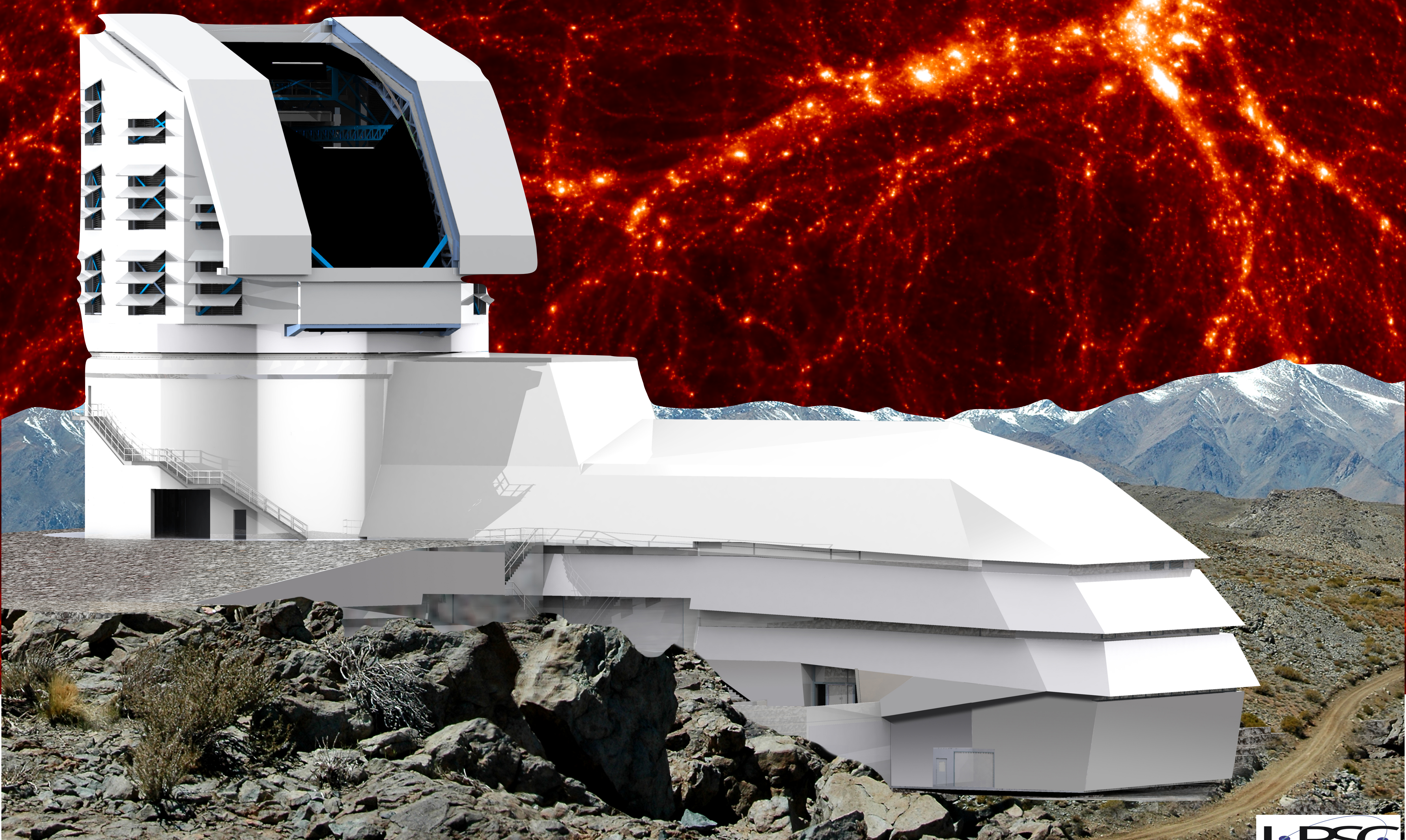
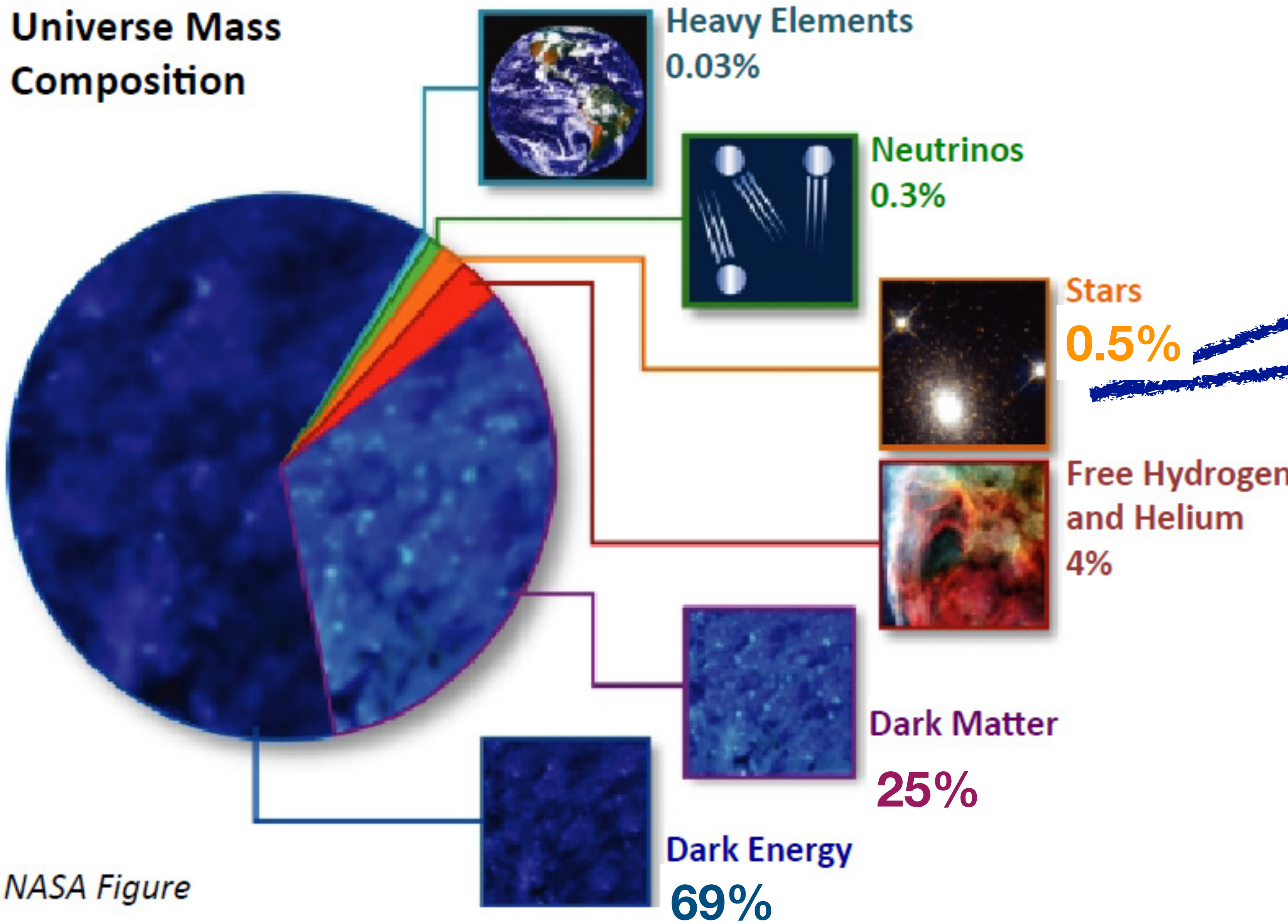
Large-Scale Structures and Baryonic Acoustic Oscillations in the era of LSST



Credit : S. Colombi + LSST Project/NSF/AURA

Cécile Renault

LPSC Grenoble



NASA Figure

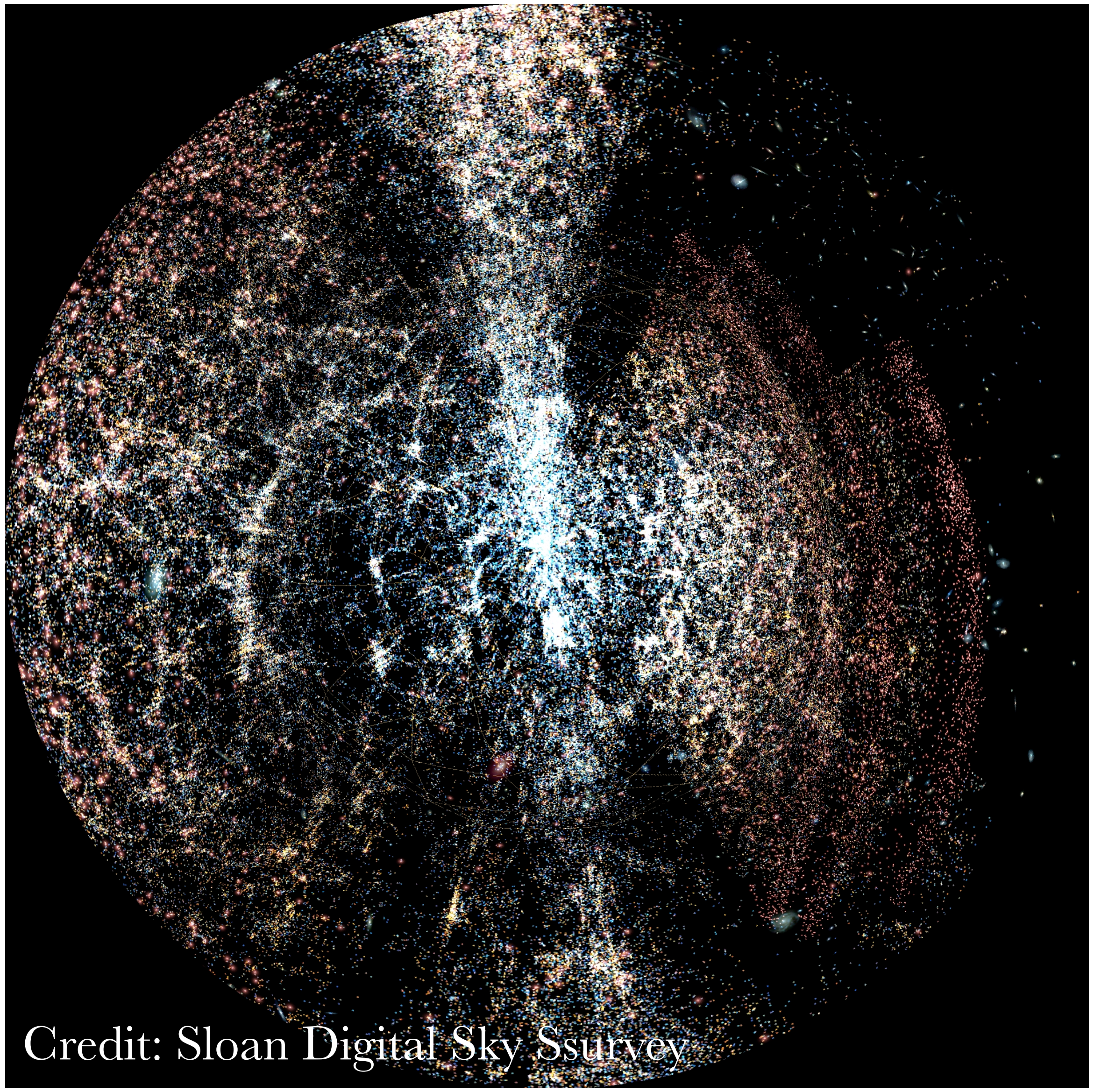
LSST will only see stars …
gathered in a few 10^9 galaxies over 18,000 deg^2

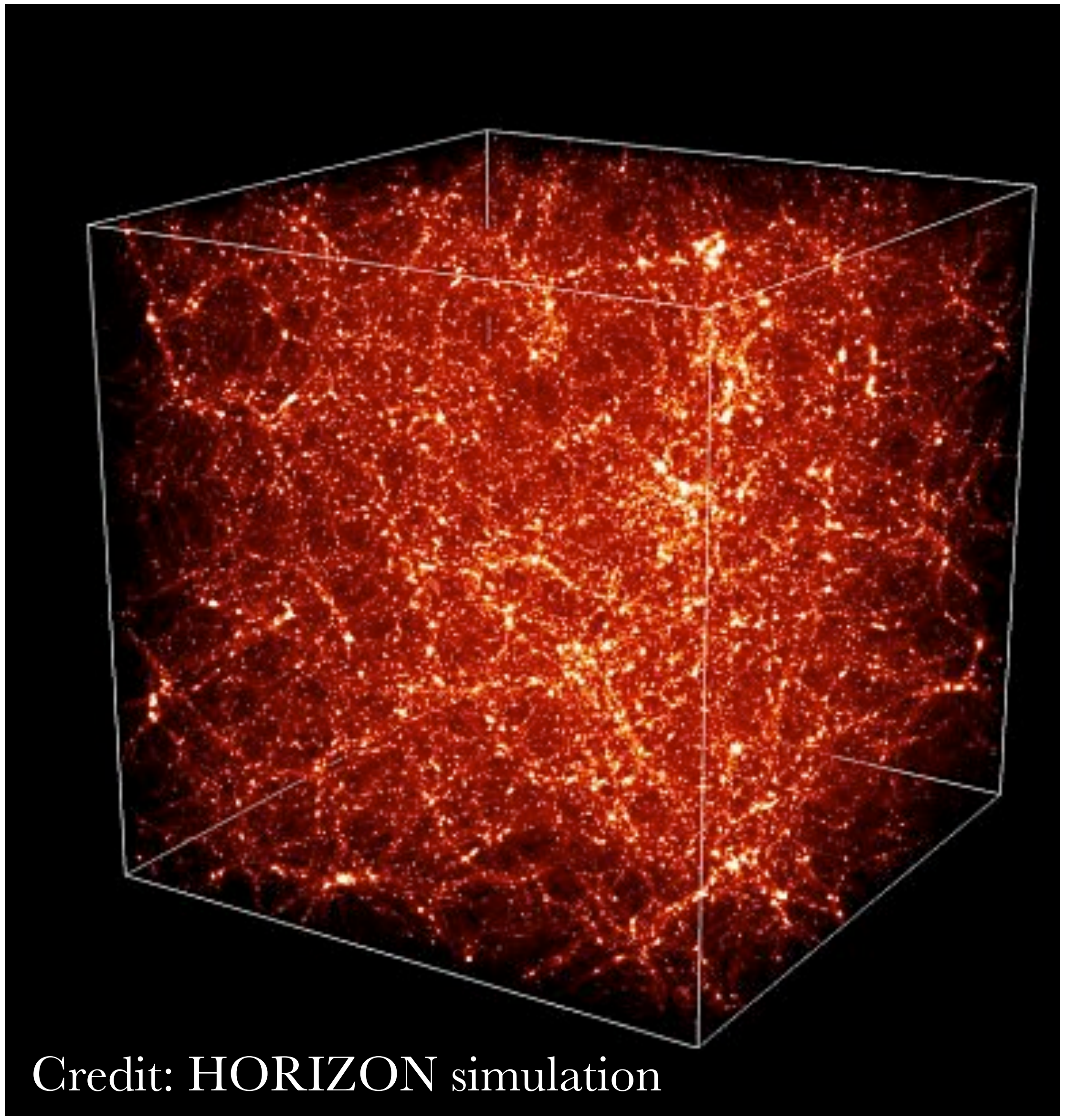
LSST DESC
Dark Energy Science Collaboration

What is the mysterious dark energy
that is driving the acceleration of the cosmic expansion?

