The Origin of the Universe and the Arrow of Time

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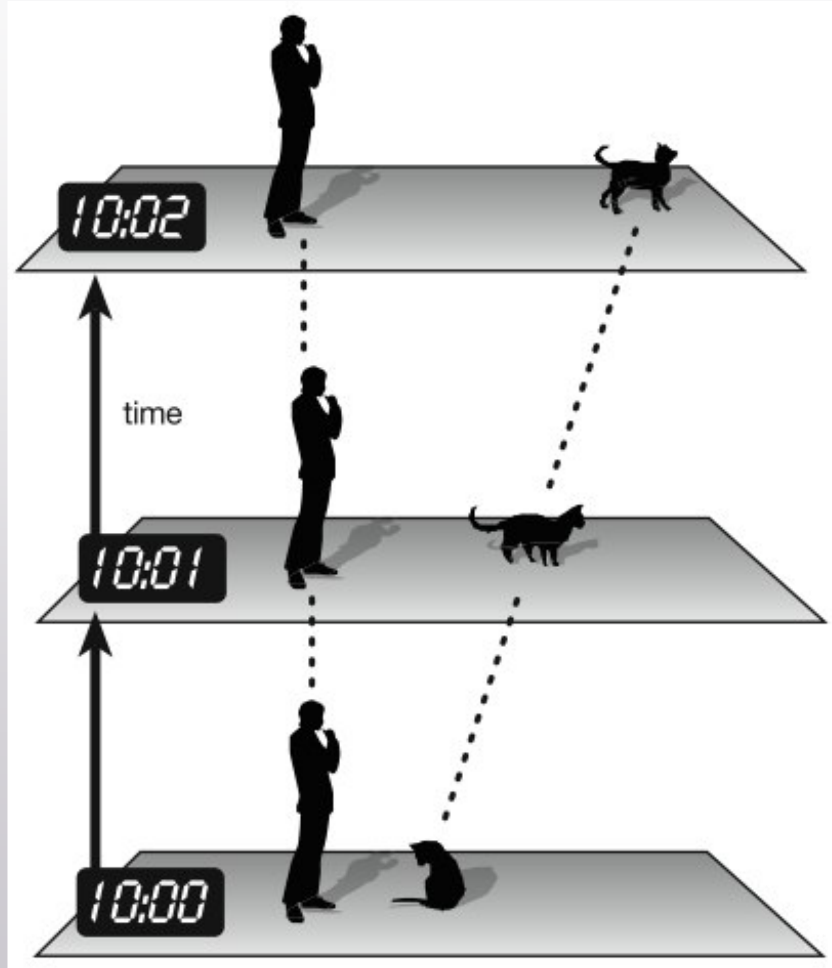
Caltech

What is Time?

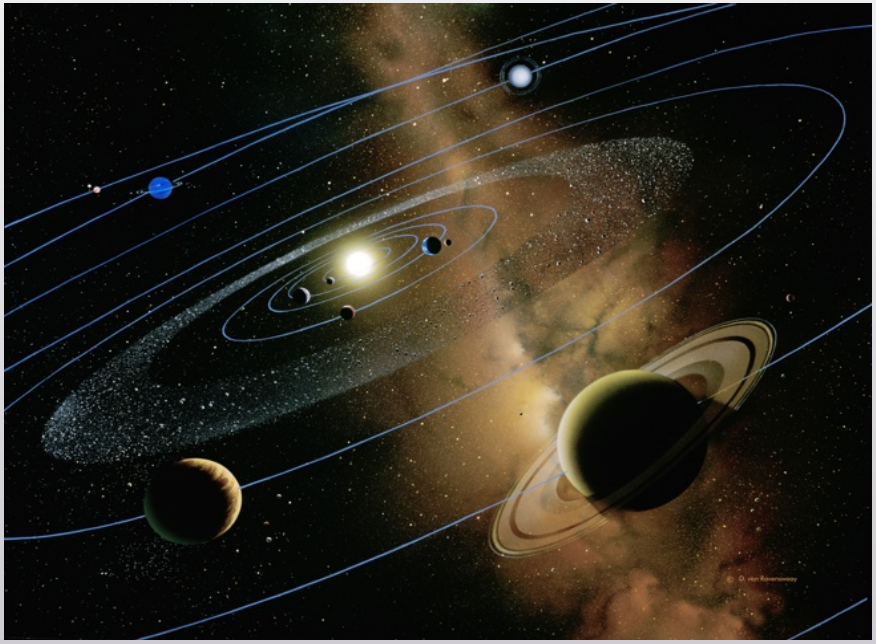
A label on points in the universe, just like space.

Time helps us locate things.



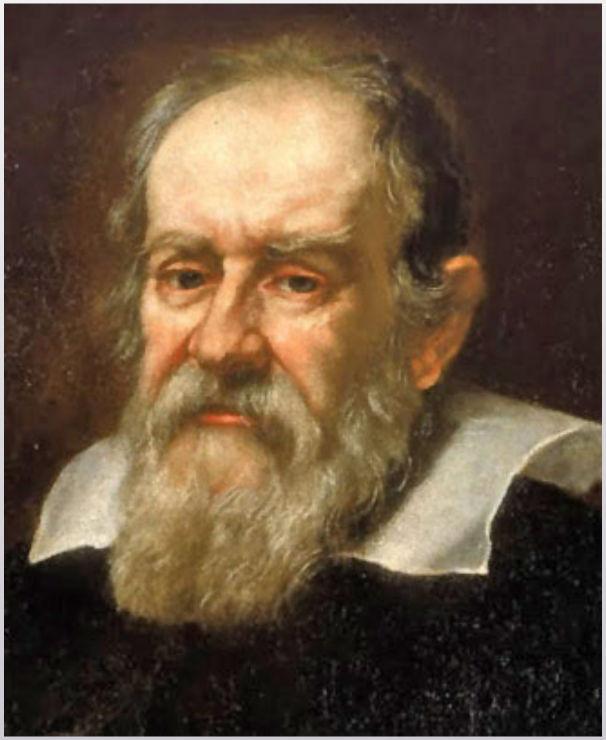
[Jason Torchinsky]

We measure time using clocks:
repetitive, predictable motions.

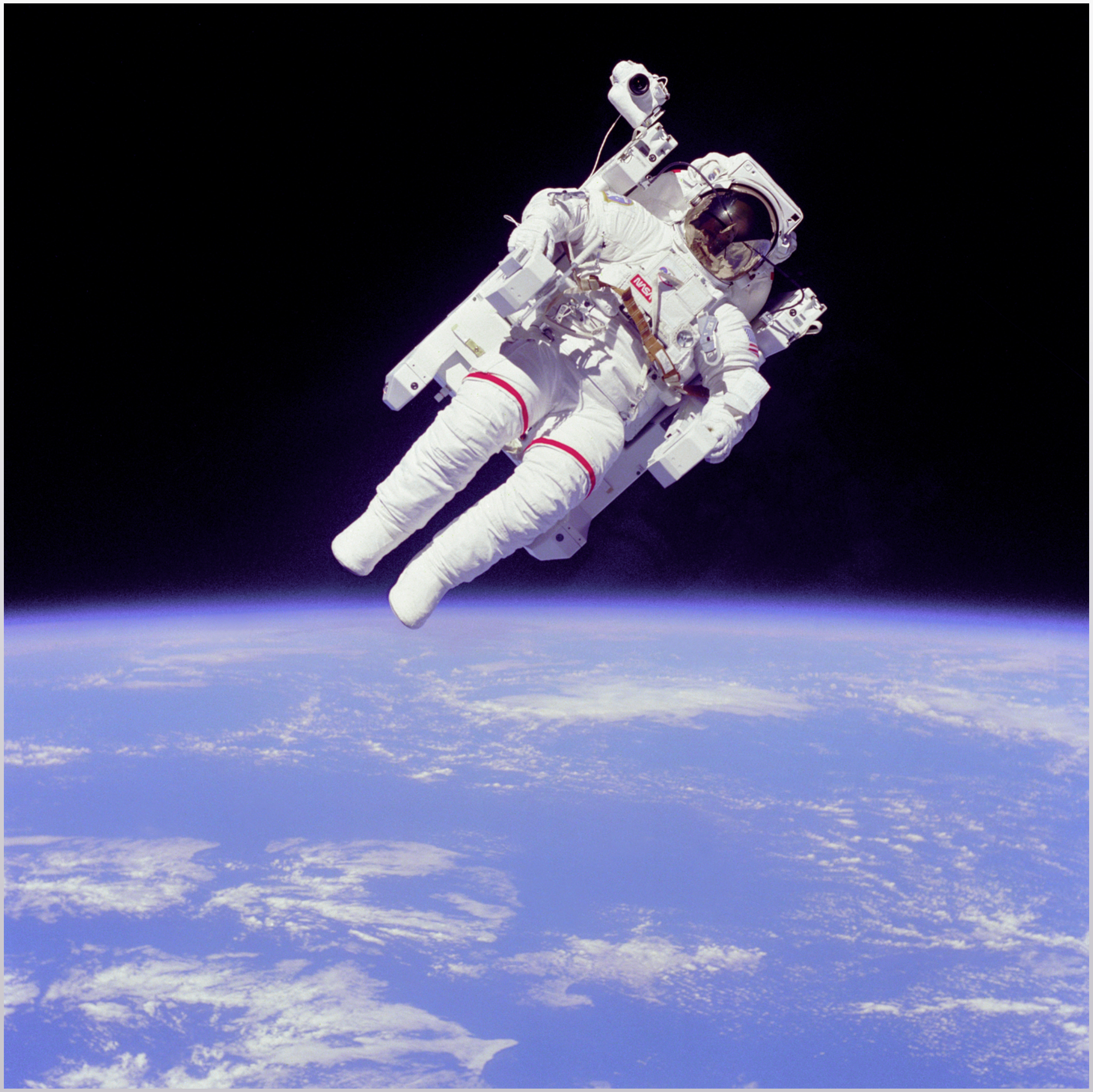


Biological rhythms -- our pulse, breathing, nervous system -- are (somewhat) reliable clocks. They allow us to feel the passage of time.

[Pattie Lee, Flickr]



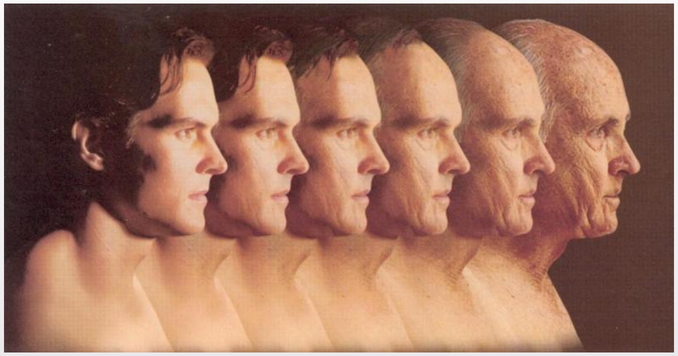
A profound difference between time and space:
time has a direction, space does not.



