Big Bounce and Inflation from Spin and Torsion

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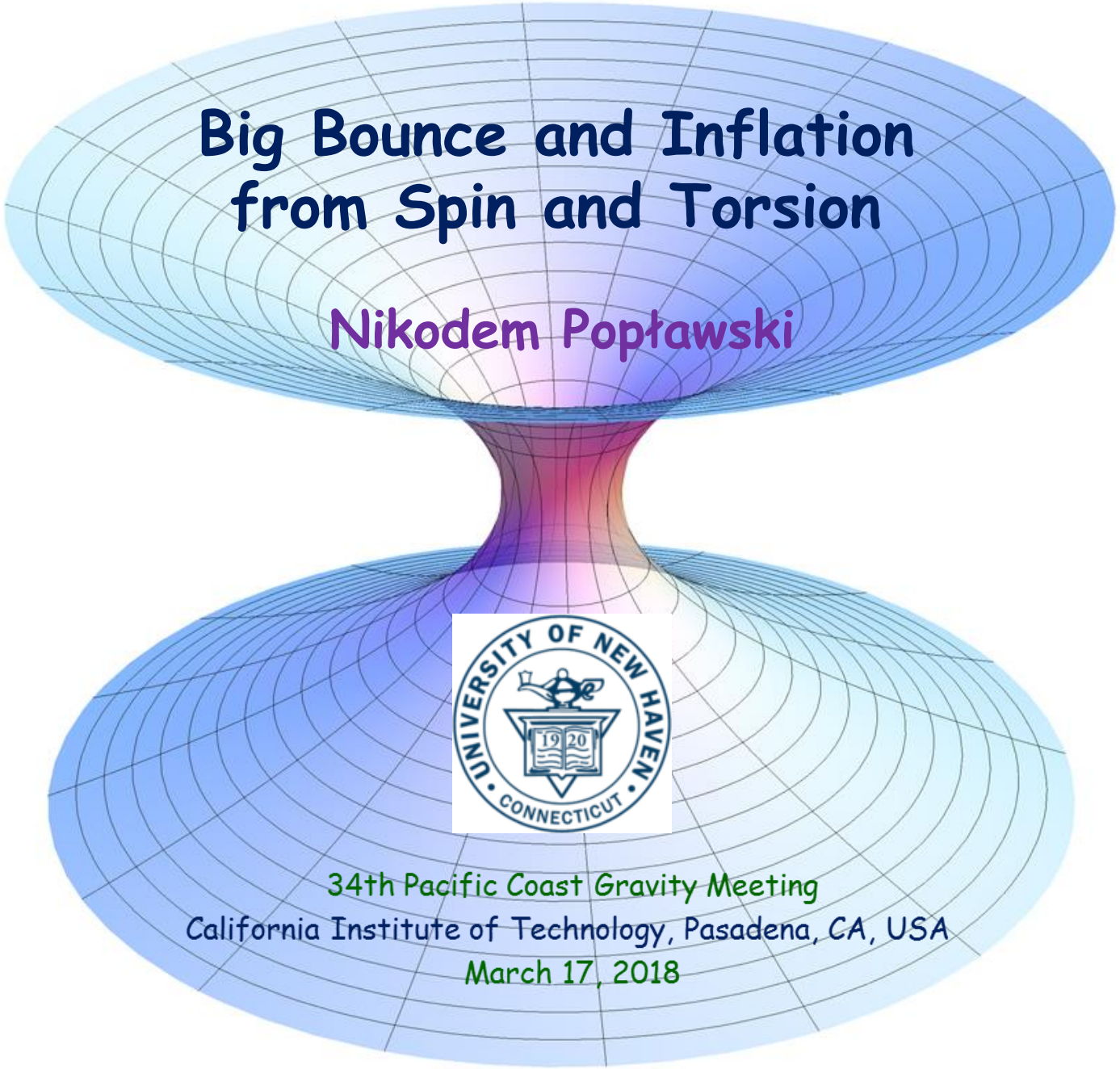

