The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2419-21

Workshop on Large Scale Structure

30 July - 2 August, 2012

Tracing the growth of structure with redshift-space distortions in current and future surveys

L. Guzzo

INAF - OA di Brera

Strada Costiera, 11 - 34151 - Trieste - Italy • Tel. +39 0402240111 • Fax. +39 040224163 • sci_info@ictp.it • www.ictp.it

ICTP is governed by UNESCO, IAEA, and Italy, and it is a UNESCO Category 1 Institute

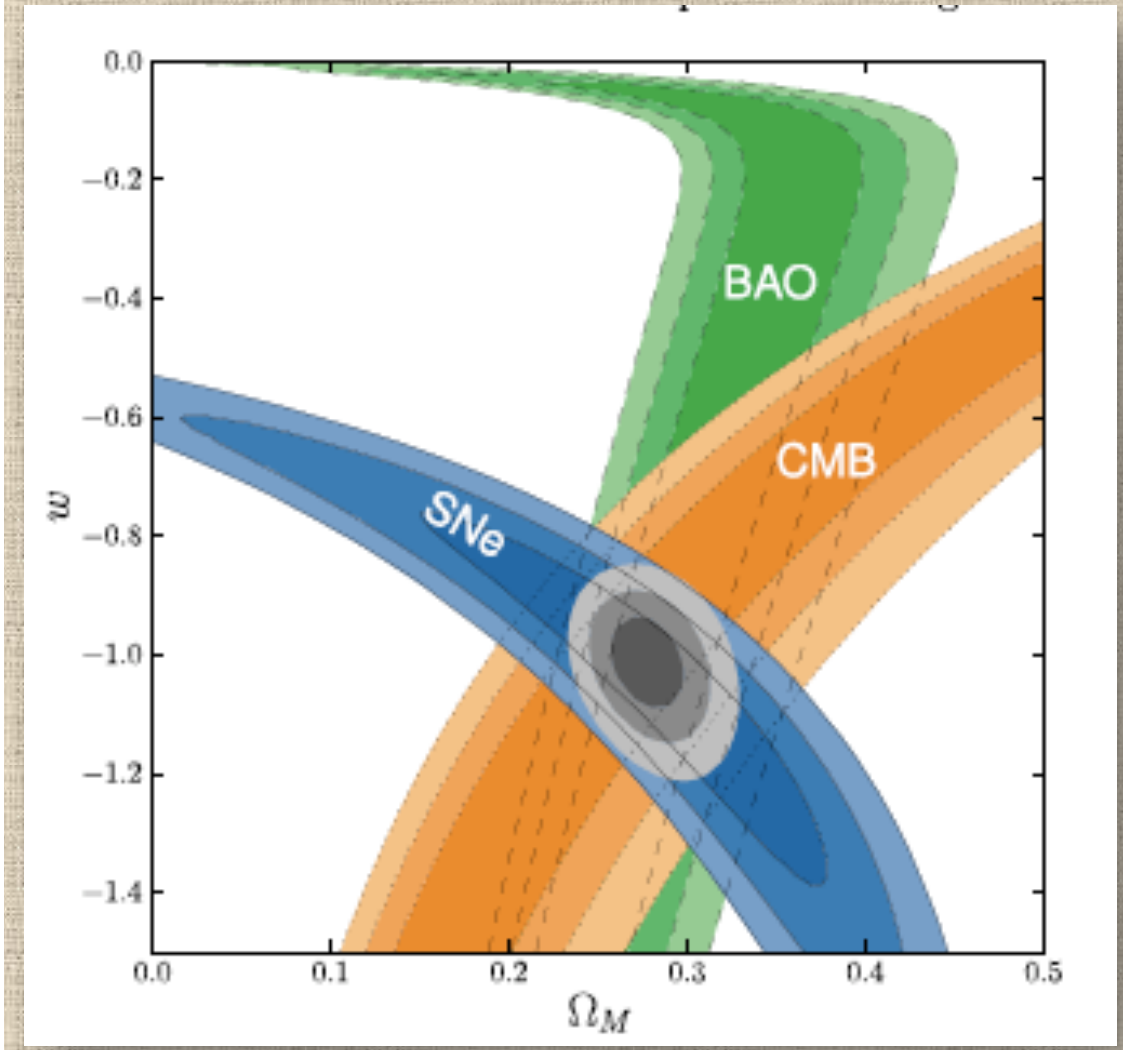
Measuring the growth of structure with Redshift-Space Distortions

Luigi (Gigi) Guzzo
INAF - Osservatorio di Brera, Milano

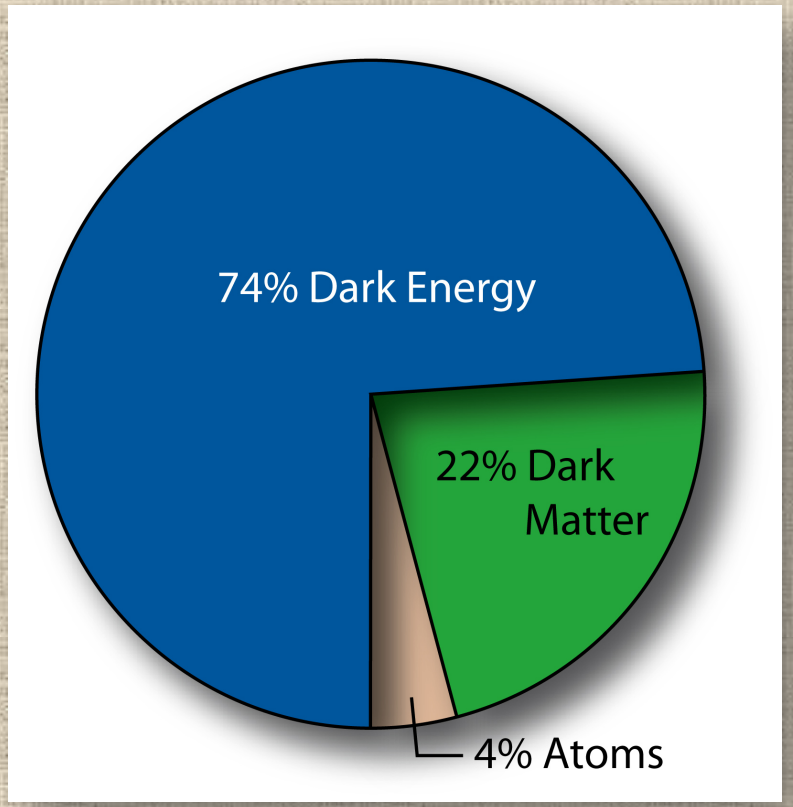
Outline

- Intro: understanding the origin (or reality?) of cosmic acceleration through galaxy clustering
- Redshift-space distortions (RSD) an old tool in a new context
- Improving the data: the VIPERS project at ESO
- Improving the tools: modelling RSD in the precision cosmology era, systematic errors and forecasts

Cosmic concordance: a w=-1 Universe?



Amanullah et al. 2010 (Union supernovae)



However, lambda (or dark energy) is not the end of the story…

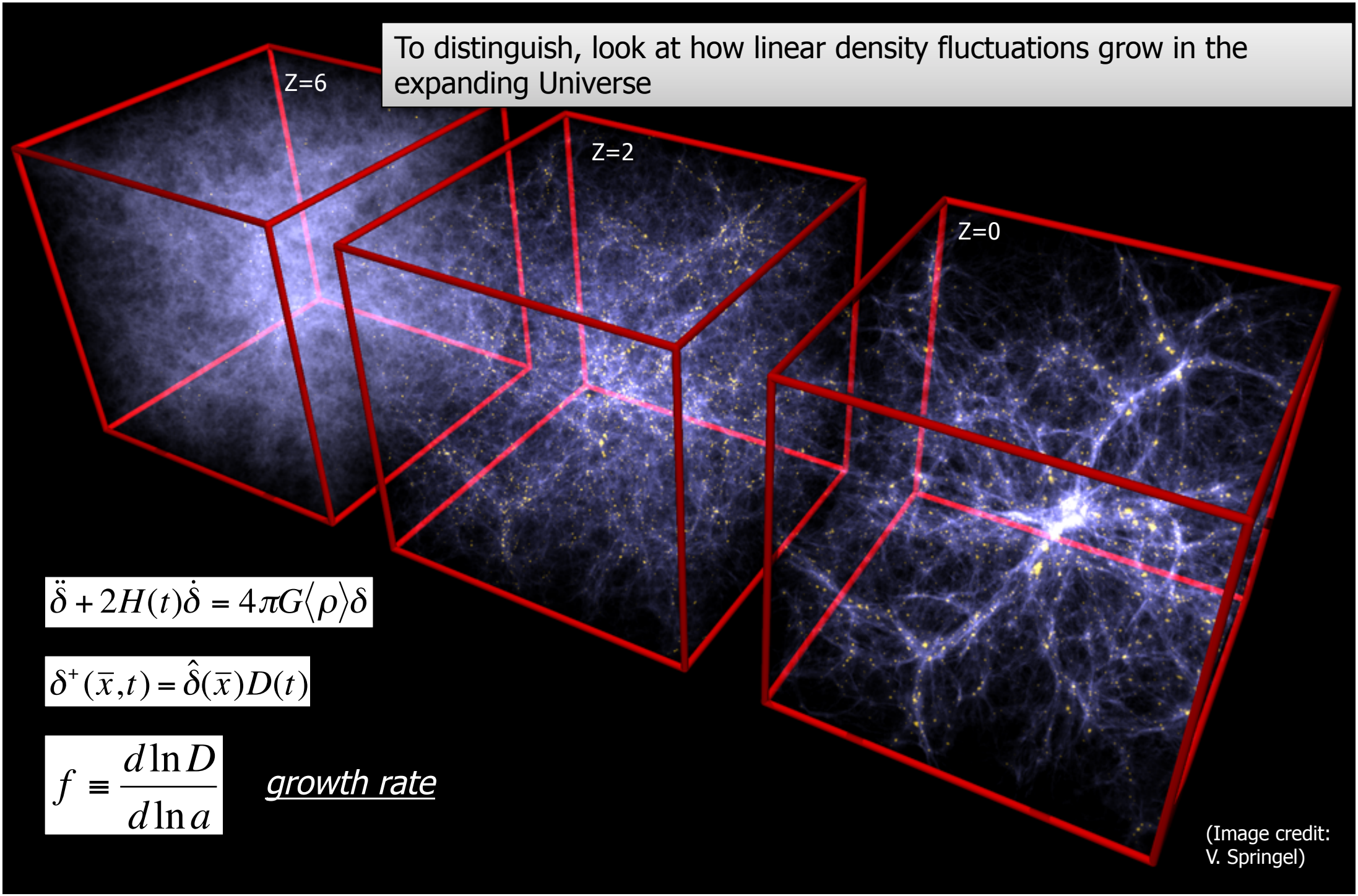
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Modify gravity theory [e.g. $R \rightarrow f(R)$]

"…the Force be with you"

Add dark energy

To distinguish, look at how linear density fluctuations grow in the expanding Universe



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

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

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

growth rate

(Image credit: V. Springel)

Growth produces motions: galaxy peculiar velocities

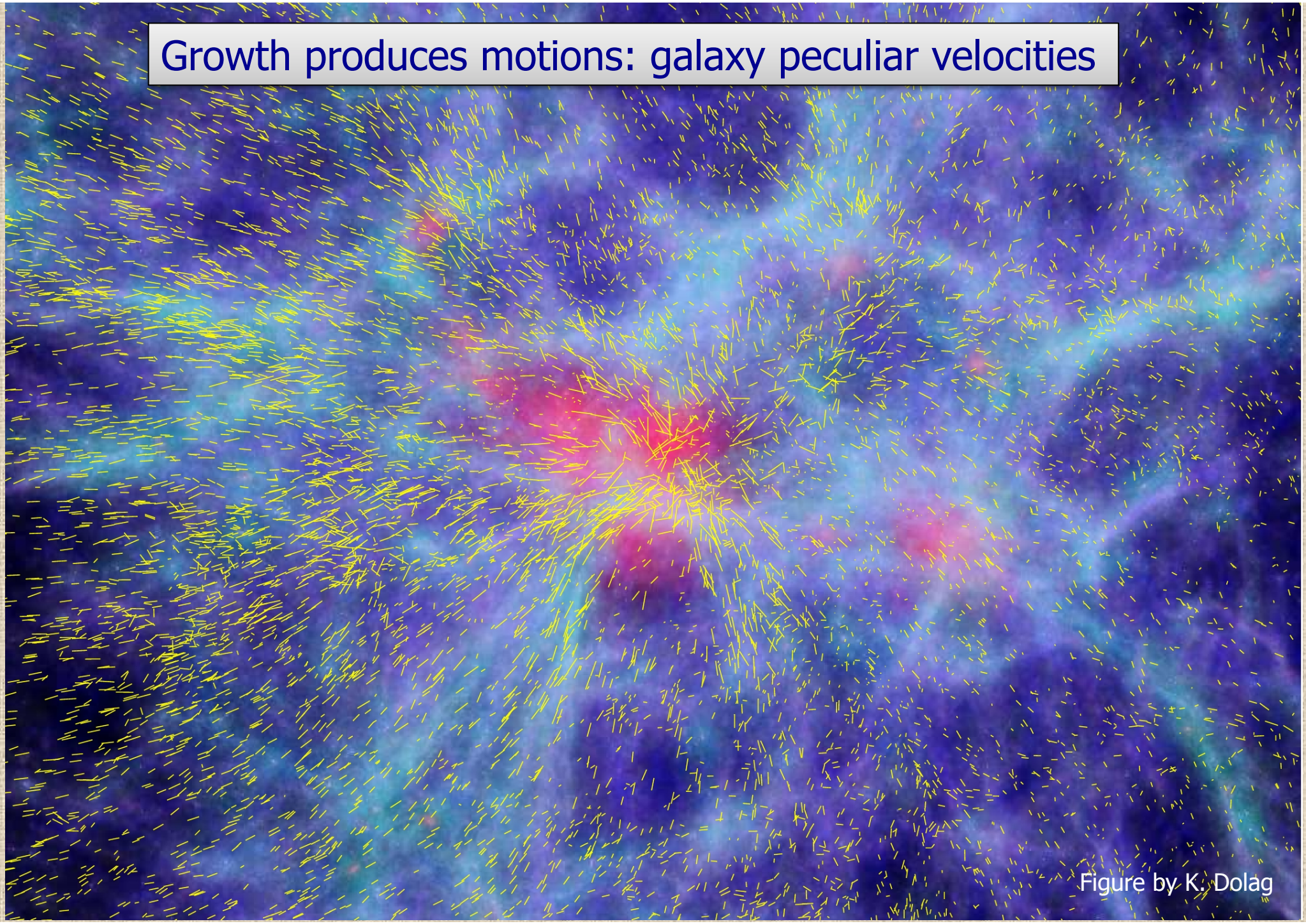
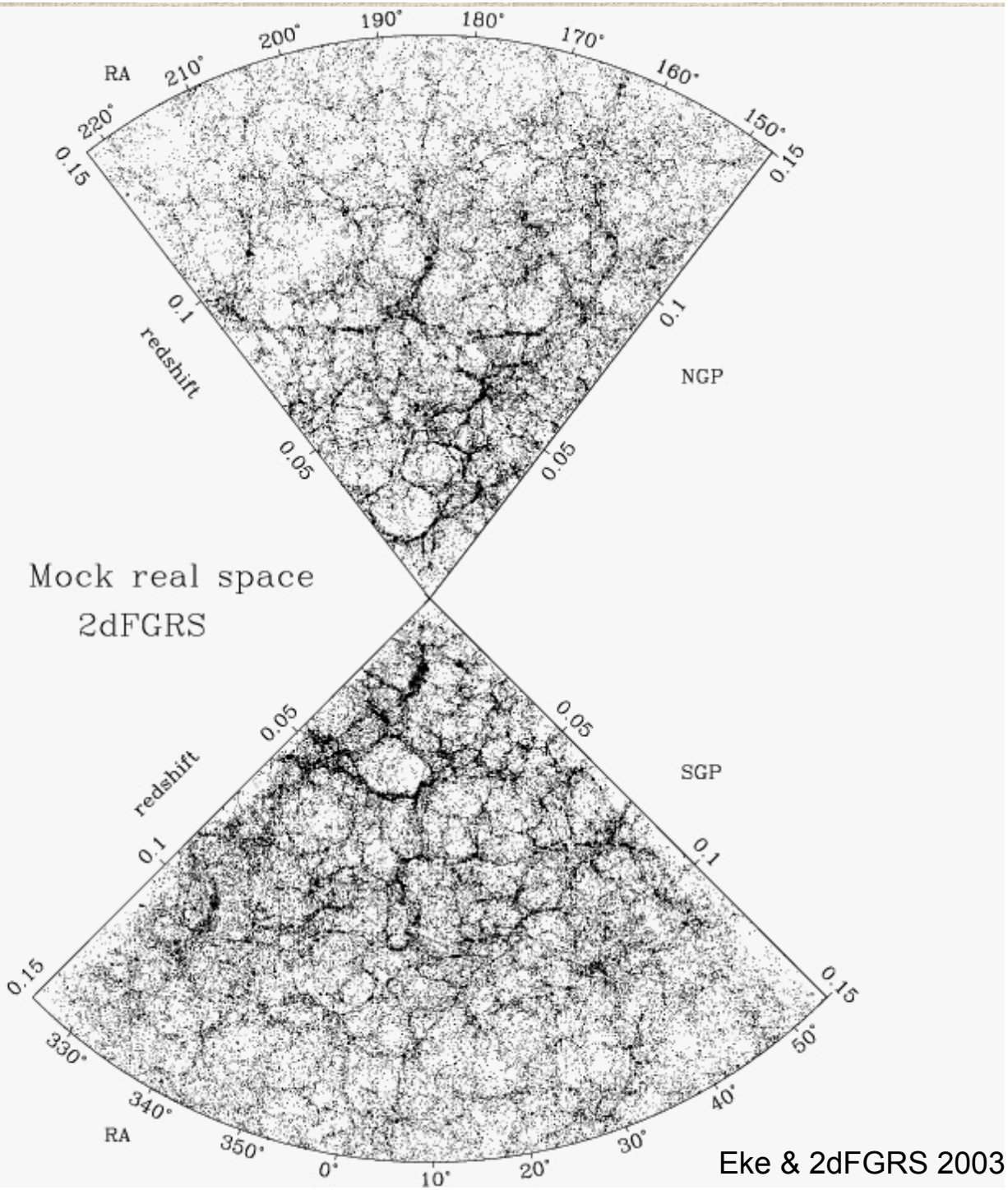


