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THE RADIO COUNTERPART TO THE LUMINOUS X-RAY SUPERNOVA REMNANT IN NGC 6946

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ABSTRACT

We report detection from VLA observations of the radio counterpart to the very luminous X-ray and optical supernova remnant in the galaxy NGC 6946 (Schlegel 1994; Blair & Fesen 1994). We find it to be a very luminous radio source, being ~3 times more powerful than Cas A and within an order of magnitude of the extraordinarily powerful supernova remnant in NGC 4449. We suggest that the NGC 6946 supernova remnant is analogous to the NGC 4449 supernova remnant, but is probably much older. The high luminosity at radio wavelengths for the NGC 6946 supernova remnant likely results from interaction with a dense local environment.

Subject headings: galaxies: individual: NGC 6946 — radio continuum: galaxies — radio continuum: ISM — supernova remnants

1. INTRODUCTION

The nearly face-on spiral galaxy NGC 6946 has been host to six historical supernovae and possesses a large number of H II regions (Bonnarel, Boulsteix, & Marcelin 1986), which indicates both a very high supernova rate and a current star formation rate. It is expected, then, that this galaxy should have many supernova remnants (SNRs) distributed throughout its disk. Over the last decade we have monitored at 6 and 20 cm wavelength the behavior of the radio supernova SN 1980K (see Weiler et al. 1986, 1992) using the Very Large Array (VLA).[3] As a result we have accumulated a large radio database, which we are utilizing to map bright H II regions, possibly recover the historical supernovae, and detect any SNRs (Hyman et al. 1993). One particularly prominent example of a possible SNR has been recently found by *ROSAT* along the northern arm of NGC 6946 (Schlegel 1992).

Schlegel (1994) has more thoroughly analyzed his X-ray data for this source and concludes that it is most likely a very luminous SNR, with an X-ray luminosity of 2.8×10^{39} ergs s^{-1}, assuming a distance of 5.1 Mpc (de Vaucouleurs 1979). This is at least two orders of magnitude higher than the bright, young Galactic SNR Cas A, putting this SNR in NGC 6946 among the most X-ray luminous remnants. Schlegel points out that the X-ray luminosity of this SNR would argue for a young age, with the luminosity possibly explained by shock interaction with a dense circumstellar environment.

Blair & Fesen (1994) have studied this source in the optical and also conclude that it is probably an unusually luminous SNR. The object was originally cataloged as an H II region (region 237) by Bonnarel et al. (1986), and it is visible with relatively constant brightness on optical plates dating back to 1921 and, possibly, back to 1899 (Blair & Fesen 1994). Blair & Fesen (1994) estimate the total optical luminosity at $\sim 2 \times 10^{39}$ ergs s^{-1}, putting this object at the upper limit for known SNRs. They argue, however, that it is a normal, older, ISM-dominated SNR, not young and ejecta-dominated. Their conclusion is supported by the appearance of the optical spectrum, which is similar to those of evolved Galactic and extragalactic SNRs, and by the upper limit to the expansion velocity ($\lesssim 400$ km s^{-1}), which is also consistent with that of older Galactic SNRs (Blair & Fesen 1994). Blair & Fesen (1994) conclude that the high optical luminosity may be due to interaction with a very dense interstellar medium and also due to a low column density along our line of sight. They estimate from the energetics of the SNR that its age is ≤ 3500 yr, as opposed to the young ($\lesssim 150$ yr) age indicated by its high X-ray luminosity (Schlegel 1994).

We examined our radio maps of NGC 6946 to locate a possible radio counterpart to this object. A radio source at the proper position is definitely detected on our 20 cm maps. Due to the smaller size of the VLA field of view at 6 cm and the fact that our observations of SN 1980K are substantially displaced from the SNR position, our 6 cm results could not be used to search for the X-ray source. However, we recently reobserved NGC 6946 at both 6 and 20 cm using the VLA, with the field center approximately located at the position of the SNR, and it is clearly detected at both wavelengths. We therefore confirm that this very luminous X-ray and optical source in NGC 6946 is also a bright radio source and likely to be a SNR. Here we compare its radio properties to those of known Galactic and extragalactic SNRs.

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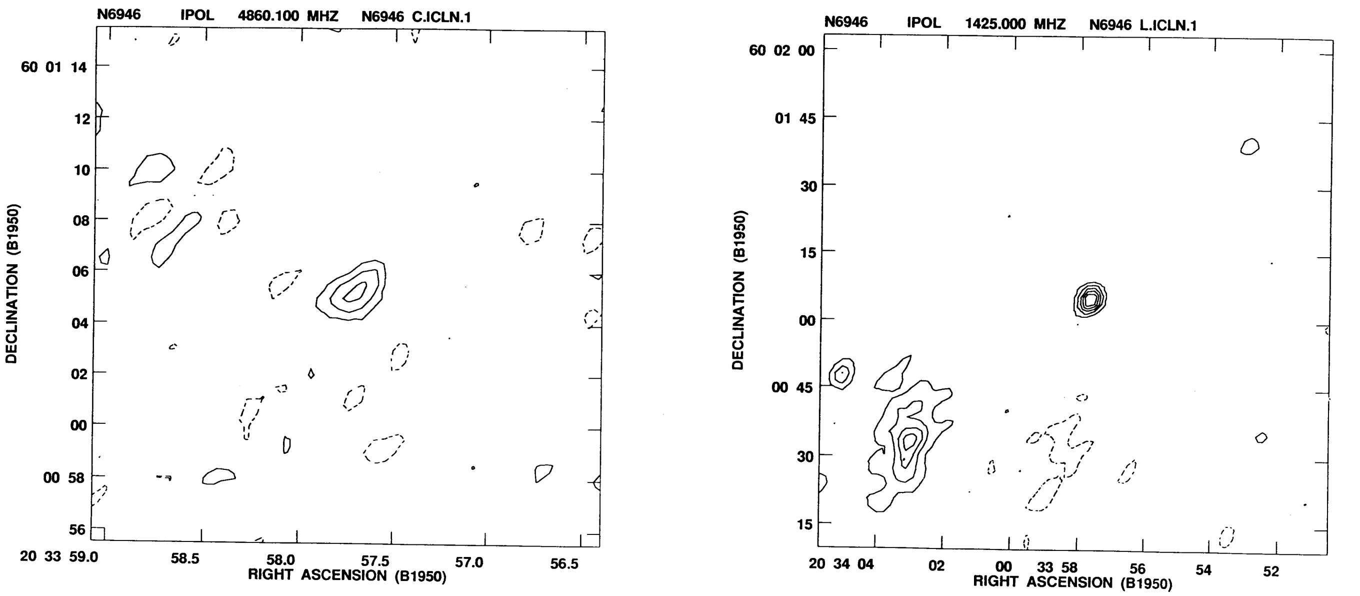

