Restitution talk on the String-Cosmo Day

David Andriot

LAPTh, CNRS, Annecy, France

GDR CoPhy Episode 2

21/05/24
IP2I, Lyon

Setting the stage

String-Cosmo Day: one day meeting bringing together **String Theorists** and **Cosmologists**

APC Paris, 28th November 2023, 9:00 – 18:00, https://indico.in2p3.fr/event/30602/

Organisers: David Andriot, Francesco Nitti, Vivian Poulin

Funding: GdR CoPhy, ERC, APC, LUPM

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48 participants, ~ 55 % string theorists

(nearby event: Deconstructing the String Landscape, IPhT, Saclay)

Speakers and discussion conveners:

Julien Larena
Marco Raveri
Sébastien Renaux-Petel
Nils Schöneberg (review)
Danièle Steer (discussion)

Fernando Quevedo (discussion)
Gary Shiu
Dimitrios Tsimpis
Irene Valenzuela (review)

Scientific motivations

Since BICEP2 (2014) and the Swampland de Sitter Conjecture (2018) and DESI (2024):

⟶ important activity / renewed interest in **string theory** to **derive cosmological models**

1. Inflation
2. Cosmological constant / de Sitter solutions (dark energy)
3. Quintessence (dynamical dark energy)

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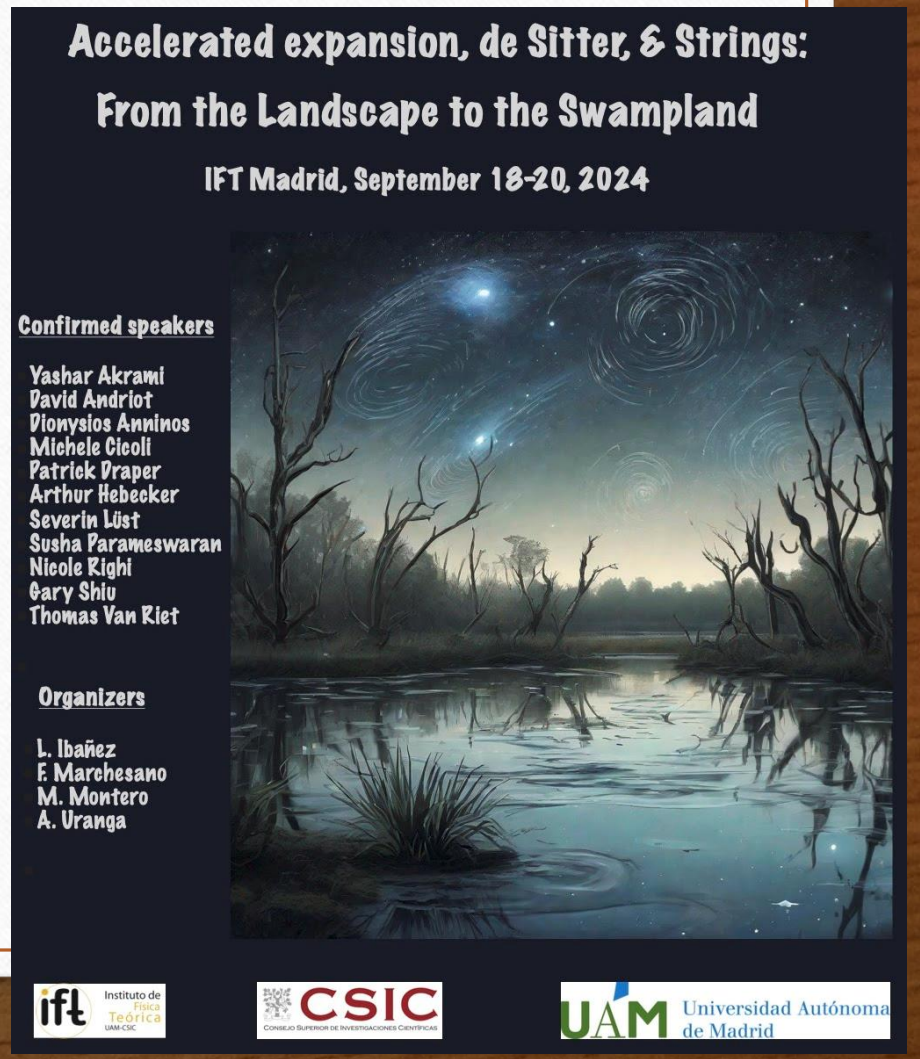

