RECENT RADIO STUDIES OF SNR

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I. INTRODUCTION

SNR can generally be recognized as extended sources of continuum radio emission with non-thermal spectra located near the galactic plane. The emission is synchrotron radiation from relativistic electrons which have either been accelerated or trapped in the expanding shell and its associated shocks. Early lists of remnants (e.g. Milne 1970) were culled from general catalogs of radio sources and confirmed by several other kinds of evidence including the presence of shell structure, significant polarization, lack of recombination line emission, strong optical [S II] lines, and soft x-ray emission. While a few efforts to detect more data on faint remnants are continuing (e.g. Bonsignori and Tomasi 1979; Reich and Braunsfurth 1981), about 150 SNR are now known in the Milky Way and most studies have turned to detailed investigation of specific objects to determine their energy sources, emission mechanisms, and interactions with their surroundings. These studies have shown that while most remnants fall within two general categories, standard shell and filled center, there is no unique evolution within a class and irregularities in the local interstellar medium dominate any statistical properties of individual remnants. A few objects, in particular Cas A and CTB80, do not fit within either category.

Surveys of SNR in other galaxies of the local group are now producing significant results, although the required high resolution and sensitivity have generally limited detailed radio studies to remnants identified by optical or x-ray techniques. As well as providing some statistical information on SNR, the data may be used to indicate variations among different galaxies.

In the following sections we shall describe the kinds of observations currently being obtained and what they tell us about the objects. The data include continuum observations which can reach resolutions of about 1 arcsec using aperture synthesis techniques and also spectral line observations of the interstellar matter being encountered by the remnants.

J. Danziger and P. Gorenstein (eds.), Supernova Remnants and their X-Ray Emission, 213–219.

II. SNR IN OUR GALAXY

A. Standard-Shell Objects

1. Young SNR. The radio emission from young supernova remnants can be well characterized by the map of Tycho's SNR shown by Strom (this volume). Although somewhat patchy, the basic structure is that of a quite amorphous shell. The brightest emission arises just inside a few optical filaments which probably delineate denser areas of the interstellar medium which have just been encountered by the shock. There is also faint radio emission with a very sharp edge lying a short distance outside the main bright part of the shell suggesting the presence of both a forward shock expanding into the interstellar medium and a reserve shock propagating back into the ejectum. The relativistic particles responsible for the radio emission have apparently been accelerated in situ by Rayleigh-Taylor instabilities at the shock interfaces. This acceleration approximately balances losses due to expansion as the overall flux density is decreasing only marginally. The gas has also been heated by the shocks as evidenced by a very close association of x-ray and radio morphologies. As the shock enters into the concentrations seen in the optical recombination emission they should be heated further and undergo more particle acceleration to enter the x-ray and radio emitting regimes.

The overall magnetic field structure in the young remnants has a net radial alignment although there must be much small scale turbulence as the net polarization of the emission even with the best resolution is only about 10%.

2. Older SNR. The older remnants such as IC443 or the Cygnus Loop are qualitatively different from the young objects. The radio emission arises in thin sheets or filaments which show a one-to-one correlation with optical features (e.g. Dickel and Willis 1980) and there is little or no correlation with the x-ray morphology (Watson, this volume). Recent radio observations are beginning to resolve individual filaments which appear to be the same size and shape as their optical counterparts. After the interstellar medium has been heated by the expanding shocks, thermal instabilities will produce cool, dense sheets which can then break into filaments while remaining in pressure equilibrium with their surroundings (Duin and van der Laan 1975). Increased radio emissivity is provided by the compression of the relativistic particle frozen-in magnetic fields.

The structure and conditions in the old remnants are completely dominated by the surrounding interstellar medium. This can be seen in their very irregular shapes and also in the disordered magnetic fields which are observed. The field orientations generally have quite cellular patterns and tend to merge into the general galactic background with little discontinuity (e.g. Dickel and Milne 1976). Again, the polarization percentages are somewhat small, indicating unresolved structure, although they often reach 20 - 30%, somewhat larger than in the young objects.

