Looking for prematurely 'dying', young, compact radio sources

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Abstract. We present VLBA 1.6, 5, 8.4 and 15 GHz observations of a new sample of weak, young, compact candidates for radio faders selected from the VLA FIRST survey. We claim that some, or even the majority of young sources, may be short-lived phenomena due to a lack of stable fuelling from the black hole and fade before evolving to large extended objects.

1. Introduction

The activity period for radio-loud AGNs (RLAGN) can last up to $\sim 10^8$ years (Alexander & Leahy, 1987; Liu et al., 1992) and, as their lobes are huge reservoirs of energy, even if the energy supply from the central engine to the hotspots and the lobes eventually cuts off, the radio sources are still observable for a substantial period of time. This so-called 'coasting phase' of the lobes of a RLAGN can last up to 10^8 yr (Komissarov & Gubanov, 1994; Slee et al., 2001) and preserves the information of past nuclear activity. As the source gradually fades out, its spectrum becomes steeper and steeper because of radiation and expansion losses. Objects possessing these features are sometimes termed 'faders'.

Many examples of diffuse radio emission have already been found in clusters of galaxies (see e.g. Dewdney et al., 1991; Harris et al., 1993; Giovannini et al., 1999; Govoni et al., 2001; Murgia et al., 2004) and this number is still increasing. These objects have been identified as radio relics taking the form of e.g. diffuse lobes without hotspots or radio 'haloes'. Cordey (1987) has also described the structure and properties of a double radio source B2 0924+30 as a possible relic radio galaxy. The projected linear size of the whole system is 1.7 Mpc which indicates that this source is a 'dying' giant radio galaxy (GRG). A question that naturally arises is whether activity periods can be shorter than for those in GRGs.

Readhead et al. (1996) proposed an evolutionary scheme unifying three classes of objects: Compact Symmetric Objects (CSOs), Compact Steep Spectrum sources (CSSs) and Large Symmetric Objects (LSOs). One of the main arguments in favour of this hypothesis is that CSOs and some CSS sources, namely Medium-sized Symmetric Objects (MSOs), which are unbeamed CSSs, have similar morphologies to LSOs. Snellen et al. (1999, 2000) discussed many aspects of the above scenario in detail. In particular they concluded that the radio luminosities of CSO objects increase as they evolve, reach a maximum in the CSS/MSO phase and then gradually decrease as these objects grow further to become LSOs. Marecki et al. (2003b) claim that this evolutionary track is not the only one possible. In fact, a whole family (a continuum?) of such tracks might exist and the one shown by Snellen et al. (1999, 2000) just *appears* as the only one, simply because of selection effects. If the energy supply cuts off earlier, the object leaves that 'main sequence' proposed by Snellen et al. (1999, 2000) and it will never reach the LSO stage (at least in that phase of activity). Thus, there should exist a class of small-scale objects that resemble large-scale faders.

Strong support for such an idea comes from Reynolds & Begelman (1997). They proposed a model in which extragalactic radio sources are intermittent on timescales of $\sim 10^4 - 10^5$ years. When the power supply cuts off, the radio source fades rapidly in radio luminosity. However, the shocked matter continues to expand supersonically and keeps the basic source structure intact. This model predicts that there should be a large number of weaker MSOs than those known so far because of the power cut-off. The findings of Reynolds & Begelman (1997) and Marecki et al. (2003b) clearly suggest that compact faders may exist. The main goal of our observations has therefore been the study of the evolution of RLAGNs and the location of *weak* CSSs in the evolutionary scheme of radio sources.

2. The observations

Using the VLA FIRST catalogue we have selected a sample of 60 candidates which could be weak Compact Steep Spectrum sources. The selection criteria have been given by Kunert et al. (2002). All the sources were initially observed with MERLIN at 5 GHz. The results of these observations led to the selection of several groups of objects for further study with VLBI (Marecki et al., 2003a). One of those groups contains 6 sources (see Table 1) that have been completely unresolved by MERLIN at 5 GHz but still have very steep ($\alpha \leq -0.7$) spectra between 1.6 and 5 GHz. We think that the nature of such sources can be explained using the theoretical framework outlined in the previous section. If the main evolutionary sequence proposed by Snellen et al. (1999, 2000) is, as we claim not the only one, potentially every steep spectrum source, could be a candidate for a fader regardless of its size — i.e. even the most compact CSOs *could* be dying if they have plain steep spectra and not Gigahertz-Peaked Spectra as CSOs normally do.

Therefore, we decided to observe the 6 unresolved sources mentioned above with the VLBA at 1.6, 5, 8.4 and 15 GHz in a snapshot mode. In a first set of observations at 1.6 GHz, the Effelsberg telescope was included in the VLBA in order to improve the resolution at that relatively low frequency. The suc-

Table 1. Names and coordinates of target sources (J2000)

Source Name (1)	RA h m s (2)	DEC ° ′ ″ (3)
0809+404	08 12 53.124	40 18 59.878
0949+287	09 52 06.091	28 28 32.406
1159+395	12 01 49.965	39 19 11.023
1315+396	13 17 18.635	39 25 28.141
1502+291	15 04 26.696	28 54 30.548
1616+366	16 18 23.581	36 32 01.811

cessful outcome from these observations led to a second set of observations at the higher frequencies quoted above.

