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Article

The Halo Effect and Quantum Vortices. Not So Dark with Alena Tensor

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Abstract

Alena Tensor is a recently discovered class of energy-momentum tensors that proposes a general equivalence of the curved path and geodesic for analyzed spacetimes which allows the analysis of physical systems in curvilinear (GR), classical and quantum descriptions. This paper demonstrates that extending the existing dust description to a form that provides a full matter energy-momentum tensor in GR, naturally leads to the development of a halo effect for continuum media. This result predicts inclination-dependent lensing signal and provides a good approximation of the galaxy rotation curve for approximately 100 analyzed objects from the SPARC catalog allowing for further adjustments dependent on anisotropy and energy flux. The same equations in flat spacetime allow for the inclusion of rotation-related effects in the quantum description, model quantum vortices and reproduce Mashhoon effect. This provides a physical interpretation of mass generation as an emergent property of the phase-spin equilibrium and enables an effective reconstruction of the Yukawa and Higgs-like mechanisms as consequence of the stability conditions of quantum vortices.

Keywords: unification; Alena tensor; dark energy; dark matter; spin-vorticity coupling

1. Introduction

Research on the dark sector has been ongoing for many years [1] and there is still no theoretical consensus [2] or convincing experimental evidence regarding its nature [3]. We have not found dark matter signals for the WIMP models [4], axions/ALPs [5], SIDM [6], despite new experimental approaches [7], experiments in underground detectors, LZ experiments, XENON-nT [8] or SuperCDMS [9], and the latest observational data (e.g., "Hubble tension", "Sigma-8 tension") make the issue of the dark sector even more puzzling [10]. The dominant theoretical model is still Λ CDM with dark matter haloes [11], although alternative theories such as MOND/relativistic generalizations [12,13], dark photons [14], TeVeS/related constructions, $f(R)$ [15], black holes [16], or the recently popular "emergent/entropic gravity" [17] have achieved some success at selected scales. However, all these approaches experience ups and downs depending on the subsequent observational data [18].

There is also considered the possibility of hybrid models (e.g., a superfluid DM combining features of MOND and DM) [19], or even incorrect/weakened estimates of baryon masses and systematic errors in the M/L estimate [20], and the interaction of dark matter and energy [21] but so far this entire massive effort by the scientific community has not yielded a definitive conclusion. We have more certainty about dark energy because the universe is definitely expanding, and there are ample, multiple, independent confirmations, eg. from SN Ia, BAO, and CMB [11,22]. It is still uncertain whether the cosmological constant is indeed constant, although recent DESI (BAO) analyses indicate the possibility of $w(z)$ dynamics [23], and the Euclid mission is rapidly delivering high-quality weak lensing maps and surveys that will be crucial for measuring the dark energy equation of state [24].

The Alena Tensor is a relatively young field of research and has not had much relevance to the dark sector until now. Previous work has focused on developing a dual description for physical systems with matter and fields in which the metric tensor is not a feature of spacetime but only a method of describing it. Its aim was to provide a smooth transition between curvilinear description consistent

with GR [25] and a flat (classical and quantum [26]) description for simple cases with dust [27], which was analyzed mainly for physical systems with electromagnetic fields [28]. This paper will demonstrate that extending the Alena Tensor to the general case yields results, that provide possible representation of the spherical dark matter halo and provide an interpretation for the cosmological constant. This work, however, does not modify Einstein equations but modifies the matter sector through anisotropic rotational stresses. There will be also derived Noether tensor with Belinfante improvement and the quantum effective Lagrangian, which enables quantum description of vortices and ensures, that the same energy-momentum tensor governs GR, flat-space dynamics, and quantization.

In the first part of the paper, an introduction to the Alena Tensor model for dust will be presented, then this approach will be extended to the general form of the matter energy-momentum tensor and analyzed for quantum and GR description. The obtained GR equations will then be analyzed for their ability to describe the halo effect and lensing. The quantum description will also be analyzed in effective field-theoretic model and tested for its ability to describe elementary particles. The results will be discussed and shown to lead to the conclusions described in the abstract.

2. The Extended Alena Tensor

In this chapter, the conclusions reached so far regarding the Alena Tensor will be recalled, the notation will be introduced, and the reasoning from the previous articles will be generalized to all gauge fields and all forces acting in the physical system. The author uses the Einstein summation convention, metric signature $(+, -, -, -)$ and commonly used notations.

2.1. Transforming Curved Path Into Geodesic For Dust

As a first step, one may generalize the solution proposed in [27] in such a way that the forces resulting from all gauge fields are related to the metric tensor of curved spacetime.

One may begin the reasoning by introducing tensor $F^{\mu\nu\alpha\beta}$ defined in terms of the gauge field tensors $\mathbb{F}_A^{\mu\nu}$ for each gauge group A, and the stress-energy tensor $Y^{\mu\nu}$ for such generalized field

$$F^{\mu\nu\alpha\beta} \equiv \sum_A \mathbb{F}_A^{\mu\nu} \otimes \mathbb{F}_A^{\alpha\beta}; \quad Y^{\mu\nu} \equiv F^{\mu\alpha\nu\beta} g_{\alpha\beta} - g^{\mu\nu} \frac{1}{4} F^{\alpha\gamma\beta\delta} g_{\alpha\beta} g_{\gamma\delta} \quad (1)$$

and denote the invariant of this field as p_Λ . Following reasoning from [27] let this field invariant be defined dually as follows

$$p_\Lambda \equiv \frac{1}{4} F^{\alpha\gamma\beta\delta} g_{\alpha\beta} g_{\gamma\delta} \equiv p_o \mathbb{k}^2 \quad ; \quad \mathbb{k} \equiv \mathbb{k}_{\mu\nu} g^{\mu\nu} \quad (2)$$

where p_o is certain constant (or simply invariant, independent of the metric) and where $\mathbb{k}^{\mu\nu}$, as raised in [26], in this approach is a metric tensor describing a curved spacetime in which all motion occurs along geodesics. By making variation on $-p_\Lambda$ with respect to metric $g_{\mu\nu}$ (Hilbert's method) one obtains the energy-momentum tensor of the field from (1) expressed dually as

$$Y^{\mu\nu} = p_\Lambda \left(\frac{4}{\mathbb{k}} \mathbb{k}^{\mu\nu} - g^{\mu\nu} \right) \quad (3)$$

Such approach, exactly as shown in [27], establishes a relationship between the field and the metric tensor $\mathbb{k}^{\mu\nu}$ and in the spacetime considered as described by the metric tensor $g^{\mu\nu} \rightarrow \mathbb{k}^{\mu\nu}$, one obtains $\mathbb{k} = 4$ what yields that in curvilinear description of the system, energy-momentum tensor of the field $Y^{\mu\nu}$ vanishes, maintaining continuity of function. As shown in previous articles, this causes the presence of a field in curved spacetime to manifest itself solely through curvature, which replaces the four-force densities in flat spacetime.

In flat spacetime, one may assume that the equations of motion for the gauge fields A are satisfied, thus one obtains gauge four-currents $J_A^\nu \equiv D_\mu \mathbb{F}_A^{\mu\nu}$. Therefore, the total density of the Yang-Mills four-forces [29,30] f_{YM}^ν is

$$f_{YM}^\nu = \partial_\mu Y^{\mu\nu} = \sum_A J_A^\alpha \mathbb{F}_{A\alpha}^\nu \quad (4)$$

where the self-interactions of gauge fields in a non-Abelian theory are reducing. Then, following the reasoning presented in [27] one may define coefficient $\chi_m \equiv \frac{\varrho c^2}{p_\Lambda}$ where ϱ represents matter density and is associated with the translational current $\chi_m U^\mu$. In the Alena Tensor approach, the existence of matter is thus a manifestation of the existence of fields what ensures, that without fields matter does not exist.

This allows to define the Lagrangian $\mathcal{L}_{dust}$ and obtain from it the stress-energy tensor (Alena Tensor) for the system with dust $T_{dust}^{\mu\nu}$ by variation on the metric

$$\mathcal{L}_{dust} \equiv p_\Lambda (1 - \chi_m) \rightarrow T_{dust}^{\mu\nu} \equiv \varrho U^\mu U^\nu - (1 - \chi_m) Y^{\mu\nu} \quad (5)$$

In accordance with [28], assuming ϱ_0 as rest mass density, four-momentum density is defined as $\varrho U^\alpha \equiv \varrho_0 \gamma U^\alpha$ what takes into account motion and Lorentz contraction of the volume. Total four-force density acting on matter is therefore defined as

$$f^\nu \equiv \partial_\mu \varrho U^\mu U^\nu = \varrho U^\mu \partial_\mu U^\nu = \varrho \frac{dU^\nu}{d\tau}; \quad \partial_\mu \varrho U^\mu = 0 \quad (6)$$

As shown in [26], the above amendment introduces a natural property concerning curved spacetime, assuming that for dust, geodesic motion is expected

$$\partial_\alpha \varrho U^\alpha = 0 \rightarrow U^\alpha_{;\alpha} = -\frac{d\gamma}{dt} \rightarrow U^\alpha_{;\alpha} = 0 \quad (7)$$

$$U^\alpha U^\beta_{;\alpha} = 0 \rightarrow \frac{D U^\beta}{D \tau} = 0; \quad (\varrho U^\alpha U^\beta)_{;\alpha} = 0 \quad (8)$$

Now it can be noticed, that in flat spacetime the four-divergence of the tensor $T_{dust}^{\mu\nu}$ can be interpreted as the density of the four-forces acting on matter f^ν reduced by the density of the field-related four-forces

$$f_{field}^\nu \equiv \partial_\mu [(1 - \chi_m) Y^{\mu\nu}] = (1 - \chi_m) f_{YM}^\nu + f_{gr}^\nu \quad (9)$$

$$f_{gr}^\nu \equiv Y^{\mu\nu} \partial_\mu (1 - \chi_m) = -Y^{\mu\nu} \partial_\mu \chi_m \quad (10)$$

As shown in [26], f_{gr}^ν can be associated with the existence of gravity in the system, while $f_{rr}^\nu \equiv \chi_m f_{YM}^\nu$ behaves as a radiation-reaction force, reducing the value of forces due to the field and upholding the conservation of energy, ensuring that the increasing energy density associated with matter ϱc^2 does not exceed the total energy density p_Λ available in the system

$$\partial_\mu T_{dust}^{\mu\nu} = f^\nu - f_{field}^\nu = f^\nu - f_{YM}^\nu - f_{gr}^\nu + f_{rr}^\nu \quad (11)$$

where $\lim_{\chi_m \rightarrow 1} f_{field}^\nu = 0$. Presented approach also indicates the ansatz for the Kerr-Schild type metrics for curved spacetime

$$\mathbb{K}^{\mu\nu} \equiv \sum_i c_i l_i^\mu l_i^\nu + \frac{\mathbb{K}}{4} \eta^{\mu\nu}; \quad 0 = \eta_{\mu\nu} l_i^\mu l_i^\nu \quad (12)$$

where l_i^μ are null vectors and c_i are related coefficients.

