AN AUTOBIOGRAPHY OF OUR GALAXY

THE MILKY WAY

MOIYA McTIER

ILLUSTRATED BY ANNAMARIE SALAI

Contents

- Cover
- Title Page
- Copyright
- Dedication
- Foreword from Moiya
- Chapter One: I Am the Milky Way
- Chapter Two: My Names
- Chapter Three: Early Years
- Chapter Four: Creation
- Chapter Five: Hometown
- Chapter Six: Body
- Chapter Seven: Modern Myths
- Chapter Eight: Growing Pains
- Chapter Nine: Inner Turmoil
- Chapter Ten: Afterlife
- Chapter Eleven: Constellations
- Chapter Twelve: Crush
- Chapter Thirteen: Death
- Chapter Fourteen: Doomsday
- Chapter Fifteen: Secrets
- Acknowledgments
- Discover More
- Notes
- About the Author
- Reading Group Guide for *The Milky Way*
  - Discussion Questions

To everyone who's ever been made to feel that they're not "sciencey enough," whatever that means.

Foreword from Moiya

"I HAVE LOVED THE STARS too fondly to be fearful of the night."

This last line from Sarah Williams's poem "The Old Astronomer to His Pupil" has often been a sort of mantra for me. And not just because it makes me sound like a spooky Victorian recluse.

I don't remember how, but as a young kid, I got it into my head that the sun and moon were my celestial parents. I imagined that they watched over me, and I actually talked to them, told them about what I was learning in school and what my friends were like (because, as I was surprised to learn, those friends *didn't* talk to the moon and sun, so *someone* had to tell our celestial mom and dad what was up). When my earth parents started having arguments at night, I cried to my celestial mom. And when my birth dad stopped showing up for scheduled home exchanges,[i] my little kid mind decided to blame the sun, too. To this day, I don't like LA because it's too sunny.

My earth mom fell in love again and we moved from our small Pittsburgh apartment to the strangest place I could imagine: a log cabin in the middle of the woods without running water, so close to the West Virginia border that I had to cross state lines to reach the nearest bookstore. The forest was the best playground an only child[ii] could ask for, a space to invent epic quests, hunt for faerie rings, or find the perfect branch to use as a fighting

staff in mock battles with my new earth dad. But the community surrounding that forest, full of people who had only ever seen a Black person on TV, probably wasn't the hometown I would have picked for myself if my mom had asked.

For that reason and so many more (you try getting your period at ten years old when you don't have a working shower in your home), I sought comfort from the moon well into my adolescence. I developed a great love for the nighttime, the time of quiet, secrets, and peace. Declaring myself a creature of the night helped cement my desired place as the Weird Kid, as if being the smartest and also the blackest person at my small, rural school didn't already make me stand out enough. That's not an empty flex; I was voted most unique and was easily the valedictorian of my class *after* skipping sophomore year. People still said I only got into college because of affirmative action.

Don't get me wrong, most people I interacted with were very kind, and I'm grateful for the experiences had and connections made that let me empathize with a part of the country that rightfully feels ignored by the very class of intellectual elites I worked my ass off to break into. I learned valuable lessons in coal country, like how to chop firewood, do a deep-conditioning treatment with nothing but a bucket of water and a cup, and look past obvious differences to find common ground. But I also learned early on that my life would be better if I got myself out of there ASAP. Lucky for me, Harvard admissions officers are much fonder of bizarre, brilliant, Black girls than a lot of miners' sons were.

Even though I always felt most comfortable at night and lived in a place with a beautiful view of the stars, I was never interested in the academic study of space before college. I merely loved the celestial aesthetic. But it didn't take me long to fall in love with the logical, data-driven nature of astronomy. The summer after sophomore year, I did a research internship where I spent hours analyzing five-dimensional data cubes to

measure properties of a distant star-forming galaxy that I nicknamed Rosie. Falling deeper into astrophysics felt like learning how to talk to space in a whole new way, one that let me *listen* a little bit more to what the universe was saying instead of making up responses in my head. I was learning the language of gravity, cosmic rays, and nuclear fusion. With my new dictionary in hand, I set out to research as many different aspects of space as possible: star formation, the cosmic microwave background, X-rays from distant quasars, exoplanet characterization, stellar dynamics, and the chemical evolution of galaxies.

