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Optically faint radio sources: reborn AGN?

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Abstract. We have discovered eight relatively strong radio sources that have no optical counterparts. A NIR follow-up has detected faint (17–20 mag) host galaxies in all targets. In general, the radio properties are similar to those observed in 3CRR sources but the optical-radio slopes are consistent with moderate to high redshift (z <4) GHz-peaked spectrum sources. Our results suggest that these are galaxies whose black hole has been recently re-ignited into activity but that retain large-scale radio structures, signatures of previous AGN activity.

Keywords. Galaxies: active

1. The Sources

The SDSS maxBCG cluster catalog (Koester *et al.* 2007) was used as the seed catalog for our study. We first cross-correlated the cluster sample with the FIRST radio catalog (White *et al.* 1997). We retained 291 cluster fields that contained at least one FIRST radio source within 1 Mpc in projection from the BCG.

During this process, we identified eight radio sources with no optical SDSS counterpart, indicating that $r_{\rm AB}$ >22 mag. Three of the sources, however, have been identified on Stripe 82 (with $r_{\rm AB}$-band magnitudes in the range 23–25 mag. The radio sources are further characterized by their radio-loudness (large radio-to-optical ratio), arcsec-scale FR II radio morphology, and relatively strong FIRST flux densities (1 mJy<$F_{1.4\,\rm GHz}$ < 80 mJy).

The unidentified radio sources were followed-up with NIR imaging using the wide-field imager HAWK-I. The HAWK-I observations were successful, as NIR emission, coincident with the centers of the radio structures and that we interpret as host-related emission, was detected in all the targets. The NIR magnitudes of these sources are in the range 17–20 mag (Vega system) and their NIR sizes are typically ∼1.5 arcsec (Fig. 1).

2. Results

Overall, if we focus on the radio properties alone, we may conclude that our optically faint radio sources appear similar to the radio sources found in the 3CRR catalog†, grazing the upper envelope of the 3CRR distribution in terms of radio morphology (Fig. 1), LLS, and (total) radio power (Fig. 2).

We have also explored the radio-to-optical SED, adopting a similar approach to Huynh *et al.* (2010). We have compared our sample data with a set of SED templates from the 3CR catalog (Spinrad 1985), a GPS sample (Labiano *et al.* 2007) and galaxies that span

† http://3crr.extragalactic.info/cgi/database

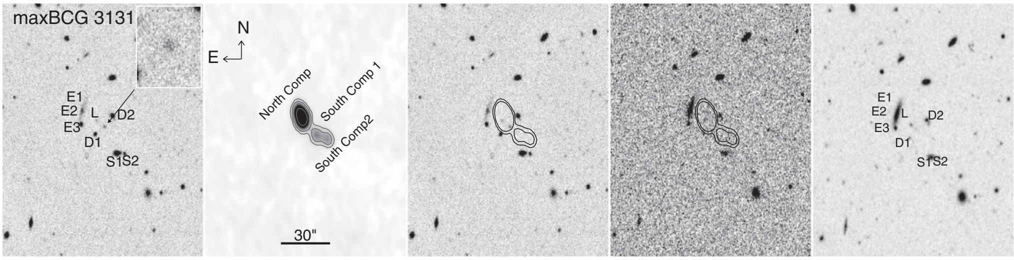

Figure 1. The radio source in the maxBCG cluster field 3131. From left o right: the NIR image, the FIRST image with radio contours, radio contours superimposed on the NIR, SDSS r_{AB}-band and Stripe 82 r_{AB}-band image. The arrow and inlay shows the position of the NIR host galaxy. Other designations refer to the radio components and secondary (unrelated) NIR/optical sources in the field.

