The Standard Model and Dark Matter in a Timeless Euclidean Model

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Abstract

This work continues the program of operational reconstruction of observable physics from a timeless Euclidean model with a single real field. Building on the already reconstructed special-relativistic, gravitational, and minimal quantum layers of description, we show that, within a physically relevant family of reconstruction classes, a minimal Standard-Model realization of the operationally visible sector is singled out. The visible sector is thereby interpreted not as the full physical content of the class, but as an immediately observable gauge–fermionic substructure selected by phenomenologically motivated class parameters compatible with a stable observer, causal consistency, and a local relativistic quantum-field-theoretic regime.

It is further shown that the selective extraction of the visible sector entails the existence of an invisible complement to it. Hidden content is introduced as an additional part of this complement, while its physically relevant part is treated as a hidden sector remaining compatible with the same working regime. Its gravitationally relevant non-vacuum part, insofar as it is essential for the purposes of the present work, is interpreted as dark matter. Thus, dark matter arises not as an external phenomenological appendage, but as a natural consequence of the incompleteness of the visible sector.

In addition, it is shown that generational multiplicity is naturally interpreted as a parameter of the reconstruction class, while the space of Yukawa couplings arises as part of a finer parametrization of the visible sector. Finally, a structural formulation of the inverse problem for the parameters of the reconstruction class is given: observable physics is treated not only as a consequence of the class structure, but also as a basis for its partial phenomenological identification. In this way, the paper connects the extraction of a minimal Standard-Model realization of the visible sector, hidden content, dark matter, and the inverse problem within a unified class-structural scheme.

1 Introduction

The present work continues the program of operational reconstruction of observable physics from a timeless Euclidean model with a single real field. In previous works within this program, the operational special-relativistic structure [1], the compensating gravitational sector [2], and the minimal quantum core of the effective description [3] were identified. A working framework has thereby already been constructed, within which observable physics arises not as a fundamentally given spacetime theory, but as the result of admissible reconstruction relative to an observer. What is essential here is that both the reconstructed gravitational structure and the minimal quantum core are obtained within one and the same fundamental setting with a single real field; the present work continues precisely this unified scheme.

The subject of the present article is to show how, within a physically relevant family of reconstruction classes, a minimal Standard-Model realization of the directly observable, that is, visible, sector can be singled out, and why this does not exhaust the full physical content of the corresponding class. The analysis is therefore directed not only toward isolating the gauge–fermionic organization of the visible world, but also toward substantiating that additional content, compatible with the same working regime, may remain beyond it. On this basis, hidden content is introduced below; its physically relevant part is treated as a hidden sector, while its gravitationally relevant non-vacuum part, insofar as it is essential for the purposes of the present article, is interpreted as dark matter.

The main thesis of the article is formulated in class-conditional form. The Standard Model is not introduced here as an initial postulate. It is argued that, given the already constructed minimal quantum core and upon introducing phenomenologically motivated parameters of the reconstruction class that identify a physically relevant subset of admissible classes, a minimal Standard-Model realization of the visible sector is singled out. At the same time, the visible sector specifies the directly observable non-gravitational organization of the world, but need not exhaust the full physical content of the reconstruction class. It is precisely this distinction between the visible sector and the full content of the class that opens a natural place for hidden content, for its physically relevant part as a hidden sector, and, in the narrower sense, for its gravitationally relevant non-vacuum part, which in the present article is interpreted as dark matter.

It is essential that the additional assumptions used below are understood not as arbitrary external insertions, but as parameters or structural restrictions identifying a physically relevant reconstruction class. In accordance with the logic of the previous article on reconstruction classes and the fine-tuning problem [4], such parameters should be understood as phenomenologically motivated conditions for the physical actualization of a world admitting an observer of the type realized in our Universe. In the empirically accessible case, this means an observer of the type realized in the world we observe; at the same time, the framework does not require one to assert that other types of observer are impossible in principle, but only to single out the reconstruction class corresponding to our world. It is in this sense that the assumptions leading to a minimal Standard-Model realization of the visible sector are treated as parameters of the reconstruction class rather than as independent phenomenological corrections.

A finer parametrization of the visible sector arises only after its structural extraction. At this level, questions such as generational multiplicity and the admissible space of Yukawa couplings arise naturally. In the present work, the number of generations is treated as a parameter of the reconstruction class, while the Yukawa matrices are treated as part of a finer parametrization of the visible sector. Their concrete fixation, however, does not belong to the main result of the article: they are considered here as natural objects of the next level of the structurally formulated inverse problem, rather than as already fully derived quantities.

The hidden content considered in the present article need not in all cases form an autonomous sector of locally observable particles. It may remain outside standard local observational protocols and manifest itself predominantly through gravitational response or through more subtle indirect effects on the visible sector. Accordingly, within the present work the hidden sector is analyzed not in the full range of its possible realizations, but primarily to the extent that its physically relevant part yields a gravitationally relevant non-vacuum contribution. It is this part that is interpreted below as dark matter. Other possible physically relevant hidden subsectors that do not reduce to such a contribution are not specifically analyzed in the present article. Dark energy is not considered in the present article and is not included in the notion of the hidden sector; the question of its origin belongs to a separate line of analysis.

It should be noted that the present work does not develop in isolation from the literature on the deeper origin of the Standard Model. Among the closest neighboring directions are, in particular, noncommutative-geometric approaches, in which the structure of the Standard Model and its relation to gravity are encoded geometrically; the causal fermion systems approach, where the Standard Model, gravity, and the quantum-field-theoretic regime are treated as limiting manifestations of a more general structure; as well as programs of emergent gauge symmetry and UV-consistency approaches, including asymptotic safety, where the Standard-Model sector is constrained by a deeper theory [5, 6, 7, 8]. However, the scheme proposed here differs from these directions both in its underlying fundamental setting—a timeless Euclidean model with a single real field—and in the sequential operational reconstruction of the special-relativistic, gravitational, quantum, and Standard-Model levels within a unified class-structural program.

1.1 The Place of the Present Work in the Reconstruction Program

The present article takes as its initial working regime the already constructed operational causality, the locally inertial special-relativistic structure, the compensating effective geometry, and the minimal quantum core. Accordingly, the derivations of special relativity, the gravitational sector, and the quantum layer are not reproduced here. The further extraction of a minimal Standard-Model realization of the visible sector and the analysis of hidden content should be understood as a continuation of the same unified scheme: it is constructed in the regime of the already reconstructed gravitational structure and the minimal quantum core and does not require the introduction of additional fundamental fields.

The new task consists in moving from the already identified special-relativistic–gravitational–quantum regime to an analysis of the visible sector, its possible incompleteness, and the additional content that may remain beyond the directly observable structure of the world. Thus, the article forms a transition from the reconstruction of spacetime and the quantum core to a more detailed analysis of the minimal Standard-Model realization of the visible sector, hidden content, and the inverse problem for the parameters of the physically relevant reconstruction class.

1.2 Aim, Status of the Result, and Structure of the Work

The aim of the present article is, within the already constructed special-relativistic–gravitational–quantum working regime, to single out a minimal Standard-Model realization of the visible sector of a physically relevant reconstruction class, to show that this sector need not exhaust the full physical content of the class, and thereby to introduce hidden content, identify its physically relevant part as a hidden sector, and interpret its gravitationally relevant non-vacuum part as dark matter.

The status of the obtained result is class-conditional. The article does not claim that the structure of the Standard Model is derived as the uniquely possible structure in all admissible reconstructions. A more precise claim is made: upon introducing phenomenologically motivated parameters identifying a physically relevant family of reconstruction classes, a minimal Standard-Model realization of the visible sector of such a class is singled out. The realization parameters, including generational multiplicity and the space of Yukawa couplings, are treated not as external phenomenological additions, but as finer parameters of the reconstruction class, subject to further analysis within the inverse problem.

The article does not undertake a complete phenomenological reconstruction of the observable world in all its details. No unique fixation is given here of the full mass hierarchies, the specific textures of the Yukawa matrices, the quark and lepton mixing structures, the full phenomenology of hidden content, or the mechanism of dark energy. Nor is a full classification constructed of all possible forms of hidden content, including such physically relevant hidden subsectors as do not reduce to a gravitationally relevant non-vacuum contribution and may influence the visible sector only indirectly. Instead, a structural preliminary stage of such a reconstruction is formulated: a structural formulation of the inverse problem for the parameters of the reconstruction class.

