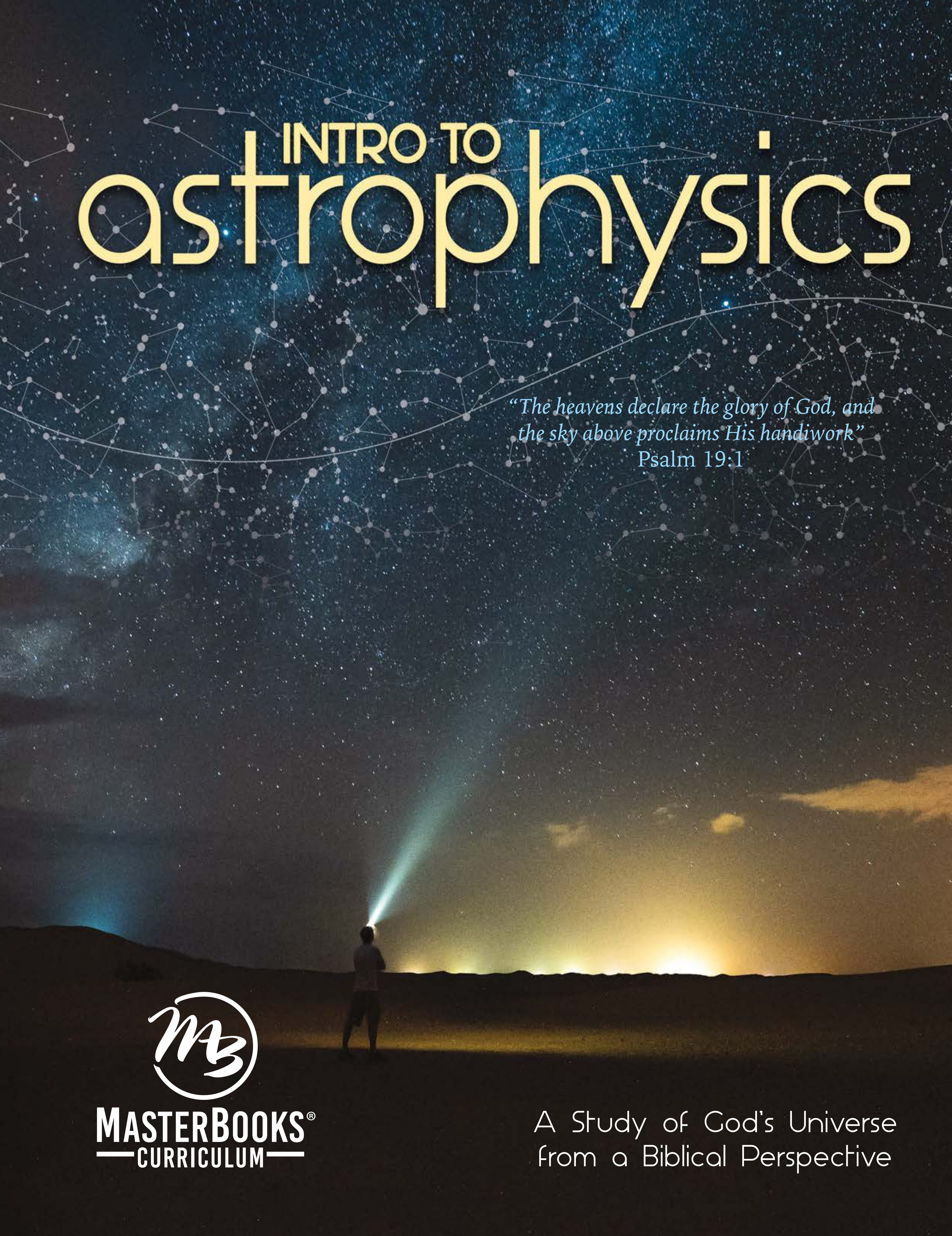

INTRO TO astrophysics

"The heavens declare the glory of God, and the sky above proclaims His handiwork"
Psalm 19:1

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CURRICULUM

A Study of God's Universe from a Biblical Perspective

Author: Danny Faulkner

Curriculum Development:
Kristen Pratt

Editor-in-Chief:
Laura Welch

Editorial Team:
Craig Froman
Willow Meek
Judy Lewis

Art Director:
Diana Bogardus

Design Team:
Diana Bogardus
Terry White
Jennifer Bauer

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ABOUT THE AUTHOR

Dr. Danny Faulkner graduated from Bob Jones University with a degree in mathematics. He received a master's degree in physics from Clemson University and a master's degree and PhD, both in astronomy, from Indiana University. Dr. Faulkner is Distinguished Professor Emeritus at the University of South Carolina Lancaster, where he taught astronomy and physics for more than a quarter century. Since 2013, Dr. Faulkner has been the staff astronomer at Answers in Genesis. The author of more than a half dozen books, Dr. Faulkner frequently writes and speaks about astronomy and creation. He continues to research and publish on eclipsing binary stars in professional astronomical literature.

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Milky Way

ASTROPHYSICS: AN INTRODUCTION

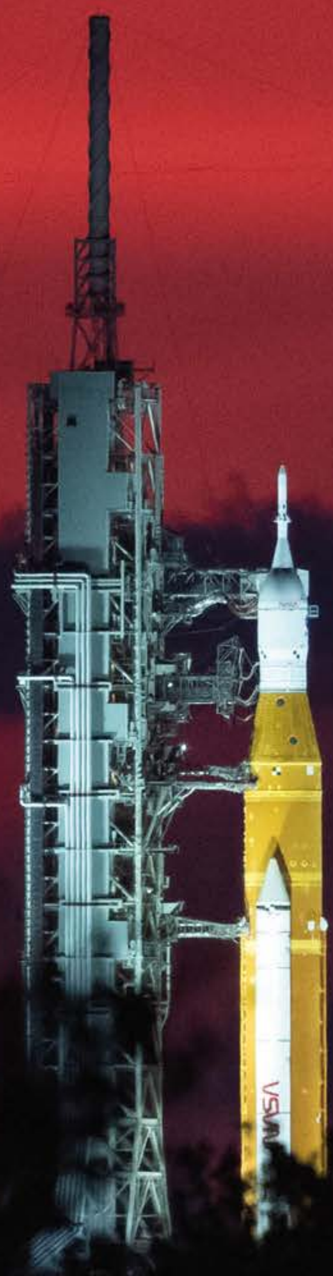
The word astronomy comes from two Greek words — one that means "star" and the other that means "to arrange." Thus, very literally, the word astronomy means "to arrange the stars." Astronomy is a study of the planets, stars, comets, and other objects found throughout the universe. It measures positions, distances, luminosities, and nature of various objects in space.

This text focuses on what is known as astrophysics. Astrophysics considers what is learned in astronomy, yet goes a little deeper into how the universe began, how it works, and how things like black holes, dark matter, and gravity are used by God to sustain His creation. Astrophysics utilizes the information obtained from physics and chemistry to propose theories behind the origins of objects we know about and discover, as well as their purpose. In this study it will also include discussions on cosmology, which studies the chronology and nature of the universe as a whole.

The study of the planets and stars has a powerful purpose – its purpose is to bring us closer to God. Psalm 19:1 tells us that the heavens above declare God's glory. Psalm 8:2–8 goes further in pointing out that even though we are very tiny compared to the universe, we are very special in God's sight. Romans 1:18–20 builds upon this, arguing that the world around us demonstrates that God exists, and is very powerful so that men are without excuse.

Most people readily agree that there is much beauty in gazing into the night sky. In this course, you will learn a bit about how chemistry and physics play a part in astronomical studies. But if one's understanding ends there, then one has entirely missed the point. God has created a wondrous creation, but sin has tainted that world. The study of the universe ought to bring people to understand these facts and bring them to repentance and salvation through God's only Son, Jesus Christ.

The luminous, hot star Wolf-Rayet 124 (WR 124)



Introduction to Lesson 1

Many of you might think that facts and theories are opposites. It is important to realize facts and theories are two very different kinds of things. We use facts to support or oppose theories. We use theories in all areas of human endeavor. For instance, some schools offer a course in music theory. Music theory is the study of the basics of music, such as meter, timing, pitch, and dynamics. We use all these elements and more to create music. Far from being an untrue statement about music, music theory is a well-established way of studying music. Economists have different theories, or systems of belief, about how the economy works. Different theological systems or different methods of Bible study are theories. The most important aspect of all of these is that they work. A good theory should be useful. The same is true with scientific theories.

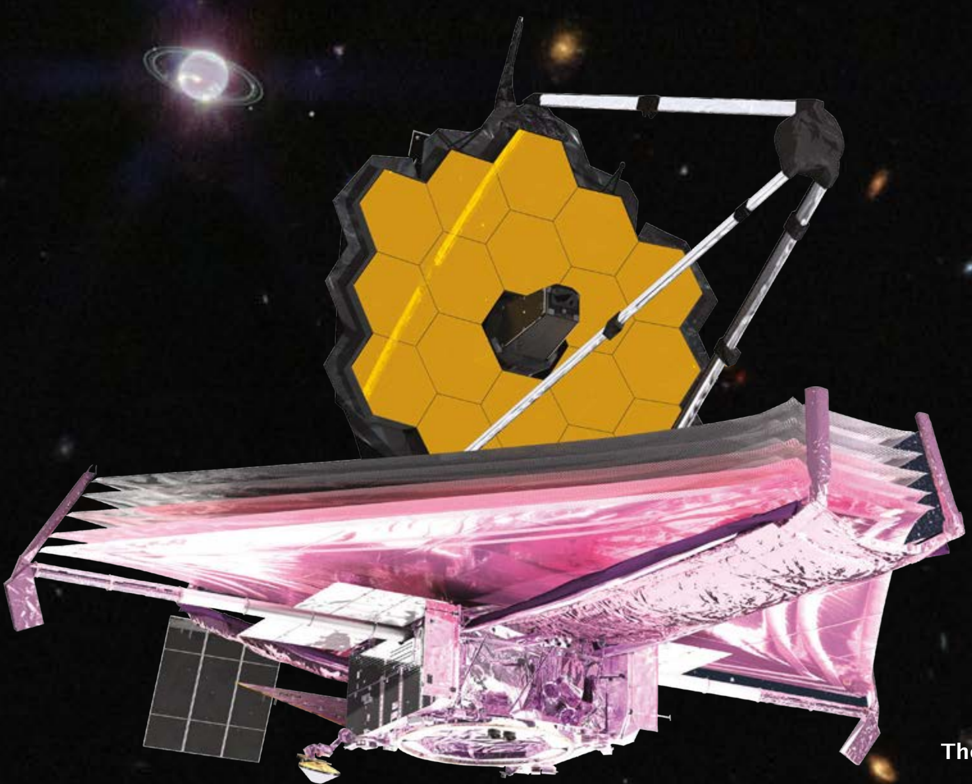
Since this course is intended for upper-level high school grades, you may have varying degrees of experience with science. You should have knowledge of the scientific method. If all of you have had previous science courses, then you may wish to refresh your memory quickly and then move on.

The same is true of scientific notation and significant figures. If you are well versed in these topics, then there is no need to spend much time on it. However, if you are weak in working with numbers scientifically, then you must take the time to cover these topics adequately. Since subsequent lessons do not include a lot of quantitative information and handling of numbers, these topics were relegated to a Feature. However, the lab book does use numbers extensively.

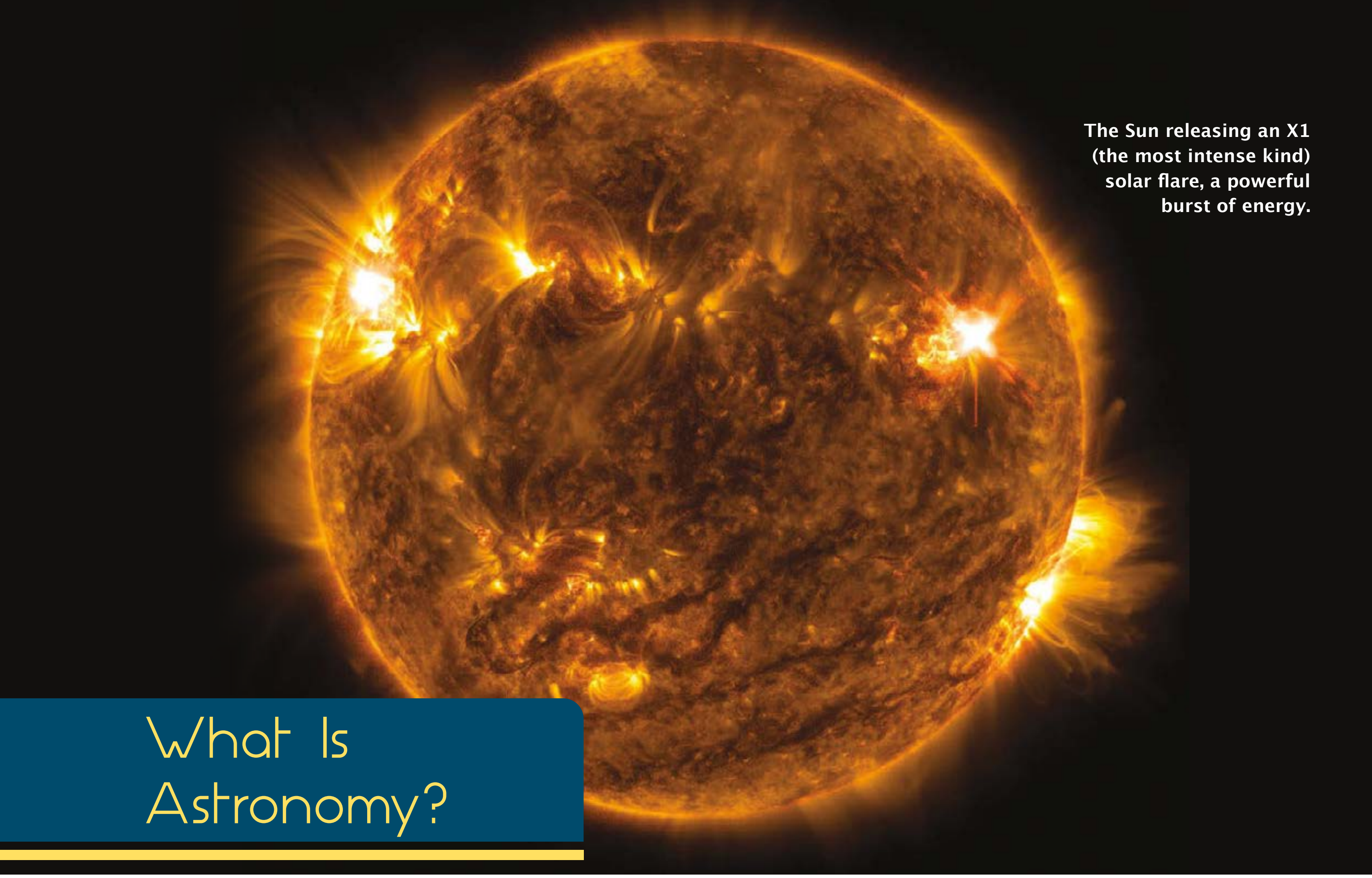
Be aware of what a bias is. Note that biases are not necessarily bad. We should not be ashamed of our biblical bias. Objectivity is not necessarily lost if we have a bias. It is more important that we acknowledge that we have a bias so that we can deal with it accordingly. Those who believe in evolution and naturalism generally deny that they have any bias. This does not allow them to be objective in certain matters.

Worldview: Through the Lens

CREATIONISTS	EVOLUTIONISTS
Hold certain foundational things to be eternally true and hence beyond debate	Hold that truth is relative and changeable by new information or new perspectives
There is a Creator, and He accomplished His creation in the not too-distant past	There is no creator, and the universe has been evolving for billions of years
The belief about origins is based on the Biblical record	The belief about origins is based on philosophical reasoning
Have a bias toward God and the supernatural	Have a bias against the possibility of the supernatural
Use a divine, supernatural explanation of how everything came to be	Use a purely physical, purely natural explanation of how everything came to be
Base understanding in the assumption that God exists and has revealed himself in Scripture	Base understanding in the assumption that the physical world is all that exists



The James Webb Telescope



The Sun releasing an X1 (the most intense kind) solar flare, a powerful burst of energy.

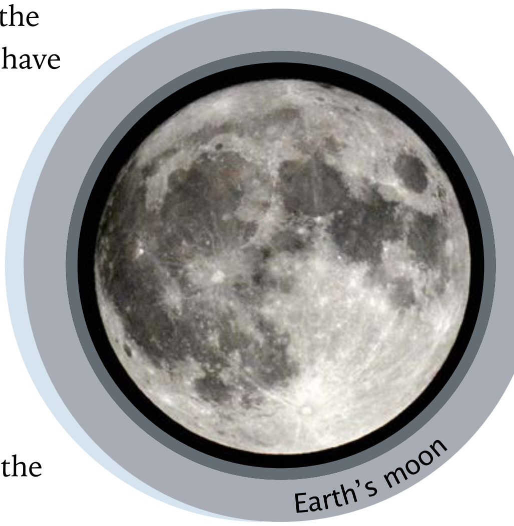
What Is Astronomy?

Astronomy: The Oldest Science

The word **astronomy** comes from two Greek words — one that means "star" and the other that means "to arrange." Thus, very literally the word astronomy means "to arrange stars." The arrangement here refers to information about stars, and so more loosely, astronomy means the study of stars. Today we understand that astronomy is more than just the study of stars but includes the study of other objects beyond the earth, such as planets, comets, and asteroids as well.

Astronomy is perhaps the oldest of all sciences. Genesis 1:1 tells us that God created the heavens, along with the earth, in the beginning. God made the sun, moon, and stars on the fourth day of creation. According to Genesis 1:16, the greater light (the sun) was created to rule the day, and the lesser light (the moon) was created to rule the night. Besides being separators of night and day, Genesis 1:14–16 gives three other purposes for lights in the firmament (expanse). One purpose is to provide light upon the earth, another is to be for signs, and the third is to mark the passage of time and seasons. It is conceivable that just as Adam named the animals, he may have named some of the astronomical bodies as well.

The first purpose of the lights in the heavens, to provide light, is obvious. During the



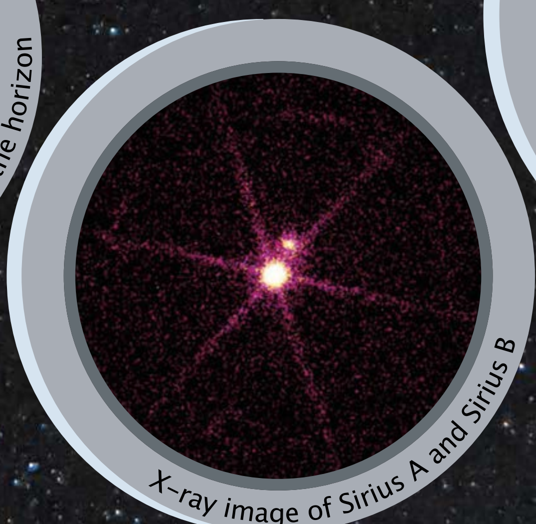
Earth's moon

day, we have the sun that allows us to see well enough to go about our daily lives. Historically, people have been less active at night because artificial means of light, such as candles, were not too bright. The invention of electric lights made it possible for us to produce well-lit conditions at night so that our activities need not cease after sundown. In the past, people relied more upon natural light. For instance, people often used a bright full moon to work after sunset. When we discuss the phases of the moon, we will learn that farmers used the harvest moon to help them gather their crops. A full moon at the first Passover allowed the Hebrews to travel at night. Even when the moon is not in the sky, the light of the stars can give enough light for us to see our way, albeit poorly. Unfortunately, with our many bright lights today, few people now ever get the opportunity to see the night sky in the splendor that our ancestors did.

Another purpose for heavenly bodies is the marking of seasons and time. Astronomical motions have always served as the definitions of time measurements. The day is the length of time that it takes the earth to spin. We define the month as the orbital period of the moon around the earth. The period that the earth requires to orbit the sun is the year. While modern definitions of time passage have changed from this, the astronomical basis is still there. If we watch the skies, the motions that are the bases of time measurement are obvious. For example, the stars that are visible at night vary by season. If we watch how the stars change, we can anticipate the coming of each season. This time reckoning is very important in determining when one should plant crops. Ancient societies were aware that sunlight, warmth, and, in some cases, seasonal rains were necessary to grow crops successfully. The ancients knew that not only did the sun return each day, but that the seasons returned each year at regular intervals. From careful observations, they realized that they could accurately anticipate these events.

