THE *ROSAT* PSPC SURVEY OF THE WOLF-RAYET STARS

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Abstract. We report X-ray measurements of nearly all known galactic Wolf-Rayet stars from the *ROSAT* all-sky survey and derive 0.2–2.4 keV luminosties.

Key words: stars: Wolf-Rayet – X-rays

1. Introduction

During the first months of its operational life the X-ray telescope aboard *ROSAT* was used to perform a complete survey of the sky in the waveband 0.2–2.4 keV, giving the opportunity for the first complete X-ray survey of the Wolf-Rayet stars. The high sensitivity and almost complete absence of instrumental background combined to allow a detection threshold similar to that achieved by the *Einstein Observatory* despite typical exposure times of only a few hundred seconds. We have combined these data with pointed observations both of our own and those available from the public archive maintained at the NASA Goddard Space Flight Center to give the preliminary results shown in the tables below. The final results will be ready in due course.

2. Preliminary results of the survey

The tables I to V have the following columns: WR star numbers are from the van der Hucht *et al.*'s (1981) WR catalogue; Observation, identifying a survey or pointed observation; Time, the exposure time including vignetting and other corrections; λ, the log-likelihood detection statistic (Pollock 1987); Count rate, the maximum-likelihood estimate of the star's X-ray count rate; Distance, from van der Hucht *et al.* (1988, 1992); and L_X, the X-ray luminosity. Conversion of the count-rates to luminosities assumed a spectrum like that of WR25 (HD 93162). A correction for interstellar absorption was calculated from the colour excess. The errors quoted are statistical only and thus, it should be emphasised, do not contain any allowances for uncertainties in the distances that are likely to be substantial in some cases. The detection statistic, λ, which is the difference between the log-likelihood maximised with respect to count-rate and the zero count rate log-likelihood, gives a continuous scale of the weight of evidence of a star's detection although it is usual *ROSAT* Survey practice to take $\lambda > 10$ as the threshold. In a more extensive article currently in preparation full details will be given of the statistical method and the colours and distances used.

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TABLE I

ROSAT Wolf-Rayet star survey $0.2 < E(\mathrm{keV}) < 2.4$

WR	observation	time (s)	λ	count-rate (/100s)			distance (kpc)	L_X (10^{32} ergs s^{-1})		
1	Survey	472	10.6	2.18	±	0.88	2.6	7.07	±	2.85
2	WP200720	9636	63.2	0.49	±	0.08	2.5	0.90	±	0.15
2	Survey	441	0.1	0.12	±	0.18	2.5	0.22	±	0.33
3	Survey	219	0.4	0.42	±	0.30	3.4	1.07	±	0.76
4	Survey	592	0.1	0.09	±	0.16	2.9	0.24	±	0.43
5	Survey	584	0.0	0.06	±	0.17	2.1	0.13	±	0.37
6	WP200781	8898	1162.2	4.72	±	0.22	1.4	2.07	±	0.10
6	WP900027	5796	1978.5	9.93	±	0.33	1.4	4.35	±	0.14
6	Survey	519	48.9	6.81	±	1.34	1.4	2.98	±	0.59
7	WP200718	7149	15.8	0.20	±	0.07	3.5	0.99	±	0.35
7	Survey	391	0.4	0.17	±	0.11	3.5	0.84	±	0.54
8	Survey	179	0.0	0.00	±	0.52	3.5	0.00	±	2.71
9	Survey	214	0.0	0.00	±	0.23	2.3	0.00	±	0.90
10	Survey	317	1.2	0.38	±	0.20	4.6	2.57	±	1.35
11	WP400142	5199	591.6	19.43	±	0.74	0.4	0.50	±	0.02
11	Survey	697	121.1	25.08	±	2.21	0.4	0.64	±	0.06
12	Survey	623	0.7	0.56	±	0.30	8.1	17.49	±	9.37
13	Survey	647	2.9	1.58	±	0.63	4.1	19.01	±	7.58
14	Survey	774	2.3	0.68	±	0.28	2.0	0.82	±	0.34
15	Survey	593	0.0	0.00	±	0.12	1.8	0.00	±	0.25
16	WP200715	7048	0.0	0.00	±	0.02	4.0	0.00	±	0.11
16	Survey	512	3.9	0.40	±	0.26	4.0	2.26	±	1.47
17	Survey	246	0.3	0.27	±	0.21	5.1	1.77	±	1.38
18	WP900318	7734	15.9	0.22	±	0.07	3.5	1.39	±	0.44
18	Survey	210	4.9	1.29	±	0.65	3.5	8.14	±	4.10
19	Survey	212	1.3	0.72	±	0.37	2.3	3.24	±	1.66
20	Survey	243	0.0	0.00	±	0.38	10.3	0.00	±	26.06
20a	Survey	433	24.4	5.80	±	1.40				
21	Survey	217	2.2	0.53	±	0.31	3.5	2.62	±	1.53
22	WP200108	632	0.0	0.00	±	0.16	2.6	0.00	±	0.25
22	Survey	235	3.4	1.89	±	1.12	2.6	2.92	±	1.73
23	Survey	206	0.7	0.73	±	0.40	2.6	1.27	±	0.70
24	WP200709	4421	1.5	0.14	±	0.10	2.6	0.21	±	0.15
24	WP200108	1269	0.0	0.00	±	0.08	2.6	0.00	±	0.12
24	Survey	272	1.9	1.35	±	0.61	2.6	2.00	±	0.90
25	WP200108	1571	526.9	196.00	±	11.00	3.8	1031.00	±	58.00
26	Survey	216	0.5	0.37	±	0.24	12.2	34.98	±	22.69
27	Survey	234	0.0	0.00	±	0.40	4.1	0.00	±	6.10
28	Survey	252	1.1	0.50	±	0.26	12.5	49.47	±	25.73
29	WP200709	2644	0.0	0.00	±	0.09	12.5	0.00	±	8.10
29	Survey	268	0.0	0.00	±	0.34	12.5	0.00	±	30.60
30	Survey	244	0.4	0.49	±	0.36	8.2	12.73	±	9.35
30a	Survey	260	0.0	0.00	±	0.45	15.4	0.00	±	61.91

