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Observations of hard X-rays of auroral origin with Polar Patrol Balloons No. 8 and 10

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Abstract: In the Polar Patrol Balloon (PPB) project, two balloons named PPB-8 and -10 were launched in rapid succession to form a cluster of balloons during their flight on January 13, 2003, from Syowa Station, Antarctica. In order to make the two-dimensional images for auroral X-rays and to obtain the energy spectra of auroras with energy range from 30 keV to 778 keV, the same instruments for hard X-rays were installed on PPB-8 and -10, respectively. These detection systems observed several auroral X-ray events during the flight. In particularly on January 25, 2003, strong auroral events were detected at about 0919 UT by PPB-10 and at 0927 UT by PPB-8. The aurora observed by PPB-10 was observed after about 8 min by PPB-8 located a 650 km west of PPB-10. The energy spectra of the bright aurora at 0919 UT and 0927 UT for PPB-10 and -8 is obtained as $E_0=(78\pm5)$ keV and (70 ± 5) keV, respectively.

key words: Polar Patrol Balloon, auroral X-rays

1. Introduction

The “Polar Patrol Balloon (PPB)” Experiment was planned as a collaborative research between the National Institute of Polar Research (NIPR) and the Institute of Space and Astronautical Science (ISAS). This experiment called as the 2nd-PPB project was scheduled as a 3-year project and was carried out at Antarctica during the December 2002 to January 2003 in the austral summer season. For geophysical observations, the payload configurations of two balloons named PPB-8 and -10 are identical, and it is planned to launch these in as rapid succession to locate in adjacent areas of the trajectory to form a cluster of balloons. Hence, the two balloons are referred to a “Balloon Cluster”. Therefore it is possible to observe simultaneously the spatial distribution and temporal variations of various phenomena occurred during the flight (Kadokura *et al.*, 2002).

The purpose of AXI, Auroral X-ray Imager, is to observe two-dimensional images of auroral X-rays, and to obtain wider energy spectrum of auroral X-rays than that were observed by PPB-6 (Nakagawa *et al.*, 1997). Additionally, using a "Balloon Cluster" it is possible to investigate the spatial and temporal variations of a wide aurora. From observed data, we will be able to reveal the arrival direction of the auroral X-rays and the variations of the auroral high-energy X-ray emission.

In this paper, we present the detectors installed on PPB-8 and -10 in Section 2, the observation in Section 3, the specific results of the observed data on January 25 in Section 4, and finally the summary in Section 5.

2. Detection systems

The AXI detection system consisted of two kinds of auroral X-ray detectors shown in Fig. 1; a NaI(Tl) detector and a BGO detector. As shown in Fig.1a, the NaI(Tl) sensor was 12.7 mm in diameter and 5 mm in thickness. The photomultiplier tube (PMT) was 13.5 mm

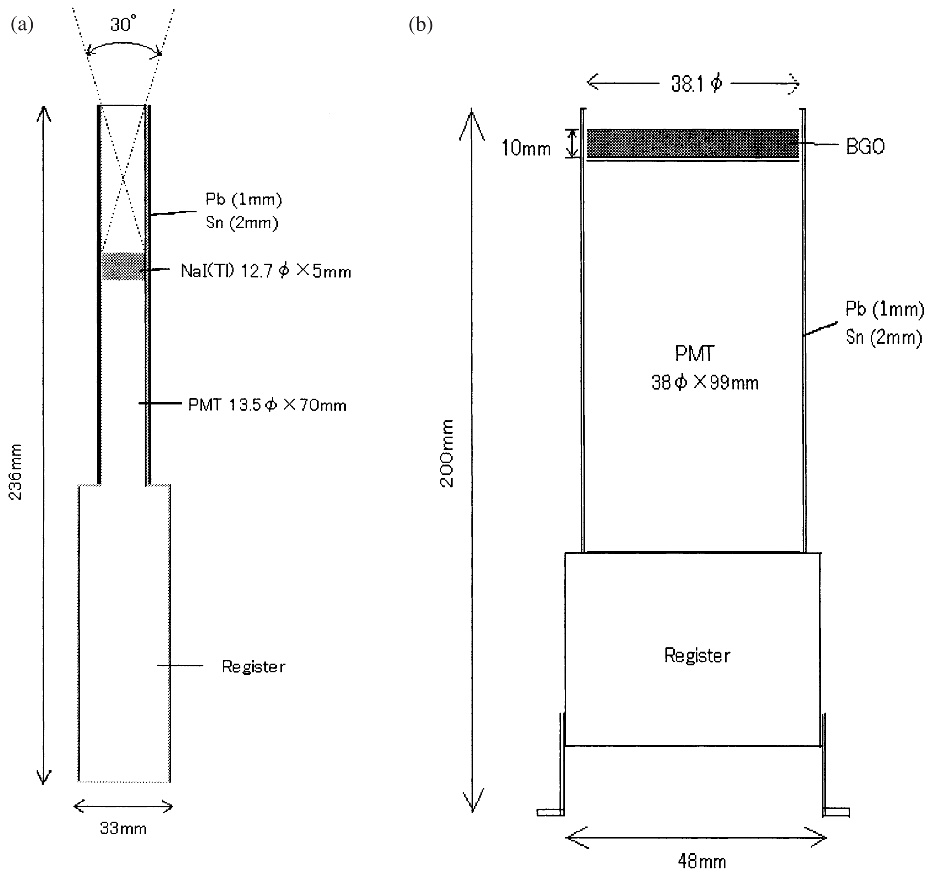

Fig. 1. Detector schematics. (a) NaI(Tl) detector, (b) BGO detector.

