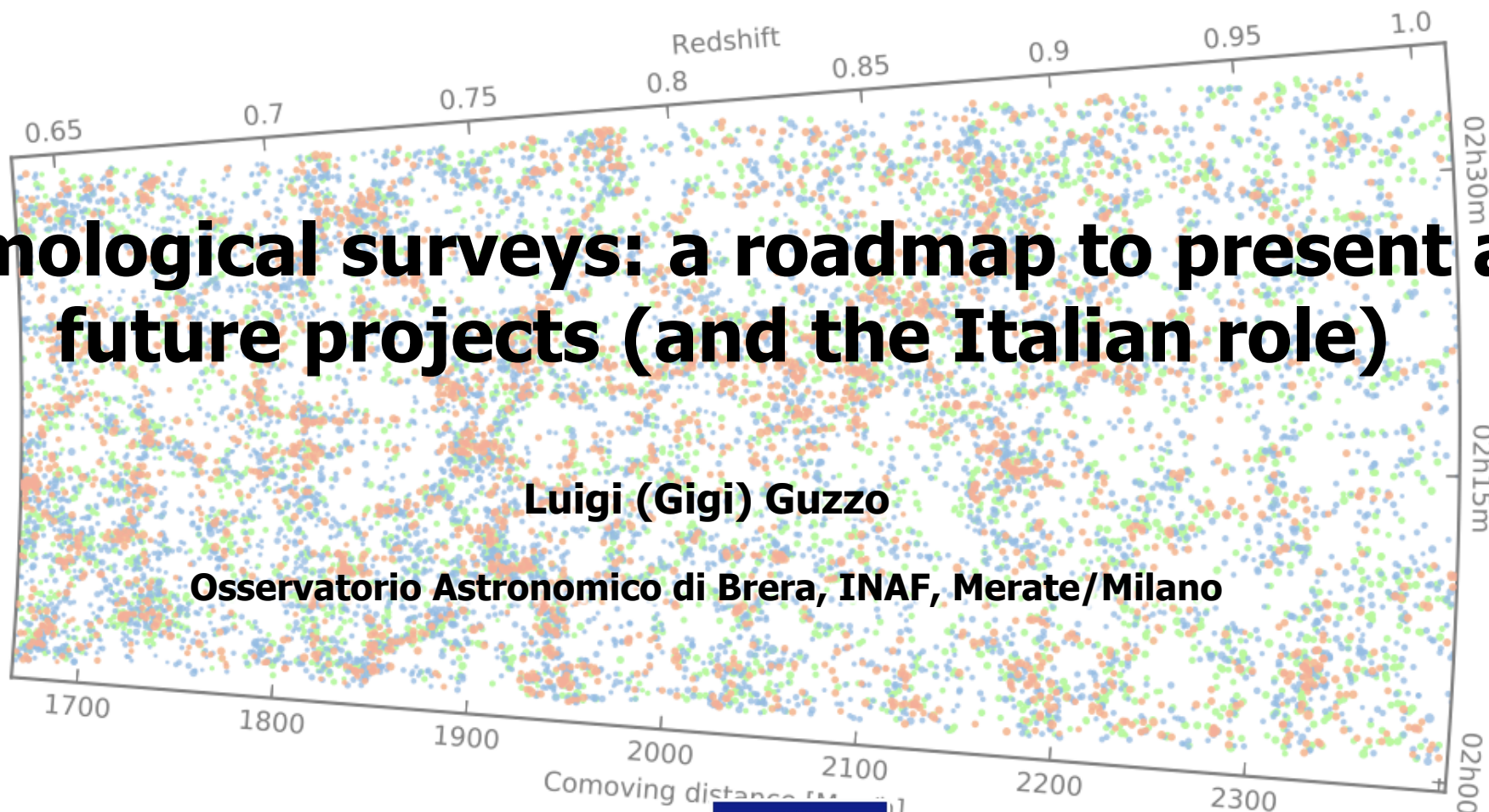


Cosmological surveys: a roadmap to present and future projects (and the Italian role)

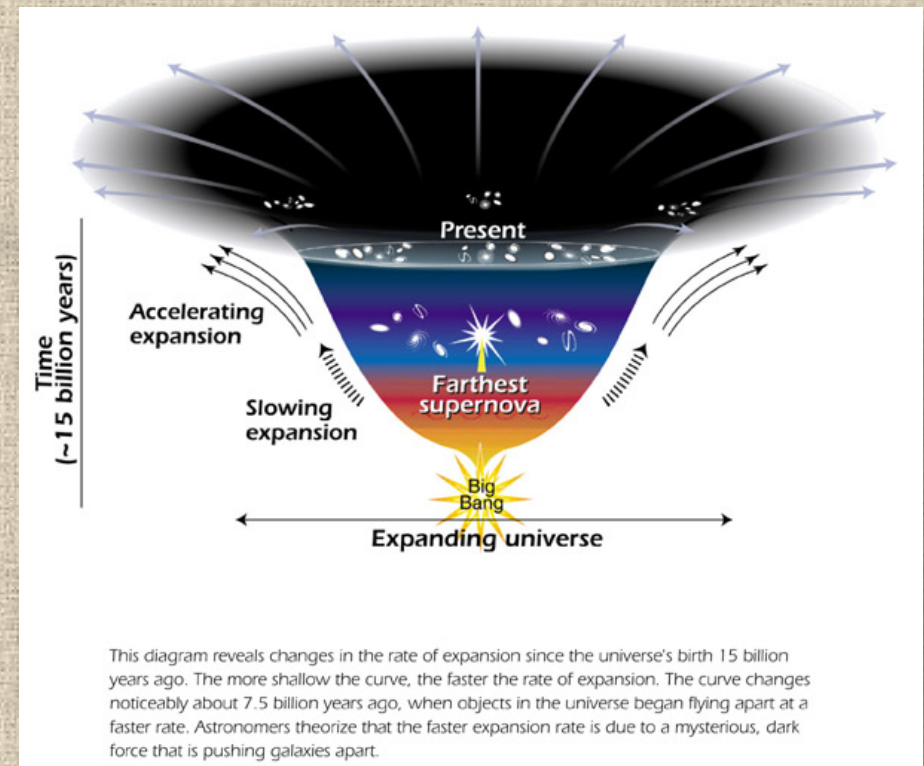
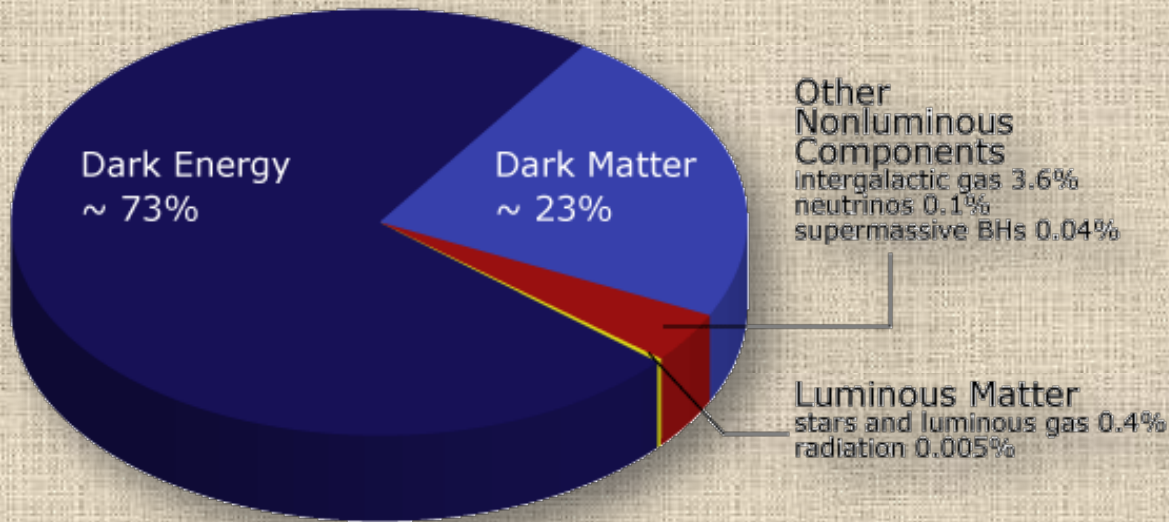
Luigi (Gigi) Guzzo

Osservatorio Astronomico di Brera, INAF, Merate/Milano



Projects presented here have received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration, under grant agreement no 291521

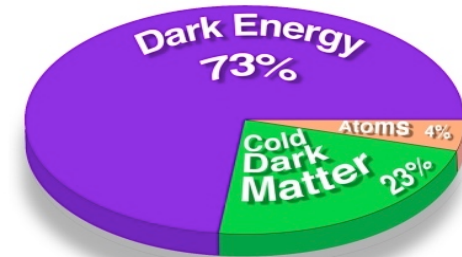
The "cosmic pie" of the 21st century: but who ordered it?



2011 Nobel Prize

High-level questions (Stefano's talk)

- Nature of Dark Matter ?
- Nature of Dark Energy ?
- Behaviour of gravity at the largest scales ?
- Physics of the initial conditions (inflation) ?
- How constant are fundamental constants ?



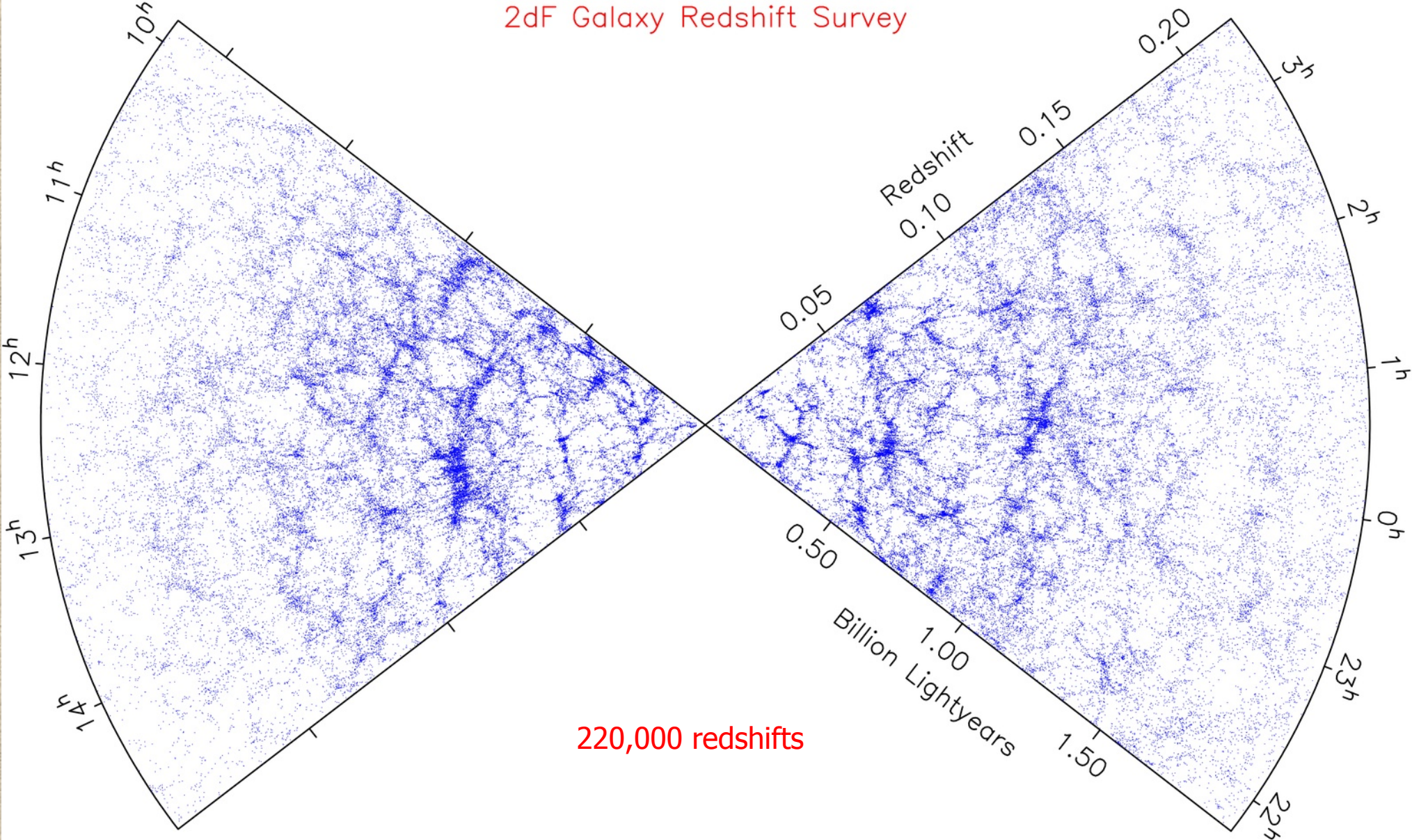
Implications for the physics beyond

→ the Standard Λ CDM Cosmological Model

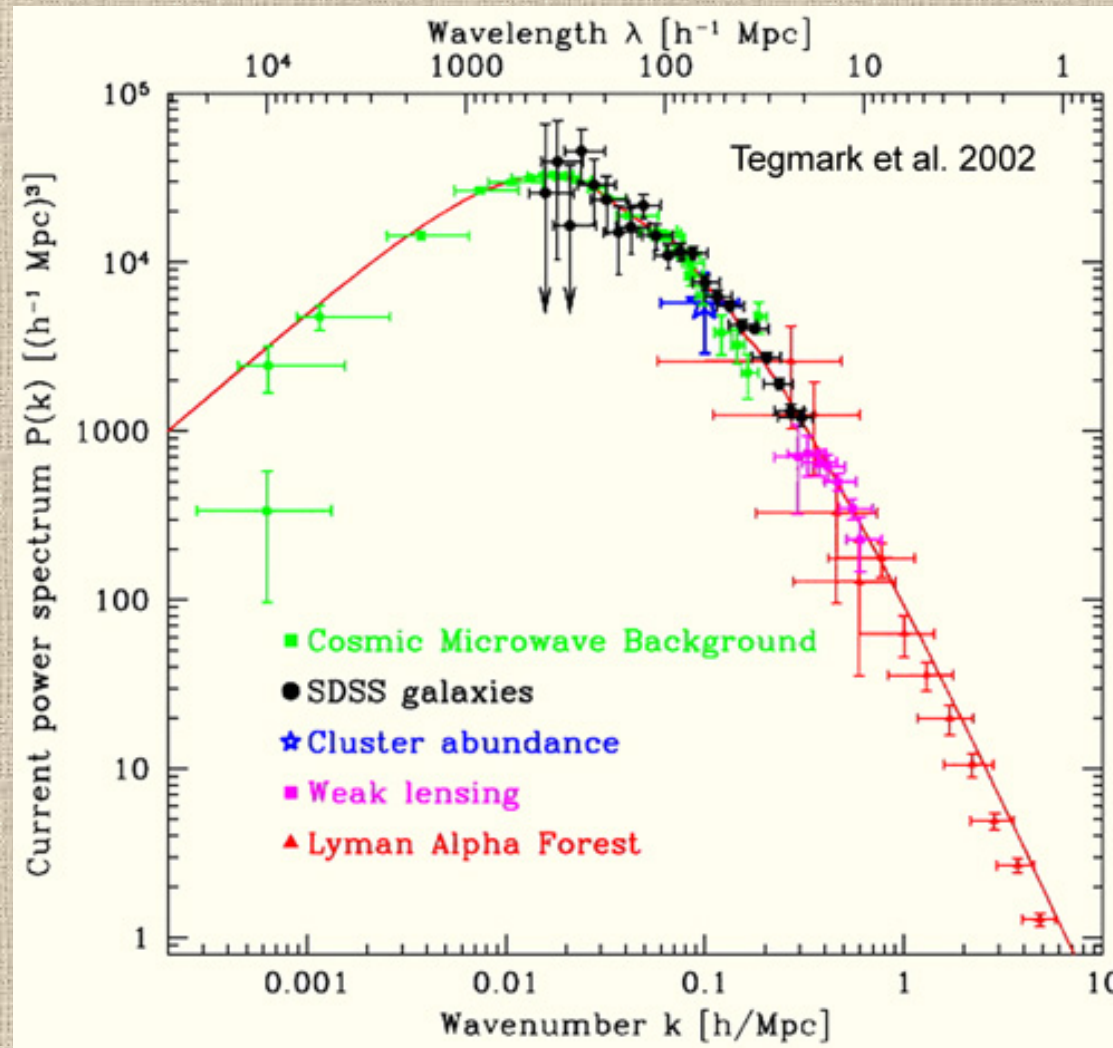
→ the Standard Model of particle physics

Lots of astrophysics to be learnt in the process!!

