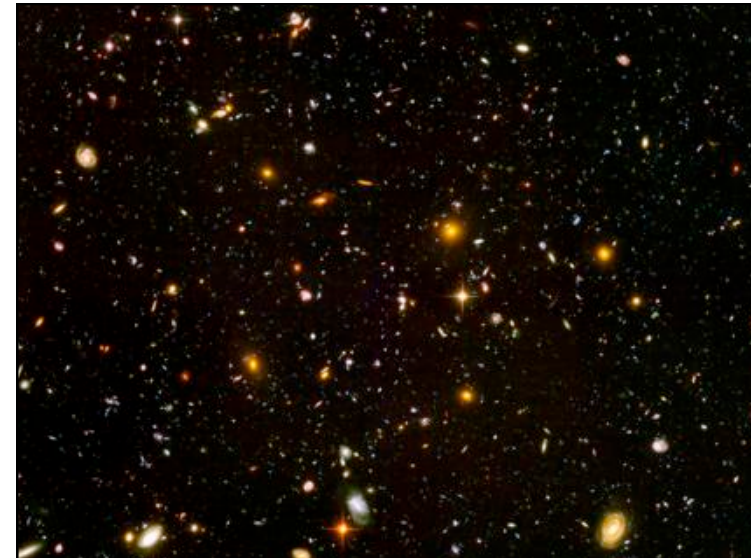
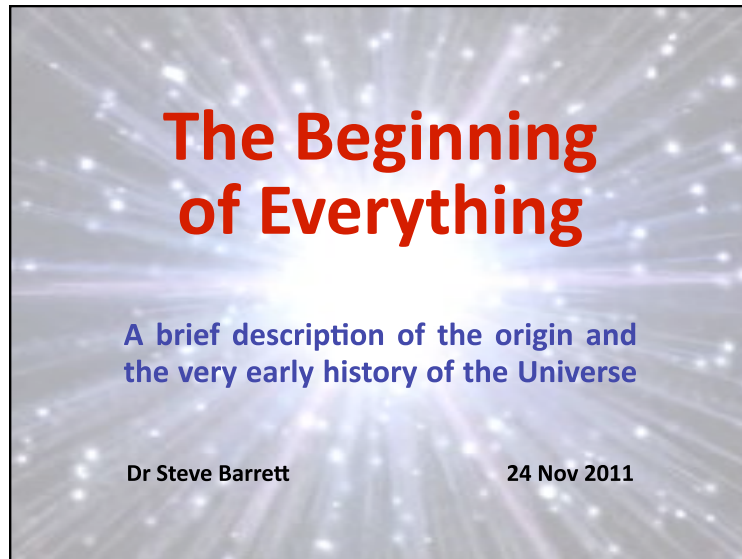


The Beginning of Everything



The Beginning of Everything

What am I talking about?	Creation of the Universe
When did it happen?	13.7 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

The Beginning of Everything / Introduction 3

How Stars Tick

The life of a star...

Hydrogen Cloud → Now → Red Giant → White Dwarf

Timeline: 0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28 Billions of years

Big Bang at 0, Now at 13.7

...but where did all the hydrogen come from?

The Beginning of Everything / Introduction 4

The Beginning of Everything

Nature

Nature is not
repetitive

(If it was, it would be boring)

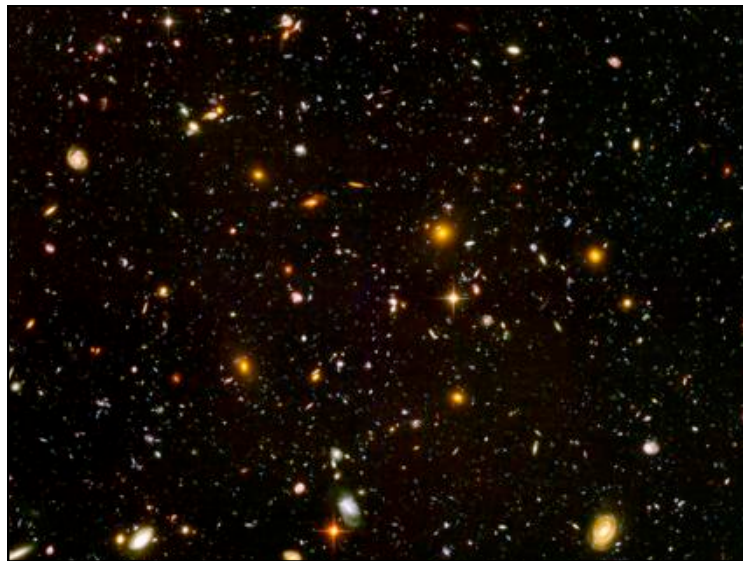
Nature is not
unpredictable

(If it was, it would be impossible
to make sense of the world)

