

Article

Not peer-reviewed version

GravitationalWaves from Alena Tensor

[Piotr Ogonowski](#) *

Posted Date: 5 February 2025

doi: 10.20944/preprints202502.0263.v1

Keywords: alena tensor; gravitational waves; general relativity; Electromagnetism



Preprints.org is a free multidisciplinary platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This open access article is published under a Creative Commons CC BY 4.0 license, which permit the free download, distribution, and reuse, provided that the author and preprint are cited in any reuse.

Article

Gravitational Waves from Alena Tensor

Piotr Ogonowski

Kozminski University, Jagiellonska 57/59, Warsaw, 03-301, Poland; piotrogonowski@kozminski.edu.pl

Abstract: Alena Tensor is a recently discovered class of energy-momentum tensors that provides a general equivalence of the curved path and the geodesic for the analyzed spacetimes which allows for a faithful reproduction of GR results in flat spacetime. In this paper it is shown that using this approach naturally leads to the existence of gravitational waves, which can be interpreted as vacuum pressure waves with tensor amplitude. The calculated trace of the metric tensor describing curved spacetime turned out to be invariant. A certain simplification of the analysis of gravitational waves has also been proposed, which may help both in their analysis and in the proof of the validity of the Alena Tensor. The article has been supplemented with the Alena Tensor equations with a positive value of the electromagnetic field tensor invariant (related to cosmological constant) which may help in further analysis of this approach.

Keywords: alena tensor; gravitational waves; general relativity; Electromagnetism

1. Introduction

Gravitational waves are a well-understood and researched issue [1], and it seems that the area of this research will develop dynamically both in theoretical understanding [2] and methods of their detection [3,4]. The existence of gravitational waves is the key argument for the correctness of the General Relativity, and for this reason it is also a good tool for verifying the correctness of alternative to GR theories [5–7] and the theories of quantum gravity [8].

Alena Tensor is at the beginning of its research journey. It is a recently discovered class of energy-momentum tensors that allows for equivalent description and analysis of physical systems in flat spacetime (with fields and forces) and in curved spacetime (using Einstein Field Equations) providing the overall equivalence of the curved path and the geodesic. In previous publications [9–11] it was already shown that this approach allows for a unified description of a physical system (curvilinear, classical and quantum) ensuring compliance with GR and QM results. In this paper it will be analyzed the possibility of describing gravitational waves using the Alena Tensor.

Many researchers try to reproduce the GR equations in flat spacetime or vice versa [12,13] or include electromagnetism in GR, connecting the spacetime geometry with electromagnetism [14–21]. There are known such approaches on the basis of differential geometry [22,22,23], based on field equations [24,25] as well as promising analyses of spinor fields [26] or helpful approximations for a weak field [27]. For this reason, the Alena Tensor should be viewed as another theory requiring theoretical and experimental verification, and therefore it seems necessary to analyze whether the Alena Tensor ensures the existence of gravitational waves and what their interpretation is.

In this method it is assumed that the metric tensor is not a feature of spacetime, but only a method of its mathematical description. The use of the Alena Tensor already allows for transformation of equations in such a way that they can be used in curvilinear (General Relativity), classical (fields and forces) and quantum (Quantum Mechanics and Quantum Field Theory) descriptions as well as in Cosmology, Continuum Mechanics and Thermodynamics. Due to this property, the Alena Tensor is a useful tool for studying unification problems, quantum gravity and many other applications in physics. In this short article, the research will be expanded to include analysis of gravitational waves.

Due to the fact that research on the Alena Tensor is a relatively young field, to facilitate the analysis of the article, the next section summarizes the results obtained so far and introduces the necessary notation.

2. Short Introduction to Alena Tensor

The following chapter briefly explains the conclusions from the previous publications on Alena Tensor. The author uses the metric signature $(+,-,-,-)$ which provides a positive value of the electromagnetic field tensor invariant. In previous publications it was treated as negative which resulted from the reversal of the order of terms in the energy-momentum tensor of the electromagnetic field. The following equations remove this inconvenience while maintaining the correctness of the obtained results.

