr. Paolo Massa, and the STIX team.

References

- [1] https://www.esa.int/Science_Exploration/Space_Science/Solar_Orbiter
 - [2] Krucker et al. (2020), https://www.aanda.org/articles/aa/full_html/2020/10/aa37362-19/aa37362-19.html
 - [3] <https://github.com/sunpy/sunkit-spex>
 - [4] https://fits.gsfc.nasa.gov/fits_primer.html
 - [5] <https://datacenter.stix.i4ds.net/>
 - [6] <https://github.com/i4Ds/STIXCore>
 - [7] Massa et al., (2024),
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