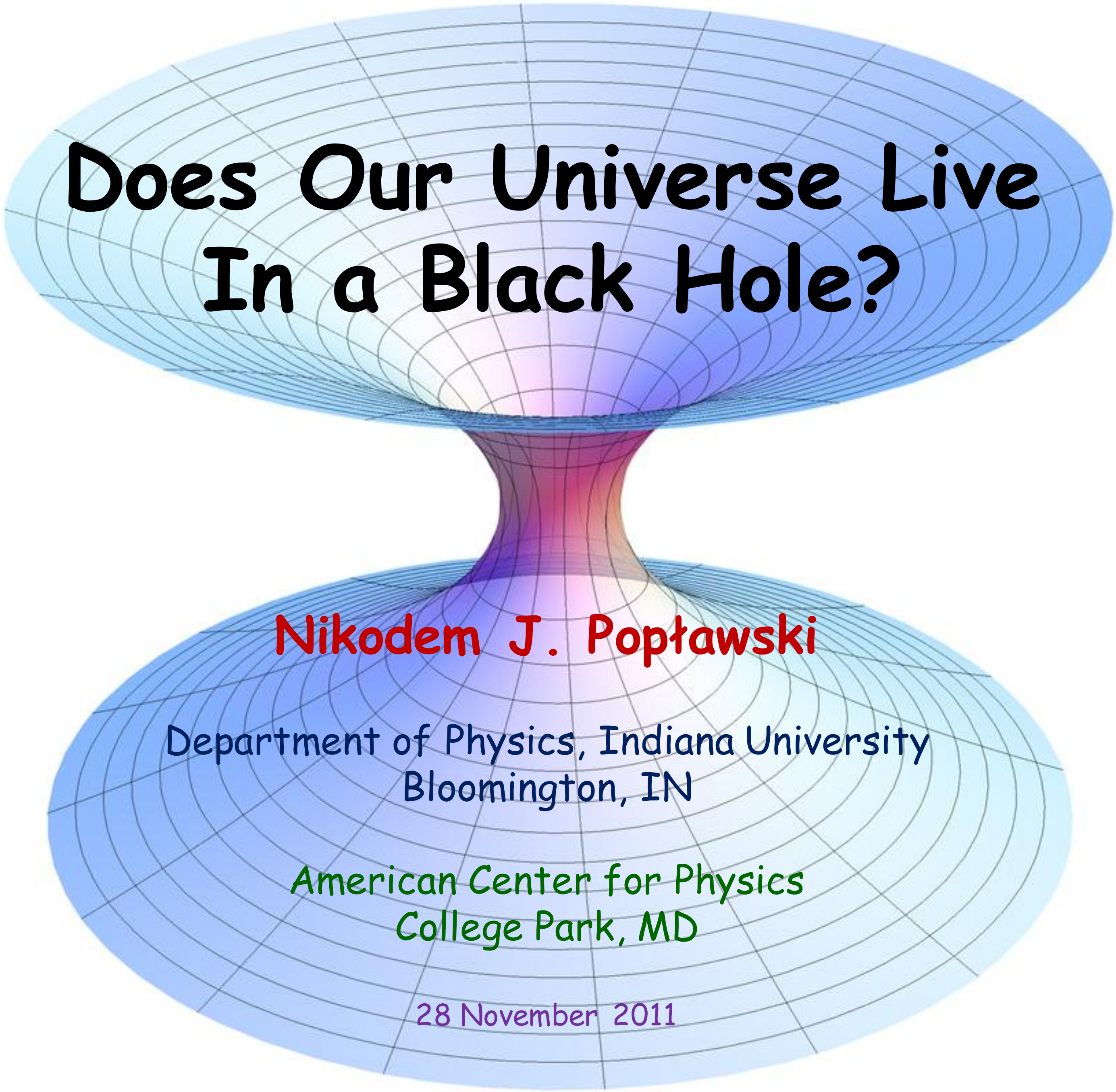

Does Our Universe Live In a Black Hole?

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28 November 2011

Outline

1. Problems of general relativity and cosmology

2. Solution: gravity with torsion

3. Einstein-Cartan-Sciama-Kibble gravity

4. Big bounce instead of big bang

5. Torsion as alternative to inflation

6. Nonsingular black holes: every black hole as a wormhole to a new universe

7. Torsion as a source of matter-antimatter asymmetry, dark matter, and dark energy

Big-bang cosmology

- Albert Einstein (1915)

– general theory of relativity

- K. Schwarzschild (1916)

– exact solution: spherically symmetric gravitational field
→ black holes

- A. Friedman (1922)

– exact solution: homogeneous and isotropic Universe
→ Universe is expanding, Einstein introduces cosmological constant to describe a static Universe

- E. Hubble (1929)

– observable Universe is expanding

Big-bang cosmology

- G. Lemaître (1931)

– Universe originated from primeval atom (big bang)

- R. Alpher & G. Gamov (1940s)

– big-bang (primordial) nucleosynthesis

- R. Alpher, R. Herman & G. Gamov (1948)

– prediction of cosmic microwave background radiation (CMBR)

- A. Penzias & R. Wilson (1964)

– discovery of CMBR

Problems of big-bang cosmology

- Initial singularity: infinite density

- Origin of expansion from extremely hot and dense state?

