OSSE Observations of Starburst Galaxy M82

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ABSTRACT

OSSE observed the starburst galaxy M82 in two viewing periods of 8 and 14 days. M82's priority as a target had been established on the grounds that the average supernova rate may be very high there, so that a significant chance of ^{56}Co detection exists. If M82 is at 3.4 Mpc distance, normal Type II (e.g. SN1987A) are too dim in ^{56}Co lines, but the Wolf-Rayet derived Type Ib, which are also massive-star core implosion objects, might be detectable to OSSE.[1,2] Expected fluxes of the 847 keV γ-line of ^{56}Co would be near $(2\text{-}5)\times 10^{-5}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. A Type Ia in M82 would be very bright,[3] near $(3\text{-}6)\times 10^{-4}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. We present OSSE background subtracted spectra of the M82 region for viewing periods 7 and 18. These spectra show no significant excess at 847 keV or at 1238 keV, the two strongest ^{56}Co γ-lines. When we fit a smooth gamma continuum plus a feature having both the 847 keV and 1238 keV lines to the OSSE data, we obtain for the 847 keV line amplitude the values $(-4.18 \pm 3.45) \times 10^{-5}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ for viewing period 7 and $(0.84 \pm 2.85) \times 10^{-5}\ \gamma\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ for viewing period 18. We discuss the implications on the supernova rate in M82.

INTRODUCTION

Evidence of a very high star formation rate in the starburst galaxy M82 is quite extensive. Its supernova rate[4,5] may be $\sim 0.1\ \mathrm{yr}^{-1}$, as suggested by Kronberg and Wilkinson.[6] Rieke et al.[4] analyzed IRAS infrared data to conclude that very high rates of star formation are occurring in M82. Moreover, this high rate of formation of O and B stars is also required to account for the radio luminosity of M82.[7] Detailed analysis of radio data has been interpreted as requiring the burst of star formation in M82 to produce only massive stars.[8] This implication has been revived recently by evolutionary models of starburst activity in M82.[9] The initial mass function of M82 requires stars to have mass $\geq 3\ M_\odot$ in order that the models can simultaneously match the observed M82 supernova rate and the dynamical mass.[4] Stars more massive than $\sim 9\ M_\odot$ are believed to be the progenitors of Type II or Type Ib supernovae. Therefore these observations suggest that M82 probably has a high rate of core-collapse supernovae.

Clayton, Colgate, and Fishman[10] described an observation that could confirm such speculations. Radioactive ^{56}Ni is produced in the supernova event, and gamma radiation by its daughter nucleus ^{56}Co can be sought. This prediction has now been confirmed by the detection of ^{56}Co γ-lines from supernova 1987A (e.g., Leising and Share[11] and references therein). Gamma-ray observations have become a promising diagnostic tool of supernova structure. Gamma-ray line supernova are not obscured by dust, which is the condition in the inner nucleus of M82. The γ-line and x-ray fluxes of massive star supernovae have been calculated by many investigators.[12–17] Ensman and Woosley[18] have constructed detailed evolutionary models of Wolf-Rayet supernova explosion and find that only 4-6 $M_\odot$ models produce acceptable fits to light curves of Type Ib supernovae. The γ-line fluxes from these models peak between 3.1×10^{-5} to 4.4×10^{-4} γ cm^{-2} sec^{-1} at distance of 1 Mpc.[1] Nomoto, Kumagai, and Shigeyama[2] in their calculations of helium star explosions[19] find maximum line fluxes to be 3.9×10^{-5} to 8.8×10^{-4} γ cm^{-2} sec^{-1} at distance of 1 Mpc. This indicates that OSSE has a potential range out to 4 Mpc for detecting Type Ib supernova. For Type Ia supernova the OSSE range is $\sim$ 10 Mpc.

OBSERVATIONS

The Oriented Scintillation Spectrometer Experiment (OSSE), which is sensitive to gamma rays in the range of 0.05 to 10 MeV is designed to study nucleosynthesis by detecting γ-ray lines from radioactive elements. The characteristics and performance of the OSSE instrument have been described by Johnson et al.[20] OSSE observed the starburst galaxy M82 (NGC 3034) during its viewing periods 7 (8-15 August 1991) and 18 (10-23 January 1992). M82 is located at $\alpha = 9^h 56^m$ and $\delta = +69^o 41'$. The pointing strategy follows the simple OSSE pointing strategy shown in Figure 3 of Purcell et al.[21] with accumulation time for every pointing being $\sim$ 130 seconds. The total live time of four detectors for period 7 is 7.834×10^5 seconds and for period 18 is 1.651×10^6 seconds.