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TABLE II

WR	observation	time (s)	λ	count-rate (/100s)	distance (kpc)	L_X (10^{32} ergs s^{-1})
31	Survey	293	0.0	0.00 ± 0.22	4.4	0.00 ± 1.67
32	Survey	280	0.9	0.32 ± 0.17		
33	Survey	247	0.0	0.00 ± 0.20	6.7	0.00 ± 2.86
34	Survey	243	1.0	1.09 ± 0.52	9.5	64.71 ± 30.87
35	Survey	250	1.0	0.38 ± 0.20	9.6	23.20 ± 12.21
36	Survey	301	0.5	0.31 ± 0.20	3.8	2.96 ± 1.91
37	Survey	273	1.2	0.42 ± 0.22	2.5	3.34 ± 1.75
38	Survey	271	0.9	0.32 ± 0.17	2.0	1.00 ± 0.53
39	Survey	271	0.1	0.12 ± 0.23	1.6	0.46 ± 0.88
40	Survey	461	0.0	0.00 ± 0.12	4.0	0.00 ± 0.55
41	Survey	254	0.3	0.29 ± 0.26	7.4	12.80 ± 11.48
42	WP200699	4308	0.0	0.00 ± 0.07	2.9	0.00 ± 0.14
42	Survey	268	0.2	0.19 ± 0.19	2.9	0.38 ± 0.38
43	WP200699	3426	342.2	10.63 ± 0.69	7.0	494.86 ± 32.12
43	Survey	282	32.2	9.14 ± 2.21	7.0	425.50 ± 102.88
43	Survey	254	33.3	10.33 ± 2.34	7.0	480.90 ± 108.94
44	Survey	256	0.2	0.19 ± 0.20	6.0	2.79 ± 2.94
45	Survey	398	0.0	0.00 ± 0.16	6.1	0.00 ± 4.43
46	Survey	367	1.3	0.52 ± 0.24	3.5	1.53 ± 0.71
47	Survey	194	0.6	0.38 ± 0.23	3.8	3.61 ± 2.18
48	WP200160	3982	1566.8	11.06 ± 0.42	2.4	14.03 ± 0.53
48	Survey	167	50.1	14.76 ± 3.36	2.4	18.72 ± 4.26
49	WP200160	2188	0.5	0.06 ± 0.19	11.6 4.22	± 13.35
49	Survey	233	2.1	0.51 ± 0.30	11.6	35.85 ± 21.09
51	Survey	37	0.3	1.56 ± 1.28	3.6	18.44 ± 15.13
52	Survey	171	0.0	0.00 ± 0.50	2.5	0.00 ± 0.91
53	Survey	205	0.2	0.26 ± 0.24	5.3	2.58 ± 2.38
54	Survey	232	1.4	0.39 ± 0.21	5.1	4.71 ± 2.54
55	Survey	257	0.0	0.00 ± 0.37	8.6	0.00 ± 11.82
56	Survey	214	0.0	0.00 ± 0.51	19.3	0.00 ± 70.95
57	Survey	533	0.0	0.00 ± 0.12	3.8	0.00 ± 0.33
58	Survey	463	0.0	0.00 ± 0.16	5.8	0.00 ± 2.32
59	Survey	236	0.0	0.00 ± 0.41	2.5	0.00 ± 3.13
60	Survey	267	1.5	0.71 ± 0.32	3.3	7.09 ± 3.20
61	Survey	458	0.0	0.00 ± 0.37	9.6	0.00 ± 12.26
62	Survey	440	2.0	0.23 ± 0.14	2.3	1.89 ± 1.15
63	Survey	417	0.4	0.34 ± 0.25	2.2	1.90 ± 1.40
64	Survey	375	0.0	0.00 ± 0.28		
66	Survey	455	1.1	0.41 ± 0.20	7.4	14.35 ± 7.00
67	Survey	449	7.5	1.32 ± 0.69	3.6	11.18 ± 5.84
68	Survey	444	1.0	0.39 ± 0.20	5.7	11.13 ± 5.71
69	Survey	572	2.4	0.23 ± 0.14	2.5	0.53 ± 0.32
70	Survey	483	0.0	0.00 ± 0.25	2.3	0.00 ± 1.09

