THE IDENTIFICATION OF RADIO STARS

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I. Introduction

The first discrete source of radio noise was observed by Hey, Parson and Phillips (1946), in the constellation of Cygnus. Since then nearly 300 of these objects have been reported by various observers in Australia and England (see Table I). Their identification with visual objects has met with little success. Only 16 of them have been identified so far, 5 with objects in our own galaxy and the rest with extra-galactic objects (Baade and Minkowski, 1954*a*, *b*).

The discrete sources are usually referred to as radio stars, although we know that several of them are unusual objects or even extra-galactic nebulae.

The major difficulty in their identification is the extremely poor resolution obtained at radio wavelengths. Thus a precise position of a radio star is not known. Ryle, Smith and Elsmore (1950) compared the positions of the radio stars observed by them with those of extra-galactic nebulae, stars brighter than the 4th magnitude, unusual but fainter visual stars (up to 11th magnitude only), nearby stars, large proper-motion stars, novae and supernovae and galactic nebulae and clusters but they failed to detect any significant coincidences.

Mills (1952) discussed the galactic distribution of 77 radio stars, and classified them into two classes. Class I objects are the brighter radio stars and show a galactic concentration. They are presumably at great galactic distances which, according to Mills' estimation, may be of the order of 1,000 parsecs. Class II objects are the fainter radio stars, which are more or less randomly distributed. From the random distribution of the Class II objects two possibilities arise: (1) they are of extra-galactic origin, or (2) they are nearby objects within our own galaxy. In the present paper we have considered the second possibility. The most common type of nearby stars are the *M* dwarf stars of the main sequence. Earlier, Unsöld (1949) had suggested that the general galactic radio noise may arise from the late type dwarf stars.

The coincidences in the position of the radio stars and the *M* dwarfs appear to us to be quite significant. At present the surveys of the radio stars as well as those of the *M* dwarfs are quite incomplete, so that even if the *M* dwarfs are the radio stars we would not expect to find perfect coincidences. When the surveys become more complete, this identification can be tested again.

II. Comparison of Positions of the Radio Stars and the *M* Dwarfs

Table I gives the sources of observed data on the radio stars. The total number of objects reported by various workers is 313, but several objects are common to two or more lists. The frequencies used by various workers are not much different from one another except the frequency of 18·3 Mc/s used by Shain

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and Higgins (1954*a*). The range of flux densities of radio stars as observed by different observers are comparable and lie between 5×10^{-25} and 2000×10^{-25} watts m^{-2} $(c/s)^{-1}$ except for the flux densities at 18·3 Mc/s, which lie between 250×10^{-25} and 66000×10^{-25} watts m^{-2} $(c/s)^{-1}$. A few radio stars are common between the lists of Shain and Higgins and that of Bolton, Stanley and Slee. A comparison of the flux densities for the two frequencies shows (also see Shain and Higgins, 1954*b*) that the reasons for the higher range of flux densities observed by Shain and Higgins is due to the different frequency used by them rather than that their radio stars have intrinsically higher brightnesses.

TABLE I

No.	Observer	Frequency	Region covered	Flux density 10^{-25} watts $m^{-2}(c/s)^{-1}$	No. of stars
		Mc/sec.	Dec.		
1	Stanley and Slee (1950) ..	100	+50° to −50°	10 to 1250	22
2	Ryle, Smith and Elsmore (1950) ..	81	+90° to +10°	2·5 to 2200	50
3	Mills (1952)	100	+50° to −90°	5 to 1300	77
4	Brown and Hazard (1953) ..	158	+70° to +40°	0·5 to 925	23
5	Shain and Higgins (1954*a*) ..	18·3	+10° to −90°	250 to 66000	37
6	Bolton, Stanley and Slee (1954) ..	100	+50° to −50°	4 to 1200	104

Various authors have given the probable errors in right ascension and declination, except Bolton, Stanley and Slee (1954), who have given the probable errors in rising time and azimuth. When the latter are converted into probable errors in right ascension and declination a number of them turn out to be very large. The maximum limits of probable error considered by us are $\Delta\alpha = 20$ min. and $\Delta\delta = 5°$. All probable errors larger than the above limits have been considered equal to these values.