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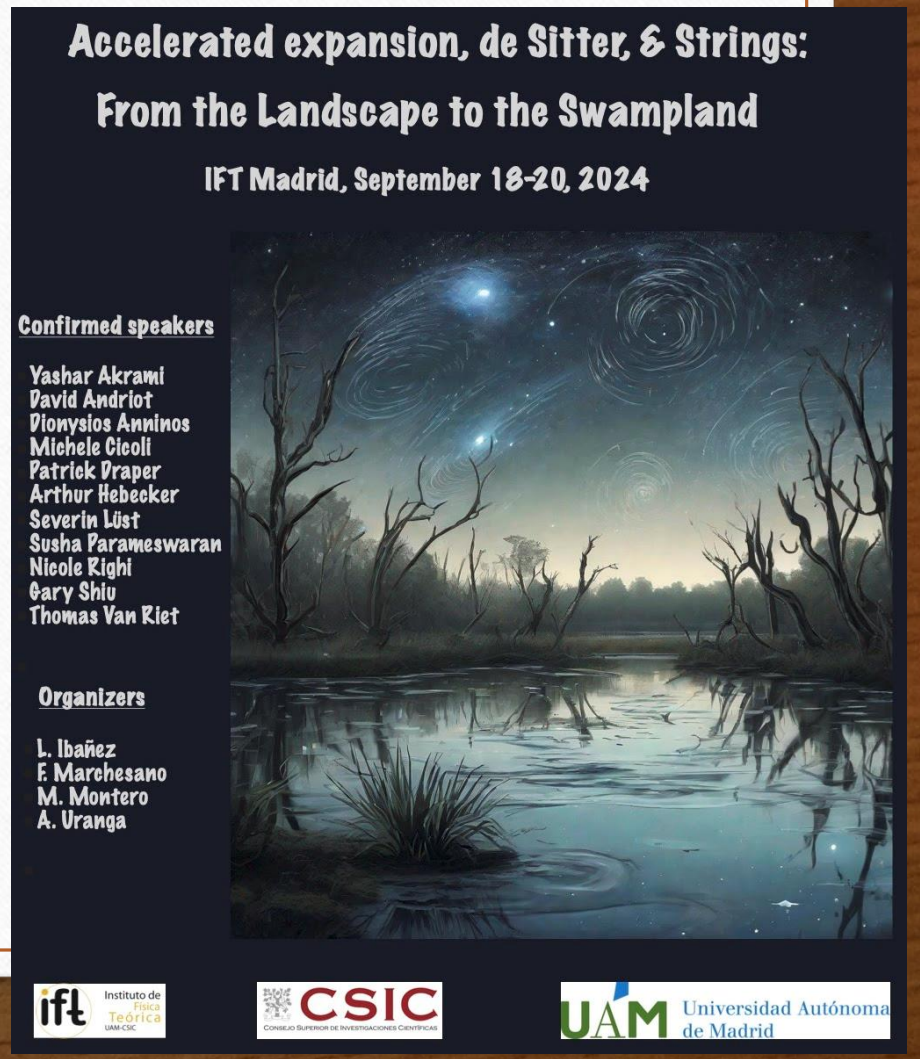
+ difficult to get observationally valid models

Rather on the edge of ok ⟶ Need to talk to cosmologists!



