RADIO STUDIES OF SUPERNOVA REMNANTS: PATTERNS AND STATISTICS

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Abstract: Most supernova remnants (SNRs) in our galaxy have been discovered from their radio emission and for the majority this remains the only means of studying them. In this review the impact of new radio observations is discussed.

The increased detail of recent radio maps reveals some common patterns among SNRs, despite their generally diverse appearance. The patterns can give us clues to both the intrinsic properties of the supernova and the influence of the interstellar medium. With a fuller understanding of individual remnants, there are better prospects for meaningful interpretation of statistical studies.

1. INTRODUCTION

My objective is to discuss recent radio observations and to assess what they tell us about the supernova and what they reveal about interactions with the interstellar medium (ISM).

From the earliest studies of radio supernova remnants (SNRs) it was clear that the majority were shells (appearing as bright rings in projection on the sky), the Crab nebula being a notable exception. However, the quality of the maps used in early analyses (e.g. Milne,1970; Downes,1971; Clark and Caswell,1976) ranged from those showing considerable detail to others where only a crude flux density, angular size, and spectrum were available. With improved maps it has become possible to recognise more examples of centrally concentrated remnants resembling the Crab nebula (e.g. Caswell, 1979; Weiler,1983; Wilson,1983) and also 'composite' remnants which exhibit a flat-spectrum (Crab-like) central feature, enveloped by a steeper-spectrum shell (e.g. Clark et al.,1975; Helfand et al.,1986). A comparison with the Crab nebula suggests that centrally concentrated emission is excited by an embedded neutron star (pulsar). In contrast, emission from the shells of SNRs originates near the shock front where ejecta interact with the swept up interstellar medium (or circumstellar material); a fraction of the kinetic energy is converted to synchrotron radio emission by the amplification of magnetic fields and the acceleration of electrons to relativistic energies, probably by turbulence.

The increased detail seen in the latest radio maps reveals marked deviations from simple shells, and also hitherto unrecognised patterns. Spectral line radio maps of nearby HI and CO also have been used to study

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the impact of the expanding shell on the surrounding interstellar medium. I will deal first with these observations and then turn to investigations of a statistical nature - how useful are they and what do they tell us? Finally I will look ahead to the problems that will need to be tackled next.

2. RADIO CONTINUUM OBSERVATIONS

New observations show continued steady improvements with respect to:

a) Higher angular resolution for bright small-diameter remnants.

b) Increased sensitivity to large-diameter low surface-brightness remnants.

d) Modest improvements in the high-frequency (Mezger at al.,1986) and low-frequency (Odegaard,1986a,b) extremes at which maps are attainable without excessive loss of sensitivity or resolution respectively.

e) Improved dynamic range in maps - permitting much better recognition of faint detail. This has been assisted by new data presentations using grey scales and colour.

f) Improved algorithms (Masson,1986) facilitating proper motion measurements for additional remnants, and ultimately contributing age estimates for more remnants (see 5.1).

2.1 New measurements of known remnants. In some cases, new maps of remnants that previously had indeterminate morphology now enable us to classify them as shells, Crab-like or composite. The following examples illustrate typical results flowing from the new measurements.

a) VLA maps of Cas A with unprecedented resolution (Braun et al.,1987) permit the study of the miniscule changes that occur on a timescale of just a few years.

b) Wide-field mapping with the DRAO synthesis telescope at low frequency (408MHz) permits maps of low-brightness, large-diameter remnants in confused regions such as HB3 (Landecker et al.,1987).

c) Single-dish mapping at high frequency has led to the recognition of more Crab-like remnants (Reich et al.,1984). Basket-weaving mapping techniques yield good sensitivity over the field covered by very large SNRs such as S147 (Furst and Reich,1986).

d) Many of the southern galactic SNRs have now been surveyed by the MOST, which provides a good combination of resolution and sensitivity; references to the bulk of these observations are given by Milne et al.(1985).

