MULTI-TEMPERATURE ANALYSIS OF HARD X-RAY SPECTRA MEASURED ABOARD THE PROGNOZ 5 SATELLITE

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МНОГОТЕМПЕРАТУРНЫЙ АНАЛИЗ ЖЕСТКИХ РЕНТГЕНОВСКИХ СПЕКТРОВ ИЗМЕРЕННЫХ НА СПУТНИКЕ ПРОГНОЗ 5

Употребляя метод многотемпературного анализа жесткого рентгеновского излучения, предложенный в работе Б. Сильвестер и др. (1981), в статье анализируются рентгеновские спектры полученные по данным чехословацкого фотометра на борту спутника Прогноз 5. Пример подробного анализа представлен на основании регистрации вспышки 11. февраля 1977 г. Исходя из потоков рентгеновского излучения, измеренных в 4 энергетических диапазонах, а именно 6-10-19-39-58 кэв, мы рассчитали распределение дифференциальной меры эмиссии для выбранных моментов времени на фазе роста, в максимуме, и на затухающей фазе развития вспышки. Результаты анализа показывают, что в случае изучаемой вспышки жесткое рентгеновское излучение с 6 по 60 кэв можно обьяснить тормозным излучением термической, многотемпературной плазмы.

Following the method of multi-temperature analysis of hard X-ray spectra presented in the paper by B. Sylwester et al. (1981), in the present paper we analyse the hard X-ray radiation measured aboard the Prognoz 5 satellite by means of a Czechoslovak photometer. The analysis concerns the Feb. 11, 1977 flare event. Using the fluxes measured in 4 energy bands, i.e. 6-10-19-39-58 keV, we have calculated the differential emission measure distributions for selected moments during the rise, maximum and decay phases of the flare development. The results of the analysis show that, in the case of the flare in question, the hard X-ray radiation from 6 to 60 keV could have been produced by purely thermal, multi-temperature plasma.

1. Introduction

Since 1976, four Prognoz satellites (No. 5, 6, 7, 8) have been successfully launched into a highly eccentric orbit (apogee 200 000 km, perigee 500 km). The main purpose of the scientific package placed aboard each satellite was to monitor the solar activity and solar-terrestrial relationships. As a standard instrument for measurements of solar X-ray radiation, a hard X-ray photometer of the Ondřejov Observatory, Czechoslovakia, was placed aboard each of the satellites. The main advantage of the highly-eccentric satellite orbit for monitoring solar X-rays is that the data gaps due to the Earth radiation belts and the satellites nights constitute only 5% of the total life-time of the photometer.

A detailed description of the hard X-ray photometer placed aboard Prognoz 5 (P-5) satellite was published by Valníček et al. (1979). The photometer was similar to the earlier types designed for the Interkosmos satellites. The analysis of IK-4 hard X-ray spectra were published by B. Sylwester et al. (1981). In the analysis we have interpreted the measured hard X-rays as if resulting from thermal bremsstrahlung in a hot flare plasma. For the first time the model of the multi-temperature plasma in the analysis of the hard X-ray spectra has been used. Recently a number of papers were published indicating renewed interest in the idea of thermal interpretation of flare hard X-rays:

Kahler (1971), Smith and Lilliequits (1979), Matzler et al. (1978), Crannell et al. (1978), Brown et al. (1979), Smith and Auer (1980), Brown et al. (1980), Brown and Hayward (1981).

We will adopt the assumption of the thermal character of the hard X-ray flare radiation in the present paper, bearing in mind that in some flare events this assumption may be inadequate.

2. Observations

The P-5 satellite was launched on 25th Nov. 1976, thus practically operating during the minimum of solar activity. However, at the beginning of 1977 the Sun's activity was somewhat higher but strong flares were still very seldom. We have chosen for the

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analysis the relatively strong solar flare, which took place on February 11, 1977 (start-time at 2127 UT, max. at 2132 UT, end at 2152 UT), near the end of P-5's operation. It was a class 1 B flare in the H-alpha classification and it was connected with McMath plage region 14 637 (S 40 W 01), (Solar Geophysical Data, 1977). The recorded fluxes in four energy bands of the P-5 scintillation detector at the time of the analysed flare were above the sensitivity thresholds, namely in the 6-10-19-39-58 keV bands. They were reduced by a computational technique (Fárník, 1978) at the Ondřejov Observatory and their time profiles (in photons $\mathrm{cm}^{-2}\,\mathrm{sec}^{-1}\,\mathrm{keV}^{-1}$) are shown in Fig. 1. According to this figure the flare was long-drawn and was preceded by small precursors at about 2100 UT and 2120 UT in the lowest energy channels. The time variations of the fluxes measured in various channels are different. In the first two channels one can see the fast rise and smooth, long decaying, while in the two higher energy channels, the times of the rise and the decay are comparable.

