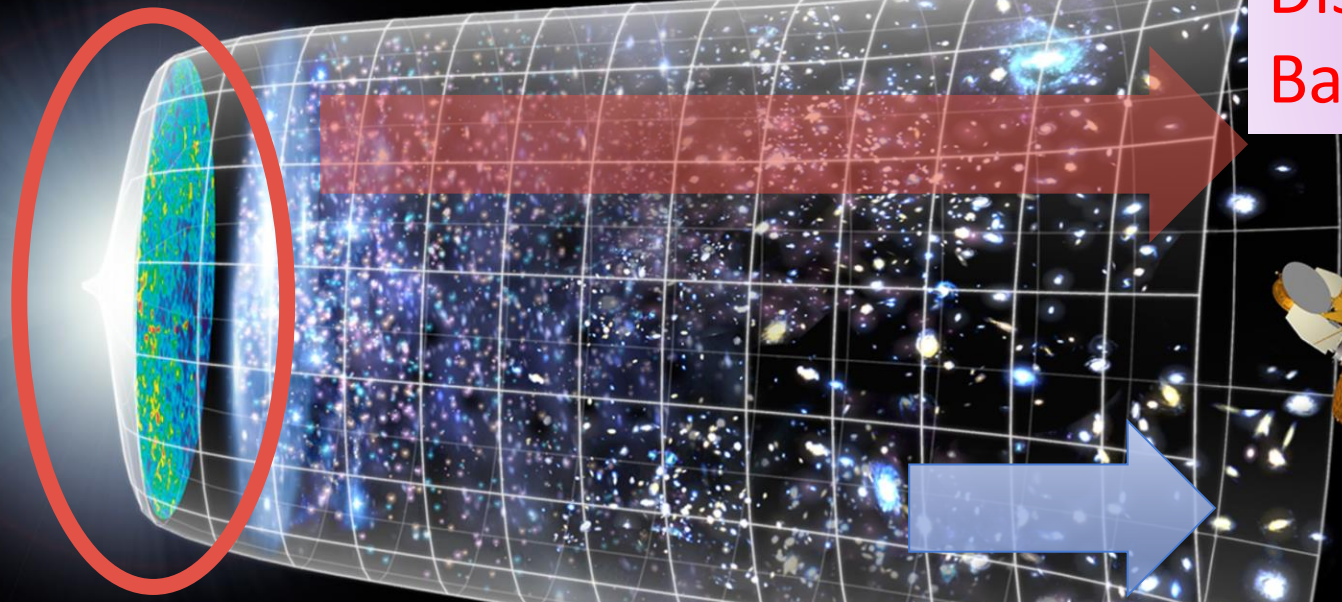
EXTRA COMPONENTS CONSISTENCY IN THE HUBBLE TENSION AND BBN

YO TODA

HOKKAIDO UNIVERSITY

Osamu Seto, Yo Toda *Phys.Rev.D* 103 (2021) 12, 123501

The Λ CDM model goes well
in exaining the evolution of our Universe.



Distant observation
Based on Λ CDM model

Hubble Tension

Local observation

TODAY I WILL

Focus on the Extra radiation and Early dark Energy
to solve the Hubble tension

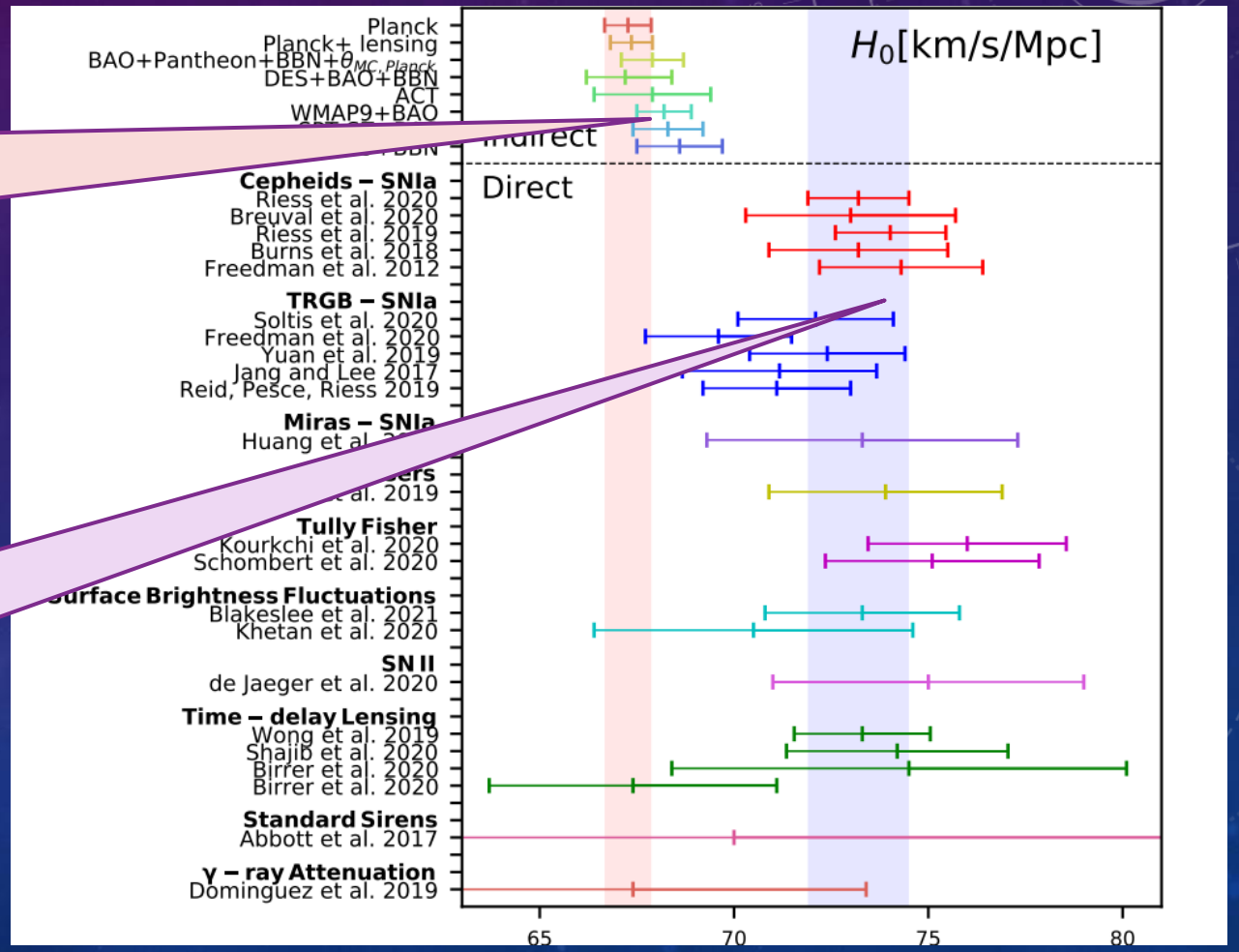
Consider the extra components solutions to the Hubble tension
and the consistency with BBN

Summarize that
extra radiation and Early dark Energy are the promising solutions
But two scenarios are limited from BBN measurements

WHAT IS HUBBLE TENSION?

