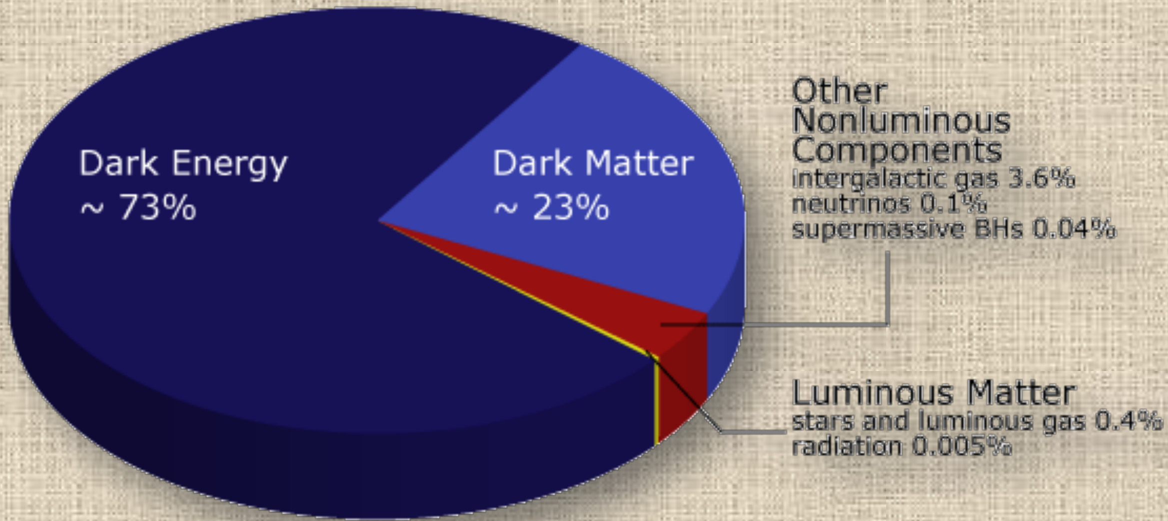
DARK LIGHT

Illuminating Dark Energy with the Next Generation of Cosmological Redshift Surveys

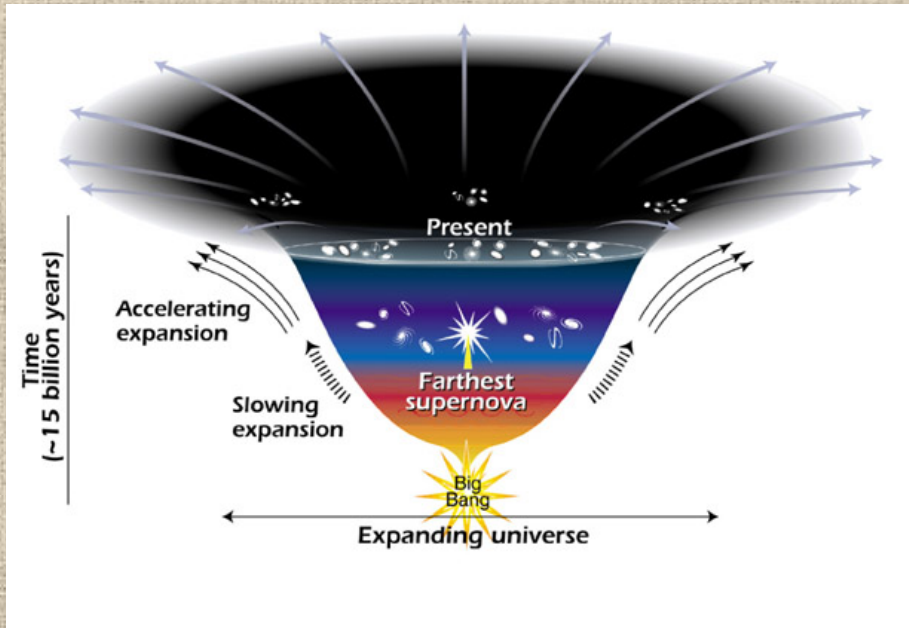
Luigi Guzzo

Osservatorio Astronomico di Brera, INAF, Merate/Milano

The “cosmic soup” of the 21st century: but who ordered it?



2011 Nobel Prize



This diagram reveals changes in the rate of expansion since the universe's birth 15 billion years ago. The more shallow the curve, the faster the rate of expansion. The curve changes noticeably about 7.5 billion years ago, when objects in the universe began flying apart at a faster rate. Astronomers theorize that the faster expansion rate is due to a mysterious, dark force that is pushing galaxies apart.

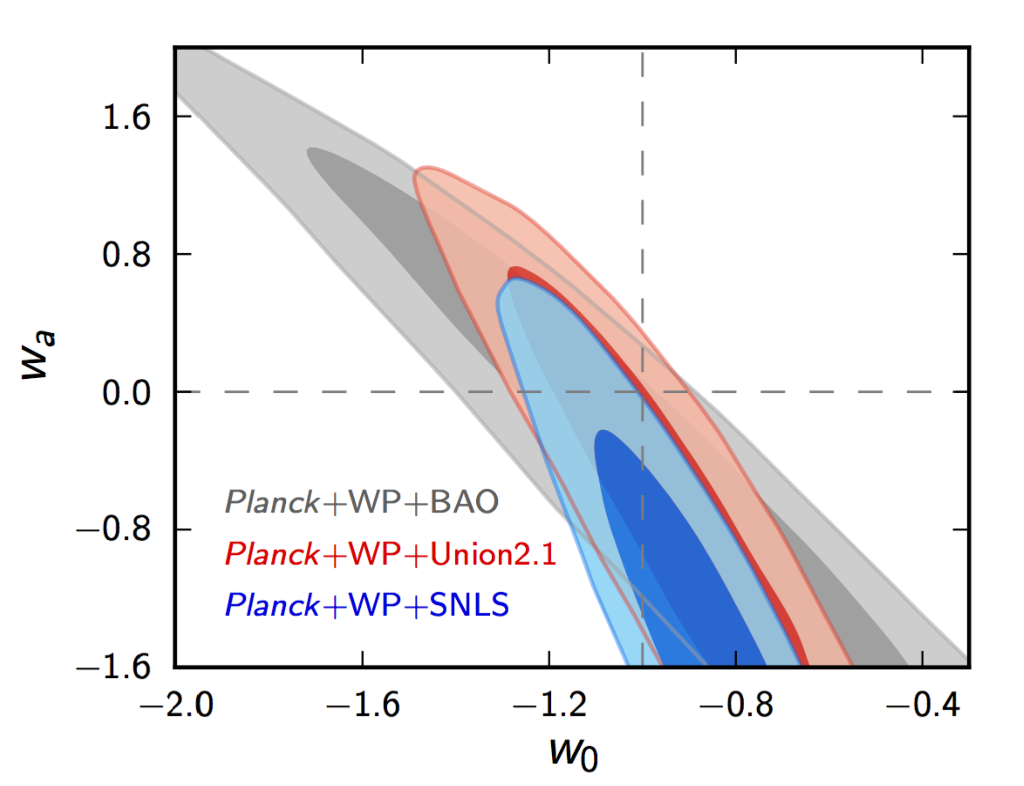
Λ is too small and fine-tuned: an evolving equation of state *w(a)*?

Parameterizing our ignorance on the evolution

$$w(a) = w_0 + w_a(1-a)$$

A Figure of Merit for dark energy experiments (DETF – Albrecht et al. 2006):

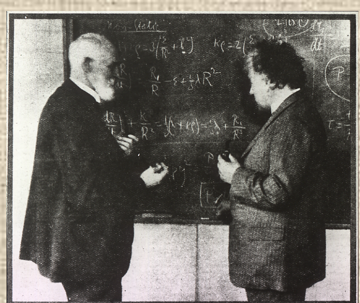
$$\mathrm{FoM} = 1/(\Delta w_0 \times \Delta w_a)$$



Planck Collaboration 2013, XVI

But, is the cosmological constant (or dark energy) the end of the story?

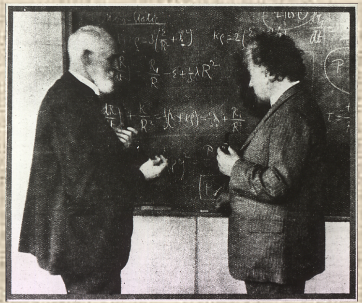
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu}$$



But, is the cosmological constant (or dark energy) the end of the story?

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

Add dark energy



But, is the cosmological constant (or dark energy) the end of the story?

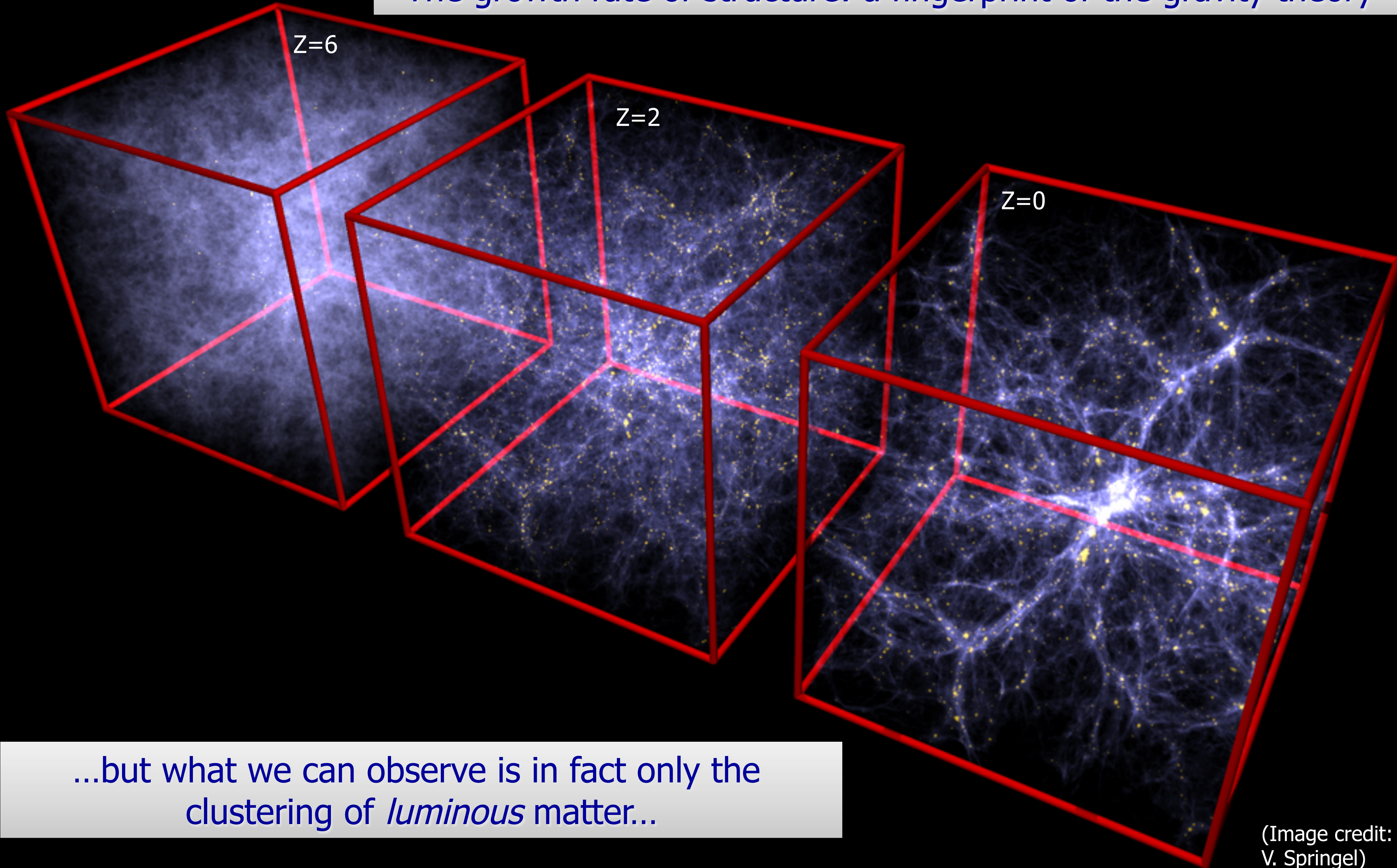
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = -\frac{8\pi G}{c^2} T_{\mu\nu} + \Lambda g_{\mu\nu}$$

?

