Measurement conditions in the space experiment
MONICA

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Abstract. The present contribution is dedicated to the investigation of the background conditions for cosmic ray ion ionization state measurements in MONICA experiment [1]. The future experiment MONICA is aimed to study the cosmic ray ion fluxes from H till Ni in energy range 10-300 MeV/n by multilayer semiconductor telescope-spectrometer installed onboard satellite. The satellite orbit parameters (circular, altitude is about 600 km, polar) were chosen for the realization of the unique method for the measurement of the charge state of the ions with energies >10 MeV/n by using the Earth magnetic field as a separator of ion charge. The analysis of the background particle fluxes is presented taking into account the recent data of the satellite experiments and known AE-8, AP-8 models and elaborated the recommendations to improve the background conditions for the MONICA experiment.

1. Introduction
New onboard experiment MONICA is aimed for studying the cosmic ray ion fluxes from H to Ni in the energy range 10-300 MeV/n in the near-Earth space [1]. The main scientific objective of the experiment is to measure ion charge states, elemental and isotope composition and energy spectra of SEP fluxes for the individual Solar events as well as to study of evolution of these characteristics over time. At the same time MONICA will investigate ionization states and isotope composition of anomalous and galactic cosmic rays as well.

Ion charge states of the SEP observed in the near-Earth space are considered to be sensitive probes for the conditions in acceleration region such as particle acceleration dynamics and efficiency, solar plasma mean electron density and temperature [2-4]. As it is known the mean ionization state of iron ions with energies more than 10 MeV/n is about \( Q_{Fe} \sim +14 \) for gradual SEP events and more than \( Q_{Fe} \sim +20 \) for impulsive events [5], [6]. Thus, Fe mean charge state can be used for identification of SEP event type. The mean charges of more light SEP ions He, O, Mg, Si, Ar, Ca with energies \( > 10 \) MeV/n observed during a few gradual events are the following: \( Q_{He} \sim +2 \), \( Q_{O} \sim +7 \), \( Q_{Mg} \sim +10 \), \( Q_{Si} \sim +10.5 \), \( Q_{Ar} \sim +10 \), \( Q_{Ca} \sim +11.5 \) [4]. The He, O, Mg, Si, Ar and Ca ions with energies more 10 MeV/n observed during impulsive solar events are to be practically totally ionized.

Ion charge composition of the cosmic ray fluxes observed during solar quiet times reflects the features of the processes involved in acceleration and propagation of ACRs and GCRs. As it is known today the ACRs are primarily singly charge ions of the elements with high first ionization potential (H, He, C, N, O, Ne, Ar and possibly some others) with energies from several up to 50 MeV/n [7].
The investigations will be carried out with the high-acceptance multilayer silicon telescope-spectrometer MONICA installed onboard a satellite which will be launched into the low Earth polar orbit with an altitude about 600 km [1]. The instrument will be pointed to zenith. The spectrometer will detect nuclei in the following energy ranges: H and He from 5 to 70 MeV/n, CNO group from 10 to 150 MeV/n, Fe group from 15 to 300 MeV/n. The instrument will measure nuclear charge (Z), mass, energy, and incident angle for each detected particle. The identification of the registered nuclei will be implemented by modified $\Delta E - E$ method [8]. The spectrometer acceptance is about 100 cm$^2$sr, the field of view (FOV) is $\pm 45^\circ$.

In the MONICA experiment the method of ion charge (Q) measurement based on the using of the Earth magnetic field as a particle charge separator will be implemented. Electrostatic analyzers [9] and other instrumentation are impossible to use for energies more than 10 MeV/n as the ions will be stripped within several $\mu g/cm^2$ of the material [10].

This contribution is dedicated to study the background conditions for ion charge measurements in MONICA experiment.

2. The measurement of ion charge [11]

The method for the ion charge state measurement uses of Earth magnetic field as their separator. It is well known that the penetration depth of ions into the magnetosphere depends on their gyro radius. This can be observed as a flux cut-off for the particles with rigidity $R$ at a corresponding magnetic $L$-shell $L_C$. This figure 1 shows dependence of registration efficiency $Eff(\Delta E)$ of ions detecting by the instrument in energy range $\Delta E$ on $L$-shell number. This efficiency is defined as a ratio between the counting rate of the ions detected inside the magnetosphere $N_{in}(\Delta E)$ and the counting rate of the ions detected outside it in interplanetary space $N_{out}(\Delta E)$.

\[ Eff = \frac{N_{in}}{N_{out}} \]

Figure 1. Detection efficiency of ions registered by instrument versus $L$-shell. $L_1 \div L_2$ is the inflection zone.

