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A SEARCH FOR RADIO REMNANTS OF ANCIENT ORIENTAL "GUEST STARS" WITH THE WESTERBORK TELESCOPE

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Seven 1.5° × 1.5° fields in which "guest stars" had been reported by ancient oriental astronomers have been surveyed at 610 MHz for radio remnants with the Westerbork Telescope. No diffuse radio emission was detected. A list of discrete radio sources in the fields is given together with suggested optical identifications for those sources with $|b| < 15°$.

1. INTRODUCTION

At least eight extended non-thermal radio sources have been identified with "guest stars" observed by ancient oriental astronomers. The association of the remnant with an explosive event recorded in the past provides a precise determination of the age of the radio object. The original motivation of the work reported in this paper was to provide additional observational material for "guest stars" selected from the list of 90 compiled by Xi Ze-Zong and Bo Shu-ren [1]. Some objects on the list are associated with well known supernovae and many of the rest are likely to heve been either novae or supernovae. The list was based on Chinese, Korean and Japanese historical records taking care to exclude comets and "normal" variable stars.

From this list we selected for observation with the Westerbork Synthesis Radio Telescope (WSRT) at 610 MHz objects which: 1) brightened for more than a month, and 2) were not yet identified with radio sources. Because of its excellent sensitivity and dynamic range properties this instrument, when used at low frequencies is ideal for searching for weak non-thermal emission. We therefore hoped to find some cases of extended emission associated with supernova remnants or of point sources identified with radio stars.
A posteriori, our expectation seems to have been overoptimistic since as Clark and Stephenson [2] (hereafter CS) have recently shown errors associated with positions of "guest stars" listed by ancient astronomers may be larger than we predicted.

2. OBSERVATIONS AND REDUCTIONS

The objects observed are listed in TABLE 1. All observations were made between the 22nd and the 28th of January 1976.

The WSRT system has been described in detail in Baars and Hooghoudt [3], and Hogbom and Brouw [4].

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Table 1 Parameters of the Observations

Xi Ze-zong Bo Shu-ren NUMBER	R. A. (1950)		DEC. (1950)	Date (A.D.)	complete-ness level (mJy)	CS R.A. (1950)		CS DEC. (1950)	CS NUMBER
	h	m	°						
XP 83	00	20	+58	+1592	6	00 00	50 00	+60 +60	73 74
XP 24	03	12	+68	+ 369	8	--	--	+65	23
XP 27	04	00	+20	+ 396	10	04	00	+20	26
XP 86	08	40	+20	+1645	6				
XP 46	12	00	+05	+ 837	10	12	10	+05	39
XP10/51/52+	17	20	+15	+ 29	6				
				+ 911		17	10	+15	44
				+ 980					
XP 69	18	20	+20	+1230	7				

+ This corresponds to 3 different entries in the Xi Ze-zong and Bo Shu-ren list and could have been a recurrent nova.

System parameters relevant to the present observations are given in TABLE 1. Observations were all carried out at 610 MHz for 6 × 15 minutes on each field. The observations were calibrated with respect to 3C38 and 3C147 with assumed flux densities of 15.7 and 21.6 Jy respectively and whose positions were taken from Elsmore and Ryle [5]. The calibrated fringe visibility data were Fourier transformed into intensity maps, and cleaned [4] using the Leiden batch processing system (van Someren Greve [6]). In general the effective noise on the maps due to incomplete cleaning exceeded the minimal noise values and prevented detection of sources much below the stated completion levels. The position (α,δ), flux densities (S), position angles of the major axis (PA) were extracted from the data by one or more of the following methods:

1) For unresolved sources the source brightness distribution was fitted by the synthesized beam to give α, δ and S.

2) For resolved sources the source brightness distribution was fitted by an elliptical Gaussian function.

Optical identifications for radio sources with galactic latitude $|b| > 15°$ were sought on the Palomar Sky Survey Prints (PSSP) by means of the optical identification system in use at the Laboratorio di Radioastronomia in Bologna. A "conventional" overlay was drawn by a computer. With such an overlay the radio position was located on the PSSP and the nearby field then photographed. The positions of a number of AGK2 reference stars were read by a device which digitizes the positions together with 6 reference stars within a few arcminutes of the radio position. A computer program successively produced a second overlay which was positioned on an enlargement of the field using the newly measured reference stars. The RMS error in this procedure is estimated to be $\leq$ 2 arcseconds. Objects which lay within the 2σ radio positional uncertainties were accepted as candidate identifications and the relative positions were measured.