What is dark matter, how is it distributed,
and how do its properties affect the formation of stars,
galaxies, and larger structures ?

LSS based on galaxies distribution



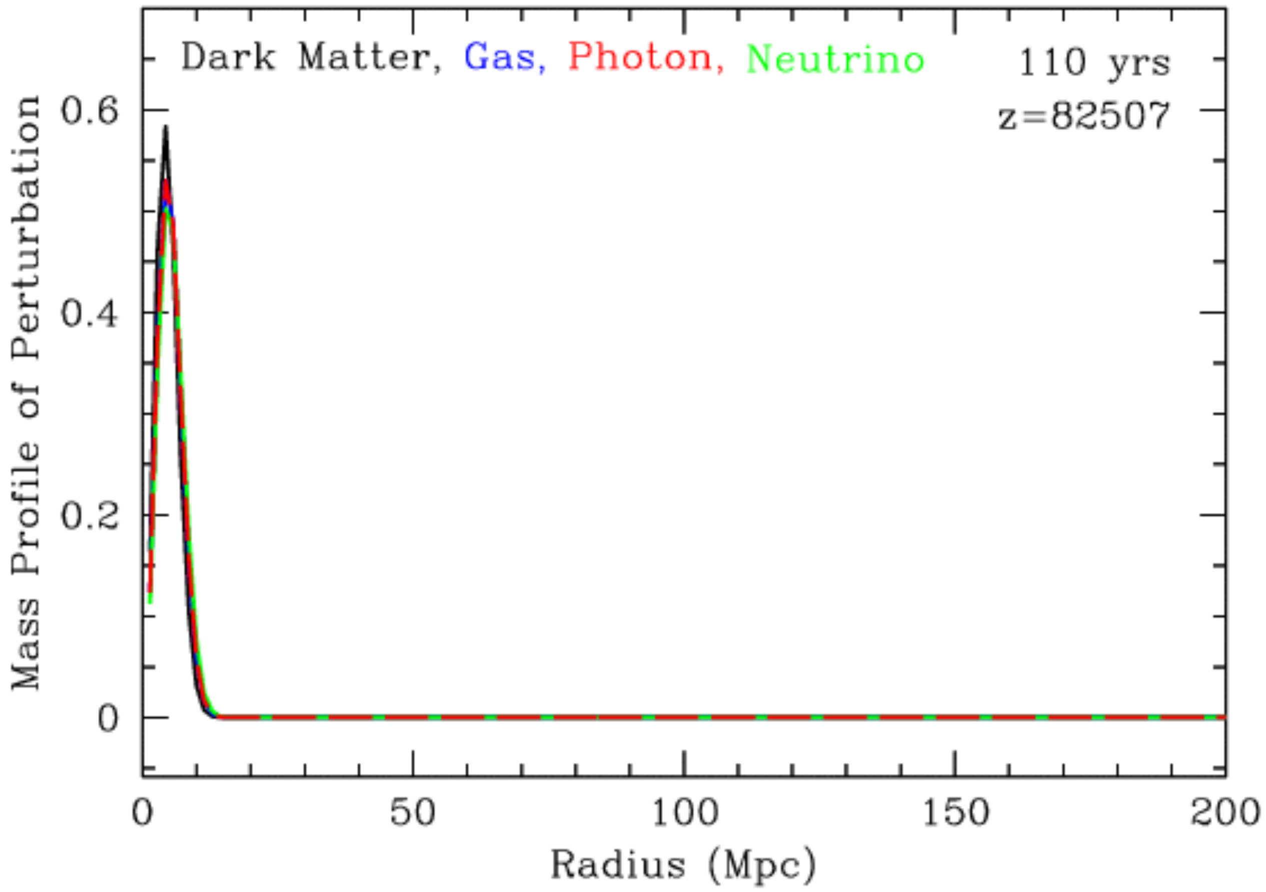


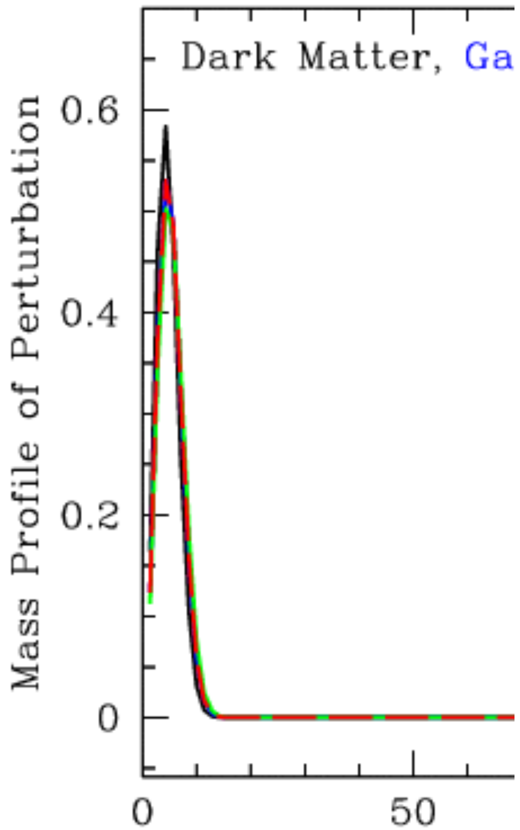
Mapping our observable universe
—> improve sensitivity to increase galaxy number density and depth
—> improve the sky coverage to access the large scales and check homogeneity and isotropy

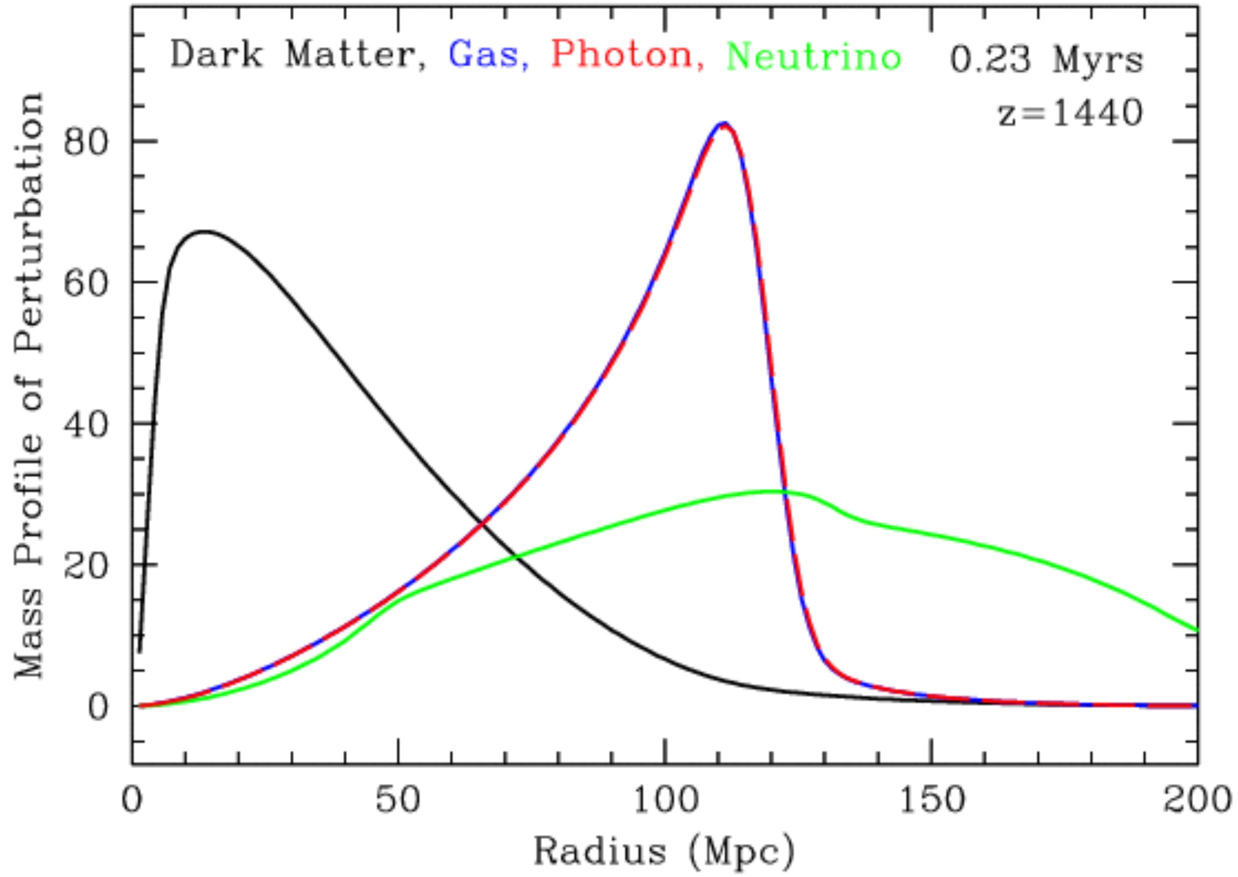
Simulation of dark matter distribution (+ baryons)
—> check time evolution
—> check matter distribution
—> cosmological parameters dependency

2-point (3-point) correlation function or **matter power (bi)spectrum**

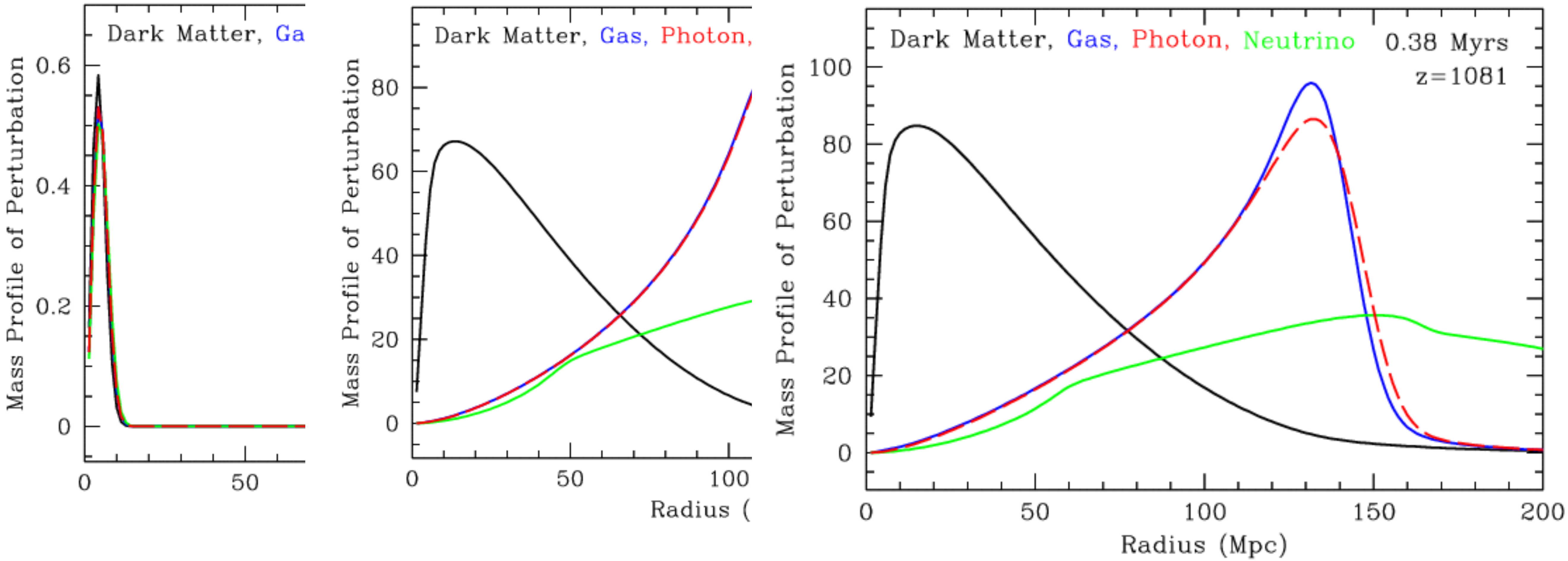
Cécile Renault


Dark Matter, Gas, Photon, Neutrino
110 yrs
z=82507
Mass Profile of Perturbation
0.6
0.4
0.2
0
0
50
100
150
200
Radius (Mpc)





Credit: from Daniel Eisenstein



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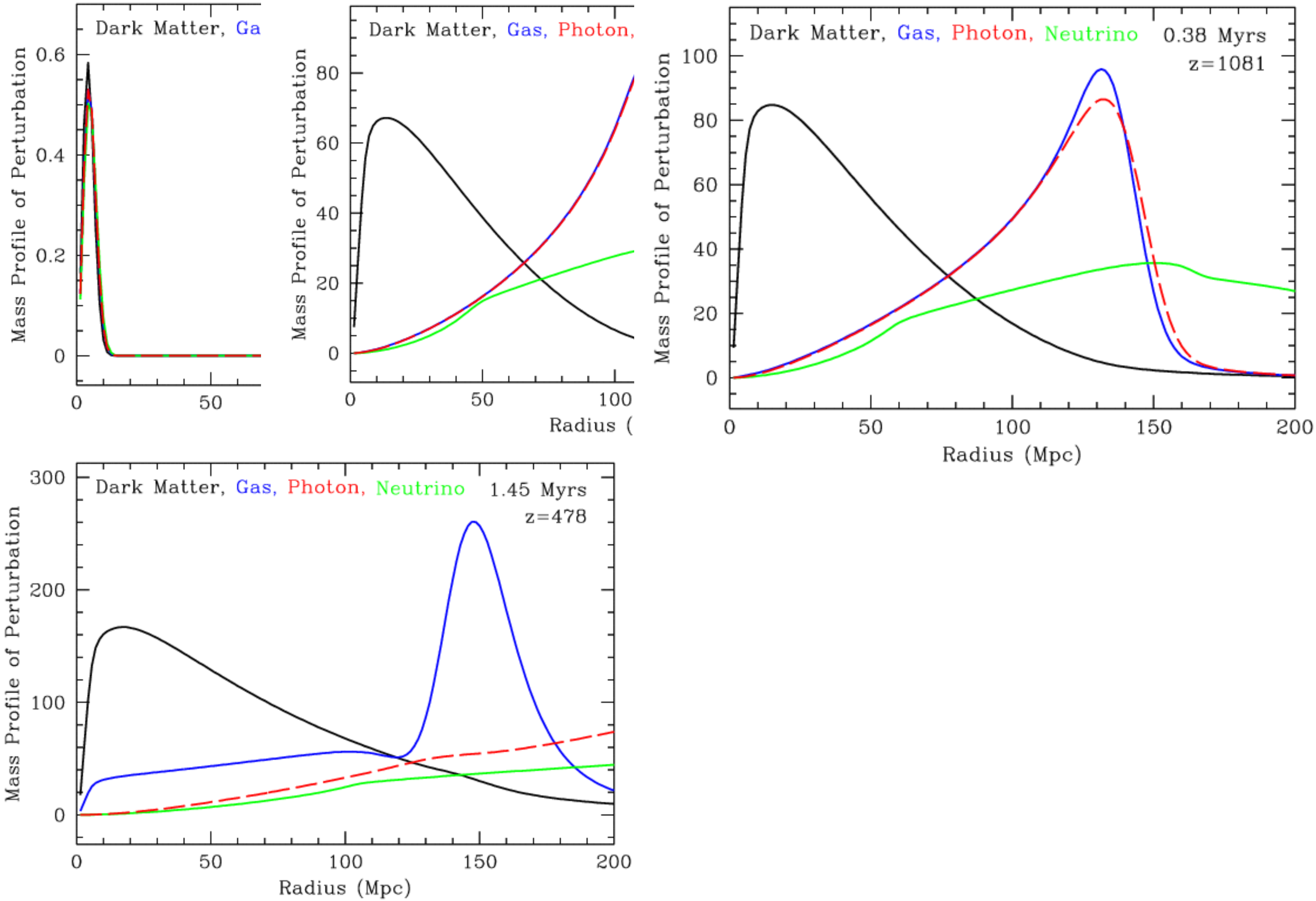

