Probing the Growth of Structure with Redshift-Space Distortions (with VIPERS and not only)

Luigi (Gigi) Guzzo

Osservatorio Astronomico di Brera, INAF, Merate/Milano

Outline

- Redshift-space distortions (RSD) an old tool in a new context: understanding the nature of cosmic acceleration

- Progress with the data: science and perspectives with early 50,000 redshift from the VIPERS project with the ESO VLT

- Progress with the methods: modelling RSD in the precision cosmology era

Lambda (or dark energy) may not be the end of the story…

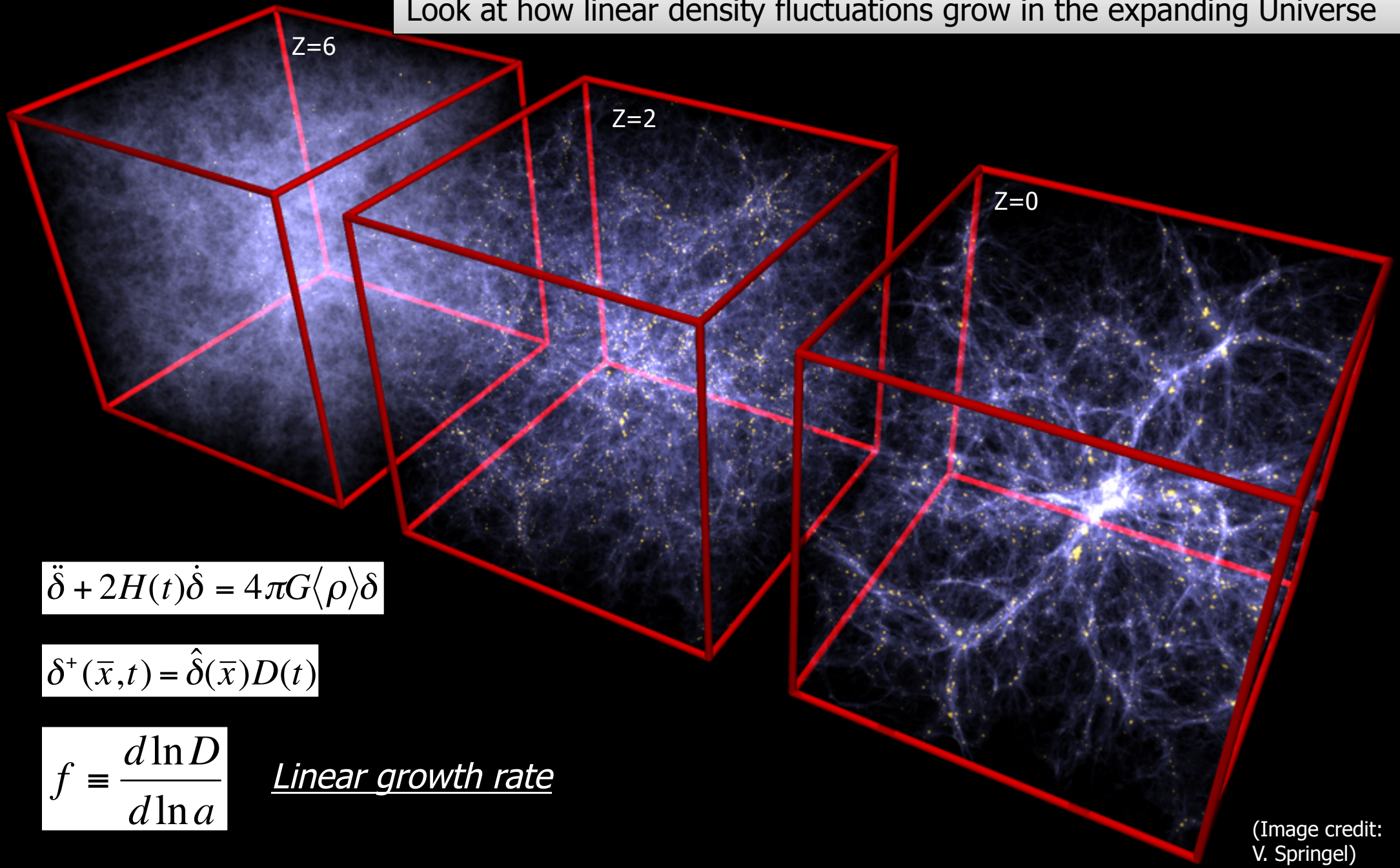
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Modify gravity theory [e.g. ***R*** → ***f(R)***]

"…the Force be with you"

Add dark energy

Look at how linear density fluctuations grow in the expanding Universe



$$\ddot{\delta} + 2H(t)\dot{\delta} = 4\pi G\langle\rho\rangle\delta$$

$$\delta^{+}(\bar{x},t) = \hat{\delta}(\bar{x})D(t)$$

$$f \equiv \frac{d\ln D}{d\ln a}$$

Linear growth rate

(Image credit: V. Springel)

Growth produces motions: galaxy peculiar velocities

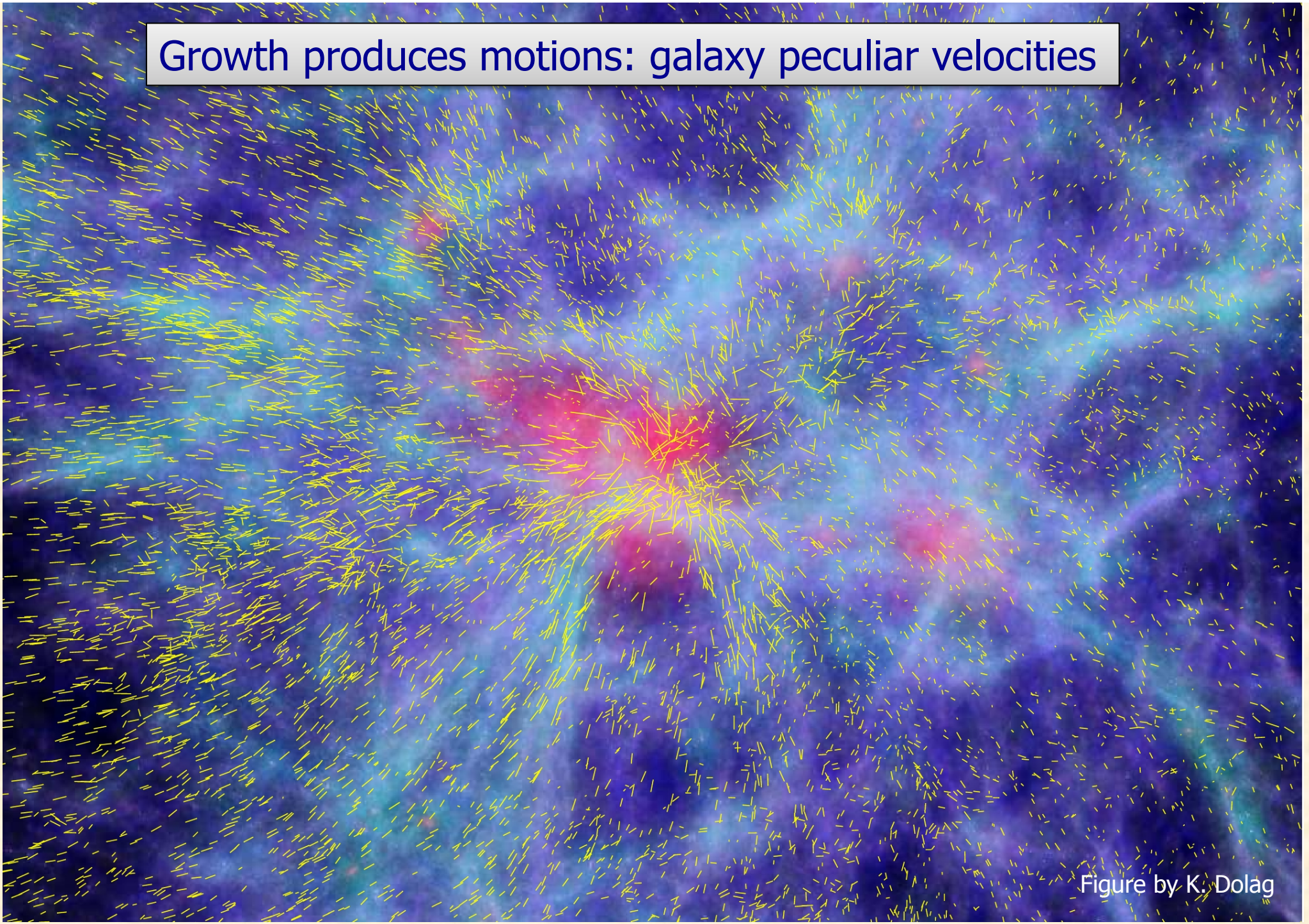


Figure by K. Dolag

2007/2008: the renaissance of Redshift-Space Distortions…

Mon. Not. R. astr. Soc. (1987) **227**, 1–21

Clustering in real space and in redshift space

1987

Nick Kaiser *Institute of Astronomy, University of Cambridge, Madingley R*
Cambridge CB3 0HA

Vol 451|31 January 2008|doi:10.1038/nature06555 nature

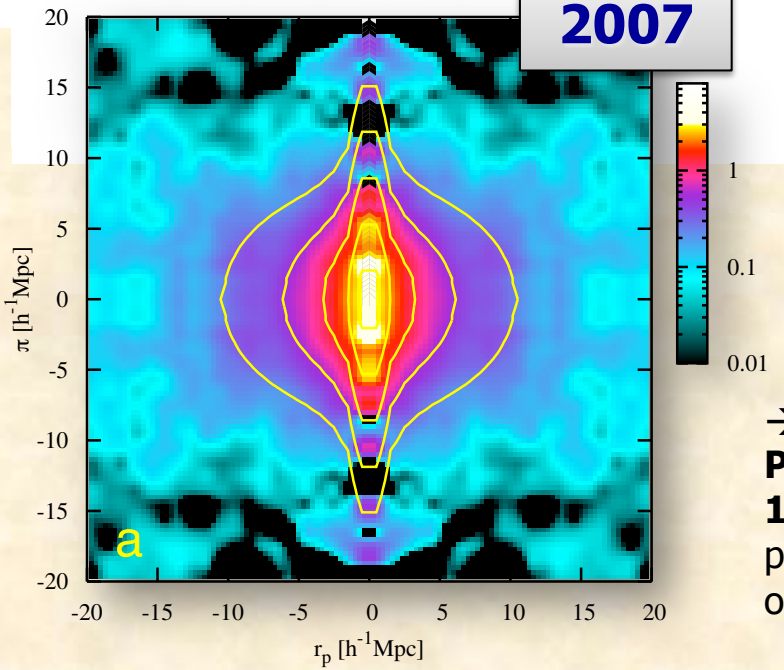
Nature 451, 541 (2008)

LETTERS

A test of the nature of cosmic acceleration using galaxy redshift distortions

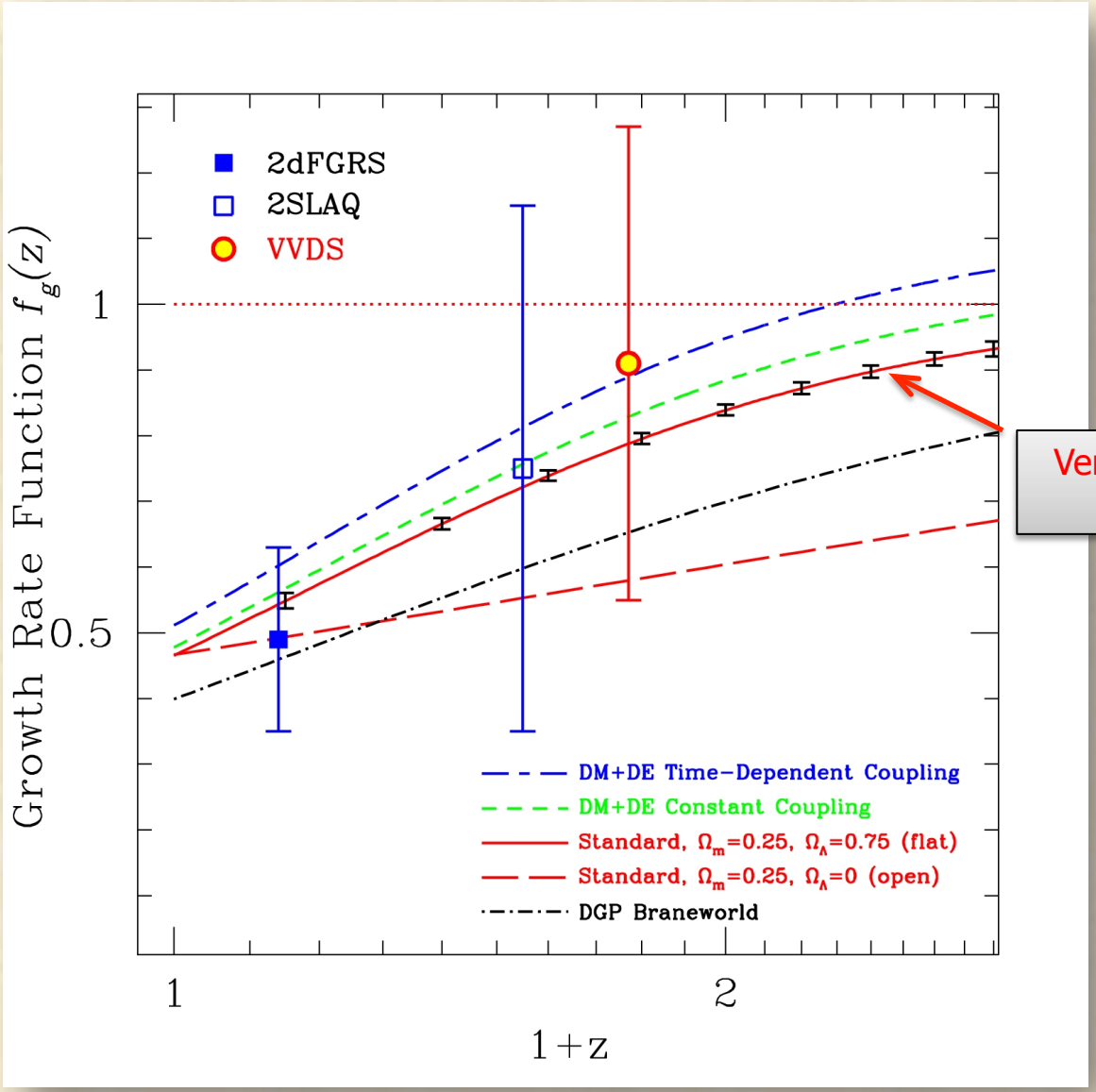
L. Guzzo[1,2,3,4], M. Pierleoni[3], B. Meneux[5], E. Branchini[6], O. Le Fèvre[7], C. Marinoni[8], B. Garilli[5], J. Blaizot[3], G. De Lucia[3], A. Pollo[7,9], H. J. McCracken[10,11], D. Bottini[5], V. Le Brun[7], D. Maccagni[5], J. P. Picat[12], R. Scaramella[13,14], M. Scodeggio[5], L. Tresse[7], G. Vettolani[13], A. Zanichelli[13], C. Adami[7], S. Arnouts[7], S. Bardelli[15], M. Bolzonella[15], A. Bongiorno[16], A. Cappi[15], S. Charlot[10], P. Ciliegi[15], T. Contini[12], O. Cucciati[1,17], S. de la Torre[7], K. Dolag[3], S. Foucaud[18], P. Franzetti[5], I. Gavignaud[19], O. Ilbert[20], A. Iovino[1], F. Lamareille[15], B. Marano[16], A. Mazure[7], P. Memeo[5], R. Merighi[15], L. Moscardini[16,21], S. Paltani[22,23], R. Pellò[12], E. Perez-Montero[12], L. Pozzetti[15], M. Radovich[24], D. Vergani[5], G. Zamorani[15] & E. Zucca[15]

