Title: Uber-Gravity and H0 tension

Date: Aug 29, 2017 11:00 AM

URL: http://pirsa.org/17080076

Abstract: Recently, the idea of taking ensemble average over gravity models has been introduced. Based on this idea, we study the ensemble average over (effectively) all the gravity models dubbing the name uber-gravity which is a fixed point in the model space. The uber-gravity has interesting universal properties, independent from the choice of basis: i) it mimics Einstein-Hilbert gravity for high-curvature regime, ii) it predicts stronger gravitational force for an intermediate-curvature regime, iii) surprisingly, for low-curvature regime, i.e. R<R0 where R is Ricci scalar and R0 is a given scale, the Lagrangian vanishes automatically and iiii) there is a sharp transition between low- and intermediate-curvature regimes at R=R0.
Finally, we will study the cosmology of this model and argue it can reduce to a cosmology model named "either Lambda or CDM" which is even simpler than standard LCDM. This model can address H0 tension and is distinguishable from LCDM in its prediction for the perturbations.

UBER-GRAVITY AND H_0 PROBLEM

Nima Khosravi

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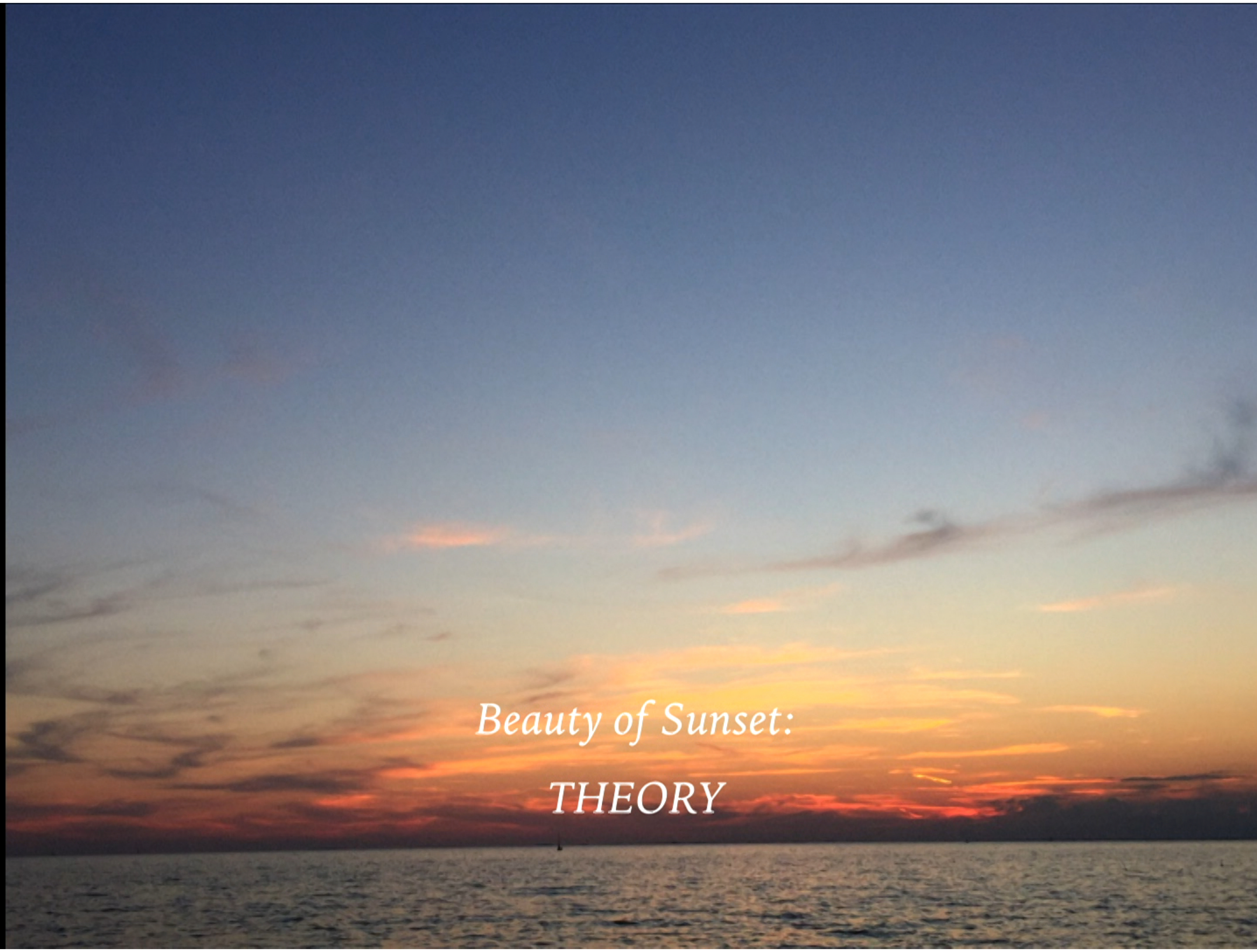
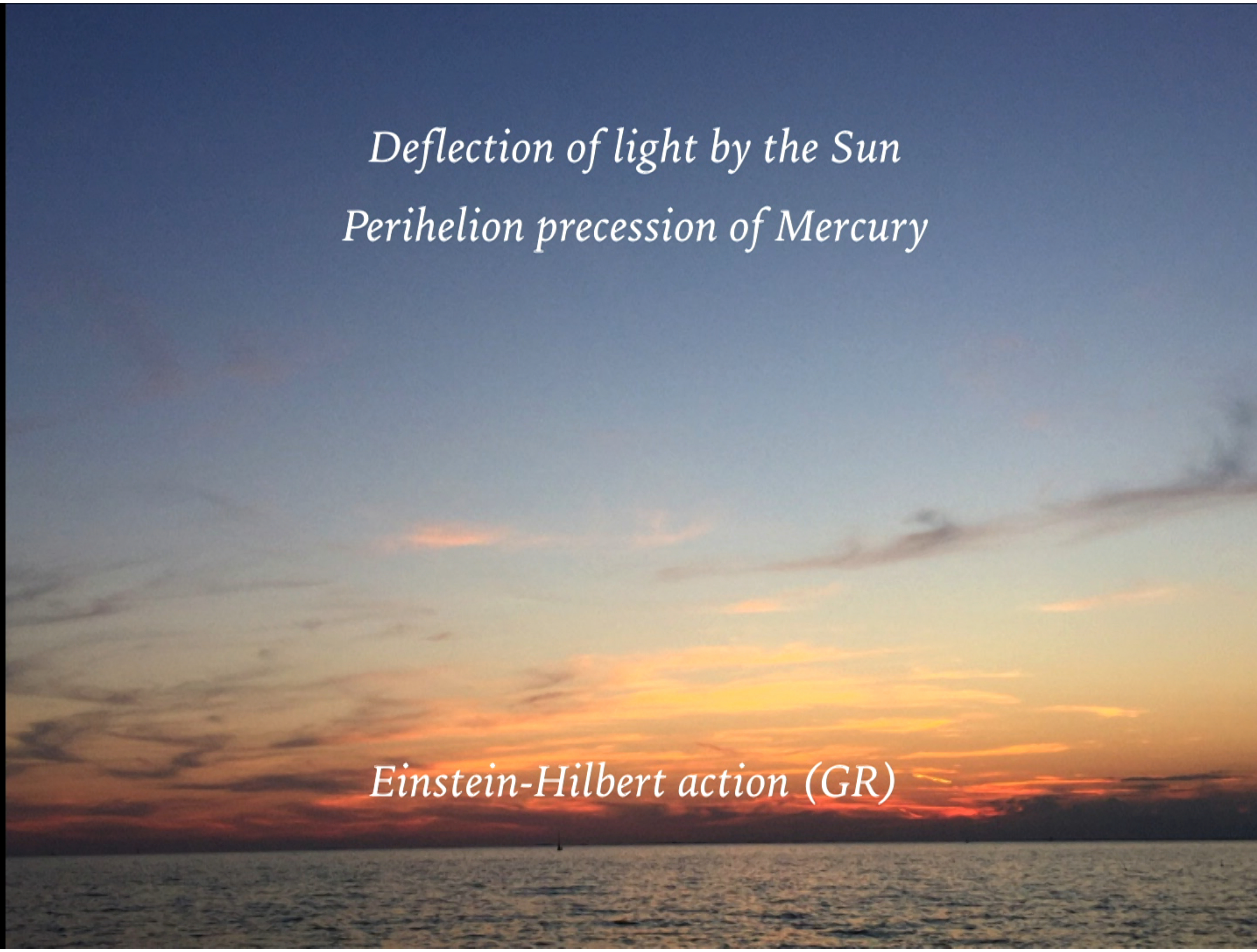
29 August 2017 — Perimeter Institute