2.1. Transforming a Curved Path into a Geodesic

To understand the Alena Tensor, it is easiest to recreate the reasoning that led to its creation [10] using the example of the electromagnetic field. One may consider the energy-momentum tensor in flat spacetime for a physical system with an electromagnetic field in the following form

$$T^{\alpha\beta} = \varrho U^\alpha U^\beta - \frac{1}{\mu_r} Y^{\alpha\beta} \quad (1)$$

where $T^{\alpha\beta}$ is energy-momentum tensor for a physical system, ϱ is density of matter, U^α is four-velocity, μ_r is relative permeability, $Y^{\alpha\beta}$ is energy-momentum tensor for the electromagnetic field.

The density of four-forces acting in a physical system can be considered as a four-divergence. One may therefore denote the four-force densities occurring in the system:

- $f^\beta \equiv \partial_\alpha \varrho U^\alpha U^\beta$ is the density of the total four-force acting on matter
- $\frac{1}{\mu_r} f_{em}^\beta + f_{gr}^\beta \equiv \partial_\alpha \frac{1}{\mu_r} Y^{\alpha\beta}$ are forces due to the field, where
- f_{em}^β is the density of the electromagnetic four-force
- $f_{gr}^\beta = Y^{\alpha\beta} \partial_\alpha \frac{1}{\mu_r}$ was shown in [9] as related to the gravitational force.

One may assume that the forces balance, which will provide a vanishing four-divergence of the energy-momentum tensor for the entire system

$$0 = \partial_\alpha T^{\alpha\beta} = f^\beta - \frac{1}{\mu_r} f_{em}^\beta - f_{gr}^\beta \quad (2)$$

It may be noticed, that if one wanted to use $T^{\alpha\beta}$ for a curvilinear description, which would describe the same physical system but curvilinearly, then in curved spacetime the forces due to the field can be replaced by Christoffel symbols of the second kind. The vanishing four-divergence in the curvilinear system makes forces due to the field unnecessary in the equation. This means, that the entire field term can simply disappear from the equation, because instead of a field and the forces associated with it, there will be curvature. This would mean, that in curved spacetime $\frac{1}{\mu_r} Y^{\alpha\beta} = 0 \rightarrow T^{\alpha\beta} = \varrho U^\alpha U^\beta$. As shown in [10], a minor amendment to continuum mechanics provides this property.

One may thus generalize $Y^{\alpha\beta}$ making the following substitution

$$Y^{\alpha\beta} \equiv \Lambda_\rho \left(\frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} - g^{\alpha\beta} \right) = \frac{1}{\mu_o} F^{\alpha\delta} g_{\delta\gamma} F^{\beta\gamma} - \Lambda_\rho g^{\alpha\beta} \quad (3)$$

where $F^{\alpha\delta}$ is electromagnetic field strength tensor, μ_o is vacuum magnetic permeability, $g^{\alpha\beta}$ is metric tensor with the help of which the spacetime is considered, and

- $\Lambda_\rho = \frac{1}{4\mu_o} F^{\alpha\mu} g_{\mu\gamma} F^{\beta\gamma} g_{\alpha\beta}$ is invariant of the electromagnetic field tensor,
- $\mathbb{K} = g_{\mu\nu} \mathbb{K}^{\mu\nu}$ is trace of $\mathbb{K}^{\alpha\beta}$,

- $\mathbb{K}^{\alpha\beta} \equiv 2 \frac{F^{\alpha\delta} g_{\delta\gamma} F^{\beta\gamma}}{\sqrt{F^{\alpha\delta} g_{\delta\gamma} F^{\beta\gamma} g_{\mu\beta} F_{\alpha\eta} g^{\eta\zeta} F^\mu_\zeta}}$ is a metric tensor of a spacetime for which $Y^{\alpha\beta}$ vanishes.

