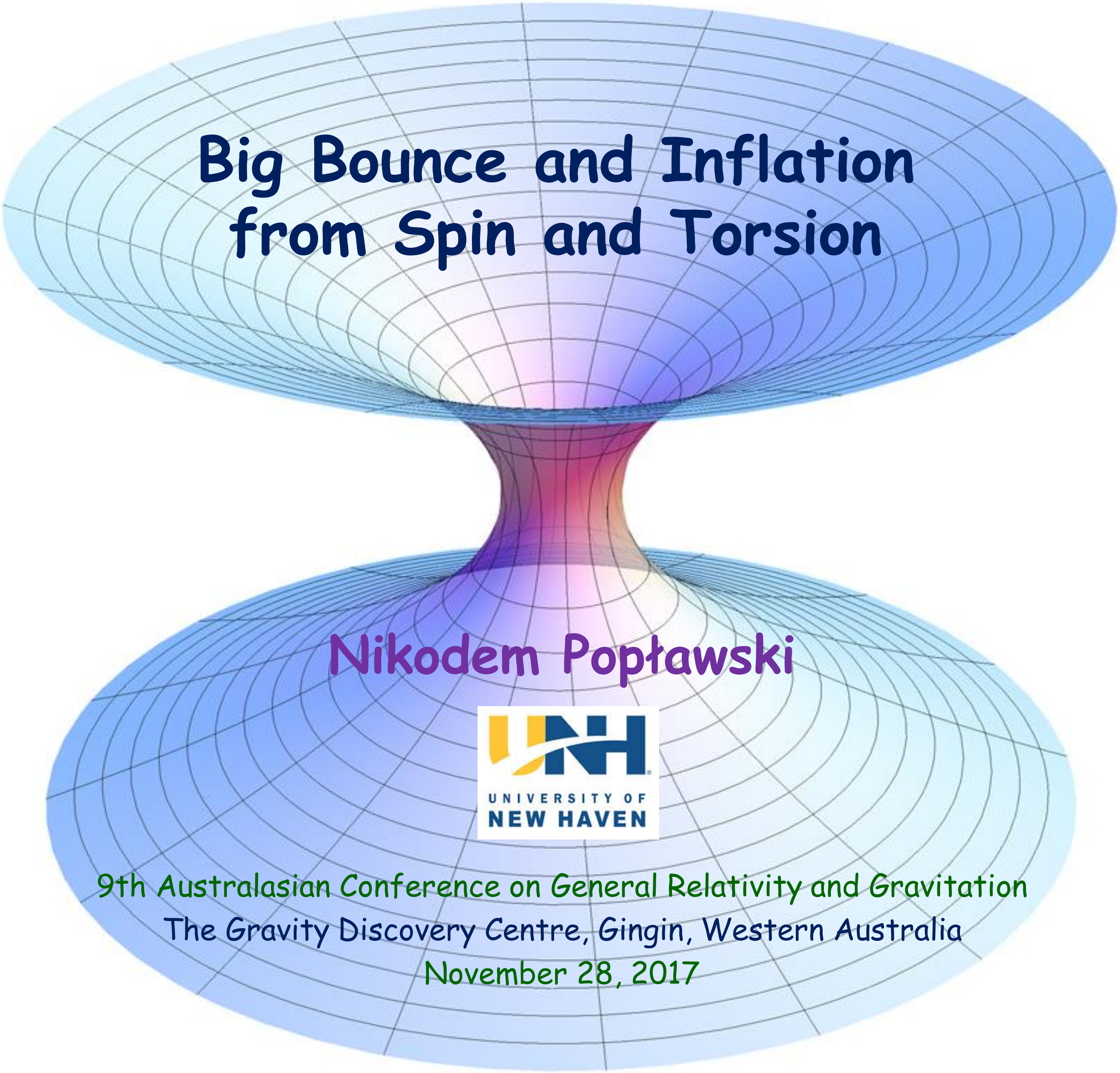

Big Bounce and Inflation from Spin and Torsion

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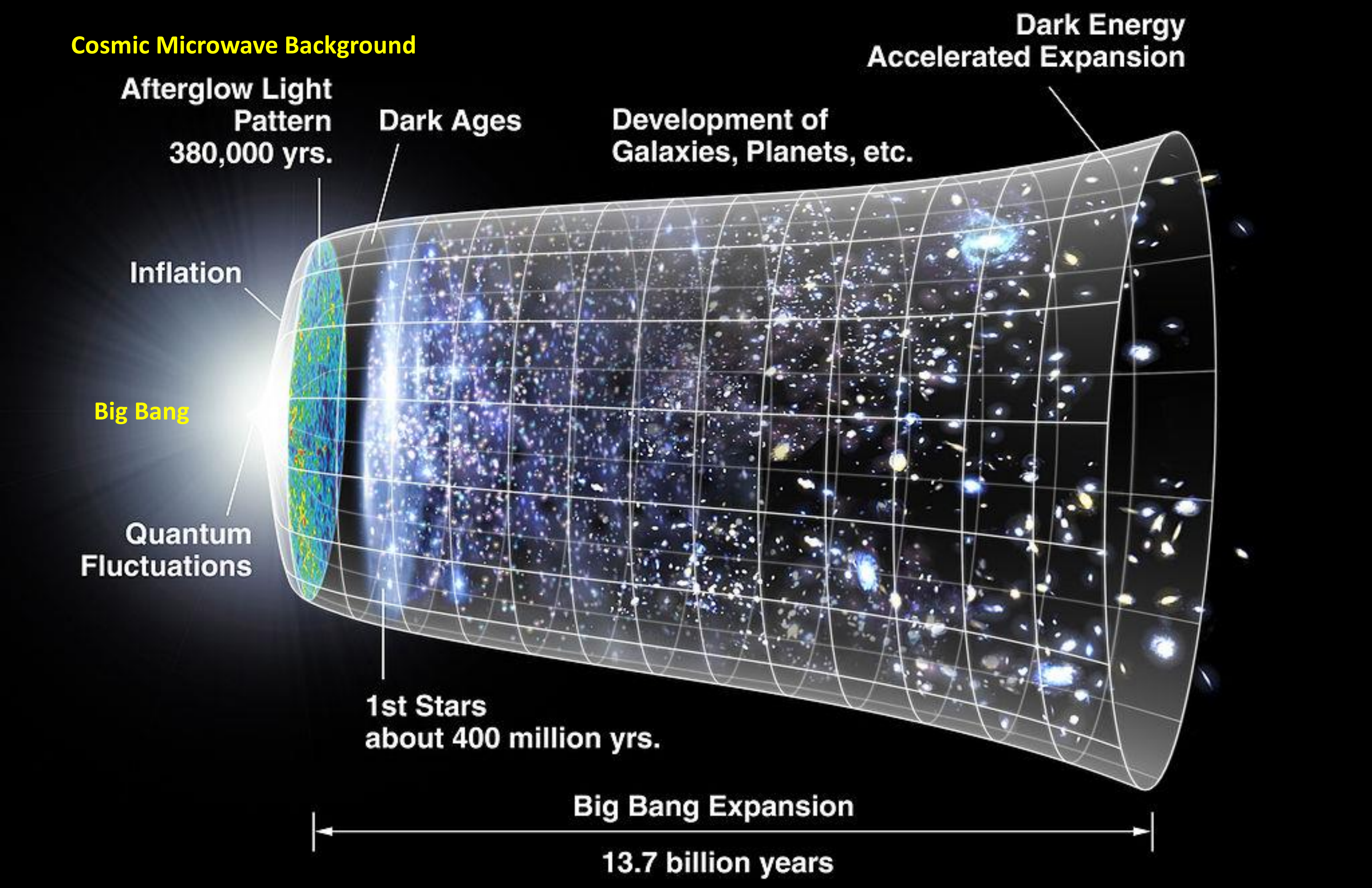

Cosmic Microwave Background
Afterglow Light Pattern 380,000 yrs.
Dark Ages
Development of Galaxies, Planets, etc.
Dark Energy Accelerated Expansion
Inflation
Big Bang
Quantum Fluctuations
1st Stars about 400 million yrs.
Big Bang Expansion
13.7 billion years

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**.

$$S^k{}_{ij} = \Gamma^{\ k}_{[i\ j]}$$

- Cartan equations:

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

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

arXiv.org > gr-qc > arXiv:0911.0334

- Einstein equations:

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

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

Universe with spin fluid

Dirac particles can be averaged macroscopically as a spin fluid.

