UBER-GRAVITY AND H_0 PROBLEM

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25 September 2017 — DarkMod — Saclay


GR, Lambda and CDM

? H_0 tension

? \sigma_8 tension

? void phenomenon

? missing satellite problem

GR, Lambda and CDM

? the cosmological constant problem

? why GR should govern gravity force

ENSEMBLE AVERAGE THEORY OF GRAVITY

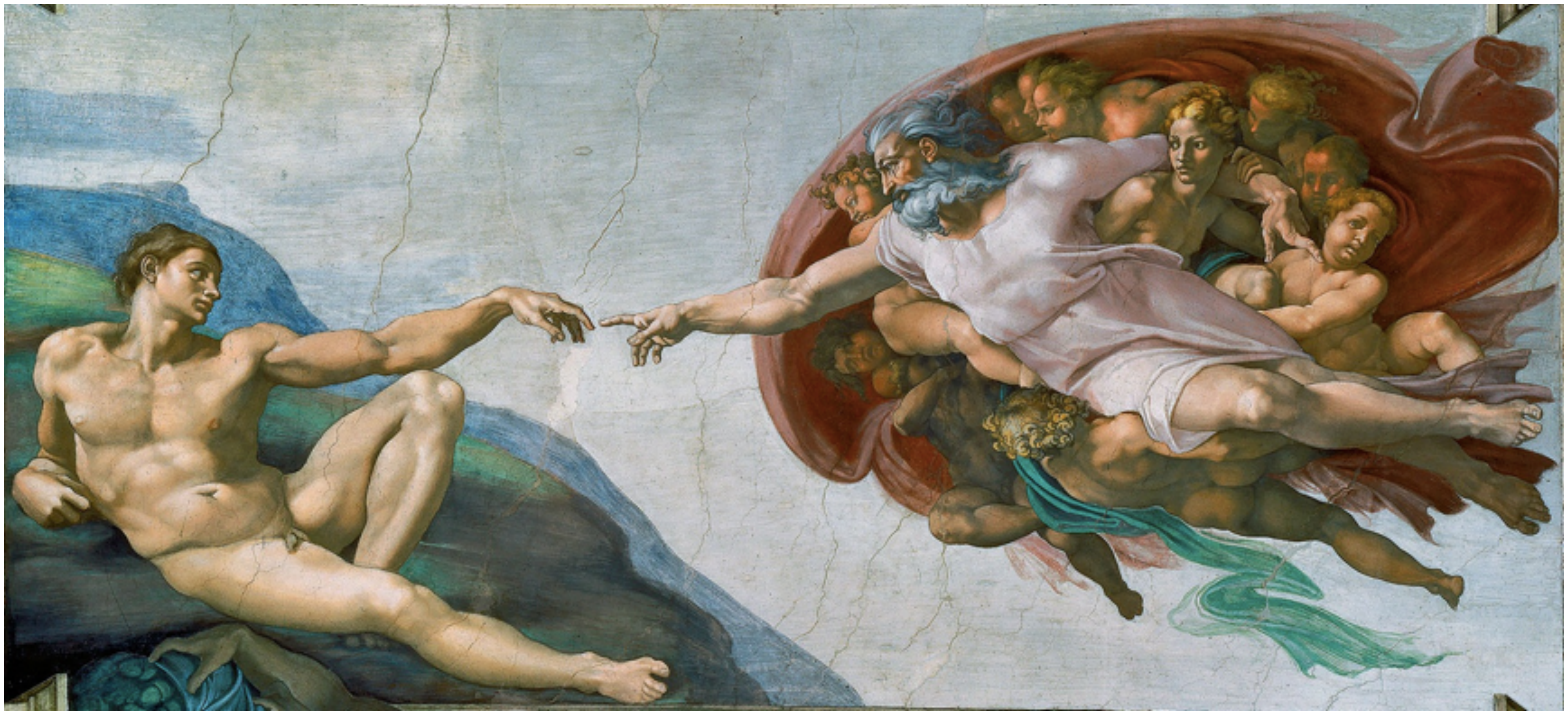
- A. Einstein:

  “What really interests me is whether God had any choice in the creation of the World”

A REAL STORY:

— THE FIRST DAY: IT WAS ASKED FOR A THEORY!

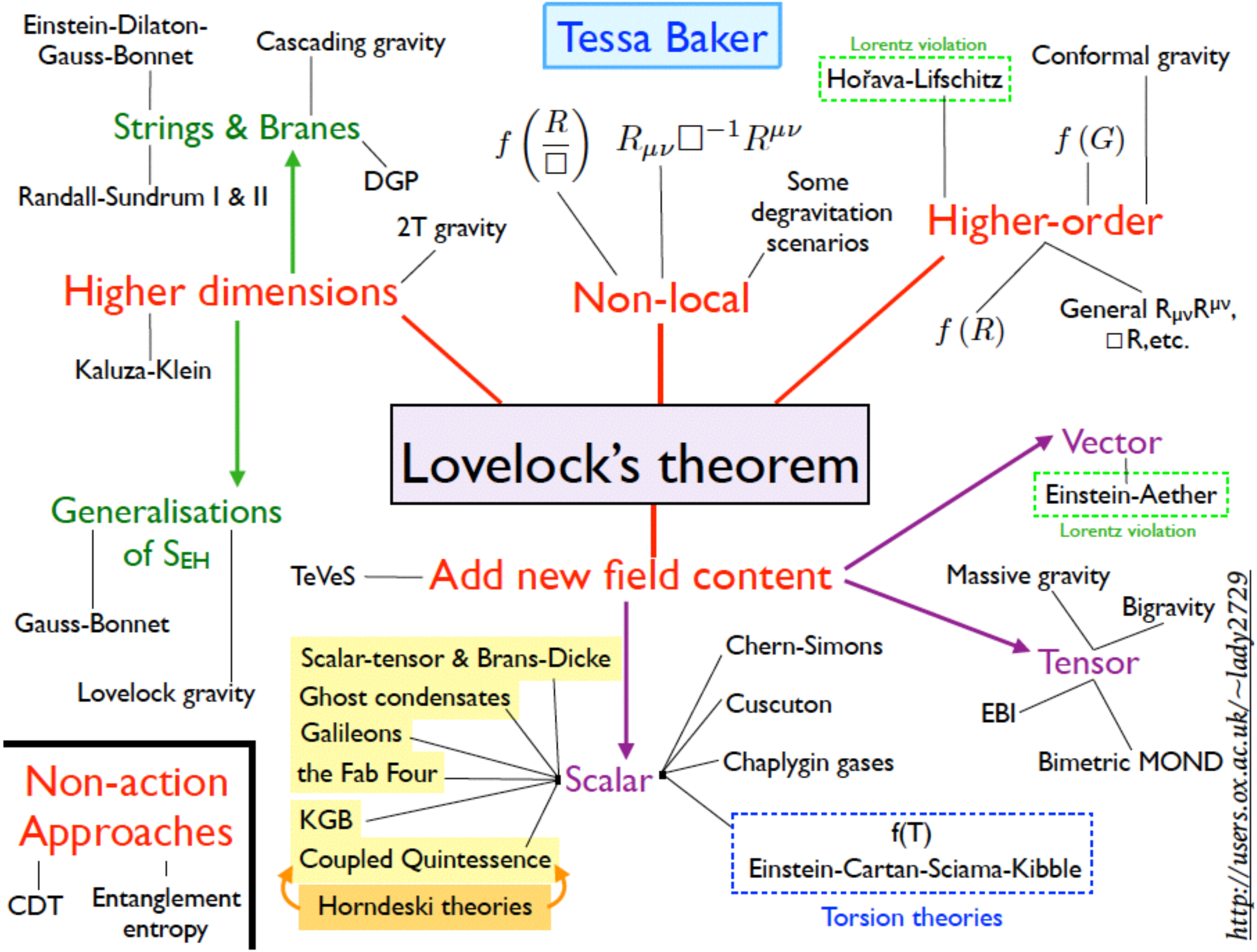
the creation of Adam, Michelangelo:



A. Einstein:

“What really interests me is whether God had any choice in the creation of the World”

— THEN, MANY THEORIES WERE PROPOSED BY THINKERS!



Tessa Baker
Lovelock's theorem
Higher dimensions
Strings & Branes
Einstein-Dilaton-Gauss-Bonnet
Cascading gravity
DGP
Randall-Sundrum I & II
2T gravity
Kaluza-Klein
Generalisations of S_{EH}
Gauss-Bonnet
Lovelock gravity
Non-local
$f\left(\frac{R}{\Box}\right)$
$R_{\mu\nu}\Box^{-1}R^{\mu\nu}$
Some degravitation scenarios
Higher-order
Lorentz violation
Hořava-Lifschitz
Conformal gravity
$f(G)$
$f(R)$
General $R_{\mu\nu}R^{\mu\nu}$, $\Box R$, etc.
Add new field content
TeVeS
Vector
Einstein-Aether
Lorentz violation
Tensor
Massive gravity
Bigravity
EBI
Bimetric MOND
Scalar
Scalar-tensor & Brans-Dicke
Ghost condensates
Galileons
the Fab Four
KGB
Coupled Quintessence
Horndeski theories
Chern-Simons
Cuscuton
Chaplygin gases
f(T)
Einstein-Cartan-Sciama-Kibble
Torsion theories
Non-action Approaches
CDT
Entanglement entropy
http://users.ox.ac.uk/~lady2729

— EUREKA: THE ANSWER IS “AVERAGING”!

death of Socrates, David:

ENSEMBLE AVERAGE THEORY OF GRAVITY

- let's recall Einstein quote:
  "What really interests me is whether God had any choice in the creation of the World"

- what is your answer to his question?
  - no! ⟶ why not? why GR is unique?
  - yes! ⟶ how can we check this "yes"?
  - it is not a well-defined question! ⟶ see you at break!

ENSEMBLE AVERAGE THEORY OF GRAVITY

- what is my answer to his question?
  - my answer to this question is “yes” and “no” both!
  - “yes”: all the theoretically consistent models have been used in the creation of the World!
  - “no”: at the end there is just a “unique model” which is the “ensemble average” of all the theoretically possible models!
- based on PRD 94 (2016) 124035, arXiv:1606.01887
- for a very similar idea see also: N. Arkani-Hamed et al., PRL 117 (2016) 251801, arXiv:1607.06821

ENSEMBLE AVERAGE THEORY OF GRAVITY

$$\mathbb{M}$$

the space of all the (consistent) models for gravity!

