Relationship Between Solar Coronal X-Ray Brightness and Active Region Magnetic Fields: A Study Using High Resolution Observations

Soumitra Hazra (s.hazra@iiserkol.ac.in)
Department of Physical Sciences, Indian Institute of Science Education and Research, Kolkata, Mohanpur 741246, West Bengal, India

Dibyendu Nandy (dnandi@iiserkol.ac.in)
Department of Physical Sciences, Indian Institute of Science Education and Research, Kolkata, Mohanpur 741246, West Bengal, India
Center of Excellence in Space Sciences India, IISER Kolkata, Mohanpur 741246, West Bengal, India

B Ravindra (ravindra@iiap.res.in)
Indian Institute of Astrophysics, Koramangala, Bengaluru 560034

Abstract. By utilizing high resolution observations of nearly co-temporal and co-spatial SOT spectropolarimeter and XRT coronal X-ray data onboard Hinode, we revisit the contentious issue of the relationship between global magnetic quantities and coronal X-ray intensity. Co-aligned vector magnetogram and X-ray data are used for this study. We find that there is no pixel-to-pixel correlation between the observed loop brightness and magnetic quantities. However, the X-ray brightness is well correlated with the integrated magnetic quantities such as total unsigned magnetic flux, total unsigned vertical current, area integrated square of the vertical magnetic field and horizontal magnetic fields. Comparing all these quantities we find that the total magnetic flux correlates well with the observed integrated X-ray brightness, though there is some differences in the strength of the correlation when we use the X-ray data from different filters. While we get a good correlation between X-ray brightness and total unsigned vertical current when we use the X-ray data sets obtained from the Al-poly filter, we find no correlation between them using data sets obtained from the Ti-poly filter. We confirm that there is no consistent correlation between measures of non-potentiality and coronal X-ray intensity in these high resolution observations; thus earlier results using low resolution observations in this context are validated. We discuss the implications of these observational results for the heating of the solar corona.

Keywords: Sun: activity – Sun: corona –Sun: magnetic fields –Sun: X-rays, gamma rays

1. Introduction

Active region coronal loops appear bright in EUV and X-ray wavelengths suggesting very high temperature of the order of million degree Kelvin. The mechanism behind this high temperature coronal structure remains unknown. It is about $10^7$ ergs cm$^2$ s$^{-1}$ of energy flux required...
to maintain such a high temperature of the coronal plasma (Withbroe & Noyes, 1977). To explore this issue, during 80’s it has been suggested that there is a one-to-one correspondence between the location of the magnetic fields in the photosphere and bright coronal structures in the corona (Vaiana et al., 1973). It is also revealed that most of the X-ray luminosity is concentrated within the active region.

Several theories have been proposed to explain the heating of the coronal structures (Narain, 1996; Aschwanden, 2004; Klimchuk, 2006). These theories are broadly classified into two subcategories namely, DC heating model i.e. the nano flare heating model (Parker, 1988) and AC heating model i.e. the wave heating theory (e.g. see reviews by Aschwanden (2004)). In the AC heating model high frequency MHD waves get generated in magnetic footpoints of active regions and propagate through magnetic loops up in the corona. In the corona these waves dissipate their energy (Narain, 1996). Though recent observations reveal the propagation of MHD waves into the quiet solar corona (Tomczyk et al., 2007), it is not very clear whether these MHD waves can solely heat up active regions to such high temperature (Mandrini et al., 2000; Curtin et al., 2013). Alternatively, DC heating models are proposed to explain the heating of active regions where nanoflare like small bursts (each of energy $10^{24}$ erg) can get generated because of the magnetic reconnection (due to constant shuffling of the magnetic footpoints by the turbulent convective motions at the photosphere) and can sufficiently heat the lower solar corona (Parker, 1988; Curtin et al., 2013). Recently it has been thought that wave heating may be the major mechanism to heat quiet Sun corona (McIntosh et al., 2011; Wedemeyer-Bohm et al., 2012) while in case of coronal active regions, additional heating comes from the DC heating mechanism (Parker, 1988; Klimchuk, 2006).

