

Nonsingular Big-Bounce Cosmology without Inflation from Torsion

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What is Torsion?

- Differentiation of tensors in curved spacetime requires geometrical structure: affine connection $\Gamma^{\rho}_{\mu\nu}$

- Covariant derivative

$$\nabla_{\nu} V^{\mu} = \partial_{\nu} V^{\mu} + \Gamma^{\mu}_{\rho\nu} V^{\rho}$$

- Curvature tensor

$$R^{\rho}_{\sigma\mu\nu} = \partial_{\mu} \Gamma^{\rho}_{\sigma\nu} - \partial_{\nu} \Gamma^{\rho}_{\sigma\mu} + \Gamma^{\rho}_{\tau\mu} \Gamma^{\tau}_{\sigma\nu} - \Gamma^{\rho}_{\tau\nu} \Gamma^{\tau}_{\sigma\mu}$$

- **Torsion tensor** – antisymmetric part of affine connection
(Cartan – 1921)

$$S^k_{ij} = \Gamma^k_{[ij]}$$

Einstein-Cartan-Sciama-Kibble gravity

Special Relativity - no curvature & no torsion

Dynamical variables: matter fields

$$g_{ik} = \eta_{ik} \quad S^k_{ij} = 0$$



General Relativity - no torsion

Dynamical variables: matter fields + metric tensor g_{ik}

$$S^k_{ij} = 0$$



ECSK Gravity (same Lagrangian as GR, simplest theory with torsion)

Dynamical variables: matter fields + metric g_{ik} + torsion S^k_{ij}

More degrees
of freedom



Why ECSK gravity?

- ❖ Takes into account **intrinsic angular momentum (spin)**
(Sciama; Kibble – 1961)
- ❖ Avoids curvature **singularities** from fermionic matter
(Kopczyński; Trautman; Hehl, von der Heyde & Kerlick; Kuchowicz)
- ❖ Generates effective **four-fermion** interaction for Dirac fields
(Kibble; Hehl & Datta)
-> **self-regulation of UV behavior of fermions in QFT?** (van der Merve)
- ❖ No free parameters
- ❖ Different from GR only at densities $> 10^{45} \text{ g/cm}^3$
-> **ECSK passes all tests of GR**

Big-bounce cosmology

- Origin of Universe?
- Nature of black-hole interiors?

Torsion combines both problems

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Torsion in ECSK gravity averts big-bang singularity and singularities in black holes via **gravitational repulsion at high densities**



Big bounce instead of big bang
(Kuchowicz; Gasperini)

Loop quantum gravity -> big bounce too

Universe in a black hole

Our Universe was contracting before bounce – from what?

Idea: **every black hole produces a nonsingular, closed universe**



Our Universe born in a black hole existing in another universe
(Pathria; Frolov, Markov & Mukhanov; Smolin; Stuckey)

- Can explain the arrow of time
- Torsion provides a simple and natural **mechanism** for this scenario -> **Einstein-Rosen bridges** connect universes

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Spin fluids

- Macroscopic matter with spin -> spin fluid
(Nomura, Shirafuji & Hayashi)
- Dynamical energy-momentum tensor for unpolarized spins

$$T^{ij} + U^{ij} = \left(\epsilon - \frac{1}{4} \kappa s^2 \right) u^i u^j - \left(p - \frac{1}{4} \kappa s^2 \right) (g^{ij} - u^i u^j)$$

Energy density **Pressure**

(Hehl et al.)

$$s^2 = \frac{1}{8} (\hbar c n)^2$$

(Nurgaliev & Ponomariev; Gasperini)

Closed universe with torsion

Spin-torsion contribution to energy density

$$\epsilon_S = -\frac{1}{4}\kappa s^2 \propto a^{-6}$$

$$\hat{a} = a/a_0$$

negative & dominant at small a

gravitational
repulsion

Friedman equations \rightarrow Universe begins to expand from nonsingular state (bounce)

$$\hat{a}_m = \sqrt{-\frac{\Omega_S}{\Omega_R}}$$

$\Omega_S = -8.6 \times 10^{-70}$ (negative, extremely small in magnitude)

Cosmology with torsion

Density parameter

$$\Omega(\hat{a}) = 1 + \frac{(\Omega - 1)\hat{a}^4}{\Omega_R\hat{a}^2 + \Omega_S}$$

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$$\dot{a} = \frac{1}{\sqrt{\Omega(\hat{a}) - 1}}$$

