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The Galactic distribution of SNRs

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Abstract. It is not straightforward to determine the distribution of supernova remnants (SNRs) in the Galaxy. The two main difficulties are that there are observational selection effects that mean that catalogues of SNRs are incomplete, and distances are not available for most remnants. Here I discuss the selection effects that apply to the latest catalogue of Galactic SNRs. I then compare the observed distribution of 'bright' SNRs in Galactic longitude with that expected from models in order to constrain the Galactic distribution of SNRs.

1. Introduction

The distribution of supernova remnants (SNRs) within the Galaxy is of interest for a variety of reasons, not least because they are important sources of energy and high energy particles in the Galaxy. I discuss here the observational selection effects that make current catalogues of SNRs incomplete, and the difficulties in obtaining distances for most remnants. Both of these issues make it difficult to derive the Galactic distribution of SNRs directly. I present constraints on the distribution of SNRs with Galactocentric radius, by comparison of the distribution of bright remnants with Galactic longitude with those expected from simple models. These results are similar to those presented in Green (2012), but here I concentrate more on a discussion of the selection effects that apply to current SNR catalogues. In addition, the analysis presented here excludes the region near $l = 0°$, where the observational selection effects are extreme.

2. Background

I have produced several catalogues of Galactic SNRs. The earliest version, from 1984, contained 145 remnants Green (1984). The number of known remnants has almost doubled in the following 25 years, with the most recent version Green (2009a) containing 274 SNRs. Note, however, that there are many other possible and probable remnants that have also been proposed, which are briefly described in the documentation for the web version of the catalogue†. These objects are not included in the main catalogue of 274 remnants, as further observations are required to confirm their nature, or their parameters, e.g. their full extent. The largest increases in the number of identified remnants are due to large area Galactic radio surveys, e.g. the Effelsberg 2.7-GHz survey and the MOST survey, see Section 2.1.

There are two problems that make it difficult to derive the Galactic distribution of SNRs directly: (i) there are significant observational selection effects that means that the catalogue of SNRs in incomplete, and (ii) distances are not available for all SNRs. These two issues are discussed further in the next two subsections.

† See: http://www.mrao.cam.ac.uk/surveys/snrs/

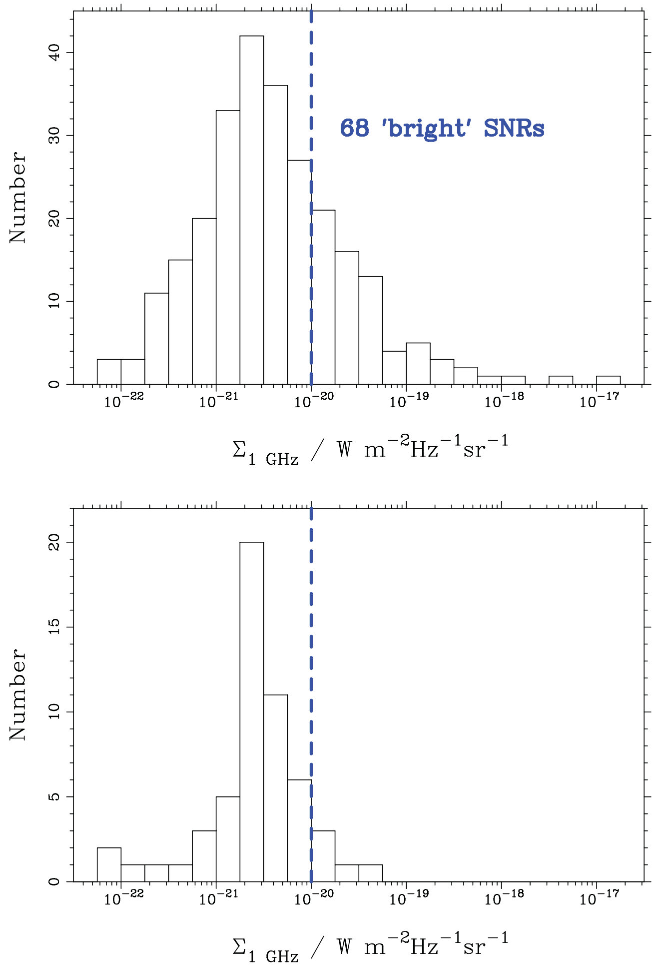

Figure 1. Histograms of the 1-GHz surface brightness of: (top) all catalogued SNRs, and (bottom) those in the area covered by the Effelsberg 2.7-GHz survey added to the catalogue since 1991.

