Plentiful Nothingness:
The Void in Modern Art and Modern Science

Matilde Marcolli

2014
The Vacuum

What do we mean by Void, Vacuum, Emptiness?

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


“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

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

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

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 dodecahedral 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

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

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

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

(i) One-loop Feynman diagrams for point particle

(ii) Corresponding closed-string diagrams of same topology
Quantum field theory and Feynman graphs

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

\[ S(\phi) = \int \mathcal{L}(\phi) d^Dx = S_{\text{free}}(\phi) + S_{\text{interaction}}(\phi) \]

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

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

\[ S_{\text{eff}}(\phi) = S_{\text{free}}(\phi) + \sum_{\Gamma} \frac{U(\Gamma, \phi)}{\#\text{Aut}(\Gamma)} \]

\[ U(\Gamma, \phi) \text{ integral of momenta flowing through the graph} \]
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 $\Lambda$

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

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

- for instance QED vacuum energy

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

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

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

**Problem**: this would give rise to an enormously large $\Lambda$: 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 plates

Vacuum fluctuations
Casimir effect
experimental evidence of vacuum energy
(predicted 1948, measured 1996)

- conducting plates at submicron scale distance $a$
  (in $xy$-plane)
- electromagnetic waves
  \[ \psi_n = e^{-i\omega_n t} e^{ik_xx + ik_y y} \sin \left( \frac{n\pi}{a} z \right) \]
  \[ \omega_n = c\sqrt{k_x^2 + k_y^2 + \frac{n^2\pi^2}{a^2}} \]
- 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
  \[ F = -\frac{d}{da} E = -\frac{\hbar c\pi^2}{240 a^4} \]

⇒ 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 ⇒ 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

\[ S(\phi) = \int \frac{1}{2} |\partial \phi|^2 - \lambda(|\phi|^2 - v^2)^2 \]

when coupled to matter (a boson field \( A \))

\[ S(\phi, A) = \int -\frac{1}{4} F^{\mu\nu} F_{\mu\nu} + |(\partial - iqA)\phi|^2 - \lambda(|\phi|^2 - v^2)^2 dv \]

\( \Rightarrow \) mass term \( \frac{1}{2} q^2 v^2 A^2 \) mass \( m = qv \)
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’s 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