The ancients also realized that they could predict other important events as well. An example of this was the annual flooding of the Nile River in Egypt. This was an important event to anticipate, because this was the time in which planting should occur. The Egyptians did not know that torrential rains far to the south caused


The Dog star Sirius just above the horizon


X-ray image of Sirius A and Sirius B


Sirius the bright star at the bottom

the flooding. However, they did learn that the annual first rising of the star Sirius with the sun in the morning always happened shortly before the Nile flooding occurred each year. They were able to use this observation to predict when the Nile would flood. Another name for Sirius is "the Dog Star," and so the ancient Egyptians came to call this time of year, "dog days," a custom continued even today.

However, in the past many people lost sight of the true purpose of the stars and began to worship the "creature more than the Creator" (Romans 1:25). As men forgot the true God, they substituted various pagan ones. Since most ancients did not know what caused the daily return of the sun or the yearly return of the seasons or the annual flooding of the Nile, we can understand why people began to believe that the signs of coming events were the causes of the events. If the signs in the sky were the cause of seasonal events, then it follows that people might be able to influence those events by appeasing those signs. Thus, the sun, the moon, the stars, and the wandering stars, or planets, became objects of worship and honor.

Psalm 19:1 reveals that a purpose for the heavens is that they declare God's glory.

Astrology

The ancient belief that astronomical bodies affect our lives and our destinies quickly developed into a religion called **astrology**. Astrology is a pagan religion that is opposed to Christianity, and there are biblical passages that warn against it (Deuteronomy 4:19, 17:3; Isaiah 47:13–14). Although people today do not seem to practice the religion of astrology, it is more prevalent than many realize. Most newspapers carry horoscopes, and many bookstores have larger sections on astrology and the occult than they do for science. Many gardeners plant by the "signs" published in farmers' almanacs, never realizing the astrological basis.

For most of history, astronomy and astrology were closely related, and in many cultures, they were one and the same. Having a lunar calendar, the Hebrews obviously made astronomical observations, so they would have had to take extraordinary steps to avoid lapsing into astrology. Other societies had no such scruples, and so they intertwined reckoning of time and of seasons with the casting of horoscopes and pagan worship.

With the rise of modern science in the 17th century, astronomy (a science) and astrology (a false religion) distinctly split. The word *astrology* comes from two Greek words, *aster* and *logos*. The first word means, "star," and the second literally means "word." We have loosened the word *logos* to mean "knowledge." Many other sciences use the same root. Examples include biology (the study of life) and geology (the study of the earth). The similarity of the word *astrology* to the names of other sciences such as *biology* and *geology* and its similarity to the word *astronomy* are most confusing. Even many educated people have difficulty remembering which is which, and probably every astronomer has been called an astrologer on more than one occasion. Many people enroll in astronomy courses expecting to learn about astrology. You should commit the difference to memory.

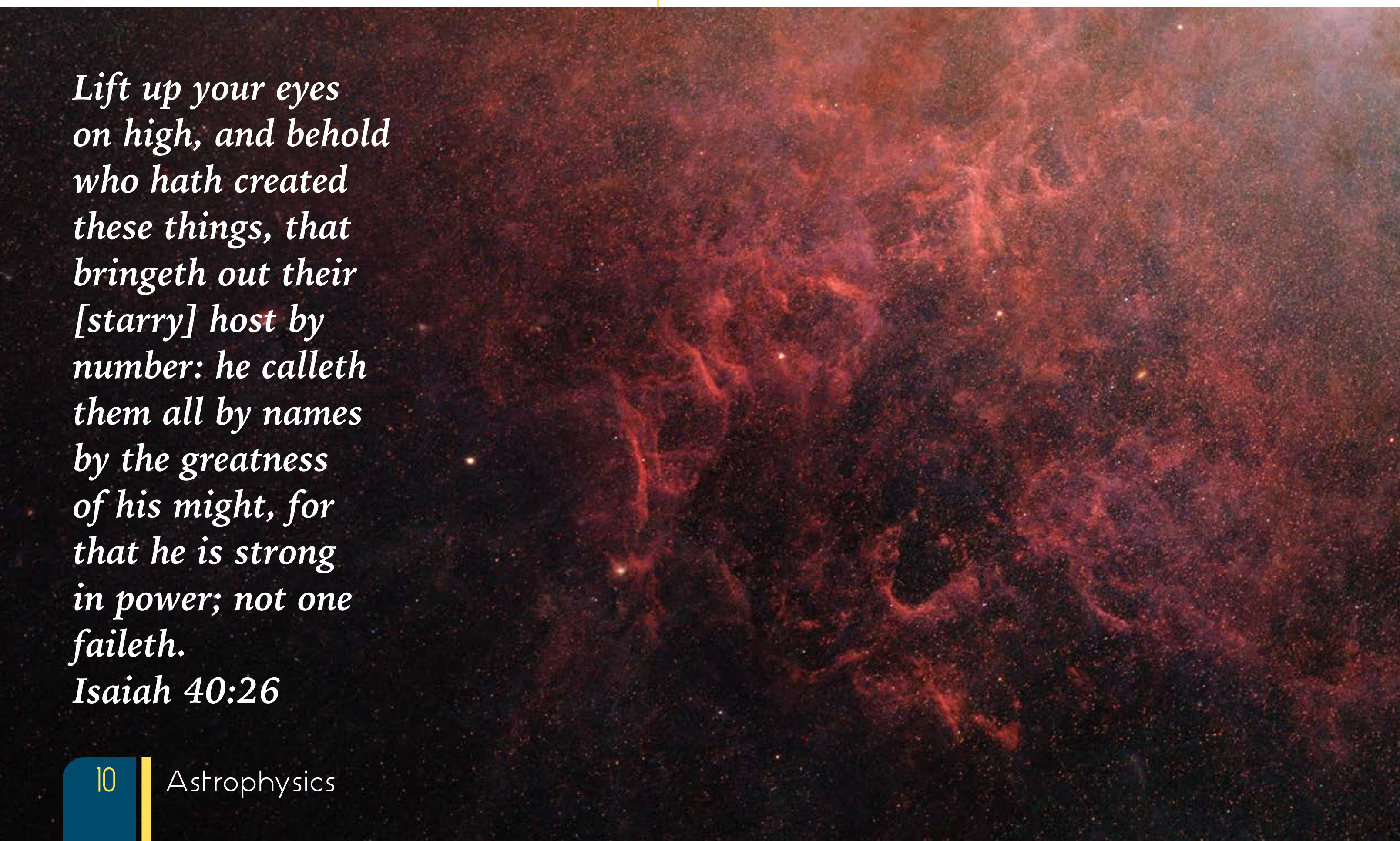
Scriptural Perspective

Astronomy is the science that the Bible most explicitly mentions. Psalm 19:1 reveals that a purpose for the heavens is that they declare God's glory. Or consider Psalm 147:4, which states that God knows the number of the stars and calls them all by name. It is impossible for man to count the stars, but conservative estimates place their total at more than several hundred billion billion. It is obvious that only an omnipotent and omniscient God could create and then know how many stars there are, but on top of that, He has unique names for each one!

Isaiah 40:26 builds upon this information to challenge us, "Lift up your eyes on high, and behold who hath created these things, that bringeth out their [starry] host by number: he calleth them all by names by the greatness of his might, for that he is strong in power; not one faileth." This sentiment is echoed in Romans 1:19–20 where it declares that the creation itself reveals God's existence and power, so that sinful men are without excuse. With the tremendous advances we are making in astronomy today, the evidence of God's power in creation has never been clearer.

Natural revelation is the concept that the world shows that God exists. Sometimes we refer to natural revelation as general revelation. While most astronomers probably believe that there is a God, it is sad that few of them know the true God personally. This underscores the fact that natural revelation alone is inadequate to bring one to Jesus. All that Psalm 19:1–6 and Romans 1:19–20 tell us is that there is a God and that He is very powerful. This is very limited information about the Creator. All that natural revelation can do is cause us to search for more information. Of course, we find that additional information in the Bible. **Special revelation** is the revealed truth of the Bible (2 Timothy 3:16–17).

Some Christians teach the **dual revelation** theory. This is the belief that natural revelation and special revelation are parallel, nearly equal, ways of finding God's truth. Those who teach this argue that all truth is God's truth and as such all truth must agree. Another way to state the dual revelation theory is that the book of nature

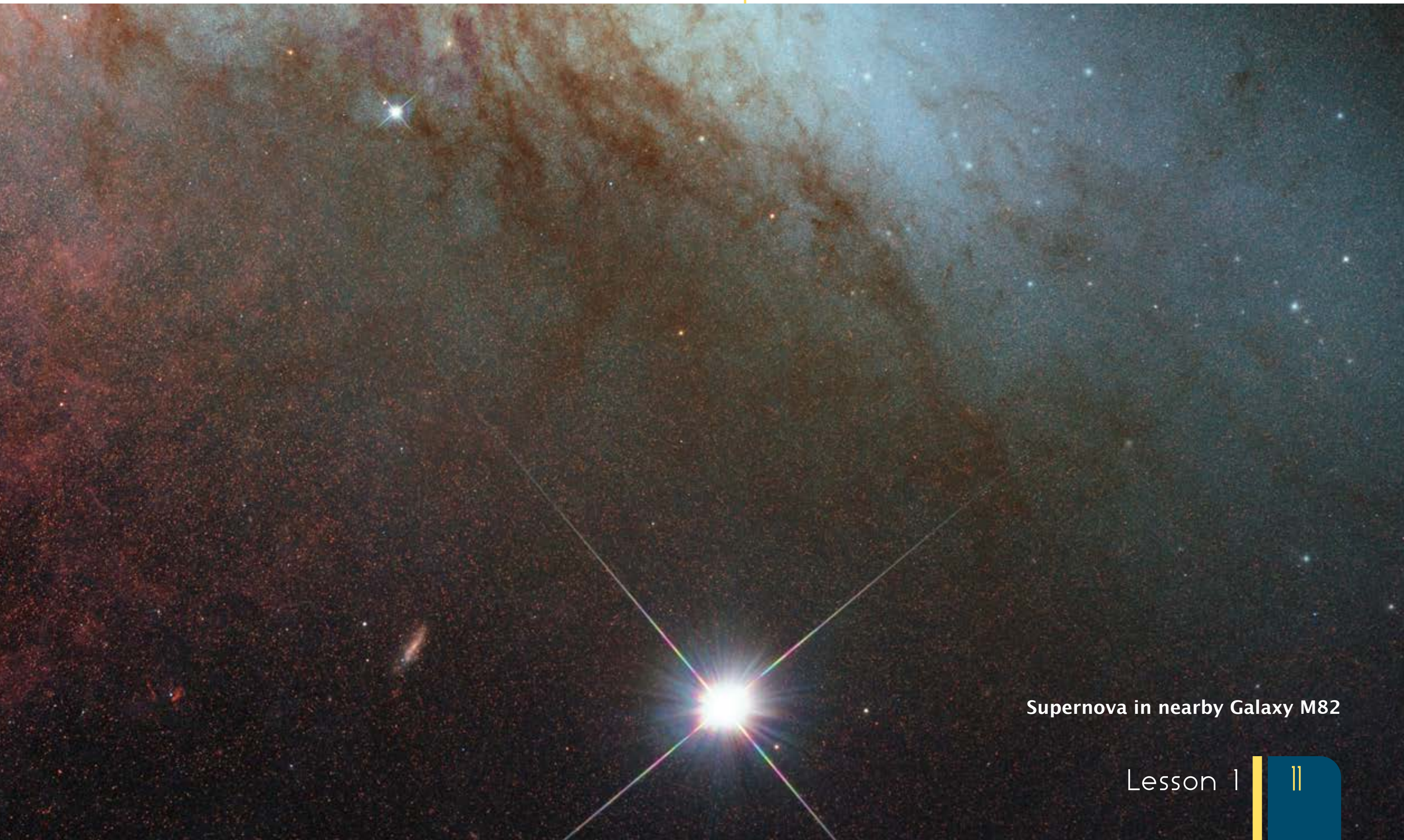


and the Bible must agree. The danger here is in elevating natural revelation to the same level as the Bible. Romans 1:19–20 and other passages do not support this.

Proponents of the dual revelation theory often engage in a very subtle shift. They begin by talking about the book of nature, but then eventually substitute science for nature. Science is not nature, but instead it is the man-made method of studying the natural world. Since science is a man-made process practiced by humans, it is subject to the same failings that people have. Scientists frequently make errors in judgment. Scientists must entertain new ideas as we perform new experiments and new facts become known. Science is a very changeable thing, but the Word of God never changes.

Another problem with the dual revelation theory is that we know what the facts of the Bible are, but what are the facts of nature? The facts of the Bible are in its 66 books, and that information does not change. However, the facts of nature, as determined by science, do change. There are many things that scientists today believe to be true, but that does not make those things true. We can never be sure just what scientific facts will survive further scrutiny, but we can be sure that the Bible will not change.

By their actions, many of those who believe the dual revelation theory hold science in higher regard than the Bible. They frequently reinterpret the Bible to fit the latest ideas of science. This has it completely backward from a true Christian worldview. The Christian must hold to the truth of the Bible. We must reinterpret through Scripture any area of human endeavor that is contrary to what the Bible says. In this textbook, we will take the proper biblical approach, which will mean that this book will disagree with modern astronomy on some points.



Supernova in nearby Galaxy M82

What is Science, and How is Science Done?

Science is defined several different ways. The definition adopted by this textbook is science is the study of the natural world using the five senses. Many sources now say that science is the search for natural explanations. This definition may sound similar to the first definition, but it is very different. Hidden in this second definition is the assumption of **naturalism**, the belief that the natural world is all that exists. Therefore, this definition excludes consideration that there may be a God. A scientist need not believe in God, but a good scientist will at least hold out the existence of God as a possibility. Otherwise, the scientist eliminates from consideration a logical possibility before he even begins his work. This amounts to a bias.

The late astronomer Carl Sagan expressed the assumption of naturalism very well. In 1980, Sagan hosted a popular PBS television series called "Cosmos: A Personal Journey," accompanied by a book with the shorter title *Cosmos*. Both the TV series and the book began with the statement, "The cosmos is all there is, all there ever was, and all there ever will be." Many people hearing or reading that statement think it was a profound scientific statement. However, that statement contains no science at all. Rather, it is a bold statement of Sagan's philosophy. The cosmos is another word for the universe, the totality of physical existence. Since God is not physical, then with this statement Sagan was denying God's existence.

Sagan could not make this statement with any certainty. How could Sagan have known that the cosmos is all there is? The only way Sagan could have known this would have been to get outside of the physical realm and seen that there is nothing outside the physical realm. How could Sagan have known the cosmos is all there ever was? He would have needed to have gotten outside the physical realm throughout all time past and seen that there was nothing there. How could Sagan have known that the cosmos is all there ever will be? He would have needed to have gotten outside the physical realm at all future times and seen that there was nothing there. If Sagan could have done all this, he would have been God. But Sagan's statement is a denial that God exists. Hence, Sagan's quote was not a scientific statement but rather an assertion of his philosophy.

The late secular astronomer, Carl Sagan

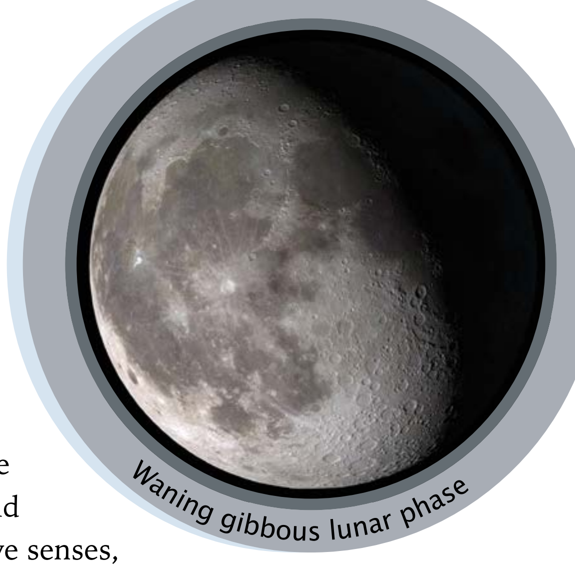
In other science classes you have probably learned about "the **scientific method**." The first step in the scientific method is to define a problem or question to solve. Examples of possible questions might be "What is the source of the sun's energy?" or "What is the composition of the Jovian planets?" The next step in the scientific method is to do preliminary research of relevant literature to find if anyone else has already worked on the problem. You may find that the question has already been successfully answered, in which further investigation may not be necessary. On the other hand, you may find that we lack enough data or that the question is too complex for there to be an answer satisfactory to everyone. Any information that you gather could guide you to aspects of the problem that remain unsolved or help you avoid mistakes that others previously may have made.

Once you think that you adequately understand the problem, you may formulate a **hypothesis** to explain what you observe. Sometimes a hypothesis is defined as an educated guess. Notice that an educated guess is not a wild guess. You must have some information for your hypothesis to explain. Furthermore, your hypothesis must be reasonable.

Next, you must develop a strategy to collect data, or information, that will either verify or contradict your hypothesis. In most sciences, this means planning an experiment, but astronomy is different from other sciences in that it is largely an observational rather than an experimental science. Except for meteorites, rocks returned from the moon, or the probes on the surface of Mars, we have no astronomical bodies on which we can perform experiments. Given the large sizes and great distances of stars, how can we expect to do something like a dissection? Instead, we must position ourselves in a good location and wait for astronomical bodies to reveal themselves. This puts the astronomer at a disadvantage when compared to other scientists, but the rest of the basics of the scientific method hold.

Once we conduct an experiment or observation, we must organize and analyze the data to make sense of it. We may find that our hypothesis correctly predicted the outcome of the experiment or observation. If so, we say that we verified our hypothesis, and we have some confidence that our hypothesis is correct. However, we may find that our hypothesis or certain aspects of it may be incorrect, and so this is a time to refine the hypothesis. Then we can make new predictions and plan future experiments. As we test and improve our hypothesis through this repeated process, we have increased confidence that our hypothesis is true.

Unfortunately, this very basic cookbook approach to science is rarely followed by scientists. As it turns out, science is not that simple. Science is more about an empirical approach to studying the natural world. As we study the natural world using the five senses, we can draw inferences about how the natural world works. In this course, we will see how inferences are drawn to reach conclusions about how the astronomical world works, inferences that cannot be tested by the very simplified cookbook "scientific method" that is often taught in schools. Examples of this include the cause of lunar phases and the cause of eclipses. But this does not mean that the conclusions we reach in astronomy are not scientific. Again, in doing science, scientists rarely follow this very simplified "scientific method." Why do schools teach this very simplified approach to science? Much of what you learn in school is very simplified. Often the simplification is so great as to make it wrong.


Waning gibbous lunar phase

In your study of science, you certainly have encountered the term theory. Most people misunderstand what a theory is. Many people think that a theory is some untested idea, often in contrast to established facts. From time to time, someone may dismiss an idea by stating, "That's just a theory." An illustration of this thinking is from an apocryphal letter to the editor printed in *Superman* comic book many years ago. The supposed writer of the letter objected to a story in a previous issue in which Superman had flown at the speed of light or faster. The letter writer stated that according to Einstein's theory of relativity that was impossible. A response states, "What Einstein said was theory, what Superman flies is fact." However, this is not what a theory is at all. A theory is a well-formulated statement of how some aspect of the world occurs which has been tested and refined in numerous experiments. Through the process of science, some clear picture (theory) begins to emerge, but it is always subject to refinement and to possible discarding. The history of science is littered with many discarded ideas, so one can never be sure from a scientific standpoint that any theory is "true."

This tentative and changing nature of science has caused critics of creation to argue that one cannot be a creationist and a scientist. This is because creationists hold certain things forever to be true and hence beyond debate. Among these assumptions is that there is a Creator and that He accomplished His creation in the not-too-distant past. Evolutionists sometimes ask if there is any evidence that they could present to dissuade the creationist from that view. Since the answer to that is no, creationists would appear to have closed minds on this issue and hence do not practice the tentative and changing nature that science is supposed to have.

However, we can turn this argument around. Is there any evidence that we could present that would convince an evolutionist that evolution is not true or that creation is true? The honest answer would be no, revealing that belief in evolution is no more or less scientific than belief in creation is. Consider the Carl Sagan statement that amounted to a denial of God's existence. The denial of God is just as much a non-negotiable position for many scientists. Sagan also addressed evolution, stating that evolution is a fact. It does not appear that Sagan changed his mind about this before his death. The personal tragedy is that this belief resulted in a Christ-less eternity for Sagan. In this world, it is sad that eminent scientists such as Sagan sometimes fall into the false dichotomy between fact and theory.

This line of reasoning just illustrates that the question of ultimate origins is not a scientific question at all. Science relies upon observation and experiment. The process by which the universe and the world came into existence happened in the past, and without a time machine, we cannot study it. Scientists may offer opinions on past and other non-repeatable processes, but we cannot base such opinions upon purely scientific principles. Thus, the study of origins is philosophical or religious, but it is not scientific.

