G64.5+0.9: a new shell supernova remnant with unusual central emission

AMI Consortium: Natasha Hurley-Walker, Matthew L. Davies, Thomas M. O. Franzen, Keith Grainge, D. A. Green, Michael P. Hobson, Anthony Lasenby, Guy Pooley, Carmen Rodríguez-González, Richard D. E. Saunders, A. M. M. Scaife, Paul F. Scott, Timothy Shimwell, David Titterington, Elizabeth Waldram and Jonathan T. L. Zwart

Astrophysics Group, Cavendish Laboratory, 19 J. J. Thomson Avenue, Cambridge CB3 0HE

Accepted 2009 May 17. Received 2009 May 11; in original form 2009 March 25

ABSTRACT
We present observations between 1.4 and 18 GHz confirming that G64.5+0.9 is a new Galactic shell supernova remnant, using the Very Large Array and the Arcminute Microkelvin Imager. The remnant is a shell ∼8 arcmin in diameter with a spectral index of α = 0.47 ± 0.03 (with α defined such that flux density S varies with frequency ν as S ∝ ν^−α). There is also emission near the centre of the shell, ∼1 arcmin in extent, with a spectral index of α = 0.81 ± 0.02. We do not find any evidence for spectral breaks for either source within our frequency range. The nature of the central object is unclear and requires further investigation, but we argue that it is most unlikely to be extragalactic. It is difficult to avoid the conclusion that it is associated with the shell, although its spectrum is very unlike that of known pulsar wind nebulae.

Key words: radiation mechanisms: non-thermal – supernova remnants – radio continuum: ISM.

1 INTRODUCTION
An arc of extended emission was noted near RA = 19°50′25″, Dec. = 28°16′ in an NRAO (National Radio Astronomy Observatory) VLA (Very Large Array) Sky Survey (NVSS) image of the region. As the arc resembles part of a ring and lies in the Galactic plane, it was identified as a possible supernova remnant (SNR). Tian & Leahy (2006) also noted this structure in Canadian Galactic Plane Survey (CGPS; Taylor et al. 2003) data with similar sensitivity to but poorer resolution than the NVSS data, and proposed it as a possible SNR. It has now been observed with the VLA and the newly commissioned Arcminute Microkelvin Imager (AMI; see AMI Consortium: Zwart et al. 2008). These observations are described in Section 2, and calibration and data reduction in Section 3. Results are presented in Section 4, and we analyse and discuss all available data in Section 5, confirming G64.5+0.9 as a new Galactic SNR.

2 OBSERVATIONS
The position of the apparently central source was chosen as the pointing centre for observations with the VLA and AMI: RA = 19°50′24″, Dec. = 28°16′25″. AMI is a dual set of interferometric arrays located at the Mullard Radio Astronomy Observatory, Lord’s Bridge, Cambridge, UK. The AMI Small Array (SA) consists of ten 3.7-m-diameter equatorially mounted dishes with a baseline range of ∼5–20 m, while the AMI Large Array (LA) has eight 12.8-m-diameter dishes with a baseline range of ∼20–100 m. Both arrays observe I + Q in the band 12–18 GHz, each with system temperatures of about 25 K.

The backends are analogue Fourier transform spectrometers, from which the complex signals in each of the eight channels of 750 MHz bandwidth are synthesized, and the signals in the synthesized channels are correlated at the ∼10 per cent level. In practice, the lowest two frequency channels are generally not used due to a poor correlator response in this frequency range and, currently, interference.

Frequencies, resolutions, dates, calibrators and observing times for each observation are shown in Table 1. The AMI SA observed a single pointing, while the AMI LA used a seven-point raster mode with 4 arcmin spacing. J2023+318 (RA = 20°23′00.0, Dec. = 31°53′02.3) was chosen as a phase calibrator from the Jodrell Bank VLA Survey (Patnaik et al. 1992; Browne et al. 1998; Wilkinson et al. 1998) on the basis of its proximity and flux density (1.1 Jy at 15 GHz).