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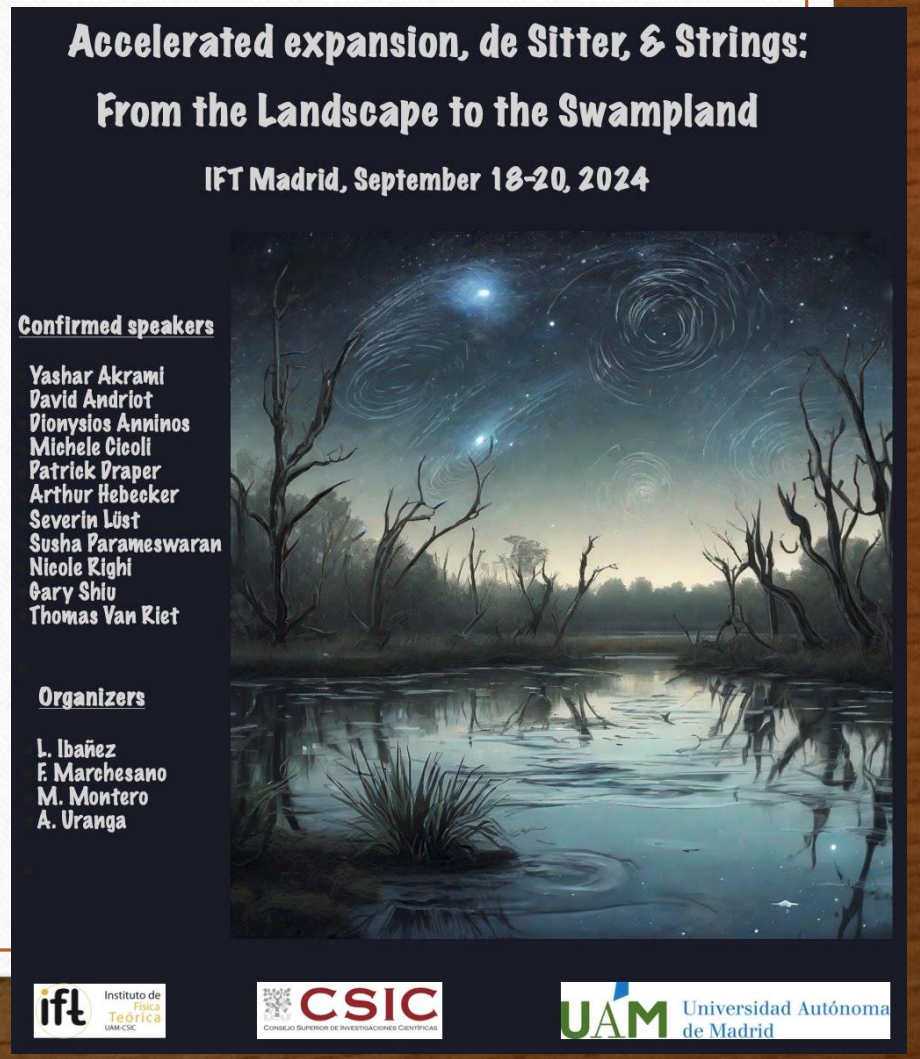
Cosmologists:

- Informed of string theory attempts/constraints on models

- General questions and curiosity (see discussion session)



Topics and results

Interested in cosmological models
derived from string theory,
of the form:

String Theory

↓

4d EFT: $\int \mathrm{d}^4x\sqrt{|g_4|}\left(\frac{M_p^2}{2}\mathcal{R}_4 - \frac{1}{2}g_{ij}\partial_\mu\varphi^i\partial^\mu\varphi^j - V(\varphi^k)\right)$

Gravity, minimally coupled to scalar fields φ^i, with scalar potential $V(\varphi^k)$

⟶ **inflation**, **dark energy** (cosmo. constant: $V = \Lambda\, M_p^2$, quintessence)

(no matter, no radiation)

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Note: simple model, no Horndeski etc.

More constraints: what $V(\varphi^k)$ do we get?

(shape: hilltop, exponential, etc. ; values of ϵ_V, η_V …)

One answer: model by model, example based

General characterisation: Swampland program

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  You cannot get anything (any model) from string theory / quantum gravity

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  Main constraints arise in asymptotic of field space: $\varphi \to \infty$

  (local/gauge symmetries become global ; cut-off of 4d EFT goes to 0 ; tower of light states appears)

  Constraint on scalar potential $V(\varphi^k)$: $\frac{\nabla V}{V} \geq \sqrt{2} \longleftrightarrow \epsilon_V \geq 1$ when $\varphi \to \infty$

  (Strong de Sitter Conjecture, no known counter-example)

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  Quintessence?

  Challenges for string cosmology!

