# THE GREEN BANK SURVEYS AT 1400 MHZ

J. Maslowski
Max-Planck-Institut für Radioastronomie, Bonn, West Germany
and Astronomical Observatory, Jagellonian University,
Cracow, Poland

The present 1400 MHz complete pencil-beam survey, made with the NRAO 300-foot telescope*, consists of four parts which cover four different regions of the sky, as shown in Fig. 1.

The first survey (GA, unpublished), made by M.M. Davis in 1968, covers 0.45 sr in the zone defined by $23\overset{\circ}{.}5 \le \delta \le 30\overset{\circ}{.}5$, $b^{II} > 20^{\circ}$. According to Fomalont et al. (1974), the survey is to be complete above 0.55 Jy and lists 185 sources with $0.55 \le S \le 2.0$ Jy.

The second survey (GB), made by Maslowski (1971, 1972) in 1970 covers 0.1586 sr in the zone defined by $7^h15^m \le \alpha < 16^h20^m$, $45\overset{\circ}{.}9 \le \delta \le 51\overset{\circ}{.}8$, $b^{II} > 20^{\circ}$. The catalogue lists 1086 sources with $S \ge 0.09$ Jy but the survey is to be essentially complete above 0.16 Jy. So there are 602 sources with $0.16 \le S < 2.0$ Jy which can be used for

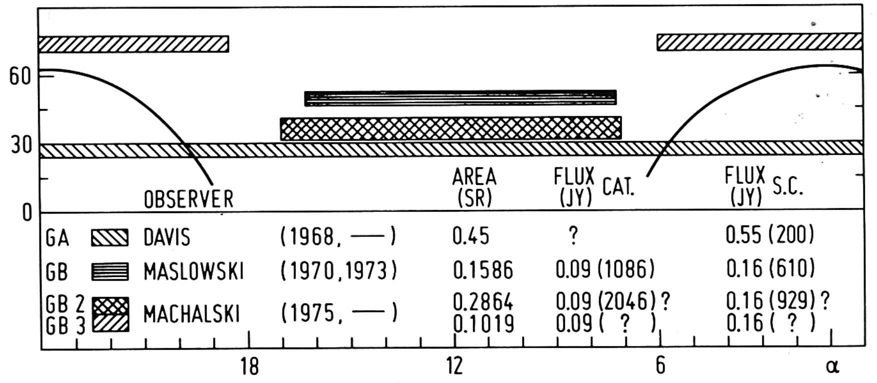


Figure 1. A map of the regions covered by the Green Bank surveys at 1400 MHz

* National Radio Astronomy Observatory is operated by Associated Universities Inc. under contract with the National Science Foundation

*D. L. Jauncey (ed.), Radio Astronomy and Cosmology, 47-54.* 

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press

source counting purposes or rather 518 sources, if the appropriate corrections resulting from noise and confusion are taken into account (Maslowski, 1973).

The third survey (GB2), made by Machalski in 1975, covers 0.2864 sr in the zone defined by $7^h08^m.1 \le \alpha \le 16^h58^m.8$, $31°.8 \le \delta \le 39°.6$, $b^{II} > 20°$. The observational data are already reduced but the results have not been published yet. The numbers presented here, prior to publication (Machalski, 1976, personal information), may change slightly during the final stage of data analysis for several reasons. Therefore, the present results should be treated with some caution. The number of sources found in the survey is 2046 with $S \ge 0.09$ Jy, but the survey is to be essentially complete above 0.16 Jy. So there are 910 sources with $0.16 \le S < 2.0$ Jy available for source counting purposes or about 782 sources, if the corrections similar to that used in case of the GB survey (Maslowski, 1973) are applied.

The fourth survey (GB3) has also been made by Machalski in 1975, but the observational data have not been reduced yet. The survey covers 0.102 sr in the zone defined by $18^h30^m \le \alpha \le 5^h58^m$, $70°.0 \le \delta \le 76°.8$.