Figure by K. Dolag

In galaxy redshift surveys peculiar velocities manifest themselves as *redshift-space distortions* (Kaiser 1987)

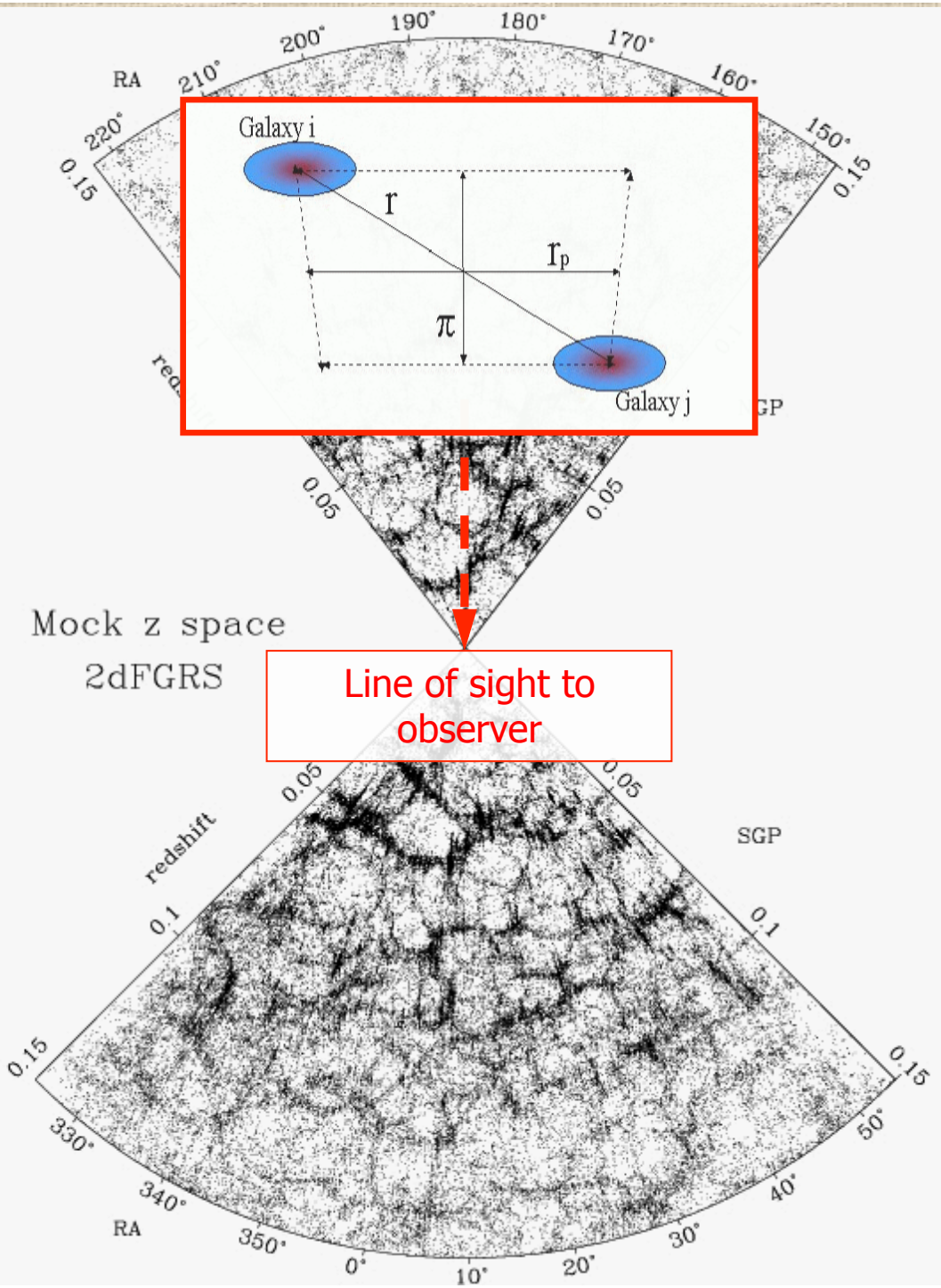
real space



Eke & 2dFGRS 2003

In galaxy redshift surveys peculiar velocities manifest themselves as *redshift-space distortions* (Kaiser 1987)

redshift space



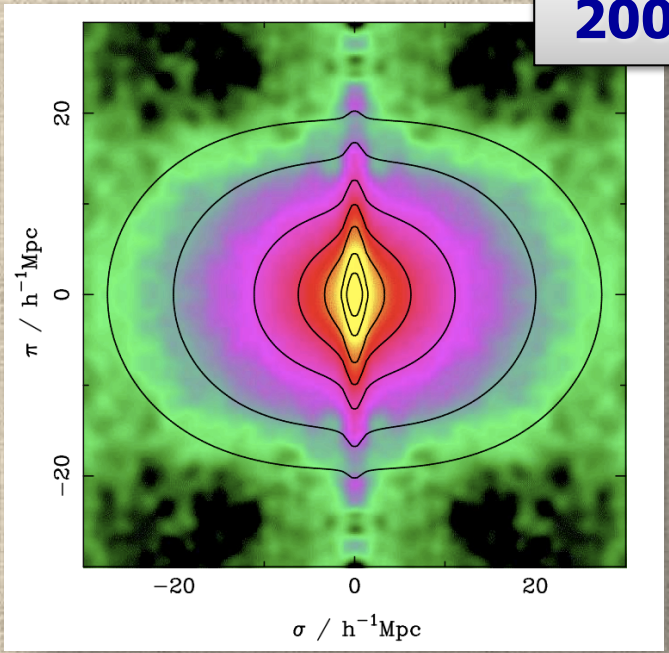
The renaissance of RSD… a change of perspective

Nature 410, 169 (2001)

A measurement of the cosmological mass density from clustering in the 2dF Galaxy Redshift Survey

John A. Peacock[1], Shaun Cole[2], Peder Norberg[2], Carlton M. Baugh[2], Joss Bland-Hawthorn[3], Terry Bridges[3], Russell D. Cannon[3], Matthew Colless[4], Chris Collins[5], Warrick Couch[6], Gavin Dalton[7], Kathryn Deeley[6], Roberto De Propris[6], Simon P. Driver[8], George Efstathiou[9], Richard S. Ellis[9,10], Carlos S. Frenk[2], Karl Glazebrook[11], Carole Jackson[4], Ofer Lahav[9], Ian Lewis[3], Stuart Lumsden[12], Steve Maddox[13], Will J. Percival[1], Bruce A. Peterson[4], Ian Price[4], Will Sutherland[1,7] & Keith Taylor[3,10]

2001



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

nature

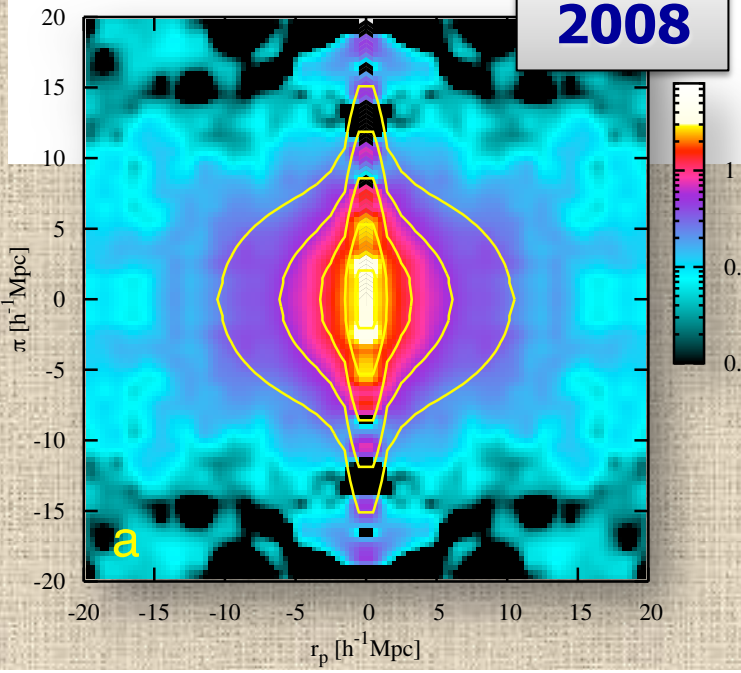
Nature 451, 541 (2008)

LETTERS

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

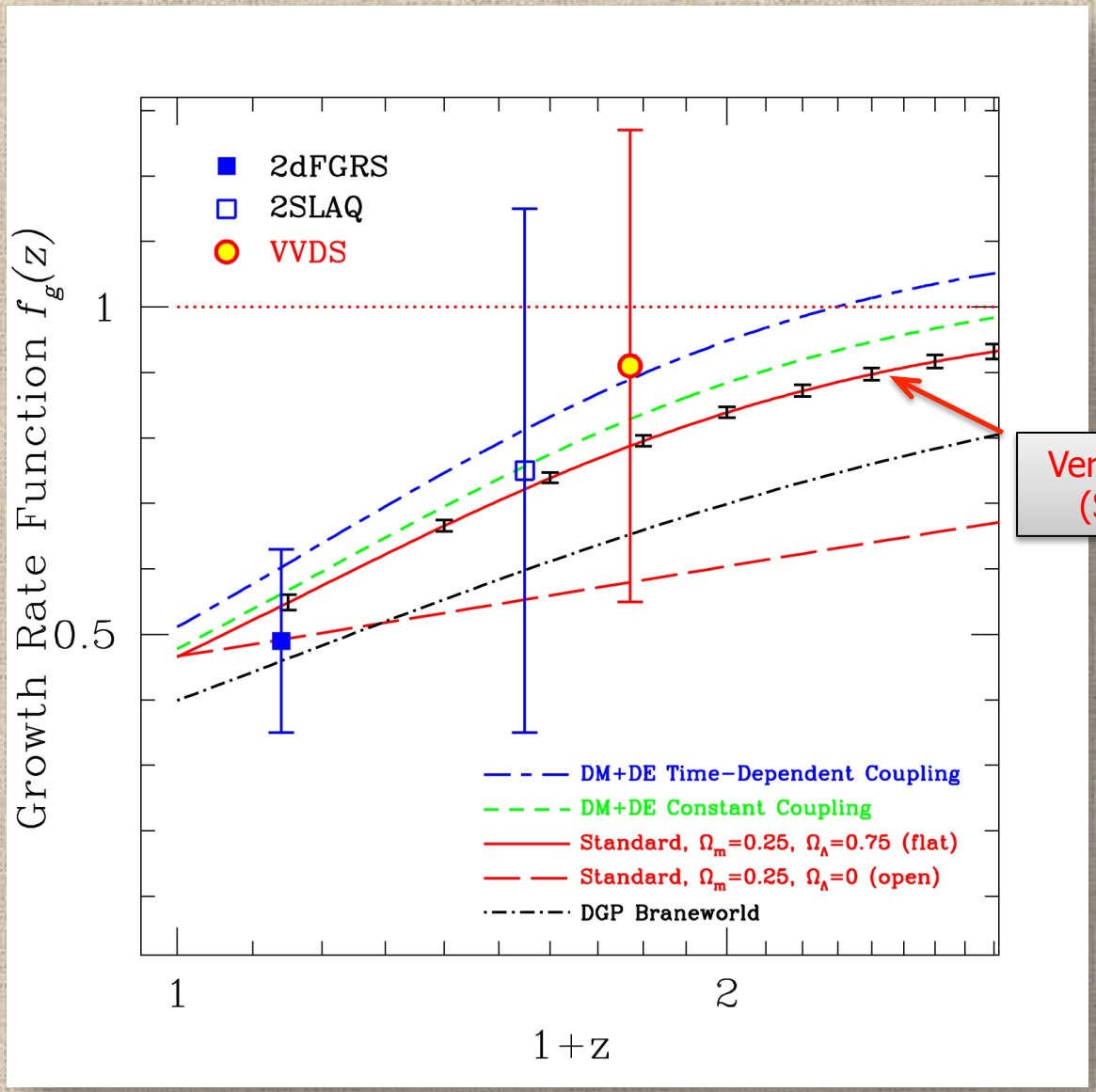
L. Guzzo[1,2,3,4], M. Pierleoni[3], B. Meneux[5], E. Branchini[6], O. Le Fèvre[7], C. Marinoni[8], B. Garilli[5], J. Blaizot[3], G. De Lucia[3], A. Pollo[7,9], H. J. McCracken[10,11], D. Bottini[5], V. Le Brun[7], D. Maccagni[5], J. P. Picat[12], R. Scaramella[13,14], M. Scodeggio[5], L. Tresse[7], G. 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]

