

Revisiting the relationship between full sun X-ray irradiance and total magnetic flux using Hinode/XRT and SDO/HMI

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Introduction

Pevtsov et al. (2003) studied the relationship between total unsigned magnetic flux and X-ray spectral irradiance over 12 orders of magnitude, from quiet region of the Sun through T Tauri stars, and found that power-law (index = 1.15) could well express the relationship for the whole range. The solar portion of their study was based on the X-ray data from Yohkoh/SXT and magnetic flux data from NSO/KP and they reported that the power-law index for the full disk integrated flux changes from the low magnetic flux end (index ~2) to high end (index ~1), which forms a "knee" in the plot of X-ray irradiance vs magnetic flux.

We used more recent data set, Hinode/XRT and SDO/HMI magnetograms, to see if we can confirm the same change of the power-law index for the full Sun data.

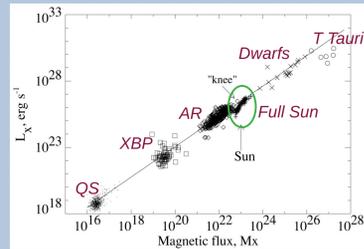


Fig.1
From Pevtsov et al (2003)

Data and Method:

[X-ray irradiance] Details can be found in Takeda et al. (2021).

- (1) Derive temperature (T_e) and emission measure (EM) from full disk X-ray flux by the filter ratio method (Vaiana et al. 1973)
- (2) Calculate isothermal coronal spectrum from the T_e and EM
- (3) Integrate the spectrum over the wavelength range 2.8 – 36.6 Å

- CHIANTI ver. 10.0.0
- Abundance : Corona
- Flux from the pixels inside 1.1 solar radii ($R = 1.1$)
- Filter pairs: Al-Mesh+ Al-Poly, and Al-Mesh+Ti-Poly
- XRT Data in the Synoptic Composite Image Archive (takeda et al. 2016)

- Correction of open fraction of pre-filter (after 2012/05)
- Correction of extra contaminant layer on filters (after 2010)

[Magnetic flux]

- 720 sec cadence HMI magnetogram
- Cut-off magnetic field strength < 75G
- Use only pixels within 60 degree of disk center
- No correction of projection effect

1-day average (Both irradiance and magnetic flux)

Result:

Single power-law (index ~1.17) fits well (Fig.2)

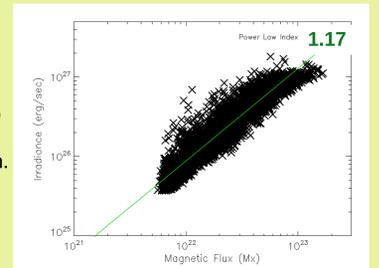


Fig.2

Total unsigned magnetic flux (HMI) v.s. X-ray irradiance (XRT). The power-law fitted line is plotted green.

Study-2

Use more data sets and try various parameters

[X-ray irradiance]

- CHIANTI ver. 10.0.0 / 9.0.1
- Abundance : Corona / Hybrid
- $R = 1.1, 1.01$
- More filter pairs: Thin-Be, C-poly,...
- All full disk observation including 4x4 binning data
- With or without some calibrations to check the impacts of them to the results

[Magnetic Flux]

- MDI Full disk 96min cadence magnetogram included
- Cut-off : 100G (It is too high. But lower cut-off caused a problem for some reason. Need to identify the cause.)

27-day average as in Pevtsov et al. (2013)

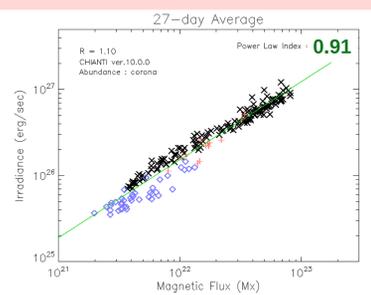


Fig.3
Blue diamond: MDI
Red plus: Both MDI and HMI
Black Cross: HMI

The power law index is smaller than 1, which is not consistent with the results of Pevtsov et al. (2003) or "study-1" above. Toriumi and Airapetian (2022) also reported power law indices larger than 1 for any various coronal radiations.

Data points using MDI magnetogram tend to be lower than HMI. It may be due to the filter pairs of XRT observation during the time. (see fig.7a)

We compare the results of other parameters with this one.

[1] CHIANTI version, abundance model: *No Major change*

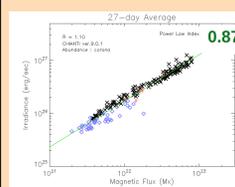


Fig.4a
CHIANTI 9.0.1

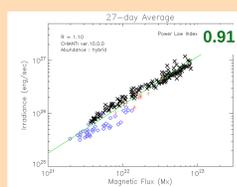


Fig.4b
Hybrid abundance model

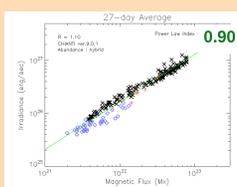


Fig.4c
Hybrid abundance model + CHIANTI 9.0.1

[2] X-ray irradiance of different energy range (5~60Å):