2.1. *Selection effects*

Although some SNRs have first been identified at other than radio wavelengths, in practice the vast majority have been identified from radio observations (which, unlike the optical or X-rays, are not affected by absorption). Furthermore, it is large-area radio surveys that define the completeness of current SNR catalogues, not other (better) observations, which cover specific targets, or are of only limited areas of the Galactic plane.

For much of the Galactic plane – $358° < l < 240°$, $|b| < 5°$ – the deepest, large-scale survey is that made at 2.7-GHz with the Effelsberg 100-m telescope (Reich *et al.* 1990; Fürst *et al.* 1990). The rest of the Galactic plane has been covered by a survey at 843 MHz made with MOST. Both these surveys identified many new SNRs, see Reich *et al.* (1988) and Whiteoak & Green (1996) respectively. New remnants identified from these surveys were added to the 1991 and 1996 versions of my SNR catalogue. For a SNR to be identified it needs to be bright enough to be distinguished from the Galactic background. The approximate surface brightness limit for the Effelsberg 2.7-GHz survey is thought to be about 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz.

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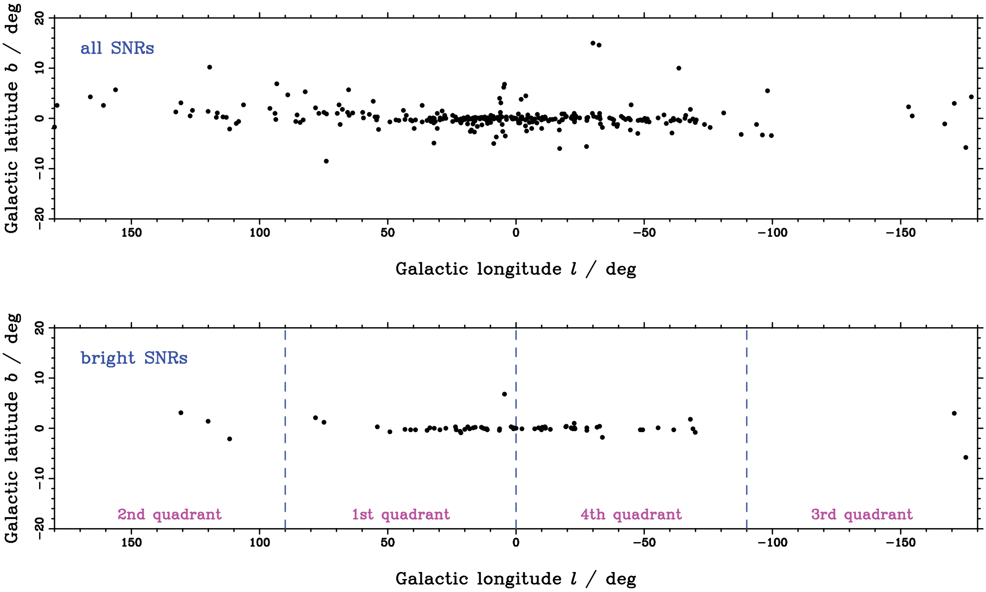

Figure 2. Galactic distribution of: (top) all 274 catalogued SNRs, and (bottom) the brighter 68 remnants, with surface brightnesses above 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz. (Note that the l- and b-axes are not on the same scale.)