The remainder of the article is organized as follows. Section 2 fixes the initial structure and the inherited working regime, including operationally reconstructed spacetime, effective fields, admissible reconstruction classes, and the class-identifying parameters relevant for the visible sector. Section 3 introduces the parameters that single out a minimal Standard-Model realization of the visible sector, examines the corresponding gauge–fermionic structure, and discusses the parameters of its concrete realization. Section 4 analyzes the incompleteness of the visible sector, introduces hidden content, identifies its physically relevant part, and discusses that gravitationally relevant non-vacuum part of it which is interpreted as dark matter. Section 5 presents a structural formulation of the inverse problem for the parameters of the reconstruction class and specifies which elements of the class structure can in principle be constrained, localized, or partially reconstructed from data on the visible sector and the indirect manifestations of hidden content. Section 6 discusses the status of the result, empirical constraints, conditions of falsifiability, and the difference between the present framework and ordinary phenomenological quantum-field-theoretic practice. Finally, Section 7 summarizes the main conclusions of the work.

2 Initial Structure and Working Regime

The present article relies on the layers of reconstruction already constructed in previous works and does not reproduce their proofs. Accordingly, this section fixes the initial working regime within which the minimal Standard-Model realization of the visible sector, hidden content, and the parameters of the reconstruction class are considered below.

For ease of reading, the principal elements of the inherited working regime are first listed briefly, after which those of its aspects that are directly used in the subsequent analysis are specified in greater detail.

2.1 Brief Summary of the Inherited Working Regime

The present article uses a number of results obtained in previous works [1, 2, 3, 4] and does not reproduce their proofs. For convenience, let us fix here in compact form those elements of the working regime that are regarded as inherited and are used directly below.

The fundamental setting of the entire program is given by a timeless Euclidean model on $\mathbb{E}^4$ with a single real field Φ satisfying the Laplace equation. At this level, neither a preassigned Lorentzian metric, nor a fundamental causal structure, nor an external time parameter is assumed. Observable spacetime and physical structures arise only as the result of admissible reconstruction relative to a localized observer.

By *operational causality* in the present program is meant not a fundamentally given ordering of events, but a reconstructed structure arising from stable acts of local registration and their coordinated ordering within the observer's working regime. It is in this sense that causal relations, events, and the time parameter have not an initial but an operational-reconstructive status [1].

By the *locally inertial regime* is meant such a regime of reconstruction in which, on sufficiently small scales, a special-relativistic description with an observable Lorentzian structure is admissible. In this regime, inertial reference frames, local relativistic degrees of freedom, and the standard language of local quantum-field-theoretic analysis become meaningful. In the more general case, slowly varying foliations give rise to an effective geometry of the working type; in the previous work, the corresponding gravitational sector was interpreted as a compensating geometric structure necessary for consistent causal reconstruction [2].

By the *minimal quantum core* below is meant the already isolated level of effective description at which, in the locally inertial regime, local fields, local algebras of observables, and a minimal quantum-field-theoretic organization of the working type are admissible [3]. The present article does not derive this core anew, but uses it as the initial working layer within which the question of gauge and fermionic structures of the visible sector can already be posed.

Finally, by a *reconstruction class* $\mathcal{K}$ is meant a collection of mutually consistent effective descriptions compatible with one and the same set of structural constraints and reproducing a common type of observable world. Such a class fixes not one individual foliation or one local mode decomposition, but an admissible type of reconstruction as a whole: which observers are possible, which events and causal relations are stably reconstructed, which effective fields and algebras of observables are accessible, and which parameters are compatible with the given regime [4]. It is precisely this language of reconstruction classes that is used below for the extraction of the visible sector, hidden content, and the formulation of the inverse problem.

Thus, in the present work the following are taken as already given as the initial working regime: operational causality, the locally inertial special-relativistic structure, the compensating gravitational sector, the minimal quantum core, and the language of admissible reconstruction classes. All subsequent results pertain to this inherited working regime and are formulated without introducing additional fundamental fields.

2.2 Operationally Reconstructed Spacetime and Effective Fields

For the purposes of the present article, after the brief summary given above it is sufficient to fix additionally that minimal level of the construction which is used directly below. Observable spacetime structures arise only as the result of admissible reconstruction relative to an observer.

By an observer in the present program is meant not an external agent, but a localized subsystem of the same fundamental configuration, possessing stable internal registers and the capacity for operationally consistent causal reconstruction. It is precisely the presence of such an observer that makes it possible to single out local acts of registration, specify a working foliation, introduce an operational time parameter, and reconstruct the structure of events.

In this scheme, events are not assumed to be given in advance as points of a global spacetime. They arise as the result of local acts of registration and subsequent causal reconstruction. Accordingly, causal structure is likewise not fundamental, but is reconstructed from the ordering of operationally significant events, coordinated with the local dynamics and the observer's working regime. In this sense, reconstructed spacetime has an operational character.

In the special-relativistic regime, such a reconstruction leads to the selection of inertial reference frames and an observable Lorentzian structure. In the more general case, under slowly varying foliations, an effective geometry of the working type arises, providing a consistent generalization of the locally inertial description. For the present article, it is essential only that the discussion below concerns precisely the locally inertial regime, in which free relativistic sectors and their quantum description are already admissible.

In this setting, effective fields are not new fundamental entities, but working degrees of freedom parametrizing stable modes of the reconstructed description on the chosen slices. It is at this level that local algebras of observables, gauge sectors, fermionic representations, intermode couplings, and mixing parameters acquire meaning. Therefore, when the discussion below concerns the structure of the Standard Model, the generational organization of the visible sector, Yukawa matrices, or hidden content, it refers not to the addition of new fundamental fields to the initial model, but to the internal structure of the already isolated working layer of description.

2.3 Admissible Reconstruction Classes

The key concept of the subsequent analysis is that of an admissible reconstruction class. After the brief summary given above, it is important here to clarify not only the general meaning of this concept, but also the role it plays in the present article.

Decisive for the present article is the fact that the inherited working regime in general admits not a unique mode of physical realization. Accordingly, the subsequent analysis must be conducted not simply at the level of admissible modes or admissible local structures in general, but at the level of a physically relevant family of reconstruction classes compatible with the observable world of our type. It is in this sense that the parameters leading below to a minimal Standard-Model realization of the visible sector are treated not as external phenomenological additions, but as constraints identifying the corresponding subset of admissible classes.

In the present program, a physically relevant world is not specified either by a single configuration of the fundamental field or by an arbitrary local reconstruction of the observer. It must be understood as a class of such reconstructions in which the conditions of observer stability, reproducible operational event structure, causal consistency, the locally inertial regime, and the minimal quantum layer are jointly satisfied [4].

By a reconstruction class $\mathcal{K}$ below, in accordance with the brief summary given above, is meant a collection of mutually consistent effective descriptions possessing a common structure of the observable world and compatible with one and the same set of structural constraints. Such a class is not reducible to the choice of a single foliation or a single local mode decomposition; it fixes which observers are admissible, which events and causal relations can be stably reconstructed, which effective fields and algebras of observables are accessible, and which parameters are compatible with the given type of reconstruction. In this sense, a reconstruction class forms an intermediate level between the fundamental model and observable phenomenology.

However, for the present article this general definition is insufficient. The point is not merely admissible classes in general, but the selection of a physically relevant family of classes corresponding to the observable world of our type. Thus, the transition to the language of reconstruction classes serves not only as a means of general systematization, but also as a means of selection: the parameters considered below are precisely those class parameters that are phenomenologically motivated by the conditions for the physical actualization of a world of our type and can therefore serve as identifying constraints for the family sought. When no ambiguity arises, $\mathcal{K}$ will denote an arbitrary class from this family.

It is precisely in this that the strictness of the formulation of the present article consists. The point is not to phenomenologically fit a set of fields and symmetries resembling the Standard Model, but to show that in a physically relevant reconstruction class, selected by the corresponding set of parameters, a minimal Standard-Model realization naturally arises as the visible sector. Likewise, hidden content is understood not as any conceivable additional structure, but as that additional content which remains admissible within the same class without entering the directly observable structure of the world.

Consequently, an admissible reconstruction class must satisfy two requirements. First, it must be internally consistent: parameters, fields, symmetries, and regimes of observability cannot be chosen arbitrarily and independently of one another. Second, it must be phenomenologically identifiable: observable physics must make it possible not only to derive the visible sector from the class parameters, but also, conversely, to constrain, localize, or partially reconstruct these parameters from the data of the observable world. It is in this sense that a reconstruction class is an object not only of direct derivation, but also of the inverse problem.