In a few instances we can observe the encounter of a remnant with a molecular or neutral hydrogen cloud. The spectral line data usually indicate that the cloud virtually stops the expansion, although in IC443 the presence of shocked molecular emission from within the remnant (DeNoyer and Frerking 1981) possibly suggests that the expanding shell may have overtaken a molecular cloud which is now being heated and evaporated.

3. The Relations Between Size and Brightness. Generally older, larger SNR appear to be fainter than the young ones, but there is tremendous scatter between individual objects. Remnants with the same diameters can have differences in surface brightness of over 10 to 1 (Milne 1979; Caswell and Lerche 1979) and single remnants can have sectors with radii differences greater than 3 to 1 but nearly the same surface brightness (Landecker et al. 1982). Most of the shells appear to be quite thin ($\Delta R/R$ typically 0.1 to 0.2) and there is no apparent relation between shell thickness and luminosity. Finally, as discussed above, there is a quantitative difference in the radio morphologies and also the sources of relativistic particles between the young and old remnants. The shock heating and acceleration in the young objects is very dependent upon the ejected mass and velocity plus irregularities in the ambient medium. The thermal-instability compression in old SNR will be controlled by such factors as the composition (affecting the cooling rate), the relativistic particle spectrum, the magnetic field strength and orientation in the surrounding medium, and the varying shock strengths. The transition from one phase to the other will depend critically upon the interrelationship of the various factors. We note that perhaps Puppis A may represent an intermediate stage; its radio, optical and x-ray structures are all rather filamentary but do not show good coincidence (Petre et al. 1982).

Not all of the above phenomena have been fully evaluated theoretically making it difficult to predict accurately the behavior and observed characteristics of a given remnant. Furthermore, ambient conditions can vary drastically around the galaxy and attempts to derive mean relations, such as those for surface brightness and diameter as a function of height above the galactic plane (Milne 1979; Caswell and Lerche 1979), remain fraught with large scatter. We conclude that there is neither an observational nor a theoretical basis for a unique surface brightness-diameter relation for SNR. The properties of individual remnants cannot be evaluated by this statistical approximation.

B. Crab-like SNR or Plerions

A complete review of the characteristics of these objects has been presented by Weiler (this volume). They include a filled distribution of emission from within the whole volume of the source, nearly uniform magnetic fields, and a flat radio spectrum. The power for such objects is attributed to the spindown of a central neutron star.

Recently several sources of this type have been discovered within standard-shell SNR and a number of examples are presented in this volume by various authors. In general, the compact filled feature bears little or no relation to the structure of the extended shell. This supports the idea that the pulsar-like activity may be a transient phase. An early occurence of such activity may mask the young shell stage of the SNR while a later occurrence may stay independent of the shell and decay before seriously affecting it. This leaves unresolved the question of whether every supernova produces both an ejected SNR and a neutron star.

C. Unclassifiable Objects

1. Cas A. At the current time, Cas A has several unique properties, although further detailed study of G292.0-1.8, which appears similar optically (Tuohy, this volume), or other objects may reveal additional sources of this kind. As well as being the brightest SNR (by a factor of about 100 over Tycho's), Cas A contains numerous fine scale components, many of which are unresolved with 1-arcsec resolution. The total remnant is expanding but the proper motions of individual features also show large random components (Tuffs, this volume). The overall flux density of the remnant is decreasing at about 0.7%/year (Dent, Aller, and Olsen 1974) and individual knots change rapidly. They turn on quickly and then decrease with a mean 1/e lifetime of 48 years (Dickel and Greisen 1979). Presumably much of the observed motion may be attributed to varying excitation and acceleration in the interacting wakes of rapidly moving optical filaments rather than physical motion of the emitting material. Hopefully further monitoring will tell us in detail just how the object is changing and whether we may be viewing a very irregular circumstellar envelope which is slower than most young SNR to arrive near adiabatic equilibrium, perhaps an extreme case of multiple reverse shocks, or some other phenomenon.

