International Journal of Theoretical Physics (2026) 65:77
https://doi.org/10.1007/s10773-026-06292-7

RESEARCH

# Torsion-Induced Modification to Friedmann Equations in $AdSL_4$ Gauged Gravity

**Oktay Cebecioğlu[1] · Salih Kibaroğlu[2]**

Received: 2 December 2025 / Accepted: 17 February 2026
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2026

**Abstract**
We study the solution of the gravitational field equations in $AdSL_4$–gauged gravity, a gauge-theoretic extension of general relativity based on the $AdSL_4$ algebra. In this formulation, the antisymmetric gauge field $B^{ab}$, associated with additional $AdSL_4$ tensorial generators, induces space-time torsion via the relation $K^{ab} = \mu B^{ab}$, where $K^{ab}$ denotes the contorsion 1-form. The presence of torsion modifies both the spin connection and curvature, leading to an extended set of Einstein–Cartan field equations. Focusing on spatially homogeneous and isotropic cosmological backgrounds, we derive the modified Friedmann equations which explicitly incorporate the torsional contribution. The resulting acceleration equation admits de Sitter–like solutions in which cosmic acceleration originates purely from the gauge–theoretic structure of enlarged four-dimensional space-time symmetries. Within this formulation, the dynamical components of the gauge field $B^{ab}$ emerge naturally as a source of the effective cosmological constants, without the introduction of exotic matter sources. Furthermore, our analysis shows that the torsion-driven cosmological phase in $AdSL_4$–gauged gravity can reproduce an effective equation-of-state parameter $\omega_B = -1/3$, establishing a connection between space-time torsion and cosmic-string–like dynamics.

**Keywords** Cosmology · Extended lie algebras · Generalized theory of gravity · Torsion

## 1 Introduction

Modern cosmology increasingly relies on gravitational theories that extend general relativity (GR) to address phenomena such as early-universe inflation, late-time cosmic acceleration, and possible deviations from Einstein's theory at high energies. Such extended theories of gravity, including higher-curvature models, scalar–tensor theories, and gauge-algebra-based formulations, aim to capture geometric or dynamical features of space-time that lie beyond the purely Riemannian structure of GR [1–7].

✉ Oktay Cebecioğlu
ocebecioglu@kocaeli.edu.tr

Salih Kibaroğlu
salihkibaroglu@maltepe.edu.tr

[1] Faculty of Arts and Sciences, Department of Physics, Kocaeli University, 41001 Kocaeli, Türkiye

[2] Maltepe University, Faculty of Engineering and Natural Sciences, 34857 Istanbul, Türkiye

Published online: 02 March 2026

Among these approaches, gauge-theoretic formulations of gravity provide a natural framework in which space-time geometry emerges from symmetry principles [8–10]. A particularly interesting case is Maxwell–gauged gravity [11], based on the Maxwell algebra [12–14], which augments the Poincaré symmetry with additional tensorial generators. In their pioneering work [11], the authors developed a local four-dimensional gauge theory based on the Maxwell algebra, applying it to generalize Einstein's gravity through bilinear invariant curvature two-forms. While their action is invariant under local Lorentz transformations, it does not preserve full local Maxwell invariance; a fully Maxwell-symmetric formulation was later proposed by [15] using $AdSL_4$-valued gauge connections. By employing the İnönü–Wigner contraction [15, 16], these constructions establish Maxwell gravity as a contraction limit of $AdSL_4$-gravity.

Previous studies have investigated the geometric and dynamical consequences of this framework [15–31] as well as its cosmological solutions [32–35]. However, most of these works have either neglected or only partially addressed the role of torsion, a manifestation of the antisymmetric part of spacetime's affine connection, which can have significant effects on gravitational dynamics, particularly in high-curvature regimes relevant to the early universe.

In the development of cosmological models within the framework of gauge theories of gravity, a central challenge lies in the consistent incorporation of gauge fields. Various studies have explored gauge field configurations in the Friedmann–Lemaître–Robertson–Walker (FLRW) cosmology [36–43]. A particular line of research concerns non-Abelian Yang–Mills (YM) theories, where the nonminimal coupling between YM fields and scalar curvature has been investigated to assess its implications for cosmological dynamics [42, 44–46] (see also [47] for a comprehensive review). Beyond its role in inflationary scenarios, YM theory has been extensively applied in the context of dark energy [40, 41, 48–53] and dark matter models [54–56].

In this work, we conduct an investigation of $AdSL_4$–gauged gravity within the framework of FLRW metric. By explicitly incorporating the torsional degrees of freedom induced by the additional tensorial gauge contributions, we examine how these contributions modify the effective gravitational field equations, influence the evolution of the scale factor, and potentially offer novel mechanisms for realizing cosmological solutions.

The paper is organized as follows. In Section 2, we review the gauge theory construction based on the semi-simple extension of the Poincaré group, commonly referred to as $AdSL_4$–gauged gravity. We then introduce the gravitational action functional incorporating the extended gauge fields. This is followed by a comprehensive geometric analysis of torsion, highlighting its connection to the $AdSL_4$ gauge field and its influence on the spin connection and curvature. Section 3 develops the cosmological setup by specializing the field equations to homogeneous and isotropic space-times and explores corresponding Friedmann equations. Finally, Section 4 summarizes our main results and discusses potential directions for future work.