2.4 Class-Identifying Parameters Relevant for the Visible Sector

If a minimal Standard-Model realization is to be treated as the visible sector of a physically relevant reconstruction class $\mathcal{K}$, then it is necessary to specify explicitly which parameters or structural constraints of this class are essential for its selection. The point is not an arbitrary phenomenological set of desired properties, but rather such characteristics of the class as are simultaneously admissible within the fundamental model, compatible with the already constructed special-relativistic, gravitational, and quantum working regime, and sufficient for singling out within the full physical content of the class the visible sector of the Standard Model.

It is important to emphasize that the parameters considered here are not external additions to an already finished construction. In accordance with the logic of the introduction and the preceding article on reconstruction classes, they are to be understood as phenomenologically motivated conditions for the physical actualization of a world admitting an observer of the type realized in our Universe. It is for this reason that they appear not merely as conditions for the extraction of the visible sector, but as parameters of the reconstruction class identifying that class $\mathcal{K}$ in which a minimal Standard-Model realization of the visible sector is singled out as part of the observable world.

First of all, this includes the constraints ensuring the very observability of the visible sector. It must be compatible with the existence of stable internal registers of the observer, with the operational resolvability of local states, and with the reproducibility of those interaction channels that actually participate in the reconstruction of the observable world. Consequently, the corresponding parameters must specify not only the algebraic organization of the modes, but also their operational status.

At the next level, the parameters determining the minimal gauge organization of the visible sector are essential. If, in the class $\mathcal{K}$, a minimal Standard-Model realization of the visible sector is indeed singled out, then among all admissible effective modes there must exist a local organization sufficient for the realization of the color channel, the chiral weak sector, and the electromagnetic long-range component. Accordingly, the identifying parameters include not only the types of admissible modes themselves, but also the conditions restricting their gauge representations, chiral organization, admissible local couplings, and anomaly-freedom requirements.

A finer parametrization of the visible sector arises only after this minimal realization has been singled out. If more than one family-isomorphic chiral block is admitted in a reconstruction class, then the generational multiplicity $N_{\mathrm{gen}}(\mathcal{K})$ and the space of admissible intergenerational couplings naturally take their place among the class parameters. In the same sense, the Yukawa matrices may also be regarded as part of a finer parametrization of the visible sector. At the present stage, however, what is essential is primarily not their specific values, but the very fact that such objects naturally arise within the language of the reconstruction class after a minimal Standard-Model realization of the visible sector has been singled out.

Thus, the identifying parameters of the class $\mathcal{K}$ specify a joint set of constraints on the type of admissible effective modes, their gauge and chiral representations, the conditions of observability, and the finer parametrization that emerges after the visible sector has been singled out. Such parameters are not external *ad hoc* insertions, but express the internal conditions of compatibility of a physically relevant reconstruction class. It is in this sense that the further extraction of a minimal Standard-Model realization of the visible sector will have a class-conditional character.

3 The Visible Sector and the Parameters of Its Selection

After fixing the initial working regime and the language of admissible reconstruction classes, one can proceed to the central question of the present article: how, from the multitude of admissible classes, there is singled out such a physically relevant family in which a minimal Standard-Model realization of the visible sector arises. The issue is not an external phenomenological fitting of fields and symmetries, but the identification of such a subset of the parameters of the reconstruction class as is compatible with the already constructed special-relativistic, gravitational, and quantum working regime and admits the physical actualization of an observable world of our type.

It is essential that the structural derivation need not uniquely fix a single reconstruction class. It is more natural to assume that it singles out some physically relevant family of admissible classes in which the form of the visible sector coincides, whereas the specific numerical values of constants and other realization parameters may differ. For definiteness, let us denote this family by

$$\mathfrak{K}_{\mathrm{SM}} \subset \mathfrak{K}_{\mathrm{adm}},$$

where $\mathfrak{K}_{\mathrm{adm}}$ is the set of admissible reconstruction classes, and $\mathfrak{K}_{\mathrm{SM}}$ is the subset of those classes in which a minimal Standard-Model realization of the visible sector is singled out. Hereafter, unless otherwise stated, $\mathcal{K} \in \mathfrak{K}_{\mathrm{SM}}$ will denote an arbitrary class from this family.

For the purposes of the subsequent analysis, it is convenient to single out not the entire set of parameters of the class $\mathcal{K}$, but only that subset of it which is essential for singling out a minimal Standard-Model realization of the visible sector. Let us denote this subset by

$$\mathcal{P}_{\mathrm{SM}}(\mathcal{K}) \subseteq \mathcal{P}(\mathcal{K}),$$

where $\mathcal{P}(\mathcal{K})$ is the full set of parameters of the reconstruction class. Then

$$\mathcal{P}_{\mathrm{SM}}(\mathcal{K}) = \mathcal{P}_{\mathrm{sel}}(\mathcal{K}) \cup \mathcal{P}_{\mathrm{real}}(\mathcal{K}),$$

where $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ denotes the structural-selection parameters determining the very possibility of the visible sector, while $\mathcal{P}_{\mathrm{real}}(\mathcal{K})$ denotes the parameters of the concrete realization of the already singled-out Standard-Model structure. Other parameters of the reconstruction class not belonging to $\mathcal{P}_{\mathrm{SM}}(\mathcal{K})$ are not analyzed in the present section.

At the same time, the hidden sector is not posited here as an initial and coequal goal of the construction. The principal task is to single out a minimal Standard-Model realization of the visible sector. Hidden content then arises as a consequence of the fact that the visible sector, selected by the set of parameters $\mathcal{P}_{\mathrm{SM}}(\mathcal{K})$, need not exhaust the full physical content of the reconstruction class. It is precisely this incompleteness that makes the emergence of the hidden sector not an external insertion but an additional structural result of the scheme under consideration.

3.1 Structural-Selection Parameters

If a minimal Standard-Model realization is to be regarded as the visible sector in classes $\mathcal{K} \in \mathfrak{K}_{\mathrm{SM}}$, then it is necessary to specify which parameters or structural constraints make this possible. In the present work, such parameters are understood broadly: they need not be numerical quantities and may specify both structural constraints and conditions of observability, admissible types of couplings, and regimes of realization of effective modes.

For definiteness, let us specify the structural-selection parameters as

$$\mathcal{P}_{\mathrm{sel}}(\mathcal{K}) = \{P_1, P_2, P_3, P_4, P_5, P_6\},$$

where

P_1 : compatibility with the existence of stable internal registers of the observer,

P_2 : the presence of at least one long-range channel,

P_3 : the existence of stable color-neutral composites,

P_4 : the presence of a chiral weak structure,

P_5 : anomaly freedom of the admissible gauge–fermionic sector,

P_6 : compatibility with a local relativistic quantum-field-theoretic regime.

Parameter P_1 means that the visible sector must be compatible with the existence of stable material subsystems capable of playing the role of observer bodies and their registers. Consequently, it cannot reduce to an arbitrary algebraic set of modes that does not admit reproducible local registration and long-term fixation of measurement results.

However, it is insufficient to understand this only in an abstract operational sense. It is also necessary that the visible sector specify that set of effective modes on the basis of which, in a given reconstruction class, the observer's body, its internal registers, and the standard channels of registration are realized. In other words, a sector is called visible not simply because it formally admits observation, but because it is precisely its modes that participate in the material organization of the observer itself and thereby specify the standard scheme of local observability. In this sense, the visibility of the sector is an internal property of the class $\mathcal{K}$: the observer is not external to the structure being singled out, but is realized through it. It is for this reason that the subsequent singling out of a minimal Standard-Model realization of the visible sector should be understood simultaneously as the singling out of that sector which forms the standard material organization of the observer in a world of our type.

Parameter P_2 expresses the necessity of a channel ensuring macroscopic information transfer and the coordination of observations. Without such a component, the observable world would remain operationally fragmented into local pieces.

Parameter P_3 imposes the requirement of stable composite matter. It is precisely this that forces one to consider such a sector in which elementary modes admit organization into stable color-neutral bound states.

Parameter P_4 fixes the necessity of a chiral weak structure, that is, a nontrivial distinction between left- and right-handed fermionic degrees of freedom.

Parameter P_5 expresses the condition of internal quantum consistency: the admissible set of gauge and fermionic degrees of freedom must not lead to local anomalies.

Parameter P_6 links the subsequent analysis to the already constructed quantum core. It means that the visible sector must admit a description in terms of local fields, local algebras of observables, and a standard quantum-field-theoretic organization in the locally inertial approximation.