- Horizon problem (1970s): distant regions of Universe have not contacted each other, but they have same temperatures (Universe is isotropic)

- R. Dicke (1969)

Flatness problem: Universe appears nearly flat at large scales

In order for Universe to be nearly flat now, it must have been very flat in past – why?

Inflation

Kazanas, Guth, Linde & Steinhardt (1980s)
– solution to horizon & flatness problems:
cosmic inflation:
extremely rapid, exponential expansion of early Universe

- Universe started from one causally connected region
- Universe was nearly flat before inflation

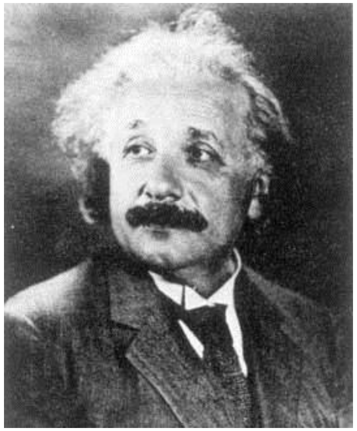
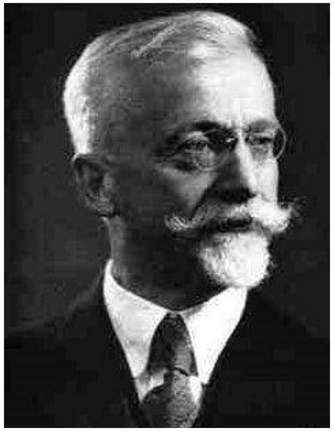
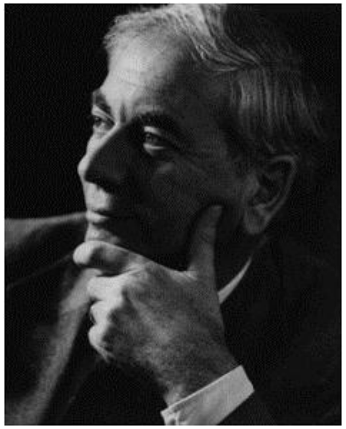
Advantage: predicts observed temperature fluctuations in CMBR

Problems of big-bang cosmology with inflation:

- Initial singularity unresolved
- Need additional assumptions about what causes inflation
- Why Universe was nearly flat before inflation?
- What ends inflation?

Solution: gravity with torsion?

Simplest theory:

Einstein-Cartan-Sciama-Kibble

(ECSK)

theory of gravity

What is torsion?

- Differentiation of vectors in curved spacetime requires subtracting two vectors at separate points with different geometrical properties

- Parallel transport brings one vector to origin of another, so that their subtraction makes sense

Change of vector under parallel transport
= vector x displacement x affine connection

Affine connection is a geometrical property of spacetime

arXiv.org > gr-qc > arXiv:0911.0334

What is torsion?

- From affine connection one can construct

Curvature – “bending” of spacetime

Torsion – “twisting” of spacetime

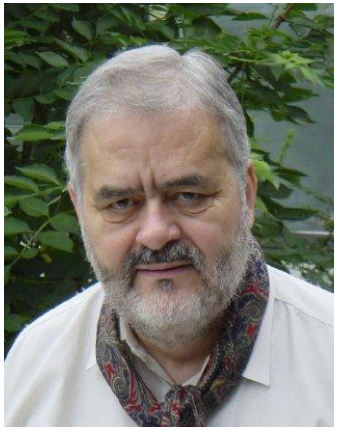
- Spacetime has also metric which measures distances

- General relativity (GR): torsion = 0

arXiv.org > gr-qc > arXiv:0911.0334

What is torsion?

PHYSICS TODAY



Note on the torsion tensor

March 2007, page 16

In commenting on letters responding to his Einstein article (PHYSICS TODAY, November 2005, page 31, and April 2006, page 10), Steven Weinberg states that he "never understood what is so important physically about the possibility of torsion in differential geometry." He basically argues that torsion "is just a tensor" and could be treated like any additional tensor field in the context of general relativity.

