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The Steep Spectrum Pulsar Population

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Abstract. We have sampled the population of compact ($\theta \leq 25''$) radio sources with spectral indices $1.5 \leq \alpha \leq 3.2$ (where $S_\nu \propto \nu^{-\alpha}$) using two large scale radio surveys. This yields a statistically useful sample of 74 radio sources with $S_{1.4\mathrm{GHz}} \geq 2.5$ mJy and $S_{365\mathrm{MHz}} \geq 200$ mJy. The majority of the sources appear to be extragalactic, resembling either high redshift radio galaxies or relic radio galaxies. However, six known pulsars were detected, as well as 16 sources of unknown nature that appear too small and have spectra too steep to be extragalactic. We are using VLBA, pulsar searching, optical/IR spectroscopy, and other techniques to definitively classify these sources. If any are new pulsars, they are potentially very interesting as they were missed by previous surveys.

Although many new pulsars have been found in recent years, almost all have been found as the result of standard period-dispersion searches. Such searches are limited in the parameter space they can explore. While appropriate for the majority of pulsars, they can miss pulsars that have unusually short periods, that are very highly dispersed, that are in very tight binary systems, or have very little intrinsic modulation (see *e.g.* Cordes & Chernoff 1997). We therefore attempted to use the enormous amount of information present in large-scale radio surveys to find pulsars that had been missed previously. We did this by selecting all sources in the 1.4 GHz NRAO VLA Sky Survey (NVSS; Condon *et al.* 1998) and the 365 MHz Texas survey (Douglas *et al.* 1996) with spectral index $\alpha \geq 1.5$ (where $S_\nu \propto \nu^{-\alpha}$). This is approximately the median spectral index for pulsars (Lorimer *et al.* 1995), but selects the 0.3% of general radio sources with the steepest spectra. We are above 90% complete for sources with $S_{365\mathrm{MHz}} \geq 250$ mJy, $1.5 \leq \alpha \leq 3.2$, $\theta \leq 25''$, and $-35.5° \leq \delta \leq 71.5°$. For sample details, see Kaplan *et al.* (2000) and Kaplan, Cordes, & Condon (2000).

Given the volume of sample space we wished to search, we believe that our criteria are reasonably good. Achieving a lower flux density limit would have meant sacrificing sky coverage. Relaxing the spectral index criterion would allow too many extragalactic sources into the sample. Applying additional criteria such as polarization, galactic latitude, or flux correlation could eliminate pulsars, given the range of observed properties (*e.g.* Xilouris *et al.* 1998 for polarization).

To futher classify the sources we obtained VLA A-array images at 1.4 GHz and 5 GHz, with resolutions of $1\farcs5$ and $0\farcs5$ respectively. These observations, along with data from other catalogs, allow us to classify sources based on radio

morphology and angular size. We found that of the 74 sources in the sample, 6 were known pulsars, 50 are clearly extragalactic, 2 have unknown morphologies, and 16 are unresolved (with $\theta \lesssim 0''.1$).

Of these sources, the ones of interest are the 6 known pulsars and the 16 unresolved sources. The unresolved sources appear superficially similar to the majority of the sources in the sample, in terms of their flux and spectral index distributions, their variability, and their galactic coordinates. However, their angular sizes do not agree with what one would expect for extragalactic sources of this nature (see O'Dea 1998). Sources with spectra this steep and sizes this small typically have spectral maxima at a few hundred MHz; using data from other surveys we see no evidence of spectral maxima for our sources, often down to frequencies of 100 MHz and below. These sources are therefore intriguing, and while the majority are probably not pulsars, a small number may be previously unknown pulsars. Regardless of number, all pulsars detected in this sample form a statistically homogeneous and useful sample, to which one can apply population analysis methods similar to those in Cordes & Chernoff (1997).

In order to definitely classify these sources we are pursuing additional observations with a variety of techniques and wavelengths. Optical/IR imaging of those sources with counterparts (only $\sim 50\%$; see Djorgovski *et al.* 2000) should allow us to determine spectroscopic redshifts, from which we could conclude whether the sources are extragalactic or not. We have also obtained but not yet reduced VLBA images of the most compact sources: if still unresolved by the VLBA the sources are almost certainly not extragalactic. Further observations, such as pulsar searches and improved radio spectra, are planned.

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