The VIMOS Public Extragalactic Redshift Survey (VIPERS): Universe at z~1

Katarzyna Małek, Agnieszka Pollo, Małgorzata Siudek, Anna Durkalec
collaborators and students from other institutes
VIPERS, started in 2008, released its final set of nearly **90 000** galaxy redshifts in November 2016, together with a series of science papers that range from the detailed evolution of galaxies **over the past 8 Gyr** to the growth rate and the power spectrum of cosmological structures measured at about half the Hubble time.

The VIPERS data, obtained within the framework of an ESO Large Programme over the equivalent of just under 55 nights at the Very Large Telescope, will remain **the largest legacy of the VIMOS spectrograph** and its still unsurpassed ability to reach target densities close to 10 000 spectra per square degree.
http://vipers.inaf.it/

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- Stefanie Phias
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- Ola Solarz
- Melody Wolk
Final public release of complete VIPERS galaxy catalogue of ~90,000 redshifts (PDR-2)
- 18 November 2016 -

Go to PDR-2 data download page

For the press: final science release information page

The large-scale distribution of galaxies as it was between 5 and 8 billion years ago, unveiled by the nearly 90,000 new galaxy distances mapped by the VIPERS project.
### NASA/ADS Metrics Summary

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We apply the method to \( \sim 90,000 \) spectra from the VIPERS survey and compare the results with a subset for which careful editing was performed by hand. We find that the automatic technique reproduces the time-consuming manual cleaning in a uniform and objective manner across a large data sample. The mask data products produced in this work are released together with the VIPERS second public data release (PDR-2).
The VIMOS Public Extragalactic Redshift Survey (VIPERS)*,**

The coevolution of galaxy morphology and colour to $z \sim 1$


(Affiliations can be found after the references)

Received 17 May 2016 / Accepted 12 October 2016

ABSTRACT

Context. The study of the separation of galaxy types into different classes that share the same characteristics, and of the evolution of the specific parameters used in the classification are fundamental for understanding galaxy evolution.

Aims. We explore the evolution of the statistical distribution of galaxy morphological properties and colours combining high-quality imaging data from the CFHT Legacy Survey with the large number of redshifts and extended photometry from the VIPERS survey.

Methods. Galaxy structural parameters were combined with absolute magnitudes, colours and redshifts in order to trace evolution in a multi-parameter space. Using a new method we analysed the combination of colours and structural parameters of early- and late-type galaxies in luminosity-redshift space.

Results. We find that both the rest-frame colour distributions in the $(U - B)$ vs. $(B - V)$ plane and the Sérsic index distributions are well fitted by a sum of two Gaussians, with a remarkable consistency of red-spheroidal and blue-disk galaxy populations, over the explored redshift $(0.5 < z < 1)$ and luminosity $(−1.5 < B − B_0 < 0.1)$ ranges. The combination of the rest-frame colour and Sérsic index as a function of redshift and luminosity allows us to present the structure of both galaxy types and their evolution. We find that early-type galaxies display only a slow change in their concentrations after $z = 1$. Their high concentrations were already established at $z \sim 1$ and depend much more strongly on their luminosity than redshift. In contrast, late-type galaxies clearly become more concentrated with cosmic time with only little evolution in colour, which remains dependent mainly on their luminosity.

Conclusions. The combination of rest-frame colours and Sérsic index as a function of redshift and luminosity leads to a precise statistical description of the structure of galaxies and their evolution. Additionally, the proposed method provides a robust way to split galaxies into early and late types.

Key words. cosmology: observations – galaxies: general – galaxies: structure – galaxies: evolution – galaxies: statistics

important extra value has been added to VIPERS by the morphological analysis of the CFHTLS images, which allowed us to obtain reliable Sérsic indexes and effective radii for the majority of the objects in the catalogue (Krywult et al., 2017)

Galaxy evolution
The VIMOS Public Extragalactic Redshift Survey (VIPERS)

Star formation history of passive red galaxies


Received 17 May 2016 / Accepted 2 November 2016

ABSTRACT

Aims. We trace the evolution and the star formation history of passive red galaxies, using a subset of the VIMOS Public Extragalactic Redshift Survey (VIPERS). The detailed spectral analysis of stellar populations of intermediate-redshift passive red galaxies allows the build up of their stellar content to be followed over the last 8 billion years.

