# The project MONICA: monitor of cosmic ray nuclei and ions

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***Abstract*. The description of new onboard experiment MONICA for study of the fluxes of cosmic ray energetic ions from He to Ni in the energy range 10-300 MeV/n in vicinity of the Earth is presented.**
**MONICA main scientific objective is the measurement of ion charge states, as well as elemental, isotope composition and energy spectra of Solar Energetic Particle (SEP) fluxes for individual SEP events (including impulsive events), and study the evolution of these characteristics in time. MONICA will be able to investigate ion and isotopic composition of Anomalous Cosmic Rays (ACR) and Galactic Cosmic Rays (GCR), and study the nuclear fluxes in Earth radiation belt also.**
**The observation of ion fluxes will be carried out with the large-acceptance multilayer silicon telescope-spectrometer MONICA onboard the polar-orbiting small-size satellite developed by Lavochkin Science and Production Association (Russia). The satellite orbit parameters (near-Earth, circular with altitude about 600 km, polar) were chosen for the realization of unique method for the measurement of charge state of ions at energies more 10 MeV/n based on the usage of Earth magnetic field as a separator of ion charge. The experiment will be started in 2011-2012 for 5 years observation in the maximum phase of $24^{th}$ solar cycle.**

***Keywords*: Space instrumentation, solar cosmic rays, ion composition**

## I. Introduction

Despite the extensive investigation of the Sun and solar radiation during last several decades, the problems concerning the mechanisms and regions of Solar Energetic Particles (SEP) generation are still open today. The latest experimental data reflects the variety and complexity of SEP generation mechanisms, starting from the processes in flare area and finishing by the propagation in interplanetary space. It is clear today that for the progress in this field the complex investigation of the ion charge to mass ratio (Q/A), element abundances, and energy spectra of SEPs are required.

The acceleration of SEPs occurs in electromagnetic fields, and so the acceleration and transport processes depend significantly on velocity and rigidity, i.e. on the mass and ion charge of the ions. That is why the ion charge composition is especially important for the ultimate understanding of SEP acceleration mechanisms. The ion charge is formed in temperature-dependent ionization and recombination processes in corona. When particles emerge from the Sun, the plasma density decreases rapidly, and the ion charge states "freeze in". The charge state distribution of the SEP therefore reflects the source conditions. So the observed (for example, at 1 AU) ion charge states of SEPs are considered to be sensitive probes of the conditions in acceleration region, e.g., particle acceleration dynamics, solar plasma mean electron density and temperature.

Unfortunately, the present experimental data on ion charge states of SEPs, especially in the high energy region (E>10 MeV/n), are extremely fragmental and not sufficient for the detailed understanding of SEP generation processes.

New experiment MONICA aimed, first of all, for the study of ion charge as well as isotope composition of SEPs from H to Ni in 10-300 MeV/n energy range. In this experiment for the measurement of ion charge the method based on the usage of Earth magnetic field as a separator of particle charge will be utilized. At the same time MONICA will investigate ion and isotope composition of ACR and GCR.

The investigations will be carry out with high-acceptance semiconductor spectrometer installed onboard of small size satellite SSA n.2 developed by Lavochkin Association. The satellite will be launched in to near-earth polar orbit with altitude about 600 km. The high geometrical factor of MONICA spectrometer (about 100 $cm^2 sr$) will allow to measure the ion composition of SEPs during separate events and to study it evolution during events.

The development and realization of MONICA experiment will be carry out by Moscow Engineering Physics Institute (MEPhI) in collaboration with Lebedev Physical Institute (LPI), Ioffe Physics Technical Institute (PTI) and Joint Institute for Nuclear Research (JINR). The launch of SSA n.2 with MONICA instrument is planned in 2011-2012.

## II. MONICA scientific objectives

The main scientific objectives of MONICA experiment are the following:

1) Measurement of ionic charge states, as well as elemental, isotope composition and energy spectra of SEP fluxes from H to Ni in 10-300 MeV/n energy range for individual SEP events (including impulsive SEP events). Study the evolution of these characteristics in time during development of active processes on the Sun.
2) Measurement of ACR ion ionic charge and isotope composition, including new elements and isotopes, which have been observed on ACE (sulfur, isotopes of oxygen and neon and others); measurement of ACR energy spectra.
3) Measurement of GCR and ACR fluxes modulation with the purpose to study the conditions of particle propagation in heliosphere.
4) Study of CR penetration into Earth magnetosphere under conditions of its strong disturbances during the solar-magnetosphere events.

The additional objectives are:

1) Measurements of isotope fluxes inside Earth radiation belt (RB). Study of RB dynamics.
2) Study of albedo isotope fluxes.