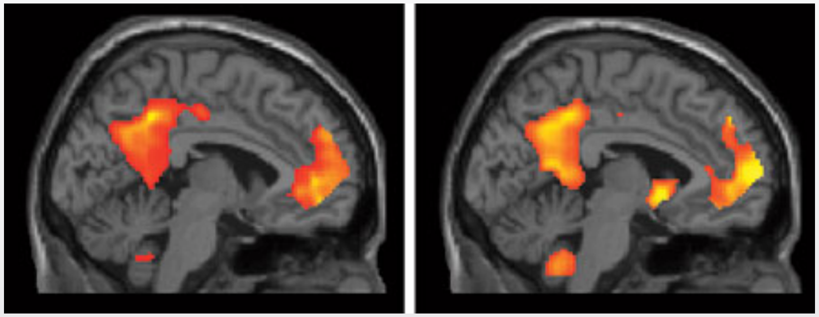
[NASA]

The arrow of time -- the difference between past and future -- is one of reality's most blatant features.

Aspects of Time's Arrow



Aging

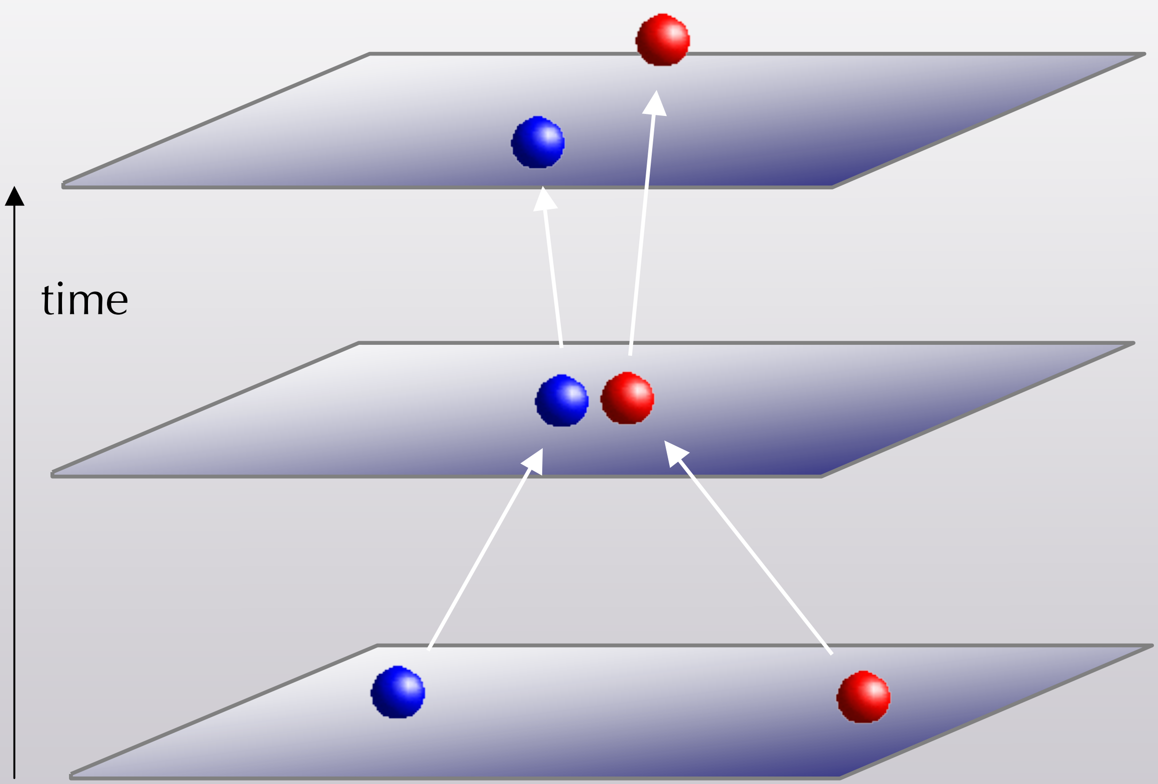


Memory

Free Will

Causality

The twist:
the fundamental laws of nature
have no arrow of time.

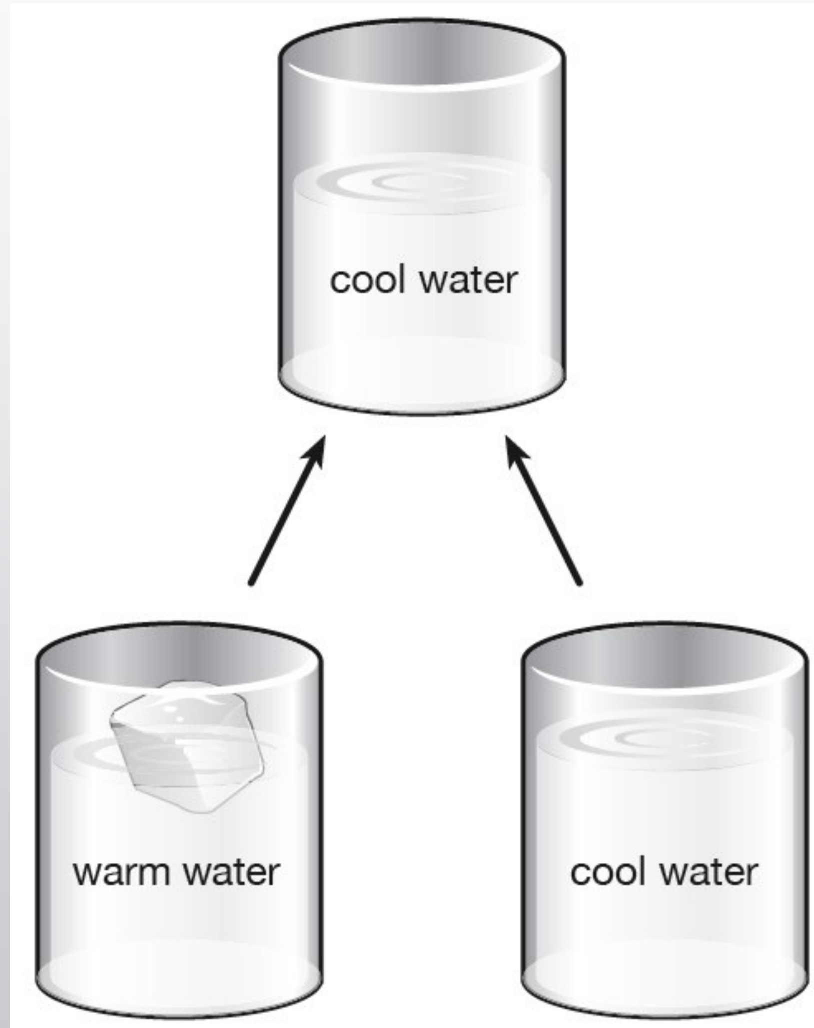


Simple ("fundamental")
motions are reversible.

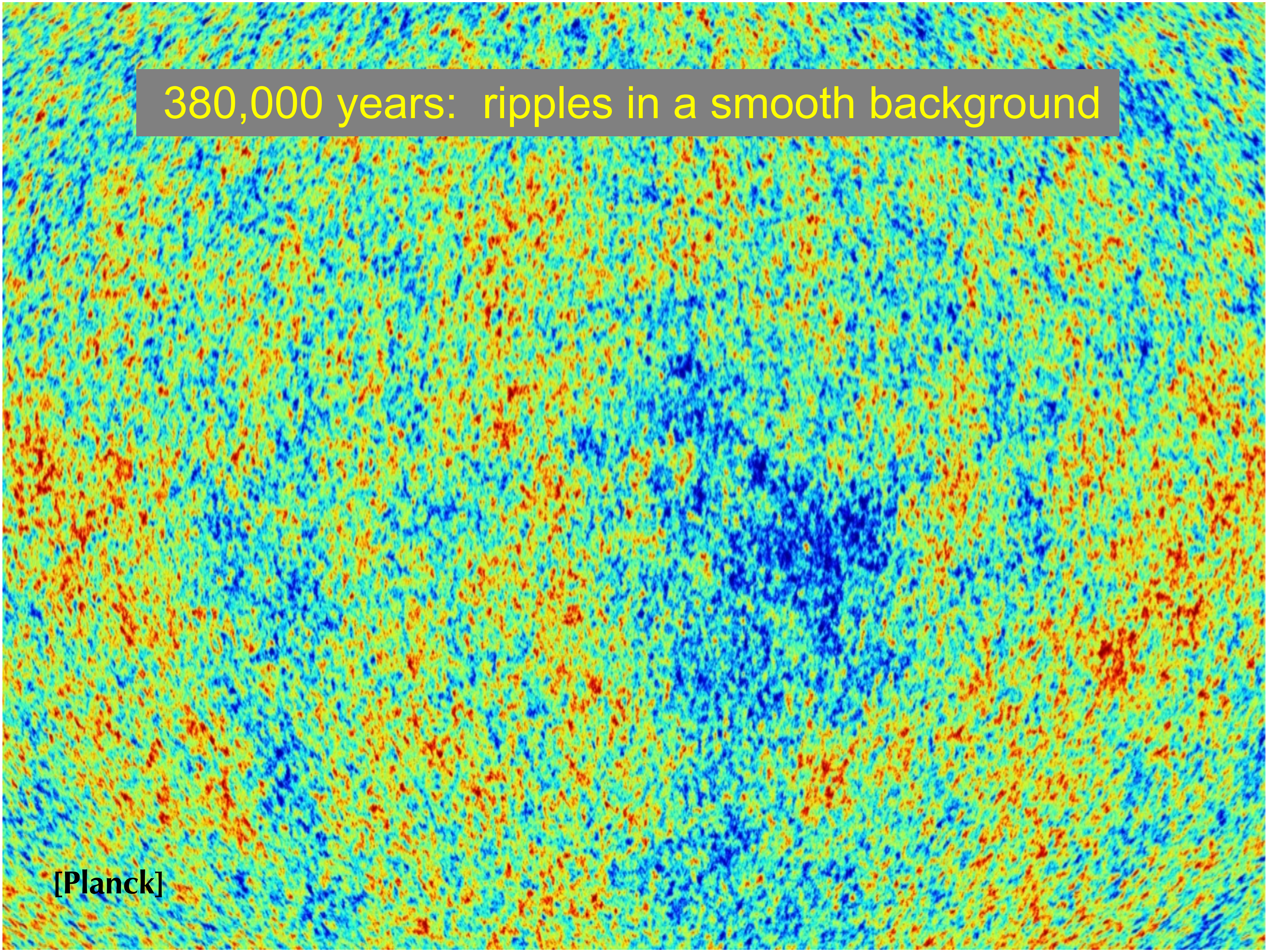
Time's arrow only appears in the macroscopic world (many particles).

