Some Statistics of Galactic SNRs, and G1·9+0·3

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Outline

- Galactic SNR selection effects
- missing young but distant SNRs
- G1·9+0·3: the youngest known Galactic SNR
- future prospects . . . EVLA!
- conclusions

Some simple statistics of SNRs

In 1984 there were 145 catalogued SNRs – the most recent (2009) version contains 274 remnnats:

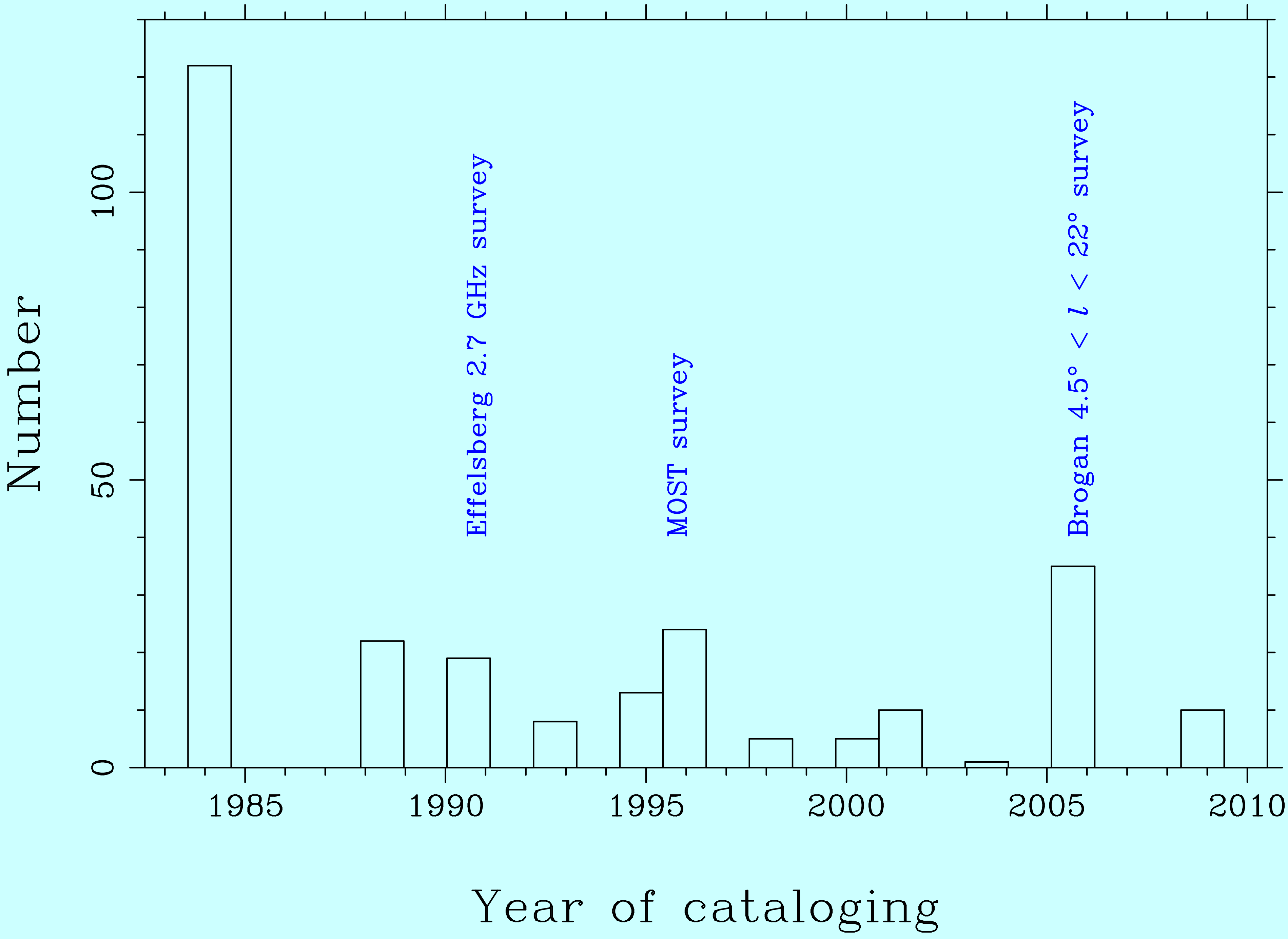
- 78% are classed as shell (or possible shell) remnants
- 12% are composite (or possible composite) remnants
- 4% are filled-centre (or possible filled centre) remnants

(the remaining 6% have not yet been observed well, or are objects which are conventionally regarded as SNRs, even though they do not fit into the standard types)

Over the last decade, the proportion of shell SNRs has stayed very similar, with the proportion of composite remnants increasing from 8%, and the proportion of filled centre remnants decreasing from 7%

16 SNRs are either not detected at radio wavelengths, or are poorly defined by current radio observations, i.e.

- 94% have a flux density at 1 GHz included in the catalogue.
- 40% are detected in X-rays
- 20% are detected in the optical



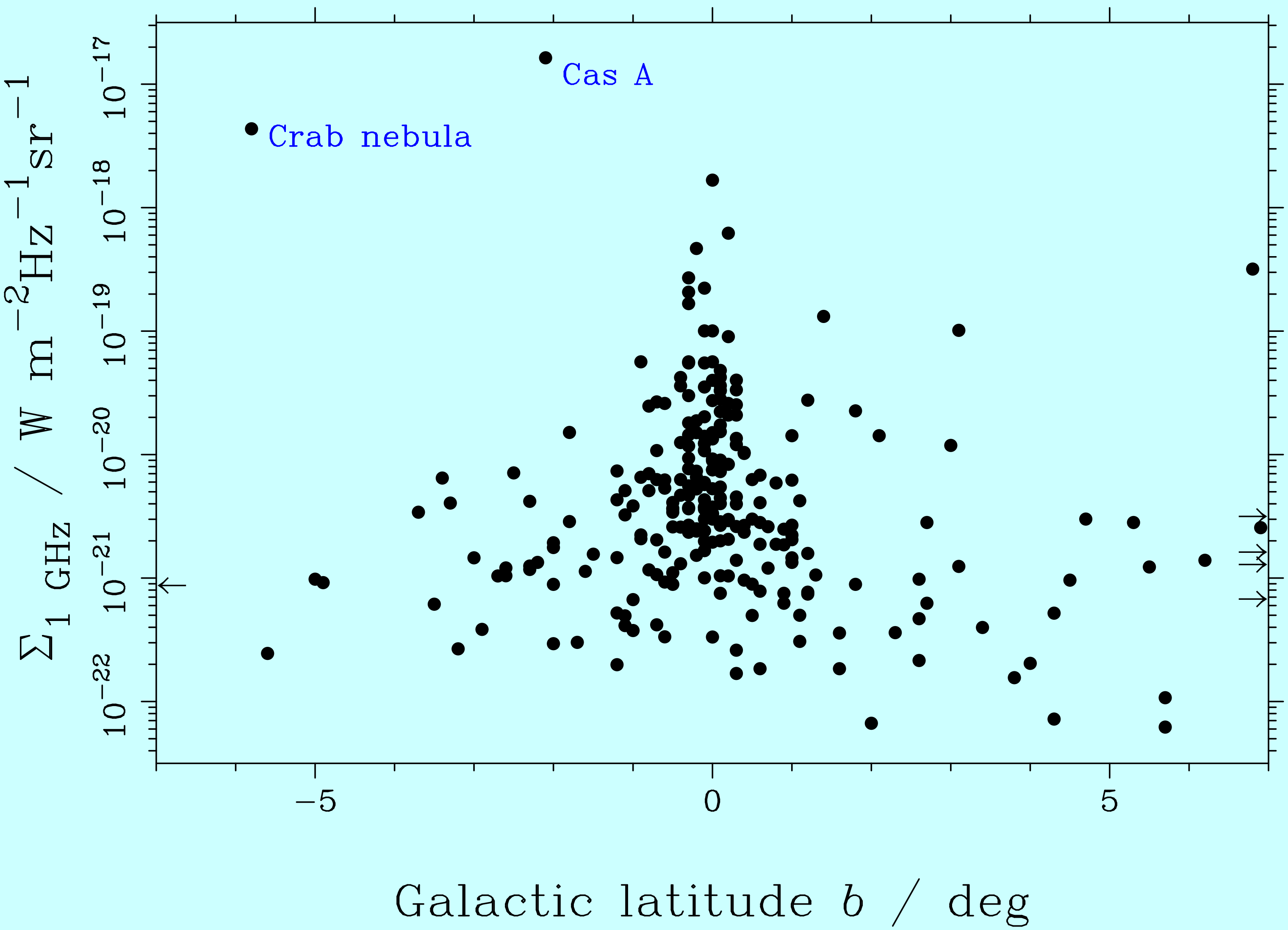
Date of inclusion of SNRs in catalogue – 274 in total now

Selection effects

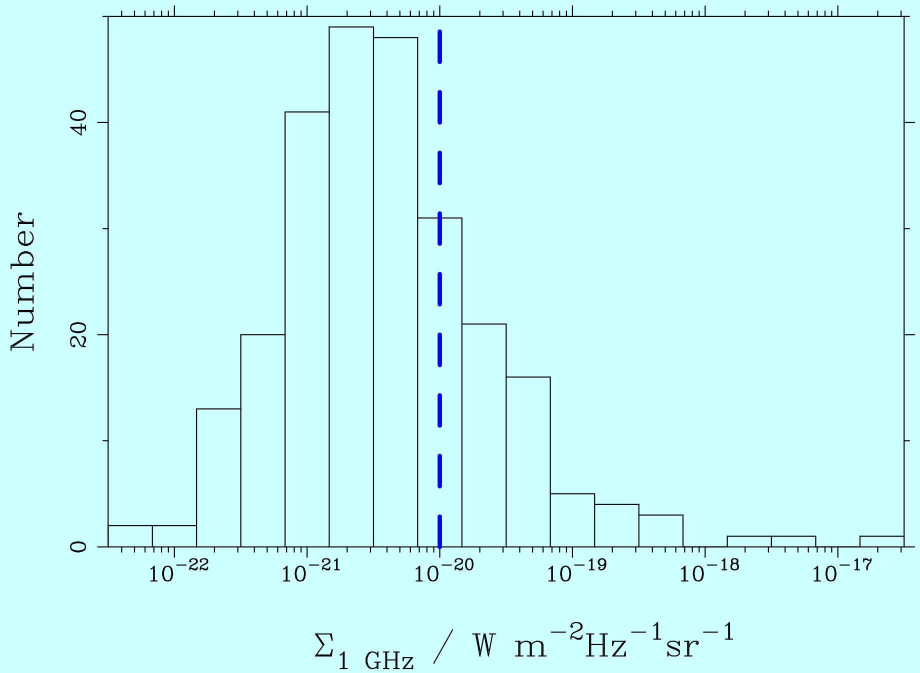
Although several Galactic SNRs have been first identified at other than radio wavelengths, in practice the dominant selection effects are those that are applicable at radio wavelengths.

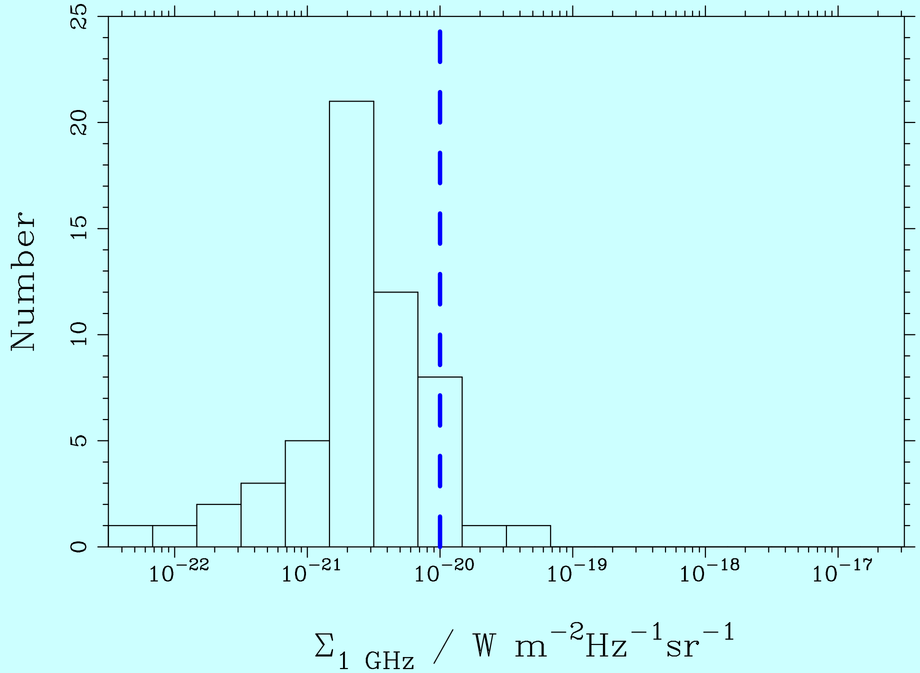
Simplistically two selection effects apply:

1) faint remnants are difficult to recognise against the varying Galactic background, and
2) small angular size remnants are not resolved in wide-field surveys, so are not recognised

