AstroParticleWorkshop: Cosmo Week

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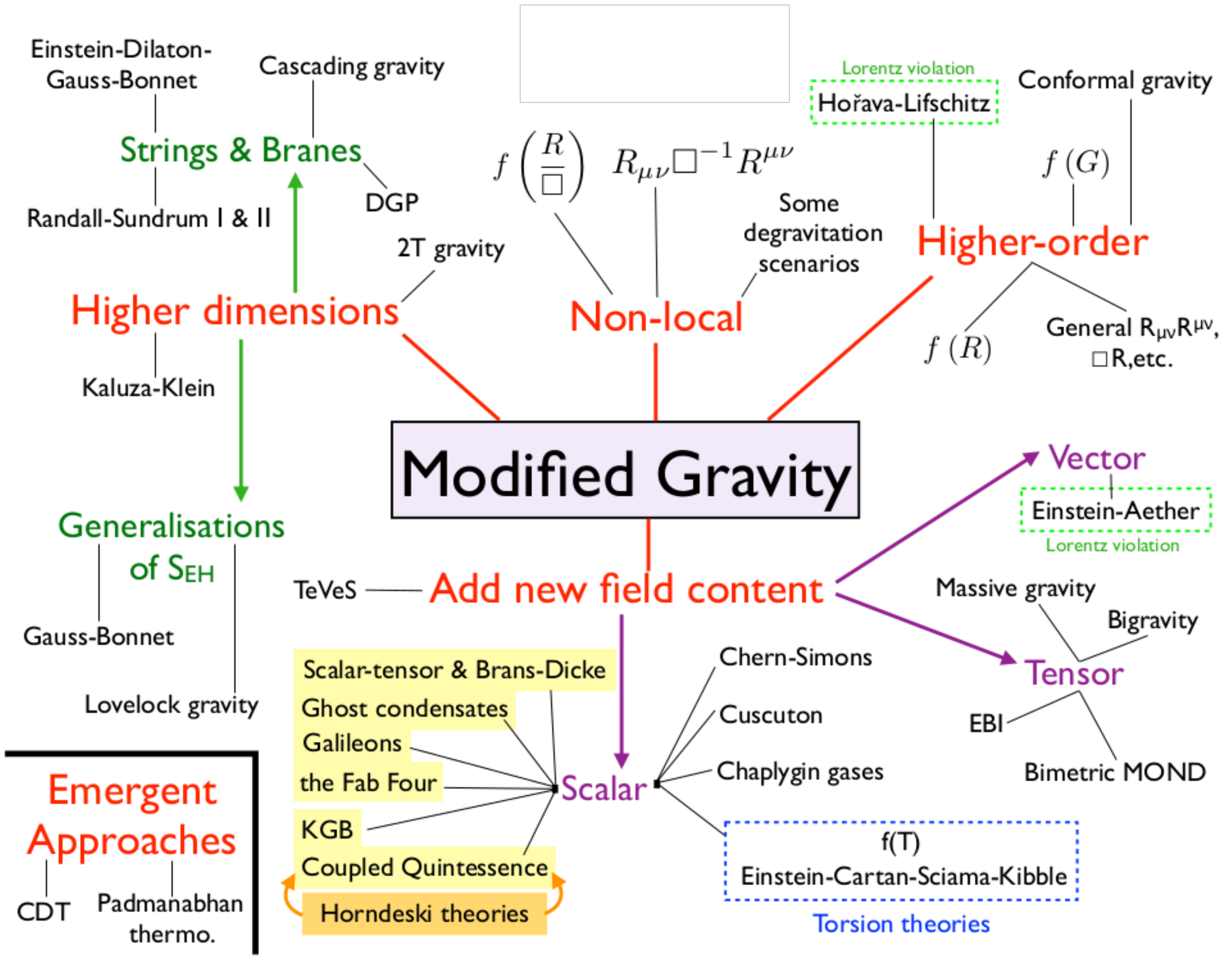
Constraining Beyond ΛCDM Models With 21cm Intensity Mapping Forecasted Observations Combined With Latest CMB Data