In the next section, the above model will be expanded to include rotation-related components, which will prove crucial for describing dark sector phenomena and allow to obtain a description that agrees with the observational results.

2.2. Rotational Energy

It can be noticed that the radiation reaction force should take into account the total energy associated with the body, so in addition to the energy associated with the translational motion, it seems necessary to take into account the rotational energy.

One may thus introduce a projector $\Delta^{\mu\nu}$, flow vorticity tensor $\omega^{\mu\nu}$, positive coefficient χ_ω equal to the rotational energy $\mathcal{E}_{rot}$ up to p_Λ thus ($\mathcal{E}_{rot} \equiv p_\Lambda \chi_\omega$) and some metric independent auxiliary α with the dimension of the square of time

$$\Delta^\mu{}_\nu \equiv g^\mu{}_\nu - \frac{1}{c^2} U^\mu U_\nu; \quad \omega_{\mu\nu} \equiv \Delta_\mu{}^\alpha \Delta_\nu{}^\beta \nabla_{[\alpha} U_{\beta]}; \quad \chi_\omega \equiv \frac{\alpha}{2} \omega^{\mu\nu} \omega_{\mu\nu} \quad (13)$$

Defining Lagrangian density $\mathcal{L}_T$ for the whole system and tensor $B^{\lambda\mu\nu}$ to describe emerging boundary terms

$$\mathcal{L}_T = p_\Lambda (1 - \chi_\omega - \chi_m); \quad B^{\lambda\mu\nu} \equiv p_\Lambda \alpha (U^\lambda \omega^{\mu\nu} - U^{(\mu} \omega^{\nu)\lambda}) \quad (14)$$

and introducing $\Xi^{\mu\nu}$ tensor related to rotational properties of the system

$$-\Xi^{\mu\nu} \equiv \alpha p_\Lambda \left(\omega^{\mu\gamma} \omega^\nu{}_\gamma - \frac{1}{2} \Delta^{\mu\nu} \omega^{\alpha\beta} \omega_{\alpha\beta} \right) + \nabla_\lambda B^{\lambda(\mu\nu)} \quad (15)$$

one obtains Alena Tensor $T^{\mu\nu}$ for the system derived with help of variational method on $\mathcal{L}_T$ in the form

$$T^{\mu\nu} = \varrho U^\mu U^\nu - \Xi^{\mu\nu} - (1 - \chi_\omega - \chi_m) Y^{\mu\nu}; \quad T^{\mu\nu} g_{\mu\nu} = \varrho c^2 - \mathcal{E}_{rot} \quad (16)$$

Considering description in curved spacetime, described by the metric tensor $\mathbb{K}^{\mu\nu}$, the field tensor $Y^{\mu\nu}$ vanishes, the system tensor reduces to the form $T_{matt}^{\mu\nu} \equiv \varrho U^\mu U^\nu - \Xi^{\mu\nu}$ and its vanishing four-divergence means that any deviations from the geodesic motion with $a^\mu \equiv U^\nu \nabla_\nu U^\mu$ are compensated by rotation related forces. Using the standard kinematic decomposition one may calculate

$$\varepsilon \equiv \frac{1}{c^2} T_{matt}^{\mu\nu} U_\mu U_\nu = \varrho c^2 + 2\mathcal{E}_{rot} \quad (17)$$

$$T_{matt}^{\mu\nu} U_\nu = (\varrho c^2 + 2\mathcal{E}_{rot}) U^\mu - \alpha p_\Lambda \left(a_\nu \omega^{\nu\mu} + \frac{c^2}{2} \Delta^\mu{}_\nu \nabla_\lambda \omega^{\lambda\nu} \right) \quad (18)$$

where the element in brackets in last equation represents in fact the purely spatial vorticity divergence. Assuming the classical definition of the energy flux q^α one also gets

$$q^\alpha \equiv \frac{1}{c^2} \Delta^\alpha{}_\mu T_{matt}^{\mu\nu} U_\nu = -\alpha p_\Lambda \left(a_\nu \omega^{\nu\alpha} + \frac{c^2}{2} \Delta^\alpha{}_\nu \nabla_\lambda \omega^{\lambda\nu} \right) \quad (19)$$

Introducing classical shear tensor $\sigma^{\mu\nu}$ and effective vortex stress tensor $\tau^{\mu\nu}$ as

$$\sigma^{\mu\nu} \equiv \Delta^{\mu\alpha} \Delta^{\nu\beta} \nabla_{(\alpha} U_{\beta)} - \frac{1}{3} \nabla_\alpha U^\alpha \Delta^{\mu\nu}; \quad \tau^{\mu\nu} \equiv \frac{p_\Lambda \alpha}{2} (\sigma^\mu{}_\lambda \omega^{\nu\lambda} + \sigma^\nu{}_\lambda \omega^{\mu\lambda}) \quad (20)$$

one may thus rewrite $T_{matt}^{\mu\nu}$ in curved spacetime as

$$T_{matt}^{\mu\nu} = \frac{\varepsilon}{c^2} U^\mu U^\nu + \frac{1}{c^2} (U^\mu q^\nu + U^\nu q^\mu) - \mathcal{E}_{rot} \Delta^{\mu\nu} - \tau^{\mu\nu} \quad (21)$$

One may notice, that the system has a built-in anisotropic stress described by $\tau^{\mu\nu}$, but its source is not viscosity, but the coupling between shear and vorticity (between flow deformation and local spin angular momentum).

Considered in flat spacetime such approach introduces additional four-force density f_{Ξ}^{ν} acting on matter and also changes f_{gr}^{ν} and the radiation reaction f_{rr}^{ν} to the form

$$f_{\Xi}^{\nu} \equiv \partial_{\mu} \Xi^{\mu\nu}; \quad f_{rr}^{\nu} = (\chi_m + \chi_{\omega}) f_{YM}^{\nu}; \quad f_{gr}^{\nu} = Y^{\mu\nu} \partial_{\mu} (1 - \chi_{\omega} - \chi_m) \quad (22)$$

One may now consider the impact of the above expansion of the Alena Tensor on quantum equations and GR equations.

2.2.1. Noether Tensor And Quantum Interpretation

One may consider $\mathcal{L}_T$ from (14) in flat spacetime. The canonical Noether energy-momentum tensor associated with translations is

$$T_{\text{can}}^{\mu\nu} \equiv \sum_{\phi} \frac{\partial \mathcal{L}_T}{\partial (\partial_{\mu} \phi)} \partial^{\nu} \phi - \eta^{\mu\nu} \mathcal{L}_T \quad ; \quad \partial_{\mu} T_{\text{can}}^{\mu\nu} = 0 \quad (\text{on-shell}) \quad (23)$$

where the sum runs over all dynamical fields ϕ (here: U_{α} and gauge fields $\mathbb{A}_{\alpha A}$). Lorentz invariance implies conservation of the total angular momentum current $J^{\lambda\mu\nu}$ as

$$J^{\lambda\mu\nu} \equiv x^{\mu} T_{\text{can}}^{\lambda\nu} - x^{\nu} T_{\text{can}}^{\lambda\mu} + S^{\lambda\mu\nu} \quad ; \quad \partial_{\lambda} J^{\lambda\mu\nu} = 0 \quad (24)$$

with the spin current $S^{\lambda\mu\nu}$ written by the generators of Lorentz transformations acting on the space of field components marked as $\Sigma^{\mu\nu}$

$$S^{\lambda\mu\nu} \equiv \sum_{\phi} \frac{\partial \mathcal{L}_T}{\partial (\partial_{\lambda} \phi)} (\Sigma^{\mu\nu} \phi) \quad (25)$$

For a Lorentz vector field V_{ρ} one has $(\Sigma^{\mu\nu} V)_{\rho} = \eta^{\mu}_{\rho} V^{\nu} - \eta^{\nu}_{\rho} V^{\mu}$, hence in particular

$$S_U^{\lambda\mu\nu} = \Pi^{\lambda\mu}(U) U^{\nu} - \Pi^{\lambda\nu}(U) U^{\mu}; \quad S_{\text{gauge}}^{\lambda\mu\nu} = \sum_A \left(\Pi^{\lambda A\mu}(A) \mathbb{A}_A^{\nu} - \Pi^{\lambda A\nu}(A) \mathbb{A}_A^{\mu} \right) \quad (26)$$

and $S^{\lambda\mu\nu} = S_U^{\lambda\mu\nu} + S_{\text{gauge}}^{\lambda\mu\nu}$. One may thus define the Belinfante superpotential $Q^{\lambda\mu\nu}$ as in [29] which is antisymmetric in the first two indices $Q^{\lambda\mu\nu} = -Q^{\mu\lambda\nu}$, and the Belinfante tensor $T_B^{\mu\nu}$ as

$$Q^{\lambda\mu\nu} \equiv \frac{1}{2} (S^{\mu\lambda\nu} + S^{\nu\lambda\mu} - S^{\lambda\mu\nu}) \quad ; \quad T_B^{\mu\nu} \equiv T_{\text{can}}^{\mu\nu} + \partial_{\lambda} Q^{\lambda\mu\nu} \quad (27)$$

Since partial derivatives commute in flat spacetime and $Q^{\lambda\mu\nu}$ is antisymmetric in (λ, μ) , therefore $\partial_{\mu} \partial_{\lambda} Q^{\lambda\mu\nu} = 0$ and thus $\partial_{\mu} T_B^{\mu\nu} = 0$ on-shell. Using (24) and (27) one gets the standard identity

$$T_{\text{can}}^{\mu\nu} - T_{\text{can}}^{\nu\mu} = -\partial_{\lambda} S^{\lambda\mu\nu} \quad \rightarrow \quad T_B^{\mu\nu} = T_B^{\nu\mu} \quad (28)$$

For the U -sector the momentum conjugate to $\partial_{\mu} U_{\alpha}$ is

$$\Pi^{\mu\alpha}(U) \equiv -\frac{\partial \mathcal{E}_{\text{rot}}}{\partial (\partial_{\mu} U_{\alpha})} = -\alpha p_{\Lambda} \omega^{\mu\alpha} \quad (29)$$

For the gauge sector, using definition of p_{Λ} from (2), one finds

$$\Pi^{\mu A}_{\alpha}(A) \equiv \frac{\partial \mathcal{L}_T}{\partial (\partial_{\mu} \mathbb{A}_A^{\alpha})} = (1 - \chi_{\omega}) \mathbb{F}_{A\alpha}^{\mu} \quad (30)$$

since the mass term $p_{\Lambda} \chi_m = q c^2$ does not depend on $\partial_{\mu} \mathbb{A}_A^{\alpha}$.

