The Radio Identification of New Planetary Nebulae

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Abstract Using 1.4 GHz NRAO VLA Sky Survey (NVSS) data base, over 200 newly identified planetary nebulae with J2000 declination $b \geq -40°$ have been found to be radio sources at 20 cm. It is shown that the radio emission at 20 cm is optical thick for most of the planetary nebulae. This effect has to be taken into account when using radio flux and H_α flux to derive the optical extinction of the sources.

1 Introduction

Most planetary nebulae are weak radio sources. Thermal radio emission is an useful tracer of the ionization degree of a nebula. Because the radio emission is not affected by dust grains, it is also used to get the interstellar extinction by comparing the radio flux and optical flux of H Balmer lines. For these and other reasons, there have been several large-scale radio surveys of planetary nebulae before 1990 (See Milne & Aller 1982, Zijlstra, Pattasch, & Bignell 1989; Aaquist & Kwork 1990).

A survey covered nearly all of the sky north of $Dec \geq -40°$ was taken by Condon et al. (1998) at 1.4 GHz using VLA (NVSS). Using this data base, 702 radio sources have been identified (Condon & Kaplan 1998; Condon et al., 1999) for 885 planetary nebulae listed in the Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker et al. 1992, hereafter GPN92).

Recently a lot of efforts have been put to find new planetary nebulae. Kohoutek (2001) have edited a new PN catalogue including 1510 PNe updated to 1999. Parker et al. (1998) have undertaken a high resolution, narrow-band H_α survey of the Southern Galactic Plane. In the CDROM version released in 2001 (Parker and Phillipps, 2001), 1214 PNe are included. We have compared these two catalog with the GPN92 and found that 919 enters of $Dec \geq -40°$ are new, 569 from Parker's catalogue and 382 from Kohoutek's catalogue (32 listed in both catalog). Besides, some new observations of planetary nebulae have been carried out recently by Cappellaro et al.(2001), Kohoutek (2002), Van de Steene & Jacoby (2001). After comparing these data with Parker's and Kohoutek's catalog as well as GPN92, 67 sources are found to be new.

If these new planetary nebulae were identified with radio data, the number of known radio planetary nebulae would be doubled. We are trying to find the radio correspondents of these new optical discoveries using the NVSS data. Though the detected radio emission did not necessary excludes the contaminations by coincident objects, it increases the reliable radio sources as a planetary nebulae significantly. Besides, the radio data would also give some information about the optical extinction of sources if their fluxes of H Balmer lines are available.

2 The Radio Identification of Newly Found Planetary Nebulae

The radio identification was made by comparing the optical positions of new planetary nebular candidates and those in NVSS data base. Usually, when the position difference between optical and radio source is less than 20", they are identified to be the same source. Over 200 NVSS sources have been identified to be associated with newly discovered planetary nebular candidates. For about 80 per cent of the identified sources, the position differences between optical and radio centers are less than 10". For about 30 sources these differences are somewhat larger than 20" but less than 45". They are probably the same source because of the complex in structure or relatively diffuse in emission. The optical and radio positions as well as fluxes at 20 cm for 36 sources are listed in Table 1. A complete catalogue of newly identified radio sources would be published elsewhere.