The positions of *M* dwarfs are taken from the three lists by Vyssotsky and his co-workers (1943, 1946, 1952). These lists give the right ascension and declination, the spectral class, etc. for all the stars and trigonometric parallaxes for about 46% of the stars. The declinations lie between −30° and +90°.

In comparing the positions of the radio stars and the *M* dwarfs, we have restricted ourselves to the limit of declination from −25° to +60°. In this range there are 156 radio stars and about 300 *M* dwarfs. Twelve out of the sixteen radio stars already identified lie within our range of declination and are also included here. We find that 41 *M* dwarfs lie within the range of probable error of 28 radio stars. Table IIA gives the positions, etc. for these coincidences.

Further 20 *M* dwarfs lie within the range of probable error of either the right ascension or the declination and within twice the range of probable error of the other co-ordinate of 17 radio stars. The relevant data on the second set of coincidences is given in Table IIB. The total number of radio stars listed in Tables IIA and IIB is 45 or about 30% of the total number of radio stars considered.

In order to obtain an idea of the significance we can attach to the above-mentioned coincidences, we selected two areas as follows:

Selected area I $\alpha = 0$ to 4 hours $\delta = -14°$ to $+60°$
Selected area II $\alpha = 8$ to 12 hours $\delta = -14°$ to $+60°$

TABLE IIA

S. No.	Radio Source									Optical Source						
	Catalogue No.	Position (1950)							Flux density	Catalogue No.	Position (1950)				Spectral class	Distance
		R.A.				Dec.					R.A.		Dec.			
		h	m	±m	s	°	′± °	′	Units*	BD or AC °	h	m	°	′		Pc
1	R. 00·01 ..	00	42	6		38	5		4	+34·106	00	40	35	16	dM0	..
2	B.S.S. 105 ..	00	27	15	45	−20	4		5	−19·111	00	42	−19	13	dM0	19·0
3	B.S.S. 92 ..	01	38	17	40	32	3	45	6	+29·4398	01	55	29	34	dM0	..
4	B.S.S. 97 ..	02	36	14		03	4	10	5	+ 3·339	02	25	04	12	dM2	14·0
5	B.S.S. 40 ..	03	09	18	45	41	2	40	8	+39·710	03	04	40	11	dM0	34·5
6	B.S.S. 100 ..	04	20	13	15	−16	3		5	−15·728	04	07	−14	48	dM0	..
7	B.S.S. 84 ..	08	00	20		48	5		6	+44·1710	08	01	44	07	dM0	33·3
8	B.S.S. 86 ..	09	16	20		46	2	20	7	+47·2368–79	09	08	46	49	dM0	..
9	R. 09·02 ..	09	32	6		39	2		3·5	+40·2208	09	28	39	44	dK8	..
10	S. 09−1 ..	09	23			−12			400	− 8·2689	09	26	−9	02	dM0	..
										− 9·2895	09	37	−9	58	dK5	..
										−12·2918	09	29	−13	17	dM2	10·1
11	H.B. 13 ..	10	30	2	30	57	2		⩾0·5	+57·1274	10	29	57	22	dM0	..
12	S. 10+1 ..	10	45			16			1300	..	11	00	16	38	dM0	..
13	B.S.S. 98 ..	10	42	7	30	00	2		12	+ 1·2013–63	10	50	00	45	dM0	..
										− 1·2457	10	50	−01	48	dK8	..
14	B.S.S. 87 ..	11	42	20		31	5		10	+33·238	11	42	32	50	dM0	..
										+31·2290	11	42	31	15	dK8	..
										+30·2201	11	52	29	50	dK8	..
										+29·2228	11	52	29	01	dM0	..
15	H.B. 15 ..	12	15		3	47	1	30	0·5	..	12	15	46	52	dM	..
16	B.S.S. 30 ..	12	19	6	30	05	1	40	14	+ 6·2572	12	13	05	56	dK8	..
										+ 4·2612	12	22	04	12	dM0	..
17	S. 12−0 ..	12	53			−01			4100	− 1·2754	12	59	−02	26	dM0	16·4
18	R. 13·02 ..	13	40	2	30	38	1	30	3	+39·2675	13	41	39	30	dK8	..
19	B.S.S. 78 ..	13	26	15		10	4	10	4	+11·2576	13	27	10	41	dM2	8·1
										+10·2540	13	18	10	11	dM0	..