Velocity of antipode

$$v_a = \pi c \dot{a}$$

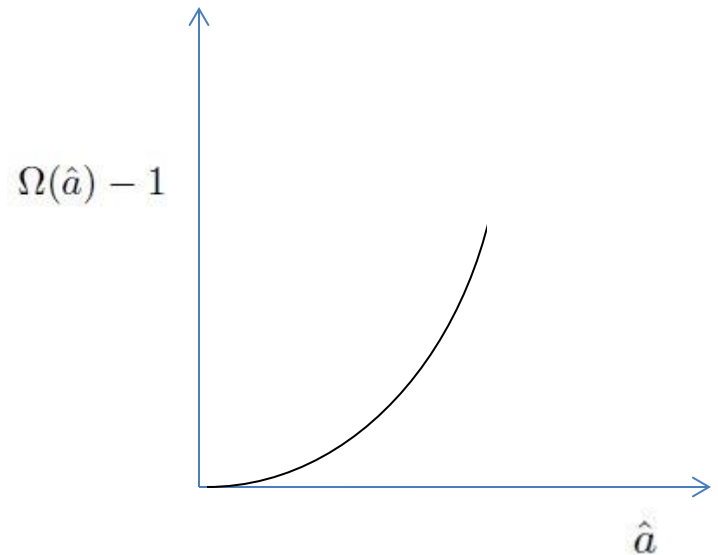
Standard cosmology

GR

$$\Omega_S = 0 \text{ and } a_m = 0$$

$\Omega \sim 1$ today $\rightarrow \Omega(a)$ at GUT

must be tuned to 1 to a precision of > 52 decimal places



Solved by **cosmic inflation** – consistent with cosmic perturbations

Problems:

- Initial (big-bang) singularity
- Needs additional (scalar) fields, specific forms of potential (to stop inflation), free parameters
- Why $\Omega \sim 1$ before inflation?

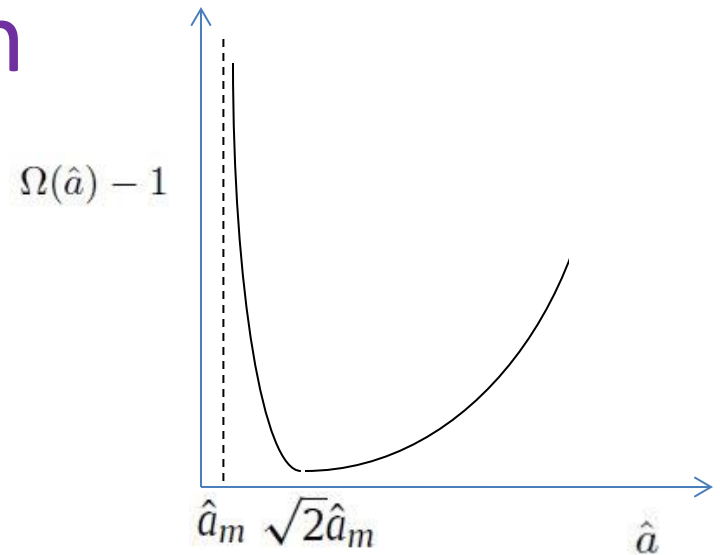
Cosmology with torsion

ECSK

$$\Omega_S < 0 \text{ and } a_m > 0$$

$$\Omega(\sqrt{2}\hat{a}_m) = 1 - \frac{4\Omega_S(\Omega - 1)}{\Omega_R^2}$$

$$\hat{a}_m = 3.1 \times 10^{-33}, \quad a_m = 9 \times 10^{-6} \text{ m}$$



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$$\Omega(\sqrt{2}\hat{a}_m) = 1 + 8.9 \times 10^{-64}$$

Appears tuned to 1 to a precision of ~ 63 decimal places!