But perhaps this criticism is too harsh. Many creationists now recognize that science is often used two ways now. The traditional way that science is done is sometimes called "operational science," or "experimental/observational science." This is the study of the natural world as it now exists. However, scientists, including creation scientists, often use scientific principles gleaned from the way the world now exists to speculate what might have happened in the past. This "historical science" or "origin science" has a different set of rules of evidence from operational science.

Investigator comparing shoe indentations with print left at the crime scene

One example of historical science is forensic science. Crime-scene investigators use principles of operational science to infer what might have happened in the past. One cannot directly observe or test what might have happened at the crime scene, but one can reach reasonable conclusions about what likely happened. Another example of historical science is historical geology. Geologists can use what we learn by observing natural processes today to infer what might have happened in the past. Creation geologists use knowledge of sedimentation and erosion to propose theories of how the rock layers of Grand Canyon may have formed and how the canyon may have been carved as a direct result of the flood.

The problem is that people often confuse these two very different ways of doing science. Critics of creationists sometimes say that doubting evolution is like doubting gravity. However, physicists often conduct experiments in the world today to test various theories of gravity. These are not tests of how gravity may have operated in the past, but how gravity works now. On the other hand, one cannot test in the present how evolution might have worked in the past. We must remember that the conclusions of historical/origin science are less certain that experimental/observational science.

Another fair question to ask is, "In constructing a theory or a model (another word for a theory) are we really concerned with 'truth'?" The **heliocentric** theory is the model that the sun is the center of motion and that the earth and the other planets orbit about it (**Figure 1.1**). The **geocentric** theory is the model that the earth is the center, and the sun and planets move around it (**Figure 1.2**). Nearly all people today believe that the heliocentric theory is true. Does that mean that the geocentric model is not useful? No. The terms "sunrise" and "sunset" which everyone uses, are geocentric. A planetarium is a geocentric model of the universe, and most navigation is based upon the geocentric model. Though we do not believe this model to be true, we still use it because it works. See **Feature 1.1** for more discussion about the geocentric theory.

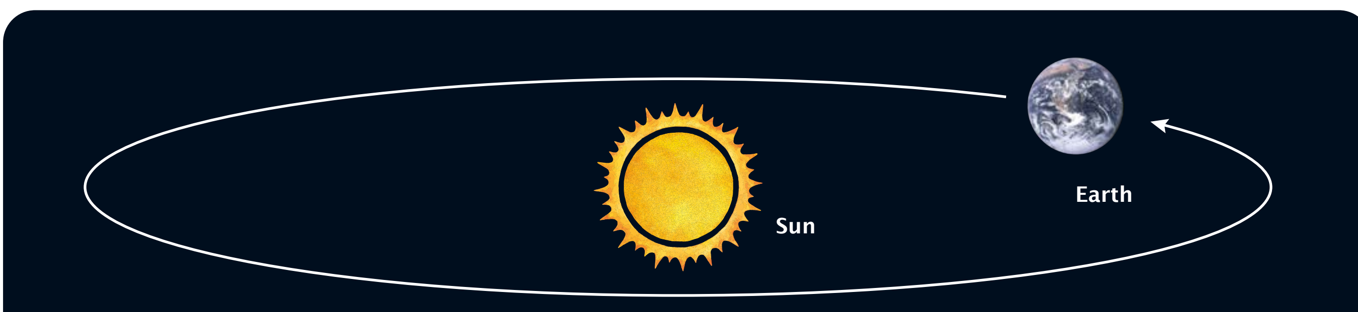


Figure 1.1 In the heliocentric theory, the earth orbits the sun once each year.

Figure 1.2 In the geocentric model, the sun orbits the earth once each day.

FEATURE 1.1

GEOCENTRISM AND CREATION

Until about four centuries ago, most people believed that the earth did not move. The motions that we see in astronomical bodies were explained by those bodies moving around the earth. We call this geocentrism, meaning the earth is the center of everything. Geocentrism reached its high point in the early second century A.D., with publication of the Ptolemaic model. The Ptolemaic model remained the dominant cosmology for 15 centuries. During the Middle Ages, the Roman Catholic Church came to interpret the Bible in terms of the Ptolemaic model. However, four centuries ago most people abandoned the Ptolemaic model in favor of the heliocentric theory, the belief that the earth is one of several planets that orbit the sun. The heliocentric model has been the dominant cosmology ever since. We will discuss this history of geocentrism and heliocentrism in more detail in lesson 3.

Despite the widespread acceptance of heliocentrism over the past four centuries, recent decades have seen a return to geocentrism among some Christians. However, the version of the geocentric theory that modern geocentrists believe is different from the Ptolemaic model, the theory that the ancients followed. We can trace the modern geocentric theory to a 16th century Danish astronomer named Tycho Brahe. In the Tychonic model most of the things in the universe orbit the sun, and the sun in turn orbits the earth each day.

Much of the support for the Tychonic model comes from a very literal interpretation of biblical passages. Examples include Joshua 10:12–13, which records that the sun (and not the earth) stood still, and Psalm 104:5, which states that the foundation of the earth shall not be moved. Most people would conclude that we ought to take the former passage in a phenomenological sense, that is, it is in the language of what we observe. Likewise, many people understand that the latter passage ought to be taken figuratively at least in part.

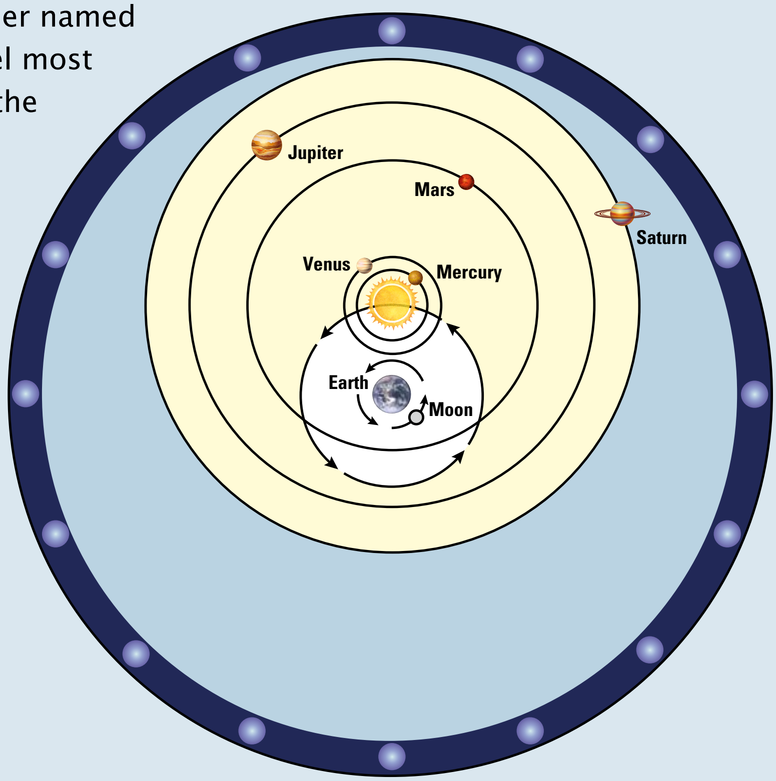
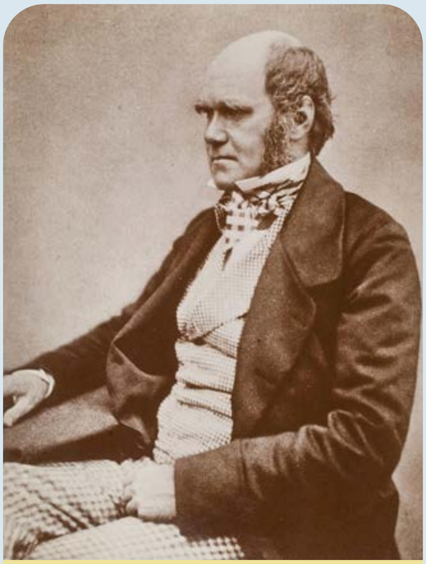


Diagram depicting the Tychonian geocentric system. The moon, sun, and the fixed stars revolve around the Earth, while Mercury, Venus, Mars, Jupiter, and Saturn revolve around the sun. The inferior planets (Mercury and Venus) orbit the sun more closely than the sun orbits the earth, so they always appear near the sun in the sky. The superior planets (Mars, Jupiter, and Saturn) orbit the sun farther than the sun orbits the earth, so they can appear anywhere in the sky.

Geocentricists will have no part of this, claiming that any who so interpret these passages are guilty of not taking the Bible seriously.



Charles Darwin

Geocentrists have found some obscure physics experiments to give scientific support for their theory. They correctly point out that the heliocentric theory gained nearly universal acceptance in the 17th century, despite that there was no direct experimental evidence of the theory until the 18th century. Of course, there has been additional evidence since then. Why did most people conclude that the heliocentric theory was true before there was direct evidence for it? The main reason that the heliocentric theory became accepted was that it offered a much simpler explanation than the competing theory of the day. As discussed in this lesson, it is a general rule in science and in logic that when given a choice between two otherwise equal theories, the simpler one is the correct one (Occam's razor).

Creationists believe that the theory of evolution is a great attack upon God's Word in that it brings into question the authority of Scripture in the first Chapters of Genesis. This attack is usually traced to the 19th century, particularly to the publication of Darwin's *Origin of Species* in 1859. But the roots go back a bit earlier. Prior to Darwin, geologists of the late 18th century had argued for geological evolution and millions of years. However, geocentrists believe that the root of the problem began much earlier with the adoption of the heliocentric theory. They argue that the acceptance of the heliocentric theory attacked scriptural integrity and laid the groundwork for the later assault of evolution.

Diagram of the geocentric theory.

Those who support the geocentric theory insist that their theory should prevail unless others can prove the heliocentric theory to their satisfaction. Science does not work this way. As challengers to the accepted idea of the day, the geocentrists must make their case. While we may admire their commitment to scriptural integrity, their condescending attitude toward those who disagree with their extreme understanding of a few passages makes it difficult for others to work with these people.

It is the opinion of the author of this textbook that the heliocentric theory is correct and poses no danger to biblical Christianity. Therefore, throughout this textbook we will assume that the heliocentric theory is true.

Limitations of Science

In an earlier section, we saw that science is a product of human beings and so is subject to the same limitations that people have. One limitation is fallibility. That is, we make mistakes. We make errors in measurement, judgment, and reasoning. If this were not enough, science suffers from other problems as well. We have incomplete knowledge. We can never be sure whether we may find new data that contradicts our current theories.

Another problem stems from the way in which science works. In explaining some phenomenon, we select a hypothesis that fits the data. However, there could be many different hypotheses that could equally explain our observations, so how do we know that we have found the correct one? A good hypothesis will allow us to make predictions of the outcomes of experiments. As we conduct various experiments, either we gain confidence in our hypothesis or we replace or alter our hypothesis. As discussed earlier, this can lead to the development of a theory. We hope that the process of refinement through predictions and experimentation will lead us to the correct explanation. We must realize, however, that competing theories may equally explain the data. Usually, we will be aware of only one theory at a time, so it is entirely possible that we have concentrated on an incorrect theory while the correct one remains unknown to us. Therefore, repeated experimentation is very important. If we have developed an incorrect theory, we hope that some future experiment will tell us that we have.

Another limitation of science is that all people have biases. A bias is a preconception or prejudice. ... The bias of this textbook is that God exists, He created and interacts with this world, and that He has revealed himself through the Bible.

Another limitation of science is that all people have biases. A **bias** is a preconception or prejudice. One bias that all scientists have is that the natural world is understandable. If we believed that the natural world was not understandable, we would not spend any time studying it in order to make sense of it. Another bias that all scientists have is the assumption that the world is simple. When confronted with two competing explanations of some phenomenon, one simple and one complicated, we usually choose the simple one as the correct explanation. (This principle is known as Occam's razor, named for William of Ockham, an early 14th-century philosopher and theologian.)

William of Ockham (1285–1347)

Of course, it is impossible for a person to be unbiased. It is obvious that a bias can be harmful. If we close our minds to certain possibilities, then that could prevent us from considering the correct theory. However, not all biases are bad. The two biases just mentioned make science possible — without them science could not exist. It is important that we acknowledge that we have biases and deal with them accordingly. It is not a question of whether we have biases, but a question of what our biases are and if we are aware of our biases. If we are aware of our biases, there is some hope that we can compensate for them. But if we are blind to our biases, there is no possibility for making allowances for them.

One very powerful bias present in scientists today is the exclusion of the possibility of the supernatural. This is quite different from the situation when modern science arose four centuries ago. At that time, scientists such as Johannes Kepler pursued their work to the glory of God and freely wrote such opinions in their work. They viewed their study as thinking God's thoughts after Him. Today, evolution heavily influences science, and has done so for more than a century. Most scientists now assume that everything must have a material explanation, rather than assuming the world is a creation of God.


Johannes Kepler (1571–1630)


Fossil trilobite imprint in the sediment

Astronomy has not escaped the influence of **evolution**. To most people, the mention of evolution brings to mind biological evolution. However, evolution is much broader than that, and it has become the single unifying theme of science to many scientists and science educators. To account for this broad approach of modern evolution, we ought to have a broad definition of evolution. The one that we will use is that evolution is a purely physical, purely natural explanation of how we and our world came to be. Notice that this definition fits biological evolution. It also fits geological, chemical, cosmic, and astronomical evolution.

If evolution were true, then there is no need for a Creator. This does not mean that one cannot believe in both evolution and God, for there are many people who do believe in both. However, belief in evolution ultimately causes one to dismiss God's existence and influence upon the world when developing scientific ideas. This leads to the assumption that the physical world is all that exists. As we have seen earlier, we call this view of the world naturalism. This means that at its core evolution is an atheistic idea. I repeat that this does not necessarily mean that an evolutionist must be an atheist, or that an evolutionist cannot be a Christian. However, a Christian who believes in evolution fails to see the philosophical foundation of evolution.

The bias of this textbook is that God exists, He created and interacts with this world, and that He has revealed himself through the Bible. Of course, most scientists consider this to be out of the mainstream of modern science. However, for the Christian there can be no other starting point. We will assume that when the Bible and science disagree, it must be science that is in error. Therefore, we will interpret science in the light of Scripture. To do otherwise ultimately leads to science reinterpreting the Bible. This is very dangerous. After all, modern science confidently tells us that a virgin birth and the resurrection of a man who has been profoundly dead for three days are both impossible. If we give more credence to the pronouncements of science on the matter of how the world came to be, why should we not do likewise on these other important Christian doctrines?

Astronomy deals with some of the smallest things (atoms and subatomic particles) and some of the largest things (what is bigger than the universe itself?).

The Use of Numbers

All sciences involve measurements and numbers. However, different sciences use numbers to varying degrees. For instance, physics and chemistry are very quantitative. On the other hand, other sciences, such as the life sciences, are less quantitative. Astronomy is somewhere in between these two extremes. Astronomy deals with some of the smallest things (atoms and subatomic particles) and some of the largest things (what is bigger than the universe itself?). To express such a great range in dimensions it is usually necessary to use scientific notation. You probably are familiar with scientific notation already, but if you are not, you should review the material in **Feature 1.2**. Astronomers also define new units of measure such as the astronomical unit and parsec. We will define these units, as we need them.


Carina Nebula

FEATURE 1.2

SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES

Scientific notation is useful for two reasons. First, in calculations without a calculator the work is much easier. Second, scientific notation lets everyone know how accurately we know the numbers. As an example of the first reason, let us find the distance to the sun in kilometers, given that it is 93,000,000 miles away. A mile is equal to 1.61 kilometers. Working with a piece of paper, many people would write

$$\begin{array}{r} 93{,}000{,}000 \\ \underline{\times \qquad\quad 1.61} \end{array}$$

and then proceed to include 18 zeroes in doing the long multiplication. Even with a calculator, numbers much larger than this may not fit into the display if the calculator does not have scientific notation.

$$93{,}000{,}000 \longrightarrow 9.3 \times 10^{7}$$

$$149{,}730{,}000 \longrightarrow 1.4973 \times 10^{8}$$

A much easier way is to write 93,000,000 in scientific notation first. Scientific notation consists of two parts: a number between one and ten, and a multiplier of some power of ten. To get 93,000,000 between one and ten, we must move the decimal point to the left seven places. The movement of the decimal point tells us what power of ten the multiplier must be. So, we write 93,000,000 as 9.3×10^7. For a number less than one, we must move the decimal point to the right, and the power of the multiplier will be negative.

Multiplying 9.3×10^7 by 1.61 is very easy. We could write the second number as 1.61×10^0, because this number was already between one and ten and we did not move the decimal point, and so the exponent of ten is zero. To multiply these two numbers, you multiply the numbers between one and ten, and then you multiply the powers of ten. Notice that you do these two products separately. Therefore, 9.3×1.61 equals 14.973, and $10^7 \times 10^0$ equals 10^7. Recall that when multiplying numbers with exponents, you add the exponents, and when dividing, we subtract the exponents. Therefore, the answer is 14.973×10^7. Notice that this is not in standard form, because 14.973 is greater than ten. We should move the decimal point one digit to the left and increase the exponent by one. Therefore, the final answer is 1.4973×10^8.

The answer 1.4973×10^8 brings up the second purpose of using scientific notation: precision or apparent accuracy. This answer tells us that the sun is 149,730,000 kilometers away, but this answer seems more accurate than the 93,000,000 miles that we started with. How accurate was the figure 93,000,000? Most people would assume that the number is closer to 93,000,000 than it is to 92,000,000 or 94,000,000. If that is the case, then we say that the number has two significant figures. In other words, the zeroes are not significant, at least concerning the question of accuracy. However, what if we wanted to express the idea that the number is *exactly* 93,000,000? In that case, the zeroes would be significant, but there is no convenient way to express that in the way that we usually write numbers.

Scientific notation allows us unambiguously to convey the accuracy of numbers. All digits in scientific notation are significant. In the above calculation, we wrote 93,000,000 as 9.3×10^7, which has two significant figures. If we wished to indicate that all the zeroes were significant, we would have written the number as 9.3000000×10^7. The way that we wrote that number indicates that all the zeroes are significant, and we say that the number has eight significant figures. Therefore, we could have written the distance to the sun to any number of significant figures by including more or fewer zeroes after the decimal point.

You should see that it is very important how you write a number, because it tells how accurately we know the number. Let us return to our example. We determined that the answer was 1.4973×10^8. Is this written correctly? We multiplied two numbers, 9.3×10^7 and 1.61. The first number had two significant figures while the second had three. Our answer appears to have five significant figures. If this were permissible, it would seem to suggest that we could improve accuracy merely by multiplying numbers together. This is not possible, so we must have overstated the accuracy of our final answer. Since one of the numbers that we multiplied had only two significant figures, our final answer can have no more than that as well. Therefore, we ought to write our final answer as 1.5×10^8. To do this, we must round off our answer. Always make certain that you properly write your numbers to reflect the accuracy.

Galaxy cluster SMACS 0723

Introduction to Lesson 9

This lesson contains some memory work that may appear disconnected at first. Examples include the kinds of minor planets based upon composition, the types of meteors, and the classes of comets. However, many of these disparate facts are tied together in the course of the lesson. Discover how these facts will be tied together, and know their relationship.

Be aware that comet tails do not trail behind comets, but instead always point away from the sun. Throughout history, people thought that comets were portends of disasters, such as plagues and the fall of kingdoms and empires. For instance, Halley's Comet was prominent at the time of the destruction of Jerusalem in a.d. 70 and at the Battle of Hastings in 1066. Additionally, at the time that the Spanish conquered the Aztecs, the leader of the Aztecs had a fatalistic attitude, because he had recently had a disturbing dream about losing his empire, which was confirmed in his mind by a bright comet.

You should realize that there is no evidence for the Oort cloud, so it really is not a scientific idea.

Know the difference between the terms *meteor*, *meteorite*, and *meteoroid*. These words are very similar and have related meanings, but they are very different. For that matter, many people confuse comets with meteors. When they see a meteor, many people exclaim, "Oh! A comet!"

It is good to be aware of evolutionary ideas, such as the ones presented in this lesson concerning the Oort cloud and the origin of the solar system. You will encounter these ideas elsewhere, and you need to understand how and why they are contrary to the Bible.

Worldview: Through the Lens

CREATIONIST	EVOLUTIONIST
Was not surprised to learn that Pluto has few craters on portions of its surface	Was surprised to learn that Pluto has regions on its surface with few craters
Believes comets indicate the solar system is not billions of years old	Thinks that comets originate from the Kuiper belt and the Oort cloud
Believes that God made the small bodies of the solar system on day four, along with the rest of the solar system	Believes that the small bodies of the solar system are remains from the naturalistic origin of the planets
Believes that God specially formed the moon on day four to fulfill specific purposes	Believes that studying the natural satellites of the other planets may reveal how the moon came to be

Small Solar System Bodies

Astronomers recognize two types of Small Solar System Bodies (SSSBs), asteroids and comets. Let’s begin our discussion of SSSBs with Pluto, the largest of the SSSBs.

