Plentiful Nothingness: The Void in Modern Art and Modern Science

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The Vacuum

What do we mean by *Void*, *Vacuum*, *Emptyness*?

A concept that plays a crucial role in both *Modern Art* (early 20th century avant-garde, and post WWII artistic movements) and *Modern Science* (quantum physics and general relativity)

The classical vacuum is passive and undifferentiated, the modern vacuum is active, differentiated and dynamical

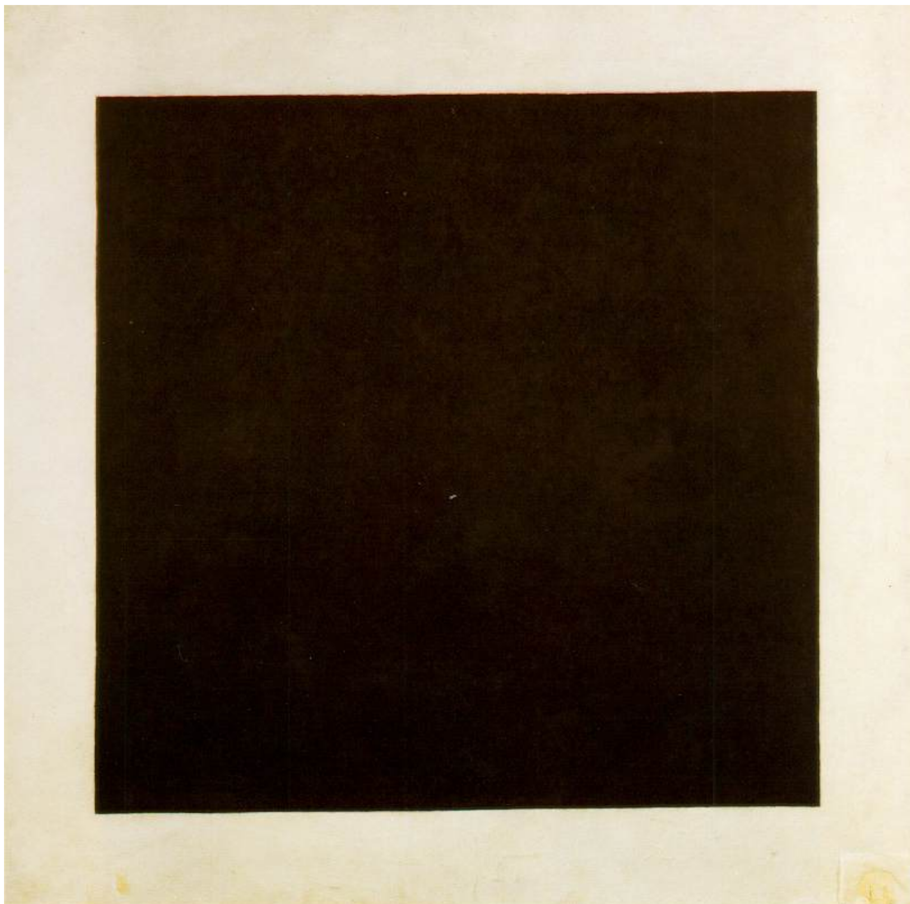
Main concept: the vacuum has structure

The Classical Void: the frame of reference, coordinate system, receptacle, container

Albrecht Dürer, *The Drawing Frame*, ca. 1500

Empty space in both classical physics and classical figurative art is an absolute rigid grid of coordinates, a set stage in which action takes place

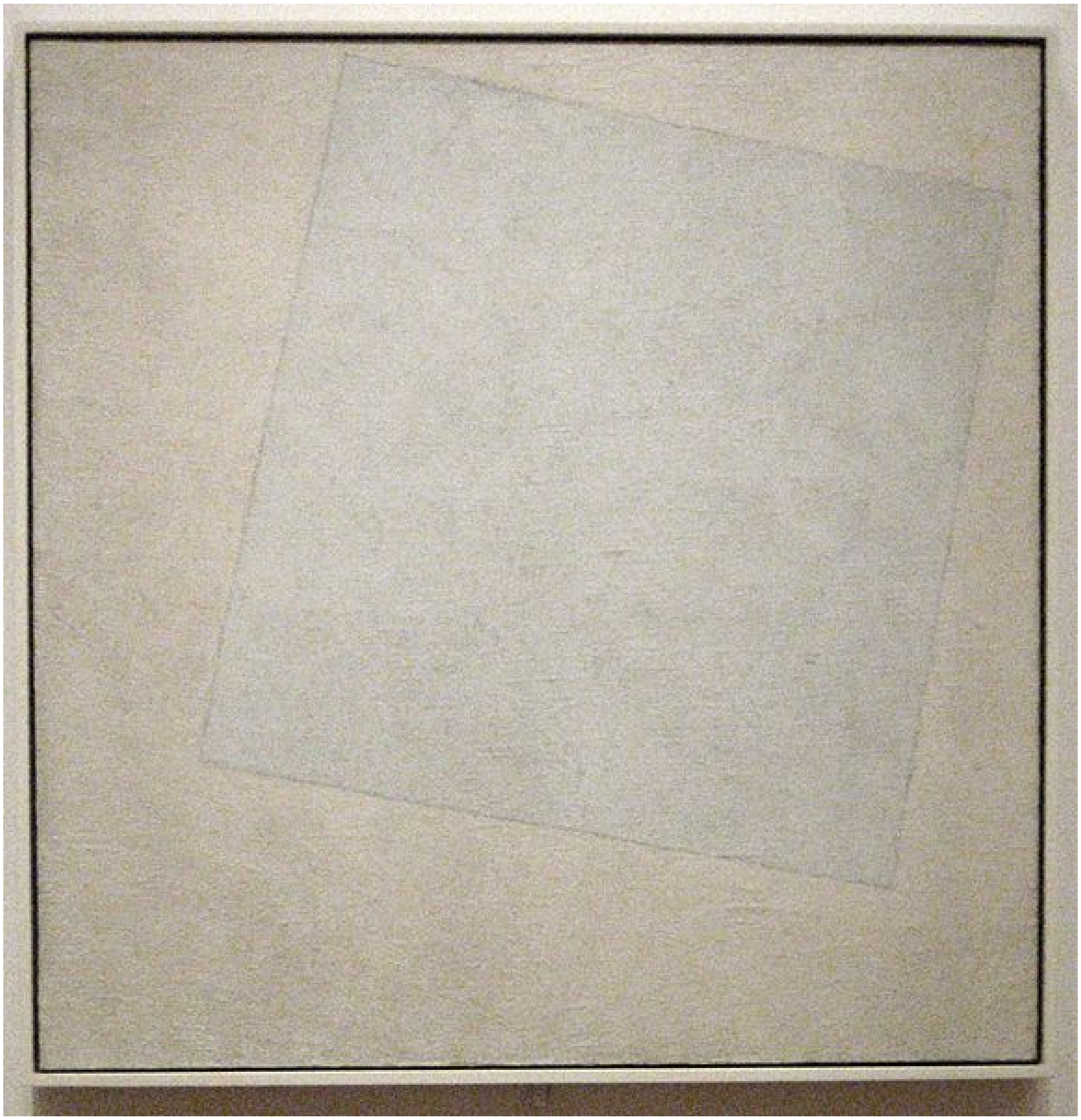
The Suprematist Void



Kasimir Malevich, *Black Square*, 1913.

"the square – sensation, the white field, the void beyond sensation" (Malevich, 1918)

Note: the black square has *texture*, the white background is flat



Kasimir Malevich, *White on white*, 1918

"the vacuum is filled with the most profound physical content" (Isaak Pomeranchuk, physicist, 1950)

Kasimir Malevich, *Supremus 58*, 1916

Space is defined relationally by the shapes (matter, fields, energy) that occupy it and their interactions

The Void has shape (gravity = geometry)

The metric and curvature describe *gravity*
Vacuum = no *matter* to interact with

- Einstein–Hilbert action for gravity

$$S = \frac{1}{2\kappa} \int R \sqrt{-g} d^4x$$

Einstein field equations in vacuum (principle of least action):

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 0$$

Solutions of Einstein's equations in vacuum describe a *curved space*

- Gravity coupled to matter

$$S = \int (\frac{1}{2\kappa} R + \mathcal{L}_M) \sqrt{-g} d^4x$$

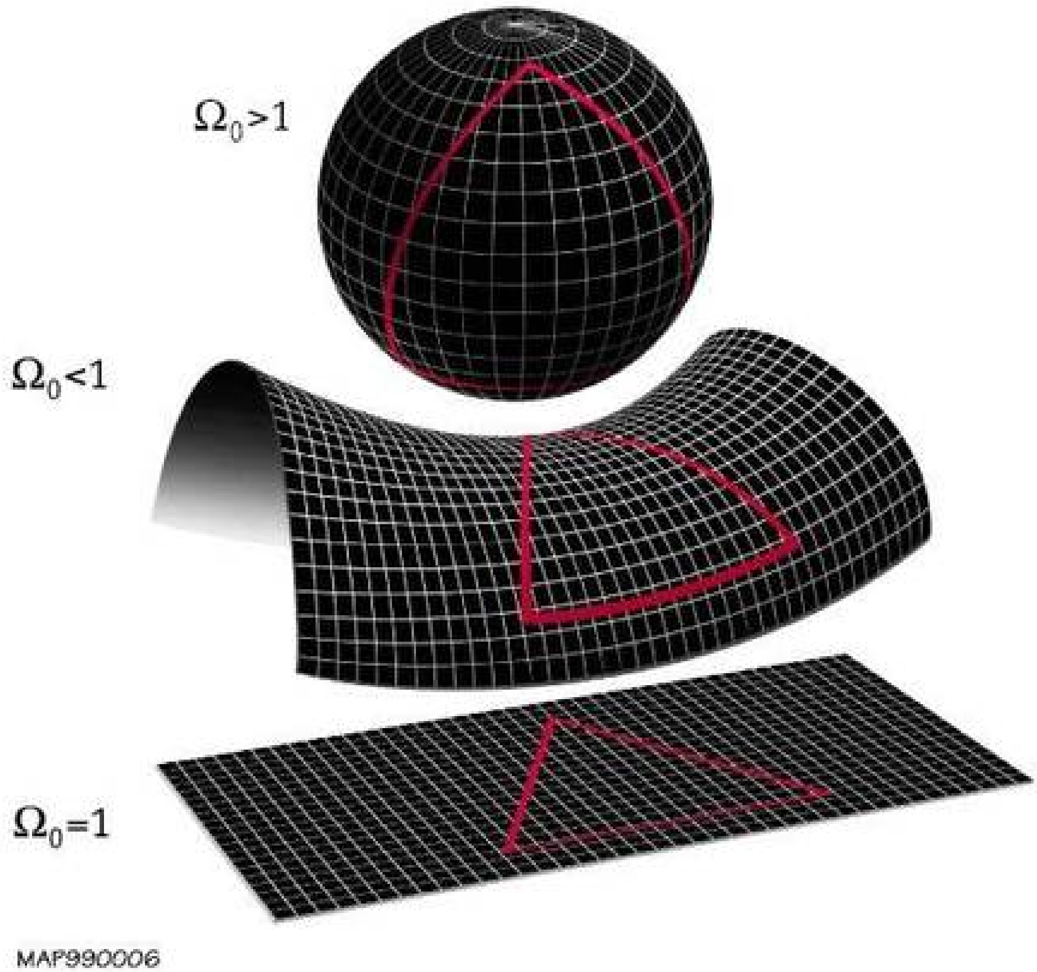
$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = \frac{8\pi G}{c^4} T_\mu \nu$$

Einstein equation with energy-momentum tensor

$$T_{\mu\nu} = -2 \frac{\delta \mathcal{L}_M}{\delta g^{\mu\nu}} + g_{\mu\nu} \mathcal{L}_M$$

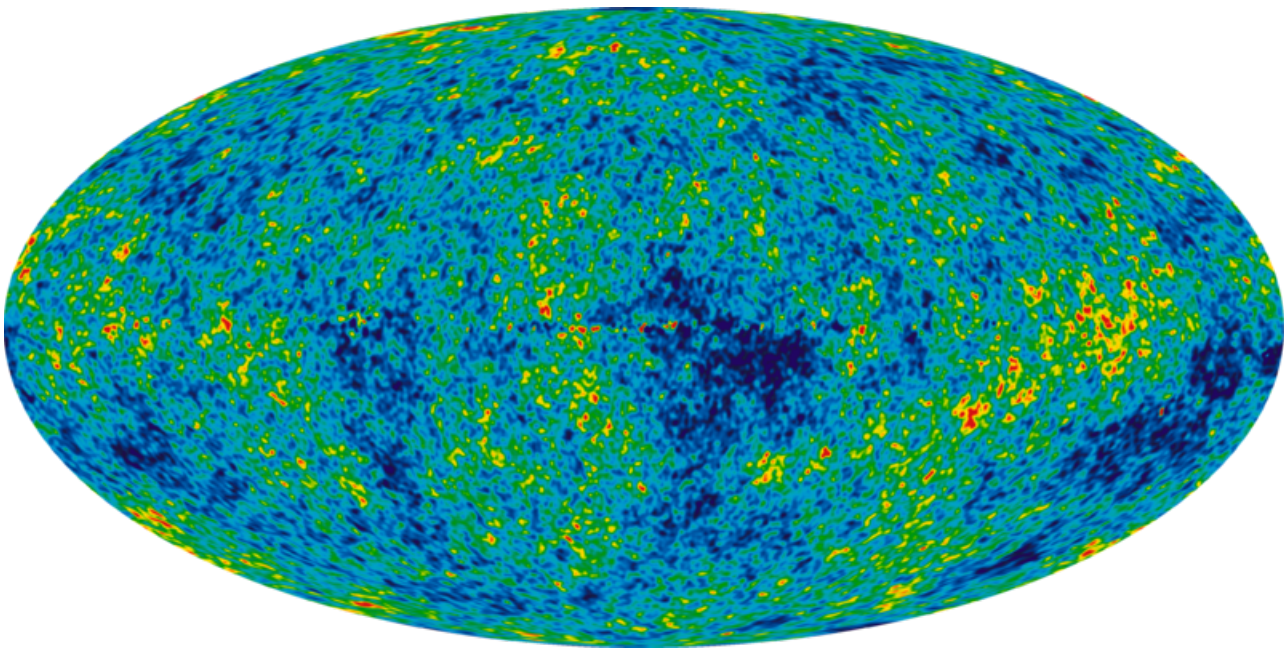
still use a background (topological) space

