Chin. J. Astron. Astrophys. Vol. 5 (2005), **Suppl.**, 229–234
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Faint Radio Active Galactic Nuclei

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Abstract To separate the faint radio AGN population and a population of star-forming galaxies and then to determine the properties of each population it is necessary to couple deep radio and optical observations over a reasonably large area of sky. Here we present the preliminary results obtained cross-matching the photometric VIMOS survey (Visible MultiObject Spectrograph for the Very Large Telescope) and Very Large Array data at 1.4 GHz.

Key words: galaxies: nuclei — galaxies: starburst — radio continuum: galaxies

1 INTRODUCTION

Deep radio surveys have clearly indicated that radio counts show an upturn below a few millijansky (mJy) (see Fig. 1, where the weighted normalized differential counts are given for different samples of radio sources). Classical radio sources, powered by active galactic nuclei (AGN) and typically hosted by giant ellipticals and quasars (see Fig. 2) are known to dominate at high flux densities (99% above 60 mJy, Windhorst et al. 1990), but their contribution decreases going to fainter fluxes. Therefore the rapid increase in the number of faint sources has been interpreted as being due to the presence of a new population of radio sources which does not show up at higher flux densities.

The new faint radio population is thought to be composed predominantly of star-forming galaxies, with a contribution also from early type galaxies and low-power AGNs. However the relative fraction of the various populations responsible of the excess in the sub-mJy radio counts is not well established.

Unfortunately, the optical identification work and subsequent spectroscopy, needed to establish the nature of the radio sources, are both very demanding in terms of telescope time, since faint radio sources have usually very faint optical counterparts.

To give an example, Table 1 lists the area covered, the limiting flux of the radio data, the limiting magnitude of the optical counterpart, and the percentage of the sample which has optically identified and spectroscopically observed for four samples. Typically, no more than $50-60\%$ of the faint radio sources have been identified on optical images and only ∼20% have spectra. Only in the microJy survey of the Hubble Deep Field, 80% of the 111 radio sources have spectra (Richards et al. 1999).

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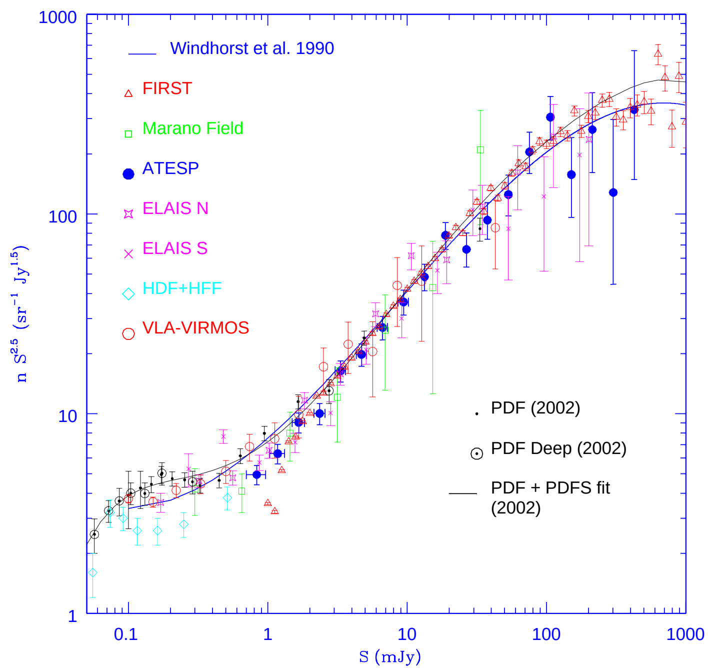

Fig. 1 The normalized differential source counts at 1.4 GHz. The different symbols represent source counts from several samples: the FIRST (triangles, White et al. 1997), the Marano Field (squares, Gruppioni et al. 1997), the ATESP (filled circles, Prandoni et al. 2001), The ELAIS North and South (stars and crosses, Ciliegi et al. 1999; Gruppioni et al. 1999), the Hubble Deep Field + Flanking Fields (diamonds, Richards 2000), the Phoenix Deep Survey (dots and circled dots, Hopkins et al. 1998), the VLA-VIMOS (open circles, Bondi et al. 2003). The solid lines are the third-order polynomial fit from Katgert et al. (1988) and the sixth-order least-squares polynomial fit from Hopkins et al. (2003).

Table 1

Survey name	Reference	Area deg^2	S(mJy) mJy	mag.	Opt. ID %	Spect. ID %
2dFGRS/NVSS	Sadler et al. 2002	325	2.5	$b_j < 19.5$	5	5
ATESP/EIS	Prandoni et al. 2001	3.0	0.47	$I < 22.5$	57	18
Marano Field	Gruppioni et al. 1997	0.36	0.2	$b_j < 22.5$	63	50
HDF	Richards et al. 1999	0.3	0.04	$I < 25$	80	80

