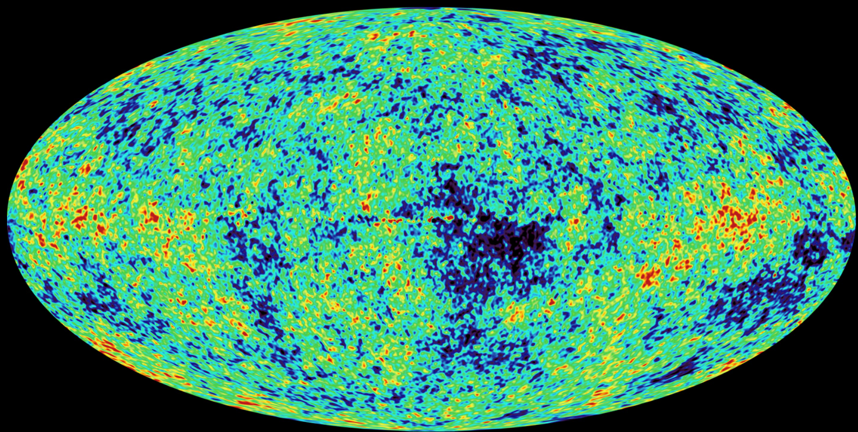
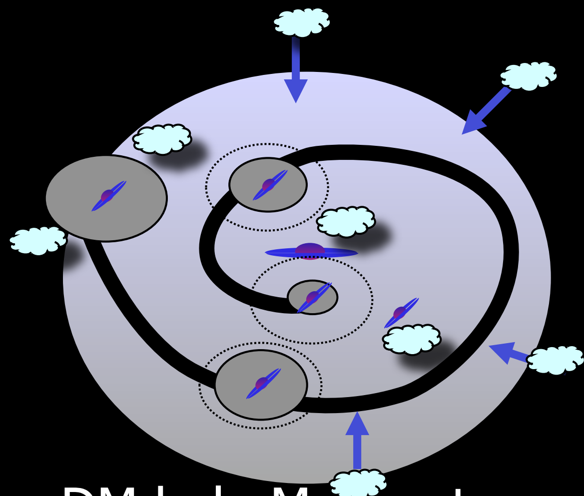
Lecture 3:
From surveys of luminous objects to cosmological constraints

Standard model ingredients

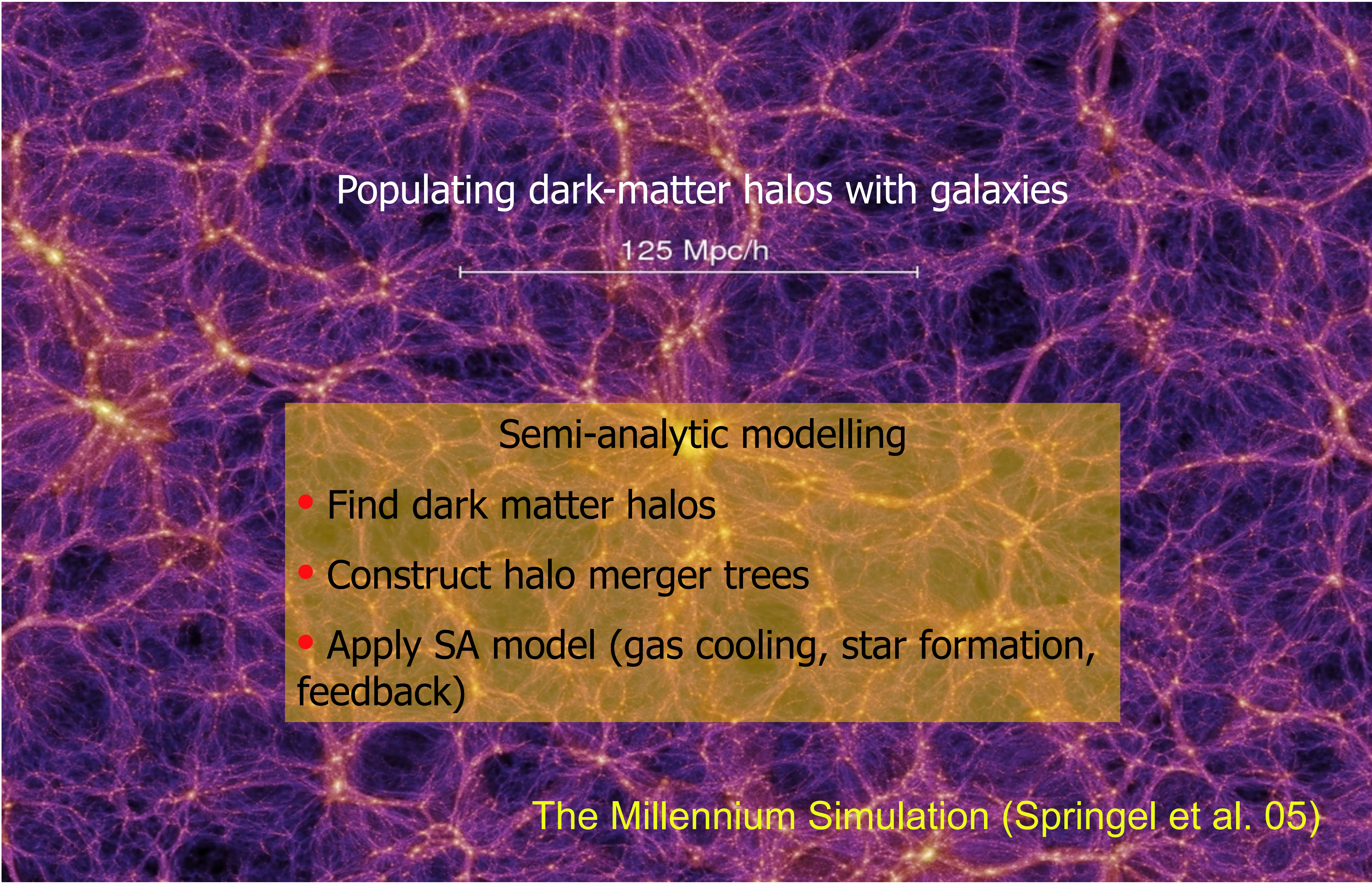
- Global parameters



- Galaxy formation



- DM halo Merger trees
- Gas cooling
- Star formation
- Feedback

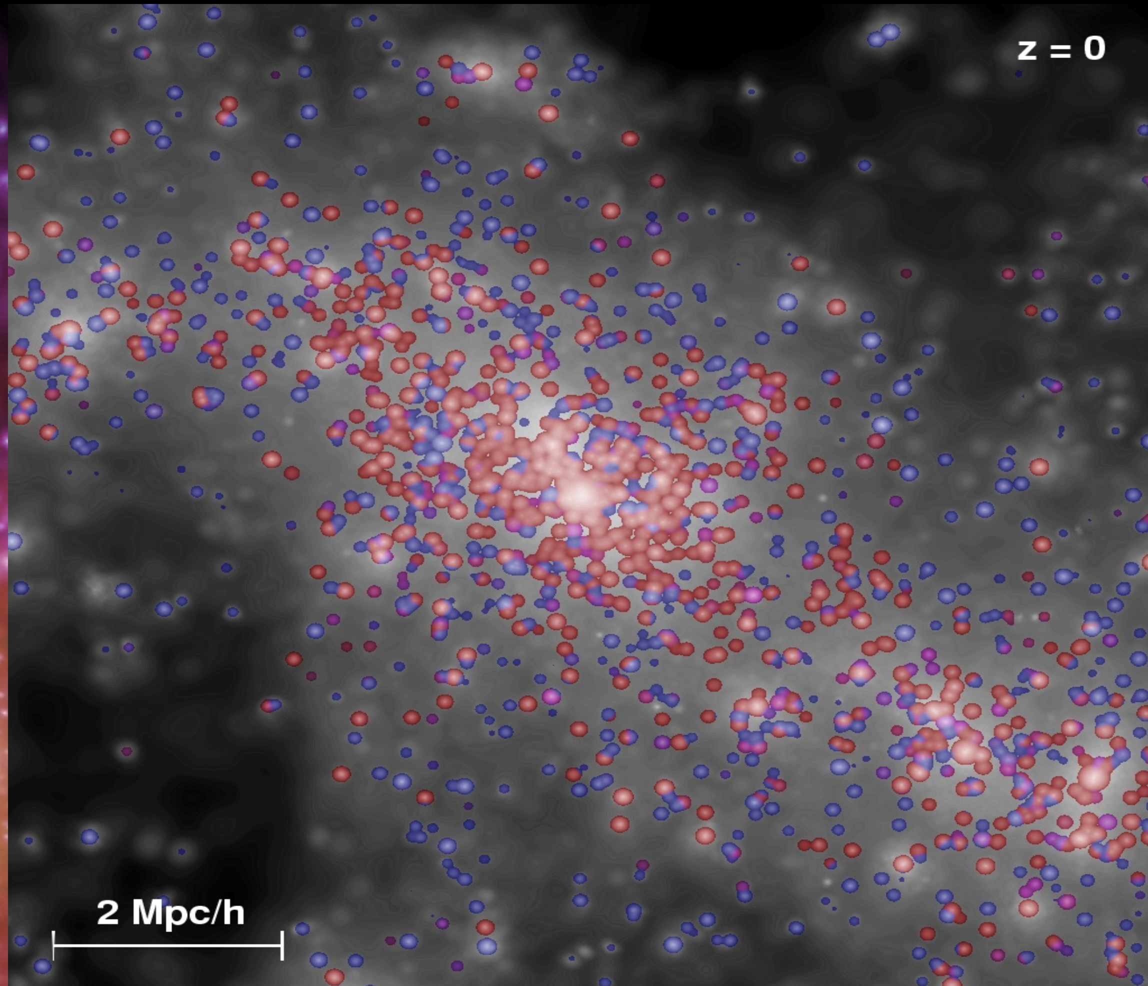

Populating dark-matter halos with galaxies
125 Mpc/h
Semi-analytic modelling
• Find dark matter halos
• Construct halo merger trees
• Apply SA model (gas cooling, star formation, feedback)
The Millennium Simulation (Springel et al. 05)

GALAXY BIAS

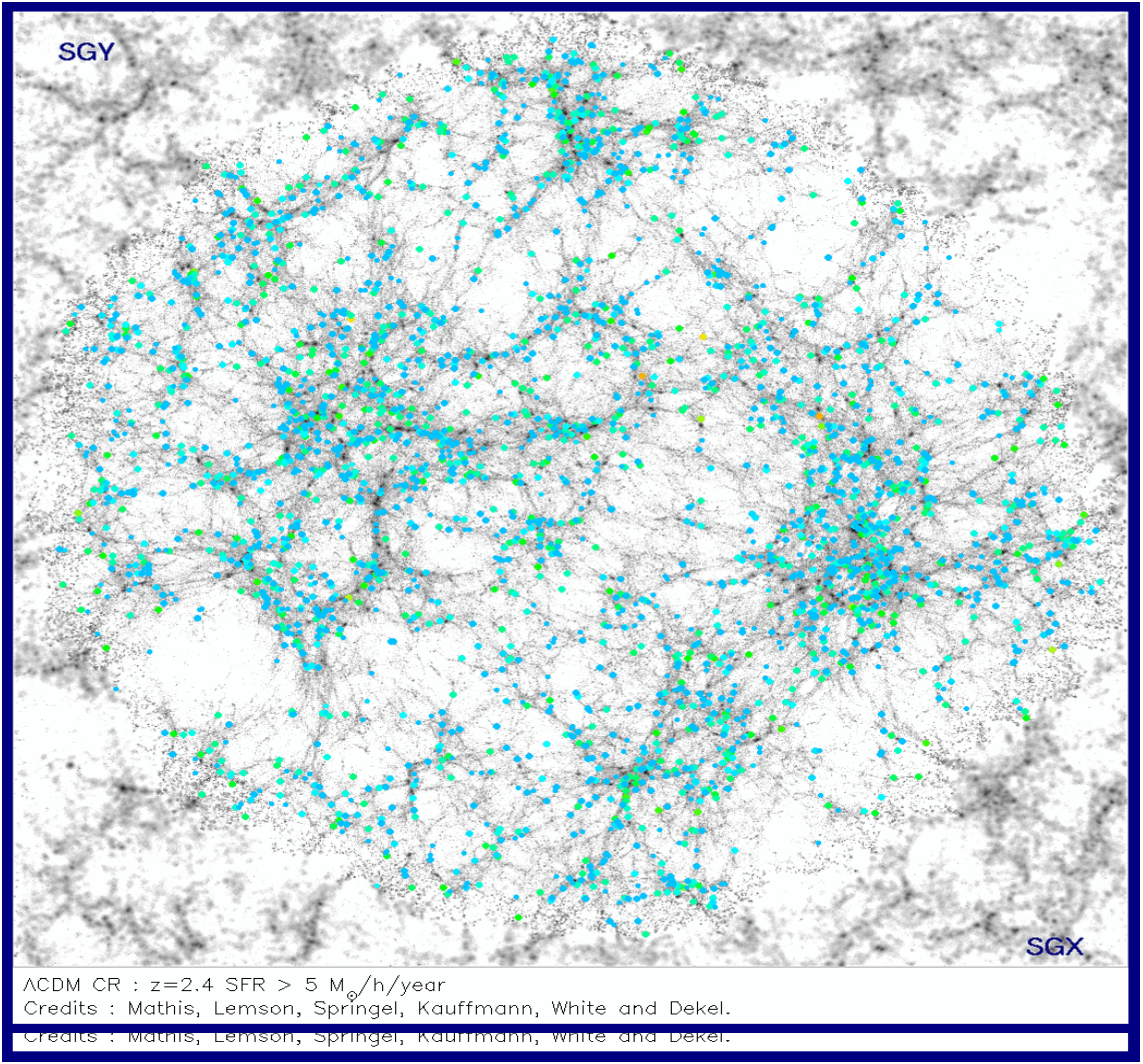
A $10^{14}\ M_{sun}$ DM halo at z=0: a rich cluster of galaxies

Dark matter

Galaxies



Springel et al. 05



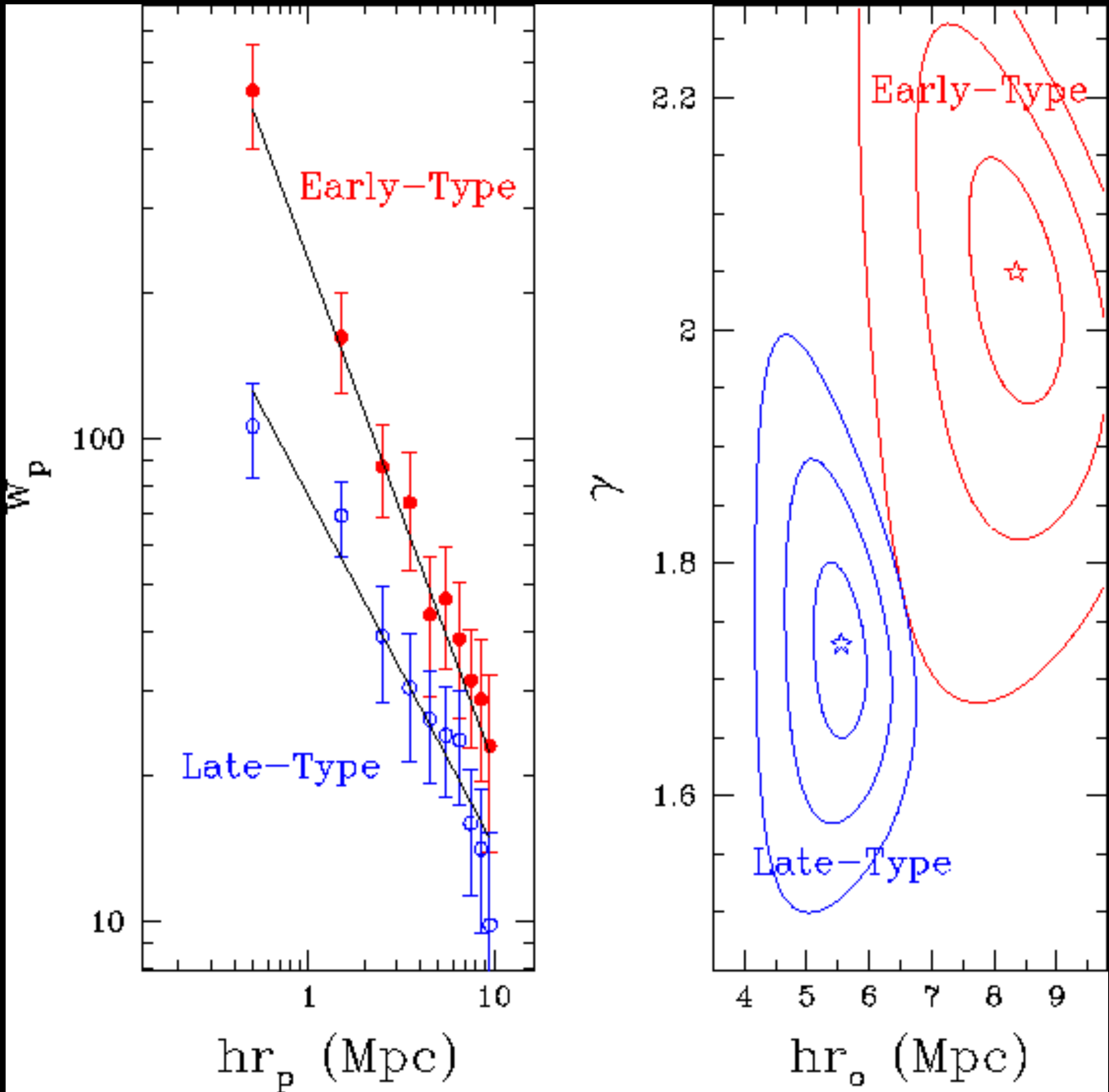
Credits : Mathis, Lemson, Springel, Kauffmann, White and Dekel.

