The technique of Forbush decrease registration in tomography mode

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Abstract

A new method of studies of dynamic processes in heliosphere by means of muon hodoscope with a high angular resolution is considered. Coronal mass ejections produce dynamic inhomogeneities in interplanetary magnetic field (IMF). Hodoscope continuously registers flux of muons from 65025 spatial directions. The simultaneous observation of cosmic ray flux from various directions as a sequence of two-dimensional "muon-graphs" with high angular resolution allows to study dynamic picture of IMF.

1. Introduction

Muon tomography (registration of high-energy atmospheric muons from a chain of transformations $p + N \to \pi \to \mu$) is based on simultaneous observation of spatial pictures of intensity of muon flux (2D-graphs) and their frequency variations in a wide range of angles [1]. The sequence of such graphs reflects the dynamics of the process. In particular, this method is applied to registration of the Forbush decrease (FD) dynamics. Powerful active processes on the Sun lead to coronal mass ejection (CME). The expansion of CME magnetic field causes modulation and anisotropy of high-energy primary cosmic ray flux (PCR) passing through it (Fig.1). When CME approaches the Earth's orbit, standard neutron monitors and muon telescopes register FD as a sharp decrease of intensity of particles. The muon telescopes data relate to PCR with energies several times higher, than for neutron monitors.

Changes of PCR intensity with energies of tens GeV during FD are caused mainly by variation of the magnetic field in the Earth's vicinity. Therefore registration of spatial-temporal distribution of muons flux as a sequence of 2D-graphs is analogous to tomography measurements that reflect the dynamics of magnetic field over distances 0.1 – 0.2 AU. Two large-aperture muon detectors with high resolution in MEPhI and Nagoya University are running at present. Hodoscope in Moscow [2] consists of two pairs of coordinate planes (X, Y) with sensitive area of 9 m^2 and it is located at depth 2 m w. e. The angular resolution is $1-2°$. Separate planes are assembled from narrow extended scintillator counters-strips (2.5 cm $\times$ 1 cm $\times$ 300 cm). The total number of counters is 512. The data are

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continuously registered as intensity arrays with dimension 255 × 255 cells. The multidirectional muon telescope with area of 16 m^2 operates at Mt. Norikura [3]. The angular resolution is ±7°. Data are registered as sets of intensity arrays with 21 × 21 dimension.

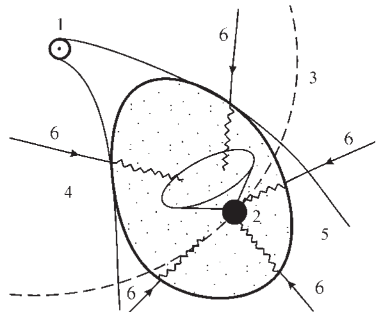

Fig. 1. Scheme of the observation of CME dynamic characteristics by means of muon hodoscope: 1 – the Sun; 2 – the Earth; 3 – Earth's orbit; 4 – the muon hodoscope; 5 – CME; 6 – spatial flux of PCR. The panoramic picture of the heliosphere can be observed due to Earth's rotation.

2. Spatial-temporal structure of the IMF

The hodoscope continuously registers one-minute muon flux from 65025 directions as a sequence of intensity arrays $N_{ik}(t)$. At any moment, certain zenith and azimuth angles correspond to each element ik [4]. To exclude the detector geometrical factor and angular dependence of atmospheric muon flux, the data are transformed to normalized deviations $n_{ik}(t)$ from average values N_{ik} in each direction ik. In case of the quiet Sun, the data arrays $n_{ik}(t)$ follow nearly Gaussian law. The random fluctuations are uniformly distributed over the array area. Fig.2a (17.08.1998) shows the example of such distribution. When CME passages in the vicinity of the Earth, the picture is broken. Fig.2 shows the changes of PCR flux homogeneity for different phases of CME passage in 26.08.1998 event. The angular size of individual cells is 2° × 2°. Values $n_{ik}(t)$ are taken as deviations from the average calculated before the beginning of the FD, at the absence of disturbances. Changes of anisotropy of PCR in time are visible. The sporadically moving "dark spots" on the array area are observed. The form and sizes of inhomogeneities are considerably varying. Such processing was carried out for several FD with big amplitude. In all events, the azimuth anisotropy of the muons flux was observed. Similar "2D-maps" with anisotropy were presented in work [5] for the same event (26.08.1998) during several hours after the front of the Forbush decrease.

