

Universe or Multiverse?

Andrei Linde

Multiverse according to Google Trends

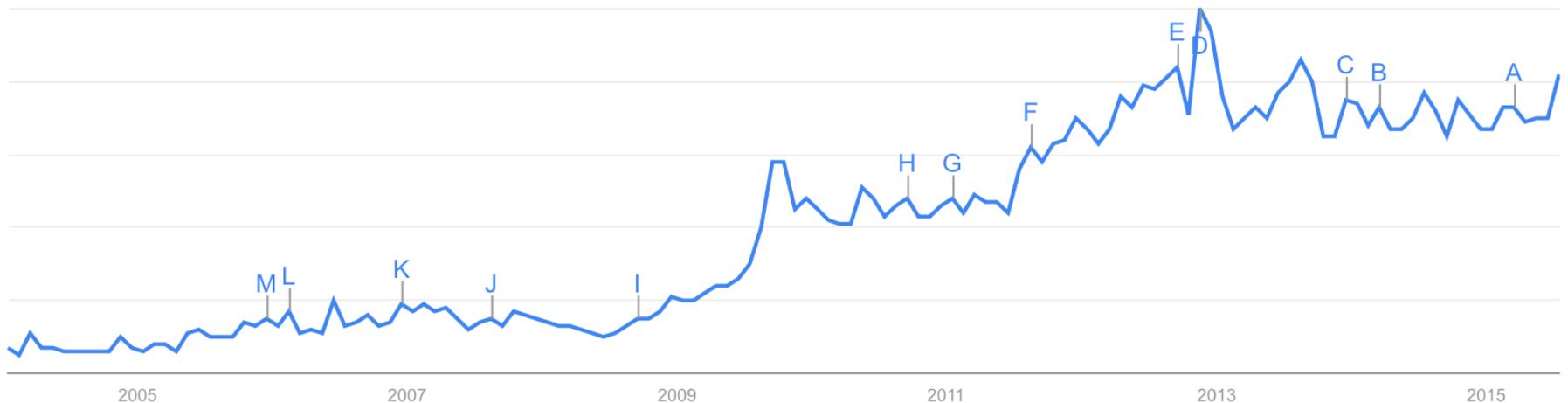
Compare Search terms ▾

multiverse
Search term

+ Add term

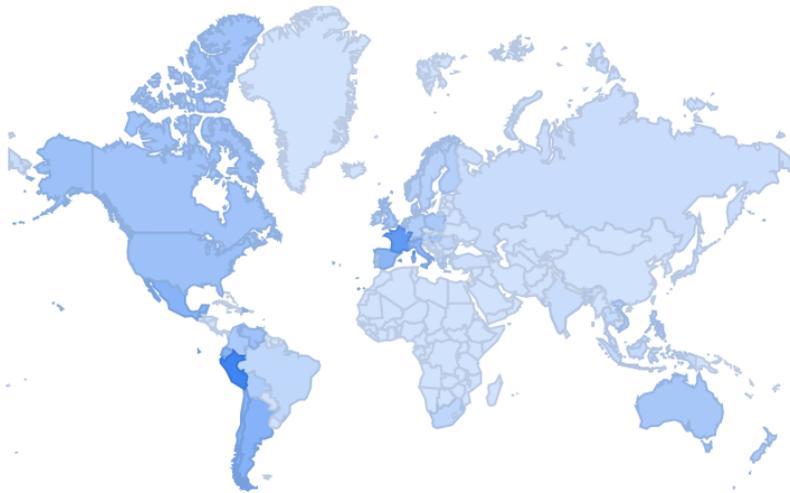
Interest over time ?

News headlines Forecast ?



Multiverse according to *Google Trends*

Regional interest ?



▶ View change over time ?



Region | City

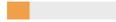
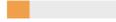
Peru	100	
France	77	
Chile	53	
Argentina	52	
Ecuador	51	
Mexico	50	
Spain	47	



Multiverse according to Google Trends

Related searches ?

Topics	Top Rising	
	Top	Rising
Multiverse	100	
Dragon Ball - Manga series	40	
Family Guy: Back to the Multiver...	5	

Queries	Top Rising	
	Top	Rising
dragon multiverse	100	
dragon ball multiverse	100	
the multiverse	45	
family guy multiverse	20	
dbz multiverse	20	
db multiverse	20	
multiverse dragonball	20	



A newborn universe could be as small as 10^{-33} cm (Planck length) and as light as 10^{-5} g (Planck mass).

