Cosmology and large scale structure from existing and future deep sky surveys

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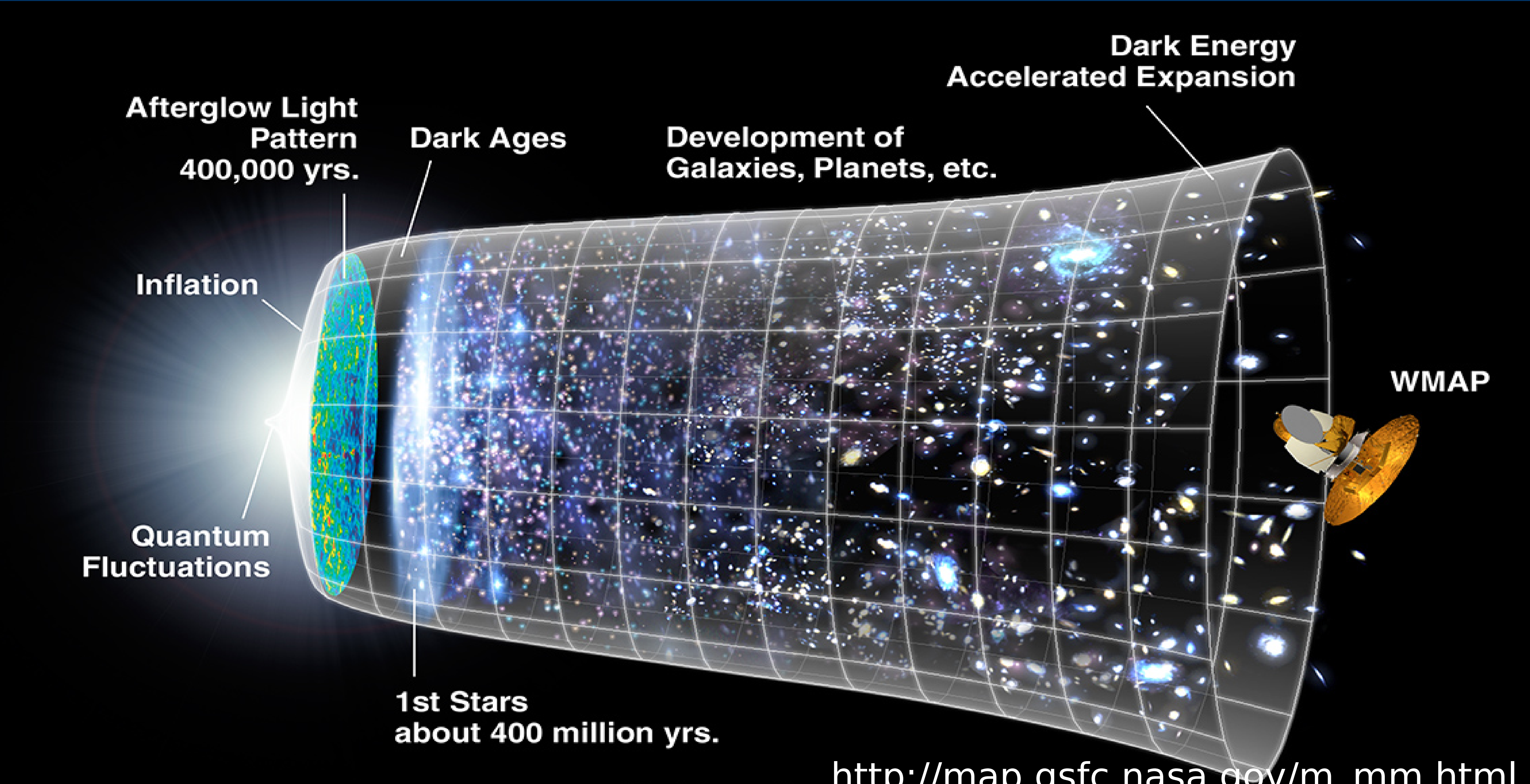
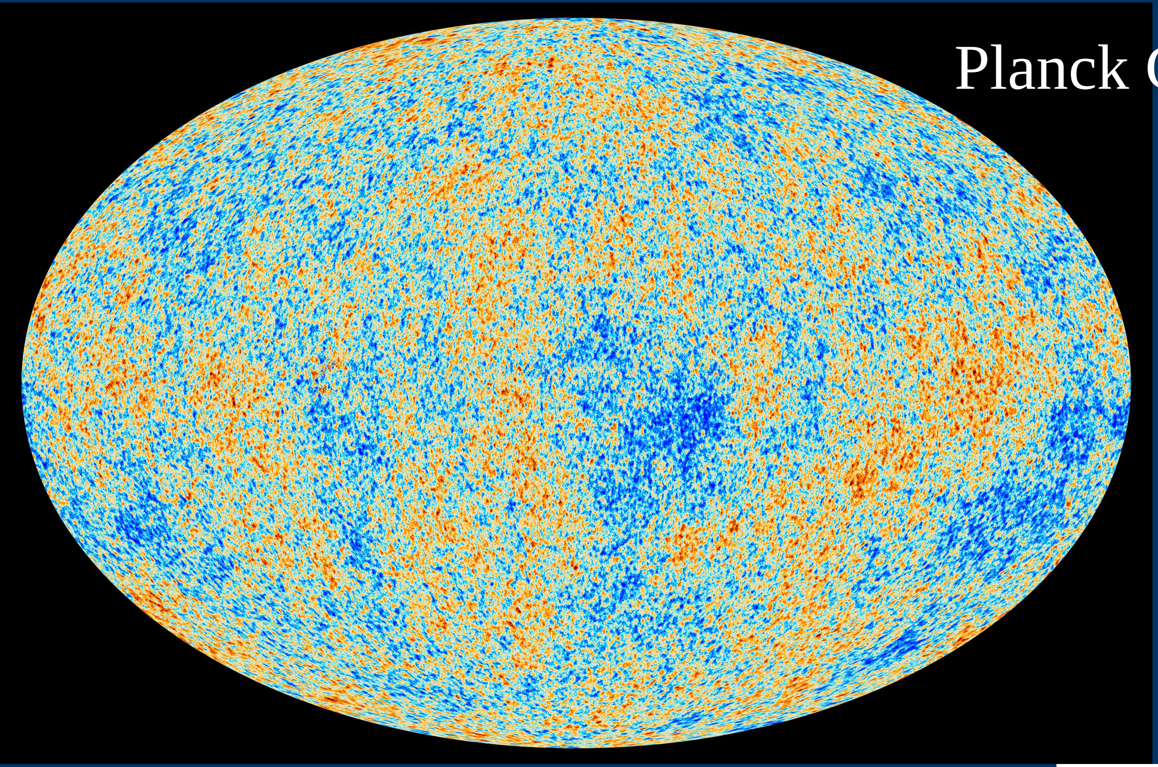
Cosmology: the history and structure of the Universe as a whole



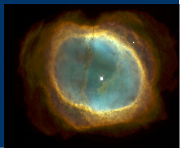
http://map.gsfc.nasa.gov/m_mm.html

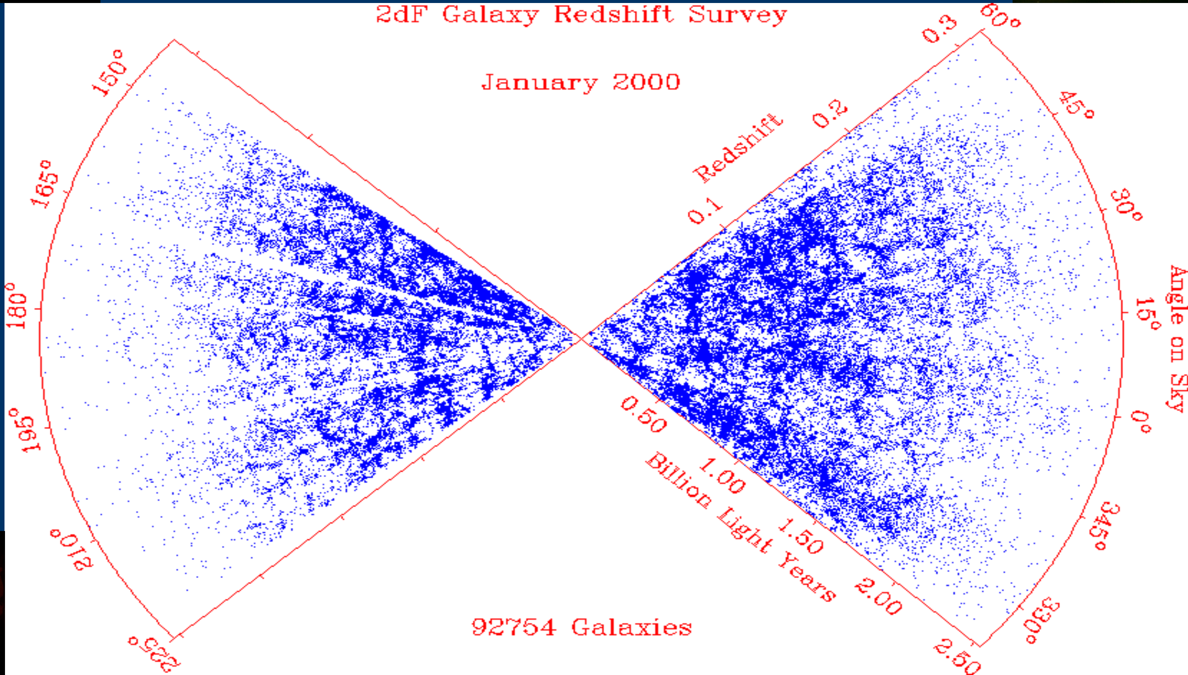


Planck Collaboration (2013, 2015)

?

?





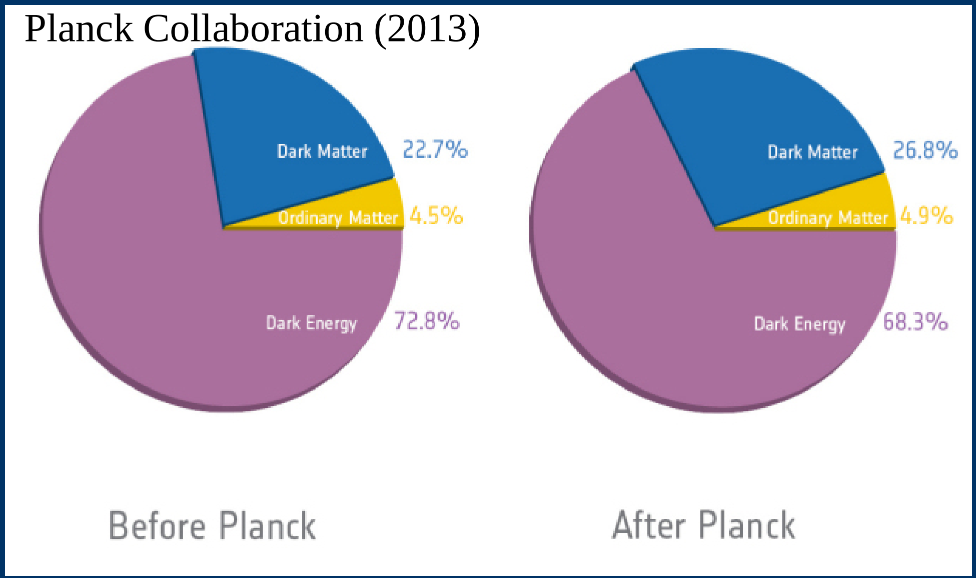
Detailed scenario... with a long series of unknowns

- The basis of the “standard model” is the Einstein's general relativity. But is it correct? Especially on large scales?
- Are the basic assumptions of the Friedman family of the cosmological models correct? Is the Universe really isotropic, homogeneous etc?

Detailed scenario... with a long series of unknowns

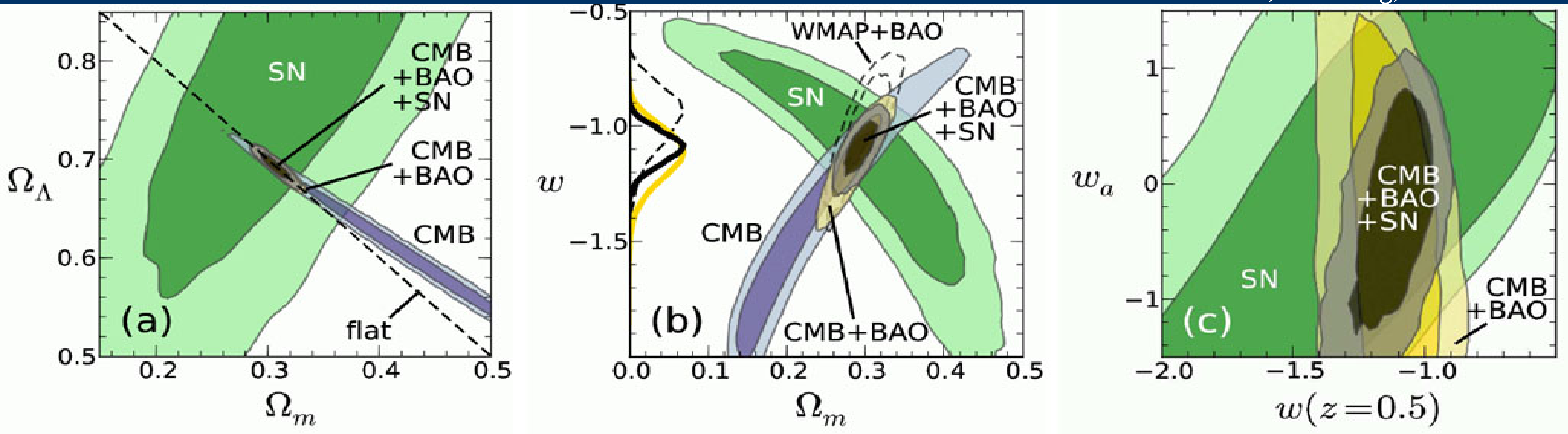
- If so... can we already feel convinced by the observational evidence that the ΛCDM model is "the one"?
- …that we know the basic cosmological parameters (Λ, Ω_m, Ω_k, H_0) sufficiently well?

Going to the details of the ΛCDM Universe...