2 COMPOSITION OF THE FAINT RADIO POPULATION

Sadler et al. (2002) have cross-matched the 1.4GHz NRAO Very Large Array Sky Survey with the first 210 fields observed in the 2dF Galaxy Redshift Survey and have found that the mJy population is a mixture of active galaxies (60 per cent) and star-forming galaxies (40 per cent). Going to fainter regime, Prandoni et al. (2001) have found that the composition of the population abruptly changes going from mJy to sub-mJy fluxes, where star forming

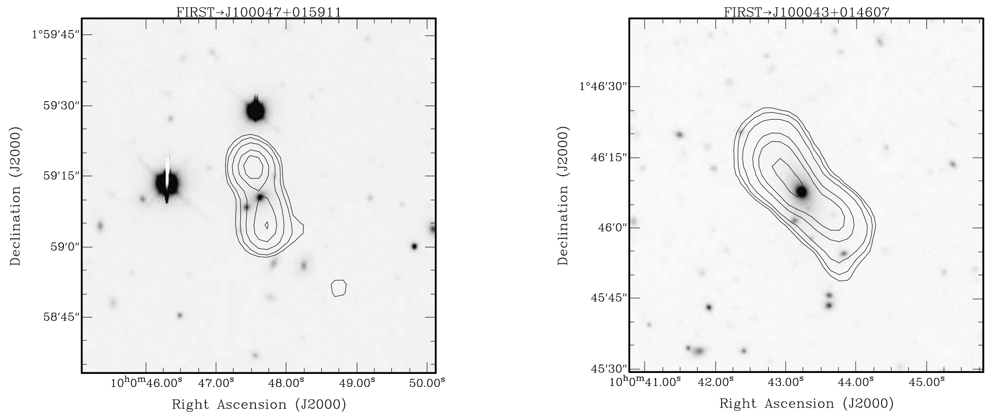

Fig. 2 Examples of classical radio galaxies: on the left the magnitude of the optical counterpart is $I_{AB} = 18.3$, on the right it is $I_{AB} = 17.5$.

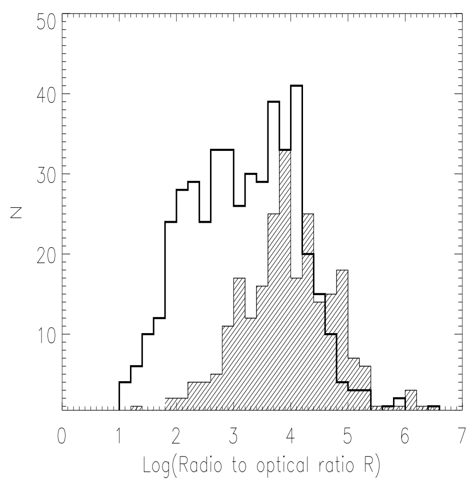

Fig. 3 Distribution of the radio-to-optical ratio R for the sample of early type galaxies (shaded histogram) and for the sample of late type galaxies (empty histogram)in the "0226−04" field. $R = S \cdot 10^{0.4(I-12.5)}$, where S is the 1.4 GHz radio flux in mJy and I is the optical magnitude.

processes become important. Nevertheless, at sub-mJy fluxes, AGNs constitute a significant fraction (∼30%) of the whole population.

It is therefore clear that in order to separate the AGN population and a population of star-forming galaxies and then to determine the properties of each population it is necessary to couple deep radio and optical observations over a reasonably large area of sky.

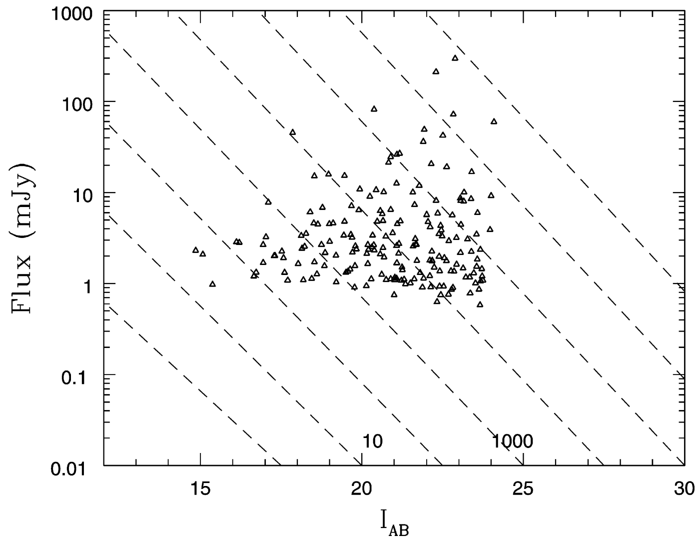

Fig. 4 The I_{AB} band magnitude versus 1.4 GHz radio flux for the FIRST radio sources with a reliable optical identification ("1003+01" field). The lines represent different radio-to-optical ratio R, corresponding to $R = 1, 10, 10^2$, 10^3, 10^4, 10^5, 10^6, 10^7.

