

X-RAY EMISSION FROM THE HISTORICAL SUPERNOVAE IN THE SPIRAL GALAXY
NGC 6946: SN 1980K AND SN 1968D RECOVERED?

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ABSTRACT

This paper describes a study of the *ROSAT* PSPC observation of the spiral galaxy NGC 6946 to search for x-ray emission from the six historical supernovae that have occurred in that galaxy. At the age of these supernovae, all could be emitting x rays due to circumstellar interactions. SN 1980K may be present based upon the hardness ratio and the coincidence of an x-ray source with the optical position. Its luminosity agrees with a recent prediction by Chevalier & Fransson. The situation for SN 1968D, apparently recovered in VLA data, is less clear due to source confusion, but suggests SN 1968D has not been recovered. Only upper limits are available for the remaining four supernovae that have occurred in this galaxy.

1. INTRODUCTION

X-ray emission may be detected from supernovae by at least three possible processes during their evolution (cf., Schlegel 1994a). First, there is a prompt thermal burst due to shock breakout. If this burst is sufficiently hot, x rays may be produced. Second, Compton scattered γ rays from the radioactive decay of nuclides synthesized in the explosion produce x rays at least down to the photoelectric absorption cutoff at ~ 16 – 20 keV. Third, the interaction of a shock with circumstellar matter generates x-ray emission as well as radio emission (Chevalier 1990, and references therein). Two possible x-ray emitting regions are present in the circumstellar interaction model: at the outgoing shock where x rays (up to ~ 100 keV) are generated; at the reverse shock softer x rays (~ 1 keV) are produced.

Observations of supernovae have yielded five detections to date (for a review, see Schlegel 1994a). Only two supernovae have been seen at early times (< 50 days old), both almost certainly due to circumstellar interaction: SN 1980K (Canizares *et al.* 1982) and SN 1993J (Zimmermann *et al.* 1994). SN 1994I in NGC 5194 may be a promising addition to this list based upon its early radio detection (Rupen *et al.* 1994). Three supernovae have been seen at later times: SN 1987A, due to Compton-scattered γ rays (Kumagai *et al.* 1989); SN 1986J (Bregman & Pildis 1992) and SN 1978K (Ryder *et al.* 1993) due to circumstellar interactions. Two of these sources (SN 1986J, SN 1978K) are still under observation as they are extremely x-ray luminous (10^{39-40} erg s⁻¹) in the 0.5–2.0 keV band. The x-ray light curve of SN 1978K is under construction and will be the first late-time x-ray light curve of a supernova (Schlegel *et al.* 1994). Other detections of historical supernovae may also be reported soon. For example, Pietsch (1992) notes that some x-ray emission is observed “near” the sites of SN 1970G and SN 1951H in M101, although the details have not yet been published.

At some point, however, a supernova becomes a super-

nova remnant. Is the transition observable? Supernova remnants (SNRs) are known x-ray sources with luminosities generally in the range 10^{34-36} erg s⁻¹ (cf. Seward 1989). A few SNRs are much brighter with luminosities approaching 10^{38-40} erg s⁻¹. This list of luminous SNRs includes the SNR in NGC 4449 (Blair *et al.* 1983), N49 in the LMC (Vancura *et al.* 1992), and the SNR in NGC 6946 (Schlegel 1994b). Is there a connection between these luminous SNRs and luminous supernovae such as SN 1986J and SN 1978K? What is the nature of the transition?

Two approaches exist to observe the transition or to understand whether a connection exists. First, one can follow a single supernova (or a small set) from supernova to remnant. If one chooses wisely, one may live sufficiently long to see this transition. The second approach examines as many supernovae as possible. The supernovae will exist in different stages of their evolution, but the observer may at least see if any have made the transition and exhibit properties similar to known SNRs. Two galaxies exist that are ideally suited for such a study: NGC 5236 (M83) and NGC 6946. Both galaxies have six historical supernovae each spread over ~ 80 yr. Each galaxy also happens to be the parent of one of the relatively bright supernovae that have occurred in the last decade or so: SN 1983N in NGC 5236 and SN 1980K in NGC 6946.

