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

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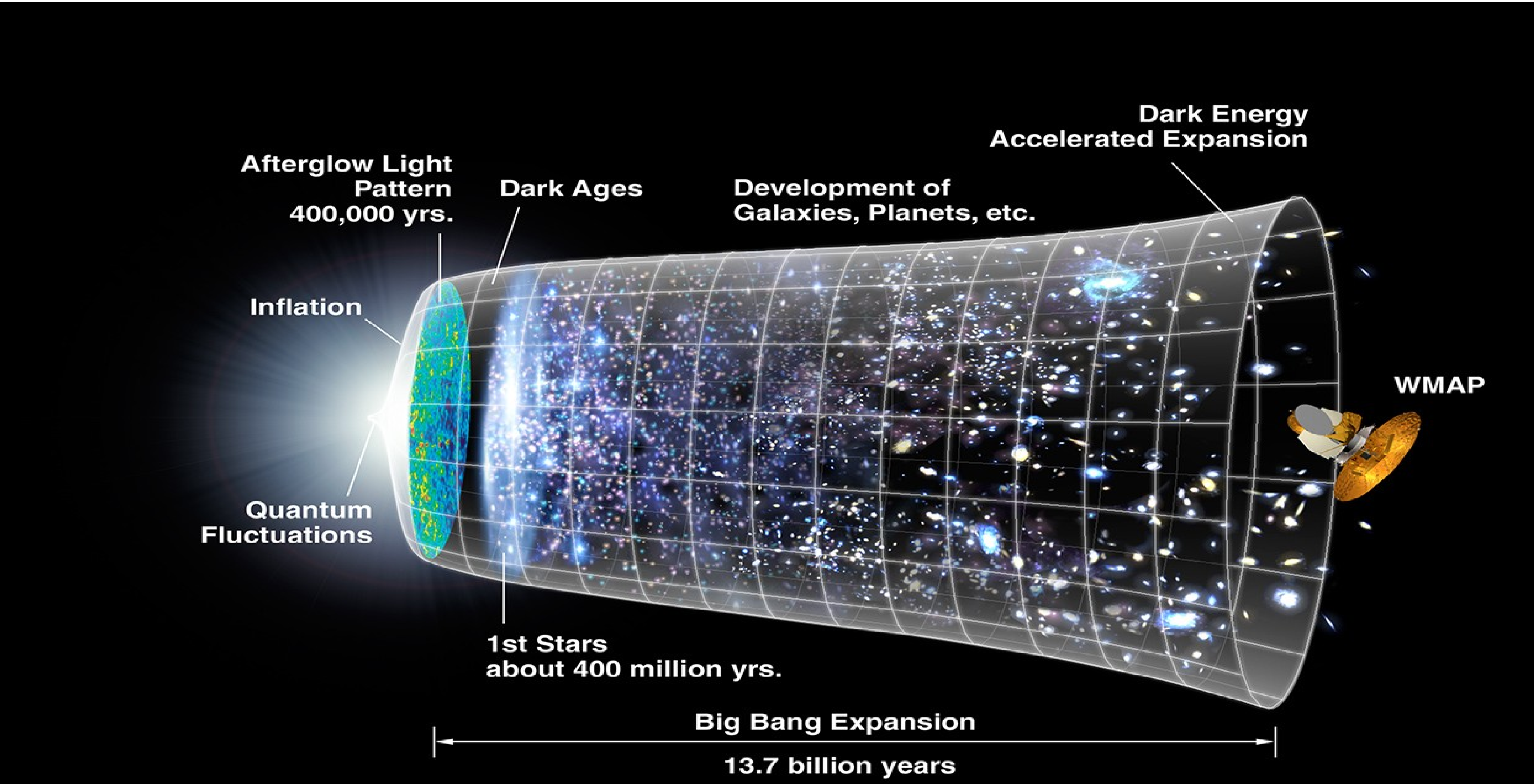
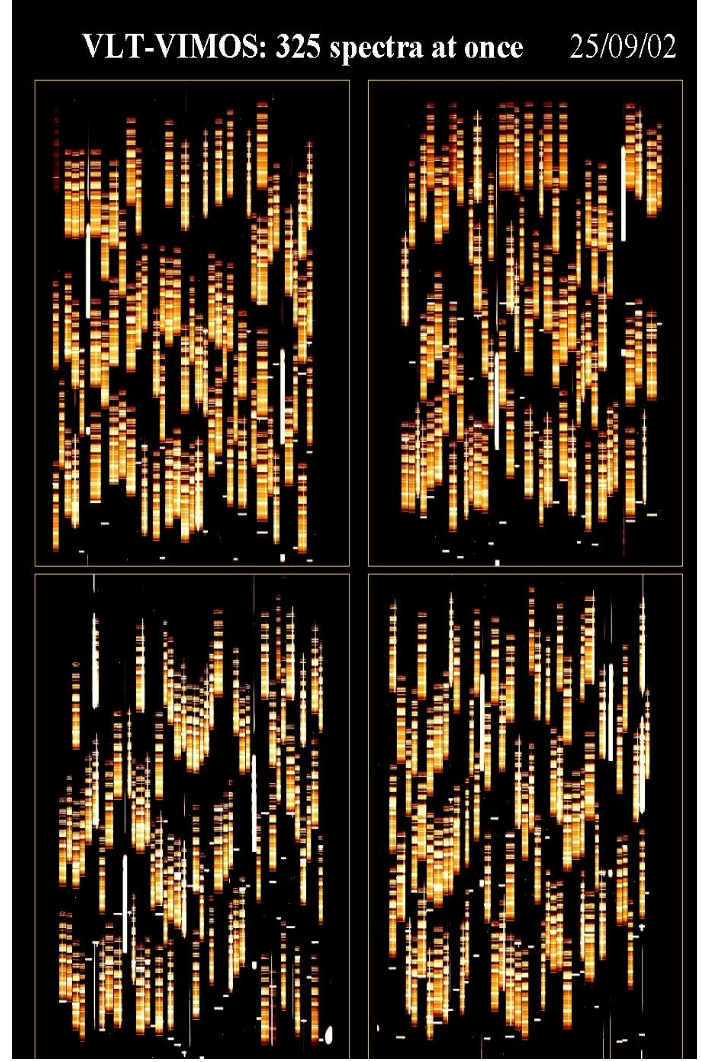



http://map.gsfc.nasa.gov/m_mm.html

VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY




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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- Luigi Paioro
- Stefanie Phleps
- Holger Schlagenhaufer
- Ola Solarz
- Melody Wolk

