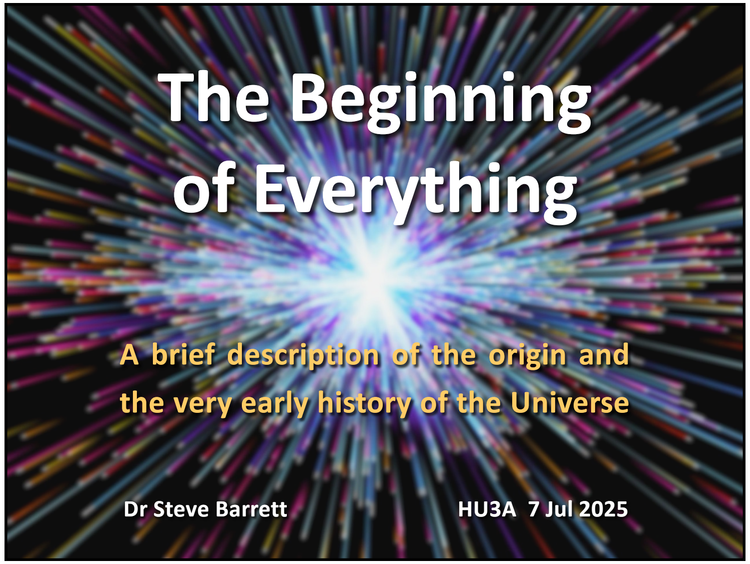

The Beginning of Everything

What am I talking about?	Creation of the Universe
When did it happen?	13.8 billion years ago
How long did it take?	About three minutes
Where did it happen?	Everywhere
Why did it evolve the way it did?	Laws of Physics
How do we know all this?	Laws of Physics

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Rules of the Game

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Snapshot of a Galaxy

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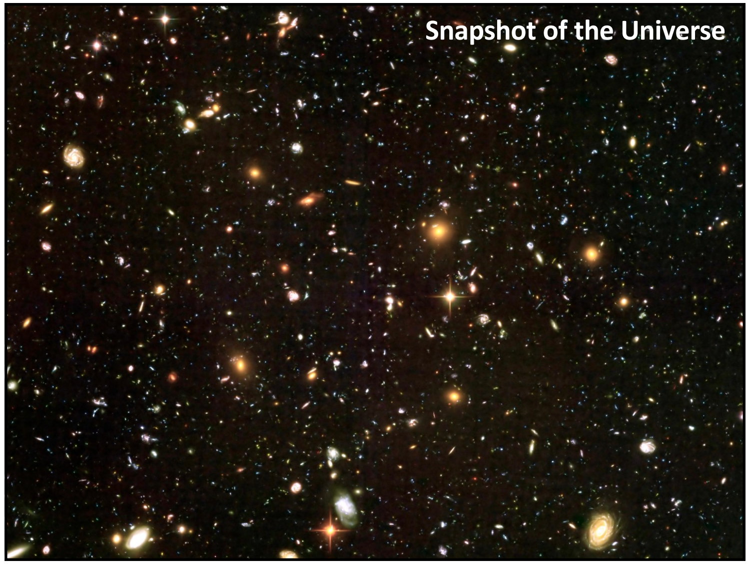
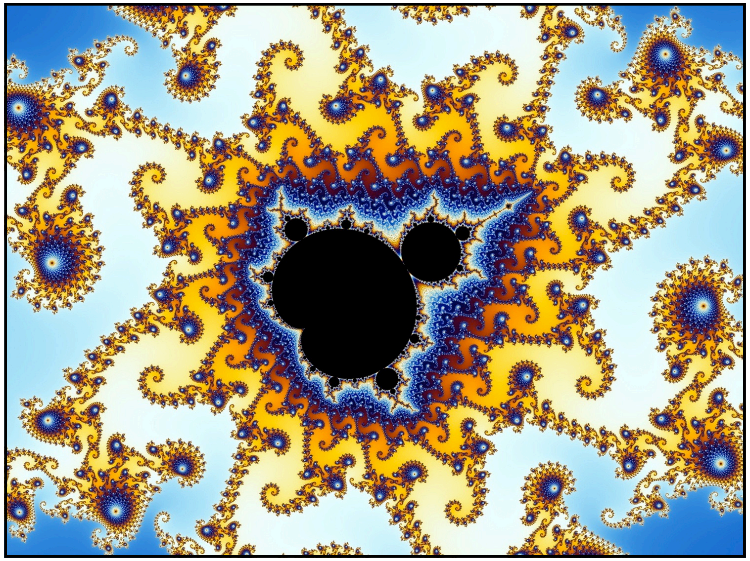
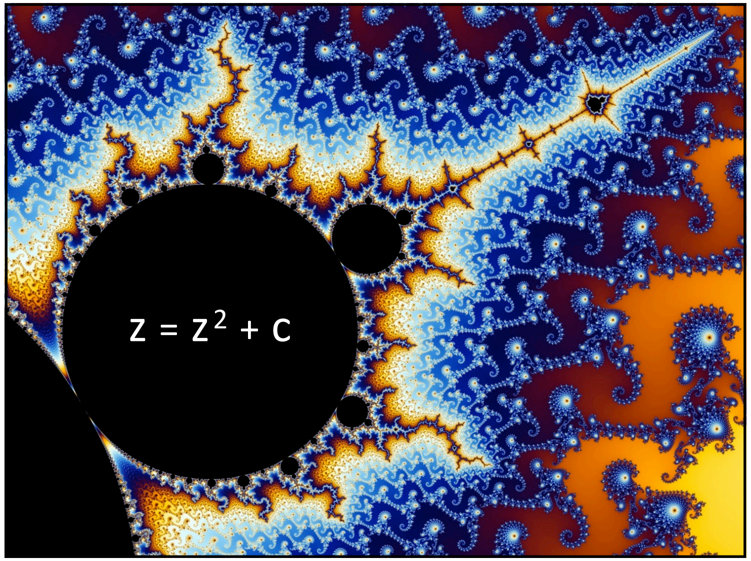
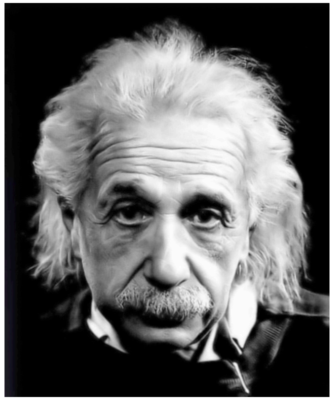
The Beginning of Everything