Modify gravity theory [e.g. ***R → f(R)***]

"…the Force be with you"

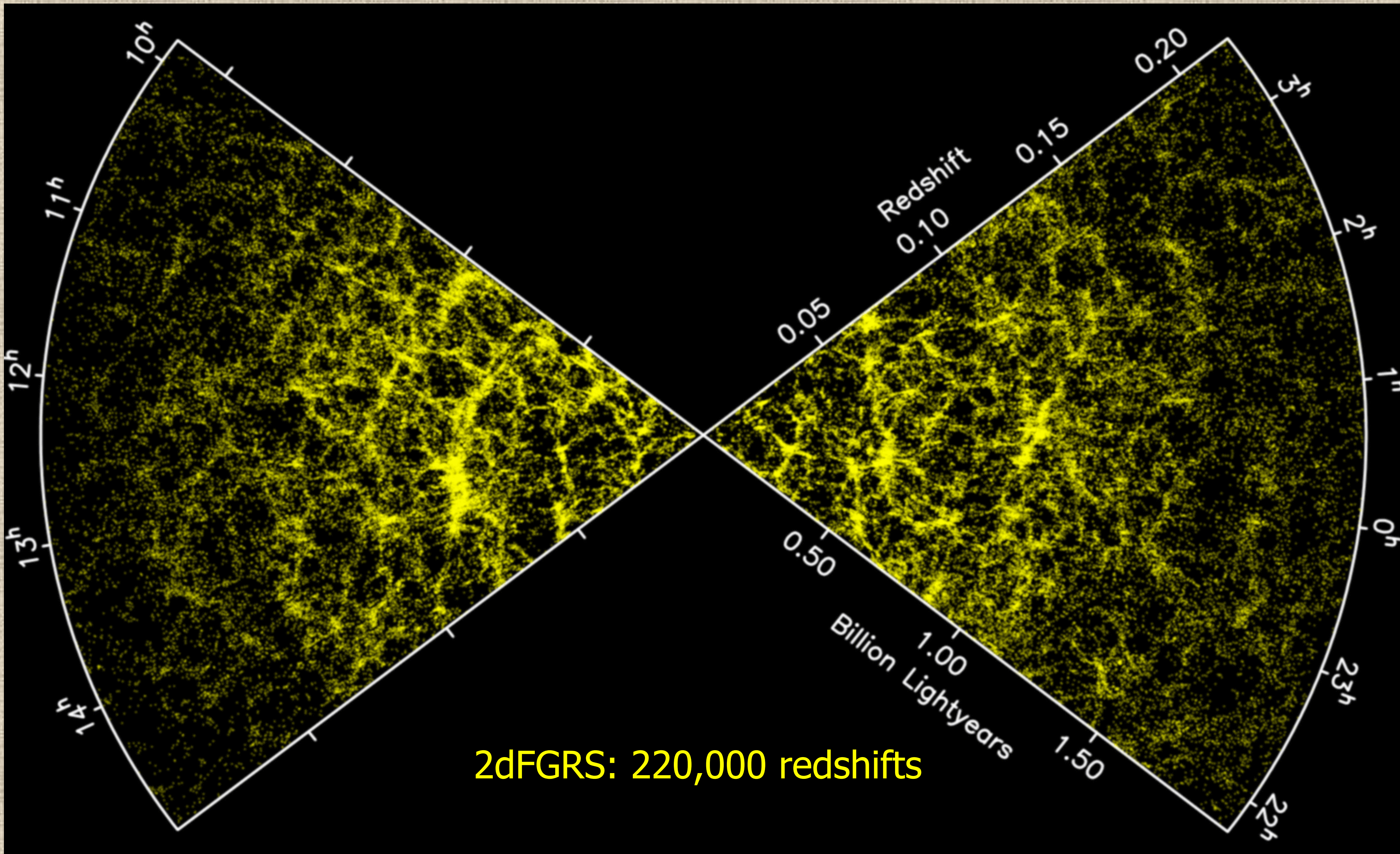
The growth rate of structure: a fingerprint of the gravity theory



…but what we can observe is in fact only the clustering of *luminous* matter…

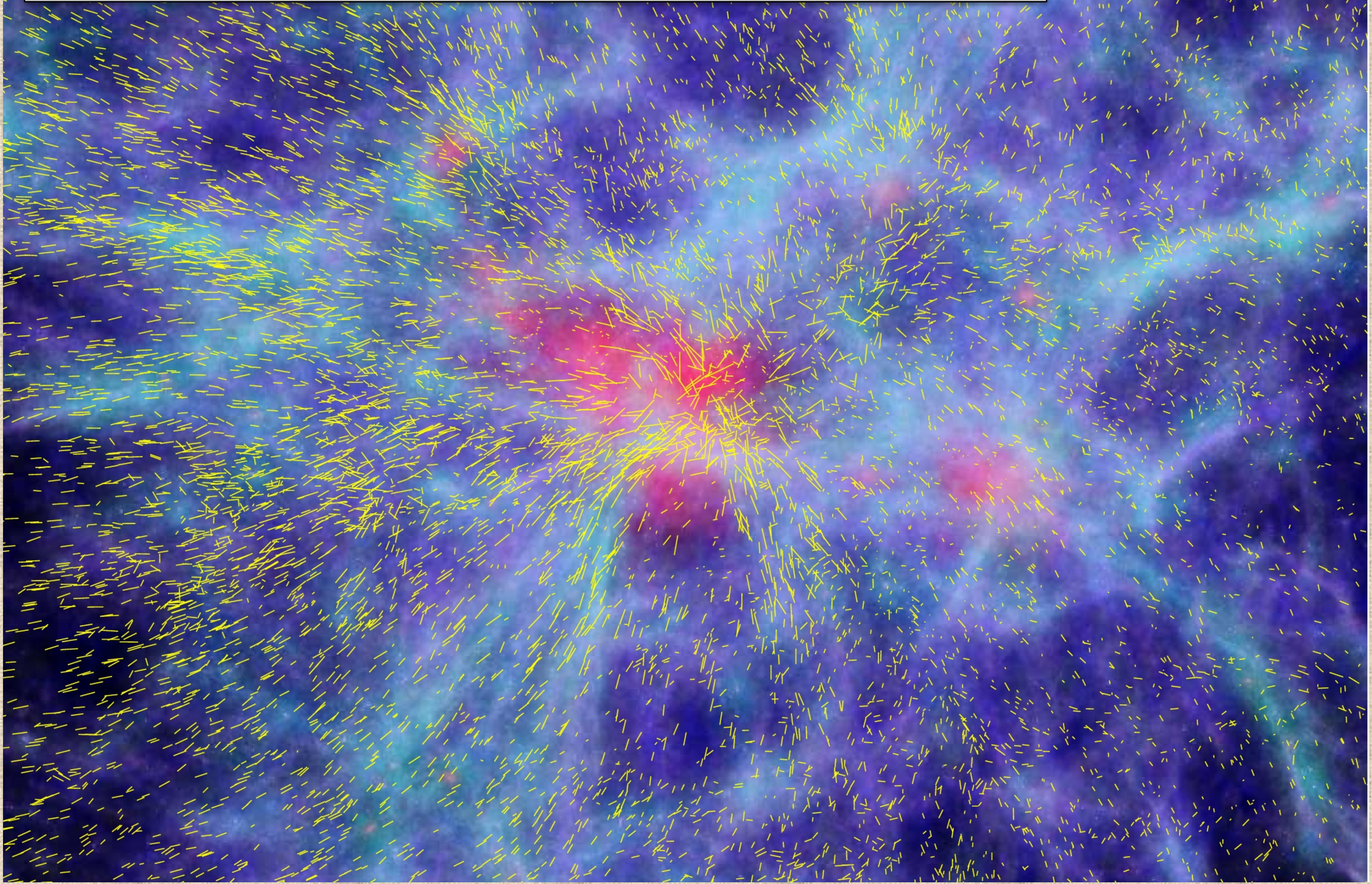
(Image credit: V. Springel)

Galaxy redshift surveys: reconstructing the 3D structure of the Universe



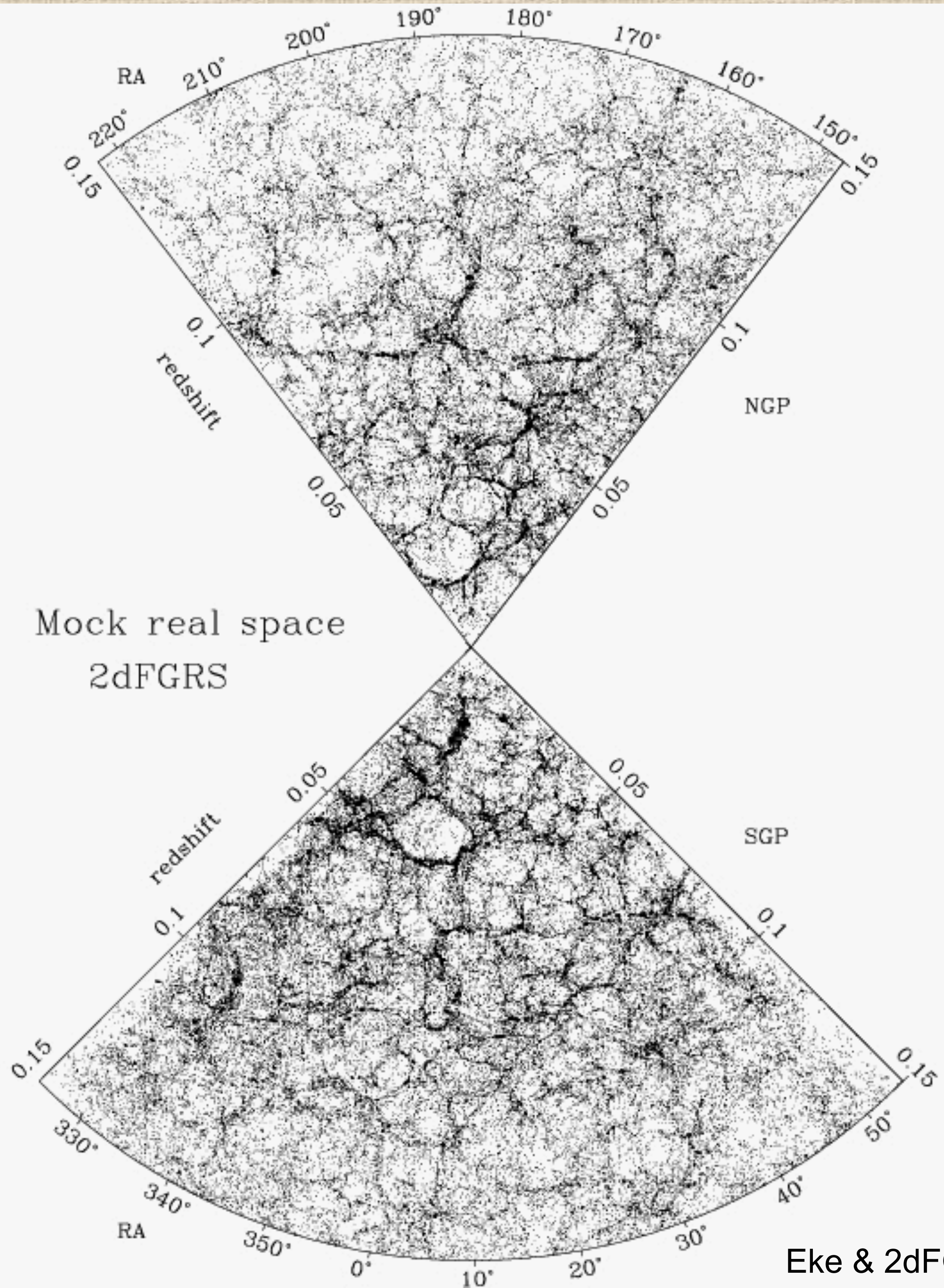
But growth is just mass moving towards minima of the potential…

