International Journal of Modern Physics A

October 28, 2003 X10 Flare: High Energy Gamma Emission, Type II Radio Emission and Solar Particle Observations

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The 28 October 2003 flare gave us the unique opportunity to compare the acceleration time of high-energy protons with the escaping time of those particles which have been measured onboard spacecraft and as GLE event. The comparison of high energy emission and shock wave height and velocity time dependences were also performed.

Keywords: solar flare, gamma-ray emission, solar energetic particles, GLE, shock wave

The Experiment SONG (SOlar Neutrons and Gamma-rays) is designed for the detection of X-ray and γ-ray emission in the energy range $0.05 \div 100$ MeV, neutrons $E_n > 20$ MeV, electrons $E_e = 12 \div 100$ MeV, as well as protons with $Ep > 75$ MeV. Gamma ray emission > 60 MeV observed by SONG onboard CORONAS-F in the October 28, 2003 major flare $X17.2/4B$ (S16, E08) provided evidence for the relativistic particle apperance during the flare developement. Consequently we got an unique opportunity to compare the acceleration time to the escaping time of protons with $Ep > 300$ MeV energies measured as GLE and onboard the Spacecraft.

The flare impulsive phase start time was defined according to the measurements in the various wave-lengths as $T_0 = 60 \div 120$ s after 11:00:00 UT. Figure 1(left) shows the most representative response of SONG detector to the γ-ray emission in $7 \div 15$ MeV and $60 \div 100$ MeV energy ranges. First 60 s of the high-energy emission correspond to the most bright outburst for the energy ≤ 40 MeV. Subsequent delayed emission began suddenly at 225 s and extends more than 400 s with the photon energy reached 100 MeV. Figure 1 (right-top) demonstrates that the first impulsive flare phase is characterized by a mainly bremsstrahlung spectrum (generated by electrons) with a small excess in the γ -line range $0.5 \div 6$ MeV (γ -line produced by protons with E_p $10 \div 30$ MeV). The spectrum shape of the delayed phase has a remarkable plateau in the energy range > 25 MeV. The nature of this spectrum irregularity is attributed to the γ -emission resulted by π^0 decay process which may be recognized by a shape of gamma-ray radiation energy spectrum with a broad maximum in the range of $50 \div 70$ MeV. The latter process needs the protons with $E_p > 300$ MeV. The absence of smooth transition from the impulsive phase to delayed phase for all energy γ-ray emission makes it tempting to assume that two different acceleration mechanism were in operation causing both impulsive and delayed phase of the flare (Refs. 1, 2).

The question "does a shock wave propagating in the Corona accelerate particles up to ultra-relativistic energies during the delay phase of the flare" is being discussed. The shock wave formation, its height-time and height-velocity dependences were calculated based on the radiospectrograph ARTEMITH Type II radio emission in the 650 ± 20 MHz range data and were compared with the analogous dependences of CME (*http://cdaw.gsfc.nasa.gov/*). Comparing the MHD wave velocity, calculated from the type II frequency drift, with the CME velocity we note that the former is a model dependent calculation, assuming a Newkirk corona and radial propagation; the latter is subject to projection effects. However, the calculated velocities are close enough (see Figure 3) to allow us to characterise the type II burst as a shock driven by the front of CME (Ref. 3). The extrapolation back to the Sun surface of shock wave and CME trajectories permit to define their liftoff time equal to 100 ± 30 s that coincides with the T_0-time of the main flare energy release. The initial velocity of the blob is $9 * 10^2 \div 1.4 * 10^3$ km $*$ s $^{-1}$, and acceleration value of 0.12 ± 0.3 km $*$ s^{-2} . The appearance at 188 s of type II burst in the middle corona at $0.2 R_{Sun}$ indicates the time of supersonic shock wave formation. The shock is formed at $30 \div 35$ s before the sharp onset of γ-ray emission delayed phase. This time difference could be related to the fact that the mechanism of the particle acceleration near shock does not operate. Alternative acceleration mechanism has been proposed in models invoking reconnection. The rising CME/shock front and neutral point are connected by a stretched current sheet. According to (Ref. 4), protons can actually be accelerated to GeV energies in high temperature turbulent reconnection current sheet during the late phase of solar flare.

Now let us compare the arrival time of proton at the Earth with the time of the γ -ray emission. The McMurdo, Norilsk, Potchefstrom neutron monitors indicated the earliest onset among neutron monitor network at 750 ± 30 s. The arrival time of protons with energy $E_p = 200 \div 300$ MeV at CORONAS-F is equal to 750 s and coincides with monitors onset time (see Fig.1 left)

The shortest possible propagation time values for the protons having zero pitch angle can be estimated for the 200 MeV energy proton ($v = 0.566c$) as 1000 s and for the 300 MeV protons ($v = 0.652c$) as 888 s in the assumption that their path along the interplanetary magnetic field lines is 1.17 AU. Taking into account that propagation time of γ -ray emission is equal to 508 s we can compare time of γ -ray emission with the escaping time of the protons which arrived to the Earth at 750 s. Calculated time delay $\simeq 500$ s and $\simeq 388$ s in respect to γ -ray detection gives us the latest time when protons could escape from the Sun. This time interval marked as a shaded box in Figure 1 (bottom left) indicats the 'leakeage' of $200 \div 300$ MeV protons into interplanetary space. From the other hand the pion decay γ -ray emission indicates the time of the acceleration of proton with energy $\geq$ 300 MeV. It proves that protons start to escape from the Sun in the same moment when the pion decay γ -ray emission was generated without any time delay.

References

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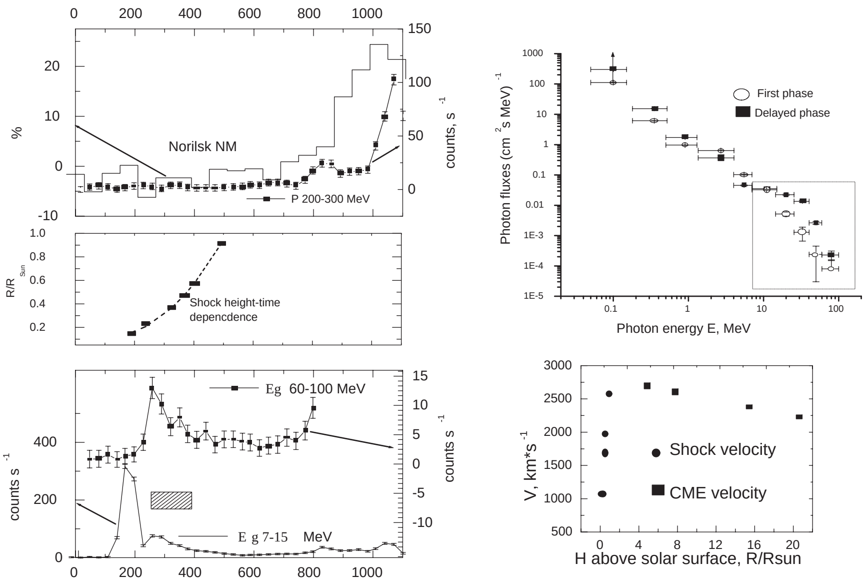

Fig. 1. *SONG detector response to the γ-ray emission in $7 \div 15$ MeV and $60 \div 100$ MeV energy ranges and protons onset (left). The γ-ray emission spectrum shape integrated over impulsive and delayed phases (right top). Shock wave height versus time (left middle panel). Combined shock wave - CME height-velocity dependence (right bottom).*