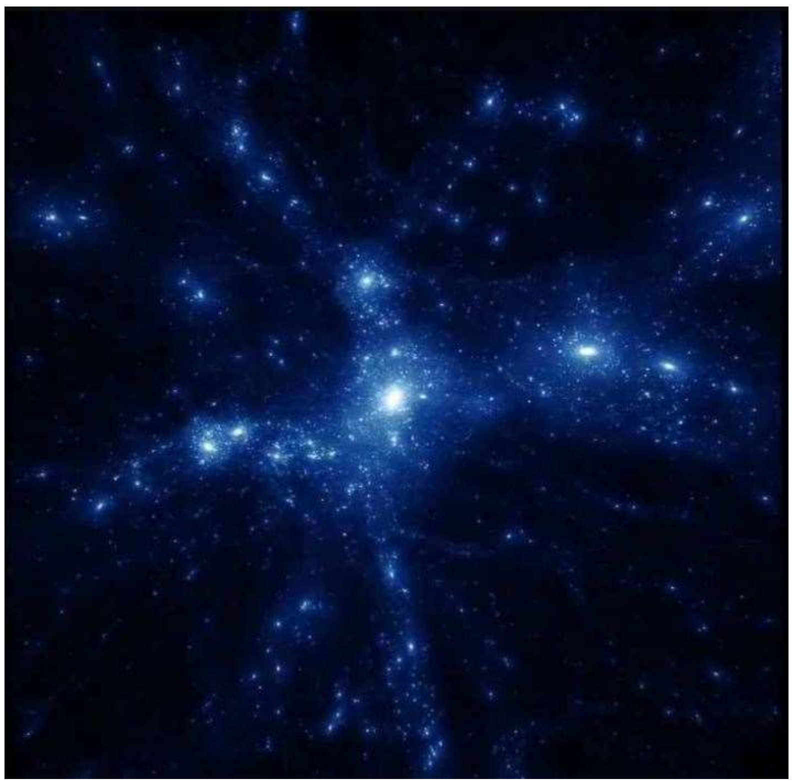
The Big Picture



The Origin, History and Ultimate Fate of the Universe

The Big Picture

The Origin, History, and Ultimate Fate of the Universe

Adapted from a presentation made to
the 50-year reunion of
the Dartmouth College Class of 1968

by Gerry Bell

Dedication

To my grandson Eric, who likes
to look at the stars in the night sky,
and who is a star himself

The Big Picture

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Introduction

My part of this story began when I was eight years old. I would lie in bed at night, looking at the stars and wondering about the great questions of the universe. How big was it? Did it have a beginning? What was that like? What happened before the beginning? What happened right after? How did it get to be the way it was? What would become of it?

I was absolutely consumed with curiosity about these questions. I actually remember thinking one night that if I could only know the answers for sure I could die a happy man.

The prevailing theory of the universe was called the "Steady State" theory. It held that the universe was infinite, unchanging, and eternal – infinite in space, infinite backward in time as well as forward. It had always existed, it always would, just as it was now.

Most astronomers embraced Steady State because it allowed them to dodge the issue of the Creation and a Creator. They could believe that the universe had always been able to support life and always would. There was little support for an alternative, because there wasn't much observational basis for a universe beginning from a single point. The study of an "early" universe was not the sort of thing to which a "respectable" scientist would devote his time.

Well, the majority of astronomers may have liked Steady State, but I – all of eight years old – did not. I felt in my bones, in my soul, that the universe *had* to have had a beginning; it couldn't possibly have existed forever, in an infinity of time backward. And it couldn't have sprung full-blown immediately across infinite reaches of space either. "Infinity" seemed to me to be a cop-out: fine for the mathematical notion of the number of geometric points on a line, but not a viable concept for physical reality.

So I believed that the universe had to have originated at a definite time in the past, and grown and evolved from a single point. Nothing else made any sense to me.

There was a term for my point of view. It was called the "Big Bang" theory. It was a derisive term, coined by a British astronomer named Fred Hoyle, who was the main proponent of the Steady State theory. In a radio debate in 1952 he'd sneered at his opponent, asking, "What do you think there was? A big bang?"

In the spring of 1964, just before we came to Dartmouth, I was proven right … well, I along with a few others who had PhD's … The universe did start with a big bang, some 13.8 billion years ago, and has been expanding and evolving ever since.

What I'd like to do today is take you through the history of the universe from the beginning to the present day, sharing with you what we know and how we know it, and then give you a glimpse of the future and the ultimate fate of the universe.

We'll follow an outline that roughly parallels the milestones in a human life: infancy, toddlerhood, early childhood, growing up, maturity, destiny, legacy … I'll end with a couple of thought-provoking images close to home.

The Infant Universe

<u>The First Second</u> – So, in the beginning there was this Big Bang, right? Not exactly. I think most of us instinctively picture the Big Bang as starting with an incredibly dense, tiny speck of matter hanging in a black void; it blows up in a cataclysmic explosion, and all the grenade fragments form all the galaxies and stars and planets.

It didn't happen that way. In the beginning there was … nothing. No tiny dot of matter, no black void of space … nothing. And no time either, because with nothing going on, how could time be measured? No matter, no space, and no time … nothing.

But it turns out that nothing is a *very* unstable state. It is brimming with possibility, with potential energy; nothing *desperately* wants to become *something.* Remember the paleontologist in Jurassic Park explaining the dinosaurs' asexual reproduction to the young girl? "Life will find a way," he said.

Some 13.8 billion years ago, nothing found a way. It winked into existence through an incredibly tiny gap into reality – an almost inconceivable amount of potential energy transformed into kinetic energy (motion) and thermal energy (heat). It was accompanied and governed by a superforce of perfect symmetry, combining the four fundamental forces of nature: gravity, electromagnetism, the strong nuclear force, and the weak nuclear force.

Here are the first few events in the first second:

The Big Picture
First Second Milestones

Time	Milestone
10^{-43}	Perfect symmetry broken; gravity splits off from the superforce
$10^{-43} – 10^{-36}$	Grand Unified Epoch
10^{-36}	Strong nuclear force splits off; triggers inflation
$10^{-36} – 10^{-32}$	Inflation: the real Big Bang

At 10^{-43} seconds after the beginning the universe was very small, 100 billion billion times smaller than a proton; and very hot, 100 billion billion trillion degrees. It was 10^{-35} meters across. That's the smallest dimension we can imagine with length, breadth, or height. Smaller than that and all our physical laws break down, and everything disappears into what we call quantum foam.

The same interval -- 10^{-43} seconds – is the smallest interval of "smooth" time we can imagine. We call it Planck time, after Max Planck, creator of quantum theory. It's one tick of the cosmic clock, and it's the time light would take to cross the distance of 10^{-35} meters, which we call Planck length.

At that one tick, the perfect symmetry of the superforce was broken, and gravity split off. The next interval, from 10^{-43} to 10^{-36} seconds, is called the Grand Unified Epoch, because the other three fundamental forces were still combined, and we have a pretty good understanding of that. We call it the Standard Model, and we can write out all the equations for it.

During the Grand Unified Epoch, the universe expanded to 480,000 Planck lengths. It was now 10^{-30} meters across – "only" a million billion times smaller than a proton. It wasn't exploding; picture instead a sphere, like a balloon expanding very rapidly, full not of air or water, but of pure and very hot energy that was interchangeable with matter.

At 10^{-36} seconds, the strong nuclear force – the force that holds atomic nuclei together – split off. And that triggered something very strange. The expansion of the universe ran away with itself. We call this exponential growth "Inflation." From 10^{-36} to 10^{-32} seconds the universe doubled in size some 50 to 100 times. I don't mean it became 100 to 200 times bigger; I mean 2-4-8-16-32-64-128 … So 2^{100} would be about 10^{30} – 10 with 30 zeroes – and since the volume of a sphere is proportional to the cube of the radius, the volume would increase on the order of 10^{90}. The universe expanded from a million billion times smaller than a proton to the size of … a grapefruit.

A *grapefruit*?? Big deal, right? Well, consider this. In that same time interval , and keeping the same proportions of scale, a grain of sand would have grown to something larger than the Milky Way galaxy, more than 100,000 light years across.

So … Planck time and the Grand Unified Epoch may have been the Creation, but Inflation was the *real* Big Bang. At the end of it, all the energy of the universe had been released. It just needed somewhere to go – and since the universe was creating its own space as it went along, it would have a universe full of room to go to.

Here are the next few events in the first second:

The Big Picture
First Second Milestones (Cont.)

<u>Time</u>	<u>Milestone</u>
10^{-32}	Inflation's "graceful exit"; reheating; vacuum energy transformed; flood of massless subatomic particles; first seed matter for the universe
$10^{-32} – 10^{-24}$	Quark Era; quarks and anti-quarks form from background energy and annihilate back to energy
$10^{-24} – 10^{-12}$	X-boson decay; more matter than antimatter

At 10^{-32} seconds, inflation stopped. The universe's expansion didn't stop; it was still roaring along. But inflation's exponential doubling found a "graceful exit" -- something we're still trying to fully understand. But it's a good thing it happened. If inflation had continued much longer all that energy would have dissipated across trillions of light years within one second.

When inflation made its graceful exit, the energy that carried it – for want of a better term, we call it "vacuum energy" – was transformed back to thermal energy in a process called “reheating.” A flood of massless subatomic particles was created, and became the first “seed matter” -- about the weight of an apple – for the universe.

The next two periods, from 10^{-32} to 10^{-12} seconds, are called the “particle desert” because no atomic particles emerged that stuck around permanently.

From 10^{-32} to 10^{-24} second, quarks – we’ll get to their permanent presence shortly – and their antimatter counterparts emerged in pairs from the hot background energy, immediately annihilated with one another, and were transformed back to energy.

In the next interval, a high mass particle called the X-boson and its counterpart emerged. These were very unstable, and they decayed -- fell apart – very quickly into quarks, antiquarks, electrons, and antielectrons. Remember that perfect symmetry had already been broken, and it happened again; this new asymmetry produced a tiny excess of particles over antiparticles, about one part in a billion.

Now for two very important events:

The Big Picture
First Second Milestones (Cont.)

Time	**Milestone**
10^{-15}	Dark matter; last stable supersymmetric particle
10^{-12}	Electroweak symmetry broken; electromagnetism and the weak nuclear force split apart

Somewhere in this interval, perhaps about 10^{-15} seconds, we think dark matter was created. We call it "dark" because it doesn't interact with light, or with atomic matter, or with anything except gravity and the weak nuclear force. We can't see it or any direct physical footprint of it except for the effect its gravity has.

We think that dark matter might have come about because of supersymmetry: the idea that for each particle in the beginning there was a heavy symmetrical superparticle partner. Almost all these heavy particles decayed to become light ones, except – maybe – dark matter might be the last remaining stable supersymmetric particle.

Now, dark matter is spread very thinly across the universe. There is only about a kilogram's worth of dark matter in a volume of space the size of the Earth. That doesn't seem like much, until you realize that the volume of space in and around a galaxy is more than a trillion trillion trillion times the volume of the Earth.

So whatever dark matter is, there's a lot of it. Dark matter is six times more plentiful than atomic matter, which is all the stuff we see. As we'll see, it played a huge role in the evolution of the universe.

At 10^{-12} seconds, electromagnetism and the weak nuclear force – which enables atomic decay, and thermonuclear reactions, and the shining of stars – split apart. The four fundamental forces of nature were now separate and distinct.

From here on, we are absolutely sure about what happened, because we can recreate these conditions experimentally in our particle accelerators.

Now for the last few events in the first second:

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First Second Milestones (Cont.)