To examine which of these mechanisms contribute more towards the heating of the corona it is essential to have coronal magnetic field and velocity field information. However, with the present instrumentation it is still in the initial phase (Lin et al., 2004). Since coronal field lines are linked to the photosphere, one can choose another approach that is to find the relationship between photospheric magnetic field parameters and brightness of the coronal loops. For example, Fisher et al. (1998) and Tan et al. (2007) investigated the relationship between the X-ray luminosity and photospheric magnetic field parameters. Both this results reported a strong correlation between the X-ray luminosity and total unsigned magnetic flux. Tan et al. (2007) also found a good correlation between the average X-ray brightness and average poynting flux but could not find any correlation between velocity of footpoint motions and total X-ray brightness. Their computed Poynting flux had
a range between $10^{6.7}$ to $10^{7.6}$ ergs cm$^{-2}$ s$^{-1}$ which is good enough to heat the corona (Withbroe & Noyes, 1977). Using data from other wavelengths (UV-EUV channels), Chandrashekhar et al. (2013) also found a good correlation between total emission from bright points and total unsigned photospheric magnetic flux. Forward modelling of active regions also suggest a direct correlation between magnetic flux and X-ray luminosity (Lundquist et al., 2008).

The net current is a measure of non-potentiality of the magnetic field in the active region. In active region flare and coronal mass ejection processes, the non-potentiality of the magnetic field can play a significant role (Schrijver et al., 2006). Due to low resistivity, large scale ($10^3$ km) currents can not dissipate sufficiently in the corona (Hagyard, 1988); it is thus expected to have a little large scale current contribution in the coronal heating mechanism. Also from observation, no strong correlation was found between the total X-ray luminosity and total vertical current (Metcalf et al., 1994; Fisher et al., 1998). Another measure for magnetic non-potentiality is twist in the solar active region. Observation shows that there is no significant correlation between X-ray brightness and twist in solar active region (Fisher et al., 1998; Nandy, 2008). It is said that presence of a polarity inversion line near coronal loop footpoints and strong magnetic shear are the characteristic of enhanced coronal heating (Falconer et al., 1997), confirmed later in subsequent papers by Falconer (1997) and Falconer et al. (2000). This indicates a link between coronal heating and magnetic nonpotentiality.

Longcope (1996) proposed minimum current corona model where coronal heating was described as a series of small reconnection events punctuating the quasi-static evolution of coronal field. This model predicts qualitatively the variation of the X-ray luminosity with the total flux that closely matches with observations (Fisher et al., 1998). Wang et al. (2000) have observed bright coronal loops and diffused coronal loops that are associated with the quasi separatrix layers (QSLs). Since QSLs are the places where energy release occur through 3D magnetic reconnection, they concluded that QSLs are important for heating the active region corona and chromosphere. By analysing the X-ray images taken from XRT/HINODE and corresponding MDI line-of-sight magnetograms, Lee et al. (2010) found a relationship between coronal loop brightness and magnetic topologies in AR 10963. They also found that frequent transient brightening in coronal loops are related to separators which have large amount of free energy.

Several works have been done on the active region X-ray loop brightness with different direction. Here we revisit the problem with space based vector magnetogram data which are free from atmospheric seeing effect that can produce the cross talk between various Stokes parame-
ters. Such space based magnetic field measurements also have reduced atmospheric scatter light contribution. The obtained vector field data is of highest resolution, thereby reducing the effect of fill-factor. In this paper, we use the X-ray images taken from two filters (Ti-poly and Thin Al-poly) of XRT telescope onboard HINODE satellite and vector magnetic field measurements taken from the SP/SOT telescope to study the relationship between the X-ray brightness in the active region and magnetic field parameters. Though this study has been carried out in the past using YOKOHO data set, this has not been tested so far with the currently available high-resolution data. Our intention is also to study the effect of filter response (which is mainly affected by deposition of unknown materials on CCD within few months after launching HINODE) on the relationship between X-ray brightness and magnetic field parameters. Hence we repeat the study to the data taken from HINODE telescope which is free from seeing effects. In Section 2 we provide the details of the data used in this study. In Section 3, we explain the results obtained. In Section 4, we compare the current results with the results obtained in the past.