- we take average over all the models
- to do this we need to assigned to each model a probability

$$\mathcal{M} = \sum_i p_i \mathcal{M}_i = \frac{1}{\sum_j e^{-\mathcal{S}_j}} \times \sum_i e^{-\mathcal{S}_i} \mathcal{M}_i$$

ENSEMBLE AVERAGE THEORY OF GRAVITY

- practically I will assign to each model a Lagrangian
- the averaged Lagrangian will be like

$$\mathcal{L} = \sqrt{-g}\left(\sum_{i=1}^{N} L_i e^{-\beta L_i}\right) \Big/ \left(\sum_{j=1}^{N} e^{-\beta L_j}\right)$$

i'th Lagrangian its weight

averaged Lagrangian normalization factor

ENSEMBLE AVERAGE THEORY OF GRAVITY

- an example: higher order gravity
- in 4-dimension we have Ricci scalar and Gauss-Bonnet term

$$\mathcal{L} = \sqrt{-g}\left[\frac{M^2 R\, e^{-\beta M^2 R}}{e^{-\beta M^2 R} + e^{-\beta\alpha G}} + \frac{\alpha G\, e^{-\beta\alpha G}}{e^{-\beta M^2 R} + e^{-\beta\alpha G}}\right]$$

Ricci scalar

Gauss-Bonnet term

temperature of model space??

UBER-GRAVITY

- based on “Uber-Gravity and the CPP”, arXiv:1703.02052
- a generalization of EAT-of-Gravity for all analytical functions of f(R). so we have

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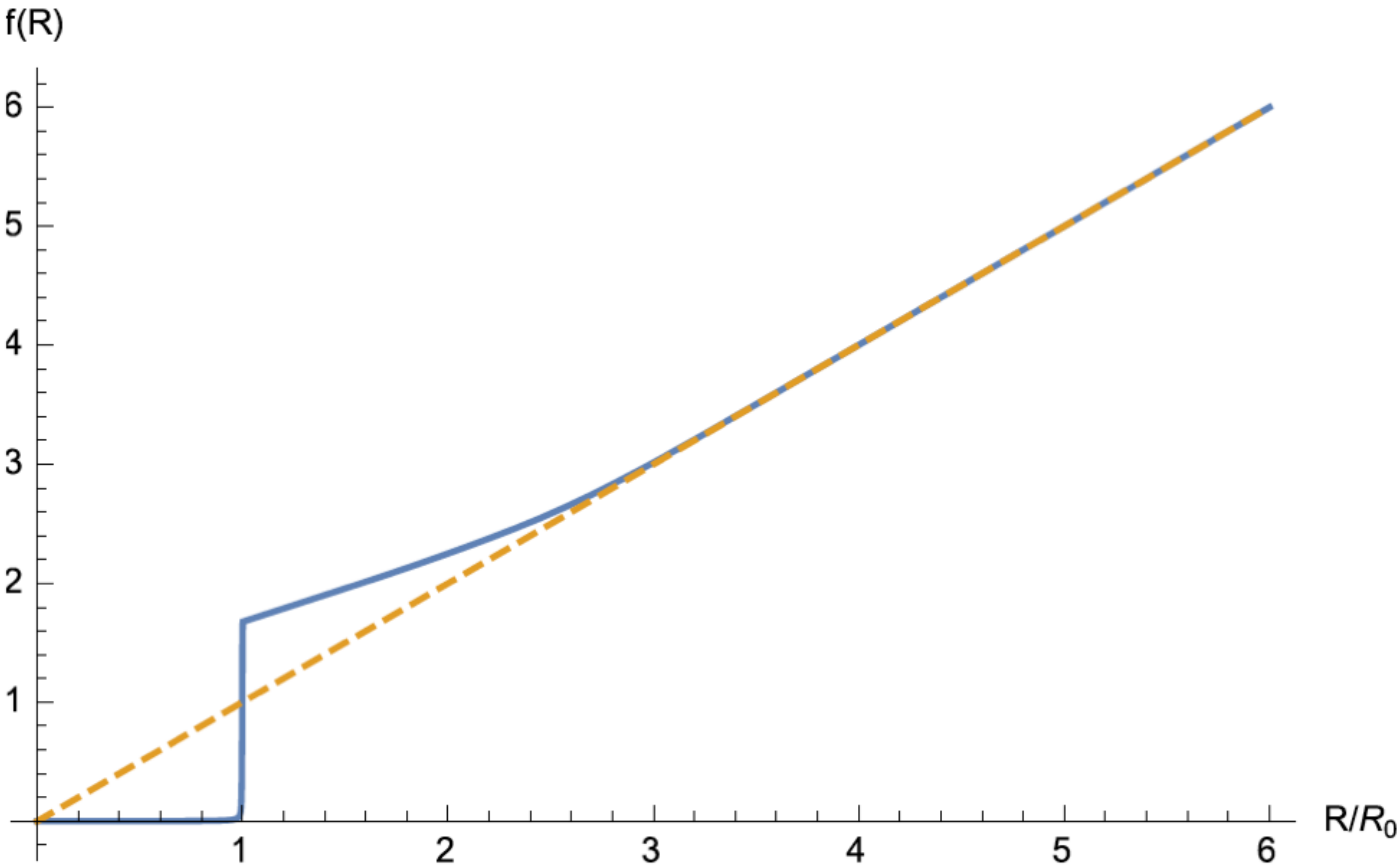
$$\mathbb{M} = \{R^n \mid \forall\, n \in \mathbb{N}\}$$

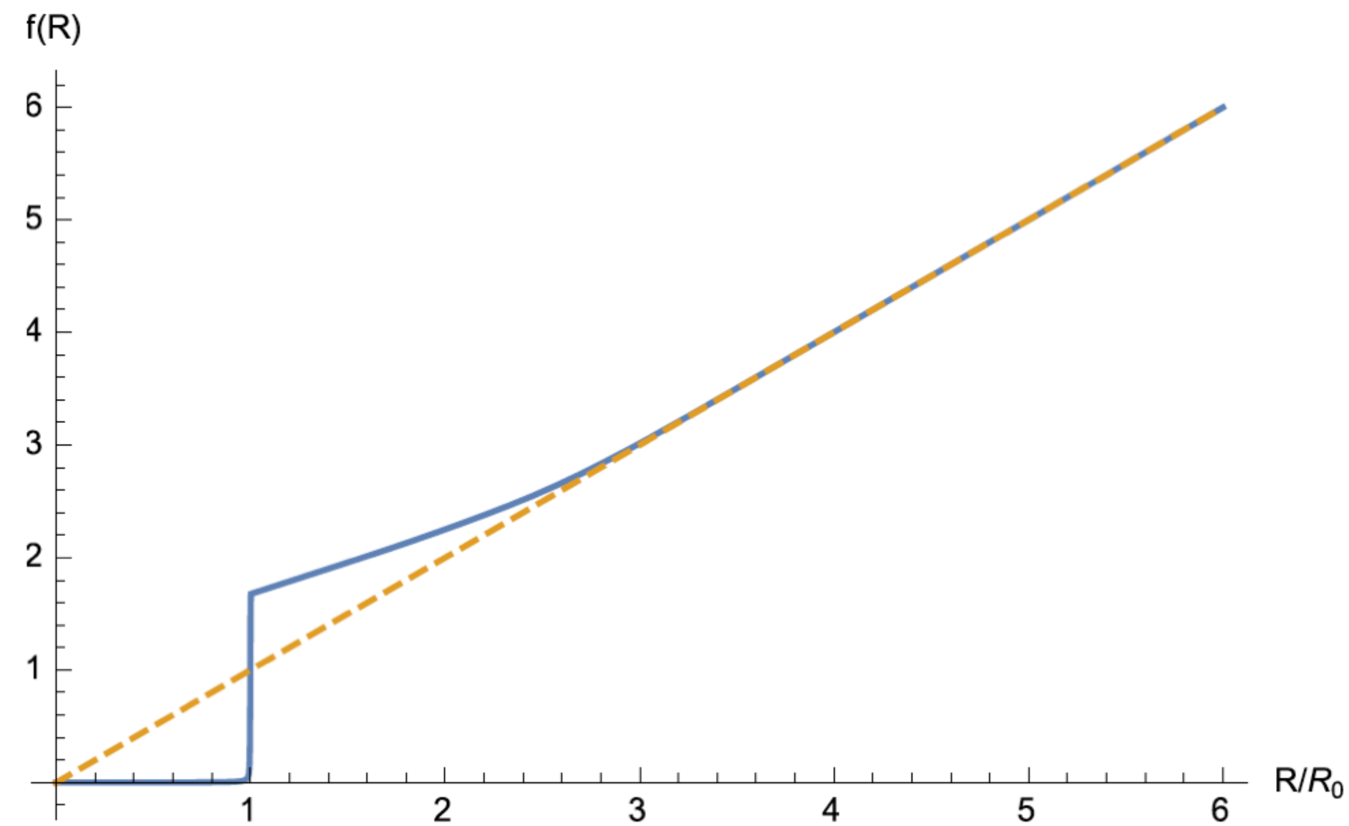
$$\mathcal{L} = \left(\sum_{n=1}^{\infty} \bar{R}^n e^{-\beta \bar{R}^n}\right) \Big/ \left(\sum_{n=1}^{\infty} e^{-\beta \bar{R}^n}\right)$$

UBER-GRAVITY



UBER-GRAVITY: UNIVERSAL PROPERTIES

- for high-curvature regime it reduces to GR
- for intermediate-curvature regime it predicts stronger gravity than GR
- it is vanishing for low-curvature regime (R < R_0)
- there is a sharp transition at R_0



