Faint Gigahertz Peaked Spectrum sources and the evolution of young radio sources

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Abstract

GPS sources are the objects of choice to study the initial evolution of extragalactic radio sources, since it is most likely that they are the young counterparts of large scale radio sources. Correlations found between their peak frequency, peak flux density and angular size provide strong evidence that synchrotron self absorption is the cause of the spectral turnovers, and indicate that young radio sources evolve in a self-similar way. The difference in redshift distribution between young and old radio sources must be due to a difference in slope of their luminosity functions, and we argue that this slope is strongly affected by the luminosity evolution of the individual sources. A luminosity evolution scenario is proposed in which GPS sources increase in luminosity and large scale radio sources decrease in luminosity with time. It is shown that such a scenario agrees with the local luminosity function of GPS galaxies.

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1 GPS versus CSO

Gigahertz Peaked Spectrum (GPS) sources optically identified with galaxies are most likely to possess compact symmetric radio morphologies (Stanghellini et al., 1997). In addition, the large majority of Compact Symmetric Objects (CSO) exhibit a gigahertz-peaked spectrum. The large but not complete overlap between these two classes of sources is caused by the synchrotron selfabsorbed 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. However, not all CSOs are GPS galaxies. If a CSO is oriented at a small angle to the line of sight, the contributions of the central core and fast-moving jet feeding the approaching mini-lobe become important, producing a flatish and variable spectrum (Snellen et al., 1998c). Observed at such a small viewing angle, the large contrast between the approaching and receding side of the radio source makes it also increasingly difficult to identify the object as a CSO, and explains why only a small fraction of CSOs are identified with quasars. GPS sources identified with quasars have (almost) similar radio spectral properties to GPS galaxies. However, it is unlikely that these high redshift objects are unified with GPS galaxies by orientation, and are probably unrelated (Snellen et al., 1998a,b).

CSO and GPS galaxies have recently been proposed (Fanti et al., 1995; Readhead et al., 1996) as the young counterparts of "old" FRI/FRII extended objects. The alternative hypothesis that GPS sources are themselves old and situated in particularly dense media seems unlikely, since their surrounding media are insufficiently dense to confine them (Fanti et al., 1995). Conclusive evidence that they are young has been given by Owsianik and collaborators (Owsianik & Conway, 1998) who measured the propagation velocity of the hot spots of several prototype GPS sources and CSOs to be $\sim 0.2c$, which implies dynamical ages of typically $\sim 10^3$ years.

Although research has always been concentrated on the question of whether GPS sources are young or old and situated in a dense medium, the recent breakthrough on this matter does not mean that the subject of GPS and CSOs is now closed. On the contrary, GPS sources and CSOs are the objects of choice to study the initial evolution of extragalactic radio sources.

2 A sample of faint GPS sources

It is relatively straightforward to select young radio sources on the basis of their GHz peaked spectrum. The disadvantage of this approach is that some sources with CSO morphology will be missed. However, for the very compact and/or faint radio sources in particular, it is virtually impossible with the current resolution and sensitivity of VLBI networks to establish whether they are CSOs, while it remains possible to determine their radio spectra.

Here we present results on a sample of relatively faint GPS sources selected from the Westerbork Northern Sky Survey (Rengelink et al., 1997) using additional observations with the WSRT and the VLA (Snellen et al., 1998d). It consists of 47 sources with peak frequencies between 500 MHz and 15 GHz, and peak flux densities ranging from $\sim$ 30 to $\sim$ 900 mJy. The combination of this new faint sample and existing brighter samples (Fanti et al., 1990; Stanghellini et al., 1998) allow for the first time the disentanglement of redshift and radio luminosity effects. 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 $\sim$ 87% (Snellen et al., 1998a), and redshifts for $\sim$ 19% of the sources (Snellen et al., 1998b). About 40% of the sample consists of high redshift quasars (which we will further ignore), a fraction comparable to that found in bright GPS samples. Only a few of the redshifts of GPS galaxies have been determined yet, due to their faint magnitudes and weak emission lines. Fortunately their redshifts can be estimated due to their well established Hubble diagram (Snellen et al., 1996). Global VLBI observations at 5 GHz were obtained for all sources in the sample. In addition, VLBA observations at 15 GHz were obtained for the sources with peak frequencies $\nu_p > 5$ GHz, and global VLBI observations at 1.6 GHz for sources with $\nu_p < 5$ GHz which were found to be extended at 5 GHz (Snellen et al., in prep.). The angular sizes of the GPS galaxies, measured as the distance between the two outermost components or the deconvolved FWHM for a single component source, were found to be between 0.5 and 33 mas, while the sizes of the GPS galaxies in the bright Stanghellini et al. (1998) sample range from 6 to 350 mas.

3 Morphological evolution of young radio sources

In addition to the correlation between peak frequency ν_p and angular size θ as found in the bright samples (the higher ν_p, the smaller θ, *e.g.* Fanti et al. 1990), we found a correlation between the peak flux density S_p and θ (the higher S_p, the larger θ). The strength of these correlations are as expected from Synchrotron Self Absorption (SSA) theory, in which $\theta^2 \propto S_p \nu_p^{-5/2}$, and therefore provide strong evidence that the spectral peak is indeed caused by SSA and not by free-free absorption, as proposed by Bicknell et al. (1997). The spectral peak mainly originates in the dominant features of the radio source, the mini-lobes, and therefore reflects the sizes of the mini-lobes. Note that θ is the overall size of the radio source, *e.g.* the distance between the two mini-lobes for the correlations discussed above. The correlations between ν_p, S_p and θ 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 minilobes is constant. This suggests they evolve in a self-similar way (Snellen, 1997).