* 1 Unit = 10^{-25} watts m^{-2} $(c/s)^{-1}$.

TABLE IIA—(*Contd.*)

S. No.	Radio Source: Catalogue No.	Position (1950) R.A. h	m	±m	s	Dec. °	′±	°	′	Flux density Units*	Optical Source: Catalogue No. BD or AC °	Position (1950) R.A. h	m	Dec. °	′	Spectral class	Distance Pc
20	B.S.S. 81 ..	16	36	20		41		4	15	8	+39·3048	16	48	39	22	$dM0_p$	66·7
21	B.S.S. 55 ..	17	23	13	10	20		3	15	7	+23·3151	17	36	22	59	dM0	..
											+19·997–273	17	36	18	35	dM0	9·0
22	B.S.S. 36 ..	18	47	14	45	12		4	10	10	+10·3724	18	53	10	55	dM0	..
											+10·3665	18	46	10	42	dK8	17·9
23	B.S.S. 23 .	18	45	17	45	08		5		12	+10·3665	18	46	10	42	dK8	17·9
											+ 8·142–349	18	53	08	21	dM2	..
											+ 5·3993	18	55	05	53	dM2	12·9
24	B.S.S. 11 ..	18	39	8	45	02		2	30	27	+ 3·2528–176	18	48	03	01	dM2	15·0
25	S.S. 18 ..	18	11			−15				20	−12·4935	18	07	−11	31	dM2	..
26	S. 19+0 ..	19	30			02				1100	+ 4·4157	19	32	04	27	dM0	12·3
											+ 0·4241	19	30	00	29	dM0	..
27	S. 21−1 ..	21	20			−15				1400	+ 3·5945	21	27	−12	44	dK8	20·8
28	B.S.S. 77 ..	23	07	13	20	05		4	10	4	+ 4·4988	23	14	05	25	dM0	..
											+ 3·2781–116	23	06	03	03	dM0	..

* 1 Unit 10^{-25} watts m^{-2} $(c/s)^{-1}$.

TABLE IIB

S. No.	Radio Source									Optical Source						
	Catalogue No.	Position (1950)							Flux density	Catalogue No.	Position (1950)				Spectral class	Distance
		R.A.				Dec.					R.A.		Dec.			
		h	m±m		s	°	′± °	′	Units*	BD or AC °	h	m	°	′		Pc
1	M. 01-2 ..	01	50	8		−22		20	8	−23·693	01	51	−22	39	dM2	12·3
2	B.S.S. 40 ..	03	09	18	45	41	2	40	8	+37·748	03	15	38	04	dM2	14·3
3	B.S.S. 53 ..	03		8	45	03	2	30	9	+ 1·543	02	50	01	50	dM0	17·2
4	S.S. 8 ..	04	38			28			30	+25·733	04	45	26	06	dM0	..
5	B.S.S. 32 ..	07		20		15	5		6	+14·1684	07	28	14	49	dK8	..
6	R. 08·03 ..	08	22	3		36	1	30	4	+36·28826	08	25	35	13	dM0	..
7	M. 08+1 ..	08	50	4		13		40	16	+12·1944	08	54	11	51	dM5	..
8	R. 10·03 ..	10	33	4		56	1		3·3	+56·1458	10	27	56	15	dM0	12·2
9	M. 11+3A ..	11	45	8		37		40	10	+36·2219	11	49	35	31	dM2	..
10	M. 11+3B ..	11	35	4		31		40	10	+31·2290	11	42	31	15	dK8	..
11	B.S.S. 65 ..	13	08	10	20	30	2	15	10	..	13	16	33	37	dM2	..
										+35·2439	13	18	34	33	dM0	..
										+35·2406	13	05	34	39	dK8	..
										+29·2405	13	21	29	29	dM0p	15·4
12	B.S.S. 44 ..	14	43	20		30	5		10	+30·2512	14	20	29	53	dM0	14·1
13	B.S.S. 74 ..	15	20	8	30	−2	1	40	5	− 4·3873	15	19	−04	36	dM0	16·7
14	B.S.S. 31 ..	21	13	20		20	4	50	10	+24·4329	21	06	24	59	..	..
15	B.S.S. 45 ..	22	20	12		04	3	20	5	+ 8·4887	22	30	09	16	dM2	..
16	B.S.S. 77 ..	23	07	13	20	05	4	10	4	+ 0·5017	23	33	01	19	dM0	..
17	B.S.S. 48 ..	23	17	14	15	−17	4		5	−13·6464	23	46	−13	16	dK8	..