Distant observations suggest
$H_0 \fallingdotseq 67$ km/s/Mpc

Local observations suggest
$H_0 \fallingdotseq 74$ km/s/Mpc



Di Valentino, arXiv:2011.00246 [astro-ph.CO]

WHAT IS HUBBLE TENSION?

How is this derived?

Distant observations suggest
$H_0 \fallingdotseq 67$ km/s/Mpc

Local observations suggest
$H_0 \fallingdotseq 74$ km/s/Mpc

This tension may indicate
Beyond ΛCDM Physics

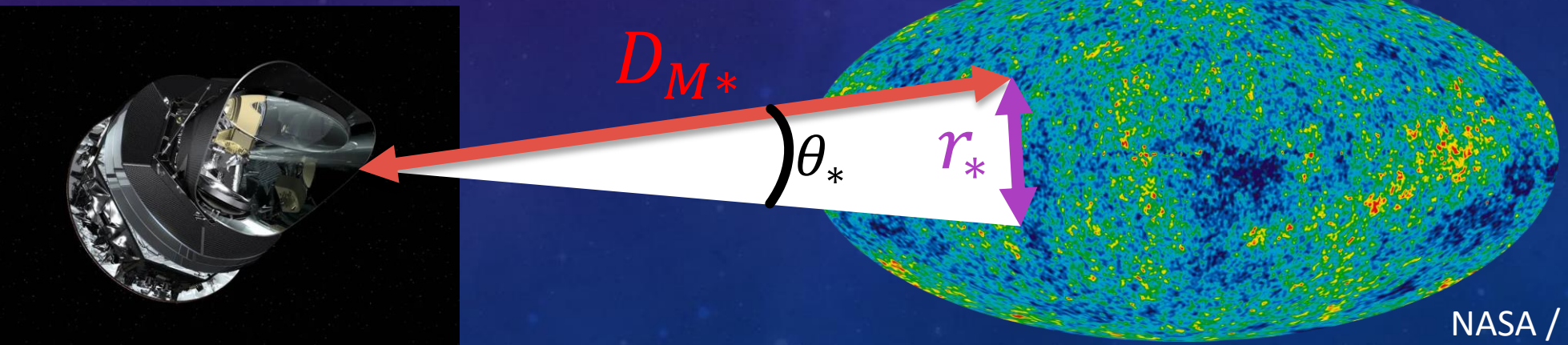
ANGULAR SIZE OF THE SOUND HORIZON

Directly Measured

Angular Size : $\theta_* = \frac{r_*}{D_{M*}} = (1.0411 \pm 0.0003) \times 10^{-2}$

$r_* = \int_0^{t_*} \frac{c_s d\tilde{t}}{a(\tilde{t})}$: comoving sound horizon at the recombination

$D_{M*} = \int_{t_*}^{t_0} \frac{d\tilde{t}}{a(\tilde{t})}$: comoving angular diameter distance



NASA / WMAP Science Team

ANGULAR SIZE OF THE SOUND HORIZON

Directly Measured

Angular Size : $\theta_* = \frac{r_*}{D_{M*}} = (1.0411 \pm 0.0003) \times 10^{-2}$

$$\propto H_0 \frac{1}{\sqrt{\rho \text{ in the early universe}}}$$

$$\because \frac{dt}{a(t)} = \frac{dz}{H_0\sqrt{\rho(z)/\rho_0}}$$

ρ : energy density

Increase ρ in the early universe

$\Rightarrow$ Higher H_0

EXTRA COMPONENTS IN MY PRESENTATION

Increase ρ in the early universe

$\Rightarrow$ Higher H_0

Promising ways to increase ρ in the early universe are to introduce …

Extra radiation

or

Early Dark Energy

EXTRA RADIATION

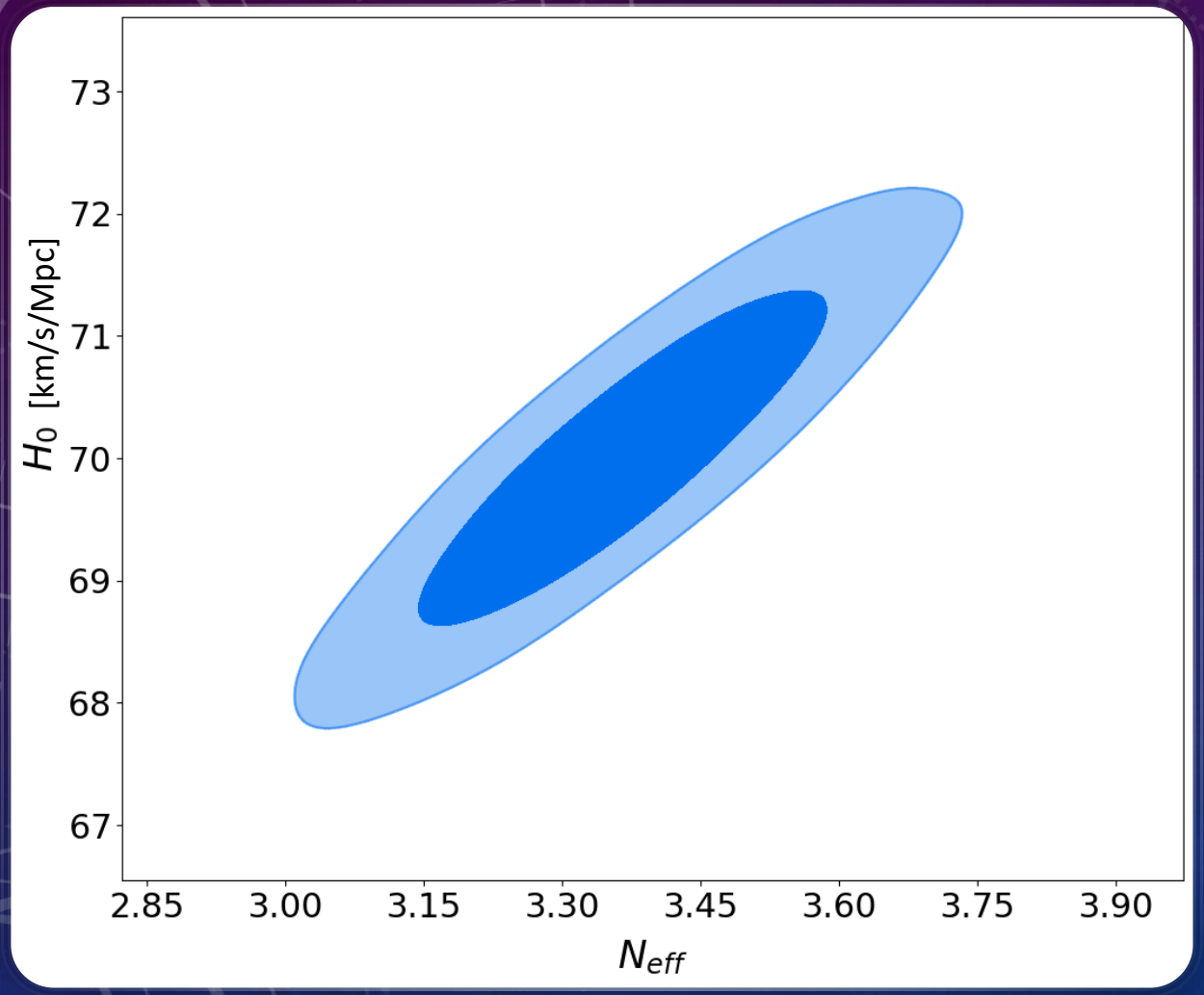
The relativistic degrees of freedom N_{eff}

