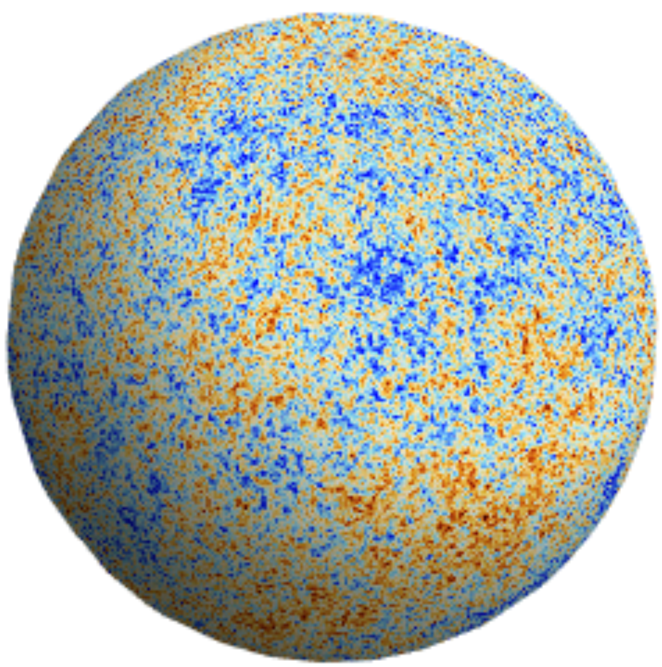
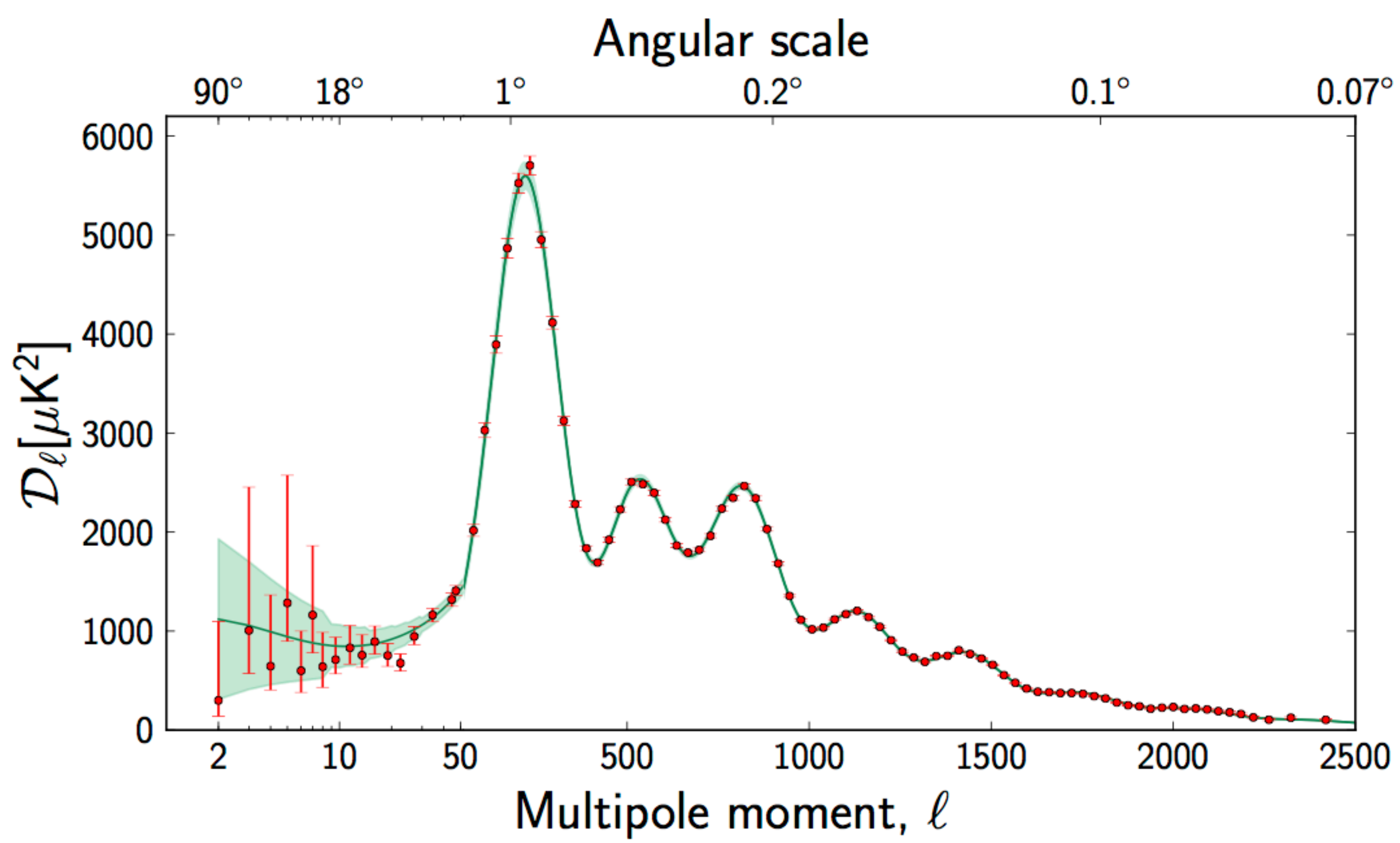
Theory of matter density fluctuations on cosmological scales