## 2 Gauge Theory of the $AdSL_4$ Group

We begin by providing an overview of the semi-simple extension of the Poincaré group, originally introduced by [20]. The algebra associated with this extension was independently re-derived by [17] through a deformation of the Maxwell algebra. In contemporary literature, this structure is often referred to as the $AdS$–Lorentz algebra [19]. More specifically, the $AdSL_4$ algebra can be systematically constructed from the $AdS$ algebra via the $S$-expansion

procedure, as developed by [57] and further elaborated by [58]. The fundamental commutation relations defining this algebra are given by

$$\begin{aligned}
[M_{ab}, M_{cd}] &= i\left(\eta_{ad}M_{bc} + \eta_{bc}M_{ad} - \eta_{ac}M_{bd} - \eta_{bd}M_{ac}\right), \\
[M_{ab}, Z_{cd}] &= i\left(\eta_{ad}Z_{bc} + \eta_{bc}Z_{ad} - \eta_{ac}Z_{bd} - \eta_{bd}Z_{ac}\right), \\
[Z_{ab}, Z_{cd}] &= i\mu\left(\eta_{ad}M_{bc} + \eta_{bc}M_{ad} - \eta_{ac}M_{bd} - \eta_{bd}M_{ac}\right), \\
[P_a, P_b] &= i\lambda Z_{ab}, \\
[M_{ab}, P_c] &= i\left(\eta_{bc}P_a - \eta_{ac}P_b\right), \\
[Z_{ab}, P_c] &= i\mu\left(\eta_{bc}P_a - \eta_{ac}P_b\right).
\end{aligned} \tag{1}$$

In this framework, the generators are defined as $X_A = \{P_a, M_{ab}, Z_{ab}\}$, where $P_a$ correspond to translations, $M_{ab}$ to Lorentz transformations, and $Z_{ab}$ to the $AdSL_4$ symmetry. For dimensional consistency, the constant $\lambda$ is related to the cosmological constant $\Lambda$ which will be discussed later. The tangent space metric is taken to be $\eta_{ab} = \text{diag}\,(+,-,-,-)$. In contrast to the conventional Maxwell algebra, the generators $Z_{ab}$ in this semi-simple extension are tensorial but non-Abelian and closed into an angular momentum generator as given in (1). A notable property of the semi-simple Poincaré algebra is that the Maxwell algebra can be recovered from it via the İnönü-Wigner–Wigner contraction procedure.

Following the approach of [11], we formulate the theory in terms of differential forms. To construct an action based on the semi-simple Poincaré algebra, we begin with the gauge connection expressed as the 1-form $A(x) = A^A X_A$,

$$A(x) = e^a P_a - \frac{1}{2}\omega^{ab}M_{ab} + \frac{1}{2}B^{ab}Z_{ab}, \tag{2}$$

where the 16 gauge fields $A^A(x) = \left\{e^a, \omega^{ab}, B^{ab}\right\}$ correspond to the generators $AdSL_4$ symmetry transformations, respectively. The associated curvature 2-form is defined by

$$F(x) = dA + \tfrac{i}{2}[A, A] = F^a P_a - \frac{1}{2}R^{ab}M_{ab} + \frac{1}{2}F^{ab}Z_{ab}, \tag{3}$$

where $F^a$, $R^{ab}$ and $F^{ab}$ denote the generalized torsion, the Lorentz curvature 2-form, and the additional $AdSL_4$ curvature 2-form. These are explicitly given by

$$\begin{aligned}
F^a &= de^a + \omega^a_{\ c} \wedge e^c - \mu B^a_{\ c} \wedge e^c \\
&= T^a - \mu B^a_{\ c} \wedge e^c \\
&= \widetilde{D}e^a,
\end{aligned} \tag{4}$$

$$R^{ab} = d\omega^{ab} + \omega^a_{\ c} \wedge \omega^{cb}, \tag{5}$$

$$\begin{aligned}
F^{ab} &= dB^{ab} + \omega^{[a}_{\ c} \wedge B^{c|b]} - \mu B^a_{\ c} \wedge B^{cb} - \lambda e^a \wedge e^b \\
&= DB^{ab} - \mu B^a_{\ c} \wedge B^{cb} - \lambda e^a \wedge e^b \\
&= \widetilde{D}B^{ab} - \lambda e^a \wedge e^b,
\end{aligned} \tag{6}$$

where $T^a = De^a$ represents the ordinary torsion term, $D = d + \omega$ denotes the Lorentz exterior covariant derivative, while $\widetilde{D} = d + \widetilde{\omega}$ is defined with respect to the shifted connection

$$\widetilde{\omega}^{ab} = \omega^{ab} - \mu B^{ab}. \tag{7}$$

The shifted connection thus provides a natural extension of the Riemannian spin connection $\omega^{ab}$ to a non-Riemannian geometry with torsion. In this sense, the resulting framework

may be viewed as an Einstein–Cartan-type [10, 59] geometry determined by the algebraic structure of the $AdSL_4$ algebra. Importantly, since the gauge field $B^{ab}$ is antisymmetric ($B^{ab} = -B^{ba}$), the symmetric part of the connection is absent. Consequently, the non-metricity tensor vanishes, and the resulting geometry is torsional but metric-compatible [11].

Within this framework, we introduce the shifted curvature as follows;

$$J^{ab} = R^{ab}(\omega) - \mu F^{ab} \equiv \widetilde{R}^{ab}(\widetilde{\omega}) + \mu\lambda e^a \wedge e^b, \tag{8}$$

where $\widetilde{R}^{ab}(\widetilde{\omega}) = \widetilde{D}\widetilde{\omega}^{ab}$ denotes the Lorentz curvature 2-form constructed from the shifted connection (7). This modification is not merely technical; it plays a central role in constructing an action that remains strictly invariant under the subalgebra $\{M, Z\}$. By encoding the contributions of the additional algebraic structure into the curvature sector, the shifted curvature allows for a systematic derivation of the gravitational dynamics associated with the algebra (1), while the remaining generators define the gauge structure through on-shell diffeomorphisms.