2. Data Analysis

2.1. Data Selection

The X-ray telescope (Golub et al., 2007, XRT;) onboard Hinode satellite (Kosugi et al., 2007) makes the images of the solar corona at a spatial resolution of 1 arc-sec per pixel using different filters. XRT images are of the size 2K×2K pixel which covers 34×34 square arcmin field-of-view (FOV) of the solar corona. For the full FOV, the images are taken at a cadence of 2 sec and the partial FOV can be captured at much lesser time. XRT observes coronal plasma emission in the temperature range $5.5 < \log T < 8$, which is realized by different X-ray filters, having their own passband, corresponds to different response to plasma temperature. Within few months of launching Hinode satellite, there was a deposition of contaminating materials on CCD which significantly affects the filter response, specifically for observations of longer wavelength contribution by thinner filters. Regular CCD beakouts also are not able to remove this contaminations completely. As the effect of the contamination is mainly wavelength dependent (mostly the high wavelength observation is affected), the observations from thin Al-poly/Al-mesh filter are affected more than the other filters such as Ti-poly, Be-med etc. For the present study, we have used the data taken from Ti-poly and thin Al-poly filter which observe the solar coronal plasma...
at a temperature larger than 2 MK and 0.1 MK respectively.

The spectro-polarimeter (Ichimoto et al., 2008, [SP;]) is a separate back-end instrument of the Solar Optical Telescope (Tsuneta et al., 2008, [SOT;]) onboard Hinode satellite. The SP provides the Stokes signal with high polarimetric accuracy in 6301 and 6302 Å photospheric lines. The primary product of stokes polarimeter is stokes IQUV line suitable for derivation of vector magnetogram of photosphere. The spatial resolution along the slit direction is 0.295" pixel$^{-1}$ and in scanning direction is 0.317" pixel$^{-1}$. The Stokes vector has been inverted using the MERLIN code which is based on the Milne-Eddington inversion method. The inverted data provides the field strength, inclination, azimuth along with the Doppler velocity, continuum images and many other parameters. The inverted data sets are stored in Community Spectropolarimetric Analysis Center (http://sot.lmsal.com/data/sot/level2d and http://www.csac.hao.ucar.edu/). We obtain the data from the same website. The correction for the ambiguity in the transverse field of the vector magnetograms is done using the minimum energy algorithm (Metcalf, 1994; Leka, 2009). The resulting magnetic field vectors have been transformed to the heliographic co-ordinates (Venkatkrishnan & Gray, 1989). The final error in measuring the vertical and transverse field strength is 10 G and 30 G respectively.

For our present study, we have selected 20 different NOAA active regions observed at different times of the year. We have also excluded the active regions whose central meridional distance larger than 30° from disk centre. We take the vector magnetogram data close to the timings of soft X-ray data obtained from both Ti-poly and Al-poly filter of XRT telescope. In Table 1 and 2 we list the different active regions used in the study, the date and time of the observations of the vector magnetogram and the corresponding soft X-ray data. Following these two sets of data we have also obtained the G-band data taken by the X-ray telescope. This data has been used for co-alignment of each of the data sets. For each selected vector magnetogram, we have taken both XRT X-ray (Ti-poly and Al-poly) data and G-band data at the same time. For the convenience of our readers, we use the word Ti-poly data sets to represent X-ray image obtained from Ti-poly filter and their corresponding magnetogram and similarly we use the word Al-poly data sets for Al-poly filter X-ray image and corresponding magnetogram. The obtained X-ray data are calibrated using the XRT_PREP.PRO available in the solarsoft routine. The calibrated data are normalized to one second exposure time. These data are in units of data number.
Table I.

| Date      | No of Active Region | Magnetogram Scan start time | XRT X-ray (Ti-Poly) observation time |
|-----------|---------------------|----------------------------|-------------------------------------|
| 01.05.2007 | NOAA 10953          | 05:00:04                   | 05:00:57                            |
| 01.07.2007 | NOAA 10962          | 13:32:05                   | 13:31:51                            |
| 15.07.2010 | NOAA 11087          | 16:31:19                   | 16:30:53                            |
| 10.08.2010 | NOAA 11093          | 09:15:04                   | 09:14:18                            |
| 31.08.2010 | NOAA 11102          | 02:30:04                   | 02:30:42                            |
| 23.09.2010 | NOAA 11108          | 07:21:05                   | 07:21:12                            |
| 26.10.2010 | NOAA 11117          | 10:45:46                   | 10:51:55                            |
| 22.01.2011 | NOAA 11149          | 09:31:28                   | 09:43:22                            |
| 14.02.2011 | NOAA 11158          | 06:30:04                   | 06:30:02                            |
| 04.03.2011 | NOAA 11164          | 06:15:06                   | 06:15:04                            |