Methods. We extracted a sample of passive red galaxies in the redshift range $0.4 < z < 1.0$ and stellar mass range $10 < M_{\text{star}}/M_{\odot} < 12$ from the VIPERS survey. The sample was selected using an evolving cut in the rest-frame $U - V$ color distribution and additional cuts that ensured high quality. The spectra of passive red galaxies were stacked in narrow bins of stellar mass and redshift. We use the stacked spectra to measure the 4000 Å break ($D4000$) and the Hα Lick index (Hα) with high precision. These spectral features are used as indicators of the star formation history of passive red galaxies. We compare the results with a grid of synthetic spectra to constrain the star formation epochs of these galaxies. We characterize the formation redshift-stellar mass relation for intermediate-redshift passive red galaxies.

Results. We find that at $z \sim 1$ stellar populations in low-mass passive red galaxies are younger than in high-mass passive red galaxies, similar to what is observed at the present epoch. Over the full analyzed redshift range $0.4 < z < 1.0$ and stellar mass range $10 < M_{\text{star}}/M_{\odot} < 12$, the $D4000$ index increases with redshift, while Hα gets lower. This implies that the stellar populations are getting older with increasing stellar mass. Comparison to the spectra of passive red galaxies in the SDSS survey ($z \sim 0.2$) shows that the shape of the relations of $D4000$ and Hα with stellar mass has not changed significantly with redshift. Assuming a single burst formation, this implies that high-mass passive red galaxies formed their stars at $z_{\text{form}} \sim 1.7$, while low-mass galaxies formed their main stellar populations more recently, at $z_{\text{form}} \sim 1$. The consistency of these results, which were obtained using two independent estimators of the formation redshift ($D4000$ and Hα), further strengthens a scenario in which star formation proceeds from higher to lower mass systems as time passes, i.e., what has become known as the downsizing picture.

Key words. galaxies: evolution – galaxies: stellar content
Our analysis confirms the downsizing scenario, as the redshift of formation increases with stellar mass, and massive galaxies have older stellar populations than less massive galaxies, with metallicity variations with stellar mass providing only a relatively minor perturbation to this overall evolutionary picture.

**Fig. 2.** Exemplary stacked spectrum of passive red galaxies taken from the VIPERS database in the wavelength range 3800–5000 Å. Blue shaded areas show the ranges used to evaluate the D4000, break. Red regions correspond to pseudocontinua for the HδA, while the hatched area shows the HδA bandpass.

**Fig. 12.** Mean epoch of the last starburst derived from the D4000, and HδA features estimated for VIPERS passive red galaxies observed at 0.4 < z < 1.0 as a function of stellar mass. Error bars represent the standard deviation within each stellar mass bin. Formation redshifts of stellar populations in intermediate-redshift passive red galaxies derived by Onodera et al. (2015), Jørgensen and Chiboucas (2013), and Moresc et al. (2010) are shown by black pentagon, stars, triangles, respectively. Redshifts of formation at which 50% of the stellar mass of SDSS ETGs was formed as computed by Thomas et al. (2010) are shown with gray circles. Errors correspond to the difference in z\text{form} of 50% and 80% of the stellar mass. Epochs of star formation in local quiescent galaxies established by Choi et al. (2014) are shown with gray diamonds.
The fraction of star-forming vs. passive galaxies is quantified as a function of local density revealing that it is higher in low-density regions and for the most massive galaxies at redshift approaching unity.
The paper revealing the developing bi-modality of galaxies into those whose optical light is still dominated by young stars (D4000 \sim 1.2; the blue cloud population) and the red sequence of old, passive galaxies (D4000 \sim 1.9).
The VIMOS Public Extragalactic Redshift Survey (VIPERS)

The distinct build-up of dense and normal massive passive galaxies


(Affiliations can be found after the references)

