Gigahertz Peaked Spectrum sources from the Jodrell Bank–VLA Astrometric Survey

I. Sources in the region $35^\circ \leq \delta \leq 75^\circ$

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Abstract. Observations with MERLIN$^1$ at 408 MHz have been used to establish the low-frequency part of the spectra of more than a hundred compact radio sources taken from the part of the Jodrell Bank–VLA Astrometric Survey limited by $35^\circ \leq \delta \leq 75^\circ$. These sources were selected from JVAS and other catalogues to have convex spectra between 1.4 and 8.4 GHz, characteristic of Gigahertz Peaked Spectrum (GPS) sources. We have confirmed convex shapes of the spectra of 76 objects (one half of our initial candidates) thereby yielding the largest genuine sample of GPS sources compiled so far. Seven of 17 identified quasars in the sample have large ($z > \sim 2$) redshifts.

Key words: catalogs - galaxies: active - quasars: general - radio continuum: general

1. Introduction

By definition, Gigahertz Peaked Spectrum (GPS) sources have convex spectra with a turnover frequency $\nu_{\text{max}} > 1$ GHz. It is generally accepted that such a spectral shape results from synchrotron self-absorption due to a high compactness. Indeed, the linear sizes of GPS sources are very small (10–1000 pc) and their radio luminosities are large ($L_{\text{radio}} \sim 10^{45}$ erg/s). An important feature which makes the GPS class particularly interesting, is that GPS objects identified with quasars often have very large redshifts. A review on the properties of GPS sources has been given by O’Dea et al. (1991) — hereinafter OBS91 — and O’Dea (1998). De Vries et al. (1997) compiled spectra of 72 GPS sources and constructed a canonical GPS radio spectrum. They found it to have a constant shape independent of AGN type, redshift or radio luminosity.

As Gopal-Krishna & Spoelstra (1993) pointed out, the great potential of GPS sources for discovering high-z objects continues to be the major motivation factor for enlarging the sample of GPS sources. A second motivation for increasing the number of known GPS sources comes from the discovery (Wilkinson et al. 1994) of a new class of Compact Symmetric Objects (CSO). Five archetypal CSOs (cf. Readhead et al. 1996a) are all acknowledged GPS sources. Readhead et al. (1996b) argue that CSOs are the young precursors of classical double radio sources. Increasing the list of known GPS sources offers a promising way to find more CSOs.

The search for GPS sources can be difficult because it requires both high resolution and high sensitivity observations at frequencies well below 1 GHz and high sensitivity observations at $\nu > 5$ GHz, well above the potential peak of the spectrum. Therefore, unlike in the case of flat spectrum sources, only a modest number of GPS sources can simply be extracted from classical large catalogues e.g. the Green Bank (GB) surveys at 1.4 GHz and 4.85 GHz (White & Becker 1992 and references therein — hereinafter WB92) and the Texas Survey at 365 MHz (Douglas et al. 1996). For example, the sample of Stanghellini et al. (1990) was derived from the Texas Survey and the 1 Jy catalogue of Kühr et al. (1981a). Out of 55 sources and candidates they listed, 41 are currently acknowledged as GPS sources (O’Dea, priv. comm. 1996) and 33 make a complete sample (Stanghellini et al. 1996).

The lists published by Gopal-Krishna et al. (1983) and Spoelstra et al. (1985) resulting from dedicated observations, e.g. with the Westerbork Synthesis Radio Telescope...
(WSRT) or the Ooty telescope, are not very large: each one contains 25 sources (5 and 2 out of these two samples respectively had been retracted later). The sources gathered by the authors mentioned above have been collected in OBS91 in the so called "working sample" encompassing 95 objects. Gopal-Krishna & Spoelstra (1993) confirmed the existence of 10 GPS sources and Cersosimo et al. (1994) found 7 more\(^2\). On the other hand 6 sources from the list in OBS91, namely 0218+357, 0528+134, 0902+490, 1851+488, 2053−201 and 2230+114 proved to be "not so good" examples of the class and have been retracted. By the end of 1997 very few other GPS sources had been discovered.

There are two ways to achieve a "bulk" increase of this number. The first one has been followed by Snellen et al. (1998) — hereinafter SSB98 — the second is the basis of this paper. The former one is based on the Westerbork Northern Sky Survey (WENSS) being carried out with WSRT at 325 and 609 MHz. Naturally, the sources with inverted spectra in the WENSS are GPS candidates, which are followed up with observations at higher frequencies. This survey is particularly useful since it is the most sensitive survey at low frequencies (more than an order of magnitude better than the Texas Survey).

The published part of WENSS called "mini–survey" (Rengelink et al. 1997) is limited to \(14^{h}10^{m} < \alpha < 20^{h}30^{m}, \ 57^{\circ} < \delta < 72^{\circ}50^{\prime}\) and covers \(\sim 570\) square degrees only, so there are still large parts of the sky where this method cannot be applied. Nevertheless, SSB98 using the mini–survey plus an unpublished part of WENSS \((4^{h} < \alpha < 8^{h}30^{m}, \) the same declination range as the mini–survey\) were able to establish a list of 47 "new" GPS sources.