During the time of our VLA observations, about half of the antennas of the VLA were upgraded Expanded VLA (EVLA) antennas. This necessitated an extra step of calibration on VLA–EVLA
baselines. The telescope was in D-array, and we used the \( L \), \( C \) and \( X \)-band receivers at centre frequencies of 1.43, 4.86 and 8.46 GHz, respectively. J1925+211 (RA = 19\(^{h}\)25\(^{m}\)59.6\(^{s}\), Dec. = 21\(^{\circ}\)06\('\)26\(''\)2) was selected from the VLA Calibrator Manual\(^1\) as the phase calibrator at 1.43, 4.86 and 8.46 GHz in D-array; with flux densities over 1 Jy and no extended structure, it is a suitable choice of phase calibrator for all three bands.

### 3 CALIBRATION AND DATA REDUCTION

The AMI data reduction was performed using our software tool \textsc{reduce}. This is used to apply path-compensator and path-delay corrections, to flag interference, shadowing and hardware errors, to apply phase and amplitude calibrations and to Fourier transform the correlator data readout to synthesize the frequency channels, before outputting to disk in \textsc{uvfits} format suitable for imaging in \textsc{aips}.

Flux calibration was performed using short observations of 3C48 and 3C286 near the beginning and end of each run, with assumed \( I + Q \) flux densities for these sources in the AMI channels consistent with Baars et al. (1977) (see Table 2). As Baars et al. measure \( I \) and AMI measures \( I + Q \), these flux densities include corrections for the polarization of the sources derived by interpolating from VLA 5-, 8- and 22-GHz observations. After phase calibration, the phase of AMI over 1 hour is generally stable to 5\(\sigma\) rms of the AMI LA observations are shown in Figs 2 and 3, respectively. The VLA and AMI SA images shown are not corrected for the primary beams of the telescopes, but when measuring flux densities this correction is made. In order to produce a raster map, the AMI LA images are of course primary-beam-corrected. The signal-to-noise ratio of the 1.43-GHz image was large enough that self-calibration from the first non-negative clean components was used to enhance the image.

### 4 RESULTS

We note that the maps show two sources of emission: a ring-like structure surrounding a slightly extended, apparently central object. As we are using interferometers sensitive to a limited range of angular scales, it is not possible to obtain accurate flux densities for structures on all scales from all of the observations. Only the VLA 1.43-GHz and AMI SA observations have the required short baselines to provide sensitivity to the extended ring emission. The AMI SA does not have the required resolution to measure the flux density of the central emission without confusion with the ring.

To measure flux density, we adopt the fitting method of Green (2007), using the program \textsc{fitflux}. In this method, a flux density is fitted by drawing a polygon around the object and fitting a tilted plane to the pixels around the edges of the polygon. The tilted plane is then removed from the image before integrating the emission within the polygon. This method is sensitive to the fitting area selected but only at the one per cent level, which is included in the estimate of the error. This method allows us to remove contribution from the background, especially the contribution from the ring in the case of measuring the flux density of the central emission.

The main sources of error on the flux density measurements are the thermal noise \( \sigma_{\text{rms}} \) and the error on the flux calibration \( \sigma_{S} \). Long-term measurements of the AMI flux calibration show it to have an rms error of 3 per cent. The VLA flux calibration is performed using \textsc{getflux} which scales the fluxes of the field and phase calibrator using the flux density of 3C48 consistent with Baars et al. This process has an error of less than 1 per cent for each of the frequency channels. Therefore, to obtain the error on a flux density measurement, the Q may be positive or negative, but is expected to be small when integrated over the whole source.

VLA data reduction was performed entirely within \textsc{aips}. The VLA-EVLA baselines were also calibrated using \textsc{bical} as described in the guidelines for post-processing EVLA data in \textsc{aips}.$^2$

Maps were made using \textsc{imagr} in \textsc{aips} from each channel of the AMI SA, AMI LA and the VLA (Fig. 1). Combined-channel maps of the AMI SA and AMI LA observations are shown in Figs 2 and 3, respectively. The VLA and AMI SA images shown are not corrected for the primary beams of the telescopes, but when measuring flux densities this correction is made. In order to produce a raster map, the AMI LA images are of course primary-beam-corrected. The signal-to-noise ratio of the 1.43-GHz image was large enough that self-calibration from the first non-negative clean components was used to enhance the image.