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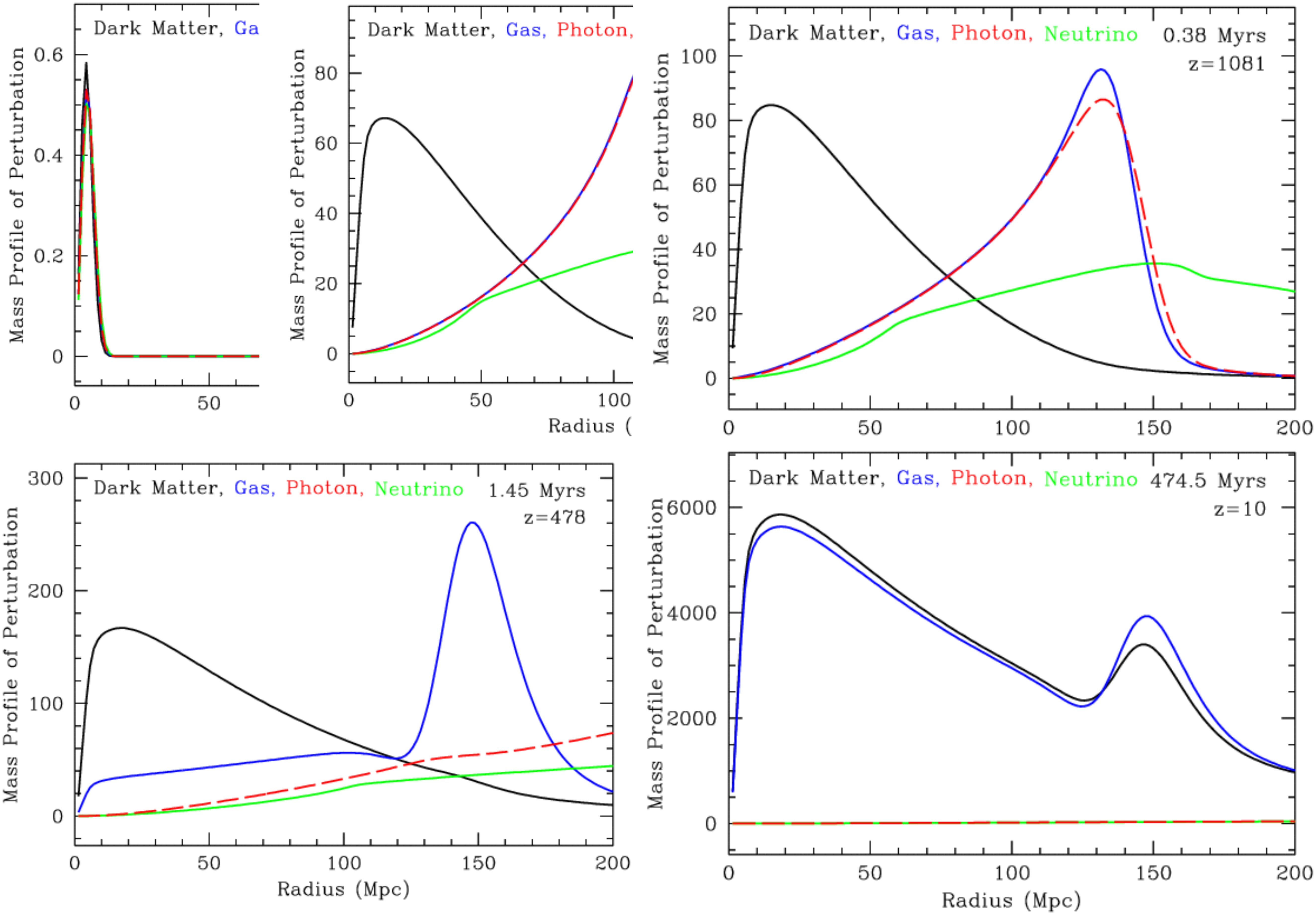

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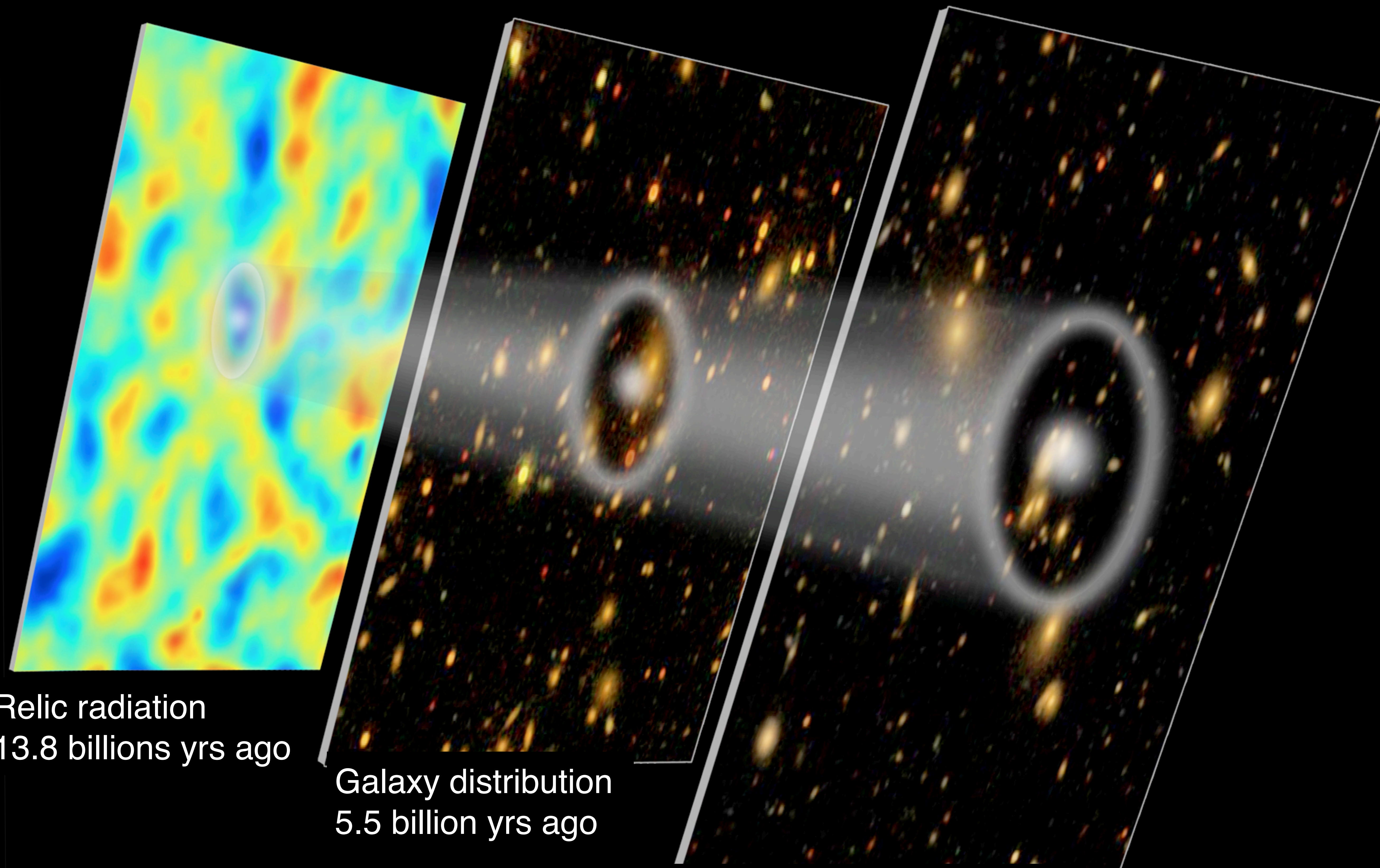
Cosmic standard ruler