2007



→ also **Zhang et al., Phys. Rev. Lett. 99, 141302 (2007)**, proposing combination of RSD and lensing

RSD at z~1 in 2007: slightly more than a proof of concept, but…



Very first Euclid-spectroscopy (SPACE) forecast

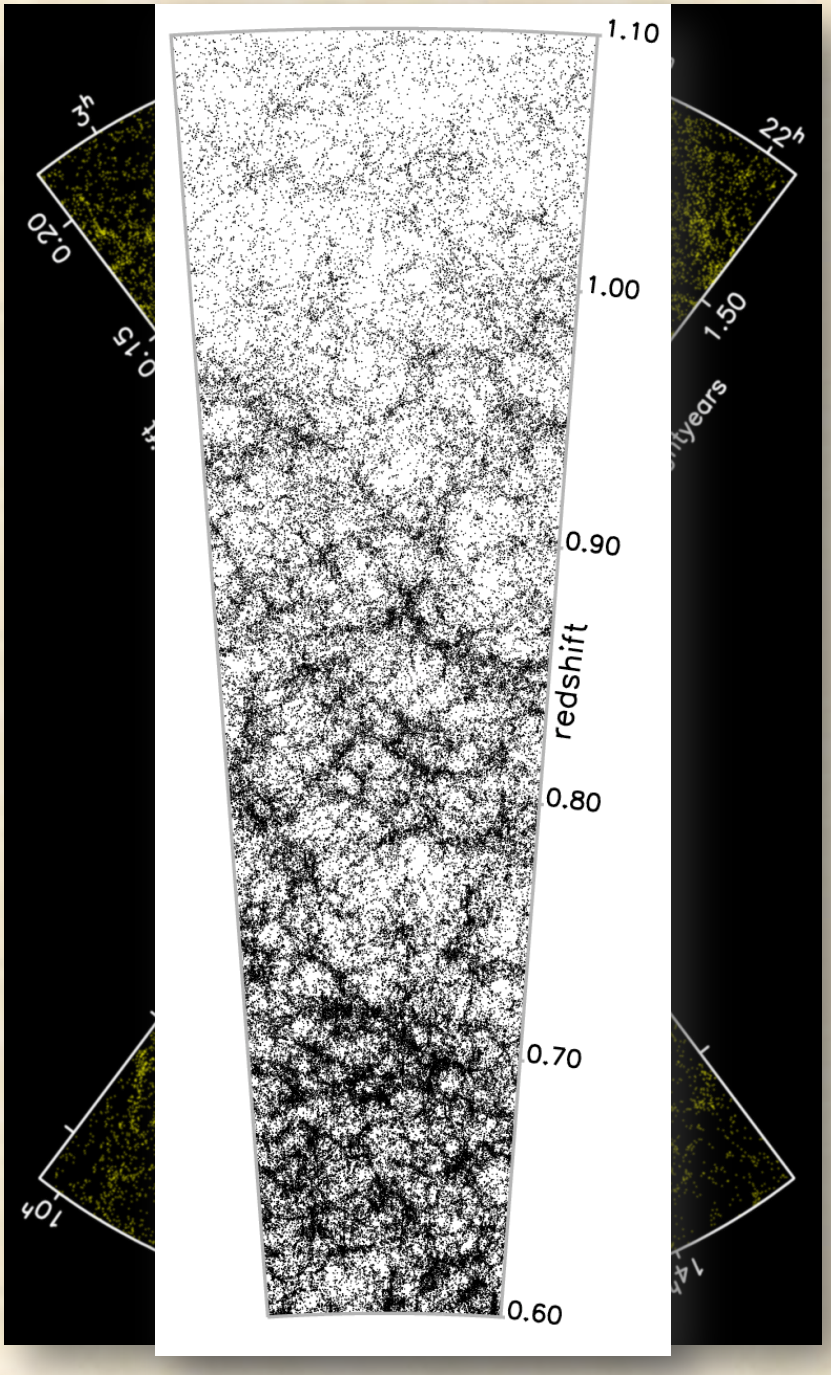
Nature 451, 541 (2008)

Waiting for Euclid: improving the z~1 data…


VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY

VIPERS goals and strategy

- **~100,000 redshifts, >40% sampling**
- **Density and volume comparable to 2dFGRS, but at z=[0.5-1]**
- **Cosmology driven, but with broader legacy return (environment, clusters, AGN, …)**
- ~24 deg^2 over W1 and W4 CFHTLS wide fields (~16 + 8)
- I_{AB}<22.5, LR Red grism, 45 min exp.
- z>0.5 color-color pre-selection
- PSF + SED –based star-galaxy separation (AGN color recovery)
- 288 VIMOS pointings
- 440.5 VLT hours



Sample ~all galaxies in representative volume: ~100k :

6dFGS 1m

SDSS 2m

2dFGRS 4m

VIPERS 8m

z~0.05

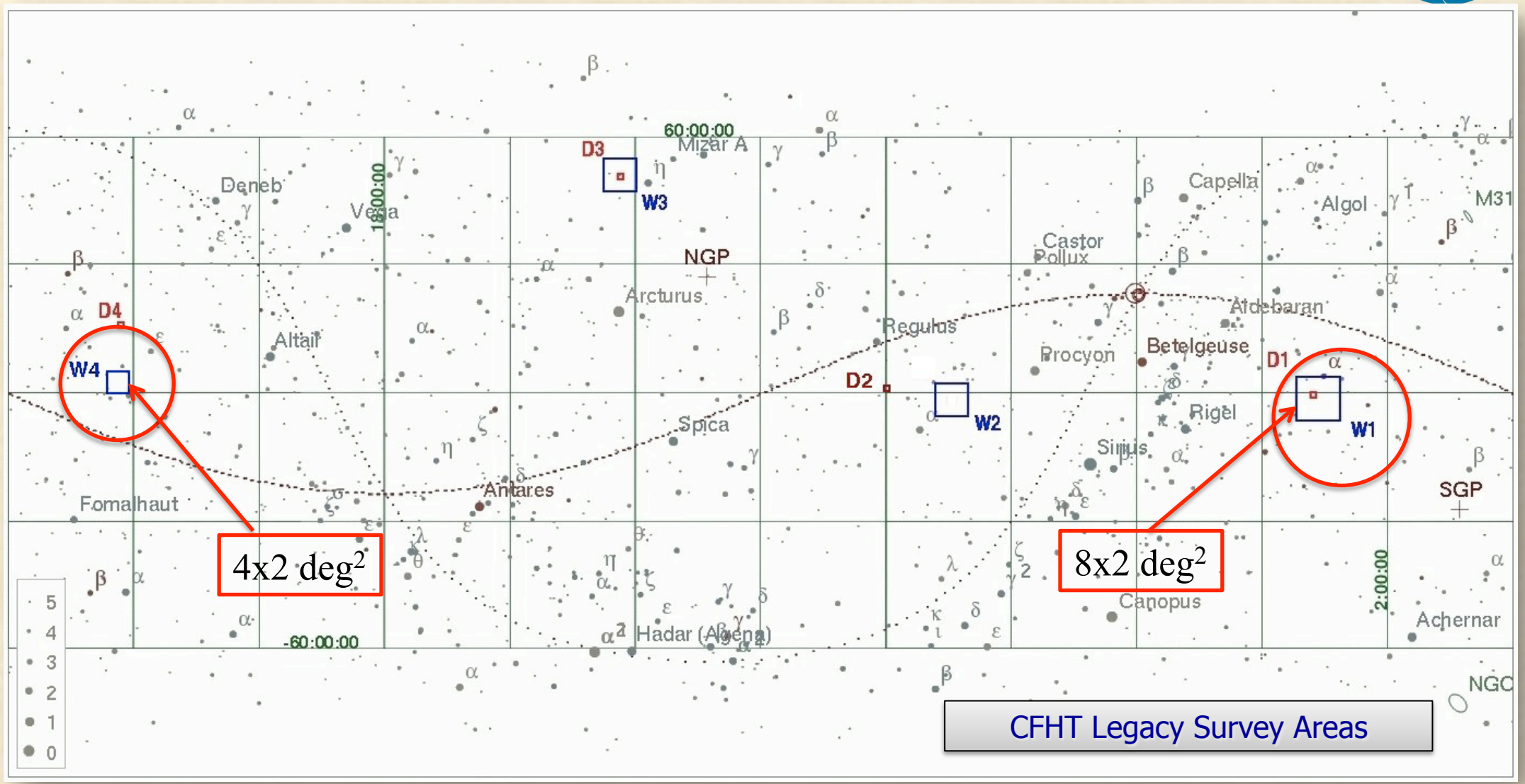
to

z~1

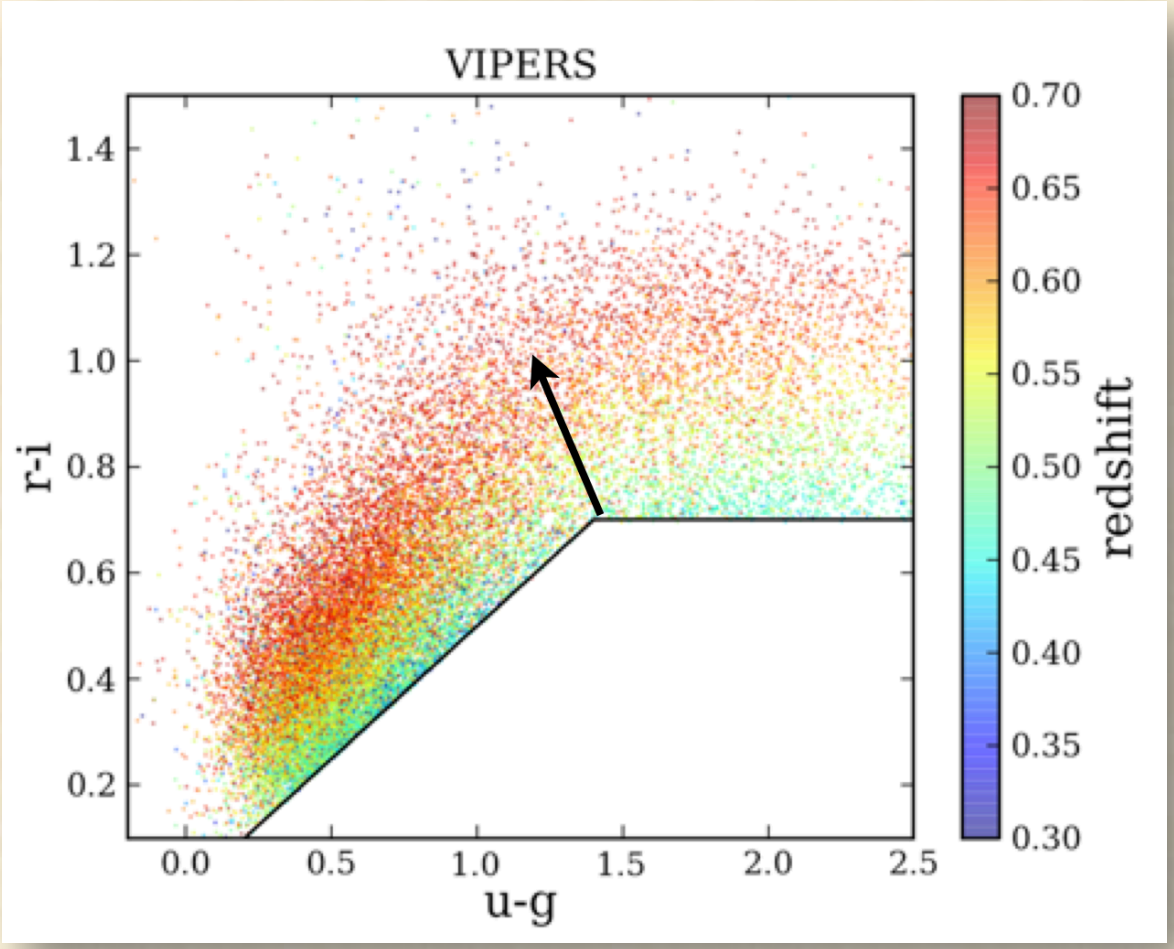
Complementary to dilute tracers over larger volumes (SDSS/BOSS LRGs), efficient statistically, but poorer at probing nonlinear structure

