Einstein-Cartan cosmology and the matter kinematic dipole anomaly

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Abstract

The recent precise measurements of the kinematic dipole of radio galaxies and quasars reveal that its magnitude is much larger than the CMB dipole and the expectation from the standard LCDM cosmological model. We show that the Einstein-Cartan cosmology predicts the matter dipole in accordance with the observations. The reason for the discrepancy between the predictions of the LCDM model based on the General Relativity and the Einstein-Cartan cosmology lies on the fact that the massless CMB photons, unlike the massive CDM, baryons and light neutrinos consisting the matter of the Universe, do not couple to torsion of spacetime.

1 Introduction and motivation

Besides the Hubble tension, the rapid growth of structures or the σ_8 problem and the high-redshift number densities underestimates of the LCDM model, the new kinematic dipole problem emerges for LCDM (see ref. [1] and references therein). Since this last problem could be regarded presently as the most important cosmological problem, we attempt to resolve it without hesitation within the framework of the Einstein-Cartan (EC) theory of gravity.

The EC theory, formulated by Sciama [2] and Kibble [3], represents the natural generalization of the General Relativity including not only a relation of the curvature of spacetime to the energy-momentum of matter, but also a relation of the spacetime torsion to the spin-angular momentum of matter. We show in our earlier work that within EC cosmology it is possible to fix matter density at infinity [4] or induce the primordial density fluctuations [5]. It is well known that the EC cosmology can avoid singularity [6] and the resulting minimal distance is compatible with the minimal distance in our theory of noncontractible space in particle physics [7] that contains light neutrinos and heavy neutrinos as the CDM particles. The broken lepton number by the Majorana heavy neutrinos induces the breaking of the baryon number with the observed value [8].

Since the EC cosmology predicted [9] and later observed by JWST much higher abundances of structures at high redshifts, we point out to much higher $\sigma_8(z)$ in EC theory causing more rapid growth of structures than in LCDM [10].

It is worth now to stress the very important consequence of the EC gravity; a torsion affects only massive particle and not the massless photon, though the photon has a spin. The reason is that it is not possible to construct invariant photon-torsion coupling within the EC gravity (see [11] and references therein). Even the spin of the electromagnetic field is not invariant [11]. The EC equations of motions for massive spinning particles like baryons,light and heavy neutrinos look like:

$$\frac{d^2x^\mu}{ds^2} + \Gamma^\mu_{(\lambda\nu)}\frac{dx^\lambda}{ds}\frac{dx^\nu}{ds} = 0. \tag{1}$$

The equations for a photon contain $\Gamma^\mu_{\lambda\nu} = Christoffel\ symbols$, thus torsion-free affine connection. It means that one can anticipate substantial difference between kinematic observables in EC cosmology between CMB photons and matter.

In the next chapter we evaluate and explore the kinematic dipole of matter within the LCDM and EC models.

2 Kinematic dipole for EC and LCDM models

The reader can find in ref. [1] description and detailed review of the cosmic dipole anomaly from the Ellis-Baldwin test to present. However we find it instructive to carry out calculations and comparisons in close resemblance with the analysis of CatWISE quasars in ref. [12].

Let us recall a definition of the kinematic dipole:

$$\begin{aligned}
\vec{d}_k &= A_k(\vec{v}_{halo} + \vec{v}_{vir}), \qquad (2)\\
\vec{v}_{halo} &= smooth\ coherent\ part\ of\ velocity,\ \vec{v}_{vir} = virial\ motions,\\
A_k &= includes\ special\ relativistic\ and\ redshift\ corrections.
\end{aligned}$$

We use the fitting formula of Bryan and Norman for the virial velocity dispersion [13]:

$$\begin{aligned}
\bar{v}_{vir}(a,R) &= \frac{1}{\sqrt{3}}476 g_\sigma(\Delta_{nl}E^2)^{1/6}(\frac{m}{10^{15}M_\odot/h})^{1/3} kms^{-1}, \qquad (3)\\
g_\sigma &= 0.9,\ \Delta_{nl} = 18\pi^2 + 60x - 32x^2,\ x = \Omega(a) - 1,\\
\Omega(a) &= \Omega_m/a^3\frac{1}{E^2(a)},\ E^2(a) = H^2(a)/H_0^2.\\
a &= \frac{1}{1+z},\ m = \frac{4\pi}{3}R^3\bar{\rho}_m.
\end{aligned}$$