Time	Milestone
10^{-11}	Higgs mechanism begins; quarks and electrons acquire mass
$10^{-12} – 10^{-6}$	Quark freeze-out and annihilation
10^{-6}	Quark confinement
1 second	10 billion degrees; 1 ton/cubic cm; 20 light years wide

At 10^{-11} seconds, the Higgs mechanism came into play, and matter acquired mass. You've probably heard of the Higgs boson, nicknamed the God Particle? Talk about overrated – the Higgs *boson* had nothing to do with imparting mass to matter, but it did prove the existence of the Higgs *field*, which did.

The Higgs field is a quantum field that permeates all of space. Think of its operation like this. Women are frequently reluctant to saturate their hair with hair spray – it makes it all icky – so they will often spray the air two feet in front of them, and then walk through the fine mist. Imparts body and hold to their hair without overdoing it – just right.

The Higgs field operates in much the same way to impart mass to the matter passing through it – except, of course, there's no hair and no mist. But you get the idea.

From 10^{-12} to 10^{-6} seconds we had a period of quark freeze out and annihilation. As in the particle desert, quarks and antiquarks emerged from the background energy, but the temperature of the universe had cooled enough with expansion that they didn't immediately flash back. They "froze out" in the cooler temperature and sped around for a bit, then collided and annihilated with one another – except that billion-and-one to a billion asymmetry still held, and matter won out and acquired mass in the Higgs field.

At 10^{-6} seconds, the temperature had fallen enough that the strong nuclear force could bind quarks together in groups of three; that is, it "confined" them to form protons and neutrons. Neutrons can decay; but protons are just about forever. Think about the protons in your body: each one of their constituent quarks survived billion-to-one odds to be here, and each proton has an unbroken history back to this time – a millionth of a second.

So the next time some science denier disputes the Big Bang theory of creation by sneering, "How do you know? Were you there??" you can say, "Yeah! Most of me was! Just about every subatomic particle in my body was there! Yeah!"

Finally, at one second, the temperature of the universe was 10 billion degrees; its density was one ton per cubic centimeter – by contrast, the density of the Earth is 5 grams per cubic centimeter -- and the universe was 20 light years across.

I'm sure at this point you have some questions. Let me try to anticipate and answer some of them.

What triggered the Creation? What caused it?

There are a lot of answers for this:

- A Creator. Okay, but who created the Creator? That's an endless loop. It's philosophy and religion, which I respect – but it's not physics.
- The Creator is in the things we don't know, and can't comprehend – that are beyond our understanding. This is called the "God of the Gaps" argument. Except we keep filling in gaps – people devote their entire careers trying to fill in one gap or another. We fill in the last one, and there's nothing left for a Creator to do!
- Intelligent design – This is not the spurious "intelligent design" that denies evolution; it's the idea of intelligent design on a cosmic scale. It says that, if certain values and ratios and percentages were the slightest bit different, the universe wouldn't be the way it is, or it wouldn't exist at all, and we wouldn't be here. So, the argument goes, someone had to fine tune the dials. But that's like learning that Lou Gehrig died of Lou Gehrig's disease and saying, "What are the odds of that?"

Look, the universe is the way it is, and the way it is permitted us to evolve and be here. And if such an against-all-odds circumstance troubles you, consider this: who says this universe was the first shot out of the box? There wasn't anyone around to count any failed attempts.

Actually, that idea helps me a little in accepting the possibility of "a universe from nothing." Maybe there were millions of times that the universe tried to wink into existence out of nothing, but gravity emerged too soon, or proved too strong, or inflation didn't start "on time", and gravity sucked everything back into nothingness …

Many false starts out of nothing … until that one Goldilocks moment that resulted in this universe. That may give the truth to what one cosmologist famously said: "Maybe the universe is just one of those things that happen from time to time. It's the ultimate free lunch."

Second question: How could all this have happened in one second? That's an impossibly short time.

No, it isn't. A second is an eternity to Mother Nature.   Just because we can't think or imagine that fast doesn't mean it can't happen. There are ten million billion billion billion billion Planck times in one second; by contrast, the universe isn't even a billion billion seconds old. A second is plenty of time.

Consider some of the things going on in your own body. In one blink of your eye – 2/5ths of a second -- the molecules in your eye vibrate 10 billion times. For each vibration, electrons orbit atomic nuclei a million times; for each of those orbits, protons and neutrons orbit the center of the nucleus a million times; and for each of those, the quarks orbit inside the proton and neutron shells a million times.

Ten billion million million million events, in the blink of an eye, in your own body. It really happens. As Ferris Bueller said, "Life moves pretty fast. You gotta slow down every once in a while to appreciate it."

Third question, and an obvious one. How could the universe be 20 light years across at one second? That's 120 trillion miles. The speed of light is 186,000 miles per second, and the speed of light is the cosmic speed limit. Nothing can travel faster than light. So what gives?

"Nothing can travel faster than light." That's the most misleading, incomplete sentence in physics. The fact is nothing can travel *through* *space* faster than light. But space itself can expand faster than light – way faster. And the expansion of space can carry objects along with it, like the crest of a wave carries a surfer, or a gust of wind carries a leaf – or the expansion of space carries a galaxy. Also, space expands not just at the edge, but everywhere – so as it expands between two objects, they can look like they're moving away from each other at faster than light speed.

Just for fun, I played Captain Kirk and computed the warp factors – the multiples of the speed of light – that occurred as space expanded during the first second.

The Big Picture
Warp Drive, Mr. Scott!

Time	**Radius**	**Cumulative Warp Factor**
10^{-36}	3.8×10^{-30} m	.013
10^{-32}	0.1 m; 4 inches	3.0×10^{22}; 30 billion trillion
10^{-12}	50,000,000 miles	2.6×10^{14}; 260 trillion
1 second	10 light years	315 million

Throughout most of the first second, except for the very beginning, the cumulative expansion speed was trillions and billions and millions of times faster than the speed of light – thanks to inflation. But the .013 fraction of the speed of light during the Grand Unified Epoch is really important in solving what we call the "horizon problem": how is it that the laws of physics are the same throughout the universe, if the universe expanded at faster than light speed? The answer: the Grand

Unified Epoch, and its .013 fractional speed of expansion, was the only time that the entire universe was in "causal contact." It was only then that the laws of physics could be transmitted across the entire universe before the expansion exploded to almost unimaginable multiples of light speed and made further universe-wide communication impossible.

Now, in spite of all of these huge multiples of the speed of light, the warp factor number is decreasing. What's slowing the expansion? Gravity. Gravity is the weak sister among the four forces – the weakest by dozens of orders of magnitude – but her reach extends across the universe. She's everywhere, and she's relentless. She never stops. She is the crucial catalyst in the evolution of the universe. We'll be referring to her again and again as we move along.

<u>The First Three Minutes</u> -- Let's move on to the balance of the first three minutes, after the first second. To recap: at one second, 10 billion degrees, 1 ton per cubic centimeter, 20 light years across. At that point, neutrinos – which turn neutrons into protons – decoupled. That is, the universe had cooled enough that neutrinos no longer had the energy to interact with matter. Good thing too, because if that interaction had continued, the proportion of neutrons to protons would have continued to drop. By 10 seconds the ratio of neutrons to protons would have been nearly zero, and we'd have a universe made only of hydrogen and nothing else. But when decoupling occurred at one second, the ratio of neutrons to protons was 1:6. Neutrons decay over the course of an hour, so at one minute there were fewer of them, and the ratio had decreased to 1:7.

After a minute, the expansion reduced the temperature to about 3 billion degrees and the matter density to 100 gm/cubic centimeter.

That's very much like the conditions in a hydrogen bomb one nanosecond after detonation of the fission trigger.   So think of the universe at this moment as an inconceivably large hydrogen bomb. An H-bomb's release of energy comes from a fusion reaction: hydrogen nuclei (protons) and deuterium nuclei (a hydrogen isotope with one proton and one neutron) fuse to form helium nuclei (two protons, two neutrons) with some matter converted to energy: $E=mc^2$, Einstein's equation, the most famous in physics. Think of c^2 (the speed of light squared) as the currency exchange rate between matter and energy, with the exchange much in energy's favor: turn a kilogram of matter into energy and you have a 10-megaton explosion.

So the giant hydrogen bomb went on fusing hydrogen into helium for the balance of the first three minutes, until the universe expanded and cooled so much that the temperature and pressure were no longer high enough to allow continued fusion reactions – and they stopped.

But at that point, we had a recognizable universe. Virtually all the atomic matter that there would ever be had been created. As Bill Bryson says in "A Short History of Nearly Everything" -- "… in about the time it takes to make a sandwich."

How do we know all this? A ratio of 7 protons to 1 neutron – what we had at one minute -- is the same ratio as 14 to 2. There are two protons and two neutrons in a helium nucleus, one proton in a hydrogen nucleus. By number, twelve hydrogen nuclei (one proton, atomic mass 1) for each helium nucleus (two protons and two neutrons, atomic mass 4) – but 75% hydrogen and 25% helium by *mass.* And that is almost exactly what we have in the universe today. More important, 13.8 billion years is not long enough to fuse that much hydrogen into helium in stars across the universe. It had to have happened in the Big Bang – and it did.

We call this fusion process, and the production of helium from hydrogen, nucleosynthesis; and a physicist named Stephen Weinberg won a Nobel Prize for solving and proving the first three minutes. I told you that people spend their entire careers figuring out the gaps!

<u>The First 57,000 Years</u> By 10 seconds, electrons and antielectrons had annihilated in the same billion-and-one to a billion ratio that quarks did during the first second. Radiation – light – then became the dominant constituent of the universe. We equate light with photons, massless particles that carry its energy. And we know from $E=mc^2$ that matter and energy, with the help of an exchange rate, are equivalent; both have density, and both exert gravitational force.

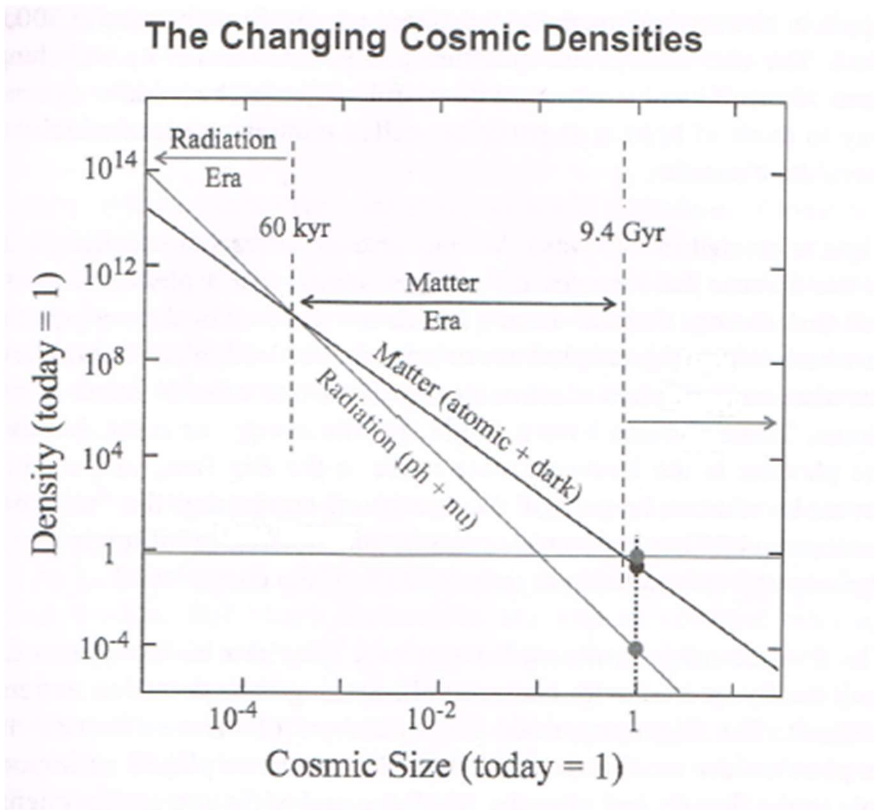
Light was so dominant that at 10 seconds, it had a density 200 times that of lead – much denser than matter at the time! The obvious thought is, "Wow, must have been really bright! What did the universe look like?"