2.2 Newly discovered remnants. There is a slow trickle of newly discovered remnants - both shell and Crab-like. The brighter fairly large-diameter shells have mostly been found already, but detailed comparisons of high-resolution radio maps over a wide frequency range, and comparisons with IR data should allow the trickle of new ones to continue (Haslam and

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Osborne,1987). Extension of sensitive radio surveys to larger distances from the galactic plane is also paying dividends, as reported by Reich and Furst (1987,this colloquium). The wide fields achieved from single-dish basket-weaving (Bonn) or from synthesis telescopes (at DRAO) now make it feasible to search thoroughly for new remnants at large displacements from the galactic plane, where the expected low yield has previously discouraged such searches. New high-latitude remnants will be especially valuable in providing a sample in an environment less complex than close to the galactic plane (see the discussion of 'gradients' and 'barrels' in 3.1 and polarization in 3.2).

Centrally concentrated (Crab-like) remnants, with quite flat spectra have previously been discovered in a rather haphazard way. However, the recombination line survey by Caswell and Haynes (1987) searched sources in the southern galactic plane down to a peak brightness of ~1.3 Jy (at 5 GHz, with a 4' arc beam) and revealed very few remnants, suggesting that at least above this brightness level there are very few to be found. Reich et al.(1985) argue that G54.09+0.26 is a new, albeit weak, SNR in the Crab-like category, but much of the data, including that from IRAS, seem compatible with an HII region interpretation.

Dedicated searches for faint small-diameter remnants have begun with limited success (e.g.Turtle and Mills,1984; Green and Gull,1984;1986). This is a developing problem area that I will return to later, in Section 6.

The remainder of this review will concentrate on shells and composites, to the exclusion of centrally bright SNRs, which show little evidence of interaction with the ISM.

3. PATTERNS

I now turn to some of the more subtle patterns that can be discerned. In the radio continuum at least five principal patterns have been claimed in at least some remnants. Polarization and spectral line observations also reveal patterns which I will mention briefly.

3.1 Continuum.

a) Gradients. Shell SNRs tend to be brighter on the side closest to the galactic plane (Caswell,1977). Despite individual counter-examples, new observations (subsequent to the quantitative analysis by Caswell and Lerche,1979) have reinforced this conclusion. This can be seen qualitatively from the new data summarized in Table 1 which comprises roughly equal numbers of new remnants and previously known ones (with improved observations). The sample is restricted to SNRs estimated to lie more than 50 pc from the plane. Remnants that are brighter towards the plane are in the majority.

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Table 1. Brightness gradients from new SNR observations.

SNR	Brighter towards plane?	References
G9.8+0.6	Yes	Caswell (1983)
G18.9–1.1*	?	Furst et al.(1985)
G30.7+1.0	No	Reich et al.(1986)
G33.2–0.6	Yes	Reich (1982)
G39.2–0.3	Yes	Caswell et al.(1982)
G40.5–0.5	Yes	Downes et al.(1980)
G41.1–0.3	Yes	Caswell et al.(1982)
G65.2+5.7	Yes	Reich et al.(1979)
G94.0+1.0	Yes	Landecker et al.(1985)
G340.4+0.4	Yes	Caswell et al.(1983)
G340.6+0.3	Yes	Caswell et al.(1983)
G359.1–0.5	?	Reich and Furst (1984)

*Probably a composite remnant - see papers presented at this colloquium by Furst et al. and by Barnes and Turtle.

A new analysis is now overdue and could be improved by treating separately the region of the Galaxy within the solar circle (where the disc is relatively thin and flat) and the outer region, which flares in thickness and is warped and may lead to less clearcut conclusions.

b) Barrels. In many SNRs the basically ring appearance (or inferred 3-dimensional shell structure) is modified in a regular manner to show two opposing arcs. Figure 1 illustrates an example (and is also an example of a remnant with increased brightness towards the galactic plane).

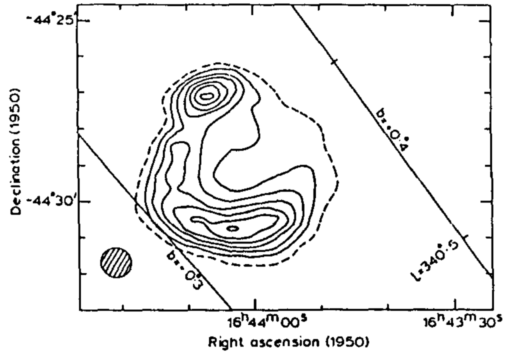

Figure 1. The SNR G340.6+0.3; it shows two opposing arcs of emission and is also brighter towards the galactic plane. FIRST map, taken from Caswell et al.(1983).

