solar cosmic rays: mechanism of acceleration and propagation

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The continuous flux of high-energy particles, mainly protons, which are coming from the space to the Earth, is called as cosmic rays in 1925 by H. McMillan. The hypothesis of particles acceleration by shock waves is mostly popular. In 1942 S.E. Forbush discovered a sharp increase of accelerated proton flux after some large solar flares. Among the variety of phenomena that accompany a solar flare, the generation of relativistic protons remained the most enigmatic. Part of accelerated particles hits the Sun and causes nuclear reactions. The measurements with the spacecrafts GOES show that duration of accelerated protons coincides with flare duration, and it rarely exceeds 30 minutes, but duration of proton flux on the Earth orbit is three days. Three days is the typical time of solar wind propagation with speed of ~5 × 107 cm/s from the Sun to the Earth. The front of protons flux from the flares, which appear on the West of the solar disk, comes to the Earth along the spiral lines of interplanetary magnetic field with delay about 20 minutes which is equal to flying-pass time, i. e the particles are accelerated directly in the flare and the collisionless particle flux is registered on the Earth orbit. The form of Archimedes spiral magnetic lines is defined by the solar wind and Sun rotation. The protons spectrum on the front of flux, obtained by analysis of measurements on the worldwide network of neutron monitor in the Polar Geophysical Institute of the Kola Science Centre of the Russian Academy of Sciences, have the exponential form. In these measurements the worldwide network of neutron monitor is used as multichannel analyzer of energy of particles which are deviating by the Earth magnetic field.

The flux front from the East flares is delayed on several hours, and it has the sloping form. The protons, which are accelerated in the eastern flares, cannot come to the Earth along spiral lines of the magnetic field. They reach the Earth moving across the interplanetary magnetic field. These particles are carried by solar wind across the magnetic field due to frozen-in condition, and they are diffused by scattering on the magnetic fluctuations. Numerical MHD simulation show, that the protons are accelerated by the Lorentz electric field along a singular line of the current sheet, which is responsible for the flare. The measured spectrum is coincides with the spectrum, which is calculated for acceleration in the current sheet at the magnetic reconnection rate equal to ~2 × 107 cm/s. There is no reason to consider a shock wave as a source of solar cosmic rays. Apparently, the particles are accelerated in the same way and in the stars.