DATA ANALYSIS

The OSSE spectral analysis technique subtracts the background offset pointing of the detectors from the source spectrum.[21] The data analysis process presented here is similar to the one that has been reported in OSSE detection of ^{57}Co in SN1987A.[22] For each day of observation, initial data selection is performed to exclude poor data due to telemetry, environment, or positioning errors. The quadratically fitted background estimates are subtracted from the source spectrum to obtain a difference spectrum for each 2-minute integration. The sum of all spectra from four detectors over an entire observing period is obtained. See Figure 1 for period 7 (1 week) and period 18 (2 weeks) data from M82. We fit the spectrum of Figure 1 to power law, linear, or exponential continuum photon spectra plus a γ-line at energy 847 keV or 1238 keV. These photon spectra are folded through the OSSE instrument response and the resulting count spectra are least-squares fitted to the observed count spectra. Linear continuum photon spectra give the best fit for both observing periods for the count spectra. The results of a linear continuum plus a γ-line fitting are presented in Table 1 along with χ^2_ν, the χ^2 per degree of freedom (d.o.f.), for the best-fit γ-line fluxes at 0.847 and 1.238 MeV.

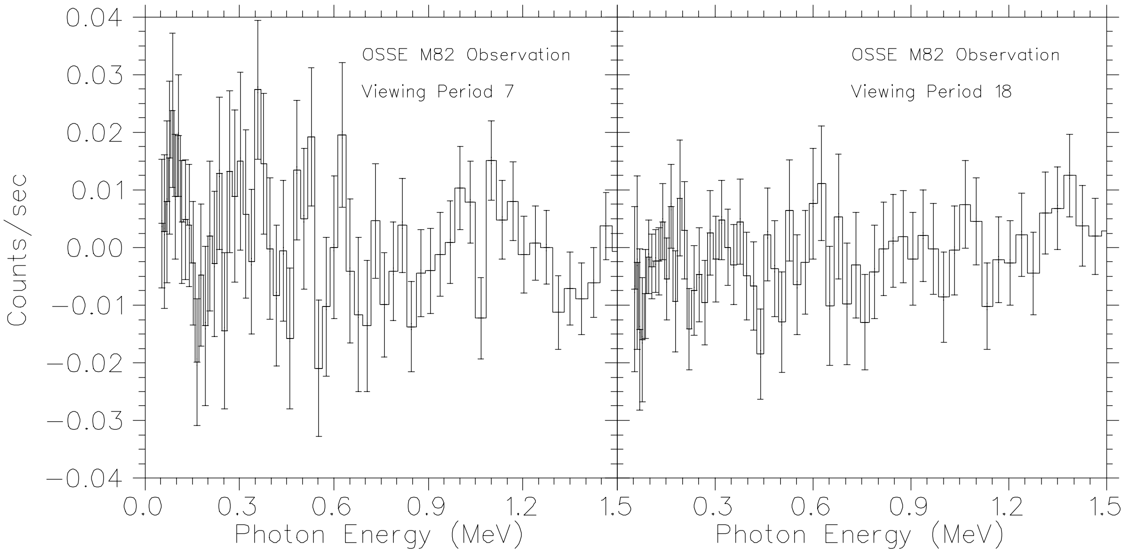

Figure 1: *Average count spectra of OSSE M82 observations for viewing periods 7 and 18. The spectrum is the average counts from four OSSE detectors of 8-day (VP 7) and 14-day (VP 18) observations.*

TABLE 1

RESULTS OF TWO M82 OBSERVATIONS BY OSSE

Period No.	847 keV γ-line Flux[a]		1238 keV γ-line Flux[a]		847 keV Combined Fit Flux[b] $r_{1238/847}=0.68$		$r_{1238/847}=1.0$	
	χ^2_ν	d.o.f.	χ^2_ν	d.o.f.	χ^2_ν	d.o.f.	χ^2_ν	d.o.f.
7	-6.11 ± 3.77		+0.53 ± 4.32		-4.18 ± 3.45		-2.99 ± 3.03	
	0.86	23	1.00	19	1.01	39	1.02	39
18	+2.22 ± 3.43		-1.28 ± 3.61		+0.84 ± 2.85		+0.51 ± 2.53	
	0.68	23	0.56	19	0.63	39	0.63	39

[a] *When fitting the 847 (1238) keV γ-ray line, the linear continuum is fit from 0.6-1.2 (0.9-1.5) MeV; flux is in units of 10^{-5} γ cm^{-2} sec^{-1}.*
[b] *The 847 keV γ-line flux is obtained by fitting the 847 and 1238 keV γ-lines simultaneously with their ratio fixed to $r_{1238/847}$ together with a linear continuum from 0.5-1.5 MeV; flux is in units of 10^{-5} γ cm^{-2} sec^{-1}.*

Table 1 also shows the best fit of a linear continuum spectrum plus both γ-ray lines simultaneously for two values of the line flux ratio $r_{1238/847} = f_{1238}/f_{847}$. One flux ratio is chosen to be 0.68, the relative emission rate in ^{56}Co. We also fit the count spectra with the ratio fixed to 1.0, the approximate ratio of line fluxes at early times in the supernova. The results in Table 1 offer no evidence of the line features searched for. In Fig. 2 we use the 3σ confidence limits for this simultaneous fit to test the probability of supernova recurrence rates. We also examined the eye-catching bump between 0.9-1.2 MeV of the count spectra of VP 7. The bump appears to be a statistical fluctuation. Surprisingly, it is dominated by the first day's counts, a curiosity for which we have no explanation.