3. General Formalism

In the thermal interpretation of X-ray radiation the plasma properties are very often described in term of the temperature distribution of the emitting plasma. Ususally the distribution of the differential emission measure vs the temperature is calculated and this is called the model of the emitting plasma $\varphi(T)$,

$$\varphi(T) = N_e^2(\mathrm{d}V/\mathrm{d}T)\,, \tag{1}$$

where N_e is the plasma density, T is the temperature and V is the emitting volume.

Withbroe (1975) proposed an iterative procedure to calculate the model of the transition region between the chromosphere and corona based on the measured line fluxes in UV lines. The applicability of this method to soft X-ray emitting flare plasma has been proved by J. Sylwester (1977) and to the hard X-ray emitting regions by B. Sylwester (1979). This method has been successfully used to interpret soft X-ray line spectra recorded by the spectrometers aboard the Interkosmos and Solar Maximum Mission satellites: J. Sylwester (1977), B. Sylwester et al. (1980), J. Sylwester et al. (1980), narrow-band observations made by OSO 7: B. Sylwester (1979), and to the combined soft and hard X-ray data obtained from the IK-4 satellite: B. Sylwester et al. (1981).

The applicability of this method to the P-5 data is investigated in the present paper. The tests were made similarly as in the above-mentioned papers:

1. We have assumed some continuous and discrete tentative models $\varphi_t(T)$;
2. We have calculated the fluxes which should be measured by the P-5 scintillation counter from each of these models;
3. These fluxes were treated as the measured ones and we have used them as the input data in the iterative procedure to computed the model $\varphi_c(T)$;
4. The degree of agreement of the computed and tentative models was investigated.

The indicator of the fitness of each computed model, as in the paper by B. Sylwester et al. (1981), was the parameter defined as:

$$\log(\sigma + 1) = \frac{1}{n}\sum_{m=1}^{n}\left|\log F_m^{\mathrm{obs}}/F_m^{\mathrm{calc}}\right|\,, \tag{2}$$

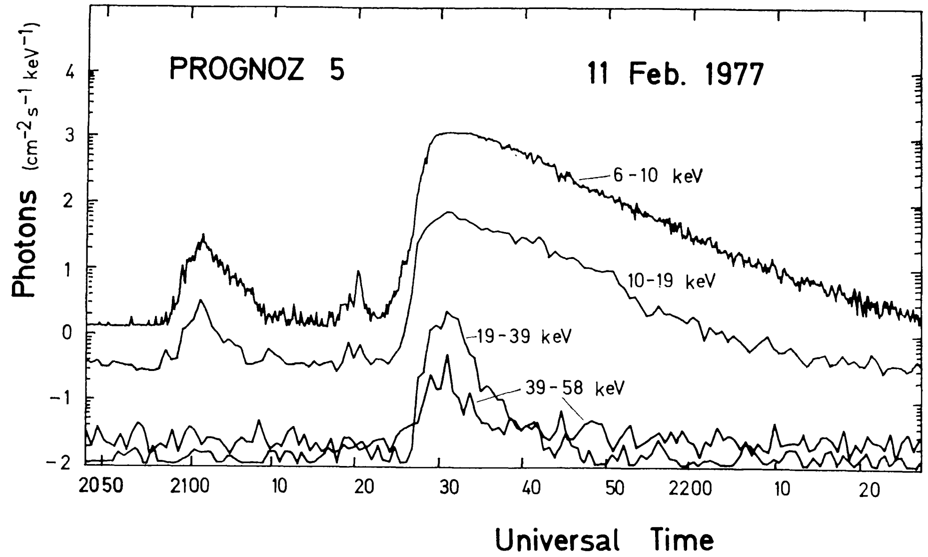

Fig. 1. The time profiles of the hard X-ray fluxes from the 1 B flare at 2130 UT on February 11, 1977, located at S 40 W 01.

where F_m^{obs} is the flux measured in the energy band m and F_m^{calc} is the flux computed from the model. If the observed and calculated fluxes agree well for all energy bands the parameter σ has a low value.

