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The Radio Spectral Index of 3C58

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Abstract.

We report on 74 MHz and 330 MHz VLA observations of the plerionic supernova remnant 3C58. The radio spectral index, α, is uniform across the remnant to within 0.18, indicating a single source for the accelerated electrons. We find no emission from any shell surrounding the remnant. Our 3σ brightness limit on shell emission surrounding 3C58 is $< 1.3\times10^{-21}$ W m^{-2} Hz^{-1} sr^{-1} at 330 MHz.

1. Introduction

Plerionic, or filled center supernova remnants (Weiler 1983) have become established as a class, for which the Crab Nebula is taken as the prototype. The remnant 3C58 has often been described as the Crab's twin. It has a similar radio morphology (Green 1986, Reynolds & Aller 1988), and has a similarly flat radio spectral index, α, of -0.10 ± 0.02 from 40 MHz to 15 GHz (Green, 1986; $S \propto \nu^{\alpha}$). 3C58 is at a distance of 3.2 kpc.

Plerions are thought to be powered by pulsars, which inject relativistic particles and magnetic field into the remnant. The injection and acceleration processes are not yet well understood. In addition, in the case of 3C58, the basic energetics of the remnant are still problematic. 3C58 has been moderately well identified with SN1181. While this association is consistent with optical radial velocities of < 900 km s^{-1} measured for the filaments, the age of only 819 years, along with the distance of 3.2 kpc imply a rather low energy supernova event. This suggests that there may be an as yet undetected shell around 3C58.

2. Observations, Data Reduction and Results

We observed 3C58 using the A and B configurations of the NRAO Very Large Array (VLA) at 74 and 330 MHz. In order to better eliminate radio frequency interference (RFI) we observed in spectral line mode. The data were calibrated

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and reduced using NRAO's $\mathcal{AIPS}$ software package[1]. RFI is a significant problem, especially at 74 MHz and we developed an experimental AIPS task KILRF in order to remove some of the RFI[2]. The maps of 3C58 at 330 and 74 MHz are shown in Fig. 1, and Fig. 2 (left) respectively.

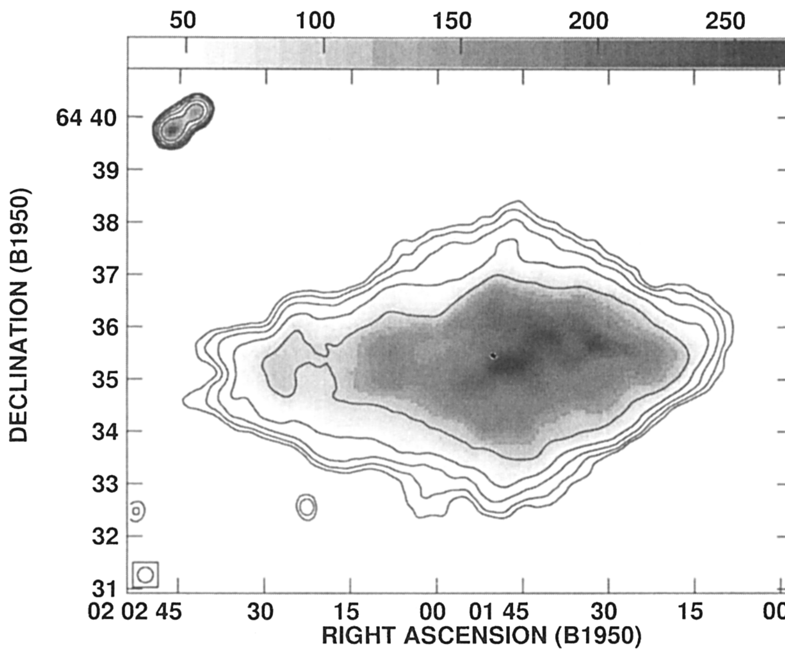

Figure 1. Image of 3C58 at 330 MHz. Flux density is in m Jy beam^{-1}, and the contours are drawn at -2, 2, 4, 8, 16 and 32% of the peak brightness. The FWHM size of the restoring beam was 17.5″ (shown at lower left) and the background rms was 1.2 m Jy beam^{-1}.

We also made a map of the spectral index between 74 MHz and 330 MHz, α, which is shown in Figure 2 (right). Over the remnant, the a mean value of α was -0.04, with rms variations of 0.18. No specific structure is apparent in the the α map. In particular, no steepening towards the edge of the remnant is observed, and no point source near the center is observed.

The evenness of the spectral index over the remnant suggests a common origin for the radio emitting electrons, presumably the neutron star in the center of 3C58. If there is a shock at the outside edge of the remnant, than the efficiency

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[1] See `http://rsd-www.nrl.navy.mil/7213/lazio/tutorial` for an introduction to 74 MHz data reduction.

[2] KILRF can be obtained from M. Bietenholz, `michael@polaris.phys.yorku.ca`

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of accelerating electrons there must be small, since we see no sign of the steeper spectrum associated with shock acceleration.