Thus, the set of parameters $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ specifies that level of selection at which the singling out of a minimal Standard-Model realization of the visible sector becomes possible. The distinction between visible and hidden content thereby acquires not only an operational, but also a bodily-realizational expression: the visible sector forms the standard material structure of the observer and its registers, whereas hidden content, generally speaking, may remain outside this structure and therefore need not be directly accessible to standard channels of observation.

It is essential that the parameters $\mathcal{P}_{\text{sel}}(\mathcal{K})$ be regarded below not as arbitrary additional constraints, but only as such conditions as are compatible with the already constructed minimal quantum core. Compatibility here means that the corresponding structures can be realized within the same locally inertial relativistic quantum-field-theoretic regime, without requiring the abandonment of locality, causality, the operator organization of observables, and other elements of the previously isolated quantum layer. For this reason, the parameters introduced below should be understood not as an alternative to the quantum core, but as a further specification of admissible structures within the already constructed quantum regime.

3.2 A Minimal Standard-Model Realization of the Visible Sector

Given the already constructed quantum core and the fulfillment of the parameters $\mathcal{P}_{\text{sel}}(\mathcal{K})$ for classes $\mathcal{K} \in \mathfrak{K}_{\text{SM}}$, the minimal compatible visible gauge–fermionic organization admits a Standard-Model realization. At the gauge level, this leads to the structure

$$G_{\text{vis}} \sim SU(3) \times SU(2) \times U(1),$$

understood in the local sense, with the usual reservation concerning a possible global identification.

The necessity of the color sector is determined by parameter P_3: if the visible sector is to contain carriers of registers and macroscopically stable matter, then it cannot dispense with a non-Abelian component admitting the formation of color-neutral composites. For this reason, the minimal compatible strong structure takes the form of an $SU(3)$-type sector.

The necessity of the weak sector is determined by parameter P_4: if the visible sector is to reproduce the observed type of distinction between left- and right-handed fermionic modes, then an additional non-Abelian structure is required, specifying the minimal chiral organization of local interactions. It is in this role that an $SU(2)$-type sector arises.

The necessity of the Abelian component is determined by parameter P_2: if all gauge degrees of freedom are confined or have a finite range, then no mechanism arises that ensures macroscopic information transfer and the coordination of observations. Consequently, the visible sector must include a $U(1)$-type Abelian component.

It is important in content that the parameters $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ specify not an arbitrary set of desired symmetries, but a minimal set of requirements on the visible sector. The requirement of stable color-neutral composite matter points to the necessity of a confining non-Abelian strong sector; the requirement of a chiral weak structure points to the presence of a separate non-Abelian component distinguishing left- and right-handed fermionic degrees of freedom; the requirement of a long-range channel points to an Abelian component that remains non-confined in the observable regime. Together with the conditions of local quantum-field-theoretic consistency and anomaly freedom, this singles out a Standard-Model realization as the natural minimal response to the set of constraints under consideration.

At the same time, the present work does not claim that the set of parameters $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ is exhaustive in an absolute sense. It is not excluded that further development of the model will reveal additional structural constraints that narrow the family of physically relevant reconstruction classes even more strongly. However, for the principal result of the present article, a weaker yet sufficient claim is essential: the already considered set of parameters is sufficient for singling out a minimal Standard-Model realization of the visible sector in the class-conditional sense. It is precisely in this that the logical status of the obtained result consists: it requires neither the global completeness of the present set of parameters nor a prior resolution of the question of the extendability or non-extendability of the visible sector.

For this reason, at the present stage the issue is not a full uniqueness theorem excluding all alternative gauge structures compatible with the underlying model. The established result has a more precise and more limited character: for parameters $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ singling out a physically relevant family of reconstruction classes, the Standard-Model structure appears as the minimal compatible realization of the visible sector. The analysis of the extent to which larger or other gauge structures may be excluded by additional conditions of anomaly freedom, confinement, minimality, and compatibility with the observable working regime belongs to the next level of classification of admissible reconstruction classes.

After fixing these reconstructive conditions, the further identification of the corresponding minimal gauge–fermionic structure relies on standard results of Standard Model theory [9, 10]. The point is precisely a minimal Standard-Model realization of the visible sector for classes $\mathcal{K} \in \mathfrak{K}_{\mathrm{SM}}$, rather than the full physical content of these classes.

At the fermionic level, the corresponding structure is first singled out as a minimal anomaly-free chiral block containing the color and leptonic sectors in a consistent local organization. In this sense, the Standard-Model realization is initially specified at the level of a single family. Here one uses the standard classification of the anomaly-free chiral family of the Standard Model and the associated conditions of consistency [9, 11, 12].

3.3 Realization Parameters

After the singling out of a minimal Standard-Model realization of the visible sector, the next level of parametrization arises, pertaining already not to the form of this structure itself, but to its concrete realization in a class $\mathcal{K} \in \mathfrak{K}_{\mathrm{SM}}$. The parameters $\mathcal{P}_{\mathrm{real}}(\mathcal{K})$ should be understood not as external phenomenological data, but as finer identifying parameters of the reconstruction class itself. If the parameters $\mathcal{P}_{\mathrm{sel}}(\mathcal{K})$ single out a family of classes in which a minimal Standard-Model realization of the visible sector is admitted, then the parameters $\mathcal{P}_{\mathrm{real}}(\mathcal{K})$ distinguish concrete realizations of this structure within the already singled-out family.

For definiteness, let us denote the realization parameters as

$$\mathcal{P}_{\mathrm{real}}(\mathcal{K}) = \{R_1, R_2\},$$

where

R_1 : generational multiplicity $N_{\mathrm{gen}}(\mathcal{K})$,

R_2 : the space of admissible Yukawa and associated intergenerational couplings.

Parameter R_1 specifies the number of family-isomorphic chiral sets of modes in the visible sector. Thus, generations are treated not as externally added fields, but as one of the realization parameters of the already singled-out minimal Standard-Model structure and, consequently, as one of the finer parameters of the reconstruction class itself.

By a generation in the present work is meant not an arbitrary set of additional particles, but a family-isomorphic chiral block carrying the same gauge quantum numbers and realizing the same structure of representations as the original minimal family. Consequently, the distinction between generations does not affect the form of the gauge organization itself, but pertains to the multiplicity of the admissible fermionic realization of this form. At this level, one uses the standard structure of the anomaly-free chiral family of the Standard Model and the associated conditions of consistency [9, 11, 12].

Parameter R_2 specifies a finer level of parametrization. If several family-isomorphic chiral sets of modes are admissible in the visible sector, then operators may arise that couple these sets to each other and to the scalar sector. In that case, the Yukawa matrices appear as a natural part of the parameters of the class $\mathcal{K}$, describing admissible intergenerational and scalar–fermionic couplings. The very fact that such a space of couplings arises is here a standard consequence of the structure of the visible sector [10, 12]; the novelty of the present work lies not in this fact as such, but in its inclusion in the parametrization of the reconstruction class.

At the same time, the present article claims not a final derivation of the values of the parameters $\mathcal{P}_{\mathrm{real}}(\mathcal{K})$, but only that they naturally enter the parametrization of the realization of the minimal Standard-Model structure within the physically relevant family of classes $\mathfrak{K}_{\mathrm{SM}}$.

3.4 Status of the Result

The obtained result has a class-conditional character. What is asserted is not the global uniqueness of the Standard Model as the whole of physics, but the following: structural analysis singles out a physically relevant family of reconstruction classes $\mathfrak{K}_{\mathrm{SM}} \subset \mathfrak{K}_{\mathrm{adm}}$, in which a minimal Standard-Model realization of the visible sector is admitted.

This means that what is fixed in the present section is not an arbitrary phenomenological coincidence, but a structural result: for a given subset of parameters

$$\mathcal{P}_{\mathrm{SM}}(\mathcal{K}) = \mathcal{P}_{\mathrm{sel}}(\mathcal{K}) \cup \mathcal{P}_{\mathrm{real}}(\mathcal{K}), \qquad \mathcal{K} \in \mathfrak{K}_{\mathrm{SM}},$$

there arises a Standard-Model-like gauge–fermionic organization compatible with operational observability, internal consistency, and the already constructed quantum regime. Accordingly, the minimal Standard-Model realization of the visible sector is singled out here not as a separate theory superimposed on a ready-made background, but as part of a unified reconstruction scheme from the same fundamental field from which the special-relativistic, gravitational, and quantum layers were previously obtained.

