Universe 101 Reading Packet

Space is a pretty big place and there is a lot to learn. This packet will guide you through some of the basics of astronomy, starting with the big bang and ending with why our planet is so unique. We'll start with the structure of the universe.

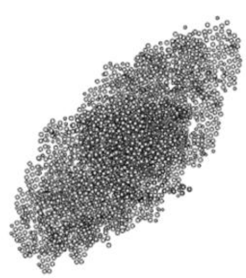
The Universe

The universe… do we really comprehend what that word means? There isn't anywhere that we can look and not be looking at it. It's everywhere. It's *everything*. It includes all matter and energy, and not just the stuff that we see here on Earth, it also includes all of outer space no matter how far away.

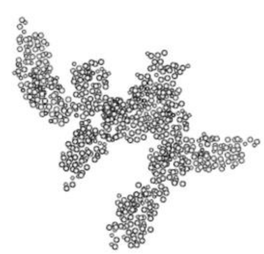
Galaxies

The next level down from a universe is a galaxy. Galaxies are large collections of stars held together by gravity. There are billions of galaxies in our universe and each one is made up of billions of stars. Galaxies are separated from each other by open areas of dust and dark matter. There are three main types of galaxies, each named for their shape – spiral, elliptical, and irregular. Spiral galaxies are the most common and have, if you can imagine, a spiral shape. Elliptical galaxies are oval in shape and are fairly common. Irregular galaxies come in all sorts of shapes and sizes and are the most rare of the three types. What's the one thing that they all have in common? They are each made up of billions of stars and are held together by gravity. Our galaxy is a spiral galaxy. We call it the Milky Way Galaxy.

Spiral



Elliptical



Irregular

Stars

From earliest recorded history people have been staring up at the night sky and wondering – what are the stars? Stars are simply giant nuclear furnaces. Stars like our sun spend all of their time converting the hydrogen in their core into helium and releasing a ton of energy in the process. That's why the sun glows so brightly and gives off so much heat. This process that powers stars is called **nuclear fusion**. It means that two or more elements fuse together to make a different element and give off energy along the way. In order for fusion to occur regularly the surroundings need to be very hot and very dense – just like it is down in the middle of a star.

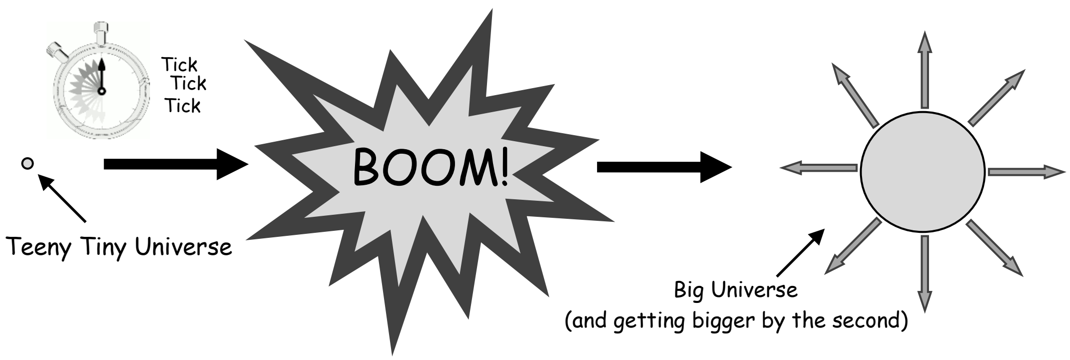
The Beginning

So now we understand that stars are giant nuclear furnaces and that when billions of them group together bound by gravity we call it a galaxy. We also know that when we consider all of the galaxies and the galactic dust and dark matter between them we have a universe, but how did it all begin? Does it even *have* a beginning or was it just always there? Doesn't it make your head want to *explode* just thinking about it?

The Big Bang Theory

The evidence shows that the universe *did* have a beginning. The origin and general nature of the universe is described by scientists in what is called the **Big Bang Theory**. This theory states three major things:

1. That the universe is expanding and has always been expanding since it began.
2. In the beginning (some 13-15 billion years ago) the universe was very small, hot and compact – smaller than the size of the period at the end of this sentence.
3. The universe has cooled down over time.