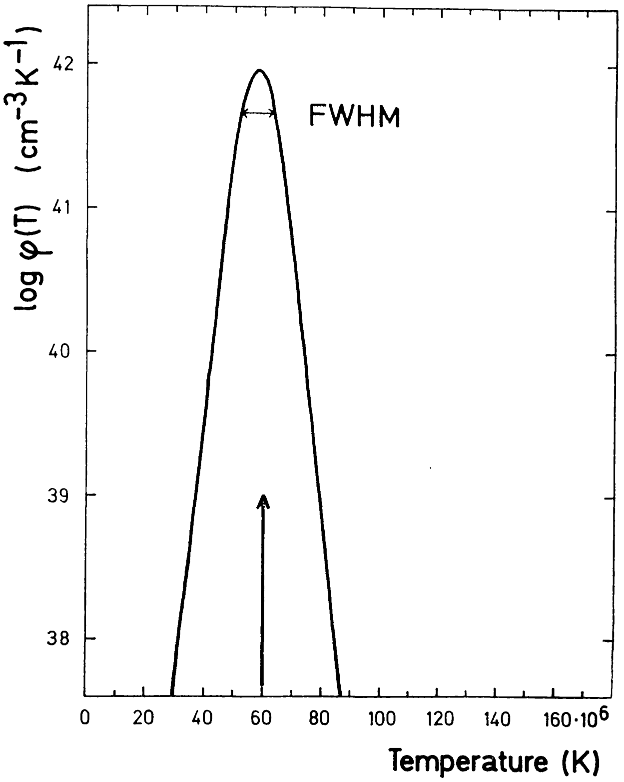

Fig. 2. The differential emission measure distribution vs. the temperature for the tentative model in which the plasma is isothermal with a temperature of 60×10^6 K.

In Fig. 2 an example of one test is presented. Here the tentative model was such that all the plasma had the same temperature of 60×10^6 K. The continuous curve represents the model computed after 200 iterative steps. The finite half width of the computed model (FWHM = 11×10^6 K) is attributed to the fact that the emission functions for the bremsstrahlung radiation, which dominates in the analysed energy region, are very flat functions of the temperature.

We have made a large number of similar tests using various tentative models (in particular $\varphi_t(T) = 10^{-\alpha T}$). In each case we obtained very good agreement between the tentative and computed models and we have thus concluded that the P-5 data could be analysed by means of this iterative procedure.

4. Computations and Results

Using the fluxes measured in four energy channels during the flare of February 11, 1977 as the input data a number of models was calculated by means of the iterative procedure. From this analysis it was found that, if the pre-flight experimentally calibrated discrimination levels for the P-5 experiment (6-10-19-39-58 keV) were adopted, it would be impossible to find a model which would fit the observed fluxes properly in all energy bands at the same time. By analysing the obtained ratios of the measured-to-calculated fluxes ($F_m^{\mathrm{obs}}/F_m^{\mathrm{calc}}$) using the trial-and-error method, it was found that good agreement between the measured and calculated fluxes could be obtained for the following discrimination levels: 6-9-19-36-58 keV. As a result of this change, the channel's widths were changed by 25%, 11%, 15% and 16%, respectively, which is within the errors due to the accuracy of the energy calibration. Due to the weight and dimension limitations, the in-flight calibration of the scintillation detector was not made. Under such conditions, it is necessary to consider an error in the energy discrimination levels of at least ±2 keV in the lower energy part and ±5 keV in the higher energy part. These errors are due to, for example, pre-flight calibration errors and temperature changes during the flight. The ratio of particular levels is, of course, stable.

It is worth noting that this is the only possible change of the energy levels which shows good agreement between the measured and calculated fluxes in all energy bands. As an example the ratios $F_m^{\mathrm{obs}}/F_m^{\mathrm{calc}}$ for 4 times are presented in Tab. 1.

Table 1

Time UT	$F_m^{\mathrm{obs}}/F_m^{\mathrm{calc}}$			
	$m = 1$	$m = 2$	$m = 3$	$m = 4$
2129	0·995	1·006	0·985	1·018
2131	0·992	1·011	0·852	1·156
2135	0·957	1·051	0·989	1·012
2145	0·959	1·047	0·997	1·001

In Fig. 3, the example of the model calculated for the moment of the rising phase (2129 UT) of the flare development is presented. The model consists of a large amount of plasma at the temperature $T < 40 \times 10^6$ K and a much smaller amount of very high temperature plasma ($T > 100 \times 10^6$ K). The area between the dashed lines in this figure represents the "continuous" error area – every model inside this area is in agreement with the observed fluxes (for details see J. Sylwester et al., 1980).