Beauty of Sunset:
THEORY


Deflection of light by the Sun
Perihelion precession of Mercury
Einstein-Hilbert action (GR)


Late-time acceleration
GR cannot explain it?
so we modify GR by adding a cosmological constant


Lambda and CDM


? H_0 tension
? \sigma_8 tension
? void phenomenon
? missing satellite problem
Lambda and CDM
? the cosmological constant problem
? why GR should govern gravity force

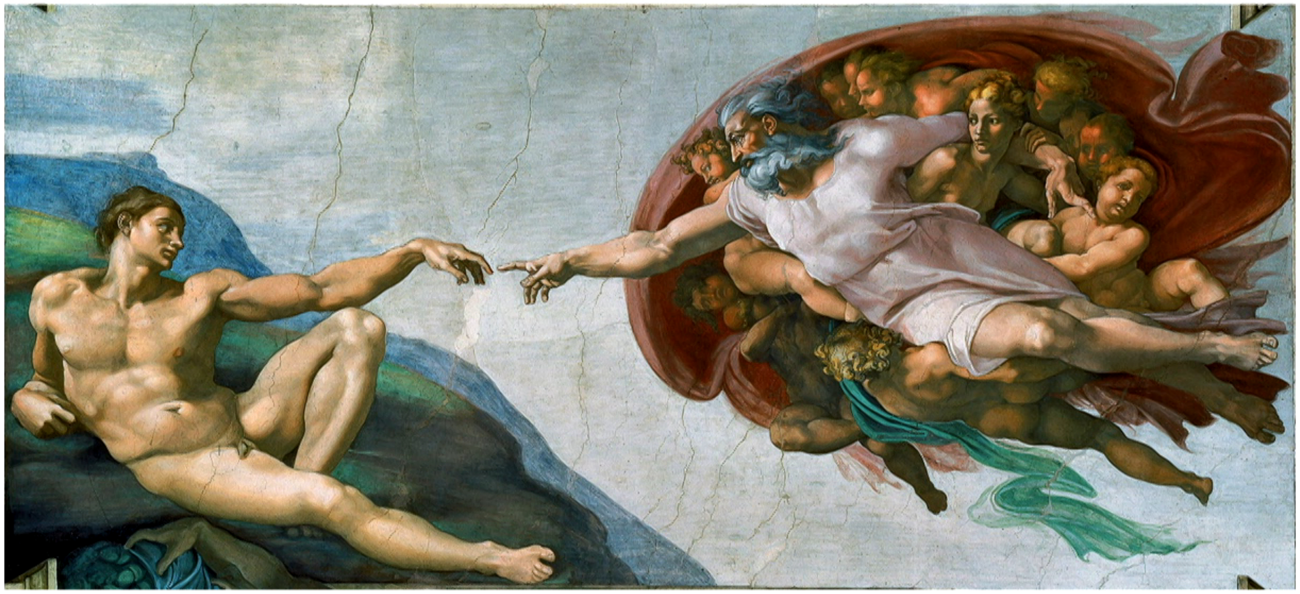
ENSEMBLE AVERAGE THEORY OF GRAVITY

- A. Einstein:

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

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

the creation of Adam, Michelangelo:



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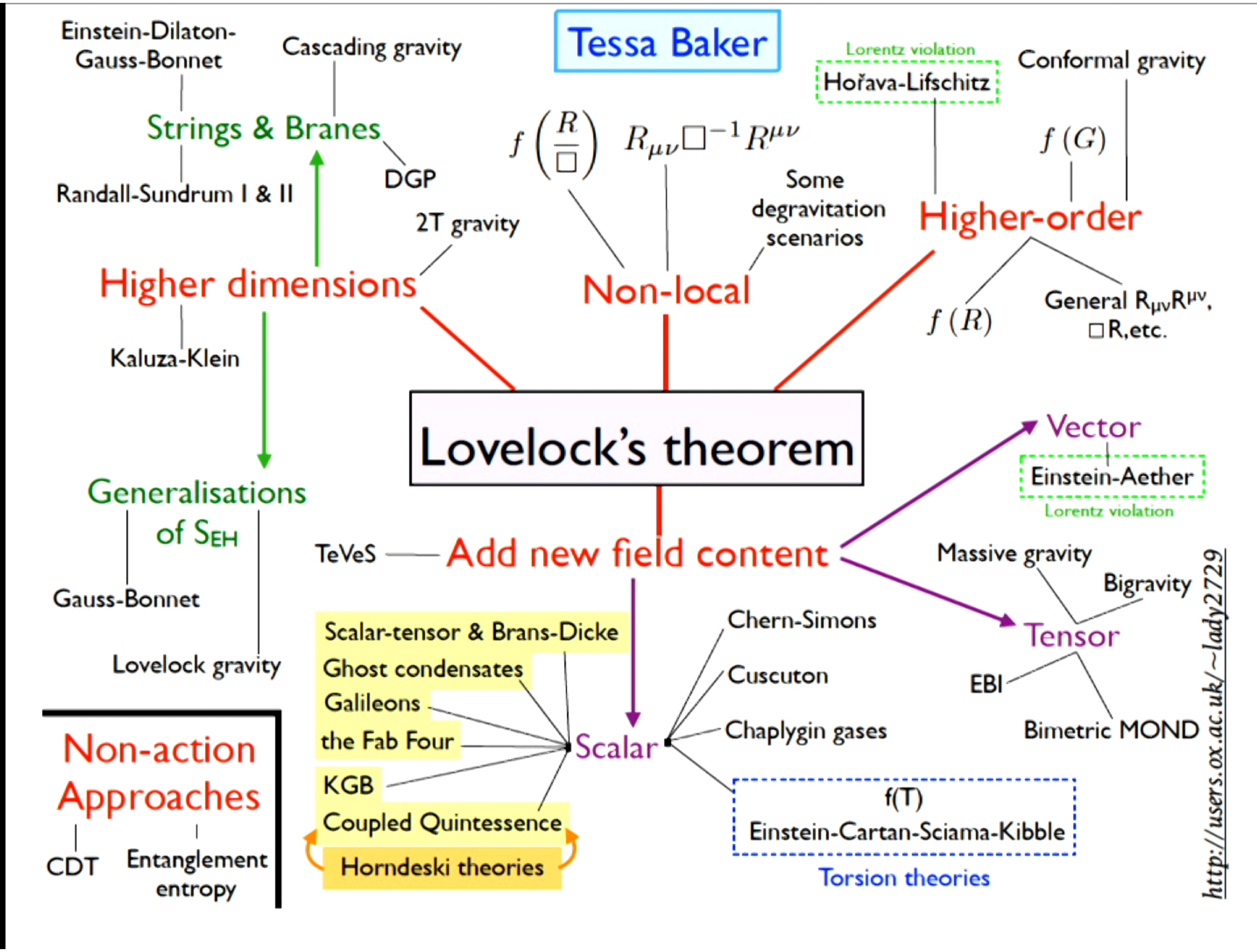


