I. A. Zhitnik, É. Ya. Kononov, V. V. Korneev, V. V. Krutov, S. L. Mandel'shtam, and A. M. Urnov. *Spectra of solar x-ray flares.* The spectra of x-ray flares give us important information on the physical parameters of the flare regions on the sun and on the elementary processes that take place in them.

The paper reports new results from reduction of the spectra of a group of strong flares that occurred in October–November 1970.[1]

The spectra were obtained on the Intercosmos-4 satellite with the aid of Bragg spectrometers with quartz crystals.[2] They cover the wavelength range from 1.70 to 1.95 Å with record-high resolution: $3\cdot10^{-4}-1\cdot10^{-3}$ Å. This region includes the "hottest" lines of the solar spectrum, which belong to helium- and hydrogen-like iron ions (FeXXV and FeXXVI). To identify the solar lines reliably, we produced laboratory spectra of the corresponding iron ions using a special variant of the vacuum spark with very small total circuit inductance.[3]

Detailed study of the solar spectra indicated the presence of the following main lines: a resonance line of hydrogen-like iron FeXXVI $L_\alpha 2p^2P_{1/2,3/2}\to 1S^2S_{1/2}\lambda=1.78$ Å, a resonance line of helium-like iron FeXXV ions—the line $1s2p^1P_1\to 1s^{2\,1}S_0\lambda=1.8506$ Å (ω), the intercombination line $1s2p^3P_1\to 1s^{2\,1}S_0\lambda=1.8596$ Å (y), the forbidden magnetic-dipole line $1s2s^3S_1\to 1s^{2\,1}S_0\lambda=8684$ Å (z) and the forbidden magnetic-quadrupole line $1s2p^3P_2\to 1s^{2\,1}S_0\lambda=1.8556$ Å (x). Figure 1 shows the corresponding segments of the 1970 November 16 flare spectrum and the laboratory spectrum. There are, in addition, a large number of so-called satellite lines near the FeXXVI and FeXXV resonance lines; they belong to FeXXV and FeXXIV, respectively, and are two-electron transitions of the types $2l2l'\to 1s2l''$ and $1s2l2l'\to 1s^22l''$. In the short segment of the spectrum studied, calculations indicate about 500 satellite lines that are unresolved because of Doppler broadening; this is a new type of spectrum, the "quasicontinuous spectrum," and

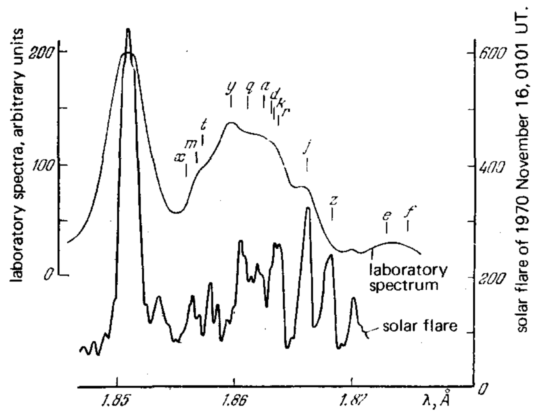

FIG. 1. Segments of solar-flare and laboratory spectra. 1) laboratory spectra, arbitrary units; 2) laboratory spectrum; 3) solar flare; 4) solar flare of 1970 November, 16 0101 UT.

about 95% of the energy radiated in this region of the spectrum is concentrated in it. The wavelengths of the FeXXV lines listed above and those of the strongest satellite lines were measured accurate to ±0.0004 Å. The lines of the 1970 November 16 flare were found to be Doppler-shifted, indicating motion of a hot volume of plasma at a velocity of ≈600 km/sec at the beginning of the flare.

It was possible for the first time to eliminate the possible errors introduced by the spatial inhomogeneity and nonstationarity of the plasma in determining the electron temperature of the flare [$\approx(15-25)\cdot 10^6$ °K around flare maximum] from the intensity ratio of FeXXV resonance and satellite lines and, from the flux in the resonance line, a measure of the emission ($\approx 10^{48}-10^{49}$ electrons^2/cm^3).