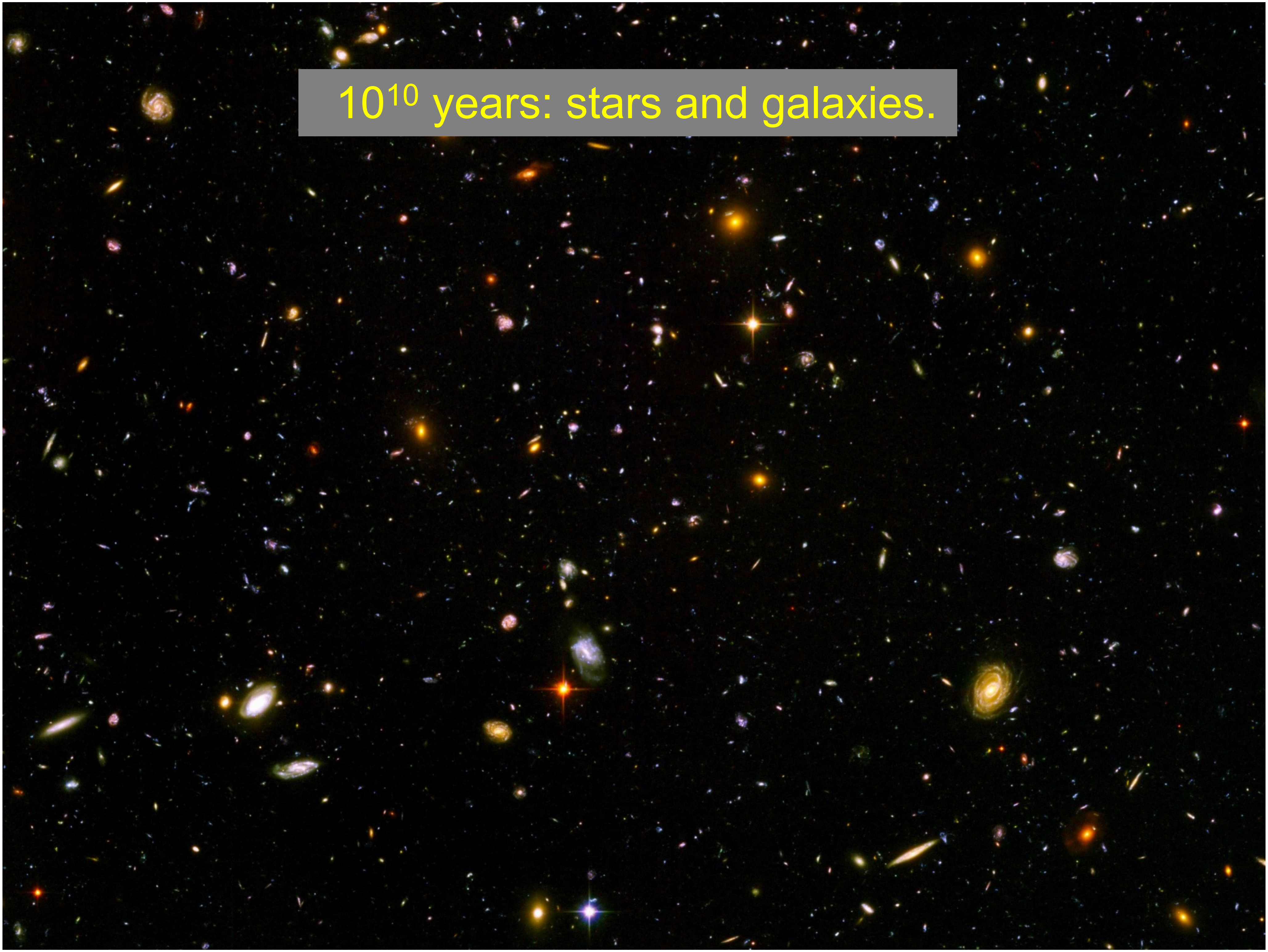
There, evolution is frequently irreversible.

The arrow is a feature of the arrangement of matter in our universe, not the underlying laws.



1 second: hot, smooth plasma.


380,000 years: ripples in a smooth background
[Planck]

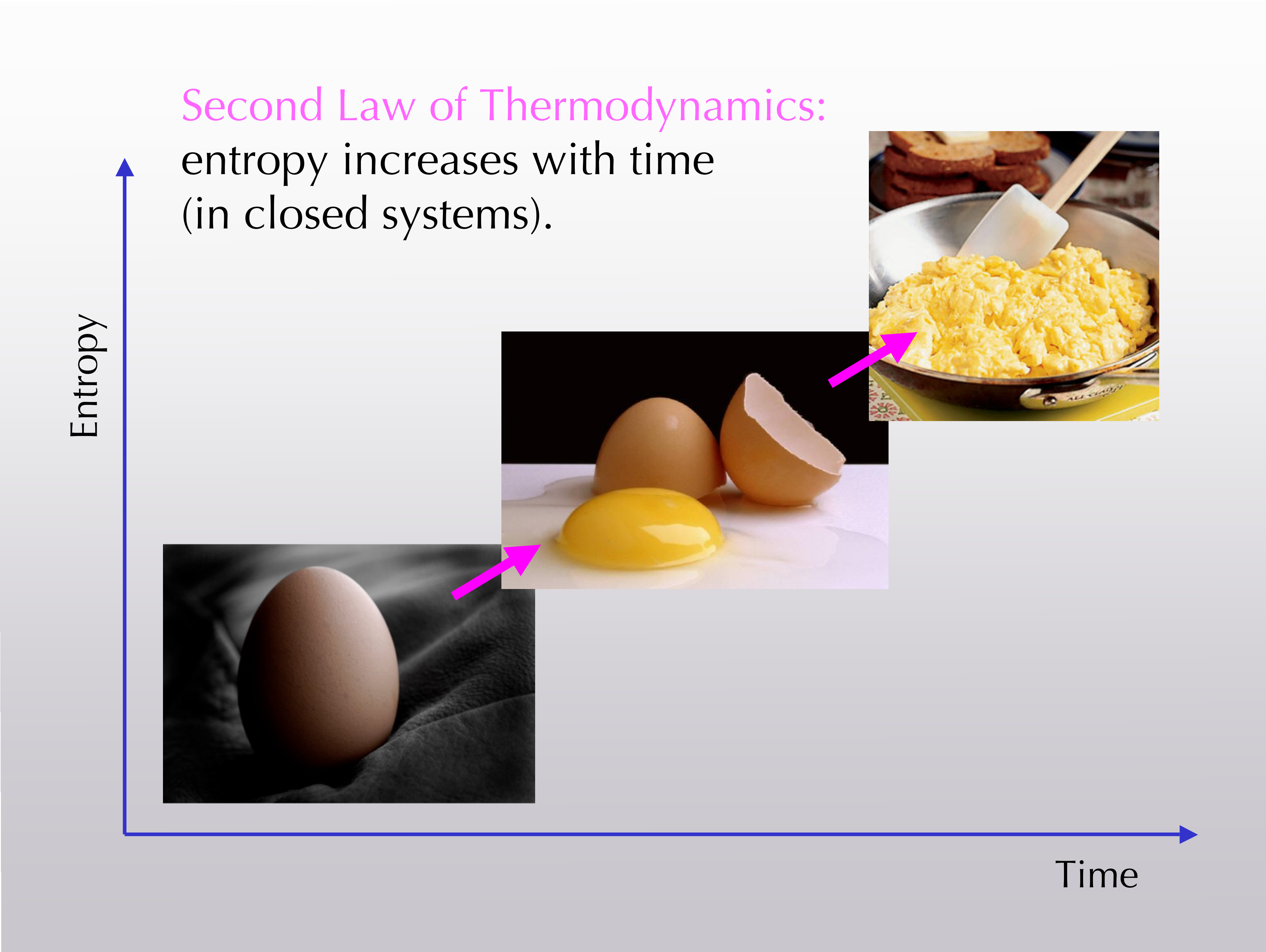

10^{10} years: stars and galaxies.

10^{15} years: black holes and rocks.

10^{100} years: empty space (dark energy).

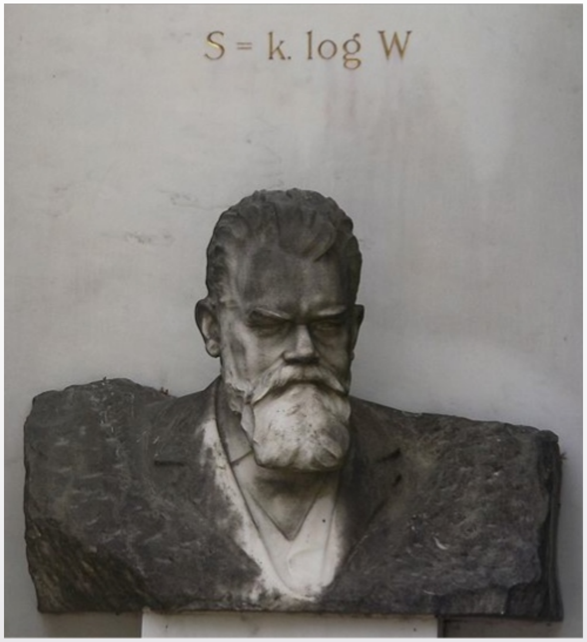
A single phenomenon underlies all manifestations of time's arrow: increasing entropy.

Entropy is a measure of disorderliness, messiness, randomness.


