HOW WAS STARDUST CREATED?

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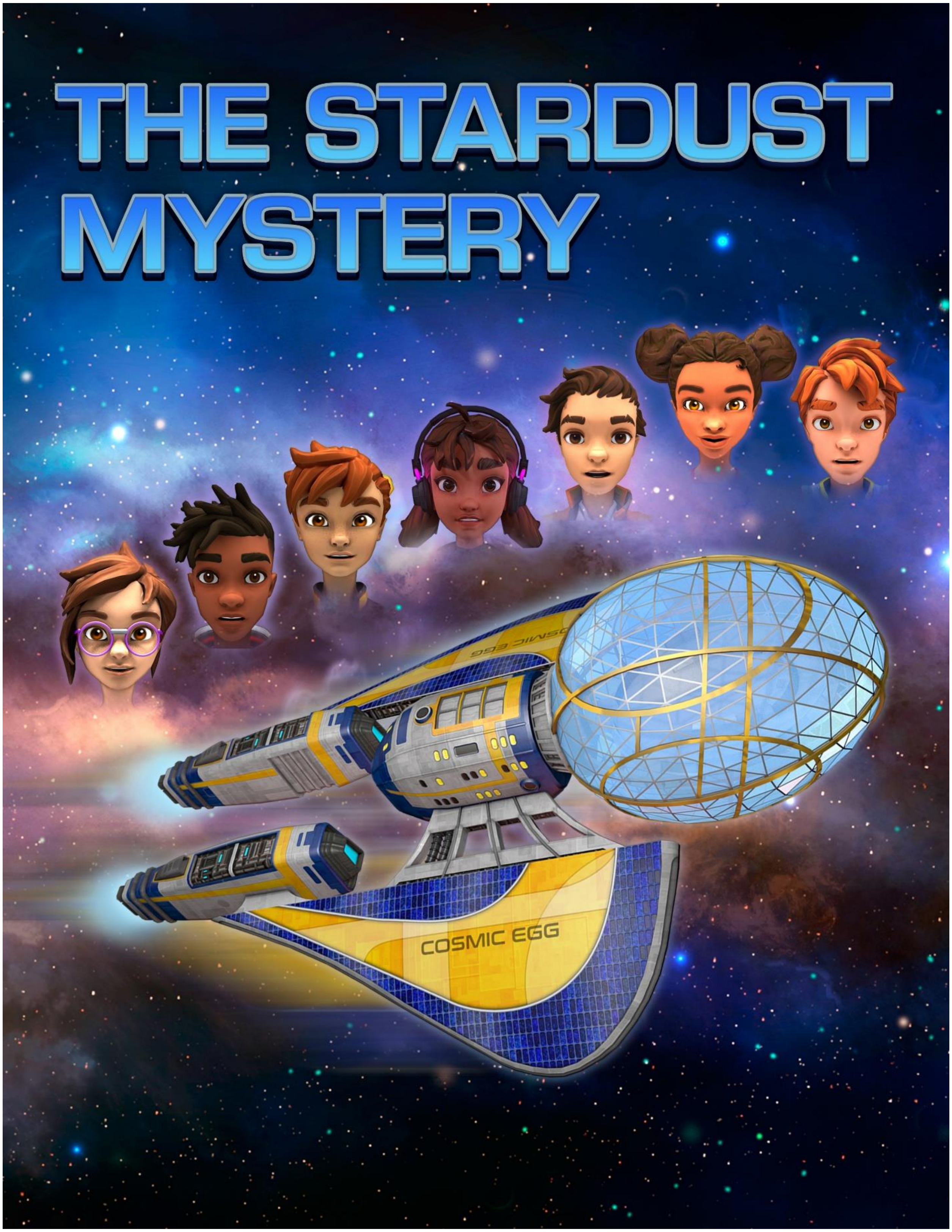


NEDDY'S STORIES

HOW WAS STARDUST CREATED? (AS TOLD BY NEDDY)

I just finished this awesome time travel adventure with Jackson, Milo, and my sister Lizzy. We started at the *Big Bang* and went forward to find out when stardust was created. Jackson wrote a report of the trip and put it on his web page.

His report has a picture that Lizzy created. It shows what we know is happening at different times during the evolution of the universe. "Right, Neddy," she said. "It starts with the *Big Bang* and covers the 13.8 billion years up to today."

"We found out," Milo jumped in, "that there is proof of hydrogen, helium, and a little bit of lithium and beryllium formed right after the *Big Bang*. But today, there are many other *atoms*, including the carbon, oxygen, nitrogen, and iron in our bodies and all the other atoms on Earth. We think that these *heavier atoms*—"

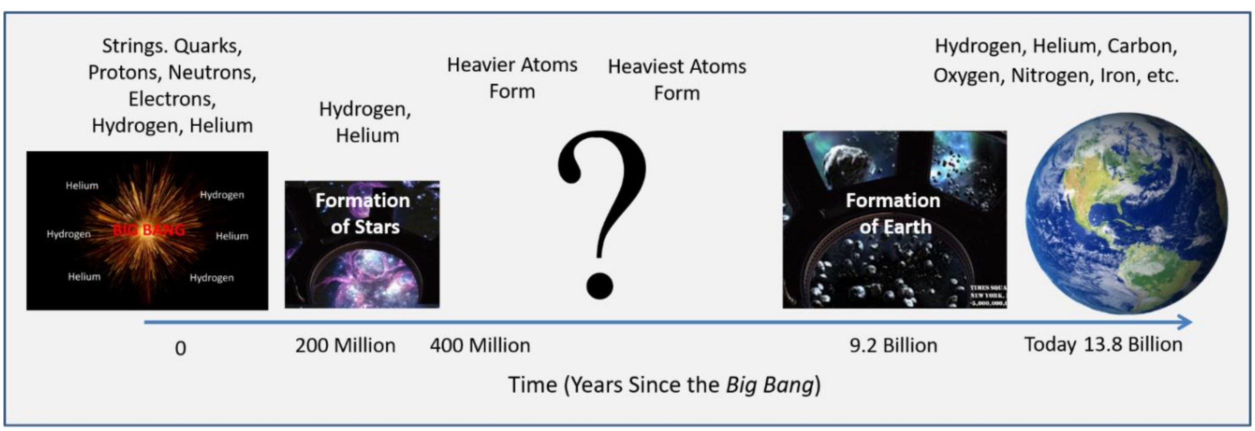
I finished his sentence, - "are what stardust is! The *heavier atoms* have atomic numbers—that is the atom's number of protons or electrons—of more than four all the way up to ninety-two, uranium. But this is what we don't know. *How was it created*? And *why is it called stardust*? That is the question mark in Lizzy's picture. It covers the time from the formation of the first stars to the formation of Earth 9.2 billion years later.