3. Results and comments on 0809+404

The whole data reduction process from the initial editing and calibration to the production of final images was carried out using AIPS. Flux densities of the principal components of the sources were measured using JMFIT and their spectral indices from 1.6 to 4.9 GHz, 4.9 to 8.4 GHz and 8.4 to 15.4 GHz were calculated. It is to be noted that only three sources were detected at 15.4 GHz.

In this paper, only the results for one of the 6 sources will be presented, namely for the galaxy 0809+404. The results of all the observations, which seem to indicate that there does exist a class of highly compact, but not necessarily core-dominated radio sources with steep spectra, will be presented in a forthcoming paper. Our VLBA maps of 0809+404, show it to have a double structure (Fig. 1). However, it is important to note that VLA observations at 4.86 and 8.46 GHz made by Fanti et al. (2001) also show a weak western component separated from the double structure by 1″.3. Both components of the double structure are fading away at the higher frequencies, so neither of them is a core. Eventually, at 15.4 GHz we have been unable to detect 0809+404 at all. Thus, the possibility this source might have a core-jet structure has been excluded. The spectral indices calculated between 1.6 and 4.9 GHz are very steep (Table 2), although it was not easy to assess them precisely because of a break-up of the structure. There is no indication of any hotspots. Therefore, in our opinion, 0809+404 is the **best example** of an **ultra-compact fader** so far.

4. Conclusions

VLBI maps for 0809+404, one of 6 highly compact yet steep spectrum objects, provide a compelling evidence that the activity of a RLAGN can cease almost at any stage of its evolution and the length of the active phase can span a few orders of magnitude. Such a possibility has been examined by Hatziminaoglou et al. (2001) and Janiuk et al. (2004). According to them, galaxies spend the greater part of their lifetime, say ~70%, in a 'quiescent' state and ~30% in an active state and with length of the active phase of an AGN as well as the timescale of the re-occurrence of activity being determined by the mass of the Supermassive Black Hole (SMBH).

Specifically, if the SMBH mass is assumed to be of the order of 10^7 $M_\odot$ — and such an assumption is plausible for RLAGNs (Woo et al., 2002; Oshlack et al., 2002) — the length of the activity period may be as low as $\sim 10^3$ years. This means the transition to the fader phase can also happen at a very early stage of evolution i.e. at the CSO stage. Our discovery of ultra-compact steep spectrum radio sources seems to be in an accordance with that model. Note also that such an interpretation is in agreement with an early hypothesis on the nature of CSOs given by Readhead et al. (1994). According to them, some, or even the majority of CSOs, may be short-lived phenomena because of a lack of stable, long-lasting fuelling.

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Table 2. Flux densities of 0809+404 principal components at observed frequencies

RA h m s (1)	DEC ° ′ ″ (2)	$S_{1.6GHz}$ mJy (3)	$S_{4.9GHz}$ mJy (4)	$\alpha_{1.6GHz}^{4.9GHz}$ (5)	$S_{8.4GHz}$ mJy (6)	$\alpha_{4.9GHz}^{8.4GHz}$ (7)
08 12 53.123	40 18 59.880	155.5	12.9	−2.25	6.7	−1.27
08 12 53.124	40 18 59.871	154.3	6.2	−2.92	5.3	−0.27
08 12 53.126	40 18 59.851	—	1.1	—	—	—
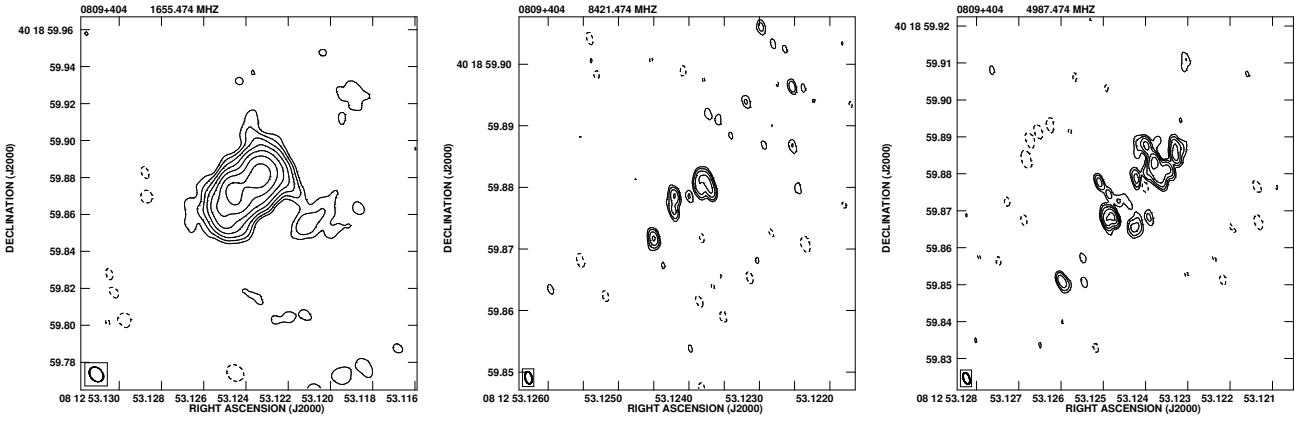
Fig. 1. VLBA+Effelsberg map of 0809+404 at 1.6 GHz and VLBA 5 and 8.4 GHz maps. Contours increase by a factor 2 and the first contour level corresponds to ≈ 3σ, which is 0.33 mJy/beam for 1.6 GHz map, 0.11 mJy/beam for 5 GHz map and 0.17 mJy/beam for 8.4 GHz map.