Observations and Statistics of the Cosmic Web at z~1

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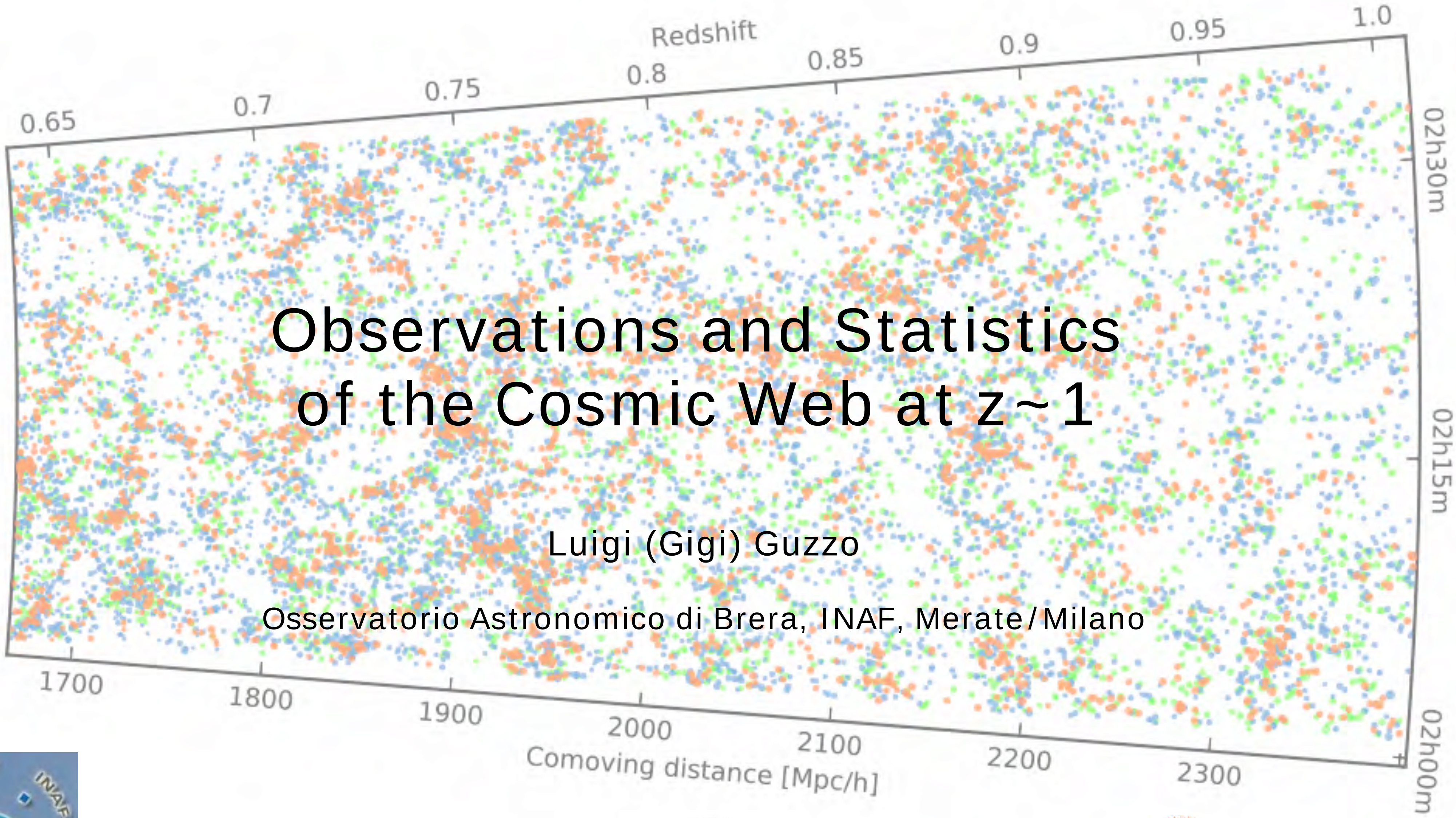
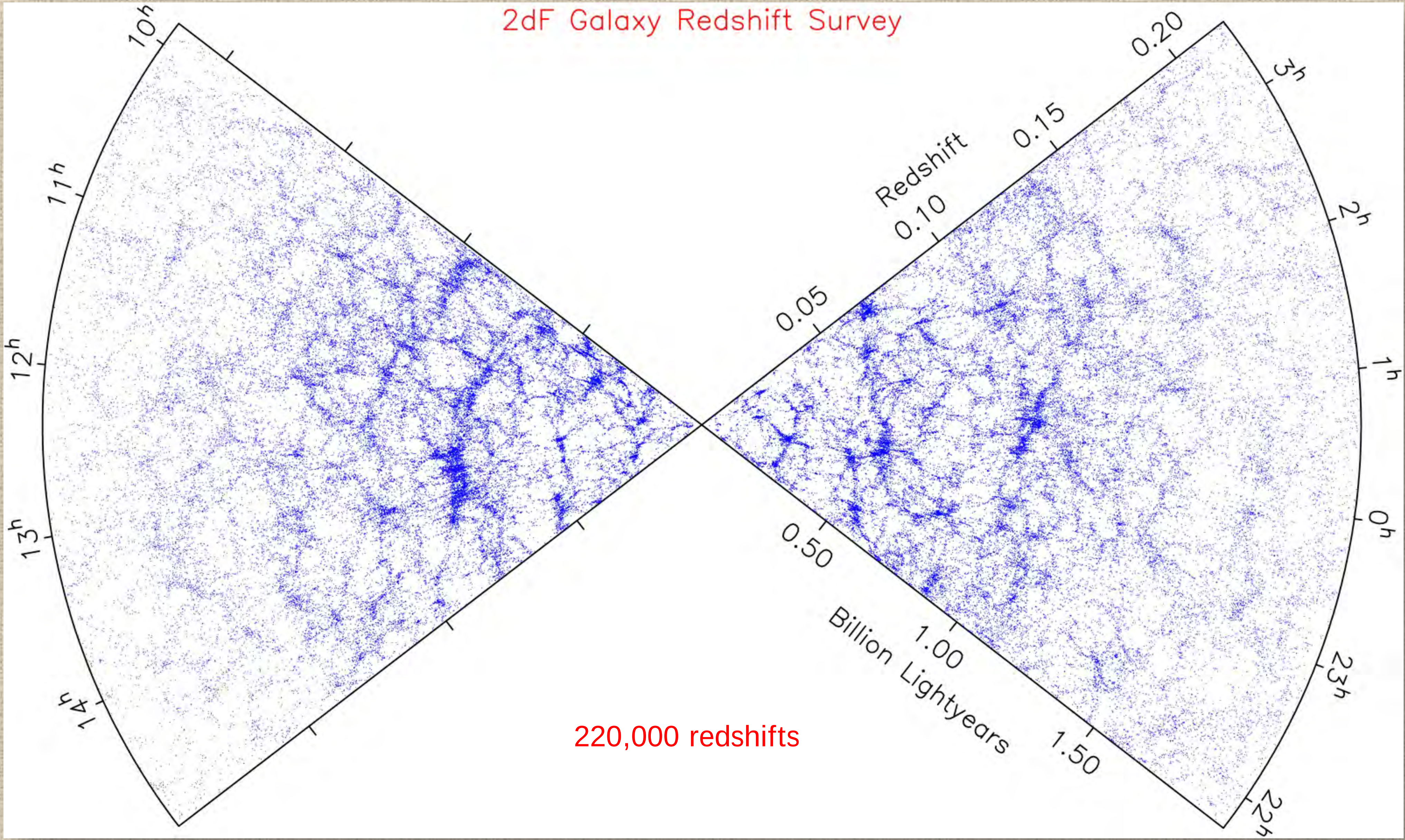
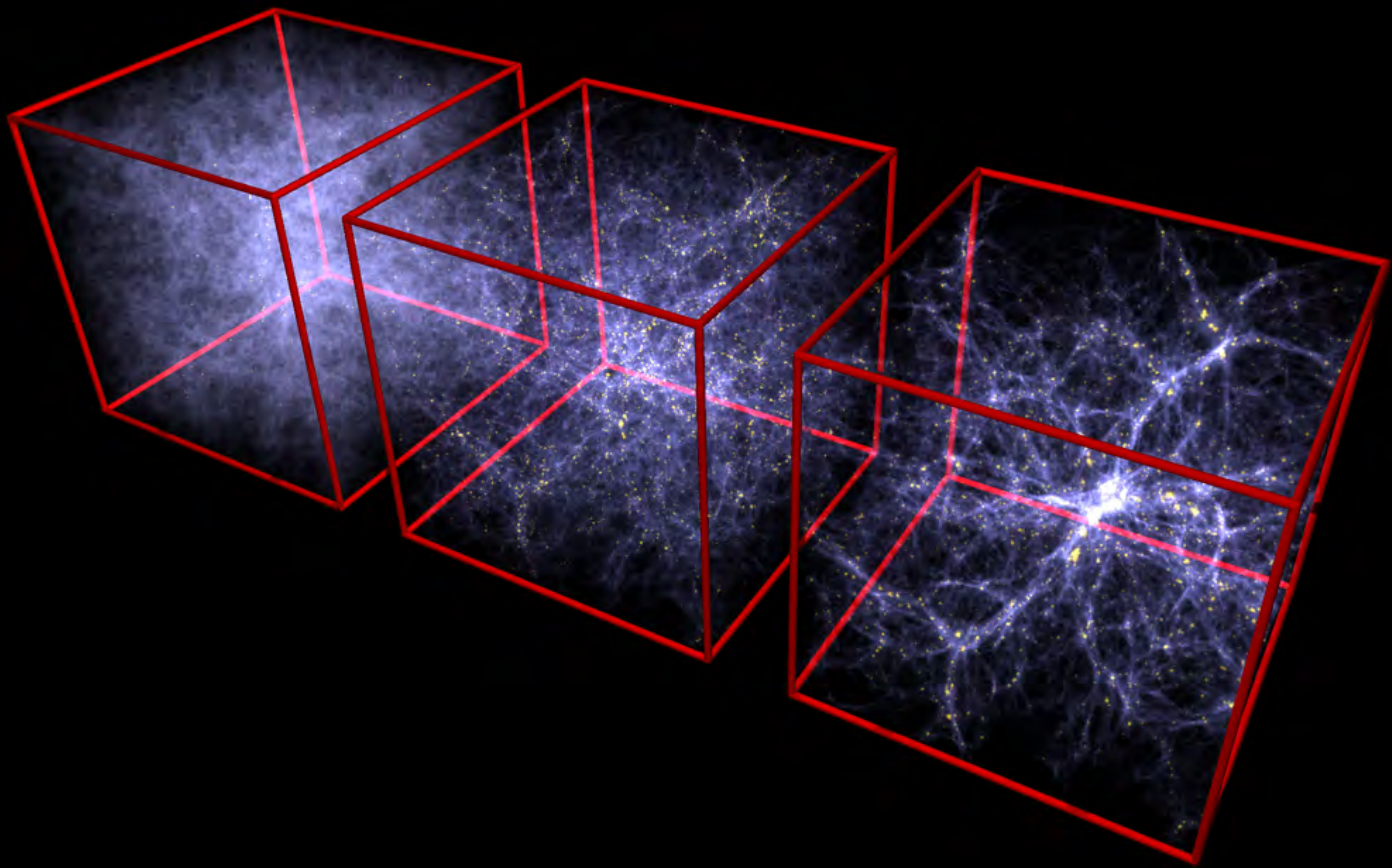


The cosmic web at z<0.2 (JAP talk)



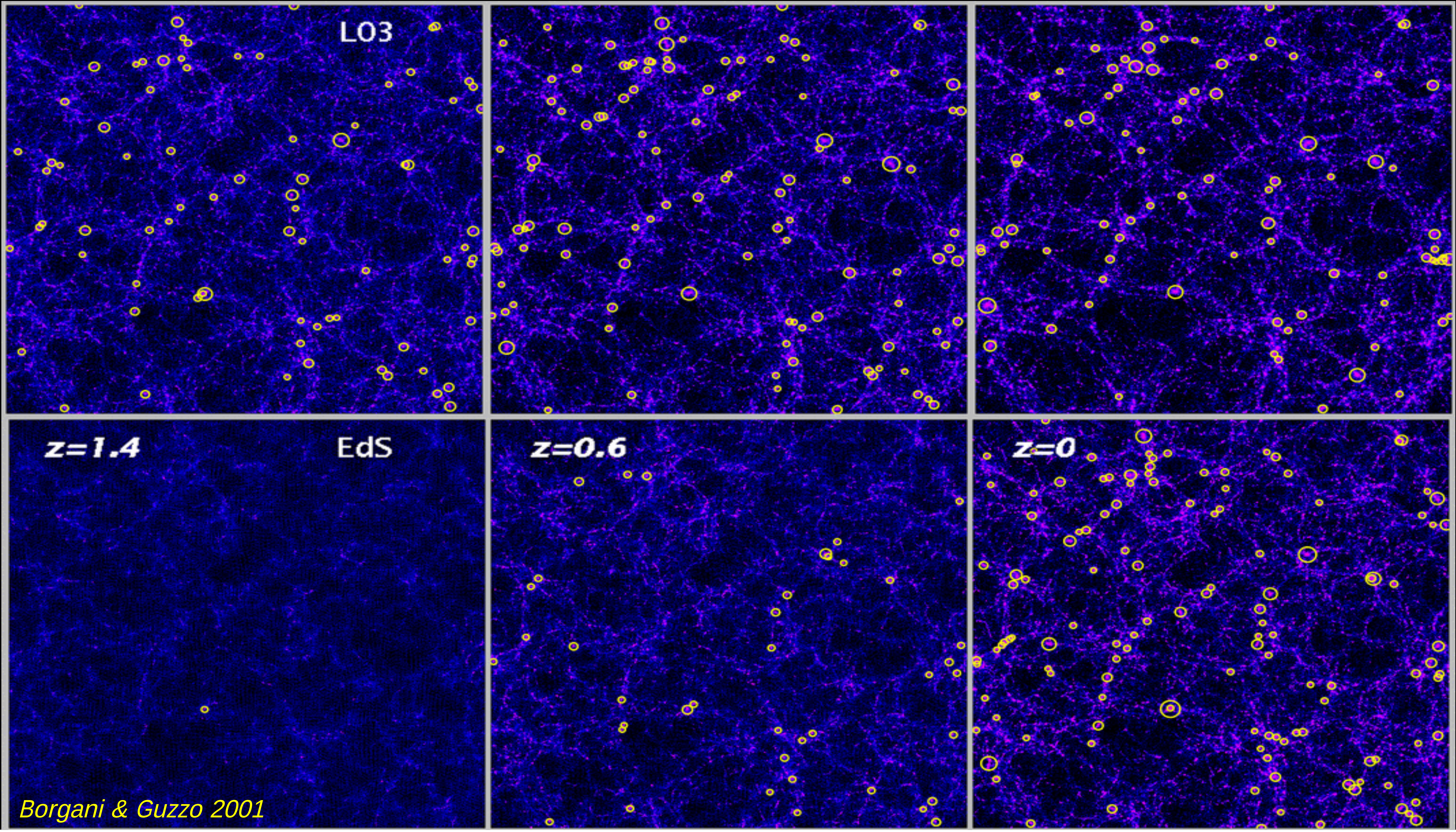
220,000 redshifts

SEE THE WHOLE MOVIE, NOT JUST THE FINAL PICTURE...



(Image by
V. Springel)

SEE THE WHOLE MOVIE, NOT JUST THE FINAL PICTURE...

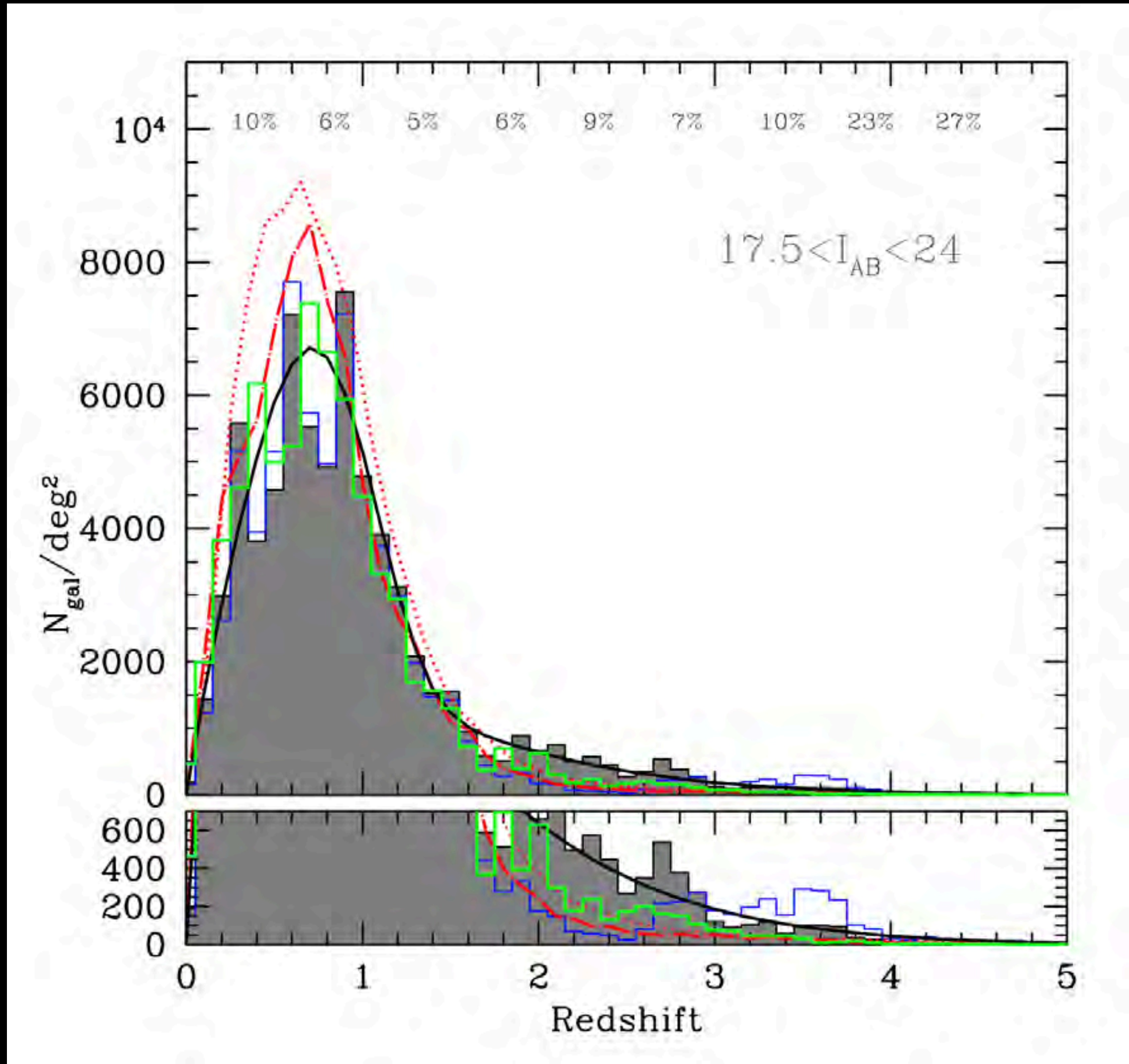


Borgani & Guzzo 2001

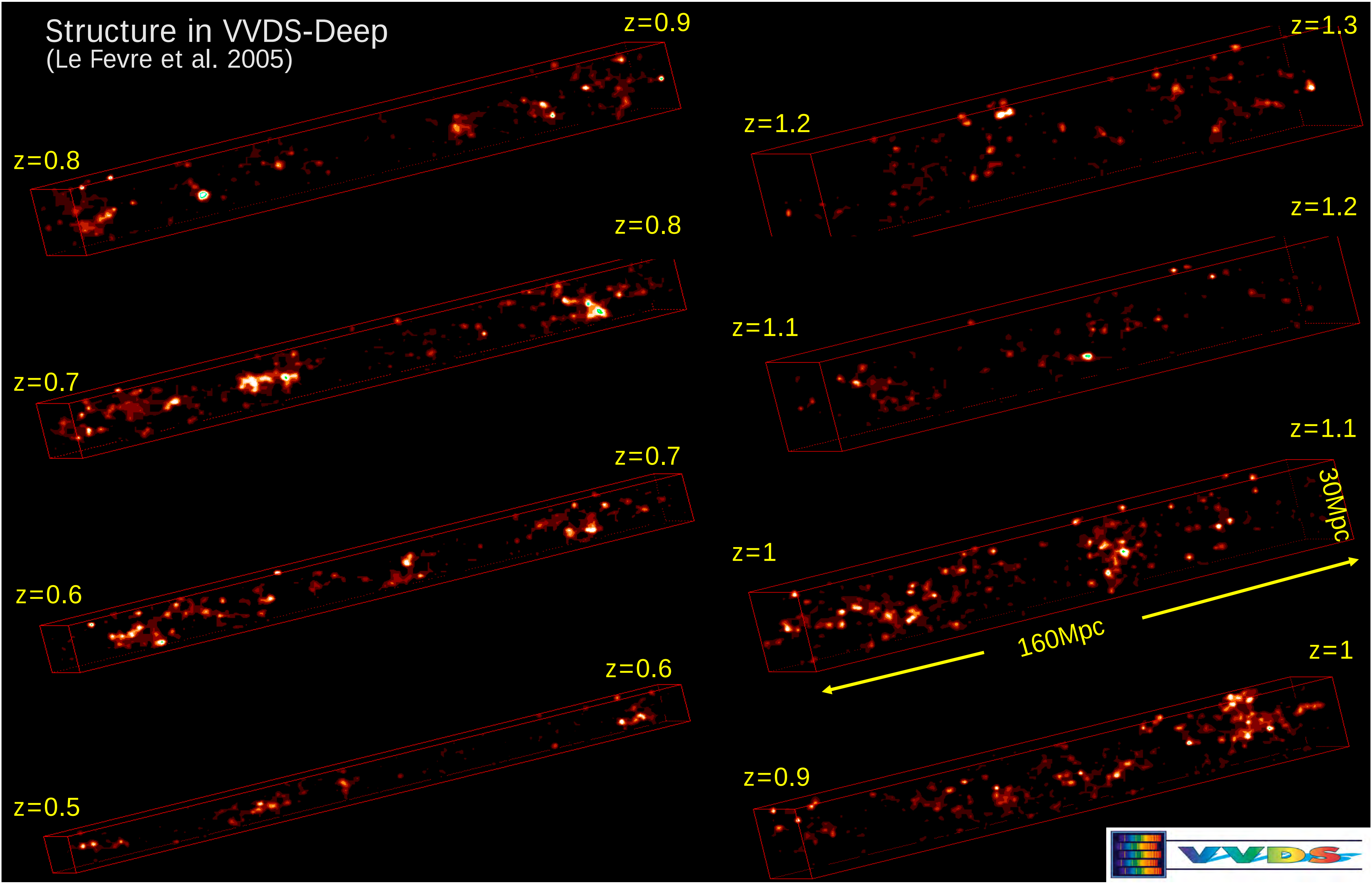
2000's, Going beyond the local Universe: galaxy evolution and (some) LSS