"So, what happened during that time that created all the *atoms* on Earth?" VC asked.

"That's our mystery!" Milo said. "We're gonna use the *Cosmic Egg* to find out."

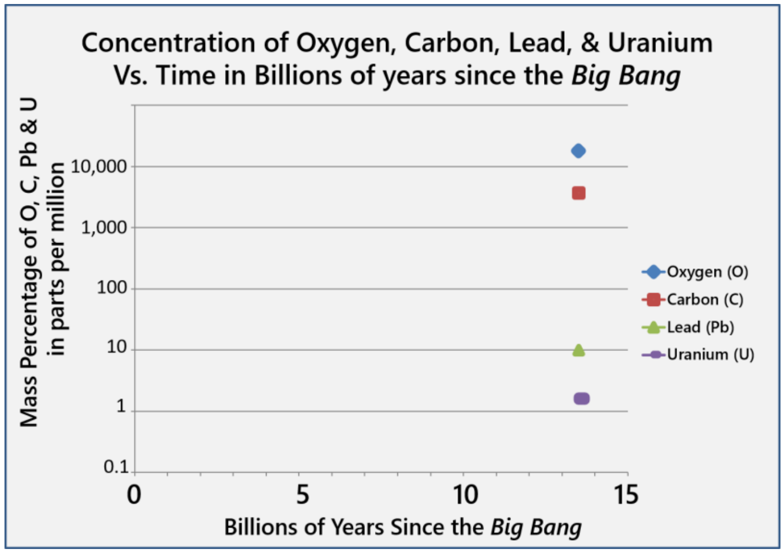
For this trip it was going to be just the Cosmic Kids, me, Milo, Lizzy, and VC.

We teleported to the *Cosmic Egg,* and I set up our instruments to take automatic measurements. It will record the elemental (atomic) composition and temperature at each point on



our way back through time to the *Big Bang*. That will let us see when the stardust appeared. Then we can find out where it came from and how it was formed.

First, we recorded the temperature and composition for the present time. We could choose between measuring concentration in a small area or an average over the universe. Since we wanted to know when the heavier elements appeared, we started with the average over the universe, recording the percent of each element. Our composition instrument determined that hydrogen made up 74 percent of the mass of the universe today. Helium made up 24 percent. Then I picked 4 elements to graph, two of the lighter elements, oxygen and carbon, and two of the heavier elements, lead and uranium.



Oxygen was a little over 10,000 parts per million or ppm (about 1%) and Carbon was just under 5,000 ppm, (0.5%). Lead at 10 ppm and Uranium at just 2 ppm were low.

Once all of that was figured out, I set the location to 300,000 kilometers above the Earth and pushed the button to go back in time. We went back fifty thousand years.

We looked out the window at Earth.

"OMG," I said, "our planet is almost all white!"

"That's ice," said Milo, looking at a readout for the temperature of the Earth's surface. "This must be the ice age. The US and Canada are almost completely covered in ice."

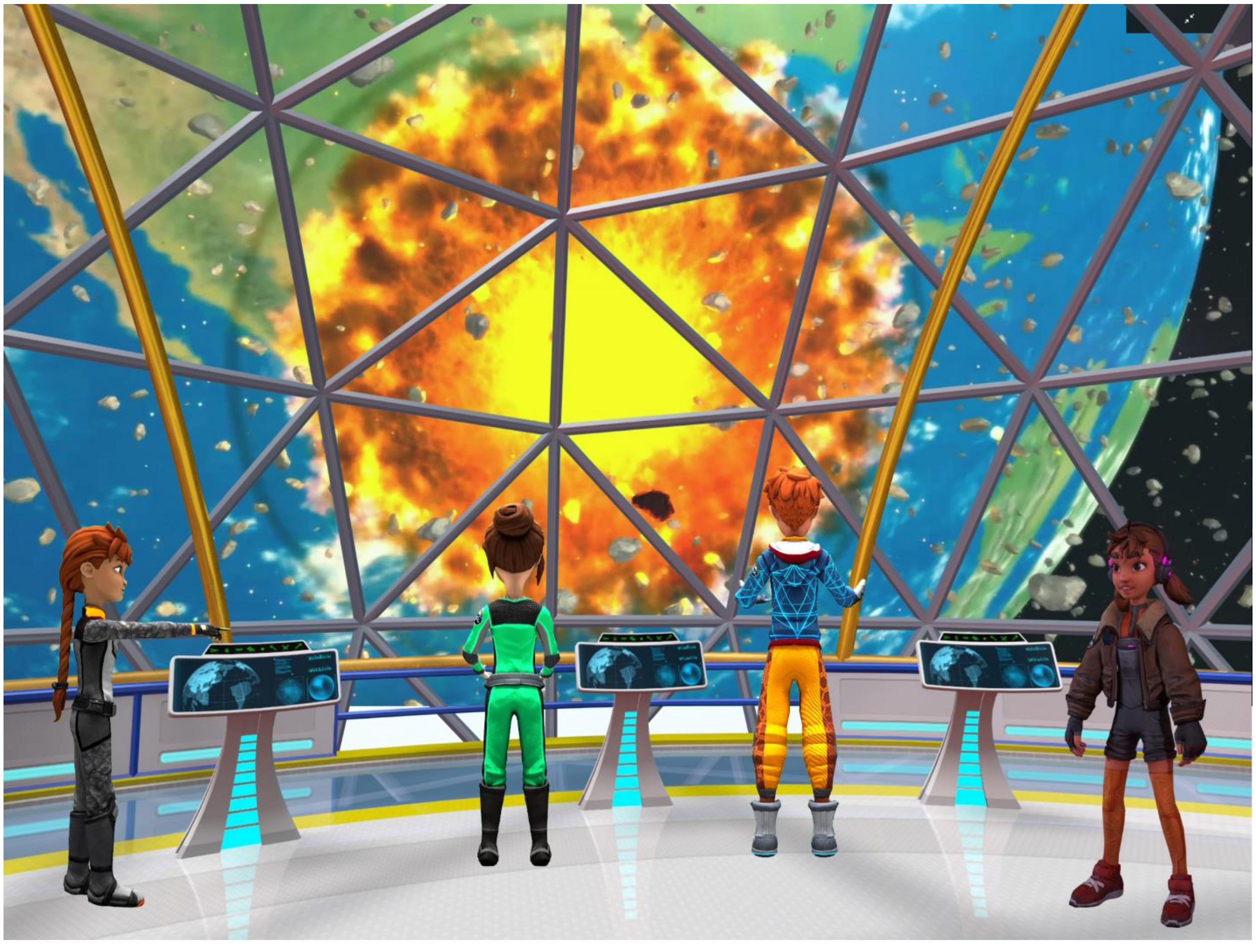
After looking out the window for a bit, we started recording data. First, we concentrated on the atomic percentages and temperature. What percentage of the universe did each element make up? What was the temperature of the target region? The atomic percentages were the same as when we started, but the temperature was 5 degrees centigrade cooler.