in diameter, and was covered with a metal that can interrupt magnetism. The NaI(Tl) sensor and the PMT with registers which divide high voltage were covered with a material which composed tin and lead with 2 mm and 1 mm in thickness, respectively. The field of view of the NaI(Tl) detector was 15° (FWHM). The energy range of this detector was from 30 keV to 180 keV. As shown in Fig. 1b, the BGO detector used a BGO crystal that was 38.1 mm in diameter and 10 mm in thickness, and its field of view was 155° (bottom to bottom). This detector's energy region ranged from 100 keV to 778 keV. To make the two-dimensional images of the auroral X-rays, 16 NaI(Tl) detectors were installed in the gondola, as shown in Fig. 2. Those are divided into 4 groups, each group is situated at each rim of the top surface namely to the north, east, south, and west for azimuthal direction. The center of view of each of the 4 NaI(Tl) detectors in every group was inclined to 10°, 20°, 30°, and 40° from the zenith, and the center of view of the BGO detector was toward the zenith. The fields of view for all the NaI(Tl) detectors on the gondola are shown in Fig. 3. Two-dimensional image of the auroral X-rays in the sky of a radius of 40° can be drawn and the center of the circle is the gondola's zenith. Each counting rate outputted from the 16 NaI(Tl) detectors and the 1 BGO detector on the gondola were recorded every 2 s. The auroral X-ray energy spectra were measured per 20 s in the wide region between 30 keV and 778 keV with these two kinds of detectors. These detection systems were installed on PPB-8 and

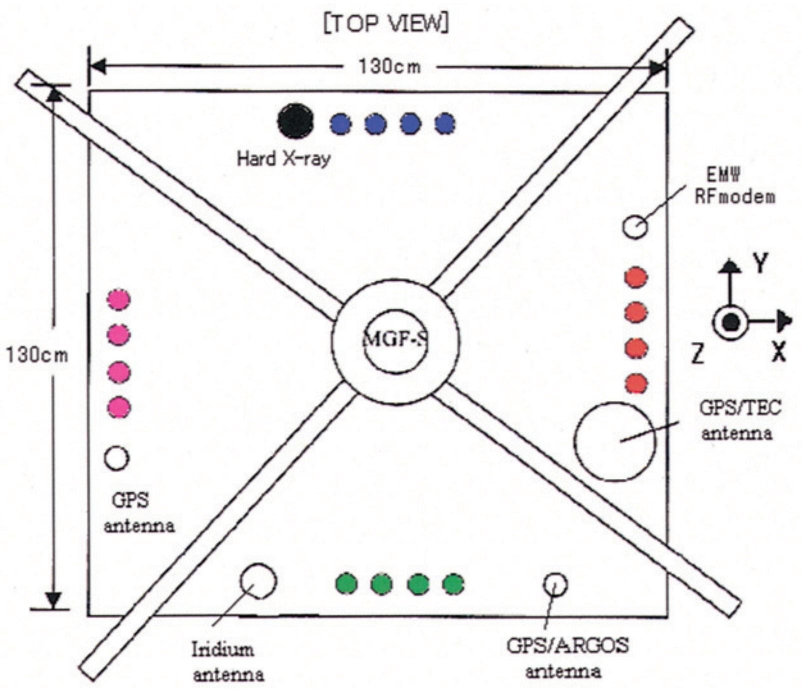

Fig. 2. Schematic view of gondola.
16 NaI(Tl) detectors divided in 4 groups are situated at each rim of the gondola's top surface. The 4 detectors in each groups are inclined at 10°, 20°, 30°, and 40° from the zenith.

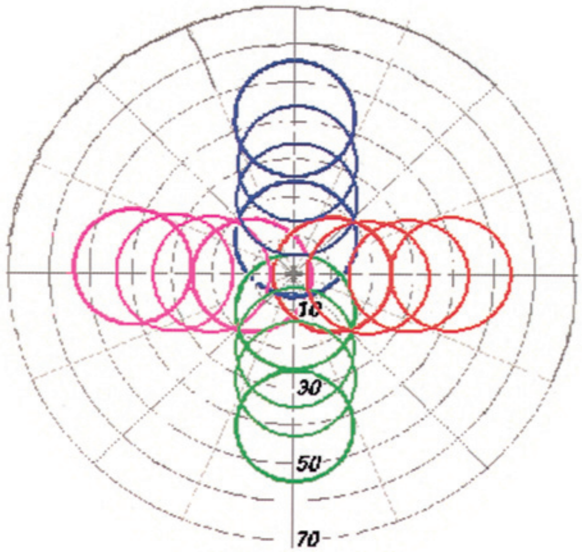

Fig. 3. Overall field of view for all 16 NaI(Tl) detectors. The field of view of each NaI(Tl) detector is 15° (FWHM).

Table. 1. Properties of hard X-ray detectors.

	NaI (Tl)	BGO
Energy range	30–180 keV	100–778 keV
Size of crystal	Diameter: 12.7 mm	Diameter: 38.1 mm
	Thickness: 5 mm	Thickness: 10 mm
Field of view	15°(FWHM)	155°(Bottm to bottom)
Number of units	16 detectors	1 detector
Role	Aurora X-ray	Energy spectrum
	Imager	
	Energy spectrum	

-10. These systems are shown in Table 1.

Observed data were transferred to Japan with Iridium satellite telephone system every 30 min. These were quickly recorded on the host computer prepared in the National Institute of Polar Research (NIPR) and were shown in QuickLook display simultaneously. In this system, three files were ordinary transferred on the hour and the half hour. The one file contained the data for 10 min inserted between the start and end markers. The data for 10 min is divided into 30 blocks. In the one block, there were 10 data trains of counting rate for auroral events per 2 s for all detectors and the energy spectra of the aurora per 20 s divided into five channels for each detector. The data format mentioned above is shown in Fig. 4.