For a Poincaré-invariant theory in flat spacetime one has the Rosenfeld-Belinfante identity $T^{\mu\nu} = T_B^{\mu\nu} + \partial_{\lambda} \partial_{\rho} Y^{\lambda\rho\mu\nu}$, where $\partial_{\lambda} \partial_{\rho} Y^{\lambda\rho\mu\nu}$ is an identically conserved (pure-improvement) term. In above, the physical (symmetric, conserved) energy-momentum tensor $T^{\mu\nu}$ is Hilbert tensor from (16). Upon quantization, $T^{\mu\nu}$ is promoted to an operator and $q c^2 = \chi_m p_{\Lambda}$ admits a natural interpretation as

$mc^2\bar{\psi}\psi$. This also yields, that in the quantum theory the four-velocity field U^μ is identified with the hydrodynamic limit of the Dirac current, $U^\mu = c \langle \bar{\psi}\gamma^\mu\psi \rangle / \sqrt{\langle \bar{\psi}\gamma^\nu\psi \rangle \langle \bar{\psi}\gamma_\nu\psi \rangle}$, rendering χ_ω a composite quantity determined by fermionic correlators. For a Dirac field coupled to gauge fields via $D_\mu = \partial_\mu - i \sum_A g_A \mathbb{A}_{\mu A} T_A$, one obtains in flat spacetime Lagrangian $\mathcal{L}_Q$ and the standard symmetric form

$$T^{\mu\nu} = \frac{i\hbar c}{4} \bar{\psi} \gamma^{(\mu} \overleftrightarrow{D}^{\nu)} \psi - \Xi^{\mu\nu} - (1 - \chi_\omega - \chi_m) Y^{\mu\nu} \quad (31)$$

$$\mathcal{L}_Q \equiv \frac{i\hbar c}{2} \bar{\psi} \gamma^\mu \overleftrightarrow{D}_\mu \psi + (1 - \chi_\omega - \chi_m) p_\Lambda \quad (32)$$

where $\overleftrightarrow{D}$ denotes the two-way covariant derivative. The rotational sector described by $\Xi^{\mu\nu}$ and the vorticity-dependent screening of p_Λ provide an effective dark sector. It contributes to the gravitational energy-momentum tensor while remaining non-interacting with gauge currents and visible matter.

2.2.2. General Relativity Interpretation

One may now repeat the reasoning from [27] and define the generalized Ricci and Einstein tensors, where the $\tilde{\sim}$ indicates normalization with the constant $\kappa/2 = \frac{4\pi G}{c^4}$, and additional tensor $\Theta^{\mu\nu}$ as

$$\tilde{R}^{\mu\nu} \equiv 2T_{matt}^{\mu\nu} + 2\chi_\omega Y^{\mu\nu} + (p_\Lambda + \mathcal{E}_{rot} - \varrho c^2) g^{\mu\nu} \quad (33)$$

$$\tilde{R} \equiv \tilde{R}^{\mu\nu} g_{\mu\nu} = 4p_\Lambda + 2\mathcal{E}_{rot} - 2\varrho c^2 \quad (34)$$

$$\tilde{G}^{\mu\nu} \equiv \tilde{R}^{\mu\nu} - \frac{\tilde{R}}{2} \mathbb{K}^{\mu\nu} = \tilde{R}^{\mu\nu} - \frac{\tilde{R}}{2} g^{\mu\nu} - \frac{\tilde{R}}{2p_\Lambda} Y^{\mu\nu} = 2T_{matt}^{\mu\nu} - (2 - \chi_m - \chi_\omega) Y^{\mu\nu} - p_\Lambda g^{\mu\nu} \quad (35)$$

$$\Theta^{\mu\nu} \equiv -(\chi_m + \chi_\omega) Y^{\mu\nu} \rightarrow \tilde{G}^{\mu\nu} + p_\Lambda g^{\mu\nu} = 2T^{\mu\nu} + \Theta^{\mu\nu} \quad (36)$$

where the last equality holds in any considered spacetime and for $G^{\mu\nu} = \frac{\kappa}{2} \tilde{G}^{\mu\nu}$, $\Lambda = \frac{\kappa}{2} p_\Lambda$ becomes the classical GR equation in curved spacetime (in curved spacetime $Y^{\mu\nu}$ and $\Theta^{\mu\nu}$ vanish).

The Lagrangian $\mathcal{L}_\Theta$ for $\Theta^{\mu\nu}$ may be obtained the same way as in [27] with the use of the interpolating path method $g^{\mu\nu}(\lambda) = (1 - \lambda)\mathbb{K}^{\mu\nu} + \lambda g^{\mu\nu}$. Using this method one obtains

$$\sqrt{-g} \mathcal{L}_\Theta \equiv \frac{1}{2} \int_0^1 d\lambda \sqrt{-g(\lambda)} \Theta_{\mu\nu} [g^{\mu\nu}(\lambda)] \partial_\lambda g^{\mu\nu}(\lambda) \quad (37)$$

Since the variation of the functional is located on the boundary $\lambda = 1$, thus $\Theta_{\mu\nu} = \frac{2}{\sqrt{-g}} \frac{\delta(\sqrt{-g} \mathcal{L}_\Theta)}{\delta g^{\mu\nu}}$.

In the last equation of (36) considered in curved spacetime ($g^{\mu\nu} \rightarrow \mathbb{K}^{\mu\nu}$) field invariant p_Λ acts as double the vacuum energy density (vacuum pressure). This equation may be derived from the Lagrangian density $\mathcal{L}_G$ in the form

$$\mathcal{L}_G \equiv 2\mathcal{L}_T + \mathcal{L}_\Theta = \mathcal{L}_{matt} + \frac{1}{2} \tilde{R} - 2\mathcal{E}_{rot}; \quad \mathcal{L}_{matt} \equiv \mathcal{L}_\Theta - p_\Lambda(\chi_m + \chi_\omega) \quad (38)$$

where the variation by Hilbert's method on $\mathcal{L}_{matt}$ gives $T_{matt}^{\mu\nu} \equiv \varrho U^\mu U^\nu - \Xi^{\mu\nu}$.

The equation (35) considered in curved spacetime simplifies to $\tilde{G}^{\mu\nu} = \tilde{R}^{\mu\nu} - \frac{\tilde{R}}{2} g^{\mu\nu}$ where $Y^{\mu\nu}$ and thus also $\Theta^{\mu\nu}$ vanishes. It is also worth noting that in flat spacetime the generalized Einstein tensor is associated with the four-divergence of $\Theta^{\mu\nu}$

$$\partial_\mu \tilde{G}^{\mu\nu} = \partial_\mu \Theta^{\mu\nu} = f_{gr}^\nu - f_{rr}^\nu \quad (39)$$

so the curvature it describes in curved spacetime replaces this four-force density, where f_{gr}^ν is related to gravity and f_{rr}^ν is the density of radiation-reaction four-force. The presence of the radiation-reaction force has already been discussed in previous works [25], and it now prevents the matter energy and rotational energy from increasing beyond the maximum energy density p_Λ available in the system.

It is worth noting that internal energy density and rotational energy, essentially exhaust the possible forms of energy that can be attributed to material bodies (other forms of energy, e.g., chemical

energy, can be treated as their components) which could be present in the radiation reaction force. This means that the model proposed here seems complete (with the possible extension of α to a tensor form for more complex systems) and should allow for reproducing the results obtained from GR, as well as reproducing observational results that are inconsistent (such as the dark sector) with currently used interpretation of GR.

Alena Tensor approach therefore allows to look at Einstein's equations in a new light and analyze the possibilities of explaining the dark sector in a consistent mathematical framework that allows analysis in both flat and curved spacetime. Importantly, it is also possible to analyze the system using a quantum approach (in the description for flat spacetime) and to use standard tools of continuum mechanics for continuous media in flat and curved spacetime, where the description of the behavior of matter has been separated into effects related to fundamental interactions f_{YM}^V , gravity and radiation reaction $f_{gr}^V - f_{rr}^V$, and forces related to the distribution of matter f_{Ξ}^V .

3. Results

The following section will present the results of applying the Alena Tensor model both to cosmological objects and to describe quantum vortices.

3.1. The Halo Effect

The obtained results de facto means, that Alena Tensor ensures correct operation of the standard continuum mechanics equations and GR equations (Euler equations, EOS, TOV, first integrals for rotating stars, etc.), with assumption that the energy density used in them is $\varepsilon = \varrho c^2 + 2\mathcal{E}_{rot}$ and pressure is equal to $\mathcal{E}_{rot}$. In the next steps, this approach will be analyzed to show that it leads to consistency with the observational data.

It's worth starting with a simple approximation. Denoting u_{rot} as rotational velocity and assuming

$$p_{\Lambda\alpha} = \frac{1}{c^2\kappa}; \quad \varrho_{rot} \equiv \frac{2\mathcal{E}_{rot}}{c^2} = \frac{\omega^{\alpha\beta}\omega_{\alpha\beta}}{8\pi G} \rightarrow \lim_{r \rightarrow \infty} \varrho_{rot} = \frac{u_{rot}^2}{4\pi G r^2} \quad (40)$$

one may notice, that $p_{\Lambda\alpha}$ in (15) plays the role of the density of the moment of inertia, while ϱ_{rot} increases the body's effective mass within its own frame. This would allow to consider galaxies as continuous media, where the effective mass M_{eff} and its density ϱ_{eff} responsible for gravity $\varrho_{eff} \equiv \frac{\varepsilon}{c^2} = \varrho + \varrho_{rot}$ from (17) increases with the galactic disk size and angular velocity, causing the halo effect.