Second Law of Thermodynamics:
entropy increases with time
(in closed systems).
Entropy
Time

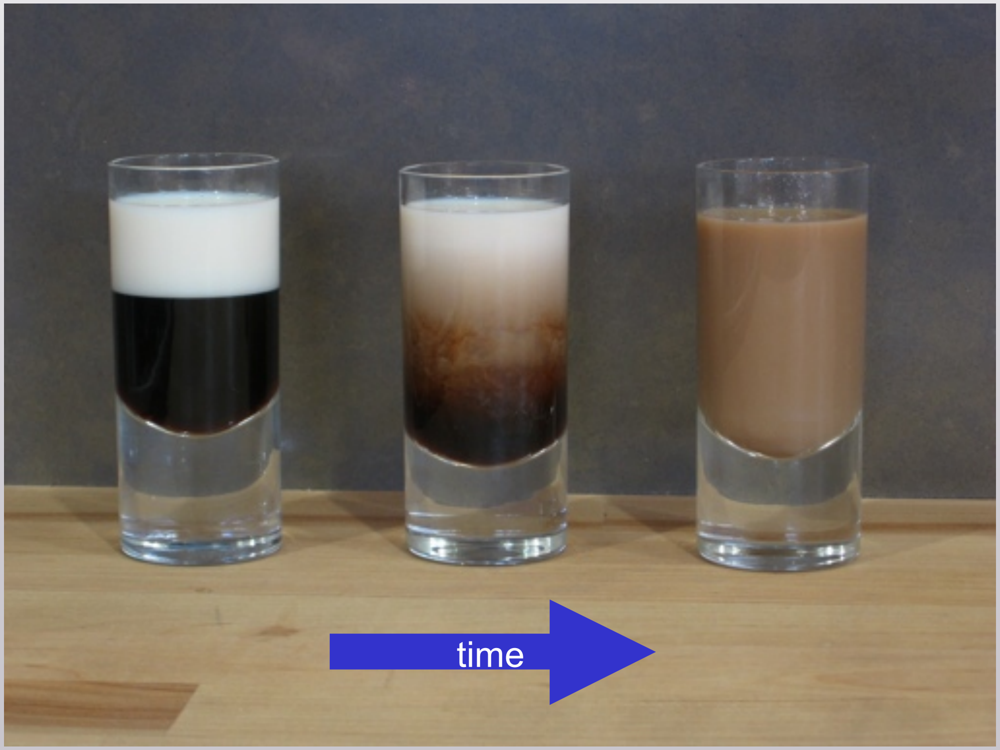
Ludwig Boltzmann, 1870's:

Entropy counts the number of ways we can re-arrange a system without changing its basic appearance.

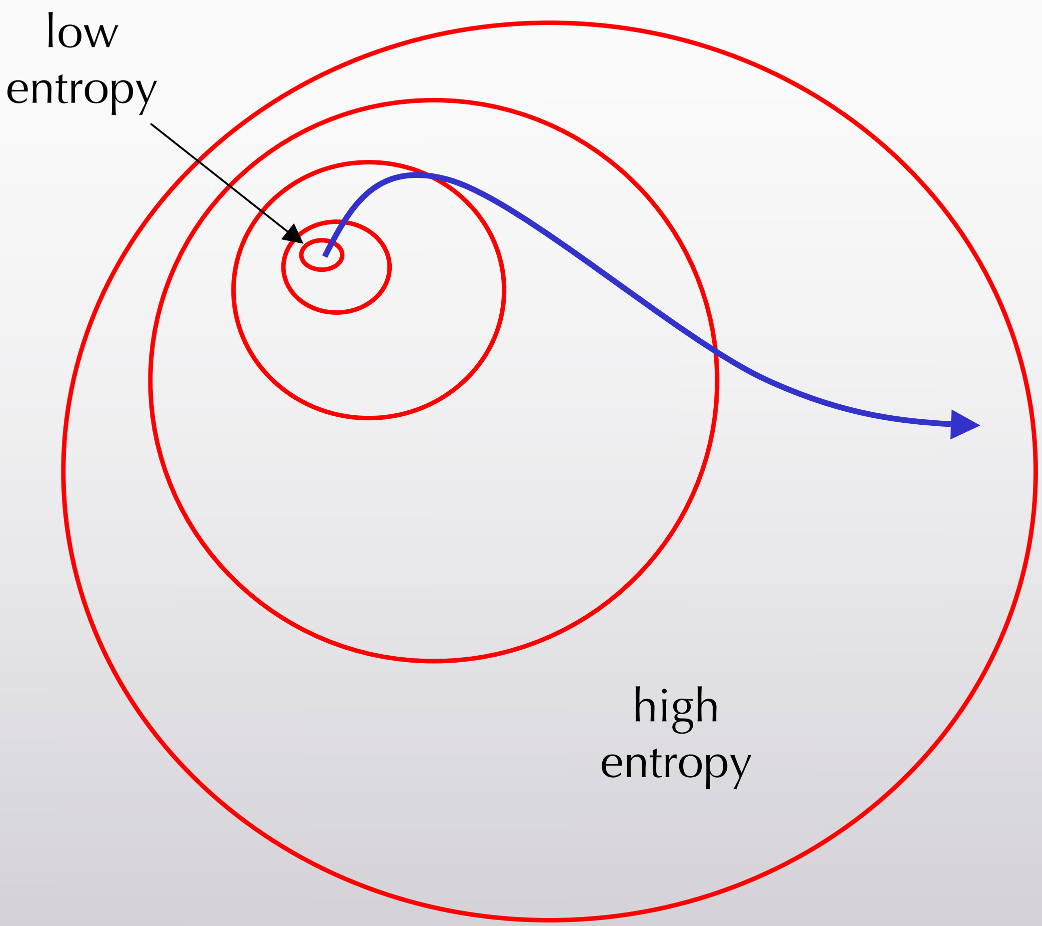


[Martin Röll]

low entropy: delicately ordered



high entropy: all mixed up

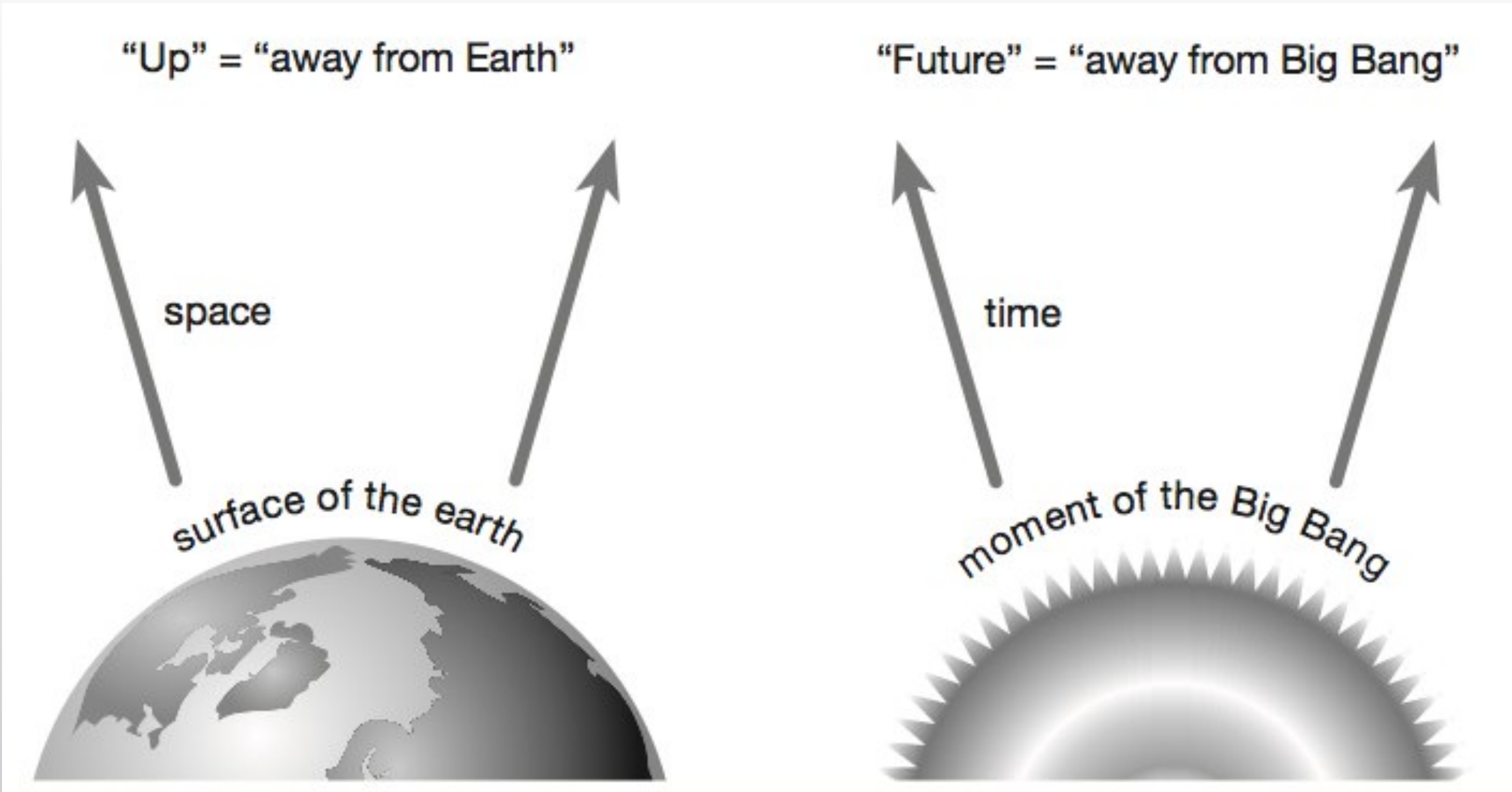


possible arrangements of atoms/molecules, grouped by macroscopic indistinguishability

Entropy increases simply because there are more ways to be high-entropy than low-entropy.

All makes sense, *if* the entropy was low to begin with.

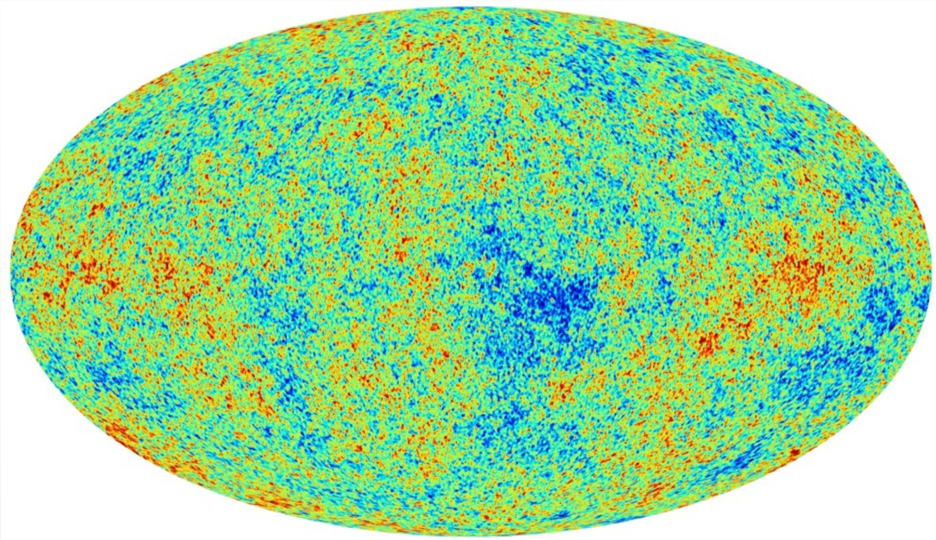
The Past Hypothesis:
our universe started in a low-entropy state.