### Table 1. Observations of G64.5+0.9.

| Telescope | AMI SA | AMI LA | VLA |
|-----------|--------|--------|-----|
| Date      | 2007 October | 2008 October | 2008 July |
| Flux calibrator | 3C286 | 3C48 | 3C48 |
| Phase calibrator | J2023+318 | J2023+318 | J1925+211 |
| Frequency (GHz) | 14–18 | 14–18 | 1.43 | 4.86 | 8.46 |
| Observation(s) length | 16 h | 10 h | 40 min | 40 min | 20 min |
| Synthesized beam FWHM (arcmin) | 3–2 | 1–0.3 | 0.75 | 0.22 | 0.12 |
| Primary beam FWHM (arcmin) | 22–16 | 5.6–5.0 | 32 | 9.3 | 5.3 |

### Table 2. Assumed flux densities of the flux calibrators over the VLA and AMI frequencies used.

| Channel | \( v \) (GHz) | \( S_{3C286} \) (Jy) | \( S_{3C48} \) (Jy) |
|---------|---------------|---------------------|------------------|
| VLA \( L \) | 1.43 | – | 14.71 |
| VLA \( C \) | 4.86 | – | 5.43 |
| VLA \( X \) | 8.46 | – | 3.15 |
| AMI \( 3 \) | 14.2 | 3.61 | 1.73 |
| AMI \( 4 \) | 15.0 | 3.49 | 1.65 |
| AMI \( 5 \) | 15.7 | 3.37 | 1.57 |
| AMI \( 6 \) | 16.4 | 3.26 | 1.49 |
| AMI \( 7 \) | 17.1 | 3.16 | 1.43 |
| AMI \( 8 \) | 17.9 | 3.06 | 1.37 |

---

1 http://www.aoc.nrao.edu/~gtaylor/csource.html

2 http://www.vla.nrao.edu/astro/guides/evlareturn/postproc.shtml
Figure 1. VLA images of G64.5+0.9. Top panel: 1.43 GHz, $\sigma_{\text{rms}} = 110 \, \mu$Jy beam$^{-1}$, uniform weighting; middle panel: 4.86 GHz, $\sigma_{\text{rms}} = 38.5 \, \mu$Jy beam$^{-1}$, uniform weighting; bottom panel: 8.46 GHz, $\sigma_{\text{rms}} = 43.5 \, \mu$Jy beam$^{-1}$, natural weighting with 3$\sigma$ contours. The box in the middle panel indicates the area that is shown in the lower panel. In these and subsequent images, the full width at half-maximum (FWHM) of the CLEAN restoring beam of the observation is shown as an ellipse inside a box in the lower left.

Figure 2. AMI SA combined-channel (14–18 GHz) image of G64.5+0.9; the map noise is 192 $\mu$Jy beam$^{-1}$.

Figure 3. Map of a primary-beam-corrected combined-channel (14–18 GHz) seven-point raster of G64.5+0.9 observed by the AMI LA. The central pointing has a thermal noise of 32 $\mu$Jy beam$^{-1}$ and the surrounding six pointings have a thermal noise of 58 $\mu$Jy beam$^{-1}$.

We now discuss the results from each observation in turn.

4.1 VLA 1.43 GHz

Fig. 1 shows that this object strongly resembles a shell SNR, with slight brightening in the north-east. Interestingly, the central emission is also brightest in this direction. The full ring structure is clearly discernible in this map, as compared to the partial structure found in the NVSS map. This is due to the enhanced uv coverage and lower noise of the longer pointed observation.

$\textit{FITFLUX}$ was used to obtain the flux density of the central object as $17.1 \pm 0.8$ mJy, and the flux density of the ring and the central
source combined as 119 ± 5 mJy. The former was subtracted from the latter to obtain the flux density of the ring as 102 ± 5 mJy.

4.2 VLA 4.85 GHz

At 4.85 GHz, the ring is resolved out to the extent that it is not possible to extract a reliable estimate of its integrated flux density. However, the structure of the emission close to the ring centre becomes more clear; its integrated flux density is listed in Table 3. The north-east section of the ring shows possible contamination with a point source. Using the \textsc{amps} routine \textsc{slice}, a cross-sectional profile across this source, perpendicular to a tangent along the ring at this point, was produced in order to measure the flux levels. The base flux level from the ring is 220 \mu Jy beam^{-1} and the peak point source flux is 620 \mu Jy beam^{-1}. The width of the source profile at 420 \mu Jy beam^{-1} is 12 arcsec, which is the resolution of the telescope at this frequency. Therefore, the source is unresolved, and we postulate that it is a background contaminating source. \textsc{fitflux} gives a flux density estimate of 0.41 ± 0.04 mJy for this source.

