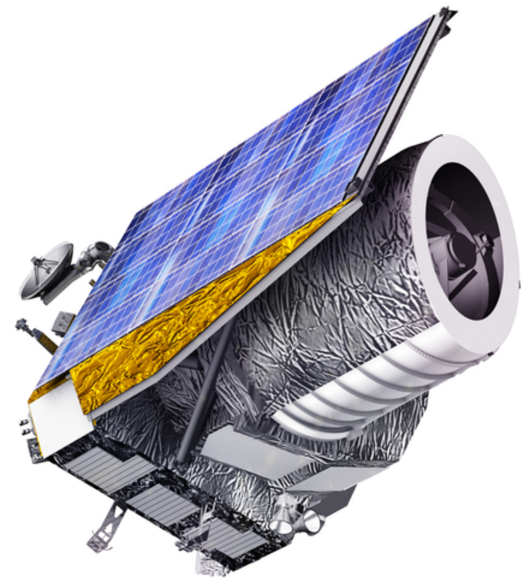

Mapping the large-scale structure of the Universe with VIPERS and Euclid (Cosmology with Multi-Object Spectrographs)

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12 December 2018

Cosmic Cartography

Cosmological model
- ★ Dark energy
- ★ Gravity
- ★ Early Universe

Moments of the density field
- ★ Correlation function
- ★ Power spectrum
- ★ Higher order statistics
- ★ Redshift-space distortions

Massively multi-object spectroscopic surveys

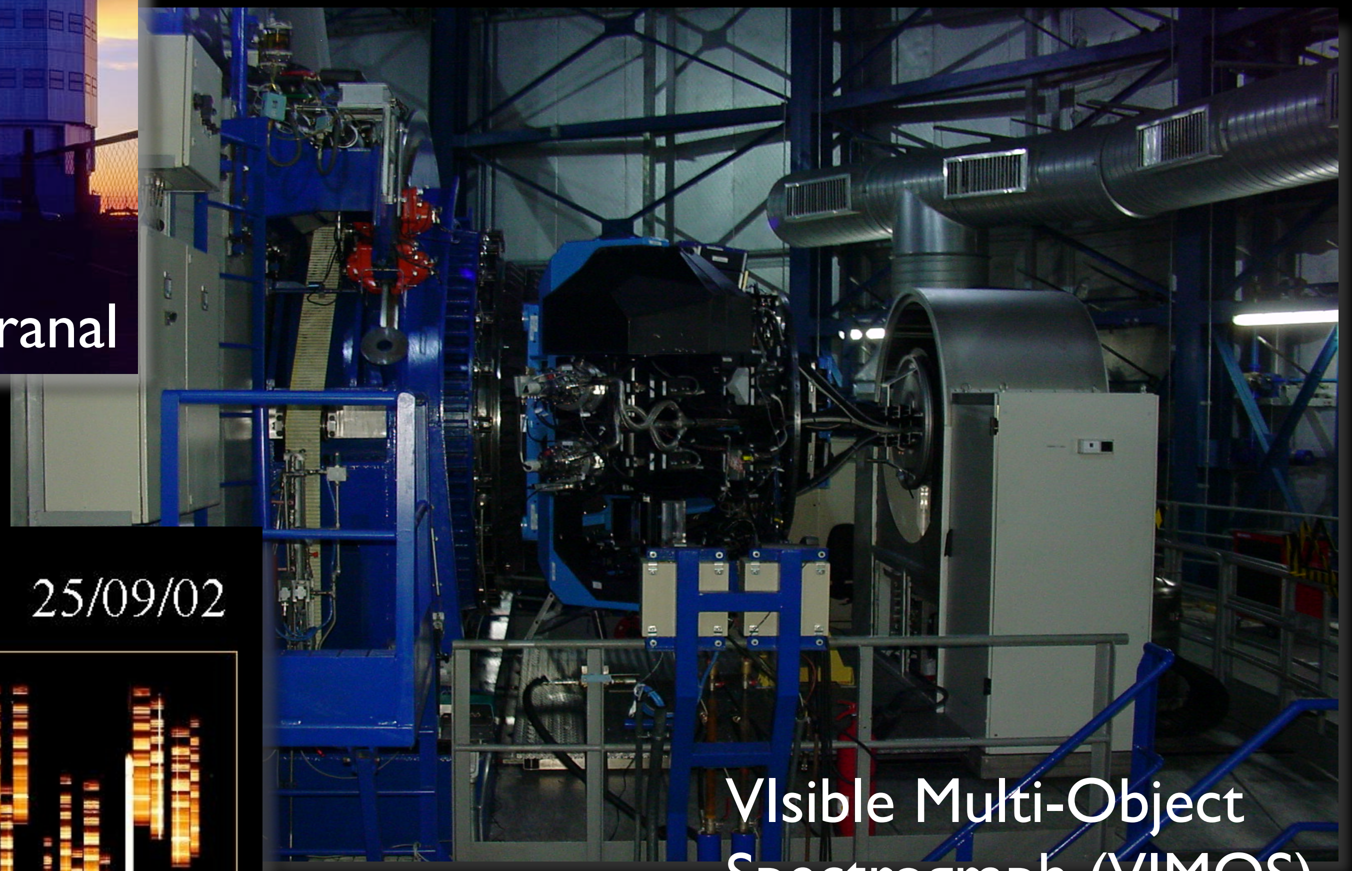
The Cosmic web
- ★ groups, clusters
- ★ filaments
- ★ voids

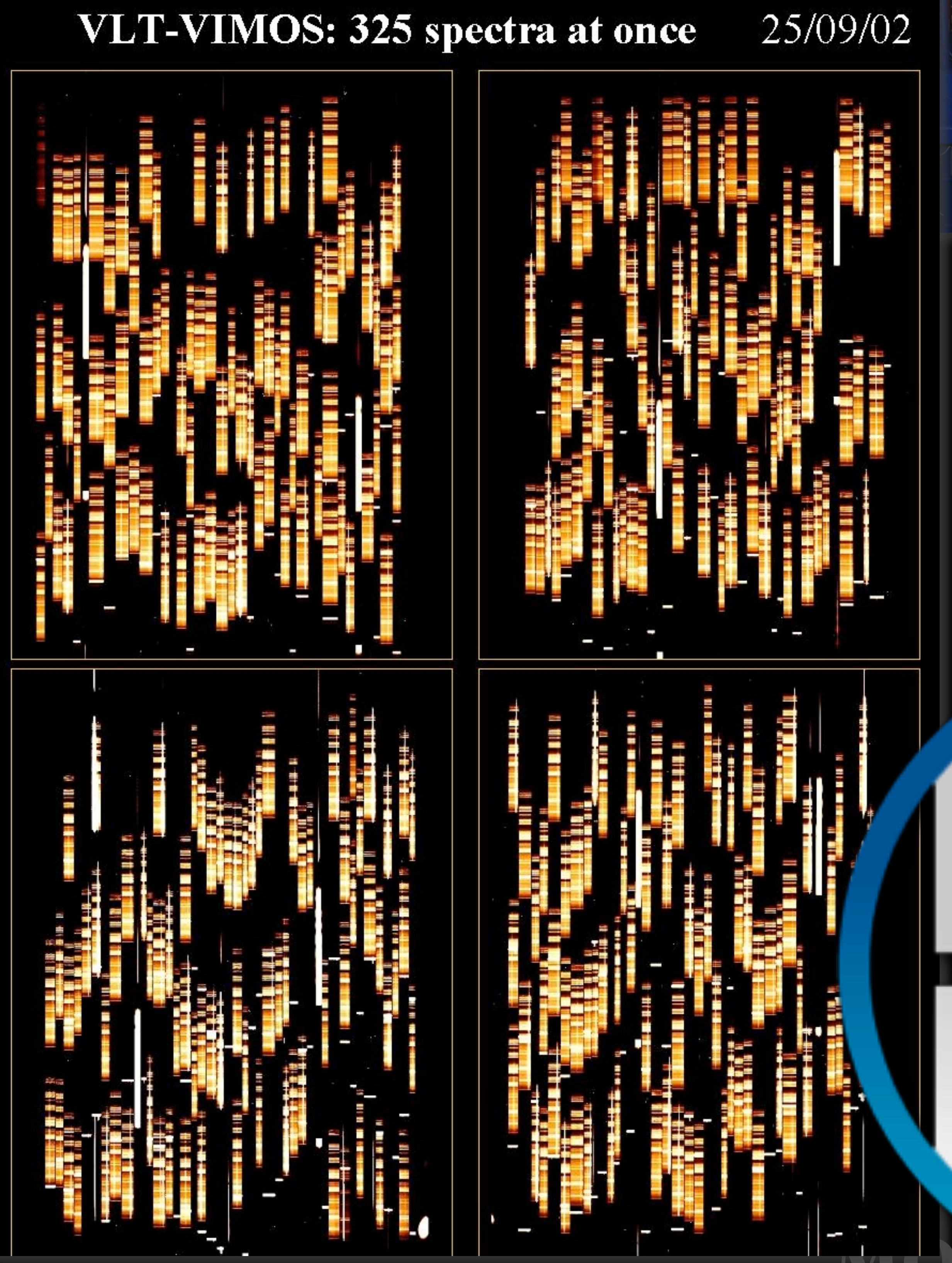
Galaxy - dark matter connection
- ★ Galaxy formation
- ★ Semi-analytic models
- ★ Halo occupation distribution

VIPERS

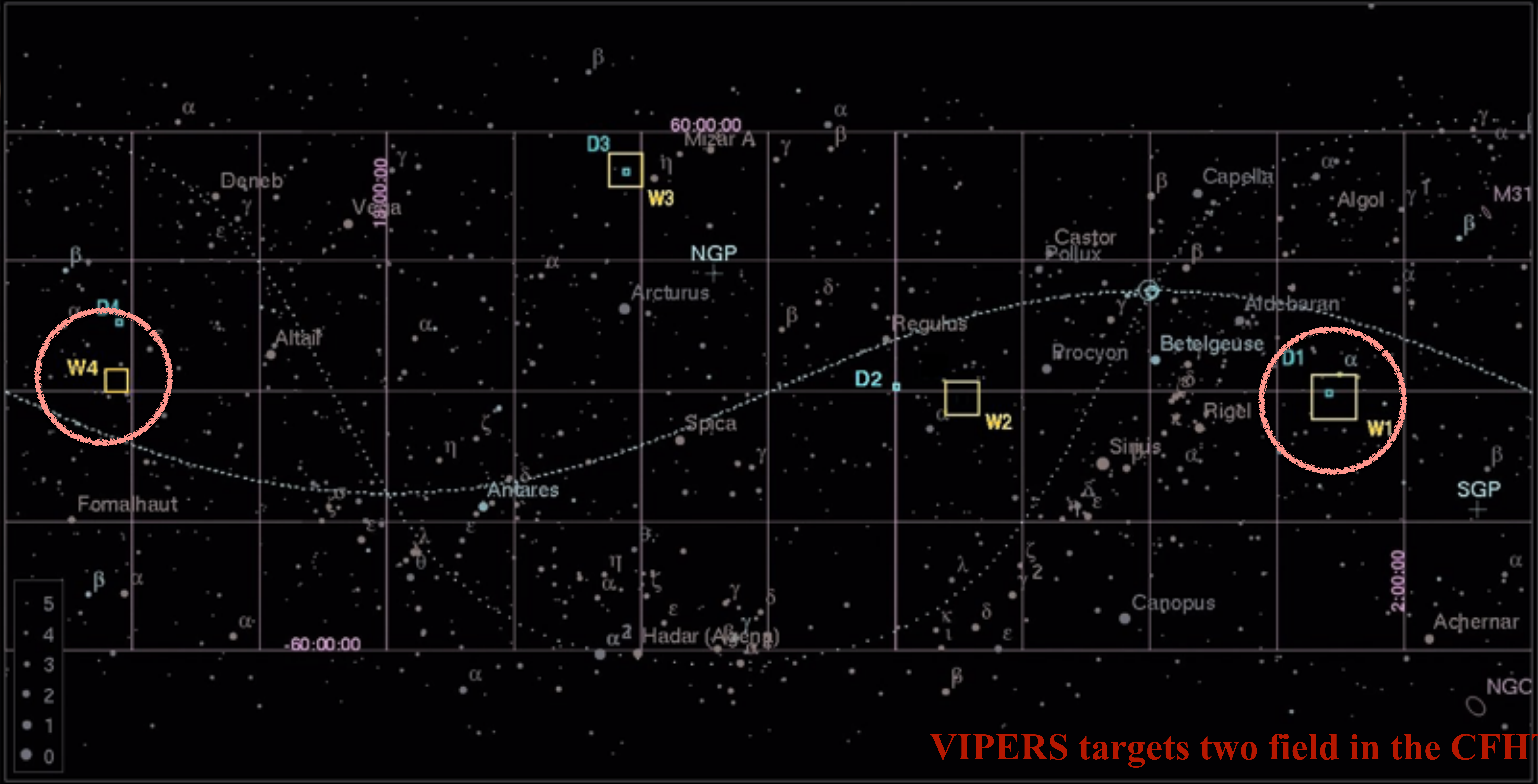
★ VIMOS Public Extragalactic Redshift Survey

- ➜ Headquarters in Milano (PI: Guzzo)
- ➜ Strong international collaboration with ~ 70 scientists (Italy, France, Poland, UK, Japan)
- ➜ ESO large program
- ➜ 90k spectra
- ➜ Redshift > 0.5
- ➜ Ancillary data including X-ray, UV to IR plus galaxy shapes & morphologies
- ➜ Lensing sheer field over same area - CFHTLens
- ➜ Data releases: vipers.inaf.it





