IN THE BEGINNING

Joseph Silk (IAP/JHU/Oxford)

Gresham Lecture, 28 November 2018

We can’t prove the Big Bang occurred, there is just a theory with lots of circumstantial evidence

There is a high probability that it happened

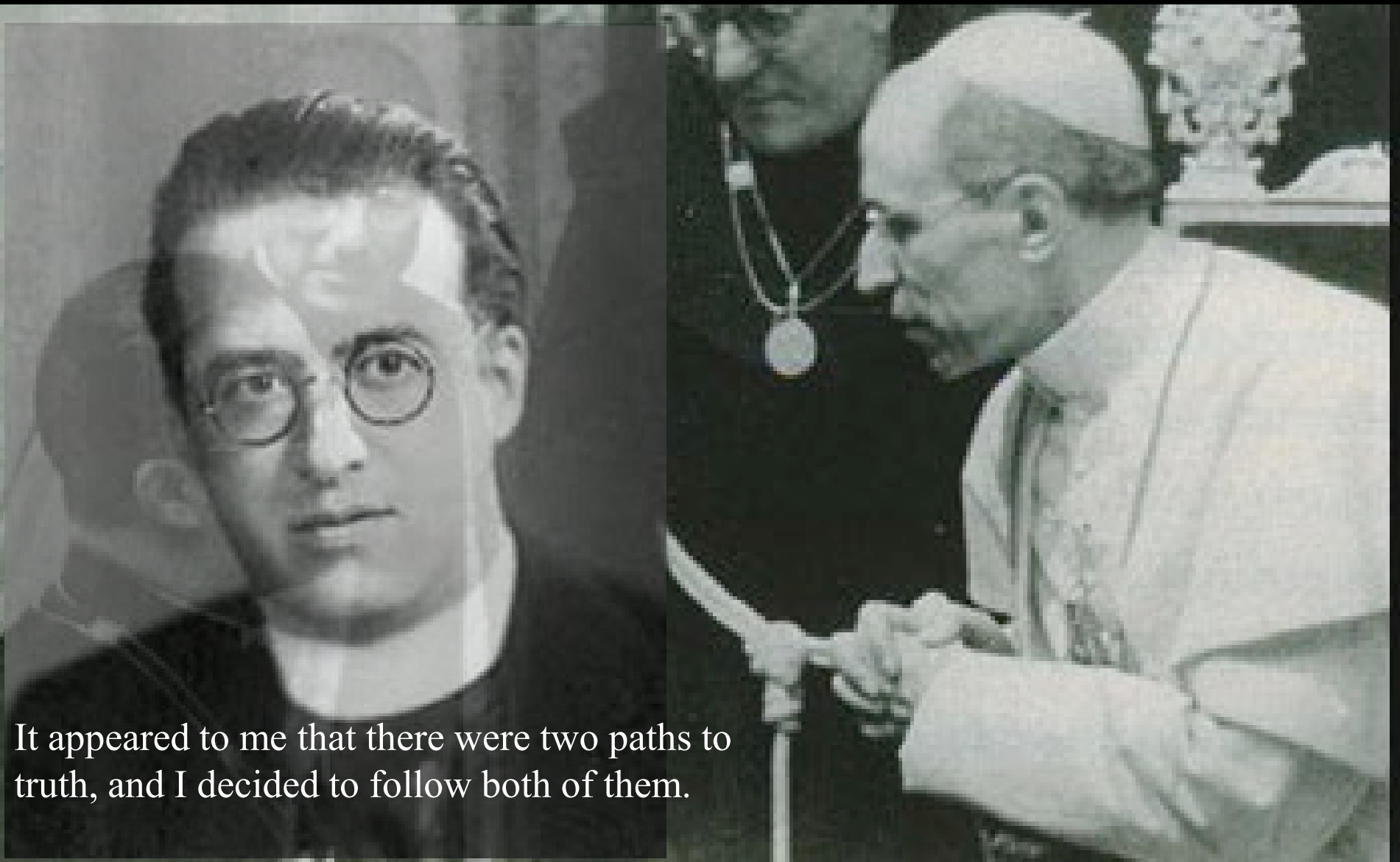
We can’t see the beginning

after all who has seen a quark?

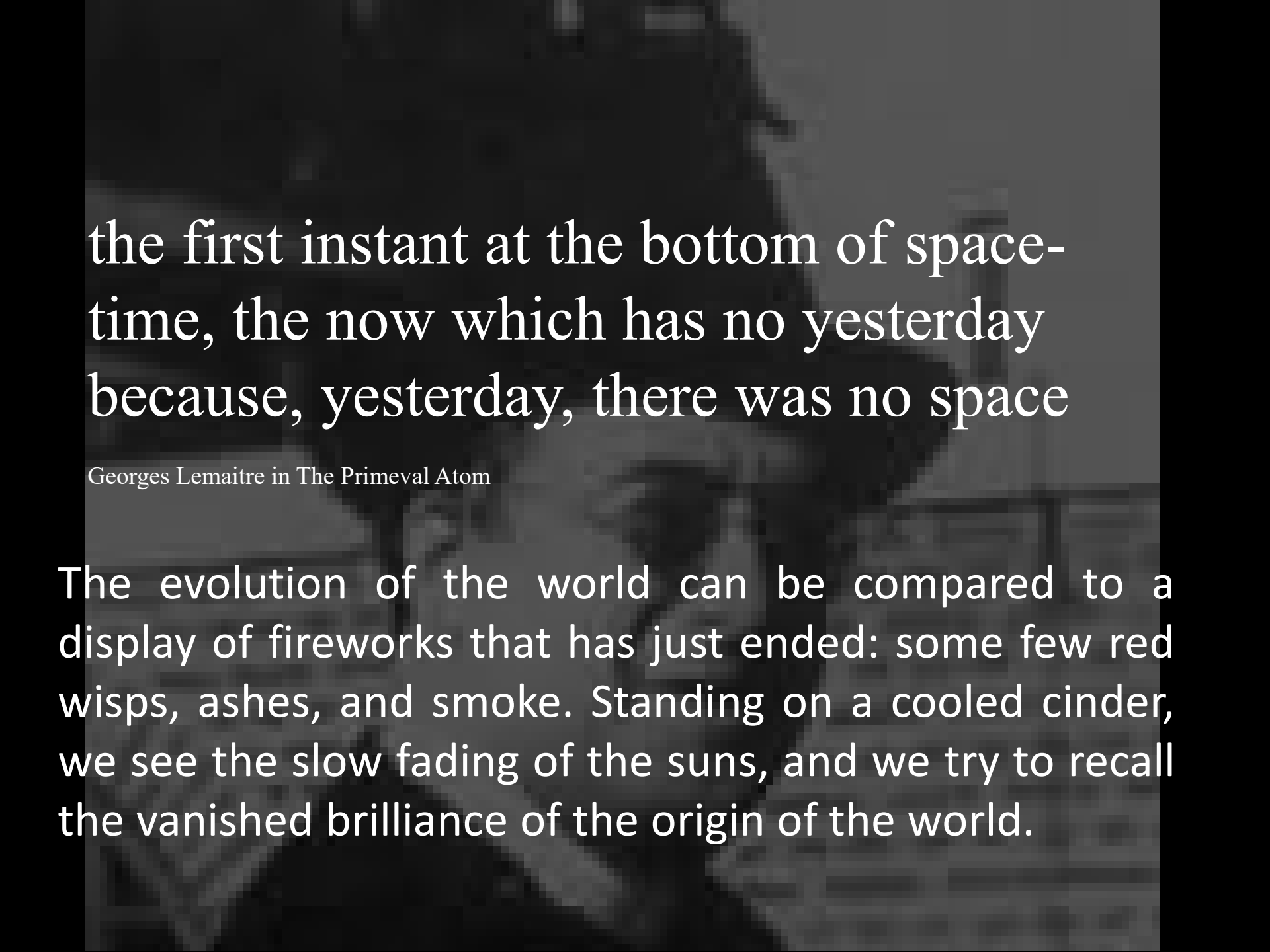
The first word of the bible: fiat lux

Georges Lemaitre

Pius XII



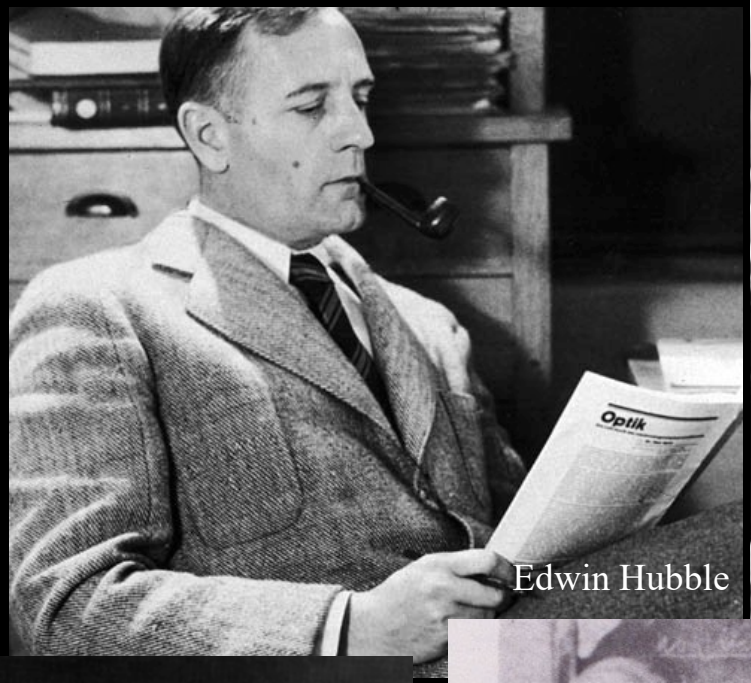
It appeared to me that there were two paths to truth, and I decided to follow both of them.



