

Tijana Prodanovic

29 years old, born in Novi Sad, Serbia

Place of work: University of Novi Sad, Department of Physics Novi Sad, Serbia

Website: http://cosmicdiary.org/blogs/tijana_prodanovic/



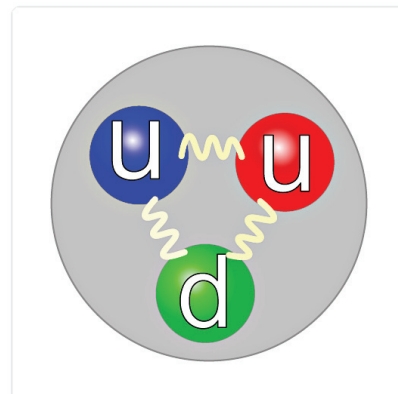
15 May 2009

Tijana's interest in astronomy began at the tender age of ten. Since then she has pursued science as a career, obtaining a PhD in astrophysics. Finding new ways of communicating science to the public ranks highly in her list of interests.

Making chemicals in the Universe is almost like following a recipe, which is the theme of this feature. Condensing quarks, getting the right temperature for protons and then cooking up elements are all studied. Everything has to be just right to get high quality results and the timings have to be spot on, otherwise you may end up with some very unexpected results...

The Great Universal Cookout: The Origin Of Elements

Say you want to make pancakes but are missing all the key ingredients. What do you do? You go grocery shopping of course! But have you ever wondered about those groceries? How did they get there? How were they made? Well, that's one question I think about a lot – how did we get the ingredients for the ingredients? How did we get all the nice chemical elements like H in the H₂O essential for every living thing, like O in the O₂ we breathe, like lithium in our long-lived lithium batteries? And not just that, but also the questions like why is hydrogen so cheap when it's so essential for our survival, and gold so expensive when it's just bling? And I'm not talking about chemistry here. I'm talking about pure and very cool astrophysics at work – the great Universal cookout!

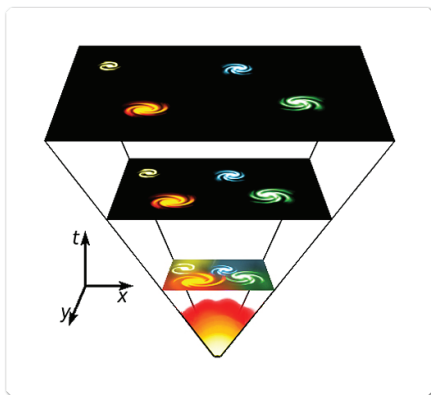


Protons are made from different types of quark.
Image credit: Arpad Horvath.

Recipes for astronomers

There are two main recipes for making chemical elements in the Universe. One can be found in the very beginning, what we call the Big Bang – the birth of our Universe. Some 13 billion years ago, just a tiny fraction of a second after the Big Bang, the Universe was an unpleasant newborn. It was an extremely dense and hot place, worse than the centre of the Sun. But it was growing, fast, and because of that it was cooling, becoming less and less dense. There's much we still don't know about the very first moments, but we believe that it was all just highly concentrated energy mixed with the most fundamental, unsplitable particles, – quarks and leptons.

In a millionth fraction of a second after the Big Bang, quarks started sticking together to make protons – the essence of the most abundant element in the Universe – hydrogen. A proton is a positively charged particle that is a "naked" version of hydrogen, that is, the nucleus of the hydrogen atom, and when you add an electron, an unsplitable, negatively charged particle, and let it bond with this proton, you get a hydrogen atom. Because hydrogen, specifically a single proton is the lightest element of all, it was the simplest and thus the first thing the Universe made in its first second! At that moment the temperature of the Universe was about ten thousand billion degrees Celsius, about a million times hotter than the centre of the Sun! Besides protons, another type of particle was formed from quarks – neutrons. These are very similar to protons but have no charge. The way to then create heavier chemical elements is to fuse them, to build them up, from lighter ones.



The modern Universe's origins can be traced back to the Big Bang, when the first elements were formed.