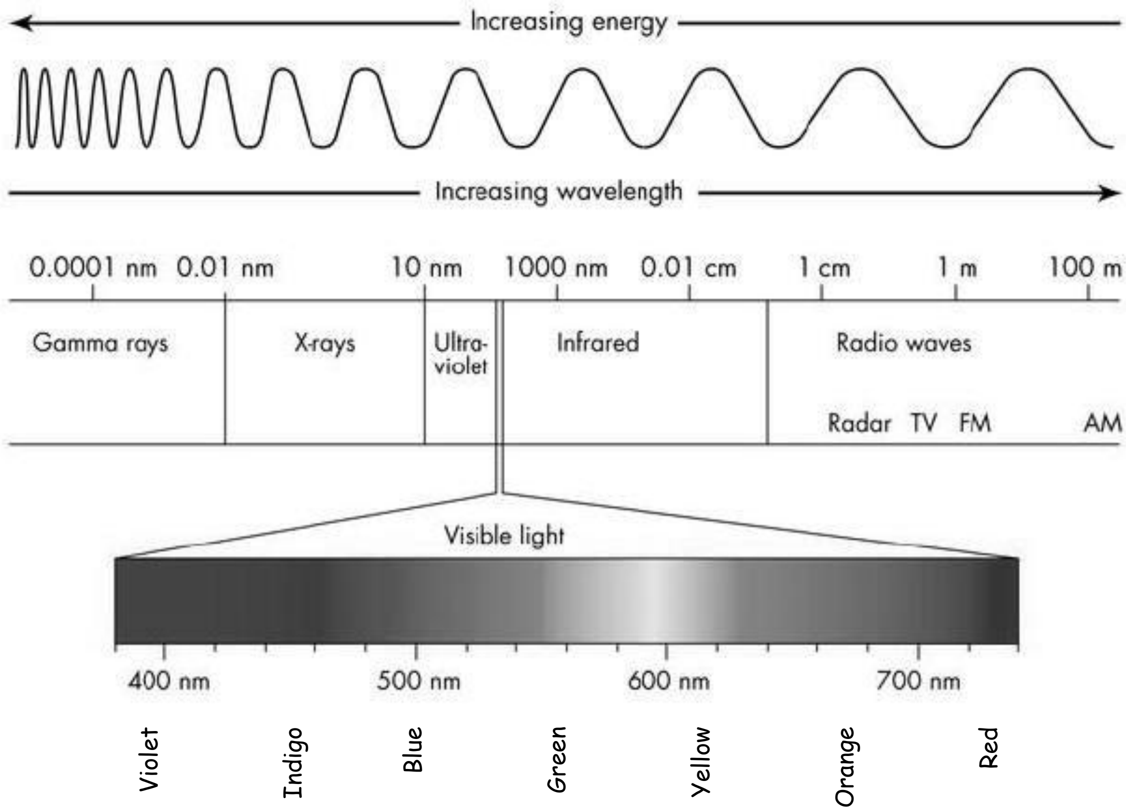
The theory itself is not very hard to understand, it's the evidence that sometimes gets complicated. There is lots of evidence supporting the Big Bang Theory, but for the sake of keeping things short we will only cover the three biggest ones here.

Let there be light

How do we know what we know about the stars? Can we wander up close to one, collect some data and then fly on home? No… no we cannot. It's *LIGHT.* Everything that we know about stars we know because of the light that they give off. Before we can really get into the evidences for the Big Bang Theory, we need to brush up on what we know about light. Ready for a quiz?

First question: *Why do we see the colors that we see when we look at things?* Why do we see red when we look at blood, or green when we see grass, or blue when we gaze at the sky?

Short answer: It's because the thing that you are looking at absorbs every color besides the one that you see.



When light gets divided up into its wavelengths you call it a **spectrum**. Think about the colors of the rainbow. Maybe you have heard the acronym "ROY G BIV" to help you remember them. The colors are: **R**ed **O**range **Y**ellow **G**reen **B**lue **I**ndigo **V**iolet (ROY G BIV). In order to understand starlight we also need to remember that light is a wave. Different colors have different wavelengths. Of visible light, red is the most mild (longer wavelengths) and violet is the most intense (shorter wavelengths). So say you decide to wear your nicest yellow shirt. You're looking good… but do you know why your shirt is yellow? It's because when it comes to red, orange, green, blue, indigo and violet the shirt absorbs those colors, but when it comes to yellow… *BAM! Rejected!* It doesn't absorb yellow, so that's what gets reflected to our eyes and that is the color that you see.