Power law index gets smaller

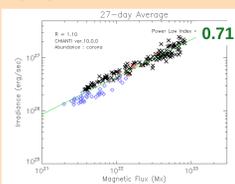


Fig.5
X-ray range (5 – 60 Å)

[3] Pixels outside of 1.01 solar radii are excluded for X-ray flux calculation:
No Major change, shifted downward

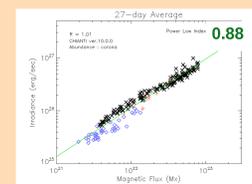


Fig.6
R=1.01

[4] Each set of XRT filter pairs:

Power law indices are sensitive to the selection of filter pairs

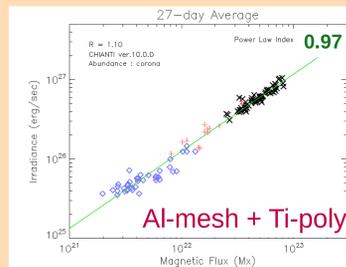


Fig.7a
Al-mesh and Ti-poly

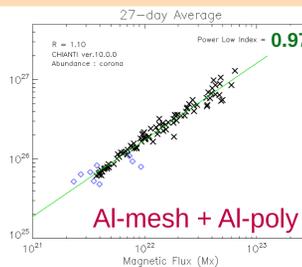


Fig.7b
Al-mesh and Al-poly

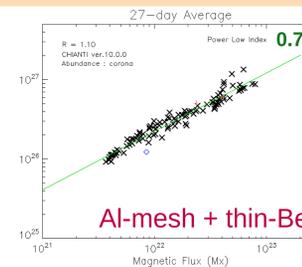


Fig.7c
Al-mesh and thin-Be

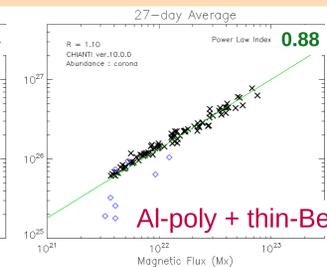


Fig.7d
Al-poly and thin-Be

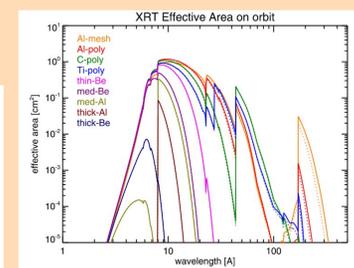


Fig.8
XRT effective area.
From Narukage et al. (2011)

[5] Without some corrections:

Minor change. The deviation from the fitted power-law line gets smaller in the case of "no correction".

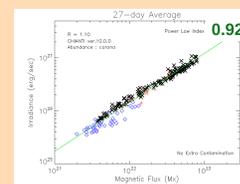


Fig.9a
No "extra contamination" correction

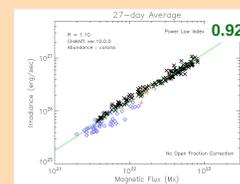


Fig.9b
No "pre-filter open fraction" correction

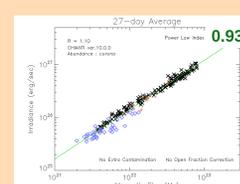


Fig.9c
No "extra contamination" nor "pre-filter open fraction" correction

[6] Different cut-off values for magnetic field strength (HMI – XRT data only):

Power law indices change drastically. Small sign of different power-law index appears in the lower magnetic flux end for the lower cut-off value

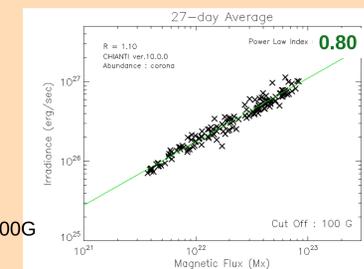


Fig.10a
Cut off : 100G

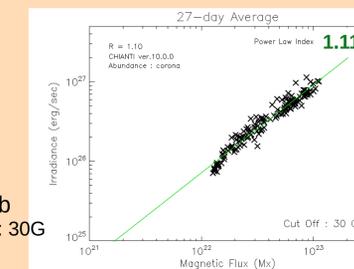


Fig.10b
Cut off : 30G

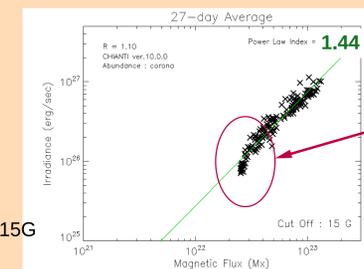


Fig.10c
Cut off : 15G

Higher power law index?

Summary:

- The power law index is sensitive to "Selection of XRT filter" and "Cut-off magnetic strength", while insensitive to other parameters.
- We found no clear "knee" of power law distribution. But we see small sign of "knee" in the plot of low cut-off value for magnetic field strength.

References

- Narukage et al. 2011, Sol.Phys., 269, 169
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Takeda et al. 2016, Sol.Phys., 291, 317
Takeda et al. 2021, Hinode-14/IRIS-11 Sci. Meeting
Toriumi and Airapetian 2022, ApJ, 927, 179
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