VVDS-Deep

- P.I.s O. Le Fevre & G. Vettolani
- 0.54 deg², $I_{AB}<24$, 6217 redshifts
- Based on guaranteed time for VIMOS construction
- Following pioneering CFRS (Le Fevre, Lilly et al. 1996)
- Trace combined evolution of galaxies and structure

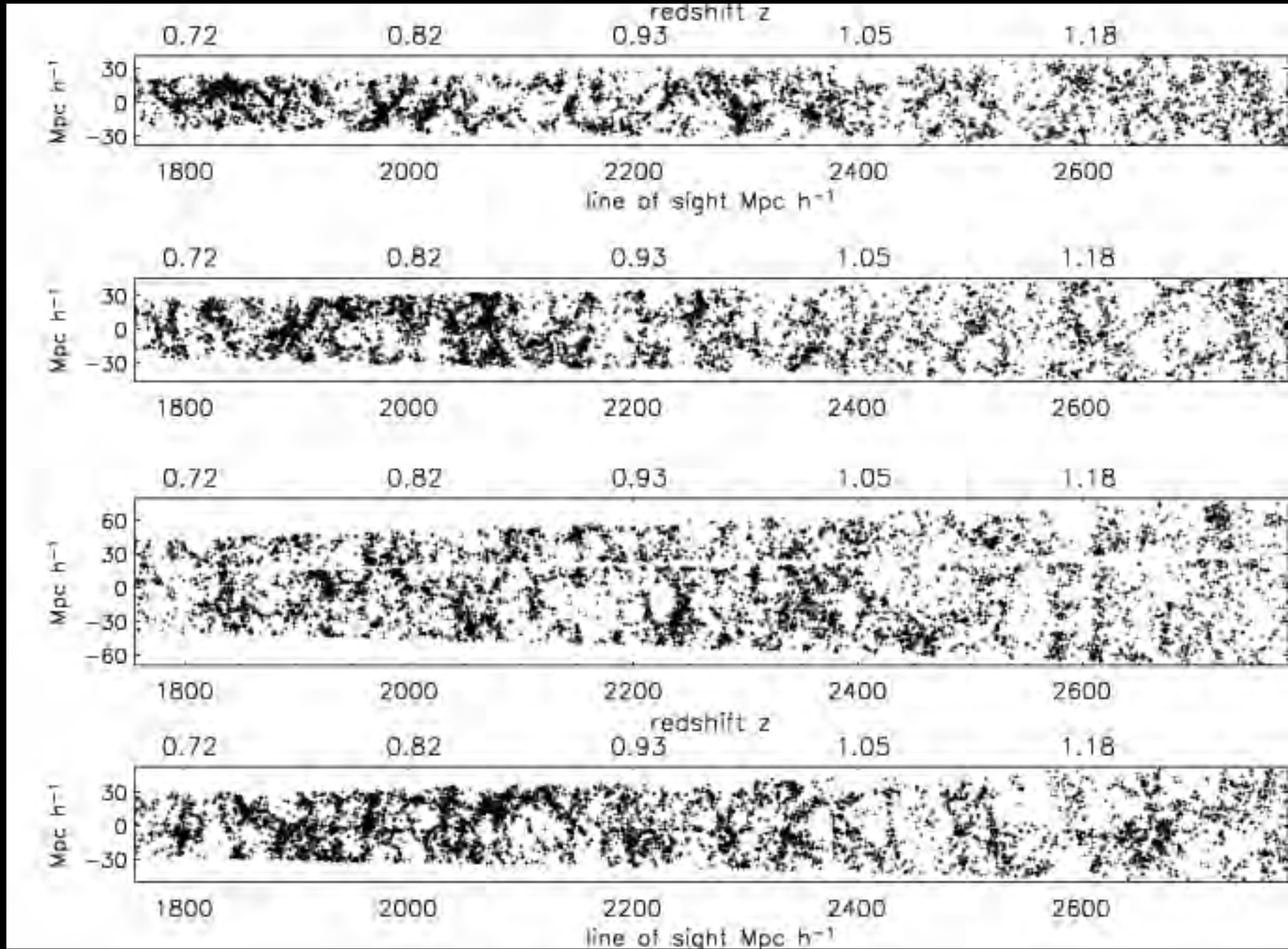


(Le Fevre et al. 2005; 2011; 2013)


Structure in VVDS-Deep
(Le Fevre et al. 2005)
z=0.9
z=0.8
z=0.8
z=0.7
z=0.7
z=0.6
z=0.6
z=0.5
z=1.3
z=1.2
z=1.2
z=1.1
z=1.1
z=1
30Mpc
160Mpc
z=1
z=0.9

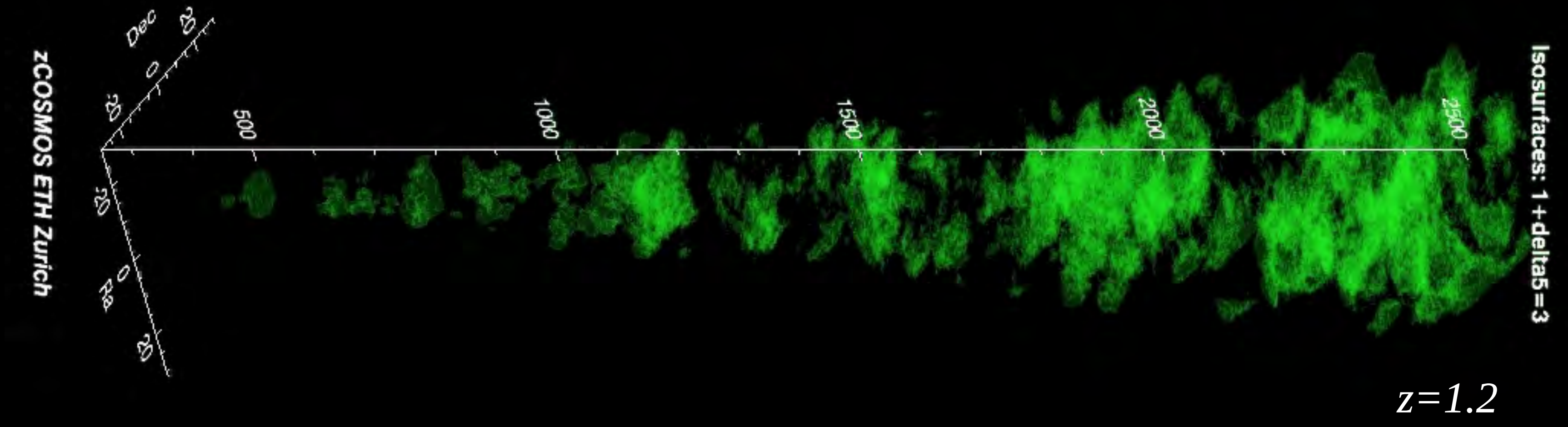
DEEP-2

- P.I. M. Davis
- 3 deg^2 split over 4 fields, R_{AB}<24.1, >40,000 redshifts
- BRI colour pre-selection to z~[0.7-1.4]



(see Newman et al. 2013, ApJ)S 208, 5)

zCOSMOS

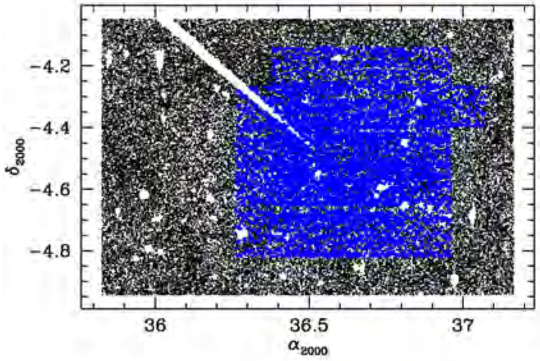


- P.I. S. Lilly
- 1.7 deg^2, I_{AB}<22.5, 10,000 redshifts
- HST ACS coverage (Scoville et al.) → galaxy morphologies
- Unique photometic coverage (31 bands)

(e.g. Lilly et al. 2009 – Density field from Kovac et al. 2010)

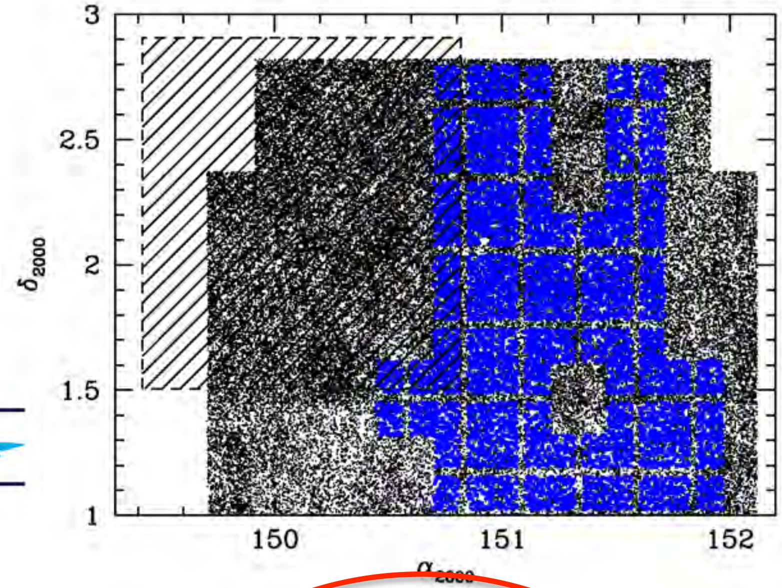
Enlarging the probes of structure at z~1: VVDS-Wide ($I_{AB}<22.5$)

F02-Deep



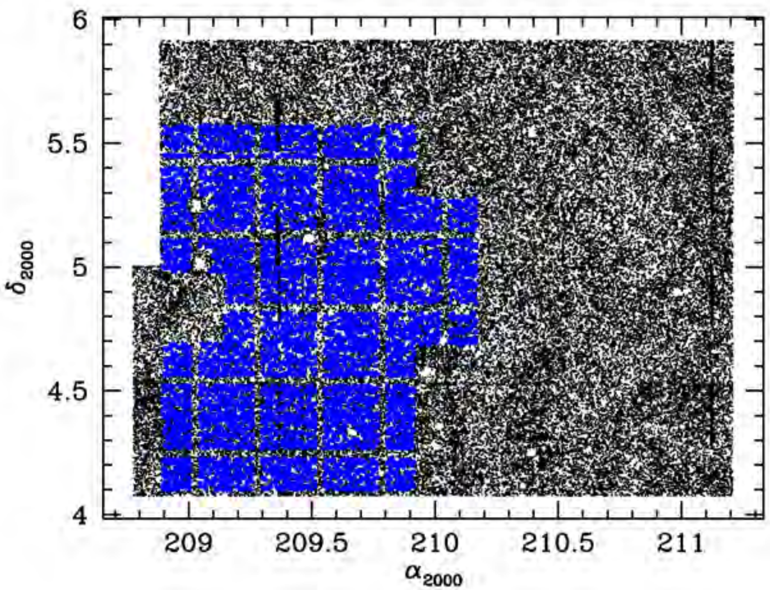
>13,000 spectra ($I_{AB}<24$)

F10-Wide



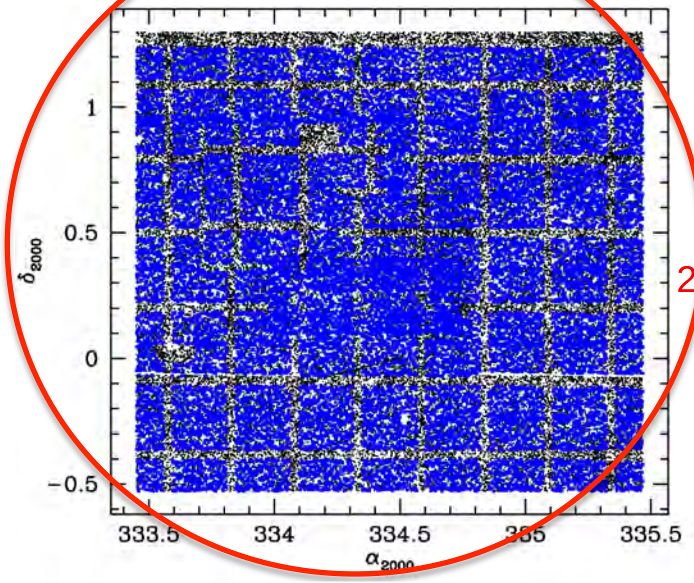
5984 spectra

F14-Wide



8455 spectra

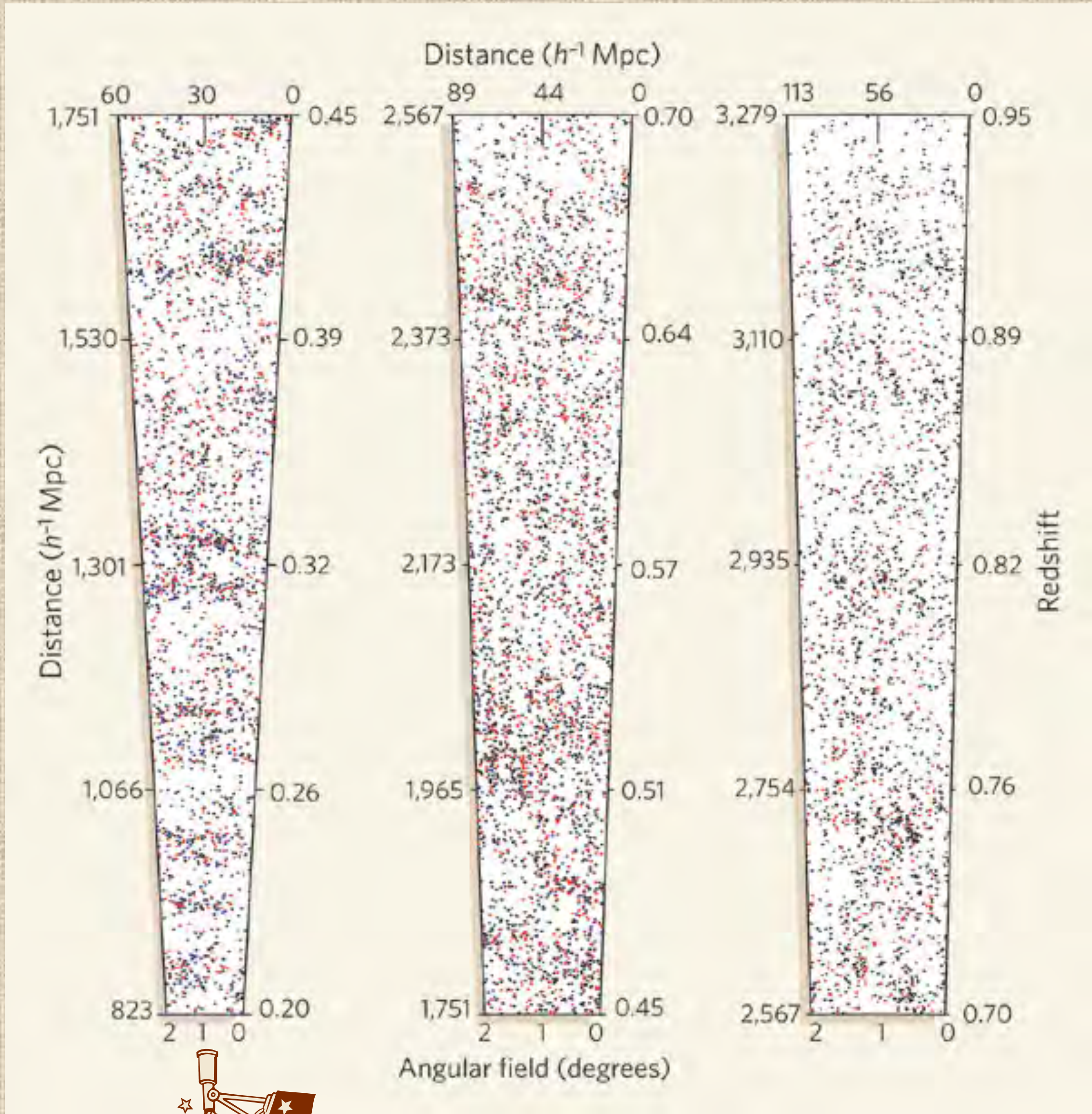
F22-Wide



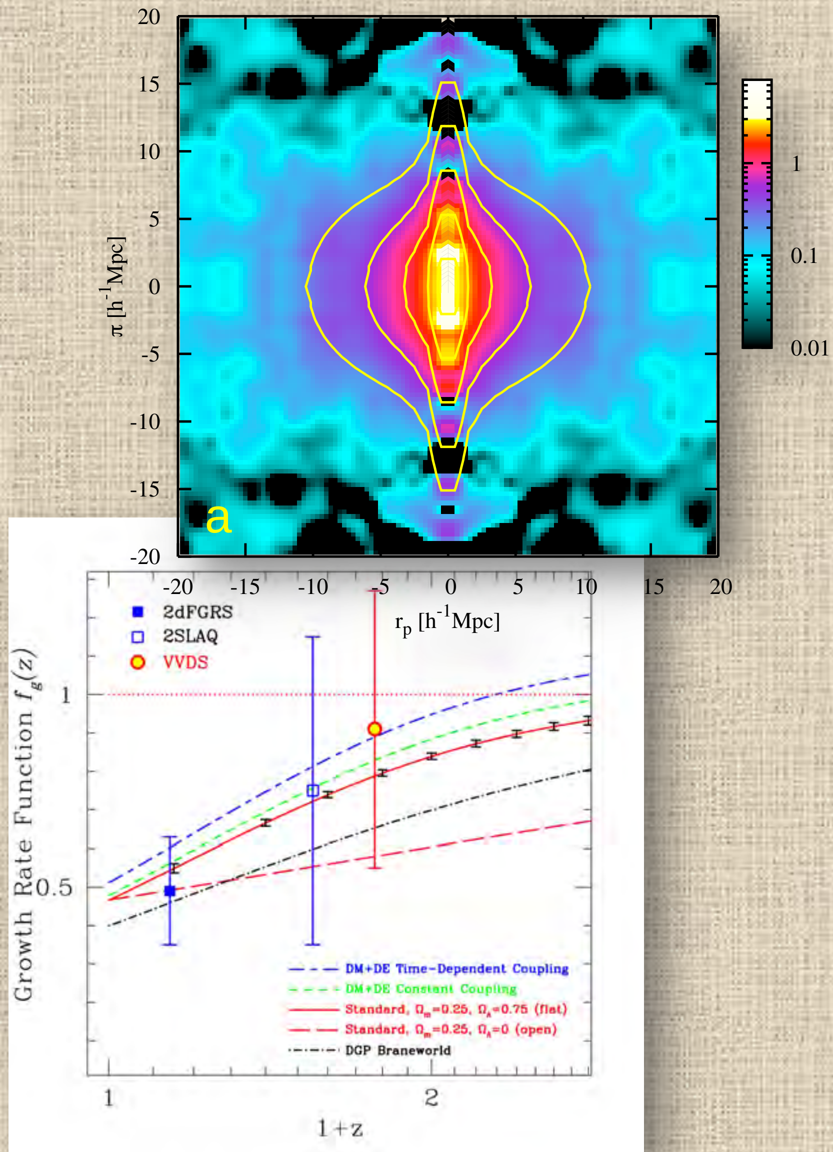
21753 spectra

(Garilli et al. 2008; Le Fevre et al. 2014)