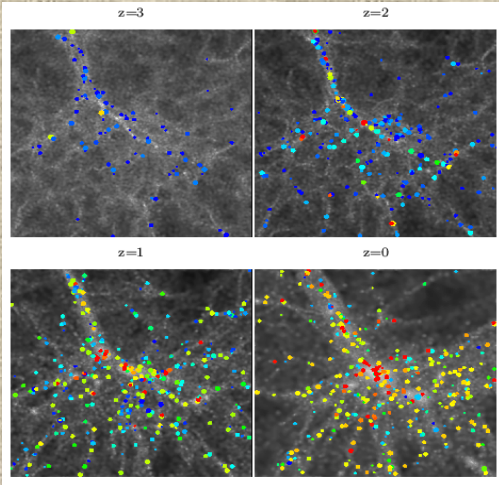
Redshift surveys: a pillar of current cosmology



The **clustering power spectrum**: a probe of the underlying cosmology



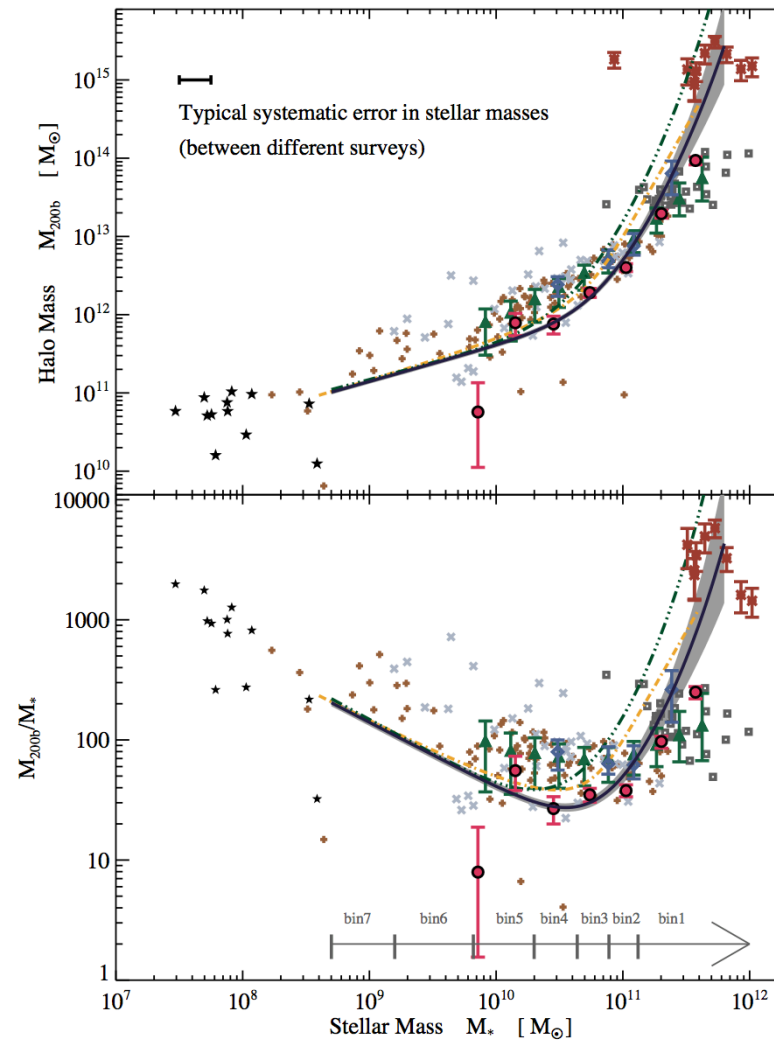
We need to understand galaxies, to do cosmology...



Kauffman & Diaferio 1998

18

A. Leauthaud et al.



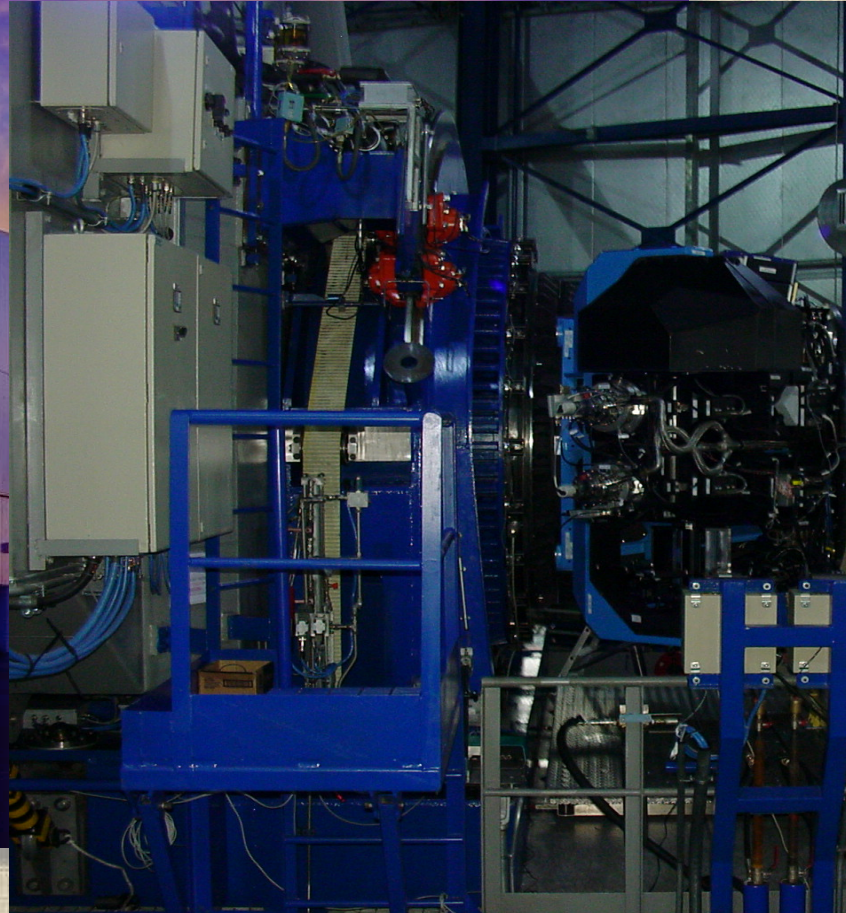
- WL, COSMOS this paper, $z=0.37$
- WL, Mandelbaum *et al.* 2006, $z=0.1$
- WL, Leauthaud *et al.* 2010, $z=0.3$
- ✱ WL, Hoekstra *et al.* 2007, $z\sim 0.2$
- - - AM, Moster *et al.* 2010, $z=0.1$
- · - · - AM, Behroozi *et al.* 2010, $z=0.1$
- ◇ SK, Conroy *et al.* 2007, $z\sim 0.06$
- △ SK, More *et al.* 2010, $z\sim 0.05$
- ★ TF, Geha *et al.* 2006, $z=0$
- × TF, Pizagno *et al.* 2006, $z=0$
- + TF, Springob *et al.* 2005, $z=0$

Leauthaud et al. 2012

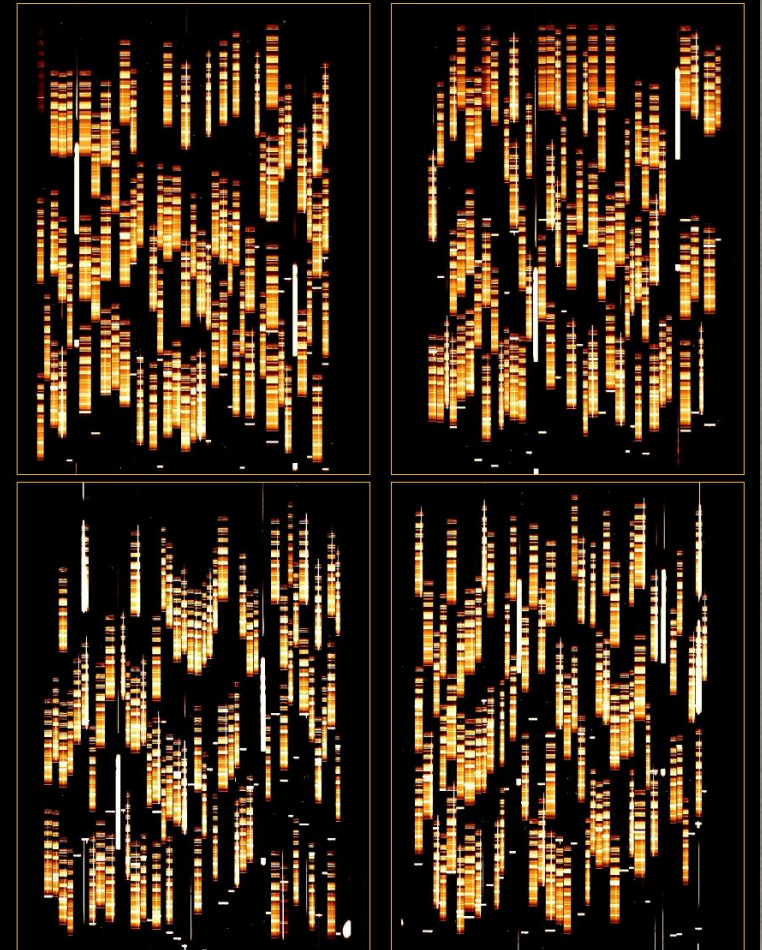


→ Push large-scale structure study to $z \sim 1$, but aim at comparable statistical accuracy and completeness on structure and galaxy properties (i.e. volume, density, population) as we had from SDSS and 2dFGRS at $z \sim 0$

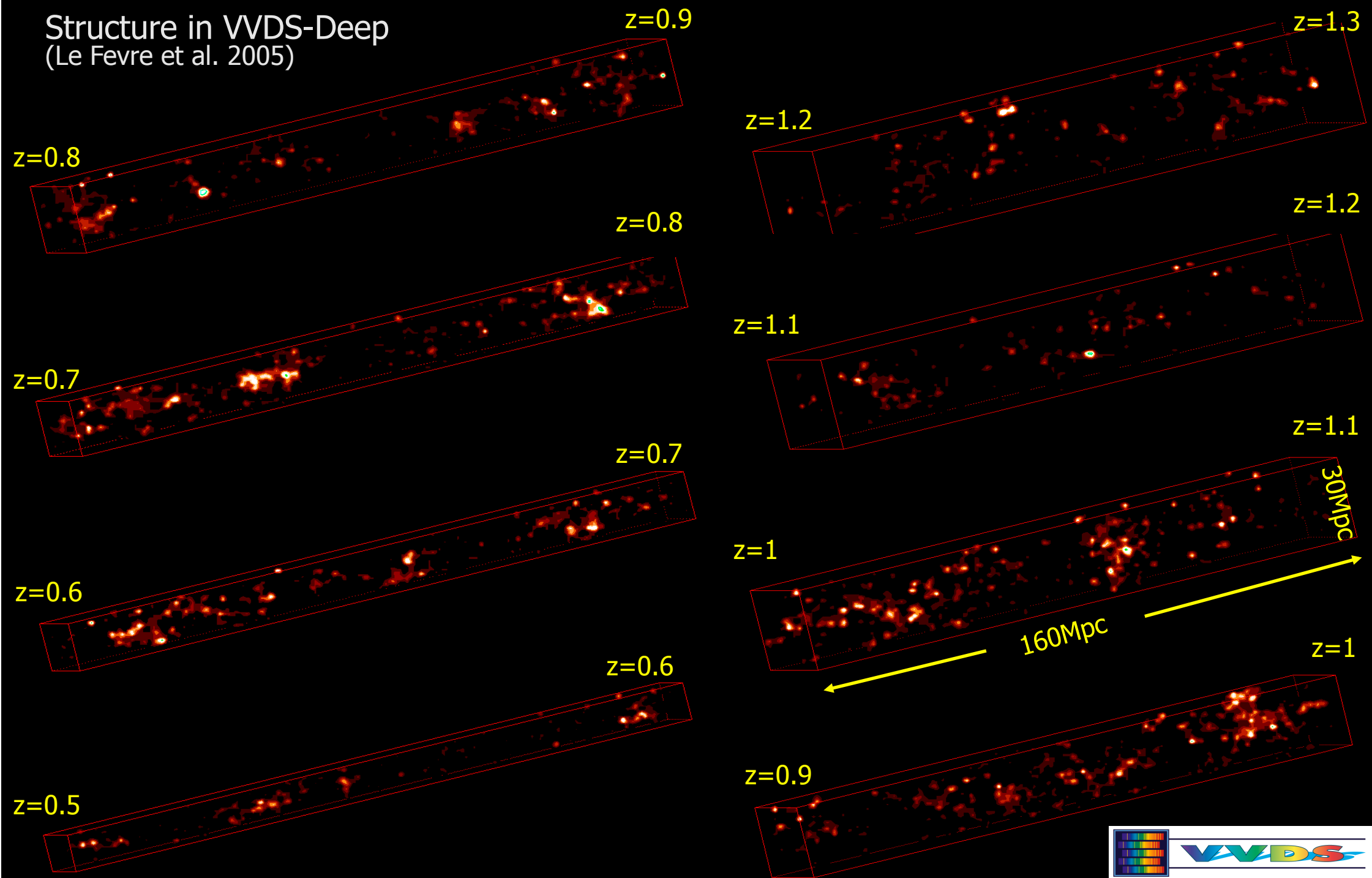
VIMOS @ VLT fills unique niche in density-area space



