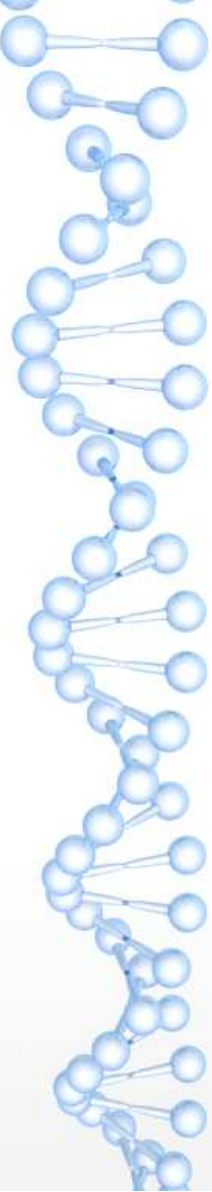


El Multiverso y las otras dimensiones: un viaje matemático y filosófico



	Electron ($R \simeq 0$)	Proton	Hydrogen Atom	Billiard Ball	Moon	Earth	Solar System ($1\text{AU}/M_{\odot}G$)	Milky Way (visible)	Sun	Galaxy Cluster	Universe ($M \propto R^3$)
$R/(MG)$	0^+	7.1×10^{38}	2.0×10^{43}	2.4×10^{26}	3.2×10^{10}	1.4×10^9	1.0×10^8	1.5×10^6	4.7×10^5	$\sim 10^5$	0^+



Plan:

- Part (I): Understanding the (mathematical) multiverses.
- Part (II): Advanced stuff

PART(I)→ Introduction to the Multiverses: the mathematical reality hypothesis!

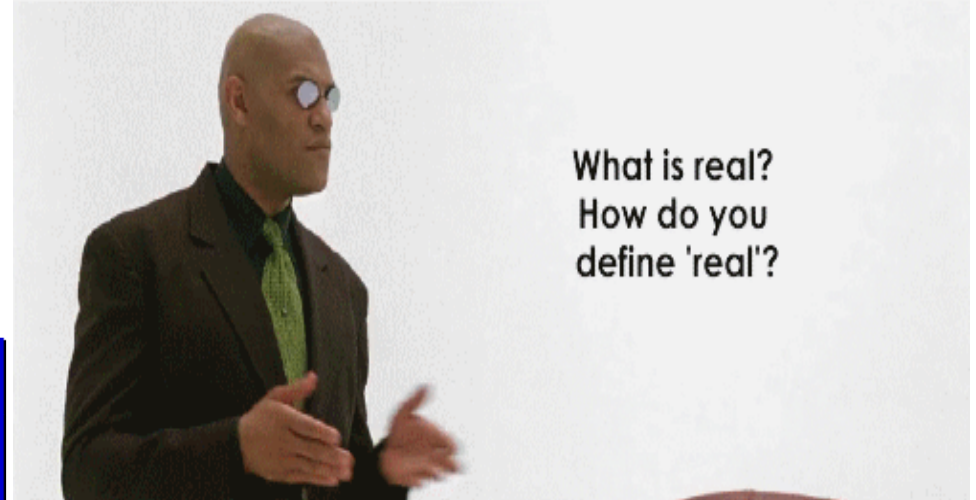
External Reality Hypothesis (ERH):

There exists an external physical reality completely independent of us humans.



Mathematical Universe Hypothesis (MUH):

Or external physical reality is a mathematical structure.

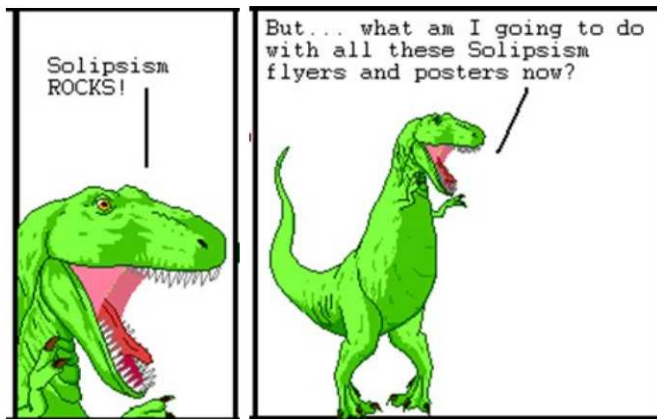


- Physmatics = Physics + Mathematics
- Physchematics = Physics + Chemistry + Mathemics

Solipsistists here?

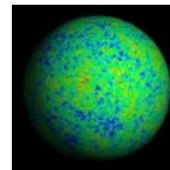
External Reality Hypothesis (ERH):

There exists an external physical reality completely independent of us humans.

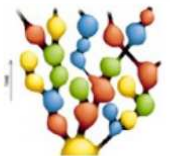


Where are the parallel universes?

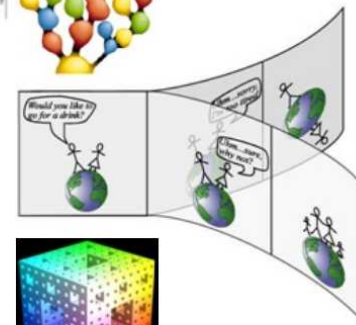
1) Far away in space



2) Infinitely far away in space



3) Elsewhere in Hilbert space



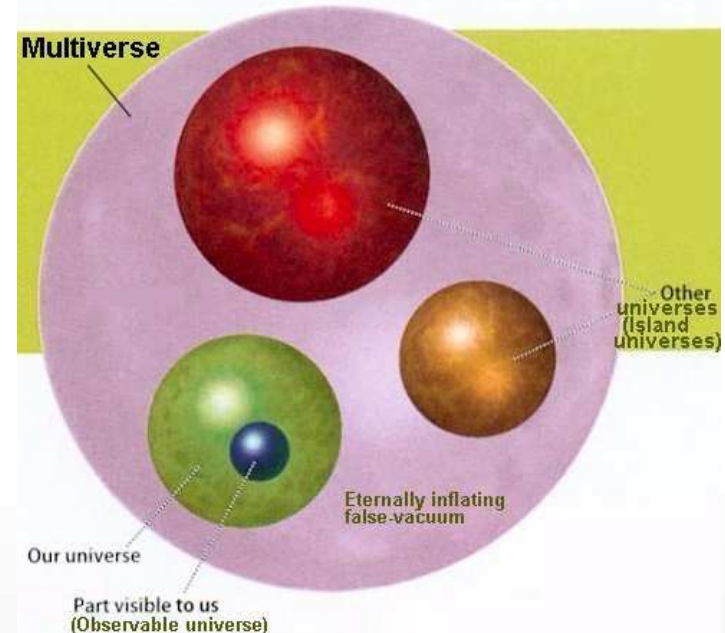
4) Elsewhere in “math space”