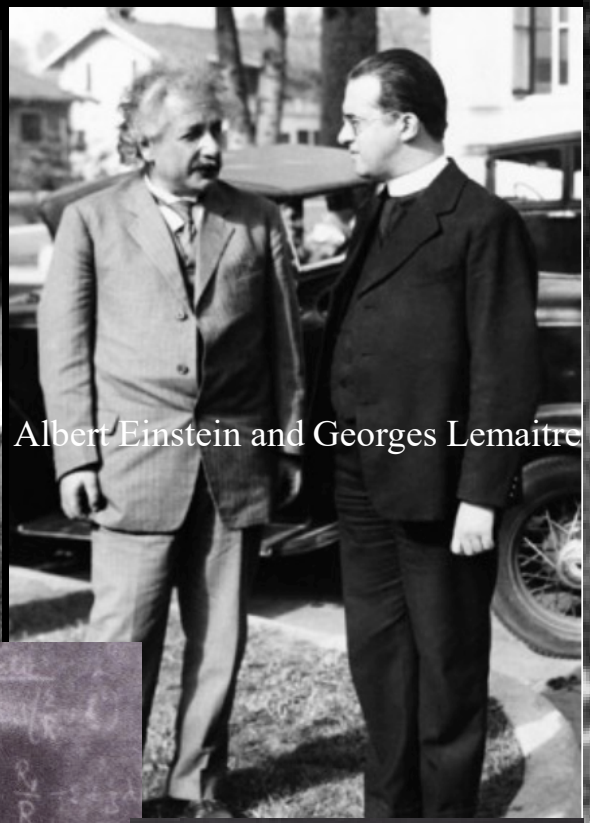
the first instant at the bottom of space-time, the now which has no yesterday because, yesterday, there was no space

Georges Lemaitre in The Primeval Atom

The evolution of the world can be compared to a display of fireworks that has just ended: some few red wisps, ashes, and smoke. Standing on a cooled cinder, we see the slow fading of the suns, and we try to recall the vanished brilliance of the origin of the world.

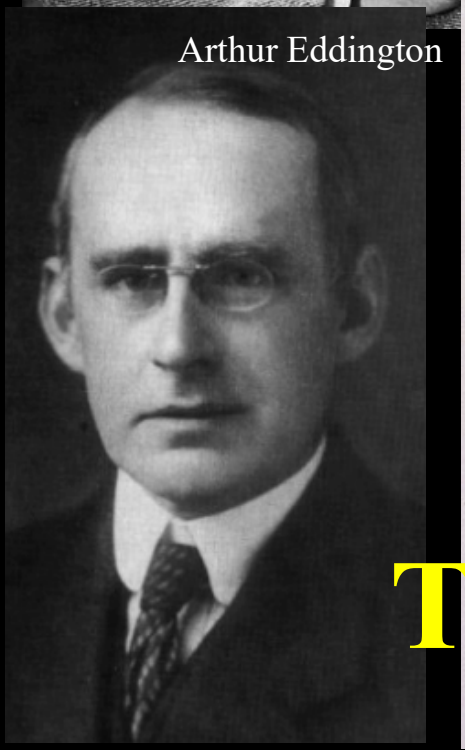


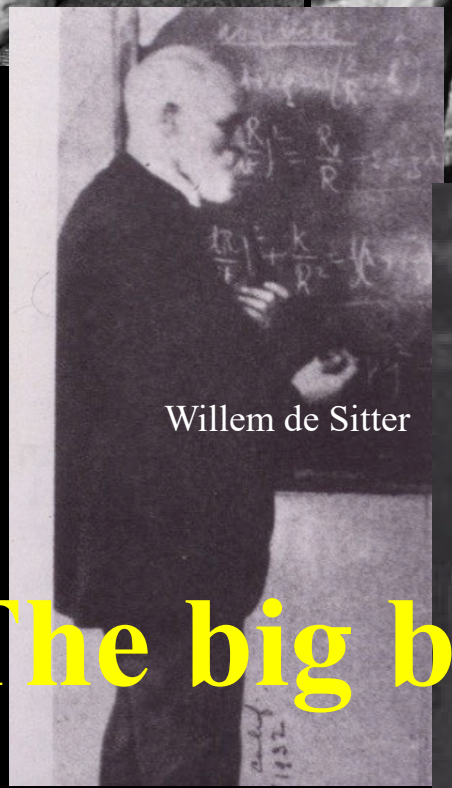
Edwin Hubble


Albert Einstein and Georges Lemaitre

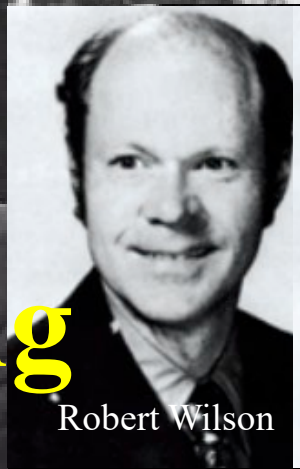

Alexandre Friedmann


Fred Hoyle


Arthur Eddington


Willem de Sitter

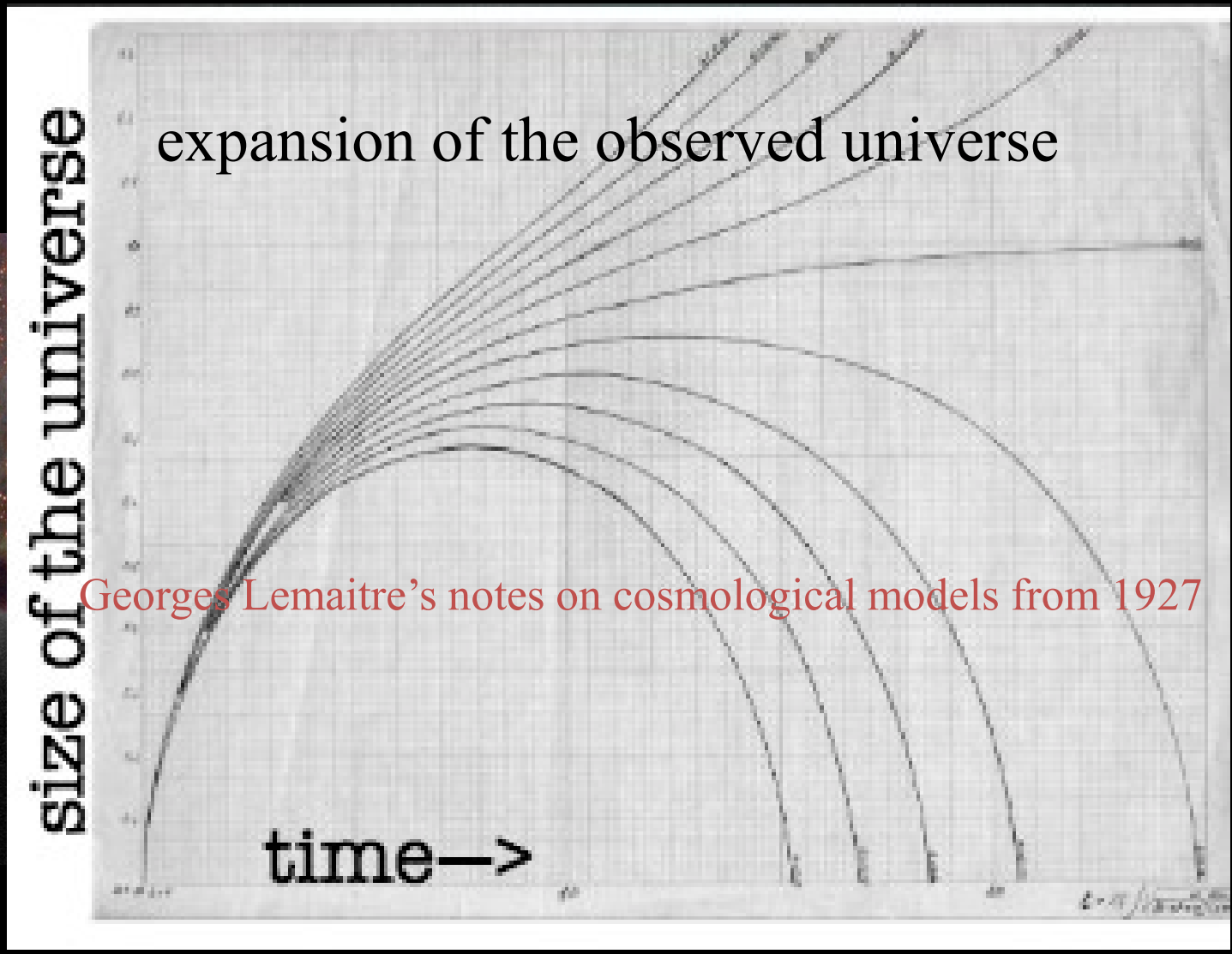

George Gamow


Robert Wilson


Arno Penzias

The big bang gang

Einstein's theory of gravity in 1916 excited the world
But his universe was static. Then along came Friedmann and Lemaitre



Georges Lemaitre's notes on cosmological models from 1927

Einstein: Your calculations are correct, but your physics is atrocious…This is too much… suggesting… a creation.

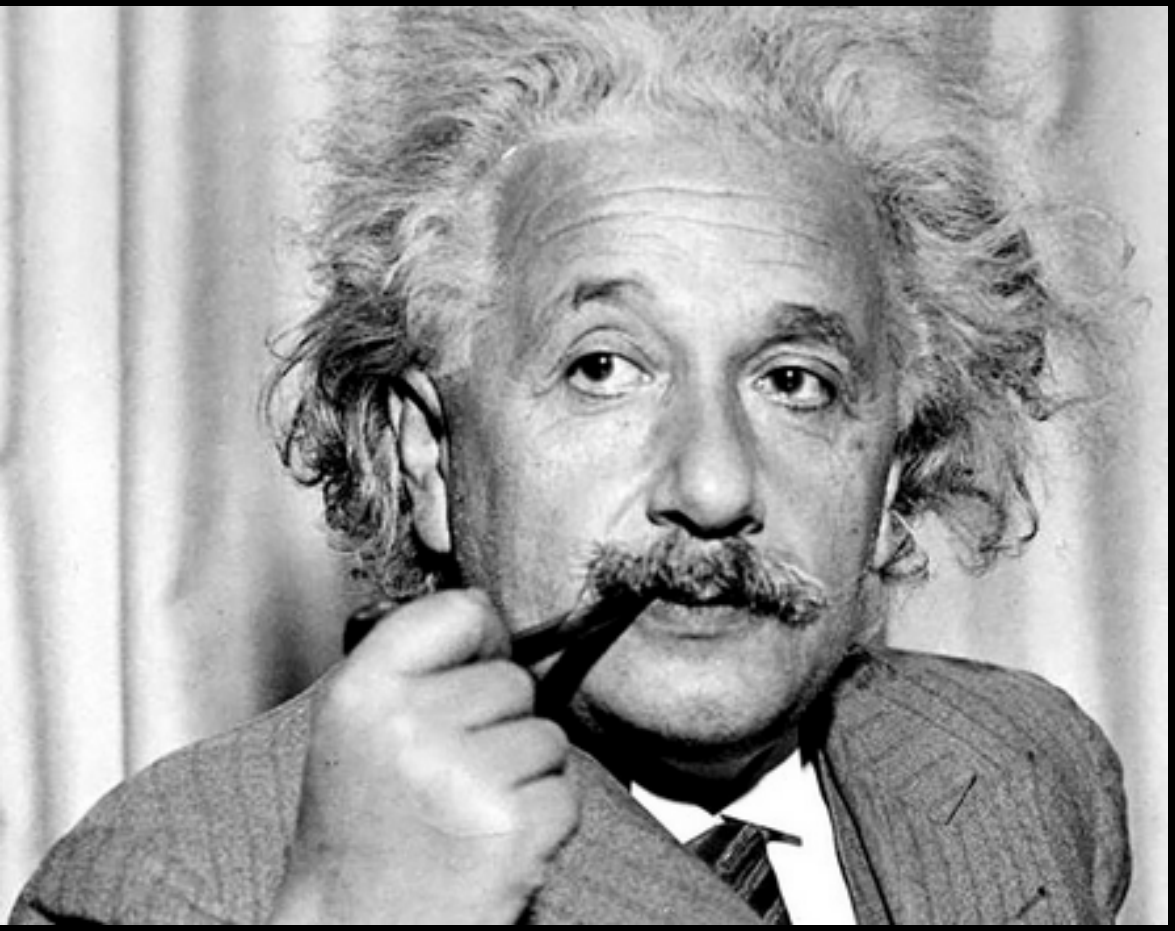
1927

Lemaître: The hypothesis of the primeval atom is the antithesis of a supernatural creation.