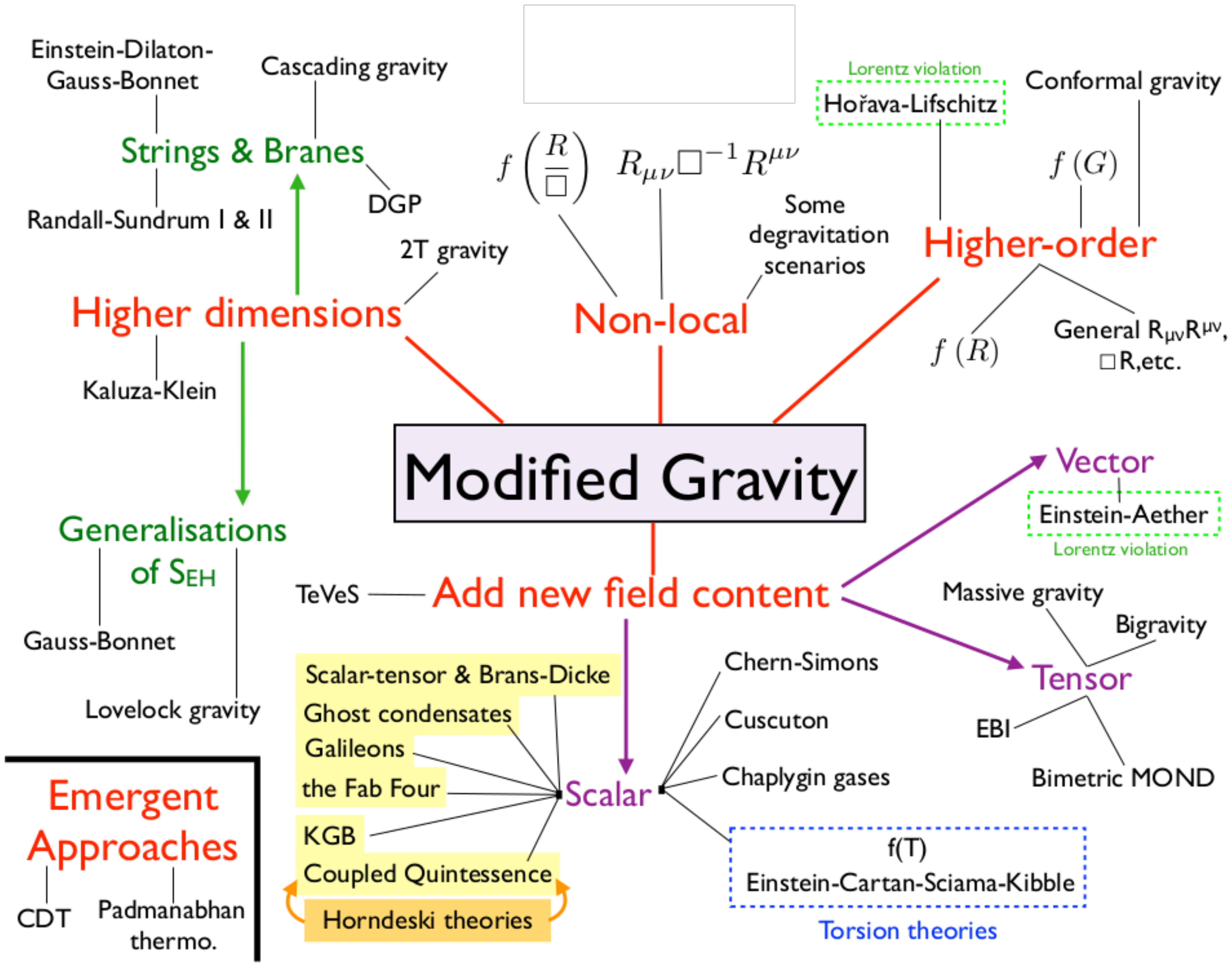
State-of-the-art



Bull et al. (2016)

- Plethora of models beyond ΛCDM
- All the results are broadly compatible with ΛCDM
- Future observations (**Euclid**, **SKAO**, ...) → improve constraints
- New observables →21cm signal observations

State-of-the-art



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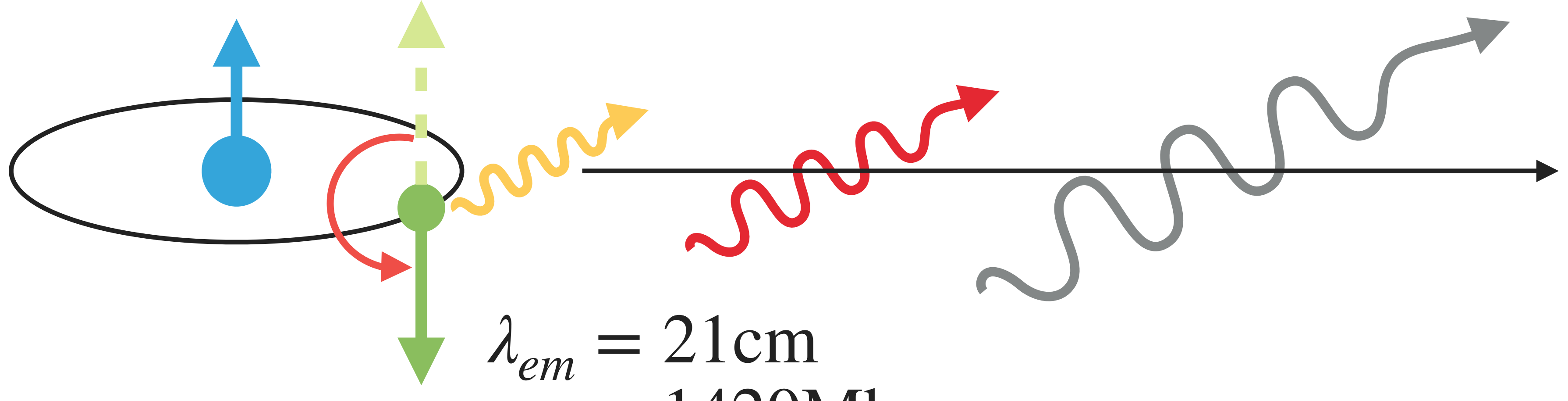
Forecast the constraining power of 21cm observations on EFT for Dark Energy

