Geomagnetically Trapped Particles and Soft Errors on IC Observed in a Satellite

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journal or publication title	CYRIC annual report
volume	1990
page range	246-250
year	1990
URL	http://hdl.handle.net/10097/49616

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Introduction

Experimental observation and its analysis of radiation in the space environment are very important for spacecraft shielding design and mission planning.

The geomagnetically trapped particles have being measured with the detector mounted in EXOS-D, a scientific satellite of the Institute of Space and Astronautical Science (ISAS) launched on February 22nd, 1989.[1)]

Radiation monitor (RDM) loaded on EXOS-D is composed of two components, one is High energy Particle Monitor (HPM) that measures the intensities of electrons, protons, and alpha particles, and the energy distributions of electrons and protons, and the other is Radiation effect on IC monitor (RIC) that measures the radiation effect on integrated circuits, such as single events and total dose effect.

We show the observed data of the contour map of trapped particles and of the soft errors.

Trapped particles

HPM can measure the intensities of electrons and protons, divided into three energy ranges of 2.0 MeV to 7.0 MeV (eE1), 0.7 MeV to 2.0 MeV (eE2), 0.25 MeV to 0.7 MeV (eE3) for electrons and 30 MeV to 38 MeV (pE1), 15 MeV to 30 MeV (pE2), 6.4 MeV to 15 MeV (pE3) for protons, and those of alpha particles. Fig. 1. shows the time course of the maximum intensities of particles in each day from March 1st to October 30th, 1989. During this time, the satellite perigee point was in the Northern Hemisphere, and the apogee point was in the Southern Hemisphere.

The intensities rapidly increased on March 13th (19 elapsed days), September 27th (210 elapsed days), and October 20th (240 elapsed days), 1989, and these anomaly is reduced to the big solar flare occurred at those time. The overall tendency was shown that the intensities increased slowly until about 150 elapsed days and then decreased again. It can be explained from the fact that the perigee point of the satellite trajectory was about the North Pole and the satellite passed geomagnetic equator at about 3000 km altitude, which is in the peak region of the radiation belt, at 150 elapsed days.

In order to make contour map of particle population, we selected the data which included no effect of the solar flare, that is, the data from May 10th to September 10th, 1989 in Fig.1. We divided the whole globe into every 10 degree geomagnetic latitude and every 1000 km altitude mesh, and the intensity in every mesh was obtained by an arithmetic average of all data over the same longitude in the mesh, under the approximation that the intensity is independent to the longitude. Fig. 2 exemplifies the result of protons (6.4-15 MeV). Data have not been collected yet at high altitude of the Northern Hemisphere and low altitude of the Southern Hemisphere in that period, and the data of these points will be come out hereafter.

From Fig. 2, iso-flux contours of protons (pE3) have the maximum flux values at the space area, around the geomagnetic equator and about 3000 km altitude (about 1.5 earth radius), as above. Protons of other energy ranges, electrons and alpha particles have the maximum flux value also at the same space area, but the flux value of alpha particles was about 1/100 of that of protons.

Protons showed very low population in the polar cap region (> 60 degree of latitude), and iso-flux contour showed a "leg" at high altitude, especially in the Southern Hemisphere, which might be the effect of the particles from the small solar flares that could not be removed in Fig. 1.

We could get the counter mapping of alpha particles, electrons, and protons. Since the present values of the intensities were obtained as arithmetic averages of all measured data under the approximation that the particles were isotropically distributed, we next calculate them considering the pitch angle distributions to the geomagnetic line of force.

Soft errors

RIC is composed of two components, one is the four 64kbits-SRAMs that measure the single events occurred there, such as soft error and latch up, and the other is the MOS-FET to measure the total dose effect from the change of the threshold voltage of MOS-FET.

Fig. 3 shows the time course of the counts of soft error occurred in the SRAMs every one week until December 27th, 1990, from the time when EXOS-D was launched. There are three broad peaks at about 120 elapsed days, 410 elapsed days, and 670 elapsed days, and sharply increased peaks at 210 elapsed days, 240 elapsed days, 360 elapsed days, and 470 elapsed days. The three broad peaks were caused by the satellite trajectory which passed through the high intensity area of the trapped particles in Fig. 2, with the satellite perigee point at the North Pole, the South Pole, and the North Pole, respectively, similarly as in the HPM detector count increase. The peaks at 210 elapsed days and 240 elapsed days were also caused by the same reason that the big solar flare occurred and a lot of high energitic particles came in, as in the case of HPM.

We also made a map indicating the geomagnetic latitude and the altitude of the positions where the soft errors have occurred until December, 1989 from the time when EXOS-D launched, and show it in Fig. 4. We could identify the position where only a few percent of the whole soft errors occurred, because the satellite could not be seen all the time from the ground stations. The circles in this figure are the positions where the soft errors have occurred, and they are distributed mostly around the area of the equator near 1.6 earth radius of altitude where the intensities of trapped particles were high. The white circles in this figure especially show the place where the soft errors due to a big solar flare have occurred during October 20th to October 25th, 1989 (210 to 215 elapsed days). They are distributed like a "tail" which corresponds to the satellite trajectory at that period.