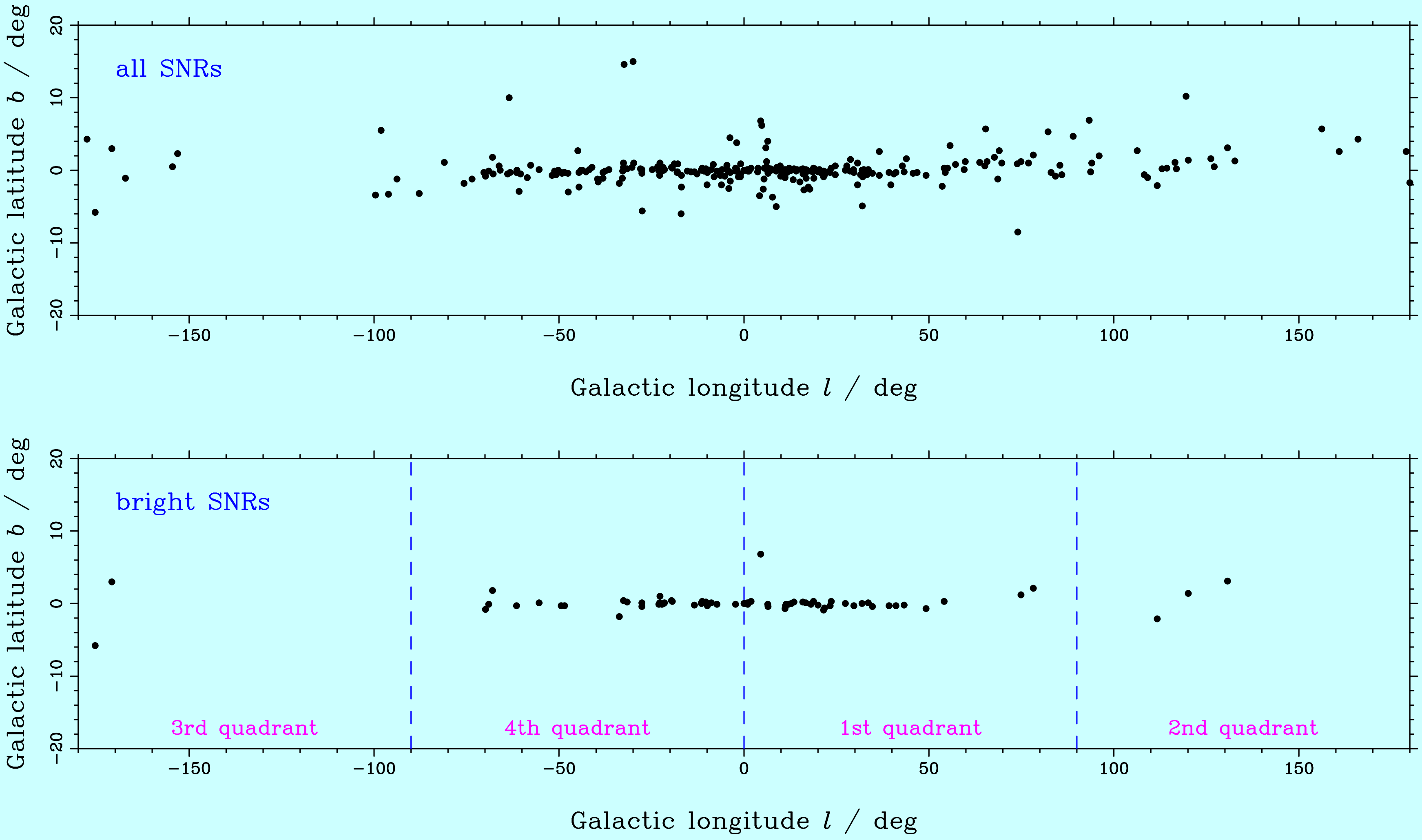


The distribution of surface brightness against latitude for 253 Galactic SNRs (the surface brightnesses of the other 5 remnants with |b| > 7° are indicated by arrows at the left and right edges of the plot)





(left) Σ histogram for all SNRs, and (right) for 111 SNRs identified post 1991

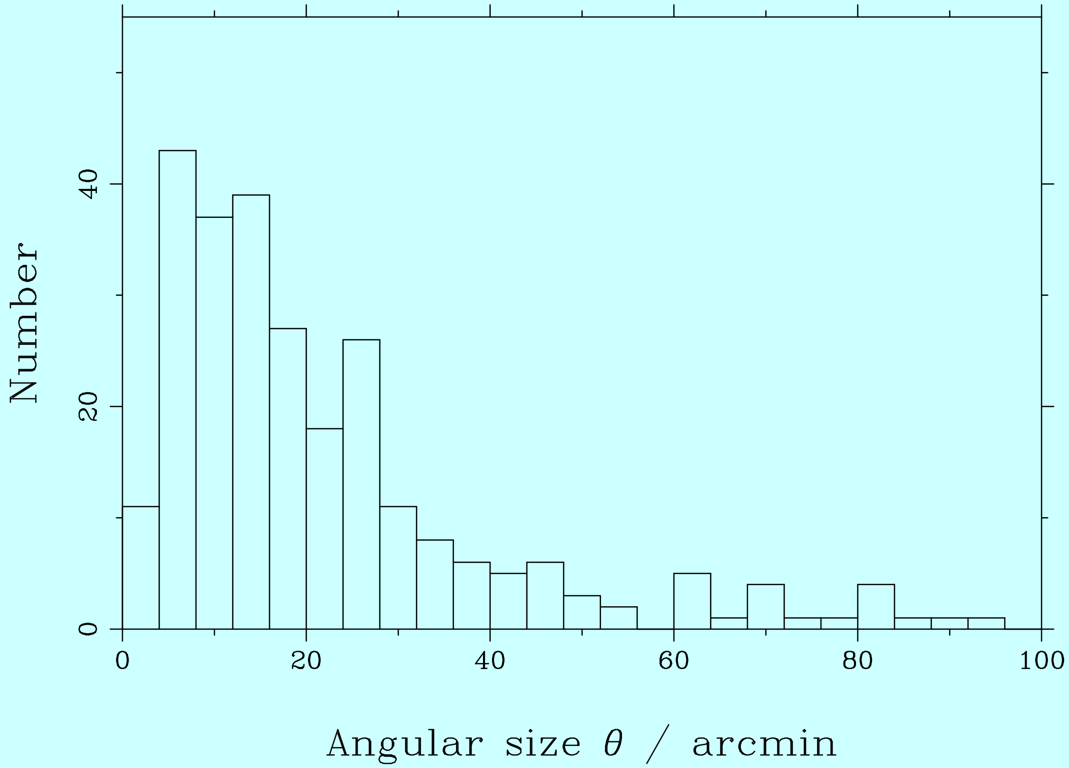


Galactic distribution of (top) all Galactic SNR and (bottom) those SNRs with a surface brightness at 1 GHz greater than 10^{-20} W m^{-2} Hz^{-1} sr^{-1} *(the latitude and longitude axes are not to scale)*

The angular size (θ) selection effect

Small angular size SNRs are likely to be missing from current catalogues, as their structure is not well resolved

- e.g. the Effelsberg 2.7-GHz survey had a resolution of ≈ 4.3 arcmin, so remnants less than about 13 arcmin in diameter (i.e. 3 beamwidths) are not easily recognised



Angular sizes of 261 Galactic SNRs (13 remnants larger than 100 arcmin are not included)

Missing young but Distant SNRs (1)

The lack of small angular size remnants – i.e. young but distant remnants – is clear when the remnants of known 'historical' Galactic supernovae are considered

Parameters of known historical SNRs (plus Cas A)

date	name or remnant	distance /kpc	as observed: size /arcmin	as observed: $\Sigma_{1\ \mathrm{GHz}}$ /W m^{-2} Hz^{-1} sr^{-1}	as observed: $S_{1\ \mathrm{GHz}}$ /Jy
–	Cas A	3.4	5	1.6×10^{-17}	2720
AD 1604	Kepler's	2.9	3	3.2×10^{-19}	19
AD 1572	Tycho's	2.3	8	1.3×10^{-19}	56
AD 1181	3C58	3.2	7	1.0×10^{-19}	33
AD 1054	Crab nebula	1.9	6	4.4×10^{-18}	1040
AD 1006	G327·6+14·6	2.2	30	3.2×10^{-21}	19

- these remnants are relatively close-by – as is expected – so they sample only a small fraction of the Galactic disc

Missing young but Distant SNRs (2)

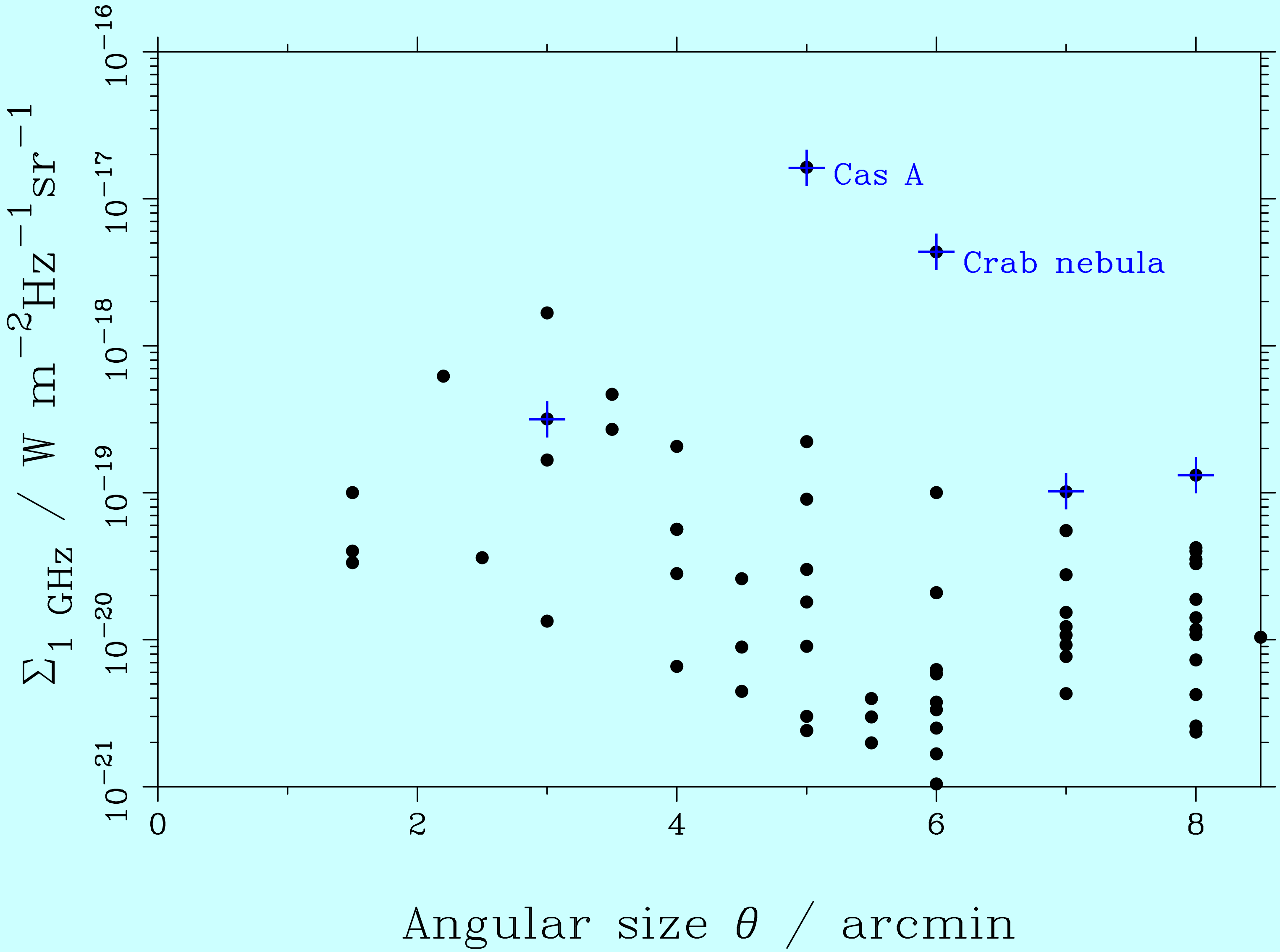
Consequently we expect many more similar, but more distant remnants in our Galaxy – a dozen or more

- so consider what the known historical remnants would look like 'at the other side of the Galaxy' (i.e. at distances from 8.5 to 17 kpc)

Parameters of known historical SNRs (plus Cas A) at larger distances

date	name or remnant	if at 8.5 kpc size /arcmin	if at 8.5 kpc $S_{1\ \mathrm{GHz}}$ /Jy	if at 17 kpc size /arcmin	if at 17 kpc $S_{1\ \mathrm{GHz}}$ /Jy
–	Cas A	2.0	435	1.0	109
AD 1604	Kepler's	1.0	2.2	0.5	0.55
AD 1572	Tycho's	2.3	4.1	1.1	1.0
AD 1181	3C58	2.6	4.7	1.3	1.2
AD 1054	Crab nebula	1.4	52	0.7	13
AD 1006	G327·6+14·6	7.7	1.3	3.9	0.31

- but these are *not* present in current catalogues – there are only 3 remnants with angular sizes less than 2 arcmin



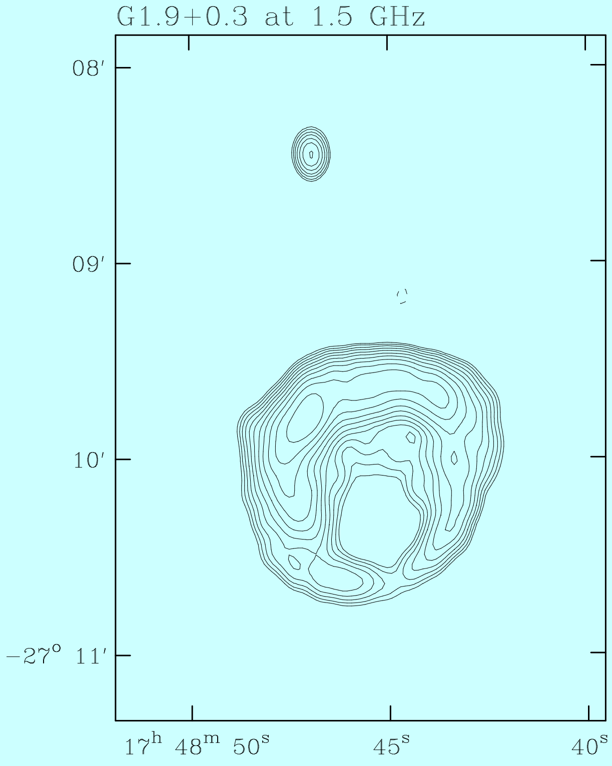
Surface brightness at 1 GHz against angular size for known Galactic SNRs of angular size ≤ 8 arcmin (the five historical remnants are indicated by additional crosses)

G1·9+0·3: the youngest Galactic SNRs

The rate of SN in our Galaxy estimated at 2 to 3 per century, so there should be some very young remnants, but there are only about ten ‘young’ SNRs (less than about a thousand years old) known.