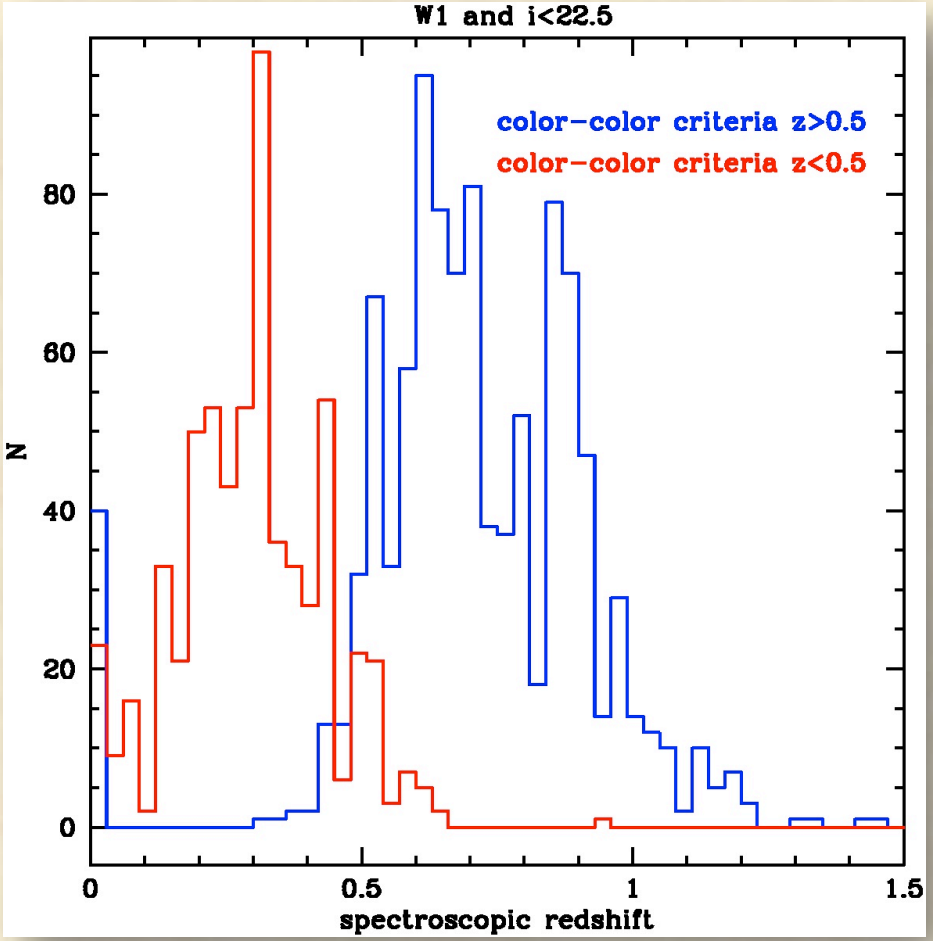
VIPERS Team

Starting point: CFHT Legacy Survey 5-band photometry over ~140 deg^2

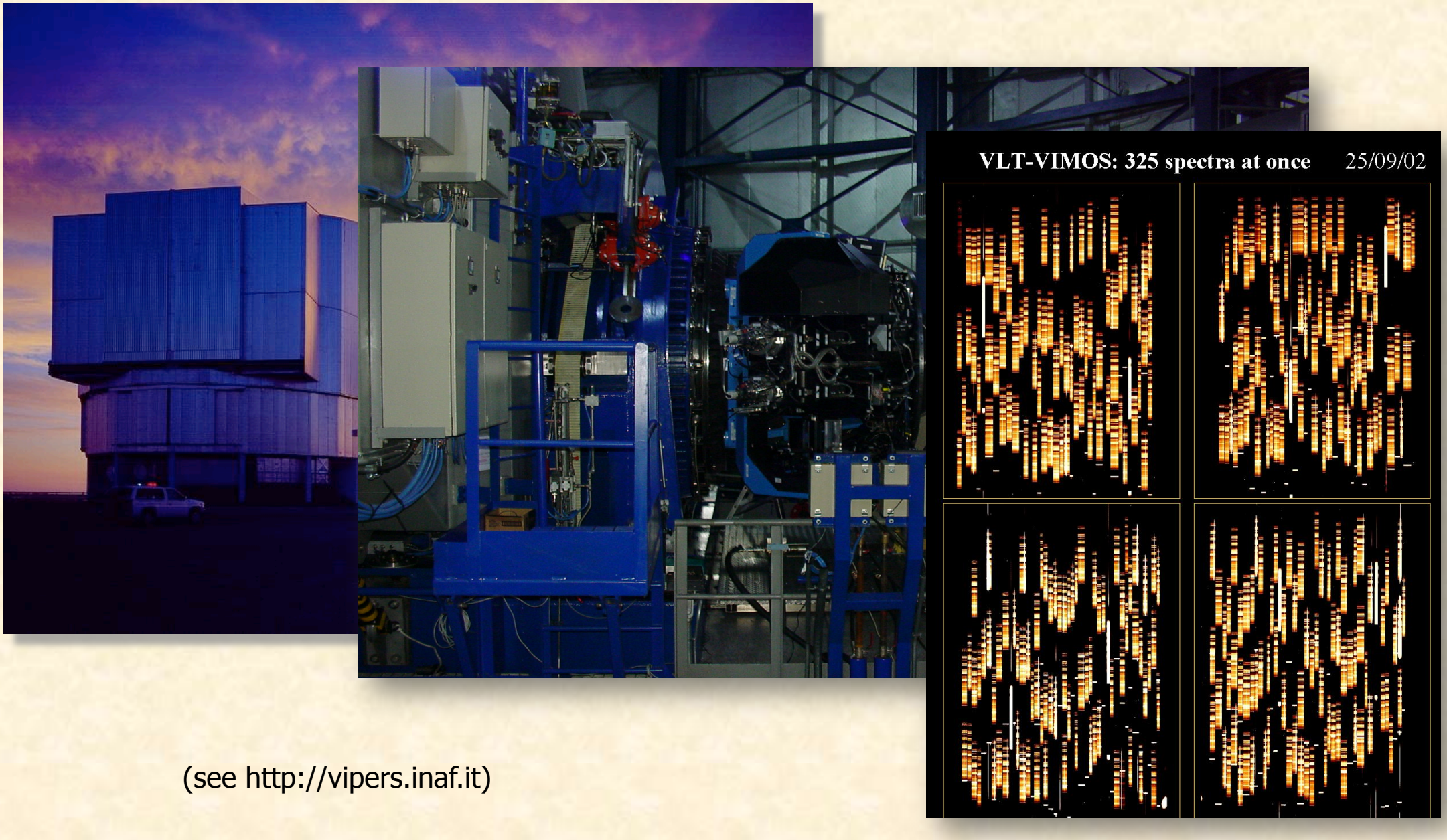


VIPERS Colour-Colour selection: isolating z>0.5 galaxies with VVDS calibration





VIMOS at the ESO Very Large Telescope

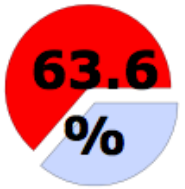


(see http://vipers.inaf.it)

VIPERS Public Data Release 1 (PDR-1)

- **Data observed prior to Spring 2012: public release in September 2013**

SURVEY STATUS AS OF 12/07/2012

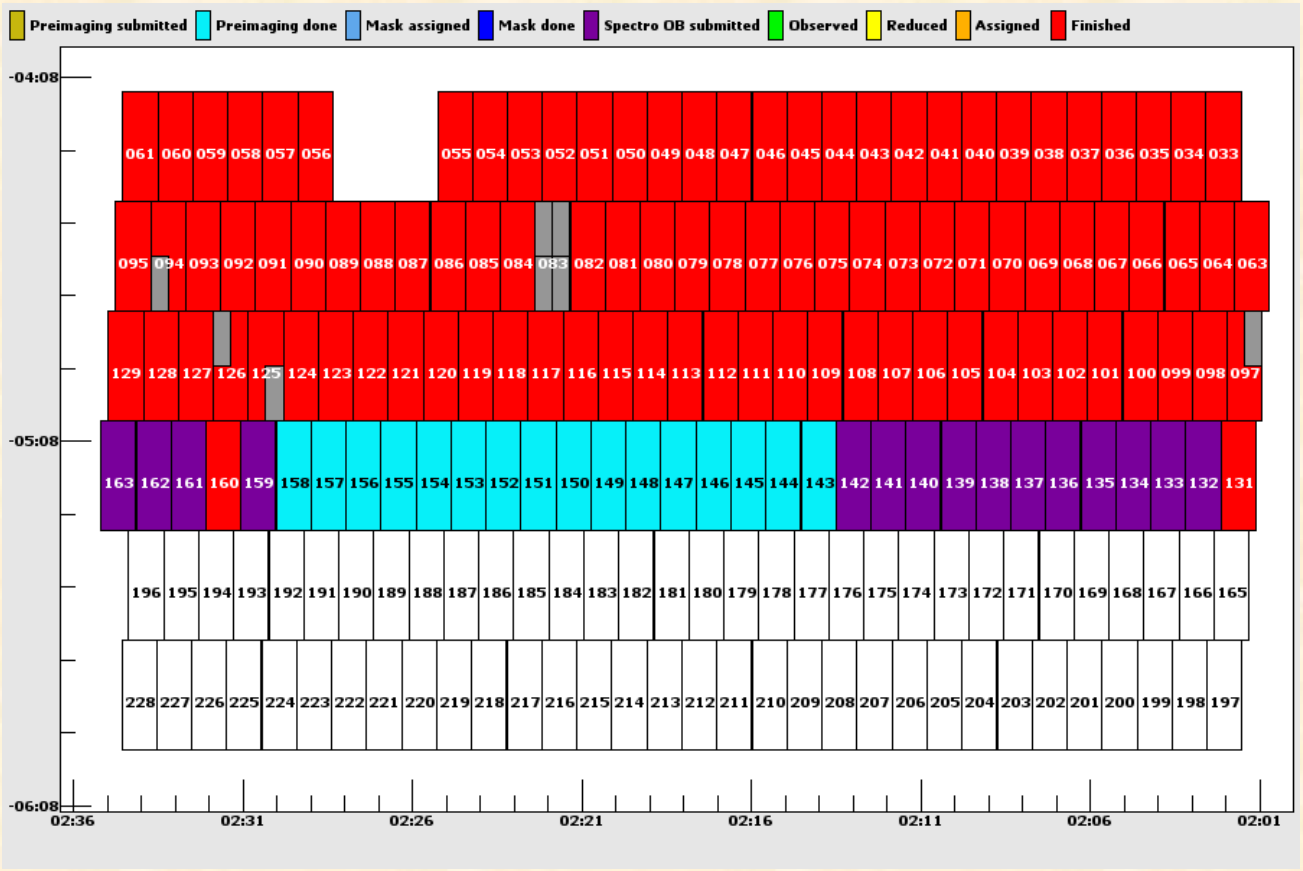
EFFECTIVE TARGETS	MEASURED REDSHIFTS	STELLAR CONTAMINATION	COVERED AREA
59013	55359	1750 (3.2 %)	

- **193 VIMOS pointings, out of 288 (W4 virtually complete)**

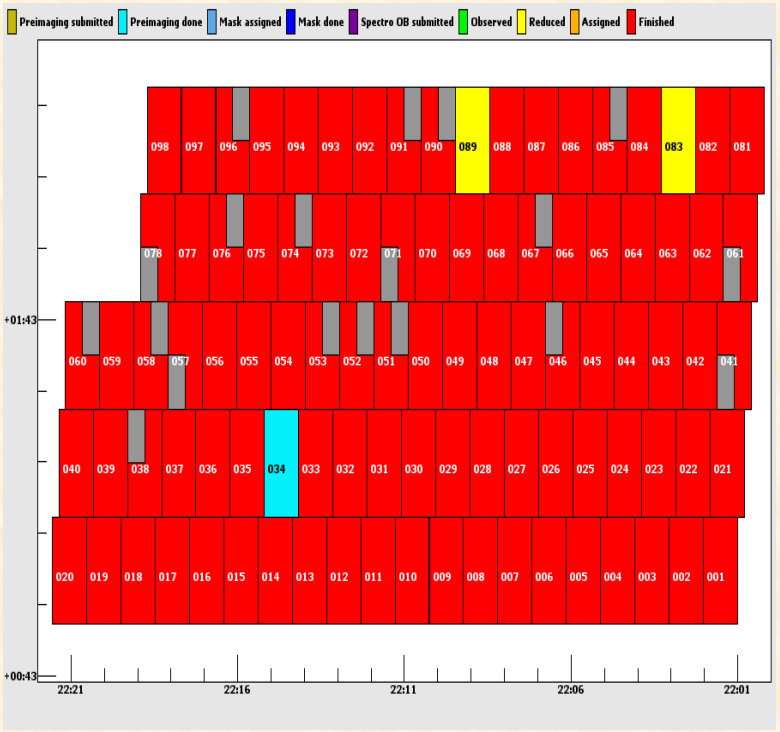
- 12 March 2013: First science release: 6 papers
- Expected survey completion: 2014 - 2015