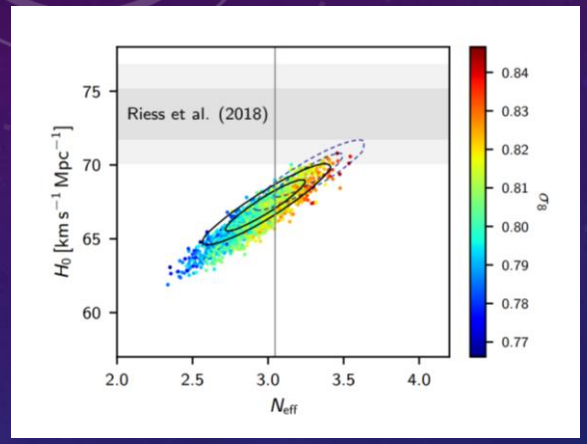
(increased by dark radiation, axion …)

$$\rho_{\mathrm{radiation}} = \left(\underbrace{1}_{\text{photon}} + \underbrace{\frac{7}{8}\left(\frac{4}{11}\right)^{\frac{4}{3}} N_{\mathrm{eff}}}_{\text{Neutrino + α}} \right) * \rho_{\mathrm{photon}}$$

$$N_{\mathrm{eff}} = \underbrace{3}_{\text{neutrino}} + \underbrace{0.046}_{e^+e^- \text{ annihilation}} + (\text{Extra contribution})$$