We took the next step back in time to 66 MYA—that's 66 *million years ago*.

"Oh, man," exclaimed Milo, "remember the Mission KT video game, that's the KT extinction event that killed all the land dinosaurs."

Out the front window we could see a giant asteroid hit the Earth.

"I made a YouTube video about that with Lizzy, Jackson and Grandpa," I said. "Richie's web page about *What Killed the Last T-Rex?* has a link to that video and other resources."

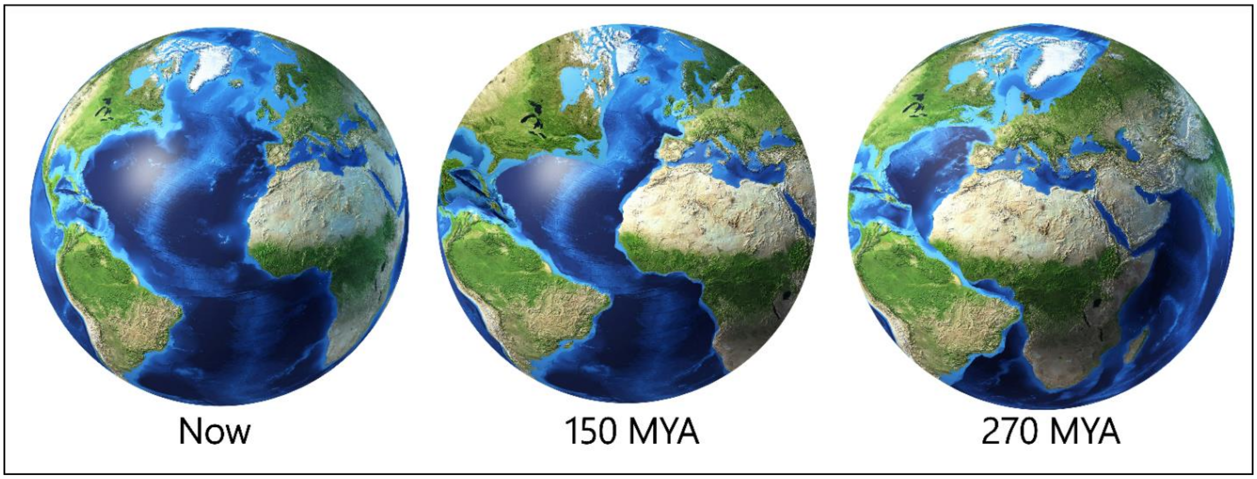


Richie's web page tells us that the effect of that asteroid was so huge that its dust eventually covered the entire planet. It took planet Earth a million years to recover from that disaster. We are pretty sure that it was that asteroid that killed all the land dinosaurs. Scientists figured out in 1978 that a crater in Chicxulub, Mexico was ground zero for the asteroid's impact. Researchers also discovered a unique rock layer in Gubbio, Italy created by asteroid dust. Geologists subsequently found the same layer all over the Earth. They named it the Gubbio layer. The age of the Gubbio layer was the same as the crater so the layer was most likely formed by the Chicxulub asteroid. It's also the time that dinosaurs—at least the ones on land—disappeared. In other words, no land-based dinosaur fossils have ever been found above the Gubbio layer, while there are plenty below.

"Maybe this is one of the reasons that Stephen Hawking said we need to colonize other planets," said Milo. "It makes sense if this kind of catastrophe can happen again."

During our next step back in time we noticed that the continents were moving. VC did a computer search on moving continents and told us, "what we are seeing is continental drift. The continents are moving because of plate tectonics."

We watched as North America—that's the United States, Mexico, and Canada—and South America got closer to Europe and Africa.



We watched the giant continent Pangaea form as the *Cosmic Egg* moved us back through time to 270 MYA.

"Huge continents moving like that is amazing," I said.

"Yes," agreed VC. "According to the information I found, you can't notice the continents drifting, but it still happens today. It's about an inch a year. But if something moves an inch a year over many millions of years, a continent can move halfway around the Earth."

As we moved back in time, Earth looked mostly the same, except for the shape and positioning of the continents. But then around 3,300 MYA the land started disappearing, until one large ocean remained covering almost the entire planet.

At 4,000 MYA, everyone gasped as the scene outside our windows changed from dark to bright orange. It was a huge change in the Earth. Suddenly it had become big and round and very, very hot.

"What happened to the Earth?" asked Lizzy. "This thing looks more like the sun. But it isn't the sun because, I can see the sun out the other window!"

"I know, I know" I yelled! "That is baby Earth. When the Earth was first being formed, gravity pulled lots of gas and space rocks together. As pieces crashed into one another it created lots of heat. And so, the Earth was hot when it first formed. That's what we're seeing! We are nearing the time when Earth started forming!"