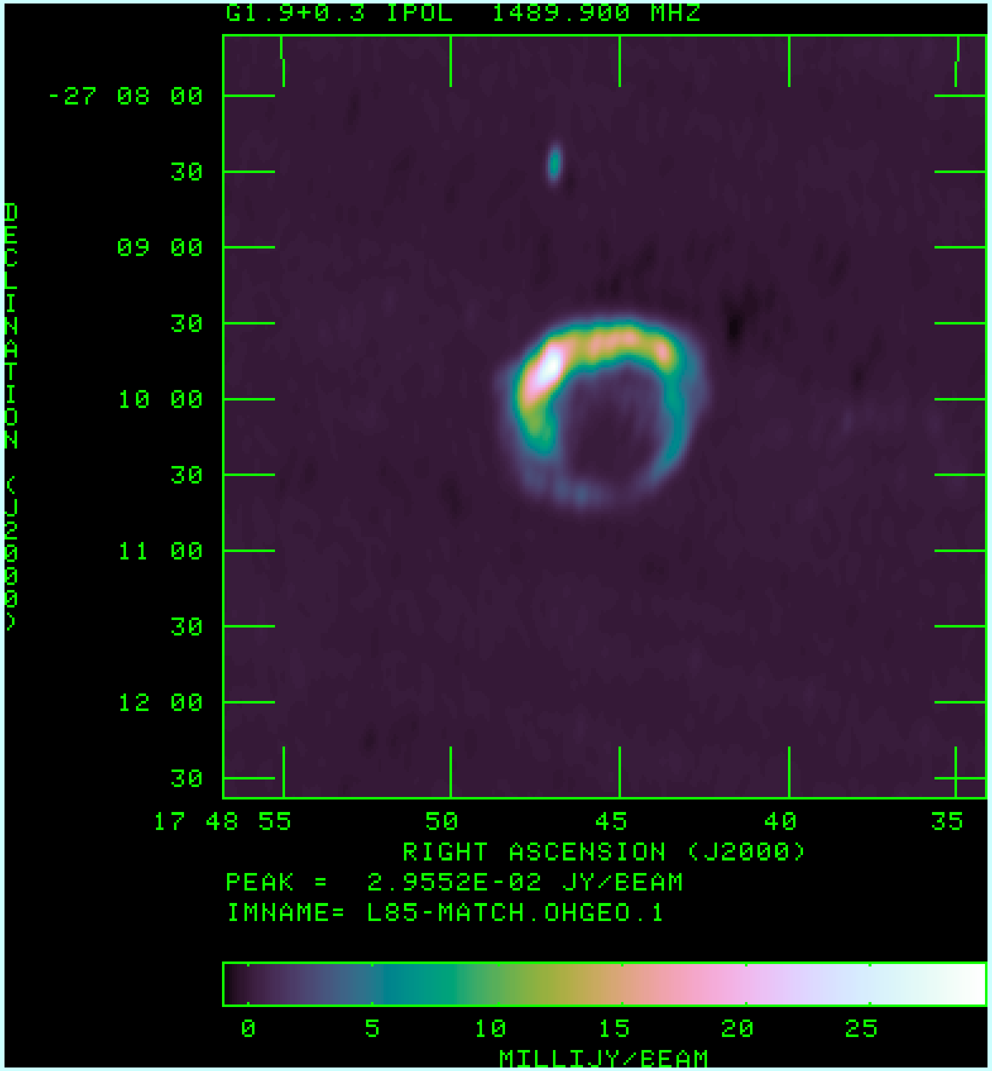
G1·9+0·3 is a small SNR, which is obviously young

- identified in 1984, from VLA observations (a deliberate search for missing young but distant SNRs)
- small (≈ 1.2 arcmin) shell remnant
- distance then not known, but even if on the far side of the Galaxy, is physically small, and therefore young (less than a thousand years old)