- ...we need to be aware that all the "standard" values of cosmological parameters arise from fitting multi-parameter models simultaneously to many different sets of data
- …no one type of a data set (CMB, BAO, SneIa, WL) is able to provide a complete set of constraints

Mortenson, Weinberg, White 2014



What gives us the possibility to speak about the era of the “precision cosmology” is the power of combining different datasets...
...in particular:
- CMB data (temperature + polarisation) on one side and
- different kinds of galaxy (and galaxy-related sources: AGNs, SNIa, ...) surveys on another side
...and (weak) lensing surveys, which may be regarded as a separate category.

Further questions to solve

If dark matter exists – what are its properties?

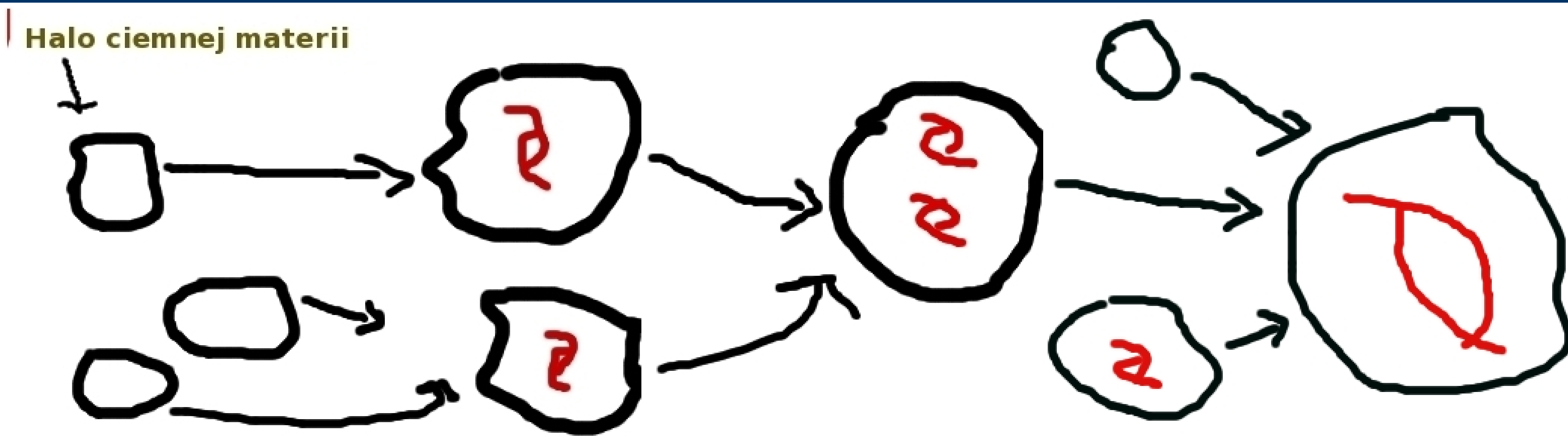
If dark energy exists – what is its nature and properties? Is it constant or does it vary with scale and time?

What is the origin of cosmic density fluctuations?

Further unknowns

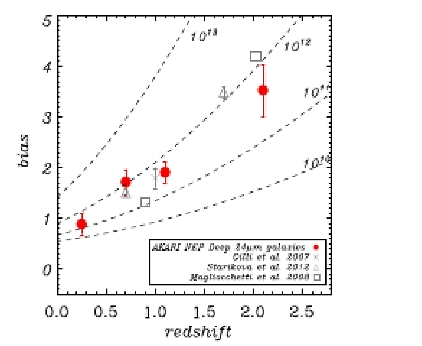
Mass contained in stars corresponds to only ~ 0.2% of the present mass-energy budget of the Universe. Yet stars and galaxies are our main source of information about the underlying dark matter field and hence the parameters of the Universe. How faithful tracers they are?

In the hierarchical model of large scale structure formation: galaxies from and grow in dark matter haloes, due to accretion and mergers. But a dynamics of this process and its dependence of exact properties of the DM halo and small- and large-scale environment is still a matter of debate. Why some galaxies are red and some blue? When did this bimodality establish and which are the fairest tracers of DM field at different redshifts?

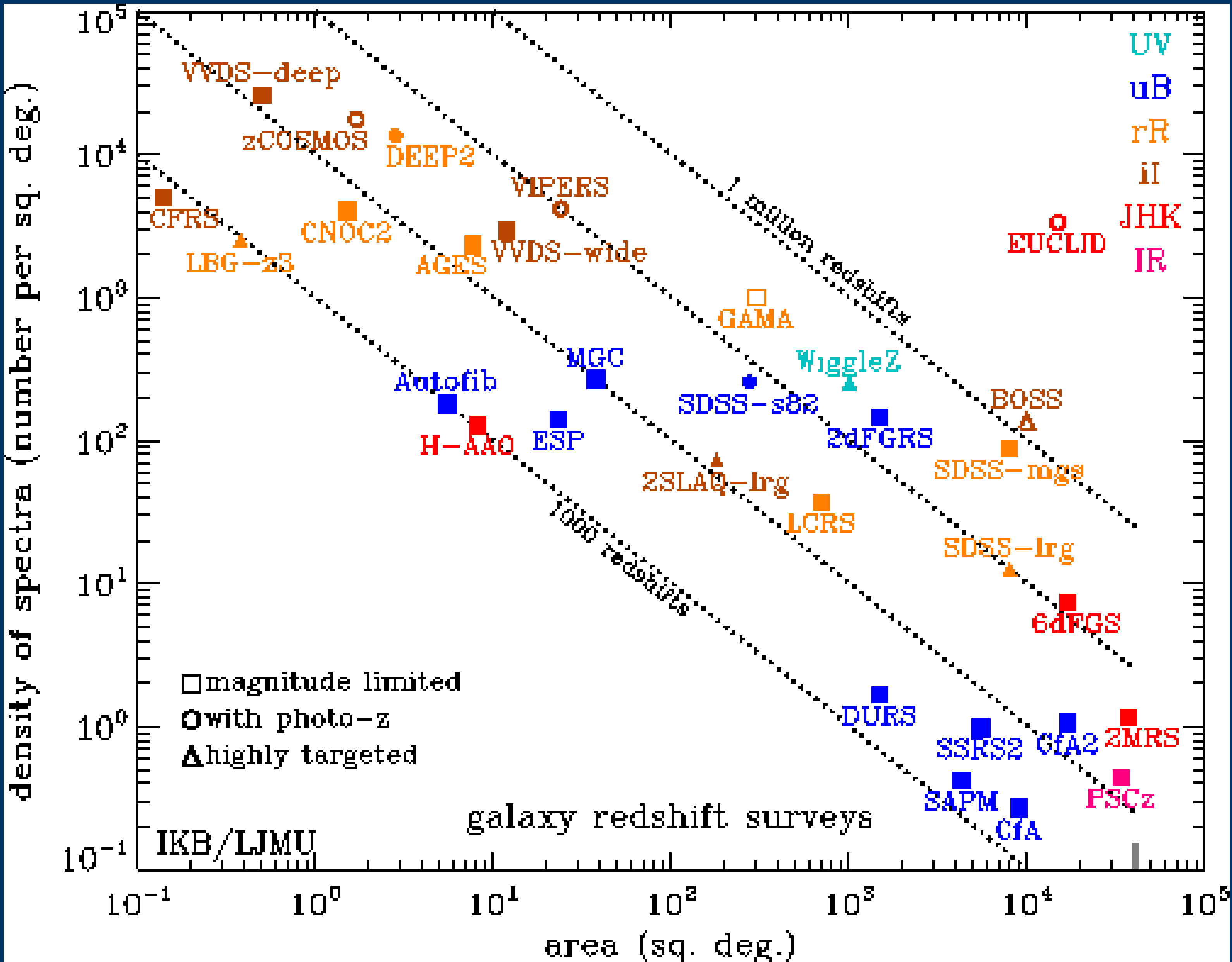


Galaxy surveys

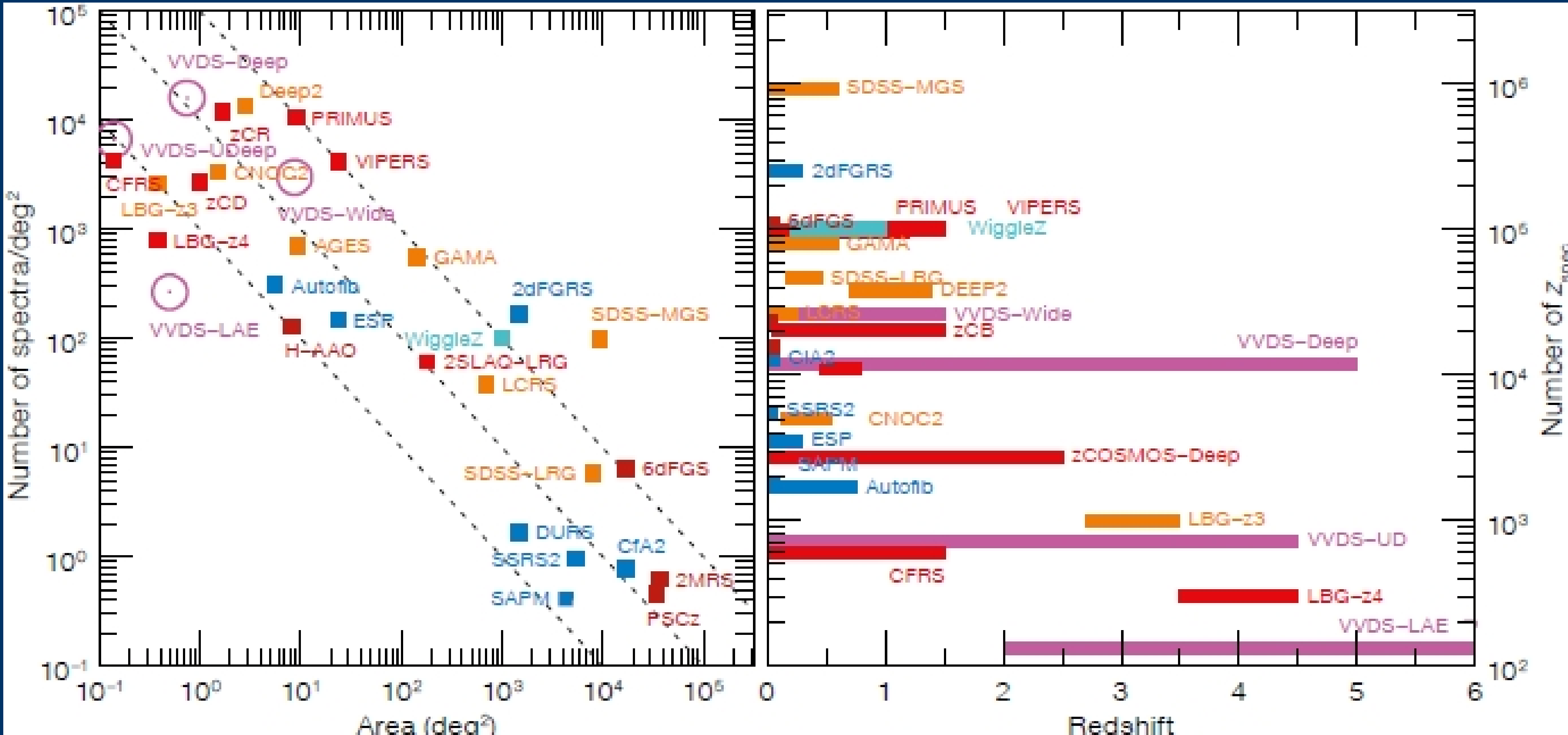
- Photometric: position on the sky + photometry (at different wavelengths)
  - deeper
  - more complete
  - easier to obtain at different wavelengths
    - (see e.g. a poster by Ola Solarz for an example what we can squeeze out of the NIR surveys)
- Spectroscopic (with redshift a measurement) – less complete, with a more complex geometric structure: usually optical... but in 3D



Surveys are usually a result of a compromise between the need for a large area, redshift range (=> volume), spectral density, and representativeness of the sample.



Credit:
Ivan K. Baldry
2010



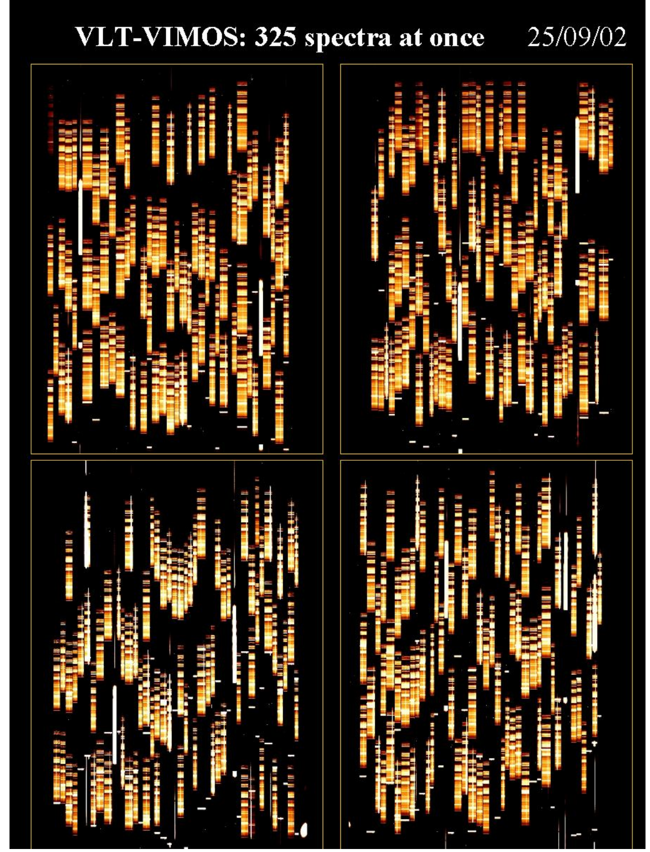
Credit:
Olivier Le Fevre
2014

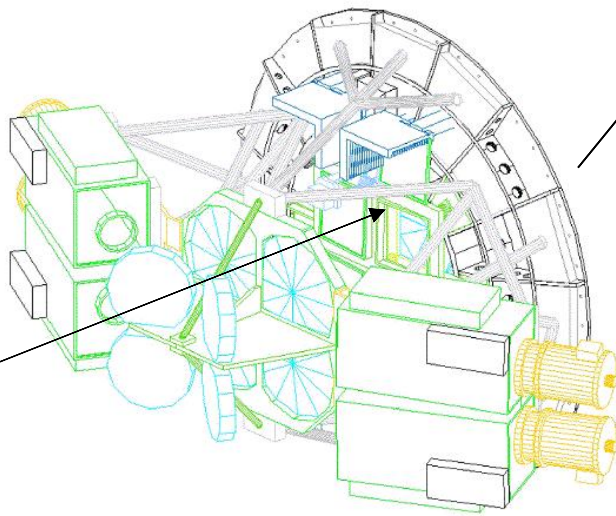
Main today's questions to be solved by galaxy surveys