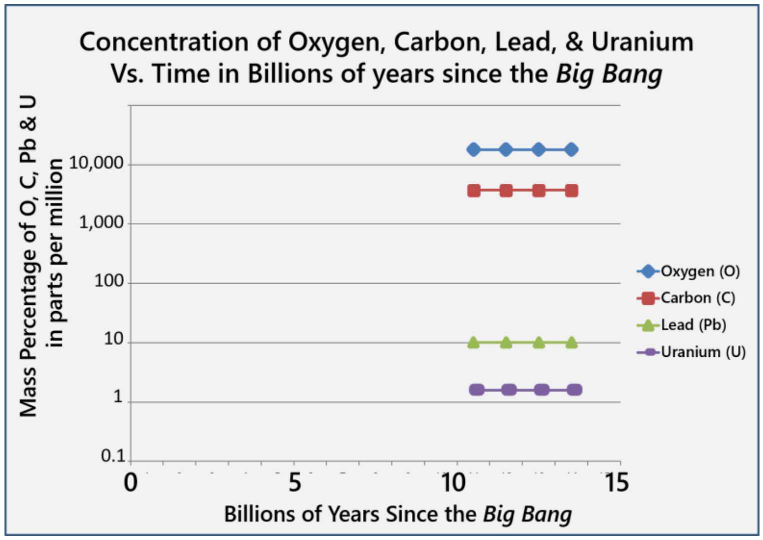
I was jumping up and down when Milo set the time to 4,500 MYA so we could see how it all began.

Just before we moved back in time to see the Earth form, we watched as a huge asteroid hit the Earth and left a giant chunk circling it. "That's our moon," said VC.

Finally, at 4,543 MYA, we were at the time when the Earth was forming. All kinds of space junk gathered together into a hot ball. When I recorded the temperature, it read 1,000 degrees centigrade, The elemental concentrations of our four test elements were pretty much the same as they are today—which is something I think is pretty cool.

The next step back in time was 4,600 MYA. There was no Earth at all. Meanwhile, the sun was just starting to form from a huge cloud of gas pulled together by gravity.

Back in 5,250 MYA, everything got weird, I mean, *weirder*.



"This is pretty awesome," exclaimed Milo.

There was no Earth, and no sun. There was just a collection of space rocks and gas clouds.

"Maybe this stuff is made of stardust," I suggested.

"I'll go outside and make measurements," Milo offered.

The rest of us were happy to stay inside.

Milo checked the temperature and atmosphere outside and found he would need to use a breathing helmet to exit the *Cosmic Egg*, which seemed like kind of obvious if anyone had asked me. Milo dressed his avatar in a space suit and entered the airlock before venturing out into space. A jet pack helped him move about.

As Milo took rock measurements, he explained that they were made from many of the same types of elements we had on Earth. "There are lots of atoms heavier than helium!" he said. "The gases contain hydrogen, helium, carbon, oxygen, and nitrogen! The rocks contained iron, silicon, oxygen, gold, lead, and even some uranium. So, all the stuff outside has the same types of atoms that are on Earth and has all the atoms that are in our bodies."

"Wow," said Milo after he came back into the *Cosmic Egg*, "that was awesome. It really was."

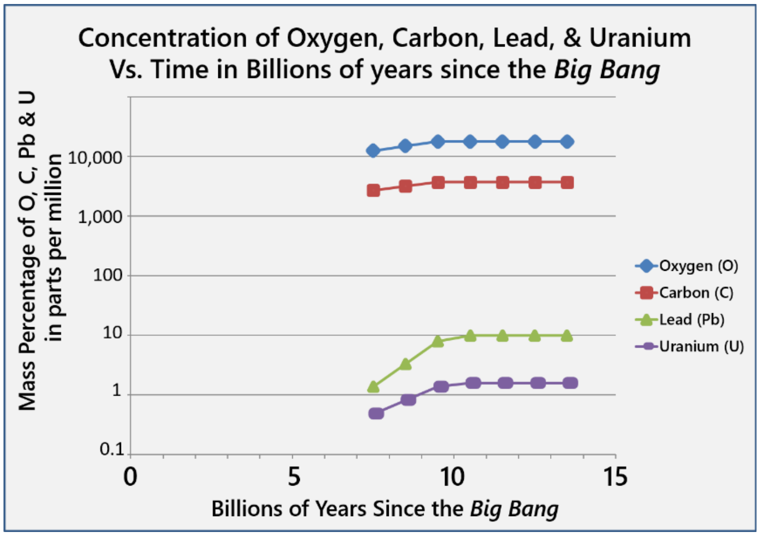
"I took the measurements for the elemental composition in the universe," I said. "They are pretty much the same as they are on the Earth today."

"So, this stuff, the gas and rocks, has to be stardust!" said Lizzy.

So, the Earth was formed from stardust and the stardust became *us*!" VC added beaming.

I felt myself smiling too. There was something . . . I don't know . . . *comforting* to me about knowing it—that all of us, every single one of us, was made of the dust of stars.

"Hey, guys," Milo suggested, "we know from Jackson's research on *When was Stardust Created?* that the light atoms were formed shortly after the Big Bang, while the heaviest atoms were formed much later. Neddy's graph includes two heavy atoms (lead with atomic number 82 and uranium with atomic number 92) and two light atoms (oxygen with atomic number 8 and carbon with atomic number 6). When we see their concentration decreasing as we go back in time, we'll know that it was the time when they were created. Then we can search for their source of creation."



"That is a good idea," agreed Lizzy.

"I'll start moving us back in time," said VC.

We zoomed away from the location where Earth was located so we could look at our galaxy, the Milky Way, from a distance. It still looked the same.

As we moved back in time, I looked at my computer screen and screamed, "hey guys, the concentrations of the light elements are decreasing slowly, but the heavy element concentrations are dropping fast."

We stopped at 7 billion years after the Big Bang to look for whatever it was that was causing the formation of those elements. I switched from measuring the average concentration in the universe to looking at the concentrations in regions of space. "OK, guys," I said, "I found a region directly ahead of us where lead and uranium have slightly higher concentrations. VC, please move us forward."

I kept pointing the way to where the concentrations were highest, and VC continued moving us in that direction.

"I see what looks like a really bright star," said Lizzy. "Maybe that is the source."

As we moved closer, Milo yelled out, "awesome! That thing is like a million times brighter than any of the other stars."

"It doesn't look like a normal star," said Lizzy. "There is stuff shooting out the top and bottom."

"And the concentrations of the heavy atoms in those shoots are huge," I added.

"It has got to be the source," declared Milo.

"And I know what it is," I said. "Remember my Science Fair exhibit about the birth, life and death of a star. Well, that is a dying star. It has collapsed after its hydrogen was all burned up and exploded in a *supernova*."