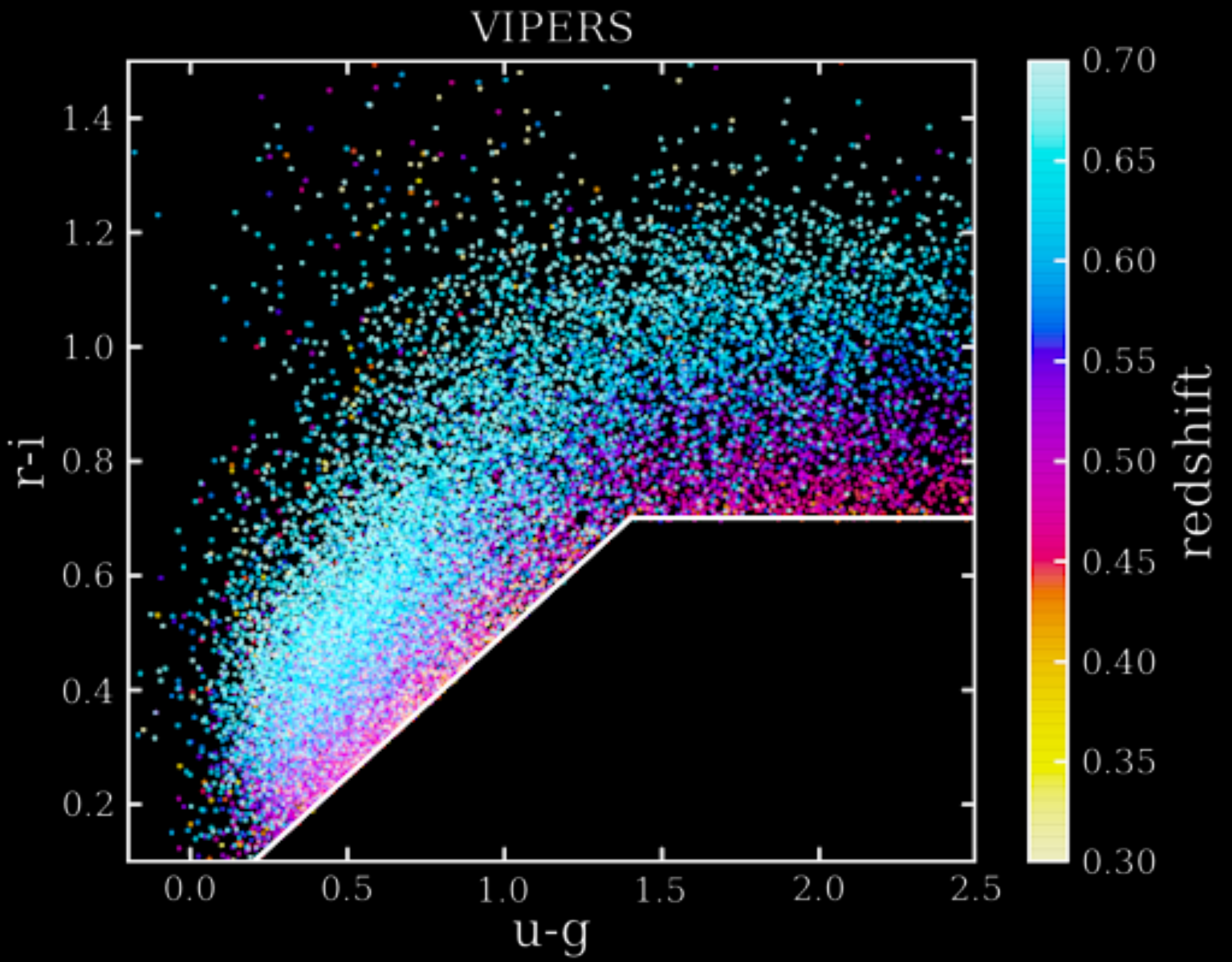
VIPERS Targeting



VIPERS targets two field in the CFHTLS

VIPERS Photometric Selection

- ★ Selection is optimized for the target redshift range (Scodeggio, Coupon, Guzzo)
- ★ i_{AB}=22.5 flux limit
- ★ Color pre-selection effectively targets galaxies at z>0.5

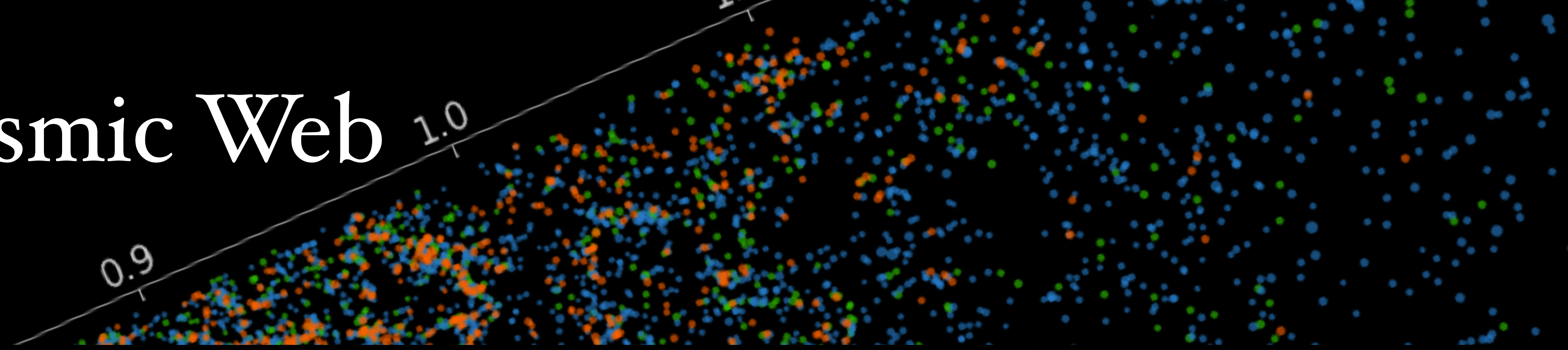


Guzzo et al, 2014

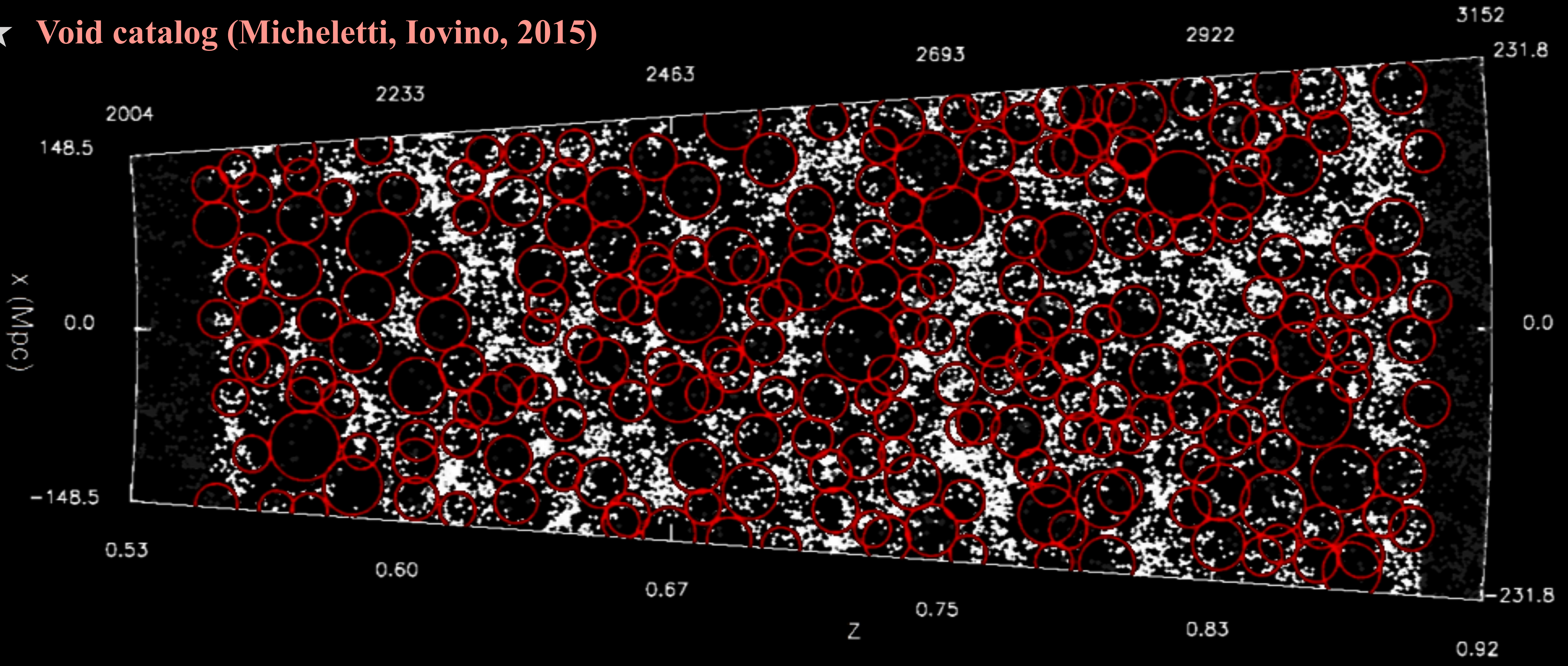
Cosmic Web

★ **VIPERS measured 90k redshifts tracing the cosmic web at z > 0.5 as a function of galaxy properties**

Cosmic Web



★ Void catalog (Micheletti, Iovino, 2015)