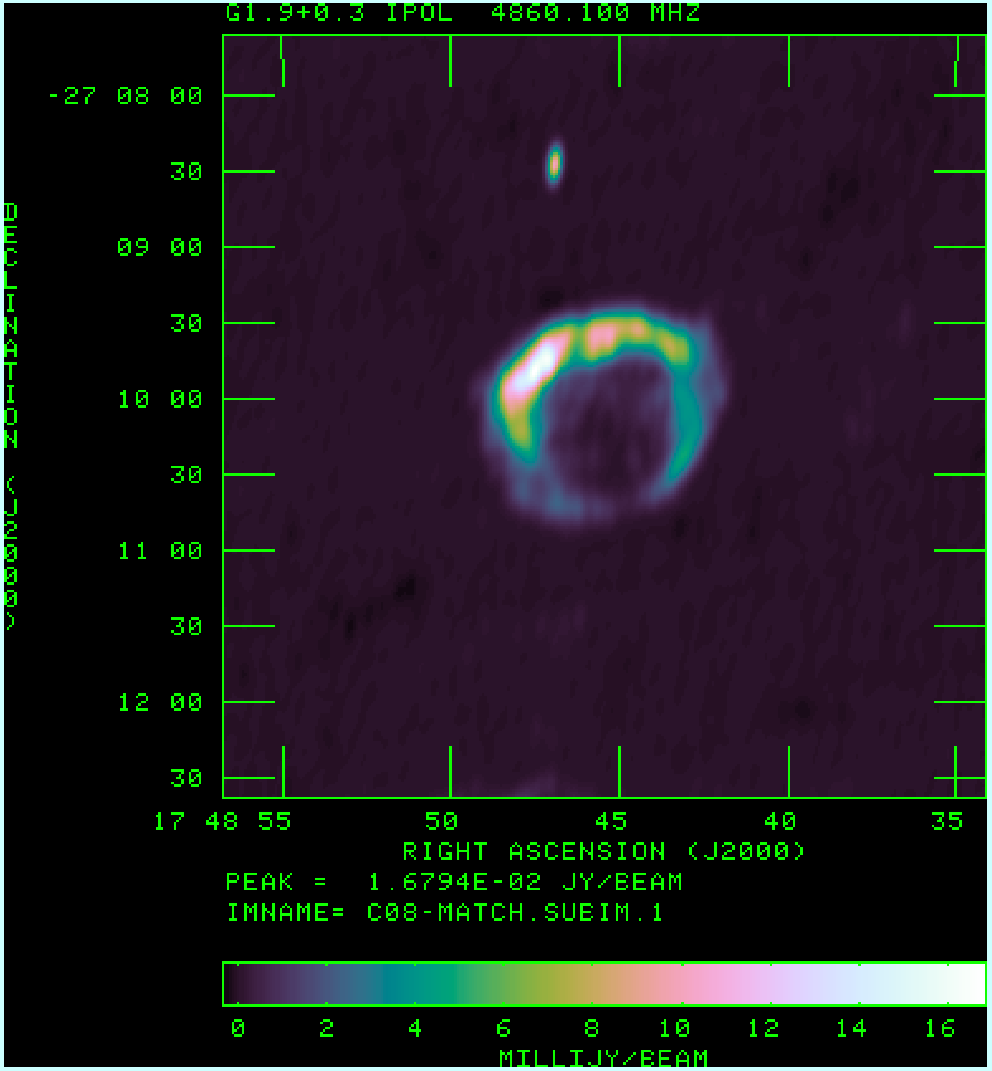
VLA radio image from 1985

Radio observations 1985–2008



1985 radio image

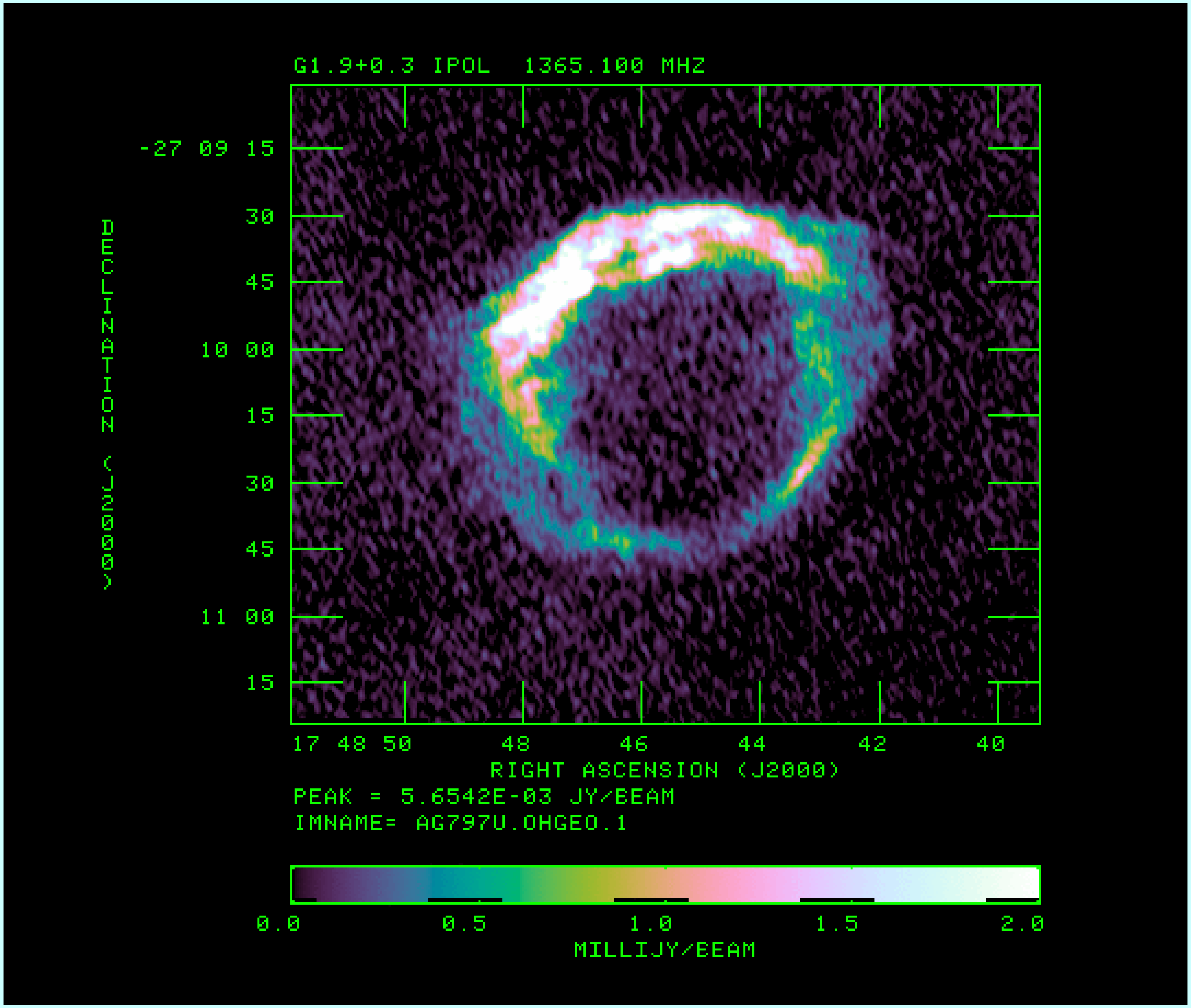
Radio observations 1985–2008



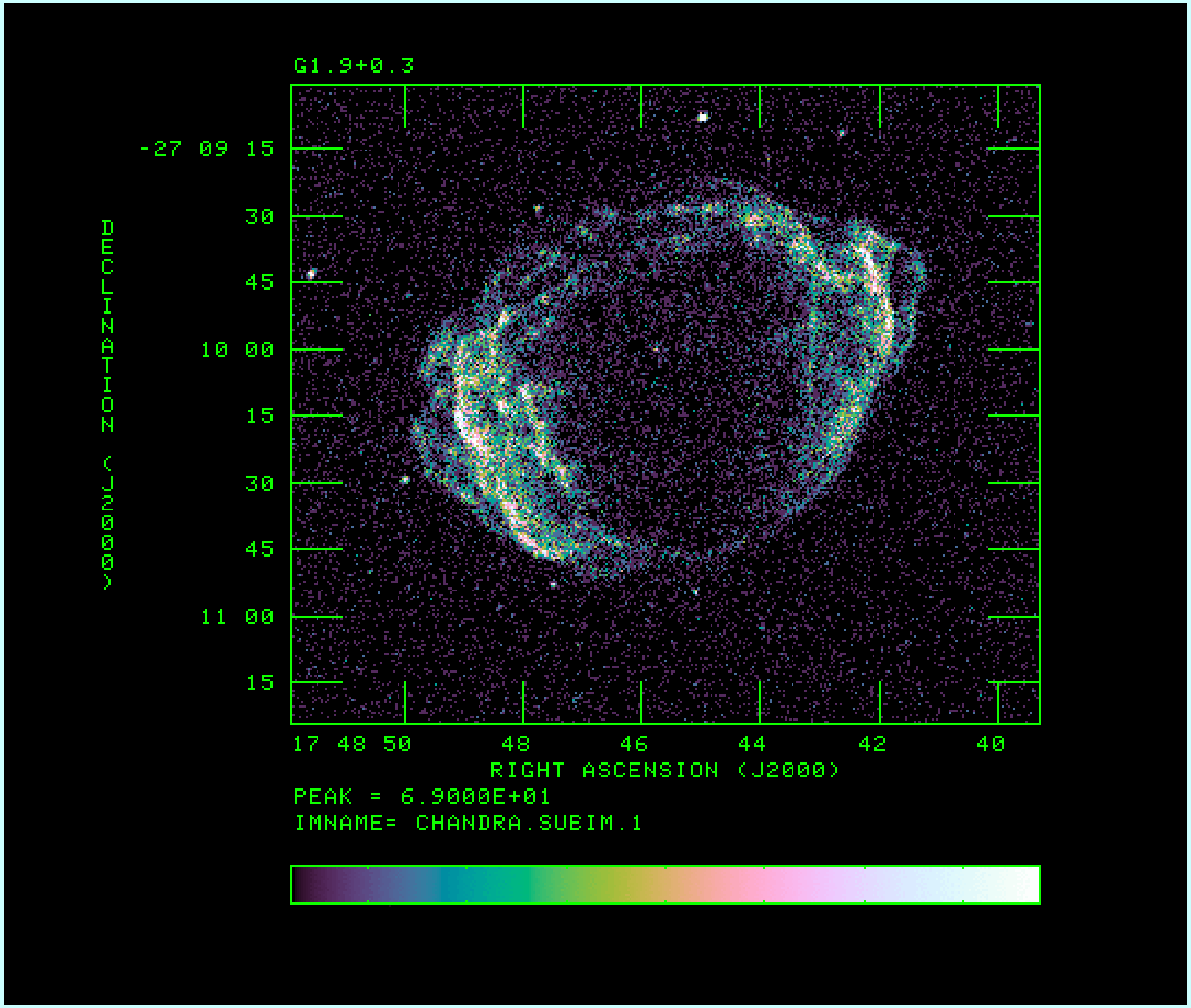
2008 radio image, from Green et al. (2008)

The radio expansion implies G1·9+0·3 is *very* young

- 15% in 23 years, i.e. 0.65%/year means it is 150 years old at most (assuming no deceleration, somewhat young with some deceleration)
- it is the youngest known SNR (fits in the gap between the oldest radio SN, and Cas A which is about 330 years old)
- at about 8.5 kpc, current expansion speed is about 12,000 km/s
- high X-ray turnover energy

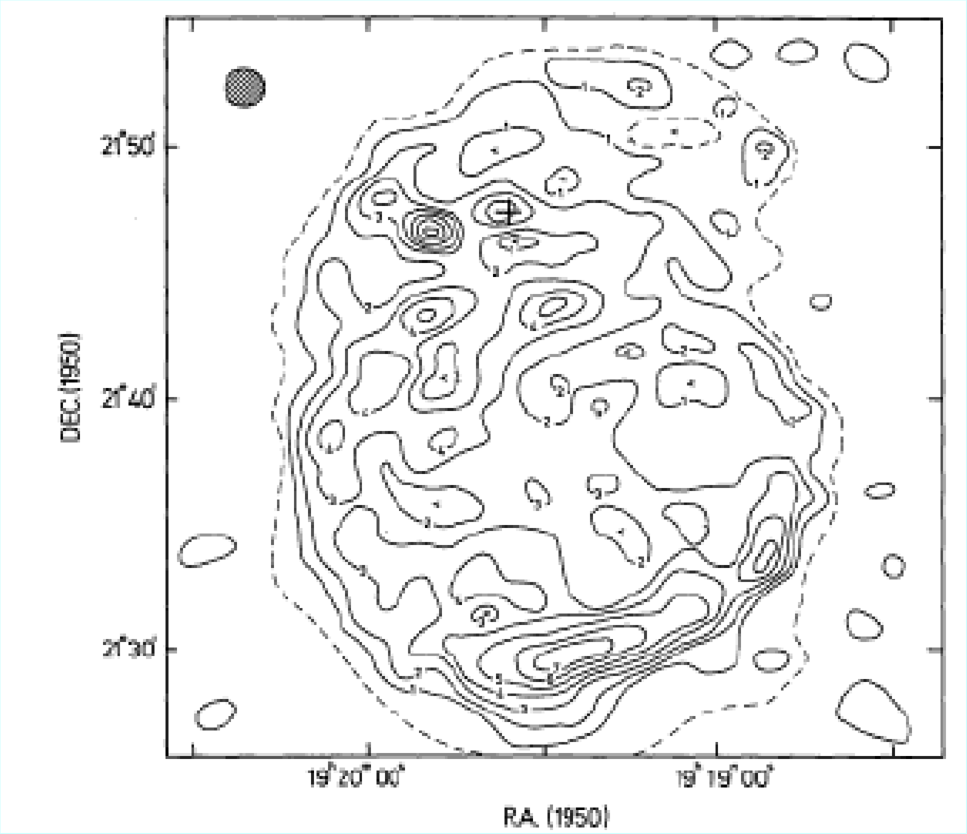


2008/9 radio image (VLA A-, B- and C-array combined)



Deep 2009 Chandra X-ray image

Observational improvements: G55·7+3·4



WSRT 1.4 GHz Goss et al. (1977)

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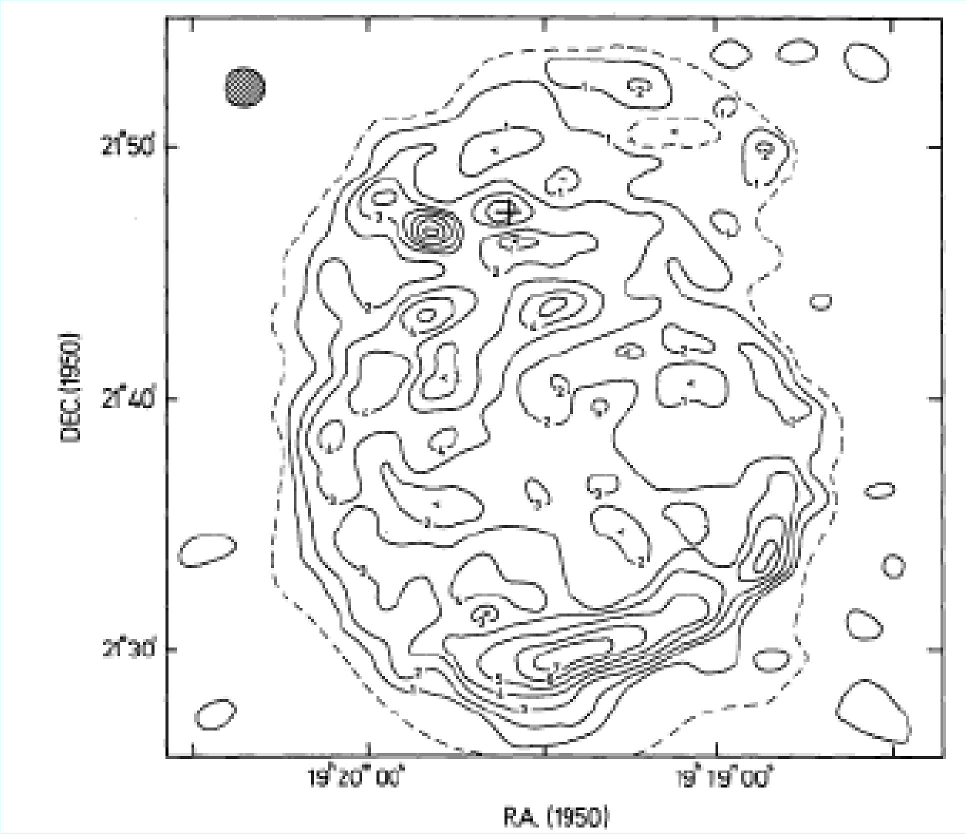

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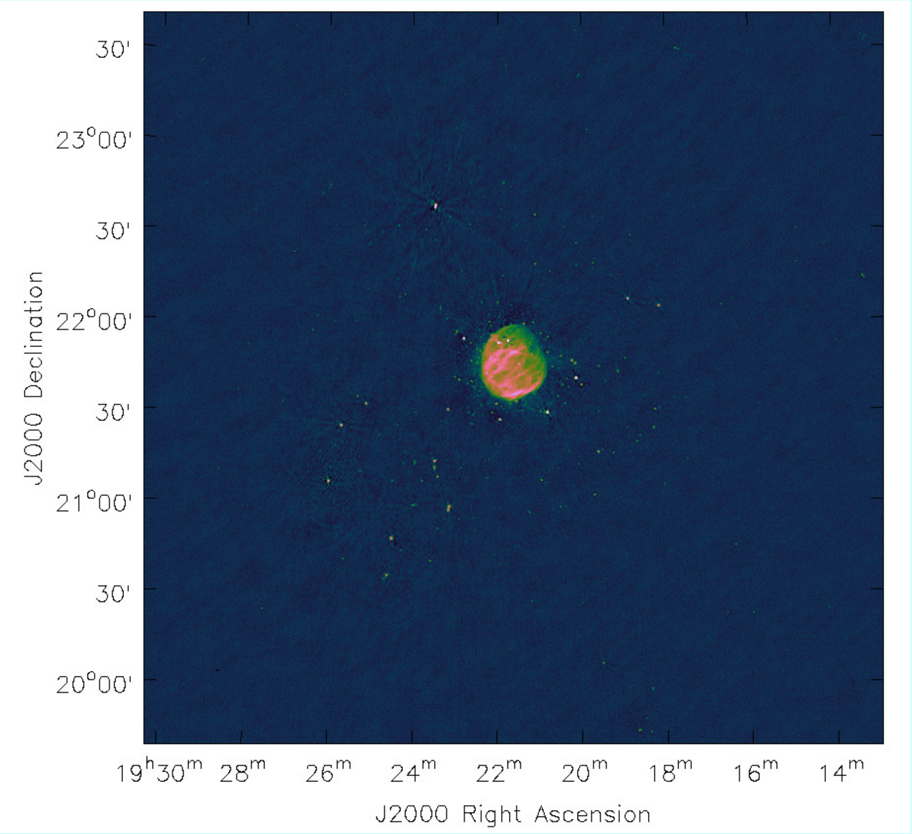

EVLA 1–2 GHz Bhatnagar et al. (2011)

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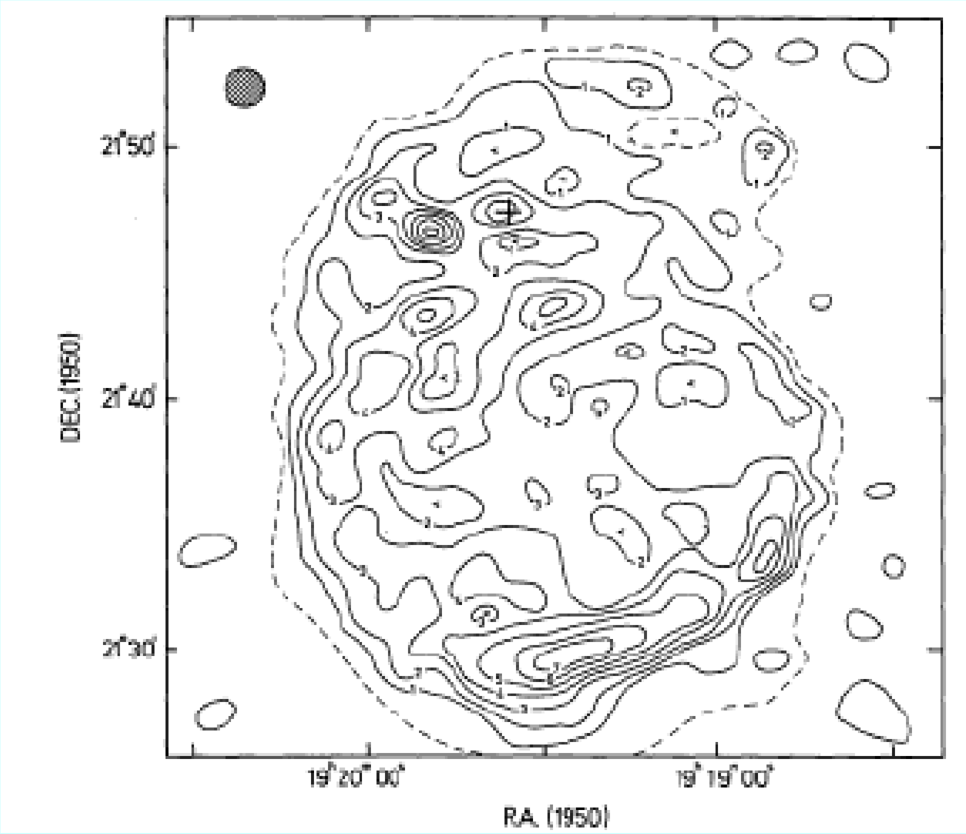