In my opinion, however, a decisive point was overlooked. Torsion is not just a tensor, but rather a very specific tensor that is intrinsically related to the translation group, as was shown by Élie Cartan[1] in 1923–24. In fact, in the Yang–Mills sense, it is the field strength of the translations. Torsion is related to translations and curvature to Lorentz rotations. As one consequence, torsion cracks an infinitesimal parallelogram in the spacetime continuum and gives rise to a closure failure described by a vector (in dislocation theory in solids in three dimensions, it is the Burgers vector).

The simplest gravitational theory with torsion, the Einstein–Cartan theory, is a viable one.[2] Incidentally, torsion could be measured by the precession of nuclear spins, even though the effects are expected to be minute in the present-day cosmos.[3]

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What is torsion?

PHYSICS TODAY

Weinberg replies: Sorry, I still don't get it. Is there any physical principle, such as a principle of invariance, that would require the Christoffel symbol to be accompanied by some specific additional tensor? Or that would forbid it? And if there is such a principle, does it have any other testable consequences?

Steven Weinberg
(weinberg@physics.utexas.edu)
University of Texas at Austin

Theories of spacetime

Special Relativity – flat spacetime (no curvature, no torsion)
Variables: matter fields (such as particles, electromagnetism)

More degrees of freedom

General Relativity – (curvature, no torsion)
Variables: matter fields + metric

ECSK Gravity (simplest theory with curvature & **torsion**)
Variables: matter fields + metric + torsion

Why ECSK gravity?

	GR	**ECSK**
Intrinsic angular momentum (spin) of matter couples to spacetime	NO	YES
Matter can form singularities	YES	**NO**

ECSK gravitational repulsion at densities >> nuclear:

- Nonsingular black holes
- **Big bounce** instead of big bang
- Cosmic inflation not needed

Why ECSK gravity?

	GR	ECSK
Dirac equation (describes electrons and quarks, combines quantum mechanics and special relativity) is linear	YES	NO

May explain:

- Dark energy
- Matter-antimatter asymmetry
- Dark matter

Why ECSK gravity?

Does this new treatment conflict with what is already known?

- Torsion significant only at densities >> nuclear
- In vacuum torsion vanishes: ECSK = GR
- **ECSK passes all current GR tests**

Is this treatment testable?

- Cosmology of very early Universe can test ECSK
- Electrons and quarks cannot be point particles in ECSK gravity:

spatial structure at 10^{-25} m

History of torsion

Torsion is older than Schrödinger equation

- Élie Cartan (1921)

torsion

- Dennis Sciama and Tom Kibble (1960s)

spin produces torsion (energy & momentum produce curvature)

T. W. B. Kibble, J. Math. Phys. **2**, 212 (1961)
D. W. Sciama, Rev. Mod. Phys. **36**, 463 (1964)

- Trautman, Kopczyński (1970s)

torsion may avert cosmological singularities (polarized spins)

History of torsion

- Hehl and Datta (1971)

Dirac equation with torsion is nonlinear

- Hehl and collaborators, Kuchowicz (1970s)

torsion induces gravitational repulsion at extremely high densities and **averts cosmological singularities** (unpolarized spins)

→ big-bounce cosmology

Big-bounce cosmology

- Our Universe was contracting before bounce – from what?

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

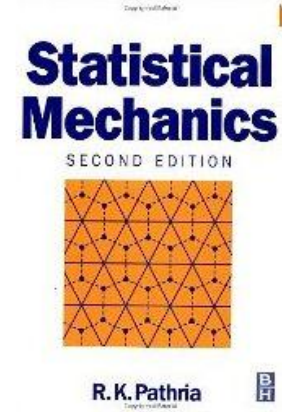
Origin of Universe and nature of black-hole interiors are related

- Our Universe born in a black hole existing in another universe (Pathria 1972, Smolin 1992) – how?

Simplest mechanism – **torsion**

NJP, Phys. Lett. **B** 694, 181 (2010)

Universe in a black hole



R. K. PATHRIA

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Received June 19; revised September 20, 1972.

LETTERS TO NATURE

PHYSICAL SCIENCES

The Universe as a Black Hole

SINCE Einstein applied his general theory of relativity to study the structure of the universe as a whole[1], cosmologists have wondered if the universe is geometrically closed or open. Neither theory nor observation has been able to settle this question unambiguously. Several authors have hoped that the universe may after all be a closed, yet unbounded, system. This would solve many problems regarding the nature and origin of the universe, and would fit many of the observations of distant sources made at radio, optical and other wavelengths[2]. Here I demonstrate that the universe may not only be a closed structure (as perceived by its inhabitants at the present epoch) but may also be a black hole, confined to a localized region of space which cannot expand without limit.

