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Solar cosmic ray observations with PAMELA experiment.

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Abstract: PAMELA is a cosmic rays detector flying in a high inclination (70^o), low Earth Orbit (350-600 km) on board the Resurs-DK1 satellite. It is a multi-purpose device composed of a permanent magnet spectrometer to provide particle charge, rigidity and incoming angle information. A series of six segmented scintillator counters arranged at its extremities provides redundant Time-of-Flight and charge information. Lepton/hadron identification is performed by a Silicon-Tungsten calorimeter and a Neutron detector placed at the bottom of the device. An Anticounter system is used offline to reject false triggers coming from interactions with the satellite. The device is capable of detecting protons ($80MeV - 700GeV$), antiprotons (80 MeV-190 GeV), electrons (50 MeV - 400 GeV), positrons (50 MeV - 270 Gev) and nuclei ($\simeq$ 100 MeV/n - 200 GeV/nuc). For its characteristics PAMELA is capable of addressing various items of heliospheric physics performing for the first time a very precise measurement of the high energy component in solar events and to detect directly positrons produced in these events. Up to now three solar particle events - generated by active region 930 between December 7 and 17 2006 have been detected. We will describe the observational capabilities of the detector in relation of Solar physics.

Introduction

The PAMELA experiment is a satellite-borne apparatus devoted to the study of cosmic rays, with an emphasis on its antiparticle component. The device is constituted by a number of redundant detectors capable of identifying particles providing charge, mass, rigidity and beta information over a very wide energy range [1, 2, 3]. The instrument is built around a permanent magnet with a microstrip tracker (6 double sided planes) providing rigidity and sign of charge information [4]. A scintillator system (six layers arranged in three planes for a total of 48 phototubes) is used to provide trigger, charge and time of flight information [5]. Hadron/lepton separation is performed with a 44 plane silicon-tungsten calorimeter[6] (16.3 radiation lengths, 0.6 interaction lengths). A shower tail catcher and a neutron detector [7] at the bottom of the apparatus increase this separation. An Anticounter[8] system is used to reject spurious events in the off-line phase. Around the detectors are housed the readout electronics, the interfaces with the CPU [9] and all primary and secondary power supplies. The system is enclosed in a pressurized container located on one side of the Resurs-DK satellite. Total weight of PAMELA is 470 kg; power consumption is 355W, geometrical factor is 21.5 cm^2sr. The detector is capable of identifying protons (in the energy range 80 MeV - 700 GeV), electrons (50 MeV - 400 GeV), antiprotons (80 MeV - 190 GeV), positrons (50 MeV - 270 GeV) and nuclei up to Z=8 up to $\simeq 100\ GeV$. Launch occurred on June the 15^{th} 2006 from the cosmodrome of Baikonur with a Soyuz rocket. The satellite flies on a quasi-polar (inclination 70°), elliptical (altitude 350–600 km) orbit with an expected mission duration of 3 years. The orbit, the long observational lifetime, and the structure of the detector allow PAMELA to address several items in cosmic-ray physics, increasing knowledge of cosmic ray origin and propagation[10]. Also cosmological issues related to detection of a dark matter signature and search for antimatter (PAMELA will search for $\bar{H}e$ with a sensitivity of $\approx 10^-8$) will therefore be addressed with this device. In this work we focus on the the scientific objectives and observational capabilities for PAMELA to detect solar and heliospheric cosmic rays [11, 12].

Solar Energetic Particles

The launch of PAMELA took place during solar minimum and data taking will be performed for at least three years in the recovery phase going toward solar maximum of cycle 24. The number of expected solar proton events in the three years of mission can be estimated from [13]: we expect about 10 solar events with $E > 80MeV$ (necessary to trigger the apparatus) in the three years of the nominal experiment lifetime. Events can be observed at lower energies ($E > 35$ MeV) using a scintillator counting technique [14, 15]. The observation of solar energetic particle (SEP) events with a magnetic spectrometer will allow several aspects of solar and heliospheric cosmic ray physics to be addressed for the first time:

