# INTEGRAL Observation of GRB 030406 in the Compton Mode

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GRB030406 is one of the strongest gamma-ray bursts detected by the INTEGRAL SPI anticoincidence shield. We analyzed the IBIS Compton Mode data for this burst and present its localization, lightcurve and spectrum in the 200 keV to 2.5 MeV range. We discuss the ongoing analysis of other bursts seen by INTEGRAL in the IBIS Compton mode.

## 1. INTRODUCTION

The IBIS telescope is the coded mask, imaging instrument on-board the INTEGRAL satellite [1, 3]. The detector plane consists of two detection layers: ISGRI and PICsIT. ISGRI is an array ($128 \times 128$) of pixels made of semiconductive CdTe, sensitive to photons between 15 keV and $\sim$1 MeV. PICsIT, having the same detection area as ISGRI, is an array ($64 \times 64$) of CsI scintillators, sensitive between $\sim$170 keV and 15 MeV. The distance between two layers is about 94 mm.

A small number of gamma-ray bursts (up to ten per year) is detected by INTEGRAL inside its field of view. A much larger number (approx 150 per year) is detected outside the filed of view mainly using the SPI anti coincidence shield (SPI-ACS). For these bursts localization was achieved by the triangulation within the $3^{rd}$ Interplantery Network of Gamma-ray burst detectors. We note that some of these burst are also detected in the IBIS telescope. The analysis of the IBIS data can yield their localizations using the Compton mode data. Given the localization one can perform the spectral analysis, once a response matrix is produced.

In this paper we present such analysis performed in the case of GRB030406.

## 2. COMPTON MODE

This mode makes use of photons with energy mainly between few hundreds of keV and a few MeV. About 2-5% of them are Compton scattered in one and absorbed in the other layer (Figure 2 left panel). Coincidences within appropriate time window are detected on board. The energies and positions of both interactions are recorded. Compton kinematics allows to determine the Compton scattering angle $\theta_C$, the energy of the primary photon $E_0 = E_1 + E_2$ and the direction of the scattered photon($\gamma_2$).

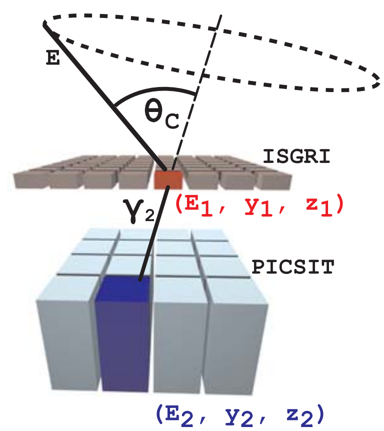


Figure 1: A Compton event in IBIS: the photon is scattered in ISGRI pixel and absorbed in PICsIT crystal

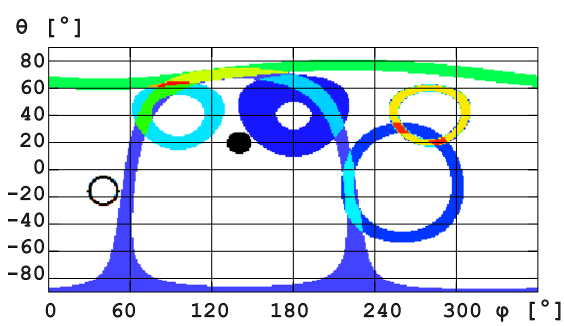


Figure 2: Examples of eight Compton rings on the all sky map in a Cartesian projection. Each ring corresponds to one Compton event.