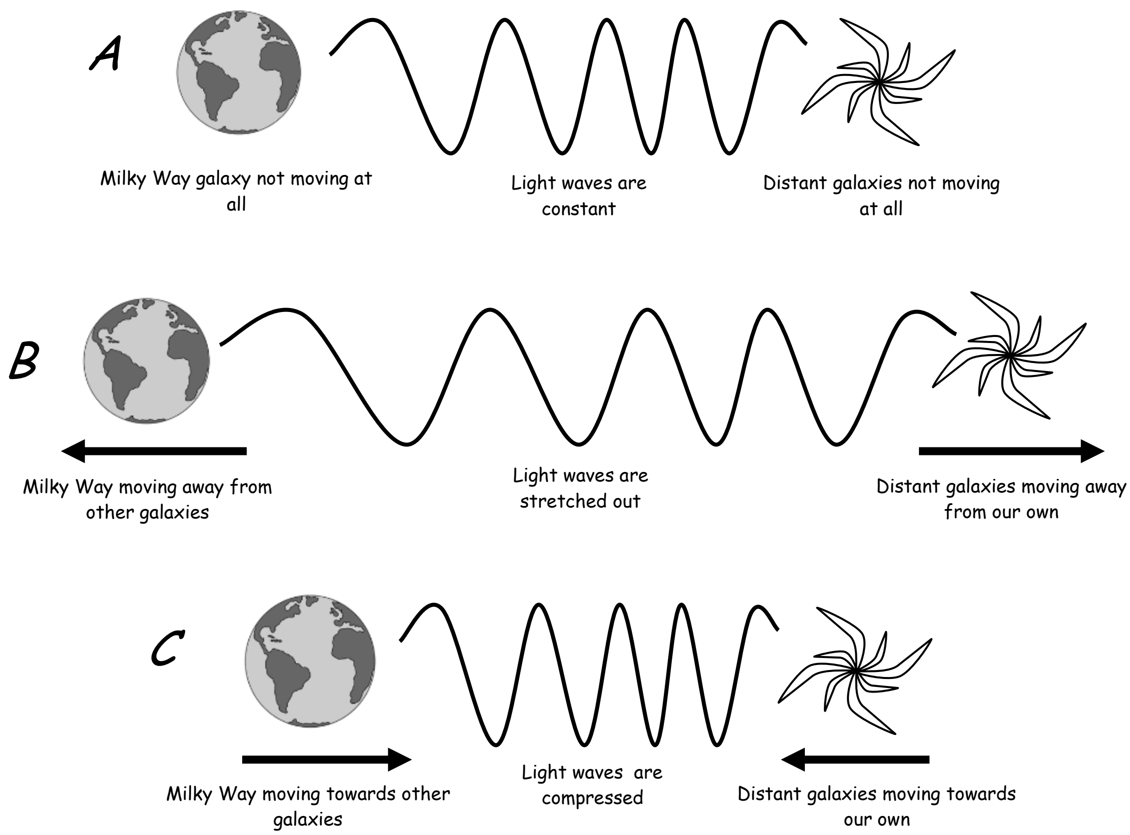
Last Question: *Is it possible to stretch or compress light waves?*

Answer: YES! Want an example? Think of another kind of wave that you're very familiar with… sound. Have you ever stood on the side of the road as an ambulance races past? The sound seems to build up and get louder and higher pitched as the ambulance gets closer. Then the sound seems to fade out, getting more quiet and lower in pitch as the ambulance gets farther away. Is the ambulance itself making a different noise? ***NO!*** The sound wave is getting compressed as the ambulance approaches and stretched out as the ambulance drives away. You may have heard of this described as the ***Doppler Effect.*** Light waves are no different; they can also be stretched out or compressed.

All right! Now we're ready for the first evidence supporting the big bang theory.

Evidence #1 - One shift, two shift, red shift, blue shift

Only one of three things can be happening to our universe: either it's staying the same, getting bigger, or getting smaller. In the lovely diagram below we see these three possibilities using Earth (representing the Milky Way) and a distant galaxy as a model.



In example "A" our galaxy and the distant galaxy are always the same distance from each other. No matter how many times you measure the distance (using the light) that distance will be the same.

