Journal of Physics: Conference Series

Features of the cosmic ray 27-day variation within 2014 November-December

Features of the cosmic ray 27-day variation within 2014 November-December

V E Sdobnov, M V Kravtsova, S V Olemskoy

Institute of Solar-Terrestrial Physics of Siberian Branch of Russian Academy of Sciences, Irkutsk, RF

E-mail: *sdobnov@iszf.irk.ru*

Abstract. From the ground-based measurements at the global world network of neutron monitors and from the GOES-15 satellites, investigated was the cosmic ray (CR) intensity 27-day variation within 2013, 2014, and 2015 November–December.

Significant changes in the energy losses as particles move in the heliosphere regular electromagnetic fields were shown to be the determining factor for the considerable difference in the amplitudes of the CR 27-day variation within 2014 November-December (as compared with that of 2013 and 2015 November–December). Within 2014 November–December, there was a long-living corotating trap under the action of a vast coronal hole in the Sun south in the interplanetary space. This trap configuration facilitated the energy loss of CRs with the ~3–20 GV rigidity, due to which ground-based neutron monitors measured an abnormally large amplitude of the 27-day variation.

1. Introduction

An important feature of the interplanetary magnetic field (IMF) is its structure. This means that, in the interplanetary space, there may be an even number of the sectors with different IMF radial component direction in the ecliptic plane.

The IMF sector structure is related to the existence of the neutral current sheet dividing the hemispheres, in which the solar magnetic field radial component has the opposite direction (because the magnetic flux through any closed surface is equal to zero, the magnetic field in different regions of space should be directed in opposite directions). Every 22 years, the Sun magnetic field changes its sign (polarity reversal). The current sheet is approximately in the solar equator plane and has a corrugated structure: it alternately declines north- and southward of the equator. As a result of the Sun rotation, the current sheet folds twist in spirals.

An observer on the Earth, who moves in the plane, is either below, or above the current sheet. Due to this, he passes through the sectors with different direction of the IMF radial component. Because of longitudinal and latitudinal solar wind (SW) velocity gradients that occur near the Sun, there emerge radial velocity gradients (when moving away from the Sun) that lead to the production of collisionless shocks near the sector boundaries. Such waves originate at >1 AU, and are traced at several AU.

As long as an active region exists within several rotations of the Sun, then it will corotate with the Sun, because the magnetic inhomogeneity is, as though, bound to a certain field line "leaving" the given meridian. The cosmic ray (CR) propagation in the heliosphere in the presence of such inhomogeneities causes a 27-day variation. There are numerous papers that study the effect of corotating SW structures on the CR behavior, for example [1–3].

Normally, the amplitude of the CR neutron component 27-day variation measured at the sea-level does not surpass ~0.7–1.0 % [4].

Starting with the 2014 second half until 2015 March, the world network CR stations recorded the 27-day variation of an abnormally large amplitude [5]. Thus, at the Irkutsk CR station (threshold rigidity R=3.66 GV) located at 433 m above the sea-level, the amplitude of the CR 27-day variation was ~8% in 2014 November–December. The amplitudes of the CR 27-day variation in 2013 November-December, and in 2015 did not show any abnormal values.

Unlike the situation in the heliosphere within 2013 November–December and in 2015, the existence of a huge coronal hole near the South Pole of the Sun [6] in the 2014 second half led to an asymmetric magnetic configuration at the mid- and high-heliolatitudes. The 2014 November–December current sheet inclination was ~52° [7]. Besides, during this period, there was a polarity reversal on the Sun [7].

In this study, we interpret the abnormally large amplitude of the 2014 November–December CR 27-day variation.

2. Data and method

For the analysis, we used the data of ground-based measurements with world-network neutron monitors. The data were averaged over hour intervals. For 2013 November–December, there were data from 45 stations, for 2014 November–December – from 39 stations, for 2015 November–December – from 41 stations. Also, the GOES-15 satellite data were involved [8].