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TABLE III

WR	observation	time (s)	λ	count-rate (/100s)			distance (kpc)	L_X (10^{32} ergs s^{-1})		
71	Survey	355	0.3	0.17	±	0.14	6.7	2.01	±	1.65
73	Survey	355	0.0	0.00	±	0.24	9.7	0.00	±	20.85
74	Survey	357	0.9	0.45	±	0.23	4.4	12.68	±	6.48
75	Survey	332	3.1	1.39	±	0.57	4.0	12.60	±	5.17
76	Survey	333	1.5	0.44	±	0.22	6.3	19.83	±	9.92
77	Survey	338	0.1	0.19	±	0.32	6.0	4.34	±	7.31
78	Survey	323	0.0	0.00	±	0.22	2.0	0.00	±	0.27
79	RP200066	12457		0.54	±	0.10	2.0	0.59	±	0.11
80	Survey	344	2.5	0.28	±	0.18	4.4	6.04	±	3.88
81	Survey	284	0.0	0.00	±	0.33	1.8	0.00	±	1.16
82	Survey	240	0.2	0.27	±	0.27	8.8	14.72	±	14.72
84	Survey	134	0.1	0.40	±	0.86	3.7	5.88	±	12.64
86	Survey	298	1.7	0.31	±	0.17	2.0	0.56	±	0.31
87	Survey	310	0.0	0.00	±	0.21	2.9	0.00	±	2.17
88	Survey	307	3.7	1.32	±	0.54	2.9	11.28	±	4.61
89	Survey	311	3.5	0.88	±	0.56	2.9	8.29	±	5.28
90	Survey	266	0.0	0.00	±	0.37	2.0	0.00	±	0.31
91	Survey	304	0.8	0.51	±	0.27				
92	Survey	279	0.5	0.54	±	0.35	5.0	4.37	±	2.83
93	Survey	313	18.4	4.10	±	1.33	1.7	12.53	±	4.07
94	Survey	319	0.1	0.12	±	0.22	4.8	1.79	±	3.28
95	Survey	303	0.0	0.00	±	0.21	1.9	0.00	±	1.21
96	Survey	301	1.1	0.36	±	0.19	4.2	6.53	±	3.45
97	Survey	308	10.9	2.88	±	1.19	2.9	15.97	±	6.60
98	Survey	312	0.0	0.00	±	0.21	2.8	0.00	±	1.49
98a	Survey	314	1.9	0.30	±	0.17				
100	Survey	327	0.8	0.33	±	0.18	3.6	4.50	±	2.45
101	Survey	309	0.0	0.00	±	0.40	4.9	0.00	±	14.95
102	Survey	308	1.8	0.51	±	0.28	4.0	5.82	±	3.20
103	Survey	180	0.0	0.00	±	0.33	2.5	0.00	±	0.66
104	Survey	295	0.8	0.81	±	0.42	1.6	2.75	±	1.42
105	Survey	294	0.4	0.41	±	0.32	1.6	1.94	±	1.52
106	Survey	277	0.8	0.62	±	0.37	3.2	4.70	±	2.80
107	Survey	277	0.0	0.00	±	0.32	7.0	0.00	±	18.67
108	Survey	273	2.0	0.57	±	0.31	3.7	4.92	±	2.68
109	Survey	147	0.1	0.39	±	0.53				
110	WP200717	8287	262.9	1.67	±	0.17	1.9	3.97	±	0.40
110	Survey	304	6.9	2.08	±	1.11	1.9	4.94	±	2.64
111	RP201060	8970	22.4	0.21	±	0.06	1.6	0.12	±	0.03
111	Survey	292	0.2	0.18	±	0.17	1.6	0.10	±	0.10
112	Survey	233	0.2	0.26	±	0.26	1.2	0.50	±	0.50
113	Survey	314	0.0	0.00	±	0.22	2.0	0.00	±	0.45
114	Survey	341	2.6	0.70	±	0.30	2.2	2.64	±	1.13