At the same time, what remains open are primarily the parameters of the concrete realization within the family $\mathfrak{K}_{\mathrm{SM}}$. They belong to a finer level of parametrization of physically relevant reconstruction classes and are subject to further analysis within the inverse problem. It is not excluded that, as the mathematical structure of the model develops, some of the parameters that at the present stage are introduced separately and appear independent will turn out to be interrelated at the level of the model itself, or derivable from other parameters or from deeper conditions of compatibility. In that case, the number of genuinely independent class parameters will decrease.

Finally, the minimal Standard-Model realization is singled out here precisely as the visible sector, and not as the full physical content of the classes in $\mathfrak{K}_{\mathrm{SM}}$. If, for a fixed set of parameters $\mathcal{P}_{\mathrm{SM}}(\mathcal{K})$, it does not exhaust the full content of the class $\mathcal{K}$, then additional content remains beyond the visible sector. It is precisely this content that will become the subject of the analysis of the hidden sector below.

4 From the Incompleteness of the Visible Sector to Hidden Content and Dark Matter

The singling out of a minimal Standard-Model realization of the visible sector does not yet complete the analysis of a physically relevant reconstruction class. On the contrary, it is precisely after the visible gauge–fermionic organization has been established that the following question arises: does this sector exhaust the entire physical content of the class $\mathcal{K}$, or does it constitute only the directly observable part of a broader structure? In the present section, the second alternative is substantiated. It is shown that the very manner in which the visible sector is singled out directly implies the existence of content not included in the minimal Standard-Model realization. A distinction is then introduced between the invisible complement to the visible sector, its physically relevant part, and that gravitationally relevant non-vacuum part of hidden content which, in the present article, is interpreted as dark matter.

4.1 The Incompleteness of the Visible Sector as a Consequence of Its Selective Extraction

In the present work, a minimal Standard-Model realization is singled out as the structure of the directly observable sector. However, the very manner of its extraction already shows that what is at issue is not a complete description of the reconstruction class, but that part of it which is selected by the conditions of observability, the stability of registers, the existence of a long-range channel, color-neutral composite matter, chiral weak structure, and local quantum-field-theoretic consistency.

These conditions are, by their very meaning, conditions for singling out the visible sector, not conditions for exhausting the entire modal or physical content of the class. Consequently, unless an additional principle of completeness is introduced, according to which every physically admissible mode must belong to the observable structure of the visible sector, it follows directly from the selection procedure itself that part of the content of the class does not enter this structure.

Thus, the minimal Standard-Model realization fixes the directly observable non-gravitational organization of the world, but does not automatically exhaust the entire content of the reconstruction class. Beyond it there remains an invisible complement arising as a structural residue after the selective extraction of the visible sector. It is in this sense that the incompleteness of the visible sector is not an external hypothesis, but a direct consequence of the manner of its construction.

This circumstance remains in force even after generational multiplicity has been introduced. The parameter $N_{\mathrm{gen}}(\mathcal{K})$ complicates the internal organization of the visible sector, but does not eliminate the distinction between the conditions of its extraction and the full content of the class. Consequently, even in the presence of generations, the minimal Standard-Model realization remains precisely the visible sector, and not automatically the whole physics of the class $\mathcal{K}$.

4.2 Hidden Content as the Physically Relevant Part of the Invisible Complement

From the extraction of a minimal Standard-Model realization of the visible sector it directly follows that there exists content not included in this visible structure. However, the question whether all of this invisible complement should be assigned to the hidden sector in the physical sense cannot be resolved at a purely classificatory level. For this reason, a more precise distinction is required in the present work.

By the *invisible complement* below is meant the whole part of the content of the reconstruction class that does not enter the visible sector. By the *hidden sector* in the present article is meant not all of this complement automatically, but its physically relevant part in the working regime under consideration. In other words, the hidden sector is introduced not as an external hypothesis about new fields, but as the physically significant part of that content which did not enter the minimal Standard-Model realization when it was selectively extracted.

At the same time, the physical relevance of hidden content is not exhausted by a single possibility. In principle, different types of hidden subsectors are not excluded: some of them may acquire significance primarily through gravitational contribution, others through more subtle indirect effects on the visible sector, for example through additional correlations, mixing, or other effective couplings. The present article does not aim at a full classification of all such possibilities and is restricted to that level of analysis required for posing the question of dark matter.

Such a definition leaves open an important question. It is not excluded that a more complete mathematical analysis will show the coincidence of the entire invisible complement with the hidden sector. It is also not excluded, however, that a further distinction will be required between physically relevant hidden content and other modes that acquire no operational, gravitational, or other physically significant realization within the present regime. In the present article, this question is not closed definitively and must be regarded as part of a more complete inverse problem.

Thus, in the present work the hidden sector has a reconstructive rather than an external phenomenological status. It arises not as an arbitrarily added superstructure over the visible world, but as the physically relevant part of the invisible complement generated by the very procedure of extracting the visible sector.

4.3 Operational Darkness and Gravitational Relevance

After the hidden sector has been introduced, it is necessary to clarify in what sense it is "dark." In the present work, darkness is understood operationally. Hidden content is called dark insofar as it does not enter the standard local protocols of observation realized by the visible sector, or enters them only indirectly and in a substantially weakened form.

This means that hidden content should not manifest itself stably as part of the ordinary local picture of the world specified by the structure of the visible sector. It does not form a standard channel of registration, does not directly determine the structure of observational registers, and does not enter the usual scheme of reproducible local measurements. It is in this sense, and not in any metaphysical sense, that it is dark.

However, operational darkness is not identical with physical irrelevance. Since the reconstructed gravitational dynamics in this program has a universal character with respect to effective fields, hidden content may remain physically significant even when it does not enter the standard non-gravitational protocols of observation. In other words, the absence of direct local observability does not yet imply the absence of a contribution to the reconstructed dynamics of the world.

For the purposes of the present article, hidden content is considered primarily to the extent that it may be gravitationally relevant. If some hidden component is compatible with the reconstruction class $\mathcal{K}$ and contributes to the effective energy–momentum tensor, then it has physical status even in the absence of direct standard observability. It is precisely this that creates the conceptual bridge from hidden content to the question of dark matter. At the same time, the present article does not claim that every physically relevant hidden structure must be exhausted by a gravitational contribution alone; the claim is only that the gravitationally relevant part of hidden content is already sufficient for posing the question of dark matter within the working regime under consideration.

4.4 Dark Matter as the Gravitationally Relevant Non-Vacuum Part of the Hidden Sector

From the foregoing it follows that the hidden sector and dark matter must not be identified automatically. The hidden sector is the physically relevant part of the invisible content of the reconstruction class lying beyond the visible sector. Dark matter, by contrast, represents only that part of it which possesses a certain physical profile.

In the present work, dark matter is understood as that part of the hidden sector which remains operationally dark with respect to the visible sector, is gravitationally relevant, and yields a non-vacuum contribution in the reconstructed dynamics. At the same time, what is meant is not a necessary reduction of hidden content to an autonomous sector of ordinary particles, but only that part of it which acquires an operationally dark, gravitationally relevant, and non-vacuum status in the reconstructed dynamics. It is in this working sense that the corresponding part of hidden content is interpreted here as dark matter.

This distinction is essential for two reasons. First, it prevents the whole of hidden content from being conflated with one particular realization of it. Second, it fixes the precise working meaning of dark matter within the present article: what is meant is not an arbitrary invisible component, but precisely that part of hidden content which manifests itself as an additional non-vacuum gravitationally active contribution in the reconstructed dynamics.

At the same time, the present article does not claim that every physically relevant hidden structure must have precisely this character. In principle, other hidden subsectors are not excluded, including such as may influence the visible sector indirectly but are not reducible to a gravitationally relevant non-vacuum contribution. However, for the purposes of the present work, what is essential is precisely that part of hidden content which is connected with posing the question of dark matter. For this reason, the hidden sector is analyzed here primarily to the extent that it yields a gravitationally relevant non-vacuum contribution. It is in this working sense that hidden content is associated below with dark matter.

4.5 What Is Deliberately Left Outside the Scope of the Article

For a correct interpretation of the obtained result, it is necessary to state explicitly the limits of the present analysis.

First of all, the mechanism of dark energy is not considered in the article.

This restriction is of a principled character. Dark energy is not included here in the notion of the hidden sector and is not treated as yet another of its components. The question of its origin belongs to a separate line of analysis and must be considered independently.