Solutions of Einstein's equation in vacuum can have different curvature



positively curved, negatively curved, flat

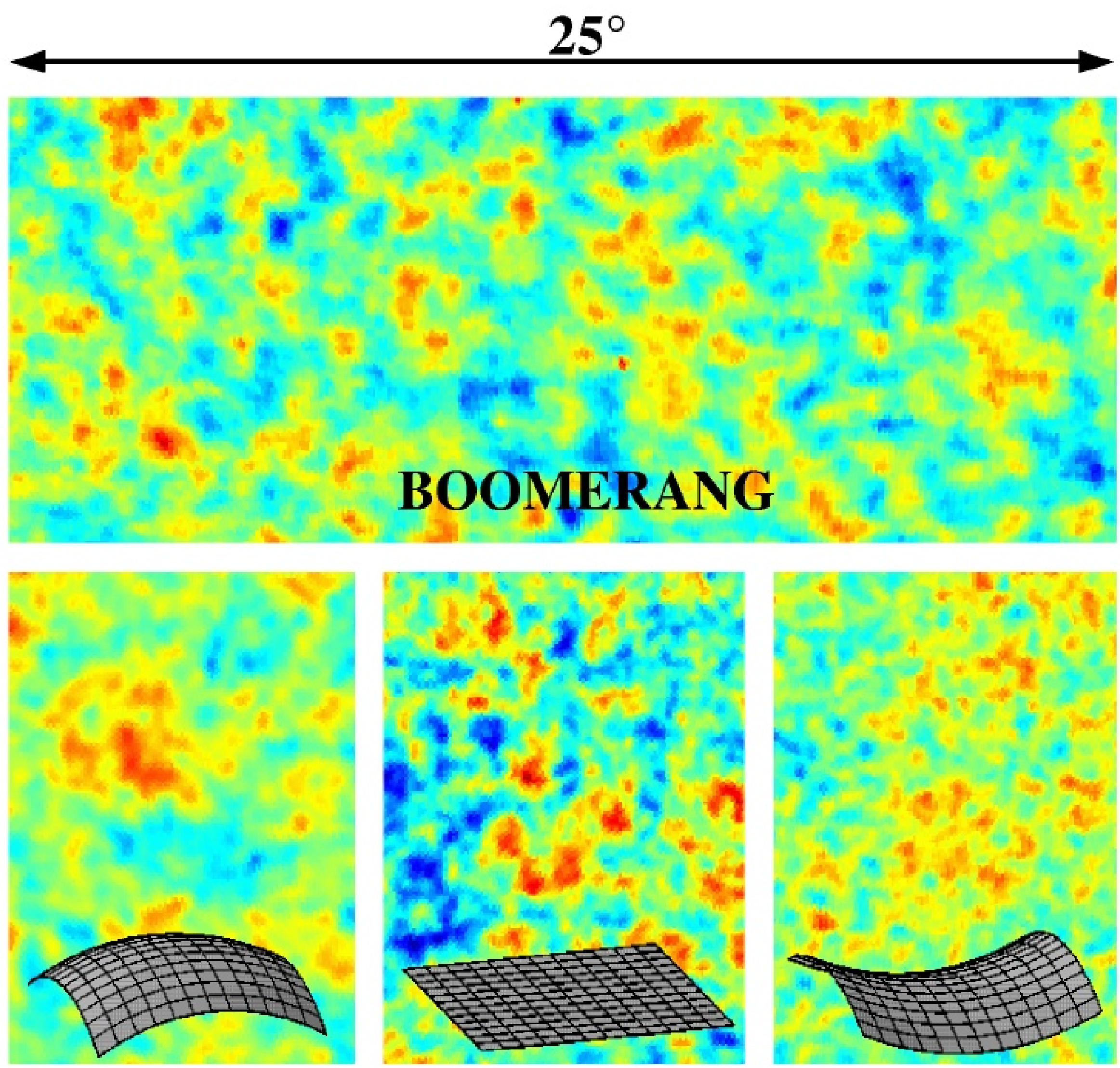
How do we *see* the geometry of the universe?



WMAP 2010: map of the CMB (cosmic microwave background)

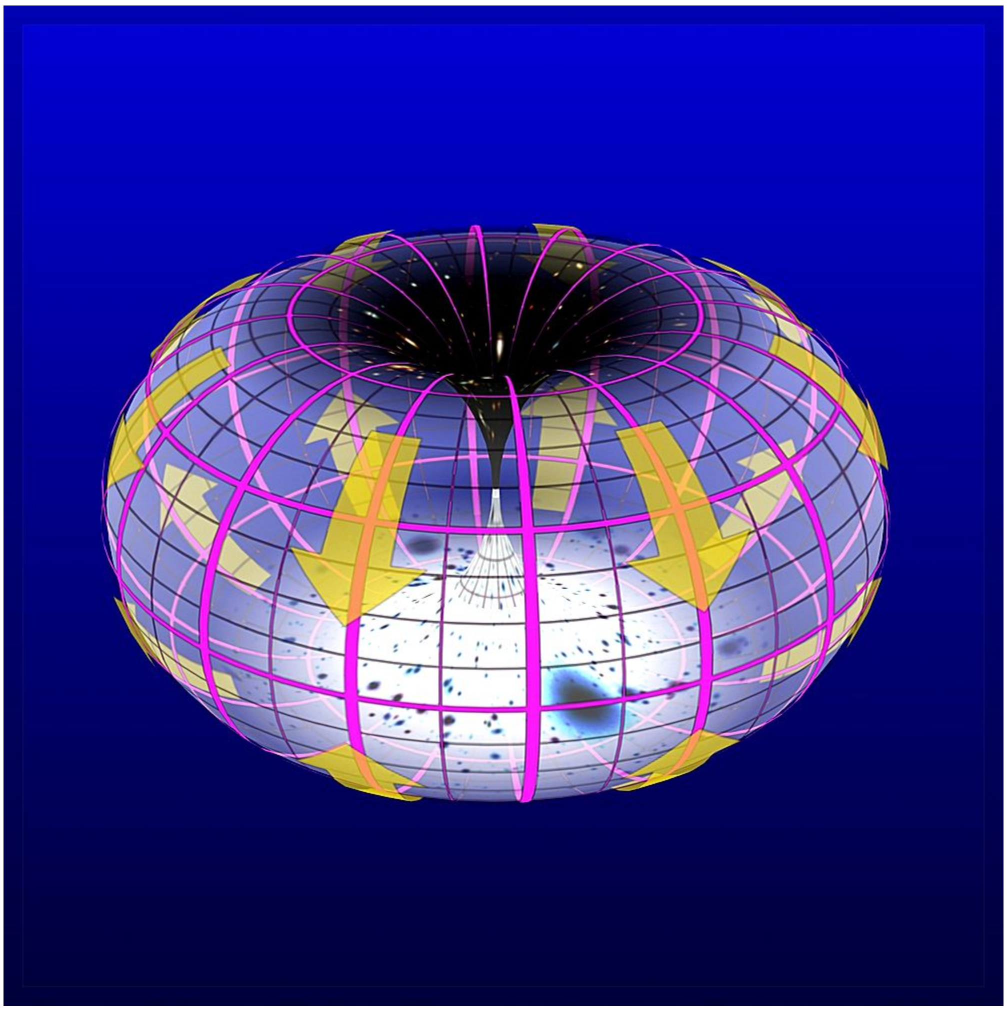
New maps now from Planck satellite

Different curvatures of empty space leave detectable traces in the CMB map



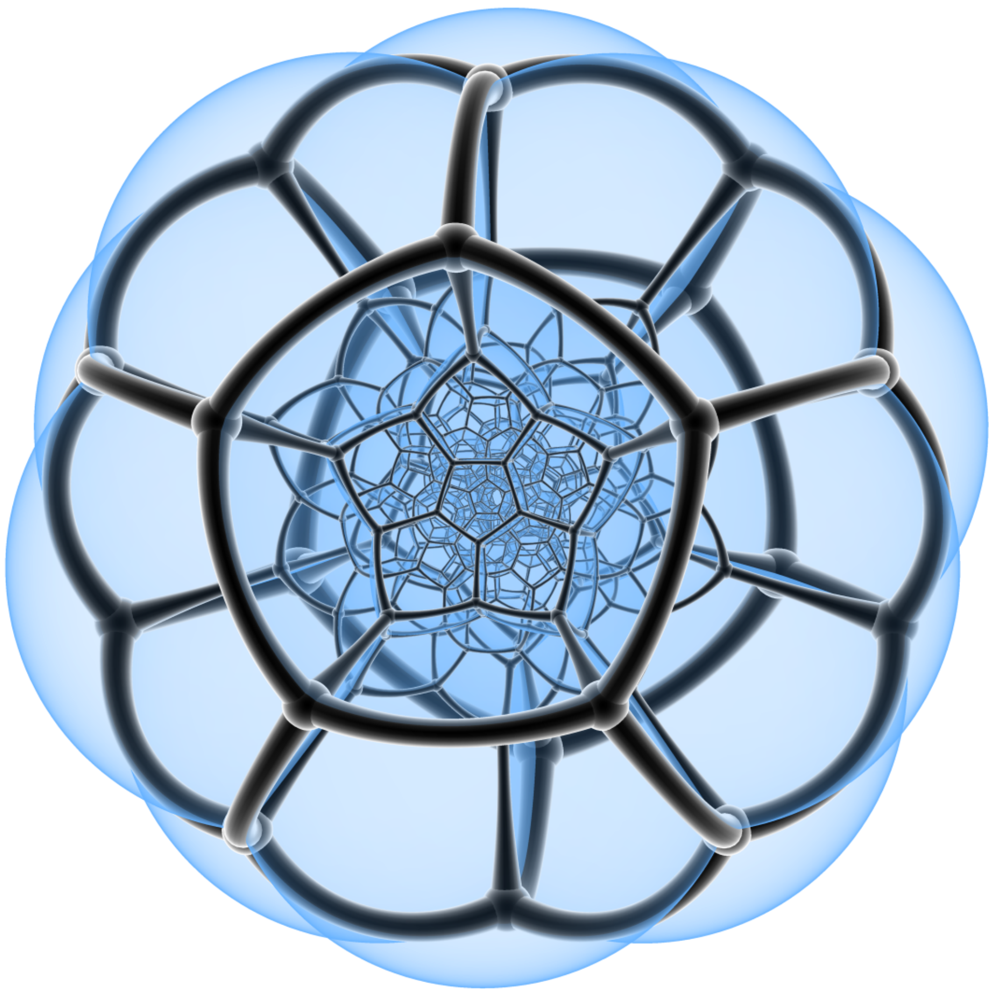
Topologies of empty space

The "cosmic topology problem": Einstein's equation predict local curvature not global shape

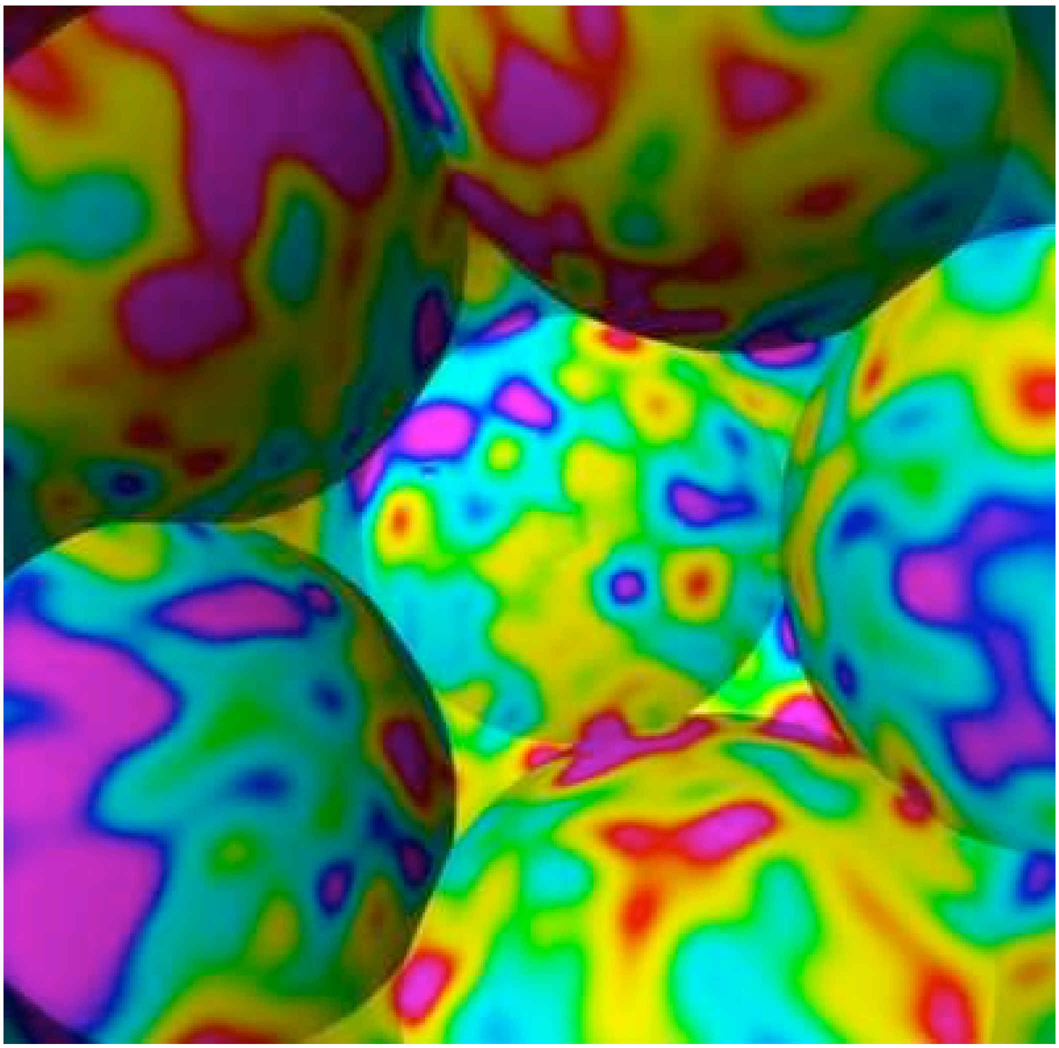


A *flat* universe is not necessarily (spatially) infinite: it can be a *torus*

A *positively curved* universe can be a sphere or a Poincaré sphere (dodecahedral space)