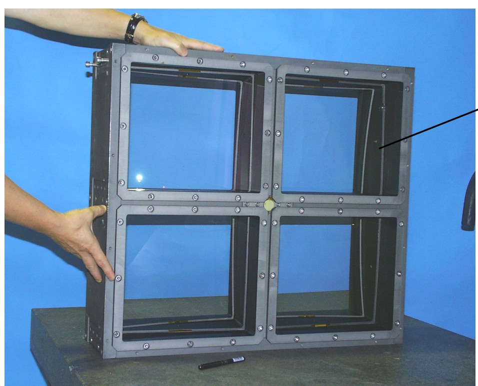
- Galaxy evolution: globally (like star formation history in the Universe) and in the context LSS evolution
- Large scale structure:
  - Evolution
  - cosmic parameters
  - galaxy-DM bias
  - Properties of “dark energy” and dark matter

Large spectroscopic surveys

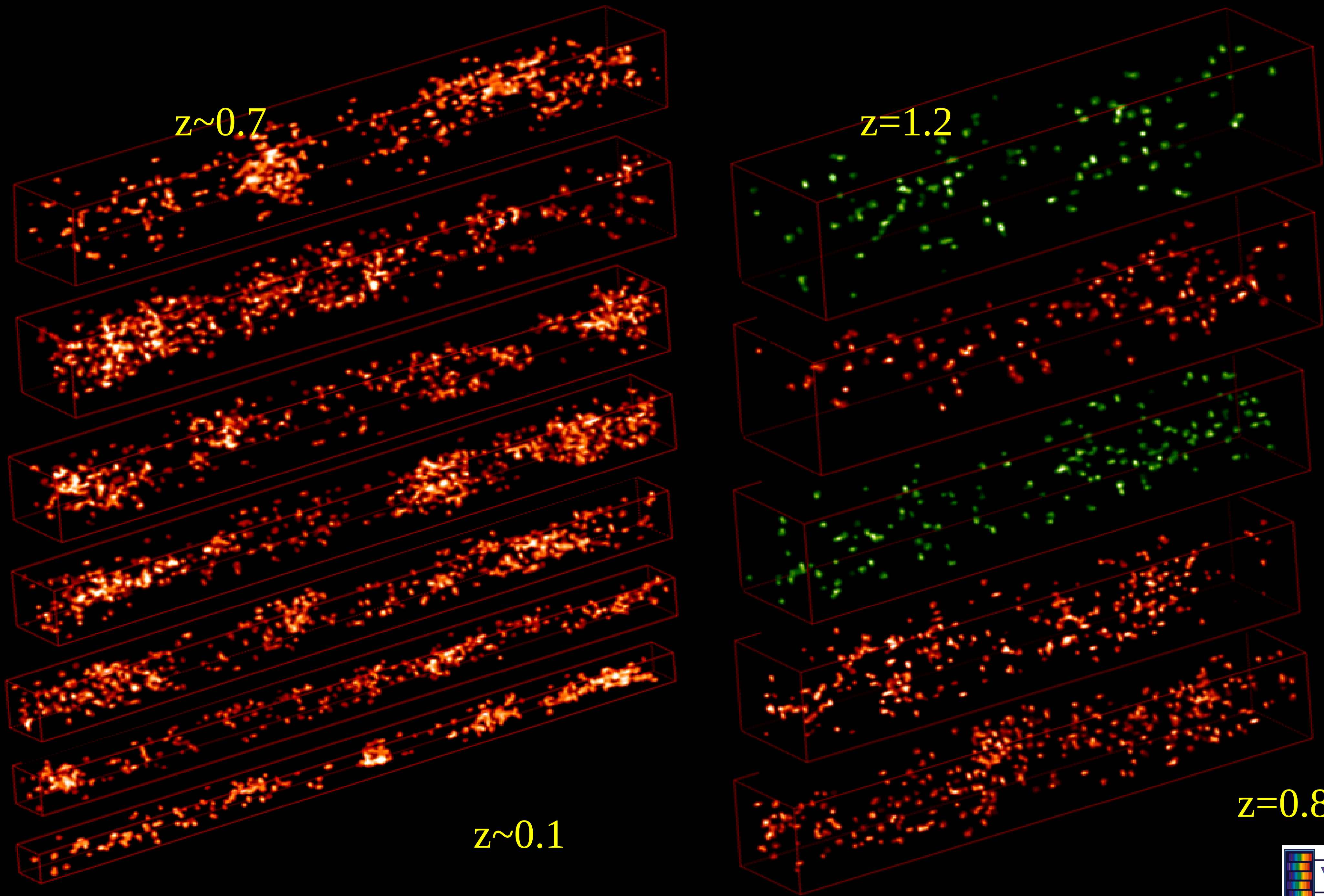
-Deep and -Wide
around 35 000 spectra of galaxies and AGNs
in 5 fields in the range 0<z<5 (finished,
see Le Fevre et al 2013 and 2014)

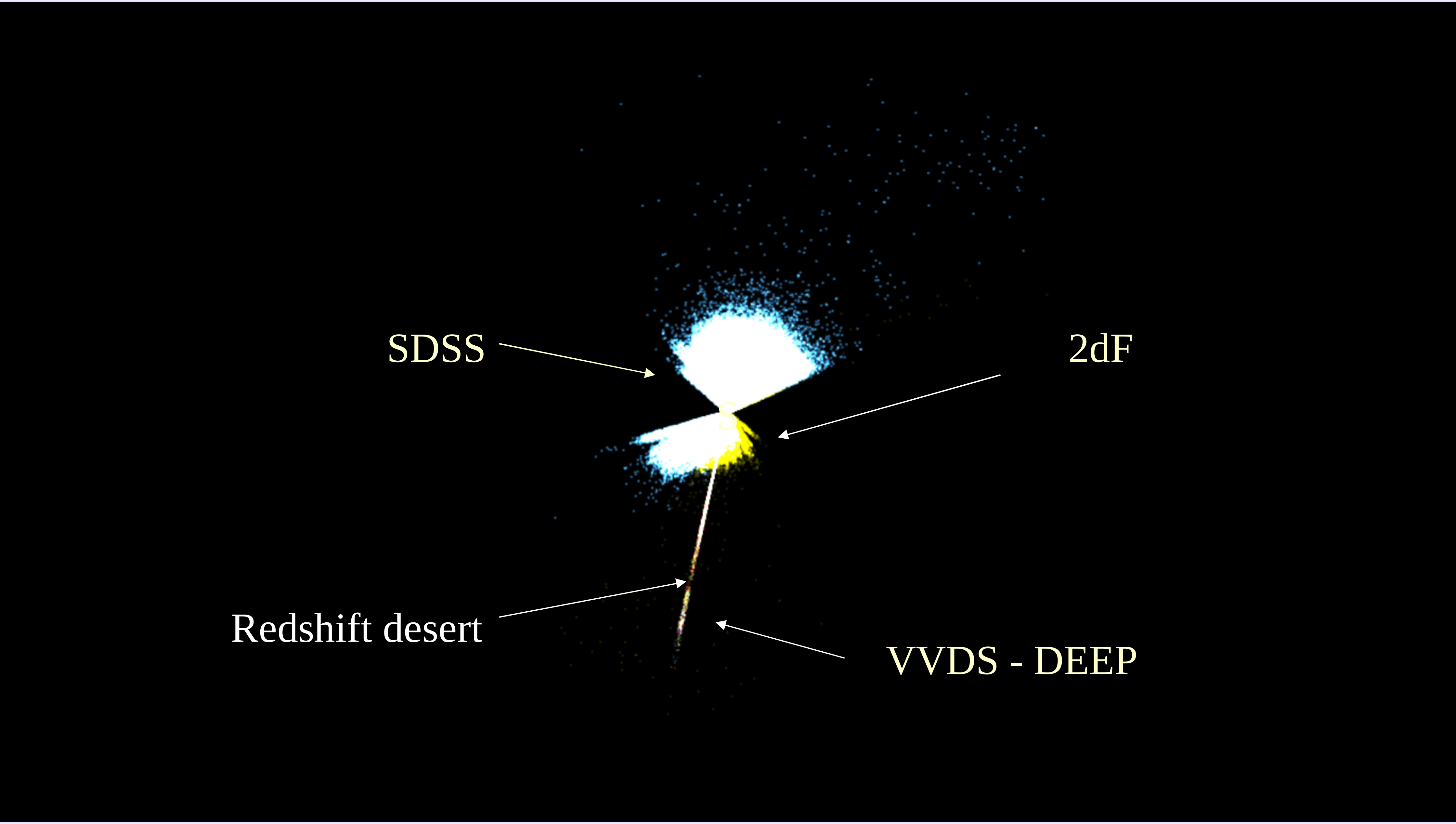




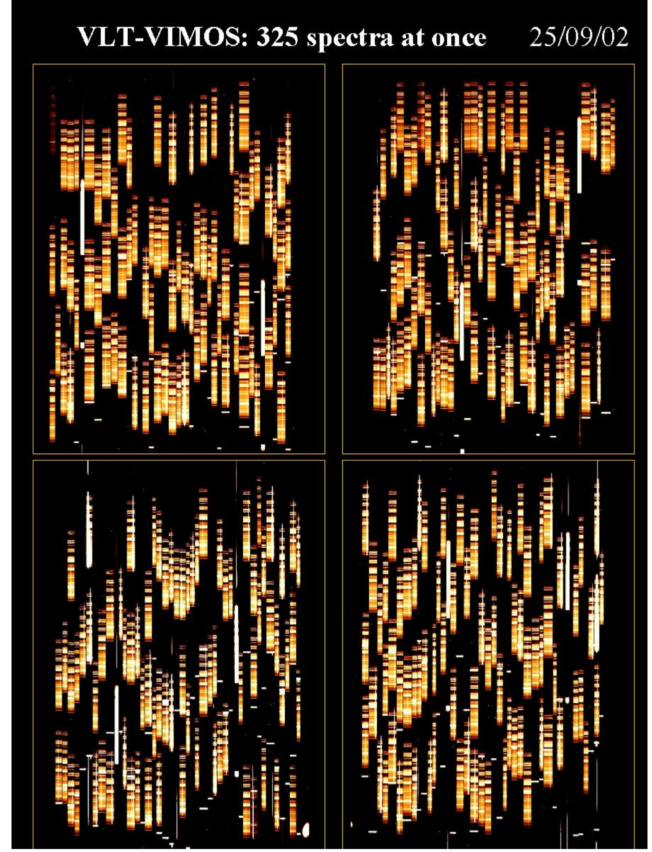


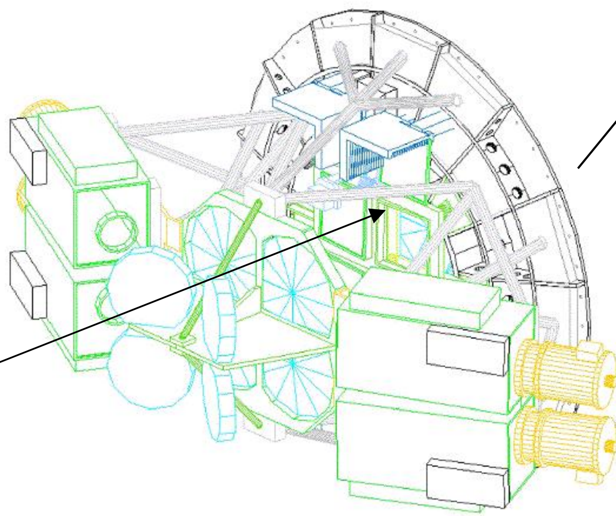
ESO VLT Large Programme:
measurements with a high
statistical accuracy of galaxy
clustering and evolution at
z \sim 1

