M8 – Weak-Limit Exchange Structure on Scalar–Conformal NUVO Space

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Notation and Conventions

- $\mathcal{M}$ denotes the spacetime manifold.
- η denotes the reference Lorentzian metric (typically Minkowski in a global chart).
- g denotes the physical metric.
- The scalar field $\Lambda : \mathcal{M} \to \mathbb{R}_{>0}$ is the NUVO modulation field.
- The physical metric is scalar–conformal:

$$g_{\mu\nu} = \Lambda^2 \, \eta_{\mu\nu}.$$

- $\Lambda_0 > 0$ denotes the baseline scalar availability level supported by the intrinsic delivery structure of the underlying field. In the absence of localized structural occupation the scalar field satisfies $\Lambda(x) = \Lambda_0$.
- The dimensionless scalar diagnostic is

$$\mathcal{A}(x) \coloneqq \frac{\Lambda(x)}{\Lambda_0}.$$

- The scalar field represents the *locally available structural capacity* of the underlying delivery field. Localized structures may reduce this availability through occupation or transport, but the intrinsic delivery baseline Λ_0 remains fixed.
- Greek indices $\mu, \nu, \ldots$ range over spacetime coordinates $0, 1, 2, 3$.
- We use the Einstein summation convention unless explicitly stated otherwise.

[*]Bibliography is provisional. Cross-references to companion NUVO-series papers (M-, SR-, Q-, QB-, QM-series) will be updated with Zenodo DOIs in subsequent versions.

Notation convention. We reserve distinct symbols for fundamental fields and derived quantities. The scalar field Λ represents structural availability, while $\mathcal{A}$ denotes a derived normalized response field. These should not be conflated.

Remark 0.1. *Unless otherwise stated, the background signature is* $(-,+,+,+)$.

Abstract

We develop the weak-limit continuum structure of the exchange sector on scalar–conformal NUVO space. The present paper is restricted to the open-loop exchange sector and does not modify the support-sector ontology developed in M6.5, M7, and M7.5, where capacity is treated as a locally presented delivery process and persistent bundled structures are sustained through fixed total intake, whose support-sector state is represented by boundary flux.

Within this sector, exchange transport is represented by a conserved exchange current and a gauge potential whose physically relevant content is encoded in circulation-based exchange observables and the associated antisymmetric field strength.

Under the assumptions of locality, Lorentz covariance, parity symmetry, and lowest-order derivative structure, the weak-limit exchange dynamics are uniquely described by the Maxwell system on the scalar–conformal background. Static localized exchange couplings reproduce Coulomb scaling through exchange-current conservation, while exchange-field stress–energy bookkeeping yields the standard weak-limit momentum-transfer law for localized bundled structures through their open-loop exchange interfaces. Throughout, the exchange sector remains kinematically coupled to the scalar–conformal geometry but does not source the scalar diagnostic field. The result establishes the classical weak-limit field structure associated with open-loop exchange processes within the M-series framework.

1 Introduction

The preceding papers of the M-series [1] establish the scalar–conformal framework of NUVO space. The physical metric takes the form

$$g_{\mu\nu} = \Lambda^2 \eta_{\mu\nu},$$

with the scalar field interpreted as encoding the local structure of capacity delivery, with the normalized quantity $\mathcal{A}(x) = \Lambda(x)/\Lambda_0$ serving as a diagnostic of the resulting geometric response. Earlier work developed the scalar–conformal geometry, its weak-field gravitational correspondence, the exchange sector, and the structural role of persistent bundled configurations. More recently, M6.5, M7, and M7.5 [2–4] refined the support-sector interpretation by treating capacity not as a conserved transported substance, but as a uniform delivery process presented locally to persistent bundled structures through an effective boundary-flux description. Within that refinement, the support-sector state is represented by the boundary flux distribution, and the closed evolution law governing support-sector response is formulated at the level of boundary-state evolution.

This support-sector refinement is essential for the present paper. The weak-limit exchange theory developed here must remain strictly separated from the support sector. In particular, the present analysis does not treat exchange transport as a source of the scalar diagnostic field, does not modify the boundary-flux ontology of support-sector dynamics, and does not reintroduce force as a primitive support-sector concept. The role of the present paper is narrower: to determine the minimal continuum field structure governing open-loop exchange transport on a given scalar–conformal background.