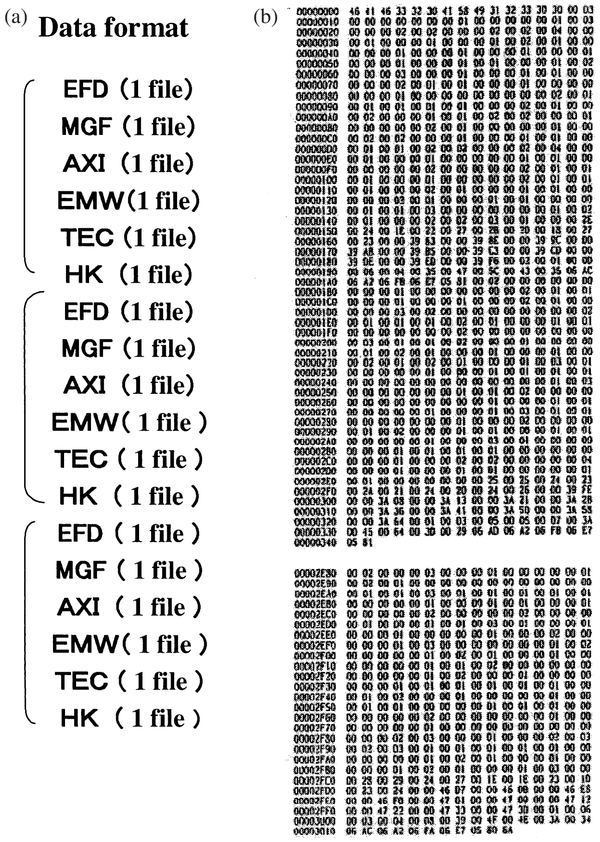

Fig. 4. AXI data format.
(a) Data format, when it is transferred from the Iridium satellite telephone system.
(b) Sample of 1 AXI data file.

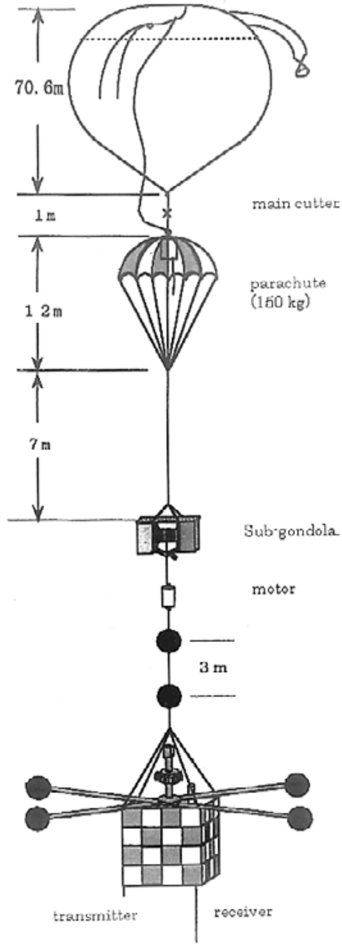

Fig. 5. Flight configuration for geo-physical observations.

3. Observations

Two 50000 m^3 balloons (named as PPB-8 and -10) were launched at 0649 and 1216 UT on the January 13th 2003, from Syowa Station in Antarctica, respectively. The payload configurations of the two balloons shown in Fig. 5 were identical. As shown in this figure, scientific payload weight, total ballast weight, and total weight were 133 kg, 200 kg, and 588 kg, respectively. After their launch from Syowa Station, the two balloons formed a cluster of balloons and drifted westward about 0.5 circumpolar rounds. As shown in Fig. 6, the ceiling altitude for PPB-8 and -10 were controlled within an altitude from 30 km to 31 km by the auto-ballasting system. Figure 7 shows the trajectory of the two balloons for their entire flights. This experiment data was disconnected on January 31st for PPB-10 and on February 7th for PPB-8.

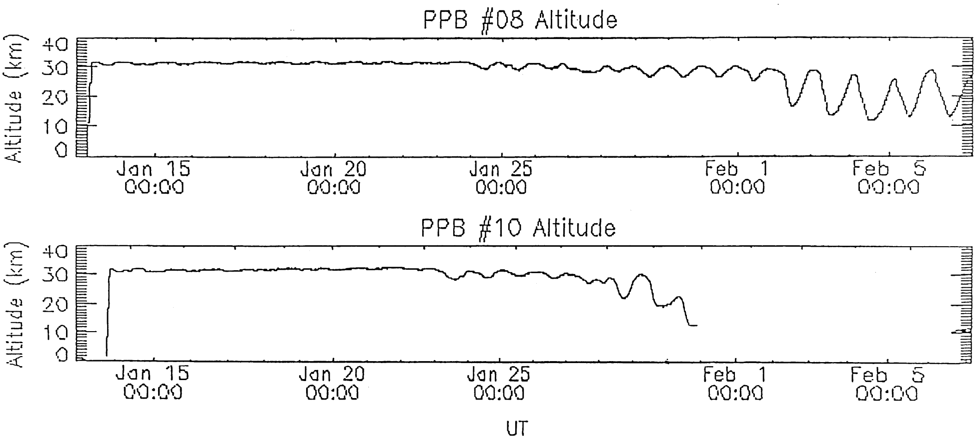

Fig. 6. The variation of altitude for PPB-8 and -10.