I describe here the search for x-ray emission from the historical supernovae in NGC 6946 using *ROSAT* PSPC data. The paper is organized as follows. Section 2 describes the observations and analysis. Section 3 details the SN 1980K observation, Sec. 4 describes SN 1968D, and Sec. 5 describes the upper limits on the remaining four supernovae. A brief summary ends the paper. In this paper, I use a value of 5.1 Mpc (deVaucouleurs 1979) for the distance to NGC 6946.

2. OBSERVATIONS

The *ROSAT* PSPC observed NGC 6946 on 1992 June 16–21, obtaining a total exposure time of 36 713 s scattered

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TABLE 1. Upper limits on the historical supernovae.

SN Name	RA (2000) Dec (2000)	Date of opt. max	Mag at max	Source Cts ^a	Bkgrd Cts ^a	99% UL Counts	Flux Limit ^b	L_X^c
SN 1980K ^d	20:35:30.3 +60:06:23.6	1980 Oct 31	V11.4	31	10.5±1.9	37.2	1.0(-14)	3.1(37)
SN 1969P	20:34:51.3 +60:06:14.9	1969 Dec 11	PG13.9	19	11.3±4.4	20.6	8.3(-15)	2.6(37)
SN 1968D	20:34:58.4 +60:09:32.4	1968 Feb 29	PG13.5	96	71.9±9.5	50.6	2.0(-14)	6.2(37)
SN 1948B	20:35:21.5 +60:10:16.6	1948 Jun 15	PG14.9	37	34.0±6.9	20.7	8.3(-15)	2.6(37)
SN 1939C	20:34:23.0 +60:09:37.3	1939 Jul 17	PG13.0	24	23.1±5.8	16.2	6.5(-15)	2.0(37)
SN 1917A	20:34:46.9 +60:07:29.7	1917 Jul 19	PG14.6	31	32.2±6.7	16.6	6.7(-15)	2.2(37)

Notes to TABLE 1

^aBoth “source” and background counts were extracted in the energy range 0.2–2.0 keV.

^bUnits are $\text{erg s}^{-1} \text{cm}^{-2}$. The flux upper limit comes from the spectrum with the equivalent number of counts. The energy range is 0.5–2.0 keV.

^cUnits are erg s^{-1} in the 0.5–2.0 keV range. The assumed distance is 5.1 Mpc (de Vaucouleurs 1979).

^dThe “upper limit” is included here for completeness, or if the reader does not believe the evidence for the detection of SN 1980K.

over 14 observation intervals. The mean count rate in each observation interval was calculated, as well as the mean of these means. Observation intervals in which an interval’s mean count rate was more than 3σ from the total mean count rate were screened out. A total of 70 s failed this criterion, leaving a total exposure time of 36 643 s. The background light curve showed a relatively constant rate of ~ 5 counts s^{-1} for each observation interval. No evidence for short- or long-term enhancements, as described in Snowden *et al.* (1994), was seen. No systematic effects were seen in the master veto rate (Plucinsky *et al.* 1993; Snowden *et al.* 1992). More complete details of the data reduction are in Schlegel (1994c).

The positions of the historical supernovae in NGC 6946 are known to rather high accuracy (Table 1). The values were converted from 1950 coordinates to J2000. These coordinates must then be “corrected” to the PSPC image coordinates. The positional accuracy of the PSPC was tested by comparing the optical positions of three sources within $20'$ of NGC 6946 with their corresponding x-ray positions. Each of the three sources had at least several tens of counts, so the position centroids should be accurate to $\sim 8''$ – $10''$ (Briel *et al.* 1988). Two of the sources are known *Einstein* sources (Harris *et al.* 1990; Hertz & Grindlay 1988), so the x-ray and optical correspondence is known. The resulting, average RA offset (optical–x-ray) was $+1.6''$ and the resulting Dec offset was $-6.4''$. These values are typical of the boresight shifts of *ROSAT* (Kürster & Hasinger 1993). The corrections were then applied to the coordinates of the historical supernovae to obtain “raw” coordinates.