EXTRA RADIATION RELIVE THE HUBBLE TENSION





Planck 2018 results VI

arxiv:1807.06209

CMB only

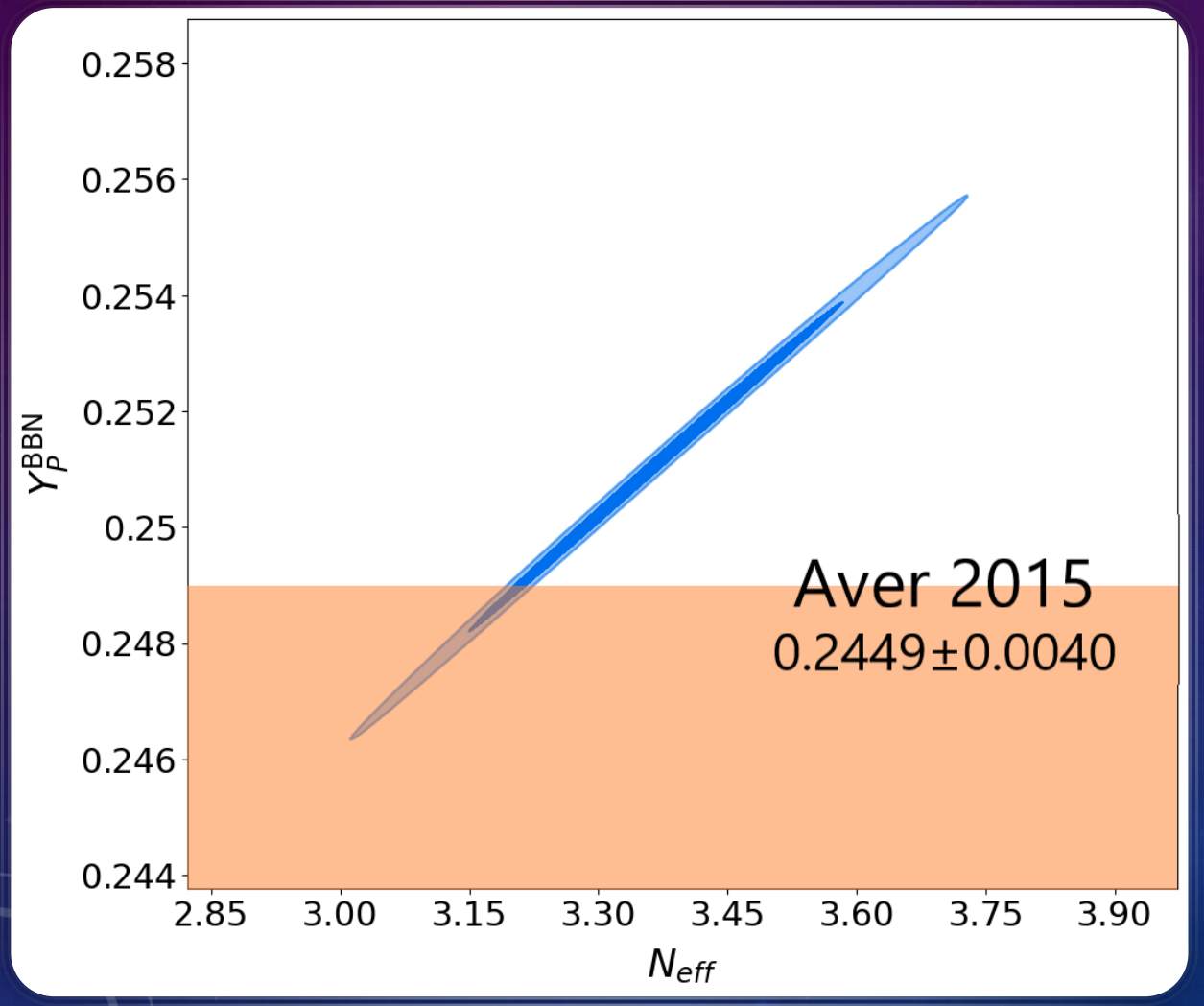
Higher $N_{\rm eff}$

increase H_0

$$N_{\rm eff} = 3.046 + (\text{Extra contribution})$$

Planck + Pantheon + BAO + R19

N_{eff} VS. HELIUM MASS FRACTION Y_P MEASUREMENT



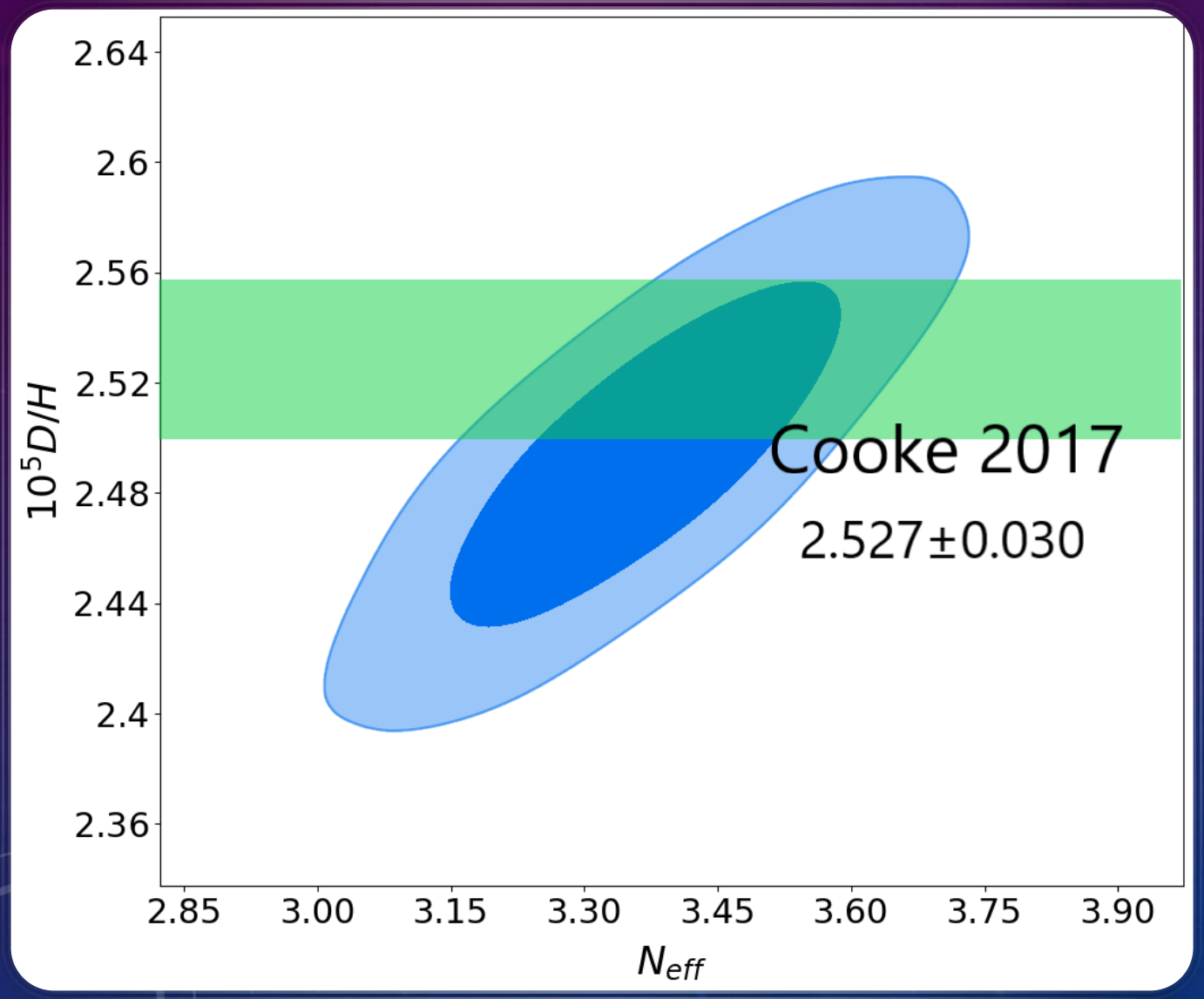
the additional component
increases the expansion rate of the universe,
the decoupling temperature of the weak interaction,
the neutron-to-proton ratio

