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LIMIT ON X-RAY EMISSION FROM A SUPERNOVA DURING MAXIMUM LIGHT*

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ABSTRACT

The MIT 1–60 keV X-ray detector on the OSO-7 satellite observed the supernova SN 1971s in NGC 493 during the period of its optical rise and maximum. The data were examined for steady and pulsed X-ray emission. Analysis of the light curve shows that the supernova was most likely of Type II. The upper limit (3 σ) to the continuous X-ray luminosity during the week of the optical rise and maximum is $\sim 5 \times 10^{43}$ ergs s^{-1} (1–5 keV), a factor of 40 less than previous upper limits for this portion of the light curve. The upper limit to the energy of an X-ray pulse of duration between 2 seconds and 3 minutes is $\sim 5 \times 10^{48}$ ergs (1–9 keV). The data examined for such a pulse covered 31 percent of the total observation time.

Subject headings: supernova — X-ray sources

I. INTRODUCTION

A high X-ray luminosity of supernovae in their early stages has been postulated by Tucker (1970) to explain the continuous X-ray background. On the other hand, steady X-ray emission from supernovae of sufficient intensity to be detected at megaparsec distances is not predicted by current detailed theories, although the emission of an X-ray and γ-ray pulse from a supernova collapse has been suggested (Colgate 1968). Recently, X-ray/γ-ray pulses from unidentified celestial sources have been observed by satellite-borne detectors (Klebesadel, Strong, and Olson 1973; Wheaton *et al.* 1973). In the light of these developments it is important that X-ray and γ-ray observations coincident with the birth of known supernovae be examined for evidence of steady and pulsed emission. Only two such X-ray observations have been reported previously (Ulmer *et al.* 1972). The present results reduce the earlier upper limits for steady emission by a factor of 40 and provide the first published search for an X-ray pulse from a supernova outburst.

On 1971 November 15.9, a supernova of magnitude $m_{pg} = 15.6$ was detected by one of the authors (L. P.) in the galaxy NGC 493 at a position 48″ east and 38″ north of its nucleus. Previous to that, on 1971 November 8.9, the same galaxy had been photographed by Kohoutek (1972) and there was no trace of the supernova to a limiting magnitude of $m_{pg} = 17.5$. During the period from November 9.5 to November 16.2, NGC 493 was in view of one of the two MIT X-ray detectors on the OSO-7 satellite. Thus, the X-ray data cover the period of the initial rise and peak optical intensity.

II. OPTICAL OBSERVATIONS

NGC 493 is an edgewise spiral showing a spotty structure and some knots, and is probably of an Sc type. According to Zwicky's catalog (Zwicky *et al.* 1965), its integrated photographic magnitude is 13.0. No redshift or distance to this galaxy is known. The supernova lies close to the equatorial plane of NGC 493, according to a photograph taken shortly after the time of maximum emission.

After 1971 November 15.9, when the supernova was first detected, photographic observations were continued at Asiago for two months. Figure 1 depicts the light curve as derived from these observations. It shows a steady decrease in B magnitude from 15.6 on 1971 November 15 to 16.8 on 1972 January 11, with an average gradient of 0.02 mag per day. This could suggest either a supernova of Type I about one month after maximum, or a supernova of Type II during its first decline. Since Kohoutek (1972) reports that the supernova must have been fainter than $m_{pg} = 17.5$ on November 9, it is apparent that the supernova was not at maximum before this date. Therefore, it was most likely a Type II supernova which was within a few days and 0.2 mag of maximum luminosity when first sighted. This conclusion gains support from other data obtained at Asiago: a negative $U - B$ color index of -0.75 measured on November 20, and the $B - V$ index (see fig. 1) which was close to zero at first and then slowly increased. The position of the supernova in the galaxy is also consistent with its being a Type II supernova.

Taking $\langle M_{pg} \rangle_{av} = -17.9$ for the peak Type II luminosity (Kowal 1968, adjusted to $H = 53$ km s^{-1} Mpc^{-1}), and allowing for a possible 1-mag deviation, we find 80 Mpc for the upper limit to the distance to the supernova. We cannot exclude a significant amount of interstellar absorption and hence a smaller distance to the object. The absorption in the Galaxy may be $A = 0.3$ mag based on the relation $A_{pg} = 0.25$ cosec b^{II} (Minkowski 1964). The absorption in NGC 493 is probably substantial in view of its edgewise orientation toward us, but the amount is unknown. The peak