13.7 billion years ago, at the Big Bang.

Why "hypothesis"?

Don't we *observe* that the early universe had low entropy?

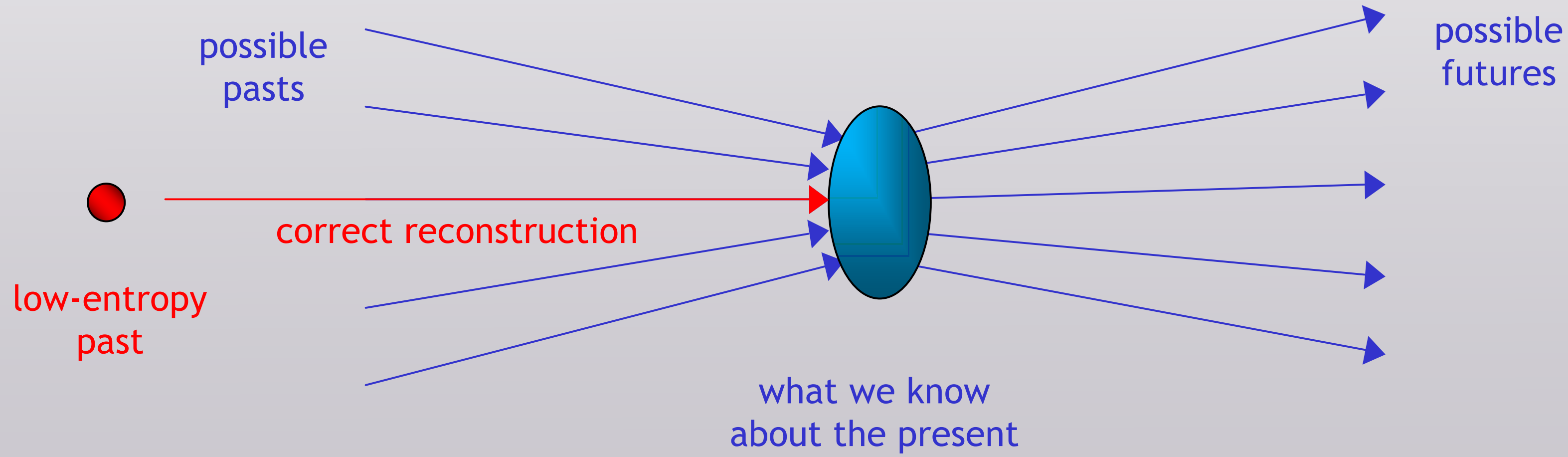


No. We *observe* photons hitting our telescopes here in the present day.

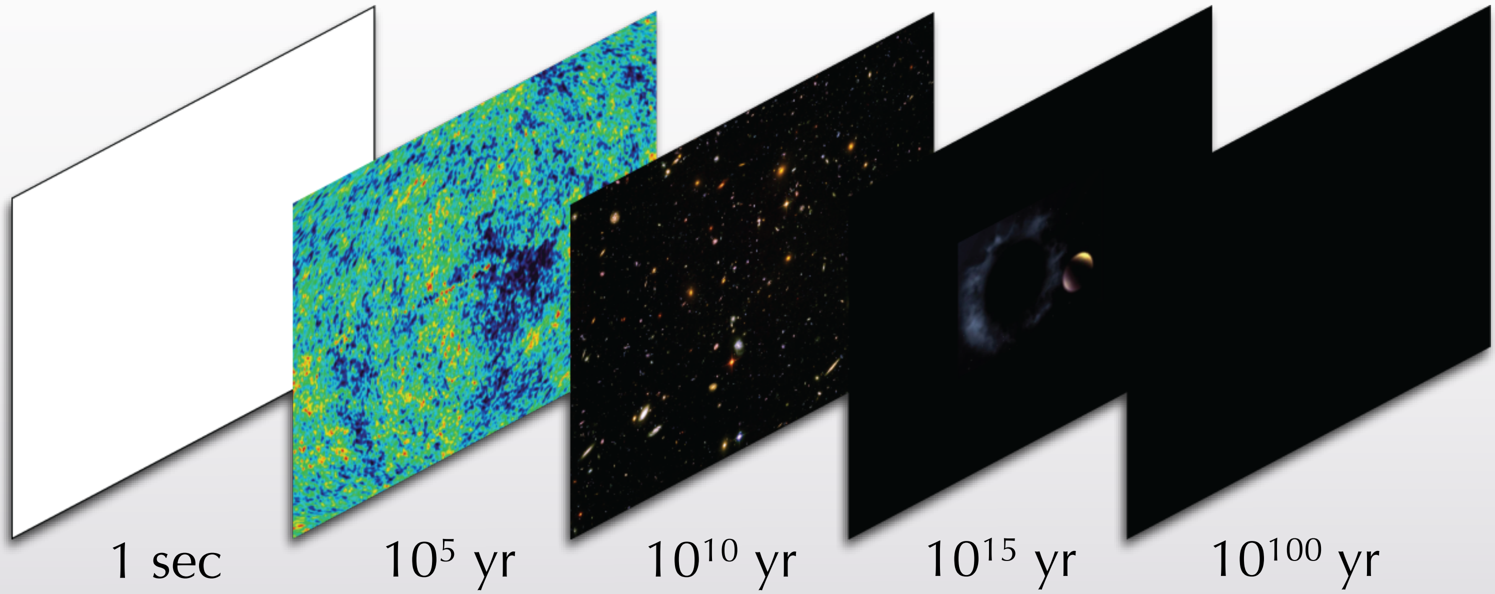
We use that data to *infer* conditions in the early universe … but only by assuming low entropy.

The past hypothesis helps reconcile reversible microphysics with macroscopic directionality.

Why do we remember the past and not the future?



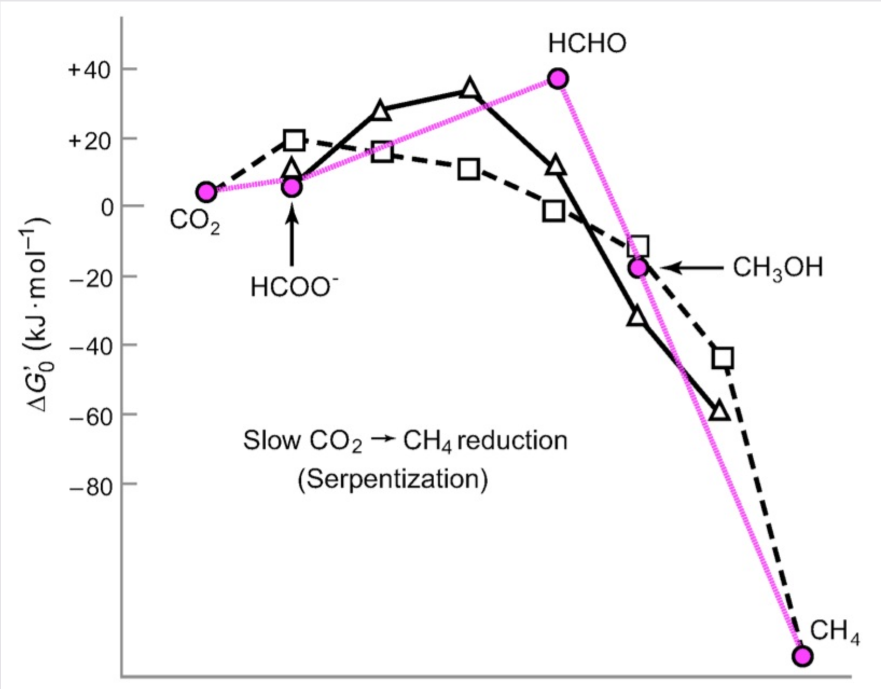
Entropy vs. Complexity



Entropy increases.
Complexity first increases,
then decreases.

Origin of life:

Complexity isn't merely compatible with the Second Law, it's a <u>consequence</u> of increasing entropy.

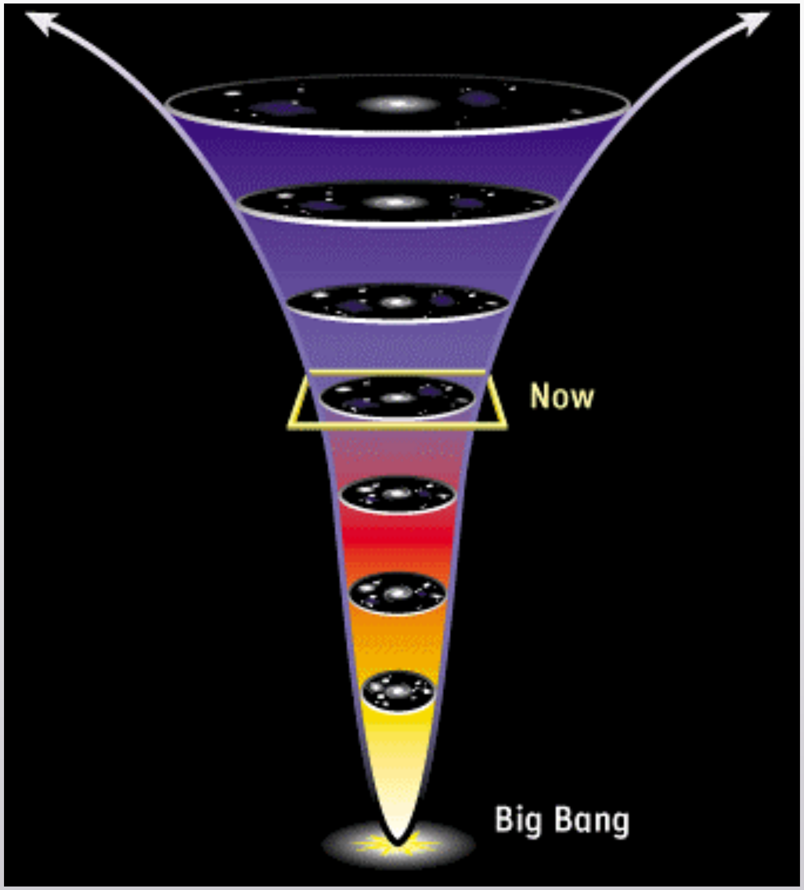


[Yung, Russell & Parkinson]

Sustaining life:

energy is constant, but organisms take low-entropy energy and degrade it into high-entropy energy.

