The SPECFIND V2.0 catalogue of radio cross-identifications and spectra.

**SPECFIND meets the Virtual Observatory**

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**ABSTRACT**

The new release of the SPECFIND radio cross-identification catalogue, SPECFIND V2.0, is presented. It contains 107488 cross-identified objects with at least three radio sources observed at three independent frequencies. Compared to the previous release the number of entry radio catalogues is increased from 20 to 97 containing 115 tables. This large increase was only made possible by the development of four tools at CDS which use the standards and infrastructure of the Virtual Observatory (VO). This was done in the framework of the VO-TECH European Design Study of the Sixth Framework Program. We give an overview of the different classes of radio sources that a user can encounter. Due to the increase of frequency coverage of the input radio catalogues, this release demonstrates that the SPECFIND algorithm is able to detect spectral breaks around a frequency of ~ 1 GHz.

**Key words.** Astronomical data bases: miscellaneous – Radio continuum: general

1. Introduction

The cross-identification of radio sources observed in the centimeter to meter wavelength domain with different instruments is a rather difficult task, because of huge differences in sensitivity, spatial resolution, and the non-simultaneous observations of variable sources. Especially the very different spatial resolutions of single dish telescopes and interferometers are difficult to handle. On the other hand, most sources show a power-law spectral energy distribution in these wavelengths due to synchrotron or thermal emission. Synchrotron emission produces a power law spectrum with a possible cut-off or reversal of the spectral index at low frequencies due to self-absorption or comptonization. The spectrum of thermal electrons is flat in the optically thin domain.

In Vollmer et al. (2005a) we presented the SPECFIND tool for the extraction of cross-identifications and radio continuum spectra from radio source catalogues contained in the VizieR database of the Centre de Données astronomiques de Strasbourg (CDS). The SPECFIND cross-identification tool takes advantage of the power-law shape of the spectra. In addition, it takes into account the angular resolution of the observations, the source size, and the flux densities observed at a given frequency. The SPECFIND tool also insures that a radio source cannot be assigned to more than one physical object.

In a first release (SPECFIND V1.0; Vollmer et al. 2005a,b) we cross-identified the sources of the 20 largest radio catalogues in VizieR (Ochsenbein et al. 2000), representing 3.5 million sources. Our work led to more than 700 000 independent cross-identifications between sources from different radio catalogues and ~ 67 000 independent radio spectra with more than two independent frequencies.

The information contained in radio catalogues is heterogeneous containing different entries, (e.g. peak flux or integrated flux) and physical units (e.g. source extent in arcsec, arcmin, or beamsizes). On the other hand, a cross-identification tool needs uniform input: at least a source name, position, and flux density at the measured frequency. The uniformisation of the 20 SPECFIND V1.0 entry catalogues was done by hand. For a significant increase of independent radio cross-identifications, an input of sources from more than a hundred radio catalogues is needed. This goal could only be attained by taking advantage of Virtual Observatory (VO) capabilities, which are described in Sect. 2. The new release of the SPECFIND catalogue is presented in Sect. 3.
VO, as required in the VO “Characterization” data model (Louys et al. 2008). For example, the angular resolution of the observations is not provided as a standard parameter in the VizieR catalogue description. During the development the tools were kept as general as possible. They can thus be used in other astronomical contexts. We also plan to include the extended radio catalogue description gathered by the characterization tool into VizieR. These tools together with the associated manuals are available at 
http://eurovotec.org/twiki/bin/view/VOTech

2.1. Registry query tool TABFIND

This tool identifies VO resources based on Unified Content Descriptors (UCDs). The UCDs are a controlled vocabulary defined by the VO to describe astronomical quantities (Derrière et al. 2004). TABFIND is written in Java and uses XMLDB API to get data from the VO registry of resources. The latter is a kind of telephone book where all web servers are listed that comply with VO standards. The user specifies a required set of UCDs. TABFIND searches the VO registry for all catalogues whose descriptions contain these UCDs. For example, in our project the minimum set of parameters needed for the radio cross-identification are source coordinates and a radio flux.

The result of the query is a list of relevant radio catalogues. The catalogues can then be sorted into useful and not useful catalogues by displaying the catalogue descriptions. A workspace permits to save and restore all actions performed on the catalogues. At the end, a final list of relevant catalogues is established.

2.2. Data homogenisation tool TABUNIF

The relevant catalogues obtained from TABFIND can be directly loaded into the data homogenization tool. TABUNIF creates homogenized data from a heterogeneous set of catalogues. It is written in Java and works on XML tables. In a first step the user specifies a set of columns for the output table which can be based on the list of UCDs. In our case we defined the output columns according to the needs of the SPECFIND cross-identification tool (Vollmer et al. 2005a). In a second step the tool generates an interface where a column of the entry radio catalogue is assigned to a user specified output column.

The user is free to change the input column that he/she wants to assign to an output column. It is also possible to assign an arithmetic combination of different input columns or conditions on input columns to an output column. As a result the tool generates an ASCII output table for each input radio catalogue. The ASCII output tables can be directly used by the SPECFIND cross-identification tool. Alternatively, the output table can be produced in the VOTable format for future usage by VO tools.

2.3. Characterisation tool CAMEA

We realized that the description of the radio catalogues in VizieR does not contain all necessary information for the cross-identification. Basic information such as the identity of the instrument, frequency, resolution, and observation dates are not included in the catalogue metadata. We therefore decided to develop a third VO tool which permits to specify this missing information. More generally, it will permit to create a full description of a VO resource based on the VO Characterization data model (Louys et al. 2008). In the future, CAMEA will help to provide the input for the data homogenization tool TABUNIF described above. In this way we plan to complement the VizieR metadata of radio catalogues by adding the frequency, angular resolution, observation dates, etc.