The raw coordinates were used to place the extraction apertures in their proper location on the PSPC image. Figure 1 shows the apertures on a background-subtracted, smoothed version (described in Schlegel 1994c). The apertures are all $24''$ in size, which is comparable to the overall FWHM of the PSPC point spread function, and which samples $\sim 90\%$ of the point spread function at 1 keV (Hasinger *et al.* 1992). The counts were extracted within the aperture and treated as

“source”+background counts. The background was determined from a nearby, source-free region. Most of the historical supernovae happened to have occurred at a sizeable distance from the nucleus, hence, most are in relatively source-free regions. SN 1968D requires additional work as it lies atop the diffuse emission from the hot interstellar medium of NGC 6946 (Schlegel 1994c). For this source, the background extraction region was also taken from a region apparently free of point sources, but encircling a region in which the emission comes from the hot interstellar medium of NGC 6946. That location lies just north of the site of SN 1968D. As all of the sources are essentially on-axis (the largest offset

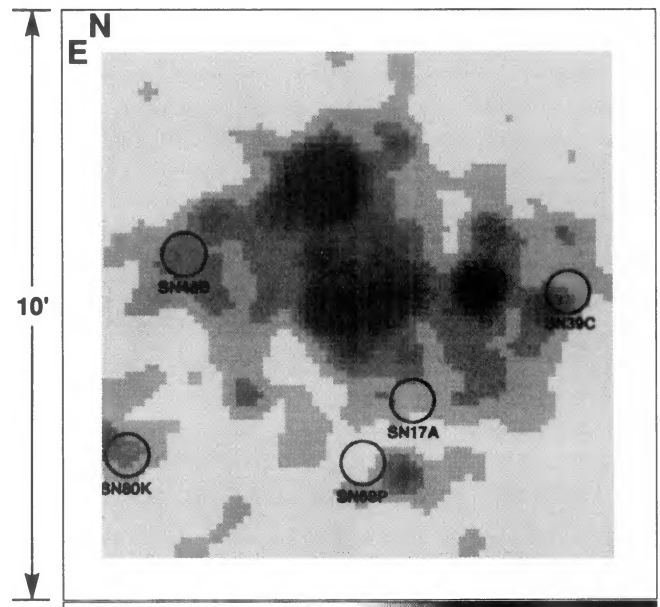


FIG. 1. A background-subtracted, smoothed image of NGC 6946 in the *ROSAT* band (0.2–2.0 keV). North is up and east is left. The positions of the historical supernovae are indicated by circles $24''$ in diameter. This image emphasizes the diffuse background present in the galaxy.

is SN 1980K at $\sim 5'$), vignetting corrections, while applied, are essentially negligible.