### 2.1 Gravitational Action

In close analogy with the Einstein–Hilbert action, we consider the pure gravitational action constructed from the shifted curvature [30]:

$$S_{EHJ} = \frac{1}{2\kappa}\int \mathcal{L}_{EHJ} \tag{9}$$

where, upon promoting $R^{ab} \to J^{ab}$, the Lagrangian 4-form becomes

$$\mathcal{L}_{EHJ} = \frac{1}{2}\varepsilon_{abcd} J^{ab} \wedge e^c \wedge e^d = J^{ab} \wedge {}^*e_{ab} = J^*1. \tag{10}$$

To simplify the notation, we introduce the basis $p$-forms defined by the wedge product of vielbeins as $e_{a_1\ldots a_p} = e_{a_1} \wedge \ldots \wedge e_{a_p}$. Under this convention, the exterior products of basis 1-forms in 4D are expressed as $e_a$, $e_{ab} = e_a \wedge e_b$ and $e_{abc} = e_a \wedge e_b \wedge e_c$, etc. The Hodge star duals of these forms are defined as: ${}^*e_{a_1\ldots a_p} = \frac{1}{(4-p)}\varepsilon_{a_1\ldots a_4} e^{a_{(p+1)}\ldots a_4}$ and where ${}^*1 = \frac{1}{4!}\varepsilon_{abcd}e^{abcd}$ denotes the invariant volume element. This Lagrangian naturally includes the Einstein–Hilbert term and the $AdSL_4$ contribution, formulated within the framework of the shifted connection (8), together with a cosmological constant term.

To derive the field equations, one may proceed in two ways. The first is to vary the Lagrangian independently with respect to the vierbein $e^a$ and the connection 1-forms $\tilde{\omega}^{ab}$ (Palatini's method), subsequently solving for the extended torsion. The second approach is to impose the vanishing of extended torsion from the outset and consider constrained variations. For Einstein–Hilbert-type Lagrangians (linear in curvature) in the absence of matter, both methods yield the same field equations, namely the source-free Einstein equations with a cosmological term [60]. In this work, we adopt the first-order Palatini formalism, treating the dynamical variables as $(e^a, \tilde{\omega}^{ab})$ as independent.

The variation of the action reads,

$$\begin{aligned}
\delta\mathcal{L}_{EHJ} &= \delta J^{ab} \wedge {}^*e_{ab} + J^{ab} \wedge \delta {}^*e_{ab} \\
&= \left(\widetilde{D}\delta\widetilde{\omega}^{ab} + \mu\lambda\delta e^{[a} \wedge e^{|b]}\right) \wedge {}^*e_{ab} + J^{ab} \wedge \delta e^c \wedge {}^*e_{abc} \\
&= \widetilde{D}\delta\widetilde{\omega}^{ab} \wedge {}^*e_{ab} + \delta e^c \wedge \left[J^{ab} \wedge {}^*e_{abc} + 6\mu\lambda {}^*e_c\right],
\end{aligned} \tag{11}$$

where resulting expression leads to two sets of field equations. One can write the (11) up to a total exterior derivative term and set the variation to zero:

$$\delta\mathcal{L}_{EHJ} = \delta\widetilde{\omega}^{ab} \wedge F^{c} \wedge {}^{*}e_{abc} + \delta e^{c} \wedge \left[ J^{ab} \wedge {}^{*}e_{abc} + 6\mu\lambda {}^{*}e_{c} \right] = 0, \tag{12}$$

the first arises from variations with respect to the shifted connection and gives the torsion equation:

$$F^{c} = 0 \Rightarrow T^{c} = \mu B^{c}_{\ d} \wedge e^{d}. \tag{13}$$

This relation highlights that torsion emerges naturally from the gauge fields $B^{ab}$. While the original connection $\omega^{ab}$ may allow for torsion, the shifted connection $\widetilde{\omega}^{ab}$ is torsion-free on-shell. Hence, the antisymmetric field $B^{ab}$ acts as a genuine source of torsion (13), even in vacuum states, which will be discussed in the next subsection.

The second set of equations follows from variations with respect to the vierbein and yields a generalized Einstein equation:

$$J^{ab} \wedge {}^{*}e_{abc} + 6\mu\lambda {}^{*}e_{c} = 0, \tag{14}$$

and it can be decomposed as

$$R^{ab} \wedge {}^{*}e_{abc} + 6\mu\lambda {}^{*}e_{c} = \mu F^{ab} \wedge {}^{*}e_{abc}. \tag{15}$$

Recasting this relation into tensorial form by using the relations $e_{a}^{\ \mu} e_{b}^{\ \nu} R^{ab} = \frac{1}{2} R_{\rho\sigma}^{\ \ \mu\nu} dx^{\rho} \wedge dx^{\sigma}$ and $e_{a}^{\ \mu} e_{b}^{\ \nu} F^{ab} = \frac{1}{2} F_{\rho\sigma}^{\ \ \mu\nu} dx^{\rho} \wedge dx^{\sigma}$, we find

$$R^{\mu}_{\ \alpha} - \frac{1}{2} R \delta^{\mu}_{\ \alpha} - \Lambda \delta^{\mu}_{\ \alpha} = T_{B}{}^{\mu}_{\ \alpha}, \tag{16}$$

where the cosmological constant is $\Lambda = 6\mu\lambda$ and the stress-energy tensors of the $AdSL_4$ gauge field $B^{ab}_{\mu}$ is defined by

$$T_{B}{}^{\mu}_{\ \alpha} = \mu e_{a}^{\ \nu} e_{b}^{\ \mu} \left( D_{[\nu} B^{\ ab}_{\alpha]} - \mu B^{\ a}_{[\nu\ c} B^{\ cb}_{\alpha]} \right) - \frac{\mu}{2} \delta^{\mu}_{\ \alpha} e_{a}^{\ \gamma} e_{b}^{\ \kappa} \left( D_{[\gamma} B^{\ ab}_{\kappa]} - \mu B^{\ a}_{[\gamma\ c} B^{\ cb}_{\kappa]} \right), \tag{17}$$

where, in our notation, the square brackets around the indices imply antisymmetrization. Additionally, we define the stress-energy tensor related to the cosmological constant as $T_{\Lambda}{}^{\mu}_{\ \alpha} = \Lambda \delta^{\mu}_{\alpha}$, therefore the total stress-energy tensor can be written as $T^{\mu}_{\alpha} = T_{B}{}^{\mu}_{\ \alpha} + T_{\Lambda}{}^{\mu}_{\ \alpha}$.