2008



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

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

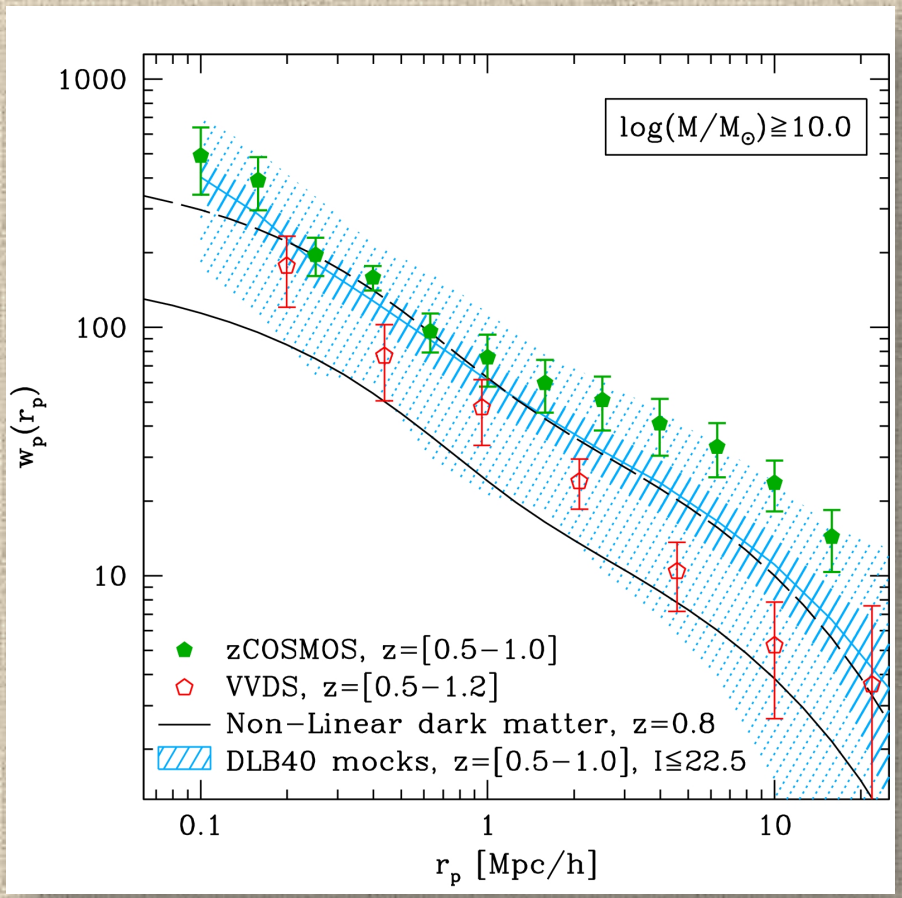


Very first Euclid-spec (SPACE) forecast

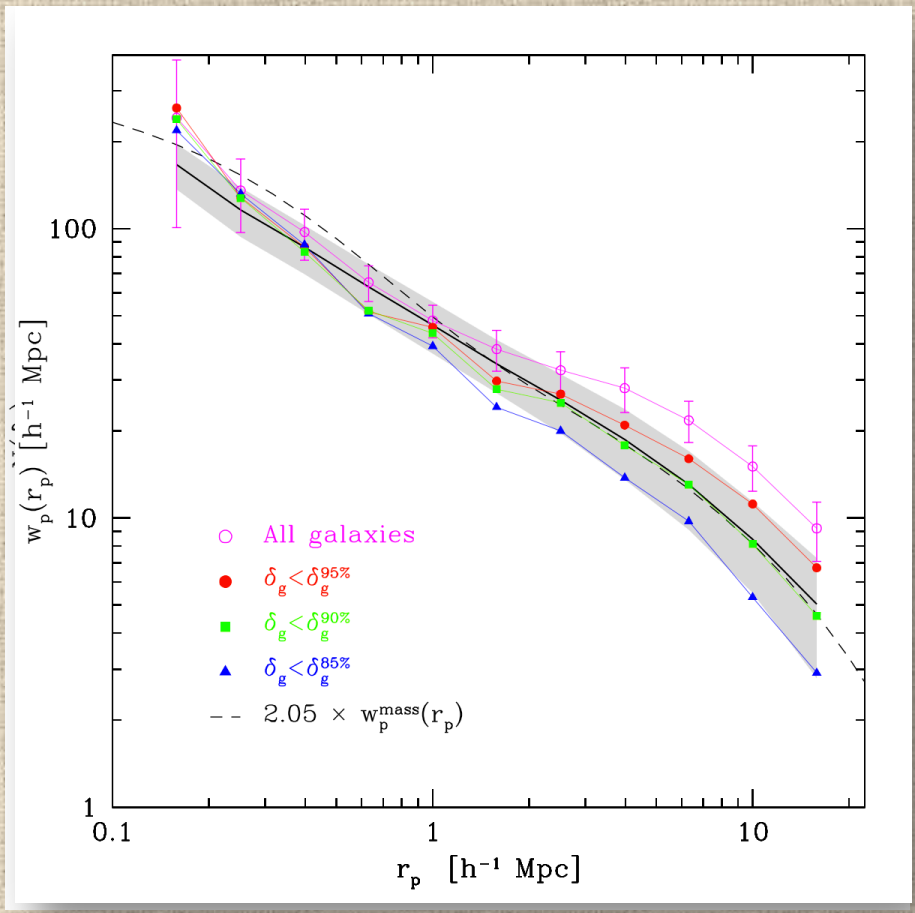
Nature 451, 541 (2008)

Waiting for Euclid: improving the z~1 data…

Status in 2008: at z~1 still small volumes and low statistics



Meneux & ZCOSMOS Collaboration, 2009

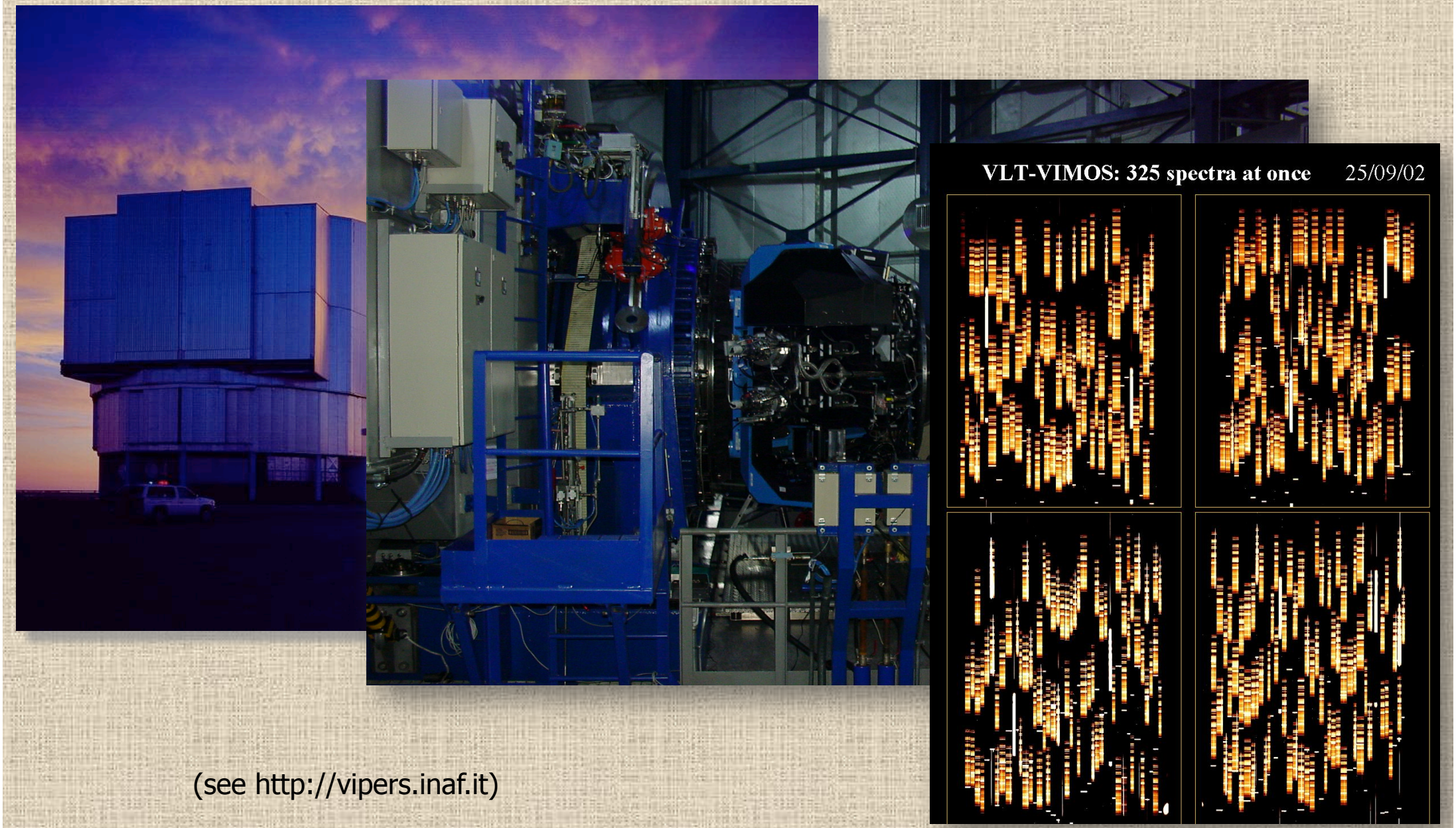


De la Torre, LG & ZCOSMOS Collaboration, 2010, MNRAS, 409, 867

→ Enviromental dependence of clustering in hierarchical models (Abbas & Sheth 2005)


VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY

VIPERS: exploiting VIMOS Multi-Object Spectroscopy at the VLT (440 hours)



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

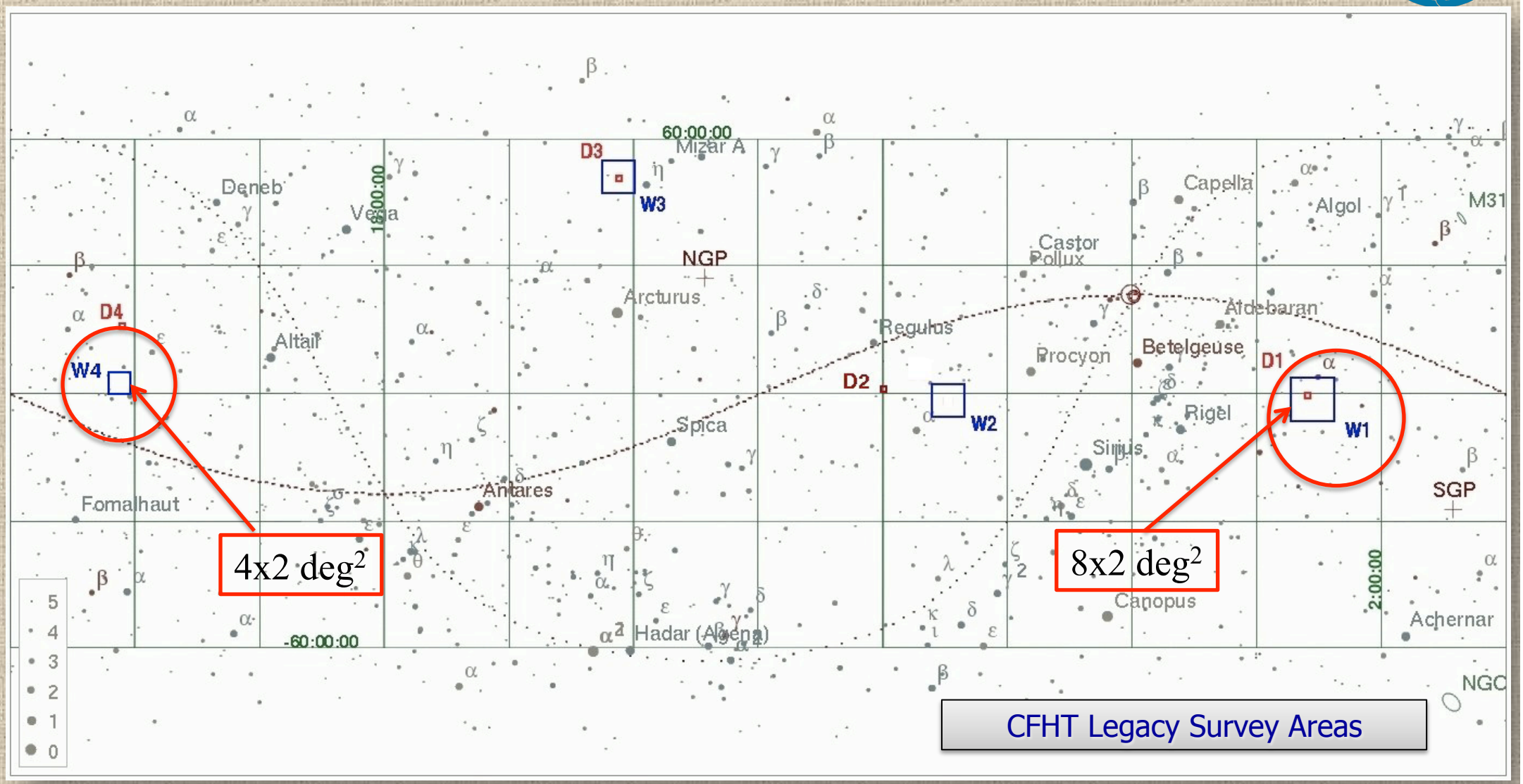
Survey design goals

- Maximize volume (minimize cosmic variance)
- Focus on z=0.5-1.2 range
- Keep good sampling (n~10^{-2} gal h^3 Mpc^{-3} , comparable to 2dFGRS and SDSS)
- Optimize cosmology, but keep high legacy return (ESO time)

VIPERS in a nut-shell

- ~24 deg^2 over W1 and W4 CFHTLS wide fields (~16 + 8)
- I_{AB}<22.5, LR Red grism, 45 min exp.
- 288 VIMOS pointings
- PSF + SED –based star-galaxy separation (AGN color recovery)
- z>0.5 color-color pre-selection
- **~100,000 redshifts, >40% sampling**
- **440.5 VLT hours**
- Density and volume comparable to 2dFGRS, but at z~0.8
- Builds upon the VVDS/ZCOSMOS experience

Location of VIPERS fields



VIPERS Team

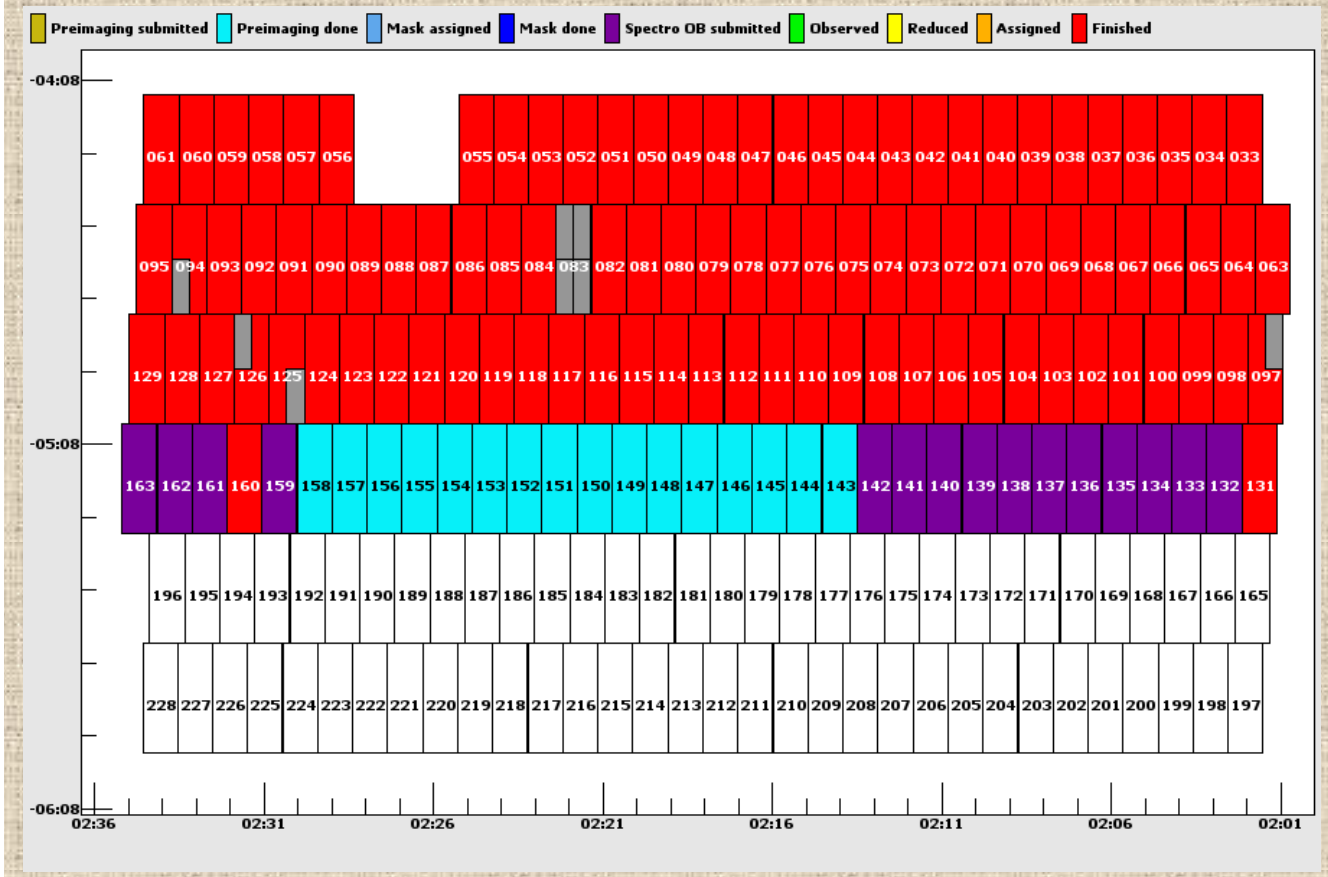
- **MILANO OAB (Project Office)**: L. Guzzo, B. Granett, A. Iovino, A. Marchetti, S. Rota, U. Abbas (Turin)
- **MILANO IASF (Data Reduction Centre)**: B. Garilli, M. Scodeggio, D. Bottini, A. Fritz, P. Franzetti, D. Maccagni, L. Paioro, M. Polletta
- **BOLOGNA**: M. Bolzonella, L. Moscardini, A. Cappi, Y. Davidzon, C. Di Porto, F. Marulli, D. Vergani, G. Zamorani, A. Zanichelli, E. Branchini (Rome)
- **EDINBURGH**: J. Peacock, S. de la Torre
- **GARCHING MPE**: S. Phleps, H. Schlagenhaufer
- **MARSEILLE**: O. Le Fevre, C. Adami, J. Bel, V. Le Brun, L. Guennou, L. Tasca, C. Marinoni
- **PARIS (TERAPIX CFHTLS)**: H. McCracken, Y. Mellier, M. Volk, J. Coupon (Tokyo), J. Blaizot (Lyon)
- **TRIESTE**: G. De Lucia, O. Cucciati
- **PORTSMOUTH**: W. Percival, R. Tojeiro, R. Nichol, A. Burden
- **WARSAW/NAGOYA**: A. Pollo, K. Malek, O. Solarz, J. Krywult (Kielce)

