HTML ABSTRACT + LINKS

Gamma-Ray Polarisation Measurements with INTEGRAL/IBIS

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Abstract. The IBIS telescope on board the INTEGRAL satellite, while designed to produce high resolution images of the gamma-ray sky, will also be able to measure the polarisation of strong high energy sources. We present an estimate of the polarization sensitivities of both the high energy detector (PICsIT) operating in polarization mode and of the IBIS Compton events which scatter from the low energy to the high energy detector, for possible observations of the CRAB pulsar and for the case of a strong gamma-ray burst in the fully coded field of view.

INTRODUCTION

The IBIS instrument on board the INTEGRAL satellite [1] will create images of the gamma-ray sky over a wide energy range of ~20 keV - ~10 MeV. This is achieved by the use of two discrete detection planes, one (ISGRI, [2]) composed of 16384 CdTe micro-detectors for use between ~20 keV and ~1 MeV and the second (PICsIT, [3]) comprising 4096 CsI scintillator crystals functioning above ~150 keV. While the data from ISGRI are always transmitted in photon-by-photon mode, those from PICsIT are usually (the 'standard' mode) transmitted in the form of accumulated detector 'images' and as high resolution timing (without spatial information). However, due to the importance of potential polarisation measurements at high energy, a dedicated polarisation mode of operation has been incorporated in PICsIT. Furthermore, the data from Compton events between ISGRI and PICsIT are continuously transmitted in photon-by-photon mode, allowing possible polarisation measurements to be performed even when the high energy detector is in the 'standard' mode of operation. The IBIS instrument on board INTEGRAL may be used to investigate source polarisation in two modes of operation:

- The dedicated (PICsIT) Polarimetry mode
- The IBIS (ISGRI-PICsIT) Compton Mode

While the second mode is always present and so is particularly useful to study impulsive events such as gamma-ray bursts (GRBs) which may occur in the field of view, the former is a dedicated mode and would be useful to study persistent sources such as the CRAB pulsar. In the following sections we estimate the polarisation sensitivity in both modes by means of Monte-Carlo simulations.

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THE MONTE-CARLO MODEL

The Monte-Carlo model employed uses both a very simplified IBIS design as well as a reduced data simulation. The ISGRI plane was considered to be a unique plane of 128 x 128 CdTe detectors i.e. with the correct number of detectors but ignoring the fact that in reality the plane is divided into 8 modules with a gap between each. In an analogous manner the PICsIT plane consisted of 64 x 64 CsI detectors but again without considering the modularity. The data for the polarimetry mode simulation were generated by irradiating only one pixel of CsI in the centre of the plane, while those for the Compton mode were generated by irradiating 4 (2x2) pixels of CdTe near the centre of the plane and constructing a map of Compton events in PICsIT. Obviously in neither case do we take into account edge effects or off-axis distortion. Three simulations were performed – at 250 keV, 511 keV and 1 MeV. It is important to note that not all Compton events are useful for the polarisation measurement. In particular, the only events which carry useful information are those which undergo a Compton scattering in ISGRI followed by ONE interaction in PICsIT. This is because during the on-board computations the position information for events which interact more than once in PICsIT is lost (a statistically reconstructed position is all that is recorded).

POLARISATION DEFINITIONS

The minimum detectable polarisation (MDP) in the absence of background noise can be described [4] by the formula:

$$MDP = \frac{n_\sigma}{Q_{100}}\sqrt{\frac{1}{C_C}} \quad ; \quad Q_{100} = \frac{N_\perp - N_\parallel}{N_\perp + N_\parallel} \qquad (1)$$

where n_s is the significance of the measurement, Q_{100} is the Q-factor (or sensitivity to 100% polarised photons) of the detector, $N_\perp$ and $N_\parallel$ are the number of Compton counts in areas perpendicular and parallel to the polarisation vector of the incoming photons and C_C refers to the number of Compton events *used in the calculation of* Q_{100}. Clearly $C_C = N_\perp + N_\parallel$.

In order to make explicit the inter-relationship between Q_{100} and the Compton efficiency, we can rewrite (1) using the total number of Compton events (C_T) and the *effective* Q_{100}:

$$MDP = \frac{n_\sigma}{Q_{100}^{eff}}\sqrt{\frac{1}{C_T}} \quad ; \quad Q_{100}^{eff} = Q_{100}\sqrt{{C_C}/{C_T}} \qquad (2)$$

This effective factor automatically takes into account the fact that Compton events with different linear separation may have both widely different Q-factors, but also widely different probabilities. We shall use the formulation of equation (2) for both

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modes of operation, assuming that for the IBIS Compton mode the data used can be selected for time around the GRB such that the source dominates over the background rate.