(arXiv:2109.03256)

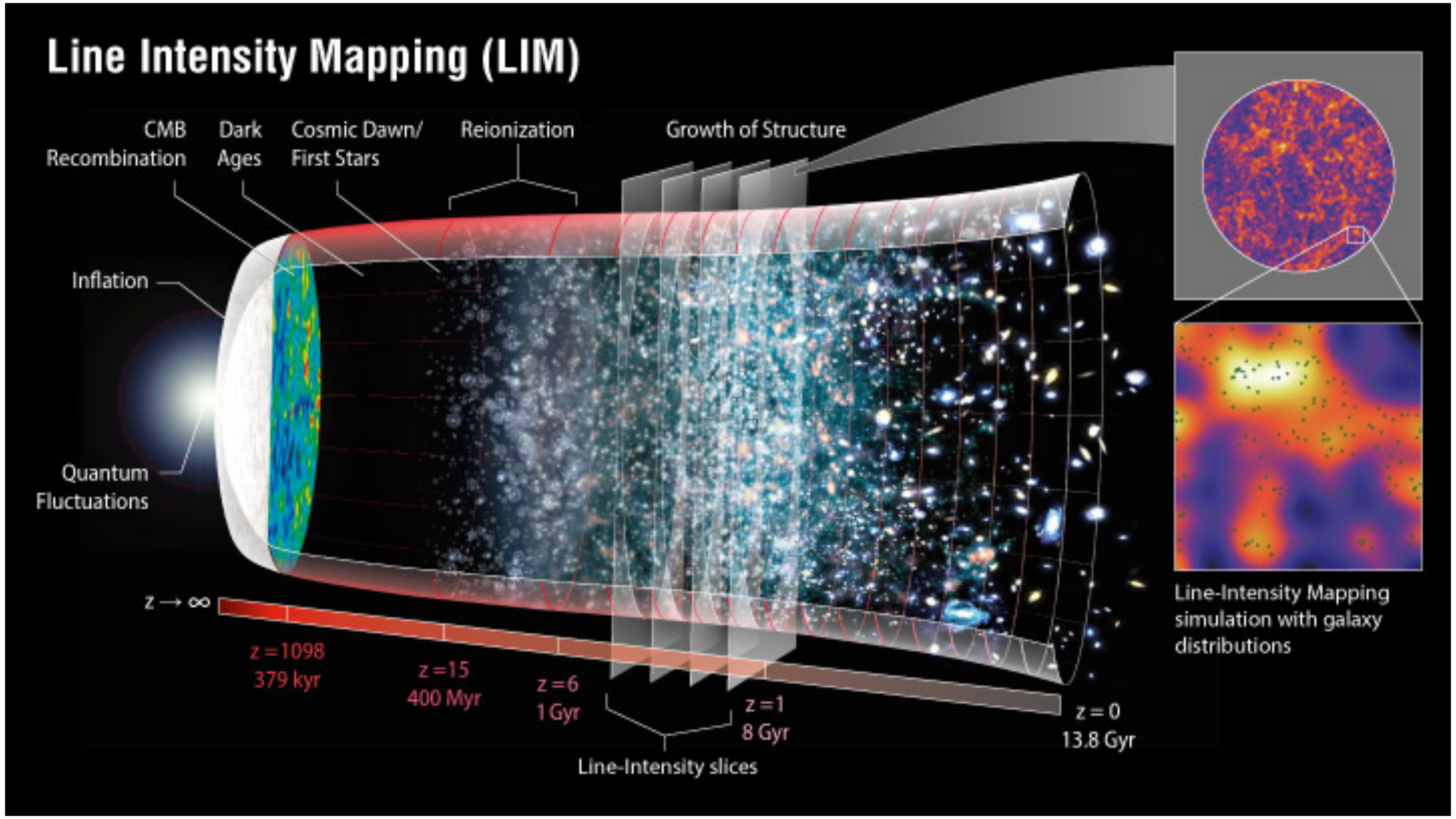
21cm Intensity Mapping



$\lambda_{em} = 21\text{cm}$
$\nu_{em} = 1420\text{Mhz}$

- 21cm signal → spin-flip transition
- Observable is $P_{21}(k, z)$
- Look at the total intensity of the emission line in a large 3D pixel
- Wide redshift range $1 + z = \frac{\nu_{em}}{\nu_{obs}}$