3. SPECFIND V2.0

The use of the registry query tool and data homogenization tool enabled us to include 97 radio catalogues and 117 tables (a catalogue corresponds to one reference and can contain multiple tables) from VizieR (Ochsenbein et al. 2000) into the SPECFIND radio cross-identification tool (20 catalogues from Vollmer et al. 2005a (Table 1 and the catalogues listed in Table 2). The number of sources from these catalogues is $3.76 \times 10^6$ giving rise to 107 488 cross-identified objects, i.e. objects with at least 3 flux densities observed at 3 independent frequencies. Compared to the first release of the SPECFIND V1.0 catalogue this is an increase of available radio sources by $\sim 8\%$. This relatively small increase is due to the fact that the number of catalogues with a given number of radio sources increases rapidly with decreasing number of radio sources contained in the catalogue. However, the smaller catalogues often provide the missing third flux density to establish a radio spectrum. For example, in the northern hemisphere there is a multitude of radio objects with available NVSS (1.4 GHz; Condon et al. 1998) and WENSS (325 MHz; Rengelink et al. 1997) flux densities. The surveys at higher frequencies, which were included in SPECFIND V1.0, are rather shallow and thus did not detect the majority of the sources. Observations at high frequencies underlying small catalogues are almost always more sensitive than observations which give rise to large catalogues, with the drawback that they are made within small areas on the sky. This is the reason why a modest increase of source available for the cross-identification ($\sim 8\%$) leads to a significant increase of cross-identified radio objects of $\sim 60\%$. The source coverage of the first and the second release of the SPECFIND catalogues are shown in Fig. 6.

The SPECFIND V2.0 catalogue is available via Vizier at CDS. It has the same data structure as SPECFIND V1.0. Each radio source represents one line of the catalogue. The radio sources from one physical object are linked via a common sequence number. For each radio source SPECFIND V2.0 gives a flag for extended/confused/complex sources (based on the NVSS), the source name, coordinates, flux density, error of the flux density as used in SPECFIND, number of sources with the same sequence number, slope and abscissa of the radio spectrum, positional difference to the NVSS source which is part of the spectrum, and the difference between the interpolated 20cm and the NVSS flux density. In addition, we provide a link to the plot of

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1 http://xmldb-org.sourceforge.net/xapi/
2 http://www.ivoa.net/Documents/latest/UCDlist.html
3 The VOTable format is an XML standard for the interchange of data represented as a set of tables; http://www.ivoa.net/Documents/latest/VOT.html
the radio spectrum and a link to the Aladin applet in which
the NVSS/DSS images and the positions of the SPECFIND
V2.0 radio sources together with the beam sizes of the dif-
ferent observations are displayed. Moreover, we provide ac-
cess to the radio sources that are cross-identified only with
respect to their position (overlapping beams or extents),
but do not fit the radio spectrum.

The distribution of the spectral indices\(^4\) is shown in
Fig.\(^2\). The distribution peaks at \(\alpha \sim -0.9\), which is consis-
tent with the result from the first release (see also Zhang et
al. 2003). As in SPECFIND V1.0, there is a wing towards
positive spectral indices, which is most probably caused by
the flattening of the spectrum at low frequencies due to
synchrotron self-absorption and at high frequencies due to
the emission of thermal electrons.

The number of objects as a function of the number of
catalogued sources contained in an object is shown in Fig.\(^3\).
The shape of the distribution is a broken power law with a
break at about 12 sources per object. The maximum num-
ber of catalogued sources in a physical object is 30.

The distributions of the spectral indices as a function
of the measured or interpolated flux density at 325 MHz
from SPECFIND V1.0 and V2.0 are shown in Fig.\(^4\). In
SPECFIND V1.0 the straight, almost horizontal edge of
the distribution in the left part of the plot (marked as (a)
in the upper panel of Fig.\(^4\)) is due to a selection effect.
For these low flux density sources with a steep spectrum,
SPECFIND found a source at 20 cm (NVSS) and 50 cm
(WENSS), but none at 6 cm, where the sensitivity of the
surveys (~ 20 mJy) is insufficient. The inclusion of the
new radio catalogues at 4850 MHz into SPECFIND V2.0
improved this situation only mildly.

\(^4\) The spectral index \(\alpha\) is defined by \(S_\nu \propto \nu^{\alpha}\).
Table 1. SPECFIND V1.0 catalogue entries.