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  Property of $V(\varphi^k)$ for $\varphi \to \infty$: why not exploring bulk of field space, not asymptotic?
  Because trustable region of $V(\varphi^k)$ in derivation (weak coupling regime), less sure of $V(\varphi^k)$ in bulk…

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  Swampland conjectures (de Sitter and distance conj.) and observational constraints

  Single field slow-roll inflation in tension ⟶ more complicated models (multifield…)

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Observations: $\lambda \leq 2$

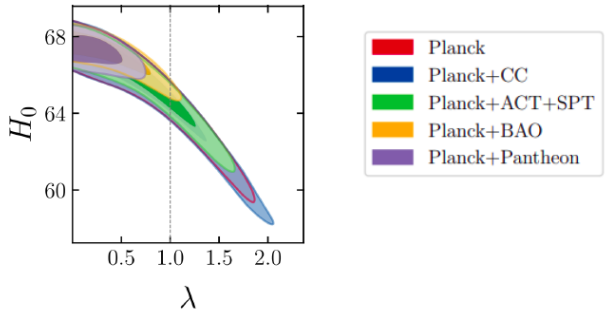
⟶ Tension, challenging (but not hopeless)

Nils Schöneberg nils.science@gmail.

From Theory to Practice

- Exponential:

$V(\phi) = V_0 \exp(-\lambda\phi)$



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Hilltop potential favored…

Coupling to matter…

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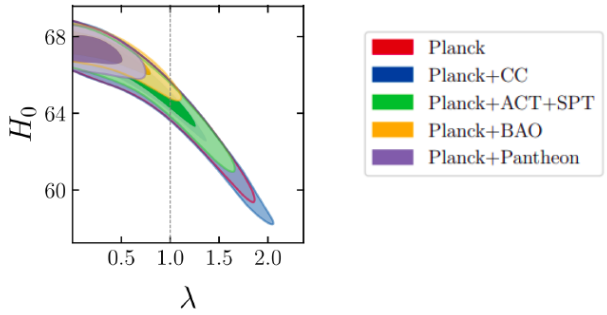

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- **Marco Raveri:** Lost in the Cosmological Swampland

  Similar topics and motivations: comparing observational constraints and swampland constraints

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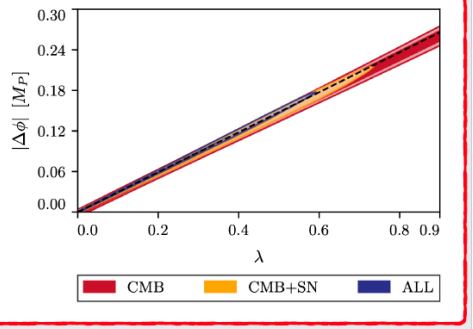
Initial constraints on string swampland

Hierarchy of constraints

Data set	λ 68% (95%) C.L.	$\lvert\Delta\phi\rvert$ $[M_P]$ 68% (95%) C.L.
CMB	$\lambda < 1.1\,(1.9)$	$\lvert\Delta\phi\rvert < 0.33\,(0.52)$
CMB + SN	$\lambda < 0.38\,(0.64)$	$\lvert\Delta\phi\rvert < 0.11\,(0.19)$
CMB + H_0	$\lambda < 0.29\,(0.56)$	$\lvert\Delta\phi\rvert < 0.08\,(0.16)$
ALL	$\lambda < 0.28\,(0.51)$	$\lvert\Delta\phi\rvert < 0.08\,(0.15)$

Data set	c 68% (95%) C.L.
CMB	$c < 2.3\,(3.1)$
CMB + SN	$c < 0.25\,(1.4)$
CMB + H_0	$c < 0.17\,(0.84)$
ALL	$c < 0.16\,(0.73)$



(MR, Wayne Hu, Savdeep Sethi, arXiv:1812.10448)

Marco Raveri 12

Similar constraints and challenge

Coupling to matter…

- **Gary Shiu:** Late-time Attractors and Cosmic Acceleration

  Multifield and multi-exponential case: $V = \sum_{a,i} V_{0a}\, e^{-\lambda_{ai}\,\varphi^i}$

  $\frac{\nabla V}{V} = \sqrt{2\,\epsilon}$ (not ϵ_V)

