GRESHAM

COLLEGE

JOURNEY TO THE ANTIWORLD

Lecture 1

A GIANT LEaP

by

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A Giant LEaP
(from Big Bang to Big Ben)

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A time machine has been at work at CERN Geneva for the last ten years. This month it makes its final experiments. In this lecture we travel to the first split second after the Big bang at the start of the universe and see how matter was born.

Take a deep breath, you have just breathed oxygen atoms that are 5 billion years old - that's as old as the Earth, one third the age of the Universe. In a glass of water there is stuff that is even more ancient. Water is H2O - O is oxygen and the H represents hydrogen - hydrogen is almost as old as the universe itself.

There is still some uncertainty about the exact time since the Big Bang – 12 to 15 billion (thousand million) years is the number. It is hard to realise what this means. Imagine that a billion years is represented by an hour of real time and that Creation was at 23.00 last night, around bedtime. So if the universe were say 15 billion years old, the end of this lunchtime session at 14.00 will represent "now". Recall what has happened since 23.00. You were fast asleep, I hope, until breakfast time: during that time there was no Sun nor Earth. Hydrogen had been burning inside stars, cooking heavier elements, such as carbon, oxygen, iron and gold. Around 9 o'clock one of those stars exploded, spewing a whole Mendeleevian periodic table of the elements into the cosmos. It was around this time that our solar system formed, and those elements are now you, me and everything that we see around us. So we are stardust, or if you are less romantic, nuclear waste products. But that story is for another occasion. Move on to 13.00; "now" in effect. Primitive life forms exist but it will not be until 13.30 that the oldest fossils (500 million years in real time) will appear. Humans: we only come on the scene during that last half a minute, and all of recorded history is within the time it takes Big Ben to strike two. So there is the life of the universe from Big Ben back to the Big Bang.

One of the nice features of becoming a Gresham professor is that people whom one might otherwise never have met come into contact with you. Thus it was that Jonathan Charkham, author of *Conversations with a Silent Friend,* directed my attention to a question that he had posed therein. In a nutshell: why, because we are born and have a finite existence, do we impose such ideas on the universe? What evidence is there that the universe erupted out of nothing and has not always been in existence?

It is questions such as these that I hope to address during my tenure. The short answer is that we do not actually know whether there was anything before the Big Bang. What I will do today is tell you something about an experiment that has been running for ten years and shows what the universe was like within a split second after what we call "The Big Bang". By 2003, in my final year, we may know more, but this is the best we have at present.

A key discovery was in 1927-9 when Edwin Hubble, the American astronomer, discovered that the universe is expanding - the galaxies are rushing apart from one another. If you imagine playing the film backwards, then in the past the universe must have been much denser than it is now. 15 billion years ago its density was in some sense infinite: it is the out-rushing from that state that we call the Big Bang.

And it was a hot Big Bang. If you are of the generation that pumped up bicycle tyres you will recall how hot the valve became as you compressed the air into it. Now imagine compressing the entire universe into such a volume - or even less! From the temperature of the microwave background radiation (more in another lecture) which is 3 degrees K (Kelvin = above absolute zero) one can calculate back and determine the temperature of the universe at various times as it expanded from that initial explosion.

At this point people often ask where is the centre of the universe, that is to say, where did the Big Bang happen? I even was once asked a more bizarre, related, question: why didn't the Big Bang happen sooner? These questions are based on an incorrect mental image of the Big Bang, in which it has been viewed as an explosion taking place in some pre-existing space and time. However, that is not what it was like. Space and time, as we understand them, were created with the Big Bang.

How might we travel to the Big Bang?

Alan Parsons used me on a record called the Time Machine. My narration was as follows:

> When you look out into the night sky, and you see the stars far away, you're seeing them because of light that has travelled from them to you. But it takes time for light to travel from there to here. So what were doing is seeing the stars as they were in the past, in the amount of time it has taken for the light to reach us. The further and further away the stars are, the further back in time we're looking.
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> Now we're seeing a star that, let's say, is 6000 years ago. Imagine someone on that star looking at us. They would be seeing us as we were 6000 years ago.
>
> Which of those two is "now"?
>
> So space and time are linked together. We are looking across the space, we are looking back in time.

With the Hubble space telescope we can look back billions of years. But we cannot look into the Big Bang: it was hotter than the Sun and we can no more look into the Sun with our eyes than we can into the Big Bang. (There are ways of looking into the Sun and we shall meet those next season.) But we can do so in other ways and that is where my main expertise - the field of high energy particle physics - comes to our aid.

