XRTpy : A Hinode-X-Ray Telescope Python Package

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Summary

The XRTpy Python package is a specialized tool developed for the analysis of observations made by the X-Ray Telescope (XRT) (Golub et al., 2007) aboard the Hinode spacecraft (Kosugi et al., 2007). Hinode, a joint mission involving space agencies from Japan, the United States, Europe, and the United Kingdom, was launched with the primary aim of providing multi-wavelength data from the photosphere to the upper corona, enabling continuous observations of the Sun. Within this mission, the XRT instrument stands out as a remarkable piece of technology, capable of capturing high-resolution images of the solar corona's hottest material, spanning temperatures from 106 to 107 K.

Statement of need

XRTpy is a Python package developed for the analysis of observations from the X-Ray Telescope (XRT) aboard the Hinode spacecraft. It offers a comprehensive range of functionalities, including object-oriented representation of instrument configuration, effective area calculations, temperature response computation, light leak subtraction, image sharpening, estimation of electron temperature, and emission measure derivation. These capabilities empower researchers to explore and analyze XRT data comprehensively, contributing to a deeper understanding of solar phenomena.

The official analysis routines for Hinode are scripted in the Interactive Data Language (IDL). The SolarSoft XRT Analysis Guide serves as the official software and instrument guide for XRT data analysis. XRTpy has been carefully written to ensure the consistency and replication of results obtained from the official IDL routines as described in the SolarSoft XRT Analysis Guide. Although currently XRTpy does not have all the capabilities of the SolarSoft routines for XRT, the package is in continual development and more functionality will be added in the future. This alignment with established practices and standards aims to facilitate a seamless transition for researchers while harnessing the benefits of Python in solar data analysis.

A shift towards Python is underway within both NASA and the wider scientific community. With XRTpy, Python users can efficiently analyze and process Hinode/XRT data, bridging the gap between traditional IDL routines and the increasing adoption of Python within the scientific community. This transition not only enhances accessibility but also supports the broader trend in the scientific community toward Python-based data analysis tools, thereby fostering a collaborative and efficient environment for solar researchers.

Package Structure

XRTpy is equipped with a range of capabilities tailored for the comprehensive analysis of XRT observations. The package is structured into distinct modules, each serving a specific purpose:

- `xrtpy.response.channel`: This module defines the `Channel` class which offers access to the properties of XRT filters, including information on the CCD, Entrance Filter, Focus-Filter(s), Geometry, and Mirror(s).

- `xrtpy.response.effective_area`: XRTpy's capability to calculate effective areas for various XRT filter channels, combined with CCD contamination layer thickness information, is crucial for understanding instrumental spectral responses, as depicted in Figure 1.

- `xrtpy.response.temperature_response`: XRTpy provides the capability of computing the temperature response of all the XRT filter channels. It does this by relying on a spectral emission model, drawing from (Narukage et al., 2011) and (Narukage et al., 2014). Users can choose from a range of CHIANTI abundance sets, including the default model with coronal abundances, hybrid, and photospheric options. Figure 2 shows XRTpy's temperature response calculations for all XRT filters across the different CHIANTI abundance sets.

- `xrtpy.response.temperature_from_filter_ratio`: This module contains the `temperature_from_filter_ratio` function, which derives temperature and emission measure maps for a pair of images using the filter ratio method. Figure 3 illustrates an example usage of this function.

- `xrtpy.image_correction.deconvolve`: Deconvolution is a powerful technique for improving image sharpness. The `deconvolve` function applies deconvolution to XRT images, effectively reducing blurring effects caused by the telescope's point spread function.

- `xrtpy.image_correction.remove_lightleak.py`: The `remove_lightleak` function in this module eliminates light leak (visible stray light) from XRT synoptic composite images. This results in cleaner and more precise images suitable for in-depth analysis.

XRTpy supports multiple elemental abundance sets, including CHIANTI coronal abundances ((Feldman et al., 1992) and (**Feldman:2014?**)) , hybrid abundances (based on [Fludra-and-Schmelz:1999] and (Schmelz et al., 2012)), and photospheric abundances (based on (Grevesse et al., 2007), (Scott et al., 2015), and (Asplund et al., 2009)).