Tensor $\mathbb{K}^{\alpha\beta}$ may be calculated in flat spacetime as $\mathbb{K}^{\alpha\beta} = 2 \frac{F^{\alpha\gamma} F^\beta_\gamma}{\sqrt{F^{\alpha\gamma} F^\mu_\gamma F_{\alpha\nu} F^\nu_\mu}}$ based on the argument from [10]: assuming that there is a curved spacetime with the metric tensor $\mathbb{K}^{\alpha\beta}$, the value of this metric tensor is independent of the $g^{\alpha\beta}$ adopted for analysis. For this reason, the value of $\mathbb{K}^{\alpha\beta}$ can be calculated in flat spacetime and does not change, irrespective of the $g^{\alpha\beta}$ adopted.

In this way one obtains a generalized description of the tensor $Y^{\alpha\beta}$, which has the following properties:

- in flat spacetime $Y^{\alpha\beta}$ is the usual, classical energy-momentum tensor of the electromagnetic field
- its trace vanishes in any spacetime, regardless of the considered metric tensor $g^{\alpha\beta}$
- in spacetime for which $g^{\alpha\beta} = \mathbb{K}^{\alpha\beta}$ the entire tensor $Y^{\alpha\beta}$ vanishes
- $\mathbb{K}^{\alpha\beta} \mathbb{K}_{\alpha\beta} = 4$ which is expected property of the metric tensor (it was already shown in [10] that $\mathbb{K}^{\alpha\beta}$ indeed is a metric tensor)

In the above manner one obtains the Alena Tensor $T^{\alpha\beta}$ in form of

$$T^{\alpha\beta} = \varrho U^\alpha U^\beta - \frac{1}{\mu_r} \Lambda_\rho \left(\frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} - g^{\alpha\beta} \right) \quad (4)$$

with the yet unknown $\frac{1}{\mu_r}$ for which in curved spacetime ($g^{\alpha\beta} = \mathbb{K}^{\alpha\beta}$) the energy-momentum tensor of the field $Y^{\alpha\beta}$ vanishes.

The reasoning carried out above for electromagnetism is universal and allows to consider the Alena Tensor also for energy-momentum tensors associated with other fields. This leads to obtaining an energy-momentum tensor $T^{\alpha\beta}$ for the system that can be considered both in flat spacetime and in curved spacetime.

2.2. Connection with Continuum Mechanics, GR and QFT/QM

To make the Alena Tensor consistent with Continuum Mechanics in flat spacetime, it is enough to adopt the substitution $\frac{1}{\mu_r} \equiv \frac{-p}{\Lambda_\rho}$ where p is the negative pressure in the system and is equal to $p \equiv \varrho c^2 - \Lambda_\rho$ where c is the speed of light in a vacuum. Such substitution yields

$$\varrho U^\alpha U^\beta - T^{\alpha\beta} = p \eta^{\alpha\beta} - c^2 \varrho \frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} + \Lambda_\rho \frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} \quad (5)$$

where $\eta^{\alpha\beta}$ is the metric tensor of flat Minkowski spacetime. One may now introduce an additional tensor $\Pi^{\alpha\beta} \equiv -c^2 \varrho \frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta}$ which will play the role of deviatoric stress tensor. The vanishing four-divergence of $T^{\alpha\beta}$ leads to the relativistic equivalence of Cauchy momentum equation (convective form) in which only f_{em} appears as a body force

$$f^\alpha = \partial^\alpha p + \partial_\beta \Pi^{\alpha\beta} + f_{em}^\alpha \quad (6)$$

The above substitution also provides a connection to General Relativity in curved spacetime. For this purpose, one may introduce the following tensors, which can be analyzed in both flat and curved spacetime

$$R^{\alpha\beta} \equiv 2\varrho U^\alpha U^\beta - p g^{\alpha\beta} \quad ; \quad R \equiv R^{\alpha\beta} g_{\alpha\beta} = 2\Lambda_\rho - 2p \quad ; \quad G^{\alpha\beta} \equiv R^{\alpha\beta} - \frac{1}{2} R \frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} \quad (7)$$

Above allows to rewrite Alena Tensor as

$$G^{\alpha\beta} + \Lambda_\rho g^{\alpha\beta} = 2 T^{\alpha\beta} + \varrho c^2 \left(g^{\alpha\beta} - \frac{4}{\mathbb{K}} \mathbb{K}^{\alpha\beta} \right) \quad (8)$$