However, galaxies and DM play a more complex (and more interesting) game together…

Example of simulation in ΛCDM standard model for cosmology and structure formation

Dominated by vacuum energy and collisionless dark matter

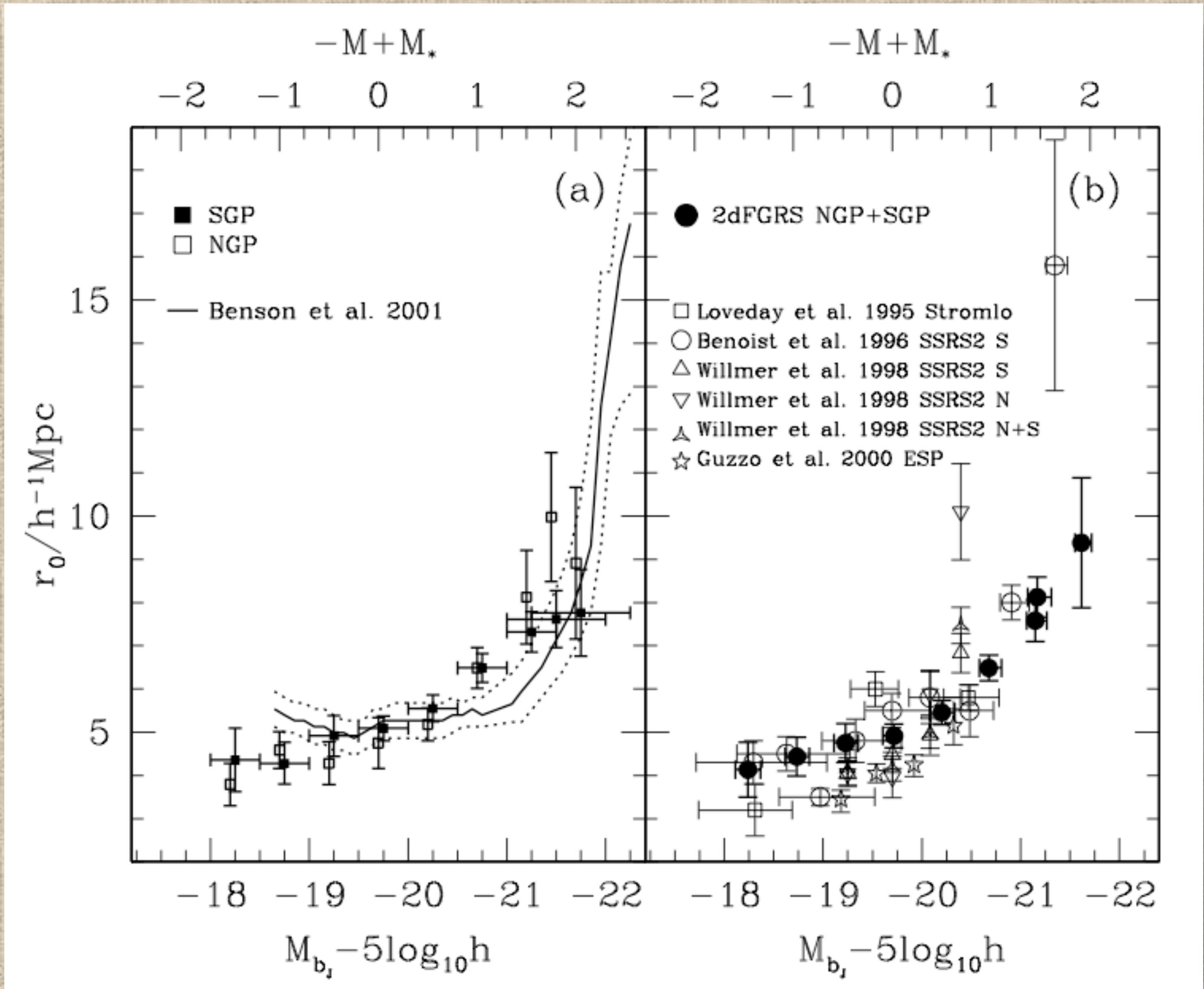
Biasing in action: dependence of clustering on morphology/color: at z~0



(e.g. Guzzo et al. 1997)

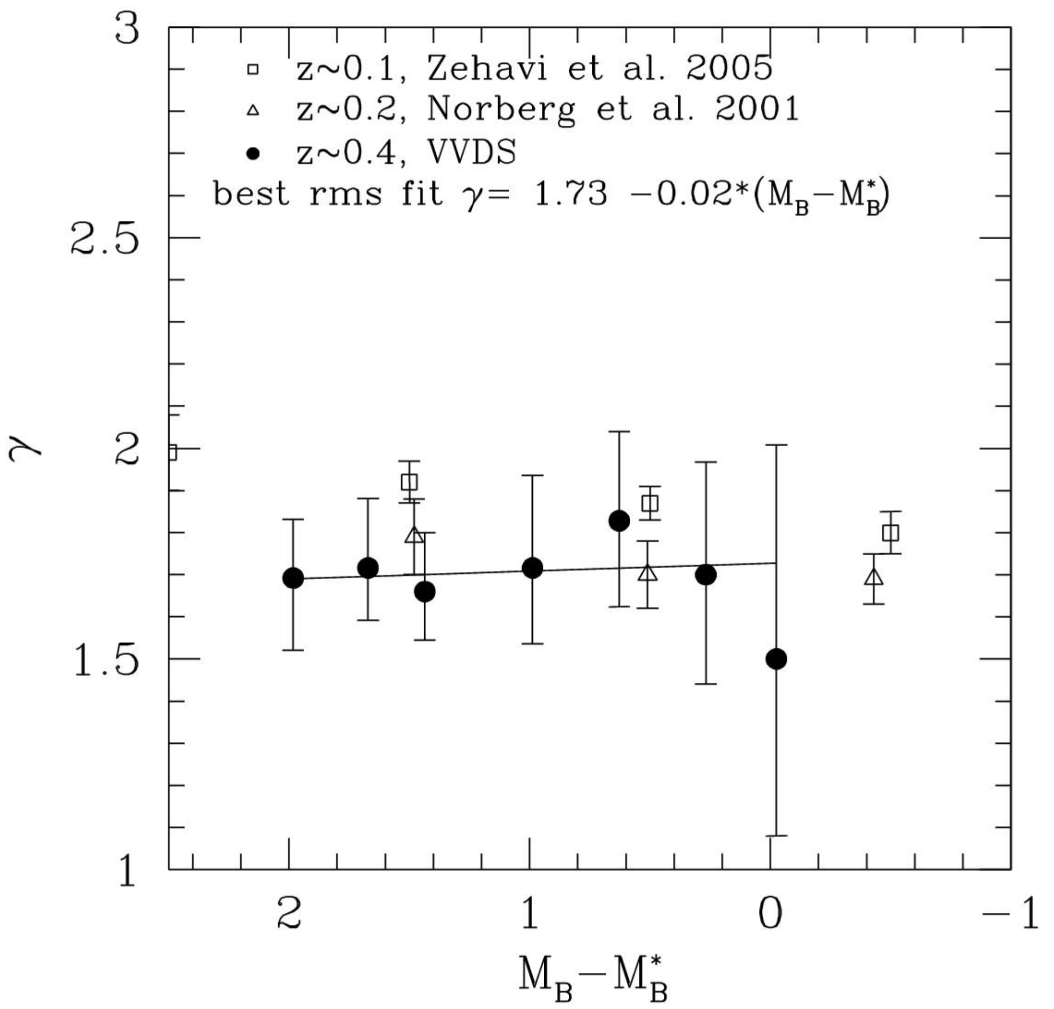
Galaxy Cluster Abell 1689

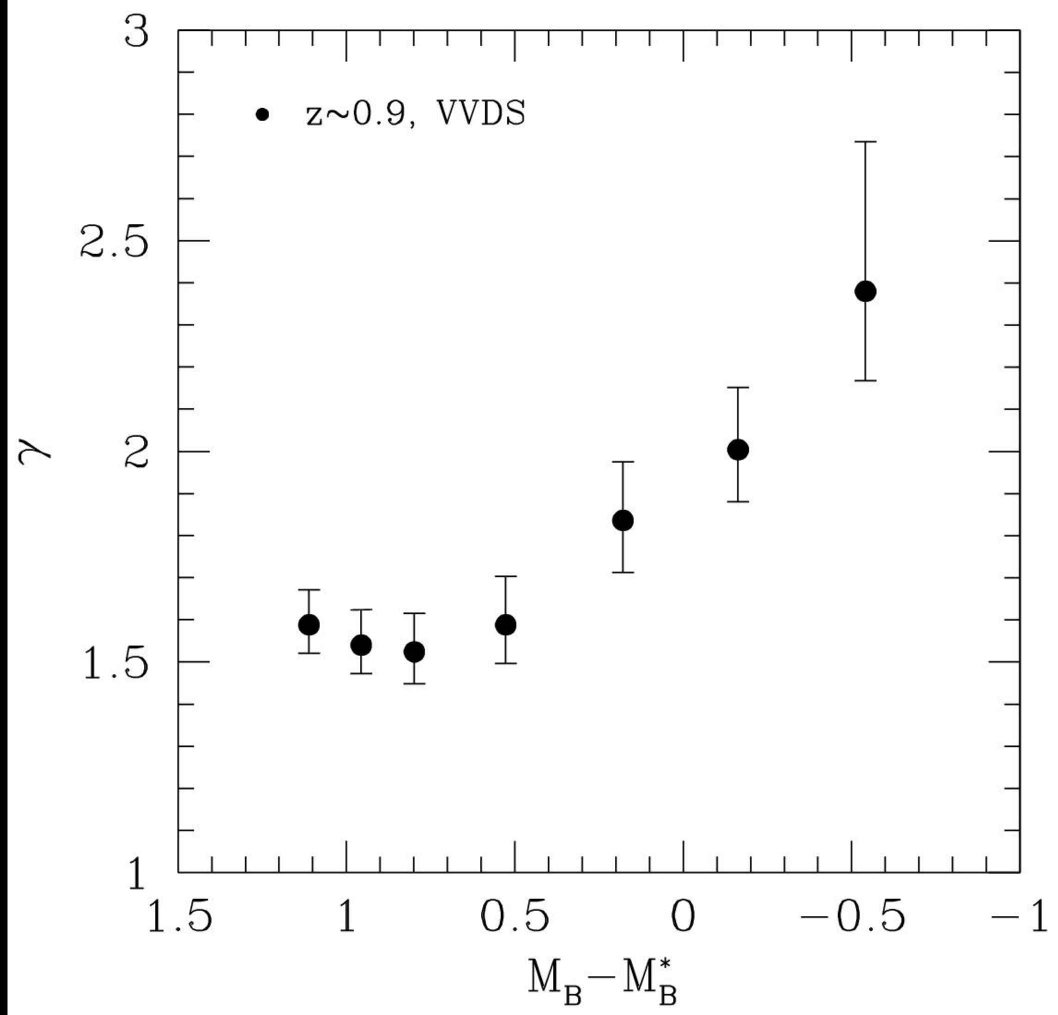
Direct evidence for biasing: clustering depends on galaxy luminosity



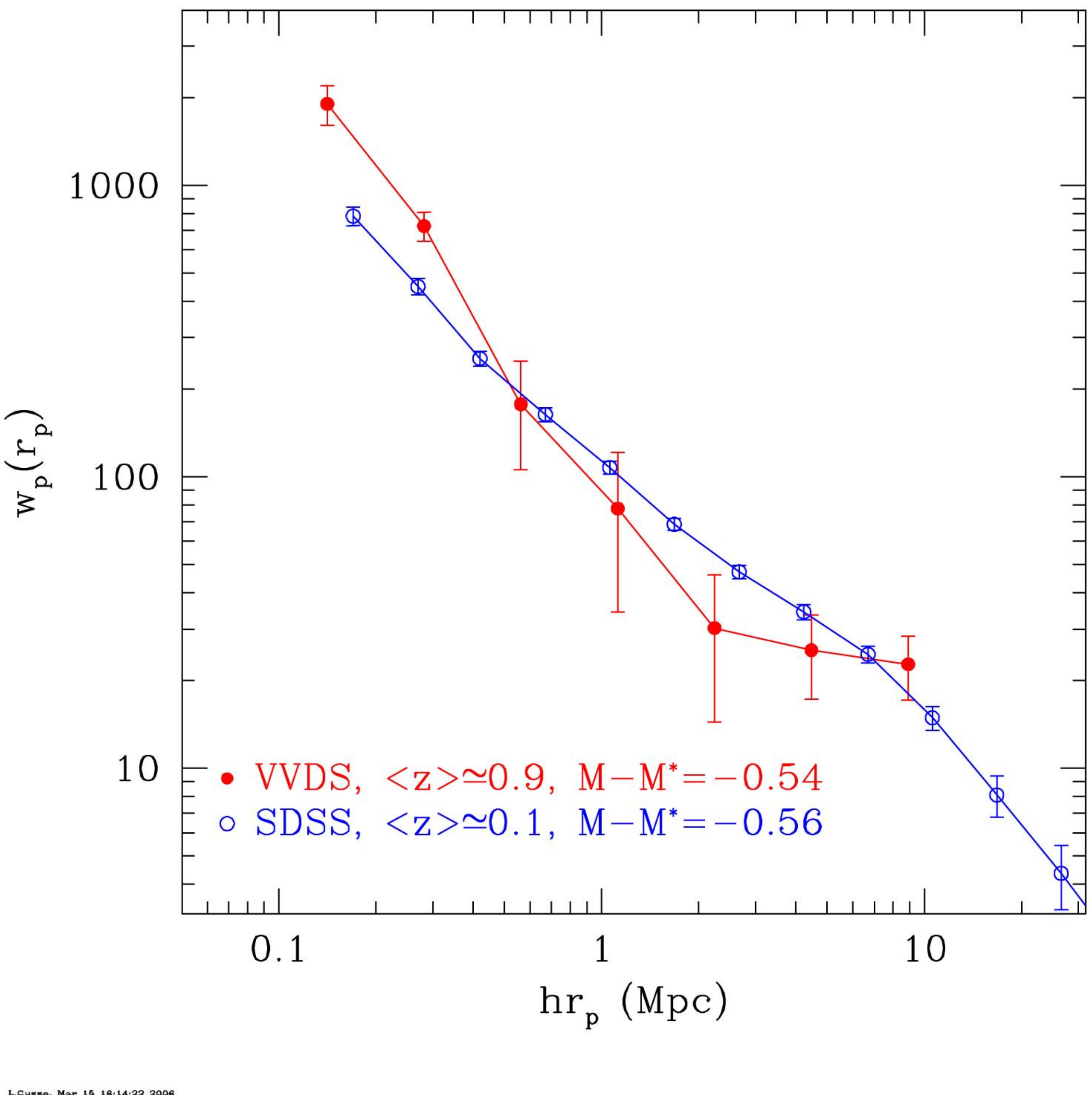
Norberg & 2dFGRS Team

VVDS: luminous galaxies are clustered in a more "peaked" way at z=1 than they are today





Pollo, Guzzo & VVDS Team, 2006, A&A, 451, 409



1000
100
10
$w_p(r_p)$
0.1
1
10
hr_p (Mpc)
VVDS, <z>≃0.9, M−M*=−0.54
SDSS, <z>≃0.1, M−M*=−0.56

Relative clustering of galaxies and clusters of galaxies

REFLEX X-ray clusters

Schuecker & REFLEX Team, 2001, 2002

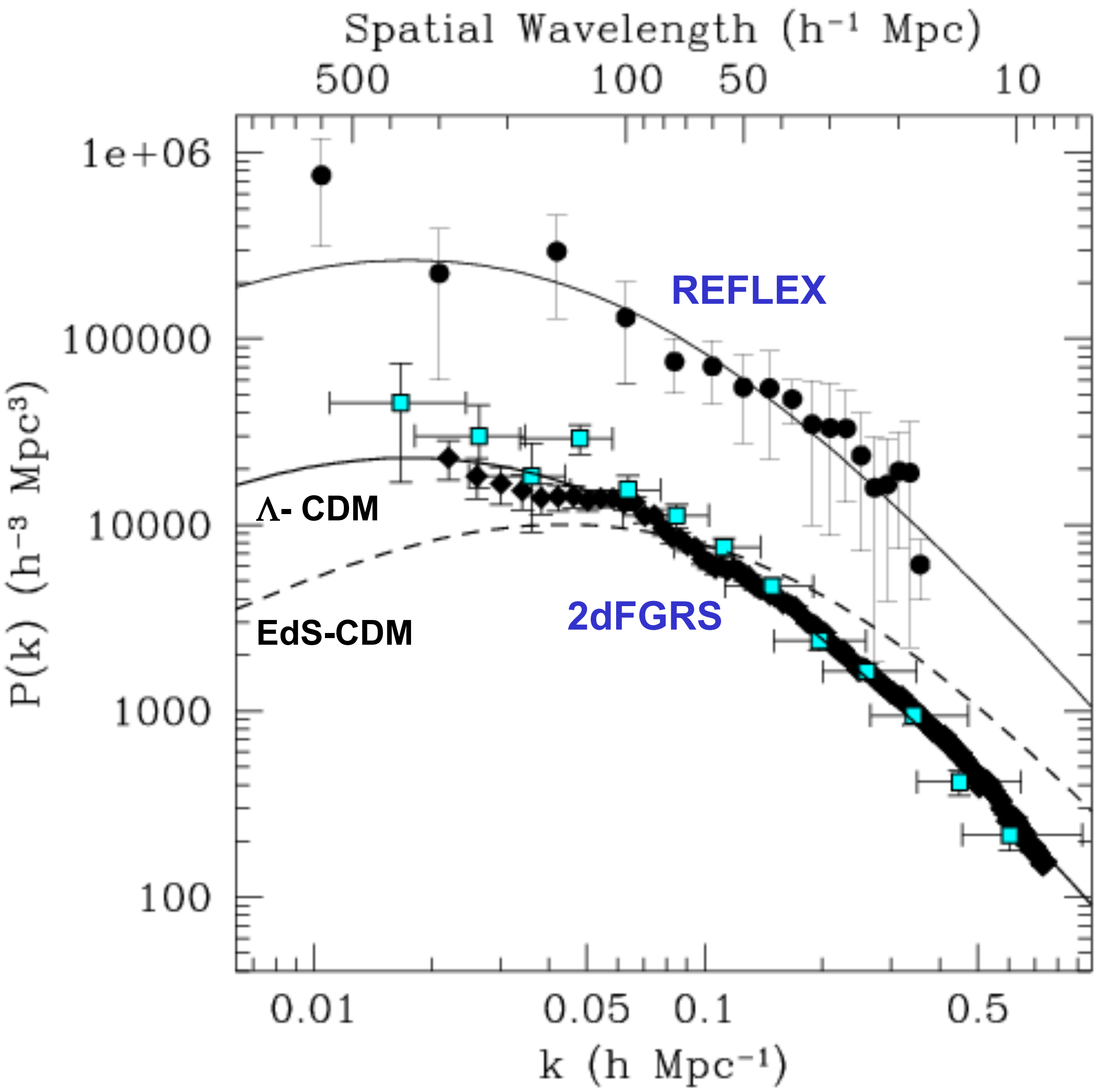
2dF optically-selected galaxies

Percival & 2dFGRS Team, 2001

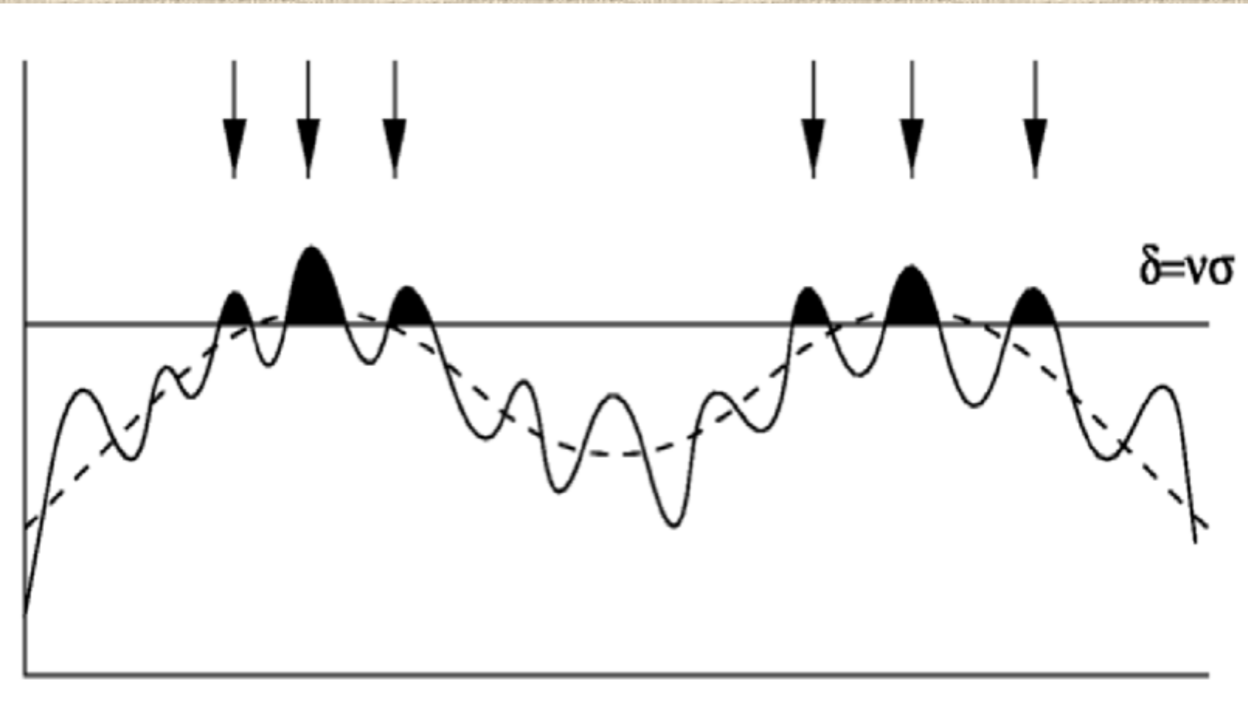
Tegmark, Hamilton & Xu, 2002

Cole et al. 2005

$$P(k)_{clus} = b_{cg}^2 P(k)_{gal}$$



Statistical bias inevitable for rare systems



$$\xi_{peaks} \approx \left(\frac{\nu}{\sigma}\right)^2 \xi_{gal}$$

(Kaiser 1984)

Connecting theory to clustering observations

observed redshift-space galaxy clustering power

galaxies might not trace the mass: galaxy-halo scale dependent bias?

redshift-space distortions

$$\frac{P^s_{\rm gal}}{P_{\rm lin}} = \frac{P^r_{\rm gal}}{P_{\rm nl}} \times \frac{P_{\rm nl}}{P_{\rm lin}} \times \frac{P^s_{\rm gal}}{P^r_{\rm gal}}$$

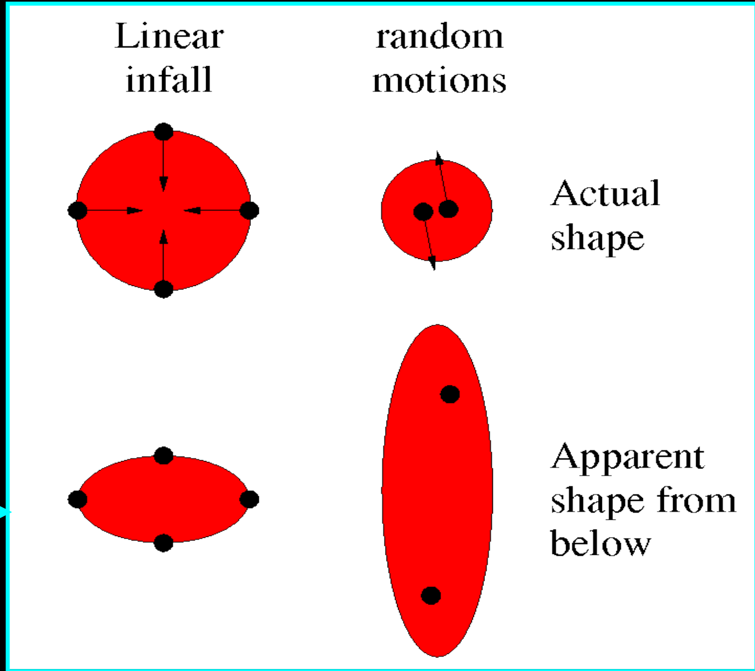
linear matter power spectrum from theory