You couldn't have seen it. For one thing, there was no place to stand to look at it – remember that the balloon was making its own space as it went along, and outside of it was not empty space, but *nothing*. Even if you could have manufactured a place to stand, you would have been engulfed by the fireball before you saw anything, because space was expanding far faster than light speed. And even if you could have solved those two problems, you wouldn't have seen anything anyway because the universe was opaque – the photons couldn't travel in straight lines to carry light to an observer, because the primordial soup was so dense that the photons kept bumping into other particles and getting deflected from their paths.

It's a little bit like your waiter in a crowded cocktail lounge being unable to bring your drinks to you on the terrace – he keeps bumping into people, backing up, trying another direction, bumping into someone else, trying again, but unable to move in a straight line to get to the terrace.

If you were indestructible and inside the fireball, the photons – very hot, with enormous energy, but unable to travel in straight lines – would have formed a brilliantly glowing but impenetrable fog. You wouldn't have been able to see your hand in front of your face. But as the universe expanded and cooled some more, the density of light decreased, the fog got less thick, and indestructible you would have been able to see a few light years out before the fog shut down your visibility.

And something else happened. We know that the density of matter decreases with volume, with the cube of the radius. But the density of radiation not only decreases with volume, its energy decreases as well because of red shift: the lengthening of light's wavelength as the waves are stretched by the expansion of space. And longer wavelength means less energy. So the density of radiation decreases with the *4^{th}* power of the radius -- faster than the density of matter. By 57,000 years, the Radiation Era was over, and the Matter Era, when matter is the dominant component, had begun. Plotted on a logarithmic scale, the transition looks like this:



That horizontal line near the bottom is intriguing, isn't it? We'll get to him later; he's pretty important.

Baby Pictures: 380,000 Years and First Light

First Light -- Our universe continued to expand and cool. At 380,000 years, it was 92 million light years across and its temperature was 2700 degrees.

Cooling the universe to that temperature changed things dramatically. Electrons were no longer so active that they could zoom about freely. The force of electromagnetism overcame their kinetic energy and connected negatively charged electrons with positively charged hydrogen and helium nuclei. In today's parlance, they "hooked up" – we call the process "recombination." Stable, electrically neutral hydrogen and helium atoms were born.

With order emerging out of chaos among electrons and atomic nuclei, photons decoupled. Like neutrinos at one second, they stopped interacting with matter. They stopped banging into other particles and getting deflected; they could now travel in straight lines. Your waiter could finally bring your drinks to you.

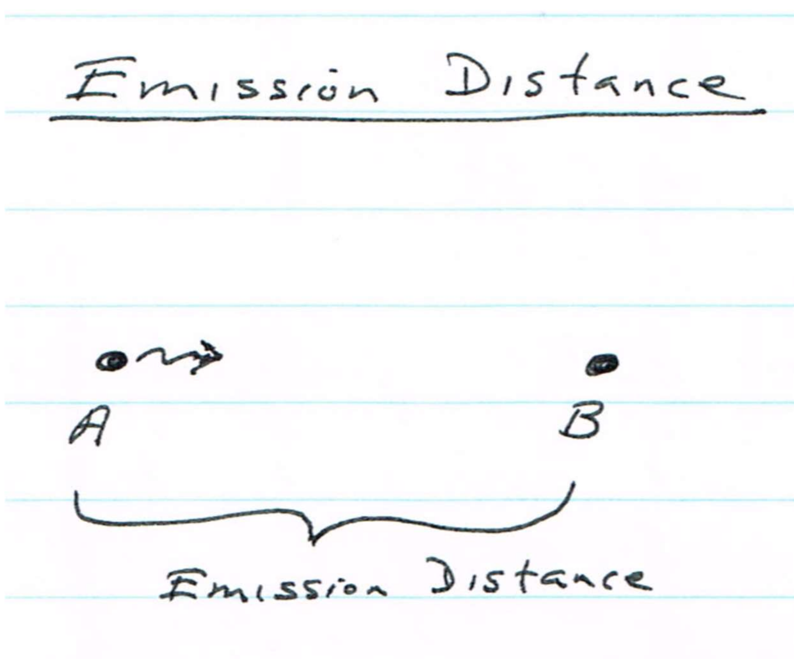
Put simply, the fog lifted. The universe became transparent. Inside the balloon, it was like being bathed everywhere in brilliant light – as if the face of the sun covered the entire sky.

Can we see that glow, that first light? Yes, we can. But let's set the stage by considering some of the distances associated with the speed of light, and some of the forms that light can take.

We generally measure astronomical distances in light years: the distance light travels in a year is about 6 trillion miles, and we'll say something is "a million light years away."

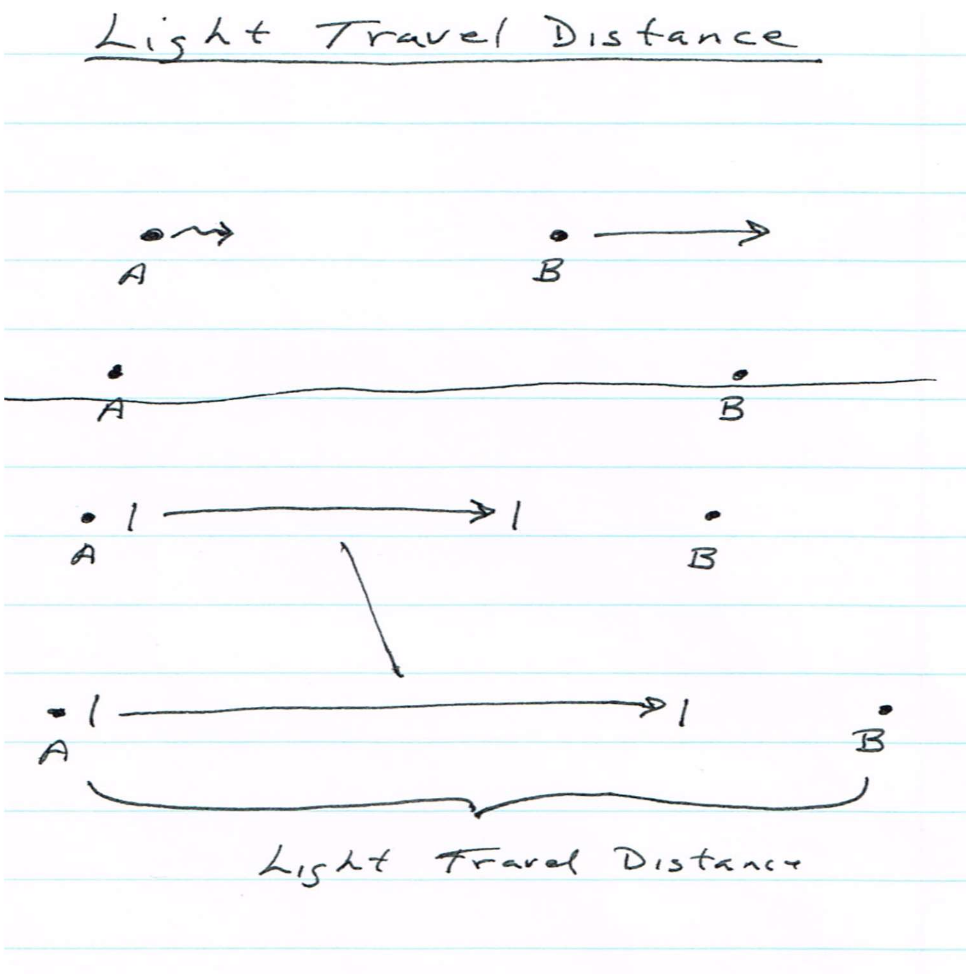
Except it isn't. There are three measures of distance associated with light:

- Emission distance:



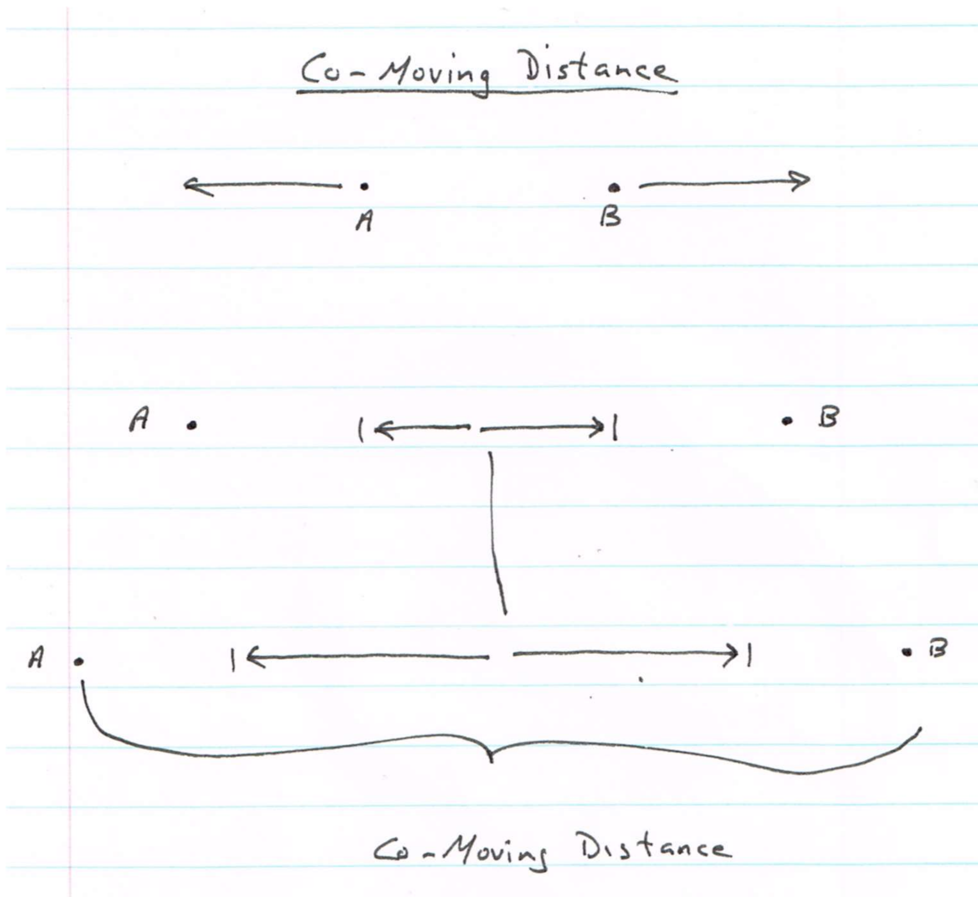
How many light years apart are two objects A and B when light from one starts its journey to the other?

- Light travel distance **:**



B is moving away from A because of the kinetic energy of the Big Bang itself. Also, the space through which light has to travel from the emission point of A is expanding. Both the motion of B and the expansion of space increase the time it takes light to travel from A to B. Equate this time interval to light years and you have “light travel distance.” This is also called “look-back distance,” because when the light from A arrives at B, an observer on B is seeing A as it appeared when the light started its journey. This “look-back” concept is the yardstick we use when we say something is "a million light years away." But as we'll see in a moment, that isn't quite true.

