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Preliminary results from COMPTEL on a search for gamma-ray line emission from SN 1991T

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Abstract. — The COMPTEL experiment aboard the Compton Gamma-Ray Observatory (CGRO) is designed to image celestial gamma-radiation in the energy range from 0.7-30 MeV. With a field of view of 1 sr it is capable of locating strong point sources with an accuracy of better than 0.5^0. From June 15 to 28, 1991 and a second time from October 3 to 17, 1991 the region containing the supernova SN 1991T was observed by COMPTEL. Here preliminary results from these observations are presented, with special attention to a search for γ-ray line emission from the supernova.

Key words: gamma-rays — gamma-ray lines — nucleosynthesis — supernovae — SN 1991T.

1. Introduction.

On April 10, 1991 just after the launch of CGRO one of the brightest type Ia supernovae in recent years (Burrows *et al.* 1991) was observed on the periphery of the Virgo cluster in the Sb galaxy NGC 4527. Located at a distance of $\sim$ 13.5 Mpc (Tully 1988) this supernova was considered a potential target for CGRO. Since the γ-ray flux from such a supernova peaks between 20 and 100 days after the explosion (Burrows *et al.* 1991; Chan & Lingenfelter 1991; Höflich *et al.* 1992), the observation program of CGRO was rearranged so that the region of the Virgo cluster could be observed during this period.

The bulk of the expected emission from the induced radioactivity is in the low-energy γ-ray range covered by COMPTEL which measures γ-rays in the energy range from 0.7 - 30 MeV with a 1σ angular resolution around 1 MeV of $\sim 2.4^0$, and a $FWHM$ energy resolution around 1 MeV of $\sim$ 8.7 % having its maximum sensitivity around the same energy. Further details can be found in Schönfelder *et al.* (1991).

2. Observations.

COMPTEL began its sky survey on May 16, 1991. On June 15, 1991 the first observation of SN 1991T started which lasted until June 28, 1991. Four months later, from October 3 to 17, 1991 the observation was repeated. During both observations SN 1991T was close to the pointing axis of COMPTEL, the angular distance to the axis being 3^0 for the first and 1.8^0 for the second observation.

Unfortunately the quasar 3C 273, the strongest low-energy γ-ray source within the field of view of these observations, is located at an angular distance of only 1.4^0. Therefore it is difficult to separate the two sources and to derive a sensitive upper limit on the line emission from the supernova.

3. Analysis method.

For both observations raw energy spectra of photons detected within 2.5^0 of the position of the supernova ($l = 292.61^0$; $b = 65.19^0$) were produced with an exposure of about 5×10^6 cm^2 s. They are shown in figures 1a and 2a. Also shown (Figs. 1b and 2b) are background spectra which were produced from the same observations. For the first observation a background spectrum was obtained in the same way as the source spectrum selecting events from a mirror-source position (this position is defined by mirroring the source position relative to the telescope axis). In the second observation this procedure could not be applied, because the supernova was too close to the telescope axis. Therefore a point on the sky with the same exposure as for the supernova was selected. Again all photons coming from within a 2.5^0 circle around this position were collected as background events. It should be noted, however, that due to the principle of measurement (Diehl *et al.* 1991) the source and background datasets are not independent.

4. Results.

Apart from the well known instrumental background lines at 1.5 MeV and 2.2 MeV, Figures 1 and 2 show no obvious evidence for line features. In particular, the two strongest lines expected from the supernova (at 0.847 and 1.238 MeV) are not seen. The source and background spectra look very similar.

The background subtracted spectra for the two observations are shown in Figure 3a and b. The counts scatter in a random way around zero (the statistical error is ~ 33). The dashed lines indicate how a 3σ signal would appear in the data. No obvious lines are present.

Upper limits were derived from the spectra in figures 1 and 2 by determining the number of counts in a $\pm 2\sigma$ energy band around each line energy in the source and background spectra. From these numbers 2σ upper limits for the two line energies and for the two observations were calculated multiplying the square root of their sum by two and dividing the result by the exposure. The result is given in Table 1.

TABLE 1. 2σ *upper flux limits in units of* $\gamma/(cm^2\ s)$.