Is the universe itself a black hole? To investigate this question, the customary view of the universe, which is necessarily internal, is not sufficient; it has to be supplemented with an external view—I assume that there exists, outside our universe, an external world from which one may take a "detached" look at our universe. It turns out that these two views are not only mutually compatible but also show considerable similarities. Both views are presented here.

implications as well. For instance, we are now faced with several questions: How did the universe come to be a black hole—through a gravitational collapse, followed by a phase of expansion? In the cosmos, which includes the exterior as well as the interior of the universe, can our universe be unique? If not, what would its status be *vis-a-vis* other such structures in the cosmos? Investigation of these and other related questions, including the possible existence of an hierarchy of black holes, is clearly a matter of some importance.

Every black hole forms a new universe

Class. Quantum Grav. 9 (1992) 173–191. Printed in the UK

Not a resolution

Did the universe evolve?†

Lee Smolin

Department of Physics, Syracuse University, Syracuse, NY 13244-1130, USA

Received 9 May 1991

The mechanism is contained in the following two postulates concerning the physics near spacetime singularities.

(i) Each final singularity is followed by an initial singularity, which evolves into a universe which is spatially closed. An alternative hypothesis, which is equivalent as far as its consequences for the subject of this paper, is that instead of an ending in a final singularity, the interior of a black hole tunnels into a new spatially compact universe. We may note that this hypothesis has been advocated as a resolution for the problem of information loss in black hole evaporation [9] and has also been discussed recently in connection with the baby universe scenario [10].

Black holes as Einstein-Rosen bridges

Physics Letters B 687 (2010) 110–113

Radial motion into an Einstein–Rosen bridge

Nikodem J. Popławski

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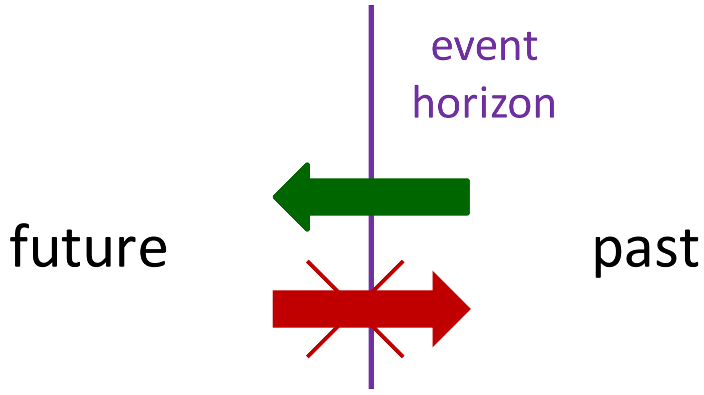
We consider the radial geodesic motion of a massive particle into a black hole in isotropic coordinates, which represents the exterior region of an Einstein–Rosen bridge (wormhole). The particle enters the interior region, which is regular and physically equivalent to the asymptotically flat exterior of a white hole, and the particle's proper time extends to infinity. Since the radial motion into a wormhole after passing the event horizon is physically different from the motion into a Schwarzschild black hole, Einstein–Rosen and Schwarzschild black holes are different, physical realizations of general relativity. Yet for distant observers, both solutions are indistinguishable. We show that timelike geodesics in the field of a wormhole are complete because the expansion scalar in the Raychaudhuri equation has a discontinuity at the horizon, and because the Einstein–Rosen bridge is represented by the Kruskal diagram with Rindler's elliptic identification of the two antipodal future event horizons. These results suggest that observed astrophysical black holes may be Einstein–Rosen bridges, each with a new universe inside that formed simultaneously with the black hole. Accordingly, our own Universe may be the interior of a black hole existing inside another universe.

Arrow of time

- Why does time flow only in one direction?