Einstein saw the evidence…

Einstein and Hubble at Mount Wilson in 1931, and the universe changed

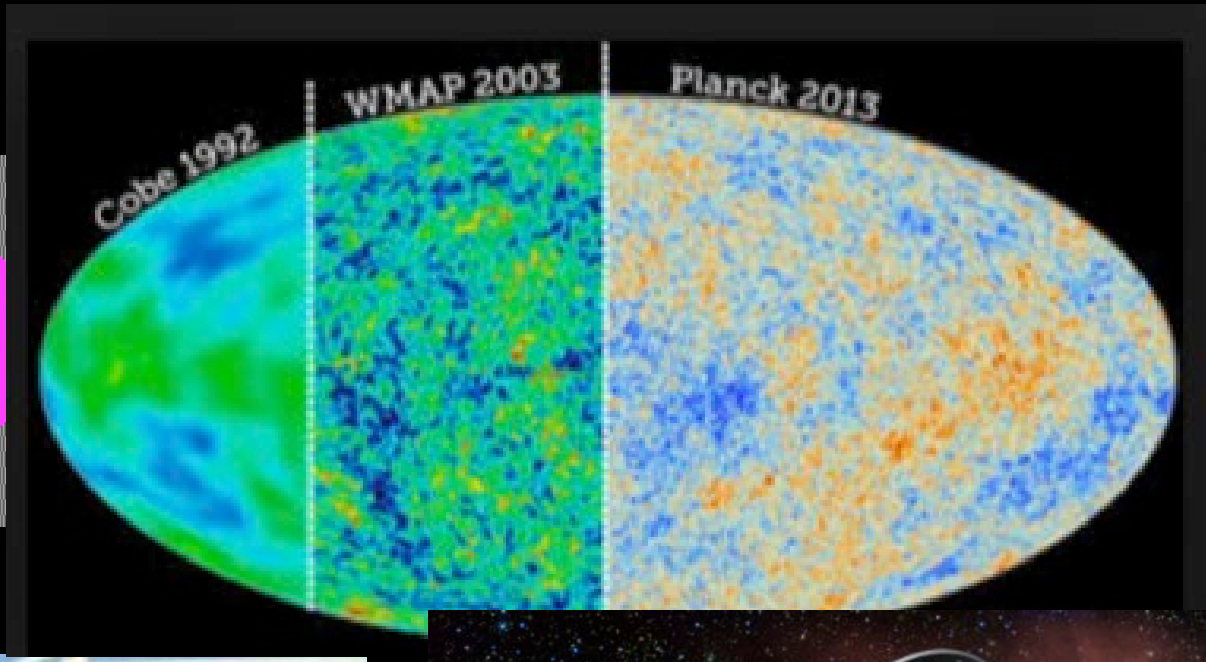
and Einstein soon changed his mind: 1933



This is the most beautiful and satisfactory explanation of creation I have ever listened to.

1964 RELIC RADIATION DISCOVERED BY PENZIAS AND WILSON
1990 COBE
2003-18 WMAP/PLANCK

before 1990



THE INDEPENDENT

FRIDAY 24 APRIL 1992

★★★ Published i

pacecraft has detected echoes of the galaxies' birth fourteen thousand million years ago. The discovery about the fo
after the Big Bang has been hailed by excited scientists as the Holy Grail of cosmology. **Susan Watts** and **Tom Wi**

How the universe began

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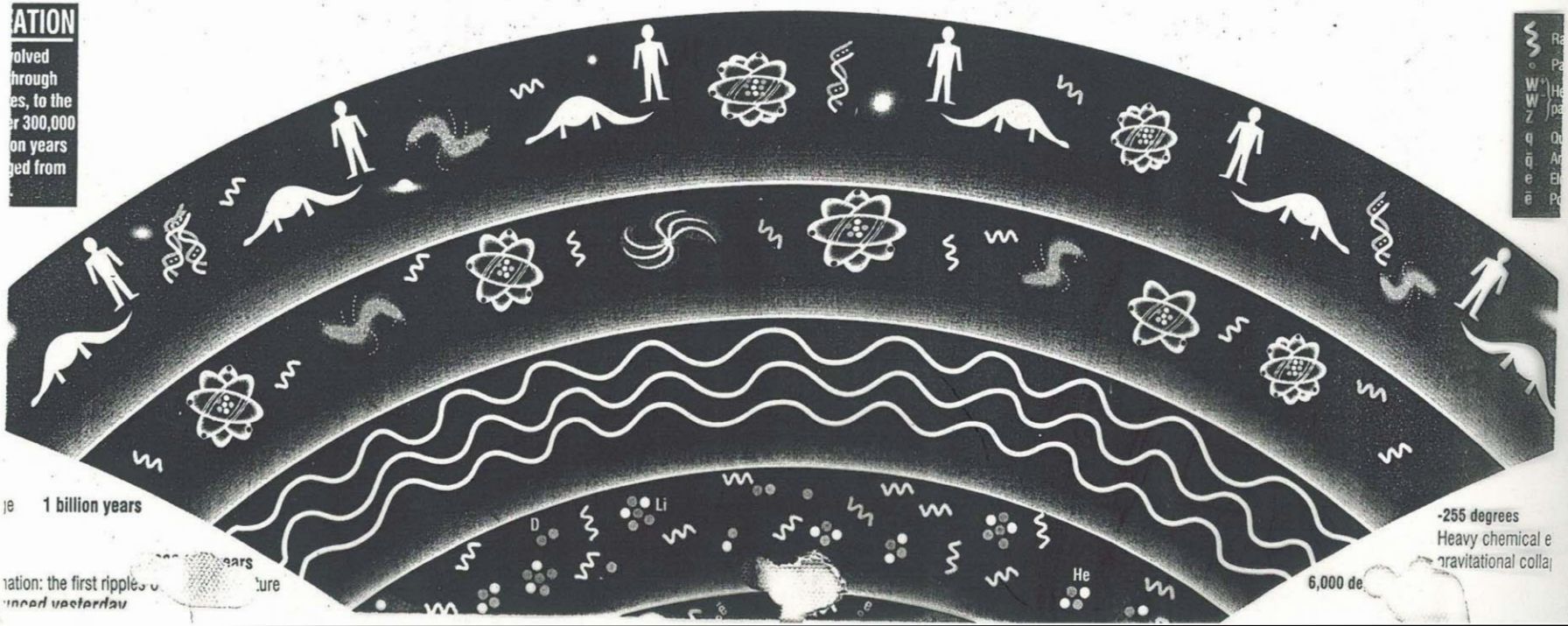
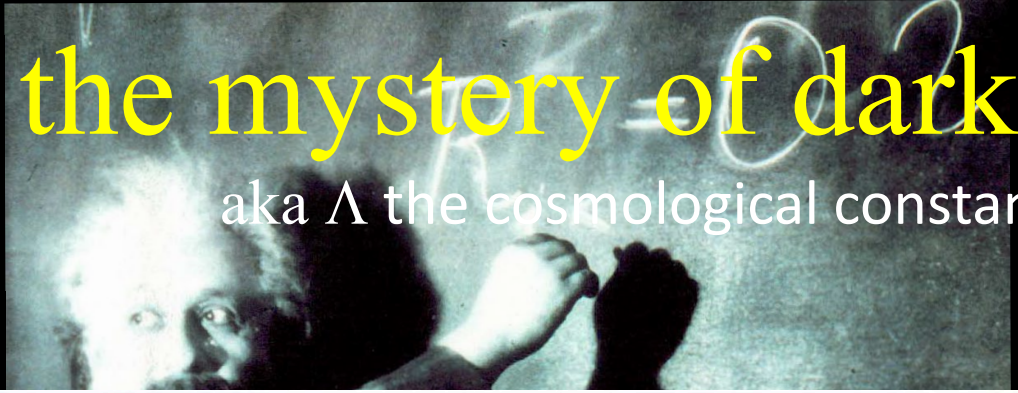


nation: the first ripples o ture
unced yesterday

the mystery of dark energy

aka Λ the cosmological constant



EVOLUTION OF THE EXPANDING UNIVERSE

By G. Lemaitre

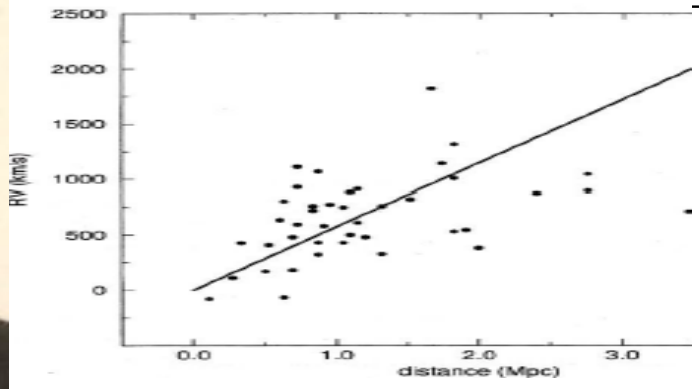
University of Louvain

Read before the Academy, Monday, November 20, 1933

The problem of the universe is essentially an application of the law of gravitation to a region of extremely low density. The mean density of matter up to a distance of some ten millions of light years from us is of the order of 10^{-30} gr./cm.^{3}; if all the atoms of the stars were equally distributed through space there would be about one atom per cubic yard, or the total energy would be that of an equilibrium radiation at the temperature of liquid hydrogen. The theory of relativity points out the possibility of a modification of the law of gravitation under such extreme conditions. It suggests that, when we identify gravitational mass and energy, we have to introduce a cosmical constant. Everything happens as though the energy *in vacuo* would be different from zero. In order that absolute motion, i.e., motion relative to vacuum, may not be detected, we must associate a pressure $p = -\rho c^2$ to the density of energy ρc^2 of vacuum. This is essentially the meaning of the cosmical constant λ which corresponds to a negative density of vacuum ρ_0 according to

Energy of the vacuum

The case for acceleration



Betoule

Dark energy accelerates

we measure **dark matter minus dark energy**

Since it's a constant
its just a late-time effect
…but dominant!