| Catalog name | I/S | Frequency (MHz) | Resolution (arcmin) | $S_{\text{min}}$ (mJy) | Number of sources | Percentage | Reference |
|--------------|-----|-----------------|---------------------|-------------------------|-------------------|------------|-----------|
| JVAS         | I   | 8400            | 5.5x10^{-3}         | 30                      | 2246              | 72         | Patnaik et al. (1992) |
| GB6          | S   | 4850            | 3.5                 | 18                      | 75162             | 59         | Gregory et al. (1996) |
| 87GB         | S   | 4850            | 3.5                 | 25                      | 54579             | 64         | Gregory & Condon (1991) |
| BWE          | S   | 4850            | 3.5                 | 25                      | 53522             | 61         | Becker et al. (1991) |
| PMN          | S   | 4850            | 3.5                 | 20                      | 50814             | 30         | Wright et al. (1994; 1996) |
| MITG         | S   | 4850            | 2.8                 | 40                      | 24180             | 52         | Bennett et al. (1986) |
| PKS          | S   | 2700            | 8.0                 | 50                      | 8264              | 65         | Otrupcek & Wright (1991) |
| F3R          | S   | 2700            | 4.3                 | 40                      | 6495              | 61         | First et al. (1990) |
| FIRST        | I   | 1400            | 0.083               | 1                       | 81117             | 1.5        | White et al. (1998) |
| NVSS         | I   | 1400            | 0.75                | 2                       | 1773484           | 3.6        | Condon et al. (1998) |
| WB           | S   | 1400            | 10.0                | 100                     | 31524             | 60         | White & Becker (1992) |
| SUMSS        | I   | 843             | 0.75                | 8                       | 134870            | 1.8        | Mauch et al. (2003) |
| B2           | I   | 408             | 8.0                 | 250                     | 9929              | 72         | Colla et al. (1970; 1972; 1973) |
| B3           | I   | 408             | 5.0                 | 100                     | 13340             | 66         | Fanti et al. (1974) |
| MRC          | I   | 408             | 3.0                 | 700                     | 12141             | 73         | Douglas et al. (1996) |
| TXS          | I   | 365             | 0.1                 | 250                     | 66841             | 57         | Large et al. (1991) |
| WISH         | I   | 325             | 0.9                 | 10                      | 90357             | 8.4        | De Breuck et al. (2002) |
| WENSS        | I   | 325             | 0.9                 | 18                      | 229420            | 17         | Rengelink et al. (1997) |
| MIYUN        | I   | 232             | 3.8                 | 100                     | 34426             | 40         | Zhang et al. (1997) |
| 4C           | I   | 178             | 11.5                | 2000                    | 4844              | 53         | Pilkington & Scott (1965) |
| 3CR          | I   | 178             | 6.0                 | 5000                    | 327               | 31         | Bennet (1962) |
| 3C           | I   | 159             | 10.0                | 7000                    | 470               | 3.4        | Edge et al. (1959) |

1: S: single dish; I: interferometer
2: Percentage of sources with identified spectrum. Only unambiguous source names could be counted.

separately resulting in different spectral indices of sources belonging to the same object. In crowded fields with a high source density the cross-identification might not be unique and depends on the weight given to each source in the physical object. The resulting degeneracy in the cross-identification is solved by a self-consistency check of all physical objects found by SPECFIND (for details see Vollmer et al. 2005a). This procedure insures that a radio source cannot be associated to two different physical objects.

Once sources of new catalogues are added to the input of the SPECFIND cross-identification tool, sources in crowded fields can be redistributed among physical objects, former objects can disappear and new ones can be created. To insure the compatibility between the SPECFIND V1.0 and V2.0 catalogues, we developed a tool to check the coherence between these catalogues. This tool searches for (i) radio sources of SPECFIND V1.0 which are not found in V2.0 and (ii) radio sources of a physical object in SPECFIND V1.0 which are found in different physical objects in V2.0. The tool displays the V1.0 and V2.0 object lists together with the V1.0 and V2.0 spectra. As an additional step the user can display the NVSS 20 cm image within Aladin (Bonarel et al. 2000) together with the source positions and the beam sizes (angular resolution) (Fig. 5 – Fig. 9). This information allowed us to (i) merge both spectra, or to keep the (ii) V1.0 or (iii) V2.0 spectrum. In this way we visualized and modified about 1000 physical objects in the SPECFIND V2.0 catalogue.

This procedure also allowed us to detect complicated cases of the radio cross-identification. In the following we present the 5 major classes of physical objects that a user finds in the SPECFIND V2.0 catalogue: (i) well-behaved, (ii) extended, (iii) complex, (iv) physical double, and (v) unphysical double sources. Sources of class (ii)–(v) can be recognized by a spread of spectral indices $\alpha$ of the sources contained in a physical object which is larger than the uncertainty due to the flux density errors ($\Delta \alpha > 0.3$; Vollmer et al. 2005b). We decided to leave all these sources in the catalogue. We therefore caution the user against a blind use of the SPECFIND V2.0 catalogue. To help the user, we provide flags for sources which (i) have at least one neighboring NVSS source within a radius of 2 $'$ (possible confusion), (ii) have deconvolved sizes larger than 45  $''$ in the NVSS catalogue (extended sources), and (iii) are marked as complex in the NVSS catalogue.

4.1. Well-behaved sources

The vast majority of the SPECFIND V2.0 objects are well-behaved (Fig. 5), i.e. they are unresolved or marginally resolved in most of the surveys and exhibit consistent spectral indices for all sources (the uncertainty of the spectral index is $\pm 0.3$; Vollmer et al. 2005a). In the case of sources which are only present in one of the catalogues SPECFIND V1.0
Table 2. Additional SPECFIND V2.0 catalogue entries.

