Evolution of the 1.4 GHz Radio Luminosity Function

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Abstract. The results of an optical and infrared investigation of a complete sub-sample of the Leiden-Berkeley Deep Survey are presented. Optical counterparts have been identified for 69 of the 73 sources in the two Hercules fields, and redshifts obtained for 49 of them. Photometric redshifts are computed from the $griK$ data for the remaining 21 sources. This complete sample is compared with the radio luminosity functions (RLFs) of Dunlop and Peacock (1990) [1]. The RLF models successfully trace the evolution of the radio sources with redshift, but there is some disagreement between the luminosity-dependence of the models and the data. The observed RLF for the lower luminosity population ($\log_{10} P < 26$) shows evidence for a cut-off at lower redshifts ($z \sim 0.5-1.5$) than for the more powerful objects.

INTRODUCTION

The purpose of the Leiden-Berkeley Deep Survey (hereafter “the LBDS”) was to gain a better understanding of the nature of faint radio galaxies and quasars, and to determine their cosmological evolution. Several high latitude fields in the selected areas SA28, SA57, SA68 and an area in Hercules had been selected for the purpose of faint galaxy and quasar photometry, and a collection of good multi-color prime focus photographic plates had been acquired. Nine of these fields were then surveyed with the Westerbork Synthesis Radio Telescope at 21 cm (1.412 GHz), reaching a 5-$\sigma$ limiting flux density of 1 mJy [2].

Following this selection of the radio sample, 171 of the radio sources (53%) were identified on the photographic plates, whilst for the Hercules fields there were 47 out of 73 sources identified [3,4]. Presented here are the results of an extensive optical/infrared investigation of the two Hercules fields, with the aim of completing the identification and redshift content of this sub-sample [5]. A cosmology of $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$, $\Omega_0 = 1$ and $\Lambda = 0$ is assumed throughout.
FIGURE 1. Magnitude distributions for the LBDS Hercules sample. Shaded histograms show the sources with $S_{1.4} \geq 2$ mJy. Arrows denote 3-$\sigma$ upper limits at $H$ and $K$.

THE DATA

The Hercules field was observed on the 200 inch Hale telescope at Palomar Observatory between 1984 and 1988. Multiple observations were made through Gunn $g$, $r$ and $i$ filters over the six runs. After processing and stacking of the multiple-epoch images, optical counterparts for 22 of the sources were found, leaving only four sources unidentified to $r \simeq 26$. Near-infrared observations have been made of the entire subsample at $K$, yielding 60/73 detections down to $K \simeq 19–21$. Half of the sources have been observed in $H$ and approximately one-third in $J$. Observations of the brighter sources were made by Thuan et al. (1984) [6] and by Neugebauer et al. and Katgert et al. (priv. comm.). $K$-band observations of the sample were completed by the present authors at UKIRT.

Figure 1 presents the optical and infrared magnitude distributions. For those sources without CCD observations, photographic magnitudes from Kron et al. (1985) [4] have been transformed to the Gunn system [7]. It is seen that the distribution turns over at $r \sim 22$, a consequence of evolution in the redshift and/or luminosity distributions of the radio sources. The the $r$-band magnitude distribution is essentially unchanged from this milli-Jansky survey down to micro-Jansky surveys, a thousand times fainter in radio flux [8].

Prior to the start of the current work, only 16 of the 73 sources in the LBDS Hercules fields had redshifts published in the literature. Another 16 sources had unpublished redshifts. The author and collaborators have successfully observed a further 17 sources during the past few years, using both the 4.2 m William Herschel
Photometric redshifts were calculated for the remaining one-third of the sample. Using the spectral population synthesis models of Jimenez et al. (1998) [12], synthetic $griJHK$ magnitudes were computed and fitted to the observed magnitudes, giving the most-probable redshift and a measure of its uncertainty. Comparison of the estimated and the true redshifts for those sources with spectroscopic observations, showed that the average difference was $\sim 0.1$ in $z$.

**THE 1.4 GHZ RADIO LUMINOSITY FUNCTION AND THE REDSHIFT CUT-OFF**

Dunlop and Peacock (1990) [1] used a sample of radio sources brighter than 0.1 Jy at 2.7 GHz to investigate the radio luminosity function. They concluded that the comoving density of both flat- and steep-spectrum sources suffers a cut-off at redshifts $z \simeq 2$–4. This conclusion was drawn from the behavior of both free-form and simple parametric models (PLE/LDE), and the model-independent, banded $V/V_{\text{max}}$ test. However, the results were crucially dependent upon the accuracy of their redshift estimates in the Parkes Selected Regions (PSR).
With a flux limit \( \sim 100 \times \) fainter than the PSR, the LBDS is well-suited to test the reliability of those RLF models and the redshift cut-off, via its potential to detect powerful radio galaxies at very high redshifts. In figure 2 [left] the cumulative redshift distribution of the LBDS Hercules sample (only sources with \( S_{1.4} \geq 2 \) mJy) is compared with the predictions of [1]. It is seen that two of the free-form models (FF-4 and FF-5) provide a reasonable fit to the data over all redshifts. The “bump” in the best-fit histogram at \( 0.4 \leq z \leq 1 \) is due to two spikes in the redshift distribution, that may be the result of possible large-scale structures (sheets) along the line of sight.

The observed 1.4 GHz luminosity function presented in figure 2 [right] was also compared with the models. It was found that the two models which fit the cumulative counts (FF-4 and FF-5) do not predict the observed luminosity dependence of the data nearly as well as the overall redshift dependence. The observed RLF shows some indication that it turns over at \( z \approx 0.5–1.5 \), and that the redshift of this cut-off is a function of the radio luminosity. However, the small number of sources makes it difficult to separate the redshift and luminosity dependence of the RLF sufficiently to be certain of this trend.

The full results of this project are presented in [5], and in forthcoming papers by the author and collaborators.

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