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- **Sébastien Renaux-Petel:** Seven lessons for inflationary model-builders (in string theory)

  (Multifield) inflation review + motivations/connections to string theory + 7 messages

  1. inflation by itself is not predictive in general!
  2. integrating out is not truncating
  3. curved field space matters (a lot)
  4. other ways to inflate than slow-roll
  5. inflation as a cosmological collider
  6. features are well motivated
  7. a lot to learn from dark era of inflation

- **Dimitrios Tsimpis:** Accelerated Expansion in an Open Universe

  Concrete string theory derivations giving $V = V_0\, e^{-\lambda\,\varphi}\ ,\ \lambda \geq \sqrt{2}$

  With (negative) **spatial curvature**: $\Omega_k > 0$

  Dynamical system analysis, various cosmological solutions

  ⟶ transient, (semi-) eternal acceleration

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  CMB-independent evaluation of Ω_k in ΛCDM + Ω_k

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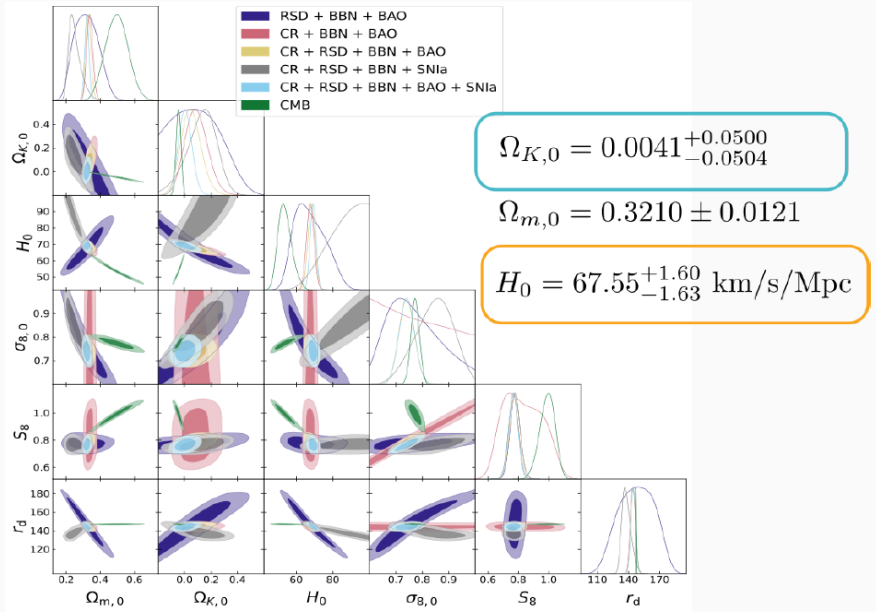
Clustering + Geometric probes



$\Omega_{K,0} = 0.0041^{+0.0500}_{-0.0504}$

$\Omega_{m,0} = 0.3210 \pm 0.0121$

$H_0 = 67.55^{+1.60}_{-1.63}$ km/s/Mpc

- Flat ΛCDM okay without CMB
- H_0 tension persists

Very useful day
(at least to me!)

Exponential
quintessence
+ curvature
+ string theory origin

Exponential Quintessence: curved, steep and stringy?

David Andriot[1], Susha Parameswaran[2], Dimitrios Tsimpis[3], Timm Wrase[4], Ivonne Zavala[5]

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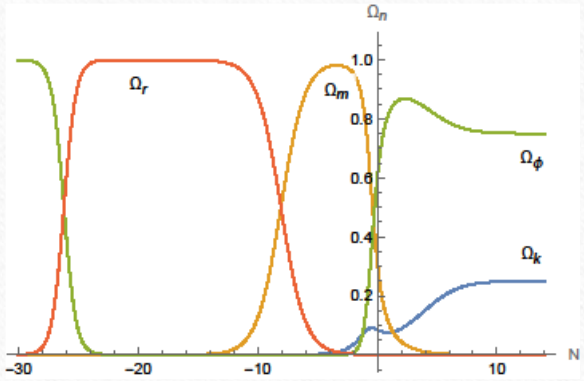
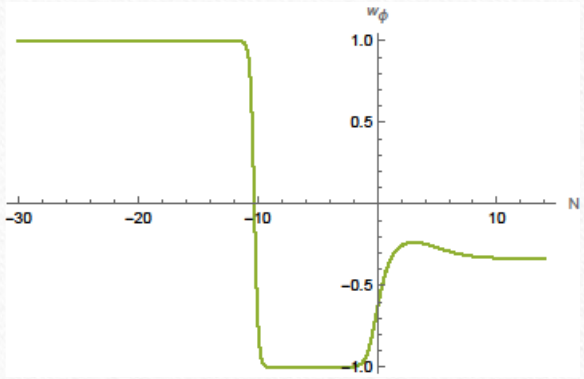
tsimpis@ipnl.in2p3.fr; timm.wrase@lehigh.edu;
e.i.zavalacarrasco@swansea.ac.uk