Through the spectrographic global survey [9, 10], we obtained the information on variations in the primary CR angular and energy distributions outside the Earth magnetosphere, as well as on the variations in the geomagnetic cutoff rigidity planetary system for each observational hour. The modulation amplitudes were counted off from the 2013 November 19 background level (for 2013 November–December), from the 2014 November 28 background level (for 2014 November–December), and from the 2015 November 24 – for 2015 November–December. From the world-network CR station data, and from the GOES-15 data on protons in the Earth orbit [10], we calculated the CR proton spectra at individual instants of the investigated events. To calculate the CR spectra, we used the expression obtained within the model for the CR modulation by heliospheric regular electromagnetic fields [11].

3. Results and conclusions

The existence of a huge coronal hole in the 2014 second half and early 2015 [6] led to the presence of quasi-stationary high-velocity flows of solar plasma in the interplanetary space. When propagating in the interplanetary space, the high-velocity flow overtakes the slow one, and, as a result of coupling between the two flows, there forms a magnetic trap that corotates with the Sun at the 27-day periodicity, thus causing the 27-day variation in the CR intensity.

According to [12], the CR 27-day variations imply the presence of the ordered IMF. Therefore, the CR energy variation (when moving in the heliospheric regular electromagnetic fields) may be? to a great extent, an important factor in the CR modulation with a 27-day periodicity. The energy variation, in its turn, is determined by the value and by the nature of the interplanetary medium electric fields, and by the time of particle interaction with those fields [11]. That time is notably determined by the IMF structures of "magnetic trap" type. At such an approach, the energy variation is described by the expression [11]

$$\Delta\varepsilon = \frac{ze\Omega B_0 r_0^2}{c}(1-\cos\lambda_E) = zeU,$$

where $U = \Omega B_0 r_0^2(1-\cos\lambda_E)$ is the electric field potential at the λ_E heliolatitude, Ω is the Sun rotation angular velocity, B_0 is the strength of the mean magnetic field at r_0. The CR rigidity spectrum in the Earth orbit is described by the expression [11]

$$J(R) = A\frac{\left(\varepsilon^2-\varepsilon_0^2\right)^{3/2}}{\varepsilon\left[(\varepsilon+\Delta\varepsilon)^2-\varepsilon_0^2\right]}\left(\frac{\varepsilon+\Delta\varepsilon}{T_0+\varepsilon_0}\right)^{-\gamma},$$

where ε is the total energy of particles with the rigidity R; $\Delta\varepsilon$ is its variations within the heliospheric electromagnetic fields; ε_0 is the rest energy; T_0 is the kinetic energy of particles, at which the CR intensity corresponding to the rigidity in the Galaxy is A; γ are the spectral index of the galactic spectrum.

Apparently, the particle energy losses at the potential electric field do not depend on the particle rigidity, and, at the IMF characteristic strength (~5 nT), are ~200 MeV.

In that case, when the IMF has the structure different from spiral (for example, in the presence of loop-like structures or "magnetic clouds", i.e. "magnetic traps"), the $\Delta\varepsilon$ values will depend on the strength of the magnetic fields of the provided structures and on the SW velocity, and may surpass 200 MeV by almost an order of magnitude [11].

Figure 1 presents the IMF strength modulus (|B|), the IMF orientation longitudinal angle (Long), and the solar wind velocity (V) for 2013, 2014, and 2015 November–December. Within the presented intervals, one can clearly see the periods, when the IMF was directed away from the Sun, and when the magnetic field direction turned to the opposite one, i.e., one can see a sectoral IMF structure. This figure also provides: the CR variation amplitudes (ΔI/I, blue line) at the Irkutsk Station (Rc=3.66 GV); the CR variation amplitude with the 10 GV rigidity in the Earth orbit (ΔJ/J, red line); the CR geomagnetic cutoff rigidity variations (ΔR, blue line) in Irkutsk; the Dst-index (red line); $\Delta\varepsilon$ being the particle energy variations within the heliospheric electromagnetic fields during the indicated periods.