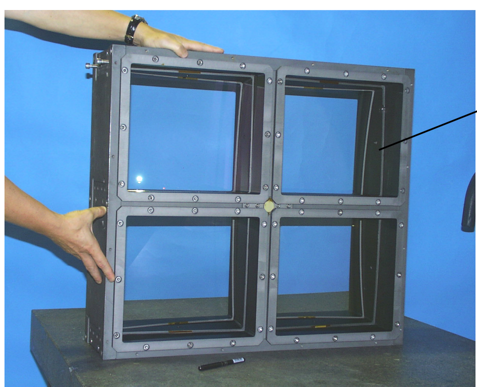

z~0.7
z=1.2
z~0.1
z=0.8


SDSS
2dF
Redshift desert
VVDS - DEEP

Large spectroscopic surveys







around 10 000 spectra
of very faint galaxies
at 2<z<6

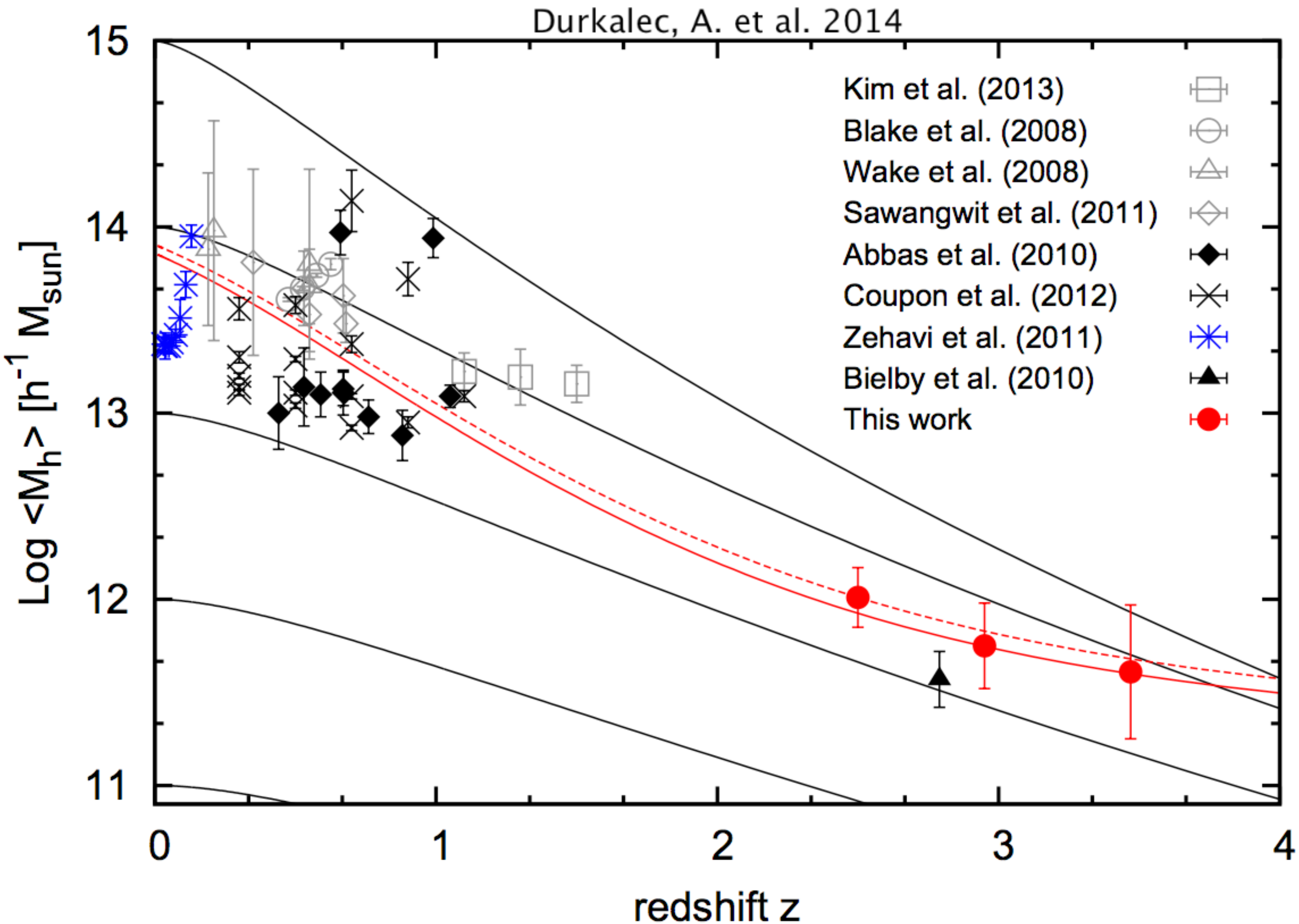
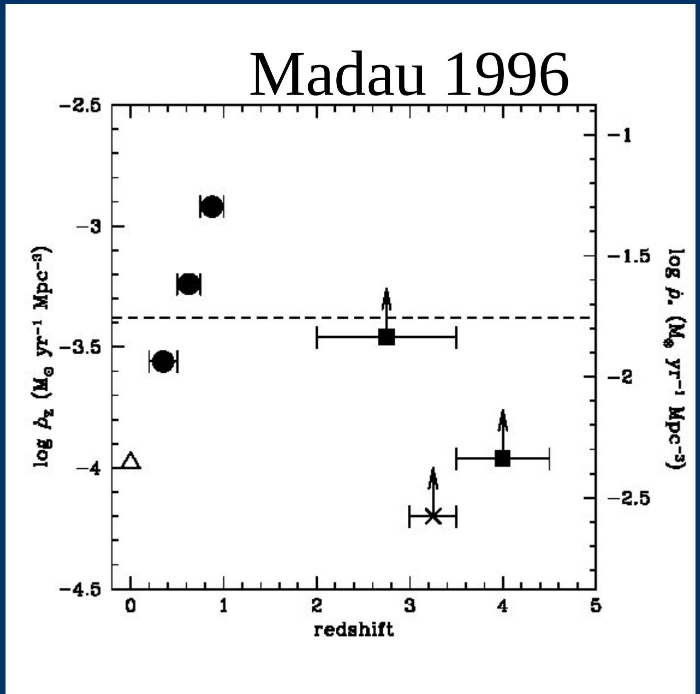


Fig. 7. The evolution of the number-weighted average host halo mass given by Eq. 10 for the three redshift ranges analysed in this study. The red filled circles indicate mass estimations from VUDS. Black and grey symbols represent the results of previous work based on spectroscopic and photometric surveys respectively. The solid black lines indicate how a host halo of a given mass M_0 at $z = 0$ evolves with redshift, according to the model given by van den Bosch (2002). The solid red line represents the halo mass evolution derived using Eq. 21, with the HOD parameters obtained from the best-fit HOD model at a redshift $z \sim 3$. The dashed red line is using the HOD best-fit parameters for $z \sim 2.5$. VUDS galaxies with a typical $L_\star$ luminosity are likely to evolve into galaxies with a luminosity $>L_\star$ today.

SFH history of the Universe: when did galaxies (especially today's red massive galaxies which seem to be “red and dead” from well before z \sim 1) form their stars?



Did massive galaxies form a majority of their stars at z \sim 3?

Durkalec, A. et al. 2014b

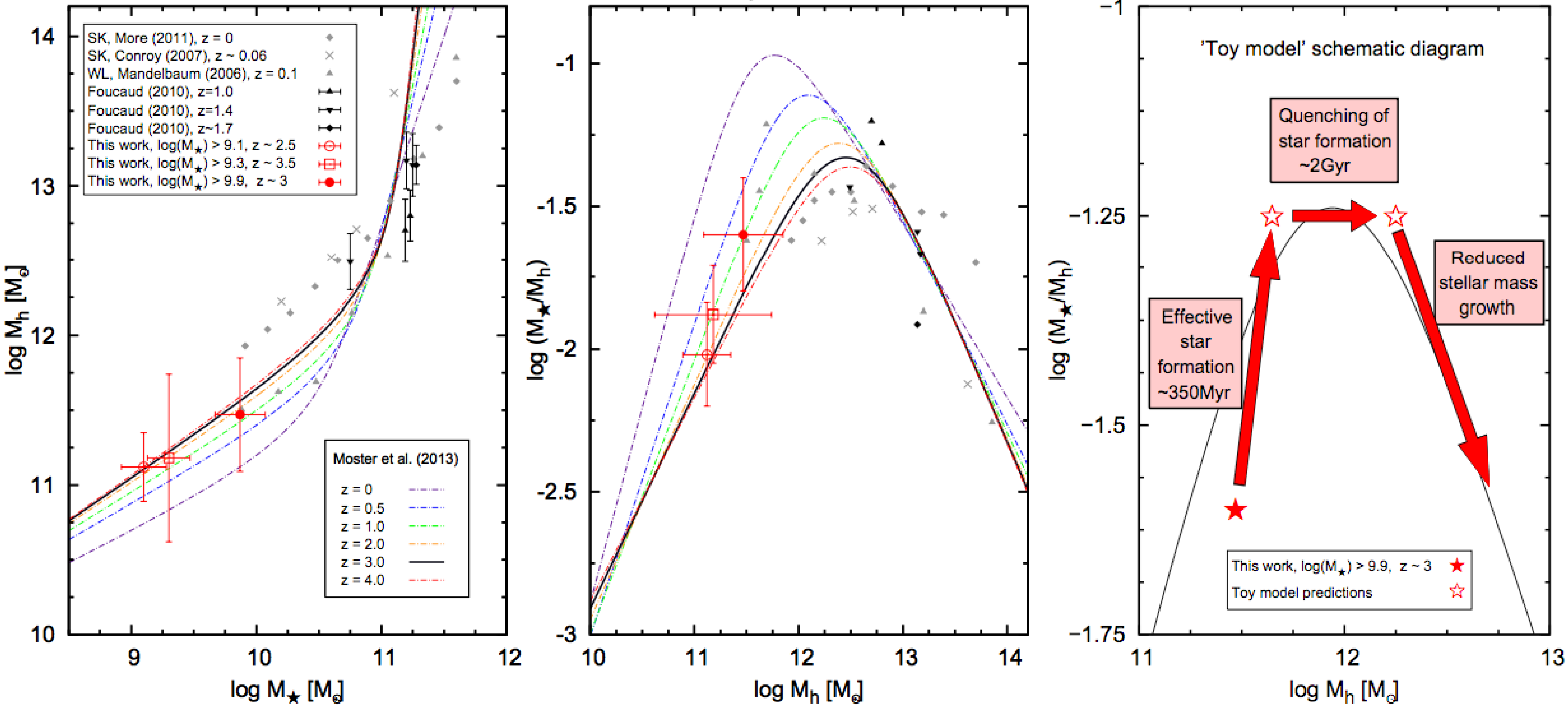
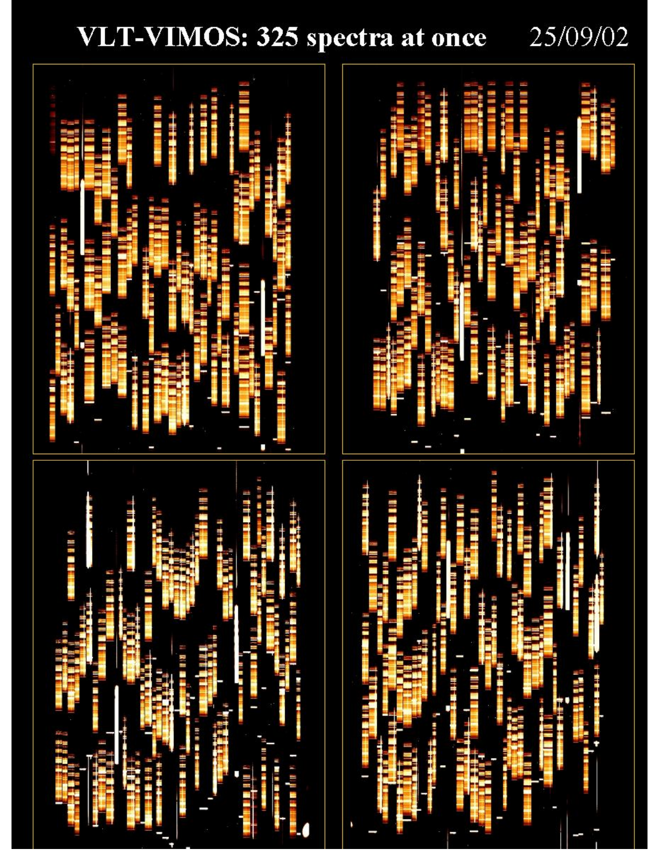
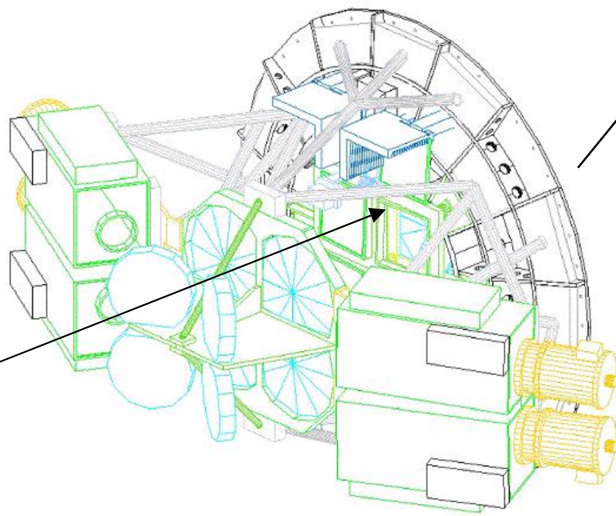
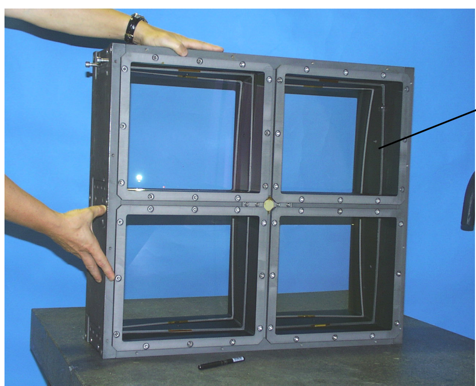


Fig. 2. *Left:* The relation between the stellar mass $M_\star$ and the halo mass M_h in VUDS for different $M_\star$ and redshifts (red symbols). $M_\star$ is derived from SED fitting of the multi-wavelength photometric data using known spectroscopic redshifts; error bars in $M_\star$ indicate expected uncertainties of the SED fitting method. M_h is obtained from HOD modelling of the two-point correlation function in different redshift and mass ranges. The VUDS data is compared to low and intermediate redshift measurements from satellite kinematics (Conroy et al. 2007; More et al. 2011) weak lensing (Mandelbaum et al. 2006), galaxy clustering (Foucaud et al. 2010). The lines represents model predictions derived from abundance matching at various redshift (Moster et al. 2013). *Center:* The stellar mass $M_\star$ over halo mass M_h ratio vs. halo mass at $z = 3$ in the VUDS survey. The colour scheme is the same as for the left panel. *Right:* Evolution of the $M_\star/M_h$ ratio with time predicted from stellar and halo mass accretion histories

