SPACE

A Tour of the Cosmos

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HORSEHEAD NEBULA

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A Tour of the Cosmos

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“Where were you when I laid the foundation of the earth?”

–Job 38:4

MARS "VICTORIA CRATER"

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PREFACE

When I think about the scientific study of the natural world, two phrases from the writings of Pope St. John Paul II come to mind:

(1) a rigorous pursuit of truth and

(2) a love of learning.

The first—a rigorous pursuit of truth—describes science and its processes. Scientists make careful observations, design experiments, and collect data to learn more about how the world works. Too often, though, science may seem like something you do in a big research facility with a lab coat.

But we are all scientists!

Anyone can study the living world in a scientific way. From an early age, everyone has a curiosity to understand the world. Think of a baby repeatedly dropping something onto the floor; they are discovering how gravity works! It is this basic curiosity that drives science.

The second piece—a love of learning—also describes what science should inspire. Sometimes science is depicted as a dry, boring set of facts, but nothing could be further from the truth. The world is a fascinating place. I have been interested in the natural world my whole life. This love of nature led me to obtain undergraduate and postgraduate degrees that have allowed me to teach biology classes every day for a living, and yet I am still constantly amazed by the wonders of our world.

A composite Viking orbiter image of Olympus Mons on Mars, the tallest known volcano and mountain in the solar system.

There is always something new to learn in biology and all the natural sciences. Within biology, there is so much inspiring beauty in the endless forms continually evolving and unfolding. Life on Earth, and the expanding cosmos beyond, consistently exceed the capacity of my imagination.

For example, did you know:

- The distance between Earth and the Moon is about 238,900 miles?
- Venus rotates on its axis in the opposite direction of most planets—so the Sun rises in the west and sets in the east?
- Olympus Mons is an ancient volcano on Mars that forms the tallest mountain in our solar system at almost fifteen miles high, three times larger than Mount Everest?

How could we not be fascinated by this vast universe we inhabit?

Finally, it is too often assumed in our society today that faith and science act in opposition to one another, that somehow if we learn enough about the world, it would disprove the existence of God. But it is important for each of us to be confident in our Faith and the fact that truth cannot be in opposition with itself.

"[Science and faith] each can draw the other into a wider world, a world in which both can flourish."