Analyzing the above equation in curved spacetime ($g^{\alpha\beta} = \mathbb{K}^{\alpha\beta}$), one obtains its simplification to the form

$$G^{\alpha\beta} + \Lambda_\rho g^{\alpha\beta} = 2 T^{\alpha\beta} \quad (9)$$

which can be interpreted as the main equation of General Relativity up to the constant $\frac{4\pi G}{c^4}$. Since in curved spacetime one gets

$$G^{\alpha\beta} = R^{\alpha\beta} - \frac{1}{2} R g^{\alpha\beta} \quad (10)$$

therefore $G^{\alpha\beta}$ and $R^{\alpha\beta}$ can be interpreted in curved spacetime, respectively, as Einstein curvature tensor and Ricci tensor both with an accuracy of $\frac{4\pi G}{c^4}$ constant.

Analyzing the $G^{\alpha\beta}$ tensor in flat spacetime ($g^{\alpha\beta} = \eta^{\alpha\beta}$) one can also see that it is related to the non-body forces seen in the description of the Cauchy momentum equation

$$\partial_\beta G^{\alpha\beta} = \partial^\alpha p + \partial_\beta \Pi^{\alpha\beta} \quad (11)$$

This means that in the Alena Tensor analysis method, gravity is not a body force. In flat spacetime, based on the conclusions from [9], the four-force densities associated with the tensor $G^{\alpha\beta}$ can be also represented as

$$\partial_\beta G^{\alpha\beta} = f_{gr}^\alpha + f_{rr}^\alpha \quad (12)$$

where

- $f_{rr}^\alpha = \left(\frac{1}{\mu_r} - 1\right) f_{em}^\alpha$ is the density of the radiation reaction four-force
- $f_{gr}^\alpha = q \left(\frac{d\phi}{d\tau} U^\alpha - c^2 \partial^\alpha \phi \right)$ is density of the four-force related to gravity, where
- $\phi = -\ln(\mu_r)$ is related to the effective potential in the system with gravity.

It can be calculated that f_{gr}^α vanishes in two cases:

- $-\vec{u} = c \frac{\nabla \phi}{\partial^0 \phi}$ - which turns out to be the case of free fall
- $\partial^\alpha \phi = 0$ which occurs in the case of circular orbits

Neglecting the electromagnetic force and the radiation reaction force, using the above equation one can reproduce the motion of bodies in the effective potential obtained from the solutions of General Relativity. Such a description has already been done for the Schwarzschild metric [9] for

$$\phi + c_0 \equiv \sqrt{\frac{E^2}{m^2 c^4} - \left(\frac{1}{c} r\right)^2} = \sqrt{\left(1 - \frac{r_s}{r}\right) \left(1 + \frac{L^2}{r^2}\right)} \quad (13)$$

where c_0 is a certain constant. The solutions obtained in this way enforce the existence of gravitational waves due to time-varying ϕ (except for free fall and circular orbits).

In the above description, gravity itself is not a force, because the above description is based on an effective potential. However, one can see a similarity to Newton's classical equations for the case of a stationary observer, for which f_{gr}^α can be approximated by Newton's gravitational force with the opposite sign what represents a force that must exist for a stationary observer suspended above the source of gravity to stay in one place.

The description of gravity obtained in this way is surprisingly consistent with current knowledge, despite the fact that gravity itself in this description is not a force, and the force f_{gr}^α is not a body force.

The Alena Tensor constructed in presented way may be simplified in flat spacetime to

$$T^{\alpha\beta} = \Lambda_\rho \eta^{\alpha\beta} - \frac{1}{\mu_0} F^{\alpha\gamma} \partial^\beta A_\gamma \quad ; \quad T^{00} = \mathcal{L} = -\Lambda_\rho = -\frac{1}{4\mu_0} F^{\alpha\beta} F_{\alpha\beta} \quad (14)$$

which allows its analysis in classical field theory and quantum theories.