Complex Does Not Mean Incomprehensible



" The most incomprehensible thing about the world is that it is comprehensible "

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Flow of Thought

Observation	Galaxies are moving away from each other
Conclusion	The Universe is expanding
Observation	Particle physics experiments (such as the LHC)
Assumption	Laws of physics (here) = laws of physics (there) Laws of physics (now) = laws of physics (then)
Conclusion	The Universe was created in a very hot dense state 13.8 billion years ago and has been expanding and cooling ever since
Big Question	Where did all the matter we see today come from?

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How Far Back?

How far back can we go (before we give up on the laws of physics)?

The first year of the 13.8 billion year history?

The first day? The first hour? The first minute? The first second?

The first ms? The first µs? The first ns? The first ps?

Before the first picosecond, we are on slightly shakey ground.

Everything after that is relatively well understood.

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Contents

- Introduction
- A few basic ideas
- The first fraction of a second
- The first few seconds
- The first few minutes
- The next 380,000 years
- The next 13.8 billion years (in brief)

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The Beginning of Everything

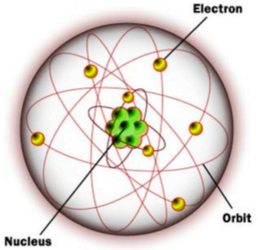
A Few Basic Ideas

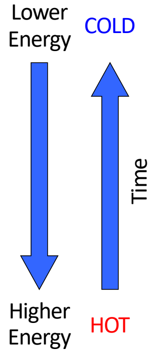
We are made of atoms

atom = nucleus + electrons

nucleus = protons + neutrons

proton = 3 quarks





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t = 0

What happened at the instant of t = 0?

Science cannot provide a definitive answer.

Maybe it was a 'quantum fluctuation' in which energy, and hence matter ($E = mc^2$), is borrowed from nothing. This sounds weird, but quantum mechanics ***is*** weird.*

How big can the fluctuation be? Energy x time has an upper limit.