Large spectroscopic surveys

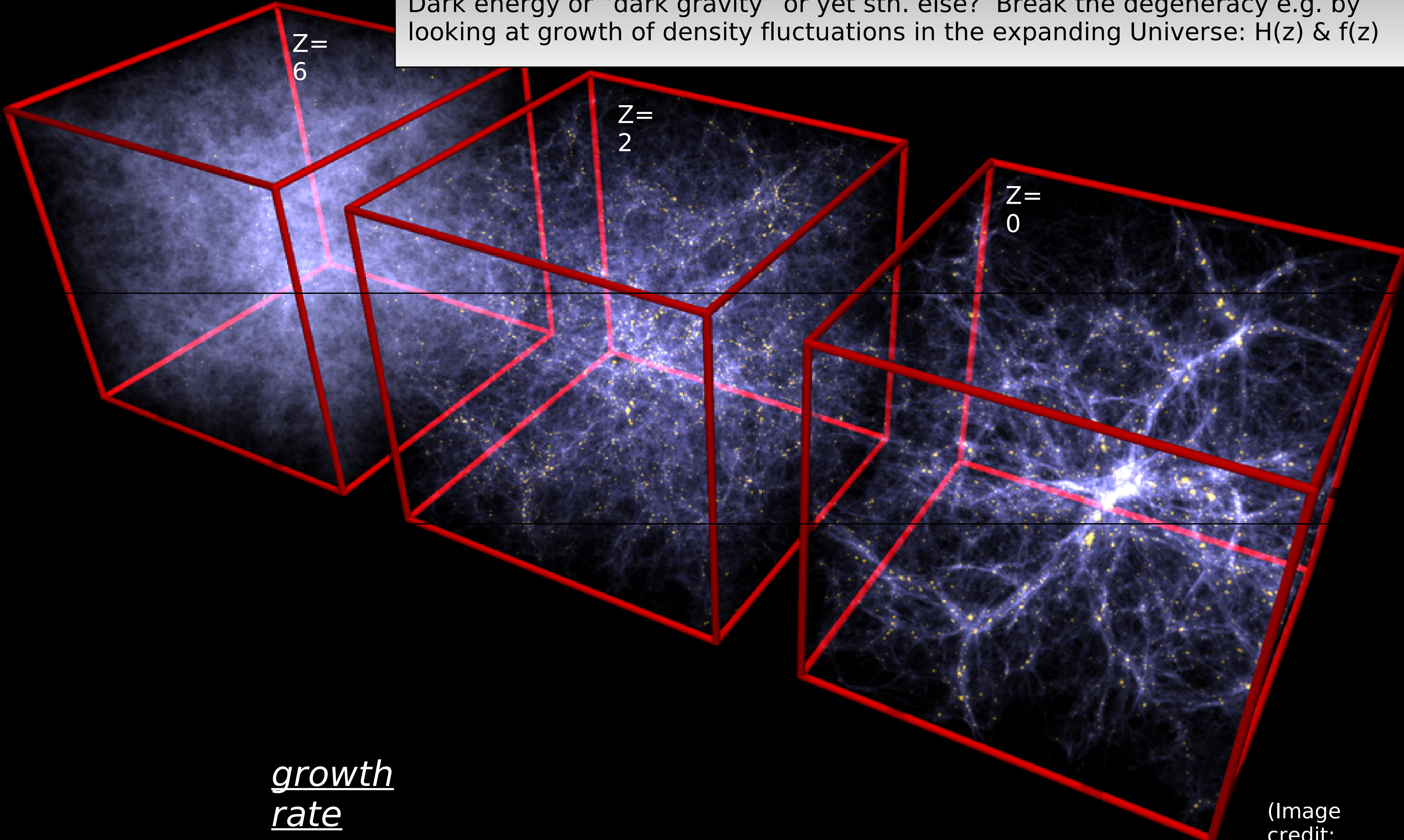






close to **100 000** spectra
of normal galaxies
at 0.5<z<1.2

Dark energy or “dark gravity” or yet sth. else? Break the degeneracy e.g. by looking at growth of density fluctuations in the expanding Universe: H(z) & f(z)



growth rate

(Image credit: V. Springel)

growth produces motions -> galaxy peculiar velocities

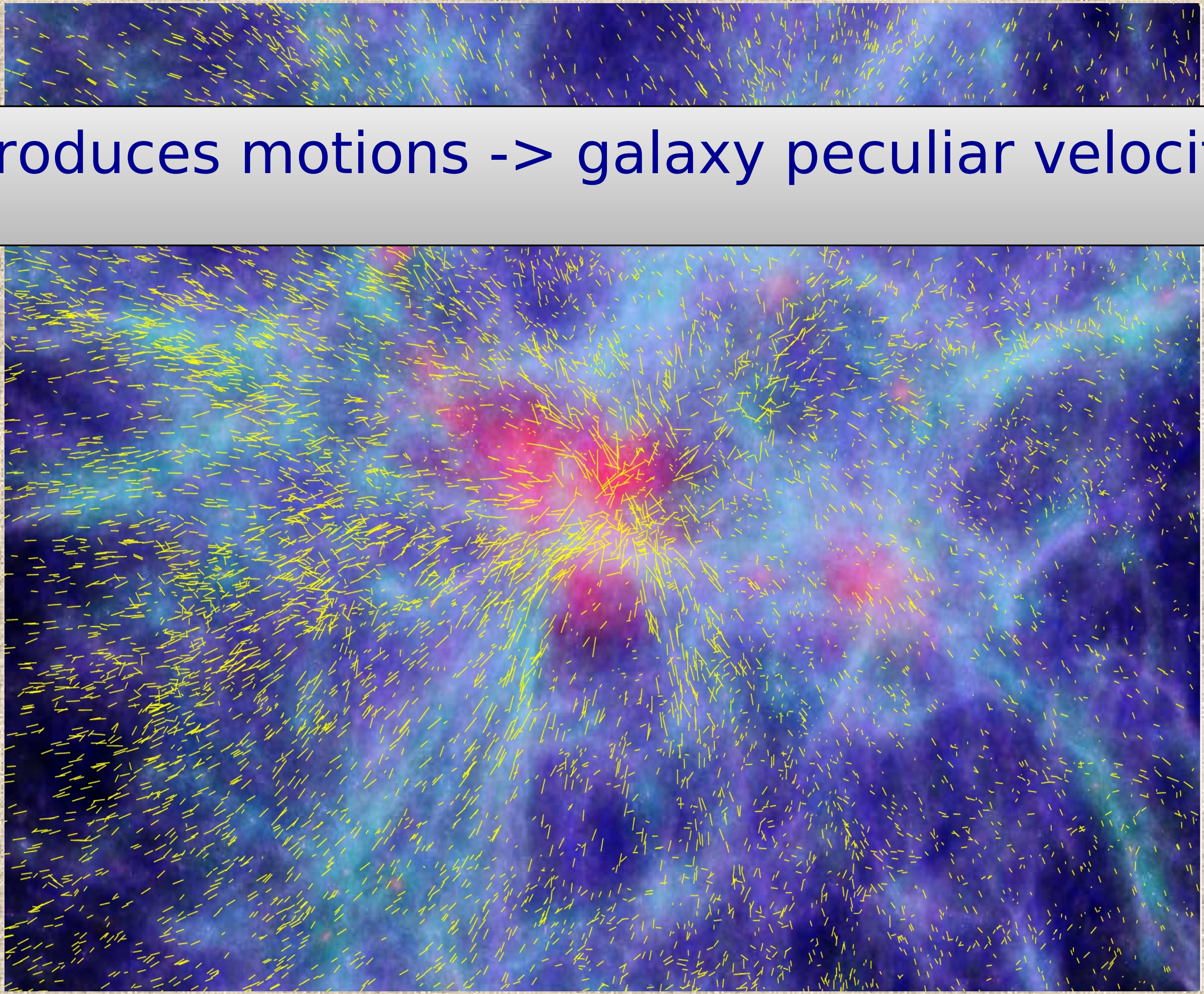
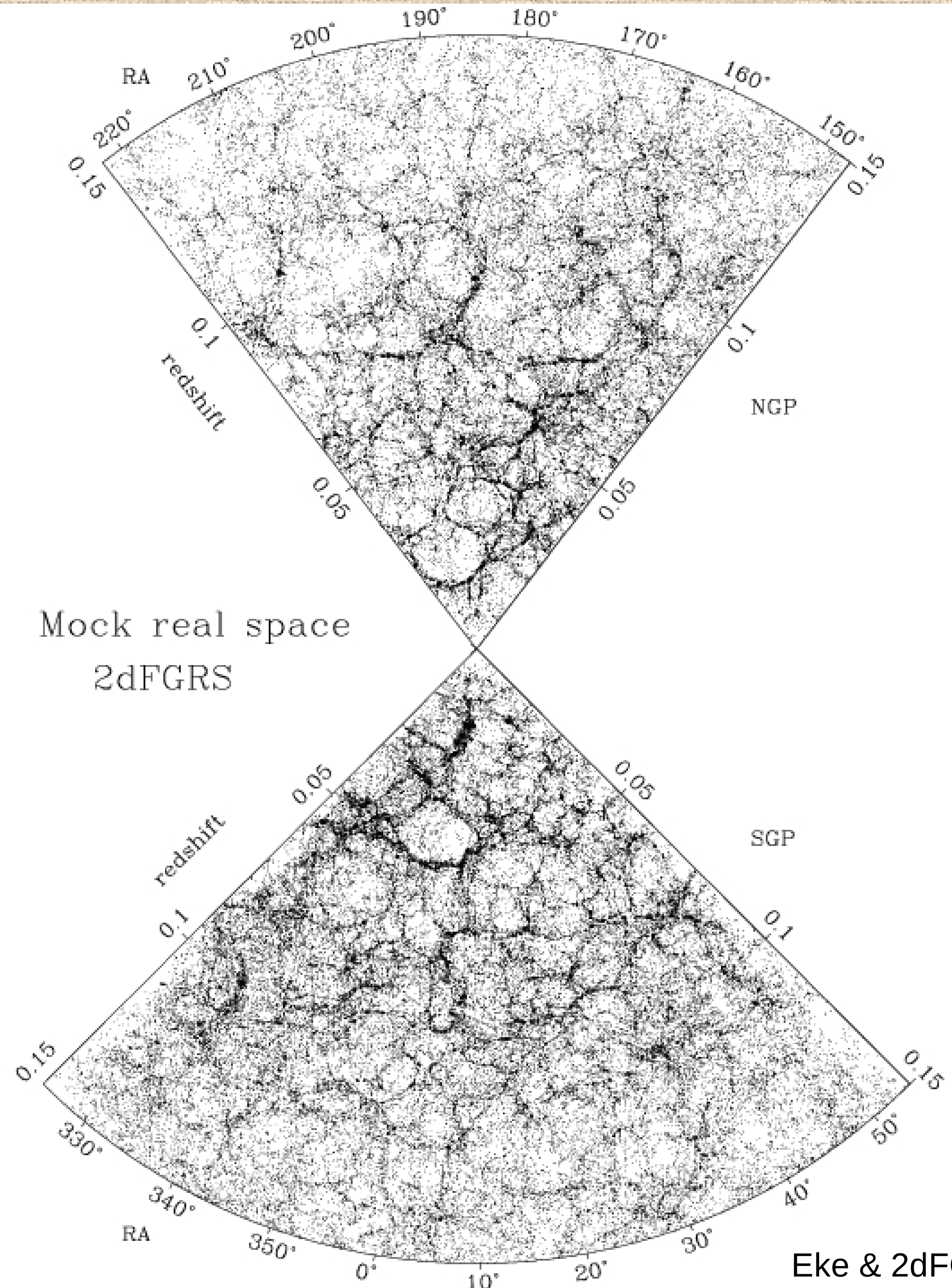


Figure by K. Dolag

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

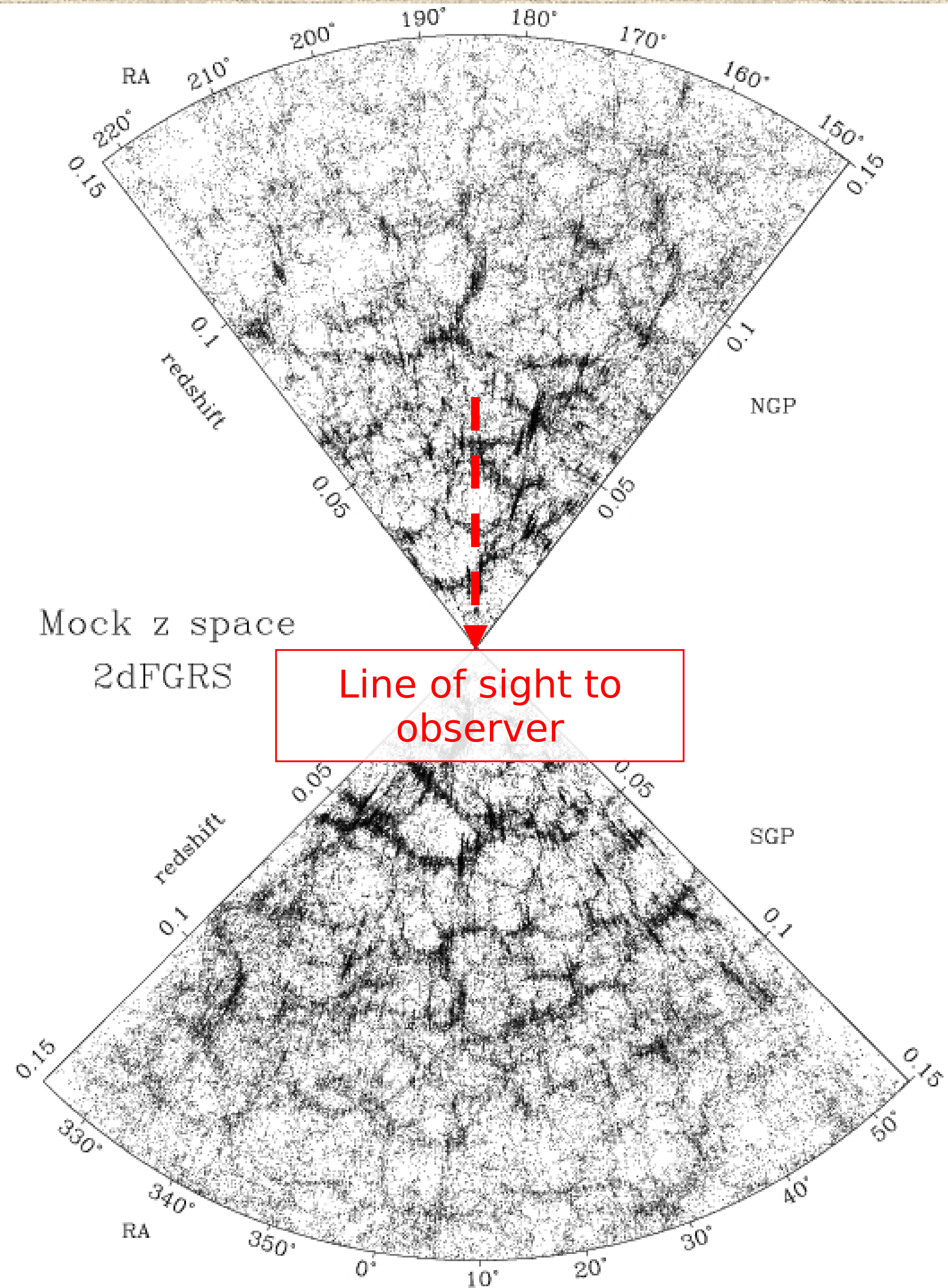
real space



Eke & 2dFGRS 2003

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

redshift space



· The growth equation (and thus the growth rate) depends not only on the expansion history *H(z)* (and thus on *w(z)*) but also on the gravitation theory

· Measuring *f(z)* we can break the degeneracy between models with same effective *H(z)*, but completely different physics (unless DE clusters, e.g. Kunz & Sapone 2007)

