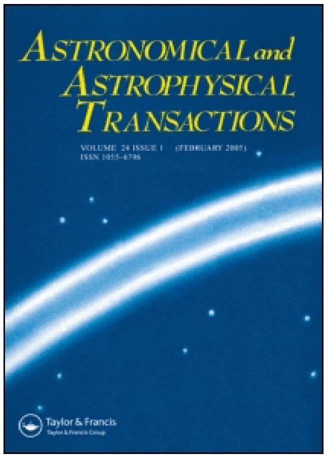

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RATAN-600–VLA–BTA-6m ('BIG TRIO') PROJECT: MULTICOLOR STUDY OF DISTANT FRII RADIO GALAXIES

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Powerful radio galaxies belong to the population of massive stellar systems that can be picked at high redshifts. With a measured redshift, morphology and age determination these objects can help greatly in understanding the way in which formation and evolution of giant elliptical galaxies with massive Black Holes occurred in the Early Universe.

We presents some recent results of a study of the sample of 105 faint steep spectrum radio sources from RATAN-600 RC catalog. All the objects have been mapped with the VLA and optical identification has been carried out with the 6 m BTA telescope. Using multicolor CCD photometry in B, V, R_c, I_c bands the photometric redshift and the age of the stellar population are estimated for a subsample of 50 FRII and CSS radio galaxies. RC J0105+0501 is a very probable candidate for a radio galaxy at $z \approx 3.5$.

The distribution of objects on colour–colour and magnitude–redshift diagrams shows a rough agreement with expectations of theoretical models of SED evolution for giant elliptical galaxies. On the $[m_R - z_{\rm phot}]$ diagram two populations of faint ($m_R = 22^{\rm m} - 24^{\rm m}$) radio galaxies are possibly revealed. The first population at $z \approx 1$ consists of mainly old (a half with age ≥ 5 Gyr) and large ($LAS \approx 20''$) objects, the second one at $z = 1.5$–3.5 includes both younger ($\lesssim 3$ Gyr) and smaller ($LAS \sim 5''$) objects.

There are 12 more faint or still undetected ($m_R \geq 24\overset{\rm m}{.}5$) sources in the sample which can presumably be very distant radio galaxies ($z > 3.5$) or intermediate redshift old or dusty ones.

KEY WORDS Radio galaxies, observations, multicolor photometry

Table 1. Sample of RC USS objects.

Parameter	*Range*	*Median*
$S_{3.9\mathrm{GHz}}$	15–350 mJy	67 mJy
$\alpha_{3.9}^{0.365}$	0.9–1.5	1.0
LAS	$\leq 0''.7$–$120''$	$10''$
m_r	18^m–$\geq 25^m$	$22^m.5$

1 INTRODUCTION

Radio galaxies of FRII type (FRII RGs) belong to the most powerful radio objects of the Universe and at least at low redshifts they are connected with the most massive galaxies with extremely massive ($\sim 10^9 M_\odot$) and energetic central engines. The evolution of this population and the giant Black Hole inside it is not well understood yet. Many groups are trying to check very different scenarios of stellar population evolution existing in the literature by observations.

It was realised recently that cm-wavelength 10–50 mJy flux density range is very interesting: FRII objects dominate here and at the same time they are rather bright yet to be observed optically. A suggested approach is to optimize the solution of the radio selection of the objects which were born at very high redshifts (HZ). The 'Big Trio' project incorporates the opportunities of three large telescopes (RATAN-600, VLA and BTA-6m) to realize a selection of the powerful radio galaxies between extremely deep 'pencil beam' very small field surveys (HST, VLA), where fields are smaller than the mean distance between HZ FRII RGs, and all sky surveys (NVSS, FIRST, SLOAN), where objects cannot be explored deeply ($R > 23$) using optical astronomy in the most interesting radio flux density range.

2 THE SAMPLE OF RC STEEP SPECTRUM OBJECTS

The 'Big Trio' project belongs to the deepest, ones in attempts to select the powerful FRII radio galaxies with ultra steep spectra (FRII USS RG) at the limiting flux density level below 3C, PKS, B2, GB samples of FRII USS objects.