$P(k) \sim k^n\, |T(k)|^2$

non-linear evolution due to gravitational collapse; clumps above a given mass are more clustered than overall DM: ratio found by analytic descriptions (e.g. Kaiser 1984, Mo & White 1996) or by fitting simulations

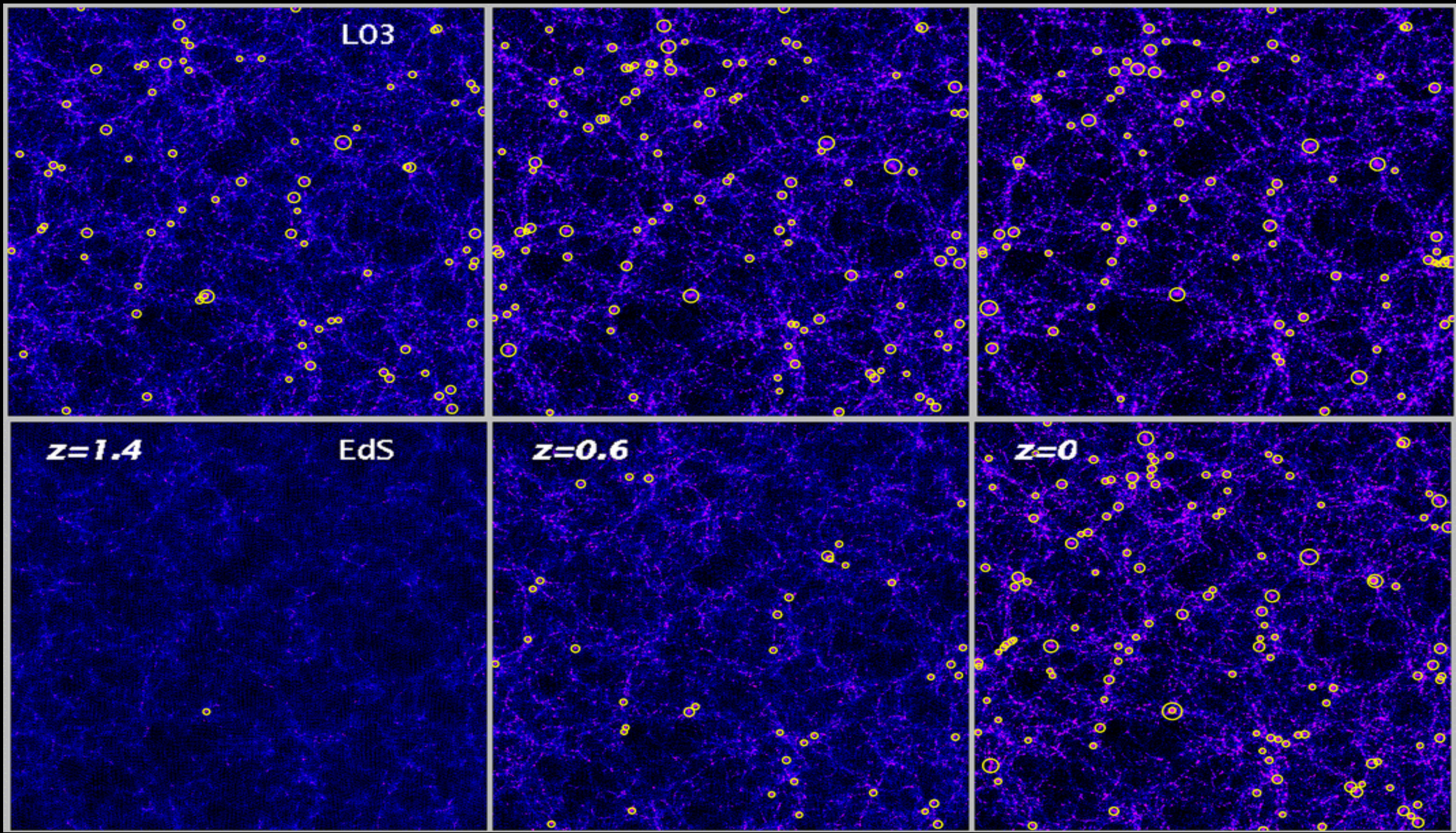
At large distances, redshift-space distortions affect the power spectrum through:

$$P_s = P_r(1+\beta\mu^2)^2(1+k^2\mu^2\sigma_p^2/2)^{-1}$$



CLUSTERS ARE THE CLOSEST OBSERVABLE REALIZATION OF A DM HALO, STILL…

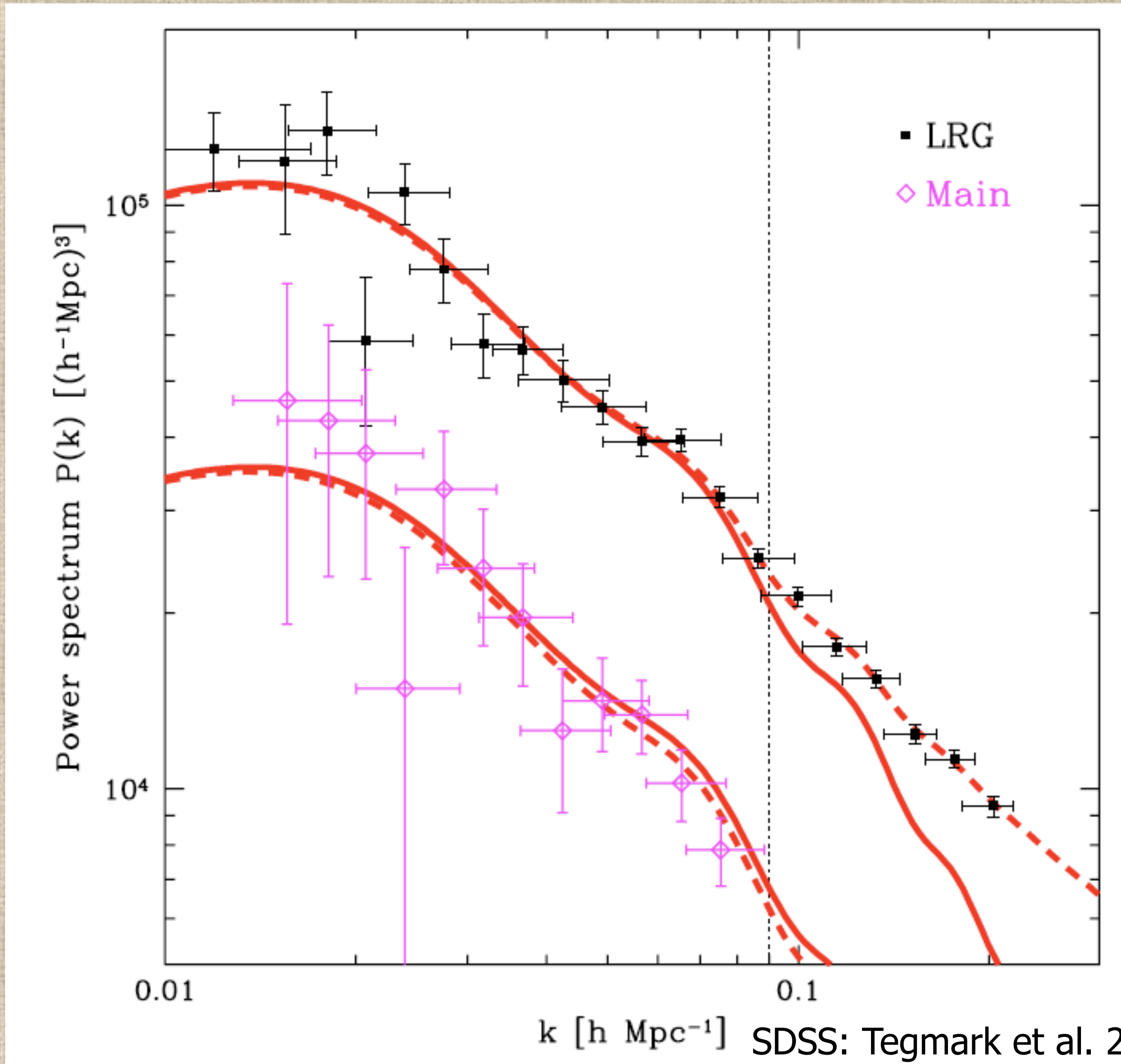
→ Evolution of number of massive clusters (e.g. Rosati et al. 2001; Mullis et al. 2004), probes evolution of structure on ~10 h^{-1} Mpc co-moving scale, but needs precise estimate of cluster masses



Borgani & Guzzo 2001, Nature

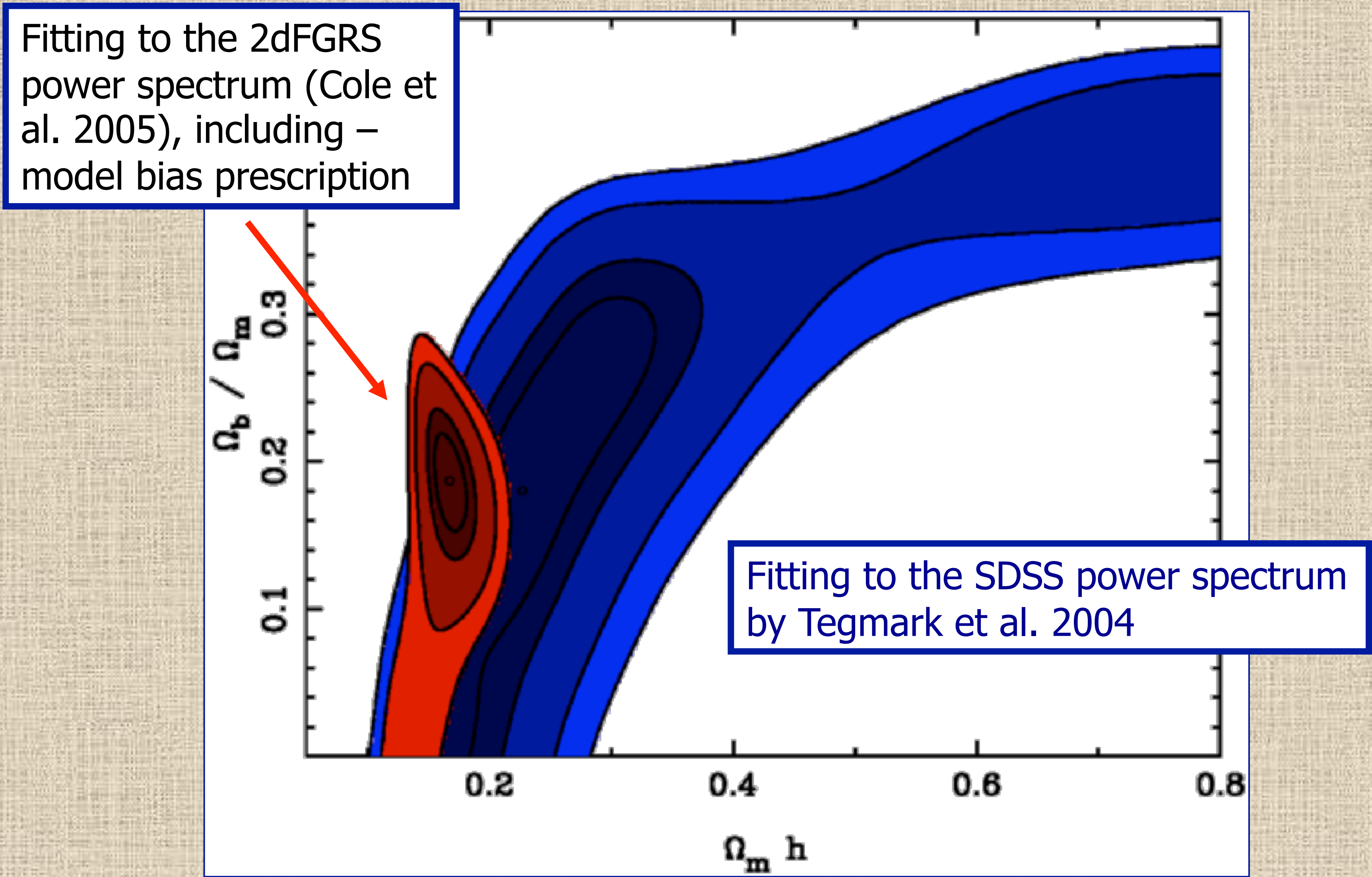
Further complications: we observe non-linear structures

Bias and non-linearities need to be properly modelled, to be able to match to theory predictions (for DM !)

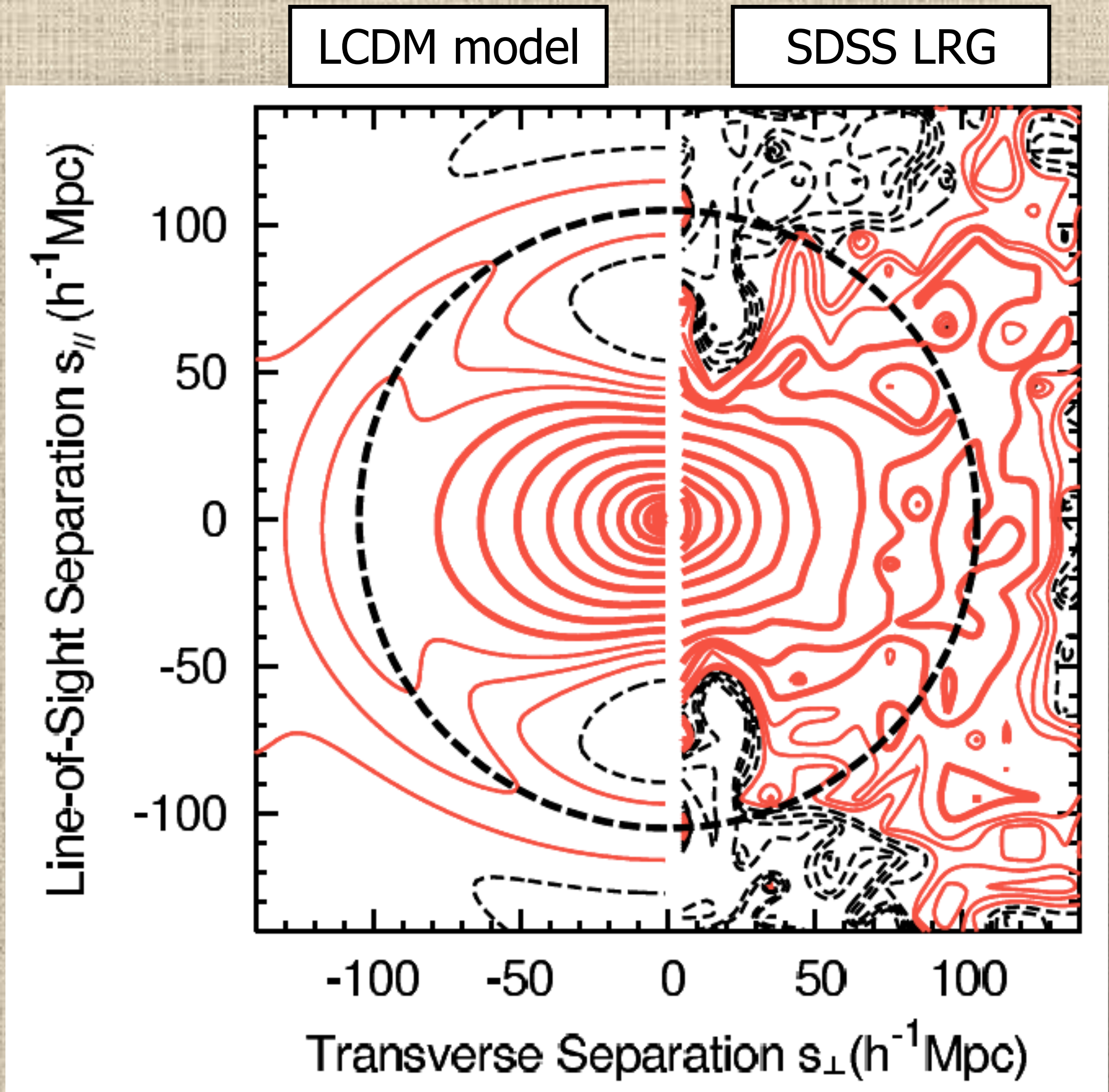


SDSS: Tegmark et al. 2007

Shape of power spectrum: depends on Ω_m (total) and Ω_b (wiggles)



BAO and z-distortions are favourable probes (use large scales and galaxy dynamics), together with weak lensing

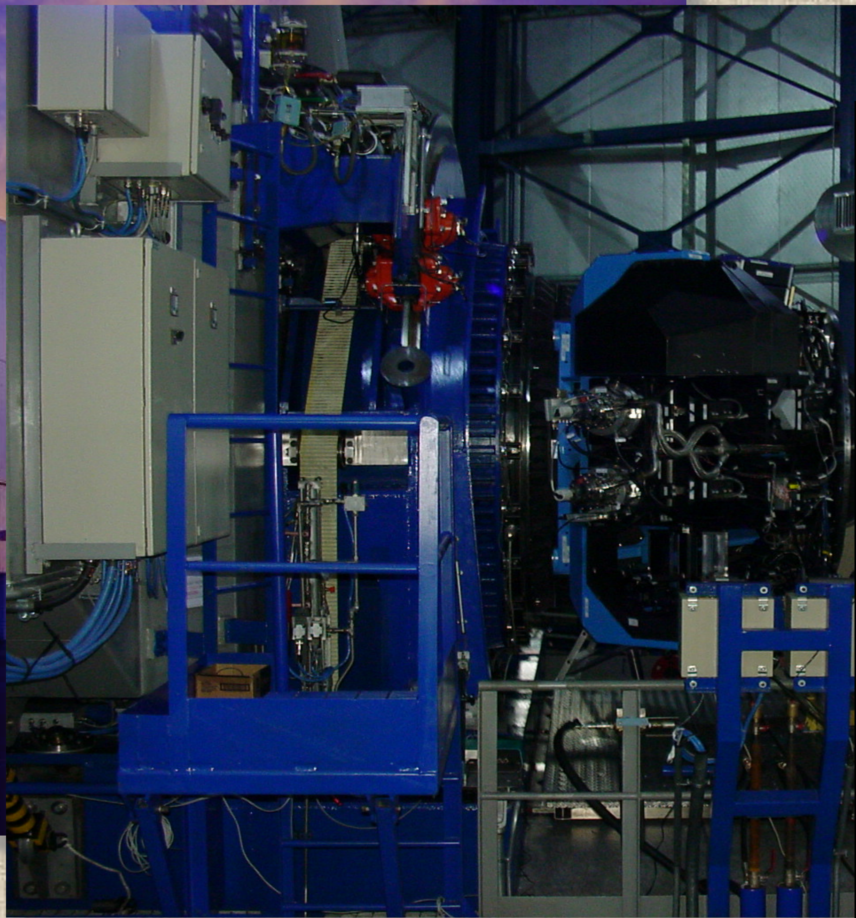


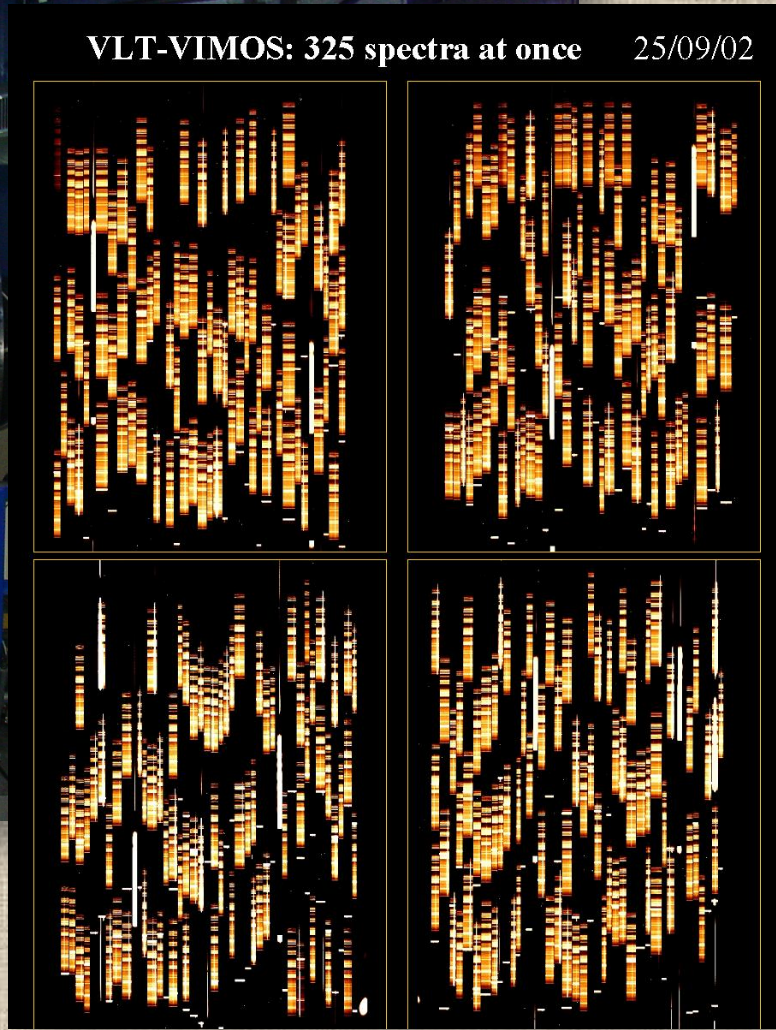
2D BAO in the redshift-space correlation function $\xi(r_p,\pi)$