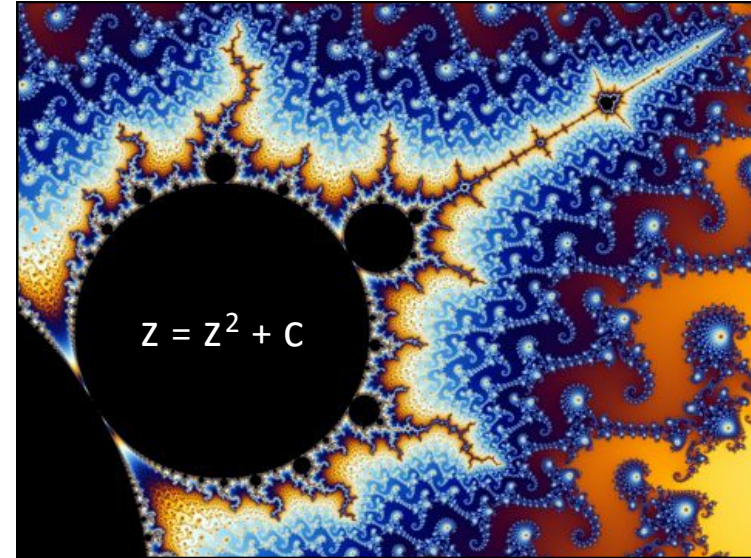
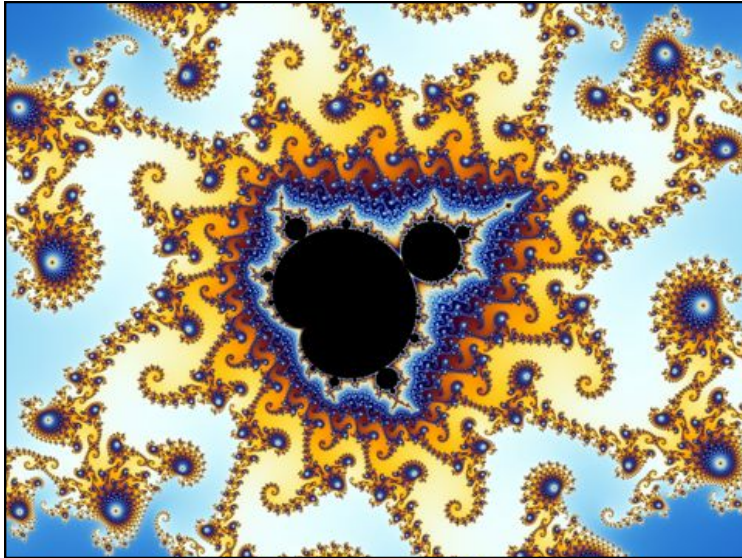
Hence, Nature is
interesting

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

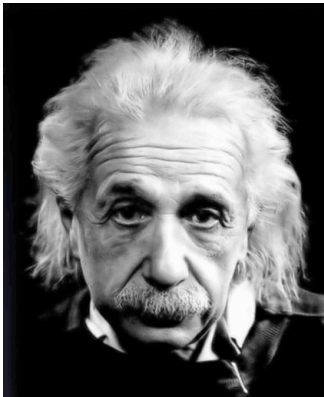
Rules of the Game



The Beginning of Everything



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** Universe is expanding
- Observation** Particle physics experiments (such as the LHC)
- Assumption** Laws of physics (today) = laws of physics (always)
- Conclusion** The Universe was created in a very hot dense state 13.7 billion years ago and has been expanding and cooling ever since
- Big Question** Where did all the matter we see today come from?

The Beginning of Everything

How Far Back?

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

The first billion years of the 13.7 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're on slightly shakey ground.