Thus, the Einstein–Hilbert–like dynamics are extended by a natural contribution from the $AdSL_4$ field $B^{ab}_{\mu}$, with the cosmological constant term arising intrinsically from the algebraic structure of the theory, rather than being introduced by hand. In this formulation, the entire matter–energy content of the Universe is encoded in the $AdSL_4$ gauge fields.

### 2.2 Geometric Analysis of Torsion

Torsion is a fundamental geometrical quantity in gauge formulations of gravity, measuring the failure of parallel transport to preserve the position of a vector in the tangent space. In recent decades, the role of torsion in gravitational theory has been extensively studied, primarily in the context of advancing gravity toward a gauge-theoretic formulation and incorporating spin within a geometric framework. For the cosmological point of view, torsion can influence the dynamics of the early universe by introducing additional effective energy–momentum

contributions, thereby becoming significant near Planckian regimes. Such effects can regularize singularities, alter inflationary dynamics, and leave imprints on primordial perturbations [61–65].

Let $e^a = e^a_\mu dx^\mu$ be the orthonormal coframe (vierbein) and $\omega^{ab} = \omega^{ab}_\mu dx^\mu$ the full spin connection (1-forms). The torsion 2-form is defined by

$$T^a = De^a = de^a + \omega^a{}_b \wedge e^b. \tag{18}$$

We decompose the full spin connection into the torsionless (Levi–Civita / Lorentz) part $\mathring{\omega}^a{}_b$ and the contorsion 1-form $K^a{}_b$:

$$\omega^a{}_b = \mathring{\omega}^a{}_b + K^a{}_b \tag{19}$$

where $\mathring{\omega}^a{}_b$ can be expressed in terms of the Christoffel symbols $\Gamma^\lambda{}_{\mu\nu} = \frac{1}{2} g^{\lambda\rho}\left(\partial_\mu g_{\nu\rho} + \partial_\nu g_{\mu\rho} - \partial_\rho g_{\mu\nu}\right)$ as

$$\mathring{\omega}^{ab}_\mu = e^a_\nu \partial_\mu e^{b\,\nu} + e^a_\nu \Gamma^\nu_{\mu\sigma} e^{b\,\sigma}. \tag{20}$$

By definition $\mathring{\omega}^a{}_b$ satisfies $de^a + \mathring{\omega}^a{}_b \wedge e^b = 0$, hence we obtain the standard algebraic relation

$$T^a = K^a{}_b \wedge e^b. \tag{21}$$

From the previous calculation (13), we know $F^a = 0$ then we get

$$T^a = \mu B^a{}_c \wedge e^c. \tag{22}$$

Comparing (21) and (22) shows that the contorsion 1-form is directly given by the $AdSL_4$ gauge field:

$$K^a{}_b = \mu B^a{}_b. \tag{23}$$

Hence, the $AdSL_4$–gauge field $B^{ab}$ is not just an auxiliary object: it generates torsion and therefore modifies both the spin connection and curvature built from $\omega = \mathring{\omega} + K$. Therefore, the full spin connection can be written in terms of the $AdSL_4$ gauge field

$$\omega^a{}_b = \mathring{\omega}^a{}_b + \mu B^a{}_b. \tag{24}$$

So the full $AdSL_4$ spin connection becomes

$$\omega^{ab}_\mu = e^a_\nu \partial_\mu e^{b\,\nu} + e^a_\nu \Gamma^\nu_{\mu\sigma} e^{b\,\sigma} + \mu B^{ab}_\mu. \tag{25}$$

Furthermore, the Lorentz curvature 2-form of the full connection $\omega$ is

$$R^{ab}(\omega) = d\omega^{ab} + \omega^a{}_c \wedge \omega^{cb}, \tag{26}$$

and using (19) yields the decomposition

$$R^{ab}(\omega) = R^{ab}\left(\mathring{\omega}\right) + \mathring{D} K^{ab} + K^a{}_c \wedge K^{cb}, \tag{27}$$

where $\mathring{D}$ is the covariant derivative w.r.t. $\mathring{\omega}$. Torsion thus affects the curvature dynamically and altering the Einstein tensor, consequently, the gravitational field equations. Within this framework, the gauge field $B^{ab}$ acts as the geometrical source of torsion, which in turn provides a natural mechanism for these phenomena within a gauge-theoretic formulation of gravity.

Finally, we remark that upon considering the shifted connection $\tilde{\omega}^a{}_b$ (7), it becomes evident that this connection coincides with the Levi-Civita connection, $\tilde{\omega}^a{}_b = \mathring{\omega}^a{}_b$. This identification immediately implies a torsion-free configuration, as ensured by the full torsion equation

(4). Consequently, the extended torsion, constructed from the shifted connection, vanishes identically, i.e., $\tilde{D}e^a = 0$. In this sense, the shifted framework effectively eliminates the extended torsional contributions, thereby reducing the theory to a purely metric-compatible formulation.

## 3 Generalized Friedmann Equations

The Einstein–Yang–Mills cosmology is a theoretical framework that unifies general relativity with Yang–Mills theory to describe the large-scale dynamics of the Universe. Within this approach, gravitation is formulated as a connection between space-time and a non-Abelian gauge field. Non-Abelian gauge fields have been extensively employed to model the Universe during its early stages, particularly in scenarios involving inflation and the subsequent formation of large-scale structures such as galaxies and galaxy clusters. Motivated by these studies, we investigate the possible cosmological implications of the gauge fields $B_\mu^{ab}(x)$, which explicitly appear in the gravitational field equations (16).