Sky coverage: PDR-1 sample

W1

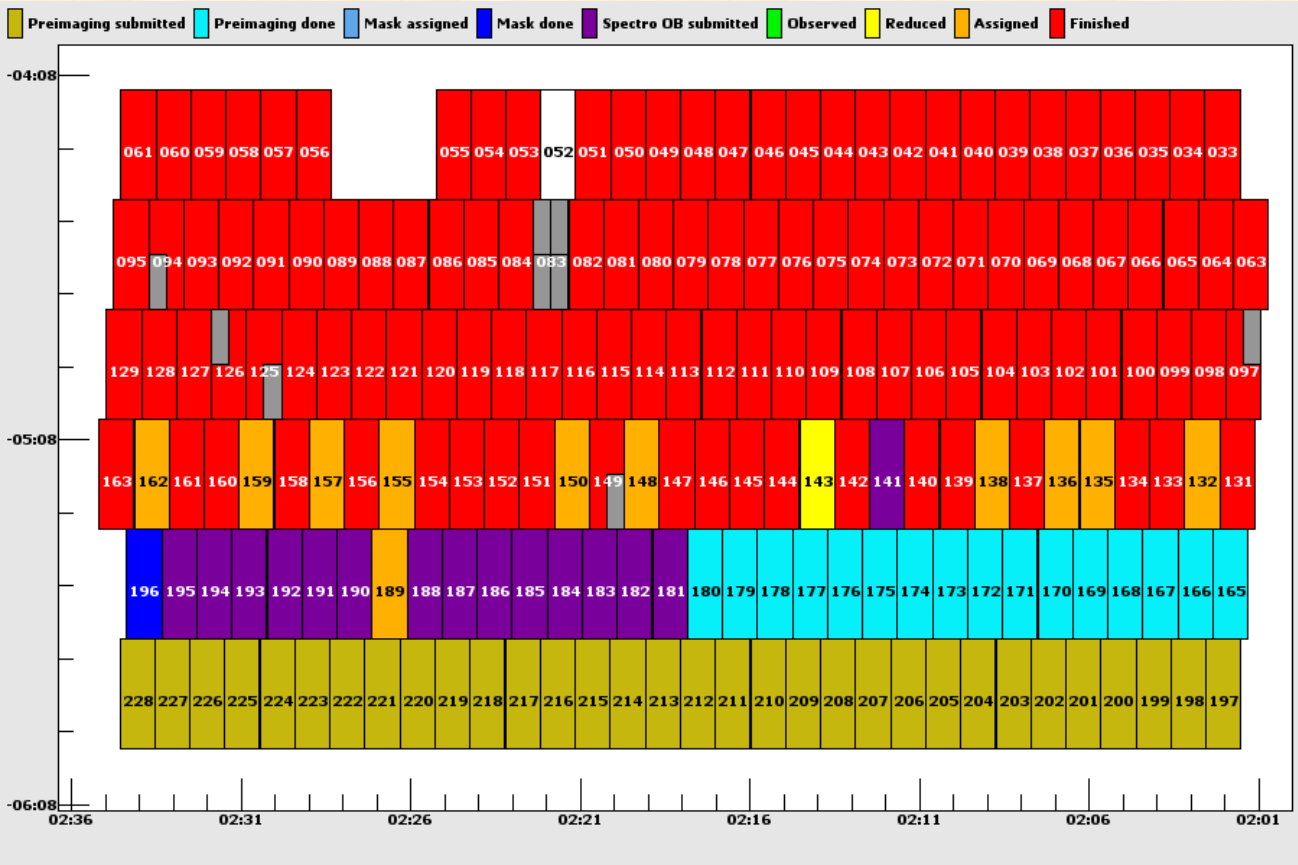


W4

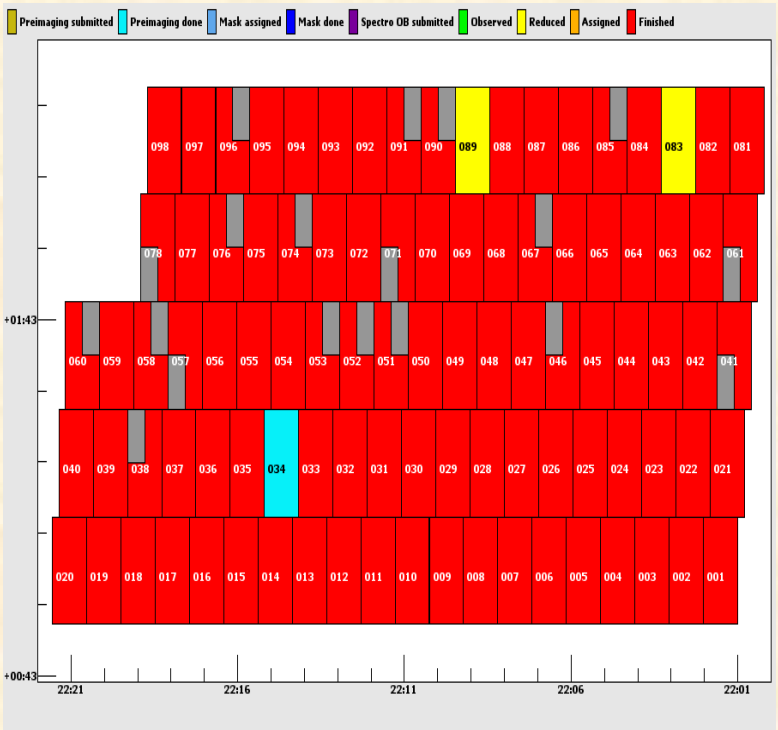


Sky coverage: 15 July 2013

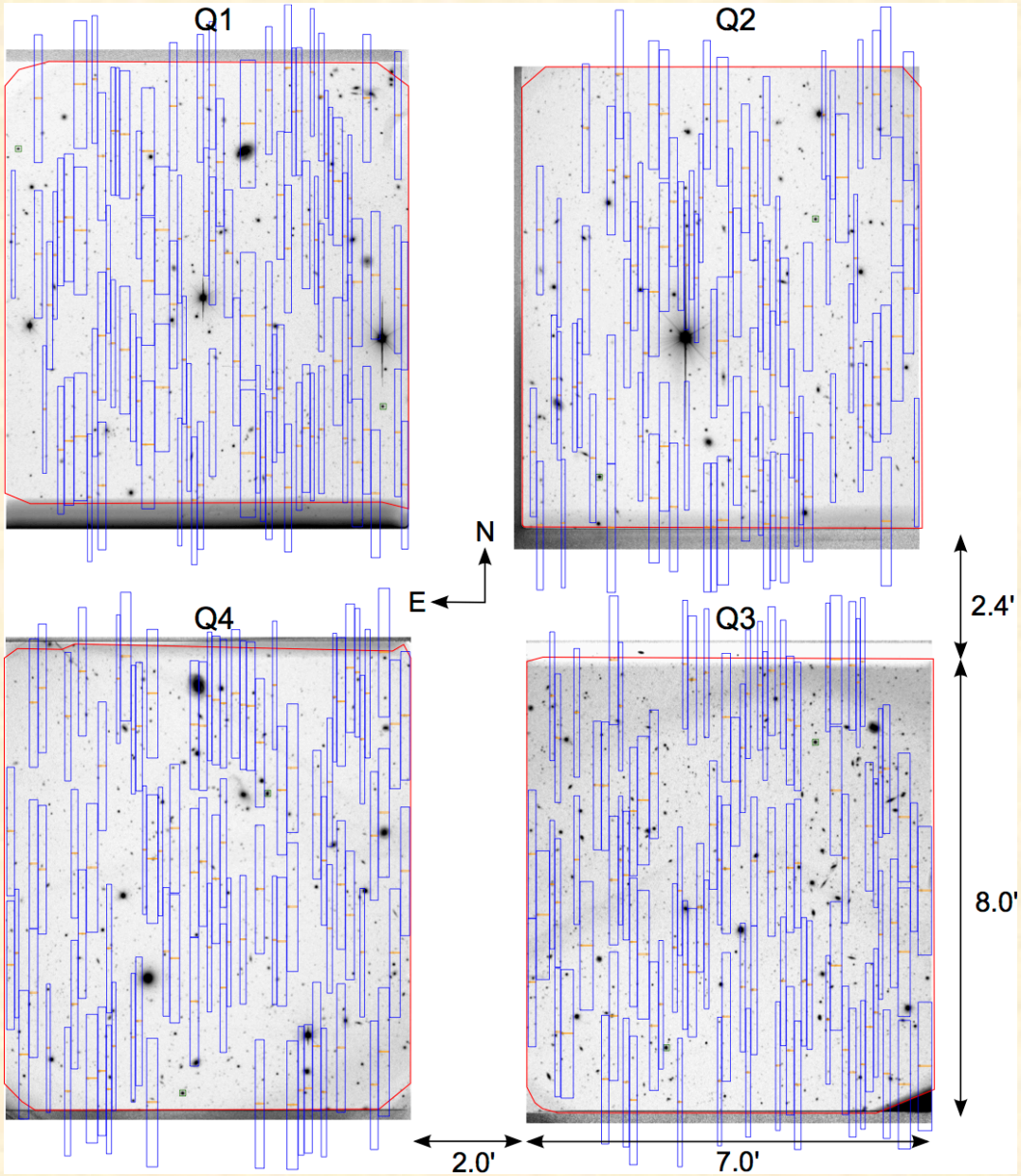
W1



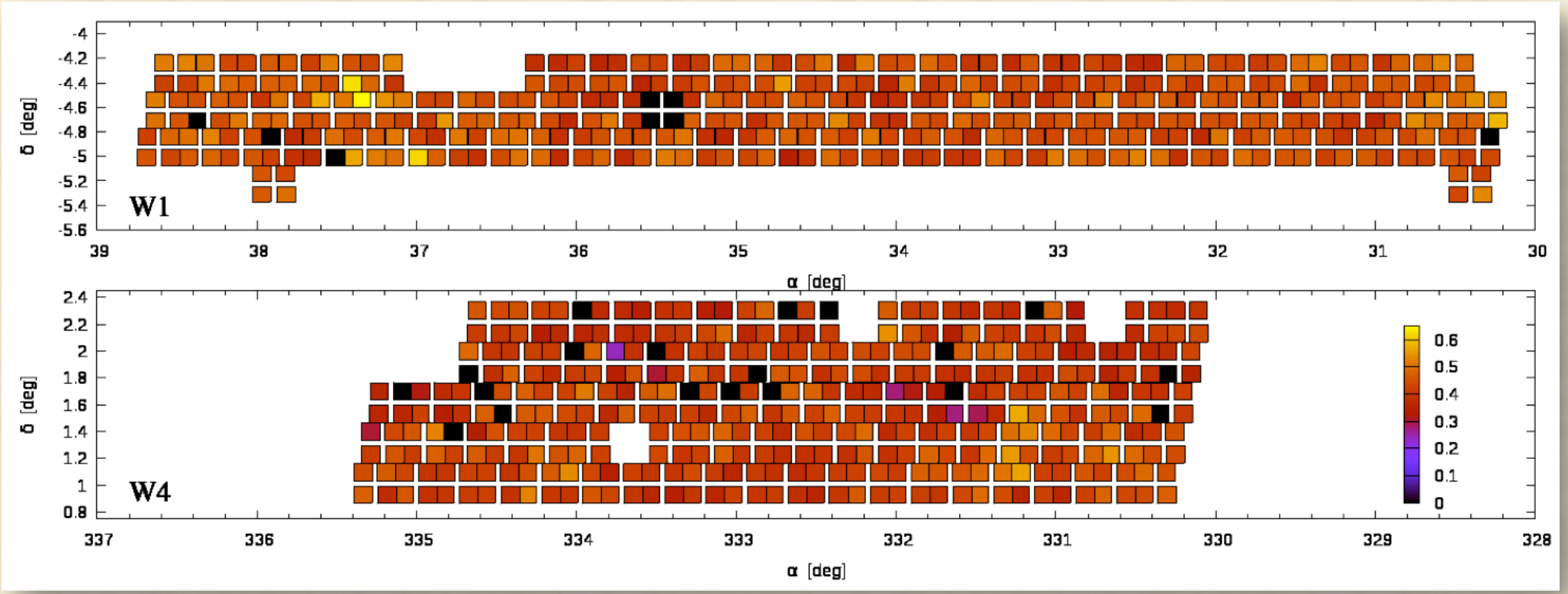
W4



VIMOS footprint on the sky

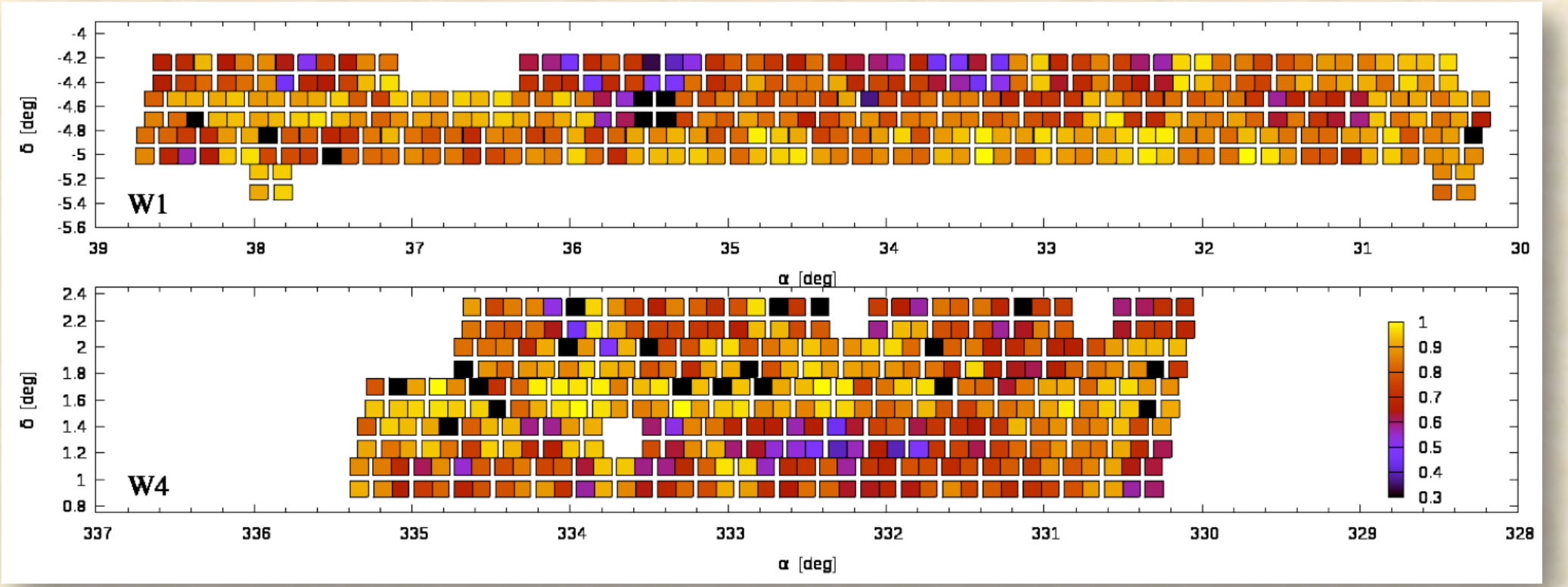


VIPERS Target Sampling Rate (N_{target}/N_{parent})



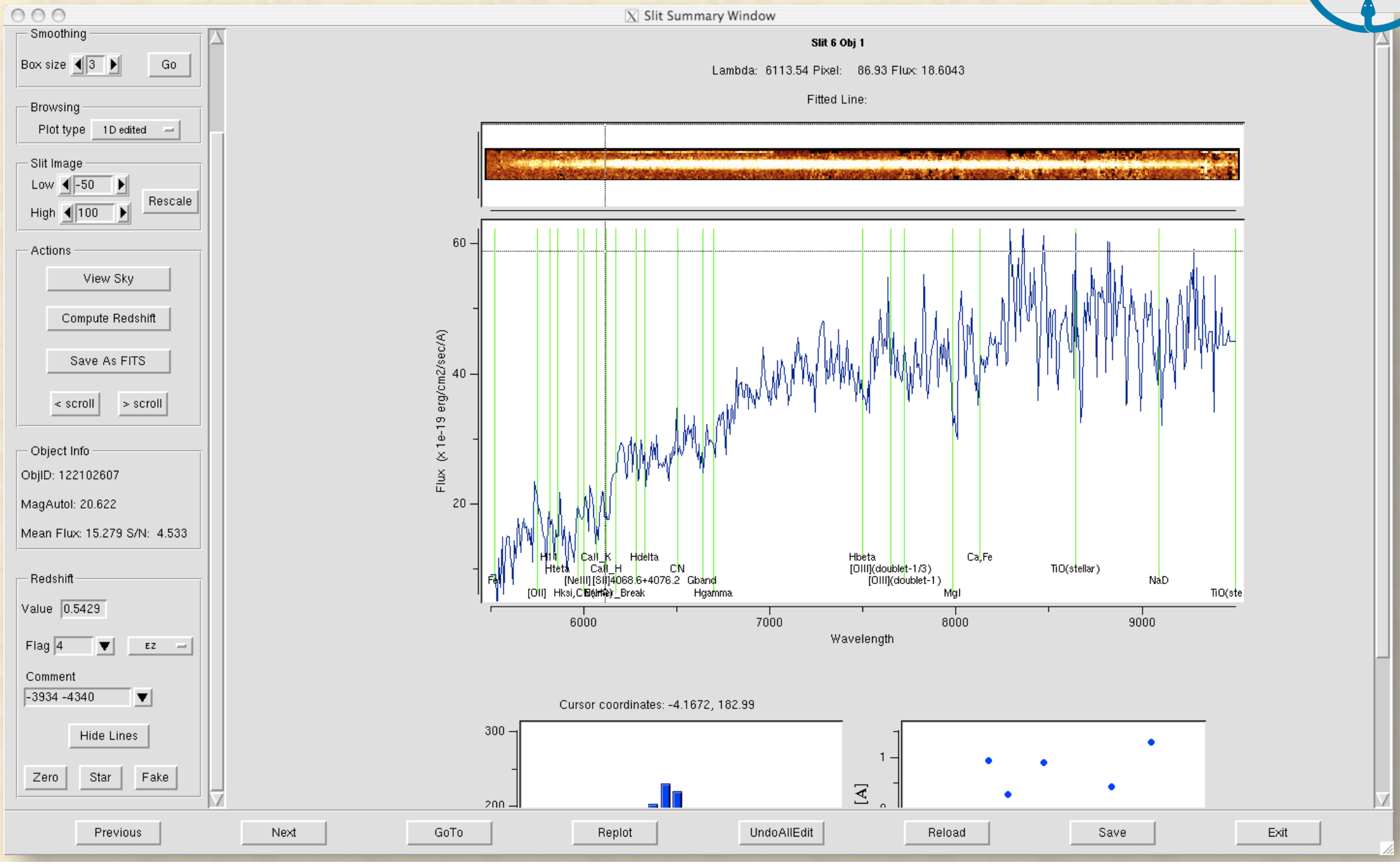
de la Torre et al. 2013; Guzzo et al. 2013

VIPERS Success Rate ($N_{measured}/N_{targeted}$)

