Chapter 2
The Events of August 1972 and the Discovery of Solar Gamma-Radiation

As mentioned in Section 1.2, before the events of August 1972, all attempts to search for solar gamma-rays during quiet periods and during chromospheric flare events gave only upper limits for the fluxes from the Sun.

2.1 Main Peculiarities of the August 1972 Events

The data observations from high energy particles, radio, X-ray, gamma-ray emissions and interplanetary shock waves generated by the flares of August 4 and 7, 1972 are used by Hudson et al. (1975) to study the non-thermal processes in great solar flares. The data observed from the X-rays of the August 4 flare have shown that the $\geq$25 keV electrons with a total energy of $\geq 2 \times 10^{32}$ erg were generated during the explosive phase. The transfer of the $\approx$500 Gs magnetic field energy in a $\approx 10^{29}$ cm^3 volume to the fast electron energy is realised in the flare with high efficiency. The transferred energy is sufficient for the lower corona and the upper chromosphere region to be suddenly heated, for plasma to be ejected and for powerful interplanetary shock waves to be generated (it is also possible that in such a way the fast electrons are also responsible for Hα emissions and for chromospheric emissions of white light).

The results of observations of the relativistic electrons with an energy $\geq$20 MeV generated in the class 3B chromospheric flare on August 7, 1972 have been analyzed by Maccagni et al. (1973). These electrons were detected at a distance of $\approx 33\ r_E$ from the Earth. The initial electrons were detected at 15:35–15:37 UT on the 7th of August, within 5–10 min after the arrival of $\leq 4 \times 10^9$ eV protons. The maximum bursts of the 9.4, 19.0 and 37.0 MHz radio emissions from the Sun were observed at 15:14 UT, the X-ray maximum at 15:13 UT and the Hα intensity maximum was observed as late as 15:26 UT. The acceleration of relativistic particles (electrons and protons) lasted for 8–10 min up to 15:15 UT. The analysis of the radio emissions and the X-ray bursts have shown that the electrons were accelerated in a pulsed mode, that the duration of each pulse was less than a minute

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and that four pulses were produced within 10 min. The delay of the electron arrival relative to the moment of arrival of the relativistic protons indicates that the electrons resided in the solar corona during a period of 5–10 min after acceleration.

2.2 The Discovery of Solar Gamma-Radiation

The 0.3–10 MeV gamma-ray detector on OSO-7 was used by Chupp et al. (1974a, b, 1974) to look for gamma-quanta in the periods of intense X-ray emission of ≥ 4 erg cm^{-2} s^{-1} (class $\geq$ M4) in the 1–8 Å band during the first 2 weeks of August 1972. Excluding two short periods of several minutes each, only the upper limits of the 0.5, 2.2, 4.4 and 6.1 MeV gamma-quantum fluxes (mainly $\leq 5 \times 10^{-3}$ photon cm s^{-1} for all gamma-ray lines) were obtained during the measurement period (see Table 2.1).

Figure 2.1 shows the gamma-ray spectrum for 6:23–6:32 UT of August 4, 1972. From Table 2.1 and Fig. 2.1 it is possible to see that at 6:24–6:33 UT on August 4, 1972 the reliable fluxes in the lines 0.5, 2.2, 4.4 and 6.1 MeV were in the first time detected:

$$I_\gamma(0.5\ \mathrm{MeV}) = (7.0 \pm 1.5) \times 10^{-2}\ \mathrm{photons} \times \mathrm{cm}^{-2} \times \mathrm{s}^{-1} \tag{2.1}$$

$$I_\gamma(2.2\ \mathrm{MeV}) = (2.2 \pm 0.2) \times 10^{-1}\ \mathrm{photons} \times \mathrm{cm}^{-2} \times \mathrm{s}^{-1} \tag{2.2}$$

$$I_\gamma(4.4\ \mathrm{MeV}) = (3 \pm 1) \times 10^{-2}\ \mathrm{photons} \times \mathrm{cm}^{-2} \times \mathrm{s}^{-1} \tag{2.3}$$

$$I_\gamma(6.1\ \mathrm{MeV}) = (3 \pm 1) \times 10^{-2}\ \mathrm{photons} \times \mathrm{cm}^{-2} \times \mathrm{s}^{-1} \tag{2.4}$$

The corresponding values at 15:38–15:47 UT on August 7, were 1.5–4 times smaller: $(3.7 \pm 0.9) \times 10^{-2}$, $(4.8 \pm 1.0) \times 10^{-2}$, 2×10^{-2}, and 2×10^{-2} photon cm^{-2} s^{-1} in 0.5, 2.2, 4.4 and 6.1 MeV lines. The two periods (06:24–06:33 UT on August 4 and 15:38–15:47 UT on August 7) correspond to the development maximum of class 3B optical flares and to the $>5 \times 10^{-1}$ erg cm^{-2} s^{-1} X-ray flux in the 1–8 Å band (class >X5). During these periods the 60–120 keV X-ray flux also reached its maximum ($\approx$600 photon cm^{-2} s^{-1}).

According to Hudson et al. (1975), the data on gamma-ray emission in the August 1972 events, have shown that the fast protons and heavier nuclei appeared within several minutes after the electrons. Some of the 5% of the generated electrons and $\geq$99% of the fast protons and nuclei moved in the direction from the photosphere where they were ejected into the interplanetary space.