2. CTB80. This amazing non-thermal galactic radio source contains a filled central object with faint edge brightening (Dickel et al. 1981). The brightest spot corresponds with what may be a point x-ray souce (Becker, Helfand, and Szymkowiak 1982). The central feature has an angular extent of about 1 arcmin and sits on a plateau which appears to trail off almost like a wake toward the east for over 30 arcmin. Finally, three jets extend outward 40 arcmin from the core toward the north and southwest without any apparent symmetry (Angerhofer et al. 1981). Very likely, multiple events are involved but the cause of the jet-like structures remains a mystery.

III. SNR IN OTHER GALAXIES

Currently available radio telescopes now allow the detection and even mapping of SNR in other galaxies within the local group but high sensitivity and resolution measurements have so far been limited to small selected regions. Therefore the most complete investigations have relied upon identification of the SNR by other techniques. In the Magellanic Clouds, Mills (this volume) has used the x-ray surveys by the Einstein Observatory (Long, Helfand, and Grabelsky 1981; Seward and Mitchell 1981). A plot of number versus diameter suggests that most remnants are still in a nearly free-expansion phase with little retardation by the surrounding interstellar medium and are thus younger than previously estimated. In M31, Dickel et al. (1982), using a list of optical candidates based upon bright [S II] emission (D'Odorico, Dopita and Benvenuti 1980), tentatively conclude that the SNR in that galaxy are on the average several times fainter at radio wavelengths than their counterparts in the Milky Way. Although we do not know of any biases in the radio properties of SNR in our own galaxy caused by optical or x-ray selection criteria, we are sampling only a fraction of the total number of renmants in these other galaxies and there could be serious deficiencies. Any conclusions must be treated with caution until we are certain of an unbiased list of sources.

IV. CONCLUDING REMARKS

In this review we have deliberately avoided attempts to redo various statistical analyses to determine such parameters as the supernova rate. Although a few new remnants have been found in the past ten years, the basic numbers have remained unchanged and the detailed investigations have revealed that many assumptions of uniformity and unique evolutionary scenarios do not appear to be valid. Further progress will require considerably more observational and theoretical work on just what governs the dynamics and emission processes in the remnants. The new data are beginning to tell us exactly where the radio emission arises and how the varying conditions in the interstellar medium affect the expansion. It is now important to collect such information for many remnants spanning a full range of ages and properties. Then we can determine where each remnant fits into the over evolutionary pattern. On the theoretical side, we need more magnetohydrodynamic calculations on how structures of various sizes can form and dissipate and the effects of shocks on regions with different physical conditions.

Even with a more complete understanding of the physical processes occurring in SNR, it will be difficult to improve statistical studies because of the uncertainty in distances to most remnants. This limits the determination of their true sizes and absolute luminosities. In addition, measurement limits which depend upon size and brightness are functions of position within the Galaxy, making it difficult to establish any true physical variations in galactic distribution. Both of these problems can be avoided by studies of other galaxies whose SNR are all at essentially the same distance from the observer. As mentioned above, we now have the means to acquire the large well-calibrated data bases necessary for such studies, although the project will require long term systematic surveys with major synthesis instruments. The prospect of obtaining such answers should certainly justify the effort.

In summary, current radio studies of SNR in the Milky Way are providing us with exciting new details of the emission processes and dynamics of such objects in all stages of their evolution and we look forward to refined statistical analyses based upon complete samples of the SNR in external galaxies.

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DISCUSSION

R. P. KIRSHNER: Isn't it likely that remnants selected optically (like the M31 remnants) will be fainter, on the average, than remnants selected by radio means as in our galaxy?

S. VAN DEN BERGH: In our galaxy, the bias in favor of radio-bright SNR's can be avoided by looking only at objects with 90° < ℓ < 270°

because most all of these remnants are seen at both radio and optical wavelengths.

W.P. BLAIR: It is interesting that even the early, low resolution radio surveys had the sensitivity to detect objects similar to Cas A or the Crab Nebula in M31, yet none have been found! This seems to be another indication that things are different in M31.

J.R. DICKEL: There are some point sources in the 5C3 and Westerbork surveys which could be such objects, but they have not yet been followed up optically. There are also a number of sources in these surveys which are clearly too bright to be any form of standard SNR and are probably unassociated with M31.