

Correcting high resolution imaging for the effects of the geomagnetic field

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Abstract. Under certain circumstances, the geomagnetic field has been demonstrated to cause distortions of the images of gamma rays in imaging atmospheric Cherenkov telescopes. Our previous analysis of this effect has concentrated on telescopes with characteristics typical of the Mark 6 telescope. We have extended our simulations to telescopes with higher angular resolution and lower energy threshold. We discuss the implications of these results.

1 Introduction

We and others (Bowden et al., 1991; Lang et al., 1994; Chadwick et al., 1999a,b, 2000) have previously investigated the distortion of the images in Cherenkov light of atmospheric electromagnetic showers caused by the geomagnetic field. Our earlier work was based on simulations and on observations carried out using the Durham Mark 6 Cherenkov telescope in Narrabri, NSW. The specific values of both the telescope parameters, in particular the point spread function, and of the local geomagnetic field (0.56 Gauss) render the results indicative of a significant effect but the detailed results are specific to that experiment. We have made detailed simulations of gamma ray showers for several values of the geomagnetic field and for a 'perfect' telescope, that is: a telescope with perfect optical performance and no pixellation. Our experience in Narrabri, NSW was in a high value of geomagnetic field. We show in figure 1 a map of the variation of the geomagnetic field strength across the world and note that Australia has as strong a field as almost anywhere, Namibia has almost the lowest field strength, with North America having an intermediate value.

The results must be interpreted with care because a realistic model of a telescope will have both pixellation and an optical point spread function (PSF), which will affect the threshold value of geomagnetic field of importance for that

telescope.

2 Simulations

Monte Carlo simulations of gamma rays have been made at several values of magnetic field strength for a single generic telescope of 10m diameter. All showers were simulated for a primary gamma ray energy of 250 GeV and at a zenith angle of 30° . The location was recorder of every photon striking the focal plane and these were used to calculate the parameters of the image. Images from actual telescopes, in addition to being pixellated and subject to the mirror's PSF, will suffer from effects of noise. These include the truncation of the peripheral photons which cannot be detected reliably above the noise within a pixel.

The most important image parameters which are affected by the geomagnetic field are those by which gamma rays are discriminated from hadrons. The two parameters of most interest are

1. *ALPHA* which indicates the angular separation of the source direction and the observed axis of the shower,
2. the width of the image.

The first-order effect of the geomagnetic field is to spread the image in a direction perpendicular to the direction of the geomagnetic field as projected on to the focal plane, which is effectively perpendicular to the shower arrival direction. The effect of this spreading depends on the location of the shower image in the camera. When an image of a gamma ray shower is located away from the source position in the camera and along the projected field direction, the effect is only to increase the width of the image. For images in directions 90° away from these, the effect is to elongate them. For intermediate directions, both width and length are increased, but more importantly the direction of the apparent shower axis is rotated by an amount which depends on the amount of spreading in comparison with the ellipticity of the image.

2.1 The effect on *ALPHA*

The effect of the broadening and rotating of the observed image by the magnetic field depends on the ellipticity of the image, which in turn depends directly on the angular distance of the image from the source. This is demonstrated in figure 2 in which the coordinates are:

1. Signed *ALPHA* - the sign indicating whether the shower image has been rotated clockwise or anti-clockwise from the projected shower direction,
2. *magang* - the angle of the radius vector from the source position to the centroid of the image, measured clockwise from the projected direction of the magnetic field.

The showers were generated by gamma rays moving perpendicularly to a magnetic field of 0.56 Gauss and as seen by a 'perfect' camera of diameter 5° . Each small diagram is for a separate range of values of angular distance of the centroid of the image from the source position and it can be seen that the magnitude of the change in alpha falls off rapidly with increasing distance from the camera centre. The sensitivity of the effect with magnetic field can be seen by comparing figure 2 with figure 3 which is for a similar batch of simulated showers but with a perpendicular field of 0.2 Gauss.

2.2 The effect on *WIDTH*

The effect of various values of perpendicular geomagnetic fields on *WIDTH* can be seen in figure 4 which is based on simulations of gamma rays with image positions between 0.6° and 0.7° from the source position in the camera. The broadening of the image perpendicular to the projected direction of the magnetic field on the focal plane can be seen clearly by the increase in image width when the value of *magang* is near to either 90° or 270° . A secondary effect of this broadening is that the peak intensity of the image is reduced in certain directions with a resulting loss of events triggering a telescope. This effect was clearly seen in our observations in NarrabriBowden et al. (1991).

3 Conclusions

The sensitivity of a single Cherenkov telescope can be significantly affected by the geomagnetic field. Earlier telescopes which had pixels of large angular size and possibly poorer optical quality would be affected less by the field in that the addition of the instrumental smearing will reduce the sensitivity to the spreading due to the field alone. It is expected that newer telescopes with pixels of smaller size and mirrors with better point spread functions will be affected more.

References

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