It is necessary to note, that the intensity anisotropy in the form of "spots"

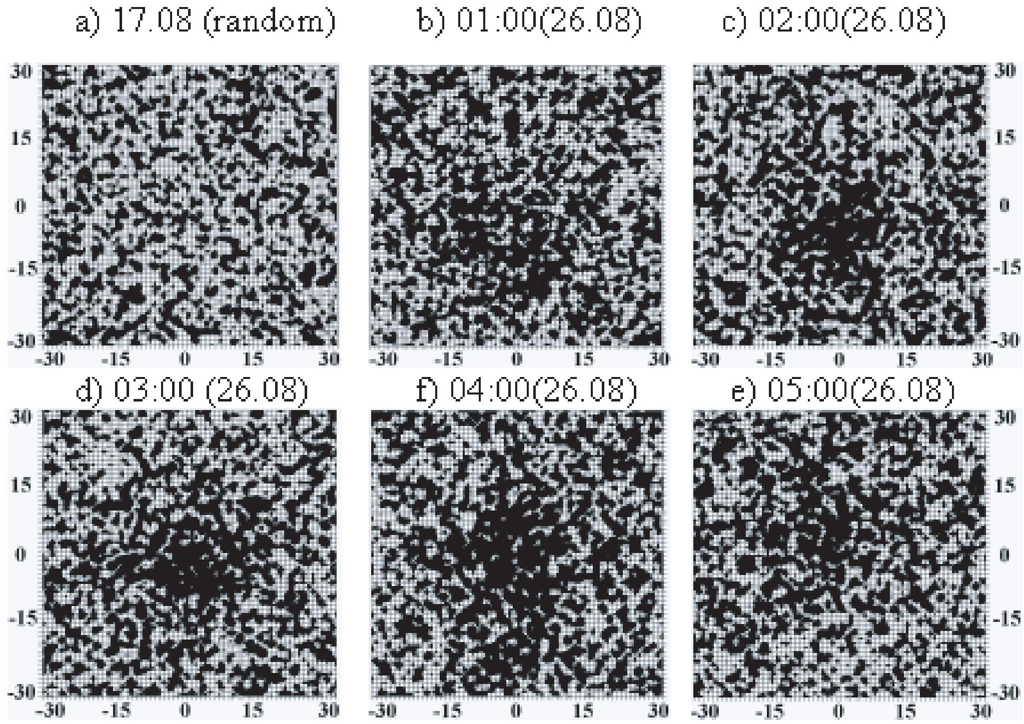

Fig. 2. 2D muon-graphs of cosmic rays intensity n_{ik} from 4096 spatial directions at central part of matrix (64×64) at FD 26.08.1998. Arrays correspond to half-hour long exposure intervals at 01, 02, 03, 04, 05 hr LT. The dark color corresponds to the decrease of muon intensity ($n_{ik} < 0$); the light color – to increased intensity ($n_{ik} > 0$).

begins to occur prior to the arrival of the front of FD. It may form a basis for a predictor of occurrence of shock waves near the Earth.

3. Dynamics of CME frequency fluctuations

Long-period (hours, days) fluctuations of PCR flux are connected with large-scale structure of the IMF. Measurement of the directed in space ($\mathbf{r}$) short-term variations (minutes) give the information about dynamic structure of separate elements of CME during its passage through the Earth's orbit. The stationary PCR fluxes crossing inhomogeneities with characteristic size L acquire modulation with frequency about $f = V/L$, where V is the velocity of CME propagation. Using frequency spectra of PCR intensity modulation in various directions $\mathbf{r}$, it is possible to estimate the sizes of inhomogeneities and magnetic field B in them: $L = V/f(\mathbf{r})$, $B(\mathbf{r}) = P \cdot c \cdot f(\mathbf{r})/(300 \cdot V)$, where P is the average momentum of relativistic PCR protons.

The hodoscope simultaneously registers (on the inside of CME) a big number of time series of intensity of PCR passing through different areas of the disturbed magnetic field (Fig.1). During the day, a continuous scanning of various areas of this field in a wide spatial angle is performed. Analysis of synchronous measurements of muon intensity $N_{ik}(t)$ during the FD (26.08.1998) for several spatial directions, including the ecliptic plane, was carried out. No correlations in high-frequency fluctuations between these time series were found. However, non-stationary wave trains with several hours duration are observed. These variations are significantly changed during the day. The harmonic fluctuations within time interval 5 – 10 hr with the period about of 50 min are seen [6] at ecliptic plane. In many measured time series, there are variations of different duration with characteristic periods about 3 – 5 min. It corresponds to inhomogeneities in CME near the Earth's orbit $L = (0.2 - 0.3) \times 10^6$ km. The analysis of the Forbush decreases for a long period of hodoscope operation is now in progress.

4. Conclusion

The application of large-aperture detectors with high angular resolution for obtaining spatial "pictures" of anisotropy and short-term variations of high-energy cosmic rays offers new opportunities for studying the dynamic processes in the heliosphere, caused by high-energy phenomena on the Sun.

The network of muon hodoscopes located in different time zones could provide a panoramic image of all directions in the heliosphere. It would qualitatively extend the possibilities of monitoring of solar-terrestrial connections and Space Weather.

5. Acknowledgements

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6. References

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