The Discovery of Pluto

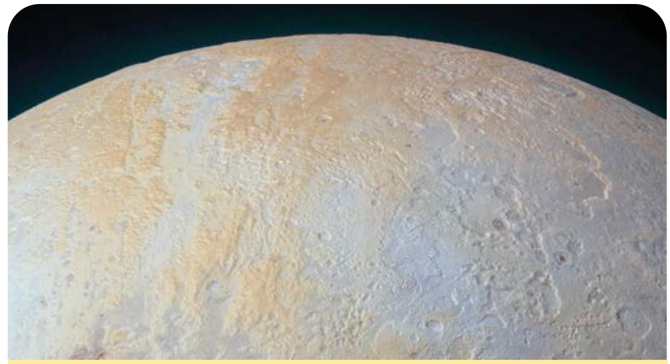
A few decades after the discovery of Neptune, both Uranus and Neptune appeared to have slight discrepancies in their orbits. This sounded like the circumstances that led to the discovery of Neptune, so some astronomers concluded that there must be a ninth planet beyond Neptune perturbing both Uranus and Neptune. But unlike before, the discrepancies were smaller than they had been with Uranus, so the problem was poorly defined. This meant that there was much uncertainty in the predicted location of Planet X, the unknown planet responsible for the discrepancies in the orbits of Uranus and Neptune. The search for this Planet X lasted many years, with most of the work done at Lowell Observatory in Arizona.

Clyde Tombaugh discoverer of Pluto shown with his homemade 9-inch telescope.

At one point, Lowell Observatory hired a young man from Kansas named Clyde Tombaugh to work on this problem. Researchers used photography in the search. The image of the new planet would be small, resembling a faint star. The only way that astronomers could detect the planet was for them to look for a change in position from one night to the next. The region of sky that they needed to search was along the Milky Way where there are many faint stars, so the search was very tedious. A special instrument called a **blink microscope** was invented for the search. A blink microscope allows a person to rapidly alternate views of two photographs made on separate nights. As the view switched back and forth, star images would remain fixed, but any moving objects would immediately become obvious as it jumped back and forth. This is very similar to how a movie or video projector works, except that the movie in a blink microscope is a looped, two-frame movie. Astronomers have often used the blink microscope to search for asteroids. In fact, the search for Planet X resulted in the discovery of many asteroids.

Early in 1930, Tombaugh blinked two photographs that showed another moving object. Calculation of an orbit for this new object revealed that it was

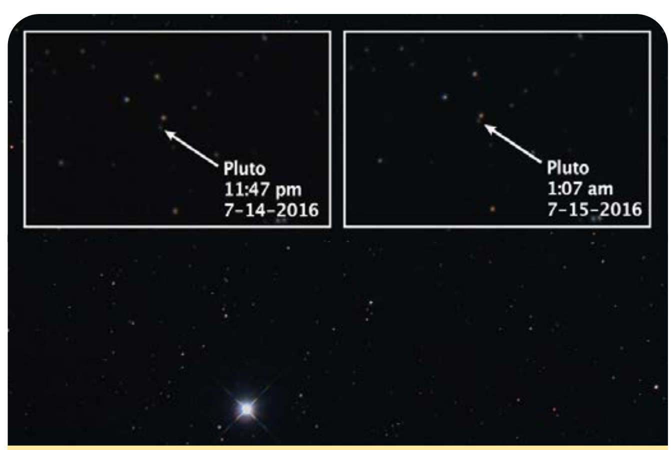
The author with the telescope Tombaugh used to discover Pluto.



The Frozen Canyons of Pluto's North Pole

orbiting beyond Neptune. Tombaugh had found Planet X. Astronomers chose the name Pluto, the god of the underworld. This was big news that generated much popular interest. Businesses cashed in on the craze, such as restaurants offering "Pluto burgers" on their menus. The up-and-coming cartoonist Walt Disney had decided to give his relatively new character Mickey Mouse a pet dog, and he chose the name Pluto to capitalize on the new planet craze.

Except that Pluto isn't a planet, at least since 2006 when the IAU said otherwise. As discussed in lesson 7, the IAU decided that Pluto wasn't a planet, primarily based upon the fact that it is too small to be a planet. At the time, the public largely disapproved, though opposition to the change seems to have waned considerably since. If Pluto isn't a planet, then what is it? Astronomers now classify Pluto as an asteroid, or minor planet.



Two photographs of Pluto taken only 80 minutes apart, showing the slight change in Pluto's position, indicating that it is not a star.

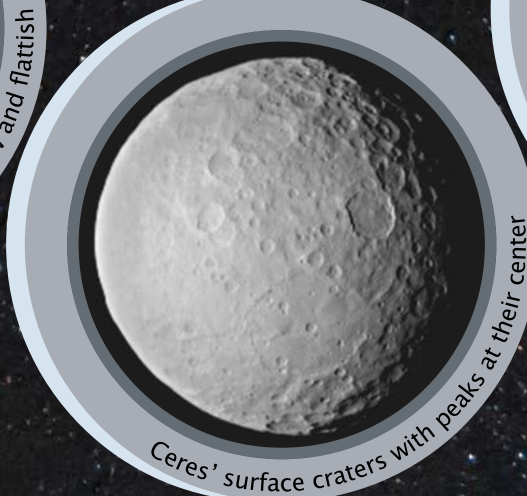
Asteroids

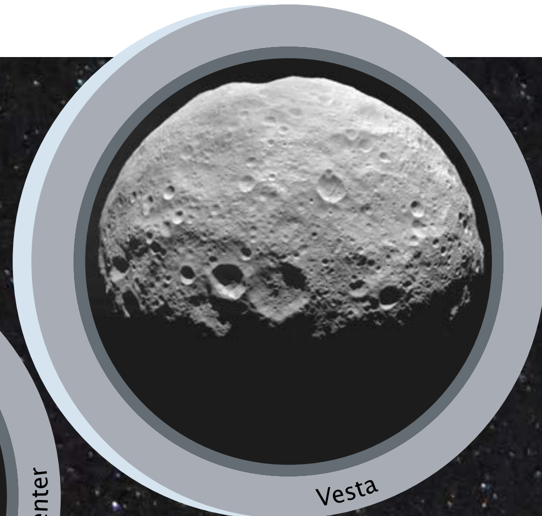
In 1801, the Sicilian astronomer Giuseppe Piazzi discovered a faint star-like object that appeared to move from night to night. A few nights of observations allowed calculation of an orbit for the object. The object followed a nearly circular path about 2.8 AU from the sun, between the orbits of Mars and Jupiter. This orbit was very similar to those of planets. In fact, many people thought that there should be a planet in just this kind of orbit (see **Feature 9.1**). Therefore, this discovery was hailed as a new planet. A planet-sized object in this orbit should have been very bright. However, this object generally was too faint to see without a telescope. Therefore, the object had to be much smaller than the other planets. At Piazzi's request, it was named after the Roman goddess Ceres. This followed the custom of naming planets after Roman Gods.

People continued to refer to Ceres as a planet for more than 40 years. Why was Ceres eventually reclassified, and what was it reclassified as being? Within a few years, astronomers discovered more small bodies between the orbits of Mars and Jupiter. As was realized with Pluto in 2006, astronomers gradually came to understand that these objects were too small to be planets. Eventually astronomers settled upon calling them asteroids, meaning "star-like," due to their similar appearance to stars when viewed through a telescope. An asteroid is a rocky object orbiting the sun in a planet-like orbit. Because they have planet-like orbits, we sometimes call them planetoids (planet-like). But now the preferred term is minor planet. Henceforth, we generally shall use this term rather than "asteroid." This modern term drives home the fact that minor planets have orbits very similar to those of planets, yet are very small.

By 1807, astronomers had discovered three additional minor planets, Pallas, Juno, and Vesta, all with similar orbits to Ceres. But it was not until 1845 when the fifth one was found. By 1890, astronomers had catalogued about 300 minor planets. Starting in 1891, photography became the tool used to search for new minor planets. Astronomers often used a blink microscope to search for minor planets. But now automated telescopes and search programs look for new minor planets. By the beginning of the 21st century, there were about 20,000 minor planets. Today there are more than a million.


Ceres' surface craters that are shallow and flattish


Ceres' surface craters with peaks at their center


Vesta

FEATURE 9.1

MYSTERIES OF THE ASTEROID BELT

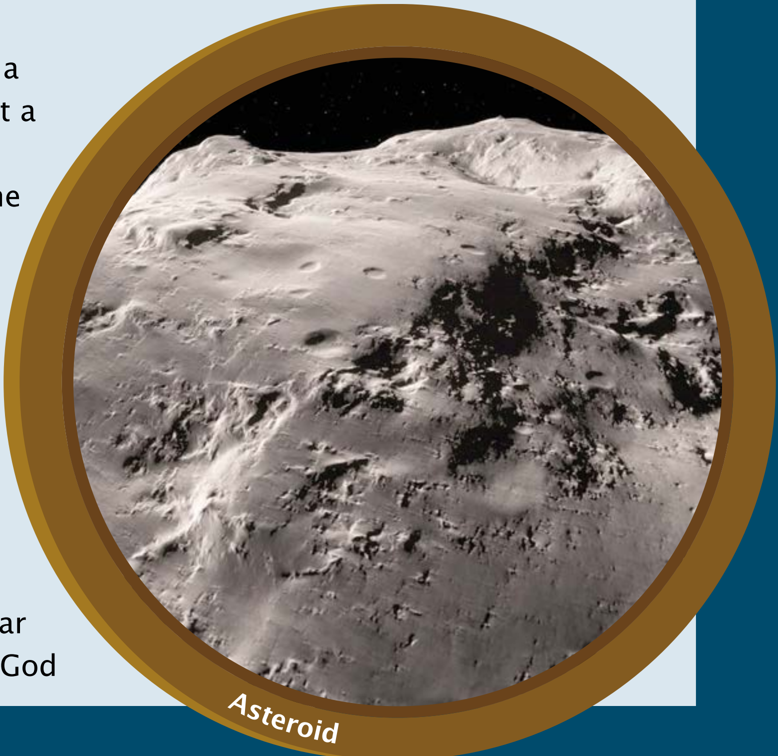
Start with the numbers 0.0 and 0.3 and then double the last number. If you repeatedly double the last number, the result is the sequence 0.0, 0.3, 0.6, 1.2, 2.4, 4.8…. If you add 0.4 to each number, the sequence gives the approximate distance of most of the planets from the sun in astronomical units. **Table 9.1** shows a comparison of the distances using this formula with the actual distances. Notice how well it fits the planets from Mercury to Saturn. We often call this formula Bode's law, after J.E. Bode, a German astronomer who popularized it in 1772. Another German astronomer named Titius had discovered the "law" six years earlier.

There are a couple of interesting things about Bode's law. It was formulated several years before the discovery of Uranus, and it "predicts" the distance of Uranus from the sun well. Second, Bode's Law predicts a planet between Mars and Jupiter that is not there, but the discovery of minor planets appeared to fill the predicted position. These two "predictions" convinced many people that Bode's law really was a law. The eventual discovery of Neptune far from its predicted position destroyed confidence in the "law." Pluto is even farther off. Today we do not think that Bode's law is a physical law in the sense that it is derived from basic principles. It is merely an approximation of planetary distances from the sun that just happens to work.

Planet	Bode's Law Distance	Actual Distance
Mercury	0.4	0.387
Venus	0.7	0.723
Earth	1.0	1.000
Mars	1.6	1.524
Vesta	2.8	
Jupiter	5.2	5.20
Saturn	10.0	9.58
Uranus	19.6	19.3
Neptune	38.8	30.2
Pluto	77.2	39.3

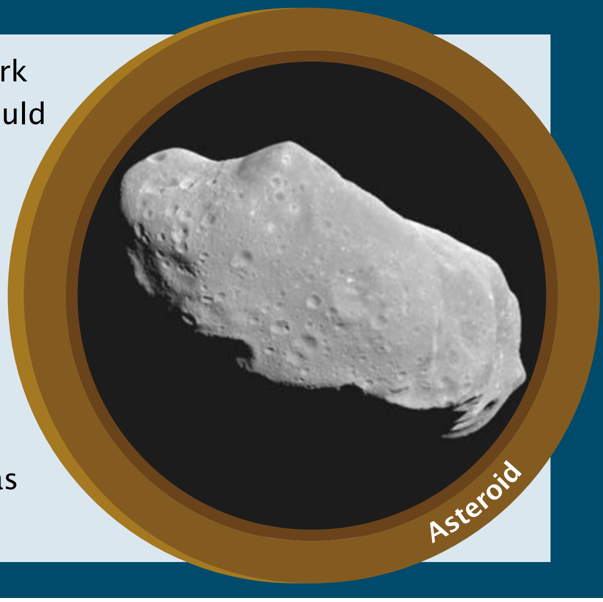
Table 9.1

Some creationists think that there used to be a planet where the asteroid belt is now, but that a catastrophe destroyed the planet. Generally, those creationists suggest that the catastrophe was a planetary collision about the time of the Flood. Some have very elaborate theories of planetary collisions and near collisions to explain the Flood, Joshua's long day, and other biblical miracles. There are at least two problems with this. One problem is that the mass of all the minor planets combined is less than 1/1000 of the earth's mass. This would hardly be enough material to make a respectable planet. Secondly, there are no clear biblical arguments for such a scenario. While God

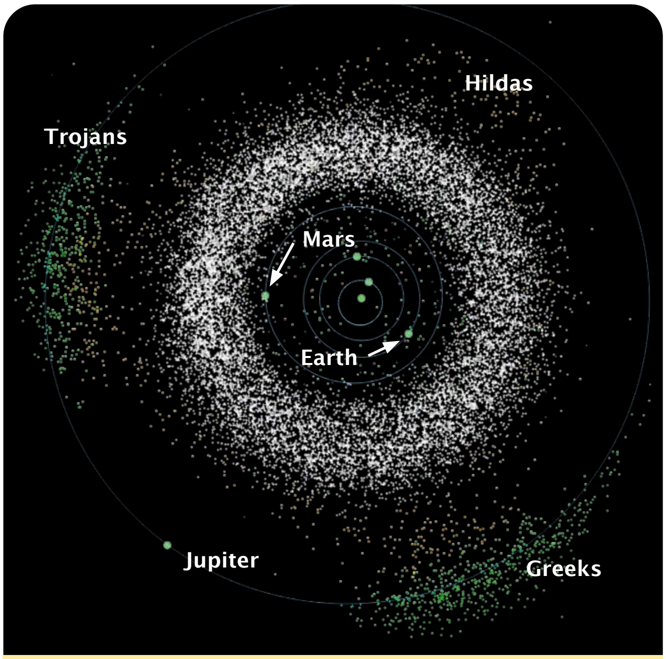

Asteroid

sometimes uses physical causes at peculiar times to work miraculous events, He often intervenes in a way that would violate normal physical law. The Flood could have had a physical mechanism that God brought on, or He could have made it happen in a way that violates the normal operation of the world.

Creation astronomers would like to have an explanation for the existence of asteroids and their different types. However, an explanation may not be necessary. It is possible that God merely created them as they are on day four of the creation week.



Following discovery of a minor planet, astronomers compute an orbit. After conjunction with the sun, if we find the asteroid in the position predicted by the orbit, then we say that we have confirmed the orbit. After confirmation, a minor planet receives a sequential number and a name. The discoverer usually chooses the name. Many of the early-discovered asteroids have names from characters in various mythologies. Today, most mythological names are exhausted. Various famous people and universities have been honored with names. In recent years, the IAU has tightened the rules for the naming of minor planets. When submitting a name, one generally must make a persuasive case that the person honored has made a significant contribution of some sort. Many scientists, authors, poets, and musicians have been so honored. The proper way to mention a minor planet is its number, followed by its name. For instance, the first minor planet discovered is 1 Ceres. With so many minor planets known today, relatively few of them have proper names. **Feature 9.2** explains how we refer to the minor planets without names.



The inner Solar System, from the Sun to Jupiter, including the Main Asteroid Belt (the white donut-shaped cloud). Just inside the orbit of Jupiter are the Hildas (the orange "triangle"). In Jupiter's orbit the "Greeks" are the group leading it. The group that leads Jupiter are called the "Greeks" and the trailing group are the "Trojans".

We can classify minor planets by the kinds of orbits that they follow. There are many different groups, so we will discuss only a few of them. Many asteroids orbit between the orbits of Mars and Jupiter in a region we know as the asteroid belt. Ceres is an example of a belt asteroid. Other minor planets have orbits that cross the earth's orbit. We call these minor planets, Near Earth Object (NEO) minor planets. Of course, the NEO's present a very real danger of collision (see **Feature 9.3**).

FEATURE 9.3

EARTH CROSSING ASTEROIDS

Astronomers know that a few dozen minor planets have orbits that cross the earth's orbit. These are the near-earth orbit (NEO) asteroids. This produces the remote possibility that these minor planets might collide with the earth. However, none of the known minor planets will collide with us for at least a few thousand years. However, for every such minor planet that we know about it, there are probably many others that we have not yet discovered. One of these asteroids could sneak up on us and provide no warning of its collision. During March 2004 a small minor planet, Asteroid 204 FH, passed within 42,700 km of the earth's surface (remember that the moon is about 380,000 km away, and the earth's diameter is about 13,000 km)! The LINEAR (Lincoln Near-Earth Asteroid Research) robotic telescope in New Mexico discovered this minor planet just a few days before the close pass. This near miss remains the record for close passage of a NEO. The LINEAR telescope's purpose is to look for such asteroids.


Arizona Meteor Crater

How serious would one of these collisions be? The asteroid that made the mile-wide Arizona Meteor Crater was probably no bigger than 100 meters. An impact of that size would have killed people within a few miles. Something a kilometer in diameter would produce a crater many kilometers across and could kill millions of people, depending upon where it struck. Not only would the impact kill people within the immediate area of the crater, but shock waves spreading outward would produce earthquake-like damage for some distance as well. An impact over an ocean would produce a huge tsunami that likely would kill people thousands of miles away.

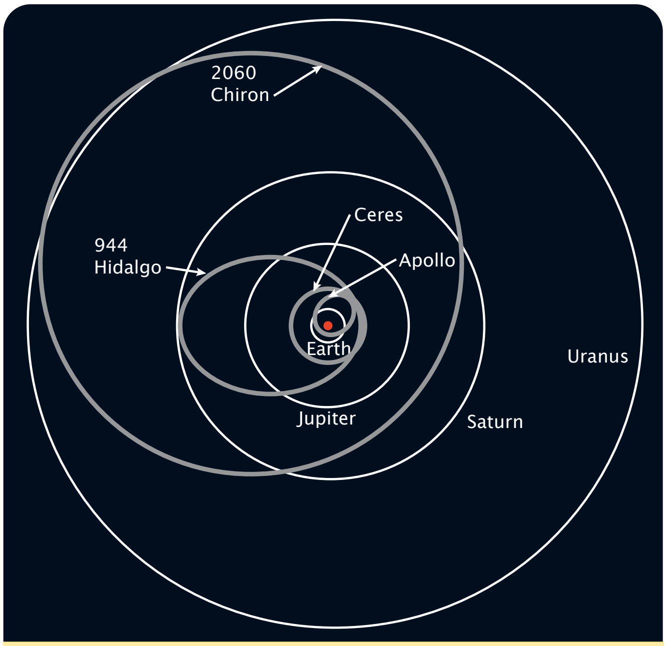
A larger impact could introduce fine particles into the upper atmosphere. These particles could remain aloft for more than a year, and they could block a significant amount of sunlight in that time. This might lead to drastic temperature drops that would destroy much plant life around the world.

In fact, just this kind of scenario is the most widely accepted theory of what happened to the dinosaurs. Many scientists think that an impact about 60 million years ago produced global cooling that directly killed many dinosaurs, while many other dinosaurs starved in the collapse of the food chain. Most scientists think that other rare catastrophic impacts were responsible for mass extinctions throughout time. Evolutionists even suggest that this sort of catastrophe allowed other animals, such as mammals, to evolve.

Some fear that this kind of event could destroy civilization. To better prepare for this possibility, some astronomers have embarked on a program to search for earth crossing minor planets. One of these efforts is the LINEAR robotic telescope in New Mexico. These efforts have discovered several such objects so far. We have witnessed a few minor planets passing within the moon's orbit. Passage this close is a near miss. Currently there are no plans to avoid such a catastrophe. In recent years, several Hollywood movies have explored this possibility. The solutions in these movies have not been very realistic.