Credit: *NASA / LAMBDA Archive Team*



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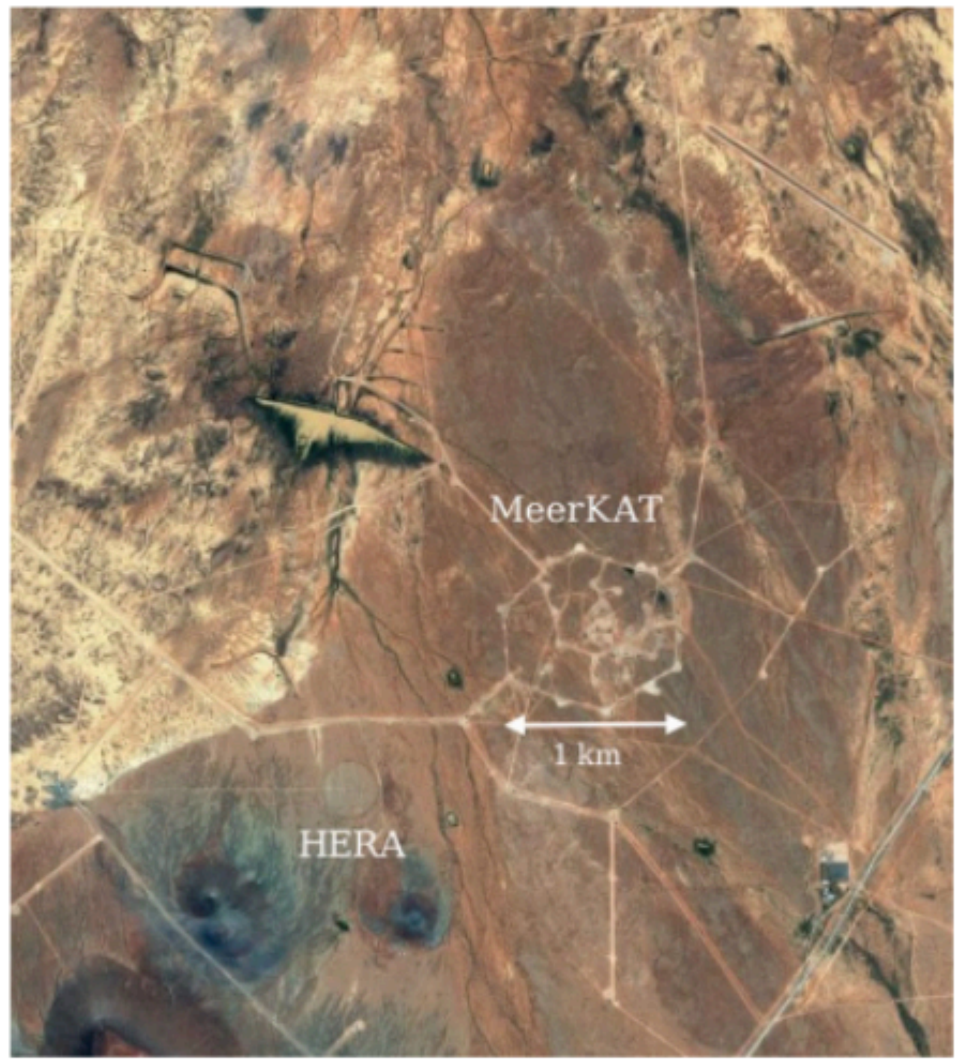
TOMOGRAPHY

Could help significantly in constraining DE

Intensity Mapping With the MeerKAT Telescope



Credit: *www.sarao.ac.za*

MeerKLASS (*Santos et al., 2017*)

