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Microflares as Possible Sources for Coronal Heating

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Abstract. We present a preliminary study of 27 microflares observed by Solar X-ray Spectrometer (SOXS) mission during July 2003 to August 2006. We found that all 27 microflares show the Fe-line feature peaking around 6.7 keV, which is an indicator of the presence of coronal plasma temperature $\geq$ 9 MK. On the other hand, the spectra of microflares show hybrid model of thermal and non-thermal emission, which further supports them as possible sources of coronal heating. Our results based on the analysis show that the energy relapsed by the microflares is good enough for heating of the active corona. We discuss our results in the light of the hybrid model of microflares production.

Key words. Solar flares: microflares, Fe-line feature—coronal heating.

1. Introduction

The solar corona is some 200 times hotter than the surface of the Sun. The main source of energy for heating the corona is believed to be the magnetic field which dominates the corona. Magnetic reconnection is probably the most important mechanism for releasing magnetic energy and may, therefore, be important for coronal heating or micro-flaring. The best observational examples of reconnection in the corona are thought to be X-ray bright points, which are small-scale brightenings seen randomly throughout the whole corona. These brightenings are called as microflares and further small scale brightening as nanoflares. The coronal heating mechanisms so far widely known are based on two fundamental physical processes viz., acoustic wave dissipation and micro/nanoflares. Acoustic heating is ruled out due to the dependency of Lx on rotational speed. Magneto-acoustic heating by waves and/or particles induced from magnetic fields at the bottom of the corona is, however, proposed as a fundamental source. However, the observational fact that the Sun emits a large number of strong bursts of X-rays before the UV emission of flares, known as 'nanoflares' was proposed as a mechanism to heat the corona. Parker (1988) proposed that at 250,000 K some magnetic reconnection takes place between chromosphere and corona. Thus low altitude reconnection in the upper chromosphere or low transition region might be the possible source of energy release to heating the corona. The SOHO observed low temperature gas ($<$ 400,000 K) going down; hotter gas going up and nowadays it is thought to be one of the mechanisms involved in coronal heating. In this context, one of the most potential candidates for coronal heating proposed in the last decade is micro and nanoflares, which have been observed in EUV and X-ray waveband by EIT/SOHO and SXT/Yohkoh missions. It has been proposed that these small-scale flares exhibit hard X-ray spectrum indicative of electron acceleration process in them and these electrons move down and heat the lower corona and transition region layers. Recently it has been proposed that microflares show thermal plus non-thermal hybrid mechanism, which may indicate them as a strong source for coronal heating (Jain *et al.* 2006b).

The Solar X-ray Spectrometer (SOXS) mission (Jain *et al.* 2005, 2006a) observes full disk integrated X-ray emission from the Sun to observe solar flares of low intensity to very high intensity and has been found to be a very useful instrument to study microflares. We have considered the microflares from SOXS mission simultaneously to other optical and radio wavebands in order to confirm their occurrence and identification for the current investigation. The SOXS mission data provide excellent spectra in the energy range 4–56 keV using Si and CZT detectors. The X-ray spectra from Si detector in the energy range 4–25 keV, enable us to study Fe and Fe/Ni line features. The Fe and Fe/Ni X-ray emission features are not visible in the coronal X-ray emission due to gravitational settling unless the temperature exceeds 9 MK during flares (Jain *et al.* 2005, 2006a). Recently, Liu *et al.* (2004) have reported that microflares are seen in Hα, soft and hard X-ray wavelengths and their temporal evolution resembles large flares. They found that the small impulsive microflare events originate near well-defined magnetic neutral lines in active regions. The X-ray spectral analysis of the microflares and their association with type III radio bursts could enable them to conclude that the X-rays over 10 keV are emitted by non-thermal electrons.

In the present paper, we have studied 27 microflares using temporal and spectral data from the Si detector of the SOXS mission. We aim to address the question whether microflares are the most possible candidates for coronal heating.

