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An Observational Test for Solar Atmospheric Heating

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Abstract. We study the evolution of the emissivity correlated with magnetic flux density of an active region from its birth until its decay throughout all atmospheric layers. We analyse multi-wavelength data obtained from SOHO, Yohkoh, GOES, SOLSTICE and 10.7 cm radio data from DRAO, Canada. We utilise our results to understand the scaling laws in different atmospheric layers. We confirm that the relationship between the emitted excess flux (flux - basal flux) and photospheric magnetic flux density $\Delta F(< fB >)$ follow power laws, and the powers depend on the formation temperature of the line(s) involved.

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Instrument	Temperature	Exponent (b)
GOES 1-8 Å	$6\ 10^6$K	2.28 ± 0.24*
SXT AlMg, halfres.	$3\ 10^6$K	1.82 ± 0.20
SXT Al.1, halfres.	$3\ 10^6$K	1.67 ± 0.18
SXT AlMg, fullres.	$3\ 10^6$K	1.94 ± 0.08
SXT Al.1, fullres.	$3\ 10^6$K	1.87 ± 0.08
CDS Fe XVI	$2\ 10^6$K	1.49 ± 0.62
CDS Mg IX	$1\ 10^6$K	1.02 ± 0.52
CDS O V	$3\ 10^5$K	0.94 ± 0.36
C IV	$1\ 10^5$K	1.12 ± 0.24*
Lyman α	$4\ 10^4$K	1.10 ± 0.16*
CDS He I	$2\ 10^4$K	0.99 ± 0.22
DRAO 10.7 cm		1.84 ± 0.14*
EIT 284 Å	$2\ 10^6$K	1.11 ± 0.18
EIT 195 Å	$1.6\ 10^6$K	0.94 ± 0.20
EIT 171 Å	$1.3\ 10^6$K	0.98 ± 0.24
EIT 304 Å	$5\ 10^4$K	0.93 ± 0.14

Table 1. Exponents b in the power-law function $\Delta F \propto < fB >^b$. The instruments which have a broad sensitivity in temperature (DRAO and EIT) are tabulated separately. Asterisks indicate one-dimensional data.

1. Introduction

In the atmospheres of cool stars and the Sun a two-component heating mechanism seems to be present: an acoustic heating of the chromosphere (basal flux) and a magnetic heating of the corona (excess flux). A power law dependence was found between the photospheric magnetic flux density $< fB >$ and the excess flux ΔF in different atmospheric layers (e.g. Golub et al 1982; Schrijver et al., 1985; Schrijver, 1991; Harvey and White, 1999). Here we revisit the problem and analyse observations obtained with a large set of new instruments following the evolution of one single isolated bipolar active region (NOAA 7978) during six months (July-Dec. 1996).

2. Results

Using SOHO/MDI magnetic maps we find that the magnetic area of the active region (AR) increased roughly linearly at a rate of $1.28\ 10^4$ km^{2}sec^{-1}. The magnetic flux density (B averaged over the entire AR) reached the highest level (188 Mx cm^{-2}) by the fourth day of the emergence and steadily decreased after that.

We explore the relationship between the magnetic flux density and intensity, emission measure (EM) and temperature (T) of the AR. We measure the total flux emitted by the active region in different spectral domains and average it over the area where the emission came from, and then subtract a basal flux. Then, we produce log-log plots of the emitted flux density ΔF versus the magnetic

Parameter	Exponent (b)
SXT emission measure, fulldisc	1.18 ± 0.22
SXT emission measure, partial	1.22 ± 0.08
SXT temperature, halfres.	0.29 ± 0.08
SXT temperature, fullres.	0.30 ± 0.01
BCS temperature	$0.49 \pm 0.03*$
MDI magnetic area	-1.02 ± 0.12

Table 2. Exponents b in the power-law function $a < fB >^b$ fitted to T, EM and magnetic area data.

flux density. We find that the ΔF, EM and T vs. $< fB >$ relationship follow power-laws (Tables 1 & 2.), and the exponents seem to depend on the formation temperature of the radiation analysed. Since in this study we concentrated on the decay phase of the long-term evolution, the exponents listed in Table 1 represent the decay period (July 10 (max) - Dec. 16 (min)). For the one-dimensional data (SOLSTICE, 10.7 cm radio) we considered the Aug. 2 - Oct. 23 period only, when the AR was alone on the disc.

Computing scaling laws and deducing relationships between T, EM, electron density, plasma pressure (P) and $< fB >$ we find that the fluxes emitted in the corona and the transition region have different dependence on P: $F_{corona} \propto P^2$, and $F \propto P$ for the transition region. This is the basic reason for different exponents in the relation between the emitted fluxes and the averaged photospheric field strength $\Delta F(< fB >)$. Within the error bars of the observations, a simple static model of the 1-D thermal structure along loops permits us to understand the difference of scaling between the observed coronal and TR fluxes. Understanding the radio flux at 10.7 cm is more difficult since two mechanisms are certainly contributing (free-free and the gyroresonance emission). The dependence of chromospheric emission on $< fB >$ is linked to the expansion of the thin magnetic flux tubes.

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