A NONTHERMAL SUPERBUBBLE IN THE IRREGULAR GALAXY IC 10

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Abstract: New high resolution radio continuum images of the nearby irregular galaxy IC 10 have revealed a large (> 250 pc) nonthermal source. The source is roughly circular with a spectral index of ~ -0.5, and is most likely a very large supernova remnant. Its large size suggests that it is the result of several supernovae, and may be related to the supershells observed in our own and other galaxies.

Introduction

IC 10 is a nearby irregular galaxy. Because it lies at a very low galactic latitude (-3°), its distance is very uncertain. Estimates of its distance range from as near as 1 Mpc (Roberts 1962) to as far as 3 Mpc (Bottinelli et al. 1972). Neutral hydrogen studies of IC 10 have revealed that it has an extended HI envelope which shows a velocity gradient of opposite sign to the central condensation (Cohen 1979). Klein and Grave (1986) have studied the radio continuum emission from IC 10 and have found a global spectral index of -0.33 between 1 and 10 GHz. Because the thermal free-free emission from HII regions normally dominates the radio continuum emission from irregular galaxies in the frequency range of 1 to 10 GHz, it was decided to obtain high resolution radio observations of IC 10 to search for the source(s) of the nonthermal component.

New Observations

Radio continuum observations were made at $\lambda 6$ cm with the Westerbork Synthesis Radio Telescope (WSRT) and at $\lambda 21$ cm with the NRAO Very Large Array. Care was taken to insure that the uv coverages of the two observations were properly matched, and images at an identical resolution of 5" (FWHM) were produced. Figure 1 shows the $\lambda 21$ cm image of IC 10. Several HII regions were identified by their correspondence with known Hα emission and thermal (flat) radio spectra, but an additional extended nonthermal source was also discovered. This large nonthermal source is nearly circular and is not limb-brightened. It is confused on one side where it is adjacent to a collection of HII regions. If one assumes that the major deviations from radial symmetry are due totally to confusion with the HII regions, a total flux of 39 mJy at $\lambda 21$ cm and a spectral index of about -0.5 are derived. The diameter of 0.8' corresponds to a size of 230 pc for the minimum distance estimate of 1 Mpc. This represents a truly outstanding size for a single supernova remnant, and makes it more likely that this source is a result of several supernovae. This source will therefore be referred to as a superbubble.

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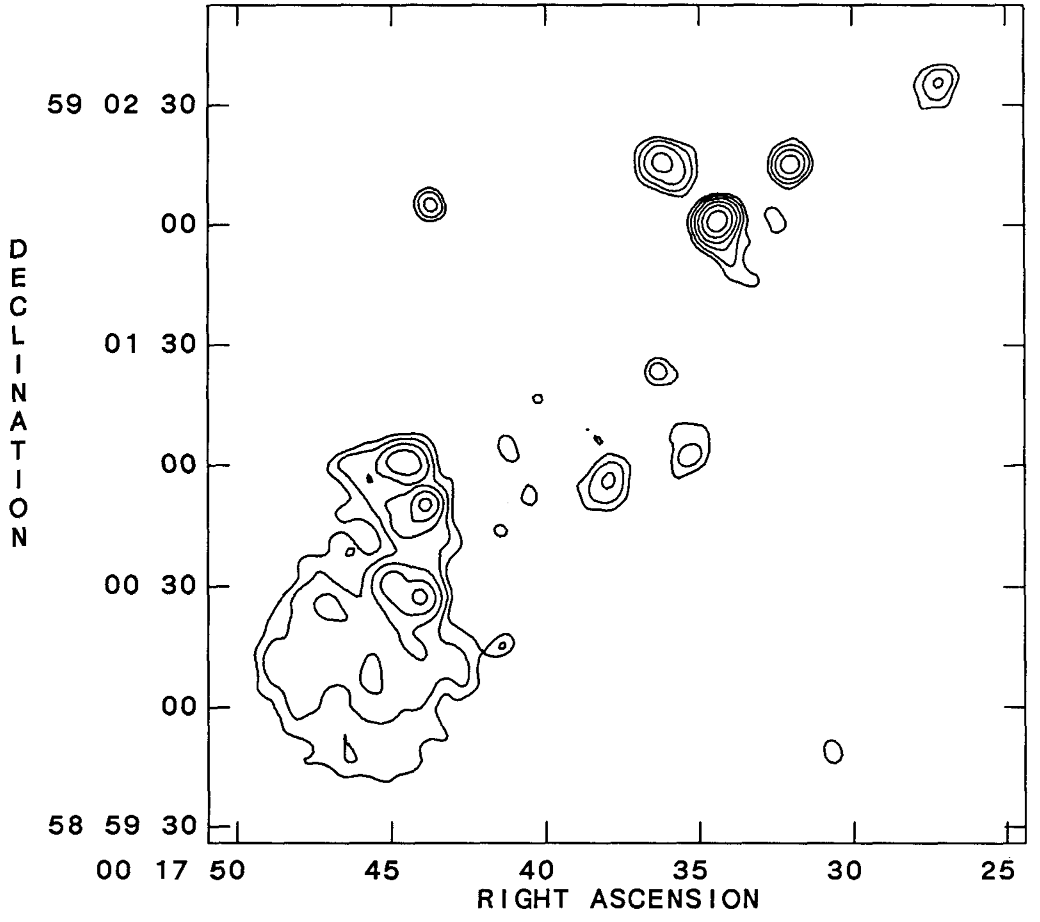