If its energy density is dominated by V , inflation immediately begins



$$l \sim 10^{-33} \text{ cm}$$

$$m \sim 10^{-5} \text{ g}$$

Inflationary universe 10^{-35} seconds old

$10^{1000000000000}$

in ANY units of length

Any customer can have a car painted any color that he wants so long as it is black

Henry Ford



The Ford Tudor Sedan with all steel body, five wire wheels and four Ballon Tires. Pyroxilin finish in Fawn Grey, Highland Green or Royal Macon. \$495
J. & B. Demaree



The Ford Fordor Sedan with five wire wheels and four Ballon Tires. Pyroxilin finish in Fawn Grey, Highland Green or Royal Macon. \$545
J. & B. Demaree



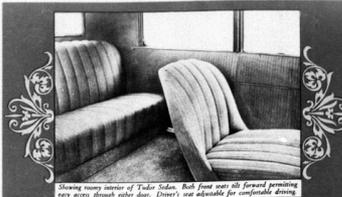
The Ford Coupe with all steel body, five wire wheels and 4 Ballon Tires. Spacious luggage compartment under rear deck. Pyroxilin finish in Fawn Grey, Highland Green or Royal Macon. \$485
J. & B. Demaree



The Ford Touring Car with all steel body, one-piece folding top and weather-proof storm curtains opening with all doors. Four Ballon Tires, Pyroxilin finish in Gun Metal Blue or Phoenix Brown. \$380
J. & B. Demaree



The Ford Runabout with all steel body. Reversible luggage compartment under rear deck. Weather-proof storm curtains opening with all doors. Four Ballon Tires, Pyroxilin finish in Gun Metal Blue or Phoenix Brown. \$360
J. & B. Demaree



Showing roomy interior of Tudor Sedan. Both front seats tilt forward permitting easy access through either door. Interior is adaptable for comfortable driving.

Meeting every modern need of TRANSPORTATION

Unless you have inspected and driven a Ford car recently built, you will be amazed at the many features which make Ford ownership so desirable.

Closed car interiors are roomy with every provision made for comfort and convenience. Seats are set at the proper angle for relaxation, deeply cushioned and with plenty of leg room for both front and rear seat occupants. Upholstery and trim have been selected for beauty and durability, and harmonize with body colors, which may be had in optional shades of Pyroxilin finish.

Both without and within there are refinements and features in the all-steel bodies that must be seen to be properly appreciated.

Furthermore, you are not familiar with Ford performance and operating economy unless you have driven a Ford car manufactured within the last few months. Many improvements have been effected including a new carburetor vaporizer, which makes the Ford engine smoother, quieter, and more powerful at all speeds—with greatly increased gasoline mileage.

We urge you to go to the Ford dealer whose name appears on this folder, and let him show you what Ford value means today.

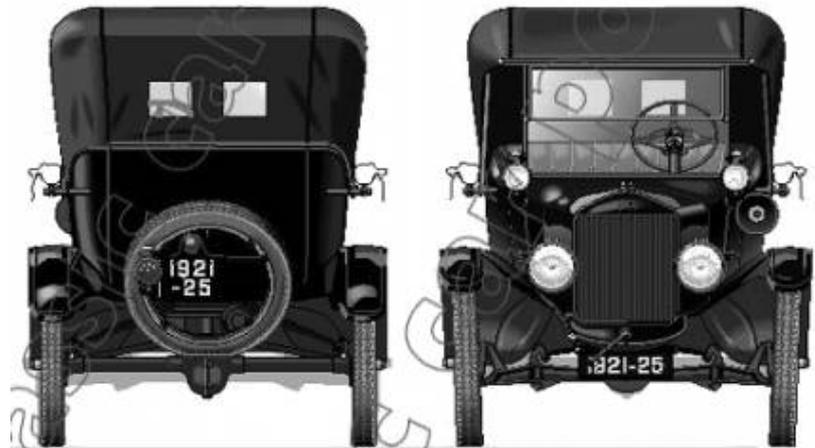
Ford Motor Company
DETROIT, MICH.



