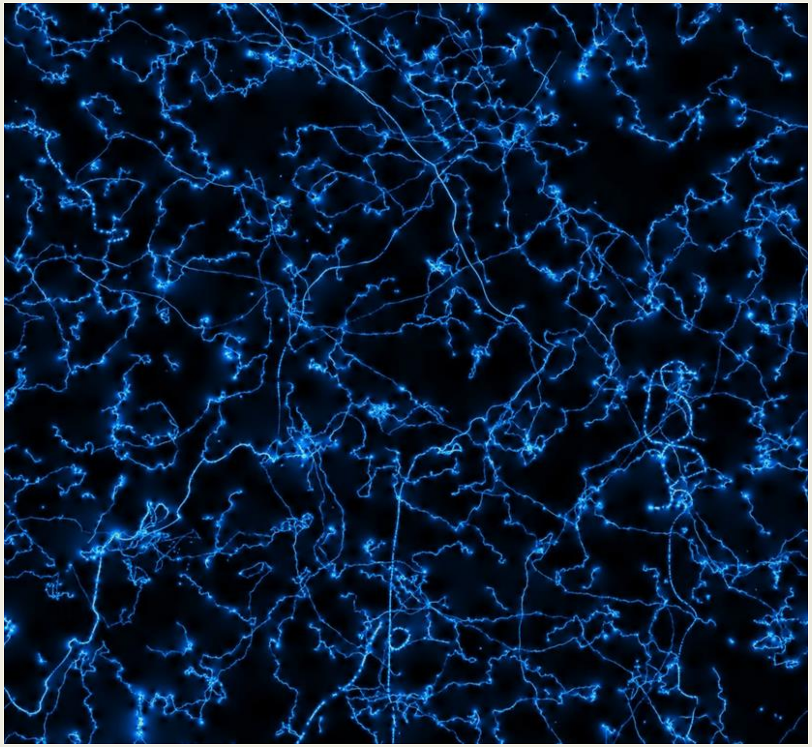
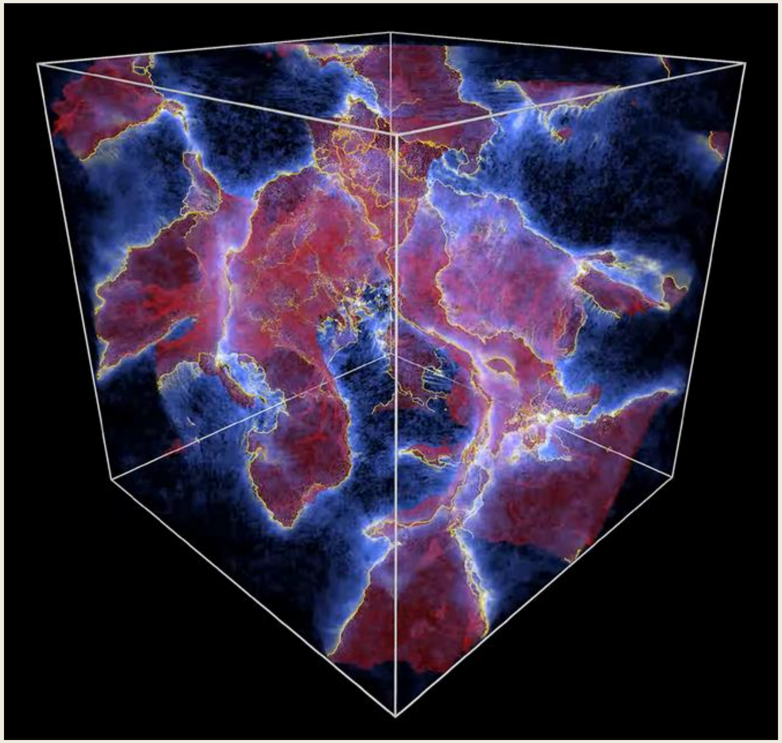
Cosmic Strings, Domain Walls and the Cosmological Vacuum