Referring to [4] the inverse square of cut-off $L$-shell value $L_C$ depends on the particle rigidity $R$ linearly:
1/L_c^2 = aR + b
This dependence is to be used to obtain the mean charge of the particles Q:
QR = P = \sqrt{(2M + E)E}, Q = a\sqrt{(2M + E)E}/(1/L_c^2 - b),
where E, M = m_0c^2 and P = pc are the measured ion kinetic energy, the mass at rest and momentum in energy units (eV) correspondingly.

3. Region of the ion charge separation and the sources of the background
The registration of the cosmic ray ions should be carry out at middle and low latitudes where the satellite with instrument onboard will cross the outer and inner Earth radiation belts (RB).

Figure 2. Calculated L-shell intervals L_{min} ÷ L_{max}, where the inflection zones of the Eff(L) dependences L_1 ÷ L_2 (see Fig. 1) will be observed in the MONICA experiment, for ions of the different elements from H to Fe.

In Fig. 2 the evaluated L-shell intervals L_{min} ÷ L_{max} are presented where the inflection zones L_1 ÷ L_2 (see Fig. 1) will be observed in MONICA experiment for the different ions from hydrogen to iron. It is seen to realize the geomagnetic separation the observation of the ion fluxes should be carried out in the region where L < 6.

In Fig. 3 the ion charge separation region is shown in geographic coordinates. It is localized between L=6 lines. In addition, It is shown the counting rate of the top detector of the ARINA spectrometer onboard Resurs-DK1 satellite [12] obtained during the solar quiet period 1 - 30 September 2006. The ARINA top detector detects protons with energy >20 MeV and electrons with energy >1 MeV.

The following main background sources are to be mentioned in the MONICA experiment in the area of the ion charge separation (see Fig. 3): 1) the fluxes of the electrons with energy from some hundred keV to some MeV inside zone of the outer RB (3.5 < L < 6), 2) the fluxes of the protons with energy from several MeV to some hundred MeV and electrons with energy from some hundred keV to several tens MeV inside inner zone.
Figure 3. The region of the ion charge measurement in the MONICA experiment and map of the counting rate of the ARINA spectrometer top detector obtained during the period from 01.09.2006 until 30.09.2006.

The intense fluxes of the high energy protons and electrons of the inner RB will penetrate through the MONICA instrument in the South Atlantic Anomaly (SAA) (see Fig. 3) and will cause an overload of all its detectors. As a result the detection of cosmic ray ions will be exceedingly difficult in the SAA region. As the SAA occupies relatively small region in southern hemisphere at altitudes about 600 km the effective detection of ions outside of the SAA can be carried out at all $L$-shell ($L < 6$). The SAA zone will lead to a decrease of exposure.

In Fig. 4 the ratio of the calculated exposures outside and inside the SAA are presented for $L$-shell interval $L_{\min} \div L_{\max}$ ($\eta = T_{L_{\min} \div L_{\max}}(\text{outside SAA})/T_{L_{\min} \div L_{\max}}$) for different ions. The evaluations of $\eta$ were implemented for Solar minimum and maximum conditions. The position of the SAA was determined with AP-8 model. One can see from Fig. 4 that the rejection of the SAA zone leads to decreasing of the exposure not more than 20%.

Unlike the inner RB the satellite with the MONICA instrument onboard will cross the outer RB for all longitudes in $L$-shell range $3.5 < L < 6$. As follows from Fig. 2 this range substantially intersects with intervals of the $L$-shell $L_{\min} \div L_{\max}$ where the ion charge measurements will be implemented. So if ion detection will be impossible in outer RB zone this will lead to substantial increase of the low boundary of the measured particle rigidities from 93 V (5 MeV proton energy) up to 870 MV (corresponding to vertical cut-off rigidity at $L=3.5$).

4. The background conditions in outer zone
The zone of the outer RB can be divided into two regions: 1) the region of the stably trapped particles (it is shown by hatching in Fig. 3); 2) the region of the quasi-trapped particles located inside other part of outer RB zone. Inside the first region electrons can be trapped in geomagnetic field the long time doing big number of drift rotations around the Earth. Inside the second region electrons lives short time and can do only one drift rotation after which they are absorbed by
Figure 4. The ratio of the calculated exposures \( \eta \) outside and inside the SAA in \( L \)-shell interval \( L_{\text{min}} \div L_{\text{max}} \) for ions of the different elements from H to Fe for Solar minimum and maximum. The evaluations were carried out for the polar circular satellite orbit with inclination 82° and altitude about 600 km.

The Earth atmosphere during drift from the East to the West near the west boundary of stable trapped particle area. The quasi-trapped electron fluxes are generated by particle precipitation out of the outer RB. The zone of the quasi-trapped electrons is characterized by high variability of particle fluxes. In the period from 01.09.2006 until 30.09.2006 the changes of these fluxes in several times in the ARINA experiment were observed.