For far regions, denoting M_b as baryonic mass, for spherical symmetry one obtains from Poisson's equation simple linear ODE in the Newtonian limit. In the far regions it could determine a constant rotation speed and might be used to measure of deviation from the vacuum solution.

Vacuum solution in curved spacetime from (16) and (17) yields

$$\begin{aligned} \tilde{R} &= 0; \quad p_{\Lambda} = 2\varepsilon \rightarrow \\ \varrho c^2 &= -3\mathcal{E}_{rot}; \quad p_{\Lambda} = -2\mathcal{E}_{rot}; \quad \Lambda = -\kappa\mathcal{E}_{rot}; \quad 0 = \tau^{\mu\nu} = U^{(\mu}q^{\nu)}; \quad \mathcal{L}_T = 0 \end{aligned} \quad (41)$$

This means that Keplerian profiles are still possible for systems that can be approximated by a vacuum solution or does not rotate ($\mathcal{E}_{rot} \approx 0$).

Going into a more detailed analysis, one may analyse axisymmetric, stationary metric

$$ds^2 = N^2 c^2 dt^2 - A^2 (dr^2 + r^2 d\theta^2) - B^2 r^2 \sin^2 \theta (d\phi - \omega dt)^2 \quad (42)$$

which in general case implies the existence of two Killing vectors $\xi^\mu = (\partial_t)^\mu$, $\eta^\mu = (\partial_\phi)^\mu$. For the energy-momentum tensor in the hydrodynamic distribution as in (21), one can therefore define Killing

currents $J_E^\mu \equiv T^{\mu\nu} \xi_\nu = T_t^\mu$ and $J_L^\mu \equiv T^{\mu\nu} \eta_\nu = T_\phi^\mu$ which satisfy $0 = \nabla_\mu J_E^\mu = \nabla_\mu J_L^\mu$. From the algebraic identity (for any Killing vector K^μ)

$$J^\mu[K] \equiv T^{\mu\nu} K_\nu = \frac{\varepsilon}{c^2} U^\mu (U \cdot K) + \frac{1}{c^2} [U^\mu (q \cdot K) + (U \cdot K) q^\mu] - \mathcal{E}_{\text{rot}} \Delta^{\mu\nu} K_\nu - \tau^{\mu\nu} K_\nu \quad (43)$$

one obtains, in particular, for the angular momentum ($K = \eta$) the form of a mixed component

$$T^\mu_\phi = \frac{\varepsilon + \mathcal{E}_{\text{rot}}}{c^2} U^\mu U_\phi + \frac{1}{c^2} (U^\mu q_\phi + q^\mu U_\phi) - \tau^\mu_\phi - \mathcal{E}_{\text{rot}} \delta^\mu_\phi \quad (44)$$

Consequently, the transport components (radial and meridional) have the form

$$T^r_\phi = \frac{\varepsilon + \mathcal{E}_{\text{rot}}}{c^2} U^r U_\phi + \frac{1}{c^2} (U^r q_\phi + q^r U_\phi) - \tau^r_\phi \quad (45)$$

$$T^\theta_\phi = \frac{\varepsilon + \mathcal{E}_{\text{rot}}}{c^2} U^\theta U_\phi + \frac{1}{c^2} (U^\theta q_\phi + q^\theta U_\phi) - \tau^\theta_\phi \quad (46)$$

For circular flow $0 = U^r = U^\theta$, the convective terms from U^r , U^θ disappear, so the currents reduce to

$$T^r_\phi = \frac{q^r U_\phi}{c^2} - \tau^r_\phi \quad ; \quad T^\theta_\phi = \frac{q^\theta U_\phi}{c^2} - \tau^\theta_\phi \quad (47)$$

This means that in the stationary and axisymmetric regime, the "halo" can be interpreted not as additional mass, but as a result of angular momentum transport via the energy flux q^μ and anisotropic stresses τ^μ_ν , which generate non-zero fluxes T^r_ϕ and/or T^θ_ϕ .

One may also propose simplified analysis based on simple ideal fluid system idealization ($0 = \tau^{\mu\nu} = U^{(\mu} q^{\nu)}$) leaving only the effect of the existence of the current described above in the form of pressure $p \equiv \mathcal{E}_{\text{rot}}$ what may be denoted as

$$T_{\text{ideal}}^{\mu\nu} \equiv \left(\varrho + \frac{2p}{c^2} \right) U^\mu U^\nu - p \Delta^{\mu\nu} \quad (48)$$

Analyzing Euler's energy and momentum equations for introduced $\nabla_\mu T_{\text{ideal}}^{\mu\nu} = 0$ one may notice, that u_{ZAMO} is not a geodesic movement, and on the equator it takes the value

$$\frac{u_{\text{ZAMO}}^2}{c^2} = \frac{(Br)^2}{N^2} \left(\frac{d\phi}{dt} - \omega \right)^2 = r \partial_r \ln N + \gamma_p^2 - 1; \quad \gamma_p^2 \equiv 1 - r \frac{p'}{\varrho c^2 + 3p} \quad (49)$$

where γ_p coefficient determines the deviation from the geodesic. One may therefore define pressure as follows, what yields

$$\kappa p \equiv \frac{u_{\text{ZAMO}}^2}{r^2 c^2} \rightarrow \frac{dM_{\text{eff}}}{dr} = 4\pi r^2 \varrho(r) + \frac{u_{\text{ZAMO}}^2}{G} \rightarrow \frac{d}{dr} u_{\text{ZAMO}}^2 = 4\pi G r \varrho(r) \quad (50)$$

In obtained picture the velocity increase depends solely on the baryon mass distribution, while the flattening of the tail is maintained by the rotational energy. This precisely corresponds to the expected behavior of a dark matter "halo."

The introduction of q^μ and $\tau^{\mu\nu}$ into a system can be approximated by defining parameter $\chi(r)$ changing original p used for isotropic model

$$p_r \equiv \alpha p; \quad p_\theta \equiv \beta p; \quad p_\phi \equiv p \rightarrow \chi = \alpha + \beta; \quad 3p_\chi \rightarrow (1 + \chi)p; \quad 2p \rightarrow \chi p \quad (51)$$

The constant χ analysis should be regarded as an illustrative limit rather than a physical assumption and is comparable in quality to standard one-parameter halo models. In practice, even a constant χ should be sufficient for analyzing the fit of galaxy rotation curves. Using a constant χ also provides a

simpler ODE and the ability to quickly perform preliminary fits of χ to observational data for large amounts of data.

$$\begin{aligned} \frac{dM_{eff}}{dr} &= 4\pi r^2 \varrho(r) + \frac{\chi}{2} \frac{u_{ZAMO}^2}{G} \rightarrow \\ \frac{d}{dr} u_{ZAMO}^2 &= 4\pi G r \varrho(r) + \left(\frac{\chi}{2} - 1\right) \frac{u_{ZAMO}^2}{r}; \quad \lim_{\varrho \rightarrow 0} u_{ZAMO}^2 \propto r^{\frac{\chi}{2}-1} \end{aligned} \quad (52)$$

On the Figure 1 below, one may find the expected course of the rotation curves depending on the assumed constant χ . The calculations used an averaged Hernquist bulge baryon model ϱ_{bulge} and a "spherical proxy" of the exponential disk ϱ_{disc}

$$\varrho_{bulge} = \frac{M_{bulge}}{2\pi} \frac{a}{r(r+a)^3} \quad ; \quad M_{bulge} = 10^{10} M_{\odot} \quad ; \quad a = 1 \text{ kpc} \quad (53)$$

$$\varrho_{disc} = \frac{M_{disc}}{4\pi R_d^2} \frac{e^{-r/R_d}}{r} \quad ; \quad R_d = 3 \text{ kpc} \quad (54)$$

with total baryon density $\varrho_b(r) = \varrho_{bulge} + \varrho_{disc}$, standard G value, anisotropy and energy stream simulated by constant χ . As can be seen from the graph, the increasing anisotropy towards the outskirts of the galaxy $\chi(r=0) = 0$; $\lim_{r \rightarrow \infty} \chi(r) = \text{const}$ would allow the graph to align with the expected curve shapes for spiral galaxies.

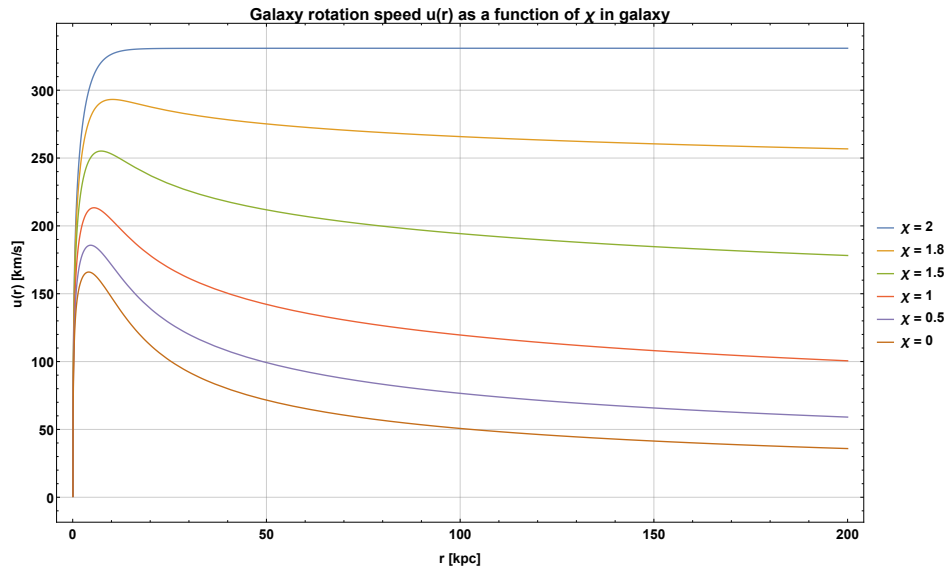


Figure 1. Approx. rotation curves in Alena Tensor model

As it appears, constant χ actually allows to tune the rotation velocity distribution for some part of galaxies what gives an overview of the method and may help in further analysis and tuning of $\chi(r)$ function to achieve full agreement with observations. The Appendix A presents the results of tuning the χ constant for about 100 galaxies from the SPARC catalog [31]. For each galaxy χ was the only free parameter where the baryonic contribution was fixed directly from the SPARC photometric data. The results seem encouraging, and worth further analysis with the $\chi(r)$ function or with the full $T^{\mu\nu}$ tensor representation. For most galaxies the fit is very good, and for the rest it is obtainable by introducing a simple function $\chi(r)$ which provides $\chi(r) \approx 0$ for small r (chaotic motions in the center, no ordered rotation) to a stabilized rotation in the outskirts with a fixed χ .