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

Einstein-Cartan equations for a (closed) FLRW Universe become Friedman 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 with a negative term proportional to the square of the fermion number density, which acts like repulsive gravity and prevents the scale factor from reaching zero. The Big Bang singularity is avoided.

Universe with spin fluid

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

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

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

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

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

2nd Friedman equation is rewritten as 1st law of thermodynamics for constant entropy. Parker-Starobinskii-Zel'dovich particle production rate *K*, proportional to the square of curvature, produces 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: $\beta < \beta_{\rm cr} = \frac{\sqrt{6}}{32}\frac{h_{n1}h_{nf}^3(\hbar c)^3}{h_\star^3} \approx \frac{1}{929}$

During an expansion phase, near critical value of particle production coefficient β:

$$\dot{T} \approx 0$$

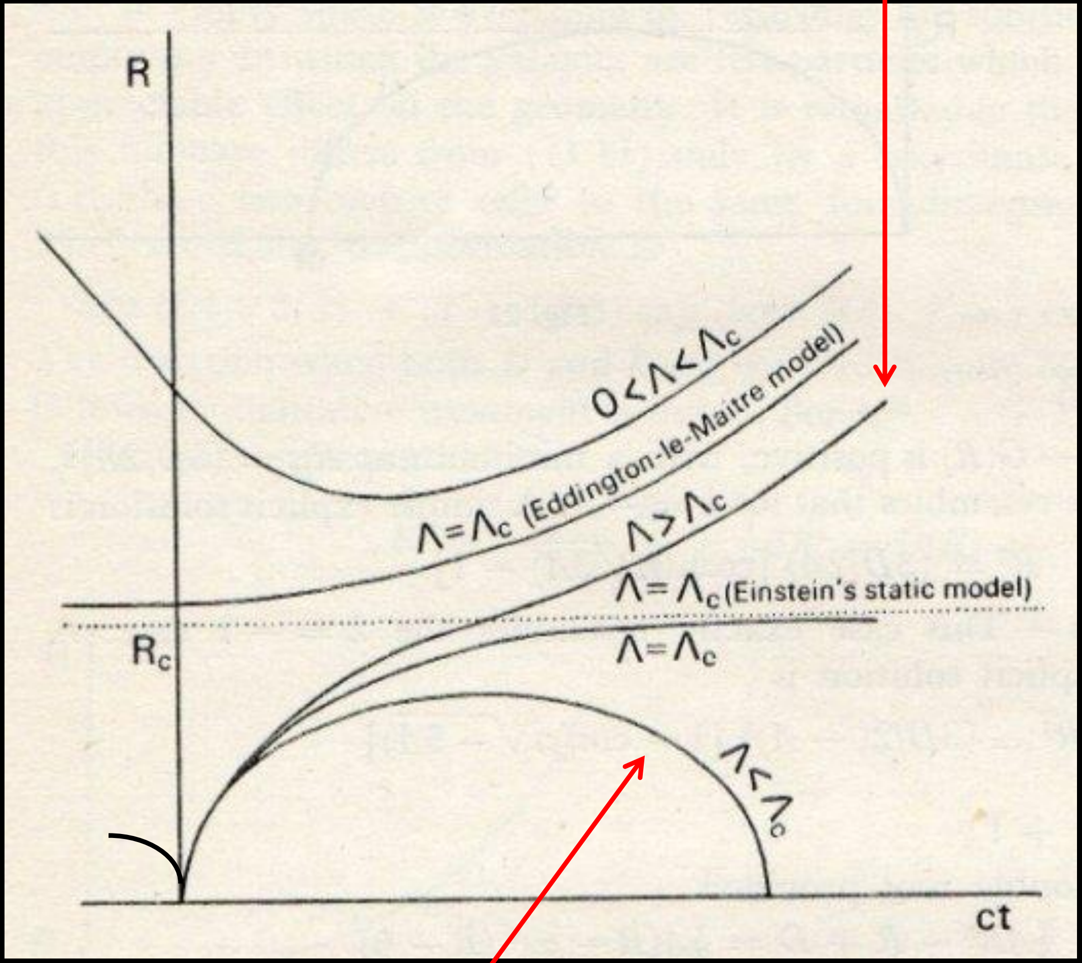
$$\frac{\dot{a}}{a} \approx \frac{c\beta(\kappa\tilde{\epsilon})^2}{3h_{n1}T^3} \approx c\left(\frac{1}{3}\kappa\tilde{\epsilon}\right)^{1/2}$$

$$\tilde{\epsilon} \approx \frac{h_\star^3}{8\alpha^2 h_{nf}^4}$$

Exponential expansion lasts about $\tau = \frac{\alpha h_{nf}^2}{c}\left(\frac{3}{\kappa h_\star^3}\right)^{1/2}$ then *T* decreases.