Received 22 November 2016 / Accepted 19 May 2017

ABSTRACT

We have used the final data from the VIPERS redshift survey to extract an unparalleled sample of more than 2000 massive \( M \geq 10^{11} M_\odot \) passive galaxies (MPGs) at redshift \( 0.5 \leq z \leq 1.0 \), based on their NUVrK colours. This has enabled us to investigate how the population of these objects was built up over cosmic time. We find that the evolution of the number density depends on the galaxy mean surface stellar mass density, \( \Sigma \). In particular, dense \(( \Sigma \geq 2000 M_\odot \text{ pc}^{-2})\) MPG show a constant comoving number density over this redshift range, whilst this increases by a factor of approximately four for the least dense objects, defined as having \( \Sigma < 1000 M_\odot \text{ pc}^{-2}\). We estimated stellar ages for the MPG population both fitting the spectral energy distribution (SED) and through the D4000_ index, obtaining results in good agreement. Our findings are consistent with passive ageing of the stellar content of dense MPGs. We show that at any redshift the less dense MPGs are younger than dense ones, and that their stellar populations evolve at a slower rate than predicted by passive evolution. This points to a scenario in which the overall population of MPGs was built up over the cosmic time by continuous addition of less dense galaxies; on top of an initial population of dense objects that passively evolves, new, larger, and younger MPGs continuously join the population at later epochs. Finally, we demonstrate that the observed increase in the number density of MPGs is totally accounted for by the observed decrease in the number density of correspondingly massive star forming galaxies (i.e. all the non-passive \( M \geq 10^{11} M_\odot \) objects). Such systems observed at \( z \approx 1 \) in VIPERS, therefore, represent the most plausible progenitors of the subsequent emerging class of larger MPGs.

Key words. galaxies: elliptical and lenticular, cD – galaxies: evolution – galaxies: formation – galaxies: high-redshift

The evolution of the number density of massive \(( > 10^{11} M_\odot)\) passive galaxies (MPGs) and their stellar population ages, separating objects by surface stellar mass density. With an unprecedented sample of about 2000 such galaxies, VIPERS provides a novel picture of how the current population of MPGs could have been formed.

Fig. 9. Evolution of the number density of MPGs (filled red circles) and of star forming massive galaxies (MSFGs, blue filled stars). Open circles show the expected growth in the abundance of MPGs below \( z < 0.8 \), assuming that this is fully due to the observed decline of MSFGs. Solid and open circles have been shifted for visualisation purposes.
SUMMARY – galaxy evolution

The description of the physical properties of VIPERS galaxies is significantly enhanced by the availability of a series of ancillary data. These data are combined to perform reliable spectral energy distribution (SED) fits and, in turn, estimate luminosities, colours and stellar masses. All these quantities, coupled to spectral information (like the amplitude of the 4000 Å break) and structural parameters from a morphological analysis (Krywult et al., 2017), have allowed us to look at the evolution of classic relationships observed at z ~ 0.
The VIMOS Public Extragalactic Redshift Survey (VIPERS)

The growth of structure at 0.5 < z < 1.2 from redshift-space distortions in the clustering of the PDR-2 final sample


(Affiliations can be found after the references)

Received 20 December 2016 / Accepted 19 May 2017

ABSTRACT

We present measurements of the growth rate of cosmological structure from the modelling of the anisotropic galaxy clustering measured in the final data release of the VIPERS survey. The analysis is carried out in configuration space and based on measurements of the first two even multipole moments of the anisotropic galaxy auto-correlation function, in two redshift bins spanning the range 0.5 < z < 1.2. We provide robust and cosmology-independent corrections for the VIPERS angular selection function, allowing recovery of the underlying clustering amplitude at the percent level down to the Mpc scale. We discuss several improvements on the non-linear modelling of redshift-space distortions (RSD) and perform detailed tests of a variety of approaches against a set of realistic VIPERS-like mock realisations. This includes using novel fitting functions to describe the velocity divergence and density power spectra $\sigma_8$ and $\sigma_0$ that appear in RSD models. These tests show that we are able to measure the growth rate with negligible bias down to separations of $5 h^{-1}$ Mpc. Interestingly, the application to real data shows a weaker sensitivity to the details of non-linear RSD corrections compared to mock results. We obtain consistent values for the growth rate times the matter power spectrum normalisation parameter of $\sigma_8 = 0.55 \pm 0.12$ and $0.40 \pm 0.11$ at effective redshifts of $z = 0.6$ and $z = 0.86$ respectively. These results are in agreement with standard cosmology predictions assuming Einstein gravity in a $\Lambda$CDM background.