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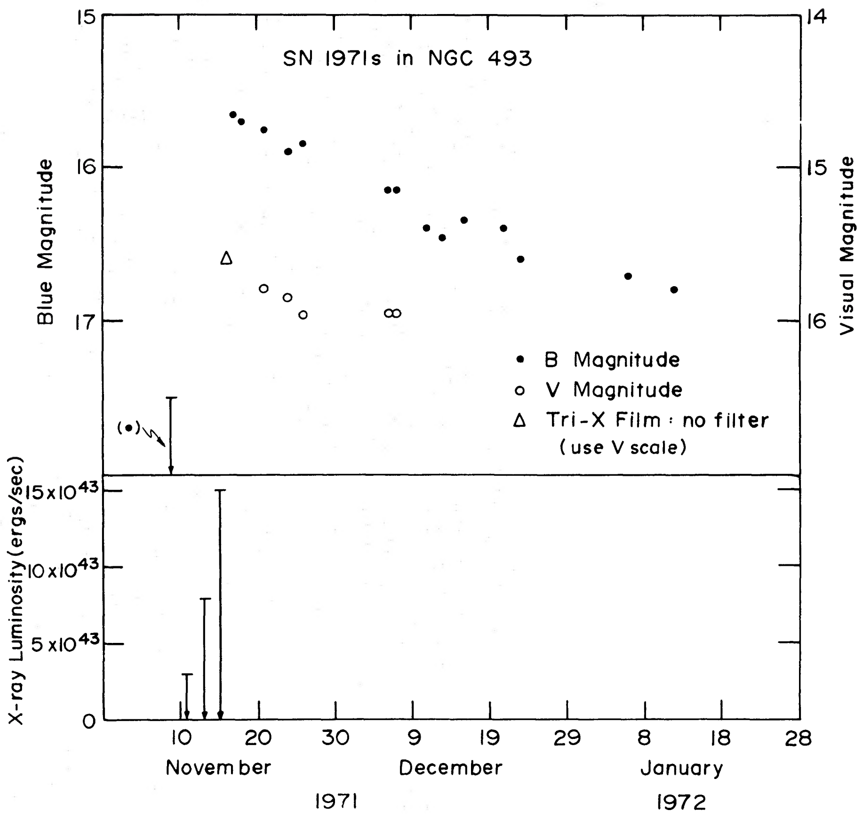

FIG. 1.—*Upper*, light curve of the supernova in NGC 493 including the upper limit obtained by Kohoutek (1972) seven days prior to the supernova discovery. *Lower*, X-ray intensity upper limits for NGC 493 averaged over 2-day intervals.

optical energy flux from the supernova thus has a lower limit of 6.8×10^{-12} ergs cm^{-2} s^{-1} over the wavelength range 3800–6200 Å characteristic of the V and B spectral bands.

III. X-RAY OBSERVATIONS

The MIT X-ray detector on OSO-7 has been described in an earlier paper (Clark *et al.* 1973). It has two banks of counters located in the rotating-wheel section of the satellite. Each bank has multiple gas-filled proportional counters which cover the range 1–60 keV. The detector bank which scanned NGC 493 in 1971 November has a collimator with a 3° FWHM circular field of view. The motion of the satellite spin axis was such that the sensitivity of the detector to the supernova was near zero on November 9.0, reached its maximum on November 12.0, and had returned to zero by November 16.2. Background rates were derived continuously from observations of regions of the sky near the supernova.

We divided the data into several time intervals, and for each interval we determined the maximum-likelihood intensity of an X-ray source whose position was fixed at $\alpha = 19.^{\circ}9$, $\delta = 0.^{\circ}66$ (1950), the position of NGC 493. We found no evidence for an X-ray source at this position. The results are summarized in table 1 for three separate 2-day periods from November 9.5 to November 16.2 and for the total 6-day period. The calculated upper limits to the energy flux are not very sensitive to the assumed spectral shape, for which we used a power law of the form $dN/dE \sim E^{-2}$. The upper limits to the X-ray luminosity are based on the upper limit of 80 Mpc estimated earlier for the distance to the source.

We have examined our data for evidence that X-rays might have been emitted in the form of one or more pulses. Our method is sensitive to a pulse with a duration between 2 s (the spacecraft spin period) and 6 hours. No pulse at a confidence level greater than 95 percent was found (table 1). The usable data which were examined for short pulses (2–180 s) covered 31 percent of the total observation time.

The upper limits to the ratios of the X-ray energy fluxes during the 6-day period to the optical energy flux at the peak are given in table 1. These ratios are obtained by dividing the measured X-ray upper limits by the lower limit of the optical flux given earlier. The results are independent of the assumed distance to the supernova. Also, they remain valid if the optical interstellar absorption is increased or if the supernova reached maximum significantly earlier than the first optical observation.