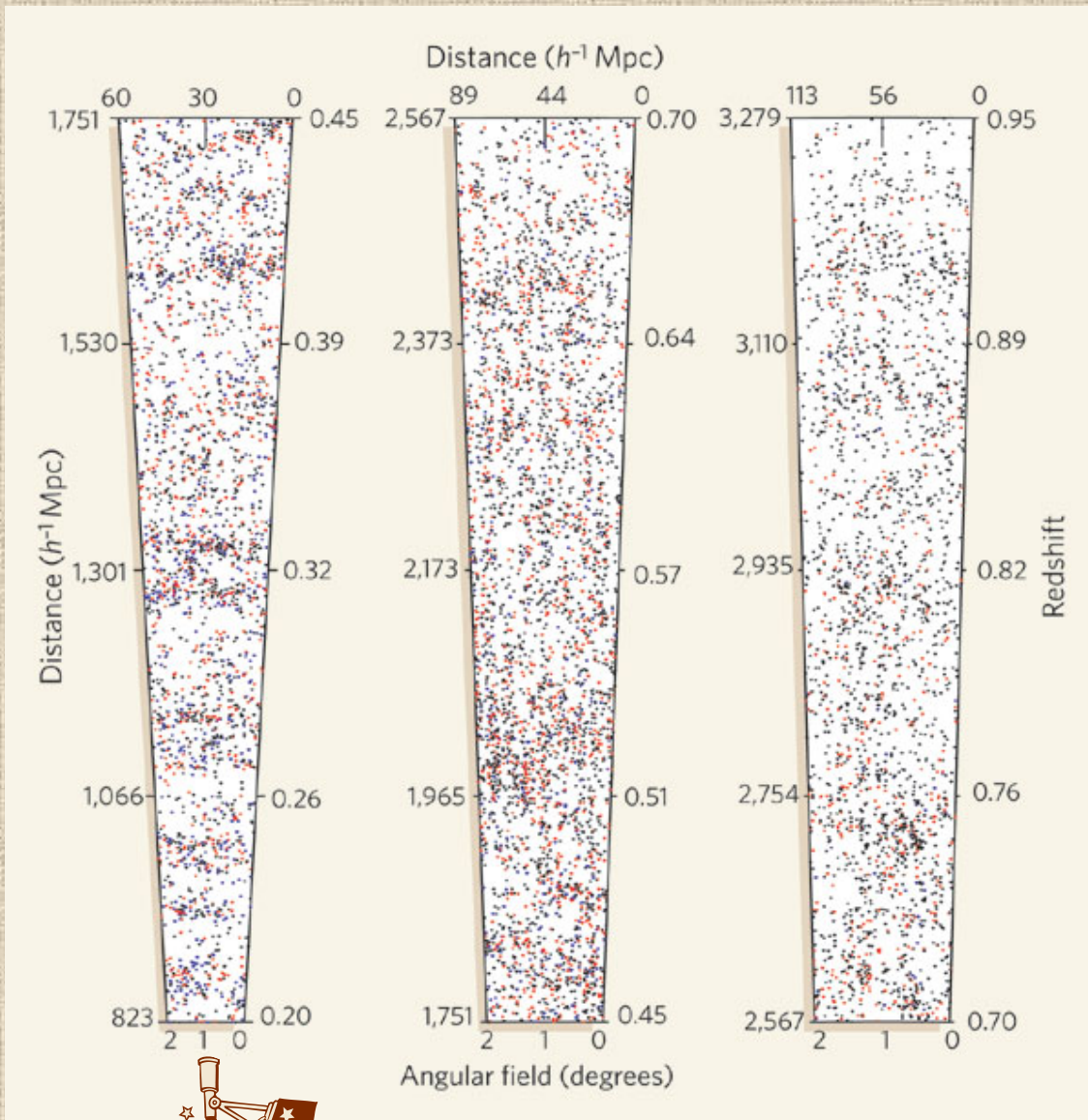
VLT-VIMOS: 325 spectra at once 25/09/02



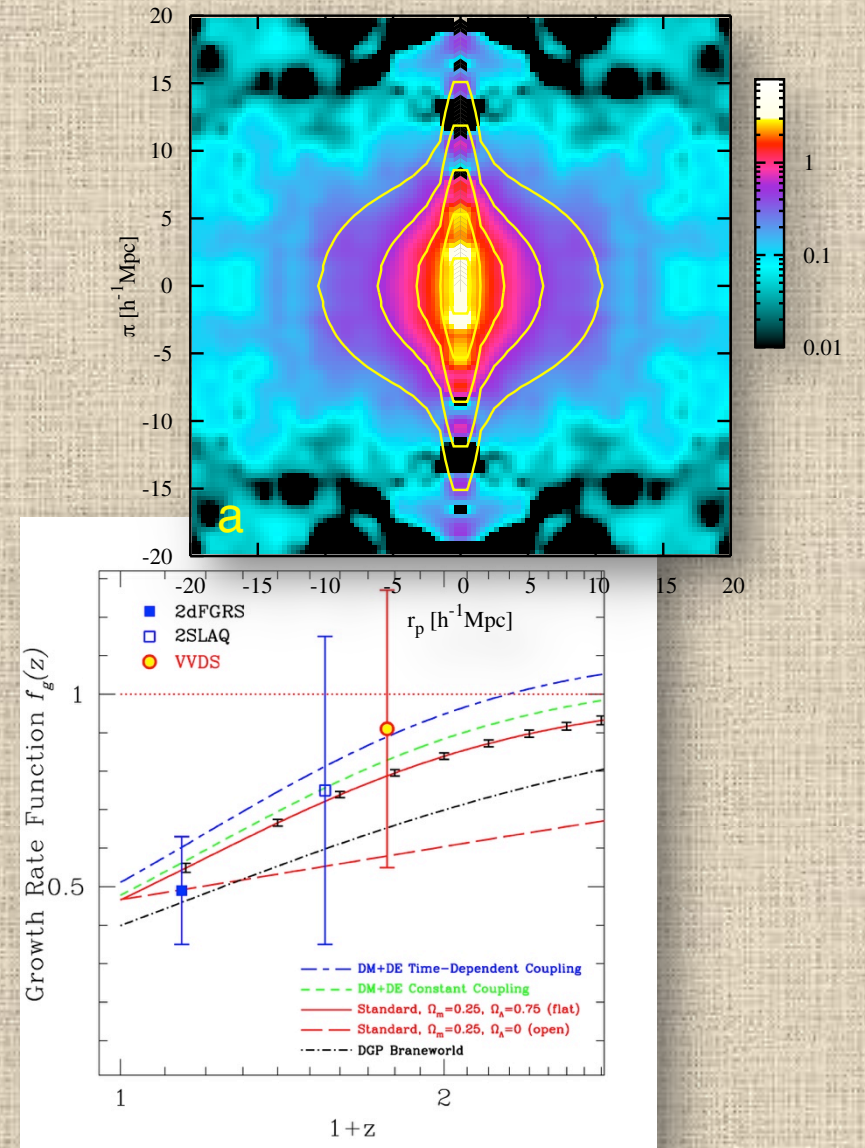
Structure in VVDS-Deep (Le Fevre et al. 2005)



VVDS-Wide F22 field: 4 deg², 10,000 redshifts to $z \sim 1.2$

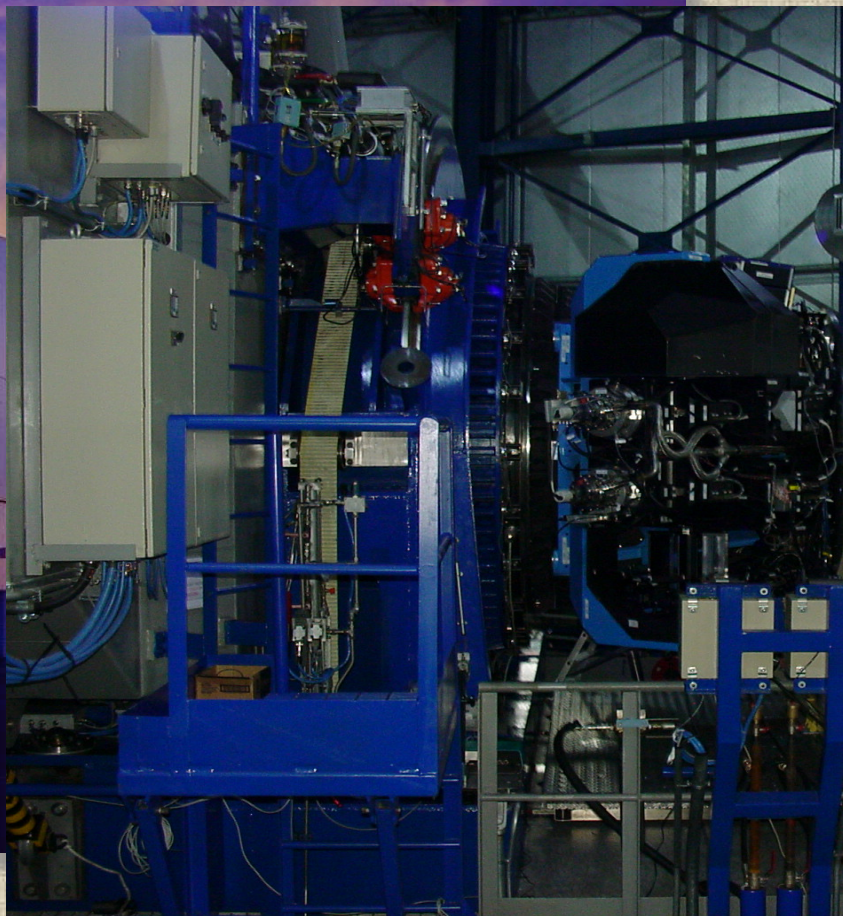


(Garilli et al. 2008, A&A 486, 683)

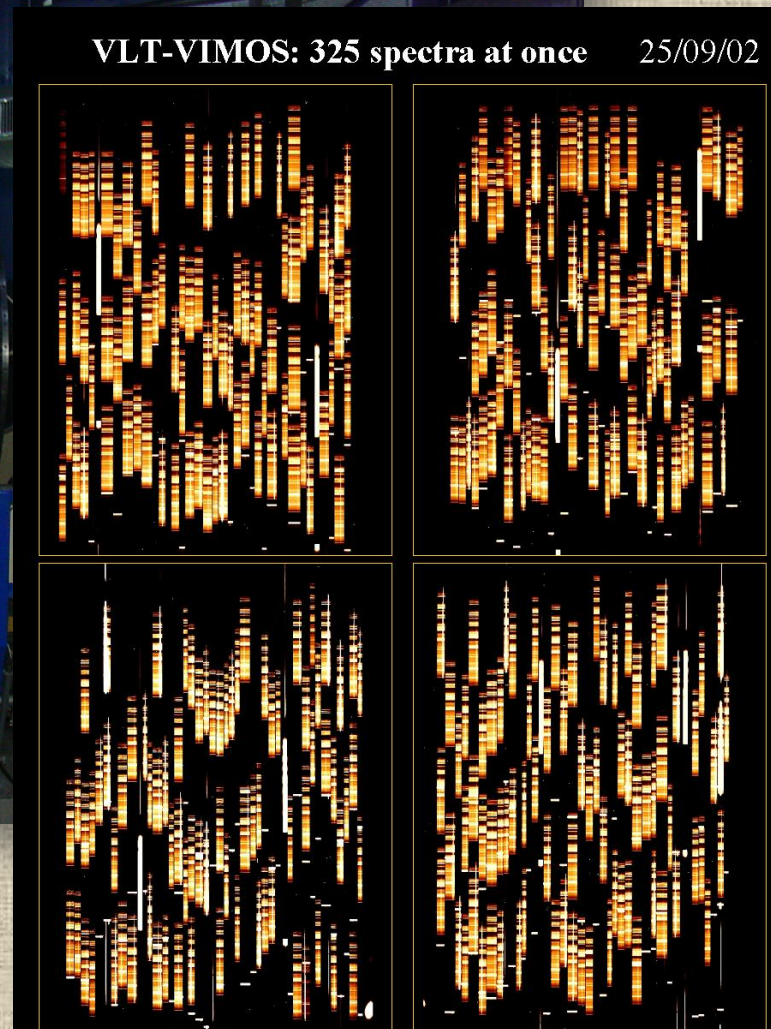


(Guzzo et al. 2008, Nature 451, 541)

VIMOS @ VLT fills unique niche in density-area space



VLT-VIMOS: 325 spectra at once 25/09/02



At VIPERS depth: ~ 100 gal/quadrant \rightarrow
 $400/224$ gal/arcmin² \sim **6500 gal/deg²**



VIPERS Team

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

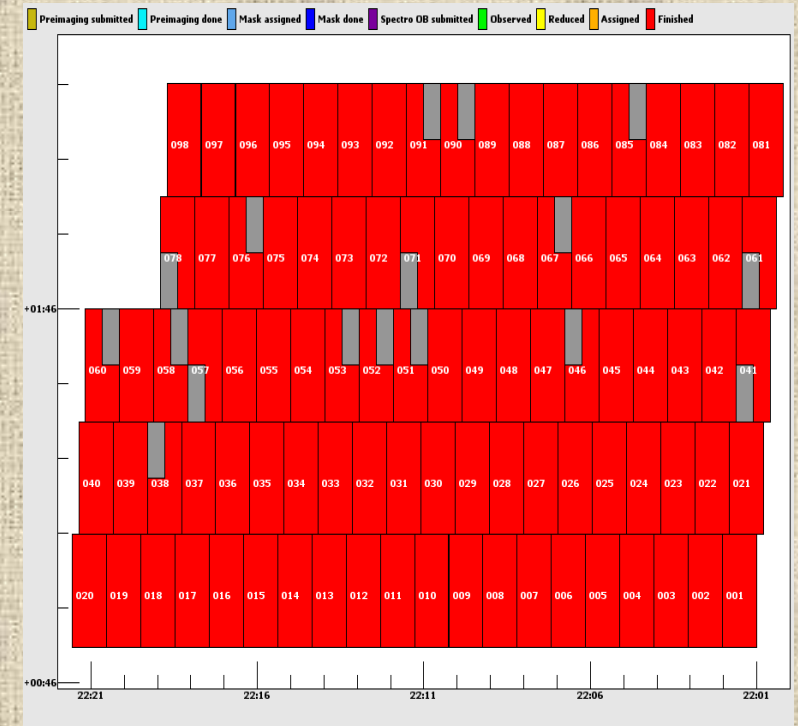
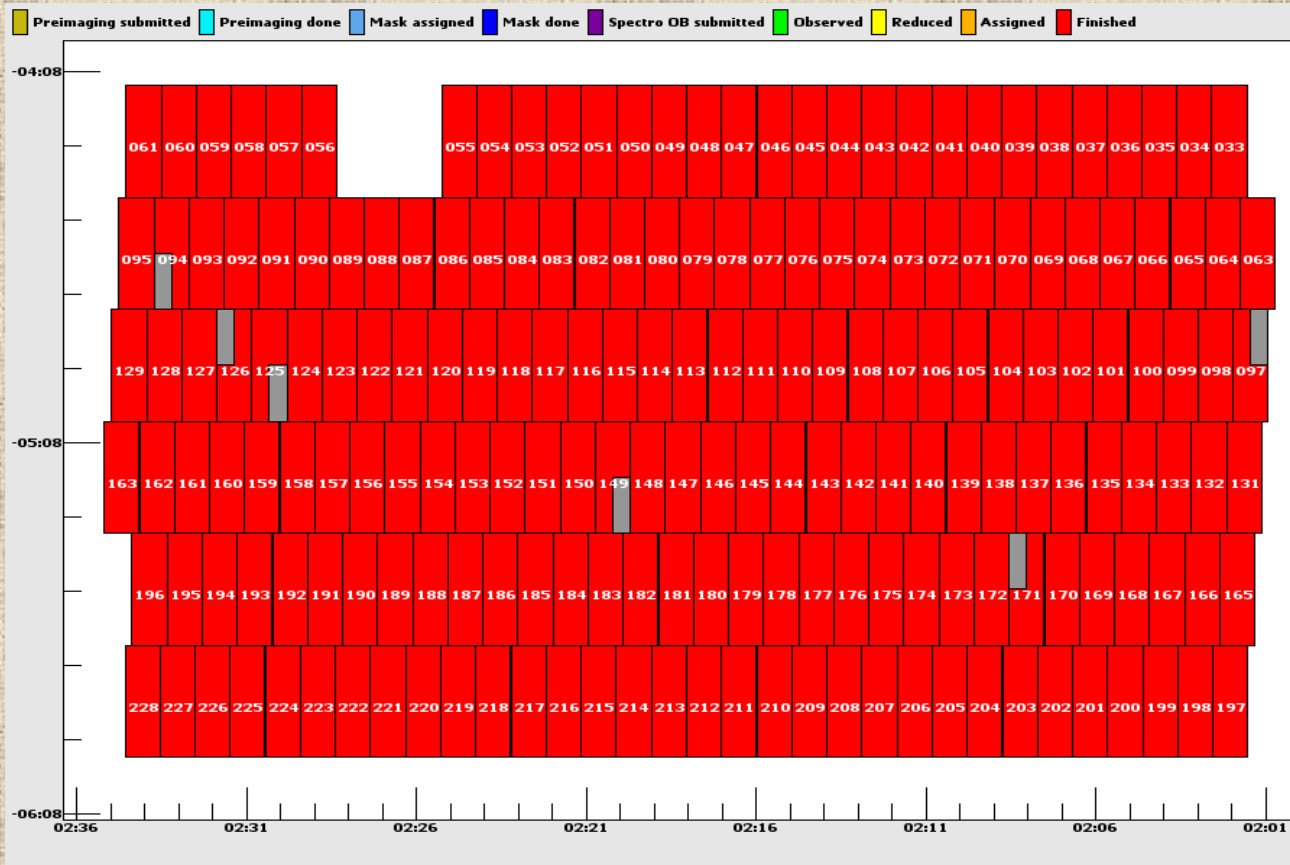




Sky coverage today: VIPERS is finished!