Chris Ringeval/CC0 1.0



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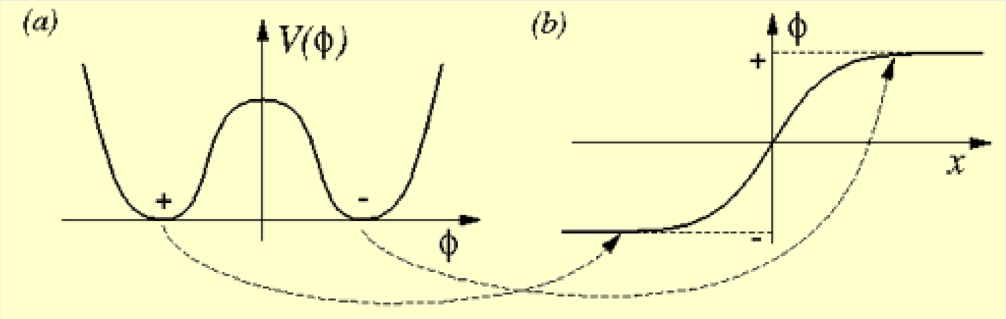
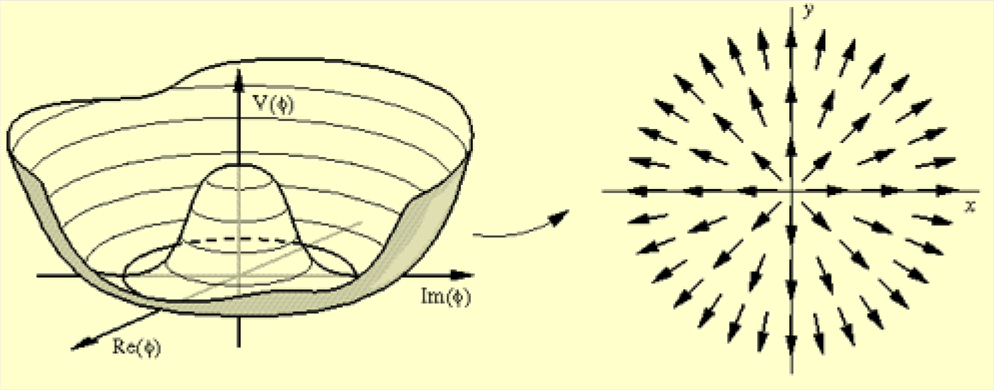
Topological deffects

Topological defects are stable configurations of matter formed at phase transitions in the very early Universe.

Domain walls are two-dimensional objects that form when a **discrete symmetry** is broken at a phase transition.

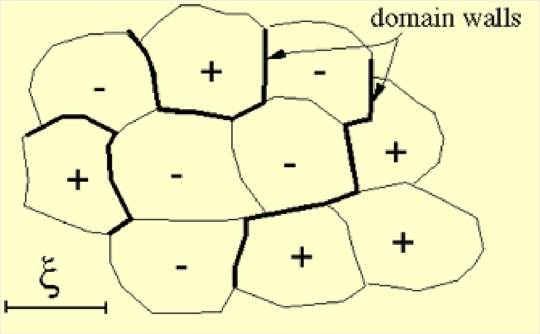


Cosmic strings are one-dimensional objects which form when axial or cylindrical symmetry is broken. Strings can be associated with grand unified particle physics models.