| catalog name | I/S | frequency (MHz) | resolution (arcmin) | \( S_{\text{min}} \) (mJy) | number of sources | percentage \(^2\) | Reference |
|--------------|-----|----------------|---------------------|-----------------|------------------|----------------|-----------|
| NEK I        | 31  | 12.0           | 2000                | 703             | 4                | Kassim (1988) |
| 8C I         | 38  | 4.5            | 700                 | 5859            | 66               | Hales et al. (1995) |
| CRJ2004 I    | 74  | 0.42           | 150                 | 949             | 63               | Cohen et al. (2004) |
| VLSS I       | 74  | 1.33           | 400                 | 68308           | 66               | Cohen et al. (2007) |
| TRC2006b I   | 74  | 0.5            | 0.3                 | 725             | 0.2              | Tasse et al. (2006) |
| Cula I       | 80  | 3.7            | 2000                | 2173            | 49               | Slee (1995) |
| 6C I         | 151 | 4.2            | 300                 | 27666           | 84               | Baldwin et al. (1985) |
| 7C I         | 151 | 1.17           | 200                 | 43683           | 77               | Hales et al. (2007) |
| Culb I       | 160 | 1.85           | 1000                | 2042            | 66               | Slee (1995) |
| TRB2007a I   | 240 | 0.25           | 6                   | 466             | 63               | Tasse et al. (2007) |
| TRC2006a I   | 325 | 0.12           | 2.5                 | 843             | 47               | Tasse et al. (2006) |
| WSTB90 I     | 327 | 1.5            | 3                   | 407             | Oort et al. (1988) |
| W93a I       | 327 | 1.0            | 1                   | 4157            | 32               | Wieringa (1993) |
| WSTB2 I      | 327 | 1.5            | 10                  | 309             | Righetti et al. (1988) |
| WSRTGP I     | 327 | 1.0            | 5                   | 3984            | 14               | Taylor et al. (1996) |
| PSRa I       | 400 | 1.0            | 0.1                 | 561             | 0.4              | Taylor et al. (1993) |
| 32P I        | 408 | 4.0            | 30                  | 494             | 61               | Leahy & Roger (1996) |
| 5C5 I        | 408 | 1.5            | 10                  | 214             | 60               | Pearson (1975) |
| 5C6 I        | 408 | 1.5            | 6                   | 267             | 68               | Pearson (1978) |
| 5C7 I        | 408 | 1.5            | 10                  | 235             | 41               | Pearson (1978) |
| 5C12 I       | 408 | 1.5            | 2                   | 308             | 70               | Benn et al. (1982) |
| 5C13 I       | 408 | 1.5            | 12                  | 233             | 60               | Benn (1995) |
| 51P I        | 408 | 4.0            | 80                  | 383             | 31               | Green & Riley (1995) |
| 5C12a I      | 408 | 1.33           | 5                   | 680             | 49               | Benn & Kenderdine (1991) |
| DRAOP I      | 408 | 3.5            | 5                   | 915             | 62               | Landecker & Caswell (1983) |
| CGPSEa I     | 408 | 3.0            | 10                  | 140             | 24               | Kerton et al. (2007) |
| PSRb I       | 600 | 1.0            | 0.4                 | 352             | 0.4              | Taylor et al. (1993) |
| W93b I       | 608 | 0.5            | 1                   | 1693            | 62               | Wieringa (1993) |
| TRB2007b I   | 610 | 0.11           | 1                   | 1037            | 35               | Tasse et al. (2007) |
| FLSGMRT I    | 610 | 0.1            | 0.1                 | 3944            | 1                | Garn et al. (2007) |
| NAIC S       | 611 | 12.6           | 350                 | 3122            | 45               | Durdin et al. (1975) |
| MOST I       | 843 | 0.733          | 40                  | 348             | 59               | Jones & McAdam (1992) |
| MGPS2 I      | 843 | 0.75           | 10                  | 48850           | 3                | Murphy et al. (2007) |
| ATESP I      | 1400| 0.23           | 0.3                 | 3370            | 1                | Wieringa & Ekers (2000) |
| PSRc I       | 1400| 1.0            | 0.1                 | 445             | 0.4              | Taylor et al. (1993) |
| OWH82 S      | 1400| 10.0           | 100                 | 457             | 63               | Owen et al. (1982) |
| GPSR I       | 1400| 0.083          | 5                   | 1992            | 11               | Zoonematkermani et al. (1990) |
| LO95 I       | 1400| 0.25           | 10                  | 375             | Ledlow & Owen (1995) |
| PDF I        | 1400| 0.15           | 0.1                 | 1079            | 0.1              | Hopkins et al. (1998) |
| VIRMOS I     | 1400| 0.1            | 1.1                 | 1103            | 4                | Bondi et al. (2003) |
| FH895a S     | 1400| 15.2           | 40                  | 192             | 45               | Filipovic et al. (1995) |
| WST32 I      | 1400| 1.2            | 10                  | 215             | 29               | Fanti et al. (1981) |
| 37W I        | 1400| 0.6            | 1                   | 53              | 28               | Walterbos et al. (1985) |
| ELAISR I     | 1400| 0.25           | 0.1                 | 965             | 1                | Ciliegi et al. (1999) |
| MG2004 I     | 1400| 0.23           | 0.03                | 1048            | 1                | Morganti et al. (2004) |
| WBIH2005 I   | 1400| 0.1            | 2                   | 6919            | 4                | White et al. (2005) |
| RRF1 S       | 1410| 9.4            | 100                 | 884             | Reich et al. (1990) |
| RRF S        | 1410| 9.4            | 80                  | 1830            | Reich et al. (1997) |
| QC93 S       | 1410| 10.0           | 400                 | 171             | 57               | Quiniento & Cersosimo (1993) |
| CH85 I       | 1411| 0.33           | 5                   | 208             | 9                | Coleman et al. (1985) |
| WSTB I       | 1412| 0.385          | 1                   | 536             | Windhorst et al. (1984) |
| WSTB1 I      | 1412| 0.385          | 1                   | 359             | Oort (1987) |

1: S: single dish; I: interferometer

2: Percentage of sources with identified spectrum. Only unambiguous source names could be counted.

3: This catalogue is a compilation of tables in 27 articles. Landecker & Caswell (1983) is the first reference.

or V2.0, we merged the spectra of all these well-behaved sources.

4.2. Extended sources

The second class of sources are those which are extended with respect to the mean resolution of the input catalogues which is \( \sim 1–2' \). An example for such a source is shown in...
Table 2. Additional SPECFIND V2.0 catalogue entries (continued).