Within the NUVO framework, open-loop exchange processes provide directed interaction channels linking bundled structures [5]. These exchange processes are distinct from the stable closed-loop intake configurations that sustain persistent anchors. Accordingly, any language of loop circulation used in the present paper refers only to exchange-sector observables and not to internal support-sector transport within an anchor.

The central aim of this paper is to determine the minimal weak-limit description of this exchange sector consistent with the structural constraints established in the preceding M-series papers. We show that circulation-based exchange observables naturally introduce gauge redundancy in local potential descriptions and that oriented exchange flux requires an antisymmetric field-strength representation. Under the assumptions of locality, Lorentz covariance, parity symmetry, and lowest-order derivative structure, these requirements uniquely lead to the Maxwell system on the scalar–conformal background.

In this weak-limit description, localized bundled structures carrying open-loop exchange coupling act as effective exchange sources. Static configurations reproduce Coulomb scaling through exchange-current conservation, while conservation of exchange-field stress–energy yields the corresponding weak-limit momentum-transfer law on localized bundled exchange interfaces. These results are exchange-sector correspondences only: they describe the continuum field behavior associated with open-loop interaction on a prescribed scalar–conformal geometry and do not replace the closed support-sector response law developed in M7.5.

The result establishes the classical weak-limit interaction structure associated with open-loop exchange processes within the M-series framework.

Anchors, bundles, and exchange interfaces. Within the revised M-series framework, the minimal admissible persistent physical structure is a *bundle* [6]: a configuration containing a persistent closed component together with its associated open-loop exchange interfaces. In the support sector, such structures are represented through an effective anchor description at the level of boundary intake and boundary flux.

The present paper operates at the level of bundled structures in this effective sense. The persistent closed component provides the baseline support-sector intake structure of the bundle, while the open-loop exchange interfaces provide directional interaction channels through which exchange coupling occurs.

It is essential to distinguish two claims. First, propagating exchange-sector transport does *not* source the scalar diagnostic field. Second, this does *not* imply that the open-loop component is irrelevant to the bundled structure as a whole. Rather, open-loop configuration contributes to the physical architecture of the bundle and may therefore affect its effective support-sector properties indirectly through bundle configuration, even though exchange transport itself is not a scalar source. The normalized scalar response

$$\mathcal{A}(x) = \frac{\Lambda(x)}{\Lambda_0}$$

provides a dimensionless diagnostic of the conformal geometry, but does not independently determine the metric structure.

2 Exchange Transport on Scalar–Conformal NUVO Space

Within the M-series framework, the exchange sector describes open-loop interaction transport on scalar–conformal NUVO space. This sector is distinct from the support sector developed in M6.5, M7, and M7.5 [2–4]. In the support sector, capacity is treated as a locally presented delivery process sustaining persistent bundled structures through an effective boundary-flux description at fixed total intake. In the exchange sector, by contrast, the relevant continuum object is an effective exchange current describing directional interaction transport through open-loop exchange interfaces supported by bundled structures.

Accordingly, the present paper does not model exchange as a form of support-sector capacity flow. Exchange transport is introduced only as a separate weak-limit description of interaction throughput on a given scalar–conformal background. Its role is to encode how anchored bundles couple directionally to external systems through open-loop channels, while leaving unchanged the support-sector ontology of anchor sustenance and boundary-presented delivery.

We represent the exchange sector by a conserved four-current

$$J^\mu_{\rm ex},$$

satisfying

$$\nabla_\mu J^\mu_{\rm ex} = 0. \tag{1}$$

Equation (1) expresses the local conservation of exchange throughput in the weak-limit continuum description. Physically, it states that the exchange sector describes a redistributive interaction transport law rather than localized support consumption. The exchange current therefore records directional interaction transport associated with open-loop coupling, not the delivery process that sustains persistent anchors.

Exchange coupling parameter. Bundled structures may support open-loop exchange interfaces linking the bundle to external systems. In the weak-limit continuum description, the strength of this coupling is characterized by an effective exchange parameter q.