Protons

PAMELA is able to measure the solar component over a very wide energy range (where the upper limit will be limited by statistics and therefore the size of the event and its spectral characteristics). Up to now there has been no direct measurement of the high energy (>1 GeV) proton component of SEPs. The importance of a direct measurement of this spectrum is related to the fact [16] that there are many solar events where the energy of protons is above the highest ($\simeq$100 MeV) detectable energy range of current spacecrafts, but is below the detection threshold of ground Neutron Monitors. With PAMELA it will be possible to examine the turnover of the spectrum, where the limit of acceleration processes at the Sun is reached. Our instrument has a maximum trigger rate of about 60 Hz and a geometrical factor of 21.5 cm^2 sr. This implies that we will be able to read all events with an integral flux (above 80 MeV) up to 4 particles / (cm^2 s sr). For such events we expect about 2×10^6 particles/day (assuming a spectral index of γ = 3 we have 2×10^3 events / day above 1 GeV). Larger events will saturate the trigger, so in this case the number of protons will be reduced by dead time and mass memory limitations.

Positrons

Positrons are produced mainly in the decay of π^+ coming from nuclear reactions occurring at the flare site. Up to now, they have only been measured indirectly by remote sensing of the gamma ray annihilation line at 511 keV. Using the magnetic spectrometer of PAMELA it will be possible to separately analyze the high energy tail of the positron spectra obtaining information both on particle production and charge dependent propagation in the heliosphere through comparison of the temporal and energetic profile of the e^- and e^+ flux.

Nuclei

PAMELA can identify light nuclei up to Oxygen[17] and isotopes of Hydrogen and Helium at low β. Thus it is possible to investigate the light nuclear component related to SEP events over a wide energy range. Applying the same estimates as above, we can expect $\simeq10^4$ ^{4}He and $\simeq10^2$ ^{3}He nuclei for gradual events, and more for impulsive ones. Such a high statistics will allow us to examine in detail the amount of the ^{3}He and deuterium up to 3 GeV/c. This should contribute to establish whether there are differences in the composition of the high energy (1 GeV) ions to the low energy component ($\simeq$ 20 MeV) producing γ rays or the quiescent solar corona and better understand the selective acceleration processes in the higher energy impulsive events.

Neutrons

Neutrons are produced in nuclear reactions at the flare site and can reach the Earth before decaying[18]. Although there is no devoted trigger for neutrons in PAMELA, the background counting of the neutron detector will measure in great detail the temporal profile and distribution of solar neutrons. In Figure 1 is shown neutron counting rate in different points of PAMELA orbit. It is possible to see the contribution of secondary neutrons produced by protons interacting in the spacecraft main body. The background counting system keeps track of the number of neutrons which hit the neutron detector in the time elapsed since the last trigger. The counter is reset each time it is read

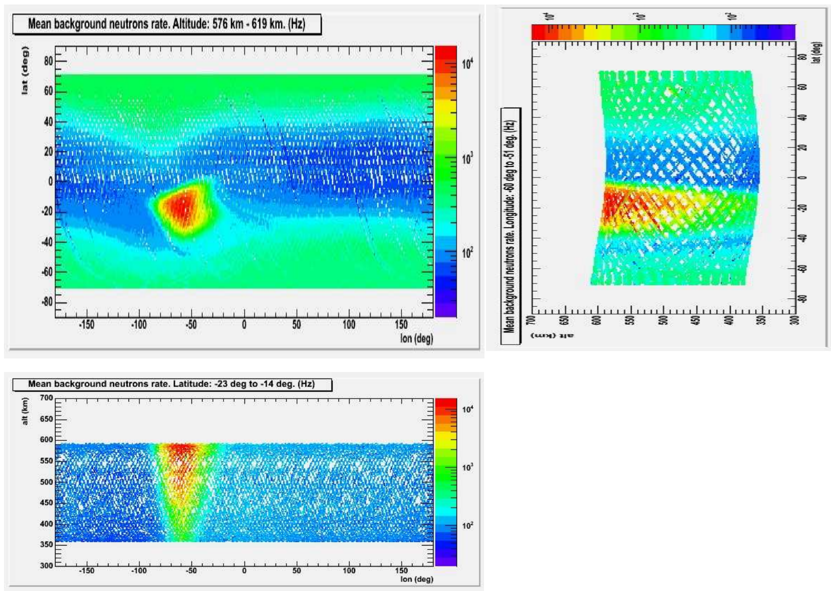

Figure 1: Counting rate of neutrons as function of latitude- longitude (altitude of 576-619 km, top left panel); altitude-latitude (longitude of 60^{o}W-51^{o}W, top right panel) and latitude-longitude (latitude of 23^{o}S - 14^{o}S, lower left panel).