You can borrow a lot of energy for a short time, or *vice versa*.

The total energy in the universe might be zero and so the time period we are given to 'pay back the loan' might be infinite.

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* See "The Weird World of the Very Very Small"

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t > 0

t ≈ 0.0000000000000000000000000000000001 s

At the unimaginably early time of 10^{-35} seconds after its creation, the Universe has expanded to the size of a golf ball.

Just like a golf ball, the Universe is not perfectly smooth, but has 'dimples' in it.

Eventually, when the Universe is much, much bigger, these dimples will give rise to variations in the density of matter spread across the Universe. These will result in the formation of large-scale structures such as clusters of galaxies.

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The First Picosecond

t ≈ 0.000000000001 s

One picosecond (10^{-12} seconds) after its creation, the Universe has expanded to the size of the Solar System — which, of course, does not yet exist.

The temperature has fallen to $T \approx 10^{15}$ K and the energy of each of the constituents of the quark soup is ≈ the energy of the LHC.

Because we can test our ideas in an accelerator, from this point on we have a reasonably good idea of how the Universe evolved.

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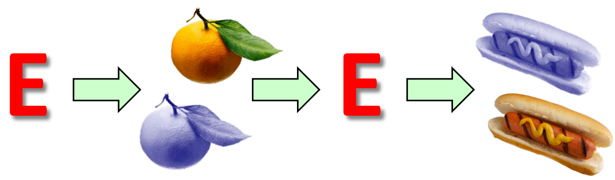
Matter and Antimatter

t ≈ 0.000000000001 s

Energy and matter were continually exchanging back and forth.

Matter and antimatter were originally made in equal amounts.



Somehow, matter gained a very small excess over antimatter.

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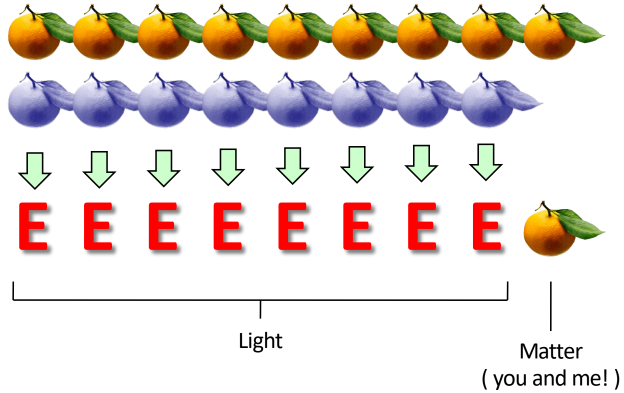
Matter and Antimatter

t ≈ 0.000000000001 s



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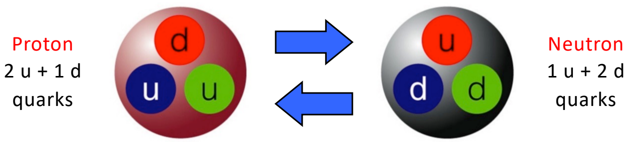
The First Millisecond

t ≈ 0.001 s

Matter and antimatter continue to pop in to and out of existence.

Protons and neutrons, both made from three constituent quarks, are continually transforming into each other.



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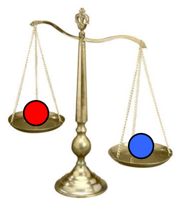
The First Few Seconds

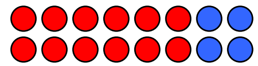
t ≈ 1 s

The Universe has cooled to T ≈ 1 billion K.

It is now too cold for protons and neutrons to readily swap back and forth. Protons are a little lighter than neutrons (by ~ 0.1 %) ...



... and so protons outnumber neutrons in the ratio 75 : 25.



(Nature always favours the lower energy)

(or the lower mass)

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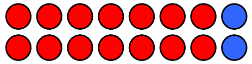
The First Few Minutes

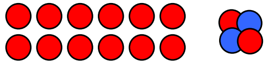
t ≈ 100 s

Neutrons are unstable and some decay into protons.

The ratio of protons : neutrons is now ≈ 14 : 2



The Universe has cooled to T ≈ 100 million K. Nuclei can now form.