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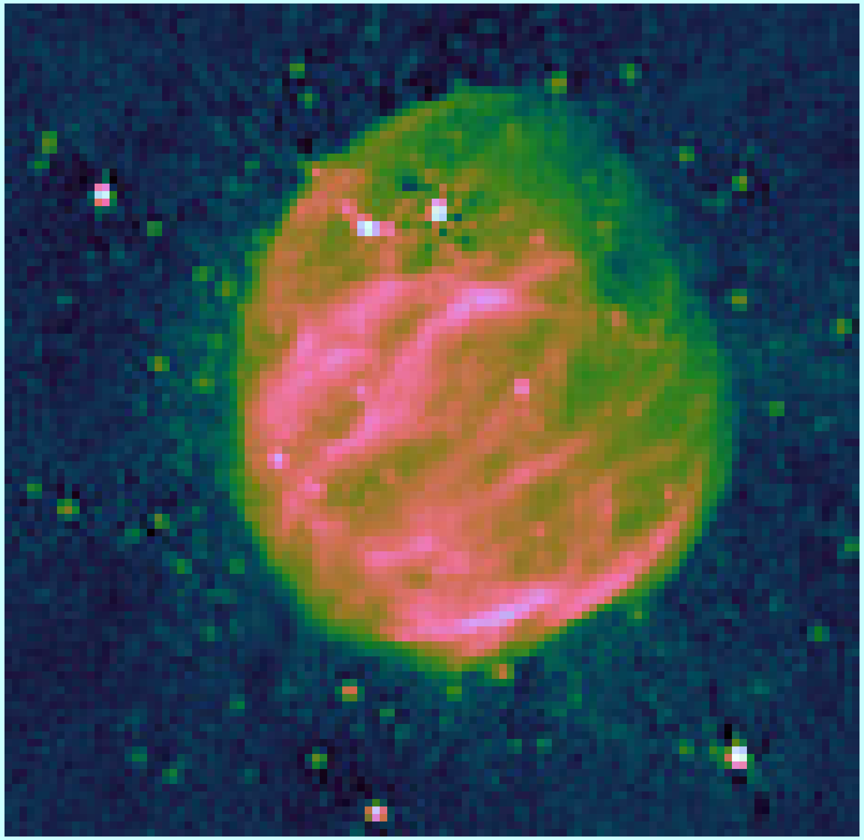

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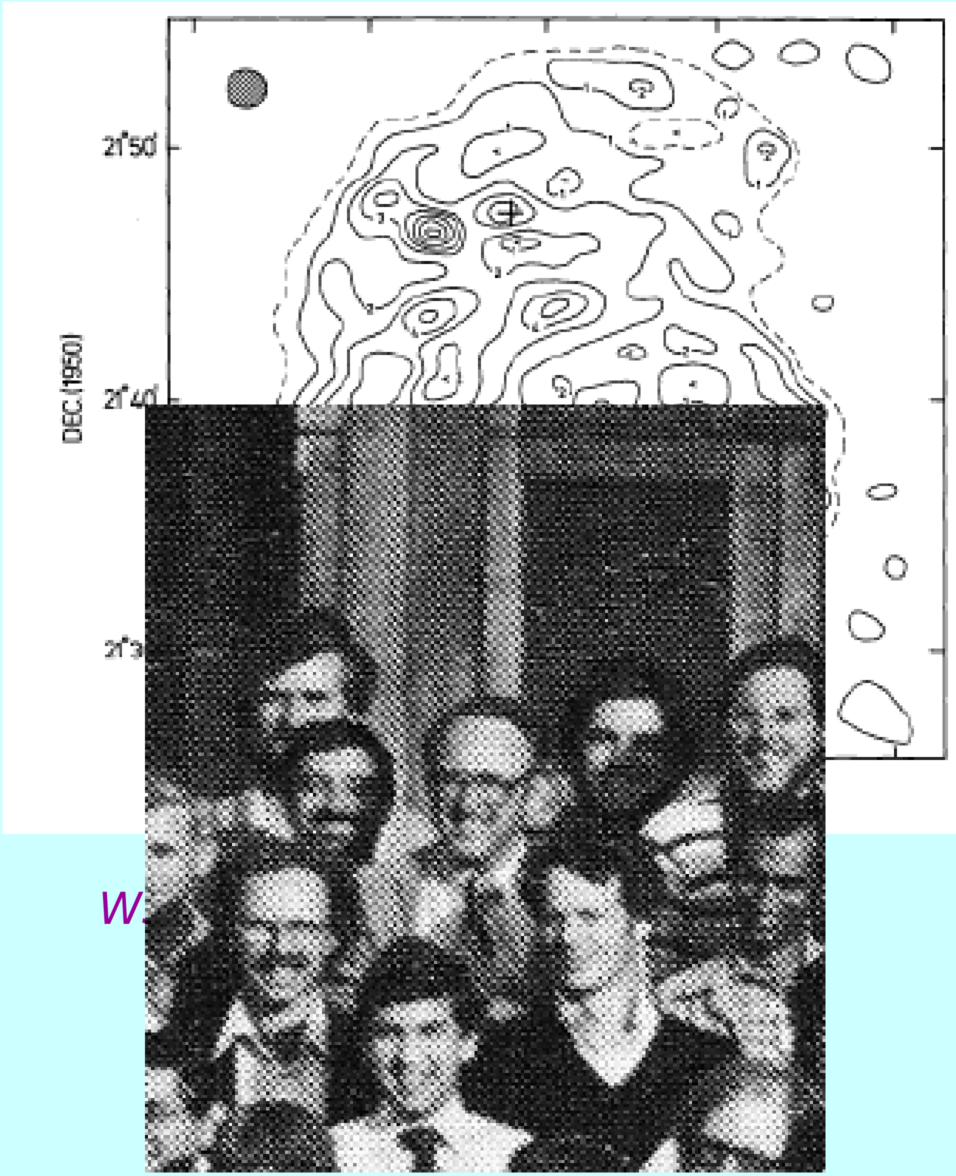

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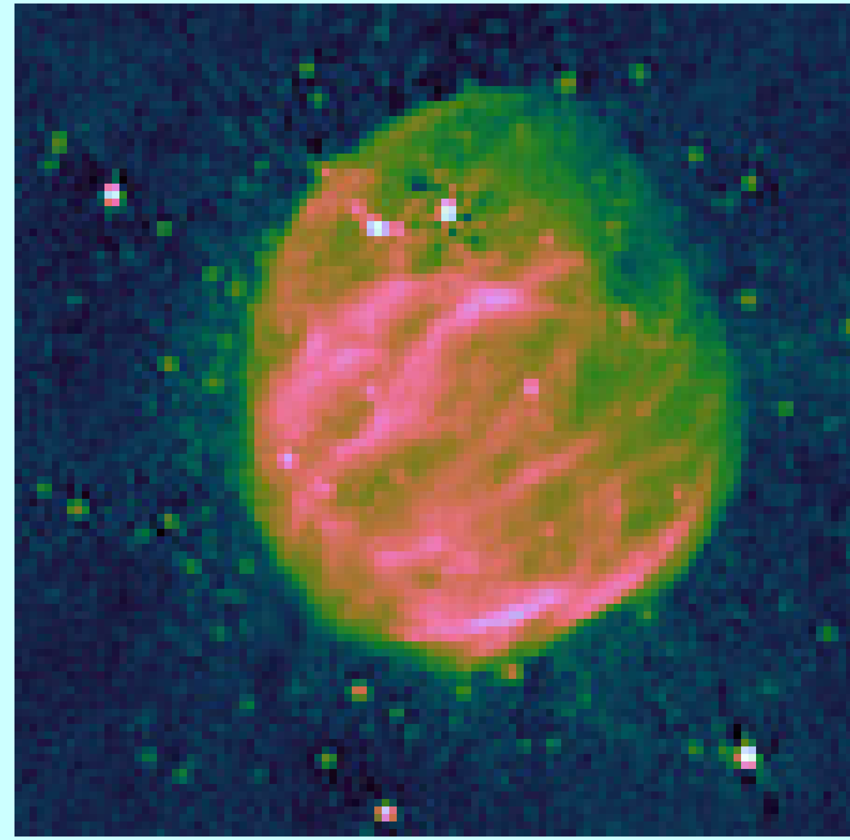
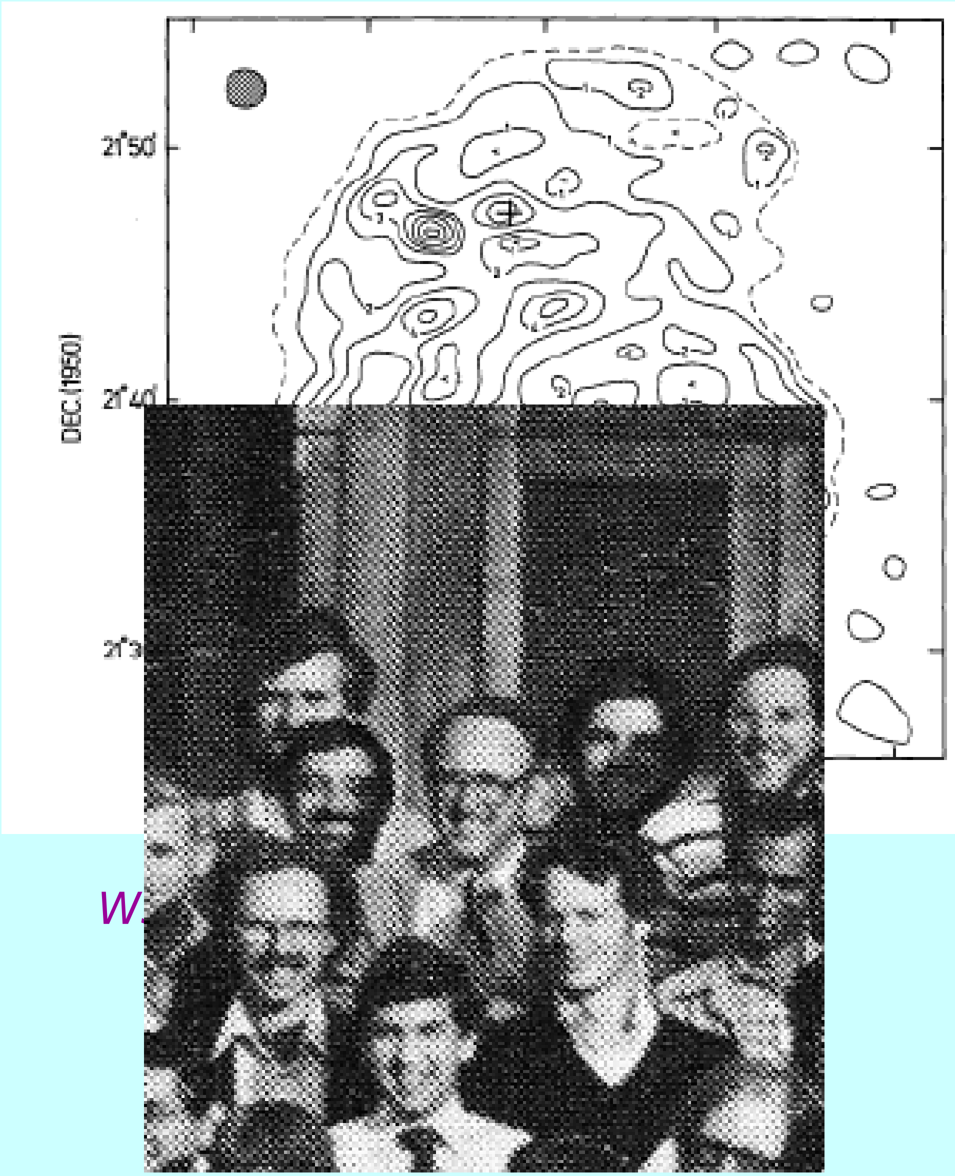
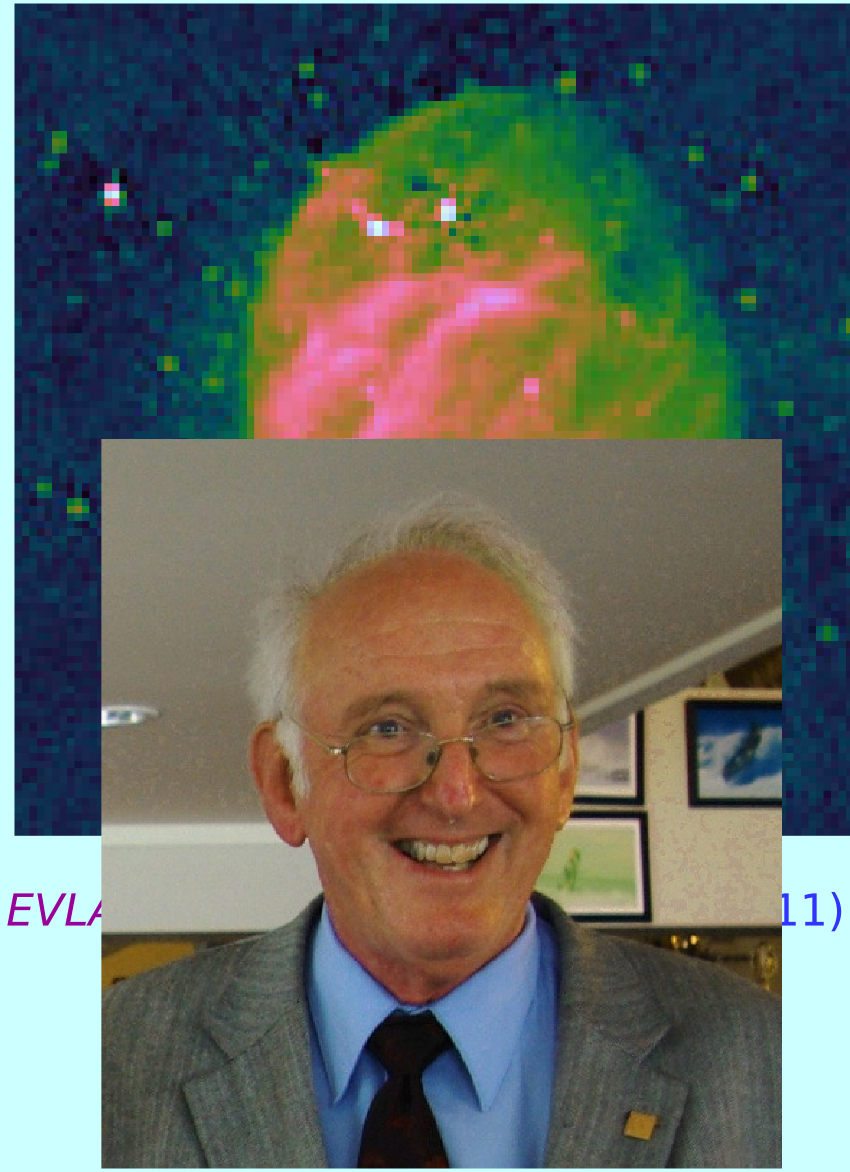