2. Construction of the sample

Since WENSS was not available when our programme started in 1994, we adopted a different approach which can be regarded as "opposite" to that of SSB98 because we started at the high frequencies end instead of the low one. Hence, to determine candidate GPS sources, we used 8.4 GHz fluxes from the first part of the Jodrell Bank–VLA Astrometric Survey (JVAS)\(^3\) (Patnaik 1992) containing all compact radio sources in the range \(35^{\circ} \leq \delta \leq 75^{\circ}\) with fluxes \(> 200\) mJy at 5 GHz. We combined them with 1.4 GHz and 4.85 GHz fluxes from the GB catalogues (WB92). For 32 sources 1.4 GHz fluxes were missing in WB92 so we substituted them with the catalogue flux density limit. Then we fitted the data with a second order polynomial of the form:

\[
\log S_{\nu} = S_{0} + \alpha \log \nu - c (\log \nu)^{2},
\]

\(^2\) Cersosimo et al. claim to discover more sources but only 7 have been finally recognised as GPS.

\(^3\) JVAS resulted from observations made with the VLA in "A" configuration.

\[
\text{where } \nu \text{ is the observed frequency in GHz and } S_{\nu} \text{ the flux density in mJy and selected the sources with convex spectral shapes. The criterion for selecting an initial list of candidate GPS sources was that the curvature } c \text{ had to be greater than 1 with a peak in the spectrum in the observable range (the limit of } c > 1 \text{ is rather conservative and includes also spectra which are much flatter than those of typical GPS sources). Admittedly, although this criterion seems to be conservative enough, a few sources from the OBS91 "working sample" which happen to be JVAS members, and therefore have been fitted with polynomials.

| Table 1. Subsample One |
|------------------------|
| IAUname (B1950) | R.A. (J2000) | Dec. | Opt. ID |
|------------------|-------------|------|---------|
| 0059+581 | 01 02 45.7630 | 58 24 11.139 | CW |
| 0102+480 | 01 05 49.9295 | 48 19 03.183 | EF |
| 0627+532 | 06 31 34.6860 | 53 11 27.754 | BS |
| 0652+426 | 06 56 10.6629 | 42 37 02.751 | G |
| 0652+577 | 06 57 12.5027 | 57 41 56.740 | EF |
| 0750+535 | 07 54 15.2177 | 53 24 56.450 | EF |
| 0828+493 | 08 32 23.2171 | 49 13 21.036 | BL |
| 1107+485 | 11 10 36.3237 | 48 17 52.446 | EF |
| 1239+552 | 12 41 27.7043 | 54 58 19.040 | EF |
| 1256+546 | 12 58 15.6078 | 54 21 52.112 | EF |
| 1311+552 | 13 13 37.8518 | 54 58 23.894 | EF |
| 1428+422 | 14 30 23.7418 | 42 04 36.503 | EF |
| 1532+680 | 15 32 43.3426 | 67 55 13.992 | EF |
| 1602+576 | 16 03 55.9311 | 57 30 54.415 | BS |
| 1627+476 | 16 28 37.5064 | 47 34 10.414 | BS |
| 1630+358 | 16 32 31.2578 | 35 47 37.740 | EF |
| 1745+670 | 17 45 54.3577 | 67 03 49.302 | EF |
| 1755+578 | 17 56 03.6825 | 57 48 47.990 | BS |
| 1815+614 | 18 15 36.7920 | 61 27 11.641 | EF |
| 1946+708 | 19 45 53.5197 | 70 55 48.723 | ? |
| 2253+417 | 22 55 36.7082 | 42 02 52.535 | BS |
| 2310+385 | 23 12 58.7950 | 38 47 42.668 | BS |
| 2323+478 | 23 25 44.9131 | 48 06 25.280 | BS |
| 2356+385 | 23 59 33.1809 | 38 50 42.322 | BS |

Explanation of ID field:

BL: BL Lac object
BS: blue stellar object (without the spectrum — basically a quasar)
BG: blue galaxy?
CW: crowded field — too many objects for a clean identification
EF: empty field
G: galaxy
NS: obscured field
OB: obscured field
Q: quasar
RS: red stellar object
(0018+729, 0248+430, 0552+398, 2015+657, 2021+614, 2352+495), did not fulfill it. In the end, the \( c > 1 \) threshold was chosen as a good compromise, to produce a reasonably sized sample for future observations. The number of the initial candidates selected with the above procedure was 163.

This list contained 14 known GPS sources: 0108+388, 0153+744, 0636+680, 0646+600, 0710+439, 0711+356, 1031+567, 1225+368, 1333+459, 1843+356 and 2050+364 listed in OBS91; 0903+684 from Gopal-Krishna & Spoelstra (1993) and two discovered by Snellen et al. (1995) — 0700+470 and 1324+574. These were not considered for further observations.

We divided the remaining sample of 149 sources into two parts. The first one — hereinafter "Subsample One" — contains those which are found in the 365 MHz Texas survey (24 sources). They are listed in Table 1 along with JVAS positions rounded to 1 milliarcsecond and our identifications made using POSS. Nine of these are also listed in the 6C catalogue which has a flux density limit of 200 mJy at 151 MHz (Hales et al. 1993 and references therein).

For the remaining 125 sources — hereinafter "Subsample Two" — we had virtually no low frequency data. Although 19 of these sources were present in the B3 survey at 408 MHz (Ficarra et al. 1985), its overlap in sky coverage with the first part of the JVAS survey we use here is small and, furthermore, the B3 survey has significant errors in flux density near the catalogue limit of 100 mJy.