12 nuclei of H + 1 nucleus of He

After 3 minutes, the relative abundance of H and He is determined.

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The Next 380,000 Years

Nothing (much) happens for the next third of a million years.
The Universe continues to expand and cool.

Eventually the Universe cools to T ≈ 3000 K.

At this temperature nuclei can hang on to electrons and so atoms can exist for the first time. The Universe changes from an ionised plasma to a collection of atoms. It becomes transparent to light.

Light that was, until this point, 'trapped' inside the plasma is now free to fly around the Universe. We see this light today, but much stretched out by the subsequent expansion of the Universe.

The wavelength of the light is now 1000 x longer — microwaves.

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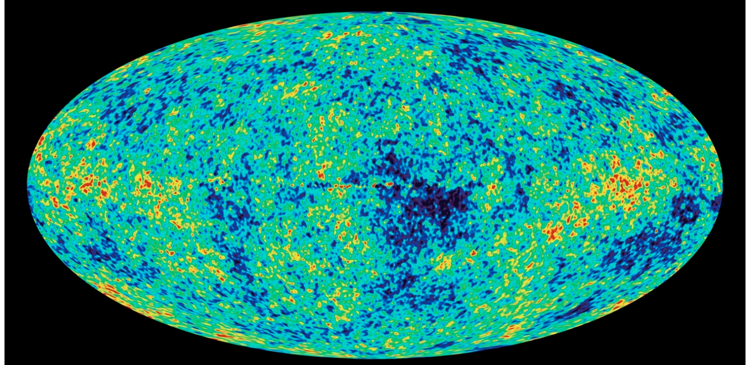
Cosmic Microwave Background



red = higher intensity

blue = lower intensity

Cosmic Microwave Background

The cosmic microwave background (CMB) that we observe today is approximately the same intensity in all directions, but is not perfectly smooth.

The small variations in intensity seen in the all-sky map are the result of the 'dimples' in the cosmic golf ball.

Satellites are being used to study the CMB to greater precision to improve our understanding of the very early Universe.

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Cosmic Web

The 'dimples' in the cosmic golf ball gave rise to the variations in the CMB …

… and over billions of years collapsed into a cosmic web of filaments and voids.

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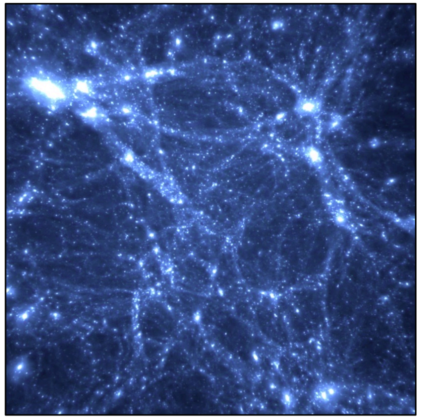
Cosmic Web

The 'dimples' in the cosmic golf ball gave rise to the variations in the CMB …



… and over billions of years collapsed into a cosmic web of filaments and voids.