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.

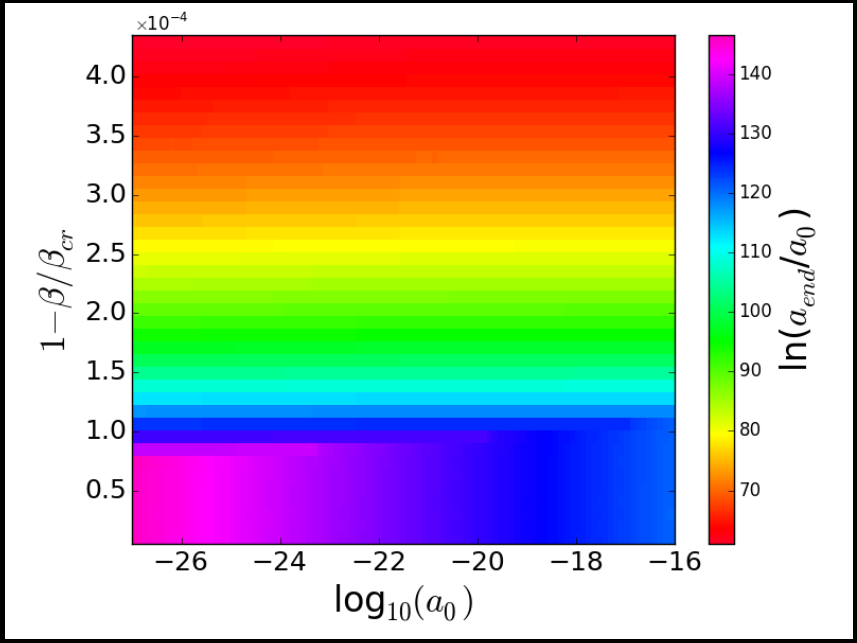
(Image: Lord, *Tensors, Relativity, and Cosmology*.)

- The temperature at a bounce depends on the number of elementary particles and the Planck temperature.

- Numerical integration of the equations shows that the numbers of bounces and e-folds depend on the particle production coefficient but are not too sensitive to the initial scale factor.

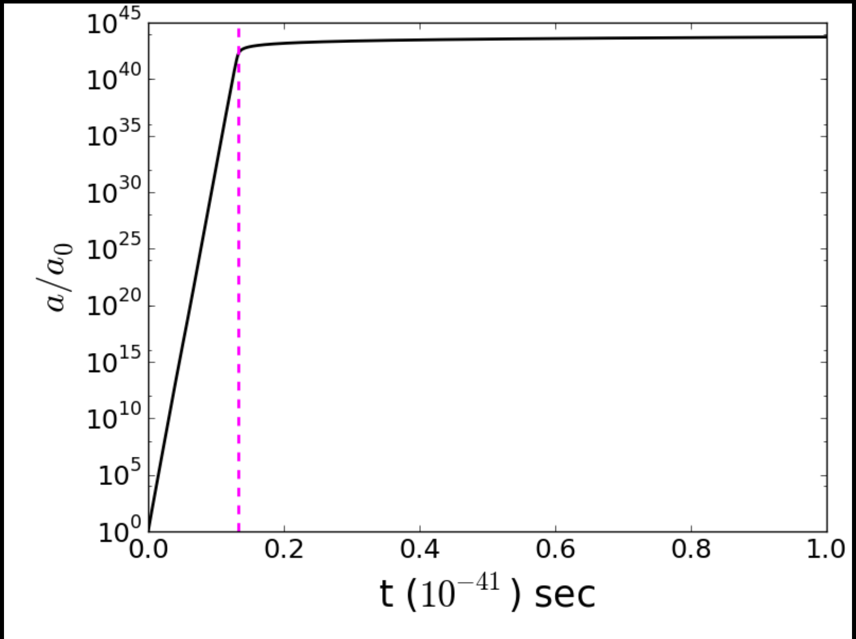
β/β_{cr}	Number of bounces
0.996	1
0.984	2
0.965	3
0.914	5
0.757	10