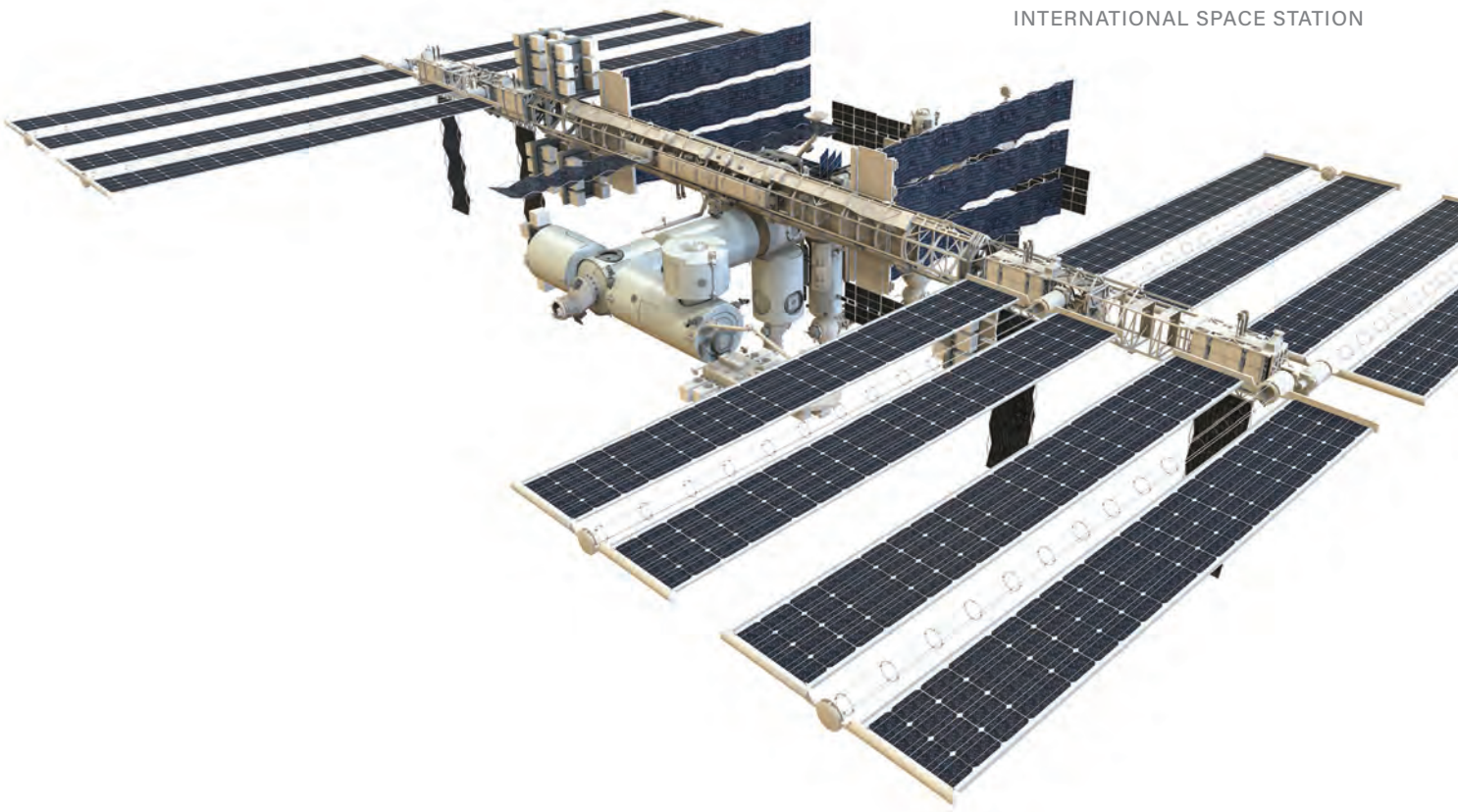
– Pope St. John Paul II in *Physics, Philosophy and Theology*