W1

W4



VIPERS Status



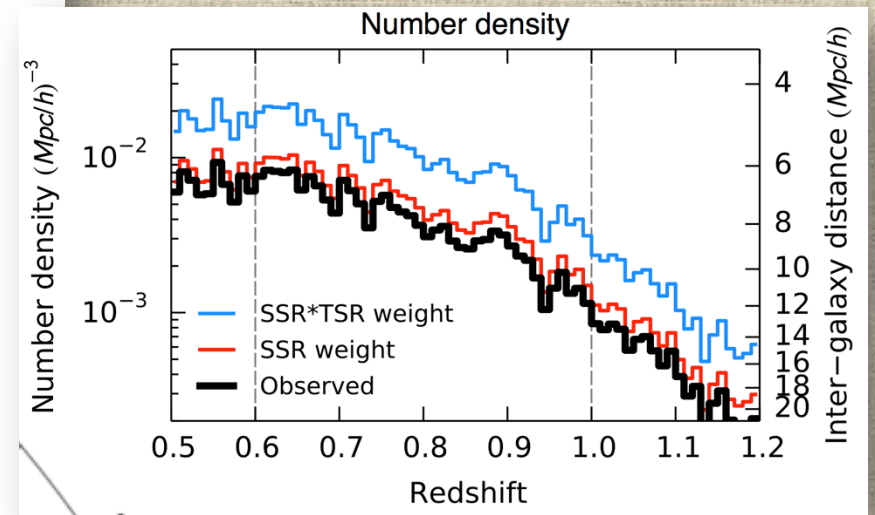
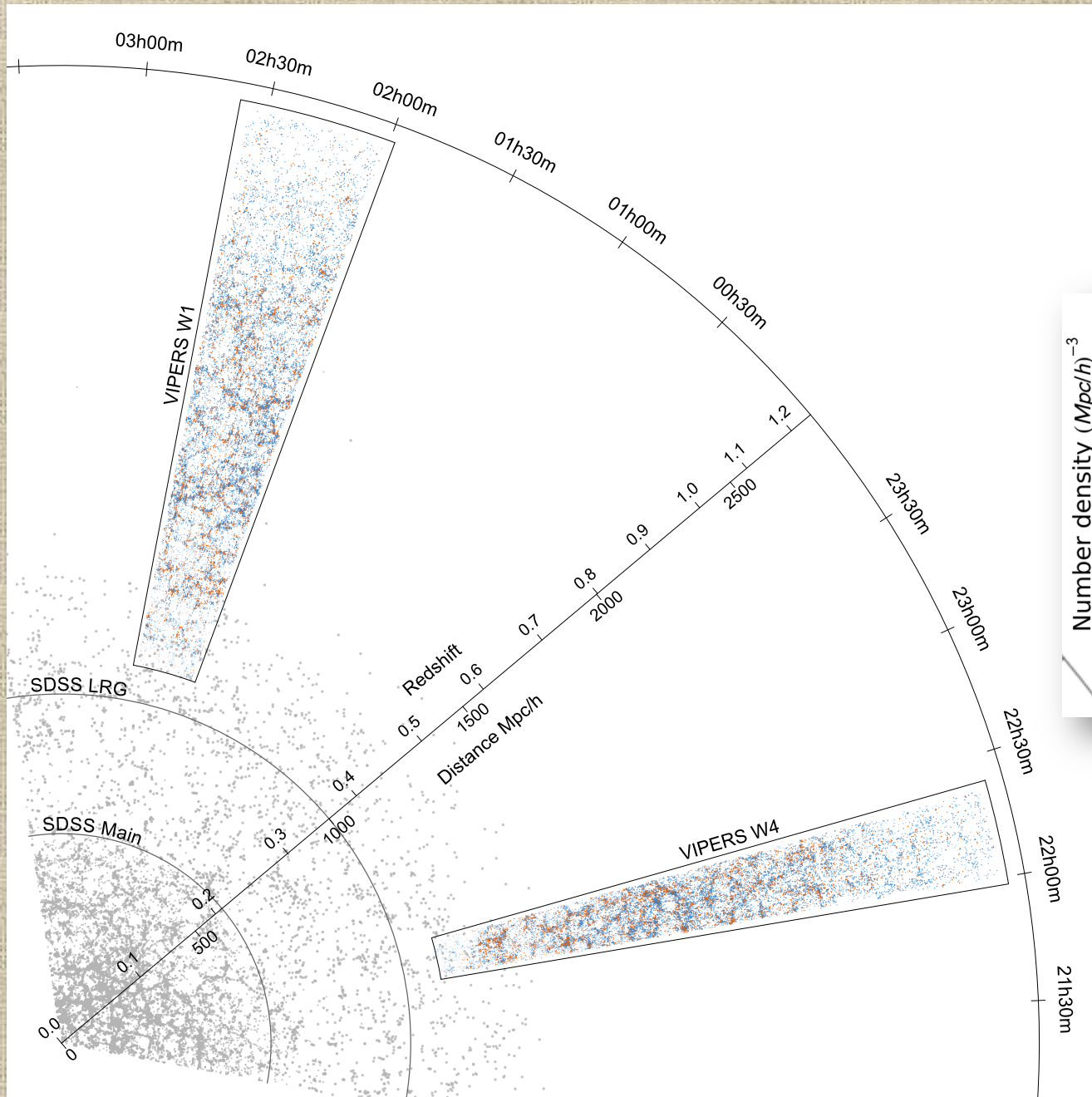
- Observations completed in January 2015; all data reduced and validated: final catalogue (V7.0) available to team

SURVEY STATUS AS OF 14/05/2015

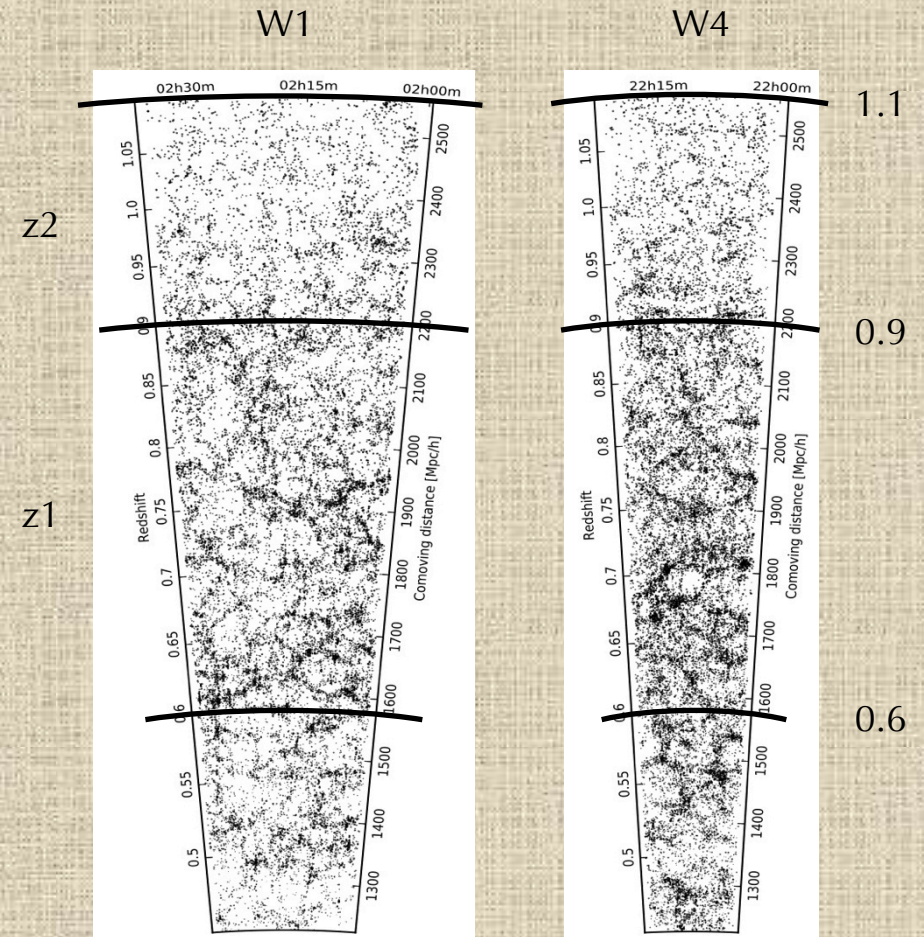
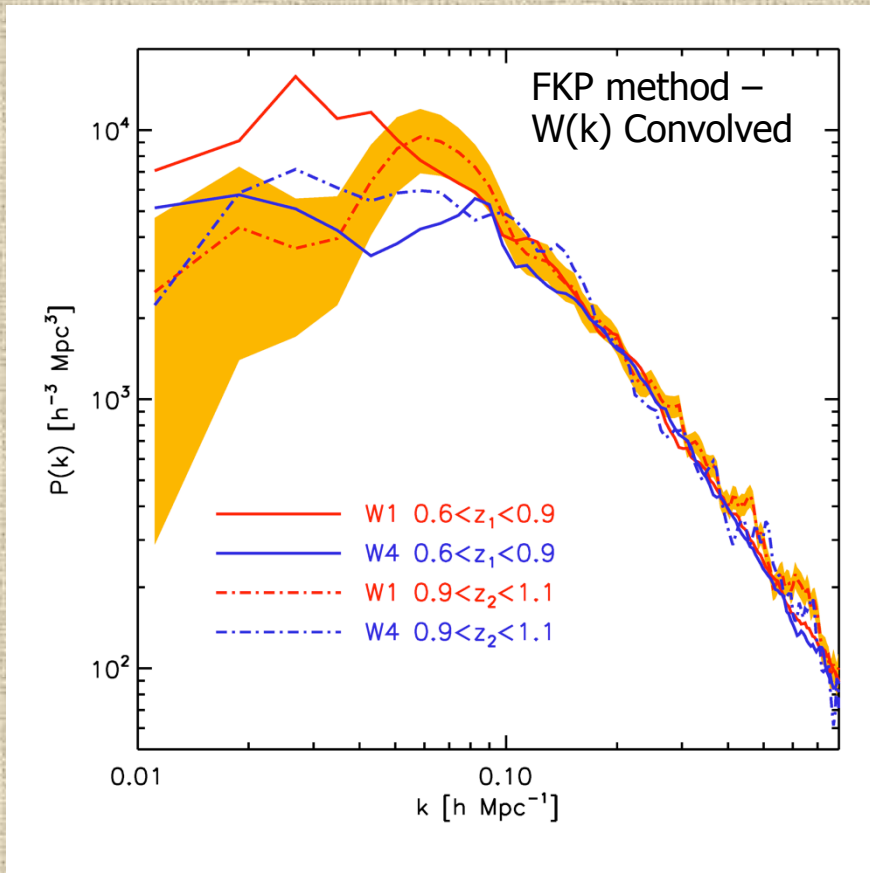
| EFFECTIVE TARGETS | MEASURED REDSHIFTS | STELLAR CONTAMINATION | COVERED AREA |
|-------------------|--------------------|-----------------------|----------------|
| 93252 | 88901 | 2265 (2.5 %) | 100.0 % |

EFFECTIVE TARGETS (ET) are all the primary targeted objects with the exclusion of the ones flagged as -10 (undetected). MEASURED REDSHIFTS (MR) are the fraction of ET for which a redshift has been measured. STELLAR CONTAMINATION are the MR objects which have been identified as stars.

- September 2016: public release of full data set



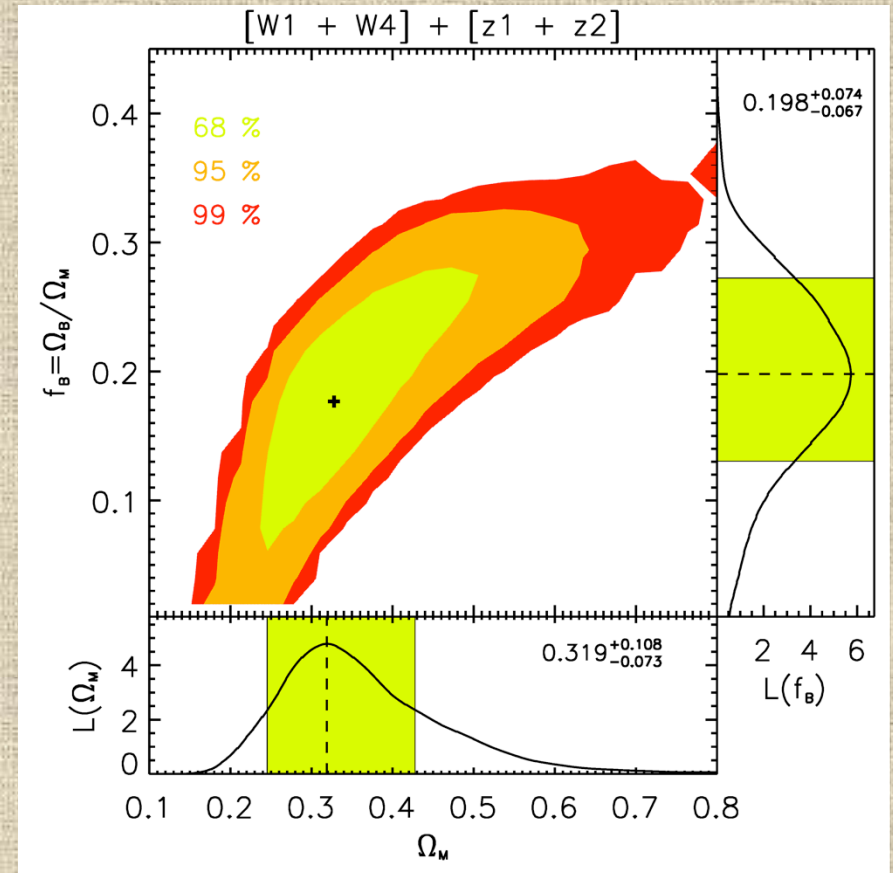
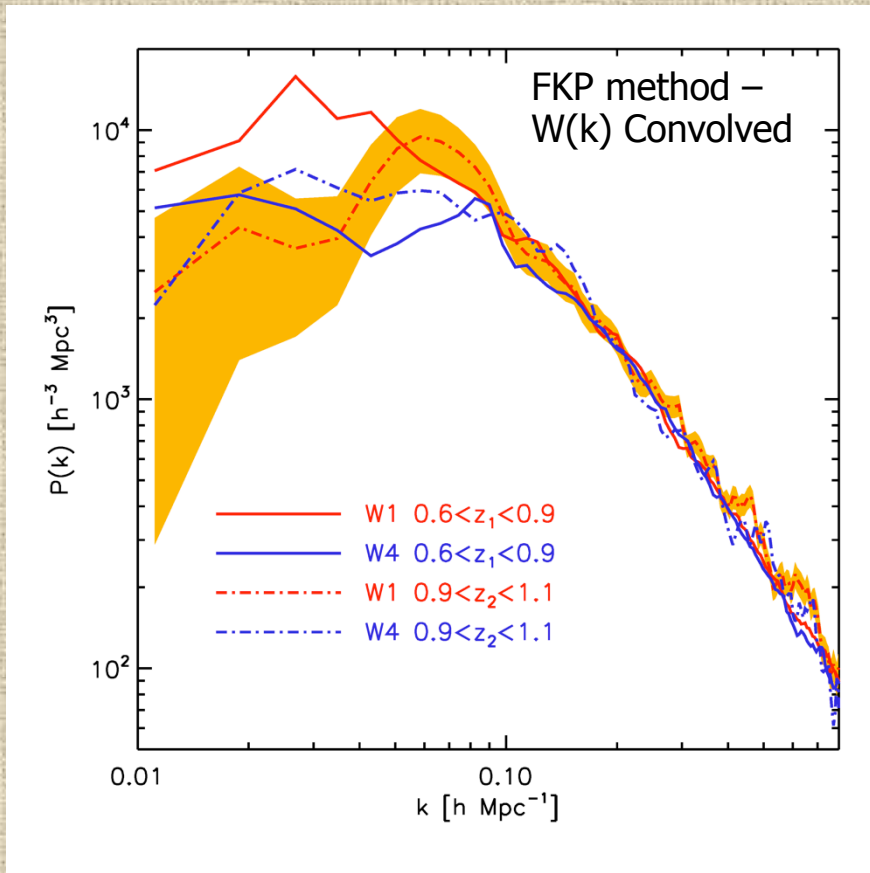
The power spectrum of the galaxy distribution at $z=0.5-1.1$ from VIPERS (S. Rota PhD work)