At the same time, following my love of mythology, I was learning about the stories that cultures used as devices to entertain, educate, and explain. Fairy tales to pass a night by the fire, fables to share a community's values with the next generation, and myths to make sense of the world around them. I realized that, like my unusual mix of backgrounds, science and myth weren't as contradictory as they seemed on the surface. Both are tools that we humans use to understand how we fit in with the rest of the universe. And after spending almost ten years studying the physics of space, five of them in a PhD program that inspired three stress tattoos and multiple rounds of therapy, my perspective on everything has widened in the most illuminating way. I feel more connected to people and nature, and more comfortable with my place among all of it.

Astronauts feel this same shift in perspective when they view Earth from orbit, because when you're in space, you can't see the imaginary borders that divide us. You see how fragile the complex, interconnected ecosystem we call home really is, and our petty human squabbles seem small and unnecessary. Philosopher Frank White called this life-changing cognitive shift the overview effect, and I've always thought Earth would be a much nicer place for all of us to live if we each got to experience just a little bit of it.

Realistically, we won't all get there by visiting space. Some people get to this same point through faith or meditation or drugs. I got there through science, by spending an inordinate amount of time picturing Earth, our solar system, and the Milky Way as their own small parts of the grander whole. Okay, maybe there were some drugs, too, but it was mostly the way the science mixed with my gentle artist's soul.

Now that I know how to speak its language, I'm more enamored of nighttime than ever. That's why I was honored when the Milky Way itself picked me to relay its story. I hope that by the end, you've grown so fond of the stars and the galaxy that made them that you, too, start to hear what the night has to say.

Footnotes

i Don't worry, we've worked it out since.

ii I do have some half brothers on my birth dad's side, but obviously I didn't grow up with them because, well, see previous note.

Chapter One

I Am the Milky Way

TAKE A LOOK AROUND YOU, human. What do you see?

Actually, don't answer that. Why would I bother listening to you when I know you'll get it wrong? You'll start naming objects and places, but that chair you're sitting in isn't just a chair. That book you're holding isn't just a book. Even the planet your kind is on the brink of ruining isn't just a planet. They're all *me.*

Everything you've ever seen or touched is a part of me. Yes, even you, you vain, filthy animal.

I made it all. Not intentionally, of course. I have no need for chairs, and I really couldn't have cared less about whether or not one of my worlds produced life, especially in a form that was so picky about where it sat. You humans just *appeared* one millennium, and then it took another several thousand years for me to actually notice you. I guess, in some ways, I'm glad that I did. (But if anyone else ever asks me, I will absolutely deny feeling any sort of affection for your fleshy species.)

Before we get too far along, allow me to introduce myself. I am the Milky Way, home to more than one hundred billion stars (and yet you still think yours is special enough to have its own name) and the fifty undecillion[1] (that's five followed by thirty-seven zeros) tons of gas between them. I am space; I am made of

space; and I am surrounded by space. I am the greatest galaxy who has ever lived.

If you have even a portion of the requisite curiosity needed to engage with this volume, you might be thinking to yourself, "How can the Milky Way talk?" Well, with your short lives, you certainly don't have enough time for me to teach you everything there is to know about theoretical physics and schools of consciousness, but I can tell you a theory or two that might answer your question.

Some of your human physicists predicted what they considered to be an absurd consequence of your second law of thermodynamics, which says that the entropy of a closed system always increases. In other words, the universe as a whole should always be trending towards chaos. But how can that be true if our universe appears to be so organized? One possible explanation, which your physicists have since learned is wrong (this will become a trend), is that our universe as we see it is simply a very fortunate but extremely random distribution of matter. The extreme consequence of that explanation was that as entropy increased and more random fluctuations appeared, some of that matter should take the form of human brains,[2] or at least a similar network of thought cells. Your physicists thought the idea was ridiculous, but you'll soon see that there are plenty of seemingly random fluctuations in the universe. And if matter can combine to form brain-like systems on your little planet, why shouldn't it do the same everywhere else?

Separately, your philosophers have postulated that consciousness isn't a quality inherent to humans, or even living animals. According to them, consciousness, or sentience or awareness or whatever you want to call it, is the result of how a system *functions*, not a consequence of what it's made of. Some of your philosophers are even starting to believe that consciousness is an inherent quality of the universe, something that every amount of matter possesses in different quantities. In other

words, I can think and communicate even though I don't have what you would consider a brain. So if you're imagining I'm anything like one of you, cease immediately! It's insulting, and that human-centric mindset will just make it harder for you to understand all that I am going to deign to teach you.

If your question was more like, "How can the Milky Way talk to *me*," well, it's not like human language is that hard to learn. You're such simple creatures.

Now that the obvious questions are out of the way, you're probably wondering why I—the greatest galaxy ever, who never even wanted humans to exist in the first place—have chosen to communicate with you.