Since 1991, when the new SNRs identified in the Effelsberg survey were added to the catalogue, an additional 61 SNRs have been identified in the region covered by this survey. Of these only 5 are brighter than a surface brightness of 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz (G0.3+0.0, G1.0−0.1, G6.5−0.4, G12.8+0.0 and G18.1−0.1; see Gray 1994; Kassim & Frail 1996; Yusef-Zadeh *et al.* 2000; Brogan *et al.* 2005, 2006), with the brightest being $\sim 3 \times 10^{-20}$ W m^{-2} Hz^{-1} sr^{-1}. As shown in Figure 1, the vast majority of the more recently identified SNRs in the Effelsberg survey region are fainter than 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz. The numbers of catalogued remnants with a surface brightness above 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz in the 1st and 4th Galactic quadrants are 35 and 29 respectively, which are consistent within Poisson statistics. Thus I take a surface brightness of 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz to be the approximate effective Σ-limit of the current Galactic SNR catalogue. Figure 2 shows the observed distribution in Galactic coordinates of both (a) all catalogued SNRs, and (b) the 68† SNRs brighter than the nominal surface brightness completeness limit of 10^{-20} W m^{-2} Hz^{-1} sr^{-1} at 1 GHz. This clearly shows that taking the surface brightness selection into account – i.e. considering the brighter remnants only – the distribution of SNRs is more closely correlated towards both $b = 0°$ and the Galactic Centre than might be thought if all SNRs were considered. This is not surprising, as the lower radio emission from the Galaxy in the 2nd and 3rd quadrants, and away from $b = 0°$, means it is easier to identify faint SNRs in these regions. It is most difficult to identify SNRs close to this nominal surface brightness limit in regions of the Galactic plane with bright and complex background radio emission, i.e. close to the Galactic Centre.

† Note that in Green (2012), there was an error in the surface brightness of one SNR, so that 69 remnants were above this nominal surface brightness limit to provide a sample of 'bright' SNRs. In fact there are 68 above this limit in the 2009 SNR catalogue. This difference does not change the conclusions in Green (2012) significantly.

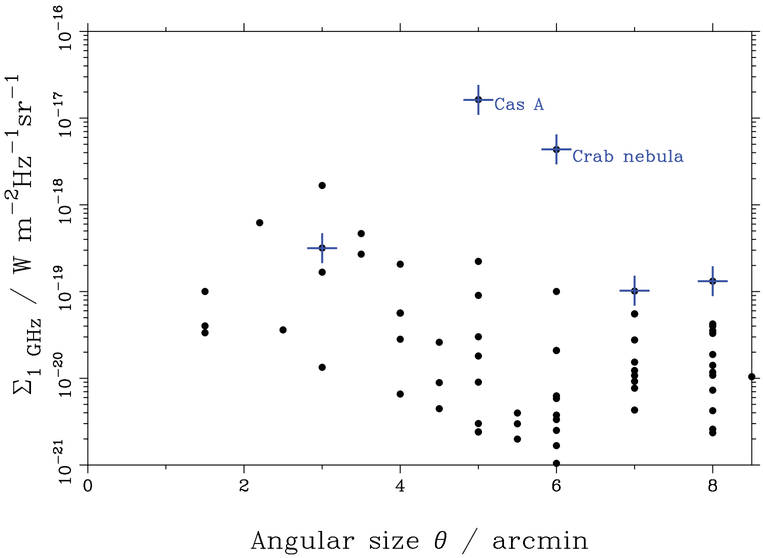

Figure 3. Surface brightness versus (mean) angular diameter for the smaller catalogued SNRs. The remnants of the known 'historical' supernovae of AD 1054 (the Crab nebulae) 1181, 1572, 1604 plus Cas A are indicated by crosses. (The remnant of the supernova of AD 1006 is not included, as it has a diameter of ≈ 30 arcmin.)

Additionally, there is a selection effect that means that some small angular size SNRs are overlooked. It is generally necessary to resolve a SNR in order to recognise it structure, but not all of the Galactic plane has been observed with sufficiently high resolution to resolve the structure of all sources. The Effelsberg 2.7-GHz survey has a resolution of 4.3 arcmin, making it difficult to recognised the structure of a remnant unless it is ~ 10 arcmin or larger in extent. This means that there is a deficit of small angular size SNRs, which is illustrated by Figure 3. This shows the surface-brightness versus angular diameter for the smaller SNRs in the current Galactic SNR catalogue. The remnants of 'historical' supernovae chronicled in the last thousand years or so are indicated. All these remnants are relatively close-by, as otherwise their parent supernova would not have been seen visibly, and therefore they sample only a small part of the Galactic disk. If these known young remnants were further away, they would have the same surface brightness, but would be smaller in angular size. Although there are some such remnants currently known – e.g. the very young SNR G1.9+0.3 (see Green *et al.* 2008; Reynolds *et al.* 2008; Carlton *et al.* 2011) – there are fewer than expected (see further discussion in Green 2005). Hence there is a selection effect against the identification of young but distant SNRs in the Galaxy. Note that most of these missing young remnants will be on the far side of the Galaxy, and therefore appear nearer $b = 0°$ and to $l = 0°$. This is the region of the Galactic plane where the background is brightest, and where there is also more likely to be confusion with other Galactic sources along the line of sight.