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TABLE IV

WR	observation	time (s)	λ	count-rate (/100s)			distance (kpc)	L_X (10^{32} ergs s^{-1})		
115	Survey	325	1.2	0.27	±	0.14	2.2	1.26	±	0.65
116	Survey	342	2.5	0.51	±	0.31	4.4	12.86	±	7.82
117	Survey	312	0.0	0.00	±	0.30	3.4	0.00	±	3.97
118	Survey	334	0.0	0.00	±	0.21	3.7	0.00	±	13.99
119	Survey	321	0.1	0.09	±	0.20	3.9	0.93	±	2.07
120	Survey	329	0.5	0.23	±	0.15	5.2	5.46	±	3.56
121	Survey	333	0.0	0.04	±	0.24	2.1	0.16	±	0.99
123	Survey	377	0.8	0.21	±	0.17	10.6	10.44	±	8.45
124	Survey	524	0.0	0.00	±	0.12	6.0	0.00	±	3.02
125	RP170260	2141	5.8	0.34	±	0.14	4.7	9.13	±	3.76
125	Survey	448	0.1	0.19	±	0.24	4.7	5.10	±	6.45
126	Survey	455	2.2	0.30	±	0.18	4.0	2.98	±	1.79
127	Survey	345	0.0	0.00	±	0.41	4.4	0.00	±	2.57
128	Survey	376	0.1	0.14	±	0.21	4.0	0.53	±	0.79
129	Survey	443	0.0	0.03	±	0.26	4.9	0.38	±	3.25
130	Survey	513	0.0	0.00	±	0.11	4.8	0.00	±	2.58
131	Survey	503	0.0	0.00	±	0.12	9.2	0.00	±	6.53
132	RP500084	2300	2.1	0.48	±	0.30	4.4	5.79	±	3.62
133	Survey	681	91.6	9.54	±	1.38	2.1	11.79	±	1.71
134	Survey	730	1.3	0.32	±	0.15	2.1	0.46	±	0.22
135	WP200564	5426	0.0	0.00	±	0.13	2.1	0.00	±	0.15
135	Survey	743	0.1	0.06	±	0.09	2.1	0.07	±	0.11
136	WP900025	7843	7.1	0.17	±	0.07	1.8	0.19	±	0.08
136	Survey	781	1.4	0.18	±	0.10	1.8	0.20	±	0.11
137	WP200564	8732	77.7	0.59	±	0.10	1.8	0.61	±	0.10
137	Survey	746	1.4	0.24	±	0.13	1.8	0.25	±	0.14
138	WP200154	758	0.0	0.00	±	0.41	1.8	0.00	±	0.47
138	Survey	765	16.3	3.26	±	0.87	1.8	3.76	±	1.00
139	RP200057	1829	149.3	3.28	±	0.42	1.7	4.30	±	0.55
139	RP200058	1884	47.2	1.72	±	0.37	1.7	2.26	±	0.49
139	RP200063	2052	145.1	3.07	±	0.46	1.7	4.03	±	0.60
139	Survey	788	2.6	0.59	±	0.24	1.7	0.77	±	0.31
140	WP200079	1429	6106.9	105.80	±	1.50	1.3	73.93	±	1.05
140	WP200080	3585	10000.	105.30	±	1.00	1.3	73.58	±	0.70
140	WP200544	1758	10000.	166.00	±	1.50	1.3	116.00	±	1.05
140	Survey	894	1557.9	72.36	±	3.00	1.3	50.56	±	2.10
141	Survey	750	0.2	0.09	±	0.09	1.8	0.19	±	0.19
142	Survey	760	1.0	0.19	±	0.09	0.9	0.22	±	0.10
143	Survey	665	2.4	0.22	±	0.13	0.8	0.16	±	0.09
144	WP900314	18245	...	0.19	±	0.15	1.7			
144	Survey	813	4.8	0.84	±	0.38	1.7			
145	WP900314	12742	...	0.28	±	0.25	1.7	1.34	±	1.20
145	Survey	805	4.3	0.74	±	0.35	1.7	3.55	±	1.68