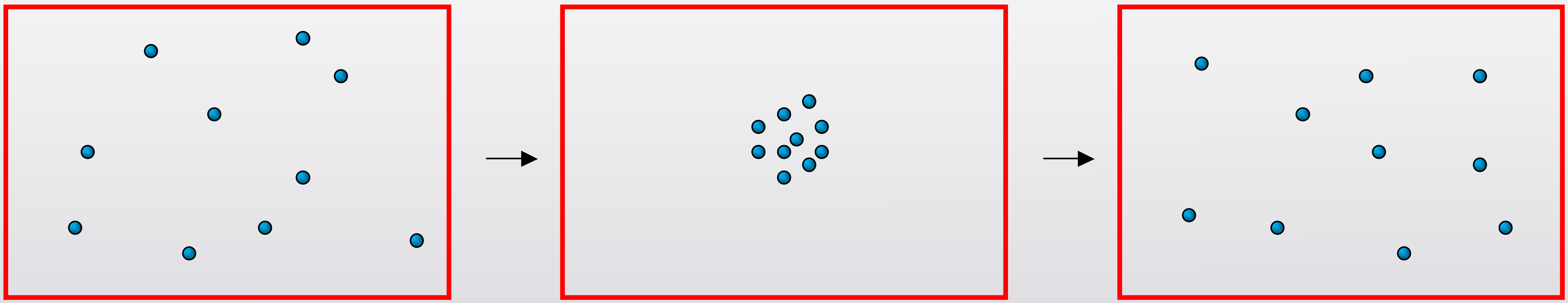
[Penrose]



Pressing question for cosmology: why did the universe start out with low entropy?

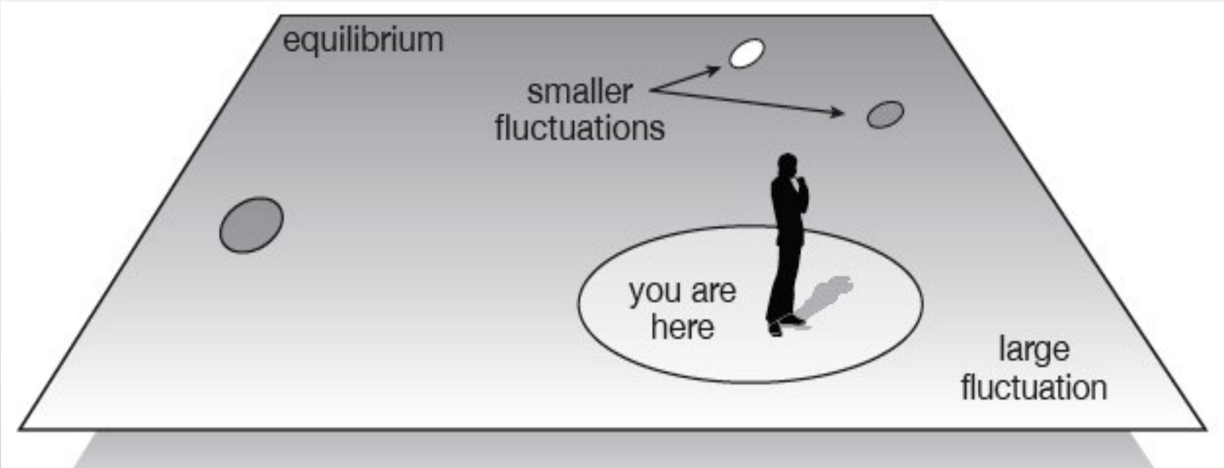
Why is the past hypothesis correct?

Could our observable universe just be a random fluctuation?



If we wait long enough, a collection of particles will randomly fluctuate into any allowed low-entropy state.

Boltzmann, 1895: maybe there is a multiverse mostly in high-entropy equilibrium, and our galaxy is just a random fluctuation.



Boltzmann's multiverse

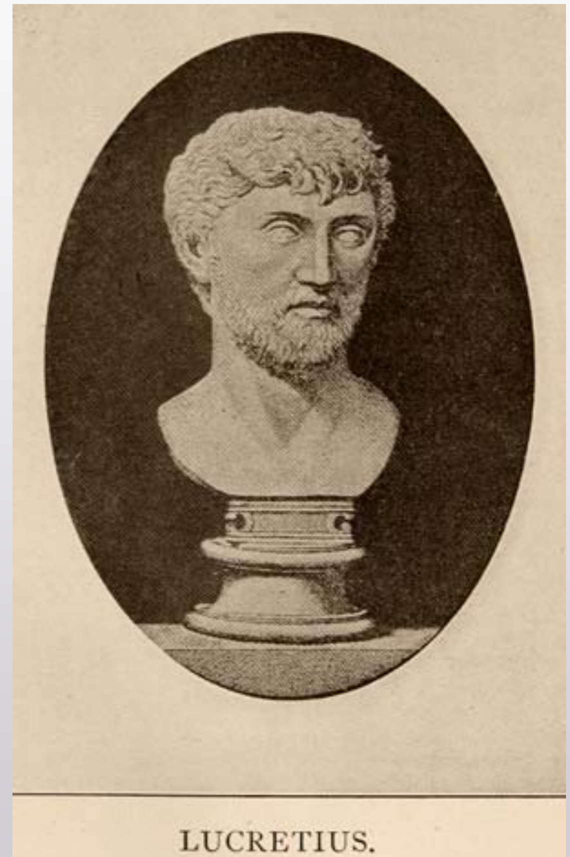
The anthropic principle: in a big universe, we will only observe those parts that are hospitable to the existence of intelligent life.

Boltzmann wasn't the first to suggest this scenario.

"For surely the atoms did not hold council, assigning order to each, flexing their keen minds with questions of place and motion and who goes where.

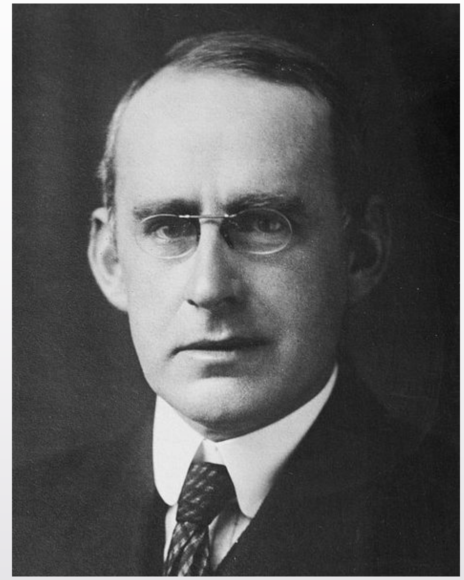
Rather they shuffled and jumbled in many ways, and in the course of endless time they are buffeted, driven along, chancing upon all motions and combinations.

At last they fall into such an arrangement as would create this universe…"



-- Lucretius, *De Rerum Natura*, c. 50 BC.

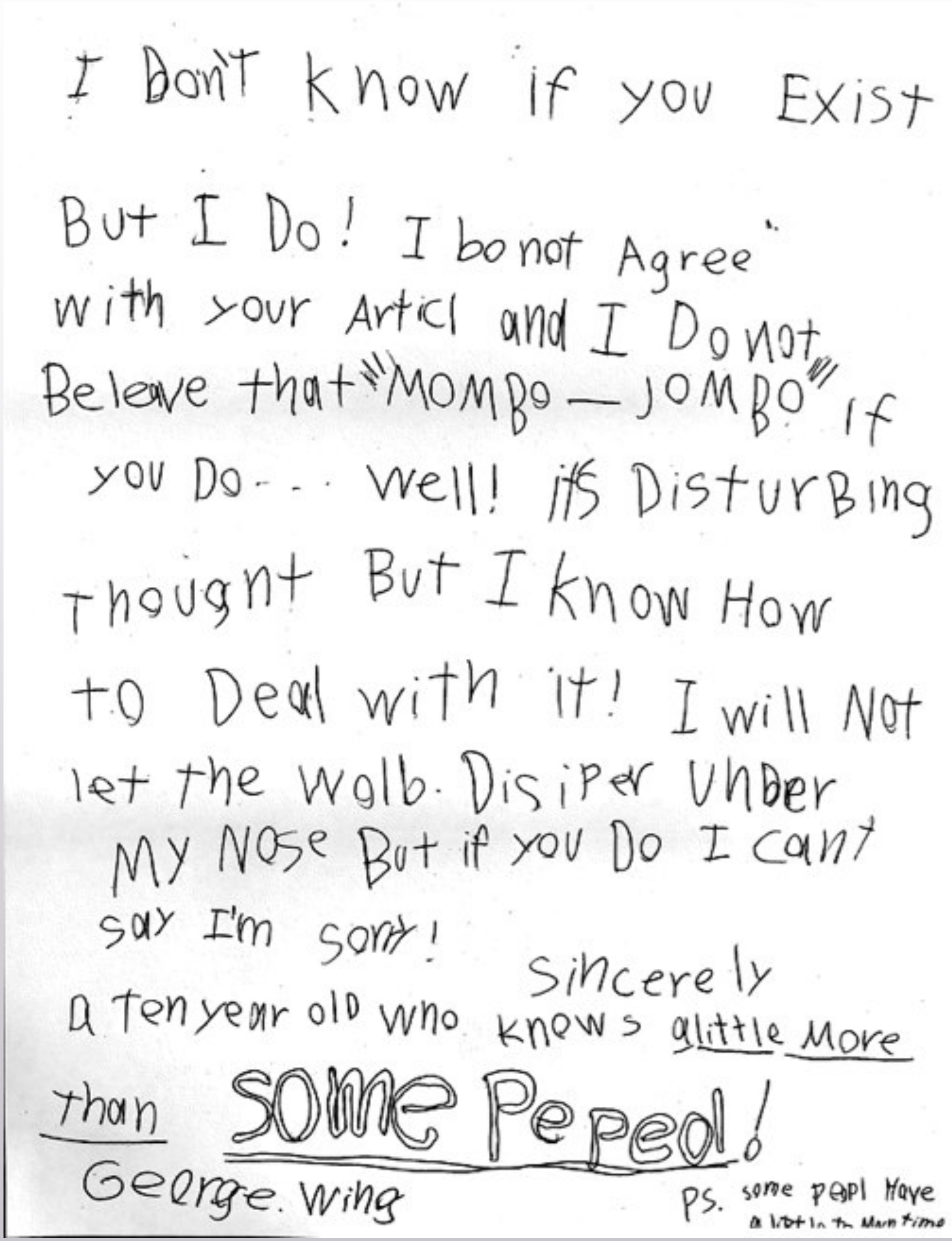
In 1931, Sir Arthur Eddington explained why we cannot be just a random fluctuation.



Fluctuations are rare, and large fluctuations are very rare.

[New York Times]

This scenario predicts that we should be the minimum possible fluctuations -- "Boltzmann Brains." [Albrecht & Sorbo, 2004]


I Don't know if you Exist
But I Do! I bo not Agree with your Artic and I Do not Beleave that "MOMBO — JOMBO" if you Do... well! it's DisturBing thought But I know How to Deal with it! I will Not let the wolb Disiper Unber My Nose But if you Do I can't say I'm sorry!