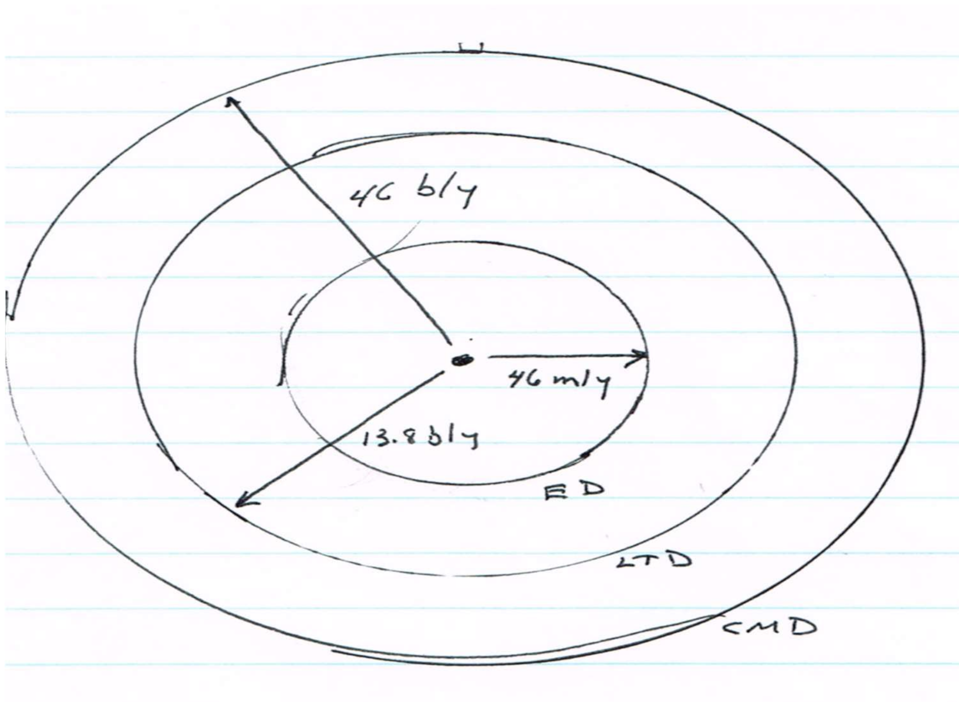
- Co-moving distance**:**



For co-moving distance, note that B and A are *both* moving because of the kinetic energy of the Big Bang. And, like two dots you might draw on the surface of an expanding balloon, they're moving *away* from each other. Further, the space between A and B is expanding, in two pieces that you can identify at any point on light's journey: the first and more obvious is the space through which light has yet to travel to arrive at B (as is the case with light travel distance); the second piece is the still-expanding space through which it's *already* traveled. All these pieces add up to the co-moving distance: the actual distance between the two objects when light finally reaches B. This is the *real* measure of "how far away" something is, even though we don't commonly use it.

Let's look at a very specific example. For the first light that we're receiving now, the emission distance is 46 million light years. That's the radius of the universe -- half its then 92 million light year diameter -- when the light was emitted 380,000 years after the Big Bang. The light travel time is 13.8 billion years, so the corresponding light travel distance is similar: 13.8 billion light years. But the co-moving distance is 46 billion light years: remember, the source of first light has moved farther away, and the intervening space has expanded, in the 13.8 billion years the light has been traveling toward us. It is now 46 billion light years away, at the cosmic light horizon of our *observable universe*.

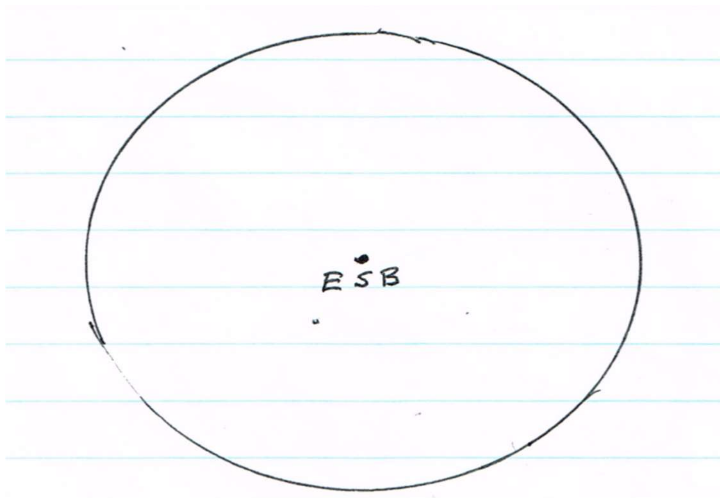
The Observable Universe -- What's that about? How is this different from the universe we've been discussing?



To answer this question, let's first draw a picture of a two-dimensional sphere (a circle!) with a radius of 46 million light years (emission distance), and we're at the center. Same as if you draw two-dimensional spheres of radii 13.8 billion light years (light travel distance) and 46 billion light years (co-moving distance). And we're at the center of the whole thing! Just as we always suspected – the center of the universe! Right? Well, thanks for playing our game, but … no. We're not at the center of the universe; but we *are* at the center of our *observable* universe – 92 billion light years across.

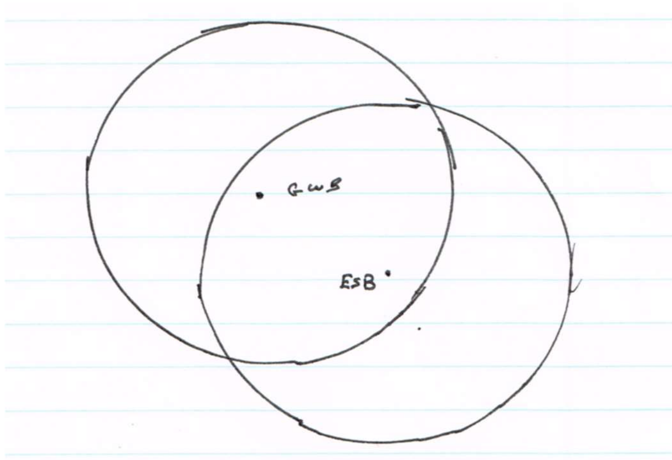
Let's create some examples of observable universes. If you stand at the top of the Empire State Building, you will have a visible limit – a circular horizon – beyond which you can't see anything:

Cosmic Horizon – Empire State Building



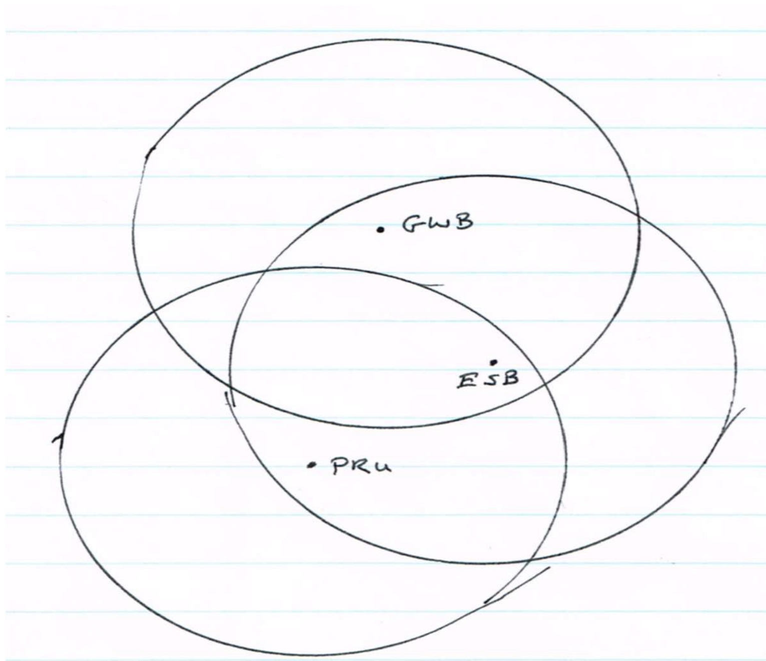
You will have another circular horizon if you stand on top of one of the towers of the George Washington Bridge. The Bridge's horizon will overlap part of the Empire State's, but it will also include geography not visible from the Empire State:

Cosmic Horizons – Empire State and George Washington Bridge:



You will get a similar result if you stand on top of the Prudential Building in Newark:

<u>Cosmic Horizons - Empire State, GW Bridge, and Prudential Building</u>:



Each of these has its own horizon analogous to the cosmic light horizon, or “edge”, of our observable universe. There is some universe beyond each of these, but it’s so far gone that light from it will never reach us – it will never overcome the expansion of space.

So – natural question – how big is the whole thing compared with our 92 billion light year observable universe? One well-publicized estimate a few years ago in Discovery Magazine suggested 150 billion light years, but that’s based on a flawed assumption about the geometry of space and – believe it or not! -- a confusion of radius and diameter. More likely the breadth of the entire universe is at least a trillion light years, probably in the trillions. Exactly how much depends on the mechanics of inflation during the first second: how much of the grapefruit our present observable universe represented at 10^{-32} seconds.

<u>CMBR</u> – Now let's return to first light, first to the form it took. The expansion of space increased the wavelength of the light rays setting out from the emission distance – so much that the wavelengths red-shifted through the red end of the visible light spectrum, through the infrared, and into the microwave part of the electromagnetic spectrum. So the "first light" that's reaching us now, 13.8 billion years later, is being received as *microwave* radiation.

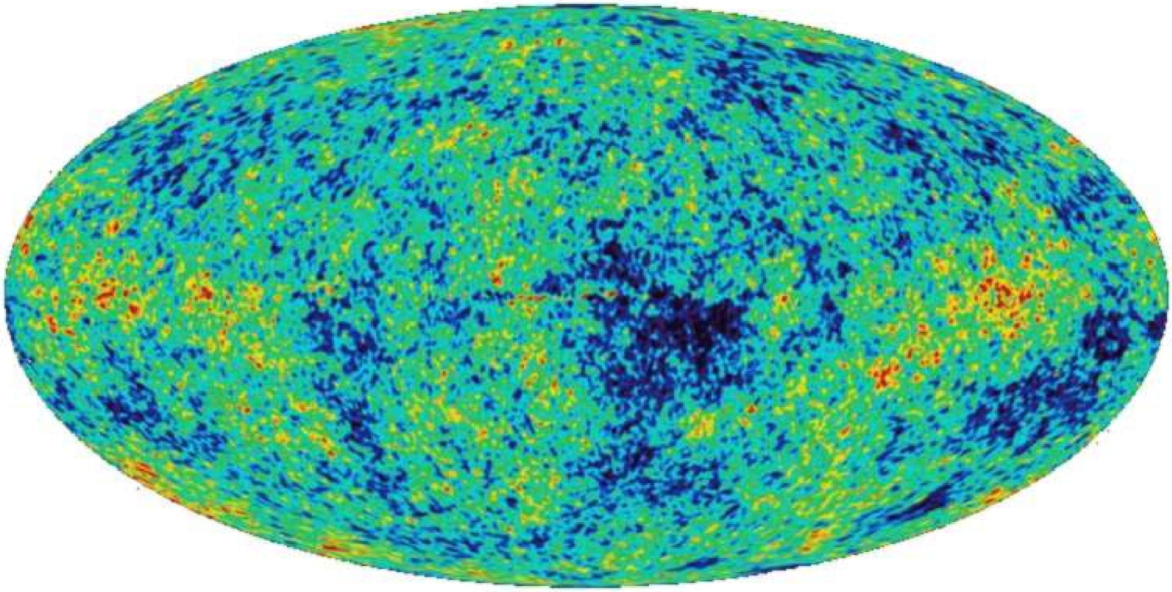
Its discovery came in 1964, by two Bell Labs scientists named Arno Penzias and Robert Wilson. They weren't looking for it; they didn't know what it was when they found it; they didn't even know that anyone had hypothesized its existence. They discovered it by accident. They were using a very sensitive radio telescope in Holmdel, NJ to study individual sources of microwave radiation, but they kept receiving an annoying background static hum – from every part of the sky, 24/7, no variation with the Earth's rotation or its path around the sun – constant. They checked the neighborhood for possible sources of radiation, but microwave ovens hadn't been invented yet so … nothing. They scrubbed the interior of the antenna free of bird droppings – and the static was still there. Finally, being good scientists, they collated all their data, put it in rows and columns, and sent it off to an astronomer named Robert Dicke, an expert on microwave radiation who was working at Princeton.

