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Diagnostics of Non-Thermal Distribution from RESIK and RHESSI Flare Spectra

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Abstract. Solar flare spectra observed by the X-ray spectrometers RESIK and RHESSI with high energy resolution enabled us to analyse possible non-thermality of plasma electron distribution in the keV range. For RESIK diagnostics (in the 2-4 keV range) we assumed that the bulk of the plasma is represented by the so-called n-distribution, which describes the deviations from the Maxwellian distribution by two parameters: n and T. Using thick-target approximation for RHESSI spectral analysis, we obtained characteristics of injected electron power-law distribution in the deka-keV range. The event presented here shows a very good time correlation of non-thermality obtained from the RESIK spectra with appearance of non-thermal component in RHESSI and/or radio spectra. However, a thermal component was still present in RHESSI. Both spectral and imaging information in RHESSI soft and hard X-ray ranges were used for the estimation of the ratio of thermal to non-thermal electron densities of the X-ray emitting plasma.

1. Motivation

It is supposed that when electron beams accelerated during the solar flare penetrate ambient plasma, a return current is created, the beam is decelerated due to Coulomb collisions, and the distribution function of electrons in the plasma can deviate from the Maxwell distribution. Generally, it is assumed that the bulk of the distribution is Maxwellian and the non-thermal part is represented by the power-law tail. Here we assumed that the bulk of the plasma electron distribution can be also non-thermal and that it can be modelled by an n-distribution which can originate e.g. due to the return current (Dzifčáková and Karlický 2008). The n-distribution can also explain the enhanced intensities of satellite lines as was observed by RESIK in soft X-rays (Dzifčáková et al. 2008). However, the n-distribution does not include the high-energy tail. Therefore we assumed that in higher deka keV range the electron distribution could be described by a single power-law distribution.

The n-distribution is defined as $f(E) \approx E^{n/2}(kT)^{-(n/2+1)}e^{-E/kT}$. For $n = 1$ the distribution becomes Maxwellian. The mean energy of the n-distribution is: $< E >=$

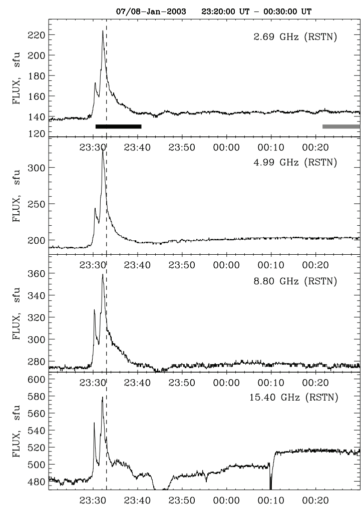

Figure 1. Radio pulse observed during the flare at four different frequencies. The background flux is not subtracted as we are interested in the timing of the pulse only. Dashed line marks the maximum at 23:33 UT as defined by GOES measurements. Thick black and grey lines at the top pannel show the time intervals when non-thermal (black, $n = 7$ - 11) and nearly thermal (grey, $n = 1$ - 3) electron distribution was obtained from RESIK spectra (see Fig. 2).

$(n + 2)kT/2 = 3k\tau/2$, where parameters n and T can be combined in τ to describe the mean energy and k is the Boltzmann constant. The injected electron flux spectrum is defined by a power-law: $F(E) \approx C \cdot (E/E_C)^{-\delta}$, where δ is a spectral index and C represents total flux of electrons above the low-energy cutoff E_C.

The RESIK (Sylwester et al. 2005) spectra enabled us to probe the existence of non-thermal distribution at low energies (2 - 4 keV) while from the RHESSI (Lin et al. 2002) spectral analysis we obtained the information about the non-thermal component at higher energies (9 - 100 keV). Our aim is to look for possible relations of non-thermal parameters in low and high energies.

2. Data and Results

We have analysed an M4.9 class flare which was almost simultaneously observed by the X-ray spectrometers RESIK and RHESSI and at several radio frequencies by RSTN network. According to GOES, the flare started on 2003 January, 7th at 23:25 UT, reached the maximum at 23:33 UT, and ended on 2003 January, 8th at 00:40 UT.

The time intervals of non-thermal effects detected from RESIK spectra were correlated with peaks of radio emission observed by RSTN network (Fig. 1).

The ratio of allowed lines Si xiv (5.22 Å)/Si xiii (5.68 Å) vs. the ratio of one allowed line to the satellite line, Si xiii (5.68 Å)/Si xiid (5.82 Å), enabled us to estimate the parameter n (Fig. 2). Using the modelled dependence of the ratio Si xiv (5.22 Å)/Si xiii (5.68 Å) on n and τ we estimated the value of the parameter τ. Assuming a combination of an isothermal component (lines+continuum) and a thick-target model producing bremsstrahlung emission, we fitted RHESSI spectra (detector 4F) and obtained T and