Within the present framework, q labels the effective exchange coupling carried by the localized bundle as seen by the continuum exchange field. Its value depends on the internal bundled structure, the admissible open-loop routing it supports, and the manner in which the bundle couples to external exchange configurations. The microscopic origin of q lies in the internal bundled architecture and is not resolved in the present weak-limit treatment. Accordingly, q is retained here as an effective continuum parameter characterizing the exchange interaction strength of a localized bundled structure.

Exchange transport is therefore associated with open-loop coupling paths linking bundled structures across the scalar–conformal manifold. These paths are not to be identified with the stable closed-loop intake configurations that define persistent anchors in the support sector. They instead represent directional interaction channels through which exchange influence propagates between bundled structures.

The exchange sector remains strictly distinct from the support sector responsible for scalar geometry. Exchange transport does not source the scalar field or its associated diagnostic response and does not alter the scalar–conformal metric

$$g_{\mu\nu} = \Lambda^2 \eta_{\mu\nu}.$$

It is therefore kinematically coupled to the scalar–conformal background through the metric and its associated covariant derivative, while remaining dynamically separate from the support-sector structure that determines scalar availability and anchor sustenance.

2.1 Energetic Interpretation of Exchange Processes

The exchange current introduced above describes interaction transport in the open-loop sector. Because it satisfies the conservation law

$$\nabla_\mu J^\mu_{\rm ex} = 0,$$

the exchange field is not treated as a source of the scalar diagnostic field and does not enter the support-sector description of bundled sustenance.

Nevertheless, exchange processes admit a weak-limit continuum description in which the exchange field supports stress–energy bookkeeping and momentum-transfer accounting, especially in the radiative regime examined later in the paper. Within the present framework, this does not mean that the exchange sector becomes a second support-delivery channel, nor that support-sector intake is literally rerouted as a transported conserved substance through the exchange field.

Rather, persistent bundled structures provide the physical conditions under which open-loop exchange transport can occur, while the exchange field provides the weak-limit continuum encoding of that transport. The support sector governs local sustenance and scalar geometry, whereas the exchange sector governs directional interaction transport on that background.

2.2 Localized Source Approximation

In the continuum treatment developed in the present work, an anchored bundle with open-loop exchange coupling is represented, at scales large compared to its internal size, by a localized source for the effective exchange current $J^{\mu}_{\rm ex}$. This should be understood as a weak-limit approximation and not as a claim that the internal bundled structure is literally pointlike.

Within the broader NUVO framework, persistent matter structures are realized as bundled configurations possessing finite internal organization. When the exchange dynamics are examined at scales large compared to the characteristic size of the bundle, that internal structure is not resolved by the continuum field. The bundle may then be represented by a localized worldtube carrying an effective exchange current determined by its open-loop interfaces and bundled configuration.

The continuum equations derived in this paper therefore describe the exchange field outside the internal structural region of the bundle. Questions concerning the detailed internal response of the anchored core, the finite-size structure of the source region, and the regularization of near-field behavior lie beyond the present weak-limit treatment and will be addressed separately.

Separation from capacity consumption. It is essential to emphasize that open-loop exchange transport does not constitute an additional capacity-consuming channel and therefore does not contribute to the sourcing of the scalar diagnostic field. Within the revised M-series framework, scalar geometry is determined by the support-sector intake structure of persistent bundled configurations, whereas the exchange sector provides an independent weak-limit description of interaction transport on that fixed scalar–conformal background.

Thus, while bundle architecture may affect effective support-sector properties through its full configuration, propagating exchange transport itself is not a scalar source.

3 Circulation Observables and Gauge Structure

Exchange transport introduced in the previous section is associated with open-loop coupling paths linking bundled structures. Within the exchange sector, physical observables are naturally organized around circulation quantities defined along closed exchange-observable paths. These paths represent operational measurement loops in the exchange sector and are not to be identified with the closed-loop intake configurations that define persistent anchors in the support sector.

Accordingly, we consider closed curves γ in spacetime representing exchange-observable cycles. The circulation associated with exchange transport along such a curve may be written schematically as

$$\oint_\gamma \mathcal{A}_\mu \, dx^\mu,$$

where $\mathcal{A}_\mu$ is a local potential representation of the exchange transport.