| catalog name | I/S | frequency (MHz) | resolution (arcmin) | $S_{\text{min}}$ (mJy) | number of sources | percentage $^2$ | Reference |
|--------------|-----|----------------|---------------------|-------------------------|------------------|----------------|-----------|
| 33P          | I   | 1420           | 1.0                 | 3                       | 275              | 36             | Leahy & Roger (1996) |
| FBR2002 I    |     | 1420           | 1.633               | 3                       | 534              | 43             | Filipovic et al. (2002) |
| CGPSeb I     |     | 1420           | 1.0                 | 3                       | 140              | 27             | Kerton et al. (2007)   |
| RLM94 I      |     | 1465           | 0.075               | 5                       | 725              | 42             | Roettgering et al. (1994) |
| P82 I        |     | 1465           | 0.4                 | 200                     | 404              | 71             | Perley (1982)          |
| NEP I        |     | 1490           | 0.333               | 1                       | 2435             | 16             | Kollgaard et al. (1994)  |
| DC78 S       |     | 2370           | 2.7                 | 1                       | 858              | 29             | Dressel & Condon (1978) |
| FBR2002a S   |     | 2370           | 0.667               | 1                       | 697              | 33             | Filipovic et al. (2002) |
| FHW95b S     |     | 2450           | 8.85                | 3                       | 334              | 54             | Filipovic et al. (1995) |
| FORa S       |     | 2695           | 4.78                | 20                      | 221              | 81             | Forkert & Altschuler (1987) |
| RFS S        |     | 2695           | 4.9                 | 30                      | 1212             | 27             | Reich et al. (1984)    |
| RGB11 S      |     | 2700           | 4.3                 | 50                      | 697              | 50             | Reich et al. (2000)    |
| PBD2003 S    |     | 2700           | 8.0                 | 100                     | 1432             | 9              | Paladini et al. (2003) |
| KMP90 S      |     | 4750           | 2.8                 | 15                      | 752              | 85             | Kulkarni et al. (1990) |
| FORb S       |     | 4750           | 2.71                | 25                      | 227              | 85             | Forkert & Altschuler (1987) |
| FHW95c S     |     | 4750           | 4.8                 | 15                      | 368              | 53             | Filipovic et al. (1995) |
| NAIICGB S    |     | 4775           | 2.8                 | 8                       | 2453             | 65             | Lawrence et al. (1983) |
| A86 S        |     | 4760           | 2.8                 | 15                      | 882              | 74             | Altschuler (1986)      |
| FBR2002b I   |     | 4800           | 0.5                 | 1                       | 75               | 40             | Filipovic et al. (2002) |
| GDP S        |     | 4850           | 0.5                 | 0.3                     | 253              | 8              | Gregorini et al. (1994) |
| CAB95 S      |     | 4850           | 3.5                 | 25                      | 351              | 76             | Condon et al. (1995)  |
| JRB99 S      |     | 4860           | 0.03                | 1                       | 298              | 28             | Jackson et al. (1999) |
| FPD2001a S   |     | 4860           | 6.7e-3              | 1                       | 213              | 36             | Fanti et al. (2001)    |
| ADP79 S      |     | 4875           | 2.6                 | 100                     | 569              | 19             | Altenhoff et al. (1979) |
| Rgb S        |     | 4885           | 0.067               | 13                      | 1861             | 56             | Laurent-Muehleisen et al. (1997) |
| P82_2 I      |     | 4885           | 0.1                 | 200                     | 404              | 82             | Perley (1982)          |
| KR I         |     | 4890           | 0.07                | 10                      | 195              | 41             | Fich (1986)           |
| GPSR5 I      |     | 4900           | 0.067               | 1                       | 1286             | 3              | Becker et al. (1994)   |
| Slee I       |     | 4900           | 0.67                | 0.2                     | 177              | 21             | Slee et al. (1998)    |
| HCS79 S      |     | 5000           | 0.54                | 240                     | 702              | 3              | Haynes et al. (1979)   |
| RGB6 S       |     | 5000           | 2.4                 | 40                      | 729              | 56             | Reich et al. (2000)    |
| GPA2 S       |     | 8350           | 9.7                 | 900                     | 555              | 6              | Langston et al. (2000) |
| CLASS I      |     | 8400           | 5.5e-3              | 0.1                     | 21486            | 39             | Myers et al. (2003)    |
| FPD2001b S   |     | 8460           | 3.3e-3              | 0.2                     | 199              | 33             | Fanti et al. (2001)    |
| FHW95d S     |     | 8550           | 2.7                 | 20                      | 205              | 47             | Filipovic et al. (1995) |
| FBR2002c I   |     | 8640           | 0.27                | 1                       | 54               | 41             | Filipovic et al. (2002) |
| NK95 S       |     | 10550          | 1.15                | 3                       | 202              | 57             | Niklas et al. (1995)   |
| B3VLA S      |     | 10600          | 1.15                | 10                      | 981              | 80             | Gregorini et al. (1998) |
| RGB2 S       |     | 10700          | 1.2                 | 30                      | 698              | 53             | Reich et al. (2000)    |
| GPA1 S       |     | 14350          | 6.6                 | 2000                    | 365              | 7              | Langston et al. (2000) |
| 9C I         |     | 15000          | 0.42                | 25                      | 242              | 71             | Waldram et al. (2003)  |

$^1$: S: single dish; I: interferometer

$^2$: Percentage of sources with identified spectrum. Only unambiguous source names could be counted.

Fig. 6. At low frequencies these objects have radio fluxes from low resolution surveys in which the source is unresolved. However, at high frequencies the radio fluxes are provided by high resolution surveys. The source is thus resolved leading to a flux density which is smaller than the total flux density. The spectrum of the physical object has two different slopes: one which is fitted to the flux density of the unresolved sources and one which is fitted to the flux density of the resolved sources. In these cases the user has to verify the resolutions of the data points and to make a choice to which points he or she wants to fit a power law. Extended sources thus exhibit different spectral indices ($\Delta \alpha > 0.3$) within the same frequency range (between 100 MHz and 500 MHz in the example of Fig. 6).

4.3. Complex sources

Nearby large Galactic radio sources often display a complex structure (Fig. 7). In the presence of a sufficient number of observations at different frequencies the SPECFIND algorithm identifies power laws, but as for the extended sources, there are multiple spectral indices within the same frequency range (here between 100 MHz and 10 GHz). In the case of such complex sources the user has to carefully inspect all resolutions and, if necessary, all source extents in the original catalogues in VizieR.