- Very careful treatment of window function
(Rota, Bel, Granett, LG & VIPERS Team, to be submitted)

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

The power spectrum of the galaxy distribution at $z=0.5-1.1$ from VIPERS (S. Rota PhD work)



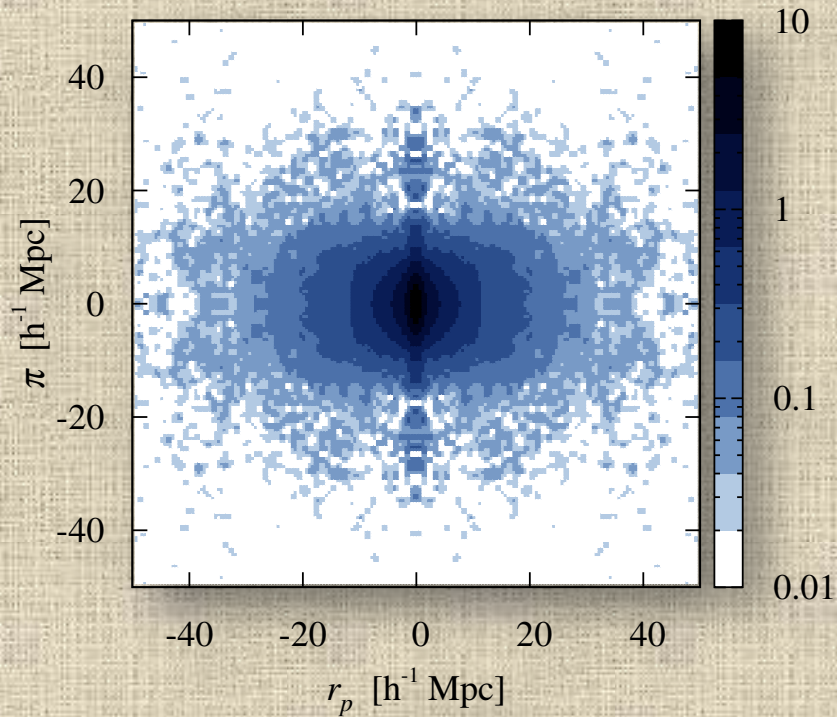
- Very careful treatment of window function

(Rota, Bel, Granett, LG & VIPERS Team, 2016, to be submitted)

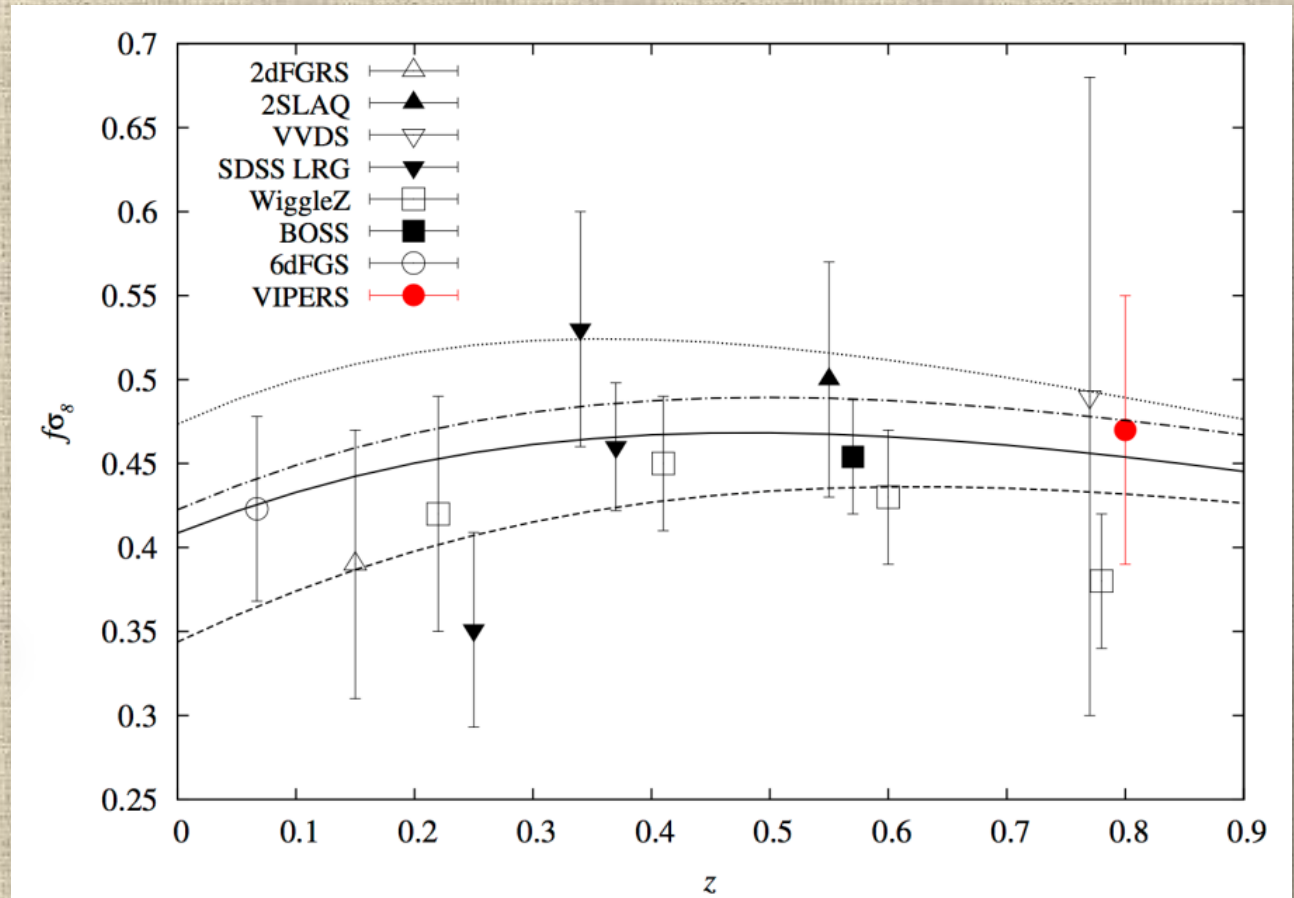
- 4 independent estimates: 2 z bins in 2 independent fields (W1 and W4)