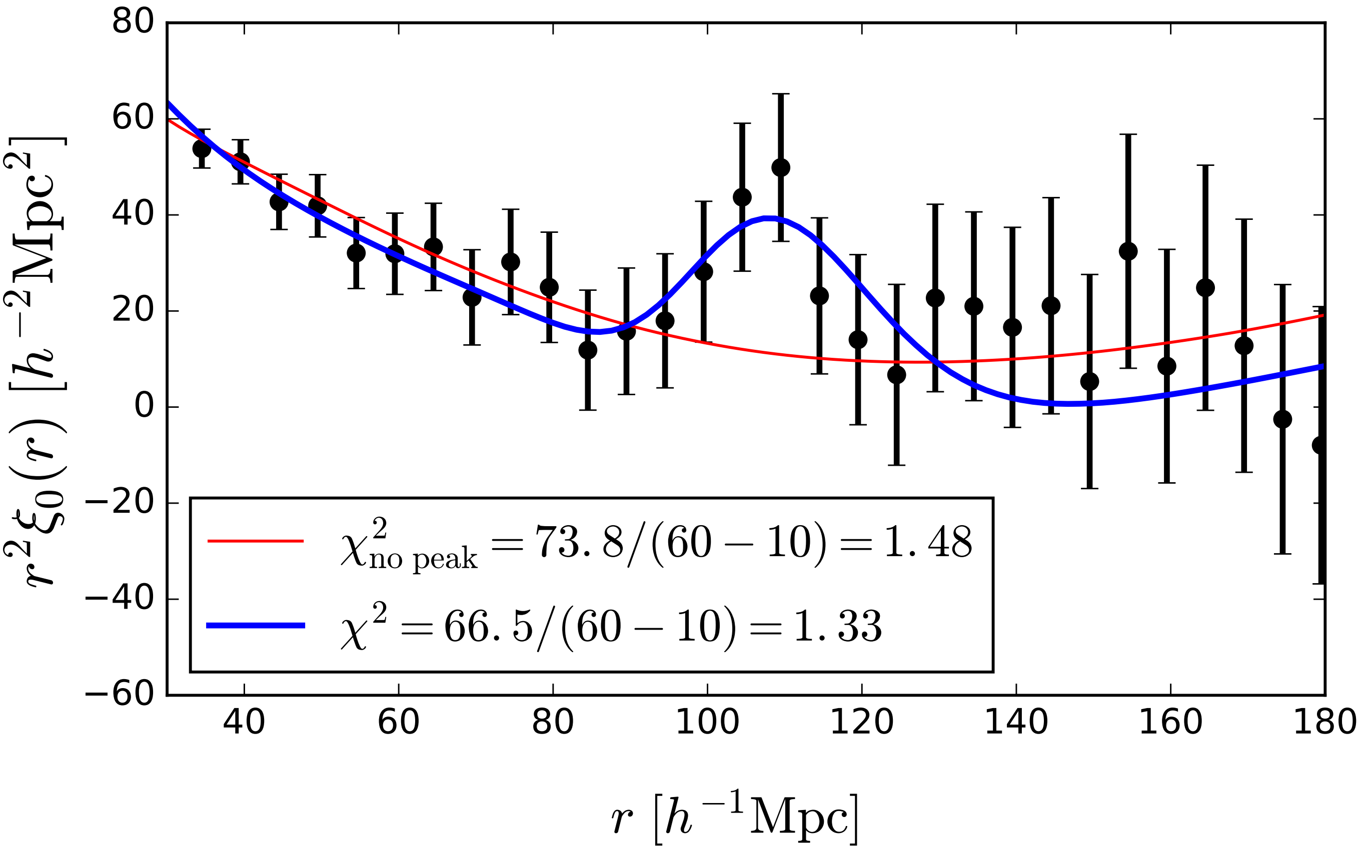


Relic radiation
13.8 billions yrs ago

Galaxy distribution
5.5 billion yrs ago

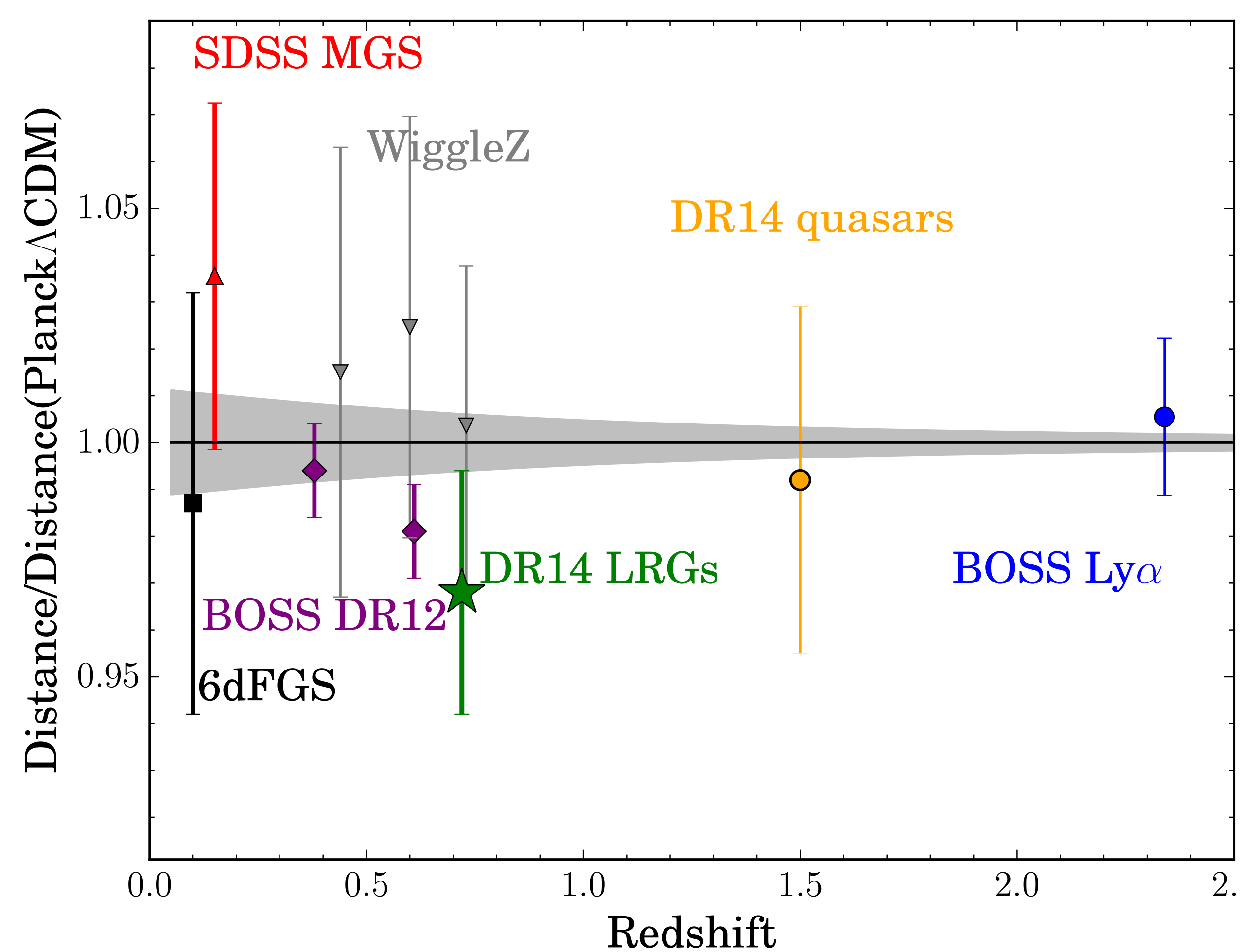
Galaxy distribution
3.5 billion yrs ago

The BAO peak - current measurements



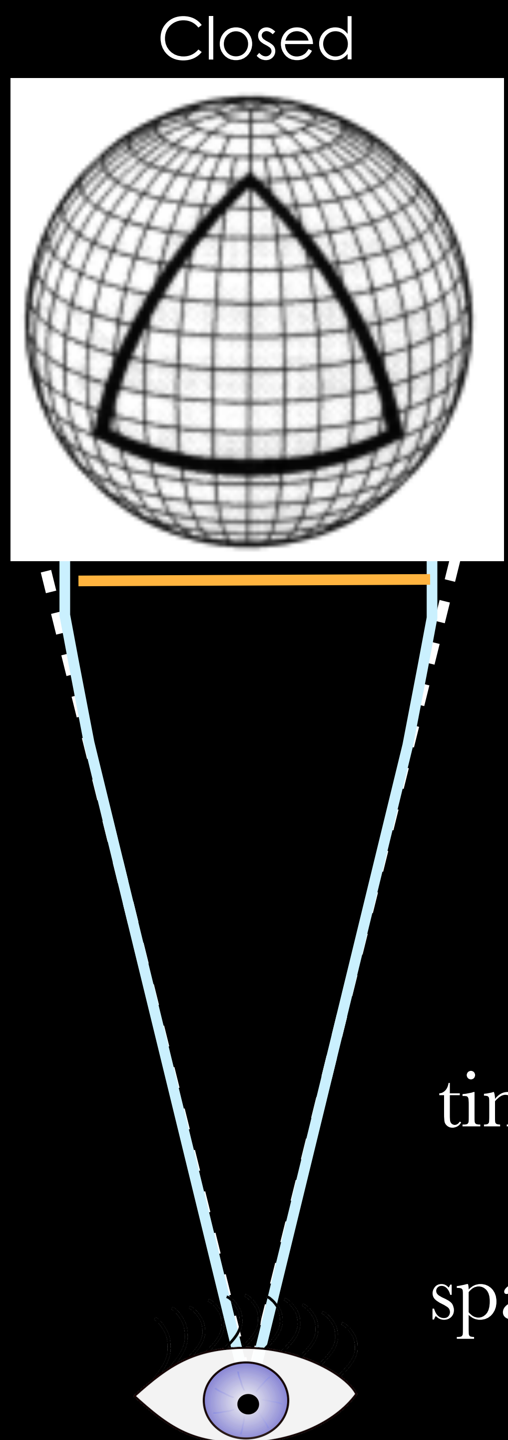
Credit: SDSS IV arXiv:1712.08064

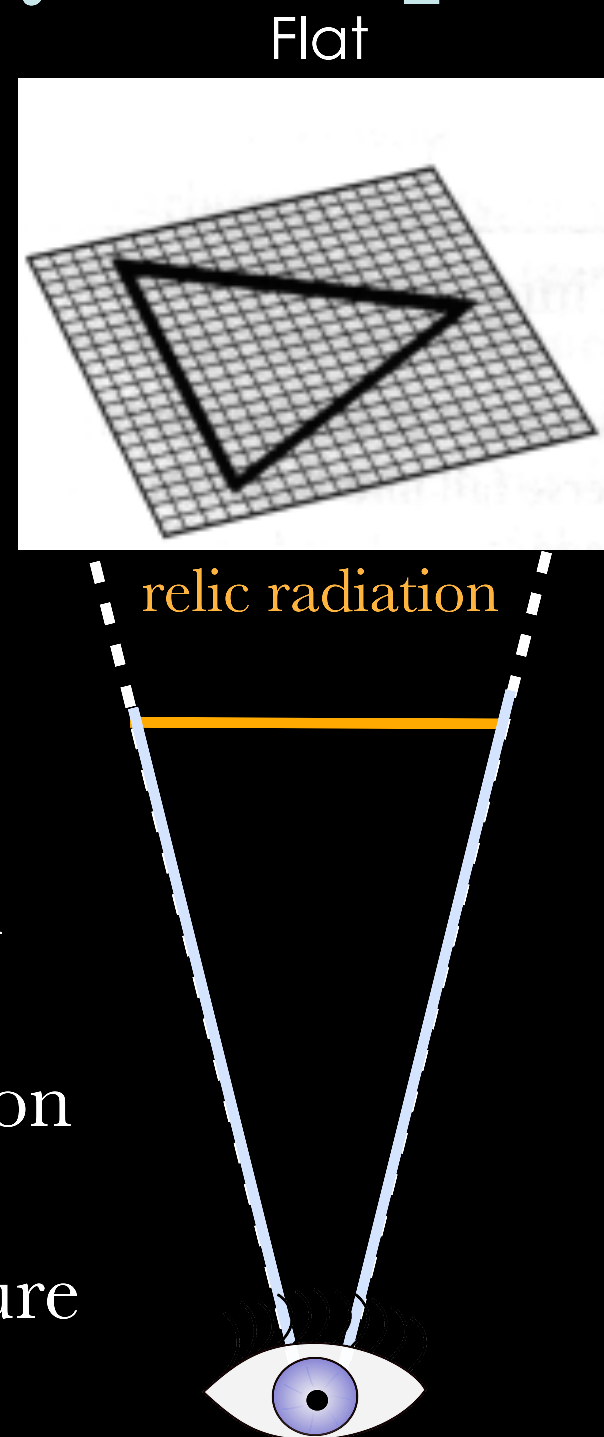
Monopole of the post-reconstruction correlation function with the best-fit models with (blue thick) and without (red thin) a BAO peak component.

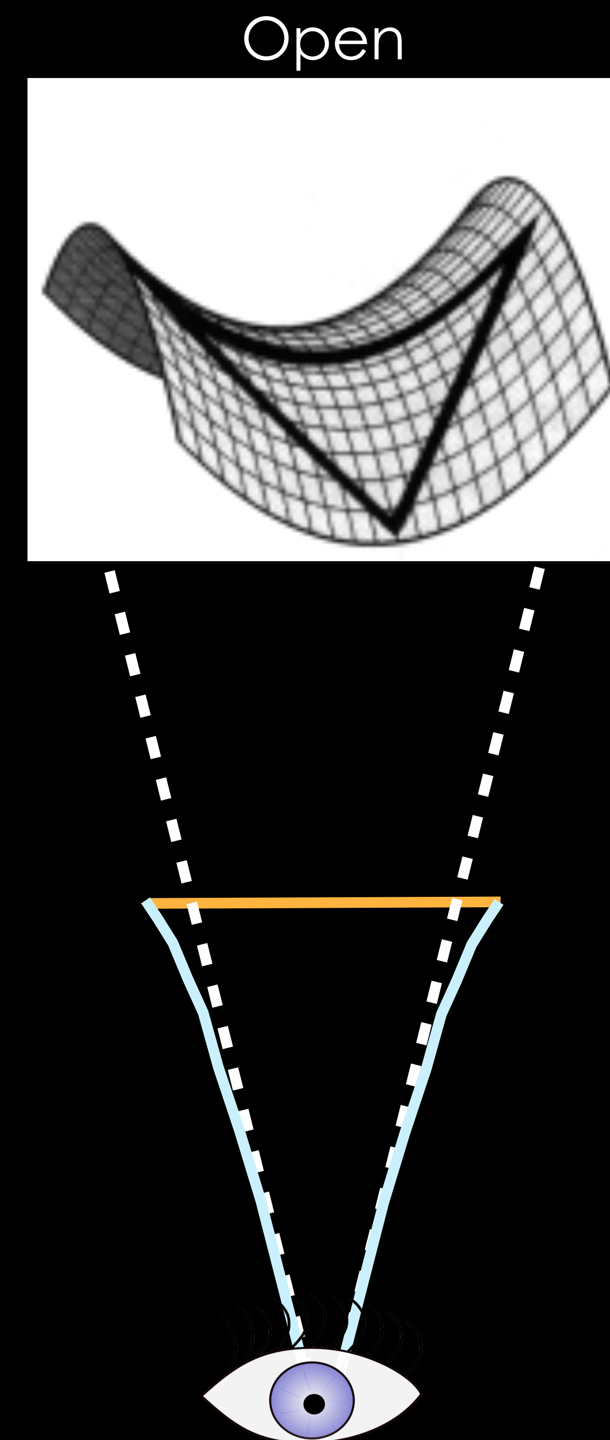


Current isotropic BAO measurements as a function of redshift compared to the prediction given by the best-fit cosmological parameters of Planck TT+TE+EE+lowP (Planck Collaboration XIII 2016).

Geometry and space curvature



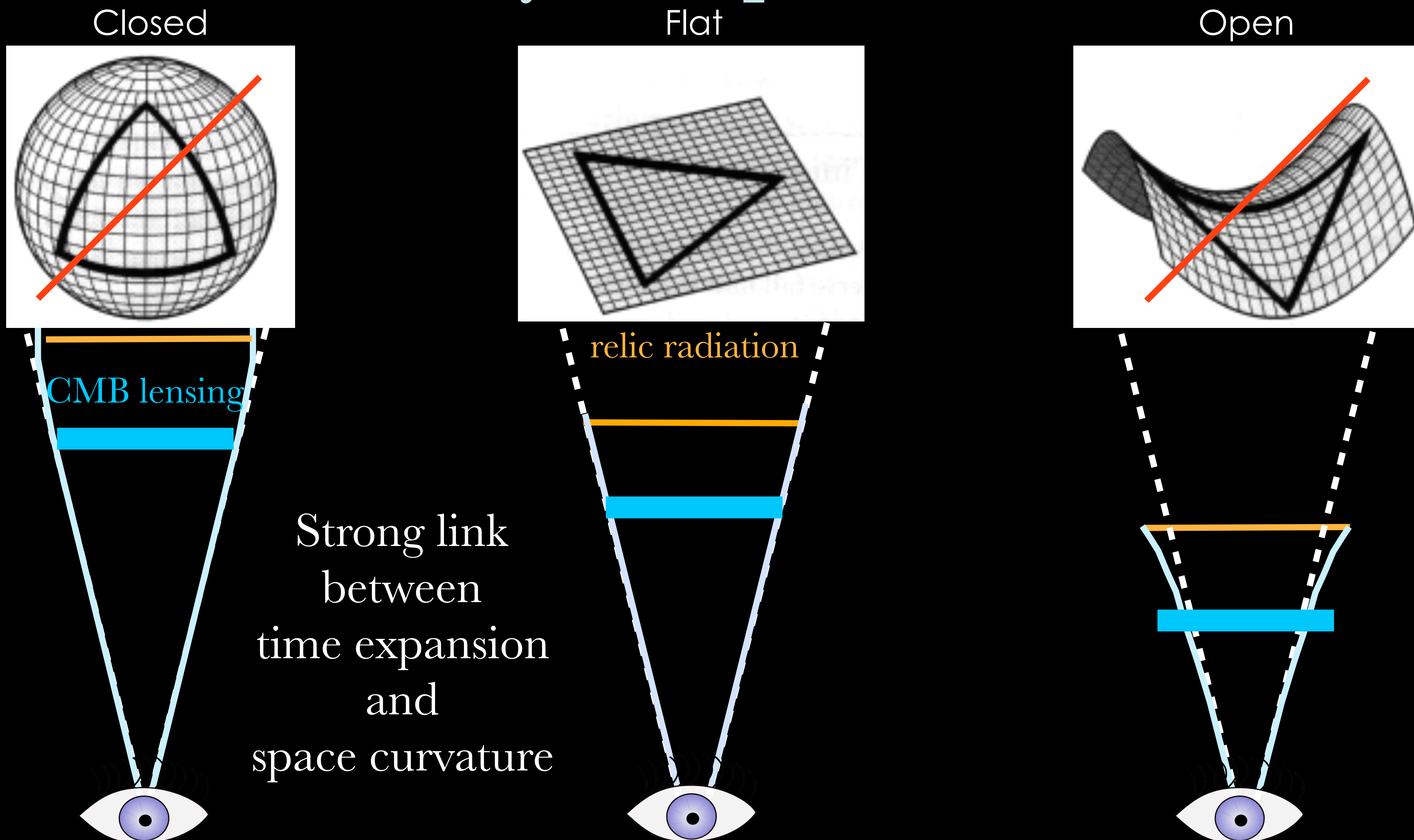




Strong link
between
time expansion
and
space curvature

$\Omega_K = -0.040 \quad +/- \;\; 0.04$ Planck (CMB)

Geometry and space curvature

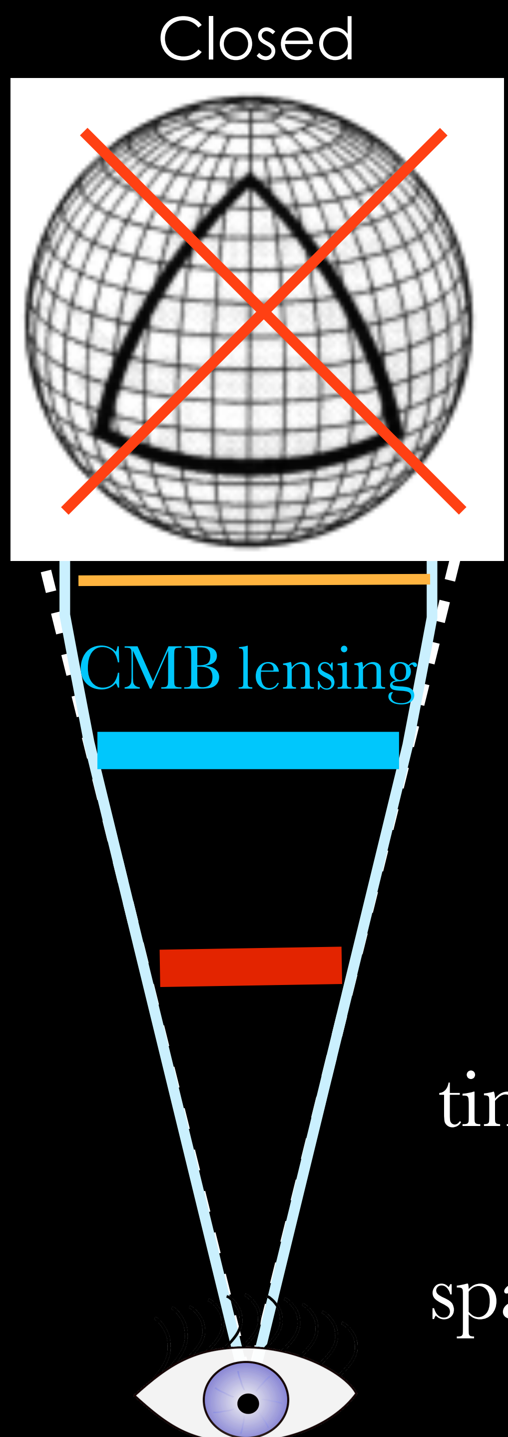


Strong link
between
time expansion
and
space curvature

$\Omega_K = -0.040$ +/- 0.04 Planck (CMB)

$\Omega_K = -0.004$ +/- 0.015 Planck (CMB + lentille)

