A SEARCH FOR SHELLS AROUND CRABS

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Abstract

Prior to conducting a survey of the galactic plane at 327 MHz using the VLA[1], we have imaged four fields near galactic longitude of 20 degrees. Each image will cover a 2.5 degree field with ~1 arcmin resolution. The fields have been chosen to include the remnants G20.0-0.2, G21.5-0.9, and G24.7+0.6. The first two are isolated Crab-like objects, that is, there is no discernible associated shell. Since such shells have relatively steep spectra, images at 327 MHz will be more sensitive to their presence. The absence of a shell can constrain the density of the ISM in the vicinity of the SNR (Reynolds and Aller 1985 A.J. 90, 2312). Since ~50% of Crabs are naked, the implications can be extended to a significant fraction of the ISM.

Introduction

Several hundred years after exploding most supernova remnants(SNR) are observable as a result of the interaction between the expanding shell of ejecta and the interstellar medium (ISM). They appear as coincident shells of nonthermal radio emission and thermal x-ray emission. In stark contrast to this, the Crab Nebula is visible as a result of the acceleration of relativistic electrons (and positrons) by the Crab Pulsar, appearing as a source of nonthermal radio and x-ray emission with a filled-center brightness distribution. Over the last 10 years, approximately 15 additional sources similar to the Crab Nebula (Crab-like remnants) have been identified, representing ~10% of the known SNR (Helfand and Becker 1987). Of these Crab-like remnants, half show evidence of a surrounding shell and half do not. The absence of a shell in these sources is something of an embarrassment if you believe pulsars form in Type II SN which presumably yield a high mass of ejecta. Alternatively, the lack of a shell could be indicative of the local environment around the supernova. In this paper we present new 327 MHz radio observations of two Crab-like remnants, G21.5 - 0.9 and G20.0 - 0.2, and place upper limits on the presence of a surrounding radio shell. In addition, we place severe limits on any x-ray shell surrounding G21.5 - 0.9 using data from the Einstein Observatory.

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Observations

The VLA is in the process of installing 327 MHz receivers on all of its telescopes. In early 1987, we carried out a pilot program for an eventual galactic plane survey which covered four 2.5 degree fields near $l^{II} = 20^{o}$. At that time 13 telescopes were available at 327 MHz. Observations were taken in C and D arrays resulting in images with ~1 arcmin resolution. Both sets of observations were made in spectral line mode utilizing 8 channels (7 narrow-band channels each ~400 KHz wide and 1 broad band channel). This mode is useful for isolating narrow-band interference. The seven narrow-band channels were concatenated together and treated as a single data base from which images were made. Images were obtained by first taking an FFT of the visibility data and then by using a maximum entropy routine in AIPS (VTESS) to deconvolve the array response function from the image.

Two of the fields were centered near G21.5 - 0.9 and G20.0 - 0.2 respectively and the remnants were clearly seen in the images. Generally the images contained 3-5 additional strong (>1 Jy) sources as well as many weaker sources. The observed 327 MHz radio fluxes of G21.5 - 0.9 and G20.0 - 0.2 were measured to be 6.8 and 10.7 Jy respectively, in reasonable agreement with their extrapolated spectra. The rms noise in both maps is ~0.015 Jy/25 arcsec pixel. We concluded that a shell around either source of surface brightness equal to or greater than the rms noise would have been discernible in the images. No evidence for a shell was apparent in either image and therefore we place an upper limit of 7×10^{-21} Wm^{-2} Hz^{-1} Sr^{-1} at 327 MHz for shell emission around G21.5 - 0.9 and G20.0 -0.2 out to a radius of 30 arcmin at which point confusion from neighboring sources becomes a problem.

We also re-examined the Einstein IPC (Giacconi et al. 1979) observation of G21.5 - 0.9 which lasted 4700 s. This data, originally published by Becker and Szymkowiak (1981), and taken in conjunction with observations by the HRI and SSS, revealed that the x-ray emission from G21.5 - 0.9 was nonthermal in origin as expected for a Crab-like SNR. The IPC image can be used to search for any thermal x-rays from a surrounding shell. In fact, there is no indication of an excess of counts between 5-15 arcmin where shadowing from the support structures becomes important. We conclude that the x-ray luminosity of a shell around G21.5 - 0.9 in the IPC band (0.5 - 4 keV) is less than 1×10^{27} W assuming a distance of ~5 kpc (Davalaar, Smith, and Becker 1986).