- Laws of ECKS gravity (and GR) are time-symmetric

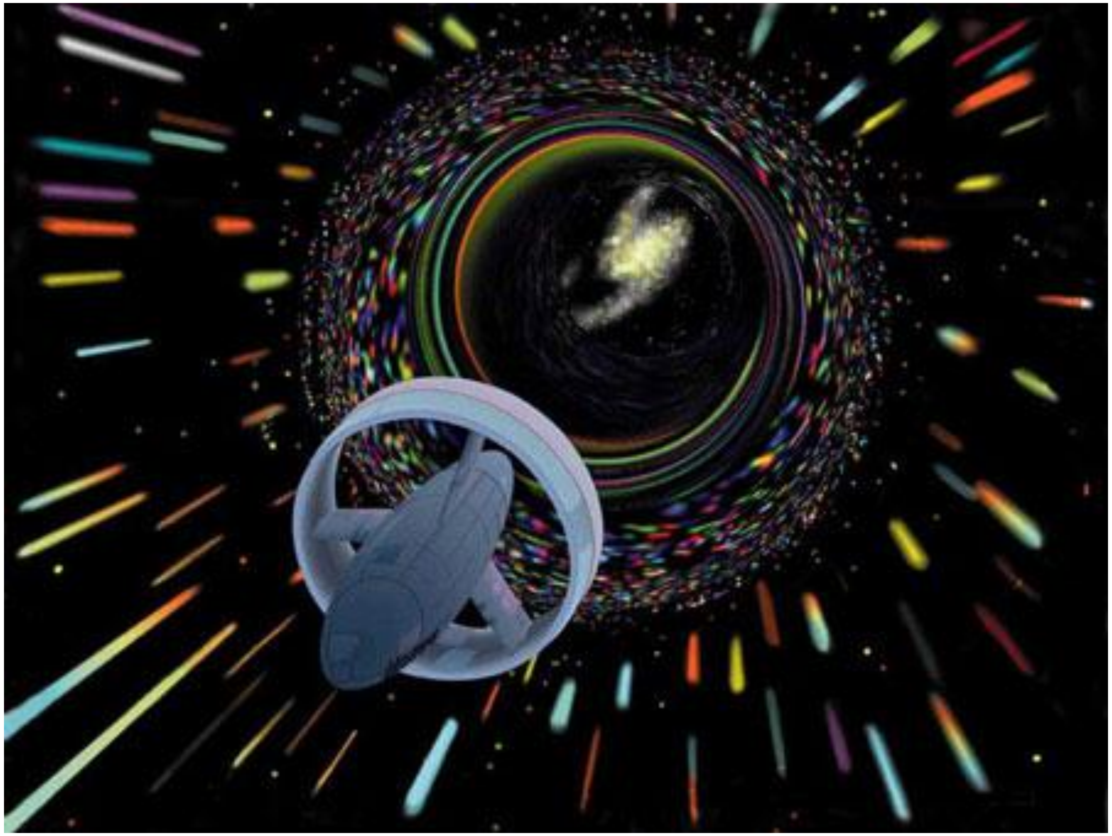
- Boundary conditions of a universe in a black hole (BH) are not: motion of matter through event horizon (EH) is **unidirectional**
→ can define arrow of time



Information not lost

- Arrow of time in the universe fixed by time-asymmetric collapse of matter through EH (before expansion)

How to test that every black hole contains a hidden universe?



To boldly go where no one has gone before

Preferred direction

- Stars rotate → rotating black holes

Universe in a rotating BH inherits its preferred direction

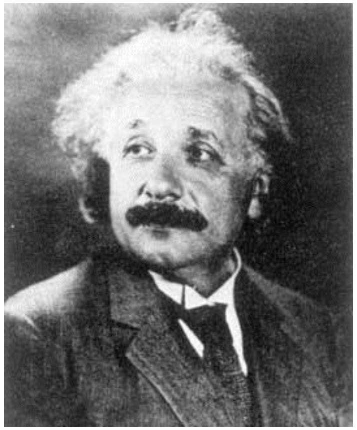
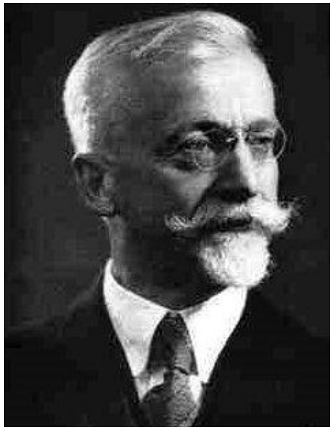
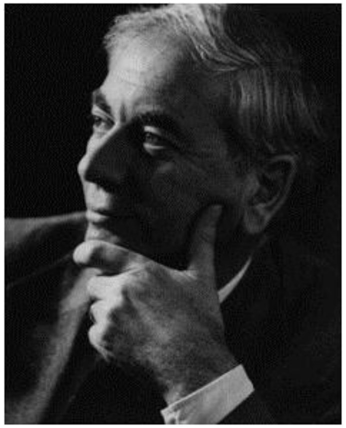
NJP, Phys. Lett. **B** 694, 181 (2010)

Physics Letters B 699 (2011) 224–229

Detection of a dipole in the handedness of spiral galaxies with redshifts $z \sim 0.04$

Michael J. Longo

A preference for spiral galaxies in one sector of the sky to be left-handed or right-handed spirals would indicate a parity violating asymmetry in the overall universe and a preferred axis. This study uses 15,158 spiral galaxies with redshifts < 0.085 from the Sloan Digital Sky Survey. An unbinned analysis for a dipole component that made no prior assumptions for the dipole axis gives a dipole asymmetry of -0.0408 ± 0.011 with a probability of occurring by chance of 7.9×10^{-4}. A similar asymmetry is seen in the southern Galaxy spin catalog of Iye and Sugai. The axis of the dipole asymmetry lies at approx. $(l, b) = (52°, 68.5°)$, roughly along that of our Galaxy and close to alignments observed in the WMAP cosmic microwave background distributions. The observed spin correlation extends out to separations ~ 210 Mpc/h, while spirals with separations < 20 Mpc/h have smaller spin correlations.