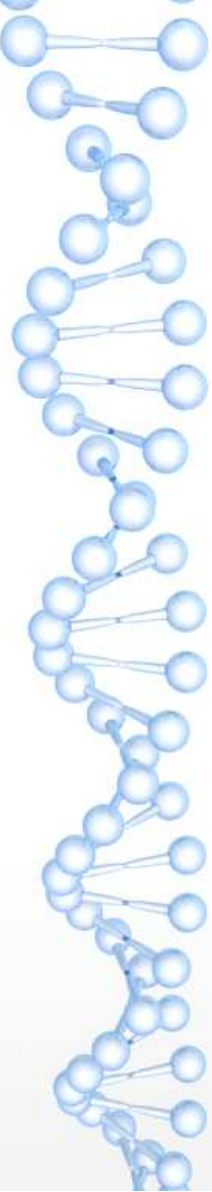


Niveles de Multiverso (Tegmark)/ Levels of the Multiverse

- Level I: Other Hubble volumes have different initial conditions
- Level II: Other post-inflation bubbles may have different effective laws of physics (constants, dimensionality, particle content)
- Level III: Other branches of the quantum wavefunction add nothing qualitatively new
- Level IV: Other mathematical structures have different fundamental equations of physics

- Pictures? A naive (not the only) one:





Multiverse: Levels 1 to 4

Level 1: Regions beyond our cosmic horizon

Features: Same laws of physics, different initial conditions

Assumptions: Infinite space, ergodic matter distribution

Evidence:

- Microwave background measurements point to flat, infinite space, large-scale smoothness
- Simplest model

Level 2: Other post-inflation bubbles

Features: Same fundamental equations of physics, but perhaps different constants, particles and dimensionality

Assumption: Chaotic inflation occurred

Evidence:

- Inflation theory explains flat space, scale-invariant fluctuations, solves horizon problem and monopole problems and can naturally explain such bubbles
- Explains fine-tuned parameters

Level 3: The Many Worlds of Quantum Physics

Features: Same as level 2

Assumption: Physics unitary

Evidence:

- Experimental support for unitary physics
- AdS/CFT correspondence suggests that even quantum gravity is unitary
- Decoherence experimentally verified
- Mathematically simplest model

Level 4: Other mathematical structures

Features: Different fundamental equations of physics

Assumption: Mathematical existence = physical existence

Evidence:

- Unreasonable effectiveness of math in physics
- Answers Wheeler/Hawking question: "why these equations, not others"



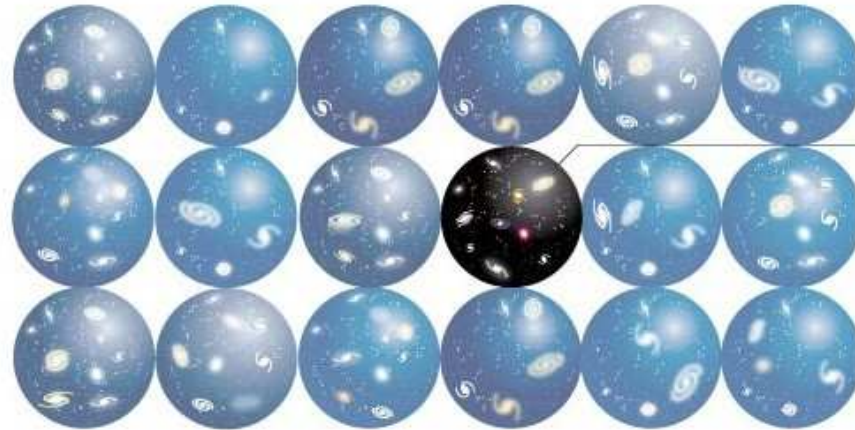
Multiverse: Level 1, details

(Todo lo que puede ocurrir, ha ocurrido u ocurrirá)

The multiverse hierarchy: level 1

©NewScientist

If the big bang started with a period of inflationary growth, there would be a multitude of universes a lot like ours – but with different arrangements of matter



Our universe
42 billion light years
across – the distance light
has travelled in our
expanding universe

Physics:

Like ours, but with all possible initial conditions and histories replicated an infinite number of times

Support:

Plays to the idea of the principle of mediocrity – that there's nothing special about the universe we see

Relationships:

All level 1 universes bear a family resemblance to ours and to each other

Connections:

Since everything that can happen in our universe has happened in some other level 1 universe, there may be a direct connection between level 1 and level 3 quantum multiverses

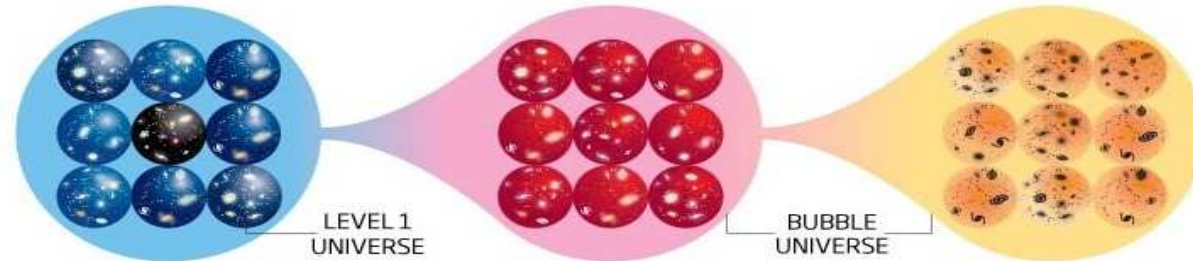
Multiverse: Level 2 details

Key idea: inflation! (Money?) Well, no...

The multiverse hierarchy: level 2

©NewScientist

In the theory of eternal inflation, the space between universes continues to expand, and a limitless number of new "bubble" universes, with very different properties, continue to form. Each bubble universe contains an infinite number of its own level 1 universes



Physics:

Other bubble universes exhibit different laws of physics and have different dimensionality, particles, constants and forces to those seen in our universe. We might eventually discover that all these parameters flow from the same "theory of everything"

Support:

Inflation explains the uniformity and flatness of our universe and details of the cosmic microwave background. Eternal inflation implies bubble universes and provides a way of supplying string theory with the many universes it demands

Relationships:

Level 2 universes vary greatly. They represent separate bubbles or domains with different properties, and are separated from each other by inflating space

Connections:

Level 2 includes all possible level 1 universes plus an enormous variety of much stranger universes. Since everything that can happen in a particular level 2 universe has happened in other universes, level 2 may also correspond to the universes in the level 3 quantum multiverse