Growth produces motions: galaxy peculiar velocities



Peculiar velocities manifest themselves in galaxy redshift surveys as *redshift-space distortions* (Kaiser 1987)

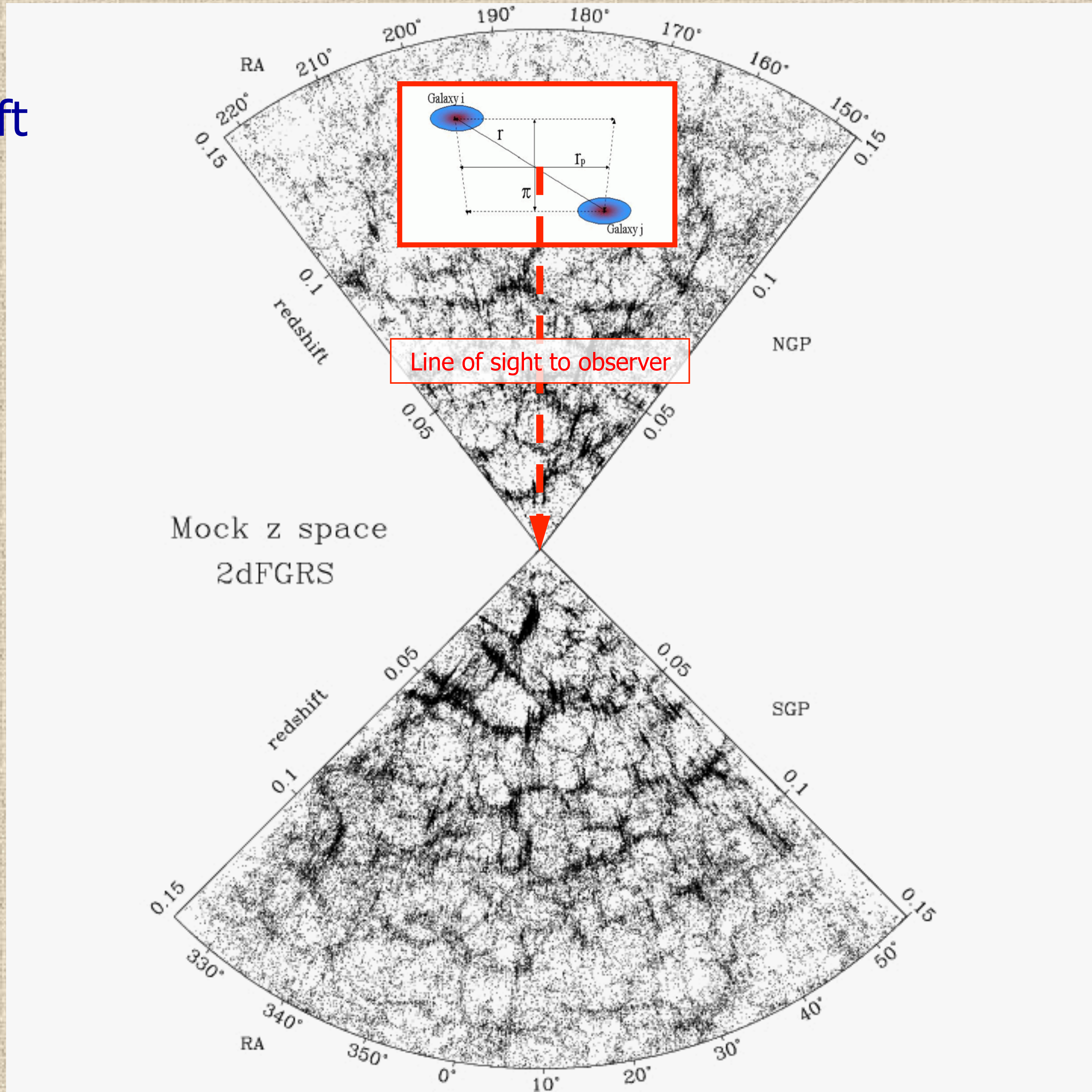
real space



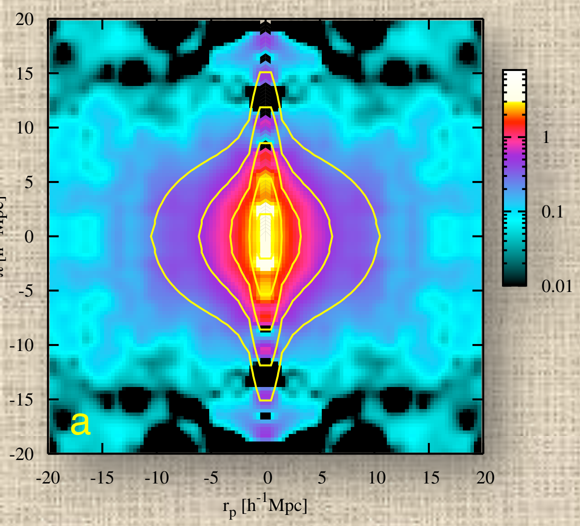
Eke & 2dFGRS 2003

Peculiar velocities manifest themselves in galaxy redshift surveys as *redshift-space distortions* (Kaiser 1987)

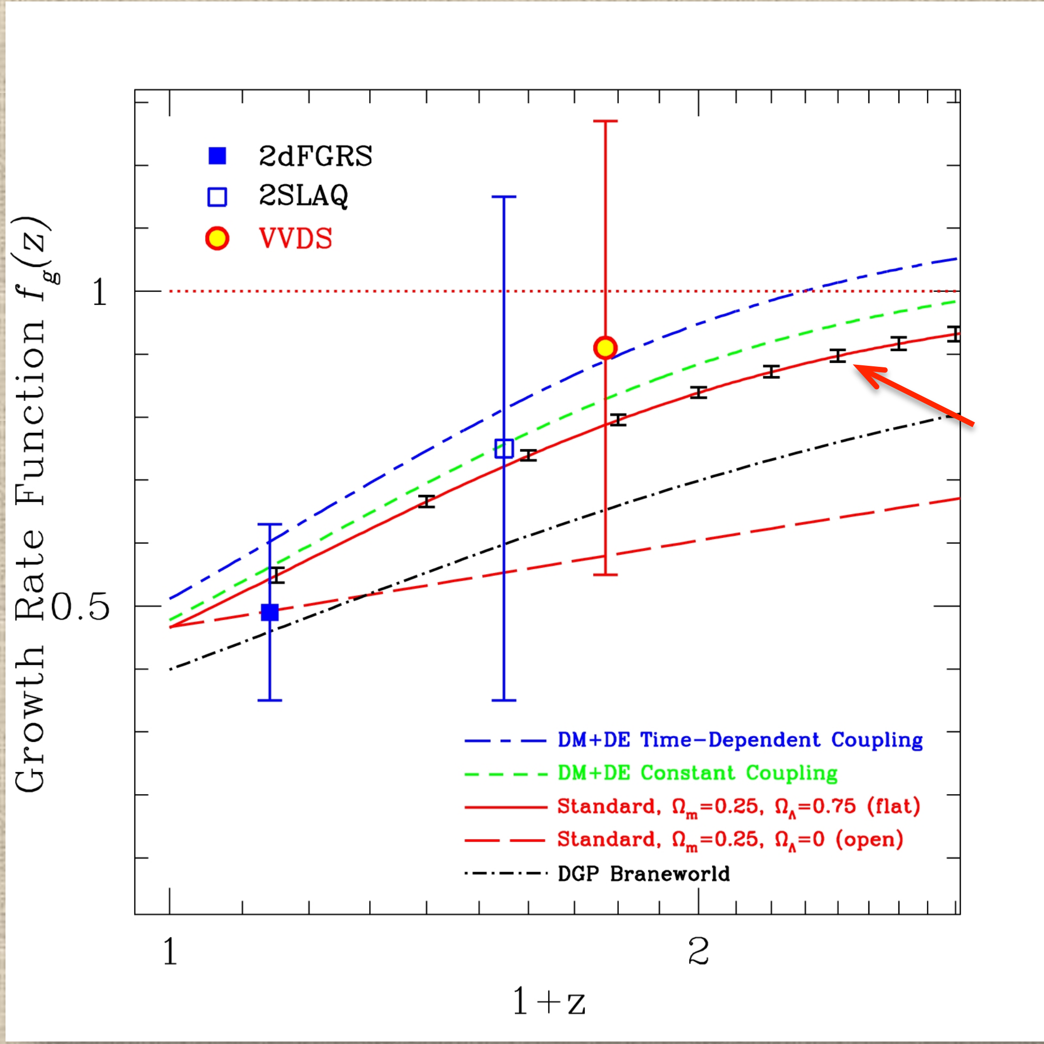
redshift space



Redshift Space Distortions as a dark energy test (2008)

