A PECULIAR LINEAR RADIO FEATURE IN THE SUPERNOVA REMNANT N206

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ABSTRACT

We present images of the supernova remnant N206 in the Large Magellanic Cloud taken with the Australia Telescope Compact Array at wavelengths of 3 and 6 cm. Based on our data and previously published flux densities, the spectral index of N206 is \(-0.20 \pm 0.07\). The 6 cm radio morphology shows a filled center. Most interesting is the discovery of a peculiar linear feature previously undetected at any wavelength. The feature lies to the east of the center of the remnant, stretching from about \(\frac{1}{4}\) to \(\frac{3}{4}\) of the remnant’s radius. It is wedge-shaped, with a steady opening angle from an apex on the eastern side. The feature resembles the disturbance expected from an object moving through the material supersonically at about 800 km s\(^{-1}\). We present arguments suggesting that the linear feature might have been produced by a low-mass star or compact object ejected from a binary system that may have led to a Type Ic supernova.

Key words: pulsars: general — radio continuum — supernova remnants

1. INTRODUCTION

Several studies of supernova remnants (SNRs) in the Large Magellanic Cloud (LMC) have included the SNR located on the northeastern edge of the H II region LH 120-N206 (Henize 1956). Following common practice, we will henceforth use the name N206 for the SNR or use its coordinate designation, B0532-710.

Radio observations were made at several frequencies, ranging from 0.4 to 14.7 GHz (Mathewson & Clarke 1973; Milne, Caswell, & Haynes 1980; Mills et al. 1984) with resolutions on the order of a few arcminutes. The data showed a bright source with a relatively flat radio spectrum with an index of about \(-0.33\) (Milne et al. 1980). However, the observations were complicated by the presence of the nearby H II region to the southwest of the SNR and were unable to resolve any structure in the interior of the remnant.

H\(\alpha\) images of N206 show a roughly circular filamentary shell around the periphery (Williams et al. 1999). Images taken in [S II] and [O II] (Lasker 1977) also show a shell structure with little central emission. When combined with the earlier radio data, the optical images indicate that the object could be considered a shell-type SNR.

X-ray data have been obtained with both Einstein and ROSAT. These images show a centrally brightened morphology with no apparent edge brightening to denote an X-ray shell (Long, Helfand, & Grabelsky 1981; Williams et al. 1999). By X-ray morphology alone, the remnant is classified as centrally brightened. However, when combined with the radio and optical morphology, the remnant has been suggested to belong to the class called “mixed morphology” (Rho & Petre 1998), because of the disparity between the observed morphologies when viewed at different wavelengths. The centrally concentrated X-ray emission from mixed morphology remnants is thermal. Currently available X-ray data are insufficient to determine whether or not the emission is thermal.

In this paper we present high-resolution (half-power beamwidths [HPBW] 1\(\degree\)1 and 1\(\degree\)8) radio images of N206 at 3 and 6 cm made with the Australia Telescope Compact Array (ATCA). These images show no detailed structure in the remnant except for a linear feature that was previously undetected at radio wavelengths and is also absent from both optical and X-ray images of the SNR.

The observations and data reduction are discussed in \(\S\) 2 of this paper. Radio images and descriptions of the radio morphology, spectral information, and polarization measurements are presented in \(\S\) 3. A discussion of the observed features is in \(\S\) 4. Conclusions are in \(\S\) 5.

2. OBSERVATIONS

We observed N206 with ATCA. Data were taken on five observing nights in late 1997. The observing parameters and observing dates are given in Table 1. The baselines were distributed between 31 m and 6 km, giving good coverage throughout that region of the spatial frequency plane. The observations were made at 4798 and 8638 MHz with bandwidths of 100 MHz in polarization mode, giving data on all four Stokes parameters.

For each observation, the flux calibrator source PKS B1934–638 was observed at the beginning and end of the run. The phase calibrator chosen was the point source PKS B0454–810 for the first four data sets and PKS B0530–727 for the fifth data set. In all observations, the phase calibrator was observed at approximately 20 minute intervals to allow for proper phase correction. Flux densities for the calibrators are given in Table 1.

