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First Spaceweather Observations at MuSTAnG — the Muon Spaceweather Telescope for Anisotropies at Greifswald

R. HIPPLER[1], A. MENGEL[1], F. JANSEN[2], G. BARTLING[2], W. GÖHLER[3], K. KUDELA[4], K. MUNAKATA[5], S. YASUE[5], C. KATO[5], M.L. DULDIG[6], J.W. BIEBER[7], P. EVENSON[7], N.J. SCHUCH[8], A. DAL LAGO[9], M.R. SILVA[9], I. SABBAH[10]
[1] *Institute of Physics, University of Greifswald, Felix-Hausdorff-Str. 6, 17487 Greifswald, Germany*
[2] *1A Greifswald, Postfach, 17461 Greifswald, Germany*
[3] *HTS GmbH, Am Glaswerk 6, 01640 Coswig, Germany*
[4] *Institute of Experimental Physics, Slovak Academy of Science, Kosice, Slovakia*
[5] *Physics Department, Shinshu University, Matsumoto 390-8621, Japan*
[6] *Australian Government Antarctic Division, Kingston, Tasmania 7050, Australia*
[7] *Bartol Research Institute, University of Delaware, Newark, DE 19716, USA*
[8] *Southern Regional Space Research Center, PB-5021, 97110-970 Santa Maria, RS, Brazil*
[9] *National Institute for Space Research, PB-515, 12201-970 Sao Jose dos Campos, SP, Brazil*
[10] *Department of Physics, Faculty of Science, Kuwait University, Kuwait*
e-mail: Hippler@physik.uni-greifswald.de

Abstract: First results of the Muon Spaceweather Telescope for Anisotropies at Greifswald (MuSTAnG) that is dedicated to spaceweather forecasting are reported.

Introduction

The near Earth space is normally surrounded by a nearly isotropic intensity of primary cosmic rays from the Galaxy. Apart from particles associated with solar flares, the cosmic radiation comes from outside the solar system and it is mainly composed of protons and helium ions, other heavy nuclei, and electrons. The incoming charged particles interact and are slightly modulated by the solar wind. A further modulation of Sun-ward directed anisotropy of cosmic ray intensity occurs in the case of a plasma cloud moving between Sun and Earth. These plasma clouds being caused by coronal mass ejections (CMEs) originating at the Sun produce a shock wave on the Earthward directed side of the cloud. It has been noted that those interplanetary CMEs accompanied by a strong interplanetary shock often form a depleted region of primary galactic cosmic rays behind the shock front during its propagation between the Sun and Earth. Since primary cosmic ray particles travel close to the speed of light and thus much faster than the interplanetary shock front (velocities in the order of up to about 2000 km/s), it carries the information about the CME and the shock region to Earth far ahead of the shock. The CME/shock affected primary cosmic ray particles thus arrive at Earth much earlier than the Earth approaching CME and thus may be used to forecast the approaching space weather hazard.

Muon telescope set-up

The Muon Spaceweather Telescope for Anisotropies at Greifswald (MuSTAnG) is a multi-directional muon telescope dedicated to spaceweather forecasting. The phase 1 telescope consists of a set of suitably arranged and coupled muon detector units in two (upper and lower) layers. Directional information is derived from the passage of muons through two, one upper and one lower, detectors. In stage 1, MuSTAnG will be composed of 4×4 detectors of 0.25 m^2 area in

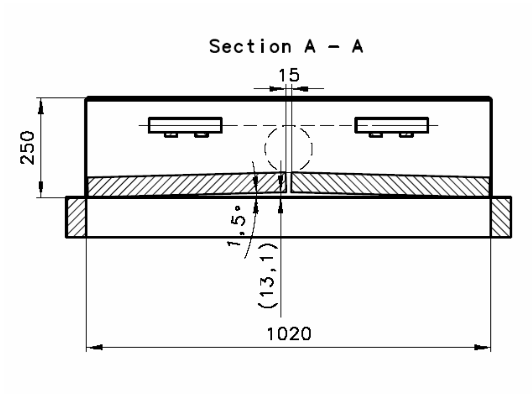

Figure 1: Cross sectional view of scintillator box showing positions of scintillator plates, wavelength-shifting fibres, and photomultiplier modules (schematic).

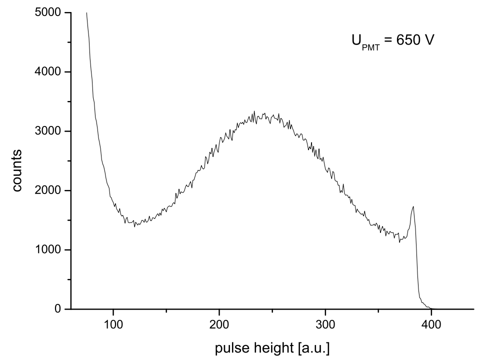

Figure 2: Pulse height distribution of muon detector pulses.