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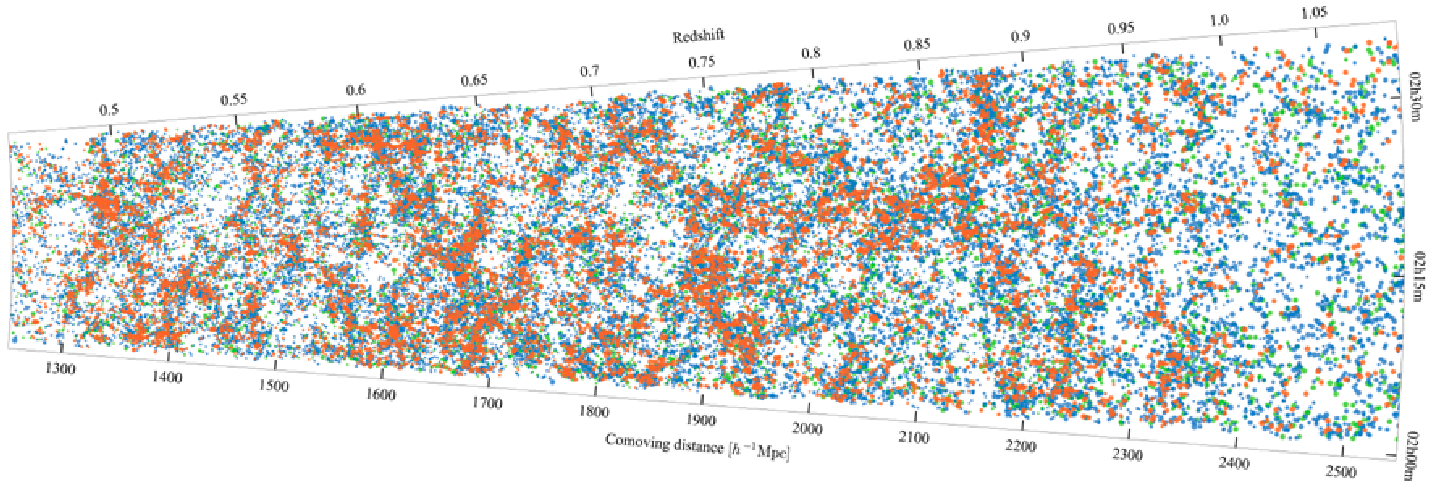
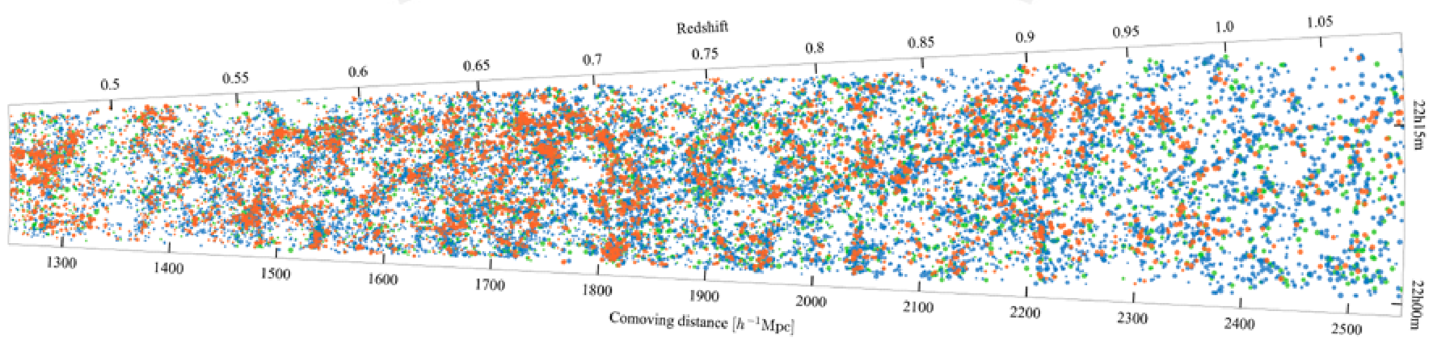
# Final public release of complete VIPERS galaxy catalogue of ~90,000 redshifts (PDR-2)

**- 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

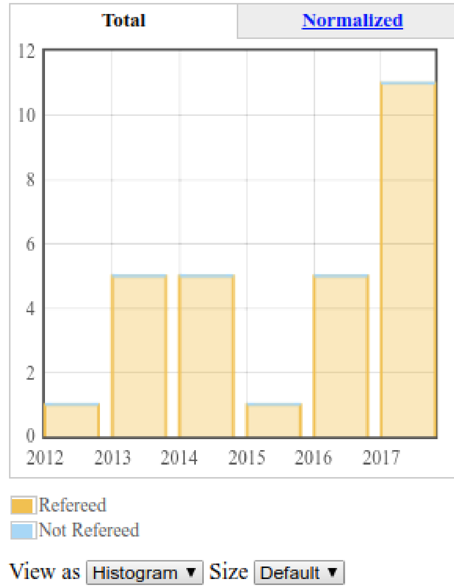
| Papers | | Total | Refereed |
|---|---|---|---|
| Number of papers | [?] | 28 | 28 |
| Normalized paper count | [?] | 0.9 | 0.9 |
| Total reads | [?] | 14,976 | 14,976 |
| Average reads | [?] | 534.9 | 534.9 |
| Median reads | [?] | 383.0 | 383.0 |
| Total downloads | [?] | 7,889 | 7,889 |
| Average downloads | [?] | 281.8 | 281.8 |
| Median downloads | [?] | 196.5 | 196.5 |

| Citations | | Total | Refereed |
|---|---|---|---|
| Number of citing papers | [?] | 490 | 490 |
| Total citations | [?] | 878 | 878 |
| Average citations | [?] | 31.4 | 31.4 |
| Median citations | [?] | 15.5 | 15.5 |
| Normalized citations | [?] | 22.7 | 22.7 |
| Refereed citations | [?] | 686 | 686 |
| Average refereed citations | [?] | 24.5 | 24.5 |
| Median refereed citations | [?] | 12.0 | 12.0 |
| Normalized refereed citations | [?] | 17.6 | 17.6 |

| Indices | | Total | Refereed |
|---|---|---|---|
| h-index | [?] | 14 | 14 |
| g-index | [?] | 28 | 28 |
| e-index | [?] | 24.2 | 24.2 |
| i10-index | [?] | 19 | 19 |
| tori index | [?] | 0.4 | 0.4 |
| riq index | [?] | 104 | 104 |
| m-index | [?] | 2.33 | 2.33 |

Export to xls

### Publications per year

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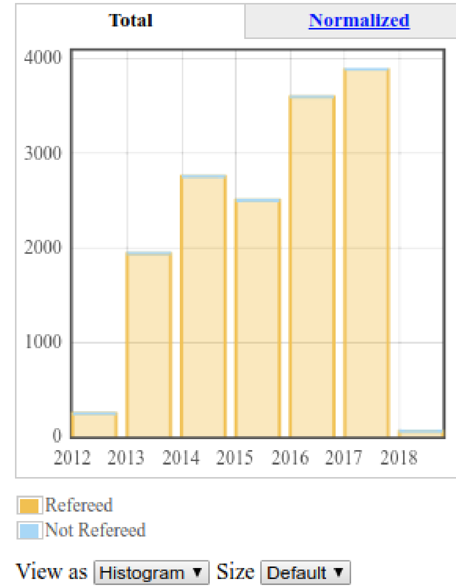
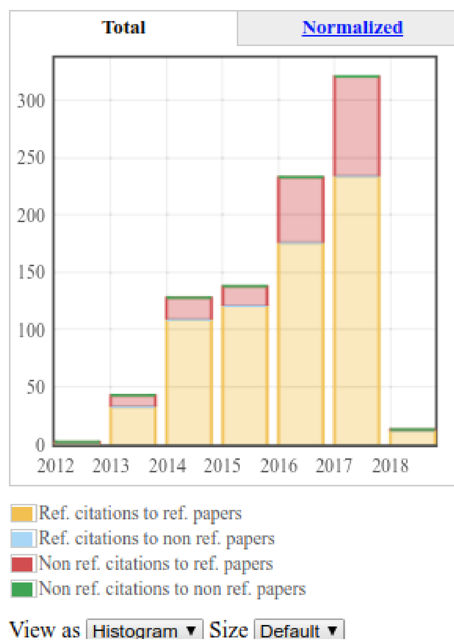
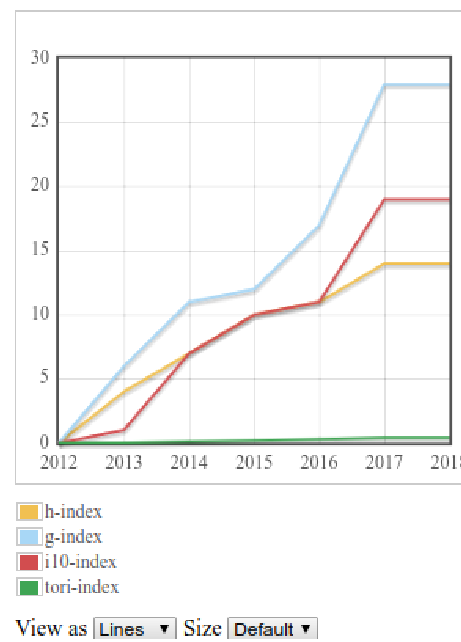



### Citations per year




### Indices



# The VIMOS Public Extragalactic Redshift Survey (VIPERS)

## PCA-based automatic cleaning and reconstruction of survey spectra★

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*(Affiliations can be found after the references)*