Energy	Observation	2σ flux limit
0.847 MeV	3	$4.4 \cdot 10^{-5}$
0.847 MeV	11	$3.9 \cdot 10^{-5}$
1.238 MeV	3	$4.1 \cdot 10^{-5}$
1.238 MeV	11	$3.4 \cdot 10^{-5}$

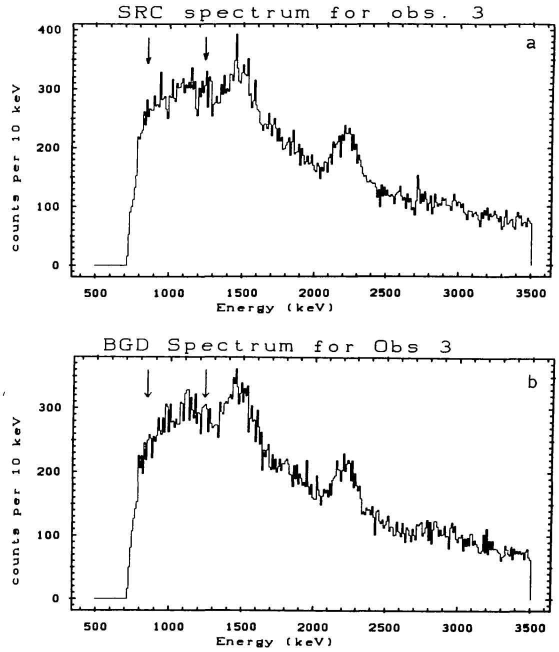

FIGURE 1. Source (top) and background (bottom) for the first observation observation period. The arrows indicate the lines.

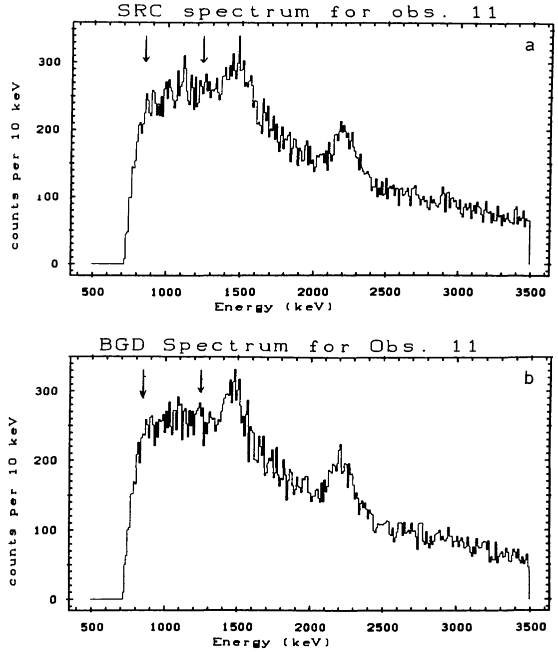

FIGURE 2. Source (top) and background (bottom) spectra for the second observation period. The arrows indicate the lines.

5. Discussion.

In Table 2 the upper limits obtained from the first observation are compared with the prediction of three theoretical models (Burrows *et al.* 1991). Model FDEFA1 of Woosley and Weaver (1991) is a delayed detonation model in which about 0.93 $M_\odot$ of ^{56}Ni is created. In the model W7 of Nomoto *et al.* (1984) a 1.378 $M_\odot$ C/O white dwarf explodes via a subsonic deflagration wave producing 0.58 $M_\odot$ of ^{56}Ni. The model cdtg7 of Woosley & Weaver (1986) is also a deflagration model which is qualitatively similar to the previous model. In this model a 1.423 $M_\odot$ C/O white dwarf generates 0.51 $M_\odot$ of ^{56}Ni.

Since the predictions of Burrows *et al.* (1991) do not extend beyond day 150 the upper limits of the second observation cannot be compared with all models of

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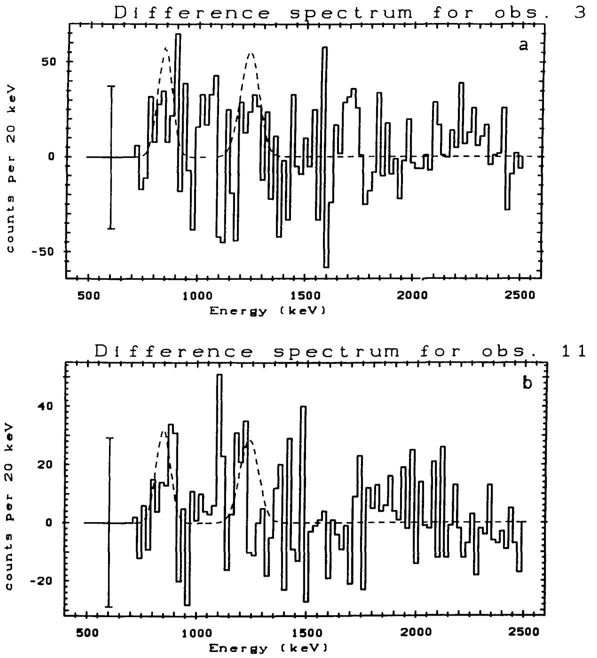

FIGURE 3. Difference spectra for the first (top) and second (bottom) observation periods. Typical error bars are shown.