No flatness problem – advantages:

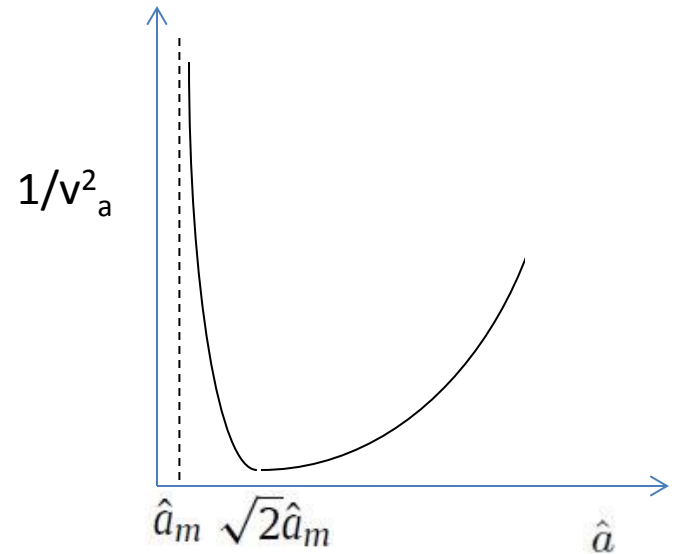
- Nonsingular bounce instead of initial singularity
- No additional fields & free parameters, values seem right
- Radiation epoch begins when torsion becomes negligible

Cosmology with torsion

ECSK

$$\Omega_S < 0 \text{ and } a_m > 0$$

$$v_a = \frac{\pi\Omega_R}{2\sqrt{-\Omega_S(\Omega - 1)}}c = 1.1 \times 10^{32}c$$



- Closed Universe causally connected at $t < 0$ remains causally connected through $t = 0$ until $v_a = c$
- Universe contains $N \sim (v_a/c)^3$ causally disconnected volumes
- $\Omega_S \sim -10^{-69}$ produces $N \approx 10^{96}$ from a single causally connected region – torsion solves **horizon problem**
- **Simpler** than other bounce cosmologies that solve both problems

Black holes with torsion

Where does the mass of the Universe come from?

- Possible solution: **stiff equation of state** $p = \epsilon$
 - Strong interaction of nucleon gas
-> **ultradense matter has stiff EoS**
(Zel'dovich; Walecka; Canuto)
 - Stiff matter – possible content of early Universe
(Zel'dovich; Lin, Carr & Fall; Barrow)
 - Stiff matter composes neutron stars
(Demorest et al.)
- > **Expected in BH**

Black holes with torsion

- Collapse of BH – truncated, closed FLRW metric
- Friedman conservation law -> mass of collapsing BH increases (external observers do not see it)
- Mass increase may be realized by intense particle production in strong fields
(Parker; Zel'dovich)
- Total energy (matter + gravity) remains constant
(Cooperstock & Israelit)

Cosmological perturbations

- Observed scale-invariant spectrum of cosmological perturbations produced by **thermal fluctuations** in a collapsing BH if

$$w_r = (w - 1)/4$$



Background

(Brandenberger et al.)

- Stiff matter $w = 1 \rightarrow w_r = 0$ (initially NR gas of fluctuating particles)

Work in progress

Black holes with torsion

Friedman equations

$$\dot{a}^2 + k = \frac{1}{3} \kappa \epsilon_0 \frac{a_0^6}{a^4} - \frac{1}{96} (\hbar c \kappa)^2 n_0^2 \frac{a_0^{12}}{a^{10}}$$