The standard procedure gives us the peculiar halo velocity dispersion [14] with smoothing top-hat window function and the normalization of the power spectrum to σ_8:

$$
\begin{aligned}
\bar{v}^2_{halo}(a,R) &= \frac{1}{3}a^2H^2(a)f^2(a)\int_0^\infty dkP(k)\frac{W^2(kR)}{2\pi^2V_W^2(R)}, \qquad (4)\\
V_W(R) &= \frac{4\pi}{3}R^3,\ W(kR) = 4\pi R^3(\frac{\sin kR}{(kR)^3} - \frac{\cos kR}{(kR)^2}),\\
\sigma_8^2 &= (\frac{\delta M}{M})^2(R = 8h^{-1}Mpc) = \int_0^\infty dkk^2P(k)\frac{W^2(kR)}{2\pi^2V_W^2(R)}.
\end{aligned}
$$

Note that we defined like in ref. [12] one-dimensional velocity dispersions (factor 1/3). The fitting formula for virial velocities and power spectrum for CDM and baryons from ref. [15] are valid even for high mass densities of matter.

It is left to find out the growth rate for the EC cosmology. The estimate of the vorticity of the Universe from the pulsar timing arrays [16] is $\omega_0 = \mathcal{O}(10^{-5})H_0$. It is in consent with the measured rotation of the polarization vector of the CMB [16]. Therefore we can ignore vorticity and acceleration parameters in the EC equations for gauge invariant density contrast in [10] (terms linear in torsion cancel out):

$$
\begin{aligned}
\mathcal{G}_\mu &= a\frac{^{(3)}\tilde{\nabla}_\mu\rho_m}{\rho_m},\ \mathcal{Z}_\mu = a^{(3)}\tilde{\nabla}_\mu\Theta,\ \Theta = 3H,\\
\mathcal{G}_\mu &= (0,G,G,G),\ \mathcal{Z}_\mu = (0,Z,Z,Z) \Rightarrow \frac{\delta\rho}{\rho} = \sqrt{-\mathcal{G}_\mu\mathcal{G}^\mu} = G/a,\\
H(a)a\frac{dG}{da} &= H(a)G - Z, \qquad (5)\\
H(a)a\frac{dZ}{da} &= -H(a)Z - \frac{1}{2}\kappa\rho_m G,\ \kappa = 8\pi G_N, \qquad (6)\\
G(a_{init}) &= a^2_{init},\ Z(a_{init}) = -\sqrt{\Omega_m}a^{1/2}_{init},\ a_{init} \simeq 10^{-3}.
\end{aligned}
$$

It is easy to verify that these equations reduce to the standard one second order equation [17] for density contrast if the Hubble function is $H(a) = H_0[\Omega_m/a^3 + \Omega_\Lambda]^{1/2}$ for LCDM cosmology. The resulting density contrast coinsides with the analytic form:

$$
\delta(a) = \frac{H(a)}{H_0}\int_0^a daa^{-3}(\frac{H_0}{H(a)})^3.
$$

The role of torsion enters explicitly in the Hubble function $H(a) = H_0[\Omega_m/a^3 - Q^2(a)]^{1/2}$ and implicitly by fixing the matter density and torsion at infinity. We know that at present $\frac{\rho_{CMB}}{\rho_{matter}} = \mathcal{O}(10^{-4})$ and the curvature term Ω_K is negligible, leading us to $\Omega_{matter} = 2$ *and* $\Omega_{torsion} = -1$ with a flat geometry three dimensional hypersurface [4, 10].

Table 1: Model parameters.

model	Ω_m	Ω_Λ	h	c_0	$z_0; z_1$	τ_U	Ω_b	n_s	σ_8
LCDM	0.307	0.693	0.677	-	-	13.83 Gyr	0.045	0.97	0.8
EC	2	0	0.74	1.85	4;6	13.92 Gyr	0.045	0.97	0.8

The final section deals with the numerical evaluations of all the relevant matter dipole ingredients to make a clear conclusions.

3 Results and conclusions

We want at first to justify our model for torsion. After decoupling of the heavy Majorana neutrinos, a dominance of right-handed helicity light Majorana neutrinos over left-handed ones induces the rise of torsion ($Q^2(a) \propto a^{-6}$) and right-handed vorticity of the Universe [18] confirmed by the observed chirality of the rotation of the CMB polarization vector [16]. However, light neutrinos spin densities are not strong enough to produce strong torsion effects. Only after the rise of nonlinear structures within now a rotating Universe, the angular momentum of matter contributes to torsion comparably as the mass density in the era of matter domination. We propose [9, 10] the considerable rise of torsion from z=6 to z=4 and from z=4 to z=0 the redshifting according to the Zeldovich model for the angular momentum [19]:

$$
\begin{aligned}
&Q(a) = 0,\ for\ a \leq a_1,\\
&Q(a) = (1 + \frac{a - a_0}{a_0 - a_1})[1 - c_0 + c_0 a^{-3}]^{\frac{1}{2}},\ for\ a_1 \leq a \leq a_0,\\
&a = \frac{1}{1+z},\ a_0 = \frac{1}{1+z_0},\ a_1 = \frac{1}{1+z_1},\\
&Q(a) = [1 - c_0 + c_0 a^{-3}]^{\frac{1}{2}},\ for\ a_0 \leq a \leq 1.
\end{aligned}
$$