In example "B" it shows our galaxy and the distant galaxy moving away from each other. As they move apart, the light traveling between them gets ***stretched out*** which means that the wavelengths are getting longer. Do you remember which color had the longest wavelength? It's red. So if you stretch out a wave of light, you change what it looks like and you shift it closer to the red side of the spectrum. This is called ***RED SHIFT*** and it is what we would see when we analyze starlight from distant galaxies if the universe was expanding

In example "C" it shows our galaxy and the distant galaxy moving towards each other. This represents a universe that is shrinking or contracting. By the time the light reaches Earth the distant galaxy will have moved closer and the light would have been compressed causing the wavelengths to get shorter. Again you would change what the light looks like, but this time you're moving it closer to the blue side of the spectrum. We call this ***BLUE SHIFT!***

So if the universe is standing still we don't see any stretching, compressing, or shifting of light. If the universe is expanding we see a ***red-shifting*** of light. If the universe is contracting we see a ***blue-shifting*** of light. So guess which one we see? Almost everywhere we point our telescopes we see red-shifted starlight from all ends of the universe.

Conclusion: Red-shifted starlight data confirms that the universe is expanding.

Evidence # 2 - Leftover Big Bang Energy

The second major evidence supporting the big bang theory deals with heat and energy. Like I mentioned, the universe was once young and hot (much the same way as you probably like to think of yourself). Scientists hypothesized that when the universe started expanding outward and cooling down it should have left behind a layer of energy that would be spread out evenly through all of space. It would be very faint by now, but it should still be there. So scientists went to work developing the technology that would allow them to test their hypothesis, and it turns out they found exactly what they were looking for. No matter where they measured in the vast cosmos (another name for the universe), they always picked up some very faint background energy. They called this ***Cosmic Background Radiation***. It is the now faint energy that was distributed across the universe as it expanded and cooled.

Conclusion: The fact that there is a uniform level of radiation spread out across the universe tells us that something must have caused it. The best explanation for this energy is that it is leftover from the big bang (**cosmic background radiation**).

Evidence # 3 - The Elements Agree

Computers are great aren't they? They can crunch numbers so much faster than we could ever hope to. They can analyze data for specific patterns in the blink of an eye where it would take us decades. Well, *computer models* that simulate the beginning of the universe all predict that the only elements that the big bang could have produced were the very basic and simplest elements. In fact, these models predict that the vast majority of the universe should be made of only two elements: Hydrogen (about 74% of the universe) and Helium (about 24% of the universe). Fortunately it's easy to test whether the computer models match reality. Each element absorbs different colors, and when looked at with a device called a spectroscope you can see the specific colors that each element absorbs – like a barcode or a fingerprint that is different for each element. We can attach these spectroscopes to telescopes and look at the universe to determine what elements are the most common. It turns out that pretty much wherever you look the universe is mostly hydrogen and helium, helium and hydrogen.

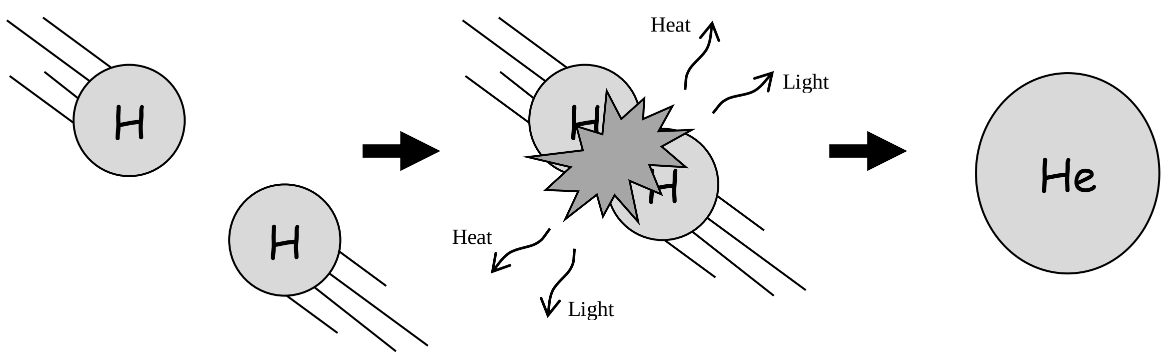
Conclusion: The observed amounts of elements in the universe match those predicted by Big Bang computer models.

So there you have it, the major evidences supporting the Big Bang Theory: red-shifted starlight, cosmic background radiation, and the distribution of elements in the universe. So now that we understand the big bang there are other mysteries to uncover.