Numerous measurements of solar gamma-rays were carried out during the powerful chromospheric flares in August 1972. For example, the gamma-ray bursts associated with the flares of August 4 and 7, 1972, were detected on Prognoz-2 (Vedren et al. 1975). The gamma-ray bursts associated with the flares of

Table 2.1 Gamma-ray line emissions from McMath region 11976 during August 1972 (According to Chupp et al. 1974a, b)

Events				Flux (photon cm^{-2} s^{-1})			
Optical class	Date Aug. 1972	Observation intervals (UT)	$I_{max}(c/s)$60–120 keV	0.5 MeV	2.2 MeV	4.4 MeV	6.1 MeV
1 B	2	18:06–18:30	81 at	$<1.4 \times 10^{-2}$	$<1.3 \times 10^{-2}$	$<7.4 \times 10^{-3}$	$<8.2 \times 10^{-3}$
		18:40–18:55	18:40 UT	$<1.8 \times 10^{-2}$	$<1.7 \times 10^{-2}$	$<1.5 \times 10^{-2}$	$<1.1 \times 10^{-2}$
2 B	2	19:38–20:30	310 at	$<1.1 \times 10^{-2}$	$<1.0 \times 10^{-2}$	$<8.3 \times 10^{-3}$	$<6.3 \times 10^{-3}$
		21:34–22:02	21:44 UT	$<1.8 \times 10^{-2}$	$<1.8 \times 10^{-2}$	$<1.0 \times 10^{-2}$	$<8.4 \times 10^{-3}$
3 B	4	05:38–06:21	7,520 at	$<1.1 \times 10^{-2}$	$<1.0 \times 10^{-2}$	$<7.7 \times 10^{-3}$	$<6.2 \times 10^{-3}$
		06:24–06:33	06:26 UT	$(7 \pm 1.5) \times 10^{-2}$	$(2.2 \pm 0.2) \times 10^{-1}$	$(3 \pm 1) \times 10^{-2}$	$(3 \pm 1) \times 10^{-2}$
1 B	7	03:55–04:07		$<1.8 \times 10^{-2}$	$<1.6 \times 10^{-2}$	$<9 \times 10^{-3}$	$<1.1 \times 10^{-2}$
3 B	7	14:03–14:58	4,855 at	$<9.7 \times 10^{-3}$	$<8.9 \times 10^{-3}$	$<7.6 \times 10^{-3}$	$<6.1 \times 10^{-3}$
		15:38–15:47	15:39 UT	$(3.7 \pm 0.9) \times 10^{-2}$	$(4.8 \pm 1) \times 10^{-2}$	$<2 \times 10^{-2}$	$<2 \times 10^{-2}$

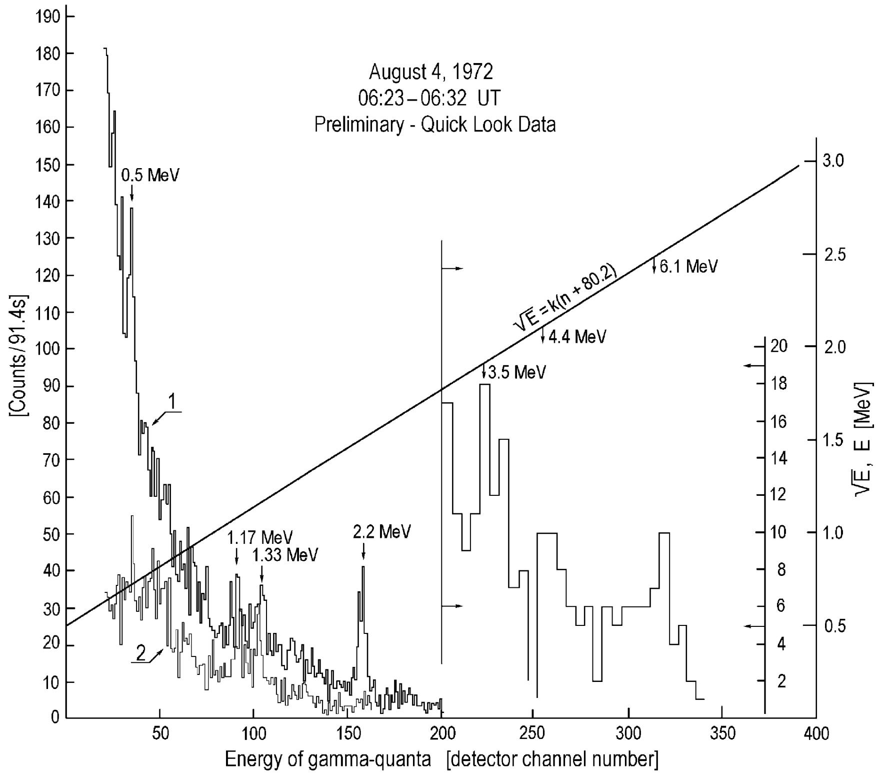

Fig. 2.1 The event of August 4, 1972 at 06:23–06:32 UT. The solar (*curve 1*) and background (*curve 2*) gamma-ray spectra during the rise of the 3B flare (According to Chupp et al. 1974a, b)

August 4 and 7, 1972, have been studied in detail in Albern et al. (1974, 1975). The study of the time dependence and spectral characteristics of the data obtained with the observations of the optical and radio emissions have revealed the important characteristic phases of flare development. The gamma-ray increases have been found to be closely associated with the appearance of high energy protons in the solar corona. A possible connection between shock waves to the mechanism of high energy particle acceleration has been noted.

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