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PAMELA Observation of the 2012 May 17 GLE Event

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Abstract: The PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) satellite-borne experiment has been collecting data in orbit since July 2006, providing accurate measurements of the energy spectra and composition of the cosmic radiation from a few hundred MeV/n up to hundred GeV/n. This wide interval of measured energies makes PAMELA a unique instrument for Solar Energetic Particle (SEP) observations. Not only does it span the energy range between the ground-based neutron monitor data and the observations of SEPs from space, but also PAMELA carries out the first direct measurements of the composition for the highest energy SEP events, including those causing Ground Level Enhancements (GLEs). PAMELA has registered many SEP events in solar cycle 24 including the 2012 May 17 GLE event (GLE 71), offering unique opportunities to address the question of high-energy SEP origin. Experimental performances and preliminary results on the 2012 May 17 events will be presented. We will discuss the derived particle injection time and compare with other time scales at the Sun including the flare and CME onset times.

Keywords: PAMELA, SEP, GLE.

1 Introduction

A major challenge in understanding the highest-energy solar energetic particle events, the SEP events that cause ground level enhancements (GLEs), has been identifying their origin and the governing acceleration process. Relating GLEs to their lower energy counterparts both in terms of the overall morphology of the energy spectra and composition has also been a challenge. This stems, in part, from the fact that there are few instruments that can measure SEPs in an energy range that bridges the gap between the low energy population and the high-energy population. PAMELA [1] is an instrument on a low-Earth-orbit polar Russian satellite. PAMELA not only spans the energy range between the ground-based neutron monitor data and the in-situ observations of SEPs, but also carries out the first direct measurements of the composition for the highest energy SEP events.

PAMELA observed SEPs from several solar energetic events (see also [2, 3]), including the GLE of 2012 May 17. We present a detailed study of velocity dispersion for this event using measurements at high energies from PAMELA and neutron monitor and lower energy data from other spacecraft. Prior to PAMELA ion measurements of GLE particles, the high energy region of ion velocity dispersion analysis plots used electrons due to lack of ion measurements at such energies. Using PAMELA data, and contextual data from other experiments we more precisely determine the time when the energetic particles were released at the Sun and magnetic pathlength the particles traveled before reaching Earth.

2 PAMELA Detector

The instrument PAMELA, in orbit since June 15^{th}, 2006, on board of the Russian satellite Resurs DK1, is designed to study charged particles in the cosmic radiation, including SEPs, spanning an energy range from ~80 MeV to several hundreds GeV, with a particular focus on antimatter and signals of dark matter annihilation. PAMELA is built around a permanent magnet spectrometer equipped with a tracking system, which allows the determination of the particle charge and rigidity with high precision. A sampling electromagnetic calorimeter is mounted below the spectrometer together to a shower tail catcher scintillator (S4), operating leptons/hadrons separation. A neutron detector at the bottom of the apparatus helps to increase this separation. A time-of-flight (ToF) system, composed by 3 planes of scintillation counters (S1, S2 and S3, from top to bottom of the apparatus) allows velocity and energy loss measurements, and provides the main trigger for the experiment. An anticoincidence system completes the apparatus, rejecting events where the presence of secondary particles generates a false trigger or the primary particle suffers an inelastic interaction.

3 2012 May 17 GLE

The first GLE of solar cycle 24, which is the event (GLE 71) of 2012 May 17, was observed by several high-latitude neutron monitors (NMs): specifically, Oulu, Apatity and the two South Pole instruments. This SEP event was registered by many space-based instruments, including PAMELA, ACE, STEREO, Wind, SDO etc. The accompanying flare, x-ray class M5.1, occurred in active region (AR) 11476. This flare started at 1:25 UT, peaked at 1:47 UT and ended at 2:14 UT. The CME was observed by STEREO COR1(1:40 UT first observation) and COR2 as well as by SOHO LASCO (1:48 UT first observation). This CME had an average speed of 1580 km/s, maximum speed of 1997 km/s, and acceleration of 1.5 km/s^2 [4]. Type II radio emission was observed by WIND/WAVES etc. This event attracted the attention of many researchers, not only for being a GLE event or the lone GLE event of this unusually quiet solar maximum 24, but also because the associated flare was relatively small as compared to those related with GLEs in the past, majority of which were X-class flares.