As in the example of Figure 1, there is often just one axis of mirror symmetry and it is found to pass through the regions of very low emision. The inferred 3-D structure is then a barrel, with emission from the staves but

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not the end caps. The phenomenon is common, and two interpretations have been briefly explored so far:

First by Kesteven and Caswell (1987), a proposal that the cylindrical symmetry is defined in the outburst, because the ejecta has a broadly toroidal distribution.

Secondly by Roger et al. (1987), that the magnetic field plays an important role, with the cylinder axis along the prevailing magnetic field.

Each interpretation can draw some support from other arguments, and it is possible that both mechanisms are operative. They clearly have considerable implications for not only the SN explosion, but also its interaction with circumstellar material, and subsequently with the ISM.

c) Double loops. Manchester (1987) has argued that the double loops seen in some remnants represent a distinct phenomenon which is present in many or even most remnants. The loops are regarded as enhancements of the shell emission in two annular zones. I think of this as a 'fresco' or 'graffiti' model (launched appropriately in Venice at IAU Symposium 101), insofar as the perturbations colour the appearance but are thought not to be dynamically important. The annuli might originate from a bi-conical flow from a pulsar. The most convincing example is G320.4–1.2, in which the presence of a pulsar prompted the interpretation. In some other examples, such as IC443, there are viable alternative explanations suggested by Braun and Strom (1986a); Green (1986b); and Mufson et al.(1986).

d) Scalloped boundaries. This variety of deviation from a roughly circular boundary is exemplified by IC443 (Braun and Strom,1986a) and OA184 (Routledge et al.,1986). Braun and Strom suggest that we are observing inter-connected spherical sub-shells, corresponding to stellar-wind driven bubbles which have pre-processed the ISM in the vicinity of the SNR before its outburst. This notion has been invoked to account for several other problems associated with SNR evolution, and we will return to it in Section 5. Two important implications are that the SNR in such an environment can rapidly expand to a large size before significant deceleration sets in, and that the kinetic energy inferred under these circumstances is much less than if the adiabatic expansion phase is reached at much smaller radius.

e) Jets. This term is intended to be descriptive and not to imply a particular physical process. The jet, unlike the barrel, is a quite rare phenomenon at the sensitivity level usually achieved. A quite remarkable example is shown in Figure 2 (see Kesteven et al.,1987); the jet is narrow and well-collimated and extends beyond the shell boundary for a further distance at least equal to the shell radius.

A more complex example is shown by Roger et al.(1985), in which a jet

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expands to a large plume and is exceedingly difficult to account for; a satisfactory interpetation has not yet been devised, but the large plume may be evidence of a pre-existing low-density cavity in the ISM.

Figure 2. This radio source, G315.8-0.0, is believed to be an SNR which possesses a remarkable highly collimated jet.

A search for more jets is important but we must be wary of likely misclassifications: IC443 might readily (from Green's 1986b map) have been regarded as a jet, and the apparent jets in some other remnants seem likely to be superposed extragalactic sources; (eg SN1006 - Reynolds and Gilmore,1986; and G54.5-0.3 - Caswell,1985).

In summary, it should be stressed that many of these patterns are not mutually exclusive. Gradients and barrels often co-exist; scalloping can hamper the recognition of barrels and can coexist with gradients. However some features are the subject of competing, mutually exclusive descriptions, e.g. IC443 (as remarked earlier in the context of the double loop interpretation).

3.2 Polarization. Polarization observations can be used to map the magnetic fields in SNRs. Milne (1987) reviews the current state of this work and has briefly summarized it at the present meeting. This reinforces the conclusion (first suggested many years ago) that young shell SNRs exhibit predominantly radial fields whereas old SNRs at high latitudes show fields tangential to the periphery. Old remnants near the galactic plane show a confused picture.

For comments on the situation regarding Faraday rotation and depolarization I refer to Milne's review.