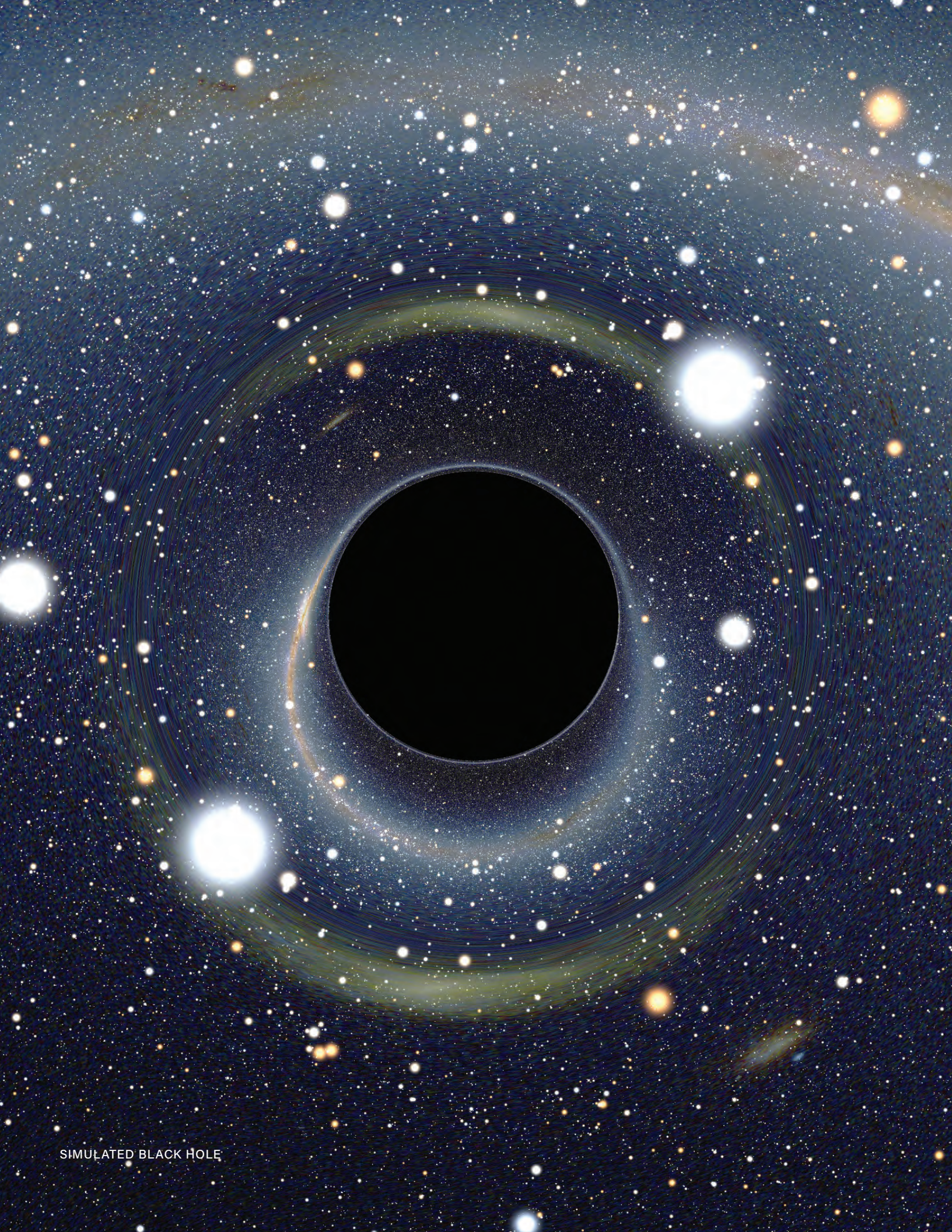
We read in the *Catechism of the Catholic Church*: "Methodical research in all branches of knowledge, provided it is carried out in a truly scientific manner and does not override moral laws, can never conflict with the faith, because the things of the world and the things of faith derive from the same God. The humble and persevering investigator of the secrets of nature is being led, as it were, by the hand of God in spite of himself, for it is God, the conserver of all things, who made them what they are" (*CCC* 159).

Holy Mother Church teaches us that we can pursue scientific knowledge unafraid. It is my hope that *The Foundations of Science* series will not simply give your family some facts about the world but instead instill a curiosity and love of learning in you that you can apply across all the disciplines of your life, both scientific and otherwise.

Timothy Polnaszek, PhD

INTERNATIONAL SPACE STATION





SIMULATED BLACK HOLE

INTRODUCTION

This book is a brief exploration of all the wonders of the cosmos, from our own planet into the great beyond. The word **cosmos** is another word for the physical universe that surrounds us. But it also implies an apparent order to that universe, one that follows specific laws (physics, gravity, etc.). This is important to scientists because it means we can study that order to learn more about the physical universe. If everything was chaos, without structure, we couldn't identify patterns and processes and learn from them to predict outcomes or understand why things happen the way they do.

The exploration you hold here is a good beginning on this topic. In other *Foundations* books, I have said similar things at the start of the book—that this text holds a lot of fascinating information but cannot really hold everything about the topic. Instead, I hope that these books inspire more exploration and learning about these topics. This idea that we cannot fully explore a topic in one book is, perhaps, most true for outer space, or the cosmos that surround us. After all, expansive rainforests, deep oceans, tall mountains, vast deserts, and big cities all occur here on what is just a relatively small planet circling an ordinary star. But there are billions of other stars in the Milky Way (our galaxy) and billions of galaxies with their own stars!

