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Polarization from GRB021206: No constraints from reanalysis of RHESSI data(*)

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Summary. — The determination of a polarization signal in Gamma Ray Bursts (GRBs) would give new information about their nature and mechanism. Using the RHESSI satellite as a Compton polarimeter, Coburn W. and Boggs S. E. (*Nature*, **423** (2003) 415) reported that GRB021206 was highly linearly polarized. This was contradicted by Rutledge R. E. and Fox D. B. (*Mon. Not. R. Astron. Soc.*, **350** (2004) 1288) who found about 10 times less scattering events suitable for measuring polarization. Applying our own method to the same data we confirm the much lower number of suitable scattering events. But we obtain three times smaller errors by using better selection criteria. Comparison with our Monte Carlo simulations shows that from the RHESSI data of GRB021206 we cannot distinguish between no and full polarization within less than 2 standard deviations. We also applied our method to other GRBs observed by RHESSI. This shows that the probability to observe a GRB suitable for polarization search with such an instrument is small.

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1. – Introduction

RHESSI is a NASA Small Explorer mission designed to study solar flares [1]. It consists mainly of two parts: an imaging system (not important in the following) and the spectrometer behind. The nine germanium detectors of the spectrometer have a cylindrical shape (diameter 7 cm, height 8 cm) and they are sensitive to photons from about 5 keV to 15 MeV. Since they are only weakly shielded, RHESSI is also a good Gamma Ray Burst (GRB) detector. The satellite always points towards the Sun, and

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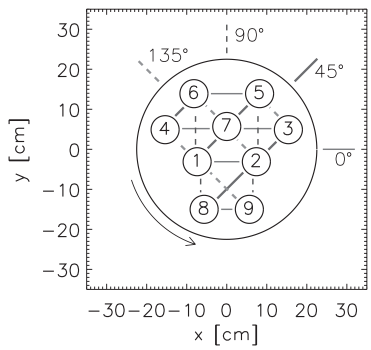

Fig. 1. – Arrangement of the 9 RHESSI Ge detectors. RHESSI rotates around an axis perpendicular to the detector plane with a period of $T_{rot} \approx 4\,\mathrm{s}$.

the Ge-detectors are arranged in a plane perpendicular to the pointing direction, see fig. 1.

For photon energies above about 150 keV, the most important interaction in germanium is Compton scattering. If the photons come in from a direction more or less perpendicular to the detector plane, RHESSI can work as a classic Compton scattering polarimeter that detects photons scattered from one detector into a neighbouring one. The azimuthal distribution of the Compton scattered photons depends on the initial photon polarization: they are preferentially scattered in the direction orthogonal to the polarization direction. The detector pairs are sensitive to different angles, and furthermore, RHESSI rotates around its axis once in 4 s. Thus, RHESSI can measure all possible scattering angles during one rotation.

A polarization analysis can be split into four steps: i) to search for coincidences, since a Compton scattering event makes two simultaneous entries in the RHESSI event list (one for each detector); ii) not all coincidences found are Compton scattering events, therefore to determine the number of Compton scattering candidates among the coincidences found; iii) to search for a polarization signal; iv) to simulate a fully polarized GRB and to compare the signal found with what is expected from simulations.

We did an independent reanalysis. After briefly presenting our method, we compare our result and the ones of refs. [2] and [3] and discuss them. The detailed description of our method and results are published in [4]. We finally present the polarization analysis of another famous GRB, namely GRB030329.

2. – Method

2˙1. *Coincidences.* – For each detector with a signal, its time t_i (in units of μs), its energy E_i and its detector number D_i are stored in an event list. Two entries in the event list are accepted as a coincidence, if they pass the following cuts:

d*t cut:* Since the time resolution of 1μs is much longer than the travelling time of a photon from one detector to another, one would expect the time difference $|t_i - t_j|$ to be 0μs or at most 1μs. A closer look at the data shows that real coincidences can have a time difference of $0, 1, 2$, or even 3μs. The reason is different readout electronics