"So, if we go back in time," asked Milo, "will we see the star before it exploded?"

"Good idea," said Lizzy, "Let's check it out."

As we went back in time, the explosion reduced in intensity until there was a normal star with normal brightness. I checked the concentrations of heavy atoms near the star, and it was pretty much the same as the average over the universe.

"So, the heavy atoms must have come from the *supernova*," concluded Lizzy.

"I think the heavy atoms must be made when the star explodes!" I answered.

"OMG you guys!" exclaimed VC. "That's why they call it *stardust*."

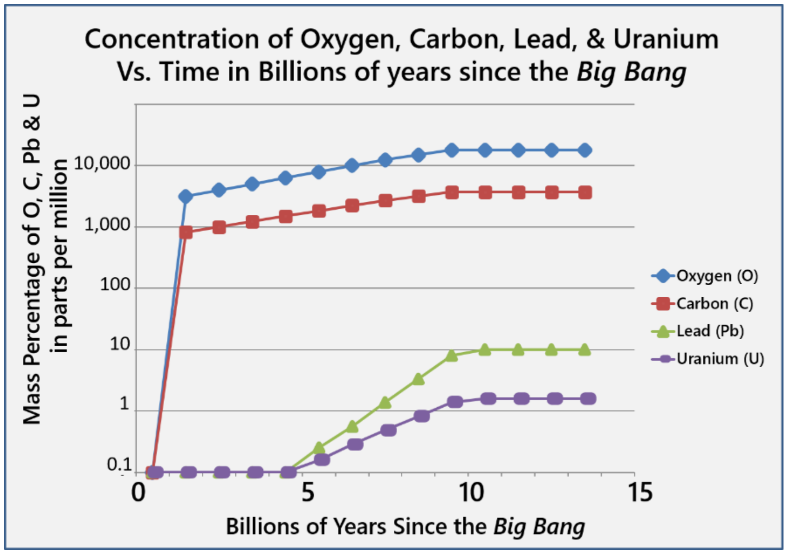
"The *supernova* has got to be the missing piece of the puzzle!" said Milo.

"But we have only seen one example," I cautioned. "Let's do some more looking to make sure this is the only answer." We search the universe and moved back in time and found 5 more *supernova* examples that were pretty much the same.

It's a good thing we didn't quit then, because we discovered something new on the next *supernova*. It looked like the others to start, but when we went back in time, instead of seeing a normal star, there were just two tiny little stars, even smaller than our moon, circling each other. And

when we went back further in time, the two little stars exploded and became two regular size stars circling each other.

We continued back in time and discovered that all the heaviest atoms were missing at times earlier than 5 million years after the *Big Bang*. When we got back to 300 million



years after the *Big Bang*, the small atoms concentrations dropped rapidly to zero. We found that the smaller atoms were created in supernovas about 100 million years after the first stars were formed in the *cosmic dawn*. The life of those stars was way shorter than the second generation of stars or our third generation. Those live about five billion years.

"So, here is what we know," said Lizzy. "Atoms up to atomic number 42 were formed in the supernovas of the first-generation stars. Heavier atoms were formed in the supernovas of second-generation stars or in the merging of two tiny stars. But how did those atoms get created?"

"We need an Expert Avatar to tell us about atom formation," I said. "Anyone have any ideas?"

We did some computer searching.

"How about Fred Hoyle?" suggested Milo. "My search says he did research on how atoms form in stars?"

Everyone agreed, so we requested a visit with the Fred Hoyle Expert Avatar.

"What year should we choose?" I asked.

"I think 1965," said Milo, "since the atomic and hydrogen bombs were already around. Scientists must have known a lot about atomic reactions by then."

Milo entered 1965 and pressed GO. The computer told us we were going to Columbia University where Hoyle was giving a lecture. When he appeared on our computer screen, he was backstage, getting ready to speak.

"Hello," he greeted us. "My name is Fred Hoyle. What are your names?"

"I'm Milo," answered Milo. "These three are my cousins: VC, Neddy, and Lizzy."

"It is nice to meet you, Milo, VC, Neddy, and Lizzy," replied Hoyle. "What can I do for you?"

"We want to ask you some questions about how heavy atoms form," I said, taking over from Milo. "We think it has something to do with supernova star explosions. Can you tell us about that?"

"Yes," responded Hoyle, "the subject is called Nucleosynthesis. I published a paper on it in 1946 and another one in 1954. Basically, the heavy atoms are formed by nuclear fusion."

"I know about that!" I interjected. "It's what happens when two atoms come together and form a new, larger atom!"

"Yes," agreed Hoyle. "On our sun, very hot, heavy hydrogen atoms fuse into helium atoms, and release lots of energy according to Einstein's equation, $E = mc^2$. All that energy is what keeps the sun burning bright."

"Doesn't fusion, hydrogen atoms combining to form bigger atoms, also happen in a hydrogen bomb," asked Milo.

"Yes, when an H-bomb detonates, fusion happens." Hoyle also told us something new: "Fusion also happened during the *Big Bang*."

"Wait!" interjected Lizzy. "We know that none of the heavier atoms in our bodies were formed in the *Big Bang*. So, where did they come from?"

"You're right, Lizzy," agreed Hoyle. "After the *Big Bang,* when hydrogen atoms formed, the temperature was high enough to form helium and lithium by nuclear fusion but wasn't high enough to form bigger atoms with atomic numbers higher than 4.

"Some bigger atoms were formed by the first-generation stars," Hoyle explained. "After the first-generation stars had burned up all their hydrogen gas, they collapsed and exploded to form supernovas. Those supernova conditions are extremely hot, hot enough to form atoms as big as the element molybdenum that has atomic number 42."

"But," he continued, "second generation stars can form big atoms in their cores where the temperature is really high."

"Like millions of degrees?" asked Milo.

"Actually, Milo, *billions* of degrees," answered Hoyle. "The hotter the star, the bigger the atoms that can form by fusion!"

"But, the supernovas of second-generation stars are even hotter," he continued. "They're as hot as 100 billion degrees centigrade. That is so hot that smaller atoms bang into each other at such high energy that they combine to form all the big atoms, even up to uranium which has 92 protons and 92 electrons. Protons, electrons and neutrons are what atoms are made of"

"The explosion blows all those new atoms out into space where they can come together to form new stars and planets, like Earth!" Professor Hoyle concluded.