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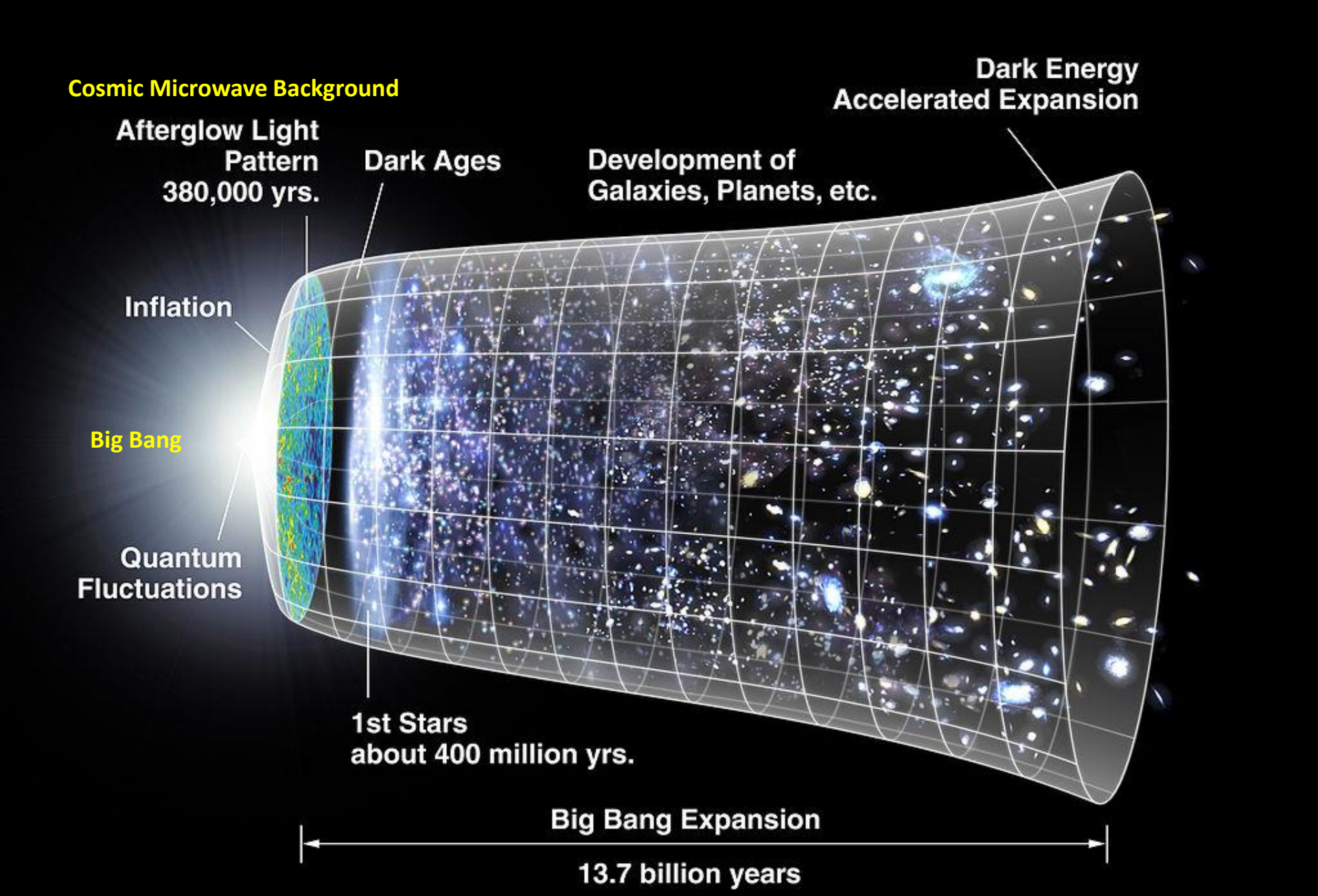


Problems of general relativity

General relativity describes gravity as curvature of spacetime.

- Singularities: points with infinite density of matter.
- Incompatible with quantum mechanics. We need quantum gravity. It may resolve the singularity problem.
- Field equations contain the conservation of orbital angular momentum, contradicting Dirac equation which gives the conservation of total angular momentum (orbital + spin) and allows spin-orbit exchange.

Simplest extension of GR to include QM spin: **Einstein-Cartan theory**. It also resolves the singularity problem.