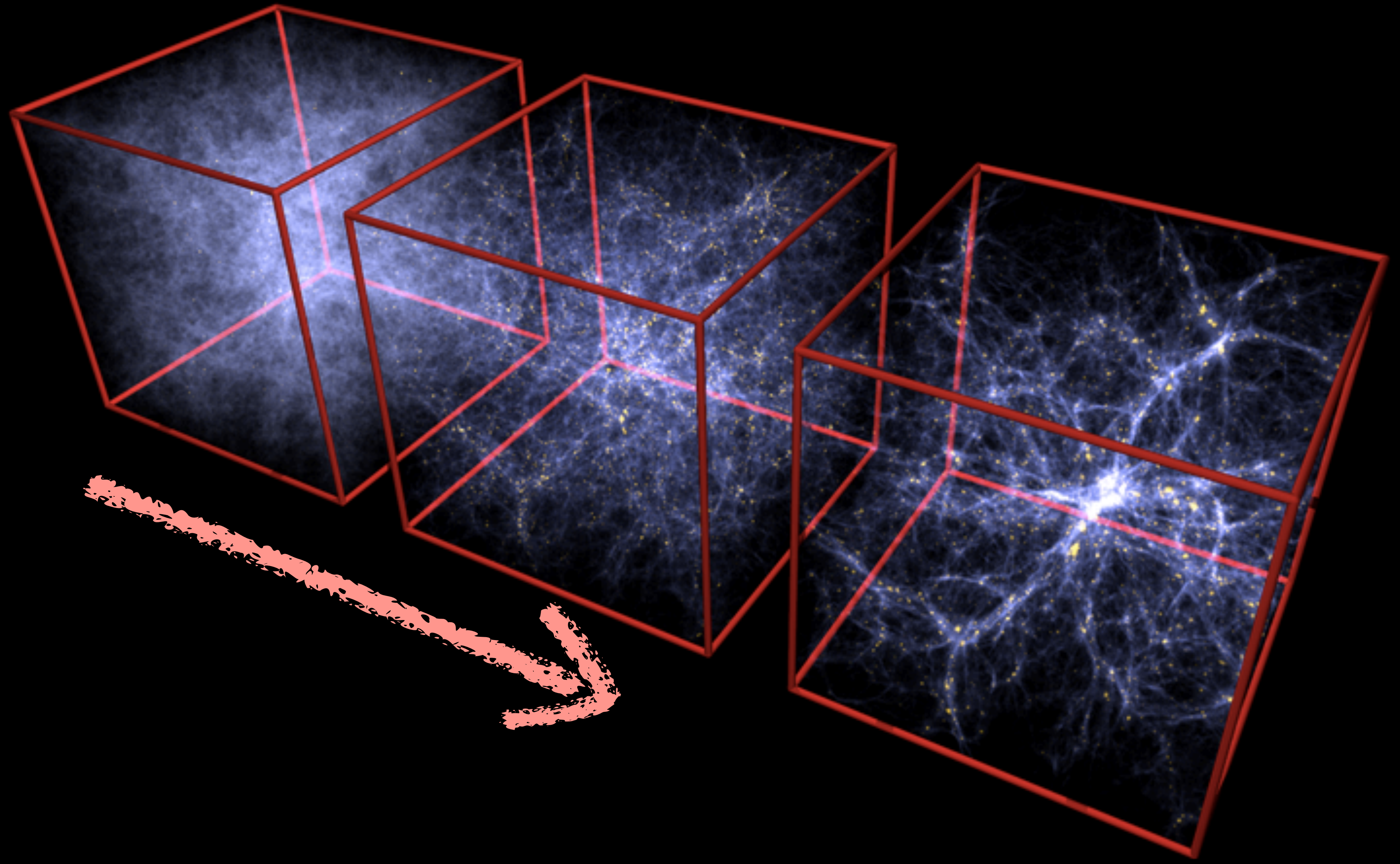


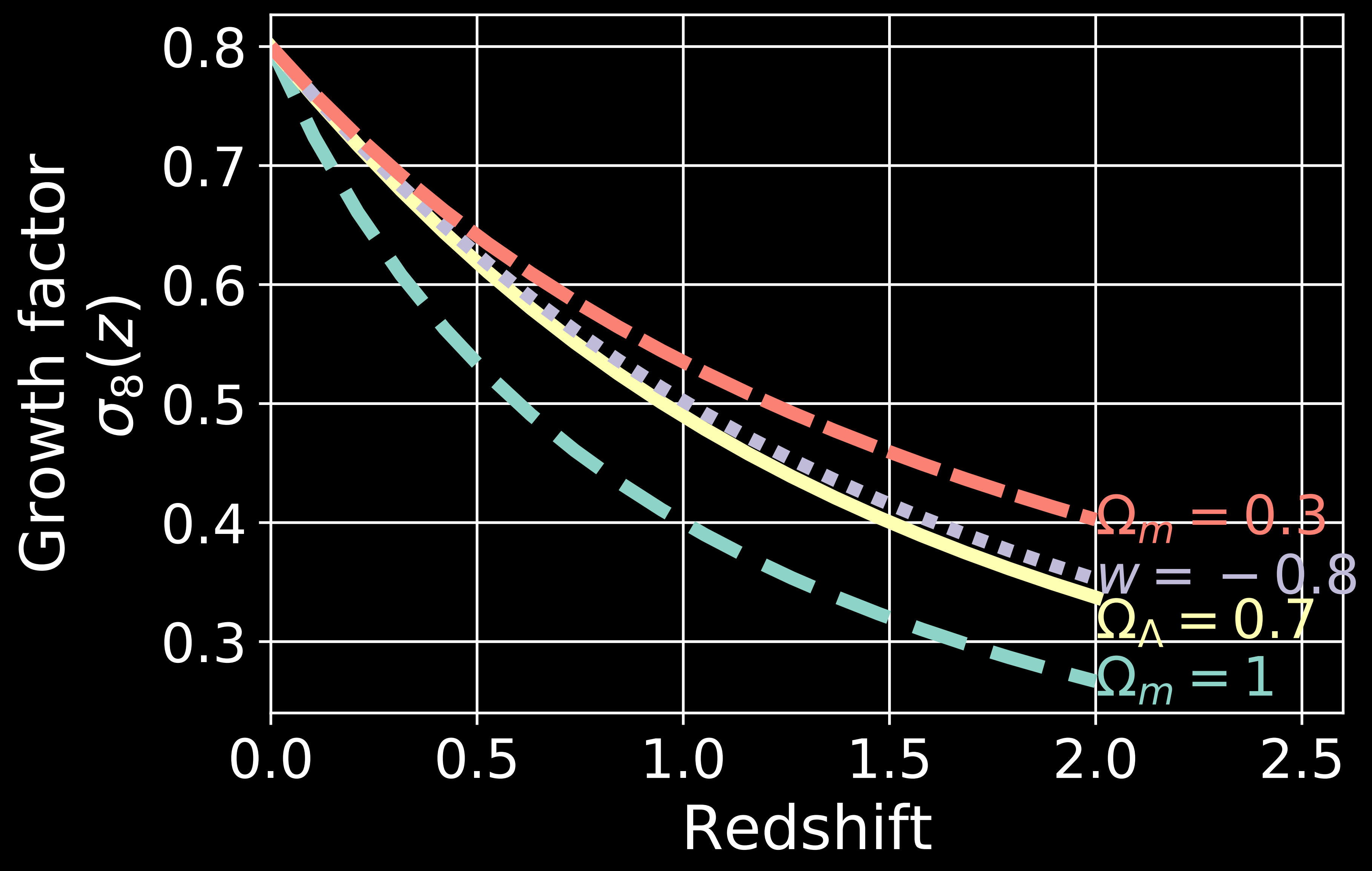
Tracking the growth of structure

★ The growth of structure with cosmic time is a sensitive probe of cosmology.

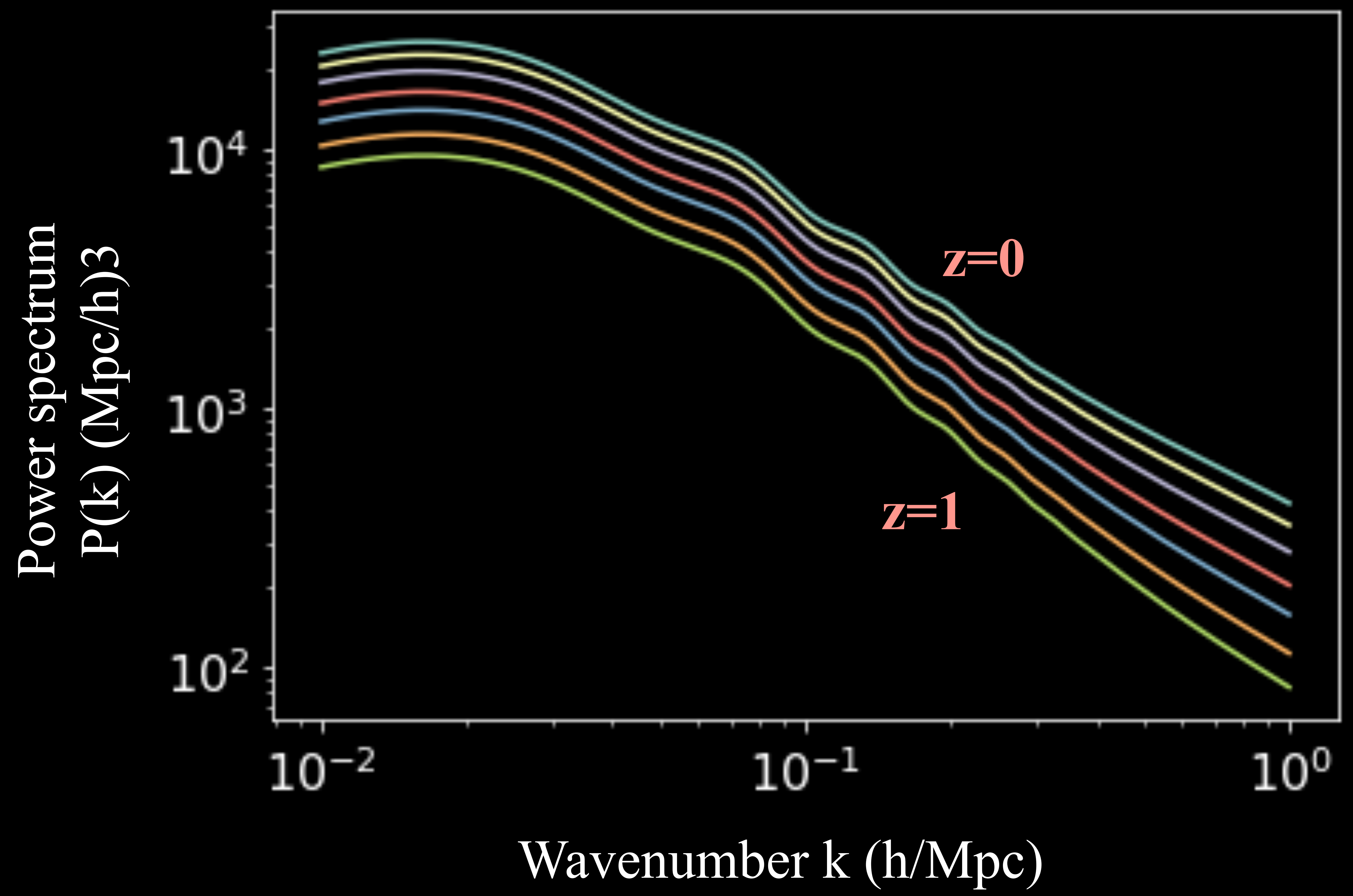
★ Acceleration slows the rate of structure formation

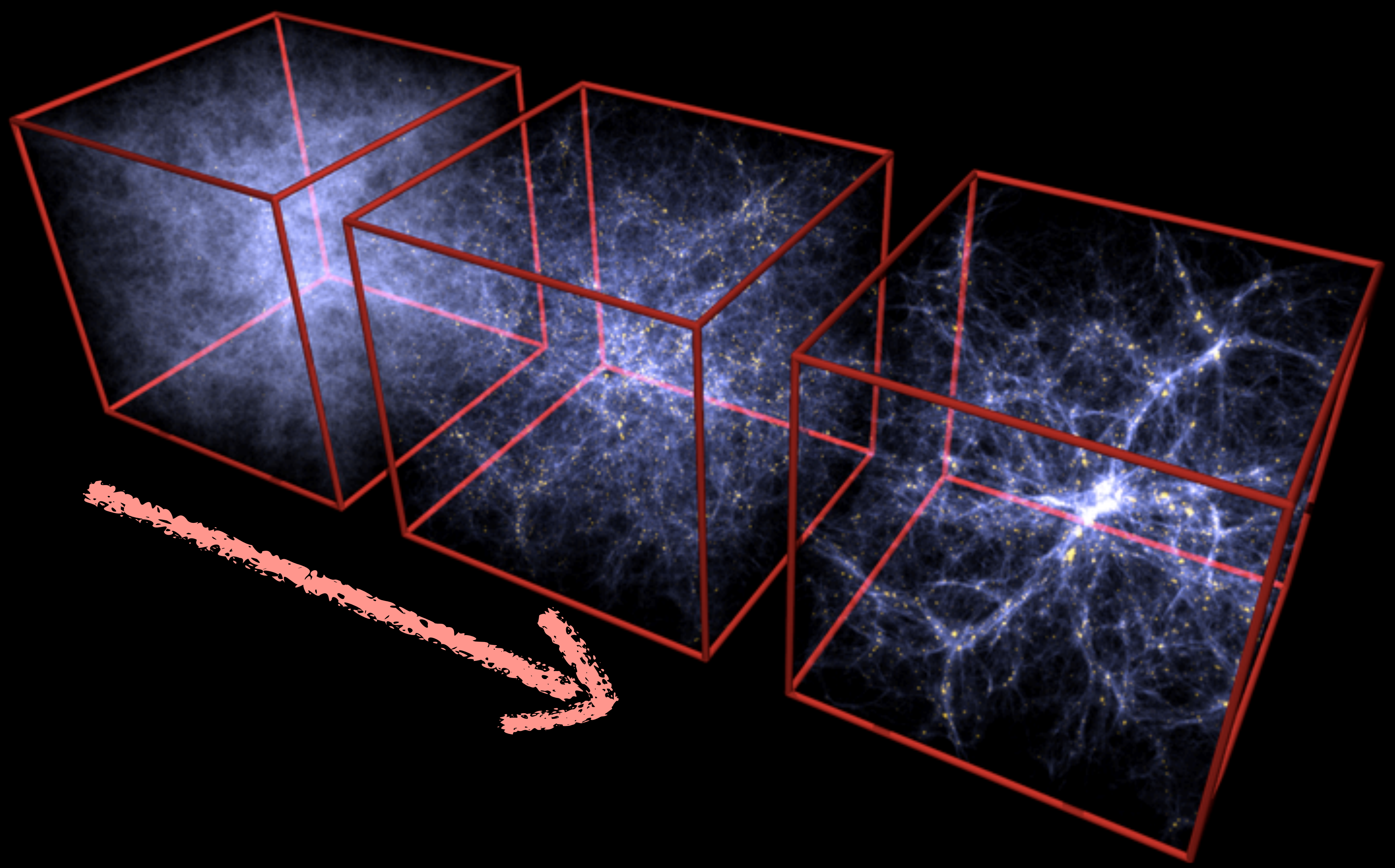
➡ Learn about dark energy and general relativity on cosmological scales