EVLA 1–2 GHz Bhatnagar et al. (2011)

Miller in 1982

Observational improvements: G55·7+3·4





W

EVLA 11)

Miller in 1982

Miller in 2011

Conclusions

- currently 274 Galactic SNRs are known (plus many possibles and probables)
- observational selection effects are *important*
  - faint SNRs are difficult to identify (and this is a more important selection effect near $b = 0°$ and in the 1st and 4th quadrants)
  - small angular size SNRs are difficult to identify
  - few young but distant remnants have yet been identified in the Galaxy
- G1·9+0·3 the youngest known Galactic SNR
  - fast expansion speed, synchrotron-dominated, high X-ray roll-over energy, uniquely is brightening at radio wavelengths

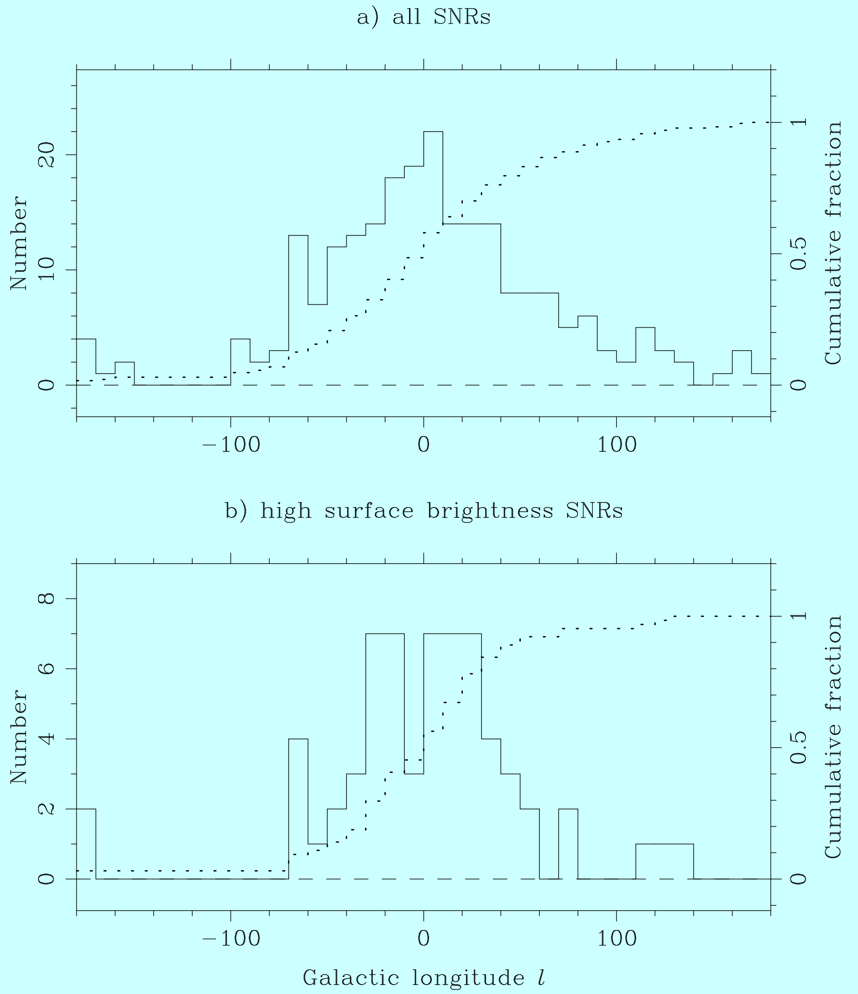
EVLA will provide sensitivity – with wide-band for spectral index discrimination – to identify more Galactic SNRs

The End

The Galactic SNR distribution (1)

From distributions of SNRs with galactic longitude

- it is clear that the distribution of bright SNRs is much more concentrated towards $l = 0°$ than that of all SNRs
- evidence for a deficit of SNRs near $l = 350°$
  - this may be a true deficit
  - but may instead be due to the difficulty of finding (small) remnants in this region of the Galactic plane



The distribution in Galactic longitude of (top) all Galactic SNRs, and (bottom) the high surface brightness SNRs

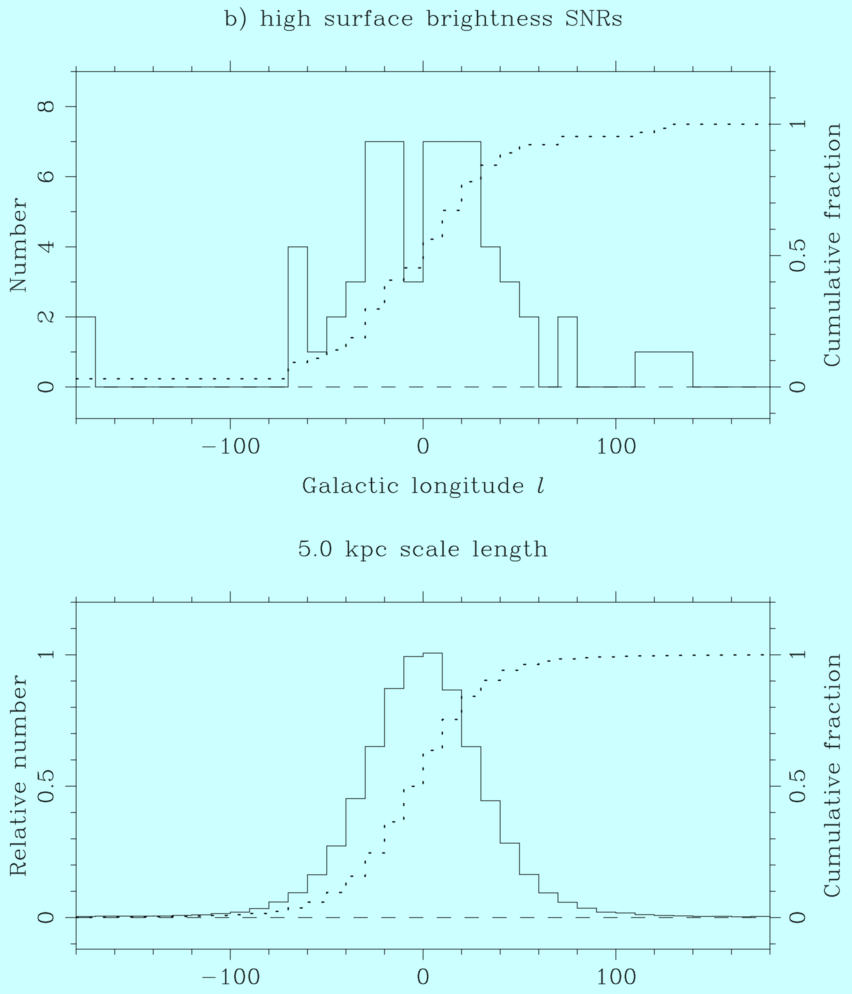
The Galactic SNR distribution (2)

Assuming a simple, circularly symmetric, Gaussian distribution, with

$$\propto e^{-(R/\sigma)^2},$$

where R is Galactocentric radius, and σ a scale length

- a simple least-squares miss-fit statistic gives a preferred scale length of 6.5 kpc
- remaining selection effect problems are likely to make the observed distribution broader than in reality
- in any case, the distribution of *observed* remnants may not be the distribution of progenitors



(top) Observed distribution for bright SNRs (bottom) model distribution of SNRs, for a scale-length of 5.0 kpc

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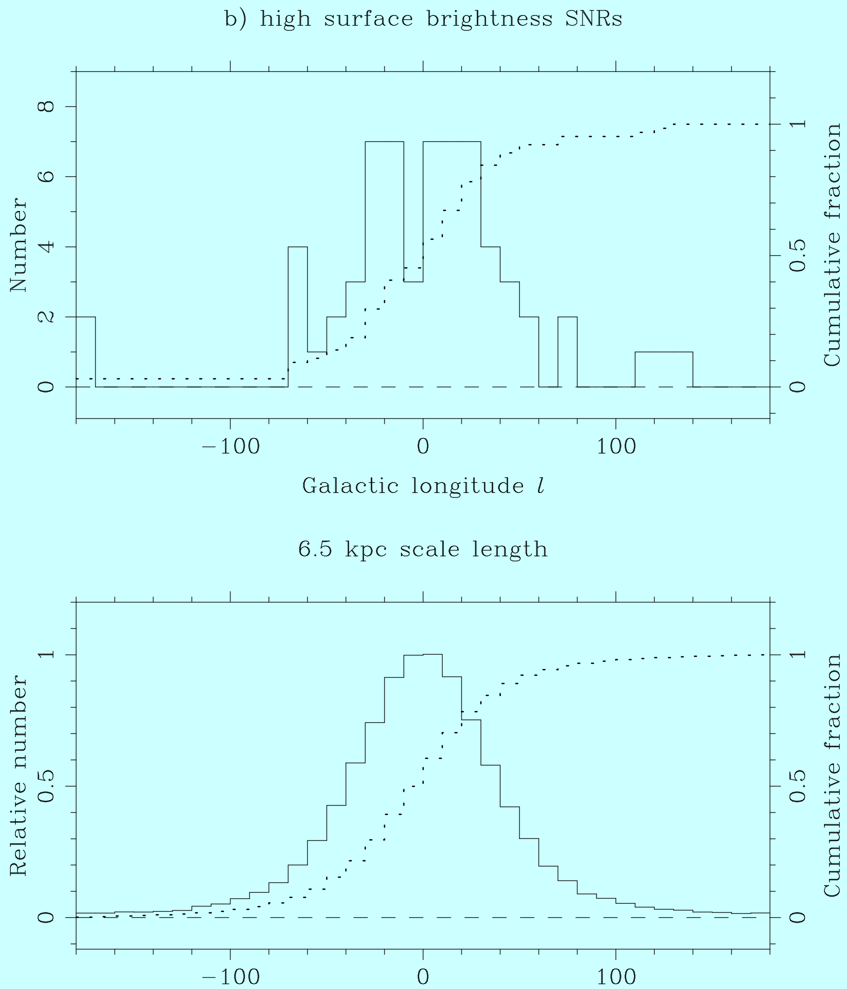