Much of the tour within this book happens within our solar system—our sun, the planets, and other celestial bodies found here. But we will also take a look at some fascinating things *beyond* our solar system. We will also look into the history of **astronomy**, the branch of science which deals with celestial objects, space, and the physical universe. This will include those who look up at the night sky and those who have traveled through it. As you read through the book, I hope you will experience a sense of awe at the sheer vastness of the universe and the God who created it. I know the more I learn about astronomy, astrophysics, and cosmology, the more I am fascinated by these topics. So let's dive right in . . . or I suppose I should say, prepare for launch!

The universe is unimaginably vast. Even traveling at the speed of light, it would take billions of years to travel from its center to the outer edge.

CHAPTER 1

SPACE
The Galactic Frontier

THE IMMENSITY OF SPACE

Space is immense.

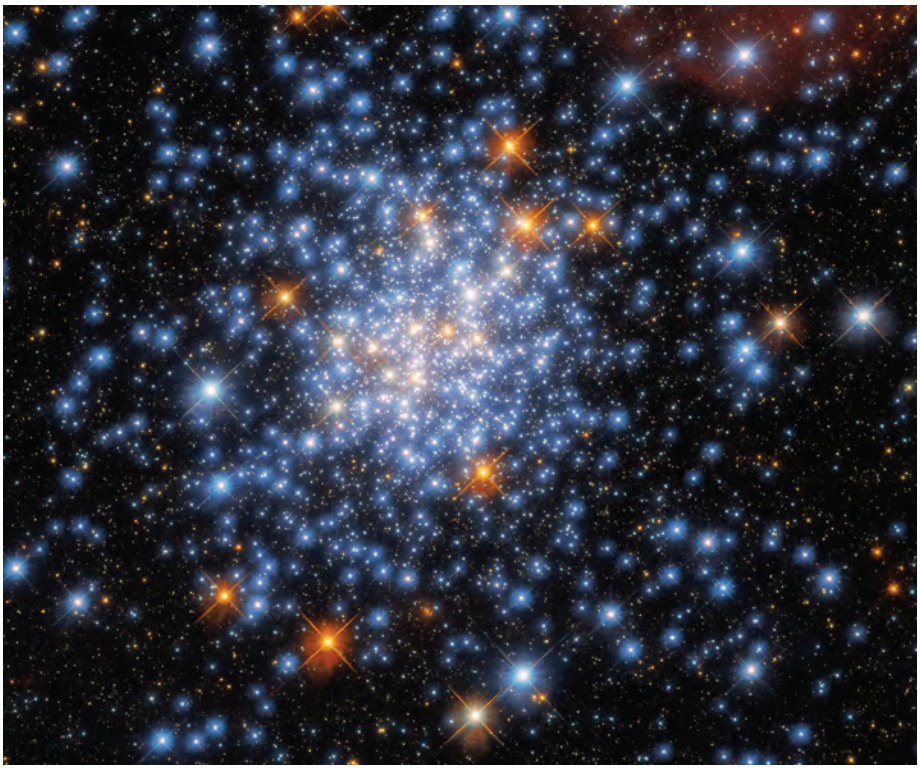
While true, this simple comment is a gross understatement. Saying that space is big or immense is like saying the ocean has some water in it. Yes, the ocean does have some water in it, more than 350,000,000,000,000,000,000 gallons! Our brains cannot easily comprehend such a large number. And yet, a number like that doesn't even begin to encompass the scope of space.

Imagine you could travel at the speed of light—670,616,629 miles per hour. That's unimaginably fast given that we experience a 100-mile-per-hour roller coaster as being frighteningly fast. Even if you could travel at the speed of light (which you really couldn't because your body couldn't withstand the force), it would still take you *billions of years* to travel from the center of the universe to the outer edge!

But wait! That just takes into account the known, or **observable universe**, meaning what we can detect, or observe, from our position on earth. Space likely stretches farther than the observable universe, and based on the observations scientists have collected, the universe looks like it is still expanding and growing larger even now! More on that in a bit.

Much of this vast area we call space remains unexplored, and yet we are already aware of amazing planets, asteroids, stars, and more. In this book, we will take a look at some of these objects that are closer to home, within our solar system, and then take a look at the far reaches of outer space.