The aforementioned crude extrapolation of the spectra applied to medium and high frequency data (1.4 GHz \(< \nu < 8.4 \) GHz) of Subsample Two plus the flux density limit of the Texas Survey gave us only an unreliable estimate of the frequency turnover and even the convex shape of the spectrum remained uncertain in some cases. Particularly some weaker sources could either be GPS or mere flat spectrum depending on their 365 MHz fluxes were far below or just below the Texas catalogue limit respectively. Another effect that will produce a spurious convex shape in our non-simultaneous data is the variability typically observed in flat spectrum sources.

3. Observations and data reduction

In order to investigate the low frequency part of the spectra of Subsample Two sources we set up a programme of flux density measurements at low frequency with a high resolution facility. We used MERLIN at 408 MHz because of its superior resolving capability — \( 1'' \). The observations were carried out in the period from November 1994 until January 1995 and each source was typically observed twice (with different hour angles) for about 15 minutes per scan.

Such short snapshots cannot be used to produce reliable maps with MERLIN, since the aperture coverage is too sparse. Confusion is a significant effect at this low frequency and therefore fringe-frequency vs. delay (FFD) plots were used to separate confusing sources from the central target source (see eg. Walker 1981). Since the data were not phase-calibrated the coherence time is limited to a few minutes. By taking \( 128 \times 4 \) second sub-samples of the data and Fourier transforming them in both time and frequency, a "map" of the field surrounding the source can be produced whose axes are fringe-frequency and delay. The target source will have close to zero fringe-frequency and delay, since its position is well known from the JVAS survey, and appear at the centre of the "map", while confusing sources will be offset from the centre. The flux density of the target source was determined from the central peak in the FFD map. The FFD plots were inspected visually; the detection threshold in a single plot was set at \( 3\sigma \) and flux density values were only listed if the target was detected in two or more plots. In all cases, the values determined from the FFD plots were consistent with simple averages of phase-calibrated data on individual baselines calculated using the Astronomical Image Processing System (AIPS). The flux density scale was determined using observations of 3C286, for which the Baars et al. (1977) value was used.

In Table 2 we report the results of successful measurements of 408 MHz fluxes for 98 sources from Subsample Two along with their JVAS positions rounded to 1 milliarcsecond and our identifications made using POSS. Interference and other problems at other sites resulted in the loss of data for the remaining 27 sources. They are listed in Table 3. The flux density values given in Table 2 resulted from averaging the measurements over all baselines involving the Delford or Knockin telescopes (6 or 8 baselines, depending on whether the Lovell telescope was used or not) and in both LL and RR polarisations. Shorter baselines were not used because they provide insufficient resolution in delay or fringe-frequency to separate the confusing sources; additionally the use of longer baselines reduces any contribution from large-scale halos seen around some GPS sources. The longest baselines involving the Cambridge telescope were not used because interference limited the useful bandwidth to 1.5 MHz, rather than the 4 MHz used elsewhere. Because baseline combinations and the volume of data per source varied form source to source the errors range form 10 to 30 mJy.

4. The new sample of GPS spectrum sources

Finally we merged Subsample One (24 sources) with those 98 sources from Subsample Two whose flux densities we had successfully measured with MERLIN at 408 MHz. Since the selection process for this project was carried out, the 5 GHz Green Bank survey of WB92 has been superseded by the GB6 survey (Gregory et al. 1996) and at 1.4 GHz we can now use the the NRAO VLA Sky Survey
Table 2. Subsample Two — flux densities of sources at 408 MHz