A roomy luggage compartment is under the rear deck of the Coupe.

Interior of coupe showing convenient package shelf for shopping.

Showing one-piece ventilating wind shield with hooded front view.



New Colors - Increased Mileage - Better Motor Operation

Here comes the multiverse





Uniformity of our **universe** is explained by **inflation**: Exponential stretching of the universe makes **our part** of the universe almost **exactly uniform**. But classical stretching of the universe does NOT imply its global uniformity.

At the quantum level, the same theory often predicts that on a much greater scale, the universe is 100% non-uniform.

Inflationary **universe** becomes a **multiverse**

Pessimist:

If each part of the multiverse is huge, we will never see other parts, so it is impossible to prove that we live in the multiverse.

Optimist:

If each part of the multiverse is huge, we will never see other parts, so it is impossible to disprove that we live in the multiverse.

I'd rather be an optimist and a fool than a pessimist and right. [Albert Einstein](#)

This scenario is **more general** (otherwise one would need to explain why all colors but one are forbidden). Therefore the theory of the **multiverse**, rather than the theory of the **universe**, is the basic theory.

Moreover, even if one begins with a single-colored universe, quantum fluctuations make it multi-colored.

Origin of structure:

In inflationary theory, original inhomogeneities are stretched away, but new ones are produced from **quantum fluctuations**, which are amplified and stretched exponentially during inflation.

Galaxies are children of quantum fluctuations produced in the first 10^{-35} seconds after the birth of the universe.

The limits of classical cosmology

By observing our part of the universe and playing the movie back, we would see galaxies moving closer to each other, particles collide, but we would never see 10^{90} particles merge into nothing and disappear, we would never see their origin in a vacuum-like state containing no galaxies and no particles at all.

Indeed, all particles were produced in the process of reheating after inflation. This is an irreversible quantum mechanical process.

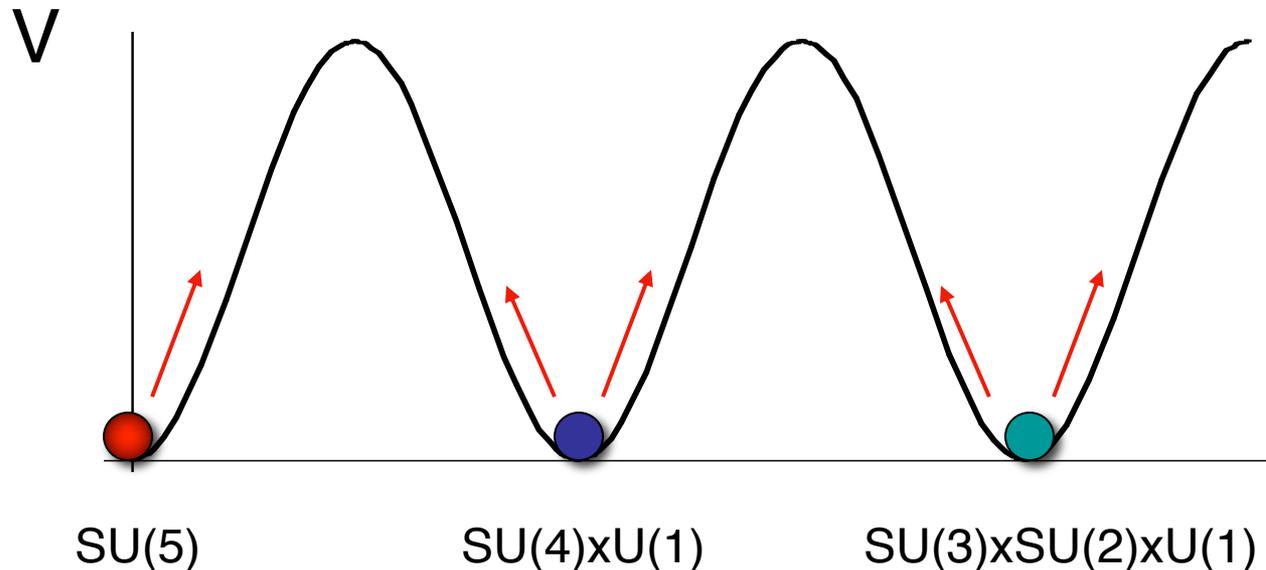
Remember the Schrodinger cat



Two consistent movies with one common element:
in the beginning, there was a cat

Example: SUSY landscape

Supersymmetric SU(5)

