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The two solar flares diagnostics based on the soft X-ray emission recording

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Abstract

The time history of the temperature and the emission measure of the solar flare plasma have been studied relying upon the experimental data on the soft X-rays recorded by the IRIS spectrometer on June 29, 2002 (F1) and March 27, 2003 (F2). F1 was a thermal flare and was not accompanied by hard X-rays. This data analysis revealed that at least two sequential energy-release processes occurred during the F1 event. The F2 event took place behind the limb, so only the top part of the flare loop being the soft X-ray source was recorded by the satellite-based spectrometer. From this data analysis it appeared that fast plasma heating occurred in the initial stage of F2 and then the flare region expanded and the emission measure of flare plasma increased.

Keywords: Solar flare; Hot plasma; Flare loop; X-ray emission.

Introduction

Measuring the parameters of electromagnetic radiation during solar flares allows to perform the diagnostics of flare plasma and obtain information on the mechanisms of accumulation and transformation of magnetic field energy into thermal plasma energy or into the energy of accelerated particles and electromagnetic radiation. It should be noted that analysis of the parameters of hard X-ray radiation (HXR) makes it possible to obtain important data on the processes of electron acceleration and propagation during flares (see, for example, [1–4]). Analysis of the parameters of soft X-ray emission provides data on the dynamics of heating and cooling of plasma and on the evolution of the emission region [5].

This study is dedicated to recording the plasma parameters for two flares based on measurements in the soft X-ray range by the IRIS spectrometer installed onboard the CORONAS-F space station [6,7].

Procedure

The intensity of soft X-ray radiation (SXR) in the 1–15 keV range is determined by the temperature (T)

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and the emission measure (EM) of the heated flare plasma under the assumption of a bremsstrahlung mechanism. The paper presents the results of calculating the temperature and emission measure for soft X-ray emission for two flares of GOES-class C: 29.06.2002 (C2.6) and 27.03.2003 (C2.2). For brevity, these flashes will be referred to as F1 and F2 from now on.

The IRIS spectrometer [6,7] is designed to measure the time and spectral characteristics of soft and hard X-rays of the Sun in the 2–150 keV energy range. Because of the low energy resolution of the detectors, the contribution of individual spectral lines to these characteristics is negligible. Soft X-ray radiation is recorded by proportional detectors, hard X-rays are recorded by scintillation detectors. Both types of this radiation are recorded in 32 energy channels.

In order to reconstruct the flare plasma parameters, we used a single-temperature approximation for soft X-rays. In this approximation, SXR is described as the thermal radiation of a hot optically thin plasma. In this case, the spectrum of thermal SXR of the plasma with a solar chemical composition at a distance of one astronomical unit from the Sun is described by the following expression [8]:

$$J(E) = 1,3 \cdot 10^3 \cdot EM \cdot \frac{\exp(-E/T)}{E^{1.4} \cdot T^{0.1}}\ , \qquad (1)$$

where $J(E)$, photon•cm^{-2} s^{-1}•(keV) $^{-1}$, is the differential X-ray flux on the Earth's orbit; E, keV, is the photon energy; T, keV, is the plasma temperature; EM $= n_e{}^2V$, 10^{45} cm^{-3}, is the emission measure of the flare plasma (n_e is the average value of the plasma electron concentration in the volume of the emission region V).

Expression (1) allows to determine the temperature and emission measure by the measured spectrum of soft X-ray radiation.

Let us briefly discuss the single-temperature plasma model in a soft X-ray source. It is obvious that such a temperature distribution cannot exist in principle. The plasma heated in the flare must expand in the process of energy release (provided that the geometry of the region is not thermally insulated, but this is unlikely), i.e., there must be a thermal wave front where the temperature changes up to coronal/chromospheric values. However, hydrodynamic calculations indicate that the temperature profile in highly ionized plasma of the solar corona is a virtually uniform high-temperature region with a sharp temperature gradient at the thermal front.

Thus, at the stage of plasma heating, soft X-ray radiation is generated mainly in uniformly heated high-temperature plasma. Expansion and cooling of the plasma naturally occurs in the source at the stage of X-ray decay; the temperature gradient at the front decreases, and the regions with a continuously decreasing temperature can make comparable contributions to the radiation. Hydrodynamic calculations of plasma heating and cooling are required for accurate detection of the temperature changes. In case only the plasma parameters are being assessed, single or two-temperature distribution of plasma particles can be used.

In the papers [9,10], interpreting the data within the two-temperature model, the presence of a high-temperature source was observed. In the paper [11] the measurement data for both X-ray (RHESSI, more sensitive to high-temperature plasma radiation) and ultraviolet (EVE) radiation was used when finding the differential emission measure of flare plasma. The temperature range for high-temperature plasma $T > (1.0\text{–}1.5)\bullet 10^7$ K is more typical for X-ray radiation with quantum energies above several keV. Since the lower energy threshold of the IRIS spectrometer is 3 keV, the plasma parameters we have obtained are much closer to the values of the high-temperature region.

Within the single-temperature approximation, the temperature and the emission measure are calculated from the measured spectrum of SXR using expression (1).

During operation, the spectrometer detects the counting rates Ne_i in various energy channels. The calculated value of the counting rate Nc_i is determined theoretically by setting a specific type of photon spectrum $J(\varepsilon)$ [4]:

$$Nc_i = \int_0^\infty \int_{A_i}^{A_{i+1}} p(A, \varepsilon) J(\varepsilon) dA d\varepsilon \qquad (2)$$

where A_i, A_{i+1} are the amplitudes of detector signals corresponding to the lower and upper boundary of an ith channel; $i = 1,\dots, I_{\max}$ ($I_{\max}$ is the number of recording channels); $p(A, \varepsilon)$ is the instrument function that takes into account the effective area of the detector as well as the probability that when a photon with the energy ε is registered, the amplitude of the signal produced by the detectors will have the value A (determined by the energy resolution of the detector); $J(\varepsilon)$ is the differential flux of X-ray radiation on the Earth's orbit (see expression (1)).

The distribution parameters (1), namely, the temperature T and the emission measure EM, were

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