3.3 Radio spectral lines. These observations have the potential for revealing the interaction of the SNR ejecta with the ISM. Over the past few years such observations have progressed greatly with the increased use of synthesis telescopes, and more efficient image-processing packages. Nonetheless, the interpretation of the mass of data is a daunting task, and looks likely to be a major bottleneck to further advances.

Studies of HI with the DRAO synthesis telescope have been made by

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Landecker et al. (1982) and Routledge et al. (1986) for example; likewise, Braun and Strom (1986b) have used the WSRT to study HI near four SNRs (see also Braun and Strom, 1986a). In several instances the observed patterns have been interpreted in terms of bubbles and thus these features are an important key to understanding interactions with the ISM.

Some of the early associations claimed for SNRs and CO seemed inconclusive but the evidence in the newer observations, such as those in the vicinity of G109.1-1.0 (Tatematsu et al.,1986; and at this meeting), seems quite compelling. The extensive studies by Huang and Thaddeus (1986) and Fukui and Tatematsu (this meeting) show probable associations for many more remnants. In some cases the systemic velocity of the CO clouds provides a useful kinematic distance for the SNR.

Because knowledge of SNR distances is so important I will briefly remark on the use of HI absorption measurements to determine kinematic distances - a technique that has been crucial for the quite young and bright SNRs that are too far away to be studied optically. Doubt was cast on these distances following marked revisions to those of 3C58 (Green and Gull, 1982) and Tycho's SNR (Albinson et al., 1986). However, such pessimism seems to be overstated. Many of the distances were determined with the Parkes interferometer more than a decade ago (Caswell et al.,1975); recent confirmatory measurements have become available with the VLA for several of these such as G29.7-0.3 (Becker and Helfand, 1984) and G21.5-0.9 (Davelaar et al.,1986); they are in very good agreement.

Within a few years we will be able to make improved measurements on the more southerly objects using the Australia Telescope.

Meanwhile, confidence in the present distance scale is provided by comparison with the Magellanic Clouds. Mills et al. (1984) show that the distance scale for the galactic SNRs (determined predominantly from HI absorption distances) is quite compatible with that of the Magellanic Cloud remnants; this is on the assumption that the distribution of remnants on the Σ - D plot is essentially similar for the two galaxies.

4. REMNANTS WITH DIFFICULT OR UNUSUAL INTERPRETATIONS

From time to time it is important to assess which remnants are really difficult to fit into a 'typical' mould. They may be so atypical as to tell us nothing about SNRs (especially if some of them ultimately prove not to be SNRs!) or they may, by exhibiting very extreme features, be a vital clue to understanding similar properties at a much lower level in all the others. My selection of remnants that may readily be misunderstood is as follows:

G166.0+4.3 The observations and discussion by Pineault et al.(1985; 1987) suggest that the two halves of this remnant appear to have evolved in quite different environments. The suggested breakout from a warm

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medium of intermediate density into a hot, low-density interstellar cavity provides a satisfactory expanation. Such a morphology is rare but the interpretation may serve to explain some other remnants not yet studied so exhaustively.

G69.0+2.7 (CTB80) For years (e.g. Salter et al.,1983) this has been the most baffling of SNR morphologies. However it would now be instructive to consider it in the light of the data on G166.0+4.3 and IC443; alternatively, Manchester claims it can be fitted into his double-loop model, and the new results presented at this meeting by Strom may also allow construction of a viable model.

G292.0+1.8 The study of this source by Braun et al. (1986) is a warning that perhaps some shell remnants may masquerade as Crabs.

G65.7+1.2 (DA495) may be an old Crab, despite some affinity with shell SNRs (Landecker and Caswell, 1983); thus some Crabs may masquerade as shells.

G263.9–3.3 (Vela) may be a simple shell rather than a composite (Milne and Manchester, 1986).

G39.7–2.0 (W50), despite containing SS433, may be essentially a typical shell (Downes et al.,1986)

G5.4-1.2 may settle into the shell category, albeit with some unusual features (Caswell et al., 1987). This source emphasises that we need a combination of high sensitivity over a quite large field size (to see the weak eastern arc), and high resolution (to recognize that the neck is a distinct feature rather than just the blending of two nearby structures).