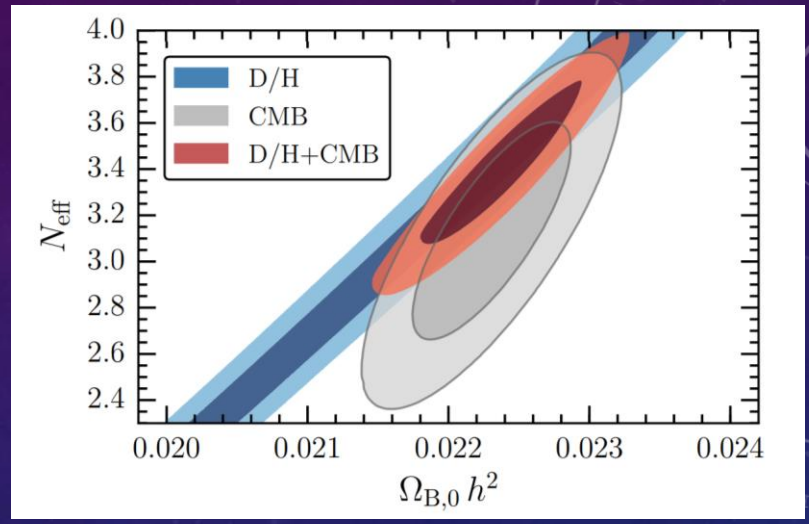
Higher N_{eff}
increase Y_P

$$N_{\mathrm{eff}} = 3.046 + (\text{Extra contribution})$$

Planck + Pantheon + BAO + R19

N_{eff} VS. DEUTERIUM MEASUREMENT



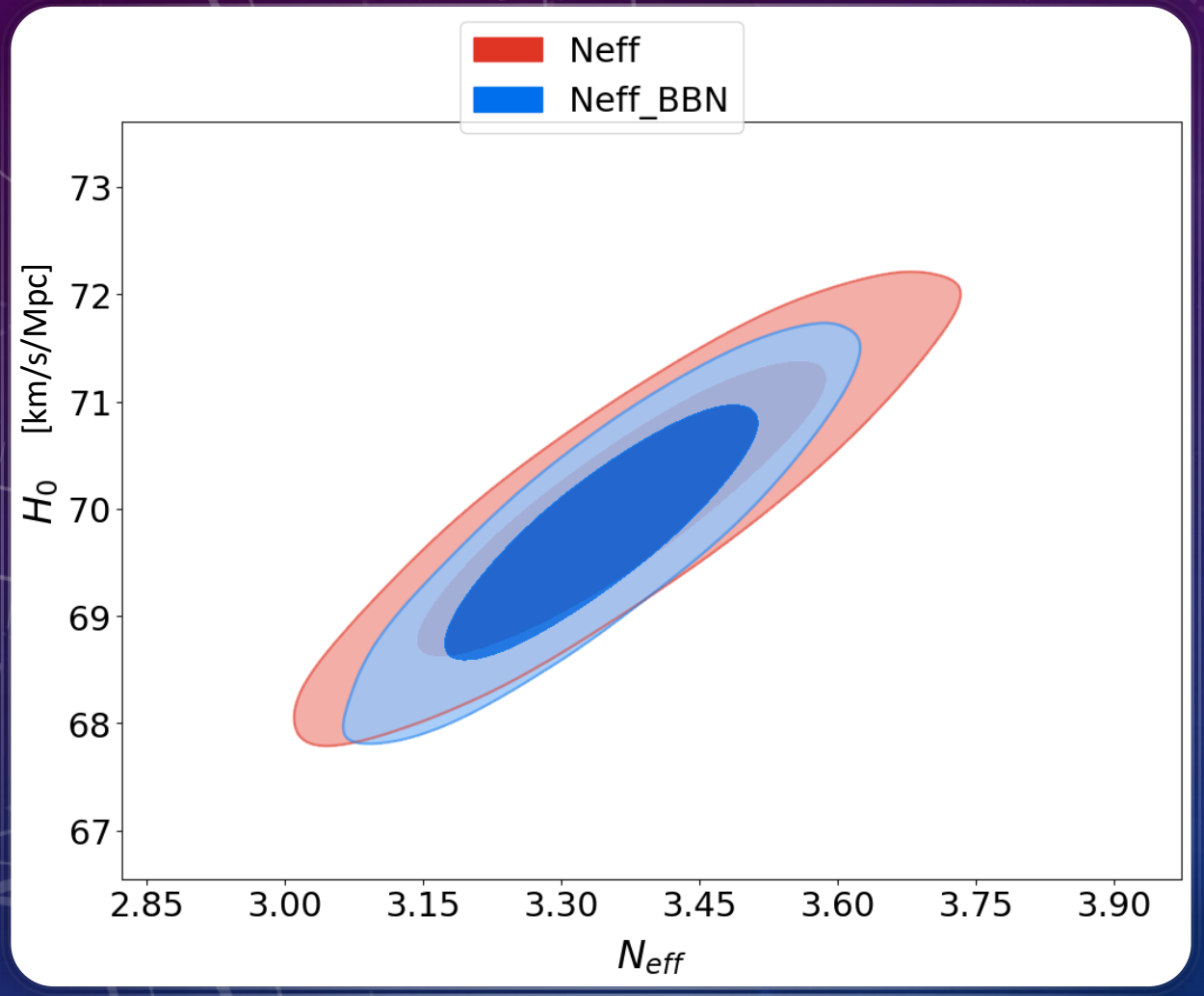


Ryan Cooke *et al.*
arXiv:1710.11129

Higher N_{eff} is favored from D/H measurement ?

Planck + Pantheon + BAO + R19

$N_{\rm eff}$ IS LIMITED FROM THE BBN CONSISTENCY



Higher $N_{\rm eff}$ is disfavored from Y_P measurement

$$N_{\rm eff} = 3.046 + (\text{Extra contribution})$$

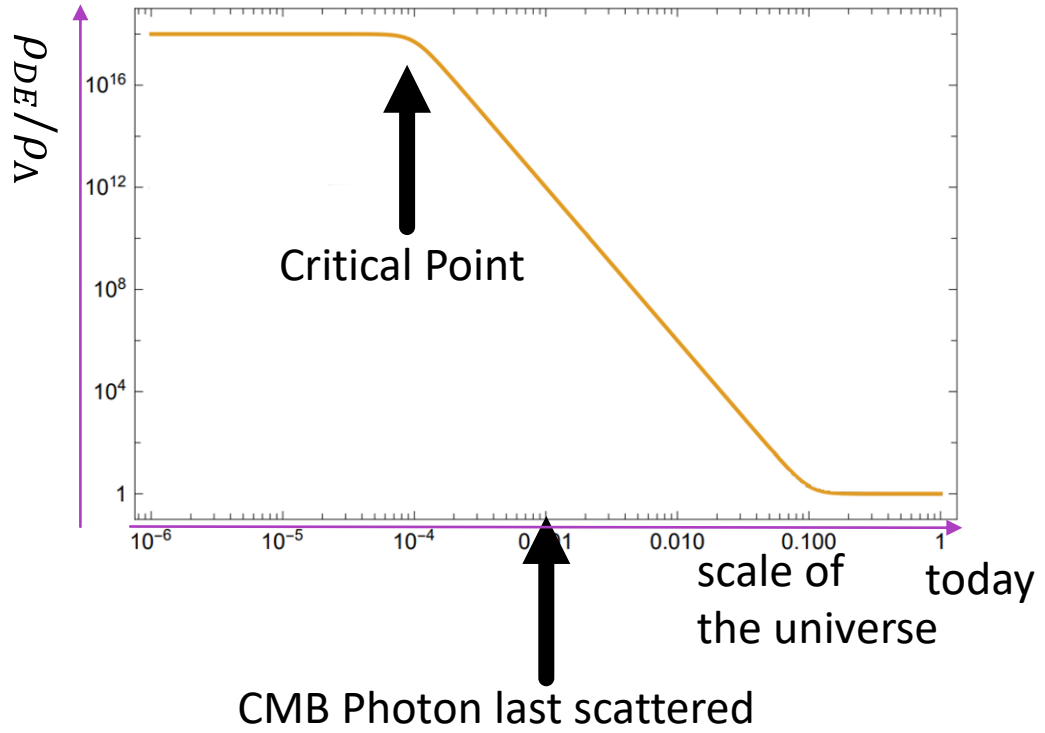
Planck + Pantheon + BAO + R19 + (Y_P & D/H)

EARLY DARK ENERGY

Poulin et al. arXiv:1811.04083
Agrawal et al. arXiv:1904.01016
Niedermann & Sloth arXiv:1910.10739