Data reduction was carried out with the MIRIAD package (Sault, Teuben, & Wright 1995). The data were calibrated and formed into dirty images before cleaning and restoring with circular beams. The circular HPBW sizes were 1\(\degree\)1 and 1\(\degree\)8 for the 3 cm and 6 images, respectively. The images were made with ROBUST weighting (Briggs
1995) to maintain high angular resolution but provide as much sensitivity as possible.

Polarization maps were also made with the MIRIAD package. Dirty images were made in Stokes $Q$, $U$, and $I$, cleaned, and restored using the circular beams mentioned above. To reduce the noise level, each image was convolved with a 5$''$ beam. The MIRIAD task IMPOL was then used to combine the convolved maps in the different Stokes parameters to make a polarized intensity map and a position angle map. These maps were used to determine the strength and direction of the magnetic field. The MIRIAD task IMRM was used to calculate the Faraday rotation measure across the SNR.

### TABLE 1

| Date        | Configuration | Calibrator | 3 cm $S_n$ (Jy) | 6 cm $S_n$ (Jy) |
|-------------|---------------|------------|----------------|----------------|
| 1997 Aug 7   | 750B          | 0454-810   | 1.657          | 1.092          |
| 1997 Aug 27  | 1.5C          | 0454-810   | 2.030          | 1.266          |
| 1997 Oct 10  | 375           | 0530-727   | 0.265          | 0.25           |
| 1997 Oct 23  | 750C          | 0454-810   | 2.509          | 1.744          |
| 1999 Aug 27  | 1.5C          | 0454-810   | 2.030          | 1.266          |
| 1999 Aug 7   | 750B          | 0454-810   | 1.657          | 1.092          |
| All.................. | All          | 1934-638   | 2.84           | 5.83           |

3. RESULTS

3.1. Morphology

3.1.1. Overall SNR

The final radio images at 6 and 3 cm are shown in Figure 1a–1b, respectively. The supernova remnant is 180$''$ × 195$''$, slightly elongated in roughly the east-west direction. Throughout the paper, we will adopt a distance to the LMC of 50 kpc (Feast 1999). Using this, we find a linear size for the remnant of 44 by 47 pc (north-south and east-west, respectively). At 6 cm, the remnant has diffuse emission across its entire face. The western side is twice as bright as the eastern side, with a steady gradient showing decreasing emission from east to west. This brightness gradient can be seen in the one-dimensional slices through the 6 cm image shown in Figure 2. Although the east-west slices may indicate the presence of a shell, they still show that the central emission from the remnant stays well above the background. Based solely on this morphology, the remnant may be classified as a filled or Crab-like or perhaps a composite remnant.

The structure of the SNR is less obvious in the 3 cm image. The morphology of the remnant from this image may indicate edge brightening on the northeastern and southwestern edges, similar to that seen at 6 cm. Unfortunately, because of the smaller beamwidth, the surface brightness of the remnant at 3 cm is significantly lower than at 6 cm. The peak brightness of the map is just over the 3 $\sigma$ ($\sigma_{3\,\text{cm}} = 3.4 \times 10^{-5}$ Jy beam$^{-1}$) noise level, in contrast to over 6 $\sigma$ ($\sigma_{6\,\text{cm}} = 6.0 \times 10^{-5}$ Jy beam$^{-1}$) for the 6 cm image. The fainter emission is lost in the noise in the 3 cm image. Natural weighting was tried to increase sensitivity to the large-scale emission, but it also emphasized the side lobes and did not significantly improve the image quality. Therefore, nothing can be said about the morphology of the remnant’s interior at 3 cm.

Figure 3a–3b shows ROSAT HRI (Williams 1999) and H$\alpha$ (Magellanic Clouds Emission Line Survey; Smith 1999) images of N206, overlaid with 6 cm radio contours. The ROSAT HRI image shows a somewhat elliptical central brightening with a gradual and isotropic decrease in brightness with increasing radial distance from the remnant’s center. There is no apparent brightening on the eastern or western edges. In contrast, the radio image does not show strong emission from the remnant’s center; the brightest region is in the eastern half of the remnant.