Is there a Christian response to this? First, it is doubtful that any minor planets killed the dinosaurs 60 million years ago. We believe that most of them perished in the Flood a few thousand years ago. Second, we believe that civilization will end one day, but it will not be the result of a natural catastrophe. Instead, it will be the judgment of God. Whether He chooses to use an asteroid as part of this or not, we can be sure that there is nothing physically that we can do to stop it.

Another interesting group of minor planets is the Trojan group. We call them this because many of them have names from characters in Homer's account of the Trojan War. These minor planets follow in the same orbit as the planet Jupiter but are grouped either 60 degrees ahead or behind Jupiter. Jupiter's immense gravity traps the Trojan asteroids in this orbit in a type of resonance.



Orbits of Apollo, Ceres, Hidalgo, and Chiron

Another resonance occurs in the asteroid belt. There are certain regions in the asteroid belt where there are very few minor planets. These gaps are the Kirkwood gaps, named after Daniel Kirkwood, the Indiana astronomer who explained them. These gaps occur at distances corresponding to fractions ($\frac{1}{2}$, $\frac{2}{3}$, $\frac{2}{5}$, etc.) of the orbital period of Jupiter. You should recall that in Saturn's rings, gravitational perturbations of the satellites, such as Mimas, form gaps. The same sort of gravitational perturbations caused by Jupiter create the Kirkwood gaps.

In 1920, astronomers discovered 944 Hidalgo. Its orbit was most strange. Its eccentricity is quite high (0.66). Hidalgo's perihelion distance is 1.94 AU, placing it near the inside edge of the asteroid belt, but its aphelion distance is 9.5 AU, nearly as far from the sun as Saturn. At the time, astronomers considered 944 Hidalgo to be a unique object. But in 1977 astronomers discovered 2060 Chiron (kye'-ron), a minor planet with orbital eccentricity 0.38, and perihelion distance of 8.4 AU and aphelion distance of 18.9 AU. Chiron is the name of a centaur in Greek mythology. This name was carefully selected.

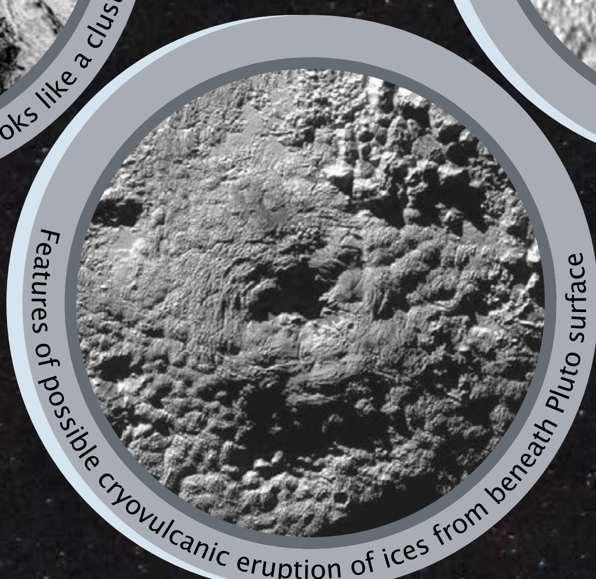
Centaurs were half man, half horse. Astronomers recognized that Hidalgo and Chiron had orbital characteristics intermediate between the two groups of SSSBs, minor planets and comets. Therefore, these two objects, along with others discovered since, are called Centaurs. Crossing the orbits of the very massive Jovian planets, the orbits of the Centaurs do not have long-term stability. Therefore, they cannot have followed the sort of orbits they have now for more than a few million years.

Since the early 1990s, astronomers have discovered hundreds of minor planets beyond the orbit of Neptune. Astronomers believe that these may be representatives of a more distant group of minor planets even more plentiful than the asteroid belt. These may be members of the hypothetical Kuiper (pronounced kye'-per) belt, which we will discuss shortly. Astronomers usually call these minor planets trans-Neptunian objects (TNOs) or Kuiper belt objects (KBOs). We shall return to our discussion of distant minor planets at the end of this lesson after we have studied comets.

In addition to classification based upon their orbits, we can group minor planets according to their composition. Spectroscopy reveals a minor planet's composition. There are several different classifications of minor planets, but there are three basic types. The C-type minor planets are most common (about $\frac{3}{4}$). Their name derives from the fact that they are carbon rich. The C-type minor planets are very dark in color. The S-type minor planets are rich in silicates. A silicate is a mineral containing SiO_4. Many rocks on earth are silicates. The **M-type minor planets** contain large amounts of metals, presumably iron and nickel. To many astronomers, the different compositions suggest that the different groups of minor planets have different origins.


A field of eye-catching craters that looks like a cluster of bright halos


Icy mountains of Pluto


Features of possible cryovulcanic eruption of ices from beneath Pluto surface

The Former Planet Pluto

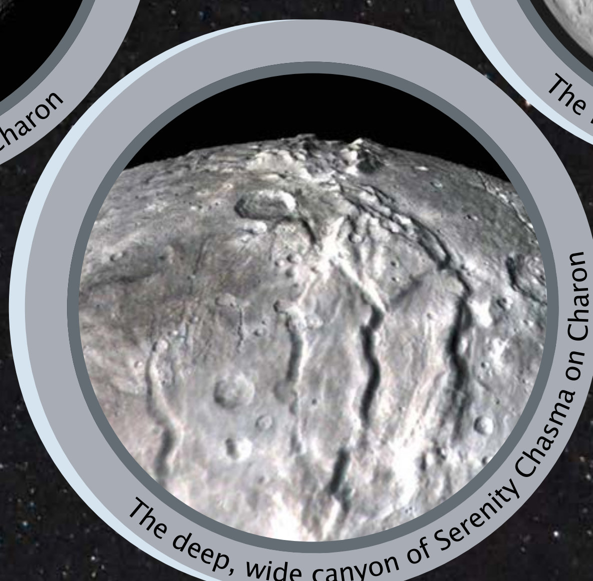
Once astronomers officially decided to reclassify Pluto as a minor planet, it required assigning it a number. Normally, the number is assigned in order of discovery, but since its official recognition as a minor planet came 76 years after its discovery, it wasn't possible to give it a number appropriate for its discovery. Therefore, Pluto was given the first available number, making its official designation 134340 Pluto.

For nearly 60 years after its discovery, we knew relatively little about Pluto. From its faintness, astronomers deduced that Pluto was very small, and that it likely didn't have enough mass to cause significant perturbations on the orbits of Uranus and Neptune. If Pluto wasn't causing slight irregularities in the orbits of those two planets, what was? That isn't entirely clear. Some astronomers have suggested that there is an additional planet farther out, but there have been extensive searches for any such planets. If they are there, they would have been found by now. Other astronomers have suggested that galactic tides may have been responsible. However, the most likely answer is that there weren't any orbital irregularities to explain in the first place. The discrepancies were on the order of the errors of measurement, so the discrepancies may have not been real. In other words, the discovery of Pluto may have been entirely an accident.

Our ignorance of Pluto's properties began to change in 1978, when an astronomer discovered Charon (share'-on), a satellite orbiting Pluto. The orbit permitted measurement of Pluto's mass for the first time, as well as Charon's mass. Astronomers quickly realized that Pluto and Charon would undergo a series of mutual eclipses a few years later, in the 1980s. The eclipse season lasts a few years, with the next eclipse season being 120 years later.


A view of Pluto's moon Charon

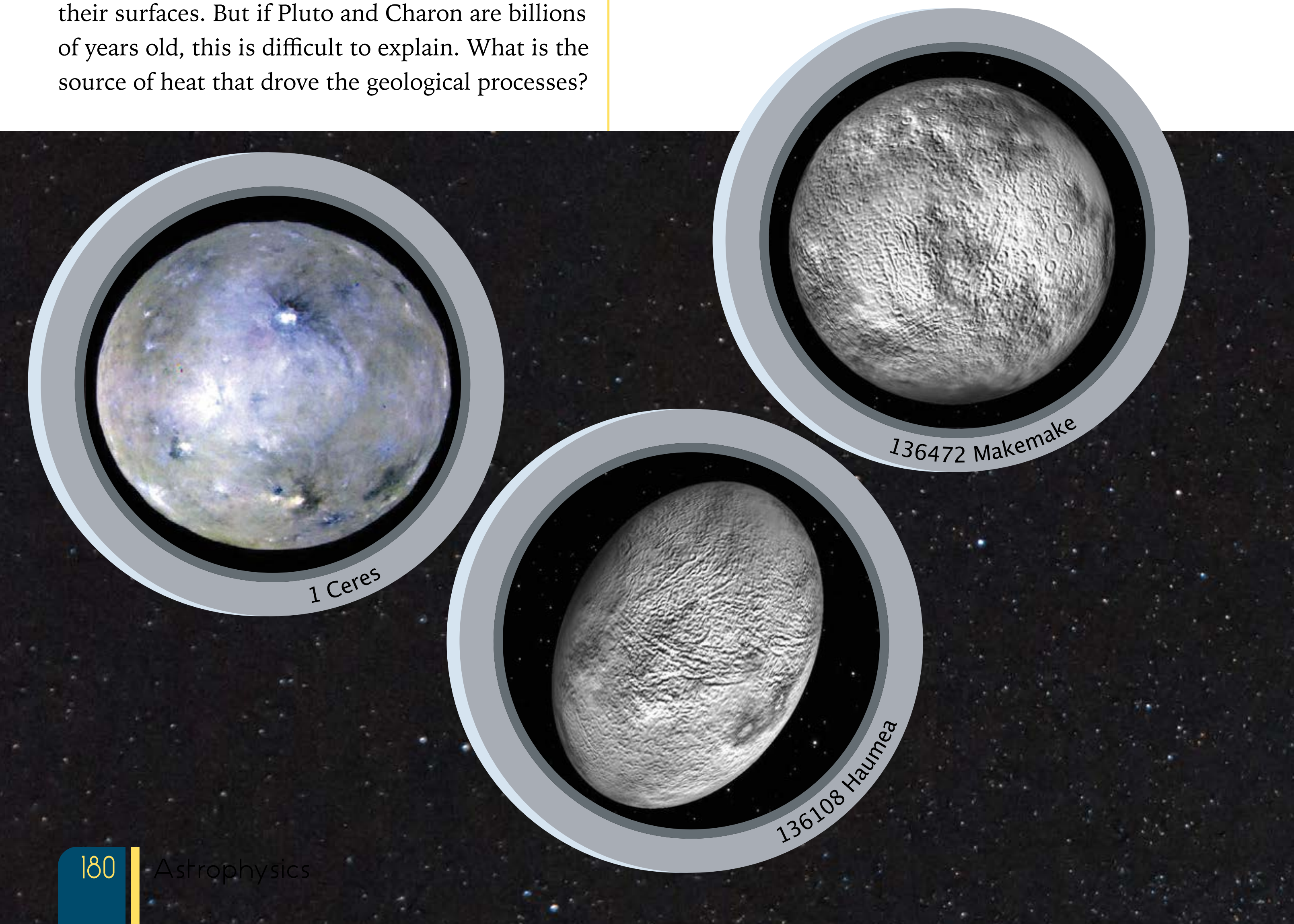

The Mordor dark region near Charon north pole


The deep, wide canyon of Serenity Chasma on Charon

To take advantage of this fortuitous opportunity, there was a concerted effort to observe these eclipses. The data allowed accurate measurement of the diameters of both Pluto and Charon. Their diameters, along with their masses, permitted computation of the densities of Pluto and Charon. In addition to Charon, we now know that Pluto has four additional small satellites.

Our understanding of Pluto improved dramatically with the arrival of the New Horizons mission to Pluto in the summer of 2015. For the first time, we had close-up photographs of both Pluto and Charon. Since the New Horizons was a flyby mission, we have photographs of only one-half of Pluto and Charon. The images revealed some heavily cratered regions. However, wide portions of their surfaces have relatively few craters. This suggests that there has been much reworking of their surfaces. But if Pluto and Charon are billions of years old, this is difficult to explain. What is the source of heat that drove the geological processes?

When astronomers reclassified Pluto as a minor planet, they also created a new category of minor planets: **dwarf planets**. Because most minor planets are so small, they lack the gravity to pull themselves into spherical shapes. However, a few of the larger minor planets do have enough gravity to be spherical. These are dwarf planets. Besides Pluto, there are four other dwarf planets, 1 Ceres, 136108 Haumea, 136199 Eris, and 136472 Makemake. It is likely that more will be added to the group. You may have noticed from the photograph of Charon earlier that it is spherical, and so you may wonder why Charon isn't a dwarf planet. Being a satellite of Pluto, it isn't eligible for the classification as a dwarf planet. Remember, a planet (even if it's a dwarf planet) orbits the sun, while a satellite orbits a planet (or another minor planet).



FEATURE 9.2

WHAT'S IN A NAME?

With so many minor planets, many of them have not yet received names and likely never will. When this is the case, a minor planet is designated with its sequential number, plus its provisional designation. The provisional designation is the year of discovery, followed by a (capitalized) two-letter code and usually a subscripted number. The first letter indicates which half-month of the year the minor planet was discovered. The letter I is omitted because it can be confused with J, and the letter Z is not needed. The second letter indicates the order of discovery within the half month (again omitting the letter I). This will allow for 25 minor planets to be discovered in the half month. More than 25 minor planets now are discovered every half month, so the second letter is recycled starting with A. The subscripted number indicates how many times the second letter has been recycled. The subscripted numbers begin with 2, because if the letters have not been recycled, there is no need for a subscripted number. For instance, 90377 Sedna was given the provisional designation 2003 VB12. This means that Sedna was the 302nd object discovered in the first half of November 2003 ($12 \times 25 + 2 = 302$). Retroactively, 1 Ceres would have been given the provisional designation 1801 AA. There was no need for a subscripted number, because the second letter hadn't been recycled yet. Confusing? You bet. Don't worry, this won't be on the test!

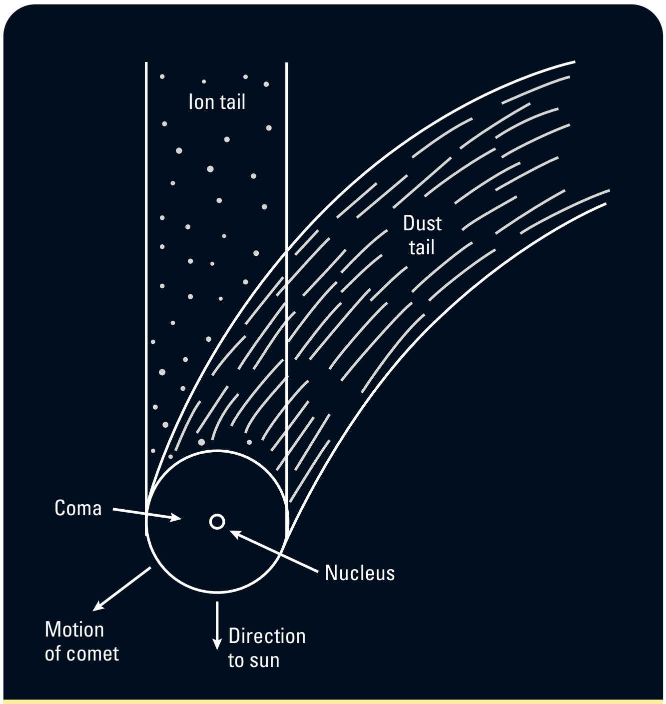


FIGURE 9.1 The structure of a comet. The nucleus is a few kilometers in diameter. The coma often is tens of thousands of kilometers in diameter. The tails may be tens of millions of kilometers long. Notice that the tails point away from the sun.

Comets

Comets are very mysterious objects. The word "comet" comes from the Latin word for "hair" from which we get the word comb. Thus, very loosely, a comet is a hairy star. **Figure 9.1** shows the structure of a comet. The **nucleus** is a chunk of ice a few kilometers across. The ices involved are water ice, carbon dioxide, and other materials with low temperature melting points. Mixed in with this ice are small bits of solid material. Much of this solid material is in the form of microscopic particles that astronomers call dust.

When the nucleus gets close to the sun, the heat of the sun evaporates much of the ice and turns it into a gas. The gas rapidly expands into space to form a **coma**. The coma can be tens of thousands of kilometers in diameter. The solar wind (an outrush of charged particles from the sun) blows the gas particles outward from the sun to form the **gas tail**. Solar radiation pushes dislodged dust particles outward to form the **dust tail**. The dust tail glows by reflected sunlight. The gas tail glows because the gas is ionized by the sun's radiation. As electrons recombine with the ions, the electrons emit light. Another name for the gas tail is the ion tail. The molecules in the gas tail move more quickly than the particles in the dust tail. The difference in speed usually makes the dust tail curved while the gas tail is straight. Either tail can extend for tens of millions of kilometers.

It is important to note that comet tails always point away from the sun. A common misconception is that a comet tail trails behind a comet as the comet moves. As a comet approaches the sun, the tail does appear to trail behind the comet. However, when a comet moves away from the sun, its tail leads the coma.

Comets are subject to the same law of gravity as the planets, so comets follow Kepler's laws of planetary motion. Recall that Kepler's second law dictates that orbiting bodies move most quickly at perihelion and slowest at aphelion. Comets follow very elliptical orbits around the sun. Therefore, comets spend most of their time near aphelion where they move very slowly. Conversely, comets spend very little time at perihelion where they move most quickly. Only during the very brief time near perihelion is the sun's heat able to form a coma and tail. For most of its orbit, a comet is too small and too faint to be visible. The orbits of comets are often highly inclined to the ecliptic. These are very different from planet and minor planet orbits, which are nearly circular and lie nearly in the same plane as the earth's orbit. **Figure 9.2** shows a typical comet orbit.

Astronomers classify comets as either long period or short period. A long period comet has a period of more than 200 years while a short period comet is less than 200 years. This is not an arbitrary distinction in time. The orbits of the two groups of comets are very different. Most short period comets have low inclinations and revolve in the same direction as the planets. Long period comets

The round coma around Comet ISON's nucleus is blue and the tail has a redder hue. Ice and gas in the coma reflect blue light from the Sun, while dust grains in the tail reflect more red light than blue light.

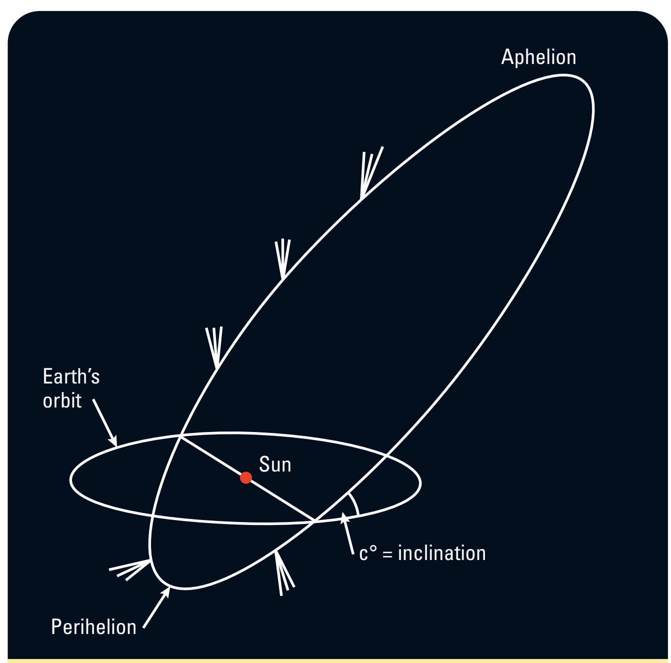
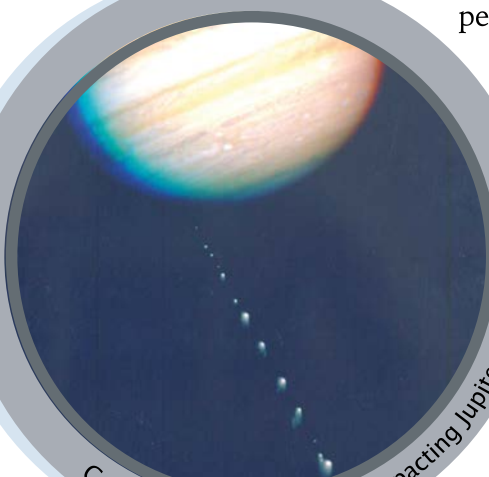


FIGURE 9.2 A typical comet orbit. Notice that the orbit is very elliptical, and that it is inclined quite a bit to the earth's orbit. The comet is brightest near perihelion.

can have any inclination, and about half revolve in the same direction as the planets, while the other half revolve the other direction. There are a few thousand known long period comets. There are about 100 short period comets. Three of the short period comets break the rule about orbiting in the same direction of the planets. Halley's Comet is the best-known exception.

Being so small and made of ice, comets are flimsy objects. During each perihelion passage, a large amount of material is lost. Estimates vary, but a typical comet cannot survive more than a few hundred trips around the sun, if that many. The C type minor planets may be the burned-out remains of comets that have lost most of their volatiles.