RATAN-600 RC catalogue of 1145 radio sources in $\approx$ 200 sq. degrees strip (at DEC $\approx 5^\circ, 40'$ wide) with limiting flux density $S_{3.9\mathrm{GHz}} \approx 10mJy$ (Parijskij *et al.*, 1991; 1992) was used to select 105 USS objects ($\alpha \geq 0.9$) by cross-identification with a preliminary version (1988), kindly provided by Douglas prior to publication, of the 0.365 GHz Texas (UTRAO) catalog (Douglas *et al.*, 1996). All selected objects were mapped by VLA to determine precise coordinates, the largest angular size (LAS) and radio morphology and optically identified down to $m_R \leq 25^m$ by a 6 m Russian telescope (Goss *et al.*, 1992; Kopylov *et al.*, 1995a,b; Fletcher *et al.*, 1996; Parijskij *et al.*, 1996a,b; 1998). Also direct imaging data of 22 objects were obtained at (or near) a subarcsecond seeing with 2.56 m Nordic Optical Telescope at La Palma (Pursimo *et al.*, 1999). In Table 1 ranges and medians of main characteristics of objects of our USS sample are given.

There are 33 compact steep spectrum (CSS) objects in the sample of which 16 has $1'' < LAS < 4''$ and 17 are unresolved or barely resolved ($LAS < 1''$). 65 objects look like FRII and about 20 of them belong presumably to the most distant generation of RGs. 16 objects were classified as quasars by their stellar appearance on CCD images.

3 BVRI-PHOTOMETRY

The technique of multicolour photometry has became the main method in selecting candidates for distant galaxies in the past few years, and the only approach at very large redshifts. Determination of the age of HZ stellar systems may be the only way of estimating the redshift at the formation of the first galaxies if star formation begins at redshifts larger than z of secondary ionization. Direct observation of protogalaxies predicted by some recent computer simulations are not possible. It was shown (Verkhodanov *et al.*, 1999) that namely BVRI colours are sufficient for accurate estimation of z and age in the redshift range of 0.5–3.5.

We have implemented this approach for 50 FRII and CSS radio galaxies of the RC catalogue that had been observed in B, V, R_c, I_c bands during 1994–1998 with a CCD camera on a 6 m telescope. Our sample of USS radio galaxies is now the largest one with a four-band optical photometry. The data obtained were used to estimate colour photometric redshifts ($z_{\rm phot}$) and ages of host galaxies by comparison with two models of evolution of spectral energy distribution (SED) (Fioc and Rocca-Volmerange, 1997; Poggianti, 1997). A few typical cases were checked spectroscopically and the reality of the color z determination was confirmed (Dodonov *et al.*, 1999).

3.1 A High Redshift Radio Galaxy RC J0105+0501

As the best example of high redshift population of our sample we present the $S_{3.9\rm GHz} = 33$ mJy radio galaxy RC J0105+0501 ($m_V = 22\overset{\rm m}{.}5$ complex object at the center of four boxes on Figure 1), which shows the colour properties and the structure characteristic of very distant powerful radio galaxies. In the V band, the galaxy is most extended and is brighter by $1\overset{\rm m}{.}5$ than in the B band, which is interpreted almost unambiguously for the given class of objects as a powerful Lyα line emission and continuum depression in the adjacent region of shorter wavelengths. The negative colour index $V - R_c = -0.3$ and the small index $R_c - I_c = 0.4$ are in agreement with this interpretation of the data. The redshift is estimated to be 3.4 ± 0.3. (Only about 20 objects of this kind (RGs at $z > 3$) have been found so far by the joint efforts of different groups. The first, radio galaxy with $z > 3$ was discovered by Lilly (1988) and the current 'champion' has $z = 5.19$ (Van Breugel *et al.*, 1999).)

