A timeless history of time

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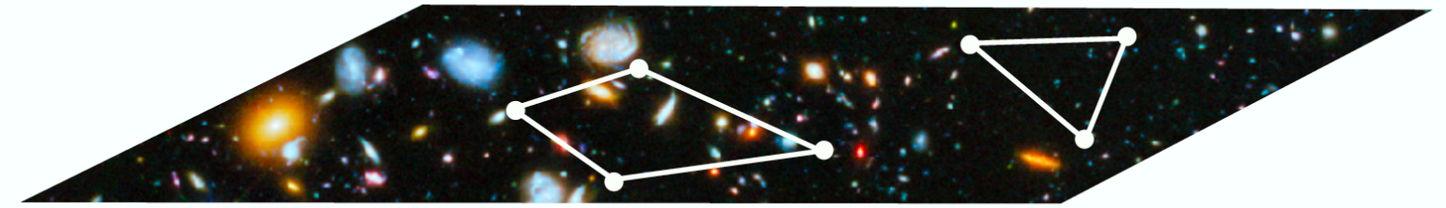
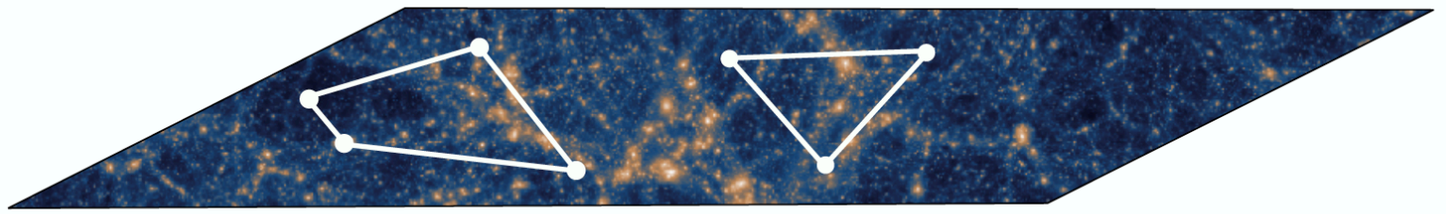
Predictions from inflation