Table 1 The radio identification of planetary nebulae

	Optical Position(J2000)		Radio Position(J2000)		S_{20}	S_6	Note
Name	RA	DEC	RA	DEC	(mJy)	(mJy)	
G124+02.1	01 02 24.76	65 46 35.9	01 02 23.18	65 46 33.7	7.4		2
G129-02.1	01 42 34.11	60 09 06.5	01 42 34.63	60 09 00.8	27.7		2
G193-04.1	05 57 08.97	15 25 28.7	05 57 08.42	15 25 53.1	6.5		2
G212.9-03.7	06 38 09.80	-01 42 26.0	06 38 09.77	-01 42 19.8	4.3		1
G222.8-04.2	06 54 13.50	-10 45 39.0	06 54 13.26	-10 45 33.8	2.7		1,2,3
G217.3-01.3	06 54 32.60	-04 31 45.0	06 54 32.44	-04 31 22.6	76.7	204	1,5
G217.3-00.0	06 59 16.00	-03 59 37.0	06 59 15.68	-03 59 36.8	53.0		1
G223.6-02.2	07 03 17.30	-10 35 06.0	07 03 17.58	-10 35 05.7	45.8		1
G222.6-01.6	07 03 27.50	-09 23 04.0	07 03 28.20	-09 22 31.1	2.8		1
G225-02.1	07 06 44.82	-11 45 21.8	07 06 44.96	-11 45 18.9	12.4		2
G234.2-01.4	07 26 16.30	-19 36 18.0	07 26 15.82	-19 36 37.9	2.8		1
G235.0-01.4	07 27 46.80	-20 19 11.0	07 27 48.32	-20 19 45.8	4.0		1
G235.7-01.2	07 30 06.10	-20 44 59.0	07 30 06.24	-20 44 48.1	5.3		1
G247.2-07.2	07 30 58.30	-33 43 05.0	07 30 57.17	-33 43 35.3	3.5		1
G234.7-00.2	07 31 48.80	-19 27 34.0	07 31 49.20	-19 27 35.2	9.8		1
G239.3-02.7	07 31 59.80	-24 39 07.0	07 32 00.35	-24 39 16.4	4.0		1
G237.2-01.2	07 33 11.40	-22 07 39.0	07 33 12.79	-22 07 31.5	9.1		1
G237.3-01.2	07 33 19.70	-22 11 06.0	07 33 19.81	-22 10 57.3	19.9		1
G237.2-01.0	07 33 57.10	-22 00 04.0	07 33 57.02	-22 00 05.3	20.1		1
G237.5+01.8	07 45 34.80	-20 51 43.0	07 45 34.83	-20 51 39.4	13.7		1
G248.3-03.6	07 48 31.90	-32 58 19.0	07 48 32.08	-32 58 21.3	23.5		1
G245.3-00.2	07 54 47.70	-28 36 43.0	07 54 46.27	-28 36 59.3	7.7		1
G250.5-03.4	07 54 55.00	-34 44 13.0	07 54 55.83	-34 44 08.5	21.2		1
G251-03.1	07 57 06.62	-36 06 51.6	07 57 06.69	-36 06 40.6	2.6		2
G246.0+01.2	08 02 35.20	-28 28 04.0	08 02 35.86	-28 27 56.3	3.2		1
G250.6-00.6	08 06 24.50	-33 17 35.0	08 06 24.47	-33 17 34.2	5.5		1
G255-03.1	08 06 28.45	-38 53 25.1	08 06 27.75	-38 53 21.1	2.8		2
G251.7+01.6	08 18 48.20	-32 58 37.0	08 18 50.96	-32 58 37.5	5.8		1
G259+00.1	08 37 07.98	-39 26 28.5	08 37 10.30	-39 26 03.3	6.6		2
G255.9+03.9	08 39 31.90	-35 00 24.0	08 39 34.02	-35 00 57.6	2.7		1
G342+15.1	15 58 46.81	-32 00 19.4	15 58 47.16	-32 00 15.5	4.4		2
G347.4+01.8	17 04 16.30	-38 19 59.0	17 04 16.89	-38 19 57.8	4.6		1
G356.4+08.6	17 04 17.70	-27 03 27.0	17 04 17.78	-27 03 26.3	5.9		1
G349.6+03.1	17 06 01.50	-35 44 34.0	17 06 01.23	-35 44 37.8	3.6		1
G011+17.1	17 06 54.94	-09 47 03.9	17 06 54.76	-09 46 51.5	3.4		2
K523	17 08 34.20	-35 48 07.7	17 08 34.36	-35 48 03.2	25.3		4

Note: 1. Parker et al.,2001; 2. Kohoutek, 2001; 3. Condon et al.,1999; 4. Kohoutek, 2002; 5. Wright et al., 1996 (PMN).

The fraction of sources with radio emission is only about one fourth of the new planetary nebular candidates. This is much less than that derived by Condon & Kaplan (1998) and Condon et al. (1999) for GPN92 sources. This is understandable because a large fraction of new discoveries in optical are low surface brightness as pointed out by Parker et al. (2001).

For these new planetary nebulae with radio emission at 20 cm, we have tried to find the corresponding radio flux at 5GHz from PMN (Wright et al., 1996) and GB6 (Gregory et al., 1996) catalog, as well as the survey taken by Becker et al. (Becker et al., 1994) for Galactic Plane. Only about 20 sources have been detected at 5GHz. The small detection ratio at 5 GHz may be caused partly by different sky coverage and low sensitivity.