VVDS-Wide F22 field: 4 deg^2, 10,000 redshifts to z~1.2

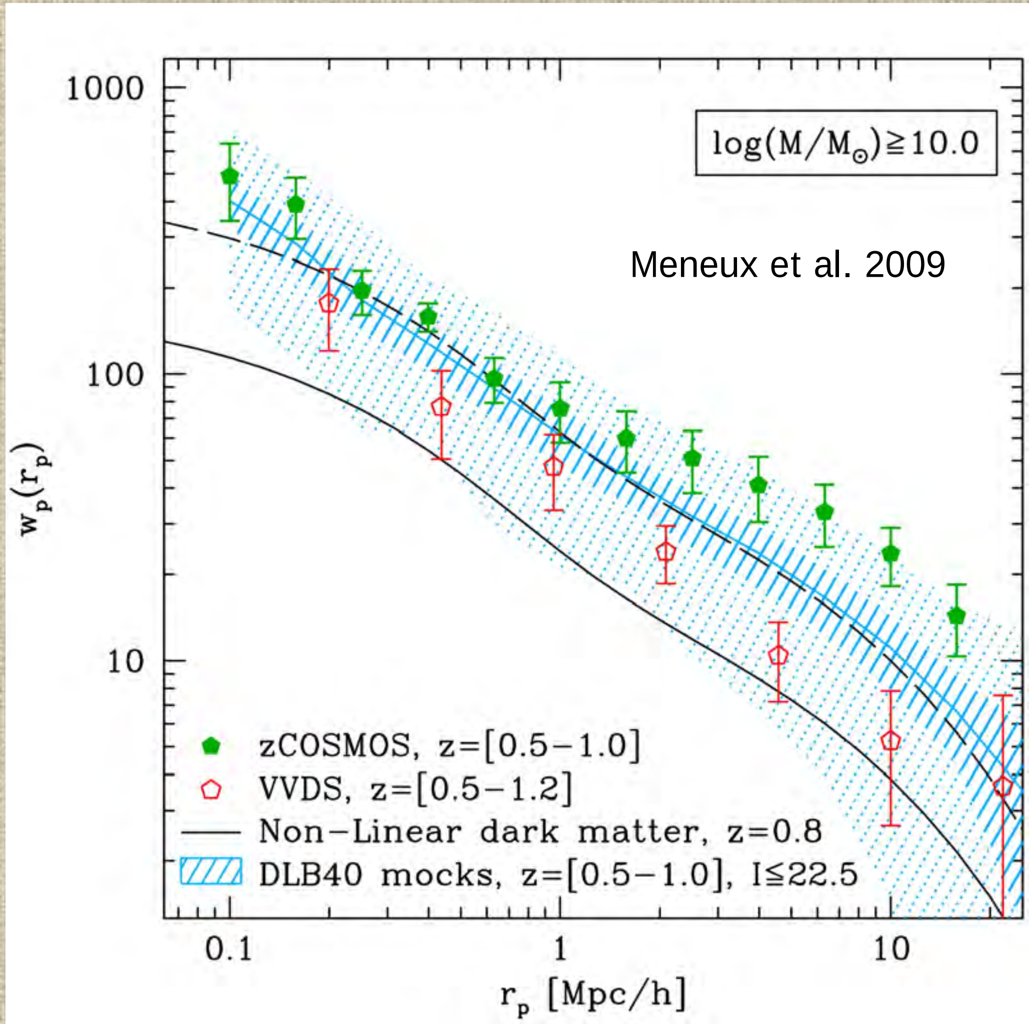


(Garilli et al. 2008, A&A 486, 683)



(Guzzo et al. 2008, Nature 451, 541)

Still small volumes: strong sample variance



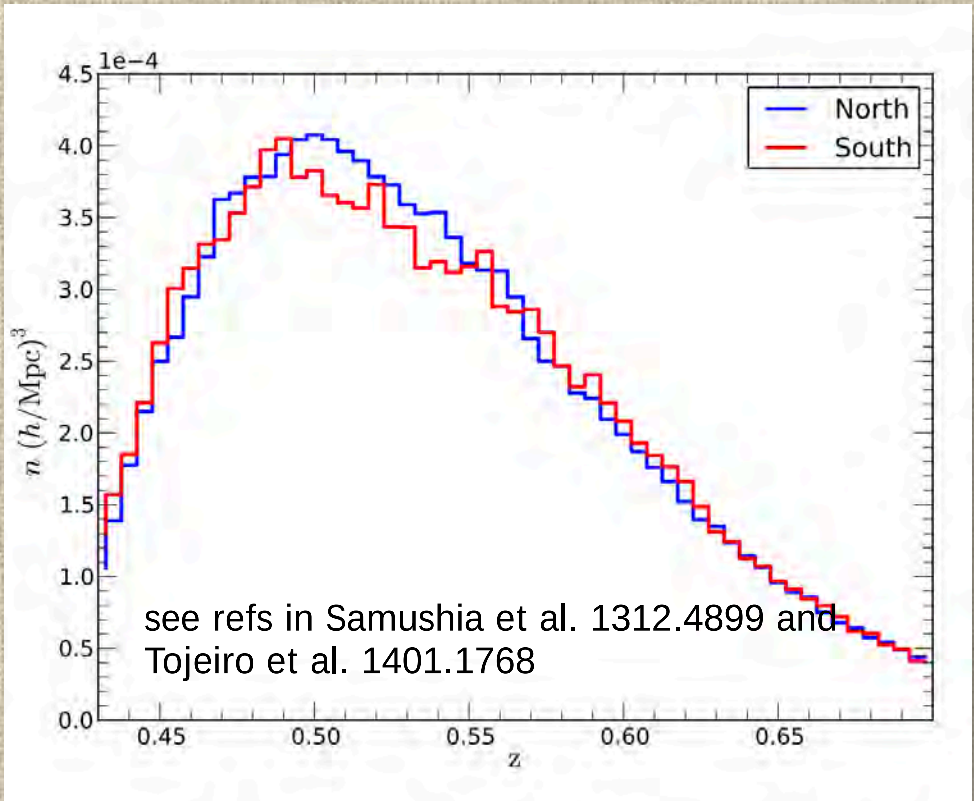
→ 2-point clustering: zCOSMOS vs VVDS-Wide F22 @<z>~0.8

→ Expected in a hierarchical scenario if density PDF not representative (here due to excess of high-density regions in zCOSMOS at these redshifts)

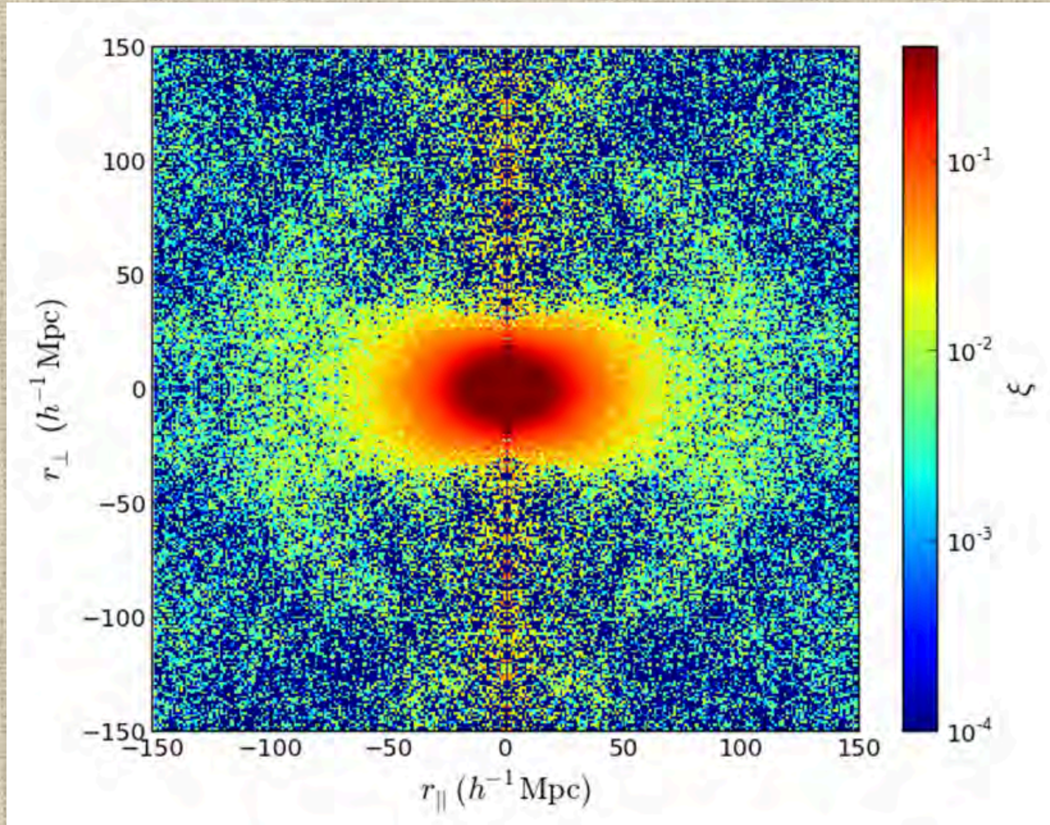
De la Torre, LG & zCOSMOS Collaboration, 2010, MNRAS, 409, 867

Pushing to z~0.7 with sparse “special” populations: BOSS

- Area=8500 deg^2 , Volume~6 h^{-3} Gpc, Ngal = 690,000
- “CMASS” LRG-like col-col selection, “loosely selecting constant mass galaxies”
- Low-density tracers
- Optimized for BAO, not for P(k) shape information (selection function)
- Excellent (a posteriori) for Redshift Space Distortions thanks to huge volume

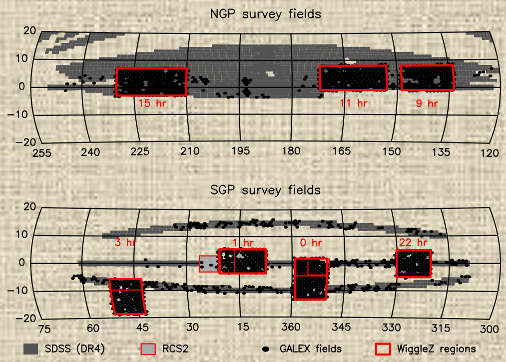


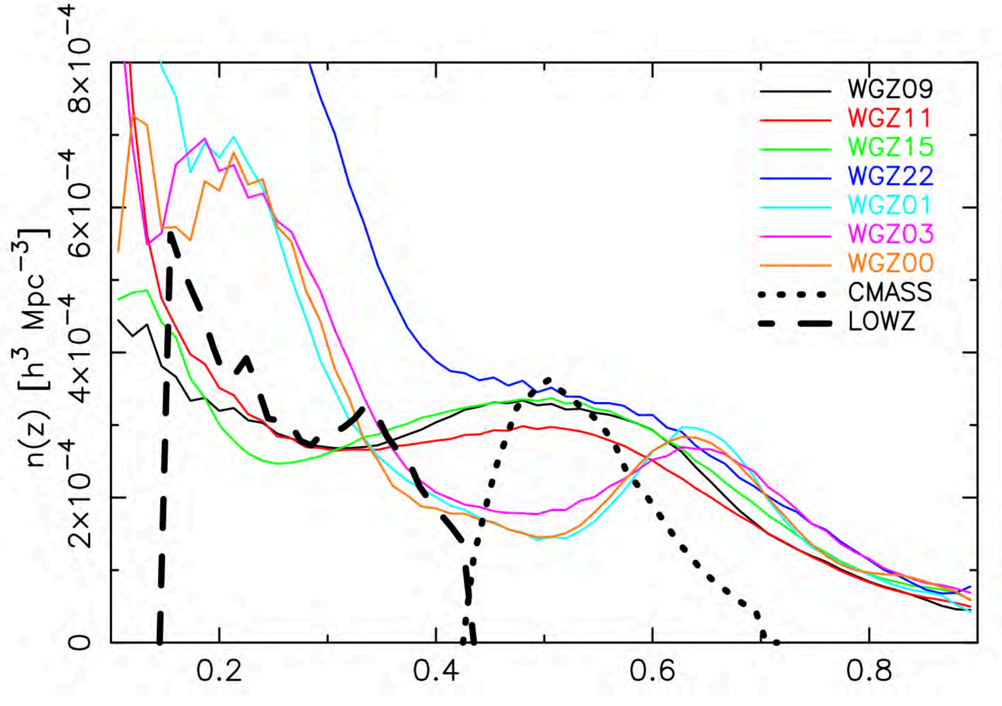
see refs in Samushia et al. 1312.4899 and
Tojeiro et al. 1401.1768

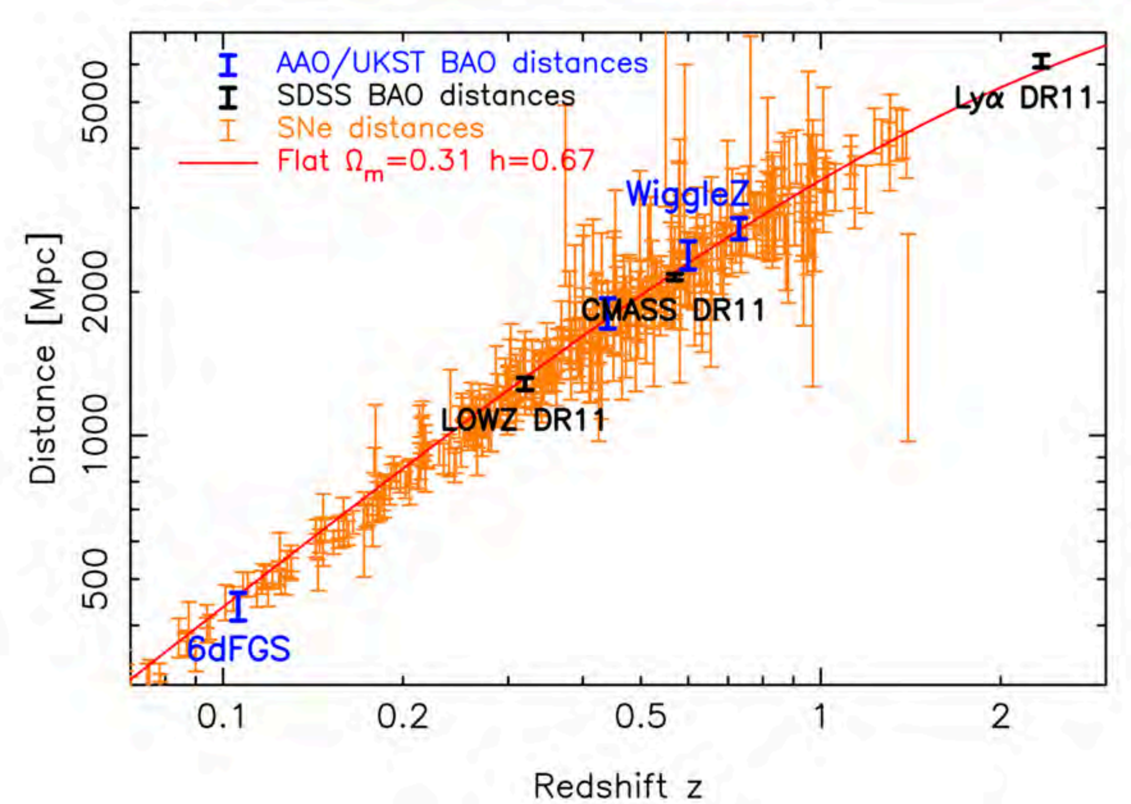


Pushing to z~0.8, with sparse tracers: Wigglez

- Area=1000 deg^2 , Volume~1 Gpc, Ngal = 200,000
- UV (GALEX) selected star-forming galaxies
- Complex selection function
- Optimized for BAO
- Excellent also for RSD