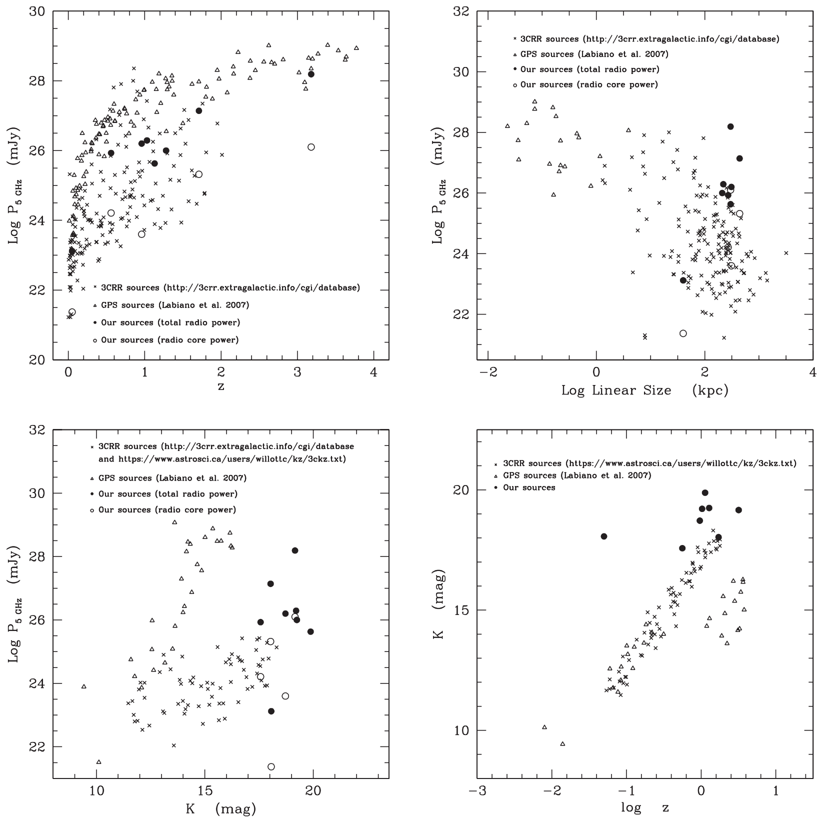

Figure 2. The redshift, 5 GHz radio power, the largest linear size (LLS), and K-band magnitude plots for the 3CRR (crosses), GPS (triangles), and our sample total radio (closed circles) and radio core (open circles) flux density.

a range of MIR galaxy classifications (Spoon *et al.* 2007): M82 a star-forming FR I, Arp 220 a Sy-type ULIRG, Mrk 231 a dusty AGN-dominated Sy 1 ULIRG, Mrk 1501 a Sy 1.2 flat-spectrum radio source, 3C 305 a Sy 2 FR I, Mrk 668 a Sy 1.5 GPS source, 3C 273 a radio-loud quasar, and 3C 295 a narrow-line FR II (Fig. 3).

Fig. 3 shows that viewed as a class, the radio-to-optical slope of our sample of sources are more consistent with those of ”young” (GPS) radio sources at z <4. Using Mrk 668 as a GPS template, we can obtain redshift estimates for our sample sources. We can

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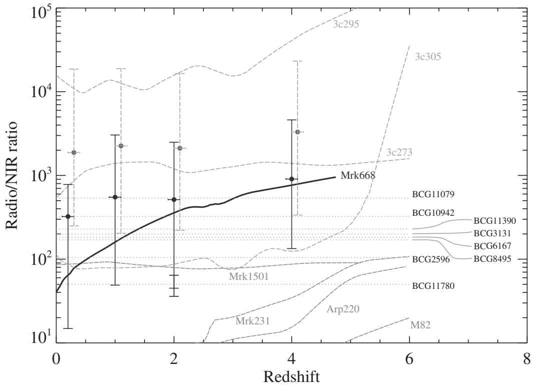

Figure 3. The radio-NIR ratio as a function of redshift for different galaxy templates (solid and dashed lines). The dotted lines are the radio-NIR ratios of our sample. The large dots are the median redshift values for the 3CR (dashed; Spinrad 1985) and GPS (solid; Labiano *et al.* 2007) sample sources, with a one σ errorbar.

Table 1. Redshift estimates.

maxBCG	$z_{\rm Mrk668}$	$z_{\rm Le Phare}$
2596	0.56	...
3131	1.03	$1.57^{+1.14}_{-0.43}$
6167	1.13	$1.00^{+3.81}_{-0.40}$
8495	0.96	$0.88^{+0.09}_{-0.08}$
10942	1.71	...
11079	3.18	...
11390	1.28	...
11780	0.05	...

also obtain an independent check by exploiting that three of the NIR sources have faint counterparts in the Stripe 82 images. By combining the Stripe 82 and NIR photometry, we have estimated photometric redshifts using the Le photometric redshift code (Arnouts *et al.* 1999; Ilbert *et al.* 2006; http://www.cfht.hawaii.edu). The resulting redshift estimates are in very good agreement (Table 1).

The way to reconcile the "young" radio source (GPS-type radio-optical slope) with the large-scale radio structure is to assume a "double-double" radio galaxy scenario (Schoenmakers *et al.* 2000a) of intermittent jets (Saikia & Jamrozy 2009), where our sample sources are recently re-ignited AGN, and the large-scale structure, a relic of a previous cycle of black hole activity.

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