## 1. SOURCE COUNTS

At present, the data from the first three Green Bank surveys, i.e. GA, GB and GB2, may be used either separately to derive a source count for a given region of the sky (the size ranges from 0.16 sr to 0.45 sr) from which the data were collected in a given flux density range, since each of the surveys contains a sufficiently large number of sources, or to amalgamate them simply in order to obtain an improved source count, since the surveys are statistically independent. The source counts mentioned above or any combination of them can be extended toward a high flux density region, using the improved data which have been assembled by Bridle et al. (1972), Bridle and Fomalont (1974) and Fomalont et al. (1974), and toward a low flux density range, using the data from the Westerbork synthesis surveys (Katgert et al., 1973; Katgert, 1975).

According to Fomalont et al. (1974) all the surveys, except GB2 (Machalski, 1975), were carefully checked and they are already on the same KPW flux density scale (Kellermann et al., 1969) after the correction of the Davis flux density scale. Concerning the Machalski scale, I believe that his survey is also on the KPW scale although, at least at present, some overestimation of the flux density of GB2 sources cannot be excluded.

The present situation for the source counts at 1400 MHz is shown in Fig. 2. All the source counts are presented in the differential form and normalised to the differential form arising from the integral count $N = 200 \cdot S^{-1.5}$, expected in the Euclidean Universe without any

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press

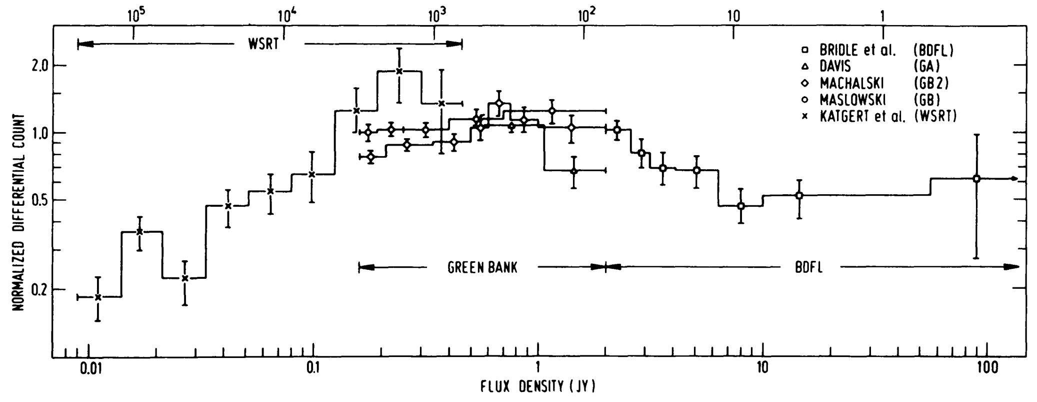


Figure 2. The combined differential counts at 1400 MHz

kind of evolution.

In spite of the significant increase of the statistics in the intermediate flux density range due to Machalski's survey, the situation is not quite clear and may be summarized as follows.

In the flux density range 0.55 - 2.0 Jy, there are three quite independent surveys of three different regions of the sky (GA, GB and GB2) made with the same instrument, so that a comparison among them can be made, using the results of the differential counts given in Table 1. The $\chi^2$ test applied to this contingency table shows that the three counts (slopes) differ significantly at the level of 1% ($\chi^2 = 13.47$ with 4 degrees of freedom). The source densities (last column in Table 1) in all the surveys in the range 0.55 to 2.0 Jy are almost the same.