A good place to start, though, is with some definitions and descriptions of outer space–categories to help us make sense of the vastness of outer space.



This NASA/ESA Hubble Space Telescope image captures the open star cluster NGC 330, which lies approximately 180,000 light-years away. Notice how the stars tend to have a bluish or reddish color—we will learn why that is soon enough!

OUTER SPACE VERSUS THE UNIVERSE

We have already mentioned the term *universe*, but what's the difference between the universe and outer space? **Outer space** (or space) is the area beyond Earth that stretches between our home planet and all the other astronomical objects (planets, moons, stars, galaxies, etc.). **Universe**, meanwhile, includes all of space and the time, energy, and **matter** (the physical "stuff" we can see, like planets, plants, animals, etc.) contained there, including you!

Outer space, the area *between* all the objects in our universe, is almost entirely empty. It isn't quite true to say it is completely empty—there are a few particles floating around—but there are so very few particles that the density of space is extremely low. **Density** measures how many particles are packed in a given space. (A muffin full of chocolate chips has a high density of chocolate chips, many packed into the one baked good, whereas a muffin with only two chocolate chips has a much lower density.)

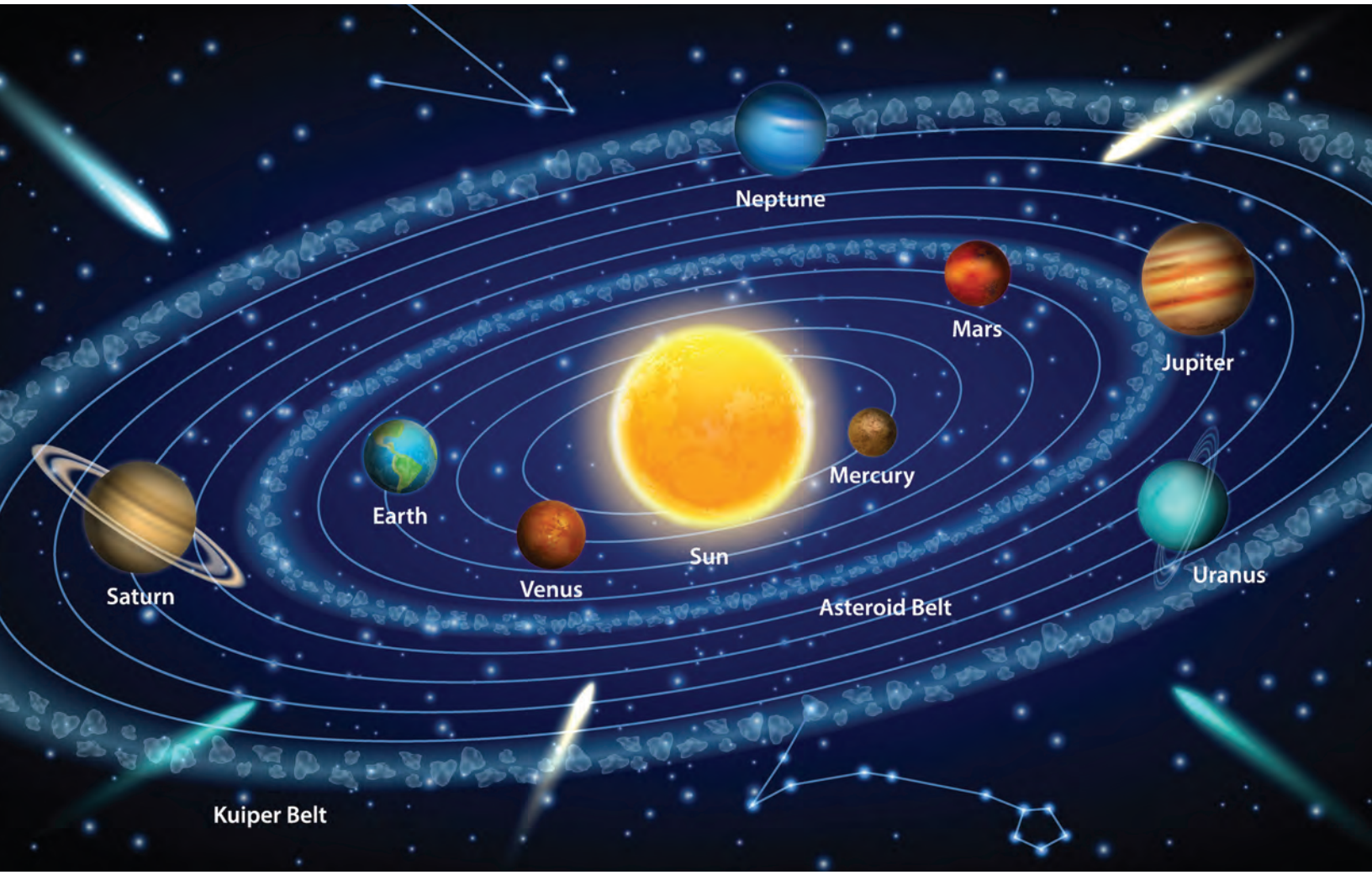
There are so few molecules in space that space is considered a **vacuum**. No, not a vacuum cleaner that you can use to clean the living room floor, but instead an area without matter. (The Latin root means "vacant" or "void.") This means that unlike our atmosphere on Earth, there isn't air to breathe in outer space, no molecules like oxygen or carbon dioxide floating around. This is why astronauts have to wear their suits and helmets when they travel into outer space, receiving oxygen through them, just like a diver would wear an oxygen tank to travel beneath the sea.