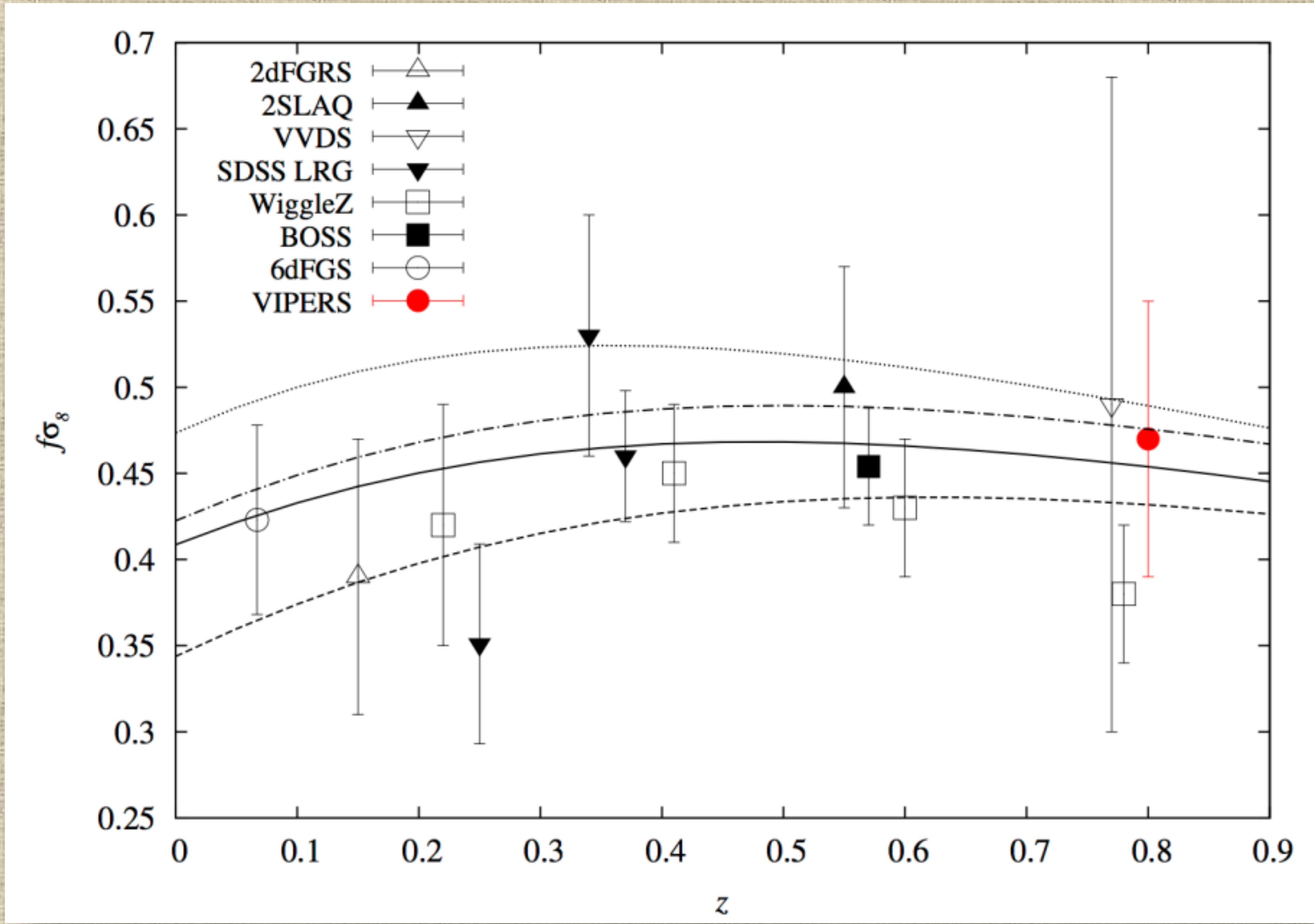


f=0.91±0.36
(at z=0.77)



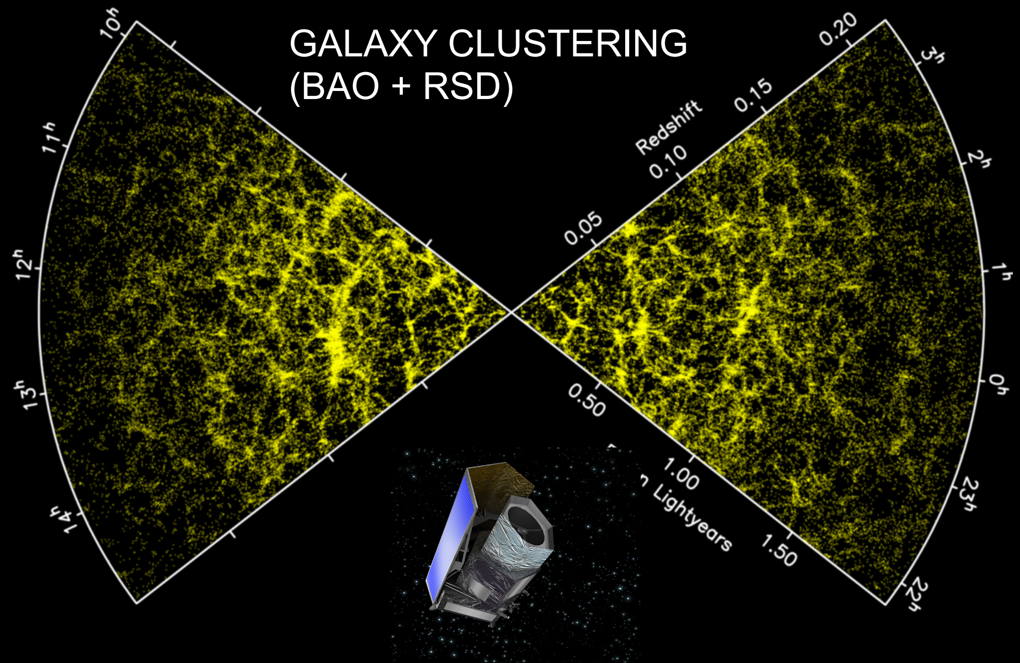
Guzzo et al., Nature 451, 541 (2008)

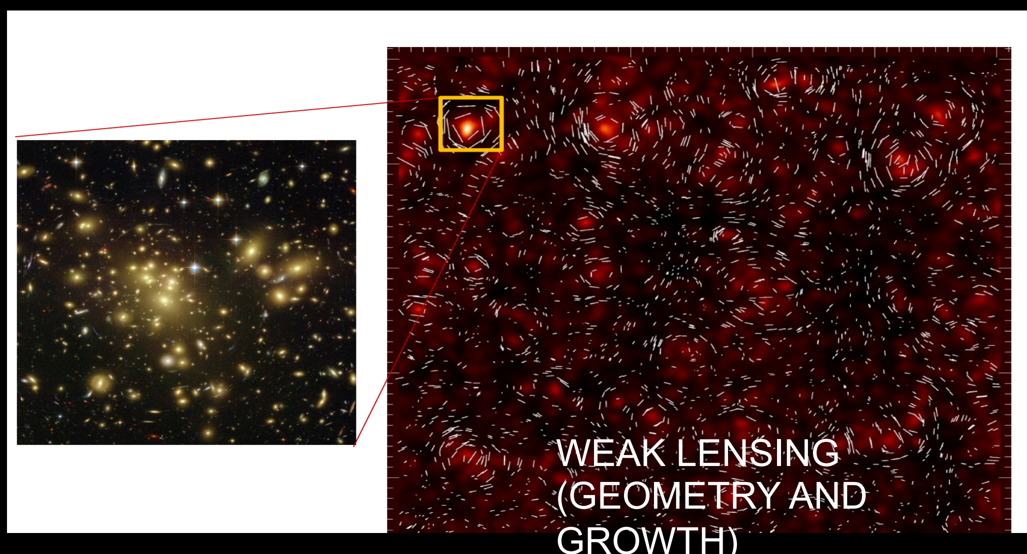
Redshift-space clustering and growth rate of structure (2013)



De la Torre, LG, et al. 2013

Euclid





OBJECTIVES:

- Build a map of dark and luminous matter over 1/3 of the sky and to z~2
- Unveil the nature of dark matter
- Solve the mystery of dark energy (cosmic acceleration)
- Use multiple probes → max control over systematic errors

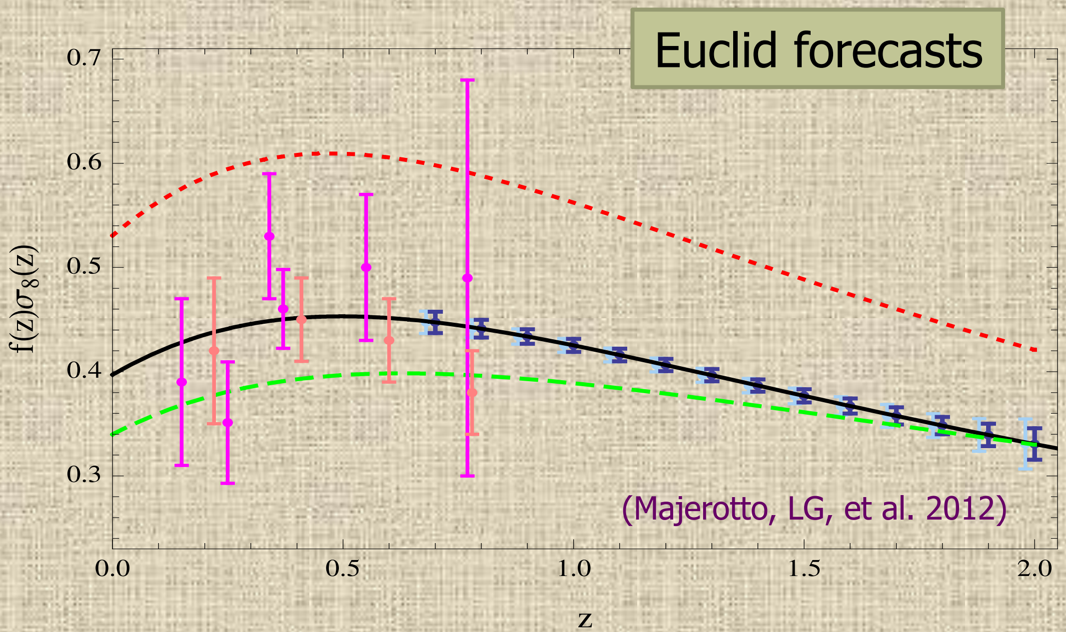
The Euclid "Red Book"

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

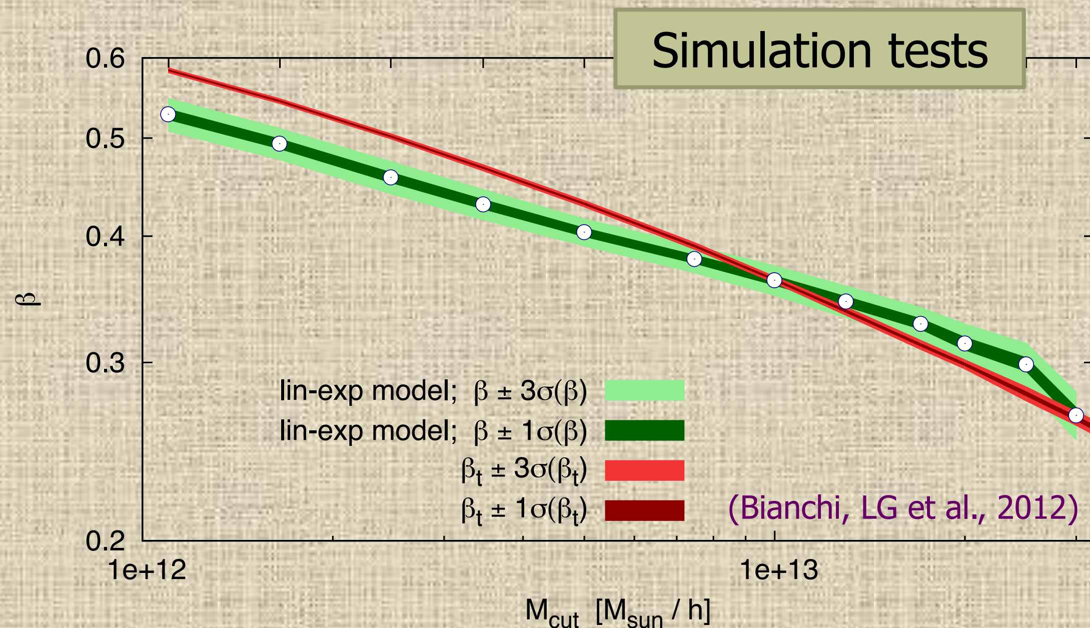
Systematic errors on Redshift-Space Distortions measurements

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

→ EUCLID: expected 1-3% precision



→ Standard RSD modelling: up to 10% systematic error



European Research Council

ERC Advanced Grant 2011
Research proposal (Part B1)

Illuminating Dark Energy with the Next Generation of Cosmological Redshift Surveys

DARKLIGHT

- Principal Investigator: **Luigi Guzzo**
- Hosting Institution: **INAF – Osservatorio di Brera**

- Project duration: **60 months**

Galaxy redshift surveys have been central in establishing the current successful cosmological model. Reconstructing the large-scale distribution of galaxies in space and time, they provide us with a unique probe of the basic constituents of the Universe, their evolution and the background fundamental physics. A new generation of even larger surveys is planned for the starting decade, with the aim of solving the remaining mysteries of the standard model using high-precision measurements of galaxy clustering. These entail the nature of the "dark sector" and in particular the origin of the accelerated cosmic expansion. While data accumulation already started, the needed analysis capabilities to reach the required percent levels in both accuracy and precision are not ready yet.