Tessa Baker
Einstein-Dilaton-Gauss-Bonnet
Cascading gravity
Strings & Branes
Randall-Sundrum I & II
DGP
2T gravity
Higher dimensions
Kaluza-Klein
Generalisations of S_{EH}
Gauss-Bonnet
Lovelock gravity
$f\left(\frac{R}{\Box}\right)$
$R_{\mu\nu}\Box^{-1}R^{\mu\nu}$
Some degravitation scenarios
Non-local
Lorentz violation
Hořava-Lifschitz
Conformal gravity
$f(G)$
Higher-order
$f(R)$
General $R_{\mu\nu}R^{\mu\nu}$, $\Box R$, etc.
Lovelock's theorem
Vector
Einstein-Aether
Lorentz violation
TeVeS
Add new field content
Massive gravity
Bigravity
Tensor
EBI
Bimetric MOND
Scalar-tensor & Brans-Dicke
Ghost condensates
Galileons
the Fab Four
KGB
Coupled Quintessence
Horndeski theories
Scalar
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"!

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

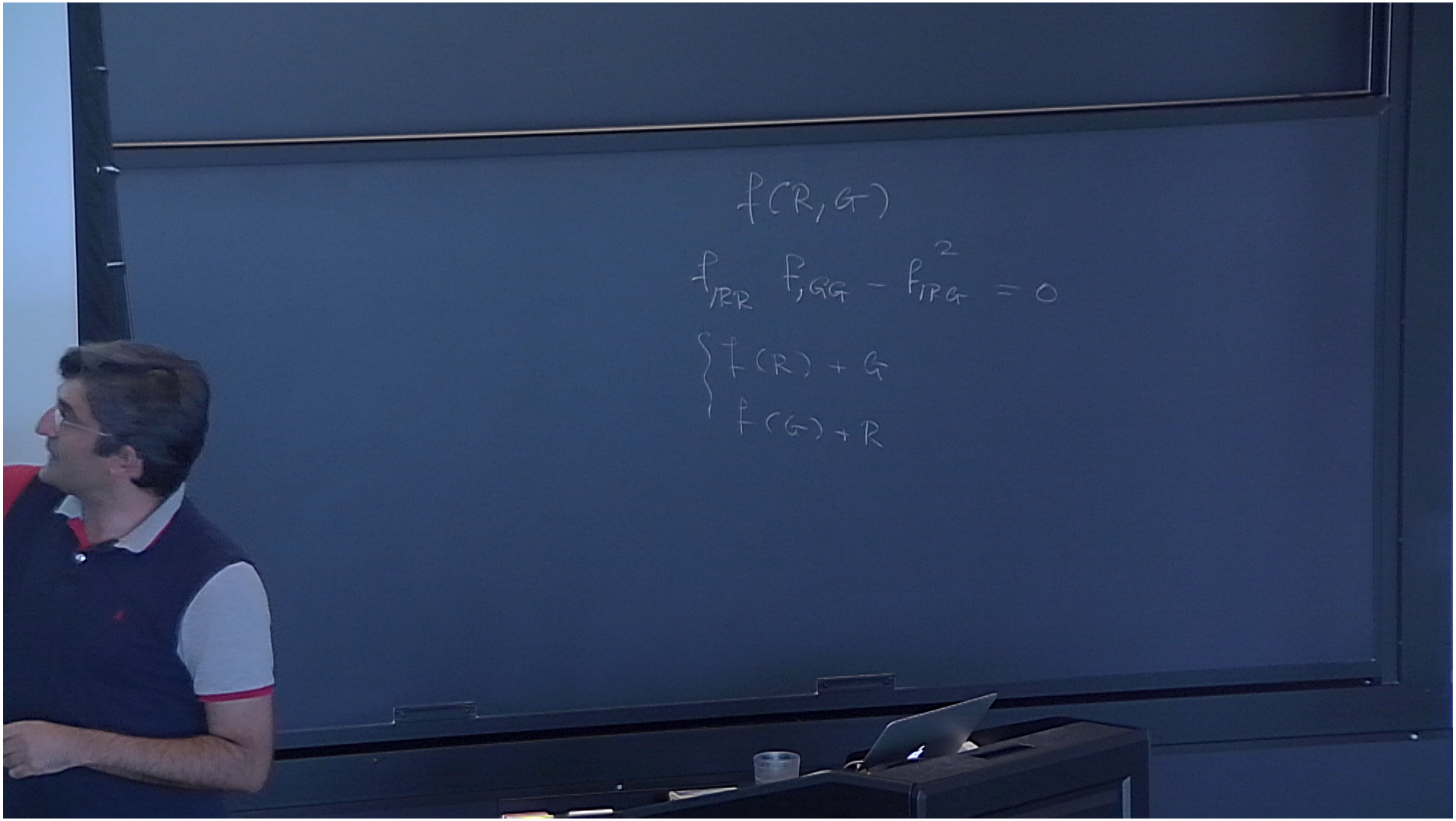
- an example: higher order gravity
- in 4-dimension we have Ricci scalar and Gauss-Bonnet term

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

Ricci scalar

Gauss-Bonnet term

temperature of model space??


$f(R, G)$
$f_{,RR} f_{,GG} - f_{,RG}^2 = 0$
$f(R) + G$
$f(G) + R$

ENSEMBLE AVERAGE THEORY OF GRAVITY

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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