The χ parameter was adjusted for each galaxy by iteratively solving the radial motion differential equation resulting from (52), with the condition of normalizing the rotation rate in the outer disk $\langle V_{\chi} \rangle_{\text{outer}} = \langle V_{\text{obs}} \rangle_{\text{outer}}$. The entire procedure, including reading the rotation data from the SPARC catalog, interpolating the baryonic component $V_{\text{bar}}(r)$, numerically solving the equation for $V_{\chi}(r, \chi)$

and saving the resulting plots in PDF format, was fully automated in the Mathematica script, and run in an environment with the SPARC source data. The script is included in the supplementary files.

It is worth emphasizing that discussed framework also leads to concrete and testable observational predictions for gravitational lensing. In this approach, the halo effect is not associated with an additional mass component, but emerges from rotational energy, energy fluxes, and anisotropic stresses contained in the matter energy-momentum tensor. In the general formulation, lensing is governed by the Ricci focusing term obtained from the contraction with a null vector $k^\mu = \omega \left(\frac{U^\mu}{c} + n^\mu \right)$ which yields, using Einstein equations

$$R_{\mu\nu}k^\mu k^\nu = \kappa T_{\mu\nu}k^\mu k^\nu = \kappa \omega^2 \left[\rho c^2 + 3\mathcal{E}_{\text{rot}} + \frac{2}{c}(q^\mu n_\mu) - \tau^{\mu\nu} n_\mu n_\nu \right] \quad (55)$$

Similar sensitivity of gravitational lensing to anisotropic stress is known to appear in relativistic weak-lensing formalisms [32]. This expression shows explicitly that, in addition to the effective energy density $\rho c^2 + 3\mathcal{E}_{\text{rot}}$, lensing is sensitive to energy fluxes q^μ and anisotropic stresses $\tau^{\mu\nu}$, which encode angular momentum transport and are responsible for the halo-like behavior in the Alena Tensor model. A simpler and more practical observational test can be constructed using the idealized fluid approximation $T_{\text{ideal}}^{\mu\nu}$, supplemented by an effective anisotropy parameter χ , defined through directional pressures. In this case, the Ricci focusing reduces to the form below, which directly translates into an effective surface density for lensing

$$\frac{T_{kk}}{\omega^2} = \rho c^2 + 2p + p_r n_r^2 + p_\theta n_\theta^2 + p_\phi n_\phi^2 \quad ; \quad \Sigma_{\text{eff}}(R) = \int dz \left[\rho + W(i) \frac{p}{c^2} \right] \quad (56)$$

where the weight $W(i)$ depends on the inclination i of the system with respect to the line of sight. For a disk galaxy, this leads to two limiting cases:

$$\Sigma_{\text{eff}}^{\text{face}} = \int dz \left[\rho + \left(2 + \frac{\chi}{2} \right) \frac{p}{c^2} \right] \quad ; \quad \Sigma_{\text{eff}}^{\text{edge}} = \int dz \left[\rho + \left(\frac{5}{2} + \frac{\chi}{4} \right) \frac{p}{c^2} \right] \quad (57)$$

Consequently, one generically predicts

$$\Sigma_{\text{eff}}^{\text{face}} - \Sigma_{\text{eff}}^{\text{edge}} = \frac{\chi - 2}{4} \Sigma_p \quad ; \quad \Sigma_p \equiv \int dz \frac{p}{c^2} \quad (58)$$

and thus a systematic inclination-dependent lensing signal whose sign and magnitude are directly controlled by the anisotropy parameter χ , for systems with identical baryonic mass distributions and rotation curves. This inclination-dependent lensing signal provides a simple and robust observational test of the Alena Tensor halo mechanism, which is not expected in standard isotropic dark matter halo models, but is indicated by the conclusions from observations e.g., in [33–35].

3.2. Quantum Vortices And Elementary Particles

In Section 2.2.1 the possibility of quantum analysis of the Alena Tensor was demonstrated, so it is worth making such a preliminary analysis. The simplified effective Lagrangian shown below can be considered as a low-energy approximation of the quantum Lagrangian L_Q from (31), obtained after integrating the degrees of freedom associated with the rotational sector of the Alena Tensor, serving as phenomenological low-energy model capturing the dominant rotational response. In this sense,

the function χ_ω is no longer an independent geometric field, but appears as a local four-dimensional operator, while retaining exactly the same energy interpretation and vacuum screening mechanism.

$$\begin{aligned} \mathcal{L}_{\text{eff}} = & \underbrace{\frac{\hbar c}{2} (\partial_\mu \rho)(\partial^\mu \rho) + \frac{\hbar c}{2} \rho^2 (\partial_\mu \phi)(\partial^\mu \phi)}_{\mathcal{L}_{\text{scalar(vortex)}}} + \underbrace{\bar{\psi} (i\hbar c \gamma^\mu D_\mu - mc^2) \psi}_{\mathcal{L}_\psi} \\ & + \underbrace{\frac{e^{-\theta(\rho)}}{2c^2 \kappa} \omega_{\mu\nu} \omega^{\mu\nu} - g\hbar \bar{\psi} \Sigma_{\mu\nu} \psi \omega^{\mu\nu}}_{\mathcal{L}_{\text{spin-vortex}}} \end{aligned} \quad (59)$$

where

- $\phi(x)$ - vortex phase field (action phase). Its gradient $\partial_\mu \phi$ represents the generalized four-momentum flow associated with the vortex structure.
- $\rho(x)$ - amplitude of the complex condensate $\varphi = \hbar c \rho e^{i\phi}$. It determines the vortex core profile and sets the symmetry-breaking scale.
- $\omega_{\mu\nu}$ - vorticity tensor of the underlying medium. In this Lagrangian it is treated as an independent antisymmetric field capturing local rotational structure analogous to the Hubbard-Stratonovich transformation [36].
- $\Sigma_{\mu\nu}$ - spin generator in the fermionic representation $\Sigma_{\mu\nu} = \frac{i}{4} [\gamma_\mu, \gamma_\nu]$.
- $e^{\theta(\rho)}$ - plays the role of the a dimensionless state-dependent stiffness function, encoding the effective elastic response of the vortex condensate, where it is assumed for calculation simplicity $p_\Lambda \alpha = e^{-\theta(\rho)} / (c^2 \kappa)$
- g - dimensionless spin-vorticity coupling constant, determining the strength of the interaction between fermionic spin and the vortex background.

The Madelung decomposition $\varphi = \hbar c \rho e^{i\phi}$ introduces an effective phase field whose gradient gives the conserved current $\hbar c \rho^2 \partial^\mu \phi$.

It may be also assumed, that the electroweak symmetry is broken by a chiral fermion condensate $\langle \bar{\psi}_R \psi_L \rangle \neq 0$ which implies $SU(2)_L \times U(1)_Y \rightarrow U(1)_{\text{em}}$. The associated three Goldstone modes are thus absorbed as the longitudinal polarizations of $W^\pm$ and Z bosons, yielding their masses in the standard, technicolor way. The Higgs boson is also identified with the lightest scalar resonance in the technicolor sector associated with the chiral condensate $\langle \bar{\psi}_R \psi_L \rangle \neq 0$, as in standard technicolor constructions [37,38]. However, the mechanism of fermion generation may result from the adopted Lagrangian.

In the next steps it will be shown that by treating the Lagrangian (59) as an effective field model and choosing an appropriate stiffness function $\theta(\rho)$, both Yukawa-type mass generation and Higgs-type potential structure can emerge naturally.

The vorticity tensor enters the Lagrangian (59) only through the elastic term and the spin-vorticity interaction. Its algebraic equation of motion yields

$$\frac{\partial \mathcal{L}_{\text{eff}}}{\partial \omega^{\mu\nu}} = 0 \quad \rightarrow \quad \omega_{\mu\nu} = c^2 \kappa e^{\theta(\rho)} g \hbar \bar{\psi} \Sigma_{\mu\nu} \psi \quad (60)$$

so that eliminating $\omega_{\mu\nu}$ produces the effective fermion term

$$\mathcal{E}_{\text{rot}} = \frac{g^2 \hbar^2 c^2 \kappa e^{\theta(\rho)}}{2} (\bar{\psi} \Sigma^{\mu\nu} \psi) (\bar{\psi} \Sigma_{\mu\nu} \psi) \quad (61)$$

Evaluated at the homogeneous equilibrium, this yields a dynamically generated fermion mass

$$m_{\text{eff}} = \frac{g^2 \hbar^2 c^2 \kappa e^{\theta(\rho)}}{2} \langle \Sigma \rangle \quad ; \quad \langle \Sigma \rangle \equiv \frac{\langle (\bar{\psi} \Sigma^{\mu\nu} \psi) (\bar{\psi} \Sigma_{\mu\nu} \psi) \rangle}{\langle \bar{\psi} \psi \rangle} \quad (62)$$

Up to Fierz rearrangements [39], the induced four-fermion operator contains a scalar channel allowing for fermion mass generation, analogously to NJL-type dynamics [40]. In this picture, the mass generation results from the equilibrium between the scalar amplitude ρ and the spin-vorticity background, rather than from a fundamental Yukawa coupling where the condensate $\langle \Sigma \rangle$ plays the role of an order parameter. For a stationary vortex configuration $\varphi = \hbar c \rho e^{i\phi}$, the scalar sector of (59) thus leads to the standard energy functional

$$E[\rho, \phi] = \frac{\hbar c}{2} \int d^3x [(\nabla \rho)^2 + \rho^2 (\nabla \phi)^2] \quad (63)$$

