Gigahertz Peaked Spectrum (GPS) sources and Compact Symmetric Objects (CSO) are selected in very different ways, but have a significant overlap in properties. Ever since their discovery it has been speculated that they are young objects, but only recently, strong evidence has been provided indicating that GPS sources and CSOs are indeed the young counterparts of large, extended sources. They are therefore the objects of choice to study the initial evolution of extragalactic radio sources. Observational constraints on the luminosity evolution of young radio sources have mainly come from number density statistics and source size distributions, indicating that young sources should decrease in luminosity by a factor $\times 10$ as they evolve to extended objects. We argue that the growth or decay in radio power of the individual objects has a strong influence on the slope of their collective luminosity function. This has led to a new method of constraining the evolution of young sources by comparing their luminosity function to that of large extended objects. The luminosity function of GPS sources is shown to be flatter than that of extended objects. This is consistent with the proposed scenario that young sources increase in radio luminosity and large size radio sources decrease in luminosity with time, but larger homogeneous samples are needed. The new large area radio surveys and the current sensitivity and flexibility of VLBI networks allow the construction and investigation of such large and homogeneous samples of young sources.

1 Selection of Young Radio Sources: GPS versus CSO

The identification and investigation of the young counterparts of ‘old’ extended radio sources is a key element in the study of the evolution of radio-loud active galactic nuclei. Two classes of compact radio source, Gigahertz Peaked Spectrum (GPS) sources and Compact Symmetric Objects (CSO), are the most likely representatives of this early evolutionary phase. GPS sources are characterised by a convex shaped radio spectrum peaking at about 1 GHz in frequency [1], and are selected on the basis of interferometric or single dish flux density measurements at several (> 4) frequencies. CSOs are characterised by their small size (< 500 pc) and two-sided radio structure, e.g. having jets/lobes on both sides of a central core [2]. They are selected on their milli-arcsecond morphology, which require high resolution VLBI observations at, at least, 2 frequencies. Since CSO and GPS sources are selected in such different ways, studies of these objects have mostly been presented separately. However, a significant overlap between these two classes exists. GPS sources optically identified with galaxies are most likely to possess compact symmetric morphologies [3], and the large majority of CSOs exhibit a gigahertz-peaked spectrum. The large but not complete overlap between these two classes of sources is caused by the synchrotron self-absorbed mini-lobes, located at the extremities of most CSOs, being the main contributors to the overall radio spectrum, and producing the peak at about 1 GHz in frequency (fig [4]). Since orientation effects can influence both the observed radio morphology and the radio spectrum, the selection of an object as a CSO or GPS source depends on its viewing angle [4].
causes the overlap to be less than 100%. Furthermore, GPS sources optically identified with quasars are preferentially found to have core-jet morphologies \([3]\). The morphological dichotomy of GPS galaxies and quasars and their very different redshift distributions, make it unlikely that GPS galaxies and quasars are related by orientation; they may just happen to have similar radio spectra \([5]\).

The study of complete samples of young objects can constrain the evolution of radio sources, e.g. by using their number counts and source size distributions as function of flux density. The selection effects in these samples have to be understood to be able to compare these statistics with those for old, large size radio sources. Radio surveys at generally two frequencies are needed to select GPS candidates. In this process strong selection effects are evident in peak frequency and peak flux density. Furthermore, the boundary between a spectrum to be peaked or not-peaked, eg. its curvature, is drawn quite arbitrarily. Since the selection surveys and additional observations are most likely to have taken place at different epochs, variability may also play a role in the selection. The selection of a complete sample of CSOs needs at least VLBI surveys at two frequencies (eg. the Caltech-Jodrell Bank I&II Surveys \([6, 7]\)). Dependent on the resolution and dynamic range of the VLBI observations at all observing frequencies, strong selection effects are made on the overall angular size of the source, the contrast of the core to the approaching and receding sides of the source, and the spectral indices of the different components which are required to establish the two-sided nature of the radio morphology. For example, if observations with infinite dynamic range were possible, all compact core-jet sources could be classified as CSOs, since their counter-jets would be visible. In addition, VLBI surveys are mainly completed on samples of flat spectrum sources. In this way, a significant fraction of CSOs with steeper spectra may be missed.