Upper limits were computed using the Bayesian prescription of Kraft *et al.* (1991). The Bayesian approach assumes the measured data constrain the experimental hypothesis by applying *a priori* knowledge of the system being measured (for example, that the flux is never less than zero). The Kraft *et al.* approach is an approximation to the proper formulation. They assume the background count rate is infinitely well measured. For a large field-of-view instrument such as the *ROSAT* PSPC, this is a reasonable approximation as a relatively large extraction region for the background may be defined. The required inputs for the Bayesian upper limit are the observed counts for the source plus background and the mean background counts. All upper limits were calculated for the 99% confidence level. The counts were then converted to fluxes by assuming a thermal bremsstrahlung spectrum of temperature 0.5 keV absorbed by the known galactic column to NGC 6946 ($N_{\text{H}} \sim 5.0 \times 10^{21} \text{ cm}^{-2}$ (Burstein & Heiles 1984). A temperature of 0.5 keV was chosen as representative of the total radiative cooling function of shocked gas (e.g., Raymond *et al.* 1976) in which free-free and line emission are important based upon observations of SN 1978K (Ryder *et al.* 1993) and SN 1986J (Bregman & Pildis 1992). Both of these x-ray bright supernovae are of comparable age to SN 1980K, so they may be in a similar evolutionary phase. The temperature range for shocked gas under the above conditions is $\sim 5 \times 10^5$ to $\sim 4 \times 10^7$ K. Below ~ 3 keV, the x rays produced by the reverse shock dominate the spectrum; their temperature is expected to be ~ 0.9 keV (Chevalier & Fransson 1994). As it turns out, the calculated fluxes are relatively insensitive to the exact value of the temperature or the exact nature of the spectrum, whether bremsstrahlung or a Raymond plasma. To obtain a flux, the normalization was increased or decreased until the reported counts in the simulated spectrum matched the number of counts from the upper limit calculation. Fluxes and luminosities were then calculated for the 0.5–2.0 keV band and at 2.0 keV. All of these entries are listed in Table 1.

3. SN 1980K

SN 1980K is among the best-studied supernovae. Of the six historical supernovae in NGC 6946, it was the brightest by ~ 2 mag. It lies well away from the nucleus ($\sim 325''$) to the southeast. SN 1980K was a Type II-Linear supernova. SN 1980K is special for two reasons. First, until the x-ray detection of SN 1993J in M81 (Zimmermann *et al.* 1994, and references therein), it was the only supernova to have been seen near optical maximum. Second, it has been one of a handful of strong radio supernovae, the observations of which have led to considerable understanding of the circumstellar interaction mechanism (Weiler *et al.* 1992). It was detected in the radio at 6 cm ~ 35 days after the optical maximum (Weiler *et al.* 1986). Its radio light curve was monitored until 1990 December when it faded below the VLA detection limit (Weiler *et al.* 1992). The 10 yr radio light curves show that the Chevalier circumstellar interaction

shell model (Chevalier 1990, and references therein) provides a good description of the data. That model predicts the radio light curve should follow the relation

$$S(\text{mJy}) = K_1 \left(\frac{\nu}{5 \text{ GHz}} \right)^\alpha \left(\frac{t-t_0}{1 \text{ day}} \right)^\beta e^{-\tau},$$

$$\tau = K_2 \left(\frac{\nu}{5 \text{ GHz}} \right)^{-2.1} \left(\frac{t-t_0}{1 \text{ day}} \right)^\delta, \quad (1)$$

with $\delta = \alpha - \beta - 3$ (Chevalier 1984). Given that the radio light curve represents the interaction of the shock with circumstellar matter, x-ray emission is also expected. An *Einstein* IPC observation of SN 1980K detected an $\sim 5\sigma$ x-ray source at the supernova's location ~ 35 days after the explosion (Canizares *et al.* 1982). A subsequent observation at ~ 50 days after maximum showed a $\sim 2\sigma$ source at that location. The resulting decline by a factor of ~ 2 in ~ 15 days was consistent with the expectations of the model. Chevalier & Fransson (1994) predict SN 1980K to be a $\sim 2 \times 10^{38} \text{ erg s}^{-1}$ source in the 0.2–4 keV x-ray band at an age of 10 yr. The predicted temperature is ~ 0.9 keV.

