An Unusual Time-Variable High Radiation Region seen by HETE-2 Satellite

Yujin E. Nakagawa,[1] Toru Tamagawa,[2] Tsugunobu Nagai,[4] Tohru Yamazaki,[1] Atsumasa Yoshida,[1] Nobuyuki Kawai,[3] Ken'ichi Torii,[2] Yuji Shirasaki,[7] Hiromasa Miyasaka,[2] Takanori Sakamoto,[3] Motoko Suzuki,[3] Yuji Urata,[3] Rie Sato,[3] George Ricker,[5] Kevin Hurley,[6] Geoff Crew,[5] and HETE-2 Team

(1) Department of Physics, Aoyama Gakuin University, Sagamihara, Kanagawa 229-8558, Japan
(2) The Institute of Physical and Chemical Research,Hirosawa, Wako, Saitama 351-0198, Japan
(3) Department of Physics, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan
(4) Department of Earth and Planetary Science, Tokyo Institute of Technology, Meguro-ku, Tokyo 152-8551, Japan
(5) Massachusetts Institute of Technology, Cambridge, MA 02139, USA
(6) UC Berkeley Space Sciences Laboratory, Berkeley, CA 94720-7450, USA
(7) National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan

Abstract

We studied the unusual high radiation region above Ecuador seen by the X-ray and gamma-ray satellite HETE-2. The WXM instrument on-board HETE-2 is position-sensitive proportional counter which has also sensitivity to charged particles. Detailed analysis of this region shows that 1) the fraction of the veto counts in total counts was concentrated on around 10% and 2) the ratio of particles which deposit energy below 100 keV in the main cell is 25∼70%. We evaluated these results quantitatively by Monte Carlo method, then found the unusual high radiation region mainly consist of electrons rather than protons. If assumed a power law distribution, the energy distribution of electrons should have a very steep index of ≥ 0.9, which is completely different from the SAA region.

1. Introduction

HETE-2 (High Energy Transient Explorer 2) is a small satellite for researching cosmic high-energy transient phenomena [1]. It was flown into an equatorial orbit with an inclination of about 2 degrees at the altitude of about 600 km. Although HETE-2 was designed and built for detecting photons, the onboard instruments are also sensitive to low-energy charged particles. Using the data from the Wide-Field X-ray Monitor (WXM) on HETE-2, we discovered an

---

pp. 4261–4264

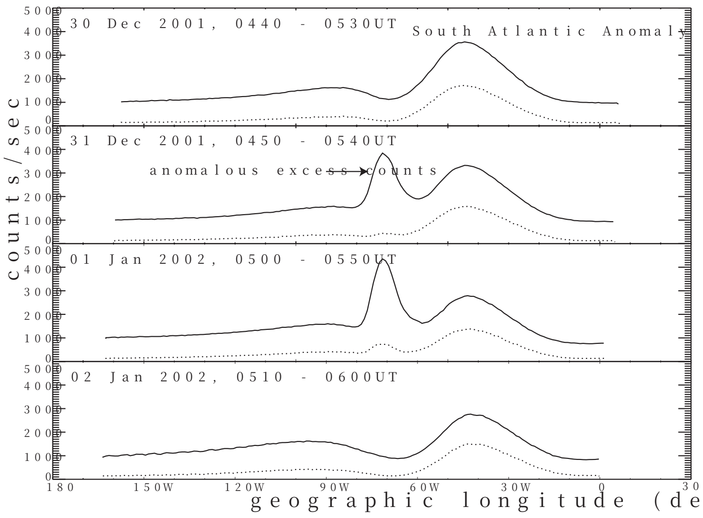

Fig. 1. Example of time variation of the WXM count rates in the four sequential orbits. Time was converted into geographic longitude. The solid and dotted line shows count rates in the main cells and the veto cell, respectively. The high radiation region near ∼40°W is the SAA and near ∼70°W is the unusual high radiation region. This region does not always appear like 30 December 2001 (upper panel) and 2 January 2002 (lower panel).

unusual high radiation region above Ecuador which was unknown to date. The semi-quantitative analysis reveal that this region is well-separated from the SAA and shows a time variability which apparently correlates with the solar activity. In addition, it implies that the incoming radiation in this region may be dominated by low-energy electrons [2]. As the WXM is designed for detecting X-rays, the detector response to charged particles has not been studied well. In order to conduct more quantitative studies, we carried out Monte Carlo simulations of the WXM response to charged particles using the Geant4 package.

2. Observations and Data Analysis

We observed the unusual high radiation region above Ecuador with the WXM on-board the HETE-2. The WXM is the Xenon-gas filled proportional counters covering the energy range of 2−25 keV with a field of view $70° \times 70°$ [3]. Fig. 2 shows a cross section of the WXM. The WXM can distinguish X-rays from charged particles by the anti-coincidence technique. The three upper cells are main cells for detecting X-rays, while the lower veto cell is used for rejecting charged particles. The entrance window are sealed by a beryllium film with a thickness of 100 μm. Fig. 1 shows an example of the WXM light curves in the four sequential orbits. As shown in the Fig. 1, high radiation region at ∼70°W, which is apart from the South Atlantic Anomaly (SAA) at 40°W, were observed.