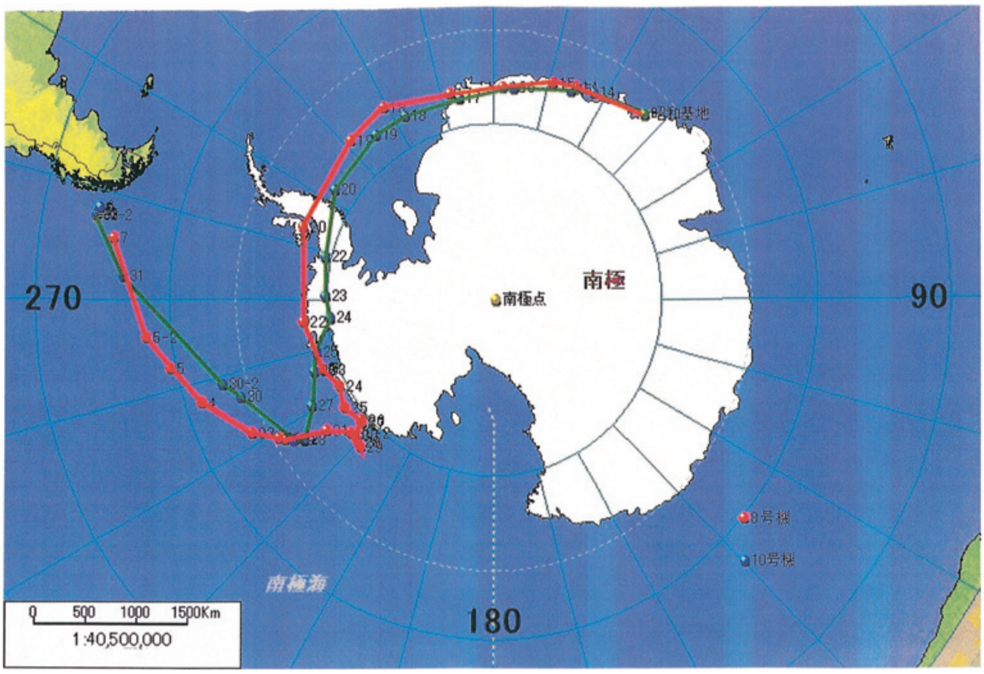

Fig. 7. Trajectory of PPB-8 and -10. Red: PPB-8, Green: PPB-10.

4. Results and discussion

Figure 8 shows the counting rates (cts/30 s) observed with 17 detectors on PPB-10 during the whole flight. As shown in this figure, an event that was higher than the background level of X-ray intensity was considered an auroral event. In this figure, on January 25th, 2003 all detectors observed particularly strong auroral events. Figure 9 shows the one day

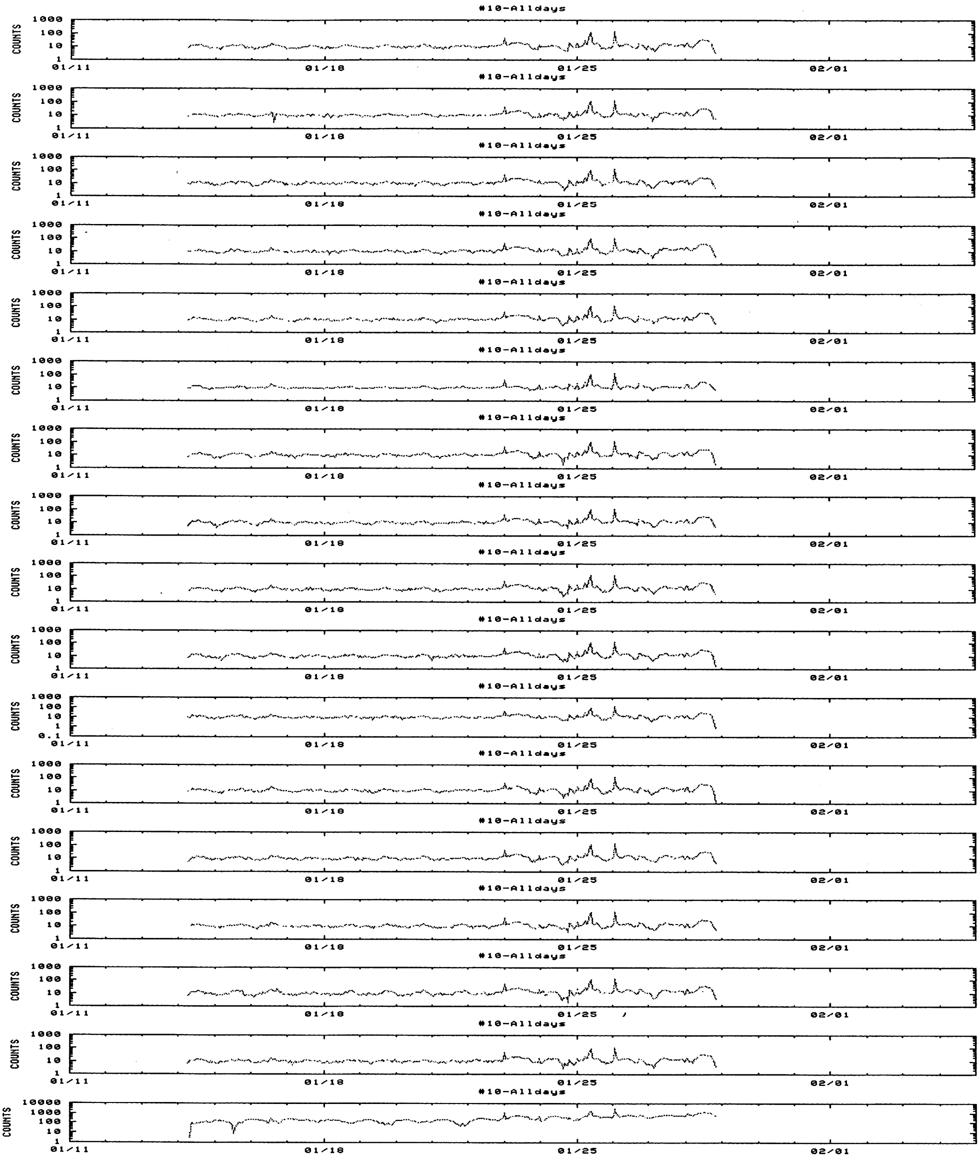

Fig. 8. Counting rates (cts/30 s) observed by all 17 detectors on PPB-10 during the whole flight. The horizontal and vertical axes are all observation times and the count number per 30 s logarithmic scale, respectively. The intensity variation of 16 NaI(Tl) detectors and 1 BGO detector are shown from top by turns.