The quantum picture obtained from the Alena Tensor [9,11] for the system with electromagnetic field leads to the conclusion that gravity and the radiation reaction force have always been present in Quantum Mechanics and Quantum Field Theory. This conclusion follows from the fact that the quantum equations obtained from the Alena Tensor in [9] are the three main quantum equations currently used:

- simplified Dirac equation for QED: $\mathcal{L}_{QED} = \frac{1}{4\mu_0} F^{\alpha\beta} F_{\alpha\beta} = \frac{1}{2\mu_0} F^{0\gamma} \partial^0 A_\gamma = \frac{1}{2} \bar{\psi} (i\hbar c \not{D} - mc^2) \psi$
- Klein-Gordon equation - fully consistent,
- relativistic equivalent of the Schrödinger equation: $i\hbar \partial^0 \psi = -\frac{\hbar^2}{m(\gamma + \frac{1}{\gamma})} \nabla^2 \psi + cq \hat{A}^0 \psi$

where A^α and \hat{A}^α are two gauges of electromagnetic four-potential, and where the last equation in the limit of small energies and particle speeds $u < 0.4c$ (Lorentz factor $\gamma \approx 1$) turns into the classical Schrödinger equation considered for charged particles.

3. Results

One may consider a flat spacetime with an electromagnetic field, described in a way provided by Alena Tensor using notation introduced in section 2. Completing the definition of the first invariant of the electromagnetic field tensor Λ_ρ , one may define the second invariant I_\perp by electric \vec{E} and magnetic \vec{B} fields as

$$I_\perp \equiv \frac{1}{c\mu_0} \vec{E} \vec{B} \quad (15)$$

It can then be seen, after some transformations, that

$$F^{\alpha\gamma} F^\mu_\gamma F_{\alpha\nu} F^\nu_\mu = 4\mu_0^2 (2\Lambda_\rho^2 + I_\perp^2) \quad (16)$$

Therefore the metric tensor for curved spacetime $\mathbb{K}^{\alpha\beta}$ and its trace \mathbb{K} (mentioned in introduction) calculated in flat spacetime are

$$\mathbb{K}^{\alpha\beta} = \frac{\frac{1}{\mu_0} F^{\alpha\gamma} F^\beta_\gamma}{\sqrt{2\Lambda_\rho^2 + I_\perp^2}} \quad ; \quad \frac{4}{\mathbb{K}} = \sqrt{2 + \frac{I_\perp^2}{\Lambda_\rho^2}} \quad (17)$$

The above simplifies further for $I_\perp \rightarrow 0$, but the key conclusion is that the trace \mathbb{K} is invariant.

Based on the above, one may reverse the reasoning and consider the electromagnetic field as a manifestation of a propagating perturbation of the curvature of spacetime, which in flat spacetime is interpreted as a field. For this purpose, one may define a certain perturbation $h^{\alpha\beta}$ of the metric tensor $\mathbb{K}^{\alpha\beta}$ that describes the deviation from flat spacetime, and also define its trace h as

$$h^{\alpha\beta} \equiv \mathbb{K}^{\alpha\beta} - \eta^{\alpha\beta} \quad ; \quad h = h^{\alpha\beta} \eta_{\alpha\beta} = \mathbb{K} - 4 \quad (18)$$

The stress-energy tensor of the electromagnetic field in flat spacetime can be thus represented as follows

$$\frac{\mathbb{K}}{4\Lambda_\rho} Y^{\alpha\beta} = h^{\alpha\beta} - \frac{h}{4} \eta^{\alpha\beta} \quad (19)$$

As one can see in the above, considering gravitational waves in the Alena Tensor is natural and does not require classical linearization. Traces h and \mathbb{K} are invariants, thus $0 = \square h = \square \mathbb{K}$ and condition $0 = \square \mathbb{K}^{\alpha\beta} = \square h^{\alpha\beta}$ can be reduced to Maxwell's equations in vacuum, which means that in vacuum these waves propagate at the speed of light.