In order to study the particle enviroment in this anomalous region, observed during September 2001, in total 74 orbits. For each orbit, we extracted the three count rates at the peak values of the WXM excess counts: the main cell counts, the veto cell counts and the total counts. The main cell counts were collected from the particles which deposit the energy only in the main cells, and the veto cell counts is that the particles deposit the energy both in the main and the veto cells.

We further define the non-overflow counts which that deposit energy in the main cell does not exceed maximum ADC channel, corresponding to ∼100 keV. Fig. 3 shows a relation between the fraction of the main cell counts and that of the veto cell counts in total counts. The ratio of the veto cell counts was concentrated on a relatively small value of ∼10%. Even the maximum value does not exceed 40%. We found that the ratio of non-overflow counts to the main cell counts distributed over 25∼70%.

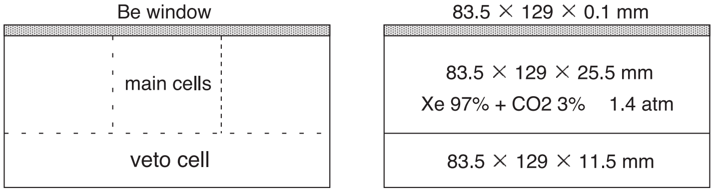

Fig. 2. Comparison of simulation (right) and actual (left) WXM detector geometry. The WXM is composed of main cells, veto cells and Be window. The three upper cells are the main cells for detecting X-rays and the lower cells are the veto cells for rejecting charged particles.

3. Simulation

We carried out the simulation by the Geant4 for studying the WXM response to charged particles. The Geant4 is the software for simulating the interaction of particles through matters. Although the four identical WXM were carried on the HETE-2, we simulated the one WXM. Right side in Fig. 2 shows a simulation geometry. The geometry which we installed to the Geant4 consist of the main cells, the veto cell and entrance window of beryllium. Both cells are filled with xenon (97%) and carbon dioxide (3%) at 1.4 atm pressure.

First, we incident electrons and/or protons with a monochromatic energy to determine the minimum energy to reach main cells and veto cell. The incident angle was set at 0 degree. We found that the minimum energy is 100 keV at electrons and 2.9 MeV at protons to reach the main cells, 180 keV at electrons and 3.8 MeV at protons to reach the veto cell. Typical energy to explain the veto ratio ∼40% is estimated at 340 keV and 3.9 MeV for electrons and protons,

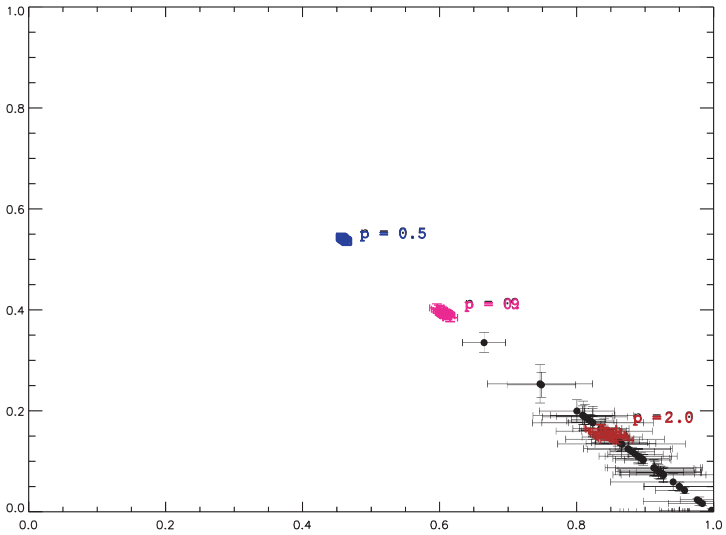

Fig. 3. Relation between the fraction of the main cell counts and the veto cell counts in total counts. The filled circles show the observation results. As we carried out the simulations at 20 times, the simulation results seems to be clustered

respectively. Next, we simulated particles with power law energy distribution expressed by equation $dN/dE = E^{-p}$, where p is the power law index. We restricted the energy range to 50∼10000 keV and 2.5∼5.0 MeV in the case of electrons and protons, respectively. Upper energy was determined so that the particles can reach the veto cell sufficiently. The ratio of the non-overflow counts to the main cell counts is 50% for electrons and 1% for protons. We also found that these values are insensitive to power law index. In comparison with the non-overflow ratio 25∼70% obtained from observation, these facts strongly suggest that the particles in anomalous region are dominated by electrons. Thus, the ratio of the main cell counts and the veto cell counts were calculated limiting the case of electrons. Fig. 3 shows comparison between the observation and the simulation. In the simulation, we assumed three power law indices: p=0.5, 0.9 and 2.0. To explain the observational results, the power law index was needed to be larger than 0.9. In other words, the energy spectrum in the anomalous region is very steep, which is different from the SAA.

4. References

1. Ricker, G. R., and HETE Science Team 2001, AAS, 198, #35.04
2. Tamagawa T. et al. 2003, Nature, submitted
3. Shirasaki Y. et al. 2003, PASJ, submitted