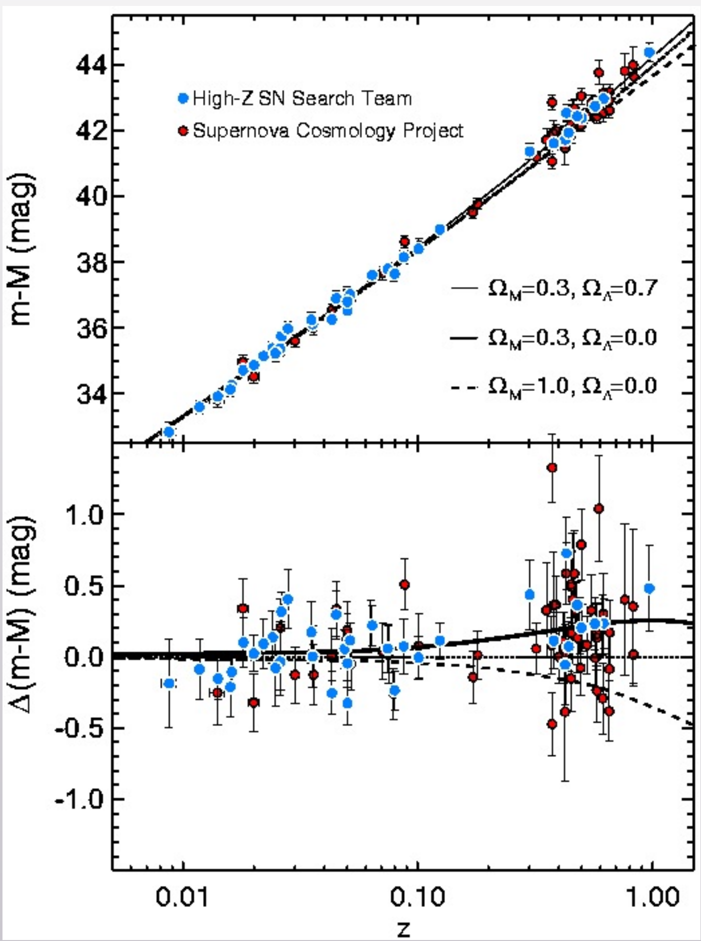
Sincerely
a Ten year old who knows a little More than some Peped!
George Wing

PS. some pepl Have a lot in th Marn time

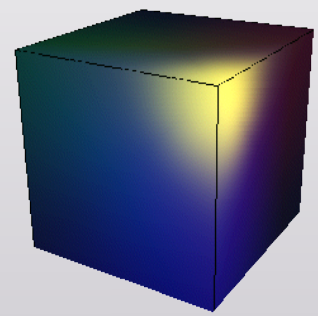
Always some skeptics.

But wait!

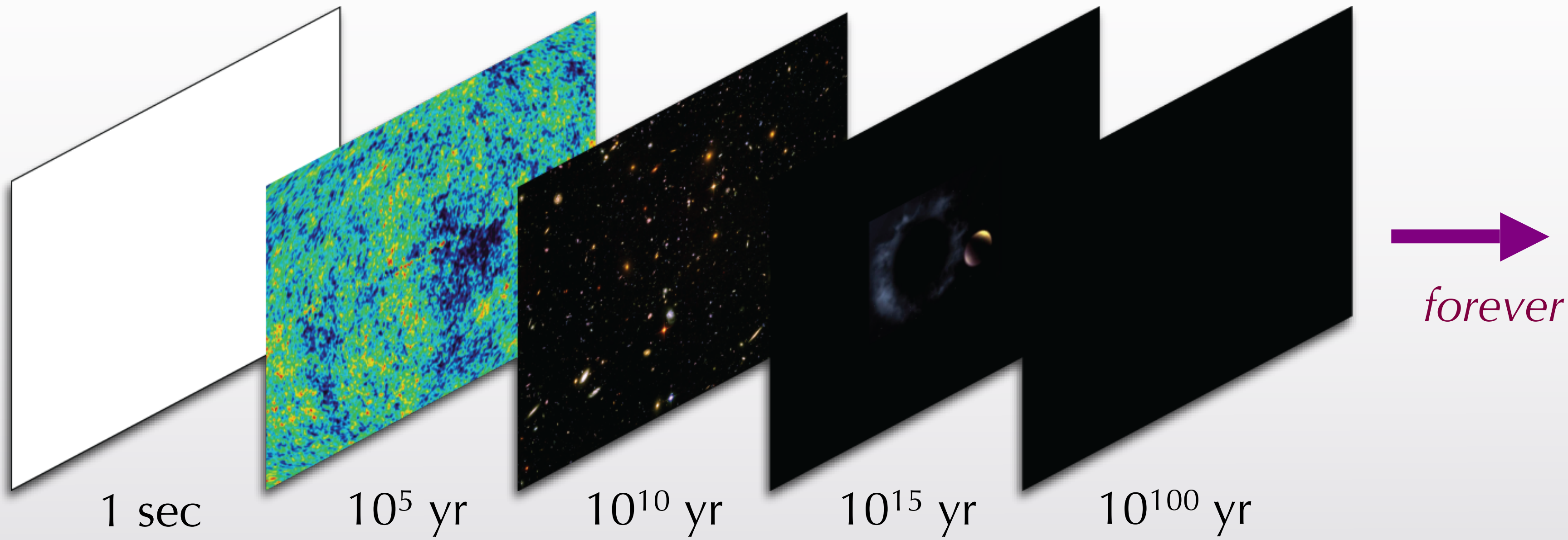
Our best theory says we actually <u>do</u> live in an eternal universe with thermal fluctuations.

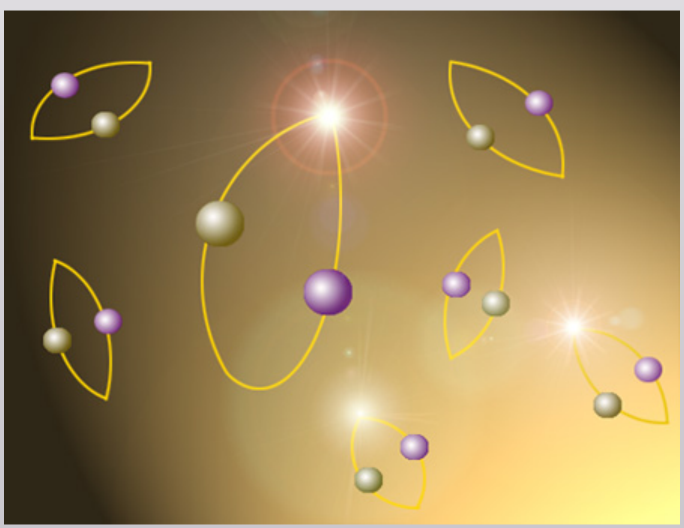


1998 discovery: the universe is accelerating.



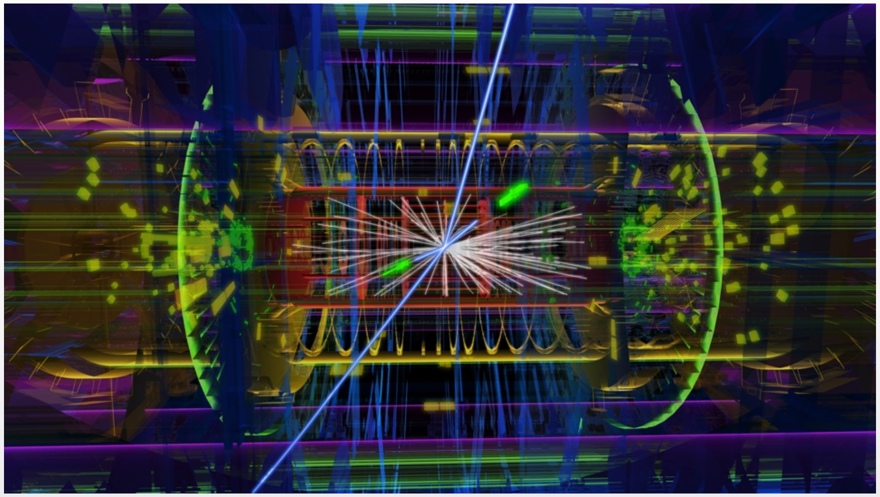
Simplest explanation: dark energy, with a fixed density through time.

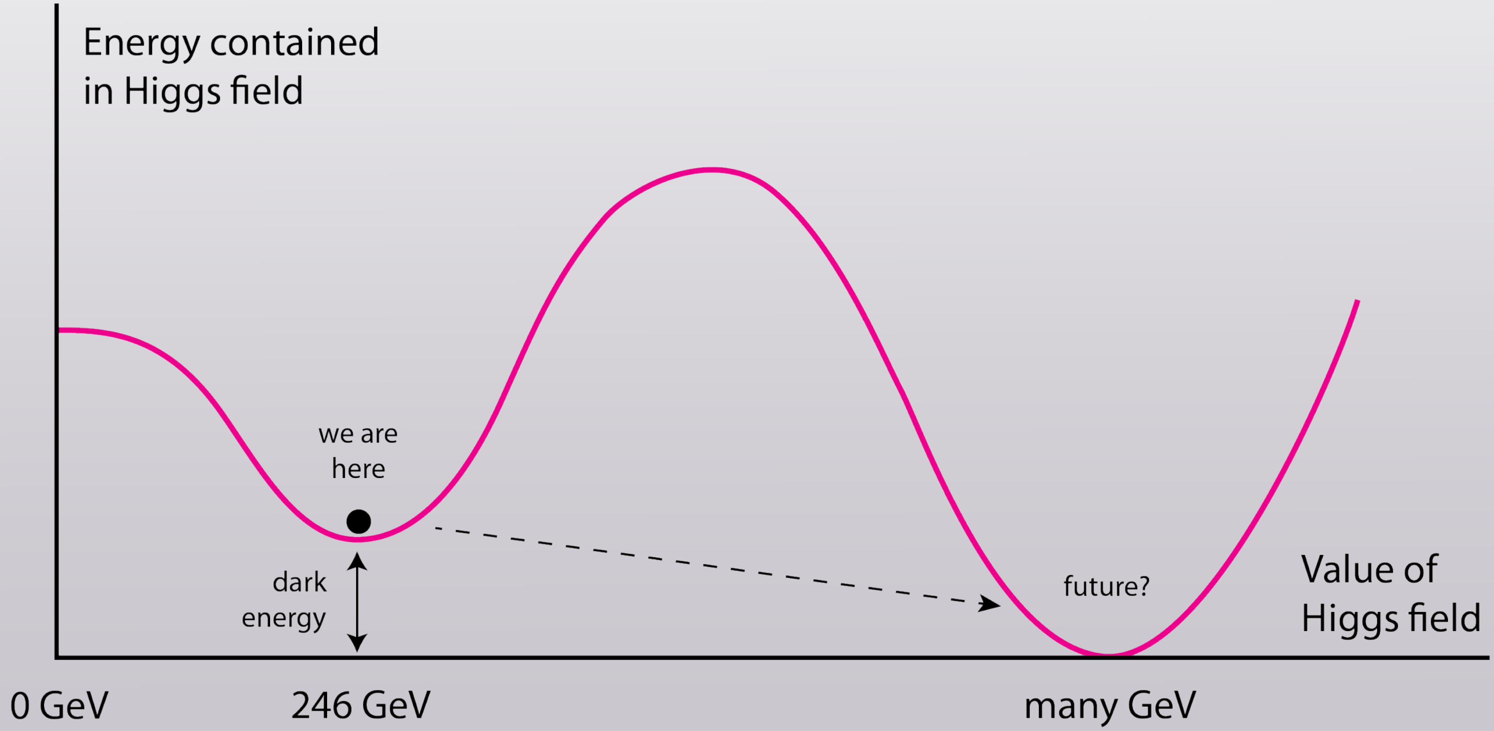




Dark energy (the cosmological constant) implies a temperature for empty space -- and therefore Boltzmann Brains.