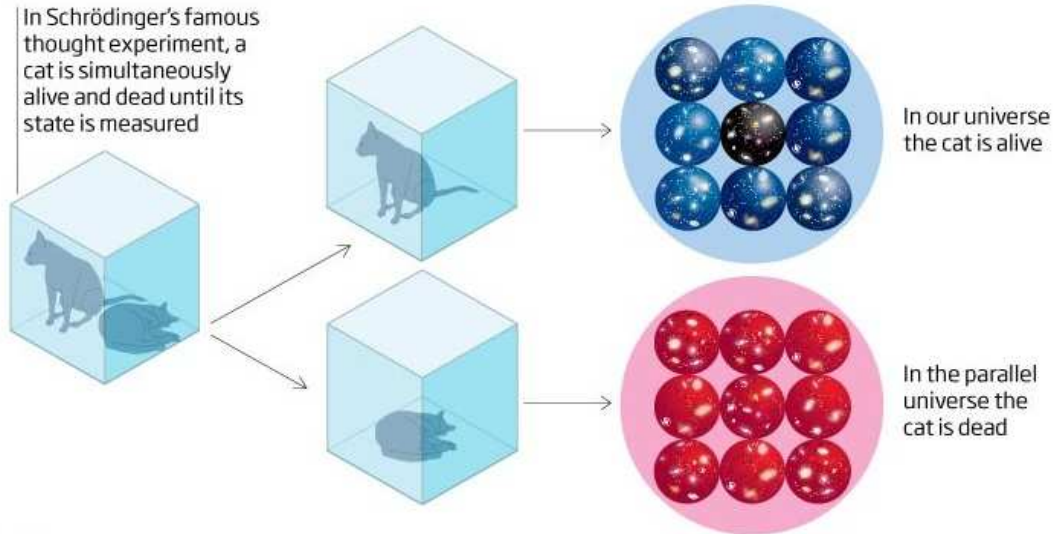
Multiverse: Level 3, details (I)

The Quantum realm...

The multiverse hierarchy: level 3

The many-worlds interpretation of quantum mechanics suggests a continually branching series of multiverses

©NewScientist



Physics: Quantum mechanics underlies all level 1 and 2 universes, but arguably with all possible virtual or parallel worlds also realised somewhere in space

Support: Quantum mechanics, including ideas of superposed states and collapsing wave functions, is one of the most thoroughly tested and successful theories in physics

Relationships: Within a given universe, parallel or branching worlds follow the same physical laws. However, once histories diverge, they can no longer interact

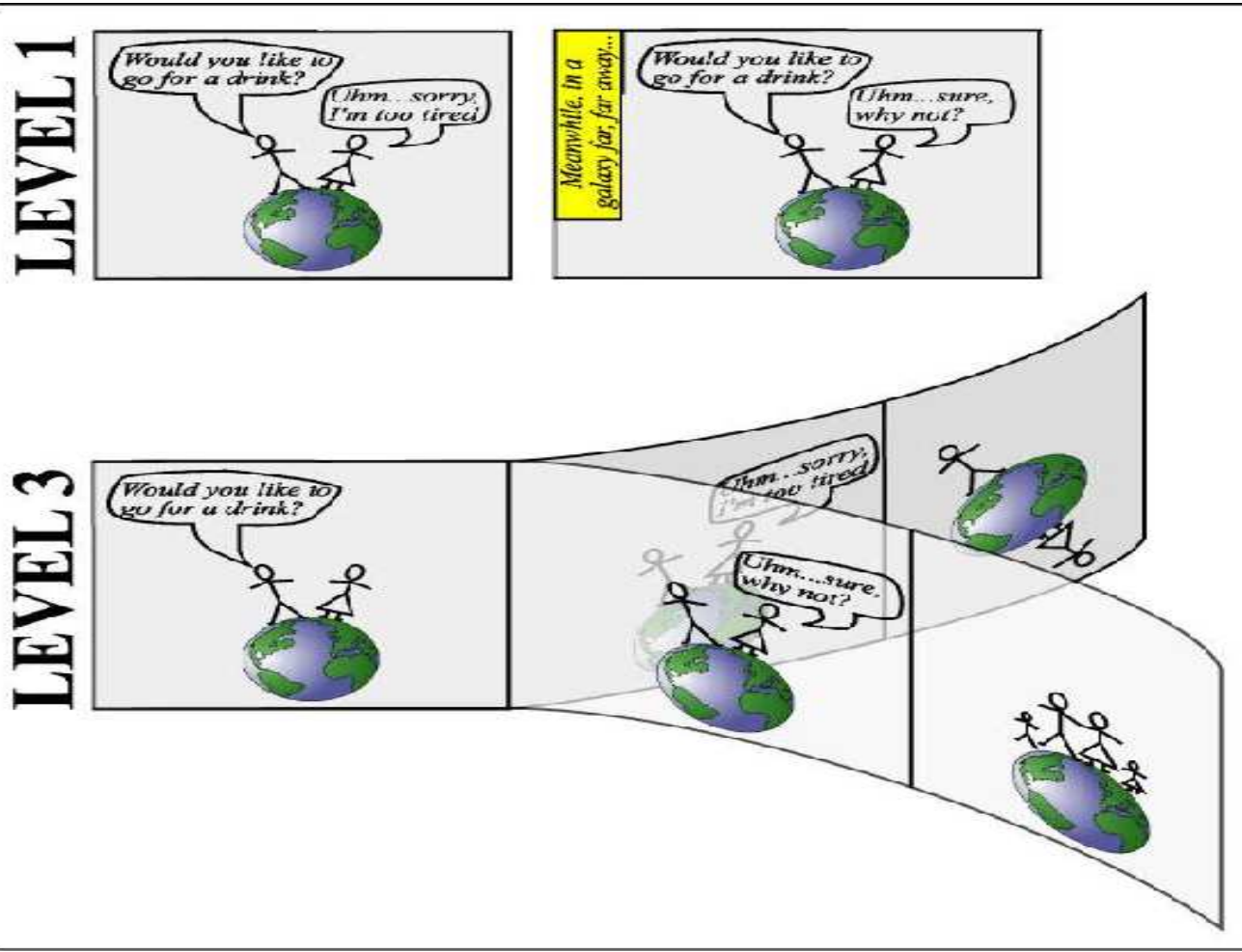
Connections: The parallel universes of level 3 may be realised in the multiverses of level 1 and 2

- The wave function rises (Is it “real”? Not really...Generally, it is...complex!)

- $$\Psi \quad | \Psi |^2$$

- Big deal. The only real stuff are...Probabilities (real stuff, literally).