The CMB map as seen from inside a dodecahedran universe



Statistically searching matching circles in the CMB map for evidence of cosmic topology

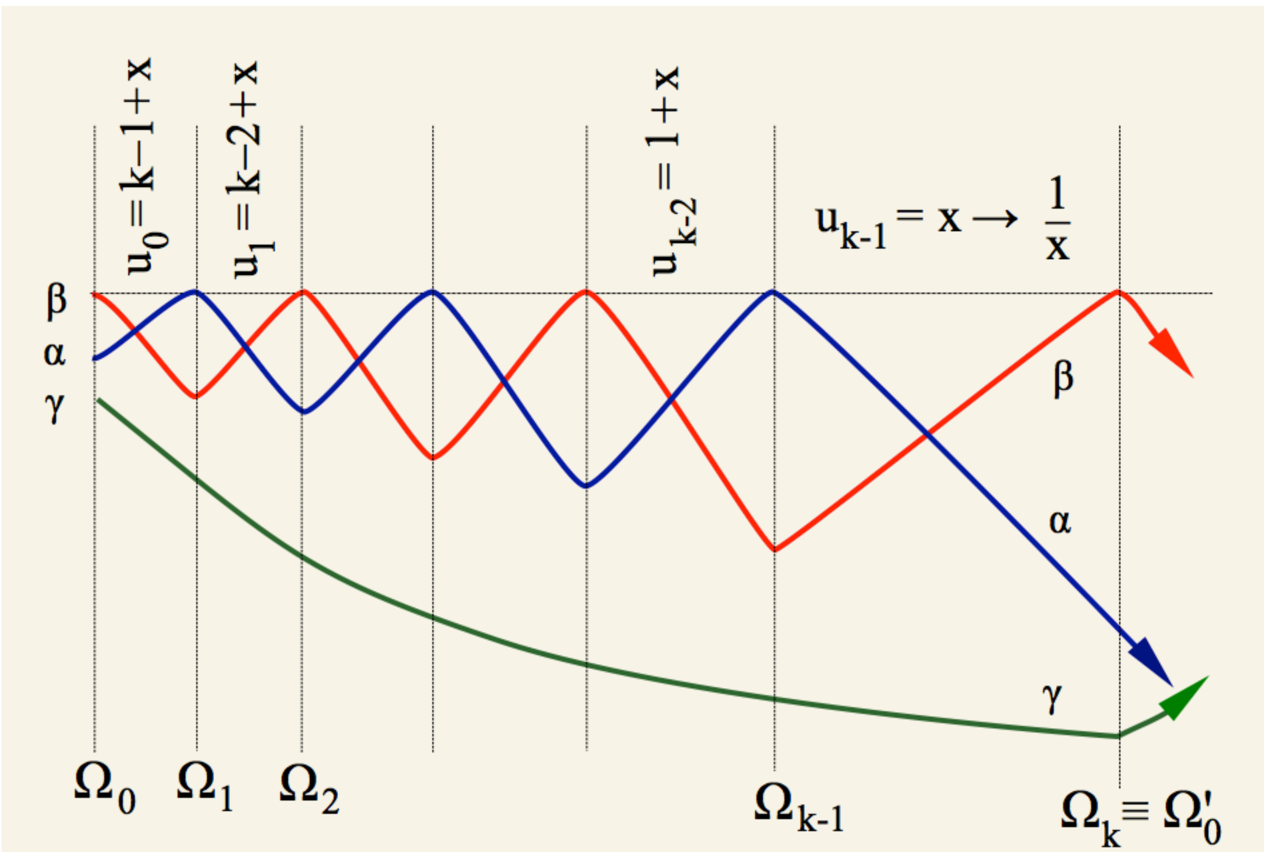
Ken Price's "cosmological" sculptures

Ken Price, ceramics, 1999-2000

Ken Price, ceramics, 1999-2000

What would the background radiation look like in strangely shaped universes?

How strange can the shape of empty space be?



...pretty strange: *mixmaster universe*

The Void is dynamical

The cosmological constant and expansion and contraction of the universe

• Einstein's equations in vacuum with cosmological constant

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R + g_{\mu\nu} \Lambda = 0$$

$$S = \int (\frac{1}{2\kappa} R - 2\Lambda) \sqrt{-g} d^4x$$

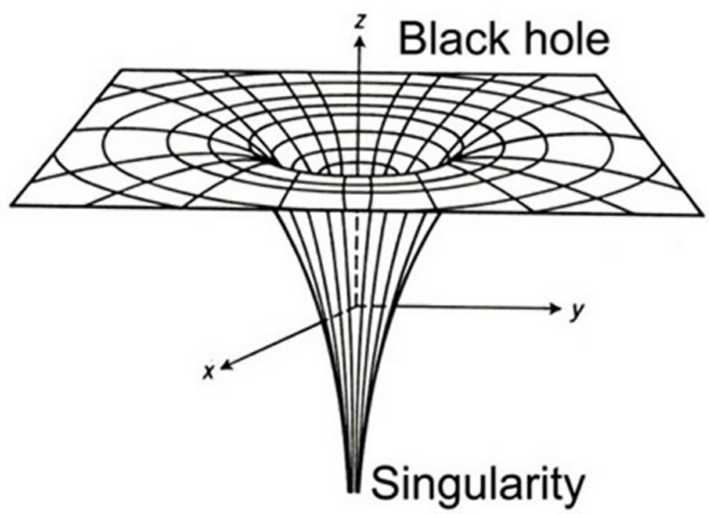
Cosmological constant as *energy of empty space*

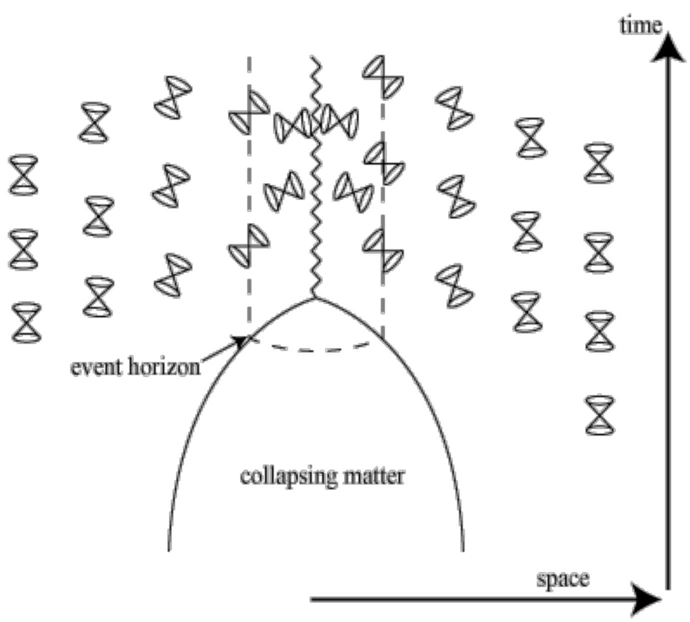
$$\rho_{\text{vacuum}} = \frac{\Lambda c^2}{8\pi G}$$

Contributions from *particle physics*

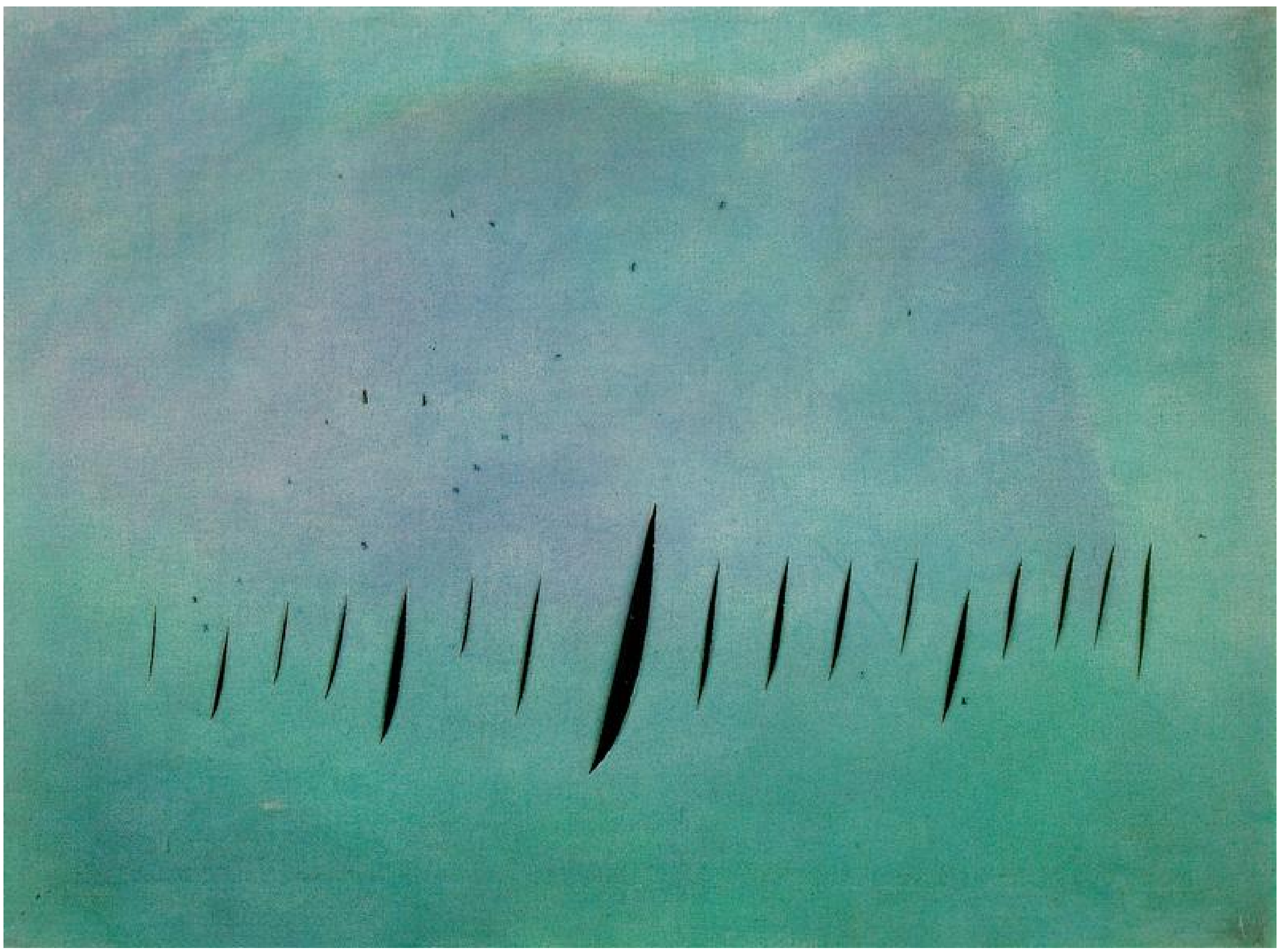
The cosmological constant can act as a "repulsive force" countering the attractive force of gravity: can cause the universe to expand or contract or remain stationary, depending on balance

