

HINODE/XRT SOLAR X-RAY IRRADIANCE USING 2D INFORMATION OF THE CORONA

Aki Takeda (Montana State University, Bozeman MT, USA)





Fig. 1: Left two images: Sample pair of XRT full-Sun composite images obtained on 10-Mar-2023 at 04:03 UT with Al_mesh and Al_poly filters. Middle two images: Filter-ratio Temperature and Emission Measure maps obtained from the left two images. Right two images: Differential EM plot and soft X-ray Irradiance map (5-60Å) caldulated from the middle two images (for the area within 1.1 Rs).

Summary

From the full-Sun soft X-ray images obtained with the X-Ray Telescope (XRT)'s Al-mesh and Al-poly filters, solar soft X-ray irradiance (5-60A) was calculated from 2015 June through 2024 December using 2D information of the corona. Original full-Sun images taken with 2.06 arcsec/pix were binned to 8.22 arcsec pixel resolution to improve the S/N ratio, taken co-alignment then applied filter-ratio method to derive 2D maps of temperature(Te) and emission measure(EM). From the Te and EM obtained at each pixel, isothermal coronal spectrum was synthesized and 2D irradiance is obtained as the spectral energy included in the wavelength range of 5-60A. From these Te, EM and Irradiance obtained in 2D EM-weighted Te average, total EM and total Irradiance included within 1.1 Rs were calculated to compare with the corresponding values obtained from the full-Sun integrated signals, or Sun-as-a-Star analysis. Compared with the values using 2D information, irradiance from the Sun-as-a-Star analysis is generally higher roughly 10% higher when the Sun is in active phase of a solar cycle, while around the Solar minimum, the range of difference increases 5% to 40% higher depending on the appearance of active regions on the solar disk. The averaged temperatures from the Sunas-a-Star analysis yield slightly(1-2%) higher value to the averaged temperatures from the 2D map during the period of Solar Maximum, while the difference increases to 3 to 8% during the Solar Minimum. The EM from the Sun-as-a-Star analysis are 10% higher than the total EM of the 2D map outside the period of Solar Minimum. However, EMs around the Solar Minimum are 4% lower than the 2D analysis.

3. New Calibration

3.1 Correction of visible stray light component

Visible stray light contamination is caused by a crack developed on the XRT's pre-filter (multiple events experienced). The correction takes the following two steps:

1. Subtract visible light component from the X-day images.

2. Then modify XRT's effective area function due to the open area of the pre-filter. From the G-band stray light data analysis, we estimated the open area fractions for each event (Table 1), and incorporated them into the effective area functions.

event	date	open fraction
1st	9-May-2012	0.1%
2nd	14-Jun-2015	3.3%
3rd	27-May-2017	7.5%
4th	29-May-2018	9.9%
5th	8-Jun-2022	10.8%
6th	5-May-2023	13.5%
7th	11-May-2024	16.5%

Table 1: Estimated open area fraction of XRT pre-filter.



Fig. 5: Same as Fig. 4 but for Emission Measures.



Ratio of XRT irrad(5-60A): full-Sun integ./summed-2D

1. Hinode/XRT and the SCIA

- XRT is a grazing incidence telescope on-board the Hinode satellite to form X-ray images in the 6 – 200Å range on a 2048x2048 CCD. The field of view is 2040x2040 arcsec.
- Full-Sun observations by XRT are mainly through the synoptic program that typically runs twice daily, using short/medium/long exposure times, which are later processed into a single composite image to increase the intensity dynamic range. These products are accessible from XRT Synoptic Composite Image Archive (SCIA) located at Montana State University.

http://solar.physics.montana.edu/HINODE/XRT/SCIA



Fig. 2: Hinode/XRT assembly and spectral response of X-ray analysis filters (from Narukage et al., 2011).

2. Data processing

3.2 Reconsidering contamination on X-ray filters

There is a growth of contaminant layers on CCD and X-ray analysis filters. It is considered to be caused by the evaporation of some material used in the telescope. The contamination on CCD was initially modeled by Narukage et al (2011), but modified since 2017 to allow the existence of the residual layer (by K. Yoshimura).

The thickness of contamination layer on the X-ray filters was investigated by Narukage et al (2011) until 2007. However, additional growth of the contaminant layer is naturally expected after the XRT Operational Heater was permanently turned off in 2010. We determined the amount of additional contaminant so that it provides natural curve of irradiance evolution.



Fig. 3: Left plot: Thickness of contaminant layer on X-ray filters by Narukage et al 2011. Right plots: Newly adopted X-ray filter contamination layer thickness.

4. Results

응 Al-poly/Al-mesh filter ratio Te (black:2D avr., blue:full-Sun)



Fig. 6: Same as Fig. 4 but for Irradiances.



1. Find pairs of Al-mesh and Al-poly filter images for the period 2015.6 through 2024.12, taken close in time (< 5 min. apart) and reviewed for checking quality.

- 2. Original full-Sun images taken with 2.06 arcsec/pix were binned to 8.22 arcsec pixel resolution to improve the signal level, taken co-alignment then applied filter-ratio method to derive 2D maps of temperature(Te) and emission measure(EM).
- 3. Isothermal coronal spectra is calculated from the derived temperatures and emission measures at each pixel, using Chianti atomic DB and software (ver. 10.0).
- Integrate obtained spectrum over XRT's effective spectral range (5-60Å) to derive a 2D map of coronal irradiance in the unit of W/m².

See Fig. 1 for sample images and derived 2D maps of Te, EM and the XRT irradiance.



Fig. 4: Top: Long term variation of Al-poly/Al-mesh filter ratio temperatures obtained from the full-sun integrated signals (black) and from EM-weighted average of 2D map (blue). Fig. 7: Te vs EM barplot for 5 selected dates. An open square (□) and a cross (×) signs in each plot show the positions of averaged Te and total EM from 2D study and Te and EM obtained from the full-Sun integated signals, respectively.

*** Jun-2025 for Hinode-18/IRIS-16 2025 science meeting ***