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# General

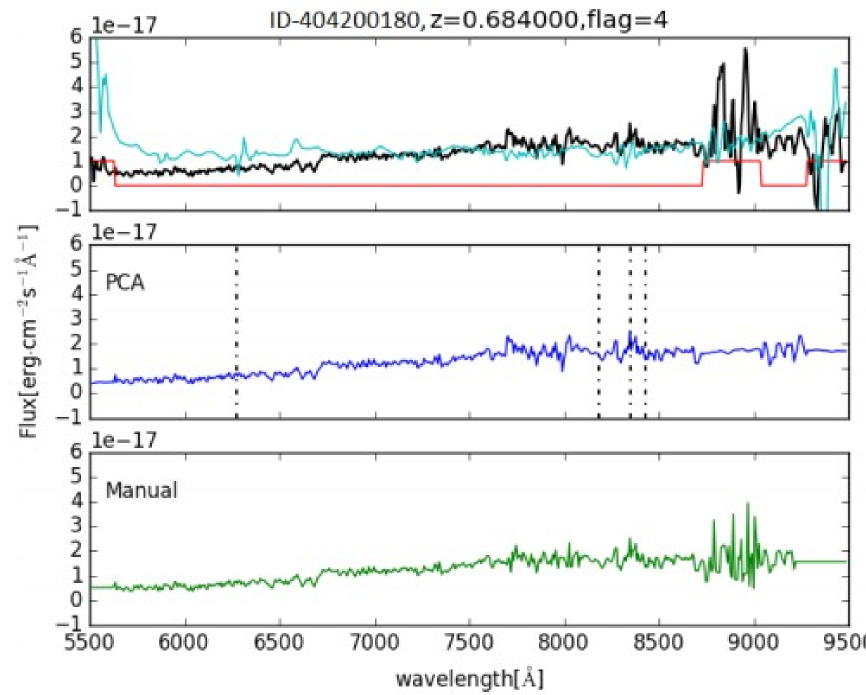
**ABSTRACT**

*Context.* Identifying spurious reduction artefacts in galaxy spectra is a challenge for large surveys.
*Aims.* We present an algorithm for identifying and repairing spurious residual features in sky-subtracted galaxy spectra by using data from the VIMOS Public Extragalactic Redshift Survey (VIPERS) as a test case.
*Methods.* The algorithm uses principal component analysis (PCA) applied to the galaxy spectra in the observed frame to identify sky line residuals imprinted at characteristic wavelengths. We further model the galaxy spectra in the rest-frame using PCA to estimate the most probable continuum in the corrupted spectral regions, which are then repaired.
*Results.* We apply the method to ~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).

**Key words.** galaxies: statistics – surveys – methods: statistical

We apply the method to ~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).

**Fig. 13.** Cleaning of a Flag 4 (*top*) and a Flag2 (*bottom*) VIPERS spectrum. For each panel: the *upper plot* is the observed (sky subtracted) spectrum (thick black), superposed to the mask (straight red lines) and the rescaled sky residuals spectrum (thin cyan); the *middle plot* shows the automatic cleaning, with the expected position of the [OII], Hβ and [OIII] lines marked in black by the dash-dotted lines; and the *bottom plot* is the manually edited spectrum.



# The VIMOS Public Extragalactic Redshift Survey (VIPERS)★,★★

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

J. Krywult[1], L. A. M. Tasca[2], A. Pollo[3,4], D. Vergani[5], M. Bolzonella[6], I. Davidzon[2,6], A. Iovino[7], A. Gargiulo[8], C. P. Haines[7], M. Scodeggio[8], L. Guzzo[7,9], G. Zamorani[6], B. Garilli[8], B. R. Granett[7], S. de la Torre[2], U. Abbas[10], C. Adami[2], D. Bottini[8], A. Cappi[6], O. Cucciati[6], P. Franzetti[8], A. Fritz[8], V. Le Brun[2], O. Le Fèvre[2], D. Maccagni[8], K. Małek[16], F. Marulli[17,18,6], M. Polletta[8,23], R. Tojeiro[21], A. Zanichelli[22], S. Arnouts[2], J. Bel[11], E. Branchini[12,13,14], J. Coupon[24], G. De Lucia[15], O. Ilbert[2], H. J. McCracken[19], L. Moscardini[17,18,6], and T. T. Takeuchi[20]

*(Affiliations can be found after the references)*

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**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.

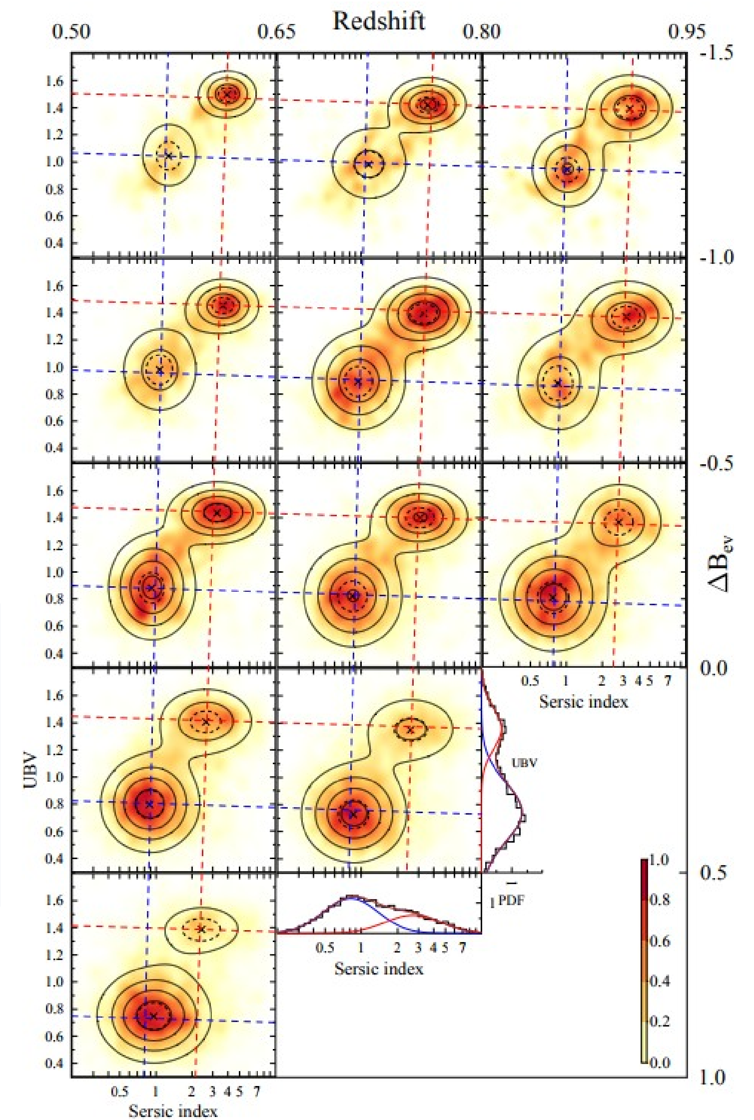
*Methods.* Galaxy structural parameters were combined with absolute magnitudes, colours and redshifts in order to trace evolution in a multi-parameter space. Using a new method we analysed the combination of colours and structural parameters of early- and late-type galaxies in luminosity-redshift space.

*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-disky galaxy populations, over the explored redshift ($0.5 < z < 1$) and luminosity ($-1.5 < B - B_* < 1.0$) 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

bimodality both in Sersic index and colors is seen at least up to z ~ 1.2, with a steeper evolution of a population of disk galaxies.




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

A&A 597, A107 (2017)
DOI: 10.1051/0004-6361/201628951


Astronomy & Astrophysics

# The VIMOS Public Extragalactic Redshift Survey (VIPERS)

## Star formation history of passive red galaxies★

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**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 $10 < \log(M_{\rm star}/M_{\odot}) < 12$ 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 H$\delta$ Lick index (H$\delta_A$) 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 $10 < \log(M_{\rm star}/M_{\odot}) < 12$, the $D4000$ index increases with redshift, while H$\delta_A$ 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 H$\delta_A$ 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 $z_{\rm form} \sim 1.7$, while low-mass galaxies formed their main stellar populations more recently, at $z_{\rm form} \sim 1$. The consistency of these results, which were obtained using two independent estimators of the formation redshift ($D4000$ and H$\delta_A$), 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

# Galaxy evolution

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.