The Void has Singularities
Black Holes; Big Bang





The Spatialist Void



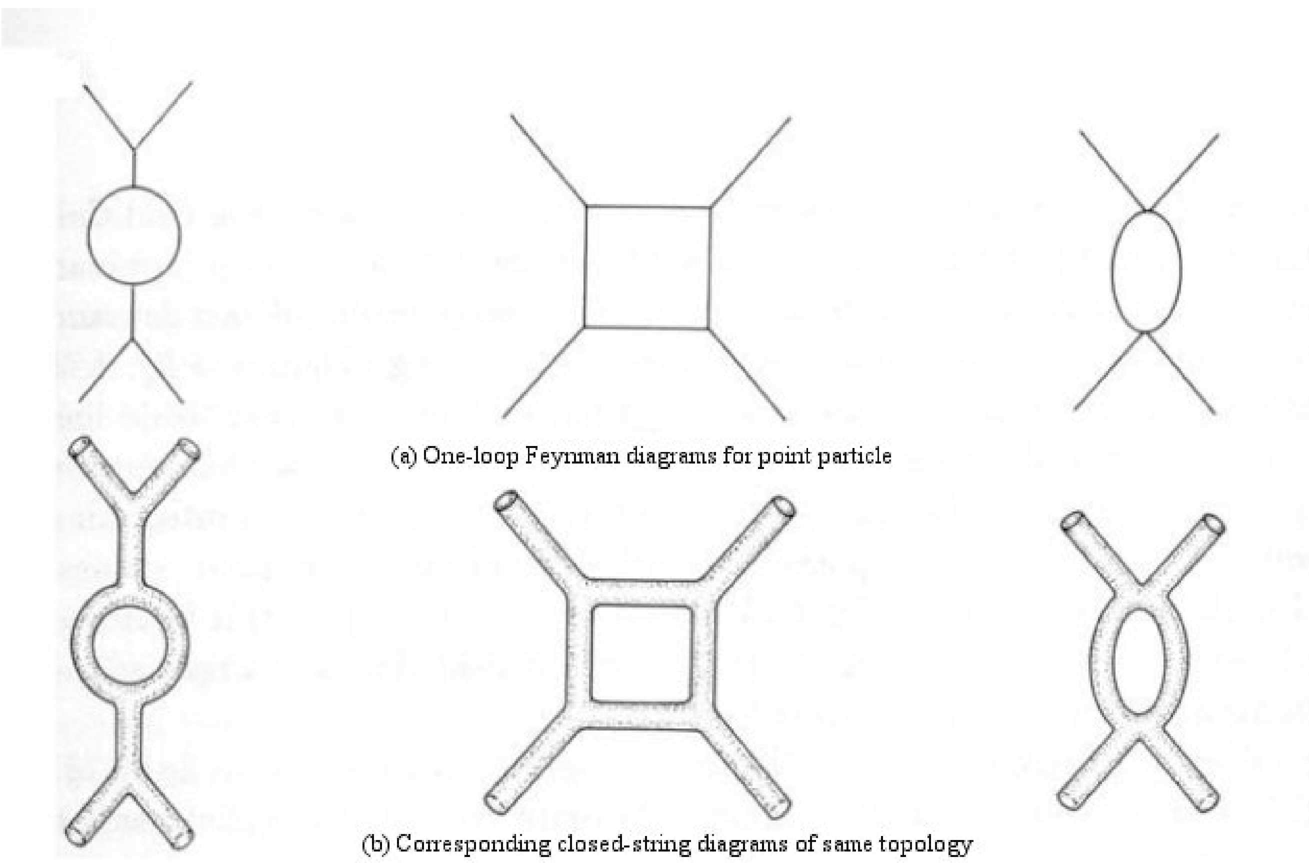
Lucio Fontana, *Concetto Spaziale, Attese*, 1968

As entropy grows the universe is progressively filled with black hole singularities

Lucio Fontana, *Concetto spaziale*, 1952

The Void in quantum physics

in Quantum Field Theory and String Theory describe processes of particle interactions diagrammatically



(a) One-loop Feynman diagrams for point particle

(b) Corresponding closed-string diagrams of same topology

Quantum field theory and Feynman graphs

• In a quantum field theory one has a classical action functional

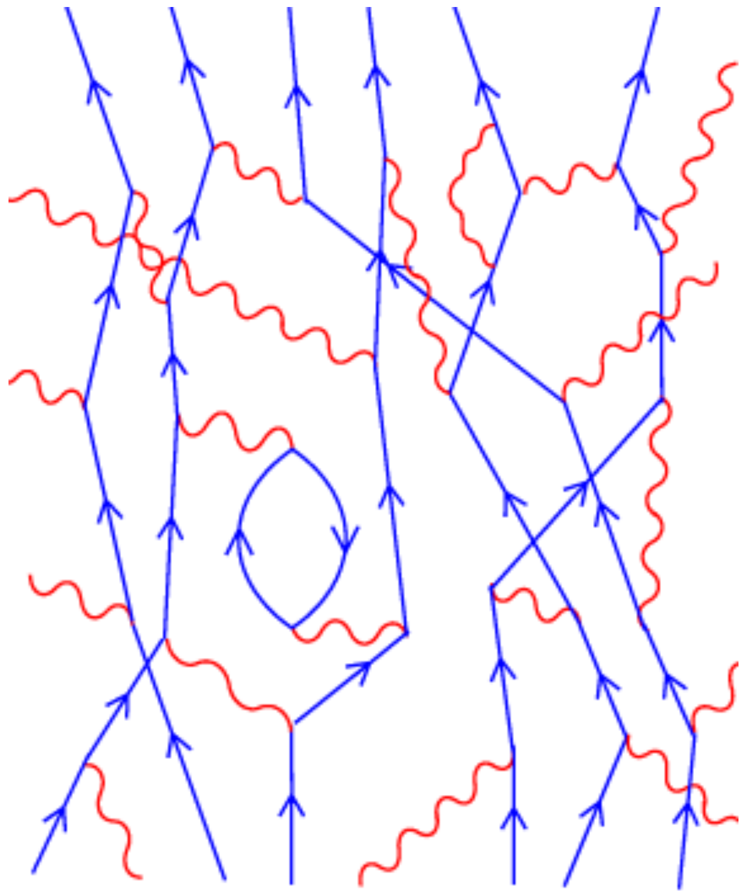
$$\mathcal{S}(\phi) = \int \mathcal{L}(\phi) d^D x = S_{\text{free}}(\phi) + S_{\text{interaction}}(\phi)$$

$$\mathcal{L}(\phi) = \frac{1}{2}(\partial\phi)^2 - \frac{m^2}{2}\phi^2 - \mathcal{L}_{\text{interaction}}(\phi)$$

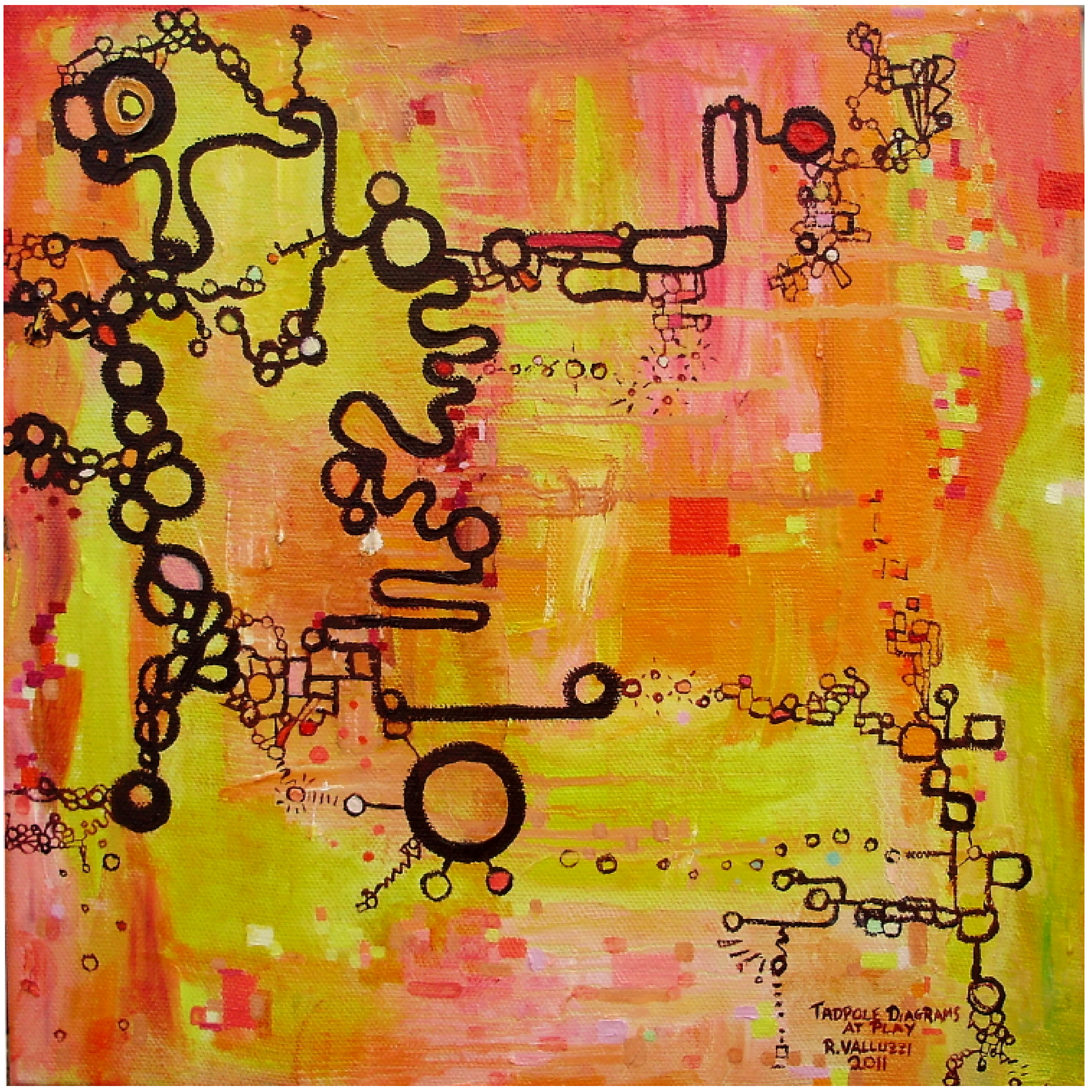
• Quantum effects are accounted for by a series of terms labelled by graphs (Feynman graphs) that describe processes of particle interactions

$$\mathcal{S}_{eff}(\phi) = \mathcal{S}_{\text{free}}(\phi) + \sum_{\Gamma} \frac{U(\Gamma, \phi)}{\#\text{Aut}(\Gamma)}$$

$U(\Gamma, \phi)$ integral of momenta flowing through the graph

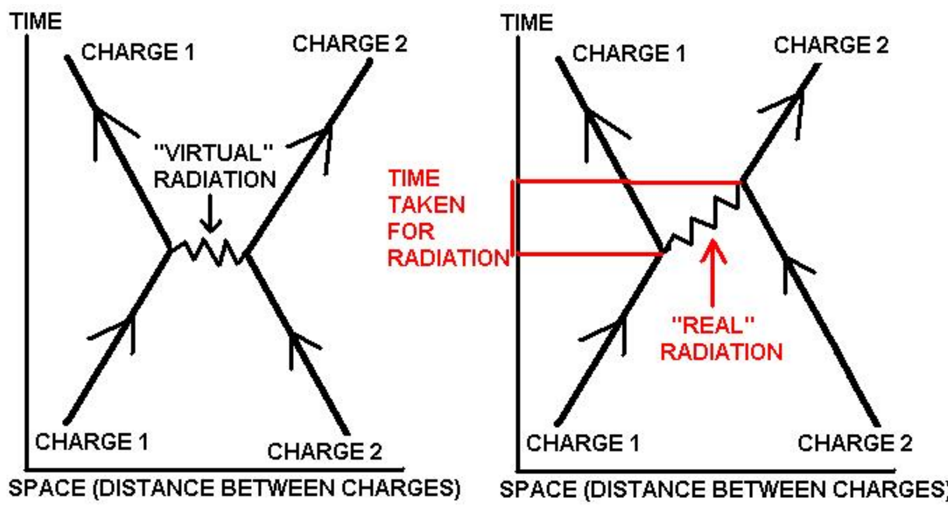


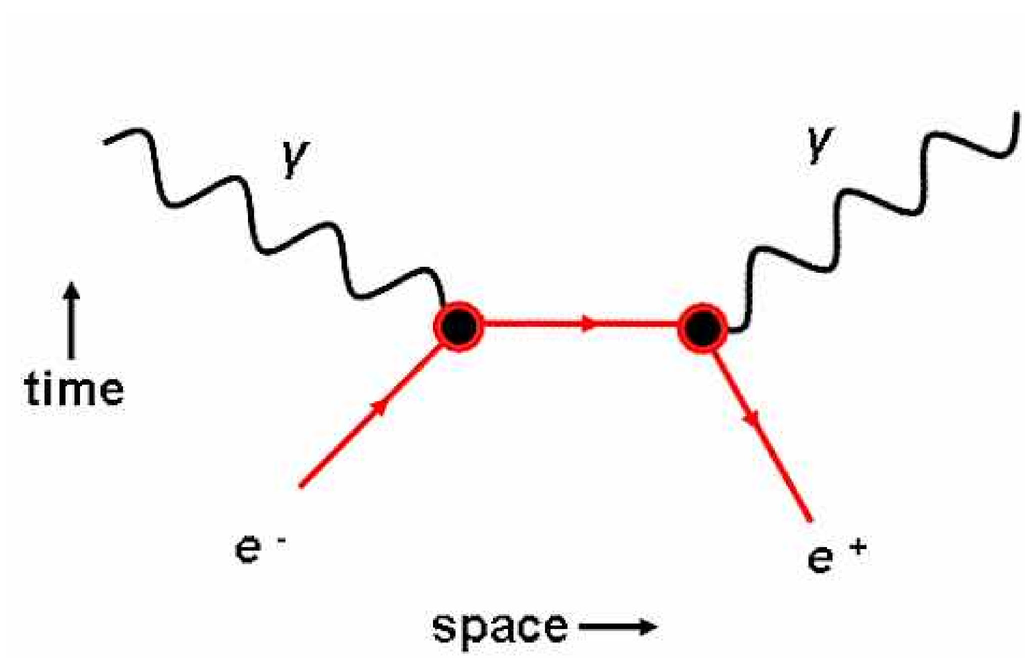
Feynman diagrams as computational devices or as possible configurations of a *material plenum* (interactions between photons and electrons)



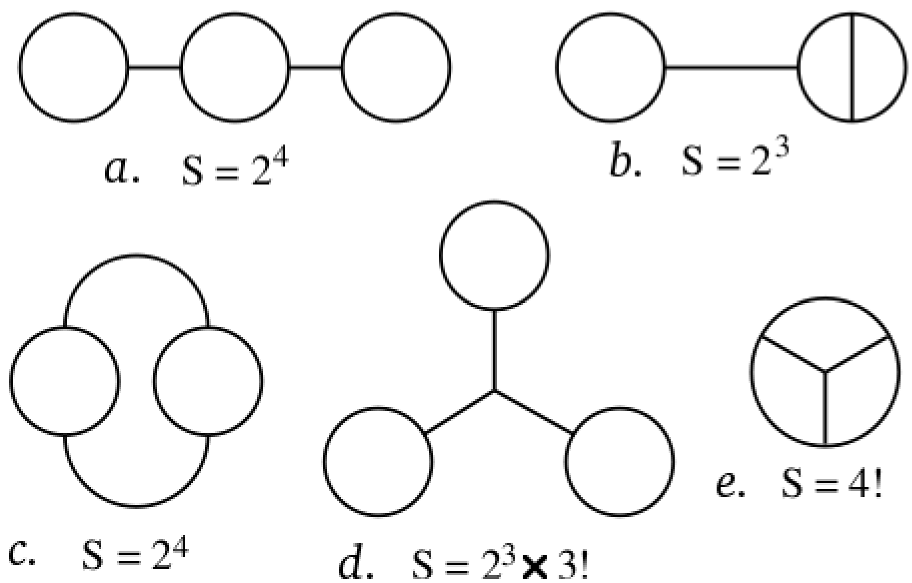
Regina Valluzzi, *Tadpole diagrams at play*, 2011