The H$\alpha$ image shows a very filamentary structure and a distinct shell to the remnant. These filaments and shell are also prominent in images taken in [S$\text{ii}$] and [O$\text{iii}$] (Lasker 1977). Although the optical emission is primarily in filaments, there is some diffuse optical emission in the center of the remnant in the H$\alpha$ image. As seen in echelle data, this central emission represents a stationary component (attributed to emission from the nearby H$\text{ii}$ region), whereas the emission from the expanding SNR has a velocity of around 250 km s$^{-1}$ (Chu & Kennicutt 1988). To further test the nature of this central emission, we interpolated between the integrated radio and X-ray flux densities. We found that the estimated flux density from synchrotron emission in the optical is several orders of magnitude too low to appear in the H$\alpha$ image. Therefore, this diffuse optical emission does indeed seem to arise from the nearby H$\text{ii}$ region rather than from optical synchrotron emission from the SNR.

3.1.2. Peculiar Linear Feature

In the eastern part of the remnant is a linear feature, oriented east-west and stretching from a point roughly 25$''$ west of the center of the remnant. This feature is approximately 55$''$ (13 pc) in length, ending approximately 20$''$ from the eastern edge of the SNR. The widest point of this feature is at its western end, narrowing steadily toward the east with FWHM less than 5$''$ at its eastern tip. Included in Figure 2 are two one-dimensional slices through the 6 cm data (slices 4 and 5). Once Gaussian profiles are fitted to each slice, the FWHM of the feature can be determined, along with the error of the fit. The results of this process are given in Figure 4, showing the FWHM of the linear feature as a function of distance from the remnant’s center.

This linear feature has never been detected before at any wavelength. Although the optical image shows that the remnant has a filamentary structure, there are no filaments that appear associated with the linear feature in the radio image. The X-ray image shows that the brightest emission is concentrated in the remnant’s center and appears to be reasonably spherically distributed. In addition, there is no point source located at either end of the feature in any of the wavelength bands. The origin of this linear structure is not known but will be further examined below (§ 4).

While some other SNRs exhibit long thin features, they can be seen as parts of shell filaments visible in both radio and optical images. One structure that may be similar to what we see in N206 is a linear feature in G84.2−0.8 that also has a point radio source at one end (Matthews & Shaver 1980). To our knowledge, the linear feature in N206 is the first such feature seen in an SNR without an accompanying filamentary structure or a point source.
Fig. 1a

Fig. 1b

Fig. 1.—Radio images of the SNR N206. Top, 6 cm; bottom, 3 cm. The units on the wedges are janskys per beam. Circular beams were used with beamwidths of 1.8" and 1.1" for the 6 and 3 cm images, respectively. Beam sizes are shown at lower left in each image.
3.2. Spectral Index

Using the ATCA data, we obtained flux densities of $0.52 \pm 0.07$ Jy at 4798 MHz and $0.49 \pm 0.12$ Jy at 8638 MHz. There is a gradient in the background level due to contamination from the H\textsc{ii} region located to the southwest of the remnant. Taking a mean value for the background led to the above flux density measurements. Although no integrated flux density measurements in the literature cite errors (with the exception of that by Mills et al. 1984, who...
Fig. 3.—*ROSAT* HRI (top) and Hα (bottom) images with 6 cm radio contours. The gray scales in the top and bottom panels show the X-ray and optical counts, respectively. The contours shown in both images are 90, 75, 50, 35, and 2 percent of the peak radio intensity.
give an expected error of around 10%), we believe that our error at 6 cm should be comparable to the other measurements.