Euler-Lagrange equations dedived from (59) are

$$\hbar c \partial_\mu \partial^\mu \rho - \left[\hbar c \rho (\partial_\mu \phi) (\partial^\mu \phi) - \frac{\vartheta'(\rho) e^{-\vartheta(\rho)}}{2c^2 \kappa} \omega_{\alpha\beta} \omega^{\alpha\beta} \right] = 0; \quad \partial_\mu (\rho^2 \partial^\mu \phi) = 0 \quad (64)$$

and show, that the amplitude adjusts to the local phase gradient. In the presented model, ρ has the dimension of the inverse of the length while Standard Model vev v_{SM} is expressed as energy. Considering the equations in the limit $\rho = v$ one may thus assume that $\hbar c v \equiv v_{\text{SM}}$ which fixes the normalization of the scalar amplitude and should be understood as a matching condition between the effective vortex sector and the electroweak vacuum scale. Since the effective Yukawa parameter can be extracted directly from (62) therefore in order to reproduce the Standard Model it should satisfy $m_{\text{eff}} c^2 = \frac{y_f}{\sqrt{2}} \hbar c v$, thus

$$\frac{y_f \hbar c}{\sqrt{2}} \equiv \left. \frac{\partial m_{\text{eff}}(\rho) c^2}{\partial \rho} \right|_{\rho=v} = m_{\text{eff}} c^2 \vartheta'(v) \rightarrow \frac{\hbar c y_f}{\sqrt{2} m_{\text{eff}} c^2} = \frac{1}{v} \rightarrow \vartheta'(v) \equiv \frac{1}{v} \quad (65)$$

Assuming the stationary energy-minimizing configuration (static state)

$$\rho(x) = v = \text{const} \quad ; \quad \partial_i \varphi = 0 \quad ; \quad \mathbb{E}(x) = \text{const} \quad ; \quad \partial_i \mathbb{E} = 0 \quad (66)$$

the Euler-Lagrange equation for $\rho = v$ reduces therefore to

$$\mathcal{E}_{\text{rot}}(v) = m_{\text{eff}} c^2 \langle \bar{\psi} \psi \rangle = \frac{e^{-\vartheta(v)}}{2c^2 \kappa} \omega_{\alpha\beta} \omega^{\alpha\beta} = \hbar c \frac{v \mu^2}{\vartheta'(v)} = \hbar c v^2 \mu^2 \quad (67)$$

Under suitable assumptions on the stiffness function $\vartheta(\rho)$ and on the spin-vorticity condensate encoded in $\omega_{\alpha\beta} \omega^{\alpha\beta}$, this relation plays the role of a gap equation, equivalent to the condition $\partial V_{\text{eff}}(\rho) / \partial \rho|_{\rho=v} = 0$ for an effective Higgs-like potential. The competition between $\mathcal{E}_{\text{rot}}$ and $\hbar c v^2 \mu^2$ might therefore reproduce the characteristic symmetry-breaking structure of the Higgs potential. Using the equilibrium equation and the condition $\vartheta'(v) = \frac{1}{v}$, the second derivative of the effective potential can be calculated as

$$\left. \frac{\partial^2 V_{\text{eff}}(\rho)}{\partial \rho^2} \right|_{\rho=v} = m_{\text{eff}} c^2 \langle \bar{\psi} \psi \rangle \left[\vartheta''(v) + (\vartheta'(v))^2 - \frac{\vartheta'(v)}{v} \right] = m_{\text{eff}} c^2 \langle \bar{\psi} \psi \rangle \vartheta''(v) \quad (68)$$

Equivalently, assuming that the effective potential $V_{\text{eff}}(\rho)$ is indeed of Higgs type, it may also be assumed that

$$\left. \frac{\partial^2 V_{\text{eff}}(\rho)}{\partial \rho^2} \right|_{\rho=v} \equiv 2 \hbar c v^2 \quad (69)$$

Therefore (68) = (69) may be further simplified, imposing a specific form on the function $\vartheta(\rho)$ as below, for the preservation of the Yukawa condition and the Higgs-like potential

$$\begin{aligned}\vartheta(\rho) &\equiv \ln \frac{\rho}{v} + \frac{\coth^2(\frac{\theta_f}{2})}{2} \left(\frac{\rho}{v} - 1 \right)^2 \rightarrow \\ \mathcal{E}_{rot}(v) &= m_{\text{eff}} c^2 \langle \bar{\psi} \psi \rangle = 2\hbar c v^2 \frac{v^2}{\coth^2(\frac{\theta_f}{2}) - 1} = 2\hbar c v^4 \sinh^2\left(\frac{\theta_f}{2}\right)\end{aligned}\quad (70)$$

The chosen form of $\vartheta(\rho)$ is the minimal analytic function satisfying simultaneously the Yukawa condition, vacuum normalization, and positivity of the Higgs curvature. It yields

$$\frac{y_f}{\sqrt{2}} \cdot \langle \bar{\psi} \psi \rangle = 2 \sinh^2\left(\frac{\theta_f}{2}\right) \cdot v^3 \quad (71)$$

Therefore, following standard dimensional estimates for strongly coupled fermion condensates one may make the natural assumption $\langle \bar{\psi} \psi \rangle = v^3$, and separate condensate from Yukawa parameter as follows

$$\frac{y_f}{\sqrt{2}} = \frac{\mu^2}{v^2} = 2 \sinh^2\left(\frac{\theta_f}{2}\right) = \cosh(\theta_f) - 1 \quad (72)$$

replacing the Yukawa parameter y_f with square of the ratio of the topological energy of the vortex to the electroweak vacuum scale. In this picture $\cosh(\theta_f) - 1$ determines the total excess energy needed to maintain the phase current where $A = 2 \sinh\left(\frac{\theta_f}{2}\right)$ can be interpreted as the amplitude of the underlying spinor wave ψ , representing a propagating, localized excess of energy above the vacuum background $\rho = v$ and carrying spin $1/2$.

In this way the above approach suggests an interpretation of elementary fermions as stable quantum vortices, reproducing the successful Yukawa and Higgs mechanism, where all stability requirements follow directly from the field equations and the structure of the effective potential. In this approach, the technicolor sector is responsible for the vacuum dynamics leading to the spontaneous breaking of the electroweak symmetry and the establishment of the v_{SM} scale, while the fermions are treated as effective excitations of this vacuum of a topological nature, described by an independent vortex sector.

This interpretation is fully consistent with the general paradigm of topological solitons, where localized and finite-energy excitations of a continuous field behave as particle-like objects, as in the Skyrme model [41,42], the Faddeev-Niemi hopfion model [43,44], and the superfluid-vacuum approach of Volovik [45]. In presented case, the spin-vorticity coupling and the rotational energy functional play the role of stabilizing terms, ensuring that the vortex configuration propagates as a massive fermionic quasiparticle, closely analogous to knotted vortical solitons in classical and quantum field theories [46].

One may also notice, that this type of effective Lagrangian (59) naturally supports four distinct conserved charges, arising from its symmetries and from the structure of the vorticity sector (with accuracy to constants)

- *Phase (Noether) charge* $Q_\phi = \int d^3x j^0$; $j^\mu \equiv \rho^2 \partial^\mu \phi$ originating from the global shift symmetry. It corresponds to the conserved circulation associated with the phase field.
- *Topological vortex number* $N_v = \frac{1}{2\pi} \oint_C \nabla \phi \cdot d\vec{\ell} \in \mathbb{Z}$ defined for static configurations with nontrivial winding of the phase ϕ around the vortex core. This integer counts the number of 2π windings.
- *Spin-vorticity flux charge* $Q_{sv} = \int d^3x \partial_\mu (g\hbar \omega^{\mu 0})$ where the vorticity tensor $\omega_{\mu\nu}$ satisfies the algebraic field equation $\omega_{\mu\nu} = c^2 \kappa e^{\theta(\rho)} g\hbar \bar{\psi} \Sigma_{\mu\nu} \psi$. This charge reflects the conserved flow associated with the spin-vorticity coupling term $g\hbar \bar{\psi} \Sigma_{\mu\nu} \psi \omega^{\mu\nu}$.
- *Hopf (linking) charge* $Q_H = \frac{1}{32\pi^2} \int d^3x \epsilon^{ijk} \mathcal{A}_i \mathcal{F}_{jk}$ defined when the dual vorticity vector $\omega_i \equiv \frac{1}{2} \epsilon_{ijk} \omega_{jk}$ is normalized to a unit field $\vec{n}(x) = \vec{\omega}/|\vec{\omega}|$, with $\mathcal{F}_{ij} = \partial_i \mathcal{A}_j - \partial_j \mathcal{A}_i$ denoting the pullback of the area form on S^2 . This integer-valued invariant characterizes the knotting and linking of vorticity lines.

It is therefore possible to expand the model based on the conserved charges and deeper analysis of the model in the context of reproducing known structural features of elementary particles, including the possibility of identifying particle families with different topological sectors.

It may be also noticed, that assuming non-zero particle's mass m , variation of (59) with respect to $\bar{\psi}$ gives the modified Dirac equation

$$(i\hbar c \gamma^\mu D_\mu - mc^2 - g\hbar \Sigma^{\mu\nu} \omega_{\mu\nu})\psi = 0 \quad (73)$$

where the last term is a local spin-vorticity coupling formally analogous to the Mashhoon effect [47,48]. For the normalization of $\omega_{\mu\nu}$ assumed in (13) this correspondence fixes $g = \frac{1}{2}$. This allows the obtained model to be applied to atomic systems and other classical settings.

One may consider the regime in which the effective vorticity field $\omega_{\mu\nu}$ is dominated by a stationary rotational background with angular velocity $\vec{\Omega}$. Using the standard identification of spatial components $\omega^i = \frac{1}{2}\epsilon^{ijk}\omega_{jk}$, the nonrelativistic Foldy-Wouthuysen expansion as in [49] therefore yields an additional spin-rotation term in the effective Hamiltonian $\Delta H_{sv} = -\frac{1}{2}\hbar \vec{\sigma} \cdot \vec{\Omega}$ corresponding to a rotation-induced spin splitting $\Delta E = \hbar|\Omega|$. This effect is directly testable in precision spin-precession experiments, atomic and neutron interferometry, and high-resolution spectroscopy in controlled rotating platforms.