This result clearly reveals the strong correlation, which means that a soft error is caused by a single high energetic particles coming from the galaxy and the sun, and the radiation belt. Although two big solar flares emerged on March 9th, 1989 and on October 20th, 1989, many soft errors were brought about only on the latter date. We are now investigating on that reason.

Latch up on IC has not been observed till December, 1990.

Reference

1) S.Takagi, et. al., CYRIC Annual Report 1989.

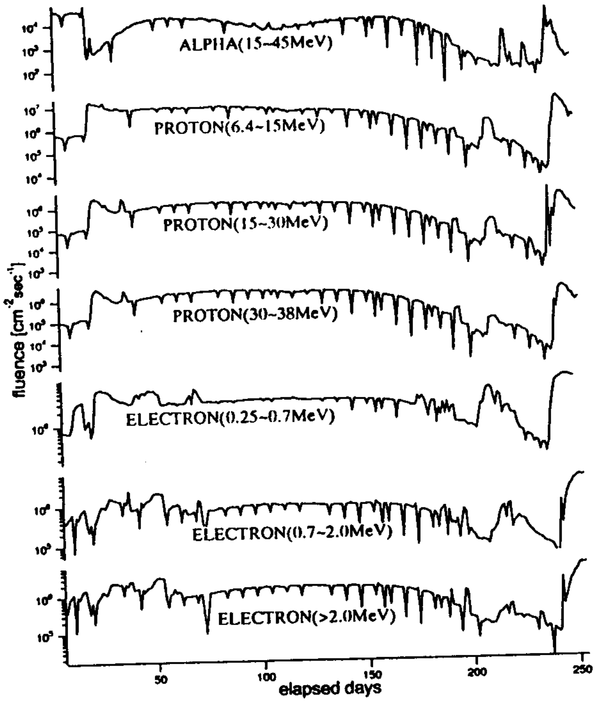

Fig. 1 Time course of maximum intensities of particlesin each day from March 1 to October 30, 1989.

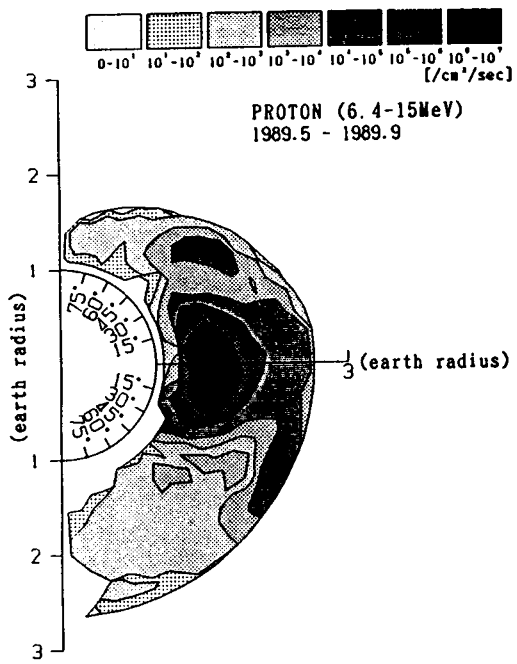

Fig. 2 Iso-flux contour of protons of energy of 6.4 to 15 MeVfrom May 10th to September 10th, 1989.

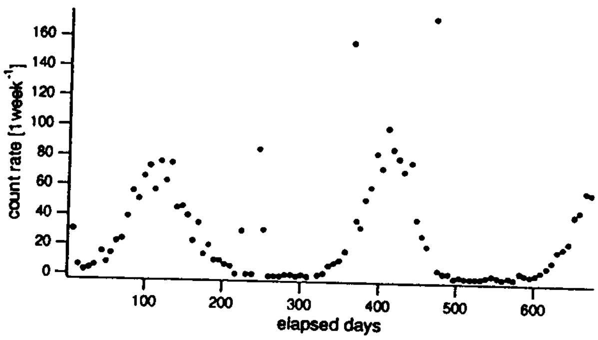

Fig. 3 Time course of soft error counts occurredin the 64 kbits-SRAMs until December, 1990.

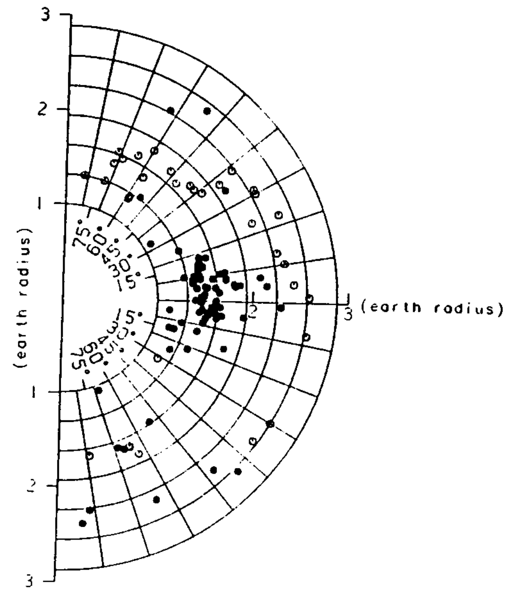

Fig. 4 Map of geomagnetic latitude and altitude of the positions where the soft errors occurred. White circles correspond to the time period of a big solar flare.