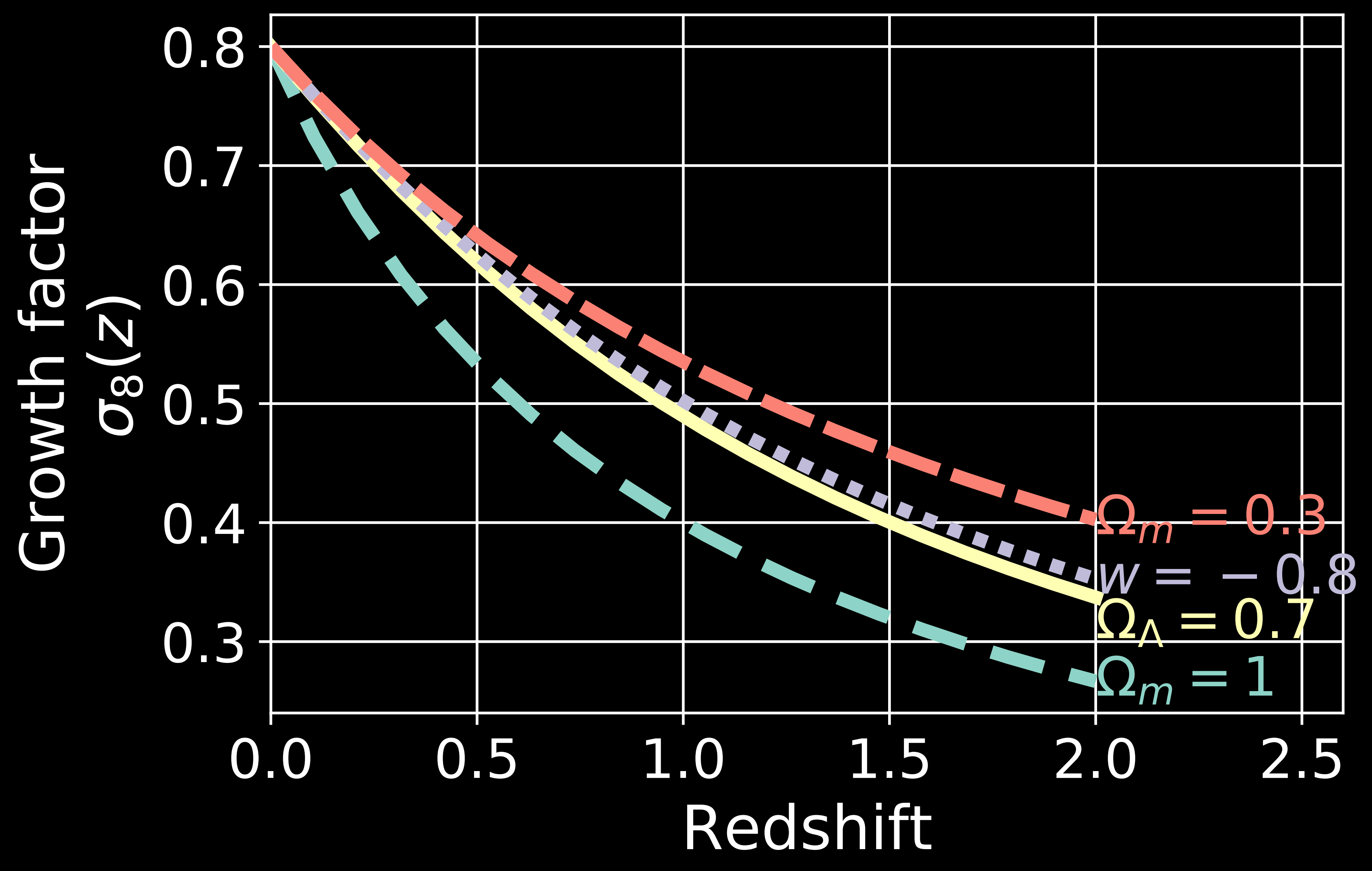




Tracking the growth of structure







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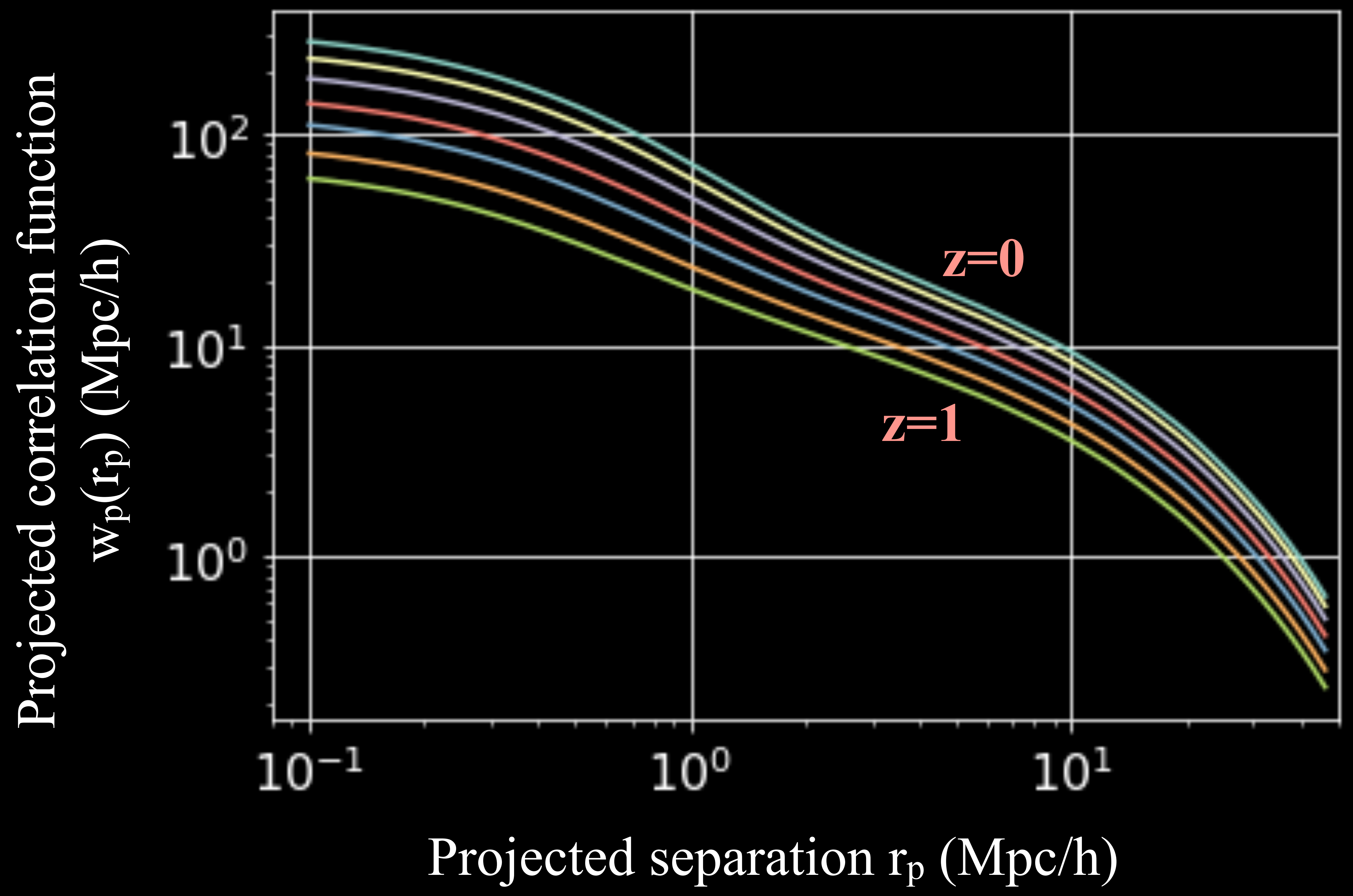
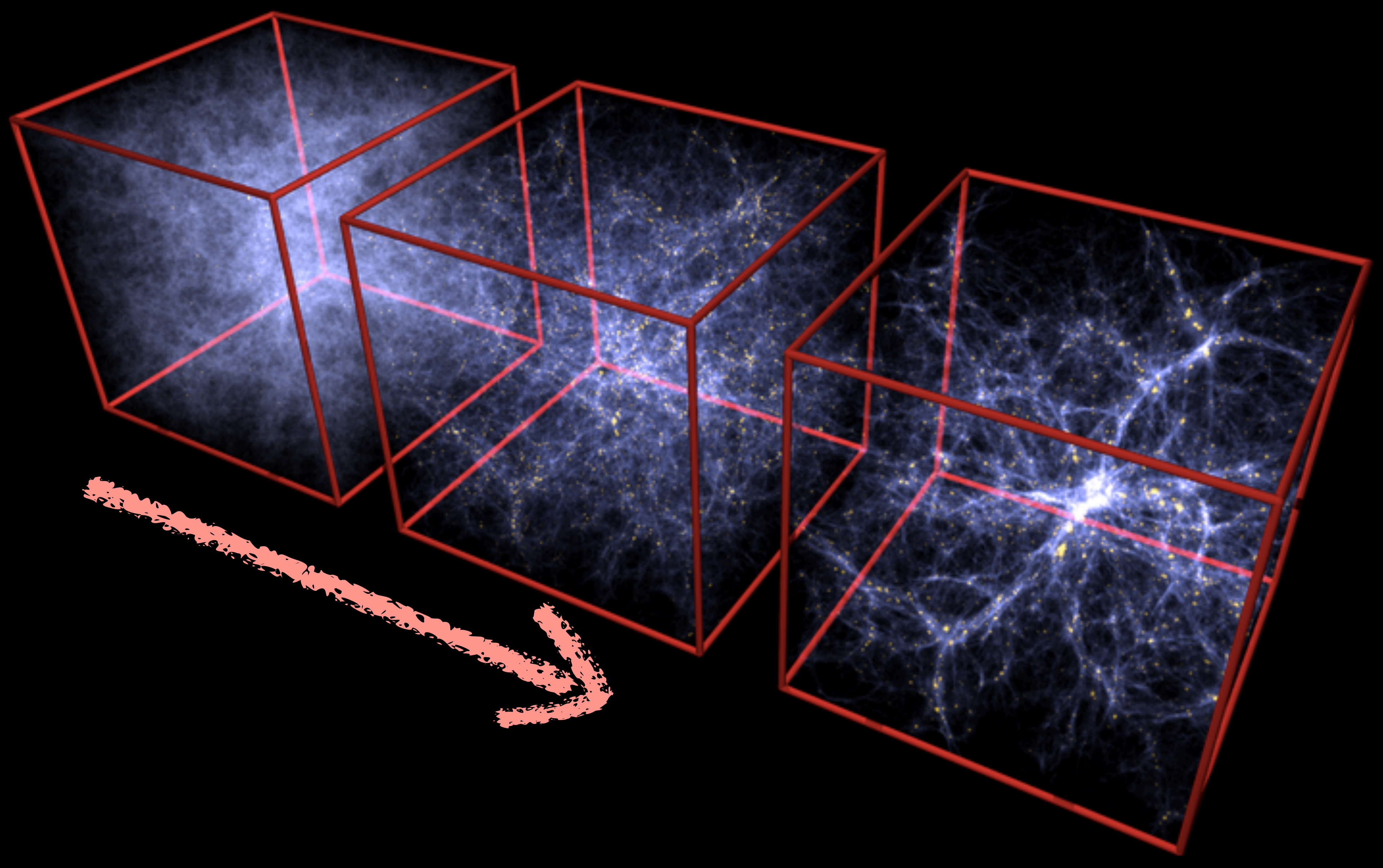
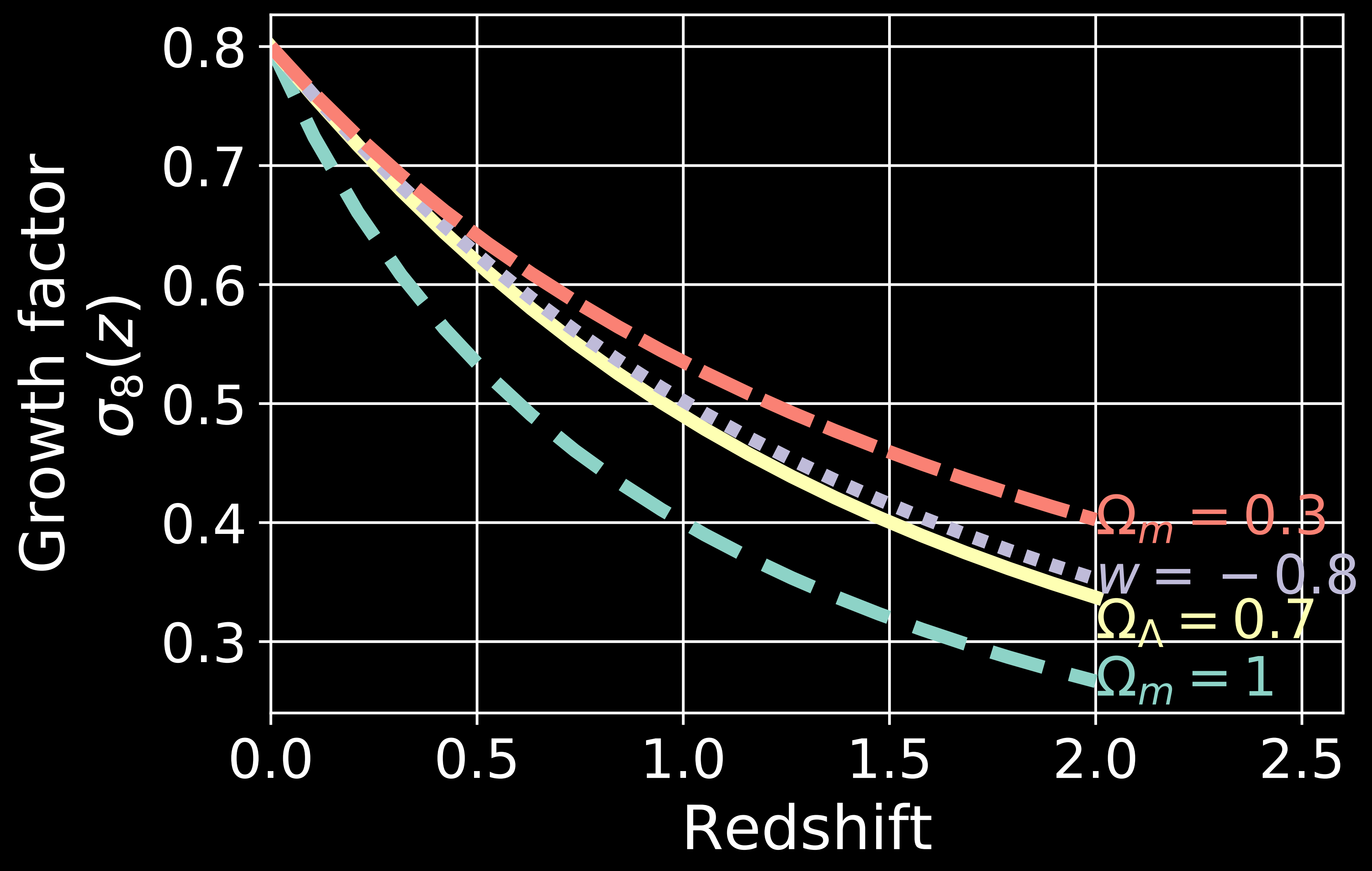