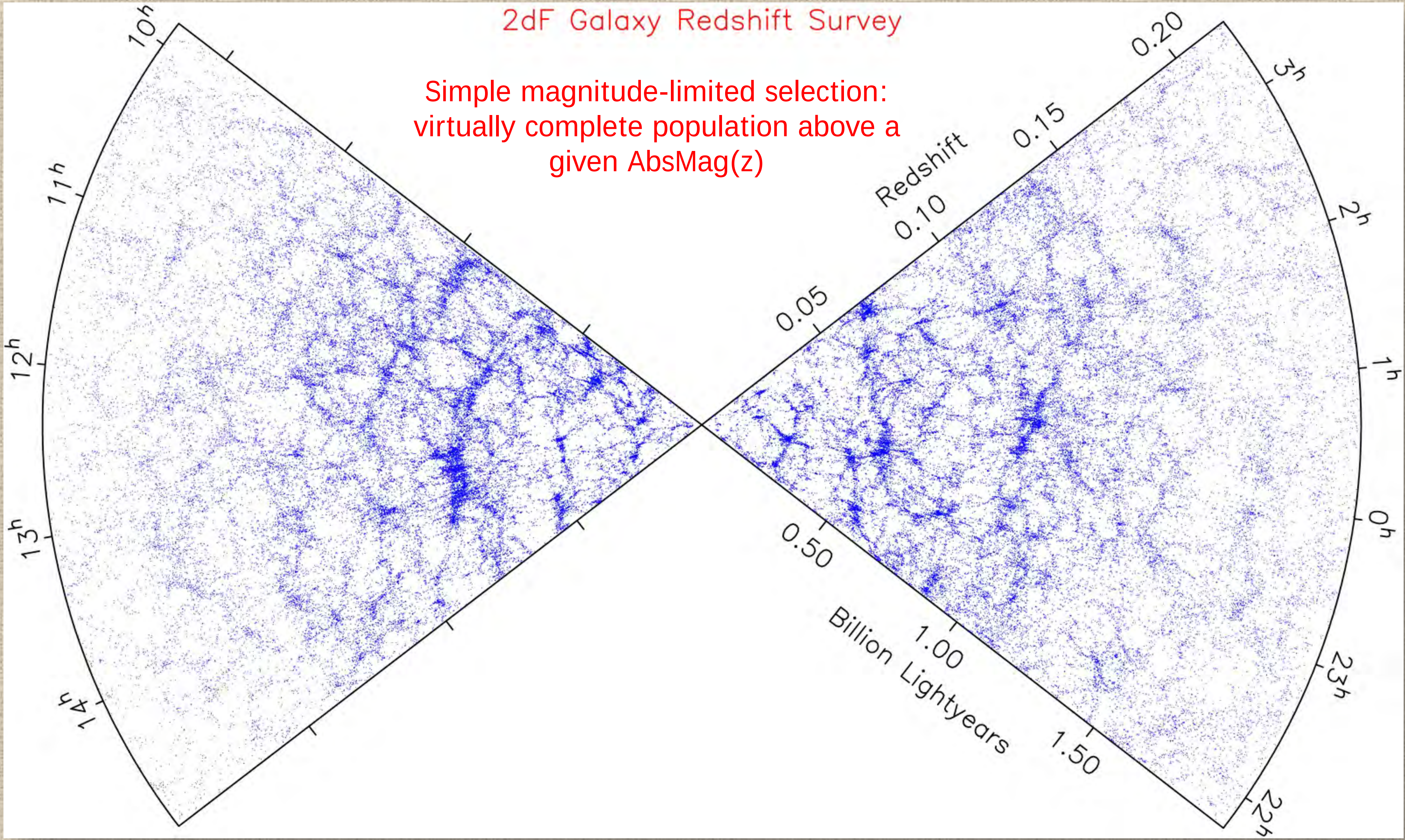




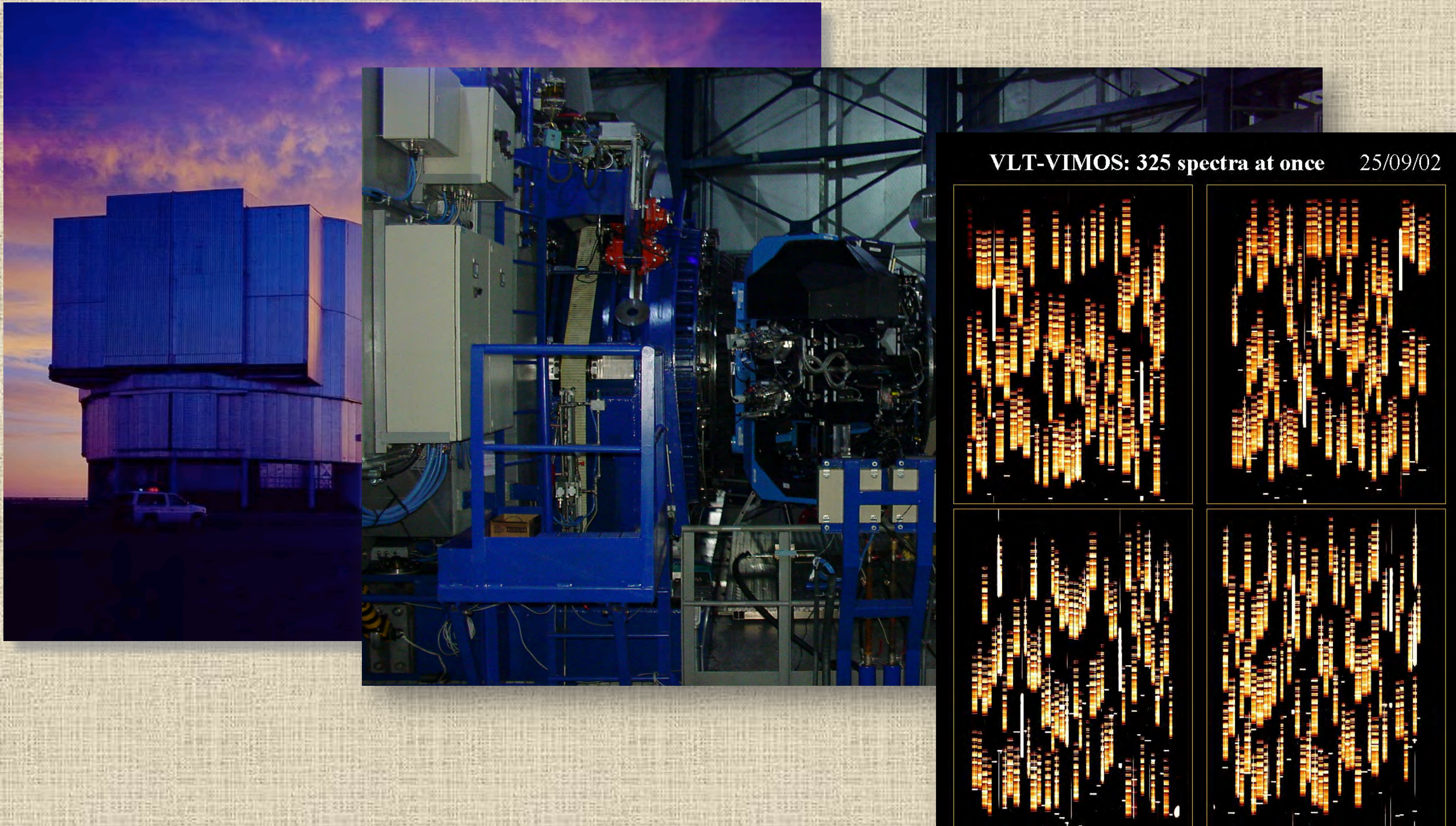


Blake et al. 2010, 2011, 2012, 2014

These surveys are quite different from what 2dF and SDSS did at z<0.2



VIMOS at the ESO Very Large Telescope



VIPERS

VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY

VIPERS goals and strategy

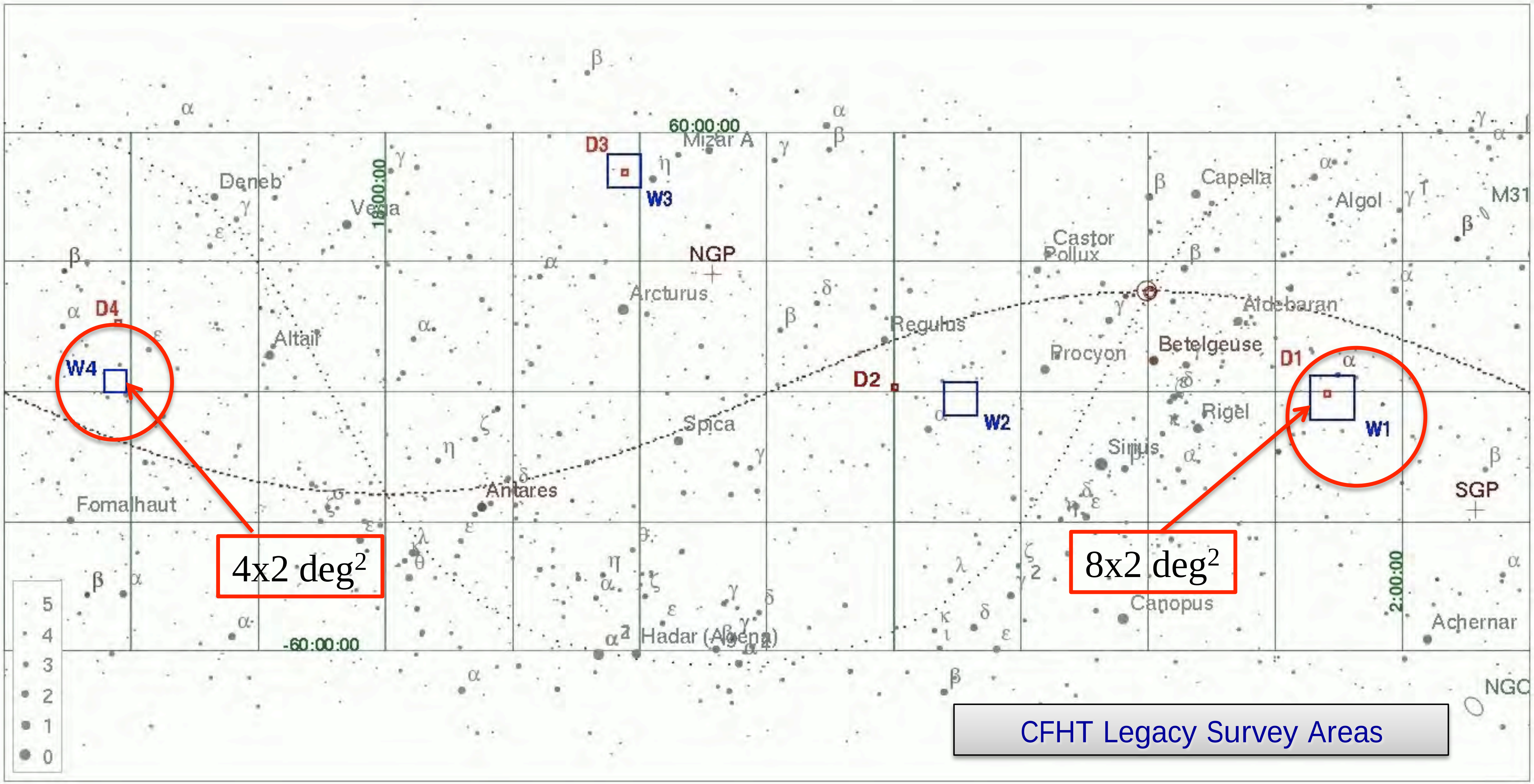
- Want volume and density comparable to a survey like 2dFGRS, but at $z=[0.5-1]$: cosmology driven, but with broader legacy return
- Means Vol $\sim 5 \times 10^7\ h^{-3}\ Mpc^3$, ~100,000 redshifts, close to full sampling
- Implies $I_{AB}<22.5$, ~24 deg^2
- Then $z>0.5$ color-color pre-selection (+star-galaxy separation) isolates range of interest and provides good match to available multiplexing at ESO (VIMOS): >40% sampling
- Based on W1 and W4 CFHTLS Wide fields (~16 + 8 deg^2): requires good multi-band photometry to start with
- VIMOS LR Red grism, 45 min exp.
- 288 pointings, 440.5 VLT hours (~55 night-equivalent)

VIPERS Team

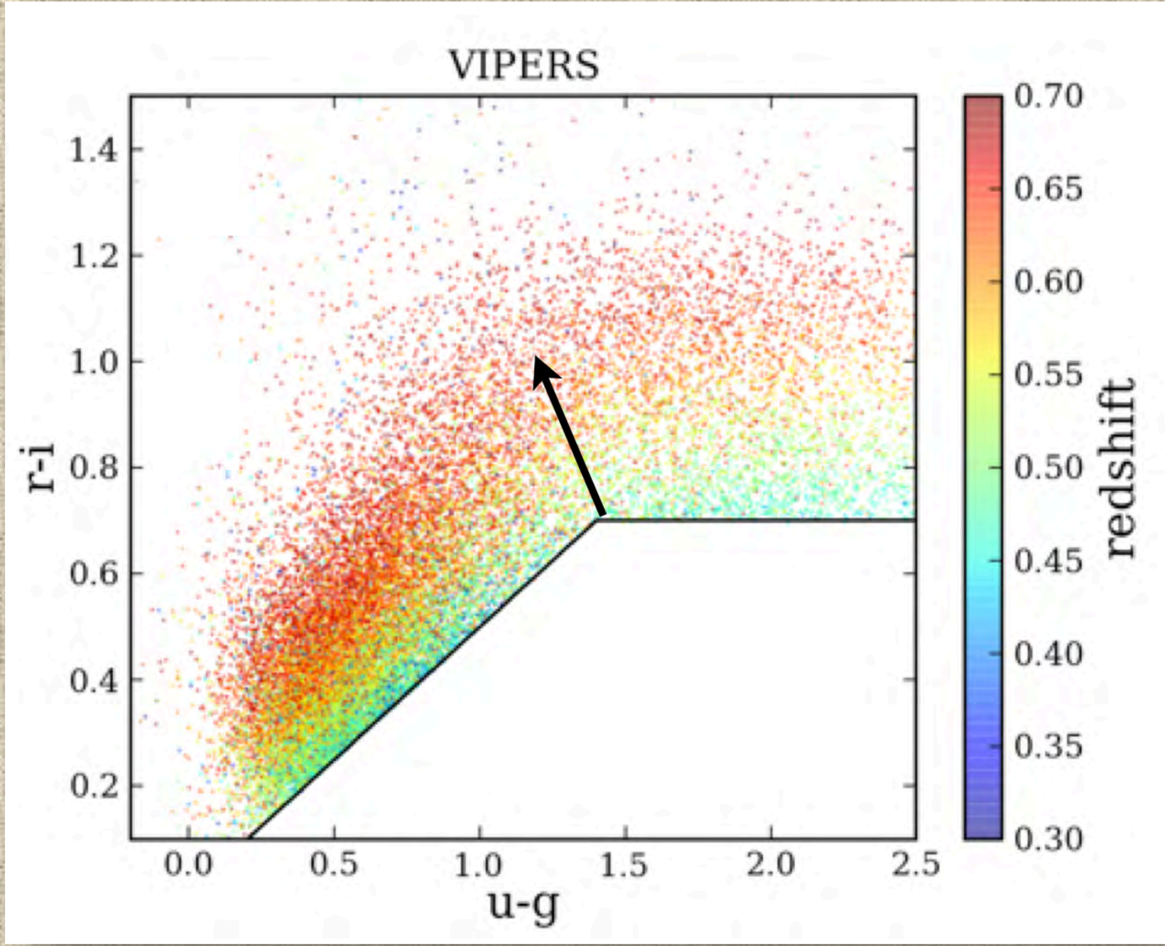
- MILANO OAB (Project Office): L. Guzzo (P.I.), B. Granett, J. Bel, A. Iovino, S. Rota, U. Abbas (Turin)
- MILANO IASF (Data Reduction Centre): B. Garilli, M. Scodeggio, A. Fritz, D. Bottini, P. Franzetti, D. Maccagni, A. Marchetti, M. Polletta, [L. Paioro]
- BOLOGNA: M. Bolzonella, O. Cucciati, Y. Davidzon,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

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

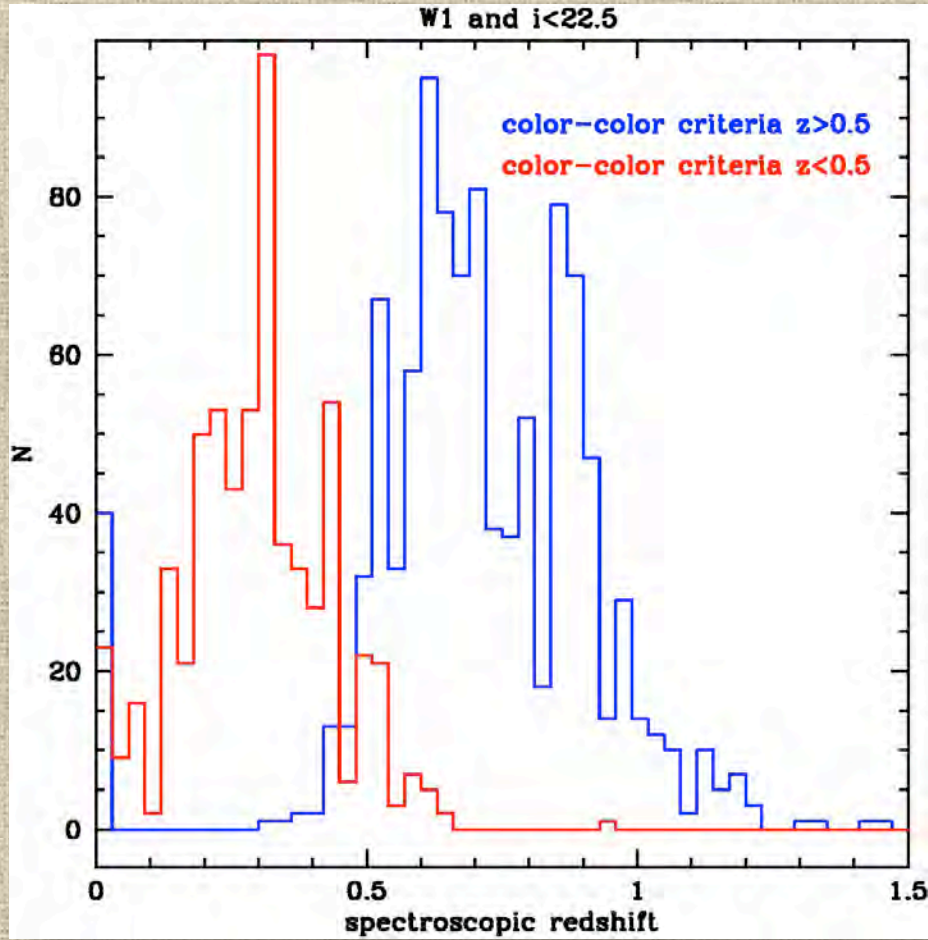
Starting point: CFHT Legacy Survey 5-band photometry over ~140 deg^2



VIPERS Colour-Colour selection: measure galaxies only where we need them, i.e. z>0.5 (calibrated using VVDS)

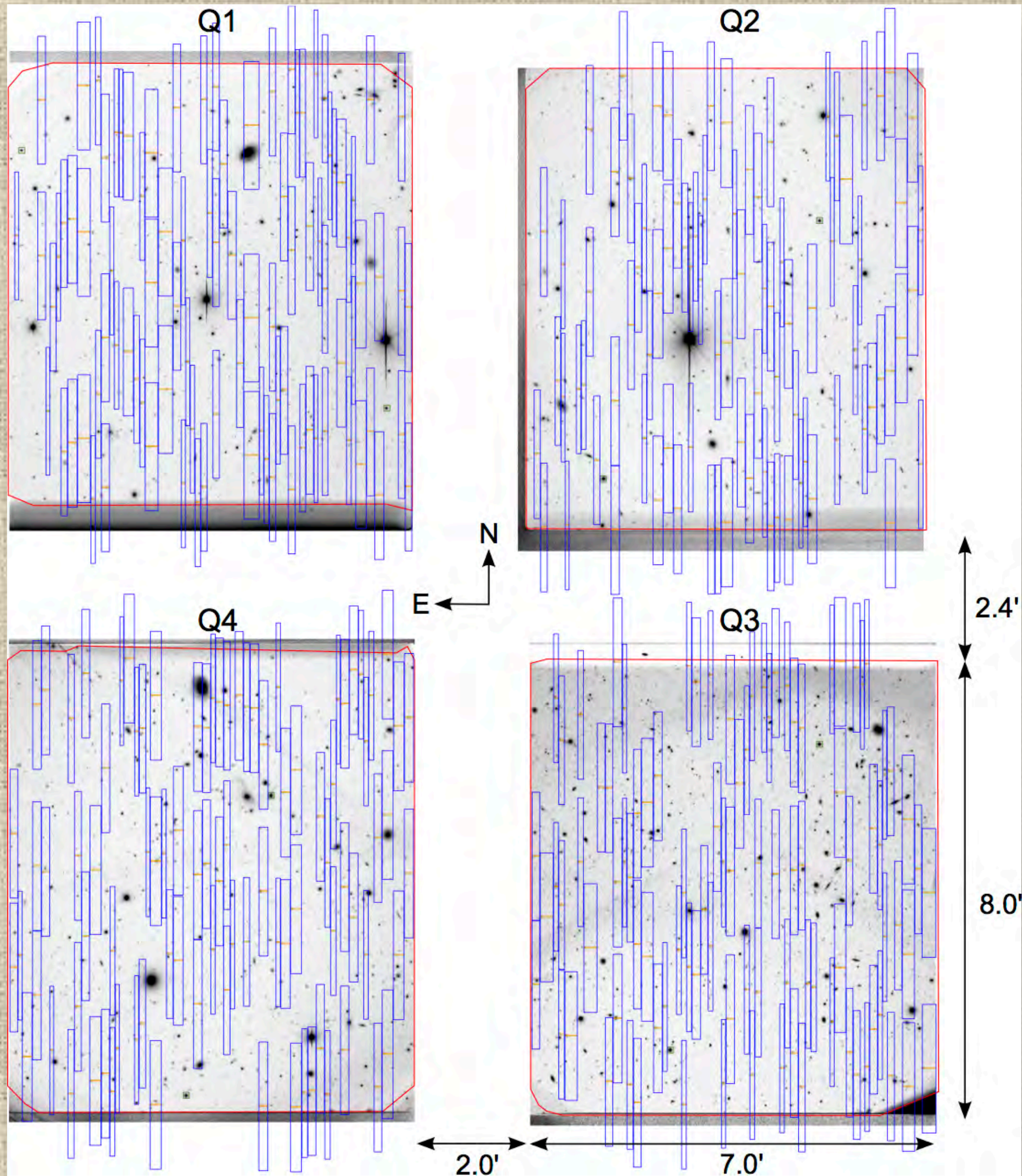


DEEP-2 like, but using 4 photometric bands



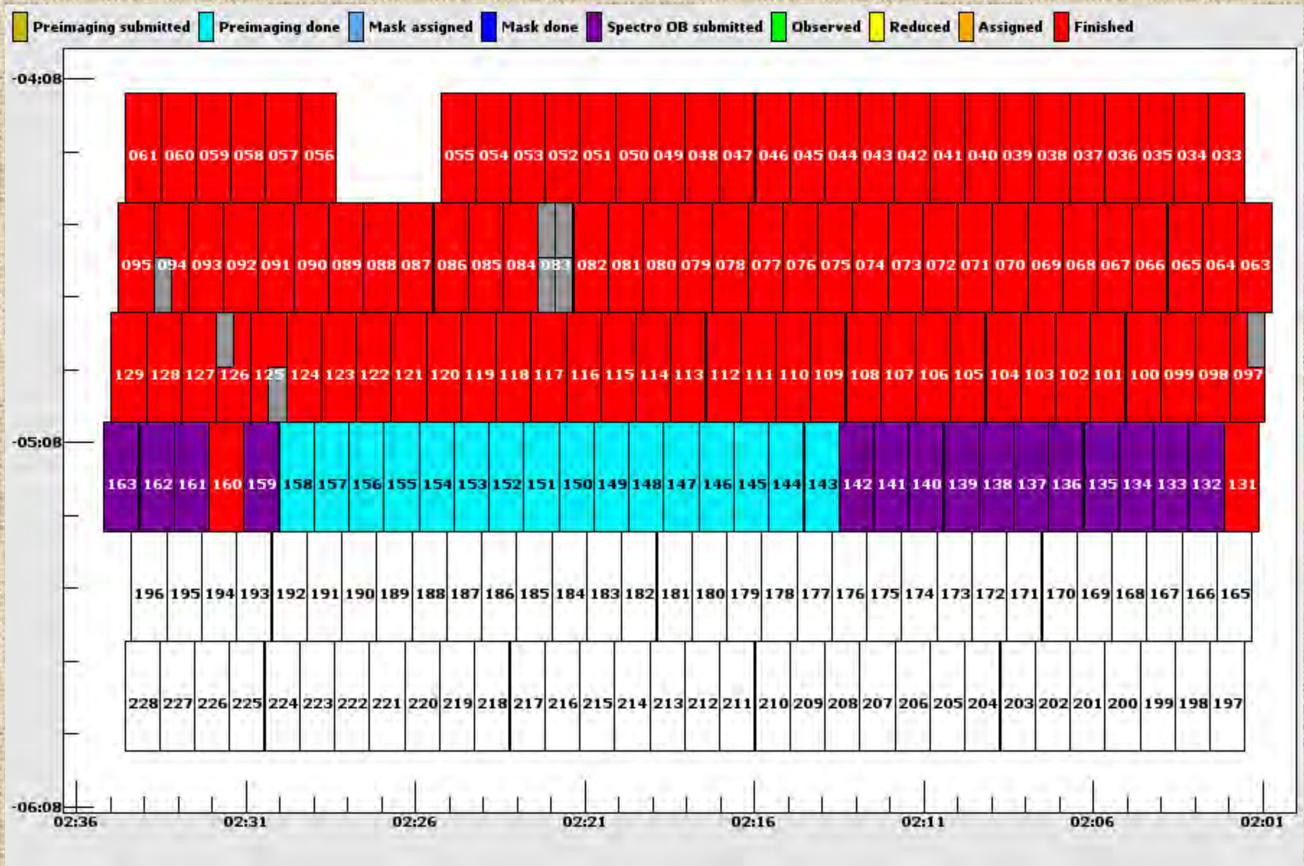
VIPERS single-shot footprint on the sky

On average, 360 spectra observed per VIMOS pointing, given VIPERS target sample surface density and clustering



Sky lay-out of Public Data Release 1 (PDR-1)

