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# First results from the VIMOS/VLT Deep Survey (VVDS): luminosity functions from z∼0 to z∼1.5

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**Abstract.** The VIMOS/VLT Deep Survey (VVDS) is an on-going program to map the evolution of galaxies, large scale structures and AGNs from the redshift measurement of more than 100000 objects down to a magnitude $I_{AB}$ = 24, in combination with a multi-wavelength dataset from radio to X-rays. We present here the results obtained from the first epoch data, regarding in particular the evolution of the luminosity function.

**Key words.** Galaxies: redshift surveys – Galaxies: evolution – Galaxies: luminosity functions –

## 1. Introduction

Understanding how galaxies and large scale structures formed and evolved is one of the major goals of modern cosmology. In order to identify the relative contributions of the various physical processes at play and the associated timescales, a comprehensive picture of the evolutionary properties of the constituents of the Universe is needed over a large volume and a large time base. Samples of high redshift galaxies known today reach less than a few thousand at redshifts $1-3$, and statistical analyses suffer from small number statistics, small explored volumes, selection biases, which prevent a detailed analysis. In the local Universe, large surveys like the 2dFGRS (Colless et al. 2001) and the SDSS (Strauss et al. 2002) contain from $2.5 \times 10^5$ up to $10^6$ galaxies to reach a high level of accuracy in measuring the fundamental parameters of the galaxy and AGN populations. Similarly, we need to gather large numbers of galaxies at high redshifts to accurately describe the various populations in environments ranging from low density to the dense cluster cores, and relate the properties observed at different redshifts to identify the main processes driving evolution. This goal can only be achieved through massive observational programs assembling galaxy and AGN samples representative of the Universe at the various look-back times. As the observed galaxies are at large distances and therefore very faint, instruments have to be conceived to combine wide field, high throughput, and high multiplex gain in order to efficiently observe large samples. Multi-object spectrographs are routinely in operation since ~15 years, and the new generation now in place on the $6-10$m telescopes, like DEIMOS on the Keck-10m or VIMOS on the VLT-8m, allows large volumes of the distant Universe to be explored through the observations of many tens of thousand of objects. Because of this leap forward in instrument performances, several large deep surveys are now in progress: we present here the first results from the VIMOS/VLT Deep Survey (VVDS).

## 2. The VIMOS/VLT Deep Survey

The goal of the VVDS is that of obtaining $\sim 100000$ spectra over more than 16deg$^2$ in 5 equatorial fields, for 3 large galaxy datasets: a wide survey to $I_{AB} \leq 22.5$, a deep survey to $I_{AB} \leq 24$ and a ultra-deep survey to $I_{AB} \leq 25$. The general strategy of the survey has been presented in e.g. Le Fèvre et al. (2001).
Multicolour photometry is available for each field (Le Fèvre et al. 2004): in particular, the B, V, R, I photometry for the VVDS-0226-04 deep field is described in detail in McCracken et al. (2003). Moreover, U band (Radovich et al. 2004) and K band (Iovino et al. 2004) data are available for smaller areas of these fields, and a radio survey has been performed on the deep field (Bondi et al. 2003).
The spectroscopic survey started in Fall 2002 and the priority was set to accumulate as many observations as possible on the VVDS-0226-04 deep field, to a depth $I_{AB} = 24$. The remaining time was spent on the VVDS-2217+00 and the VVDS-1002+03 fields, as part of the wide survey. The VIMOS observations have been performed using $\sim 1''$ wide slits and the LR-Red grism. This provides a spectral resolution of $R = 210$. The length of spectra at this resolution allows to pack on average 350–400 spectra for the wide $I_{AB} \leq 22.5$ survey on the 4 VIMOS detectors, and 500 to 600 spectra for the deep $I_{AB} \leq 24$ survey, a key factor to accumulate redshifts in a very efficient way. Spectroscopic data were reduced with VIPGI, the VIMOS Interactive Pipeline Graphical Interface (Franzetti et al. 2004), and redshift measurements were performed with the KBRED package (Scaramella et al. 2004).
Up to now, $\sim$ 30000 spectra have been obtained: we present here results based on $\sim$ 5000 fully reduced and secured spectra in the deep area.