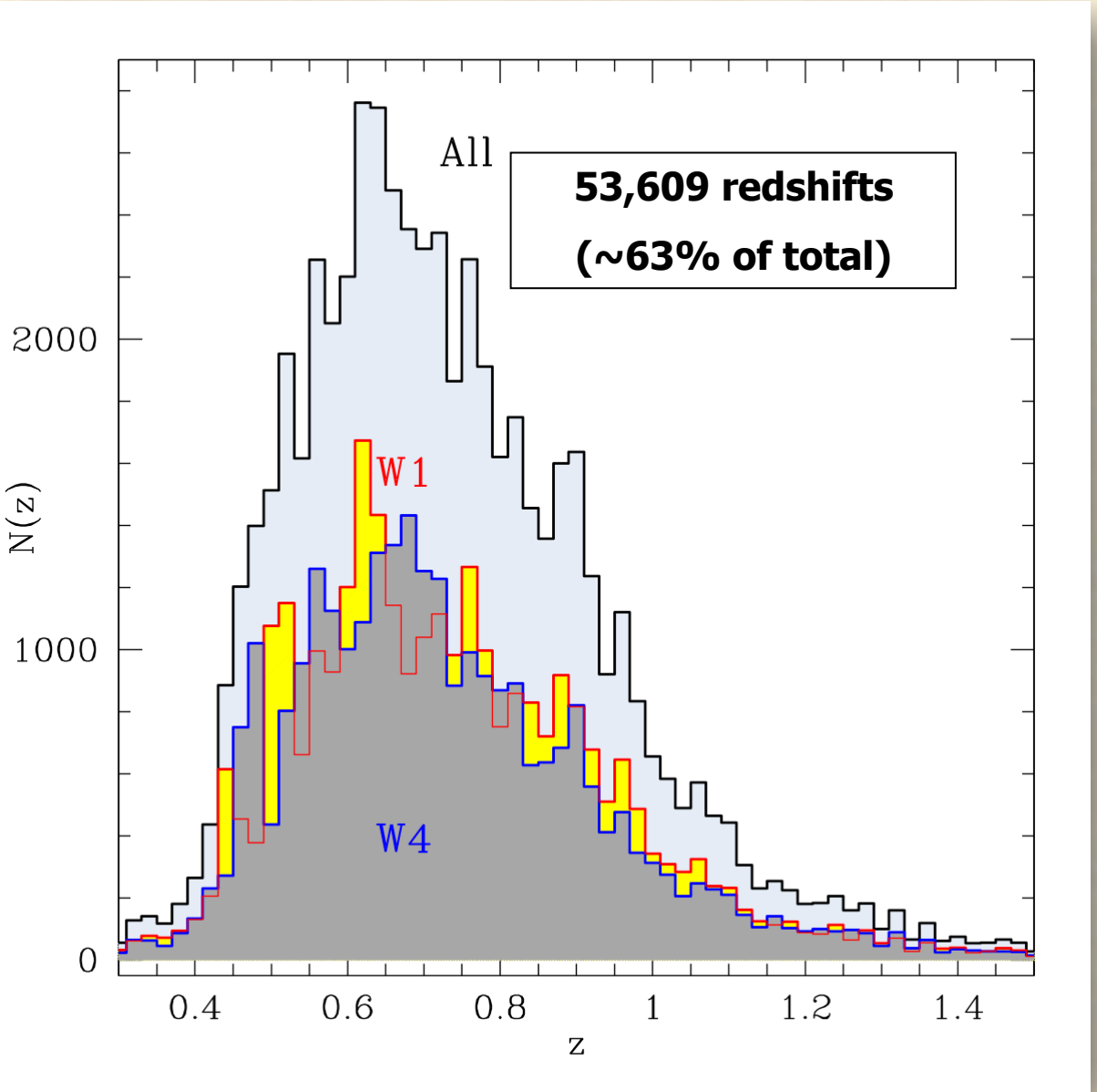


de la Torre et al. 2013; Guzzo et al. 2013

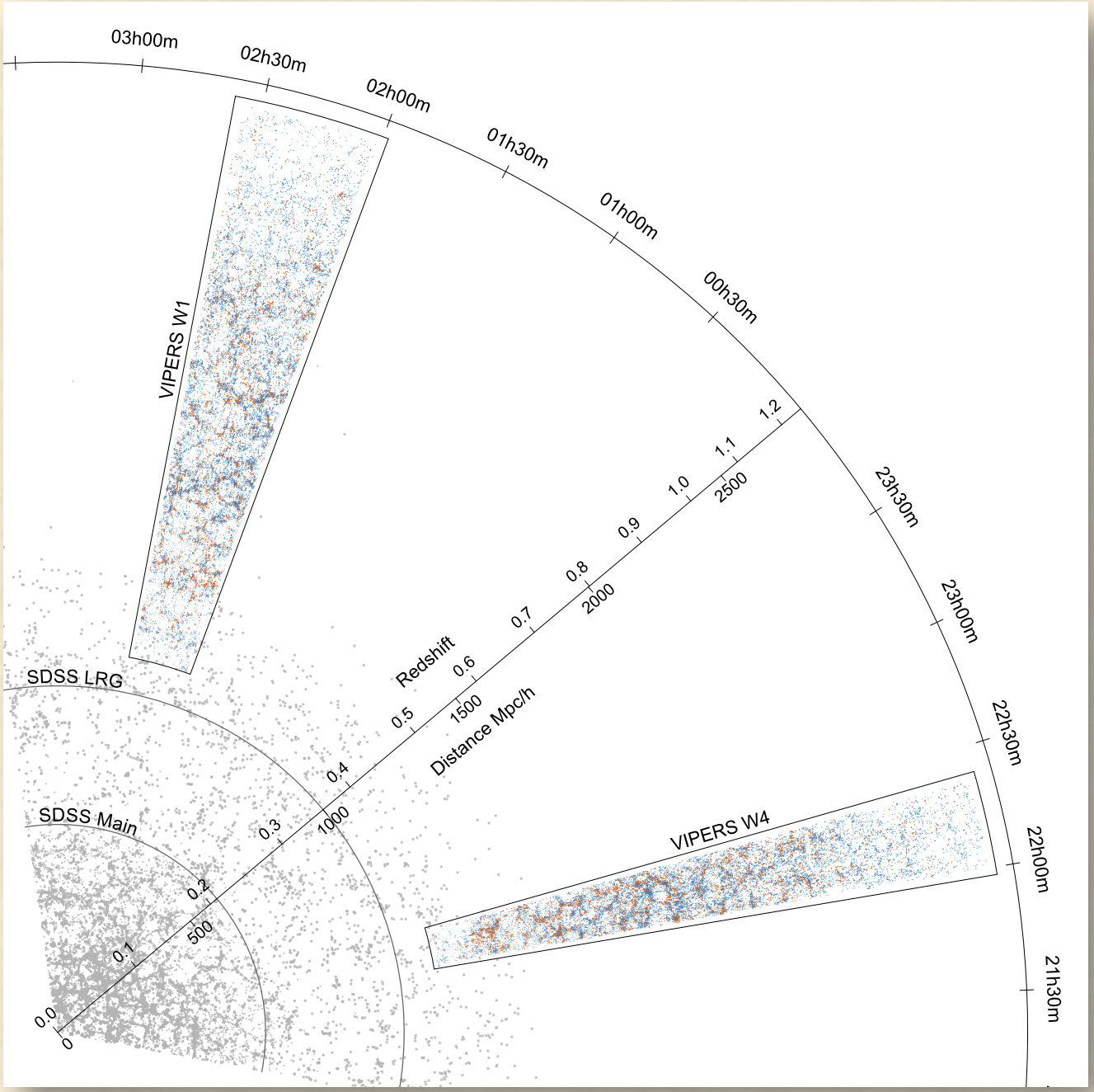
Spectral review/measurement environment: VIPGI+EZ



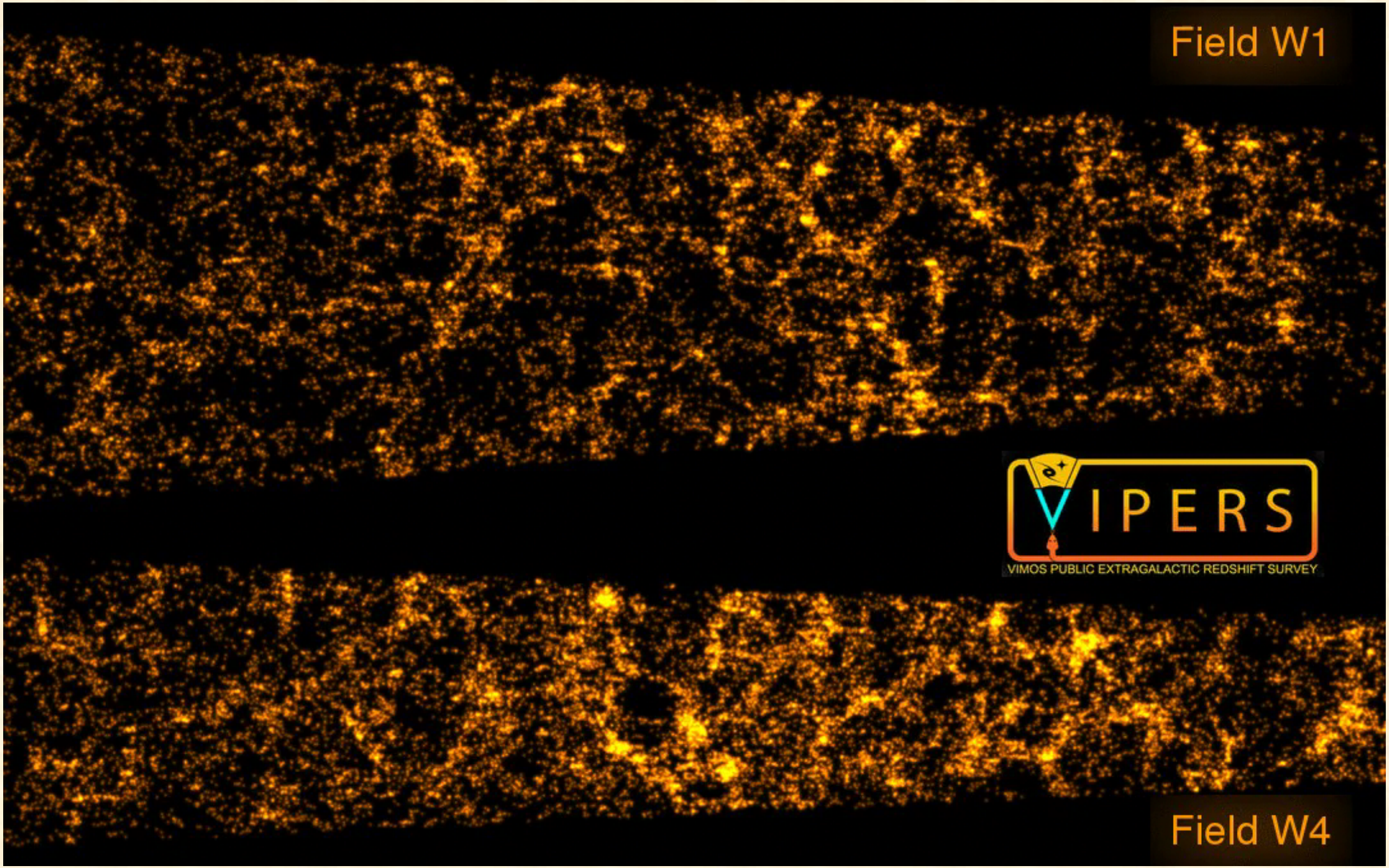
PDR-1 redshift distribution



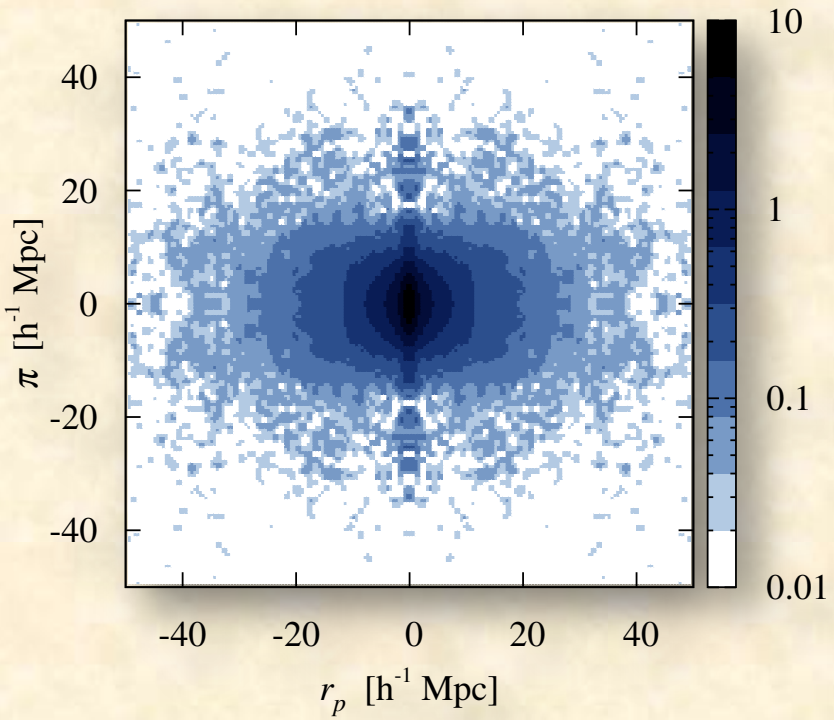
(Guzzo et al. 2013)

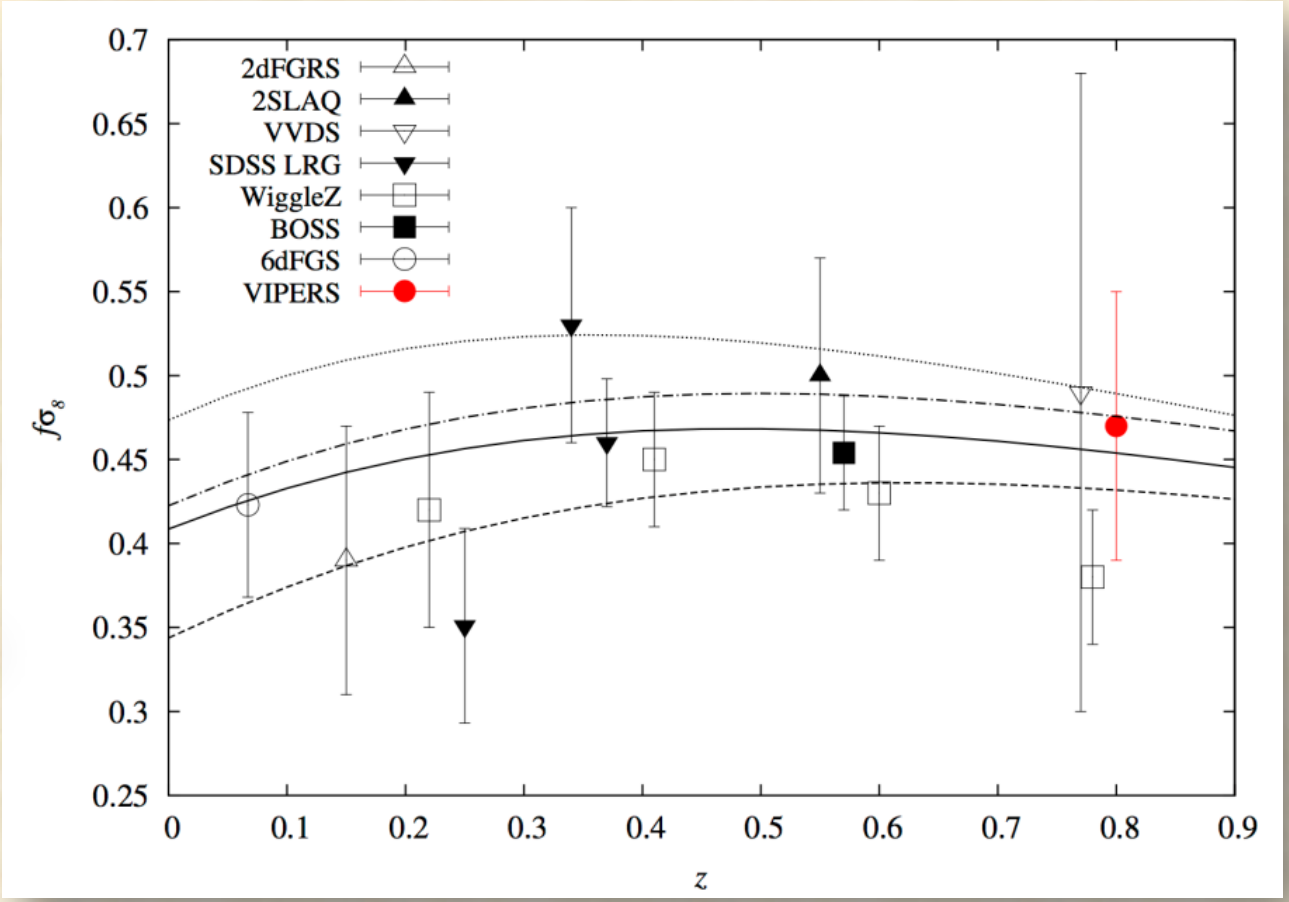


From Guzzo et al. 2013 (artwork by Ben Granett)


Field W1
VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY
Field W4

Redshift-space clustering and growth rate of structure from the VIPERS PDR-1 data