Studies of Universe's Expansion Win Physics Nobel


Adam Riess


Saul Perlmutter

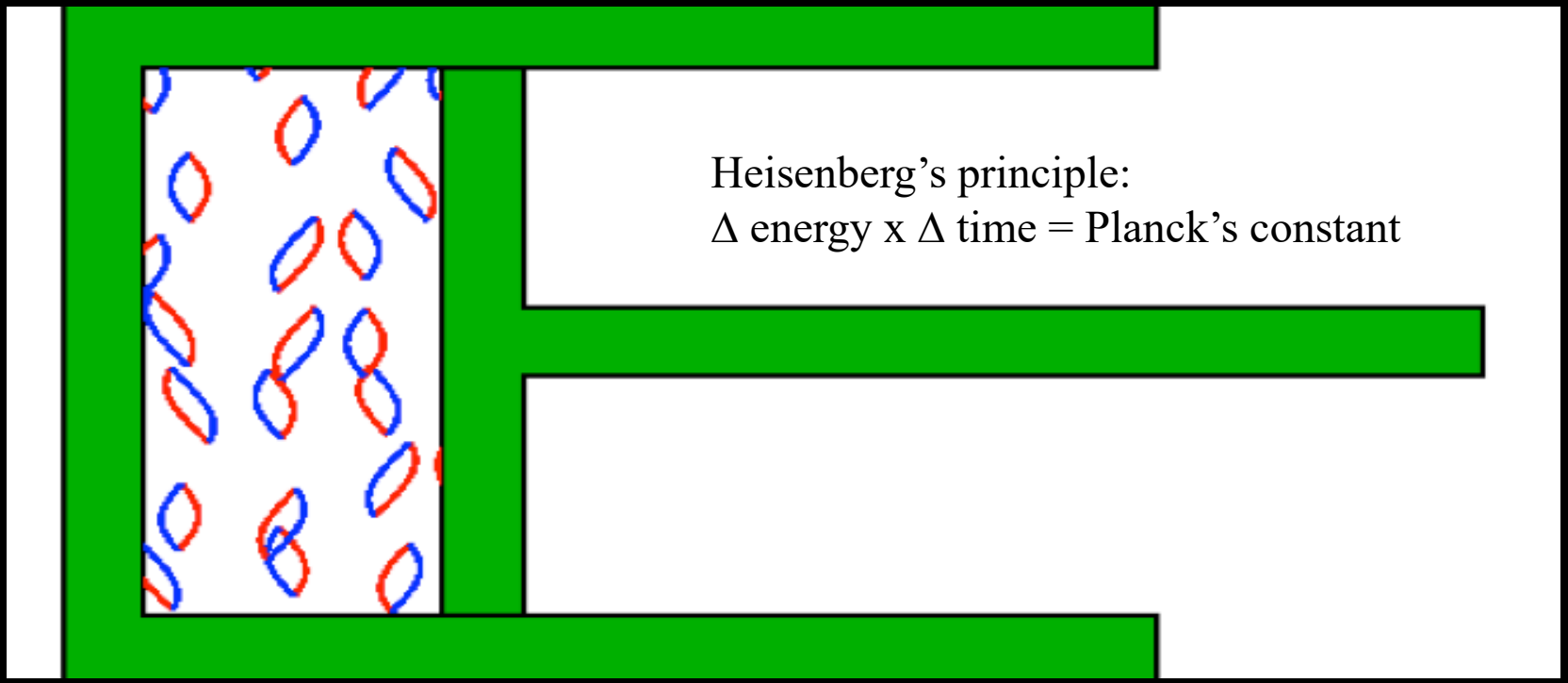

Brian Schmidt

Distant type Ia supernovae are too faint!

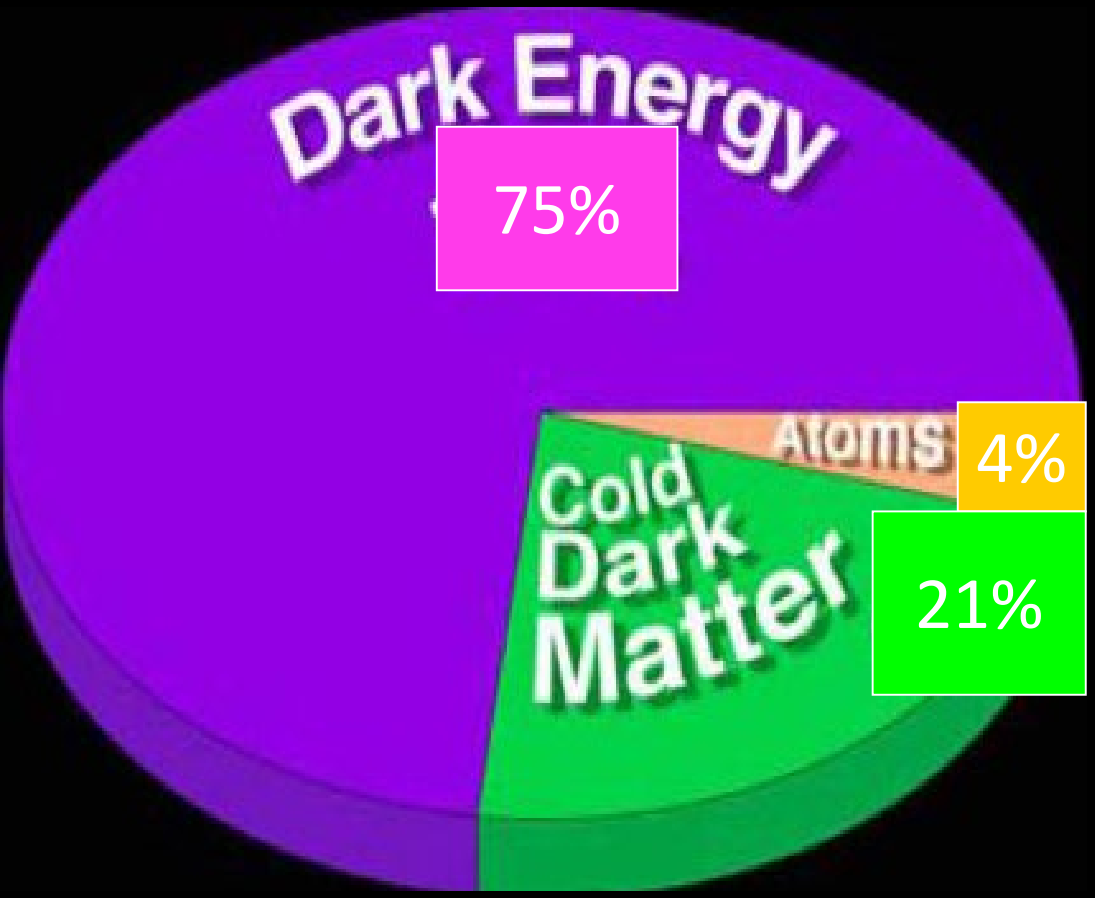
- discovery of acceleration
- due to repulsion, like antigravity
- the paradox, its so small
- its all due to nothing, aka the vacuum

Einstein: pressure acts like gravity

The vacuum has energy and pressure due to quantum fluctuations.
But its negative pressure, hence source of antigravity



compression increases normal pressure
rarefaction increases quantum pressure, oppositely to normal pressure



we observe

$$\rho_{vac} \approx 10^{-10}\,\mathrm{eV}^4$$

we predict

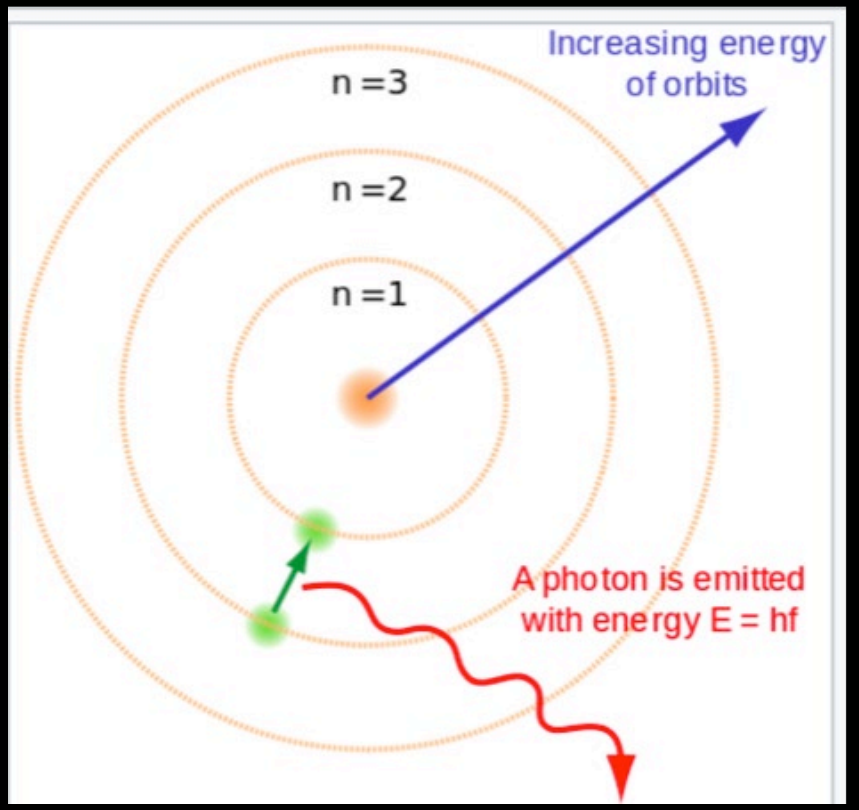
$$M \sim M_{Planck} = G^{-1/2} = 10^{28}\ \mathrm{eV} \Rightarrow \rho_{vac} \sim 10^{112}\,\mathrm{eV}^4$$

We are in error by a trillion trillion trillion trillion trillion trillion trillion trillion trillion trillion

The worst prediction in physics!