All flux density values available for N206 are listed in Table 2 and the spectrum of the remnant is shown in Figure 5. The flux density scale for all the given values, except the 843 MHz Molongo Observatory Synthesis Telescope (MOST) result (Mills et al. 1984) has been checked and is found to agree with the current Australia National Telescope Facility scale based on the calibration source PKS B1934−638 (Reynolds 1994). The calibration scale used for the MOST during the early commissioning phase when the measurement was made is somewhat uncertain but should be within 5% of the current one. A linear unweighted regression to the data (i.e., a power-law fit) with a slope of $-0.20 \pm 0.07$ is also plotted. Such a value is typical for a spectral index expected from a filled-center SNR ($S \sim \nu^\alpha$; $-0.4 < \alpha < 0$) but is flatter than that generally found for a shell-type remnant ($-0.8 < \alpha < -0.3$; Trushkin 2000).

The faintness of the 3 cm data makes it difficult to make a spectral index map of the remnant. To try to increase the sensitivity, both the 3 and 6 cm images were convolved with 5" circular beams. The convolved images were both masked at the 1 σ level, and the spectral index map shown in Figure 6 was made. Although the 3 cm image still suffers from low sensitivity, the resulting map does give reasonable results for the linear feature since the signal-to-noise ratio is considerably better in this region than in the rest of the remnant. In the vicinity of the linear feature, the spectral index is approximately $-0.2$, in good agreement with the results for the entire SNR from the previous figure.

3.3. Polarization

The polarization map of the region around the linear feature in N206 is shown in Figure 7. The vector length represents the 6 cm polarized intensity, and the vector direction is that of the intrinsic magnetic field after correcting for the Faraday rotation. For this image, the polarized intensity at both wavelengths was greater than 1.5 σ. Although most of the vectors are associated with the peculiar linear feature, this is a brightness effect. The fractional polarization on the linear feature was approximately 15%. Unfortunately, the signal-to-noise ratio on the remainder of the remnant was insufficient to reliably determine the magnetic field direction or the fractional polarization, although it does appear that there is some polarization throughout the SNR.

The rotation measure determined from the position angle rotation between 6 and 3 cm is about $+200$ radians m$^{-2}$, increasing slightly as you move from west to east along the

![Fig. 4.](image-url) FWHM of the linear feature as a function of distance from the center. The regression slope is $-0.226 \pm 0.013$ and the opening angle is $\theta = 127^\circ$. The error bars represent uncertainty in the individual Gaussian fits to the one-dimensional–slice data taken across the linear feature. Filled circles denote slices where the peak intensity of the slice was greater than 3 σ above the brightness of the surrounding remnant. Open circles represent slices for which the peak intensity of the slice was between 2 and 3 σ above the brightness of the surrounding remnant.

![Fig. 5.](image-url) Radio spectrum of the SNR N206. Flux density values and error estimates are given in Table 2.

| Frequency (MHz) | $S_\nu$ (Jy) | Quoted Uncertainty | Source of Plotted Uncertainty | Reference for $S_\nu$ |
|----------------|--------------|--------------------|-------------------------------|------------------------|
| 408            | 0.7          | None given         | Background removal estimates by others | Matthewson & Clarke 1973 |
| 843            | 0.591        | 10%                | rms noise                     | Mills et al. 1984      |
| 4798           | 0.52         | ±0.07              | Background subtraction        | This paper             |
| 8638           | 0.49         | ±0.12              | Background subtraction        | This paper             |
| 14,700         | 0.27         | ±0.22              | Background subtraction for peak| Milne et al. 1980      |
linear feature. After correcting for the Faraday rotation, we find that the magnetic field at the location of the linear feature is aligned nearly along the feature. It seems likely that this direction is representative of the field in the feature itself and not of the remnant as a whole. However, without knowledge of the global magnetic field orientation in the SNR, we cannot be certain of this assessment.

Even more interesting is the hint of a twisting of the magnetic field near the center of the linear feature. This can be seen as a change in the direction of the vectors in Figure 7 where the magnetic field vectors are oriented roughly northwest to southeast. There is also a variation in the polarized intensity at this location in the center of the jet in the figure shown. This spot has brighter emission in the total radio intensity and approximately zero rotation measure. This leads us to believe that there could be some thermal emission at this spot from a dense clump with a field alignment that adds some negative Faraday rotation to bring the mean closer to zero. The material in the linear feature is apparently clumpy.