Of the 5 sources brighter than 10^{-20} W m^{-2} Hz^{-1} sr^{-1} – i.e. above the nominal surface brightness limit of the current SNR catalogue – which have been identified since 1991 in the Effelsberg survey area, all are close (within 20°) to the Galactic Centre. Moreover, 3 of them are small, $\lesssim 8$ arcmin in diameter. Thus, it is likely that the sample of 68 'bright' SNRs may be somewhat incomplete near the Galactic Centre, due to (i) missing young but distant remnants, and (ii) the difficulty of identifying remnants near the

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surface brightness limit in this region of the Galaxy, with a relativity bright and complex background.

The 2009 version of the catalogue includes remnants identified in the refereed literature published up to the end of 2008. Since then some other remnants have been identified (e.g. G25.1−2.3 and G178.2−4.2, Gao *et al.* 2011; G35.6−0.4, Green 2009b; G64.5+0.9, Hurley-Walker *et al.* 2009; G296.7−0.9, Robbins *et al.* 2012; G308.3−1.4, Hui *et al.* 2012; G310.5+0.8, Stupar *et al.* 2011), but none of these are clearly brighter than 10^{-20} W $\mathrm{m}^{-2}\,\mathrm{Hz}^{-1}\,\mathrm{sr}^{-1}$ at 1 GHz.

2.2. *The 'Σ−D' relation*

To directly construct the Galactic distribution of SNRs it is necessary to know the distance to each remnant. Distances are only available for about 20% of currently known SNRs, and so the surface brightness–linear diameter – or 'Σ−D' – relation has often been used instead. This provides an estimated linear size for a remnant from its *observed* surface brightness, using the Σ−D correlation seen for SNRs with known distances. This correlation is usually parameterised as

$$\Sigma = CD^{-n}$$

as physically small SNRs tend to have larger surface brightnesses than larger ones. As is discussed in Green (2005), much of this correlation is arguably due to a D^{-2} bias due to the fact that $\Sigma \propto L/D^2$, where L is the luminosity of the remnant. In practice, however, there are several issues with the 'Σ−D' relation. First, SNRs show a wide range of physical diameters for a given surface brightness, approximately an order of magnitude in range. This means that a distance derived for an individual remnant is quite inaccurate. Second, due to the observational selection effect discussed above, the range of properties of SNRs may be larger than is evident from currently identified remnants, as small angular size, faint remnants are particularly difficult to identify. Third, as has been discussed in Green (2005), some 'Σ−D' studies have used inappropriate least-square straight line regressions. As there is a larger scatter in the Σ−D plane, regressions minimising deviations in Σ give quite a different correlation than one minimising deviations in D (e.g. see Isobe *et al.* 1990). Since the Σ−D relation is used to predict a value for D from the Σ value for an individual remnant, then minimising deviations in D should be used. Case & Bhattacharya (1998) minimised the deviations in Σ, and obtained a Σ−D relation with $n = 2.64 \pm 0.26$ (for 37 'shell' remnants, including Cas A), whereas a significantly steeper relation with $n = 3.53 \pm 0.33$ is obtained if deviations in D are used. This means that fainter remnants – which are the majority, see Figure 1 – have their diameters, and hence distances, *overestimated* if a Σ−D relation minimising deviations in Σ is used.