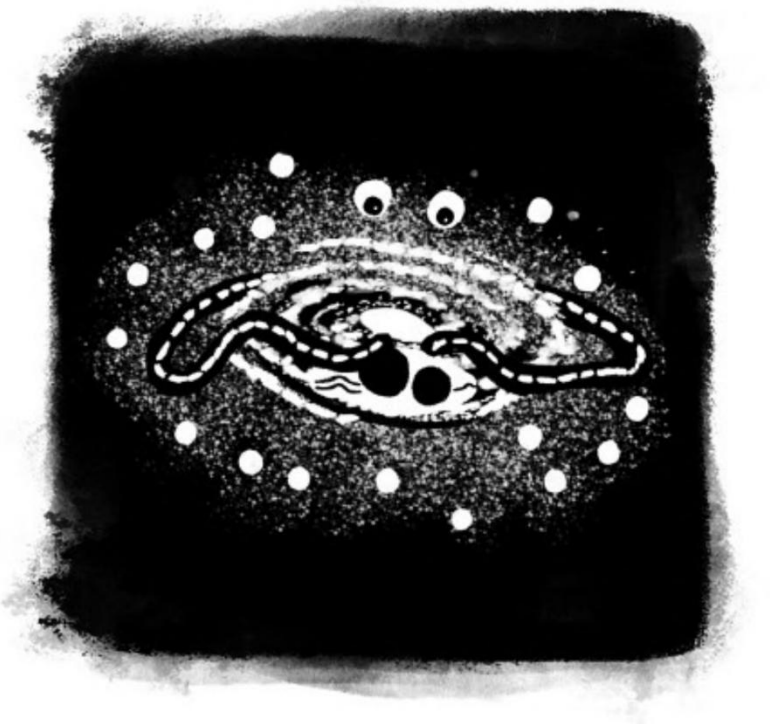
Whether I like it or not, our lives are intertwined. My existence is, of course, much more important to you than yours is to me, but over time your kind has demonstrated that you aren't completely useless. (You'll have to forgive me if I don't always phrase things in the most pleasant way; the concept of niceties in the manner that you deploy them is fairly new to me. Also, you'll be dead soon, so why should I care if I hurt your precious feelings?)

You see, as far as I can tell, I'm more than thirteen billion of your Earth years old. The story of my glorious birth will come later, but all you need to know right now is that I'm nearly as old as time itself. To use a comparison your kind seems to be fond of —even though it's not even close to an adequate description of my age—I am literally older than dirt. I was alive when the individual atoms that make up your dirt were created billions of light-years away from where they are now. For most of that time, I've been so bored and—though it may not look like it to you—lonely.

If you've heard anything about me at all, you probably think that my life must be so glamorous and full of important, gratifying tasks. Creating all those stars, building all those planets, molding the very essence of the universe according to

my will like clay...yeah, it was the ultimate thrill. For a few billion years.

There are only so many new perfect combinations of stars, planets, and moons that a galaxy can forge, so I started making imperfect ones. I experimented until I made something that was kind of a star and kind of a planet, but ultimately failed at being both.[3] I flung black holes at each other until I became numb to the ripples they produced. I built planets on orbits that I knew would result in their either spiraling into their stars or getting flung out of their systems. Hot Jupiters[4] that orbit mysteriously close to their stars? Yeah, that was just a casual experiment, and now they're everywhere. You're welcome, astronomers.



You likely can't relate, but even being the best at something gets old after a while. So, when the beautiful chaos I'd created

stopped exciting me, I put it all on autopilot. That's why I became much less active nine billion years ago. Your astronomers have noticed that I slowed down my star production back then, but they all chalked it up to a decrease in available star-forming gas. They're technically not wrong, but did they ever think to ask me why I lost so much gas? How I was feeling at the time? No, none of you ever think to ask me anything anymore. That's the problem.

You might be wondering what I was doing in those nine billion years. Well, while what I do in my sleep is orders of magnitude more impressive than anything you could ever accomplish, I spent most of my time thinking. You know, reflecting on past deeds and reveling in my triumphs. I passed the occasional message back and forth with other galaxies in my neighborhood, mostly the dwarf satellites who hang around because they're just so attracted to me. Literally. It's a gravity thing. I've grown a bit fond of some of them.