W1

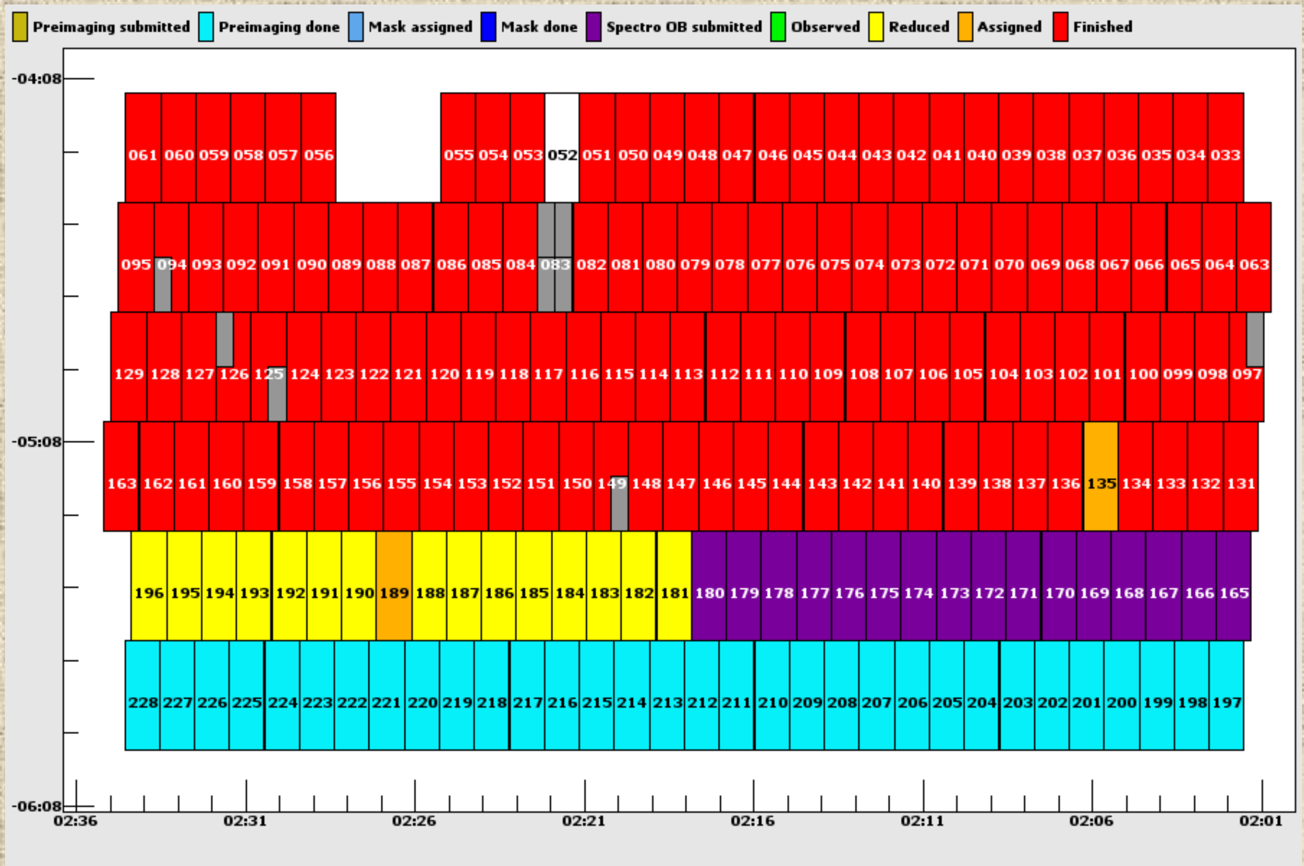


W4

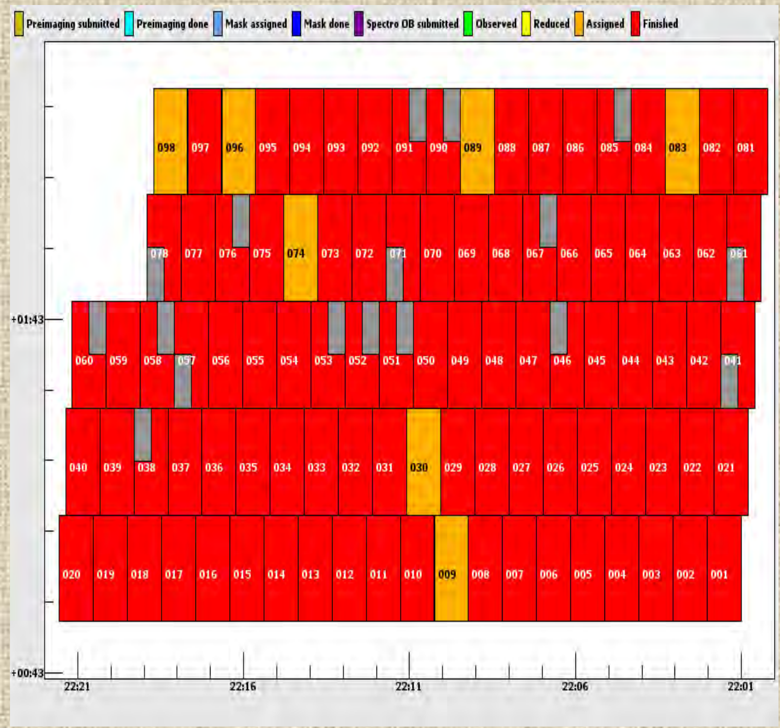
Red-coloured fields are included in PDR-1

Sky coverage: June 2014

W1



W4

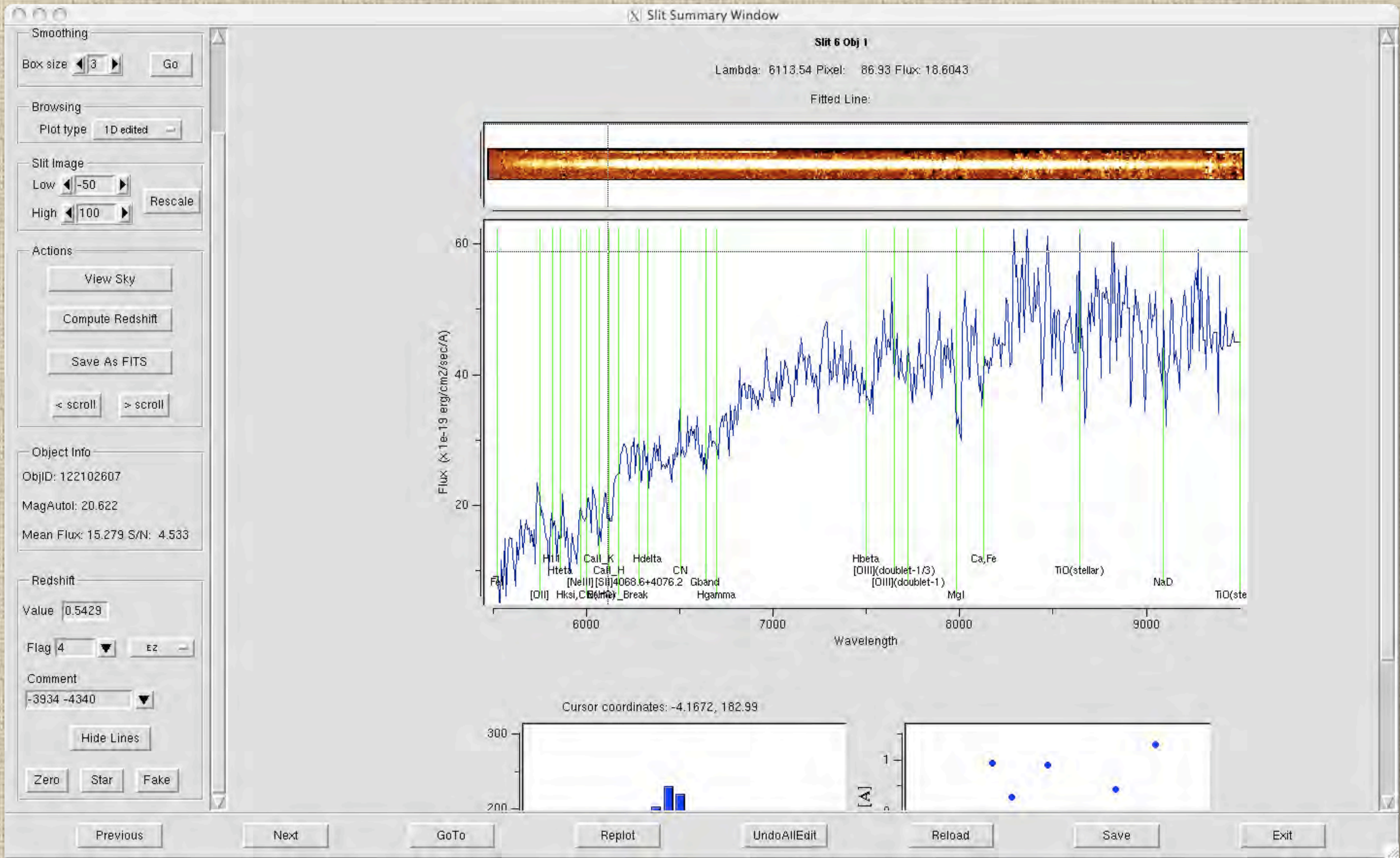


Orange fields in W4: re-observed on compensatory time for bad quality

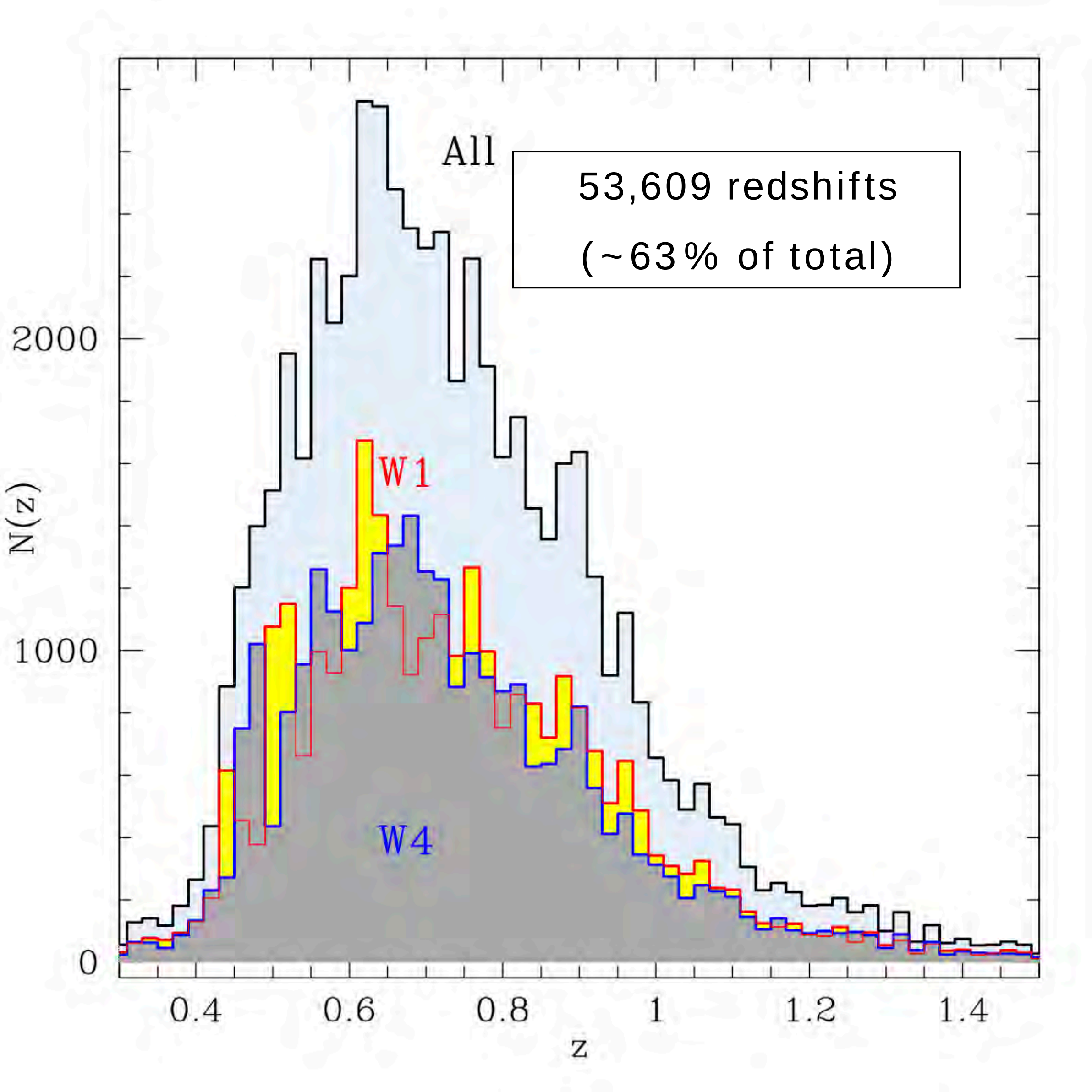
VIPERS Recent Milestones

- 12 March 2013, First science release: 6 papers
- 4 October 2013, Public Data Release 1 (PDR-1):
  - 57,204 redshifts (all observations prior to Spring 2012),
  - All ancillary information (photometry, masks, weights)
  - Details in Garilli et al. 2014 and Guzzo et al. 2014 papers
  - 193 VIMOS pointings, out of 288 (W4 virtually completed)
- Expected survey completion: 2015

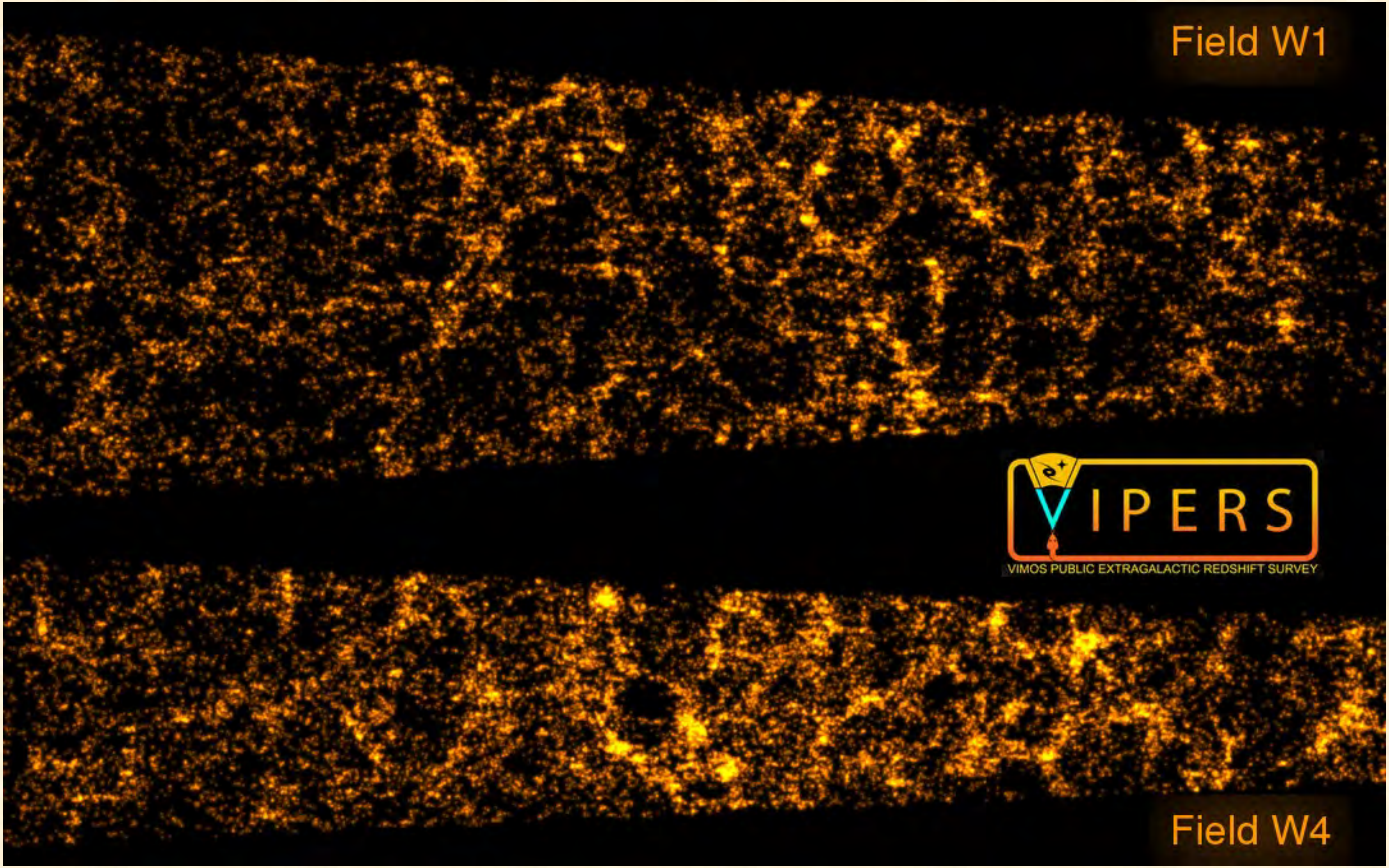
1. Automatic spectral extraction/calibration + redshift measurement: *EasyLife* pipeline running at INAF- IASF Milano (Garilli et al. 2012, PASP, 124)
2. Redshift review and validation: *VIPGI* (Scodeggio et al. 2005, PASP, 117) *&* *EZ* (Garilli et al. 2010, PASP, 122)

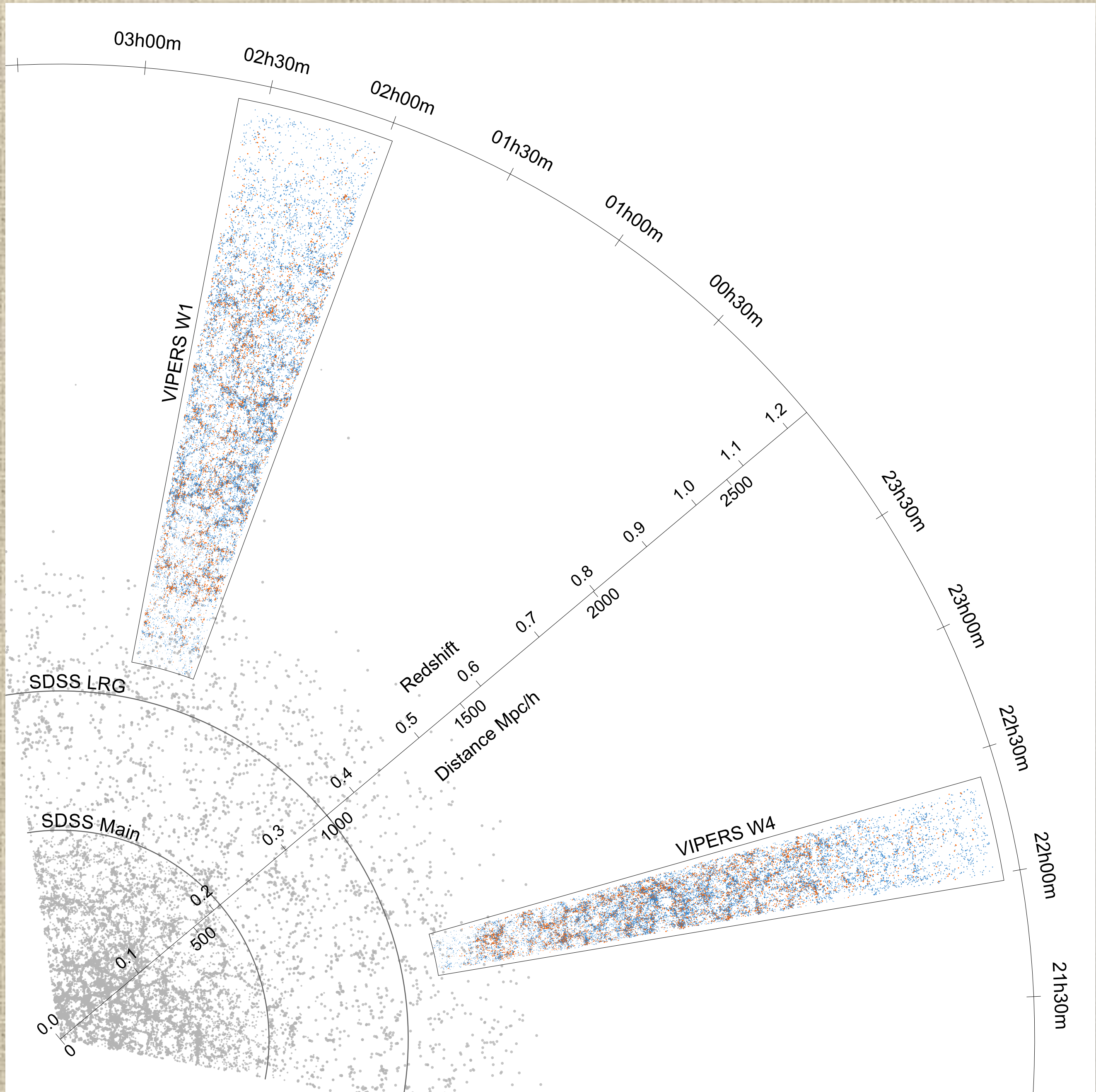


PDR-1 redshift distribution



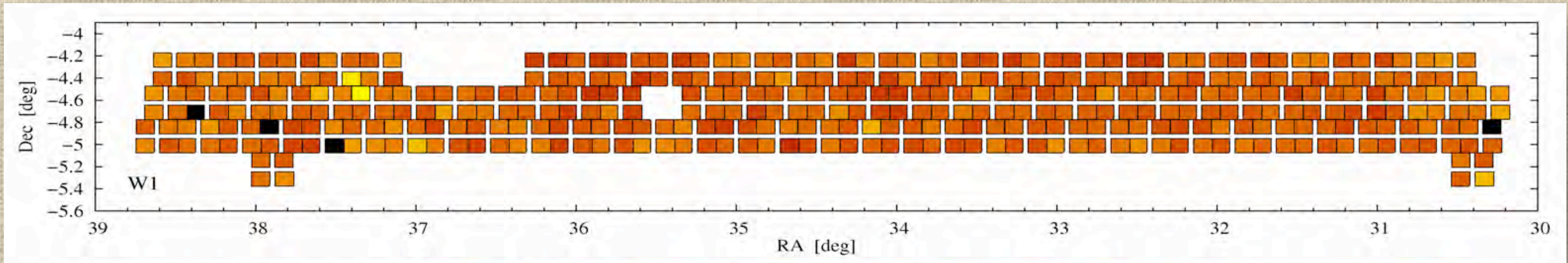
(Guzzo et al. 2014)