In the present cosmological context, we adopt the perfect fluid approximation, which is motivated by the observed large-scale homogeneity and isotropy of the Universe, consistent with the cosmological principle, and allows the $AdSL_4$ curvature sector to be interpreted as an effective matter–energy source. In this case, the total stress-energy tensor is taken to be

$$T_\alpha^\mu = diag\left(\rho(t), -P(t), -P(t), -P(t)\right), \tag{28}$$

where $\rho(t)$ and $P(t)$ denote the effective energy density and isotropic pressure, respectively. These tensors are consistent with the general form of a perfect fluid stress-energy tensor, $T_{\mu\nu} = (\rho + P) u_\mu u_\nu - P g_{\mu\nu}$ where $u_\mu$ is the fluid's four-velocity. Assuming again that both ${T_B}_\alpha^\mu$ and ${T_\Lambda}_\alpha^\mu$ have perfect fluid form, the total energy density and pressure can be written as

$$\rho = \rho_B + \rho_\Lambda, \qquad P = P_B + P_\Lambda, \tag{29}$$

where we consider all energy densities to be positive definite.

Furthermore, each fluid component can be characterized by an effective equation of state (EoS) parameter defined as $\omega_B = \frac{P_B}{\rho_B}$ and $\omega_\Lambda = \frac{P_\Lambda}{\rho_\Lambda}$, which encapsulates the relation between pressure and energy density. In the standard interpretation, $\omega_\Lambda = -1$ corresponds to the cosmological constant's vacuum energy, while $\omega_B$ corresponds to the dynamics of the $B_\mu^{ab}(x)$ gauge field. Moreover, the conservation of the stress-energy tensor in the FLRW background is represented by the equation $\nabla_\mu T^{\mu\nu} = 0$, which consequently gives rise to the continuity equation,

$$\dot{\rho} + 3H(\rho + P) = 0, \tag{30}$$

where $H(t)$ is the Hubble parameter.

In most cosmological models, the background geometry is assumed to be spatially flat FLRW, consistent with observations indicating that the Universe is nearly flat. Accordingly, we adopt the metric;

$$ds^2 = dt^2 - a(t)^2\left(dx^2 + dy^2 + dz^2\right), \tag{31}$$

where $a(t)$ is the scale factor. According to [33–35], the gauge fields $B_\mu^{ab}(x)$ can be expressed in terms of two time-dependent fields $\psi(t)$ and $\zeta(t)$,

$$B_\mu^{0s}(x) \rightarrow B_\mu^{0s}(t) = \left(0, \delta_i^s \psi(t)\right), \tag{32}$$

$$B_{\mu}^{rs}(x) \rightarrow B_{\mu}^{rs}(t) = \left(0, \epsilon_i{}^{rs}\zeta(t)\right), \tag{33}$$

The ansatz for the gauge fields in (32) and (33) is motivated by the requirement of spatial homogeneity and isotropy in the FLRW sector. Specifically, for a $(1+3)$-dimensional spacetime, the gauge field components must be invariant under joint rotations of the internal tangent indices and the $i, j, k$ spatial indices. By identifying the $r, s$ tangent indices with the spatial indices $i$ through the invariant SO(3) tensors $\delta_i^s$ and $\epsilon_i{}^{rs}$, with $\epsilon^{123} = +1$, the resulting stress-energy tensor preserves the symmetries of the FLRW metric, thereby allowing for a consistent cosmological reduction and the derivation of the corresponding Friedmann equations.

Substituting the ansatz (32), (33), together with the spin-connection expression (25), into the gravitational field equations (16), yields the corresponding Friedmann equations. From the (0, 0) component of (16), we obtain

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{2\mu^2}{a^2}\left(\psi^2 - \zeta^2\right) + \frac{\Lambda}{3}, \tag{34}$$

where a dot denotes differentiation with respect to cosmic time $t$. The spatial diagonal $(i, i)$ components of (16) lead to

$$\frac{2\ddot{a}}{a} + \left(\frac{\dot{a}}{a}\right)^2 = \frac{2\mu^2}{a^2}\left(\psi^2 - \zeta^2\right) + \Lambda. \tag{35}$$

Combining these results, the acceleration equation takes the simple form

$$\frac{\ddot{a}}{a} = \frac{\Lambda}{3}. \tag{36}$$

This result implies that the cosmic acceleration is constant and entirely governed by the effective cosmological constant $\Lambda$ emerging from the $AdSL_4$–gauged gravity framework. A positive $\Lambda$ leads to $\ddot{a} > 0$, describing an exponentially expanding universe $a(t) \propto e^{\sqrt{\Lambda}t}$, characteristic of both de Sitter inflation like in the early universe and the current dark-energy–dominated phase. A negative $\Lambda$, by contrast, would correspond to an attractive effect that decelerates expansion and could even lead to a recollapsing universe. So torsion-type contributions do not drive acceleration; they only modify the expansion rate (the Hubble term).

Here the corresponding pressure and the energy density expressions for the $B_{\mu}^{ab}$ gauge field are found as

$$P_B = -\frac{\mu^2}{4\pi G a^2}\left(\psi^2 - \zeta^2\right), \qquad \rho_B = \frac{3\mu^2}{4\pi G a^2}\left(\psi^2 - \zeta^2\right), \tag{37}$$

and considering the effective EoS for this gauge field, we get the following expression,

$$\omega_B = \frac{P_B}{\rho_B} = -\frac{1}{3}. \tag{38}$$

The obtained value reveals that the $B_{\mu}^{ab}$ gauge field behaves like a form of exotic matter with negative pressure. This value lies between that of a pressureless dust ($\omega = 0$) and a cosmological constant ($\omega = -1$), but it is particularly noteworthy because (38) marks the critical threshold separating decelerated and accelerated expansion in the Friedmann equations. At this boundary, the contribution of the $B_{\mu}^{ab}$ field neither strongly accelerates the Universe nor induces significant deceleration, instead yielding a marginal effect on the expansion rate.