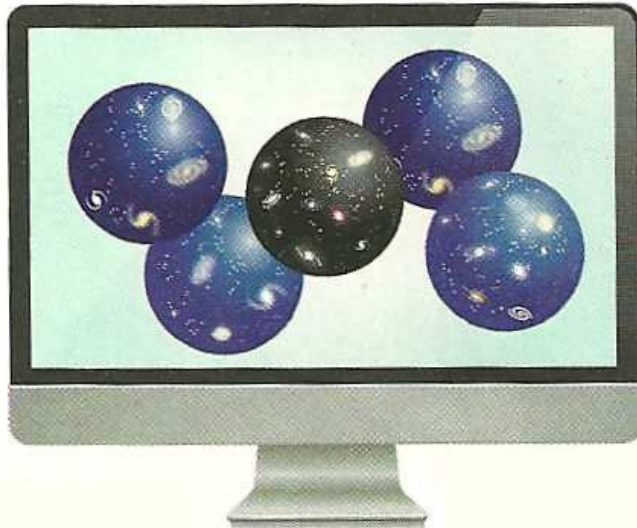
Multiverse 3 (and 1): in a joke...



Multiverse 4: Or when things go crazy...

The multiverse hierarchy: level 4

If our universe is just a simulation, there could be infinitely many kinds of universes that differ in arbitrary ways from ours



The multiverse hierarchy: level 4

The multiverse hierarchy: level 4

If our universe is just a simulation, there could be infinitely many kinds of universes that differ in arbitrary ways from ours



Physics:
Anything goes

Support:
None. The idea is that long-lived technological civilisations will probably command vast computing power and may choose to run multiple "ancestor simulations" which will soon outnumber natural universes. There may be a one-to-one relationship between mathematics and reality: every conceivable mathematical system may represent a real universe

Relationships:
Arbitrary or non-existent

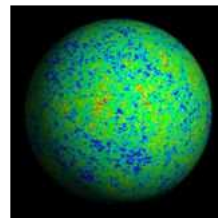
Connections:
Level 4 must contain the ultimate theory of everything. If so, there's no level 5

Multiversal review (I)

What are the 4 multiverse levels like?

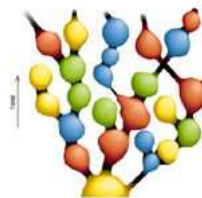
10^{100} bits?

- 1) Same effective laws of physics, different initial conditions



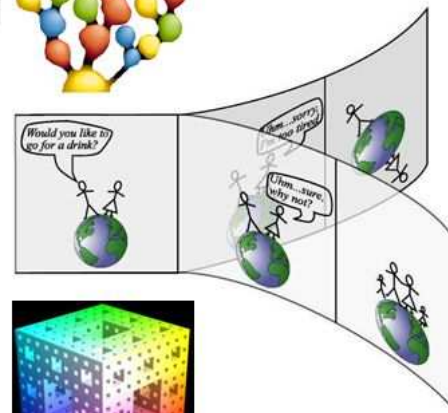
10^3 bits?

- 2) Same fundamental laws of physics, different effective laws (“bylaws”)



10^2 bits?

- 3) Nothing qualitatively new



- 4) Different fundamental laws of physics

0 bits!

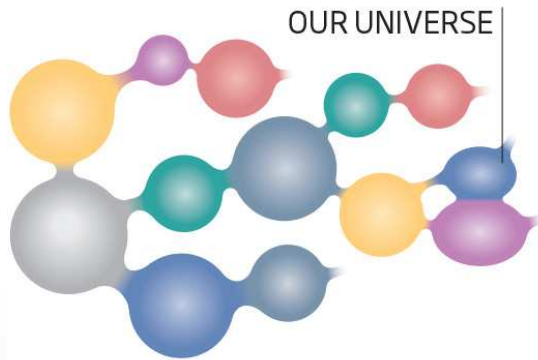


The bigger the multiverse, the simpler the theory.

Multiversal review (II)

Eternal inflation

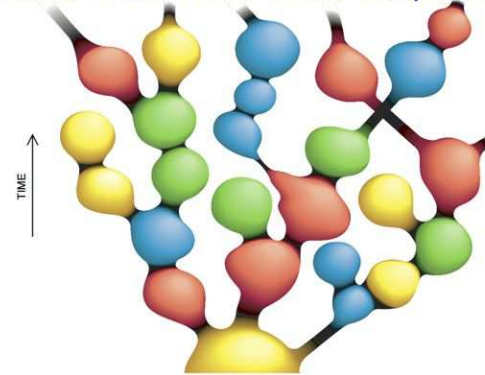
Our universe could be one of many bubble universes in a branching, ever-expanding multiverse. If we bump up against another universe, it could leave a mark on the ancient sky



Inflationary Multiverse

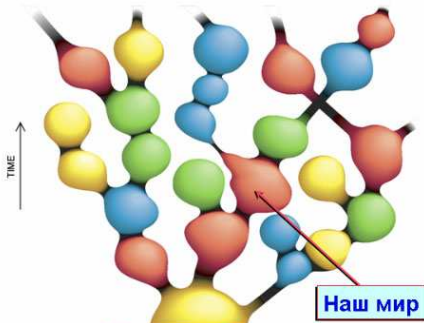
For a long time, people believed in the **cosmological principle**, which asserted that the universe is everywhere the same.

This principle is no longer required. Inflationary universe may consist of many parts with different properties depending on the local values of the scalar fields, compactifications, etc.



Multiversal review (III)

Фрактальная Вселенная

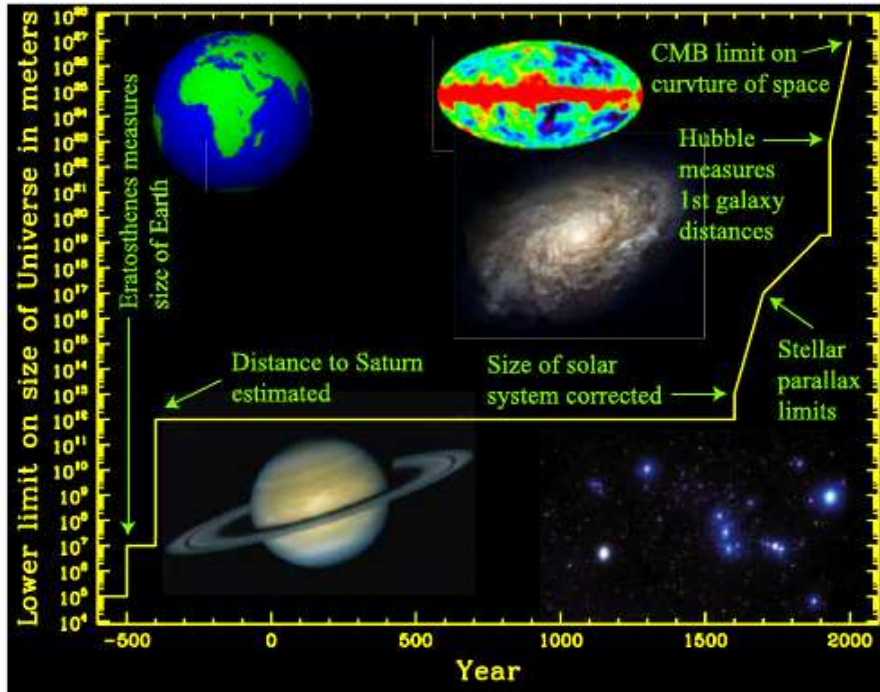


Большой Взрыв?