Einstein-Cartan-Sciama-Kibble theory of gravity

prevents singularities:
black hole interiors become new universes

T. Kibble, G. Guralnik, C. Hagen, F. Englert, R. Brout
& P. Higgs:

relativistic Anderson-Higgs mechanism

2010 APS Sakurai Prize

ECSK gravity

Lagrange-Hamilton principle of least action describes most of classical physics

- Metric → Einstein equations

Curvature = k · (energy-momentum density)

- Torsion → Cartan equations

Torsion = k · spin density

Same coupling constant k

ECSK gravity

- Torsion significant above densities $\rho_{\mathrm{C}} = \frac{m_{\mathrm{n}}^2 c^4}{G\hbar^2}$

For ordinary matter (electrons, quarks)

$\rho > 10^{45}$ kg m^{-3}

Nuclear matter in neutron stars

$\rho \sim 10^{17}$ kg m^{-3}

Gravitational effects of torsion negligible even for neutron stars

Torsion significant only in very early Universe and in black holes

Big bounce from torsion

- Friedman equations (Einstein equations for Universe) relate expansion of Universe to energy density and pressure of matter: Universe expands or contracts if energy density ≠ 0

- Spin-torsion coupling produces negative contribution to energy density → gravitational repulsion

$$\epsilon_S = -\frac{1}{4}\kappa s^2 \qquad s^2 = \frac{1}{8}(\hbar c n)^2$$

⬇

When total energy density = 0, Universe undergoes a bounce
Regular **big bounce** instead of singular big bang

- Universe starts expanding from a finite minimum radius

Cosmology with torsion

- After the bounce, Universe very rapidly expands, producing many causally disconnected regions and becoming very flat
  - Torsion: “fast” growth
  - Inflation: “large” growth

- Rapid expansion caused by extremely strong gravitational repulsion at the bounce

- When spin-torsion coupling weakens, Universe smoothly transits from torsion era to radiation-domination era (early Universe)

- Unlike inflation, big-bounce cosmology with torsion does not require additional matter fields – advantage of torsion

NJP, Phys. Lett. **B** 694, 181 (2010)

Cosmology with torsion

Physics Letters B 694 (2010) 181–185

Cosmology with torsion: An alternative to cosmic inflation

Nikodem J. Popławski

We propose a simple scenario which explains why our Universe appears spatially flat, homogeneous and isotropic. We use the Einstein–Cartan–Kibble–Sciama (ECKS) theory of gravity which naturally extends general relativity to include the spin of matter. The torsion of spacetime generates gravitational repulsion in the early Universe filled with quarks and leptons, preventing the cosmological singularity: the Universe expands from a state of minimum but finite radius. We show that the dynamics of the closed Universe immediately after this state naturally solves the flatness and horizon problems in cosmology because of an extremely small and negative torsion density parameter, $\Omega_S \approx -10^{-69}$. Thus the ECKS gravity provides a compelling alternative to speculative mechanisms of standard cosmic inflation. This scenario also suggests that the contraction of our Universe preceding the bounce at the minimum radius may correspond to the dynamics of matter inside a collapsing black hole existing in another universe, which could explain the origin of the Big Bang.

Black holes with torsion

- Where does the mass of Universe come from?

Possible solution: stiff matter (speed of sound = speed of light)
Ultradense matter (in neutron stars) is stiff

- Friedman conservation law for stiff matter → mass of collapsing BH increases (external observers do not see it)

- Mass increase occurs via Zel'dovich quantum pair production in strong anisotropic fields

Total energy (matter + gravity) remains constant

Black holes with torsion

- Particle-antiparticle pairs annihilate to radiation
- Radiation isotropizes universe which stops pair production
- Gravitational collapse proceeds until the bounce

Radius of universe at the bounce – 10^{-5} m

$$\frac{2G}{c^2}\left(M_{\mathrm{BH}}^{2/3} m_{\mathrm{Pl}}^{1/6} m_{\mathrm{n}}^{1/6}\right)$$