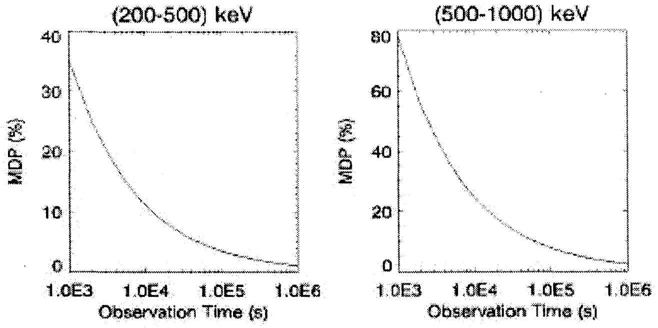

FIGURE 1. The MDP(3s) for observations of the CRAB pulsar in two energy bands PICsIT Polarimetry Mode Sensitivity

The PICsIT polarimetry mode takes into account those events which produce energy deposits in a CsI detection element and then Compton scatter and interact again *in an adjacent pixel.* The Q_{100} factor in this case is large, due to the almost 90° scattering angle, however the efficiency is low leading to an effective Q_{100} of less than 0.2 at 200 keV decreasing in an almost linear manner to a value of around 0.07 at 1 MeV. The total Compton efficiency over the same range may be approximated by two linear fits breaking at 511 keV. Then we can integrate equation (3) using these relationships to provide the minimum detectable polarisation as a function of observation time for an observation of the CRAB pulsar in two energy bands as shown in Figure 1. It must be remembered that these are upper limits as we have neglected the background term.

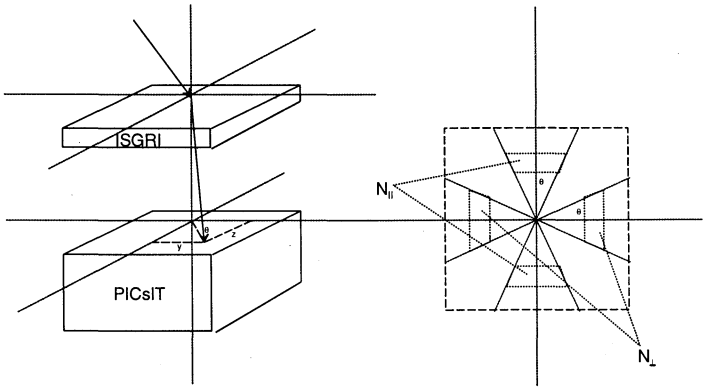

FIGURE 2. The linear separation and angle parameters for double events to be included in the calculation of the effective Q_{100}.IBIS Compton Mode Polarisation Sensitivity

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It is the use of the Compton mode between ISGRI and PICsIT for polarisation measurements where the utility of defining the effective Q_{100} becomes apparent. This is because there is no restriction on the linear distance between the point of interaction in the two planes for valid events (within the overall dimensions of the planes), thus allowing optimisation of the effective Q_{100} by defining the acceptance areas of events to be included in the sums of $N_{\perp}$ and $N_{\parallel}$ depending on (see Figure 2):

- Minimum linear distance (y/z) from point of interaction in ISGRI to that in PICsIT
- Maximum linear distance (y/z) from point of interaction in ISGRI to that in PICsIT
- Angle of the second point of interaction with respect to first (?).

This can be useful because the Q_{100} increases with linear separation, while the efficiency decreases, leading to a maximum of the *effective* Q_{100} at some distance from the original interaction point, depending on the energy of the event as shown in figure 3. Once again we can integrate equation (3) and use the relationships of Q_{100} and Compton efficiency with Energy to produce the minimum detectable polarisation. In order to apply this to the number of gamma-ray bursts INTEGRAL is expected to see within the field of view we can work forward from the CGRO catalogue and assume an average burst spectrum which consists of a broken power law with spectral index of -1 and -2.25 below and above the break energy, which itself is in the range 100 keV - 1MeV. Furthermore we can use the distribution in fluence given in [5].