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



VIPERS: $f\sigma_8(z=0.8) = 0.47 \pm 0.08$

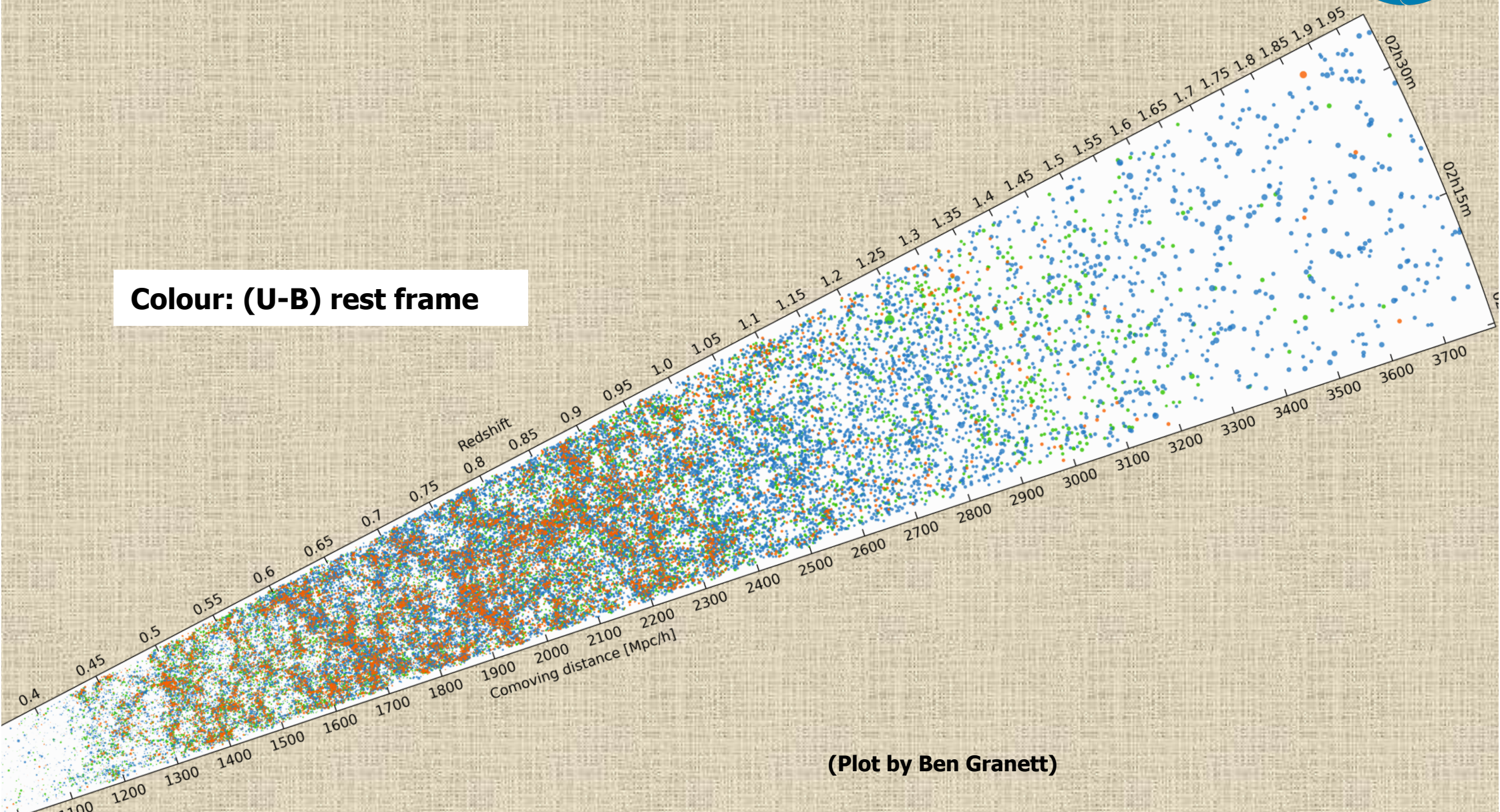


De la Torre et al. 2013

VIPERS provides detailed structure AND galaxy properties

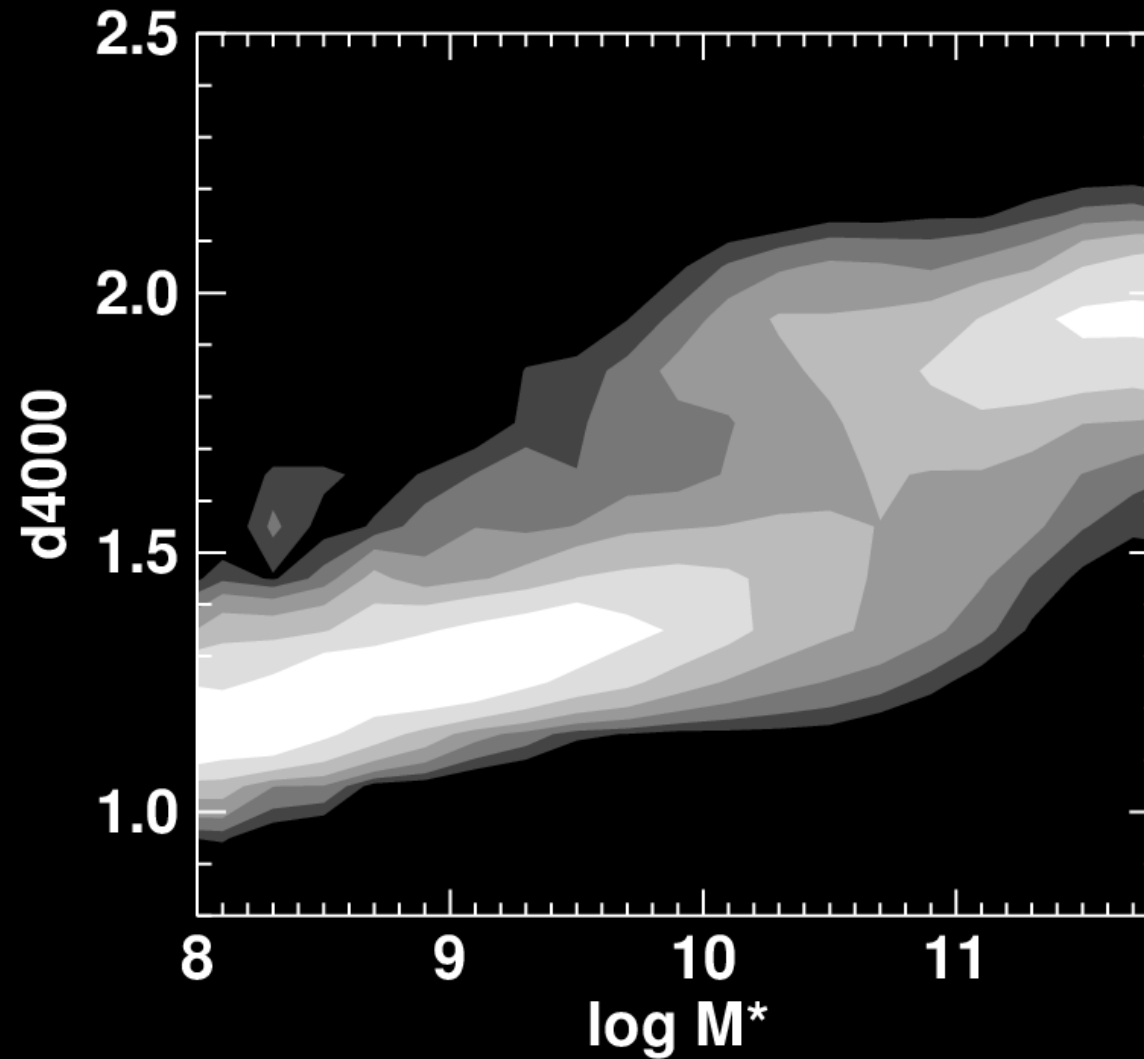


Colour: (U-B) rest frame



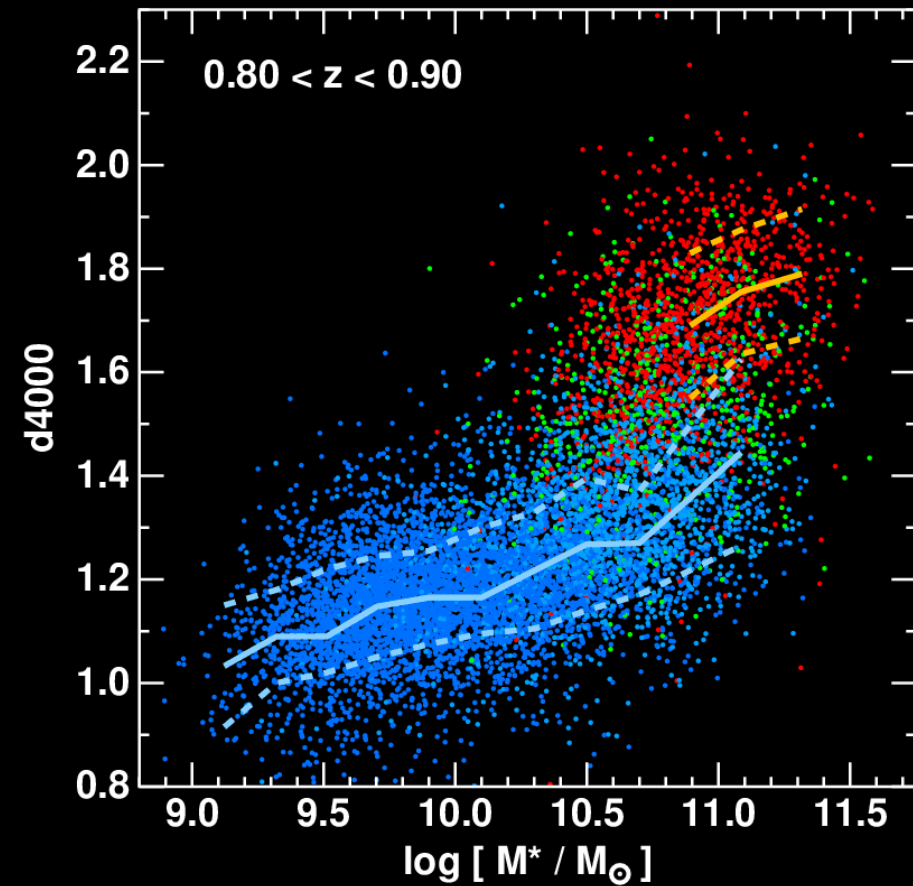
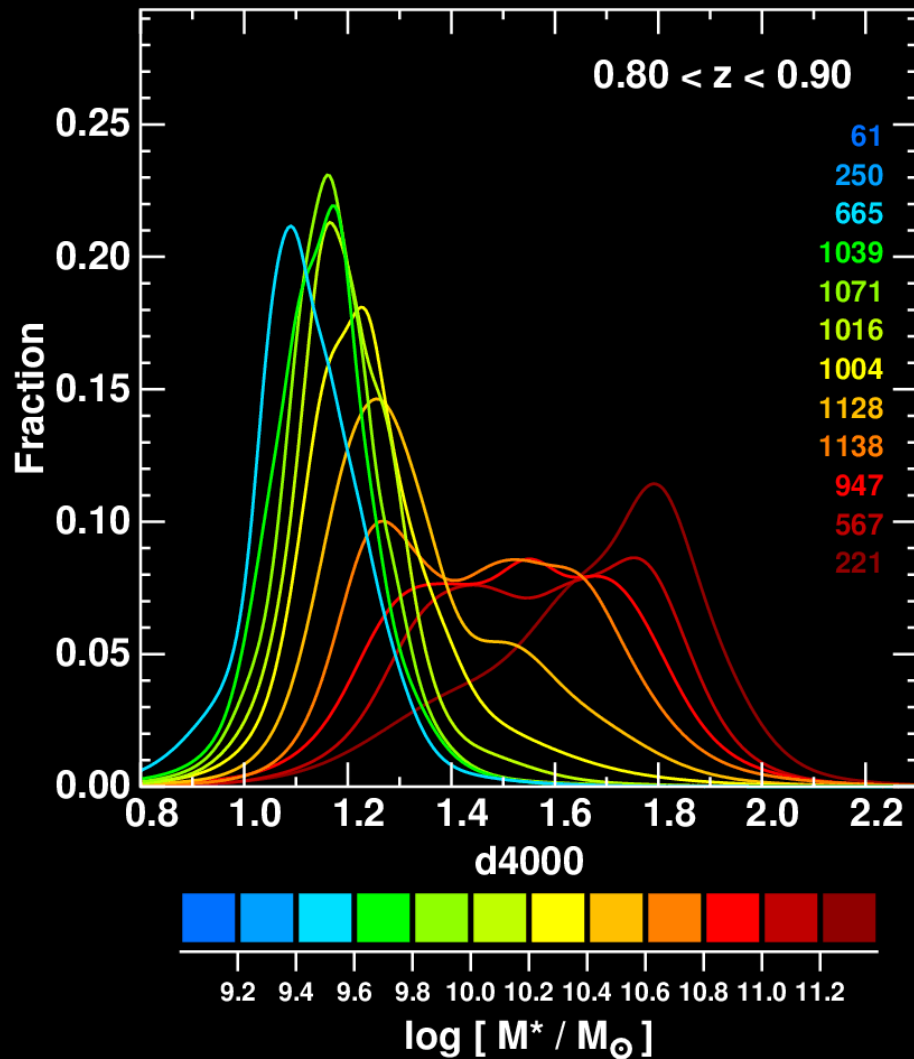
(Plot by Ben Granett)

Statistical astrophysics at $z \sim 0$ (SDSS)



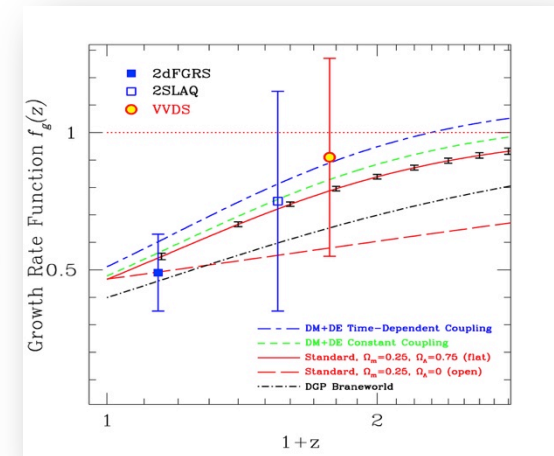
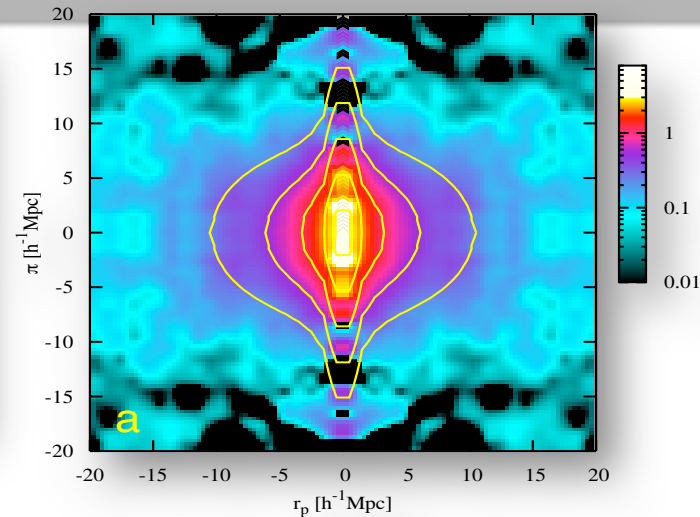
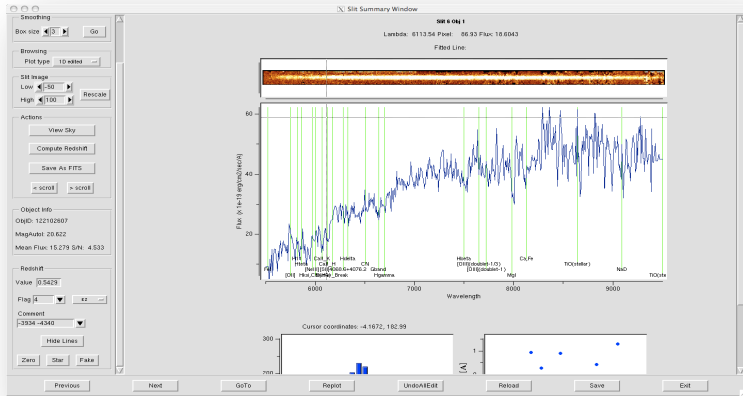
SDSS (Kauffman+)

VIPERS does the same out to $z \sim 1$



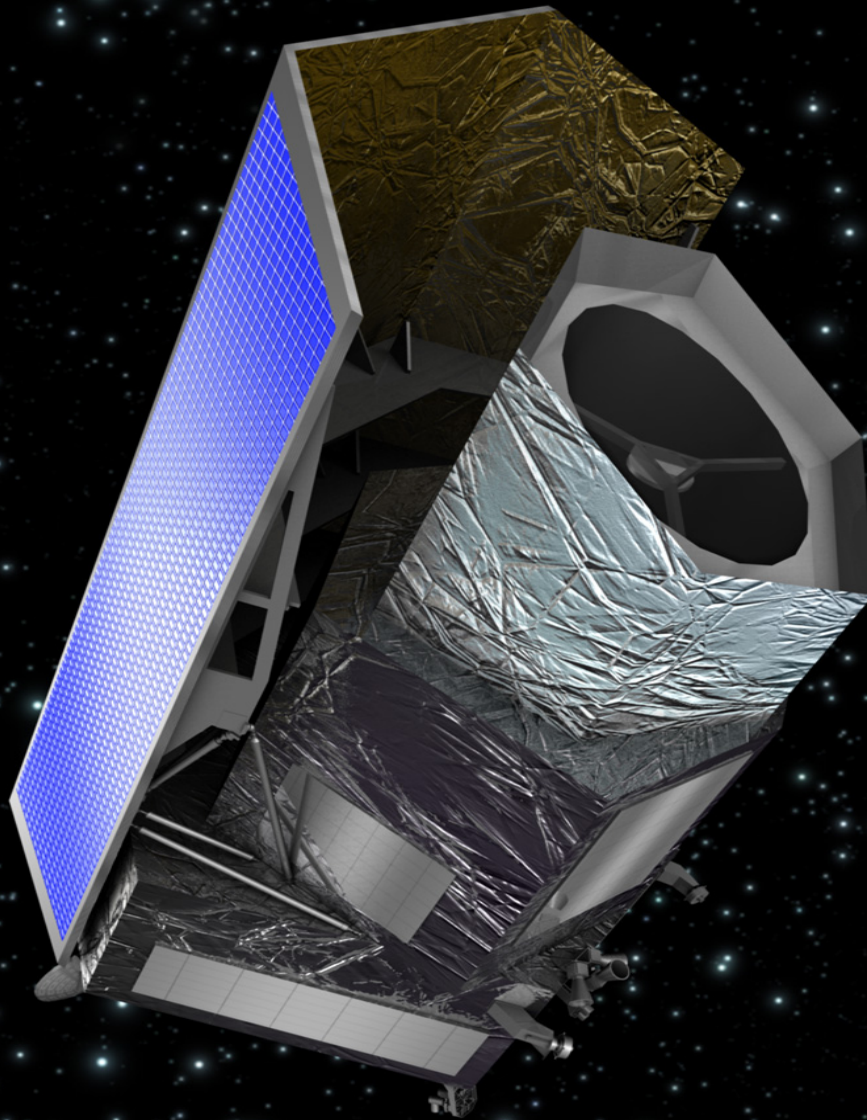
VIPERS (just one of 4 z slices) (Heines, Iovino,+, in preparation)

The lesson from VIPERS



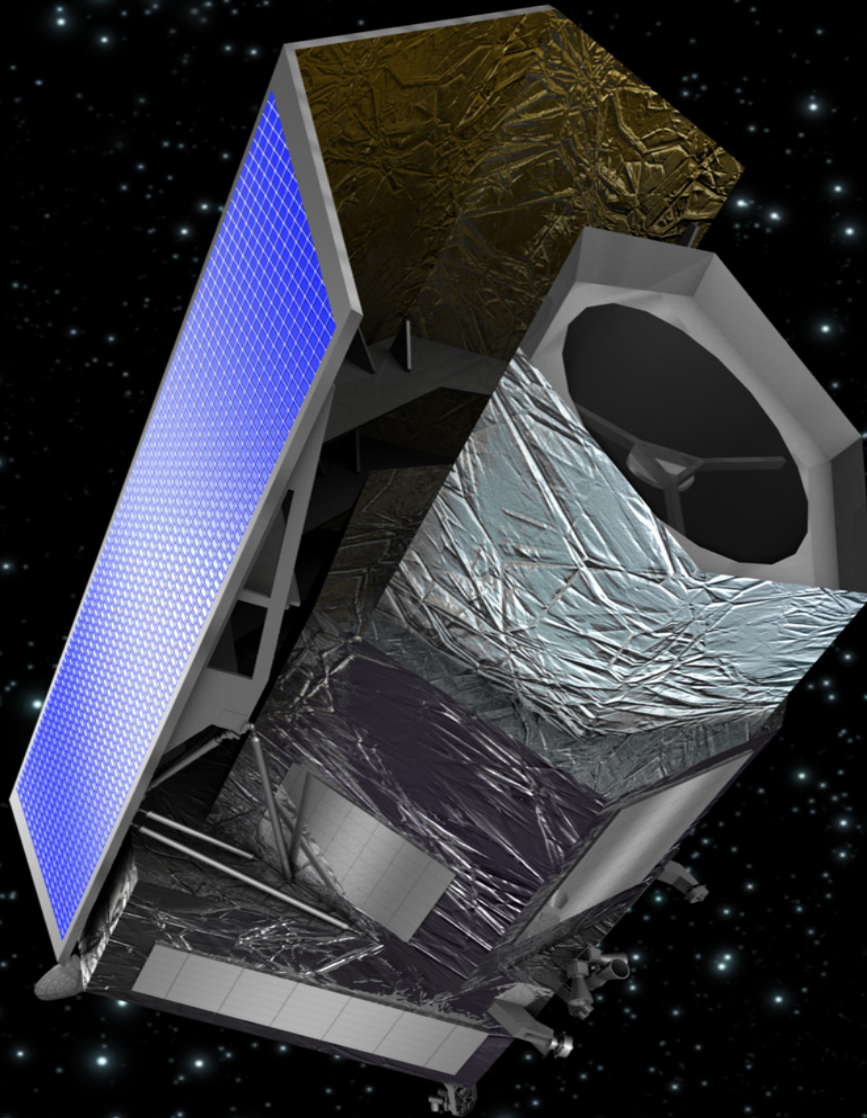
- Natural evolution of what started some time ago with **VIMOS construction** (Vettolani/Lefevre, end of 1990s), matched to growth of scientific leadership in the field (early 1990s: ESP and ESO Key Programme attempts)
- **VVDS – zCOSMOS – VUDS – VIPERS – VANDELS** : unique data analysis software expertise at INAF-IASF gave leadership position (e.g. *EasyLife* pipeline, Garilli et al. 2012, PASP, 124).
- **Combined to scientific leadership** in both areas of galaxy clustering and galaxy evolution (e.g. RSD Nature paper from VVDS). This led “naturally” to Italian P.I.-ship and coordination of VIPERS
- **All this led to natural involvement in Euclid, next ESA milestone mission**

Euclid



- An ESA mission with extra contribution by national agencies: France & Italy among main contributors as lead countries of parent DUNE (Refregier+) and SPACE (Cimatti+) projects
- Euclid Consortium Lead: Yannick Mellier (IAP)
- 1.2 m telescope
- Visible imaging (1 band)
- Infrared imaging (Y,J,H)
- Infrared slitless spectroscopy
- Launch 2020
- 15,000 deg² survey
- Images for 2×10^9 galaxies
- Spectra for $\sim 5 \times 10^7$ galaxies ($0.9 < z < 1.8$)