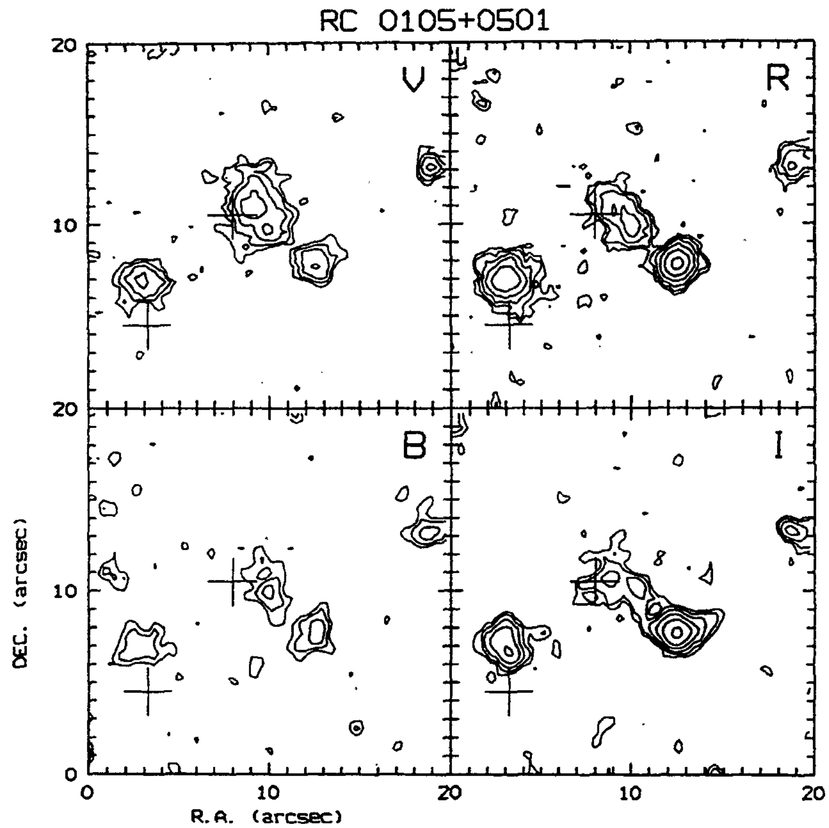

Figure 1 Contour maps in B, V, R_c, I_c bands of RC J0105+0501. Images with seeing $FWHM = 1''.4$ were obtained in August, 1998 with exposures of 600, 400, 400 and 2×400 s in B, V, R_c and I_c, respectively. The positions of two radio components are shown by pluses. North is up and East is to the left.

It can be seen that in the V-band the host galaxy is resolved into two components separated by $1''.7$. (The two brighter neighbouring galaxies, $\approx 4''$ to SW and $\approx 8''$ to SE, are likely to have nothing to do with the radio galaxy since the colour redshift for them is estimated to be about 1.) The SW-component is reliably detected on the B frame and may be an active nucleus of a radio galaxy. The second component may then be either a region of star formation induced by the jet or a gaseous cloud ionized by the radiation from the active nucleus or a combination of both. Other interpretations are also possible. For instance, the active nucleus may be identified with the NE-component or even coincide with the radio component without showing up in optics because of the strong absorption by dust. The necessity of more detailed study of this very fascinating object in the optical, IR and radio ranges for testing different hypotheses on the physics of the processes occurring in this first generation stellar system is evident.