"Wow," we all said at the exact same time.

We asked him about the two little stars that we had seen, but he didn't have an answer.

We thanked Professor Hoyle. Before leaving we checked out the audience assembling for Professor Hoyle's lecture. After we logged off, I asked, "Didn't that young guy in the first row look a little like Grandpa?"

"Way too young," answered Milo.

"No," I objected, "that's the age he would have been in 1965. I think he went to graduate school at Columbia, so he was probably in the audience. We missed a good opportunity. But we don't have time to go back. We have work to do."

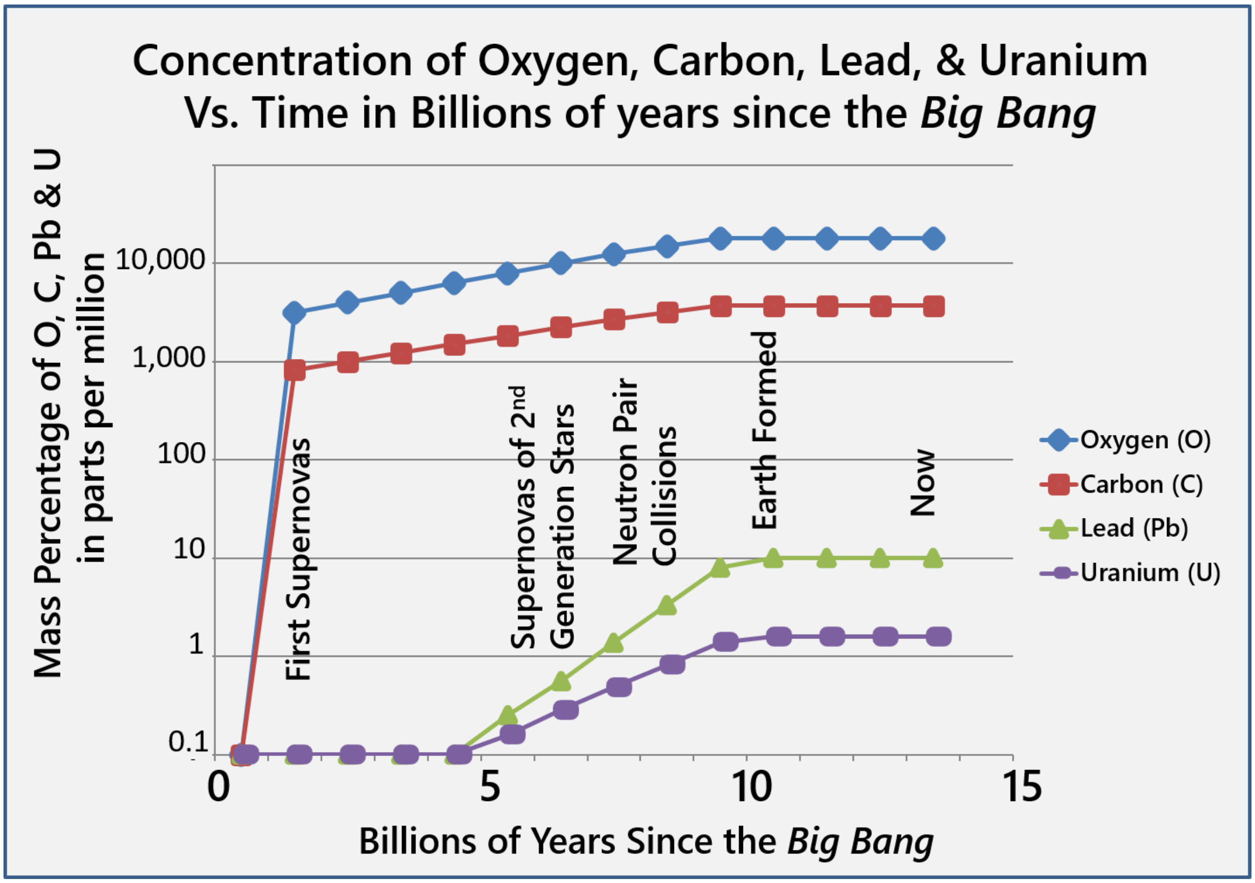
We logged off and went to find Grandpa to see if he knew about the two little stars. Grandpa told us that in the summer of 2017, astronomers identified the collision of two neutron stars by observing gravitational waves at the LIGO observatory. He said, "it happened 129 million years ago and produced an amount of gold that would weigh as much as Earth—along with other heavy elements. Neutron star collisions appear to be a major source of our heaviest elements."

"Thanks Grandpa," said Lizzy, and we went back to the family room to talk about what we found out.

"We did it!!" I screamed. "We solved the Stardust Mystery!"

We were so happy we were jumping and hugging and high fiving. Even Lizzy and Milo hugged. It was happiness for the record books, that's for sure.

I copied the data we had collected. We had tracked the four atoms' concentrations all the way back in time to the Big Bang when the universe started. To make our data clearer, we labeled the important events.



Milo summarized what we knew. "First, the *Big Bang* happened 13.8 billion years ago that produced hydrogen and helium—also known as *Big Bang* dust. Over time, gravity caused the *Big Bang* dust to come together and after 150 million years, it formed the first stars and eventually galaxies. That was called the *Cosmic Dawn*. The stars burned heavy hydrogen by nuclear fusion which produced helium, light, and heat."

"And a hundred million years later," I continued, "after those first big stars formed, they started to run out of hydrogen fuel so that they collapsed and exploded in supernovas. And the supernovas created carbon, oxygen, nitrogen, and heavier elements. That is what scientists call stardust."

"As time went by," added Lizzy, "stars continued to form and die, so that the universe became filled with more and more oxygen, carbon, nitrogen, and the other heavier elements."

Milo continued, "And then, about 4.6 billion years ago, gravity brought dust from the *Big Bang* and star supernovas together, creating our solar system with our sun and planets and asteroids."

"So, give us the bottom line," Lizzy said clapping her hands under her chin because even though she already knew—she just wanted to hear us say it.

I jumped back in. "Almost all of the elements that are heavier than helium come from nuclear fusion in stars that explode in supernovas. So, the Earth and everything on it is made of stardust and *Big Bang* dust!"