Table II.

| Date      | No of Active Region | Magnetogram Scan start time | XRT X-ray (Al-Poly) observation time |
|-----------|---------------------|----------------------------|-------------------------------------|
| 30.08.2011 | NOAA 11280          | 07:35:23                   | 07:35:36                            |
| 13.09.2011 | NOAA 11289          | 10:34:05                   | 10:34:24                            |
| 28.09.2011 | NOAA 11302          | 18:38:05                   | 18:38:16                            |
| 28.11.2011 | NOAA 11360          | 00:05:20                   | 00:03:04                            |
| 01.02.2012 | NOAA 11413          | 08:51:31                   | 09:03:35                            |
| 16.08.2012 | NOAA 11543          | 13:35:05                   | 13:35:19                            |
| 25.09.2012 | NOAA 11575          | 12:49:06                   | 12:50:37                            |
| 02.10.2012 | NOAA 11582          | 09:53:06                   | 09:54:39                            |
| 28.10.2012 | NOAA 11594          | 01:40:05                   | 01:42:23                            |
| 17.11.2012 | NOAA 11619          | 12:49:06                   | 12:50:37                            |
2.2. **Data Coalignement**

To overlay the XRT X-ray data with vector magnetograms, we first co-align the G-band data taken by XRT telescope with the continuum image. The continuum image is obtained by after inverting the Stokes data set. This has been done by first identifying the dark center of the sunspot in both G-band and continuum images. Later, we interpolate the continuum image data to the XRT image resolution. In the next step we choose the same field-of-view (FOV) in both the data sets. Then by using the maximum correlation method we co-align the continuum images with the G-band images. A similar shift has been applied to the vector field data to co-align all the data sets to X-ray images of the XRT data sets.

3. **Integrated Quantities**

In this study, various integrated quantities have been derived to compare with the X-ray brightness. We compute the individual as well as integrated quantities such as total magnetic flux, total magnetic energy etc and compare them with the X-ray brightness. Below, we describe each of those quantities.

3.1. **Active Region Coronal Loop X-Ray Brightness**

The integrated quantity X-ray brightness \( L_x \) is computed by summing up the values of each bright pixel in the image and then multiplied with the pixel area. The bright pixels are selected by using the threshold values. We find the rms value in the X-ray image and select the pixels whose value is larger than 1-\( \sigma \) level of the image. This way we select the bright pixels in the X-ray image (Fig. 2).

3.2. **Global Magnetic Field Quantities**

Since the selected active regions are close to the disk center, obtained magnetic field vectors are horizontal and vertical to the solar surface. Using the \( B_x \), \( B_y \) and \( B_z \), it is possible to derive the integrated quantities which can be correlated with the X-ray brightness for finding the relationship between the two. We select pixels in \( B_x \), \( B_y \) and \( B_z \) data corresponding to the pixels in the X-ray data. The following integrated quantities are computed from the magnetic field components.

\[
\phi_{tot} = \sum |B_z|dA
\]
Here $B_z$ and $B_t$ represents the vertical and transverse magnetic field. $\phi_{tot}$ and $J_{tot}$ are the absolute total magnetic flux and current. $J_z$ is the vertical current density and $\sum dA$ is the effective area on the solar surface corresponding to vector magnetogram. The twist component of the magnetic field is computed using the following equation

$$\alpha_z = \frac{\mu_0 J_z}{B_z}$$

where $\mu_0$ is the permeability of free space. We compute all the magnetic quantities from the vector magnetogram for all active regions. Other sub quantities such as the ratio $\frac{\mu_0 J_{tot}}{\phi_{tot}}$ are also computed and correlated with the X-ray brightness.

4. Results

Figure 1 shows the overlay of the contours of $B_z$ component of the magnetic field on the X-ray image of active region NOAA 11093. This has been done after co-alignment of both the images. The contour map shows that there is a less X-ray brightness in the umbral part of the sunspot and loops are emanating from the penumbral part of the sunspot. The bright loops are associated with the plage regions as has been observed before (Pallavicini et al., 1979). The loops are still not resolved fully at the XRT resolution. However, it is seen that the cluster of loops turn in clockwise direction. On the west side of sunspot, the loop structures are absent. At the same location in the photosphere, large scale plage structures are also absent. This may indicate that large scale plage regions are essential for the loops to appear in X-rays. Thus we find a visual correlation between the location of the plages and the bright loops in X-rays.