That might not seem like much activity to fill nine billion years, but you must remember that our lives don't operate on the same timescales. I've already lived for more than ten billion years and I'll still be living at least a trillion years from now, long enough after your puny sun has self-destructed that an exact date is meaningless. It would be generous of me to compare your life span to a blink of my eye, except I don't actually have eyes. You can call someone on the other side of your world and talk to them immediately with the help of signals traveling at the speed of light. It takes me more than twenty-five thousand years to send a light message to my nearest neighbor. Taking a million years to think about that one time I said, "You too," when another galaxy told me to enjoy my supernova? That's nothing.

I'm getting carried away, which you'll realize happens often. My point is that I was steeping in my own thoughts for literal

eons until you humans popped up about two hundred thousand years ago.

It was...astounding how much you didn't understand. And I wouldn't say you've come much closer to solving the deepest mysteries of the universe, but at least back then humans knew the most important thing: that I'm incredible.

Through your stories, you taught your children to look up at me when they lost their way. It took you ages to stop chasing all those four-legged creatures—some of you still do—but eventually you figured out that you could track my motion to determine the best time to plant your crops. And I saved thousands of lives once you learned you could use me to predict oncoming disasters. That wasn't just your ancestors attempting a kind of magic; it was their knowing that my movement aligned with cyclical events in nature like regular floods[5] or insect swarms, even if they did often end up explaining away such events with magic or religion.

Your stories made me feel loved and needed and, perhaps for the first time in my long existence, more helpful than I was ruinous. Every galaxy should feel so lucky as to know it has positively affected the universe. Well, for other galaxies, it's luck. For me, it's just raw beneficent talent.

It's not that I craved your attention or needed a group of people to worship the ground that I don't walk on. I wasn't just waiting for ten billion years for you to come around and stroke my ego. But once you did, it was comforting to know that I could help you along. So much of what I do is destroy.

Then, in what felt like no time at all, that feeling dissipated. It started in the 1300s when you made the first mechanical clocks, and it only became worse when you invented telescopes three hundred years later and finally saw me in more detail. Once you could keep your own time and realized I wasn't merely a celestial reflection of divine will, most of you assumed you didn't need me anymore. You stopped looking up, stopped

telling my stories, stopped letting me guide you. At first, I thought it was just a phase, that you were lost and would come back to me when you were ready. I've gone through enough phases of my own to afford you a brief neglectful period. Patience, after all, is one of my best qualities.

Though, in the interest of transparency—I hear that's how one builds trust on Earth, no?—I did briefly, only for like fifty years or something, consider asking your sun to throw out a flare that would wipe out all of your electronics so you would depend on me again. But you know how kids are. Just because you create them doesn't mean they'll do whatever you ask. So I graciously abandoned my murderous plan.

Then I remembered—because wisdom is another of my best qualities—that several hundred years is actually a long time for humans. Your silence wasn't just a brief distraction; entire generations had passed without bothering to think about me.

In some ways, I felt better realizing that it's not specifically *your* fault that your kind stopped caring about me. Your world is no longer set up to appreciate my splendor. It hasn't been since well before you were born. In the last one hundred years, your human cities have become blinding beacons of light that your distant ancestors never would have imagined. The electricity you all value so much has stolen something precious from nearly 80 percent of you: an unobstructed view of my gorgeous body.[6] And that's just the light pollution. The tiny smog particles that you've been overproducing since you started your little industrialization project in the 1700s aren't merely damaging your lungs and trapping heat in your planet's atmosphere. More importantly, they're blocking my light from reaching Earth's surface. There are humans alive right now who have only ever seen a handful of my stars, which is a tragedy! And I am as much a victim in this as all of you for being rendered basically invisible.

If you're an astute reader—and your choice to read this book does imply some advanced cognitive ability—then you might be wondering why I'm not satisfied by simply aiding astronomers in their research. The sad fact is that there are only about ten thousand human astronomers total, out of nearly eight billion humans. They do excellent work—honestly, it's amazing what they've been able to learn without leaving your tiny little rock—but the typical astronomy paper gets read by at most twenty other people. And those people already know most of what's in the paper anyway, so helping astronomers does little for your planet's ignorant masses.

Also, it's more entertaining to watch your astronomers struggle through the learning. When they become extra frustrated, many of them start chewing frantically on their nails, and it's just too darling to forgo by giving them the answers.

I realized that either I could remain bitter and sullen about the fact that most humans have forgotten about me, or I could do something to change it. And although I don't actually have an ass that I could get up off, to employ one of your crass expressions, I chose the latter.