"And finally," VC added, "the carbon, oxygen, and nitrogen from stardust, and hydrogen from *Big Bang* dust that was on the Earth, got made into us—you and me. And since those atoms last almost forever, they get recycled among people and plants as new people and new plants populate the Earth. So, we really are made of stardust that was once in the body of Albert Einstein and the last T-Rex!"

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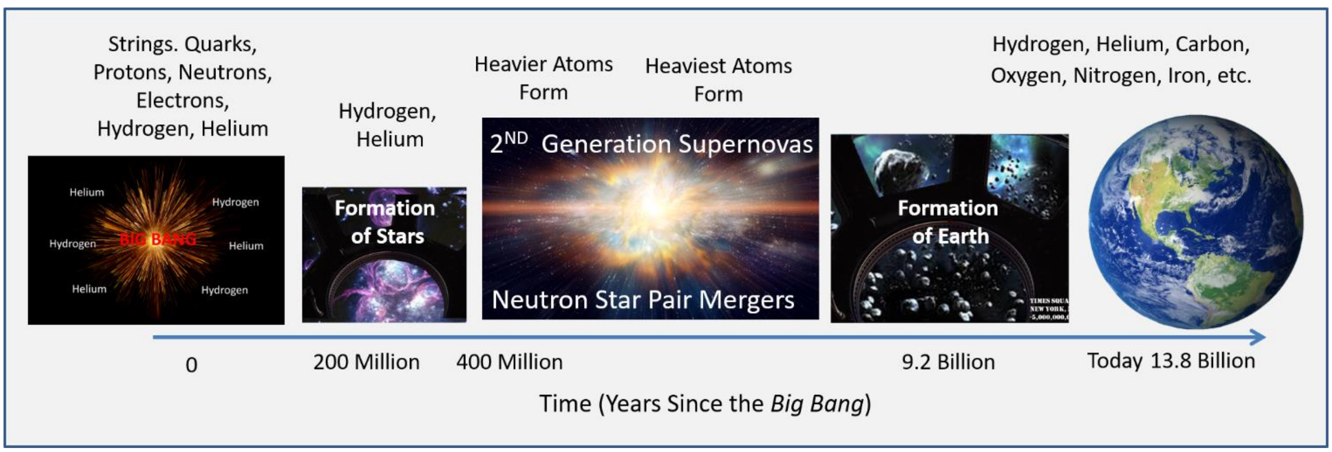


We added the supernova picture to replace the question mark on our diagram. We also made a video about the neutron star pair collision event called "A Quadrillion Tons of Gold" which you can see on our Stardust Mystery YouTube channel or on the Neddy web page.

GRANDPA'S GLOSSARY

The Big Bang: The planet Earth that we live on is sometimes called a Goldilocks planet. It is not too hot. It is not too cold. It is just right as a home to support the lives of beings such as our own species and millions of others. And our species has been constantly fascinated with the questions of where we live and how we got here.

More than two thousand years ago, humans looked at all the things in the sky and decided that the universe consisted of the Earth at the center with the sun, moon, and stars all revolving around the Earth. In the fifteenth and sixteenth centuries, Copernicus and then Kepler and Galileo said that the universe has the sun as the center, and everything revolves around the sun. Then, in the nineteenth century astronomical knowledge expanded. The imagined picture changed to the sun and planets revolving around the center of the Milky Way galaxy. In the early twentieth century, the work of Henrietta Leavitt and Edwin Hubble showed that the Milky Way galaxy was only a small part of the universe, which has billions more galaxies like the Milky Way. What's more, Hubble's measurements, and the predictions of Alexander Friedmann and Georges Lemaître showed that the universe is expanding, with the most distant stars moving away from us the fastest.

Based on the expansion of the universe, Lemaître made a bold prediction. He reasoned that if you follow the universe back in time, it gets smaller. The further back in time you look, the smaller it has to be. So, if the evolution of the universe were a movie showing its expansion, and you played it backwards it would be contracting. The contraction of the universe would put the universe in one tiny, super dense point about 14 billion years ago. Lemaître pictured the expansion of the universe from that point as the hatching of "the Cosmic Egg exploding at the moment of the creation". Other scientists call this the *Big Bang* theory.

Albert Einstein attended one of Lemaître's lectures at Princeton University. It was reported that Einstein said, "This is the most beautiful and satisfactory explanation of creation to which I have ever listened."

How do we know that the *Big Bang* theory is correct? Well, scientists can calculate what occurred as the universe expanded from that first point. They can make predictions about the concentrations of elements in the universe and about the leftover radiation from the earliest times, which can still be seen as the cosmic microwave background. They can predict the size of stars, galaxies and galaxy clusters, and the rate of the universe's expansion. When compared with these observations, the *Big Bang* theory is very accurate.

When we look at all the things that have to be just right for the universe to evolve as it has, and for us to be here on our Goldilocks planet, it seems that we live in a Goldilocks universe too. But we understand our Goldilocks planet as being the one that is just right in the millions of other planets that aren't just right. Living things may be on the ones that are just right, but not on the others that aren't. So, is our Goldilocks universe just the one that is right out of the millions of other universes that aren't just right? Are there millions of other universes out there that aren't just right? So, just like we found the Earth, and then the sun, and then the Milky Way galaxy were only a small part of the universe, maybe the universe that evolved from our *Big Bang* is only a small part of the multiverse. Or was there a creator of the Goldilocks universe that chose the conditions to be just right?

Atomic Number: Atoms are made up of protons and neutrons which form the center or nucleus of the atom and electrons which travel in orbits around the nucleus. Every atom is given an atomic number. It is the number of protons in the nucleus or electrons surrounding the nucleus. Atomic numbers go from 1 for hydrogen to 92 for uranium which is the largest naturally occurring element. Some man-made elements have higher atomic numbers.

Continental Drift: Continental drift was a theory proposed in 1912 by Alfred Wegener, a geophysicist and meteorologist, that explained how continents shift positions on Earth's surface. The theory proposed that the present continents were once joined, forming a supercontinent called Pangaea. It explained why look-alike animal fossils, plant fossils, and similar rock formations, are found on different continents. While details of how the continents moved were incorrect, the general ideas were important. Today, the theory of continental drift has been replaced by the science of plate tectonics. This science considers how the individual pieces (plates) that make up the Earth's crust are moved by a variety of forces.