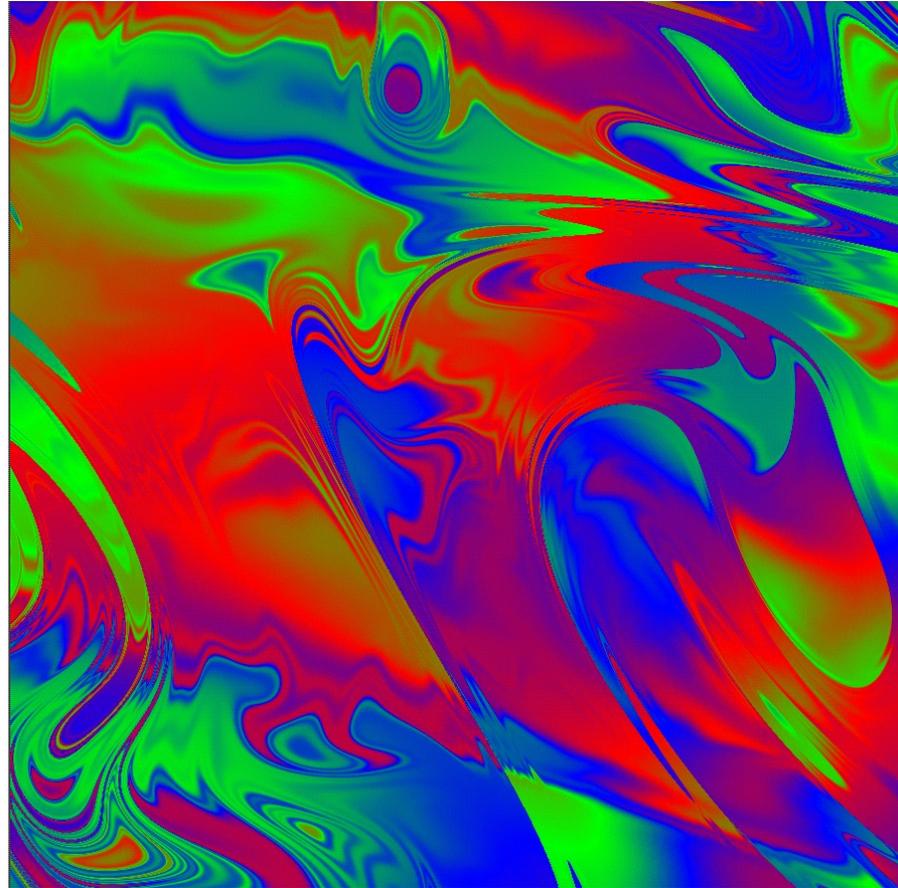


[Weinberg 1982](#): Supersymmetry forbids tunneling from $SU(5)$ to $SU(3) \times SU(2) \times U(1)$. This implied that we cannot break $SU(5)$ symmetry.

[A.L. 1983](#): Inflation solves this problem. Inflationary fluctuations bring us to each of the three minima. Inflation make each of the parts of the universe exponentially big. We can live only in the $SU(3) \times SU(2) \times U(1)$ minimum.

Kandinsky Universe

This process can be illustrated by computer simulations. We start with a small single-colored inflationary universe, and we end up in a universe consisting of many exponentially large parts with different laws of low-energy physics: $SU(5)$, $SU(4) \times U(1)$, or $SU(3) \times SU(2) \times U(1)$, as in the part where we live now.