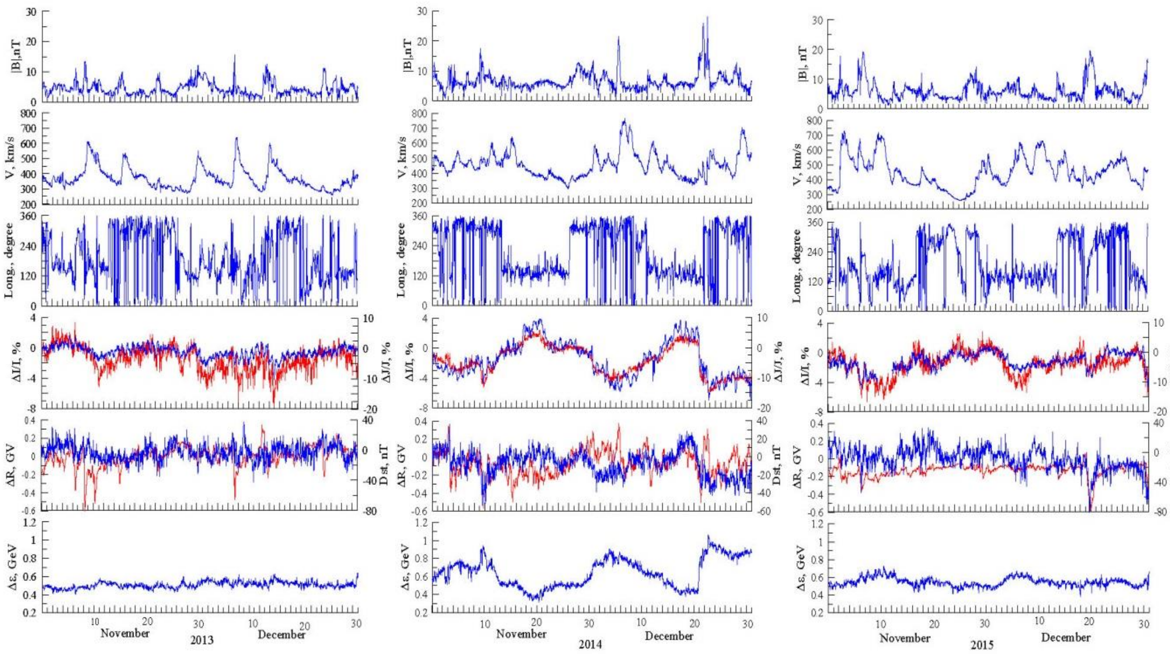

Figure 1. |B| is the IMF strength modulus, Long is the IMF orientation longitudinal angle, V is the solar wind velocity, ΔI/I is the amplitude of the CR variations at the Irkutsk Station (Rc=3.66 GV, blue line), ΔJ/J is the amplitude of the variations in the 10 GV rigidity CRs in the Earth orbit (red line), ΔR is the CR geomagnetic cutoff rigidity variation in Irkutsk (blue line), Dst-index (red line); Δε is the particle energy variation within the heliospheric electromagnetic fields.

From the satellite measurements of SW parameters [13], the IMF modulus mean value in the sector with the magnetic field sunward direction in 2014 was more (~7.2 nT), than this value in the sector with the magnetic field direction away from the Sun (~6.2 nT). In 2013 and 2015, the IMF modulus mean value in the sector with the magnetic field sunward direction (~4.6 and ~6.6 nT, respectively) was less, than this value in the sector with the magnetic field direction away from the Sun (~6.8 and ~6.7 nT, respectively).

From Figure 1, one can see that the amplitude of the CR neutron component 27-day variation in Irkutsk over 2014 November–December is much more, than that over the same period in 2013 and 2015. Such a great difference in the variation amplitudes is provided by the different values of the CR particle energy losses in the heliospheric electromagnetic fields during the indicated periods. Thus, in 2013 November–December, the $\Delta\varepsilon$ value varied between ~0.4 and ~0.6, in 2014 November–December ~ 0.3 through ~1.1, in 2015 November–December ~0.4 through ~0.7. From the above, it follows that the determining factor of the significant difference in the galactic CR flow variations in the Earth orbit over 2014 November–December (as compared with 2013 and 2015 November–December) is essential variations in the particle energy losses, as they move in the regular heliospheric electromagnetic fields. We also note that the particle energy losses over 2014 November–December in the sector, where the IMF was directed away from the Sun, are much less, than those in the sector, where the IMF was sunward.