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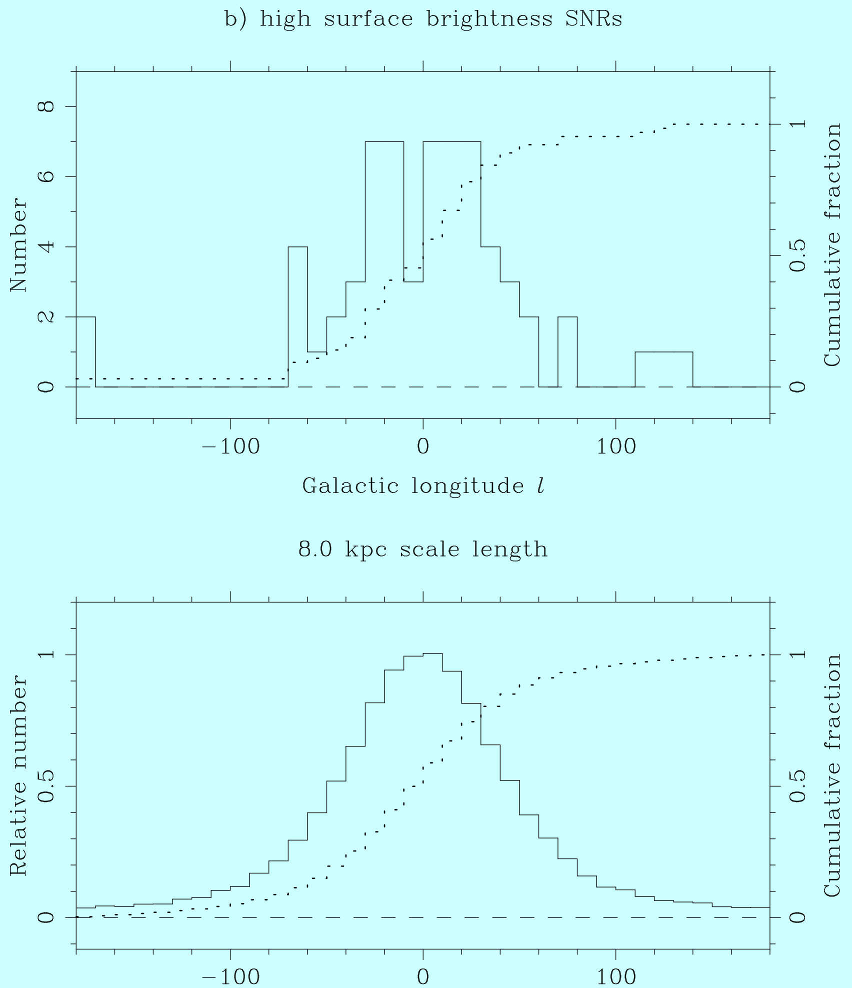
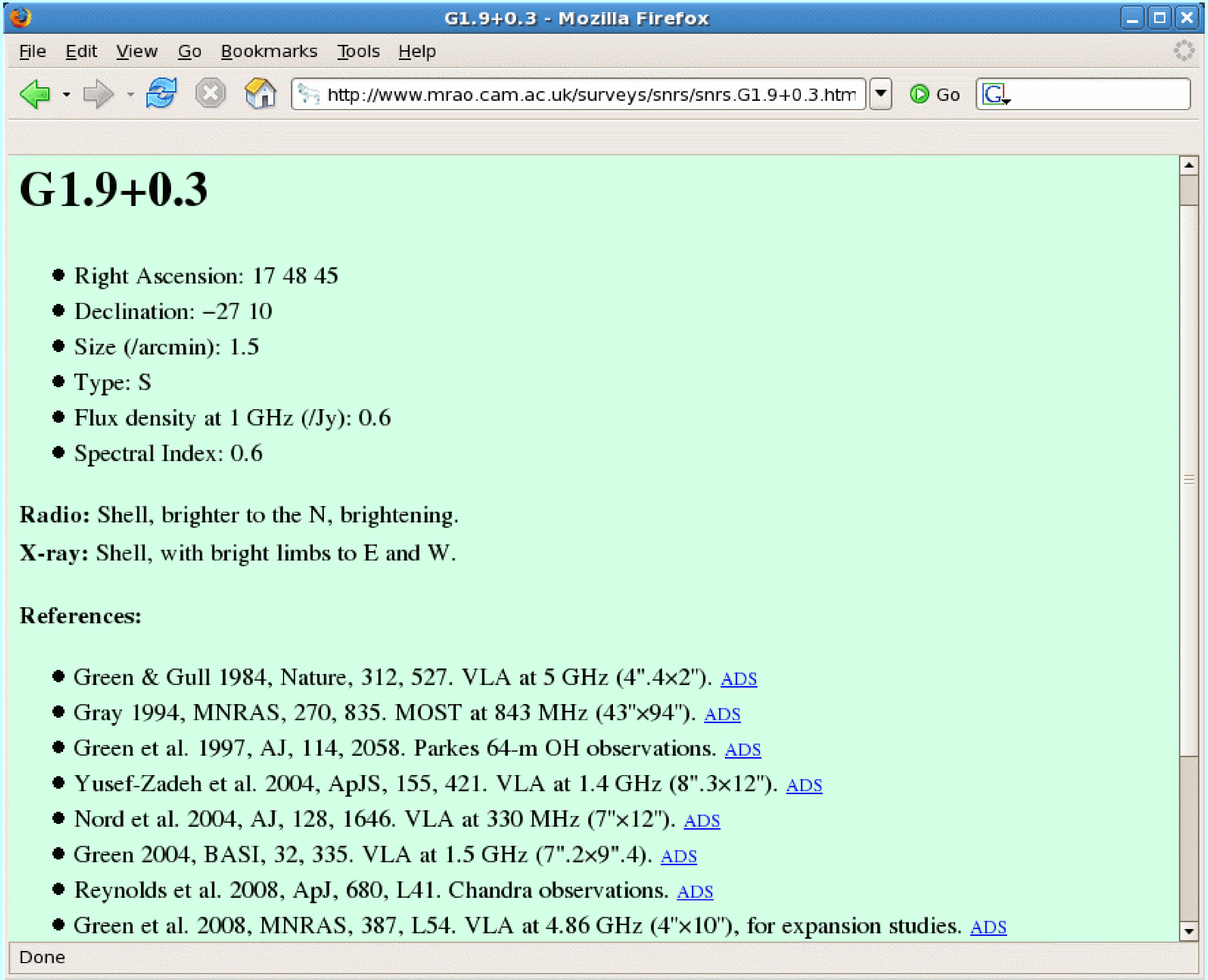


(top) Observed distribution for bright SNRs (bottom) model distribution of SNRs, for a scale-length of 8.0 kpc



G1.9+0.3

- Right Ascension: 17 48 45
- Declination: –27 10
- Size (/arcmin): 1.5
- Type: S
- Flux density at 1 GHz (/Jy): 0.6
- Spectral Index: 0.6

Radio: Shell, brighter to the N, brightening.

X-ray: Shell, with bright limbs to E and W.

References:

- Green & Gull 1984, Nature, 312, 527. VLA at 5 GHz (4".4×2"). ADS
- Gray 1994, MNRAS, 270, 835. MOST at 843 MHz (43"×94"). ADS
- Green et al. 1997, AJ, 114, 2058. Parkes 64-m OH observations. ADS
- Yusef-Zadeh et al. 2004, ApJS, 155, 421. VLA at 1.4 GHz (8".3×12"). ADS
- Nord et al. 2004, AJ, 128, 1646. VLA at 330 MHz (7"×12"). ADS
- Green 2004, BASI, 32, 335. VLA at 1.5 GHz (7".2×9".4). ADS
- Reynolds et al. 2008, ApJ, 680, L41. Chandra observations. ADS
- Green et al. 2008, MNRAS, 387, L54. VLA at 4.86 GHz (4"×10"), for expansion studies. ADS

An example webpage from the SNR catalogue

Distances to SNRs (1)

Many studies of Galactic SNRs require knowledge of the distances to remnants

- but distances are not available for most SNRs
- the available distances are from a wide variety of methods
  - optical expansion and proper motion studies
  - 21-cm H I absorption spectra
  - association with H I or CO features in the surrounding ISM
  - H I column density
  - association with other objects
  - etc

Distances to SNRs (2)

Distance measurements are currently available for 47 Galactic SNRs, i.e. only about 20% of catalogued remnants

- most of these are 'kinematic' distances, from H I absorption, or association with H I or CO features in the ISM
- kinematic distances require Galactic rotation curve, so are subject to distance ambiguity inside the Solar Circle, and not accurate near $l = 0°$ and $l = 180°$

remnant	distance /kpc	remnant	distance /kpc
G4·5+6·8	2.9	G119·5+10·2	1.4
G6·4−0·1	1.9	G120·1+1·4	2.3
G11·2−0·3	4.4	G130·7+3·1	3.2
G18·8+0·3	14.0	G132·7+1·3	2.2
G21·5−0·9	4.6	G166·0+4·3	4.5
G27·4+0·0	6.8	G166·2+2·5	8.0
G33·6+0·1	7.8	G184·6−5·8	1.9
G34·7−0·4	2.8	G189·1+3·0	1.5
G39·7−2·0	3.0	G205·5+0·5	1.6
G43·3−0·2	10.0	G260·4−3·4	2.2
G49·2−0·7	6.0	G263·9−3·3	0.3
G53·6−2·2	2.8	G292·0+1·8	6.0
G55·0+0·3	14.0	G292·2−0·5	8.4
G74·0−8·5	0.4	G296·8−0·3	9.6
G74·9+1·2	6.1	G315·4−2·3	2.3
G84·2−0·8	4.5	G320·4−1·2	5.2
G89·0+4·7	0.8	G327·4+0·4	4.8
G93·3+6·9	2.2	G327·6+14·6	2.2
G93·7−0·2	1.5	G332·4−0·4	3.1
G109·1−1·0	3.0	G337·0−0·1	11.0
G111·7−2·1	3.4	G348·5+0·1	8.0
G114·3+0·3	0.7	G348·7+0·4	8.0
G116·5+1·1	1.6	G349·7+0·2	14.8
G116·9+0·2	1.6		

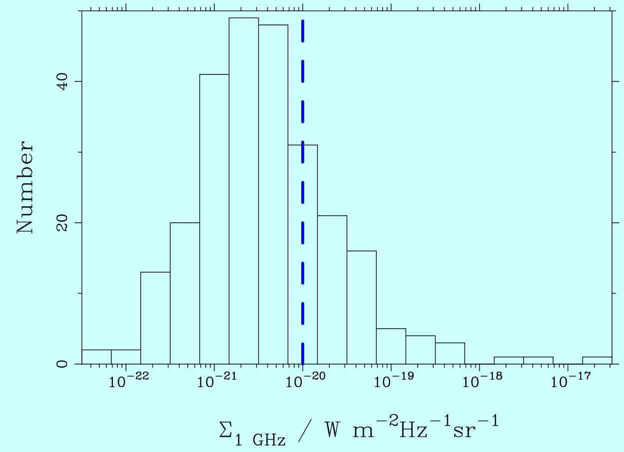
Distances from Green (2004)

Distances to SNRs (3)

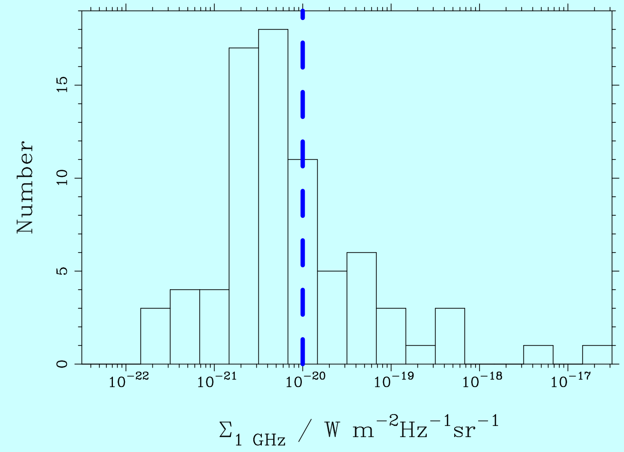
The available distances measurements (and their uncertainties) are far from homogeneous

- some of the methods used are subjective (e.g. association with features in the ISM)
- each distance method is subject to its own uncertainties (e.g. systematic, for kinematic distances, plus random from measurement uncertainties)
- there is a bias towards the brighter, more easily studied remnants

But, since distance measurements are available for only ≈ 20% of remnants, is it possible to deal with distance dependent statistics of all known SNRs?