Denoting the pressure amplitude \mathcal{P}_o and $\bar{h}^{\alpha\beta}$ one obtains

$$\mathcal{P}_o \equiv \frac{4\Lambda_\rho}{\mathbb{K}} \quad ; \quad \bar{h}^{\alpha\beta} \equiv h^{\alpha\beta} - \frac{h}{4} \eta^{\alpha\beta} \quad \rightarrow \quad Y^{\alpha\beta} = \mathcal{P}_o \bar{h}^{\alpha\beta} \quad (20)$$

which shows that the energy-momentum tensor of the field actually describes the propagating vacuum pressure waves with tensor amplitude. This means that the Alena Tensor provides the propagation of gravitational waves, proposing their physical interpretation.

One may now invoke the scalar field ϕ associated with the presence of matter and the gravitational interaction, where $e^\phi = \frac{1}{\mu_r}$. It is known from [9] that e^ϕ is responsible for the presence of sources and in their absence $\mu_r = 1$. Therefore, interpreting whole $Y^{\alpha\beta}$ as the wave amplitude tensor one would get the following representation:

$$\frac{1}{\mu_r} Y^{\alpha\beta} = \mathcal{P}_o \bar{h}^{\alpha\beta} e^\phi = \varrho U^\alpha U^\beta - T^{\alpha\beta} \quad (21)$$

which allows to search for e^ϕ as a certain wave function.

This approach allows for two simplifications related to the analysis of gravitational waves. Considering the force f_{gr}^α reproducing motion related to gravity and extracting the gravitational acceleration \mathcal{A}^α from it, one gets

$$\varrho \mathcal{A}^\alpha \equiv f_{gr}^\alpha = \varrho \left(\frac{d\phi}{d\tau} U^\alpha - c^2 \partial^\alpha \phi \right) \rightarrow c^2 \square \phi = \gamma^2 \frac{d^2 \phi}{dt^2} - \partial_\alpha \mathcal{A}^\alpha \quad (22)$$

since according amendment from [10] $\partial_\alpha \gamma U^\alpha = 0$. Since, as shown in [9], ϕ is directly related to the effective potential in gravitational systems (which can be calculated from the GR equations), this would allow searching for propagating perturbations of the effective potential itself ($\square \phi = 0$) similarly as was postulated in [28]. It would significantly simplify both the calculations and perhaps the methods of detecting gravitational waves.

The second simplification results from the possibility of analyzing only the Poynting four-vector $Y^{\alpha 0}$ as follows

$$\frac{1}{\mu_r} Y^{\alpha 0} = \mathcal{P}_o \bar{h}^{\alpha 0} e^\phi = \varrho c \gamma U^\alpha - T^{\alpha 0} \quad (23)$$

where it was already shown in [11] that $-T^{\alpha 0}$ represents density of the canonical four-momentum for the system.

4. Conclusion and Discussion

As shown in the above article, the Alena Tensor ensures the existence of gravitational waves and allows their physical interpretation. The obtained equations (21), (22), (23) lead to the possibility of detecting gravitational waves described in this way, which can help both in their current analysis and in the proof of the validity of the Alena Tensor.

It remains an open question whether the Alena Tensor is a correct way to describe physical systems, but this paper shows that it exhibits many properties that are expected from such a description, including the existence of gravitational waves.

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. Author did not receive support from any organization for the submitted work. Author have no relevant financial or non-financial interests to disclose.

References

1. Bailes, M.; Berger, B.K.; Brady, P.; Branchesi, M.; Danzmann, K.; Evans, M.; Holley-Bockelmann, K.; Iyer, B.; Kajita, T.; Katsanevas, S.; et al. Gravitational-wave physics and astronomy in the 2020s and 2030s. *Nature Reviews Physics* **2021**, *3*, 344–366.
2. Schutz, B.F. Gravitational wave astronomy. *Classical and Quantum Gravity* **1999**, *16*, A131.