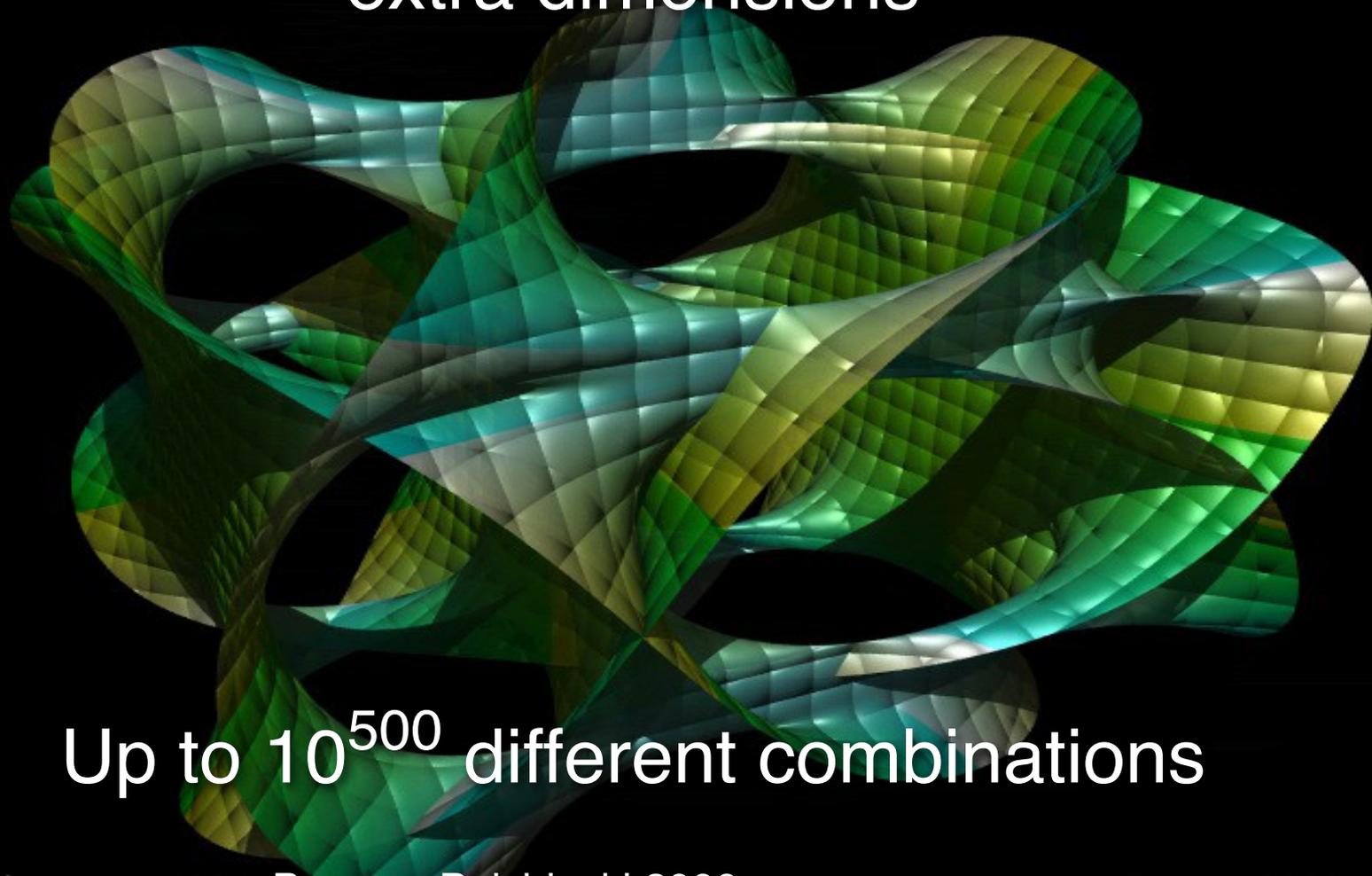


These are consequences of a simple particle physics theory, and philosophical considerations cannot change these results.

Now we may be at a new turning point, a radical change in what we accept as a legitimate foundation for a physical theory.

Steven Weinberg
“Living in the Multiverse”

In string theory, genetic code of the universe
is written in properties of compactification of
extra dimensions