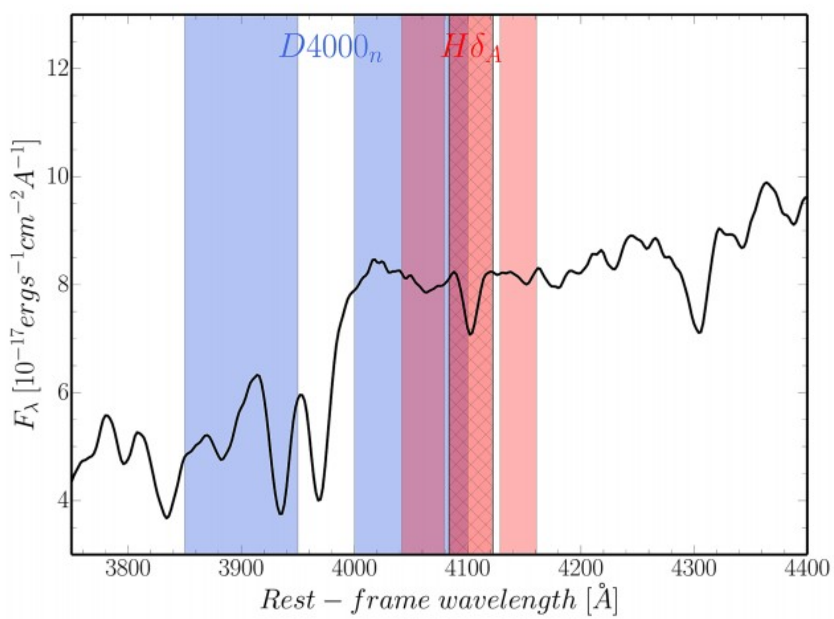


**Fig. 2.** Exemplary stacked spectrum of passive red galaxies taken from the VIPERS database in the wavelength range 3800–5000 Å. Blue shaded areas show the ranges used to evaluate the $D4000_n$ break. Red regions correspond to pseudocontinua for the $H\delta_A$, while the hatched area shows the $H\delta_A$ bandpass.

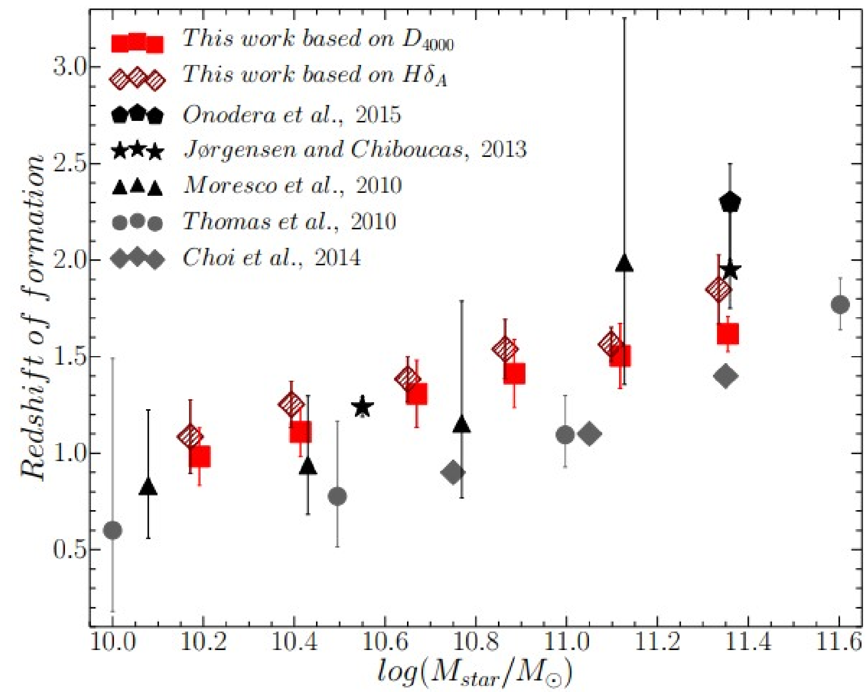


**Fig. 12.** Mean epoch of the last starburst derived from the $D4000_n$ and $H\delta_A$ features estimated for VIPERS passive red galaxies observed at $0.4 < z < 1.0$ as a function of stellar mass. Error bars represent the standard deviation within each stellar mass bin. Formation redshifts of stellar populations in intermediate-redshift passive red galaxies derived by Onodera et al. (2015), Jørgensen & Chiboucas (2013), and Moresco 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 $z_{\rm form}$ 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.

# Galaxy evolution

# The VIMOS Public Extragalactic Redshift Survey (VIPERS)

## The decline of cosmic star formation: quenching, mass, and environment connections*

O. Cucciati[1,2,**], I. Davidzon[3,1], M. Bolzonella[1], B. R. Granett[4,5], G. De Lucia[6], E. Branchini[7,8,9], G. Zamorani[1], A. Iovino[4], B. Garilli[10], L. Guzzo[4,5], M. Scodeggio[10], S. de la Torre[3], U. Abbas[11], C. Adami[3], S. Arnouts[3], D. Bottini[10], A. Cappi[1,12], P. Franzetti[10], A. Fritz[10], J. Krywult[13], V. Le Brun[3], O. Le Fèvre[3], D. Maccagni[10], K. Małek[14], F. Marulli[2,15,1], T. Moutard[16,3], M. Polletta[10,17,18], A. Pollo[14,19], L. A. M. Tasca[3], R. Tojeiro[20], D. Vergani[21], A. Zanichelli[22], J. Bel[23], J. Blaizot[24], J. Coupon[25], A. Hawken[4,5], O. Ilbert[3], L. Moscardini[2,15,1], J. A. Peacock[26], and A. Gargiulo[10]

*(Affiliations can be found after the references)*

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### ABSTRACT

We use the final data of the VIMOS Public Extragalactic Redshift Survey (VIPERS) to investigate the effect of the environment on the evolution of galaxies between $z = 0.5$ and $z = 0.9$. We characterise local environment in terms of the density contrast smoothed over a cylindrical kernel, the scale of which is defined by the distance to the fifth nearest neighbour. This is performed by using a volume-limited sub-sample of galaxies complete up to $z = 0.9$, but allows us to attach a value of local density to all galaxies in the full VIPERS magnitude-limited sample to $i < 22.5$. We use this information to estimate how the distribution of galaxy stellar masses depends on environment. More massive galaxies tend to reside in higher-density environments over the full redshift range explored. Defining star-forming and passive galaxies through their (NUV−$r$) vs. ($r - K$) colours, we then quantify the fraction of star-forming over passive galaxies, $f_{ap}$, as a function of environment at fixed stellar mass. $f_{ap}$ is higher in low-density regions for galaxies with masses ranging from $\log(\mathcal{M}/\mathcal{M}_\odot) = 10.38$ (the lowest value explored) to at least $\log(\mathcal{M}/\mathcal{M}_\odot) \sim 11.3$, although with decreasing significance going from lower to higher masses. This is the first time that environmental effects on high-mass galaxies are clearly detected at redshifts as high as $z \sim 0.9$. We compared these results to VIPERS-like galaxy mock catalogues based on a widely used galaxy formation model. The model correctly reproduces $f_{ap}$ in low-density environments, but underpredicts it at high densities. The discrepancy is particularly strong for the lowest-mass bins. We find that this discrepancy is driven by an excess of low-mass passive satellite galaxies in the model. In high-density regions, we obtain a better (although not perfect) agreement of the model $f_{ap}$ with observations by studying the accretion history of these model galaxies (that is, the times when they become satellites), by assuming either that a non-negligible fraction of satellites is destroyed, or that their quenching timescale is longer than ~2 Gyr.

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

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.