Virtual Particles





The Void in quantum physics:
Vacuum Bubbles



(Virtual) particles emerging from the vacuum interacting and disappearing back into the vacuum: graphs with no external edges

Vacuum bubbles and cosmological constant

Yakov Zeldovich (1967):

Virtual particles bubbling out of the vacuum of quantum field theory contribute to the cosmological constant Λ

- zero-point energy of a harmonic oscillator (vacuum = ground state)

$$E = \frac{1}{2}\hbar\omega$$

- for instance QED vacuum energy

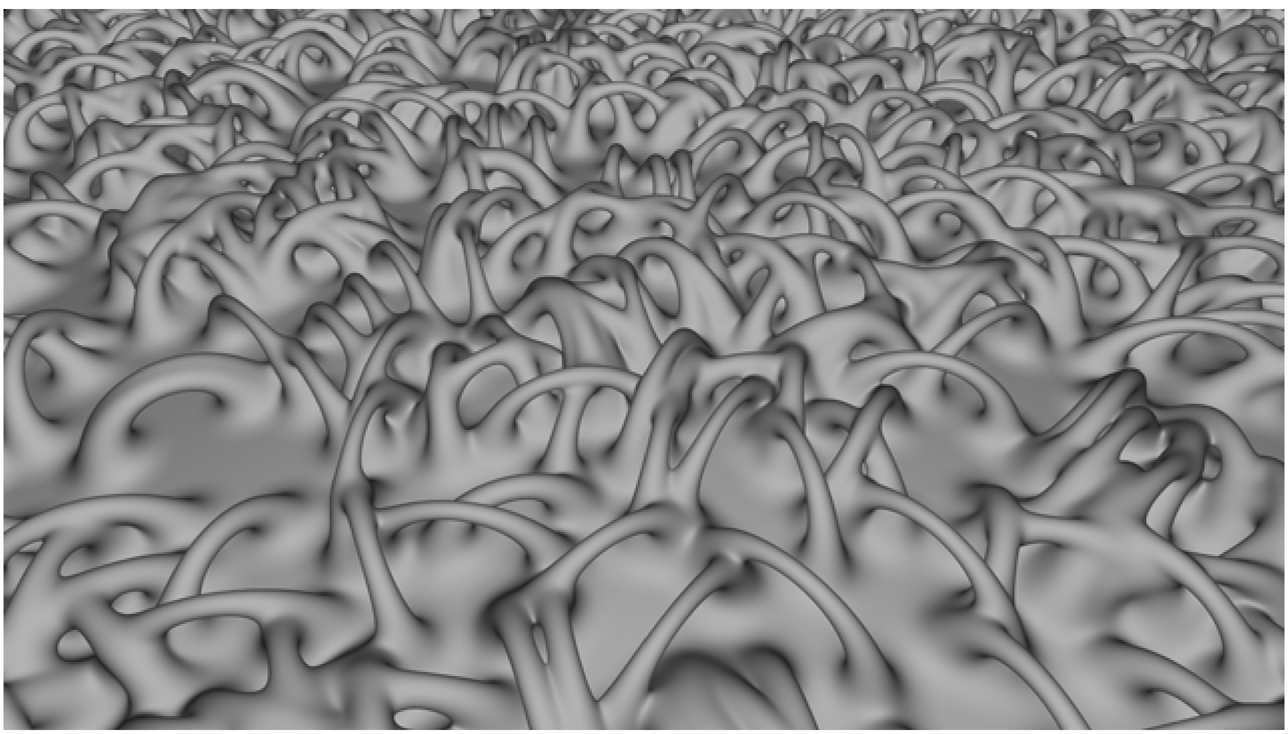
$$E = \langle 0|\hat{H}|0\rangle = \langle 0|\frac{1}{2}\int (\hat{E}^2 + \hat{B}^2)\, d^3x|0\rangle = \delta^3(0) \int \frac{1}{2}\hbar\omega_k\, d^3k$$

volume regularized with limit for $V \to \infty$

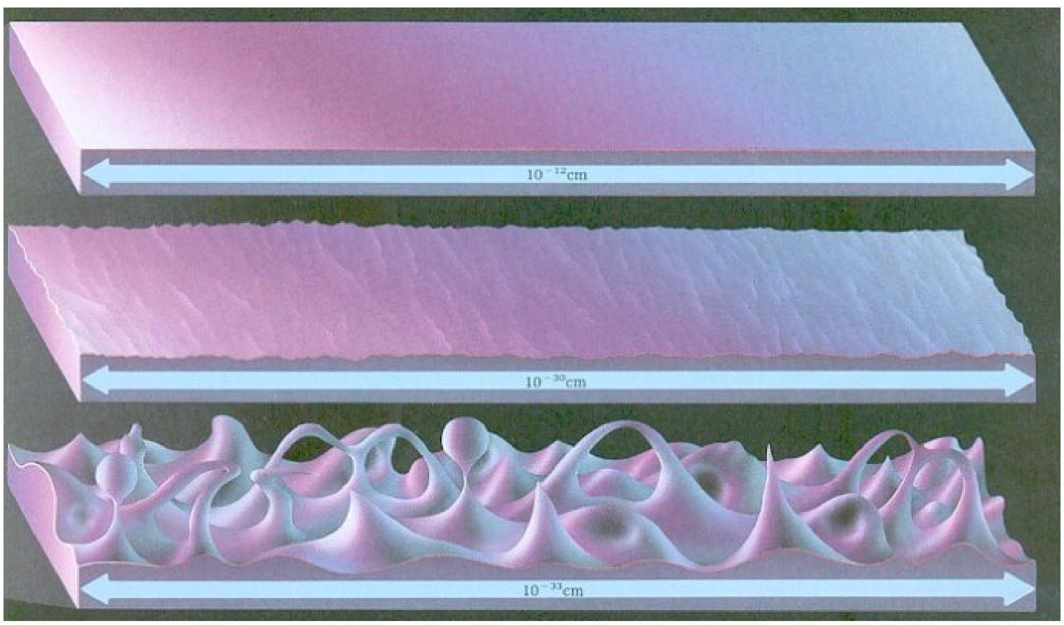
$$\frac{E}{V} \to \frac{\hbar}{8\pi^2 c^3} \int_0^{\omega_{\max}} \omega^3\, d\omega$$

Problem: this would give rise to an enormously large Λ: we know from cosmological observation it is enormously small (!!)

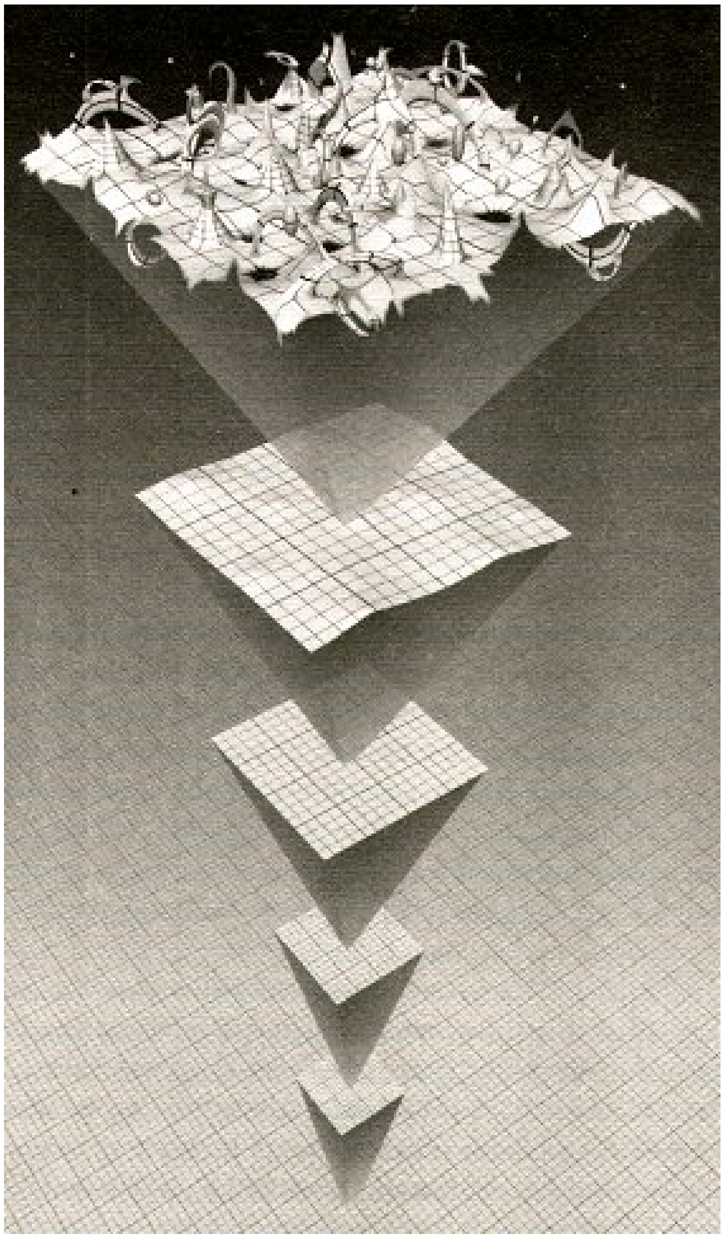
The Void in Quantum Gravity: Quantum Foam