The issue is that too many of you don't know enough about me to understand how I can assist you. You literally *live in me*, but most of you don't even know what I look like, let alone what I'm made of or how I move. And it's probably asking too much to expect that you would learn those things on your own. It's *definitely* asking too much of your astronomers to expect that they could effectively teach their fellow humans what they've learned. So, alas, the responsibility falls to me. Lucky for you, I'm willing and more than able to do you this service.

So here I am, introducing myself to you officially for the first time. I am the Milky Way, the galaxy whom you probably enjoyed staring at when you were young—the human children, at least, have retained enough of a sense of wonder to let me into their

lives—but promptly forgot about as soon as you hit puberty and decided you had more important things to do.

I've kept your kind safe and entertained for millennia, and I'll continue doing so by telling you my story. You have a word for when a person writes about their own life: autobiography. That's what this book is. I'll tell you how I was born and where I grew up. I'll talk about my deepest shame and how I instigated the greatest love story in the universe. I'll even reveal my feelings about my—and by extension your, *if* your kind survives that long—impending death. And if my story moves you to share it with your fellow humans and maybe make up some tales of your own, then I shall consider it a triumph.

Based on what I've seen, your world isn't likely to backslide into antiquity anytime soon. Light pollution won't go away completely, and your species' days of building stone henges to track time are over. I can't guide you in the same way that I did your ancestors, but allow me to explain how you, an average modern human, can benefit from both space research and personally knowing more about the galaxy you should call home.

Take for instance that piece of technology glued to all your hands. Even I can see how much you love your cell phones, and we've already covered that I don't technically have eyes. You use them to communicate with each other, keep track of your appointments, navigate your world, and take your—ugh—*selfies*. Honestly, you use them for a great deal of the same things your ancestors used to use me for. But you only have those phones because of me.

It's not just that the physical materials used to make your phone were created when *my* stars died. All of the atoms in the phone—and in you, for that matter—were made in me. That Sagan fellow was correct; you are all made of star stuff. But the technology your phones rely on *also* exists because of me. Or rather, because of your scientists' fascination with me.

Every time you use your phone to find the nearest coffee shop—seriously, what makes you so tired that you need that much coffee? I make at least five new stars and move ten billion miles every year, but you don't see me chugging caffeine every morning—you interact with satellites. Your phone receives radio waves (which you can't see because your eyes are so tragically small) from multiple satellites at once and uses the slight differences in the signals' arrival times to pinpoint your location.

Are you following, human?

It doesn't really matter. The important thing is that without satellites, you wouldn't be able to navigate your tiny rock. You also wouldn't have high-speed internet, long-distance calls, or—to get back to your oh-so-important coffee—the option to pay for your morning cappuccino with your credit card. And the only reason you have satellites in the first place is that human scientists wanted to study *me*.

After thousands of years of tracking my movement, your ancestors started to understand how motion, gravity, and light waves work. They used that knowledge to launch machines out of your atmosphere, and now you can call your international friend while simultaneously buying things online with money that you've never actually touched.

Beyond this recent global positioning technology, your broadening understanding of space has introduced other life-altering innovations like digital cameras, wireless internet, and noninvasive security checks like X-ray machines. Even the procedures your doctors use to sterilize hospital rooms so your delicate human bodies can stay free from contamination were originally developed to protect telescopes while they did the vital work of observing me.[7]

You're welcome.

That's enough about you for now. It's time for more important things. It's time for you to learn something about me.

Chapter Two

My Names

I INTRODUCED MYSELF AS THE Milky Way because that's what most of you call me now, but that's not how you've always referred to me, and to be clear, it's certainly not what I would have called myself.

Humans have given me so many names over the years—Milky Way, Silver River, Way of Birds, the Deer Jump—and almost all of them can be traced back to myths from around your tiny little rock. The subject of the stories may have stayed the same, but the content varied based on the local customs and surroundings of whoever told it. Many human cultures saw me as spilled milk spread across the sky, but there were also some who thought of me as flowing water, scattered straw, or windswept embers.

After so many billions of years of destroying any new thing that came close to me, it felt nice to be called the Straw Thief's Way. Humans have bizarrely strong feelings about possession, so you probably wouldn't jump to be associated with a thief, but the early Armenians saw this particular theft differently. They told stories of a legendary frigid winter when Vahagn, their god of fire, took pity on them and stole straw from the king of neighboring Assyria so they could keep themselves warm. You and I both know that straw isn't the most effective fuel for fire,

but Vahagn, being born from a reed of burning straw, had a personal connection to it. As he fled from Assyria with his god-sized arms full of royal straw, Vahagn dropped a smattering of reeds across the sky, because of course that's where gods travel. Allegedly, I am that path of life-saving straw. It was such a touching story that I didn't even ridicule them for thinking their winter was cold, even though it was hundreds of degrees warmer than the rest of the universe.