The prediction of Chevalier & Fransson can be tested as the prediction was made for an x-ray band largely covered by *ROSAT*. Chevalier & Fransson adopted a distance of 7.5 Mpc to NGC 6946. With their predicted luminosity, this gives a flux of $\sim 3 \times 10^{-14} \text{ erg s}^{-1} \text{ cm}^{-2}$. The prediction was given in the 0.2–4 keV band, essentially that of the *Einstein* IPC. I simulated a bremsstrahlung spectrum and a Raymond–Smith thermal plasma spectrum, both at the predicted temperature and absorbed by a column of $\sim 3\text{--}5 \times 10^{21} \text{ cm}^{-2}$. I adjusted the model normalizations until the flux in the 0.2–4.0 keV band matched the predicted flux. The flux in the 0.2–2.0 keV band was calculated, yielding a value of $\sim 2 \times 10^{-14} \text{ erg cm}^{-2} \text{ s}^{-1}$. This flux can be expected to generate ~ 29 counts in the PSPC for a $\sim 5\sigma$ detection, assuming no contribution to the background from NGC 6946 itself. The PSPC observation of NGC 6946 occurred at a supernova age of ~ 11.6 yr. As the predicted evolution is relatively slow at an age of ~ 10 yr, the expected luminosity should not differ significantly from the above prediction.

The position of SN 1980K agrees quite well with a “lump” of x-ray emission. As the supernova occurred $> \sim 5'$ from the nucleus, the quantity of diffuse emission present at that radius from the galaxy itself is small (Schlegel 1994c), so source confusion is reduced. The positional difference between SN 1980K and the nearby “lump” is $\sim 8''$ ($\Delta\alpha = 1^s.1$; $\Delta\delta = 1^s.2$). The number of net counts in the lump is 18.4, corresponding to a 99% upper limit on the flux of $\sim 7 \times 10^{-15} \text{ erg s}^{-1} \text{ cm}^{-2}$. The hardness ratio is +0.36. The number of counts at the position of SN 1980K is 20.5 with a hardness ratio of +0.49. The hardness ratio is defined as $(H-S)/(H+S)$, where S = counts in channels 20–90, $\sim 0.2\text{--}0.9$ keV, and H = counts in channels 91–210, $\sim 0.91\text{--}2.1$ keV. The error range on the extracted counts for SN 1980K and the lump easily cover this range of hardness. While 20.5 counts barely represent a detection ($\sim 3.5\sigma$), some consideration should be given to whether the “detection” is consistent with SN 1980K.

TABLE 2. Hardness ratios from simulated spectra: bremsstrahlung.^a

N_{H} (cm ⁻²)	kT (keV)									
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5
1×10^{21}	-0.82	-0.59	-0.38	-0.23	-0.12	-0.04	+0.03	+0.08	+0.12	+0.25
3×10^{21}	-0.51	-0.13	+0.12	+0.36	+0.26	+0.43	+0.48	+0.51	+0.54	+0.63
5×10^{21}	-0.16	+0.25	+0.46	+0.57	+0.64	+0.68	+0.71	+0.73	+0.75	+0.80
7×10^{21}	+0.16	+0.52	+0.67	+0.75	+0.79	+0.82	+0.84	+0.85	+0.86	+0.89

Note to TABLE 2

^aThe spectral model was a thermal bremsstrahlung of the tabulated temperature absorbed by the tabulated galactic column.

A hardness ratio of $\sim +0.4$ seems low for a source expected to be relatively hard ($kT \sim 0.9$; Chevalier & Fransson 1994). A brief digression is necessary, however, to test one's intuition on this point. A simulation is necessary to investigate the range of hardness ratios possible for various combinations of temperature and column. A simulated spectrum, assuming a bremsstrahlung continuum or a Raymond thermal plasma model at various temperatures and absorbed by several different values for the galactic column to the galaxy, yielded the results presented in Tables 2 and 3. The observed values of $\sim +0.4$ correspond to very high temperatures at low columns or low temperatures with a high column. Unfortunately, because there are so few observed counts, the range of possible hardness ratios is large. The known column to NGC 6946, even though it is not known precisely, does eliminate, however, the highest and lowest entries in Table 2 for the bremsstrahlung spectrum; the Raymond spectrum is less constrained. A reasonable match to the observed hardness may be made if the column is closer to 3×10^{21} cm⁻² than to 5×10^{21} cm⁻²; the temperature then falls in the range 0.7–0.9 keV regardless of the continuum model. Such a value for the column is within the errors determined from the spectral fits to the very luminous supernova remnant in NGC 6946 (Schlegel 1994b). The lower column also corresponds more closely with the $E(B-V)$ value to SN 1980K (0.37, Buta 1982). The hardness ratio thus lends additional evidence that SN 1980K has been detected.

