

Steep-spectrum sources and the duty cycle of the radio emission

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It is currently accepted that intrinsically compact and bright radio sources characterized by a convex spectrum peaking at frequencies ranging from 100 MHz to a few GHz are young objects. Following the evolutionary models, these objects would evolve into the population of classical radio galaxies. However, the fraction of young radio sources in flux density-limited samples is much larger than expected from the number counts of large radio sources. This may suggest that for some reason a significant fraction of young objects never become large radio galaxies with sizes up to a few Mpc. The discovery of the young radio source PKS 1518+047 characterized by an uncommonly steep spectrum confirms that the radio emission may switch off shortly after its onset. Then the source spectrum steepens and evolves due to energy losses. If the interruption is not temporary, the fate of the fading sources is to disappear at frequencies lower than those explored by current radio telescopes. Fossils of past activities has been recently found at pc-scale distances from newly born radio sources, suggesting the presence of short-lived objects with an intermittent radio emission.

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1. Introduction

Powerful ($L_{1.4\text{GHz}} > 10^{25}$ W/Hz) and intrinsically compact ($< 1''$) extragalactic radio sources represent a large fraction (15–30%) of the radio sources selected in flux-limited catalogues. Their main characteristic is the steep synchrotron spectrum that turns over at frequencies between 100 MHz and a few GHz, and is interpreted as due to synchrotron-self absorption [16, 22], although an additional contribution from free-free absorption (FFA) has been found in the most compact sources [7, 13]. When observed with sub-arcsecond resolution these sources usually display a two-sided morphology with a weak core, jets and mini-lobes/hotspots, and for this reason they were termed compact symmetric objects (CSO) by [23]. Given their intrinsically compact size and their morphology resembling a scaled-down version of the classical powerful FR II [3] radio galaxies, CSOs have been interpreted as representing an early stage in the radio source evolution. Decisive support to this scenario came from the determination of both kinematic [20] and radiative [14] ages of about 10^3 – 10^4 years, i.e. much smaller than the ages (10^7 – 10^8 years) estimated for classical radio galaxies with linear sizes up to a few Mpc [11].

In this context, it is possible to draw an evolutionary path in which CSOs are the precursors of extended radio galaxies [19]. Several evolutionary models [4, 22] have been developed aiming at describing how the physical properties, like luminosity and expansion velocity change as the radio source grows. However, many aspects, like the excess of young radio sources in flux-limited catalogues are not reproduced by the current models and additional explanations must be found.

2. Fading objects

A decrease in the radio luminosity as the source grows is required by the high fraction of young radio sources in the catalogues. The expected number of young objects may be determined roughly from the ratio of their typical age and the average age of the extended sources if luminosity does not change during the source growth. The fraction of young objects derived in this way is a few orders of magnitude lower than what found from the source counts. However, in the evolutionary models the luminosity is expected to decrease by about one order of magnitude as the source grows from a few kpc up to Mpc scale [4]. However, this is again not enough to reproduce the source counts.

A possible explanation for this discrepancy has been suggested by the distribution of the CSOs ages which peaks around 500 years [6], indicating that a significant fraction of young objects may be short-lived, never becoming extended radio sources [10]. However, fading radio sources are very difficult to find due to their very steep radio spectrum that makes them under-represented in source catalogues. Indeed, only a few objects have been suggested as faders so far, based on the absence of active regions [8, 9], and the distribution of spectral index found steep across the whole source, like in the case of PKS 1518+047 [17].

3. The case of PKS 1518+047

The radio source PKS 1518+047 is a rare gem among young radio sources. It is a powerful

