Cosmological Correlators
IHES, 2026 Summer School

July 6-17, 2026

Syllabus

Scott DODELSON
Connecting Theory to Observations

The basis of modern observational cosmology is the CMB and galaxy surveys. These lectures will start by giving an overview of the various surveys, and then diving into what they have done or will do. This includes precise determination of parameters via the two-point functions and upper limits on PNG. Then, I will provide a few examples that move beyond the two-point function, with the examples of CMB lensing and small scale clustering in lensing and galaxy surveys. I'll conclude by outlining Field Level Inference as a tool that may eventually be able to map out primordial perturbations.

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Claudia de RHAM and Andrew TOLLEY
Positivity in Particle Physics and Cosmology

1) Analytic S-matrix and Positivity Bounds
2) Crossing Symmetric Dispersion Relations and S-matrix Bootstrap
3) Positivity in Effective Theories of Gravity
4) Causality in Effective Theories

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Marko SIMONOVIC and Matias ZALDARRIAGA
Effective Field Theory of Large Scale Structure

These lectures will introduce:

1) the motivation for studying nonlinear large-scale structure and the foundations of cosmological perturbation theory and EFTofLSS;
2) perturbative solutions for dark matter and the bias expansion relating galaxies to the underlying matter distribution;
3) the structure of loop corrections to the power spectrum and computational methods;
4) infrared properties, soft theorems, BAO resummation and reconstruction and modern applications to the galaxy power spectrum and primordial non-Gaussianity.

The aim is to provide the basic theoretical framework and tools needed to describe nonlinear structure formation and connect perturbative predictions with observations.

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Charlotte SLEIGHT and Massimo TARONNA

Cosmological Bootstrap

These lectures present the bootstrap approach to cosmological correlators, organised around the guiding principles—symmetries and consistency conditions—that govern them. Topics include:

1) Symmetries and constraints
2) Analyticity and unitarity
3) Computational tools

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Enrico PAJER

An Open Systems Approach to Cosmology

Overview: Modern cosmological models and observational predictions rely heavily on the quantum field theory framework developed for particle physics. Cosmology, however, presents qualitatively new challenges. Many of its fundamental components—such as the inflaton sector, dark matter, and dark energy—possess poorly constrained macroscopic properties and, in some cases, entirely unknown microphysics. As a result, cosmological systems generically exhibit dissipation, stochastic fluctuations, out-of-equilibrium dynamics, and effectively non-unitary evolution at the macroscopic level.

Since gravity couples universally to all forms of matter, a closed-system description of cosmology would require a complete microscopic account of all cosmic constituents, which is only feasible in highly idealized toy models. An open-system approach provides a natural and systematic framework to address these challenges. These lectures introduce students to open quantum system techniques and their application to cosmology and gravitation.

Lecture 1: Density Matrices and the Operator Formalism

The first lecture introduces the foundational concepts of open quantum systems in the operator language. Topics include:

- Density matrices and the distinction between pure and mixed states
- Entanglement, coarse graining, and the origin of entropy in open systems
- Quantum master equations and effective non-unitary evolution
- The Lindblad equation and Markovian dynamics
- Completely positive and trace-preserving (CPTP) maps and their physical interpretation

The emphasis is on understanding how effective dissipative dynamics emerge when unobserved degrees of freedom are integrated out.

Lecture 2: Path Integrals and the Schwinger–Keldysh Formalism

This lecture develops the path-integral description of open quantum systems using the closed time contour. Topics include:

- The Schwinger–Keldysh (in-in) formalism
- Doubling of fields and the structure of the closed time path

- In-in Feynman rules and perturbation theory for open systems, retarded, advanced and Keldysh propagators
- Noise, dissipation, and influence functionals
- Constraints from ultraviolet unitarity, locality, and symmetries

The equivalence between operator and path-integral approaches is emphasized, together with the structural constraints imposed by unitarity and symmetries at high energies.

Lecture 3: *Open Gauge Theories and Cosmological Goldstone Modes*

This lecture focuses on general structural aspects of open quantum field theories, with particular emphasis on open gauge theories. Topics include:

- A systematic algorithm to count physical degrees of freedom in open theories
- Constraints, gauge symmetries, and gauge identities in the advanced and retarded sectors
- The open effective theory of the Nambu–Goldstone boson associated with broken time translations with aplications to inflationary cosmology
- Implications for primordial perturbations and cosmological correlators in the presence of dissipation and noise

Lecture 4: *Electromagnetism and Gravity in a Medium*

The final lecture develops concrete applications of open-system techniques to fundamental interactions:

1. Electromagnetism in a medium
    - Effective open description of photons
    - Dissipative propagation, noise fluctuations and birefringence
    - Consistent treatment of gauge invariance, constraints, and gauge identities
2. Gravity as an open system
    - General formulation of an open theory of general relativity
    - Implications for late-time cosmology, dark energy, and the propagation of gravitational waves through a dark-sector medium

Learning Outcomes

By the end of the lecture series, students will be able to:

- Understand when and why an open-system description is necessary in cosmology
- Use both operator and path-integral techniques to model open quantum dynamics
- Construct and analyze effective theories with dissipation, noise, and gauge symmetries
- Apply these ideas to inflation, electromagnetism, and gravity in cosmological settings

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