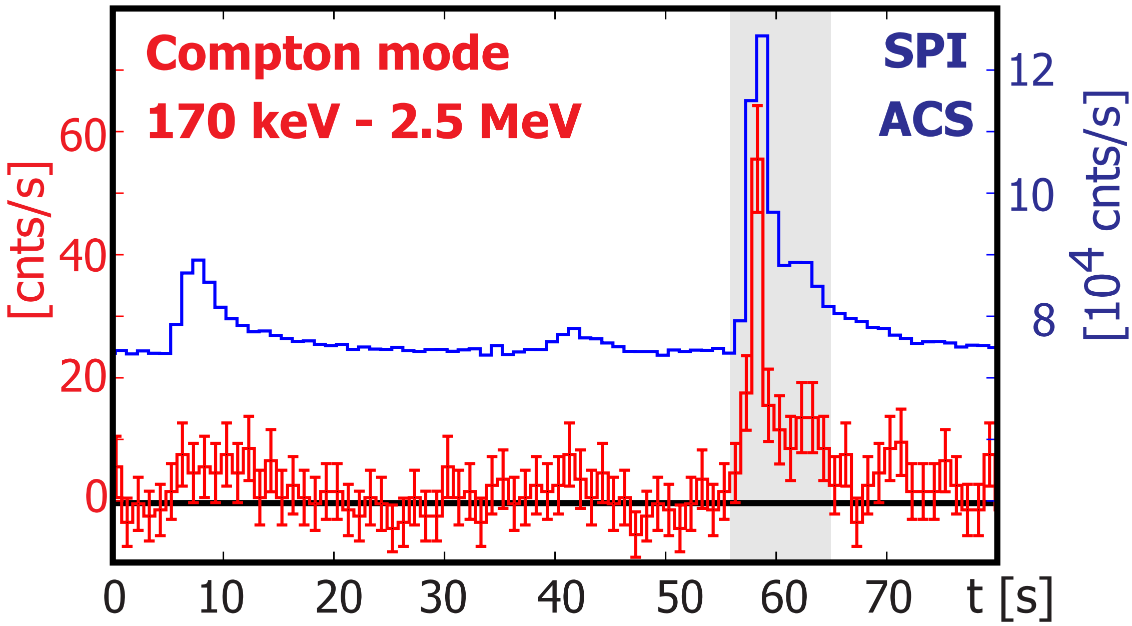


Figure 3: GRB030406 light curve from the Compton mode (bottom histogram, left scale) and count rate in SPI-ACS (top histogram, right scale). The shaded time interval has been used in the construction of the Compton map and spectral analysis

### 2.1. Compton maps

The direction of the scattered photon and the Compton angle ($\theta_C$) define a cone. Intersection of this cone with the celestial sphere gives a circle (shown as dashed ellipse in Fig. 1). One–dimensional circles are converted to two–dimensional rings with the width reflecting uncertainties of the measured energies and positions: $E_1$, $E_2$, $y_1$, $z_1$, $y_2$ and $z_2$. Figure 2 shows examples of such rings with typical widths. These "Compton rings" produce a Compton map. In case of a strong source (like a GRB), a significant excess should appear at the source position on the Compton map.

## 3. GRB030406

The SPI ACS [4] triggers, identifying the GRB, were used for the selection of time intervals for the Compton mode analysis. We have analyzed the data collected within 3 months and found a few cases where the Compton mode count rate increased significantly. At first we focused on GRB030320, which position has been well measured by ISGRI and SPI as it was inside the FOV [5]. The analysis of GRB030320 proved that the Compton mode can be used to obtain positional information about a burst which is consistent with the information obtained from the coded mask instruments.

Here we present the analysis of the one of the strongest burst seen in the Compton mode: GRB030406 (36° off axis, outside of the IBIS coded field of view). Figure 3 shows the light curve of the burst obtained with ∼200 selected Compton events. The selection made use of the Compton kinematics, i.e. only events for which Compton rings were compatible with the source position were selected. Subtracted background estimation underwent the same selection. The signal-to-noise ratio reached $\sim 11\sigma$ in the peak.

The sky map (Figure 4) comprises information from about 1200 photons corresponding to the time interval marked on the Figure 3 and takes into account about 30 minutes of independent acquisition for the background estimation. Photons with energy between 200 keV and 950 keV have been used. We have assumed that the order of photons interactions was: ISGRI–first and PICsIT–next.

The data from the same time interval as for the map have been used to fit of the GRB spectrum (Figure 5). The fit was done using XSPEC 12.0. Using Monte-Carlo simulation with the Geant (3.21) IBIS Mass Model [2] we have obtained the specific Compton mode response matrix for this event. We have obtained a satisfactory fit using a power law model with the photon index $\alpha = -1.48 \pm 0.16$

Additional simulations of a GRB030406-like burst combined with experimental background showed that the $1\sigma$ error of the position estimation is $\sim 3.5°$.