Everything after that is relatively well understood.

Contents

- Introduction
- $t = 0$
- 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 13.7 billion years (in brief)

$t = 0$



What would you see if you walked to the South Pole and then kept walking South?

What would you see?

You are asking the wrong question!

Is it possible to walk to the South Pole and then keep walking South? No.

$t = 0$

What happened **before** the Big Bang?

What if you went back in time to $t = 0$, and then kept going to earlier times?

You are asking the wrong question!

Time started at the Big Bang, therefore there was no 'before'.

It is similar to the question 'What would the Universe look like if you were to step outside it and look back at it?'.

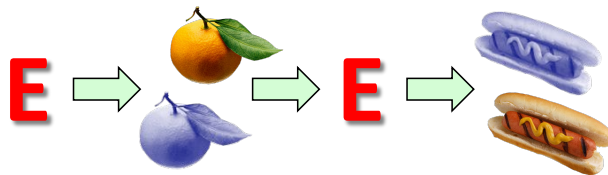
You cannot 'step outside' of space or time.

The Beginning of Everything

Matter and Anti-Matter

$t \approx 0.000000000001 \text{ s}$

Energy and matter were continually exchanging back and forth.
Matter and anti-matter were originally made in equal amounts.

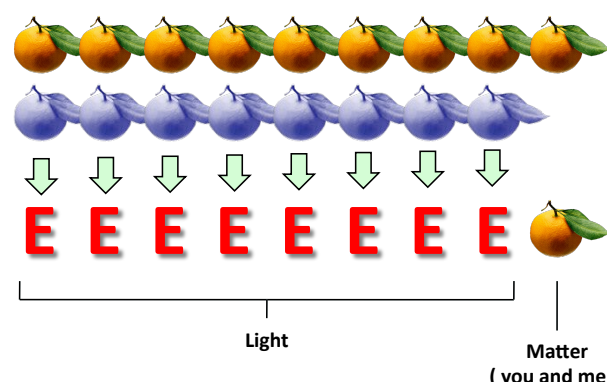


Somehow, matter gained a very small excess over anti-matter.

The Beginning of Everything / Picosecond / Matter and Anti-Matter 21

Matter and Anti-Matter

$t \approx 0.000000000001 \text{ s}$



Light

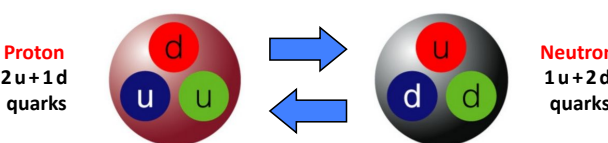
Matter (you and me!)

The Beginning of Everything / Picosecond / Matter and Anti-Matter 22

The First Millisecond

$t \approx 0.001 \text{ s}$

Matter and anti-matter continue to pop in to 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

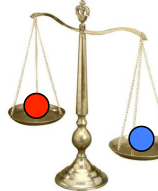
Neutron
1 u + 2 d quarks

The Beginning of Everything / Millisecond 23

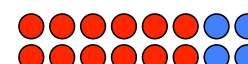
The First Few Seconds

$t \approx 1 \text{ s}$

The Universe has cooled to $T \approx 1 \text{ billion K}$.
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 Beginning of Everything / Seconds 24

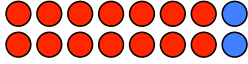
The Beginning of Everything

t ≈ 100 s

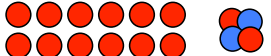
The First Few Minutes

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.