## 3. The evolution of the luminosity function

The most direct way to measure galaxy evolution is that of comparing their luminosity function at different redshifts: the current VVDS data allow a robust estimate of this function in

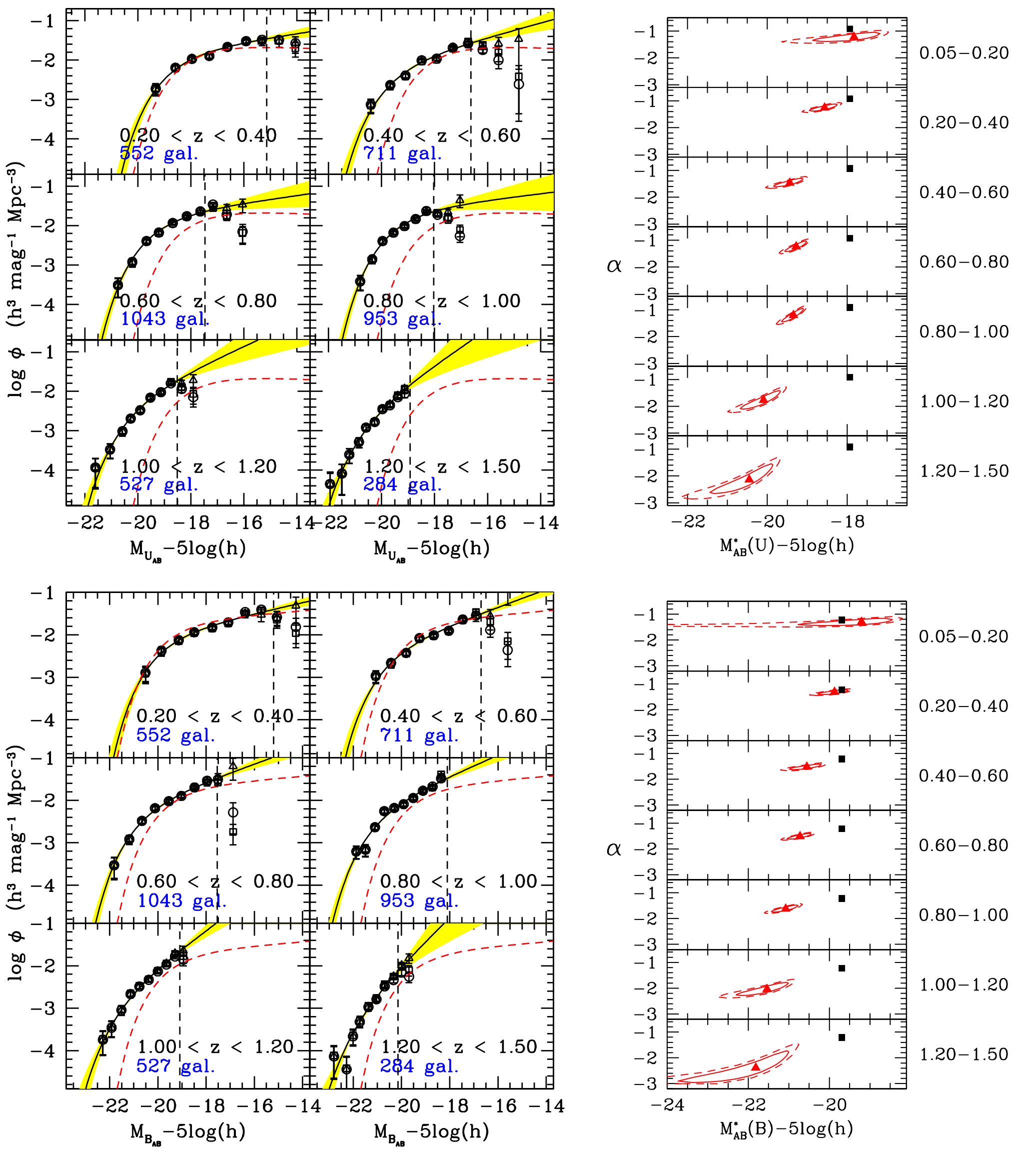


**Fig. 1.** Luminosity functions in different redshift bins, in the $U_{AB}$ (upper panels) and in the $B_{AB}$ (lower panels) rest frame bands. Symbols refer to the results of different methods: circles for $1/V_{max}$, triangles for $SWML$, squares for $C^+$ and solid line for $STY$. Yellow regions indicate the $1\sigma$ uncertainties of the $STY$ parameters, whose confidence ellipses are reported in the right panels (at $1\sigma$ and $2\sigma$ confidence level). The red dashed line refers to the local estimate of the luminosity function from SDSS, whose parameters are indicated with a black square in the right panels.