Field W1
VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY
Field W4

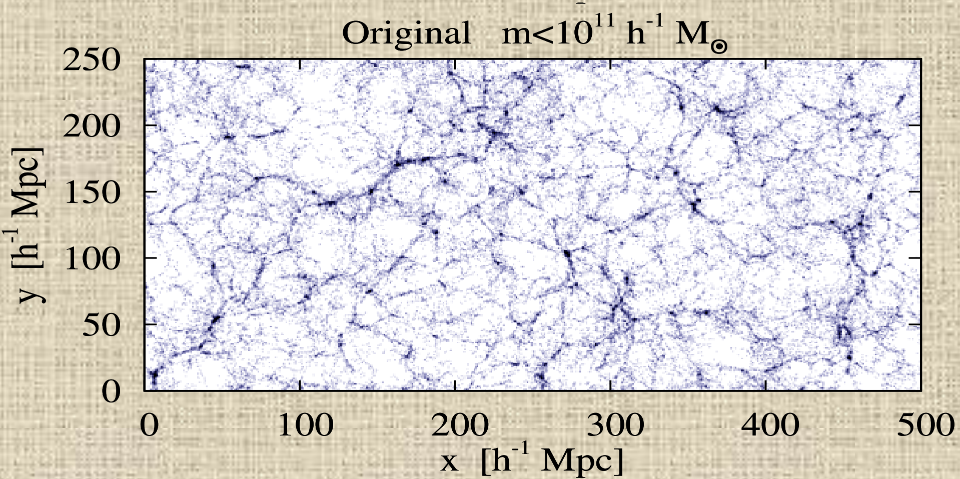


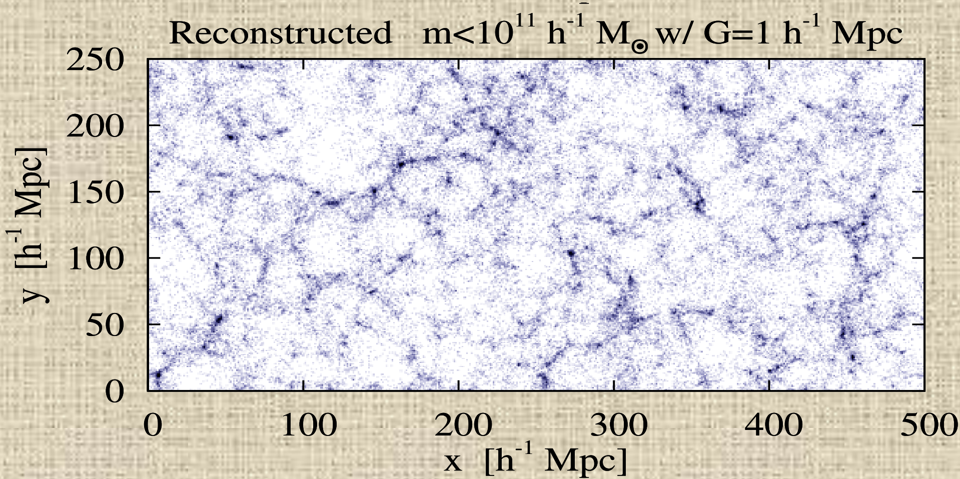
03h00m
02h30m
02h00m
01h30m
01h00m
00h30m
23h30m
23h00m
22h30m
22h00m
21h30m
VIPERS W1
VIPERS W4
SDSS LRG
SDSS Main
Redshift
Distance Mpc/h
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
0
500
1000
1500
2000
2500

Clustering and RSD require attention to details: mocks are crucial



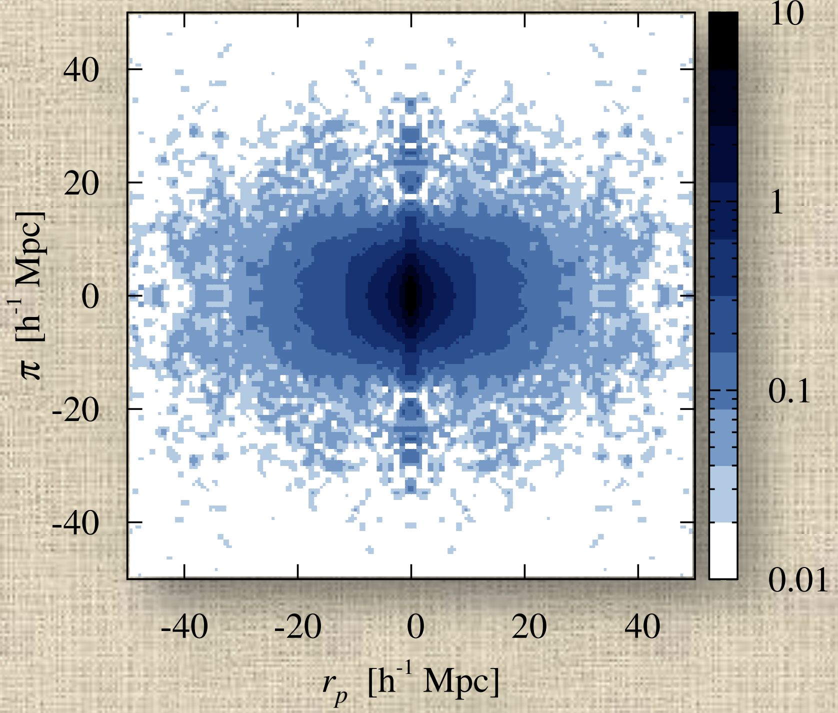
- Need realistic and numerous mock galaxy samples. Built by Sylvain de la Torre, different mocks for different purposes: (1) HOD + MultiDark "enhanced" (Prada et al.2012); (2) HOD + Pinocchio (Monaco et al. 2002); (3) Millennium + semi-analytic (De Lucia & Blaizot 2007). See posters by Rota and Pezzotta on correction of observational effects in Fourier and configuration space.

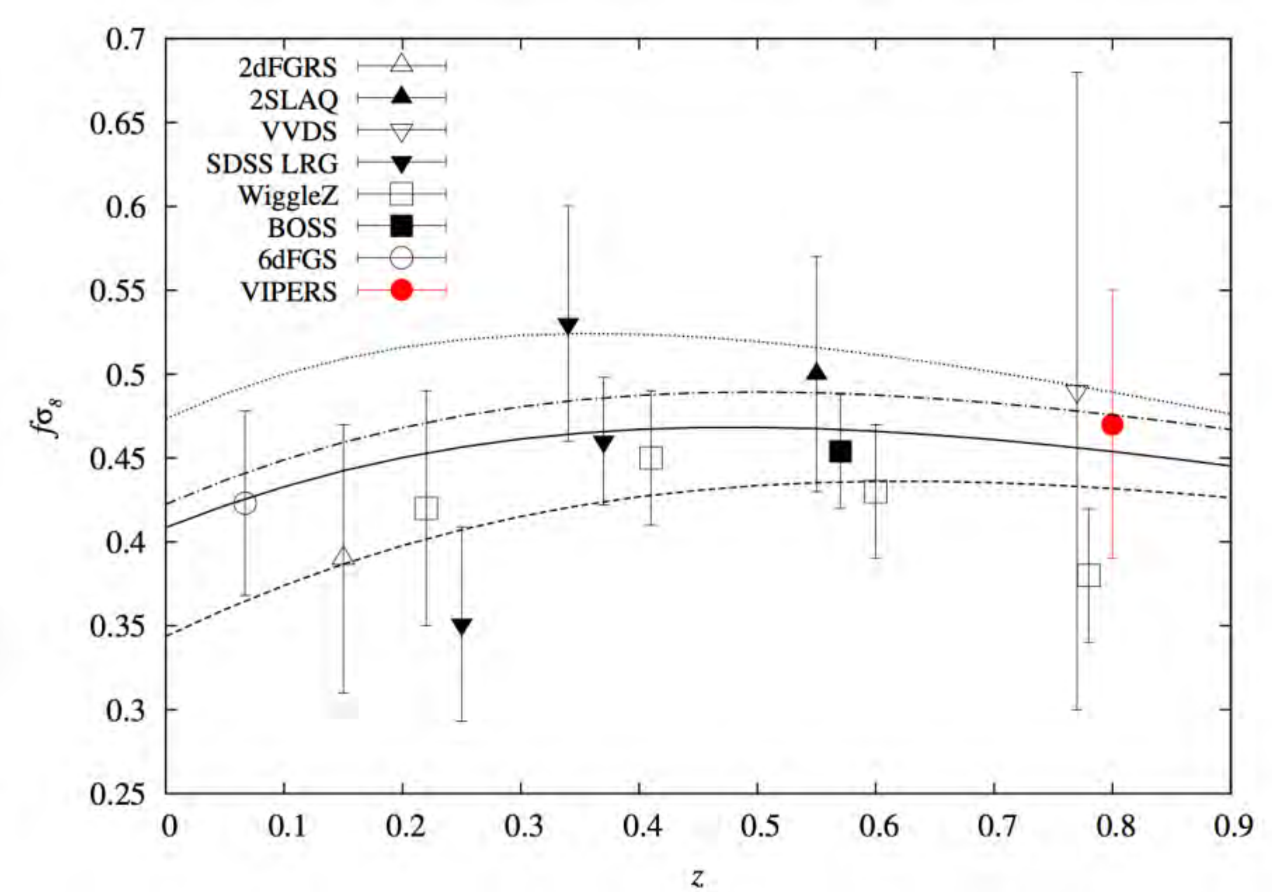




(de la Torre & Peacock 2012, de la Torre et al. 2013)

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





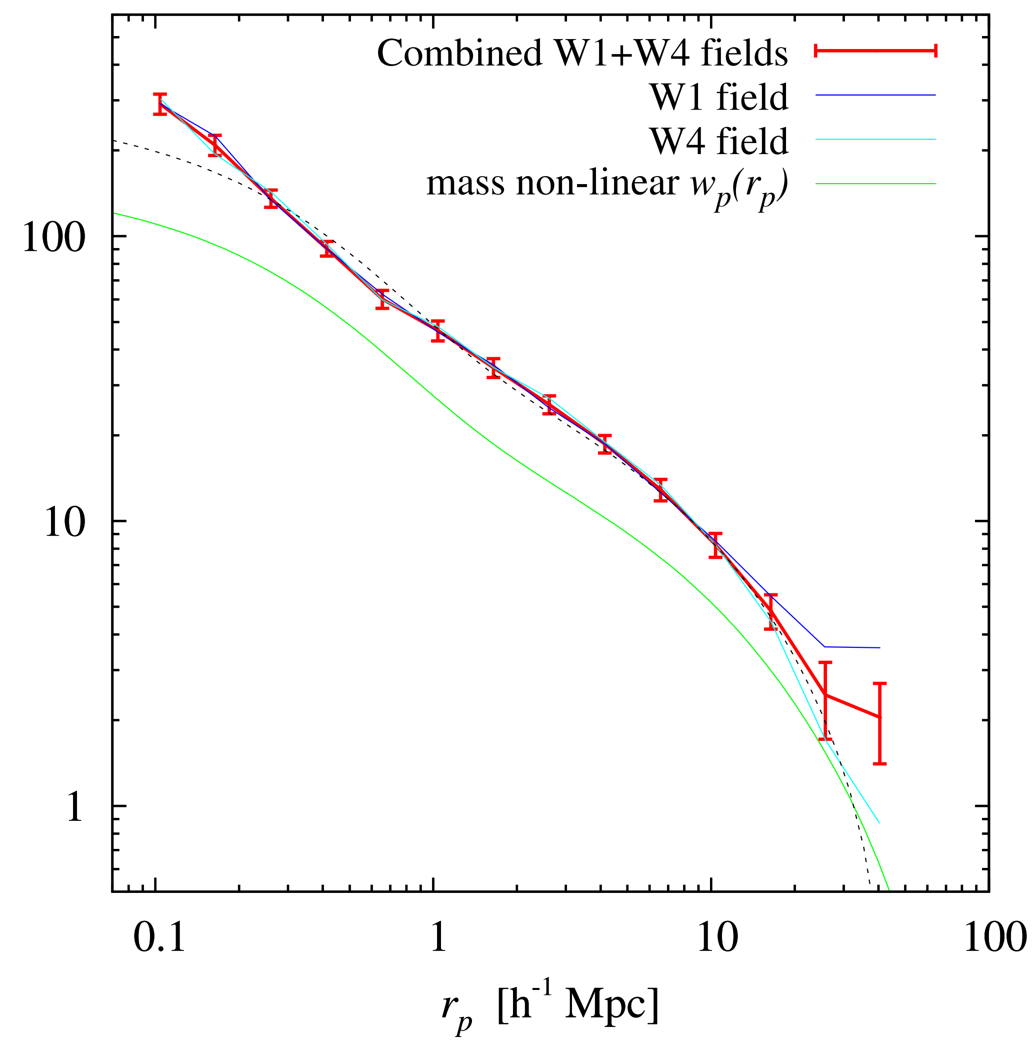
VIPERS: $f\sigma_8(z=0.8) = 0.47\pm0.08$

De la Torre et al. 2013 (SEE TALK ON FRIDAY)

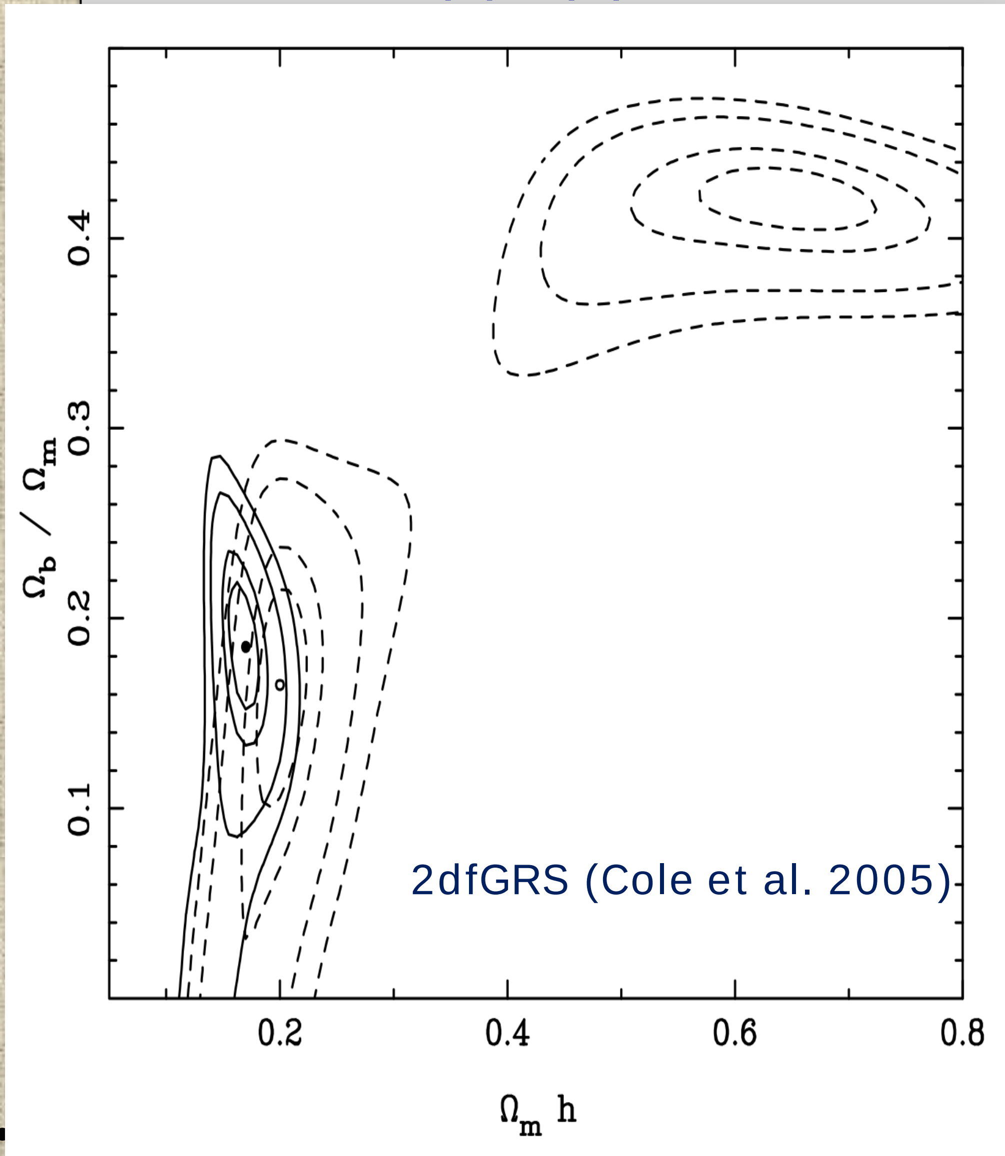
Projected correlation function $w_p(r_p)$ from the PDR-1 data

- DM-baryon connection: Halo Occupation Distribution modelling

(De la Torre & VIPERS team 2014, in preparation)



VIPERS P(k): (1) direct measurement at z=0.5-1 (S. Rota PhD … ee Poster)



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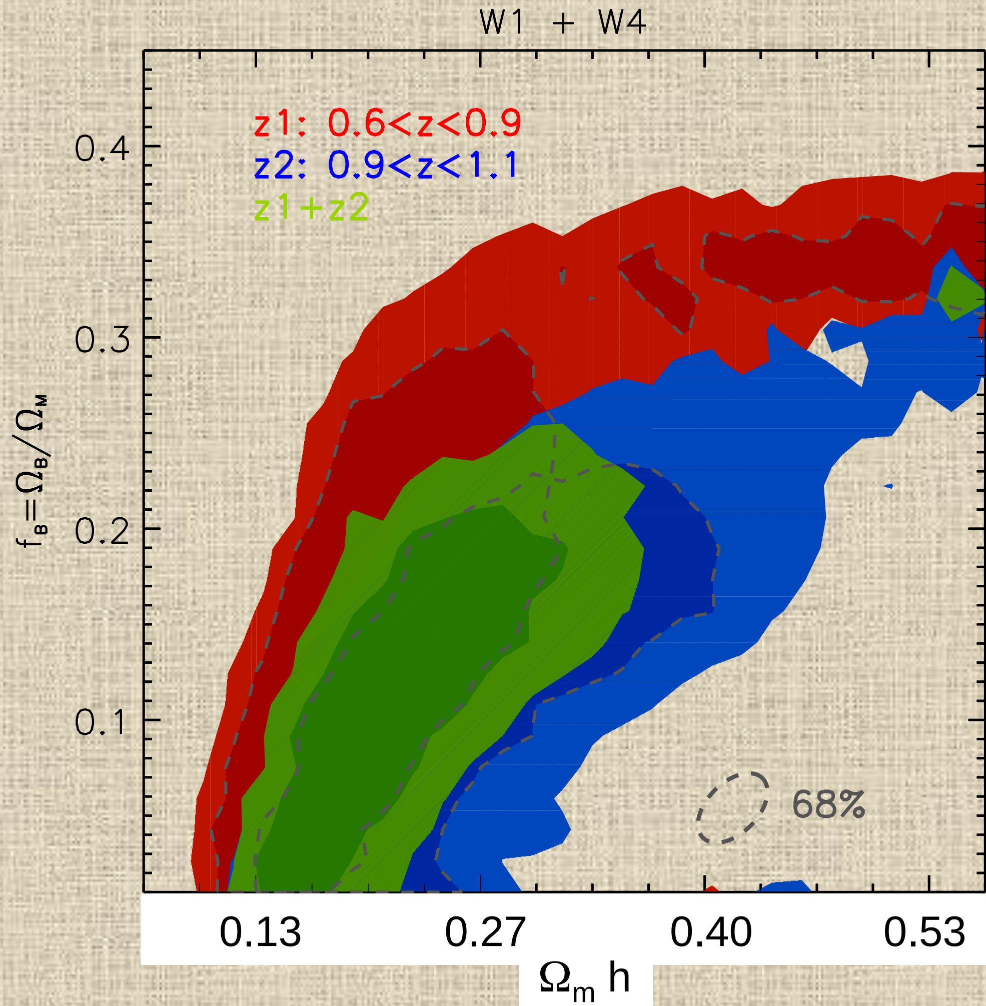
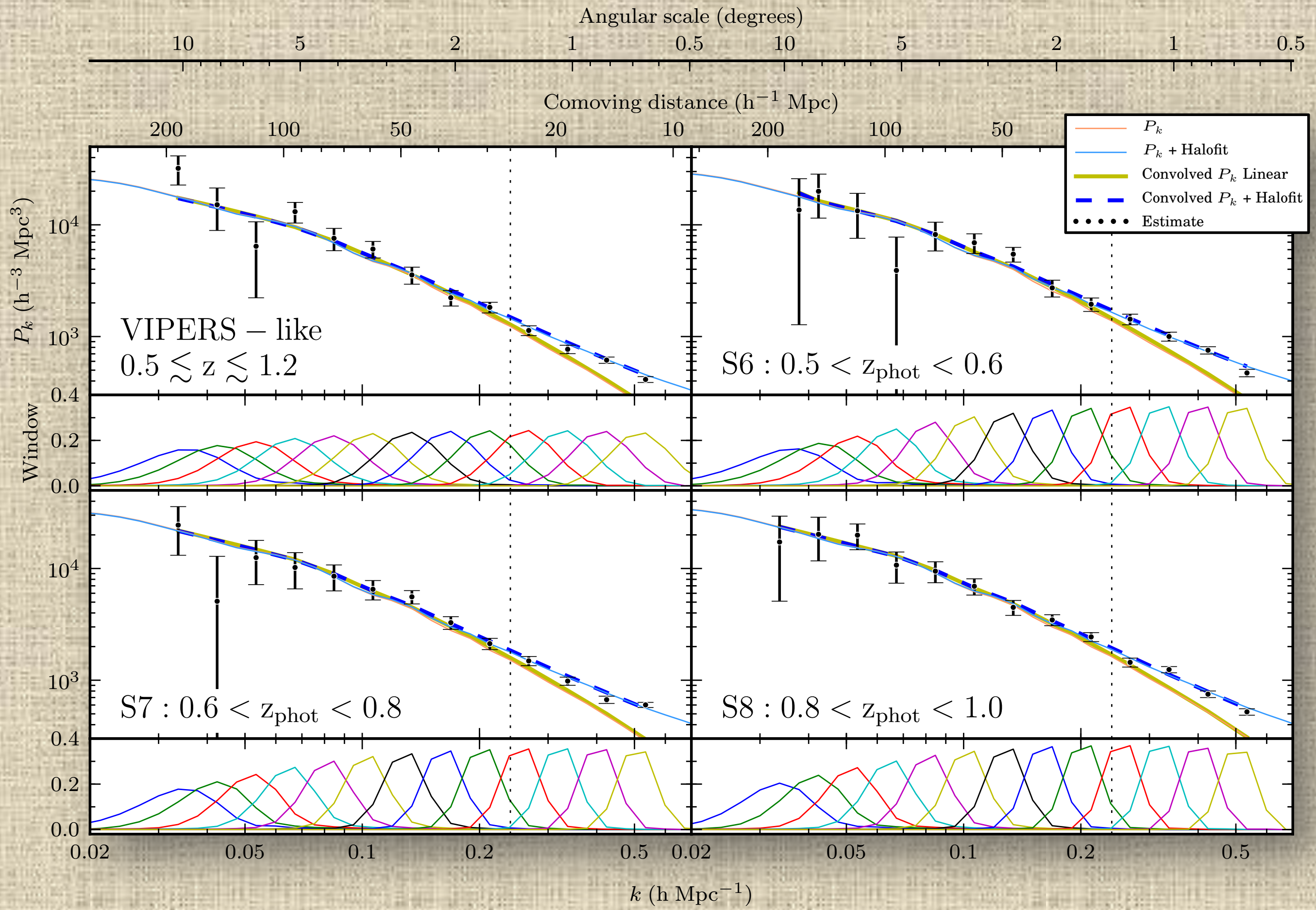
(Rota, Granett, Bel, LG & VIPERS Team, in preparation)