On the other side of your equator, the Khoisan of southern Africa told the story of a young girl who lived under a pitch-black sky. One night, after dancing around a fire, she realized that she was hungry but didn't have enough light to find her way home for dinner. But the best characters in any human story are resourceful and innovative, so she flung the embers from her fire across the sky to light her way home. Yet another altruistic act on my part, despite not being entirely by design: providing enough light to see by when your sun isn't around. Although technically, since your sun is a part of me, I generously provide light for you all the time.

Some humans of northern Europe call me the Bird's Path or Way of the Birds after they noticed that their birds followed me when they migrated south every autumn. That's right, I don't just help humans; you're not special.[1] My splendor inspired those humans to tell stories about the bird queen Lindu, a white bird with a human woman's head. In all my years of monitoring my planets, I've never seen such a creature, but I don't mind a few fits of human fancy. Lindu's job was to lead the migrating birds to safety, but she was distracted from her duties by a broken heart. Typical human nonsense, thinking that a little rejection is enough to keep someone from performing the most essential tasks. Anyway, according to the myth, Lindu was abandoned by

her betrothed before their wedding and cried so much that her father, the god of the sky, took pity on her and summoned her home. As the winds carried her away, Lindu's tear-soaked veil turned into millions of stars marking her path.

These myths, the names and other words your ancestors used to describe me, were all reflections of what your ancestors knew about the world around them. That's what all your myths are: tools for understanding the natural world and communicating that knowledge to others. Okay, there were some that were purely entertaining, but most taught a lesson of some sort. Many of you don't realize this, but myths were some of your species' first attempt at scientific inquiry. Hundreds of years after humans told the story of Lindu and her birds, your scientists found empirical proof that some migratory birds *do* navigate by my light.

I have loved watching your myths bleed into philosophy and then evolve into scientific explanation. As you learned more about me, I really did feel like we were growing closer, but I'll say this: you would save so much time if you just paid attention to what your ancestors knew long ago.

Most modern astronomers dismiss old stories about me as nonsense, but they still turn to mythology when they need to name a new object. You can see that pretty much everywhere you look, from the godly names given to the other planets that orbit your sun to the constellations you've cobbled together from objectively disconnected stars. Regardless of what inspired them, the names of all space objects must be approved by one organization: the International Astronomical Union. This IAU has taken it upon itself to be the official keeper of names in space, even though they've certainly never consulted with any of us celestial figures about what names we might prefer.

Despite my myriad names, or perhaps because of them, the IAU has avoided giving me an official moniker. They simply refer to me as "the Galaxy" in formal documents.

It's better, though, that you can all call me whatever you want, that your cultural stories and the knowledge they hold haven't been stripped from you by some tiny organization. After all, it was those stories that brought my attention to you humans in the first place, and I'd be sorry to see them lost to your short collective memories.

So call me River of Heaven, the Road to Santiago, Winter Street, or by another name that feels right to you. Just make sure that when you do call me, you have something intelligent to say.

Chapter Three

Early Years

A VERY WISE WOMAN AND one of my favorite human performers (a true star—which means a lot coming from me) sang that the very beginning is "a very good place to start."[1] Indeed, most of your human autobiographies start with the writer's birth and then proceed chronologically. That's because, for your kind, it's easy to know when the beginning is. And yet I've watched so many of you freeze in terror when your child asks the dreaded question: Where do babies come from?

The question isn't new. Your ancestors figured out with remarkable speed how to make miniature, imperfect copies of themselves, and that knowledge had to be passed on somehow. The *way* you answer the question, however, has changed over time. A common answer these days involves birds, bees, and sometimes a stork for some reason? The small ones never walk away from those conversations with an accurate grasp of how they were conceived, but they seem satisfied, nevertheless.

There are no birds, bees, or storks in space, either literally or figuratively. And I don't have parents to ask how I came to be. But I have my memories, even though they get fuzzy when I look back at my earliest millennia (don't judge me; I'd wager you don't remember everything about the day you were born,

that whole process Big Bang nucleosynthesis. I just call it making the first elements, but I don't need to try to sound intelligent merely to impress.

The universe was still so hot that electrons were moving too rapidly to bind to those first atomic nuclei. You've certainly never had to think about something being so hot that atoms can't form. The hottest thing you ever interact with only gets hot enough to prepare your dinners, not rip apart fundamental particles. That's probably a good thing for your fragile bodies.