Discussion

The VLA and Einstein observations of G21.5 - 0.9 and G20.0 - 0.2 serve to reinforce the dichotomy between Crab-like objects with shells and those without shells. Our results set limits comparable to these recently obtained for 3C58 (Green 1986). As Green pointed out for 3C58, the limits on x-ray luminosity are more compelling, being a full two orders of magnitude lower than the measured values for Kepler, Tycho, and SN1006. Green understated the importance of the limits on the radio brightness of any shell emission by comparing the limits to the average surface brightness of SN1006, the faintest young remnant shell, and finding them comparable. But in reality, the shell, by its very nature, will be enhanced by a factor of four or more over the

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average surface brightness. Therefore, the limit on a radio shell surrounding 3C58 is at least 6 times smaller than the observed shell in SN1006, while limits for G21.5 - 0.9 and G20.0 - 0.2 are at least 3 times smaller.

Becker (1987) recently reviewed the current status of Crab-like SNR and listed 15 galactic SNR split 8 to 7 between "naked" Crabs and composite remnants respectively. That is to say that approximately half of the galactic remnants known to have formed active pulsars show no indication of an expanding shell of ejecta. Either the original SN failed to eject a significant amount of material or the surrounding ISM is of so low a density that the shock front is invisible.

It is of interest to speculate on the true ratio of "naked" Crabs to composite SNR in our galaxy in so far as the selection effects for the two classes are totally different. The composite SNR are usually discovered in low frequency surveys because of their steep spectra shells while "naked" Crabs are usually found by their absence of recombination lines. As noted by Helfand and Becker (1987) "five of the eight composite remnants first catalogued as a result of their bright shells, have radio core components less luminous than the lowest luminosity Crab-like objects known." Until recombination line surveys (or polarization surveys) are extended to much weaker objects, many "naked" Crabs will remain undiscovered, suggesting that the true ratio of "naked" Crabs to composite is greater than the current observational result of unity.

Alternatively, this ratio could be misleading if the Crab-like cores in composite remnants are short-lived in comparison to the shells. To test the hypothesis we compared the linear diameter of composite shells to the diameters of all other remnants using size estimates from Milne (1979) and Helfand and Becker (1987). The comparison suffers from the small number of known composite remnants. In any case, there are four composites with diameters of 20 - 30 pc and one between 30 - 40 pc (Vela) suggesting that if the cores fade sooner than their associated shells, it's not a lot sooner.

Becker (1987) and Helfand and Becker (1987) made a number of other comparisons between "naked" Crabs, composites, and shell remnants and also concluded that no clear distinctions existed between the class of shell remnants and the shell components of composite remnants or between "naked" Crabs and the Crab cores of composite remnants.

If the majority of SN which produce active pulsars do not produce observable shells, the explanation is far from obvious. We generally assume that pulsars are formed in Type II events from high mass progenitors. These stars have the ability to alter their environment through a strong stellar wind so that the SN, when it occurs, will be within a stellar wind bubble (McKee, Van Buren, and Lazareff 1984). In an extreme case of a Wolf-Rayet star which has a mass loss rate of ~2 x 10^{-5} Mo yr^{-1}, a low density bubble could extend out to ~30 pc resulting in a very weak shell. Of course, Cas A offers one counterexample where a presumed massive star created a strong shell and no observable evidence for a pulsar. This is particularly interesting in light of the conclusion of Fesen and Becker (1987) that the progenitor of Cas A was a Wolf-Rayet star.

In conclusion, the dichotomy between composite remnants and "naked" Crabs remains one of the two important questions to be addressed in understanding Crab-like remnants; the other being the seemingly low percentage of remnants which appear to exhibit Crab-like properties.

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