The quantity $\mathcal{A}_\mu$ is not interpreted as a directly observable field. Rather, it serves as a local bookkeeping device whose loop integrals encode the circulation observables of exchange transport. Only the integrated circulation around closed curves corresponds to physically meaningful exchange quantities.

Because physical observables depend only on loop integrals, the potential representation $\mathcal{A}_\mu$ is not unique. In particular, the transformation

$$\mathcal{A}_\mu \;\to\; \mathcal{A}_\mu + \partial_\mu \chi$$

for an arbitrary scalar function $\chi(x)$ leaves all circulation observables invariant, since

$$\oint_\gamma \partial_\mu \chi \, dx^\mu = 0$$

for any closed loop γ.

The potential representation of exchange transport therefore possesses a natural redundancy: different potential fields related by gradient transformations describe the same physical exchange circulation. This redundancy is the defining feature of a gauge structure.

In the present framework, gauge redundancy arises directly from the operational structure of exchange observables. Since only circulation quantities are physically meaningful in the exchange sector, local potential descriptions are defined only up to gradient transformations. Gauge structure is therefore not imposed as an independent symmetry principle, but instead emerges as a consequence of how exchange transport is operationally measured.

This observation provides the first structural constraint on the continuum description of the exchange sector. Any admissible field-theoretic representation of exchange transport must respect this gauge redundancy inherited from the circulation structure of exchange observables.

4 Oriented Exchange Flux and Field Strength

The gauge structure identified in the previous section implies that physical exchange observables cannot depend directly on the local potential representation $\mathcal{A}_\mu$. Instead, admissible observables must be constructed from quantities that remain invariant under the gauge transformation

$$\mathcal{A}_\mu \to \mathcal{A}_\mu + \partial_\mu \chi.$$

The simplest such quantities are derivatives of the potential field. However, not all derivative combinations possess the required gauge invariance. The combination

$$\partial_\mu \mathcal{A}_\nu - \partial_\nu \mathcal{A}_\mu$$

is invariant under the gradient transformation above and therefore represents a natural candidate for the local field quantity describing exchange transport in the continuum weak-limit.

We therefore introduce the antisymmetric tensor

$$F_{\mu\nu} = \partial_\mu \mathcal{A}_\nu - \partial_\nu \mathcal{A}_\mu, \tag{2}$$

which we interpret as the local field strength associated with the exchange sector.

The antisymmetric structure of $F_{\mu\nu}$ has a direct geometric interpretation. Exchange transport is associated with oriented flux through two-dimensional surfaces in spacetime. The field strength tensor therefore measures the density of exchange flux passing through infinitesimal surface elements.

To illustrate this interpretation, consider an infinitesimal oriented surface element $d\Sigma^{\mu\nu}$. The exchange flux through this surface is given by

$$\Phi_{\text{ex}} = \frac{1}{2} F_{\mu\nu}\, d\Sigma^{\mu\nu}.$$

Because $F_{\mu\nu}$ is antisymmetric, the flux depends only on the oriented surface and not on the ordering of coordinate directions. This property reflects the fact that exchange transport is naturally associated with exchange circulation and surface flux rather than with scalar quantities defined at points.

The tensor $F_{\mu\nu}$ therefore provides the minimal local representation of exchange flux consistent with the gauge redundancy established in the previous section. Any admissible continuum description of the exchange sector must be expressible in terms of this antisymmetric field strength.

Equation (2) also implies an identity obtained by cyclic permutation of derivatives,

$$\nabla_{[\alpha} F_{\beta\gamma]} = 0,$$

which follows directly from the definition of $F_{\mu\nu}$. This identity represents a geometric consistency condition on the exchange flux field and will play the role of a homogeneous field equation in the continuum weak-limit description of the exchange sector.

The antisymmetric field strength tensor $F_{\mu\nu}$ therefore emerges as the natural geometric quantity describing oriented exchange flux in scalar–conformal NUVO space.

5 Minimal Weak-Limit Action

The previous sections established that the continuum description of exchange transport must be expressed in terms of the antisymmetric field strength tensor $F_{\mu\nu}$ defined by

$$F_{\mu\nu} = \partial_\mu \mathcal{A}_\nu - \partial_\nu \mathcal{A}_\mu.$$

The remaining question is the dynamical law governing this field in the weak-continuum limit.