Marko Simonović

Cosmic Microwave Background (CMB)





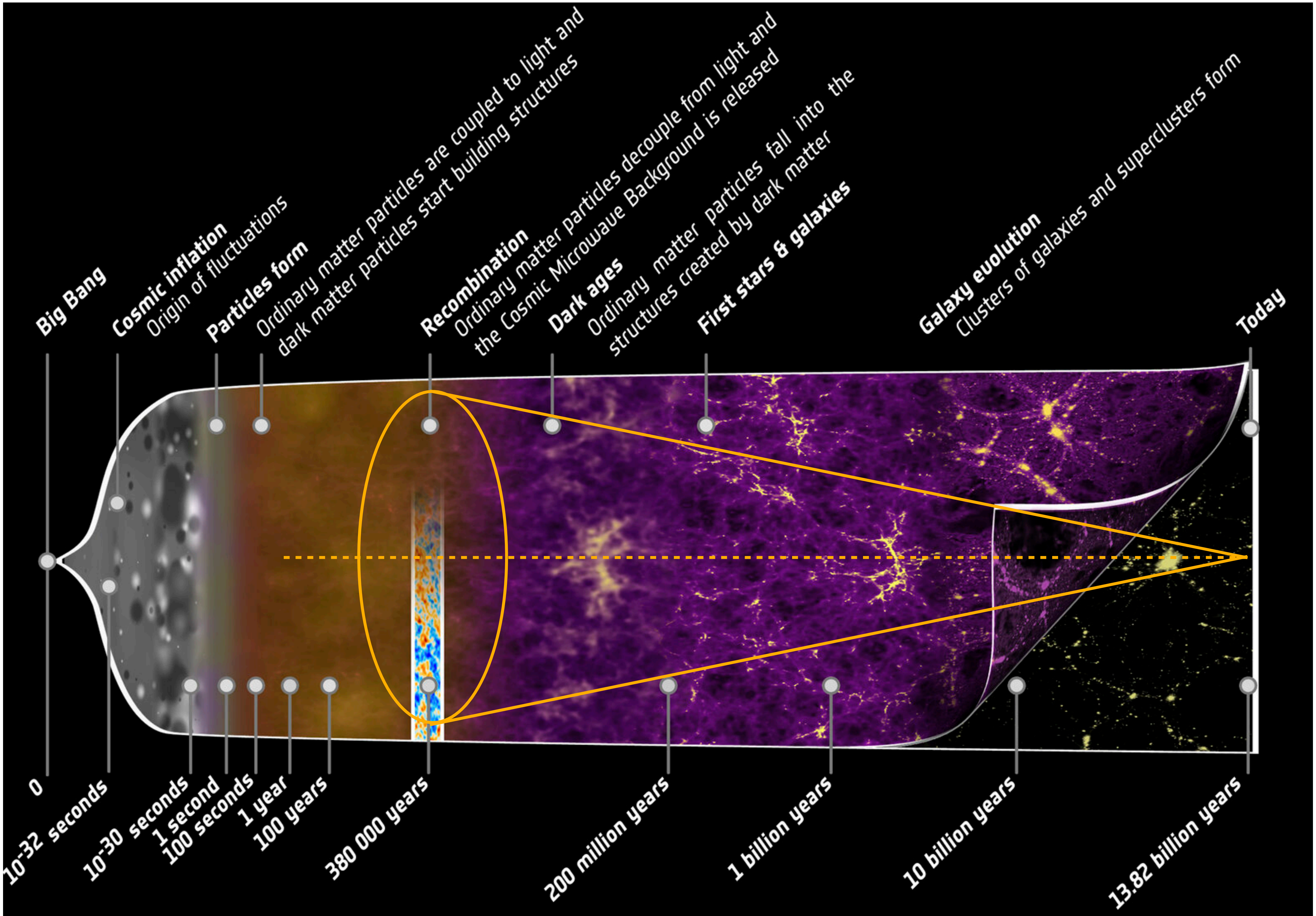
Parameter	*Planck* alone
$\Omega_b h^2$	0.02237 ± 0.00015
$\Omega_c h^2$	0.1200 ± 0.0012
$100\theta_{MC}$	1.04092 ± 0.00031
τ	0.0544 ± 0.0073
$\ln(10^{10}A_s)$	3.044 ± 0.014
n_s	0.9649 ± 0.0042
H_0	67.36 ± 0.54