Problems of Big-Bang cosmology & inflation

- Big-Bang singularity.
- What caused the Big Bang? What existed before?
- Inflation (exponential expansion of the early Universe) solves the flatness and horizon problems, and predicts the observed spectrum of CMB perturbations. What caused inflation? (scalar fields are usually used)
- Why did inflation end? (no eternal inflation)

Einstein-Cartan theory replaces the singular Big Bang by a non-singular **Big Bounce**. The dynamics immediately after the bounce explains the flatness/horizon problems. NP, PLB 694, 181 (2010).

Einstein-Cartan-Sciama-Kibble gravity

- Spacetime has curvature and **torsion**. $S^{k}{}_{ij} = \Gamma^{k}{}_{[i\,j]}$

- Lagrangian density is proportional to Ricci scalar (as in GR).

- Cartan equations:

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

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

arXiv.org > gr-qc > arXiv:0911.0334

- Einstein equations:

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

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

Universe with spin fluid

Dirac particles can be averaged macroscopically as a spin fluid.

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

Einstein-Cartan equations for a (closed) FLRW Universe become Friedmann equations.

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

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

Spin and torsion modify the energy density and pressure with a negative term proportional to the square of the fermion number density, which acts like repulsive gravity and prevents the scale factor *a* from reaching zero. The Big-Bang singularity is avoided.

Universe with spin fluid

For relativistic matter, Friedmann equations can be written in terms of temperature.

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

$$\alpha=\kappa(\hbar c)^2/32$$

$$\frac{\dot{a}}{a}+\frac{\dot{T}}{T}=\frac{cK}{3h_{n1}T^3},$$

$$K=\beta(\kappa\tilde{\epsilon})^2,$$

Parker-Starobinskii-Zel'dovich particle production rate *K*, proportional to the square of curvature, produces matter and entropy in the Universe. No reheating needed.

NP, ApJ 832, 96 (2016)

Generating inflation with only 1 parameter

Near a bounce:

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

To avoid eternal inflation: < 1 -> $\beta < \beta_{cr} \sim 1/929$.

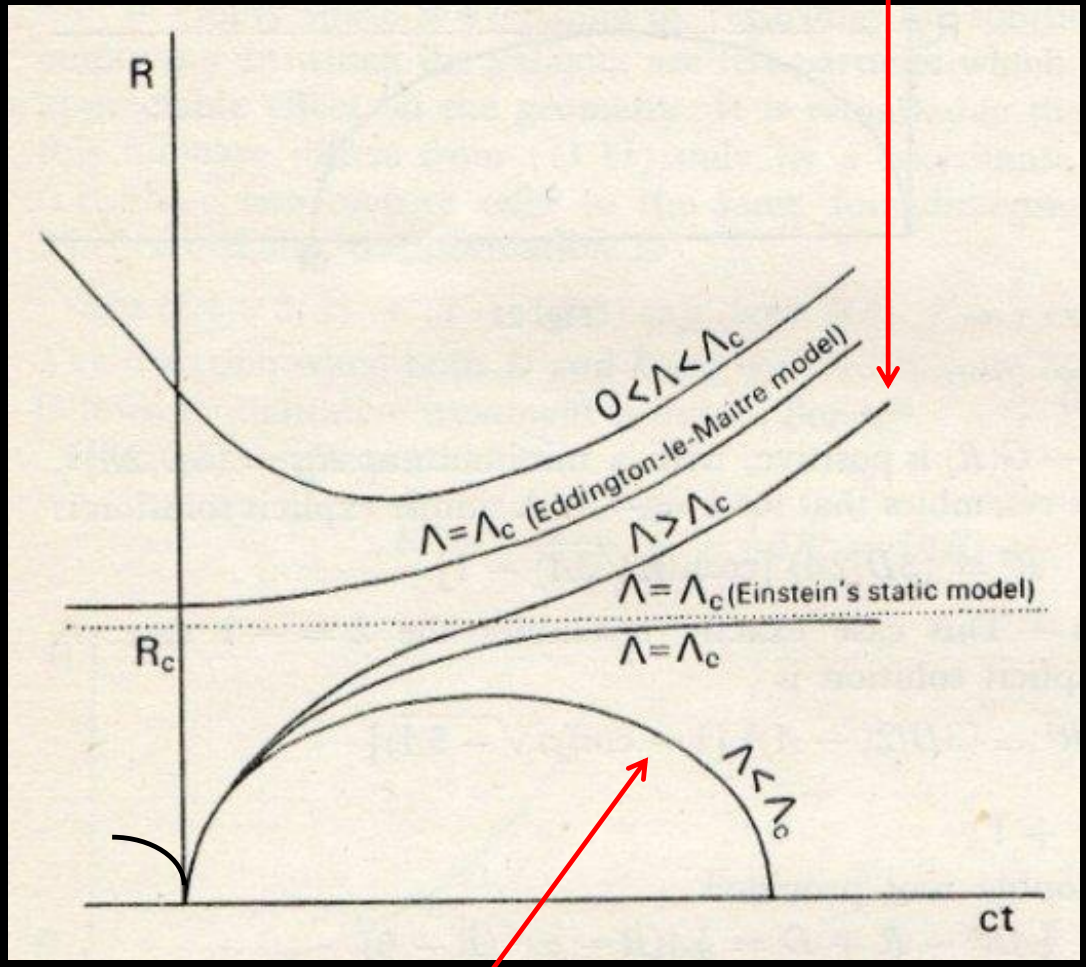
During an expansion phase, near the critical value of particle production coefficient β, when $H = \dot{a}/a$ reaches a maximum:

~ 1, $T \sim$ const, $H \sim$ const.

Exponential expansion lasts about t_{Planck} then H and T decrease.

Torsion becomes weak, inflation ends, and radiation dominated era begins. No scalar fields needed.

If quantum effects in the gravitational field near a bounce produce enough matter, then the closed Universe can reach a size at which dark energy becomes dominant and expands to infinity.



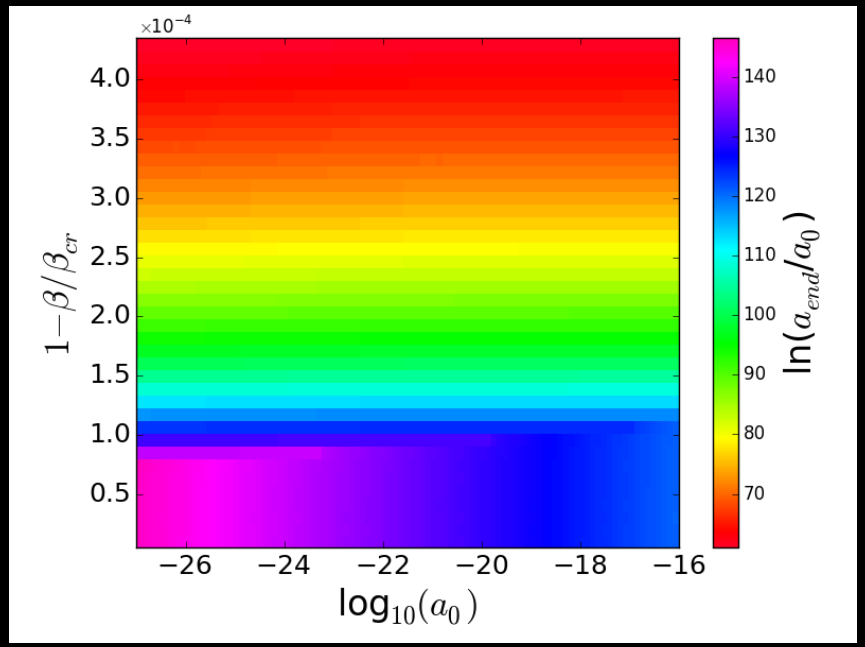
Otherwise, the Universe contracts to another bounce (with larger scale factor) at which it produces more matter, and expands again.

(Image: Lord, *Tensors, Relativity, and Cosmology*.)

- The temperature at a bounce is on the order of T_{Planck} and depends on the number of particle species.
- The numbers of bounces and e-folds depend on the particle production but are not too sensitive to the initial scale factor.
- The Big Bang was the last bounce (Big Bounce).