The vacuum normalization $e^{\theta(v)} = 1$ ensures that the coupling is fixed in vacuum and coincides with the standard spin-rotation interaction, while any deviation must arise from medium-dependent effects encoded in $\rho \neq v$. Consequently, the quantum sector of the Alena Tensor framework leads to two distinct and falsifiable implications:

- a fixed, parameter-free spin-rotation coupling in vacuum, reproducing the Mashhoon-type precession without additional degrees of freedom,
- a possible environment-dependent modification of spin-dependent interactions,

constrained by precision limits on anomalous spin couplings in vortical or rotating media. Any observed departure from the vacuum prediction thus directly bounds the response function $e^{\theta(\rho)}$, providing an experimental handle on the rotational sector of the theory. The available literature indicates that the described effect is expected [50], already observed to some extent [51] and should be measurable using standard research procedures [52,53].

4. Discussion and Conclusions

It is worth discussing the conclusions of this article by dividing them into issues concerning GR/Cosmology and quantum issues.

4.1. Discussion And Conclusions Regarding GR And Cosmology

As seen in the above article, supplementing the Alena Tensor with the energy associated with the rotation of bodies naturally leads to the creation of halo effects, known from dark matter studies. Preliminary analysis allows for a fairly good match of this effect to observational results, although this obviously requires further development and verification for a larger number of cosmological objects. Importantly, the proposed approach does not require modification of the GR equations, but rather fits naturally into the applied GR equations and continuum mechanics. The model discussed also describes the properties related to gravitational lensing, however, a dedicated analysis of light deflection, including the role of anisotropic stresses, is required to quantitatively assess the consistency of the model with lensing observations [54,55]. In standard NFW dark matter halos or in MOND-like modified gravity models, the lensing signal at fixed baryonic mass and rotation curve is expected to be largely insensitive to disk inclination, apart from trivial geometric projection effects. As shown in 3.1, the predicted inequality $\Sigma_{\text{eff}}^{\text{face}} - \Sigma_{\text{eff}}^{\text{edge}}$ makes therefore a distinctive and falsifiable signature of the Alena Tensor framework. This inclination-dependent lensing imprint has not yet been explored in dedicated observational studies and given the availability of large galaxy-galaxy lensing samples and resolved kinematic data, the proposed signal appears readily testable.

The proposed solution fits quite well with the research direction represented by [56–58] and also [59] (including baryotropy), who investigated anisotropic fluid in cosmology and its potential connections with the dark sector. However, it complements these studies with the natural halo effect resulting directly from the GR equations for the Alena Tensor. The proposed model also expands and, in a sense, substantiates the hypothesis posed by C. Rourke [60], complementing the research [61–64] with a justification for linking rotation with the halo effect. The idea that rotation-related effects can mimic dark matter is not new, but Alena Tensor gives it some additional structure, making it a direct consequence of a coherent mathematical model.

Importantly, the Alena Tensor also provides a natural interpretation of dark energy. The value of p_Λ is an invariant of the field tensor and becomes constant (or, at least, metric-independent invariant) in curvilinear description. In a sense, a nonzero value of Λ can therefore be interpreted as a scale of deviation from pure wave solutions, without matter (for example, for the electromagnetic field, $p_\Lambda = 0$ would mean that the electric and magnetic fields are equal, so the solutions must be pure electromagnetic waves). Since the value of p_Λ measured in flat spacetime is $p_\Lambda = p_o (\mathbb{K}_{\mu\nu} \eta^{\mu\nu})^2$, it is a measure of the "flatness" of spacetime, or more precisely, a measure of how much the metric tensor for the curvilinear description deviates from the Minkowski tensor. This interpretation seems particularly interesting in the context of the works [65,66], because it strengthens and details the conclusions described therein, providing a geometric, anisotropic source that can be interpreted as a specific backreaction mechanism leading to acceleration. Whether this identification can fully reproduce the phenomenology of dark energy at the level of background expansion and cosmological perturbations remains an open question and should be addressed in future work.

It seems that the next best step would be to conduct consistent tests of gravitational lensing (in galaxies and clusters), satellite dynamics, and perturbation cosmology (structure growth, ISW, CMB), which would allow to clearly confirm or falsify the assumptions presented in the article. This approach could be also applied to many other continuous systems (e.g., stars or black holes) and seems worth to describe the extreme in which $\varrho = 0$ and all the energy in the system is rotational energy. One may notice, that the source in vacuum solution (41) is indeed solely rotational energy. As shown in 3.2, replacing rotation with vorticity and treating it as a consequence of the circulating field creates the possibility to model elementary particles as quasiastable systems of three-dimensional vortices.

4.2. Discussion And Conclusions Regarding Quantum Issues

In quantum theory, the same structure of the energy-momentum tensor gives rise to topological vortices whose stability determines states with interpretable mass. The analysis presented in this work provides an effective-field reinterpretation of the Higgs mechanism in terms of vortex dynamics, in which fermion masses arise from a self-consistent spin-vorticity condensation rather than from fundamental Yukawa couplings. The elimination of the antisymmetric vorticity field leads to an effective four-fermion interaction and a gap equation for the condensate modulus, allowing for particle-like, topologically stabilized vortex excitations to emerge within the obtained Belinfante energy-momentum tensor structure.

The inclusion of rotational energy contributions in the energy-momentum tensor naturally induces a local spin-vorticity coupling, encoded in the modified Dirac equation (73). In the nonrelativistic limit this coupling reduces to a Mashhoon-type interaction, consistent with earlier analyses of inertial and rotational effects in relativistic quantum mechanics [67–69]. Such couplings are known to play a role in systems with significant vorticity, including relativistic fluids and rotating quantum media, where spin polarization effects have been discussed in hydrodynamic and condensed-matter contexts [70,71]. In this sense, the obtained vorticity field admits a direct physical interpretation as an effective rotational background, potentially relevant for vortical quantum systems such as the quark-gluon plasma [72].

The effective theory exhibits four conserved quantities: the phase charge Q_ϕ , the vortex number N_v , the spin-vorticity charge Q_{sv} , and the Hopf charge Q_H . These invariants classify vortex configurations according to their topology and are closely analogous to conserved charges appearing in well-established soliton models, including Skyrme-type constructions [73], Faddeev-Niemi

hopfions [74], and related knot-like soliton solutions [75,76]. Within the present approach, fermionic excitations may be associated with stable, spin-carrying vortex configurations, while different topological sectors could encode additional structural distinctions among particle-like solutions.

Eliminating the vorticity field yields an effective description reminiscent of dynamical mass generation mechanisms known from Nambu-Jona-Lasinio models [77], composite Higgs scenarios [78,79], and superfluid-vacuum analogies [45]. In this picture, the Higgs boson appears as a radial excitation of the condensate, with its mass determined by the curvature of the effective potential. While the present analysis remains at the level of an effective model, it suggests a unified perspective on fermion and Higgs mass generation tied to vortex stability and the structure of the condensate.

The results obtained here motivate several directions for further study, including the construction of fully nonlinear three-dimensional vortex solutions with prescribed topological charges, the analysis of their stability and energetics, and the investigation of possible phenomenological implications of spin-vorticity couplings. Potential applications range from atomic and condensed-matter systems to relativistic heavy-ion collisions [70,80] and astrophysical settings such as neutron stars [81,82]. A more detailed exploration of transport properties and spin polarization effects in vortical media [83,84] may further clarify the physical relevance and limitations of the proposed framework.

Equally interesting direction of further analysis could be e.g., the use of the possibilities of quantum description of the dark sector in the Alena Tensor model, for further development of works such as [85]. It also seems that describing matter (e.g., a neutron star, as in [86,87]) using the mechanism proposed here for GR, would be the simplest way to confirm or falsify the Alena Tensor, due to the high symmetry of such a solution. It can also be noted that the Madelung phase ϕ obtained in this paper may be e.g., interpreted as the phase of microscopic proper-time oscillations of spacetime, analogous to the scalar field ζ considered in the [88] introduced in spacetime excitation model. In this picture, the localized vortex solutions would correspond to stable, topologically protected configurations of the underlying spacetime phase. However, all these analyses deserve separate articles.

In conclusion, it remains an open question whether the Alena Tensor is a correct way to describe physical systems, but this paper shows that, beyond the compliances with available knowledge achieved so far, it naturally leads to the existence of halo effects, interpretation of dark energy and modeling quantum vortices. Taken together, these results indicate that the extended Alena Tensor offers a unified geometric and topological framework that connects elementary particles, relativistic fluids and large-scale astrophysical structures. This opens a way for theoretical and phenomenological studies, extending far beyond the cosmological applications emphasized in the present work.

The author hopes that the results obtained in this paper will facilitate further use and development of the discussed approach and, potentially, many similar concepts. It also seems that further analysis of Alena Tensor may provide useful descriptions of the transformation between curved and flat spacetime and bring new insights that will contribute to a better understanding of issues related to the broadly understood unification of physical theories.

5. Statements

All data that support the findings of this study are included within the article (and any supplementary files).

During the preparation of this work the author did not use generative AI or AI-assisted technologies, except for continuous learning.

Author did not receive support from any organization for the submitted work.

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Appendix A. Results of Fitting the Constant χ



Figure A1. Rotation curves at constant χ for galaxies 1/4.