Euclid



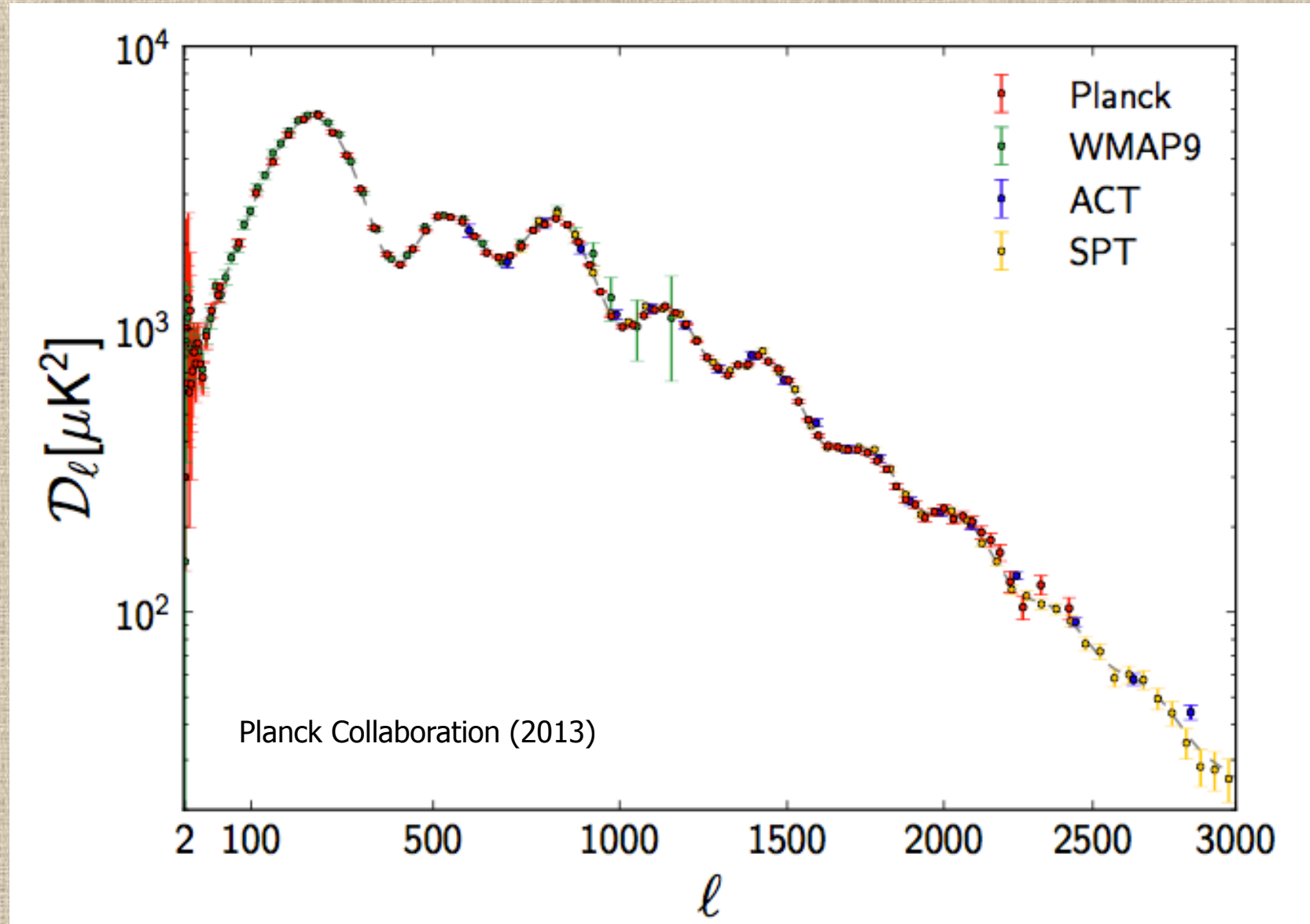
OBJECTIVES:

- Build a map of dark and luminous matter over 1/3 of the sky and to $z \sim 2$
- Unveil the nature of dark matter
- Solve the mystery of dark energy (cosmic acceleration)
- Multiple probes \rightarrow max control over systematic errors

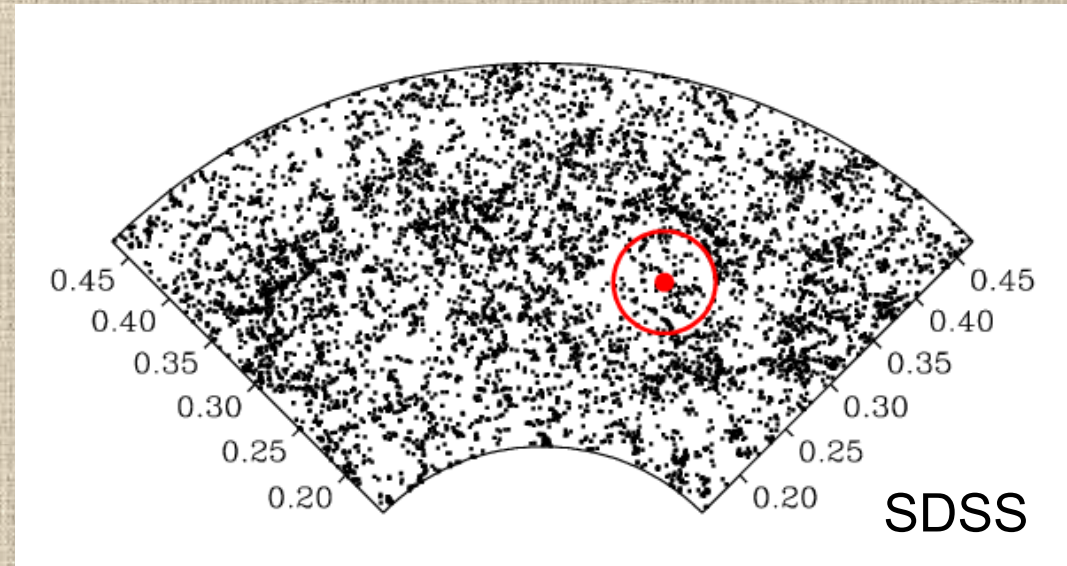
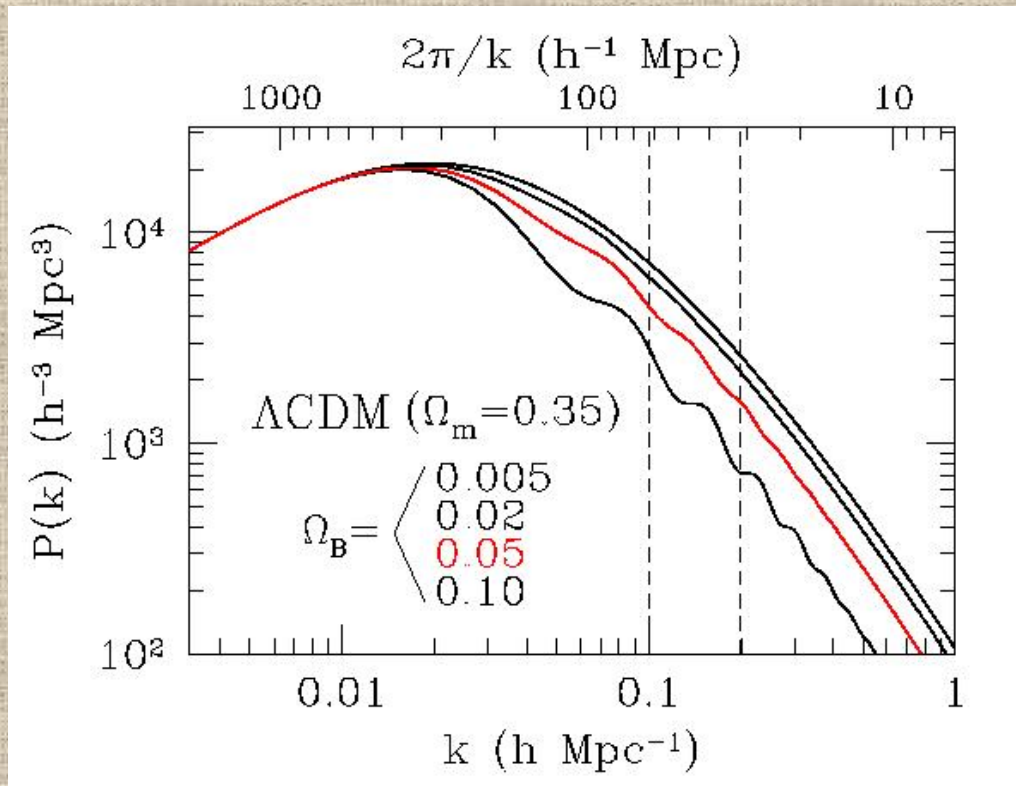
The Euclid "Red Book"

<http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=48983#>

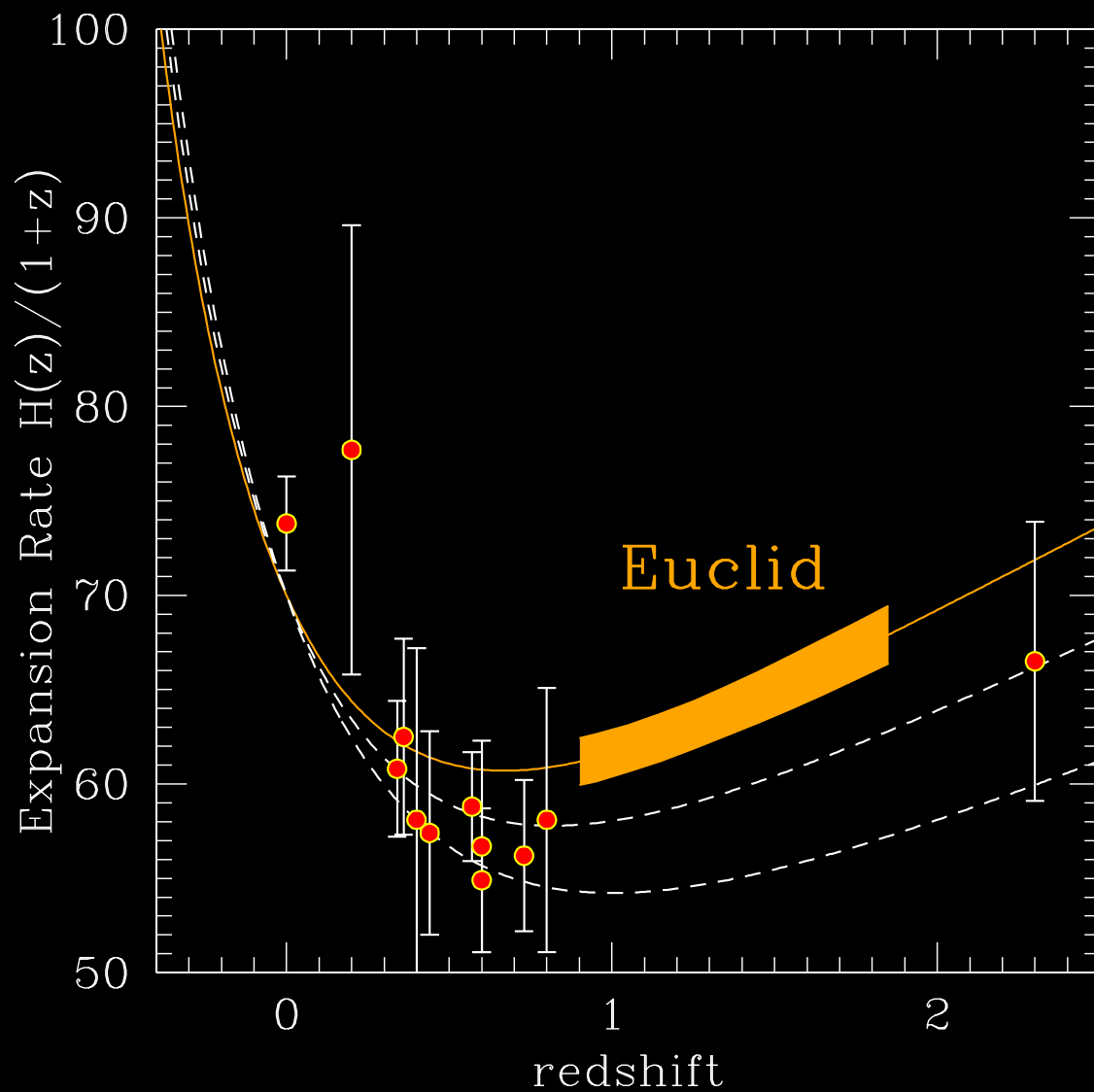
Baryonic Acoustic Oscillations in the CMB