| IAUname (B1950) | R.A. (J2000) | Dec. | Flux [mJy] | Opt. ID |
|----------------|--------------|------|-----------|---------|
| 0004+478      | 00 03 46.0413| 48 07 04.134 | 104 BS   |
| 0015+529      | 00 17 51.7596| 53 12 19.126 | 100 BS   |
| 0046+511      | 00 49 37.9901| 51 28 13.700 | 123 NS   |
| 0051+679      | 00 54 17.6237| 68 11 11.175 | 127 OB   |
| 0051+706      | 00 54 17.6884| 70 53 56.625 | 260 NS   |
| 0058+498      | 01 01 16.9988| 50 44 44.991 | 125 BS   |
| 0102+511      | 01 05 29.5588| 51 25 46.576 | 262 NS   |
| 0123+731      | 01 27 04.7169| 73 23 12.676 | 330 EF   |
| 0129+431      | 01 32 44.1273| 43 25 32.667 | 244 BS   |
| 0129+560      | 01 32 20.4503| 50 20 39.072 | 113 CW   |
| 0140+490      | 01 43 46.8791| 49 15 41.586 | 105 CW   |
| 0148+546      | 01 51 36.2876| 51 34 37.688 | 100 EF   |
| 0153+389      | 01 56 31.0488| 39 14 39.029 | 119 BS   |
| 0214+444      | 02 16 17.7107| 44 37 43.405 | 154 EF   |
| 0251+393      | 02 54 42.6316| 39 31 34.174 | 114 BS   |
| 0314+230      | 03 10 49.8805| 38 14 53.845 | 148 NS   |
| 0335+509      | 03 39 09.3942| 60 08 56.960 | 134 RS   |
| 0336+473      | 03 40 10.7897| 47 32 37.282 | 103 BS   |
| 0338+480      | 03 42 10.3522| 48 09 46.948 | 113 NS   |
| 0412+447      | 04 15 56.5246| 44 52 49.676 | 110 OB   |
| 0424+414      | 04 27 46.0455| 41 33 01.091 | 272 EF   |
| 0454+550      | 04 58 54.8417| 55 08 42.042 | 192 BS   |
| 0513+714      | 05 19 28.8853| 71 33 03.740 | 153 EF   |
| 0514+474      | 05 18 12.0899| 47 30 55.536 | 220 CW   |
| 0533+446      | 05 37 30.0630| 44 41 03.533 | 155 ?     |
| 0559+422      | 05 02 58.9438| 42 12 09.999 | 259 BS   |
| 0610+510      | 06 14 49.1589| 51 02 13.124 | 143 BG   |
| 0621+446      | 06 25 18.2652| 44 40 01.628 | 101 BS   |
| 0630+497      | 06 33 52.2068| 49 43 45.939 | 149 BS   |
| 0651+410      | 06 55 10.0243| 51 00 10.148 | 130 G    |
| 0655+696      | 07 01 06.6159| 69 36 29.414 | 293 BS   |
| 0708+742      | 07 14 46.1326| 74 08 10.142 | 105 BS   |
| 0713+669      | 07 18 05.6314| 66 51 53.322 | 145 EF   |
| 0718+374      | 07 21 00.2600| 37 22 28.628 | 64 BS    |
| 0732+755      | 07 39 13.1962| 75 27 47.702 | 141 EF   |
| 0753+373      | 07 56 28.5213| 37 14 55.647 | 59 BS    |
| 0753+519      | 07 56 59.5457| 51 51 03.207 | 98 BS    |
| 0758+594      | 08 02 24.5932| 59 21 34.800 | 102 BS   |
| 0849+675      | 08 53 34.3220| 67 22 15.665 | 212 BS   |
| 0851+719      | 08 56 54.8695| 71 46 23.894 | 105 BS   |
| 0900+520      | 09 03 58.5758| 51 00 00.658 | 354 ?     |
| 0924+732      | 09 29 42.1565| 73 04 04.553 | 114 G    |
| 0925+745      | 09 30 53.7823| 74 20 05.930 | 112 EF   |
| 0939+620      | 09 43 14.5025| 61 50 33.343 | 99 BS    |
| 1017+436      | 10 20 27.2021| 43 20 56.342 | 51 BS    |
| 1019+429      | 10 22 13.3242| 42 39 25.618 | 138 RS   |
| 1032+509      | 10 35 06.0176| 50 40 06.087 | 198 EF   |
| 1035+430      | 10 38 18.1899| 42 44 42.766 | 194 RS   |
| 1043+541      | 10 46 24.0372| 53 54 26.220 | 181 BS   |
| 1055+433      | 10 58 02.9208| 43 04 41.505 | 182 EF   |
| 1101+609      | 11 04 53.6946| 38 58 55.287 | 151 BS   |
| 1125+366      | 11 27 58.8707| 36 20 28.352 | 86 BS    |
| 1138+644      | 11 41 12.2283| 64 10 05.484 | 180 EF   |

Explanation of ID field is given in Table 1.
Table 3. Subsample Two — sources not measured at 408 MHz

| IAUname (B1950) | R.A. (J2000) | Dec. | Opt. ID |
|----------------|-------------|------|---------|
| 0310+435       | 03 14 08.0539 | 43 45 19.770 | EF |
| 0314+696       | 03 19 22.0734 | 69 49 25.603 | EF |
| 0418+437       | 04 21 52.6919 | 43 53 04.216 | CW |
| 0537+392       | 05 40 44.4377 | 39 16 12.236 | RS |
| 0601+578       | 06 05 42.2275 | 57 53 16.351 | BS |
| 0638+528       | 06 42 27.8215 | 52 47 59.282 | BS |
| 0644+491       | 06 46 47.1190 | 49 07 20.736 | BS |
| 0651+428       | 06 54 43.5263 | 42 47 57.828 | G |
| 0903+649       | 09 07 23.5240 | 64 46 49.642 | EF |
| 1238+702       | 12 40 34.6989 | 70 58 30.616 | BS |
| 1245+716       | 12 47 09.3270 | 71 24 20.018 | BS |
| 1341+691       | 13 43 00.5520 | 69 55 17.160 | BS |
| 1406+564       | 14 08 12.9466 | 56 13 32.488 | BS |
| 1436+445       | 14 38 28.5048 | 44 18 12.085 | EF |
| 1447+536       | 14 48 59.1739 | 53 26 09.282 | EF |
| 1456+375       | 14 55 44.8799 | 37 20 16.217 | BS |
| 1526+670       | 15 26 42.8732 | 67 60 54.617 | NS |
| 1550+582       | 15 51 58.2077 | 58 06 44.466 | BS |
| 1611+425       | 16 13 04.8038 | 42 23 18.903 | BS |
| 1622+665       | 16 23 04.5221 | 66 24 01.084 | G |
| 1924+420       | 19 26 31.0504 | 42 09 58.991 | G |
| 2119+664       | 21 20 46.2045 | 66 42 20.216 | EF |
| 2132+406       | 21 34 24.1053 | 40 50 11.345 | EF |
| 2230+625       | 22 32 22.8655 | 62 49 36.436 | OB |
| 2236+678       | 22 38 15.0284 | 67 64 59.758 | OB |
| 2249+402       | 22 51 59.7715 | 40 30 58.155 | BS |
| 2351+550       | 23 53 42.3011 | 55 18 40.670 | BS |

Explanation of ID field is given in Table 1.

(NVSS)\(^4\) (Condon et al. 1998) which has a resolution of 45'' and an rms sensitivity of approximately 1.5 mJy.