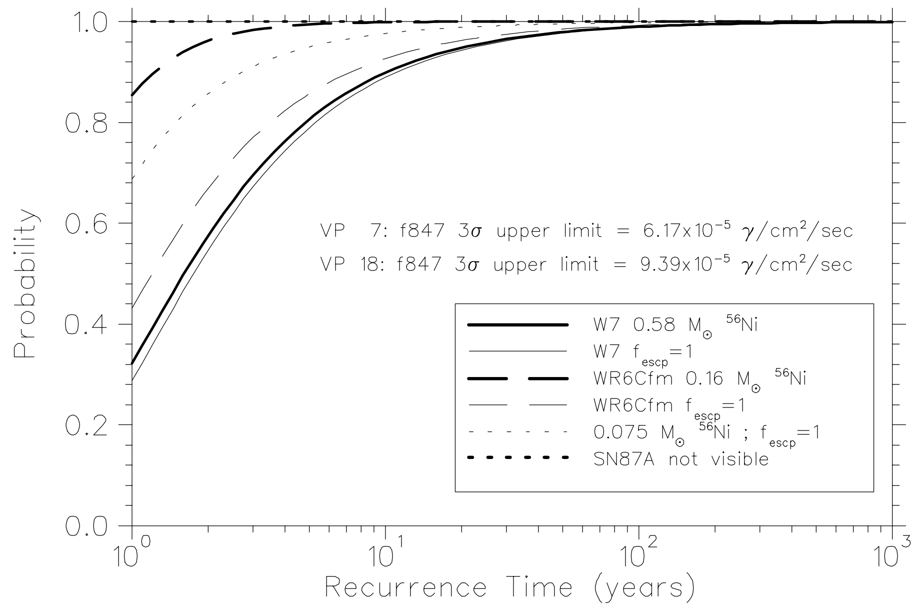

Figure 2. *Probability for the 847 keV γ-line fluxes from stochastically occurring Type Ia, Type Ib, and Type II supernovae to be less than both 3σ upper limits for the two M82 observations, which are separated by about 158 days.*

DISCUSSION

Monte Carlo simulations of randomly occurring supernova events in M82 were performed to evaluate the significance of our upper limit to the 0.847 and 1.238 MeV ^{56}Co γ-ray line fluxes on the supernova rate in M82. For this purpose we take the 3σ upper limit to mean the best-fit value plus three standard deviations from that value, even though this confidence limit may differ slightly from the expected 3σ sensitivity of OSSE to lines. The 3σ upper limit to the 0.847 MeV γ-line flux from both viewing periods (separated by 158 days) was compared with the line flux generated by the Monte Carlo histories. The fraction of galaxies in the simulations that would be fainter than both 3σ OSSE limits at 847 keV is shown in figure 2. It therefore represents the probability that that particular astrophysical simulation would not have been detected. Different types of supernova models are used in the simulation but are considered independently of each other. Model W7 is a Type Ia supernova deflagration model of carbon-oxygen white dwarf thermonuclear explosion.[23] WR6C is a Type Ib supernova model of Wolf-Rayet progenitor.[18] For Type II supernova we take the SN87A model that produces 0.075 M$_\odot$ ^{56}Ni.

Our simulations show that our observed upper limit to the γ-line fluxes does not give a strong constraint on the massive-star supernova rate of M82. For Type Ia SNe, even if the upper limit flux were as small as 1×10^{-6} γ cm^{-2} sec^{-1}, there would still be a 10% chance for the model flux to be less than that upper limit for a supernova recurrence time of 1 year. Therefore we conclude that γ-line flux upper limits from M82 cannot provide a strong constraint to the supernova rate of that galaxy unless the γ-ray detector is sensitive to fluxes of $\sim 1\times 10^{-6}$ γ cm^{-2} sec^{-1} or better, or the recurrence time is much shorter than 1 year, hence much more frequent observations are needed. However, the search for γ-line supernova should continue, particularly in high-rate star formation dust-obscured galaxies such as M82 and NGC 253,[24] because a positive detection remains possible at that distance. Also, repeating the observations will somewhat improve the constraint on the recurrence rate of supernova.

L.-S.T. would like to thank D. Bhattacharya and D. Hartmann for very useful discussions. This research was supported by NASA DPR S-10987C.

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