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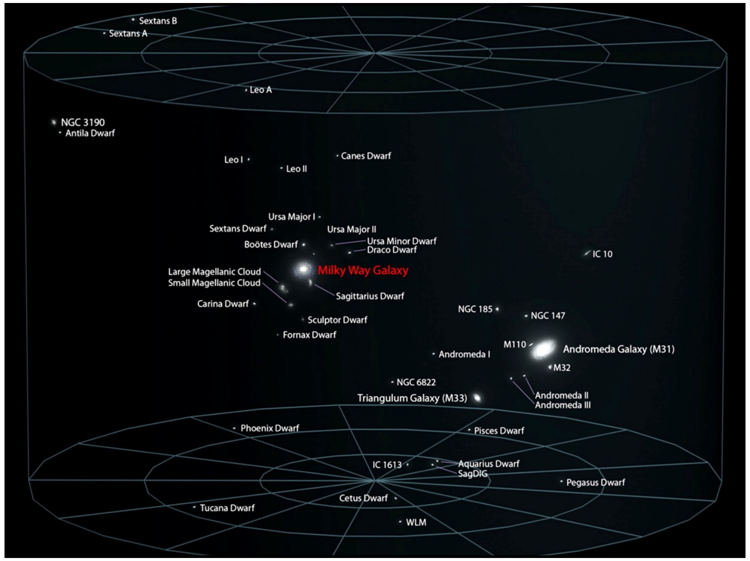
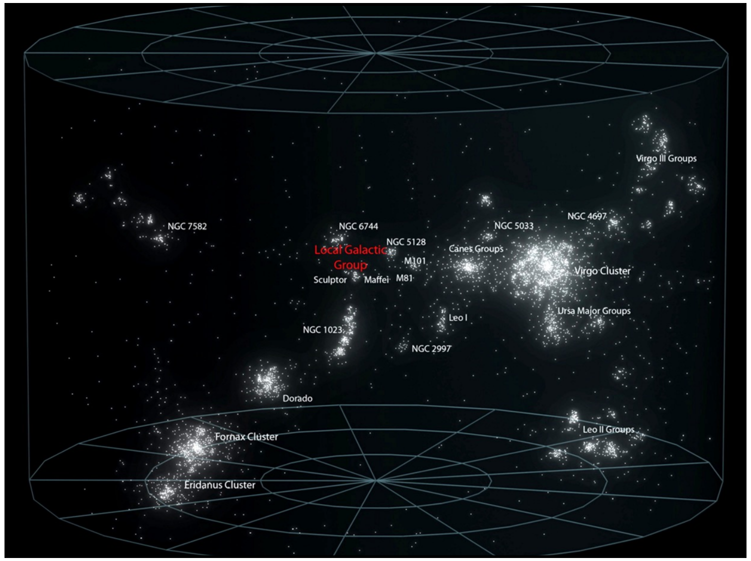
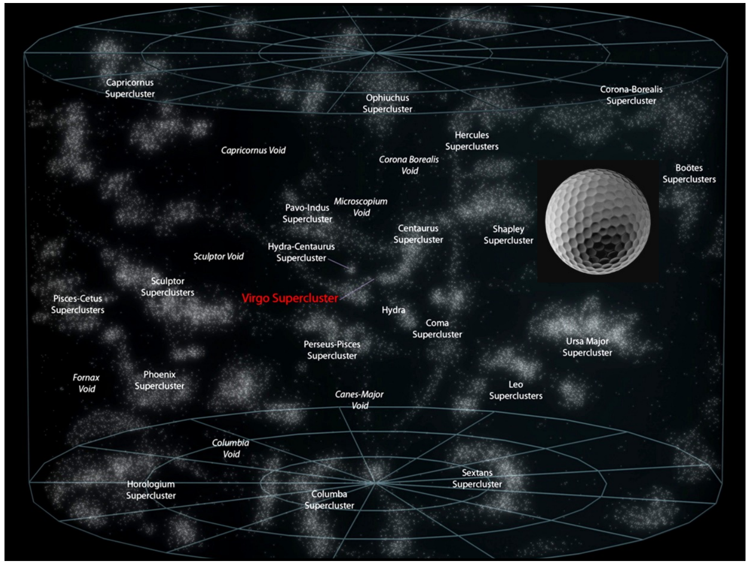
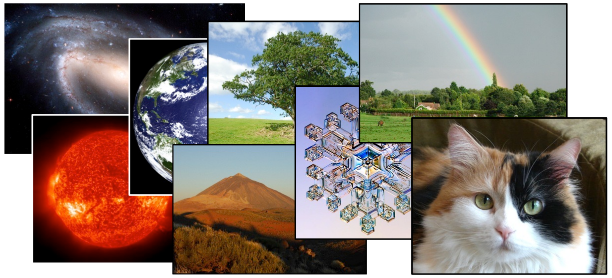






The Next 13.8 Billion Years

Now that we have hydrogen atoms we can understand …



There are still some details of cosmic evolution to be worked out, but you get the basic idea.

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There Are Still Some Gaps

The jigsaw is still not complete. The remaining questions are:

Why did Matter win over Antimatter? (what caused the asymmetry?)

What is Dark Matter? (causing galaxies to rotate at the 'wrong' speed)

What is Dark Energy? (causing the Universe to *accelerate* its expansion)

This talk is titled 'The Beginning of Everything' but all the ordinary matter in the Universe accounts for only 5% of the total.

The other 95% is still a bit of a mystery. But that's another story…

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