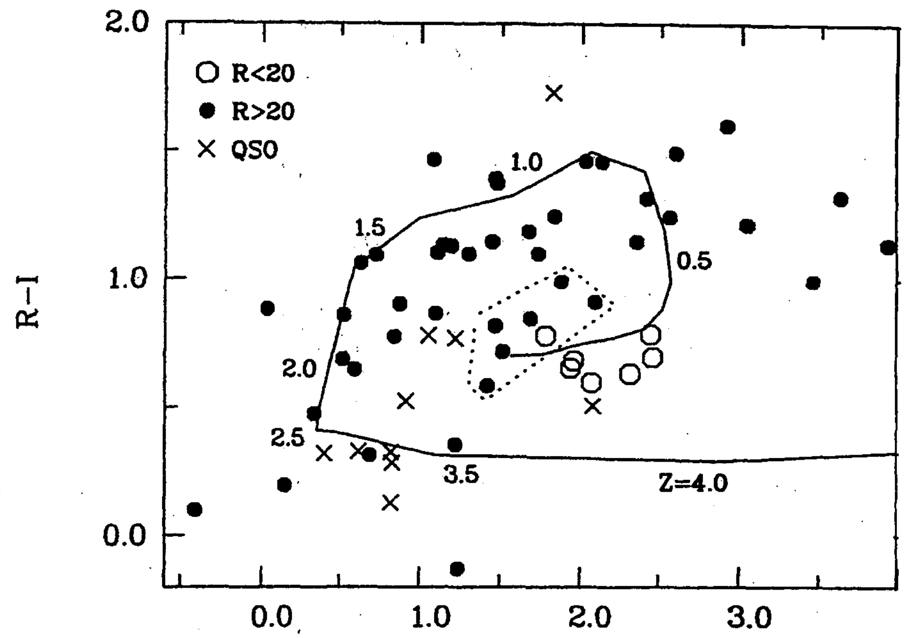

Figure 2 B–R_c – R_c–I_c diagram for 50 RGs (objects with $m_R < 20^m$ are shown by open circles and with $m_R > 20^m$ by closed circles) and 10 quasars (crosses). Galaxies with probable strong contribution of AGN light or young stellar population lie inside a dotted contour. The evolutionary track (with redshifts marked) of the PEGASE model of giant elliptical galaxy with $z_{\rm form} = 15$ and the present day age of 16 Gyr is shown for $H_0 = 50$ km s^{-1} Mpc^{-1} and $\Omega_0 = 0.1$ cosmology.

3.2 Colour–Colour Distribution

A two-colour distribution of RC-objects so far observed in comparison with the PEGASE evolutionary model of giant elliptical galaxy with a formation redshift $z_{\rm form} = 15$ and a present day age of 16 Gyr is given on Figure 2. There is a rough agreement between observations and a theoretical model taking into account typical errors in colours of $0^m\!.2$–$0^m\!.3$. These are larger for the 3 most red objects in B–R_c colour which were observed at the detection limit in the B-band. As for the 3 most blue objects in B–R_c a strong Lyα line emission in B-band could be suspected (and indeed conformed spectroscopically for one of them (Dodonov *et al.*, 1999)). A plausible explanation for several objects lying inside a dotted contour on Figure 2 may consist of a noticeable contribution of the active nucleus of galaxy or a mixture of young and old stellar populations is observed. In both cases a shift of $\approx 0^m\!.5$–$1^m\!.0$ in the upper-right direction may bring points to the location of the main stellar population of the host galaxy. The same effect could explain R_c–I_c colours of a group of points below the model curve near $z \sim 1$. Alternatively, a formation redshift, an underlying cosmological model or a stellar content of the SED model could be varied. All these considerations are by no means conclusive until spectroscopic measurement of redshifts is done. What could be affirmed now is that as a whole the sample of RC FRII USS objects follows the predictions of PEGASE in a redshift range of 0.2–3.5 and, not shown on Figure 2, Poggianti's models of SED evolution of giant elliptical galaxies formed at high redshifts.

4 MAGNITUDE–REDSHIFT DIAGRAM

A model of a passively evolving giant elliptical galaxy predicts a quite definite magnitude dependence on redshift if star formation in a galaxy begins at a rather early time. So a distribution of objects on, for example, a $[m_R - z_{\rm phot}]$ diagram can be considered as an indirect check of the accuracy of photometric redshift estimates for the sample as a whole taking into account that powerful radio sources live as a rule in luminous ($M_R \leq M^* \approx -22\overset{\rm m}{.}5$) elliptical galaxies (if there are no special problems with dust at high redshift, dispersion in $Z_s f$ and homogenity of the sample).

As can be seen on Figure 3 there is no great contradiction between the observed distribution and the expected one for Poggianti's model in an 'intermediate', $\Omega_0 = 0.45$, cosmological model. The same can be said for PEGASE model (not shown on Figure 3). Unexpected to some extent is the rather low mean redshift $\langle z_{\rm phot}\rangle = 1.63$ for 27 objects with magnitudes of $22^{\rm m} \leq m_R \leq 24^{\rm m}$. Formerly we have estimated (Parijskij *et al.*, 1998) that a mean redshift should be of about 2 for such faint objects using 3 types of calibrations (by LAS, α and m_R), based on a large data set from literature on radio galaxies with measured $z \geq 1$. But several effects could help in the interpretation of the difference.