4. DISCUSSION

4.1. Classification of the Remnant

The classification of this SNR is not straightforward. The radio emission is nearly uniform with a smooth brightness gradient from east to west across the face of the remnant (Fig. 2). The X-ray emission is centrally peaked while the optical spectral lines indicate a shell structure. We await XMM-Newton spectra to see whether the X-ray emission is thermal or nonthermal. The radio spectral index of $-0.20$ is typical of a Crab-like SNR and is lower than the value expected for a shell-type remnant.¹ It may be a composite remnant in which the plerion component has reached the shell or the shell may just be forming. In either case, we suggest that there is at least a component to the SNR that may be powered by an unseen pulsar. Several other Crab-like SNRs, e.g., 3C 58 (Bocchino et al. 2001), G21.5−0.9 (Slane

¹ See http://cats.cao.ru/snr_spectra.html.
et al. 2000), and G328.4+0.2 (Gaensler, Dickel, & Green 2000) lack a detectable pulsar.

The more rapid decay in X-ray brightness toward the edges of the remnant may be explained by the fact that the X-ray synchrotron emission would decay faster, leaving primarily radio synchrotron emission in the outer regions. A pulsar could still be bright in thermal X-rays, because of its high temperature, but available X-ray observations have insufficient spatial resolution to detect a possible X-ray point source in the SNR. The observed X-ray emission may be partly thermal as well. Additional observations are needed at higher spectral and spatial resolution.

If the remnant is indeed Crab-like, at 47 pc in diameter it is the largest one known, almost twice the size of the previously largest known Crab-type remnant G328.4+0.2 (Gaensler et al. 2000). Following the method of Gaensler et al. to relate the pulsar spin-down energy to the expansion of the surrounding wind nebula, we can estimate the age of the remnant based on the size of the apparent plerion. By taking the wind as a pressure source driving the swept-up material, one can relate the nebular age to its size, the energy injection rate, and the ambient density. Since a distinct separate radio shell is not observed, we will take the size of the plerion to be the entire measured size of the remnant, 23.5 pc in radius. Using the spectrum given above, we obtain a radio luminosity ($L_r$) for the remnant of $9.25 \times 10^{34}$ ergs s$^{-1}$ when we integrate from 100 MHz to 100 GHz. We define $\epsilon = L_r/\dot{E} \sim (1-5) \times 10^{-4}$ (Gaensler et al. 2000) for Crab-type remnants, where $\dot{E}$ is the pulsar energy loss rate. We will adopt the mean value, $\epsilon = 3 \times 10^{-4}$. Taking the initial interstellar medium particle density prior to the supernova event of 0.003 cm$^{-3}$, we obtain an age of 29,000 yr for the remnant. As we would expect, N206 is probably the oldest of the Crab-like remnants.

This age is of course only a very rough estimate. For example, the density used may be an underestimate, especially considering the presence of an H II region southwest of the remnant. However, increasing the density would lead only to an increased estimate for the age.

4.2. Peculiar Linear Feature

The linear feature seen in both the 3 and 6 cm images is unusual. It is bright and present in both the 3 and 6 cm images, and it is not associated with any filaments in the remnant. The data used to create the maps shown in Figure 1a–1b was taken on five separate observing nights, spaced over a 3 month period, and when maps were made from each individual data set, the linear feature appeared in every one. Thus, it is extremely unlikely that it could be an instrumental problem. Our conclusion is that it is a real feature that requires explanation.

One question that needs to be addressed is whether the feature is actually associated with the remnant or is the result of a line of sight coincidence. Recall that the data indicate a shallow spectral index for the feature, similar to the spectral index for the whole remnant. If the linear feature is a jet, as from a radio galaxy along the line of sight, one would expect to find a much steeper spectral index (e.g., Jarvis et al. 2001). Also, if a radio galaxy is responsible for the linear feature, we might expect the galaxy itself to appear in the images. There is no evidence for a point or extended source at either end of the linear feature in either the radio or the optical images. In addition, the linear feature is aligned radially with the center of the remnant. Such a chance alignment is unlikely unless the feature is physically associated with the SNR.