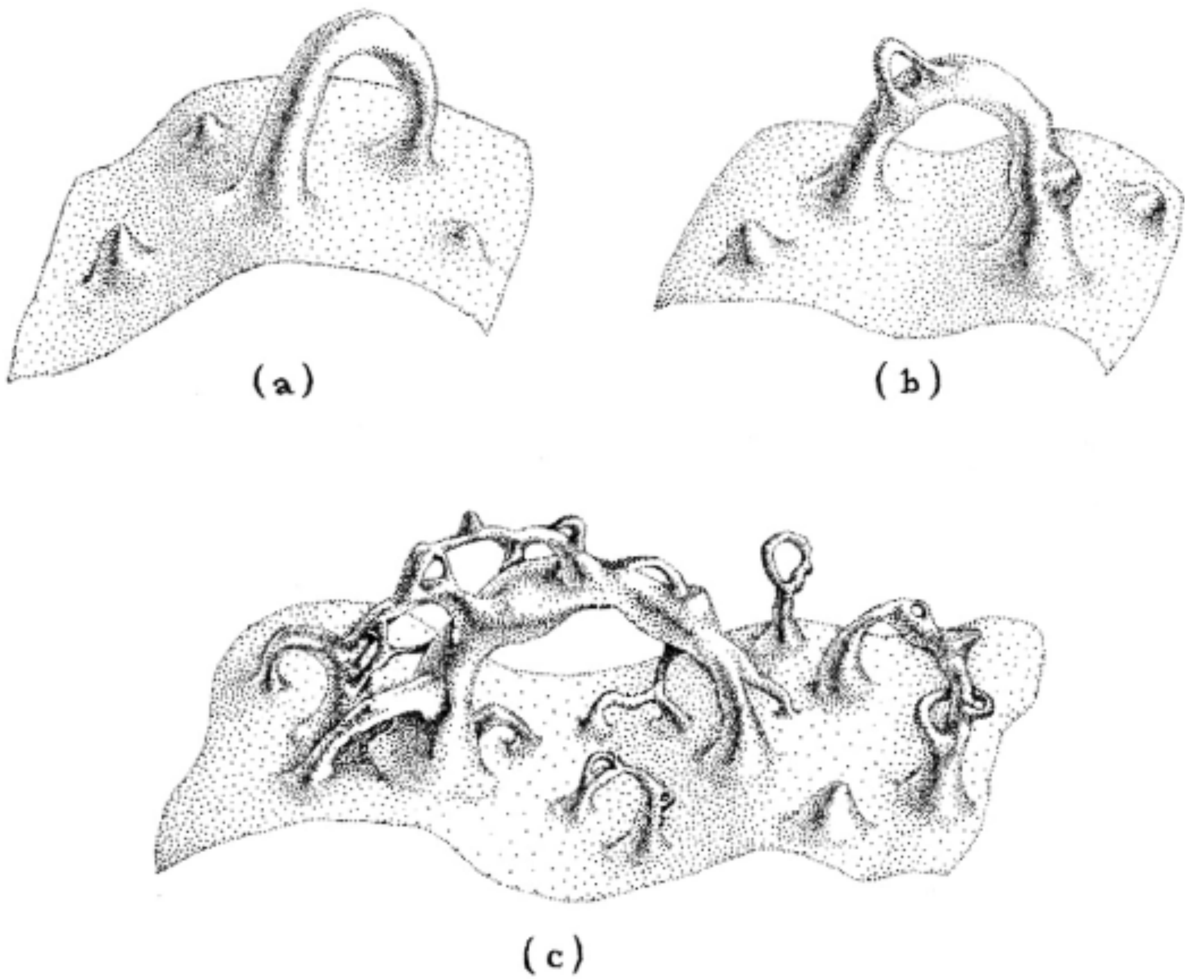


At ordinary (large) scales space-time appears smooth



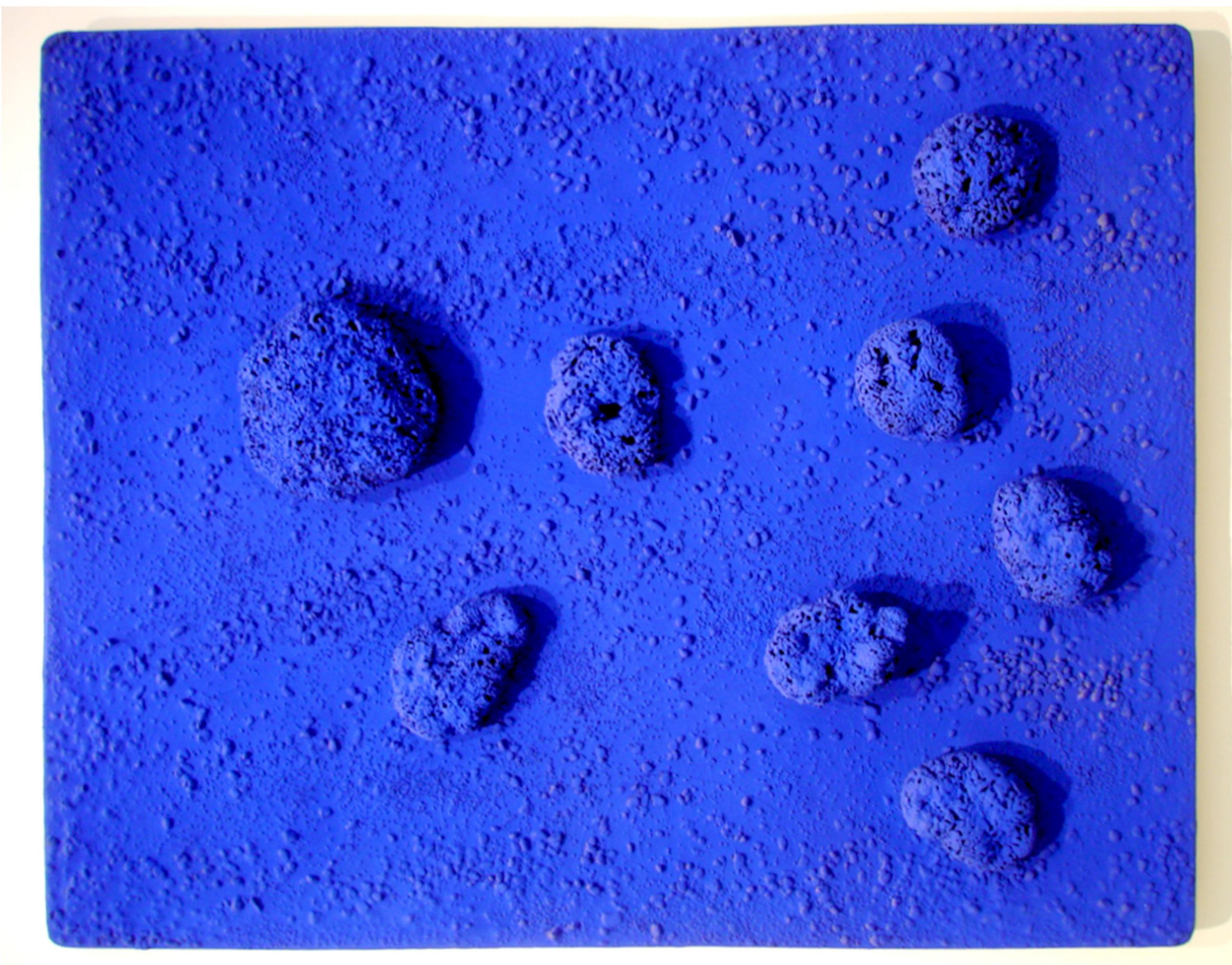
but near the Planck scale space-time loses its *smoothness* and becomes a quantum foam of shapes bubbling out of the vacuum

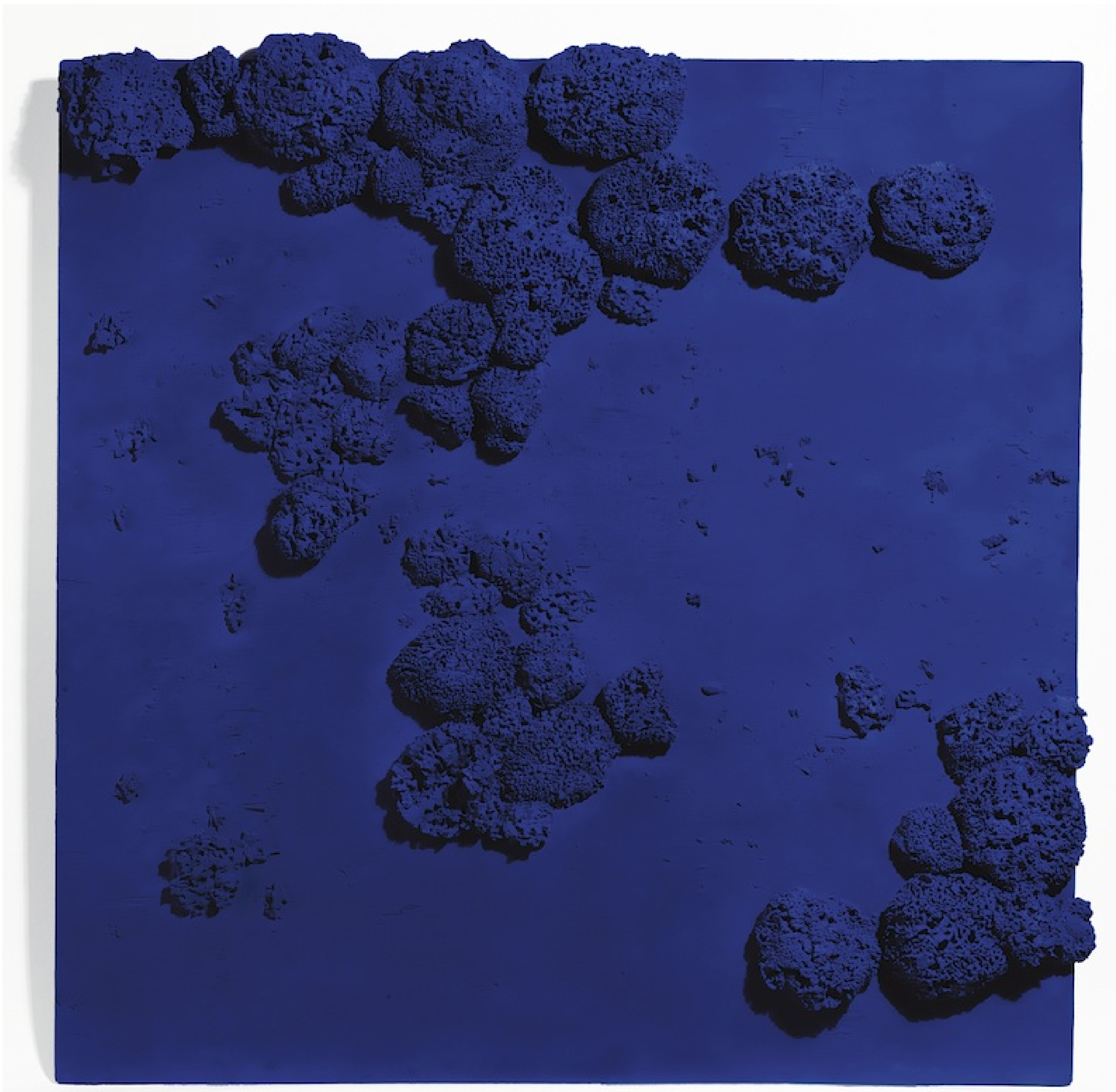




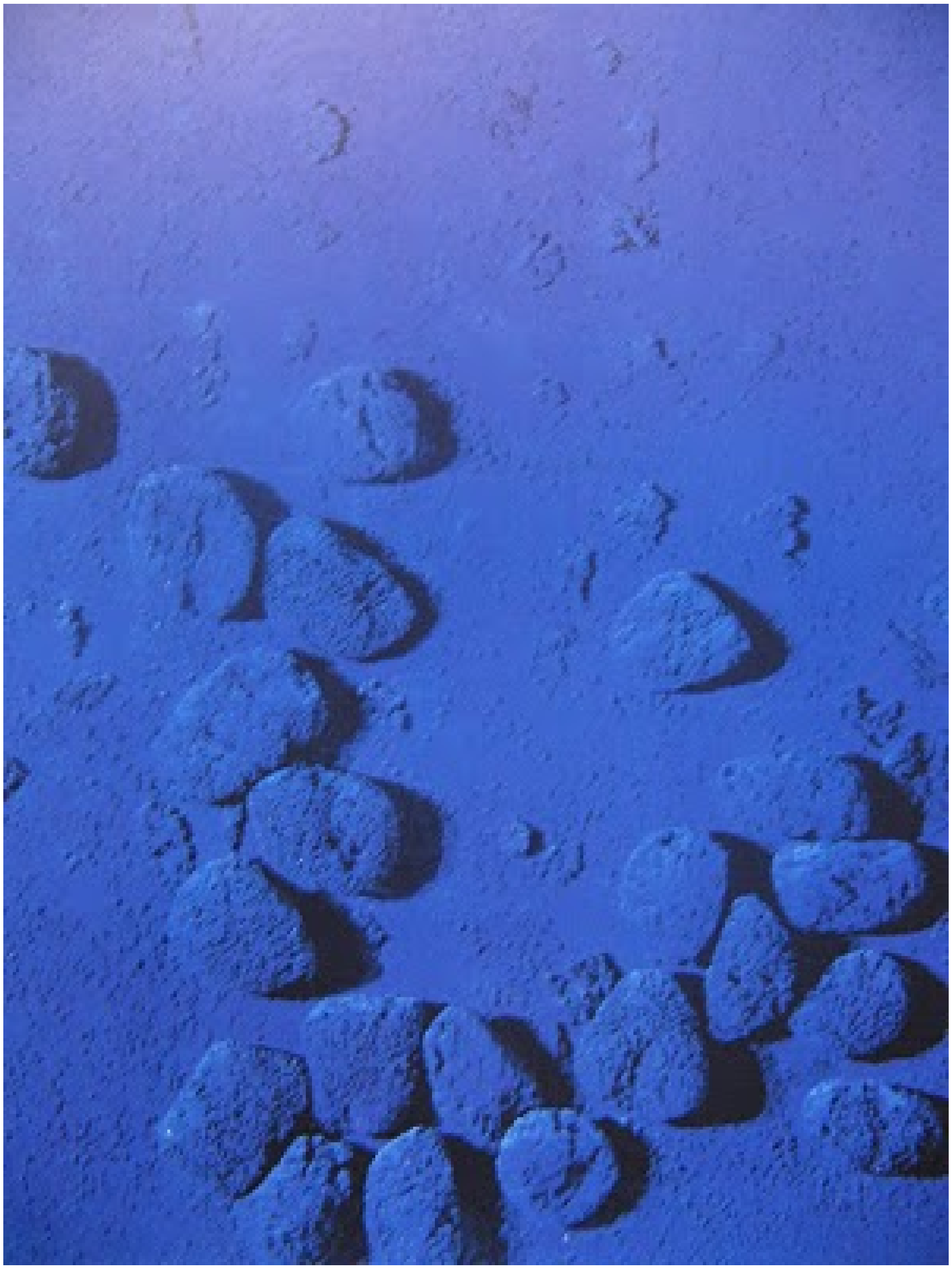
the quantum foam can have arbitrarily complicated topology

Bubbles and foams: Yves Klein's vacuum



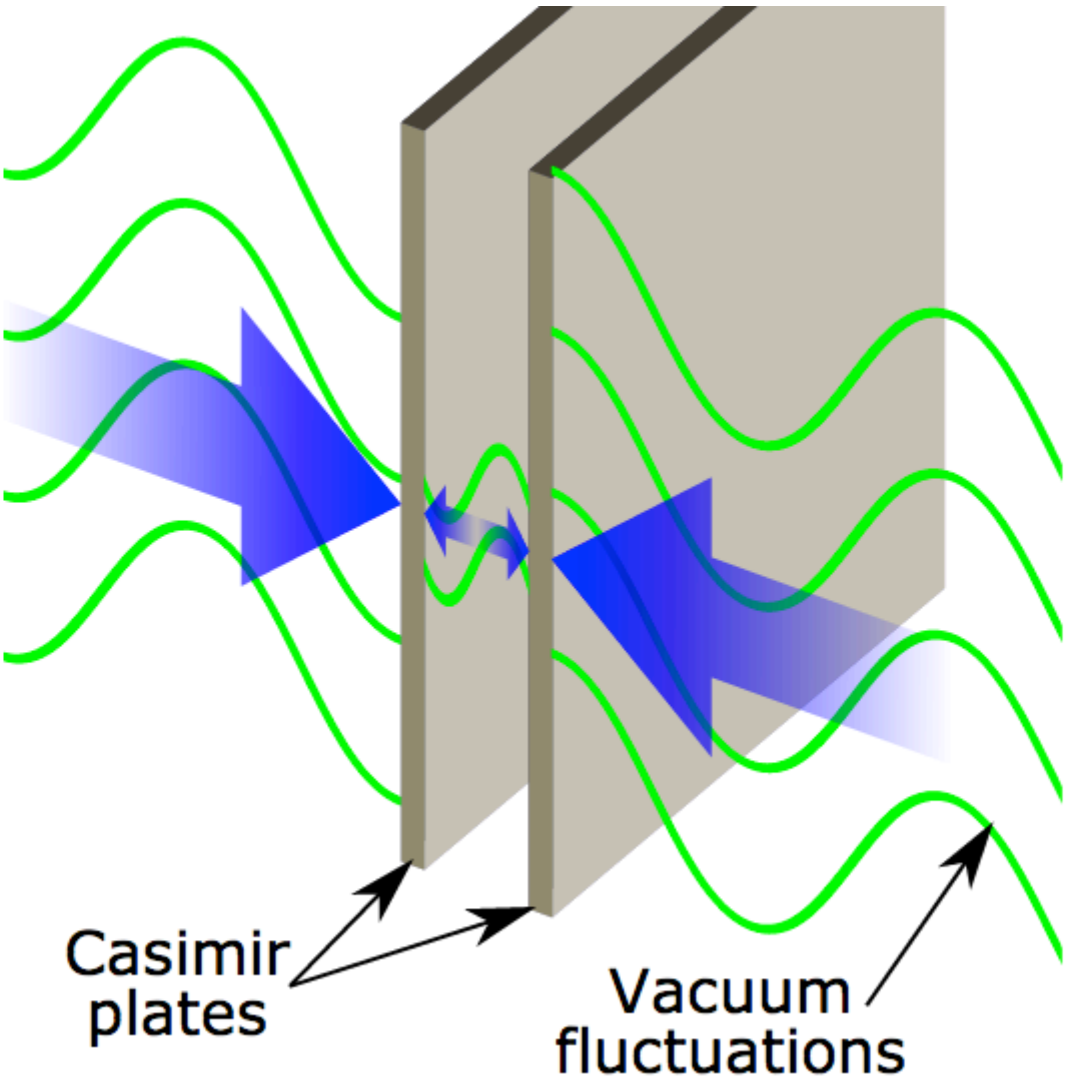


Yves Klein, *Relief éponge bleue*, 1960



Yves Klein, *Relief éponge bleue*, 1960

The Void has energy



Casimir effect

Casimir effect

experimental evidence of vacuum energy

(predicted 1948, measured 1996)