Dicke took one look at the data, turned to his colleagues, and said, "Well boys, we've just been scooped." Penzias and Wilson had discovered the *cosmic microwave background radiation* – the afterglow of the Big Bang. They won the Nobel Prize. Dicke, who had hypothesized the microwave background, figured out what it would look like, fully grasped its enormous implications, and was building an apparatus specifically designed to detect it – well, Dicke just got himself mentioned in this presentation. I know life can be unfair, but that's pretty harsh treatment even for a Princeton guy.

Don't minimize what Penzias and Wilson did; they deserved their prize. They knew they were on to something, and that's the way science works. The famous science writer Isaac Asimov once said, "A lot of great scientific discoveries start with the same two words: "That's funny …"

Personally, I think the microwave background is one of the half-dozen greatest scientific discoveries of all time: fire, gravity, electro-magnetism, relativity, the expanding universe, and the cosmic microwave background.

Now we come to our picture of first light. Here it is:



This is essentially a 360 degree Mercator projection of the microwave background, not on the outside of a globe, but on the inside of our celestial sphere, looking back through 13.8 billion years of time. It's the universe's baby picture, the first light from the Big Bang.

Actually, you can see a form of this yourself at home. Unplug your television cable, hook up an antenna, and tune to a non-broadcast station. The static you see that we used to call "snow?" One percent of that comes from the cosmic microwave background. So the next time your grandkids complain that there's nothing on TV, tell them they can always watch the creation of the universe.

<u>The Galaxy Blueprint</u> – The galaxy blueprint; what's that? Let's take a little closer look at that baby picture to see if it tells us anything else. The dark patches in the cosmic background are slightly cooler and therefore more dense. They will coalesce and eventually become

galaxies and galaxy clusters and superclusters – the large scale structure of the universe.

The amazing thing is where that patchiness came from. The patches are the result of quantum fluctuations within the grapefruit during inflation, blown up and transformed over the next 380,000 years into very slightly hotter/cooler, less dense/more dense regions. The entire blueprint for the universe – all the galaxies, all the large scale structure – was contained in a little ball the size of a grapefruit!

Just imagine that – for one brief instant, figuratively speaking, you could have held the entire universe, and all the form it would take, in the palm of your hand. I know the word “awesome” is really overused, but to me that’s … awesome.

So … the discovery of the cosmic microwave background changed everything. It confirmed the expansion of the universe first postulated by Edwin Hubble in the 1920s. It validated the Big Bang Theory – the universe grew from a single point. It showed us the key to the future large scale structure of the universe; it posed problems and requirements that only inflation theory seems able to solve; and it has borne out predictions from inflation theory that make us much more certain of the earliest events in the first second. We now know the Big Bang was really an “Inflationary Hot Big Bang”, and that’s what cosmologists now call it. Even if TV shows don’t. Still, pretty significant and dramatic conclusions from one baby picture, no?

The Terrible Two's: The Dark Ages – 200 Million Years

I'm sure you remember your children's Terrible Two's: they were a dark time of temper tantrums and self-absorption; they seemed to last forever; and there didn't seem to be a lot of development going on. But that wasn't true: the child was much different at age three than at age two, even if you didn't see any sudden dramatic change.

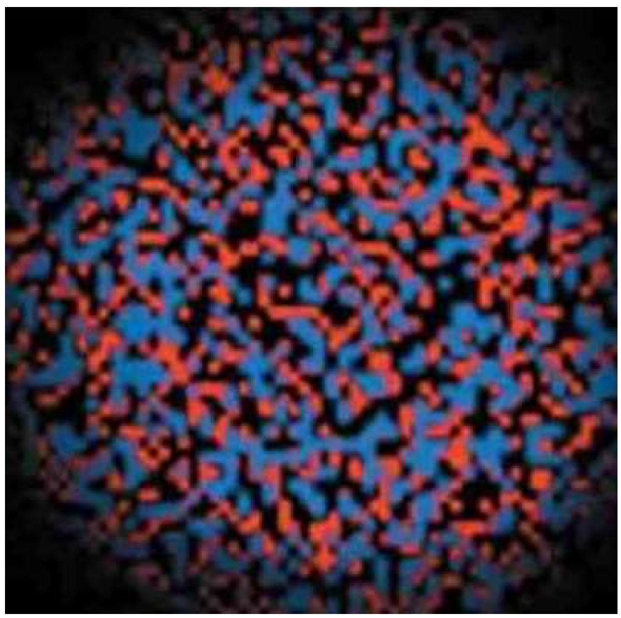
There was a similar transition for the universe. From the time of first light at 380,000 years to 100 million years, expansion and red shift made the universe dimmer and colder. After 6 million years, light had redshifted into the infrared part of the spectrum and made the universe pitch black. After 17 million years the temperature dropped below zero degrees Celsius and we entered a long frigid night called the Dark Ages.

But there *was* something going on, and it was attributable to dark matter and gravity. Dark matter exerts a gravitational pull, even on itself. At 100 million years, dark matter began to clump together and make the universe lumpy rather than smooth. Gravity then halted the expansion of the densest regions of dark matter and they began to collapse. Since dark matter particles can't collide and release any energy – we call them WIMPs, for Weakly Interacting Massive Particles – their collapse couldn't continue very far. So a dark matter clump would settle into a fuzzy sphere about half its original size, and its overall density would still be low. We call these collapsed objects "mini-halos" because they're smaller versions of the huge dark matter halos that surround entire galaxies today.

Galaxy halos of dark matter hold galaxies together and govern their rotation speed. Observing this is, in fact, how we first determined the existence of dark matter. But mini-halos were different: they're the nurseries within which atomic matter gathered to give birth to stars. At 200 million years, the nurseries were all built, and waiting. The Dark Ages were about to come to an end.

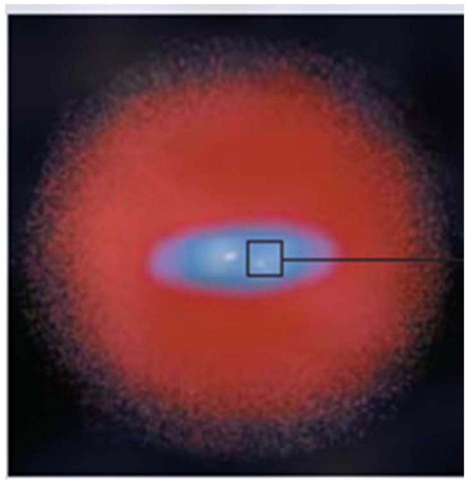
Beautiful Child: The First Stars

The mini-halos of dark matter exerted a gravitational pull on atomic matter, drawing it into the clumps. Since dark matter doesn’t interact with atomic matter, the mini-halo was mixed, and took this form: the dark matter is red, and atomic matter – mostly hydrogen gas – is blue.



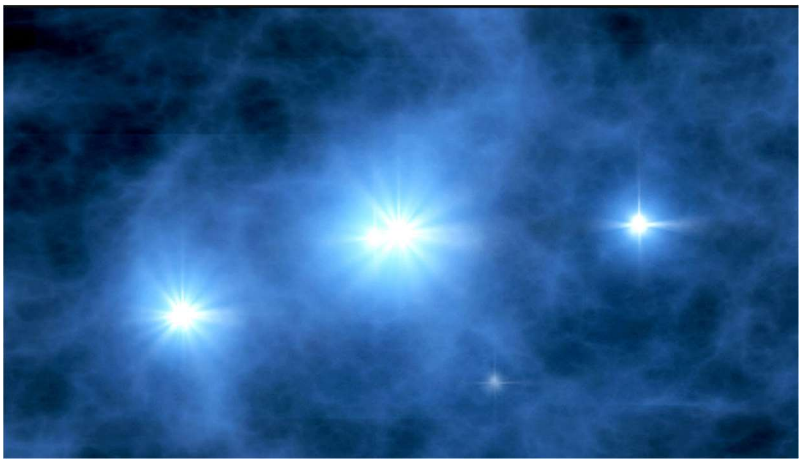
Unlike dark matter, the particles – the atoms -- within atomic matter collide with one another. The collisions produced photons that left the gas, cooling it. This reduced the outward gas pressure and allowed the atomic matter to collapse to a much smaller size.

The result looked like this:



The atomic matter has collapsed to the center of the mini-halo – dark matter particles didn’t get in the way, because they’re WIMPs and don’t interact with atomic matter. So the dark matter remained dispersed, and the atomic matter became very concentrated and very dense at the center of the mini-halo. Eventually the density, and the resulting temperature, and the resulting pressure became so high that fusion reactions could occur – and a star turned on. It was the very first starshine.

This first starshine came from very large stars. The first mini-halos contained a million solar masses of dark matter and 100,000 solar masses of atomic matter – a “solar mass” is equivalent to our sun. The atomic matter was made up entirely of a mix of hydrogen and helium. But this mix couldn’t cool as efficiently as it would have if heavier elements had been present. So, since the gas was hotter and had higher outward pressure, more of it had to gather before it could finally collapse to form a star – and it made for huge, massive stars:



Since they were so large, the first stars were also incredibly powerful, maybe a million times brighter than our Sun. And their surfaces were extremely hot, perhaps 100,000 degrees compared with our Sun's surface temperature of 6000 degrees.

The stars' superhot surfaces emitted very strongly in the ultraviolet part of the electromagnetic spectrum. The UV radiation heated any additional hydrogen gas the surrounding dark matter might have been able to attract, ionizing it and preventing any more stars from forming in that mini-halo. So the first stars were very widely dispersed, maybe part of a very loose group of stars from other mini-halos – as in the picture above -- but widely dispersed nonetheless.

In short, the first stars were huge – probably the largest stars ever; they were hot – probably the hottest stars ever; and they were bright –

probably the brightest stars ever. And because they blew off all the neighboring hydrogen, they were loners, each off by itself.

I think they were also probably the most beautiful stars ever. And next year, when the James Webb Telescope is launched, we may actually be able to see them. Think of that – the very first stars, thirteen and a half billion years ago.

They were very short-lived. Because they were so large, they had to burn their fuel very rapidly to produce enough outward core pressure to resist gravitational collapse. The fuel went quickly. Compared with the 10-15 billion year life spans of today's stars, the first stars lived for only 3 million or 5 million or 10 million years. They were the original candles in the wind. And when they died, they became the first example of the discovery that saved the Big Bang Theory.

Independence

Saving the Big Bang -- Richard Feynman, a Nobel laureate and the greatest teacher of physics who ever lived, had this to say about scientific theories:

"First, you guess. I'm serious – you guess. Then you see if your observations conform to your guess – your theory. Then you conduct experiments to generate more observations to check. Then you try to use your theory to generate predictions, and see if your predictions are borne out.

"If at any point your observations diverge from your theory, or your predictions aren't borne out, your theory is no good. Doesn't matter how beautiful it is, or how much you love it -- it's invalid, and you have to discard it."

The Big Bang Theory had worked very well until this point, but it now faced a huge obstacle. It could account only for the elements hydrogen and helium; that's essentially all that nucleosynthesis produced in the first three minutes, and all that existed when the first stars formed. Where did all the other heavier elements – the stuff that makes up the Earth and you and me – where did those come from? The Big Bang Theory seemingly couldn't account for them – was it headed for Richard Feynman's wastebasket?

