Science for Everyone

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1.1 Cosmic inflation and the Big Bang

We can't build a space ship that goes backwards in time or faster than light. But let us imagine we have such a spacetime ship. It can take us to any place and to any time. It moves faster than light. It moves at the speed of thought.

We don't need to worry about heat or radiation or pressure or space junk or meteors or stars or black holes. Nothing outside our ship can hurt us. Our spacetime ship protects us from everything. We can go backwards in time in our spacetime ship, but we can't change anything outside the ship.

We can go back to 1982, but we can't get out and buy Apple at less that $ 0.25. We can go back to 1963, but we can't get out and stop the assassination of John F. Kennedy. We can go back to 1865, but we can't save Lincoln. We can go back to 33, but we can't save Jesus. We can look out the windows of our ship, but we can't touch anything.

We get in our spacetime ship, fasten our seat belts, and go backwards in time. We go back many thousands of years, back before people invented science or law or money or writing or religion or tools or languages. We go back millions of years, before some lucky apes evolved into human beings. We go back more than five thousand million years, back before our Sun, our planet Earth, and our solar system condensed out of the ashes of exploded stars. We go all the way back before the universe flashed into existence in the Big Bang nearly 14 thousand million years ago.

We look out the windows of our spacetime ship and see absolutely nothing. It's dark, cold, flat, and empty. Quantum mechanics tells us that everything fluctuates. So there must be fluctuations, but they are too tiny to see with the unaided eye. The energy of each tiny spot of space rises and falls randomly. The smaller the spot, the bigger the fluctuations. We would have to wait a long time for any spot to vary by a large amount. Our pilot knows when and where that will happen. We go to that spot at that time and wait for the energy of the spot to jump. We don't know how big the spot is. It may be as big as a blueberry or much smaller than an atom. We know the energy of the spot will jump to a very high value, but we don't know how high.

Our spacetime ship has telescopes through which we can see the tiny quantum fluctuations of energy. They look like fireflies on a warm dark night. They flicker for a moment and then go dark.

As we look through our telescopes, we see one spot expand in a blinding flash of white light as its energy jumps to a value that is absurdly high. Ordinary physics would require the energy of the spot to go right back to its normal value of zero very quickly. Big fluctuations tend to be brief. But gravity grabs the energy of the spot and slows its return to zero. Gravity also expands the spot. Right before our eyes, gravity stretches the tiny spot in less than a thousandth of a millionth of a second (a nanosecond) to a sphere more than 100 million km in radius. This is cosmic **inflation**.

After less than a nanosecond, gravity releases the energy of the spot as radiation. This is the **Big Bang**. Our universe suddenly becomes so hot that we don't know how to describe it. Luckily our spacetime ship is well air-conditioned with walls that protect us from the intense radiation.

We've just seen our universe burst into existence out of a quantum fluctuation in a tiny spot. How did it happen? Where did all the energy come from? The answer once again is gravity. As the energy of the spot increased, the negative energy of gravity also increased. So the total energy of the universe stayed the same.

1.1.1 A second look

To find out more about what just happened, we ask our pilot to turn our spacetime ship around and to take us back for a second look. We go backwards in time again, back before the tiny spot flashed white.

Our spacetime ship has smaller spacetime ships inside it. These are our scout ships. Mia and Dylan get in one scout ship. James and Christopher get in the other. Their ships hover near the mother ship. We shrink all three ships so they fit inside the spot that soon will fluctuate to an absurdly high energy density, expand, and then release its energy as the radiation of the Big Bang. We wait. Space remains dark and empty.

All three ships are inside the special spot. Its energy fluctuates to a huge value. Within a nanosecond, the space between the ships expands to more than 100 million miles. Gravity releases the energy of the spot. Incredibly bright light surrounds our three ships.

We expand our spacetime ships to their normal sizes. Their walls protect us from the radiation, but we have lost contact with the crews in the two scout ships. We don't use ordinary radios because radio waves can't pass through the intense radiation outside the ships. We use beams of neutrinos and gravitons which can because they don't feel the radiation. After a quarter of an hour, we get a signal from the ship that Mia and Dylan are flying. That's the time it takes for the neutrinos and gravitons to get from their ship to ours. We still haven't heard from James and Christopher's ship.

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Our spacetime ships have special sensors that can detect energy remotely. They also can detect fields like the electric field, which pushes charges, and the gravitational field, which shoves masses. As we wait to watch the birth of the universe a second time, we point the sensors at the tiny spot. Space remains dark and empty.

Suddenly the sensors detect a huge increase in the energy of the spot. An unknown field has jumped to an absurd value that makes the energy of the spot huge. At the same time, the gravitational energy of the spot becomes negative, hugely negative. The total energy of the tiny spot remains tiny because negative gravitational energy cancels the positive energy of the spot. This cancellation persists as gravity holds the field at its huge value and expands the spot to a sphere that is bigger than our solar system in less than a billionth of a second. The mysterious positive energy of the spot now is enormous, as is its equally enormous negative gravitational energy.

1.2 The Big Bang

As gravity lets the unknown field fall back to its natural value, the enormous positive energy of the field is released as radiation. We see the Big Bang for a second time.

The walls and windows of our spacetime ship protect us from this radiation, but our ship is filled with bright white light. We look outside and see intense light without any pattern, the same in all directions. The universe will remain filled with hot white featureless light for another 380 thousand years.

About a tenth of a nanosecond after the Big Bang, the universe has cooled to about ten thousand million million degrees, 10^{16} K, which is the highest temperature at which we understand what physics is like. Above that temperature, all elementary particles are, as far as we know, massless.

1.2.1 What the radiation is made of

The radiation outside our spacetime ship is zillions of particles moving at nearly the speed of light (300,000 km per second). We know some of these particles but not all of them and not even most of them. We call the ones we know **bosons** and **fermions**. The light we see is made of bosons called **photons**, and gravity is made of bosons called **gravitons**. Bosons like to stick together; they act like sheep.

Fermions avoid each other. They act like cats. We call the ones we know **leptons** and **quarks**. The one we know best is the **electron**. An electric current in a wire is a zillion electrons moving down the wire. Among the ones we know least, are mysterious particles we call **neutrinos**.

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Below it, they interact enough with the Higgs boson to become massive. The European Center for Nuclear Research (CERN) announced their discovery of the Higgs boson on 4 July 2012. A Higgs boson weighs about as much as an atom of cesium, which has an atomic weight of 132.9.

1.3 The first second

About a tenth of a thousandth of a second later, the temperature has dropped to a million million degrees, 10^{12} K. Below this temperature, gluons can hold quarks together to form protons and neutrons and many other particles.

About a second later, the temperature has dropped to ten thousand million degrees, 10^{10} K, and the universe becomes transparent to neutrinos, which are very light neutral particles. About a thousand million million neutrinos pass through our bodies every second without harming us. There are three kinds of neutrinos.

1.4 The first three minutes

During the next three minutes, some of the protons and neutrons combine to form helium nuclei. After the first three minutes, the most common nucleus in the universe is hydrogen at 74 percent of all ordinary matter, and the second most common element is helium at 24 percent (by weight) of all ordinary matter. Other elements, mostly made later in stars, amount to only 2 percent of ordinary matter.

Most matter doesn't interact much with light and is called **dark matter**. Dark matter makes up about 84 percent of all matter. The atoms we know about make up only 15.7 percent of all matter.