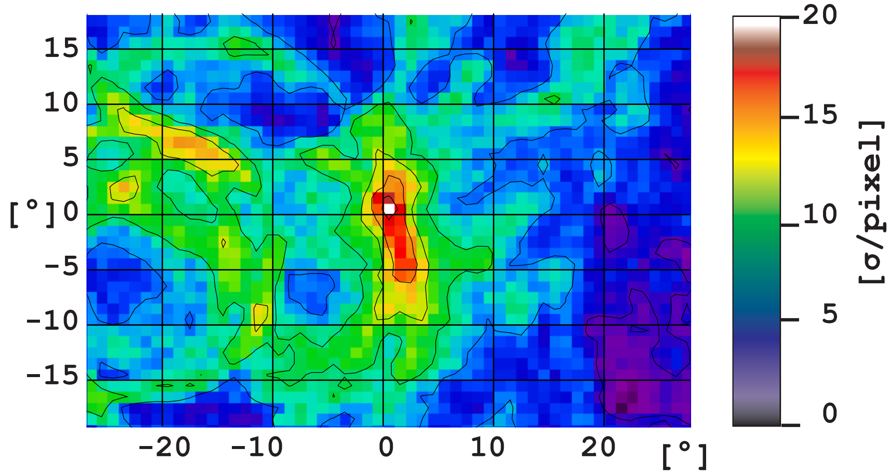


Figure 4: Compton mode significance map of the burst region centered on the IPN [7] reconstructed position of GRB030406 RA(2000) = 285.43° DEC(2000) = −68.08°. IPN's 3$\sigma$ position uncertainty was about 9'x9' (not shown).

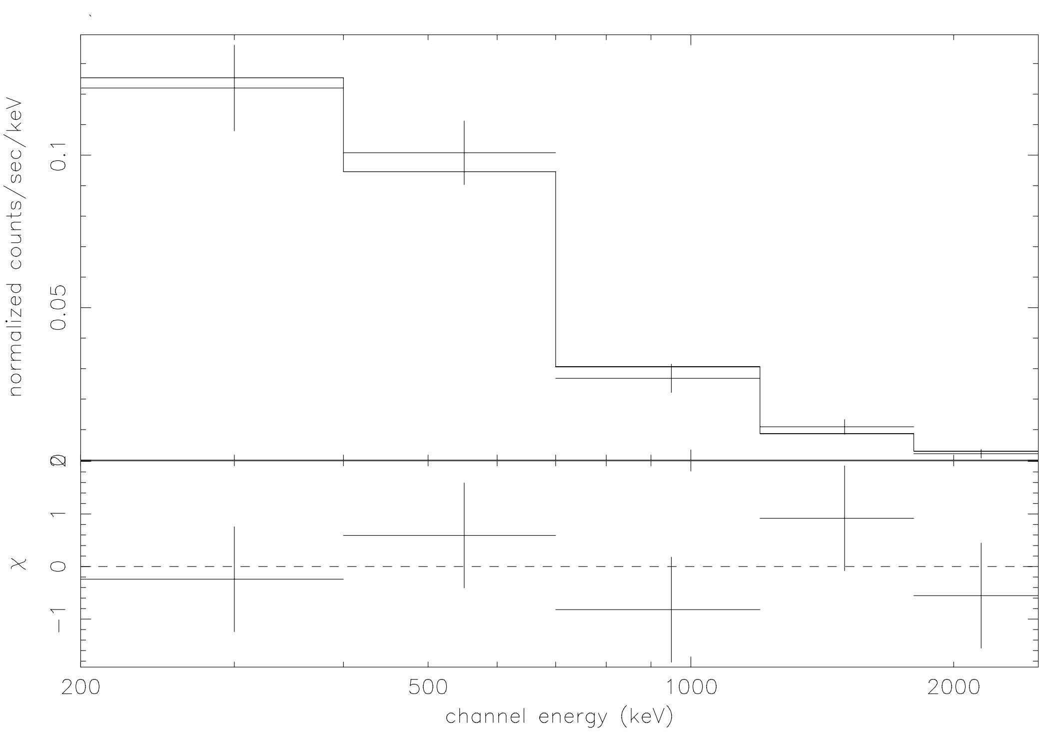


Figure 5: GRB030406 spectral fit. Top panel: Spectral fit to the Compton mode data of GRB030406. The data points and the best fitting power law spectrum $\sim E^{-1.48\pm0.16}$ are shown. The reduced $\chi^2$ is 0.74 for 3 degrees of freedom and the normalization is arbitrary. Bottom panel: residuals of the model fit.

## 4. SUMMARY

We have demonstrated that the Compton mode imaging is possible for some GRBs detected outside the field of view of the INTEGRAL telescopes. The principal advantages of the IBIS Compton mode are the wide field of view, which theoretically reaches $2\pi$ steradians, and the energy range from 200 keV up to almost 6 MeV.

The IBIS Compton mode is able to:

- detect GRBs in the raw count rate (almost in real time)
- localize GRBs with up to a few degrees error box
- provide photon spectra
- complement INTEGRAL GRB detection and localization capabilities

Finally, we note that the power law index of the photon spectrum is $\approx -1.5$. This means that the index of the $\nu F_\nu$ spectrum is positive, and the spectrum is extremely hard. This implies that the peak energy of the $\nu F_\nu$ spectrum lies above $\approx 2\,\mathrm{MeV}$ where our spectral sensitivity starts to decrease. Thus, GRB030406could belong to a class of extremely hard bursts.

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