## III. The description of MONICA experiment

### A. Method of ion charge measurement

Today the direct SEP ionic charge state measurements are carried out up to the energies of ions about 5 MeV/n only. For these measurements the ion charge analyzers are utilized (for example, ULEZEQ onboard ISEE-1, ISEE-3 and SEPICA onboard ACE [1]). As a rule, these sensors combine the determination of the electrostatic deflection of incoming ions in a collimator-analyzer assembly by the measurement of the impact position in the detector plane and a dE/dx - E telescope. For ions with energies >5 MeV/n the direct measurement of their charge state is impossible (the required electric field strength in analyzer should be unreal high; the analyzer acceptance must be unrealistic).

The unique method for the measurement of charge state of ions at energies more then 10 MeV/n is the method based on the usage of Earth magnetic field as a separator of ionic charge. This method was successfully approved in SAMPEX experiment [2]. It is well known that the penetration depth of ions into the magnetosphere depends on their gyroradius. On a polar-orbiting satellite, moving from a pole to the equator, this can be observed as a flux cut-off of particles of a given magnetic rigidity at a certain magnetic L-shell (or invariant latitude $\lambda$). This effect is demonstrated in Fig. 1, where the simulated counting rate of $Fe^{+20}$ ions in energy range 16-22 MeV/n, detected by the zenith-pointed telescope with 45° field of view moving from geomagnetic equator to pole, versus $\lambda$ is shown. Above the energies of few MeV/n, the inverse square of this magnetic cut-off L-shell value is linearly depended on the particle rigidity. This can be used to determine the mean charge of the particles [2]. It is clear that the accuracy of charge measurement

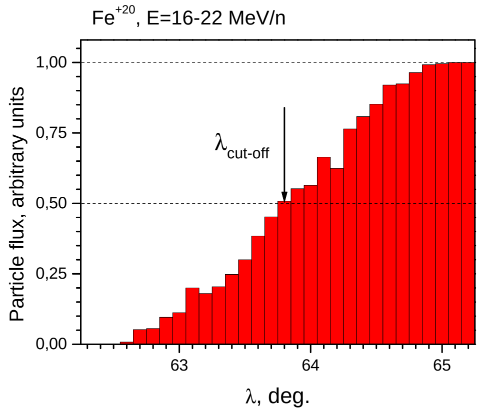



Fig. 1: The demonstration of particle flux cut-off effect.

directly depends on the collected statistics of ions. Therefore for the realization of this method the using of high-acceptance spectrometer of ions is required. Another problem is the necessity to know the geomagnetic cut-off rigidity in real time. During SEP events the Earth magnetosphere is strongly disturbed by gusts of solar wind and cut-off rigidity could vary very rapidly. So, for the measurement of SEPs ionic charge the technique described above should take into account this fact. It can be done by using the proton flux measured along the satellite orbit [2].

Thus, for realizations of this method the large-acceptance spectrometer-telescope of ions as well as fast proton monitor both installed onboard of near-earth polar-orbiting satellite are required.

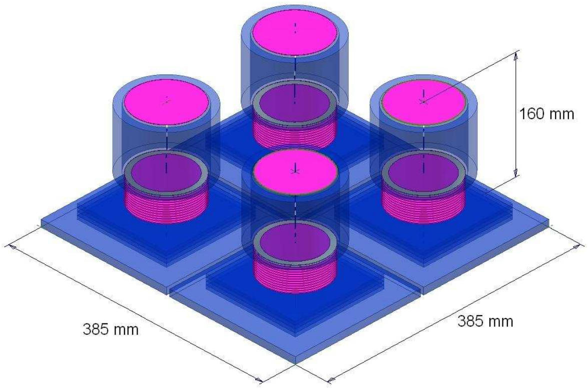
### B. Instrumentation

In MONICA experiment the detecting of CR nuclei fluxes from H to Ni in 10-300 MeV/n energy range will be carried out with the high acceptance spectrometer-telescope MONICA, developed on the base of stacks of silicon strip detectors having the high spatial, mass and energy resolutions.

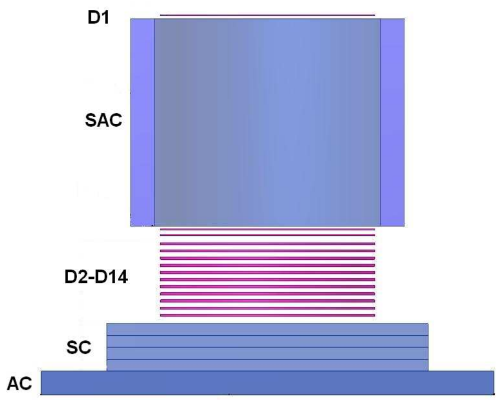
For monitoring of current geomagnetic cutoff (which value is extremely important for reconstruction of ion charge) the special separate proton monitor will be used.