In the flux density range 0.50 to 2.0 Jy, we have now the two different surveys, GB and GB2, the count results of which can be compared. The differential counts from these surveys are given in Table 2. The $\chi^2$ test applied to the data in Table 2 shows that the difference between the two counts (in the slopes) is statistically significant at

Table 1. Comparison of the GA, GB and GB2 source counts

| Survey | Flux density range | | | $\Sigma$ | Density/sr |
|---|---|---|---|---|---|
| | 0.555 - 0.704 | 0.705 - 1.062 | 1.063 - 1.994 | | $(0.55 \leq S < 2.0)$ |
| GA | 67 | 84 | 34 | 185 | 411 ± 30 |
| GB | 24 | 27 | 26 | 77 | 485 ± 55 |
| GB2 | 63 | 43 | 38 | 144 | 502 ± 42 |

Table 2. Comparison of the GB and GB2 source counts

| Survey | Flux density range | | | $\Sigma$ | Density/sr |
|---|---|---|---|---|---|
| | 0.50 - 0.62 | 0.63 - 0.89 | 0.90 - 2.00 | | $(0.50 \leq S < 2.0)$ |
| GB | 31 | 21 | 41 | 93 | 586 ± 61 |
| GB2 | 48 | 67 | 47 | 162 | 566 ± 44 |

the level of 0.6% ($\chi^2$ = 10.17 with 2 degrees of freedom). The source density in both the surveys is again the same in the range of 0.50 to 2.0 Jy.

So if the Machalski flux density scale does not differ significantly from the KPW scale, then the presented data of the three surveys with source density of about 500 $sr^{-1}$ suggest that none of the three differential counts (in the slope) is to be representative. There is, of course, the matter of personal judgement whether the observed differences can be considered as being statistically significant or not, i.e. whether they are just statistical fluctuations. We would like to emphasize only that the observed differences between the three surveys (GA, GB and GB2) at a source density of $\sim$ 500 $sr^{-1}$ are statistically more significant than the difference between the observed and the predicted count in the high flux density range (BDFL data). It is obvious that the careful check of the GB2 flux density scale is indispensable before any further and more detailed investigations of the GB2 source count can be made.

## 2. SPECTRAL INDEX DISTRIBUTIONS

The question of dependence of the mean spectral slope on flux density ($\alpha$ - S) is very important for both the cosmology and the source evolution itself. Significant evidence of the variation of the spectral index distribution with flux density for a complete sample of sources, selected at high frequencies (5 GHz and 2.7 GHz), has been found by Pauliny-Toth and Kellermann (1972a), Wall (1972), Pauliny-Toth et al. (1974), Fanti et al. (1974), Condon and Jauncey (1974) and Balonek et al. (1975). This variation is such that the mean spectral slope is considerably steeper for the weak sources than for the strong sources in a lower frequency range, i.e. between the survey frequency and a low frequency (178 MHz or 408 MHz). In the higher frequency range, i.e. between the survey frequency and a high frequency (10.7 GHz or 15 GHz), the variation of the spectral index distribution with flux density is not significant. The situation is much less clear for samples selected at low frequencies, i.e. below 1.4 GHz. Many investigations have been made to detect the $\alpha$ - S dependence for sources selected either at 178 MHz or 408 MHz (Pauliny-Toth and Kellermann

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press

1972b; Willson 1972) but no significant change in the spectral index distributions with decreasing S has been found. However, some results obtained from a study of the Molonglo catalogues MC2 and MC3 (Sutton et al. 1974) have shown that the increase in the mean spectral slope for weaker sources in the sample complete at 408 MHz is significant (Murdoch 1976) if comparison is made with an all-sky catalogue of strong sources (Robertson 1973).

As far as I am aware, no such investigations have been made for large samples of sources complete at 1400 MHz down to 0.2 Jy in the high frequency range. Some effect, namely the increase in the mean spectral slope for weaker sources, has been reported by Willson (1973) in the low frequency range, but his result must be viewed with some caution, because it is based on sources taken from the 5C surveys which suffer a serious, radially dependent systematic bias in the aperture synthesis flux density (Condon and Jauncey 1973).

At present both the GB and GB2 surveys provide a sufficiently large sample of sources for a study of this effect and very preliminary results are presented here for obvious reasons. All GB2 sources (Machalski, private information) found in the 1400 MHz survey to be stronger than 0.5 Jy were measured at 5 GHz using the NRAO 300-foot telescope to provide the two-point spectral indices, $\alpha(1400, 5000)$, (the spectral index, $\alpha$, is defined by $S \propto \nu^{-\alpha}$ and the notation $\alpha(\nu_1, \nu_2)$ used here means $\alpha$ between $\nu_1$ and $\nu_2$ for sources selected at $\nu_1$) in the high frequency range. Concerning the low frequency range, the Bologna 408 MHz flux densities from the B2 survey (Colla et al. 1970; Colla et al. 1972) are available for the GB2 sources, so that the two-point spectral indices $\alpha(1400, 408)$ could be determined.