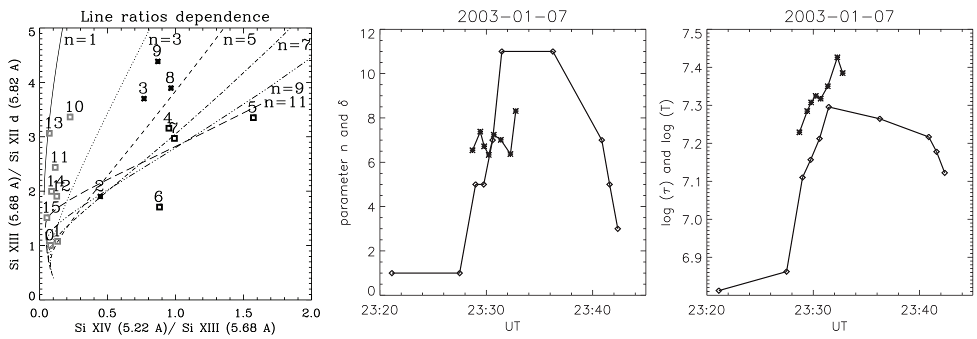

Figure 2. Left: The measured line ratios are plotted against the synthetic ones (the curves) calculated for n-distributions with different parameter *n*. Black and grey squares correspond to the times marked by the black and grey lines Fig. 1. Middle: Time evolution of parameters *n* (diamonds) and δ (stars). During the flare the weak non-thermal component ($\delta \sim 6$ - 8) was observed in RHESSI spectrum at the time of increasing parameter n as obtained from RESIK. Right: Time evolution of log(τ) (diamonds) derived from RESIK spectral analysis and log (T) (stars) of the thermal component derived from RHESSI spectral analysis.

EM for the thermal component and δ, E_{C}, C for the injected electron spectrum. Time evolution of δ and T are depicted together with n and τ in Fig. 2.

Table 1. Summary of parameters obtained from RHESSI fits in A0 and A1 state for the M4.9 flare from 7/8 January 2003. The time interval is in the form of mm:ss after 23:00:00 UT.

Time UT	χ^2	EM$\times10^{49}$ [cm^{-3}]	$k{\cdot}T$ [keV]	$C\times10^{35}$ [el.s^{-1}]	δ	E_c [keV]	Range [keV]	nth/th
28:28 - 28:56	1.04	0.01	1.46	16.9	6.54	11.2	6 - 35	0.0140
29:16 - 29:36	0.89	0.06	1.66	3.14	7.38	19.1	9 - 40	0.0010
29:36 - 30:00	0.88	0.1	1.75	9.48	6.72	18.8	9 - 50	0.0020
30:00 - 30:28	0.91	0.19	1.82	10.8	6.33	19.4	9 - 70	0.0020
30:28 - 31:00	0.98	0.4	1.79	20.5	7.24	18.7	9 - 55	0.0020
31:00 - 31:44	1.59	0.63	1.93	26.8	7.01	19.6	9 - 75	0.0020

Table 1 summarizes the parameters from RHESSI fits and the ratio of non-thermal to thermal electron density. We suggest this ratio characterises the level of non-thermal processes. So that a significant portion of high-energy electrons (high ratio value) leads to existence of the n-distribution (e.g. caused by the return current accompanying the beam) at low energies in a part of plasma. To obtain the ratio of non-thermal to thermal electron density, the area of the non-thermal and thermal emission was needed. For this purpose we took the area within 50% contour of RHESSI images in respective hard and soft channels.

Further, we attempted to add the bremsstrahlung from the n-distribution to RHESSI spectral analysis. We used only the spectra observed with attenuator state A0 which allowed us to use the energies below 8 keV. It is clear that the n-distribution contributes to X-ray emission at low energies (Fig. 3) but it turned out that the thermal component cannot be ruled out. The parameters of n-distribution obtained from RHESSI are in

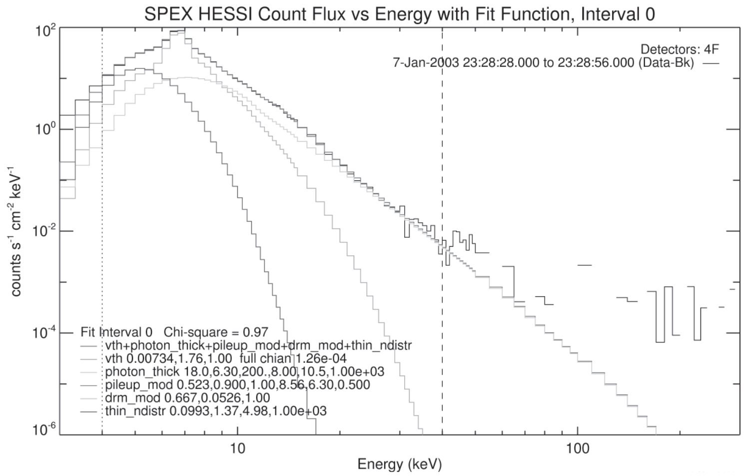

Figure 3. An example of RHESSI fit including the thin-target bremsstrahlung radiation from n-distribution. The fitting range is 4 - 40 keV.

a good agreement with those from RESIK: RHESSI - $n = 4.9$, $k \cdot \tau = 1.4$; RESIK - $n = 5 - 11$, $k \cdot \tau = 1.1 - 1.4$.

3. Conclusion

It is possible to probe the deviation of the electron distribution function from thermal distribution in flaring plasma using the RESIK and RHESSI data. The resulting values of parameters n and $k \cdot \tau$ obtained from RHESSI bremsstrahlung are in good agreement with those diagnosed from spectral lines observed by RESIK.

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References

Dzifčáková, E., & Karlický M. 2008, Solar Phys., 250, 329
Dzifčáková, E., et al. 2008, A&A, 488, 311
Lin R. P., et al. 2002, Solar Phys., 210, 3
Sylwester, J., et al. 2005, Solar Phys., 226, 45