Mass of universe at the bounce – 10^{62} kg (for a typical BH)

$$M_{\mathrm{BH}}^{2} m_{\mathrm{Pl}}^{-3/2} m_{\mathrm{n}}^{1/2}$$

NJP, arXiv:1105.6127

Black holes with torsion

- After the bounce, universe in BH expands
- Spin-torsion coupling introduces matter-antimatter asymmetry which is significant at extremely high densities
- This asymmetry results in decay asymmetry
- Possible scenario: heavy antifermions in very early Universe decayed into weakly interacting massive particles that form dark matter, while heavy fermions decayed into visible matter

Missing antimatter is hidden as dark matter (2000s)

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

Matter-antimatter asymmetry

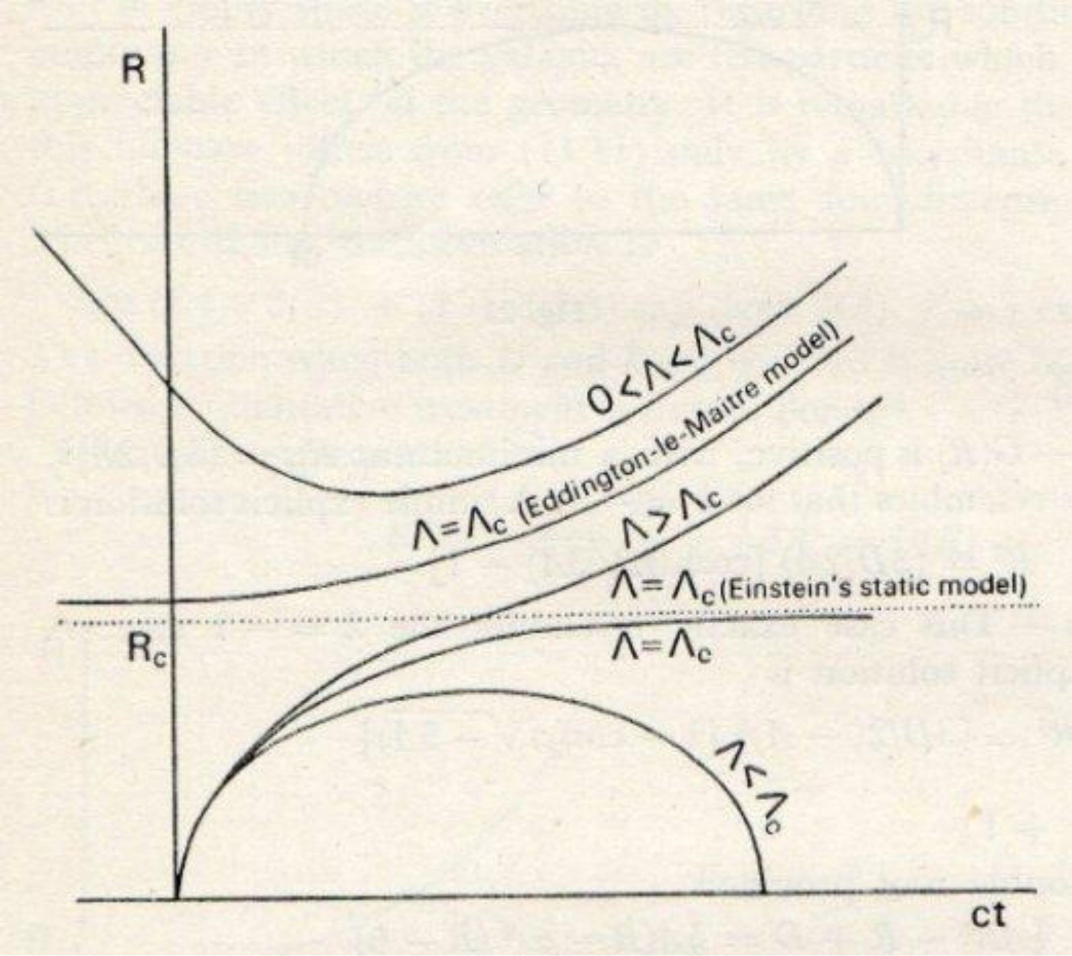
PHYSICAL REVIEW D **83,** 084033 (2011)

Matter-antimatter asymmetry and dark matter from torsion

Nikodem J. Popławski*

We propose a simple scenario which explains the observed matter-antimatter imbalance and the origin of dark matter in the Universe. We use the Einstein-Cartan-Sciama-Kibble theory of gravity which naturally extends general relativity to include the intrinsic spin of matter. Spacetime torsion produced by spin generates, in the classical Dirac equation, the Hehl-Datta term which is cubic in spinor fields. We show that under a charge-conjugation transformation this term changes sign relative to the mass term. A classical Dirac spinor and its charge conjugate therefore satisfy different field equations. Fermions in the presence of torsion have higher energy levels than antifermions, which leads to their decay asymmetry. Such a difference is significant only at extremely high densities that existed in the very early Universe. We propose that this difference caused a mechanism, according to which heavy fermions existing in such a Universe and carrying the baryon number decayed mostly to normal matter, whereas their antiparticles decayed mostly to hidden antimatter which forms dark matter. The conserved total baryon number of the Universe remained zero.