- $4000\ \mathrm{deg}^2$, 4000 h
- *Radio Continuum HI galaxies*

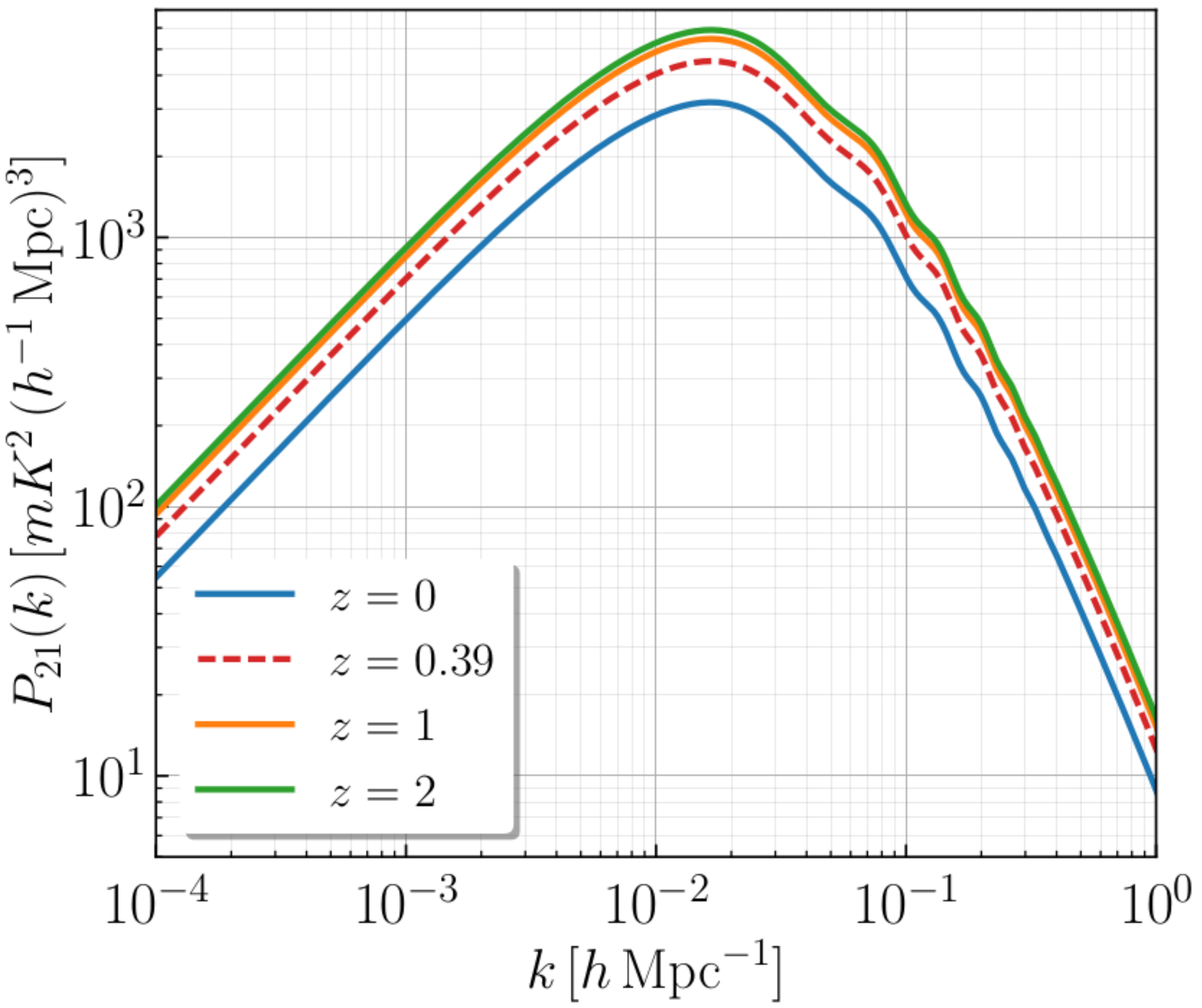
Science Verification data

Antennas	All 64 MeerKAT dishes
Observation mode	Single-dish
Frequency range	0.856-1.712 GHz

Wang et al. (2021)

- The Square Kilometre Array Observatory (SKAO) precursor (South Africa)
- Already taking data
- we build a very realistic data set of future MeerKAT observations at $z = 0.39$
- We explore also effects of tomography

Theoretical 21cm Linear Power Spectrum



We model it as[1]

$$P_{21}(z,k,\mu) = \bar{T}_b^2(z)\left[\, b_{HI}(z) + f(z)\,\mu^2 \,\right]^2 P_m(z,k)$$

