PROLOGUE

We inhabit a universe that seems, at first sight, to need no justification for being what it is. Events influence one another. Stars burn, structures take shape, and traces endure. What has happened makes a difference to what can happen next. Out of those differences comes something we call a physical history.

Modern physics describes much of that history with remarkable precision. Relativity tells us how events can be connected; thermodynamics describes the physical consequences of irreversible change; quantum theory tells us how matter behaves at its smallest scales. Cosmology traces the expansion of our universe backward toward conditions unlike anything we encounter today. Yet even an extraordinarily successful description leaves a prior question open.

What must be true of a universe for it to be capable of having a physical history at all?

A history is more than a sequence of events. Events must be able to influence one another in a coherent order, and some effects must persist long enough to affect what follows. A record, in this sense, is not merely a memory held by an observer. It is a physical trace through which an earlier event continues to constrain later possibilities. Without lasting traces, there may be change, but there is no physically accessible past. A lasting, record-bearing history requires irreversible processes, even though microscopic laws need not themselves be irreversible.

These requirements must be met from within the universe. In other sciences, the surroundings of a system can supply a clock, a reservoir, or conditions that help explain its behavior. Cosmology, when it treats the universe as the complete physical system, has no such exterior. Its causal order, its records, and the conditions sustaining its history must belong to the physical reality being explained. This is what we mean by intelligibility from within: a universe must contain the physical conditions that make its own history possible.

We begin with causal coherence and irreversible, record-bearing history. For the class examined here, finite distinguishable capacity and the stronger structural-closure restriction H_{C} are adopted separately. Chapter 4 distinguishes their motivation, content, and conditional consequences. Neither restriction is derived from irreversibility alone.

A finite capacity changes what it means for a physical history to continue. We call a self-contained domain of coherent causal evolution a causal regime. Within the subclass additionally selected by $H_{\mathrm{C},}$ a regime cannot sustain its ordered, record-bearing history without limit while remaining the same regime. We call the limiting condition closure. Closure does not mean that every physical process suddenly stops, nor does it name a known event in the future of our universe. It marks the limit beyond which the regime cannot continue its history under the same causal organization.

That conclusion raises a new question. If one causal regime cannot continue indefinitely as itself, is every possible physical history thereby exhausted? Or could a distinct regime begin, with its own causal order and its own records, rather than prolonging the history of the first?

A successor cannot be introduced merely by giving the continuation a different name. Nor can its existence be explained by appealing to a larger spacetime in which successive universes are already arranged. If a distinct regime becomes physically possible, it must satisfy the requirements of an intelligible history independently. It cannot simply receive its predecessor's state, stored memories, entropy, or laws. The problem is therefore not how to carry the old universe across a boundary, but whether known physics can provide conditions under which a new, self-contained regime might be realized.

This is why the investigation turns to physical mediation. A mediator, as the term is used here, is a configuration arising within an existing regime that might provide the local conditions needed for a distinct one. It is not an external agent, and identifying such a configuration does not establish that succession occurs. The candidate must make a region causally inaccessible to its surroundings and bring it into conditions where the usual classical description can no longer give a complete account of its evolution. Gravitational collapse brings these requirements into focus: it can produce extreme causal isolation and lead classical general relativity toward a singularity, where that description reaches its limit.

We then ask what can happen in place of that singular endpoint. In the effective quantum-gravitational description adopted for the investigation, a sufficiently idealized contracting domain can pass through a finite-curvature bounce and begin expanding. The bounce is a physical turning point in the model, not the sudden appearance of a complete universe. An expanding region, however isolated, is not automatically a new cosmological regime. Establishing such a regime would require further conditions of global completion and physical independence. The distinction between a possible local transition and a realized successor must remain clear throughout the argument.

Even so, the expanding domain gives the argument a definite process to follow. Immediately after the bounce, the conditions are too extreme for the familiar description of interacting fields to be assumed without qualification. As expansion proceeds, the density falls. Eventually the adopted realization reaches a boundary at which a first effective field theory—a description in terms of identifiable fields and their interactions—is taken to become applicable. We call the intervening expansion the pre-inflationary bridge. The bridge is not a pause between two universes: it is an evolving physical interval within a regime, from the high-curvature bounce toward the first effective field description.

We describe the bridge as radiation-like. Here, the term refers to a specific relation between pressure and energy density, rather than to the presence of ordinary photons or the particle content of a later effective field theory. This relation determines how the density decreases as the domain expands and how the energy contained in a chosen expanding reference domain changes. Once the densities at the two ends of the bridge are specified, the resulting energy attenuation can be calculated.

We therefore need two physical anchors. One comes from the adopted effective description of the bounce and fixes the critical density. The other identifies the density of the first effective field regime, using external physical input. These anchors are not both derived from the foundational requirements. Given them and the bridge dynamics, the decrease in the reference-

domain energy follows. That is a result about evolution within one regime; it is not yet a relation between different universes.

To make the next step, a separate assumption must be stated. We adopt a minimal correspondence between a reference energy at the end of the bridge in one regime and a reference energy at the high-curvature transition of a possible successor. We call this the Regime-Scale Correspondence. It introduces no additional adjustable coefficient. But its simplicity does not demonstrate that nature must realize it, or that it is the only possible correspondence. The assumption is kept explicit because the quantitative ordering that follows depends on it.

Under that correspondence, the energy attenuation across the bridge determines a formal sequence of characteristic cosmic scales. The sequence tells us how those scales would be related if succession were physically realized. It does not show that the corresponding regimes have existed, nor does it describe energy transferred from one universe to another. We can compare a reference scale associated with our observable universe with the other scales, but this cannot establish its place in an actual lineage. Nor does the scaling determine whether a later phase of accelerated expansion, such as inflation, occurs in every possible successor. Those questions require their own physical conditions.

The same distinction becomes decisive when we turn toward the past. An indefinitely long realized ancestry would, under the adopted scaling relation, require characteristic energies to grow without bound. Whether nature allows successive complete regimes at arbitrarily large scales is a further physical question. We can identify that frontier without proving the existence of a first ancestor, calculating its scale, or counting how many universes have actually occurred. A limit on the history of each regime is not, by itself, a proof of a beginning for the lineage as a whole.

This is the path we shall follow. We begin with events and records, ask what makes their history intelligible, and examine what follows when irreversible history is considered with the adopted capacity restriction and H_{C}. The limit of one regime leads us to the question of succession; that question leads to gravitational mediation, a possible bounce, and the bridge toward the first field description. Only after separating what the bridge determines from what must be adopted do we arrive at a quantitative ordering of possible cosmic scales. At every stage the distinction matters: a premise is not a deduction, a physically permitted transition is not a demonstrated successor, and a formal ordering is not an observed genealogy.

The title of this book names the thread connecting those steps. To have a past is to preserve traces of it. To preserve traces is to change what remains possible. A history is not free of consequences; its continuity has a cost.

And if a causal regime reaches the limit of what it can sustain, its closure need not be the end of physical becoming.

It may instead be the condition from which another universe begins.