3 DATA

The VIMOS consortium has defined the VIMOS-VLT Deep Survey (Visible MultiObject Spectrograph for the Very Large Telescope), as a major programme to study the evolution of galaxies, clusters, large-scale structures, and AGNs, over more than 90% of the current age of the Universe (Le Févre et al. 2003). The survey will produce spectroscopic redshifts for about 10^5 galaxies selected from an unbiased photometric sample of more than 1 million galaxies. Four fields with total area covered of ∼16 deg^2 are targeted during the course of the spectroscopic survey. Extensive imaging has been carried out in these four fields allowing to assemble a sample of about 2 million galaxies with BVRI photometry, with smaller subsets having in addition U and/or K photometry.

Therefore the VIMOS survey is ideal to study the faint radio population, considering the high quality of the photometric multiband data, down to $I_{AB} \sim 25$, $B_{AB} \sim 26$, $R_{AB} \sim 26$ and $V_{AB} \sim 26$ (Le Févre et al. 2004).

For the field "0226–04" we have carried out deep radio observations with the Very Large Array (VLA) at 1.4 GHz (Bondi et al. 2003). The deep radio data have allowed to derive a complete sample of 1054 radio sources with a limiting flux of ∼80 microJy and angular resolution of 6″.

For the remaining VIMOS fields we have utilized the public radio survey Faint Image of the Radio Sky at Twenty-cm (FIRST, White et al. 1997) carried out at 1.4 GHz with the VLA. The observations have produced nearly uniform-sensitivity images of the sky with a median rms of 0.14 mJy, corresponding with a point-source flux density limit of 1.0 mJy, and an angular resolution of 5″. For the analysis described here, we have utilized the 11Apr03 version of the FIRST catalogue, which contains positions, peak and integrated flux densities, source morphological parameters, and information on the field from which each entry was derived.

Here we present preliminary results on the first two fields ("0226–04" and "1003+01"), whose photometric data analysis is completed.

4 PRELIMINARY RESULTS

In the "0226–04" field we have identified $\sim 74\%$ of the whole sample (Ciliegi et al. in preparation). Using the color and the photometric redshift for the radio sources with a reliable optical counterpart, we have tentatively divided the radio sample in two subsamples: the early type galaxies and the late type galaxies. The analysis of the radio-to-optical ratio R, which is a measure of the radio excess in a galaxy of given optical luminosity, confirms that AGNs and the majority of the early-type galaxies populate the region of high R (e.g., Roche et al. 2002) (see Fig. 3).

Only deep optical data permit to extract statistically large samples of these faint radio AGNs. In fact the cross-matching of the FIRST survey and the deep photometry of the "1003+01" field shows that the $\sim 72\%$ of the identified radio sources have a radio-to-optical ratio greater than 1000 (see Fig. 4) and that their median angular dimensions are $\sim 3''$, suggesting a nuclear origin for the radio emission (see in Fig. 5 two examples).

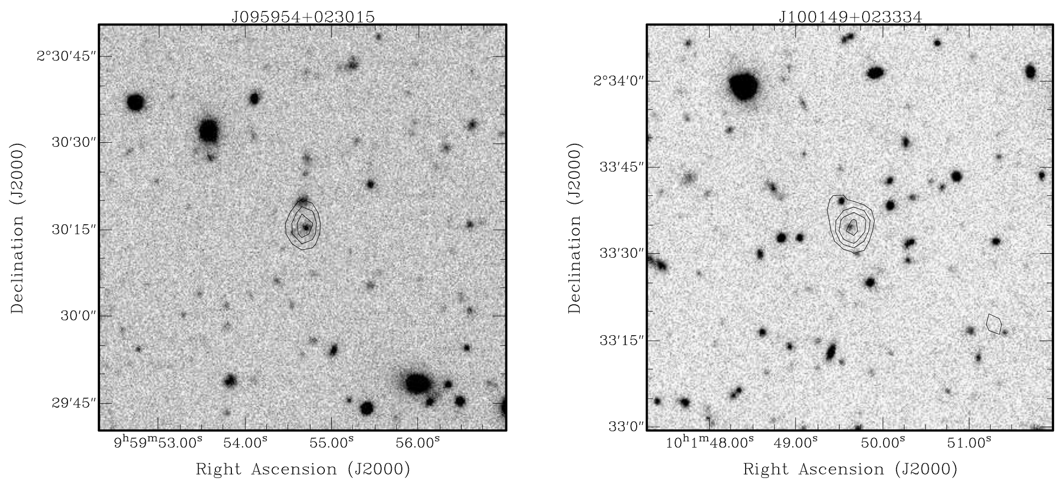

Fig. 5 Examples of faint radio sources identified with an object with magnitude $I_{AB} = 22.2$ (on the left) and $I_{AB} = 23.1$ (on the right)

The main ingredients of the central engine are believed to be a super-massive black hole and an accretion disk surrounding it. However, despite many efforts, the processes that control the presence of nuclear activity are not established: the mass of the central compact objects spans nine order of magnitude (from $few \times 10^9 M_{\rm solar}$ in AGNs to $few \times M_{\rm solar}$ in X-ray binaries), and the accretion conditions are unknown.

The properties of faint radio AGNs could help to shed light on the origin of nuclear activity in galaxies.

Acknowledgements The National Radio Astronomy Observatory is operated by associated Universities, Inc., under cooperative agreement with the National Science Foundation. This research has been developed within the framework of the VVDS consortium.

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