Unfortunately, at the time of writing, NVSS — although almost complete — did not cover all areas of the sky within its declination limits. Many NVSS maps (4° × 4° each) appear to be "patchy" and the "holes" can sometimes be quite large. Our survey suffered considerably from this shortcoming of the current edition of NVSS — 9 sources out of those 122 sources we wanted to study were simply not present in the NVSS catalogue. (One source out of these nine was also unavailable in GB6.) Additionally we decided to remove 2 other sources from the further processing: one of these is blended with a nearby source and the second one has an extended structure which should be studied in more detail.

At 1.4 GHz we also tried to use the Faint Images of Radio Sky at Twenty (FIRST) catalogue\(^5\) (White et al. 1997) — 24 our sources could be found there. For 20 objects out of these we noted a very good compatibil-

\(^4\) available at ftp://nvss.cv.nrao.edu/pub/nvss/CATALOG
\(^5\) available at http://sundog.stsci.edu/
possible flux variations. Firstly, because a significant variability of the flux density would mean that the source in question is likely not to be a GPS and secondly — since our data are not simultaneous — any variability makes derivation of spectra questionable. The part of sources’ spectra around 1.4 GHz is obviously the most "sensitive" with regard to the GPS phenomenon so we compared fluxes at this frequency given in WB92 to those from NVSS. We applied corrections for the different beam sizes of these two measurements. If a particular source had changed its flux between epochs of the GB surveys and NVSS/FIRST more than 25% or the 1.4 GHz GB flux was missing in WB92 we treated such a source as potentially variable, unless we could find a second epoch flux density measurement elsewhere. We assigned a "candidate" status for such objects and listed them in Table 6. Among these there are 4 sources (0412+447, 1125+366, 1357+404, 2005+642) with inverted spectra only, i.e. apparently having turnovers in their spectra at frequencies larger than 8.4 GHz. This feature was yet another reason to assign them a candidate status.

5. Notes on individual sources
Apart from the information in Table 5 we note that:
- 0627+532, 0652+577, 1107+485, 1256+546 and 1311+552 are 6C sources (Hales et al. 1993 and references therein)
- 1107+485 is a member of the DRAO 408 MHz survey (Green & Riley 1995)
- 1745+670 and 1753+648 are members of the NEP survey (Kollgaard et al. 1994)
- 1607+563, 1755+578 and 1815+614 are members of the 7C survey (Visser et al. 1995)
- 0514+474 was observed by Leahy & Roger (1996)
- 0102+480 and 2253+417 are members of the CJ1 survey (Polatidis et al. 1995)
- 1245+676 is a giant radio galaxy with a GPS core (O'Dea priv. comm. 1996).
- 0140+490 has a large scale symmetric structure 2′5 across.
- 1389+548 and 2119+709 are marked as "quasi-point" sources in JVAS. All other sources are pointlike i.e. they are unresolved by the VLA in "A" configuration at 8.4 GHz.
- 1815+614 and 1946+708 are CSOs (Taylor et al. 1996, Taylor & Vermeulen 1997)

6. Summary
Gigahertz Peaked Spectrum objects are an astrophysically significant and important class yet they are still not well understood (O'Dea 1998). They are not necessarily a uniform class, and one can easily name subclasses among the whole GPS ensemble. For example CSOs make one well-defined group — all of them are GPS galaxies with characteristic VLBI morphologies. It is claimed by Readhead et al. (1996b) that CSOs play a key role as an initial stage in the evolutionary scenario of radio-loud AGNs.

Another fascinating subset of GPS class are objects with extreme (z > 3) redshifts. There are 9 such objects in the "working sample" (O’Dea, priv. comm. 1996). Additionally there are ~ 20 objects with high (1 < z < 3) redshifts. All the objects with z > 1 are identified with quasars.

The above two issues alone are already a good argument to extend the number of known GPS radio sources. With such a goal in mind we have made a search for candidate GPS sources in the part of the Jodrell Bank–VLA Astrometric Survey limited to 35° ≤ δ ≤ 75°, namely we compared 8.4 GHz flux densities derived from JVAS with respective 1.4 GHz and 5 GHz fluxes in available catalogues. We treated a source as a plausible candidate if its spectrum seemed to be convex according to the criterion we had arbitrarily assumed.

Quite expectedly some of the candidates selected in this manner are already recognised as GPS objects so we did not deal with them here. Using flux densities at low frequencies i.e. 365 MHz and sometimes even 151 MHz in available catalogues we were able to classify 24 objects as GPS sources without any further measurements. For the majority of selected objects the flux densities at frequencies well below 1 GHz were not available. In these cases we performed observations with MERLIN at 408 MHz to establish the low-frequency part of the spectra.

Our final decision on which of our candidates are and which are not GPS sources has been made based on our MERLIN data (or Texas catalogue when available), NVSS, GB6 and JVAS catalogues. Combining flux density measurements made with high resolution both at low (MERLIN, 408 MHz) and high (VLA, 8.4 GHz) frequencies enabled us to eliminate the effects of confusion and any contribution from possible extended "halos". We regarded a source as a GPS if it had fitted well a "broken power-law" function and was not variable.

The sample we present here is the largest single contribution to the pool of known GPS sources collected so far. Only 3 of our sources (0513+714, 0758+594, 1946+708) are overlapping with another large collection of GPS sources, namely with the WENSS based sample\(^7\) (SSB98). Seven sources in our sample have large redshifts (z ≥ 2); the largest one is \(z = 3.103\).