In what I think is the greatest irony in the history of cosmology, the man who solved the problem and saved the Big Bang Theory was … Fred Hoyle, the great proponent of the Steady State Theory, the implacable foe of the Big Bang.

He wasn’t trying to save the Big Bang; he was trying to buttress Steady State by explaining how, in an expanding universe, the new space vacated by diverging galaxies could be filled with new galaxies, so that the universe would be unchanging.

His reasoning went like this: “I’m here, and I’m made up of heavier elements. They had to come from somewhere. They couldn’t have come from what the Big Bang guys call nucleosynthesis; even they admit it wasn’t hot enough for fusion reactions to create heavier elements.”

The only place Hoyle could think of that would be hot enough to fuse helium into heavier elements like carbon and oxygen and then work their way up the chain to even heavier elements … was the interior of stars. What Hoyle reasoned out and explained – what saved the Big Bang Theory – was *stellar nucleosynthesis.*

We know that as the first stars burned through their hydrogen to make helium, the fusion reactions slowed. The temperature and pressure produced at the star’s core dropped, and gravity made the outer layers of the star start to collapse. That made the star’s core much denser, therefore hotter, therefore heavier element fusion reactions could occur. The increased outward pressure from these reactions made the star expand. When the fuel for that round of fusion reactions was used up, another cycle of contraction, new fusion reactions, and expansion would occur, until one final cycle and an ultimate collapse. If the star were massive enough, like the first stars, the final collapse would be very sudden, and the last fusion reactions would take only a short time – a couple of days at most, a few seconds for the largest stars. Then the collapsing star would rebound off its superdense core and explode as a supernova, spewing atoms of newly manufactured heavy elements all over interstellar space. What remained might be a superdense neutron star, or even a black hole.

Here's a supernova from a thousand years ago, its output of new heavy elements still expanding at 1000 miles a second.

We call these heavier elements – anything heavier than hydrogen or helium – "metals." It turns out that the presence of a small amount of metals along with hydrogen and helium promotes much more rapid and efficient star formation – and those stars don't have to be as massive or as hot as the first stars in order to turn on. But then these second generation stars, while living much longer, will go through the same end-of-life experiences as the first stars, spreading even more metals throughout space.

The atoms of the metals from all these exploded stars may float around in clouds of dust and gas for a few billion years, but eventually their own gravity and the gravity of dark matter will start clumping them together. New stars will be formed; and discs of dust and gas made from the heavier elements will start circling the new stars; then the material in the discs will start to clump together and make huge gas planets, or small rocky planets … or, in one specific case, people.

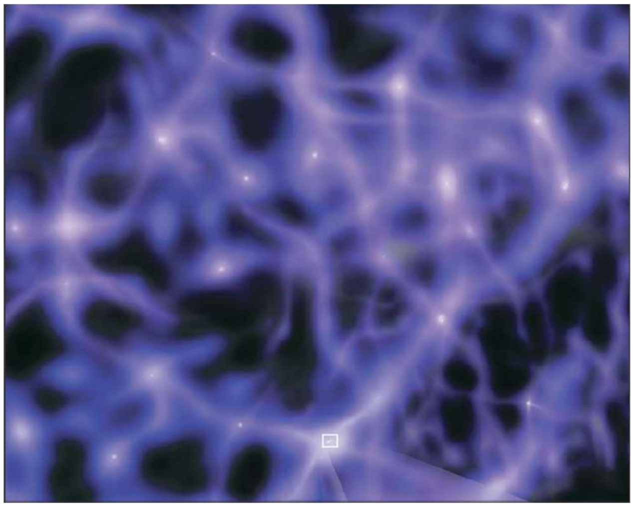
Think about that for a minute. You can debate who might have died for your sins, but there is no question that the stars died so you could live. We are all stardust. Every atom in your body – every single one -- was born in the heart of a dying star. In fact, the atoms in your left hand probably came from a different star than the atoms in your right hand.

Remember the old line about the Zen hot dog vendor? "He can make you one with everything." Well, you already *are* one with everything. You are one with the universe. Somehow that connection makes me feel a little less small when I look at the night sky.

<u>The First Billion Years and Proto-Galaxies</u> – Let's go back to the first billion years, and the period following the Dark Ages and the first stars. This is the time of the first proto-galaxies – a spectacular period we can see with our best telescopes.

Two ideas are at work here: smaller things merge to make bigger things, in a hierarchy of assembly; and the assembly was very rapid compared with the sedate pace of today's universe.

The first stars were loners; but dark matter, if not present in mini-halos, took the form of a network of filaments:



The first stars and second generation stars eventually started to coalesce at the nodes of these networks, and made small scale systems perhaps 30 to 100 light years across: star clusters.

Then gravity became the life of the party, and star clusters started to form groups called proto-galaxies, and after that infant galaxies. Computer simulations can show us this process. They typically follow the motion of simulated dark matter particles, each one pulled by all the others, so it's a complex, self-interacting system.

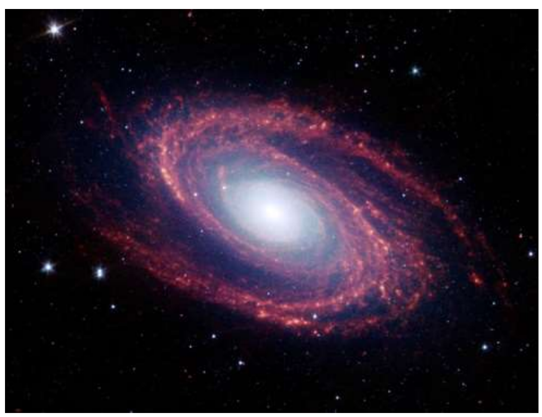
If we compare these very young galaxies with today's galaxies, it's like comparing toddlers with adults. Young galaxies are smaller, less than 10,000 light years across compared with the Milky Way's 100,000 light years. Many are interacting, about to merge or merging, and most of them appear chaotic and blotchy, unlike the beautiful symmetrical spiral and elliptical galaxies we see in Hubble photos.

But that was a long time ago, in galaxies far, far away. What's happened in the meantime?

Growth Spurt: 1–3 Billion Years

Infant Galaxies and Mergers – Over the past 12 billion years, the blotchy infant galaxies of a billion years became the majestic Hubble Telescope images we see today. The primary cause of this was *galaxy collisions.* These ranged from fly-bys, to minor collisions, to head-on collisions, to multi-galaxy pile-ups.

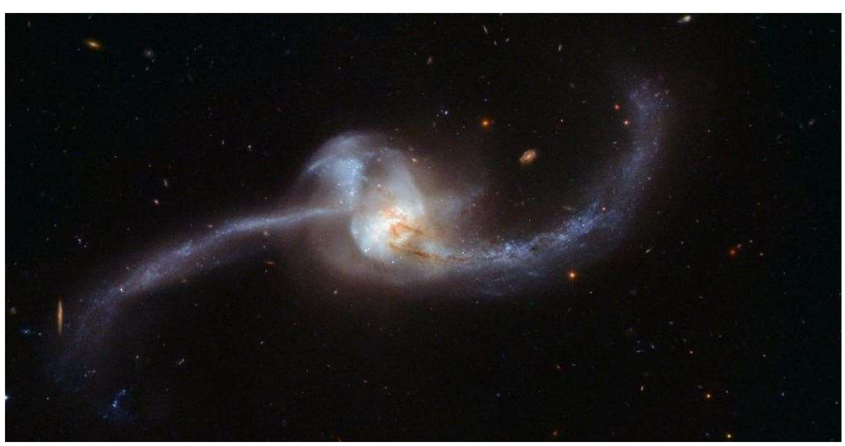
In a *fly-by*, the gravitational pull of the smaller passing galaxy disturbs the orbits of stars in the larger one, and the result is two tidal arms in the larger galaxy that form an “S” shape.



A *minor collision* is a relatively gentle process with the ungentle name of “galactic cannibalism.” The gravity of the larger galaxy slowly shreds the smaller and pulls off stars, which then form large tidal streams that orbit the larger galaxy.

Ultimately the smaller galaxy may be completely destroyed. We are fairly certain that all major galaxies, including our own Milky Way, “eat” smaller galaxies in this way. Gross, right? Not really. It’s *nature.*

Head-on collisions are much more dramatic. Take the case of two spiral galaxies colliding: as their spiral discs pass through one another, both are destroyed, and long tidal arms are flung out.



You might expect a multitude of stars to collide, but they don't, because they're so small compared with the space between them. All the effects we see are simply caused by gravity altering each star's trajectory.

Ultimately, the two galaxies merge to form a single large elliptical galaxy, the largest type of galaxy we know, containing up to a trillion stars.

Incidentally, this is what's in our relatively near future: in three to five billion years, the Milky Way and the Andromeda galaxy – both spirals – will begin a billion-year-long merger to become a huge elliptical galaxy.

<u>The Baby Boom</u> – The stars involved in galaxy collisions didn't collide, but the gas within the galaxies did. This compressed and heated the gas; some of it expanded out to the galactic dark matter halo, some cooled and sunk toward the galactic center. Both ultimately made stars

in huge numbers within the new galaxy, from the same mechanisms we've already seen.

So, when the pace of galaxy collisions was high, so was the star birth rate. If we look at distant galaxies – far back in time – we can measure the rate of star formation. In 1996, an astronomer named Piero Madau created the Madau Plot of the birth rate of stars from the Big Bang to today. It shows a rapid rise in the first billion years, a peak between one and three billion years – a Baby Boom! – and a steady decline after that.

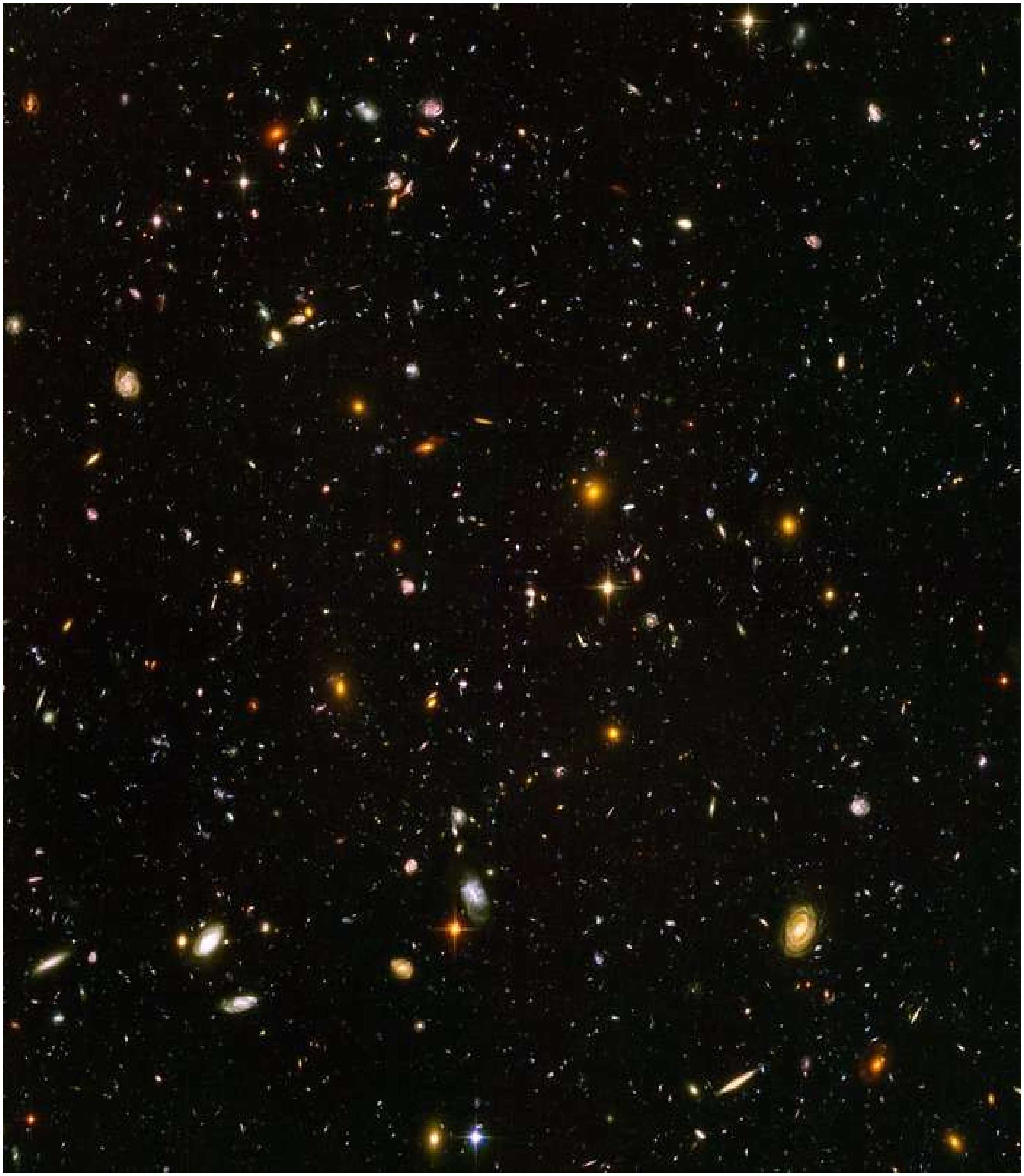
Why the decline? Because galaxy collisions, which were extremely common in the young universe, are now less frequent because of cosmic expansion – there's a lot more space between galaxies -- and because many galaxies have already merged. Today only 2% of galaxies collide, and the corresponding birth rate of stars is only 5% of what it was at its peak.