The Beginning of Everything / Minutes 25

The Next 377,000 Years

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

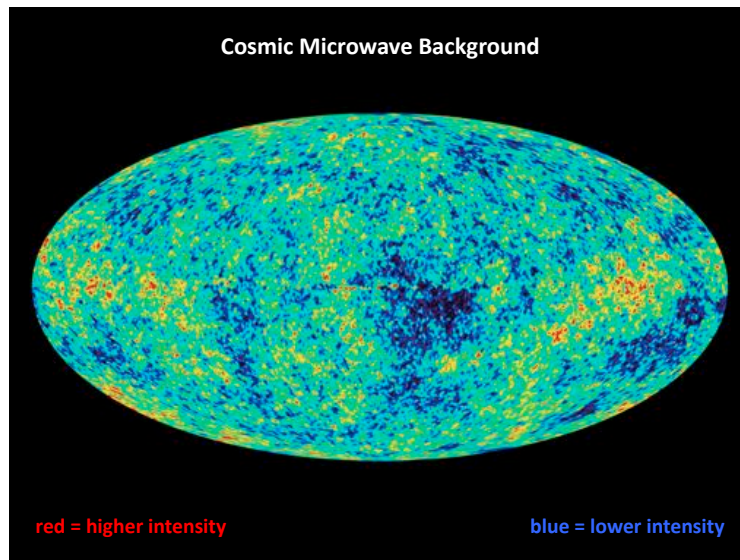
Eventually the Universe cools to T = 3000 K.

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 very much stretched out by the subsequent expansion of the Universe.

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

The Beginning of Everything / Next 377,000 Years 26



Cosmic Microwave Background

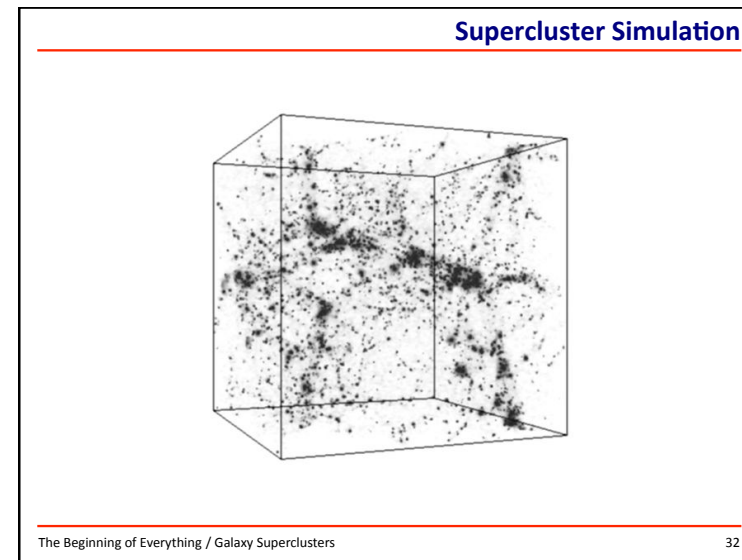
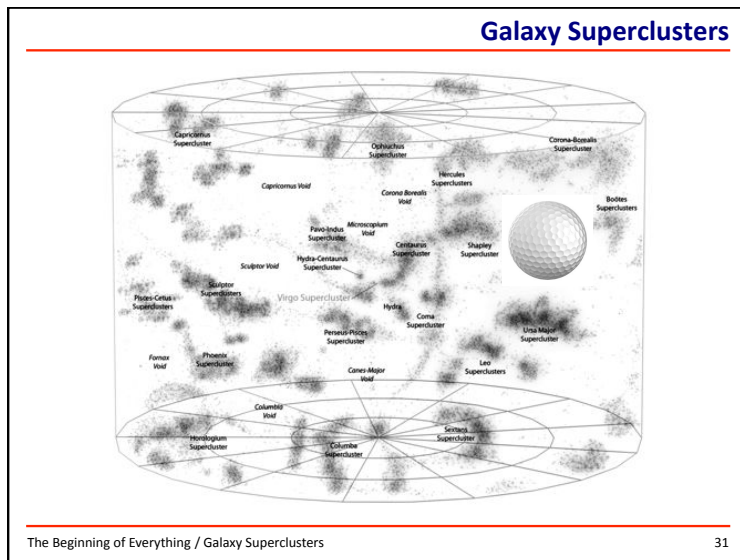
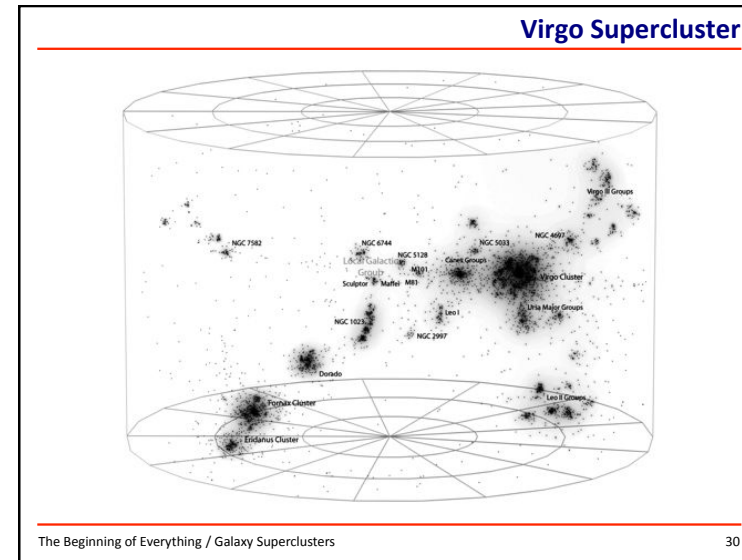
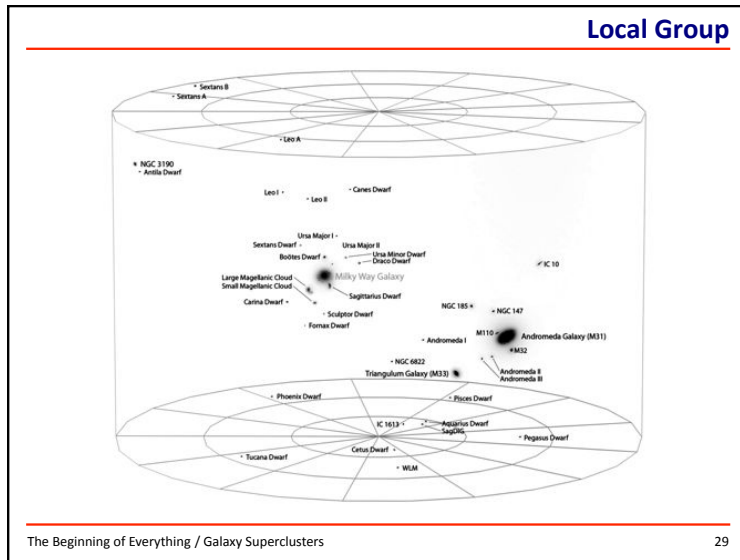
The cosmic microwave background (CMB) that we observe today is approximately the same intensity in all directions, but is not perfectly smooth.