4.4. Physical double sources

Since the typical resolution of the SPECFIND entry surveys is $\sim 2'$ (Table 2), radio sources which are separated by less than this distance will most frequently end up in one object in the SPECFIND catalogue (Fig. 8). There are ob-
4.5. Unphysical multiple sources

Other sources which are separated by less than 2′ are not physically related, i.e. the sources are only close in projection (Fig. 9). When these sources exhibit two largely different spectral indices, they can be separated easily with the help of the radio spectrum. If these source have about the same spectral index the user has to rely on the NVSS image.

5. Spectral breaks

As described in Vollmer et al. (2005a) the SPECFIND algorithm is able to detect a spectral break if enough data points at independent frequencies are available. Due to the increased number of input frequencies in the SPECFIND V2.0 catalogue, we could identify 18 sources which show a spectral break (Fig. 10). Since the frequency coverage of the input survey ranges between ~100 MHz and ~10 GHz,
the break is located in the middle of this interval around 1 GHz. These Giga Hertz Peaked Sources (GPS) are powerful (log $P_{1.4 \ GHz} > 25 \ W \ Hz^{-1}$) and compact (< 1 kpc) extragalactic radio sources, which show a convex radio spectrum peaking between 500 MHz and 10 GHz in the observer’s frame (for a review see O’Dea 1998). The physical mechanism responsible for the turnover of the spectrum is still unclear with two competing models proposed: the synchrotron self-absorption caused by dense plasma within the source or the free-free absorption caused by a screen external to the source. GPS sources are associated with either quasars or galaxies. All but one objects of Fig. 6 were already included in the SPECFIND V1.0 catalogue, but the limited frequency range often prevented the detection of the spectral break. Four objects are included in the GPS sample of Vollmer et al. (2008) which was based on SPECFIND V1.0 objects showing an inverted radio spectrum.
6. Accuracy of radio catalogues

The cross-identification realized for SPECFIND V2.0 allowed us to evaluate the accuracy in position and flux density of the 97 radio catalogues with respect to the NVSS source catalogue. We do not find significant systematic offset in position or flux densities between the entry catalogues (Table 2) and the NVSS catalogue.

7. Summary

We present the second release of the SPECFIND catalogue, SPECFIND V2.0, which is available at CDS’s VizieR. The catalogue contains 107488 cross-identified objects with at least three radio sources observed at three independent frequencies. The cross-identification algorithm is based on proximity, source extent, survey resolution, flux density at

http://vizier.u-strasbg.fr/viz-bin/VizieR
the same frequency, and power law spectra at different frequencies (Vollmer et al. 2005a). We increased the number of entry catalogues from 20 to 97 containing 115 tables (Table 2). This large increase was only made possible by the development of 4 tools at CDS which use the standards and infrastructure of the Virtual Observatory (VO). This was done in the framework of the VO-TECH Design Study. The first three tools described below are not specifically designed for radio data and can be used for other purposes. Together with the associated manuals they are available at http://eurovotech.org/twiki/bin/view/VOTech. These tools are:

1. TABFIND: discovery of relevant resources based on Unified Content Descriptors (see Sect. 2.1).
2. TABUNIF: Uniformisation of a heterogeneous set of catalogues (see Sect. 2.2).
3. CAMEA: Description of the catalogue data (see Sect. 2.3).
4. A SPECFIND-specific tool to insure the compatibility between two successive releases of the SPECFIND catalogue.

With a modest increase in the number of input sources (~ 8%) we could increase the number of cross-identified objects by ~ 60%. We decided not to remove extended and complex sources from SPECFIND V2.0 and therefore caution the user against a blind use of the catalogue. Typical source geometries and subsequent radio spectra are given in the same frequency, and power law spectra at different parts of the radio spectrum. The SPECFIND V2.0 sequence number from VizieR and the name of one of the radio sources are marked in each box.

Fig. 10. Radio objects with spectral breaks identified by SPECFIND. The different lines correspond to fits of different parts of the radio spectrum. The SPECFIND V2.0 objects by ∼ With a modest increase in the number of input sources, the user against a blind use of the catalogue. Typical source geometries and subsequent radio spectra are given in the same frequency, and power law spectra at different parts of the radio spectrum. The SPECFIND V2.0 sequence number from VizieR and the name of one of the radio sources are marked in each box.

Sect. [1]. Most frequently, the user can separate the underlying objects with the help of the SPECFIND radio spectrum and the NVSS image. Due to the larger frequency coverage of the SPECFIND entry catalogues with respect to that of the previous release spectral breaks are present in the SPECFIND V2.0 catalogue.