Energy density of Dark Energy
in the early universe
was much larger than today

After the critical point
energy density decreases faster
than the background



EARLY DARK ENERGY

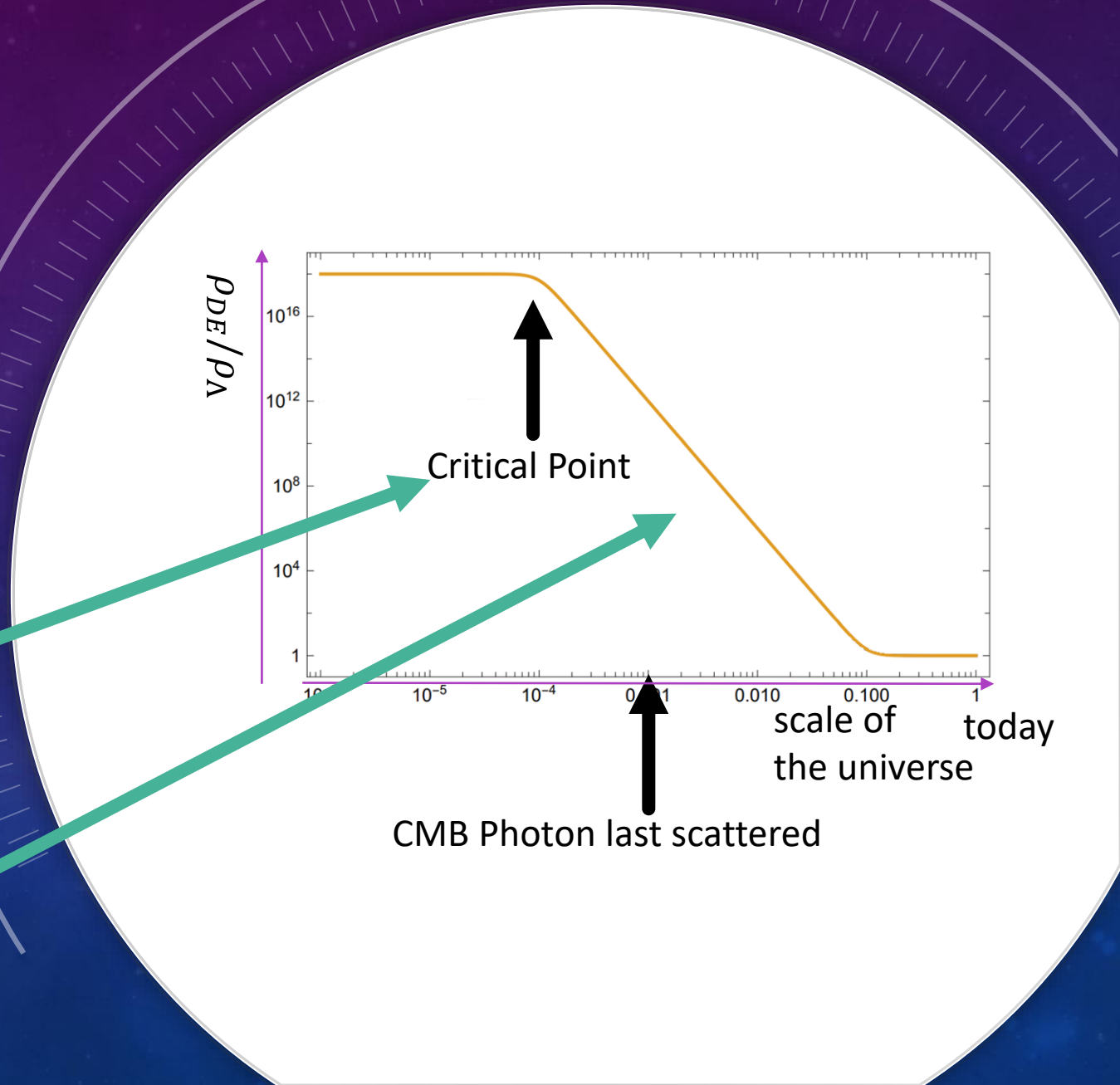
In our analysis

Vary the amount of early dark energy $\frac{\Omega_{\mathrm{EDE}}}{\Omega_{\Lambda}}$

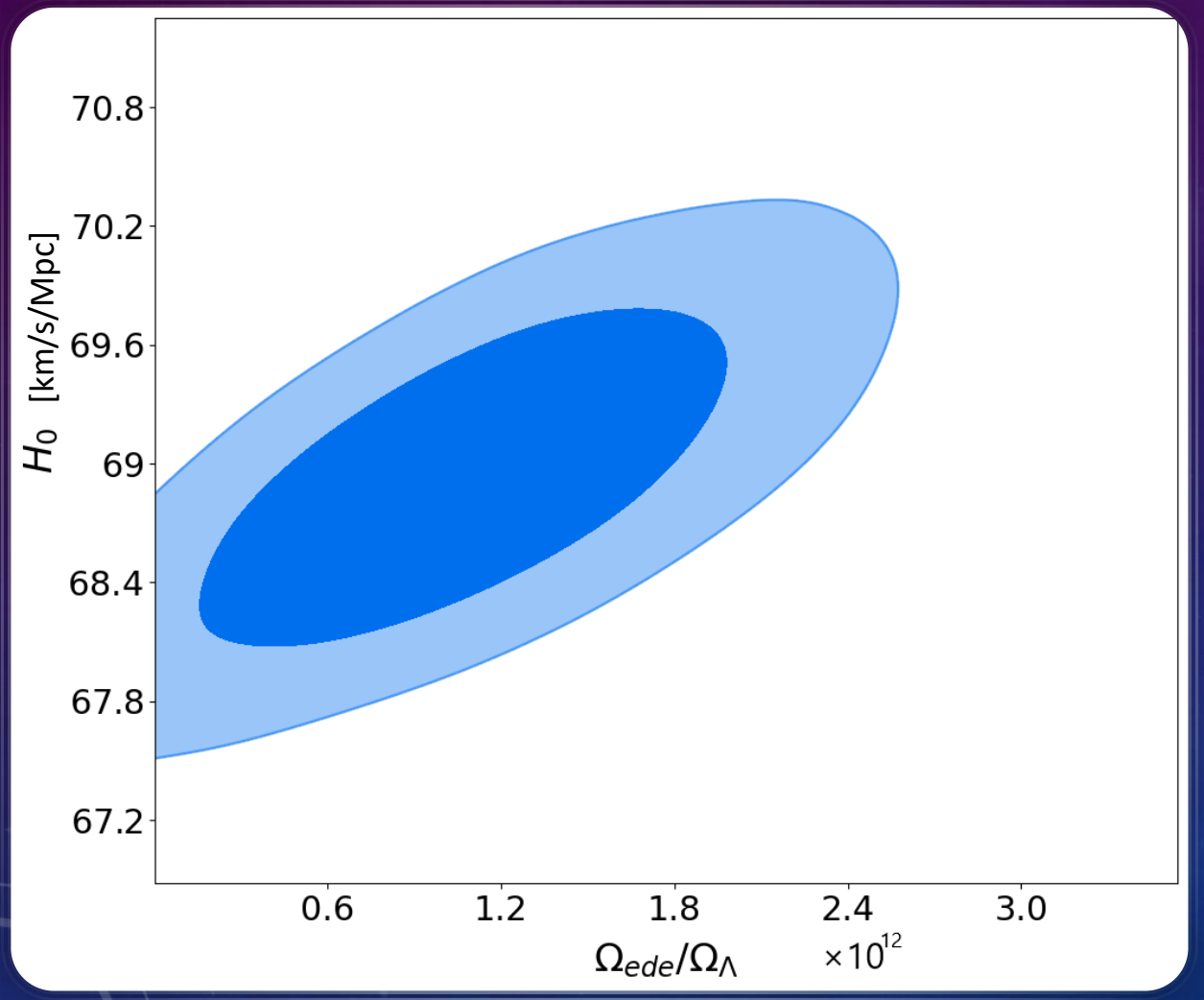
(Referring to previous research)

Fix the critical point $z \fallingdotseq 3000$

After the critical point,
EDE decrease like kination (a^{-6})