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

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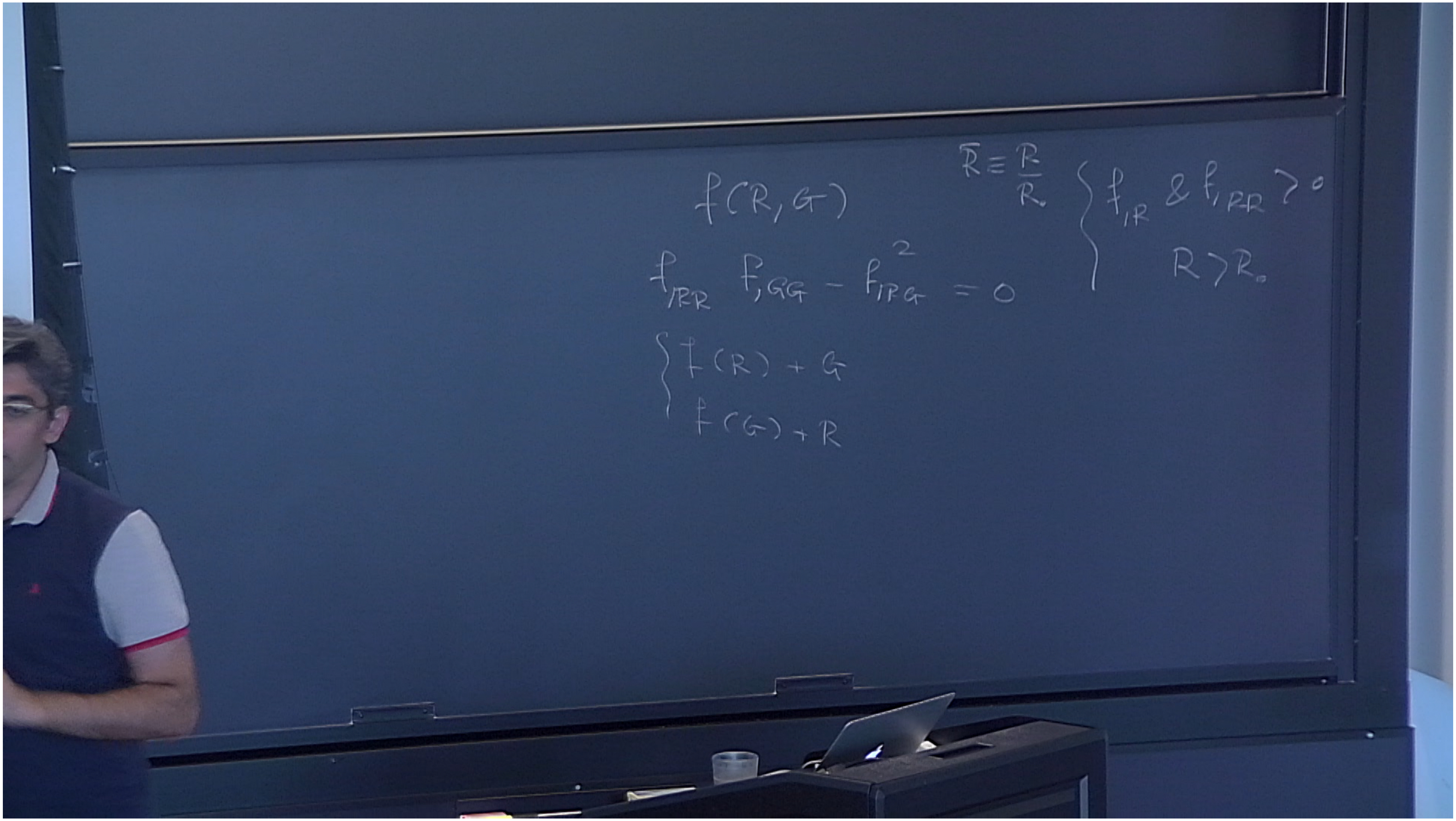
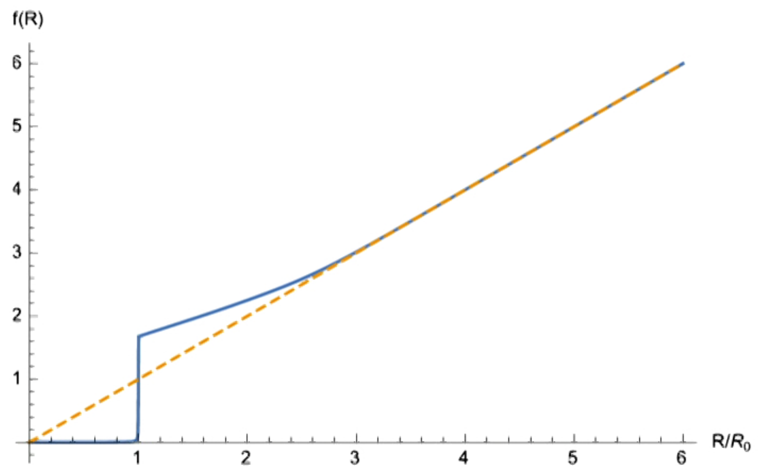
$$\mathcal{L} = \left(\sum_{n=1}^{\infty} \bar{R}^n e^{-\beta \bar{R}^n} \right) \Big/ \left(\sum_{n=1}^{\infty} e^{-\beta \bar{R}^n} \right)$$


f(R, G)
f,RR f,GG − f,RG² = 0
{ f(R) + G
f(G) + R
R̄ ≡ R / R₀
{ f,R & f,RR > 0
R > R₀

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



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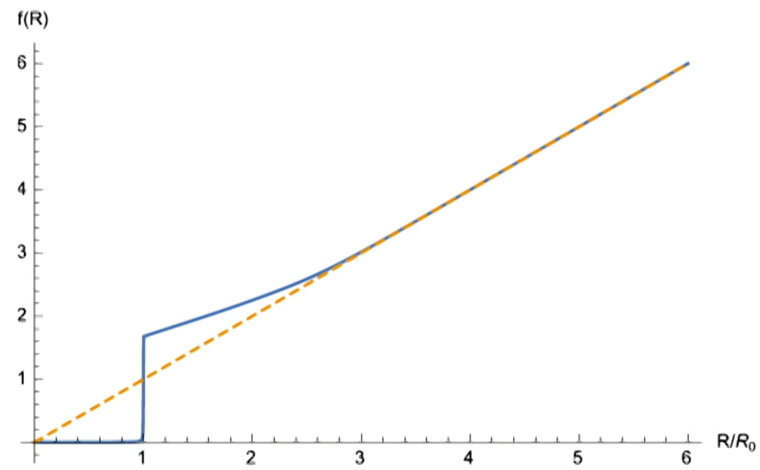


UBER-GRAVITY: A SIMPLIFIED MODEL

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

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 $n \longrightarrow \infty$ results in $R \rightarrow R_0$!!

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


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

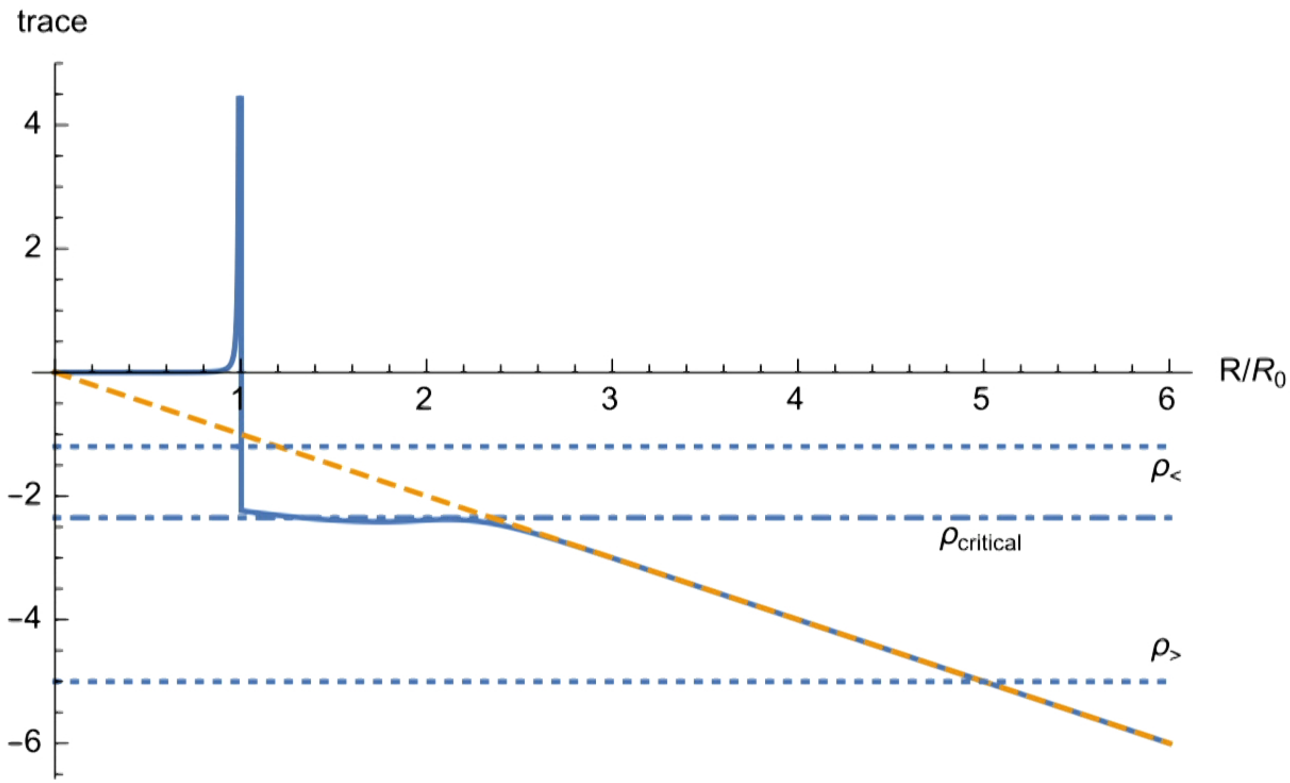
LAMBDA XOR CDM MODEL:

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:

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

which is dubbed as "either Lambda or CDM":

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

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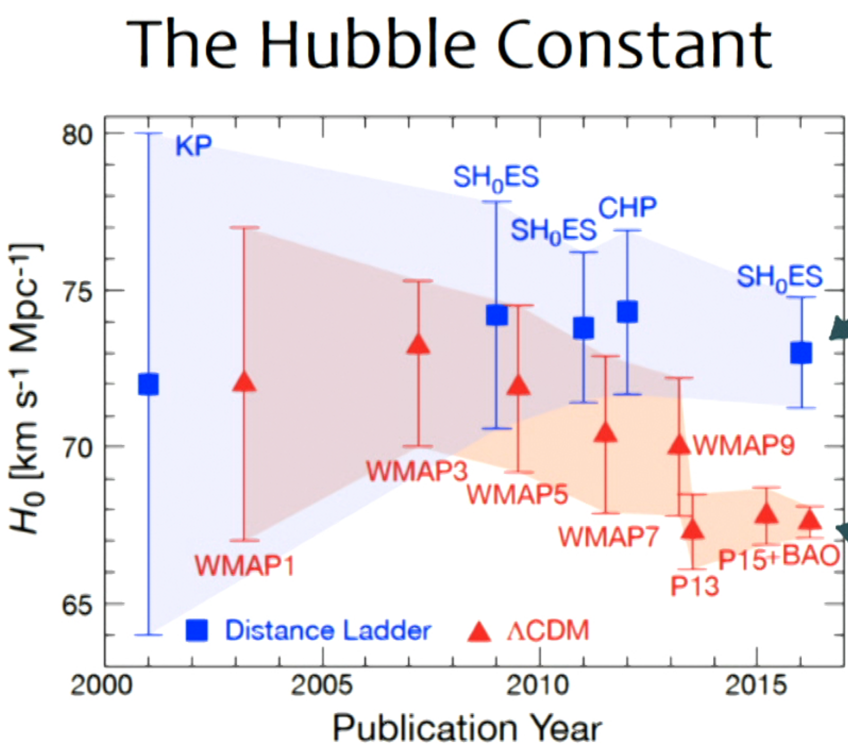
LAMBDA XOR CDM MODEL: BACKGROUND



low-redshift

i.e. SN

high-redshift

i.e. CMB

Freedman 2017
Beaton et al. 2016

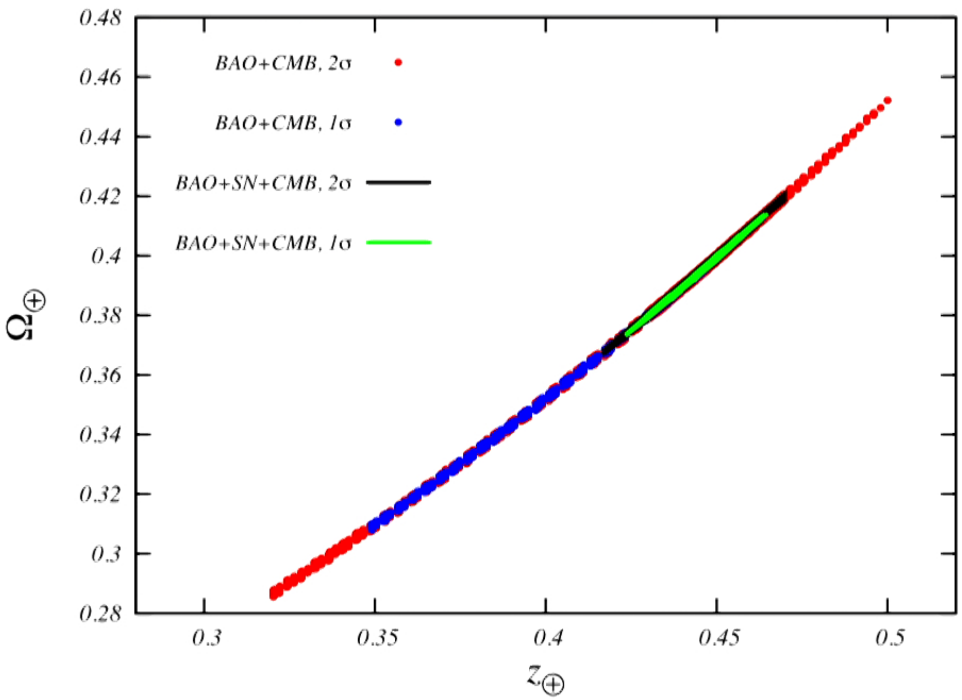
LAMBDA XOR CDM MODEL: BACKGROUND

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

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

LAMBDA XOR CDM MODEL: BACKGROUND

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



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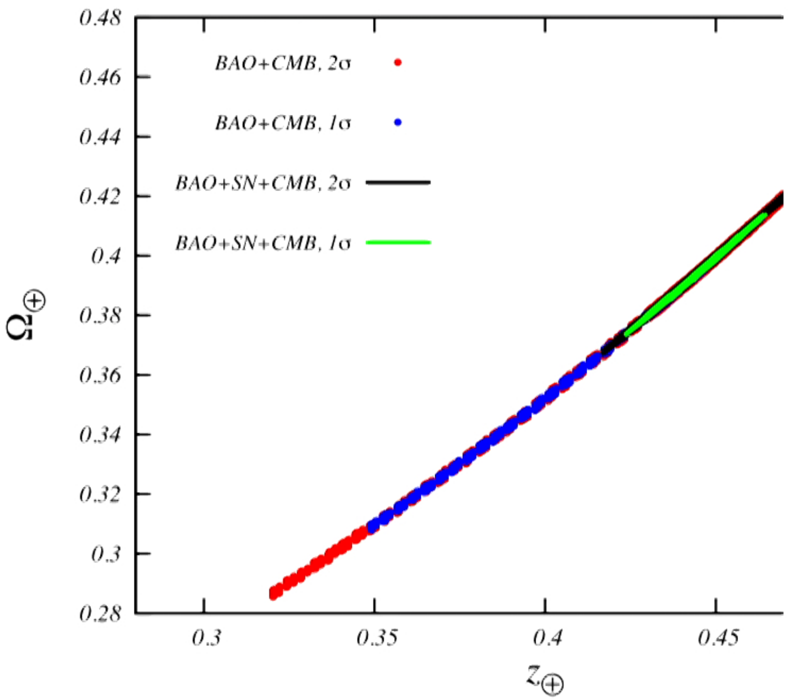