The radio nebula surrounding Cir X-1 (Haynes et al. 1987) suggests that there may exist other similar nebulae which are not necessarily SNRs.

At the other extreme, Kepler's SNR is undoubtedly an SNR, but a novel interpretation for its appearance is suggested by Bandiera (1987).

5. STATISTICS

We might expect that the interaction of SNRs with the ISM could best be determined from detailed studies of individual remnants, but important clues can also be gleaned from the ensemble of SNRs and their statistics. Unfortunately, the interpretations are not straightforward and two major areas of controversy lie in the Σ - D (surface brightness - diameter) relation and the N - D (number-diameter) relation. Some interpretations draw on both Σ - D and N - D results but it is convenient to discuss them separately.

5.1 Σ - D relation. If there proves to be a reasonably good correlation between radio brightness (a parameter essentially independent of distance) and diameter, then this can be used to derive distances for remnants when the brightness and angular size are measured but the distance is not known. Green (1984) has been generally pessimistic about the use of the Σ - D diagram and Allakhverdiyev et al. (1983) have disputed any Σ - D - z relation. Mills (1983), from a study of the Magellanic Cloud remnants, remarks on the large scatter and suggested that perhaps a constant luminosity independent of diameter (corresponding to $\Sigma \propto D^{-2}$) fits the data; however, in the more detailed analysis of Mills et al. (1984) the steeper relation $\Sigma \propto D^{-3}$ is noted as better representing the Magellanic Cloud data, after rejection of three unresolved and two very faint remnants.

On the positive side, Huang and Thaddeus (1985) argue that there is indeed a tight Σ - D relation for SNRs in our galaxy provided that one limits the analysis to the Type II SNRs associated with molecular clouds (as traced by CO). Other SNRs may be subluminous relative to this and thus the relationship derived is the upper boundary to the population distribution in the Σ - D plane. Berkhuijsen (1986) has investigated a combined Σ - D diagram for the Galaxy, other galaxies, and even prompt emission from very young supernovae. She argues that there is a well-defined upper boundary to the distribution.

Thus despite much criticism, the Σ - D diagram does provide a useful indication of likely distances for newly discovered SNRs with no other distance determination, and provides a yardstick to gauge whether some individual SNRs are subluminous.

Physical interpretation is much more contentious. Clearly, expanding SNRs increase in diameter as they evolve; it is less clear whether the brightness monotonically decreases, although, since the large-diameter SNRs are of low brightness, they must eventually fade as they evolve.

A simple explanation of the Σ - D evolution was suggested by Duric and Seaquist (1986) and is a more detailed development of earlier models. It provides a satisfactory conventional explanation on the assumption that remnants evolve as $\Sigma \propto D^{-3}$.

In contrast, Berkhuijsen (1987) has argued that comparison of X-ray and radio brightnesses suggests a quite different radio evolution, in which SNRs expand at constant brightness (corresponding to luminosity increasing as D^2) and then fade rapidly. Mills et al. (1984) also suggest rapid fading eventually. However, if the large galactic loops are assumed to be old SNRs, the fading cannot be very rapid. Returning to the suggested early evolution:

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this could occur if the SN progenitor has generated a low-density cavity with the radio emission not reaching a peak until the SN ejecta have reached the boundary of the cavity. This interpretation has recently been favoured on other grounds but is controversial as to the origin and size of the cavity. Two possible origins are (1) the stellar wind of the progenitor, and (2) the HII region formed by its uv ionizing radiation. Berkhuijsen discounts bubbles from stellar winds, because the expected sizes are too large.

A detailed 'cavity' model for the LMC remnant N132D has been given by Hughes (1987; earlier suggestions along these lines were made by Chevalier, 1984). Hughes concludes that, for this particular remnant at least, the stellar wind bubble is, again, unsatisfactory, whereas a cavity formed by the HII region yields good correspondence with the data.

Additional support for an early phase of rapid expansion comes from G320.4-1.2 if the pulsar near its centre is indeed the core of the SN, and if the spin-down age is a valid measure, and if the distance (implying a quite large diameter) is reliable. In this case one could argue that the ejecta rapidly expanded to almost its present diameter, then was rapidly decelerated and the radio shell became bright. The non-detection of proper motion of the optical filaments (van den Bergh and Kamper, 1984) is only a slight problem, since the filaments could be regarded as dense regions of the ISM not appreciably accelerated by the shock.