Speaking of Elements…

Like I mentioned, Hydrogen and Helium are the two most common elements. They are also the two lightest elements. In fact every other element besides hydrogen and helium is considered a ***heavy element.*** Carbon, Oxygen, Calcium, Sulfur, Phosphorous, Gold, Silver – and all of the rest are called heavy elements.

So here's the mystery: if the big bang only made two elements – Hydrogen and Helium – where did all of those heavy elements come from? The answer might surprise you, but you're staring at the source of these elements every night when you look up at the stars! Clear back on page number one we learned that stars spend all of their time performing ***nuclear fusion,*** the process of fusing two or more elements together to make new elements. In order for nuclear fusion to occur it needs to be very hot, like millions of degrees hot. The intense pressure in the core of a star is the ideal place for nuclear fusion to happen. So how does it really work? Let's use a very simple example. Hydrogen is element number one. That means it has one proton in its nucleus. At extremely high temperatures hydrogen atoms are moving at incredible speeds, and when they collide, they stick, giving off light and heat in the process. Fusing two hydrogen atoms together gives you two protons, but an atom with two protons is no longer hydrogen – it's helium. Another example is when three helium atoms (each with two protons) fuse together they make a carbon atom, which has six protons. It's not always as simple as that, but it's a good enough explanation for now.



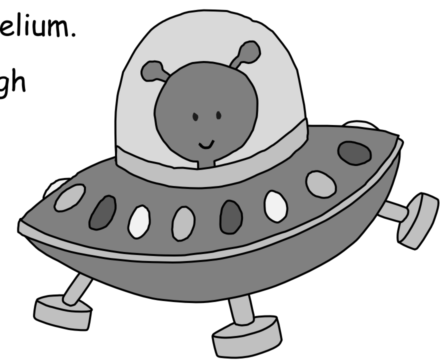
Super simplified version of nuclear fusion

There's one more thing that you need to know. Stars have different life stages (just like us). Our sun is in a stage called **the main sequence.** This is the longest stage of any star's life. During this stage stars spend all of their time fusing hydrogen into helium in their core. Our sun has been doing this for about 5 billion years and has about 5 billion more to go. Sooner or later a star will run out of hydrogen and that's when the more interesting stuff begins to happen. Without any more fuel a star will die, so the star thinks "Hey, I don't have anymore hydrogen, but I've got plenty of helium… why don't I start fusing that?" (Disclaimer: stars do not really think) And that's how it works. That's how we get the first elements not created during the big bang. Stars will start fusing heavier and heavier elements as they run out of lighter ones. Our sun is a small star compared to others and will never make any elements much heavier than carbon. The biggest stars will make new elements all the way up until iron. When large stars reach the point where they have fused all of the elements that they possibly can, they begin to collapse until … BOOM! The star violently explodes in what we call a **supernova.** It is during a supernova that all of the heaviest elements on the periodic table are made as the atoms get slammed together with incredible force. Supernova explosions also send stardust flying out into space to be recycled and used elsewhere. Sadly our sun will never be large enough to go out in such a spectacular show. Our sun, like most average and small stars, will end up as a **white dwarf**, living off of built up energy for billions of years after it runs out of fuel, dimly twinkling until it fades.

One last thing… you're made of stardust

Yes… I know… this is probably news to you, but it makes sense if you follow the logic:

1. The only elements made in the big bang were hydrogen and helium.
2. The rest of the elements (heavy elements) were made through nuclear fusion in the core of stars and during supernovas.
3. You have many more elements than just hydrogen and helium that make up your body.
4. The heavy elements in your body are mainly incorporated into your body from the food you eat and things you drink.
5. The elements in your food and drink can be traced back to the Earth, it's water, or it's atmosphere.
6. The Earth formed in a neighborhood in space rich in recycled stardust,



Conclusion: Yep… you are made of stardust. Stars that explode send their matter flying in every direction. Everything in the universe is recycled. This matter gets used to build new stars, and sometimes, clumps of matter will stick together and begin to rotate around them. These eventually become planets. Our planet is one such ball of recycled stardust that revolves around our sun. Fascinating, isn't it?

Our Blue Planet

Our galaxy, the Milky Way galaxy, is very normal. It contains over one-hundred billion stars, one of which is a very ordinary star that we call the sun. Rotating around this very average star is something not-so-average, something extraordinary – the only place that we know of in the entire universe that can support life. Earth.