The $\alpha$ - S dependences in the complete sample of GB2 sources with $0.5 \leq S < 2.0$ Jy were investigated by breaking the sample into two population subsamples in the two flux density intervals, separately in the low and high frequency ranges. The results of the investigations are summarized in Table 3 in which the following parameters, determined for each subsample, are given: the median and width of the spectral index distribution of the normal component (upper number), using a

Table 3. Spectral parameters of the sources ($S \geq 0.5$) in the GB2 survey

| Flux at 1400 MHz | $\alpha_L$ (1400,408) | | | $\alpha_H$ (1400,5000) | | | Number of sources |
|---|---|---|---|---|---|---|---|
| | Median | Width | F | Median | Width | F | |
| 0.70 - 2.00 | 0.75 ± .017 | .130 | .20 ± .044 | 0.89 ± .019 | .145 | .17 ± .042 | 81 |
| | 0.74 ± .028 | .250 | | 0.82 ± .031 | .275 | | |
| 0.50 - 0.69 | 0.85 ± .014 | .110 | .21 ± .045 | 0.86 ± .019 | .150 | .12 ± .035 | 85 |
| | 0.80 ± .028 | .260 | | 0.84 ± .025 | .225 | | |

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press

method of passing mathematical "windows" of various widths $\Delta\alpha$ (Condon and Jauncey 1974), the median and width of the whole spectral index distribution (lower number), the fraction (F) of flat spectrum sources ($\alpha < 0.5$) and the number of sources in the subsample. Several features are readily apparent from Table 3. Firstly, there is a strong mean spectral curvature for the sources stronger than 0.7 Jy in the normal component. The sources with S < 0.7 Jy have, on the average, straight spectra over the range of 408 - 1400 - 5000 MHz. Secondly, there is a rapid change in the median $\alpha$(1400, 408) of the normal component in the lower frequency range. The spectral steepening of the weaker subsample (S < 0.7 Jy) seems to be statistically significant, while in the higher frequency range there is no spectral difference between the strong (S > 0.7 Jy) and the weak (S < 0.7 Jy) sources in the normal components. Thirdly, it is to be noted that no significant differences exist among the subsamples if they are compared in the $\chi^2$ test. More details of the $\alpha$ - S dependence will be given by Machalski in his forthcoming paper.

In the case of GB sources, the analysis of the $\alpha$ - S dependence has to be restricted to the higher frequency range, since the low frequency flux densities are not available for a majority of them. All sources found in the GB survey to be stronger than 0.2 Jy at 1400 MHz were observed at 2695 MHz using the NRAO 300-foot telescope (Maslowski, unpublished). These observations provided the two-point spectral indices $\alpha$(1400, 2695) for the sample of GB sources. Several investigations of the distribution of $\alpha$(1400, 2695) have been made to find, if any, the variation of the spectral index distribution with flux density. The search for the intensity dependence of the $\alpha$(1400, 2695) spectral index distribution was performed by splitting the sample into four almost equal subsamples in four flux density intervals and determining, as previously, median and width for both the normal com-

Table 4. Spectral parameters of the GB sources.

| Flux at 1400 MHz | $\alpha$ (1400, 2695) | | | Number of sources |
|---|---|---|---|---|
| | Median | Width | F | |
| 0.50 - ∞ | 0.92 ± .022<br>0.89 ± .036 | .180<br>.360 | .21 ± .039 | 99 |
| 0.33 - 0.49 | 0.81 ± .017<br>0.79 ± .035 | .135<br>.350 | .20 ± .039 | 102 |
| 0.24 - 0.32 | 0.94 ± .016<br>0.89 ± .025 | .170<br>.270 | .11 ± .030 | 114 |
| 0.20 - 0.23 | 0.92 ± .020<br>0.85 ± .036 | .210<br>.375 | .20 ± .038 | 107 |

