Kernel Law in Cosmology

FLRW Particle Number as Bogoliubov Gauge; the Universe as a Correlation Machine

Interface Boundary

2026

Abstract

We formulate a Kernel-Law classification of "particle number" in Friedmann–Lemaître–Robertson–Walker (FLRW) spacetimes and related time-dependent backgrounds. The central claim is structural: particle number in a non-stationary geometry is not an observer-invariant property of the underlying history space, but a quotient-dependent coordinate induced by an observer algebra (equivalently, by a choice of mode decomposition). In this view, Bogoliubov transformations act as gauge changes on the quotient representation, while physically stable content is carried by correlation structure and invariant observables rather than absolute occupation counts. We derive the classification in terms of an observer map whose kernel identifies distinctions erased by local access, and we state consequences for "No Asymptotia" regimes in which no unique in/out vacuum exists. The result is a concrete cosmological instance of kernel-bounded indistinguishability: multiple inequivalent particle narratives correspond to the same accessible correlation surface.

Keywords: cosmology; FLRW; particle number; Bogoliubov transformation; observer algebra; kernel quotient; indistinguishability; correlations

1 Setup and Notation

Let $\mathcal{X}$ denote the underlying history space of the substrate (fields on a time-dependent background, together with any additional degrees of freedom required to specify a history). An observer is modeled by an *observer algebra* $\mathcal{O}$, representing the finite and localized set of distinctions that can be realized.

We represent access by an induced report map

$$\pi_{\mathcal{O}} : \mathcal{X} \to \mathcal{Y}_{\mathcal{O}},$$

where $\mathcal{Y}_{\mathcal{O}}$ is the observer's accessible report space. Define an equivalence relation

$$x \sim_{\mathcal{O}} x' \quad \Longleftrightarrow \quad \pi_{\mathcal{O}}(x) = \pi_{\mathcal{O}}(x').$$

The induced *kernel* $\mathcal{K}_{\mathcal{O}}$ is the indistinguishability structure associated to $\sim_{\mathcal{O}}$, and the *experienced state space* is the quotient

$$\mathcal{Q}_{\mathcal{O}} := \mathcal{X}/\mathcal{K}_{\mathcal{O}}.$$

Kernel Law asserts that stable statements about "what exists for the observer" should be formulated on $\mathcal{Q}_{\mathcal{O}}$ (and its dynamics), not on $\mathcal{X}$ directly.

2 Statement of the Cosmology Claim

In stationary spacetimes, time-translation symmetry provides a preferred mode decomposition and a corresponding notion of particles. In FLRW and other time-dependent backgrounds, such symmetry is generally absent; mode decompositions are not unique, and particle number becomes representation-dependent.

Claim (Particle number as quotient coordinate). In non-stationary cosmological backgrounds, "particle number" is not an observer-invariant property of the history space $\mathcal{X}$. It is a coordinate on a particular quotient representation $\mathcal{Q}_{\mathcal{O}}$ induced by an observer algebra $\mathcal{O}$ (equivalently, by a choice of modes compatible with that algebra). Distinct mode choices correspond to distinct quotient coordinatizations of the same accessible correlation surface.

3 Bogoliubov Transformations as Gauge

Let a field be expanded in two admissible mode bases, producing two sets of annihilation/creation operators. The transformations between these bases are Bogoliubov transformations. In time-dependent geometries, these transformations generically mix positive and negative frequency components and therefore alter occupation numbers.

Interpretation (Gauge on the quotient). Within Kernel Law, a Bogoliubov transformation is interpreted as a gauge change in the observer's quotient representation: it changes the coordinatization of $\mathcal{Q}_{\mathcal{O}}$ (and hence the bookkeeping of "particles"), without necessarily changing the observer-accessible invariant content. In particular, absolute occupation counts are not privileged unless additional access constraints select a unique algebra.

4 No Asymptotia and the Absence of a Unique Vacuum

In many cosmological regimes there is no operationally meaningful "in" and "out" region providing a preferred vacuum. We refer to this as *No Asymptotia*: the absence of boundary conditions that uniquely fix a particle basis.

Consequence. In No Asymptotia regimes, particle narratives become non-unique even in principle. Multiple inequivalent "vacua" and their associated particle counts can correspond to the same observer-accessible correlation surface. The kernel-bounded description therefore prioritizes quantities stable under access-limited transformations.

5 What is Invariant: Correlations and Accessible Observables

Although particle number is representation-dependent, correlations (two-point functions, response functions, and other access-realizable observables) can remain stable under changes that merely relabel quotient coordinates.

Kernel Law diagnostic. An observer algebra $\mathcal{O}$ fixes which correlation features are accessible. The invariant content for that observer is the structure that survives the kernel $\mathcal{K}_{\mathcal{O}}$. Statements about cosmological "content" should therefore be made in terms of those surviving correlation features, rather than absolute occupation numbers.

6 Discussion: "Universe as a Correlation Machine"

Under this framing, cosmology is not primarily a story about absolute particle inventories. It is a story about which correlation structures are generated and persist under the access constraints of the observer. Particle number is a convenient narrative coordinate when symmetry or access selects a preferred algebra; otherwise it is a gauge-dependent description.

7 Summary

- In time-dependent cosmological backgrounds, particle number is not an invariant of the history space $\mathcal{X}$.
- A choice of observer algebra (or compatible mode decomposition) induces a quotient $\mathcal{Q}_{\mathcal{O}} = \mathcal{X}/\mathcal{K}_{\mathcal{O}}$; "particle number" is a coordinate on that quotient representation.
- Bogoliubov transformations act as gauge changes on the quotient coordinatization, altering occupation counts without necessarily changing observer-accessible invariant content.
- In No Asymptotia regimes, no unique vacuum is fixed by boundary conditions; multiple particle narratives can correspond to the same accessible correlation surface.
- The physically stable content, relative to an observer, is carried by correlation structure and access-realizable observables.

Final line. In cosmology, particles are often a story we tell; correlations are what survive the kernel.