ABSTRACT

The type Ia supernova SN1998bu in M96 was observed by COMPTEL for a total of 88 days starting 17 days after the first detection of the supernova. The accumulated effective observation time was 4.14 Msec. The COMPTEL observations were performed in a special instrument mode improving the low-energy sensitivity. We generated images in the 847 keV and 1238 keV lines of $^{56}$Co, using improved point spread functions for the low-energy mode. We do not detect SN1998bu. A spectral analysis of our data also confirms the non-detection of the supernova. We discuss the event for which our upper limits constrain the standard supernova models.

Key words: gamma-rays; SN1a.

1. THE OBSERVATIONS

On May 9.9 UT 1998 (TJD 10942.9) M. Villi (1998) observed a supernova in M96 (NGC 3368), which was labelled SN1998bu. From spectrograms it was classified as type Ia supernova (Ayani & Meikle 1998). Based on pre-explosion observations and an estimate of the maximum blue light at $t_{\text{exp, max}} = 10952.7 \pm 0.5$ TJD Meikle & Hernandez (1998) determined the explosion date to be May 2 ± 1 UT 1998 (i.e. TJD 10935 ± 1). Hjorth & Tanvir (1997) determined the distance to M96 by Cepheid measurements to 11.3 ± 0.9 Mpc. Observations of supernovae in the optical and neighbouring wavelength bands concentrate on information on the light curves from such events. The time evolution of these light curves could be understood as being powered by reprocessed $\gamma$-ray line emission from freshly synthesised short-lived radio-isotopes (e.g. decay chain of $^{56}$Ni). However, due to the creation of the low energy photons by secondary processes long after the explosion itself most of the information on the initial state right after the explosion is lost. Therefore the distinction of different supernova models via their predicted light curves alone is uncertain. In contrast $\gamma$-ray lines carry information from the very early phase of the supernova and may allow a discrimination of the theoretical models (Höflich et al., 1998). Depending on the particular type Ia supernova model and the sensitivity of current days $\gamma$-ray instruments (OSSE & COMPTEL) the observations of $\gamma$-ray lines are limited to a maximum distance of $\sim 15$ Mpc. Up to now only one type Ia supernova (SN1991T) was marginally detected (Morris et al., 1997). According to the distance estimate SN1998bu opened a second chance to observe low energy $\gamma$-ray lines from a type Ia supernova. The COMPTEL observations in direction of M96 started 17 days after the explosion (TJD 10952) and covered the time until TJD 11071 (i.e. 136 days after the SN). Due to some breaks we had in total 88 days of supernova observations, which sums to an effective observation time of $\sim 4.14 \times 10^6$ s. To increase COMPTEls low energy sensitivity the telescope was switched into a dedicated low-energy mode, decreasing the module thresholds of the D2 detectors well below 600 keV. (For a detailed description of the COMPTEL instrument see Schönfelder et al. (1993)). Due to the late start of the observation program COMPTEL missed the decay of $^{56}$Ni ($\gamma_{1/2} = 8.8$ d). So the observations were focused on the detection of 847 and 1238 keV lines from the secondary isotope $^{56}$Co (Gomez-Gomar et al., 1998).

2. IMAGING ANALYSIS

The observations have been performed in a special 'low energy' mode, in which the D2 module thresholds were lowered to the minimum. By using appropriate point spread functions taking care of the real hardware thresholds we gain in low energy sensitivity. Due to the strong contamination of the D2 data due to the 511 keV background line in some D2 modules a higher low energy cutoff (560 to 600 keV) was applied for these modules. However, in imaging...
analysis another possibility is given by an adequate Compton scatter angle selection. Figure 1 shows the different possibilities of 511 keV background suppression by cutting the data-space in a $E_1$-$E_2$-representation (For a description of the measurement principle and its realisation see Schönfelder et al. (1993)). The band of contour lines represents the distribution of observed events with a total energy deposit (sum of $E_1$ and $E_2$) of $847 \pm 75.3$ keV.

Figure 1. Cuts in the energy data-space in the case of the 847 keV line.

The 511 keV contamination could be clearly seen as an area of increased density below the horizontal 600 keV line. This background could be suppressed either by an energy selection in $E_2$ or an cut in the scatter angle distribution $\bar{\phi}$. To really make use of the low mode data new point spread functions (PSF) have to be generated. The COMPTEL team today uses two approaches to generate point spread functions, one based on a Monte Carlo simulation of the detector response (SIMPSFs) and the other based on model assumptions using measured data (MODPSFs). In standard case with sufficient statistics both methods give rather identical point spread functions. However, we used of both methods to generate low mode PSFs.