VIPERS: $f\sigma_8(z=0.8) = 0.47\pm0.08$

De la Torre et al. 2013

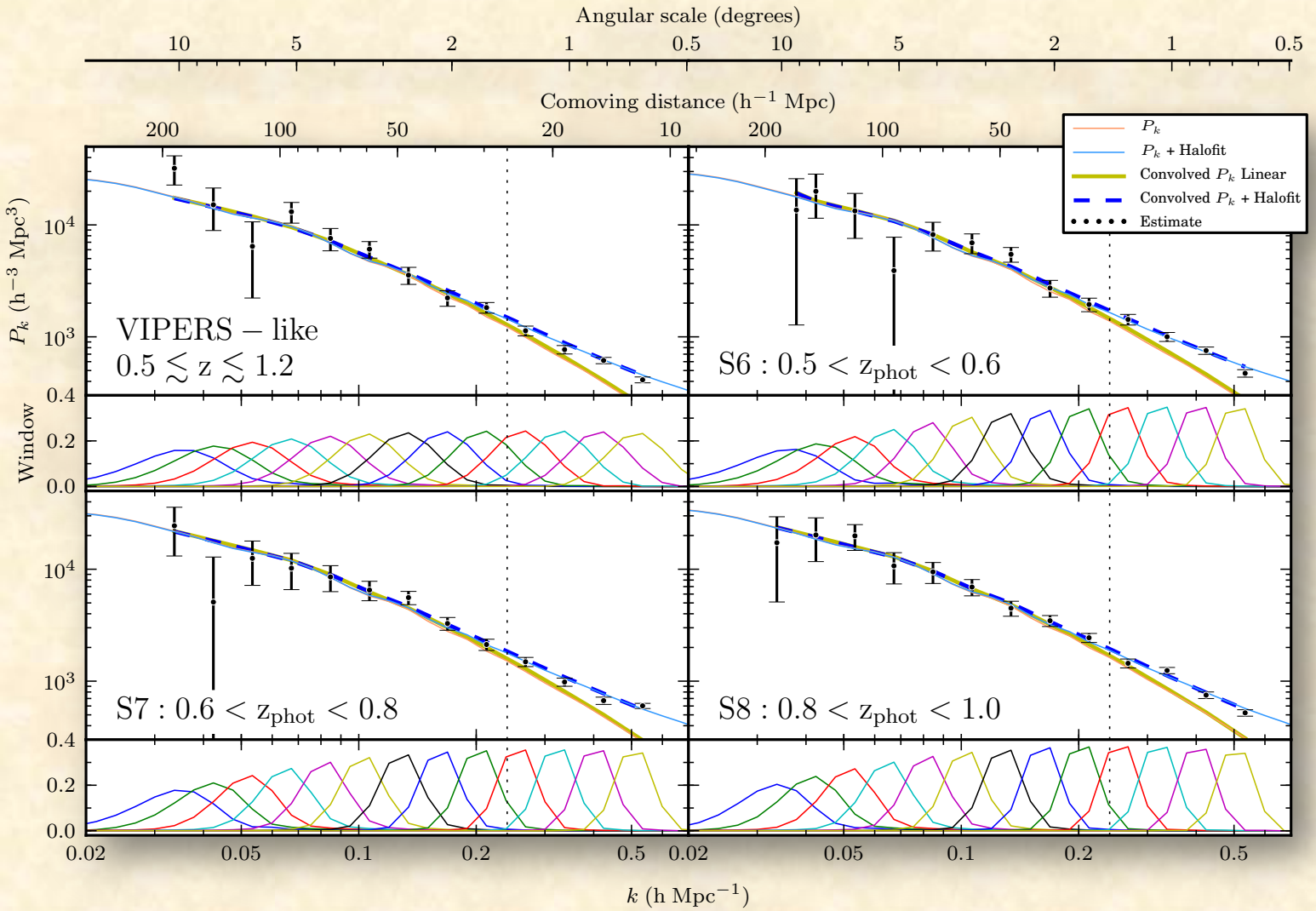
Real space P(k) at z~0.7 from CFHTLS-Wide + VIPERS N(z)

W1+W2+W3+W4

1) Cl spectrum using Tegmark 1997 quadratic estimator

2) Deconvolved following Efstathiou & Moody 2001

Complementary to recent Cl estimate at z~0.5 from SDSS LRGs (Thomas, Abdalla & Lahav 2011)



B. Granett, LG & VIPERS Team, 2012 MNRAS, 421, 251 (arXiv 1112.0008)

Xia, Granett, Viel et al., MNRAS, arXiv 1203.5105: improved constraints on neutrino masses (**see VIEL talk**)

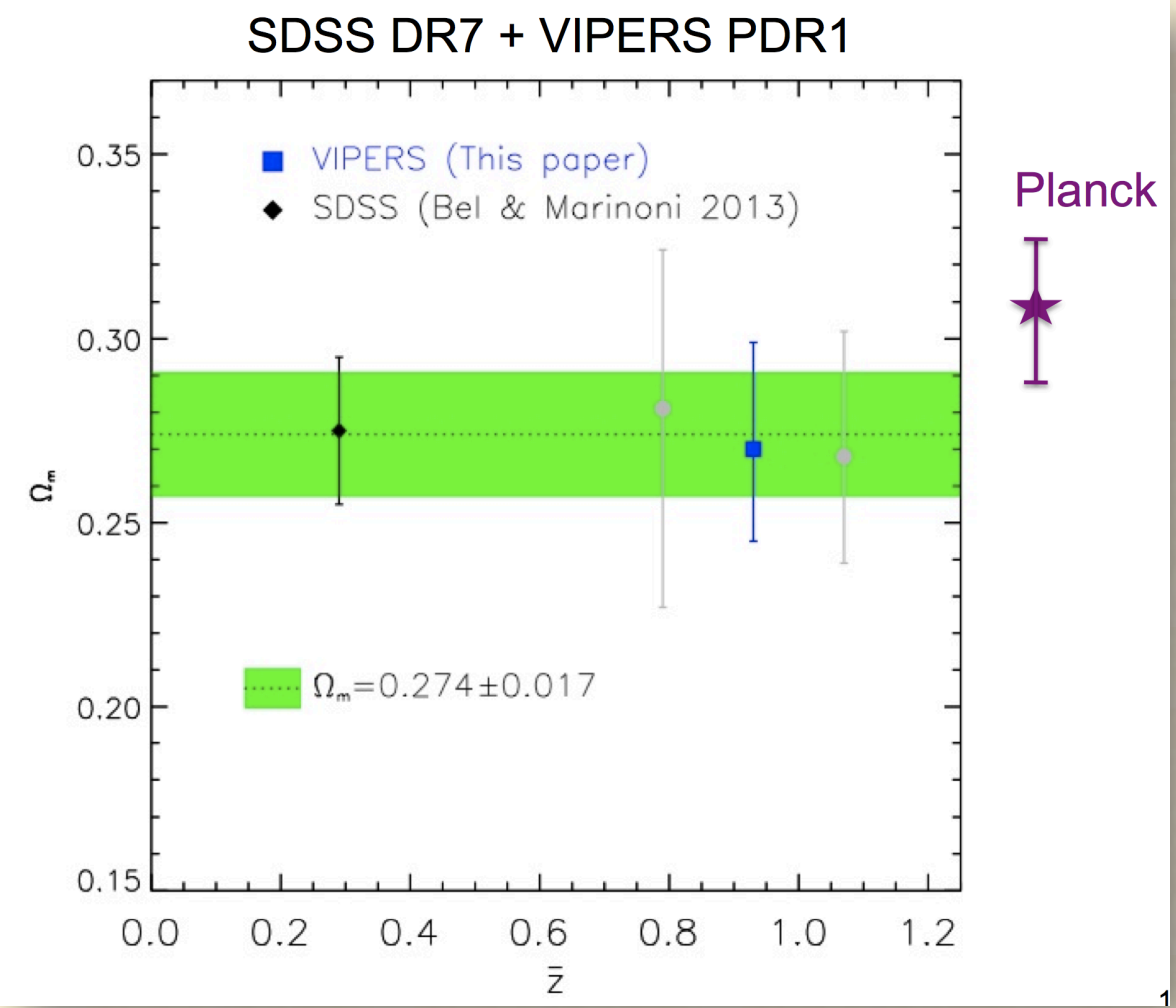
Cosmology with the shape of the VIPERS P(k) at z~0.8 (through counts in cells and the "clustering ratio")

The clustering ratio: $$\eta_R(r) \equiv \frac{\xi_R(r)}{\sigma_R^2}$$

Where:

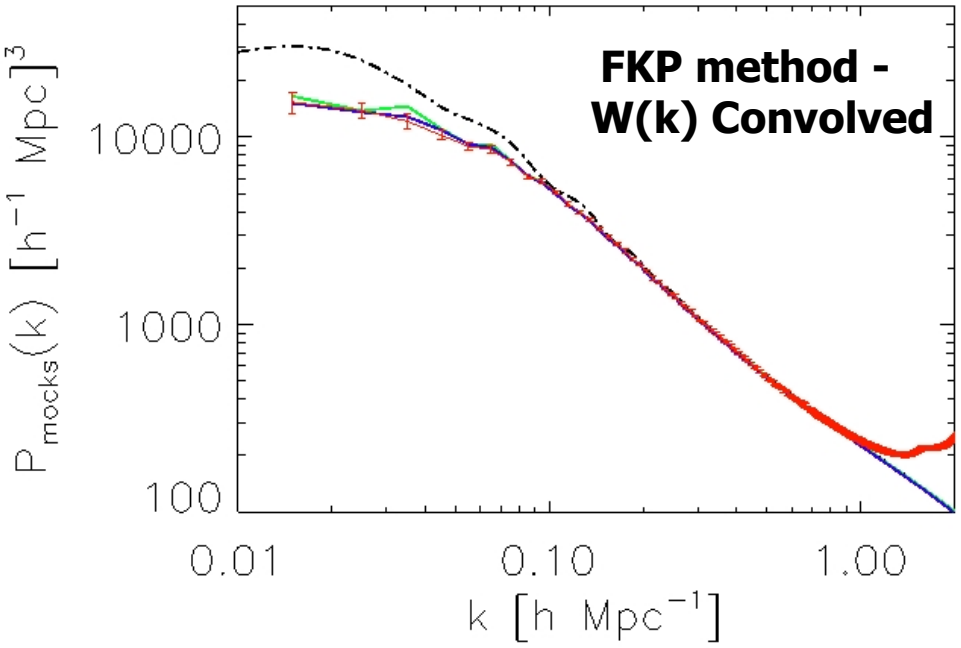
- R=smoothing radius of galaxy field
- r=nR (n=3,4,5) i.e. correlated on larger scales
- Ratio has favourable propertites wrt to quasi-linear/mildly nonlinear effects on the P(k): most of the effects factor out
- Essentially a ratio of power in two different k bands

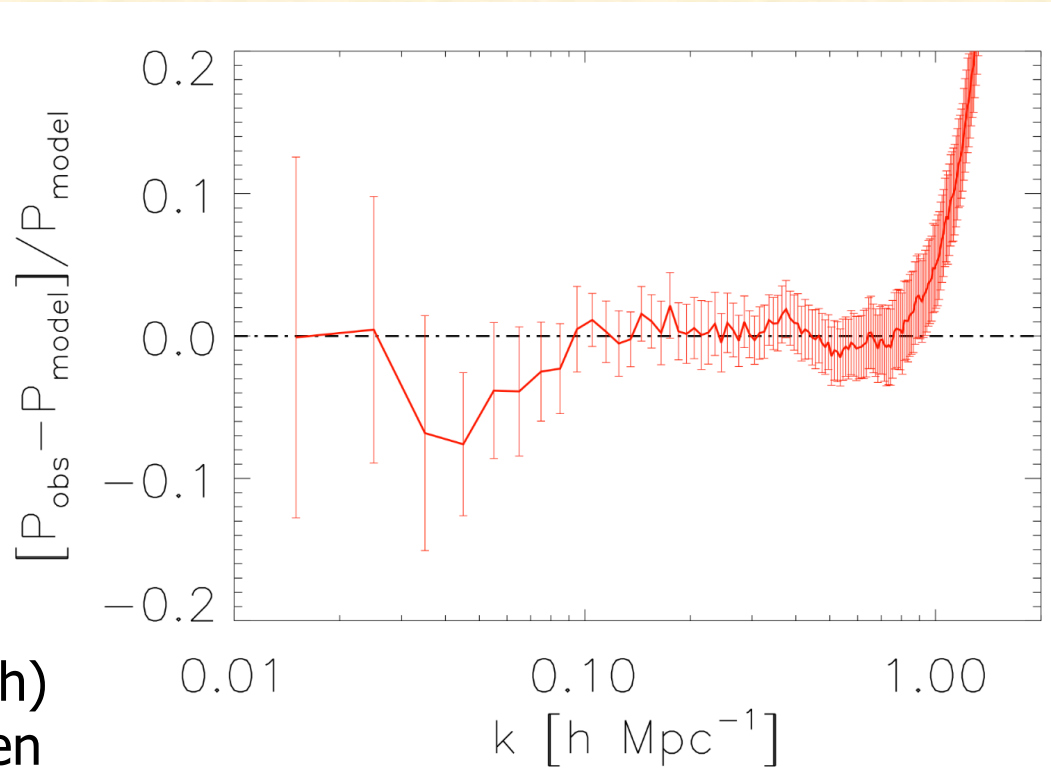
Bel et al., 2013, submitted



Work in progress: VIPERS direct measurement of power spectrum

(Stefano Rota PhD project)



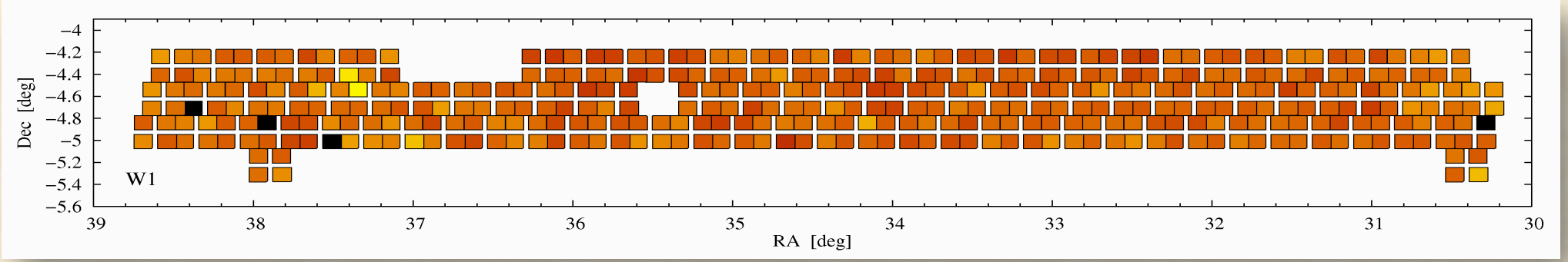


• Key is understanding and modelling the (tough) VIPERS window function. Promising results when convolving the theory: "observed" P(k) reconstructed to a few % for k=[0.01,0.8]

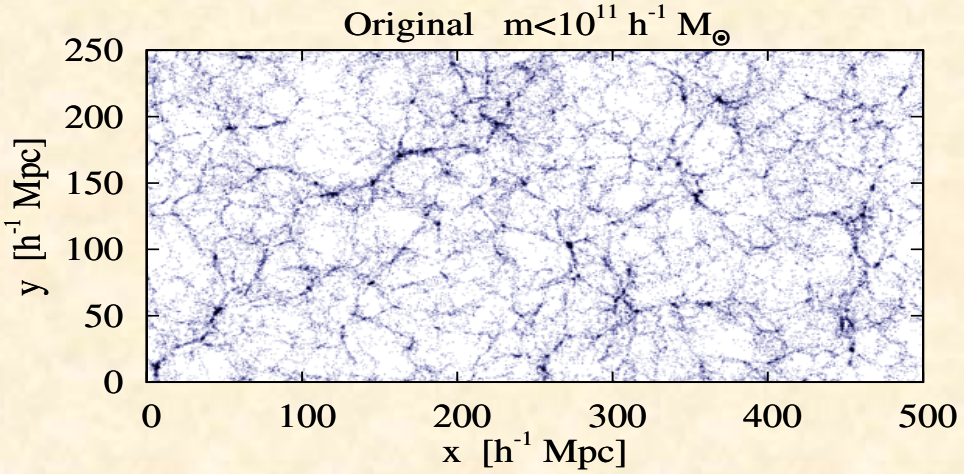
Rota, Granett, LG et al., in prep.