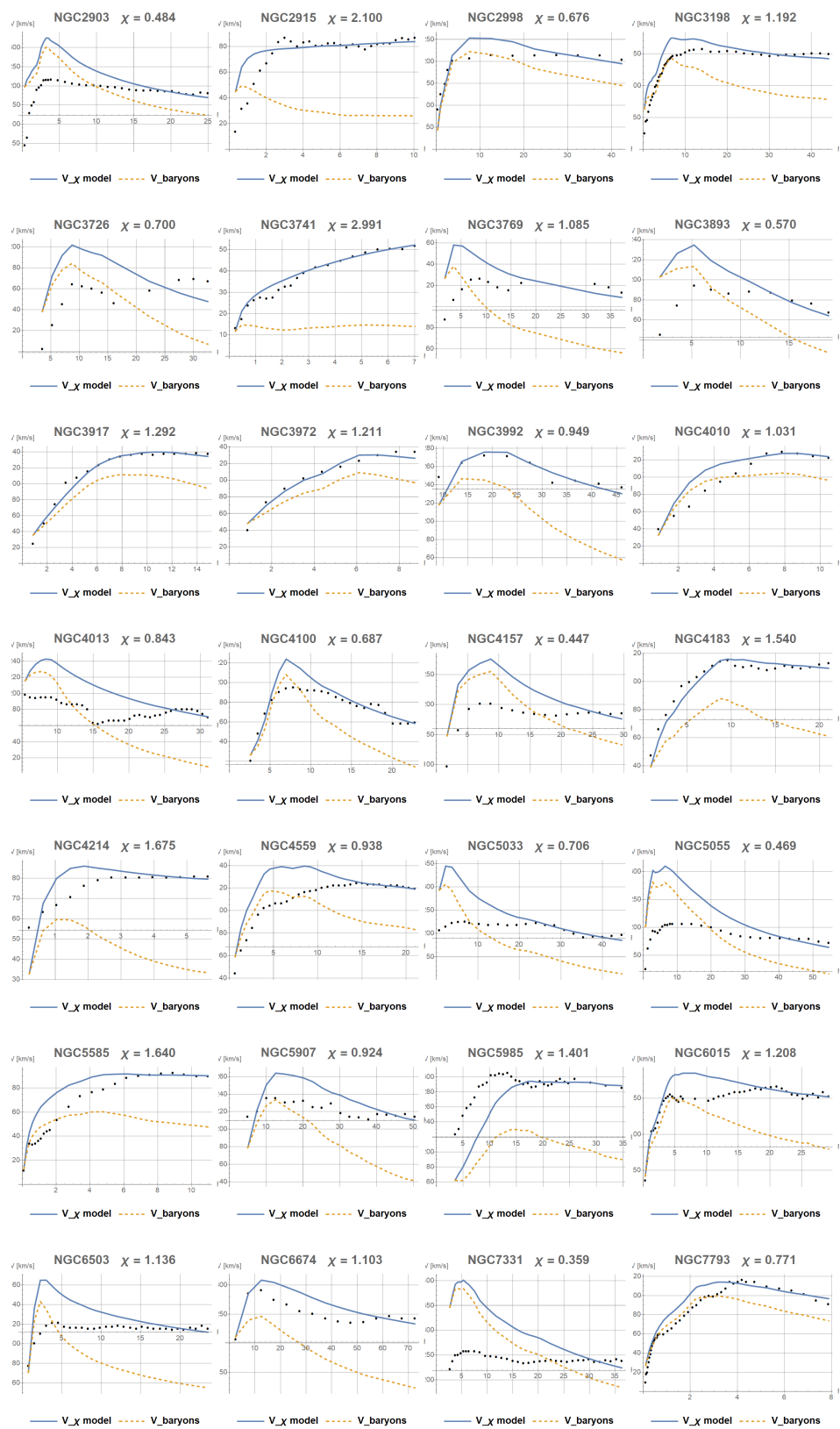


Figure A2. Rotation curves at constant χ for galaxies 2/4.

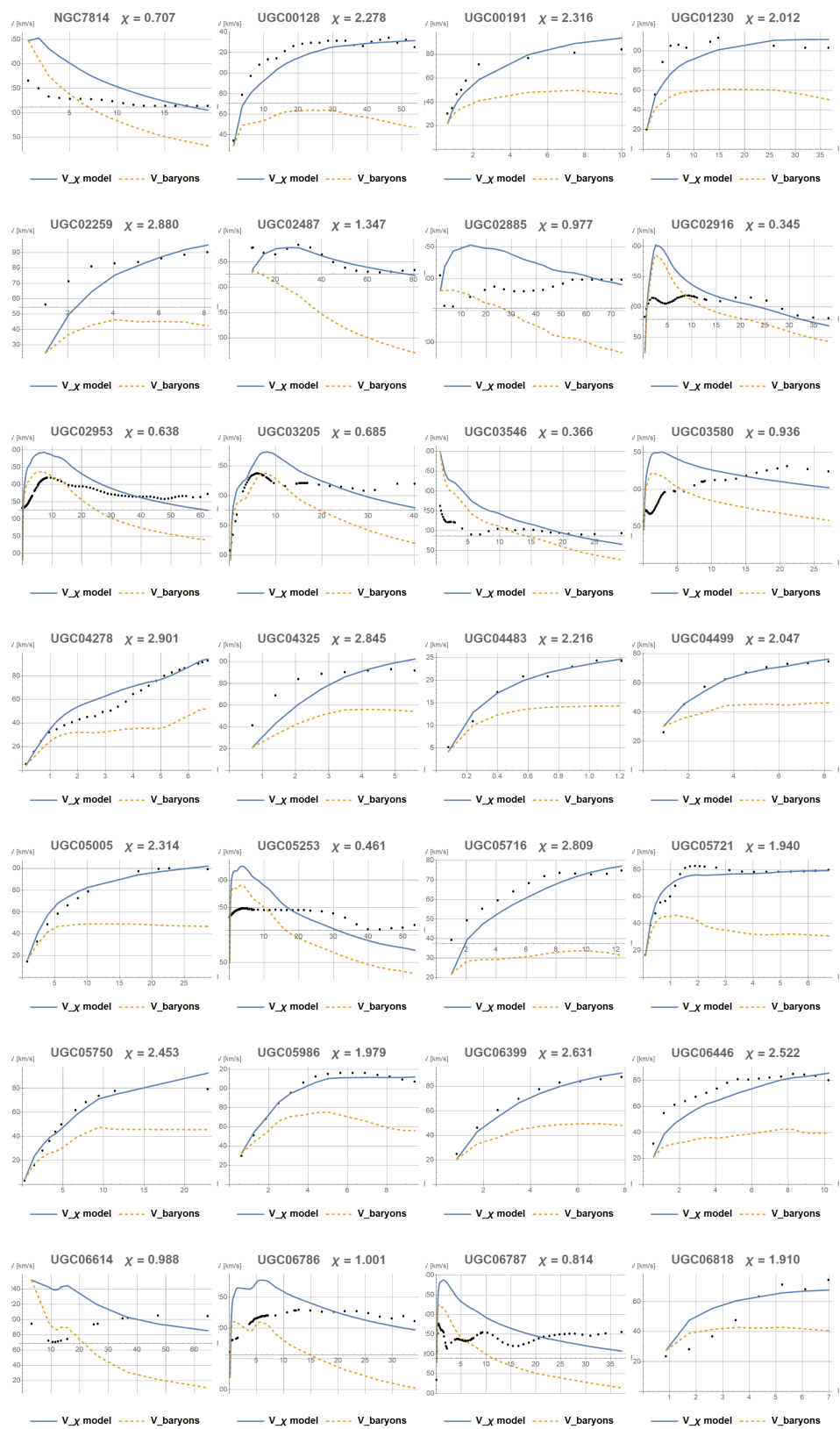


Figure A3. Rotation curves at constant χ for galaxies 3/4.

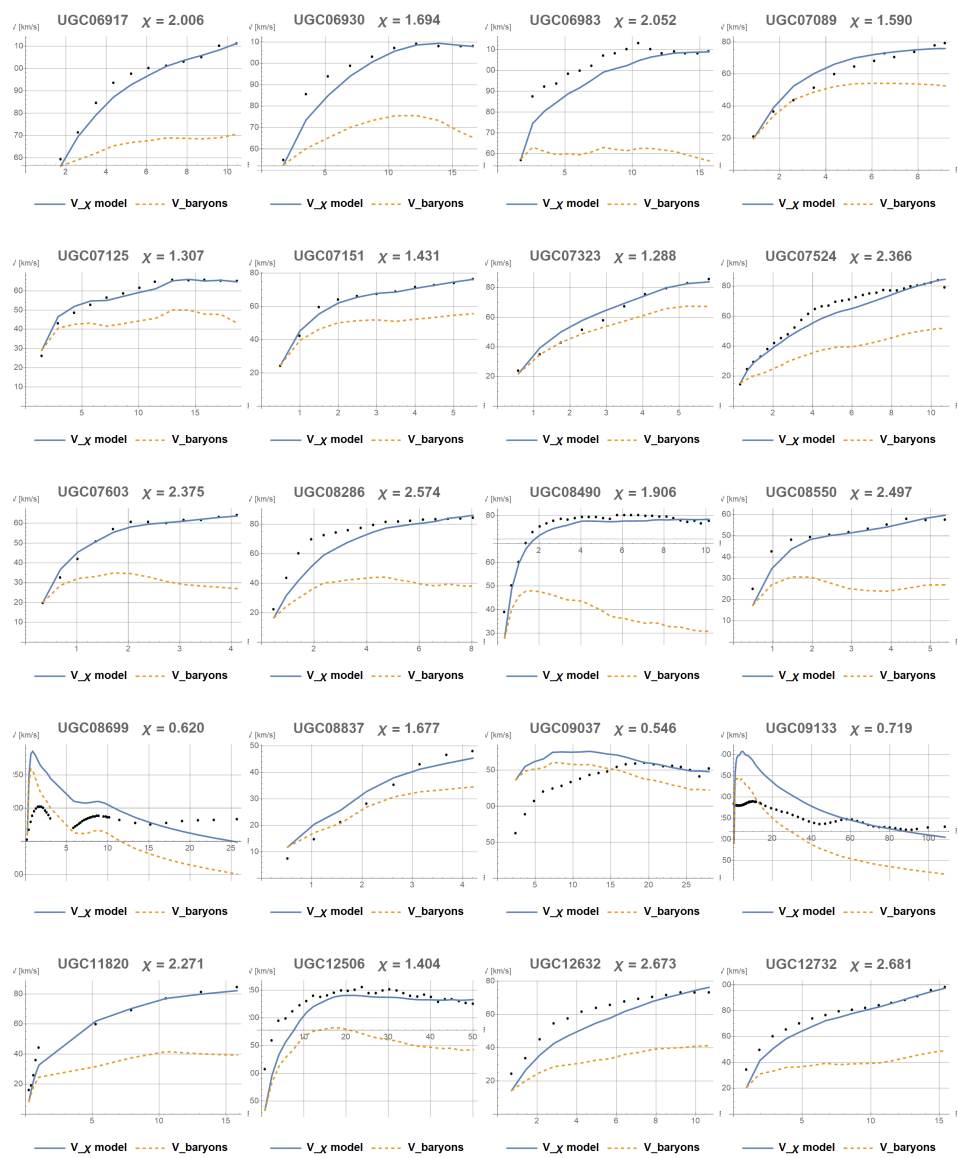


Figure A4. Rotation curves at constant χ for galaxies 4/4.

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