Our approach to finding GPS sources was to search from high frequency to lower ones. WENSS has been equally successful in defining GPS sources but searching...
from low frequencies to higher ones. We want to stress though that our approach can successfully be applied to the areas of the sky not planned to be covered by WENSS ($\delta < 30^\circ$) but already covered by the other catalogues we used (NVSS, GB6, JVAS). For the part of JVAS we used so far (Patnaik et al. 1992) we found that 9% of JVAS sources are GPS; therefore the whole JVAS encompassing around 3000 sources could easily yield 250 – 300 of such objects.

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Fig. 1. Spectra of non-GPS sources. Abscissae: frequency in GHz, ordinates: flux densities in mJy
Fig. 1. continued
Fig. 2. Spectra of GPS sources. Abscissae: frequency in GHz, ordinates: flux densities in mJy
Fig. 2. continued
Fig. 2. continued
Fig. 2. continued
Table 4. GPS sources’ spectra fitting parameters

| Number | B1950 name | $S_0$ | $\nu_0$ | $k$ | $l$ | $S_{max}$ | $\nu_{max}$ | unconstrained |
|--------|------------|-------|---------|-----|-----|----------|------------|---------------|
| 1      | 0001+478  | 286   | 3.66    | 0.671 | -2.1 | 332 | 2.68 |
| 2      | 0015+529  | 657   | 3.47    | 1.13  | -0.381 | 687 | 4.82 |
| 3      | 0046+511  | 246   | 7.14    | 0.549 | -1.63 | 284 | 4.85 |
| 4      | 0051+679  | 324   | 6.97    | 0.577 | -1.85 | 379 | 4.85 |
| 5      | 0058+498  | 187   | 5.94    | 0.322 | -1.76 | 237 | 3.49 |
| 6      | 0102+480  | 1110  | 3.03    | 1.06  | -0.774 | 1110 | 3.01 |
| 7      | 0102+511  | 530   | 1.85    | 0.775 | -1.33 | 564 | 1.42 |
| 8      | 0123+731  | 361   | 3.25    | 0.264 | -1.27 | 449 | 1.63 |
| 9      | 0129+560  | 659   | 3.42    | 1.05  | -0.956 | 662 | 3.14 |
| 10     | 0140+490  | 228   | 4.28    | 0.524 | -1.53 | 262 | 2.85 |
| 11     | 0148+546  | 137   | 8.39    | 0.256 | -1.85 | 181 | 4.73 |
| 12     | 0153+389  | 203   | 7.44    | 0.404 | -2.17 | 257 | 4.85 |
| 13     | 0159+739  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 14     | 0207+478  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 15     | 0219+478  | 621   | 1.61    | 0.862 | -1.66 | 628 | 4.85 |
| 16     | 0233+599  | 192   | 7.92    | 0.309 | -2.12 | 251 | 4.85 |
| 17     | 0242+473  | 295   | 2.96    | 0.762 | -0.886 | 301 | 2.43 |
| 18     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 19     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 20     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 21     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 22     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 23     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 24     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 25     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 26     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 27     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 28     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 29     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 30     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 31     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 32     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 33     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 34     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 35     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 36     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 37     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 38     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 39     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 40     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 41     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 42     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 43     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 44     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 45     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 46     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 47     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 48     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
| 49     | 0242+473  | 257   | 7.85    | 0.302 | -2.23 | 340 | 4.85 |
| 50     | 0242+473  | 277   | 7.84    | 0.349 | +0.349 | 301 | 2.43 |
Table 4. continued

| Number | B1950 name | $S_0$ | $\nu_0$ | $k$ | $l$ | $S_{\text{max}}$ | $\nu_{\text{max}}$ | unconstrained |
|--------|------------|------|--------|----|----|----------------|----------------|------------|
| 51     | 1454+447   | 206. | 2.36   | +0.588 | −0.407 | 206. | 2.43   | •           |
| 52     | 1532+680   | 455. | 2.57   | +0.329 | −1.32 | 551. | 1.42   | •           |
| 53     | 1534+501   | 341. | 6.97   | +0.584 | −1.09 | 367. | 4.85   | •           |
| 54     | 1544+398   | 221. | 6.4    | +0.363 | −4.67 | 310. | 4.85   | •           |
| 55     | 1607+563   | 261. | 3.54   | +0.538 | −0.797 | 273. | 2.48   | •           |
| 56     | 1627+476   | 219. | 3.06   | +0.241 | −1.11 | 271. | 1.42   | •           |
| 57     | 1630+358   | 466. | 2.5    | +0.377 | −1.11 | 537. | 1.42   | •           |
| 58     | 1745+670   | 548. | 2.7    | +0.266 | −1.46 | 696. | 1.42   | •           |
| 59     | 1753+648   | 220. | 7.26   | +0.519 | −1.66 | 257. | 4.85   | •           |
| 60     | 1755+578   | 785. | 2.07   | +1.06 | −1.07 | 793. | 1.86   | •           |
| 61     | 1801+459   | 231. | 2.78   | +0.337 | −0.77 | 256. | 1.46   | •           |
| 62     | 1815+614   | 580. | 3.9    | +0.0731 | −1.69 | 852. | 1.61   | •           |
| 63     | 1820+397   | 753. | 0.457  | −0.519 | +0.527 | 761. | 0.575  | •           |
| 64     | 1839+548   | 240. | 5.62   | +0.436 | −0.983 | 265. | 3.42   | •           |
| 65     | 1946+708   | 965. | 1.92   | +0.818 | −0.755 | 970. | 1.72   | •           |
| 66     | 2000+472   | 946. | 4.11   | +0.996 | −0.588 | 949. | 4.51   | •           |
| 67     | 2005+642   | 227. | 0.502  | +0.346 | +3.4  |      |        | •           |
| 68     | 2013+508   | 363. | 1.67   | +0.849 | −0.927 | 369. | 1.42   | •           |
| 69     | 2014+463   | 153. | 8.03   | +0.231 | −1.88 | 205. | 4.44   | •           |
| 70     | 2119+709   | 167. | 9.07   | +0.217 | −1.79 | 224. | 4.85   | •           |
| 71     | 2151+431   | 257. | 3.25   | +0.63 | −0.917 | 268. | 2.41   | •           |
| 72     | 2248+555   | 469. | 4.72   | +0.512 | −0.633 | 481. | 3.43   | •           |
| 73     | 2253+417   | 1840. | 1.83   | +0.706 | −0.909 | 1900. | 1.44  | •           |
| 74     | 2310+385   | 682. | 3.2    | +0.6  | −1.14 | 735. | 2.25   | •           |
| 75     | 2341+697   | 155. | 7.5    | +0.147 | −1.59 | 213. | 3.45   | •           |
| 76     | 2356+385   | 560. | 3.85   | +0.524 | −1.34 | 632. | 2.55   | •           |
Table 5. Some other parameters of JVAS GPS sources