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TABLE V

WR	observation	time (s)	λ	count-rate (/100s)	distance (kpc)	L_X (10^{32} ergs s^{-1})
146	Survey	800	3.6	0.35 ± 0.19	1.0	
147	Survey	775	5.3	0.60 ± 0.32	0.6	0.58 ± 0.31
148	Survey	1043	3.8	0.25 ± 0.13	7.7	6.04 ± 3.14
149	Survey	855	0.6	0.13 ± 0.08	6.1	5.22 ± 3.21
150	Survey	677	0.0	0.00 ± 0.10	6.0	0.00 ± 1.82
151	Survey	571	2.7	0.32 ± 0.19	6.0	7.19 ± 4.27
152	Survey	593	2.1	0.21 ± 0.12	3.5	0.78 ± 0.45
153	Survey	548	6.0	0.69 ± 0.38	3.5	3.55 ± 1.96
154	Survey	532	4.3	0.35 ± 0.20	3.5	1.71 ± 0.98
155	Survey	553	0.0	0.01 ± 0.20	3.5	0.05 ± 0.98
156	Survey	553	0.4	0.11 ± 0.08	4.6	1.67 ± 1.21
157	WP201279	2434	2.0	0.08 ± 0.12	3.5	0.47 ± 0.71
157	Survey	577	1.5	0.37 ± 0.19	3.5	2.19 ± 1.12
158	WP400323	5519	0.0	0.00 ± 0.02	5.9	0.00 ± 0.45
158	Survey	595	1.4	0.34 ± 0.16	5.9	7.68 ± 3.61

3. Some highlights of the survey

In common with the *Einstein Observatory* measurements of 48 stars reported by Pollock (1987), the single WN stars are roughly a factor of 4 brighter on average than the single WC stars.

WR43 (HD 97950, WN6+O5) is a newly-discovered bright X-ray source. Its very high luminosity is partly a consequence of its adopted distance of 7 kpc. WR43 is the dense luminous central core of the NGC 3603 star cluster (see, *e.g.*, Hoffman, Weigelt & Seggewiss, these proceedings).

WR133 (HD 190918, WN4.5+O9.5Ia , P =112.7 d) is a newly-discovered bright X-ray source in common with other massive binaries (on WR133, see also Bertrand, these proceedings).

Some apparently single WR stars now have well-determined X-ray luminosites. Particularly notable are WR110 (WN6) with $L_X = 4.0 \times 10^{32}$ ergs s^{-1} and WR111 (WC5) with $L_X = 1.2 \times 10^{31}$ ergs s^{-1}.

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