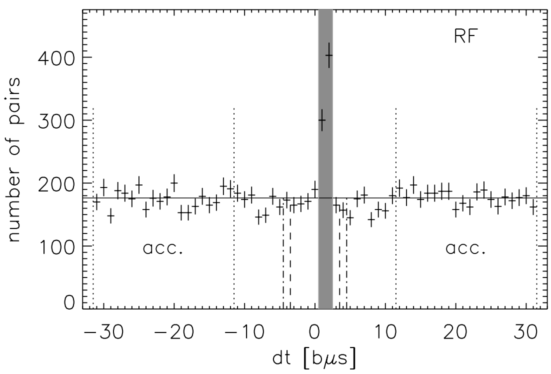

Fig. 2. – Histogram of time differences $dt = t_F - t_R$ of any pairs where a front and a rear segment are involved. The pairs had to fulfil the energy cut. Shaded area: accepted by our dt cut; broken lines: time window accepted in ref. [2], respectively [5]; dashed/dotted lines: time window accepted in ref. [3]. The data between the dotted lines were used to interpolate the number of accidental coincidences, see Subsect. **2**˙2.

involved ([1]). Depending on the detector segments involved in a coincidence, the allowed time window is 1 or maximal 2μs wide, see also fig. 2. For more details see [4].

Energy cut: We require $E_{1l} \leq E_i \leq E_{1h}$ for the single energy, and $E_{2l} \leq E_i + E_j \leq E_{2h}$ for the sum of the energies. Typical values are (for GRB021206): $E_{1l} = 25\,\text{keV}$, $E_{2l} = 150\,\text{keV}$, $E_{1h} = E_{2h} = 2000\,\text{keV}$.

Close-pairs cut: Since the mean free path of a typical Compton scattered photon is only 1 or 2 cm, the chance for a Compton scattering coincidence is much higher for neighbouring detector pairs (such as, *e.g.*, detectors 6 and 7, see fig. 1) than for more distant detector pairs (such as, *e.g.*, detectors 3 and 1). We accept only the 19 detector pairs marked in fig. 1.

Kinematical cut: Assuming that E_i is the energy of the recoil electron and E_j the energy of the Compton scattered photon, the (polar) scattering angle θ can be determined. We require: $45° \leq \theta \leq 135°$.

No-multiples cut: One finds multiple coincidences of more than two detectors. Since one does not know the scattering direction in such cases, we do not accept them.

2˙2. *Compton scattering candidates.* – After the definition of a coincidence, the light-curve of coincidences can be plotted ($N_{tot}(t)$). We call the acceptable coincidences before and after the GRB "background coincidences" (N_{BG}). If the single count rate is high enough—as was the case during GRB021206—it can happen that two independent photons hit two different detectors within the accepted time window. We call them "accidental coincidencs" (N_{acc}). The number N_C of "Compton scattering candidates" is then: $N_C = N_{tot} - N_{BG} - N_{acc}$ with $\sigma_{N_C} > \sqrt{N_{tot}}$ for its error. Since the accuracy of the polarization result is proportional to σ_{N_C}/N_C, it is important to start with a low number N_{tot}.

([1]) The detectors are electronically segmented into a thin front and a thick rear segment. The segments are read out separately. Detector 2 does not work properly and was read out as a single block at the time of the GRBs presented here.

TABLE I. – *Number of Coindences. Our numbers found are listed (ref.* [4]*), the numbers of refs.* [2] *and* [3]*, and our attempt to reproduce them.*

Ref.	N_{tot}	N_{acc}	N_{BG}	N_C
[4]	2141	1081	290	770 ± 49
[2]	14916	4488	588	9840 ± 96
our repr. of [2]	15810	13786	848	1176 ± 138
[3]	8230	6640	760	830 ± 150
our repr. of [3]	7788	6329	648	811 ± 93

2˙3. *Polarization analysis and comparison with simulations.* – The accepted detector pairs can naturally be grouped into 4 scattering directions, see fig. 1, two orthogonal to the other two. If the scattering rate was high for one direction, it would be low for the orthogonal direction. A quarter of a rotation later, the roles would be reversed.

Simulations of a fully polarized Gamma Ray Burst show that our method works. We define an asymmetry of the two orthogonal directions, and this asymmetry would be sinusoidal with an amplitude of about 0.2 = 20%. More about our simulations can be found in [4] or in the article by W. Hajdas [6] in these proceedings.