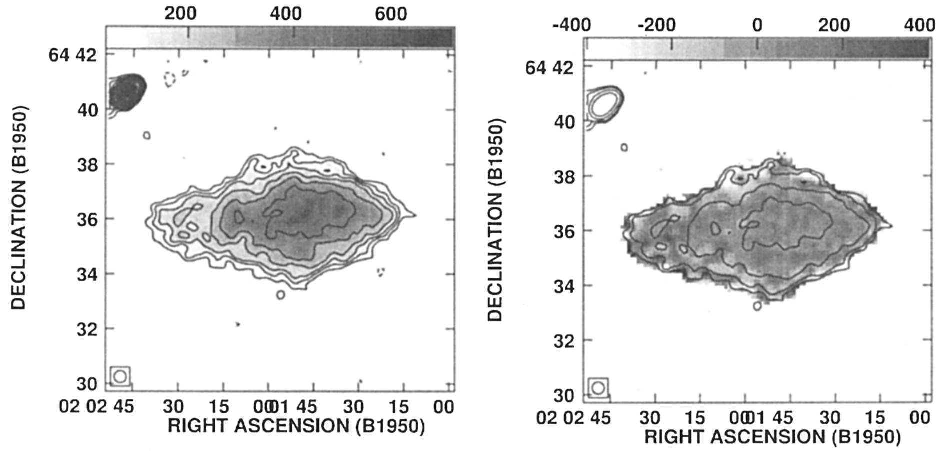

Figure 2. Left: An image of 3C58 at 74 MHz. The flux density scale is in m Jy beam^{-1} and the contours are drawn at -60, 60, 100, 150, 200, 300, 400 m Jy beam^{-1}. The FWHM resolution is 26″ (shown at lower left), and the background rms level was 20 m Jy beam^{-1}.
Right: the spectral index of 3C58 between 74 and 330 MHz at the same resolution (greyscale), with overlaid contours in flux density at 74 MHz at 60, 100, 200 and 400 m Jy beam^{-1}.

3. A Shell around 3C58?

The low energy in the remnant itself leads us to expect that there may be a rapidly moving shell present. Convincing arguments for the existence of such a shell outside the Crab have been given by Sankrit & Hester (1998), although no radio emission from it has yet been detected (Frail et al. 1995; Bietenholz et al. 1997). No sign of radio emission from a shell around 3C58 has yet been detected either, despite several searches, notably by Reynolds & Aller (1985).

In order to emphasize faint extended structures, we convolved our naturally weighted, 330 MHz image with a 3.3′ beam. The convolved image has a background rms of 46 mJy beam^{-1} and is shown in Fig. 3. No sign of a shell is visible.

Thus we can place 3σ limit on any shell emission $< 3\mu$Jy arcsec^{-2}, or $< 1.3\times10^{-21}$ W m^{-2} Hz^{-1} sr^{-1}. On a similarly convolved 74 MHz image, the background rms was 0.52 Jy beam^{-1}, resulting in a 3σ limit on extended structure of $< 5.7\times10^{-21}$ W m^{-2} Hz^{-1} sr^{-1} (scaled to 330 MHz using an assumed α for the shell of 0.6).

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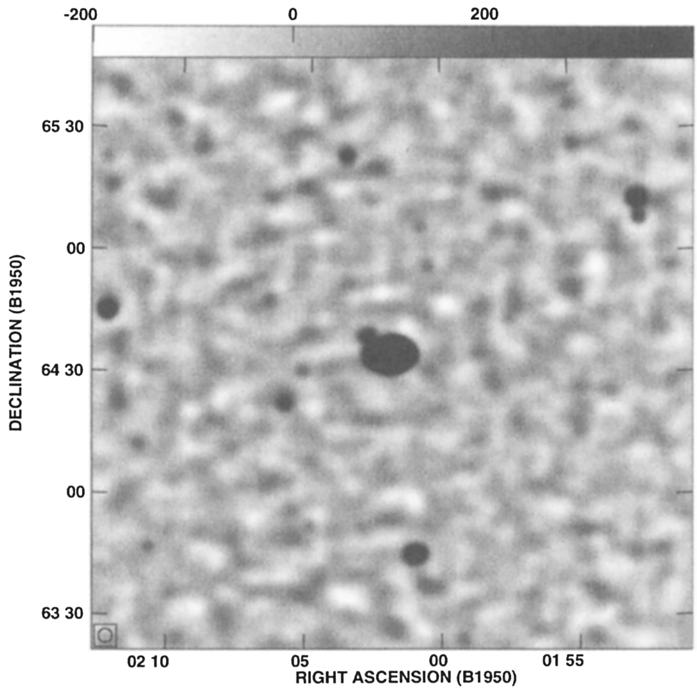

Figure 3. A low resolution image of the 3C58 field at 330 MHz, showing the absence of any shell structure surrounding the remnant. Flux density is in in m Jy beam^{-1}. The convolving beam size was 3.3′ (shown at lower left), and the background rms is 46 m Jy beam^{-1}.

In comparison, Reynolds & Aller (1985) obtained a limit of $< 1.1\times10^{-21}$ W m^{-2} Hz^{-1} sr^{-1} (again scaled to 330 MHz with an assumed shell α of 0.6). However, they were only sensitive to shells with angular diameters, D, of $< 30'$, whereas the wider field of view at 330 and 74 MHz means we are sensitive to much larger shells. While these limits are much fainter than known shell remnants, our knowledge of faint shells is almost certainly incomplete.

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