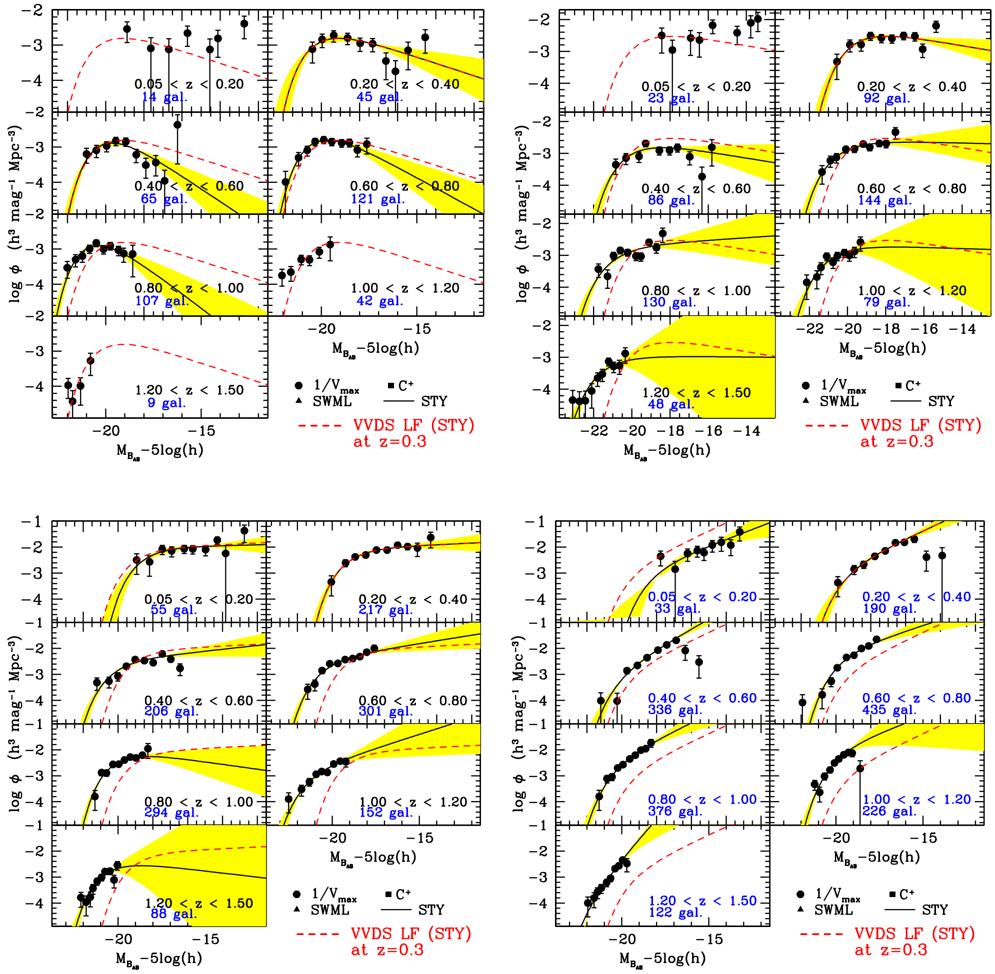


**Fig. 2.** Luminosity functions in different redshift bins in the $B_{AB}$ rest frame band, divided in four spectral types. Symbols are the same as in Figure 1, except for the red dashed line, that now refers to the VVDS estimate at $z = 0.3$. Upper left: early-type (type 1). Upper right: early spirals (type 2). Lower left: late spirals (type 3). Lower right: irregulars (type 4).

many redshift bins, from $z \sim 0$ to $z \sim 1.5$.

The estimate of the luminosity function in such a large redshift interval is not a simple task, because a number of possible biases could be present in the sample, such as e.g. redshift incompleteness and different spectral coverage at different redshifts: a detailed discussion of these points is presented in Ilbert et al. (2004a). For this reason we built a specific dedicated tool to derive the luminosity function with different statistical estimators (Ilbert et al. 2004b).

Given our multicolour photometric catalogue, we can derive the luminosity function in the $U_{AB}$, $B_{AB}$, $V_{AB}$, $R_{AB}$ and $I_{AB}$ rest frame bands. In Figure 1 we show the results for the $U_{AB}$ and $B_{AB}$ bands, obtained with $1/V_{max}$ (Schmidt 1968), $SWML$ (Efstathiou et al. 1988), $C^+$ (Lynden-Bell 1971) and $STY$ (Sandage et al.