Okumura et al. 2008

NEXT GENERATION SURVEYS

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

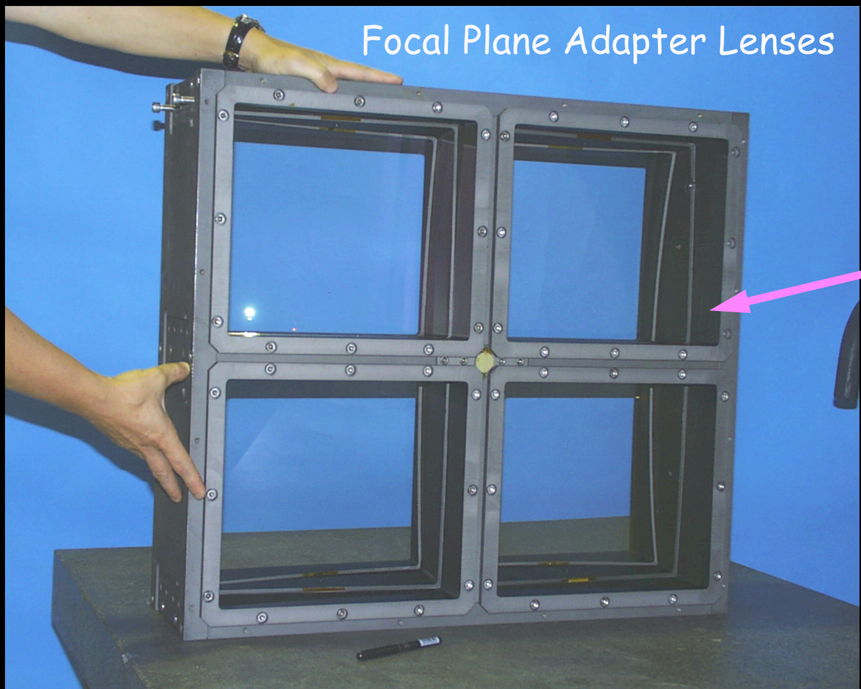


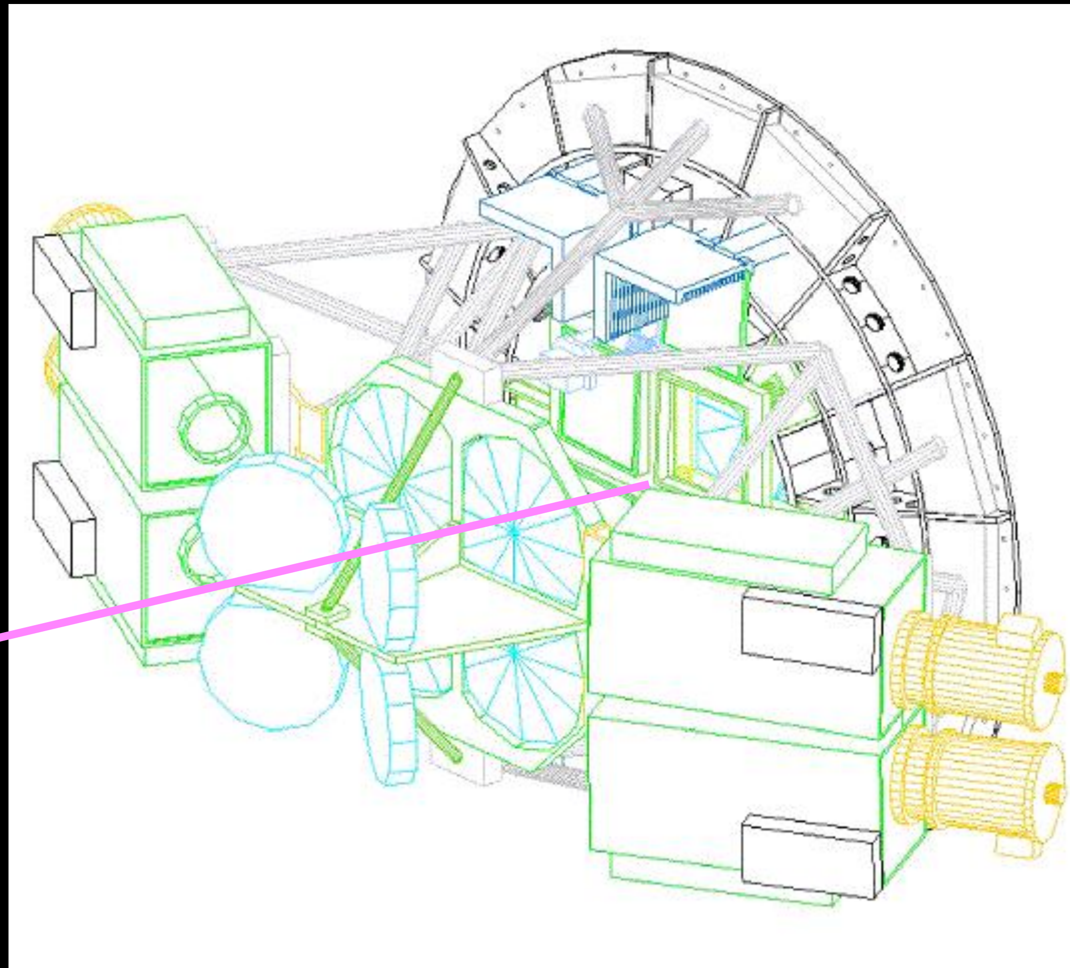


(see http://vipers.inaf.it)

VIMOS layout

VLT Nasmith focus flattened separately into 4 channels, fed into 4 CCD cameras (7x8 arcmin field of view each)





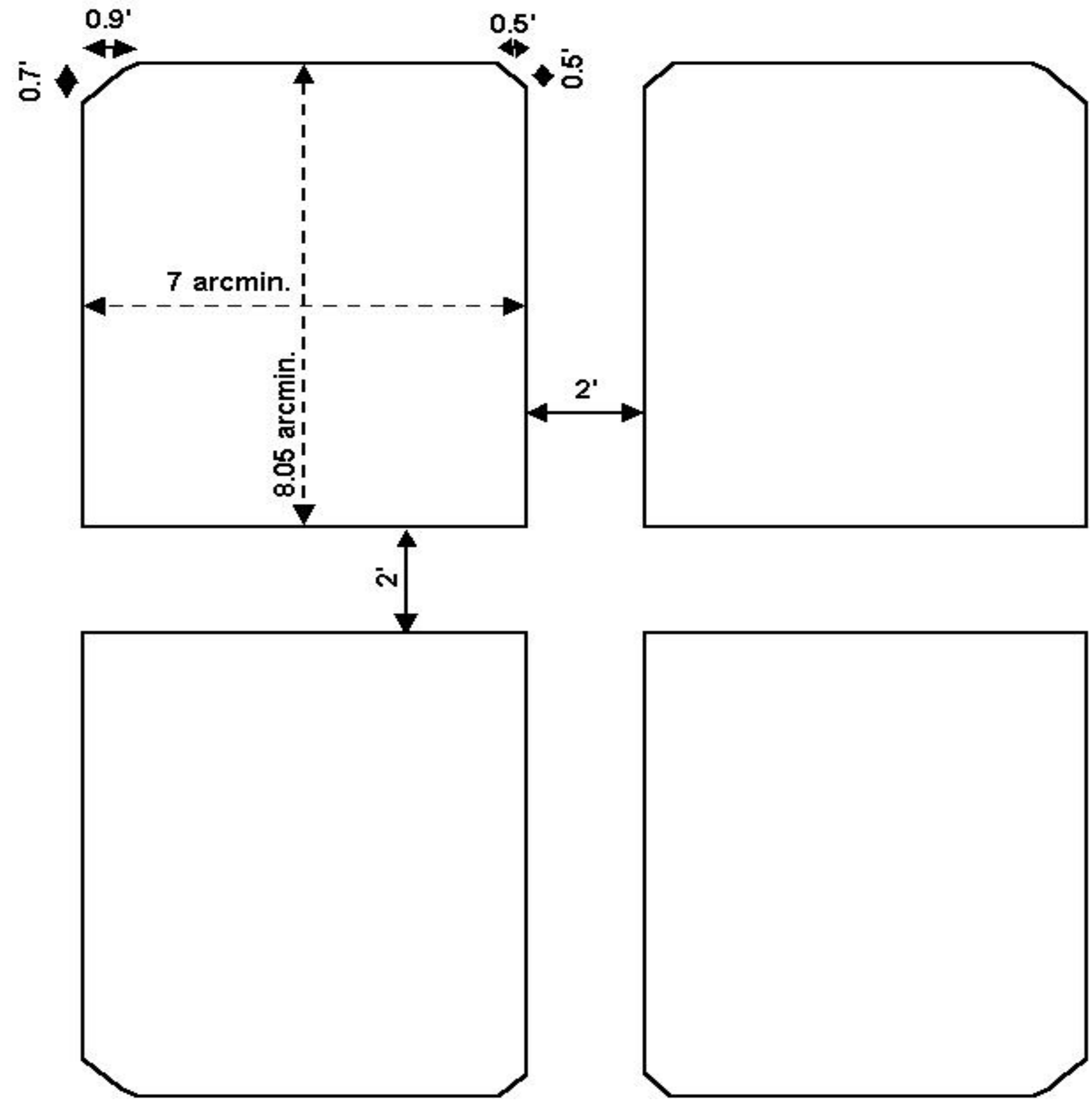
A redshift machine: > 500 spectra in one shot