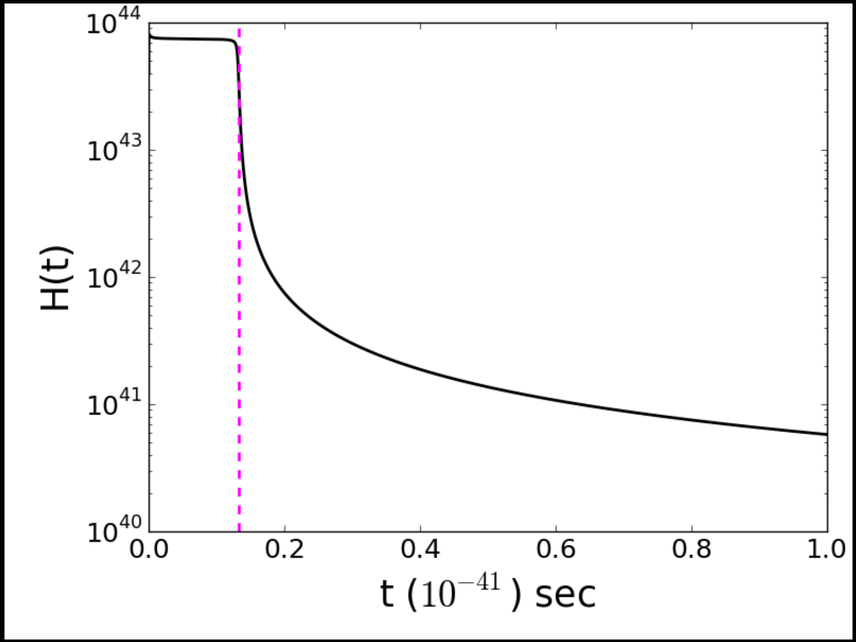
The Universe might have originated from the interior of a black hole. Accordingly, every black hole may create a new universe on the other side of its event horizon and become a wormhole to that universe (Novikov, Pathria, Smolin, NP, and others).