Coming too near the planets is another way that comets may be lost. Since most comets cross most, if not all, the orbits of the planets, they risk having their orbits affected by the gravity of the planets. Because it has so much mass, Jupiter is particularly dangerous to comets. These gravitational interactions may shorten comet orbits, or they can increase the sizes of the orbits. If one of these perturbations increases a comet's orbit too much, the comet will permanently leave the solar system. On the other hand, if a gravitational perturbation shortens a comet's orbit, the comet will encounter perihelion passage more frequently. More frequent perihelion passage leads to more rapid loss of material as previously described. Therefore, a comet that undergoes a period decrease will more rapidly evaporate and cease to exist. Lastly, gravitational interactions can alter a comet's orbit so that the comet collides with a planet. This happened to Comet Shoemaker-Levy 9 in 1994 when it collided with Jupiter. The collision was set up two years earlier when the comet passed very close to Jupiter and Jupiter greatly perturbed the orbit.



Comet Shoemaker-Levy 9 impacting Jupiter

If the solar system is 4.6 billion years old, there should be no comets left.

All these mechanisms of destruction eliminate comets. We can estimate how long a typical comet can survive. An average lifetime is far less than the supposed 4.6 billion years of the solar system. Therefore, if the solar system is 4.6 billion years old, there should be no comets left. Creationists have long used this as an argument for the recent origin of the solar system.

Of course, evolutionists are aware of this problem, and they have proposed a solution. In 1950, the Dutch astronomer Jan Oort suggested that billions of comet nuclei orbit the sun at great distances from the sun. If the perihelion distances are hundreds or thousands of AUs, then we will not see them. Being so far from the sun, these comet nuclei will last indefinitely. Astronomers call these billions of comet nuclei far from the sun the **Oort cloud**. Oort supposed that occasional gravitational perturbations of passing stars could change the orbits to cause the comets to enter the inner solar system. Thus, as old comets fade or are lost to the solar system, new comets from the Oort cloud replace them. If new comets continuously enter the inner solar system at a rate that is slow enough, then there would still be billions of comets after billions of years.

It is conceivable that the Oort cloud exists, but simple conception is not how science works. Science requires evidence. If we cannot see, measure, or otherwise detect something, then that something is not scientific. There is no evidence that the Oort cloud exists. Consider this quote by the late Carl Sagan, a famous, secular Cornell University astronomer:

> *Many scientific papers are written each year about the Oort Cloud, its properties, its origin, its evolution. Yet there is not yet a shred of direct observational evidence for its existence.*

Many scientific papers are written each year about the Oort Cloud, its properties, its origin, its evolution. Yet there is not yet a shred of direct observational evidence for its existence.
~ Carl Sagan

This is not to say that the Oort cloud does or does not exist. It merely means that its existence is not a scientific question any more than the question of God's existence is a scientific question. Until we can test for the existence of the Oort cloud, it is not a scientific concept.

For many years, astronomers thought that gravitational perturbations of the planets could convert long period comets into short period ones. During the 1980s, computer simulations revealed that this is not so. The transformation of long period comets into short period ones proceeds too slowly: the length of time required greatly exceeds the lifetimes of individual comets. To answer this problem, astronomers began to conclude that while long period comets come from the Oort cloud, short period comets come from the Kuiper belt.

Gerard Kuiper suggested his belt about the time Oort devised his cloud. The **Kuiper belt** is a hypothetical doughnut-shaped distribution of comets just beyond the orbit of Neptune. Therefore, Kuiper belt comets are much closer to the planets of the solar system. Many scientists think that the accumulated perturbations of the outer planets slowly pull Kuiper belt comets inward toward the inner solar system. Since these comets are already orbiting in the same direction of the planets with low inclinations, scientists expect that these orbital properties are preserved as the orbits are shortened further. **Figure 9.3** is a sketch of the hypothesized Oort cloud and Kuiper belt.

Interestingly, Kuiper didn't develop his idea of the Kuiper belt to explain the origin of short period comets. Rather, Kuiper suggested that a belt of debris left over from the origin of the solar system existed beyond the orbit of Neptune billions of years ago, but that it was no longer was there. Gravitational perturbations in the early solar system would have removed this

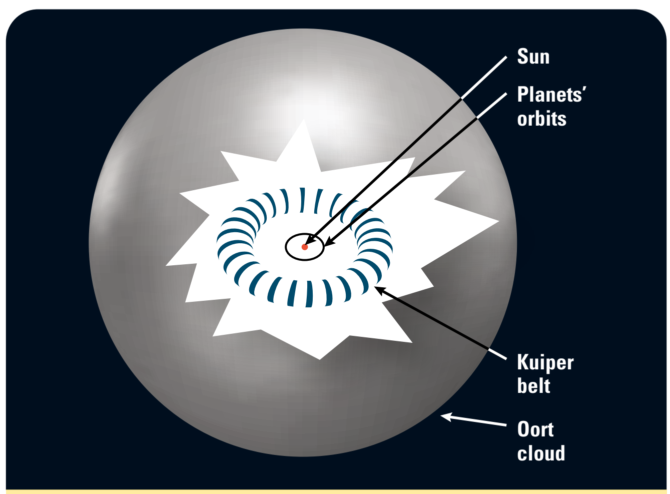
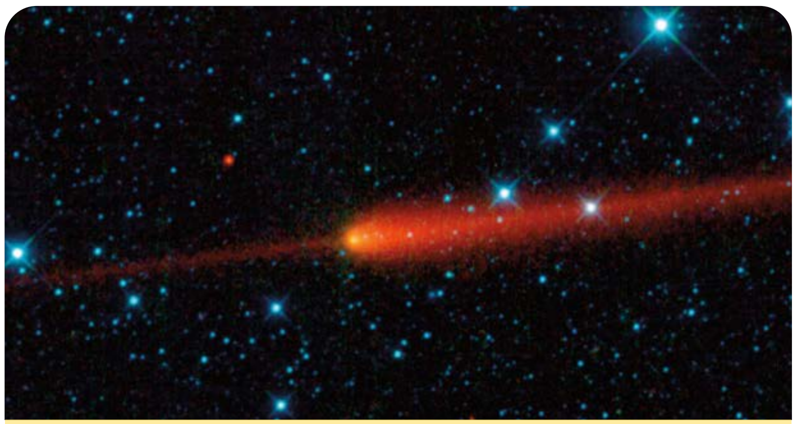


FIGURE 9.3 The relationship between the orbits of the planets and the Oort cloud and Kuiper belt. The diagram is not to scale. The Kuiper belt is a doughnut-shaped distribution of comet nuclei in the same plane as the planets' orbits. The Kuiper belt begins just beyond the orbit of Neptune. The Oort cloud is a far larger spherical distribution of comet nuclei.

debris, with many of the particles originally in the Kuiper belt populating the Oort cloud. It was only after astronomers realized the Oort cloud could not account for short period comets that they resurrected the Kuiper belt to explain the origin of short period comets.

Unlike the Oort cloud, there may be evidence that the Kuiper belt exists. In 1988, astronomers observed the distant asteroid Chiron brighten significantly and develop a faint coma. This suggested that Chiron was not rocky but is an icy body (i.e., a comet nucleus). In the early 1990s, two astronomers in Hawaii pioneered the use of a large telescope to look for objects orbiting just beyond Neptune. They have used techniques like those used to search for Pluto and minor planets. They and other astronomers have found hundreds of objects beyond the orbit of Neptune so far. These are the KBOs and TNOs previously mentioned.

What is the difference between KBOs and TNOs? The term TNO is descriptive in that it reflects what we know about TNOs: they orbit the sun beyond the orbit of Neptune. However, the term KBO is laden with evolutionary ideas about where short period comets come from. Therefore, the author of this textbook prefers the more descriptive term, TNOs. Among astronomers in general there has been a shift in recent years away from KBOs toward TNOs. This may reflect a recognition that even within the evolutionary paradigm there is a difference between simply orbiting beyond Neptune and being the source of short-period comets. Astronomers increasingly are discovering TNOs that extend beyond the bounds of what is thought to be the Kuiper belt. One example is 2014 FE72. It follows a very elliptical orbit (e = 0.976) with a perihelion distance of 36.3 (within the hypothetical Kuiper belt) and aphelion distance of 3060 AU (well beyond the hypothetical Kuiper belt). These objects with very distant aphelia are considered intermediate between the Kuiper belt and the Oort cloud.



This image from NASA Wide-field Infrared Survey Explorer features comet 65/PGunn. Comets are balls of dust and ice left over from the formation of the solar system. The comet tail is seen here in red trailing off to the right of the comet nucleus.

It is not yet possible to determine the composition of TNOs, but since they are so far from the sun astronomers assume that they are icy and hence match the composition of comets. Recall from the previous lesson that most objects far from the sun are icy. One problem with these objects being comet nuclei is their sizes. The largest comet nucleus ever observed was that of Comet Hale-Bopp in 1997. It had a diameter estimated to be about 40 km (25 miles). Many of the Kuiper belt objects allegedly discovered so far are far bigger than this. If these are comet nuclei, one must ask why we have never seen such large comets before. Furthermore, the composition of some of the larger TNOs (Pluto and Charon) as inferred from their densities do not match the compositions of comets. While they must have much ice to account for their densities, the densities of both Pluto and Charon indicate that they have far more refractory elements than comets.

FEATURE 9.4

HOW ARE COMETS NAMED?

There have been several systems for naming comets. Each one of the systems attempts to convey some information about the named comets. In 1995, astronomers adopted a single new way of naming comets. The first part of a name begins with one of four letters and a slash. The prefix P/ stands for a periodic or short period comet, C/ for long period comet, D/ for a defunct comet, and X/ for a questionable comet. Additionally, the more than 100 periodic comets are numbered sequentially starting with Halley's Comet. Therefore, Halley's Comet has the designation 1P.

The next part of the name is the year of discovery, or in the case of a periodic comet, recovery. After the year is a code for the half month of discovery or recovery. The letter A is the code for the first half of January, B the second half of January, and so forth (the letters I and Z are not used). After the half-month code, we use a number to indicate the order in which a comet was discovered in the half-month. Lastly, the name of the discoverer is in parenthesis. In the case of a near simultaneous discovery by more than one person, the names are hyphenated. As an example of the naming system, consider C/1996 B2 (Hyakutake). It was a long period comet discovered by someone named Hyakutake in late January of 1996. It was the second comet discovered in the second half of January that year.

There are strict rules governing the selection of names of astronomical bodies. Comets are the only astronomical objects that are named after the people who discover them. Until recently, amateur astronomers discovered most comets. Amateur comet hunters invest huge amounts of time scanning the skies looking for comets. Professional astronomers usually do not search for comets and observe a very small part of the sky in their research, and so they are far less likely to find new comets when there are others looking for them. Many of the comet hunters live in places with dark skies and climates that allow many clear nights. Comet hunters usually scan regions of the sky near the horizon after dusk and before dawn. Faint objects, such as very distant galaxies and star clusters, can be confused for comets. To avoid this confusion, many amateur comet hunters memorize the locations of many of these faint objects in the sky.

Notice that the system for naming comets is similar to the way that we give names to minor planets. Historically, comets and minor planets were considered distinct objects. However, in recent years astronomers have come to realize that comets and minor planets are extremes of a continuum of SSSBs. With improved detection, astronomers now occasionally see outgassing from objects once thought to be minor planets. When this occurs, the object is recognized as being a comet. However, the minor planet designation remains, but with a P/ prefix.

Meteors And Meteorites

A **meteor** is a brief streak of light in the sky due to release of kinetic energy as a piece of ice or rock entering the upper atmosphere of the earth at high speed. Interaction with molecules of air rapidly slows the particle down. The particle's kinetic energy must go somewhere, usually into heating the air around the particle and the particle itself. Though they are incorrect, common names for meteors are shooting stars and falling stars. Since stars are very far away and much larger than the earth, a star obviously cannot fall to the earth. Before striking the earth's atmosphere, the debris of rock or ice moving through space is a **meteoroid**. If a solid piece of material survives to the ground, we call it a **meteorite**. Meteors burn about 100 kilometers (60 miles) above the earth.

Most meteoroids are very small. One the size of a pea would appear quite bright. One originally the size of a baseball would light the night sky. How can this be? Though meteoroids may be very small, they are moving very fast (tens of kilometers/second). The fact that we see meteors against the dark of the night sky makes them easier to see. Many meteors visible to the naked eye result from meteoroids not much bigger than a grain of sand.

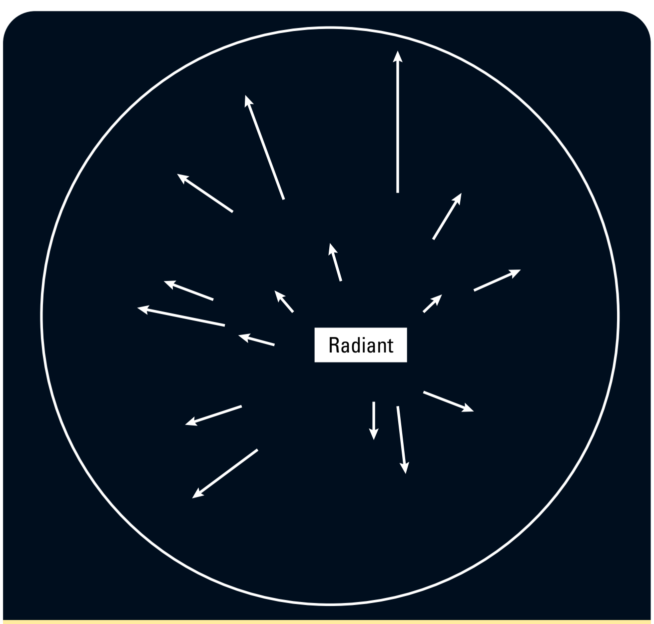


FIGURE 9.4 The radiant of a meteor shower. The circle represents the sky, and the arrows indicate the lengths and directions of meteor trails. Notice that while a meteor trail may be in any part of the sky, the tracks of all shower members diverge from the radiant if we trace the trails backward.

On any dark, clear night, a person may see several meteors per hour. However, several times per year, the earth encounters a swarm of meteoroids and a **meteor shower** results. During a meteor shower, we see far more meteors than usual. Sometimes the number per hour can be several score (a score is 20). On rare occasions, we briefly can see thousands per hour. The meteors from a meteor shower may be seen anywhere in the sky, but if we extend the trails backward, all the meteors appear to diverge from one spot in the sky. See **Figure 9.4**. This point is the radiant. We name a meteor shower for the location of its radiant. For instance, the Perseid shower each August has its radiant in the constellation Perseus. The Leonid meteor shower each November has its radiant in the constellation Leo. The meteoroids that cause a meteor shower travel in parallel paths in their common orbit around the sun. They appear to diverge from the radiant because of perspective. The parallel rails of a railroad track or the sides of a straight road appear to converge in the distance for the same reason.

Even when there is no meteor shower, there is always a background of a few meteors per hour. These meteors come from random directions, and they usually are single. Since these meteors do not appear to be associated with any shower, we call them **sporadic meteors**.

What is the source of meteors? It appears that sporadic and shower meteors come from different sources. From the paths of meteors in our sky, we can find the orbits of their meteoroids. In the case of sporadic meteors, the meteoroids were following orbits like the earth-crossing asteroids.

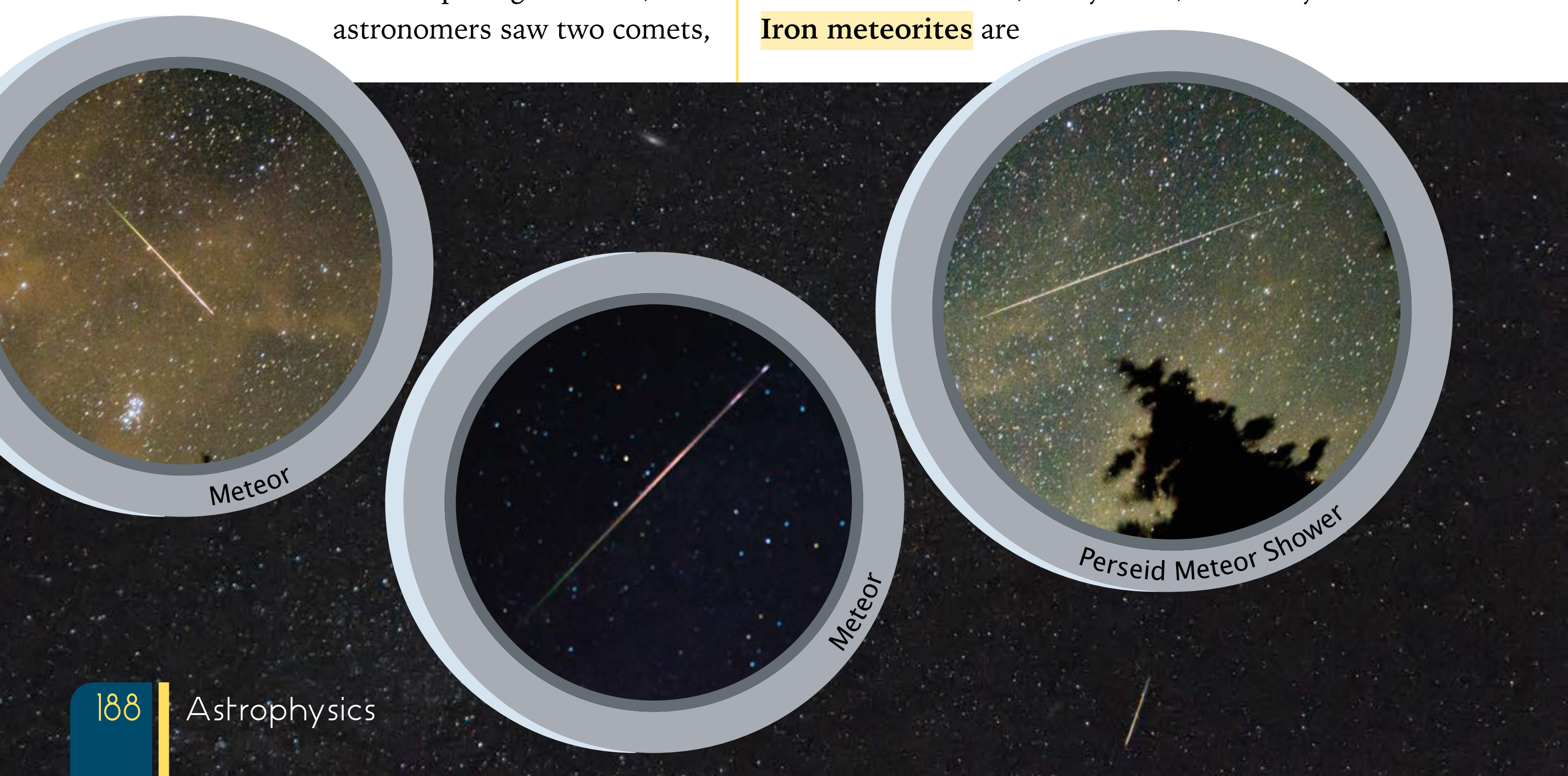
Therefore, sporadic meteors probably are fragments of asteroids that happen to collide with the earth. Nearly all sporadic meteors are single. That is, they do not occur in groups as the shower meteors do.

The meteoroids that cause meteor showers follow comet-like orbits. In fact, astronomers have identified several meteor showers with the orbits of known comets. For instance, a stream of meteoroids following the 133-year orbit of Comet Swift-Tuttle causes the Perseid meteor shower. Given the fragile nature of comets, it is not surprising that they break up into billions of debris that are scattered along their orbits. Since the particles are following the same orbit, they travel parallel paths so that they appear to diverge from the radiant as we discussed earlier.

In most cases, we cannot identify a meteor shower with a known comet. This probably means that the parent comets of those showers have ceased to exist. An illustration of this may be the Andromedid meteor shower each November. We know that the meteoroids of this shower follow the orbit of the 6.7-year period Comet Biela. In 1846, astronomers watched Comet Biela break in two. At its next passage in 1852, astronomers saw two comets, but no one has seen any of these comets since. If Comet Biela had fallen apart a few centuries earlier, today we would not have known about it or its orbit, but the debris would have indicated its past existence by the meteor shower each fall.

Additional evidence as to the identification of the parent bodies of the two types of meteors comes from meteorites. When there is a particularly bright meteor, people occasionally have been able to find a meteorite fragment from the meteor. All such finds have come from sporadic meteors. No one has ever recovered a meteorite from a meteor shower. This suggests that all meteorites found have come from sporadic meteors. Why do shower meteors fail to produce meteorites? The best answer is that the meteoroids that cause meteor showers are very fragile, while those that cause sporadic meteors are more substantial. We have already seen that comets are made of ice and dust. One would not expect such material to survive the fiery trip through the earth's atmosphere. On the other hand, we have seen that minor planets are made of rocky and metallic material, things that could survive the plunge to the earth's surface.