VIPERS broader scientific goals

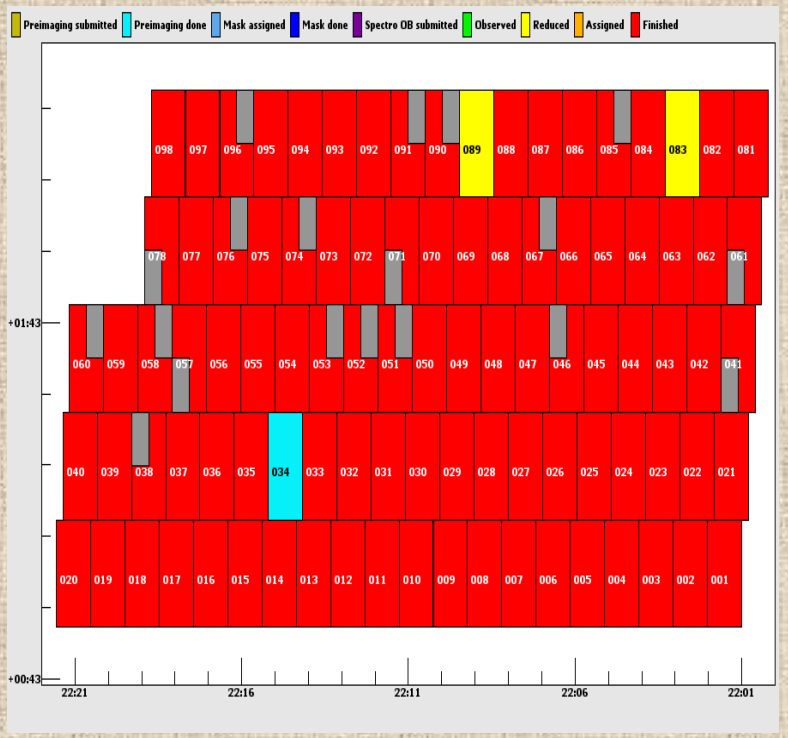
- Growth rate from redshift-space distortions
- Galaxy clustering at z~1 with comparable precision to z~0:
  - Evolution of $\xi(r)$ and P(k) (Ω_m, Ω_b at z~1)
  - Dependence on galaxy properties
  - Galaxy-DM relations (HOD modeling)
- Galaxy biasing
- Massive clusters and super-clusters of galaxies (large volume)
- Evolution of galaxy colors and environmental effects (good sampling)
- Bright/massive/rare galaxies and the galaxy luminosity and stellar mass functions (large volume)
- Evolution of AGN's
- Weak-lensing (photo-z calibration, combination with CFHTLenS)
- Multi-wavelength studies (SWIRE, XMM-XXL, UDS)

Sky coverage (as of June 2012)

W1



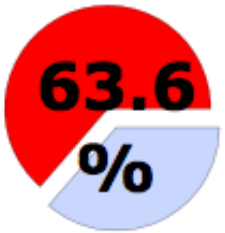
W4



Current Overall Status

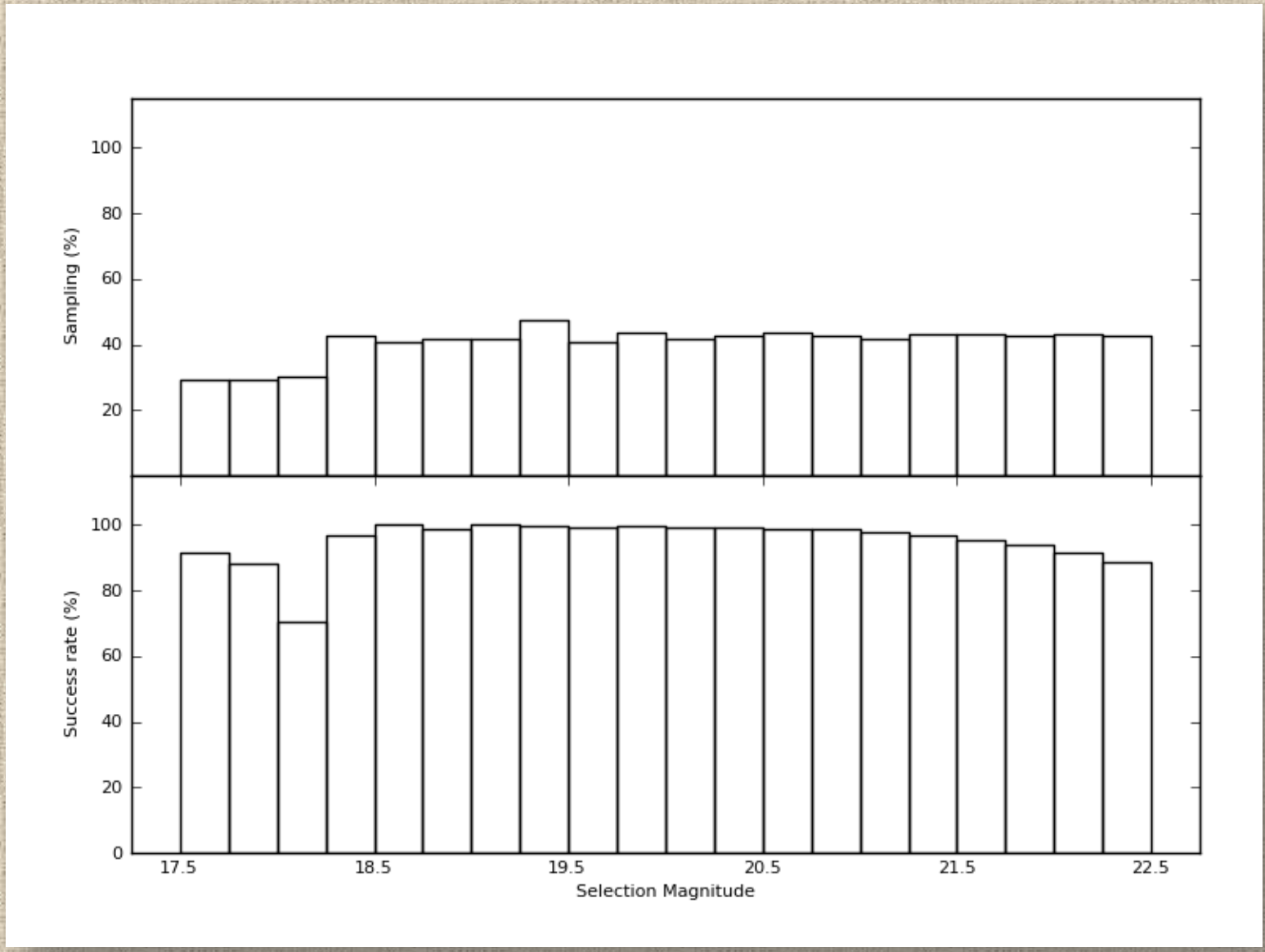
- **June 12, 2012: internal V3.0 release**

SURVEY STATUS AS OF 12/07/2012

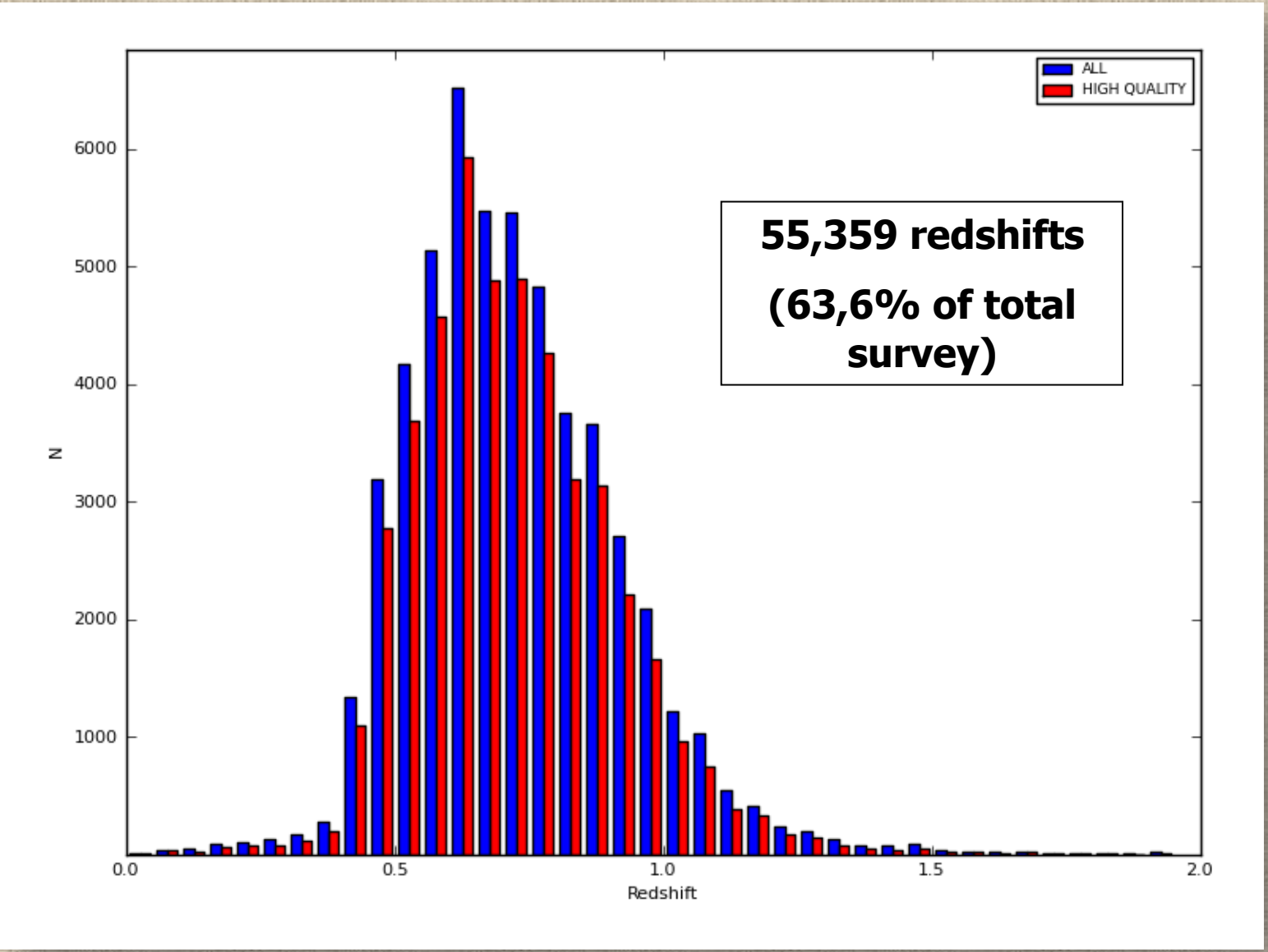
EFFECTIVE TARGETS	MEASURED REDSHIFTS	STELLAR CONTAMINATION	COVERED AREA
59013	55359	1750 (3.2 %)	

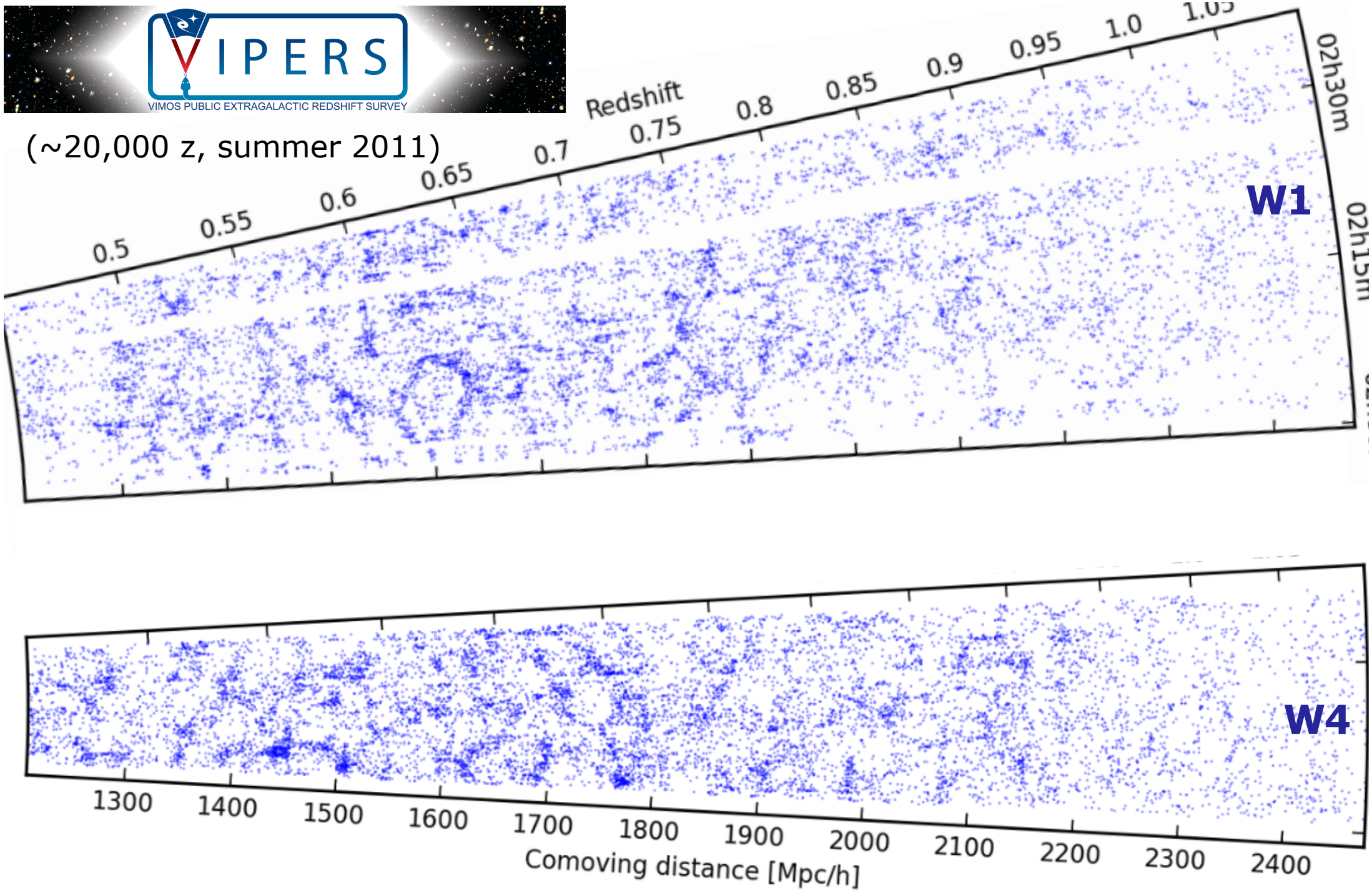
- **193 VIMOS pointings, out of 288**
- W4 fully covered
- A few pointings of very bad quality to be re-observed
- First public release (~20,000 z) before end of 2012
- Expected completion: 2014