*Spectrometer-telescope MONICA* consists of four separate stacks (see Fig. 2a). Each stack (see Fig. 2b) is comprised of the following subsystems:

1) *Multilayer silicon spectrometer.* It is intended for detection of CR nuclei in energy range from few MeV/n to about 200 MeV/n (the low limit corresponds to hydrogen and upper - to nickel) with excellent isotope and energy resolutions. This subsystem consists of 14 circular silicon detectors D1-D14. First two planes D1, D2 define the aperture of the instrument (about 45°). They have diameters 90 and 70 mm, correspondingly. The




(a) The structure of whole spectrometer-telescope.




(b) The physical scheme of one detecting stack.

Fig. 2: The physical scheme of telescope-spectrometer MONICA.

distance between D1 and D2 is 80 mm. The diameter of D3-D14 is 90 mm. The thickness of D1, D2 is 100 $\mu$m, D3-D5 is 300 $\mu$m, D6-D14 - 1000 $\mu$m. The total thickness of silicon is 1,01 cm×2,33 g/cm$^3$=2,35 g/cm$^2$. D1, D2 are double sided silicon detectors with 64 strips in each X and Y planes. The other D3-D14 are single side detectors with four radial stips each.

2) *Scintillation calorimeter.* Scintillation calorimeter SC is intended for detection of nuclei in extended energy range (up to about 300 MeV/n for Ni) with acceptable element and energy resolutions. It consists of stack of plastic scintillation detectors. Calorimeter total thickness is 3 cm of polystyrene (or about 3 g/cm$^2$).
3) *Anticoincidence system.* The anticoincidence system is intended for rejection of high-energy non-stopping nuclei as well as secondary isotopes generated in the instrument material by high energy CR particles. This system consists of bottom anticoincidence scintillation detector AC mounted under scintillation calorimeter and side cylindrical detector SAC installed between D1 and D2. The thickness of anticoincidence detectors is 10 mm.

The main first level trigger is following:

$$T = T_1 + T_2 + T_3 + T_4, \quad (1)$$

$$T_i = \left(T_i^{Z\geq1}/n_1 + T_i^{Z\geq2}/n_2 + T_i^{Z\geq3}\right) \times ANTI\left(AC + SAC_i\right), \quad (2)$$

$$T_i^{Z\geq1} = D1_i^{Z\geq1} \times D2_i^{Z\geq1} \times D3_i^{Z\geq1}, \quad (3)$$

$$T_i^{Z\geq2} = D1_i^{Z\geq2} \times D2_i^{Z\geq2} \times D3_i^{Z\geq2}, \quad (4)$$

$$T_i^{Z\geq3} = D1_i^{Z\geq3} \times D2_i^{Z\geq3}. \quad (5)$$

Where:
$T_i$ - triggers from separate four spectrometers;
$n_1$, $n_2$ - scaling coefficients;
$D1_i^{Z\geq1}$, $D2_i^{Z\geq1}$, $D3_i^{Z\geq1}$ - the signals from $D1_i - D3_i$ discriminators with threshold corresponding the detection of nuclei with $Z \geq 1$;
$D1_i^{Z\geq2}$, $D2_i^{Z\geq2}$, $D3_i^{Z\geq2}$ - the signals from $D1_i - D3_i$ discriminators with threshold corresponding the detection of nuclei with $Z \geq 2$;
$D1_i^{Z\geq3}$, $D2_i^{Z\geq3}$ - the signals from $D1_i - D2_i$ discriminators with threshold corresponding the detection of nuclei with $Z \geq 3$;
$AC$ - signal from bottom anticoincidence detector;
$SAC_i$ - the signal from the side anticoincidence detector.

TABLE I: The physics characteristics of MONICA spectrometer-telescope.

| n. | Characteristic | Value |
|---|---|---|
| 1. | Geometrical factor | 100 cm$^2$sr |
| 2. | Field of view | ±45° |
| 3. | Angular resolution | 1° |
| 4. | Energy range for: | |
| | H | 7-70 MeV |
| | He | 7-70 MeV/n |
| | O | 16-150 MeV/n |
| | Si | 20-210 MeV/n |
| | Ca | 24-260 MeV/n |
| | Fe | 25-290 MeV/n |
| | Ni | 27-310 MeV/n |
| 5. | Energy resolution | <1%[1] |
| | | <4%[2] |
| 6. | Mass resolution for:[1] | |
| | He | 0.03 a.m.u. |
| | CNO | 0.08 a.m.u. |
| | Fe | 0.3 a.m.u. |
| 7. | Charge resolution for:[2] | |
| | Fe | <0.3 |
| 8. | Resolution time | 100 ns |
| 9. | Dead time | <1 ms |

The identification of particles detected by spectrometer-telescope MONICA (definition of charge and mass) is carried out by the ΔE-E method and its modifications. The particle incident angle is defined by coordinates of hitted strips in detectors D1, D2. The energy of detected particle is determined as by range and by energy deposits in each detector.