FOV: 4x56 sq arcmin

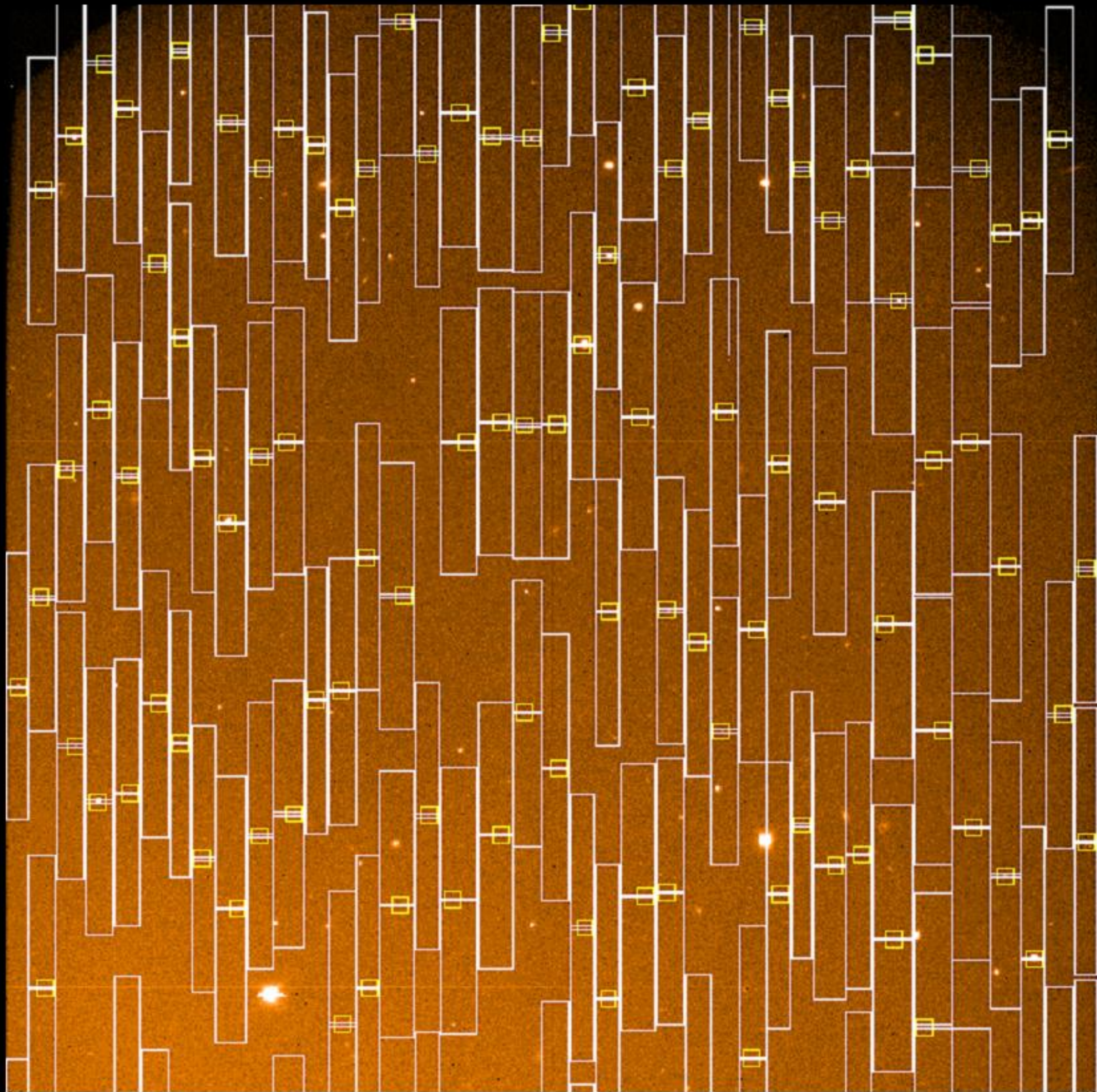
multiplexing 800

spectral resolution: 200 -5000

IFU 1'x 1', 6400 fibres

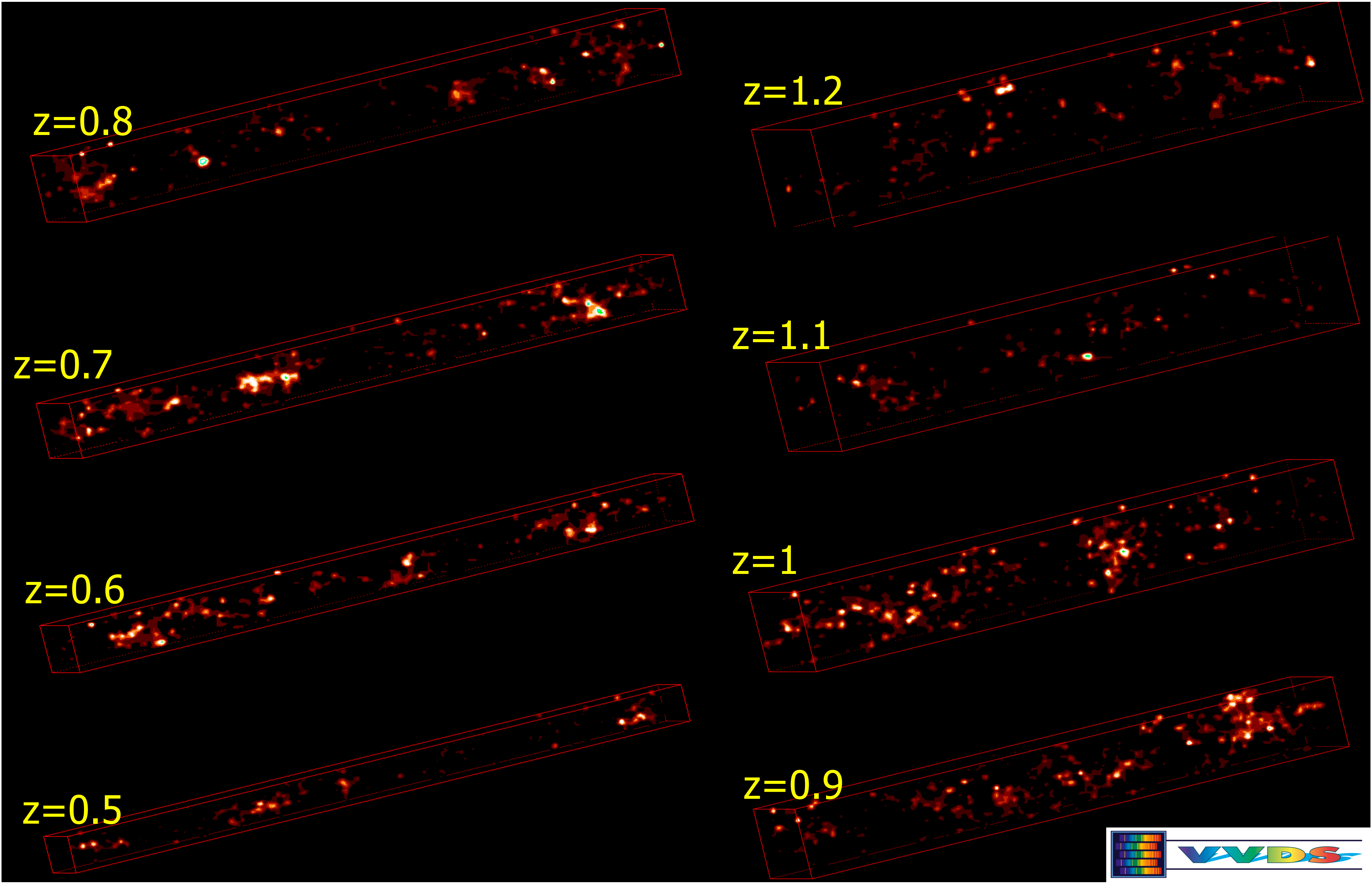


18 arcmin



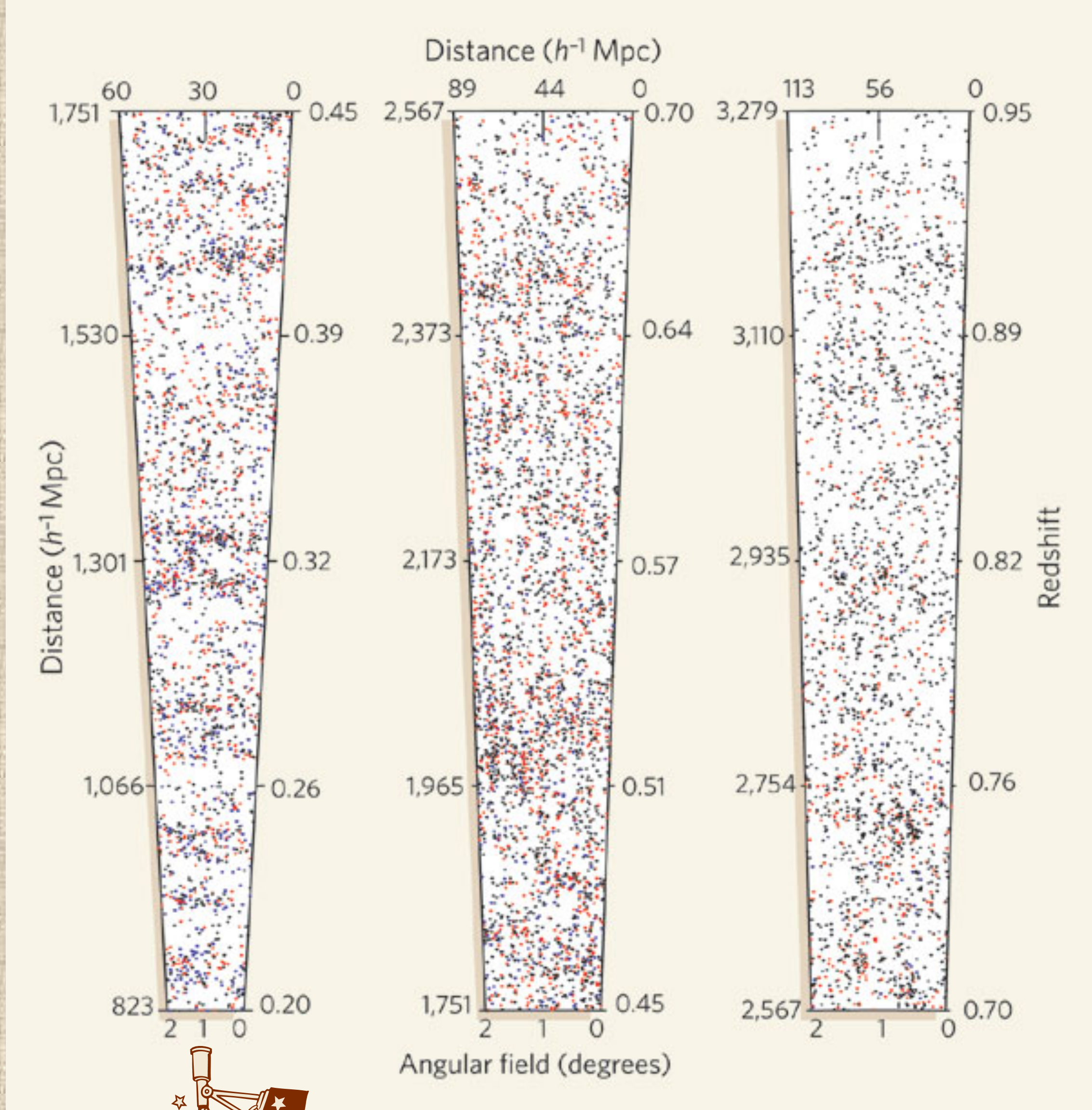
17 arcmin

x 4


z=0.8
z=1.2
z=0.7
z=1.1
z=0.6
z=1
z=0.5
z=0.9

The VVDS-Wide F22 field: 2x2 deg^2 to I_{AB}=22.5

VVDS-Wide F22 field: 10,000 redshifts to z~1.2



Fully public

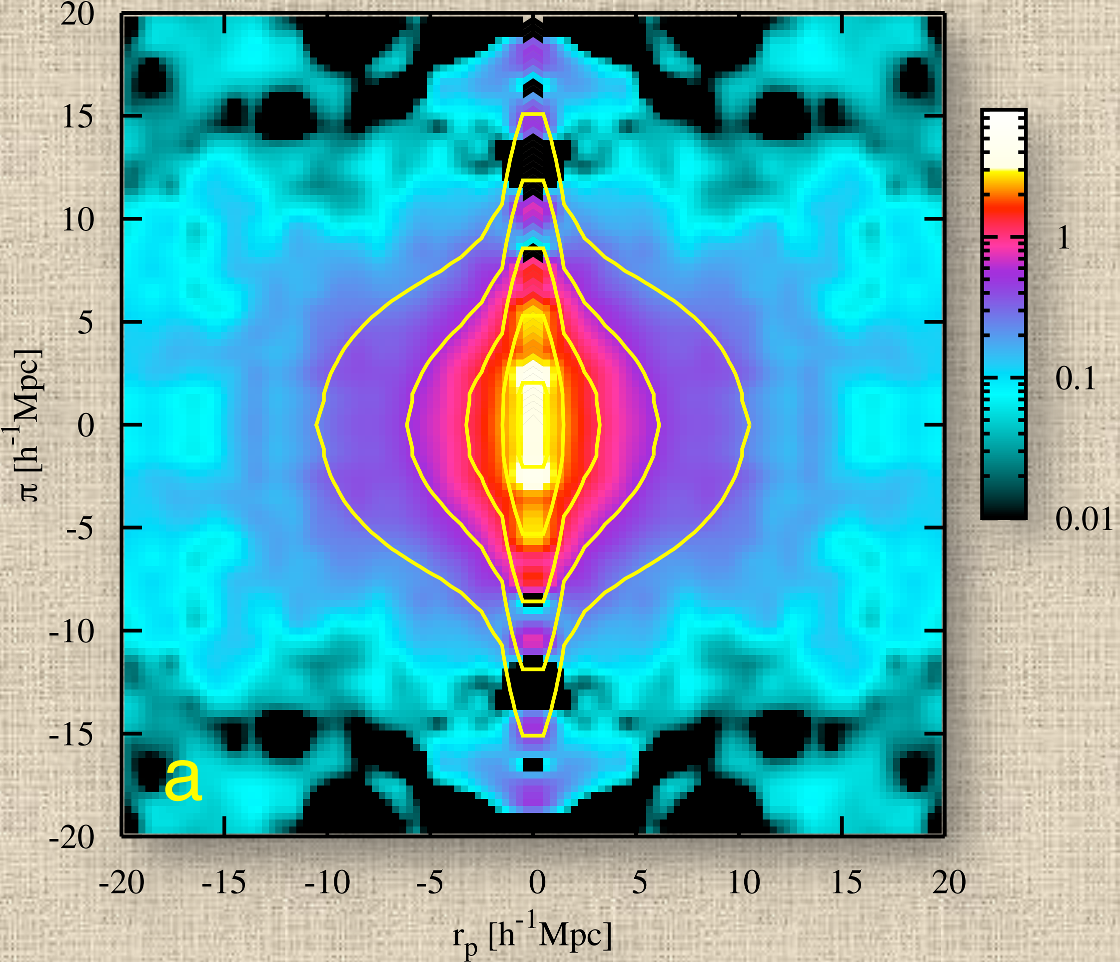
(Garilli et al. 2008, A&A 486, 683)

The signature of linear growth at z~1

- VVDS-Wide F22 field: 4 deg^2
- IAB<22.5
- 0.6<z<1.2 --> 5988 redshift
- Effective <z>=0.77

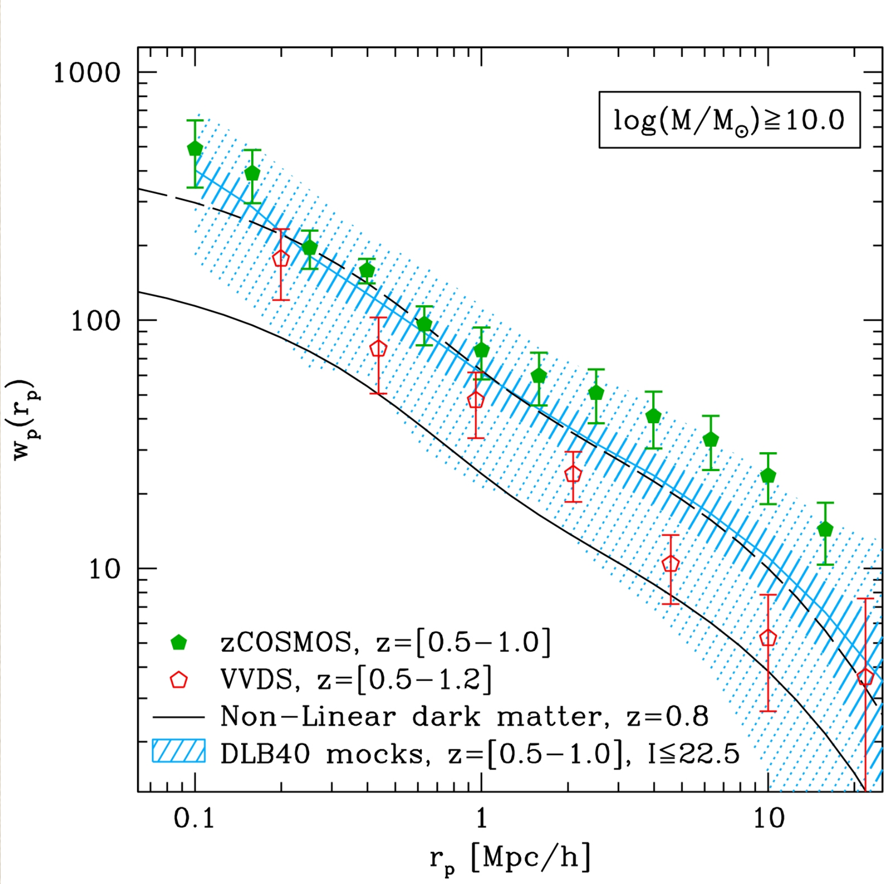
A maximum likelihood fit of $\xi(r_p,\pi)$ with Kaiser-Hamilton distortion model gives

β=0.70±0.26

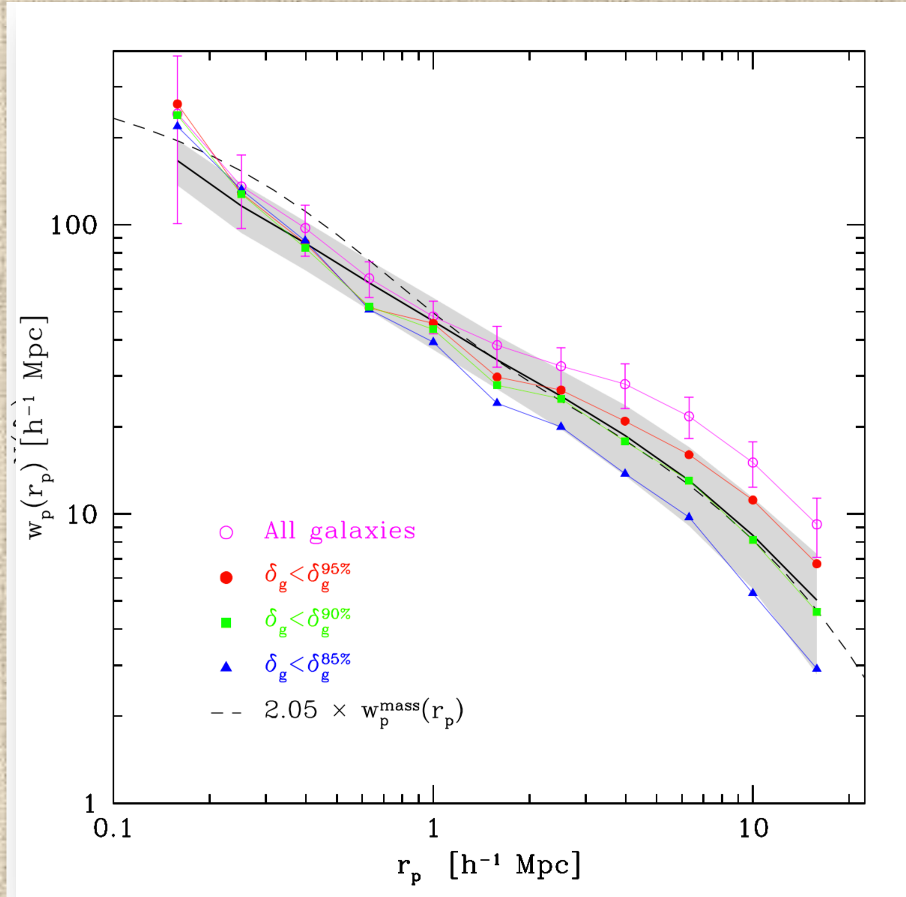


Guzzo et al. 2008, Nature 451, 541

VVDS vs ZCOSMOS at similar redshift: impact of survey-size fluctuations (cosmic variance)



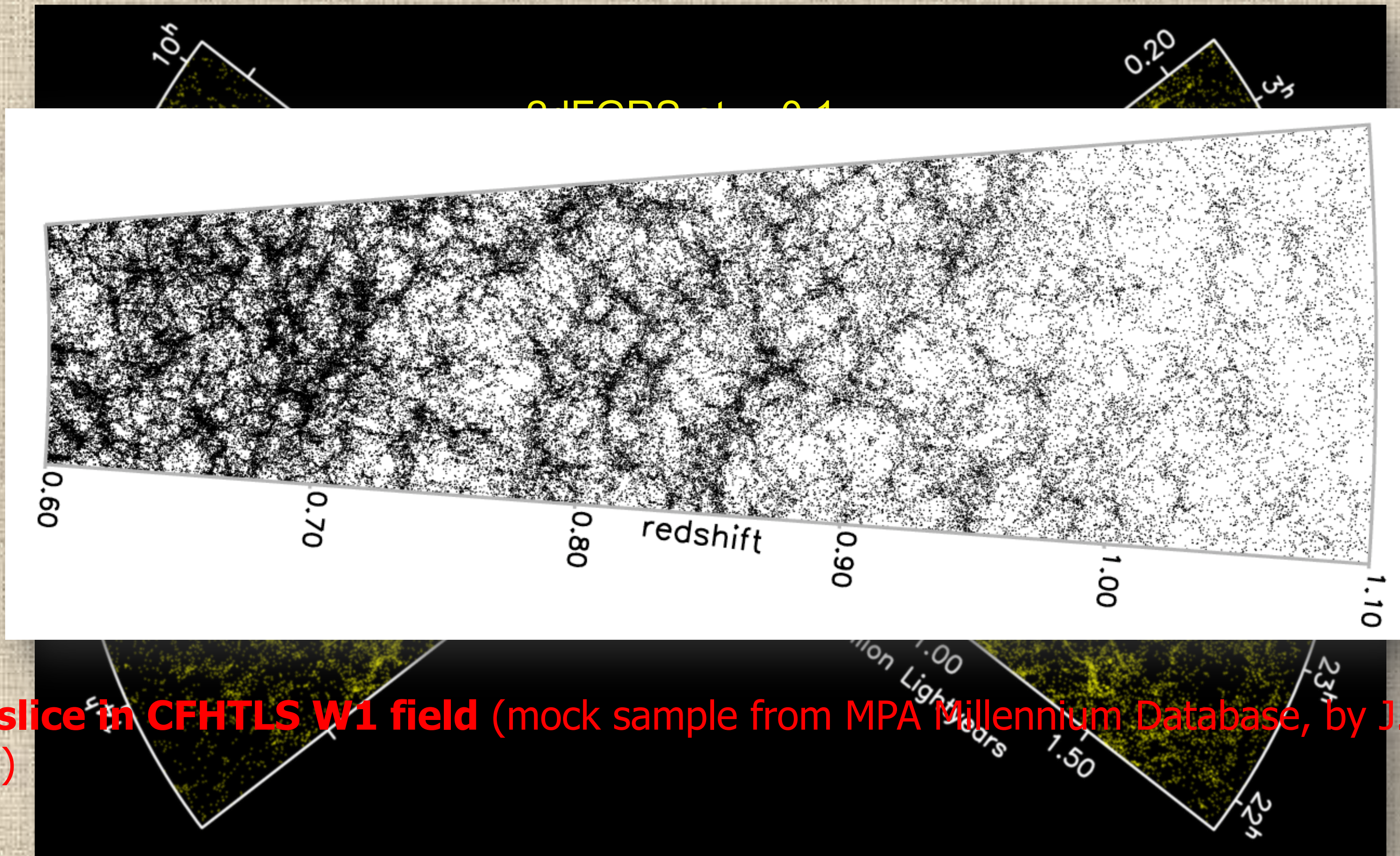
Meneux, LG & ZCOSMOS Collaboration, 2009



De la Torre, LG & ZCOSMOS Collaboration, 2010

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

The VIMOS Public Extragalactic Redshift Survey (VIPERS): a 2dFGRS at 0.5<z<1.2



2x8 deg2 slice in CFHTLS W1 field (mock sample from MPA Millennium Database, by J. Blaizot & G. De Lucia)

+2x4 deg2 slice in CFHTLS W4 field (VVDS F22)

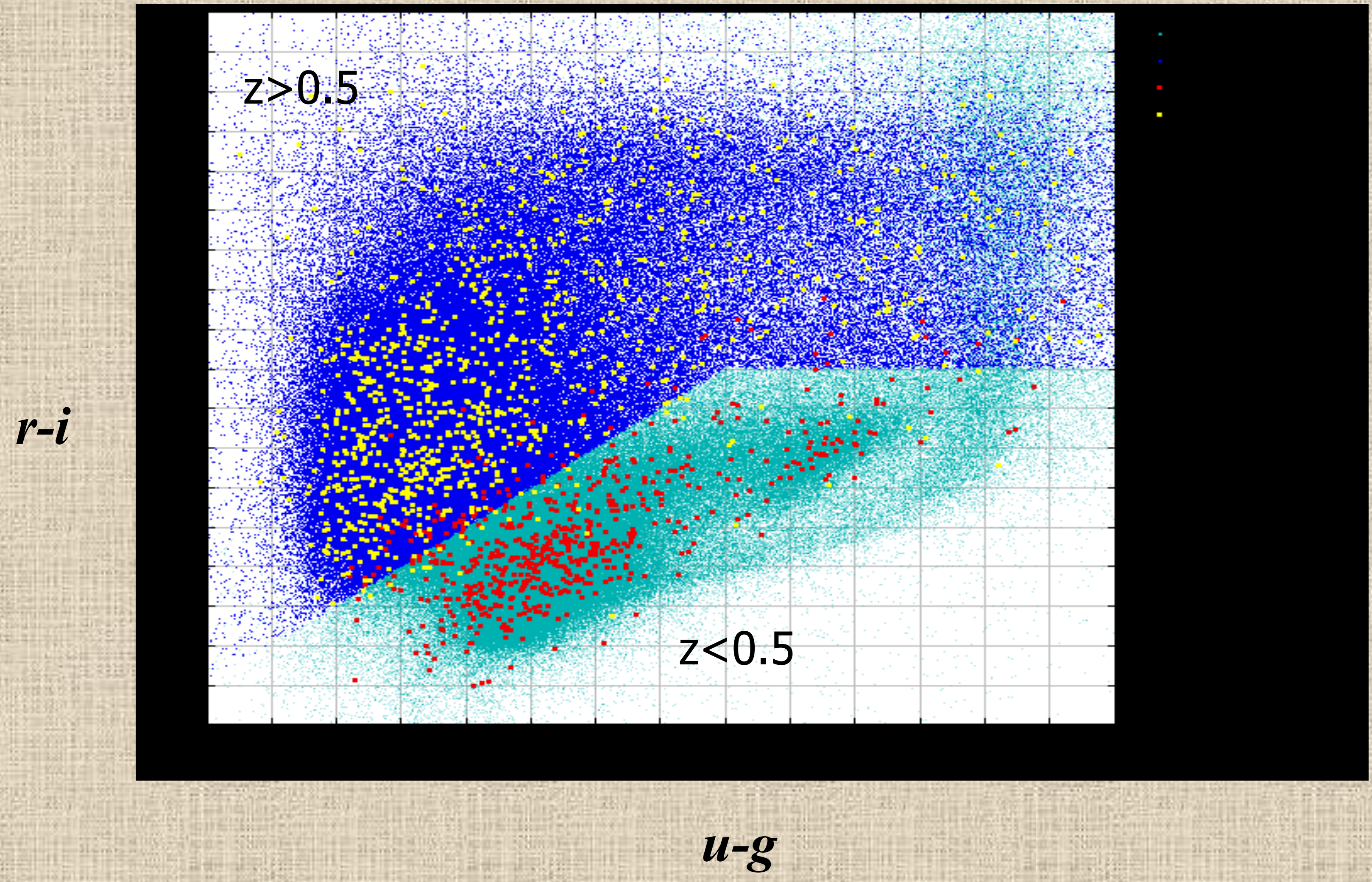
VIPERS in a nut-shell

- 440.5 VLT hours
- ~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
- z>0.5 color-color pre-selection
- PSF + SED –based star-galaxy separation (AGN color recovery)
- **~100,000 redshifts, >40% sampling**
- **Density and volume comparable to 2dFGRS, but at z~0.8**