allowing for a precise measurement of background neutron conditions during the mission. On the occurrence of solar events, neutrons are expected to reach Earth before protons as they have no charge. They are not deflected by any magnetic field and will be directly recorded by PAMELA (if it is not in Earth's shadow) increasing counts over the expected background. A careful measurement of the arrival time of neutrons is necessary to separate the solar neutron component from the secondary neutrons produced by solar protons interacting with the satellite.

Preliminary observations

At the time of writing the most significant events occurred between December 6th and 17th 2006 and were originated from region 930. Dec 6th event was originated in the East, resulting in a gradual proton event reaching Earth on Dec 7th and lasting until the events of Dec 13 and 14[19]. In Figure 2 is shown the differential energy spectrum measured in different periods of the event of the 13 December. It is possible to see that the

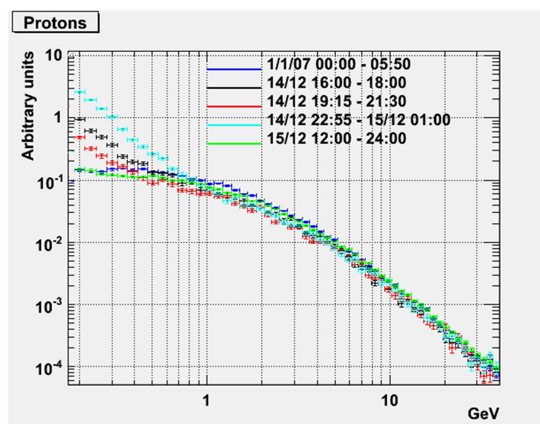

Figure 2: Differential energy spectrum measured during the December 13 2006 event. It is possible to see the increase at high energies during the first phase of the event. The high energy component subsequently decreases and the low energy component increases as low energy particles reach the Earth

event produced particles up to 4 GeV. A second smaller event occurred on Dec 14, superimposing on the Forbush decrease caused by the Coronal

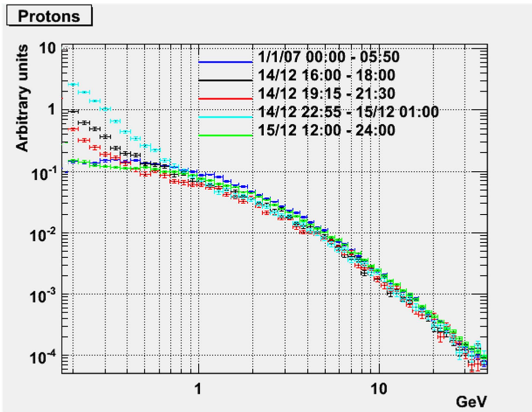

Figure 3: Differential energy spectrum measured during the December 14 2006 event. It is possible to see the tail of the 13 Dec event (16:00-18:00), the increase due to the arrival of the 14 December event (14/12 22:55 - 15/12 1:00) and the subsequent decrease. At higher energies, up to 5 GeV is visible the decrease of galactic particles due to the Forbush decrease caused by the arrival of the Coronal Mass ejection at $\simeq 14:00$ UTC. For comparison also solar quiet spectra are plotted

Mass Ejection of the previous event reacing Earth. Galactic particle flux thus decreased in the energy range up to 3 GeV, whereas solar particles were accelerated up to 1 GeV for this event. Data analysis is currently in progress to provide nuclear spectra for these events.

Conclusions

In this work we have briefly described some of the observational possibilities of PAMELA in relation to solar and heliospheric physics. Thus it will be first time a magnetic spectrometer telescope in low Earth orbit is operational for long duration observation. It will thus be possible to perform direct measurements in an energy range and with a precision never reached for direct observations.

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