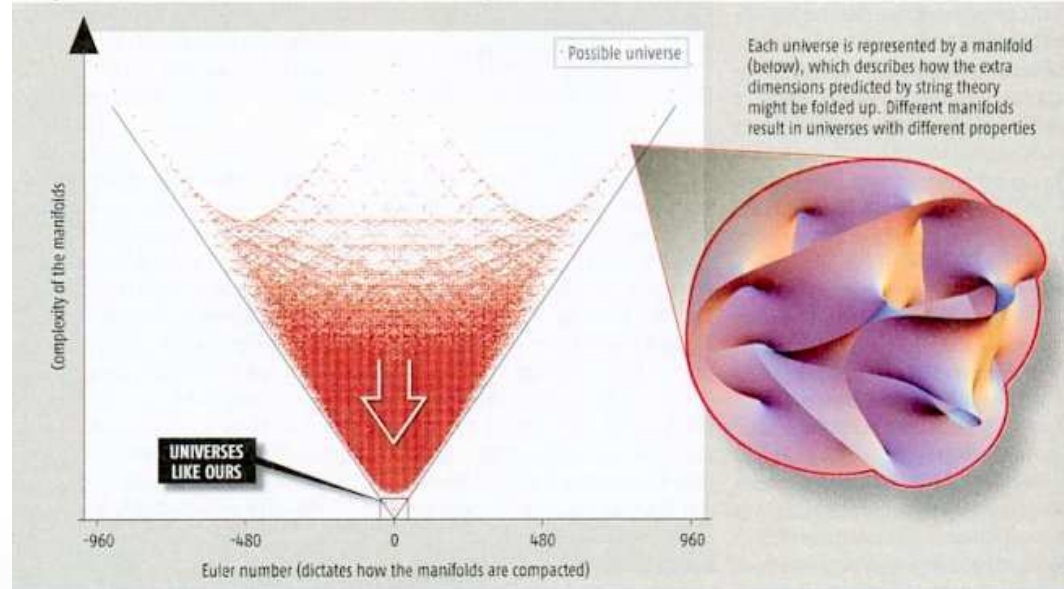
Multiverse: beyond. How many?

More dimensions?

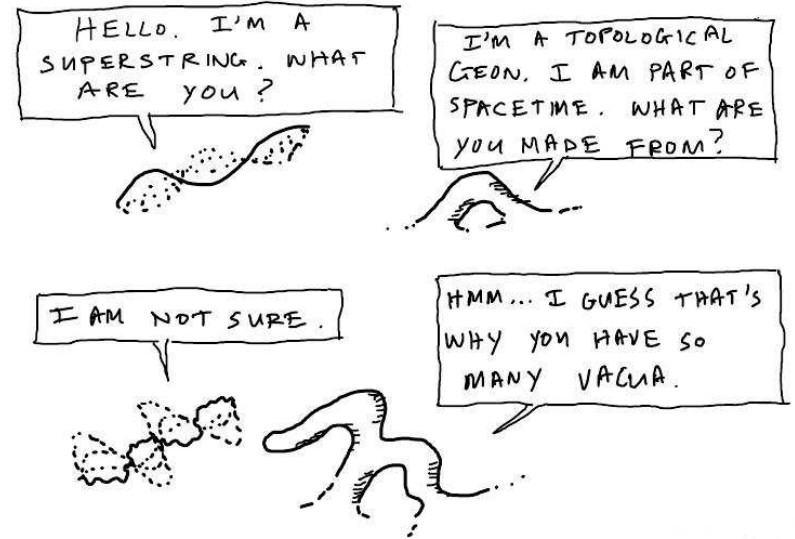
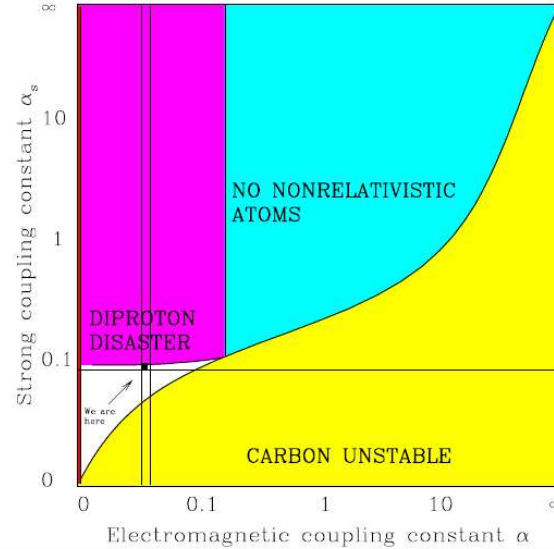
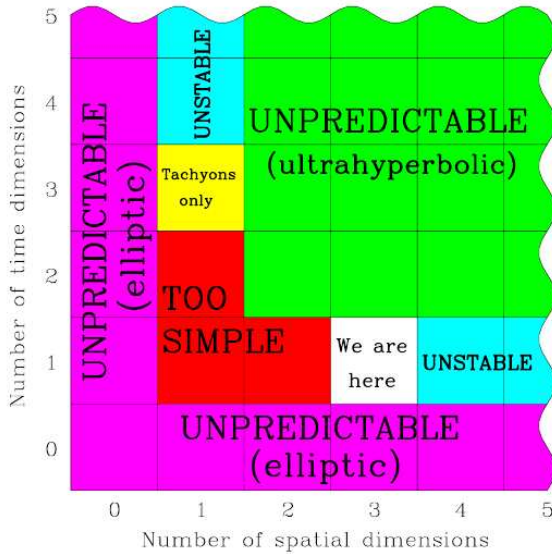