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press

ponent and the whole spectral index distribution in each of the subsamples. The results of the analysis are summarized in Table 4. It can be seen from the table that there is a rapid change in the median of the normal component which occurs over a very narrow range in flux density, namely from 0.33 Jy to 0.50 Jy. The median spectral slope of the normal component is considerably steeper for the sources stronger than 0.49 Jy and weaker than 0.33 Jy. When the subsamples are compared in the $\chi^2$ test, they do not show significant differences.

I thank Dr. J. Machalski for permission to quote results prior to publication.

REFERENCES

Balonek, T.J., Broderick, J.J., Condon, J.J., Drawford, D.F. and Jauncey, D.L. 1975, Astrophys. J. 201, 20
Bridle, A.H., Davis, M.M., Fomalont, E.B. and Lequeux, J. 1972, Astron. J. 77, 405
Bridle, A.H., Davis, M.M., Fomalont, E.B. and Lequeux, J. 1972, Nature Phys. Sci. 235, 123
Bridle, A.H. and Fomalont, E.B. 1974, Astron. J. 79, 1000
Colla, G. et al. 1970, Astron. Astrophys. Suppl. 1, 281
Colla, G. et al. 1972, Astron. Astrophys. Suppl. 7, 1
Condon, J.J. and Jauncey, D.L. 1973, Astrophys. J. Letters 184, L33
Condon, J.J. and Jauncey, D.L. 1974, Astron. J. 79, 437
Davis, M.M. 1969, unpublished
Fanti, R., Ficarra, L., Formiggini, I., Gioia, I. and Pardrielli, L. 1974, Astron. Astrophys. 32. 155
Fomalont, E.B., Bridle, A.H. and Davis, M.M. 1974, Astron. Astrophys. 36, 273
Katgert, P. 1976, Astron. Astrophys. 38, 87
Katgert, P., Katgert-Merkelijn, J.K., LePoole, R.S. and van der Laan, H. 1973, Astron. Astrophys. 23, 171
Kellermann, K.I. 1972, Astron. J. 77, 531
Kellermann, K.I., Pauliny-Toth, I.I.K. and Williams, P.J.S. 1969, Astrophys. J. 157, 1
Machalski, J. 1976, unpublished
Maslowski, J. 1971, Astron. Astrophys. 14, 215
Maslowski, J. 1972, Acta Astron. 22, 197
Maslowski, J. 1973, Astron. Astrophys. 26, 343
Murdoch, H.S. 1976, preprint
Pauliny-Toth, I.I.K. and Kellermann, K.I. 1972a, Astron. J. 77, 560
Pauliny-Toth, I.I.K. and Kellermann, K.I. 1972b, Astron. J. 77, 797
Pauliny-Toth, I.I.K., Witzel, A. and Preuss, E. 1974, Astron. Astrophys. 35, 421
Robertson, J.G. 1973, Australian J. Phys. 26, 403
Sutton, J.M., Davies, I.M., Little, A.G. and Murdoch, H.S. 1974, Australian J. Phys. Astrophys. Suppl. No. 33
Wall, J.V. 1972, Australian J. Phys. Astrophys. Suppl. No. 24
Willson, M.A.G. 1972, Monthly Notices Roy. Astron. Soc. 156, 7

DISCUSSION

*Davis:* Do you still find a difference between the GB A and B surveys? I don't feel there is a significant difference any longer?

*Maslowski:* It is significant at the 2.5% level after the GA flux density corrections have been made.

THE AGGREGATE FLUX OF WEAK POINT SOURCES AT 1404 MHz
S.J. Goldstein, Jr., A.P. Marscher, R.T. Rood.
Astrophys. J. 210, 321 (1976).

https://doi.org/10.1017/S007418090001603X Published online by Cambridge University Press