- string theory accounts for all particles
- requires 6 extra space dimensions
- many, many options for geometry
- each is a separate universe, in the multiverse
- each has a a different value of dark energy

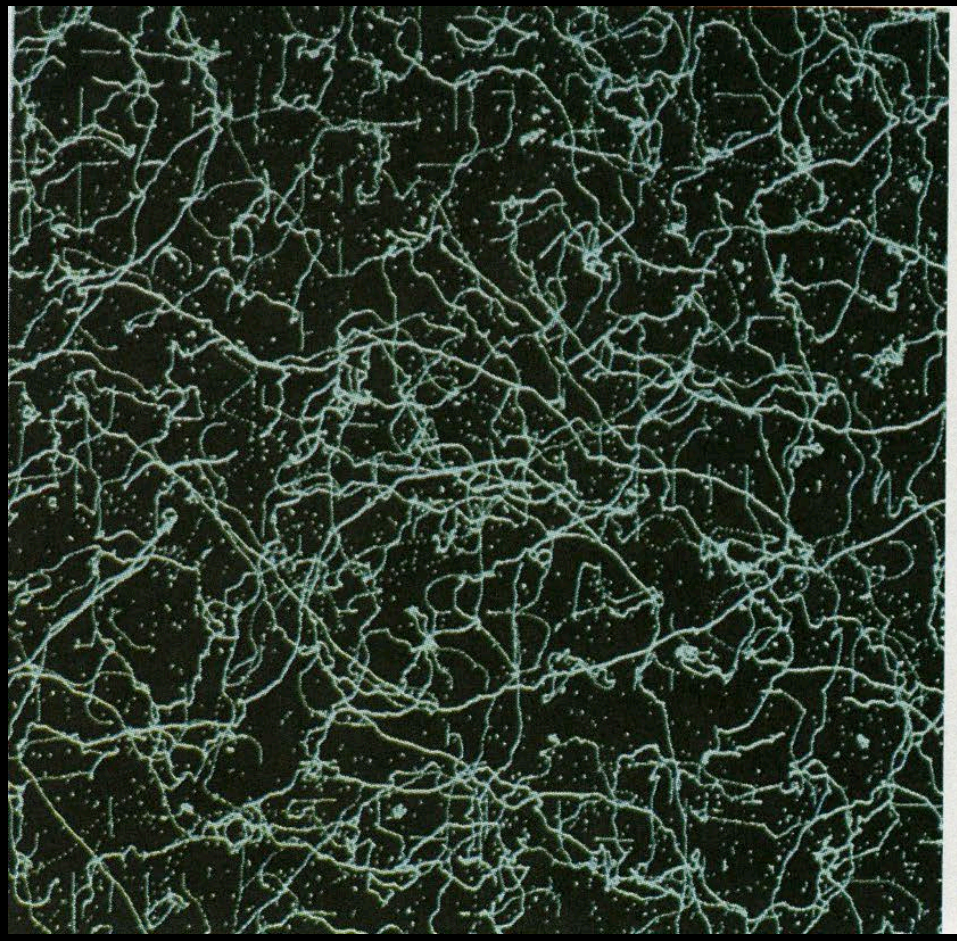
Elementary particles are strings

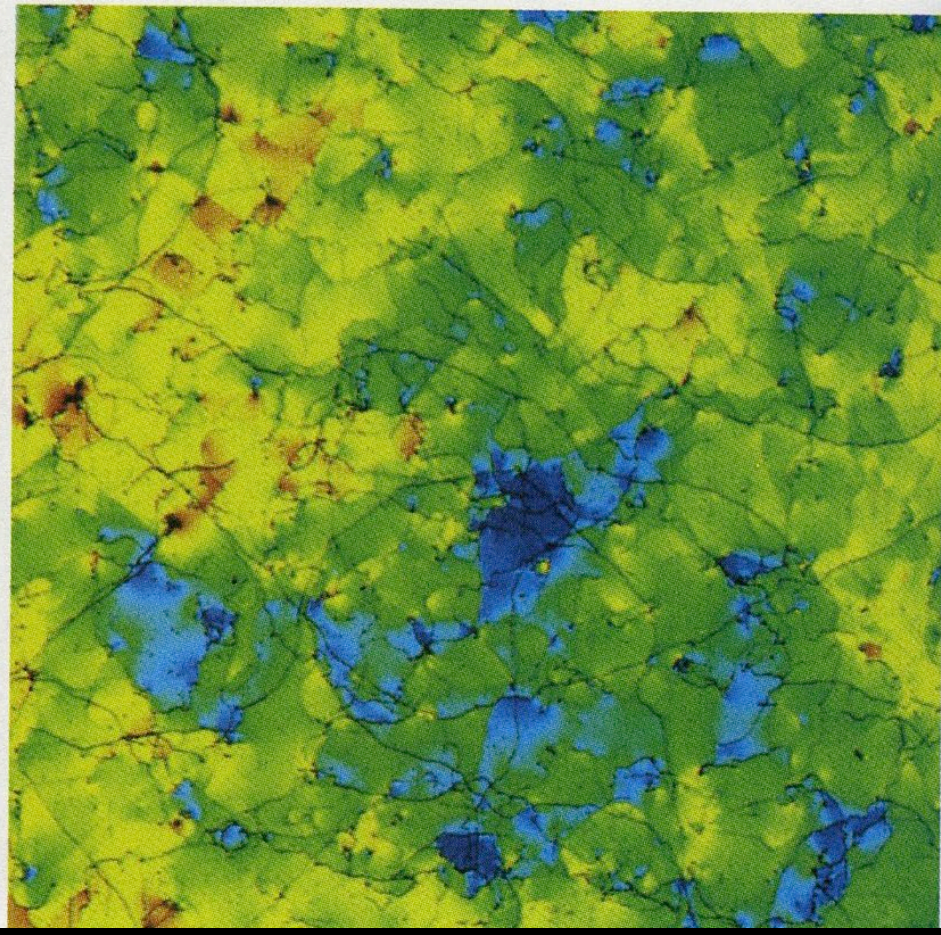


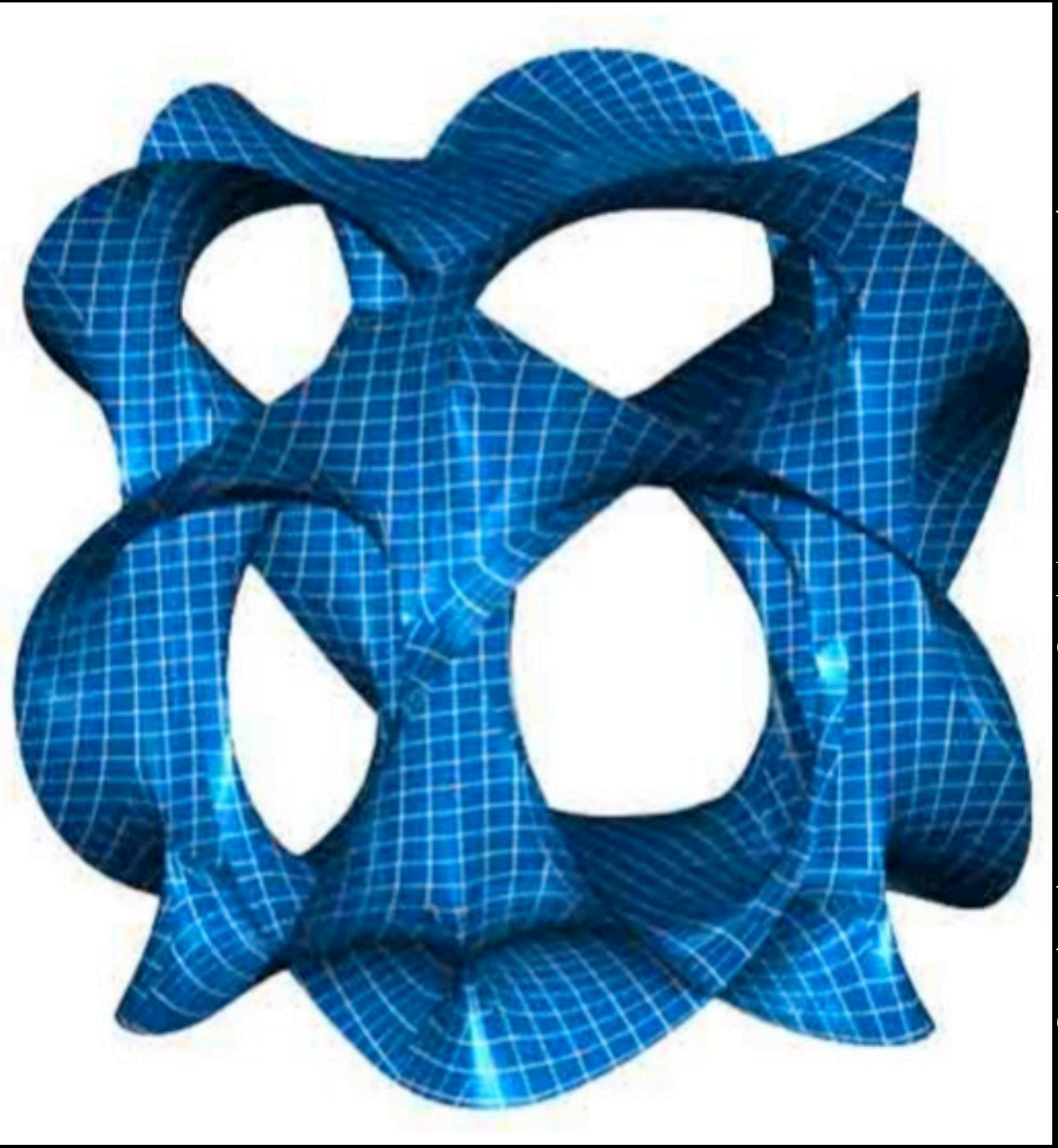
Particles

Strings

Strings in the sky?
a prediction