A Vacuum within a Vacuum?

Do vacuum cleaners use an actual vacuum to clean floors? Not really. Some styles of vacuums use a motor which blows air outside of the device, and this creates an area of low pressure and density. This is sort of like creating a vacuum inside the vacuum (though it doesn't fit the technical definition). Other air rushes to fill the void, creating the suction effect and carrying dirt and debris and an old LEGO piece or two into the vacuum cleaner.

So the vastness of outer space stretching between astronomical objects, like between our planet and other planets, is mostly empty. As such, you will find that most of our book discusses those larger objects moving around in space (like moons and stars). Before we focus on any particular part of space, though, let's take a quick look at a "map" of space, naming certain regions:

- **Geospace**: This is the first part of space nearest Earth, where satellites orbit.
- **Cislunar space**: This is the space between Earth and the Moon, the distance a few brave astronauts have traveled (about 238,900 miles!).
- **Interplanetary space**: This term refers to the space within our **solar system** (the gravitational area around the Sun), between our star (the Sun) and the planets that orbit it. The distance between the Sun and the distant planet Neptune is around 2.8 billion miles! That's over eleven thousand trips between Earth and the Moon.
- **Interstellar space**: **Interstellar** means between stars; thus, this refers to the area between stars, or solar systems. Our solar system is a part of the Milky Way galaxy. The distance in miles is now so large that we start using light-years to measure interstellar distances. (We'll talk more about this in later chapters.)



- **Intergalactic space**: Our **galaxy** (a huge collection of stars, or solar systems, gravitationally bound to one another) is called the **Milky Way**. It is not the only one in the universe. Far from it, as there are at least hundreds of billions of galaxies in the known universe. The distance between these galaxies is intergalactic space.

Returning to our definition of the universe, we can say that *universe* is the name we give to all these regions together. Thinking about all this and the distances between these regions as we scale up helps us to see just how infinitely large the universe is. Our planet is a small part of a solar system, which is a tiny part of a galaxy, which is one of hundreds of billions of galaxies in the universe. It's fascinating to think about the magnitude of creation!