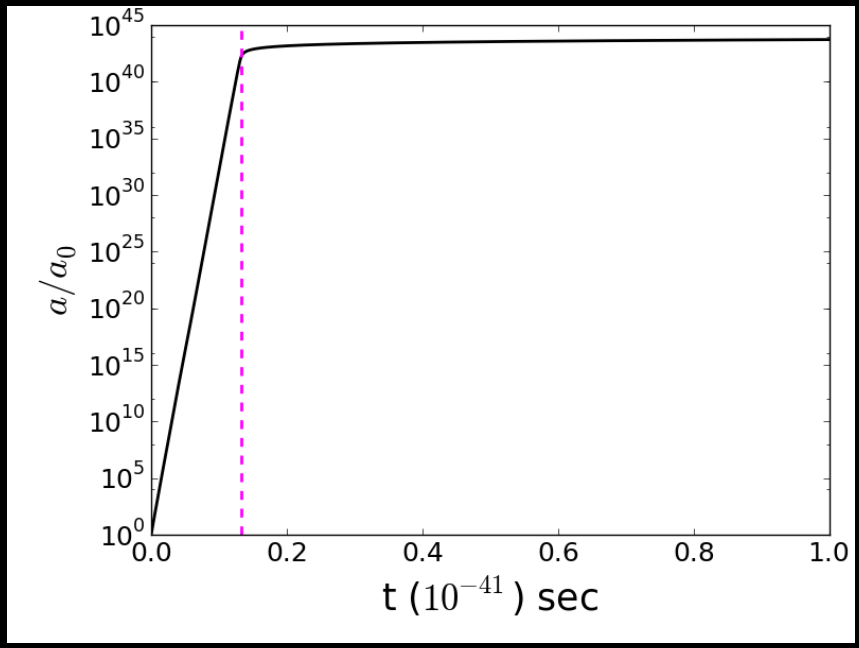
β/β_{cr}	Number of bounces
0.996	1
0.984	2
0.965	3
0.914	5
0.757	10

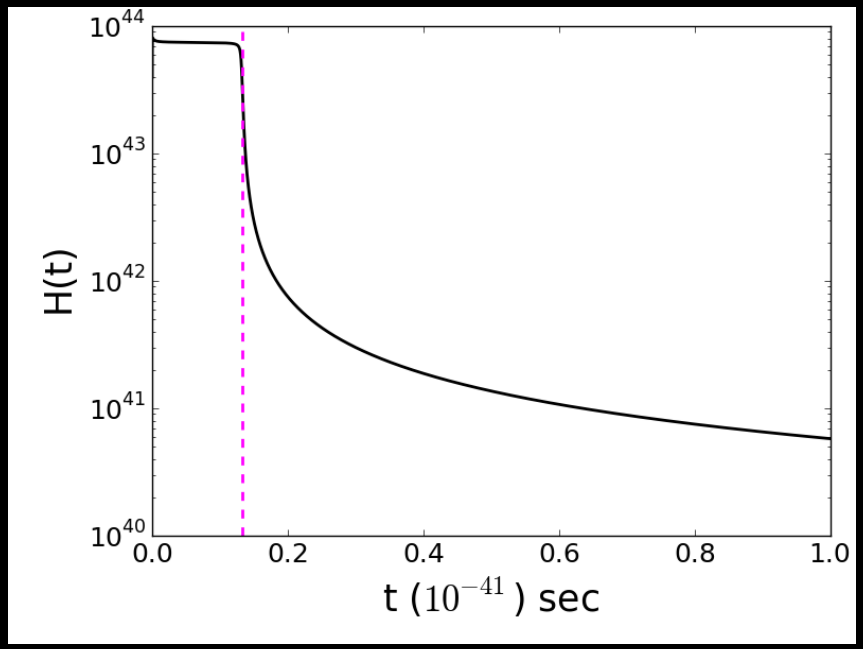
The Universe might have originated from the interior of a black hole. Accordingly, every black hole may create a new, baby universe on the other side of its event horizon and become a wormhole (Novikov, Pathria, Hawking, Smolin, NP).