- conducting plates at submicron scale distance a (in xy-plane)
- electromagnetic waves

$$\psi_n = e^{-i\omega_n t} e^{ik_x x + ik_y y} \sin(\frac{n\pi}{a} z)$$

$$\omega_n = c\sqrt{k_x^2 + k_y^2 + \frac{n^2\pi^2}{a^2}}$$

- vacuum energy (by area and zeta-regularized)

$$E(s) = \hbar \int \frac{dk_x dk_y}{(2\pi)^2} \sum_n \omega_n |\omega_n|^{-s} = -\frac{\hbar c^{1-s}\pi^{2-s}}{2a^{3-s}(3-s)} \sum_n |n|^{3-s}$$

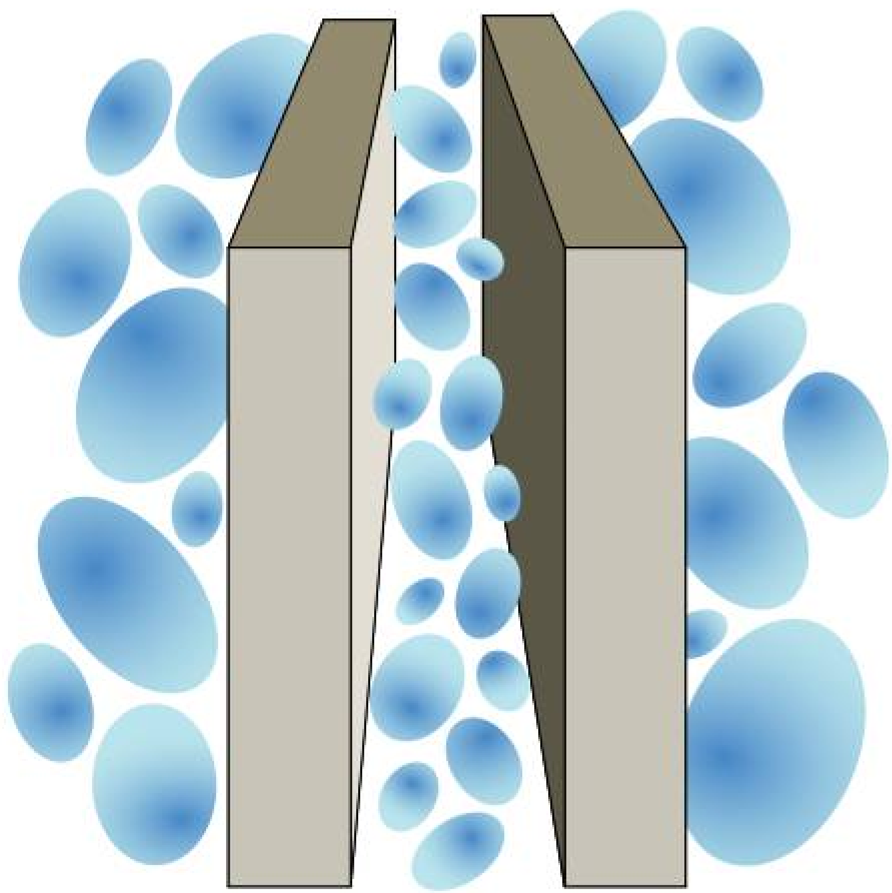
$$\lim_{s\to 0} E(s) = -\frac{\hbar c \pi^2}{6a^3}\zeta(-3)$$

- Force

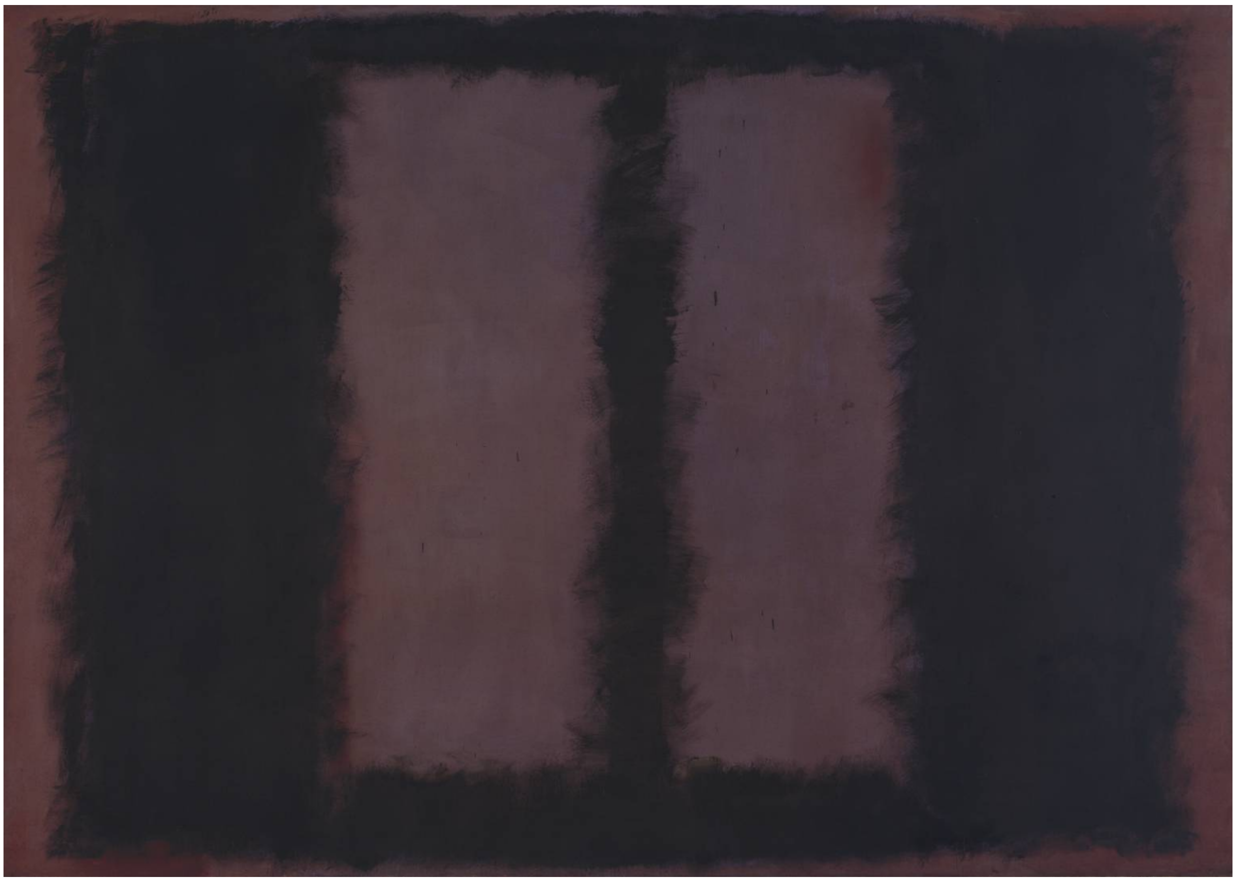
$$F = -\frac{d}{da}E = -\frac{\hbar c \pi^2}{240\, a^4}$$

$\Rightarrow$ Attractive force between the plates caused only by the vacuum !

In the gap only virtual photons with wavelength multiple of distance contribute to vacuum energy $\Rightarrow$ attractive force



Mark Rothko's Void



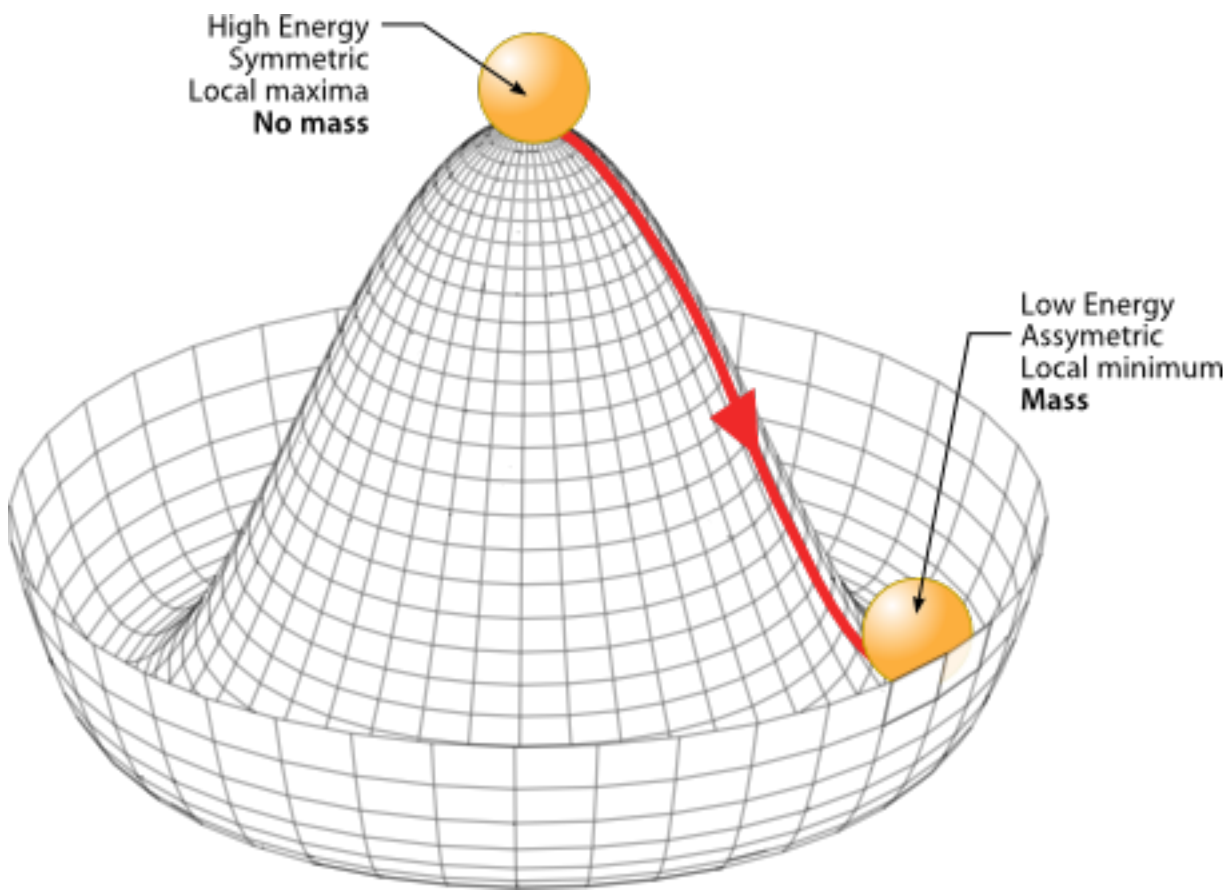
Mark Rothko, *Black on Maroon*, 1958

A luminous vacuum

Mark Rothko, *Light Red over Black*, 1957

Mark Rothko, *Red and Black*, 1968

False and True Vacua: the Higgs field



Higgs field quartic potential

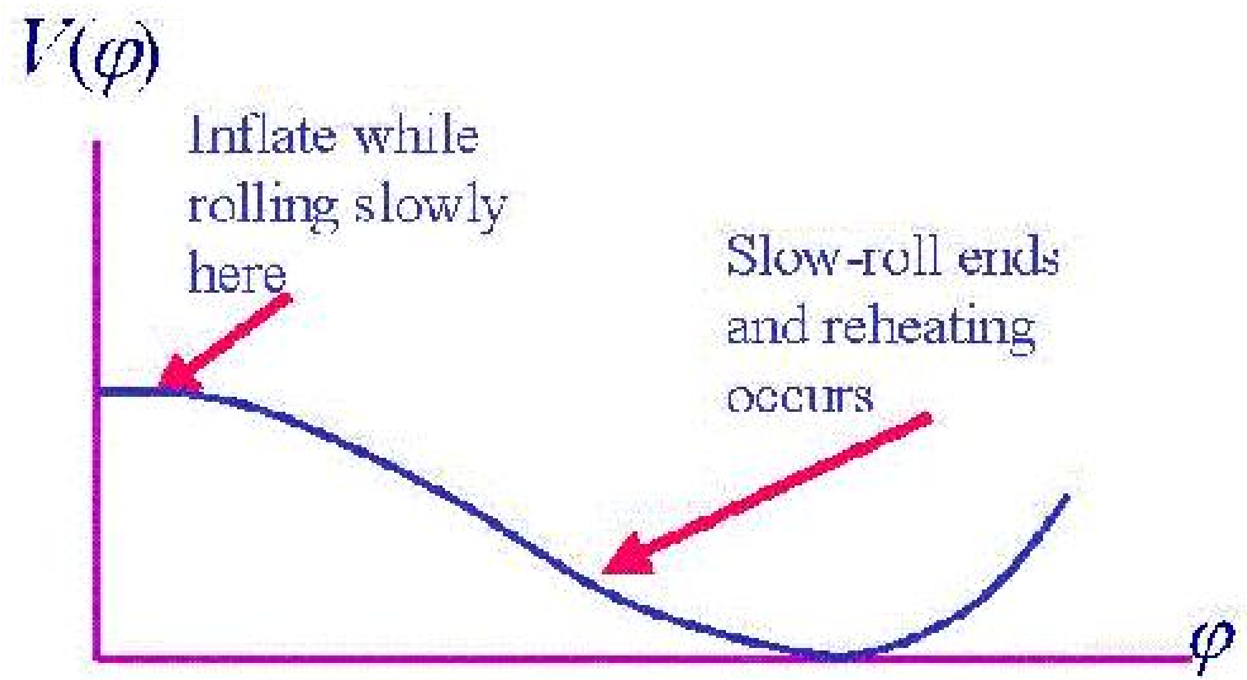
$$\mathcal{S}(\phi) = \int \frac{1}{2}|\partial\phi|^2 - \lambda(|\phi|^2 - \upsilon^2)^2$$

when coupled to matter (a boson field A)

$$\mathcal{S}(\phi, A) = \int -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + |(\partial - iqA)\phi|^2 - \lambda(|\phi|^2 - \upsilon^2)^2 \, d\upsilon$$