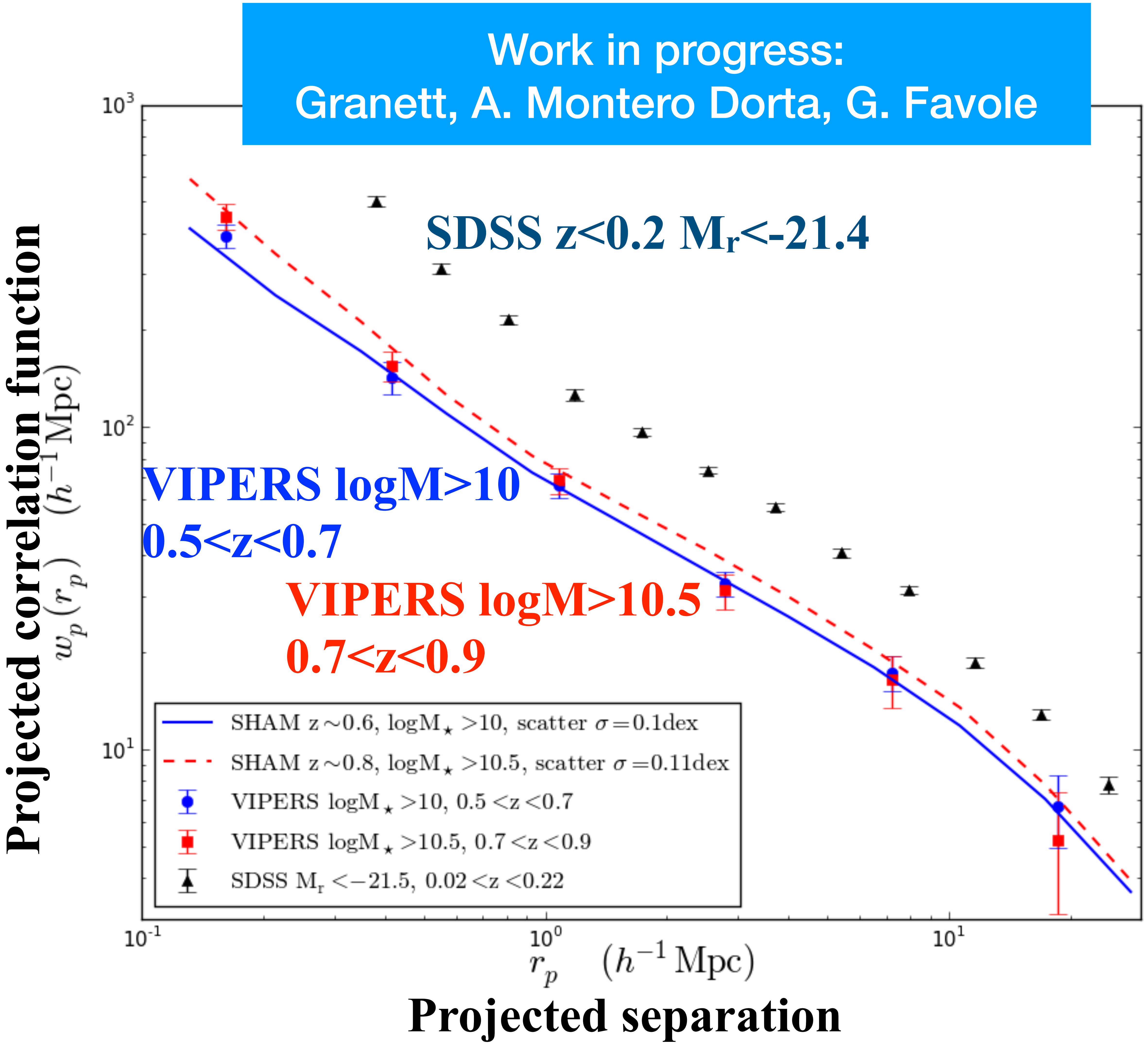


Growth over 4 Gyr (z=0 to z=0.8)

★ We must carefully control for galaxy bias to compare galaxy clustering at different redshifts.

➜ Sub-halo abundance matching (SHAM) with N-body simulation predicts galaxy bias. (Multidark)

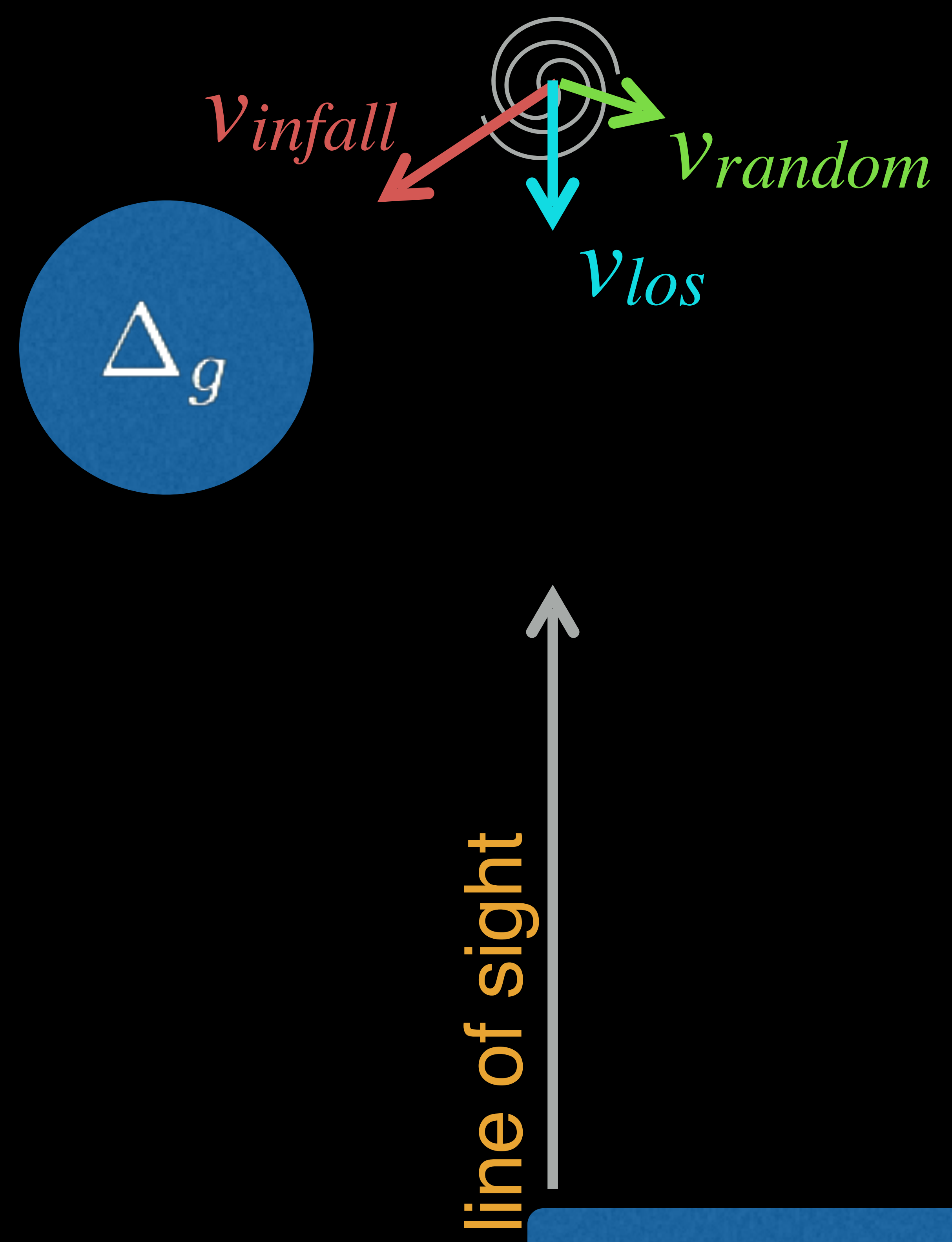
➜ Rescaling simulations (Angulo & White 2010)



Going to redshift space

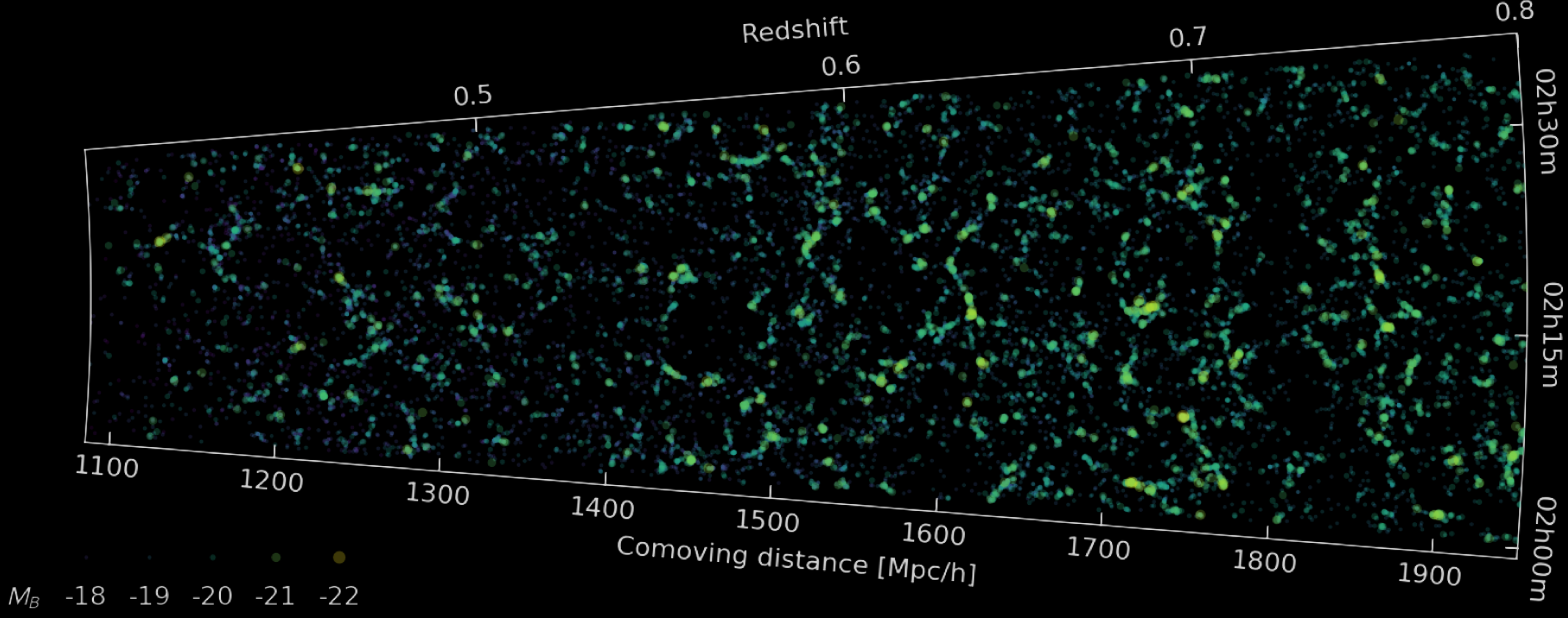
- ★ Spectroscopic surveys map the 3D distribution of galaxies in redshift space.
- ★ Line of sight distances are distorted due to peculiar velocities arising from:
  - ➡ Bulk flows
  - ➡ Random motions
- ★ Measures the derivative of the growth factor (Kaiser)

$$f = \frac{d \log D}{d \log a}$$



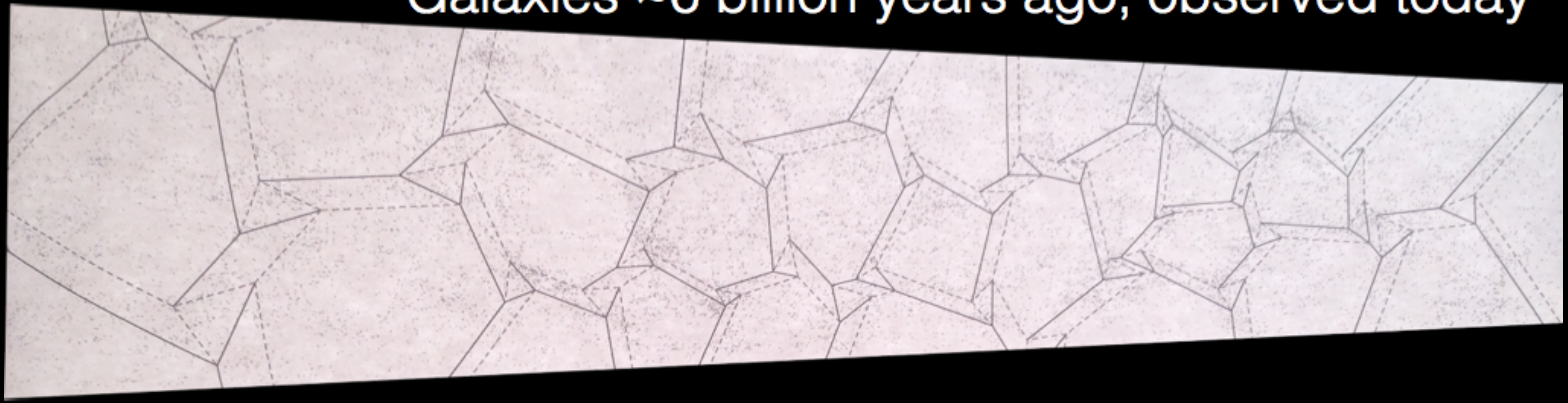
Let's look at the distortions in VIPERS mocks.