Furthermore, when we solve (36), the scale factor takes the following form;

$$a(t) = C_1 e^{kt} + C_2 e^{-kt}, \tag{39}$$

where $k = \sqrt{\Lambda/3}$, $C_1$ and $C_2$ are the constants of integration determined by the initial conditions of the system. Substituting the solution (39) into (34), one derives the expression for the cosmological constant,

$$\Lambda = -\frac{3\mu^2\left(\psi^2 - \zeta^2\right)}{2C_1C_2}. \tag{40}$$

The result explicitly demonstrates that the scalar fields $\psi(t)$ and $\zeta(t)$ can be physically interpreted as the effective source of the cosmological constant within this specific theoretical framework. Additionally, from the definition of $\Lambda = 6\lambda\mu$, the relation between the parameters $\lambda$ and $\mu$ can be given by

$$\lambda = -\frac{\mu\left(\psi^2 - \zeta^2\right)}{4C_1C_2}. \tag{41}$$

## 4 Conclusion

In this work, we examined the potential modification for the Friedmann equations in the context of $AdSL_4$–gauged gravity. In this formulation, an antisymmetric tensorial gauge field $B^{ab}_{\mu}$, associated with the additional generators of the $AdSL_4$ algebra, generates spacetime torsion through the relation $T^a = \mu B^a_{\ c} \wedge e^c$ (22). Incorporating this torsion into the spin connection (25) and curvature yields the $AdSL_4$ extended Einstein–Cartan equations. By specializing these equations to spatially homogeneous and isotropic geometries, we derived their cosmological sector, preserving all torsional contributions without invoking additional matter sources or altering the underlying gauge-theoretic structure.

By substituting the ansatz for the $AdSL_4$ gauge fields (32) and (33) together with the modified spin connection into the generalized Einstein equations, we obtained a modified Friedmann system in which the combination $\psi^2 - \zeta^2$ of the gauge field amplitudes appears in both the temporal (00) and spatial $(ii)$ components. Eliminating this term between the two equations yields an acceleration equation (36) identical in form to that of a pure de Sitter universe, with acceleration determined solely by the cosmological constant $\Lambda$. According to the modified Friedmann equations given in (34) and (35), the gauge field $B^{ab}_{\mu}$ influences the cosmic expansion history through its contribution to the effective energy density in (37). Moreover, the scalar fields $\psi$ and $\zeta$, which constitute the dynamical components of $B^{ab}_{\mu}$, arise as a source of the cosmological constant $\Lambda$, thereby directly modifying the cosmic acceleration rate, as shown in (40).

The EoS parameter $\omega_B = -1/3$ (38) obtained for the $B^{ab}_{\mu}$ gauge field is particularly intriguing, as it corresponds to a form of matter with a negative pressure that scales as $P_B = -\frac{1}{3}\rho_B$. This specific value of the EoS parameter is characteristic of a network of cosmic strings [66–69] in the Universe, where the string tension effectively generates the same dynamical behavior in the cosmological expansion. In the standard cosmological context, such an EoS marks the critical boundary between decelerating and coasting expansion, leading to a scale factor evolution that is linear in cosmic time. The presence of a cosmic string–like component, whether arising from fundamental field-theoretic defects or emergent gauge-field dynamics as in our case, could have important implications for structure formation, gravitational wave backgrounds [70, 71], and the thermal history of the early universe. This connection enriches

the physical interpretation of the $B_{\mu}^{ab}$ gauge field, suggesting that its cosmological role might parallel that of topological defects formed during symmetry-breaking phase transitions in the early cosmos.

These results demonstrate that $AdSL_4$–gauged gravity with torsion provides a mathematically consistent and physically motivated extension of general relativity, capable of generating cosmic string-like components in the cosmic energy budget from purely geometric origins. While the late-time acceleration is entirely $\Lambda$-driven in the isotropic background case, the torsional gauge fields may play a significant role in intermediate epochs, spatial curvature dynamics, or anisotropic settings [72–74]. Future research directions include constraining the model parameters $\mu$ and $\lambda$ using cosmological observations, studying perturbations to assess effects on structure formation and gravitational waves, and exploring whether the curvature-like behavior of the $B_{\mu}^{ab}$ sector may contribute to the resolution of cosmological singularities or provide novel signatures of topological defects in a unified gauge–gravity framework.

**Author Contributions** O.C. : Writing—review & editing, Writing—original draft, Validation, Methodology, Investigation, Formal analysis, Conceptualization. S. K.: Writing—review & editing, Validation, Software, Methodology, Investigation, Formal analysis.

**Data Availability** No datasets were generated or analysed during the current study.

## Declarations

**Competing interests** The authors declare no competing interests.

**Generative AI and AI-assisted technologies in the writing process** During the preparation of this work the author used ChatGPT - GPT-4o in order to improve readability of the text. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

## References

1. Capozziello, S., De Laurentis, M.: Extended Theories of Gravity. Phys. Rept. **509**, 167 (2011)
2. Clifton, T., Ferreira, P.G., Padilla, A., Skordis, C.: Modified Gravity and Cosmology. Phys. Rept. **513**, 1 (2012)
3. Nojiri, S., Odintsov, S.D., Oikonomou, V.K.: Modified Gravity Theories on a Nutshell: Inflation, Bounce and Late-time Evolution. Phys. Rept. **692**, 1 (2017)
4. Bars, I., Steinhardt, P., Turok, N.: Local Conformal Symmetry in Physics and Cosmology. Phys. Rev. D **89**, 043515 (2014)
5. Dereli, T., Senikoglu, Y.: Gravitational plane waves in a non-Riemannian description of Brans-Dicke gravity. Phys. Scripta **95**, 045223 (2020)
6. Ghilencea, D.M.: Gauging scale symmetry and inflation: Weyl versus Palatini gravity. Eur. Phys. J. C **81**, 510 (2021)
7. Dereli, T., Şenikoğlu, Y.: Dark Range of $\omega$ In Brans-Dicke Gravity. J. Phys: Conf. Ser. **2191**, 012010 (2022)
8. Yang, C.-N., Mills, R.L.: Conservation of Isotopic Spin and Isotopic Gauge Invariance. Phys. Rev. **96**, 191 (1954)
9. Utiyama, R.: Invariant theoretical interpretation of interaction. Phys. Rev. **101**, 1597 (1956)
10. Kibble, T.W.B.: Lorentz invariance and the gravitational field. J. Math. Phys. **2**, 212 (1961)
11. de Azcarraga, J.A., Kamimura, K., Lukierski, J.: Generalized cosmological term from Maxwell symmetries. Phys. Rev. D **83**, 124036 (2011)
12. Bacry, H., Combe, P., Richard, J. L.: Group-theoretical analysis of elementary particles in an external electromagnetic field. 1. the relativistic particle in a constant and uniform field, Nuovo Cim. A **67**, 267 (1970)