# Galaxy evolution

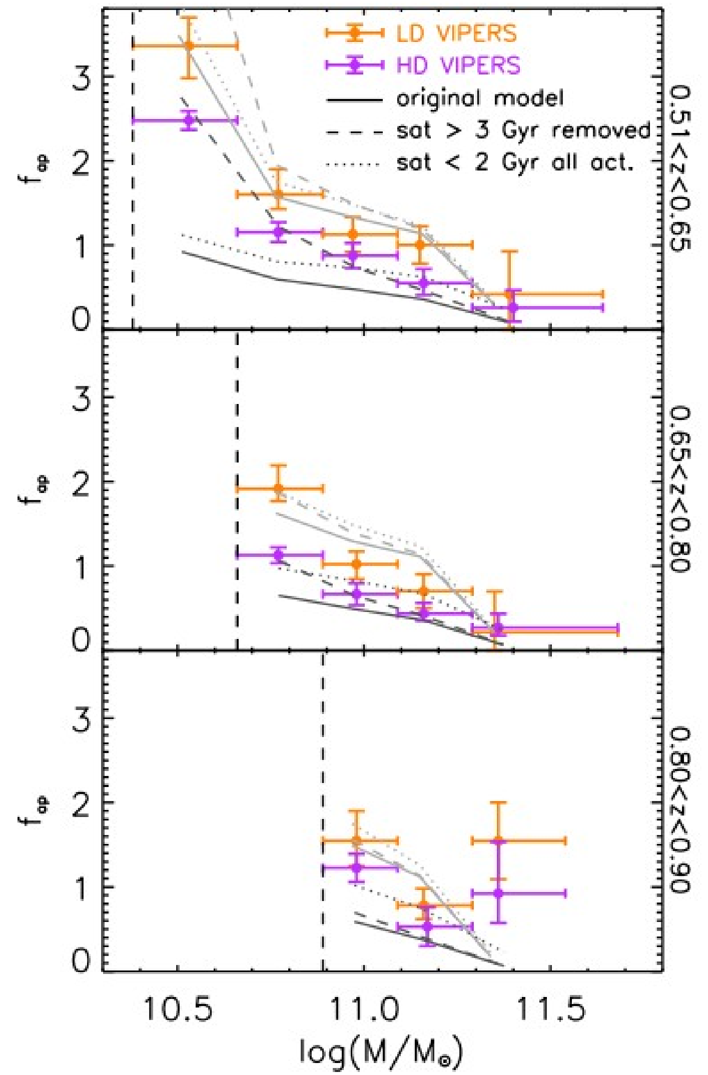


**Fig. 9.** Fraction $f_{ap}$ in the VIPERS data (orange and violet crosses) a
in the model (grey lines). Crosses are the same as in Fig. 7. Solid gr
lines refer to RMOCKS and correspond to the grey polygons of Fig.
Dashed lines refer to RMOCKS, but are computed after removing sat
lite galaxies that became satellites more than 3 Gyr before. The dott
lines refer to RMOCKS, but are computed considering all the "youn
satellite galaxies (i.e., that became satellites less than 2 Gyr before)
be active. See the text for more details.

# The VIMOS Public Extragalactic Redshift Survey (VIPERS)

## Downsizing of the blue cloud and the influence of galaxy size on mass quenching over the last eight billion years★

C. P. Haines[1], A. Iovino[1], J. Krywult[2], L. Guzzo[1,3], I. Davidzon[4,5], M. Bolzonella[5], B. Garilli[6], M. Scodeggio[6], B. R. Granett[1], S. de la Torre[4], G. De Lucia[7], U. Abbas[8], C. Adami[4], S. Arnouts[4,19], D. Bottini[6], A. Cappi[5,10], O. Cucciati[9,5], P. Franzetti[6], A. Fritz[6], A. Gargiulo[6], V. Le Brun[4], O. Le Fèvre[4], D. Maccagni[6], K. Małek[11], F. Marulli[9,12,5], T. Moutard[25,4], M. Polletta[6,13,14], A. Pollo[15,11], L. A. M. Tasca[4], R. Tojeiro[16], D. Vergani[17,5], A. Zanichelli[18], G. Zamorani[5], J. Bel[20], E. Branchini[21,22,23], J. Coupon[24], O. Ilbert[4], L. Moscardini[9,12,5], J. A. Peacock[26], and M. Siudek[27]

*(Affiliations can be found after the references)*

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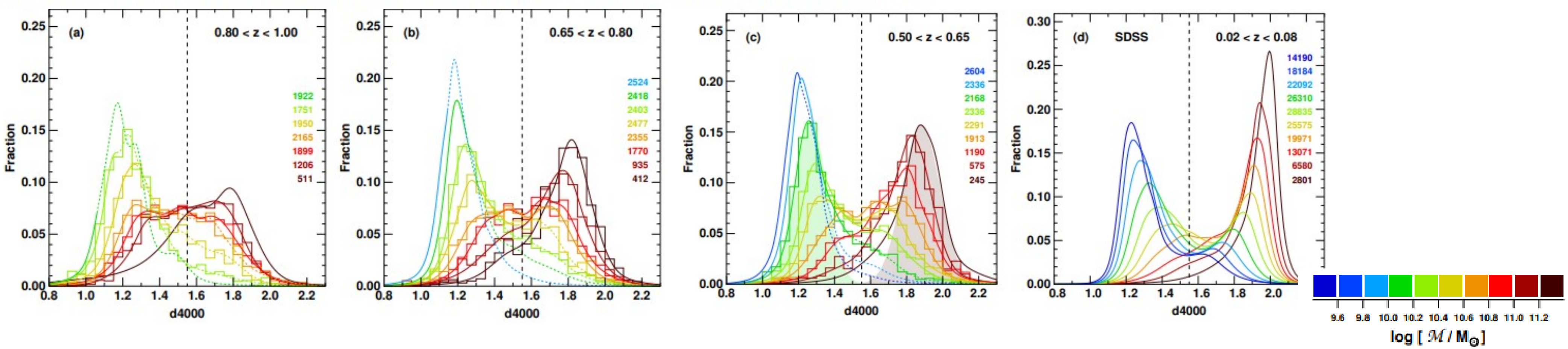
The paper revealing the developing bi-modality of galaxies into those whose optical light is still dominated by young stars (D4000 ~ 1.2; the blue cloud population) and the red sequence of old, passive galaxies (D4000 ~ 1.9).

# Galaxy evolution

**ABSTRACT**

We use the full VIPERS redshift survey in combination with SDSS-DR7 to explore the relationships between star-formation history (using d4000), stellar mass and galaxy structure, and how these relationships have evolved since $z \sim 1$. We trace the extents and evolutions of both the blue cloud and red sequence by fitting double Gaussians to the d4000 distribution of galaxies in narrow stellar mass bins, for four redshift intervals over $0 < z < 1$. This reveals downsizing in star formation, since the high-mass limit of the blue cloud has retreated steadily with time from $\mathcal{M} \sim 10^{11.2} M_\odot$ at $z \sim 0.9$ to $\mathcal{M} \sim 10^{10.7} M_\odot$ by the present day. The number density of massive blue-cloud galaxies ($\mathcal{M} > 10^{11} M_\odot$, d4000 < 1.55) drops sharply by a factor five between $z \sim 0.8$ and $z \sim 0.5$. These galaxies are becoming quiescent at a rate that largely matches the increase in the numbers of massive passive galaxies seen over this period. We examine the size-mass relation of blue-cloud galaxies, finding that its high-mass boundary runs along lines of constant $\mathcal{M}/r_e$ or equivalently inferred velocity dispersion. Larger galaxies can continue to form stars to higher stellar masses than smaller galaxies. As blue-cloud galaxies approach this high-mass limit, entering a narrow diagonal region within the size-mass plane termed the "quenching zone", they start to be quenched, their d4000 values increasing to push them towards the green valley. In parallel, their structures change, showing higher Sérsic indices and central stellar mass densities. For these galaxies, bulge growth is required for them to reach the high-mass limit of the blue cloud and be quenched by internal mechanisms. The blue-cloud galaxies that are being quenched at $z \sim 0.8$ lie along the same size-mass relation as present day quiescent galaxies and seem the likely progenitors of today's S0s.