Inflation

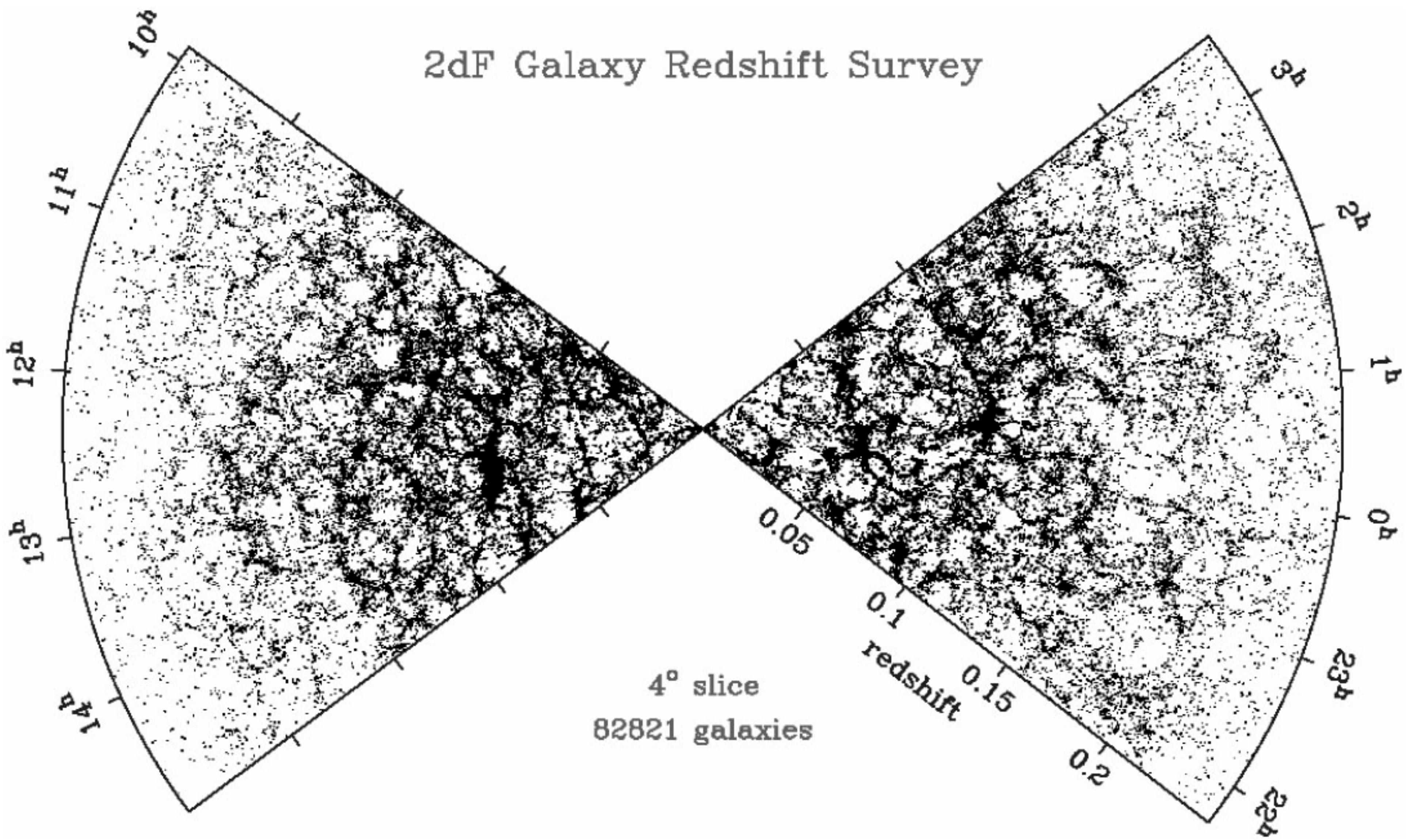
Dark Matter

Accelerated expansion

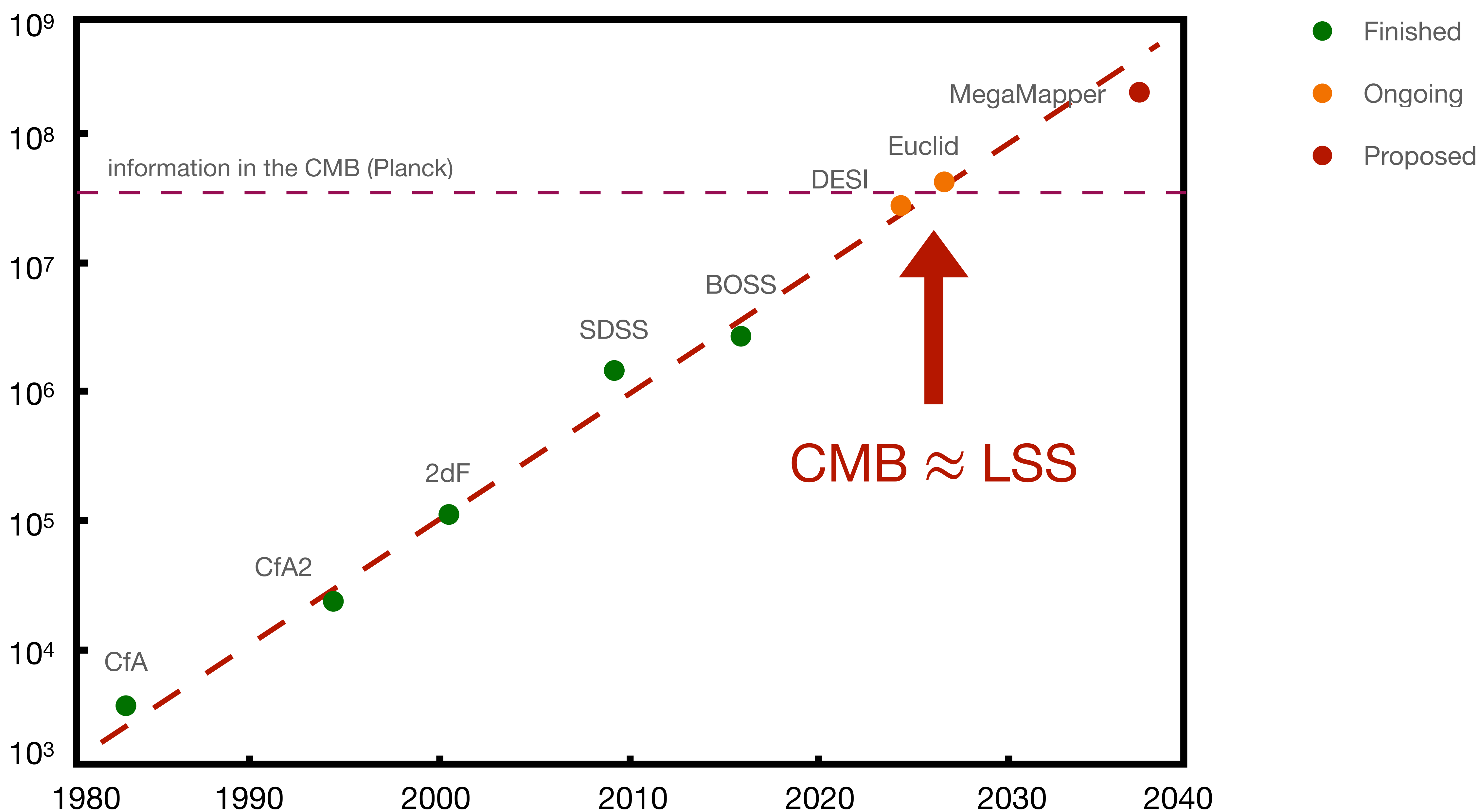
Fluctuations on the past light cone



Spectroscopic galaxy surveys



Spectroscopic galaxy surveys



Theory of matter density fluctuations

CMB: linear perturbation theory, since $\Delta T/T \sim 10^{-5}$

Density field of galaxies much more complicated
(nonlinear, we do not understand all relevant phenomena, mixing of scales…)