UBER-GRAVITY: A SIMPLIFIED MODEL

$$f(R) = \begin{cases} \bar{R}^n & R \leq R_0 \\ \bar{R} + e^{-(\bar{R}-0.7)} & R_0 < R \end{cases}$$

we focus on low-curvature regime. we have

$$(n-2)\bar{R}^n + 3\,n\,R_0^{-1}\,\Box\,\bar{R}^{n-1} = \kappa^2 T$$

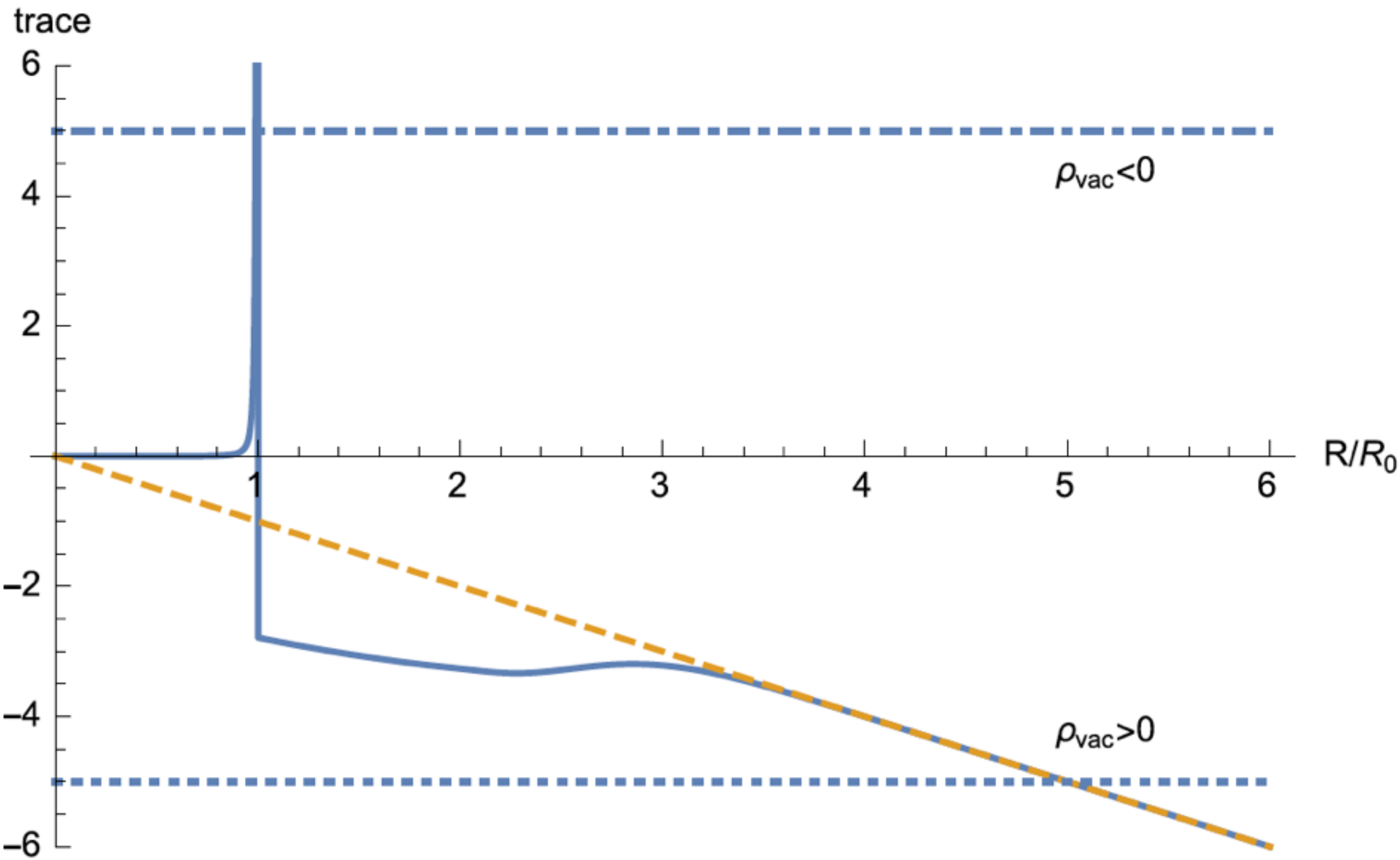
and for R = const. we have

$$\frac{R}{R_0} = \left(\frac{\kappa^2\,T}{n-2}\right)^{\frac{1}{n}}$$

which means for $n \rightarrow \infty$ results in $R \rightarrow R_0$!!

this means there is no need to fine-tuning since this model is not sensitive to vacuum energy.

UBER-GRAVITY: FULL MODEL




? H_0 tension
? \sigma_8 tension
? void phenomenon
? missing satellite problem
Uber-Gravity

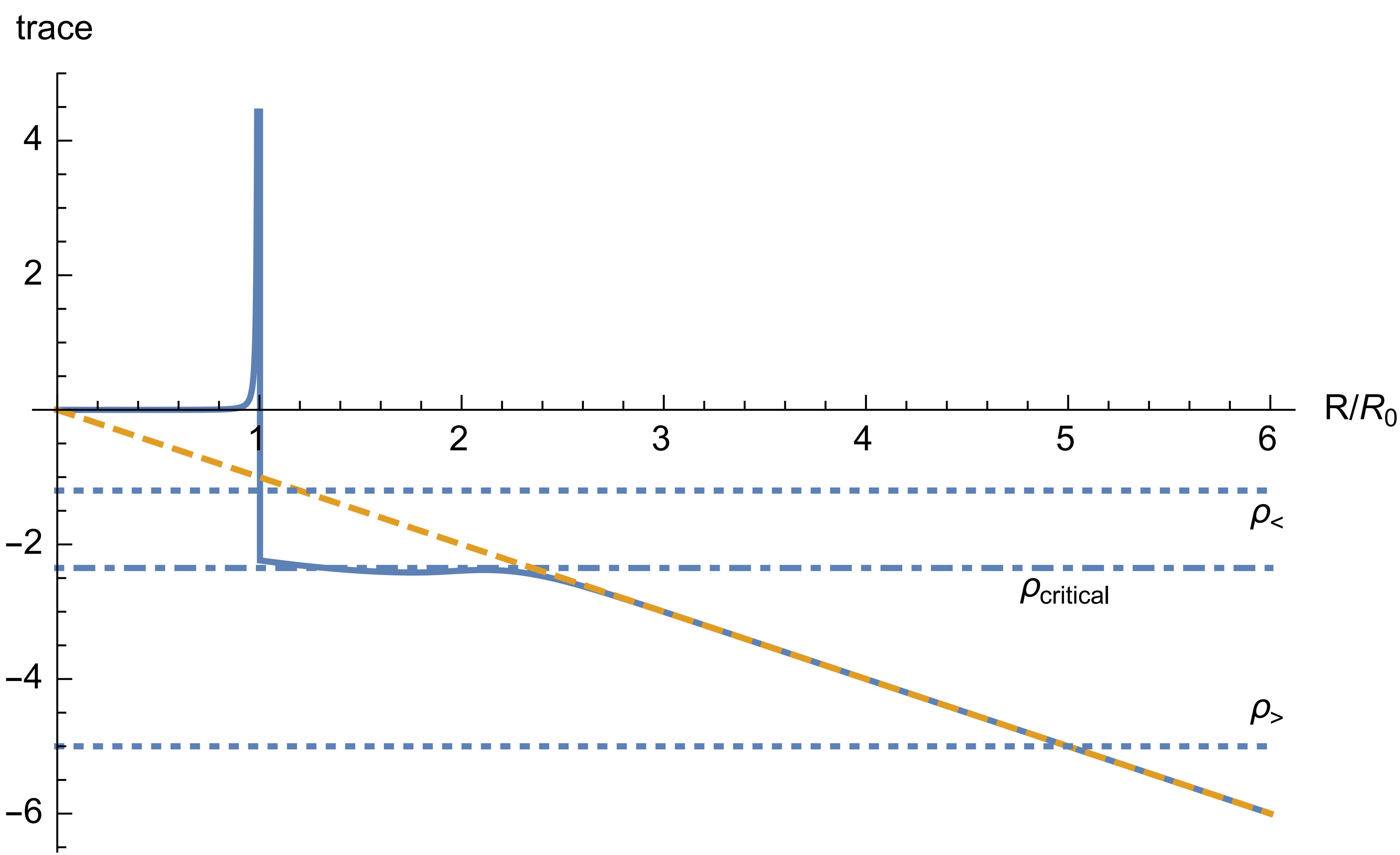
LAMBDA XOR CDM MODEL:

note: this part has been done in collaboration with

Shant Baghram

Sharif University of Technology, Tehran, Iran

UBER-GRAVITY: FULL MODEL



LAMBDA XOR CDM MODEL:

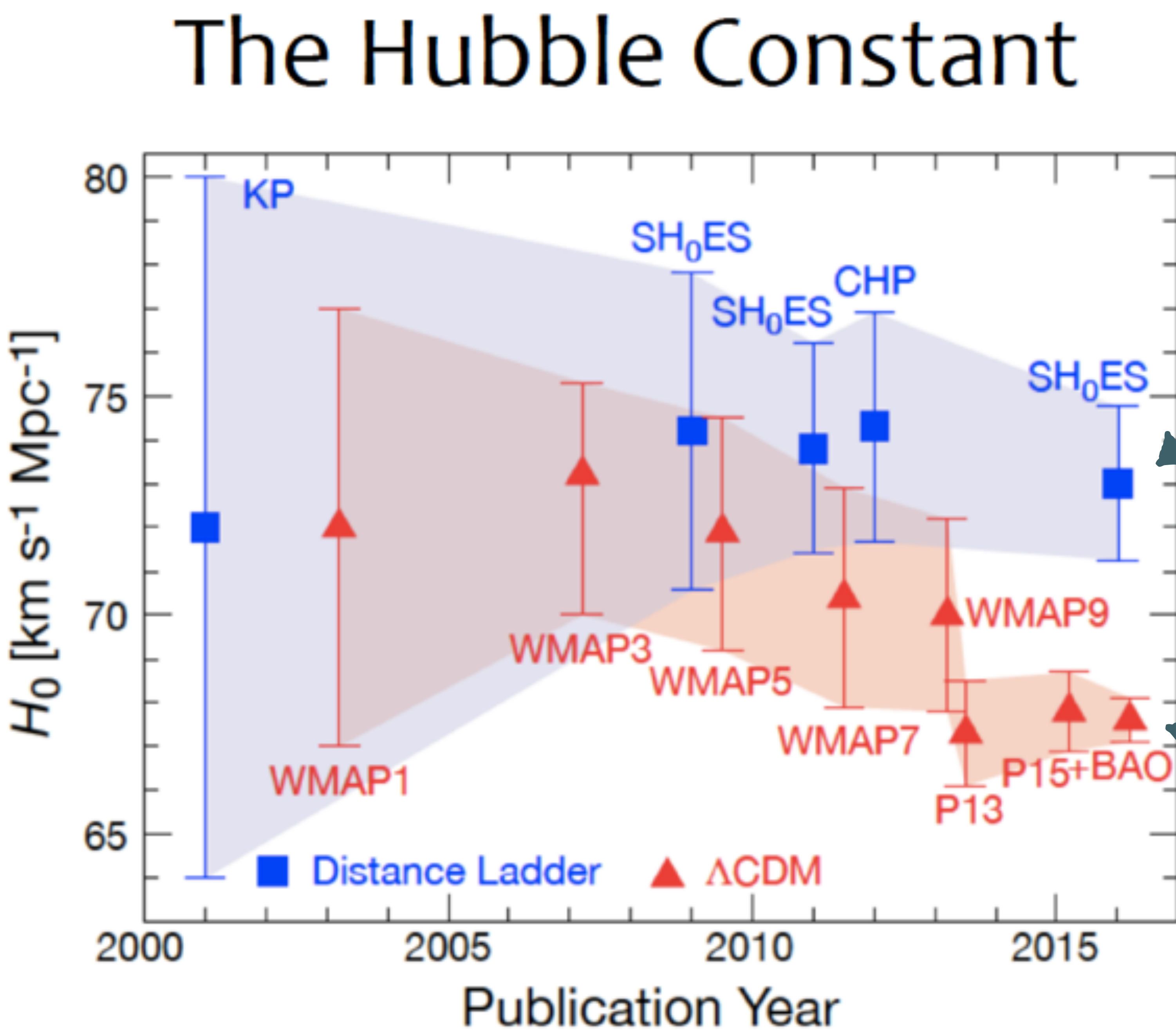
- based on uber-gravity model we suggest the following cosmological model:

$$\text{Gravity} = \begin{cases} \text{de Sitter} & \rho < \rho_{critical} \\ \text{GR + CDM} & \rho > \rho_{critical} \end{cases}$$

which is dubbed as "either Lambda or CDM":

$$\Lambda \oplus \textbf{CDM MODEL}$$

LAMBDA XOR CDM MODEL: BACKGROUND



low-redshift

i.e. SN

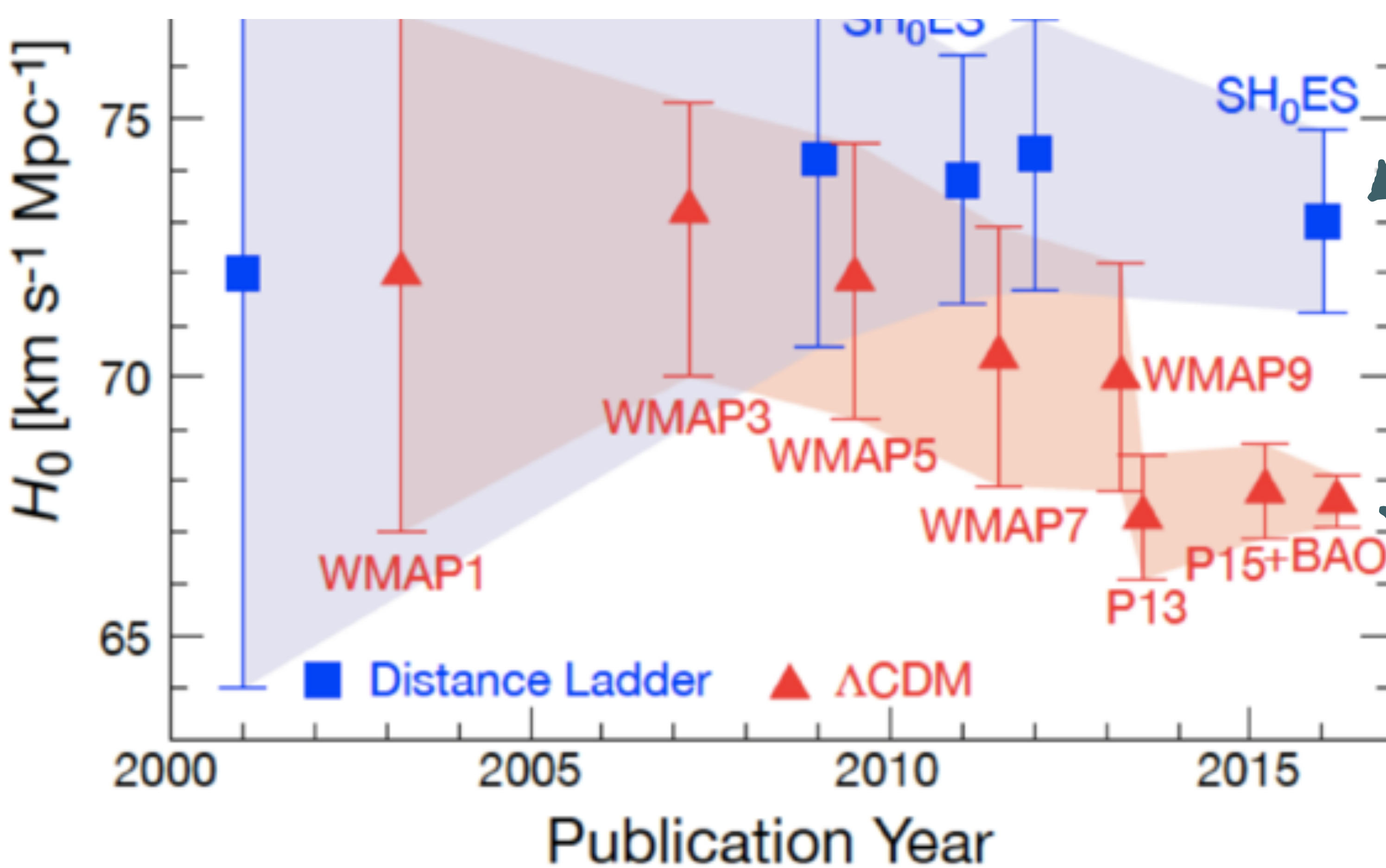
high-redshift

i.e. CMB

Freedman 2017
Beaton et al. 2016

LAMBDA XOR CDM MODEL: BACKGROUND

A 2.4% Determination of the Local Value of the Hubble Constant
Adam G. Riess (Johns Hopkins U. & Baltimore, Space Telescope Sci.) *et al.*. Apr 5, 2016. 31 pp.
Published in **Astrophys.J. 826 (2016) no.1, 56**
DOI: 10.3847/0004-637X/826/1/56
e-Print: **arXiv:1604.01424 [astro-ph.CO]** | PDF
References | BibTeX | LaTeX(US) | LaTeX(EU) | Harvmac | EndNote
ADS Abstract Service
Detailed record - Cited by 305 records 250+



low-redshift

i.e. SN

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Freedman 2017
Beaton et al. 2016

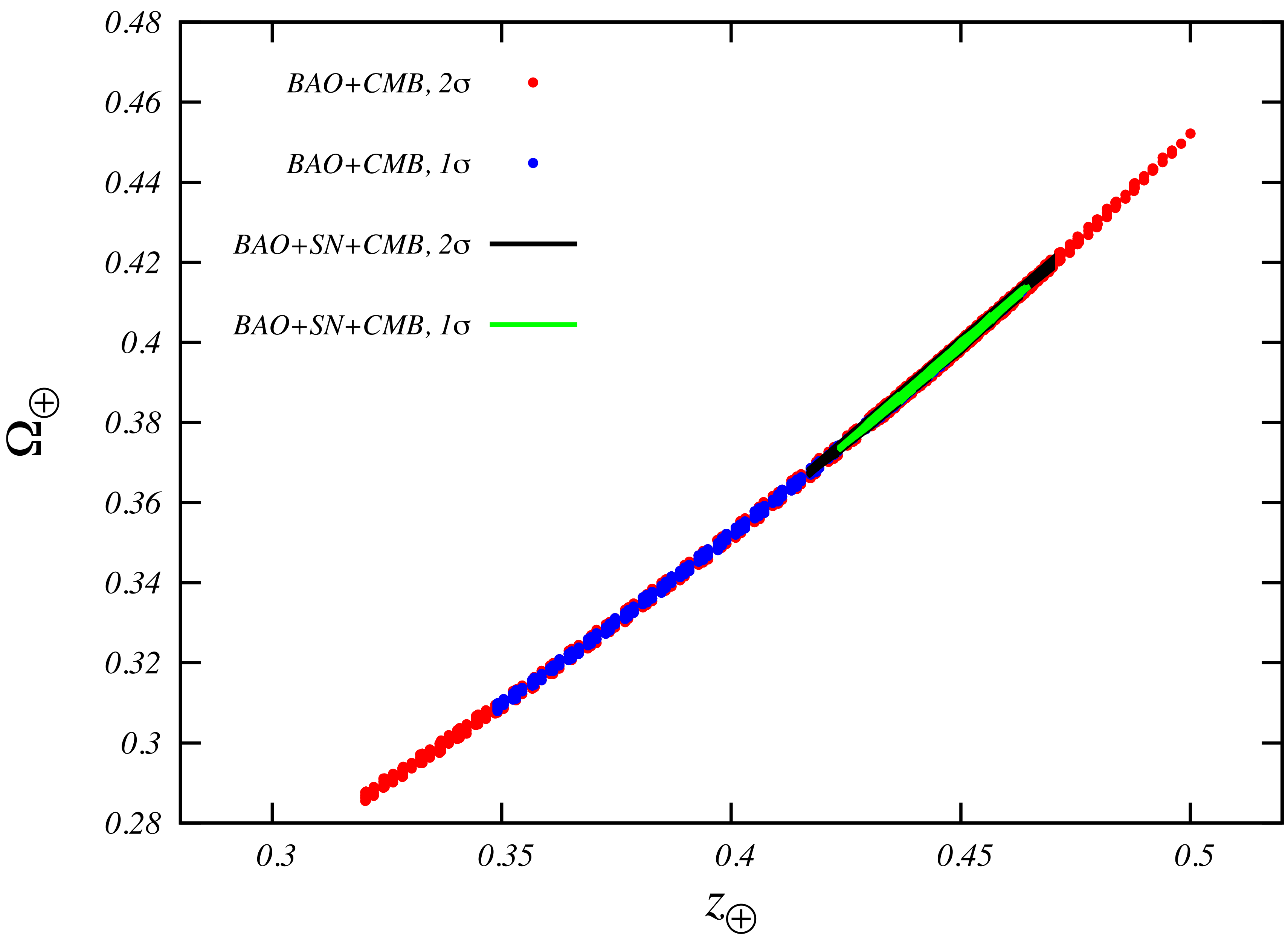
LAMBDA XOR CDM MODEL: BACKGROUND

$$E^2(z) \equiv \left(\frac{H(z)}{H_0^{low}}\right)^2 = \begin{cases} 1 & z < z_\oplus \\ \Omega_{m,\oplus}\left(\frac{1+z}{1+z_\oplus}\right)^3 & z > z_\oplus \end{cases}$$

$$\chi(z) = \frac{c}{H_0^{low}}\left[\int_0^{z_\oplus} dz + \int_{z_\oplus}^{z} \frac{dz}{\left(\Omega_{m,\oplus}\left(\frac{1+z}{1+z_\oplus}\right)^3\right)^{1/2}}\right]$$