FIG. 1*a* FIG. 1*b*

FIG. 1.—The (*a*) 6 and (*b*) 20 cm VLA maps of the field including the very luminous X-ray SNR in the galaxy NGC 6946. The SNR is clearly seen in both maps as a relatively bright radio source. Source "C" of Klein et al. (1982) can be seen to the southeast of the SNR on the 20 cm map. The 6 cm map has a beam size of 1".23 × 1".12 and 0.05 mJy beam^{-1} rms noise, while the 20 cm map has a beam size of 4".38 × 3".71 and 0.06 mJy beam^{-1} rms noise. The contours shown for the 6 cm map are −0.1, 0.1, 0.2, and 0.3 mJy beam^{-1}; the contours for the 20 cm map are −0.2, 0.2, 0.4, 0.6, 0.8, and 1.0 mJy beam^{-1}.

2. RADIO OBSERVATIONS AND RESULTS

Radio observations of the field containing the X-ray and optical SNR were made with the VLA in "B" configuration on 1993 March 14 (UT) at 6 cm (4.860 GHz) and 20 cm (1.490 GHz). VLA phase and flux density calibration and data reduction followed standard procedures, such as those described in Weiler, Panagia, & Sramek (1990). We show in Figure 1 maps of the SNR at these two frequencies, with a 1".23 × 1".12 beamsize and 0.05 mJy beam^{-1} rms noise at 6 cm and a 4".38 × 3".71 beam size and 0.06 mJy beam^{-1} rms noise at 20 cm. A source is clearly detected at both frequencies. Its J2000 position of $\alpha = 20^h35^m0^s.609 \pm 0^s.75$, $\delta = +60°11'30''.64 \pm 0''.10$ (α[1950.0] $= 20^h33^m57^s.700$, δ[1950.0] $= +60°1'5''.21$) agrees very well, to within the errors, with the positions given by Schlegel (1994) and Blair & Fesen (1994) for the X-ray SNR and its optical counterpart. We therefore conclude that it is almost certainly the radio counterpart to this SNR. Blair & Fesen (1994) find from seeing-deconvolved optical images that the SNR may have a diameter of ~1".0 (corresponding to a linear diameter of ~25 pc at 5.1 Mpc). We also find a deconvolved angular size of ~1".1 from our 6 cm map. It is possible, however, that this represents only an upper limit to the angular size of the SNR. Clearly, radio observations at higher angular resolution are necessary.

We derive flux densities for the NGC 6946 SNR of 0.74 mJy at 6 cm and 1.62 mJy at 20 cm, implying a normal nonthermal spectral index $\alpha = -0.70$, which is similar to that for Cas A and for the NGC 4449 SNR (Bignell & Seaquist 1983). Assuming an angular size of ~1" for the NGC 6946 SNR, it has surface brightnesses of 8.8×10^{-19} W m^{-2} Hz^{-1} sr^{-1} and 4.0×10^{-19} W m^{-2} Hz^{-1} sr^{-1} at 20 cm and 6 cm, respectively. Thermal emission probably does not significantly contribute to the observed radio brightness, indicating that if an underlying H II region is present, it must be faint. At a distance of 5.1 Mpc for NGC 6946 (de Vaucouleurs 1979), we find that this SNR is ~3 times more powerful than Cas A at 6 cm, making it one of the most radio luminous SNRs known.

3. DISCUSSION

Blair & Fesen (1994) make an optical comparison of the NGC 6946 SNR with the SNR N49 in the LMC and the extraordinary SNR in NGC 4449. If we make a similar comparison in the radio, we find that the NGC 6946 SNR is ~3 times *less* powerful than the NGC 4449 SNR at 5 GHz (Bignell & Seaquist 1983), assuming a distance of 3 Mpc from Tully (1988). (The NGC 6946 SNR is ~9 times less powerful than the NGC 4449 SNR, if a distance to NGC 4449 of 5 Mpc from Sandage & Tammann 1975 is assumed.) The NGC 6946 SNR is ~9 times *more* powerful than N49 and is ~3 times *more* powerful than N132D, the most luminous SNR in the LMC (Mathewson et al. 1983). It is clear that the NGC 6946 SNR is quite luminous and is among the brightest known radio SNRs.

We conclude that the NGC 6946 SNR is similar to the extraordinary NGC 4449 SNR, yet much older. The high radio brightness from the NGC 6946 SNR, as at optical and X-ray wavelengths, is probably due to interaction with a particularly dense interstellar medium. This unusual SNR is clearly deserving of further study.

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