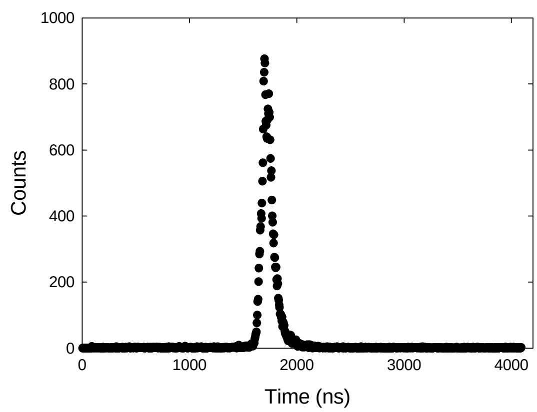

Figure 3: Time correlation between one upper and one lower muon detector.

each layer, i.e., a total of $2 \times 16 = 32$ detectors. Thus the size of the full detector is 2 m $\times$ 2 m = 4 m^2 in area. An upgrade of MuSTAnG to a larger telescope is foreseen in stage 2.

The muon detectors are arranged in detector units containing 4 detectors each. Each detector unit, hence, consists of four scintillator plates of 5 cm thickness and 0.25 m^2 size. The scintillator plates are coupled via 1 mm diameter wavelength-shifting (WLS) optical fibres to photomultiplier (PMT) modules (Fig. 1). Each scintillator plate is read-out by 17 WLS fibres that are spaced about 2.5 cm away from each other in keyhole-shaped grooves right beneath the top surface. In order to maximize the light output each scintilliator plate is painted with white reflective paint. The PMT modules are equipped with a bi-alkali photocathode of 25 mm active diameter having a quantum efficiency of 10–12 % at 500 nm. The PMT modules possess an integrated preamplifier and a high voltage supply. The passage of a single muon produces about 10,000 blue photons per MeV energy loss inside a scintillator plate, at an energy loss of 1.8 MeV/cm [1]. A fraction of typically 15 % of produced photons is absorbed by wavelength-shifting fibres and re-emitted as green photons. About 3 % of the re-emitted green photons are captured within the acceptance cone of the fibre and transmitted by internal reflections to the photomultiplier tube. The quantum efficiency of a bi-alkali photocathode is typically 10 % for green photons. The total yield of such a system is 7–8 photoelectrons/cm, and for a 5 cm thick plastic scintillator an average signal of 35–40 photoelectrons per incident muon may be expected.

Fig. 2 displays the pulse height distribution at the output of the photomultiplier tube. The distribution is composed of two contributions due to single photoelectron events (including dark current pulses) at small output amplitudes and a broad distribution at large output amplitudes due to muons. The time correlation arising from the passage of a single muon through two (one upper and one lower) detector unit recorded with a standard coincidence set-up employing an electronic delay of

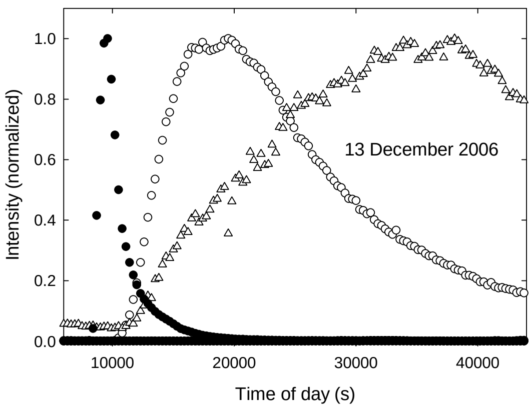

Figure 4: GOES-11 satellite data during 13 December 2006. The onset of x-ray flux (•), < 100 MeV protons (○), and < 1 MeV protons (△) is shown (see text).

the lower detector output of $\sim 1.7\,\mu$s, a time-to-amplitude converter and a PC-MCA card is displayed in Fig. 3. A pronounced time peak composed of about 25,500 true (coincident) events is noted while the background of false (random) coincidences over of 4 μs time window is only about 180.

Output pulses from the PMT tube are further amplified, discriminated and, after suitable pulse-shaping, fed into the coincidence electronics consisting of a field-programmable gate array (FPGA) logic [2]. The FPGA operates at 10 MHz and provides a time resolution of 100 ns.