Table 2 The optical depth distribution at 1.4 GHz and 5 GHz for Siodmiak's sample

τ	< 0.1	≤ 0.2	≤ 0.4	≤ 0.6	≤ 1.0	≤ 2.0	> 2.0
20cm	52	19	28	27	40	41	57
5cm	189	36	23	12	4	0	0

Table 3 The optical depths at 1.4 GHz and 5 GHz

Name	$S_{20\,cm}$	$S_{6\,cm}$	$S_{3\,cm}$	$\tau_{1.4}$	τ_5
Van 2	3.5	4.3	4.2	0.768	0.053
Van 3	5.5	12.4	10.0	2.585	0.178
Van 5	6.5	11.3	10.5	1.718	0.119
Van16	18.2	27.0	24.7	1.260	0.087
Van17	6.8	9.4	8.2	1.070	0.074
Van24	6.7	16.0	14.1	2.802	0.193
Van31	27.2	11.5	> 3.0		
Van34	3.6	1.7	> 1.5		
Van36	23.6	31.1	31.1	0.945	0.065
Van37	57.4	16.0	> 5.5		
Van38	2.6	3.0	2.0	0.614	0.042
Van41	8.8	16.7	17.6	1.992	0.138
Van42	9.8	12.9	15.5	0.942	0.065
Van46	11.7	3.8	> 1.8		
Van52	3.1	24.0	22.8	13.526	0.934
Van54	73.0	82.3	75.2	0.559	0.039
Van55	4.3	9.2	10.0	2.396	0.165
Van56	5.7	14.1	12.2	2.940	0.203
Van58	20.3	29.5	21.3	1.204	0.083
Van64	10.0	28.3	25.6	3.511	0.242
Van66	46.2	65.3	60.9	1.129	0.078
Van70	11.4	13.0	11.5	0.586	0.040
Van73	4.0	13.7	13.0	4.469	0.308
Van75	2.5	22.5	19.0	17.713	1.223
Van81	2.7	20.8	20.8	13.417	0.926
Van85	2.9	4.4		1.323	0.091
Van86	4.1	8.5	> 2.5	2.287	0.158
Van97	7.8	11.5	11.8	1.243	0.086
Van98	4.5	21.8	24.0	6.911	0.477

3 The Optical Depth at Radio Wavelengths

The optical extinction of a planetary nebula C_β at H_β can be derived by comparing the radio flux and H_β flux when the optical depth at observation frequency is much smaller than 1. The error caused by this approximation is still smaller than 10 per cent even the optical depth $\tau \sim 0.2$ at radio frequency. However, at low frequency, the influence of optical depth can not be ignored, especially for those source with small angular radius. Condon & Kaplan (1998) have discussed this problem and pointed that the radio flux observed at low frequency should be corrected for by a factor of $\tau/(1-e^{-\tau})$ when the radio flux was used to derive the optical extinction. In principle if the optical depth of a source at any frequency can be determined independently, the expected H_β flux can be derived since both optical depth at radio frequency and H_β flux have a same dependence on the emission measure E (here $E = \int {n_e}^2 dl$) if the contribution of ionized He on the electron density n_e can be ignored and the electron temperature can be determined. From the observed flux and angular radius of the source at some frequency, or from the fluxes observed at two frequencies, the optical depth at any radio frequency can be estimated. However, it is important to ensure that the signals at each observation frequency are from the same space range when using the observation fluxes at these two frequencies to determine the optical depths. Siodmiak & Tylenda (2002) have analysed radio fluxes of 264 planetary nebulae at 1.4 GHz and 5 GHz. Using these data, we calculated the optical depths at both observation frequencies. The results were listed in Table 2. It is remarkable that the optical depths are larger than 1 for about half the sources and less than 0.1 for about 20 per cent of the sources at 1.4 GHz. On the other hand, the optical depths of 225 sources are less than 0.2 and larger than 0.6 for only 16 sources at 5 GHz. This result implies that for most of the sources optical thin approximation at 5 GHz can be applied, but at 1.4 GHz only for a small number of the sources.

Van de Steene & Jacoby (2001) have observed 64 newly identified galactic bulge planetary nebulae at 5GHz and 10 GHz using Australia Telescope Compact Array (ATCA). For 29 of these 64 sources the radio fluxes at 1.4GHz were found in NVSS data base. Since the fluxes at 3 cm is less well determined than that at 6 cm as pointed by author, we only use their fluxes at 6 cm and fluxes at 20 cm from NVSS to estimate the optical depths. The optical depth of 25 sources were derived and the results were listed in Table 3. It is shown that for 18 sources, the optical depths is less than 0.2 at 6 cm, but none is less than 0.5 at 1.4 GHz for all 25 sources. For another 4 source with flux at 1.4 GHz two times larger than that at 5 GHz, we noted that the fluxes at 10 GHz are lower than the detection limit of the ATCA and therefore the radio emission may be intrinsically the nonthermal-origin. Therefore, we can conclude that for most of the planetary nebulae, they are optical thick at 20 cm. A caution must be paid when using the radio fluxes at this frequency to derive the optical extinction.

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