I propose to establish a focused research group to develop these capabilities and optimally analyze the new data. New techniques as redshift-space distortions and well-known but still debated probes as galaxy clusters will be refined to a new level. They will be combined with more established methods as baryonic acoustic oscillations and with external data as CMB anisotropies. Performances will be validated on mock samples from large numerical simulations and then applied to state-of-the-art data with enhanced control over systematic errors to obtain the best achievable measurements.

These new, coherently developed capabilities will be decisive in enabling ongoing and future surveys to address and solve the key open problems in cosmology: What is the nature of dark energy? Is it produced by an evolving scalar field? Or does it rather require a modification of the laws of gravity? How does it relate to dark matter? The answer to these questions may well revolutionize our view of physics.

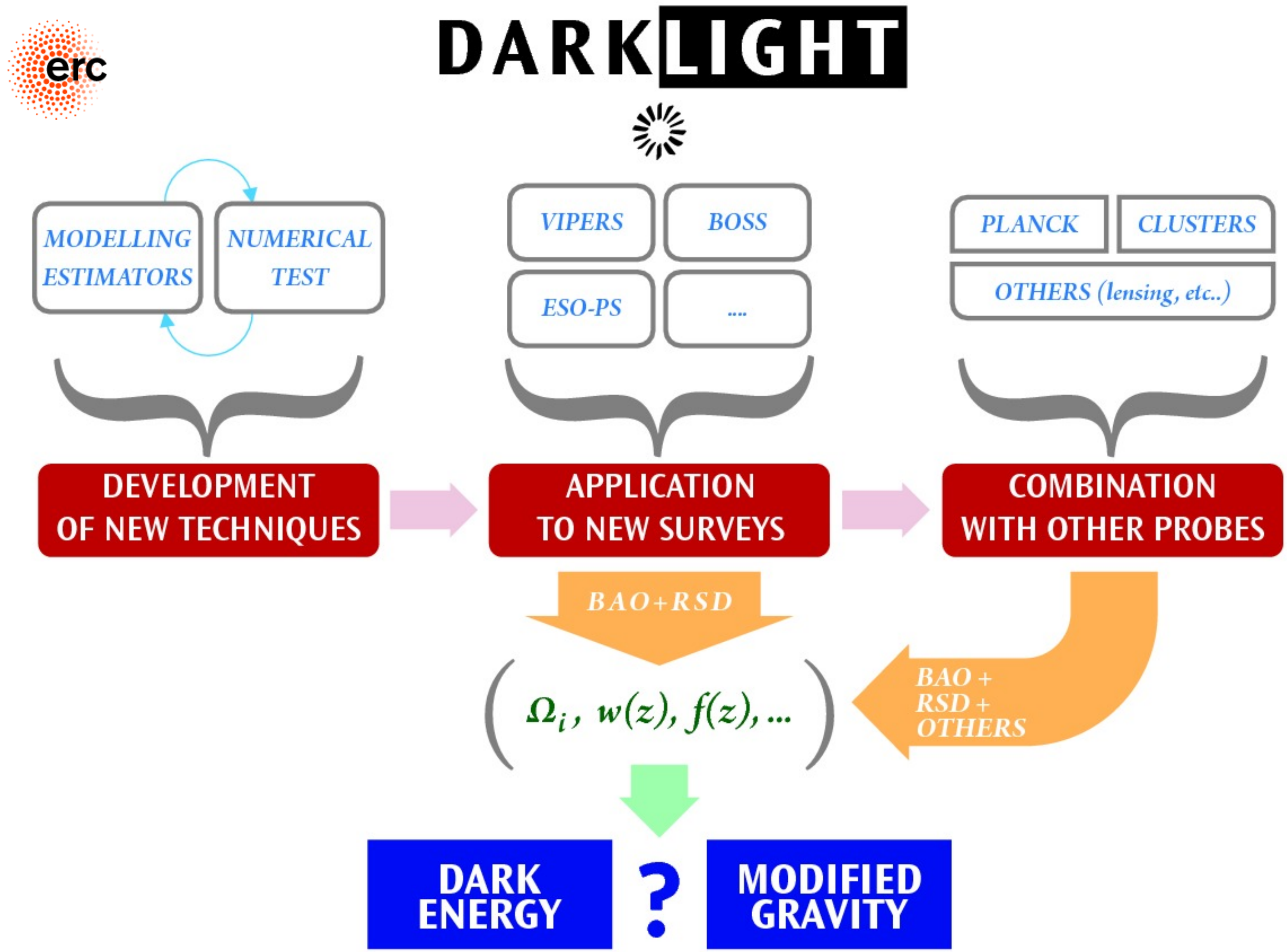
erc DARK LIGHT

"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:

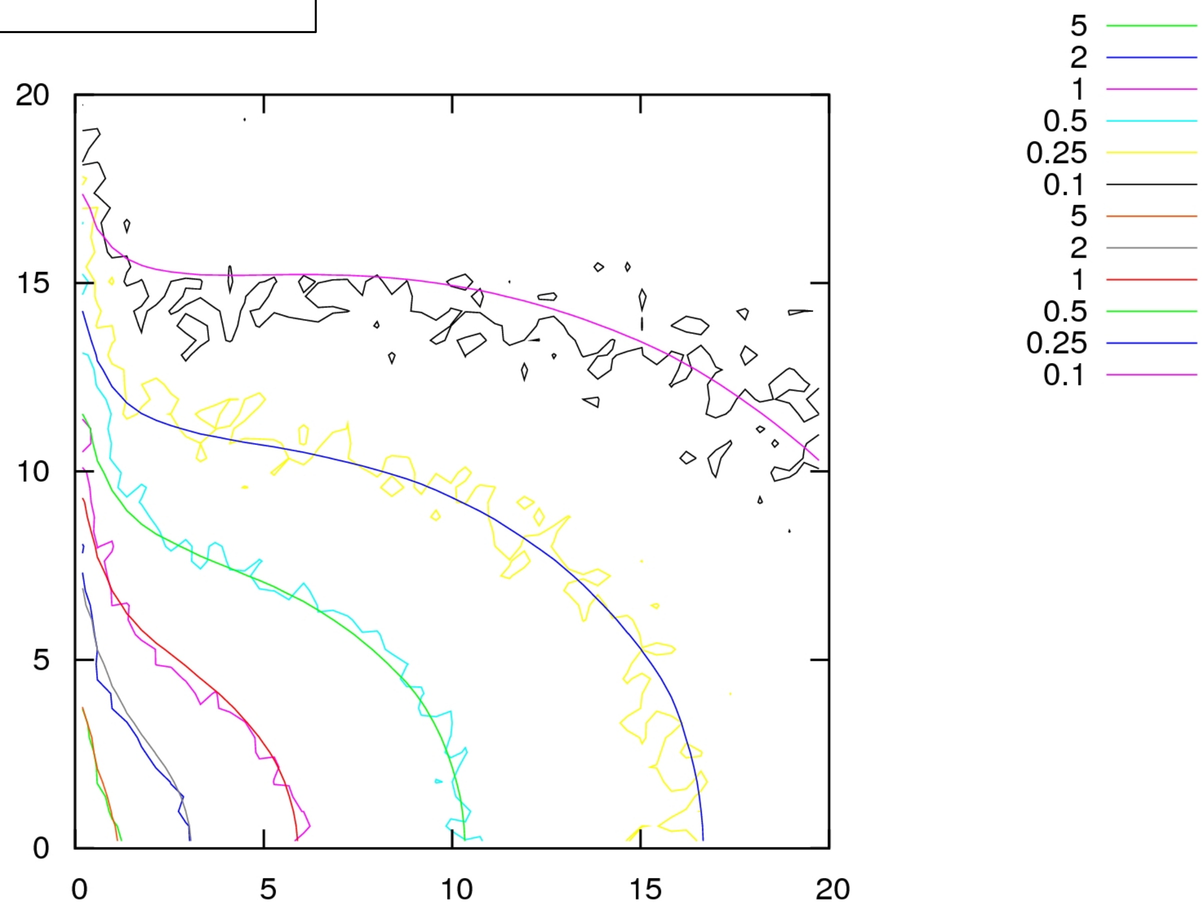
- Improve modelling and estimators of clustering and redshift distortions, preparring for precision cosmology
- Apply them to current and new surveys to fully exploit information content (VIPERS, BOSS…)
- Optimally combine with other probes (CMB, WL, clusters, …)


DARKLIGHT
erc
MODELLING ESTIMATORS
NUMERICAL TEST
VIPERS
BOSS
ESO-PS
....
PLANCK
CLUSTERS
OTHERS (lensing, etc..)
DEVELOPMENT OF NEW TECHNIQUES
APPLICATION TO NEW SURVEYS
COMBINATION WITH OTHER PROBES
BAO+RSD
BAO + RSD + OTHERS
$(\Omega_i,\ w(z),\ f(z), ...)$
DARK ENERGY
?
MODIFIED GRAVITY