Astrophysical uncertainties at least ~10%, we need ~1% precision

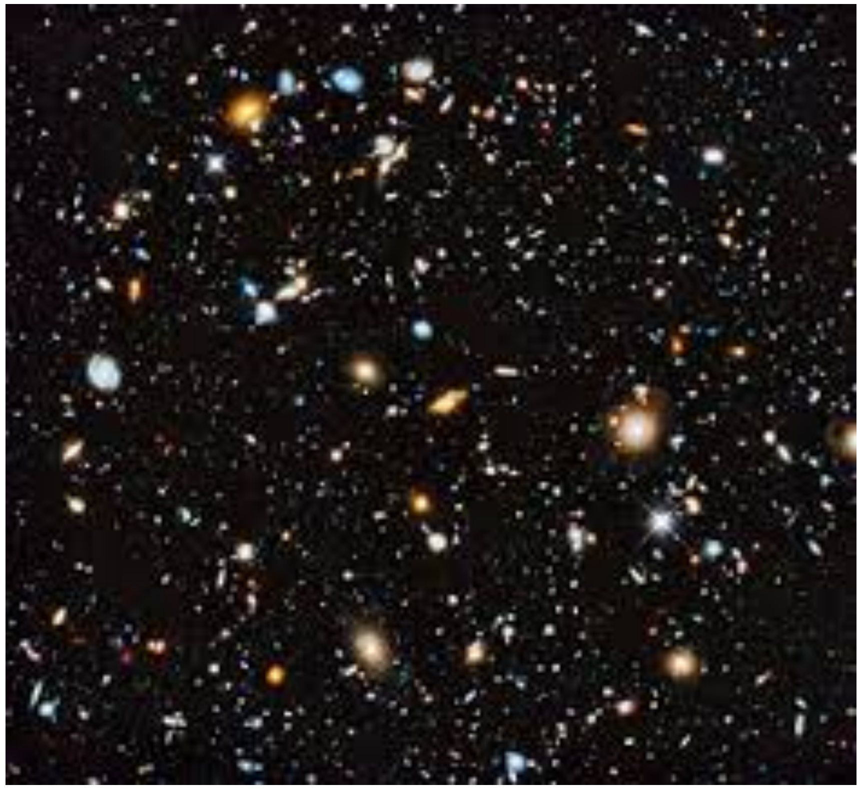
No all scales at once, but on large scales fluctuations are small

$$\sigma_R^2 \sim \frac{1}{2\pi^2}\int_0^{1/R} k^2 dk\, P_{\rm lin}(k) \sim 1$$ for $R \sim$ few Mpc at low redshifts

The horizon scale $H_0^{-1} \sim 10^4$ Mpc

Theory of matter density fluctuations

Effective field theory of large-scale structure, valid when $\sigma_R^2 \lesssim 1$



Large distance dof: $\delta_g \equiv (n_g(x) - \bar{n}_g)/\bar{n}_g$

EoM are fluid-like, including gravity

Symmetries, Equivalence Principle

Expansion parameters: δ_g, $\partial/k_{\rm NL}$

All “UV” dependence is in a handful of free parameters

On scales larger than $1/k_{\rm NL}$ this is the universal description of galaxy clustering

Theory of matter density fluctuations

An example: dark matter only

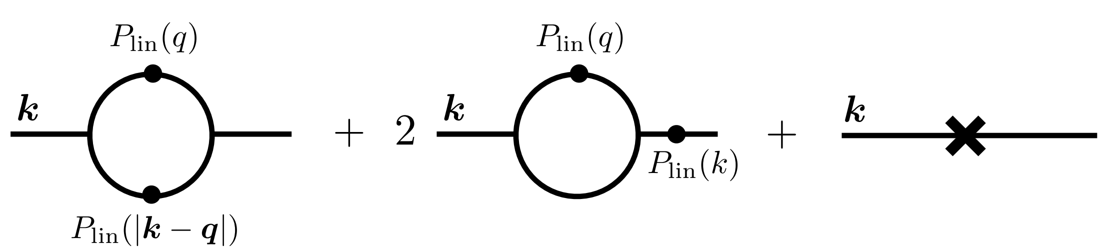
$$\partial_\tau \delta + \nabla[(1+\delta)\boldsymbol{v}] = 0$$

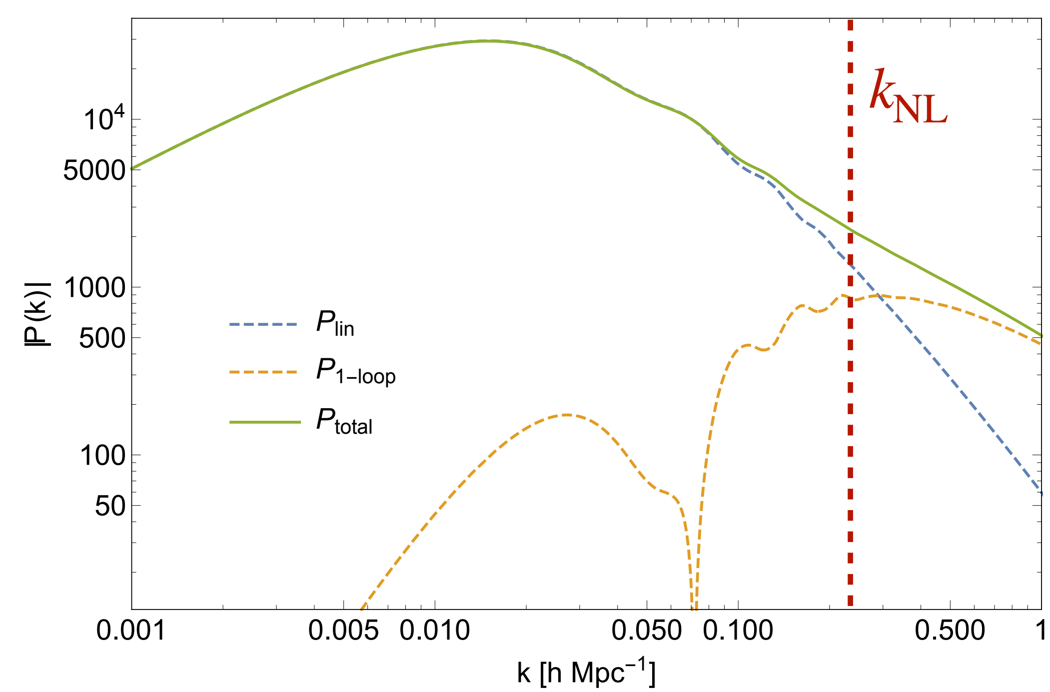
$$\partial_\tau \boldsymbol{v} + \mathcal{H}\boldsymbol{v} + \nabla\Phi + \boldsymbol{v}\cdot\nabla\boldsymbol{v} = \boxed{-c_s^2\nabla\delta + \cdots}$$