Results

MuSTAnG test phase began end of November 2006. At the time, only $2 \times 8 = 16$ detectors totaling 2 m^2 in each of the two layers were mounted. GOES-11 satellite recorded on 13 December 2006 at 2:20 hours UT an increase of solar x-ray intensity by almost 4 orders of magnitude (see figure 4), followed at 2:50 hours UT by an increase of [3] solar proton intensity (kinetic energies of < 100 MeV and < 1 MeV, corresponding to $v/c < 0.43$ and $v/c < 0.046$, respectively, where v is the proton velocity and c the speed of light), and by a ground level enhancement (GLE) that was recorded by several neutron monitors also on 13 December 2006 at 02:50 hours UT [4]. Taking the Sun-Earth travelling time into account it appears that the < 100 MeV protons are delayed by 15-20 min compared to GOES-11 x-ray data. By contrast, < 1 MeV protons require a minimum travelling time of 180 min and the earliest low-energy protons thus arrived well in advance of the scheduled arrival time. These early protons, if originating from Sun, must either have lost a considerable amount of energy before arriving in the vicinity of Earth, or are secondary particles generated in the vicinity of Earth. A further sharp increase of the < 1 MeV proton occurred on 14 December 2006 at 14.05 hours UT thereby indicating spaceweather storm arrival at Earth.

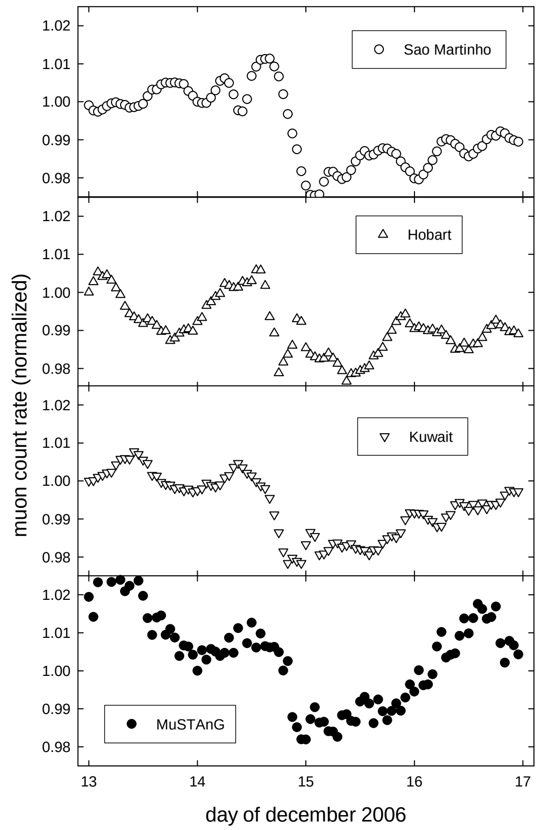

Figure 5: Normalized muon count rate during 13-17 December 2006. MuSTAnG results (•) are compared to data of other muon space weather telescopes in Sao Martinho (○), Hobart (△), and Kuwait (▽).

These recordings, hence, provided the earliest alerts for the upcoming space weather event caused by a coronal mass ejection (CME). Fig. 5 shows the muon count rate variation of MuSTAnG during 13-17 December 2006. A clear drop of the muon intensity on 14 December 2006 is noted, indicating the arrival of interplanetary shocks and the associated interplanetary CME at Earth. The drop began around 17:00 hours UT and reached the 1 % level at 20:00 hours UT. It is confirmed by similar observations of other muon telescopes around the world, e.g., at Sao Martinho (Brazil), Nagoya (Japan), Hobart (Australia), and Kuwait [4], and coincides with a pronounced enhancement of the estimated (3-hourly) geomagnetic Kp index reaching values of 7 during 15-18 hours and of 8 during 21-24 hours [3].

It is interesting to note that a clear ”loss-cone” precursor has been observed in the muon data that appeared first on 14 December 2006 at 9:00 hours UT in the vertical channel of the Sao Martinho muon telescope, propagating to Hobart and Nagoya telescopes but was not recorded in Kuwait and by MuSTAnG. The lead time of this precursor is about 5 hours prior to spaceweather storm commencement [5]. A ”loss cone” precursors is caused by a strong shock accompanying a coronal mass ejection and forming a depleted region of galactic cosmic rays behind it [6]. The present observations further indicate that spaceweather forecast is greatly facilitated by a network of multi-directional muon telescopes scanning different directions in space [7].

Conclusions

The Muon Spaceweather Telescope for Anisotropies at Greifswald (MuSTAnG) began its test phase end of November 2006. The first space weather event was recorded during 14 December 2006, in agreement with similar observations by other muon telescopes. A ”loss cone” precursor noted about 5 hours prior to spaceweather storm commencement provides a further demonstration of the forecast potential of a network of muon and neutron telescopes as was recently emphasized by [8].

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