Some evolutionary changes of the differential emission measure distributions are seen in Fig. 4, where three models (for the maximum phase at 2131 UT, and for the decaying phase at 2135 and 2145 UT) are shown. Here, to avoid confusion, the "continuous" error areas are not shown. It can be seen that the amount of the very high temperature plasma is the largest at the maximum-flux phase, while near the end of this event there is practically no plasma with temperature $T > 100 \times 10^6$ K.

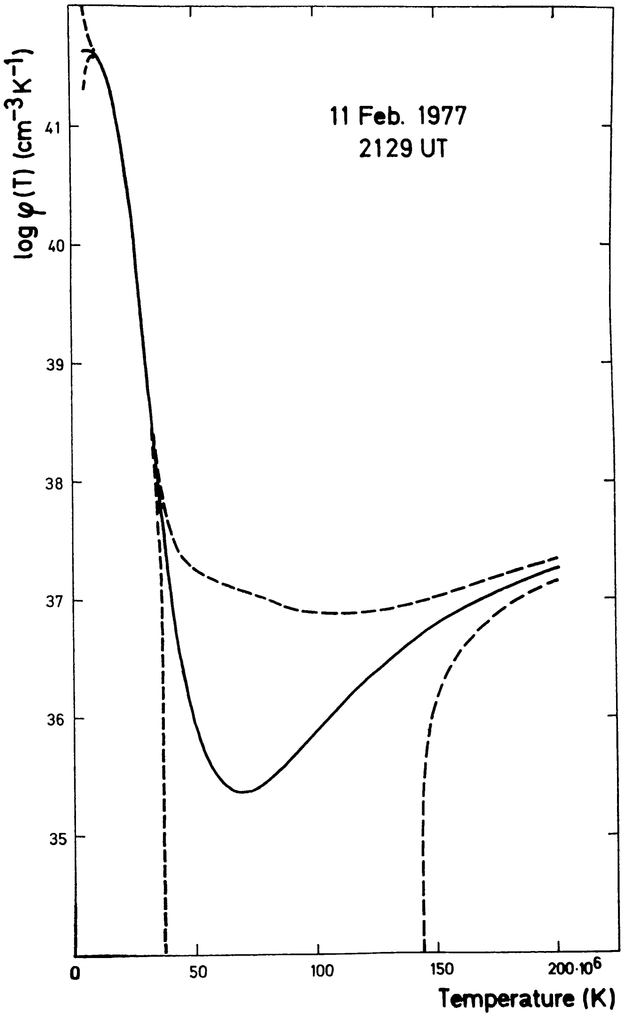

Fig. 3. The model of the flare on February 11, 1977 at 2129 UT (the bold line). The dashed lines represent the "continuous" error limits.

The total emission measure

$$\varepsilon = \int_V N_e^2 \, \mathrm{d}V \quad [\mathrm{cm}^{-3}] \tag{3}$$

was of the order of $5 \cdot 10^{48}$ cm^{-3} around the maximum phase and $4 \cdot 5 \times 10^{47}$ cm^{-3} at 2145 UT. The observed time profiles of the fluxes in the four energy bands in the analysed case are thus caused by the changes of the plasma temperature distribution, as well as by the changes of the total amount of the emitting plasma.