EARLY DARK ENERGY RELIVE THE HUBBLE TENSION



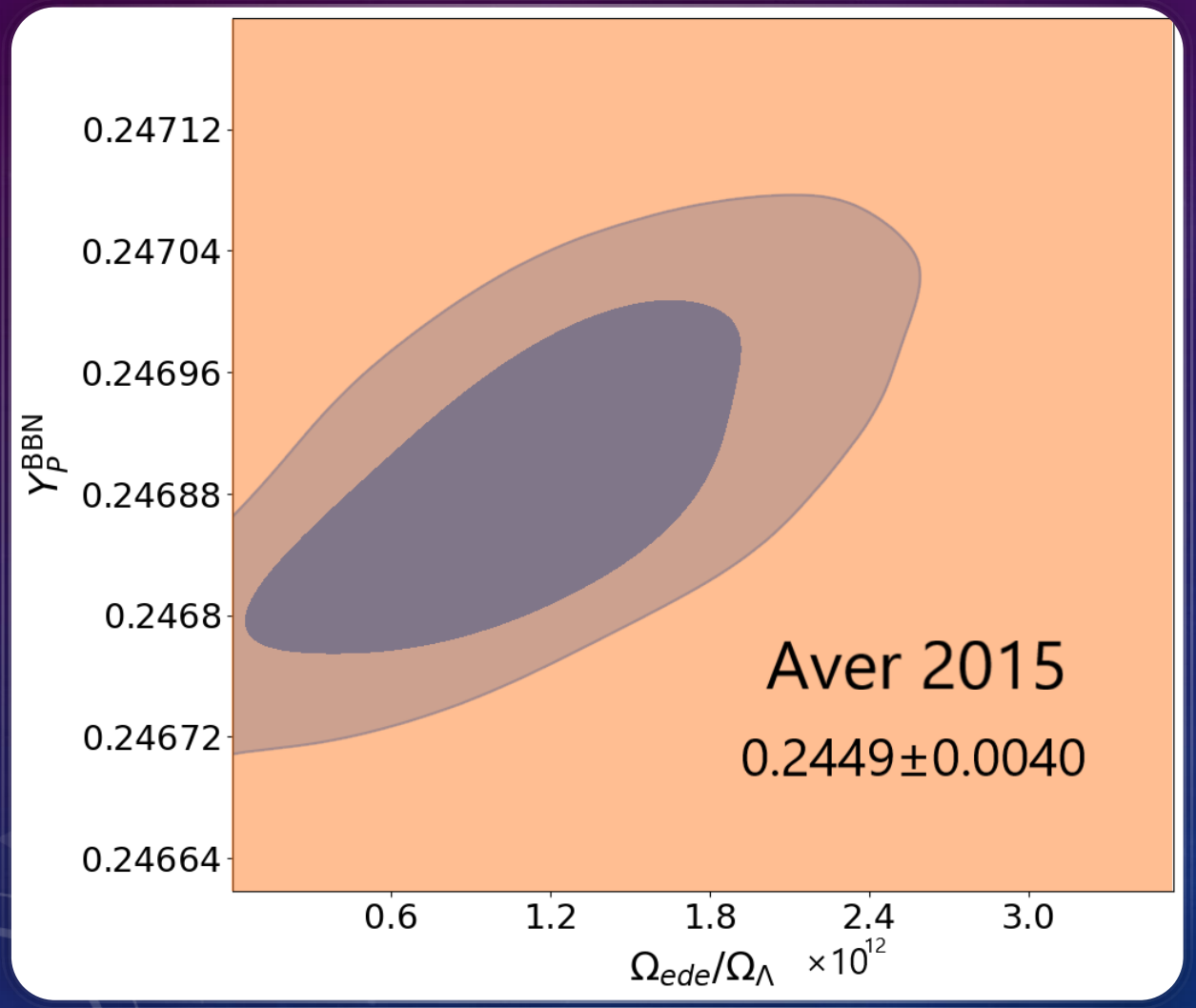
Early Dark Energy

Increase H_0

$$\frac{\Omega_{\mathrm{EDE}}}{\Omega_\Lambda} = \frac{\rho_{\mathrm{EDE}}}{\rho_\Lambda}\bigg|_{\mathrm{today}}$$