$$\nabla^2\Phi = \frac{3}{2}\mathcal{H}^2\Omega_m\delta$$

(higher order in δ_g, $\partial/k_{\rm NL}$)

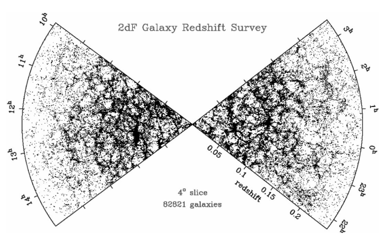
$$\langle\delta_{\boldsymbol{k}}\delta_{-\boldsymbol{k}}\rangle = \langle\delta^{(1)}_{\boldsymbol{k}}\delta^{(1)}_{-\boldsymbol{k}}\rangle + \langle\delta^{(2)}_{\boldsymbol{k}}\delta^{(2)}_{-\boldsymbol{k}}\rangle + \langle\delta^{(1)}_{\boldsymbol{k}}\delta^{(3)}_{-\boldsymbol{k}}\rangle + \langle\delta^{(3)}_{\boldsymbol{k}}\delta^{(1)}_{-\boldsymbol{k}}\rangle + \cdots$$

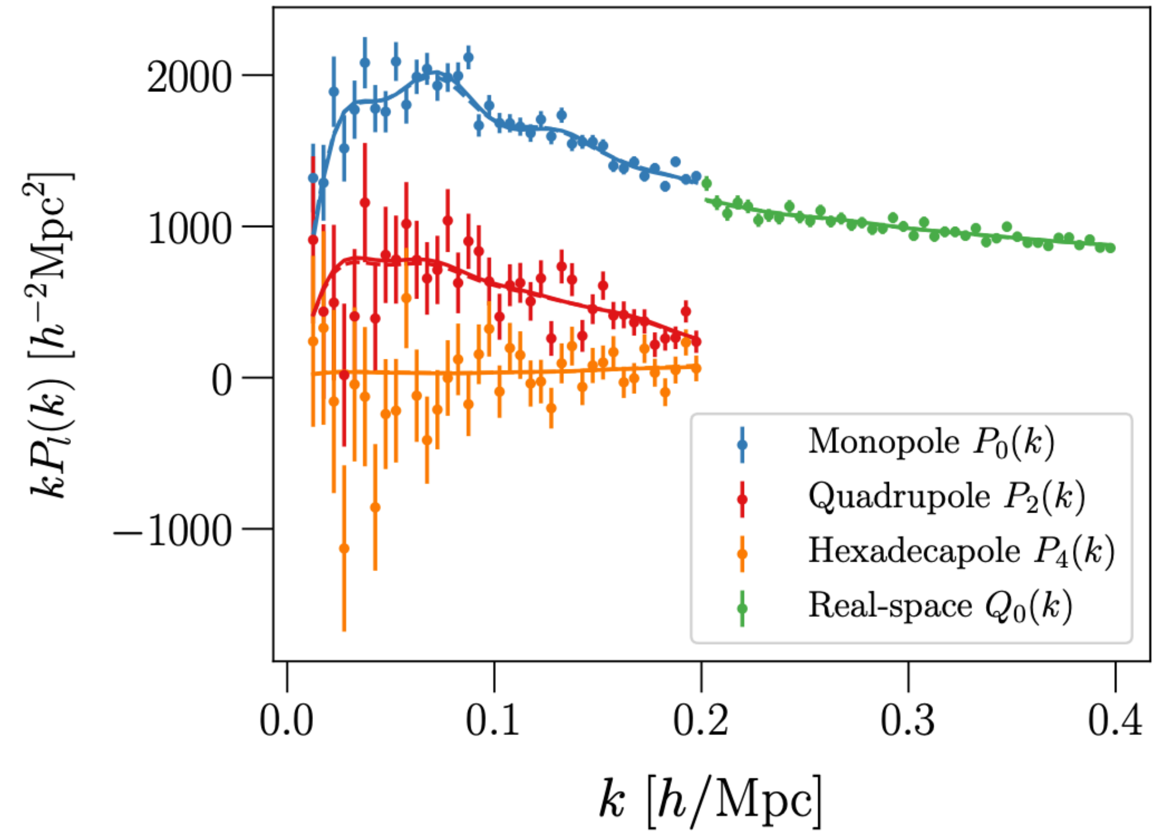
$P_{1-\mathrm{loop}}(k) =$ 



Applications to current data

Galaxy map



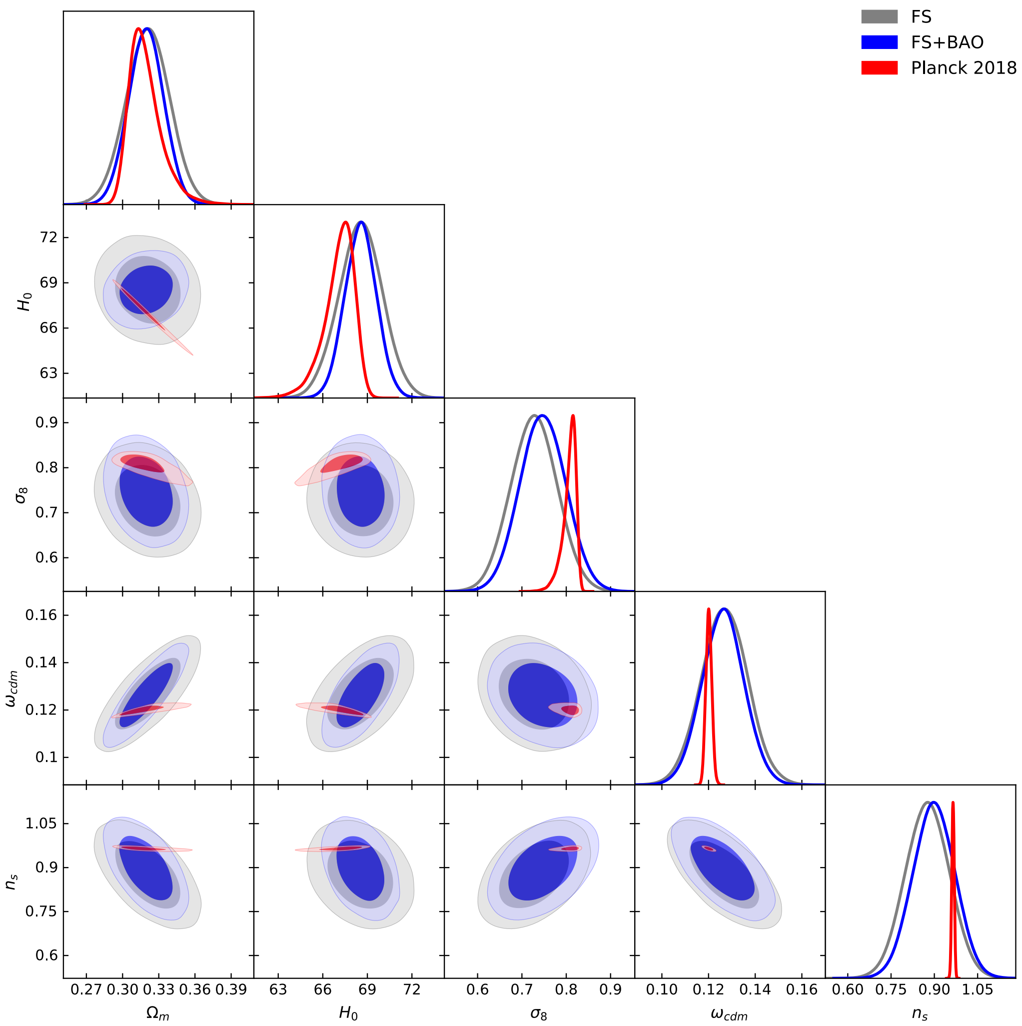


Full-shape analysis

Similar to CMB, directly measures “shape” parameters

all cosmological parameters
no CMB input needed

Applications to current data



Using BBN prior on ω_b

$$H_0 = 68.6 \pm 1.1 \text{ km/s/Mpc}$$

$$H_0 = 67.8 \pm 0.7 \text{ km/s/Mpc}$$ (fixing ns)