To learn what the something is made of, we can look at it, we can heat it or we can smash it to bits. All of these are related in that each, in their different ways, is using energy (of which more in another talk). Smashing things is exciting and that is what high energy physics experiments do. The basic idea is to accelerate electrically charged particles (electrons or protons, the basic particles of all atomic elements, are the most common) by means of electric forces. An electron, when attracted to the positive terminal of a one volt battery, will speed up and gain an energy of about 10^{-19} joules (that is one divided by 1 followed by 19 zeros; an unimaginably small number). This is a trifling amount and physicists find it easier to give it a name: one electron volt or 1eV - the energy an electron gets when accelerated by one volt. At Stanford in California they have a 2 mile long accelerator capable of accelerating electrons through a potential of 30 billion volts (the energy of each electron is thus 30 billion eV, or "giga" eV, shortened to GeV).

Now we high energy physicists insist that this is a lot; yet when you strike a match, or eat a sandwich, the energy released in joules, is vastly more than this. What is going on? The answer is that when you eat, or are burning a candle, lots of atoms are working together - typically a million million million million. The energy produced by each individual atom is trifling. Contrast this with Stanford where each individual electron is packing 30GeV. And at CERN we can do even better.

A limit on how much energy you can give to an electron is determined by how long an accelerator you build - and two miles in a straight line is already needing special real estate. Building accelerators for miles in a straight line has obvious problems. So a trick is to use electric fields to speed the particles, and magnets to turn them around corners. This way you make a circular accelerator and the electrons can swing round and round. At CERN they go round 11000 times every second and reach an energy of around 100GeV.

At CERN they do even more. In addition to sending electrons round the ring in one direction they send "positrons" (antimatter versions of electrons) round it in the opposite direction. (What antimatter is will be the theme of two more talks this season; for today all we need to know is that positrons have the same mass, shape, size and amount of electrical charge as electrons, but their charge is positive whereas the electron is negative. And, as in Star Trek, when matter and antimatter meet, they mutually annihilate into a flash of energy such as light).

The accelerator is known as LEP - "Large Electron Positron" collider. You can find images of LEP on the web at http://outreach.cern.ch/public (exact URLs and links will be provided and stored on the Gresham website later).

You can also read more about LEP, without any maths, in my new book *Lucifers Legacy - the meaning of asymmetry* (Oxford University Press), chapter 11.

The two beams are like swarms of bees - fairly diffuse. At four points around the circuit the two counter-rotating beams pass through one another, and most of their particles miss and travel round again and again, 11000 times a second. A head on collision between a random one of the billions of electrons and one of the positrons happens several times a second. The electron and positron mutually annihilate into pure energy, a flash of light. In that instant, in a region smaller than an atom's size, the energy is similar to the ambient conditions of the universe when it was less than a billionth of a second old.

Special cameras - "detectors" - record what happens. By simulating these conditions of the early universe we are able to infer what physical processes were taking place then. We see energy turning into matter - Einstein's E=mc2 at work. So we are seeing how the basic seeds of matter emerged from the energy in the hot Big Bang.

I will show a cartoon of matter today - the atom made of electrons encircling a central nucleus whose ultimate seeds are the "quarks". As far as we know electrons and quarks are the smallest pieces of matter. They are analogous to the basic letters of Nature's alphabet., from which all the words (atoms and molecules) are constructed. The fundamental forces - gravity, electromagnetic force, and two that act over exceedingly small distances, known as the weak and strong forces - are like the grammar that glue those words together to form acceptable literature (the material structures of "life the universe and everything"). In the talk we shall see that Nature has not only given us enough to make matter as we know it, but for some reason has tripled them. In the jargon, there are "three generations" of matter: grandparents, parents and children if you like. All three generations were created in harmony at the Big Bang but the first two rapidly died out leaving their progeny, the "children", as the surviving seeds of matter today.

Why did Nature do this? You may well ask. In later talks this season we shall speculate on why it is like this, but for today we will consider the fortunate "accidents" in the masses and properties of these fundamental building bricks that have enabled life to emerge. And I shall briefly introduce the "Higgs" particle that is hypothesised to be the giver of mass. For as LEP comes to the end of its life, and I was preparing this talk, a tantalising possibility has emerged. Scientists working at LEP may have glimpsed the Higgs - the holy grail of high energy physics (of which more next season). As a result, the decision has been taken to give LEP an extra month of life (it will run until Nov 2 rather than closing at the start of October as had been the original plan. They hope that this extra amount of time for experiments will be enough to tell whether the Higgs has been discovered. Whatever the outcome, I will talk more about this next season.

For further reading about this today, see my article in The Guardian, Thursday September 21.

GRESHAM COLLEGE

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- to foster academic consideration of contemporary problems;
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