Planck + Pantheon + BAO + R19

EDE VS. HELIUM MASS FRACTION Y_P MEASUREMENT

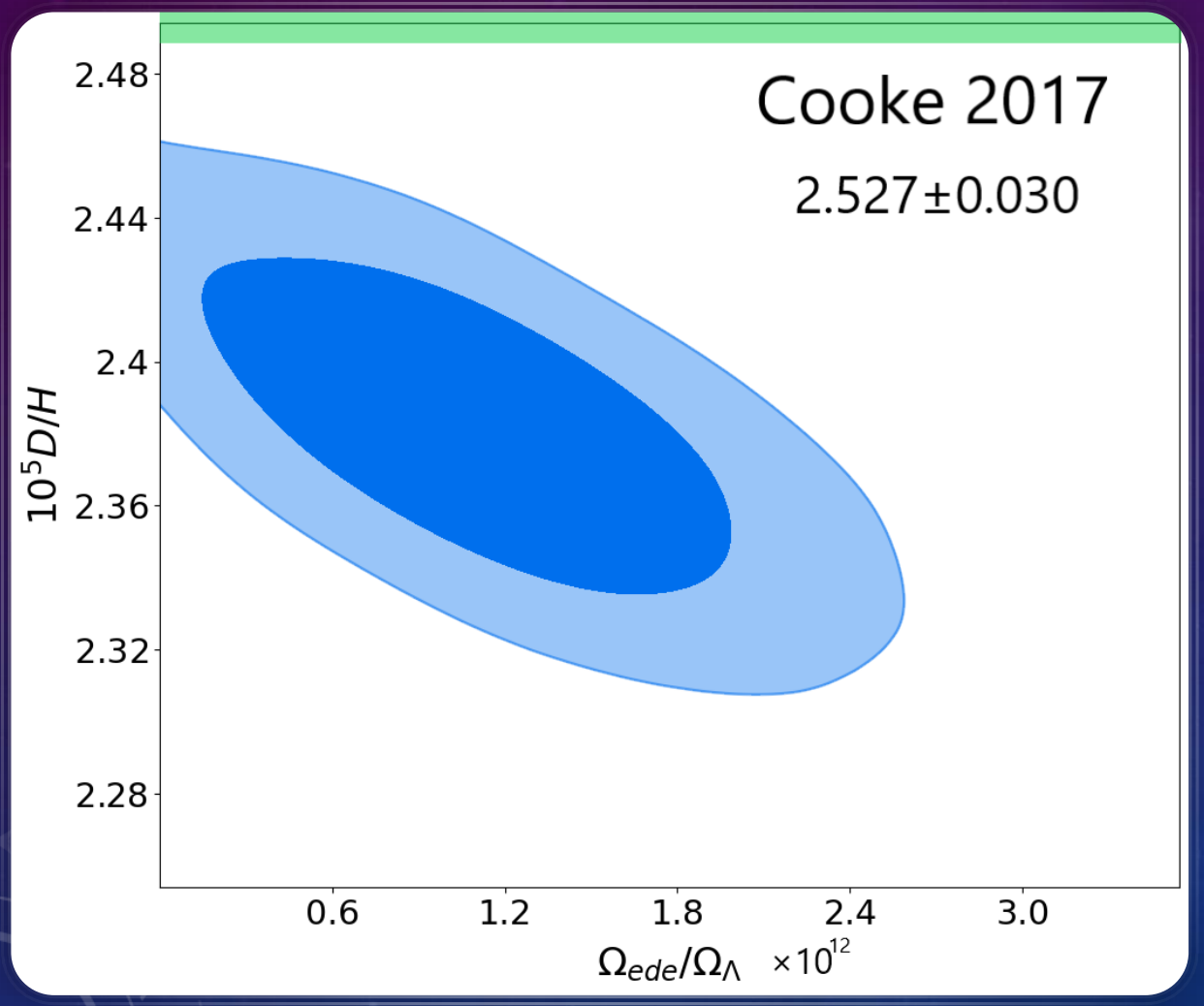


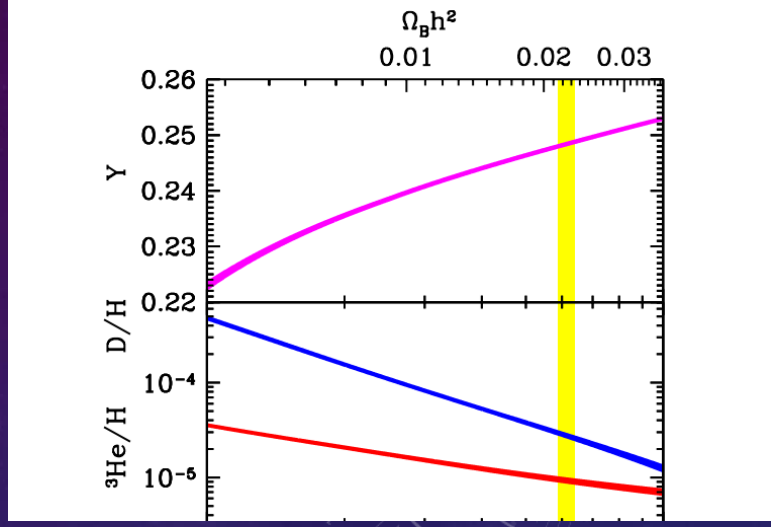
Early Dark Energy increase Y_P littel

$$\frac{\Omega_{\mathrm{EDE}}}{\Omega_\Lambda} = \frac{\rho_{\mathrm{EDE}}}{\rho_\Lambda}\bigg|_{\mathrm{today}}$$

Planck + Pantheon + BAO + R19

EDE VS. DEUTERIUM D/H MEASUREMENT



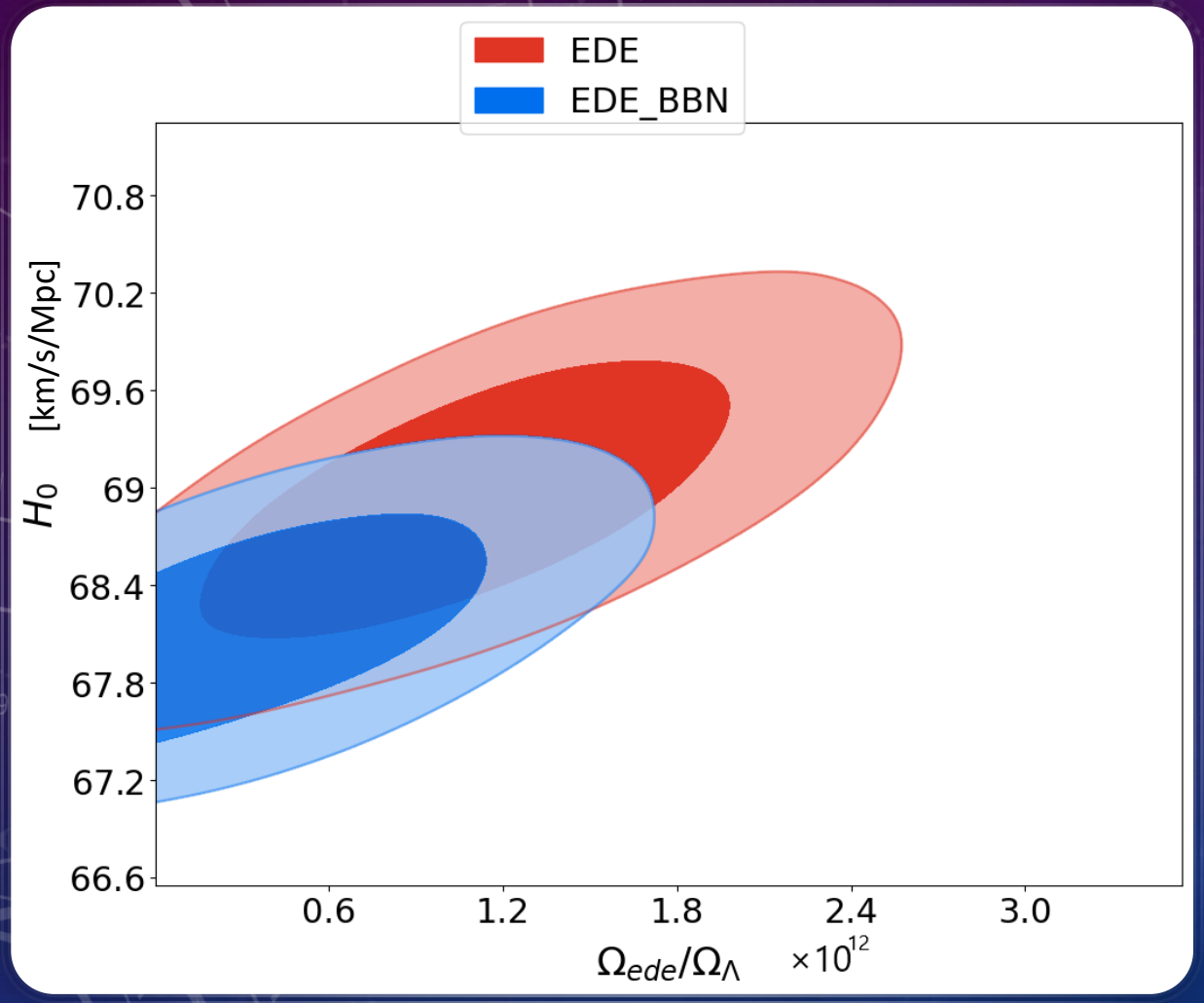


Richard H. Cyburt, Brian D. Fields, Keith A. Olive arXiv:astro-ph/0302431

Early Dark Energy
decreases D/H
through $\Omega_b h^2$

Planck + Pantheon + BAO + R19

EDE IS LIMITED FROM THE BBN CONSISTENCY



Higher Ω_{ede} is disfavored from D/H measurement

Higher N_{eff} is disfavored from Y_P measurement

Planck + Pantheon + BAO + R19 + (Y_P & D/H)

TAKE-HOME MESSAGE

- Extra radiation and Early dark Energy are the promising solution of the Hubble tension

- Extra radiation is limited by the Helium abundance

- Early Dark Energy is limited by the deuterium abundance

Thank you for your kind attention!

Osamu Seto, Yo Toda *Phys.Rev.D* 103 (2021) 12, 123501
y-toda@particle.sci.hokudai.ac.jp