Though redshifts, estimated by B, V, R_c, I_c, should be more precise they may have their own systematics. On average we have fainter radio sources in a RC USS sample than in other ones but with lower median α (Table 1). The latter property of the sample may be of greater importance for a selection of HZ objects. Indeed, the calibration by α had given the smallest of all $\langle z\rangle \approx 1.5$. A more sophisticated interpretation, which seems only speculative until a completion of multicolour observations of the remaining objects and spectroscopic redshifts measurements, is consisted in that on the $[m_R - z_{\rm phot}]$ diagram two populations of faint ($m_R = 22^{\rm m}$–$24^{\rm m}$) radio galaxies are possibly revealed. The first population at $z \approx 1$ consists of old (a half with age ≥ 5 Gyr) and large ($LAS \sim 20''$) objects, the second one at $z = 1.5$–3.5 includes both younger (≤ 3 Gyr) and smaller ($LAS \sim 5''$) objects. The low z population may come to dominate for the flux level and typical α of the RC USS catalogue, thus providing an explanation of lower mean redshift of the whole sample than expected from calibrations based on objects with higher flux level and steeper spectra.

While all but one of our objects with $m_R < 22^{\rm m}$ have multicolour data, there are 17 ones with $22^{\rm m} \leq m_R < 24^{\rm m}$ and another 12 with $m_R \geq 24^{\rm m}$ which has not been observed in $BVRI$ so far. Most of the latter ones should probably be at $z \geq 1.5$, and some may be very distant radio galaxies ($z > 3.5$) or intermediate redshift very old or dusty ones.

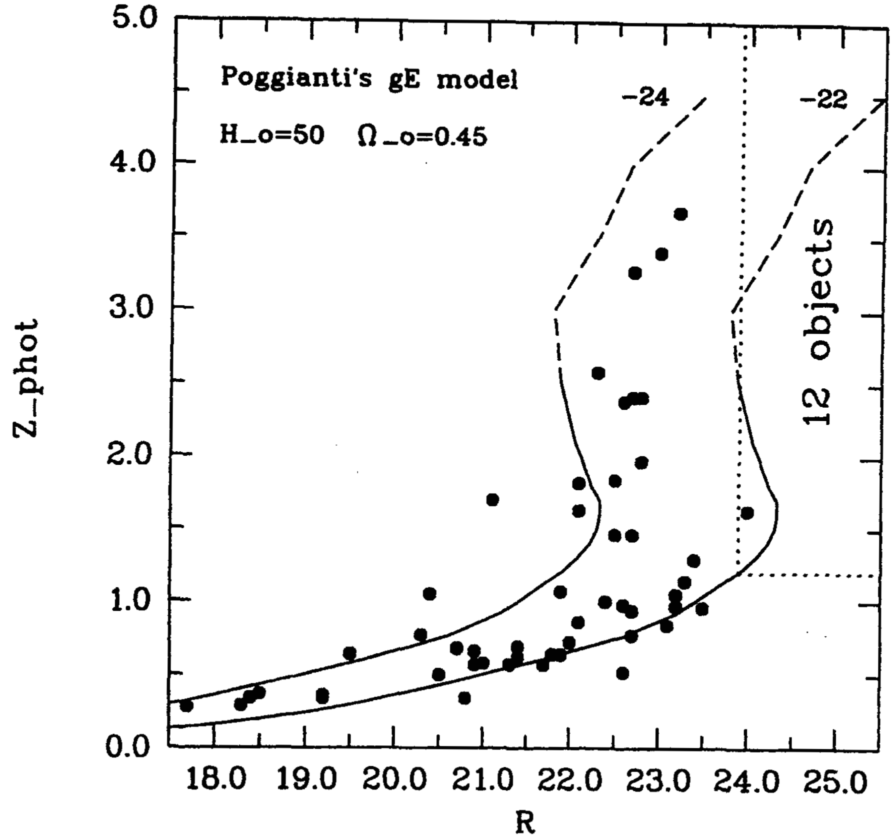

Figure 3 m_R–$z_{\rm phot}$ diagram for 50 RGs. Evolutionary tracks of Poggianti's model of elliptical galaxies of $M_R = -24^{\rm m}$ and $M_R = -22^{\rm m}$ are shown by lines. Very faint or still undetected objects should be located inside a box shown by a dotted line in the upper-right corner 12.