Sampling rate and efficiency



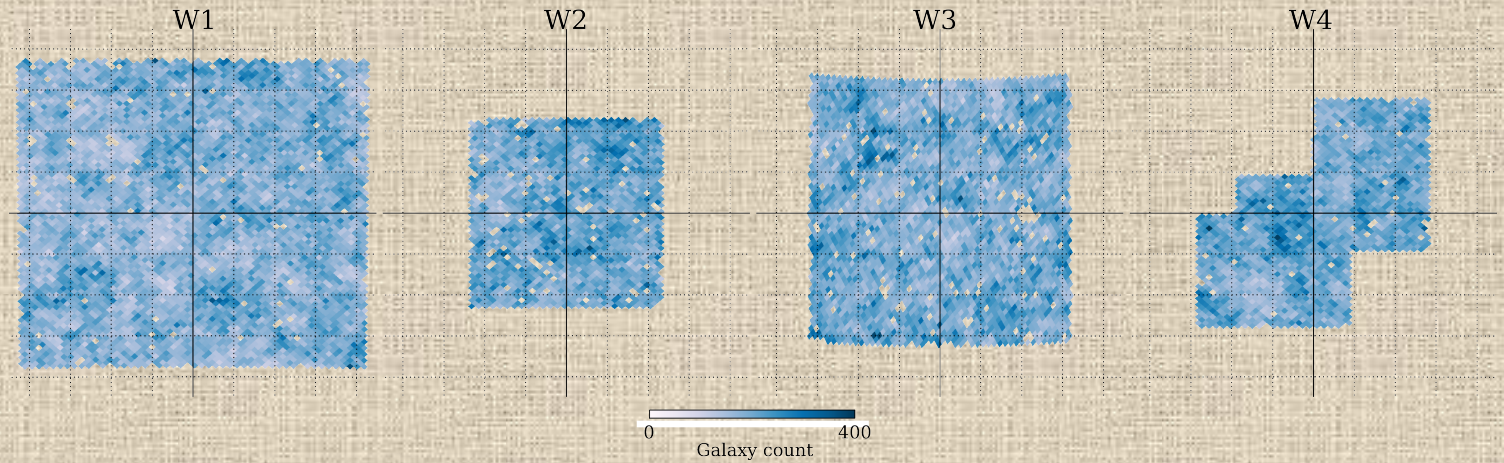
V3.0 redshift distribution




VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY
(~20,000 z, summer 2011)
Redshift
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1.0
1.05
02h30m
02h15m
W1
W4
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Comoving distance [Mpc/h]

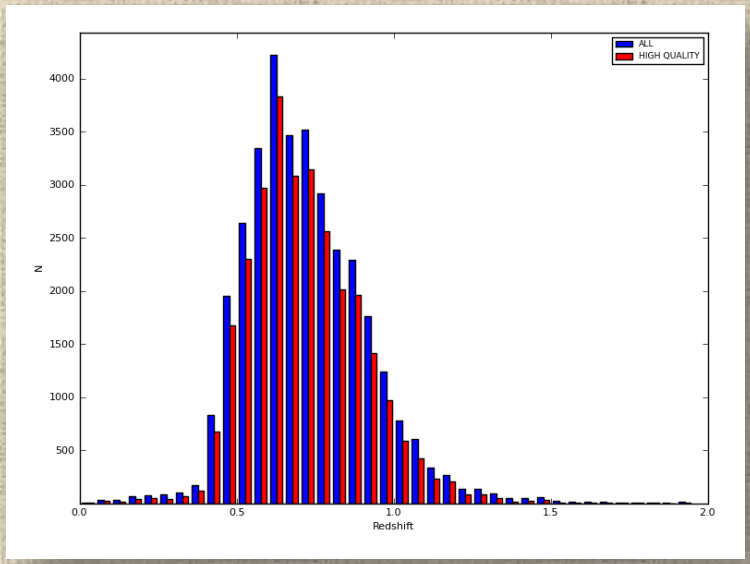
A measurement of the real-space galaxy P(k) at <z>~0.8 from the full CFHTLS-Wide data plus VIPERS N(z)

B. Granett & VIPERS Team, MNRAS, in press, **arXiv 1112.0008**



CFHTLS-Wide:

- ~140 deg^2
- 5-bands (ugriz)
- 2.1 million galaxies



- VIPERS mag/color criteria work very well in selecting 0.5<z<1.2
- Characterize VIPERS parent sub-catalogue
- Accurate N(z) crucial for de-projection: provided by VIPERS
- Exploits currently largest available volume of CFHTLS-Wide areas

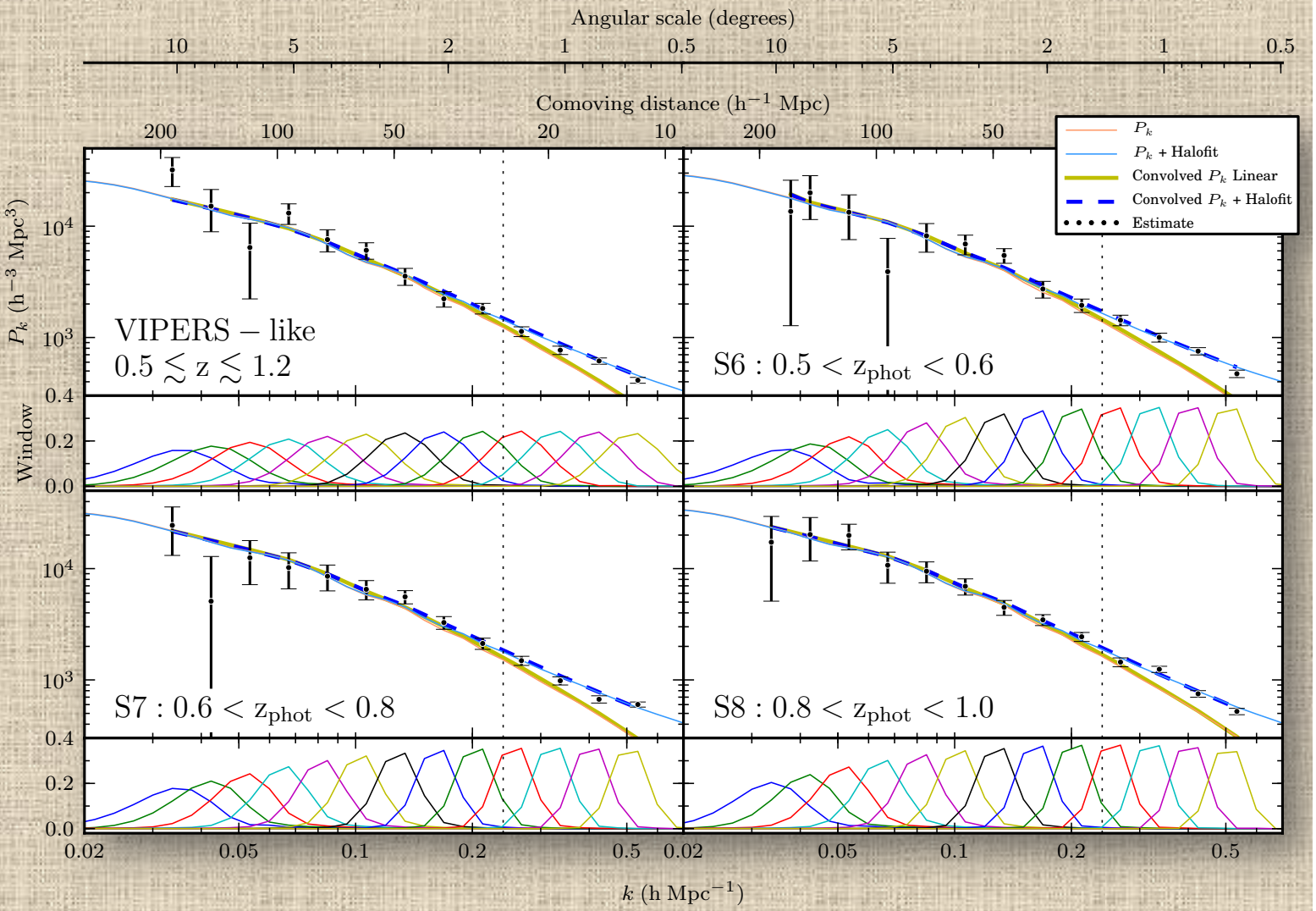
Real space P(k) at z~0.7 from CFHTLS-Wide + VIPERS N(z)

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)

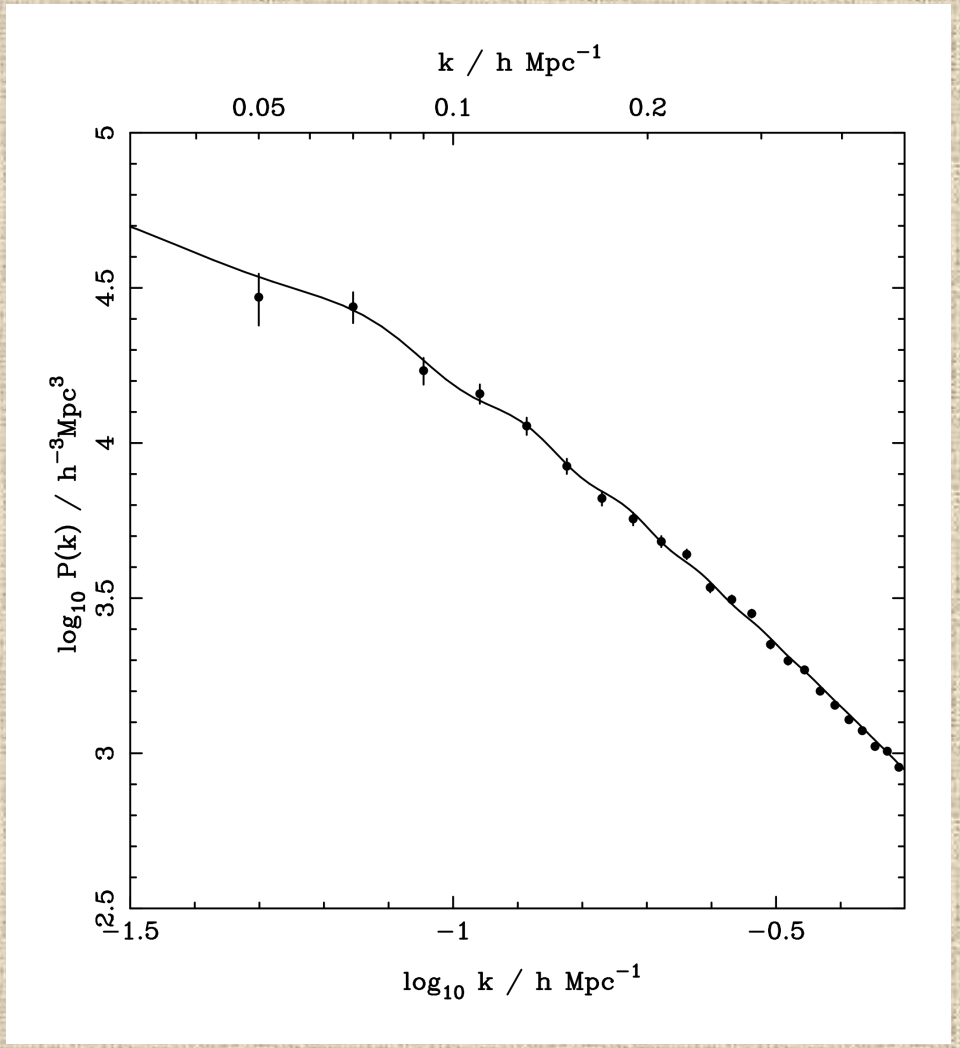


B. Granett, LG & VIPERS Team, 2012, MNRAS, 421, 251

Xia, Granett, Viel et al., MNRAS, in press – arXiv 1203.5105: improved constraints on neutrino masses

Expected full 3D P(k) at <z>~0.8 from VIPERS only

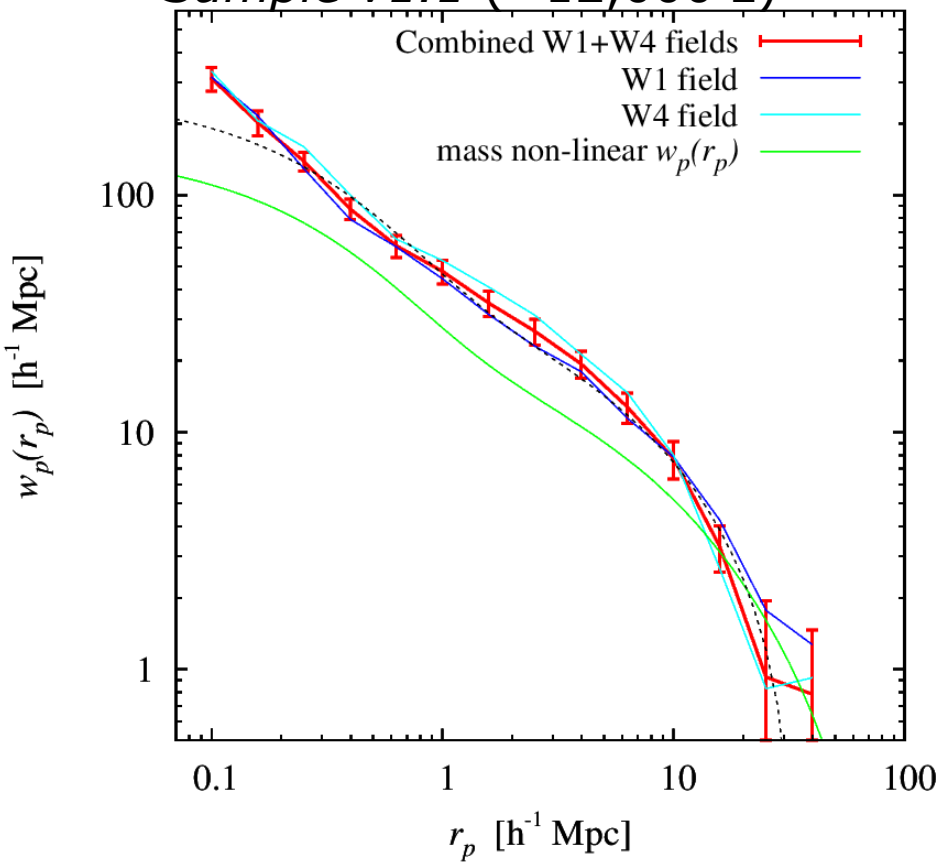
- $\Omega_m h$ from shape
- RSD in Fourier space
- neutrino mass
- large-scale bias vs galaxy properties
- BAO detection
- Improve using *reconstruction* (Burden, Percival, et al. in prep.)



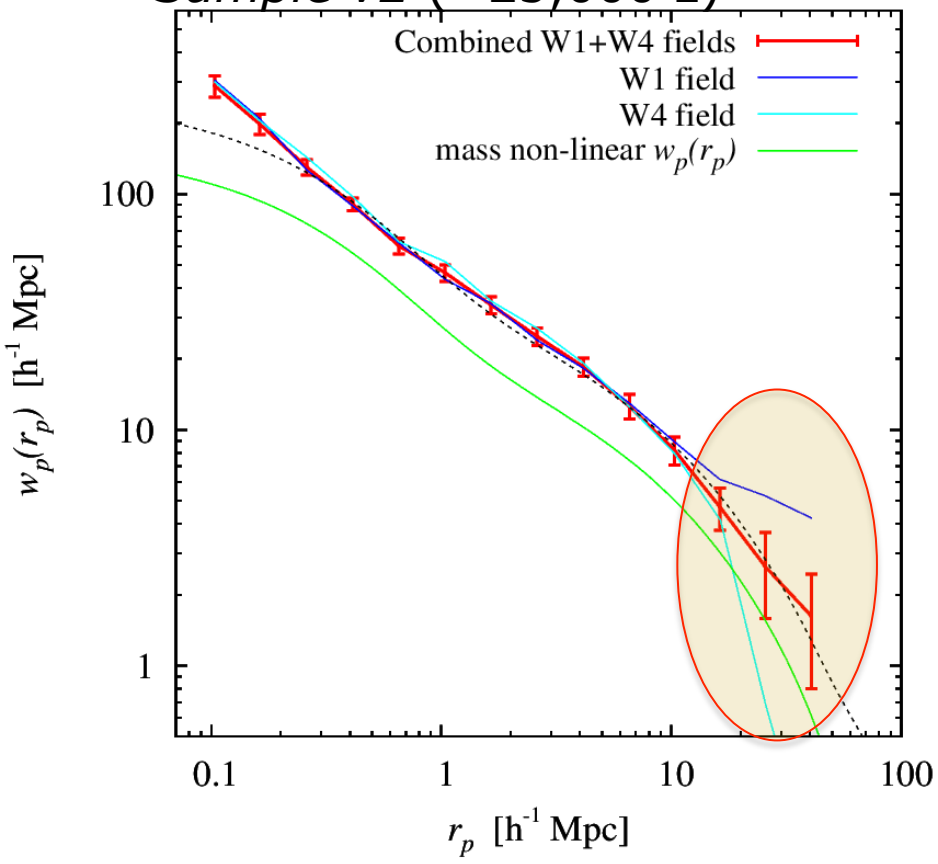
(simulation by W. Percival)

Projected correlation function (not yet from V3.0 !)