Researchers have the flexibility to select the abundance model that best aligns with their research requirements.

XRTpy's capabilities are designed to empower researchers and scientists to fully exploit the potential of XRT data, offering the scientific community a unique opportunity to study the Sun's dynamic and complex behavior in a user-friendly and efficient manner.
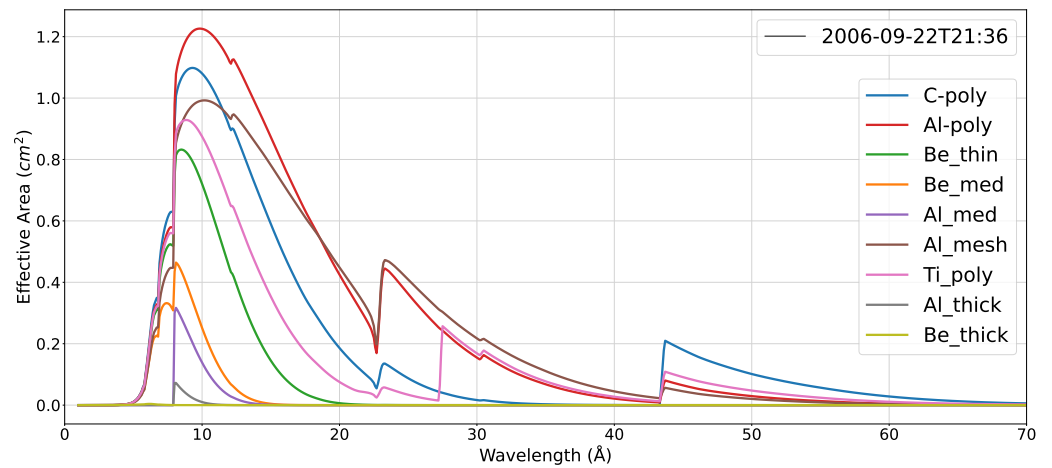
Figure 1: Figure 1: The Effective area for all XRT filters plotted using XRTpy. .
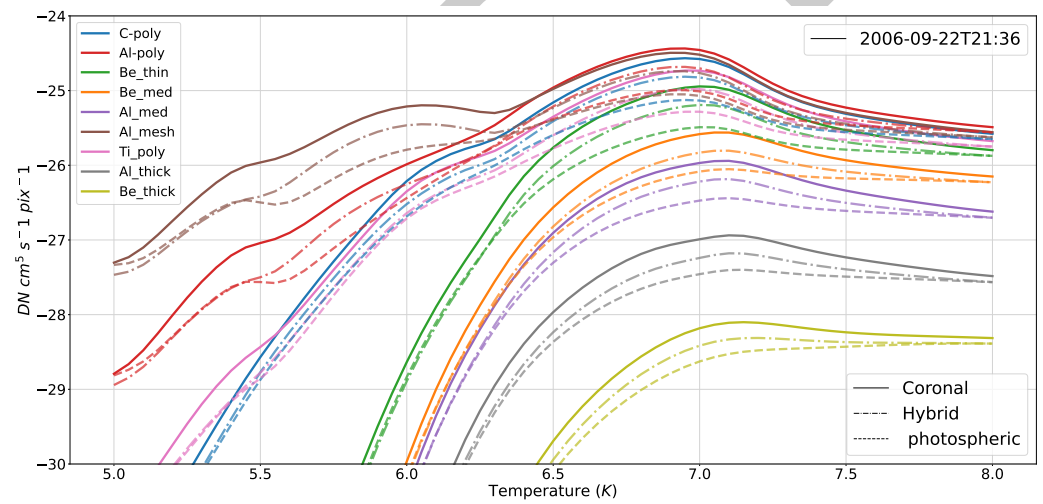