3. – GRB021206 and GRB030329

3˙1. *GRB021206.* – GRB021206 came in from the front at 18 degrees off-axis and is therefore well suited for Compton polarimetry. The numbers N_{tot}, N_{acc}, N_{BG} and N_C we found are given in table I, first line. Also the numbers of refs. [2] and [3] are given, together with our attempt to reproduce them. (Details of the cuts used can be found in [4].) It should be noted that N_{tot} depends *strongly* on the definition of a coincidence, thus an agreement within less than 10% is regarded as good. The number of Compton scattering candidates (N_C) should not depend so much on the definition. The polarization analysis yields an observed modulation amplitude of $\mu_p = (8.6 \pm 9.4)\,\%$. Simulation of such a GRB shows that a fully polarized GRB from this direction would have a modulation amplitude of $\mu_{100} = (21.0 \pm 2.7)\,\%$. Thus we conclude that within 2σ, the data of GRB021206 are compatible with *no* or *full* polarization.

3˙2. *GRB030329.* – Apart from GRB030519B that is presented in [4] we also analysed the famous GRB030329 which came in from the back at 36 degrees off-axis. From the raw energy spectrum shown in fig. 3 (right) we conclude that a reasonable energy-cut is $E_{1l} = 20\,\text{keV}$, $E_{2l} = 120\,\text{keV}$, and $E_{1h} = E_{2h} = 500\,\text{keV}$. We find: $N_{tot} = 1587$, $N_{BG} = 984$, $N_{acc} = 166$ and thus $N_C = 437 \pm 46$. Note that most of the coincidences are background coincidences. For the modulation amplitude we obtain $\mu_p = 14 \pm 13\,\%$. Since GRB030329 was less on-axis than GRB021206, we expect a smaller modulation amplitude μ_{100}. Thus we conclude that the data of GRB030329 are compatible with no or full polarization even within 1σ errors.

4. – Comparison of different results and discussion

While we can reproduce the high number of coincidences reported in ref. [2] by opening our cuts, we do not agree with the number of accidental coincidences. Details of the cuts

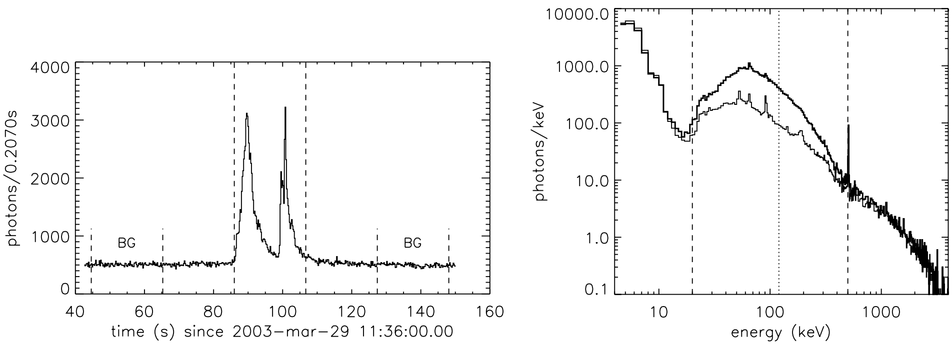

Fig. 3. – Left: Lightcurve of GRB030329 in the 20–500 keV band. The time intervals used for GRB and background analysis are marked. Right: Raw count spectrum of GRB030329. The upper thick line is the total number of photons per energy bin, whereas the lower thin line shows the number of background counts as before and after the GRB. The energies involved in the energy cut are marked by vertical lines.

used in ref. [2] became available only later, *e.g.* in ref. [5], and the identification of N_{acc} and N_{BG} is not explained. We think that the significant modulation found is due to accidental coincidences misinterpreted as Compton scattering candidates.