Key words. cosmology: observations – large-scale structure of Universe – galaxies: high-redshift – galaxies: statistics

A first VIPERS estimate of the cosmic growth rate from redshift-space distortions was obtained from the PDR-1 data (de la Torre et al., 2013). Using the PDR-2 data, therefore, a series of RSD investigations using a variety of methods has been planned, some of which are still being completed. This paper present the measurement on the full sample with a focus on the required nonlinear corrections and investigate in detail the systematic effects present in the VIPERS data.
In this work, RSD investigations have been supplemented by measurements of galaxy-galaxy lensing performed on the parent photometric sample, the CFHTLS, allowing the growth rate of structure to be separated from the amplitude of matter fluctuations.
We find a signature of an increasing contribution of filamentary structures in the correlation function.

From the analysis of the connected 3CPF, $\zeta(\theta)$, we find that more massive and luminous galaxies present a stronger clustering, with a percentage difference of $\sim 20–40\%$ between the extreme bins, which is, however, not statistically relevant given the current uncertainties. These results confirm the ones obtained at lower redshifts in SDSS, and extend them, for the first time, up to $z \sim 1.1$. 
This Figure shows the estimate of the power spectrum of the galaxy distribution, $P(k)$, from four independent sub-samples of the VIPERS PDR-2 data over the redshift range $0.6 < z < 1.1$. At about half the Hubble time, this is the highest redshift where such a measure has been produced, straddling Planck and local measurements. This classic statistic contains information about the mean total density of matter in the Universe and the baryonic-to-dark matter fraction.
Abstract

We present the first quantitative detection of large-scale filamentary structure at $z \approx 0.7$ in the large cosmological volume probed by the VIMOS Public Extragalactic Redshift Survey (VIPERS). We use simulations to show the capability of VIPERS to recover robust topological features in the galaxy distribution, in particular the filamentary network. We then investigate how galaxies with different stellar masses and stellar activities are distributed around the filaments, and find a significant segregation, with the most massive or quiescent galaxies being closer to the filament axis than less massive or active galaxies. The signal persists even after downweighting the contribution of peak regions. Our results suggest that massive and quiescent galaxies assemble their stellar mass through successive mergers during their migration along filaments towards the nodes of the cosmic web. On the other hand, low-mass star-forming galaxies prefer the outer edge of filaments, a vorticity-rich region dominated by smooth accretion, as predicted by the recent spin alignment theory. This emphasizes the role of large-scale cosmic flows in shaping galaxy properties.
We reported the first characterization of large scale filamentary structures at $z \sim 0.7$, carried out in the cosmological volume probed by the VIPERS spectroscopic survey.

We observe a small but significant trend for galaxies with different stellar masses and stellar activity to segregate near the filaments with the most massive and/or passive galaxies being closer to filaments. The signal persists even after down-weighting the contribution of nodes and high density regions.

*Figure 2.* Projected distribution of the filaments reconstructed with DisPerSE (in dark green) in the VIPERS W1 (top panel) and W4 (bottom panel) fields between $0.4 \leq z \leq 1$. The density contrast, $\log(1 + \delta_{\text{vir}})$, is averaged on cells of $5 \times 5$ Mpc$^2$ and colour-coded as indicated (white for empty cells). *Top row:* projected distribution along the declination direction ($\Delta z = 2$). *Bottom row:* projected distribution along the right ascension direction (in the central regions with $\Delta z = 2$). 3D movies are available on the VIPERS website.
SUMMARY

VIPERS has opened the way to accurate statistical studies at $z > 0.5$, refining the scaling relationships that were only hinted at so far, owing to the limited size of deep samples, and enabling novel ways to look at the data, self-consistently modelling the galaxy properties and the underlying density field through a Bayesian approach.

- Aims: large scale structure, galaxy environments and galaxy properties at $0.5 < z < 1.2$, with accuracy comparable to local state-of-the-art surveys
- In order to:
  - probe the properties of dark energy from growth of structure
  - understand the evolution of the large scale structure from $z \sim 1$
  - link with high accuracy galaxy properties, environments and cosmic web
- Main results: MANY and more soon
- Great legacy value: full data set just got public!