3. The Galactic distribution of SNRs

The direct approach to deriving the distribution of Galactic SNRs is to use the Σ−D relation to derive distances to individual remnants, and then construct the 3-D distribution of remnants. However, because of the large range of diameters shown for remnants with similar surface brightnesses, the Σ−D relation does not provide reliable distances to individual remnants. Moreover there are the observational selection effects discussed in Section 2.1, which mean that it is not possible to use treat catalogued remnants with equal weight. Instead, the approach I use is to consider only brighter remnants above the nominal surface-brightness limit, and compare their distribution in Galactic longitude with that expected from various models. This approach does not need distance estimates for individual SNRs. Because of the possible remaining selection effects close

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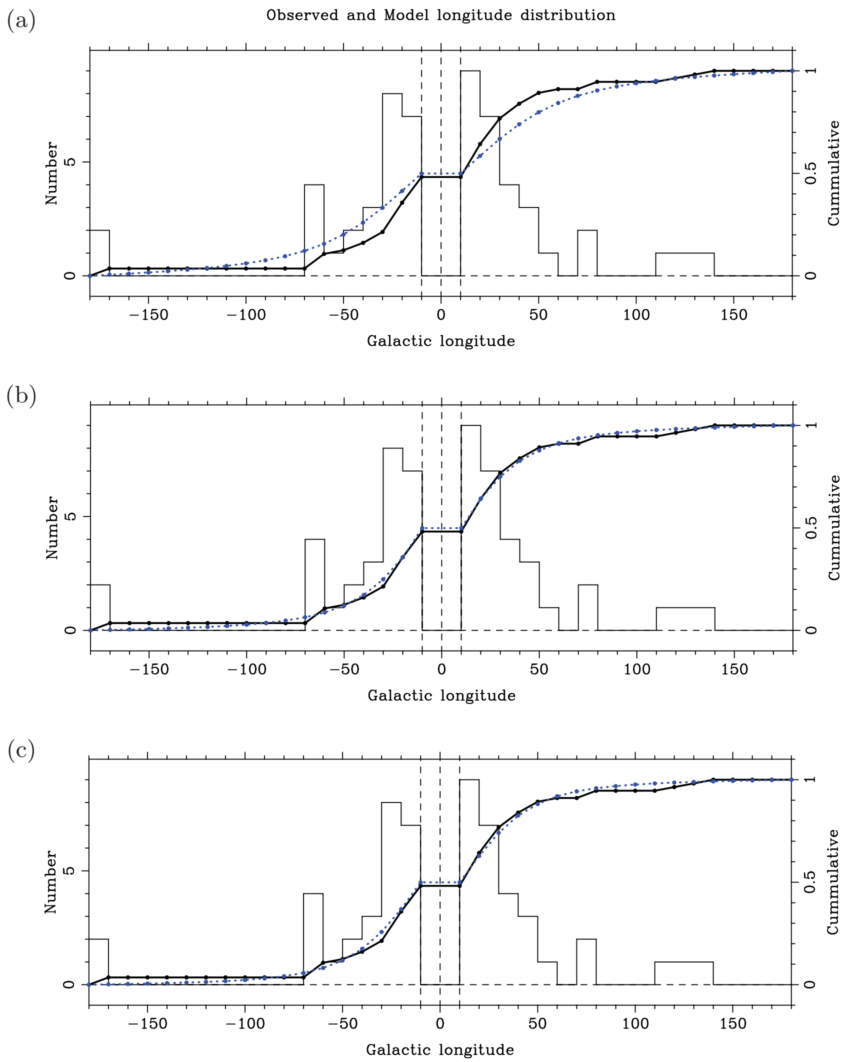

Figure 4. The l-distribution of the 56 'bright' Galactic SNRs – excluding those with $|l| \leqslant 10°$ – shown as (i) histogram (left scale), and (ii) cumulative fraction, solid line (right scale). In addition the cumulative fraction for a model distribution is also plotted, dotted line (right scale). The three models presented are for the surface density of SNRs varying with Galactocentric radius, R, as (a) $\propto (R/R_\odot)^{2.0} \exp[-3.5(R-R_\odot)/R_\odot]$ (as derived by Case & Bhattacharya 1998), (b) $\propto (R/R_\odot)^{0.7} \exp[-3.5(R-R_\odot)/R_\odot]$, and (c) $\propto (R/R_\odot)^{2.0} \exp[-5.1(R-R_\odot)/R_\odot]$.

to the Galactic centre, the region $|l| \leqslant 10°$ is excluded from the analysis presented here, leaving 56 brighter remnants.