We conclude that this linear feature is most likely to be physically associated with the remnant. If indeed this is true, the mechanism by which this emission is created must be energetic enough to account for the observed radio emission while low enough in energy not to produce detectable optical or X-ray emission. Other key constraints are the lack of a point source anywhere along the linear feature, the centrally concentrated nature of the emission at all wavelengths, and the wedgelike morphology of the linear feature.

![Polarization map of the linear feature in N206 at 6 cm](image)
4.2.1. Constraints on the Physical Origin of the Linear Feature

We have considered several possible mechanisms that might give rise to the linear feature and find that the available data powerfully constrain these scenarios. For example, a key constraint arises from the spectral index information and the filled radio morphology, which lead us to classify the remnant as Crab-like. The synchrotron emission from Crab-like remnants is powered at least in part by a pulsar, although the pulsar is often not detected. Thus, any explanation of the remnant should include a pulsar. Moreover, the central X-rays and the filled-center radio morphology seem to require that the pulsar remains near the center of the remnant.

The data thus drive us to explain the linear feature in a model with a centrally located pulsar. The first possibility is that the feature is a radio jet from the central pulsar. There are two major problems with this notion. First, the feature is widest near the center and is very narrow at its farthest end (see Fig. 4), the opposite of what would be expected from a jet emanating from a central pulsar. Also, the feature appears to start at approximately 6 pc (25") from the center of the remnant, which is unlikely for a jet created by a pulsar that originated in the center of the SNR. If it is indeed a jet, it must be rather energetic to be bright out to approximately 13 pc away from the emitting source. Such a bright emitting source aligned in the plane of the sky should have an equally bright jet on the opposite side; such emission is not observed. If the jet is not aligned in the plane of the sky, the opposite jet may not be visible because of Doppler beaming; yet there might still be emission from any material that interacts with the relativistic particles in the jet, which is not observed. It is also unlikely that the relativistic expansion of material needed for Doppler beaming would exist that far from the emitting source. In addition, any inclination to the plane of the sky would mean that the size of the jet is greater than 13 pc, and thus it would have to be more energetic. The more energetic the feature, the more likely it would be to appear in optical and X-ray bands.

Another alternative to account for the enhanced synchrotron emission is shock excitation. A shock wave can create a density enhancement in the remnant’s material. This density enhancement will also cause an enhancement in the magnetic field as the field lines are compressed. The shape of the linear feature supports the notion that it was created by an object moving supersonically through the ambient interior of the SNR and creating shock waves. Figure 4 shows that there is a correlation between the FWHM of the linear feature and its distance from the remnant’s center. If indeed the object originated in the center and moved toward the edge of the remnant at greater than the sound speed, we would expect to see a feature with this shape.

From the opening angle of the feature, we can determine the Mach number at which the object is traveling and compare the resulting length and time scales with the estimated lifetime stated previously. If this is a bow shock (because of motion in the plane of the sky), then the Mach number, \( M \), is \( M = \left[ \sin(\theta/2) \right]^{-1/2} \), where \( \theta \) is the full opening angle. From a linear regression, \( \theta = 0.222 \pm 0.013 \) radians, giving a Mach number of 9.0 \( \pm \) 0.5. If we use \( \sim 10^5 \) K as a representative temperature for the remnant, this leads to a spatial velocity for the moving object of around 800 km s\(^{-1}\). If the jet is inclined to the plane of the sky, the Mach number and velocity increase by roughly a factor of \( (\sin i)^{-1} \), where \( i \) is the inclination angle measured relative to the line of sight.

The eastern edge of the feature is 80° from the remnant’s center, corresponding to a linear distance of 19.4 pc. This leads to an age of 23,000 yr for the remnant if the object originated in the center and maintained a nearly constant velocity. Given the uncertainties, this estimate is consistent with that found above for the SNR expansion.