A distorted view



Mock

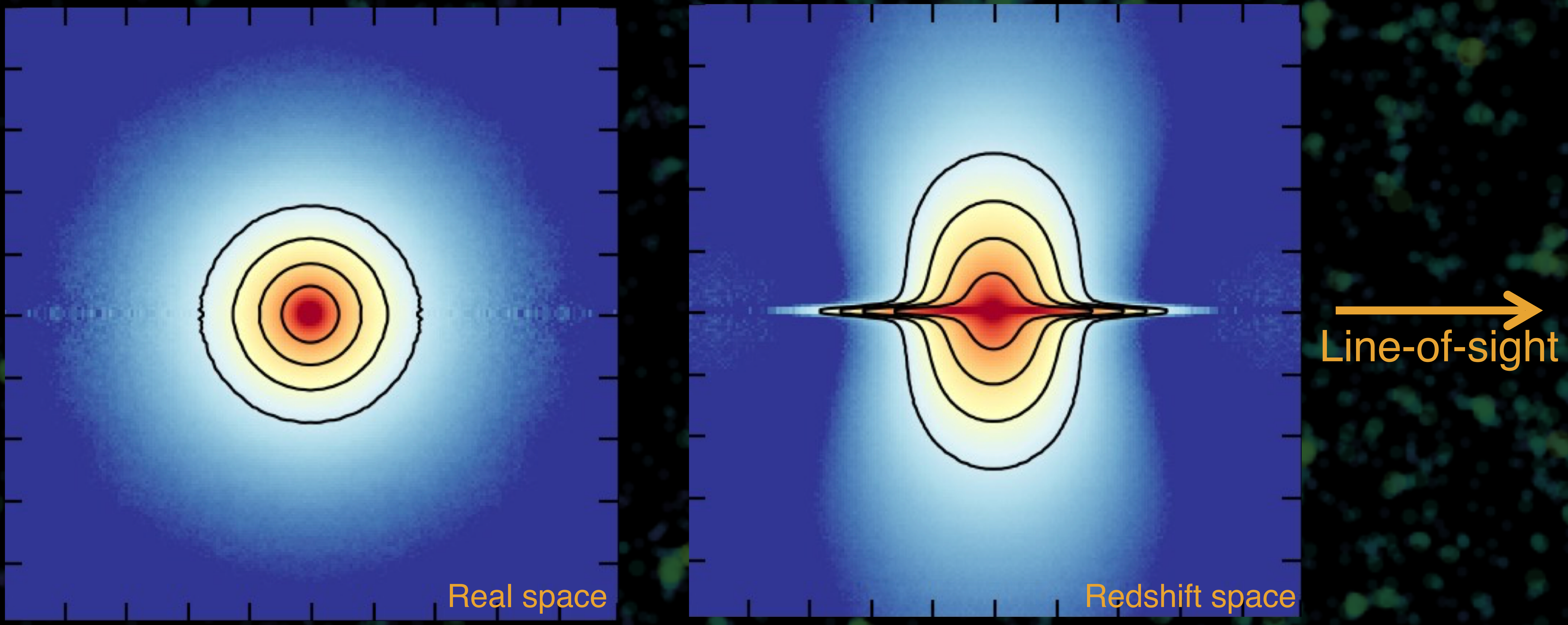
Galaxies ~6 billion years ago, observed today



Schematically what they might have done since then

Mark Neyrinck (JHU/IAP)

Two-point correlation function



Mock

Growth of Structure

- ★ Peculiar velocities enhance modes along the line of sight through the Kaiser effect:

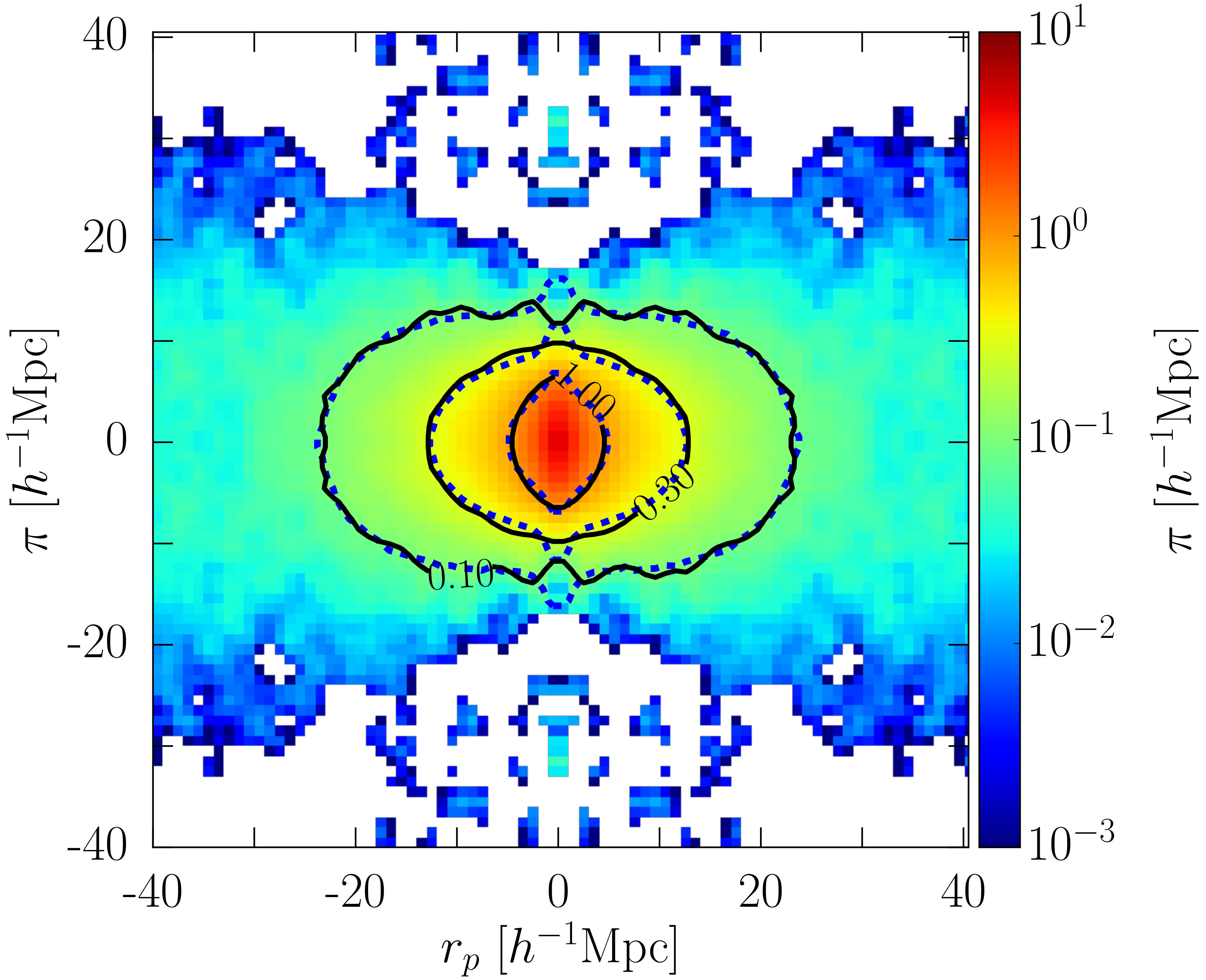
$$\delta_s(k) = \delta(k)(1+\beta\mu^2)$$

$$\beta = \frac{f}{b} \qquad f = \frac{d\log D}{d\log a}$$

→ The power spectrum is distorted:

$$P(k,\mu) = (b + f\mu^2)^2 P_m(k)$$

- ★ The growth factor *D(z)* is determined by the gravity model and acceleration and may also depend on scale.



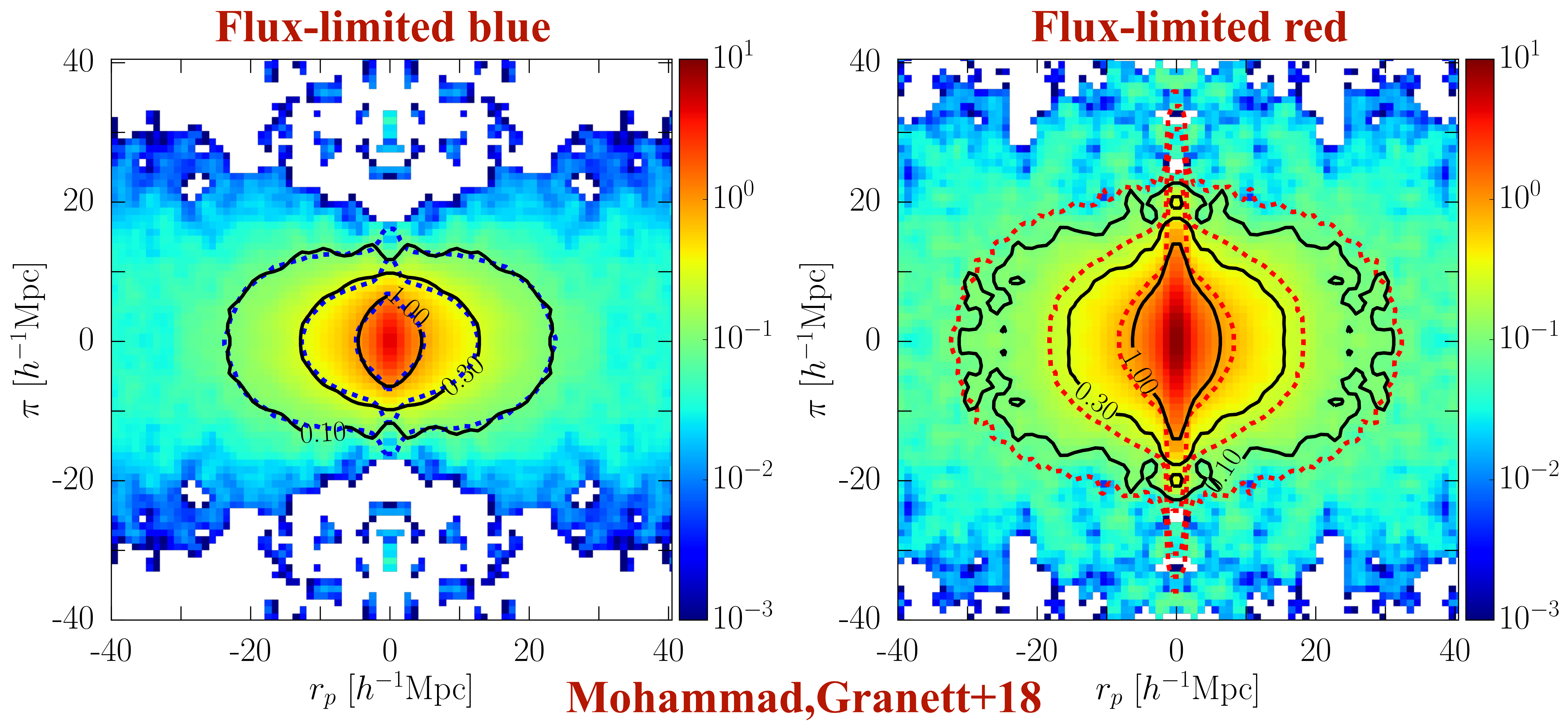
VIPERS blue galaxies
Mohammad,Granett+18

Multi-Tracer Analyses

Density field reconstructed in VIPERS 0.6<z<0.8 (Granett)

★ Red and blue galaxies trace the same density field, but with different clustering amplitude.

Multiple Tracers and Systematics

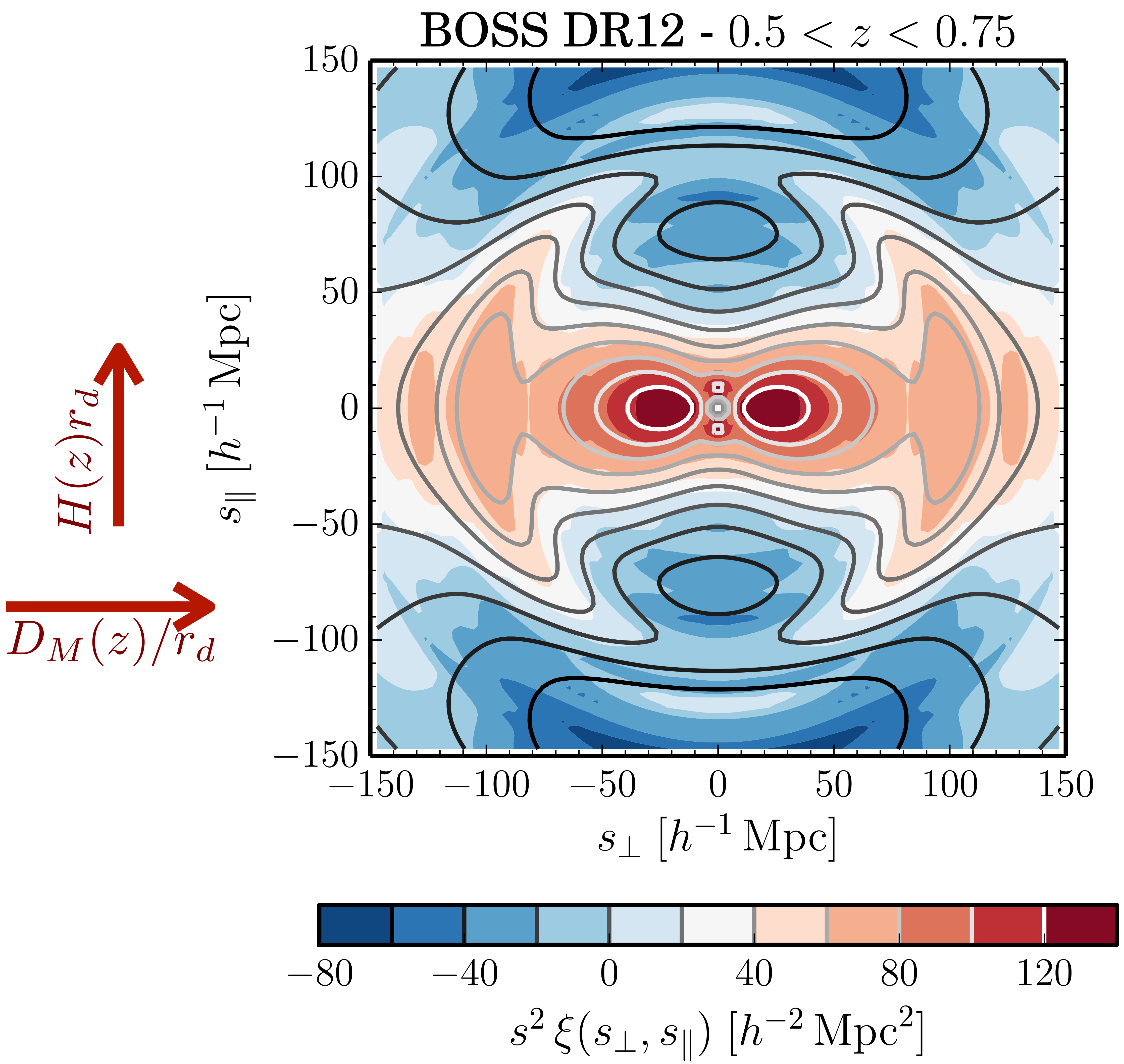


Mohammad,Granett+18

- ★ Blue galaxies tend to be central in low-mass dark matter halos
- ★ Red galaxies live in massive halos with more satellites