Growing Up: 3-9 Billion Years

It would be nice if we could see that whole progression, wouldn't it? From proto-galaxies to infant galaxies, through galaxy mergers and collisions, to the assimilation and maturing of today's galaxies …

Well, we can. In late 2003, NASA focused the Hubble Telescope on a completely black patch of night sky, about as much of the sky as you'd cover with a dime if you held it up ten paces away. Hubble stayed focused on that spot for 400 orbits of the Earth over four months, gathering all the light it could, sometimes at the rate of one photon a minute from the most distant objects.

It's been said that a picture is worth a thousand words. Sometimes it's worth even more. The result of Hubble's work is the most expensive photograph ever taken. It cost two billion dollars – and worth every penny. It's called the Hubble Ultra Deep Field, and it's the ultimate time machine, looking back through 13 billion years of the universe's history. Here it is, on the following page:



The most mature galaxies are in the foreground. Their light-travel distance is about four to five billion light years, so they'd already had eight or nine billion years to grow up and look like adults when their light started traveling toward us. Farther out, you can see an elliptical galaxy, **[Note: 8 o'clock left]** perhaps the result of a galaxy collision billions of years earlier. Right here is a collision in progress **[Note: 9 o'clock near left]**. Here are some results of galactic cannibalism: spiral galaxies with tidal arms. **[Note: 4 o'clock right, 10 o'clock left]** Here's a fly-by in progress. **[11 o'clock far left]**

As you look farther out, the shapes get more and more irregular and blotchy; the galaxies hadn't had time to mature by the time their light began its journey to us. The farthest proto-galaxies are just small blobs or even pinpoints; the most distant one in this photo has a light travel time of 13 billion years. And something else – the faintest, farthest galaxies are red – their light is redshifted because they're moving away from us so quickly. They are now 46 billion light years away, at the edge of our observable universe – just as we are at the edge of theirs!

This picture also provides further proof of the Big Bang. If Steady State were valid, these blotchy immature galaxies would appear throughout space, both near and far, as Steady State filled in newly created voids in the expanding universe and kept the universe unchanging. But the only blotchy proto-galaxies are way, way out, their light traveling almost from the beginning of time. Big Bang – not Steady State.

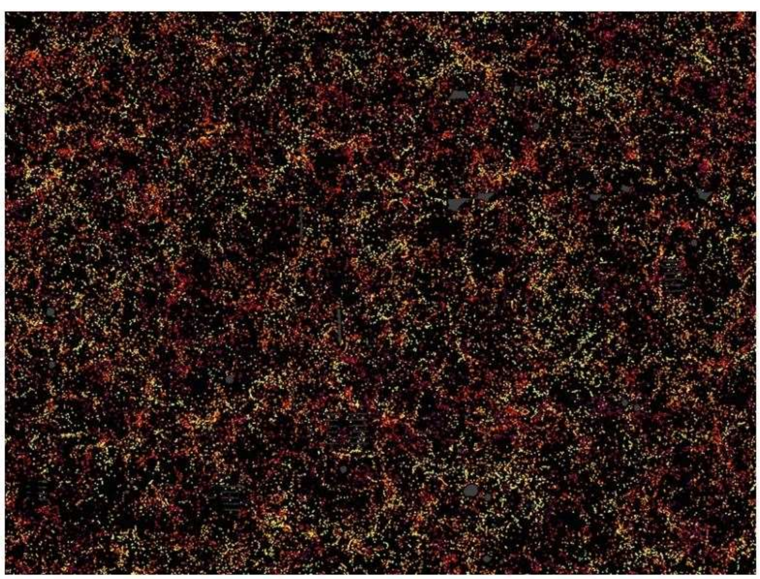
One final thought: Virtually every galaxy in this photograph – at least every surviving one -- is now 12 or 13 billion years old. All grown up. If the speed of light were instantaneous, they'd all look the same. As we're about to see, the galaxies – and the universe -- are mature.

Maturity: 9 Billion - 13.7 Billion Years

Large Scale Structure: The Cosmic Web – To look at structure, we're no longer looking at the *growth* of galaxies, but at the *pattern* of galaxies. If we look out at the universe in a sweeping pie slice, we see a sort of mottled web: voids, filaments that border the voids, and clusters where the filaments intersect.

The initial distribution we see – out to 200 million light years – is relatively smooth, but the web of filaments becomes apparent quite quickly as we get the perspective of more distance.   Galaxies appear to flow down the filaments into clusters; "downhill" is toward the clusters because of … gravity.

A pie slice of billions of cubic light years looks like this: it's called "One Million Galaxies."



It looks crowded because it's a two-dimensional picture of billions of light years of depth. Still, it all looks pretty much the same, doesn't it?

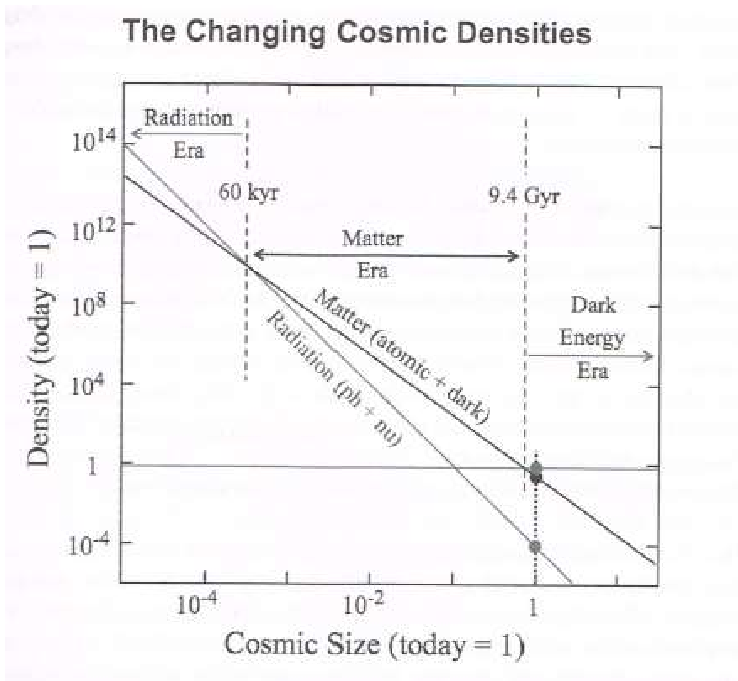
At these very large scales, we say the Cosmological Principle comes into play: the universe is homogeneous and isotropic. Homogeneous means it's made out of the same stuff everywhere; isotropic means it looks the same, no matter where you are, no matter what direction you look.

The large scale structure of the universe is just about complete; the universe is a fully mature adult.

<u>Dark Energy</u> – There was one other important development in this final maturation period: a new sheriff came to town. Well, he didn't *arrive* in town, he was there all along; he just asserted himself 5 billion years ago.

His name is dark energy. We noticed him about 20 years ago, and we now know enough about him that we can actually give him a name. But that's about all we know; the biggest quest in cosmology today is to find out more about him.

Remember the graph of changing cosmic densities we looked at, where matter became dominant over radiation? Remember the unlabeled horizontal line at the bottom? Here's the graph again, on the following page:



The horizontal line is dark energy. It's been characterized a number of different ways: a residual energy of empty space, a negative vacuum, a repulsive force … we don't know for sure, it just seems to be a property of empty space. It may well be related to the vacuum energy – or maybe the temporary anti-gravity? – that carried inflation along for the briefest of moments. Whatever it is exactly, it is the last remaining big puzzle. But it is incredibly important.

Here's why. Look at the graph and see, in the beginning, how low the mass-energy density of dark energy is compared with the densities of radiation and matter. *Very* low – remember the scale is logarithmic. Dark energy has the energy of a flea's jump in a volume the size of a football stadium – that's all.

Now look at the graph again and see how the densities of both radiation and matter, as you'd expect, decrease with increasing cosmic size. And radiation decreases faster than matter because of red shift. But the mass-energy density of dark energy *doesn't get diluted at all* by the expansion of space; it's still low, but it remains constant. The mass-energy densities of radiation and matter have now fallen *below* dark energy, so that dark energy is now the dominant component of the universe – about 68% of the total. Dark matter is about 27%; atomic matter is 5%; photons and neutrinos less than .01%.

What does this mean? We think the reason dark energy doesn't get diluted by the expansion of space is because it "borrows" energy from the release of gravity and makes space "fall outward." At 9 billion years, when it asserted itself, the expansion of the universe stopped decelerating, reversed itself, and started accelerating – the expansion of space is speeding up! And that has something to say – just about everything to say – about the ultimate fate of the universe.

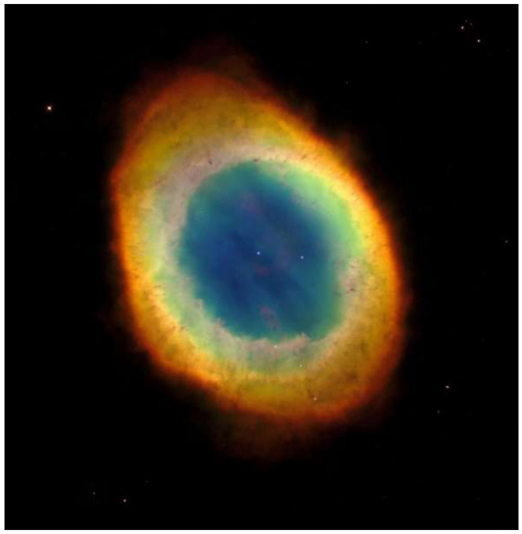
Destiny: Beyond 13.8 Billion Years

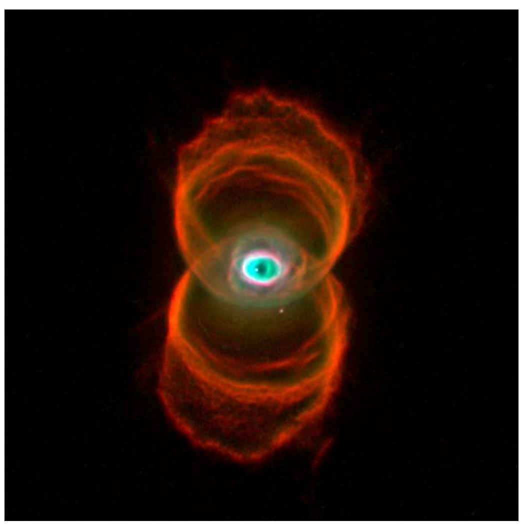
Fire or Ice? So what does the future hold? Before we get to that question for the universe on a cosmic scale, let's focus a little more locally, and answer a question posed by Robert Frost: Will our world end in fire, or will it end in ice?