$\Rightarrow$ mass term $\frac{1}{2}q^2\upsilon^2A^2$ mass $m = q\upsilon$

False and True Vacua: slow-roll inflation



Near the false (unstable) vacuum: the scalar field drives rapid inflation of the universe; rolling down to the true (stable) vacuum causes end of inflation

A proliferation of Vacua: the multiverse landscape

Origins of the multiverse hypothesis

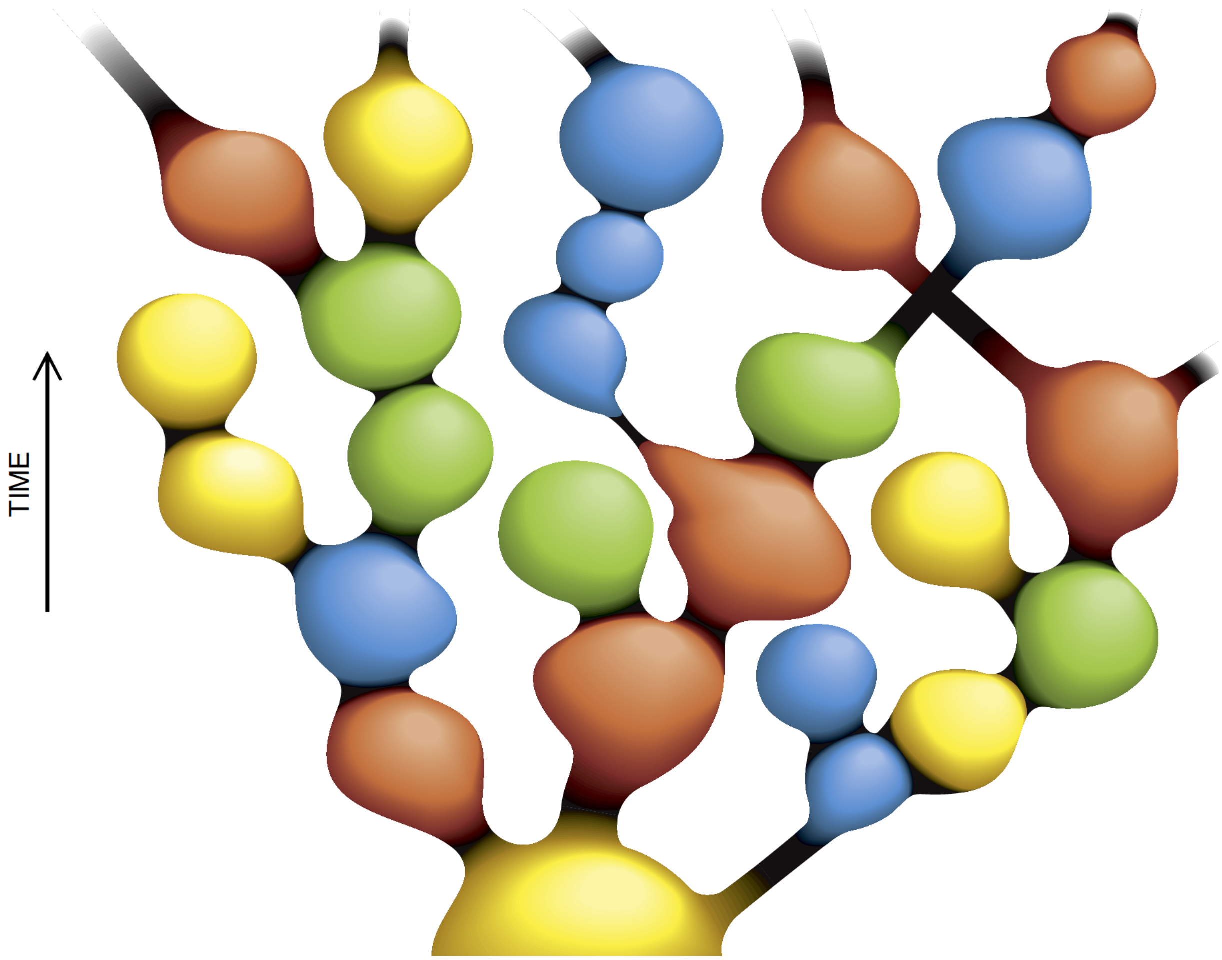
- The fine-tuning problem (anthropic principle)

- Eternal inflation

- String vacua: 10^{500} (where in this landscape is the physics we know?)

Is the multiverse physics or metaphysics?

Andrei Linde'e eternal inflation: chaotic bubbling off of new universes (with possibly different physical constants)

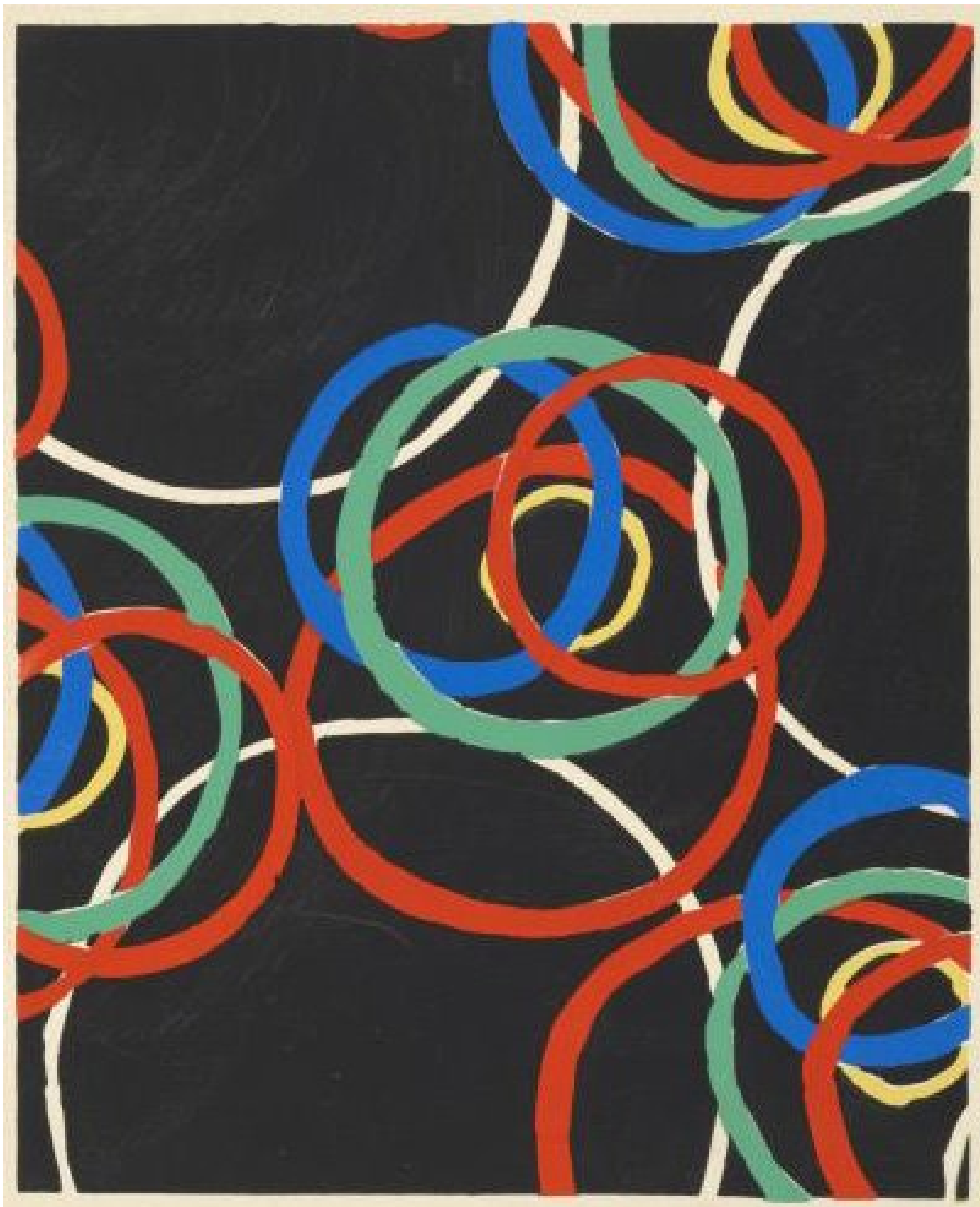


Self-reproducing universes in inflationary cosmology

Kandinsky's bubbling universes

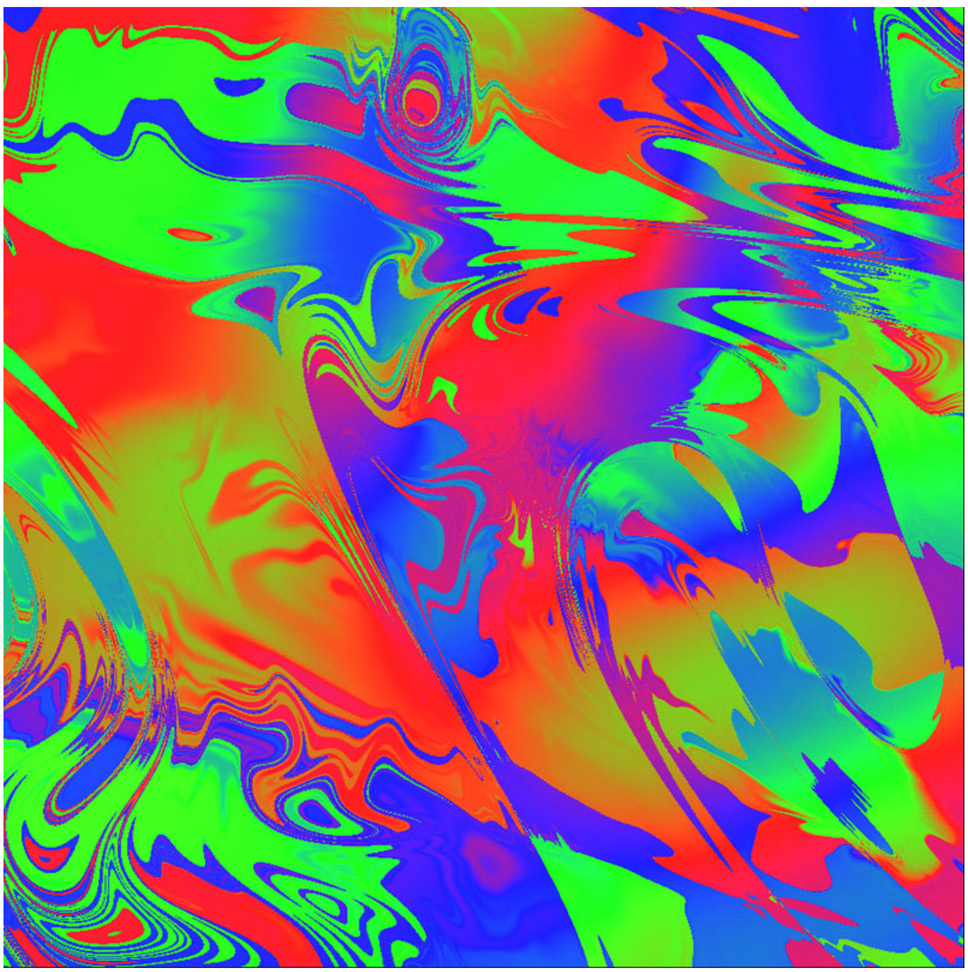
Vasily Kandinsky, *Several Circles*, 1926.

Orphism



Sonja Delaunay, *Design*, 1938 (?)

early universe quantum fluctuations of scalar field create domains with large peaks (classically rolls down to minimum); second field for symmetry breaking makes physics different in different domains



Andrei Linde's "Kandinsky Universe"

it does not look at all like a Kandinsky, but perhaps...

... more like Abstract Expressionism?...

Jackson Pollock, *Number 8*, 1949

... or like contemporary Abstract Landscape art?

Kimberly Conrad, *Life in Circles, N.29*, 2011

Some references

- Mark Levy, *The Void in Art*, Bramble Books, 2005

- Paul Schimmel, *Destroy the Picture: Painting the Void, 1949-1962*, Skira Rizzoli, 2012

- Bertrand Duplantier and Vincent Rivasseu (Eds.) *Poincaré Seminar 2002: Vacuum Energy – Renormalization*, Birkhäuser, 2003.