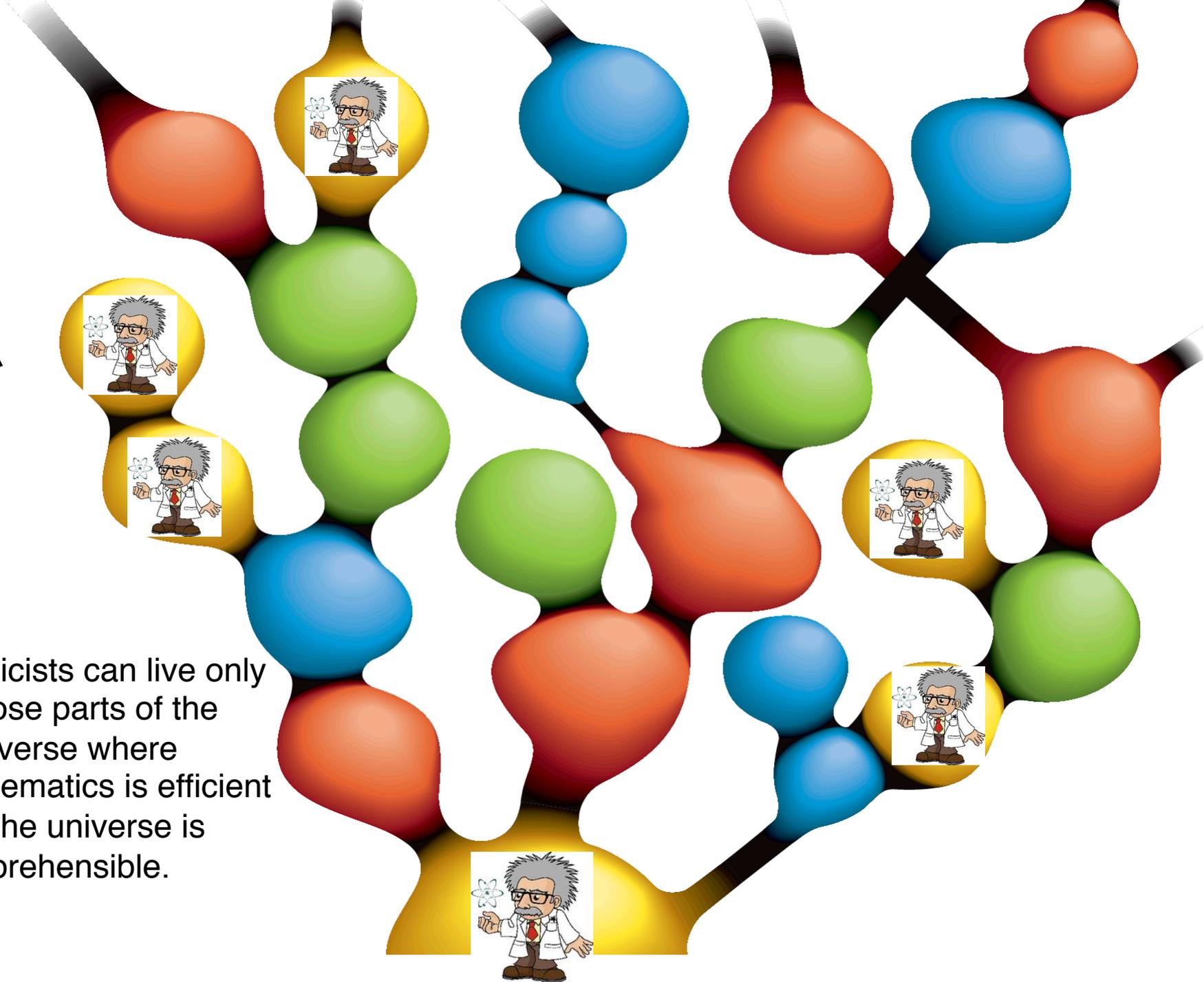


Up to 10^{500} different combinations

Sakharov 1984; Bousso, Polchinski 2000; Kachru, Kallosh, AL, Trivedi, 2003;
Douglas 2003, Susskind 2003

↑
TIME

Physicists can live only
in those parts of the
multiverse where
mathematics is efficient
and the universe is
comprehensible.



Example: Vacuum energy in string theory:

galaxies are destroyed

Anthropic bound: $|\Lambda| < 10^{-120}$

universe rapidly collapses

Before quantum corrections

After quantum corrections

Is the string theory quintessence in the swampland?

Consider exponential potential $e^{\lambda\phi}$ with $\lambda = 0.7$ (all higher values are ruled out with 95% confidence). How large should be the excursion of the field to span the distance between the Planck density $V = O(1)$ and the present value of dark energy $V = O(10^{-120}) = e^{-276}$

$$\Delta\phi \sim 400$$

This would strongly contradict the weak gravity conjecture.