TABLE 1

SUMMARY OF X-RAY RESULTS

Time Period (1971)	Counter	Observed Intensity* (counts $s^{-1} \pm 1\sigma$)	Energy Flux Upper Limit (3σ) (ergs $cm^{-2} s^{-1}$)	Continuous Energy Emission Upper Limit† (ergs s^{-1})	Upper Limit to Ratio of X-Ray Flux to Optical Flux‡	Pulsed Energy Emission in Ergs, Upper Limit†§	
						6-hr Sums	3-min Sums
Nov. 9.5 to Nov. 16.2 (total period)....	NE (1–5 keV)	0.0 ± 0.1	6.0×10^{-11}	5×10^{43}	10	8×10^{49}	2×10^{48}
	AR (3–9 keV)	0.1 ± 0.1	9.6×10^{-11}	7×10^{43}	15	9×10^{49}	3×10^{48}
	KR (15–40 keV)	0.2 ± 0.1	7.0×10^{-10}	5×10^{44}	100	...	
	XE (25–60 keV)	-0.3 ± 0.2	1.0×10^{-9}	8×10^{44}	150	...	
Nov. 9.5 to Nov. 12.0.......	NE (1–5 keV)	-0.3 ± 0.2	4.4×10^{-11}	3×10^{43}	7	1×10^{49}	
	AR (3–9 keV)	0.1 ± 0.1	1.6×10^{-10}	1×10^{44}	25	2×10^{49}	
	KR (15–40 keV)	0.3 ± 0.2	1.2×10^{-9}	9×10^{44}	180	...	
	XE (25–60 keV)	-0.0 ± 0.4	3.5×10^{-9}	3×10^{45}	500	...	
Nov. 12.0 to Nov. 14.0.......	NE (1–5 keV)	0.2 ± 0.2	1.0×10^{-10}	8×10^{43}	15	5×10^{48}	
	AR (3–0 keV)	0.0 ± 0.1	1.0×10^{-10}	8×10^{43}	15	7×10^{48}	
	KR (15–4 keV)	0.1 ± 0.2	7.7×10^{-10}	6×10^{44}	110	...	
	XE (25–60 keV)	-0.5 ± 0.3	1.3×10^{-9}	1×10^{45}	200	...	
Nov. 14.0 to Nov. 16.2.......	NE (1–5 keV)	0.0 ± 0.5	1.9×10^{-10}	2×10^{44}	30	8×10^{49}	
	AR (3–9 keV)	0.0 ± 0.2	2.3×10^{-10}	2×10^{44}	35	9×10^{49}	
	KR (15–40 keV)	0.1 ± 0.4	1.8×10^{-9}	2×10^{45}	270	...	
	XE (25–60 keV)	0.3 ± 0.8	5.9×10^{-9}	5×10^{45}	900	...	

* For incident intensity in counts $cm^{-2} s^{-1}$, multiply by 0.04.

† For an assumed upper limit to the distance of 80 Mpc.

‡ Optical flux between 3800 and 6200 Å.

§ Derived from 6-hour and 3-minute superpositions, respectively. The latter cover the period November 9.5–November 15.2.

IV. DISCUSSION

The present data establish an upper limit of 5×10^{43} ergs s^{-1} on the continuous X-ray luminosity of the supernova in NGC 493 during the week covering the optical rise and maximum. For the purpose of comparison we note other significant upper limits on supernova X-ray emission, viz., (*a*) 6×10^{42} ergs s^{-1} from SN 1967h at least 7 days but less than 34 days after maximum (Bradt *et al.* 1968), (*b*) 2×10^{45} ergs s^{-1} for a supernova in NGC 1275 at least 6 days after maximum (Gorenstein, Kellogg, and Gursky 1969; see discussion in Ulmer *et al.* 1972), (*c*) upper limits in the range from 10^{44} to 10^{46} ergs s^{-1} for five supernovae in various stages of their development observed by OSO-3 (Ulmer *et al.* 1972). (The upper limits quoted here have been adjusted to $H = 53$ km s^{-1} Mpc^{-1}.) All of these limits on continuous emission are consistent with current theories of supernova emission (Colgate and McKee 1969; Morrison and Sartori 1969; Grassberg, Imshennik, and Nadyozhin 1971; Falk and Arnett 1973). Only the observation of SN 1968h and SN 1968j by Ulmer *et al.* (1972) definitely covered the period before maximum light (see also Zwicky 1969). The minimum upper limit to the X-ray emission reported for these was 2×10^{45} ergs s^{-1} (7.2–22 keV), where again we have corrected for the reduced Hubble constant. The upper limit reported here (1–5 keV) is lower by a factor of 40.

Tucker's proposal (Tucker 1970) that the continuous X-ray background is caused by a large number of overlapping supernovae requires a total X-ray emission of 3×10^{50} ergs from a typical supernova. This corresponds to an average X-ray luminosity on the order of 10^{45} ergs s^{-1} if the emission takes place over a period of ~ 3 days, or 10^{44} ergs s^{-1} for an emission period of 30 days. Our result rules out a 3-day burst of 10^{45} ergs s^{-1} during the optical maximum of SN 1971s while the upper limit obtained by Bradt *et al.* (1968) rules out correspondingly lower emission over a longer time interval for SN 1967h. Therefore, unless both of these supernovae are unusually quiet in X-rays, Tucker's hypothesis is not the correct explanation for the X-ray background.

The upper limit of 5×10^{48} ergs (5×10^{-6} ergs cm^{-2} at the detector) in the 1–9 keV range, which we have obtained for pulsed emission (2–180 s), is greater than the total energy emission of 5×10^{47} ergs in the 15-μs X-ray/γ-ray pulse predicted by Colgate (1968). On the observational side, Klebesadel *et al.* (1973) and Wheaton *et al.* (1973) have recently reported the detection of X-ray/γ-ray pulses (0.1–80 s) of unknown origin at an integrated flux density as high as 5×10^{-4} ergs cm^{-2} in the energy range from 7 to 1500 keV. Since we did not observe SN 1971s continuously, we cannot exclude the possibility that it emitted such a pulse.

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