For a wide variety of models:

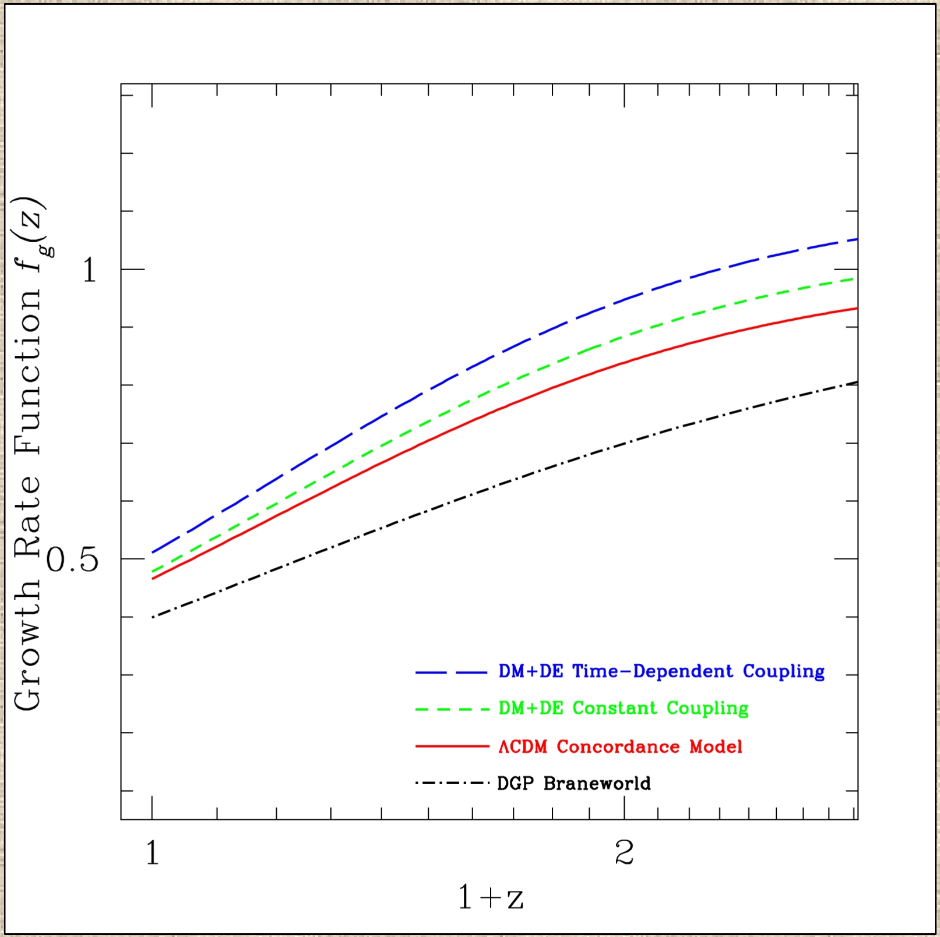
$$f(z)=[\Omega m(z)]^{\gamma}$$

(Peebles 1980, Wang & Steinhardt 1998, Amendola et al. 2005, Linder 2005)

e.g.

$\gamma=0.55$ for standard GR

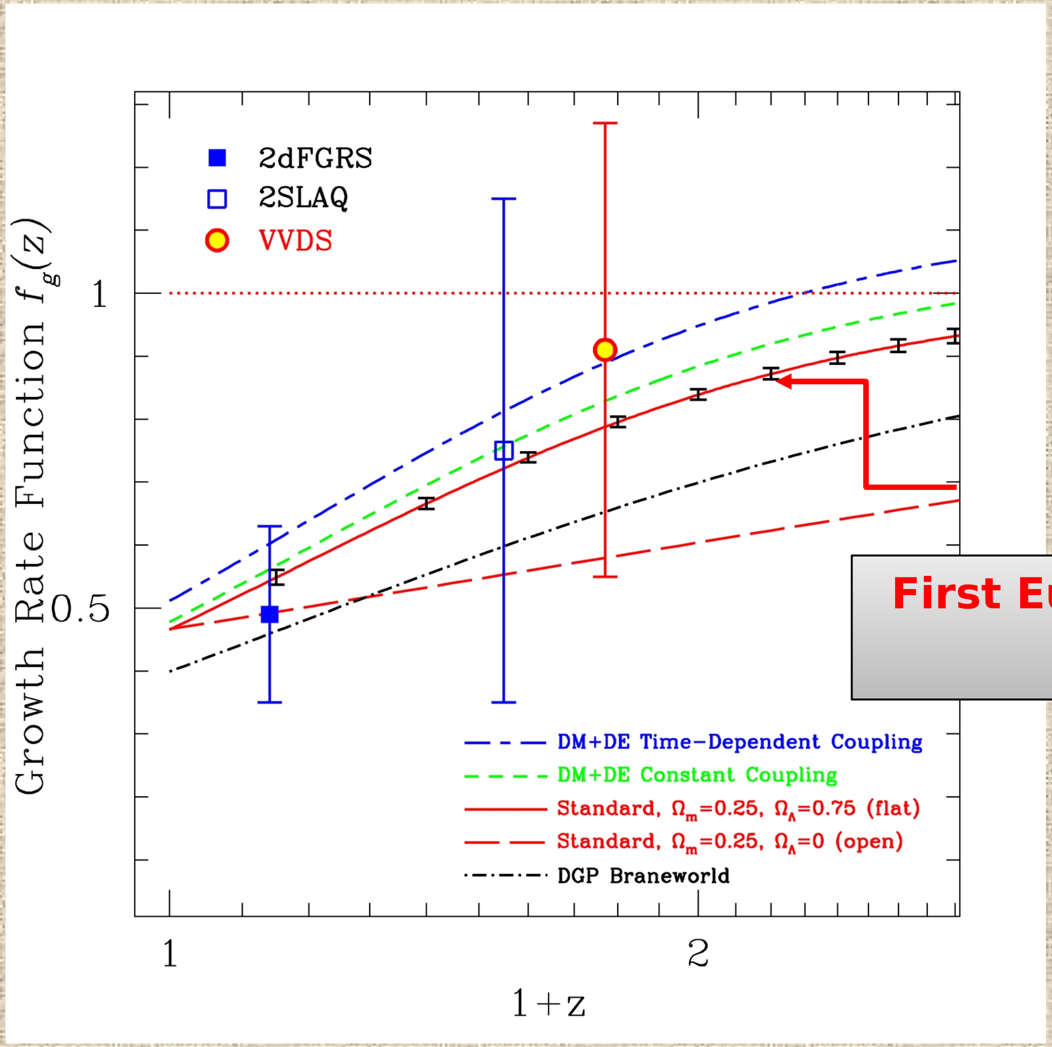
$\gamma=0.68$ for DGP braneworld



How do we measure *f(z)*?

DGP: Lue et al. 2004; DM+DE models: Di Porto & Amendola 2007

RSD from VVDS-Wide at z~1: in 2008 slightly more than a proof of concept, but…



First Euclid-spectro (space) forecast

Nature 451, 541 (2008)

VIPERS in a nut-shell

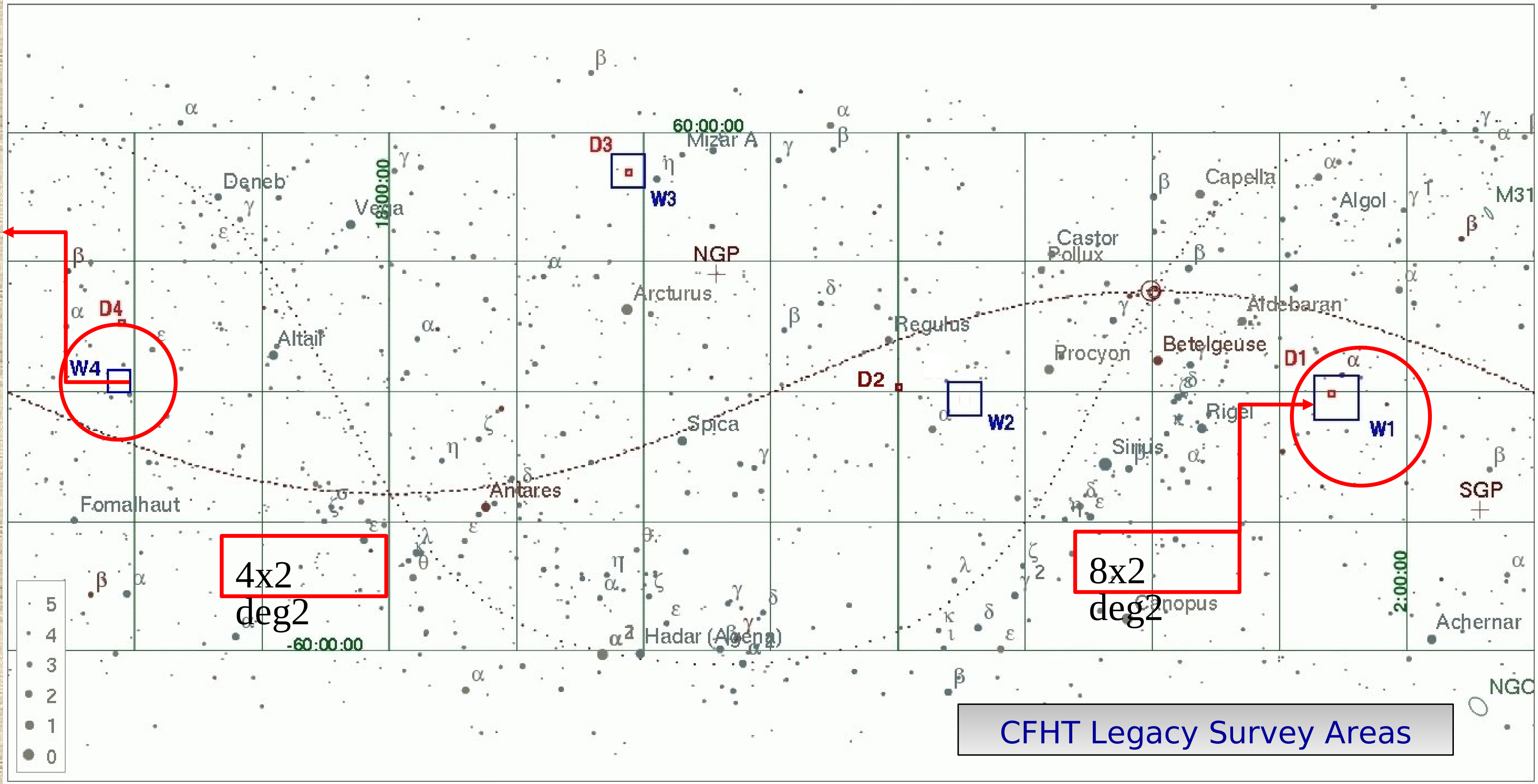
- ~24 deg2 over W1 and W4 CFHTLS wide fields (~16 + 8)
- IAB<22.5, LR Red grism, 45 min exp.
- z>0.5 color-color pre-selection
- PSF + SED –based star-galaxy separation (AGN color recovery)
- 288 VIMOS pointings
- 440.5 VLT hours
- **~100,000 redshifts, >40% sampling**
- **Density and volume comparable to 2dFGRS, but at z~0.8**
- **State for spring 2015: observations & redshift measurements completed**

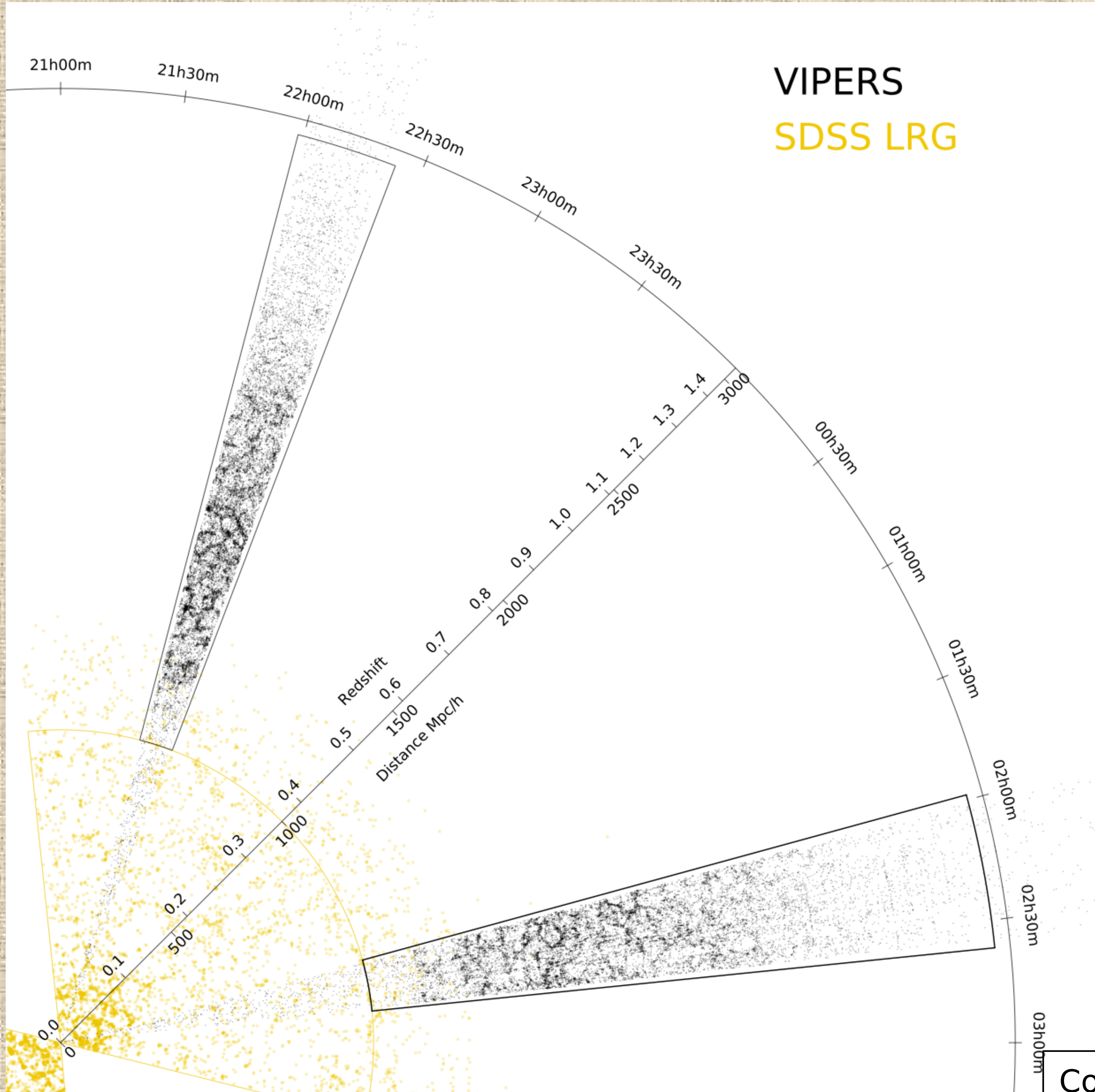
SURVEY STATUS AS OF 10/05/2015

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.