The reader can find in Table 1 parameters for the EC and LCDM models. The power spectrum P(k) of ref. [15] is corrected by the factor containing the k_{pivot} as in [20].

Numerical evaluations of the growth rate $f(a) = a\frac{d\delta(a)}{da}/\delta(a)$ appearing in the formula for the halo velocity dispersion are depicted in Fig. 1.

After normalization of the power spectrum by $\sigma_8(z=0)$ we calculate virial, halo and total velocity dispersions $\bar{v}^2_{tot} = \bar{v}^2_{vir} + \bar{v}^2_{halo}$ at z=0 for EC and CDM cosmologies at four smoothing scales: see Table 2 and Table 3.

The redshift evolutions of $\bar{v}_{tot}(z)$ are visible in Fig. 2.

The possible redshift corrections to the kinematic dipole ignoring b_e [21] defined by:

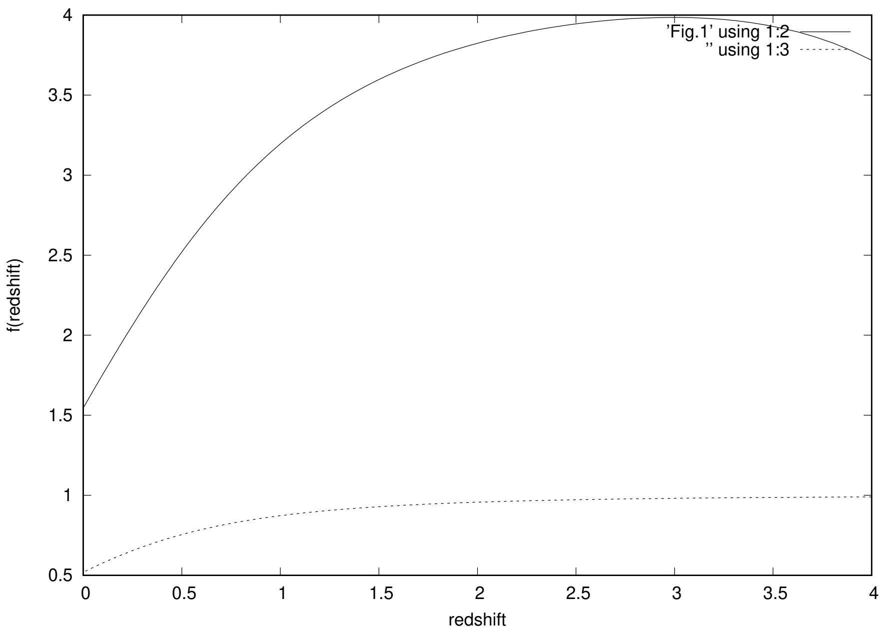

Figure 1: Growth rates f(z) for EC model (solid line) and LCDM model (dashed line).

$$d_k \propto 3 + \frac{\dot{H}}{H^2} + \frac{2(1+z)}{rH},\ r(z) = \int_0^z dz H^{-1}(z). \tag{7}$$

are evaluated and given in Fig. 3 for both cosmic models.

Inspecting Table 2 and Table 3, small difference in redshift evolutions between EC and LCDM in Fig. 2 and small difference of redshift corrections between two models in Fig. 3, we conclude with a great certainity that $d_k(EC)/d_k(LCDM) \simeq\ from\ 1.9\ to\ 2.5$ pending on the smoothing scales and redshifts. The Einstein-Cartan cosmology gives substantially larger matter kine-

Table 2: One-dimesional velocity dispersions vs. smoothing scales (z=0)
——————————— EC model ———————————

R(h^{-1}Mpc)	$\bar{v}_{vir}(kms^{-1})$	$\bar{v}_{halo}(kms^{-1})$	$\bar{v}_{tot}(kms^{-1})$
1.26	100	686	693
2.71	216	585	624
5.85	466	448	646
12.6	1003	302	1048

Table 3: One-dimesional velocity dispersions vs. smoothing scales (z=0)
——— LCDM model ———

R(h^{-1}Mpc)	$\bar{v}_{vir}(kms^{-1})$	$\bar{v}_{halo}(kms^{-1})$	$\bar{v}_{tot}(kms^{-1})$
1.26	49	273	277
2.71	106	266	286
5.85	228	251	339
12.6	491	224	540

matic dipole than the LCDM model but in agreement with the quasar and radio galaxy measurements [1, 12].