Black holes with torsion



Expansion to infinity if mass of Universe exceeds

$$\frac{c^2}{3G\sqrt{\Lambda}}$$

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

Dark energy

- Quark-to-hadron transition in early Universe and torsion produce a small, positive cosmological constant

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

- Only 10^5 times larger than observed value

- Contribution from leptons could decrease it

- Simplest model predicting small, positive cosmological constant – does not use new fields

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

Dark energy

Ann. Phys. (Berlin) **523**, No. 4, 291 – 295 (2011)

Cosmological constant from quarks and torsion

Nikodem J. Popławski*

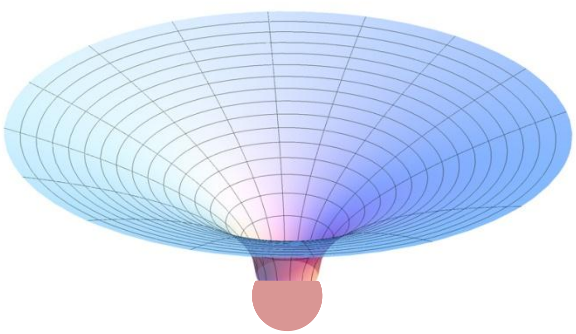
We present a simple and natural way to derive the observed small, positive cosmological constant from the gravitational interaction of condensing fermions. In the Riemann-Cartan spacetime, torsion gives rise to the axial–axial vector four-fermion interaction term in the Dirac Lagrangian for spinor fields. We show that this nonlinear term acts like a cosmological constant if these fields have a nonzero vacuum expectation value. For quark fields in QCD, such a torsion-induced cosmological constant is positive and its energy scale is only about 8 times larger than the observed value. Adding leptons to this picture could lower this scale to the observed value.

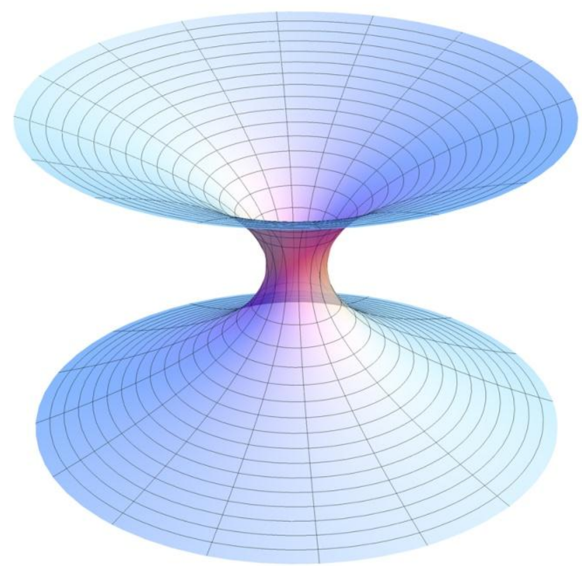
Black holes with torsion

- Universe in a BH invisible for observers outside

(EH formation and everything after occur after infinite time)

- As universe in a BH expands to infinity, BH becomes an Einstein-Rosen bridge (Flamm 1916, Weyl 1917, Einstein & Rosen 1935) connecting this (child) universe with the outer (parent) universe





Parent universe appears for its child as the only white hole

Black holes with torsion

Spherically symmetric, vacuum solutions of GR (& ECSK):

- **Schwarzschild black hole** - singular

Final stage of collapse of most massive stars in GR

- **Schwarzschild white hole** - singular

Cannot form

- **Einstein-Rosen bridge (wormhole)** - regular

Final stage of collapse of most massive stars in ECSK

GR & ECSK predict different mathematical solutions as final stages of gravitational collapse of stars

ECSK solution is advantageous over GR solution

Summary

Thank you!

- The Einstein-Cartan-Kibble-Sciama gravity accounts for spin of elementary particles, which equips spacetime with **torsion**.

- For fermionic matter at very high densities, torsion manifests itself as gravitational repulsion that prevents the formation of singularities in black holes and at big bang.

- Every black hole produces a new universe inside its event horizon.

- Our Universe may be the interior of a black hole existing in another universe. Big bounce instead of big bang.

- Torsion solves flatness and horizon problems without inflation.

- Nonlinearity of Dirac equation with torsion may explain matter-antimatter asymmetry, dark matter, and dark energy.

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