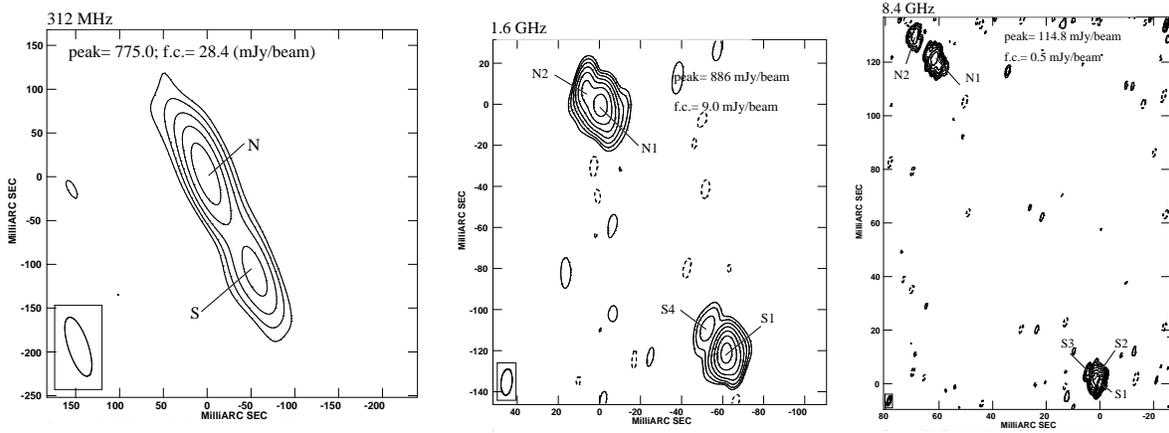


Figure 1: VLBA images at 312 MHz (*left*), 1.6 GHz (*center*), and 8.4 GHz (*right*) of the fading radio source PKS 1518+047. The first contour (f.c.) level corresponds to 3 times the 1σ noise level measured on the image. Contour levels increase by a factor 2. Adapted from [17].

($L_{1.4\text{GHz}} = 10^{28.5}$ W/Hz) radio source 1.1 kpc in size (Fig. 1), and hosted by a quasar at $z = 1.296$. Its radio spectrum peaks at 1 GHz and in the optically-thin regime is uncommonly steep ($\alpha_{4.8}^{8.4} = 1.2$, $S \propto \nu^{-\alpha}$).

To understand the physical properties of this source we carried out VLBA observations at 312, 611 and 1400/1600 MHz, and we made use of archival VLBA data at 4.8 and 8.4 GHz to constrain both the optically-thick and -thin part of the spectrum (a detailed discussion on observations and data reduction can be found in [17]).

The pc-scale resolution provided by the 312-MHz VLBA data allowed us to resolve the source structure into two main components roughly in the north-south direction. Both components are then further resolved in several sub-components with VLBA observations at higher frequencies (Fig. 1). The peculiarity of this source is that both the northern and southern complexes are characterized by steep spectral indices $\alpha = 1.0 - 1.5$, indicating that no active regions, like conventional jet knots and hotspots, are present. Strong support to the fading scenario arises from the analysis of the synchrotron spectrum where injection models fail in reproducing the spectral shape. Only models in which no particle supply is taking place provide a good fit to the spectrum (Fig. 2). From the break frequency, and assuming the equipartition magnetic field, we compute the radiative source age that results to be 2700 ± 600 years. On the other hand, from the best fit to spectrum we find that the time spent by the source in the “fader” phase should represent 20% ($t_{\text{OFF}} = 550 \pm 100$ years) of the whole source lifetime, indicating that the radio emission switched off shortly after its onset, and only electrons with $\gamma < 600$ are still radiating [17]. If the interruption of the radio activity is a temporary phase and the radio emission from the central engine will restart soon, it is possible that the source will appear again as a young radio source, perhaps with the relics of this previous activity visible at low frequencies. If this does not happen, the fate of this radio source is to emit at lower and lower frequencies, until it disappears below the frequencies explored by current radio telescopes.

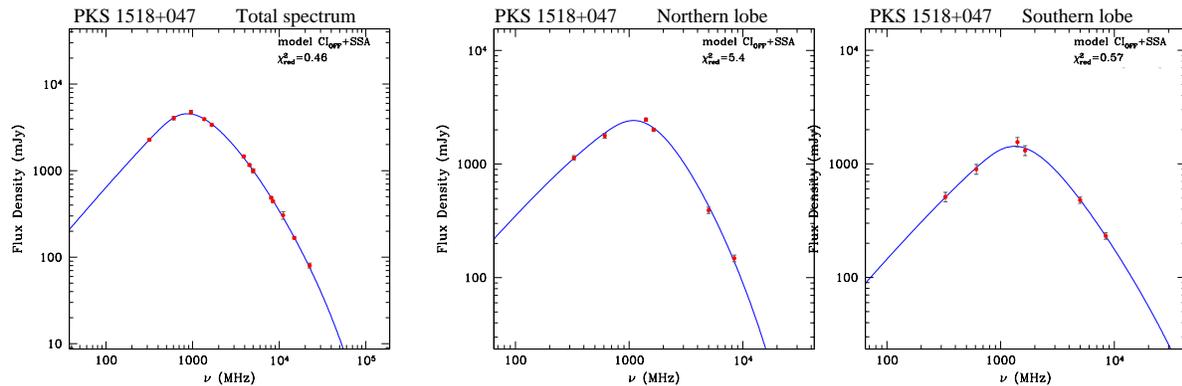


Figure 2: The best fit to the overall spectrum of PKS 1518+047 (*left*), and to the spectra of the northern (*center*) and southern (*right*) components, obtained using a synchrotron model in which the time spent in the “fader mode” is about 20% of the total source age. Adapted from [17].

