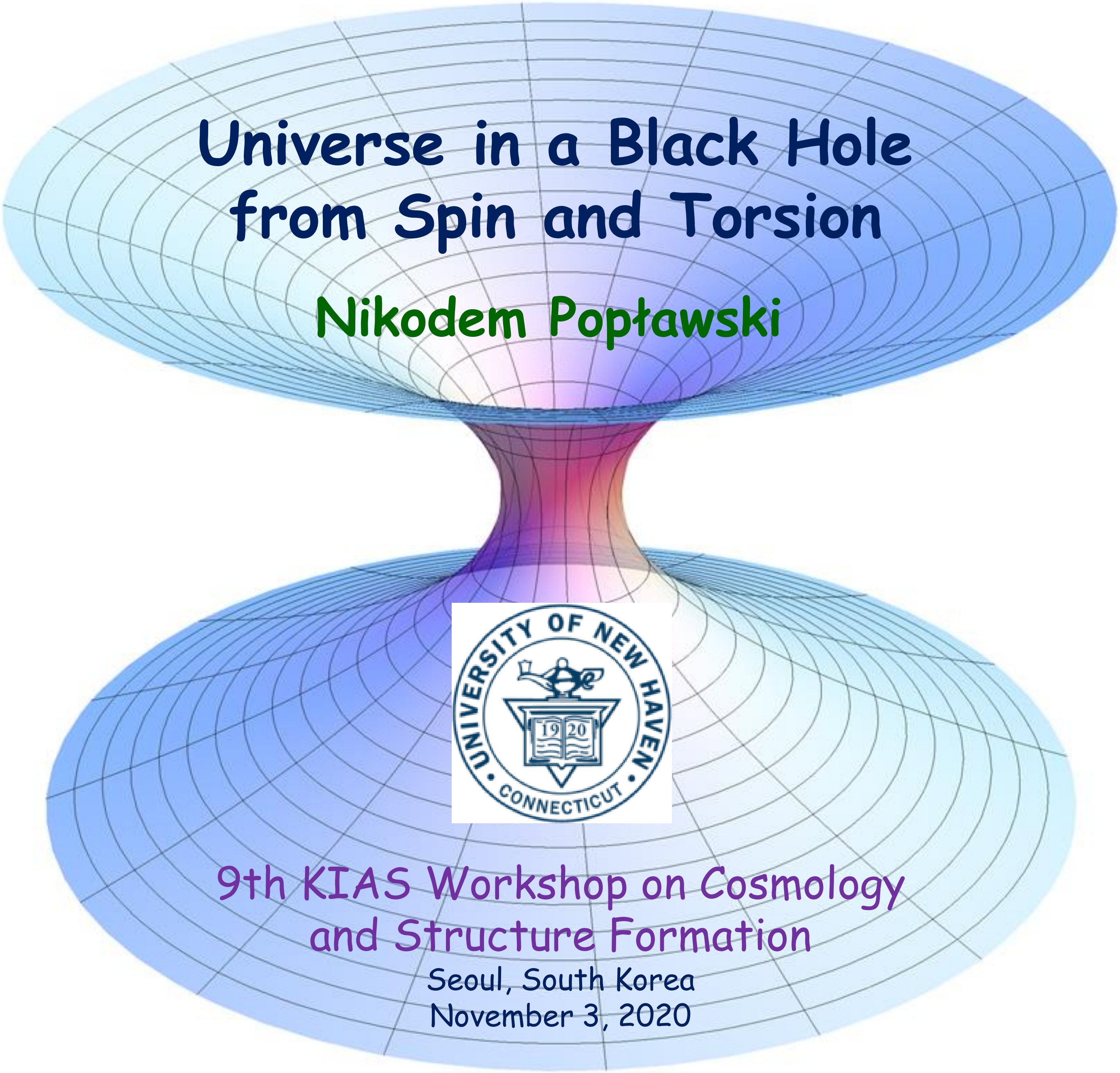

Universe in a Black Hole from Spin and Torsion

Nikodem Popławski

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Universe in a black hole

- The conservation law for total angular momentum in curved spacetime, consistent with Dirac equation, requires that the affine connection has antisymmetric part: torsion. In the simplest theory with torsion, Einstein-Cartan gravity, the torsion tensor is generated by spin of fermions.
- Gravitational collapse of a spherically symmetric sphere of a spin fluid creates an event horizon. The matter within the horizon collapses to extremely high densities, at which torsion acts like gravitational repulsion.
- Without shear, torsion prevents a singularity and replaces it with a nonsingular bounce. With shear, torsion prevents a singularity if the number of fermions increases during contraction via quantum particle production.
- Particle production during expansion produces enormous amounts of matter and can generate a finite period of inflation. The resulting closed universe on the other side of the event horizon may have several bounces. Such a universe is oscillatory, with each cycle larger in size then the previous cycle, until it reaches the cosmological size and expands indefinitely.

Einstein-Cartan-Sciama-Kibble gravity

- Action variation with respect to metric and **torsion**. $S^k{}_{ij} = \Gamma^{\ k}_{[i\ j]}$
- Covariant derivative of metric is zero. Lagrangian density is proportional to Ricci scalar (as in GR).
- Cartan equations:

Torsion is proportional to **spin** density of fermions. ECSK differs significantly from GR at densities > 10^{45} kg/m^3; passes all tests.

$$S_{jik} - S_i g_{jk} + S_k g_{ji} = -\frac{1}{2}\kappa s_{ikj}$$

arXiv:0911.0334

- Einstein equations: torsion terms moved to RHS.