If low-density cavities surrounding supernova progenitors are a general phenomenon, then the implications are considerable. Even for a small cavity size of 10 pc diameter, the cavity would be relevant to SNRs with ages up to 500 yr (assuming ejecta velocity of 10000 km/s). Not until this point would there be rapid deceleration; the subsequent evolution might then proceed roughly according to the Sedov relation. One consequence of this assumption is that very young ($\leq$ 500 yr) small-diameter SNRs might usually be undetectable since they would be in a free expansion phase with perhaps no significant radio emission.

On the other hand, in some remnants (Tycho, SN1006 - both believed to be Type I) deceleration and subsequent Sedov-like evolution has occurred at quite small diameters, requiring that any cavity in these instances be quite small. With radio maps at several epochs, sophisticated comparisons (Strom et al.,1982; Tan and Gull, 1985; Masson, 1986) should allow a determination of the expansion rate in many more SNRs.

5.2 N-D relation. The number (N) of SNRs smaller than a given diameter (D) is contentious both with respect to the data and the interpretation. If the diameter is a good measure of the age, then clearly the integral count of all SNRs up to a given age yields the rate of occurrence of supernovae. In addition, if a linear relationship between log N and log D is observed, it may be of use to infer the expansion law, D as a function of age.

Early work on SNRs in our galaxy suggested $N \propto D^{2.5}$, as expected in the adiabatic phase (Sedov relation, $D \propto t^{0.4}$). For many galactic remnants the value of D is poorly known, and has been derived indirectly from Σ. Mills et al. (1984; also Mathewson et al., 1983; Mills, 1983) showed that for the Magellanic Clouds, $N \propto D^{1.2}$, rather similar to expectations for free expansion. At face value this might suggest that the remnants we observe are indeed in the free expansion phase. In disagreement with this, there have been several alternative interpretations suggested (Green, 1984; Fusco-Femiano and Preite-Martinez, 1984; Hughes et al.,1984; and Berkhuijsen, 1987) but in every case the crucial argument is that the sample is not complete to a given age - firstly because it is not complete to even a given diameter and secondly because there is a scatter in the diameter-age relation. The latter could arise from a scatter in the energy of the ejecta, or a scatter in the ISM density, but another simple effect may be largely responsible: that the duration of the free-expansion phase is variable from source to source, causing some SNRs to become visible at quite small diameters and others not until a much larger diameter is reached. This might severely restrict the range of D over which a meaningful slope is obtainable; at still larger D there remains a completeness problem.

Note that in the simple model of Caswell and Lerche (1979), the scatter in the diameter-age relation can be corrected for because a simple analytic dependence of D and Σ on z is assumed; however, it is still necessary to assume completeness to a given diameter.

Some of the earliest suggestions that radio SNRs might be in the free-expansion phase came from Higdon and Lingenfelter (1980) and from Srinivasan and Dwarakanath (1982). Overall, it would seem fair to say that the free expansion interpretation has now met with considerable resistance and has decelerated! However, it has had the important effect of alerting us to the likelihood that even if the radio emitting remnants are not now in this phase, they may nonetheless have been in a state of free expansion for longer than hitherto realised.

6. THE FUTURE

Here I will summarize progress and problems that we expect to result from new radio observations:

a) More HI and CO studies are needed around remnants; these will help with distance estimates, and assist in understanding the interactions with the ISM.

b) More ages are needed; a contribution to this could come from proper motion studies of radio maps, which reveal current expansion rates.

c) More reliable measurements of the change of intensity with time. These might resolve disputes over the evolution of the radio brightness.

d) Better polarization data are needed to map magnetic fields.

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e) Recognition of large-diameter faint SNRs. We hope to assess whether the galactic loops are indeed just old SNRs, and whether merging of old SNRs can wholly account for the non-thermal galactic disk.

f) Recognition of small-diameter young remnants.