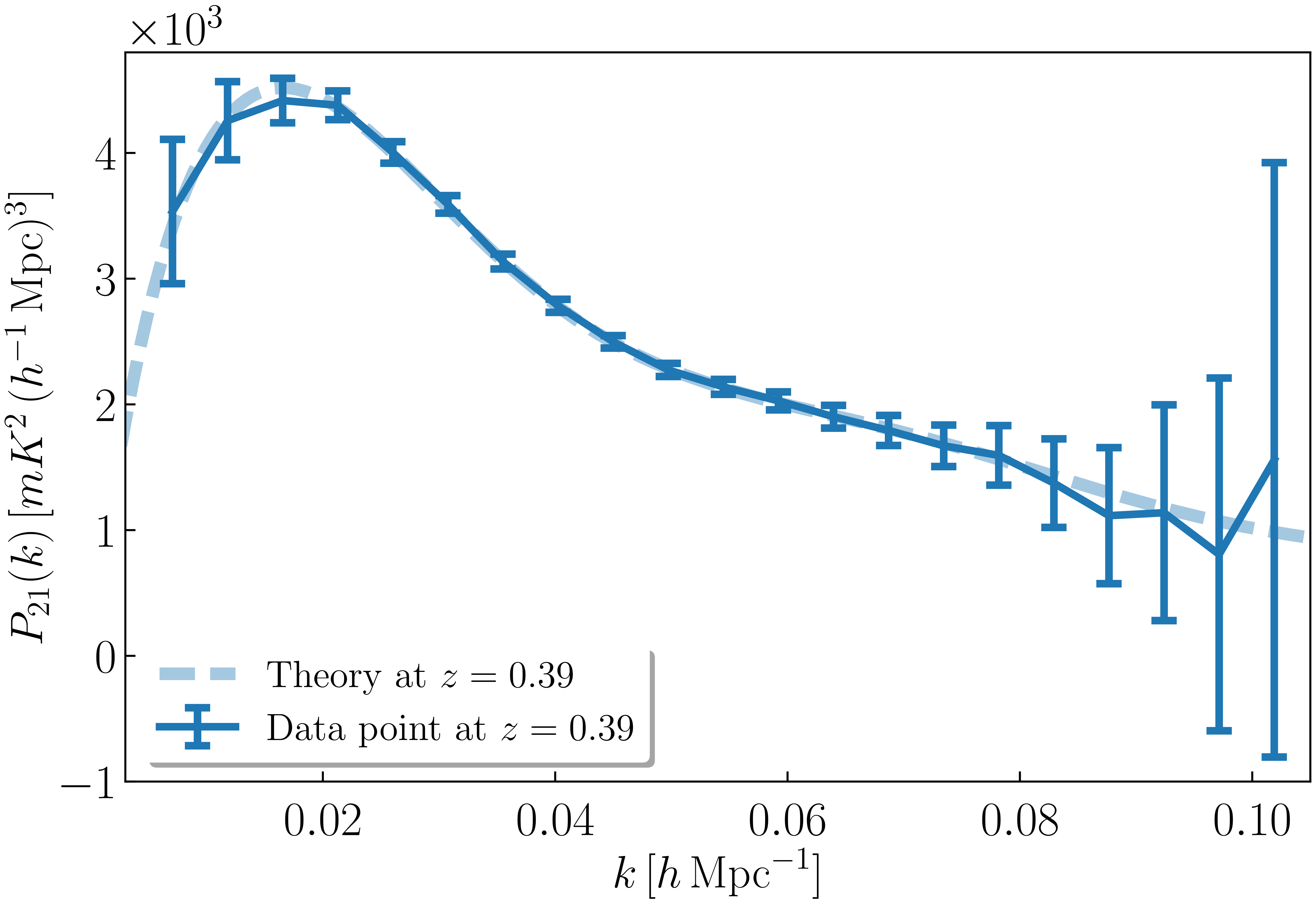
where

- $\bar{T}_b^2(z)$ is the mean brightness temperature
- $b_{HI}(z)$ is the HI bias
- $f(z)$ is the growth rate
- $\mu = \hat{k} \cdot \hat{z}$
- $P_m(z,k)$ is the matter power spectrum

✓ in good agreement with hydrodynamical simulations results (*Villaescusa-Navarro et al. 2018*)

[1] *Kaiser (1987), Bacon et al. (2019)*

The Forecasted Data Set



ERRORS

- MeerKAT like observations of P_{21}
- One redshift bin (realistic)
- 5 redshift bin (ideal)[1]

CENTRAL POINTS

- Theory predictions randomly displaced

[1] See our new paper arXiv:2209.07595!

Effective Field Theory - the Idea Behind

Introduced to describe INFLATION → later applied to late time COSMIC ACCELERATION

Creminelli et al. (2006), Cheung et al. (2008)

Creminelli et al. (2009), Gubitosi et al. (2013), Bloomfield et al. (2013)

Construct the most general

ACTION

Effective

easily interfaced
with observations

Unifying

easily interfaced
with observations

Studied Models - Generalised Brans Dicke (GBD)

Parametrise the evolution of the background EFT functions

$$S = \int d^4x\sqrt{-g}\left\{\frac{m_0^2}{2}\left[1+\Omega^{\text{EFT}}(\tau)\right]R+\Lambda(\tau)-c(\tau)a^2\delta g^{00}\right\}+S_m$$

*pure*EFT models

- Linear parametrisation

$$\Omega^{\text{EFT}}(a) = \Omega_0^{\text{EFT}}a$$

- Exponential parametrisation

$$\Omega^{\text{EFT}}(a) = \exp\left(\Omega_0^{\text{EFT}}a^{\beta}\right) - 1$$

on a ΛCDM background evolution.

