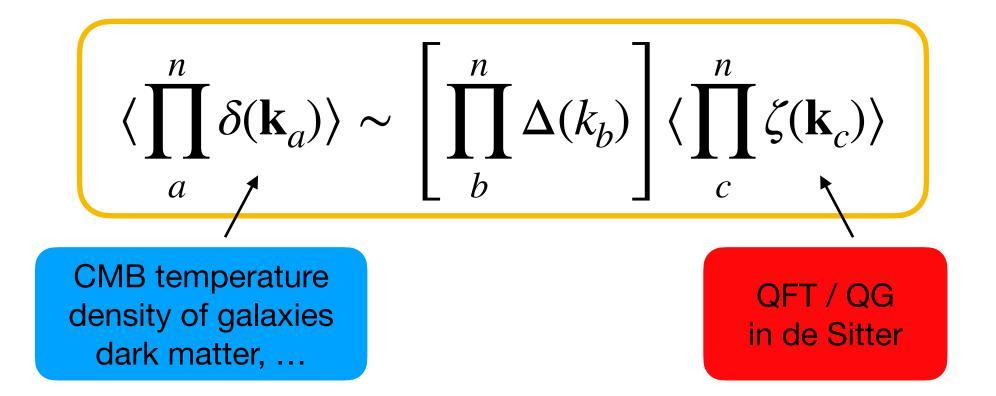
Vision/discussion session: Cosmological Bootstrap

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Primordial Cosmo = QFT in curved spacetime / Quantum Gravity

• On large scales (>> Mpc) cosmological surveys measure QFT correlators of metric fluctuation



- Gravitational floor of non-Gaussianity in single-clock inflation: $\frac{\langle \zeta^3 \rangle}{\langle \zeta^2 \rangle^2} \sim f_{NL}^{eq} \gtrsim 10^{-2}$
- The goal of primordial cosmology is to understand QFT and QG in (approximately, asymptotically) de Sitter

State of the art

- Brute force calculations in *perturbation theory*:
 - *Tree-level:* Well established machinery. Many 2-,3- and 4 point functions for massless (realistic, rational functions) and conformally coupled (toy model, related to massless in flat space) fields.
 - General masses; results are available but increasingly formal. The answer is intrinsically complicated. Beyond elementary functions.
 - Mostly equal time (as observed) correlators.
 - Coordinates: cosmologists want correlators in Fourier space. CFT's technology mostly in position space. AdS in Mellin space (see talks by Sleight & McFadden)

Constraints from fundamental principles

- Unitarity:
 - Non-perturbative spectral decomposition of 2- & 4-point correlators. Positive spectral densities
 - Non-perturbative optical theorem of "de Sitter amplitudes", with associated positivity
 - Perturbative constraints to all loop orders in any FLRW from Cosmological Optical Theorem. Formulated
 wavefunction = amplitude
 in term of more primitive wavefunction (correlator = cross section = cross sectio
- Locality/Causality/analyticity:
 - Singularity structure in perturbation theory for massless and conf. coupled scalars
 - Manifestly Local Test in perturbation theory
 - Analyticity of retarded correlators
 - Theories without Lorentz invariance (realistic for cosmo)

Outlook 1: Loops & renormalisation

- Why loops:
 - Ensure we have a consistent framework to compute observables to any desired order
 - Parity-odd correlators of a massless scalar in de Sitter vanishes at tree level, so 1-loop is the leading term!
 - Special kinematic limits can overcome loop suppression (squeezed, collinear limits)
- Renormalization schemes: explicit cutoff, dim reg, mass&dim reg, η -regulators, Mellin-Barnes regulators. Very active. Universality results, regularisation independence.
- 3 distinct types of divergences: UV divergences ($q \to \infty$, see Pajer's talk), IR divergences ($q \to 0$) and late-time ($\eta \to 0$, see McFadden's talk).
- Renormalization group: re-sum large logs using RG.

Outlook 2: positivity bounds

- What Effective Field Theories admit a consistent UV-completion? Constraints from UV unitarity, causality, locality, quantum gravity, ...
- For Lorentz invariant EFTs in flat spacetime we have many constraints leading to *positivity* bounds on effective couplings. In AdS similar bounds can be derived from CFT dual. In de Sitter such bounds are not yet known.
- Ongoing promising directions & challenges:
 - Use fundamental constraints, e.g. non-perturbative cosmo bootstrap, or de Sitter amplitudes.
 - Investigate Lorentz breaking constraints (in Mink and dS)
 - Holographic bounds?

Outlook 3: open system effects

- Unlike for collider phenomenology, in cosmology we always have a spacetime filling medium with unknown microscopic (inflaton, dark matter, dark energy, ...). We need an open system approach
- Important & studied for late-time divergences, superHubble physics (e.g. secular growth)
- Important for all models: in single field there is a thermal bath at the dS temperature. More generally other fields can have non-zero occupation numbers
- Completely different "open QFTs". Density matrices and non-Hamiltonian evolution

Outlook 4: everything else

- Still very little interplay/cross contamination between advances in cosmo correlators and ideas in *de Sitter holography*
- Yet no clear variables to make spinning correlators of gauge fields "simple" (see Skinner's talk)
- Alternative *boundary* formulation of perturbation theory (polytopes (see Benincasa's vision), differential equations, ...)