| Number | B1950name | S4/S5 | FIRST | B3 | WENSS | C32 | Opt. ID | z      | Redshift reference                  |
|--------|------------|-------|-------|----|-------|-----|---------|-------|-------------------------------------|
| 1      | 0001+478   |       |       |    |       |     |         |       |                                     |
| 2      | 0015+529   |       |       |    |       |     |         |       |                                     |
| 3      | 0046+511   |       |       |    |       |     |         |       |                                     |
| 4      | 0051+679   |       |       |    |       |     |         |       |                                     |
| 5      | 0058+498   |       |       |    |       |     |         |       |                                     |
| 6      | 0102+480   | •     | •     |    |       |     | QSO     | 0.816 | Vermeulen & Taylor, 1995            |
| 7      | 0102+511   |       |       |    |       |     |         |       |                                     |
| 8      | 0123+731   | •     | •     |    |       |     |         |       |                                     |
| 9      | 0129+560   |       |       |    |       |     |         |       |                                     |
| 10     | 0140+490   |       |       |    |       |     |         |       |                                     |
| 11     | 0148+546   |       |       |    |       |     |         |       |                                     |
| 12     | 0153+389   |       |       |    |       |     |         |       |                                     |
| 13     | 0307+380   | •     | •     |    |       |     | QSO     | 1.59  | Hook et al., 1996                  |
| 14     | 0335+599   |       |       |    |       |     |         |       |                                     |
| 15     | 0336+473   |       |       |    |       |     |         |       |                                     |
| 16     | 0412+447   |       |       |    |       |     |         |       |                                     |
| 17     | 0454+550   |       |       |    |       |     |         |       |                                     |
| 18     | 0513+714   |       |       |    |       |     |         |       |                                     |
| 19     | 0514+474   | •     | •     |    |       |     | QSO     | 1.33  | Hook et al., 1996                  |
| 20     | 0610+510   | •     | •     |    |       |     | QSO     | 1.971 | Moran et al., 1996                |
| 21     | 0627+532   | •     | •     |    |       |     | QSO     | 2.204 | Henstock et al., 1997             |
| 22     | 0630+497   | •     | •     |    |       |     | G       | 0.02156 | Marzke et al., 1996          |
| 23     | 0651+410   | •     | •     |    |       |     | QSO     | 1.96  | Hook et al., 1996                  |
| 24     | 0654+550   |       |       |    |       |     |         |       |                                     |
| 25     | 0655+696   | •     | •     |    |       |     | QSO     | 1.33  | Hook et al., 1996                  |
| 26     | 0718+374   | •     | •     |    |       |     |         |       |                                     |
| 27     | 0750+535   | •     | •     |    |       |     | QSO     | 1.96  | Hook et al., 1996                  |
| 28     | 0753+373   | •     | •     |    |       |     |         |       |                                     |
| 29     | 0753+519   | •     | •     |    |       |     | QSO     | 1.971 | Moran et al., 1996                |
| 30     | 0758+594   | •     | •     |    |       |     |         |       |                                     |
| 31     | 0849+675   | •     | •     |    |       |     |         |       |                                     |
| 32     | 0925+745   | •     | •     |    |       |     | QSO     | 1.60  | Hook et al., 1996                  |
| 33     | 1017+436   | •     | •     |    |       |     |         |       |                                     |
| 34     | 1019+429   | •     | •     |    |       |     | QSO     | 1.96  | Hook et al., 1996                  |
| 35     | 1032+509   | •     | •     |    |       |     | QSO     | 0.74  | Hook et al., 1996                  |
| 36     | 1055+433   | •     | •     |    |       |     |         |       |                                     |
| 37     | 1107+485   | •     | •     |    |       |     | QSO     | 1.60  | Hook et al., 1996                  |
| 38     | 1125+366   | •     | •     |    |       |     | QSO     | 1.60  | Hook et al., 1996                  |
| 39     | 1138+644   | •     | •     |    |       |     | QSO     | 0.103 | Marzke et al., 1996               |
| 40     | 1206+415   | •     | •     |    |       |     | QSO     | 0.613 | Vermeulen et al., 1996            |
| 41     | 1226+638   | •     | •     |    |       |     | QSO     | 0.613 | Vermeulen et al., 1996            |
| 42     | 1232+366   | •     | •     |    |       |     | QSO     | 0.613 | Vermeulen et al., 1996            |
| 43     | 1239+606   | •     | •     |    |       |     | QSO     | 0.496 | Vermeulen et al., 1996            |
| 44     | 1245+676   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| 45     | 1256+546   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| 46     | 1311+552   | •     | •     |    |       |     | QSO     | 0.496 | Vermeulen et al., 1996            |
| 47     | 1321+410   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| 48     | 1338+381   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| 49     | 1357+404   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| 50     | 1403+411   | •     | •     |    |       |     | QSO     | 3.103 | Hook et al., 1995                 |
| Number | B1950name | S4/S5 | FIRST | B3  | WENSS | CJ2 | Opt. ID | z     | Redshift reference               |
|--------|-----------|-------|-------|-----|-------|-----|---------|-------|----------------------------------|
| 51     | 1454+447  | •     |       |     |   •   |     | QSO     | 1.119 | Vermeulen & Taylor, 1995        |
| 52     | 1532+680  |       |       |     | •     |     |         |       |                                  |
| 53     | 1534+501  | •     | •     |     |       | •   | QSO     | 2.110 | Henstock et al., 1997          |
| 54     | 1544+398  | •     | •     |     | •     |     |         |       |                                  |
| 55     | 1607+563  | •     |       |     |   •   |     |         |       |                                  |
| 56     | 1627+476  | •     |       |     | •     |     |         |       |                                  |
| 57     | 1630+358  | •     |       |     | •     |     |         |       |                                  |
| 58     | 1745+670  | •     |       |     | •     |     |         |       |                                  |
| 59     | 1753+648  | •     |       |     | •     |     |         |       |                                  |
| 60     | 1755+578  | •     | •     |     |       | •   | QSO     |       |                                  |
| 61     | 1801+459  | •     |       |     | •     |     |         |       |                                  |
| 62     | 1815+614  | •     | •     |     |     | •   | QSO     | 0.601 | Vermeulen & Taylor, 1995        |
| 63     | 1820+397  | •     | •     |     |       |     |         |       |                                  |
| 64     | 1839+548  | •     |       |     | •     |     |         |       |                                  |
| 65     | 1946+708  | •     | •     |     |       | •   | QSO     | 1.574 | Henstock et al., 1997          |
| 66     | 2000+472  | •     |       |     | •     |     |         |       |                                  |
| 67     | 2005+642  | •     | •     |     | •     |     | QSO     | 1.476 | Hewitt & Burbidge, 1989         |
| 68     | 2013+508  | •     |       |     | •     |     |         |       |                                  |
| 69     | 2014+463  | •     |       |     | •     |     |         |       |                                  |
| 70     | 2119+709  | •     |       |     | •     |     |         |       |                                  |
| 71     | 2151+431  | •     |       |     | •     |     |         |       |                                  |
| 72     | 2248+555  | •     |       |     | •     |     |         |       |                                  |
| 73     | 2253+417  | •     |       |     | •     |     | QSO     | 2.17  | Hewitt & Burbidge, 1989         |
| 74     | 2310+385  | •     |       |     | •     |     | QSO     | 2.704 | Stickel & Kühr, 1994           |
| 75     | 2341+697  | •     |       |     | •     |     |         |       |                                  |
| 76     | 2356+385  | •     |       |     | •     |     | QSO     | 1.19  | Vermeulen & Taylor, 1995        |