Abstract

We explore the possibility that our universe's current accelerated expansion is explained by a quintessence model with an exponential scalar potential, $V = V_0\, e^{-\lambda\phi}$, keeping an eye towards $\lambda \geq \sqrt{2}$ and an open universe, favorable to a string theory realisation and with no cosmological horizon. We work out the full cosmology of the model, including matter, radiation, and optionally negative spatial curvature, for all $\lambda > 0$, performing an extensive analysis of the dynamical system and its phase space. The minimal physical requirements of a past epoch of radiation domination and an accelerated expansion today lead to an upper bound $\lambda \lesssim \sqrt{3}$, which is driven slightly up in the presence of observationally allowed spatial curvature. Cosmological solutions start universally in a kination epoch, go through radiation and matter dominated phases and enter an epoch of acceleration, which is only transient for $\lambda > \sqrt{2}$. Field distances traversed between BBN and today are sub-Planckian. We discuss possible string theory origins and phenomenological challenges, such as time variation of fundamental constants. We provide theoretical predictions for the model parameters to be fitted to data, most notably the varying dark energy equation of state parameter, in light of recent results from DES-Y5 and DESI.





Discussion sessions

- **Fernando Quevedo & Danièle Steer:** Questions to cosmologists and to string theorists

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cosmologists → string theorists

1. • What are the concrete implications of string theory for cosmology?
2. • What cosmological observations would you like to see realised?
3. • What are the common features of string theory that are relevant for cosmology?
4. • Could string-theorists please decide if the CC is zero? Landscape = 10^500 dS vacua (??). Vafa = none with a
5. • Is the swampland rubbish or should it be taken seriously? It seems to have taken all the space in discussions (i
6. • Which is your favourite inflation model? And why?
   • Can string theory produce a realistic inflationary potential?
7. • Does string theory rule out inflation? Or does todays inflation (dark energy) rule out string theory?
8. • Can string theory tell us anything about the initial conditions for inflation ?
9. • Can string theory tell us anything about the transplanckian problem? What should be do under the P
   • How many scalar fields do you expect?
10. • If you take the low energy limit of some QG theory, do you always get a classical GR background
11. • Can string theory help us produce bounces?
12. • Can string theory give us information on the big-bang singularity?
13. • What about holography, loop QG and their predictions for cosmology? Differences with str
14. • Should one believe there are cosmic strings in string theory?

cosmologists ← string theorists

1. Should we trust each of the different tensions, H_0, σ_8, etc.?
2. Best expectations for future observations for say r, non-gaussianities, etc.
3. Attitude about ultra-light scalars and screening mechanisms
4. Do you prefer de Sitter vacuum (cosmological constant) or rolling field?
5. Can unstable de Sitter be fine for today's dark energy?
6. What are the bounds on ε_V for quintessence? Is this altered in a multifield scenario?
7. Is it ok to have spatial curvature (Ω_k, k= -1 or +1)? Will we ever know?
8. What is the scalar field in early dark energy models? Any constraint on it?
9. How interesting is for you if after inflation there are other epochs (kination, moduli domination, etc.)
10. How much importance you give to search for gravitational waves of high frequency (e.g. Giga Hertz).
11. How seriously you take alternatives to inflation inspired by string theory?
12. What is the most fruitful direction to concentrate during the next 5,10,100 years?

Topics discussed:

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Hubble tension
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An enjoyable, informative and useful meeting !

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