Ghost Image Simulation of Auroral X-Ray Sources at Balloon Altitudes

Koichi OGURA¹, Akira YONEDA², and Masahiro KODAMA²

¹*Physical Science Laboratories, College of Industrial Technology, Nihon University,
Izumi-cho, Narashino 275, Japan*

²*Department of Physics, Yamanashi Medical College, Tamaho, Nakakoma, Yamanashi 409-38, Japan*

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Quantitative contributions of the ghost images associated with auroral X-ray image formations at balloon altitudes have been investigated by a Monte Carlo simulation. Contour maps of the ratios of the ghost peak count to real images are shown as functions of the detectors' specifications, collimation angle, the zenith angle of the collimator axis and threshold energy and balloon altitude. As a result, the count ratio decreases for smaller collimation angle and zenith angle, but is occasionally beyond unity even at a conventional balloon altitude of 10 g/cm².

1. Introduction

Several simulation studies have been carried out to investigate propagation procedures of bremsstrahlung X-rays through the atmosphere, in terms of the scattering and energy degradation of photons (PILKINGTON and ANGER, 1971; BERGER and SELTZER, 1972; LAZUTIN, 1979; OGURA and KODAMA, 1980; KODAMA and OGURA, 1989). OGURA and KODAMA (1989) first pointed out the possibility of ghost images being superposed on the real image when using a directional X-ray detector at balloon altitudes.

In general, a directional X-ray detector with a narrower collimator is less sensitive to scattered photons than one with a wider collimator. However, such collimation becomes less effective with increasing atmospheric depth, because the scattered photons have a higher probability to reenter the detector's field of view at deeper depth. In addition to these basic characteristics, a ghost image induced by scattered photons often appears in superposition with the real image, under certain situations involving an X-ray source and balloon altitude.

In a previous paper (OGURA and KODAMA, 1989), the principal characteristics of ghost images were investigated by means of a Monte Carlo simulation. Figure 1 shows a typical example of a ghost image, which appeared toward the zenithal direction against the real image represented by an oval pattern. We note that the ghost peak flux occasionally reveals a comparable order of magnitude with the real image. This simulation result implies that the inclined detector possibly observes some pseudo-image when no X-ray source exists inside its field of view, but exists near the zenithal direction out of the detector's viewfield. This suggests that spurious images are inevitable in certain cases using the collimation technique, and thus should not be ignored in experiments. The collimation angle dependence of the

Fig. 1. Two-dimensional distribution of arrival photons from an isotropic point source on the x - y coordinate (upper panel) and count histogram (lower panel) at the atmospheric depth of 10 g/cm^2 . Photon directions are specified by an inclined detector with collimator. The collimation angle is 20° and the zenith angle of the collimator axis is 40° . The threshold energy of the detector is 25 keV.

ghost image is not simple but rather in an opposite sense between 40° and 60° . Due to a limited run of calculation, it seems that a maximum ghost contribution was found for a collimator with a 40° opening angle and 40° inclination angle. The present paper is an extension work to present quantitative contributions of the ghost image in more detail. The results are demonstrated in the form of contour maps of the ghost/real count ratio as a function of various experimental parameters.

2. Simulation Results

The simulations were carried out under the assumption of an isotropic point source with an exponential-law energy spectrum (the e -folding energy was fixed to

30 keV), as described by KODAMA and OGURA (1989). To quantitatively demonstrate the degree of the ghost contribution, a ratio of the maximum photon count in the ghost image to that of the real image was taken as a function of the collimation angles with 10° steps and the zenith angles of the collimator axis with 5° or 10° steps, where the ghost background was subtracted from the peak count of the real image. Contour lines interpolated from such grid point ratios were traced by 0.1 steps for each of nine different combinations of three threshold energies of 25, 50 and 75 keV and three depths of 6, 10 and 14 g/cm^2 .

Figure 2 shows the contour maps thus obtained for various experimental parameters. The hatched area in the figure pertains to the ghost/real ratio of 1.0 or greater. A gross feature of the ratios is that the enhanced ghost image is accompanied by the following:

- 1) a wider collimation angle,
- 2) a greater zenith angle of the collimator axis,
- 3) a greater atmospheric depth, and
- 4) a lower threshold energy of the detector.

It is to be noted that the brightness of the ghost occasionally exceeds the real image at a conventional balloon altitude of 10 g/cm^2 , when the threshold energy of the detector is less than 25 keV and the collimator with an opening angle greater than 30° is directed to an inclined angle greater than 40° . In the triangular region under

Fig. 2. Contour lines of ghost/real ratios in peak photon counts are traced by 0.1 steps as a function of collimation angle and zenith angle of the collimator axis. Nine maps are given for each of three detectors' threshold energies of 25, 50 and 75 keV and three atmospheric depths of 6, 10 and 14 g/cm^2 . Hatched area pertains to the ratio of 1.0 or greater.

the broken line of Fig. 2, where the detector's viewfield always includes the zenithal direction, it is difficult to quantitatively distinguish between the ghost and the real image in the present calculation.

3. Discussion

As is clearly seen in Fig. 2, the ghost image reveals a comparable order of magnitude to the real image under certain conditions, particularly in the hatched area. The general trend of contour lines is downward on the right-hand side throughout each panel. In other words, the ghost image is depressed for smaller collimation and also smaller inclination angles. OGURA and KODAMA (1989) reported that the maximum spurious contribution is found for a collimator with a 40° opening angle and 40° zenith angle, because an apparent maximum of the

Fig. 3. The same as in Fig. 1, where the collimation angle is 50° .

ghost/real ratio appears around the 40° collimation, if the background is not subtracted from the real image. This seems to be somewhat incorrect due to a limited attempt at calculations and non-subtraction of spurious background from the real count. As is obvious from Fig. 3, at a greater collimation angle of 50° , it is rather difficult to estimate the effective count of the real image, because the count distribution is scarcely uniform inside the viewfield of the collimator. Then the maximum count adopted for deducing the ratio tends to give an overestimation of the real image count, and it introduces under-estimation of the ratios for the greater collimation. This situation bends the contour lines upward.

To reduce the ghost images practically, it is desirable to fly at higher altitudes above 10 g/cm^2 or to restrict the zenith angles of the collimator axis to within 30° . Both the selection of a narrower collimation angle and higher energy threshold of the detector are also effective for reducing the ghost image, but it should be noted that they simultaneously degrade the counting statistics. For example, the detection efficiency of 10° collimation is decreased by about one order of magnitude compared to that of 40° collimation at a depth of 10 g/cm^2 . Consequently, specifications of balloon-borne detectors used in practical experiments must be decided taking into account this matter of fact.

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