variation of the 1 NaI(Tl) detector's flux, the BGO detector's flux, the altitude, CGM-Lat (Corrected Geomagnetic Coordinate Latitude), and MLT (Magnetic Local Time) of PPB-10 on January 25th. For PPB-8, the variations of X-ray flux of the NaI(Tl) and BGO detectors, the altitude, CGM-Lat, and MLT are shown in Fig. 10.

The AXI instruments on PPB-10 and -8 observed simultaneously strong auroral events between 0912 UT and 0929 UT on January 25th. Figure 11 shows the two-dimensional

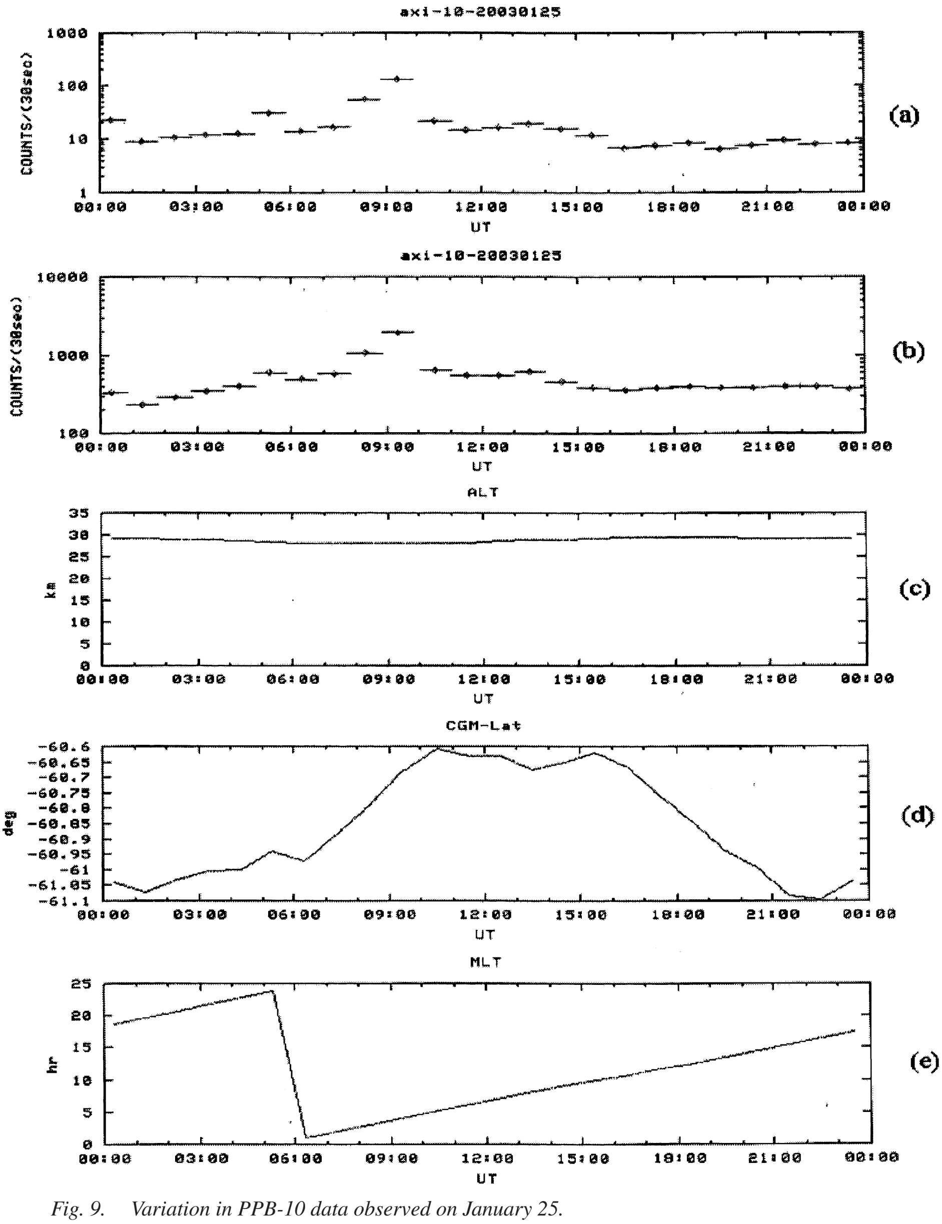

Fig. 9. Variation in PPB-10 data observed on January 25.
(a) NaI detector's flux, (b) BGO detector's flux, (c) altitude, (d) CGM-Lat, and (e) MLT.

images every one-minute for the aurora observed at this period. In this figure, the center of the circle is a gondola's zenith, and the radius is 40°. Figure 11a and b are X-ray images of PPB-10 and -8, respectively. For the images with PPB-10, in the period from 0912 UT to 0929 UT, two bright auroras are detected. The second aurora at 0919 UT is brighter than the first at 0912 UT. The temporal variation of the auroral images for PPB-8 is similar to PPB-