VIPERS Team

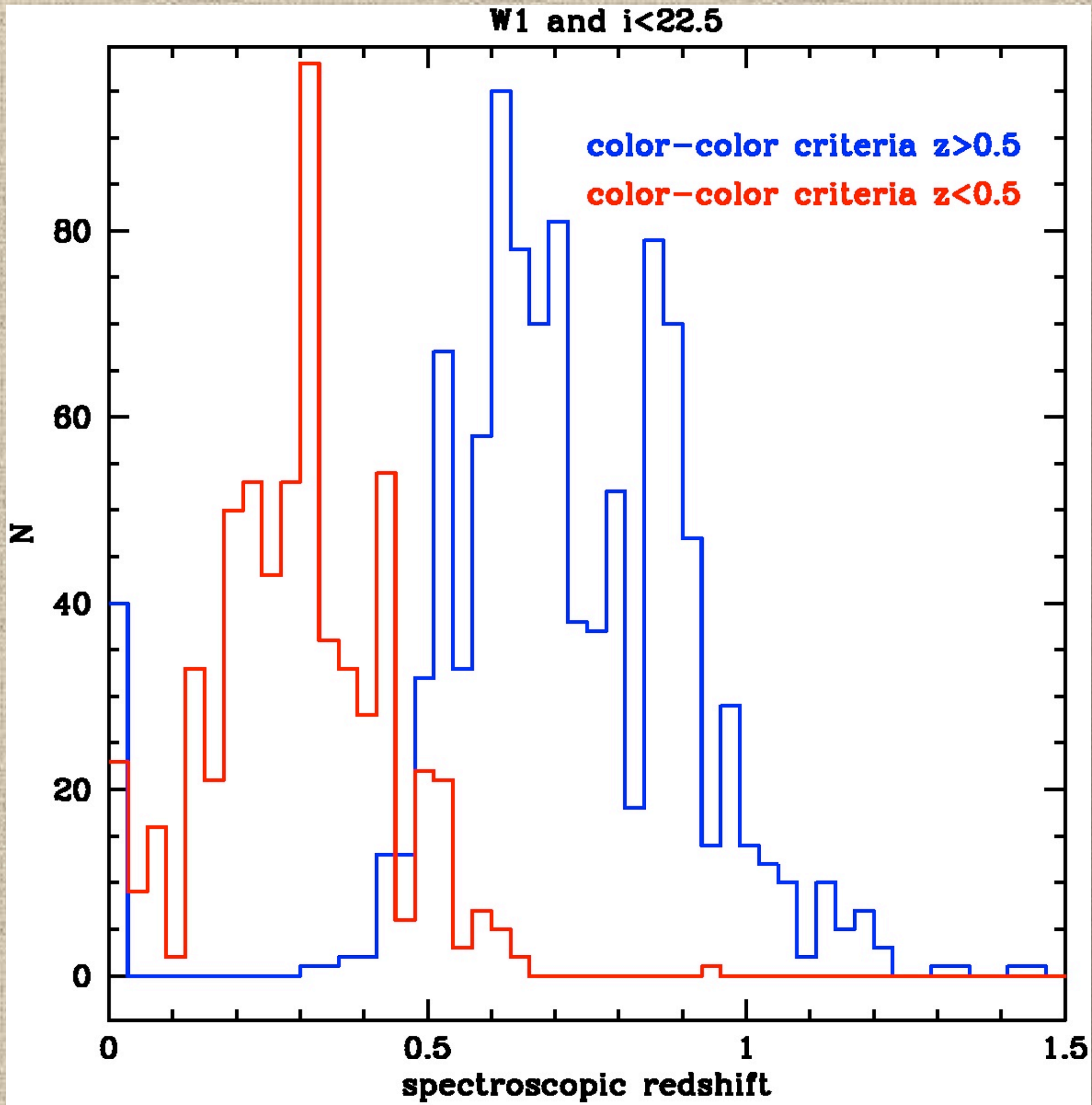
- **MILANO OAB (PI)**: L. Guzzo, B. Granett, A. Iovino, A. Marchetti, U. Abbas (Turin), G. De Lucia (Trieste)
- **MILANO IASF (data reduction centre)**: B. Garilli, M. Scodeggio, A. Fritz, D. Bottini, P. Franzetti, D. Maccagni, L. Paioro, M. Polletta, L. Tasca
- **BOLOGNA**: M. Bolzonella, L. Moscardini,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

VIPERS COLOR-COLOR SELECTION: ISOLATING z>0.5 GALAXIES



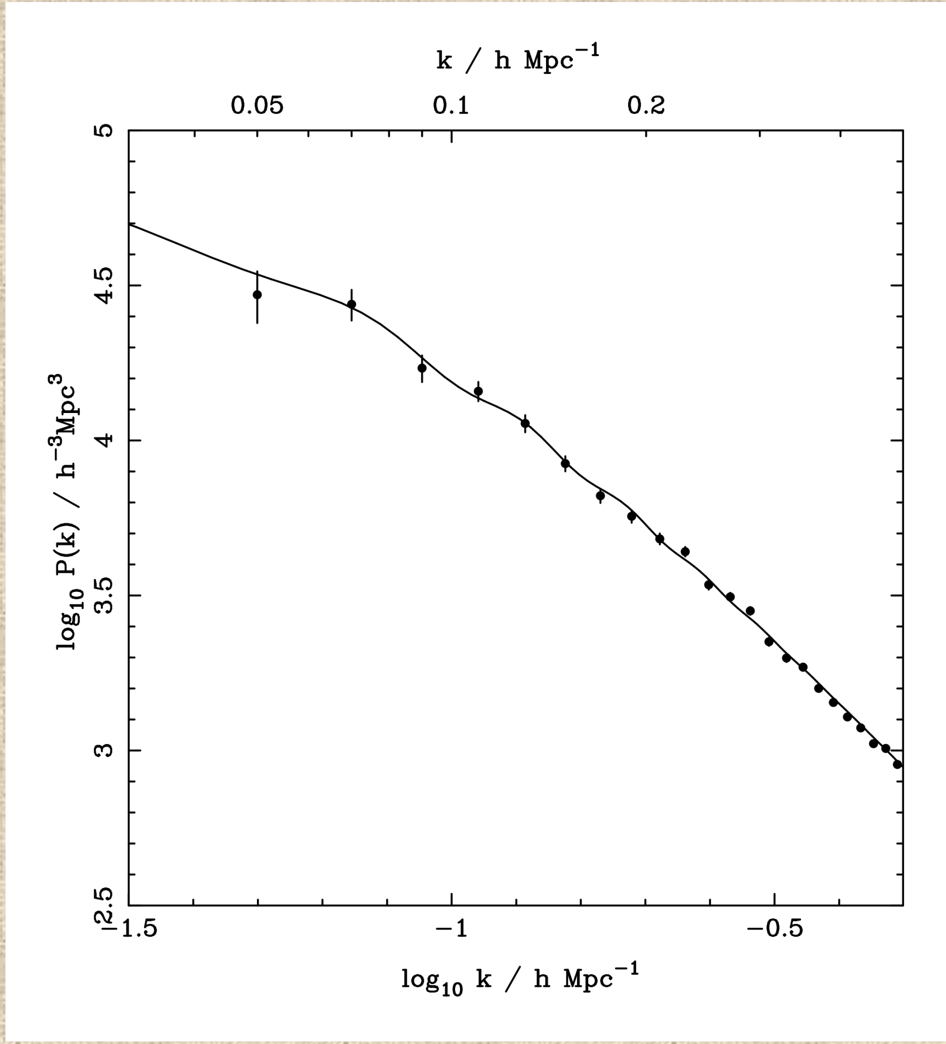
VIPERS target catalogue with VVDS check sample

Completeness/contamination of color-color selection



Expected P(k) at <z>~0.8 from VIPERS

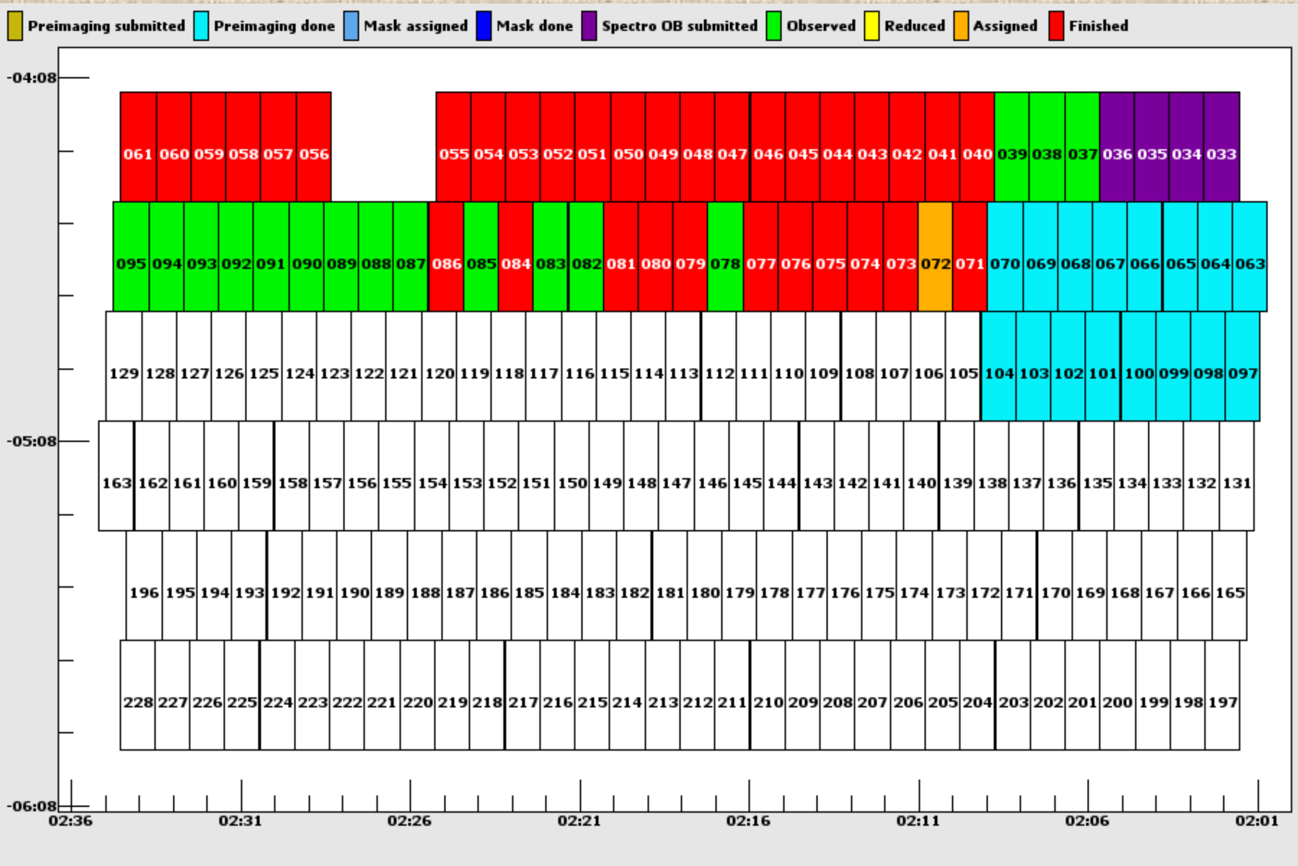
- Measure $\Omega_m h$ from shape of power spectrum
- BAO (baryon fraction, standard ruler?)
- z-space distortions
- neutrino mass?
- large-scale bias vs galaxy properties
- Comparable to 2dF P(k) at z~0.1: joint constraints will be very powerful
- …



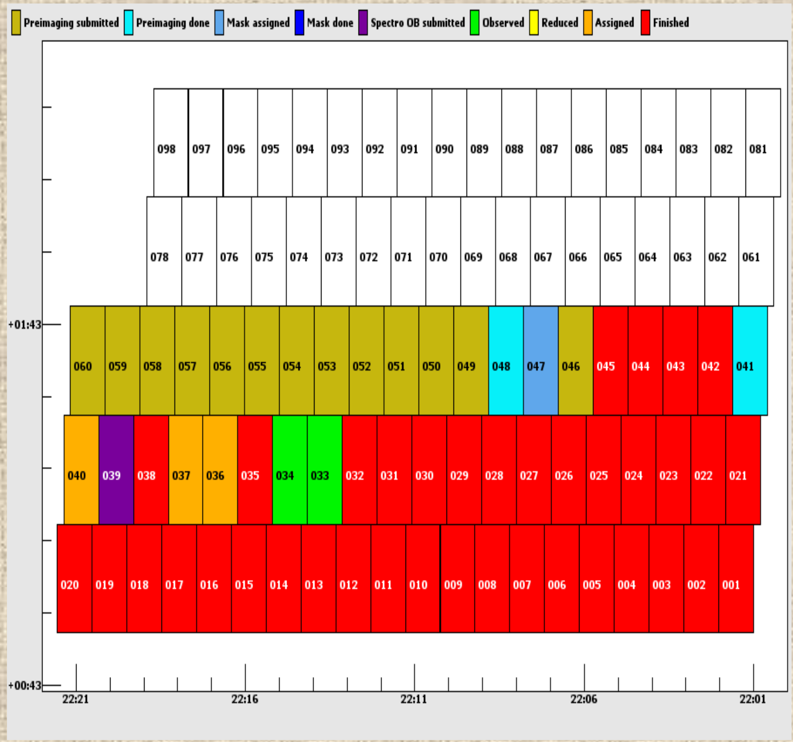
(simulation by W. Percival)

VIPERS coverage (as of today): ~24,000 spectra

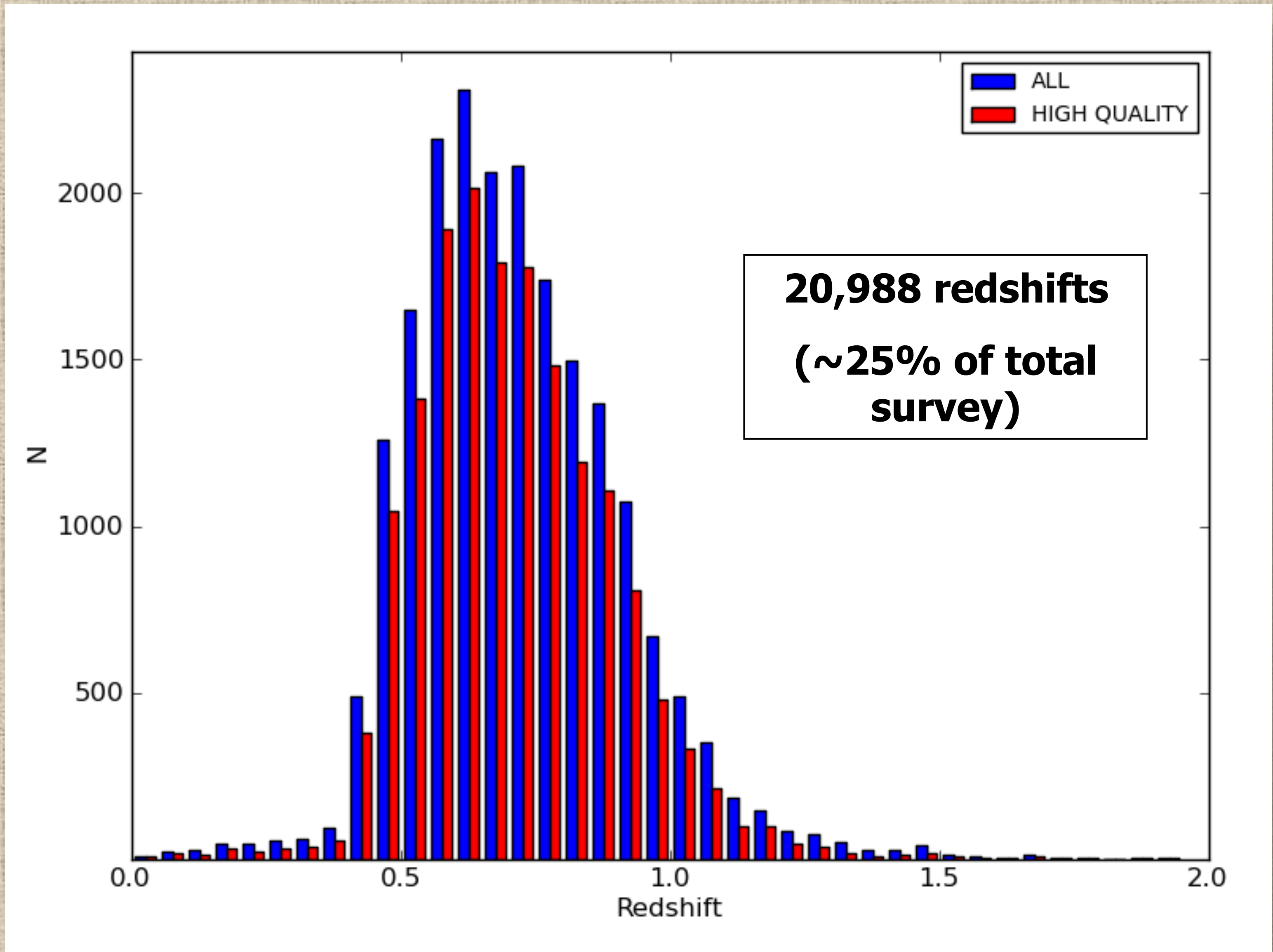
W1



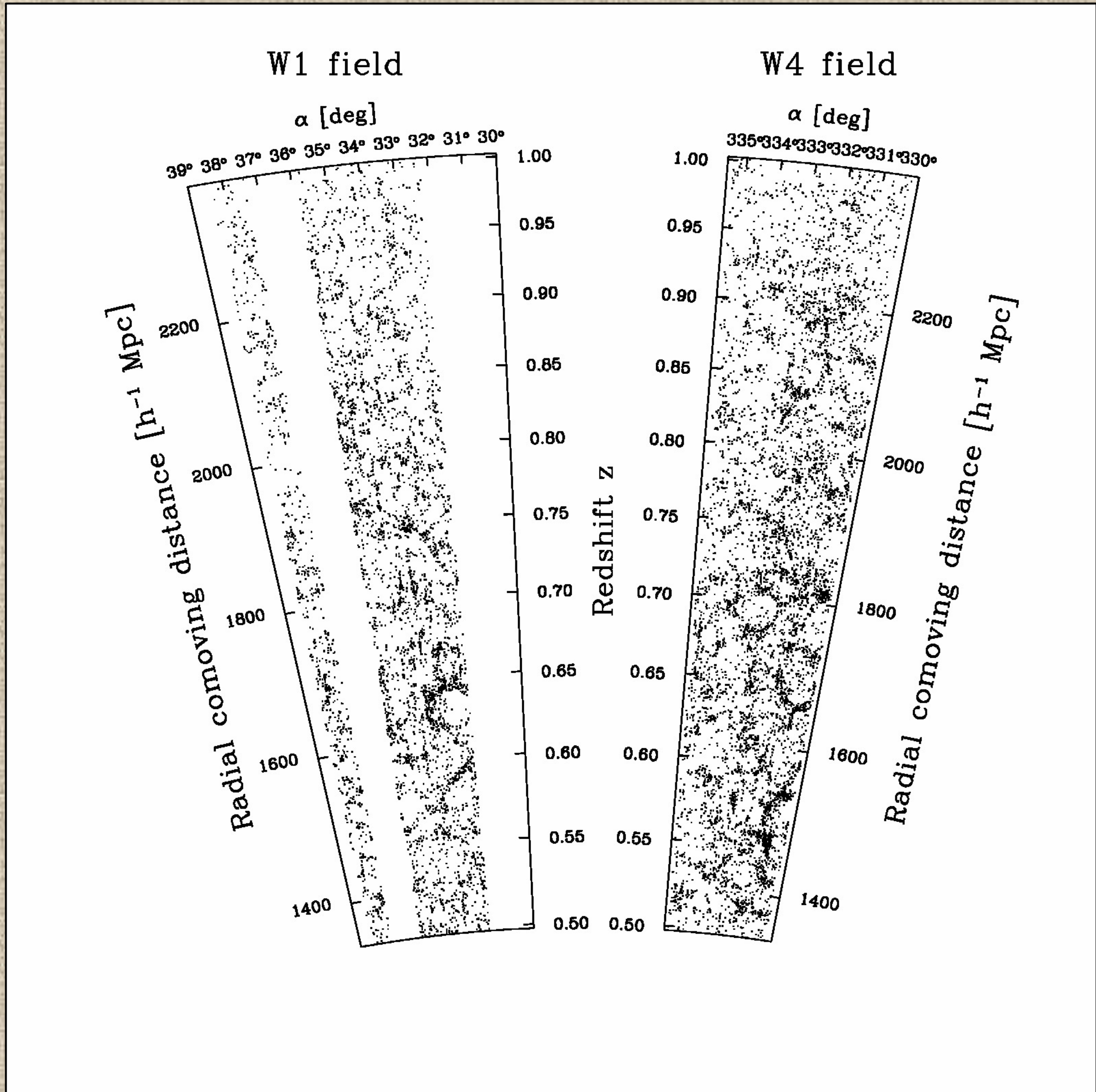
W4



VIPERS redshift distribution (14 Jun 2010)