Redshift-space distortions modelling: going beyond Kaiser-Hamilton

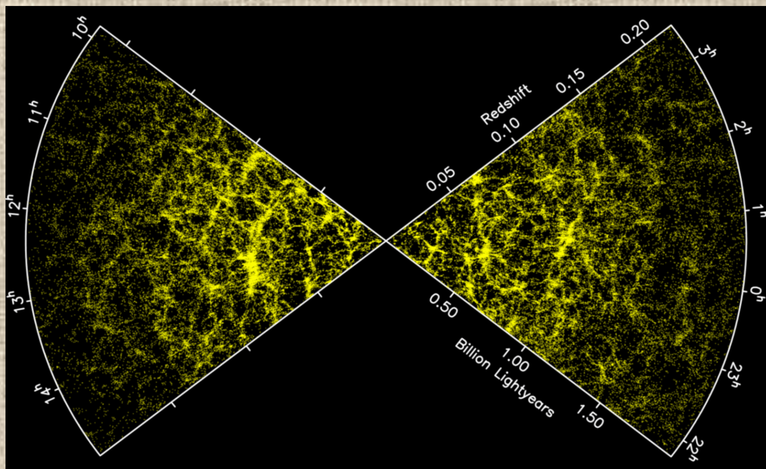
$$P(k_{||}, k_{\perp}) = P(k)\left(1 + \beta\mu^2\right)^2 D(k\mu\sigma_p).$$

$$D(k\mu\sigma_p) = \frac{1}{1 + (k\mu\sigma_p)^2/2}$$

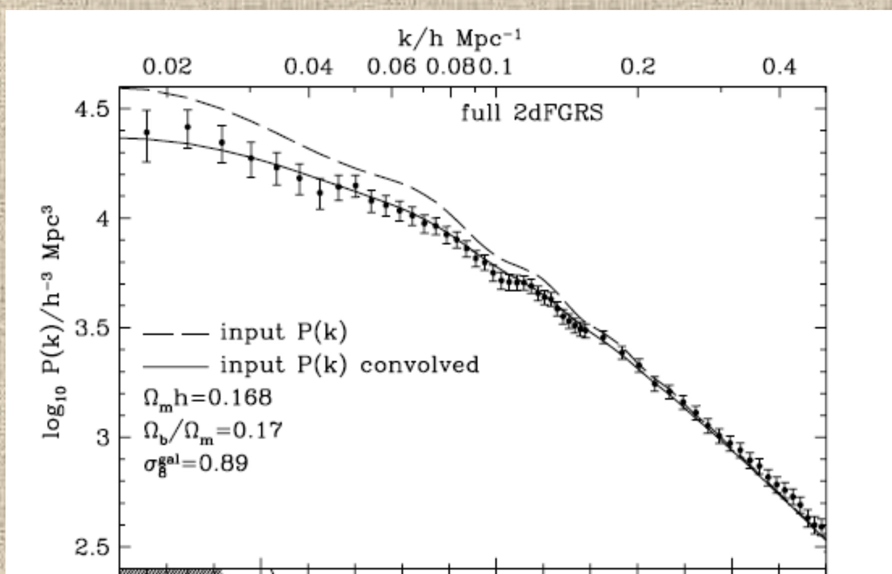


Combination of RSD with Baryonic Acoustic Oscillations

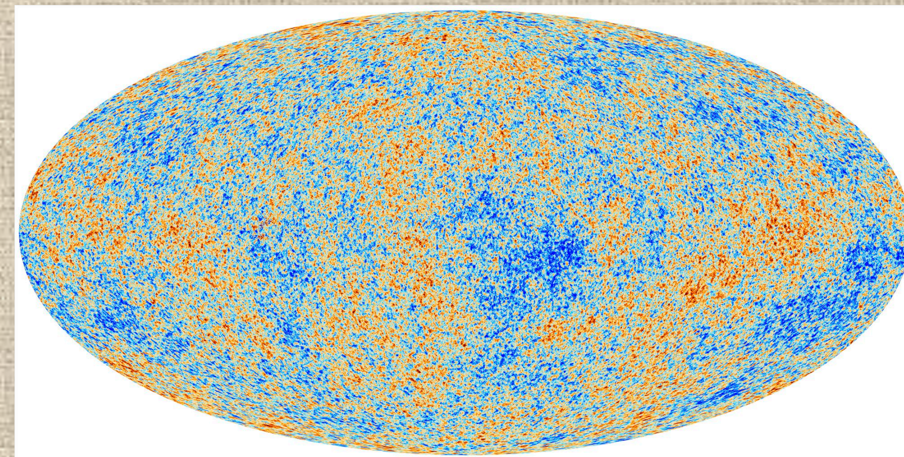
Large-scale galaxy clustering



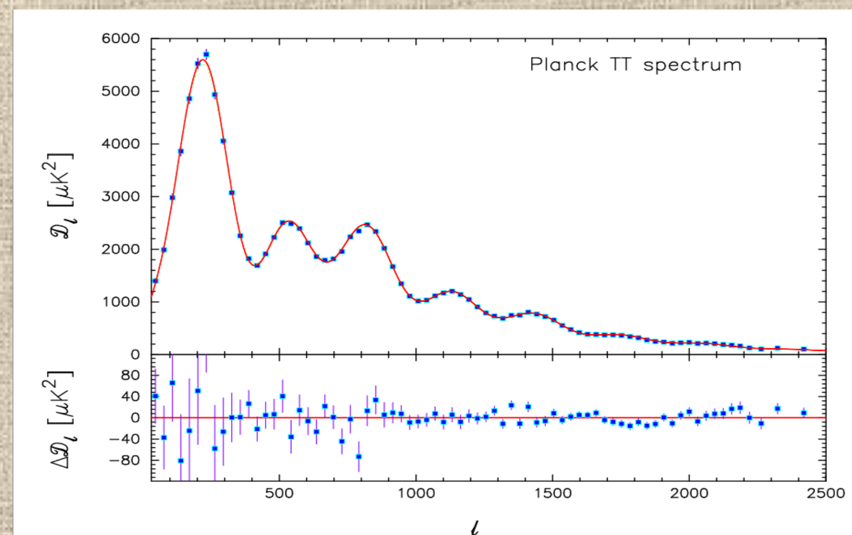
2dFGRS Collaboration (2005); Percival et al. 2010

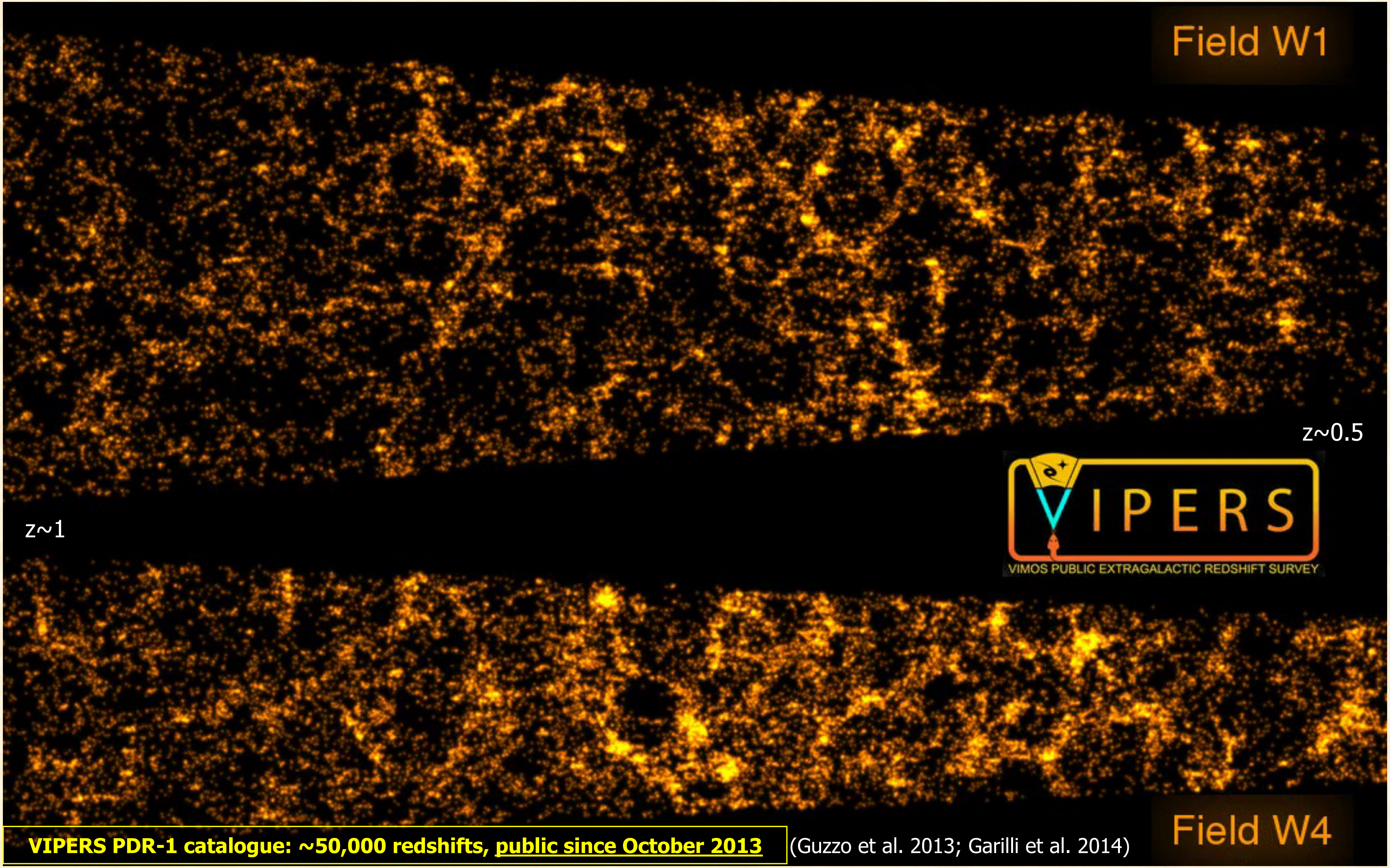


CMB temperature fluctuations

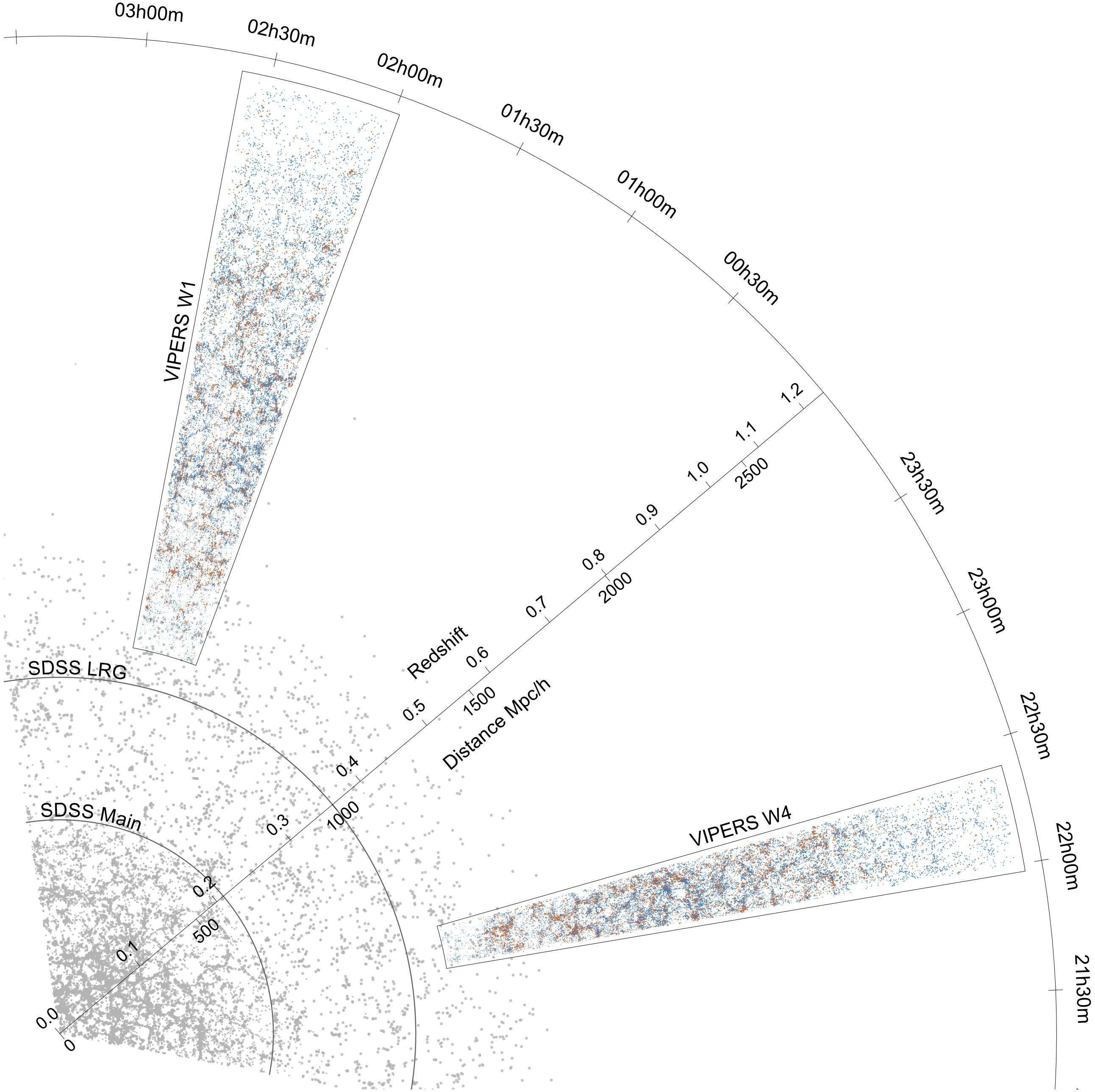


Planck Collaboration XVI (2013)