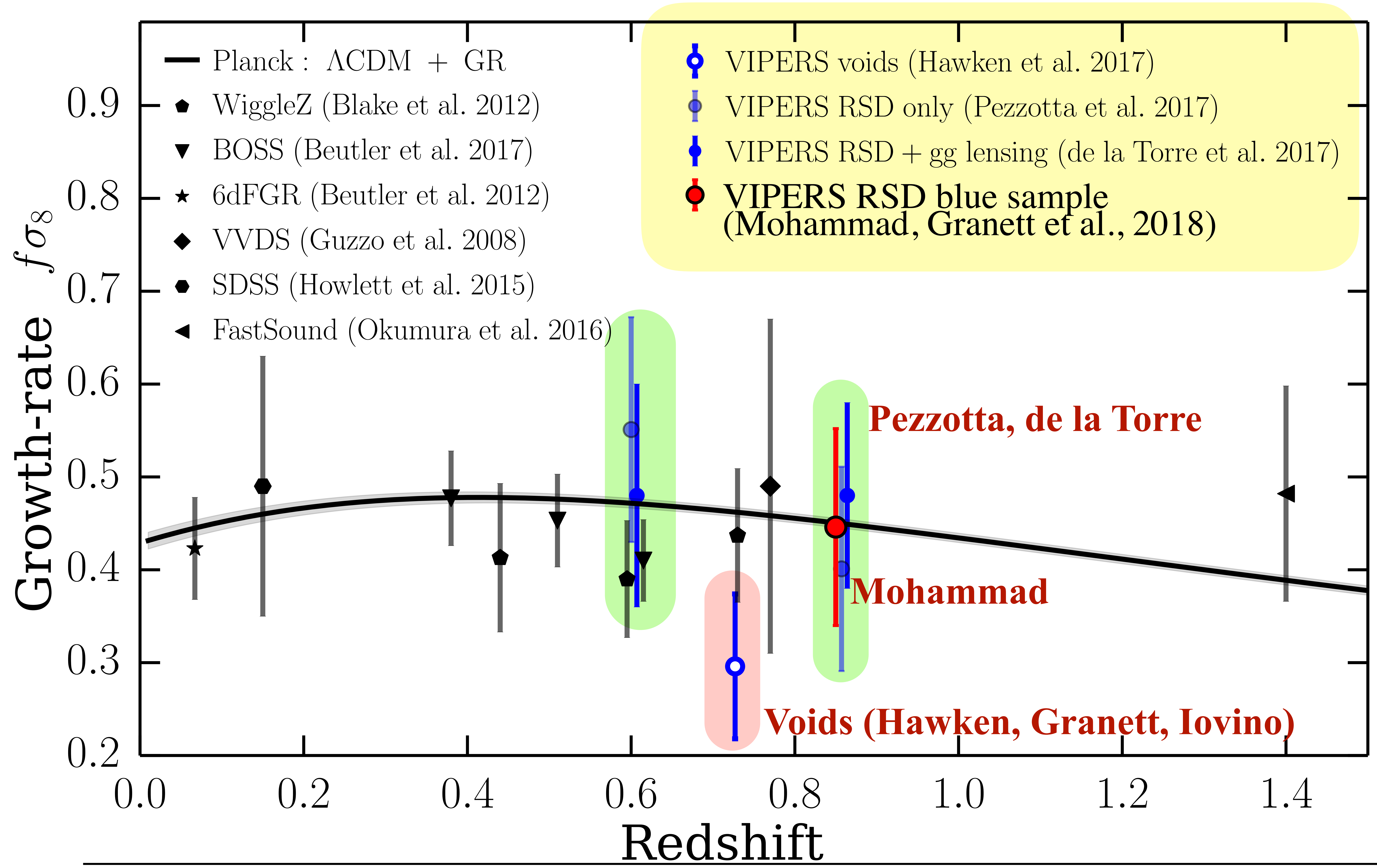
BAO & Complementary Probes of Acceleration

- ★ The baryon acoustic oscillation (BAO) feature marks a fixed co-moving scale.
  - ➜ *The inverse distance ladder*
  - ➜ Expansion history $H(z)r_d$
  - ➜ Angular diameter distance $D_M(z)/r_d$
- ★ Redshift-space distortions sourced by the growth of structure



Alam+17

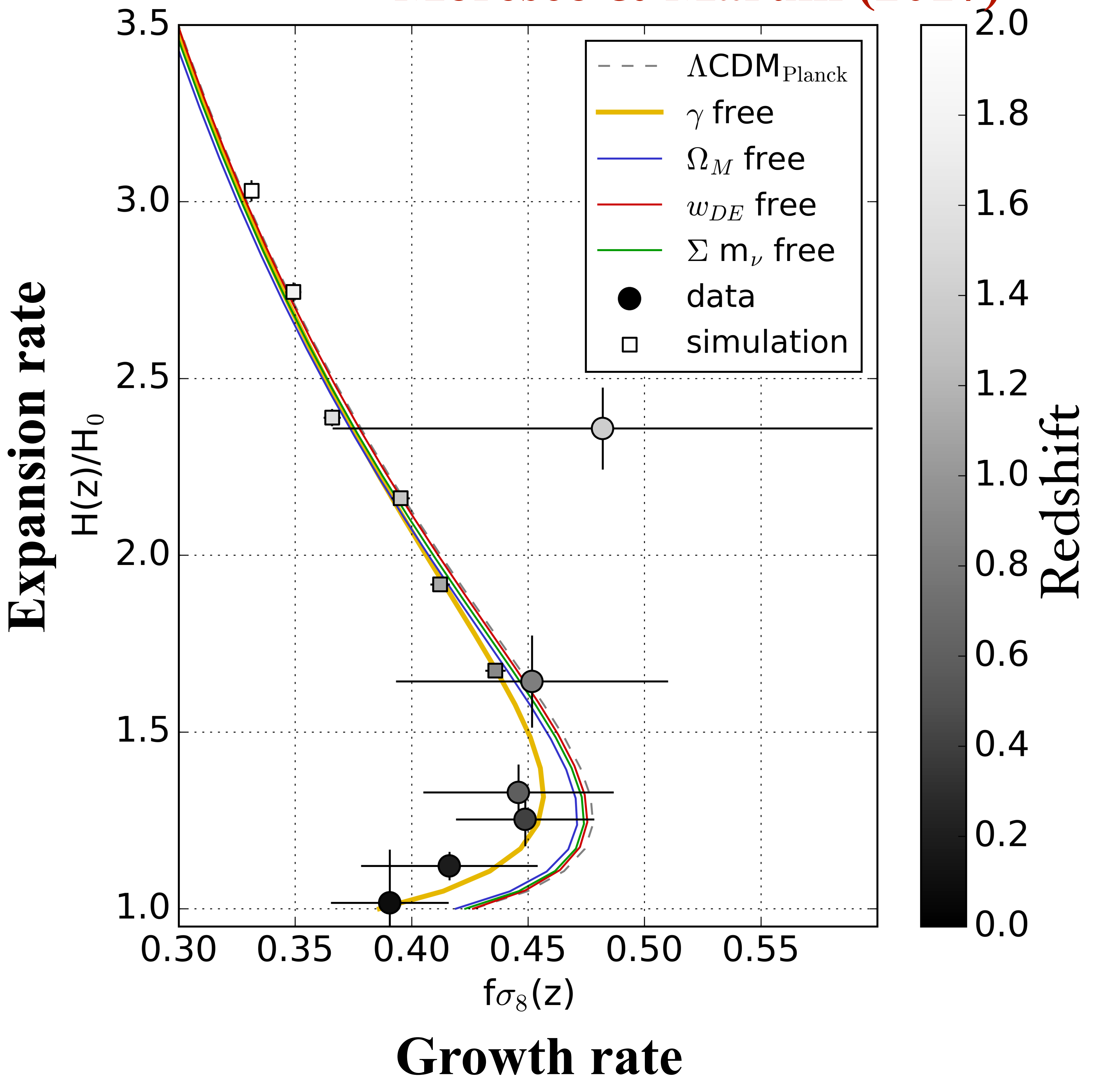
VIPERS constraints



Complementary Probes of Acceleration

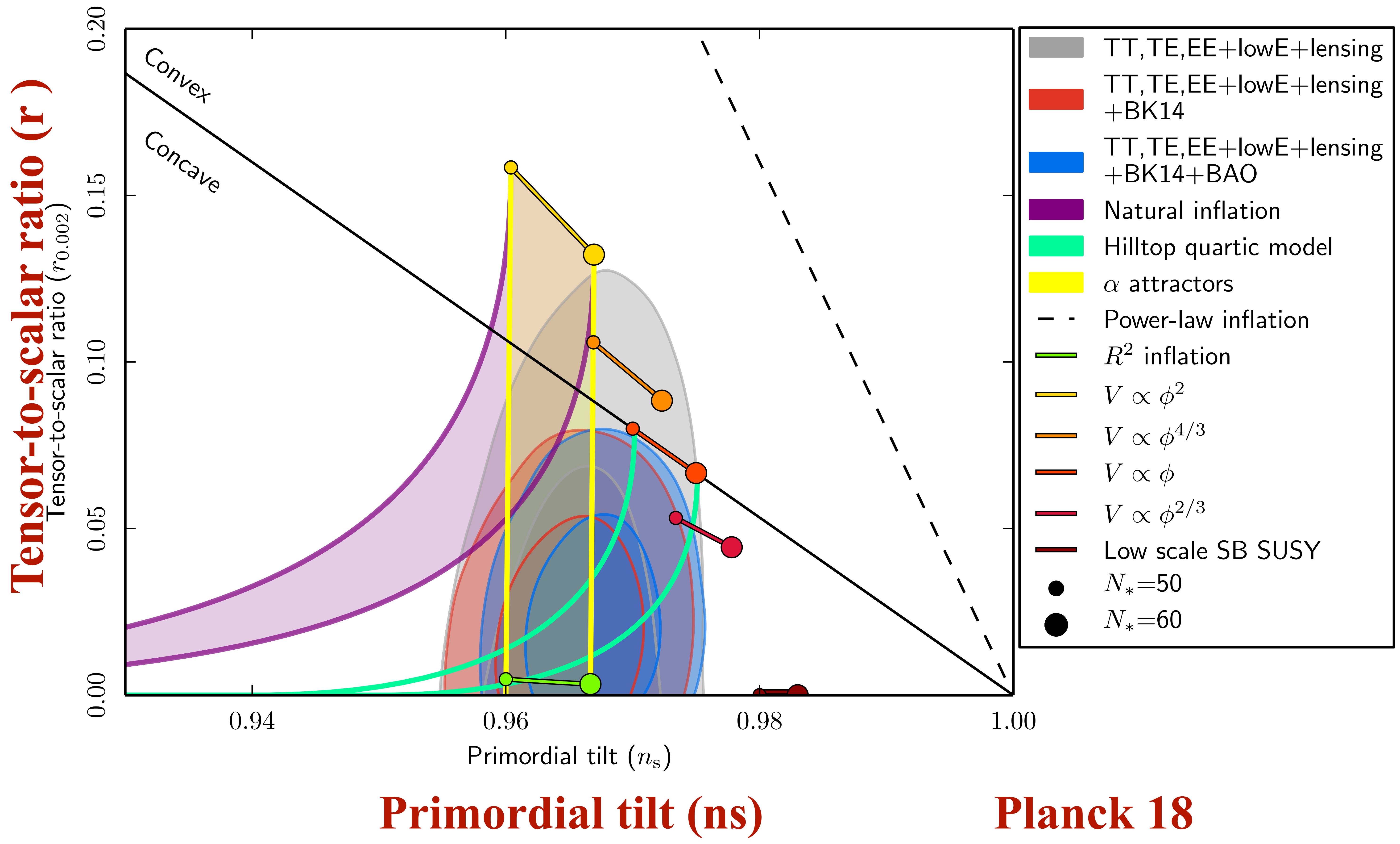
- ★ Cosmic acceleration can be explained by a dark energy component or modification of General Relativity.
- ★ Measurements of the expansion history alone cannot rule out modifications to GR.
- ★ Growth of structure measurements break the degeneracy.

Moresco & Marulli (2017)



Complementarity of Surveys

- ★ The CMB gave us the era of precision cosmology, but large-scale data enhances the science.
- ★ Upcoming galaxy surveys will inform on the spectral tilt and primordial non-Gaussianity.



