Cosmology and String Theory

Discussion Session at STRINGS 2021

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Cosmology • Requires de Sitter vacua
• Time as an emergent dimension
• Precision data: CMB, LSS

String Theory • Inflationary models are UV sensitive
• String theory motivates novel EFTs
• Signatures: B-modes, non-Gaussianity
The Standard Model

A **simple** 5 parameter model fits all observations:

\[ \Omega_b, \Omega_m, \Omega_\Lambda, A_s, n_s \]

It is a **strange** model because none of these parameters are well understood.

- Dark energy and inflation are UV sensitive (see de Sitter discussion).
- Quantum gravity is the conceptual foundation of cosmology.

→ An opportunity for string theory.
The Hubble Tension

There is a persistent disagreement in measurements of the Hubble constant:

\[ H_0 = 67.4 \pm 0.5 \]

\[ 74.0 \pm 1.4 \]

New physics or systematic errors?

“Any theory that can account for all the facts is wrong, because some of the facts are always wrong.”  Francis Crick
The Hubble Tension

Hard to explain with new physics:

\[ \theta = \frac{r_s}{D} \]

- Sound horizon at recombination
- Distance to last-scattering

Angular separation of peaks in the CMB spectrum

\[ D = \int_{0}^{z*} \frac{dz}{H_0 \sqrt{\Omega_m (1 + z)^3 + \Omega_\Lambda}} \]

• Needed: 10% reduction of the sound horizon.
• Hard to achieve without messing up the CMB.
The early universe probes **high energies** and **weak couplings**:

String theory is relevant in both regimes.
Cosmological Correlations

High-energy physics is encoded in cosmological correlations:

• What is the space of consistent correlations?
• What does string theory predict for these correlations?
• What is natural in string theory? (but maybe surprising in EFT?)
Unique Challenges of Cosmology

- Time (not space) may be emergent.
- Boundary theory is not Lorentz-invariant.
- Boundary theory is not unitary.
- Interactions are scale, but not conformally invariant.
- Lack of rigorous nonperturbative observables.
Recent Progress

Improved understanding of the analytic structure of cosmological correlators:

- Correlators can be built from scattering amplitudes.
- Singularities are connected by differential equations and unitarity constraints.

Arkani-Hamed and Maldacena [2015]
Arkani-Hamed, Benincasa and Postnikov [2017]
Arkani-Hamed, DB, Lee and Pimentel [2018]
Sleight and Taronna [2019]
Goodhew, Jazayeri and Pajer [2020]
DB, Chen, Duaso Pueyo, Joyce, Lee and Pimentel [2021]
Unique Opportunities of Cosmology

Many upcoming CMB and LSS observations:

- Atacama Desert
- South Pole
- CMB Stage 4
- SphereX
- Euclid
### Questions and Discussion Topics

#### Observational

- What are the prospects of future observations?
- What are the main observational challenges? Amenable to theoretical contributions (EFT, ML, …)?
- What are key targets for future observations?
- Is the Hubble tension real?

#### Phenomenological

- What are important effects of the UV completion?
- How do we systematically study non-Gaussianity?
- How to make the most of B-mode measurements?
- How do we further test inflation?

#### Conceptual

- Do insights from the S-matrix / conformal bootstrap have implications for cosmology?
- How does string theory behave in generic (time-dependent) backgrounds?
- Can insights from cosmological holography impact real observables in cosmology?
- Do insights into the BH information paradox have implications for cosmology?
- …