Sample v1.1 (~12,000 z)

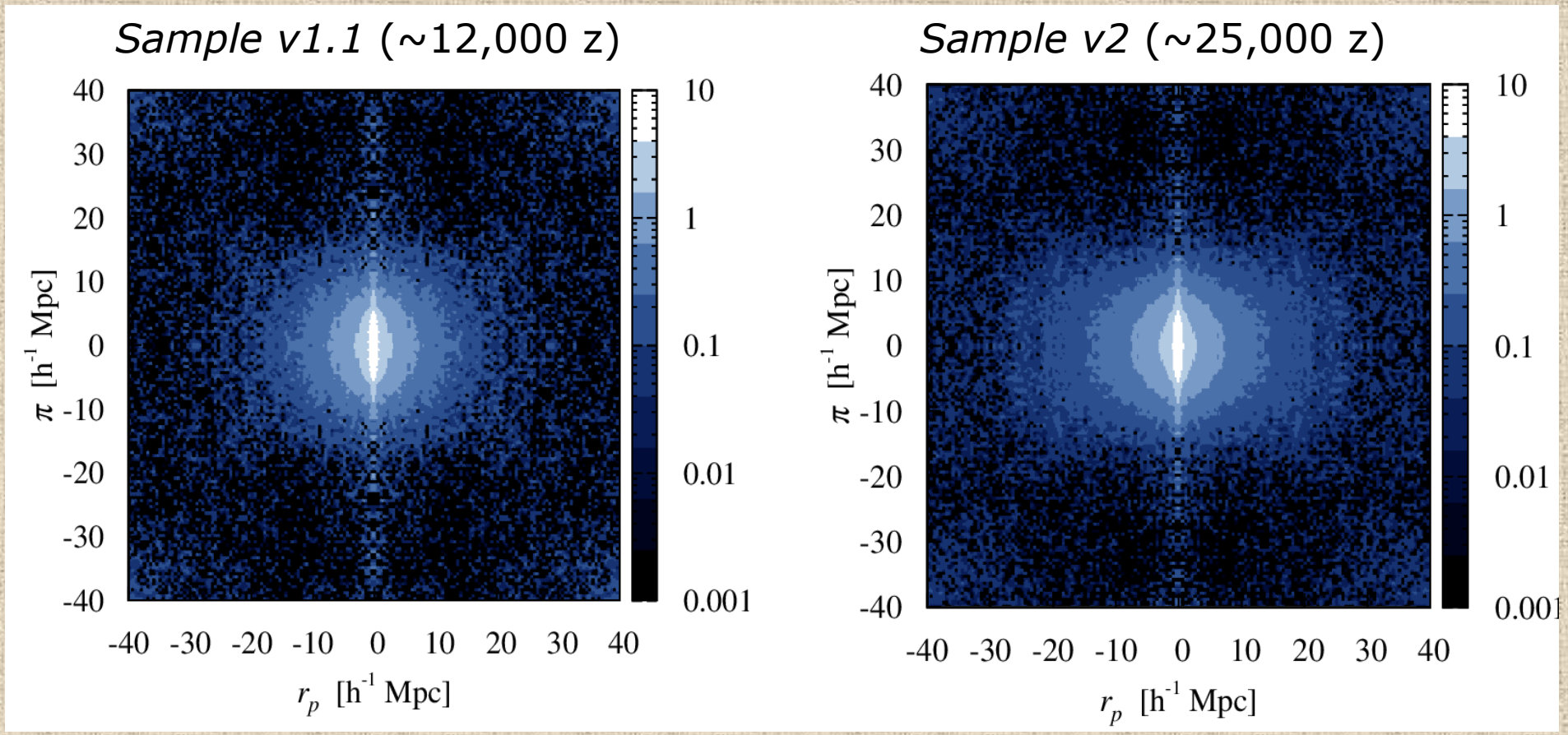


Sample v2 (~25,000 z)



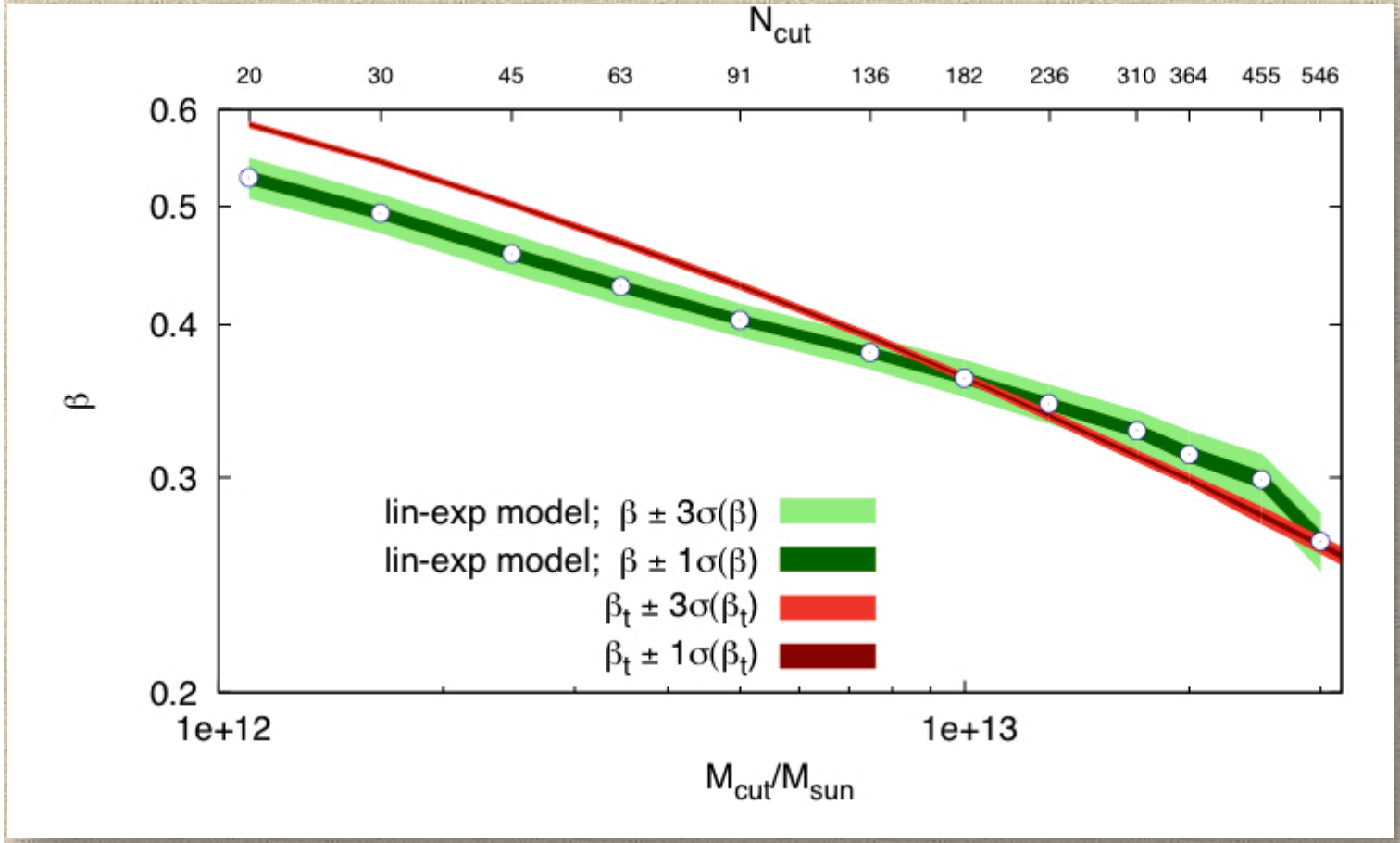
S. de la Torre et al., in prep.

Redshift-space correlation function



S. de la Torre et al., in prep.

Systematic errors in estimating β with classical linear model + exponential damping



Bianchi, LG, et al. 2012, arXiv:1203.1545

- BASICC simulation halo catalogues (Angulo, Baugh et al): 3 billion particles in a 1340 h^{-1} Mpc side box
- RESULT: ~5-10% systematic underestimate
- Hints that larger-mass halos do perform better (e.g. LRGs)
- See also Okumura & Jing 2011 using ratios of moments and Kwan et al. 2011
- Calls for improved description of RSD
- Much work ongoing (e.g. Kwan et al. 2011, Reid & White 2012, …)

Modelling VIPERS clustering: redshift-space distortions

- Mock >nL* catalogues at z=0 and z=1 built from MultiDark Run 1 halo catalogues (Prada et al. 2011) + HOD ; plus LasDamas "faint LRG" (McBride et al. in prep.)
- $P_{\delta\delta}$ from CosmicEmu (Lawrence et al. 2010), $P_{\delta\theta}$ and $P_{\theta\theta}$ from Jennings et al. (2011) fitting function

$$P_g^s(k,\mu) = D(k\mu\sigma_v) P_K(k,\mu,b)$$

$$D(k\mu\sigma_v) = \begin{cases} \exp(-(k\mu\sigma_v)^2) \\ \\ 1/(1+(k\mu\sigma_v)^2) \end{cases}$$

$$P_K(k,\mu,b) = \begin{cases} \mathrm{A}: \; b^2(k)P_{\delta\delta}(k) + 2\mu^2 f b(k) P_{\delta\delta}(k) \\ +\mu^4 f^2 P_{\delta\delta}(k) \\ \\ \mathrm{B}: \; b^2(k)P_{\delta\delta}(k) + 2\mu^2 f b(k) P_{\delta\theta}(k) \\ +\mu^4 f^2 P_{\theta\theta}(k) \\ \\ \mathrm{C}: \; b^2(k)P_{\delta\delta}(k) + 2\mu^2 f b(k) P_{\delta\theta}(k) \\ +\mu^4 f^2 P_{\theta\theta}(k) + C_A(k,\mu;f,b) \\ +C_B(k,\mu;f,b) \end{cases}$$

(Kaiser)

(Scoccimarro)

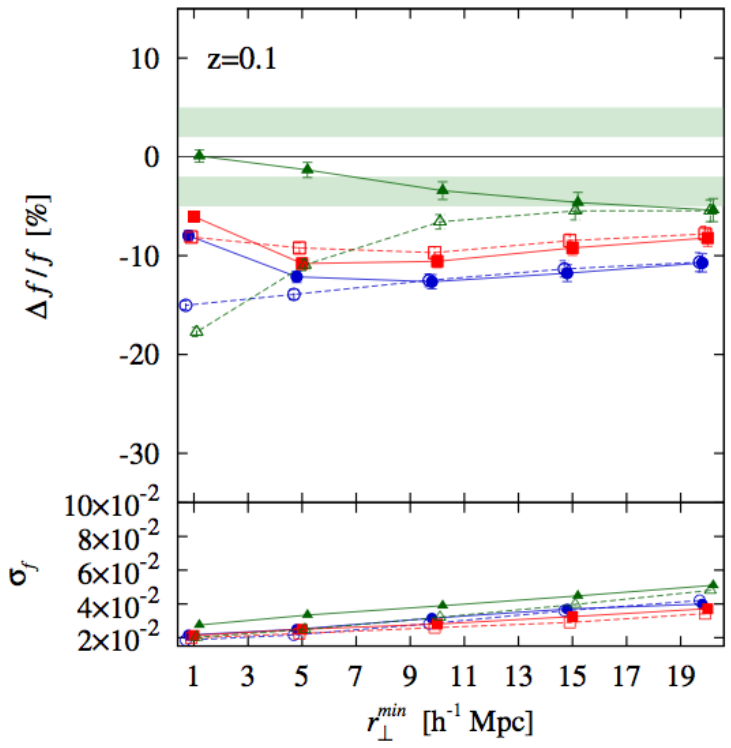
(Taruya)

Modelling non-linearities: couplings between density and velocity divergence fields + NL bias

(details in de la Torre & Guzzo 2012)

Modelling VIPERS clustering: redshift-space distortions

$$P_g^s(k,\mu) = D(k\mu\sigma_v)P_K(k,\mu,b)$$



$$D(k\mu\sigma_v) = \begin{cases} \exp(-(k\mu\sigma_v)^2) \\ 1/(1+(k\mu\sigma_v)^2) \end{cases}$$

$$P_K(k,\mu,b) = \begin{cases} \text{A}: b^2(k)P_{\delta\delta}(k) + 2\mu^2 fb(k)P_{\delta\delta}(k) + \mu^4 f^2 P_{\delta\delta}(k) & \text{(Kaiser)} \\ \text{B}: b^2(k)P_{\delta\delta}(k) + 2\mu^2 fb(k)P_{\delta\theta}(k) + \mu^4 f^2 P_{\theta\theta}(k) & \text{(Scoccimarro)} \\ \text{C}: b^2(k)P_{\delta\delta}(k) + 2\mu^2 fb(k)P_{\delta\theta}(k) + \mu^4 f^2 P_{\theta\theta}(k) + C_A(k,\mu;f,b) + C_B(k,\mu;f,b) & \text{(Taruya)} \end{cases}$$

Modelling non-linearities: couplings between density and velocity divergence fields + NL bias. NL bias has little effect on systematic errors

See De la Torre & Guzzo, 2012, in press, arXiv:1202.5559

Modelling VIPERS clustering: redshift-space distortions

(De la Torre & VIPERS Team, in preparation)

- VIPERS (as most surveys now and in the future) have stronger signal on nonlinear and quasi-nonlinear scales

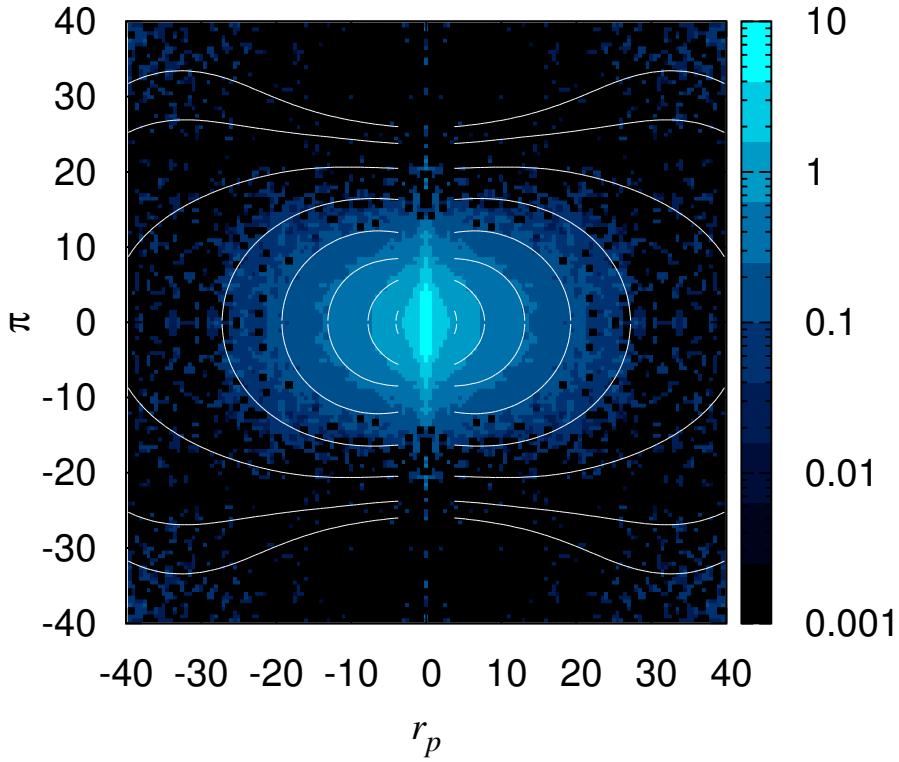
➔ Need appropriate non-linear modelling

- Preliminary modelling using Taruya et al. NL model (fit. scales: 5 Mpc/h $<r_p<$50 Mpc/h)

- Estimating proper covariance matrix is challenging (e.g. BOSS DR9)