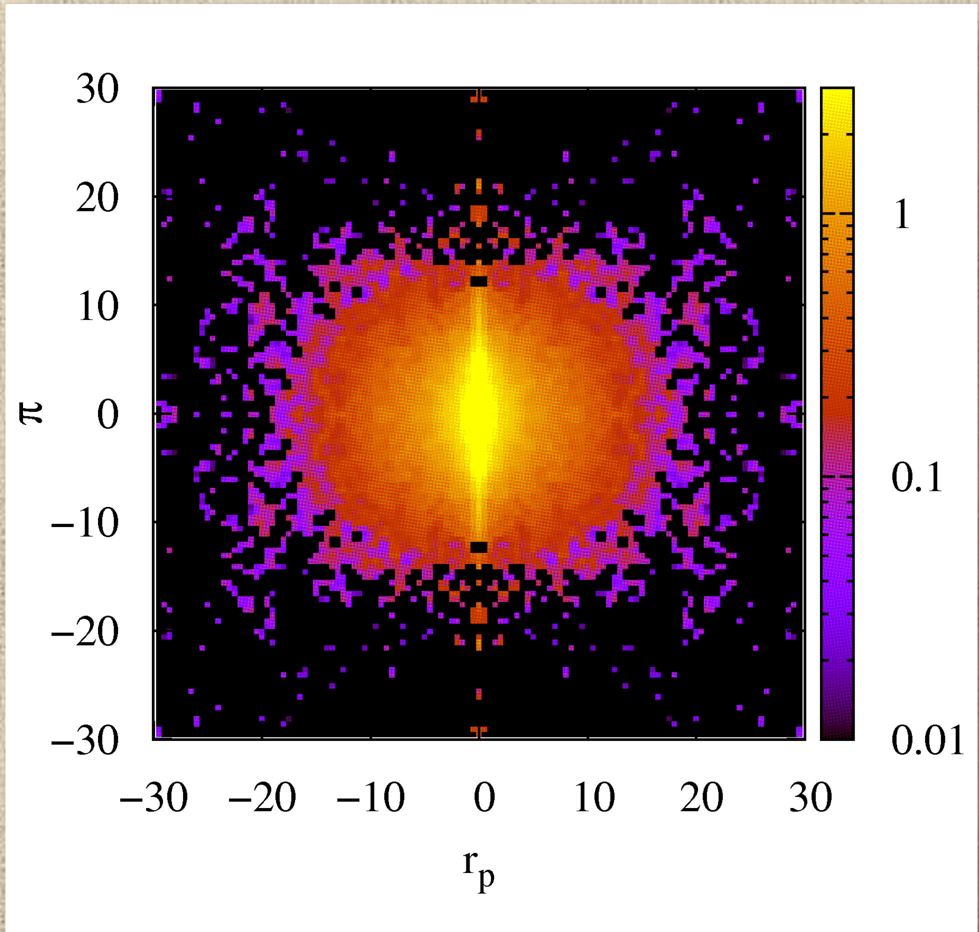
First VIPERS 3D galaxy distribution: FIRST 3D VIEW OF STRUCTURE IN THE z~0.8 UNIVERSE OVER SUCH LARGE SCALES



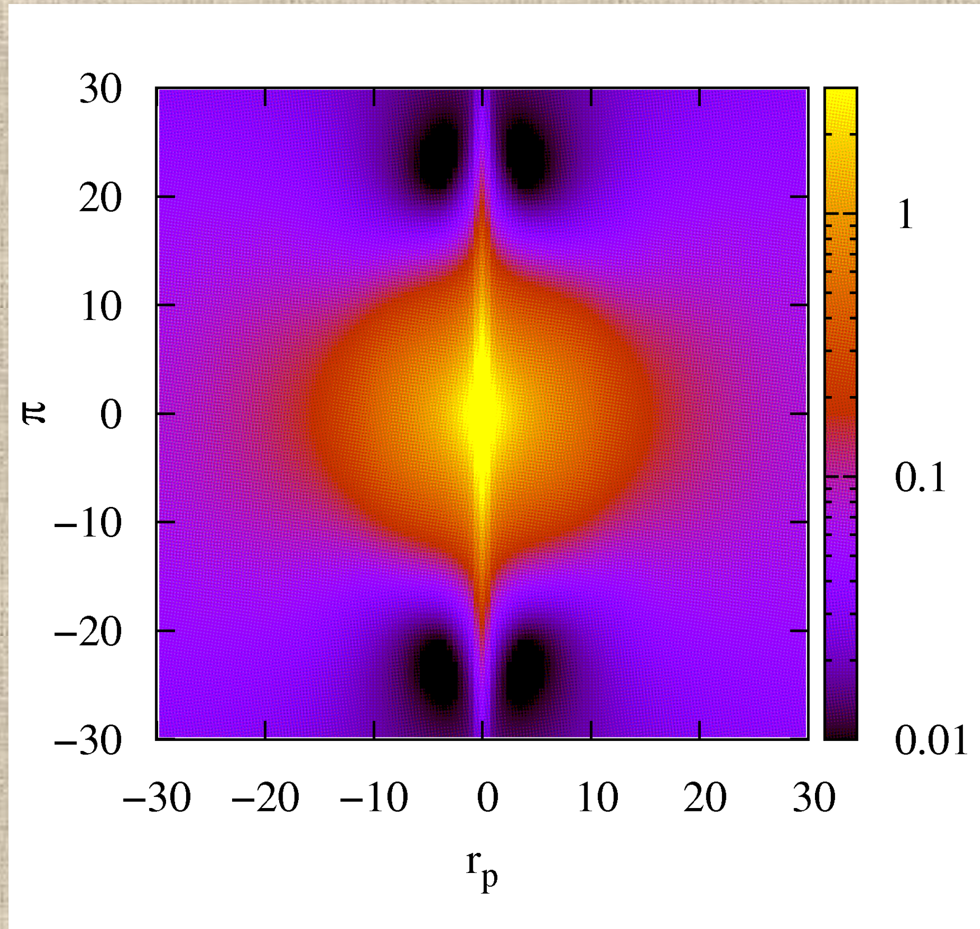
18,586 redshifts

Early $\xi(r_p,\pi)$ from first ~12,000 high-quality VIPERS redshifts at 0.5<z<1

Data



Best-fitting model (β=0.62)



2 parameter fit of the full shape of $\xi(r_p,\pi)$ on $0<r_p<20$ scale (S. de la Torre, LG, & the VIPERS Collaboration)

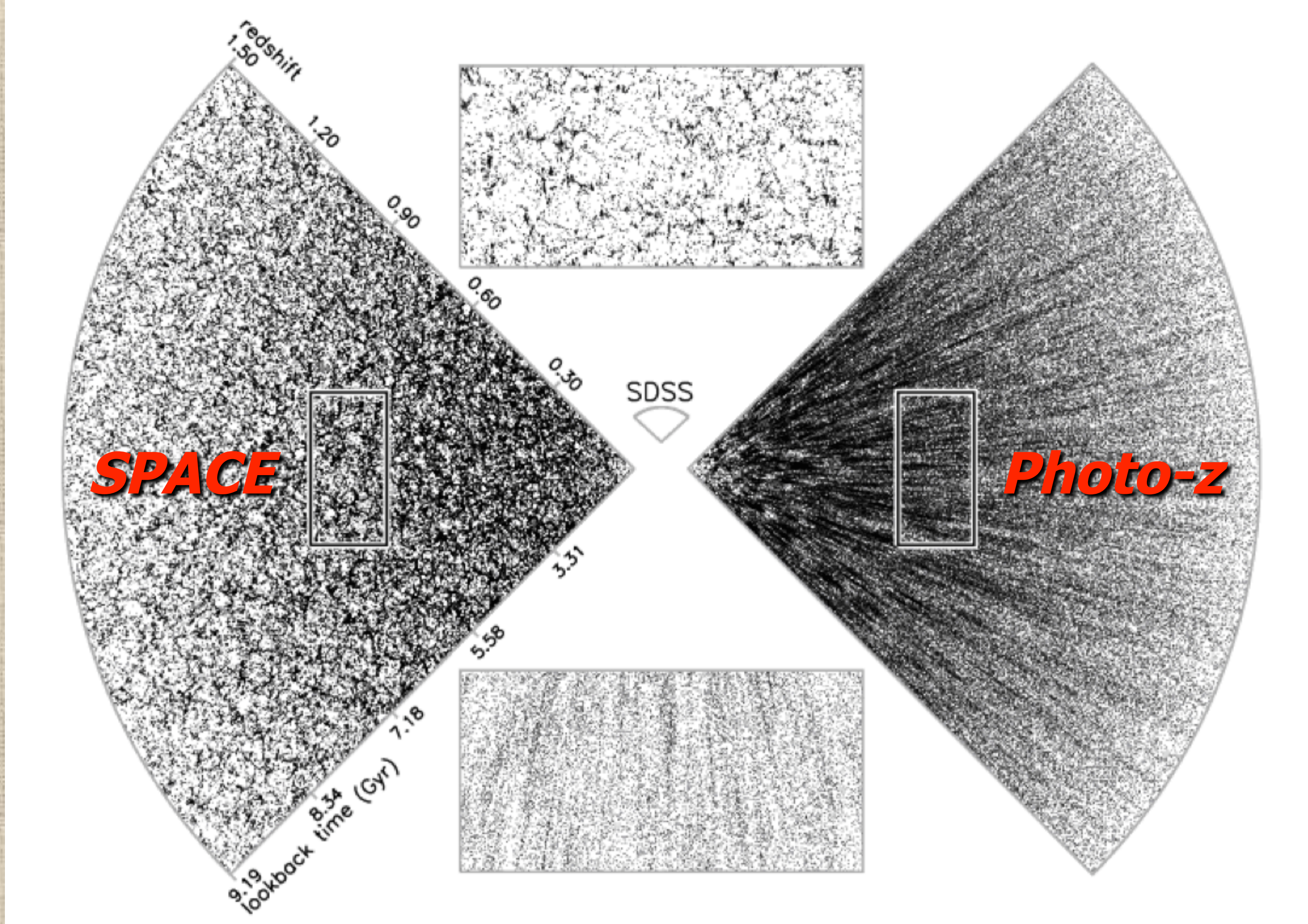
The more distant future: an all-sky redshift survey from space

Originally proposed to ESA Cosmic Vision 2007: ***SPACE***, a dedicated satellite to survey the full extragalactic sky in the near infrared to H~23 (Cimatti et al.), proposing **BAO and redshift distortions** as main dark-energy probes:

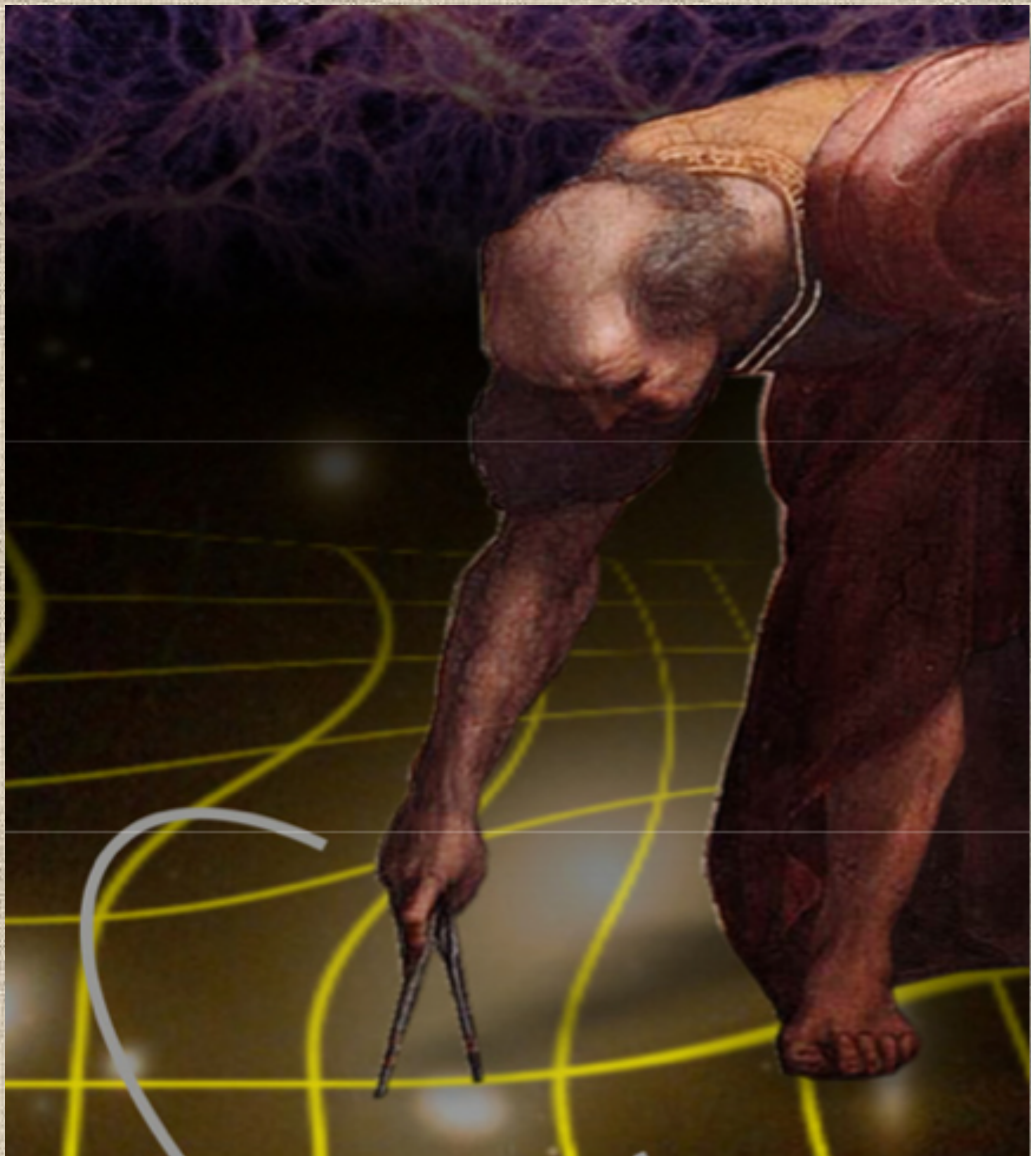
~10^8 redshifts to z~2

2008: merged with ***DUNE*** (Refregier et al.) into

EUCLID



EUCLID, an all-sky imaging and spectroscopic survey from space

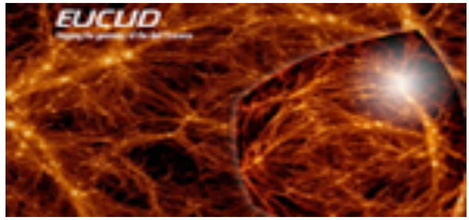


One satellite, two dark-energy probes:

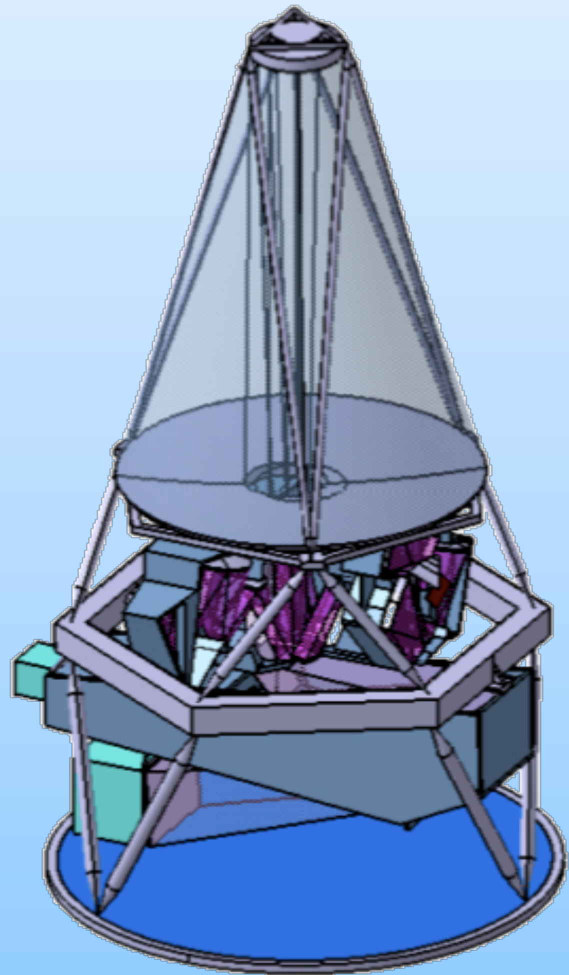
- **Weak lensing** (original imaging PI A. Refregier)
- **Galaxy clustering** (original spectroscopy PI A. Cimatti)
- Currently under study by ESA & EUCLID Consortium (lead by Y. Mellier)
- See the **EUCLID Assessment Study Report** (the "Yellow Book"), Laureijs et al. 2009, arXiv:0912.0914)

See Wang et al. 2010 and Samushia et al. 2010 for BAO and other forecasts for EUCLID-like surveys

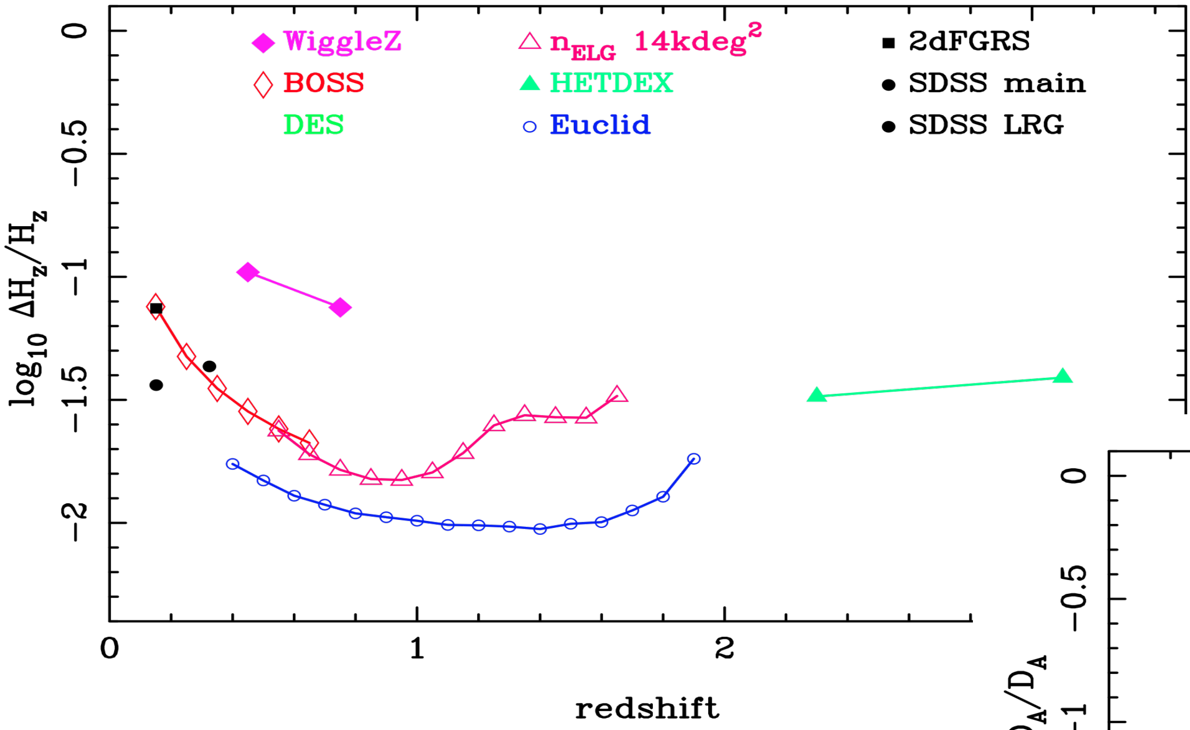
Euclid



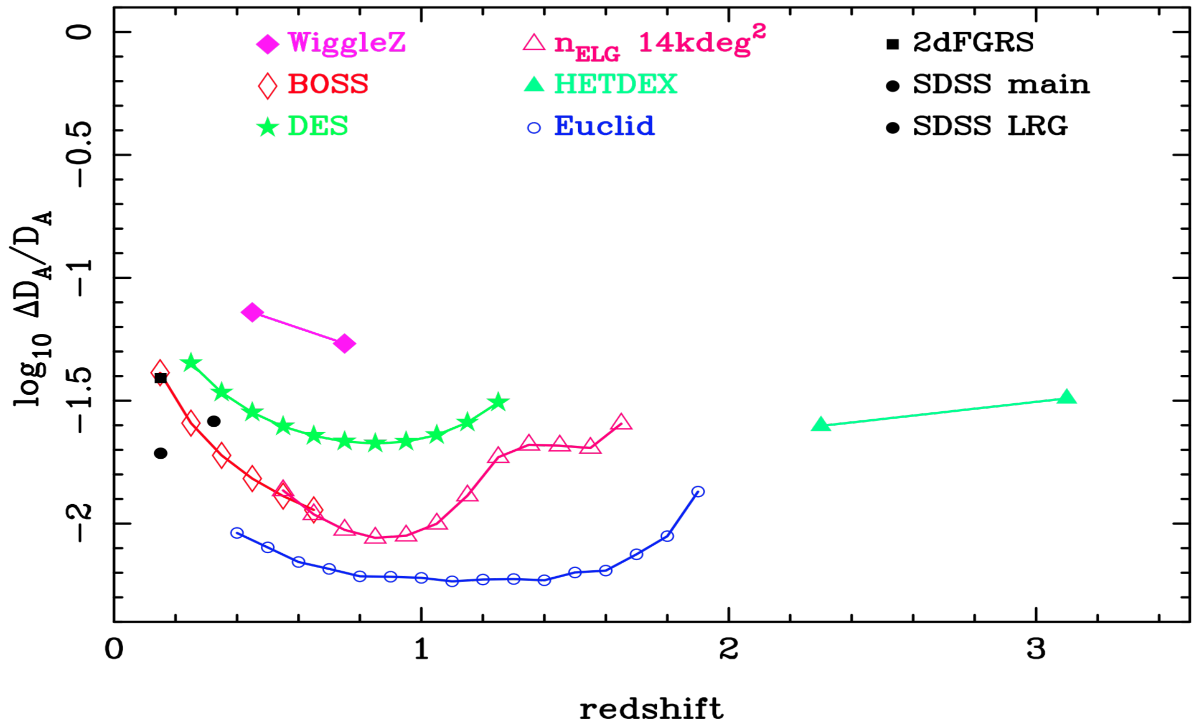
- ESA Cosmic Vision satellite proposal (600M€, M-class mission)
- 5 year mission, L2 orbit
- 1.2m primary mirror, 0.5 sq. deg FOV
- Ω = 20,000deg² imaging and spectroscopy
- slitless spectroscopy:
  - 100,000,000 galaxies (direct BAO)
  - ELGs (H-alpha emitters): z~0.5-2.1
- imaging:
  - deep broad-band optical + 3 NIR images
  - 2,900,000,000 galaxies (for WL analysis)
  - photometric redshifts
- Space-base gives robustness to systematics
- Final down-selection due mid 2011
- nominal 2017 launch date
- See also: LSST, WFIRST