Frost held with those who favor fire. He was right. Some five to eight billion years from now, our Sun will go through the same contraction/ expansion/contraction process we've talked about before. It will exhaust its supply of hydrogen, then contract, become hotter, and fuse helium into carbon and oxygen. In its subsequent expansion phase, it will become a red giant, at least 100 million miles across. It may engulf the Earth, and even if it doesn't, it will burn off the atmosphere and boil off the oceans. The Earth will become a cinder, a lump of charcoal.

Once all the helium is fused into carbon and oxygen, the Sun will start to contract again. It doesn't have enough mass to generate the heat and pressure necessary to sustain additional fusion reactions above carbon and oxygen, so they'll stop and the Sun will become a white-hot dwarf – a very dense dying ember the size of the Earth. The collapsing outer layers of gas will rebound off the core – not explode like a supernova – and disperse in a halo shell around the sun. It will become one of the most beautiful sights in the universe – a ring nebula.

Here are two of them:





You can see the white dwarf in the center of each nebula. Possible cemetery markers for the Sun and the solar system, 8 billion years from now.

Big Rip, Big Crunch, or Big Chill? As for the fate of the universe – Frost was right again: "for destruction ice/is also great/and would suffice." Dark energy will keep the expansion going. It won't be so powerful as to rip everything apart – galaxies, stars, planets, people, atoms – but powerful enough that gravity won't be able to stop the expansion and pull everything back into a Big Crunch.

So … the universe will keep expanding, ever faster, because of dark energy. And the space between objects will keep expanding. After 100 billion years or so, all other objects except for our local group of galaxies will have disappeared over the cosmic light horizon. We'll be back where we were 100 years ago, thinking that the Milky Way – well, the Milky Way/Andromeda elliptical – is the entire universe. Except that the people of the future will never have a way of telling otherwise. We figured out the answers from the only raw material we had – the light from the microwave background and from all the distant galaxies in the night sky. But they won't have that. So – take good notes, or the secrets of the universe will be lost!

Perhaps four trillion years from now, the last red dwarfs, the slowest burning stars, will exhaust their fuel and become white dwarfs – dying embers. Still later, the white dwarfs will grow cold and become black dwarfs of degenerate matter. The lights will go out. Bigger things will become smaller things. Galaxies will disintegrate; dust and gas clouds will disperse; protons will decay; black holes will evaporate.

Finally, some 10^{100} years from now – that's 10,000 trillion trillion trillion trillion trillion trillion trillion trillion trillion trillion trillion trillion years – the last photons and neutrinos will lie down as the universe approaches absolute zero and undergoes "heat death." All there will be is empty space, with nothing going on, for a very very long time. Except … if there's nothing going on, nothing happening, there's no way to measure time … does time stop too?

Will we be back where we started? I don't think so. Remember, the universe started from *nothing* – no matter, no time, and *no space*. With the universe ending in a vast amount of space, it's hard for me to see how a new universe can grow its way out of *nothing* if there's already *something* – empty space – out there.

So I think the universe is a one-off. Makes me feel a little better that I have only one life to live.

Final Images: Legacy

In 1990, the Voyager spacecraft was 13 years into its mission of exploring and reporting information about the outer planets of the Solar System. That work was almost complete, so Carl Sagan persuaded NASA to turn Voyager around and take one last picture of its origins. This is that picture.

It doesn’t look like much – a black void with a weird rainbow running through it. The rainbow isn’t real; it’s refracted sunlight in the camera lens, an example of the limitations of 1977 optics.

Otherwise unremarkable – except there, suspended in that sunbeam, one pixel wide, is a pale blue dot.

Here’s some of what Sagan had to say about this picture, along with some thoughts of my own.

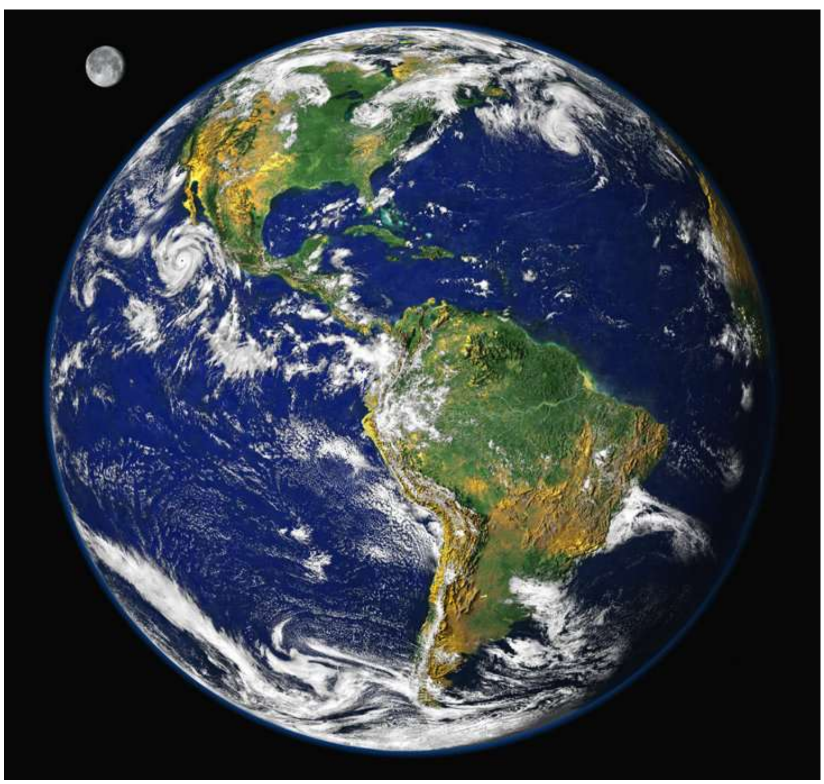
That pale blue dot? That’s here. That’s us. Every saint and sinner, every hero and villain, every king and peasant, every young couple in love, everyone you’ve ever known, everyone you’ve never known – they all lived out their lives on that pale blue dot.

It looks so insignificant. No surprise there – the dot is only 8000 miles across, and the picture was taken from 4 billion miles away. That seems like a long way until you realize that 4 billion miles is one six-thousandth of the way to our nearest neighboring star, which is considered a pretty close neighbor. And 4 billion miles is one sixty-trillionths of the way toward the cosmic light horizon – the boundary of our observable universe.

It’s been said that astronomy is the most humbling of all callings. What else can make you feel so small?

And yet … this pale blue dot is really not so insignificant. It’s the only place in the universe we know of, and given the finite speed of light and the vast distances involved, probably the only place we ever will know of where complex molecular structures have evolved that can not only look at the night sky and wonder, but gather information and figure out the answers.

In fact, when you consider all the imperfections and anomalies and asymmetries that had to occur, and all the random miniscule-probability events – like the asteroid that took this planet away from the dinosaurs 67 million years ago … and especially when you consider what is very likely the extremely limited life span of advanced civilizations – it is conceivable that right now, at this moment, this might be the only place in the universe where there's something that's aware that there's a universe at all. And that makes this pale blue dot a very, very special place indeed:



So how do we treat it, this jewel that we've been given?

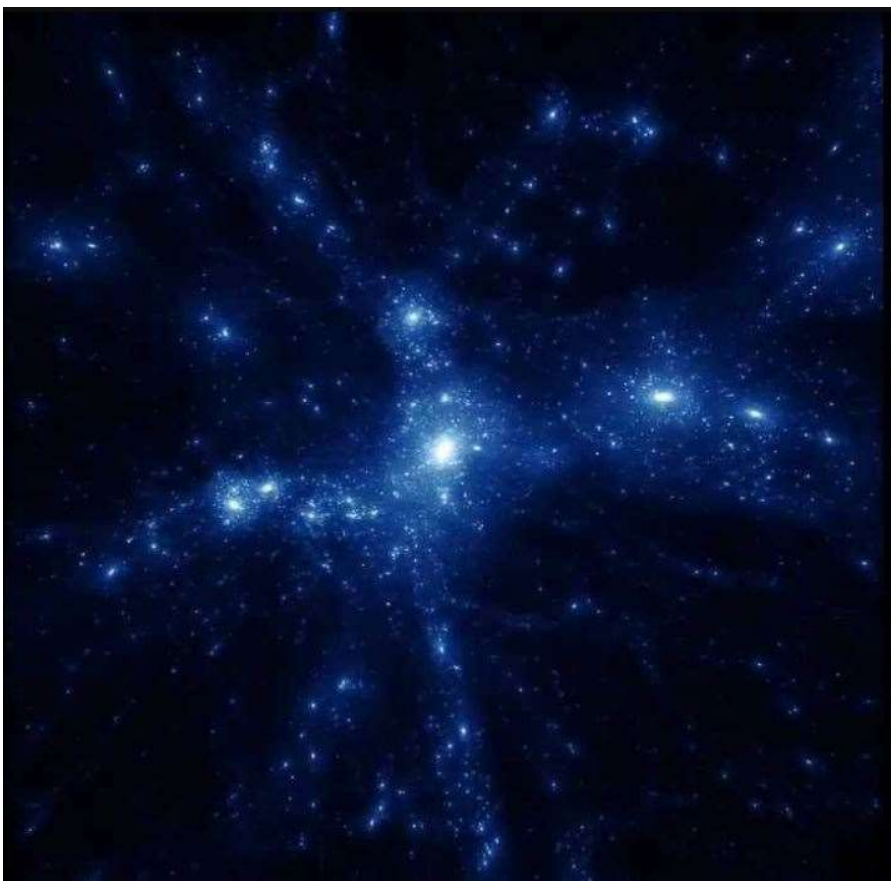
We poison it. We pollute it. We seem bent on exhausting its natural resources as quickly as we can. We fight over every scrap of land. We seek to dominate, even eradicate, anyone the slightest bit different from us – in skin color, religion, worldview, philosophy, creation myth …

Think of the rivers – the oceans – of blood that have been spilled by despots and well-intentioned people alike who have sought to extend their power and influence over some tiny incremental piece of that pale blue dot. Think of the passions that drove them: how fervent their hatreds; how meaningless their disagreements; how childish their behavior.

Stephen Hawking thought that we have about 75 years to find a new home and figure out a way to get there before we reach the tipover point that will lead to this planet becoming irreversibly uninhabitable long-term for our species and perhaps any other. I think we might have considerably less than that if some of the world's tough guys want to show everyone how macho they are and start raining down thermonuclear warheads all over the globe.

Well … I can't save the world in one reunion presentation – but I can wish. And what I wish is that, before we write an end to history on this planet, we find the last few answers, we solve the last few mysteries, we persuade Mother Nature to give up her last few secrets. Then, I hope someday soon, when an eight-year-old kid lies in bed at night and wonders, all he or she will need do is get up in the morning and Google the questions … and all the answers will be there.

On that morning, through us, because of us, the universe – this beautiful, magnificent, fleeting place we call home – will finally know itself. And we will have made a difference.



The Author and his dog Abby,
the real center of the Universe