- 4 independent estimates: 2 z bins in 2 independent fields (W1 and W4)

VIPERS P(k): (2) real-space estimate through combination of full CFHTLS-Wide (~130 deg^2) and VIPERS N(z)

W1+W2+W3+W4



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

Xia, Granett, Viel et al., 2012, JCAP, 06, 010: improved neutrino constraints

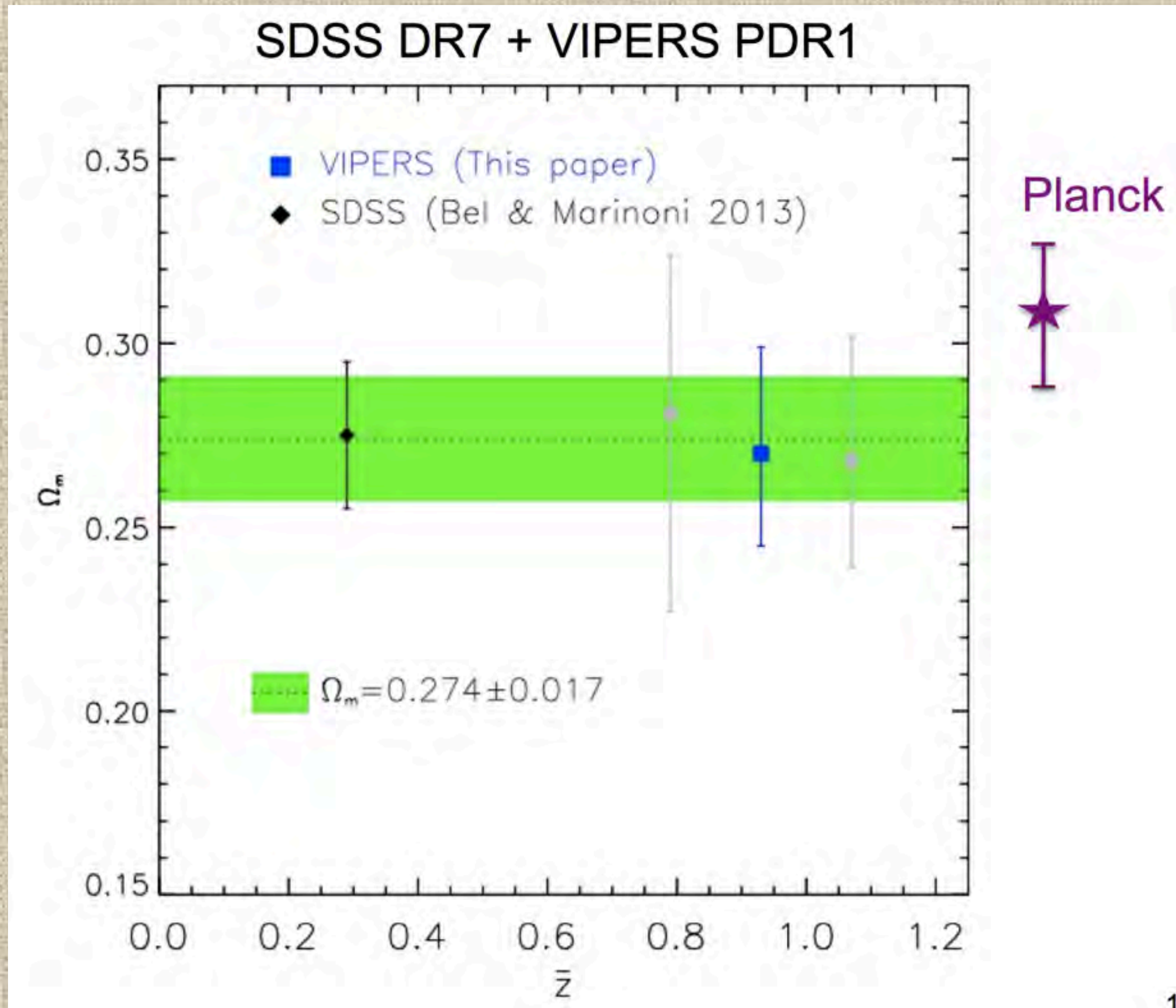
(3) Implicit probe of P(k) shape: counts in cells and the "clustering ratio" (Bel et al.)

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 these factor out
- Essentially a ratio of power in two different k bands

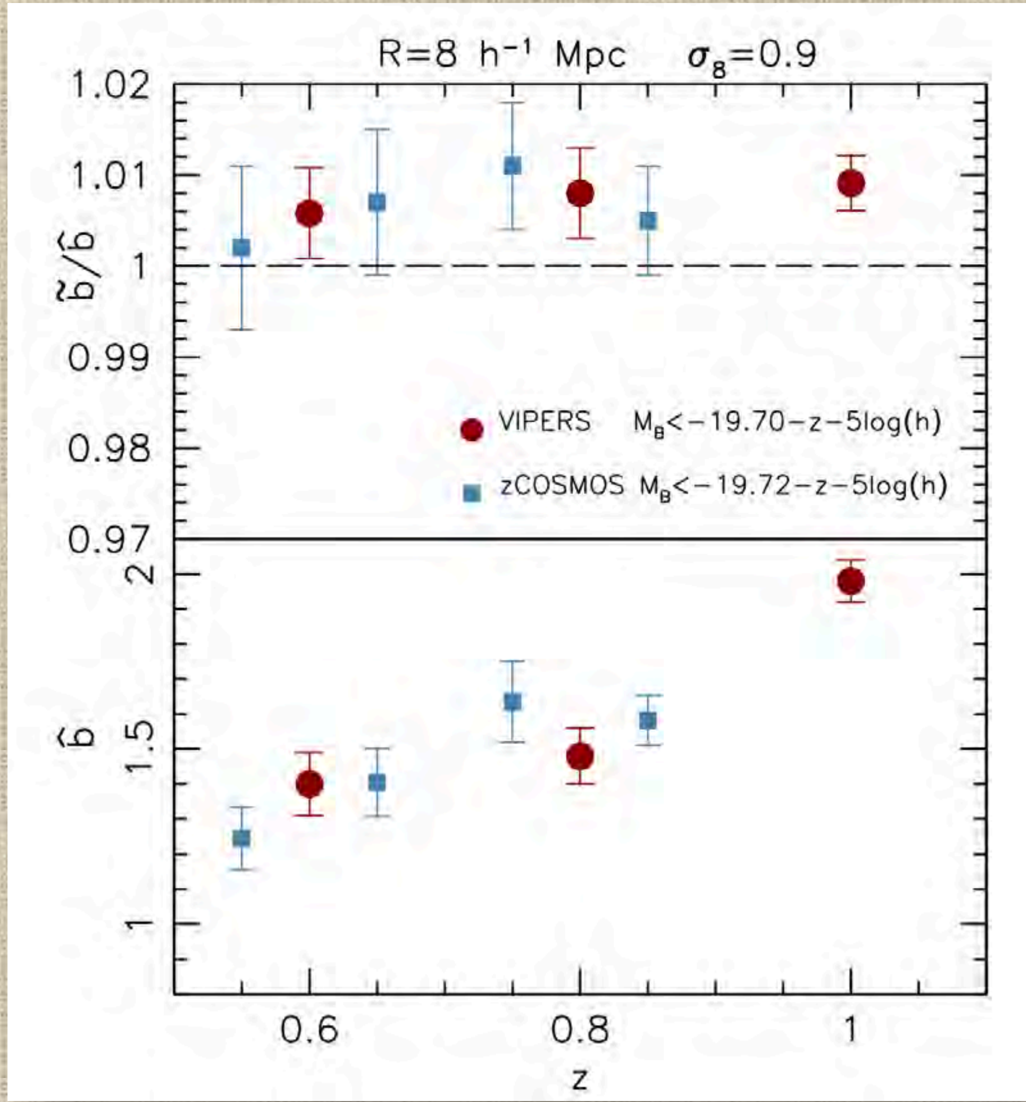
Bel et al. 2014, A&A, 563, 37



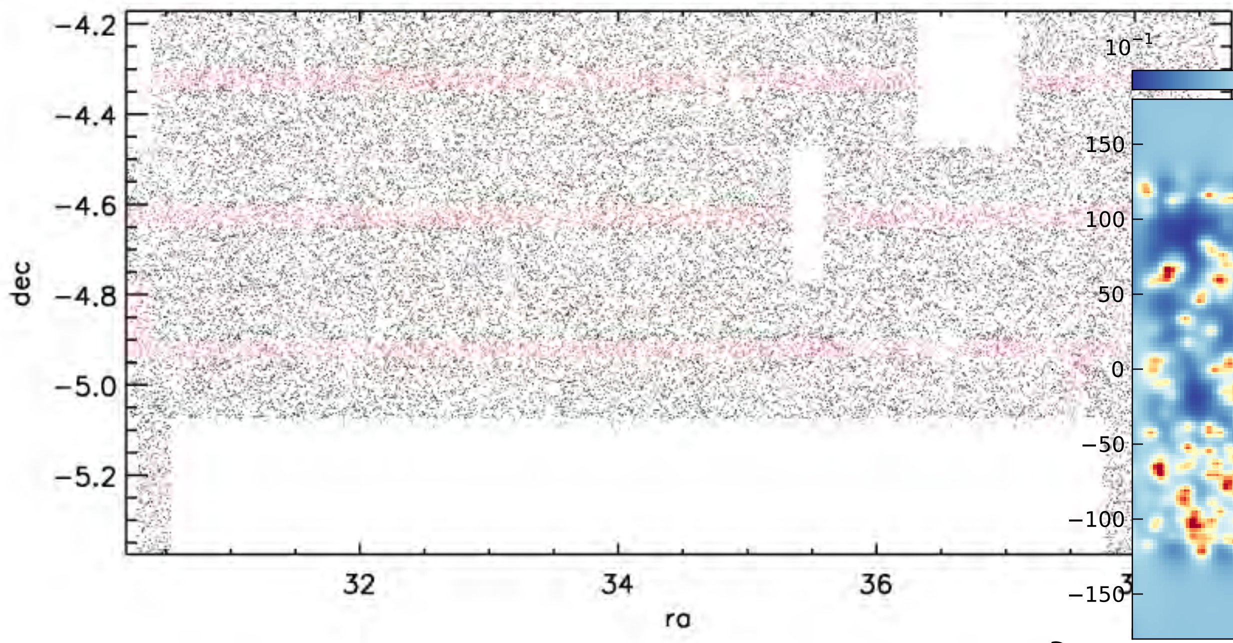
Nonlinear bias evolution

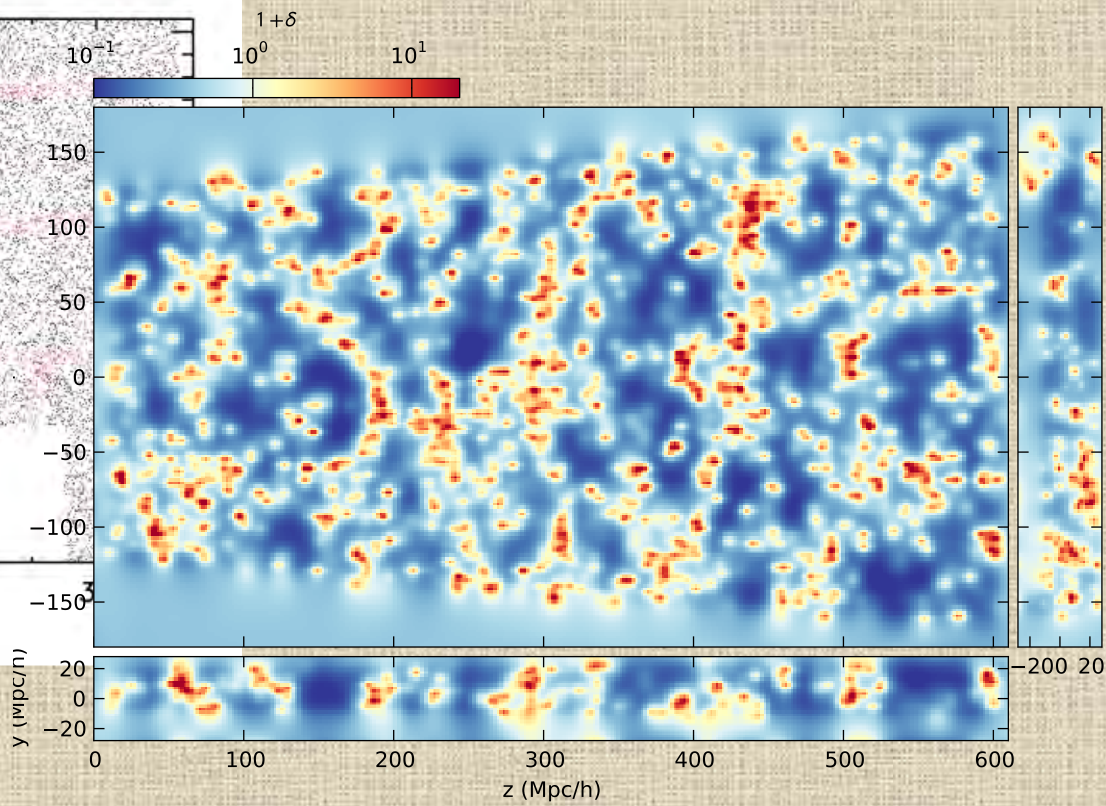
Using Sigad, Branchini& Dekel (2000) inversion technique

(Di Porto, Branchini & VIPERS Team, submitted)



The cosmic web at z~1: reconstructing the density field





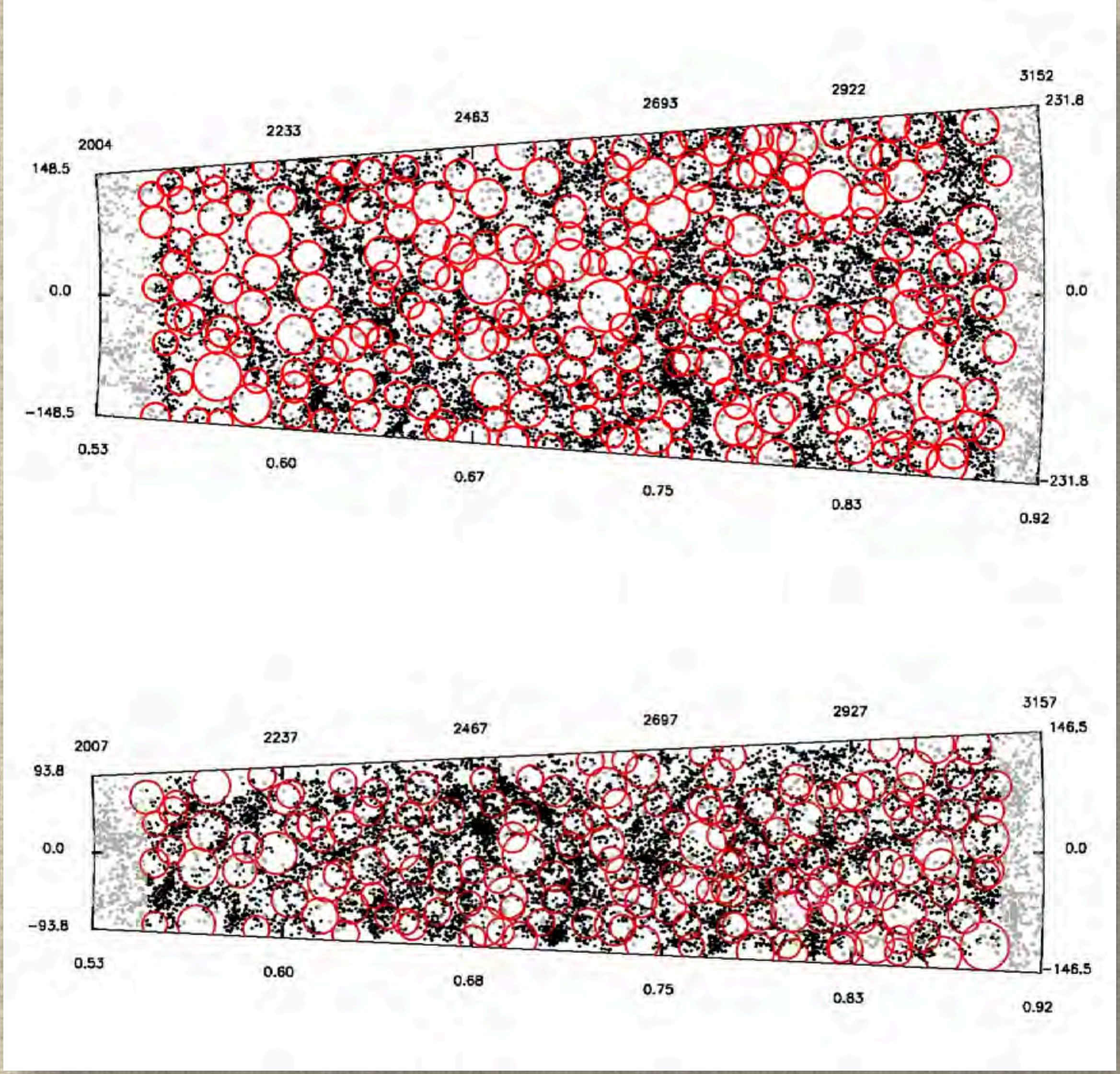
LOCAL DENSITY RECONSTRUCTION:
CLONING, “ZADE” PHOTO-Z ATTRACTOR

(Cucciati et al., in press)

STATISTICAL RECONSTRUCTION
(WIENER FILTERING – Granett, Bel, Branchini et al.)