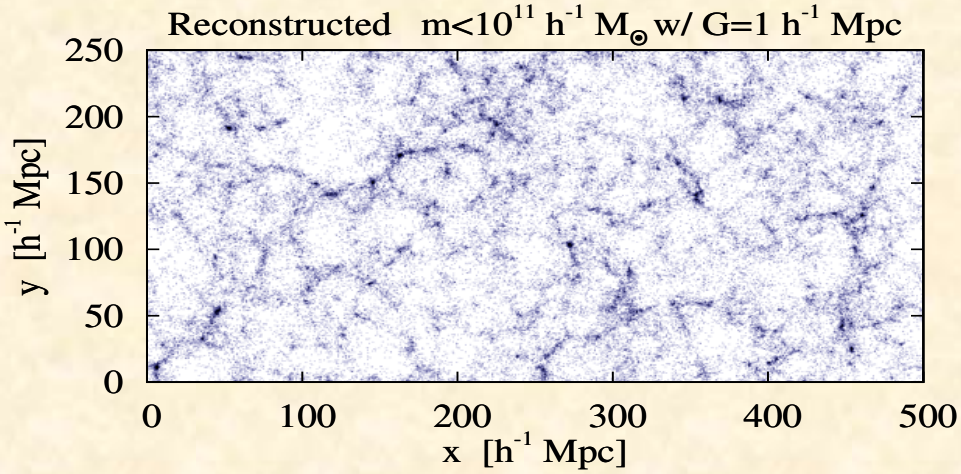
Clustering and RSD from VIPERS need attention to detail

- Precision cosmology with redshift surveys



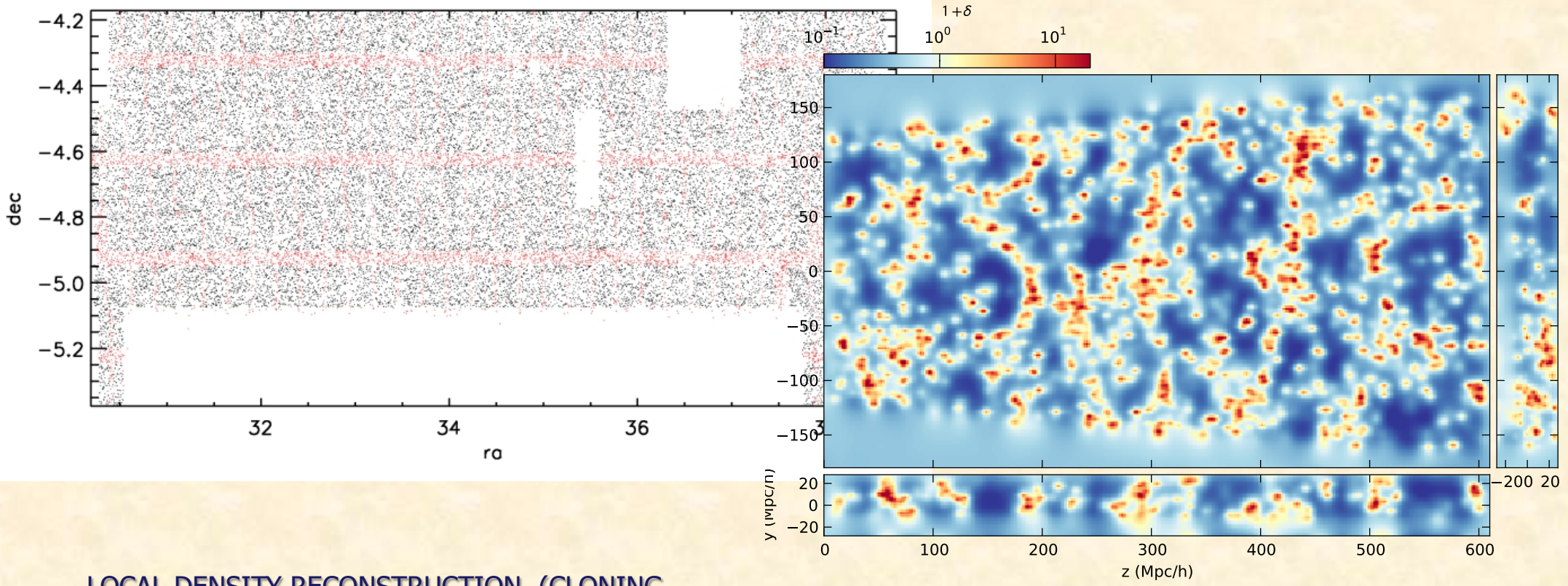
- (1) Realistic and (2) numerous mock galaxy samples are fundamental





(de la Torre & Peacock 2012, de la Torre et al. 2013)

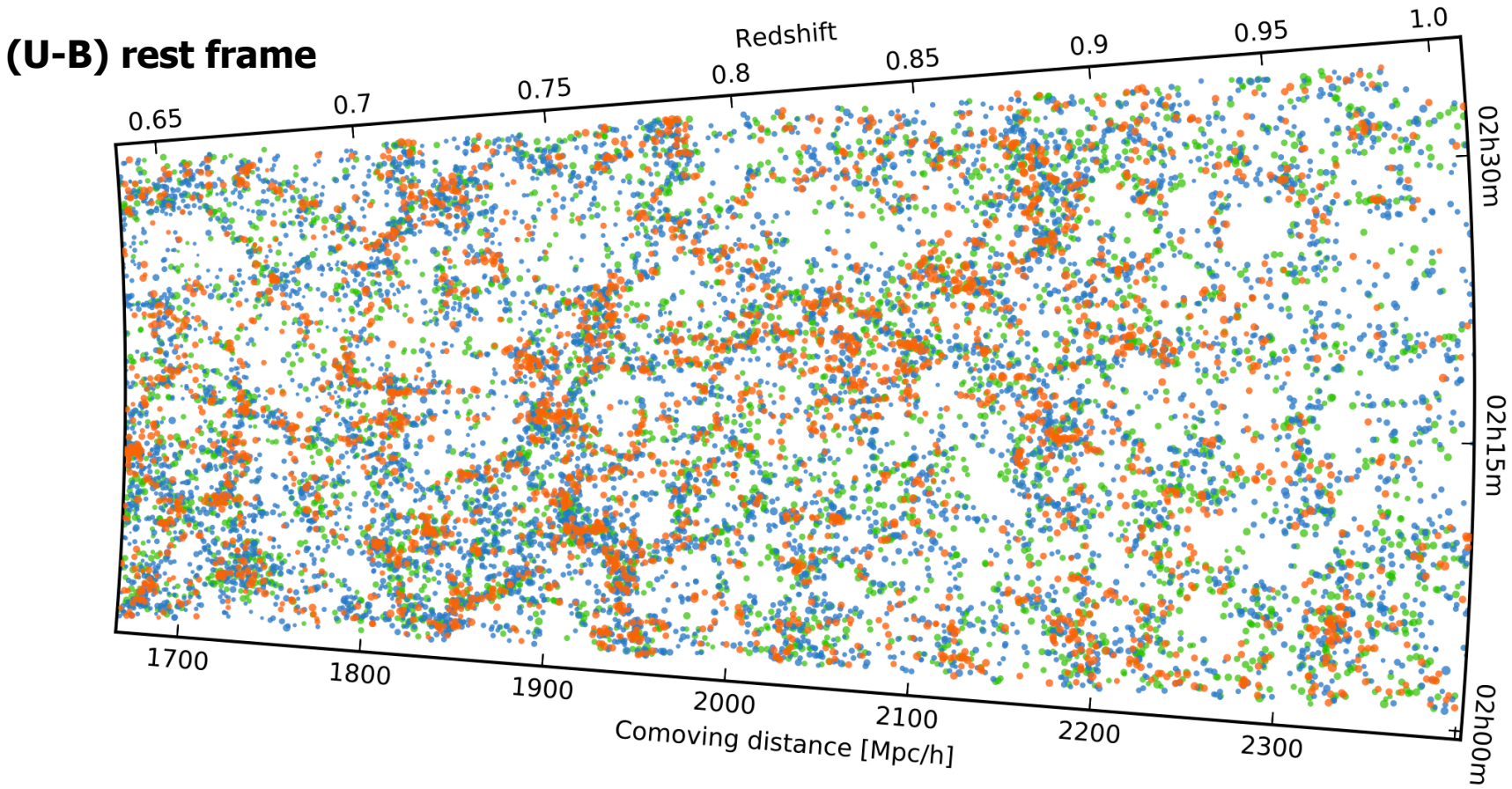
Reconstructing the density field



LOCAL DENSITY RECONSTRUCTION (CLONING, ZADE PHOTO-Z ATTRACTOR, Cucciati, Branchini, Bel et al., in preparation

STATISTICAL RECONSTRUCTION (WIENER FILTERING) Granett et al., in preparation

VIPERS: detailed LSS vs galaxy properties



Color-density relation: Cucciati et al., in prep.

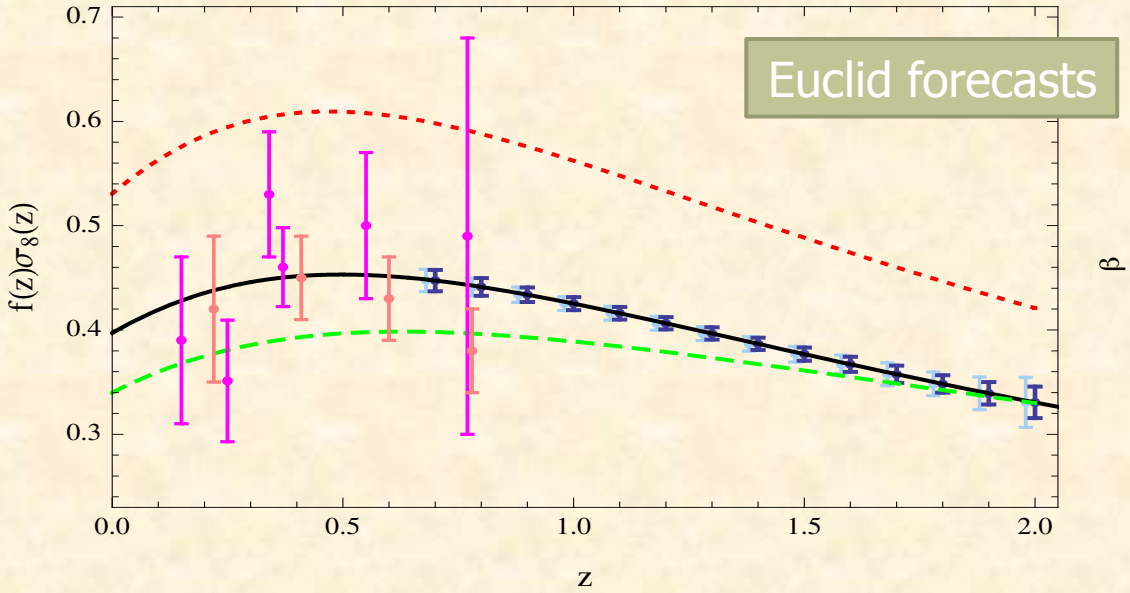
(figure: Ben Granett)

RSD modelling

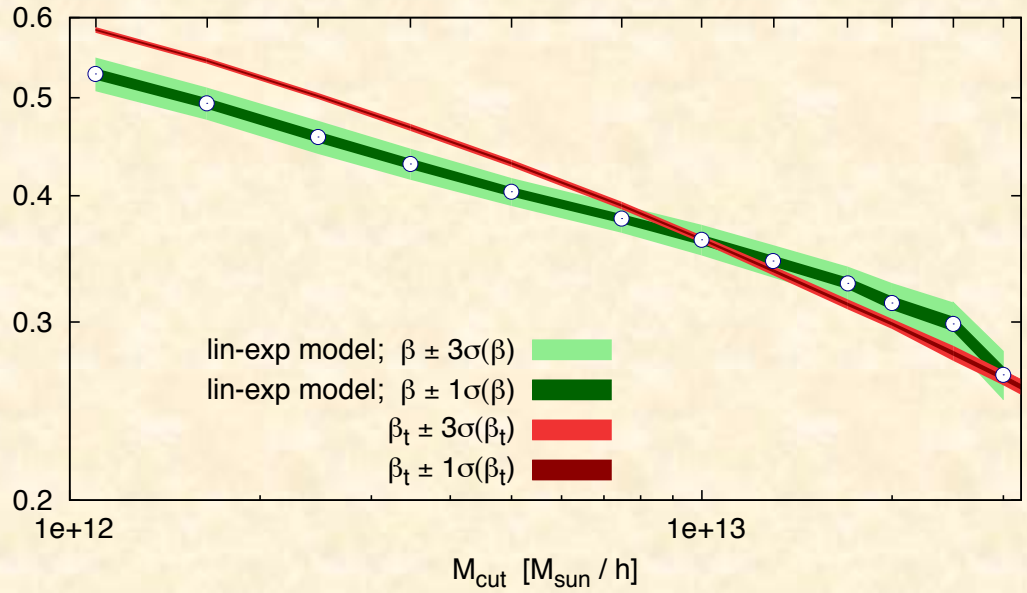
Need to improve modelling to enter *"precision RSD era"*

→ EUCLID: 1-3% precision on $f\sigma_8$

→ Standard dispersion model: up to 10% systematic error



(Majerotto, LG, Samushia et al. 2012)

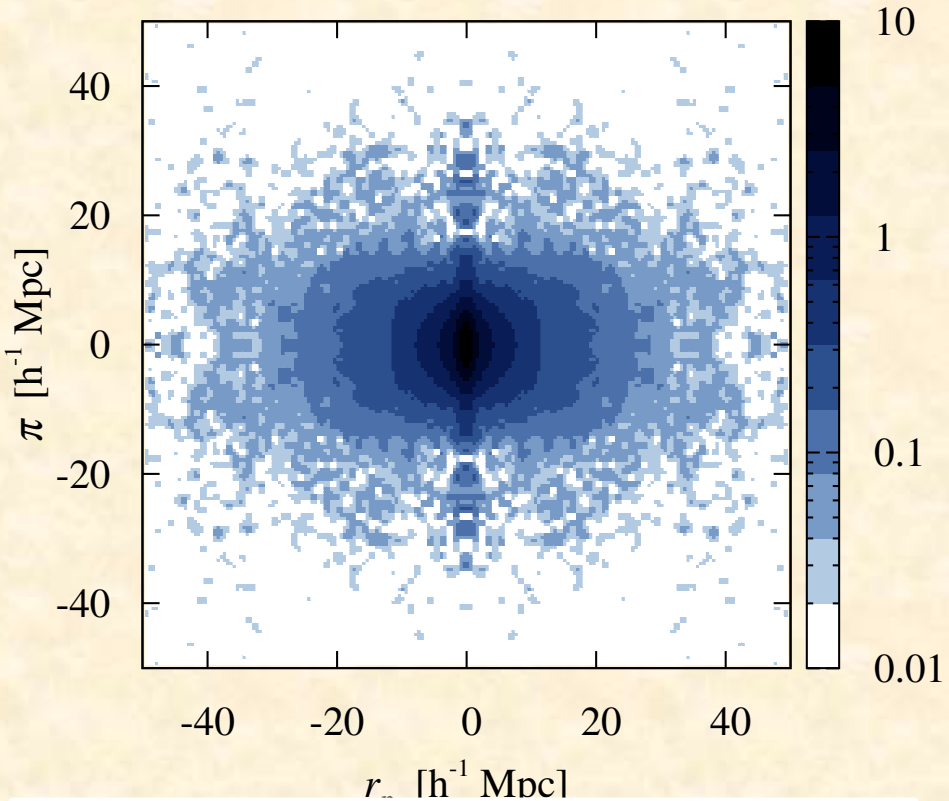


(Bianchi, LG et al., 2012)