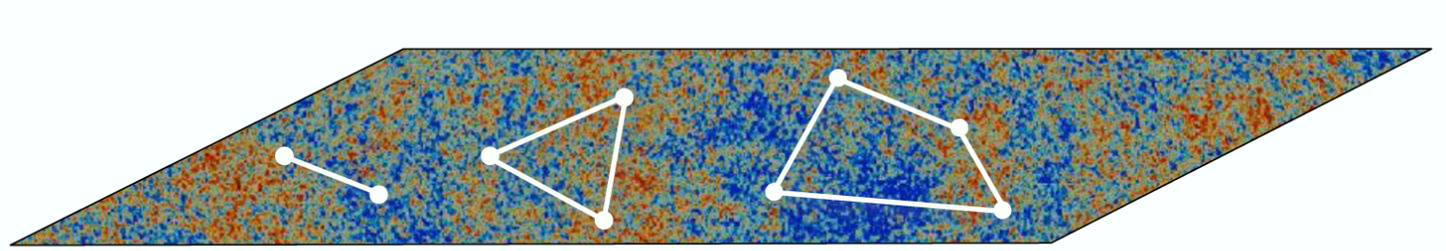
Time



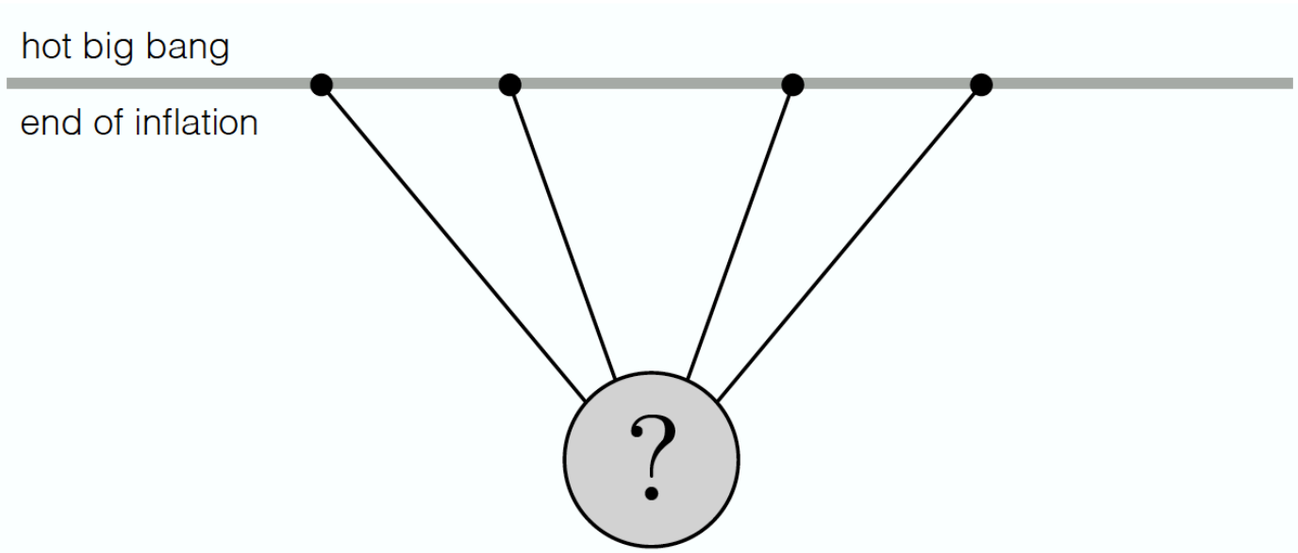
13.8 billion years



few billion years

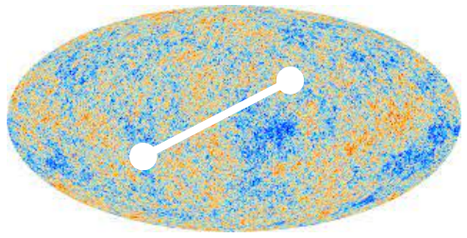


380 000 years



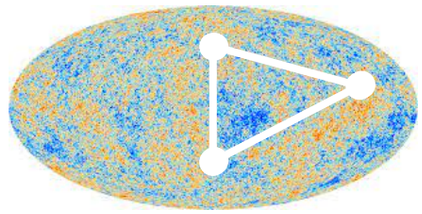
The Cosmological Bootstrap

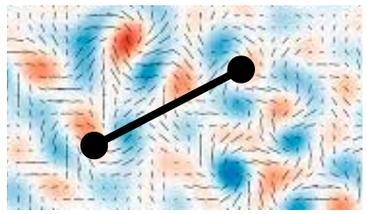
Observed



Cosmological Bootstrap

Predicted





Time

Model Building

Unitarity
Locality
Symmetry
...

Perturbative Calculations (in-in,...)