Figure 1: A λ21 cm continuum image of IC 10 at a resolution of 5". The contour levels are set at 0.2, 0.4, 0.8, 1.6, 3.2, 6.4, and 12.8 mJy/beam. The r.m.s. noise in the map is 0.05 mJy/beam. The superbubble is the large source in the lower left. All but one of the other sources are coincident with Hα emission, have thermal radio spectra, and are therefore probably HII regions.

In an effort to study the environment of the superbubble, the radio continuum images were compared with new synthesis HI observations of IC 10 made at Westerbork (Shostak and Skillman 1987). The superbubble is centered on the most massive HI concentration in IC 10. The total HI mass of this complex is 8 x 10^6 $(D/Mpc)^2$ solar masses and it is roughly four times larger in diameter than the superbubble. HI position-velocity diagrams were studied in an attempt to try to detect an interaction between the superbubble and the neutral hydrogen. Unfortunately, the velocity field in the area of the superbubble is very complex, and it is difficult to discern discrepant motions. However, there are no obvious signs of bulk motions of the neutral gas due to the interaction with the bubble.

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Interpretation

The minimum size of 230 pc lies on the border between the ranges of sizes of the HI shells and supershells discovered in our galaxy by Heiles (1976, 1979). This size is also at the large end of the distribution of sizes of the giant shells observed in the Magellanic Clouds (Meaburn 1980), although taking a larger distance estimate would make it comparable to the supergiant shells. For our galaxy, Bruhweiler et al. (1980) have shown that shells can be the natural result of the evolution of an OB association, while Heiles (1984) argues that exceptional conditions would be required to give rise to a supershell. Meaburn (1980) came to essentially the same conclusion concerning the giant and supergiant shells in the Magellanic Clouds, although Dopita et al. (1985) have shown how one supergiant shell can be interpreted as the result of self-propagating star formation. McCray and Kafatos (1987) have also discussed the creation of a supershell through self-propagating star formation.

The superbubble in IC 10 may represent evidence of a link between the giant and supergiant stage. The nonthermal emission makes it clear that supernovae play an important role, and the large size and luminosityessentially rule out a single supernova. Thus we appear to have caught a giant bubble being built by multiple supernovae. The bubble is most likely in the pressure driven phase identified by McCray and Kafatos (1987). The HII regions adjacent to the bubble may be causally connected via self-propagating star formation. Considering that the size of the HI complex that the bubble is located in is 1 (D/Mpc) kpc, this star formation event could easily propagate into a structure 1 kpc in size, leaving behind a supergiant shell.

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