Remember: *Interstellar means "between stars," therefore interstellar space refers to the area between stars, or solar systems.*

THE ORIGINS OF THE UNIVERSE

One of the ways we can study creation is to examine the universe for evidence of how it came to be. This is the science of **cosmology**. Yes, we can simply say that God created the universe. We know this because the first book of the Bible—Genesis—tells us so. But we can learn more about God, and perhaps become better scientists, by carefully examining *how* God created the universe, something the Bible is silent on. Scientists do this by making observations and carefully examining causes and effects within nature or within the universe to better understand the physical world we inhabit.

One way to study the world around us is to use experiments to give us clear evidence of cause and effect. But it's difficult to carry out experiments examining the origins of the universe. It's not exactly like studying bees or fish.

We weren't around back then to watch things unfold. The physical origins of the universe are buried in time beyond our experience. Therefore, we have to make a **hypothesis**, a statement or proposed explanation for an observation found in a nature. Cosmologists have generated hypotheses about the origins of the universe, for how things may have happened. They can then make predictions about what evidence we should find if a hypothesis is correct and observe physical evidence to see if it is consistent with that hypothesis or not.

The hypothesis about the origins of the universe which is best supported by current evidence is called the Big Bang Theory. A theory is somewhat similar to a hypothesis in that it attempts to explain a phenomenon found in nature. Note that in science, though, we use the word **theory** only when talking about well supported, repeatedly tested ideas that are broad in scope. The word "theory" sometimes comes up in everyday use, like when you examine things around you. You might say, "I have a theory that my dog is the one chewing up the couch leg." But in terms of the scientific definition of the word, this would be an imprecise use of *theory*. Instead, the dog-chewing-the-furniture idea is better phrased as a hypothesis (something we could collect evidence to test but not broad in scope). The shape of the teeth marks and knowing that your dog likes to chew on things (the "evidence") could confirm your hypothesis (or if the teeth marks don't match, you could reject your hypothesis and start with a new one).

Space Fun Fact: *Space is considered a vacuum. This means that unlike our atmosphere on Earth, there isn't air to breathe, no molecules like oxygen or carbon dioxide floating around. This is why astronauts have to wear their suits and helmets when they travel into outer space, receiving oxygen through them.*

The **Big Bang Theory** proposes that the universe started in one intense explosion (a "big bang") about fourteen billion years ago. The theory states that in less time than one second to the next, the universe grew in size from less than a pinhead to larger than our solar system, and it predicts the universe is still expanding. We can look for evidence of this expansion by noting where certain stars and galaxies are and how long it takes their light to reach us compared to times in the past. Oddly, it appears galaxies farther away from Earth are moving away from us faster than those galaxies close to us. This is consistent with a universe that began from a big bang and expanded outward at an accelerating rate.

Astronomers have also observed what seem to be "echoes" of the big bang when examining the universe. These echoes take the form of cosmic background radiation. This radiation is something we can measure everywhere in outer space, even the vast empty spaces between galaxies. It has a distinct pattern which may help us gain information about the beginning of the universe, similar to how the pattern of ripples outward from a stone hitting the water could tell us something about the splash that caused the ripples. The precise details (and physics involved) is beyond the scope of this book, but this is just an example of the types of observations scientists can make when evaluating the "how" questions of physical creation. We cannot personally travel to the moments before creation to watch God in action, but observations like the movements of galaxies or cosmic background radiation can help us evaluate ideas and learn more about the universe around us, including its history.

Interestingly, the Big Bang Theory received some of its first support from a Belgian priest and physicist named Fr. George Lemaitre. This is notable because it shows us that Catholics can seek to discover information about the origins of the physical universe without worry that it will negatively affect our belief in God. Faith and reason are both important, and they can work together toward a fuller and more complete understanding. To speculate and study the origins of the universe does not undermine our belief that God created and sustains everything we see (and cannot see, like angels!). On the contrary, seeking to understand how God created the universe can draw us closer to Him. It can give us a window into the Divine Mind.