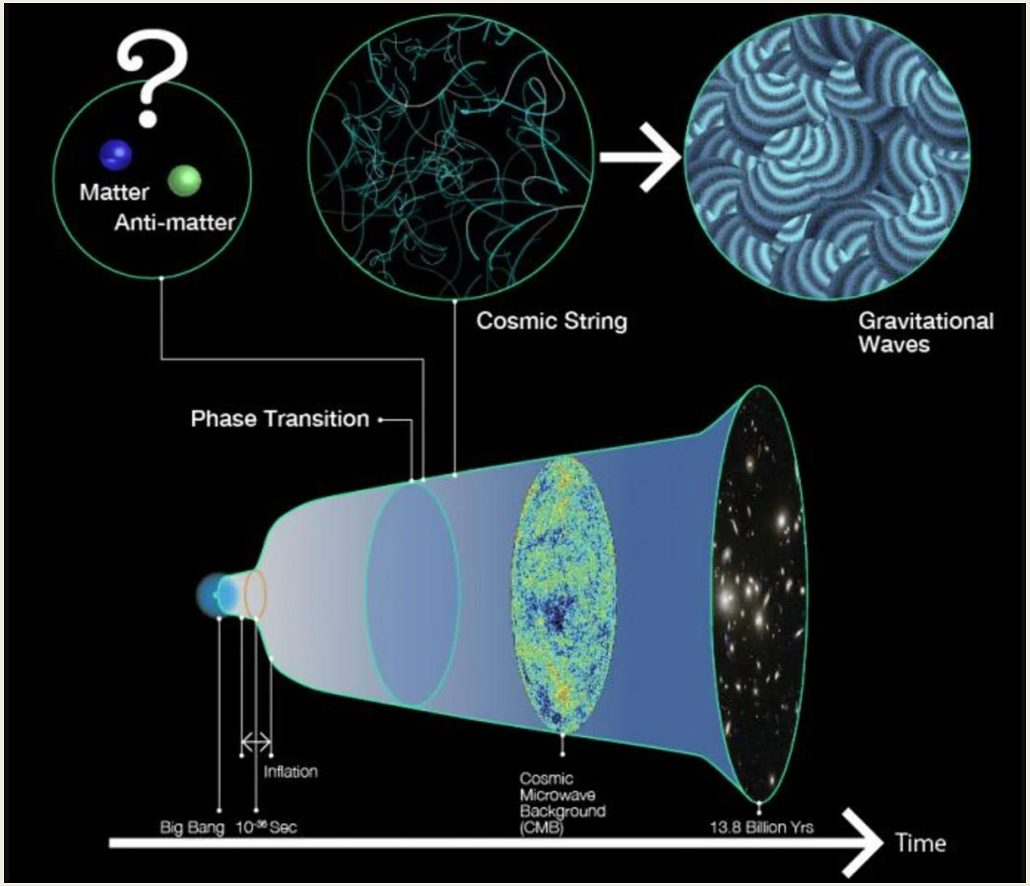


https://www.ctc.cam.ac.uk/outreach/origins/cosmic_structures_two.php

Kibble mechanism.



If topological defects *can* form at a cosmological phase transition, they *will* form.



Causal effects in the early Universe can only propagate as the speed of light c. This means that at a time t, regions of the Universe separated by more than a distance *d=ct* can know nothing about each other.

Topological defects provide a unique link to the physics of the very early Universe. They can crucially affect the evolution of the Universe!

$$R^{\nu}_{\mu} - \frac{1}{2}\delta^{\nu}_{\mu}R + \Lambda\delta^{\nu}_{\mu} = T^{\nu}_{\mu}$$

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right]$$

$$p = w\varepsilon \qquad T^{\nu}_{\mu} = (\varepsilon + p)u_{\mu}u^{\nu} + p\delta^{\nu}_{\mu}$$

$w = -1$ **Cosmological vacuum**

$w = -\frac{1}{3}$ **Cosmic Strings**

$w = -\frac{2}{3}$ **Domain walls**

Friedman equations

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda c^2}{3} - \frac{kc^2}{a^2}$$

$$\frac{\ddot{a}}{a} = \frac{\Lambda c^2}{3} - \frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right)$$

$$ds^2 = -\mathrm{d}t^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2 d\Omega^2\right]$$

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Some naïve calculations:

Take sphere of physical radius $a(t)r_0$

$$\frac{d^2(ar_0)}{dt^2} = \frac{\Lambda c^2}{3}(ar_0) - \frac{GM}{(ar_0)^2}$$

$$M = \frac{4\pi}{3}\left(\rho + \frac{3p}{c^2}\right)(ar_0)^3$$

Cosmological vacuum problem

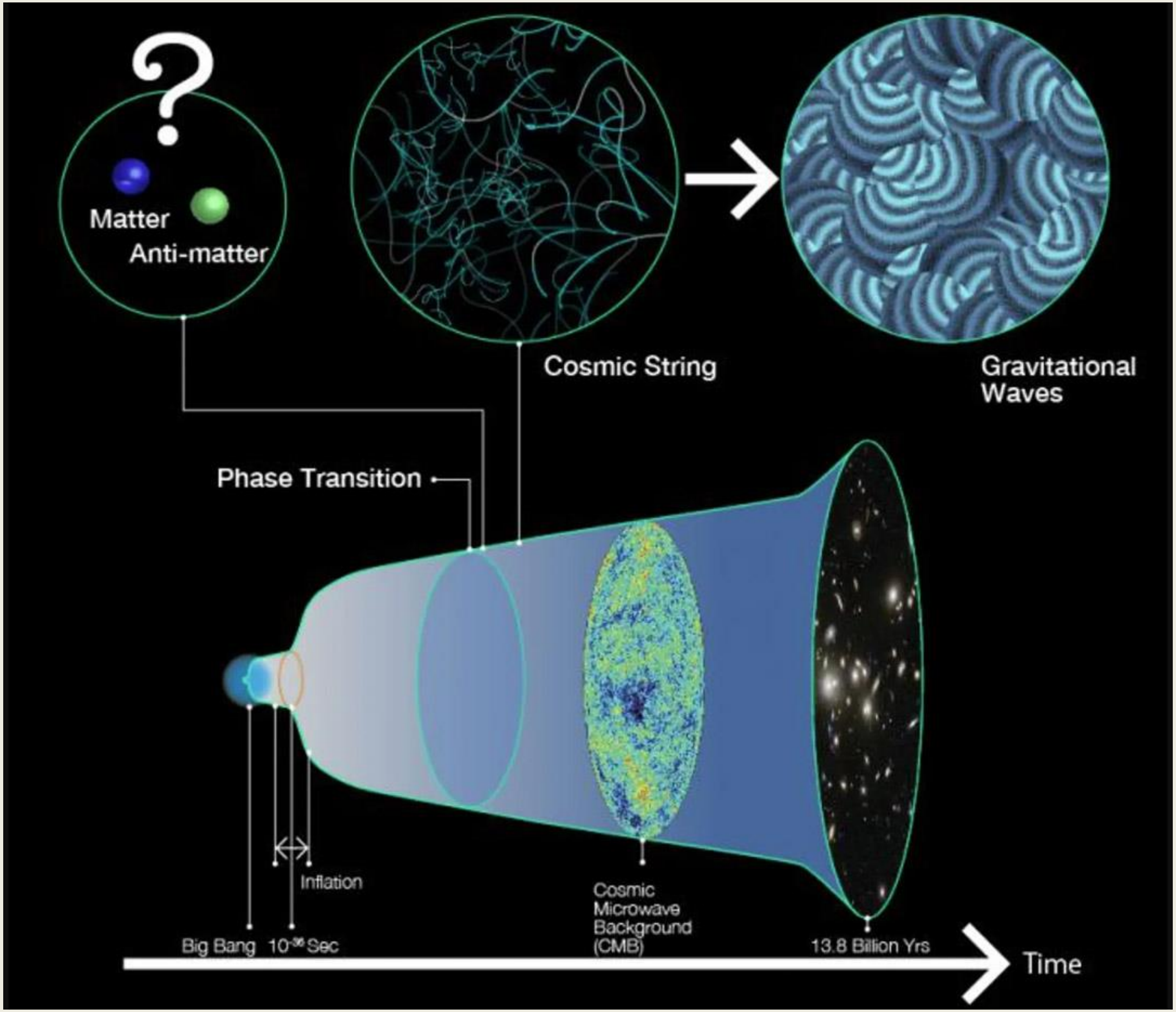
$p = -\varepsilon$ Cosmological vacuum

QFT: $T_{\mu\nu}^{\text{vac}} = -V_0 g_{\mu\nu}$

$\varepsilon_{\text{vac}} \sim (10^{18}\ \text{GeV})^4 \sim 10^{109}\text{J/m}^3$

Obs: $T_{\mu\nu}^{\text{vac}} = -\varepsilon_{\text{vac}} g_{\mu\nu}$

$|\varepsilon_{\text{vac}}| \leq (10^{-12}\ \text{GeV})^4 \sim 10^{-9}\text{J/m}^3$



Matter
Anti-matter
Cosmic String
Gravitational Waves
Phase Transition
Inflation
Cosmic Microwave Background (CMB)
Big Bang
10⁻³⁶ Sec
13.8 Billion Yrs
Time