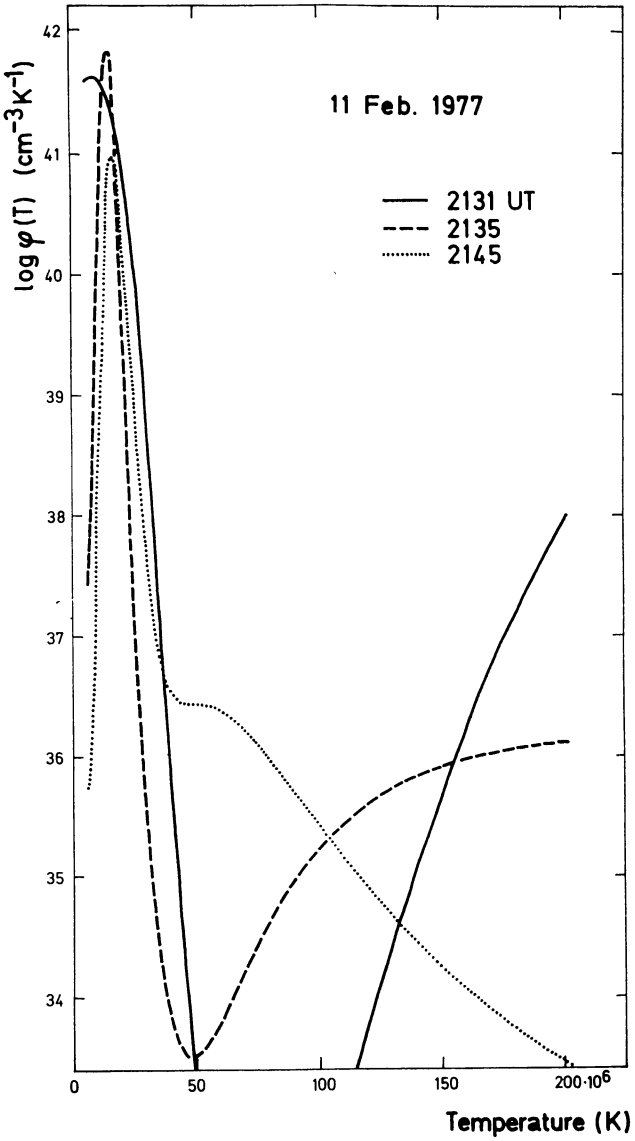

Fig. 4. Some evolutionary changes of the differential emission measure distribution for the analysed flare (the models at 2131 UT, 2135 UT and 2145 UT).

5. Conclusions

Although our results are based only on the calculated models and without some additional information on the emitting volume nothing can be said about plasma parameters such as the electron density and thermal energy content, the presented method is potentially very promising for the analysis of the hard X-ray spectra if the hard X-ray radiation is of thermal nature. In the case of P-5 data, we have tried to apply this method to the other events but we were not able to get good agreement between the fluxes observed and calculated from the models using the same energy discrimination levels. We suspect that the reason for the discrepancy was not just the energy discrimination-level errors, but the pile-up effect too, because the P-5 data were not fully corrected for this effect. In order to analyse the hard X-ray radiation measured by means of the P-5 satellite next time, one should make a detailed comparison of the P-5 fluxes with the data measured by means of other instruments in which the pile-up effect has been taken fully into considerations.

In spite of the above remarks, in the case of the analysed event the hard X-ray radiation from 6 to 60 keV could have been treated as thermal in nature.

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RADAR METEOR RATES AND SOLAR ACTIVITY

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ЧИСЛЕННОСТЬ МЕТЕОРНЫХ РАДИОЭХО И СОЛНЕЧНАЯ АКТИВНОСЬ

Изучается зависимость суточной численности метеорных радиоэхо от солнечной активности, представленной потоком солнечного радиоизлучения $F_{10,7}$ на волне 10,7 см и числом Вольфа солнечных пятен. Применяется метод накладывания эпох, и обсуждается материал наблюдений метеорных радиоэхо прибором в Крайстчерч в течение периодов 1960—61 гг. и 1963—65 гг. Во время повышенной солнечной активности наблюдается минимум суточной численности радиоэхо от метеорных следов. Наоборот, геомагнитная активность не имеет влияния на численность радиоэхо наблюдаемых прибором в Крайстчерч. Приводится возможное объяснение результатов.

The short-term variation of diurnal radar meteor rates with solar activity represented by the solar microwave flux $F_{10,7}$, and sunspots relative number R_z, is investigated. Applying the superposed-epoch analysis to the observational material of radar meteor rates from Christchurch (1960—61 and 1963—65), a decrease in the recorded radar rates is found during days of enhanced solar activity. No effect of geomagnetic activity, similar to the one reported for the Swedish and Canadian radar meteor data, has been found by the author in the Christchurch data. Possible explanation of the absence of the geomagnetic effect on radar meteor rates from New Zealand due to a lower echo ceiling height of the Christchurch radar is suggested. The variation of the atmospheric parameters as a possible cause of the observed variation in radar meteor rates is also discussed.

1. Introduction

Evidence that the radar meteor rates vary inversely with solar activity during the 11-year solar cycle has been presented by several authors (Lindblad, 1967, 1968 and 1976; Hughes 1974 and 1976; Ellyett, 1977). As a possible explanation of this effect the solar activity induced long-term variation of the atmospheric density gradient at the meteor ablation level has been generally proposed. Pecina (1975) studied the occurrence of a rare phenomenon — radar head echo in dependence on solar and geomagnetic activity, but did not find any positive results.

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