References of the catalogues:

S4 — Pauliny-Toth et al. 1978
S5 — Kühr et al. 1981b
FIRST — White et al. 1997
B3 — Ficarra et al. 1985
WENSS — Rengelink et al. 1997
CJ2 — Taylor et al. 1994
Table 6. Candidate GPS sources

| B1950 name | Reason |
|------------|--------|
| 0001+478   | GB flux is 73% greater than NVSS flux |
| 0046+511   | no 2nd epoch data |
| 0051+679   | GB flux is 36% greater than NVSS flux |
| 0058+498   | no 2nd epoch data |
| 0307+380   | poor fit to the broken power-law curve |
| 0412+447   | GB flux is 4.7 times greater than NVSS flux, inverted spectrum only |
| 0651+410   | no 2nd epoch data |
| 0655+696   | GB flux is 55% less than NVSS flux |
| 0718+374   | no 2nd epoch data |
| 0753+519   | no 2nd epoch data |
| 0758+594   | GB flux is 34% less than NVSS flux |
| 1017+436   | no 2nd epoch data |
| 1055+433   | B3 flux (420 mJy) and MERLIN 408 MHz flux (182 mJy) do not match |
| 1125+366   | FIRST flux does not match NVSS and GB fluxes, inverted spectrum only |
| 1206+415   | FIRST flux does not match NVSS and GB fluxes |
| 1232+366   | FIRST flux matches NVSS flux but they both don’t match GB and S4 fluxes — extended component? |
| 1357+404   | FIRST flux does not match NVSS and GB fluxes, inverted spectrum only |
| 1544+398   | B3 flux matches MERLIN flux but FIRST flux does not match NVSS and GB fluxes |
| 1839+548   | no 2nd epoch data |
| 2005+642   | inverted spectrum only |
| 2013+508   | GB flux is 48% less than NVSS flux |
| 2014+463   | no 2nd epoch data |
| 2248+555   | no 2nd epoch data |
| 2341+697   | no 2nd epoch data |