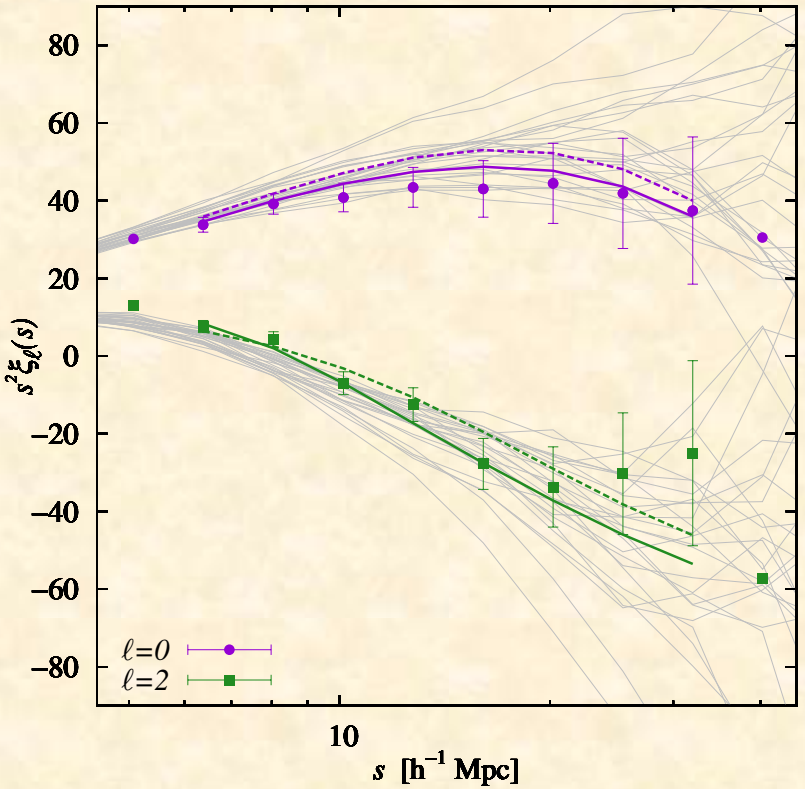
(also: Okumura & Jing, 2011)

Measuring RSD: how this is done in detail

A. **Fit the full 2D correlation function**, expressed as combination of spherical armonics (moments)



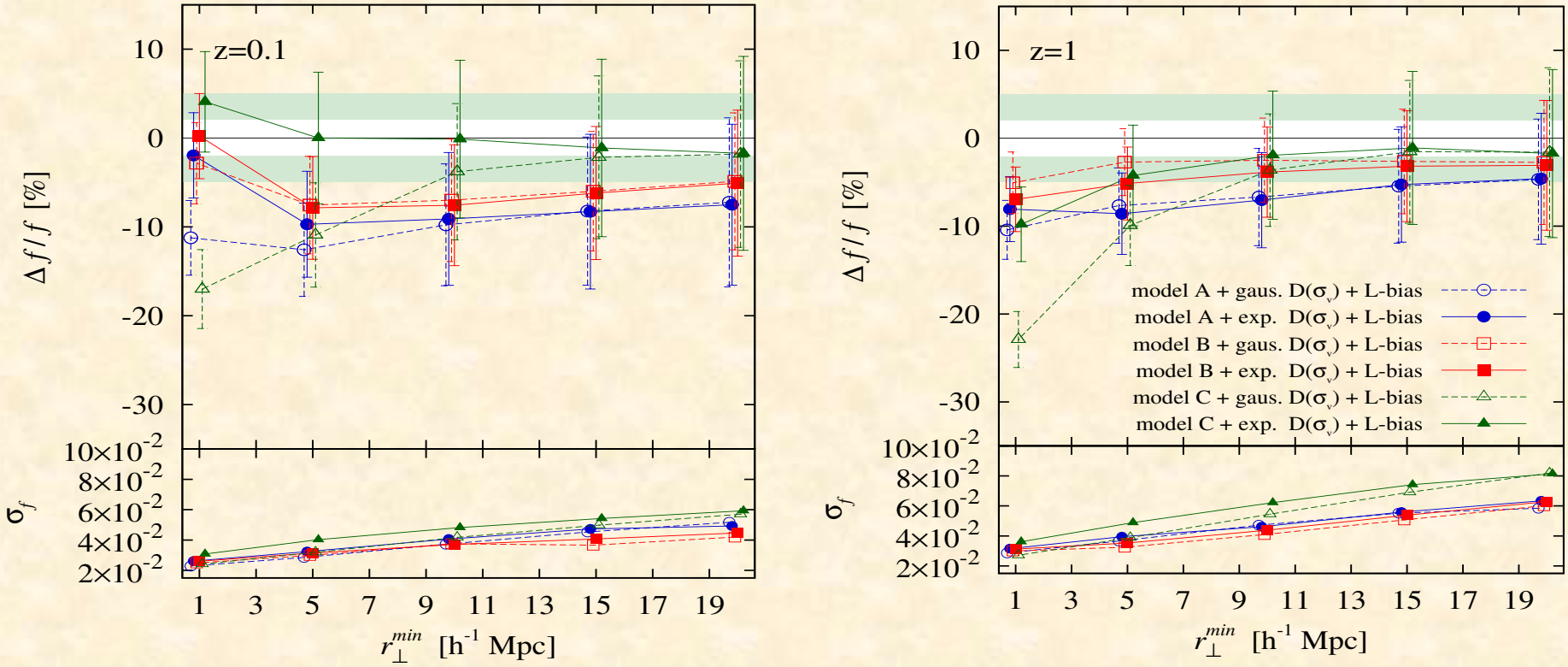
B. **Fit single multipoles**



Pros: highly non-linear scales where FoG dominates more cleanly removed
Cons: lots of d.o.f. → covariance matrix estimation more difficult

Pros: compress the information → easier to estimate covariance matrix
Cons: uncertainties in modelling small-scale non-linearity (FoG) affect all scales

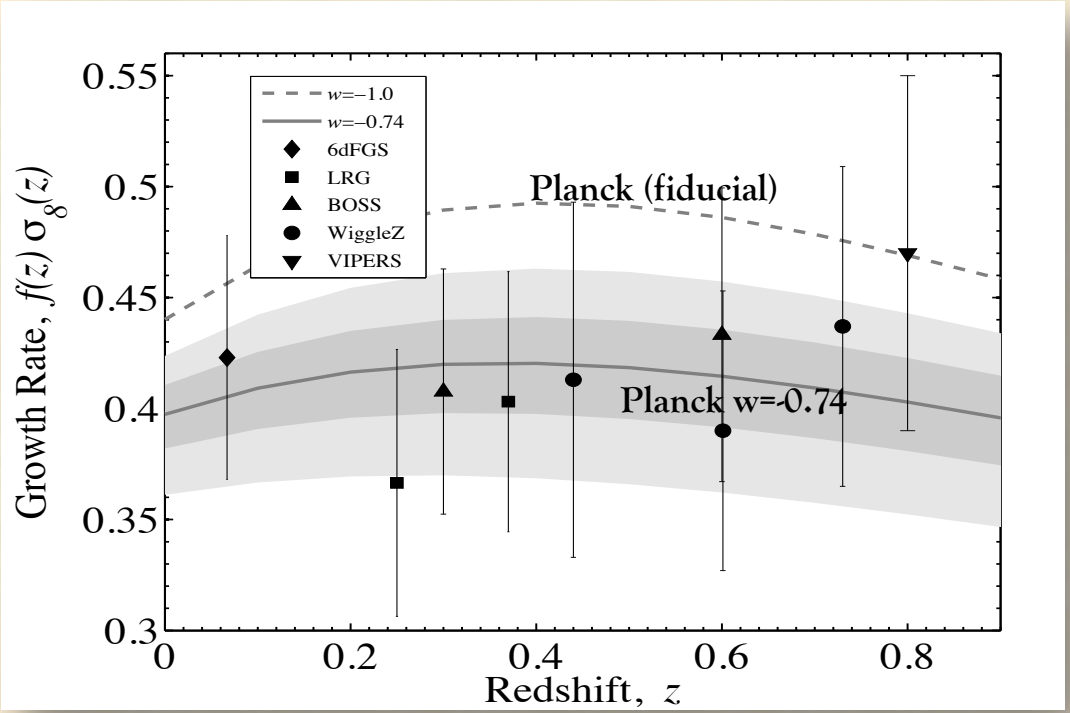
Systematic errors on *f*



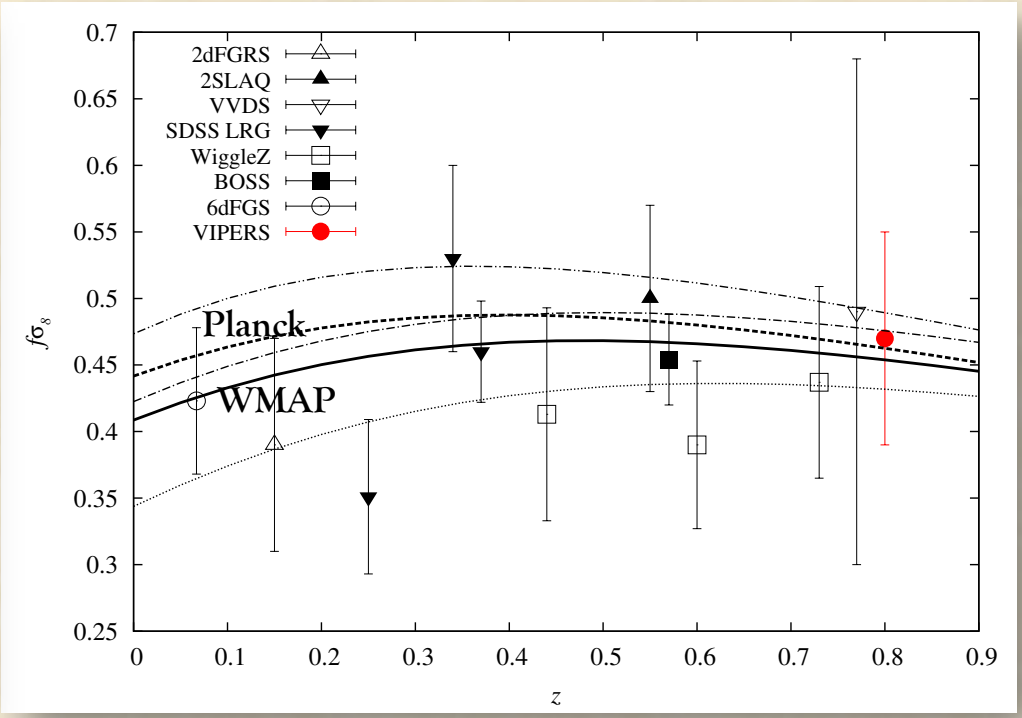
Taruya et al. 2010 model allows recovering *f* **at the 5% percent level**, *Scoccimarro* 2004 and dispersion models performing worst (3-10%)

(de la Torre & Guzzo 2012)

As an aside, is there a real tension of current constraints on $f\sigma_8$ with GR+Planck predictions?



(Macaulay et al. 2013)



(de la Torre & VIPERS 2013)

Summary

- A promising future for galaxy redshift surveys : measure both w(z) and f(z) using BAOs/P(k) and z-distortions (plus clusters…) → test dark energy vs modified gravity
- A renaissance for redshift-space distortions: not considered in this context before 2008, now a key "dark energy probe" (EUCLID)

1) RSD: Improving the data

2) Over past 2 years new z-distortions results from WiggleZ, BOSS, designed for BAO

- VIPERS fills a specific niche, high sampling, will allows multi-population tracers approach
- Several projects at the horizon (W. Percival talk)
- EUCLID is approved and will couple a massive (slitless) redshift survey with a high-resolution imaging survey, to combine galaxy clustering and weak lensing (launch 2019)

2) RSD: Improving the estimators

- Need further work, but rapid and promising development (e.g. u. Seljak talk)
- Several approaches (e.g. building upon Scoccimarro 2004)
- Streaming model approach yields promising results (Reid et al., Bianchi et al.)
- More accurate description of distribution function of velocities (Bianchi+): connect to theory on one side and data on another

VIPERS PAPERS, March 2013

1. The VIMOS Public Extragalactic Redshift Survey (VIPERS): An unprecedented view of galaxies and large-scale structure at 0.5 < z < 1.2, Guzzo, L., & VIPERS Team, 2013, A&A (arxiv.org/abs/1303.2623)

2. The VIMOS Public Extragalactic Redshift Survey (VIPERS): an unprecedented view of galaxies and large-scale structure halfway back in the life of the Universe, Guzzo, L., & VIPERS Team, 2013, The ESO Messenger, 151, 39

3. The VIMOS Public Extragalactic Redshift Survey (VIPERS): Galaxy clustering and redshift-space distortions at z ~ 0.8 in the first data release, de la Torre, S., & VIPERS Team, 2013, A&A (arxiv.org/abs/1303.2622)

4. The VIMOS Public Extragalactic Redshift Survey (VIPERS): Luminosity and stellar mass dependence of galaxy clustering at 0.5<z<1.1, Marulli, F., & VIPERS Team, 2013, A&A (arxiv.org/abs/1303.2633)

5. The VIMOS Public Extragalactic Redshift Survey (VIPERS): Galaxy stellar mass functions at intermediate redshifts, Davidzon, I., & VIPERS Team, 2013, A&A (arxiv.org/abs/1303.3808)

6. The VIMOS Public Extragalactic Redshift Survey (VIPERS): A Support Vector Machine classification of galaxies, stars and AGNs, Malek, K., & VIPERS Team, 2013, A&A, (arxiv.org/abs/1303.2621)

7. The VIMOS Public Extragalactic Redshift Survey (VIPERS): spectral classification through Principal Component Analysis, Marchetti, A. et al. & VIPERS Team, 2013, MNRAS, 428, 1424

8. The power spectrum from the angular distribution of galaxies in the CFHTLS-Wide fields at redshift ~0.7, Granett, B. R.; Guzzo, L.; Coupon, J.; Arnouts, S.; Hudelot, P.; & VIPERS Team, 2012, MNRAS, 421, 251

9. Easylife: The Data Reduction and Survey Handling System for VIPERS, Garilli, B.; Paioro, L.; Scodeggio, M.; Franzetti, P.; Fumana, M.; Guzzo, L. 2012, PASP, 124, 1232

More VIPERS PAPERS to come, June 2013

1. The VIMOS Public Extragalactic Redshift Survey (VIPERS): Omega_m from the clustering ratio measured at z~1, Bel, J., & VIPERS Team, 2013, A&A, submitted
2. The VIMOS Public Extragalactic Redshift Survey (VIPERS): the unimportance of dry mergers in the formation of massive red sequence galaxies over the past 9 Gyr, Fritz, A., & VIPERS Team, 2013, A&A, submitted
3. PCA analysis of the full PDR-1 sample, Marchetti et al.
4. Morphological bulge-disk decomposition in VIPERS, Krywult et al.
5. A detailed view of the color-density relation at z=[0.5-1], Cucciati et al.
6. Density field… (Cucciati, Branchini, Bel)
7. Multiple population RSD (Granett, Rota, LG)
8. Power spectrum analysis and cosmological constraints (Rota, Granett, Bel, LG, …)
9. …