One model from the distribution of SNRs (and other star formation tracers, e.g. pulsars and star formation regions, see Bronfman *et al.* 2000; Lorimer *et al.* 2006) is a two parameter power-law/exponential radial distribution for the density of SNRs with Galactocentric radius, R, of the form

$$\propto \left(\frac{R}{R_\odot}\right)^A \exp\left[-B\frac{(R-R_\odot)}{R_\odot}\right]$$

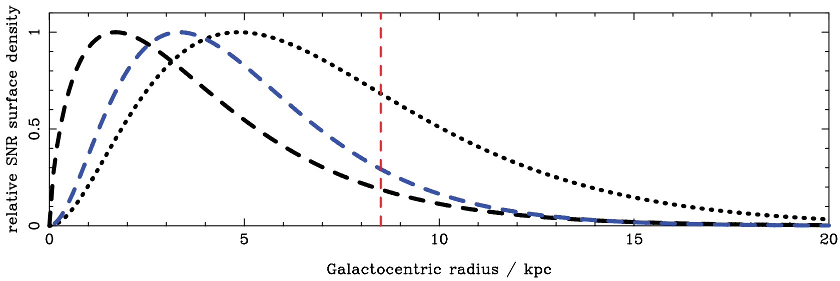

Figure 5. The distribution (in terms of surface density) of SNRs with Galactocentric radius, R, for the three power-law/exponential models shown in Figure 4 and discussed in Section 3: dotted line for Case & Bhattacharya (1998)'s distribution (a), and dashed lines for models (b) and (c).

(with $R_\odot = 8.5$ kpc, the distance to the Galactic Centre). The observed distribution in l of SNRs with $\Sigma > 10^{-20}$ W m^{-2} Hz^{-1} sr^{-1} from Green (2009a) excluding those with $|l| \leqslant 10°$ is shown in Figure 4, along with the distributions from three different power-law/exponential radial models. The models are (a) $A = 2.0$, $B = 3.5$ (i.e. the distribution obtained by Case & Bhattacharya 1998), (b) $= 0.7$, $B = 3.5$ (i.e. the same value for B as in (a), but adjusting A for a best least square fit between the observed and cumulative distributions), and (c) $= 2.0$, $B = 5.1$ (i.e. the same value for A as in (a), but adjusting B for a best fit). From Figure 4(a) it is clear that the power-law/exponential distribution obtained by Case & Bhattacharya (1998), is broader than the observed distribution of 'bright' SNRs above the nominal surface brightness limit of current SNR catalogues (which is to be expected, given the systematic effect due to the regression used by Case & Bhattacharya 1998 noted in Section 2.2). Models (b) and (c) have very similar least squares differences from the observed cumulative distribution, but correspond to somewhat different distributions in Galactocentric radius. Figure 5 shows the distribution of Galactic SNRs against Galactocentric radius for the three models. This shows that there is degeneracy between the parameters A and B in the power-law/exponential distribution model.

4. Conclusions

The lack of distances to most known Galactic SNRs, plus observational selection effects, means that it is difficult to derive the distribution of SNRs in our Galaxy directly. However, by considering 'bright' SNRs – i.e. those not strongly affected by selection effects – constraints on the Galactic distribution of SNRs can be obtained, by comparison of their l-distribution with that expected from models. This shows that the Galactic distribution of SNRs obtained by Case & Bhattacharya (1998) is too broad.