To determine the admissible form of the exchange field dynamics we consider the most general local action consistent with the structural principles established in the M-series framework. The action must satisfy the following requirements:

1. **Locality.** The action must be constructed from local fields and their derivatives.

2. **Lorentz covariance.** The theory must respect the Lorentz symmetry of the scalar–conformal background metric.

3. **Gauge invariance.** Physical observables depend only on the gauge-invariant field strength $F_{\mu\nu}$.

4. **Parity symmetry.** The weak-limit dynamics should preserve parity symmetry.

5. **Lowest derivative order.** The continuum description should involve the minimal number of derivatives required to describe the exchange flux field.

Under these conditions the action must be constructed from scalar quantities formed from the field strength tensor and the scalar–conformal metric. The unique admissible quadratic invariant satisfying these requirements is [7]

$$S_{\text{ex}} = -\frac{1}{4}\int F_{\mu\nu}F^{\mu\nu}\sqrt{-g}\, d^4x, \tag{3}$$

where g denotes the determinant of the scalar–conformal metric $g_{\mu\nu}$.

Weak-limit effective description. The quadratic invariant $F_{\mu\nu}F^{\mu\nu}$ represents the leading local scalar that can be constructed from the field strength tensor and the scalar–conformal metric while respecting gauge invariance and Lorentz covariance. In a more general effective description additional higher-order invariants such as $(F_{\mu\nu}F^{\mu\nu})^2$ or terms involving higher derivatives of the potential may also appear.

Within the weak-limit continuum regime considered in the present framework, however, such terms are suppressed relative to the quadratic invariant and therefore represent higher-order corrections to the exchange dynamics. The Maxwell action thus arises as the leading-order effective description of exchange transport on scalar–conformal NUVO space.

Variation of the action with respect to the potential $\mathcal{A}_\mu$ yields the field equations

$$\nabla_\mu F^{\mu\nu} = J^\nu_{\text{ex}}, \tag{4}$$

where J^ν_{ex} is the conserved exchange current introduced in Section 2. This current represents an effective continuum description of open-loop exchange coupling associated with anchored bundles and does not act as a source term in the capacity transport equation governing the scalar field.

Together with the geometric identity

$$\nabla_{[\alpha}F_{\beta\gamma]} = 0,$$

these equations constitute the Maxwell system [7] for the exchange field propagating on the scalar–conformal background.

The Maxwell equations therefore arise as the minimal weak-limit dynamical system consistent with the structural properties of the exchange sector established in the preceding sections. In this framework the familiar electromagnetic field equations appear as the continuum description of open-loop exchange transport on scalar–conformal NUVO space.

6 Stress-Energy Transport and Momentum Transfer to Anchors

The previous section established that bundled structures support open-loop exchange coupling channels described in the continuum weak-limit by the exchange current J^μ_{ex}. We now examine the reciprocal influence of the exchange field on anchored systems.

The exchange field carries energy and momentum through spacetime. In the continuum description these quantities are represented by the exchange stress–energy tensor constructed from the field strength tensor $F_{\mu\nu}$,

$$T^{\mu\nu}_{\text{ex}} = F^{\mu\alpha}F^{\nu}_{\ \alpha} - \frac{1}{4}g^{\mu\nu}F_{\alpha\beta}F^{\alpha\beta}. \tag{5}$$

This tensor provides an effective weak-limit description of the transport of exchange momentum and energy through the background geometry.

Conservation of the total stress–energy of the coupled system (exchange field plus anchored matter) implies that changes in the field momentum must be balanced by momentum transfer to the anchored structure.

To analyze this balance, consider a small worldtube enclosing a bundled structure with exchange current $J^{\mu}_{\rm ex}$. The net four-momentum transfer to the bundle is obtained by integrating the divergence of the exchange stress–energy tensor over the volume of the worldtube. Using the field equation

$$\nabla_\mu F^{\mu\nu} = J^{\nu}_{\rm ex},$$

one obtains

$$\nabla_\mu T^{\mu\nu}_{\rm ex} = -F^{\nu\lambda} J^{\rm ex}_{\lambda}. \tag{6}$$

The right-hand side represents the local rate of momentum exchange between the exchange field and the anchored system. Integrating this relation over the worldtube yields the effective four-force density acting on the anchor,

$$f^{\nu} = F^{\nu\lambda} J^{\rm ex}_{\lambda}. \tag{7}$$

Equation (7) corresponds to the familiar Lorentz force law [7], here arising as a consequence of stress–energy balance in the exchange sector rather than as a primitive interaction law.