Curvature is proportional to **energy and momentum** density.

$$G^{ik} = \kappa T^{ik} + \frac{1}{2}\kappa^2\left(s^{ij}{}_j s^{kl}{}_l - s^{ij}{}_l s^{kl}{}_j - s^{ijl} s^k{}_{jl} + \frac{1}{2}s^{jli} s_{jl}{}^k + \frac{1}{4}g^{ik}(2s_j{}^l{}_m s^{jm}{}_l - 2s_j{}^l{}_l s^{jm}{}_m + s^{jlm} s_{jlm})\right)$$

Gravitational collapse of spin fluid sphere

Dirac particles can be averaged macroscopically as a spin fluid.

$s^{\mu\nu\rho} = s^{\mu\nu}u^{\rho}$ $\qquad s^{\mu\nu}u_{\nu} = 0$ $\qquad s^2 = s^{\mu\nu}s_{\mu\nu}/2$

Collapse can be parametrized by the closed FLRW metric. Einstein-Cartan equations become Friedmann equations for scale factor *a*.

$$\frac{\dot{a}^2}{c^2} + 1 = \frac{1}{3}\kappa\left(\epsilon - \frac{1}{4}\kappa s^2\right)a^2$$
$$\frac{\dot{a}^2 + 2a\ddot{a}}{c^2} + 1 = -\kappa\left(p - \frac{1}{4}\kappa s^2\right)a^2$$

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

Spin and torsion modify the energy density and pressure with a negative term proportional to the square of the fermion number density *n*, which acts like repulsive gravity.

NP, PLB 694, 181 (2010); **arXiv:2008.02136**.

Torsion generating nonsingular bounce

For relativistic matter, Friedmann equations can be written in terms of temperature: $\varepsilon \approx 3p \sim T^4$, $n \sim T^3$, and put in nondimensional form with temperature x and scale factor y:

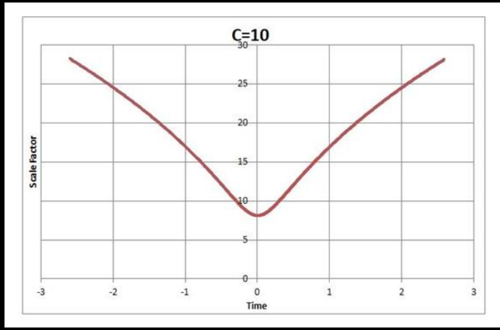
$$\frac{\dot{a}^2}{c^2} + 1 = \frac{1}{3}\kappa(h_\star T^4 - \alpha h_{nf}^2 T^6)a^2$$

$$\frac{\dot{a}}{a} + \frac{\dot{T}}{T} = 0 \qquad \alpha = \kappa(\hbar c)^2/32$$

$$\dot{y}^2 + 1 = (3x^4 - 2x^6)y^2$$

$$xy = C > 0$$

$$\dot{y}^2 + 1 = \frac{3C^4}{y^2} - \frac{2C^6}{y^4}$$



Two turning points ($\dot{y} = 0$) for a closed Universe with torsion exist if C > $(8/9)^{1/2}$. They are positive – **no cosmological singularity!**

NP, ApJ 832, 96 (2016); G. Unger & NP, ApJ 870, 78 (2019).

Particle production generating inflation

Near a bounce, particle production enters through a term ~ H^4, with β as a production parameter.

$$\frac{\dot{a}}{a}\Big[1-\frac{3\beta}{c^3 h_{n1} T^3}\Big(\frac{\dot{a}}{a}\Big)^3\Big]=-\frac{\dot{T}}{T}$$

To avoid eternal inflation: the β term < 1, so $\beta < \beta_{cr} \approx 1/929$.

For $\beta \approx \beta_{cr}$ and during an expansion phase, when $H = \dot{a}/a$ reaches a maximum, the β term is slightly lesser than 1 and:

T ~ const, H ~ const.

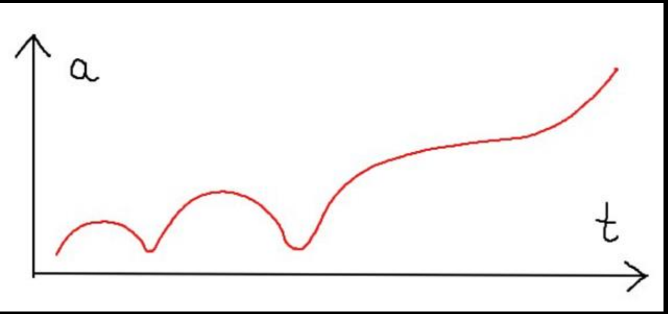
Exponential expansion lasts about t_{Planck} then H and T decrease. Inflation ends when torsion weakens. No scalar fields needed. Dynamics similar to plateau-like inflation & consistent with CMB. S. Desai & NP, PLB 755, 183 (2016).

Torsion & particle production: opposing shear and generating matter & entropy

Shear opposes torsion in Raychaudhuri equation. Shear and torsion terms grow with decreasing scale factor according to a^{-6}. To avoid singularity, fermion number density must grow faster than a^{-3}. This condition during a contracting phase can happen because of particle production.

If quantum effects in the gravitational field near a bounce do not produce enough matter, then the closed Universe reaches the maximum size and then contracts to another bounce, beginning the new cycle. Because of matter production, a new cycle reaches larger size and last longer than the previous cycle.

β/β_{cr}	Number of bounces
0.996	1
0.984	2
0.965	3
0.914	5
0.757	10



When the Universe reaches a size at which the cosmological constant is dominating, then it avoids another contraction and starts expanding to infinity.