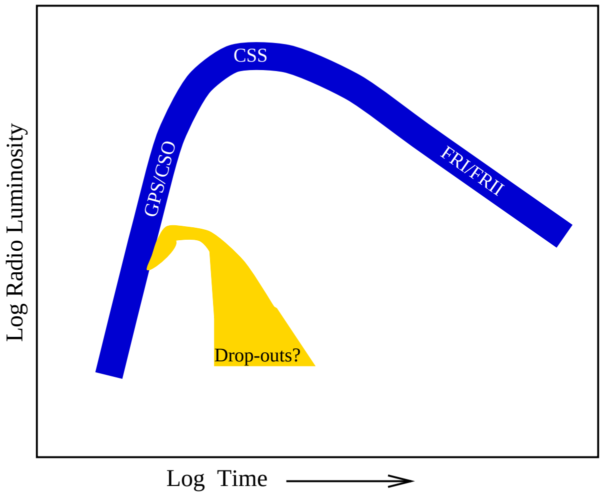

Fig. 1. The luminosity evolution proposed for extragalactic radio sources.

4 Luminosity evolution of young radio sources

The lifetimes of radio sources are short compared to cosmological timescales. The populations of young and old radio sources should therefore undergo identical cosmological evolution. However, in flux density limited samples, GPS galaxies are found at higher redshifts than large scale radio galaxies (e.g. Snellen 1997). This can only mean that the ratio between low and high luminosity sources is smaller (*e.g.* a flatter luminosity function) for the GPS galaxies than for large scale radio galaxies. We argue that the slope of the luminosity function is strongly dependent on the luminosity evolution of the individual sources, and propose an evolution scenario in which radio sources in their GPS phase increase in luminosity with time and decrease in luminosity when they become large scale radio sources (Fig. 1). Ignoring source to source variations in the surrounding media, their luminosities are only dependent on age and jet power. Sources in a volume-based sample are biased towards low jet-powers and older ages, for populations of both GPS and large scale sources. 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 luminosity evolution 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 sources 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. A very simple model of such a kind was presented by Snellen (1997), but much more sophisticated models have been constructed by Kaiser et al. (1997).

Comparison of the local luminosity function (LLF) of young and old radio sources can put strong constraints on the rise and decay of the radio luminosity, the age ratio between the old and young sources, and the percentage of 'drop-outs', young sources which are short lived and will never end up as large scale radio sources (figure 1). Unfortunately, because GPS sources are biased towards high redshifts, only a handful of young sources are known at $z < 0.2$, insufficient to construct a LLF. However, the cosmological evolution of the radio luminosity function of large scale radio sources is more or less known (Dunlop & Peacock, 1990), and we can assume that young radio sources undergo an identical cosmological evolution. In this way, all the sources in the faint and bright GPS samples can be used to construct a LLF of young radio sources. The exact redshift of each source is not important, because the 'luminosity-evolution' of the radio luminosity function counteracts the redshift dimming; sources with a similar flux density, located between $0.5 < z < 1.5$, contribute to the same luminosity bin. The combination of the faint and bright samples has to be done with great care, since they are selected in different ways (on the optically thick and thin part of their spectrum respectively), and therefore different selection effects play a role (Snellen et al., in prep.) The resulting LLF is shown in Fig. 2. The dotted line indicates a

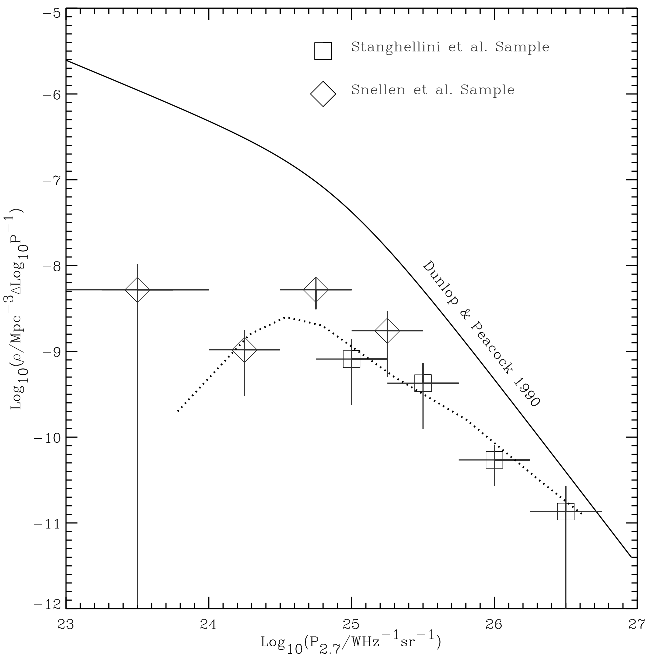

Fig. 2. The Local Luminosity Function (LLF) for GPS galaxies. The dotted line indicates the LLF for GPS galaxies, as expected for a population of radio sources undergoing the rise and decay in luminosity as described in this paper.

simulation of the LLF for GPS galaxies, assuming that a population of radio sources undergoes the rise and decay in luminosity as described above, and has a power law distribution of jet powers. Their luminosities and number counts were scaled in such way that the LLF of large radio sources matches the LLF of FRI/FRII as presented by Dunlop & Peacock (1990). Although the uncertainties on the data points are large and several free parameters enter the simulation, it shows that the shape of the LLF of GPS sources is as expected, and that large and homogeneously defined samples of GPS sources can constrain the luminosity evolution of extragalactic radio sources.

Acknowledgments

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