$$\mathcal{L}[\zeta(\mathbf{k},\eta),\gamma_{ij}(\mathbf{k},\eta),\eta]$$

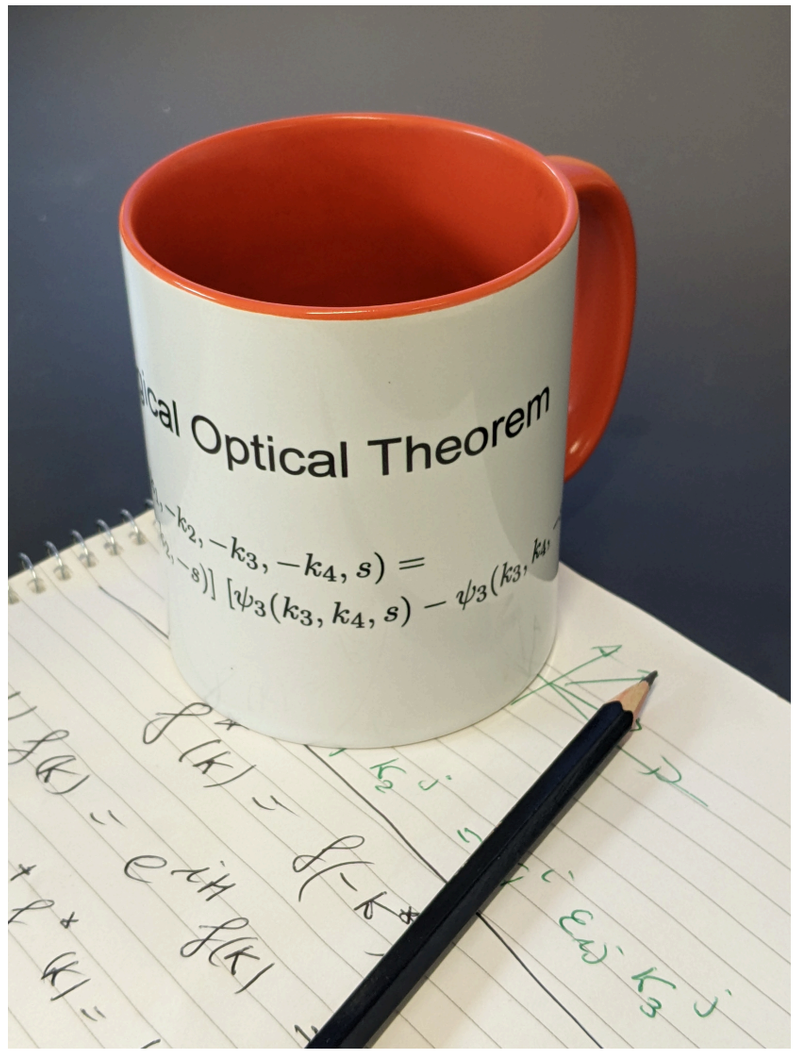
Field theory - inflation models

New results: unitarity

- *Unitarity*, namely the *conservation of probability* is a pillar of physics: it is the bridge that connects the mathematics of Hilbert spaces to physical predictions in quantum mechanics.

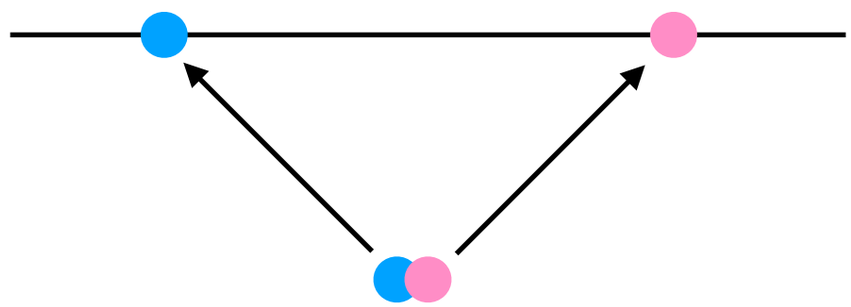
- In particle physics the consequence of unitarity have been known since the 60's and feature in almost all theoretical advance in the past 60 years

- In cosmology this was an outstanding problem for years until we found an answer: the Cosmological Optical Theorem [Goodhew, Jazayeri & EP '20]



New results: locality

- *Locality* is a fundamental principle of physics that implies the absence of “spooky action at a a distance”



- Locality highly constraints possible cosmological observables for primordial perturbation and gravitational wave (the “Manifestly Local Test”) [Jazayeri, EP & Stefanyszyn ’21]

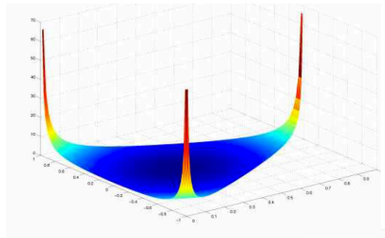
- (Locality + Unitarity + observed symmetries) are so constraining that they *fix many cosmological observables*, without the need to postulate ad hoc models. This is the *Cosmological Bootstrap*

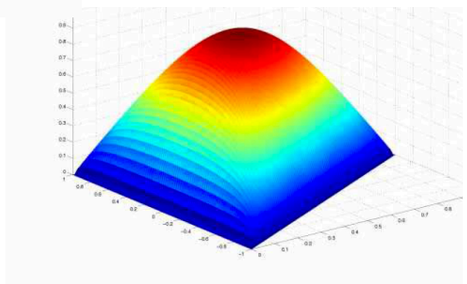
New predictions

We used the cosmological bootstrap to predict:

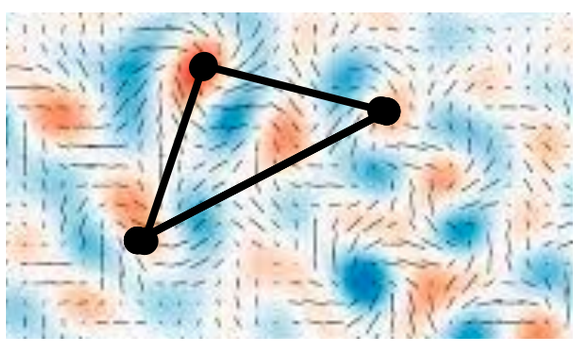
- new correlations in the Cosmic Microwave Background and large scale structures