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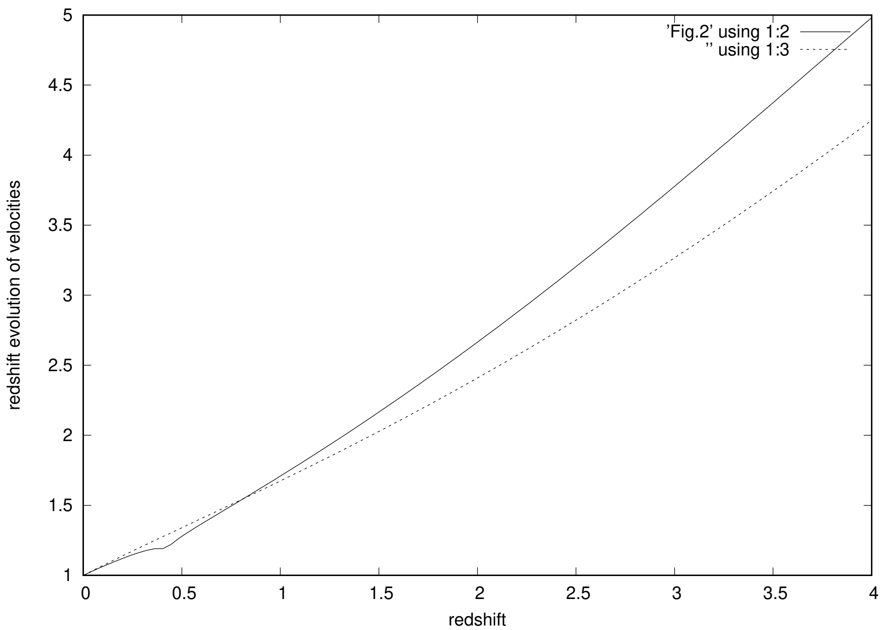

Figure 2: Redshift evolutions of $\bar{v}_{tot}(z)/\bar{v}_{tot}(0)$ for EC model (solid line) and LCDM model (dashed line) at R=2.71/h Mpc.

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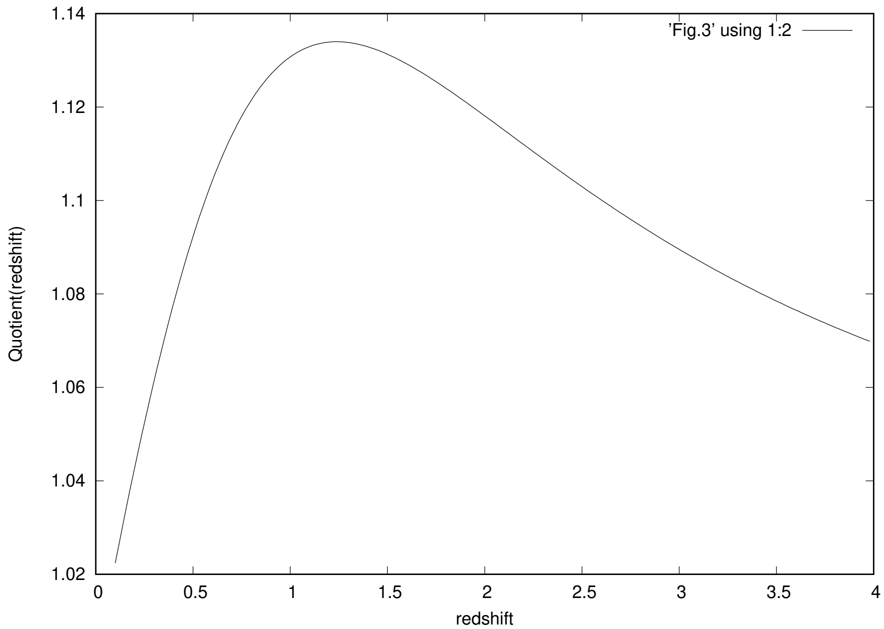

Figure 3: Quotient of redshift corrections to the kinematic dipole (EC correction divided by LCDM correction).

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