5 DISCUSSION

Multi-color photometry is of special importance for $Z > 2$, where simple $Z_{\rm ph}$ may give very large errors.

There is increasing interest in the very old distant stellar systems.

Looking at Age-Z relation for our sample of RG, we clearly see the expected trend for parent galaxies to be younger at higher redshifts, and we believe, that selection effects play a secondary role in this result. We confirm also, that the mean epoch of the parent galaxies formation may be in the redshift range 10–20, but in several cases the multi-color ages exceed the Universe SCDM age at the estimated redshift.

We have mentioned the first case of that kind in (Parijskij *et al.*, 1996), another two cases appeared recently (Spinrad *et al.*, 1997; Cowan *et al.*, 1997; de Alcaniz and

Lima, 1999). These cases were used to estimate the role of the Λ-term (Yoshii *et al.*, 1998). Even more, it was suggested to use the Age-Z relation for reconstruction of the physical conditions in the very early Universe (see Saini *et al.*, 1999; Starobinsky, 1999).

It is well known, that errors of color ages may be small enough for a young stellar population, but for an old population it is not the case, and, at some redshifts ranges, colors are not sensitive to age at all.

Dust reddening may imitate the old age of the galaxy. But, it can be shown, that separation of these effects may be done, due to the different shape of observable SED.

The high importance of the age determination suggests, that all possible ways of improving the estimation of ages should be used, and the Fe/MgII ratio is one of those suggested for distant objects with emission lines (Yoshii *et al.*, 1999). We hope to select the most interesting objects for future studies, including deep spectroscopy.

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References

de Alcaniz, J. S. and Lima (1999) *Astrophys. J. Lett.* **521**, L87 (astro-ph/9902298).
Cowan, J. J. *et al.* (1997) *Astrophys. J.* **480**, 246.
Dodonov, S. N. *et al.* (1999) *Astronomy Reports* **43**, 275 (*Astron. Zh.* **76**, No.5).
Douglas, J. N. *et al.* (1996) *Astron. J.* **111**, 1945.
Fioc, M. and Rocca-Volmerange, B. (1997) *Astron. Astrophys.* **326**, 950.
Fletcher, A. *et al.* (1996) *Astronomy Reports* **40**, 759 (*Astron. Zh.* **73**, 835).
Goss, W. M. *et al.* (1992) *Soviet Astronomy* **36**, 343 (*Astron. Zh.* **69**, 673).
Kopylov, A. I. *et al.* (1995a) *Astronomy Reports* **39**, 383 (*Astron. Zh.* **72**, 437).
Kopylov, A. I. *et al.* (1995b) *Astronomy Reports* **39**, 543 (*Astron. Zh.* **72**, 613).
Lilly, S. J. (1988) *Astrophys. J.* **333**, 161.
Parijskij, Yu. N. *et al.* (1991) *Astron. Aslrophys. Suppl. Ser.* **87**, 1.
Parijskij, Yu. N. *et al.* (1992) *Astron. Aslrophys. Suppl. Ser.* **96**, 583.
Parijskij, Yu. N. *et al.* (1996a) *Bull. Special Astrophys. Obs.* **40**, 5.
Parijskij, Yu. N. *et al.* (1996b) *IAU Symp.*, No. 175, 591.
Parijskij, Yu. N. *et al.* (1998) *Astronomy Reports* **42**, 425 (*Astron. Zh.*, **75**, 483).
Poggianti, B. M. (1997) *Astron. Astrophys. Suppl. Ser.* **122**, 399.
Pursimo, T. *et al.* (1999) *Astron. Astrophys. Suppl. Ser.* **134**, 505 (astro-ph/9811265).
Saini, T. D. *et al.* (1999) astro-ph/9910231.
Spinrad, H. *et al.* (1997) *Astrophys. J.* **484**, 581.
Starobinsky, A. A. (1999) this issue.
Van Breugel, W. *et al.* (1999) *Astrophys. J.* **518**, L61.
Verkhodanov, O. V. *et al.* (1999) *Bull. Special Astrophys. Obs.* **48**, 41 (astro-ph/9910559).
Yoshii, Y., Tsujimoto, T., and Kawara K.(1998) *Astrophys. J.* **507**, L113.