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A SEARCH FOR X-RAYS FROM SUPERNOVA 1972e WITH *UHURU* AND OSO-7

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ABSTRACT

Thirteen observations from 16 months before to two years after maximum light reveal only one possible (3.2 σ) positive result which corresponds to a luminosity of $1.0 \pm 0.3 \times 10^{41}$ ergs s^{-1} (3–10 keV) at $45^{\rm d}$ before max. The failure to detect any sizable flux contradicts a model by Shklovsky and may constrain that of Colgate and McKee.

Subject headings: supernovae — X-rays

I. INTRODUCTION

Supernovae are the result of violent events in which large amounts of energy (10^{49}–10^{50} ergs) are released in relatively short times (Shklovsky 1968). So far supernova events have been detected at optical, near-infrared, and possibly once at radio wavelengths (Shklovsky 1968; Greenstein and Minkowski 1973; Gottesmann *et al.* 1972). Although there is disagreement about the mechanism of the explosion, it is likely that at some point supernovae should be substantial X-ray emitters. This supposition is due in part to the observed X-ray power of the Crab pulsar and the assumption that pulsars are the result of supernovae and may even be their cause (Ostriker and Gunn 1971; Shklovsky 1973).

Several groups have searched for X-ray emission from supernovae and have set upper limits in the range 6×10^{42} to 10^{45} ergs s^{-1} (Bradt *et al.* 1968; Gorenstein, Kellogg, and Gursky 1969; Ulmer *et al.* 1972; Sprott *et al.* 1974). A more stringent limit of 6×10^{40} ergs s^{-1} for soft (0.6–1.6 keV) X-rays was established by Palmieri *et al.* (1973). However, these measurements were made within a month of maximum light when X-ray emission from a central core could well be obscured by the expanding shell of material postulated in present supernova models (Bahcall, Rees, and Salpeter 1970; Ostriker and Gunn 1971; Shklovsky 1973; Arnett 1971). The occurrence of a relatively nearby supernova, SN 1972e, during the lifetimes of both the *Uhuru* and OSO-7 satellites has allowed us to search for X-ray emission at lower levels than previously possible and at many different times during the evolution of the event. In this paper we present the results of observations performed with X-ray detectors aboard OSO-7 and *Uhuru* at 13 different times ranging from 16 months before to 2 years after SN 1972e maximum light.

II. SUPERNOVA 1972e

SN 1972e in the irregular galaxy NGC 5253 at $\alpha = 13^{\rm h}37^{\rm m}$, $\delta = -30°24'$ (1950), has been classified as a Type I supernova (Greenstein and Minkowski 1973). The magnitude at discovery on 1972 May 13 was $m_v = 8.5$ (Kowal 1972). Studies of the spectral evolution (Greenstein and Minkowski 1973) suggest that maximum light occurred between April 28 and May 10. However, the prediscovery observations of Fisher, Austin, and Clark (1972) show a decreasing intensity from May 6 to 9, implying maximum light before May 6. Their limit of $m_{\rm pg} < 14$ on April 15 combined with the indication that Type I supernovae require 20–25 days to brighten by 6 mag (Pskovskii 1971) narrows the probable time of maximum light to 1972 May 4–6.

III. OBSERVATIONS

The MIT OSO-7 detectors consist of two banks of proportional counters with 1° or 3° (FWHM) collimators, only one of which views the source for a given observation (see Clark *et al.* 1973). The energy ranges for these observations are 1–5, 3–10, and 15–40 keV. The *Uhuru* detectors have $0.°5 \times 5°$ and $5° \times 5°$ (FWHM) collimators which scan almost identical fields of view and are sensitive from 2 to 20 keV (see Giacconi *et al.* 1971).

The dates, durations, and other relevant parameters for each observation are listed in table 1. The OSO-7 data for each sighting were edited for contamination and then used in a maximum-likelihood fitting program to determine the intensity of a hypothetical source at NGC 5253. All the data collected with the 3° collimator show some emission from this general vicinity. However, these data are not consistent with emission from that galaxy; rather, they suggest the presence of two or more weak sources within a few degrees of it. The crude positions determined for these apparent sources do not correspond to any listed in the *Uhuru* catalog (Giacconi *et al.* 1974). Examination of the *Uhuru* exposure to this region shows that sources of less than 5 counts s^{-1} intensity might have gone undetected. The OSO-7 observation of 1972 March does show a positive intensity for emission from NGC 5253 with a 3.2 σ statistical significance. The position of this emission peak has an uncertainty of $\pm 0.°4$ (1 σ) and lies within