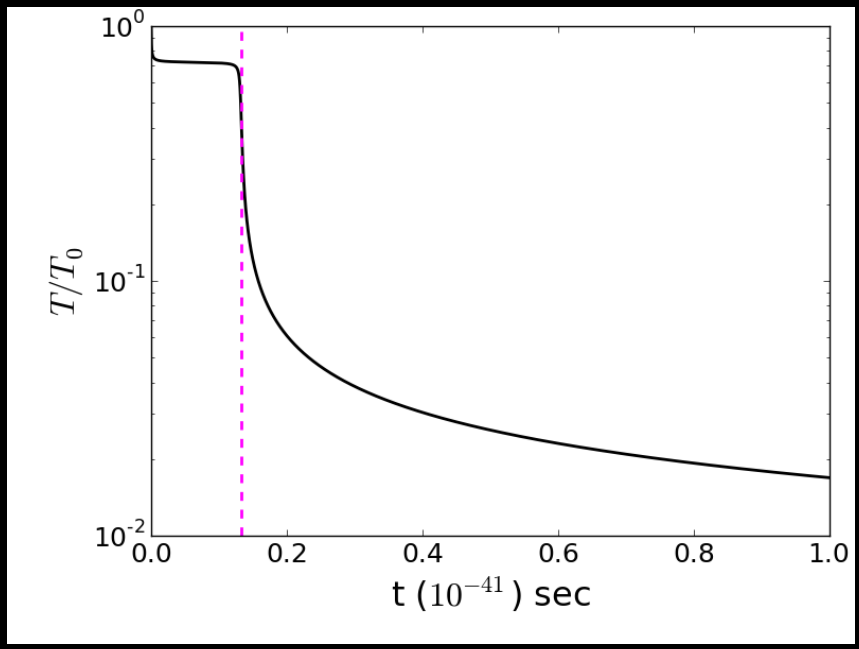


Dynamics of the early Universe

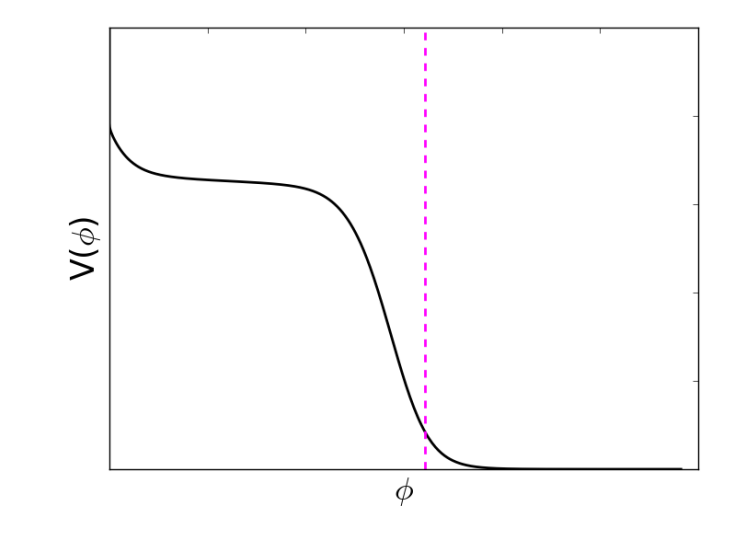
$\beta/\beta_{cr} = 0.9998$







It is possible to find a scalar field potential which generates the same time dependence of the scale factor.