The difference between the predicted x-ray flux and the upper limit for SN 1980K is about a factor of 1.5–2, well within the errors. Chevalier & Fransson (1994) show the luminosity is related to $\mathcal{M}v_w^{-1}v_s^3/(n-3)^3$, where \mathcal{M} is the mass loss rate, v_w is the wind velocity, v_s is the shock velocity, and n is the power law index. $\mathcal{M}v_w^{-1}$ is measured by the $H\alpha$ emission line to be ~ 3 . A slightly lower value of v_s by ~ 2 would decrease the expected luminosity; so also would a small change in the index. Several of the parameters

are sensitive to n ; observations to date have not placed overly restrictive limits on its value. Hence, the difference between prediction and observation is even more negligible at this stage of our understanding.

Of greater concern is the potential for source confusion. The probability of a source of the “correct” flux falling in a given detection cell of size $30''$ by $30''$ is $\sim 4 \times 10^{-3}$, using the $\log N - \log S$ relation of Hasinger *et al.* (1991). The probability is actually somewhat higher since SN 1980K lies near a galaxy which locally may not follow the $\log N - \log S$ relation. Few other types of sources are capable of mimicking SN 1980K. Stars, cataclysmic variables, and stellar coronal sources are insufficiently luminous by orders of magnitude. X-ray binaries have the correct luminosity but are usually much harder. Perhaps the only type of source that could mimic SN 1980K is another SNR. Examination of the optical recovery image of SN 1980K (Fesen & Becker 1990) shows no apparent SNR within at least $10'' - 20''$ of the position of SN 1980K.

On the basis of the available evidence, I tentatively conclude that SN 1980K has been detected. Certainty, however, will require additional observations to establish definitively whether SN 1980K is present. For example, detecting x-ray emission lines typical of a supernova remnant would establish the case. Unfortunately, it is likely that SN 1980K is fading in the x-ray band as it already has in the radio (Weiler *et al.* 1992), so additional observations may not be possible until a more sensitive instrument is available.

The possible detection of SN 1980K may be placed in a larger context. Weiler *et al.* (1986) compiled the 6 cm fluxes of supernovae and selected remnants and plotted them against the log of the age of the supernova. The result was a 6 cm radio “evolution” curve for the ensemble of supernovae then known. A start at a similar figure has been made in Fig. 2; it shows a 2 keV evolution curve for SN 1980K and a few well known supernova remnants of known age. A more

TABLE 3. Hardness ratios from simulated spectra: Raymond plasma.^a

N_{H} (cm ⁻²)	kT (keV)									
	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.5
1×10^{21}	-0.86	-0.68	-0.55	-0.43	-0.27	-0.04	+0.15	+0.41	+0.46	+0.53
3×10^{21}	-0.71	-0.48	-0.35	-0.22	-0.06	+0.17	+0.37	+0.61	+0.67	+0.78
5×10^{21}	-0.50	-0.26	-0.13	-0.01	+0.15	+0.36	+0.53	+0.74	+0.79	+0.89
7×10^{21}	-0.26	-0.02	+0.09	+0.20	+0.35	+0.53	+0.67	+0.83	+0.87	+0.94

Note to TABLE 3

^aThe spectral model was a Raymond–Smith thermal plasma of the tabulated temperature absorbed by the tabulated galactic column.