Σ for all SNRs



Σ for SNRs with distances

The $\Sigma - D$ relation: the ideal (1)

Since distance are not available for most Galactic SNRs, many statistical studies of have relied on the '$\Sigma - D$' relation

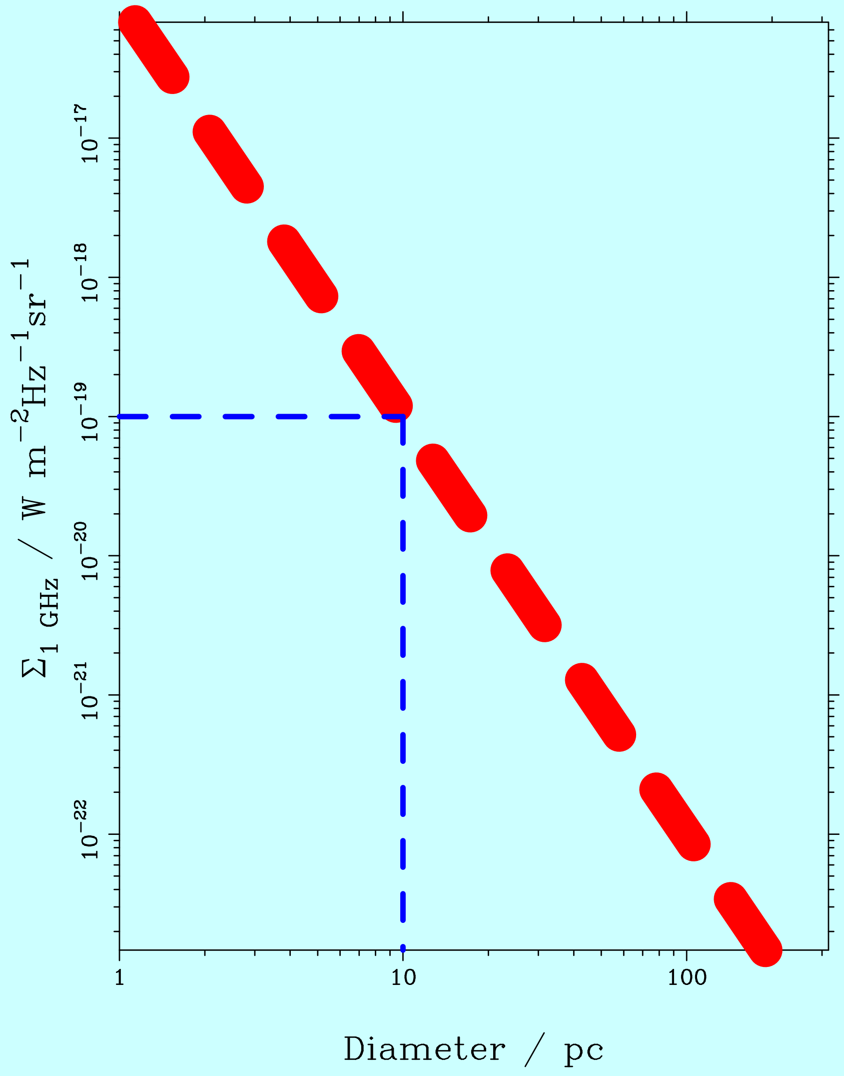
- for remnants with known distances, d, and hence known diameters ($D = \theta d$), physically large SNRs are seen to be lower surface brightnesses (Σ) than small remnants
- this correlation can be modelled as

$$\Sigma \propto D^{-n}$$

note that Σ is *distant independent*

The Σ–D relation: the ideal (2)

- a physical diameter can be deduced from the *observed* surface brightness of any remnant using the Σ–D correlation
- then a distance to the remnant can be deduced using its *observed* angular size

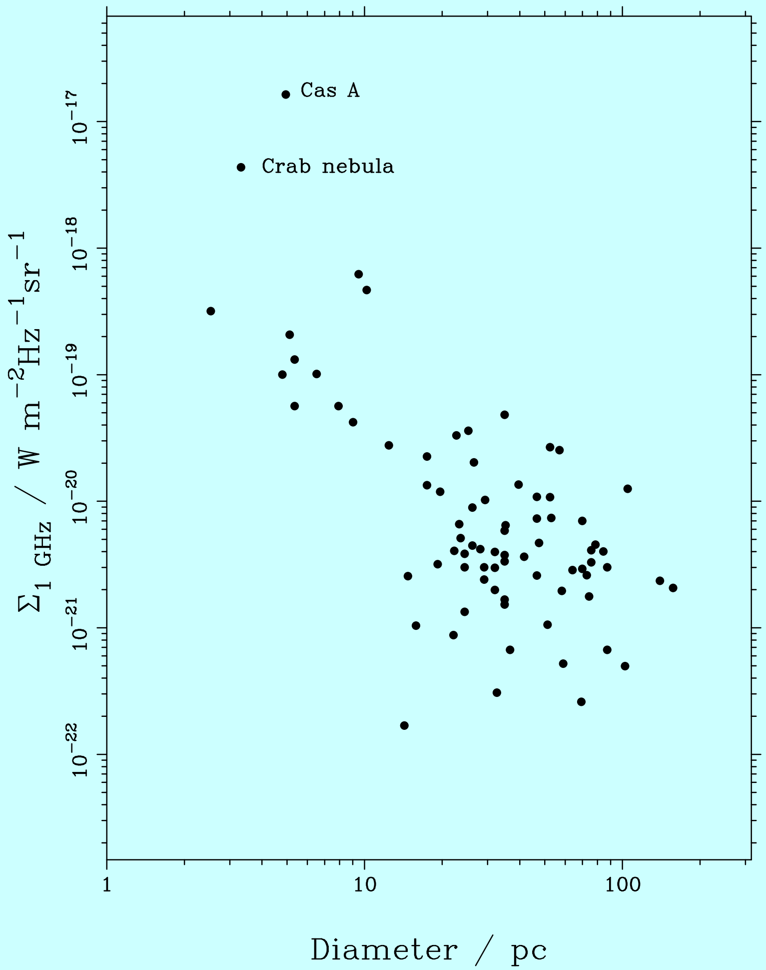


An idealised Σ–D relation for Galactic SNRs

Some reality (1): the observed Σ−D relation

But, the observed 'Σ−D' relation shows a wide range of diameters for a given surface brightness

- for a particular surface brightness the diameters of SNRs vary by up to about an order of magnitude
- given the observational selection effects, this range may be even larger



The Σ−D relation for 47 Galactic SNRs with known distances

Some reality (1): the observed $\Sigma - D$ relation

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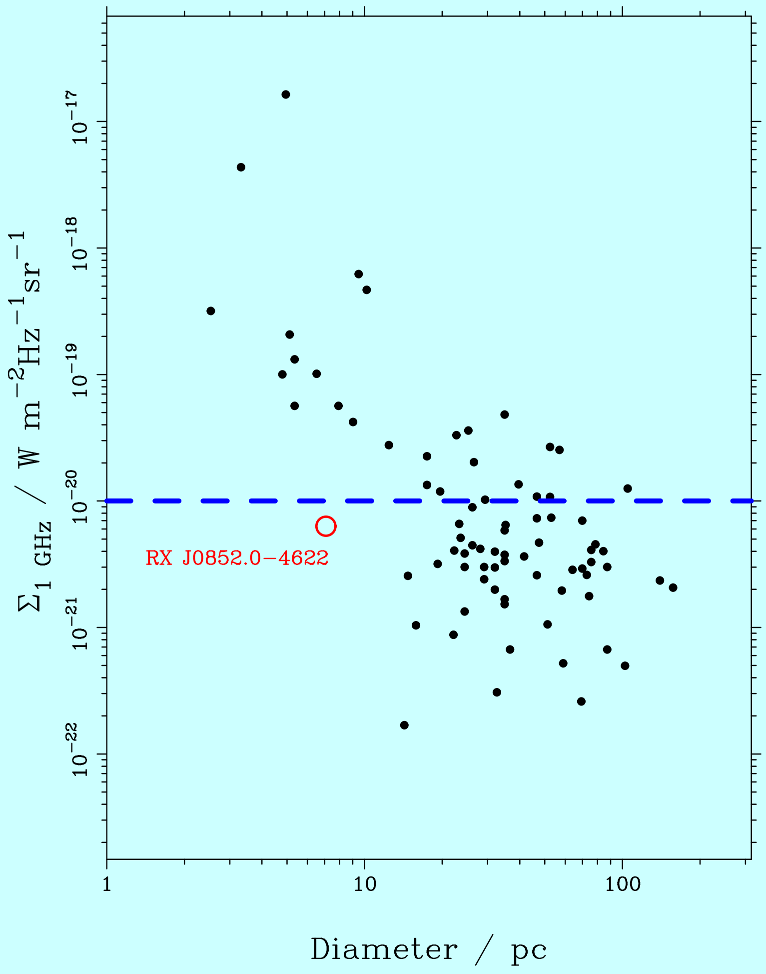


The $\Sigma - D$ relation for 47 Galactic SNRs with known distances

Some reality (2): an aside... which regression?

If the $\Sigma{-}D$ correlation is to be used to derive diameters (and hence distances) for remnants with known surface brightnesses, then we need to use an appropriate regression line

- least-squares regression by minimizing the Σ differences, and by minimizing the D differences, are *not* the same (see, for example, Isobe et al. 1990, ApJ, 364, 104)
- to *predict* D from Σ, then a least squares fit minimizing deviations in D *not* in Σ should be used
- recent published $\Sigma \propto D^n$ relations have, however, minimized deviations on Σ, e.g.
  - Case & Bhattacharya (1998, ApJ, 504, 761) derived a relationship with $n = 2.65 \pm 0.30$ for Galactic SNRs by minimizing deviations in Σ
  - but $n = 3.58 \pm 0.33$ when minimizing deviations in D
  - so their diameters (and distances) of fainter remnants are *overestimated*

However, given the large spread of properties of SNRs, and problems with selection effects, I would not advocate using the $\Sigma{-}D$ relation to derive distances to individual Galactic SNRs

Some reality (3): what are we plotting?

The $\Sigma - D$ correlation is largely a consequence of the fact that it is a plot of surface-brightness – rather than luminosity – against diameter

- surface-brightness is plotted, as it is a distance-independent *observable* for all SNRs
- instead consider the radio luminosity of the remnants (L). Since

$$\Sigma \propto \frac{S}{\theta^2} \quad \text{and} \quad L \propto S d^2$$

then

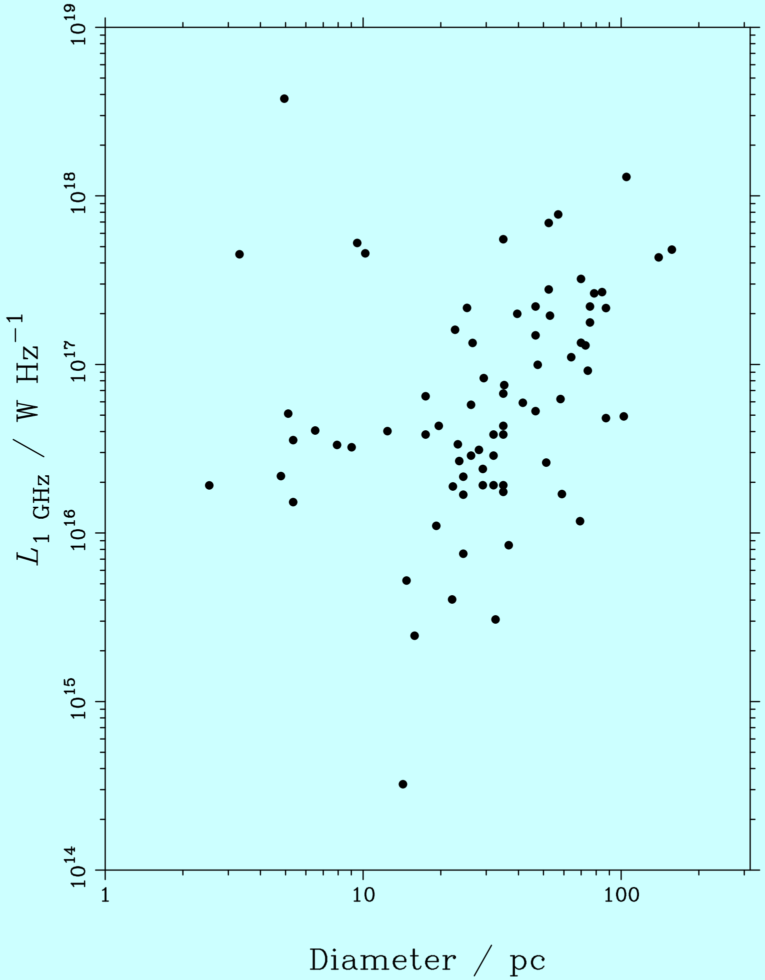
$$\Sigma \propto \frac{L}{(\theta d)^2} \quad \text{or} \quad \Sigma \propto \frac{L}{D^2}.$$

i.e. much of the correlation in the $\Sigma - D$ is inevitable, given the D^{-2} bias.

Some reality (4): the observed *L*−*D* relation

The *L*−*D* relation for Galactic SNRs with known distances shows a wide range of luminosities for SNRs of *all* diameters

- the upper bounds to the *Σ*−*D* and *L*−*D* relations are *not* limited by selection effects
- but, it is not clear that this represents the evolutionary track of any individual SNR



The L−D relation for 47 Galactic SNRs with known distances

The Galactic SNR distribution (1)

The distribution of SNRs in the Galaxy is of interest for many astrophysical studies, but difficult to determine because of

- lack of reliable distances for most SNRs
- selection effects
  - SNRs in the 2nd and 3rd quadrants are outside the Solar Circle i.e. at large Galactocentric radii
  - they are in regions where the background Galactic emission is low,
    so are relatively easy to identify

Some published studies have *not* taken the relevant selection effects into account, and have erroneously derived very broad SNR distributions

Other studies have attempted to 'deconvolve' the selection effects, using $\Sigma{-}D$ to determine distances for SNRs statistically

The Galactic SNR distribution (2)

An alternative approach is simply to compare the distribution on SNRs with Galactic longitude

- this follows van den Bergh (1988), but deals with completeness limits more realistically

Main advantage:

- does not require distances for individual SNRs, or the use of the $\Sigma - D$ relation

Main disadvantage:

- limited to the brighter SNRs, where selection effects not thought to be dominant
- so uses only 64 remnants above the nominal surface brightness completeness limit