Location of VIPERS fields

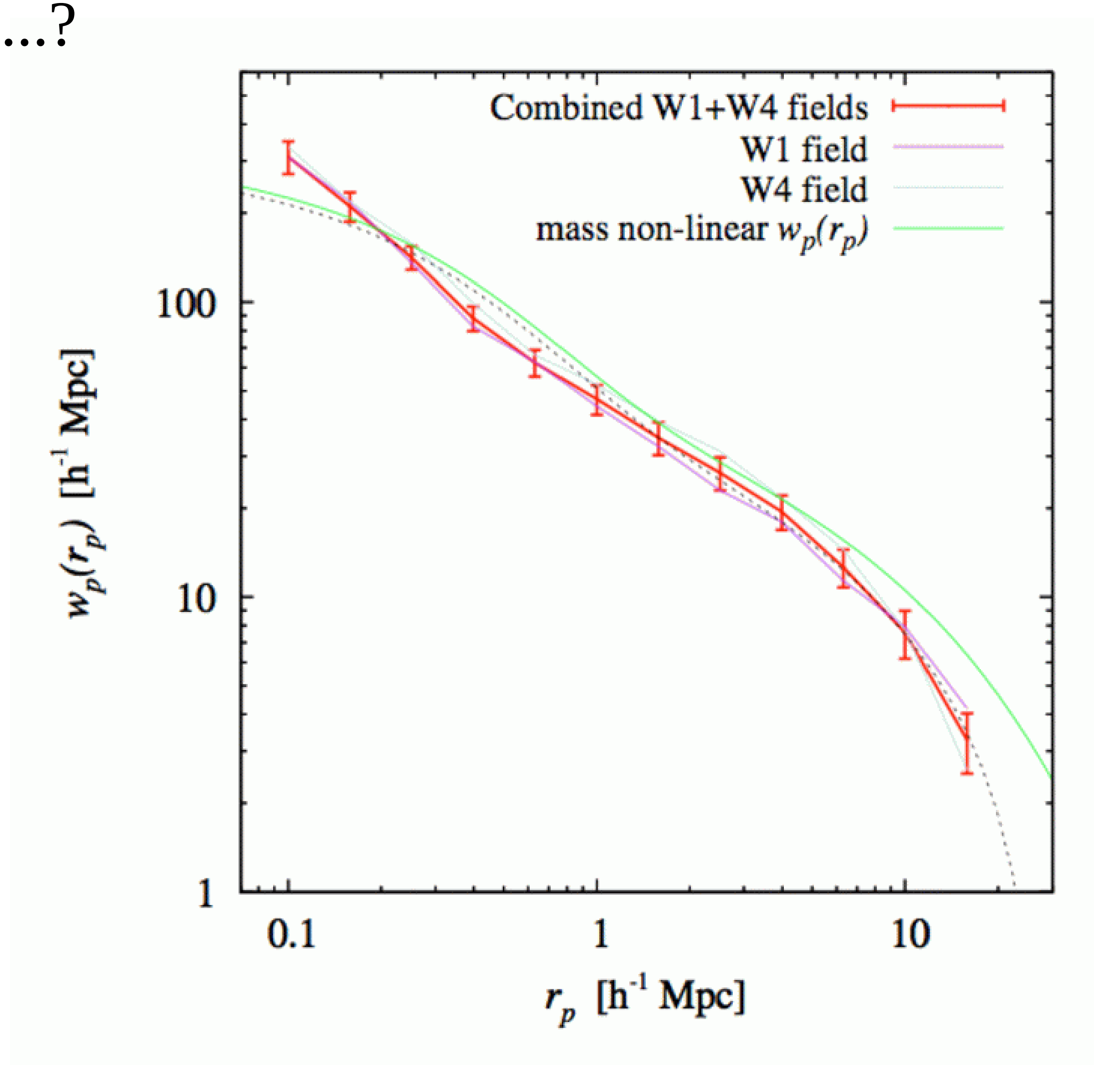


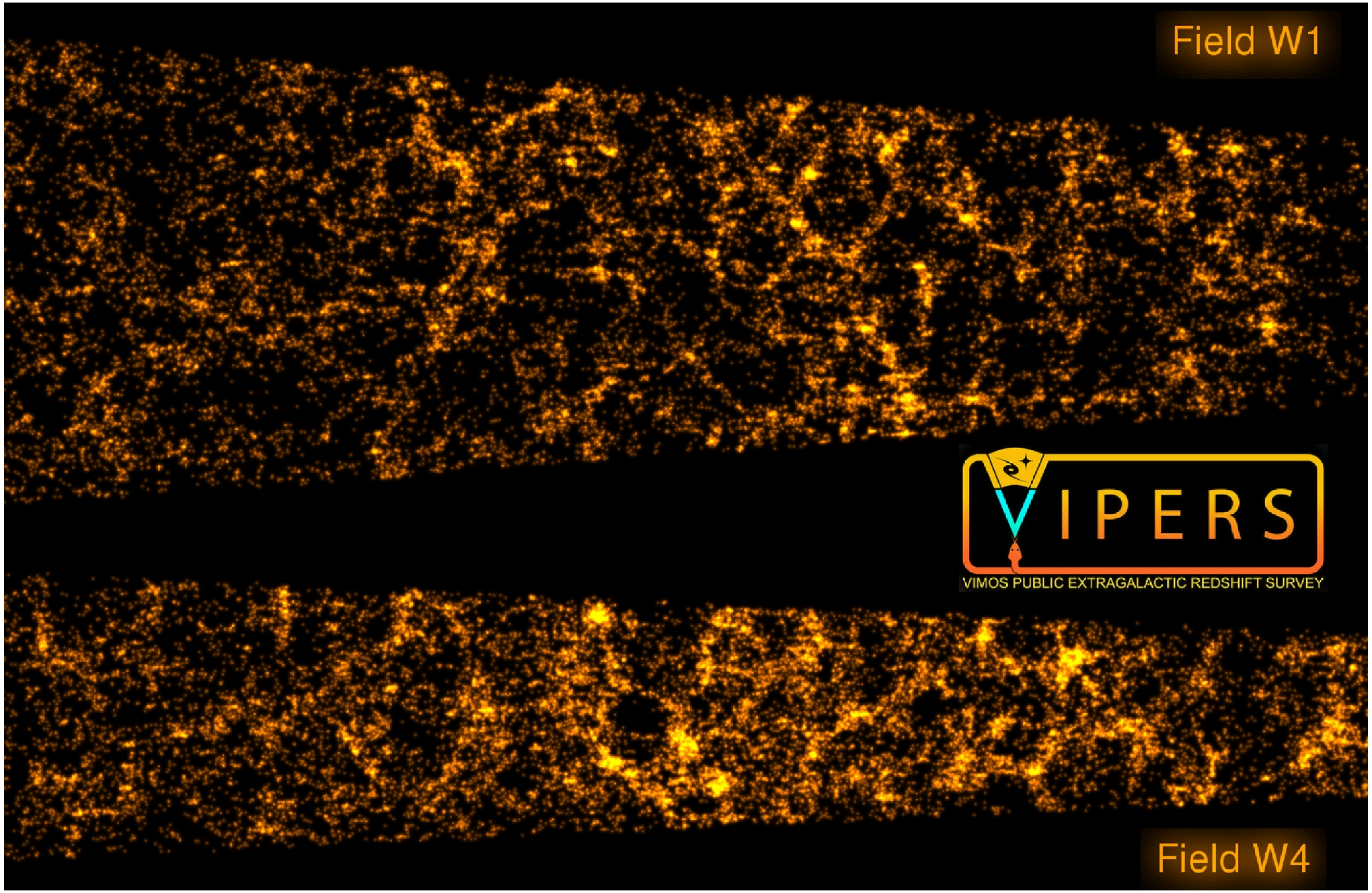


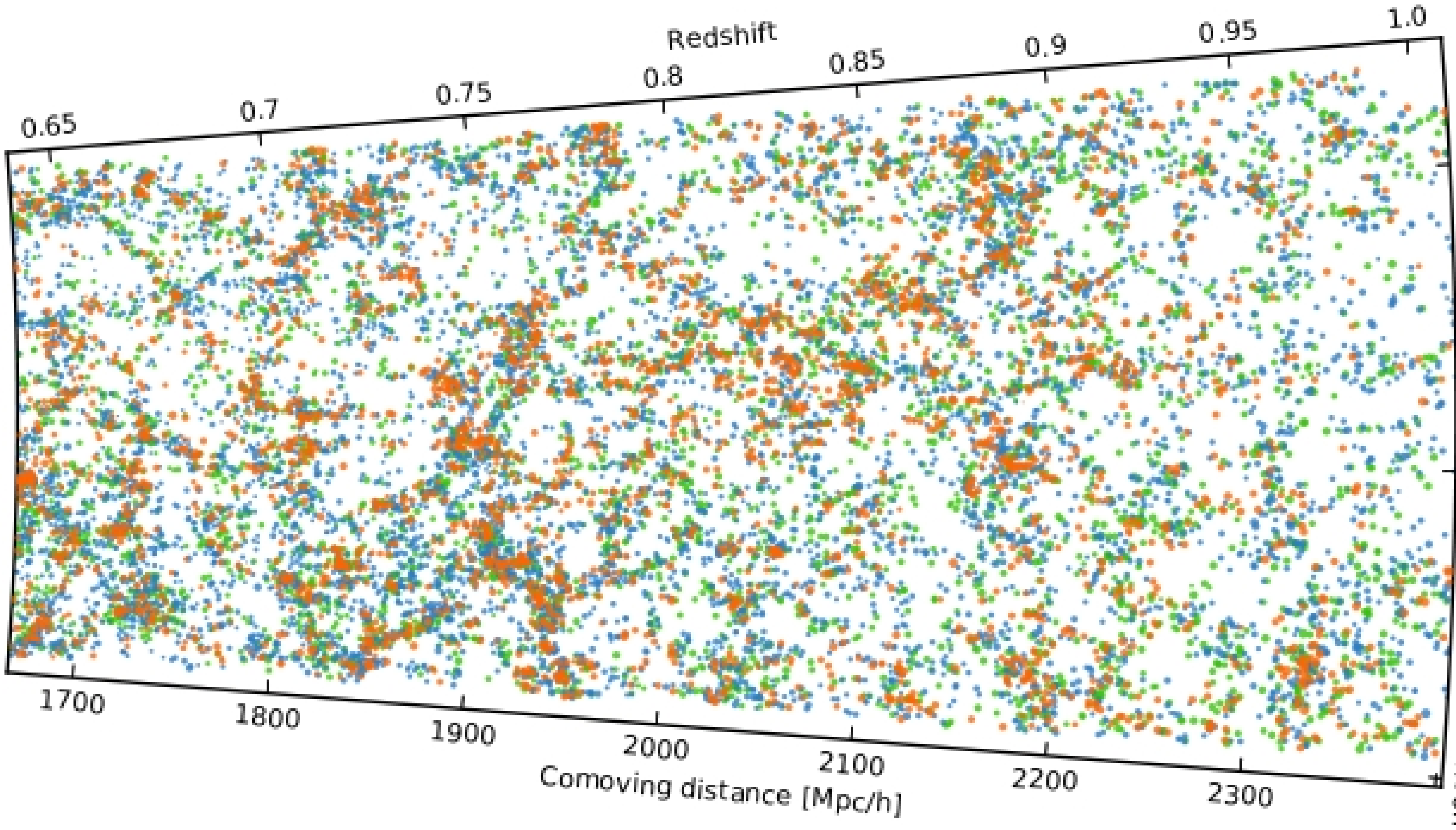
Courtesy Ben Granett

Cosmic variance overcome...?

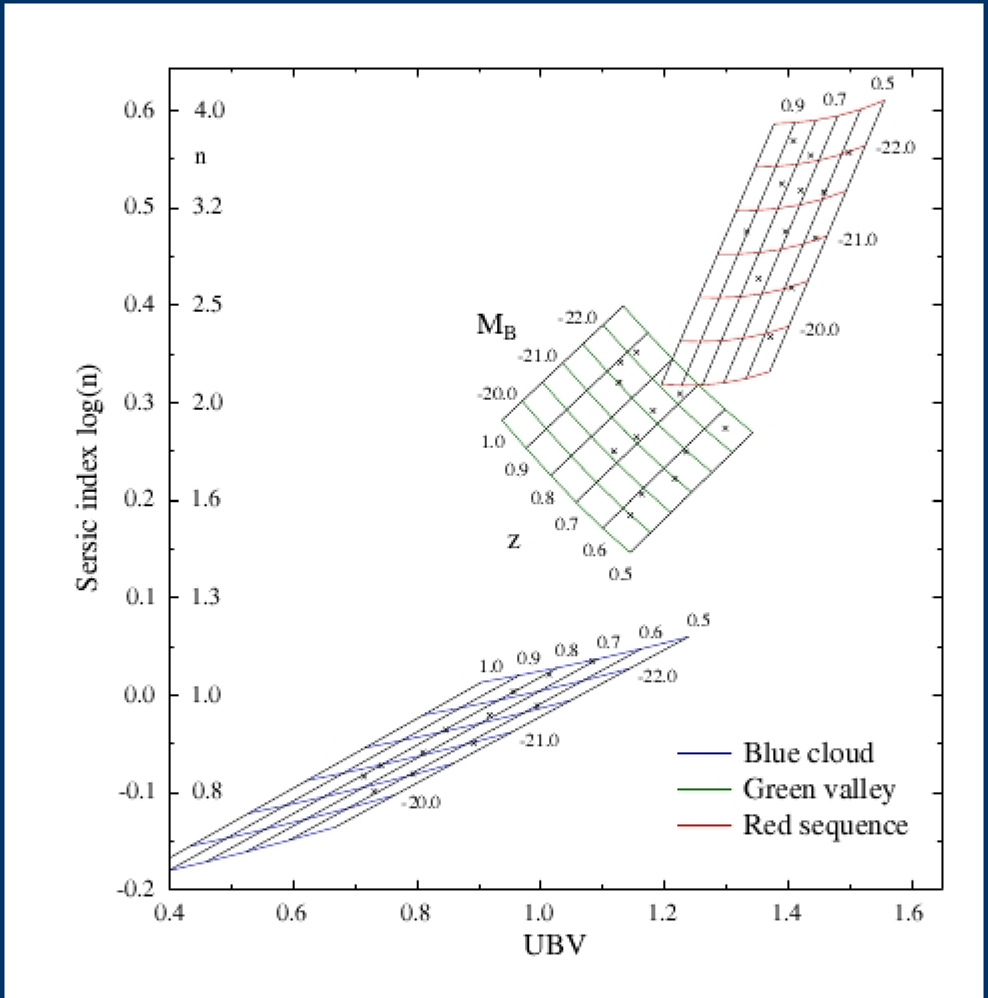
No significant statistical difference between galaxy clustering in two VIPERS fields.