Large number of extensions of LCDM explored for the first using FS analysis

(neutrino masses, spatial curvature, extra relativistic dof, ultra-light axion-like particles, light but massive relics, early dark energy, primordial non-Gaussianities…)

Outlook for the near future

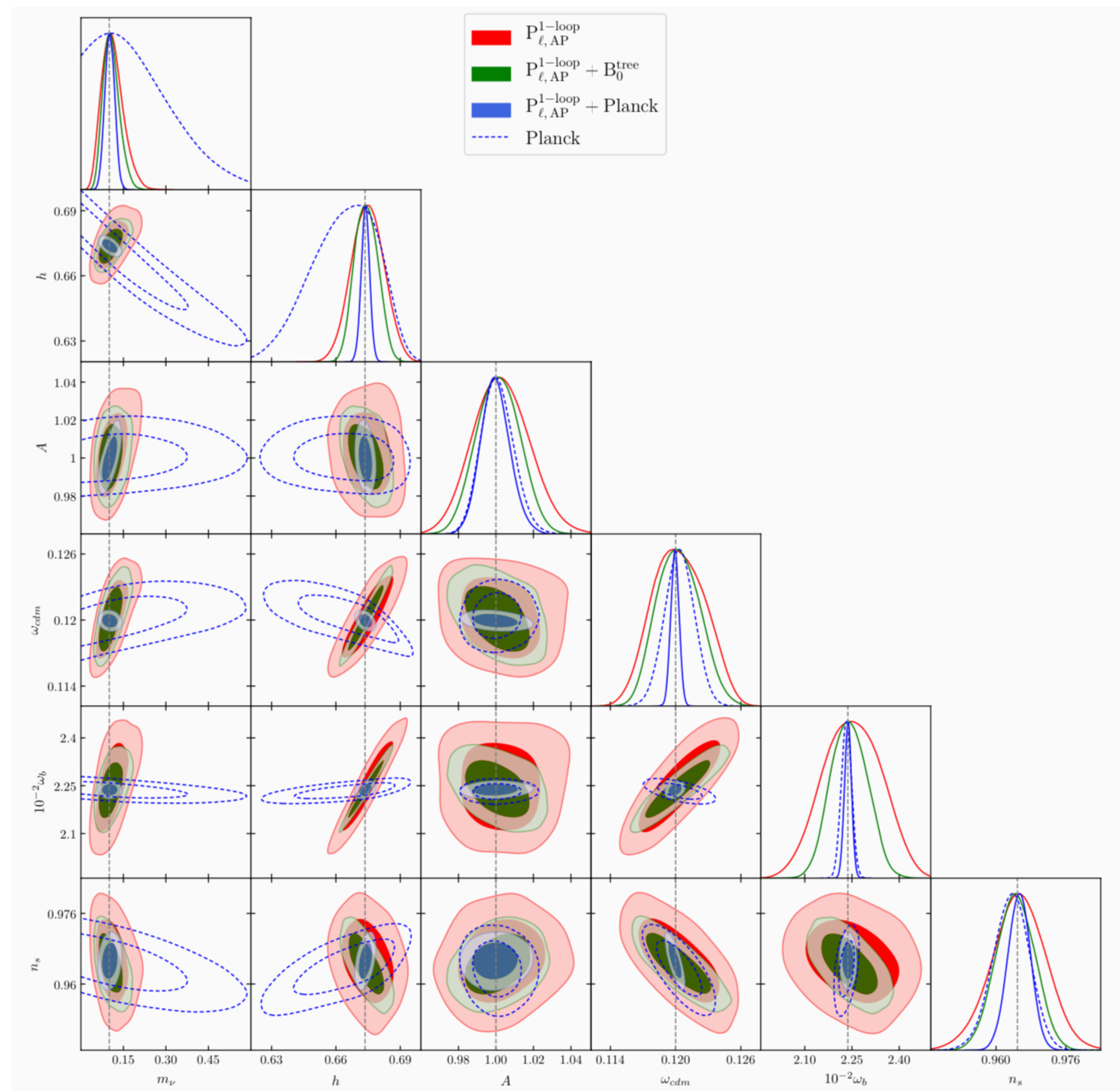
Theory: Burst of activity involving more precise calculations, new observables, application of EFTofLSS to new models, improving codes etc.

Data: New analysis techniques, improved estimators, simplified pipelines etc.

New observations by DESI and Euclid will increase the size of the observed volume by a factor of ~10 in the next couple of years!

LCDM: 2-5x improvement

New physics: ~10x improvement



Conclusions

New LSS observations this decade are a large opportunity

EFTofLSS proved to be very useful and applicable framework

There are many things to explore at the intersection of cosmology and particle physics

New physics from galaxy clustering at GGI

(a 6 week workshop in 2025)