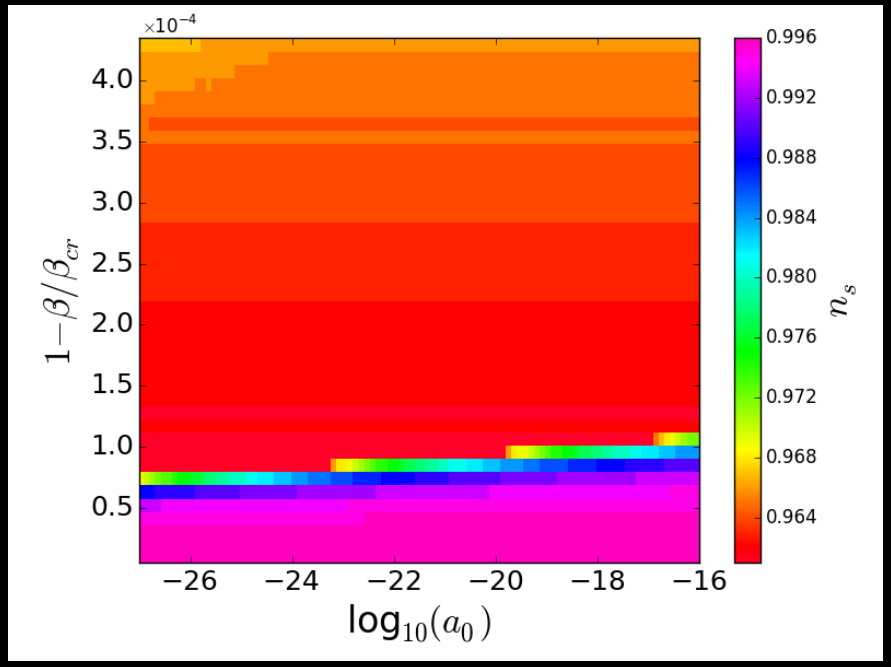


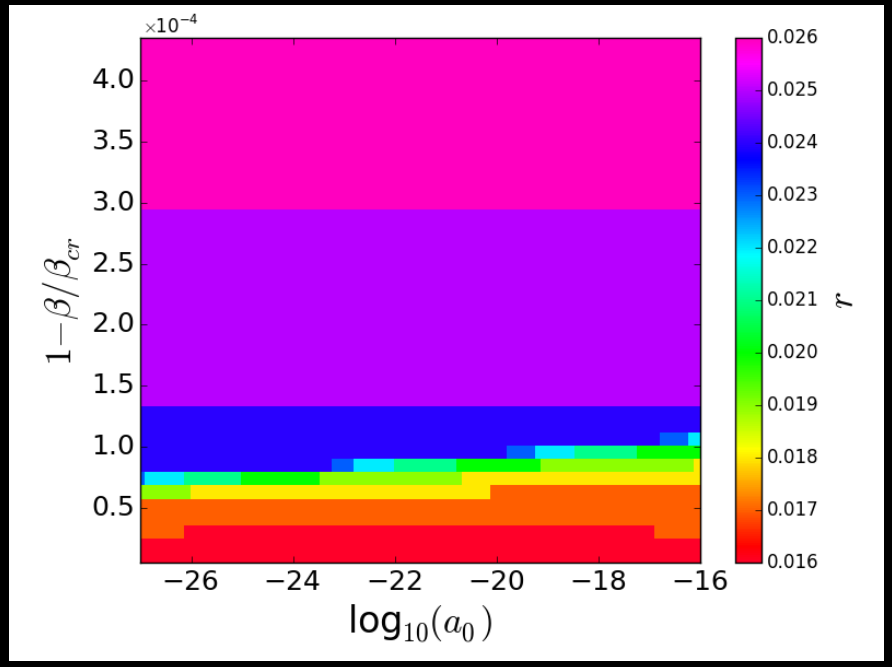
Plateau-like potential – favored by Planck 2013.

Scalar-field plateau models of inflation: initial conditions problem, eternal inflation, unlikelihood (compared to power-law), several parameters.

Torsion cosmology avoids those problems with only 1 parameter.

From the equivalent scalar field potential, one can calculate the parameters which are being measured in CMB.





Consistent with Planck 2015.

S. Desai & NP, PLB 755, 183 (2016)

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References:

Kibble, JMP 2, 212 (1961)
Sciama, RMP 36, 463 (1964)
Hehl, von der Heyde & Kerlick, PRD 10, 1066 (1974)
Ellis & Madsen, CQG 8, 667 (1991)
Ijjas, Steinhardt & Loeb, PLB 723, 261 (2013)
NP, PLB 694, 181 (2010); PRD 85, 107502 (2012); ApJ 832, 96 (2016)
Desai & NP, PLB 755, 183 (2016)

Summary

- The conservation law for total angular momentum (orbital + spin) in curved spacetime, consistent with Dirac equation, requires torsion.

- The simplest theory with torsion, Einstein-Cartan gravity, has the same Lagrangian as GR.

- Torsion is strong only at extremely high densities and manifests itself as gravitational repulsion that avoids the formation of singularities. The Big Bang was a nonsingular bounce.

- Particle production at the bounce can generate a finite period of inflation which ends when torsion becomes weak. No hypothetical fields or extra dimensions are needed. The dynamics is plateau-like and supported by the Planck data.

- EC gravity is the simplest and most natural explanation of the Big Bounce and inflation.