Figure 2: Figure 2: The temperature response is plotted for all XRT filters using XRTpy. The plot also shows the effects of using different abundance models from CHIANTI for each filter. .
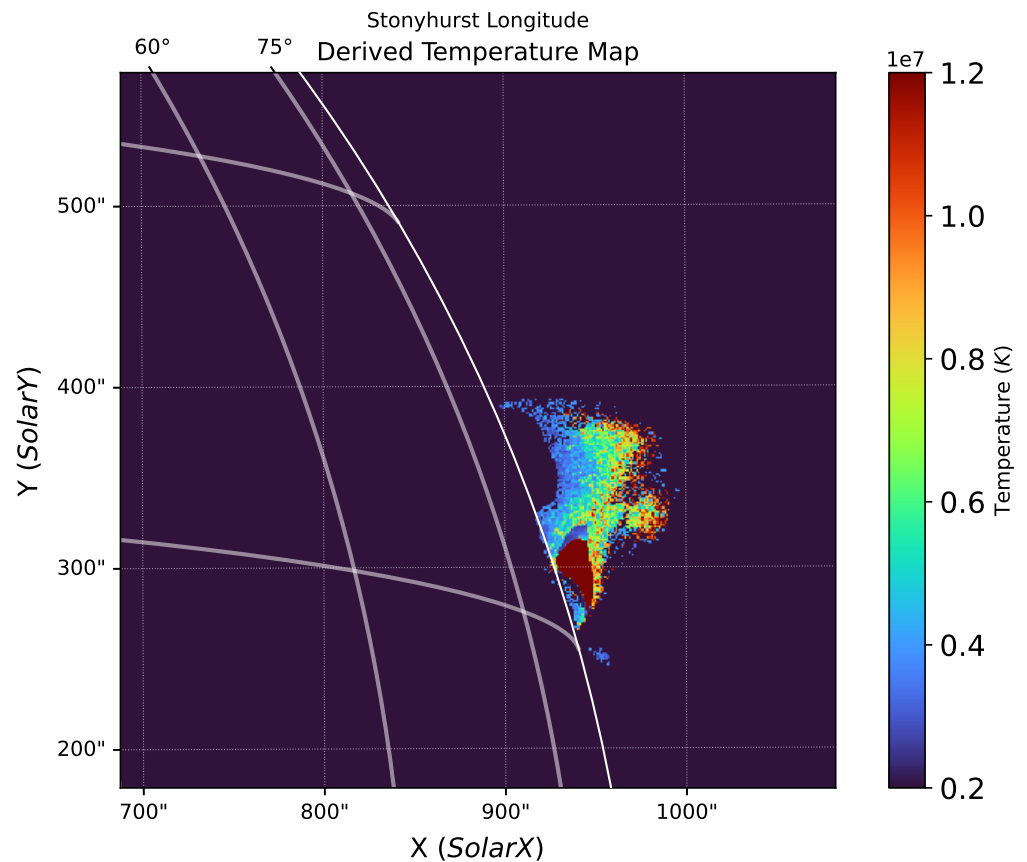
Figure 3: In Figure 3, the application of the `temperature_from_filter_ratio` function is illustrated, demonstrating its role in calculating electron temperature and volume emission measure through filter ratios. The dataset, collected on January 28, 2011, between 01:31:55 and 01:32:05 UTC, comprises two images captured with specific filters. These images offer unique insights into solar conditions during the observed moments, as shown by (Guidoni et al., 2015). .

Development of XRTpy Version 0.4.0

XRTpy version `0.4.0` was released on December 5, 2023. This version, available through the Python Package Index (PyPI), can be installed using `pip` and is compatible with Python 3.9 and later.

In fostering collaboration within the solar physics community, interoperability with other packages is a work in progress that we've started on with the developers of aiapy for SDO/AIA observations, EISpack for Hinode-EIS data analysis, and irispy-lmsal for IRIS observations. This integration provides users with a smooth and comprehensive analysis experience. Further building on the SunPy framework (SunPy Project et al., 2020), XRTpy effectively utilizes the Map object for handling Hinode/XRT image data.

The development of XRTpy is an open and collaborative effort, hosted on Github to ensure transparency and encourage community involvement. The project's documentation is comprehensive and continuously updated, available online via Read the Docs. To maintain high-quality standards, XRTpy employs a robust testing framework built on `pytest` and `GitHub Actions`. This framework covers a range of aspects including different Python versions, online functionality, documentation integrity, software functionality, and code style checks, ensuring a reliable and effective tool for users.

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