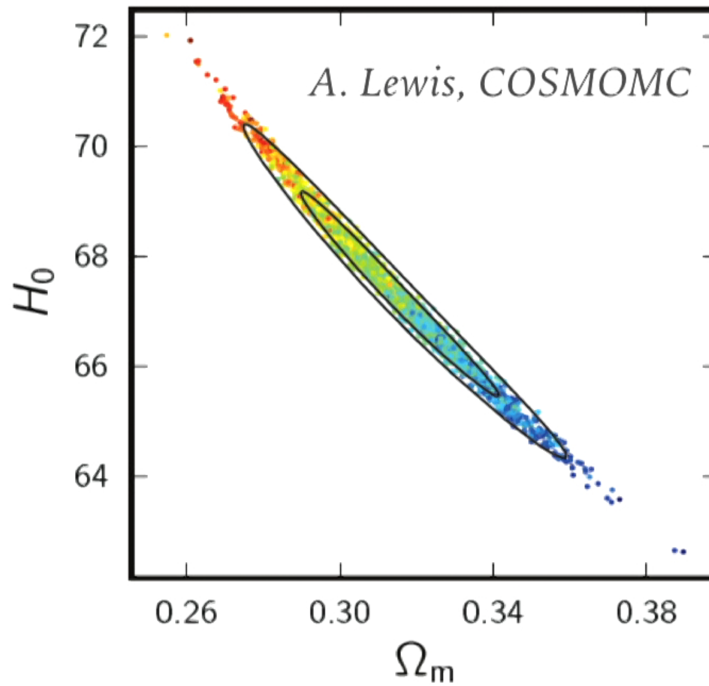

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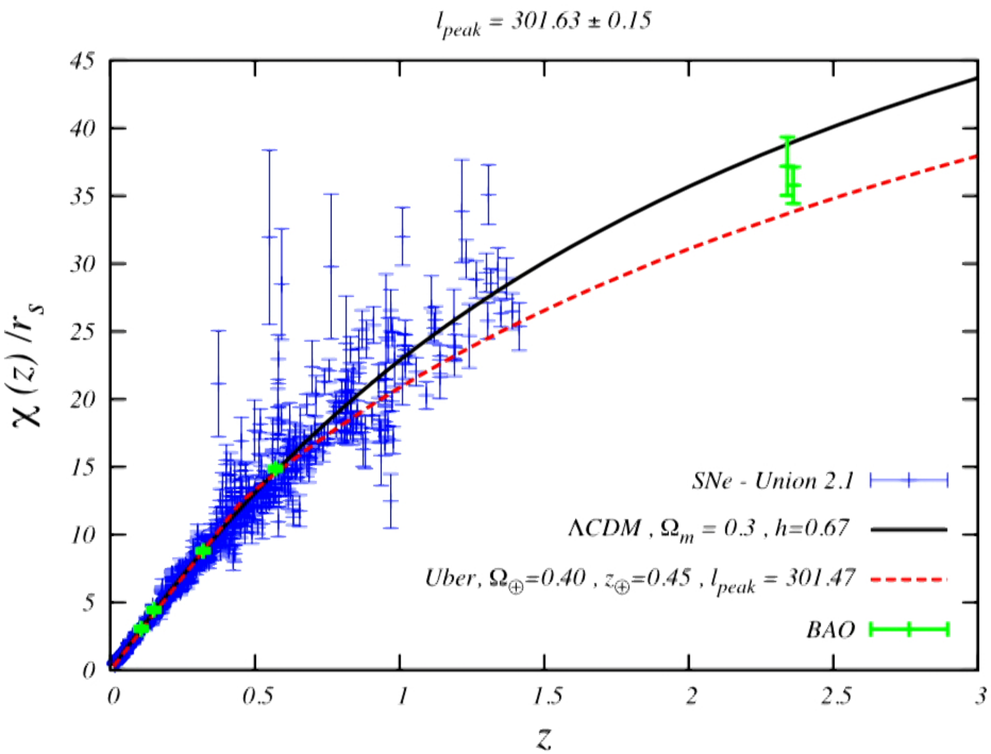
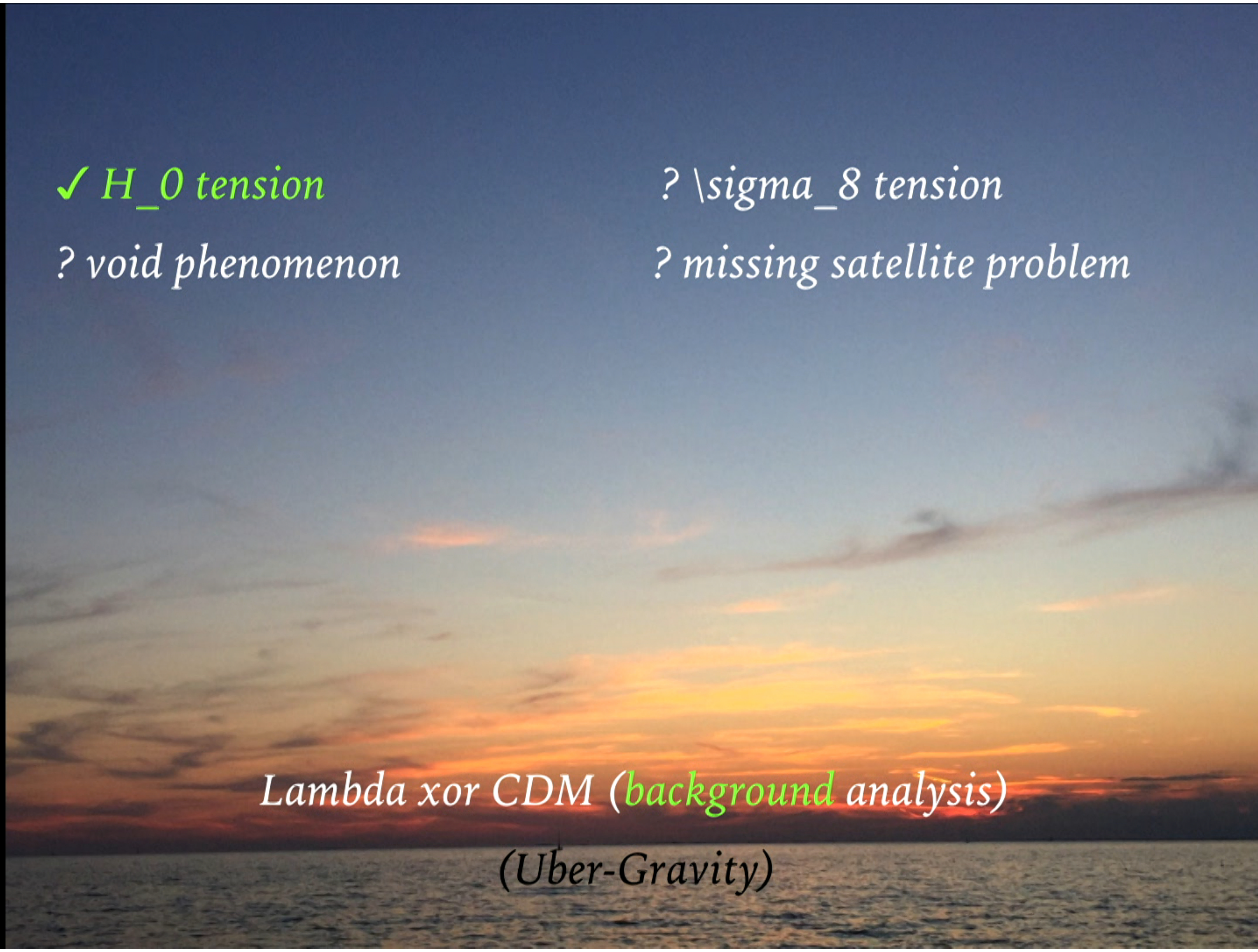


LAMBDA XOR CDM MODEL: BACKGROUND

- 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!

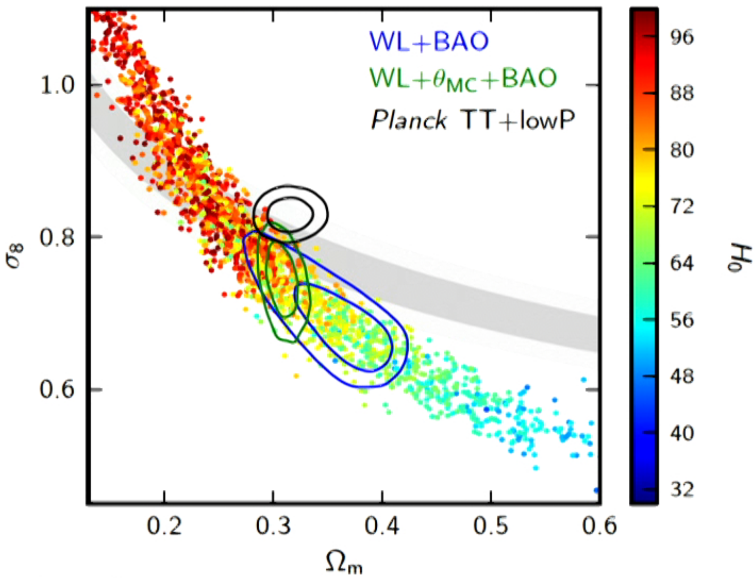
- LxorCDM automatically solves H_0 problem which was not obvious at the first look!