Geometry and space curvature



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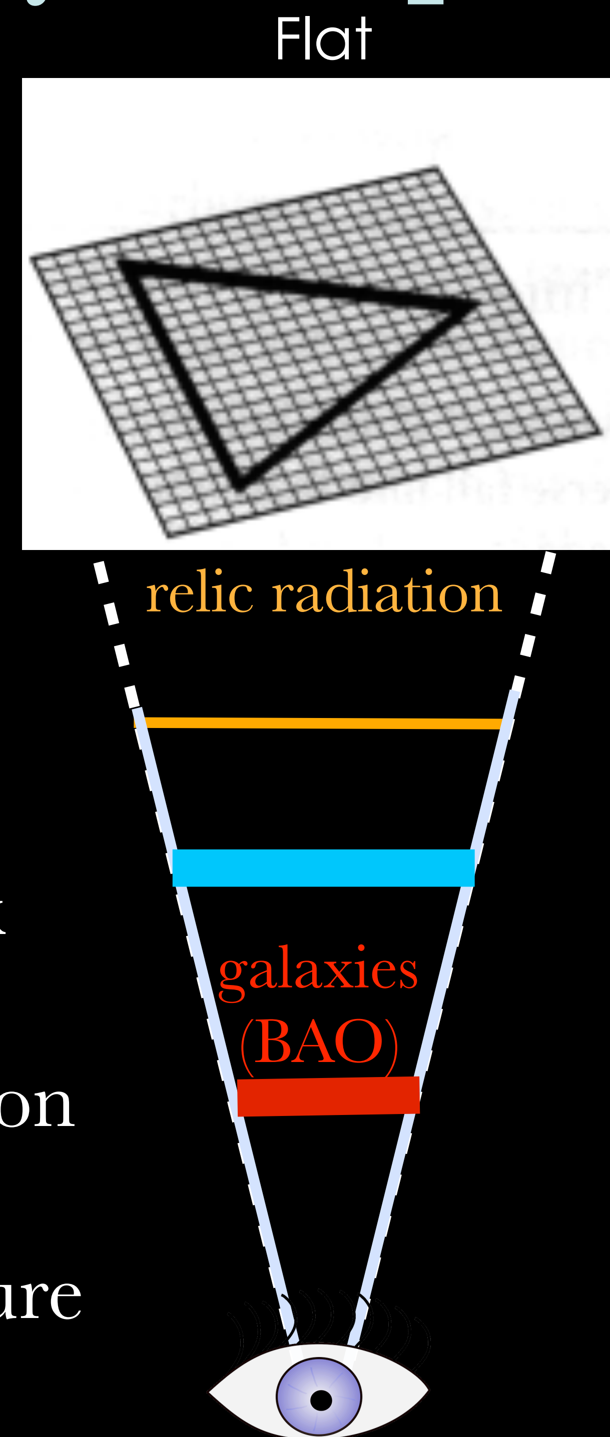
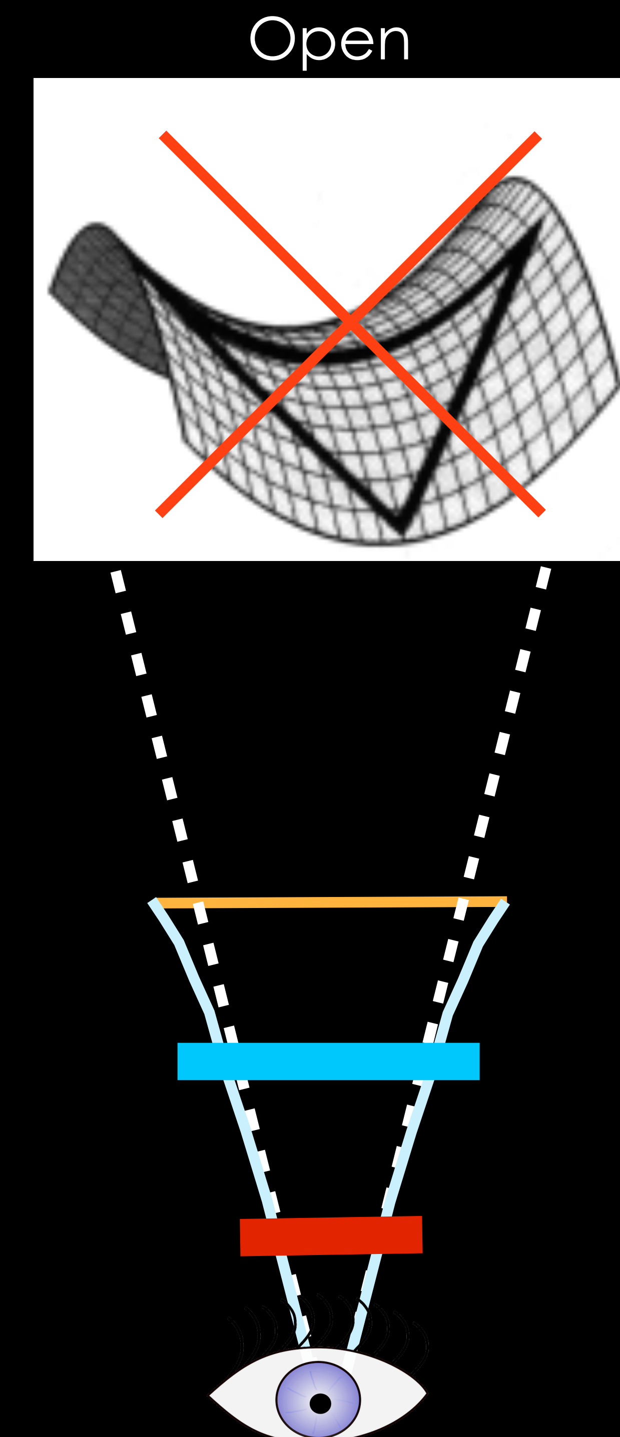




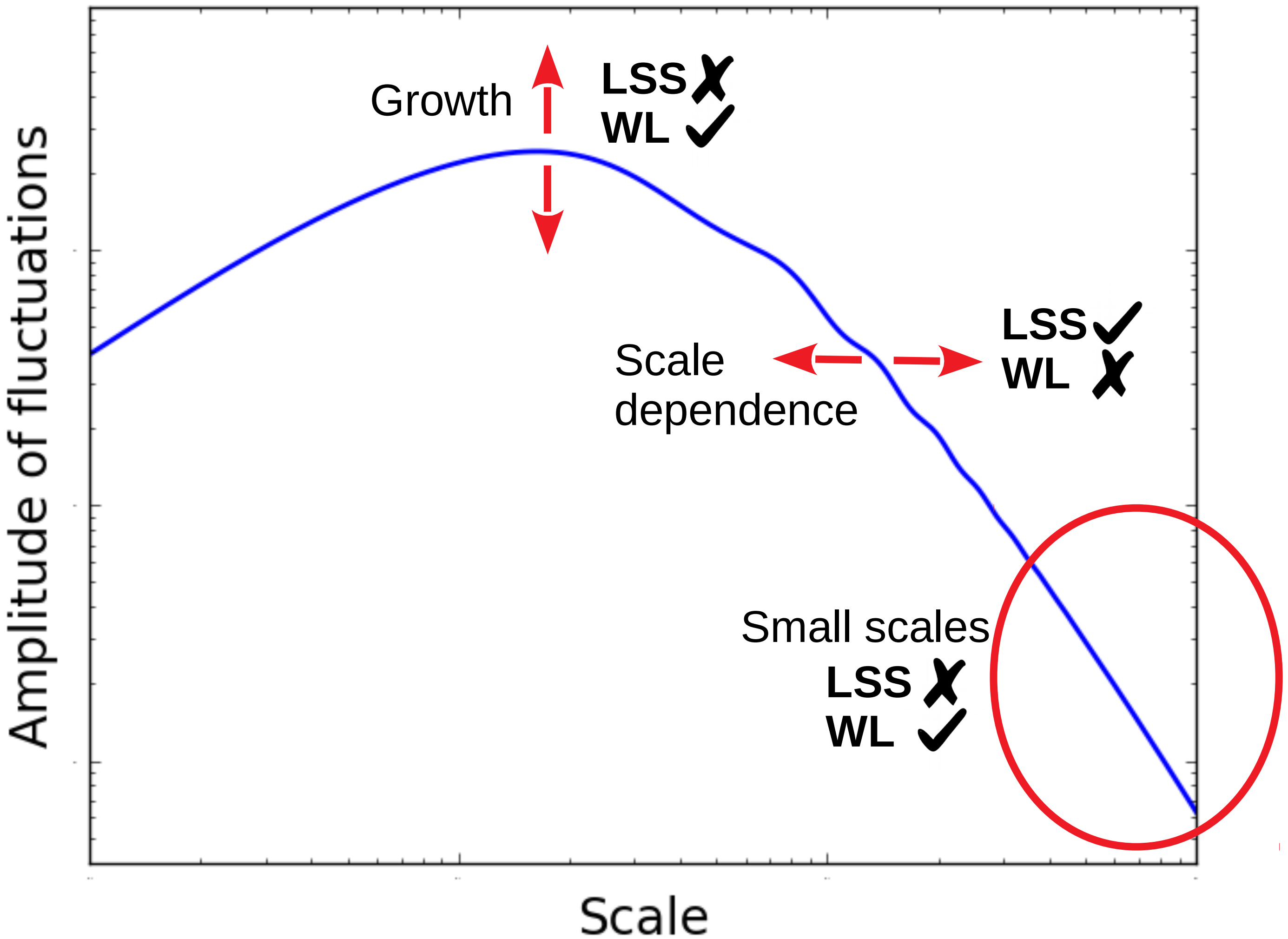
$\Omega_K = -0.040 \;\; +/- \;\; 0.04$ Planck (CMB)

$\Omega_K = -0.004 \;\; +/- \;\; 0.015$ Planck (CMB + lentille)

$\Omega_K = -0.0008 \;\; +/- \;\; 0.004$ Planck (CMB + lensing) + BAO + H_0 + SNe

Planck+BAO = ***Euclidian space*** + *moderate expansion rate 67.90±0.55 km/s/Mpc*

The matter power spectrum



Credit:: David Alonso

growth: structures evolution driven by the gravity. Amplitude increases when redshift decreases —> more and more contrasted Universe
+ capacity to test gravity theory on very large scales

BAO scale: very small oscillations superimposed on the main shape. Position provides the standard ruler

small scales: non-linear regime with complicated, but interesting !, astrophysical ingredients

—> mix of LSS & WL probes is powerful:

- complementarity (to estimate cosmological parameters)
- consistency (to check the model validity - and systematics …)

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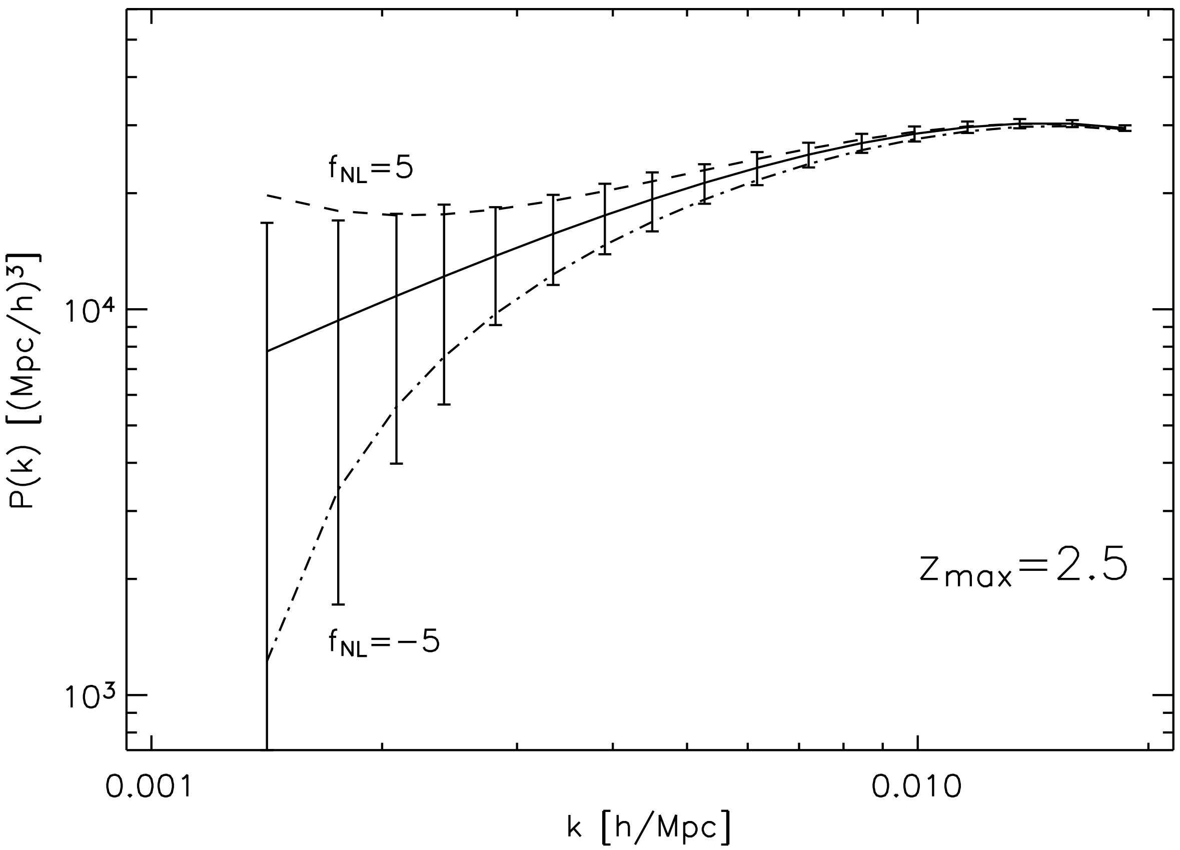
Primordial non-Gaussianity



Credit: LSST Science Book

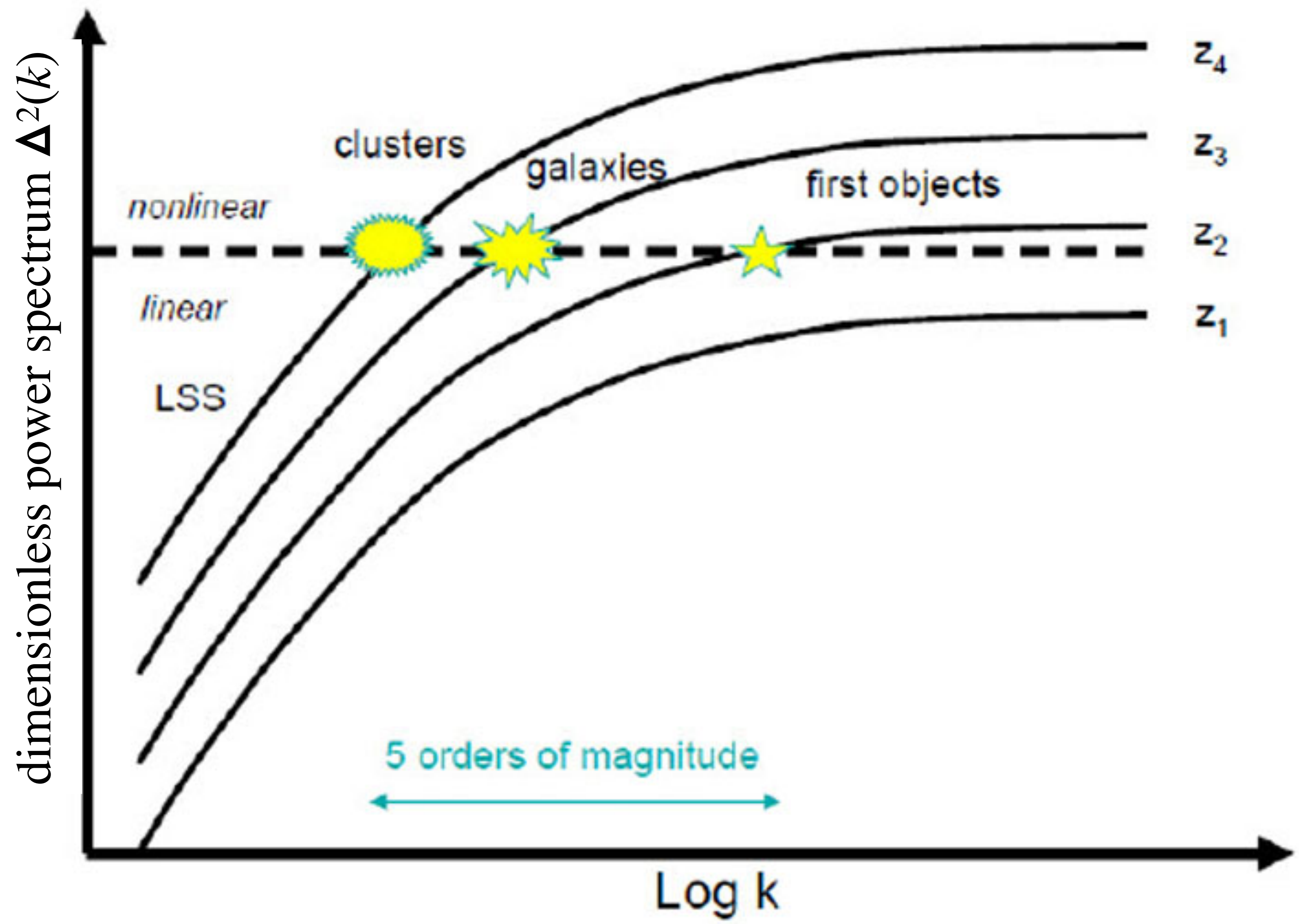
Effect on the large scale observed galaxy power spectrum of a primordial non-Gaussianity of the local type described by an f_{NL} parameter of the values ±5.