There is a simple estimate that N_{acc} of ref. [2] is too low. Two independent photons in the energy range 80–1500 keV are good candidates to pass the energy cut. One finds about $N_S \approx 100\,000$ single events in this energy range and in a time interval of $\Delta T \approx 4$ s. Assuming a constant lightcurve, the mean waiting time between the photons is $\tau = \Delta T/N_S = 40\mu$s. If one thinks of opening for each of these photons a $\delta t = 3.5\mu$s wide time window (the first photon could arrive at the beginning or at the end of the first μs), one will find in $p = \delta t/\tau \approx 9\,\%$ of them a second photon. That means, one expects 9000 accidental coincidences. Since coincidences within the same detector are not accepted, we have to multiply this number by 8/9, giving 8000 accidental coincidences. By formula: $N_{acc} = 8/9\, p\, N_S = 8/9\ (1/\tau)^2\ \Delta T\, \delta t = 8/9\ r^2\ \Delta T\, \delta t$ with r being the photon rate. This number is a lower limit, since the the lightcurves varies strongly with time which means $E(r^2) > (E(r))^2$ (where E stands for the expectation value). Our reproduction of ref. [2] agrees with this estimate, whereas the value by ref. [2] is much lower.

The authors of [3] explain their cuts, and we can reproduce their numbers. By using narrower cuts we obtain a 3 times smaller error for the number of Compton scattering candidates. The energy cut used in [3] ($E_{1l} = 150$ keV, $E_{1h} = 2000$ keV, and thus $E_{2l} = 300$ keV) is not optimal. As can be seen from fig. 4, they lose ≈ 250 coincidences, but not most as was suggested in [5].

GRB030329 was also analysed by the authors of [2] and presented in [5]. They found $N_{tot} \approx 6100$, and claim that the polarization degree is less than 80% at a 3σ level. Assuming $\mu_{100} = 20\,\%$ also for GRB030329 we would expect the 1σ-error of [5] to be $\sigma_{\mu_p} \approx 5.3\,\%$, much smaller than our value of $\sigma_{\mu_p} = 13\,\%$. On the other hand, since σ_{μ_p} is proportional to the relative error of N_C, and $\sigma_{N_C} > \sqrt{N_{tot}}$ we would expect that *our* error is at least a factor of 2 smaller. Again, we do not agree, even though this GRB was dominated by background coincidences and not by accidental coincidences (as GRB021206 was).

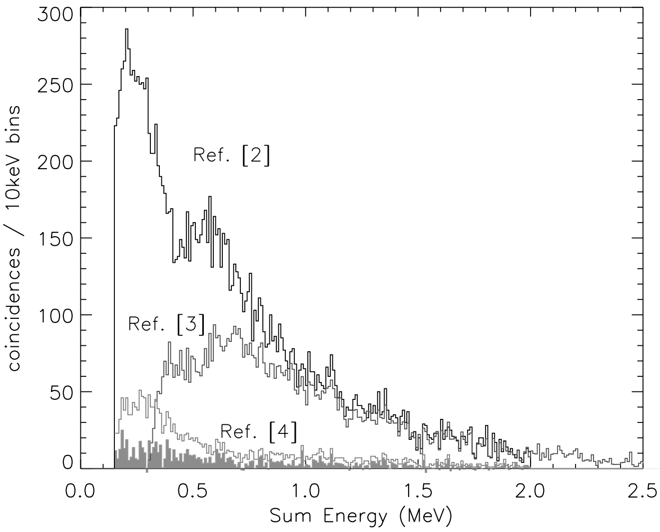

Fig. 4. – Histogram of sum energies $E_i + E_j$ of all coincidences (N_{tot}). The histograms were made using our result ([4]) and our reproductions of refs. [2] and [3]. Filled histogram: our number of Compton scattering candidates (N_C). The number of Compton scattering candidates does not so much depend on the cuts used, but would be slightly higher for refs. [2] and [3].

5. – Summary

We reanalysed the RHESSI data of GRB021206 and searched for a polarization signal. By carefully filtering events in energy, time, and scattering geometry we accept only $N_{tot} = 2141$ coincidences and find $N_C = 770 \pm 49$ Compton scattering candidates. The last number agrees with the one of ref. [3], but its error is considerably smaller. We cannot reproduce the number of accidental coincidences of ref. [2]. Our main improvements are: i) a much narrower dt-cut (see fig. 2) and ii) including only the neighbouring detector pairs (fig. 1). By this we can reduce the number of accidental coincidences substantially and obtain smaller errors. Our polarization analysis compares orthogonal scattering rates which minimizes systematic errors. But even our small errors do not allow us to significantly distinguish between no or full polarization. Also for GRB030329, no statements about the polarization can be made (in contradiction to [5]). The analysis of three strong GRBs shows that it is difficult to use RHESSI as a Compton polarimeter.

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