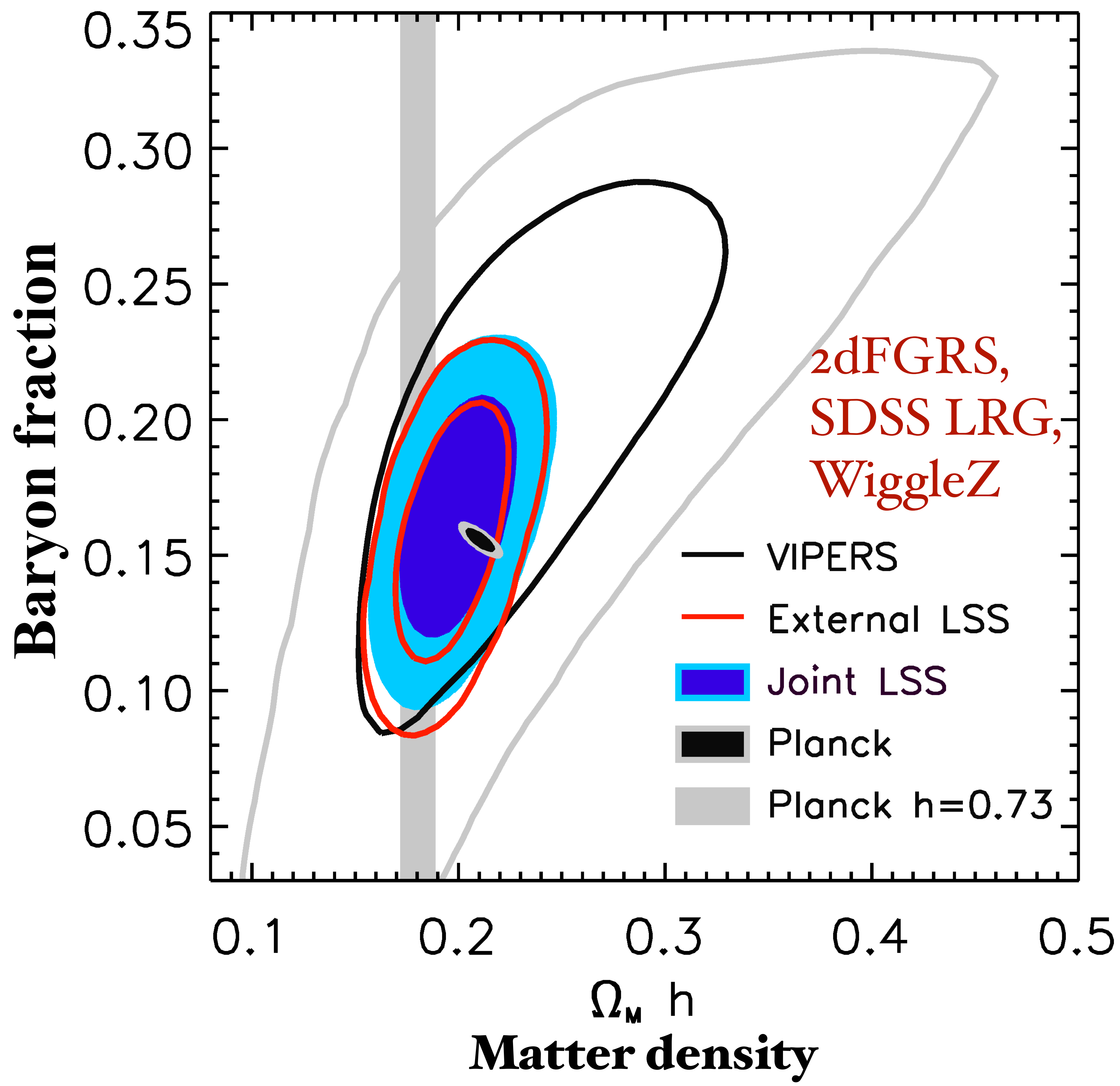
Complementarity of Surveys

★ Galaxy clustering can validate H0

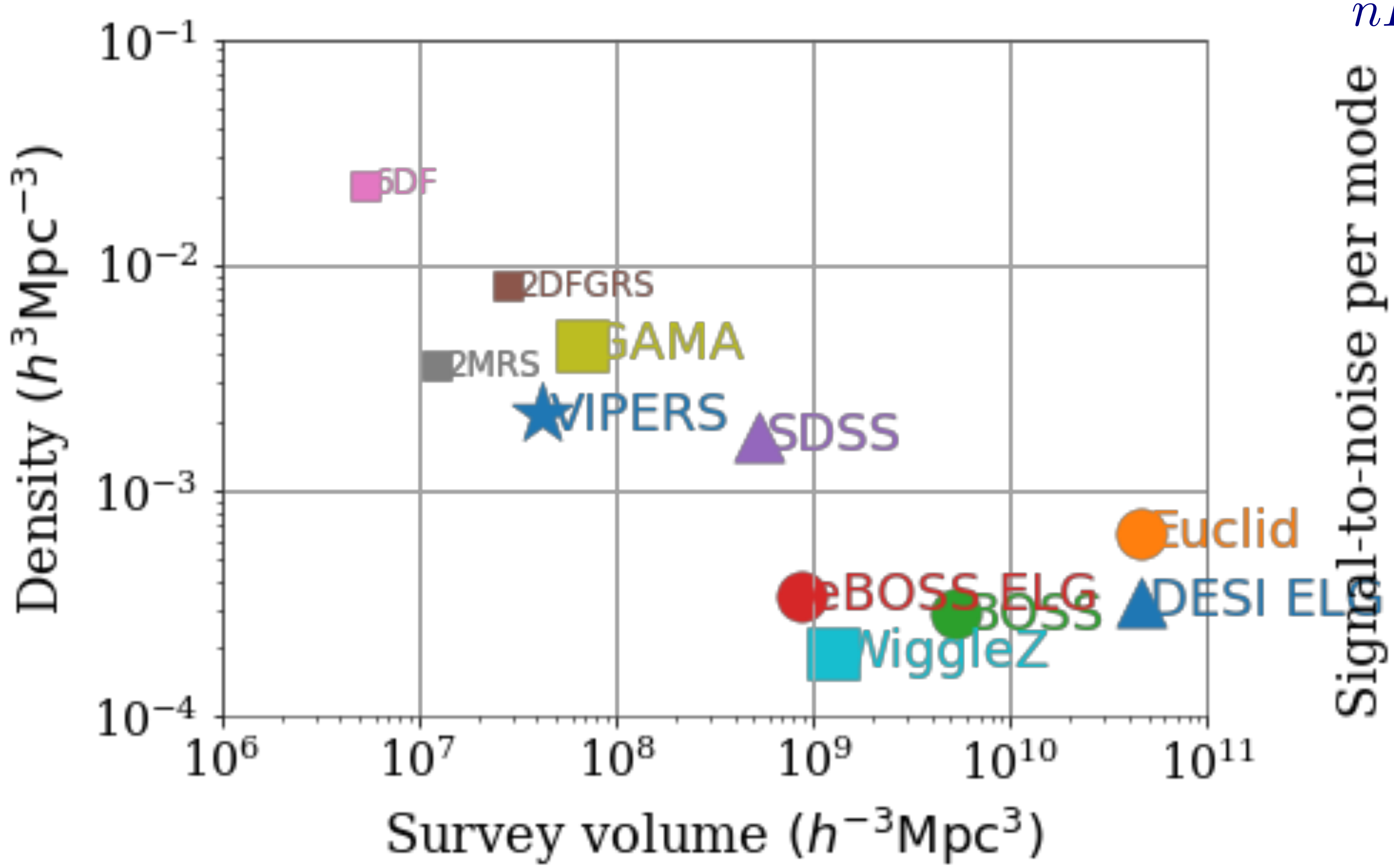
➜ The first acoustic peak on the CMB is sensitive to $\Omega_m h^3$ while galaxy clustering measures $\Omega_m h$.

➜ The precision of future surveys can provide clues to the tension with local measures of the Hubble parameter.

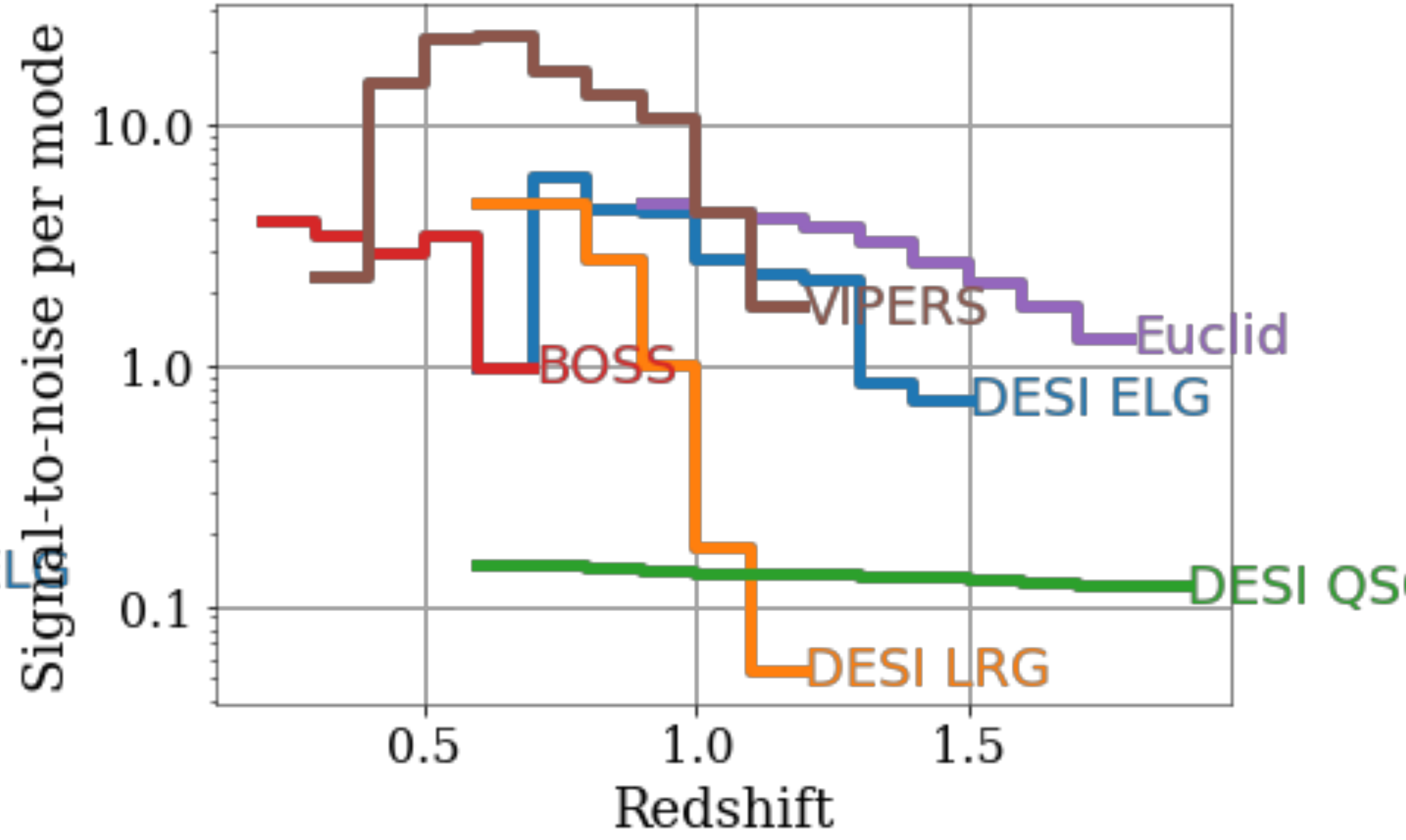
Rota, Granett+17



Survey Parameters

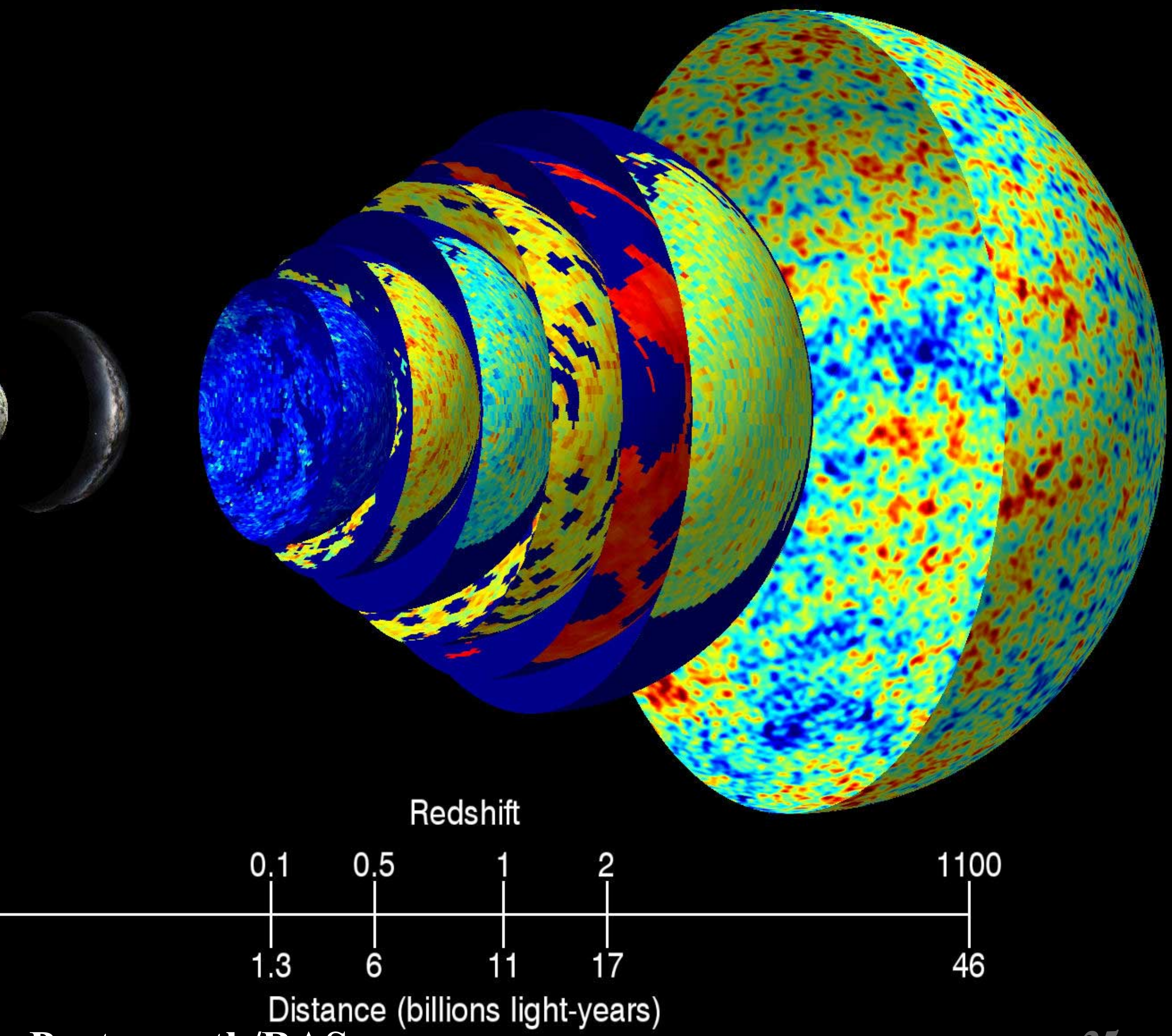


$nP(k = 0.2)$



Granett (github.com/bengranett/specsurveys)

Spectroscopic Redshift Surveys



- ★ Optical and near-IR spectroscopic surveys probe the luminous galaxy field: $0 < z < 4$
- ★ Star formation peaked at $z \sim 2$
- ★ Information content of LSS grows with volume.
  - ➡ **Future surveys promise to mine these modes!**

Portsmouth/RAS