4.1. Correlation Between Magnetic Quantities and X-ray Brightness

In order to find a correlation between the photospheric magnetic field parameters, we make a scatter plot between each of the derived parameters and the X-ray brightness for the active region NOAA 11093.
Figure 1. The contours of vertical magnetic field is overlaid upon the X-ray image of active region NOAA 11093 taken in Ti-poly filter by XRT telescope. Contour with thick solid lines (gray) represent negative vertical magnetic field and the thin solid lines (white) represents the positive magnetic fields. The contours were drawn for the field strength of 500, 1000, 1500, 2000 and 3000 G.

We use a threshold level of 1-σ to select the bright pixels in the active region loops and the corresponding pixels in the magnetograms. Figure 2 shows the contour map of 1-σ level threshold of X-ray brightness overlaid upon the X-ray image of active region NOAA 11093. Clearly, the 1-σ level threshold line of the contour map indicates the borders of the bright loops. Figure 3 shows the scatter plots between the X-ray brightness and the absolute vertical magnetic field strength (top-left), absolute current density (top-right), magnetic energy ($B_z^2$) (bottom-
left), and twist (bottom-right) parameters. Even if the contour plot (Fig. 1) shows there may be some correlation between the observed coronal loops and the magnetic field but we do not find any pixel-to-pixel correlation between the X-ray brightness and magnetic field parameters (see Fig. 3). Also no correlation has been found among these quantities for other active regions listed in Table 1 and 2 of Section 2.1

4.2. Correlation Between Global Magnetic Field Quantities and X-ray Brightness

Since we do not find any correlation between the X-ray brightness and magnetic field parameters, we make an attempt to find whether there is any correlation between the integrated magnetic quantities and X-ray brightness in active regions as has been done before (Fisher et al., 1998). We use the XRT data for 10 active regions each in the Ti-poly and Al-poly data sets (all data sets are listed in Table 1 and 2). We select only those pixels whose intensity values are above 1-σ threshold in both X-ray data. The corresponding pixels are also selected in vector magnetogram data sets. Figures 4 and 5 show the plots between the X-ray brightness and total unsigned magnetic flux (top-left), $B_{z,tot}^2$.
Figure 3. Scatter plot of X-ray brightness per pixel with magnetic quantities $B_z$ (top-left), current($J_z$)(top-right), $B_z^2$ (bottom-left) and $B_h^2$ (bottom-right) per pixel. The rank correlation coefficient for all this cases are 0.2433814, 0.00690383, 0.243814 and 0.238859 respectively (using X-ray data obtained from Ti-poly filter).

(top-right), $B_{h,tot}^2$ (bottom-left) and unsigned $J_{tot}$ (bottom-right) in logarithmic scale. Figure 4 is for the Al-poly filter and Figure 5 is for the Ti-poly filter. A good correlation is observed between the X-ray flux and the global magnetic field parameters in the Al-poly X-ray data sets. The value of correlation coefficient is reduced in Ti-poly data sets. Though the value of correlations are different in Al-poly and Ti-poly, the relationship of X-ray flux with different magnetic quantities are similar in both cases. In order to examine which of the magnetic quantities contribute more towards X-ray flux, we need to examine whether there is any correlation between global magnetic quantities. This has been done by finding the correlation between each of the magnetic parameters with the total unsigned flux and also by following partial correlation analysis method.

4.3. CORRELATIONS AMONG GLOBAL MAGNETIC FIELD QUANTITIES AND PARTIAL CORRELATION ANALYSIS

Figures 6 and 7 show the plots between total unsigned magnetic flux and all other magnetic variables such as the total absolute current,
Figure 4. Correlation between X-ray brightness with global magnetic field quantities $\phi_{\text{tot}}, B_{z,\text{tot}}, B_{h,\text{tot}}^{2}$, and $J_{z,\text{tot}}$. Both pearson and spearman correlation coefficients are listed in figure (using X-ray data obtained from Al-poly filter). Confidence level(p) for these plots are 99.55%, 97.88%, 96.06%, 99.91% respectively.

