The VIRMOS-VLT Deep Survey

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Abstract. The aim of the VIRMOS VLT Deep Survey (VVDS) is to study of the evolution of galaxies, large scale structures and AGNs from a sample of more than 150,000 galaxies with measured redshifts in the range \( 0 \leq z \leq 5+ \). The VVDS will rely on the VIMOS and NIRMOS wide field multi-object spectrographs, which the VIRMOS consortium is delivering to ESO. Together, they offer unprecedented multiplex capability in the wavelength range 0.37 – 1.8\( \mu \)m, allowing for large surveys to be carried out. The VVDS has several main aspects: (1) a deep multi-color imaging survey over 18deg² of more than one million galaxies, (2) a ”wide” spectroscopic survey with more than 130,000 redshifts measured for objects brighter than \( I_{AB} = 22.5 \) over 18deg², (3) a ”deep” survey with 50,000 redshifts measured to \( I_{AB} = 24 \), (4) ”ultra-deep” surveys with several thousand redshifts measured to \( I_{AB} = 25 \), (5) multi-wavelength observations with the VLA and XMM.

1 Introduction

The statistical study of the properties of galaxies, active galactic nuclei, or large scale structures, and their evolution, is a key to progress in our understanding of the evolution of the universe. In the past decade, our exploration of the universe has reached redshifts up to \( z \sim 1.2 \) (Fig. 1), then up to redshifts \( 3 - 4 \) (Fig. 2). Together, these data have given the first picture of the star formation history in the universe (Fig. 3).

However, available samples remain small. Only a few thousand galaxies have securely measured redshifts beyond \( z \sim 0.5 \) where most of the evolution appears to have taken place. While this provides a first evaluation of the state of the galaxy population at these redshifts, the current samples are too
small to provide the statistical basis required to investigate the dependence of evolution versus key parameters such as the local galaxy/matter density, the luminosity/mass of galaxies, or galaxy types. To trace galaxy evolution in more significant detail, it is necessary to conduct deep redshift surveys of large samples at increasingly large look-back times.

We describe here the VIRMOS VLT Deep Survey (VVDS) which is aiming to gather more than $1.5 \times 10^5$ redshifts for galaxies with $0 < z < 5+$. This project is based on the Visible and the Near-IR Multi-Object spectrographs (VIMOS and NIRMOS) being built for the ESO-Very Large Telescope by the VIRMOS consortium. This survey will allow us to study evolution over 90% of the current age of the universe with unprecedented details.

2 Survey goals

The goal of the VVDS is to study the evolution of galaxies, AGNs, and large scale structures, over a redshift range $0 < z < 5+$. The requirement is to be able to analyse the basic properties such as the luminosity function or spatial correlation function of the galaxy population, as a function of galaxy type or local density, in each of several time steps covering the above redshift range. The number of galaxies necessary to make a detailed study of the population of galaxies can be estimated e.g. from the computation of the luminosity function: considering that 50 galaxies are necessary to measure the number of galaxies per magnitude bin, in 10 magnitude bins, for 3 basic colors (type) and 3 types of environments from low to high density, in 4 fields to beat cosmic variance, and in 7 time steps, the total number of galaxies required is thus $50 \times 10 \times 3 \times 3 \times 4 \times 7 = 126,000$ galaxies.

3 The VIMOS and NIRMOS instruments

The VIRMOS consortium of French and Italian institutes led by the Institut d’Astrophysique in Marseille is building two wide field multi-object spectrographs for the ESO-VLT, in partnership with the following institutes: IRA-CNR and OABo in Bologna, IFCTR and OABr in Milan, OMP in Toulouse, Haute Provence Observatory, OAC in Naples.

VIMOS covers the wavelength range 0.37–1 microns, while NIRMOS covers 1–1.8 microns. These imaging spectrographs will allow one to obtain wide field images, multi-slit spectroscopy, or integral field spectroscopy data. Both instruments will make use of slit masks, custom-cut with a high power laser machine capable to cut 200 slits in 15 minutes.

The main emphasis of these 2 instruments is the ability to observe large numbers of spectra simultaneously. The optimised optical layout in 4 separate channels allows one to gather more than 800 spectra at once with VIMOS, or close to 200 with NIRMOS, an unprecedented multiplex gain. Spectral resolutions from $R = 200$ to $R = 2500$ will be available on VIMOS (one
arcsecond slits, higher resolutions are possible with narrower slits), while NIRMOS will operate only at resolutions higher than \( R = 2500 \) to be able to go in between the bright night sky emission lines. The field of view of VIMOS is \( 4 \times (7 \times 8) \) arcmin\(^2\), while the NIRMOS spectroscopic field is \( 4 \times (6 \times 8) \) arcmin\(^2\). VIMOS is in final integration phase at Observatoire de Haute Provence (fig.1). It will undergo commissioning at the Paranal observatory in the spring of 2001, and is being offered to the ESO community as a facility instrument on VLT telescope \#3 starting in July 2001.