It is relatively straightforward to select young radio sources on the basis of their gigahertz-peaked spectrum, while the selection on compact symmetric morphology is non trivial, in particular for very compact and/or faint sources. If a complete sample of young radio sources is required, selection on a gigahertz-peaked spectrum is therefore preferable, especially at fainter flux density levels. However, it is probably preferable to omit those optically identified with quasars, since their relation to young sources is doubtful. For the detailed analysis of individual objects, it is preferable to use confirmed CSOs, since the nature of their different components and possible orientation effects are better understood.
2 Evidence for GPS/CSO being young

Since the initial discovery of GPS sources, it has been speculated that these are young objects \[8, 9\]. However, a commonly discussed alternative to them being young was that they are small due to confinement by a particularly dense and clumpy interstellar medium that impedes the outward propagation of the jets \[10, 11\]. This latter hypothesis now looks less likely since recent observations show that the surrounding media of peaked spectrum sources are not significantly different from large scale radio sources, and insufficiently dense to confine these objects. More convincingly, the propagation velocities of the hot spots of several CSOs have now been measured to be $0.2 \, c \, \text{(12-14)}$, giving an apparent age of $10^3$ year and clearly showing that these are indeed young objects. Recent determinations of the radiative ages from the high frequency breaks GPS sources and the larger Compact Steep Spectrum (CSS) sources are found to be consistent with ages ranging from $10^3$ to $10^5$ years \[15\].

3 Current Views on Radio Source Evolution

Observational constraints on the luminosity evolution of radio sources mainly come from the source density in the power - linear size ($P-D$) diagram \[16\]. It was found that sources with large sizes ($D > 1$ Mpc) and high radio luminosities ($P > 10^{26}$ W/Hz at 178 MHz) are rare, suggesting that the luminosity of sources should decrease quickly with linear sizes approaching 1 Mpc. Several evolution scenarios have been proposed for young radio sources, in which GPS sources subsequently evolve to Compact Steep Spectrum (CSS) sources and large-scale doubles \[17-19\], and CSOs evolve in Medium Symmetric Objects (MSO), and Large Scale Objects (LSO) \[20\]. In these models, the age ratio of large scale to GPS, and LSO to CSO is typically $10^3$. The much larger fraction (say 10\%) of GPS and CSOs in radio surveys therefore implies that young radio sources have to substantially decrease (a factor $10$) in radio luminosity when evolving to large size radio sources. This can be explained by a decrease in radiation efficiency with source size \[18, 20\]. The transition from CSO to MSO does not have to occur at the same moment as the transition from GPS to CSS, and depends on the quite arbitrary definitions of the different classes of object, eg. A CSO can have such a low spectral peak frequency that it is actually defined as a CSS and not as a GPS source.

Several young radio sources (eg. 0108+388; \[21\]) exhibit low level, steep spectrum, extended emission on arcsecond scales, which seem to be relics of much older radio activity. These objects are generally classified as being intermittent or re-occurent, and not as young objects. However, the components related to their gigahertz-peaked spectra and CSO morphologies are certainly young, and we therefore believe it is correct to call them young objects. The presence of faint relic emission only indicates that the active nucleus has been active before, and may constrain the typical timescale and frequency of such an event. Based on the current knowledge of the formation of massive black-holes in the centers of galaxies (eg. \[22\]), it is unlikely that the central engine itself is young, but only the radio source.

It is unclear whether all young sources actually evolve to large extended objects. Some, or even the majority, may be short-lived phenomena due to a lack of significant fuel \[23\]. The possible existence of these objects can largely influence the source statistics of young radio sources, and their luminosity evolution.

4 GPS sources at faint flux densities

In addition to the GB6 \[24\] survey at 5 GHz, several new surveys have become available in recent years, like the WENSS at 325 MHz \[25\], and the NVSS \[26\] and FIRST \[27\] at 1.4 GHz. These surveys form a very powerful combination to select large and homogeneous samples of GPS candidates at faint flux density levels. The study of GPS samples at faint and bright flux density levels allow a disentanglement of redshift and radio luminosity effects. A small sample of 47 faint GPS sources has been investigated by our group, which was selected from first available areas of the WENSS survey \[28\]. The sample has been studied extensively in the optical to determine the nature and redshifts of the optical
identifications, resulting in an identification fraction of 87% [29]. About 40% of the sample consists of high redshift quasars (which we will further ignore). Only a few of the redshifts of GPS galaxies have been determined yet, due to their faint magnitudes and weak emission lines [5]. Fortunately their redshifts can be estimated due to their well established Hubble diagram [30]. Global VLBI observations at 5 GHz were obtained for all sources in the sample. In addition, observations at 1.6 and 15 GHz with the global array and the VLBA respectively were taken. In this way, 94% percent of the sources in the sample were observed at least at two frequencies, above and at or below their spectral peak [31].