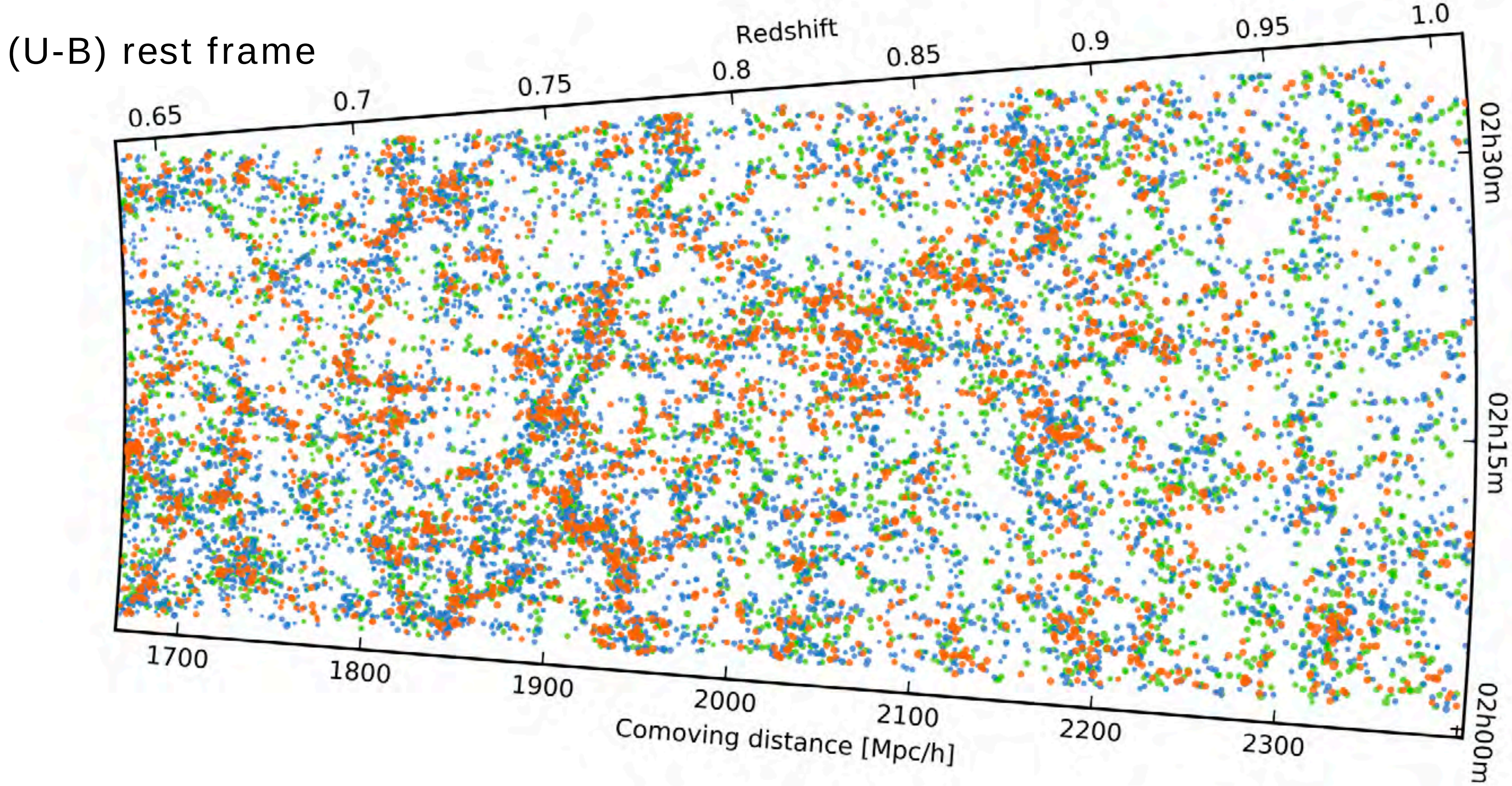
The cosmic web at z~1: cosmic voids

Micheletti, Iovino, Hawken, Granett & VIPERS team, submitted



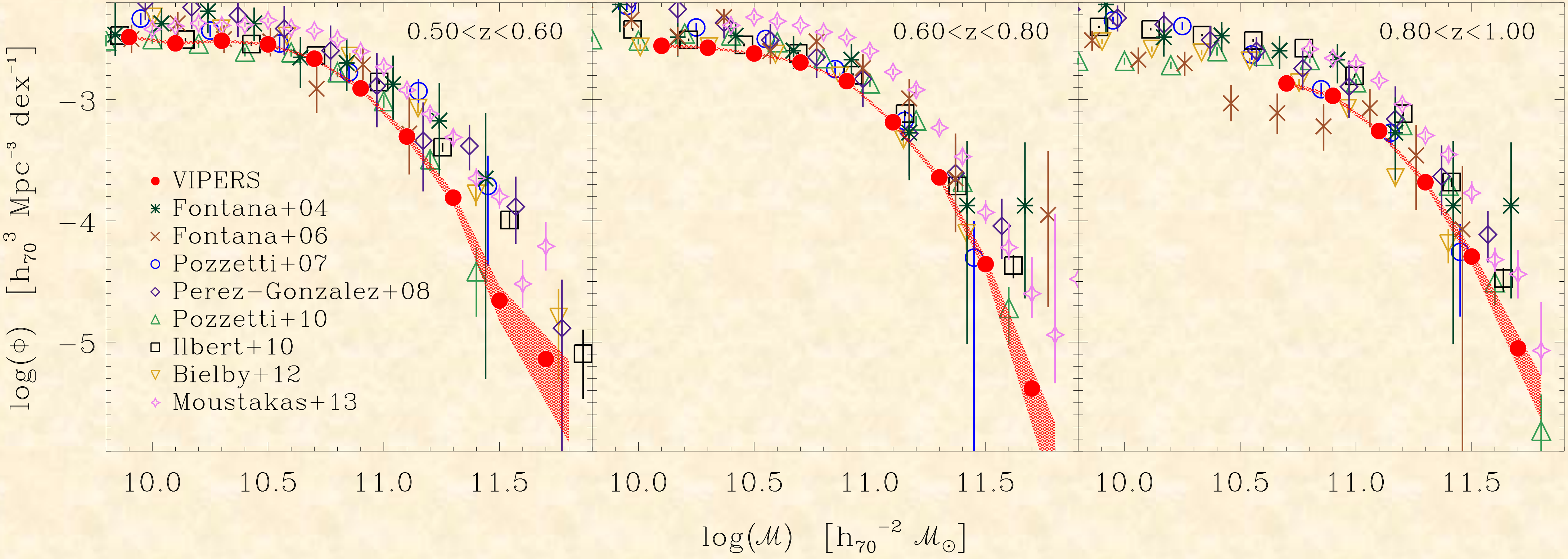
See A. Hawken talk

VIPERS provides detailed structure AND galaxy properties



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

Galaxy Stellar Mass Function



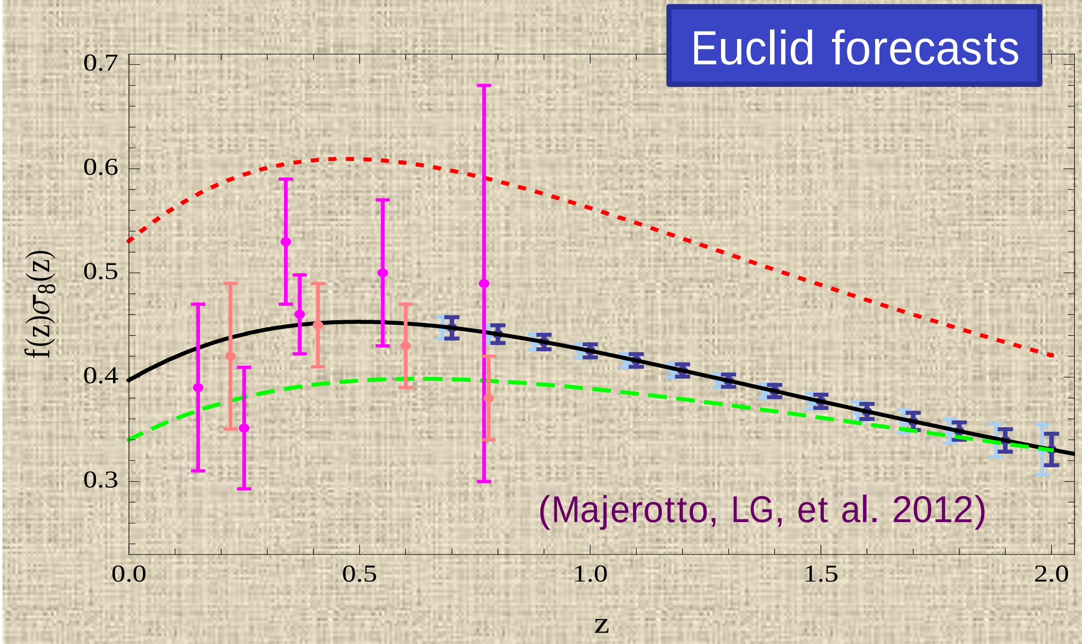
MOST PRECISE MEASUREMENT EVER OF THE NUMBER DENSITY OF MASSIVE GALAXIES AT Z~1

I. Davidzon, Bolzonella et al. 2013, A&A, 558, 23
II. Fritz et al. (CM diagram + LF), 2014, A&A, 563, 92

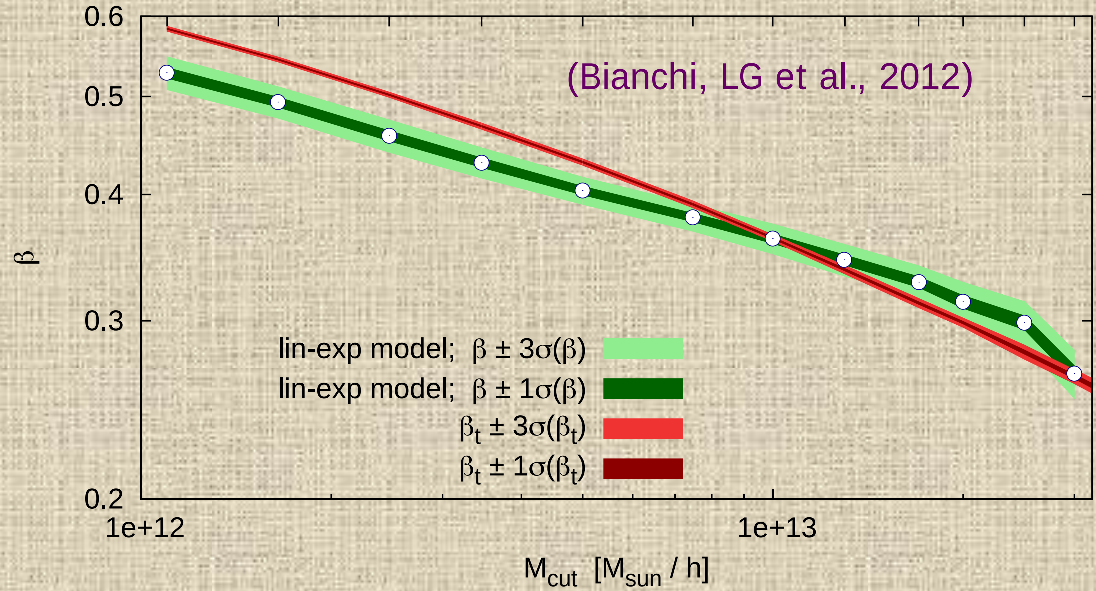
Improving models to extract cosmological quantities (e.g. RSD)

In parallel to building larger surveys, we need to improve modelling if we are to enter *"precision RSD era"*

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



→ "Standard" RSD dispersion model: up to 10% systematic error



(also Okumura & Jing, 2011)

Improving models for RSD: understand the velocity PDF

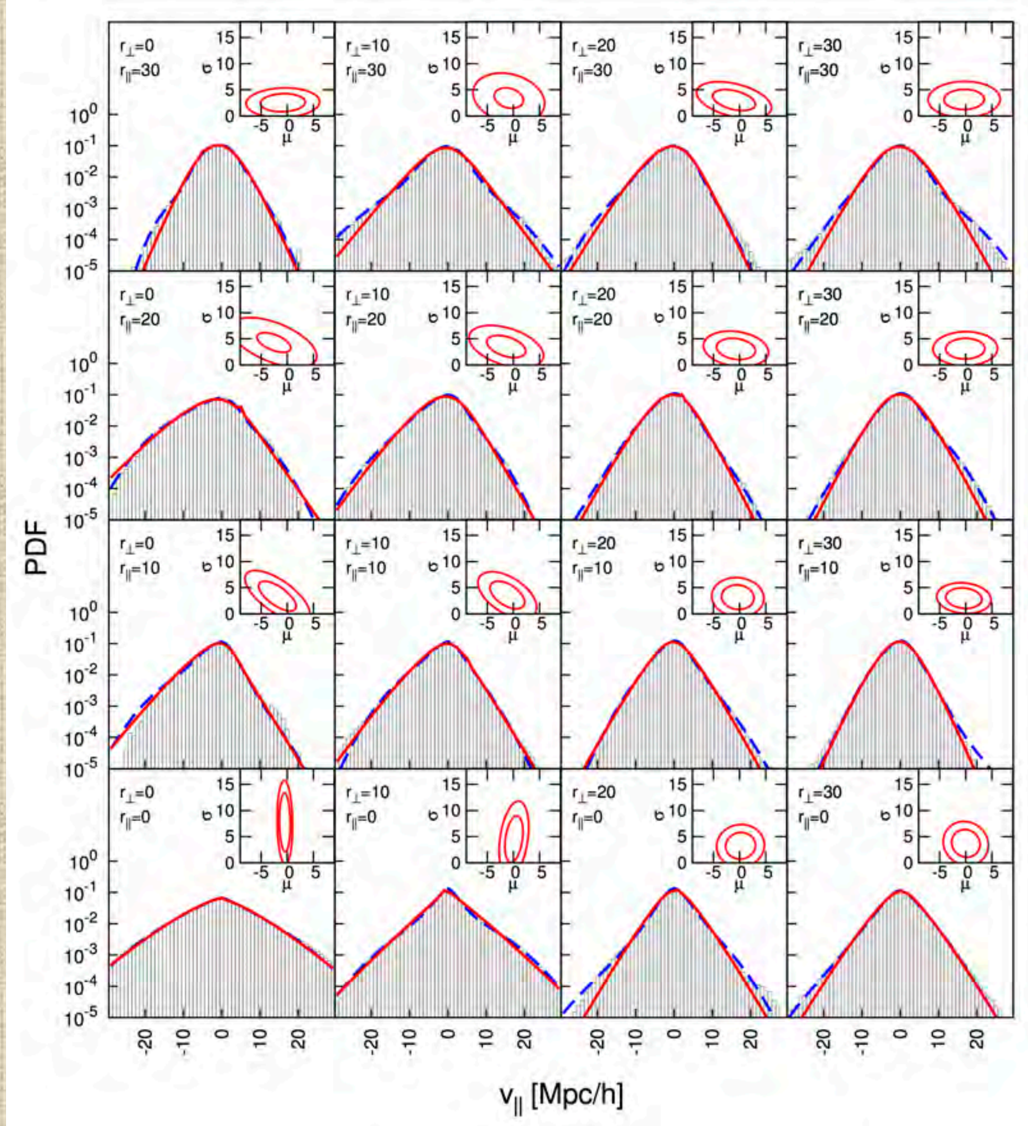
- Goal: to reduce degrees of freedom on description of the pairwise velocity PDF in the context of the *streaming model*

$$1 + \xi_S(s_\perp, s_\parallel) = \int dr_\parallel \; [1 + \xi_R(r)] \; \mathcal{P}(r_\parallel - s_\parallel | \mathbf{r})$$

- PDF described as weighted sum of Gaussians, whose mean and dispersion are described in turn by bivariate Gaussian

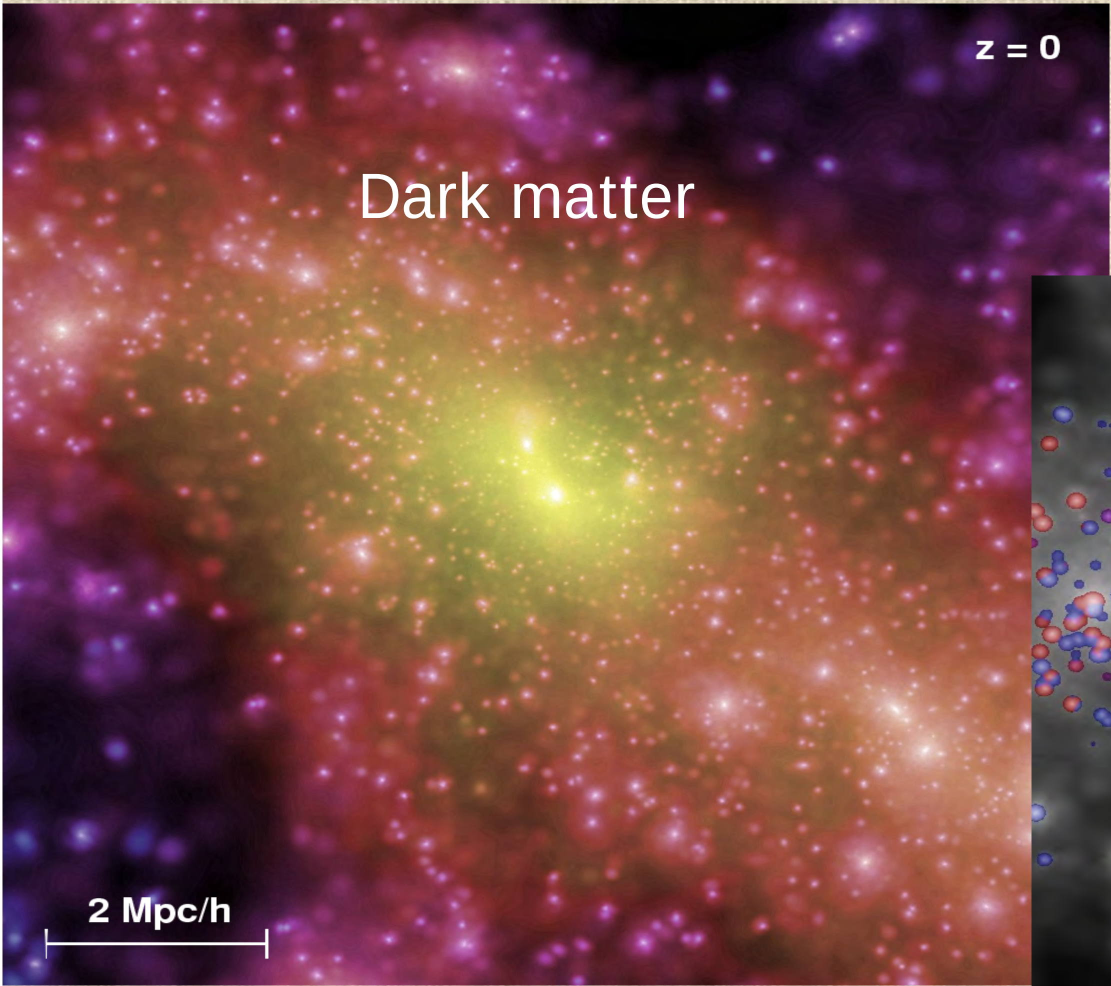
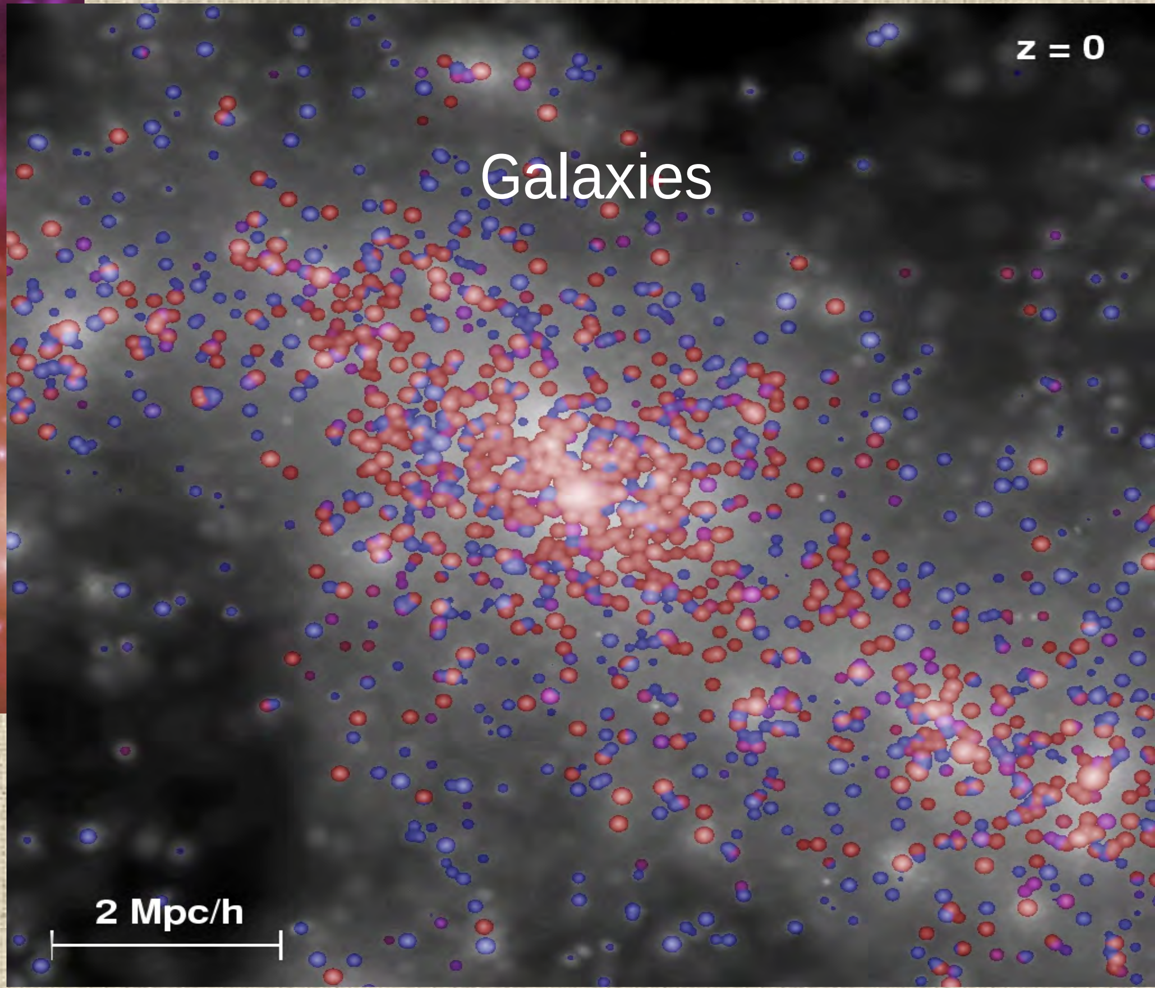
$$\mathcal{P}(v_\parallel) = \int d\mu d\sigma \; \mathcal{P}_L(v_\parallel | \mu, \sigma) \; \mathcal{F}(\mu, \sigma)$$

- Works extremely well: naturally provides exponential/Gaussian/skewed PDFs, depending on separation (Bianchi, Chiesa & LG, submitted)



Summary

- Two ways to do galaxy redshift surveys for “cosmology” at $z>0.3$:
  1. Either maximize volume with low density tracers ($<n>\sim10^{-4}\ \mathrm{Mpc}^{-3}$): very effective for cosmological applications; typically difficult selection function (pre-selection), limited use beyond primary cosmological goals (e.g. BOSS, Wigglez). Normally based on fibre-fed spectrographs with $\sim10^{3}$ fibres over 1-2 degrees radius field. Forthcoming E-Boss and DESI surveys will be of this kind.
  2. Or use fully representative galaxy population ($<n>\sim10^{-2}\ \mathrm{Mpc}^{-3}$): important extra leverage on the details of the cosmic web (voids, filaments), non-linear small-scale structure (groups), galaxy properties and population statistics (LF, MF, colours) and their relation to environment (e.g. VIPERS, and, at lower redshift, GAMA). VIMOS has ideal combination of area and sensitivity (VLT) to efficiently do such surveys at $z\sim1$.
- Both types of surveys are important, but SDSS/2dFGRS experience indicates that in the longer run nearly fully-sampled redshift surveys with “simple” selection function and good spectral coverage are crucial, if we are to trace the cosmic web using galaxies,while understanding how the tracers we are using relate to the underlying DM.


z = 0
Dark matter
2 Mpc/h

z = 0
Galaxies
2 Mpc/h

VIPERS

- Aimed at measuring clustering, growth and environmental properties of galaxies at $0.5<z<1$, with accuracy comparable to local all-purpose surveys. Highest-z measurement of growth rate: $f\sigma_8(z=0.8) = 0.47 \pm 0.08$
- A probe of the power spectrum of fluctuations when Universe was about half its current age (although difficult window function to be handled – Rota et al. Poster)
- High sampling allows defining sub-populations and optimize tracers for RSD and other LSS analyses (ongoing, Granett et al.)
- Clean selection function: a probe of galaxy evolution over 8 billion years, when compared to local data like SDSS (and benefiting of growing set of ancillary photometric data): SED, LF, MF
- Already ~70,000 spectra observed. Clean, compact set of ~55,000 redshifts (nearly 2/3 of survey) publicly released in Oct 2013 (PDR-1), together with all relevant ancillary information (masks, weights, etc). Observations completed by 2015.
- A VIPERS-like survey of ~1 million galaxies over a 10-times larger volume (i.e. a SDSS at z~1) would be complementary to “single-line” cosmological surveys like e-Boss and a precious forerunner for future projects (e.g. for Euclid calibration)