* 1 Unit = 10^{-25} watts $m^{-2} (c/s)^{-1}$.

The selected area I is represented in figure 1. The position of a radio star is indicated by a rectangle, which represents the range of probable error in right ascension and declination. The maximum probable errors used are 20 minutes in right ascension and 5° in declination. The position of *M* dwarfs are indicated by dots. The number of *M* dwarfs in the selected areas is 28 and 70 respectively. The fraction of the total area covered by all the rectangles is 12·3% for selected area I and 17% for selected area II. The number of chance coincidences to be expected is 3·4 and 11·9 for the two areas, whereas the actual number of coincidences is 9 and 17 respectively.

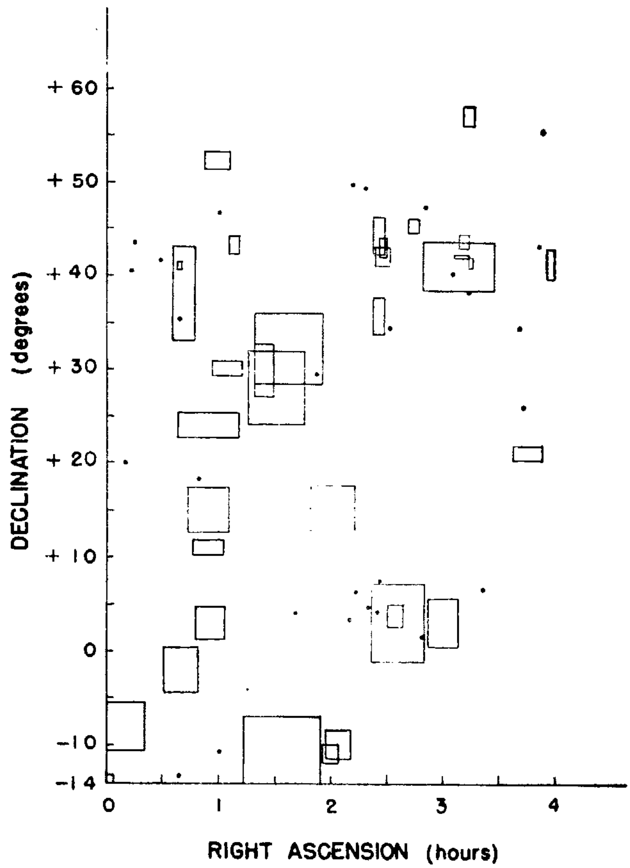

FIG. 1. The positions of the radio stars and *M* dwarf stars are indicated by the rectangles and the dots (for the selected area I) respectively. A rectangle represents the range of probable error in right ascension and declination.