If only the Planck excursions $O(1)$ are allowed, then the quintessence potential $e^{\lambda\phi}$ describing our universe can be valid only for $V = O(10^{-120})$. How can we use such a theory in cosmology?

Many string theory based models of quintessence were proposed by the authors of the swampland hypothesis in 1806.08362 and 1810.05506.

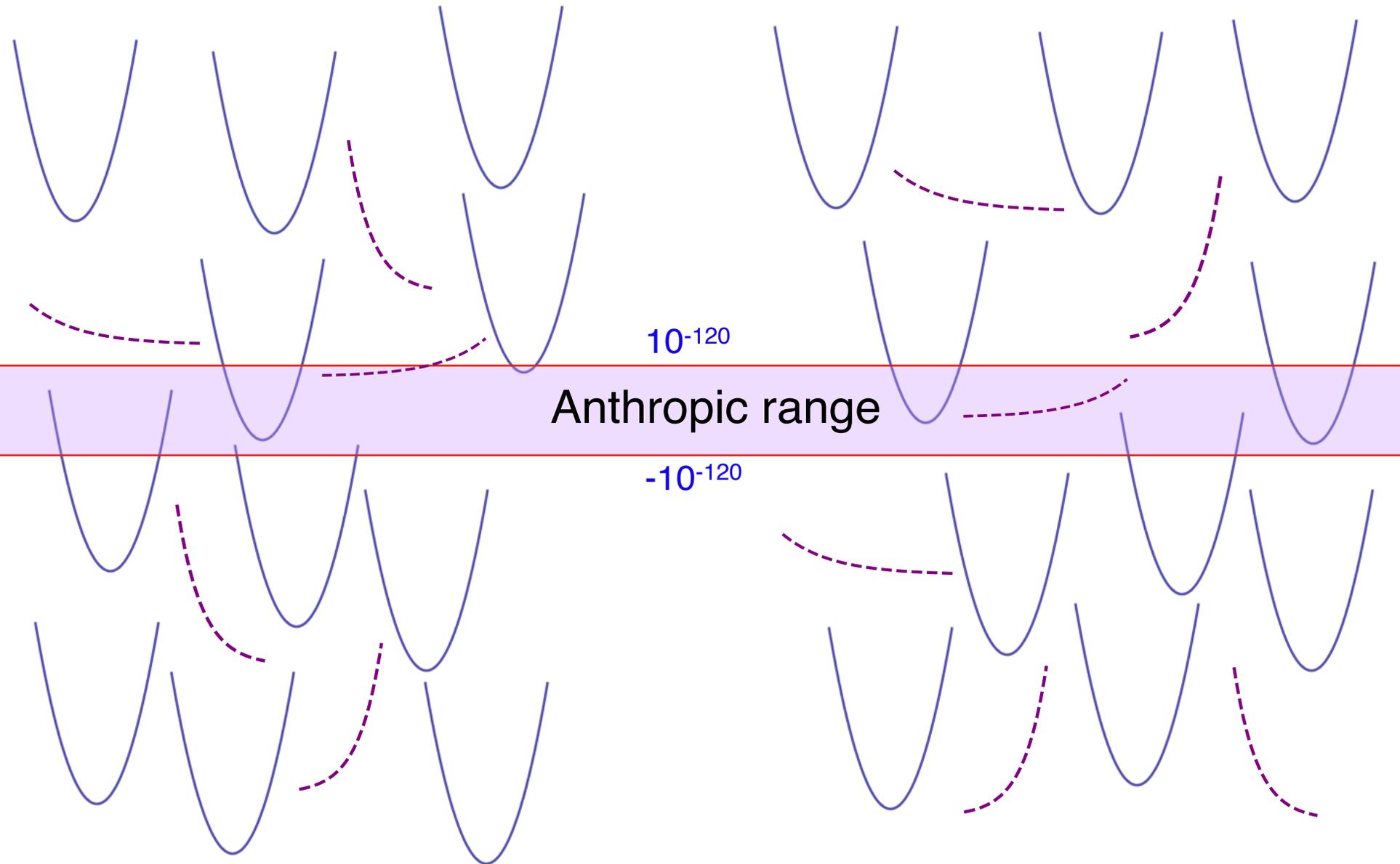
All of these models are ruled out by cosmological observations at better than 3σ level