Field W1
VIPERS
VIMOS PUBLIC EXTRAGALACTIC REDSHIFT SURVEY
Field W4


Redshift
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1.0
02h30m
02h15m
02h00m
1700
1800
1900
2000
2100
2200
2300
Comoving distance [Mpc/h]

On the galaxy evolution side: to check where did green valley dissolve...
see a poster by Janusz Krywult



Krywult et al. 2015

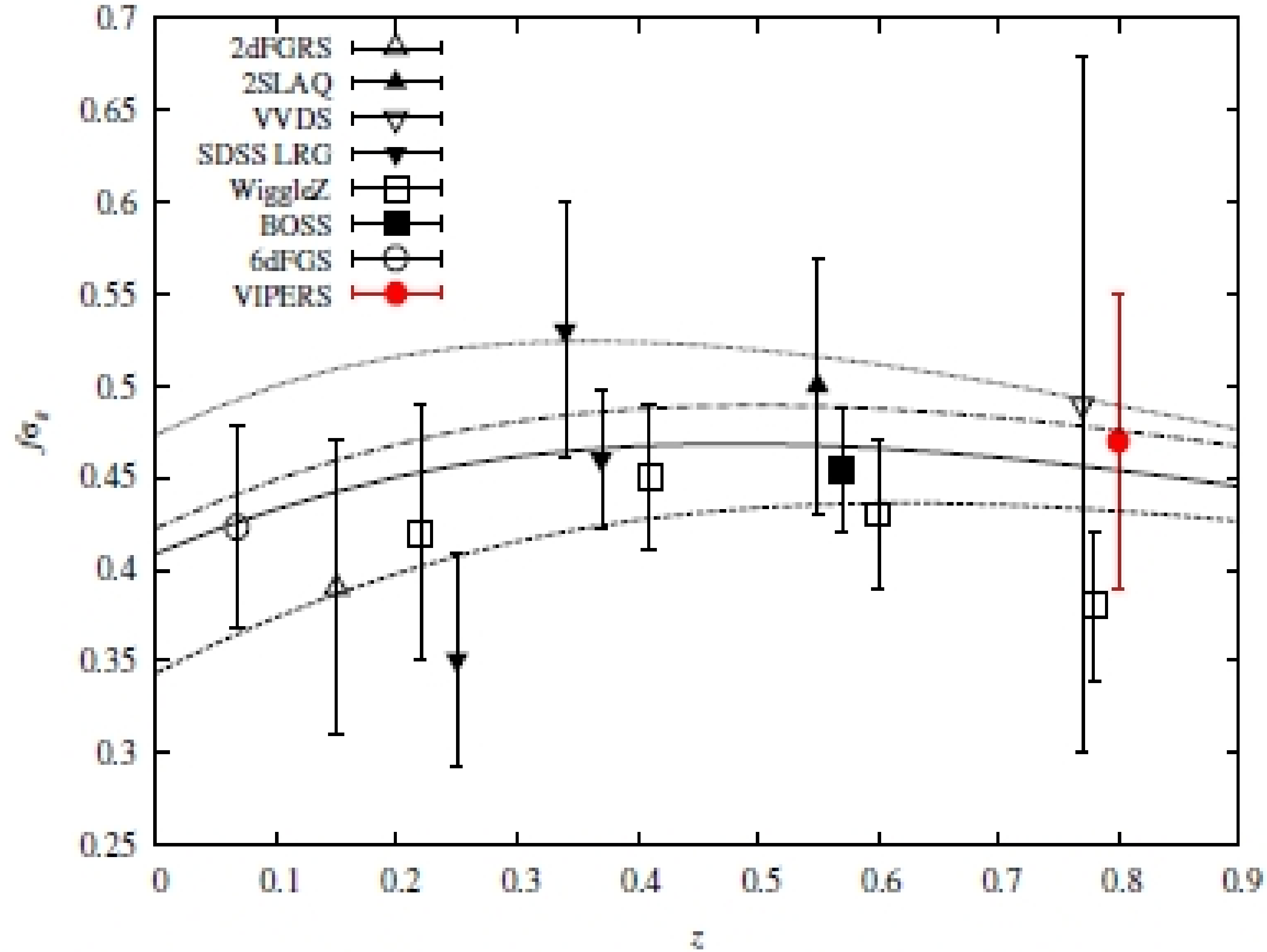


Fig. 20. A plot of $f\sigma_8$ versus redshift, showing the final VIPERS result contrasted with a compilation of recent measurements. The previous results from 2dFGRS (Hawkins et al. 2003), 2SLAQ (Ross et al. 2007), VVDS (Guzzo et al. 2008), SDSS LRG (Cabré & Gaztañaga 2009; Samushia et al. 2011), WiggleZ (Blake et al. 2011), BOSS (Reid et al. 2012), and 6dFGS (Beutler et al. 2012) surveys are shown with the different symbols (see inset). The solid curve corresponds to the prediction for General Relativity in a ΛCDM model with WMAP9 parameters, while the dashed, dotted, and dot-dashed curves are respectively Dvali-Gabadaze-Porrati (Dvali et al. 2000), $f(R)$, and coupled dark energy model expectations. For these models, the growth rate predictions given in di Porto et al. (2012) have been used.

What do we actually need to improve this measurement?

- repeat the computation for the full dataset
(but it will not be enough)

- i**mprove RSD modeling**

- work on our understanding of errors and biases

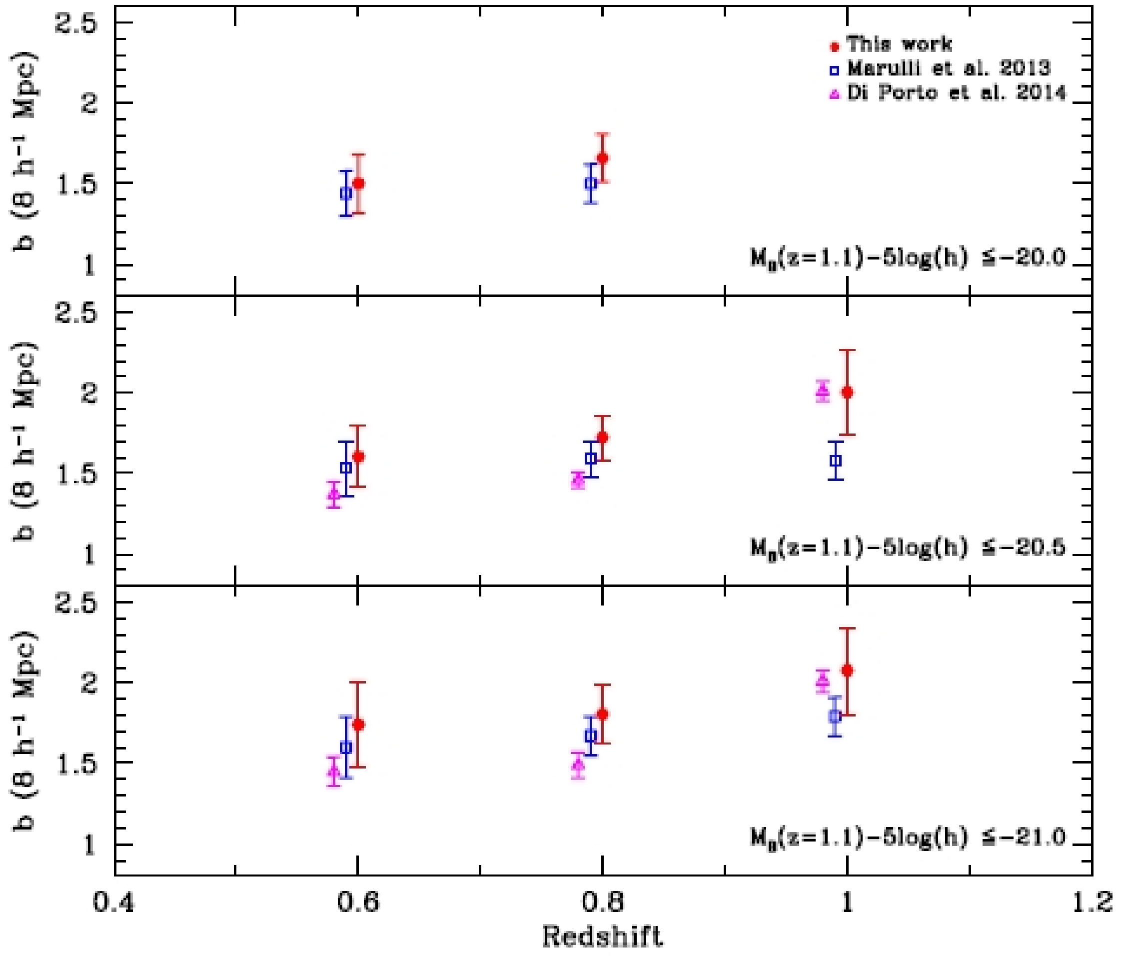


Fig. 13. The linear bias b as a function of redshift. Top panel: $M_B \leq -20.0(z = 1.1) + 5\log(h)$; middle panel: $M_B \leq -20.5(z = 1.1) + 5\log(h)$; bottom panel: $M_B \leq -21.0(z = 1.1) + 5\log(h)$. Red hexagons: our estimates of $b = \sigma_{8g}/\sigma_{8m}$. Blue squares: estimates of Marulli et al. (2013). Magenta triangles: Di Porto et al. (2014).

Galaxy linear bias: slowly rising with z and luminosity (as expected from the hierarchical model). A non-conclusive evidence for a non-zero non-linear bias term.

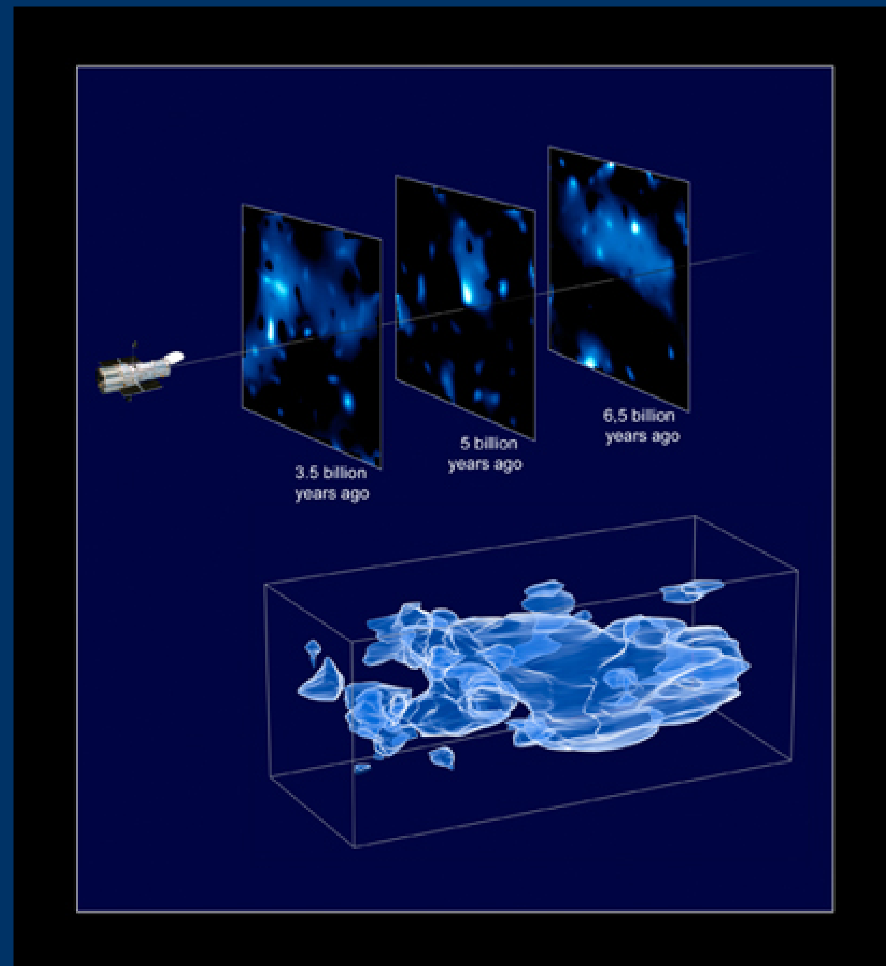
(Cappi et al. 2015)

Future: will it belong to (collaborating) big surveys?

- DES (photometric sky survey with a dedicated camera at 4m telescope in Chile, started), to probe DE through:
  - Type Ia Supernovae
  - Baryon Acoustic Oscillations (BAO)
  - Galaxy clusters (GC)
  - Weak Gravitational Lensing (WL)

Future: will it belong to (collaborating) big surveys?

- Euclid (ESA space project to be launched 2020): 1 mld galaxies in 3D up to z \sim 2, to pinpoint:
  - the evolution of BAOs
  - map DM with weak gravitational lensing
  - constrain RSDs with an accuracy \sim 2%



Future: will it belong to (collaborating) big surveys?

LSST

Large Synoptic Survey Telescope

- LSST (US telescope, planned to start 2021): photometric all sky survey every 3 days down to 27 mag
  - the evolution of BAOs
  - map DM with weak gravitational lensing
  - time-sensitive probes