2. Observations

Flares on GOES intensity class $\leq$ C1.0 are defined as microflares (Chang *et al.* 2004; Jain *et al.* 2006b). Kumar (2004) studied the statistical relationship between SOXS and GOES flares as both missions are in geostationary orbit and both measure full disk integrated X-ray emission. He found correlation coefficient ≥ 0.9 between flares observed by these two missions. Thus we have chosen only those SOXS flares as microflares, which have been observed by GOES on the intensity class $\leq$ C1.0 and also observed either in Hα or radio wavebands. The list of microflares observed by SOXS mission and chosen for the current investigation is presented in Table 1.

3. Analysis and results

Details of SOXS mission, in-flight performance, calibration, instrumental response and background are described by Jain *et al.* (2005, 2006a). The data format and data analysis techniques are also presented by them. SOXS delivers two types of data, viz., temporal and spectral mode. After unambiguous identification of the microflare, it is cross-correlated with GOES and Hα or radio observations on time and intensity scales. Then we undertook detailed spectral analysis for the period of microflare using standard OSPEX software in SolarSoft package. Fig. 1 shows, as an example, the light

Table 1. Temporal characteristics of microflares.

Sl.no.	Date	GOES class	Start time			Peak time			End time			Duration	Peak counts/s
			Hour	Min	Sec	Hour	Min	Sec	Hour	Min	Sec	Min	Si 4–9.2 keV
1	23 Dec 03	B8.7	4	55	7.1	4	57	3.2	5	1	48.9	6.70	48
2	11 Jan 04	C1.0	4	14	53.3	4	16	29.3	4	21	30.3	6.62	77
3	01 Feb 04	B6.9	6	43	33.8	6	49	36.8	6	52	7.9	8.57	68
4	25 Feb 04	B8.9	4	6	19.7	4	10	0.4	4	14	40.7	8.35	65
5	25 Feb 04	B9.8	4	59	20.5	5	6	56.2	5	24	36.8	25.27	104
6	25 Feb 04	C1.0	5	24	36.8	5	27	21.2	5	36	3.5	11.45	68
7	04 Mar 04	B4.6	4	49	4.3	4	53	56.7	5	12	41.6	23.62	113
8	06 Apr 04	C1.0	5	34	11.2	5	35	6.8	5	39	28.1	5.28	141
9	24 Oct 04	B7.1	3	46	18.4	3	48	10.5	3	55	45.6	9.45	31
10	24 Oct 04	B8.6	4	10	45.3	4	12	42.6	4	16	37.3	5.87	94
11	24 Oct 04	B9.5	4	26	31.9	4	28	17.6	4	31	5.8	4.57	93
12	24 Oct 04	B7.1	5	52	5.3	5	53	26.6	5	56	9.2	4.07	38
13	30 Oct 04	B9.2	4	52	0	4	56	0	5	1	0	9.00	176
14	30 Nov 04	B7.7	3	56	23.1	3	59	22.2	4	3	50.9	7.46	51

Table 1. (*Continued*)

Sl.no.	Date	GOES class	Start time			Peak time			End time			Duration	Peak counts/s
			Hour	Min	Sec	Hour	Min	Sec	Hour	Min	Sec	Min	Si 4–9.2 keV
15	31 Jan 05	B5.9	6	17	20.7	6	18	24.3	6	22	2.4	4.70	70
16	06 Apr 05	B7.3	4	44	49.8	4	48	58.6	4	56	59.9	12.17	78
17	24 Jan 06	B3.8	4	10	20.9	4	12	36.3	4	16	52.3	6.52	37
18	24 Jan 06	B3.3	5	21	18.6	5	24	6.3	5	27	23.9	6.09	38
19	20 Mar 06	B7.1	4	35	30.2	4	37	3.2	4	40	15.1	4.75	63
20	11 Apr 06	C1.0	4	36	24.6	4	38	14.4	4	42	58.1	6.56	133
21	24 Apr 06	C1.0	3	58	37.7	4	2	0.6	4	14	25.9	15.80	104
22	26 Apr 06	B3.7	4	43	44.2	4	46	35.5	4	48	32.6	4.81	38
23	13 Aug 06	B7.5	4	43	6.9	4	45	17.5	4	47	29.8	4.38	104
24	17 Aug 06	B1.0	4	28	16.8	4	29	54.9	4	32	56.8	4.67	179
25	21 Aug 06	B6.7	20	17	54.3	20	19	3	20	21	24.2	3.50	73
26	27 Aug 06	B3.3	5	37	29.5	5	38	39.1	5	42	29.4	5.00	36
27	31 Aug 06	B7.1	4	25	28.4	4	26	58.8	4	31	47.6	6.32	91