Baryonic Acoustic Oscillations imprint in the galaxy distribution

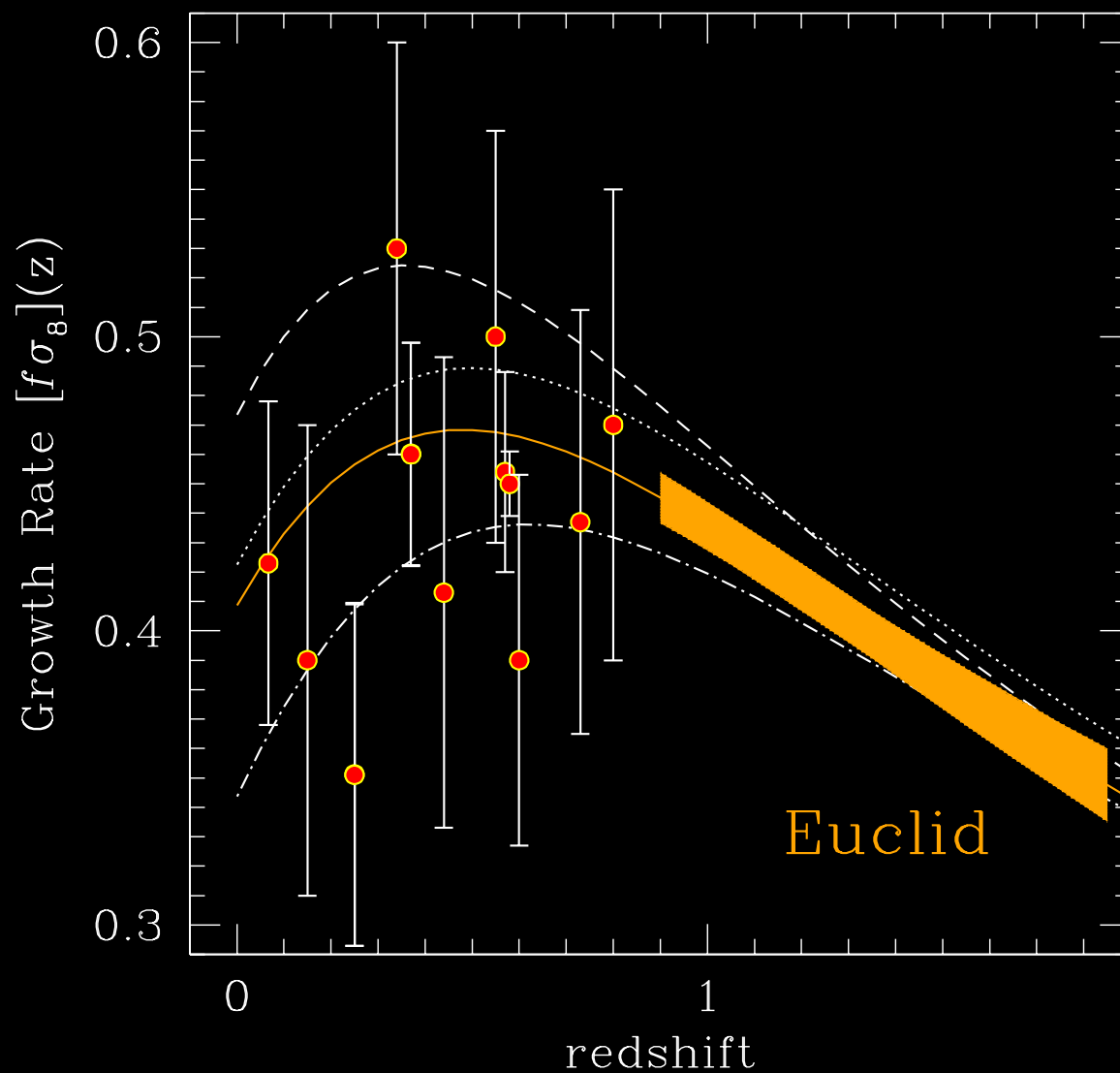


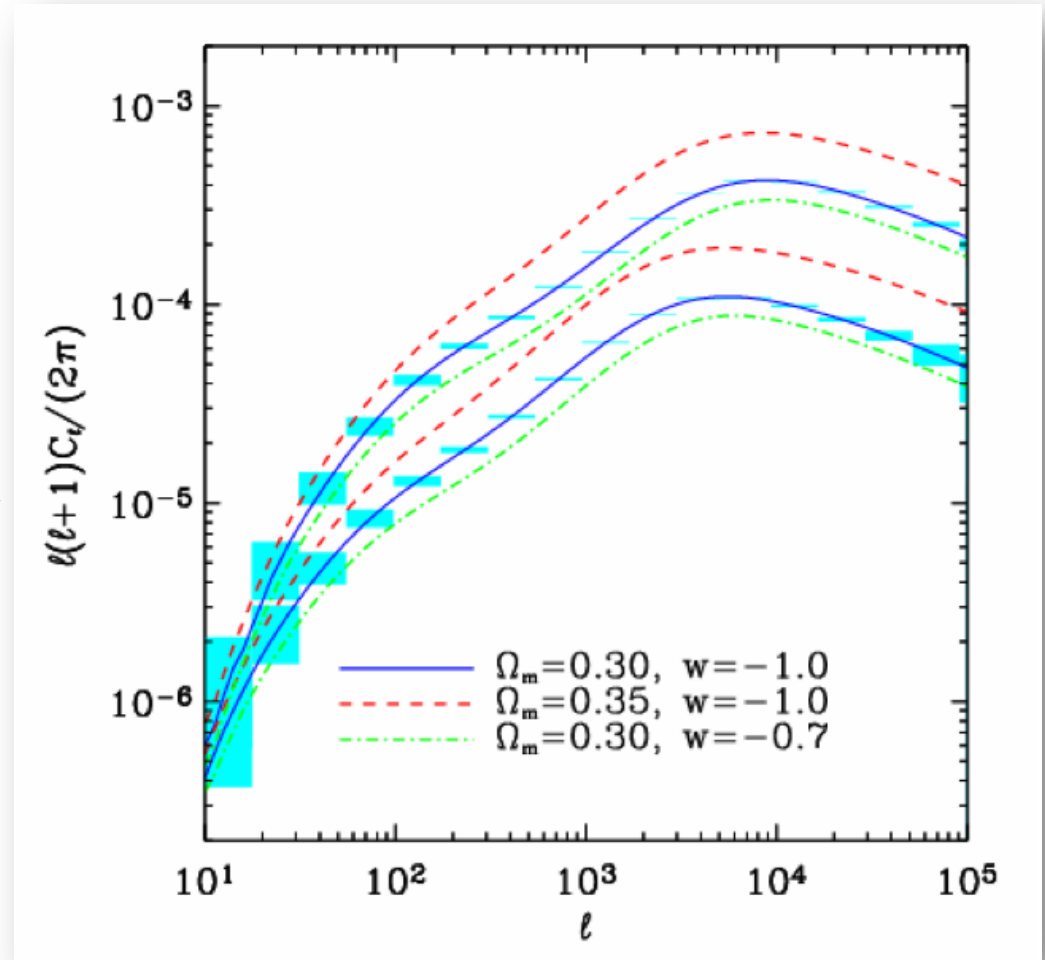
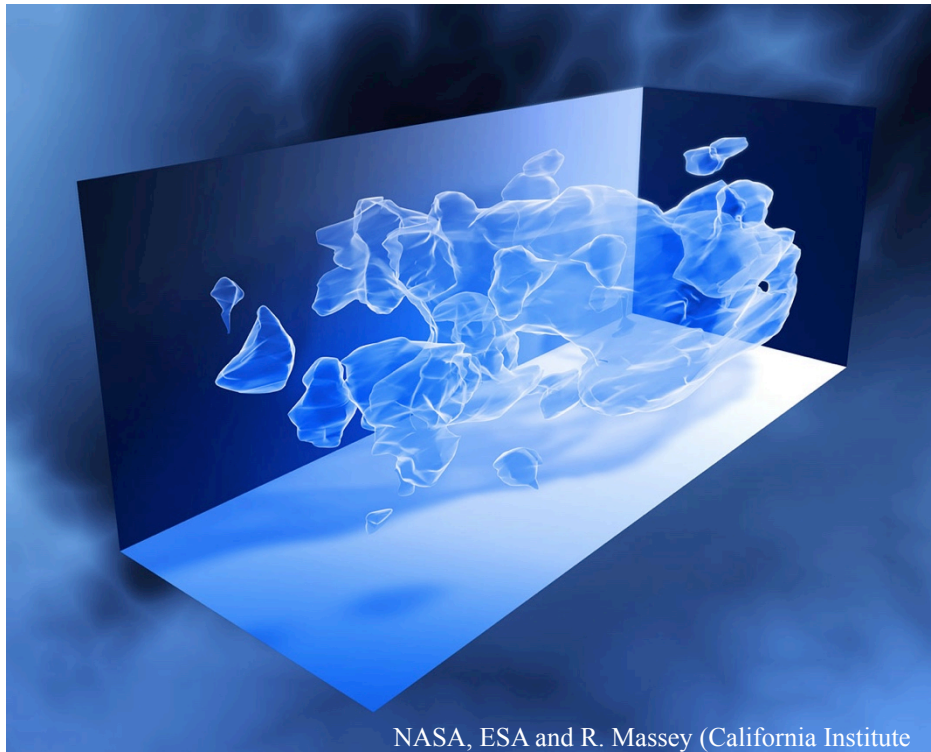
Euclid: expansion history from BAO to $\sim 1\%$ precision



Euclid: growth rate from RSD to $\sim 1\%$ precision

→ Our main contribution to original SPACE proposal





- Weak Lensing can directly map the dark matter distribution in 3D

Systematic errors on Redshift-Space Distortions measurements

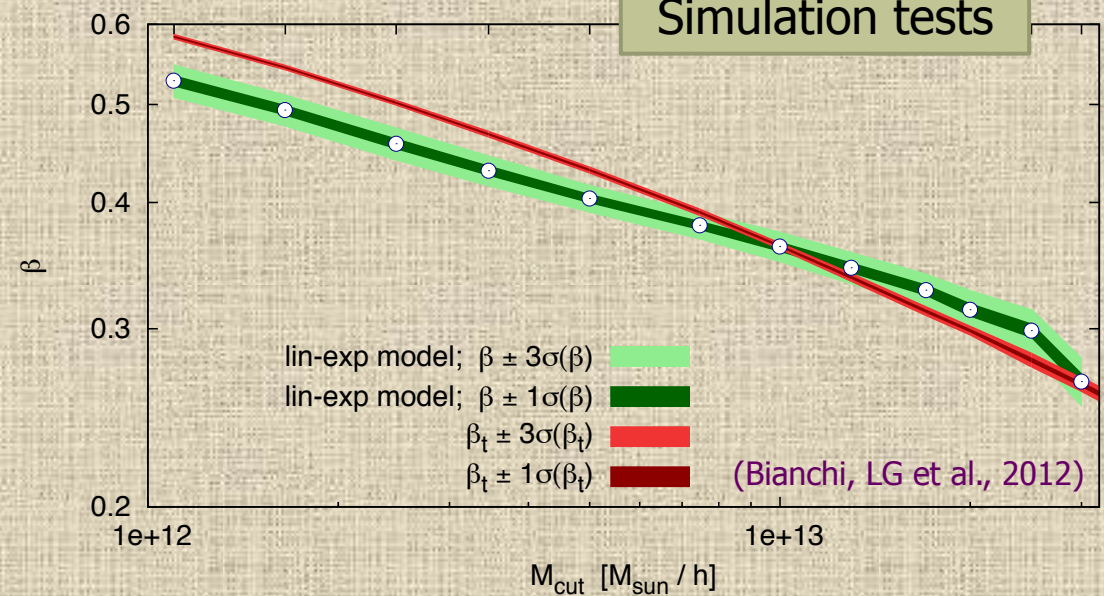
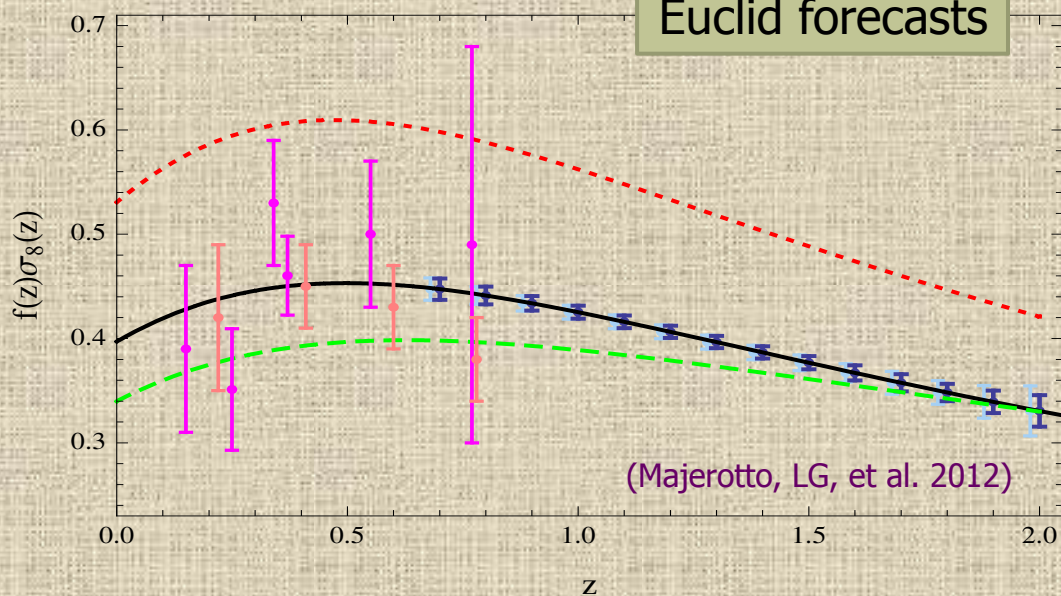
Need to improve modelling to enter "*precision RSD era*"

→ EUCLID: **expected 1-3% precision**

→ Standard RSD modelling: **up to 10% systematic error**

Euclid forecasts

Simulation tests





"ILLUMINATING DARK ENERGY WITH THE NEXT GENERATION OF COSMOLOGICAL REDSHIFT SURVEYS"

- ERC Advanced Research grant, 5 years (1 May 2012 – 30 April 2017)
- Budget: 1.72 Meuro
- 6 postdoc + 2 PhD positions

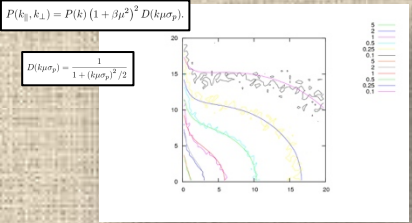
GOALS:

- Improve modelling and estimators of clustering and redshift distortions, preparing for precision cosmology
- Test on numerical simulations
- Apply them to current and new surveys to fully exploit information content (e.g. VIPERS)
- Optimally combine with other probes (CMB, WL, clusters, ...)

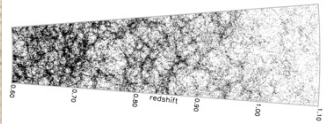


Building scientific leadership and tools for future surveys

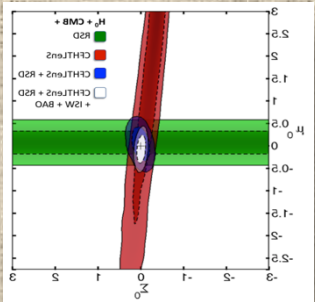
DEVELOPMENT OF NEW MODELS AND ESTIMATORS OF COSMOLOGICAL PARAMETERS FROM GALAXY CLUSTERING AND REDSHIFT-SPACE DISTORTIONS
J. Bel, B. Granett, A. Hawken, F. Mohammad (PhD), D. Bianchi (PhD)



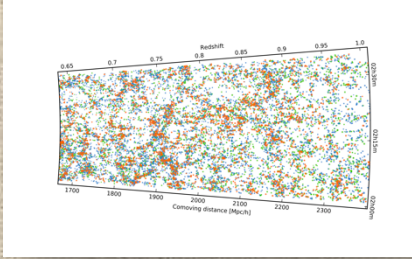
NUMERICAL SIMULATIONS AND MOCK SURVEYS
C. Carbone, Y. Koda, M. Zennaro (PhD)



TESTS AND VALIDATION ON MOCK SAMPLES
Y. Koda, A. Pezzotta (PhD)

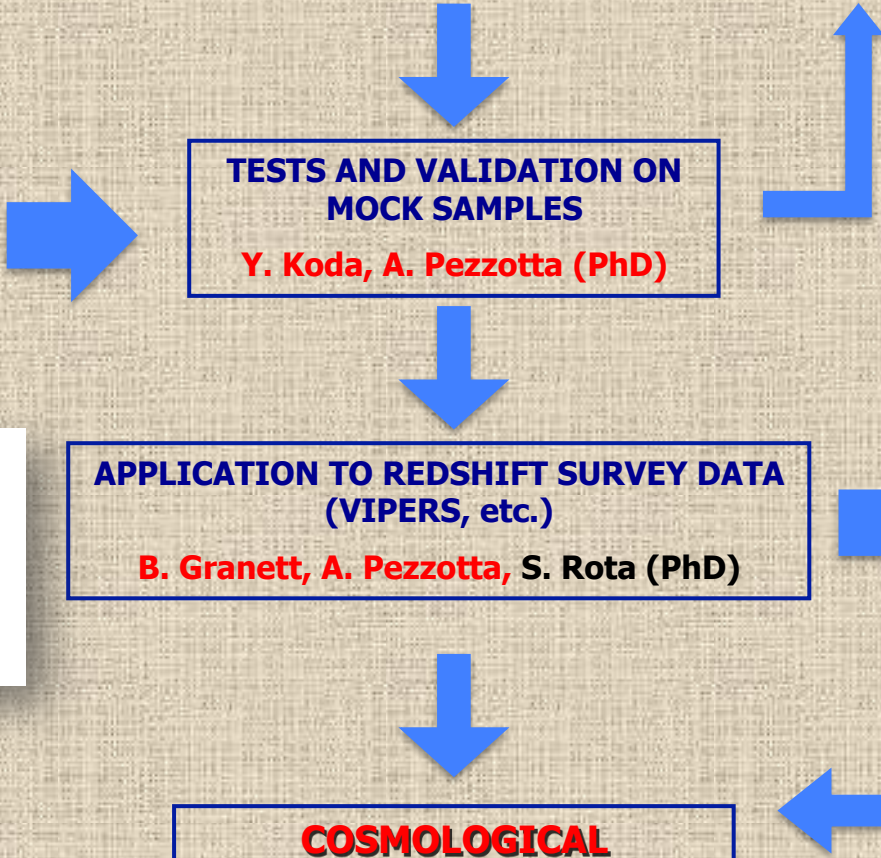


APPLICATION TO REDSHIFT SURVEY DATA (VIPERS, etc.)
B. Granett, A. Pezzotta, S. Rota (PhD)



OPTIMAL COMBINATION WITH OTHER COSMOLOGICAL PROBES (WL, CMB,...)
J. Dossett, C. Carbone

COSMOLOGICAL PARAMETERS



Some ongoing and future surveys: are we involved?



- **CFHTLS** (F): completed, 140 deg² in 5 bands, (e.g. CFHT-Lens project and weak-lensing shear results – basis for VIPERS)
- **Dark Energy Survey** (DES: US/UK/E + Munich LMU, ETH Zurich): started, 5000 deg² in 5 bands
- **VST-KIDS + VISTA-VIKING** (NL, I, D, ...): ongoing, 1500 deg² in 9 bands (from U to K) → **first interesting results shown in Lisbon**
- **LSST** (US-led consortium): dedicated 8m telescope, 20000 deg² (southern sky), in 6 bands (0.3-1.1 m), with time information
- **eBOSS**: latest SDSS redshift survey incarnation: push SDSS telescope to $z \sim 1$ using ELG and LRG + QSO
- **DESI** (US, UK, other partners – e.g. F (LAM) –): full-northern sky redshift survey, >30 million redshifts expected (ELG, LRG, QSO); **the main Euclid competitor**
- **PFS** (Japan + others – e.g. F (LAM) –): Subaru 8m prime focus, both imaging and spectroscopy, being defined
- **4MOST**: refurbished VISTA with fibre coupler (Potsdam/ESO/Australia)
- **WEAVE**: new WHT fibre spectrograph: **Italian involvement**
- **And obviously, SKA redshift surveys...**