Table 2 Source List for the XP Fields

SERIAL NUMBER 34W	R. A. (1950)				DEC. (1950)			UNCORR. MAP FLUX (mJy)	610MHz CORR. FLUX (mJy)	OPTICAL IDENTIFICATION TYPE	$\Delta\alpha''$	$\Delta\delta''$	REMARKS
1	23^h	59^m	47^s	.8	58°	26′	21″	160	310	0			
2	23	59	59	.0	59	40	51	53	195	0			73°, 99
3	00	00	00	.8	58	39	54	47	70	0			
4	00	00	33	.8	58	14	58	300	691	0			
5	00	01	17	.3	58	46	39	175	202	0			
6	00	01	26	.3	59	04	24	129	152	0			
7	00	03	05	.8	59	22	19	46	66	0			
8	00	04	17	.5	59	24	57	81	123	0			112°, 66
9	00	05	58	.5	58	32	26	61	81	0			
10	03	05	40	.6	68	07	23	84	144	0			
11	03	10	54	.4	68	41	05	138	280	0			103°, 39
12	03	11	30	.3	67	53	26	422	426	0			
13	03	12	51	.4	67	50	16	615	631	0			
14	03	13	02	.5	68	13	42	328	354	0			21°, 71
15	03	17	38	.8	68	42	15	151	476	0			
16	03	19	39	.0	68	36	45	128	477	0			
17	03	59	18	.8	19	21	00	425	824	G(15.0)?	0	+13″4	150°, 125[a]
18	04	00	04	.5	20	18	29	83	94	EF			
19	04	00	17	.3	19	28	55	69	102	EF			
20	04	00	31	.3	19	57	25	81	82	EF			
21	04	01	30	.2	19	44	15	124	164	EF			
22	08	37	09	.1	20	34	11	32	102	BSO	−5″0	+2″7	176°, 294[b]
23	08	38	31	.2	20	07	20	54	66	EF			
24	08	39	13	.9	18	46	46	43	471	EF			[c]
25	08	39	40	.9	20	25	10	131	170	EF			
26	08	40	02	.1	19	50	51	39	40	EF			
27	08	40	21	.9	19	00	04	52	242	EF			
28	08	40	41	.1	21	13	12	47	507	EF			168°, 146
29	08	40	58	.6	20	00	25	130	138	BSO	+12″2	+5.4	42°, 77
30	08	41	11	.7	19	56	04	81	90	EF			
31	08	41	14	.8	19	49	33	36	42	EF			
32	08	41	38	.2	20	54	23	106	458	EF			20°, 79
33	08	41	59	.0	19	33	19	220	406	EF			
34	11	58	11	.3	04	23	31	196	459	S	+4″7	+6″7	
35	11	58	12	.6	05	40	13	87	229	EF			
36	12	00	36	.3	04	18	57	60	125	EF			179° [d]
37	12	00	48	.1	04	30	51	758	1131	G	+3″4	−3″4	[e]
38	12	01	30	.1	06	04	50	108	814	EF			
39	12	02	49	.3	05	24	34	59	157	EF			179° [f]
40	17	17	08	.0	15	25	48	54	144	EF			
41	17	17	54	.6	15	04	46	39	57	EF			
42	17	18	10	.2	16	09	03	43	470	S			[g]
43	17	18	14	.3	16	04	25	38	302	S	−2″0 (I) +4″0 (II)	+2″7 (I) −6″7 (II)	[h]
44	17	18	16	.2	15	09	02	38	50	EF			

Table 2 (contd.)

SERIAL NUMBER 34 W	R. A. (1950)	DEC. (1950)	UNCORR MAP FLUX (mJy)	610MHz CORR. FLUX (mJy)	OPTICAL IDENTIFICATION TYPE	$\Delta\alpha''$	$\Delta\delta''$	REMARKS
45	$17^h\ 19^m\ 19^s.2$	$14°\ 52'\ 35''$	37	39	EF			0°, 167
46	17 19 26 .6	15 01 52	62	63	EF			
47	17 19 46 .9	15 12 02	91	96	EF			
48	17 20 29 .9	14 37 58	42	52	EF			90°, 46
49	17 21 20 .6	15 14 00	36	45	EF			
50	17 23 03 .5	15 08 32	61	142	EF			0°, 123
51	18 17 10 .8	19 58 60	79	151	EF			179°, 148
52	18 18 04 .8	19 57 32	85	114	EF			
53	18 18 16 .8	20 10 30	44	58	EF			
54	18 19 11 .7	20 25 04	99	134	EF			
55	18 19 45 .7	19 50 21	99	102	EF			
56	18 21 52 .2	19 29 13	121	237	PLO?	$-1''.7$	$-10''.0$	i)
57	18 22 02 .8	19 23 56	42	101	EF			90°, 77