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

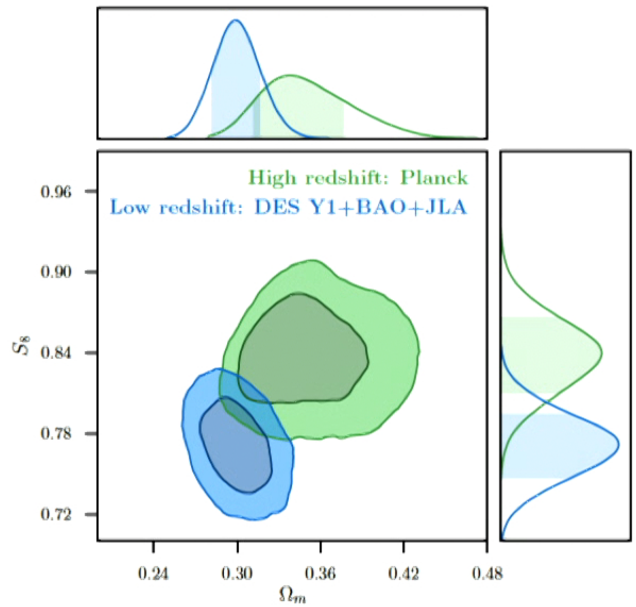
LAMBDA XOR CDM MODEL: LINEAR PERTURBATIONS

- \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:

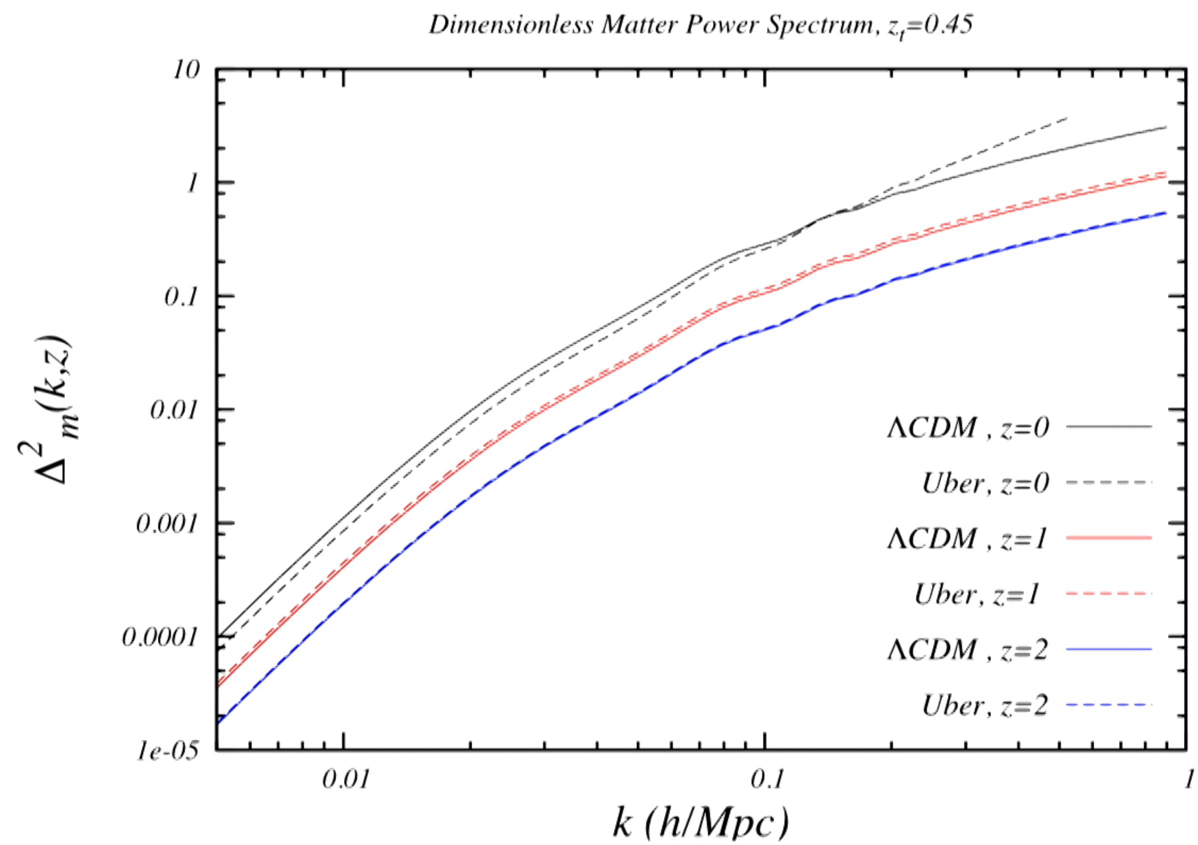
$$\bar{\rho}(z)\left[1+\delta(k,z)\right]=\rho_{critical}$$

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



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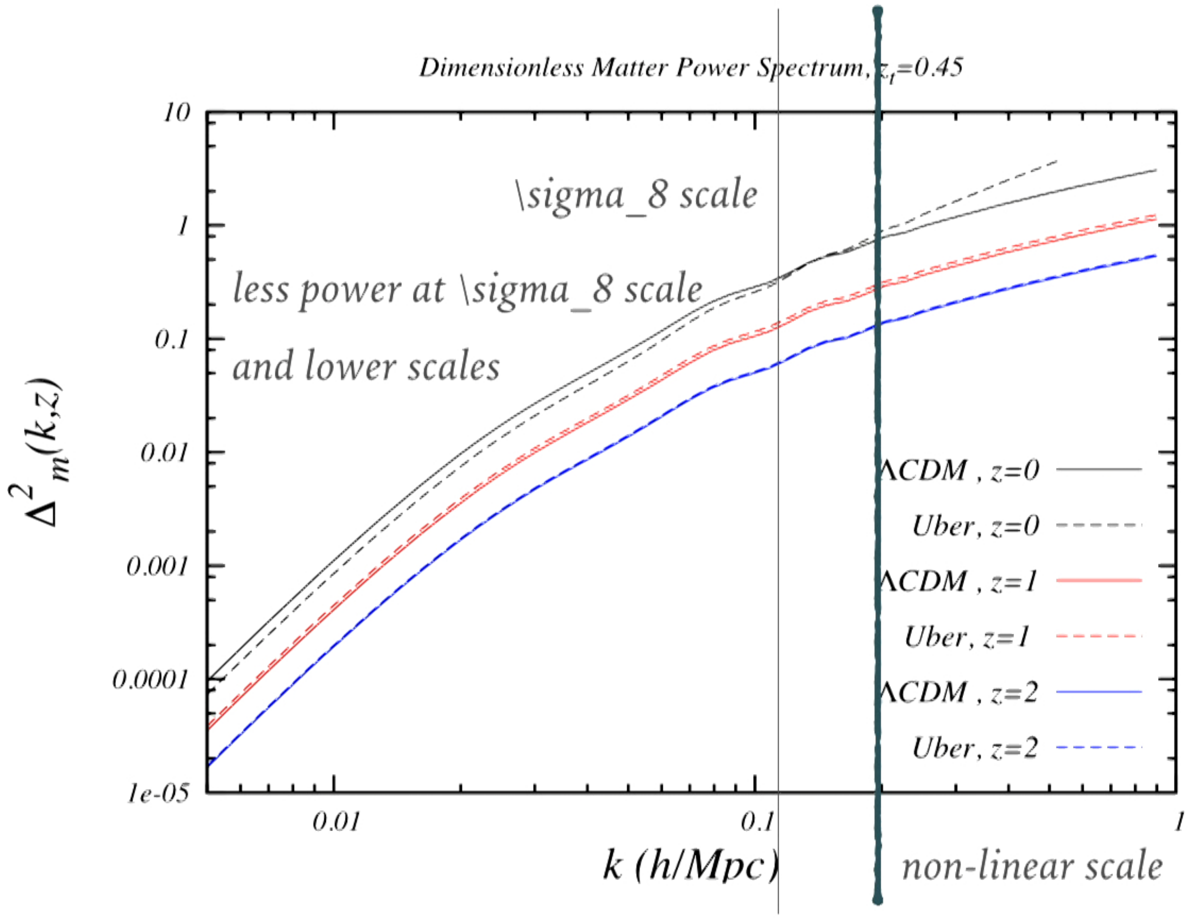