[1]for nuclei stopped in silicon stack D2-D14
[2]for nuclei stopped in plastic stack SC

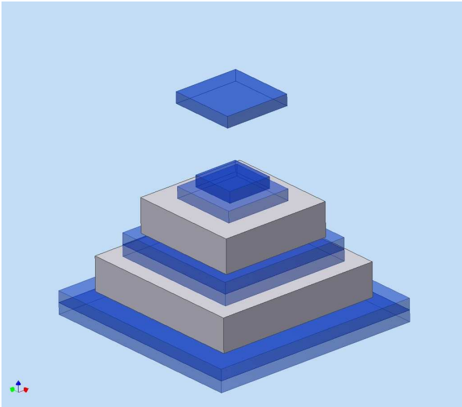


Fig. 3: The physical scheme of proton monitor.

Spectrometer MONICA has the geometrical factor two times more, than similar instruments onboard ACE [3] and at ten times more, than instruments used in experiments in orbits inside the Earth magnetosphere (MAST [4], NINA and NINA-2 [5]).
The main physics performances of spectrometer-telescope MONICA are presented in Table I.

*The proton monitor* of MONICA instrument consists of the stack of seven plastic scintillation detectors C1-C7 and three layers of alluminium absorber A1-A3 (see Fig. 3). Detectors C1 and C2 defines the monitor field of view (±45°). The thicknesses of detectors C1-C7 are 5-10 mm. Absorber (A1-A3) thicknesses are 15 mm.
The monitor triggers are the following:

$$T_1 = C1 \times C2 \times ANTI\,(C3)\,, \qquad (6)$$

$$T_2 = C1 \times C2 \times C3 \times C4 \times ANTI\,(C5)\,, \qquad (7)$$

$$T_3 = C1 \times C2 \times C3 \times C4 \times C5 \times C6 \times ANTI\,(C7)\,. \qquad (8)$$

Where C1-C7 are the signals from detectors C1-C7.
The proton monitor will detect the CR proton fluxes in three narrow energy bins in the range from 20 to 120 MeV. Monitor data will be utilized to reconstruct real current geomagnetic cutoff regidity and to estimate the current radiation environment during investigated SEP events. The main monitor physics characteristics are presented in Table II.

TABLE II: Proton monitor physics characteristics.

| n. | Characteristic | Value |
|---|---|---|
| 1. | Geometrical factor | 3 $cm^2$sr |
| 2. | Field of view | ±45° |
| 3. | Energy range | 20-120 MeV |
| 4. | Energy bins: | |
| | ΔE1 | 20-30 MeV |
| | ΔE2 | 80-90 MeV |
| | ΔE3 | 110-120 MeV |
| 5. | Resolution time | <50 ns |
| 6. | Dead time | <100 ns |

In the Table III the main technical performances of MONICA instrument are illustrated.

TABLE III: MONICA main technical performances.

| n. | Characteristic | Value |
|---|---|---|
| 1. | Outline dimensions | 650×650×300 mm |
| 2. | Mass | 40 kg |
| 3. | Power consumption | <80 W |

### C. *The description of satellite and orbit parameters*

The MONICA instrument will be installed onboard the small size satellite SSA n.2 developed by Lavochkin Association on the base of unified platform KARAT. The general platform characteristics are summarized in Table IV.

TABLE IV: KARAT platform general characteristics.

| n. | Characteristic | Value |
|---|---|---|
| 1. | Platform mass | 120 kg |
| 2. | Scientific payload mass | >40 kg |
| 3. | Service systems power consumption | 60 W |
| 4. | Scientific instruments power consumption | up to 150 W |
| 5. | Onboard mass memory size | 8 Gbytes |
| 6. | Telemetry | 3 Mbit/s |

The SSA n.2 orbit parameters will be specified to achieve the MONICA scientific objectives. The required orbit is the near-earth circular, polar with inclination >80° and altitude about 600 km. MONICA instrumentation will be pointed to zenith with accuracy better then ±0.5°. The accuracy of satellite position knowing is 1 km. The satellite axis orientation will be known with accuracy better then ±0.5°.
The observations will be carried out continuously as monitoring mode. The size of scientific data transmitted to ground per day will be >5 Gbits. Duration of the mission is more then 5 years.

## IV. Conclusion

The preparation of MONICA experiment is in progress now. The launch of SSA n.2 satellite with MONICA instrumentation is planned in 2011-2012.
The realization of MONICA experiment will allow to carry out the pioneering measurements of SEP ionic charge composition in high-energy range (20-300 MeV/n) for individual SEP events at the maximum of the next $24^{th}$ solar activity cycle.

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