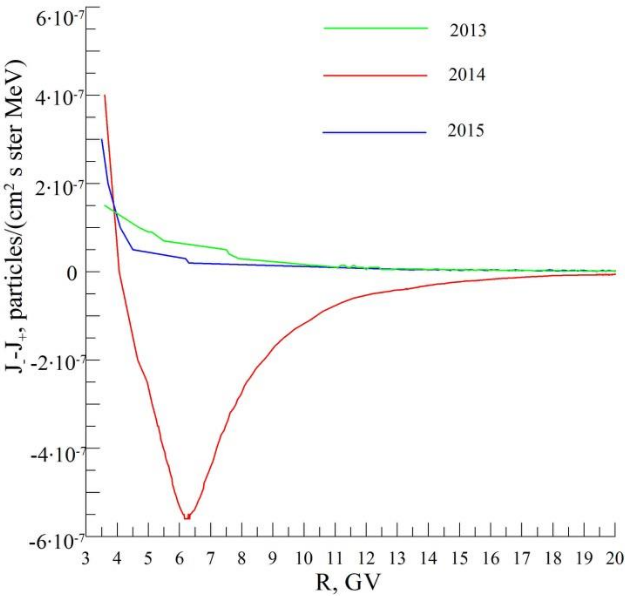

Figure 2. (J_{-}-J_{+}) is the difference in the mean CR rigidity spectra in the sectors with the IMF direction toward (J_{-}) and away from (J_{+}) the Sun.

To reveal, in which rigidity range the maximal modulation in different IMF sectors occurs, we calculated the CR mean rigidity spectra in the sectors with the IMF direction toward (J_{-}) and away from (J_{+}) the Sun for 2013, 2014, 1nd 2015 November–December. Figure 2 presents the difference in such spectra (J_{-}-J_{+}) for the above periods. Apparently, within the ~3–20 GV rigidity range, where neutron monitors are most sensitive, the 2014 November–December modulation in the sectors with the IMF direction toward the Sun prevailed over the modulation in the sectors with the IMF direction away from the Sun. Presumably, over this period, there emerged a long-lived corotating trap of such a configuration, in which the ~3–20 GV CRs were losing their energy most efficiently under the effect of the huge coronal hole in the south of the Sun. Due to that, the ground-based CR measurements with neutron monitors displayed an abnormally large amplitude of the 27-day variation.

The study was done within the 2018 State Assignment 007-00163-18-00 of 2018 January 12 by using the research equipment of the "Angara" Multi-Access Center (Angara MAC) and of the "Russian National Ground-Based Network of Cosmic Ray Stations" (CRS Network) Unique Research Facility (URF).

IOP Conf. Series: Journal of Physics: Conf. Series 1181 (2019) 012005 doi:10.1088/1742-6596/1181/1/012005

References

[1] Lee C O, Luhmann J G, I. de Pater, Mason G M, Haggerty D, Richardson I G, Cane H V,· Jian L K, Russell C T and Desai M I 2010 *Solar Phys*. 263 239-61 DOI 10.1007/s11207-010-9556-x

[2] Modzelewska R and Alania M V 2013 *Solar Phys*. 286 593-607 DOI 10.1007/s11207-013-0261-4A

[3] Gil A and Alania M V 2016 *Solar Phys*. 291 1877-86 DOI 10.1007/s11207-016-0924-z

[4] Dorman L I 1963 *Cosmic ray variations and space exploration* (Moscow: USSR AS Publishers) p 1028

[5] Gil A and Mursula K 2015 *Proc. 34th Int. Cosmic Ray Conf.* (Netherlands: Hague) p 149

[6] http://www.solarmonitor.org

[7] http://wso.stanford.edu/

[8] http://satdat.ngdc.noaa.gov./sem/goes/data/new_avg/

[9] Dvornikov V M et al 1983 *Proc.18th Int. Cosmic Ray Conf.* 3 (India: Bangalore) p 249

[10] Dvornikov V M and Sdobnov V E 2002 *Int. J. Geomagn. Aeron*. 3 3 217-28

[11] Dvornikov V M, Kravtsova M V, Sdobnov V E 2013 *Geomagnetism and Aeronomy* 53 4 430-40

[12] Krymsky G *F* 1969 *Modulation of cosmic rays in the interplanetary space* (Moscow, Nauka Science Publishers) p 152

[13] https://omniweb.gsfc.nasa.gov/ow.html