4 Wide field deep imaging survey

A deep imaging survey in UBVRIKs complete to a depth \( I_{AB} = 25 \) (5\(\sigma\) detection for extended sources in a 3 arcsec aperture) is currently underway to prepare the unbiased photometric sample of more than 1 million galaxies from which spectroscopic targets will be selected.

A total of 18 deg\(^2\) in five fields is being covered, 4 fields \( 2 \times 2 \) deg\(^2\) each selected at high galactic latitude around the celestial equator, and a \( 1 \times 2 \) deg\(^2\) field around the Chandra deep field south (CDFS, [9]), see the list at http://www.astrsp-mrs.fr/virmos/virmos_deep_survey.htm. Each field allows to probe scales up to \( \sim 100h^{-1}\) Mpc. The 0226-04 field has been selected to coincide with the high visibility area of XMM, and it is adjacent to the NOAO deep imaging survey area [10]. This field is also subject to deep VLA observations with a 5\(\sigma\) sensitivity of the order of 90\(\mu\)Jy. In each field except the CDFS, we are acquiring UBVRI data, as well as K’ data for a smaller 900 arcmin\(^2\) area. We are acquiring only I band data on the CDFS at this time.

The depth is set to probe the luminosity function of galaxies to \( M^* + 3 \) at \( z=1 \) and to select lyman-break and QSO candidates out to redshifts \( z > 3-5 \). Particular care has been given to set a limiting magnitude deep enough to allow the selection of magnitude limited samples for the spectroscopic survey, free of bias and systematics. The limiting magnitude of \( I_{AB} \leq 25 \) at 5\(\sigma\) in a 3 arcsec aperture indeed represents the magnitude at which 95\% of all galaxies with this magnitude are detected and measured. Therefore, at the limit \( I_{AB} = 24 \) of the deep spectroscopic survey, all galaxies including those with low surface brightness should be detected, and no bias is expected when conducting critical measurements like the luminosity function or star formation rate.

The 0226-04 field is observed at a depth 0.6 magnitudes deeper than the other fields as it will be the subject of the ”deep” and ”ultra-deep” spectroscopic surveys.

See [11] for more details on the imaging survey.
5 The VIRMOS spectroscopic survey

We are planning to observe the following magnitude limited samples:
1. "Wide" survey: more than $10^5$ galaxies with redshifts measured to $I_{AB} = 22.5$ (redshift up to $z \sim 1.3$), in 5 fields.
2. "Deep" survey: more than $4 \times 10^4$ galaxies with redshifts to $I_{AB} = 24$ (redshift up to $z \sim 5$) in the 0226-04 field.
3. "Ultra deep survey": more than $10^3$ galaxies with redshifts to $I_{AB} = 25$ in the 0226-04 and Hubble Deep Field South.

The spectroscopic samples will be observed with $R \sim 250$ in a first pass. A subsample of 10,000 galaxies will then be selected for spectroscopy at a resolution $R \sim 2500 - 5000$ to study the evolution of the fundamental plane, and perform a detailed analysis of the spectro-photometric properties of galaxies.

Subsamples of galaxies with specific color selection criteria will also be selected, including Lyman-break galaxy candidates, QSOs and extremely red objects (EROs). The logical flow of the survey is presented in Fig.2.

6 Preparing for data processing and analysis

A data processing pipeline is being developed to process the multi-spectra data. It automatically corrects for instrument signature, removes sky signal, extracts and calibrates 1D spectra in flux and wavelength.

A database has been built under Oracle8 to handle the imaging and spectroscopic catalog data, the images and spectra, as well as to cross correlate the survey data to other surveys.

The VVDS science team is developing the simulation and software tools necessary to analyse the survey in an efficient manner. We are integrating all analysis tools into a common "toolbox" environment accessible through a web interface connected to the database.

Strong emphasis is being put in quality control of the various processing and analysis packages to ensure bug-free and optimal performances.

7 Summary

The VIRMOS VLT Deep Survey is a major program to study the evolution of galaxies, large scale structures, AGNs, clusters of galaxies over more than 90% of the age of the universe. The VIMOS and NIRMOS instruments will provide unprecedented capabilities. The VVDS survey is expected to officially start in the summer of 2001, and will ultimately deliver more than 150,000 redshifts of galaxies and AGNs in the distant universe.
Fig. 1. The Visible Multi-Object Spectrograph (VIMOS) in final integration phase

Fig. 2. VIRMOS-VLT Deep Redshift Survey: logical flow

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