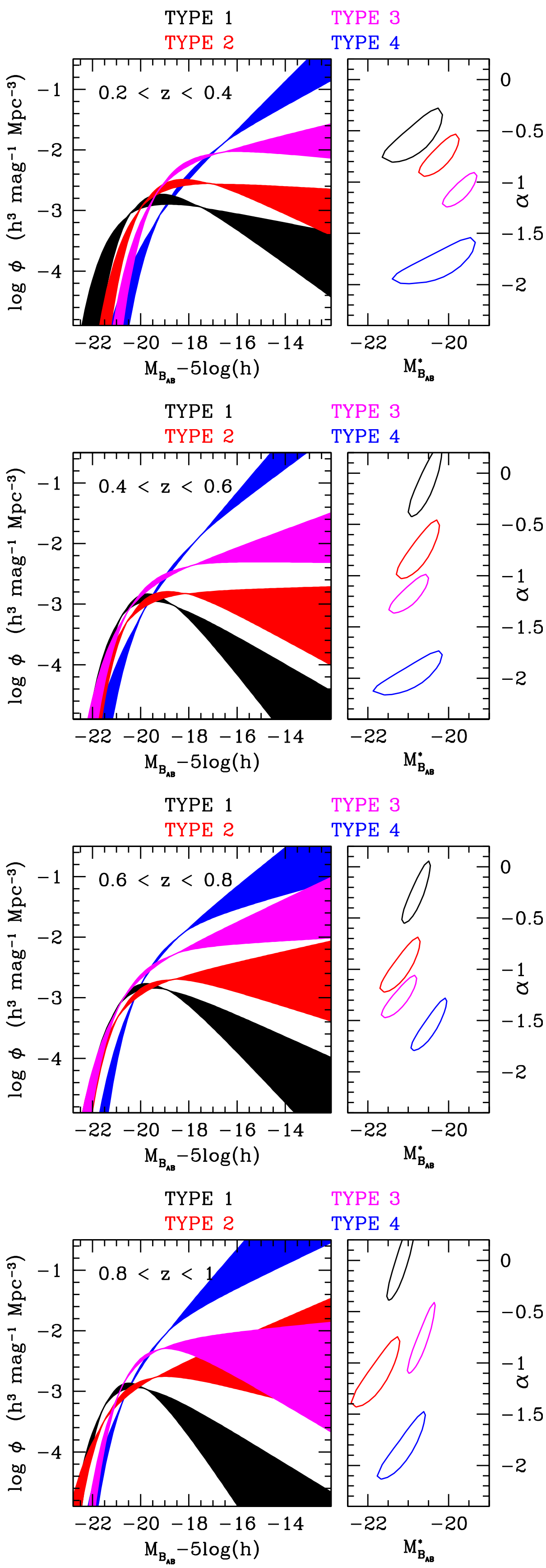


**Fig. 3.** Comparison of the luminosity functions derived with $STY$ for various spectral types, in different redshift bins.

1979). From this figure, an evolution of the luminosity function is clearly visible: in all bands, the $M^*$ parameter shows a significant brightening (which reaches $\sim$ 2 mag in the $U_{AB}$ band) from $z \sim 0$ to $z \sim 1.5$ and the faint end slope shows a significant steepening (Ilbert et al. 2004b). The analysis of the luminosity density evolution is presently in progress (Tresse et al. 2004).

Since we have sufficient number statistics, we can for the first time break up the evolution of the luminosity function by galaxy spectral types. Each galaxy can be assigned a spectral type based on the SED model fitting of the photometric data (covering a larger wavelength base than the spectra themselves). Galaxies were classified in 4 types: early-type (type 1), early spirals (type 2), late spirals (type 3) and irregulars (type 4); luminosity functions for each type in different redshift bins are reported in Figure 2.

While the early-type population seems not to be evolving by more than 0.5 magnitudes, blue star forming galaxies show a strong evolution with redshift, with a significant brightening of the $M^*$ parameter with increasing redshift (Zucca et al. 2004). In Figure 3 we report a comparison of the luminosity functions derived with $STY$ for galaxies of different type, in various redshift bins. From this comparison, it can be seen that, at a fixed redshift, later galaxies have steeper slopes and fainter $M^*$.

Our next step will be that of studying the dependence of the luminosity function on the local environment: preliminary results seem to indicate that the luminosity function of galaxies in dense regions tends to be flatter and with a brighter $M^*$.

In conclusion the VVDS, given its large number of redshifts and the multicolour information, allows us for the first time to follow in detail the evolution of the luminosity function from $z \sim 0$ to $z \sim 1.5$ within the same sample. Moreover, the high number statistics allows us to determine which galaxy population is mainly responsible of this evolution.

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