CMB Planck 2016: $f_{NL} = 0.8 \pm 5.0$ (local)

* simplest, single field, slow-roll inflation models predict $f_{NL} < 1$
—> not detectable

* several models (multi-field models, non-slow roll models) yield much larger deviations from Gaussianity
—> detectable with LSST.

Growth factor and hierarchical structure formation



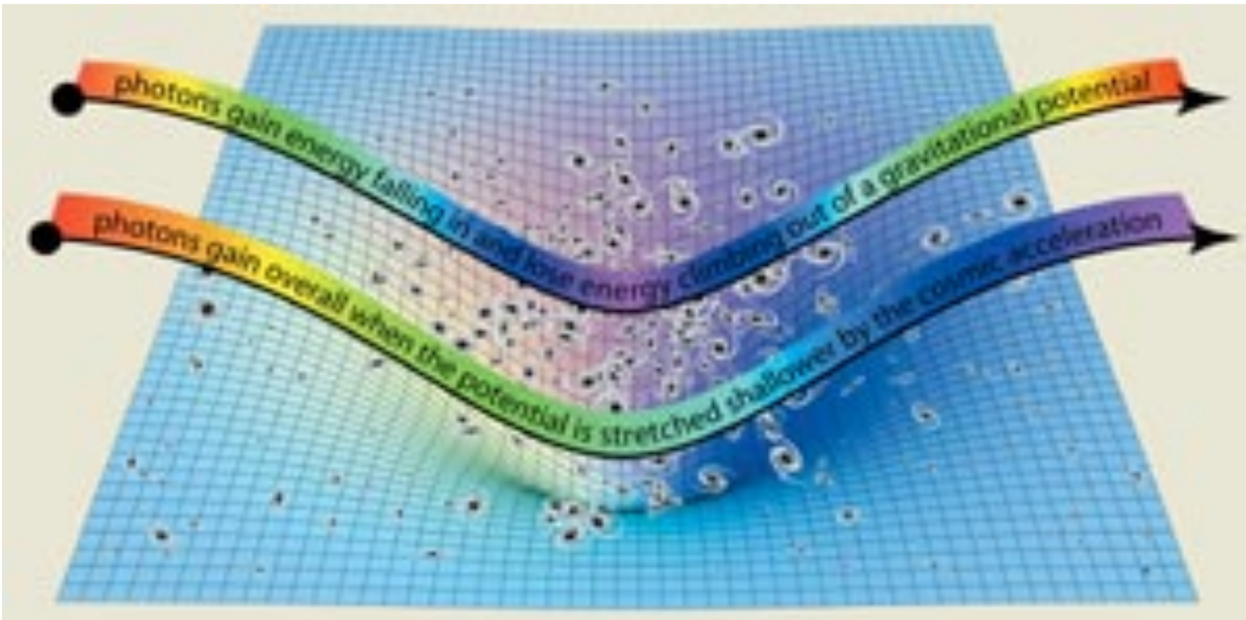
Credit:: Michael L. Norman

linear regime: increases uniformly proportional to the linear growth factor. Super- and sub-horizon scale perturbations grow as $t^{2/3}$ in the matter-dominated era.

non-linear regime: all scales with $k > k_{nl}$ (z) have collapsed into bound objects
—> "bottom-up" hierarchy model.
Numerical simulations required because the modes do not grow independently.

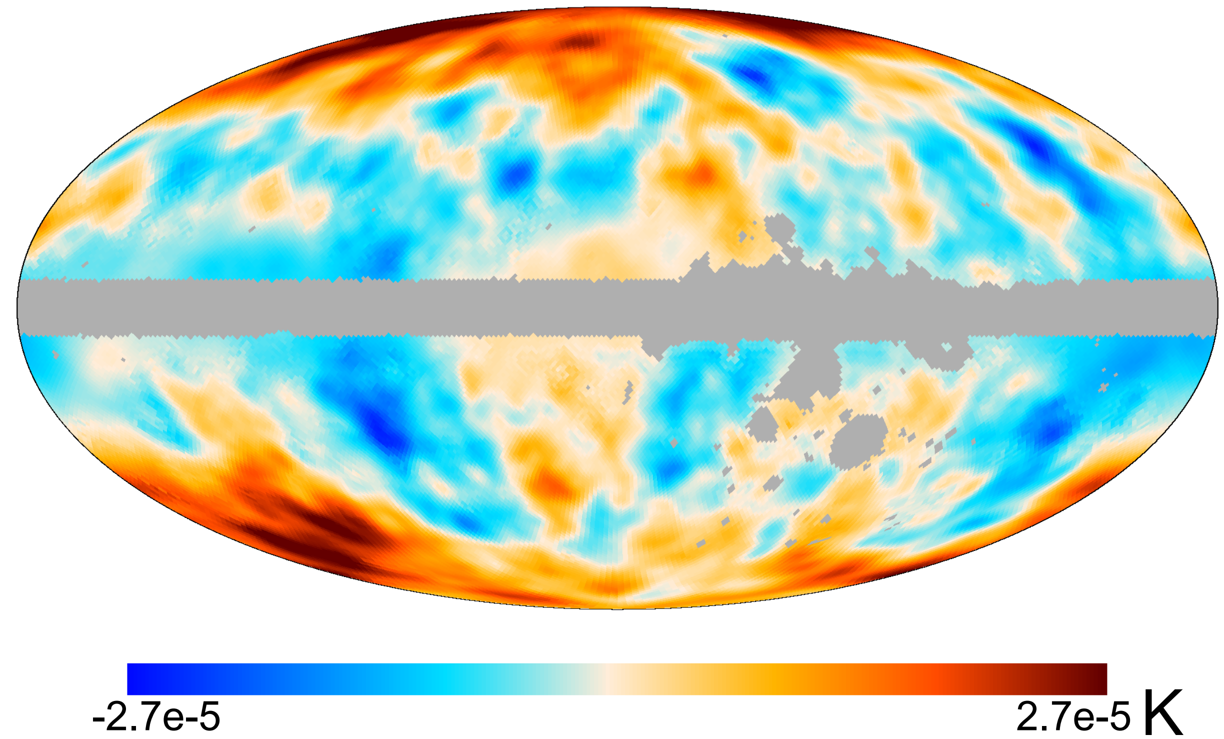
BAO scale large enough that nonlinear evolution does not alter the scales appreciably

Cross-correlations with other tracers



CMB photons traveling through a decaying potential well, such as an overdense region in the ΛCDM universe, will gain energy

—> LSS causes secondary anisotropies in the CMB, can be measured from the correlation between galaxy over-densities and CMB T fluctuations,
—> direct evidence for the existence of dark energy which stretches LSS



Map of the recovered Integrated Sachs-Wolf effect anisotropie from the combination of Planck SEVEM CMB map with radio-sources + galaxy surveys + Planck lensing

*—> detection at 4**σ** level*

Credit: Planck 2015 XXI. The integrated Sachs-Wolfe effect

Bias & non-Gaussianity

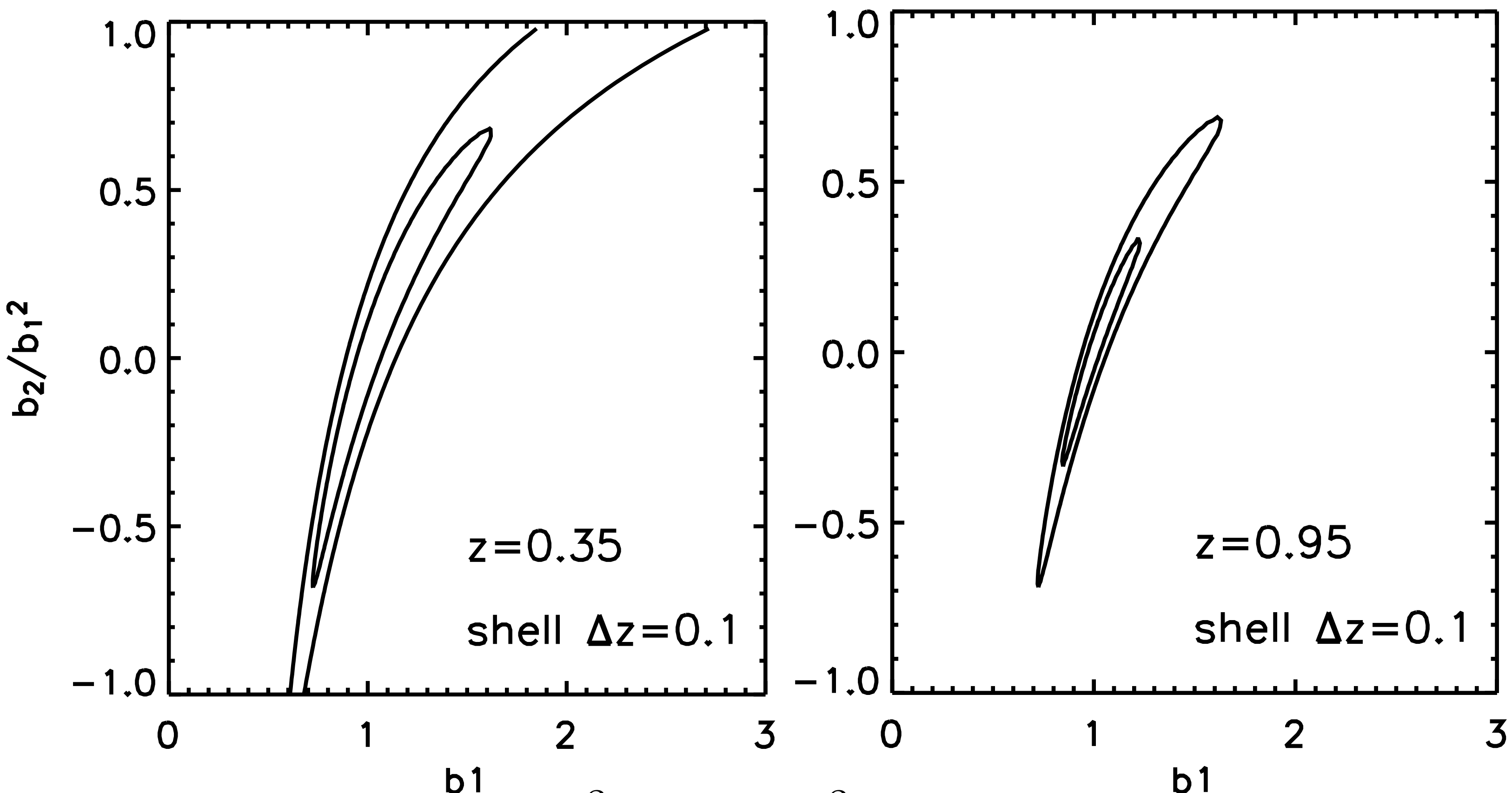
* Galaxies form at high peaks of DM —> biased tracers of the mass distribution

* Observed galaxy distribution is non-Gaussian
  - non-linear gravitational instability introduces skewness in density distribution
  - non-linear bias also skews the distribution

In linear theory, bias and the growth rate are degenerated —>bispectrum

- constrains on galaxy HOD —>tests of galaxy formation

- constrains on $\sigma_8 \Omega_M^{0.75}$



$\delta(r)_{gal} = b_1\ \delta(r)_{DM} + b_2\ (\delta^2(r)_{DM} - <\delta^2(r)_{DM}>)$ *Credit: LSST Science Book*

First objects are more biased (hierarchy model)
—> more accurate bias estimation

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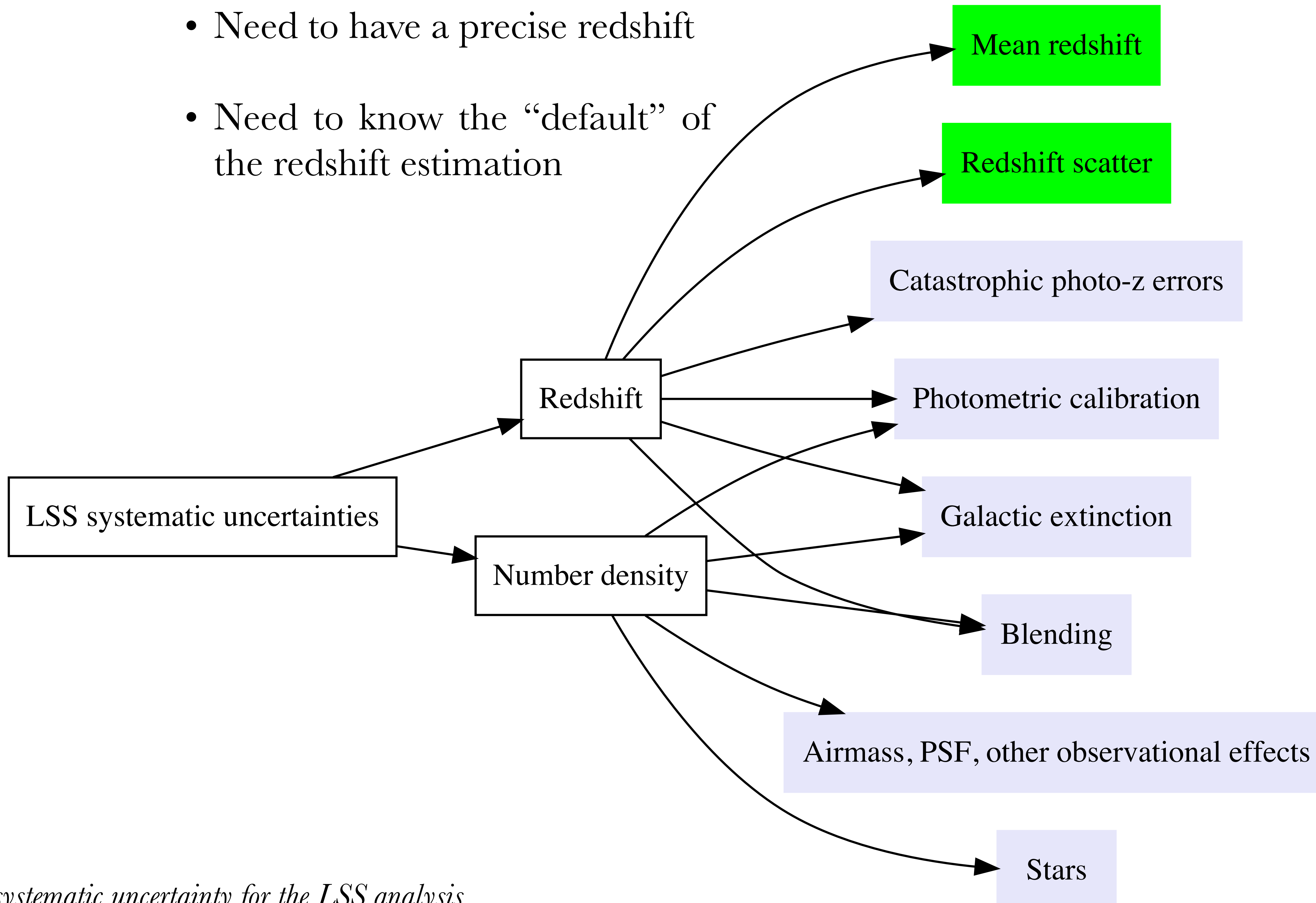
Systematic uncertainties