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.

The Beginning of Everything / Cosmic Microwave Background 28

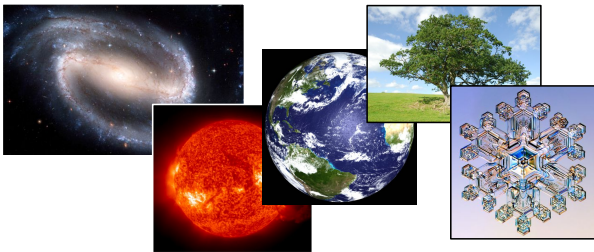
The Beginning of Everything



The Beginning of Everything

The Next 13.7 Billion Years

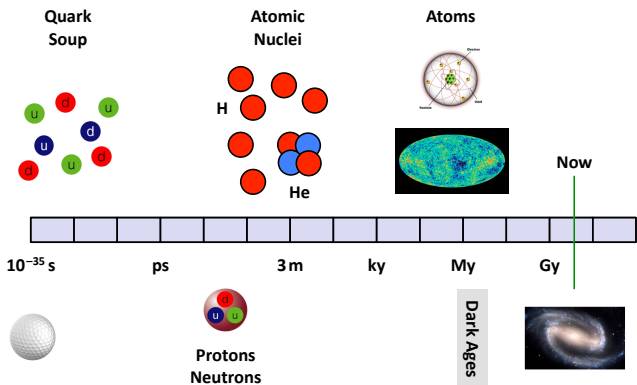
Now that we have hydrogen atoms we can understand...



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

The Beginning of Everything / Next 13.7 Billion Years 33

Time Line



Quark Soup

Atomic Nuclei

Atoms

Now

10⁻³⁵ s ps 3 m ky My Gy

Protons Neutrons

Dark Ages

The Beginning of Everything / Time Line 34

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 **Anti-matter**? (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 4% of the total.

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

The Beginning of Everything / Questions 35

The Beginning of Everything

<http://www.liv.ac.uk/~sdb/Talks>

Dr Steve Barrett 24 Nov 2011