Numerical tools

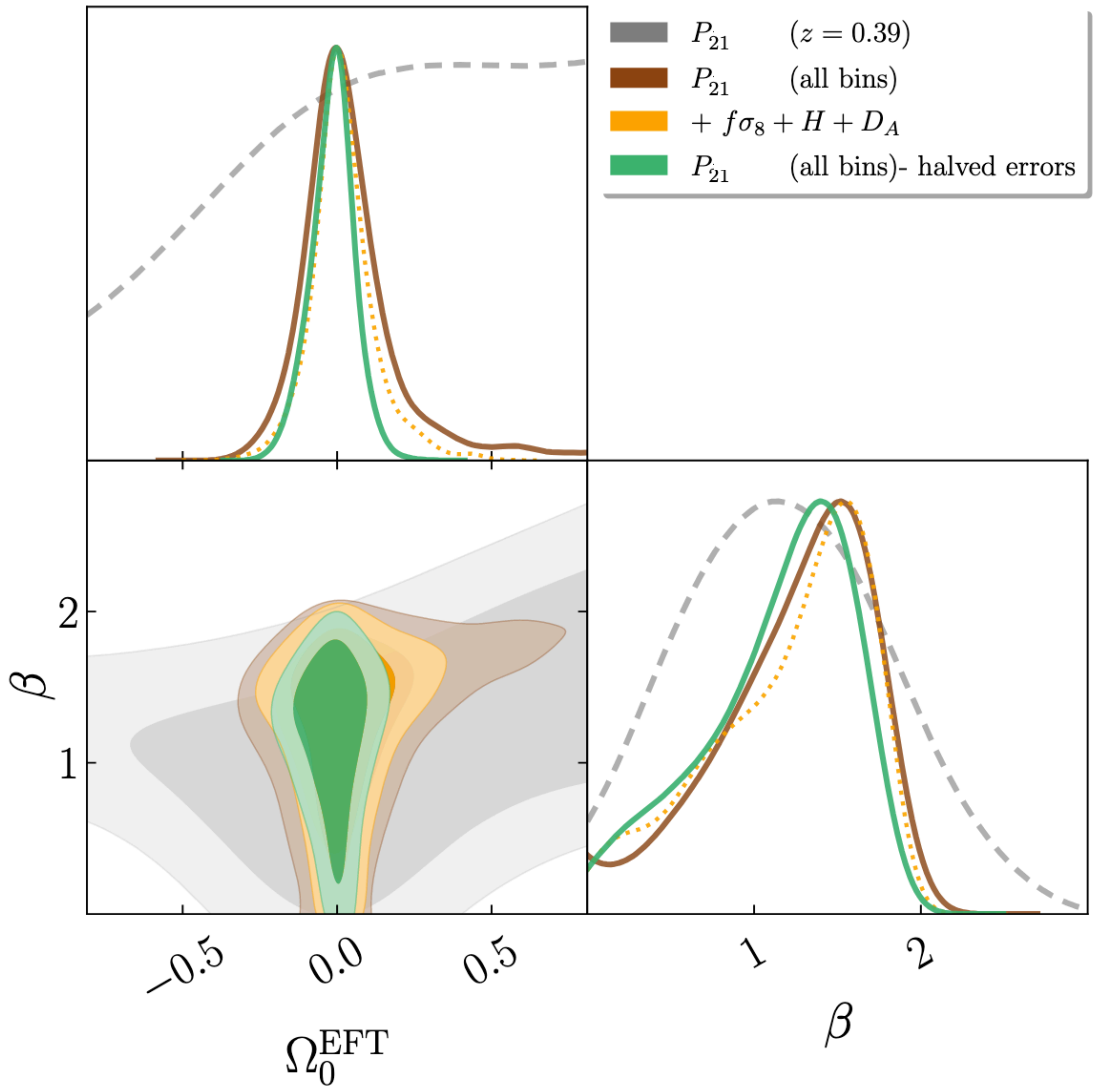
- Einstein/Boltzmann solver **EFTCAMB**
- Monte Carlo Markov Chain sampler **EFTCosmoMC**

→ EXTENDED to compute P_{21} likelihood!

see: eftcamb.org

Do We Expect To Be Sensitive?