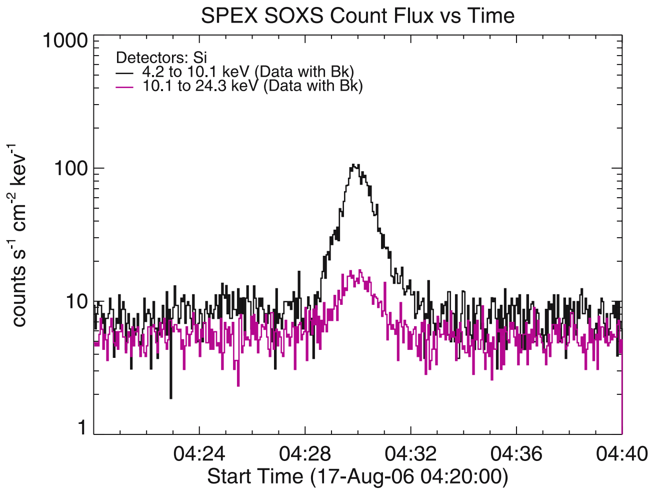

Figure 1. Light curves of the microflare observed on 17 August 2006 by Si detector of SOXS mission in 4.2–10.1 and 10.1–24.3 keV bands.

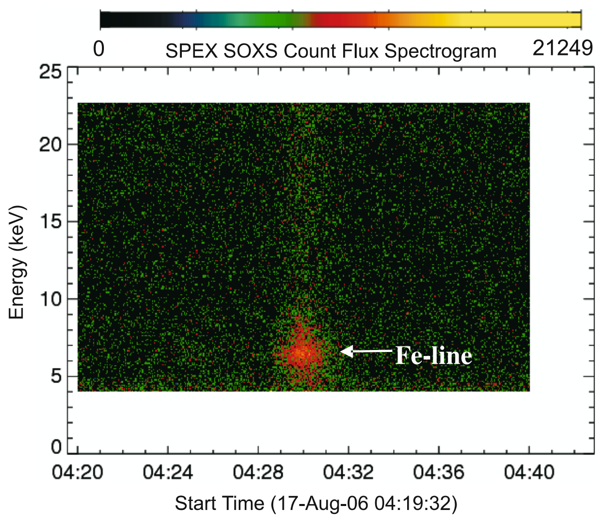

Figure 2. The spectrogram of 17 August 2006 microflare observed by Si detector of the SOXS mission. Note the Fe-line complex (red colour) shown by arrow peaking near 6.7 keV.

curves of a microflare observed on 17 August 2006 by Si detector of the SOXS in 4.2–24.3 keV. The light curves provide us the evolution and duration of the microflares. Our study of 27 microflares considered for this investigation shows the duration varies between ~ 4 and 25 min. In Hα, the microflares are classified as subflares (SF). In Fig. 2, the spectrogram of the same microflare (cf. Fig. 1) is presented, which shows unambiguously the Fe line feature indicated by arrow. It may be noted from the Fig. 2, that the microflare reveals Fe line complex (red colour) peaking at 6.7 keV. However, Fe/Ni line complex was not visible in all microflares under investigation except in two