- Need to have a precise redshift
- Need to know the “default” of the redshift estimation

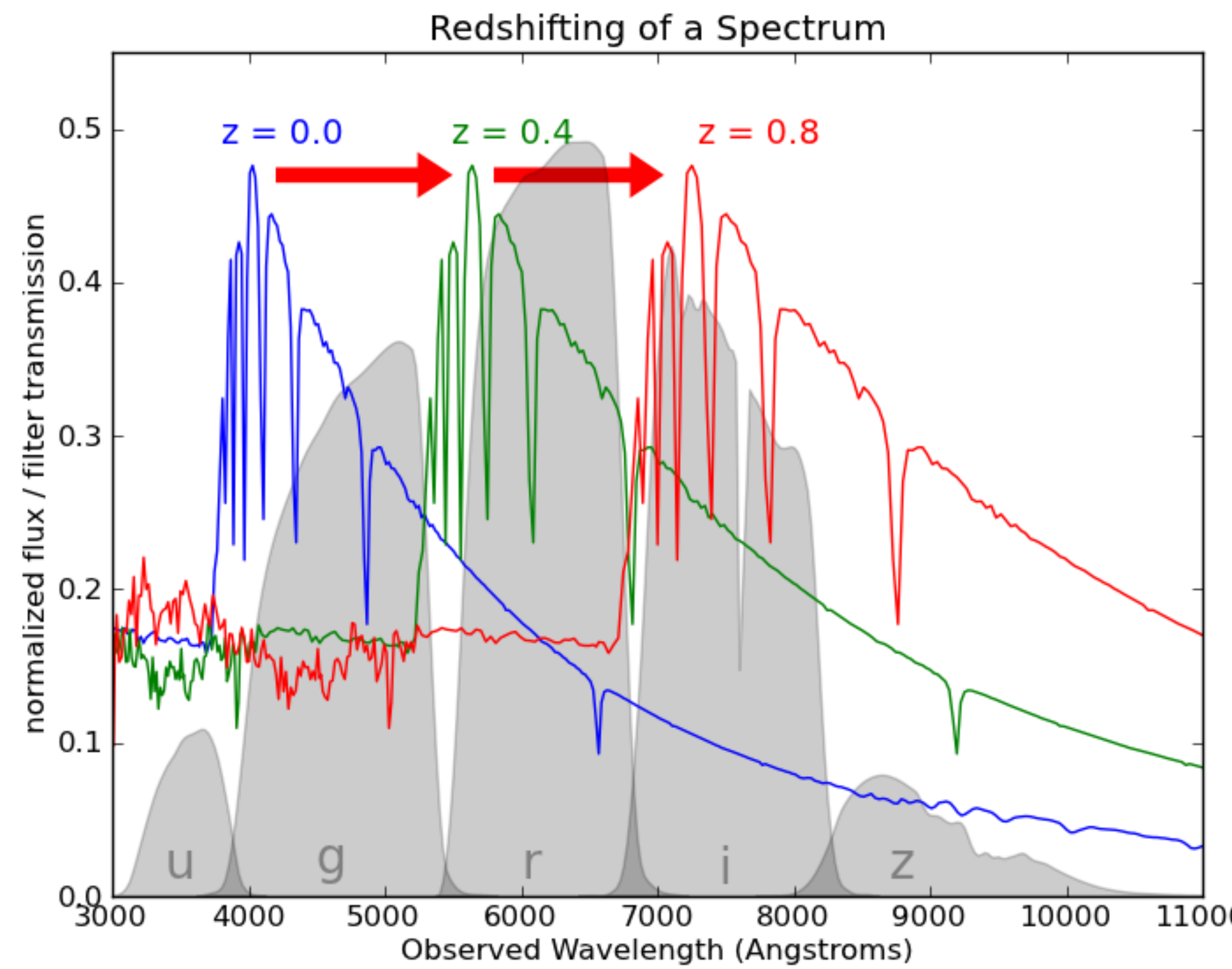


Sources of systematic uncertainty for the LSS analysis
Credit: LSST_DESC_SRD, in prep.

Where are the galaxies ?
or
the photometric redshift challenge

While the angular coordinates will be exquisitely thanks to the LSST optics and camera design, it will be more challenging to reconstruct the third coordinate, the redshift.

—> photometry in 6 bands provides a very low resolution spectrometer



Template of a galaxy spectrum at various redshifts, overlaid on the transmission functions of SDSS filters (u, g, r, i, z).
Credit :S DSS

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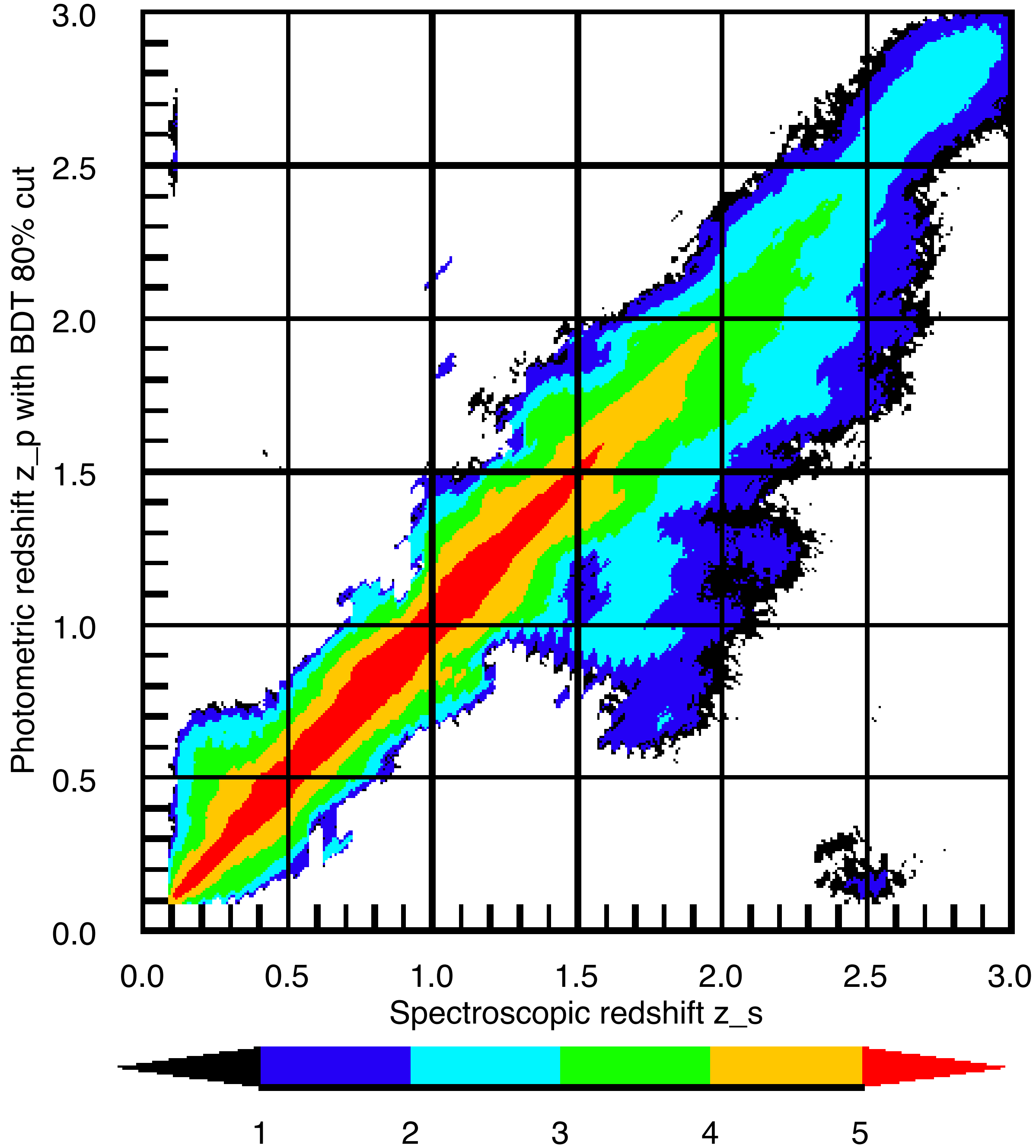
Photometric versus spectroscopic redshift



Credit : Ansari et al., in prep

Mock catalog of ~ 10^9 galaxies with photo-z which fulfils the LSST requirements up to z=2.

3 requirements :

- **dispersion** σ < 0.05 (1+z) [goal = 0.02]
- **bias** |median-mean| of $\delta z/(1+z) < 0.003$
- **outliers** less than 15%

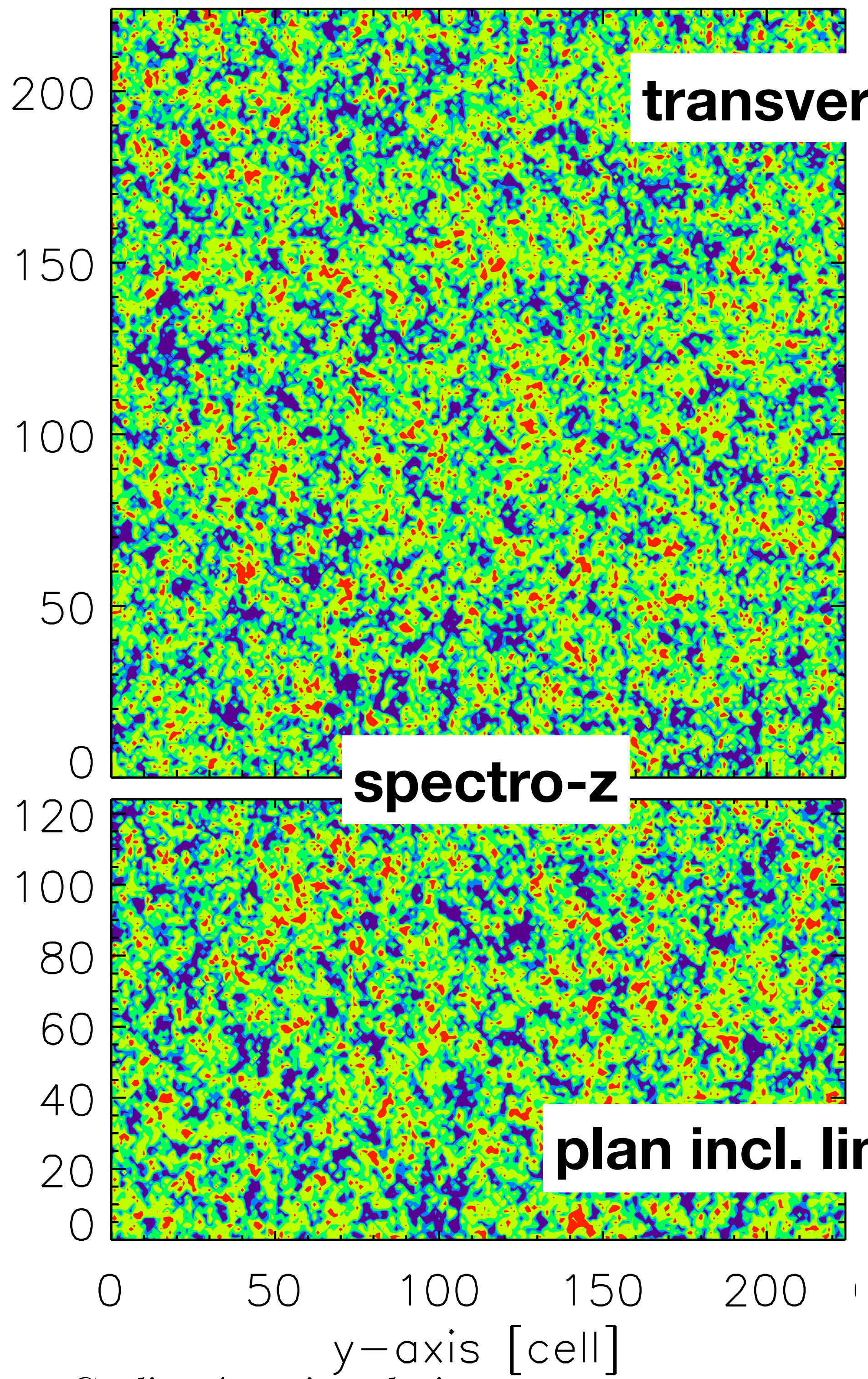
Gold sample: subset with mag _i < 25.3

Main challenges :

- Fast: billions of galaxies to monitor
- Efficient: new methods, for instance Deep learning approach (see J. Pasquet talk), cosmic web, morphology …

- Need of spectro-z on a representative sampling in galaxy type and redshift
- Data management: use of PDF, not only single photo-z values