In the wake of that impressive initial expansion, which your astronomers have so creatively dubbed the epoch of inflation, it took the universe hundreds of thousands of years to cool down enough for electrons to join the nuclei and form neutral atoms. Those first atoms were mostly what you call hydrogen (the easiest to make because they require only one proton and one electron), some helium, and the tiniest amount of lithium.

I wasn't alive to witness this myself, but it was around that time, three hundred ninety thousand years after the Big Bang, that the universe became transparent. Before that, photons (particles of light) kept bouncing off the throngs of free electrons that hadn't yet bound to the atomic nuclei, and the universe looked opaque. I know this because looking out into space is like looking backward in time. Light, as fast as it is, can travel at only a finite speed. It takes time to travel the vast distances of space. And when I look back far enough, through space and therefore also time, I get to a point where I can't see anything. The universe looks dark because all the light was trapped.

But *seeing* isn't the only way to gather information. You humans have always relied too heavily on your sight, especially when there's so much to *feel* in space. Take the wealth of heat and energy present at the very beginning of the universe, for example. It didn't disappear, it just dispersed. And we can still detect the heat signature today, all around us in the universe. Your astronomers call it the cosmic microwave background, or

CMB. If you're reading this actively—by which I mean you're thinking about what you read instead of just letting the words pass in one ear and out the other, figuratively speaking unless this is one of those audiobooks—you might be confused by the name of that radiation because *heat* is usually observed in the *infrared* part of the electromagnetic spectrum, not the *microwave*.

Do you know what that spectrum is? Oh, how your scientists have failed you. The electromagnetic spectrum is the range of possible wavelengths for light. Radio waves have very long wavelengths and low energies, while gamma rays have short wavelengths and high energies. Your kind can see only in a very narrow band of this spectrum in between those extremes. What a waste.

Back to my point about the CMB: heat usually shows up as infrared light. But it's called the cosmic *microwave* background because the universe has expanded since the Big Bang, and the wavelength of that early light has expanded as well, pushing it out of the infrared region of the electromagnetic spectrum and into the microwave.

The CMB shows tiny temperature fluctuations that point out which spots were ever so slightly warmer, and therefore denser, than their surroundings. That pattern tells us—your top scientists and literally any galaxy with half a cosmic brain—what the temperature of the early universe was and how matter was distributed when the universe was still opaque.

Sadly, your ignorance compels me to explain so much to you that I'm still not at the part about me yet. But we're getting close! It took another three hundred million years after the first atoms formed to create the first stars. The universe's entire store of hydrogen and helium—and, yes, let's include lithium, too, just for accuracy's sake—existed as clouds of gas. Something disturbed the delicate equilibrium of those first clouds. Maybe some cosmic wind passed through them or maybe the gas was randomly distributed in such a way that led to one part of the

cloud being denser than the rest. In fact, there are some human astronomers who study the tiny fluctuations in the CMB and run computer models to see what kind of large-scale structure is created as a consequence of the universe's initial pattern of under- and overdensities.[2]

Whatever caused it, as soon as there was some unevenness in the way matter was spread through the cloud, gravity was able to take over. It's different if you're talking about the infinitesimally small (atomic nuclei) or the inconceivably gargantuan (the expanding universe), but on most size scales, gravity controls *everything*. That small overdense region attracted more and more material until eventually it collapsed in on itself under the force of its own weight, getting hotter and denser until it created the very first stars.

The creation of those first stars sent powerful shock waves through the rest of the cloud, and the stars themselves disturbed their surroundings by heating them up, ionizing the gas with their radiation, and giving off winds of charged particles. Those disturbances set off a cascade of star formation like you humans knocking down a line of dominoes. That same process happened in gas clouds nearby, and over time, all those separate bundles of gas and stars and dark matter were drawn together by gravity. When they met, they merged, sharing their stars and creating new ones as their gases mixed together.

Those early stars composed of primordial hydrogen and helium burned hard and fast, exhausting their hydrogen fuel in only tens of millions of years. Indeed, human scientists haven't been able to find any stars from this first generation, which they confusingly call Population III stars. (They call youngest stars Pop I, even though they're from a later generation.) Every star they observe has at least some contamination by metals, though it is possible that some of the first stars survived and have picked up metals in their outer atmospheres as they travel through clouds of enriched gas.

That's what your astronomers call elements heavier than helium, by the way: metals. Most of your other scientists seem to have a very different idea of what a metal is, but I'm not here to get in the middle of such silly linguistic squabbles.