3. Grant, A.M.; Nichols, D.A. Outlook for detecting the gravitational-wave displacement and spin memory effects with current and future gravitational-wave detectors. *Physical Review D* **2023**, *107*, 064056.
4. Borhanian, S.; Sathyaprakash, B. Listening to the universe with next generation ground-based gravitational-wave detectors. *Physical Review D* **2024**, *110*, 083040.
5. Milgrom, M. Gravitational waves in bimetric MOND. *Physical Review D* **2014**, *89*, 024027.
6. Tahura, S.; Nichols, D.A.; Yagi, K. Gravitational-wave memory effects in Brans-Dicke theory: Waveforms and effects in the post-Newtonian approximation. *Physical Review D* **2021**, *104*, 104010.
7. Matos, I.S.; Calvão, M.O.; Waga, I. Gravitational wave propagation in $f(R)$ models: New parametrizations and observational constraints. *Physical Review D* **2021**, *103*, 104059.
8. Shapiro, I.L.; Pelinson, A.M.; de O. Salles, F. Gravitational waves and perspectives for quantum gravity. *Modern Physics Letters A* **2014**, *29*, 1430034.
9. Ogonowski, P.; Skindzier, P. Alena Tensor in unification applications. *Physica Scripta* **2024**, *100*, 015018.
10. Ogonowski, P. Proposed method of combining continuum mechanics with Einstein Field Equations. *International Journal of Modern Physics D* **2023**, *2350010*, 15.
11. Ogonowski, P. Developed method: interactions and their quantum picture. *Frontiers in Physics* **2023**, *11*:1264925. <https://doi.org/10.3389/fphy.2023.1264925>.
12. Logunov, A.; Mestvirishvili, M. Hilbert's causality principle and equations of general relativity exclude the possibility of black hole formation. *Theoretical and Mathematical Physics* **2012**, *170*, 413.
13. Friedman, Y. Superposition principle in relativistic gravity. *Physica Scripta* **2024**, *99*, 105045. <https://doi.org/10.1088/1402-4896/ad7a31>.
14. Poplawski, N.J. Geometrical formulation of classical electromagnetism. *arXiv preprint arXiv:0802.4453* **2008**.
15. Chang, Y.F. Unification of gravitational and electromagnetic fields in Riemannian geometry. *arXiv preprint arXiv:0901.0201* **2009**.
16. Chernitskii, A.A. On unification of gravitation and electromagnetism in the framework of a general-relativistic approach. *arXiv preprint arXiv:0907.2114* **2009**.
17. Kholmetskii, A.; Mishevitch, O.; Yarman, T. Generalized electromagnetic energy-momentum tensor and scalar curvature of space at the location of charged particle. *arXiv preprint arXiv:1111.2500* **2011**.
18. Novello, M.; Falciano, F.; Goulart, E. Electromagnetic Geometry. *arXiv preprint arXiv:1111.2631* **2011**.
19. de Araujo Duarte, C. The classical geometrization of the electromagnetism. *International Journal of Geometric Methods in Modern Physics* **2015**, *12*, 1560022.
20. Hojman, S.A. Geometrical unification of gravitation and electromagnetism. *The European Physical Journal Plus* **2019**, *134*, 526.
21. Woodside, R. Space-time curvature of classical electromagnetism. *arXiv preprint gr-qc/0410043* **2004**.
22. Bray, H.; Hamm, B.; Hirsch, S.; Wheeler, J.; Zhang, Y. Flatly foliated relativity. *arXiv preprint arXiv:1911.00967* **2019**.
23. Jafari, N. Evolution of the concept of the curvature in the momentum space. *arXiv preprint arXiv:2404.08553* **2024**.
24. Kaur, L.; Wazwaz, A.M. Similarity solutions of field equations with an electromagnetic stress tensor as source. *Rom. Rep. Phys* **2018**, *70*, 1–12.
25. MacKay, R.; Rourke, C. Natural observer fields and redshift. *J Cosmology* **2011**, *15*, 6079–6099.
26. Ahmadi, N.; Nouri-Zonoz, M. Massive spinor fields in flat spacetimes with nontrivial topology. *Physical Review D—Particles, Fields, Gravitation, and Cosmology* **2005**, *71*, 104012.
27. Waluk, P.; Jezierski, J. Gauge-invariant description of weak gravitational field on a spherically symmetric background with cosmological constant. *Classical and Quantum Gravity* **2019**, *36*, 215006.
28. Domènech, G. Scalar induced gravitational waves review. *Universe* **2021**, *7*, 398.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.