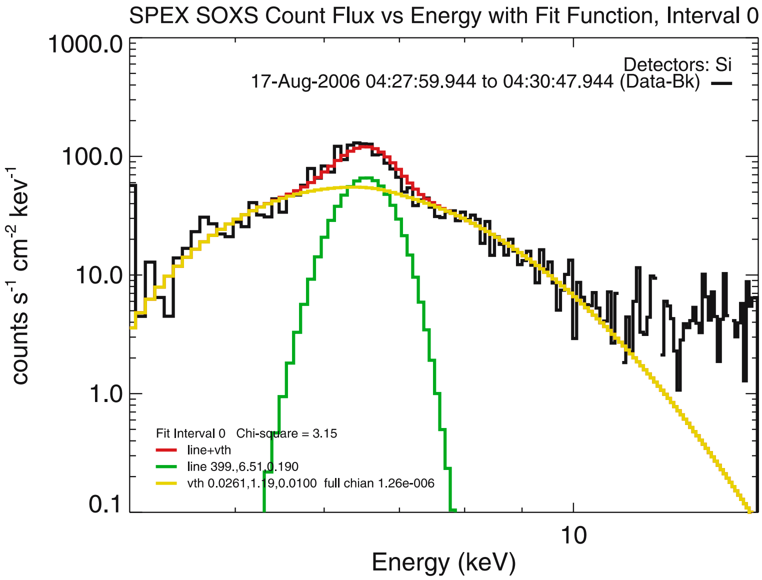

Figure 3. Count spectra of the microflare observed on 17 August 2006 by Si detector of SOXS mission and fitted with thermal and line emission.

microflares, viz., 25 February (B9.8) and 30 October 2004 (B9.2). The temperature for formation of Fe/Ni line feature has been proposed to be 15 MK (Phillips 2004; Jain *et al.* 2006a). However, the presence of Fe line feature in each microflare under study implies that the temperature in the coronal plasma had reached ≥ 9 MK, which is enough to heat the corona.

4. Discussion and conclusion

In Fig. 3, we show the count spectra of a microflare, which also shows unambiguously the presence of Fe line feature at ~ 6.7 keV. The microflares are assumed to be the result of interaction of low lying loops (Jain *et al.* 2006b; Aschwanden 2007), and thereby causing reconnection in the region ranging from the upper chromosphere to transition region or corona. The electrons accelerated during the reconnection heat the ambient plasma in the upper chromosphere, transition region or corona. They also interact with ambient material while moving down along the loops and loosing their energy to the target material to heat it during each collision. The heated plasma move up (upflows) from chromosphere or transition region to producing soft X-ray emission as revealed in the X-ray photon spectrum between 4 and 8 keV of Fig. 3 including Fe-line complex. The other possibility of microflares occurrence through reconnection is in the slightly higher altitude (~ 1–3×10^4 km) coronal loops and the accelerated electrons could heat the plasma at the intersection region of the separatrices of the active region, which however, may reveal continuum X-ray emission as seen in the spectrum beyond 8 keV in Fig. 3. We analysed 2–5 spectra depending on the duration of each microflare under study and found that the best fit to the spectra is by thermal for energy range 4–8 keV, while the continuum of the spectra at energies > 8 keV fits well by broken power-law (Jain *et al.* 2008). This result shows that the microflares are most likely the product of both mechanism viz., thermal and non-thermal, which is an indicator of hybrid mechanism in microflares as proposed earlier by Jain *et al.* (2006b). Nevertheless, our investigation enabled us to conclude that the microflares produce enough energy/temperature irrespective to their origin in upper chromosphere, transition region or corona to heat the active region coronal plasma as inferred from the presence of Fe-line feature and non-thermal spectra. The Fe has high atomic number (Z) and therefore settles down against gravitation as soon as the temperature of the active region corona goes below 9 MK. However, as inferred from our observations, during the occurrence of microflare the temperature in the active region corona exceeds 9 MK indicating that microflares are sufficient to heat the corona. It might also be possible to observe the presence of Fe-line feature in nanoflares if the detectors are designed of appropriate sensitivity.

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