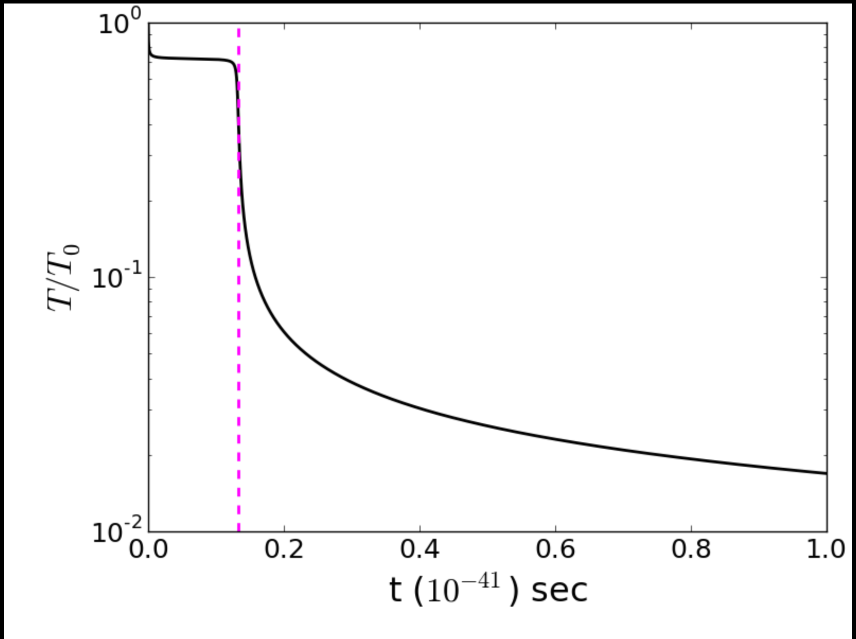


Dynamics of the early Universe

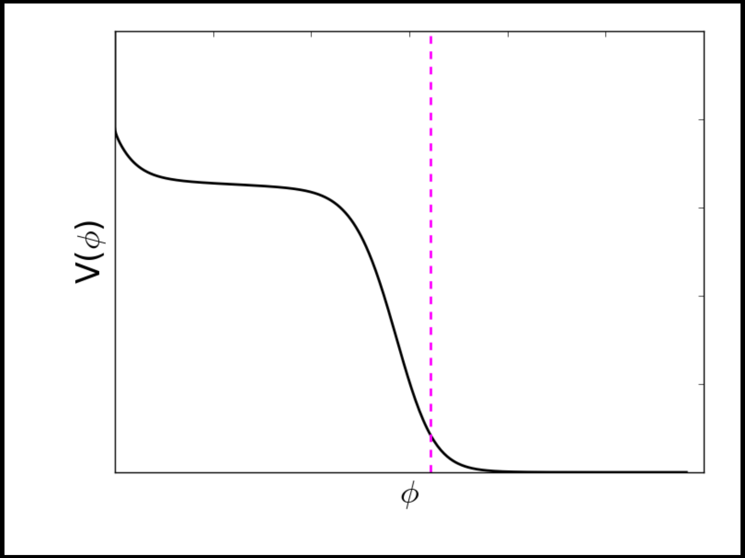
$\beta/\beta_{cr} = 0.9998$







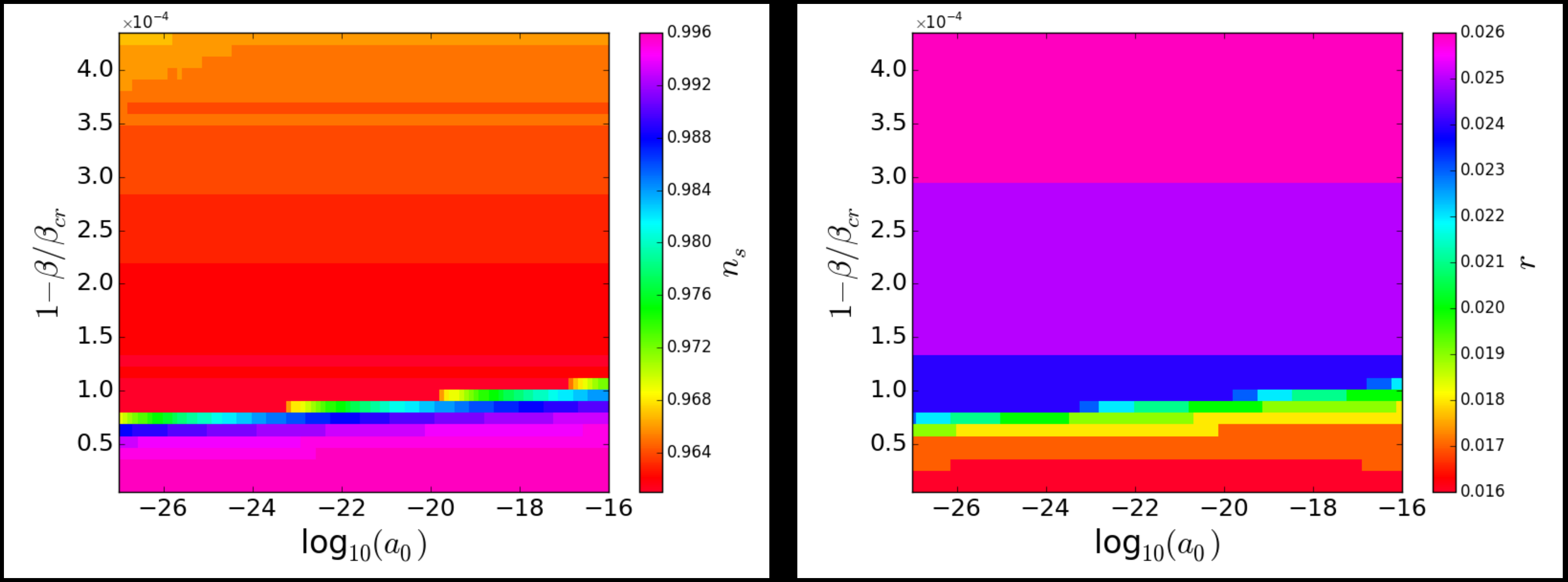
It is possible to find a scalar field potential which generates the same time dependence of the scale factor.



Plateau-like potential – favored by Planck 2013.

Scalar-field plateau models: initial conditions problem, eternal inflation, unlikelihood (compared to power-law), several parameters. Torsion cosmology avoids these problems and has 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)