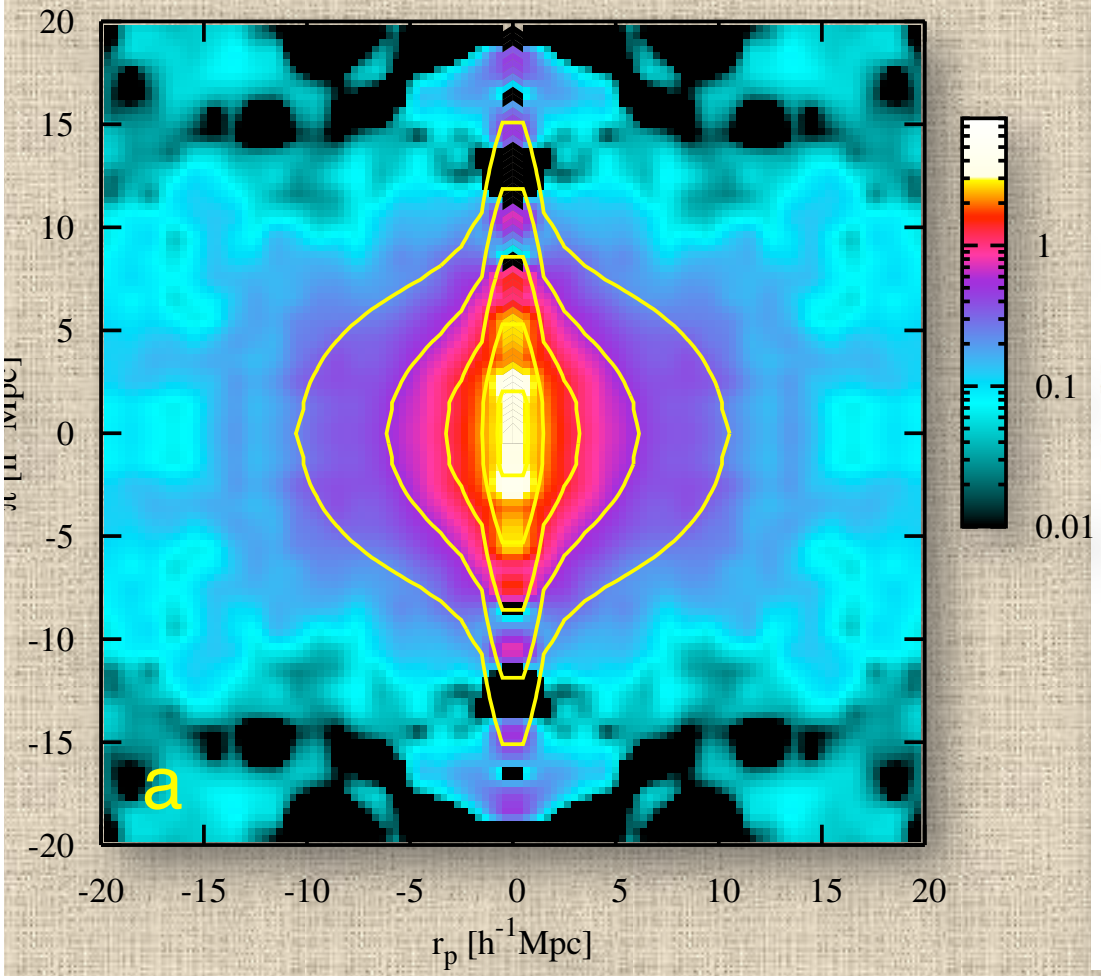
➔ Need high number of large mocks (see Manera talk)

- Different strategies being explored: Fit full $\xi(r_p,\pi)$ or just its multipole moments? (e.g. Reid & White 2011)

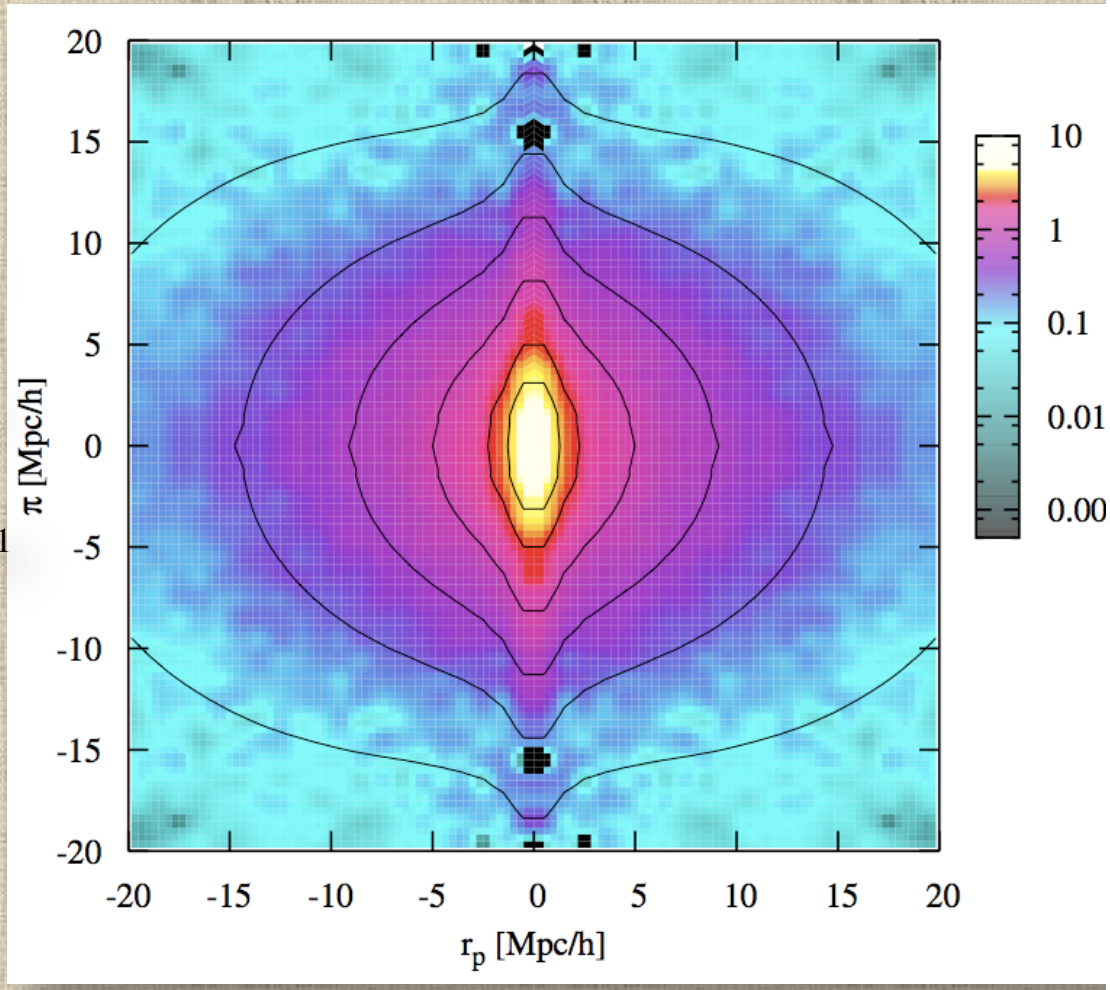


You won't get a VIPERS $f\sigma_8$ value today ! (sorry)

Expectations from fully completed survey…

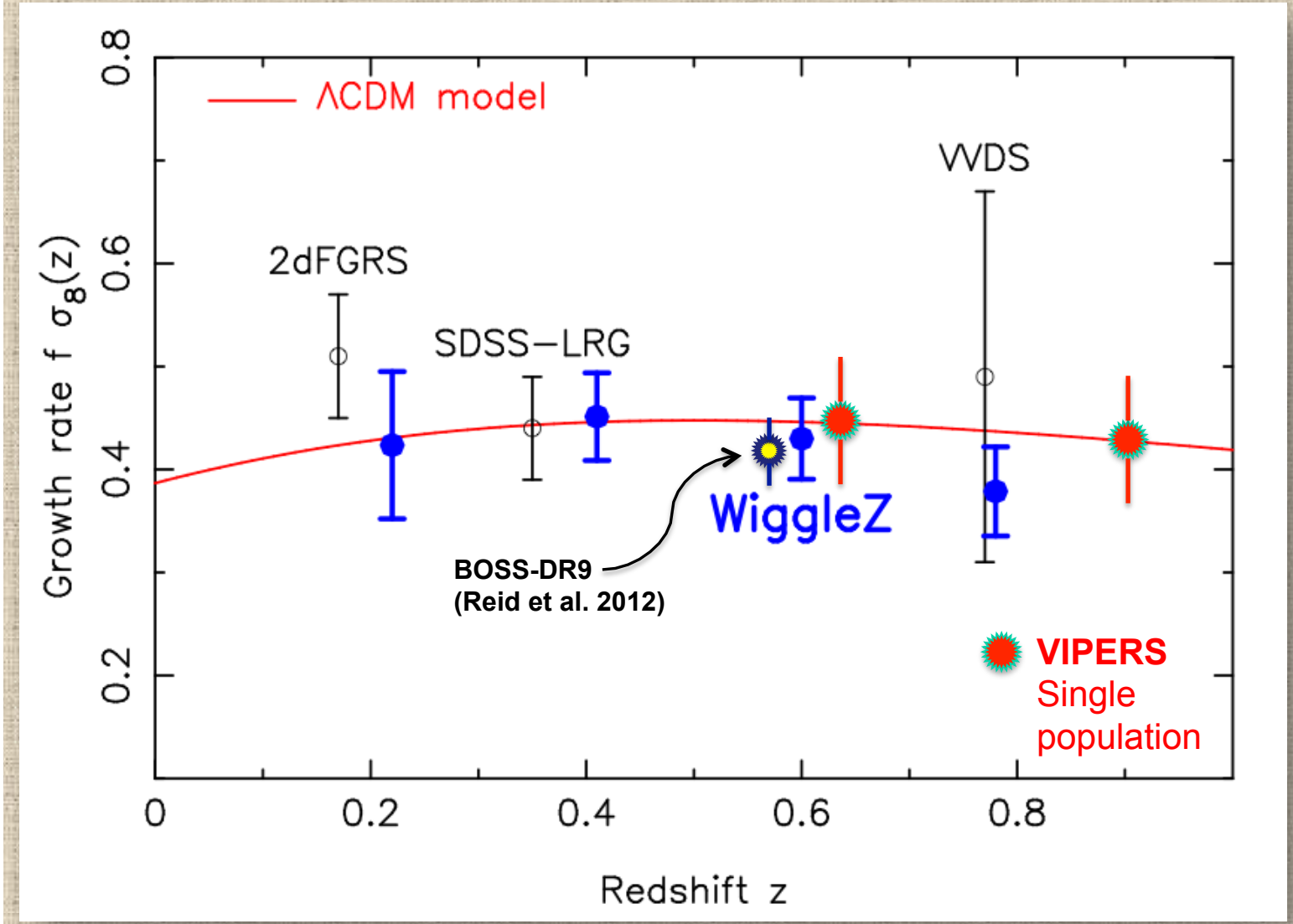


VVDS F22 (~6000 gals)



VIPERS (~100,000 gals)

...compared to current state of the art at z>0.5



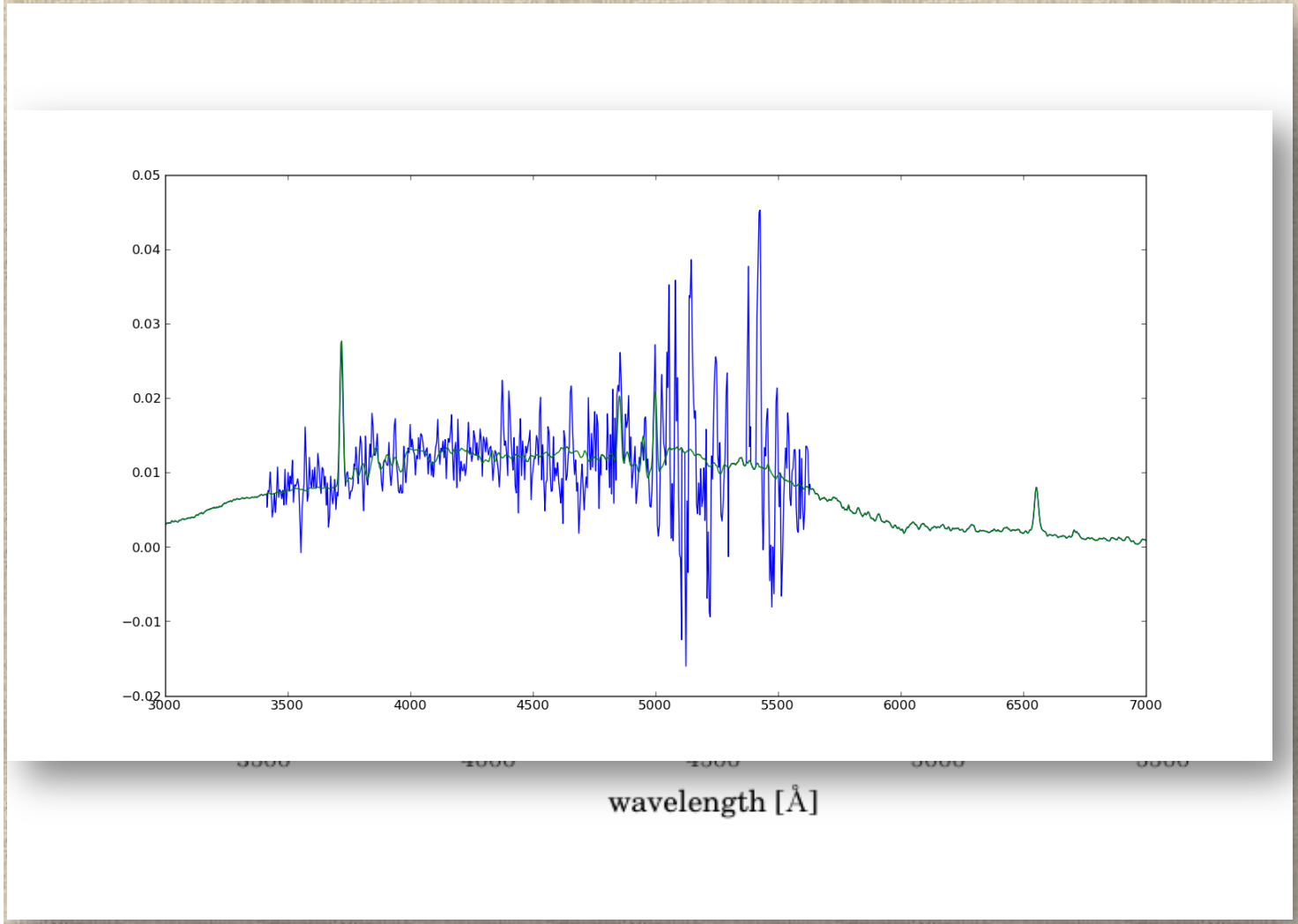
- WiggleZ: ~152,000 gals over 5000 deg^2 (Blake et al. 2011, arXiv:1104.2948)

- SDSS-III BOSS DR9: ~265,000 galaxies over 3275 deg^2 (see series of BOSS papers on astro-ph)

- However, VIPERS will measure β with multiple populations and reduce cosmic variance (McDonald & Seljak, 2009, JCAP; but see Gil-Marin et al. 2010, arXiv: 1003.3238), while testing systematic effects

- Thanks to high density, VIPERS also traces low-density regions better than BAO-focused surveys