4.3 VLA 8.46 GHz

At 8.46 GHz, the ring is almost entirely resolved out. However, we obtain good information on the structure of the near-central emission, as shown in the lowest panel of Fig. 1. \textsc{fitflux} gives a measurement of the flux density of this source, shown in Table 3.

4.4 AMI 14–18 GHz

The AMI SA, due to its sensitivity to larger angular scales, picks up much more large-scale Galactic emission in the region (see Section 4.5 and Fig. 2). The north-east part of the ring structure is clear, but is confused with the central source.

The AMI LA combined-channel raster map is shown in Fig. 3. The ring is slightly resolved out by the AMI LA, but the source apparently near the centre shows up clearly and has similar structure to that in the VLA maps at lower frequency. \textsc{fitflux} was used to find the flux density of this near-central emission for each channel, and these results are listed in Table 3. It is possible that the AMI LA is slightly resolving out this object at the higher end of its frequency coverage. However, the slight drop in flux density is within the error bars.

\textsc{fitflux} was used to find the flux density of the whole object from the AMI SA combined-channel map, and the flux density of the central source from the AMI LA combined-channel map. These were 35.3 ± 1.4 and 2.49 ± 0.10 mJy, respectively. The latter was subtracted from the former to produce an estimate of the flux density of the ring at 16 GHz of 32.8 ± 1.4 mJy.

4.5 Data from the literature

Most Galactic radio surveys do not possess the required resolution to resolve G64.5+0.9 well, as it is only 8 arcmin in diameter. The Effelsberg 2.7-GHz survey data (Reich et al. 1984) show a small knot of emission at the SNR’s location, and a large amount of emission on broader angular scales. It was not possible to extract meaningful flux densities for the ring and central source from these data.

This object is also covered by the Westerbork Synthesis Radio Telescope Galactic plane survey\(^3\) (see e.g. Taylor et al. 1996) at 327 MHz, which provides low-frequency, large-scale information, at a resolution of 1.0 × 2.1 arcmin\(^2\) at this declination. Unfortunately, the residual grating ring of a bright, distant source lies directly over the objects of interest.

Infrared data from the \textit{Infrared Astronomical Satellite} (NASA RP-1190 1987) are too low in resolution to provide any useful information about the region. Higher resolution \textit{Spitzer} Galactic Legacy Infrared Midplane Survey Extraordinaire data at 3.6–8\micron\ also show no related emission in this area. The Second Digitized Sky Survey\(^4\) shows only foreground stars in the Galaxy. The Australia Telescope National Facility Pulsar Catalogue\(^5\) (see Manchester et al. 2005) shows no pulsars within 1° of the remnant. We found no X-ray counterparts in any catalogue from the \textit{ROSAT} All-Sky Survey (Voges et al. 1999) or in the \textit{XMMS–Newton} Serendipitous Source Catalogue (Watson et al. 2009).

5 DISCUSSION

For both the ring and the near-central emission, we fit power-law spectra. We define \(\alpha\) such that flux density \(S\) varies with frequency \(\nu\) as \(S \propto \nu^{-\alpha}\). Spectra were fitted to these data using a Gaussian likelihood function sampled by a Markov Chain Monte Carlo technique. This method copes with asymmetric errors in log \(S\) across the frequency channels and provides an error estimate on the spectral index directly from the posterior distribution.

Using the VLA 1.43 GHz and AMI measurements of the flux density of the ring, we calculate that it has a spectrum with \(\alpha = 0.47 ± 0.03\). Even using conservative errors of 10 per cent on the flux densities results in an error of only 0.06, due to the large-frequency lever-arm. Thus, the structure and spectral index identify the shell source G64.5+0.9 as a shell SNR. The surface brightness of the SNR at 1 GHz is \(\geq 3 \times 10^{-22}\) W m\(^{-2}\) Hz\(^{-1}\) sr\(^{-1}\), which is faint for known SNRs (in the faintest 10 per cent of identified SNRs – see e.g. Green 2004). It is three times fainter than the faintest object detected by Brogan et al. (2006) in their multiconfiguration VLA survey, corroborating the view that the ‘missing’ SNRs in the Galaxy will be found by future deeper surveys. The relatively low surface brightness suggests that the remnant is old, but, on the other hand, its highly circular shell suggests that it is young. Tian & Leahy (2006) suggest a possible distance of 11 kpc, based on possibly related Hi features, at which it would have a diameter of \(\geq 26\) pc. This is not the first SNR visible in NVSS data which has been overlooked (see e.g. G353.9–2.0 identified by Green 2001).

