# The Beginning of Everything

A brief description of the origin and the very early history of the Universe

Dr Steve Barrett  SCAS  17 Oct 2019

## Nature

<table>
<thead>
<tr>
<th>Nature is not repetitive</th>
<th>(If it was, it would be boring)</th>
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<tbody>
<tr>
<td>Nature is not unpredictable</td>
<td>(If it was, it would be impossible to make sense of the world)</td>
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Hence, Nature is interesting

How does Nature work? What are the **Rules of the Game?**
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Complex ≠ Incomprehensible

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

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 billion years of the 13.8 billion year history?
The first million years? The first thousand years? The first year?
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 shaky ground. Everything after that is relatively well understood.

Contents

- Introduction
- A few basic ideas
- The first fraction of a second
- The first few seconds
- The first few minutes
- The next 377,000 years
- The next 13.8 billion years (in brief)

A Few Basic Ideas

We are made of atoms
atom = nucleus + electrons
nucleus = protons + neutrons
proton = 3 quarks

Time
Lower Energy COLD
Higher Energy HOT

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 $\times$ 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.

* See "The Weird World of the Very Very Small"
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$t > 0$

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.

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 $T = 10^{15} K$ and the energy of each of the constituents of the quark soup is $\sim$ 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.

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.

Matter and Antimatter

$t = 0.000000000001 s$

Energy ($E$), Light (downward arrows), Matter (you and me!)
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The First Millisecond

\( t = 0.001 \text{ s} \)

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

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

Proton: \( 2 \ u + 1 \ d \) quarks

Neutron: \( 1 \ u + 2 \ d \) quarks

The First Few Seconds

\( t = 1 \text{ s} \)

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 \( \sim 0.1 \% \)) ...

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

(Nature always favours the lower energy)

(or the lower mass)

The Next 377,000 Years

\( t = 100 \text{ s} \)

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

Eventually the Universe cools to \( T = 3000 \text{ K} \).

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**

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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**Local Group**

**Virgo Supercluster**
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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.

Questions

The jigsaw is still not complete. (We have found the corners, the edges and most of the landscape, but there are still pieces of sky missing.) 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 entitled 'The Beginning of Everything' but all the ordinary matter in the Universe accounts for only 4% of the total.

The other 96% is still a bit of a mystery. But that's another story...