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TABLE 1

X-RAY OBSERVATIONS OF SN1972e IN NGC 5253

No.	Date	JD (2,440,000+)	Days from Maximum Light* of SN 1972e	Detector	Energy (keV)	Flux† (10^{-11} ergs cm^{-2} s^{-1})	Luminosity‡ (10^{40} ergs s^{-1})
1......	1970 Dec. 19	0940	−502	*Uhuru*	2–6	<8	<5
2......	1970 Dec. 23	0944	−498	*Uhuru*	2–6	<8	<5
3......	1971 July 27–29	1160–62	−281	*Uhuru*	2–6	<26	<16
4......	1972 Mar. 15–21	1392–98	−47	OSO-7, 1°	1–5	<17	<11
					3–10	16 ±5	10±3
					15–40	<150	<96
5......	1972 Apr. 28–May 2	1436–40	−4	OSO-7, 3°	1–5	<20	<13
					3–10	<11	<7
					15–40	<130	<80
6......	1972 May 16–23	1454–61	14	*Uhuru*	2–6	<17	<11
7......	1972 June 28	1497	55	*Uhuru*	2–6	<26	<16
8......	1972 July 16–Aug. 9	1515–39	85	OSO-7, 3°	1–5	<4	<2
					3–10	<3	<2
					15–40	<50	<30
9......	1972 Aug. 18–24	1548–54	109	OSO-7, 3°	1–5	<13	<8
					3–10	<17	<11
					15–40	<90	<60
10.....	1972 Sep. 4–19	1565–80	130	OSO-7, 1°	1–5	...	
					3–10	<7	<5
					15–40	<85	<50
11.....	1972 Sep. 21–28	1582–89	143	*Uhuru*	2–6	<26	<16
12.....	1973 Jan. 8	1691	249	*Uhuru*	2–6	<68	<42
13.....	1973 Apr. 22–May 1	1795–1804	357	OSO-7, 3°	1–5	<27	<17
					3–10	<25	<16
					15–40	<40	<25

* Assuming max light at 1972 May 4, JD 2,441,442 and using center of observation period.

† Conversion of count rate to flux is valid for a spectrum that falls with energy but is relatively insensitive to its detailed shape. All upper limits are 3 σ (statistical).

‡ Assumes distance to NGC 5253 of 2.3 Mpc.

0°.25 of NGC 5253; the closest of the apparent sources mentioned above is ~2° away. A constant emission of this magnitude is ruled out by the upper limits of 1970 December and 1972 April and July.

The first three *Uhuru* observations were made while the satellite aspect system was still functioning, allowing the data of many satellite rotations to be superposed to increase sensitivity. For the subsequent sightings only individual scans were used.

IV. DISCUSSION

With the exception of the 3 σ positive result of 1972 March, we have obtained only upper limits to the X-ray emission from NGC 5253 around the time of SN 1972e. We converted the measured fluxes to the luminosities listed in table 1 by using the most probable distance to the galaxy of 2.3 Mpc (Welch 1970 sets the upper limit at 4.6 Mpc). We may compare the X-ray flux with the optical flux independent of the distance. Assuming no bolometric correction and an interstellar absorption of $A_v = 0.5$ (Lee, *et al.* 1972), we obtain ratios of X-ray to optical luminosity of no more than ~0.005 around maximum light and no more than ~0.02 three months later.

There have been no detailed model calculations of the X-ray flux expected from a supernova outburst, although several authors have made speculative estimates based on the presence of a remnant pulsar. Bahcall *et al.* (1970) use a simple backward extrapolation of the observed X-ray emission from NP 0532 with the assumption that the luminosity scales as the fourth power of the pulsar rotation frequency. They estimate that several months after the event the X-ray luminosity would be 10^{42}–10^{43} ergs s^{-1}. At this time the Thomson optical depth of a 1 $M_\odot$ cloud surrounding the pulsar would be unity if its expansion velocity were 10^4 km s^{-1}. Ostriker and Gunn (1971) suggest that the pulsar emission powers the observed supernova event. Because of their conclusion that pulsars are principally Population I objects, they apply their calculations only to Type II supernovae. For these events they obtain typical early pulsar luminosities of 2×10^{43} ergs s^{-1} initially at γ-ray energies. According to their model, strong X-ray emission would not occur until ~10 years after the outburst, although the diffusion process mentioned below might result in some prompt X-ray output. On the other hand, Shklovsky (1973) proposes that pulsars are responsible for Type I supernova light curves as well. In his model it is precisely the pulsar X-ray flux that is responsible for heating an expanding envelope, and he estimates that the X-ray luminosity should be ~3×10^{42} ergs s^{-1} several months after the explosion.

Table 1 shows that the X-ray emission of SN 1972e several months after the outburst was nearly two orders of magnitude below that predicted by the pulsar models. This suggests that (1) no pulsar was formed

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during this event, (2) the fractional X-ray luminosity of a newly formed pulsar is less than a few percent of that of NP 0532, or (3) the shell surrounding the pulsar remains opaque to X-rays for several years. The Shklovsky model would remain tenable only if one accepts hypothesis (3). This would imply larger envelope masses or smaller expansion velocities than generally accepted (Shklovsky 1968; Bahcall *et al.* 1970) or an overabundance of heavy elements in the shell. For example, silicon-burning calculations (Michaud and Fowler 1972) predict a shell composed almost entirely of Si and Fe, which if not fully ionized would achieve transparency at times later than the Thomson prediction for the same mass by a factor ~15 around 5 keV and by a factor ~3 at 20 keV.