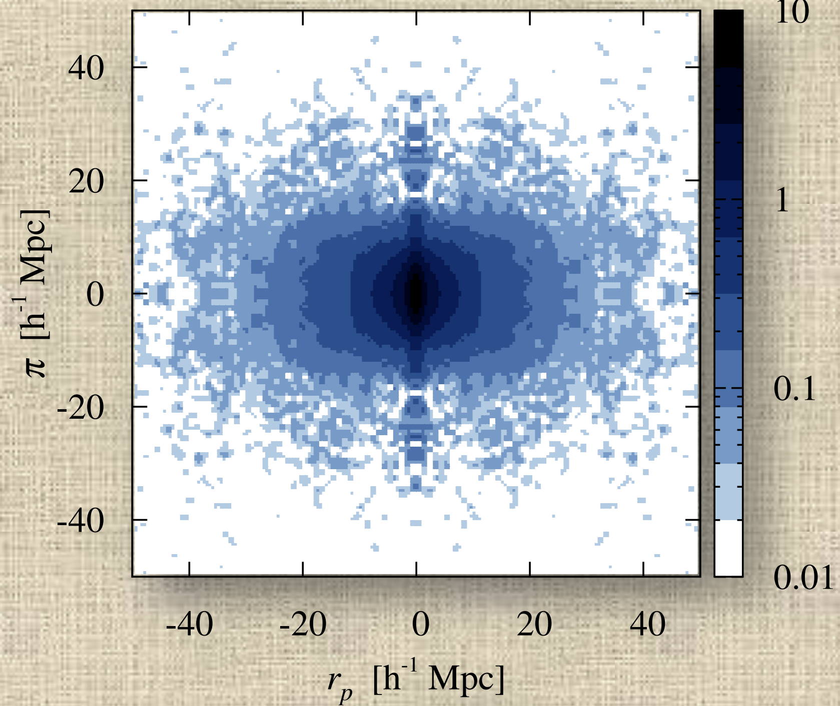


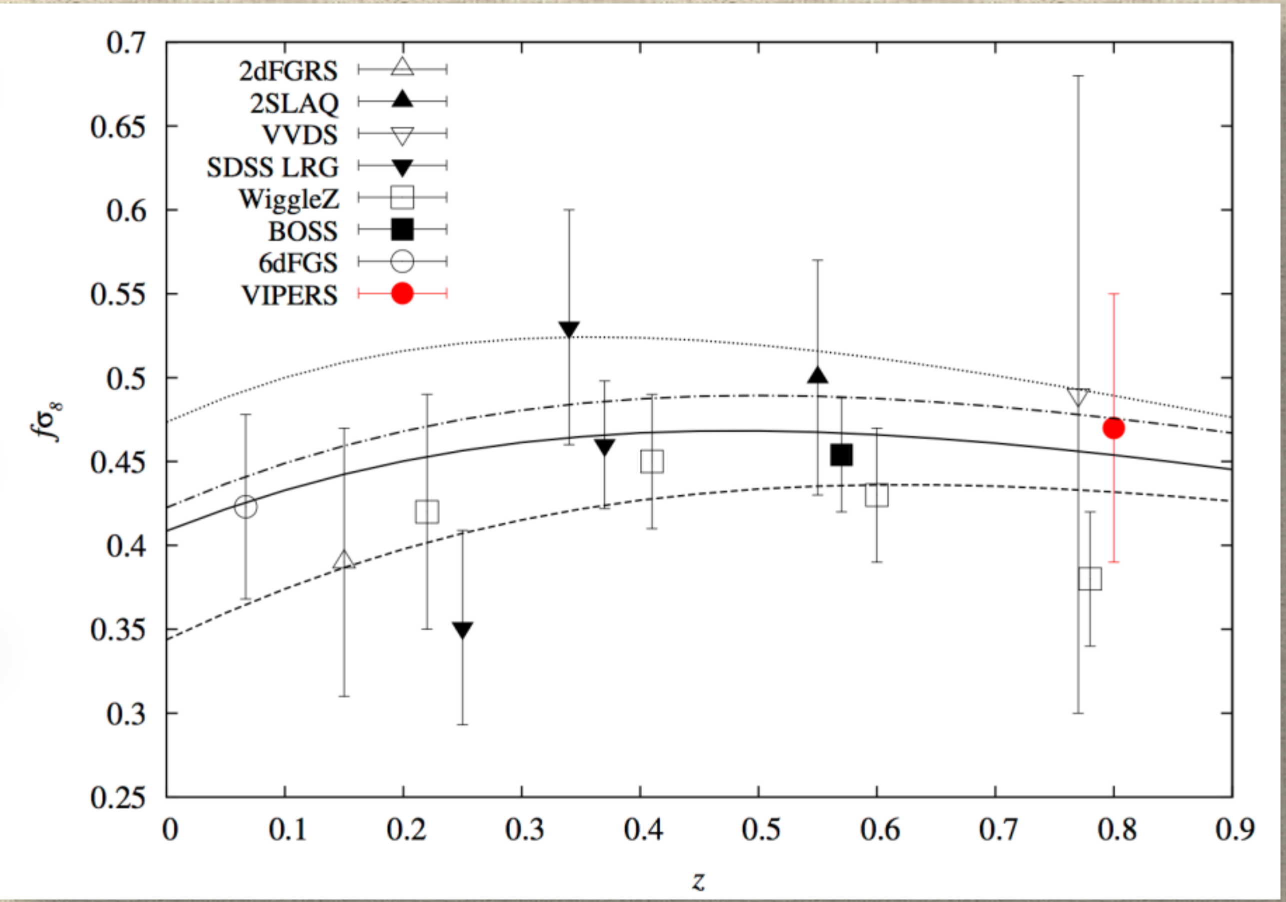
VIPERS PDR-1 catalogue: ~50,000 redshifts, public since October 2013 (Guzzo et al. 2013; Garilli et al. 2014)



From Guzzo et al. 2013 (artwork by Ben Granett)

Application to data: growth rate from VIPERS





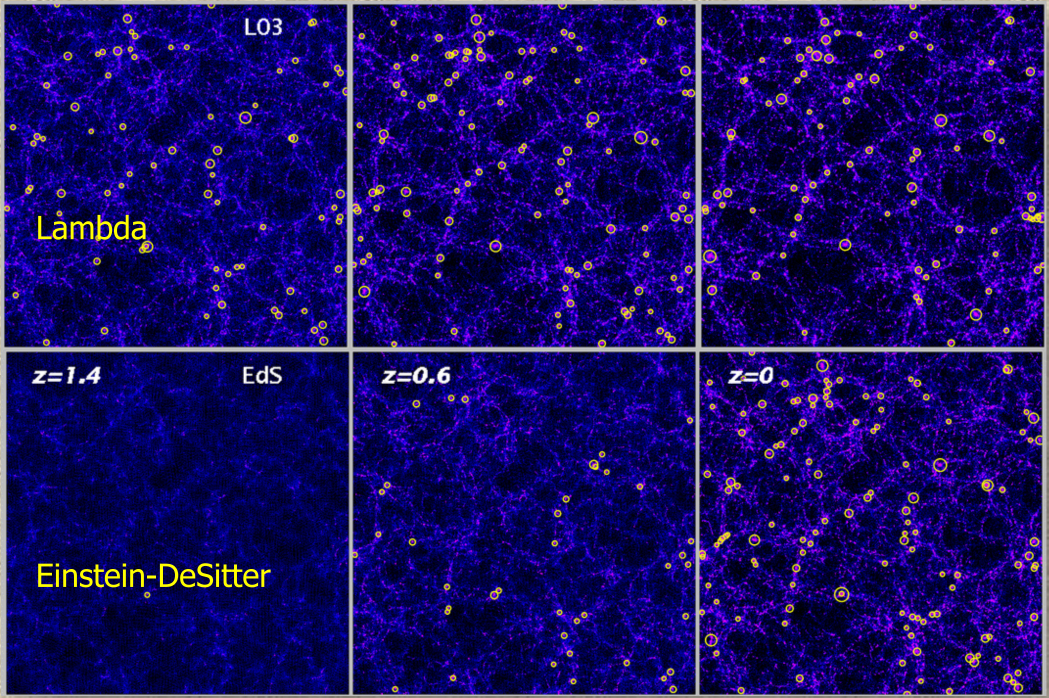
VIPERS: $fs_8(z=0.8) = 0.47 \pm 0.08$

De la Torre, LG, et al. 2013

VIPERS Team

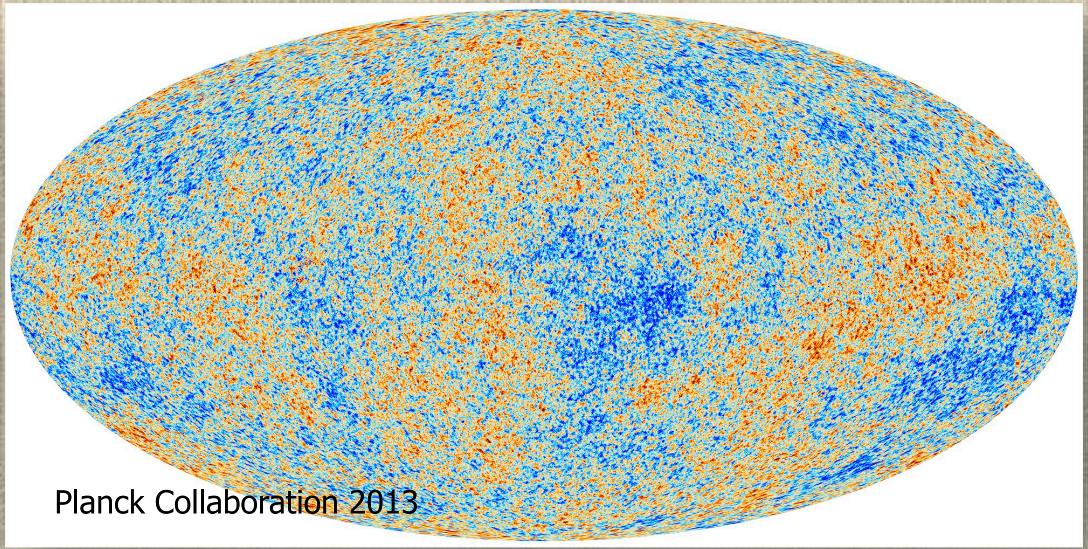
Combination of clustering with other probes: beating systematics