Moreover, the present work does not construct a complete phenomenology of all possible forms of hidden content. No exhaustive classification is given here of hidden modes, nor are their possible intrinsic dynamics, self-interactions, spectral organization, and cosmological evolution analyzed in full. Likewise, those hidden subsectors that may possess physical relevance but are not reducible to a gravitationally relevant non-vacuum contribution, including their possible indirect couplings to the visible sector, are not considered in full. Nor is the question of whether the hidden sector coincides with the entire invisible complement to the visible sector definitively closed. All these questions belong to the next stage in the development of the program.

Consequently, the principal result of the present section consists not in the construction of a complete theory of the hidden world, but in a narrower and at the same time fundamentally important claim: the minimal Standard-Model realization of the visible sector does not automatically exhaust the full content of the reconstruction class; its selective extraction entails the existence of an invisible complement; the physically relevant part of this complement forms the hidden sector; and, within the present article, its gravitationally relevant non-vacuum part is interpreted as dark matter.

5 Structural Formulation of the Inverse Problem for the Parameters of the Reconstruction Class

Up to this point, the analysis has proceeded predominantly in the direct direction: from the parameters of a physically relevant family of reconstruction classes to the singling out of a minimal Standard-Model realization of the visible sector, to the establishment of its possible incompleteness, and to the introduction of hidden content to the extent that it acquires physical relevance in the working regime under consideration. However, the logic of the program itself also requires movement in the reverse direction. If observable physics is not a fundamentally given datum, but the result of the realization of a certain reconstruction class, then observable structures must be regarded not only as consequences of its parameters, but also as sources of information about them. It is precisely this that defines the *inverse problem.*

In the present section, the inverse problem is not solved in the constructive sense of the term. Its aim is a more limited, yet fundamentally important, step: to fix its structural formulation, to indicate to which parameters of the reconstruction class it pertains, and to determine which observable data may in principle enter into its solution. The issue is not the direct problem of fully reconstructing the fundamental field configuration on $\mathbb{E}^4$, but primarily the reconstruction or restriction of parameters at the level at which the class $\mathcal{K}$ specifies an observable world of the working type. If, however, within this problem one succeeds in at least partially constraining or reconstructing properties of the fundamental configuration itself, then such a result also has independent significance. Whenever no ambiguity arises, $\mathcal{K}$ will hereafter denote an arbitrary physically relevant class from the family previously singled out.

Thus, the inverse problem does not reduce to the usual fitting of numerical constants of low-energy phenomenology. Its subject matter is broader: it concerns the structure of the reconstruction class itself, including the form of the visible sector, its generational organization, admissible intermode couplings, and physically relevant hidden content. It is precisely for this reason that observable physics must play a double role: it appears both as a result of the realization of class parameters and as a means of their phenomenological identification.

5.1 Structural Parameters, Visible-Sector Parameters, and Parameters of Hidden Content

For a correct formulation of the inverse problem, it is convenient to divide the parameters of the reconstruction class $\mathcal{K}$ according to their physical status. In the present work, it is sufficient to distinguish three types of parameters: structural parameters of the class, parameters of the visible sector, and parameters of hidden content.

By *structural parameters of the class* are meant such characteristics of $\mathcal{K}$ as determine the very possibility of the existence of the working regime. These include the conditions for the existence of a stable observer, operational event structure, causal consistency, the locally inertial special-relativistic regime, the minimal quantum core, and the overall internal compatibility of the effective description. These parameters specify not a separate sector of physics, but rather the level of conditions at which the singling out of visible and hidden content becomes meaningful at all.

Parameters of the visible sector pertain to the minimal observable substructure of the class $\mathcal{K}$. They fix the form of the SM-type gauge sector, the structure of admissible chiral fermionic representations, the set of charges, admissible intermode couplings, and the finer internal organization of the visible world. It is at this level that it is natural to introduce such quantities as generational multiplicity

$$N_{\mathrm{gen}}(\mathcal{K}),$$

and, once it has been introduced, the admissible space of Yukawa couplings. At the same time, $N_{\mathrm{gen}}(\mathcal{K})$ should be understood not as an external empirical appendage, but as an internal parameter of the class, determining the multiplicity of family-isomorphic chiral blocks in the visible sector.

Finally, *parameters of hidden content* pertain to that part of the content of the class $\mathcal{K}$ which does not belong to the minimal visible sector, but acquires physical relevance in the working regime under consideration. These include parameters determining the presence or absence of additional hidden degrees of freedom, the degree of their operational darkness, the form of their coupling to the visible sector, and the conditions under which their contribution becomes physically relevant, in particular gravitationally relevant. At this level there also arises the question of which part of hidden content yields a gravitationally relevant non-vacuum contribution and may therefore be interpreted as dark matter in the sense of the present work. At the same time, the question whether the hidden sector coincides with the entire invisible complement to the visible sector is not closed definitively in the present article and must be regarded as part of a more complete mathematical reconstruction.

This threefold division does not imply the independence of the three groups of parameters. On the contrary, they should be regarded as mutually consistent components of a single structure $\mathcal{K}$. The structural parameters constrain admissible visible and hidden content; the parameters of the visible sector determine the form of the observable substructure; and the parameters of hidden content, in turn, cannot be chosen independently of the conditions for the existence of an observable world of the working type. It is precisely for this reason that the inverse problem should be understood not as the fitting of disconnected numbers, but as the reconstruction of the consistent parametric structure of one and the same reconstruction class.

5.2 Phenomenological Identification of a Physically Relevant Class

If the reconstruction class $\mathcal{K}$ indeed specifies the observable world, then observable physics must serve not only as the result of its realization, but also as a means of its partial identification. In other words, the reconstruction class should be understood not merely as a theoretical container of admissible structures, but as an object whose parameters are, at least in principle, connected with observable data.

At the present stage, the most natural phenomenological identifiers are the features of the minimal visible sector: the Standard-Model-like form of the gauge structure, the chiral organization of fermionic content, the presence of color-neutral composite matter, the existence of a long-range Abelian channel, and anomaly-free local quantum-field-theoretic organization. Within the present program, these features are not accidental empirical facts attached to the model from outside; they express those features of the observable world that must be compatible with a physically relevant reconstruction class.

A special role is played by the phenomenologically observed multiplicity of generations. If the number of generations is treated as a class parameter $N_{\text{gen}}(\mathcal{K})$, then the empirically fixed generational structure must be understood as one of the central identifying features of $\mathcal{K}$. Once generational multiplicity has been introduced, the finer characteristics of the visible sector, including the admissible space of Yukawa couplings, acquire an analogous status. At the present stage of the work, this means not a complete recovery of such structures, but the recognition that they belong to the phenomenological profile of the class and, accordingly, fall within the scope of the inverse problem.

On the other hand, the identifiers of a class may consist not only in directly observable properties of the visible sector, but also in indirect manifestations of hidden content. If the physically relevant part of hidden content in the class $\mathcal{K}$, and in particular its gravitationally relevant non-vacuum part, yields a gravitationally significant contribution, then such effects likewise enter the phenomenological profile of the class. In this sense, the presence or absence of hidden content yielding an additional non-vacuum gravitational contribution, the character of its indirect manifestation, and the general form of the relation between visible and hidden content may also play the role of identifying features.

At the same time, phenomenological identification does not imply a fully unique reconstruction of the class in all details. One and the same set of coarse observable features may, in general, be compatible with more than one admissible reconstruction class. Accordingly, what is at issue is not necessarily a bijective correspondence between phenomenology and the class $\mathcal{K}$, but a substantial narrowing of the space of admissible realizations on the basis of observable physics.

5.3 Which Parameters Can in Principle Be Constrained from Data on the Visible Sector

One may now pose a more precise question: which parameters of the class $\mathcal{K}$ can in principle be constrained, localized, or partially reconstructed from data on the visible sector? It is important to emphasize here that the issue is not a complete inversion of the entire fundamental model, nor the reconstruction of the field configuration itself on $\mathbb{E}^4$. The subject matter of the inverse problem is substantially narrower: one must establish what information about the structure of the reconstruction class is contained in observable correlators, spectra, effective coupling constants, geometric response, and indirect gravitational manifestations of hidden content.

At the first level, the very form of the minimal gauge organization may be constrained from data on the visible sector: if observable physics reproduces the color, chiral weak, and Abelian long-range channels, then this already substantially narrows the space of admissible reconstruction classes. At the second level, the structure of fermionic content may be constrained, including the number of generations $N_{\text{gen}}(\mathcal{K})$, since the observed multiplicity of family-isomorphic modes pertains directly to the parameters of the visible sector. At the third level, the admissible types of intermode couplings may be investigated; although they need not be uniquely determined, they may be substantially constrained by observable effective coupling constants and by the spectral organization of the visible world.