Since there is consistency between the shape and the likely dynamical age for the feature, we proceed by speculating about what type of object was responsible for its creation. If a pulsar is not responsible for creating the linear feature, then from the arguments made above the most likely candidate is a companion star. From the nearly circular shape of the remnant, we make the assumption that the explosion site was very near the geometric center of the radio emission. The inferred companion velocity of 800 km s\(^{-1}\) places strong constraints on the binary system. Since the kick velocity of the pulsar must be small, the companion velocity must be due to its orbital motion. But in this case, the separation between the stars is very close: \( a \sim 3 \; R_S \left( M_f / 10 \; M_{\odot} \right) \), and thus we demand a very tight binary system. To avoid tidal destruction of the stars requires that they be relatively dense, with a massive primary having \( \rho \gtrsim 5 \; g \; cm^{-3} \), which is far higher than in a normal supergiant. We are thus forced to require that the pre-supernova be in a dense form of a bare helium (or CO) core, and thus we also demand a relatively dense companion—either a low-mass main-sequence star or a compact object.

In fact Nomoto et al. (1994) have proposed an evolutionary path that would lead to such systems and suggest that these might be the progenitors of Type Ic supernovae. Nomoto et al. estimate that the frequency of such events is about \( \sim 9\% \) the rate of Type II events. Thus, while these systems would be rare, they would not be inordinately so. Consequently, we speculate that N206 could be the remnant of a binary system that led to a Type Ic supernova, with a low-mass main-sequence or compact companion (white dwarf or neutron star) that has led to the peculiar linear feature.

While this model is able to explain the X-ray and radio morphologies, it is unfortunately not yet adequate to reproduce all the observational results. The passage of the star will produce shock waves analogous to those in a shell-type supernova remnant, in which the shock waves will propagate through the surrounding material, causing compression of that material and increased synchrotron emission. Typically, the brightest emission is expected from the shock front. Thus we would expect the production of a conical structure whose point is located at the position of the moving star. The propagating shock wave marks the outer surface of the cone. Since the cone would have a relatively evacuated center and a density enhancement behind the shock, we would expect to see an edge-brightened morphology, as in a shell-type supernova remnant. However, the brightest part of the linear feature is along the central line of the feature rather than at the edge of the wedge shape (center-brightened rather than edge-brightened). Possibly the interaction of the moving star with the supernova remnant’s material causes a large portion of the particles to become trapped at or near the center of the conical feature, rather than being carried along by the shock front, or the particles are allowed to diffuse back into the center of the cone. Perhaps the nonuniform magnetic field pattern and possible clumping found from the polarimetry data above can help to diffuse the particles back into the center of the linear fea-
ture, creating the center brightening. This line of reasoning requires further study.

5. CONCLUSIONS

We present high-resolution ATCA images of the LMC supernova remnant N206 at 3 and 6 cm wavelengths. The remnant is roughly circular and centrally brightened in the radio, with a possible radio shell. Observations at X-ray wavelengths show a centrally filled morphology. The optical observations show bright filaments around the edges, forming a full optical shell.

We found integrated flux densities of 0.52 and 0.49 Jy at 6 and 3 cm, respectively. These values are consistent with previous radio measurements. Overall, the radio data indicate a spectral index $-0.20 \pm 0.07$ for the remnant, typical of a Crab-type SNR.

Most peculiar to this SNR is the detection of a narrow linear feature seen in radio but undetected at other wavelengths. The feature has a roughly constant opening angle of 12°, stretching from inside the eastern edge of the remnant and becoming lost in the noise near 25° from the center of the remnant. Taking 50 kpc as the distance to the LMC, the feature is 13 pc in length.

The first polarimetric maps were made for the remnant. We found linear polarization on the linear feature, the only region bright enough for reliable measurements. The polarized intensity was roughly 15% over the linear feature where the signal-to-noise ratio was larger than 3 $\sigma$. The magnetic field seems to be aligned along the feature with a twist in the center. The polarimetry map is reliable only in the vicinity of the linear feature so a magnetic field map for the entire remnant could not be made.