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References
Altenhoff, W.J., Downes, D., Pauls, T., Schraml, J. 1979, A&AS, 35, 23
Altschuler, D.R. 1986, A&AS, 65, 267
Baldwin, J.E., Boysen, R.C., Hales, S.E.G., et al. 1985, MNRAS, 217, 717
Becker R.H., White R.L., & Edwards A.L. 1991, ApJS, 75, 1
Becker, R.H., White, R.L., Helfand, D.J., Zoonemakerni, S. 1994, ApJS, 91, 347
Benn, C.R., Grueff, G., Vigotti, M., Wall, J.V. 1982, 200, 747
Benn, C.R., Kenderdine, S. 1991, MNRAS, 251, 253
Benn, C.R. 1995, MNRAS, 272, 699
Bennett A.S. 1962, MNRAS, 68, 163
Bennett C.L., Lawrence C.R., Burke B.F., Hewitt J.N., & Mahoney J. 1986, ApJS, 61, 1
Bondi, M., Ciliegi, P., Zamorani, G., et al. 2003, A&A, 403, 857
Bonmard, F., Fernique, P., Bienaymé, O., et al. 2000, A&AS, 143, 133
Browne I.W.A., Patnaik A.R., Wilkinson P.N., & Wrobel J.M. 1998, MNRAS, 293, 257
Ciliegi, P., McMahon, R.G., Miley, G., et al. 1999, MNRAS, 302, 222
Cohen, A.S., Rottgering, H.J.A., Jarvis, M.J., Kassim, N.E., Lazio, T.J.W. 2004, ApJS, 150, 47
Cohen, A.S., Lane, W.M., Cotton, W.D., et al. 2007, AJ, 134, 1245
Coleman, P.H., Condon, J.J., Hazard, C. 1985, AJ, 90, 1437
Colla G., Fanti C., Fanti R. et al. 1970, A&AS, 1, 281
Colla G., Fanti C., Fanti R. et al. 1972, A&AS, 7, 1
Colla G., Fanti C., Fanti R. et al. 1973, A&AS, 11, 291
Condon J.J., Anderson, E., Broderick, J.J. 1995, AJ, 109, 2318
Condon J.J., Cotton W.D., Greisen E.W. et al. 1998, AJ, 115, 1693
de Breuck C., Tang Y., de Bruyn A.G., Rottgering H., & van Breugel W. 2002, A&A, 394, 59
Derrière S., Gray, N., McDowell, J.C., et al. 2004, in: Astronomical Society of the Pacific Conference Proceedings, Vol. 314. San Francisco: Astronomical Society of the Pacific, 2004., p.315
Douglas J.N., Bash F.N., Bozyan F.A., Torrence G.W., & Wolfe C. 1996, AJ, 111, 1945
Dressel, L.L., Condon, J.J. 1978, ApJS, 36, 53
Durdin, J.M., Bash F.N., Bozyan F.A., Torrence G.W., & Wolfe C. 1996, AJ, 111, 1945
Edge D.O., Shakeshaft J.R., McAdam W.B., Baldwin J.E., & Archer S. 1959, MNRAS, 68, 37
Fanti C., Fanti R., Farra T., & Bridi L. 1974, A&AS, 18, 147
Fanti C., Mantovani, F., Tomasi, P. 1981, A&AS, 43, 1
Fanti C., Pozzi, F., Dallacasa, D., et al. 2001, A&AS, 369, 380
Ficarra A., Grueff G., & Tomassetti G. 1985, A&AS, 59, 255
Fich, M. 1986, AJ, 90, 1437
Fich, M. 1986, AJ, 90, 1437
Filipovic, M.D., Haynes, R.F., White, G.L., et al. 1995, A&AS, 111, 311
Filipovic, M.D., Bohlsen, T., Reid, W. et al. 2002, MNRAS, 335, 1085
Forkert, T., Altschuler, D.R. 1987, A&AS, 70, 77
Fürst E., Reich W., Reich P., & Reif K. 1990, A&AS, 85, 805
Garn, T., Green, D.A., Hales, S.E.G., Riley, J.M., Alexander, P. 2007, MNRAS, 376, 1251
Gower J.F.R., Scott P.F., & Wills D. 1965, MNRAS, 1967, 71, 49
Green, D.A., Riley, J.M. 1995, MNRAS, 274, 324
Gregorini, L., de Ruiter, H.R., Parma, P., et al. 1994, A&AS, 106, 1
Gregorini, L., Vigotti, M., Mack, K.-H., Zonnchen, J., Klein, U. 1998, A&AS, 133, 129
Gregory P.C. & Condon J.J. 1991, ApJS, 75, 1011
Gregory P.C., Scott W.K., Douglas K., & Condon J.J. 1996, ApJS, 103, 427
Griffith M., Langston G., Helfin M. et al. 1990, ApJS, 74, 129
Griffith M., Langston G., Helfin M., Conner S., & Burke B. 1991, ApJS, 75, 801
Griffith M.R., Wright A.E., Burke B.F., & Ekers R.D. 1994, ApJS, 90, 179
Griffith M.R., Wright A.E., Burke B.F., & Ekers R.D. 1995, ApJS, 97, 347
Hales, S.E.G., Baldwin, J.E., Warner, P.J. 1988, MNRAS, 234, 919
Griffith M.R., Wright A.E., Burke B.F., & Ekers R.D. 1994, ApJS, 103, 474
Hales, S.E.G., Masson, C.R., Warner, P.J., Baldwin, J.E. 1990, MNRAS, 246, 256
Hales, S.E.G., Mayer, C.J., Warner, P.J., Baldwin, J.E. 1991, MNRAS, 251, 46
Hales, S.E.G., Masson, C.R., Warner, P.J., Baldwin, J.E., Green, D.A. 1993, MNRAS, 262, 1057
Hales, S.E.G., Waldram, E.M., Rees, N., Warner, P.J. 1995, MNRAS, 274, 477
Hales, S.E.G., Riley, J.M., Waldram, E.M., Warner, P.J., Baldwin, J.E. 2007, MNRAS, 382, 1639
Haynes, R.F., Caswell, J.L., Simons, L.W.J. 1979, AuJPA, 48, 1
Hopkins, A.M., Mobasher, B., Cram, L., Rowan-Robinson, M. 1998, MNRAS, 296, 839