Meteorites fall into one of three basic classifications: irons, stony-irons, and stony. **Iron meteorites** are

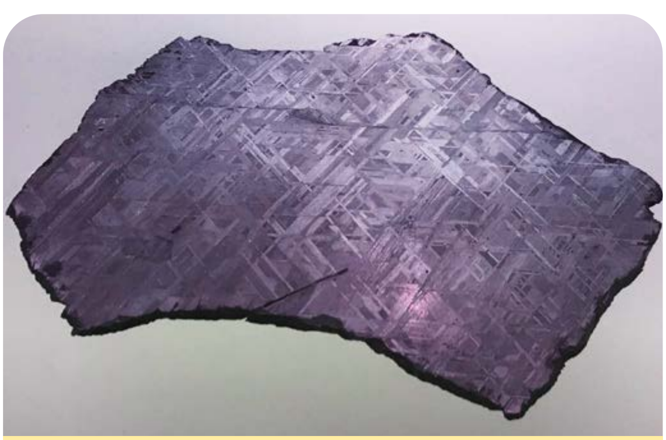


made almost entirely of iron and nickel. When cut and polished, an iron meteorite displays Widmanstätten patterns. Astronomers think that this crystal structure reveals conditions under which the parent body formed. **Stony-irons** contain about equal proportions of rocky and iron material. These are the rarest meteorites, making up no more than 1% of the total. Stony meteorites obviously have a rocky composition, but they usually contain about 10–15% iron and nickel as well. Stony meteorites make up more than 90% of all meteorites, but they represent only about half of those found. How can that be? Irons are very heavy and so they easily stand out from other rocks. If you found one, you would know that it was peculiar. On the other hand, the other types of meteorites are not that different from any other kind of rock that you might find, so they usually escape notice.

People often find unusual rocks and guess that they might be meteorites. As mentioned above, the great weight of an iron meteorite makes for easy identification. How can one tell if a rock is a stony type meteorite? Since nearly all meteorites contain some iron and nickel, magnets usually attract meteorites. If a strange rock fails magnetic attraction, it is probably not a meteorite.

One subclass of the stony type is the **carbonaceous meteorites**. They are very dark in color due to relatively high carbon content. Evolutionary scientists think that carbonaceous meteorites come from the oldest and most primitive kind of meteoroids. These scientists think that all the other types of meteoroids have undergone some amount of reworking. This thinking leads many scientists to conclude that the carbonaceous meteorites are samples of the original material from which the solar system formed. If this were true, then the radiometric ages of carbonaceous meteorites give the age of the solar system. You should recognize that these ideas are very evolutionary and require the assumption of an evolutionary history of the solar system. We will discuss the implications of this in a moment. Some carbonaceous meteorites contain amino acids, basic building blocks of proteins. Since proteins are necessary for life, many scientists accept this as evidence of how the basic chemistry of life could have formed naturally, even in space. However, a few simple amino acids are very different from life itself.

It is most likely that carbonaceous meteorites are fragments of the C-type minor planets. Recall that those minor planets are dark, as are the carbonaceous meteorites. Most other stony type meteorites probably derive from the **S-type asteroids**. The M-type minor planets are probably the meteoroids that give rise to the iron type



Iron meteorite with Widmanstätten pattern

Carbonaceous chondrite Meteorite

meteorites. The direct identification of each of the basic types of minor planets with most of the classifications of meteorites further strengthens minor planets as the source of all meteorites.

Why are there different kinds of minor planets? Perhaps we should first answer the question of the origin of minor planets. Most astronomers believe that the planets formed from the assembly of many small parts called planetesimals. See the discussion of **Feature 9.6**. In this theory, the asteroids are planetesimals that never became part of a planet. Perhaps there are so many minor planets between Mars and Jupiter because while a planet may have started to form there, it failed to do so completely. Jupiter may have formed quickly, and the perturbing effect of its strong gravity kept the planetesimals there so agitated that they could not form a planet.

If minor planets are the remains of a planet that failed to form, one might expect that the planetesimals at least started the process of forming into a planet. The largest minor planets are hundreds of kilometers across, so they must have formed from the collection of many planetesimals. As they formed, their gravity would have pulled much of the iron and nickel to their centers, leaving a rockier mantle. In an earlier lesson, we called this process differentiation. This would leave some of the larger minor planets with structure very similar to the terrestrial planets.

Later, collisions between these bodies could have fragmented the differentiated minor planets. The fragments that had been in the cores would be mostly iron and nickel, and today we would recognize these as M-type minor planets. Any meteorites from these bodies would be the iron type. The fragments from the mantle would be the S-type minor planets. Many of the stony type meteorites would be from this group of fragments. The much rarer stony-iron meteorites would result from fragments that came from near the core-mantle boundary of the differentiated planetesimals. All these types would have undergone heavy reworking, so they would not represent material from the very beginning of the solar system. Any planetesimals that managed to escape becoming part of these larger bodies would have experienced less reworking, and thus they would be samples of the early solar system. These would be the C-type minor planets and the carbonaceous meteorites. Most astronomers assume that the C-type minor planets are exhausted nuclei of comets. Evolutionists argue that **C-type asteroids** escaped reworking, because they spent much of the time since the beginning of the solar system far from the sun where there were few collisions.

You should recognize that this is an evolutionary origin of the solar system over a long time. This explanation is not consistent with a recent creation viewpoint. However, there is no single, clear creationary interpretation of minor planet types. Many creationists assume that God simply made different kinds of minor planets on the fourth day. Others think that some rapid process on the fourth day or at some other time in the recent past may have played a role in producing the various types of asteroids. Some creationists even suggest that the asteroids resulted from a catastrophe (see **Feature 9.1**). Parts of these ideas have some similarity to the evolutionary theory, except for the length of time involved and the fact that God directed the process or catastrophe that altered asteroids. Despite differences in detail, creationists generally can agree on several things. First, we agree that God created the matter that comprises minor planets during the creation week. Second, when God made the sun, moon, and planets on the fourth day, He chose not to include the material that is now in minor planets.

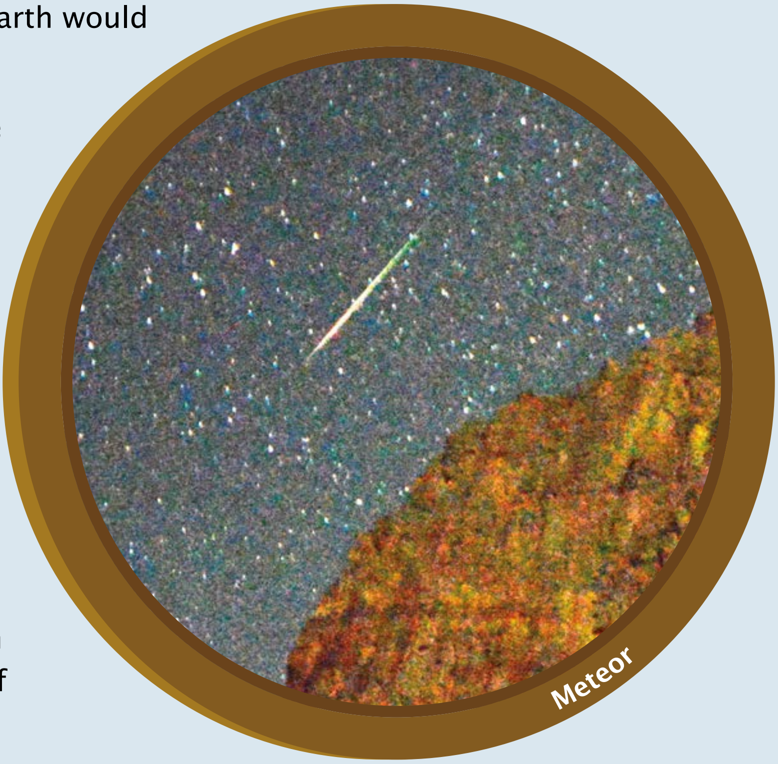
FEATURE 9.5

DO BIBLICAL PASSAGES ABOUT FALLING STARS REFER TO METEORS?

The synoptic gospels record the words of Jesus that before His return stars shall fall from heaven (Matthew. 24:29; Mark 13:25). While the parallel passage in Luke's gospel (21:25–26) does not specifically mention falling stars, it does, along with the other two, mention that the power of the heavens shall be shaken. This shaking of the heavens appears to be a reference to certain Old Testament passages about the day of the LORD (Isaiah 13:13; Haggai 2:6). Revelation 6:13 records that one of the things that happened after the opening of the sixth seal is that the stars of heaven fell to the earth.

In the original languages of the Bible, the words for star referred to any bright object in the sky other than the sun and moon. Without a telescope, planets look like stars. Even comets and meteors have the appearance of stars to the unaided eye, so usage such as this is quite understandable. The problem is, when the word for star appears in the Bible, does it mean what we mean by the word today, or does it have one of the other connotations? In a few lessons, we will find that stars are far larger and more massive than the earth, so stars cannot fall to the earth. If there were any falling, the earth would fall onto a star, and the earth would be destroyed.

It is reasonable to conclude that these falling stars are meteors. This is particularly the case if we consider Revelation 8:12. Revelation 6:13 implies that most of the stars fell from heaven, but here a couple of chapters later in Revelation 8:12, it states that $\frac{1}{3}$ of the stars were darkened when the fourth trumpet sounded. If most of the stars (as we understand the term today) fell earlier, how could there be enough left for $\frac{1}{3}$ to be darkened later? We can reasonably conclude that the falling of the stars is a reference to meteors.


Meteor

FEATURE 9.6

AN EVOLUTIONARY THEORY FOR THE ORIGIN OF THE SOLAR SYSTEM

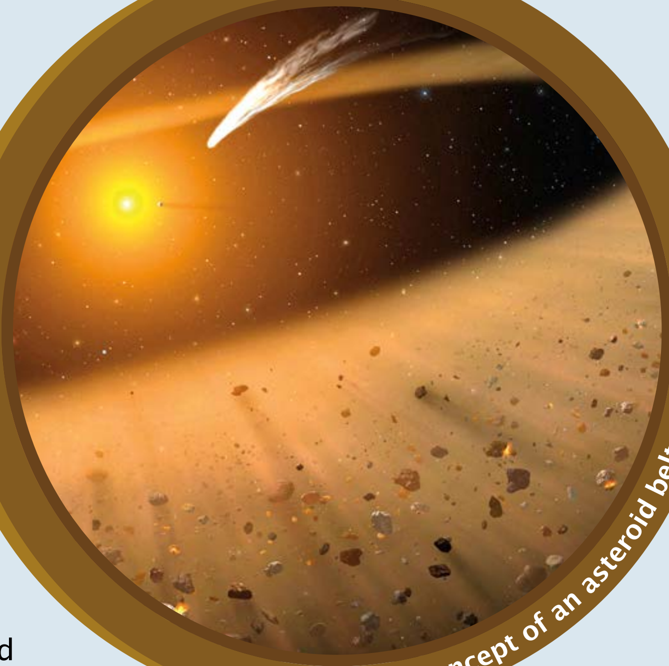
Evolutionists believe that the solar system formed from a large cloud of gas and dust about 4.6 billion years ago. We see clouds in space, and astronomers think that some of these are locations of star formation. We will discuss the topic of star formation in a few lessons. According to the theory, the original slow rotation of the cloud would have sped up as the cloud contracted. The increased rotation rate is a result of the conservation of angular momentum. A similar thing happens to a spinning ice skater as the skater pulls his arms inward. Most of the material would have fallen into the center to form what astronomers call the proto sun. The remaining material would have flattened into a disk orbiting the proto sun.

The material in the disk presumably began to stick together and coalesce into larger particles. How this process could have started is not clear. Some have suggested that static electricity allowed tiny particles to stick together. Others have suggested that sticky organic substances that coated the surfaces of solid particles got it started. Once solid particles began to form, they stuck together to form larger particles. These solid particles are called planetesimals. Once the planetesimals got large enough, their gravity became great enough to attract other planetesimals. Eventually a few planetesimals became large enough to become the dominant objects in their respective parts of the forming solar system. These large planetesimals became the planets.

While the amalgamation of planetesimals was going on, the proto sun would have heated up to form the sun. The early sun's radiation would have heated the planetesimals nearest the sun so that their volatile elements evaporated. The radiation would have blown the evaporated material outward away from the sun, but the refractory elements would have remained in orbit close to the sun. Therefore, the inner planets are rocky in composition and have little of the lighter elements. Farther from the sun, the planetesimals would have retained their volatile material. That is why the Jovian planets have retained so much of their lighter elements. Astronomers think that the Jovian planets and the sun have about the same composition.

Artistic illustration of planetesimal collision around Star HD 166191

The satellites might have resulted from the capture of some of the smaller planetesimals by the gravity of the planets. As the planets and satellites formed, the energy released in the process would have heated and melted the material. This would have allowed the heavier material to sink toward the centers of the bodies. This explains the differentiation that exists in many bodies. After much of the material had accumulated to form the planets and satellites, the surfaces would have cooled enough to become solid. There were still plenty of planetesimals left over, and their falling onto the surfaces of the moons and planets would have provided the heavy bombardment that we discussed with the moon in an earlier lesson. During the late heavy bombardment, the last few large planetesimals collided with planets and satellites to form impact basins. Since that time, there have been much fewer impacts.


Artistic concept of an asteroid belt

Most of the planetesimals were swept up in forming the planets, but there are a couple of locations where planets failed to form. One is the asteroid belt, and the other is the Kuiper belt. Being much closer to the sun, the asteroid belt planetesimals would have lost their volatile elements and so were left with a rocky composition. The much more distant Kuiper belt planetesimals would have kept their volatile elements, and so would be mostly icy in composition. The Kuiper belt objects would become comet nuclei. Gravitational perturbations of the planets would slowly change the orbits of both groups of leftover planetesimals. Asteroids orbiting in the inner solar system are presumably from the asteroid belt. The gravity of the outer planets either pulled Kuiper belt objects into the inner solar system to form short period comets or pushed the KBOs to higher orbits to populate the Oort cloud. Once in the Oort cloud, perturbation from outside the solar system would work to either remove comet nuclei from the sun’s grasp or send the nuclei into the inner solar system as long period comets.

How does a Christian respond to this? Unfortunately, all too many accept this theory as the method by which God created the solar system. While this theory gives a qualitative understanding of some features of the solar system, a more important test is how well it squares with the Genesis account of creation. There are several failings here. First, this theory is a purely physical, natural explanation for the solar system. No Creator is necessary, so His introduction at any point is unwarranted. Second, it is in direct contradiction of several clear statements from Scripture. One is the fact that creation took six days and is complete. This natural theory took millions or billions of years; in fact, it is an ongoing process today. Another biblical problem is that it has the sun forming before the earth, and the moon and earth forming about the same time. We know that the earth came first and that the sun and moon came on the fourth day. To accommodate the evolutionary theory, the Christian must be very creative in interpreting what Genesis is telling us. This is a very dangerous thing to do. It seems to elevate science above God's word.

The evolutionary theory does explain some things, such as the two types of planets and the existence of comets and asteroids, but it fails at other points. For instance, no one knows how a cloud of gas and dust can begin to contract to start the process. In fact, well-understood physical processes argue against this. We will discuss this further in a later lesson. Another problem involves angular momentum. Angular momentum is a quantity possessed by rotating or revolving objects. The sun has more than 99% of the mass of the solar system, but only about 1% of the angular momentum. The planets have less than 1% of the mass, but have 99% of the angular momentum. This should not be; most of the mass should contain most of the angular momentum. It is not clear how the sun could have shed nearly all its angular momentum.

Other problems include some of the oddities of the solar system. Two planets rotate backwards, while the other six planets rotate in the same direction that nearly everything else moves. How did this happen? Uranus has a peculiar axial tilt, and Neptune's moon Triton has a strange backward orbit. The usual explanation is that all of these resulted from late, large impacts, but the details are difficult. Satellites are common in the solar system, and yet the earth's moon is very strange. Most of the moons in the solar system orbit in the equatorial plane of their respective planets. Only the earth's moon orbits near the ecliptic. Most astronomers think that studying the rest of the solar system should allow us to learn about how our moon came to be. However, if our moon is unique, it is doubtful that the study of other satellites would tell us much about the moon's history.


Earth's moon

Most creationists believe that God recently created the solar system for His glory and man's enjoyment. While this is true, it would be helpful if we could develop more quantitative explanations about creation of the solar system. Much work remains to be done here.

Introduction to Lesson 18

When one tries to understand the concept of space curving back upon itself, it helps to consider a two-dimensional surface that closes back on itself. Examples are surfaces of spheres, such as a ball or the earth. The surface has a finite area ($A = 4\pi r^2$) yet has no boundary. You can travel in any direction as far as you care to go and never reach the edge of the surface of the sphere. Note that a sphere is a three-dimensional shape, while the surface of the sphere has only two dimensions. The three-dimensional sphere is indeed bound by the two-dimensional surface, but the surface has no boundary. The analogy that we want to make is that four-dimensional space-time may be curved in much the same way that a two-dimensional surface is.

This idea of curved space is not as weird as it sounds. The earth's surface is curved, though the earth is so large that the earth generally looks flat locally. Surveyors can detect the curvature of the earth over an area of more than 200 acres. One of the peculiar aspects of this curved geometry is that the interior angles of a triangle sum to more than 180 degrees. Of course, in plane geometry, the angles must sum exactly to 180 degrees.

A way to show why cosmologists think that the universe is homogeneous when we can see that it is not, is to consider a smooth piece of matter, such as a glass marble. The marble may appear very homogeneous to us, but we know that on a microscopic level it consists of molecules and atoms. Atoms are clumps of matter that often are separated by great distances compared to atomic sizes. Therefore, matter that we know is not homogeneous on the local scale appears homogeneous on the large scale. The universe may (repeat, may) be likewise.

Worldview: Through the Lens

CREATIONIST	EVOLUTIONIST
Knows that God created the universe for man's benefit only thousands of years ago	Believes that the universe came into existence via the big bang 13.8 billion years ago
Recognizes many problems with the big bang model	Because of this bias, does not see the problems with the big bang model
Understands that the universe will end catastrophically, to be replaced by a new heaven and a new earth	Believes that the universe will end, if it ends at all, in a naturalistic way

Two-lobed nebula in the constellation of Sagittarius with one of the hottest stars known and powerful stellar winds generating waves 100 billion kilometers high.

Cosmology

Introduction and Definition of Terms

Like some previous chapters, this lesson discusses many evolutionary ideas. Do not fret. There are some creationary ideas about cosmology.

Cosmology is the study of the structure of the universe. A related term is **cosmogony**, which is the study of the history of the universe. Much of what today passes for cosmology is cosmogony. Even though the term cosmogony is not used much today, you ought to know the difference between the words. A cosmologist is a person who studies cosmology and cosmogony.

The ancient Greeks believed that the universe is eternal. That is, the universe had no beginning and will have no end. This idea persisted in western thought well into the 20th century. Why have people believed in an eternal universe? If the universe had no beginning, then it had no Beginner, or Creator. Therefore, the avoidance of a need for God can be a motivation for believing in an eternal universe. Another reason for believing in an eternal universe is that imagining a beginning for the universe is very difficult. This raises all sorts of questions such as why there is a universe or what was here before. Of course, an eternal universe is contrary to biblical teaching, because Genesis 1:1 declares that the universe had a beginning. The eternal universe is a pagan idea that Christians never should have entertained in the first place.