From the observational data, we were able to place several constraints on our proposed model for the linear feature. From the center-filled radio morphology and spectrum, we conclude that a pulsar should exist in the SNR. Since bright X-ray emission is generally associated with a pulsar, the pulsar is not likely to be located at either end of the linear feature where little X-ray emission is detected. Rather, the X-ray emission near the center of the remnant led us to choose a model in which the pulsar is spatially coincident with the strongest X-ray emission.

To satisfy the above constraints, our proposed model to explain the presence of the linear feature is the passage of a low-mass stellar object through the remnant’s material at approximately Mach 9.0, which corresponds to 800 km s$^{-1}$ for a medium at 10$^6$ K. The resulting shock waves produce density and magnetic field enhancement behind the object, causing the enhanced synchrotron emission. From the lack of X-ray emission associated with the feature, we speculate that the object responsible is a low-mass companion star to the supernova progenitor that was ejected from the tight binary system at the time of the explosion. Such a scenario has been proposed for Type Ic supernovae. This model is still insufficient to properly explain all the observations, particularly the lack of limb brightening in the wedge-shaped feature.

Better constraints on the proposed model can be made when higher resolution X-ray images and X-ray spectra become available for the remnant. The discovery of a pulsar in the remnant may clarify the situation and should help to constrain the model discussed above.

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We present high-resolution ATCA images of the LMC supernova remnant N206 at 3 and 6 cm wavelengths. The remnant is roughly circular and centrally brightened in the radio, with a possible radio shell. Observations at X-ray wavelengths show a centrally filled morphology. The optical observations show bright filaments around the edges, forming a full optical shell.

We found integrated flux densities of 0.52 and 0.49 Jy at 6 and 3 cm, respectively. These values are consistent with previous radio measurements. Overall, the radio data indicate a spectral index $-0.20 \pm 0.07$ for the remnant, typical of a Crab-type SNR.

Most peculiar to this SNR is the detection of a narrow linear feature seen in radio but undetected at other wavelengths. The feature has a roughly constant opening angle of 12°, stretching from inside the eastern edge of the remnant and becoming lost in the noise near 25° from the center of the remnant. Taking 50 kpc as the distance to the LMC, the feature is 13 pc in length.

The first polarimetric maps were made for the remnant. We found linear polarization on the linear feature, the only region bright enough for reliable measurements. The polarized intensity was roughly 15% over the linear feature where the signal-to-noise ratio was larger than 3 $\sigma$. The magnetic field seems to be aligned along the feature with a twist in the center. The polarimetry map is reliable only in the vicinity of the linear feature so a magnetic field map for the entire remnant could not be made.

From the observational data, we were able to place several constraints on our proposed model for the linear feature. From the center-filled radio morphology and spectrum, we conclude that a pulsar should exist in the SNR. Since bright X-ray emission is generally associated with a pulsar, the pulsar is not likely to be located at either end of the linear feature where little X-ray emission is detected. Rather, the X-ray emission near the center of the remnant led us to choose a model in which the pulsar is spatially coincident with the strongest X-ray emission.

To satisfy the above constraints, our proposed model to explain the presence of the linear feature is the passage of a low-mass stellar object through the remnant’s material at approximately Mach 9.0, which corresponds to 800 km s$^{-1}$ for a medium at 10$^6$ K. The resulting shock waves produce density and magnetic field enhancement behind the object, causing the enhanced synchrotron emission. From the lack of X-ray emission associated with the feature, we speculate that the object responsible is a low-mass companion star to the supernova progenitor that was ejected from the tight binary system at the time of the explosion. Such a scenario has been proposed for Type Ic supernovae. This model is still insufficient to properly explain all the observations, particularly the lack of limb brightening in the wedge-shaped feature.

Better constraints on the proposed model can be made when higher resolution X-ray images and X-ray spectra become available for the remnant. The discovery of a pulsar in the remnant may clarify the situation and should help to constrain the model discussed above.

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