Supernova Star Explosion: Stars are bright because they are very hot due to nuclear fusion in which hydrogens combine to form helium. After billions of years, all the hydrogen is consumed, and the star starts to cool and collapse toward the center. In big stars, the collapse leads to an explosion called a supernova, in which huge amounts of light and material are released. Supernovas are bright enough to be seen on Earth with the naked eye and can last for up to two years.

Cosmic Dawn: For millions of years after the Big Bang, the universe had no sources of light. But as the universe approached 150 million years old, it started to get brighter with faint pinpoints of light. That was the *Cosmic Dawn* when the first stars were forming to light up the universe.

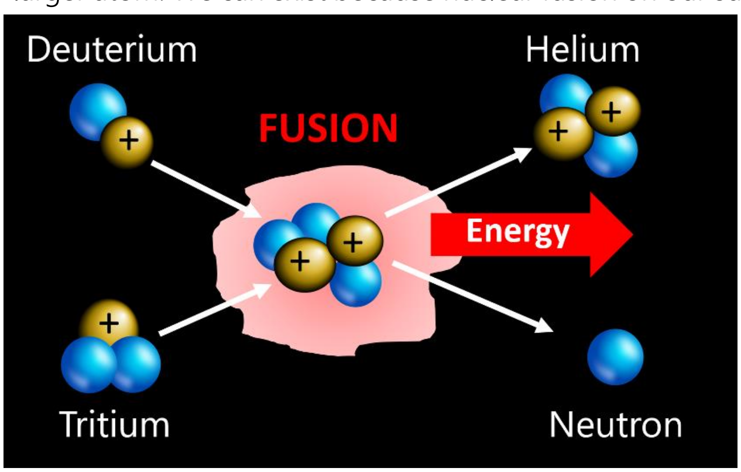
How the Heavy Atoms Form in a Supernova: In the discussion of nuclear fusion that follows, there is a picture of two heavy forms of hydrogen atoms, deuterium, and tritium, banging into one another to form helium and a neutron. The requirement for fusion to take place is that the banging must be done with lots of energy. The two hydrogens must be going very fast to make the fusion happen. In this case, where helium is formed, a temperature of 15 million degrees C is required. That temperature was available shortly after the *Big Bang* and is available at the center (the core which is the hottest part) of our sun. The temperature after the *Big Bang* and on the sun is also hot enough to form some smaller amounts of lithium (atomic number 3) and beryllium (atomic number 4), and in the core of the sun, small amounts of carbon, oxygen, nitrogen, and other elements.

The formation of larger atoms requires much higher temperatures. Where can we find higher temperatures? Stars that are bigger than the sun have more gravity crushing the atoms together, and so the temperatures in their core is hotter than on our sun. The biggest stars can form big atoms in their cores. Another place for higher temperatures is in a supernova. When big stars have used up all their hydrogen (about five billion years after they formed), they start to cool. Then gravity starts to crush all the atoms into the center. This creates fusion reactions of bigger atoms and much higher temperatures. The core gets so hot, 100 billion degrees C, that fusion runs away, producing atoms up to the size of uranium (atomic number 92) and the star explodes in what is called a supernova. The explosions are so spectacular, that they can be seen with the naked eye from Earth. They can last for up to two years.

Supernovas do three things that are important for us to exist: (1) they created the heavy atoms we needed to form a solid Earth to live on and also the atoms required to make living things; (2) the explosion rocketed those atoms out into the universe where eventually they could condense to form the Earth and us. Those atoms that formed in the supernovas are the stardust; and; (3) supernovas produce visible light and radiation (x rays and gamma rays) which may help to drive mutations, important in the evolution of species.

Nucleosynthesis: The term nucleosynthesis is used to describe the formation of new atomic nuclei by nuclear reactions. Nucleosynthesis occurred shortly after the *Big Bang* to form helium, and some other light atoms. It occurs in the interiors of stars and during supernovas and neutron star collisions to form the heavier atoms (atomic numbers from 5 to 92) in the periodic table.

Nuclear Fusion: Nuclear fusion is what happens when two atoms come together and form a new larger atom. We can exist because nuclear fusion on our sun provides light and energy to our planet.



On the sun, the main nuclear fusion reaction takes place when one hydrogen atom that has one proton and one neutron (^{2}H, called deuterium or heavy hydrogen) bangs into another hydrogen atom (^{3}H, called tritium) that has one proton and two neutrons. In order to fuse, they must bang into each other really hard, and that requires a high temperature, like 15 million degrees C. They fuse into a helium atom that has two protons and two neutrons (^{4}He) and the extra neutron comes shooting out with lots of energy. The energy is in units of million electron volts or MeVs. All that energy is what keeps the sun burning bright.

Fusion of bigger atoms on our sun can form atoms like lithium with three protons and beryllium with four protons and small amounts of bigger atoms. But big stars can form big atoms in their core where the temperature is very hot. When a star uses all its hydrogen it either becomes a white dwarf the size of Earth (like our sun would do), or if it is a big star, it collapses and forms a supernova. And in that supernova, conditions are hot enough (100 billion degrees C) to form atoms like iron that have twenty-six protons, and even uranium (that has ninety-two protons.)

Neutron Stars: When a large star with a mass of 10 to 30 solar masses ends its life, its core collapses into a neutron star. Neutron stars have a mass of about 1.4 solar masses all packed into a radius on the order of 10 kilometers (about the size of a city). They are thus incredibly dense having the density of an atomic nucleus. Pairs of neutron stars have been observed to merge producing a supernova which is a major source of the heaviest atoms in the periodic table.

Gravitational Wave: Gravitational waves are predicted by Einstein's General Theory of Relativity. They are disturbances in space (stretching and contracting) that travel at the speed of light away from the event that caused them.

LIGO: The National Science Foundation funded the development of the Laser Interferometer Gravitational-Wave Observatory (LIGO) to detect gravitational waves. Two of them were built 3000 kilometers apart (one in Hanford, Washington and the other in Livingston, Louisiana). A disturbance must be seen simultaneously by both to be identified as a real event. The first event detected in 2015 was believed to be produced by two black holes merging. In the summer of 2017, LIGO detected a gravitational wave produced by the merging of two neutron stars. Additional measurements indicated that that event had produced a weight of gold equal to the weight of planet Earth. Neutron star merging appears to be a very important source of our heaviest atoms.

THE STARDUST MYSTERY PROJECT

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