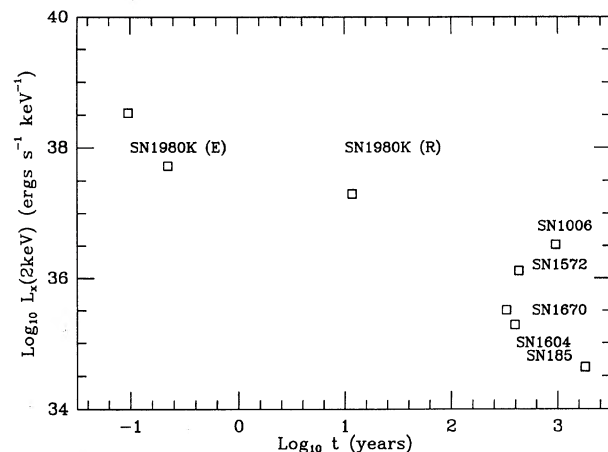


FIG. 2. The 2 keV light curve of SN 1980K and a few supernova remnants. A more complete version of this plot is in Schlegel (1994a). The SN 1980K points labeled “E” are from refits to the *Einstein* observations described in Canizares *et al.* (1982). The SN 1980K point labeled “R” is the *ROSAT* PSPC observation.

complete version is in Schlegel (1994a). The *Einstein* points represent a fit to the spectra presented in Canizares *et al.* (1982). The model used for the fitting was the thermal bremsstrahlung model described above, using $kT \sim 0.5$ keV and $N_H \sim 3 \times 10^{21} \text{ cm}^{-2}$. The flux was calculated from the model, but is relatively insensitive to the choice of model. The figure clearly shows gaps exist at the few year scale and from ~ 10 to ~ 300 yr. The SN 1980K observations are known to lie near the limit of detection; none of the well known supernova remnants would be visible were they to have occurred in a nearby galaxy such as NGC 6946. The SN 1980K detection, if real, shows a luminosity approximately 100 times larger than the ensemble of known remnants. It is likely that an evolution plot such as Fig. 2 will reveal phases of evolution from supernova to remnant once we are able to place more observations on the figure. The observed phases can then be used to test the theoretical models.

4. SN 1968D

SN 1968D occurred closest to the nucleus, $\sim 49''$ north-east of the galaxy’s optical center on 1968 February 29. It was identified as a Type II supernova. In the PSPC data, the supernova lies $\sim 30''$ from a relatively soft source labeled source S4 in Schlegel (1994c). The fitted temperature of S4 of $\sim 0.2\text{--}0.5$ keV, while not precisely measured, is consistent with a young supernova remnant (among other possibilities, such as stellar coronal sources). The hardness ratio for S4 is $\sim +0.1$. The local background is very high here due to the diffuse emission of the galaxy, so the x-ray “upper limit” is unrestrictive. Source confusion is a larger problem. Given that S4 has ~ 200 counts, its position is likely to be accurate to $\sim 8''\text{--}10''$ (Briel *et al.* 1988). A tentative detection of SN 1968D in data from the VLA has been made recently (Van Dyk *et al.* 1994). The position of the radio source is 20:34:58.4, +60:09:32.4 (J2000) which corresponds to the

optical position to $\sim 1''$. Based upon the available data, it is not clear whether the x-ray source corresponds to the radio source. Attempts are being made to identify the optical counterpart of source S4. If these succeed, the identification of the x-ray emission in this region should then be possible. Note, however, that the coordinate shift necessary to register the optical and x-ray images increases the separation between the potential x-ray counterpart and the optical position of SN 1968D. This suggests the x-ray source is not the counterpart to SN 1968D.

5. UPPER LIMITS ON THE REMAINING SUPERNOVAE

Upper limits are reported for the remaining four supernovae. In this section each supernova is discussed in turn along with a brief summary of its optical behavior.