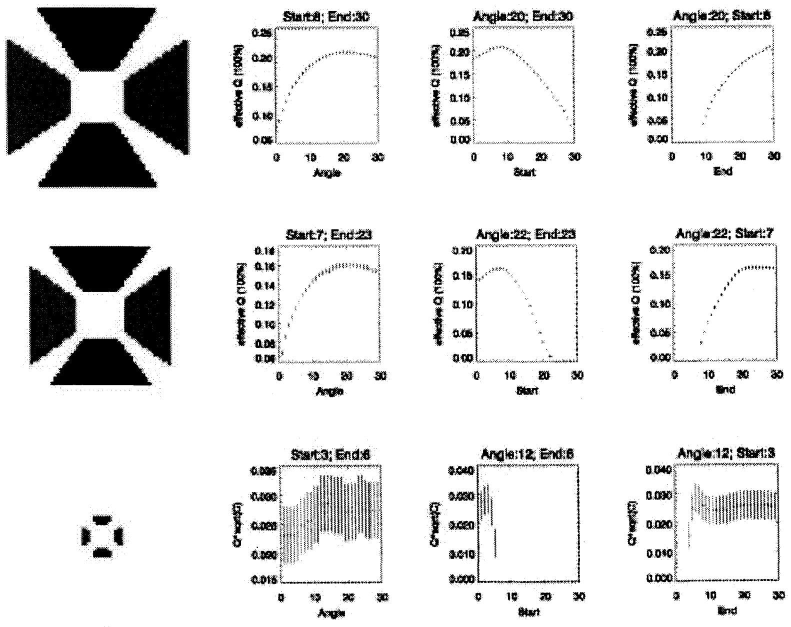

FIGURE 3. The optimum parameters y,z_{min} (start); y,z_{max} (end) (both in pixels) and acceptance angle for the calculation of the effective Q_{100} for 250 keV (*top*); 511 keV and 1 MeV (*bottom*) are depicted in the left column. In the other columns the variation in the effective Q_{100} with each parameter individually is shown. It can be seen that as energy increases, the maximum in the effective Q_{00} comes from the integration of events closer to the original interaction point as the decrease in efficiency more than cancels the effect of the increase in Q_{100} with distance

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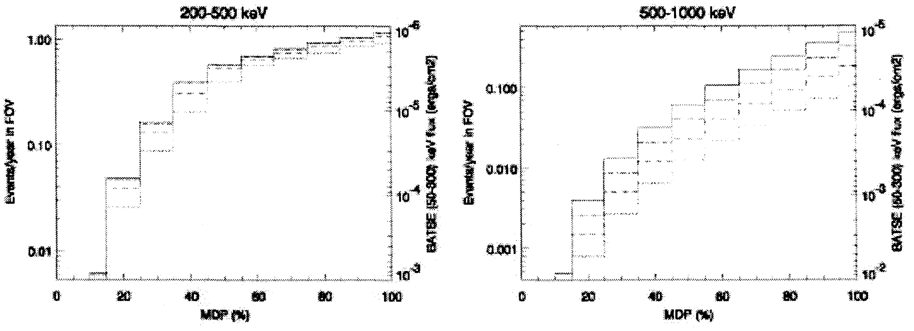

FIGURE 4. The number of events/year in the field of view for two energy bands – a low energy regime from 200 – 500 keV and a higher energy range from 500 – 1000 keV as a function of minimum detectable polarisation and for 4 GRB break points (200, 300 , 400 and 500 keV from the bottom). Also shown for comparison purposes is the equivalent energy fluence (in ergs/cm^2) for the BATSE 50-300 keV band.

The definition of the FOV of IBIS for Compton mode depends on the energy – at low energies (say < 500 keV) the hopper is opaque and so we can say that, roughly, the FOV is around 400 square degrees (corresponding to the half coded area), or one hundredth of the full sky. At higher energies (say > 500 keV) the hopper is increasingly more transparent, and so the FOV may be multiplied by up to a factor 5 (equivalent to about a 45° x 45° aperture). Using all this information we can estimate the number of GRB events per year which IBIS will be able to detect at a given MDP as a function of energy as shown in Figure 4.

CONCLUSIONS

We have shown, using a very simplified Monte-Carlo simulation that the IBIS telescope on board INTEGRAL will have some possibility of making polarimetric observations of gamma-ray sources. Detailed modelling of the instrument and more sophisticated methods of polarisation analysis will allow a more accurate evaluation of the polarimetric sensitivity to be performed.

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