Table III. List of partial correlation coefficients between different quantities for different filter

| Correlation between quantities (controlling $\phi_{\text{tot}}$) | Ti-Poly | Al-Poly |
|-------------------------------------------------------------|---------|---------|
| X-ray intensity vs $J_{\text{tot}}$                          | 0.2280  | 0.5810  |
| X-ray intensity vs $B_{z,\text{tot}}^{2}$                    | 0.0388  | -0.2583 |
| X-ray intensity vs $B_{h,\text{tot}}^{2}$                    | 0.2800  | 0.1515  |

$B_{z,\text{tot}}^{2}, B_{h,\text{tot}}^{2}, B_{h,\text{tot}}^{2}/B_{z,\text{tot}}^{2}$. Figure 6 is for the Al-poly filter and Figure 7 is for the Ti-poly filter. Each of these parameters show good correlation with the total unsigned magnetic flux except the quantity $B_{h,\text{tot}}^{2}/B_{z,\text{tot}}^{2}$ which shows a small or negative correlation with total unsigned magnetic flux. In order to find the inter relationship between each of the magnetic parameters, we have carried out the partial correlation anal-
Figure 5. Correlation between X-ray brightness with global magnetic field quantities \( \phi_{\text{tot}} \), \( B_{z,\text{tot}}^{2} \), \( B_{h,\text{tot}}^{2} \) and \( J_{z,\text{tot}} \). Both pearson and spearman correlation coefficients are shown in plots (using X-ray data obtained from Ti-poly filter). Confidence level (p) for these plots are 96.89\%, 92.69\%, 91.98\%, 91.98\% respectively.

In partial correlation technique, the correlation between the two dependent variables is examined after removing the effects of other variables. Table III shows the partial correlation coefficients between the X-ray brightness and integrated magnetic quantities (except magnetic flux) after removing the effect of magnetic flux. The obtained results are different when we use the data from different filters. It appears that the luminosity is directly related to both absolute total current (partial correlation coefficient 0.5810) and unsigned magnetic flux in the system when we use the data from Al-poly. However, it does not appear to be true in Ti-poly data. In this case, X-ray brightness is only related with unsigned magnetic flux and other magnetic quantities are related with X-ray brightness only because of their mutual correlation with magnetic flux. From principal component analysis (Kendall et al., 1983; Fisher et al. (1998) also got similar result which we obtain using Ti-poly data sets but result differs slightly when we use Al-poly data sets.
4.4. Correlations Between X-ray Brightness and Magnetic Twist Parameters

The X-ray brightness is positively correlated with the unsigned magnetic flux. It is interesting to see how the X-ray brightness is correlated with the twist parameter of the magnetic field. Figures 8 and 9 show the plots between $\mu_0 J_{\text{tot}}/\phi_{\text{tot}}$ and $\phi_{\text{tot}}$, X-ray brightness with $\alpha_{\text{best}}$ and $\mu_0 J_{\text{tot}}/\phi_{\text{tot}}$. The plots shown in Figures 8 and 9 are for the Al-poly and Ti-poly filters respectively. From these plots, we find that $\mu_0 J_{\text{tot}}/\phi_{\text{tot}}$ is anti-correlated with the magnetic flux. The X-ray brightness is also anti-correlated with $\mu_0 J_{\text{tot}}/\phi_{\text{tot}}$. However, We find a significant correlation between X-ray intensity and magnetic twist parameter ($\alpha_{\text{best}}$) when we use Ti-poly data sets. But no correlation is found when we use Al-poly data sets. Thus we get different results using X-ray data sets obtained from different filters onboard XRT. Note that this difference in results can be explained as a consequence of contamination in CCD that could have altered the filter response.

Figure 6. Correlation of global magnetic quantities $J_{z,\text{tot}}$, $B_{z,\text{tot}}^2$, $B_{h,\text{tot}}^2$ and $B_{h,\text{tot}}^2/B_{z,\text{tot}}^2$ with $\phi_{\text{tot}}$. Both pearson and spearman correlation coefficients are listed in figure (using X-ray data obtained from Al-poly filter). Confidence level(p) for these plots are 99.44%, 100%, 99.73%, 21.5% respectively.
5. Summary & Discussions