We tested the adequacy of our response treatment on Crab observations taken in the same instrument mode. In the energy window of the low energy line we clearly detect Crab with both PSFs. However, due to a more accurate treatment of the detector settings in the response simulation, the image obtained with the SIMPSF is smoother than for the MODPSF. The point-source significance rises from $3.02\sigma$ using a standard PSF to $5.1\sigma$ by applying the new SIMPSF (for the MODPSF the value is $4.9\sigma$). Also in the case of the high energy line the new PSFs increase the significance, with a smaller increase because of the $E^{-2}$ spectrum of Crab and the smaller effect of lower detector thresholds in the higher energy regime, the significance rises from $0.63\sigma$ to $1.6\sigma$.

We applied both sets of point spread functions to the accumulated SN1998bu data using a maximum likelihood reconstruction. Figure 2 shows the images obtained with the SIMPSFs. These images as well as the images obtained by applying the MODPSFs show no hint of a supernova detection. Also an additional attempt using a combined point spread function for the search of both lines simultaneously fails in detecting SN1998bu. We deduce $2\sigma$ upper limits: From the flux distribution of all independent pixels

Figure 2. Maximum-Likelihood images (left: 847 keV/right: 1238 keV) of SN1998bu source region in a local coordinate system centered on the direction towards SN1998bu. The SN position is marked with a star. The contour levels give the flux in units of $10^{-8}$ ph cm$^{-2}$ s$^{-1}$. 2900 in the left map correspond to $1\sigma$, whereas 1600 do so in the right.
of these maps their variance is determined, assuming a Gaussian distribution. Using a Bayesian method (Georgii et al., 1997), which accounts for systematic as well as statistical uncertainties, 2σ upper limits of $3.7 \cdot 10^{-5}$ ph cm$^{-2}$ s$^{-1}$ for the 847 keV line and $1.9 \cdot 10^{-5}$ ph cm$^{-2}$ s$^{-1}$ for the 1238 keV line are found.

3. SPECTRAL ANALYSIS

In addition to the imaging analysis we also performed a spectral analysis of the obtained data from the area around SN1998bu. In contrast to the imaging analysis it is possible in the spectral domain to apply a ϕ-selection to suppress the 511 keV contamination. To achieve an adequate suppression we applied an energy threshold to the D2 data at 600 keV. We then performed a spectral scan on a 3° wide grid around the position of SN1998bu. In each spectral analysis of this scan we used data from a 3° cone as source spectrum and data from a 3° - 7° cone mantle as background spectrum. After fitting the background spectrum to the source spectrum the residual spectrum should contain any excess source signal. Subsequently, we fitted template Gaussians, with a width corresponding to the instrumental energy resolution, to the residual spectrum to obtain the line intensities of the expected gamma-ray lines. Using this method no significant signals could be detected. Moreover, no significant differences between the position, position of SN1998bu, and the off-source positions in scanning grid could be detected.

We derived 2σ upper limits by the means of the following procedure: We generated histograms of the fitted intensities from all positions for both lines. The width of the distributions was then interpreted as a measure of the statistical and the systematical uncertainties of the method. In that way we derived upper limits of $4.1 \cdot 10^{-5}$ ph cm$^{-2}$ s$^{-1}$ for the 847 keV line and $2.3 \cdot 10^{-5}$ ph cm$^{-2}$ s$^{-1}$ for the 1238 keV line. The spectroscopically deduced upper limits are somewhat higher because of the lower sensitivity due to the hard D2 energy cut. The ϕ-cut in imaging analysis increases the sensitivity a little because of the $1/(E_1 + E_2)$-dependence of the ϕ-distribution. In addition the background treatment in the imaging analysis is more reliable than in the spectral domain.

4. INTERPRETATION AND CONCLUSION

For a comparison of our upper limits with recent predictions of theoretical type Ia supernova models (Gomez-Gomar et al., 1998, Kumagai, 1998) the distance estimate to the SN is essential. Manoz et al. (1998) estimated the distance to the host galaxy M96 by means of an HST Cepheid observation to $11.6 \pm 0.9$ Mpc, which was revised by North & Tanvir (1997) to $11.3 \pm 0.9$ Mpc. However, a distance determination based on Planetary Nebulae observation suggests a much closer distance of $9.6 \pm 0.6$ Mpc (Feldmeier et al., 1997). This closer distance estimate of M96 supports the deduced distance of Manoz et al. (1998) based on a revised Cepheid distance calibration.

![Figure 3. Predicted 847 and 1238 keV light curves from various explosion models.](image)

We use the greater distance estimate of 11.3 Mpc for the comparison. Figure 3 shows the predicted light curves from different type Ia supernova and radiation transfer models. As pointed out by Gomez-Gomar et al. (1998) the different treatments of the radiation transfer problem through the expanding explosion shells is a major uncertainty in comparing the explosion models. Nevertheless we exclude all but the Sub-Chandralekhar and deflagration models. In the case of a closer distance our results become even more constraining.

In summary our measurement favours the deflagration or Sub-Chandralekhar models for SN1998bu and renders the HeCD model as rather improbable. For detonation models a smaller mixing than applied in tested models is needed to be compatible with our analysis.

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