The perfect temperature

During the first seconds after the Big Bang, the Universe was still too hot for protons to merge to form the next element in line, – helium. As the Universe expanded it cooled until it reached the temperature of about a billion degrees, which was at about one minute after the Big Bang. Though still much hotter than the centre of the Sun, this temperature was perfect for protons and neutrons to start combining together to make heavier stuff. First came deuterium – a heavier version of hydrogen, and then deuterium started sticking together to make the good old helium that makes us sound funny when we inhale it. If you check a table of elements you'll see that the next element is line is lithium, which had just started forming from helium, but it was too late.



15 May 2009

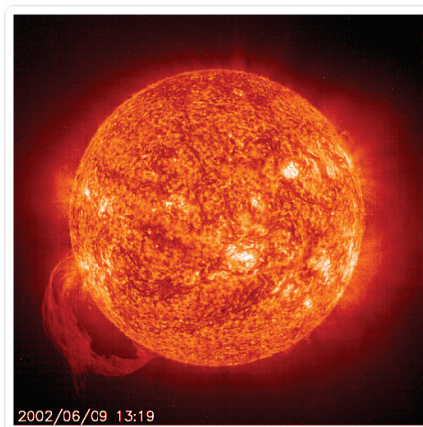
At about 3 and a half minutes after the Big Bang, the temperature dropped to a “freezing” hundred million degrees which was now way too “cold” for elements to continue to combine. And there you have it – 4 minutes after the Big Bang the Universe was made of hydrogen, deuterium, helium and trace amounts of lithium. Because the efficient cooking up of elements only lasted for about 30 seconds, little of the starting hydrogen was spent. This is why hydrogen makes 90% of the ordinary matter in the Universe, helium consists of about 10%, and deuterium and lithium can only be found in traces.

Cosmic cookers

The Universe remained this way for some 200 million years until the first ovens for cooking up elements appeared – stars. The temperature in the centre, the core of a star, is high enough for helium to start forming out of hydrogen. That same cooking process allows stars to shine and keeps them stable against gravity which tries to shrink them. But a star has a limited amount of hydrogen inside its core, and when it is all converted to helium a star has no option but to start shrinking. You may wonder ‘why doesn’t the star make heavier stuff out of helium and just continue shining?’ The problem is to cook up heavier elements you need higher temperatures, and so even though the temperature in the centre of the star was high enough for fusing hydrogen into helium, it is not enough to fuse helium to make the next element – carbon.

The star is now losing its battle against gravity and its core starts shrinking. However, as things compress they get denser and hotter, just like a hand pump. By pumping you compress the air inside the pump into a smaller volume. This forces the air to become denser and hotter, which you notice if you pump vigorously – the pump itself heats up. Thus as the star’s core shrinks, it grows hotter until the point it can start fusing helium into carbon, which helps it fight gravity and the shrinking stops. This process repeats – a star cooks up everything it has in its core making the next heavier element, then shrinks to reach higher temperature, and then starts fusing the product of the last cook up to create an even heavier element, and so on! So elements heavier than lithium are made inside stars!

However, this can only continue until the star’s core ends up being made out of iron which cannot be further combined in such way to make something even heavier. But we know there’s gold for instance which is heavier than iron! So where do these elements come from?



Stars are like cosmic cookers, producing “heavy” elements.
Image credit: NASA / JPL.



Supernova explosions spread elements throughout the Universe.
Image credit: ESA / Hubble.

Creating gold

When a star has used up all it has, and is left with an iron core which cannot be used for fusing heavier elements anymore, the battle against gravity is finally lost. This drives the star to her death in the form of one of the most violent explosions possible – the star explodes as a supernova! A supernova explosion is so violent that it can cook up all the remaining elements in the periodic table of elements, even gold! But exploding stars don’t just create elements, they spill them all over the Universe!

Remember, at first the Universe was made only out of hydrogen, helium and lithium, but as stars started exploding they began expelling all other heavy elements they had fused during their lifetimes and in their final moments as supernovae. Consider, all the carbon that makes up our human bodies, the oxygen we breathe, the iron in our blood cells, was all made in stars! And thus, just like the great astronomer Carl Sagan once beautifully put it “We are made of star stuff”!

This feature article was written as part of the Cosmic Diary Cornerstone project for the International Year of Astronomy 2009. To find out more, check out www.cosmicdiary.org and www.astronomy2009.org.