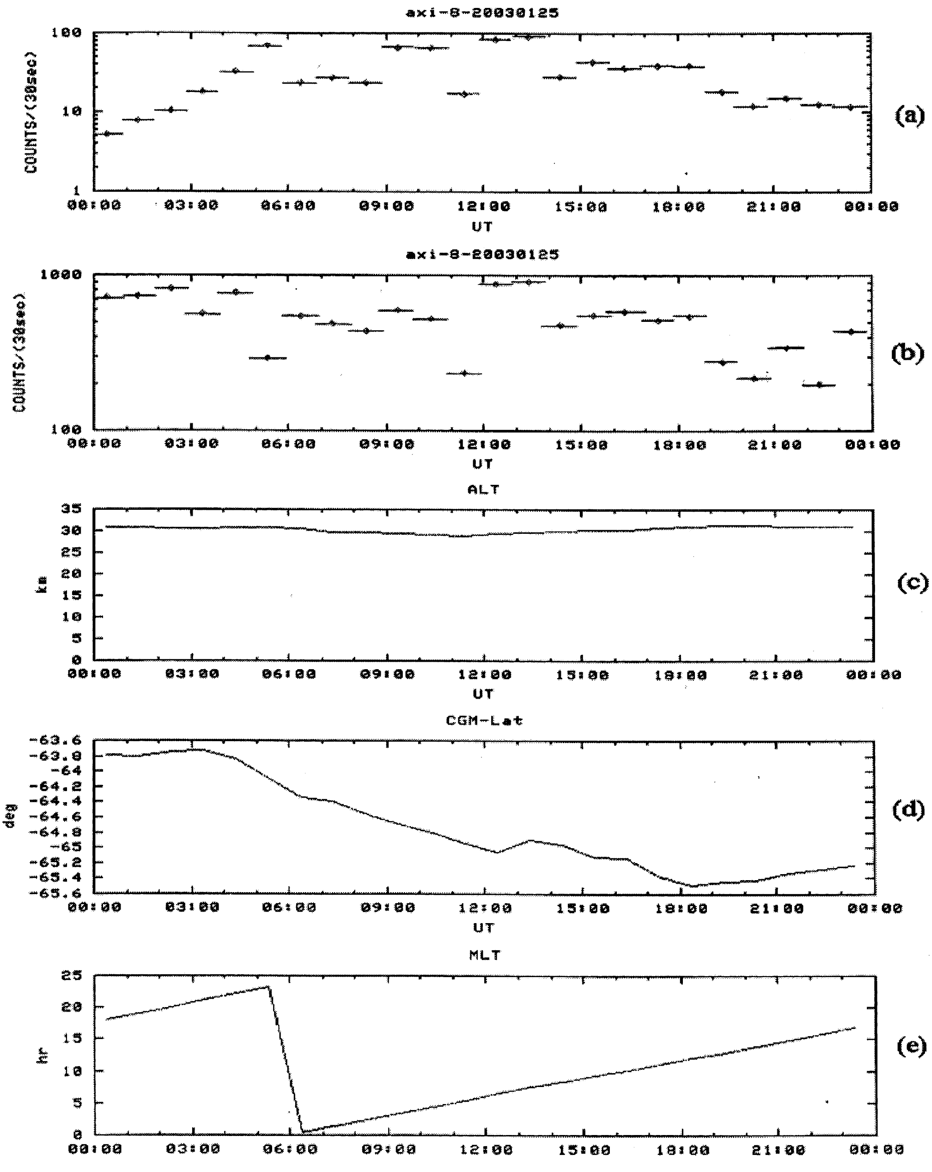

Fig. 10. Variation in PPB-8 data observed on January 25.
(a) NaI detector's flux, (b) BGO detector's flux, (c) altitude, (d) CGM-Lat, and (e) MLT.

10 with only a difference in occurrence time, namely first at 0919 UT and second at 0927 UT, respectively. In order to investigate two peaks observed by each balloon in detail, the auroral X-ray images per 20 s for each peak are shown in Fig. 12. For PPB-10, the maximum flux of the first bright auroral event is observed at 0911:54 UT, and the second bright aurora at 0919:14 UT is 1.7 times stronger than the first one. Therefore the delay time between the first and second auroras is 7 min and 20 s. The altitude, CGM-Lat, and MLT of