We also considered the possibility of the identification of the radio stars with certain other types of stars such as the *T*—Tauri stars, the metallic line stars, the flare stars, the bright *H* and *K* emission stars, but could not get any significant coincidences. The best coincidences were obtained for the *H* and *K* emission stars (list of Joy and Wilson, 1949). The comparison of the positions of 445 of these stars with those of the radio stars gave only 20 coincidences, of which 12 were dwarf stars (7 *M* dwarfs, others *G* or *K* dwarfs) and 8 were giants or super-giants. For the case of *H* and *K* emission stars the number of actual coincidences was less than the number of chance coincidences.

The coincidences of the *M* dwarfs with the radio stars obtained above are significant although they cannot be considered as conclusive.

In Table IIA and IIB we note that all the radio stars listed have low flux densities and belong to Mills' Class II. The numerically higher flux densities of the Shain and Higgins' objects in these tables, are still on the lower end of the range of flux densities observed at 18·3 Mc/s.

III. Average Intrinsic Brightness and Distance

We shall suppose here that the *M* dwarfs are chiefly responsible for the emission of radio radiation in our galaxy or in external galaxies. Other types of objects may also be radio emitters, but their number is so small that they will not contribute appreciably to the total radio emission of a galaxy.

According to Kuiper (1948) 81% of the main sequence stars are *M* dwarfs. Further 95% of all the stars in our galaxy are main sequence stars. The total number of main sequence stars in Andromeda nebula is assumed to be about 10^{10}. Therefore Andromeda nebula will contain about $0{\cdot}8\times10^{10}$ *M* dwarfs. The radio flux density from Andromeda at 100 Mc/s is $2{\cdot}3\times10^{-24}$ watts m^{-2} $(c/s)^{-1}$ (Baade and Minkowski, 1954*b*). The distance of the Andromeda nebula according to a recent revision due to Wilson (1954) is 487 kpc.

We can now calculate the flux density received from an average radio-*M* dwarf star for various distances. This is represented in figure 2. The flux density of the class II objects at 100 Mc/s ranges between about 30×10^{-25} and 10^{-25} watts m^{-2} $(c/s)^{-1}$, and the corresponding distances of the average radio stars are between 5 and 26 parsecs. The distances of only 22 of the *M* dwarfs listed in Tables IIA and IIB are known from the trigonometric parallax method. Of these stars, all but one are at distance between 8 and 36 parsecs. Thus there is good agreement between the distances of the *M* dwarfs and those of the average radio stars having flux densities in the observed range.

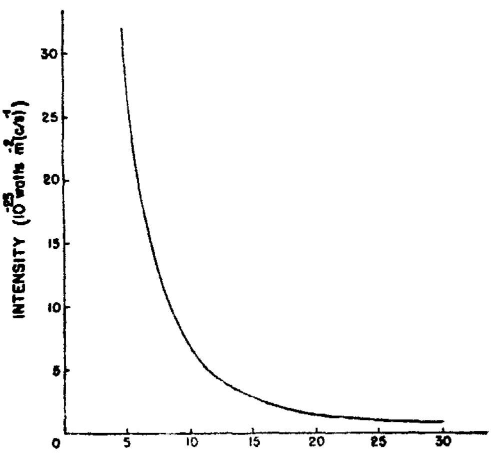

Fig. 2. Flux density versus calculated distance of the average radio-*M* dwarf stars.

Dr. A. N. Vyssotsky has kindly informed us that another list of *M* dwarf stars containing 523 entries is nearly complete. We intend to extend this work when Dr. Vyssotsky's new list and more observations of the radio stars become available to us.

We are grateful to Prof. D. S. Kothari for helpful discussion.

Summary

A comparison of the position of the radio stars with *M* dwarf stars, lying within the limits of declination $-25°$ and $+60°$, have been made. 41 *M* dwarfs lie within the range of probable error of 28 radio stars. Further 20 *M* dwarfs lie within the range of probable error of the other co-ordinate of 17 radio stars. The distance of radio stars calculated with an assumption that *M* dwarfs are mainly responsible for the radio flux from Andromeda nebula, is in agreement with the distance of the *M* dwarfs. The other types of stars such as *T*—Tauri stars, metallic line stars, flare stars, the bright *H* and *K* emission stars do not show any significant coincidences.

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