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RCR J090511.74+045536.8 — a candidate for the most distant radio galaxies

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Abstract. Using modern radio, infrared and optical sky surveys, hosts have been found for the vast majority of radio sources detected by the Cold experiment and included in the RATAN Cold Refined (RCR) catalog. In this paper, we present details of the optical identification of one of the objects in the RCR catalog — a double radio source RCR J090511.74+045536.8. Initially, we matched it with the to SDSS J090511.94+045537.6, which we assumed to be a supernova that exploded in the host galaxy of the radio source. This hypothesis had to be abandoned, however, as to its properties the SDSS database indicated that it was an asteroid. Searching for the host galaxy of the radio source in deeper optical surveys allowed us to detect an object fainter than $r \approx 26^m$ at the expected location of the host relative to the radio source lobes. We cannot use the selection criteria for Lyman-Break Galaxies (LBG) due to the faintness of the host, but we can assume that the object can be classified as one of them, since it is detected in the r-filter and brighter in the i-filter, but is absent in other filters. Then its estimated host redshift may be greater than $z \gtrsim 4$–5, making it a candidate for the most distant radio galaxies.

Keywords: galaxies: active, high redshift

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1 Introduction

Radio sources detected in the surveys of the Cold experiment surveys (Parijskij & Korol'kov 1987) and included in the RC (RATAN Cold) catalog (Pariiski et al. 1991; Parijskij et al. 1993), have been studied in the optical regime since 1984 using observations at the 6-m BTA optical telescope and sky surveys. This was done first for the RC sources (Vitkovskij et al. 1987; Parijskij et al. 1996; Zhelenkova & Kopylov 2008, 2009) and then for the RCR catalog (Soboleva et al. 2010; Zhelenkova et al. 2017). Note that massive optical identifications of radio sources became possible with the advent of deep optical surveys and high-angular resolution radio surveys. Thus, the radio sources of the RCR catalog have been almost completely identified (96%) (Zhelenkova et al. 2013).

The double radio source RCR J090511.74+045536.8 has a steep spectral index of -1.05. According to the FIRST (Helfand et al. 2015), RACS (Hale et al. 2021) and VLASS (Gordon et al. 2021) surveys, the northern of the source is twice as bright as the southern. Therefore the host galaxy should be located twice as close to the northern component. Based on the relations ≪LAS–z≫ for radio galaxies (Fig. 3, Kapahi (1987)) and ≪z–r≫ for 3C radio galaxies (Snellen et al. 1996) and the angular size of the source LAS $= 25.3''$, we obtained a rough estimate of the redshift and apparent magnitude for this source of $z \approx 0.5$ and $r \approx 19.6^m$ respectively.

2 Find a counterpart for RCR J090511.74+045536.8

In the SDSS survey DR7 (Abazajian et al. 2009) there are two suitable candidates J090511.94+045537.6 and J090512.44+045536.4 for a host of the RCR source. In the Gaia DR3 catalog Gaia Collaboration et al. (2023), J090512.44+045536.4 has significant proper motion ($\mu = 8.139$ mas/year). In addition, the object is located closer to the faint component of the radio source. Therefore we do not consider it to be a host. We identified the double radio source RCR J090511.74+045536.8 with the SDSS J090511.94+045537.6. We also note that there are no objects in this position in the sections of the PanSTARRS survey (Chambers et al. 2016) in all filters. And the PanSTARRS observations in this region of the sky were made earlier than the SDSS observations (Table 1, Id1). We therefore hypothesized that the object could be a transient event, most likely a supernova that has erupted in the host galaxy. The object J090511.94+045537.6 has several SDSS flags (see https://www.astro.princeton.edu/~rhl/flags.html). The MOVED flag indicates that the object is a candidate for moving object exclusion. Despite its name, this does not mean that the object is actually moving. However, the DEBLENDED_AS_MOVING flag indicates that an object with the MOVED flag is considered to be moving by the

Table 1. Optical objects in different surveys as host candidates: number of rows — Id, surveys and filters with catalog objects — Survey, coordinates for epoch 2000.0 — RAJ and DecJ, magnitude — Mag, date of observation or realisation — Date.

Id	Survey	RAJ	DecJ	Mag	Date
1	PanSTARRS-r				2002-03-04
2	SDSS-g J090511.94+045537.6	09:05:11.85	+04:55:38.5	21.52	2002-05-03
3	SDSS-r J090511.94+045537.6	09:05:11.95	+04:55:37.6	20.88	2002-05-03
4	DESI-r J090511.63+045538.3	09:05:11.63	+04:55:38.3	23.57	2017-06-09
5	HSC-i candidate	09:05:12.02	+04:55:37.0	>26.3	2020-08-03

deblender. The creators of the SDSS survey have no doubt that Kuiper belt objects can be detected in the SDSS data. If it is an asteroid, then there is a shift of several arcseconds in the object between exposures in the r and g filters of the SDSS camera. For SDSS J090511.94+045537.6, using the coordinates measured from the brightest pixel in the r and g sections (Table 1, Id2–Id3), we obtained an offset of $\sim 2''$. This offset and the flags assigned to the object make it more likely to be considered an asteroid rather than a supernova.

The deeper DECaLS survey (Dey et al. 2019) was conducted later than the SDSS. Here, a faint galaxy (Table 1, Id4) with a photometric redshift $z = 0.69 \pm 0.48$ (Duncan 2022) appeared in the survey area. It is located closer to the northern component. Judging from the VLASS cutouts, the radio structure of the source cannot be classified as deformed. In the FIRST and RACS-mid cutouts, the source can be considered as S-shaped. The optical candidate is located far enough away from the expected host position. Therefore, it is unlikely to be considered as a parent galaxy.

Finally, in the survey of the Hyper Suprime-Cam Subaru DR3 (Aihara et al. 2022) (HSC) strategic programme, which is almost 3 magnitudes deeper than the SDSS, we found that at the location of the SDSS object there is nothing brighter than magnitude $r \approx 26^m$. In the vicinity of the host location suggested by the morphology of the radio source, five objects about $i \approx 26^m$ were detected. One of them (Table 1, Id5), in position relative to the lobes, is most likely an optical analogue of the source. In the r-filter cutout this object looks like a point object, but in the i-filter it is an elongated diffuse object as a pair of connected objects. Bright pixels at this location can be seen in the HSC z-filter and the J and H LAS UKIDSS (Lawrence et al. 2007) filters. This object is not in the PDR3 object catalog, where detection is carried out at the $S/N = 5\sigma$ level. We cannot use the selection criteria for LBGs due to the weakness of the candidate, but we can assume that the object can be classified as this type, since it is reliably detected in the r and i-filter, but is absent in other bands.

Then the estimate of its redshift can be higher than 4–5. Galactic extinction is not responsible for the weakness of the most likely host, and its apparent magnitude $r > 26^m$ indicates a higher redshift. Currently, the most distant known radio galaxy has a redshift of 5.72 (Saxena et al. 2018).

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