Though physical evidence we collect is consistent enough for us to call this the "Big Bang Theory" (it is repeatedly supported by tests and evidence), there will always be open questions about how the history of the universe unfolded. We may not have the precise script for how God created the universe. But science is always gathering more information, and this new evidence can help us revise and refine our theories, or generate a new theory of cosmology best supported by the evidence. Regardless of what we come to know and understand in science, our faith remains the same. We will always believe that, as we know through Scripture and tradition, God created the universe and everything in it, whether through a big bang or however else He may have chosen to do so!

FOUNDATIONS REVIEW

- ✓ Space is bigger than we can possibly imagine. If we could travel at the speed of light—670,616,629 miles per hour—it would still take you billions of years to travel from the center of the universe to the outer edge of the observable universe.
- ✓ There is a difference between outer space (or space) and the universe. Space is the area beyond Earth that stretches between our home planet and all the other astronomical objects (planets, moons, stars, galaxies, etc.). The universe, meanwhile, includes all of space and the time, energy, and matter contained there. Outer space, the area between all the objects in our universe, is almost entirely empty. The density of space is so low it is considered a vacuum, which means it is an area without matter, without molecules like oxygen and carbon dioxide.

- ✓ Cosmology is the study of the origins of the universe. While all we know for sure is that God created the universe, astronomers have speculated and formulated theories about how the universe was created. One of these is the Big Bang Theory, which states that the universe started in one intense explosion and has been expanding outward since then. We can test this based on current observations of stars and galaxies moving away from Earth.

Professions that Study Outer Space

As you have read by now, the universe is an unimaginably vast and an amazing place. We will learn some things in this book, but certainly not everything there is to know about these topics. That is true because of the limited space on a page (pun intended!), but also because science is still learning more all the time. So a good way to start off our journey is to take a look at the many fields of scientific study that all interact in our exploration of space.

Astronomy is the large branch of science which explores the universe and studies celestial objects (like stars and planets). In effect, astronomy studies everything and anything beyond our atmosphere. But what does it take to become an astronomer? Well, stars and planets are made up of matter, so astronomers need to know something about chemistry and the properties of matter. For example, in our chapter on stars, we'll briefly mention the chemical reactions that take place inside stars to generate heat and light. Astronomers also use the tools of math and physics to help them learn about the universe. For example, based on observations of celestial objects and how they move through the sky, astronomers in the past were able to predict the discovery of new planets using math – they knew something large must be out there "tugging" on other things in space with its gravity (even if they couldn't see it).

So astronomers don't just look out of telescopes all day, watching for comets or taking a close-up look at planets – though this might be a small part of some astronomers' daily routines. Moreover, some telescopes they use aren't even devices that we look through. Some large telescopes are sent into space to take images and send them back to astronomers on earth, and others collect information besides just visible light. We can see things, on earth or in space, because light bounces off those objects and our eyes

detect it. But light is only a small part of the energy bouncing around in space – other forms include things like ultraviolet (UV), infrared, microwaves, and radio waves. Instead of light, some telescopes detect these forms of energy to help us learn about the universe.

Interestingly, not all scientists who study parts of space or the universe would call themselves astronomers (though maybe their expertise may fall within the field of astronomy). Some scientists are planetary geologists who specialize in the rocks, minerals, and other materials that make up planets. Others may be climatologists who compare our atmosphere and climate with that of other planets. Another example is an astroparticle physicist, who studies the connections or similarities between very large interactions (galaxies) and very small ones (tiny particles).

Together, these many different fields of science are helping us better understand the universe. There is still a lot that we are learning about, such as something called "dark matter" and "dark energy." These are mysterious because we cannot directly detect them (they don't interact with light at all!). But we know, for example, that dark matter exists because it has a gravitational pull (uses gravity to pull things together) just like "normal" matter. This is sort of like if we had a playground seesaw, and one side had an elephant sitting on it. If the side the elephant was on was way up in the air, then based on what we know about physics, we would expect that something must be sitting on the other side—even if we couldn't see it.

Dark energy is a mysterious force acting against gravity, pushing things apart. Scientists are hard at work trying to better understand these things, but still have a lot to learn. Maybe someday you will help untangle this or other mysteries in our universe!