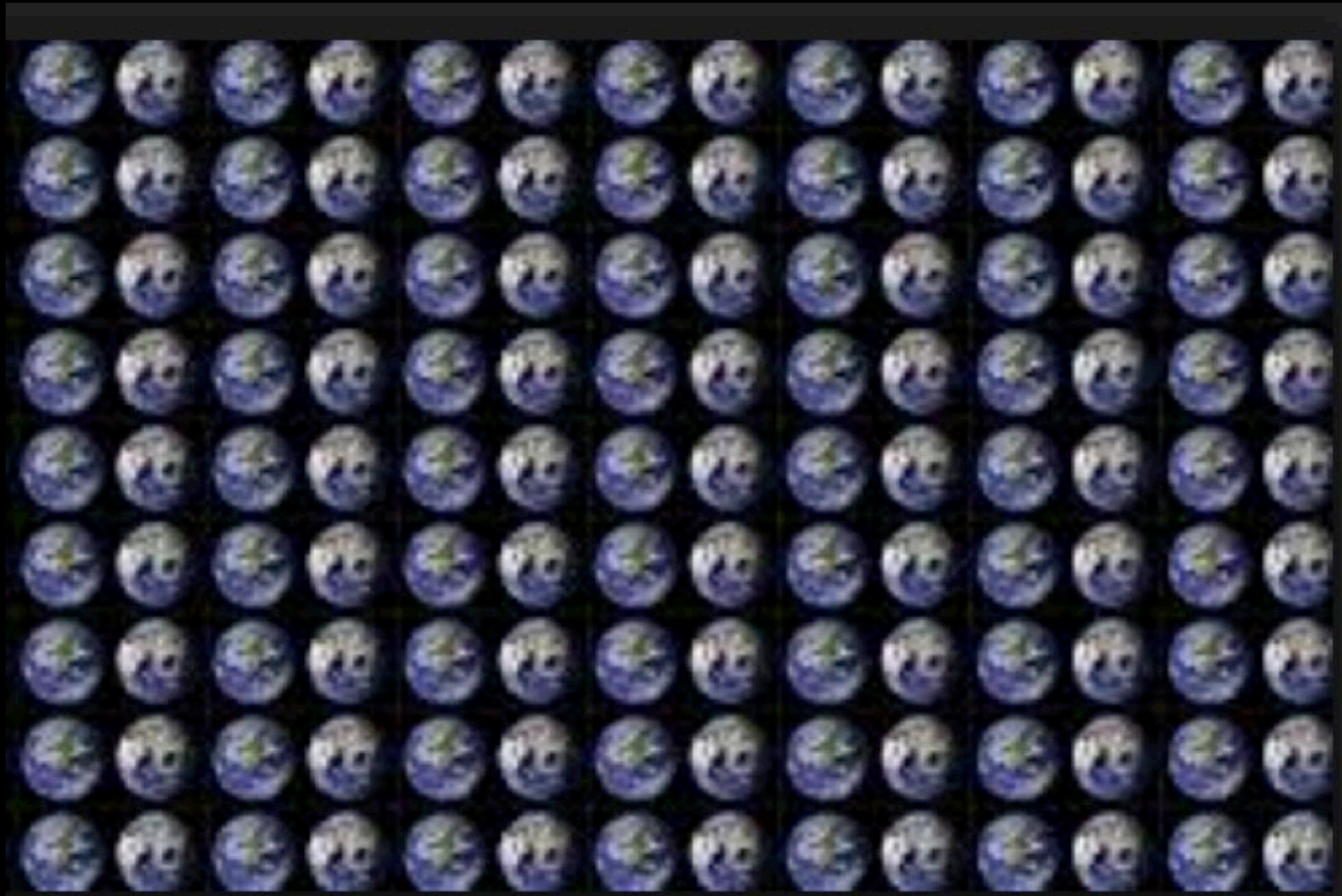
a 6-d universe viewed in 2-d

10^{-33} cm

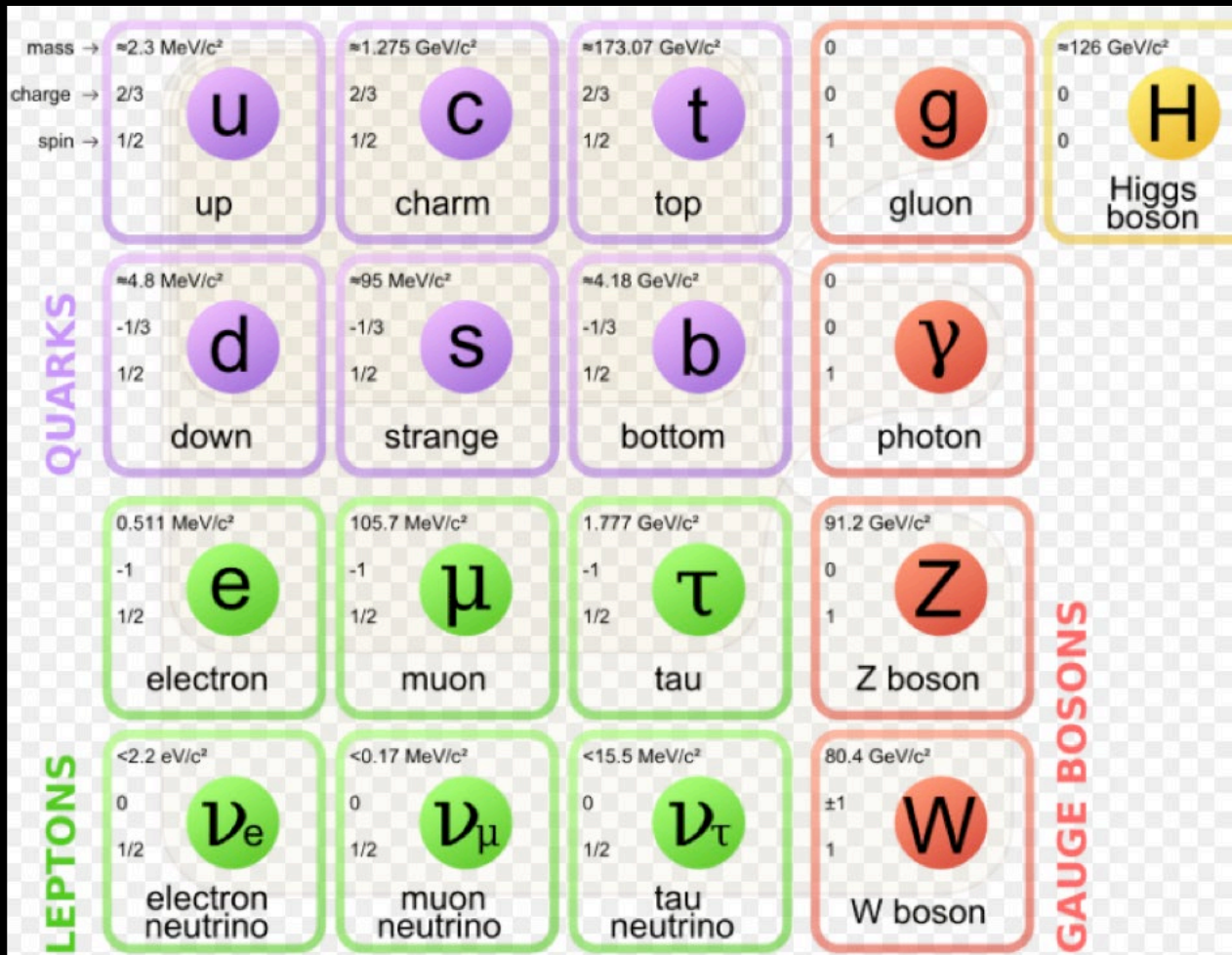
Now the extra dimensions are curled up

there are many of these, each with different dark energy

Multiverse with 10^{500} universes



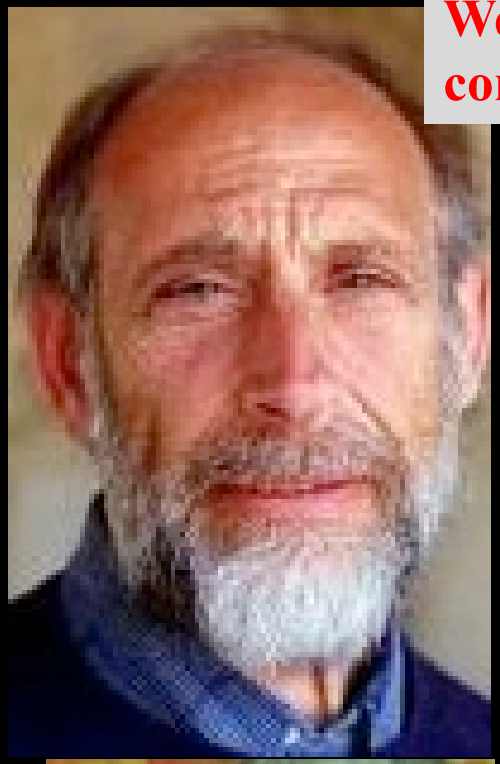
- Each universe is different
- Ours has the standard model of particle physics
- This needs fine-tuning
- This occurs in about 0.1% of the universes