The combination of this faint GPS sample, and bright GPS and CSS samples from the literature [3, 33] gave a unique opportunity to investigate the relation between spectral peak and size of young radio sources. Not surprisingly, the well-known correlation between peak frequency and angular size [33] was confirmed. However, in addition, a correlation was found between the peak flux density and angular size. Most remarkably, the strength and signs of these two correlations are exactly as expected for synchrotron self absorption (SSA). This strongly suggests that SSA is indeed the cause of the spectral turnovers in GPS and CSS sources, and not free-free absorption as recently proposed by [34].

The spectral peak originates in the dominant features of the radio source, the mini-lobes, and therefore reflects the sizes of the mini-lobes. The angular size from the VLBI observations is the overall size of the radio source, eg. the distance between the two mini-lobes. The correlations between the spectral peak and size therefore imply a linear correlation between the mini-lobes and overall sizes, meaning that during the evolution of young radio sources the ratio of the size of the mini-lobes and the distance between the two mini-lobes is constant. This suggests they evolve in a self-similar way.

5 Luminosity Evolution and the Luminosity Function

In flux density limited samples, GPS galaxies are found at higher redshifts than large size radio sources [31]. Since the lifetimes of radio sources are short compared to cosmological timescales, this can only mean that the slope of their luminosity functions are different, if GPS sources are to evolve to large size radio sources. We argue that the slope of the luminosity function is strongly dependent on the evolution in radio power of the individual sources. To explain the difference in redshift distribution, we propose a luminosity evolution scenario in which GPS sources increase in luminosity and large extended objects decrease in luminosity with time (Fig. 2). Sources in a volume-based sample are
biased towards low jet-powers and older ages, for populations of both GPS and extended objects. Low jet powers result in low luminosity sources. The higher the age of a large scale source the lower its luminosity, but the higher the age of a GPS source the higher its luminosity. This means that for a population of large scale sources the jet power and age biases strengthen each other resulting in a steep luminosity function, while they counteract for GPS sources, resulting in a flatter luminosity function. The evolution scenario proposed is expected for a ram-pressure confined radio source in a surrounding medium with a King profile density. In the inner parts of the King profile, the density of the medium is constant and the radio source builds up its luminosity, but after it grows large enough the density of the surrounding medium declines and the luminosity of the radio source decreases.

Triggered by the ideas above, a new method has been developed to constrain the luminosity evolution of radio sources by comparison of the local luminosity functions (LLF) of young and old objects. At present, an insufficient number of GPS sources are known at low redshift to construct an LLF directly. However, the cosmological number density evolution, as derived for steep spectrum (eg. large size) radio sources by [35], is used to derive a LLF for young radio sources from the GPS samples. The result, as is shown in Fig. 2 is consistent with the luminosity scenario as proposed above. Note however, that the faint and bright GPS samples were selected in different ways resulting in large uncertainties.

6 The Future and the Square Kilometer Array

The new large area radio surveys and the current sensitivity and flexibility of VLBI networks allow the construction and investigation of large and homogeneous samples of young sources. This is fueling the rapid development of this research area, with the exciting prospect this continuing to do so for the next few years at least. The total number of GPS sources in the WENSS survey selectable on the basis of their inverted spectra between 325 MHz and 1.6 GHz (NVSS), is likely to be on the order of \(2 \times 10^3\), from which about 100 - 200 can be identified with low redshift galaxies. This will allow a direct determination of the local luminosity function for young radio sources, down to a 5 GHz radio power of \(10^{24}\) W/Hz.

A strong impact on the research area of compact radio sources can be expected from the planned Square Kilometer Array (SKA), in particular if the configuration includes multi- \(10^3\) km baselines, or if it is added to ground and space VLBI networks. The unrivaled image quality provided by its quasi-continuous uv-coverage and its high sensitivity combined with m.a.s. resolution, promises to give new insights into the physics of (relativistic) jets (eg. Kirchbaum et al., this volume). The largest contribution of SKA to the statistical properties of young radio sources, as discussed in this paper, can be expected from its ability to select and investigate weak (\(P_{5\text{GHz}} < 10^{24}\) W/Hz) young radio sources out to much larger cosmological distances (\(z < 2\) instead of \(z < 0.2\)), allowing a detailed comparison of the cosmological number density evolution of young to that of old sources over a wide range of luminosity. This will put much stronger constraints on the luminosity evolution of the individual objects and it will provide new insights into the strong cosmological evolution of radio sources from high redshift to the present.

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