Within the M-series framework this relation has a restricted interpretation. It provides an effective weak-limit bookkeeping of exchange-mediated momentum transfer between the field and a bundled structure through its open-loop exchange interfaces. It does not by itself constitute the closed support-sector law of acceleration.

Instead, proper acceleration of a persistent bundled structure remains governed fundamentally by time-variation of the boundary flux distribution in the support sector, as formulated in M7.5. The present exchange-sector result should therefore be read as the weak-limit field description of exchange-mediated momentum transfer, not as a replacement for the support-sector boundary-evolution law.

The Lorentz force expression thus represents the continuum exchange-sector bookkeeping of momentum transfer, while the insertion of such transfer into the full support-sector boundary response of bundled structures belongs to the higher-level support–exchange coupling problem developed later in the series.

7 Exchange Sector and Scalar Geometry

The exchange transport sector developed in this paper remains structurally distinct from the support sector responsible for the scalar diagnostic field. This separation is a central feature of the revised M-series framework.

The scalar–conformal geometry is determined by the support sector through the capacity-delivery and boundary-intake structure of persistent bundled configurations. The physical metric is therefore governed by

$$g_{\mu\nu} = \Lambda^2 \eta_{\mu\nu}.$$

By contrast, exchange transport obeys an independent conservation law,

$$\nabla_\mu J^{\mu}_{\rm ex} = 0,$$

reflecting the fact that open-loop exchange processes encode directional interaction throughput in the weak-limit continuum description.

As a consequence, exchange transport does not contribute to the sourcing of the scalar diagnostic field. This reflects the structural separation of roles within the NUVO framework: support-sector intake determines scalar geometry, while open-loop exchange processes provide interaction transport on that fixed scalar–conformal background.

Exchange fields propagate on the scalar–conformal background through the covariant derivatives appearing in the field equations, but they do not modify the scalar field itself. The exchange sector is therefore kinematically coupled to the scalar geometry while remaining dynamically separate from the support-sector structure that produces gravitational behavior.

This separation ensures that the interaction dynamics derived in the present paper remain compatible with the support-sector and gravitational structure established in the earlier M-series papers.

8 Conclusion

We have developed the weak-continuum structure of the exchange sector on scalar–conformal NUVO space. Beginning from the exchange current introduced in earlier work, we showed that the operational structure of exchange observables naturally leads to a gauge description in terms of a potential field.

The requirement that physical observables depend only on circulation quantities implies gauge redundancy in the potential representation. This redundancy in turn leads to an antisymmetric field-strength tensor that represents oriented exchange flux through spacetime surfaces.

Imposing locality, Lorentz covariance, gauge invariance, parity symmetry, and minimal derivative order uniquely determines the quadratic weak-limit action of the exchange field. Variation of this action yields the Maxwell system governing exchange transport on the scalar–conformal background.

Localized bundled structures act as effective carriers of exchange current through their open-loop exchange interfaces and therefore appear, in the weak-limit continuum description, as localized sources of exchange throughput. This yields inverse-square field scaling in static configurations. Conservation of stress–energy for the exchange field then yields the Lorentz-force form governing weak-limit exchange-mediated momentum transfer to bundled structures.

The familiar Maxwell system together with the Lorentz-force form of weak-limit momentum-transfer bookkeeping therefore emerges as the minimal continuum description of open-loop exchange transport consistent with the structural principles established in the M-series framework.

Exchange transport remains dynamically independent of the support sector that determines scalar geometry and therefore does not source the scalar diagnostic field. The resulting exchange field propagates on the scalar–conformal geometry while preserving the support-sector and gravitational structure established in earlier work.

The present paper thus establishes the classical weak-limit interaction structure associated with open-loop exchange processes within the NUVO framework. Extensions of the exchange sector to include radiative transport and finite-core effects will be considered in future work.

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