The model of Colgate and McKee (1969) ascribes the supernova light curve to delayed heating effects of radioactive decay. After the initial explosion, such a process would produce X-rays by *K*-shell emission of ^{56}Co and ^{56}Fe following electron capture (Clayton, Colgate, and Fishman 1969) and by energy degradation of the nuclear γ-rays due to their Compton diffusion through the supernova shell (Arons 1971; Brown 1972). The *K* emission would reach maximum when $\tau \sim 1$ after a few months and, for the parameters of Colgate and McKee (1969), would have a luminosity of $\sim 2 \times 10^{39}$ ergs s^{-1} at that time. This is below our limits. On the other hand, the diffusion calculations of Arons (1971) suggest that a large fraction of γ-rays can appear as X-rays after diffusing out from $\tau \sim 5$. We estimate that X-ray luminosities of 10^{40}–10^{41} ergs s^{-1} might result, although detailed calculations will be required to determine if the predicted emission actually exceeds our limits.

The positive detection of 3–10 keV X-rays by OSO-7 in 1972 March is of marginal statistical significance and thus may be due to some systematic effect. If this flux is attributed to SN 1972e, it implies a relatively modest luminosity of $1.3 \pm 0.4 \times 10^{40}$ ergs s^{-1} over the energy range at 45 days before maximum light. This time may in fact overlap the time of the initial explosion if one accepts the rough backward extrapolations of Type I supernova light curves of Pskovskii (1971), which suggest that 40–45 days may be required for the rise to maximum.

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REFERENCES

Arnett, W. D. 1971, *Ap. J.*, **163**, 11.
Arons, J. 1971, *Ap. J.*, **164**, 437.
Bahcall, J. N., Rees, M. J., and Salpeter, E. E. 1970, *Ap. J.*, **162**, 737.
Bradt, H., Naranan, S., Rappaport, S., Zwicky, F., Ogelman, H., and Boldt, E. 1968, *Nature*, **218**, 856.
Brown, R. T. 1972, *Ap. J.*, **179**, 607.
Clark, G. W., Bradt, H. V., Lewin, W. H. G., Markert, T. H., Schnopper, H. W., and Sprott, G. F. 1973, *Ap. J.*, **179**, 263.
Clayton, D. D., Colgate, S. A., and Fishman, G. J. 1969, *Ap. J.*, **155**, 75.
Colgate, S. A., and McKee, C. 1969, *Ap. J.*, **157**, 623.
Fisher, W. J. H., Austin, R. R. D., and Clark, M. 1972, *IAU Circ.*, No. 2421.
Giacconi, R., Kellogg, E., Gorenstein, P., Gursky, H., and Tananbaum, H. 1971, *Ap. J.* (*Letters*), **165**, L27.
Giacconi, R., Murray, S., Gursky, H., Kellogg, E., Schreier, E., Matilsky, T., Koch, D., and Tananbaum, H. 1974, *Ap. J. Suppl.* No. 237, **27**, 37.
Gorenstein, P., Kellogg, E. M., and Gursky, H. 1969, *Ap. J.*, **156**, 315.
Gottesman, S. T., Broderick, J. J., Brown, Robert L., Balick, Bruce, and Palmer, Patrick. 1972, *Ap. J.*, **174**, 383.
Greenstein, J. L., and Minkowski, R. 1973, *Ap. J.*, **182**, 225.
Kowal, C. T. 1972, *IAU Circ.*, No. 2405,
Lee, T. A., Wamsteker, W., Wisniewski, W. Z., and Wdowiak, T. J. 1972, *Ap. J.* (*Letters*), **177**, L59.
Michaud, G., and Fowler, W. A. 1972, *Ap. J.*, **173**, 157.
Ostriker, J. P., and Gunn, J. E. 1971, *Ap. J.* (*Letters*), **164**, L95.
Palmieri, T. M., Burginyon, G. A., Hill, R. W., Scudder, J. K., Seward, G. D., and Toor, A. 1973, *Ap. J.*, **182**, 411.
Pskovskii, Yu. P. 1971, *Soviet Astr—AJ*, **14**, 798.
Shklovsky, I. S. 1968, *Supernovae* (London: Wiley-Interscience)
———. 1973, *Soviet Astr.—AJ.*, **16**, 749.
Sprott, G. F., Bradt, H. V., Clark, G. W., Lewin, W. H. G., Schnopper, H. W., Pigatto, L., and Rosino, L. 1974, *Ap. J.* (in press).
Ulmer, M., Grace, V., Hudson, H. S., and Schwartz, D. A. 1972. *Ap. J.*, **173**, 205.
Welch, G. A. 1970, *Ap. J.*, **161**, 821.

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