The spectra of the initial and final stages of the flares, which were obtained for the first time, were especially interesting. It was observed that for 10–20 minutes before flare maximum and for an approximately equal time after maximum phase, the intensities of the FeXXV resonance lines and the corresponding satellite lines in the flare spectra were at 1/20–1/30 of their levels in spectra recorded close to the maximum. In these spectra, however, the intensities of the L_α lines of FeXXVI increase, and there are new groups of lines corresponding to $K_\alpha(L\to K)$ and $K_\beta(M\to K)$ intrashell transitions in "colder" iron ions that according to calculations lie between FeXXVI and FeIV (Fig. 2).

The maximum concentration of FeXVII–IV ions corresponds to the temperature range $\approx 2\cdot 10^6-5\cdot 10^4$ °K, and the energy of detachment of an electron in the K shell, which is necessary to make the $L\to K$ and $M\to K$ transitions possible, corresponds to about 7 keV. Thus, these lines appear as a result of penetration of directional electron fluxes that have been accelerated to energies $\gtrsim 7$ keV from the outside into the lower layers of the corona and into the transitional layer. Comparison of these spectra with the polarization of ≈15 keV flare x-ray bremsstrahlung showed that in the initial and final flare stages, when the intensities of the K_α and K_β lines are high, the amount of polarization, which is a direct indication of the presence of directional electron beams, is also high.

The data indicate that in the initial stages of the flares, in the corona and apparently at heights of 20,000–40,000 km, where soft x-radiation is generated, the rupture of a current layer or some other mechanism[6] gives rise to fluxes of accelerated electrons that move along magnetic lines in the direction of the sun's surface and penetrate comparatively deeply into the solar atmosphere. As the flares develop, the numbers of these electrons increase rapidly and a region of the solar atmosphere with a volume of $\approx 10^{28}-10^{29}$ cm^3 and a density of $\approx 10^9-10^{11}$ electrons/cm^3 (although still higher densities cannot be excluded) is heated to a temperature of $(15-25)\cdot 10^5$ °K with thermalization of the electron velocities in magnitude and direction. In the final stage of the flare, accelerated electrons again become a basic factor, although the mechanism of their acceleration may be different from the initial mechanism in strong flares.[7]

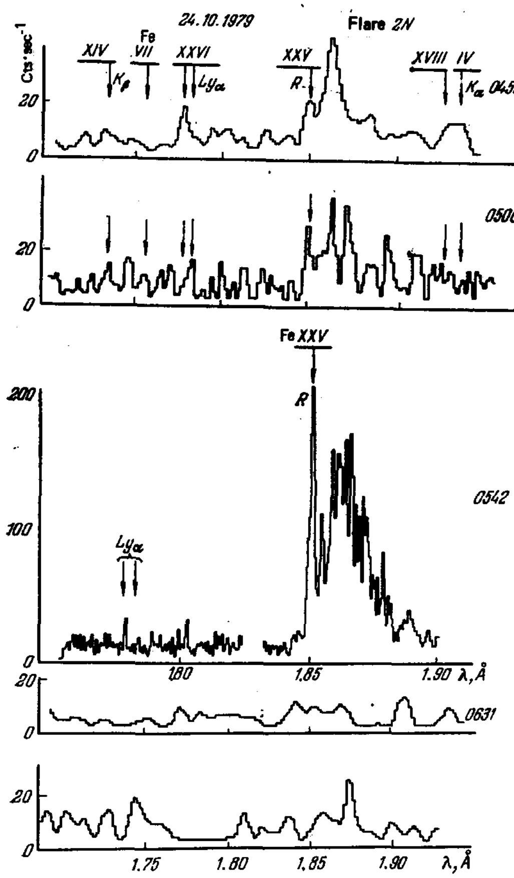

FIG. 2. Spectrum of 2N solar flare of 1970 October 24 (beginning 0447, maximum 0552, end 0631 UT).

A number of other experimental facts also support the hypothesis of accelerated directional electrons as the principal agent giving rise to flares in the radio, optical, and shortwave bands of the electromagnetic spectrum: the power-law nature of the bremsstrahlung hard x-ray spectrum from 10 to 100 keV, the structure of this radiation, with "elementary bursts" lasting a few seconds, the appearance of accelerated electrons in interplanetary space, and other phenomena. At the same time, this hypothesis has recently come up against serious theoretical difficulties.[8,9] Further theoretical and experimental research will be needed, in particular simultaneous observations with adequate resolution in space and time, to determine the heights of the regions generating x-radiation of various hardnesses in the solar atmosphere. We plan to conduct such investigations during the upcoming year of maximum solar activity.

[1] Paper to be published in the journal "Solar Physics".

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