Table 2. These upper limits can be compared, however, with calculations performed by Chan & Lingenfelter (1991) who extended their calculations till day 1000 (see Tab. 3). They performed calculations for the deflagration model cdtg7 of Woosley and Weaver (1986) and for two helium detonation models of Woosley, Taam & Weaver (1986). In the last two models helium is accreting from a binary companion onto a C/O or He white dwarf. About 1 $M_\odot$ of ^{56}Ni is produced in the C/O detonation, whereas in the He detonation the yield of ^{56}Ni is only 0.45 $M_\odot$.

TABLE 2. *Comparison of the upper limits in units of $\gamma/(cm^2\ s)$ from the first observation with different models according to Burrows* et al. *(1991). A distance to the supernova of 13.5Mpc was assumed.*

E (MeV)	2σ flux limit	FDEFA1	W7	cdtg7
0.847	$4.4 \cdot 10^{-5}$	$2.9 \cdot 10^{-5}$	$1.8 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$
1.238	$4.1 \cdot 10^{-5}$	$2.2 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$

An inspection of Tables 2 and 3 reveals that all predictions are well below the upper limits. For Table 3 this is not surprising because ^{56}Co decays with a half life of 78.8 days. For the C/O detonation model Chan & Lingenfelter (1991) predict for the 0.847 and the 1.238 MeV lines maximum fluxes of 4.8 x 10^{-5} cm^{-2} s^{-1} and 3.5 x 10^{-5} cm^{-2} s^{-1}, respectively. Since the maximum of their γ-ray light curve occurred during the time of the first observation these fluxes can be compared with the fluxes of Table 1. Upper limits and predictions are approximately equal.

TABLE 3. *Comparison of the upper limits in units of $\gamma/(cm^2\ s)$ from the second observation with different models according to Chan & Lingenfelter (1991). A distance to the supernova of 13.5 Mpc was assumed.*

E (MeV)	2σ flux limit	C/O det.	He det.	cdtg7
0.847	$3.9 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$	$7.7 \cdot 10^{-6}$	$9.3 \cdot 10^{-6}$
1.238	$3.4 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$6.1 \cdot 10^{-6}$	$6.5 \cdot 10^{-6}$

TABLE 4. *Same as Table 2 but for models of Höflich* et al. *(1992). A distance to the supernova of 13.5 Mpc was assumed.*

E (MeV)	2σ flux limit	N21	N32	DF1MIX
0.847	$4.4 \cdot 10^{-5}$	$3.6 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$	$2.2 \cdot 10^{-5}$
1.238	$4.1 \cdot 10^{-5}$	$2.6 \cdot 10^{-5}$	$1.6 \cdot 10^{-5}$	$1.5 \cdot 10^{-5}$

TABLE 5. *Same as Table 3 but for models of Höflich* et al. *(1992). A distance to the supernova of 13.5 Mpc was assumed.*

E (MeV)	2σ flux limit	N21	N32	DF1MIX
0.847	$3.9 \cdot 10^{-5}$	$2.2 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$
1.238	$3.4 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$7.0 \cdot 10^{-6}$	$7.4 \cdot 10^{-6}$

Höflich *et al.* (1992) calculated for a variety of type Ia supernova models the emerging γ-ray spectra as a function of time. Only the models with the highest flux predictions, i. e. the two delayed detonation models N21 and N32 of Khoklov (1991a, b) and the deflagration model DF1MIX with uniform mixing are compared with our observations. The fluxes corrected for a distance of 13.5 Mpc are summarized in Table 4 for the first and in Table 5 for the second observation.

6. Conclusions.

At the nominal distance to NGC 4527 the upper limits which are presented here are not good enough to reject any of the models. However, given the large uncertainty on the distance to NGC 4527 (±30%; see Tully & Shaya, 1984), it may be that SN 1991T is as close as 10 Mpc. In this case, our upper limits would begin to provide constraints on the present models.

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