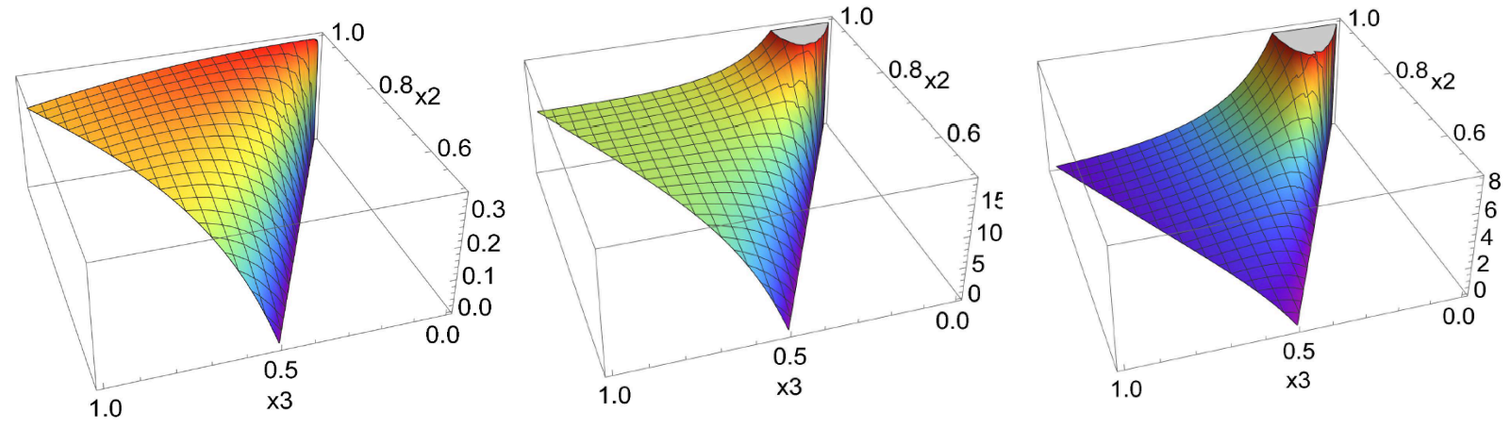
$$\psi_3^{(0)} = A_0\left[4e_3 - e_2 k_T + (3e_3 - 3e_2 k_T + k_T^3)\log(-k_T\eta/\mu)\right]$$
$$\psi_3^{(1)} = 0$$
$$\psi_3^{(2)} = A_2\left[-k_T^3 + 3k_T e_2 - 11e_3 + \frac{4e_2^2}{k_T} + \frac{4e_2 e_3}{k_T^2}\right]$$
$$\psi_3^{(3)} = A_3\frac{1}{k_T^3}(k_T^6 - 3k_T^4 e_2 + 11k_T^3 e_3 - 4k_T^2 e_2^2 - 4k_T e_2 e_3 + 12e_3^2) + A_3'\frac{e_3^2}{k_T^3}$$





- unique correlations of primordial gravity waves [Cabass, EP, Stefanyszyn, Supel '21]





Implications

- If detected, these signals will have major implications for our understanding of high energy physics, gravity, the particle content beyond the standard model and hopefully quantum gravity:

    - Confirm the (perturbative) quantisation of gravity
    - Detect new particles and new interactions beyond the standard model
    - Measure their properties (mass, spin, charges)
    - detect (new) violations of parity, time reversal or charge conjugation during inflation
    - Measure the energy scale of inflation (second most uncertain scale in physics)

Outlook

- Correlations in the cosmic microwave background and large scale structures generated during inflation are one of the *primary science goals* of current and upcoming cosmological surveys (CMB: Simons Observatory, Bicep/Keck, CMB stage 4, …; LSS: Euclid, Rubin Observatory, SphereX, …)

- Our results enable us to maximise the science output of these experiments by predicting concrete model-agnostic signals that are directly related to fundamental principles of physics such as symmetries, locality and unitarity.