5.1 SN 1917A

SN 1917A was discovered on 1917 July 19. It lies $\sim 111''$ from the nucleus in the region of low x-ray surface brightness that exists south of the nucleus (Schlegel 1994c). Based upon a photographic spectrum by Ritchey (1917), SN 1917A is a Type II supernova. The x-ray emission at its location is completely consistent with the x-ray background local to the NGC 6946 region.

5.2 SN 1939C

SN 1939C was discovered on 1939 July 17 by F. Zwicky and identified by him as a Type I supernova. The supernova lies $\sim 216''$ from the nucleus on the outer arm west of the nucleus. Little else is apparently known about this object. The x-ray emission from its location is also consistent with the x-ray background local to NGC 6946. If SN 1939C is a Type Ia supernova (no hydrogen and believed to be from a low-mass progenitor), then the upper limit is relatively unrestrictive. Type Ia supernovae are not expected to be x-ray emitters in the few decades after the detonation due to the low density of the circumstellar matter. At outburst, they may be x-ray emitters but, to date, only upper limits exist (Schlegel 1994a; Schlegel & Petre 1993). The x-ray behavior of a Type Ib supernova (no hydrogen, but believed to be from a massive progenitor) should follow that of a Type II supernova (Chevalier 1984).

5.3 SN 1948B

SN 1948B was discovered on 1948 June 15 at a position $\sim 230''$ east northeast of the nucleus on the outer limits of the prominent north arm. Based upon the spectrum (Mayall 1948) and the light curve (Barbon *et al.* 1979; Patat *et al.* 1993), the supernova is a Type II-Plateau object. X-ray emission from the location of SN 1948B is consistent with the x-ray emission of the spiral arm; that emission could be diffuse emission from a hot interstellar medium or the summed emission of unresolved point sources. The first explanation appears to be the most likely at this point (Schlegel 1994c).

5.4 SN 1969P

SN 1969P occurred on 1969 December 11. The type of the supernova was never determined, apparently, because no optical follow-up was ever done. The object lies $\sim 180''$ south of the nucleus in a region of low x-ray surface brightness. The x-ray upper limit is unrestrictive if the supernova is a Type Ia.

6. SUMMARY DISCUSSION

Estimates may be made for the average mass loss over the evolutionary life of these historical supernovae. Chevalier (1984) showed that an estimate of \mathcal{M} may be made from $L = 10^{40} A^2 (t/10 \text{ days})^{-1}$, where A is defined by $\mathcal{M}/v_w = 10^{-6} A \mathcal{M}_\odot \text{yr}^{-1} (\text{km s}^{-1})^{-1}$ with v_w the wind speed, usually assumed to be 10 km s^{-1} . This relation applies to SN Ia only, as it assumes a density profile with a power law index of 7. A similar relation is available for SN II (e.g., Fransson *et al.* 1994). Since the upper limits on the luminosities are all approximately $2 \times 10^{37} \text{ erg s}^{-1}$ and the ages of the historical supernovae fall in the range of few 10^3 to few 10^4 days, the values of \mathcal{M} are all approximately $1\text{--}2 \times 10^{-8} \mathcal{M}_\odot \text{yr}^{-1}$ for the SN Ia and $\sim 5 \times 10^{-6}$ to 5×10^{-7} for the SN II. These are very small values, and clearly represent a mass

loss averaged over the full life of these evolving remnants. The possible detections of SN 1980K and SN 1968D clearly indicate that an average mass loss does not reflect the conditions surrounding these historical supernovae. Furthermore, a high mass loss rate cannot be maintained without losing a substantial fraction of the progenitor. One thus expects the x-ray and radio flux to reflect the duration of mass loss; such behavior was observed in the optical [O III] line emission of SN 1957D (Long *et al.* 1992).

In summary, a 36 ks *ROSAT* PSPC observation of the spiral galaxy NGC 6946 has likely detected SN 1980K, may have detected SN 1968D, and places upper limits on the x-ray emission of the remaining four historical supernovae known. Observations are starting to close the gap in our understanding of the evolution of a supernova to a remnant.

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