$$m_{\max} \approx \frac{M^2 m_n}{m_{\text{Pl}}^2}$$

NJP, arXiv:1103.4192

$$M = 10 M_{\odot}$$

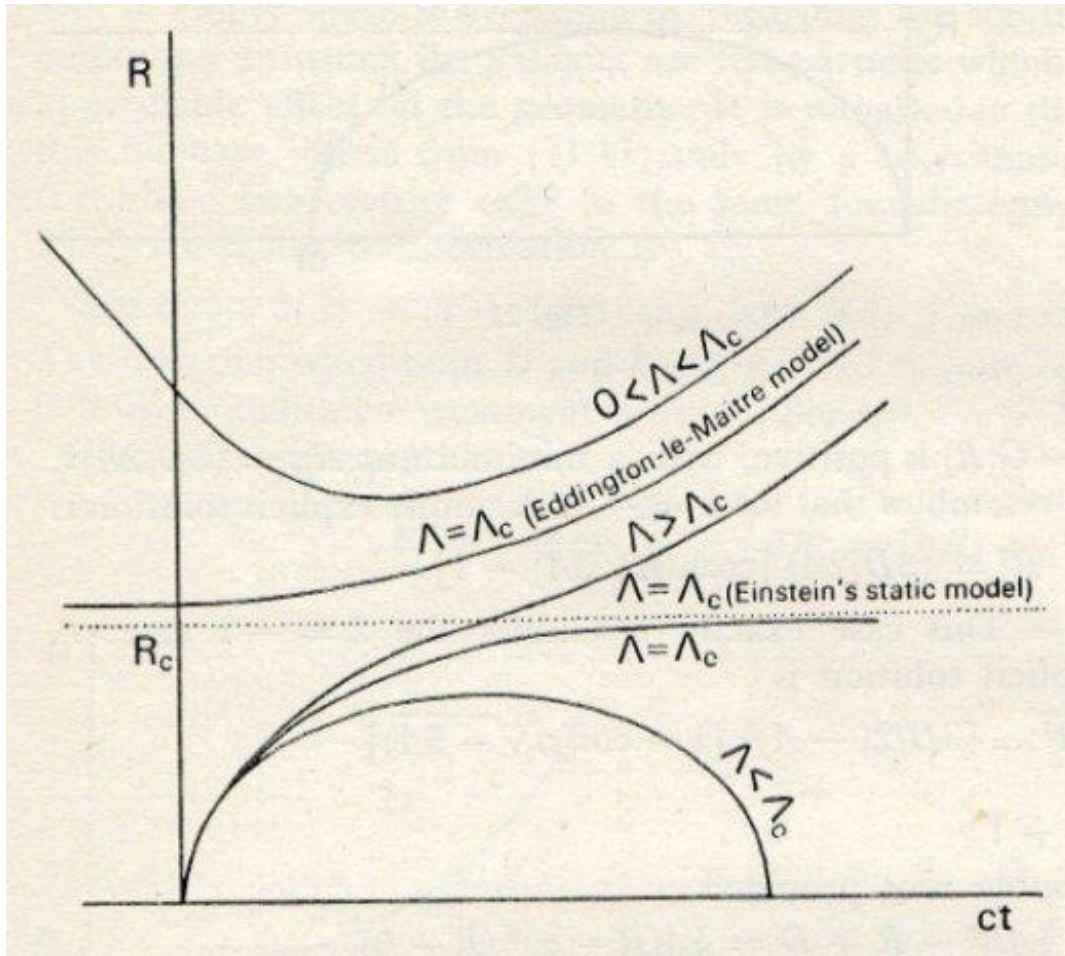


$$a_{\min} \approx 6 \times 10^{-3} \text{ m}$$

$$m_{\max} \approx 3.1 \times 10^{51} \text{ kg}$$

- Mass of the Universe at the bounce
- This mass should not dilute -> **due to four-fermion interaction?**

Universe with cosmological constant



Cosmological models with $k = 1, \Lambda \neq 0$

E. A. Lord, *Tensors, Relativity and Cosmology*

$$\dot{a}^2 + k = \frac{b}{a} + \frac{1}{3}\Lambda a^2$$

$$b = \frac{2Gm_{\max}}{c^2}$$

Expansion to infinity if

$$m_{\max} > m_c = \frac{c^2}{3G\sqrt{\Lambda}}$$

Possible oscillations until sufficient mass is generated

Black holes with torsion

$$\Lambda \approx 1.4 \times 10^{-52} \text{ m}^{-2}$$

$$M_c \approx 35 M_\odot$$

(Binary IC 10 X-1 – 24-33 M_\odot)

Mass of our Universe $1.4 \times 10^{26} M_\odot$



Mass of our parent BH

$$M \approx 3 \times 10^3 M_\odot > M_c$$

Why ECSK gravity?

- ❖ Not only avoids singularities but also solves flatness and horizon problems without inflation
- ❖ Torsion-induced **four-fermion** interaction may explain a small, positive **cosmological constant**

NJP, Annalen Phys. **523**, 291 (2011)

$$\Lambda = \frac{3\kappa^2}{16} (\bar{\psi} \gamma_j \gamma^5 \psi) (\bar{\psi} \gamma^j \gamma^5 \psi)$$

Condensing quarks $\rightarrow \langle 0 | \rho_\Lambda | 0 \rangle = \frac{\kappa}{3} (\langle 0 | \bar{\psi} \psi | 0 \rangle)^2$

$$\rho_\Lambda \sim m^6 / m_{\text{Pl}}^2$$

(Zel'dovich)

Energy scale only 8 times larger than observed

- ❖ Classical Dirac equation with this interaction is **asymmetric** under charge conjugation \rightarrow **matter-antimatter asymmetry?**

NJP, Phys. Rev. D **83**, 084033 (2011)