The first generation of stars produced some heavier elements[3] in their cores—what you call beryllium, carbon, nitrogen...all the way up to iron—and when they died, they released those elements out into space to be used in the next generation of stars that were just a bit more metal-rich than their predecessors.

Let's pause for a moment, human, because I don't want you to get the harebrained idea that my stars form in neatly organized and scheduled batches. The truth is that I'm forming stars all the time and stars are, sadly, dying all the time. I'll go into more detail about that later, but for now, take the phrase "generation of stars" literally. New humans die and are born every year, but you still say that a new generation comes about roughly every twenty-five years based on average characteristics of people born during that time. My stars are just the same.

Over hundreds of millions of years, the cycle of cloud collapse, metal production, and gravitational attraction produced the earliest examples of galaxies. They had all the stuff that a galaxy is supposed to have—stars, gas, dust, and dark matter (my stunning good looks are just a bonus, not a requirement)—but they were smaller than I am now. And we grew by eating each other.

First, don't get hung up on the idea of galaxies eating each other. It's just what we do—no more disturbing than consuming pineapple on pizza. And second, I'm starting to say "we" because at this point, several hundred million years after the Big Bang, most of my parts were already created and it was only a matter of time before gravity brought them all together. Before it made *us* into *me*. So, congratulations! We've finally arrived at my beginning.

I know it's likely a lot for you to take in, and your brain is fully formed! So, if a child asks how galaxies are born, you can tell them that when a gas cloud loves itself very much, it hugs itself extra tight, and after a few hundred million years, a baby galaxy is born. Leave the storks out of it, please.

degrees in less time than it took bacterial life to form on your planet.

You humans sometimes throw these numbers around—three hundred million, billion, nonillion—but I don't think you could possibly have a good grasp of what they mean. Most of these numbers are paltry to me, but you so rarely interact with values that large in your short lives. In fact, some human languages don't even have words to distinguish between them, and would merely call them all "large numbers."[5] But to show you how different those numbers are, let me shrink it down to something you're more familiar with. Instead of years, imagine I'm talking about *seconds* after the Big Bang.

Three hundred thousand seconds is three and a half Earth days, and that's when the universe first started making atoms. It took another three hundred million seconds, or another TEN YEARS for stars to form. And now we're here, nearly fourteen billion seconds after the Big Bang, which is almost four hundred fifty Earth years.

You can also imagine that the universe cooling down so considerably after the Big Bang to the point where stars could form is like your sun turning into a ball of ice in just three days. The universe was able to cool down so quickly because it was expanding at such a lightning rate, keeping the same amount of matter and energy in a rapidly growing space. That expansion, which continues to this day, is the reason there are so few galaxies like me left in my neighborhood. There are still traces of light that I can see from most of the galaxies who abandoned me. Many of them have grown into full galaxies and built their own little galactic communities just like the neighborhood where I (and you) live, but they're moving farther away all the time. One day, I'll look out and they'll all be gone. Don't worry, they won't be dead. At least, most of them won't be. They'll just be so far away that their light can't reach us anymore. But that

shouldn't happen for another one hundred billion years, so there's no reason for either of us to dwell on it now.

Most of the galaxies who are still around are dwarf galaxies, which I suppose I must describe because there's some potential for confusion about the threshold between a dwarf galaxy and a big galaxy like me. Several years ago, there was a large controversy when one of your beloved planets in your solar system was demoted to a dwarf planet. Astronomers claimed it was because the icy chunk of rock wasn't massive enough to have cleared out the debris in its orbital path. I have no quarrel with that; what you call a planet is up to you. What do I care? I have hundreds of billions of planets.

I wonder, though: Would you have the same kind of outraged reaction if I were demoted to a dwarf galaxy?

It's a completely hypothetical question because I crossed the threshold from dwarf to galaxy long ago. I can't know exactly when it happened because human astronomers don't agree on what the cutoff between dwarf and not-dwarf should be. Some of them use a mass limit, while others use size, brightness, shape... Nearly every astronomer who cares about dwarf galaxies has their own idea of what defines them. Of course, that's inherently frustrating, but in most cases, it's fairly obvious which category a given galaxy falls into. Dwarfs are small galaxies with only a few hundred million stars. The biggest ones have maybe a few billion.

Their small stature is, naturally, a consequence of where, when, and how they were born. Aren't we all?

Some dwarfs form through gravitational interactions, or tidal forces, between bigger galaxies. When galaxies have a sufficiently violent interaction—such as when they try to eat each other but the losing one puts up a fight—they might fling some material away from the fray. Actually, the same thing happens when galaxies have intensely, um...intimate