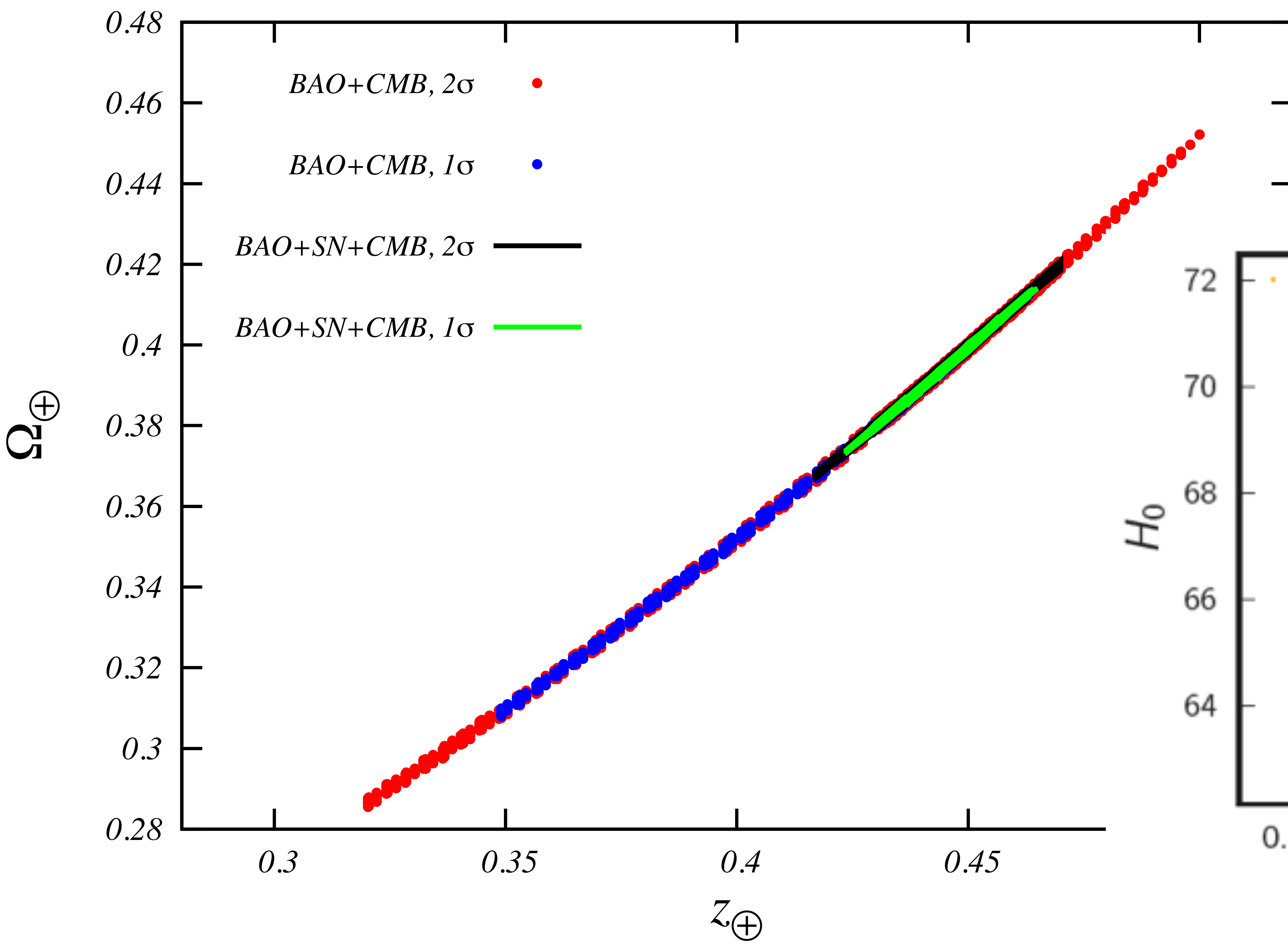
LAMBDA XOR CDM MODEL: BACKGROUND

by fitting LxorCDM with background data including SN, BAO and 1st CMB peak

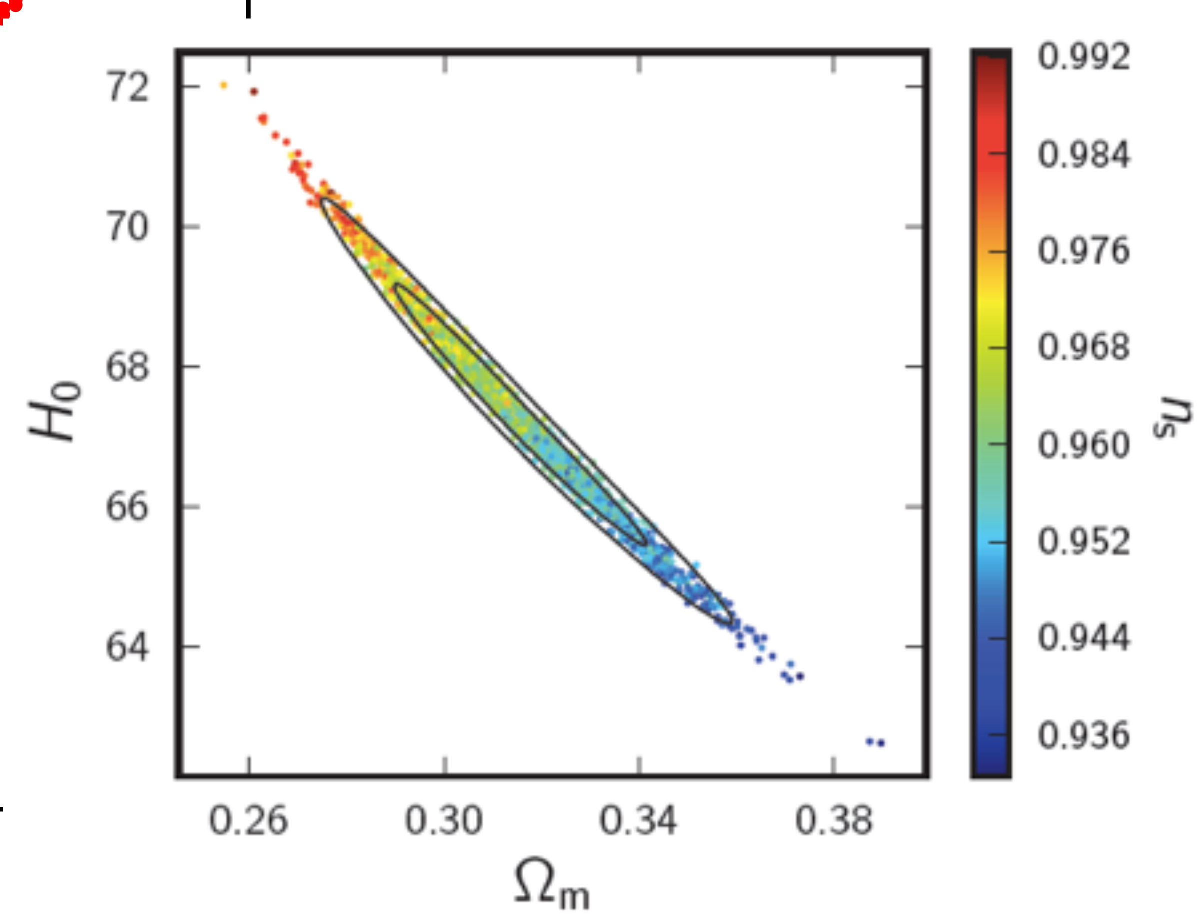


LAMBDA XOR CDM MODEL: BACKGROUND

by fitting LxorCDM with background data including SN, BAO and 1st CMB peak

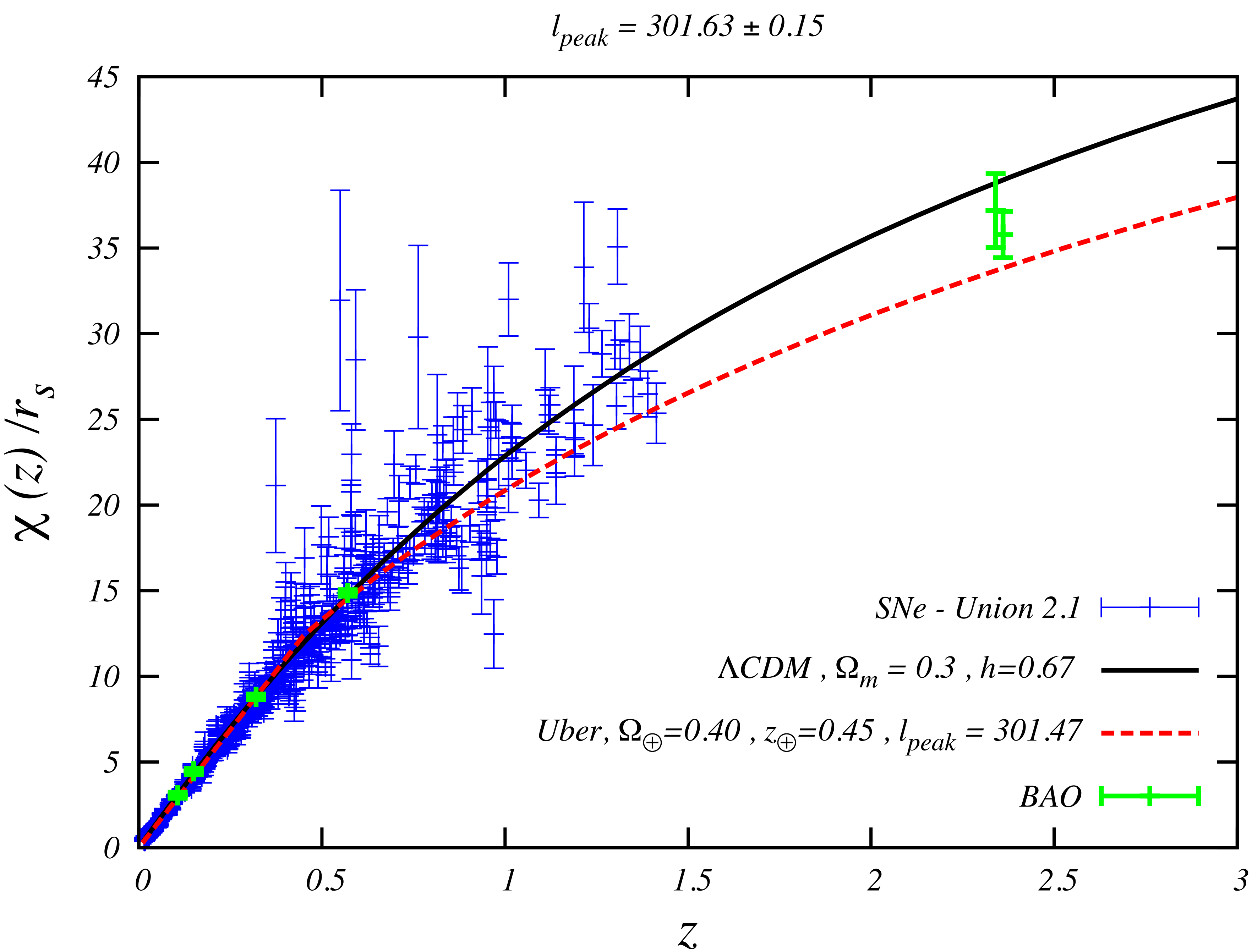


A. Lewis, COSMOMC



LAMBDA XOR CDM MODEL: BACKGROUND

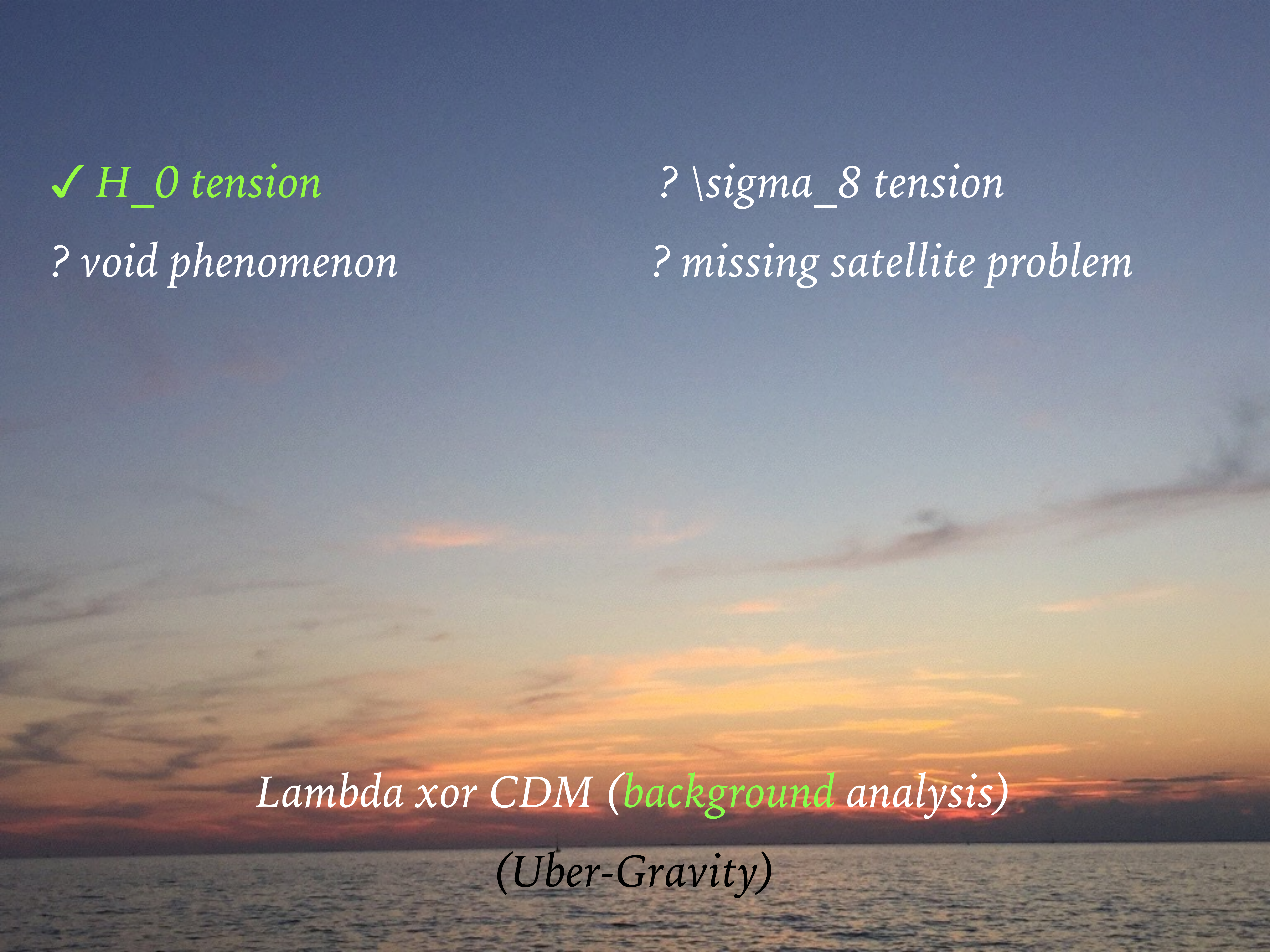
by fitting LxorCDM with background data including SN, BAO and 1st CMB peak