Acknowledgements

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References

Brogan, C. L., Gaensler, B. M., Gelfand, J. D., Lazendic, J. S., Lazio, T. J. W., Kassim, N. E., & McClure-Griffiths, N. M., 2005, *ApJ*, 629, L105

Brogan, C. L., Gelfand, J. D., Gaensler, B. M., Kassim, N. E., & Lazio, T. J. W., 2006, *ApJ*, 639, L25

Bronfman, L., Casassus, S., May, J., & Nyman, L.-Å., 2000, *A&A*, 358, 521

https://doi.org/10.1017/S1743921313009459 Published online by Cambridge University Press

Case, G. L. & Bhattacharya, D., 1998, *ApJ*, 504, 761
Carlton, A. K., Borkowski, K. J., Reynolds, S. P., Hwang, U., Petre, R., Green, D. A., Krishnamurthy, K., & Willett, R., 2011, *ApJ*, 737, L22
Fürst, E., Reich, W., Reich, P., & Reif, K., 1990, *A&AS*, 85, 691
Gao, X. Y., Sun, X. H., Han, J. L., Reich, W., Reich, P., & Wielebinski, R., 2011, *A&A*, 532, A144
Gray, A. D., 1994, *MNRAS*, 270, 835
Green, D. A., 1984, *MNRAS*, 209, 449
Green, D. A., 2005, *MmSAI*, 76, 534
Green, D. A., 2009a, *BASI*, 37, 45
Green, D. A., 2009b, *MNRAS*, 399, 177
Green, D. A., 2012, in: F. Aharonian, W. Hofmann & F. Rieger (eds), *High Energy Gamma-Ray Astronomy*, AIP Conference Proceedings, Volume 1505 (American Institute of Physics, Melville, New York), p. 5
Green, D. A., Reynolds, S. P., Borkowski, K. J., Hwang, U., Harrus, I., & Petre, R., 2008, *MNRAS*, 387, L54
Hui, C. Y., Seo, K. A., Huang, R. H. H., Trepl, L., Woo, Y. J., Lu, T.-N., Kong, A. K. H., & Walter, F. M., 2012, *ApJ*, 750, 7
Hurley-Walker, N., *et al.*, 2009, *MNRAS*, 398, 249
Isobe, T., Feigelson, E. D., Akritas, M. G., & Babu, G. J., 1990, *ApJ*, 364, 104
Kassim, N. E. & Frail, D. A., 1996, *MNRAS*, 283, L51
Lorimer, D. R., *et al.*, 2006, *MNRAS*, 372, 777
Reich, W., Fürst, E., Reich, P., Junkes, N., 1988, in: R. S. Roger & T. L. Landecker (eds), *Supernova Remnants and the Interstellar Medium*, Proc. IAU Colloquium No. 101 (Cambridge University Press), p. 293
Reich, W., Fürst, E., Reich, P., & Reif, K., 1990, *A&AS*, 85, 633
Reynolds, S. P., Borkowski, K. J., Green, D. A., Hwang, U., Harrus, I., & Petre, R., 2008, *ApJ*, 680, L41
Robbins, W. J., Gaensler, B. M., Murphy, T., Reeves, S., & Green, A. J., 2012, *MNRAS*, 419, 2623
Stupar, M., Parker, Q. A., & Filipović, M. D., 2011, *Ap&SS*, 332, 241
Whiteoak, J. B. Z. & Green, A. J., 1996, *A&AS*, 118, 329
Yusef-Zadeh, F., Shure, M., Wardle, M., & Kassim, N., 2000, *ApJ*, 540, 842

Discussion

SANKRIT: Are there likely to be any High-Latitude Remnants we haven't yet detected? If so, how best to search for them?

GREEN: Yes, there are some traces already, and they had to be fat, as it is possible to find fat remnants where the background is low. Future surveys will no doubt find more.

UNIDENTIFIED: Of course, what we really would like to know is the derived SN rate, care to tell us?

GREEN: As mentioned by Enrico Cappellaro, you can infer a note of a few per century from the known 'Historical' remnants. But it is difficult to be precise.

BRANDT: Can you bin the (bright) SNRs to the resolution of the Galactic arm?

GREEN: No. There are insufficient statistics only 68 'bright' remnants above the nominal surface brightness completeness limit.

FOLATELLI: Is there any other observational parameter that could be expected to help reduce the scatter in the Σ-D relation?

Green: There have been some attempts to identify a subset of SNRs,e.g. those interacting with a molecule cloud, which might have less scatter.

Wang: Did you compare your distribution of SNRs with that predicted by tracers such as stellar mass and SFR? I'd expect that the predicted distribution would be rather different especially in the Galactic center region.

Green: Yes, some tries have been made.

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