3.1 PAMELA measurements

In conjunction with the solar event of 2012 May 17, PAMELA recorded a significant increase in the trigger rate, principally due to an increase in number of detected protons at energies lower then 1 GeV, as reported in figure 1. Such measurements were performed very close to the North Pole, were the geomagnetical cut-off is very low, as visible from the bottom plot of figure 1. The high counting rate lasted for ~24 hours, as it is visible in figure 2, smoothly decreasing to the quiet sun level.

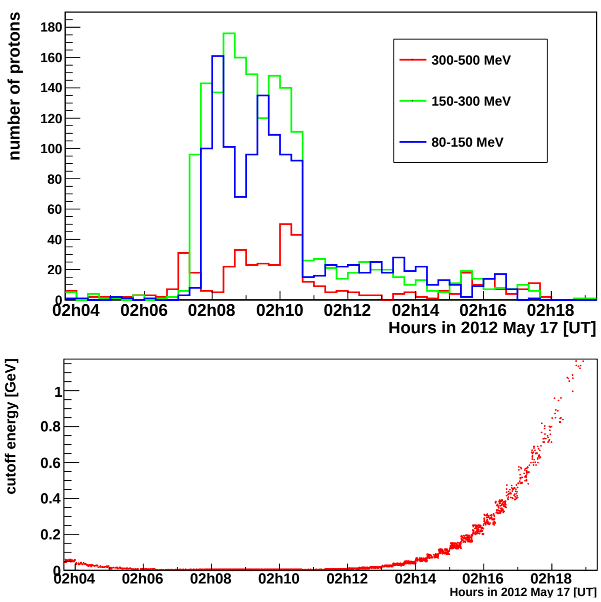

Fig. 1: In the top figure an increase in number of protons detected by PAMELA during 2012 May 17 GLE: three intervals of kinetic energies are reported. From the bottom figure it is evident that cut-off energies were always below considered kinetic energies for protons.

An increase in Helium nuclei rate has been also detected by PAMELA (as reported in figure 3), expecially in the energy range 0.75 - 1.5 GeV/n.

During 2012 May 17 GLE some other experiments measured increases in several particle samples at different energies; for example, LEMT sensor, on board NASA Wind spacecraft, detected significant increment in ^{4}He intensity below 10 MeV/n, as reported in figure 4.

4 Data Analysis

This event was magnetically well-connected. Velocity dispersion was observed in several data sets. In this analysis we have used measurements from PAMELA, Wind/LEMT and neutron monitors. The Low Energy Matrix Telescope (LEMT), on board NASA WIND spacecraft, measures primary nuclei in cosmic rays and solar wind around the L1 Lagrange point, covering energies in the 1-10 MeV/nuc

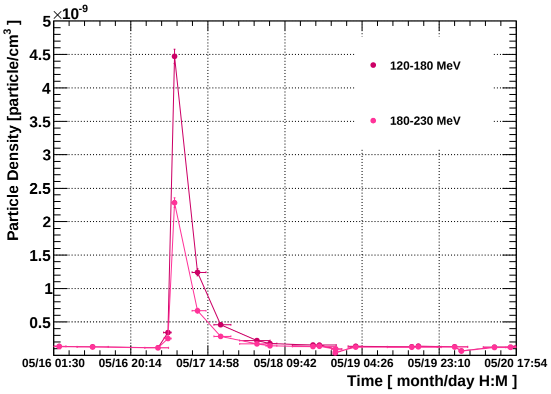

Fig. 2: Proton density measured by PAMELA during 2012 May 17 GLE (just two energy intervals are shown as example) shows a recovery time (the time before the particle flux reaches the quiet sun conditions) of ∼24 hours.