HOW OUR UNIVERSE MAY HAVE EVOLVED

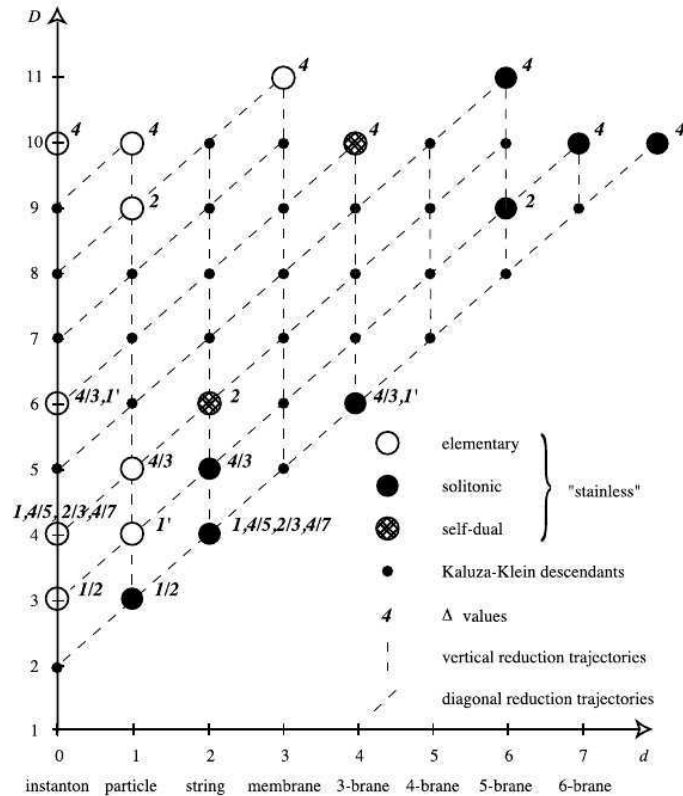
One interpretation of string theory suggests that our life-friendly universe could have descended from one of a huge range of initial configurations through a number of transformations. A universe such as ours might be the favoured result of such a process



Part (II)→ The mathematical multidimensional multiverses (physmactical, physchematical!)



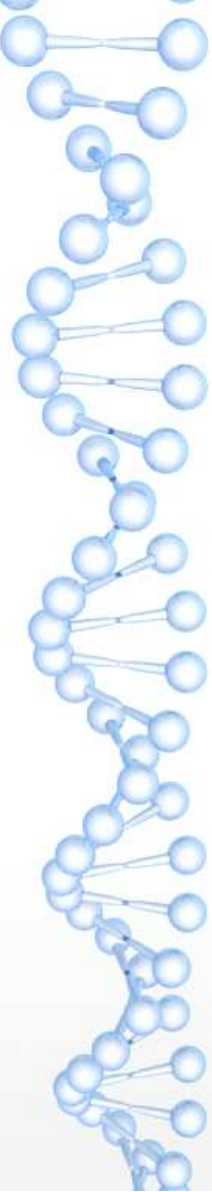
The views of superstrings and M-theory Dp-branes vs. The current Big Bang



"Brane-scan" of supergravity p -brane solutions, linked by worldvolume (diagonal) and transverse-space (vertical) dimensional reductions

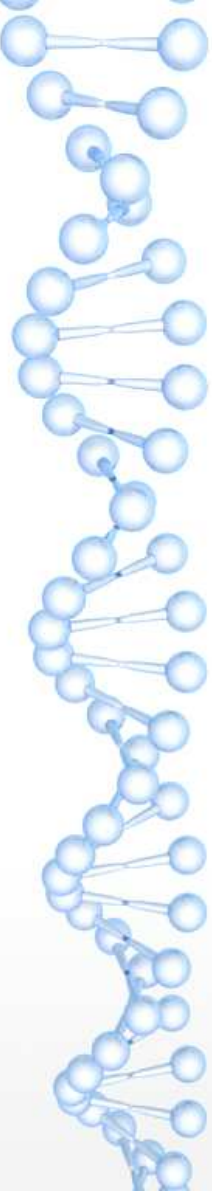
Was the Big Bang the beginning of the universe?

	$\dim \mathcal{H} = \text{finite}$	$\dim \mathcal{H} = \infty$
time is emergent	universe had a beginning	universe may or may not have had a beginning
time is fundamental	universe is eternal, with a finite recurrence time (& Boltzmann brains)	universe is eternal, and need never experience recurrence



Dimensions and hyperspaces

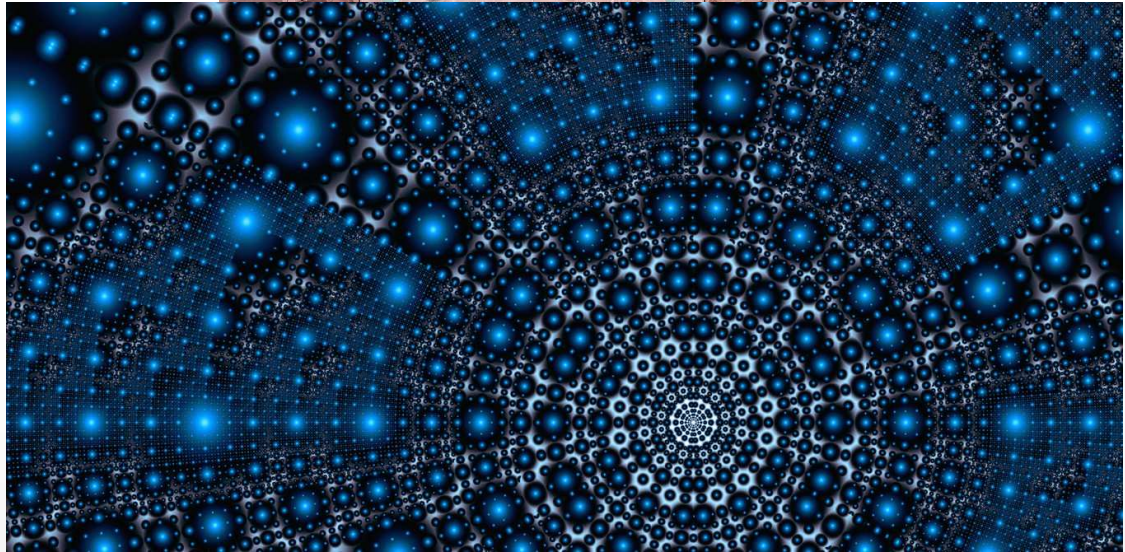
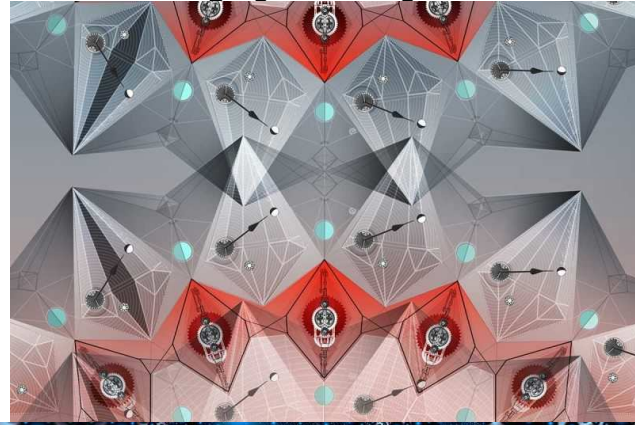
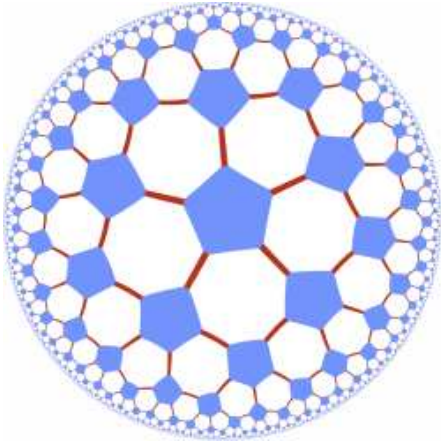
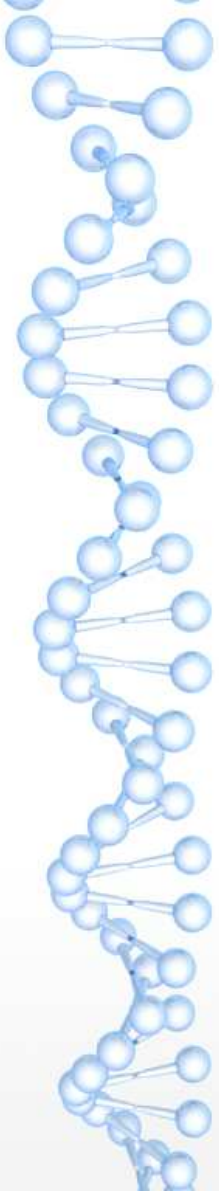
- Geometry(Geometría):
- Vacuum, point, line, plane, space,...Hyperspace! (0,1,2,3,... $D > 3$!)
- $D = -1$????? $D = -n$???
 $D = a + bi$?????
- Generally: $D \geq 0$
- Exceptionalities:
 - a) Non-integer constant dimensions: fractals!
 - b) Non-integer VARIABLE dimensions: multifractals!
 - c) Negative dimensions
(weird?)
 - d) Complex dimensions?
 - e) Something else????