## The VIMOS Public Extragalactic Redshift Survey (VIPERS)

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

A. Gargiulo[1], M. Bolzonella[2], M. Scodeggio[1], J. Krywult[3], G. De Lucia[4], L. Guzzo[5,6], B. Garilli[1], B. R. Granett[5,6], S. de la Torre[7], U. Abbas[8], C. Adami[7], S. Arnouts[7], D. Bottini[1], A. Cappi[2,9], O. Cucciati[2,10], I. Davidzon[7,2], P. Franzetti[1], A. Fritz[1], C. Haines[5], A. J. Hawken[5,6], A. Iovino[5], V. Le Brun[7], O. Le Fèvre[7], D. Maccagni[1], K. Małek[11], F. Marulli[10,12,2], T. Moutard[13,7], M. Polletta[1,14,15], A. Pollo[11,16], L. A. M. Tasca[7], R. Tojeiro[17], D. Vergani[18], A. Zanichelli[19], G. Zamorani[2], J. Bel[20], E. Branchini[21,22,23], J. Coupon[24], O. Ilbert[7], L. Moscardini[10,12,2], and J. A. Peacock[25]

*(Affiliations can be found after the references)*

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# Galaxy evolution

**ABSTRACT**

We have used the final data from the VIPERS redshift survey to extract an unparalleled sample of more than 2000 massive $\mathcal{M} \geq 10^{11}\,M_\odot$ passive galaxies (MPGs) at redshift $0.5 \leq z \leq 1.0$, based on their NUV$rK$ 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 ($\Sigma \geq 2000\,M_\odot\,\mathrm{pc}^{-2}$) MPGs 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 $\Sigma < 1000\,M_\odot\,\mathrm{pc}^{-2}$. We estimated stellar ages for the MPG population both fitting the spectral energy distribution (SED) and through the D4000$_n$ 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 $\mathcal{M} \geq 10^{11}\,M_\odot$ objects). Such systems observed at $z \simeq 1$ 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⊙) 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.

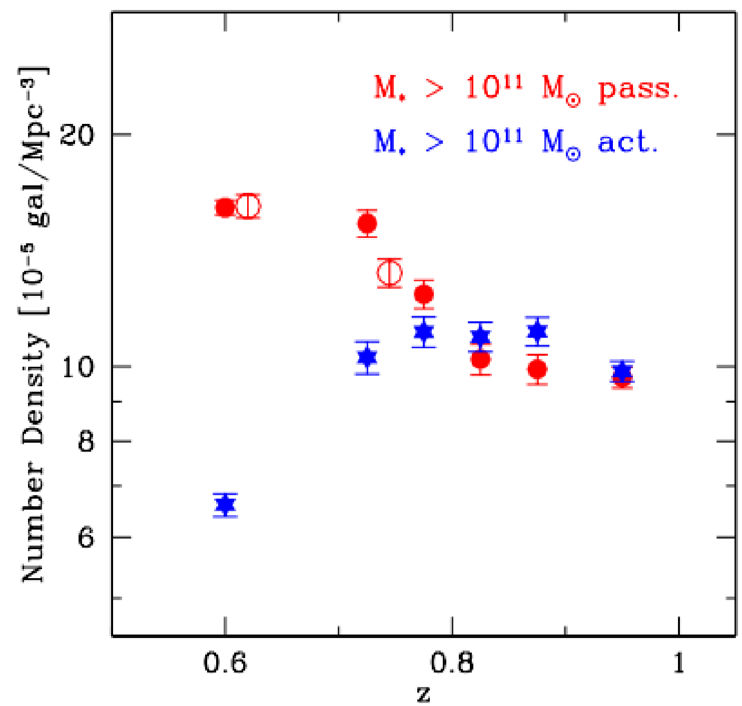


**Fig. 9.** Evolution of the number density of MPGs (filled red circles) and of star forming massive galaxies (MSFGs, blue filled stars). Open circles show the expected growth in the abundance of MPGs below $z < 0.8$, assuming that this is fully due to the observed decline of MSFGs. Solid and open circles 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 $z \sim 0$.

# Clustering

## 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*

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*(Affiliations can be found after the references)*

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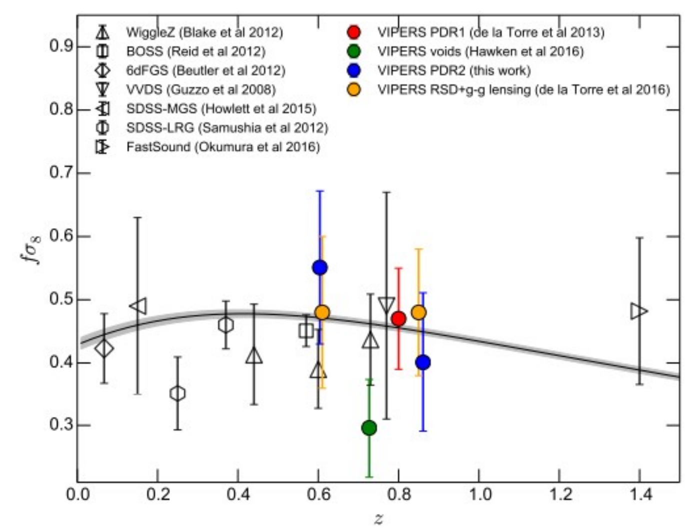
**ABSTRACT**

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 $P_{\theta\theta}$ and $P_{\delta\theta}$ 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 $f\sigma_8 = 0.55 \pm 0.12$ 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 ΛCDM 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.

**Fig. 19.** Plot of $f\sigma_8$ vs. redshift, showing the VIPERS results together with a compilation of recent measurements. The previous results from the VVDS (Guzzo et al. 2008), SDSS-MGS (Howlett et al. 2015), SDSS-LRG (Samushia et al. 2012), WiggleZ (Blake et al. 2012), BOSS (Reid et al. 2012), 6dFGS (Beutler et al. 2012), and FastSound (Okumura et al. 2016) surveys are shown with the different symbols (see inset). The solid curve and associated error correspond to the prediction for general relativity in a ΛCDM model set to Planck 2015 cosmological parameters (Planck Collaboration XIII 2016).



# Clustering

## The VIMOS Public Extragalactic Redshift Survey (VIPERS)

### Gravity test from the combination of redshift-space distortions and galaxy-galaxy lensing at $0.5 < z < 1.2$★

S. de la Torre[1], E. Jullo[1], C. Giocoli[1], A. Pezzotta[2,3], J. Bel[4], B. R. Granett[2], L. Guzzo[2,5], B. Garilli[6], M. Scodeggio[6], M. Bolzonella[7], U. Abbas[8], C. Adami[1], D. Bottini[6], A. Cappi[7,9], O. Cucciati[10,7], I. Davidzon[1,7], P. Franzetti[6], A. Fritz[6], A. Iovino[2], J. Krywult[11], V. Le Brun[1], O. Le Fèvre[1], D. Maccagni[6], K. Małek[12], F. Marulli[10,13,7], M. Polletta[6,14,15], A. Pollo[12,16], L. A. M. Tasca[1], R. Tojeiro[17], D. Vergani[18], A. Zanichelli[19], S. Arnouts[1], E. Branchini[20,21,22], J. Coupon[23], G. De Lucia[24], O. Ilbert[1], T. Moutard[25,1], L. Moscardini[10,13,7], J. A. Peacock[26], R. B. Metcalf[10], F. Prada[27,28,29], and G. Yepes[30]

*(Affiliations can be found after the references)*

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**ABSTRACT**

We carry out a joint analysis of redshift-space distortions and galaxy-galaxy lensing, with the aim of measuring the growth rate of structure; this is a key quantity for understanding the nature of gravity on cosmological scales and late-time cosmic acceleration. We make use of the final VIPERS redshift survey dataset, which maps a portion of the Universe at a redshift of $z \simeq 0.8$, and the lensing data from the CFHTLenS survey over the same area of the sky. We build a consistent theoretical model that combines non-linear galaxy biasing and redshift-space distortion models, and confront it with observations. The two probes are combined in a Bayesian maximum likelihood analysis to determine the growth rate of structure at two redshifts $z = 0.6$ and $z = 0.86$. We obtain measurements of $f\sigma_8(0.6) = 0.48 \pm 0.12$ and $f\sigma_8(0.86) = 0.48 \pm 0.10$. The additional galaxy-galaxy lensing constraint alleviates galaxy bias and $\sigma_8$ degeneracies, providing direct measurements of $f$ and $\sigma_8$: $[f(0.6), \sigma_8(0.6)] = [0.93 \pm 0.22, 0.52 \pm 0.06]$ and $[f(0.86), \sigma_8(0.86)] = [0.99 \pm 0.19, 0.48 \pm 0.04]$. These measurements are statistically consistent with a Universe where the gravitational interactions can be described by General Relativity, although they are not yet accurate enough to rule out some commonly considered alternatives. Finally, as a complementary test we measure the gravitational slip parameter, $E_G$, for the first time at $z > 0.6$. We find values of $\overline{E}_G(0.6) = 0.16 \pm 0.09$ and $\overline{E}_G(0.86) = 0.09 \pm 0.07$, when $E_G$ is averaged over scales above $3\,h^{-1}$ Mpc. We find that our $E_G$ measurements exhibit slightly lower values than expected for standard relativistic gravity in a ΛCDM background, although the results are consistent within $1{-}2\sigma$.