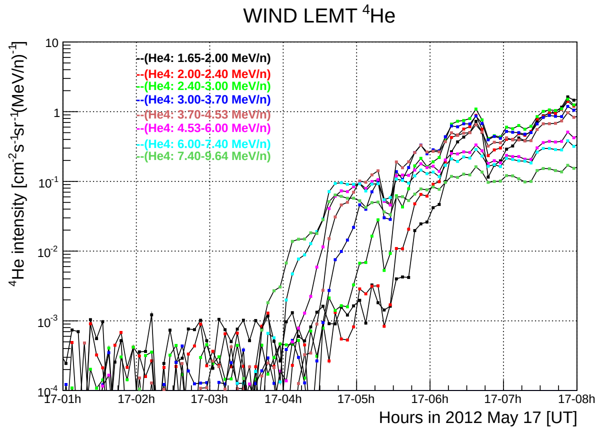

Fig. 4: The intensity-time profiles for ^{4}He of energies 1.65-9.64 MeV/n from Wind/LEMT are shown in left. While not shown here, Wind/LEMT proton, O, and Fe measurements were also used for velocity dispersion analysis.

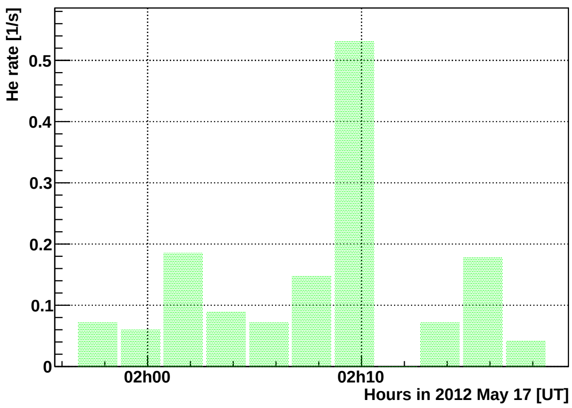

Fig. 3: Increasing in He rate measured by PAMELA during 2012 May 17 GLE. Helium nuclei at energies between 50 MeV/n and 1.5 GeV/n are considered in this plot.

range [5] and with a high time resolution. Because of its spin within the ecliptic plane and because of the large field-of-view, it provides comprehensive SEP ion anisotropy measurements that are unavailable from any other spacecraft. Measurements of ^{4}He, O and Fe, together with protons above 22 MeV are used for this analysis.

Data from Oulu Neutron Monitor [6], which detects secondary neutrons produced at the ground level by primary energetic particles with rigidity above ∼0.8 GV are also taken into account. We selected such NM because it has the highest cutoff rigidity (also higher latitude) of the NMs that observed this GLE. Its 0.81GV cutoff rigidity corresponds to 301.3 MeV energy. The GLE producing SEPs are of much higher energies than the threshold and the first arriving particles are of the highest energy, and relatively unscattered. Here we have used the effective energy of 5.3 GeV for the Oulu neutron monitor in the onset time vs. 1/v [7].

In this section we explain our analysis.

4.1 Velocity Dispersion

If all particles observed at a detector were accelerated at the same time and same location at the Sun, and traversed the same magnetic pathlength before being observed, the detector will observe a velocity dispersion such that onset of an event for higher energy particles occurs before that of the lower energy particles. A plot of onset time vs. 1/velocity for various measurements can be fit with a straight line with the time-intercept providing the solar particle release (SPR) time and the slope providing the magnetic pathlength traversed by the particles from the Sun to the detector [8]. For a GLE event, the first arriving particles can be assumed to be almost scatter free and the velocity dispersion and this principle can be justifiably used to determine the SPR time and path length.