13. Schrader, R.: The maxwell group and the quantum theory of particles in classical homogeneous electromagnetic fields. Fortschr. Phys. **20**, 701 (1972)
14. Soroka, D.V., Soroka, V.A.: Tensor extension of the Poincare' algebra. Phys. Lett. B **607**, 302 (2005)
15. Cardenas, L., Diaz, J., Salgado, P., Salgado, D.: Generalized Einstein gravities and generalized AdS symmetries. Nucl. Phys. B **984**, 115943 (2022)
16. Peñafiel, D.M., Ravera, L.: Generalized cosmological term in D = 4 supergravity from a new AdS–Lorentz superalgebra. Eur. Phys. J. C **78**, 945 (2018)
17. Gomis, J., Kamimura, K., Lukierski, J.: Deformations of Maxwell algebra and their Dynamical Realizations, JHEP **08**, 039 (2009)
18. Bonanos, S., Gomis, J., Kamimura, K., Lukierski, J.: Maxwell Superalgebra and Superparticle in Constant Gauge Badkgrounds. Phys. Rev. Lett. **104**, 090401 (2010)
19. Durka, R., Kowalski-Glikman, J., Szczachor, M.: Gauged AdS-Maxwell algebra and gravity. Mod. Phys. Lett. A **26**, 2689 (2011)
20. Soroka, D.V., Soroka, V.A.: Gauge semi-simple extension of the Poincaré group. Phys. Lett. B **707**, 160 (2012)
21. de Azcarraga, J.A., Izquierdo, J.M.: Minimal D = 4 supergravity from the superMaxwell algebra. Nucl. Phys. B **885**, 34 (2014)
22. Cebecioğlu, O., Kibaroğlu, S.: Gauge theory of the Maxwell-Weyl group. Phys. Rev. D **90**, 084053 (2014)
23. Cebecioğlu, O., Kibaroğlu, S.: Maxwell-affine gauge theory of gravity. Phys. Lett. B **751**, 131 (2015)
24. Concha, P. K., Rodríguez, E. K., Salgado, P.: Generalized supersymmetric cosmological term in N = 1 Supergravity, JHEP **08**, 009 (2015)
25. Kibaroğlu, S., Şenay, M., Cebecioğlu, O.: D = 4 topological gravity from gauging the Maxwell-special-affine group. Mod. Phys. Lett. A **34**, 1950016 (2019)
26. Kibaroğlu, S., Cebecioğlu, O.: D = 4 supergravity from the Maxwell-Weyl superalgebra. Eur. Phys. J. C **79**, 898 (2019)
27. Kibaroğlu, S., Cebecioğlu, O.: Generalized cosmological constant from gauging Maxwell-conformal algebra. Phys. Lett. B **803**, 135295 (2020)
28. Kibaroğlu, S., Cebecioğlu, O.: Gauge theory of the Maxwell and semi-simple extended (anti) de Sitter algebra. Int. J. Mod. Phys. D **30**, 2150075 (2021)
29. Cebecioğlu, O., Kibaroğlu, S.: Maxwell-modified metric affine gravity. Eur. Phys. J. C **81**, 900 (2021)
30. Cebecioğlu, O., Saban, A., Kibaroğlu, S.: Maxwell extension of f(R) gravity. Eur. Phys. J. C **83**, 95 (2023)
31. Kibaroğlu, S., Cebecioğlu, O., Saban, A.: Gauging the Maxwell extended GL(n, R) and SL(n+1, R) algebras. Symmetry **15**, 464 (2023)
32. Durka, R., Kowalski-Glikman, J.: Local Maxwell symmetry and gravity (2011). arXiv preprint arXiv:1110.6812 [hep-th])
33. de Azcárraga, J.A., Kamimura, K., Lukierski, J.: Maxwell symmetries and some applications. Int. J. Mod. Phys. Conf. Ser. **23**, 350–356 (2013)
34. Kibaroğlu, S.: Cosmological application of the Maxwell gravity. Int. J. Mod. Phys. D **32**, 2350069 (2023)
35. Kibaroğlu, S.: Modified Friedmann equations from Maxwell-Weyl gauge theory. Nucl. Phys. B **1006**, 116634 (2024)
36. Cervero, J., Jacobs, L.: Classical Yang-Mills Fields in a Robertson-walker Universe. Phys. Lett. B **78**, 427 (1978)
37. Henneaux, M.: Remarks on space-time symmetries and nonabelian gauge fields. J. Math. Phys. **23**, 830 (1982)
38. Galtsov, D.V., Volkov, M.S.: Yang-Mills cosmology: Cold matter for a hot universe. Phys. Lett. B **256**, 17 (1991)
39. Moniz, P.V., Mourao, J.M., Sa, P.M.: The dynamics of a flat friedmann-robertson-walker inflationary model in the presence of gauge fields. Class. Quant. Grav. **10**, 517 (1993)
40. Bamba, K., Nojiri, S., Odintsov, S.D.: Inflationary cosmology and the late-time accelerated expansion of the universe in non-minimal Yang-Mills-F(R) gravity and non-minimal vector-F(R) gravity. Phys. Rev. D **77**, 123532 (2008)
41. Gal'tsov, D.V.: Non-Abelian condensates as alternative for dark energy. In: 43rd Rencontres de Moriond on QCD and High Energy Interactions (2008). arXiv:0901.0115 [gr-qc]
42. Maleknejad, A., Sheikh-Jabbari, M.M.: Gauge-flation: Inflation From Non-Abelian Gauge Fields. Phys. Lett. B **723**, 224 (2013)
43. Guarnizo, A., Orjuela-Quintana, J.B., Valenzuela-Toledo, C.A.: Dynamical analysis of cosmological models with non- Abelian gauge vector fields. Phys. Rev. D **102**, 083507 (2020)
44. Maleknejad, A., Sheikh-Jabbari, M.M.: Non-abelian gauge field inflation. Phys. Rev. D **84**, 043515 (2011)
45. Sheikh-Jabbari, M.M.: Gauge-flation Vs Chromo-Natural Inflation. Phys. Lett. B **717**, 6 (2012)