Fitting a spectrum to the data in Table 3, we find that the central emission has a steep spectrum with \(\alpha = 0.81 ± 0.02\) (Fig. 4). This emission is of interest, because of both its apparent position relative to the ring and its structure. It could be a background, unrelated,

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\(\nu\) (GHz) & \(S_\nu\) (mJy) \\
\hline
1.43 & 17.07 ± 0.36 \\
4.86 & 7.92 ± 0.16 \\
8.46 & 4.01 ± 0.08 \\
14.2 & 2.69 ± 0.17 \\
15.0 & 2.58 ± 0.12 \\
15.7 & 2.50 ± 0.13 \\
16.4 & 2.48 ± 0.12 \\
17.1 & 2.27 ± 0.12 \\
17.9 & 2.02 ± 0.11 \\
\hline
\end{tabular}
\caption{VLA and AMI LA 1 + Q flux densities of the emission close to the ring centre.}
\end{table}
extragalactic source or a Galactic source that may or may not be related to the shell remnant.

First, we consider a source at redshift \( z \) around 0.1. Then, its angular size of around 1 arcmin implies a physical size of 100 kpc, and its luminosity \( P_{1.43} \) is around \( 3 \times 10^{22} \text{ W Hz}^{-1} \text{ sr}^{-1} \) (taking \( H_0 = 72 \text{ km s}^{-1} \text{ Mpc}^{-1} \)). These values are typical of Fanaroff–Riley type I (Fanaroff & Riley 1974) twin-jet or tail radio sources powered by jet-producing machines. However, the emission is not reminiscent of known twin jets or tails – particularly at 8 GHz – and the lack of spectral steepening from 1.43 to 18 GHz also tells against it being this type of radio source (see e.g. Miller 1980; Laing 2008). A substantially higher redshift for the emission appears ruled out: its structure is very difficult to reconcile with that of a powerful radio source of whatever physical size or orientation, and the emission shows no sign of the synchrotron or inverse-Compton losses associated with the extended regions of powerful sources.

‘Halo’ emission from certain galaxy clusters might resemble the shape of the near-central emission. However, ‘halo’ emission has an extremely steep radio spectrum with \( \alpha \approx 2 \) at gigahertz frequencies (see e.g. Komissarov & Gubanov 1994 or Bacchi et al. 2003).

The remaining extragalactic possibility would seem to be synchrotron emission from a nearby system of interacting galaxies. At a redshift \( z \approx 0.02 \), its angular size of around 1 arcmin implies a physical size of 20 kpc, and its flux density \( S_{1.43 \text{GHz}} \) of 17.1 mJy implies a luminosity \( P_{1.43 \text{GHz}} \) of \( 1 \times 10^{21} \text{ W Hz}^{-1} \text{ sr}^{-1} \). Thus, this source’s angular size, flux density and structure are consistent with synchrotron emission from two or three interacting galaxies at \( z \) of around 0.01–0.05 (see e.g. Hazel & Alexander 1992).

However, from source counts based on the Faint Images of the Radio Sky at Twenty centimeters (FIRST; see White et al. 1997), we estimate at 15 per cent the probability of a source of \( S_{1.43} \geq 17 \) mJy appearing to lie inside the shell of the SNR purely by chance. Thus, the probability of any extragalactic radio source of this flux density and of such large angular extent lying within 1 arcmin of the centre is minimal.

Turning to possible Galactic sources of emission for the near-central source, chance association along the line of sight with thermal Galactic sources such as H\( \alpha \) regions is excluded both by the non-thermal radio spectrum of the central source and by its lack of infrared emission. The location of the extended emission near the centre of the shell suggests that G64.5+0.9 may be a ‘composite SNR, i.e. a shell containing a central pulsar wind nebula (PWN) – for example, see G328.1–1.8 (Dickel, Milne & Strom 2000). However, the radio spectral index of \( \approx 0.8 \) for the central source is considerably larger than expected, since PWNe usually have relatively flat spectral indices at gigahertz frequencies (e.g. Kothes et al. 2008). If the central source is a PWN associated with G64.5+0.9, then it requires a spectral break at below 1.4 GHz, which would be unusual. A low-frequency spectral break, at about 1.3 GHz – three times lower than for any other PWN – has been identified in DA 495 (=G65.7±1.2, Kothes et al.). DA 495 is thought to be rather old (~20000 years), whereas the highly circular nature of the shell of G64.5+0.9 suggests that it is relatively young.