Jackson, N., Roland, J., Bremer, M., Rhee, G., Webb, J. 1999, A&AS, 143, 401
Jones, P.A., McAdam, W.B. 1992, 80, 137
Kassim, N.E. 1988, ApJS, 68, 137
Kerton, C.R., Murphy, J., Patterson, J. 2007, MNRAS, 379, 289
Kollgaard, R.L., Brinkmann W., McMath Chester M. et al. 1994, ApJS, 93, 145
Kulkarni, V.K., Mantovani, F., Pauliny-Toth, I.I.K. 1990, A&AS, 2, 41
Landecker, T.L. & Caswell, J.L. 1983, AJ, 88, 1810
Langston G.I., Heflin M.B., Conner S.R. et al. 1990, ApJS, 72, 621
Langston, G., Minter, A., D’Addario, L., et al. 2000, AJ, 119, 2801
Large M.I., Cram L.E., & Brugess A.M. 1991, The Observatory, 111, 72
Laurent-Mueheisen, S.A., Kollgaard, R.I., Ryan, P.J., et al. 1997, A&AS, 122, 235
Lawrence, C.R., Bennett, C.L., Garcia-Barreto, J.A., Greenfield, P.E., Burke, B.F. 1983, ApJS, 51, 67
Leahy, D.A., Roger, R.S. 1996, A&AS, 115, 345
Ledlow, M.J., Owen, F.N. 1995, AJ, 109, 853
Loys, M., Richards A., Bonnarel, F., et al. 2008, http://www.ivoa.net/Documents/latest/CharacterisationDM.html
Mauch, T., Murphy T., Buttery H.J. et al. 2003, MNRAS, 342, 1117
Morganti, R., Garrett, M.A., Chapman, S., et al. 2004, A&A, 424, 371
Murphy, T., Mauch, T., Green, A., et al. 2007, MNRAS, 382, 382
Myers, S.T., Jackson, N.J., Browne, I.W.A. et al. 2003, MNRAS, 341, 101
Niklas, S., Klein, U., Braine, J., Wielebinski, R. 1995, A&AS, 114, 21
Ochsenbein, F., Bauer, P., Marcout, J. 2000, A&AS, 143, 23
O’Dea, C.P. 1998, PASP, 110, 493
Oort, M.J.A. 1987, A&AS, 71, 221
Oort, M.J.A., Steemers, W.J.G., Windhorst, R.A. 1988, A&AS, 73, 103
Otrupcek R. & Wright A.E. 1991, PASAu, 9, 1700
Owen, F.N., White, R.A., Helfand, D.J., Hanisch, R.J. 1982, AJ, 87, 1083
Paladini, R., Burigana, C., Davies, R.D., et al. 2003, A&A, 397, 213
Patnaik A.R., Browne I.W.A., Wilkinson P.N., & Wrobel J.M. 1992, MNRAS, 254, 655
Pearson, T.J. 1978, MNRAS, 182, 273
Pearson, T.J. 1975, MNRAS, 171, 475
Perley, R.A. 1982, AJ, 87, 859
Pilkington J.D.H. & Scott P.F. 1965, MRAS, 69, 183
Quinniento, Z.M., Cersosimo, J.C. 1993, A&AS, 97, 435
Reich, W., Furst, E., Steffen, P., Reif, K., Haslam, C.G.T. 1984, A&AS, 58, 197
Reich, W., Reich, P., Furst, E. 1990, A&AS, 83, 539
Reich, P., Reich, W., Fuerst, E. 1997, A&AS, 126, 413
Reich, W., Fuerst, E., Reich, P., et al. 2000, A&A, 363, 141
Rengelink, R.B., Tang, Y., de Bruyn, A.G., et al. 1997, A&AS, 124, 259
Righetti, G., Giovannini, G., Feretti, L. 1988, A&AS, 74, 315
Roettgering, H.J.A., Lacy, M., Miley, G.K., Chambers, K.C., Saunders, R. 1994, A&AS, 108, 79
Slee, O.B. 1995, AuPh, 48, 143
Slee, O.B., Perley, R.A., Siegman, B.C. 1989, AuPh, 42, 633
Tasse, C., Cohen, A.S., Roettgering, H.J.A., et al. 2006, A&A, 456, 791
Tasse, C., Roettgering, H.J.A., Best, P.N., et al. 2007, A&A, 471, 1105
Taylor, J.H., Manchester, R.N., Lyne, A.G. 1993, ApJS, 88, 529
Taylor, A.R., Goss, W.M., Coleman, P.H., van Leeuwen, J., Wallace, B.J. 1996, ApJS, 107, 239
Vollmer, B., Dauvost, E., Dubois, P., et al. 2005a, A&A, 431, 1177
Vollmer, B., Dauvost, E., Dubois, P., et al. 2005b, A&A, 436, 757
Vollmer, B., Krichbaum, T.P., Angelakis, E., Kovalev, Y.Y. 2008, A&A, 489, 49
Waldram, E.M., Pooley, G.G., Grainge, K.J.B., et al. 2003, MNRAS, 342, 915
Walterbos, R.A.M., Brinks, E., Shane, W.W. 1985, A&AS, 61, 451
Wieringa, M.H. 1993, Bull. Inf. CDS 43, 17
Wieringa, M.H., Ekers, R.D. 2000, A&AS, 146, 41
White R.L., Becker R.H. 1992, ApJS, 79, 331
White R.L., Becker R.H., Helfand D.J., & Gregg M.D. 1998, ApJ, 475, 47
White, R.L., Becker, R.H., Helfand, D.J. 2005, AJ, 130, 586
Wilkinson P.N., Browne I.W.A., Patnaik A.R., Wrobel J.M., & Sorathia B. 1998, MNRAS, 300, 790
Windhorst, R.A., van Heerde, G.M., Katgert, P. 1984, A&AS, 58, 1
Wright, A.E., Griffith M.R., Burke B.F., & Ekers R.D. 1994, ApJS, 91, 111
Wright A.E., Griffith M.R., Hunt A.J. et al. 1996, ApJS, 103, 145
Zhang X., Zheng Y., Chen H. et al. 1997, A&AS, 121, 59
Zhang X., Reich W., Reich P., & Wielebinski R. 2003, A&AS, 404, 57
Zoonematkermani, S., Helfand, D.J., Becker, R.H., White, R.L., Perley, R.A. 1990, ApJS, 74, 181