46. Bielefeld, J., Caldwell, R.R.: Cosmological consequences of classical flavor-space locked gauge field radiation. Phys. Rev. D **91**, 124004 (2015)
47. Maleknejad, A., Sheikh-Jabbari, M.M., Soda, J.: Gauge Fields and Inflation. Phys. Rept. **528**, 161 (2013)
48. Zhao, W., Zhang, Y.: The state equation of the Yang-Mills field dark energy models. Class. Quant. Grav. **23**, 3405 (2006)
49. Gal'tsov, D.V., Davydov, E.A.: Yang-Mills condensates in cosmology. In: Int. J. Mod. Phys. Conf. Ser.,**14**, 316–325 (2012)
50. Elizalde, E., Lopez-Revelles, A.J., Odintsov, S.D., Vernov, S.Y.: Cosmological models with Yang-Mills fields. Phys. Atom. Nucl. **76**, 996 (2013)
51. Setare, M.R., Kamali, V.: Warm Vector Inflation. Phys. Lett. B **726**, 56 (2013)
52. Rinaldi, M.: Dark energy as a fixed point of the Einstein Yang-Mills Higgs Equations, JCAP **10**, 023 (2015)
53. Mehrabi, A., Maleknejad, A., Kamali, V.: Gaugessence: a dark energy model with early time radiation-like equation of state. Astrophys. Space Sci. **362**, 53 (2017)
54. Zhang, H., Li, C.S., Cao, Q.-H., Li, Z.: A Dark Matter Model with Non-Abelian Gauge Symmetry. Phys. Rev. D **82**, 075003 (2010)
55. Buen-Abad, M.A., Marques-Tavares, G., Schmaltz, M.: Non-Abelian dark matter and dark radiation. Phys. Rev. D **92**, 023531 (2015)
56. Gross, C., Lebedev, O., Mambrini Y.: Non-Abelian gauge fields as dark matter, JHEP 08, **158** (2015)
57. Izaurieta, F., Rodriguez, E., Salgado, P.: Expanding Lie (super)algebras through Abelian semigroups. J. Math. Phys. **47**, 123512 (2006)
58. Salgado, P., Salgado, S.: so(D − 1, 1) ⊗ so(D − 1, 2) algebras and gravity. Phys. Lett. B **728**, 5 (2014)
59. Sciama, D.W.: On the analogy between charge and spin in general relativity. In: Recent developments in general relativity (Pergamon, 1962) p. 415
60. Olmo, G.J.: Palatini Approach to Modified Gravity: f(R) Theories and Beyond. Int. J. Mod. Phys. D **20**, 413 (2011)
61. Shie, K.-F., Nester, J.M., Yo, H.-J.: Torsion Cosmology and the Accelerating Universe. Phys. Rev. D **78**, 023522 (2008)
62. Popławski, N.J.: Cosmology with torsion: An alternative to cosmic inflation, Phys. Lett. B 694, 181 (2010), [Erratum: Phys. Lett. B **701**, 672–672 (2011)]
63. Poplawski, N.J.: Nonsingular, big-bounce cosmology from spinor-torsion coupling. Phys. Rev. D **85**, 107502 (2012)
64. Cai, Y.-F., Capozziello, S., De Laurentis, M., Saridakis, E.N.: f(T) teleparallel gravity and cosmology. Rept. Prog. Phys. **79**, 106901 (2016)
65. Yan, S.-F., Zhang, P., Chen, J.-W., Zhang, X.-Z., Cai, Y.-F., Saridakis, E.N.: Interpreting cosmological tensions from the effective field theory of torsional gravity. Phys. Rev. D **101**, 121301 (2020)
66. Kibble, T.W.B.: Topology of Cosmic Domains and Strings. J. Phys. A **9**, 1387 (1976)
67. Vilenkin, A.: Cosmic Strings. Phys. Rev. D **24**, 2082 (1981)
68. Vilenkin, A.: Cosmic Strings and Domain Walls. Phys. Rept. **121**, 263 (1985)
69. Hindmarsh, M.B., Kibble, T.W.B.: Cosmic strings. Rept. Prog. Phys. **58**, 477 (1995)
70. Damour, T., Vilenkin, A.: Gravitational wave bursts from cosmic strings. Phys. Rev. Lett. **85**, 3761 (2000)
71. Caprini, C., Figueroa, D.G.: Cosmological Backgrounds of Gravitational Waves. Class. Quant. Grav. **35**, 163001 (2018)
72. Hinshaw, G., et al.: (WMAP), First year Wilkinson Microwave Anisotropy Probe (WMAP) observations: The Angular power spectrum. Astrophys. J. Suppl. **148**, 135 (2003)
73. Hinshaw, G., et al.: (WMAP), Three-year Wilkinson Microwave Anisotropy Probe (WMAP) observations: temperature analysis. Astrophys. J. Suppl. **170**, 288 (2007)
74. Hinshaw, G., et al.: (WMAP), Five-Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Data Processing, Sky Maps, and Basic Results. Astrophys. J. Suppl. **180**, 225 (2009)


**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.