LAMBDA XOR CDM MODEL: BACKGROUND

- flat LxorCDM has 3 free parameters \Omega_m, H_0 and z_transition which are related to R_0 and \beta in original uber-gravity model!
- we fixed H_0 = 73 km/sec/Mpc reported by Riess et al.
- we minimize \chi^2 for z_t and \Omega_m
- \chi^2 is comparable with number of data points!

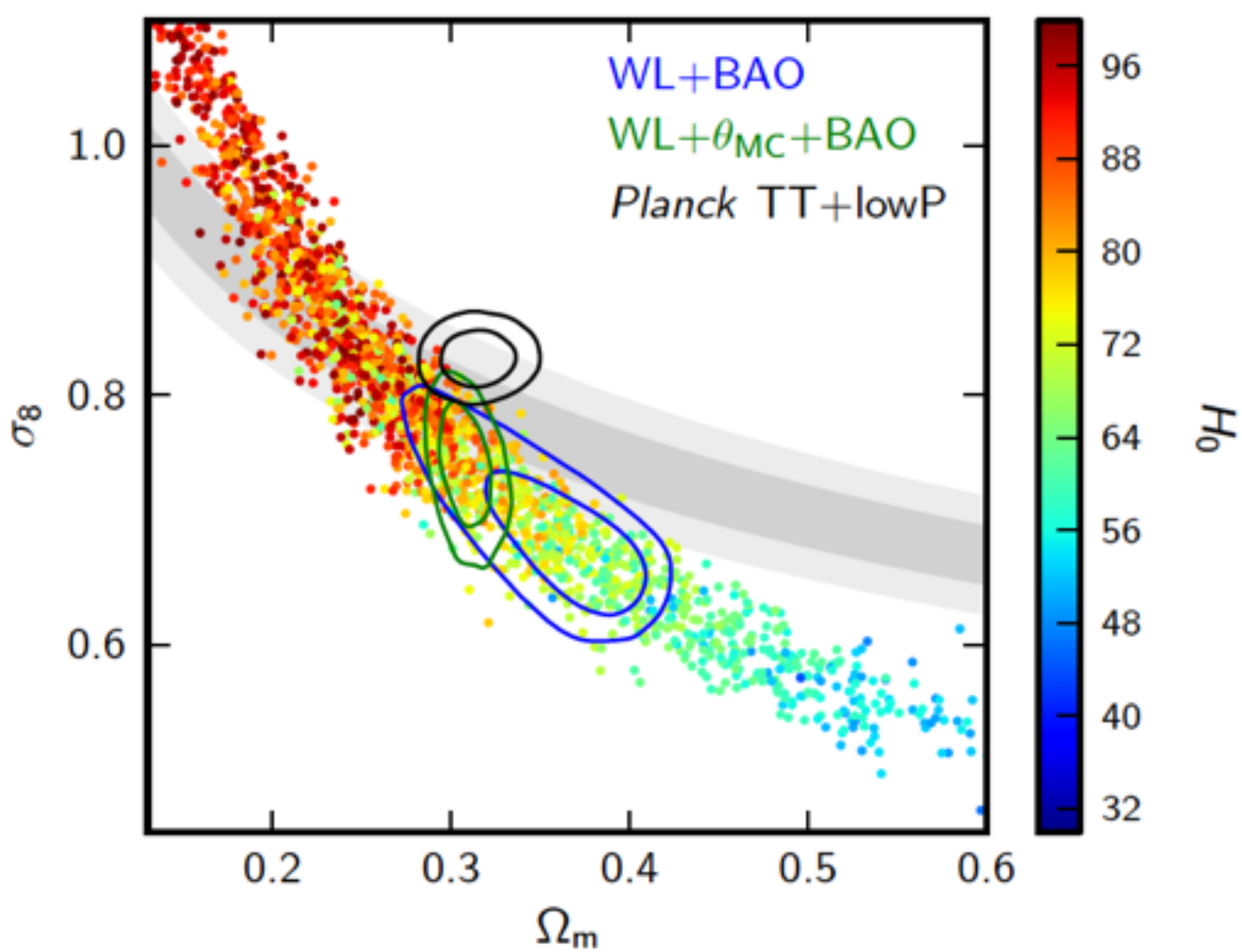
- LxorCDM automatically solves H_0 problem which was not obvious at the first look!