The coronal X-ray emission is mostly concentrated in the large scale magnetic fields. To identify which of the magnetic field parameters are directly correlated with the observed brightness of the X-ray loops we have analysed the X-ray data from XRT/HINODE and vector magnetic field measurements from SP/HINODE. Though we have not observed any pixel-to-pixel correlation between the X-ray brightness and magnetic field parameters, we have observed a good correlation between the integrated magnetic field parameters and the X-ray loop brightness. A large value of correlation is observed with the total unsigned magnetic flux. Other parameters are also correlated well with the X-ray brightness. This is because all these parameters are the subset of the magnetic flux parameter which correlates well with the X-ray brightness. Hence it appears that the magnetic flux could be responsible for the observed X-ray brightness. Generally it is observed that larger active regions have higher magnetic flux compared to smaller active regions, thus suggest-
ing large active regions are brighter than the small active regions. This result is similar to the one obtained by Fisher et al. (1998).

A large amount of total current indicates the highly nonpotential nature of the active region. This large scale current is known to produce large scale flares (Schrijver et al., 2008). Although we do not find any consistent strong correlation relationship between X-ray luminosity and total vertical current, one cannot rule out the possibility of small A class flares which can heat the corona on large scale. The value of force-free parameter $\alpha$ represents the twist in the active region magnetic fields (another measure for nonpotentiality). Larger the value of $\alpha$, larger the amount of twist in the active region. We observe a moderate correlation between the X-ray loop brightness and twist parameter ($\alpha_{\text{best}}$) when we use Ti-poly data sets but no correlation for Al-poly data sets. It has also been observed that the unsigned magnetic helicity injection well correlates with the X-ray luminosity (Yamamoto et al., 2004). Thus large amount of flux will lead to larger helicity injection and cause more X-ray brightness.

Figure 8. Scatter plots of $\mu_0J_{\text{tot}}/\phi_{\text{tot}}$ with $\phi_{\text{tot}}$, X-ray irradiance with $\alpha_{\text{best}}$ and $\mu_0J_{\text{tot}}/\phi_{\text{tot}}$. Both pearson and spearman correlation coefficients are listed in figure (using X-ray data obtained from Al-poly filter). Confidence level($p$) of these plots are 93.35%, 41.65%, 70.44% respectively.
Figure 9. Scatter plots of \( \mu_0 J_{\text{tot}}/\phi_{\text{tot}} \) with \( \phi_{\text{tot}} \), X-ray irradiance with \( \alpha_{\text{best}} \) and \( \mu_0 J_{\text{tot}}/\phi_{\text{tot}} \). Both Pearson and Spearman correlation coefficients are listed in figure (using X-ray data obtained from Ti-poly filter). Confidence level (p) of these plots are 70.44%, 90.42%, 53.03% respectively.

In case of Alfvén wave heating model (e.g. see reviews by Aschwanden (2004)), magnetic flux is related to the power dissipated at the active region through the square of the Alfvén velocity. Thus total X-ray luminosity will be some fraction of this power, which indicates that there is a strong correlation between total X-ray luminosity and total magnetic flux. Our results also suggest the same; but from a detail analysis, Fisher et al. (1998) shows that energy in the waves are not sufficient to explain observed level of coronal heating. MCC model (Longcope, 1996) also predicts a strong correlation between total X-ray intensity and total magnetic flux. On the other hand, in case of nanoflare heating model (Parker, 1988), power dissipated at the active region is related with \( B_{z, \text{tot}}^2 \), suggesting that total X-ray luminosity must be strongly correlated with \( B_{z, \text{tot}}^2 \) rather than \( \phi_{\text{tot}} \). But data shows strong correlation between total X-ray intensity and total magnetic flux.

The power law relation between the X-ray loop brightness and the magnetic flux can be useful for finding the level of activity on the
Sun and other stars where it is difficult to measure the active region magnetic field strength. The time cadence of the SP/HINODE is small, one vector magnetogram in 1 hr. Also, it takes about an hour to scan the whole active region during which lot more changes could have happened in the active region itself. The heliospheric magnetic imager (HMI) onboard the Solar Dynamic Observatory (Pesnell et al., 2012; [SDO;) provides vector magnetograms at high cadence though at moderate resolution compared to SP/HINODE. These magnetograms are useful to study the time variation of X-ray brightness and change in magnetic flux and other magnetic field parameters. This will provide a clear picture of the relationship between the coronal X-ray brightness and magnetic field parameters.

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