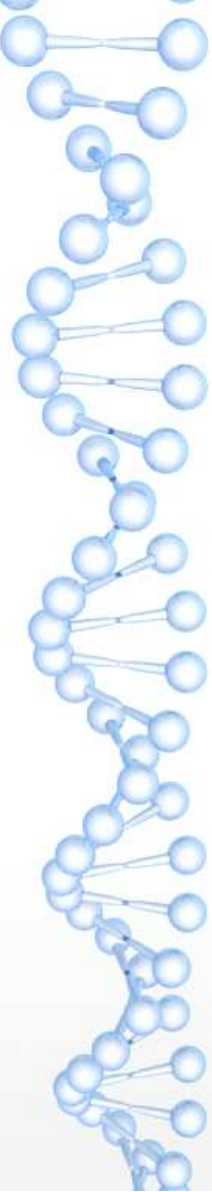


Dimensions and hyperspaces (II)

- Void = Vacuum =
Nothingless (boring?)
- Points: discrete (lattice)
- or continuous (space and time)
- Types of ordered points:
Crystals, quasicrystals,
polycrystals,
quasipolycrystals,...
- Lines, surfaces, volumes,
...Connected?
- a) Unoriented discrete
- b) Oriented discretes
- c) Continuous + oriented
- Graphs, digraphs,
multidigraphs

Dimensions and hyperspaces (III)



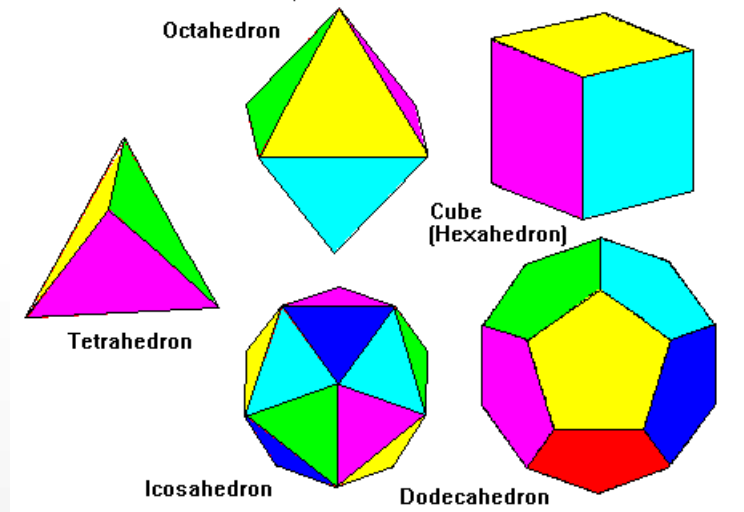


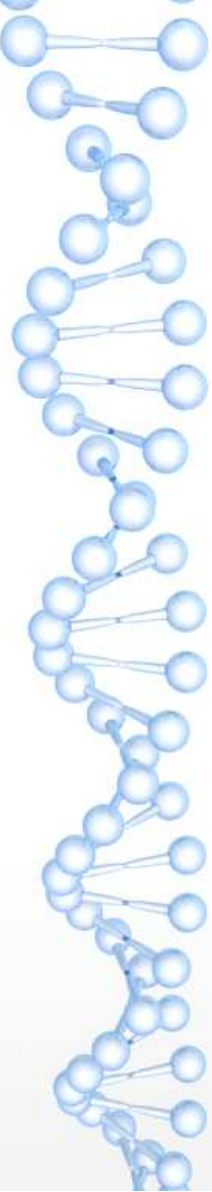
Vocabulary

- Point to point: multigraphs, multidigraphs, apeiromultidigraphs.
- Polygons, polyhedra, polytopes (apeirogons, apeirohedra, apeirotopes,...). Others: amplituhedra, associahedra, the grassmannian, positroids, ...
- Special types: regular polygons and polytopes.
- $D=2 \rightarrow$ Infinite regular polygons, $D=3 \rightarrow 1+4$ regular polytopes, $D=4 \rightarrow 6$ regular polytopes, $D>4 \rightarrow 3$ regular polytopes.

D=2 and D=3 regular polygons and polyhedra

- D=2: equilateral triangle, square, regular pentagon, ..., regular n-gon.
- D=3: tetrahedron (simplex), cube/hexahedron, octahedron, dodecahedron, icosahedron.
- The platonic
- polyhedra (3d):



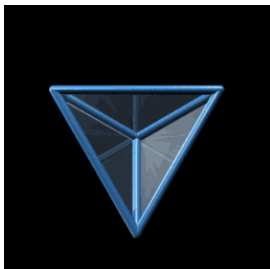


D=4 polytopes!

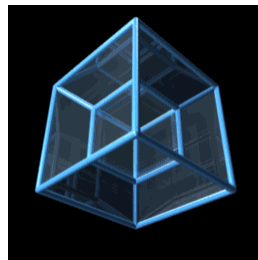
- #1. 5-cell, 4-simplex, pentatope, pentahedroid, pentachoron. C-5
- #2. C-8, 8-cell, octachoron, octahedroid, tetracube, tesseract, hypercube.
- #3. C-16, hexadecahedroid, hexadecachoron, orthoplex, 16-cell.
- #4. C-24, 24-cell, icositetrachoron, octaplex, hyperdiamond, polyoctahedron.
- #5. C-120, 120-cell, dodecaplex, hyperdodecahedron, polydodecahedron, hecatonicosachoron, dodecacontachoron and hecatonicosahedroid.
- #6. C-600. hexacosichoron and hexacosihedroid.