✓ H_0 tension
? \sigma_8 tension
? void phenomenon
? missing satellite problem
Lambda xor CDM (background analysis)
(Uber-Gravity)

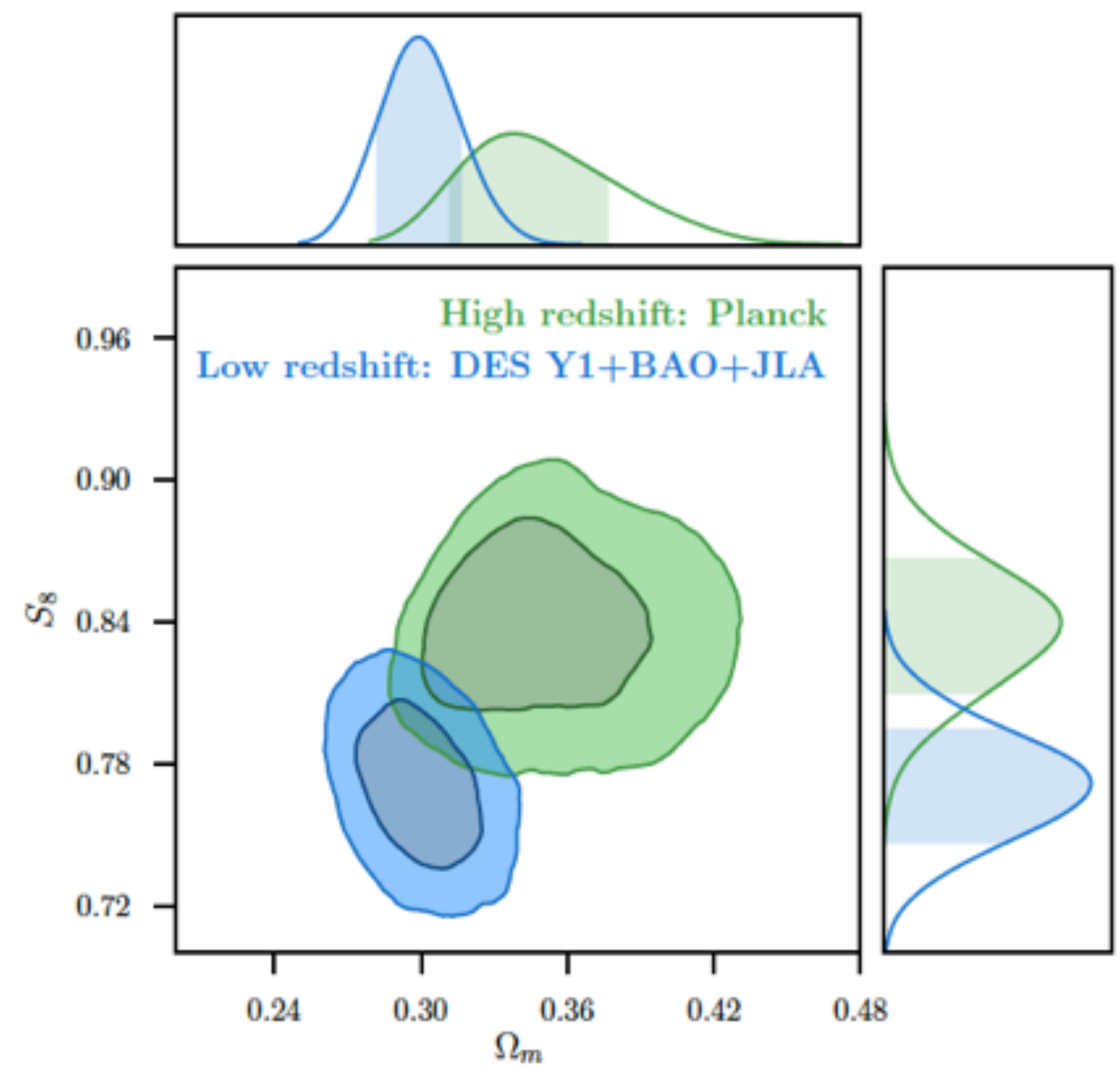
LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS

- \sigma_8 problem:

"Cosmic map reveals a not-so-lumpy Universe", Nature on DES!



Planck 2015



DES 2017

LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS

in perturbation theory we need to find the redshift where the "total density" touches the critical density:

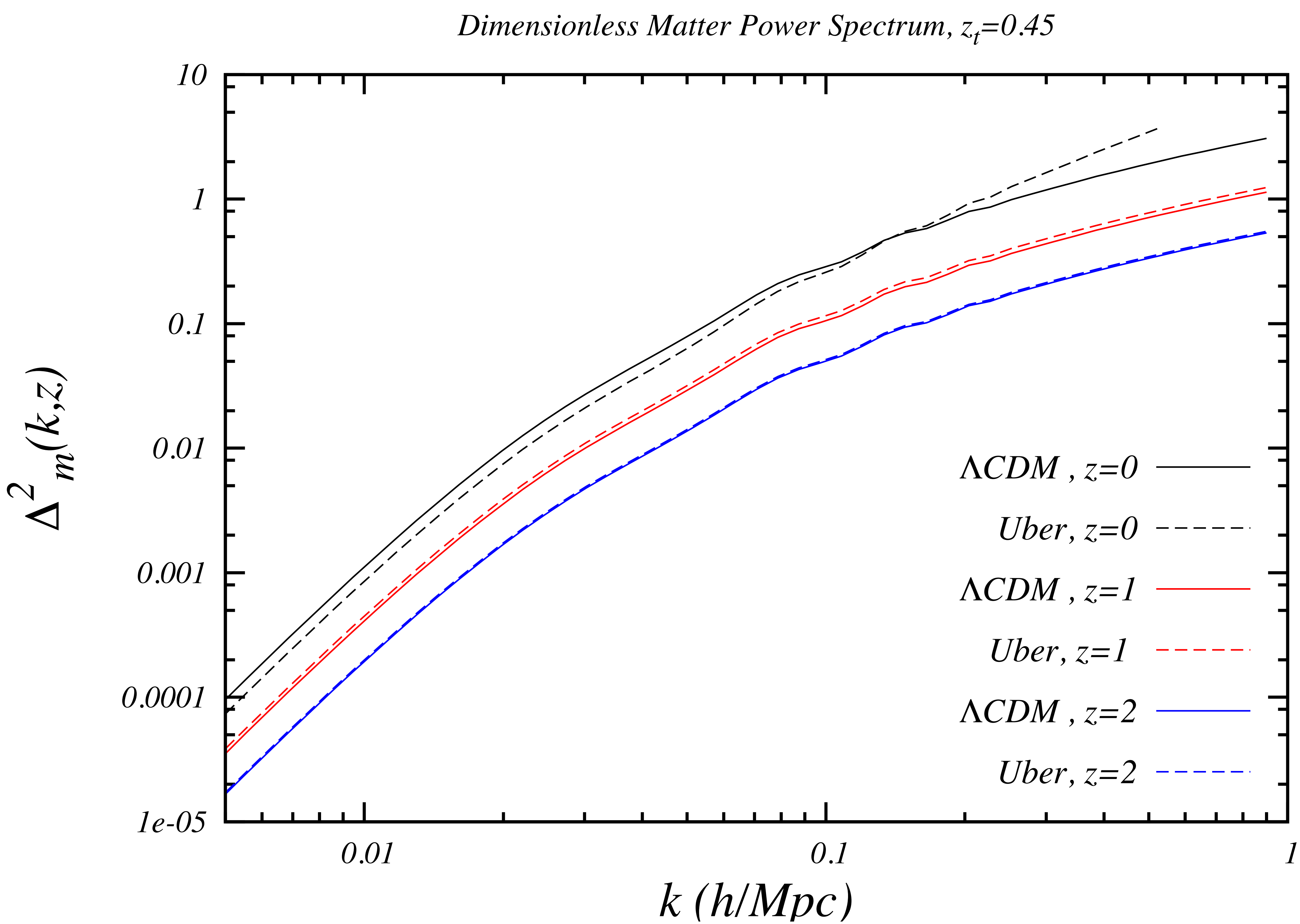
$$\bar{\rho}(z)\left[1+\delta(k,z)\right]=\rho_{critical}$$

which is equivalent to:

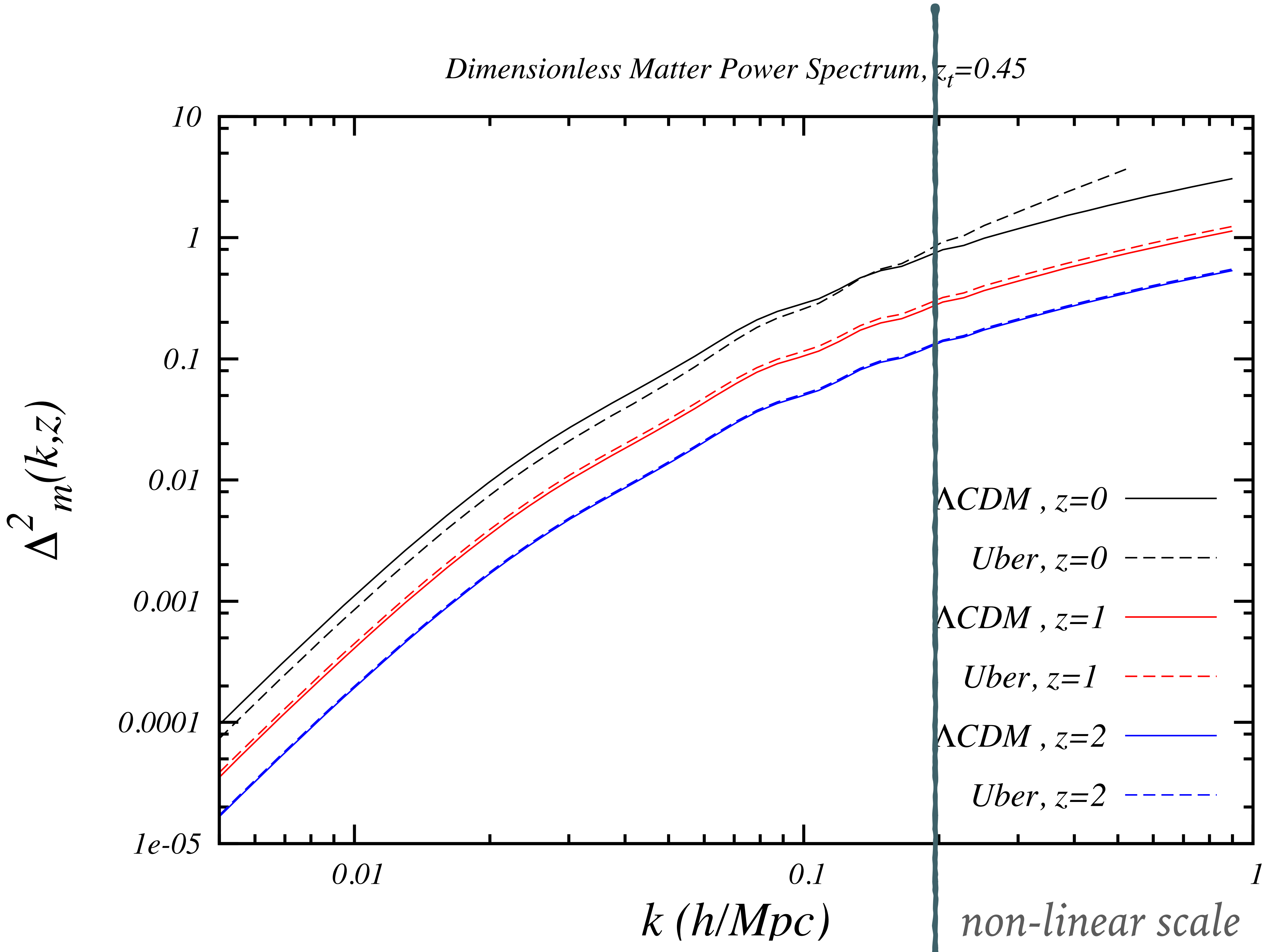
$$X^3 + A(k)\,X^2 = X_{\oplus}^3$$

for $X = 1 + z$ in deep CDM era!

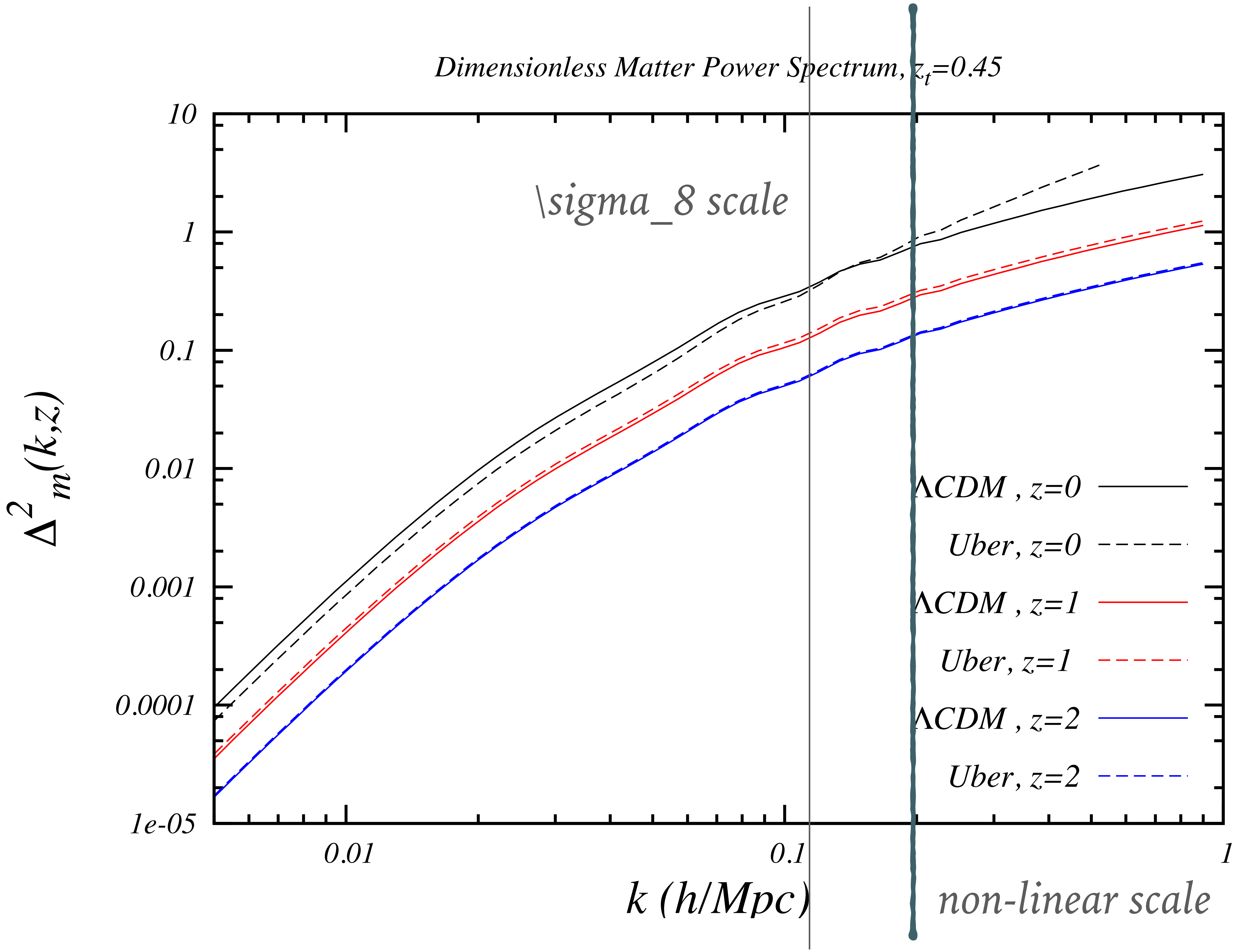
LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS



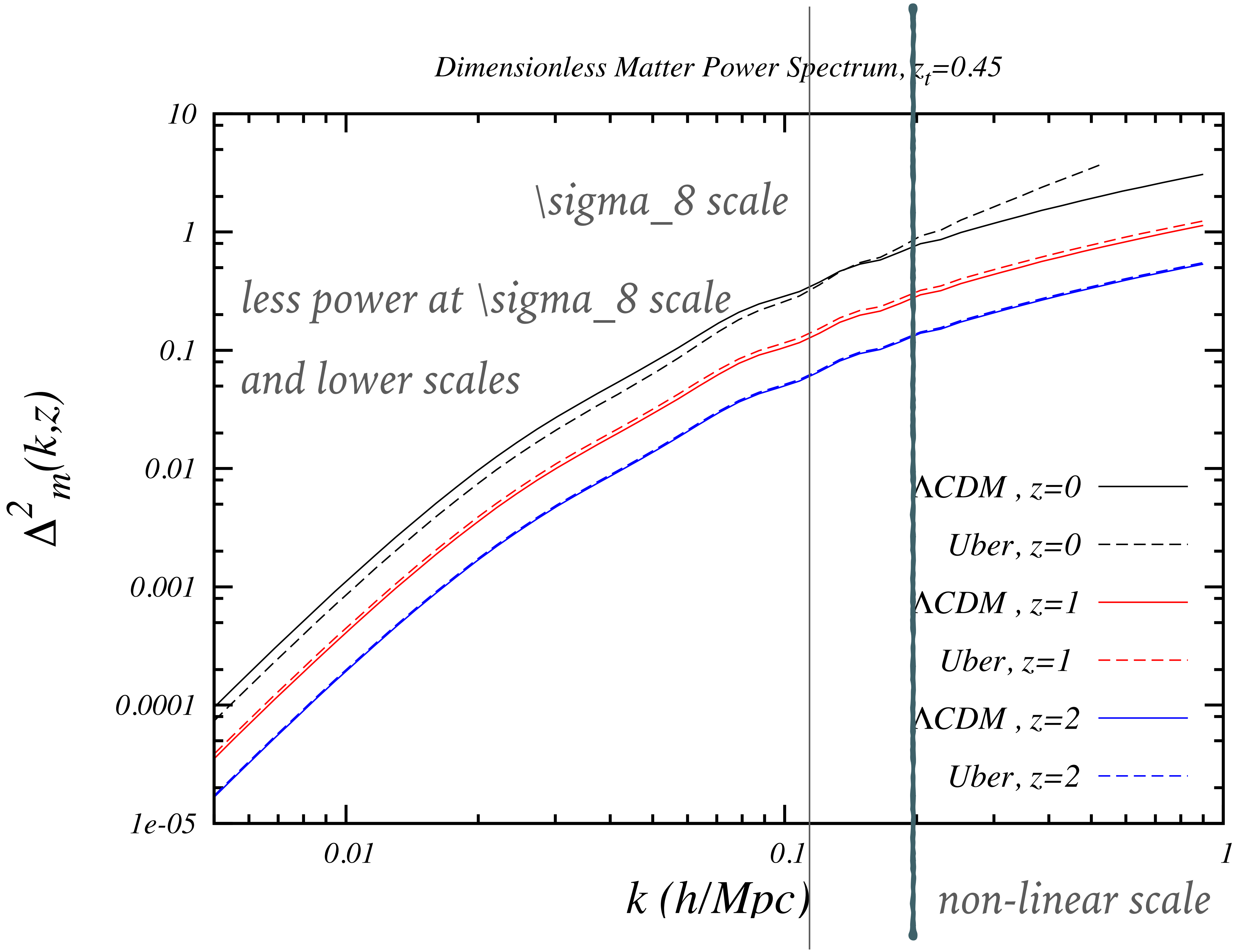
LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS



LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS



LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS



LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS

- \sigma_8 problem or less power problem?
- did "Lambda xor CDM" solve the \sigma_8 problem?
- note 1: we predict less power for \sigma_8 scale which is a good hint for our model!
- note 2: however we should be very careful that \sigma_8 scale is not well-defined in our model which predicts a

  <u>scale-dependent matter power spectrum!</u>

- note 3: we need to re-analyze all the data which gives \sigma_8 tension from scratch in our model.

✓ H_0 tension

? \sigma_8 tension

? void phenomenon

? missing satellite problem

Lambda xor CDM (linear perturbation analysis)

(Uber-Gravity)


✓ H_0 tension
? \sigma_8 tension
? void phenomenon
? missing satellite problem
Lambda xor CDM
(background, linear perturbation and non-linear analysis)
(Uber-Gravity)
? a fundamental way to define probabilities