**Key words.** large-scale structure of Universe – cosmology: observations – cosmological paramet

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

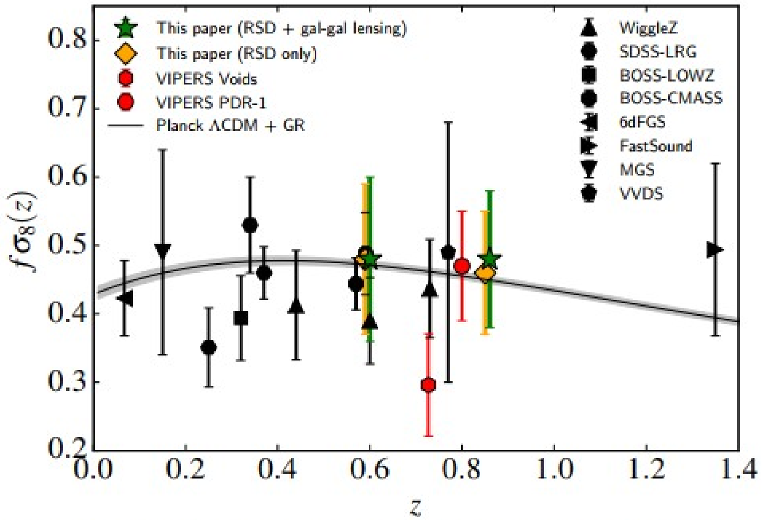


**Fig. 13.** $f\sigma_8$ as a function of redshift, showing VIPERS results contrasted with a compilation of recent measurements. The previous results from VVDS (Guzzo et al. 2008), SDSS LRG (Cabré & Gaztañaga 2009; Samushia et al. 2012), WiggleZ (Blake et al. 2012), 6dFGS (Beutler et al. 2012), VIPERS PDR-1 (de la Torre et al. 2013), MGS (Howlett et al. 2015), FastSound (Okumura et al. 2016), BOSS-LOWZ (Gil-Marín et al. 2016), BOSS-CMASS (Gil-Marín et al. 2016; Chuang et al. 2016), and VIPERS PDR-2 voids (Hawken et al. 2017) are shown with the different symbols (see labels). The solid curve and associated shaded area correspond to the expectations and 68% uncertainty for General Relativity in a ΛCDM background model set to TT+lowP+lensing *Planck* 2015 predictions (Planck Collaboration XIII 2016).

## The VIMOS Public Extragalactic Redshift Survey (VIPERS)

### Exploring the dependence of the three-point correlation function on stellar mass and luminosity at $0.5 < z < 1.1$ ★

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*(Affiliations can be found after the references)*

Received 24 March 2016 / Accepted 14 April 2017

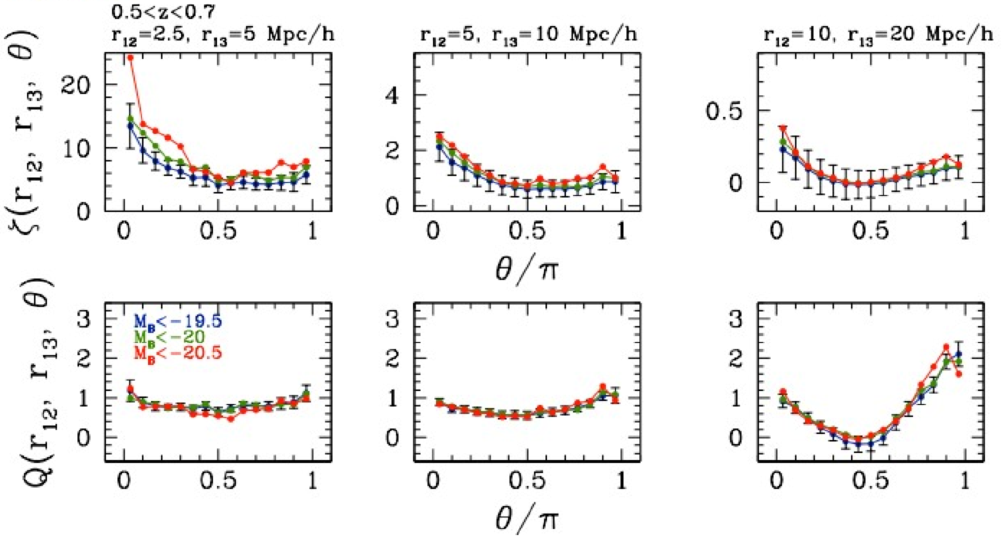
**ABSTRACT**

*Aims.* The three-point correlation function (3PCF) is a powerful probe to investigate the clustering of matter in the Universe in a complementary way with respect to lower-order statistics, providing additional information with respect to the two-point correlation function and allowing us to shed light on biasing, non-linear processes, and deviations from Gaussian statistics. In this paper, we analyse the first data release of the VIMOS Public Extragalactic Redshift Survey (VIPERS), determining the dependence of the three-point correlation function on luminosity and stellar mass at $z = [0.5, 1.1]$.

*Methods.* We exploit the VIPERS Public Data Release 1, consisting of more than 50 000 galaxies with $B$-band magnitudes in the range $-21.6 \lesssim M_B - 5\log(h) \lesssim -19.9$ and stellar masses in the range $9.8 \lesssim \log(M_\star[h^{-2} M_\odot]) \lesssim 10.7$. We measure both the connected 3PCF and the reduced 3PCF in redshift space, probing different configurations and scales, in the range $2.5 < r\,[h^{-1}\,\mathrm{Mpc}] < 20$.

*Results.* We find a significant dependence of the reduced 3PCF on scales and triangle shapes, with stronger anisotropy at larger scales ($r \sim 10\,h^{-1}$ Mpc) and an almost flat trend at smaller scales, $r \sim 2.5\,h^{-1}$ Mpc. Massive and luminous galaxies present a larger connected 3PCF, while the reduced 3PCF is remarkably insensitive to magnitude and stellar masses in the range we explored. These trends, already observed at low redshifts, are confirmed for the first time to be still valid up to $z = 1.1$, providing support to the hierarchical scenario for which massive and bright systems are expected to be more clustered. The possibility of using the measured 3PCF to provide independent constraints on the linear galaxy bias $b$ has also been explored, showing promising results in agreement with other probes.

**Fig. 6.** Redshift-space connected 3PCF (*upper panels*) and reduced 3PCF (*lower panels*) as a function of luminosity at redshift $0.5 < z < 0.7$ for different scales. Different colours show the measurements in the lower (blue), intermediate (green), and higher (red) threshold bins. For clarity reason, error-bars are shown only in the lower bin.




We find a signature of an increasing contribution of filamentary structures in the correlation function.

From the analysis of the connected 3CPF, ζ(θ), we find that more massive and luminous galaxies present a stronger clustering, with a percentage difference of ∼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 ∼ 1.1.