Akrami, Kallosh, A L, Vardanyan 1808.09440

Recently there was a significant progress in confirmation of the KKLT scenario in type IIB string theory (Kachru, Kim, McAllister, Zimet 1908.04788) and in dS vacua construction in type IIA string theory (Cribiori, Kallosh, Roupec, Wrase 1909.08629, and Kallosh and AL)

Therefore even if consistent string theory models of quintessence eventually will be found, it is quite likely that they will become a part of the string theory landscape, as shown in the next slide

Anthropic approach to Λ in string theory



Before quantum corrections

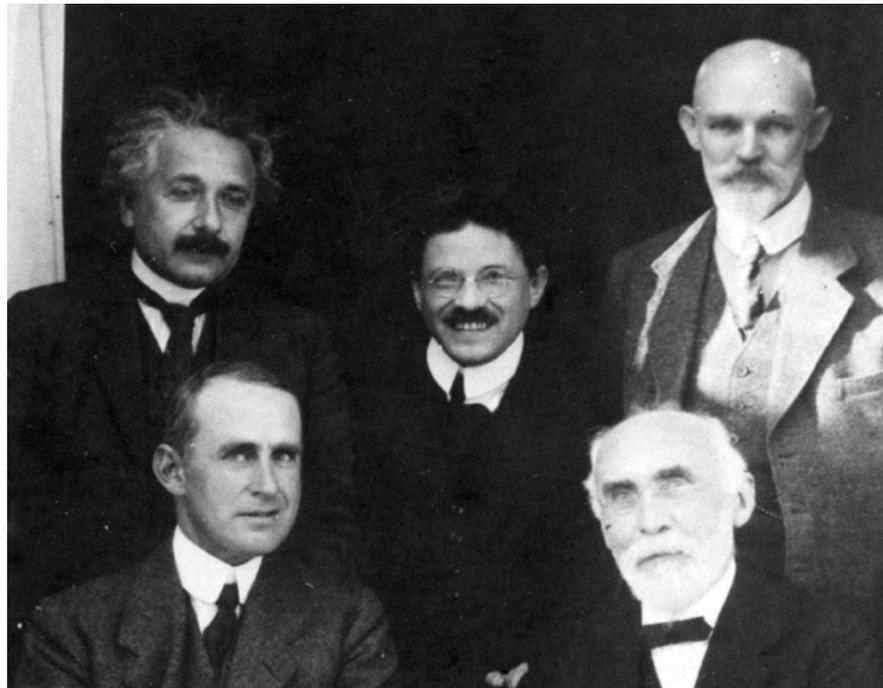
After quantum corrections

Why do we live in a 4-dimensional space-time?

P. Ehrenfest, *Proc. Amsterdam Acad.* 20, 200 (1917)

In space-time of dimension $d > 4$, planetary systems and atoms are unstable. For $d < 4$, in general theory of relativity there is no gravitational attraction between distant bodies, so planetary systems cannot exist. That is why can live only in space-time with $d = 4$.

Einstein



de Sitter

Eddington

Lorentz

Ehrenfest

Leiden Observatory, 1923

Why do we live in a 4-dimensional space-time?

P. Ehrenfest, Proc. Amsterdam Acad. 20, 200 (1917)

Back in 1917, this could seem just a mathematical curiosity: Our space has $d=4$; we simply do not have any other choice.

However, according to string theory, our world fundamentally is 10-dimensional, but some of these dimensions are tiny, **compactified**. In general, one could end with space-time of any dimension d , which would grow exponentially large due to inflation. We can live only in the parts of the world where the compactification produces space-time with $d = 4$.

Thus the observation made by Ehrenfest in 1917, in Leiden, in combination with string theory constructions developed in the beginning of this century, explains why we live in space-time with $d = 4$.

Can we test the multiverse theory ?

This theory provides the only known explanation of numerous experimental results (extremely small vacuum energy, strange masses of many elementary particles). **In this sense, it was already tested many times.**

“When you have eliminated the impossible, whatever remains, however improbable, must be the truth.”

Sherlock Holmes