CLUSTERS OF GALAXIES



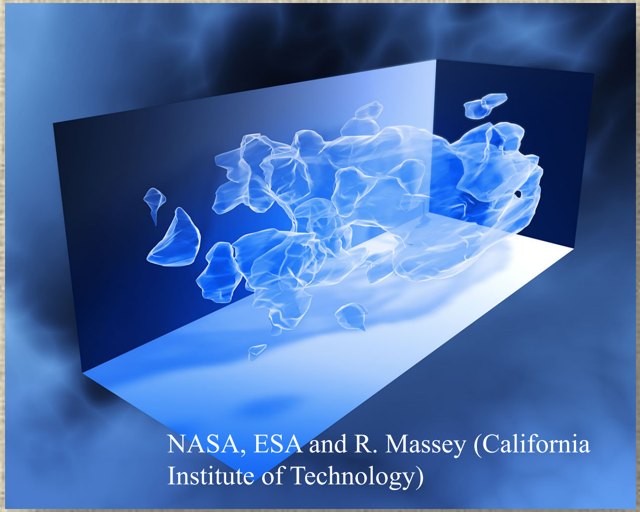
Borgani & Guzzo 2001

COSMIC MICROWAVE BACKGROUND



Planck Collaboration 2013

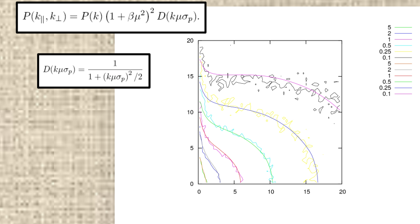
WEAK GRAVITATIONAL LENSING

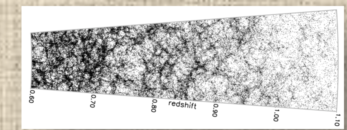


NASA, ESA and R. Massey (California Institute of Technology) erc DARK LIGHT

DEVELOPMENT OF NEW MODELS AND ESTIMATORS OF COSMOLOGICAL PARAMETERS FROM GALAXY CLUSTERING AND REDSHIFT-SPACE DISTORTIONS

J. Bel, A. Hawken, F. Mohammad (PhD), [D. Bianchi (PhD)]



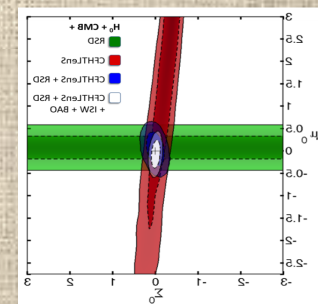


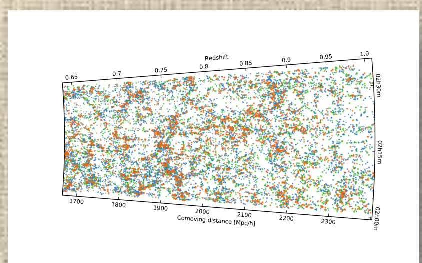
NUMERICAL SIMULATIONS AND MOCK SURVEYS

C. Carbone, [Y. Koda]

TESTS AND VALIDATION ON MOCK SAMPLES

[Y. Koda], A. Pezzotta (PhD)





APPLICATION TO REDSHIFT SURVEY DATA (VIPERS, etc.)

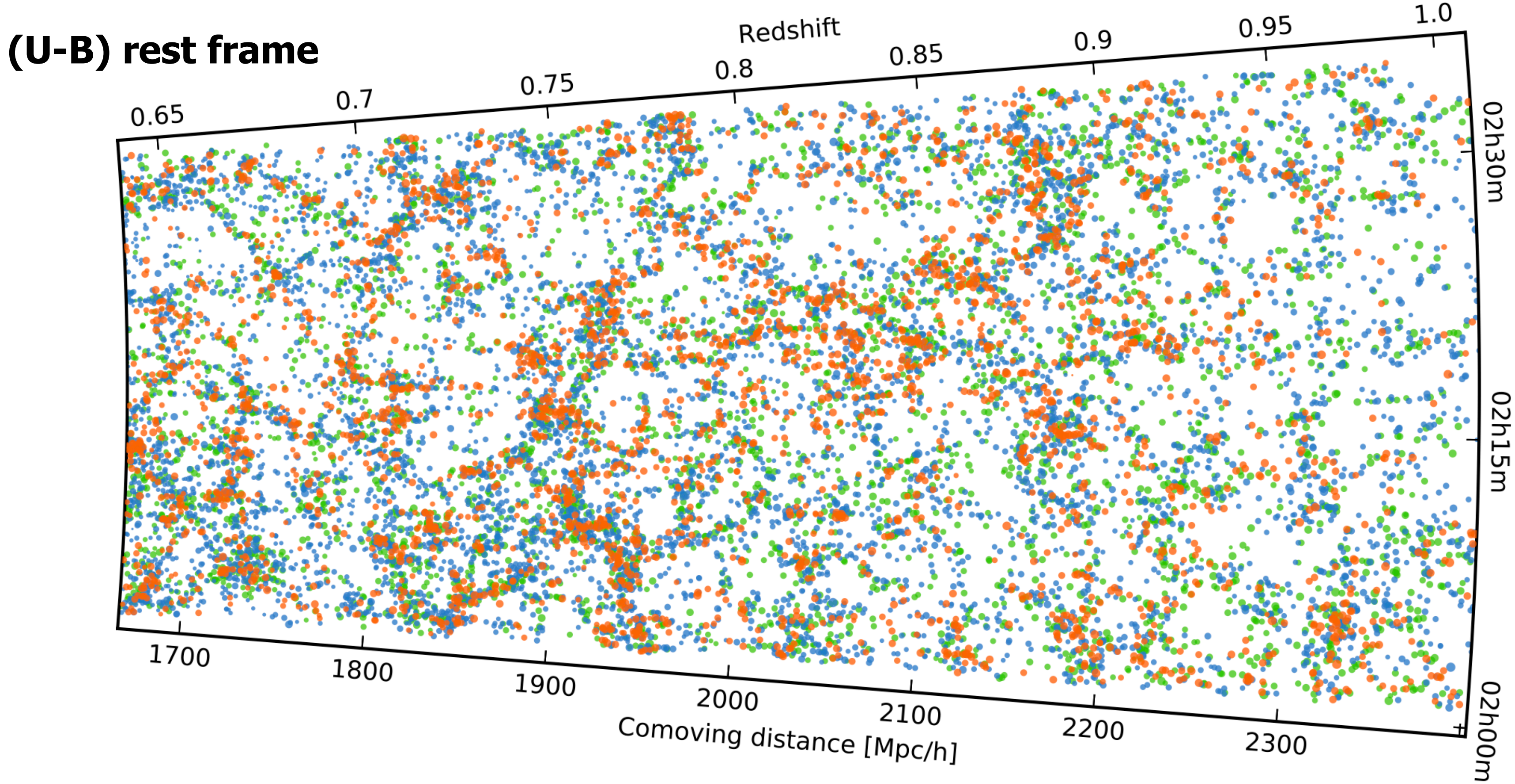
B. Granett, S. Rota (PhD)

OPTIMAL COMBINATION WITH OTHER COSMOLOGICAL PROBES (WL, CMB,…)

[J. Dossett], C. Carbone

COSMOLOGICAL PARAMETERS

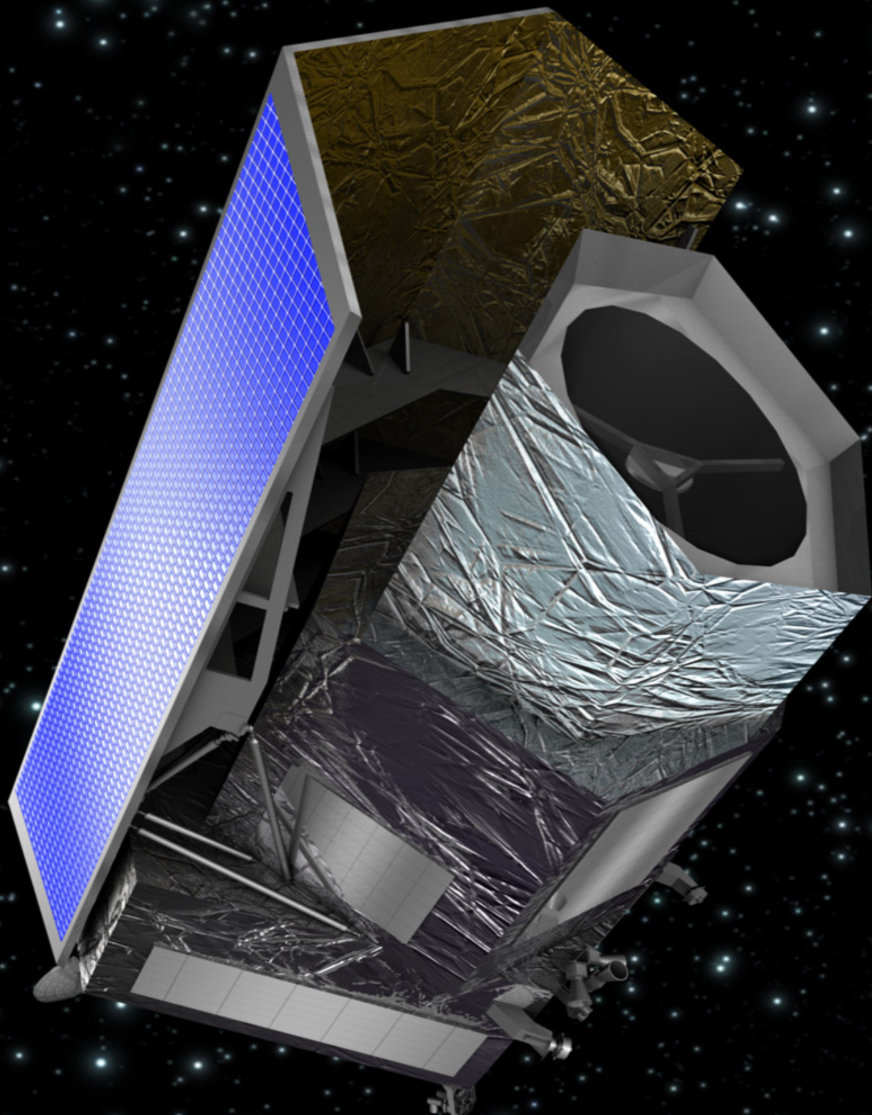
VIPERS means both detailed structure AND galaxy properties



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

(figure: Ben Granett)

Euclid



- ESA mission + extra contribution by national agencies (legacy of parent DUNE+SPACE 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 deg^2 survey
- Images for 2×10^9 galaxies
- Spectra for $\sim 5 \times 10^7$ galaxies ($0.9<z<1.8$)