The trapped electron flux in outer RB is not the omnidirectional. For each point of the RB zone there is strictly fixed range of the pitch-angles \( \alpha_{\text{min}} \div \alpha_{\text{max}} \) where exists the trapped particle flux. Outside of the range \( \alpha_{\text{min}} \div \alpha_{\text{max}} \) this flux is absent (its intensity is exactly equal to zero). Since the energy of the outer RB electrons is quite low (up to several MeV), these particles would be dangerous as a background only in case of their getting into the MONICA spectrometer field of view (FOV) through the input thin window.

The fraction of the spectrometer FOV contamination by outer RB electrons for estimation of the background conditions for MONICA experiment was calculated.

The calculation of the FOV contamination fraction was realized according an algorithm clarified in Fig. 5. At the first stage the pitch-angle range \( \alpha_{\text{min}} \div \alpha_{\text{max}} \) was calculated for given point in outer RB zone with coordinates defined by chosen hemisphere (northern or southern), \( L \)-shell and geographic longitude. At the beginning the maximum value of the geomagnetic field \( B_0 \) was determined in mirror points for trapped particles existing in given point of the satellite orbit. The fact was used that for fixes \( L \)-shell a particle can be consider quasi-trapped by geomagnetic field if its mirror points in northern and southern hemispheres (with McIlwain coordinates \( L, B_0 \)) at the observation longitude are located higher then atmosphere boundary \( (h_{\text{min}} \sim 100 \text{ km}) \), i.e. particle can make at least one oscillation between the mirror points. The evaluation of the \( B_0(h_{\text{min}} = 100 \text{ km}) \) was fulfilled by means of geomagnetic field line
tracing. Then using adiabatic invariant conservation $B/sin^2\alpha=\text{const}$ (where $B$ is the value of geomagnetic field and $\alpha$ is pitch-angle) the values $\alpha_{\text{min}}$ and $\alpha_{\text{max}}$ were determined using the following formulas:

$$a_{\text{min}} = \pi/2 - \arcsin \sqrt{B(H_{\text{orbit}})/B_0(h_{\text{min}})},$$
$$a_{\text{max}} = \pi/2 + \arcsin \sqrt{B(H_{\text{orbit}})/B_0(h_{\text{min}})},$$

where $(H_{\text{orbit}})$ is value of the geomagnetic field in studied point of the satellite orbit (see Fig. 5).

At the second stage the value of the solid angle $\Delta\Omega$ was determined which corresponds to directions of outer RB particles arriving into instrument FOV. Then the fraction of the FOV contamination $\xi$ was calculated as ratio of $\Delta\Omega$ to whole instrument FOV $\Omega_{\text{FOV}}$: $\xi = \Delta\Omega/\Omega_{\text{FOV}}$. The determining of spatial angle $\Delta\Omega$ is clarified in Fig. 5 where $\Delta\Omega$ is highlighted by green color. The spatial angle $\Delta\Omega$ corresponds to the area of the crossing the FOV (red spherical sector with angle $\gamma=1/2$ FOV in Fig. 5) and the area of the feasible trapped particle directions (blue spherical segment with angle $\Delta\alpha=\alpha_{\text{min}} - \alpha_{\text{max}}$ in Fig. 5 which axis is the direction of geomagnetic field).

In Fig. 6 the calculated dependences of the instrument FOV contamination fraction $\xi$ by outer RB particles when satellite orbit at altitude 600 km crossing the $L$-shell $L=4.5$ (where intensity of the outer RB particles is maximal) on the FOV value and geographical longitude of $L=4.5$ crossing are presented for northern (left) and southern (right) hemispheres. As it is follows from Fig. 6 the contamination of the MONICA instrument FOV by outer RB electrons is observed in southern hemisphere only in longitude range from $-120^\circ$ to $+50^\circ$ in the region of the stably trapped particles (see Fig. 3). The contamination fraction value $\xi$ does not exceed 6%.

Thus the trapped electron flux in outer RB zone practically will not affect functioning of the MONICA detectors excluding the top semiconductor detector D1 [1].

5. Conclusion

The detailed analysis of the background conditions for cosmic ray ion charge measurements for satellite experiment MONICA was implemented.
Figure 6. The calculated dependences of the instrument FOV contamination fraction $\xi$ by trapped particles in outer RB when satellite orbit at altitude 600 km crossing the $L$-shell $L=4.5$ on the FOV value and geographical longitude of $L=4.5$ crossing for northern (left) and southern (right) hemispheres.

It was shown that for chosen satellite orbit parameters (circular, polar with inclination $\geq 82^\circ$ and altitude about 600 km) the RB particle background fluxes will not have the significant impact on results of the MONICA experiment. Cosmic ray ion registration will be difficult inside SAA zone especially light ones because of the instrument detectors are overloaded. However the excluding this region out of the observations will lead to decreasing detected particle statistics only inside the regions of the ion charge measurements not more then 20%. The outer RB electron fluxes will not influence on the MONICA instrument functioning. The top semiconductor detector can be shielded against outer RB electrons by additional collimator.

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