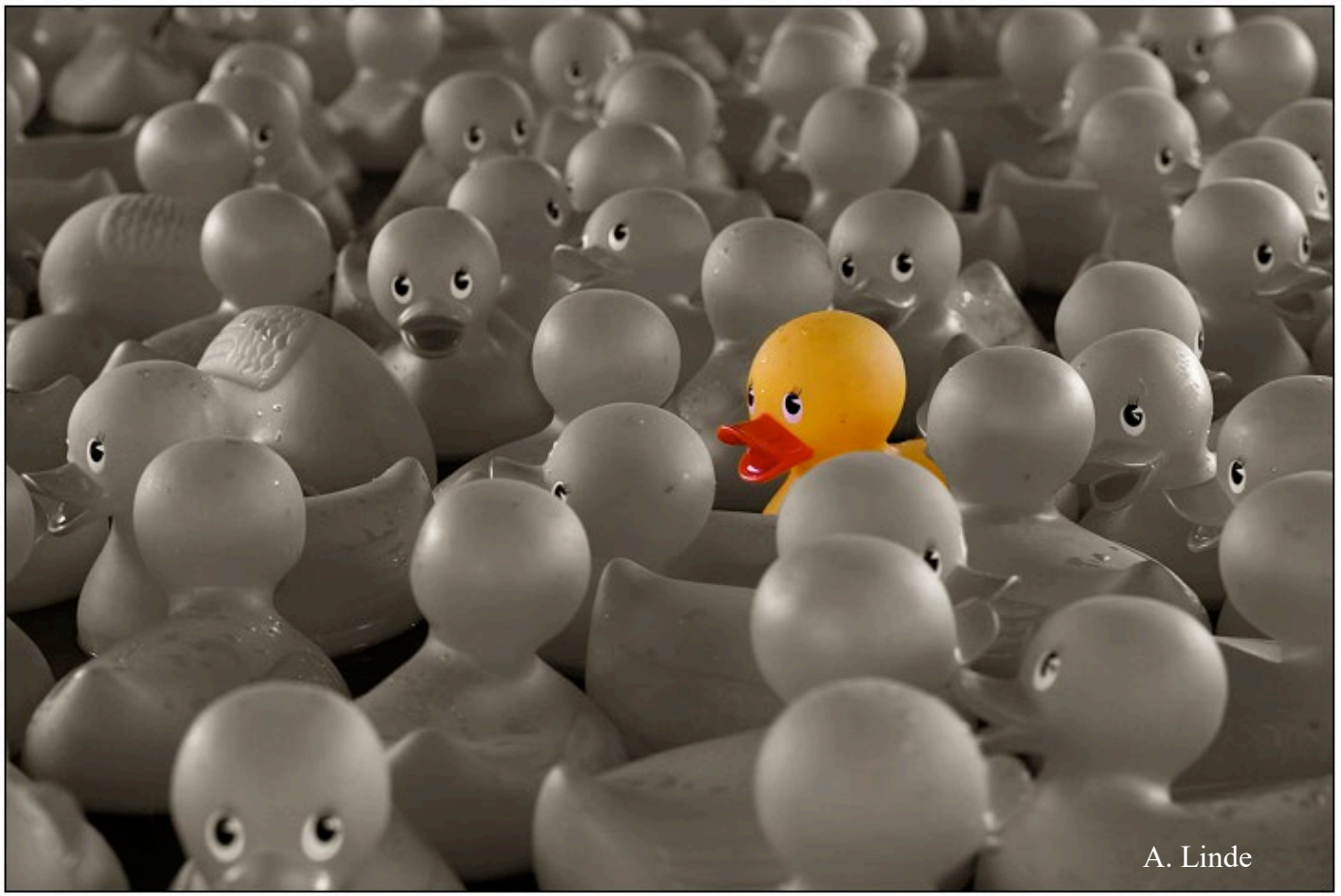


- dark energy: the incredibly low value observed requires extreme fine tuning
- by 0.00 (120 zeros) 001, but we can do it!
- we have a choice of 10^{500} different universes according to superstring theorty

We live in one tiny pocket where the value of the cosmological constant is consistent with our kind of life

Leonard Susskind





The multiverse theory can't make any predictions … it can explain anything…

George Ellis

anthropics & goldilocks: few are just right for life

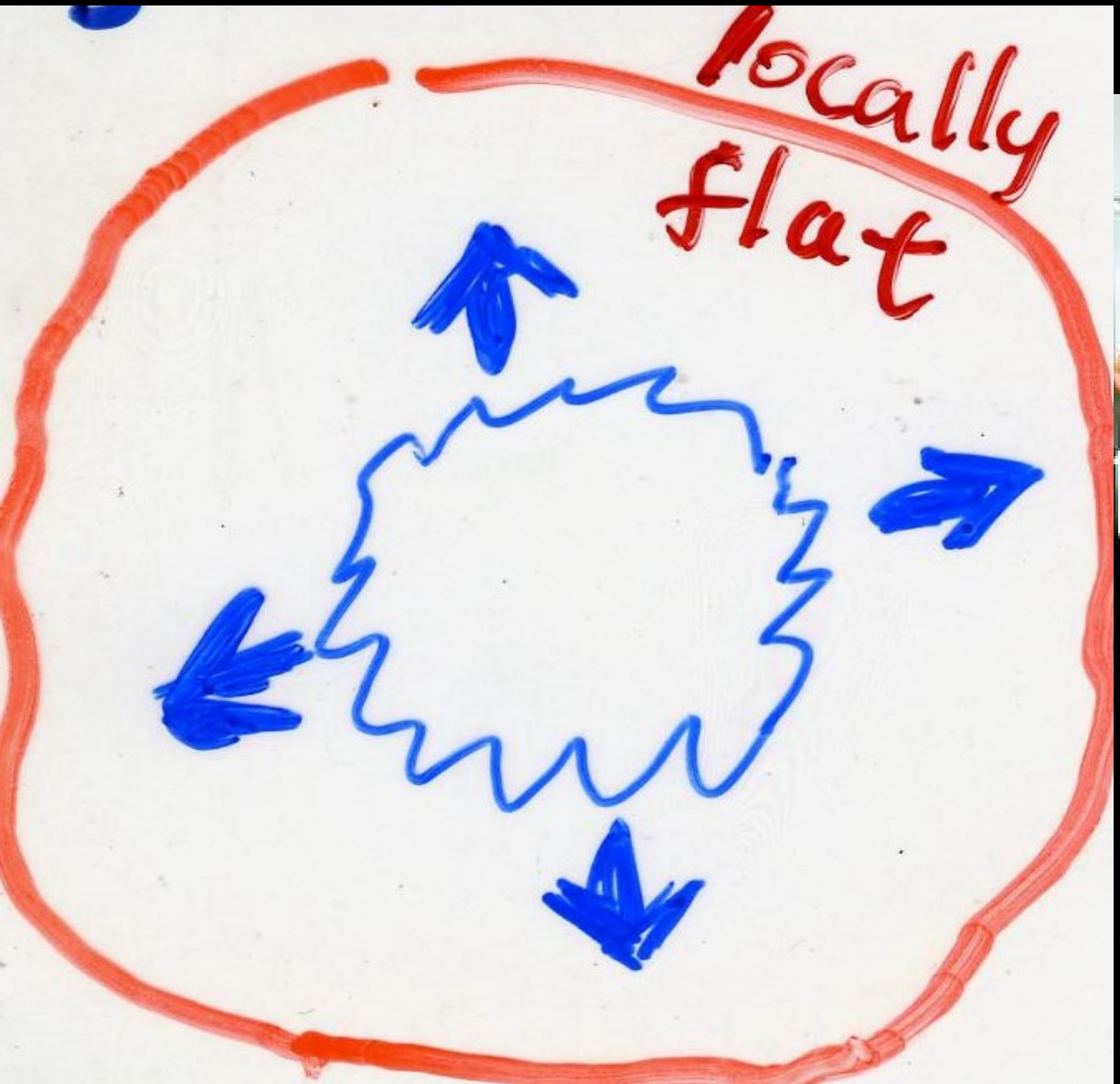
all we need is one: most have too much dark energy, too much acceleration, so too young

They are sterile: any stars and planets that form, are ripped apart by dark energy

our presence selects the universe

INFLATION

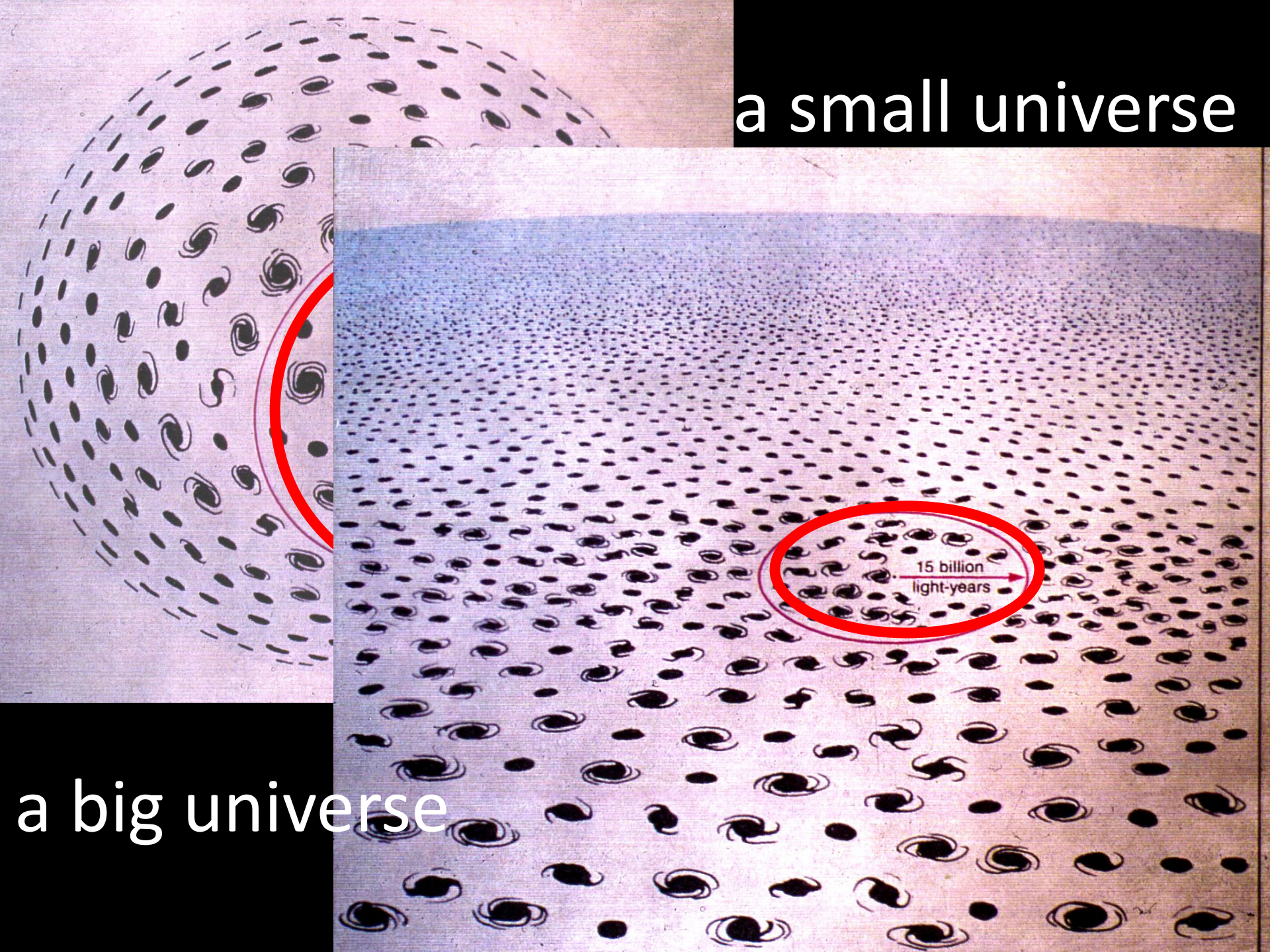
size of the universe, geometry, and fluctuations