**Clustering**

# Clustering

## The VIMOS Public Extragalactic Redshift Survey (VIPERS)

### The matter density and baryon fraction from the galaxy power spectrum at redshift 0.6 < z < 1.1*

S. Rota[1,2], B. R. Granett[2,3], J. Bel[4], L. Guzzo[2,3], J. A. Peacock[5], M. J. Wilson[5], A. Pezzotta[2,6], S. de la Torre[7], B. Garilli[1], M. Bolzonella[8], M. Scodeggio[1], U. Abbas[9], C. Adami[7], D. Bottini[1], A. Cappi[8,10], O. Cucciati[11,8], I. Davidzon[7,8], P. Franzetti[1], A. Fritz[1], A. Iovino[2], J. Krywult[12], V. Le Brun[7], O. Le Fèvre[7], D. Maccagni[1], K. Małek[13], F. Marulli[11,14,8], W. J. Percival[15], M. Polletta[1,16,17], A. Pollo[13,18], L. A. M. Tasca[7], R. Tojeiro[15], D. Vergani[19], A. Zanichelli[20], S. Arnouts[7], E. Branchini[21,22,23], J. Coupon[24], G. De Lucia[25], O. Ilbert[7], L. Moscardini[11,14,8], and T. Moutard[26,7]

*(Affiliations can be found after the references)*

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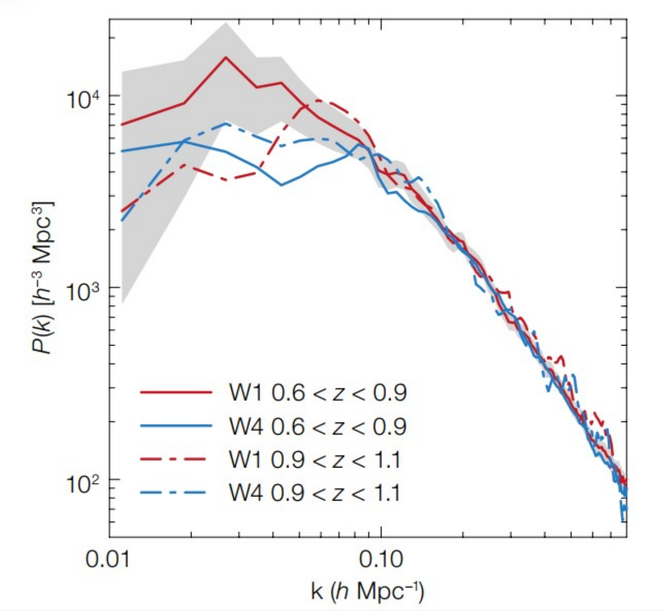
**ABSTRACT**

We use the final catalogue of the VIMOS Public Extragalactic Redshift Survey (VIPERS) to measure the power spectrum of the galaxy distribution at high redshift, presenting results that extend beyond $z = 1$ for the first time. We apply a fast Fourier transform technique to four independent subvolumes comprising a total of 51 728 galaxies at $0.6 < z < 1.1$ (out of the nearly 90 000 included in the whole survey). We concentrate here on the shape of the direction-averaged power spectrum in redshift space, explaining the level of modelling of redshift-space anisotropies and the anisotropic survey window function that are needed to deduce this in a robust fashion. We then use covariance matrices derived from a large ensemble of mock datasets in order to fit the spectral data. The results are well matched by a standard ΛCDM model, with density parameter $\Omega_M h = 0.227^{+0.063}_{-0.050}$ and baryon fraction $f_B = \Omega_B/\Omega_M = 0.220^{+0.058}_{-0.072}$. These inferences from the high-$z$ galaxy distribution are consistent with results from local galaxy surveys, and also with the cosmic microwave background. Thus the ΛCDM model gives a good match to cosmic structure at all redshifts currently accessible to observational study.

**Key words.** cosmological parameters – large-scale structure of Universe – galaxies: high-redshift – galaxies: statistics

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.



# The VIMOS Public Extragalactic Redshift Survey (VIPERS): galaxy segregation inside filaments at $z \simeq 0.7$

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**Published:** 05 November 2016 **Article history ▾**

## Abstract

We present the first quantitative detection of large-scale filamentary structure at $z \simeq 0.7$ 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.

Clustering

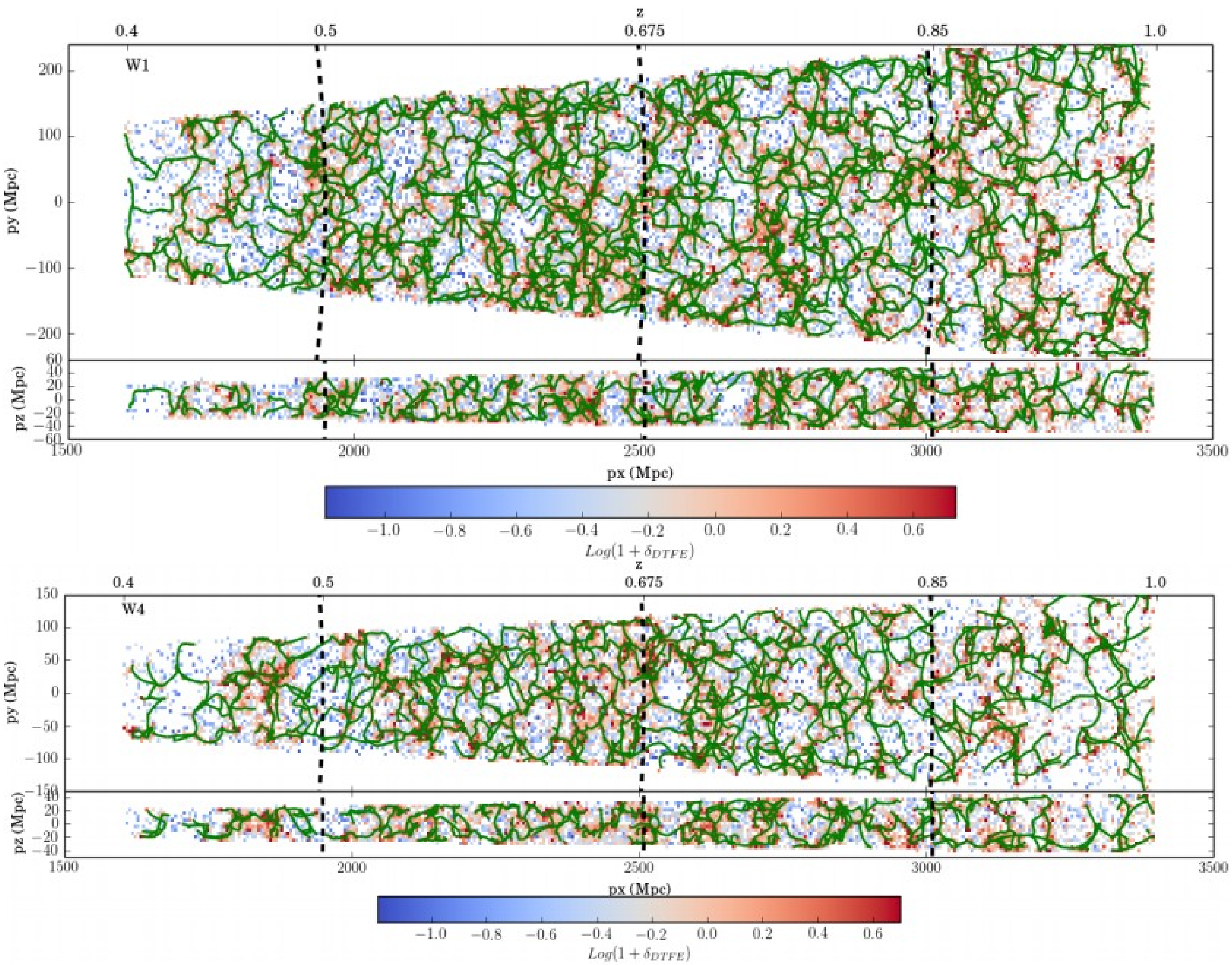


**Figure 2.** Projected distribution of the filaments reconstructed with DisPerSE (in dark green) in the VIPERS W1 (top panel) and W4 (bottom panel) fields between $0.4 \leq z \leq 1$. The density contrast, $\log(1 + \delta_{\mathrm{DTFE}})$, is averaged on cells of $5 \times 5$ $\mathrm{Mpc}^2$ and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

We reported the first characterization of large scale filamentary structures at z ~ 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.

# Clustering

# 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 $z\sim1$
  - 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!