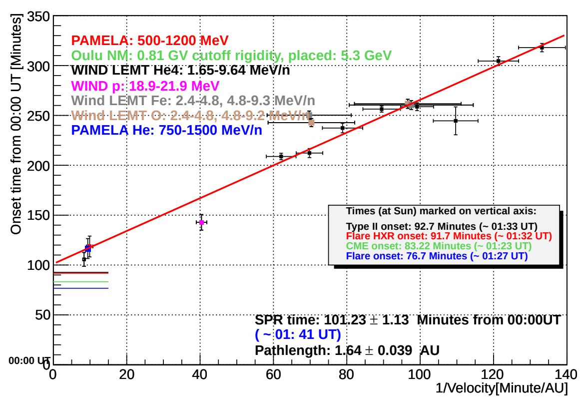

Fig. 5: Onset time versus 1/velocity using PAMELA, Oulu NM, Wind helium, oxygen and iron. The red line is actual fit to the data and the short horizontal line marks indicate the onset of the flare, CME, type II radio emission, and onset of hard x-ray emission. PAMELA provides ion measurements at higher energies.

4.2 Solar Particle Release Time

A plot of onset time versus 1/velocity, measured for different ions by various instruments, is shown in figure 5. A linear fit to these measurements provides the SPR time of 1:41 UT and the magnetic pathlength traversed by the particles to be ∼1.64 AU.

In order to associate the source of acceleration with physical processes at the Sun, we compare the SPR time with the times of flare, CME, and metric type II radio emission (also marked in figure 5). It is clear that the SPR occurred after the flare and the onset of CME-driven shock. But it is closer (in time) to the shock. However, the onset of hard x-ray is also very close to the shock onset.

4.3 Altitude of particle acceleration

Once the "when"of the particle acceleration is known, we proceed to determine "where"(altitude) this acceleration took place. If acceleration was governed by a CME-driven shock, location of the shock at the SPR time provides the altitude at which particles were injected into the interplanetary region.

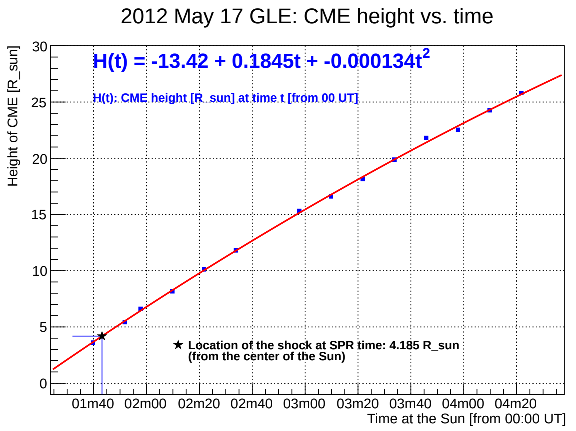

Fig. 6: Plot of the CME height as a function of time as measured by SOHO/LASCO. The altitude of the CME-driven shock is extrapolated from fit to the data, using SPR time calculated in previous section.

Using the CME height versus time measurements from SOHO/LASCO [9], as in figure 6, we determine the altitude of CME and hence, that of the CME-driven shock to be around 4.185 solar radii from the center of the Sun.

5 Conclusions

During 2012 May 17 solar flare PAMELA measured high energy SEPs, including protons up to 1 GeV and He nuclei up to 1.5 GeV/n. Banding together such results and lower energy measurements from other space experiments and ground neutron monitor we had a unique possibility to fit data in a wide energy range. We derived, this way, an estimation of the SPR time, traversed magnetic pathlenght and of the location of the CME-driven shock at SPR time. For well-connected events, the height of acceleration has been found to be between 2-6 solar radii.

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Other data were obtained from:
Advanced Composition Explorer (ACE): http://www.srl.caltech.edu/ACE/
Neutron monitor: http://www.nmdb.eu/
Solar and Heliospheric Observatory/Large Angle and Spectrometric Coronagraph Experiment (SOHO/LASCO): http://cdaw.gsfc.nasa.gov/CME_list/

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