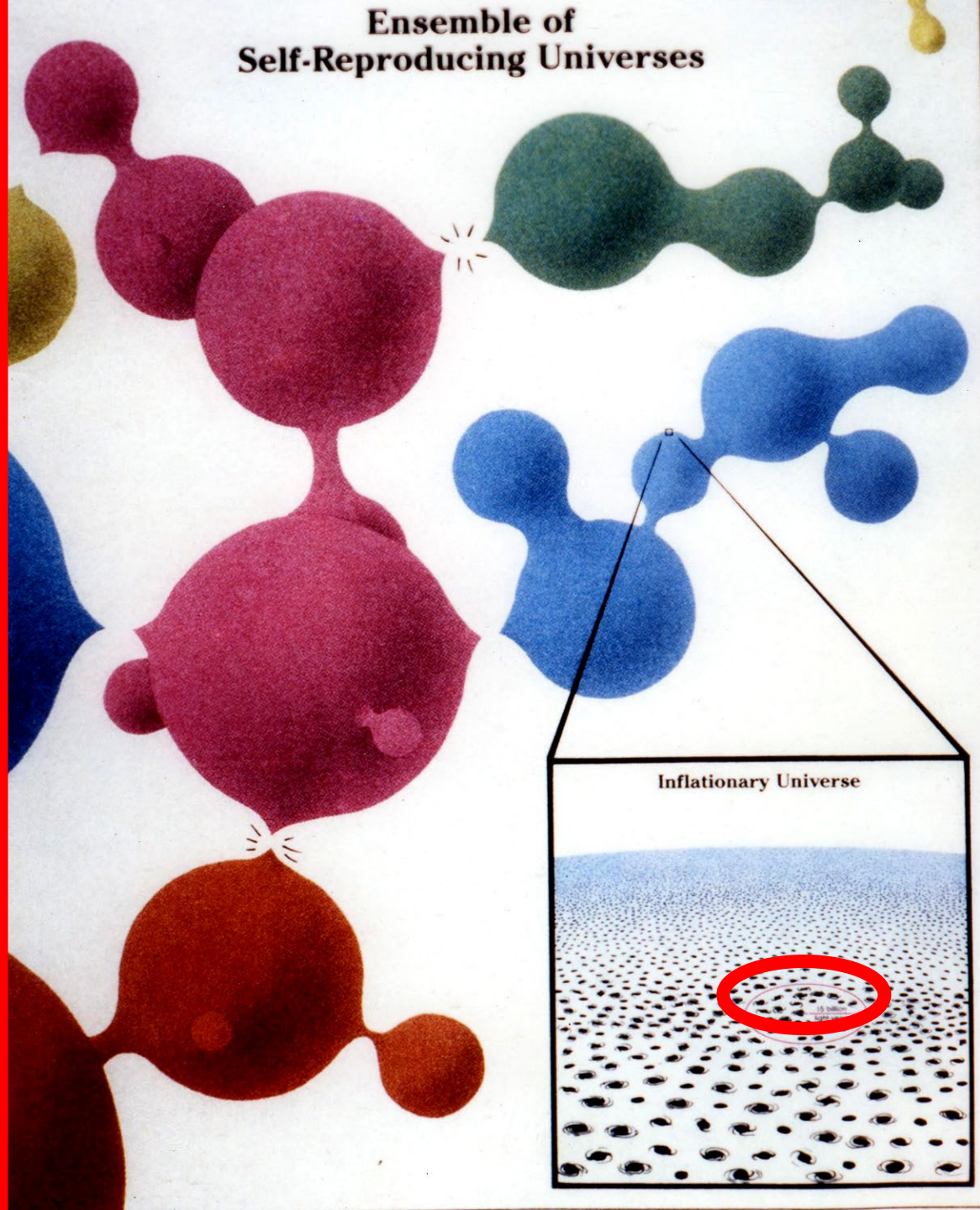
Alan Guth

1980

Andrei Linde


a small universe
15 billion
light-years
a big universe

Eternal inflation generates many big bangs



Eternal inflation creates the multiverse

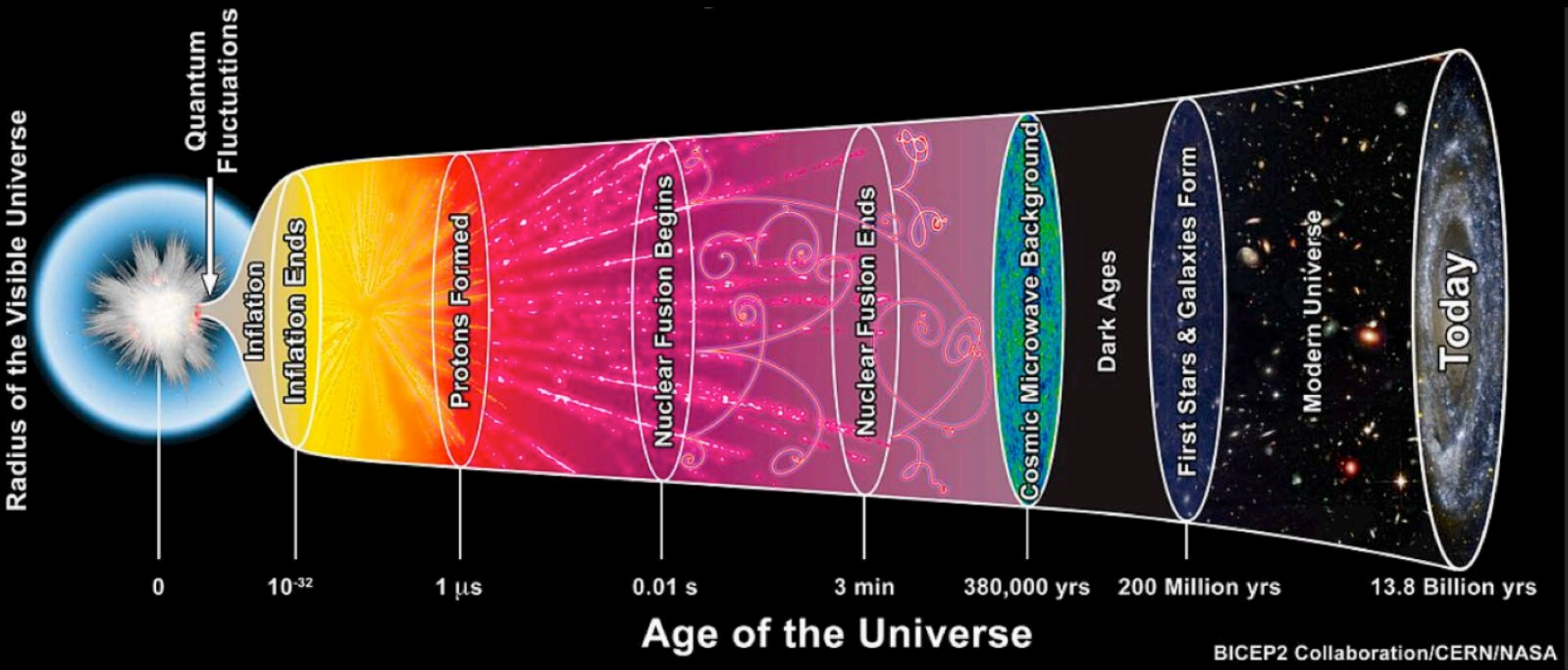
- Swampland prediction of quantum cosmology

- Almost all of the universes predicted by quantum gravity are strongly decelerating
- The big crunch is inevitable
- Bad news: It happens too soon

What next in cosmology?

- The multiverse hypothesis is untestable
- Perhaps this doesn't matter if our theory is compelling
- But now even the best theory is pessimistic
- Could assume dark energy is small because it always was: it's just one more property of nature
- Or let's wait for a new theory of everything,
- After all, general relativity is only a century old, and we probably have 5 billion years ahead of us

history of the universe



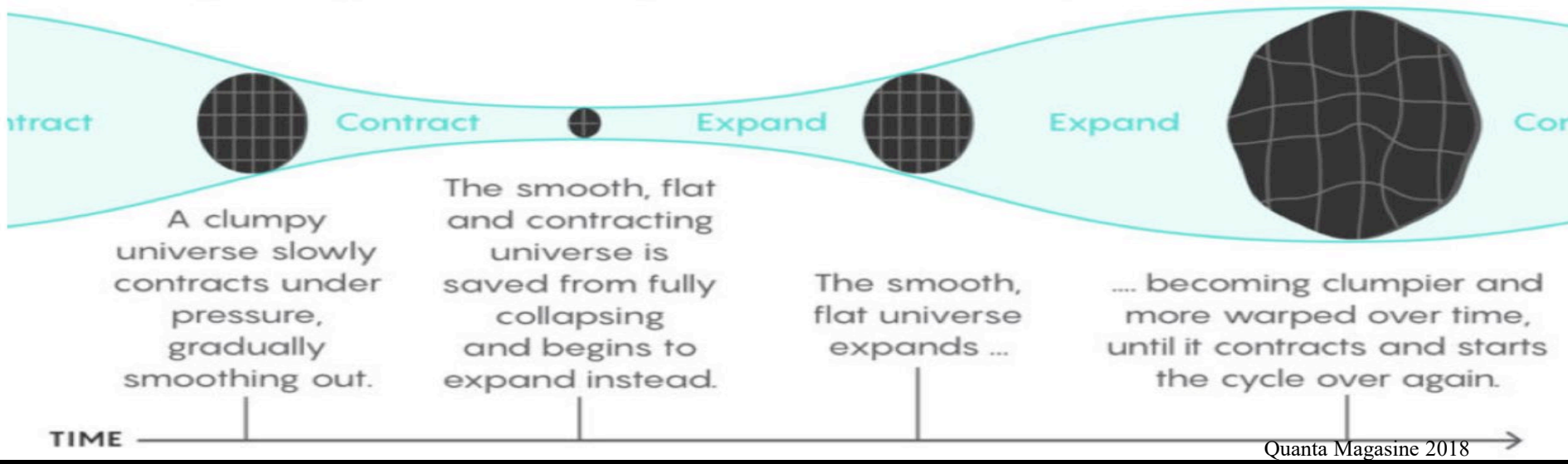
My preferred solution

- The Big Bang

"it's an irrational process, and can't be described in scientific terms"

We need a better beginning

- A bouncing universe



Quanta Magasine 2018

Unfortunately we have no theory for a bounce, yet!