Of particular importance is the fact that, in the general case, data on the visible sector carry information not only about it itself, but also about hidden content. If the hidden sector is gravitationally relevant, this may manifest itself in an indirect geometric response not reducible to the visible sector alone. Consequently, from data on observable physics one may in principle not only constrain the parameters of the minimal visible world, but also obtain constraints on the admissible structure of hidden content, at least to the extent that it affects the effective $T^{\text{eff}}_{\mu\nu}$.

In a stronger version of the formulation, the same logic extends to the finer parametrization of the visible sector. If, once $N_{\text{gen}}(\mathcal{K})$ has been introduced, a space of admissible Yukawa couplings arises, then data on spectra, generational structure, and effective coupling constants may, at least in principle, be used to constrain admissible structures of the Yukawa matrices. The present work does not claim a complete solution of this problem, but it is already significant that such structures enter the natural domain of the inverse problem rather than lying outside it.

Accordingly, from data on the visible sector the following may in principle be constrained: the form of the minimal gauge structure, the structure of admissible fermionic content, the generational multiplicity $N_{\mathrm{gen}}(\mathcal{K})$, part of the parameters of intermode and intergenerational couplings, and also, indirectly, those characteristics of hidden content that manifest themselves through geometric response and through an additional contribution to $T^{\mathrm{eff}}_{\mu\nu}$. As was shown in the previous work on reconstruction classes and the fine-tuning problem [4], such parameters should be considered not separately, but as elements of a single consistent set realized in one physically relevant reconstruction class. It is precisely in this sense that the data of the visible world appear not only as an empirical fixation of an already constructed structure, but also as a source of information about the parameters of the reconstruction class in which this structure is realized.

At the same time, the present article does not yet offer either an explicit inversion procedure, or a reconstruction algorithm, or an analysis of uniqueness, or an analysis of the stability of the solution to the inverse problem. Its result at the present stage has a programmatic-structural character: the formulation of the inverse problem is fixed, the domain of parameters to which it pertains is determined, and those observable data are indicated that may in principle be used to constrain them in further work.

6 Discussion

The result obtained in the present work should be interpreted as the next step in the program of operational reconstruction of physics from a timeless Euclidean model. If the previous works isolated the special-relativistic, gravitational, and minimal quantum layers of description, here the internal organization of the visible world and its relation to the broader physical content of the reconstruction class are considered. Accordingly, the present article does not repeat the already constructed special-relativistic–gravitational–quantum framework, but uses it as the inherited working regime for the following question: which gauge–fermionic structure must be operationally visible, and does it exhaust the entire physically relevant content of the corresponding reconstruction class?

The principal result may be formulated as follows. Structural analysis singles out a physically relevant family of reconstruction classes $\mathfrak{K}_{\mathrm{SM}} \subset \mathfrak{K}_{\mathrm{adm}}$, in which a minimal Standard-Model realization of the visible sector is admitted. Its gauge structure takes a Standard-Model-like form, while the fermionic content is naturally organized as a family chiral block of the working type. Thus, the Standard Model appears here not as an initial postulate, but as an operationally singled-out minimal realization of the visible sector within an admissible family of reconstruction classes.

Although in the present work a minimal Standard-Model realization of the visible sector is singled out within a physically relevant reconstruction class, this conclusion should be understood as class-conditional. A number of parameters and assumptions used both in singling out the visible gauge–fermionic structure itself and, at the preceding stage, in constructing the minimal quantum core, have not yet taken the form of fully closed mathematical theorems. However, this does not mean that the corresponding elements are principally heuristic in character or externally arbitrary. On the contrary, the structure of the model itself admits their subsequent rigorous resolution: either through direct structural derivation, or through the solution of the inverse problem, or through establishing a mathematical dependence between parameters that at the present stage appear independent. Thus, the conditional character of the conclusion obtained reflects not a limit of the mathematical rigor of the scheme as such, but the current stage of its formalization.

It is of fundamental importance that this visible sector is not identified with the full physical content of the reconstruction class. On the contrary, the article shows that the very manner of its selection implies the presence of an invisible complement to the visible sector. Since the visible sector is determined by the operational criteria of observability, register stability, the presence of a long-range channel, color-neutral composite matter, chiral weak structure, and local quantum-field-theoretic consistency, it specifies the directly observable non-gravitational substructure, but does not automatically exhaust the entire content of the class. It is precisely the distinction between the criterion of visibility and the criterion of admissibility that constitutes one of the central new ideas of the present work.

On this basis, the article introduces a natural place for hidden content. It is understood not as an externally added hypothesis about new fields, but as that additional content which remains beyond the visible sector. Its physically relevant part forms the hidden sector in the working regime under consideration. It is shown that such content may be operationally dark, that is, it may fail to enter the standard local protocols of observation of the visible sector, and at the same time remain physically relevant. Its physical relevance, however, need not in all cases reduce to one and the same form: in principle, various hidden subsectors are not excluded, including those that may manifest themselves predominantly through gravitational response or through more subtle indirect couplings to the visible sector. Thus, hidden content acquires not an arbitrary phenomenological, but a reconstructive status.

A further clarification is that not all hidden content is identified with dark matter. Dark matter is singled out here as the gravitationally relevant non-vacuum part of hidden content, that is, as such a component of it as simultaneously remains operationally dark, is gravitationally relevant, and makes a non-vacuum contribution in the reconstructed dynamics. What is meant here is not a necessary reduction of hidden content to an autonomous sector of ordinary particles, but only that part of it which acquires an operationally dark, gravitationally relevant, and non-vacuum status in the reconstructed dynamics. Such a distinction between hidden content and dark matter is essential, since it prevents different types of hidden content from being conflated. In particular, dark energy is deliberately left outside the scope of the present article and is not included in the discussion without a separate mechanism of origin.

It is also important in substantive terms that dark matter arises here not as an external phenomenological appendage to the already obtained minimal Standard-Model realization of the visible sector, but as a natural consequence of its selective extraction within a broader reconstruction class. In this sense, the natural emergence, in the analysis of the visible sector, of hidden content that yields an additional non-vacuum gravitationally active contribution may be regarded as an indirect argument in favor of the internal meaningfulness of the model: one and the same reconstructive scheme yields not only a minimal Standard-Model-like visible structure, but also a natural place for dark matter. Of course, this does not constitute an independent proof of the correctness of the construction, but it does strengthen its explanatory coherence. At the same time, the present article does not claim that every physically relevant hidden content must have precisely this character: other hidden subsectors, not reducible to an additional non-vacuum gravitationally active contribution, are not excluded, but remain outside the scope of the present analysis.

From a methodological point of view, an important result is also the new interpretation of the number of generations. The article shows that generational multiplicity is naturally interpreted as a parameter of the reconstruction class

$$N_{\mathrm{gen}}(\mathcal{K}),$$

rather than as an external empirical appendage. This transfers the problem of generations into the natural language of the parameters of the reconstruction class and makes it part of the internal logic of the program. Similarly, once generational multiplicity is introduced, a space of intergenerational scalar–fermionic couplings arises, so that the Yukawa matrices acquire a natural place as part of a finer parametrization of the class. At the same time, the present work does not claim a complete fixation of their specific textures, ranks, hierarchies, and mixing structure. Thus, the problem of masses and mixing is posed here as the next, finer inverse problem, rather than as an external independent phenomenological block.

A further substantial outcome is that the article provides a new structural formulation of the inverse problem in the language of reconstruction classes. Observable physics is treated not only as a consequence of the parameters of the class $\mathcal{K}$, but also as a phenomenological identifier of such a class. At the same time, what is at issue is not a constructive solution of the inverse problem, but its structural formulation and the fixation of the domain of parameters to which it pertains. The structure of the visible sector, generational multiplicity, the admissible space of Yukawa couplings, and indirect gravitational manifestations of hidden content form a joint set of features by which the reconstruction class may be constrained, localized, or partially reconstructed. Thus, the parameters of the class cease to be merely formal symbols and become the object of a structurally formulated inverse problem.

6.1 Empirical Status and Conditions of Falsifiability

From a methodological point of view, it is essential that the scheme under consideration is not unfalsifiable. Although at the present stage its quantitative phenomenology is not yet fully closed and requires the solution of the inverse problem, the model already imposes a number of substantive constraints which, given sufficient mathematical and empirical concretization, may serve as conditions of falsification.