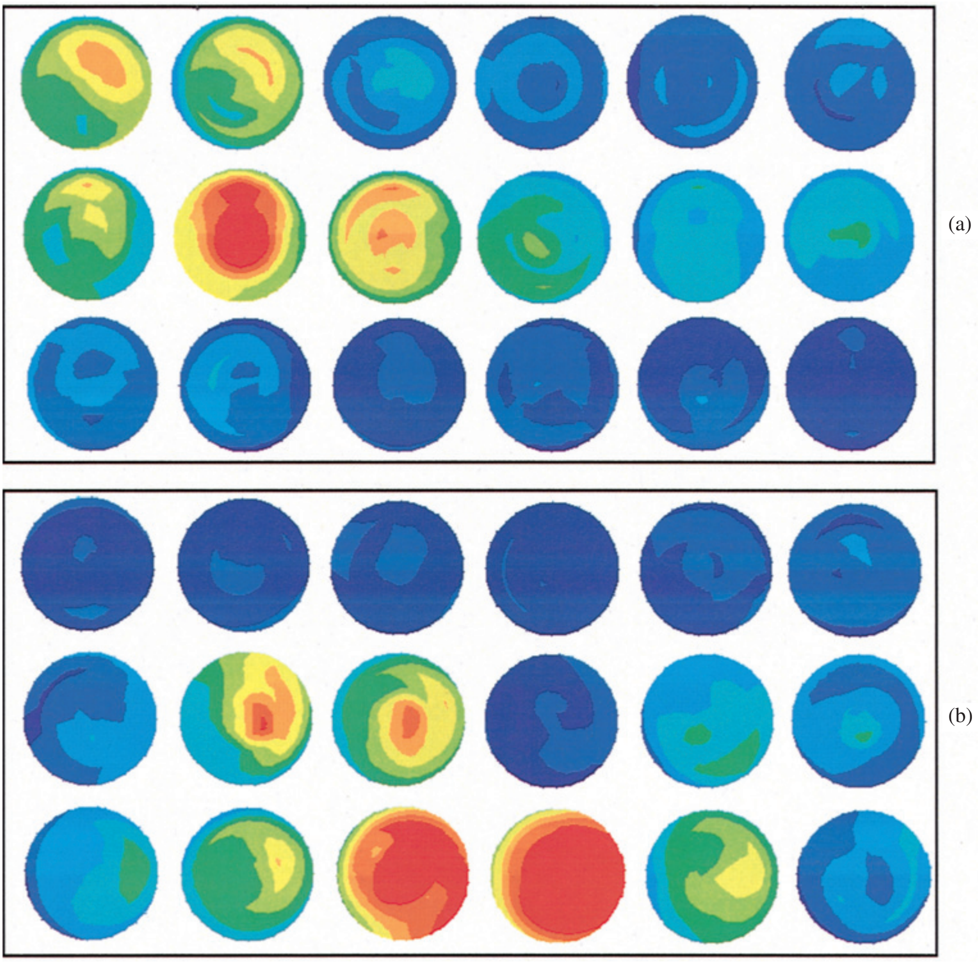

Fig. 11. Auroral images of each 1 min observations between 0912 and 0929 UT on January 25. (a) PPB-10 and (b) PPB-8.

the first for PPB-10 are 28.063 km, −60.707, and 3.806 hours, respectively. Those of the second are 28.161 km, −60.693, and 3.924 hours, respectively. For PPB-8, the aurora observed at 0920:06 UT is again observed after 7 min. The ratio of the two auroral fluxes is about 1.2. The altitude, CGM-Lat, and MLT at 0920:06 UT are 29.472 km, −64.697, and 3.298 hours, respectively. At 0927:06 UT they are 29.466 km, −64.710, and 3.417 hours, respectively.

The distance between PPB-8 and -10 at this time was about 650 km. It seems that two bright auroras observed by PPB-10 at 0911:54 UT and 0919:14 UT are detected after about 8 min by PPB-8 located to the west 650 km from PPB-10. These auroras observed by PPB-10 and -8 seem to develop westward like AKEBONO events at June 6, 1991 (Ejiri *et al.*, 1994).

Each energy spectrum of PPB-10 and -8 at 0919:14 UT and 0927:46 UT is shown in

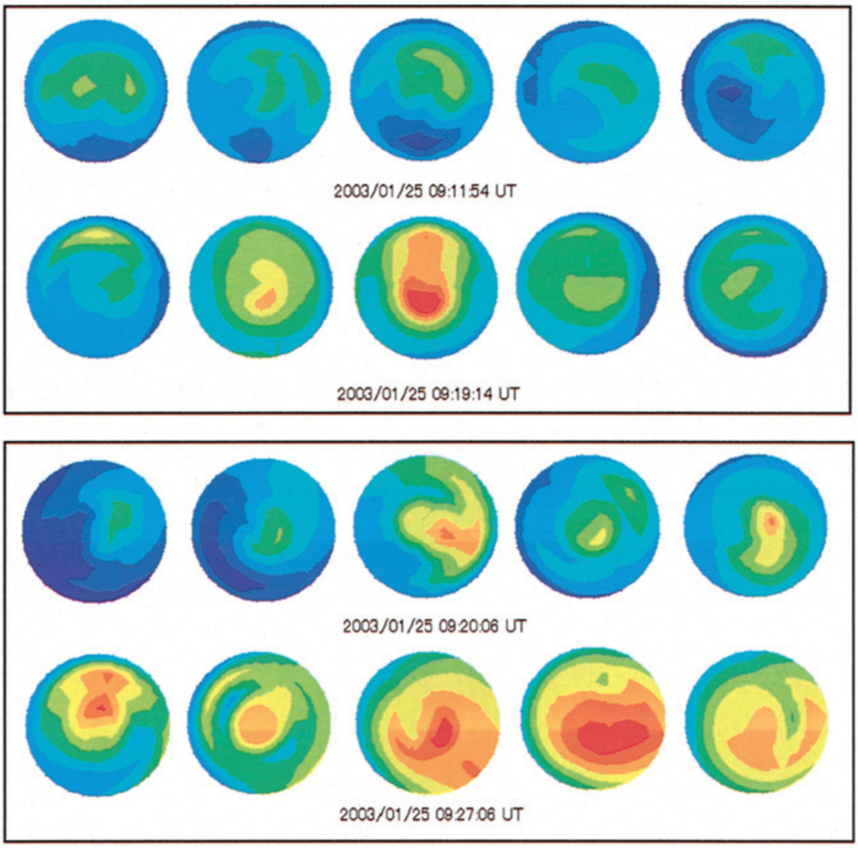

Fig. 12. The variation per 20 s for each bright aurora. (a) The variation observed at 0911:54 and 0919:14 UT on PPB-10 and (b) at 0920:06 and 0927:06 UT on PPB-8.