Predicted BAO constraints



by W. Percival



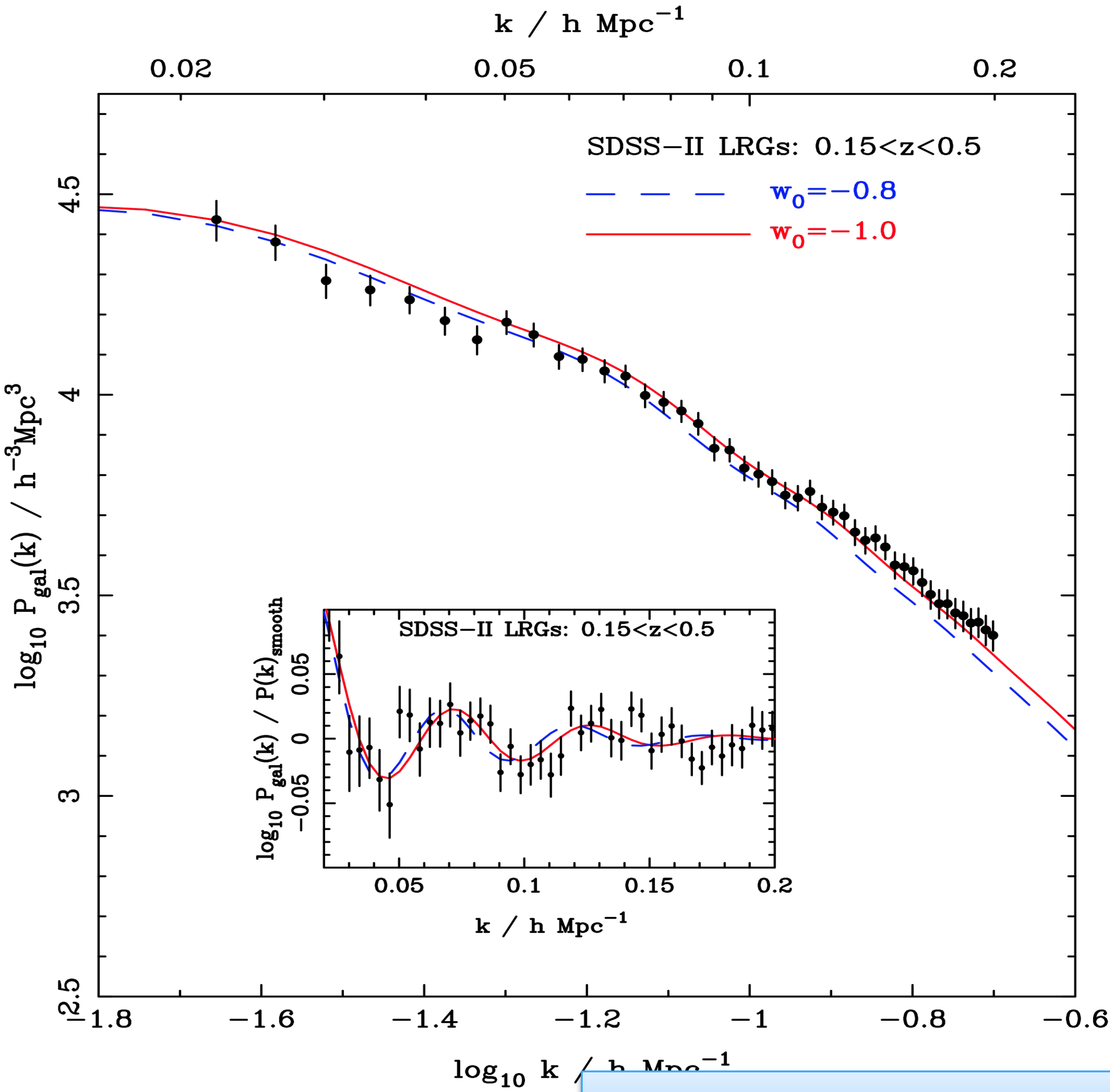
Uses public code to estimate errors from BAO measurements from Seo & Eisenstein (2007: astro-ph/0701079)

Current large-scale galaxy clustering measurements

SDSS LRGs at z~0.35

The largest volume of the Universe currently mapped

Total effective volume V_{eff} = 0.26 Gpc^3h^{-3}



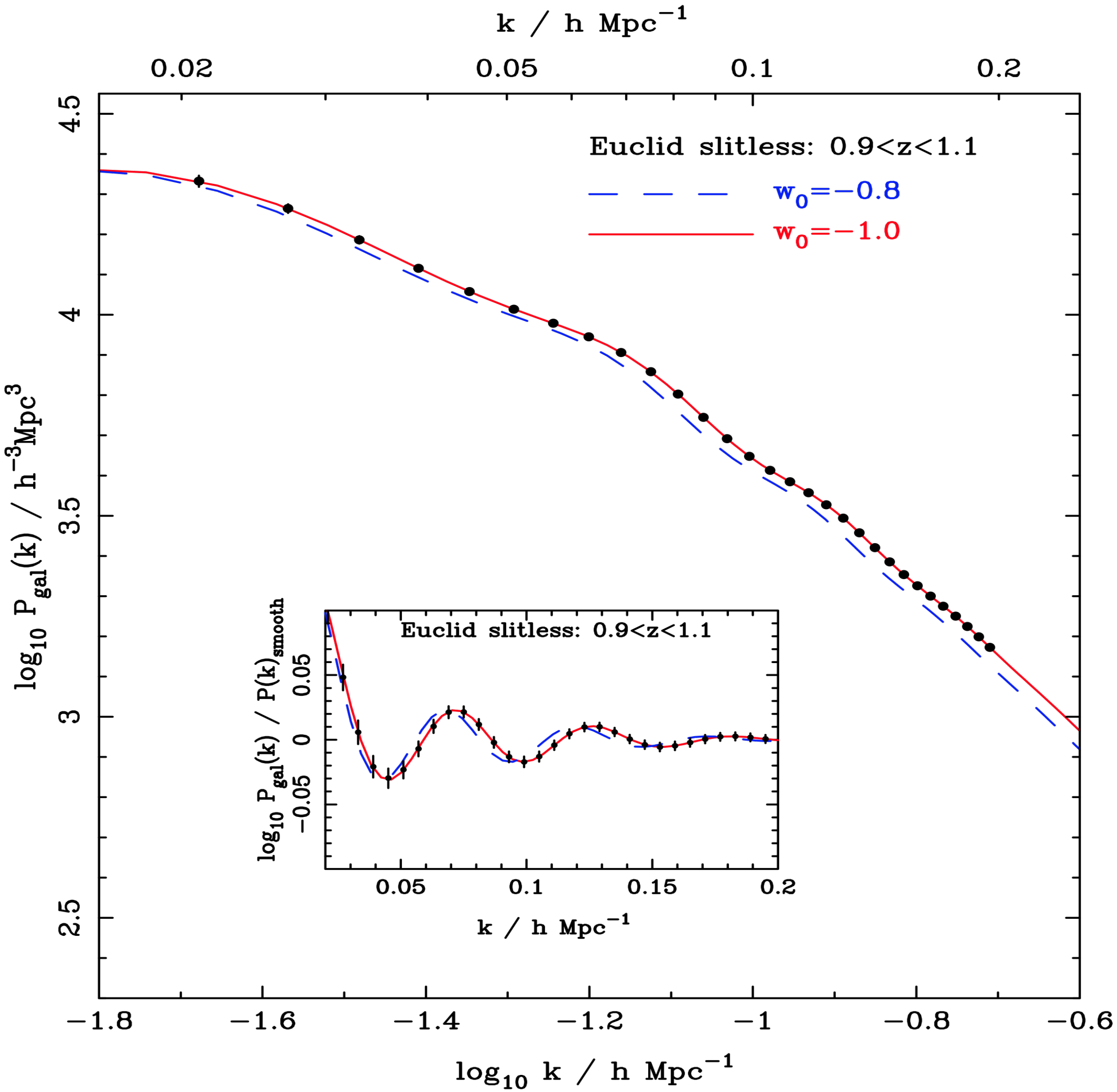
Power spectrum gives amplitude of Fourier modes, quantifying clustering strength on different scales

Percival et al. 2009; arXiv:0907.1660

Predicted galaxy clustering measurements by Euclid

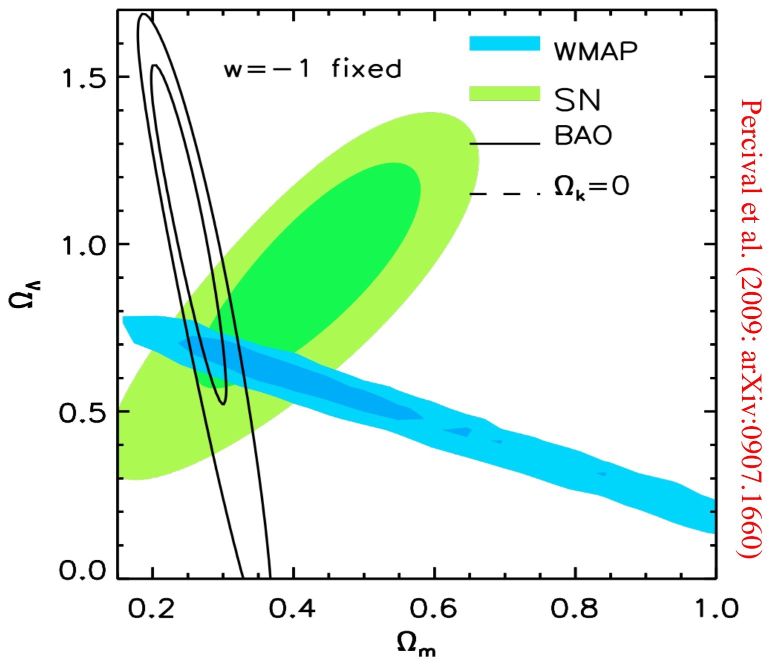
20% of the Euclid data, assuming the slitless baseline at z~1

Total effective volume (of Euclid)
V_{eff} = 19.7 Gpc^3h^{-3}

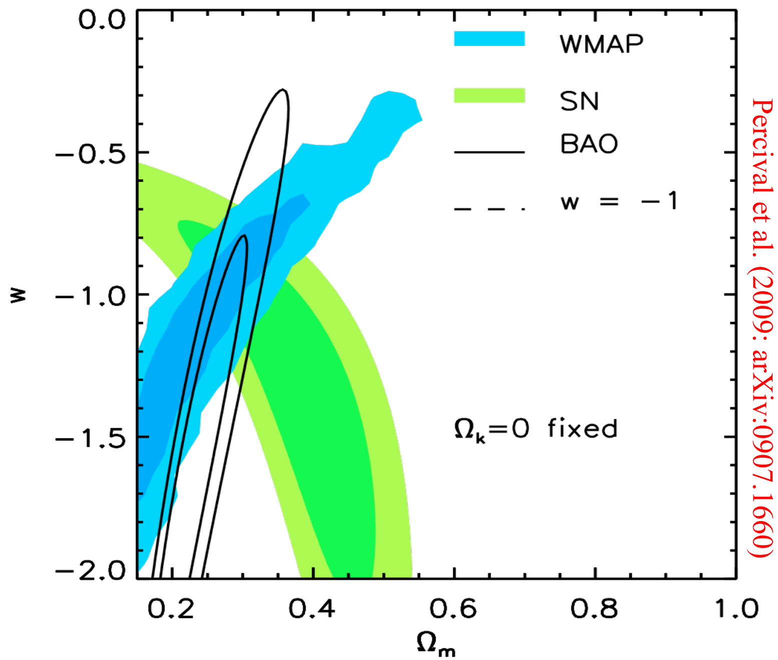


Current BAO constraints vs other data

ΛCDM models with curvature



flat wCDM models



Union supernovae

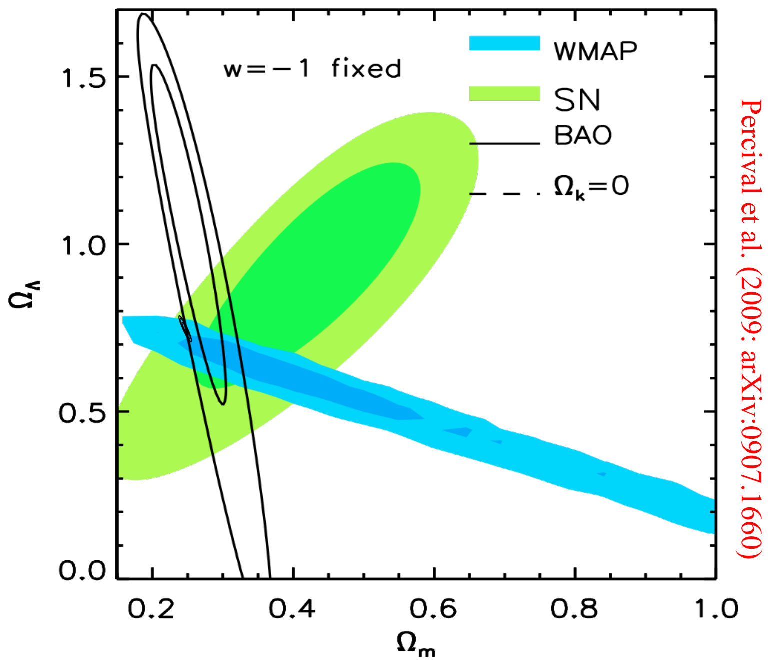
WMAP 5year

SDSS-II BAO Constraint on $r_s(z_d)/D_V(0.2)$ & $r_s(z_d)/D_V(0.$

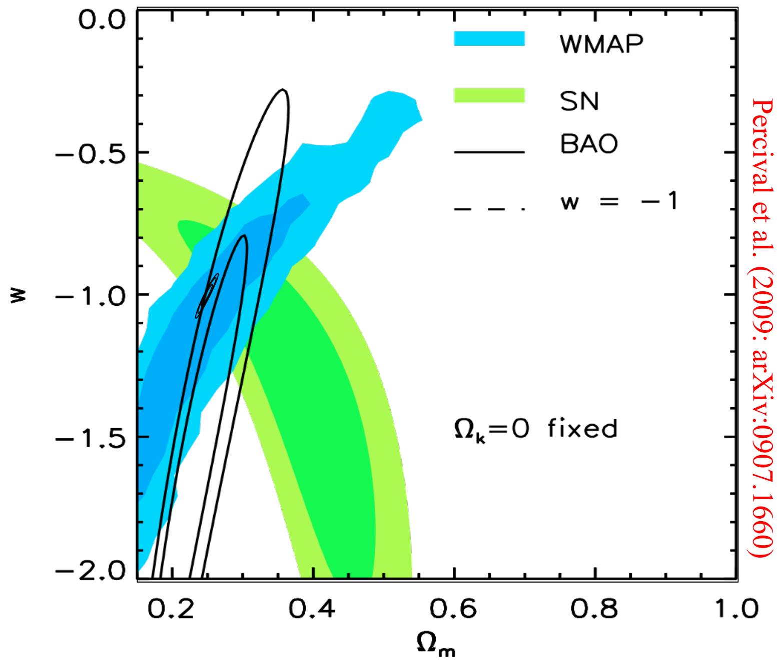
Percival et al. 2009; arXiv:0907.1660

How does Euclid BAO compare?

ΛCDM models with curvature

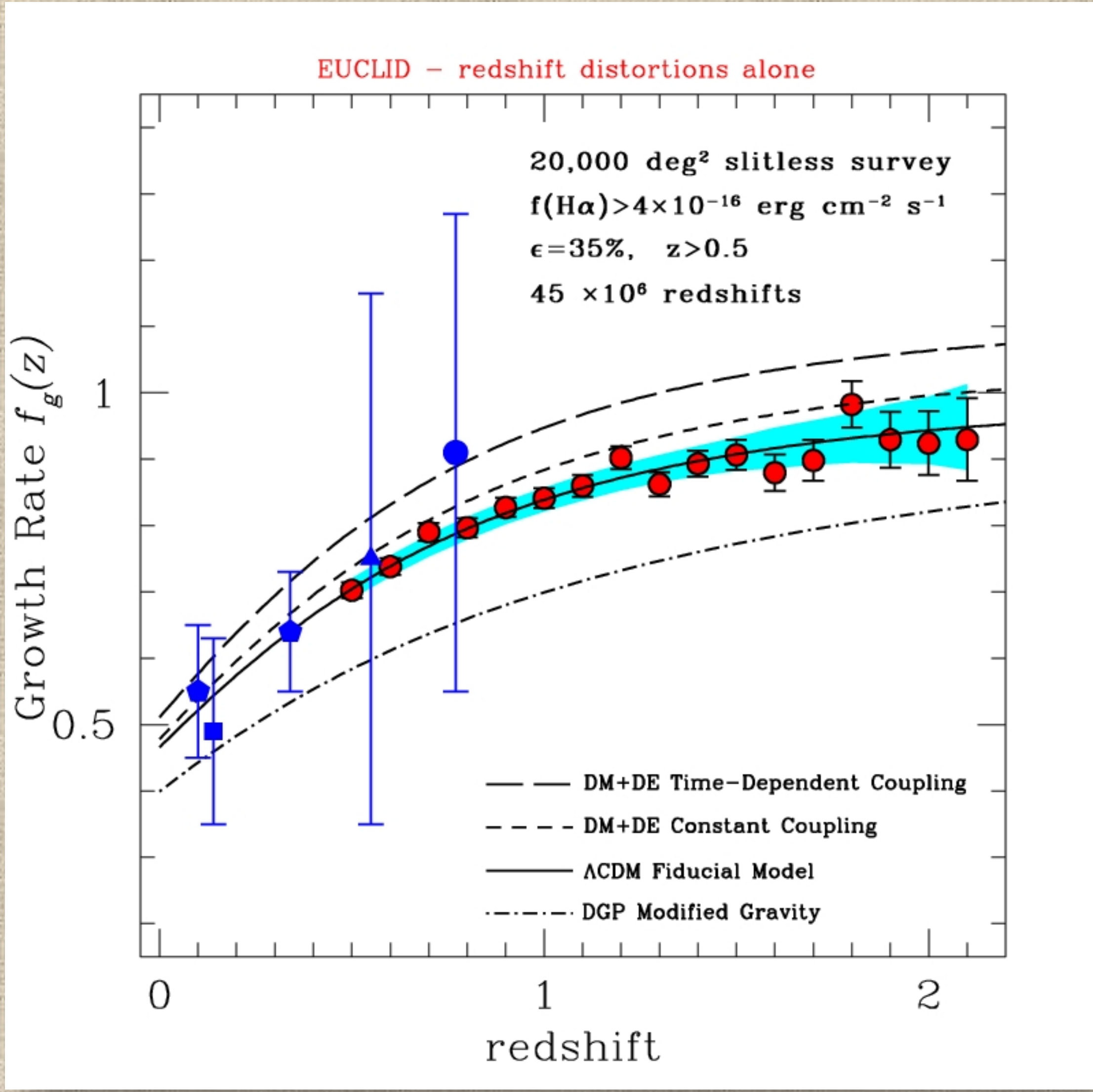


flat wCDM models



Union supernovae
WMAP 5year
SDSS-II BAO Constraint on $r_s(z_d)/D_V(0.2)$ & $r_s(z_d)/D_V(0.$

Expected growth rate measurements from EUCLID spectroscopy



LG, W. Percival, L. Samushia, E. Majerotto, Y. Wang, et al.

Summary and Outlook

- A brilliant future for galaxy redshift surveys: (1) Measure both expansion and growth histories; (2) Understand bias/astrophysics; (3) Large discovery potential
- Baryon acoustic oscillations (BAO)
  - measure cosmological geometry, tests expansion history H(z)
- Redshift-space distortions
  - measures growth of structure f(z), tests modified gravity
- Precision cosmology requires understanding/modelling bias and non-linearities: key to push down systematic errors
- More results soon from new surveys: WiggleZ, VIPERS, BOSS, DES
- EUCLID, the "ultimate" cosmology experiment: complement galaxy clustering with dark-matter mapping through weak-lensing tomography