✓ H_0 tension
? \sigma_8 tension
? void phenomenon
? missing satellite problem
Lambda xor CDM
(background, linear perturbation and non-linear analysis)
(Uber-Gravity)
? a fundamental way to define probabilities

Lambda and CDM (vanilla)

vs.

Lambda xor CDM (chocolate)

✓ H_0 tension

? \sigma_8 tension

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Lambda xor CDM

(background, linear perturbation and non-linear analysis)

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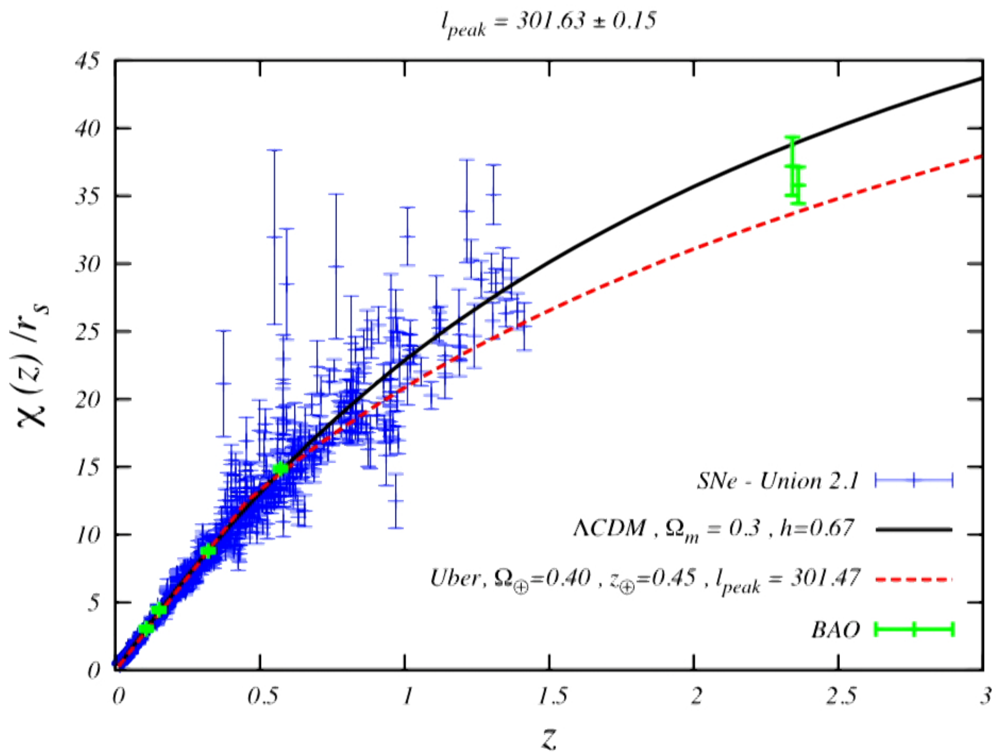

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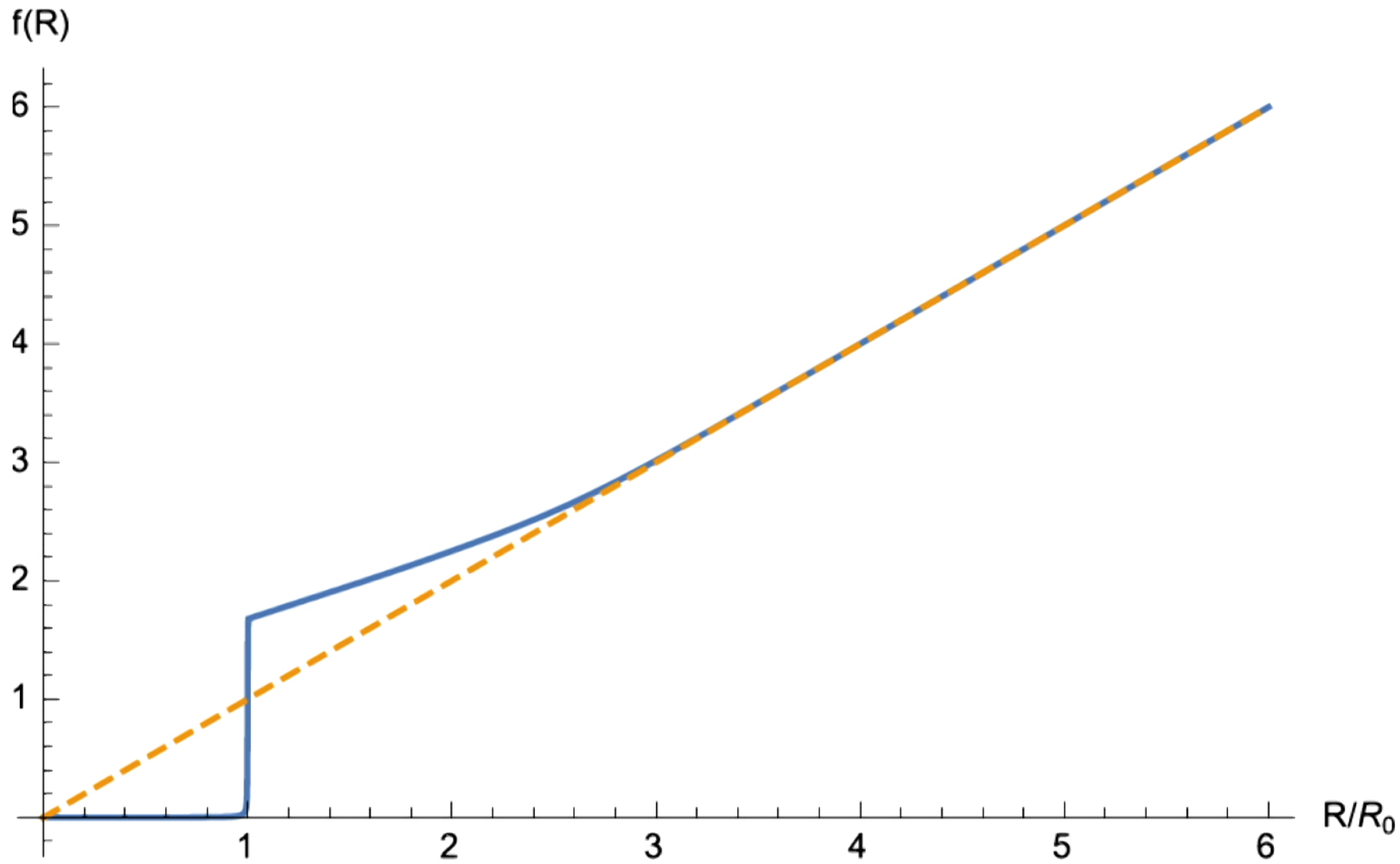
UBER-GRAVITY



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