LSS with photometric redshift



Credit : Ansari et al., in prep

photo-z

not straightforward …

But photometric surveys can have a much higher galaxy density

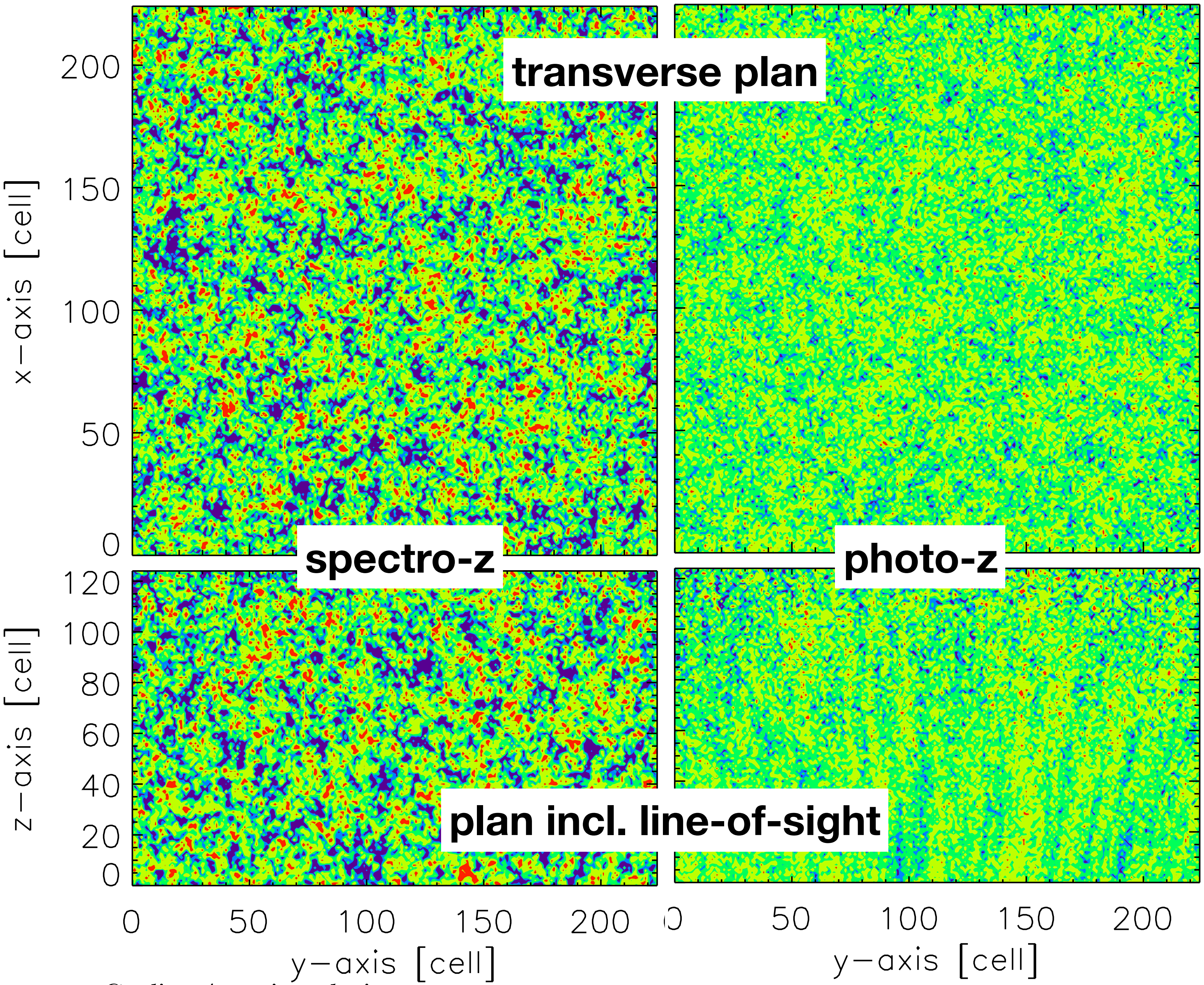
—> statistics save photo-z surveys

LSST 10y should have
30-40 gal /arc-min^2

eBOSS:
0.02 quasars /arc-min^2
0.05 emission line gal/arc-min^2
0.01 LRG /arc-min^2

—> loss of contrast everywhere
—> smoothing along the line-of-sight

LSS with photometric redshift



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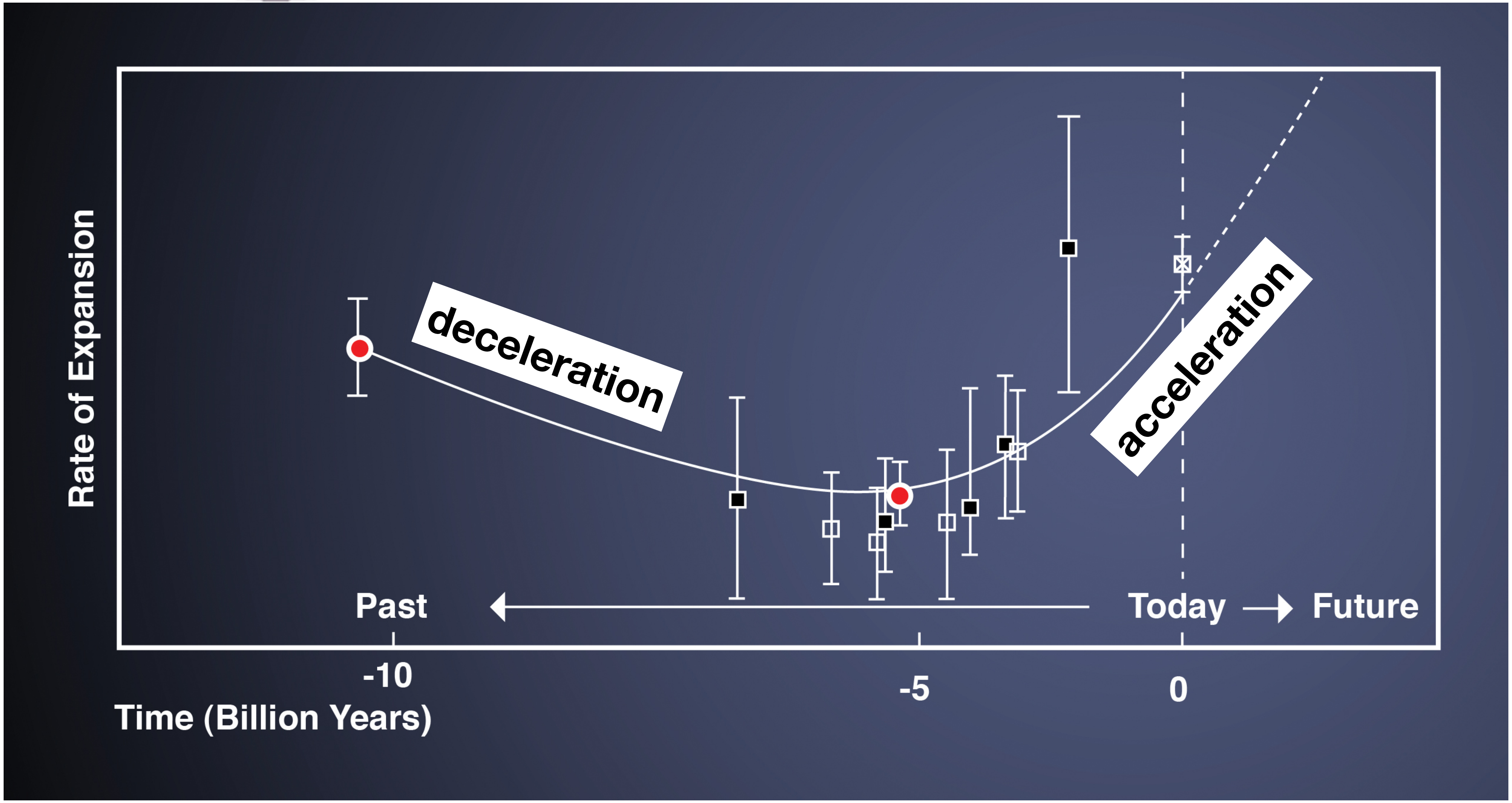
What is the mysterious dark energy that is driving the acceleration of the cosmic expansion?

Ordinary matter

Dark matter

Dark energy



Credit:: Zosia Rostomian, LBNL, and Nic Ross, BOSS Lyman-alpha team, LBNL + pies from planck.fr

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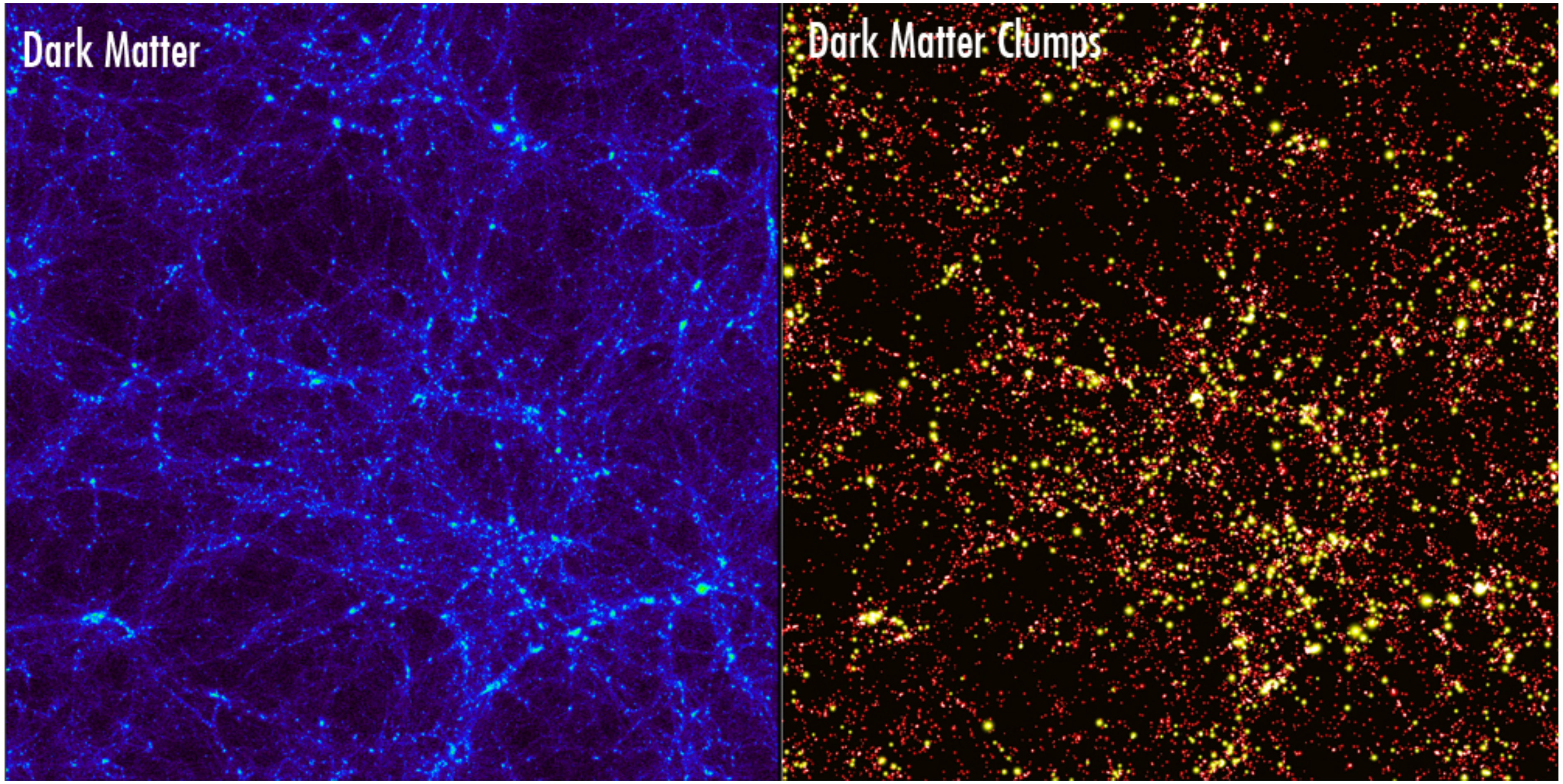
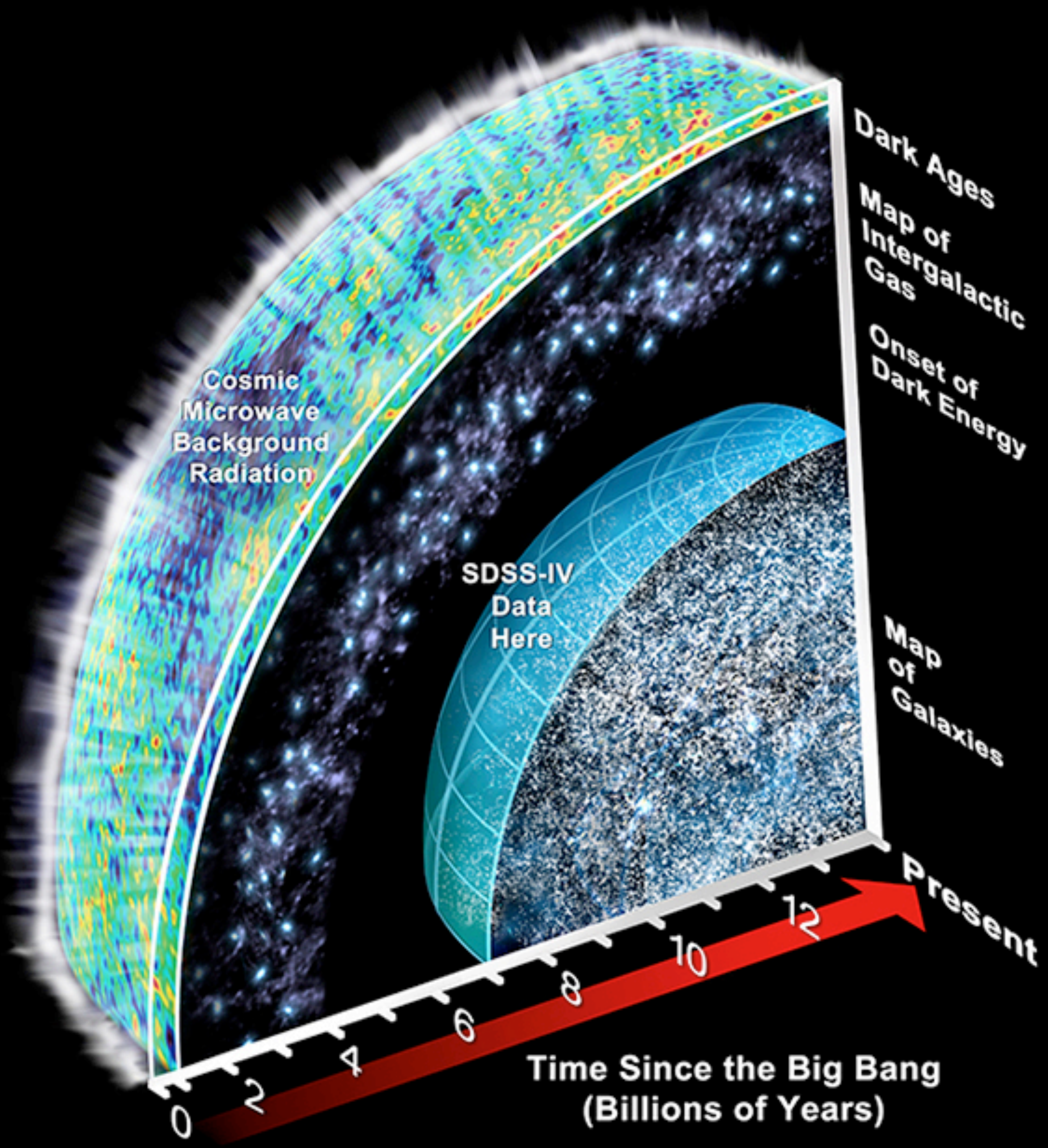
What is dark matter, how is it distributed, and how do its properties affect the formation of stars, galaxies, and larger structures ?



Simulations *of the distribution of dark matter ~ 3 billion years after the Big Bang and clumps of dark matter (red), with those larger than 300 million times the* M_{sun} *in yellow.*
Credit:: Virgo consortium / A. Amblard / ESA

Galaxies formed from clouds of gas collapsing under gravity inside halos, or clumps, of dark matter. The way in which the gas collapses depends on the amount of dark matter in the neighbourhood.

Our observable universe



LSST will provide the largest photometric galaxy sample of its time for studies of the large-scale structures

full tomographic

“3x2pt” analysis

goal = working in the cosmic-variance-limited regime

with systematic errors under control