To identify the nature of this object and fully constrain its association with the remnant, HI absorption-line observations are vital.

6 CONCLUSIONS

Follow-up observations of an arc of emission seen in NVSS and CGPS data have been made at frequencies from 1.4 to 18 GHz. We draw the following conclusions from our observations:

(i) G64.5+0.9 is confirmed as a shell SNR, and its emission follows a power-law spectrum with \( \alpha = 0.47 \pm 0.03 \);

(ii) by considering its size, shape and spectral behaviour, and a probabilistic analysis using FIRST radio source counts, we argue that the emission apparently at the centre of the ring is most unlikely to be any kind of extragalactic radio source;

(iii) it is difficult to avoid the conclusion that the apparently central emission is associated with the shell, although its spectrum is very unlike that of a PWN, and it therefore merits further investigation, particularly follow-up HI absorption-line observations.

ACKNOWLEDGMENTS

We thank the staff of the Mullard Radio Astronomy Observatory for their invaluable assistance in the commissioning and operation of AMI, which is supported by Cambridge University and the STFC. MLD, TMOF, CRG, NHW and TS acknowledge the support of PPARC/STFC studentships. We thank the editor and referee for helpful comments which significantly improved the text.

REFERENCES

AMI Consortium: Zwart J. T. L., et al., 2008, MNRAS, 391, 1545
Baars J. W. M., Gendler R., Pauliny-Toth I. I. K., Witzel A., 1977, A&A, 61, 99
Bacchi M., Feretti L., Giovannini G., Govoni F., 2003, A&A, 400, 465
Brogan C. L., Gelfand J. D., Gaensler B. M., Kassim N. E., Lazio T. J. W., 2006, ApJ, 639, 25
Browne I. A. W., Wilkinson P. N., Patnaik A. R., Wrobel J. M., 1998, MNRAS, 293, 257
Dickel J. R., Milne D. K., Strom R. G., 2000, ApJ, 115, 1693
Fanaroff B. L., Riley J. M., 1974, MNRAS, 167, 31
Green D. A., 2001, MNRAS, 326, 283
Green D. A., 2004, Bull. Astron. Soc. India, 32, 335
Green D. A., 2007, Bull. Astron. Soc. India, 35, 77
IRAS Catalogues and Atlases: The Point Source Catalog, 1987, in Bechman C. A., Neugebauer G., Habing H. J., Clegg P. E., Chester T. J., eds, NASA RP-1190. NASA, Washington, DC
Komissarov S. S., Gubanov A. G., 1994, A&A, 285, 27
Kothes R., Landecker T. L., Reich W., Safi-Harb S., 2008, ApJ, 687, 518
Laing R. A., Bridle A. H., Parma P., Feretti L., Giovanni G., Murgia M., Perley R. A., 2008, MNRAS, 386, 657
Manchester R. N., Hobbs G. B., Teoh A., Hobbs M., 2005, AJ, 129, 1993

© 2009 The Authors. Journal compilation © 2009 RAS, MNRAS 398, 249–254
AMI Consortium: N. Hurley-Walker et al.

Miley G., 1980, ARA&A, 18, 165
Patnaik A. R., Browne I. W. A., Wilkinson P. N., Wrobel J. M., 1992, MNRAS, 254, 655
Reich W., Fürst E., Haslam C. G. T., Steffen P., Reif K., 1984, A&AS, 58, 197
Sopp H., Alexander P., 1992, MNRAS, 259, 425
Taylor A. R., Goss W. M., Coleman P. H., van Leeuwen J., Wallace B. J., 1996, ApJS, 107, 239
Taylor A. R. et al., 2003, AJ, 125, 3145
Tian W. W., Leahy D. A., 2006, AJ, 455, 1053
Watson M. G. et al., 2009, A&A, 493, 339
White R. L., Becker R. H., Helfand D. J., Gregg M. D., 1997, ApJ, 475, 479
Wilkinson P. N., Browne I. W. A., Patnaik A. R., Wrobel J. M., Sorathia B., 1998, MNRAS, 300, 790
Voges W., et al, 1999, A&A, 349, 389

This paper has been typeset from a TeX/LaTeX file prepared by the author.