First of all, within the preceding reconstruction of the gravitational sector, the strong-field regime does not belong to the class of operationally accessible regions. If it were established that, in an operationally observable region, there is realized precisely such a strong-field regime as contradicts the structural constraints of the present reconstruction, this would mean the incompatibility of the corresponding observable regime with the model in its current form.

Similarly, within the reconstruction of the minimal quantum core, there does not arise an independent local quantum sector of gravity in the form of an autonomous spin-2 field of the working type. If precisely such an independent local quantum sector were established, this too would contradict the present form of the model. In this sense, the scheme contains not only explanatory but also restrictive statements.

At the same time, it should be emphasized that few direct low-energy deviations from already known effective theories are to be expected at the present stage. This is natural, since within the model special relativity, the gravitational sector, and the quantum-field-theoretic regime arise as highly accurate effective structures of the observable world. Therefore, the principal quantitatively distinguishing predictions are to be expected not at the level of a crude negation of already confirmed theories, but at the level of small corrections and additional constraints that should emerge upon a more complete solution of the inverse problem.

Thus, the empirical status of the model at the present stage is twofold. On the one hand, it already specifies substantive conditions of possible falsification. On the other hand, its most precise new predictions will presumably arise as the inverse problem is brought to mathematical closure and the parameters of the physically relevant reconstruction class are refined. It is in this sense that the model combines already available structural prohibitions with the prospect of further quantitative tests.

This also constitutes an important difference between the present program and ordinary quantum-field-theoretic practice. In the standard effective-QFT framework, a new extension—for example, an additional gauge symmetry or another sector—is often first considered formally admissible, and only then are its parameters chosen on the basis of general theoretical considerations and phenomenological constraints. In the present scheme, such a level of admissibility is insufficient. Any extension must be compatible not only with the quantum core, but also with the structure of the visible sector, its realization parameters, hidden content, and the overall compatibility of the physically relevant reconstruction class. In other words, the question of the admissibility of a new symmetry or a new sector must be posed here as a question of strict mathematical consistency within a unified reconstructive scheme even before one passes to experimental testing. It is in this sense that the structure of the Standard Model and the quantum regime corresponding to it proves more strongly constraining than in the ordinary phenomenological quantum-field-theoretic framework.

It should be emphasized that the open questions remaining in the article do not weaken its principal result, but clarify its actual status. In the present work, the value of $N_{\mathrm{gen}}(\mathcal{K})$, the concrete structures of the Yukawa matrices, the full phenomenology of hidden content, and the mechanism of dark energy are not fixed definitively. However, precisely owing to such a restriction of the subject matter, it becomes possible to isolate rigorously that level of analysis at which the following have already been obtained: a minimal Standard-Model realization of the visible sector, its incompleteness as a consequence of selective extraction, a natural place for hidden content, the identification of its gravitationally relevant non-vacuum part as dark matter in the sense of the present work, as well as the incorporation of the number of generations and the Yukawa parameters into the language of reconstruction classes.

Taken as a whole, the present work establishes the following logical configuration. A physically relevant reconstruction class contains a minimal

Standard-Model realization of the visible sector as an operationally singled-out substructure, but is not exhausted by it. The selective extraction of the visible sector entails the existence of an invisible complement, which defines a natural place for hidden content, while its physically relevant part forms the hidden sector. Its gravitationally relevant non-vacuum part constitutes dark matter within the scheme under consideration. At the same time, both the internal organization of the visible sector and the finer parameters of hidden content must be regarded as elements of a unified parametrization of the reconstruction class, rather than as independent phenomenological appendages. It is in this sense that the article links the program of reconstructing spacetime and the quantum core with the subsequent analysis of the Standard Model, dark matter, and the finer inverse problem for the parameters of the physically realized class.

7 Conclusion

The present work constitutes the next step in the program of operational reconstruction of physics from a timeless Euclidean model. It has been shown that, within a physically relevant family of reconstruction classes compatible with the already constructed special-relativistic, gravitational, and minimal quantum layers, a minimal Standard-Model realization of the operationally visible sector is singled out. Thus, the Standard-Model-like structure is interpreted not as an initial postulate and not as the full physics of the observable world, but as a gauge–fermionic substructure necessary for the stable operational organization of the visible world of the working type.

At the same time, it has been shown that the extraction of such a visible sector does not entail its completeness. The visible sector specifies the directly observable non-gravitational structure and, in general, does not exhaust the full physical content of the reconstruction class. It is precisely this distinction that opens a natural place for an invisible complement to the visible sector and thereby raises the question of its physically relevant part.

On this basis, the article introduces hidden content as that part of the content of the reconstruction class which does not enter the visible sector. Its physically relevant part is treated as a hidden sector that remains compatible with the same working regime. It is shown that such content may be operationally dark, not participating in the standard local protocols of observation of the visible sector, and at the same time remain physically relevant, including through a possible contribution to the effective energy–momentum tensor. At the same time, the question whether the hidden sector coincides with the entire invisible complement to the visible sector is not closed definitively in the present work and must be regarded as part of a more complete mathematical reconstruction.

Further, the gravitationally relevant non-vacuum part of hidden content is singled out and interpreted, within the framework of the present work, as dark matter. In this scheme, dark matter is understood not as the whole hidden sector, but only as such a part of it as simultaneously remains operationally dark, is gravitationally relevant, and has a non-vacuum character of contribution in the reconstructed dynamics. At the same time, what is meant is not the necessary reduction of hidden content to an autonomous sector of ordinary particles, but only that part of it which acquires an operationally dark, gravitationally relevant, and non-vacuum status in the reconstructed dynamics. Thus, a clear distinction is drawn between hidden content as a whole and that part of it which is interpreted as dark matter. Dark energy is deliberately left outside the scope of the present article as the object of a separate analysis. It is also important in substantive terms that the corresponding hidden content arises here not as an external phenomenological appendage, but as a natural consequence of the selective extraction of the visible sector. In this sense, the natural place for dark matter, arising within the same reconstructive scheme as the minimal Standard-Model realization of the visible sector, may be regarded as an indirect argument in favor of the internal explanatory coherence of the model itself.

Another substantial result of the work is a new interpretation of the number of generations. Generational multiplicity

$$N_{\mathrm{gen}}(\mathcal{K})$$

is interpreted as a parameter of the reconstruction class rather than as an external empirical appendage. This means that the problem of generations is transferred into the language of the internal organization of the class: what remains open is no longer the status of the number of generations itself, but the question of which structural requirements on modes, their multiplicity, compatibility, and mixing must fix its value.

Once generational multiplicity has been introduced, the Yukawa matrices also acquire a natural place. They arise as part of a finer parametrization of the visible sector, associated with admissible scalar–fermionic and intergenerational couplings. At the same time, the present work does not attempt their complete fixation: specific textures, ranks, mass hierarchies, and mixing structure are left as the subject of the next level of analysis. Thus, the space of Yukawa parameters has already been incorporated into the general language of the reconstruction class, although its detailed realization has not yet been derived.

Finally, the article provides a structural formulation of the inverse problem for the parameters of the reconstruction class. Observable physics is treated not only as a consequence of the structure of the class, but also as a phenomenological identifier of that class. The SM-type visible sector, generational multiplicity, admissible intermode couplings, and indirect manifestations of hidden content form a set of features by which a physically relevant reconstruction class may be constrained, localized, or partially reconstructed. This formulation is fixed at the programmatic-structural level, without an explicit inversion procedure, a reconstruction algorithm, or an analysis of the uniqueness or stability of the solution. It covers the visible sector, its finer parametrization, and physically relevant hidden content to the extent that the latter acquires an operational, gravitational, or other physically significant role in the working regime under consideration. Thus, a framework has been formed within which the principal part of observable physics of the given type may be reconstructed. For the full phenomenological closure of this scheme, a separate structural incorporation of the mechanism of dark energy is still required.

Thus, the principal outcome of the present work is the following: a minimal Standard-Model realization of the visible sector of a physically relevant reconstruction class has been singled out; it has been shown that this sector need not exhaust the full physical content of the class; hidden content associated with an invisible complement to the visible sector has been introduced, and its physically relevant part has been identified; its gravitationally relevant non-vacuum part is interpreted as dark matter in the sense of the present work; the number of generations and the Yukawa matrices are incorporated into the parametrization of the class; and a structural formulation of the inverse problem for the class parameters is formulated as the next necessary step of the program. Thus, the present article forms a transition from the minimal quantum core to a more detailed analysis of the visible and hidden contents of the observable world.

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