Higgs to the rescue?





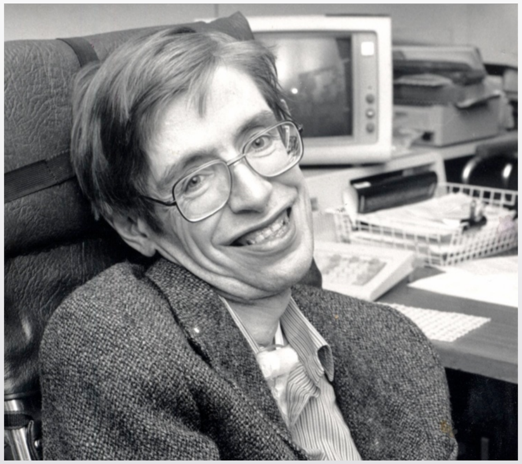
The beginning of the universe remains problematic.

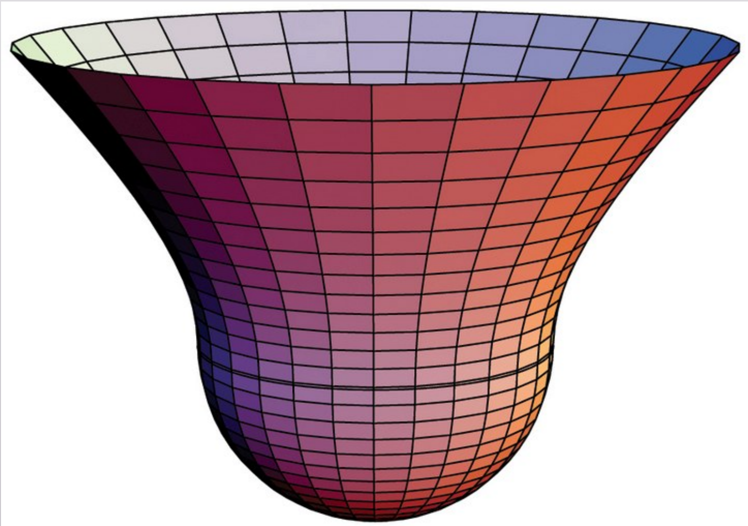
Two basic options.

Option One:

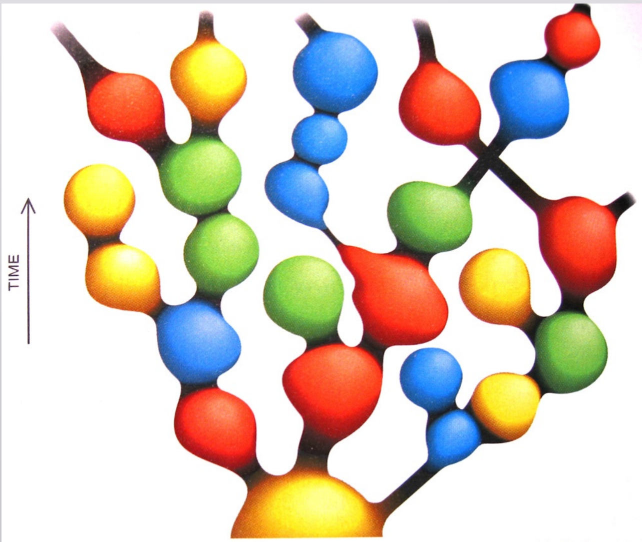
A true beginning, universe created at the Big Bang.

Low entropy imposed.





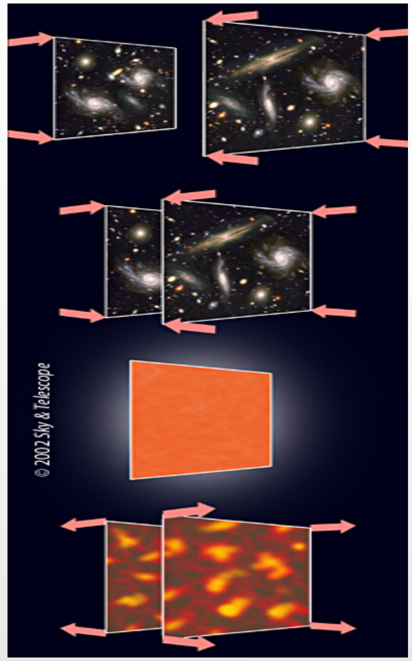
universe from nothing



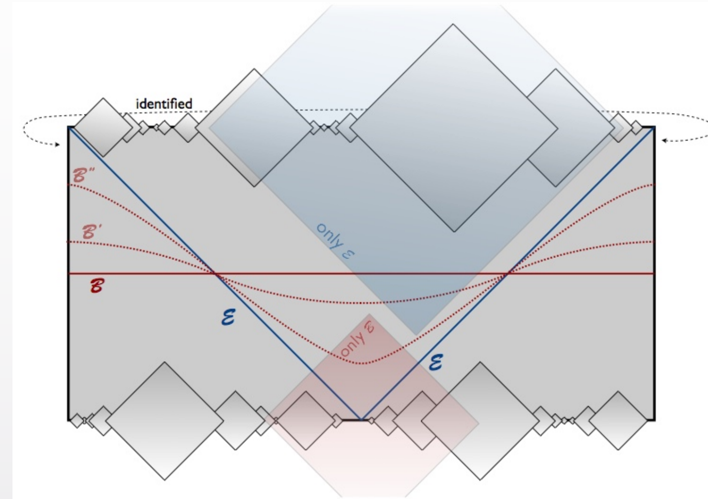
eternal inflation

Option Two:

An eternal universe.
The Big Bang is
just a phase.

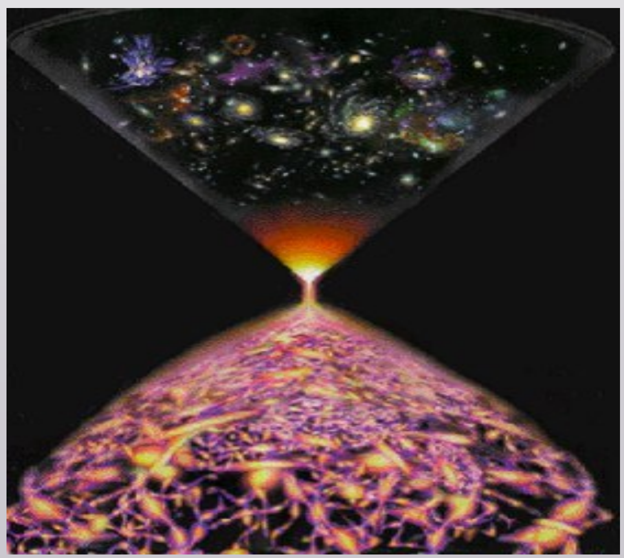


cycles

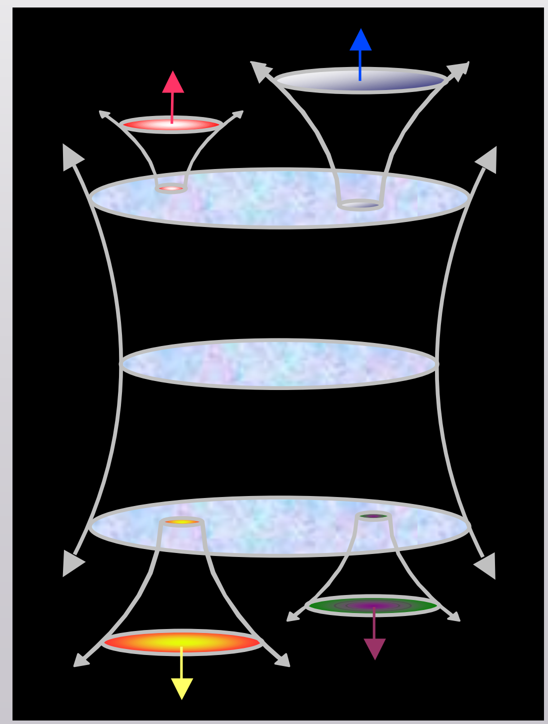


symmetric inflation

Can low-entropy
conditions arise
via dynamics?

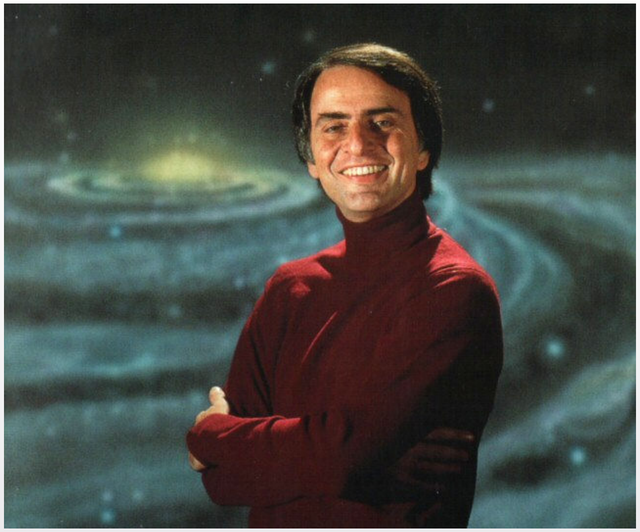


stringy bounce



baby universes

Carl Sagan: "In order to make an apple pie, you must first invent the universe."



We want that to be true.

Need to build a cosmology in which it is so.