Exponential *pure*EFT - P_{21} alone

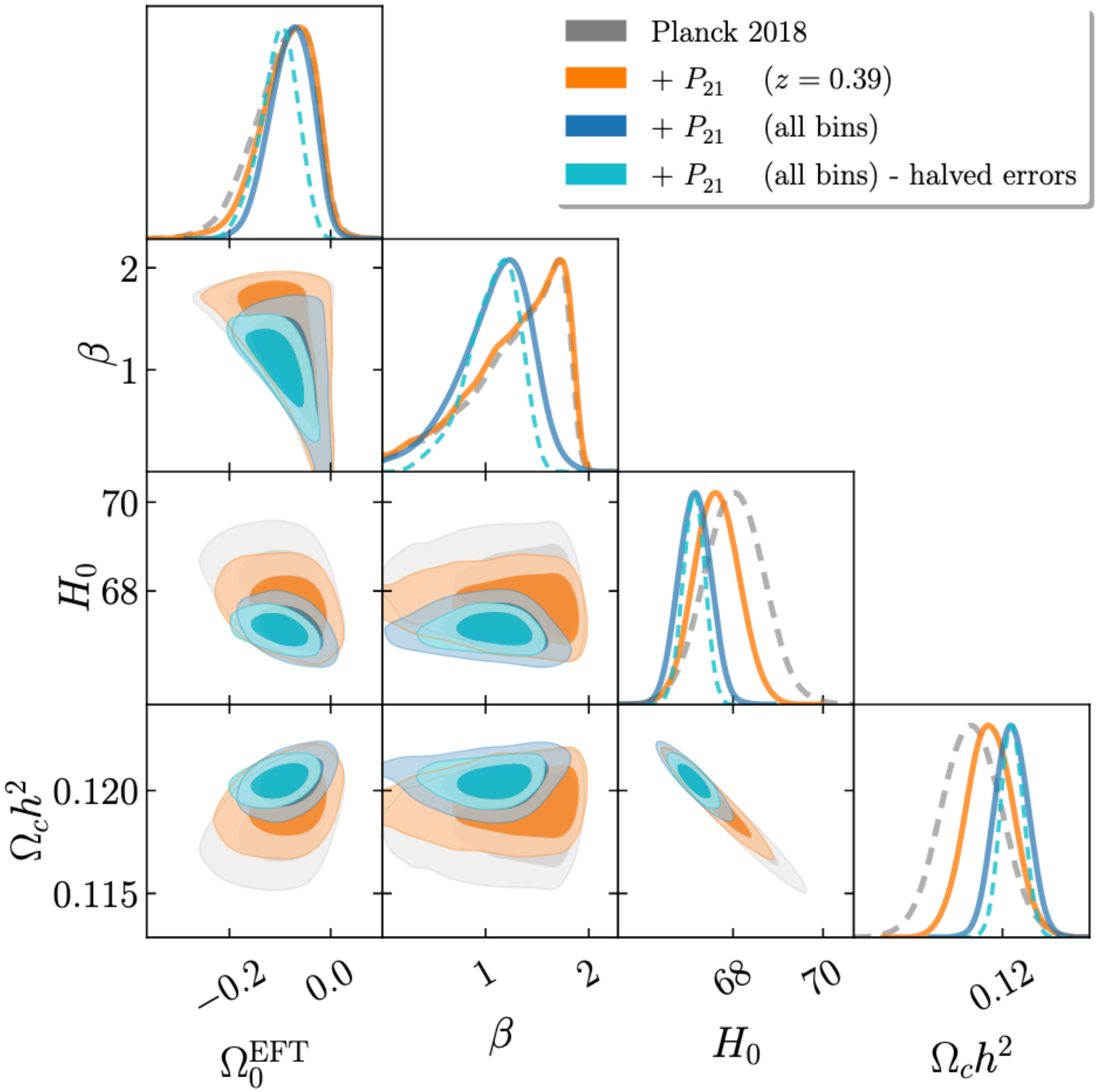


Analysis set up

- full MCMC analysis
- varying $\{\Omega_b h^2, \Omega_c h^2, \theta_{\mathrm{MC}}, \tau, n_s, A_s\}$ + EFT
- test the constraining power of P_{21} alone and combined with CMB data

- Constraints on the cosmological parameters remain unaffected
- $P_{21}(z = 0.39)$ alone has weak constraining power (realistic)
- Tomography significantly improves the constraining power (ideal)

Exponential *pure*EFT - P_{21} + CMB



Par.	Planck 2018 + P_{21} $(z = 0.39)$	Planck 2018 + P_{21} (all bins)
$\Omega_c h^2$.	0.1194 ± 0.0011 (-22%)	0.12042 ± 0.00080 (-43%)
$\Omega_0^{\rm EFT}$	$-0.086^{+0.064}_{-0.038}$ (-10%)	$-0.079^{+0.047}_{-0.036}$ $(\mathbf{-26\%})$
β	$1.28^{+0.58}_{-0.22}$ $(+4\%)$	$1.08^{+0.42}_{-0.25}$ $(\mathbf{-13\%})$
H_0 ...	67.63 ± 0.50 (-24%)	67.15 ± 0.36 (-46%)

- Planck 2018 + $P_{21}(z = 0.39)$ improvement at the 10% level (realistic)
- Planck 2018 + $P_{21}(z = 0.39)$ improvement up to the 26% level and 35% level with halved errors (ideal)
- Tighter constraints on cosmological parameters

Summary

Work done

- We extended the **EFTCAMB/EFTCosmoMC** codes by implementing a **likelihood module fully integrated** with original codes to test **21cm Intensity Mapping forecasted** observations (based on arXiv:2109.03256)
- We constructed a **realistic data set** at $z = 0.39$ and an **ideal tomographic data set** from **MeerKAT** specifications
- We tested the impact of P_{21} likelihood on **DE/MG models** in the EFT framework

Results

- Significant **improvement on** $\Omega_c h^2$, H_0 constraints from P_{21} combined with Early Universe probes, i.e. **Planck 2018** CMB data
- Impact at the level of 10% on models **beyond ΛCDM**, up to 35% with tomography