D=4 polytopes (II)!

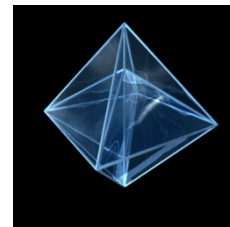
- 5-cell



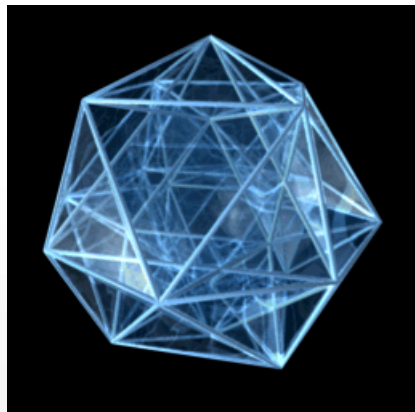
- 8-cell



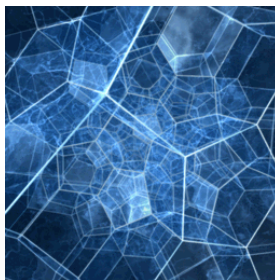
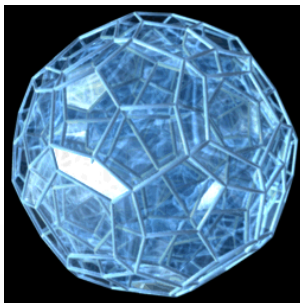
- 16-cell



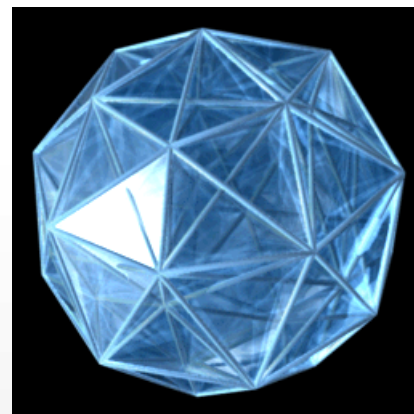
- 24-cell

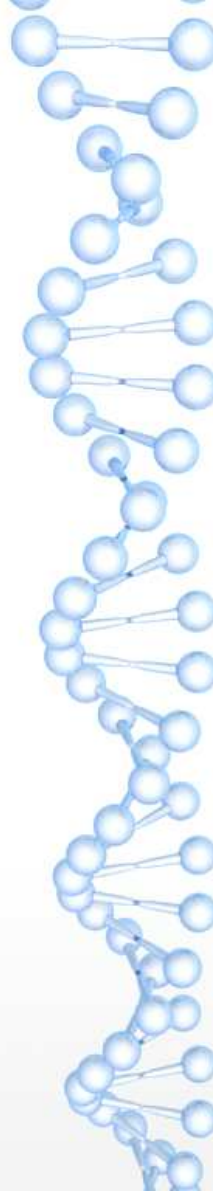


- 120-cell



- 600-cell





D>4. Stranger things happen...

- Only 3 (+1 exotica) regular polytopes.
 - #1. n-simplex (n>4). Hypertetrahedron (5-cell=4-simplex)
 - #2. cross-polytope, n-orthoplex, hyperoctahedron, cocube.
 - #3. n-cube, hypercube, hypertesseract, n-dimensional cube (non-regular→ n-orthotope).
 - Oddity: n-pentagonal polytope (non-regular uniform).
-
- Curiosities: n-cube has 2^n points, 2n-sides or faces.
 - E(m,n), m<n, m-cubes in the boundary of n-cubes: $2^{n-m} \binom{n}{m}$
 - Formulae for the n-cube:
 - $V = L^n$ $S = (2n)L^{n-1}$

D > 4. More formulae

- N-orthoplex

$$V = \frac{\sqrt{2^n}}{n!} L^n$$

$$S = \frac{\sqrt{2^{n+1}} n}{(n-1)!} L^{n-1}$$

$$E(k, n) = 2^{k+1} \binom{n}{k+1}$$

- N-simplex

$$V = \frac{\sqrt{2^{1-n}} (n+1)}{n!} L^n$$

$$S = \frac{\sqrt{2^{1-n}} n}{(n-1)!} (n+1) L^{n-1}$$

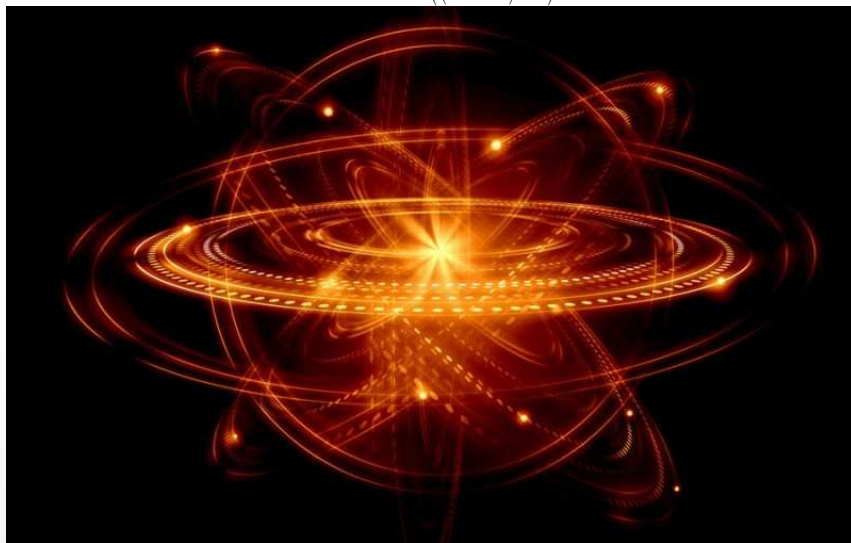
$$E(k, n) = \binom{n+1}{k+1}$$

- Not a polytope, but the hypersphere volume and hypersurface

$$V = \frac{\Gamma(1/2)^n R^n}{\Gamma(n/2+1)}$$

$$S(n-1) = dV(n)/dR \rightarrow S(n) = \frac{2\Gamma(1/2)^{n+1}}{\Gamma((n+1)/2)}$$

$$\Gamma(n) = (n-1)! \Leftrightarrow \Gamma(1/2) = \sqrt{\pi}$$



Conclusion (Waku, waku!)

Explore higher dimensions and multiverses!
(Never stop exploring!)



"The key to growth is the
introduction of higher
dimensions of consciousness
into our awareness."
Lao Tzu