Fig. 13. In this figure, the left panel shows PPB-10 at 0919:14 UT and the right panel shows PPB-8 at 0927:46 UT. The E_0 of the energy spectra for PPB-10 and -8 are shown (78 ± 5) keV and (70 ± 5) keV, respectively. In the auroral X-ray observations by PPB-6, the value of E_0 at MLT of about 0300 hours was obtained 19 keV, and at MLT of about 2000 hours was obtained 70 keV (Suzuki *et al.*, 1996). The E_0 observed by PPB-8 and -10 is different from that of PPB-6 at the same MLT, but the value of E_0 observed by PPB-8 and -10 is coincident with that obtained by PPB-6 at night in MLT. We needed the results of aurora occurred for PPB-8 and -10 at the other MLT for the confirmation.

We investigate the aurora observations at the same position of two balloons. The position where the auroral events at PPB-10 are detected on January 25th (the latitude of −73° and the longitude of 253°) was passed at PPB-8 on January 22nd. Auroral event is, however, not detected by PPB-8 at the place where PPB-10 observed the aurora.

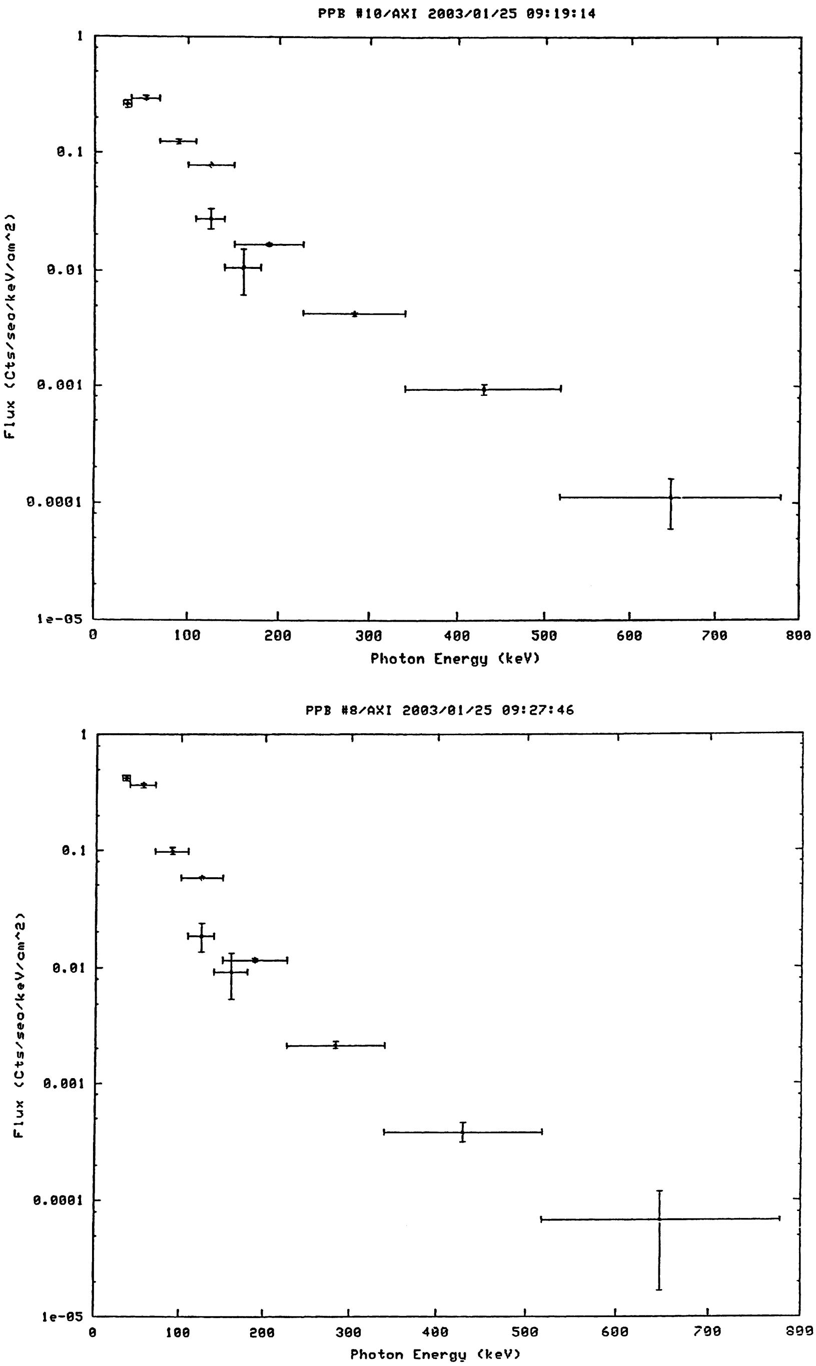

Fig. 13. Energy spectra of the bright aurora observed by PPB-10 and -8.
Upper panel: spectrum observed at 0919:14 UT on PPB-10.
Lower panel: spectrum observed at 0927:46 UT on PPB-8.

5. Summary

For PPB-10, the aurora observed at 0919:14 UT is about 1.7 times stronger than that at 0911:54 UT. While PPB-8, the aurora observed at 0927:06 UT is about 1.2 times stronger than that at 0920:06 UT. The difference of the occurrence time for the two bright auroras is about 7 min for each balloon, and the later one is stronger than the first bright aurora.

In the energy spectra of the aurora at 0919:14 for PPB-10 and 0927:46 UT for PPB-8, $E_0 = (78 \pm 5)$ keV and (70 ± 5) keV are obtained, respectively. It is considered that the energy spectra obtained by each balloon are equal within an error of one sigma. These auroral events are simultaneously observed on January 25th with PPB-10 and -8. The distance between the two balloons was about 650 km. MLT at 0919:14 UT for PPB-10 and at 0927:06 UT for PPB-8 are 3.924 hours and 3.417 hours, respectively. Therefore a couple of auroras observed by PPB-8 and -10 seem to develop westward as observed with AKEBONO at June 6, 1991.

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