a) This source is PKS 0359+19 (Clarke et al, 1966), it has a flux density of 0.8 f.u. at 1410 MHz.
The optical galaxy appears to be in a small cluster.
b) Double; the separation between the two components is given.
c) Also DW 0839+18 (Wills 1976). Identified by Hoskins et al. (1974).
d) Triple source, the flux of the central component is below our threshold and therefore is not listed. Because of the low declination the measurement of maximum separation is affected by high uncertainty. The R.A. component between the extreme peaks is 171 arcsec.
e) Also AO 1200804.5. Identified by Argue et al. (1973).
f) Extended.
g) The area is obscured by a nearly 6th magnitude star.
h) In the error circle there is a faint object partially obscured by a stronger stellar object. (I) is radio minus star position; (II) radio minus faint object position.
i) Double faint red object.

3. RESULTS

No evidence was found for diffuse non-thermal radio emission in any of the seven fields. The sources found are listed in TABLE 2 in order of increasing right ascension and are assigned serial numbers which, when preceded by the code number "34 W", serve to identify each source. (This code number indicates the number of this article in the sequence of WSRT survey papers). Column 2 and 3 give the 1950 coordinates, and flux densities are listed in Column 4. For point sources the estimated 2σ uncertainties are $\sim\pm0^s.15$ in right ascension, $\pm2''$ cosec δ in declination δ and $\sim\pm10\%$ in flux density. Column 5 gives information about the optical field and the suggested identification is given with the following abbreviations:

BSO blue stellar object

PLO plate limit object

G galaxy

S stellar object

EF empty field (no optical objects with 15")

0 the sources had $|b| < 15°$ and because of galactic obscuration and high contamination by stars no identification was attempted.

A question mark following the identification indicates that the proposed optical object is a tentative identification ($\Delta\alpha > 2\sigma$).
An estimate of the red magnitude is given in parenthesis for galaxies brighter than $m_r = 18$. Otherwise an "f" for faint object or a "b" for stars judged to be brighter than $m_r = 19$ is given. For those sources for which the optical object was measured to an accuracy of 1 arcsec, the right ascension ($\Delta\alpha''$) and declination ($\Delta\delta''$) differences are listed in the sense radio position minus optical position.

The "Notes" column contains two kinds of information;
1) when the source was significantly resolved the position angle in degrees and the extent of the major axis in arcsec is given;
2) letters indicate that more extensive notes are given following the table.

4. DISCUSSION

In view of CS's work [2] the absence of diffuse thermal radio emission is not conclusive and we cannot exclude the association of a galactic SN with the "guest stars" listed in [1]. The WSRT $1.5° \times 1.5°$ fields, in fact, may well have been insufficient to cover the range of uncertainties associated with ancient records. From CS's study emerges however that out of the eight SNR associated with historically recorded "new stars" at least two: SN AD1006 and the Crab Nebula were identified very precisely. The former within less than two degrees, the latter to better than one degree. CS produce in their TABLE 3.1 a list of events recorded by Chinese and other Far East astronomers from 523 BC to 1604 AD which they interpret as pretelescopic galactic novae and supernovae. In the last 3 columns of TABLE 1 we have reported CS positions and list numbers corresponding to fields which have been observed. The dates coincide exactly but the positions may differ with a maximum of 30^m in R.A. in the case of XP83 and 3° in DEC for XP24.

These uncertainties simply stress the fact that the remnant of a stellar explosion may have been missed because of wrong telescope position. One must point out however, that it is very unlikely that this has happened in all cases and furthermore for at least 3 events, namely XB27, XB46, XB10/51/52. the positions given by the XB list and the CS list are in good agreement.

Although spectroscopic work could show that some of the identified sources are galactic radio stars, there is at present no evidence that we have detected remnants associated with the guest stars. The present search, as stressed above, cannot be considered conclusive. The observations presented here, however, with the radio source list given in TABLE 2, may be of help to workers who intend to pursue further the radio search for SNR associated with guest stars as well as for other totally unrelated studies. The presence of a radio remnant at the position of Xi Ze-Zong and Bo Shu-ren is, in any case, excluded and the indication which emerges from CS's study i.e. that the positional uncertainty is generally quite large seems to be confirmed.

A complete survey to cover reasonably safe error boxes around a given "guest star" position, although quite demanding in telescope time as well as effort in data reduction, is probably necessary in order to confirm or disprove a SNR association with a "guest star". Such a complete search is encouraged.

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