The last of these may be a much bigger problem than previously realised. Green (1984) has argued that appreciable numbers of young, small-diameter remnants are present in the Galaxy, as yet undetected. Others have likewise expressed optimism that many more will be found. However the controversy over the source G70.68+1.20 highlights a new problem. Green (1985) showed that the source had a shell structure and Reich et al. (1985) argued that it was non-thermal and (therefore) a supernova remnant. Green (1986a) presented new data intended to demonstrate the thermal nature of the source; but his measurement at 151 MHz reinforces the argument that it is non-thermal since the flux density (0.78 Jy) combined with the small size (20"arc) implies a brightness temperature in excess of 100000 K (much too high for thermal radiation from an HII region or planetary nebula). But if we accept the source as a non-thermal radio shell, the existence of the optical nebula counterpart noted by Green (1986a) is then difficult to understand. The lack of obscuration suggests that this optical nebula is nearby (≤ 5 kpc) in which case the 20" diameter corresponds to 0.5 pc. At an expansion velocity of 10000 km/s, this would be attained in only 25 years and it is inconceivable that such a recent SN in an unobscured region should not have been noticed (since even if the outburst were in daytime it should still have been noticeable several months later as a night-time object). Even an expansion velocity as low as 2500 km/s would not allow an age greater than 100 yr.

So do we have a new category of radio source, mimicking young SNRs? If so, other sources in this category could mislead us considerably if they lie in a direction where obscuration masks any optical clues. Two other objects invite comparison. First, the non-thermal radio emission from GK Persei = Nova Persei 1901 (Reynolds and Chevalier, 1984) suggests that nova events, despite their lower energy, might sometimes mimic supernovae in their radio emission; the new observations by Seaquist et al. (this meeting), which reveal a clear shell structure for the nova remnant, emphasise that this may be a very real problem. Secondly, the radio emission from η Car (Retallack,1983; Jones,1985), which is optically a strange variable and not readily classified, suggests that this too might be a variety of object that sometimes mimics weak young SNRs. Note that the radio intensity from η Car is 1 Jy, implying a luminosity (at 2.7 kpc) comparable to that of G70.68+1.20 , but it has not been established whether it is thermal or non-thermal; the emission from Nova Persei is clearly non-thermal but it is much weaker than G70.68+1.20.

New optical observations towards G70.68+1.20 are urgently needed to

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resolve this puzzle.

This seems to be an appropriate place to consider the relevance of SN1987a in the LMC. Barring spectacular breakthroughs in medical science, those of us here today are unlikely to be embarrassed by our predictions for the future development of the remnant. However the evolution over the next few years may well tell us much about any pre-existing circumstellar shell and the ISM; our problem then will be to assess just how typical is SN1987a and whether its location in the LMC precludes its usefulness as a model for galactic SNRs.

7. CONCLUSIONS

I will end on a positive note by describing a working framework in which to fit the present observations. It is an edifice that may need shoring up and perhaps eventually ripping down, but it is habitable at present.

The Crab-like remnants have an embedded neutron star. They display a large range in their intrinsic luminosity and show little evidence of interaction with the ISM. Where they are encased in shell remnants, some systematic differences in properties should be looked for, but could be masked by an intrinsically large scatter.

The shell remnants <u>are</u> interacting with either circumstellar material or the ISM; in the case of composite remnants, the shell component should probably be regarded in the same way as isolated shells and not greatly affected by the inner Crab-like component.

Following a supernova outburst there may be a period of several to a barrel structure.

The problem of Type I and Type II SN is as acute as ever, with no certain correspondence with distinctive radio morphologies, despite the general acceptance that Tycho, Kepler, and SN1006 were Type I, and that Cas A (and perhaps the Crab nebula) may have been Type II.

The rate of occurrence of supernovae in our galaxy remains uncertain. Existing estimates may refer to only the brightest supernovae, while sub-luminous supernovae (subenergetic with respect to the kinetic energy of the ejecta, and with subluminous radio emission) may occur more often; this is a problem likely to grow in importance in the coming years.

Since the emphasis of this review is on the observations and their immediate interpretation, I will put them in perspective with a quotation from the 1958 book 'Structure and Evolution of the Stars' by Martin Schwarzschild: - 'Pillars rather than crutches are the observations on which we base our theories'.

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