How to define sub-populations: PCA spectral classification

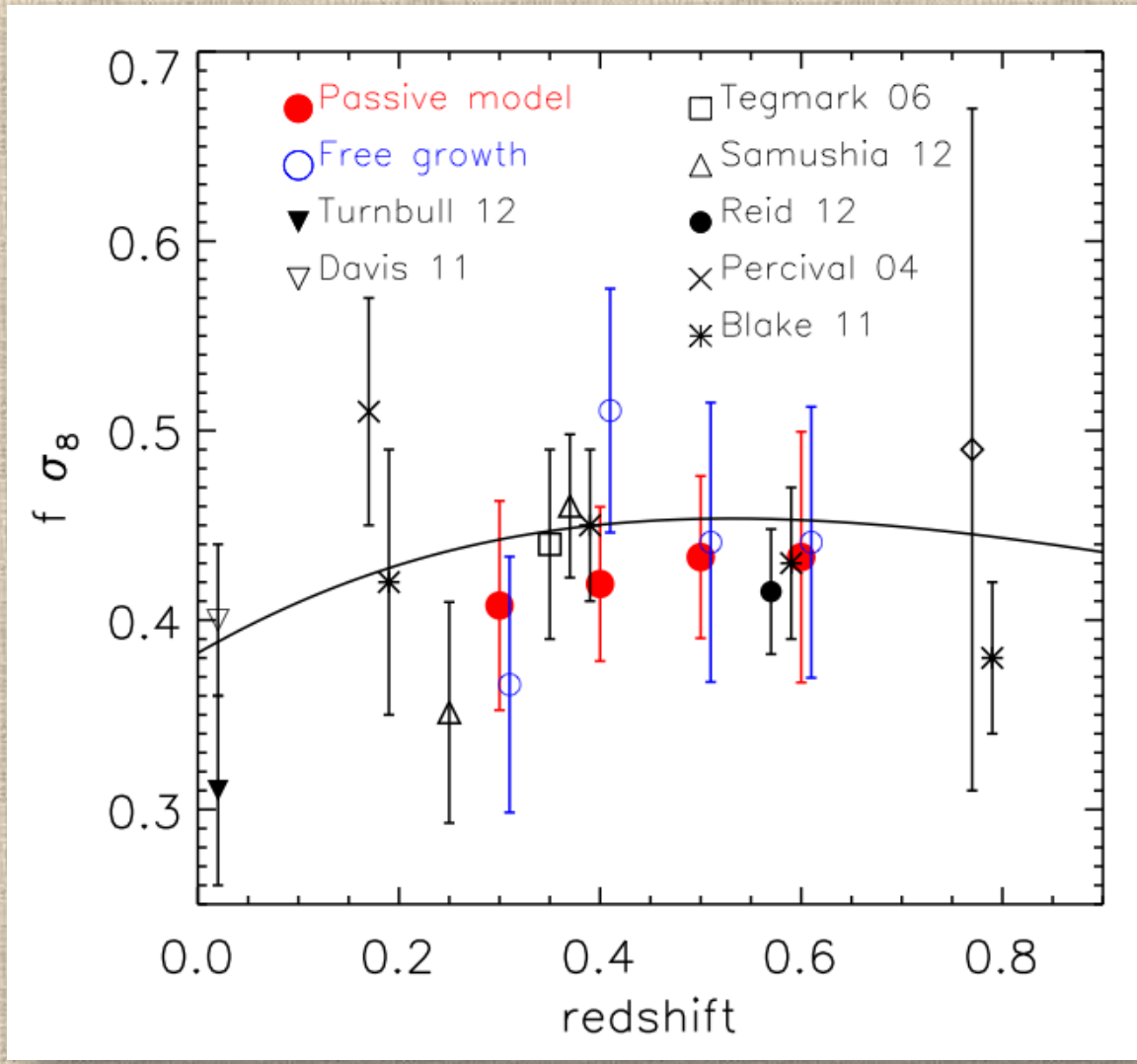


- Classify quantitatively sub-populations of galaxies (e.g. LRG-like)
- Build well-defined sub-sample for cosmological analyses
- "Repair" damaged spectra
- Consistently compare clustering/evolution with z~0 samples

Marchetti, Granett, LG + VIPERS Team, MNRAS, submitted (arXiv:1207.4374)

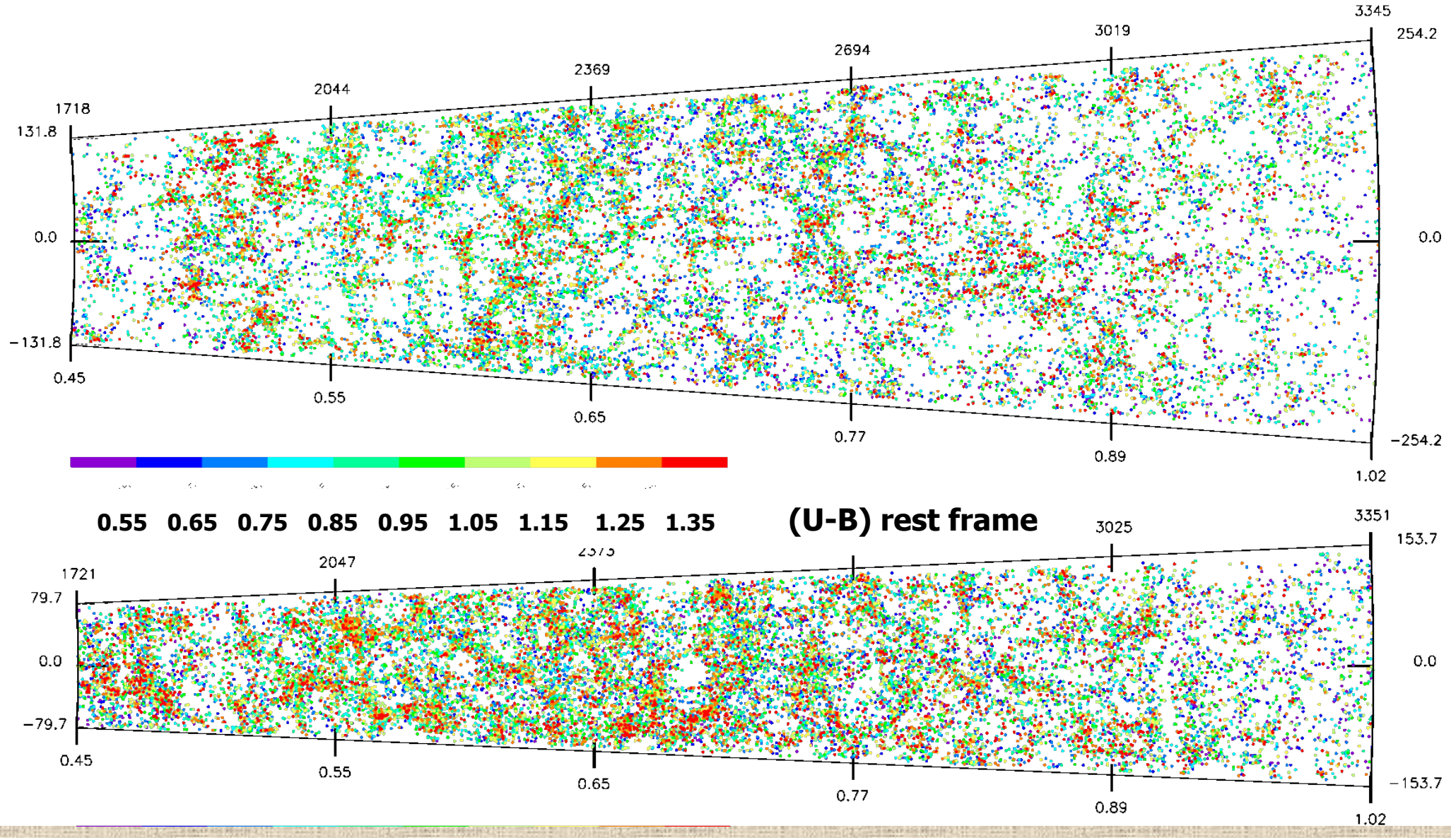
The current status including new ways to measure f(z)

1. From redshift distortions
2. From peculiar velocities at low redshift (Hudson & Turnbull 2012, astro-ph)
3. From a direct estimate of the growth of structure using passive galaxies as tracers (Tojeiro et al. 2012)



(from Tojeiro & BOSS Collaboration 2012)

Color-density relation

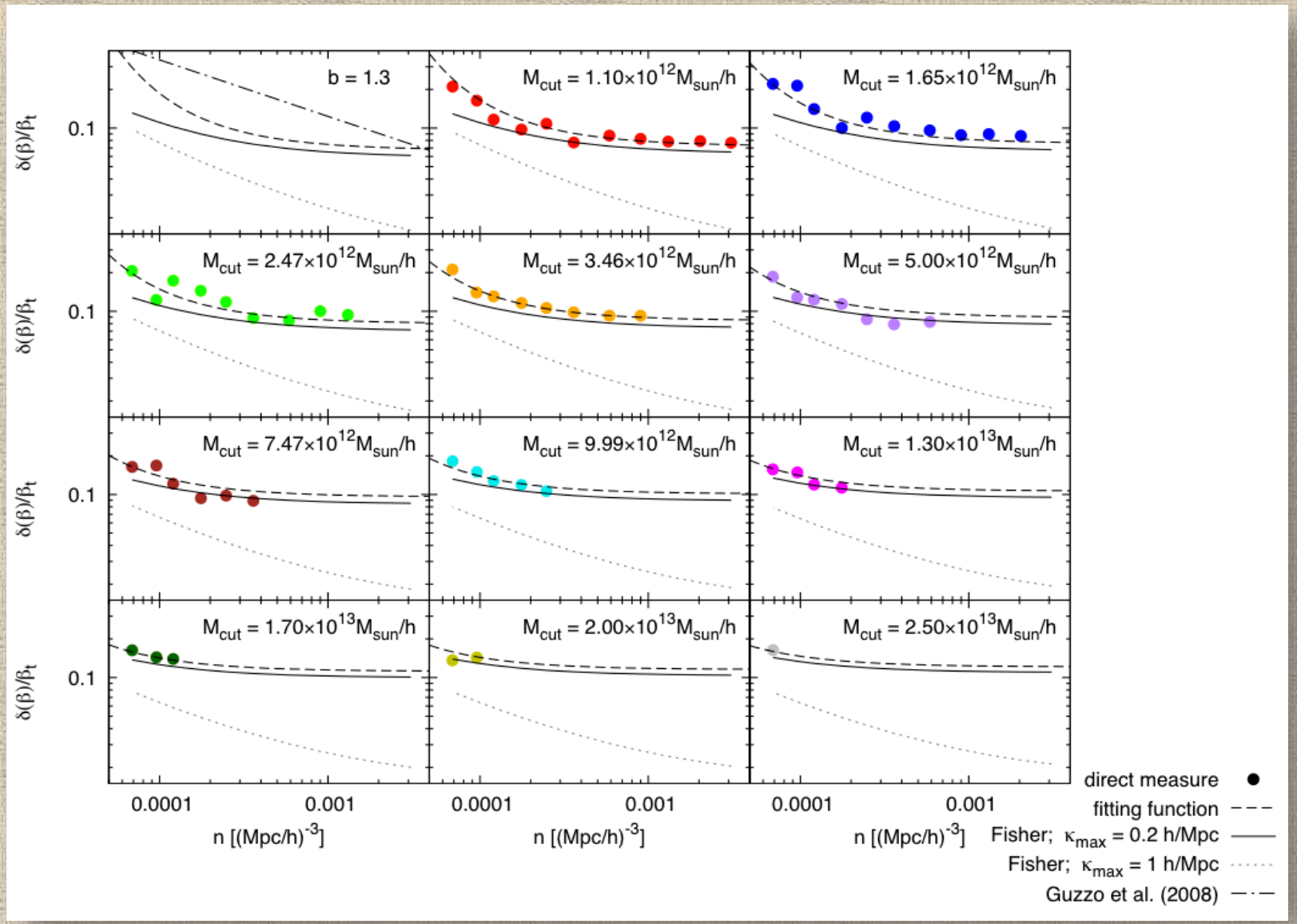


Summary of VIPERS current facts

- VIPERS exploits VIMOS capabilities for LSS study, filling a specific niche at z~1: volume 6 x 10^7 h^{-3} Mpc^3, sampling ~ 40%
- Aimed at measuring clustering and growth at 0.5<z<1, to an accuracy comparable to local state-of-the-art surveys
- Volume smaller than BAO surveys (BOSS, Wigglez), but high sampling allows defining sub-populations and optimize tracers for RSD and other LSS analyses
- In parallel, powerful probe for galaxy evolution studies over 8 billion years, (e.g. coupled to SDSS)

- Efficient survey pipeline: automatic data calibration, redshift measurement and database archiving: as of today ~55,500 secure spectra already available
- With current observing rate, completion expected by 2014
- Large set of ancillary data (GALEX, WIRCAM, VISTA, XMM)
- Raw data immediately public, redshifts released in regular tranches (first release planned for end 2012)

Predicting statistical errors: can we trust Fisher Matrix forecasts?

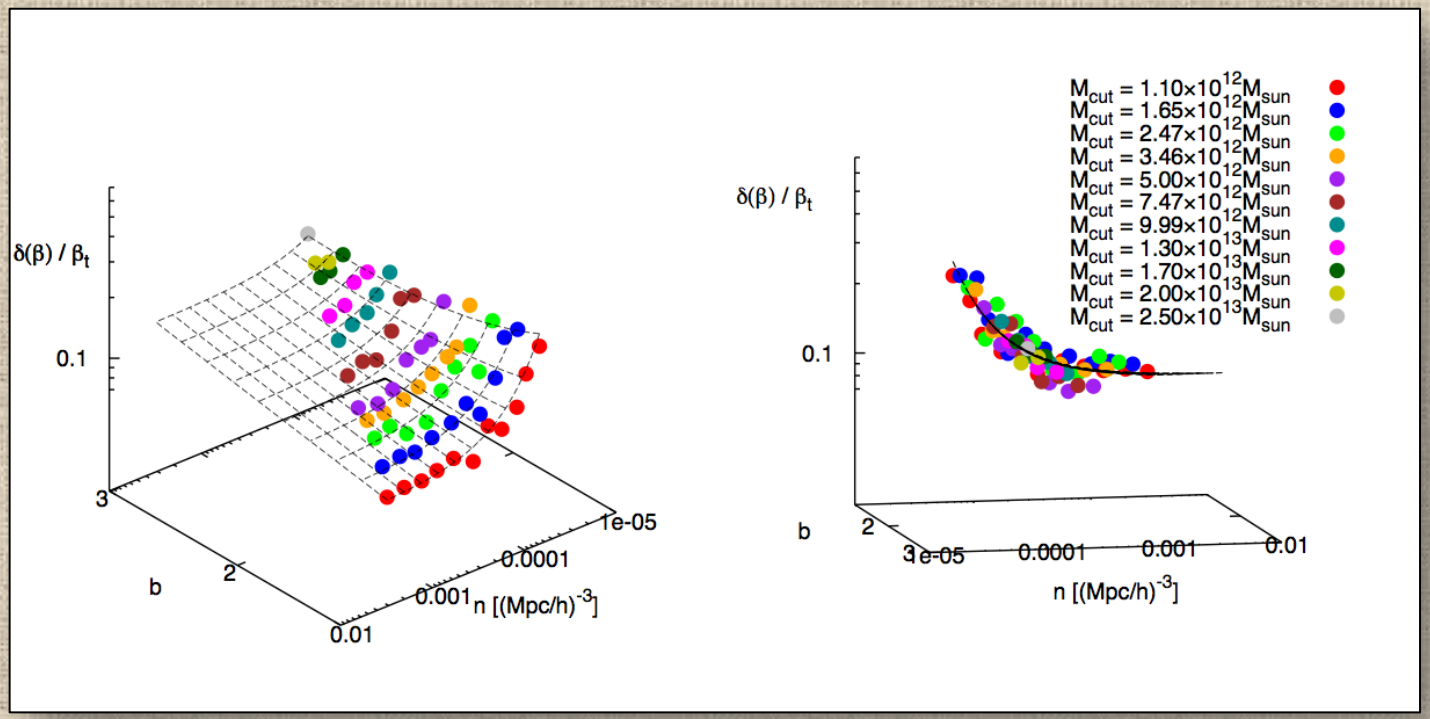


Bianchi et al. 2012, arXiv:1203:1545

Predicting statistical errors: a handy and accurate scaling formula describing the behaviour found in the Monte Carlo experiments

$$\delta(\beta)/\beta \approx C b^{0.7} V^{-0.5} \exp\left(\frac{B}{b^2 n}\right)$$

Bianchi, et al. 2012



DARKLIGHT

- *"ILLUMINATING DARK ENERGY WITH THE NEXT GENERATION OF COSMOLOGICAL REDSHIFT SURVEYS"*
- **ERC Advanced Research grant, 5 years, 1.72 Meuro**
- **5 postdoc + 3 PhD positions**
- **Starting 1 May 2012**

- Improve modelling and estimators of clustering and redshift distortions, preparring for precision cosmology
- Apply them to ongoing new surveys (e.g. VIPERS)
- Combine with other probes of LSS (clusters of galaxies) and CMB measurements (Planck)

→ PREPARE FOR EUCLID…

Summary

- Explaining the origin of cosmic acceleration is plausibly the most compelling problem in cosmology: did Einstein have the last word on gravity?
- A brilliant 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

- Exciting z-distortions results from WiggleZ and BOSS, designed for BAO
- VIPERS: a 2dFGRS at z~0.8, ~100,000 highly-sampled redshifts; early measurement of real-space P(k) in combination with CFHTLS
- 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 to go beyond Kaiser-Hamilton formalism, if we aim at precision cosmology on f(z)
- Do simultaneous estimate of BAO and z-distortions (including Alcock-Paczynski, see Simpson & Peacock 2010)
- A lot of work ongoing in the community, exciting times ahead
- **DARKLIGHT**: an ERC-supported program to bring estimators to the level of the new data