4. Recurrent activity?

The discovery of fading objects among the population of young radio sources may provide an interesting explanation for the excess of the source counts. The presence of a population of short-lived objects related to an intermittent activity of the central engine has been recently postulated by [2] as due to radiation pressure instability in the accretion disk.

The idea that the radio emission may be a recurrent phenomenon was suggested by [1] after discovering in the radio galaxy J0111+3906 an off-axis diffuse steep-spectrum emission at about 60 kpc away from the newly born ($t_{\text{age}} \sim 370$ years, [18]), compact (22 pc in size) structure. In this source the low-surface brightness feature is likely the reminiscence of a past activity that must have lasted about 10^{7-8} years in order to reach a distance of 60 kpc from the source core. Recently, fossils of previous activity at parsec-scale distance from the reborn source have been found in the two very young ($\leq 10^3$ years) radio galaxies OQ 208 [12], and J1511+0518 [16]. Extended features located at pc-scale distances from the central object may be the relic of a far more recent previous activity that occurred about 10^3 - 10^4 years ago, suggesting that at the beginning of the radio activity several subsequent short bursts may take place before the development of large radio sources [16].

5. A sample of short-lived candidates

So far there are not statistically complete samples of short-lived objects given their difficulty to be picked up in conventional flux-limited radio catalogues. Furthermore, to unambiguously identify a radio source as a short-lived object it is necessary to know the spectral index distribution across the whole source in order to be sure that no active regions are still present.

With the aim of determining the incidence of short-lived objects we selected a sub-sample of candidate fading objects from the B3-VLA CSS complete sample [5] which comprises objects with linear size (and thus ages) from 100 pc (10^3 years) and 10 kpc (10^5 years). As short-lived candidates we selected those sources with an optically-thin spectrum steeper than $\alpha > 1$, and without

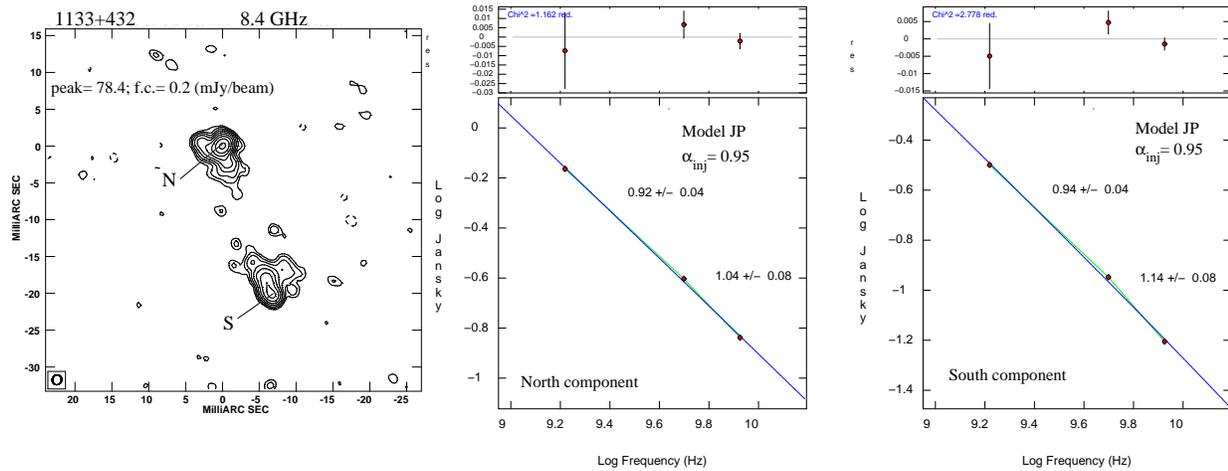


Figure 3: The radio source B1133+432 has an example of a short-lived candidate. The preliminary spectral analysis does not point out the presence of active galaxies, like hotspots, since the spectral index is found steep across the entire source. Adapted from [15].

evidence of active regions from previous multi-frequency works [15, 21]. We ended up with 18 sources: 9 with a linear size (LS) larger than 1 kpc, and 9 with $LS < 1$ kpc.

In order to reliably constrain the spectral index distribution across the source structure, and thus to be sure about the absence of any active regions, we are analysing archival multifrequency VLA data, for the sources with $LS > 1$ kpc, and VLBA data for those with $LS < 1$ kpc. For 5 sources among the most compact ones lacking high frequency data, we obtained new 8.4 GHz VLBA observations to complement the frequency coverage. A preliminary analysis of the compact radio source B1133+432 has not pointed out any region with flattish spectral index (Fig. 3), suggesting that we are dealing with a genuine fading short-lived object. When the spectral information is obtained for all the sources we will have a complete sample made of genuine fading, steep-spectrum objects. Their fraction will then be compared with the radio sources in the B3-VLA CSS sample in order to have a clearer picture on the incidence of genuine short-lived objects.

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