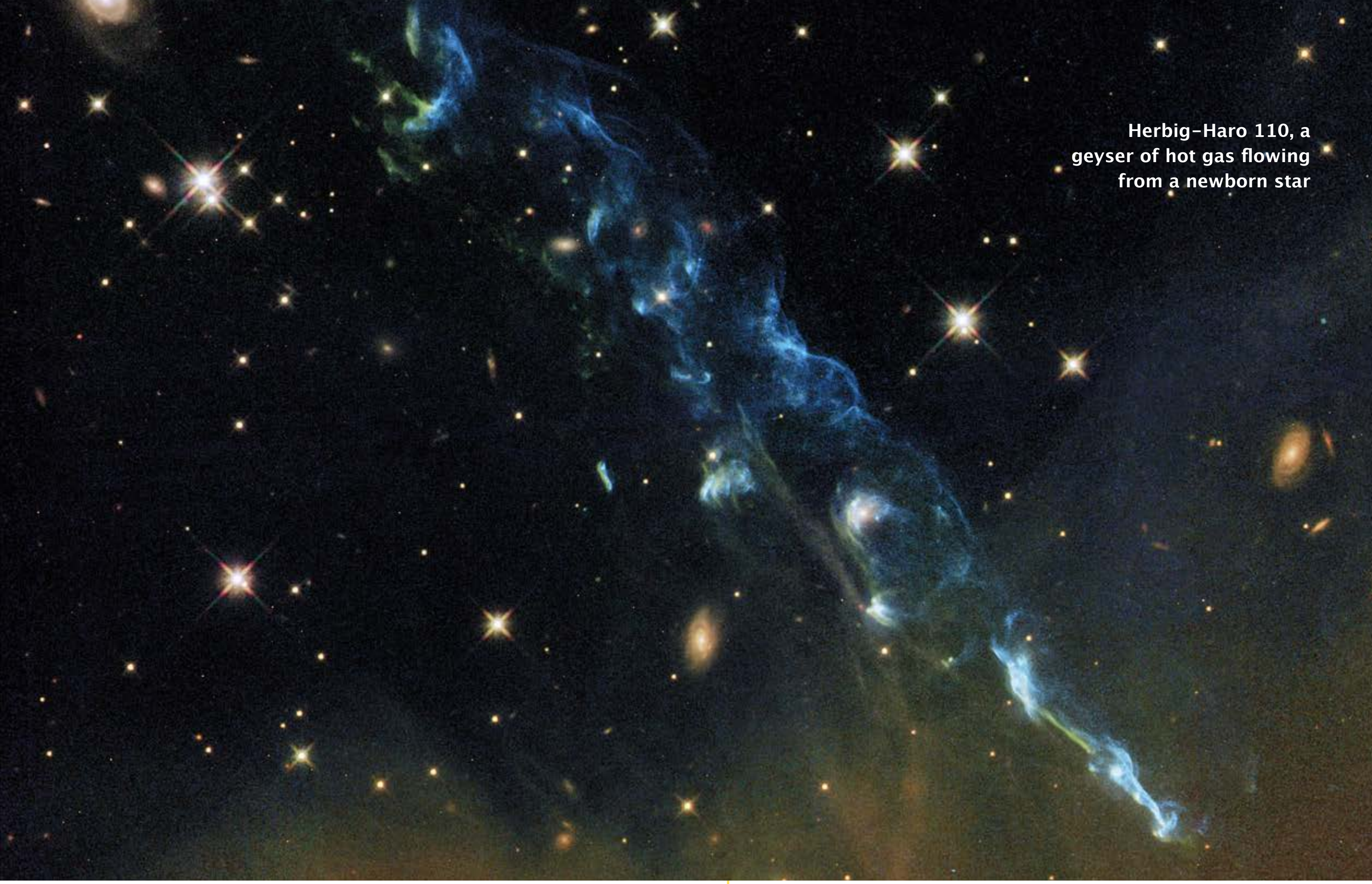
Isaac Newton believed in an eternal universe, though he apparently believed that the earth was not eternal. When Newton devised his law of gravity, he realized that if the universe were eternal, there would have been more than enough time for all the matter in the universe to collapse to its center. The universe obviously is not like this, so how could he avoid this situation? One answer would be to discard the eternal universe. Instead, Newton chose the possibility that the universe is infinite rather than finite in size. That way there would be no center toward which the material would collapse. In such a universe, gravity would affect every particle in the universe in every direction by equal amounts so that all the gravitational forces cancel. Since this model of the universe will not collapse onto itself, we call this a **static universe**. That is, there is no net motion of matter in the universe. The idea of an infinite, eternal, static universe prevailed until well into the 20th century.

During World War I, Albert Einstein (1879–1955) published his theory of **general relativity**. General relativity is the modern theory of gravity.

The bright spot located at the edge of the bluish fan-shaped structure in this Hubble image is a young star, PV Cep, a favourite target for amateur astronomers because the fan-shaped nebulosity, known as GM 1-29 or Gyulbudaghian's Nebula, changes over a timescale of months. The brightness of the star has also varied over time. Images of PV Cep taken in 1952 showed a nebulous streak, similar to a comet's tail. However, these had vanished when new images of the star were obtained some 25 years later. Instead, the blue fan-shaped nebula had appeared. At the same time as this was happening, the star itself was brightening. This provided the light to illuminate the newly formed fan-shaped nebula. This brightening might be related to the start of the hydrogen-burning phase of the star, which would mean that it was reaching maturity. PV Cep is thought to be surrounded by a disc of gas and dust, which would stop light from escaping in all directions.

Newton devised his theory of gravity so that the gravitational forces mysteriously acted through empty space. How does the moon know where the earth is and how much mass the earth has so that the moon can respond under the proper amount of force? In Newton's theory, the moon just does so without any attempt at explanation as to why. Since Newtonian gravity works through empty space, we call this action at a distance. Newton's theory addresses the question of how gravity works, but it doesn't address the more fundamental question of why.

General relativity attempts to answer better the question of why gravity works. Einstein imagined that space is something. Previously, people thought that space was nothing — space was merely a backdrop in which matter and energy operated. For that matter, time wasn't viewed in the same tangible way that matter and energy were. Einstein created a set of equations that described how the presence of matter and energy affected space and time. You can imagine that space is a like a Cartesian coordinate system that you may have used in math class. The difference is that there are four, rather than two coordinates. Three of the coordinates are the three familiar spatial ones, and the fourth dimension is time. We sometimes call these four dimensions "space-time." In the presence of matter or energy, space-time is bent, or warped. You can imagine that space-time is bent much as a piece of graph paper can be (except this is a four-dimensional piece of graph paper!). As objects move through space-time, they follow straight paths. However, the space-time through which objects follow straight lines is curved near where large masses are located. Straight-line motion in curved space-time results in what we call acceleration in how we perceive the world. Thus, the effects of gravity pass through empty space as the result of bending of space-time. Sometimes we refer to this bending


Herbig-Haro 110, a geyser of hot gas flowing from a newborn star

of space-time by large masses as ripples or waves in space-time. Einstein predicted gravitational waves in 1916, but they weren't directly detected until 2016.

However, unlike Newtonian gravity, in general relativity the universe cannot be static, even if it is infinite in size. If general relativity is the correct model of gravity, even a universe infinite in size should eventually collapse in on itself. Realizing this but still wanting to keep an eternal universe, Einstein included a **cosmological constant** in his solution to his equation. The cosmological constant acts as a sort of anti-gravity. Over great distances, the cosmological constant causes space to have a repulsive affect so that it will tend to oppose the inward pull of gravity. By exactly balancing the cosmological constant and gravity, the universe could be static.

Most cosmologists long ago concluded that the cosmological constant is zero. Einstein reportedly later stated that its inclusion in his model was the biggest blunder of his life. However, this is much too harsh. The sort of equation that Einstein solved to get his cosmology always has a constant of integration. In these sorts of problems, the constant of integration often is zero, but sometimes it's not zero. From a mathematical standpoint, there is no reason why the cosmological constant should have any value. The only way to evaluate the constant is to consider the limiting conditions of the problem. Einstein didn't have enough information to determine the constant. Most cosmologists assumed that the cosmological constant is zero. However, in 1999, cosmologists discovered evidence that the cosmological constant may not be zero after all. For several reasons, cosmologists have renamed the return of the cosmological constant as "dark energy."

We ought to explain a few terms that describe the universe. A **bound** universe is one that has a boundary, or an edge. An **unbound** universe has no boundary or edge. A boundary to the universe does not mean an edge to the matter in the universe, but rather it is an edge to space itself. Generally, people conclude that a finite universe must be bound and that an infinite universe is unbound. The reasoning is that if the universe is finite, it must have some end to it, which would amount to a boundary. On the other hand, if the universe were infinite in size, space would go on forever without any boundary. With "normal" geometry, as you may have studied in a geometry class, this is true. However, there are alternate geometries in which a finite universe does not have to have an edge. For instance, if space is curved, then it can close back upon itself, much as the surface of a sphere does. In such a universe if you could look far enough in one direction, you could see the back of your head.

Why consider such a "weird" sort of universe? Besides being a legitimate logical possibility, this sort of geometry avoids some perplexing problems. If the universe had a boundary, we must question what the nature of the boundary is. A boundary would amount to some sort of wall that we could not go through. This would raise all sorts of questions about what the wall is made of that would keep us from passing through. We could also question what is on the other side of the wall. If we could fathom that something is beyond the wall, then that something should be part of our universe, so that the boundary is not quite a boundary. On the other hand, an infinite universe would just go on and on forever. That possibility seems unsettling to many as well. A universe that neither goes on forever nor has a boundary has great appeal. A curved universe is not as weird as you might think. On a local scale, the surface of the earth appears flat. It is only when we consider large distances and areas that the curvature of the earth's surface becomes significant. In similar fashion, the three dimensions of space may appear "flat" locally but may be curved on a large scale.

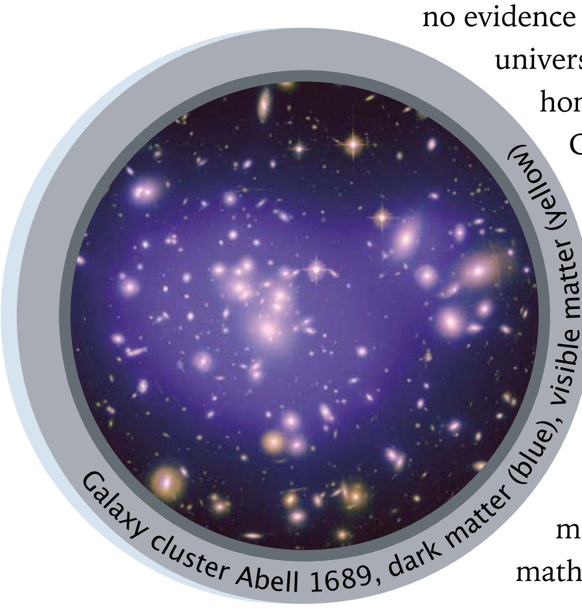

A large, bright concentration of HII and star formation

One important assumption that we make about the universe is that it is **homogeneous**. This means that the universe has the same properties throughout. Since we have not traveled everywhere in the universe (far from it!), this merely is an assumption. However, this is a very reasonable assumption, one that makes science possible. If we assume that the properties of the universe change from place to place, then we can never be sure that if we repeat an experiment in various places that the results would be the same. All evidence that we have suggests that the universe is homogeneous in this way.

More specifically, the type of homogeneity that cosmologists consider refers to density or to the appearance of matter throughout the universe. Cosmologists assume that the universe looks about the same everywhere. Is this true? Locally, it is obvious that this is not true. What you see inside and outside of your classroom is different. What we see on the earth is very different from what we would see on the moon. For that matter, most locations in the universe are far removed from any stars or planets, so a typical view of the universe would be very different from what you and I see all the time.

But when cosmologists say that the universe is homogeneous, they mean for us to ignore the local things and look at the universe as a whole. We should ignore planets (including the one that we live on), stars (including the sun), and even nearby galaxies. Instead, we should look at distant galaxies. In every direction that we look, we see countless galaxies at varying distances that seem to follow the Hubble relation, so it is likely that we would see the same thing from any other location in the universe as well. Homogeneity means that if there were alien astronomers on a distant world examining the universe on the large scale, they would see about the same things that we see.

However, galaxies are not smoothly distributed throughout space. Instead, they tend to clump together into clusters. Even clusters of galaxies seem to clump together. In fact, extensive mapping of the distribution of galaxies show that they tend to be along long intersecting strings and sheets. If the universe were homogeneous, then at a very large scale, galaxies ought to have a uniform distribution. However, at every scale that we have examined the universe thus far, the universe appears clumpy. As reasonable as the assumption of homogeneity is, there is yet no evidence that the universe indeed is homogeneous. Cosmologists assume that on the grandest scale the universe is smooth, because this makes the mathematics work, or at the very least, the clumping of matter in the universe is not significant enough to change the results.

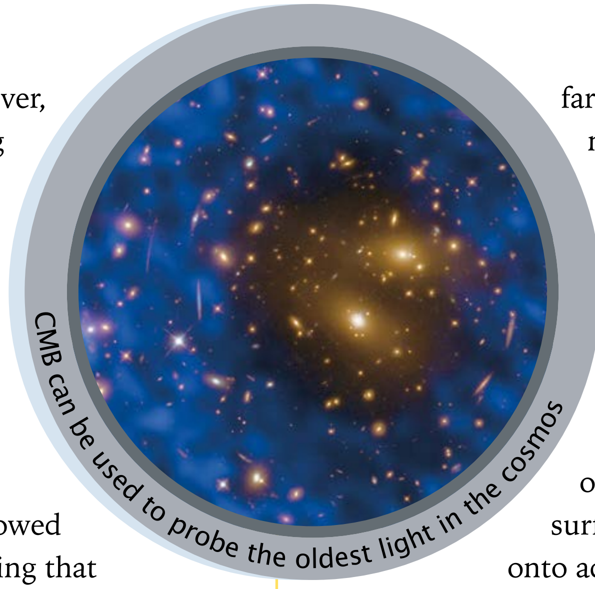

Galaxy cluster Abell 1689, dark matter (blue), visible matter (yellow)

Cosmologists also assume that the universe is **isotropic**. Isotropy means that the universe looks the same in every direction. Of course, on a local scale the universe does not appear isotropic. For instance, during the day, the sun is in one part of the sky; the sun is not in any other direction in the sky. But, as with homogeneity, we must look to the grand scale of things to see isotropy in the universe. At great distances, we see galaxies and quasars randomly distributed in every direction. Isotropy means that we see about the same number and types of galaxies and quasars regardless of which direction that we look. Observation seems to bear this out. However, there are some subtle features of the universe that bring into question whether the universe truly is isotropic.

The Big Bang Model

Despite the difficulties just discussed, cosmologists generally assume that the universe is both homogeneous and isotropic. This assumption is the **cosmological principle**. The cosmological principle usually leads to a model that we call the **big bang**. The big bang is the idea that the universe began 12–15 billion years ago as a sudden appearance of space, time, matter, and energy. Initially, the universe would have been very dense and hot. Like any dense hot gas, the universe rapidly expanded. As the universe expanded, it cooled and became less dense. Eventually, stars and galaxies formed, and late in the process the earth and people developed.

There are several misconceptions about the big bang. First, the name is a bit of a misnomer, because it suggests an explosion. Indeed, many criticisms of the big bang depend upon the big



bang being an explosion. However, the correct view of the big bang model is that the big bang was not an explosion. The big bang model says that the universe abruptly began in a very hot, dense, and expanding state and has been expanding ever since. The only comparison to an explosion is the sudden appearance of the universe followed by a rapid expansion. Recognizing that the big bang was not really an explosion, some supporters of the model have searched for a better name, but so far, they have not found a better name.

Another misconception is that the big bang occurred in one location of the universe and then proceeded to expand into the rest of the universe. Many people imagine that if they had been present at the time of the big bang, they would have seen the big bang expand outward and overtake their position. However, the actual model is that the big bang happened everywhere at the same time so that the big bang filled the universe from the very beginning. However, the universe was much smaller then, so everywhere was much closer together at the time of the big bang. If you have difficulty understanding this point, you are not alone.

The easiest way to think through this is to realize that galaxies in the expanding universe are not moving apart from each other. Galaxies may be at rest with respect to space. It is space itself that expands. An analogy that authors often use is to imagine sequins attached to the surface of a balloon. As you blow up the balloon, the sequins appear to move apart, even though the sequins are not moving. As the rubber in the balloon between the sequins expands, the expansion carries the sequins along. In like fashion, galaxies that are far apart from each other may not be moving with respect to space, but the space between the galaxies is expanding so that the galaxies appear to move apart. Notice that in this analogy the sequins do not start congregated on one portion of the balloon's surface and then move apart onto adjacent, initially unoccupied portions of the balloon. The sequins initially fill the balloon's surface and merely are carried along by the expanding rubber of the balloon. According to the big bang theory, matter and energy filled the universe and then space expanded in a similar fashion.

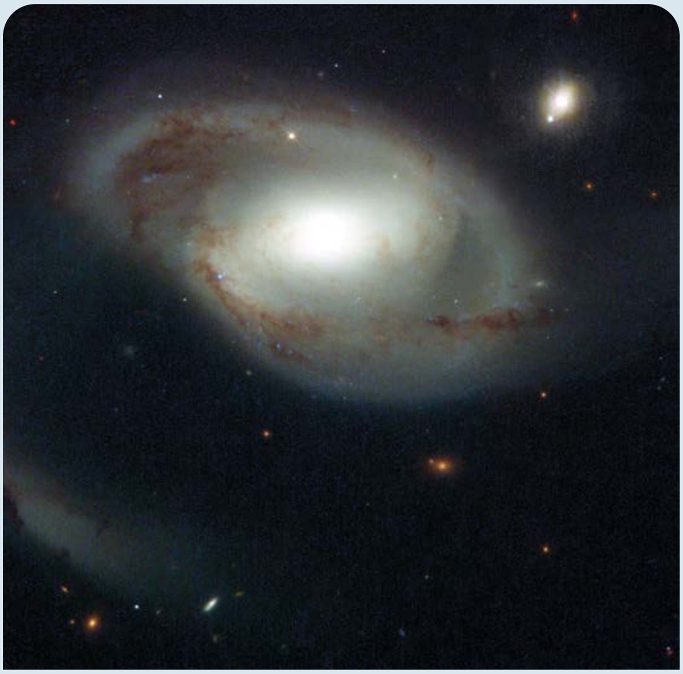
When objects move with respect to space, we refer to their motions as Doppler motions. However, when objects are at rest with respect to space and they appear to move apart solely as the result of the expansion of space, that perceived motion is **Hubble flow**. Hubble flow is very different from Doppler motion, though observationally they appear the same to us. Hubble flow is due to the expansion of the universe, while Doppler motion is due to motion of objects with respect to space. Since objects may move either toward or away from us, a Doppler motion is as likely to produce a blueshift as a redshift. Since the universe is expanding, all spectral shifts due to Hubble flow are redshifts. When a redshift is due to Hubble flow, we say that it is a **cosmological redshift**. If redshifts are cosmological, then the redshifts result from the expansion of the universe and the redshifts truly reflect distance. That is, the Hubble relation tells us the distance. Some people have questioned this. See **Feature 18.1** for more details about this.

FEATURE 18.1

ARE REDSHIFTS COSMOLOGICAL?

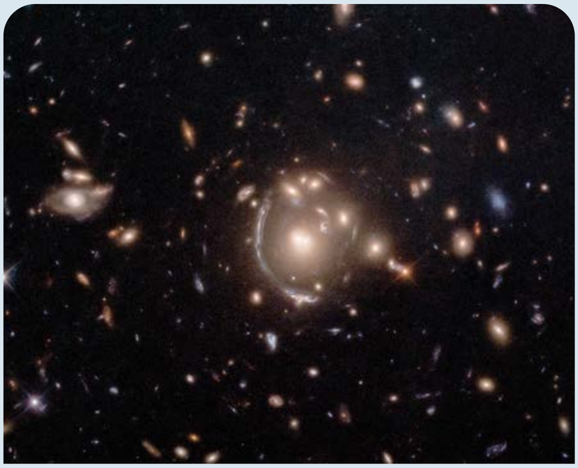
Since the 1960s, the astronomer Halton Arp has pursued observations that question whether redshifts are cosmological. He has found several interesting sorts of data. Arp has photographed pairs of galaxies that appear to be interacting. In some cases, there is a bridge of material connecting the two galaxies. In other cases, a spiral arm in one of the galaxies is distorted in such a way as to suggest that the gravity of the other galaxy has affected it. In either case, both galaxies must be close to each other, and hence about the same distance from us, for these interactions to occur. Yet, when we measure the redshifts, the redshifts of the two galaxies are very different. If we apply the Hubble law to find the distances of the galaxies, we find that the galaxies are at vastly different distances, which would make interactions impossible.

Another example is a photograph that shows a small galaxy superimposed upon the edge of a larger galaxy. It appears that the smaller galaxy is in front of the larger galaxy. Yet when we compare the redshifts, the smaller galaxy has a much larger redshift than the larger galaxy. If the Hubble relation truly reflects distance, then the smaller galaxy must be much farther away, and hence behind, the larger galaxy. Another photograph shows a large spiral galaxy, from which we can measure the apparent size of the galaxy. Once we know the distance, we can compute the actual size of the galaxy. Using the redshift to find the distance, Arp found that the galaxy is about ten times larger than any known galaxy. Arp concluded that this large size is unlikely, and so questioned the legitimacy of the Hubble relation.



Appearances are deceiving with this odd celestial duo, the spiral galaxy NGC 4319 [center] and a quasar called Markarian 205 [upper right] as they appear to be neighbors. In reality, the two objects don't even live in the same city. They are separated by time and space. NGC 4319 is 80 million light-years from Earth. Markarian 205 (Mrk 205) is more than 14 times farther away, residing 1 billion light-years from Earth. The apparent close alignment of Mrk 205 and NGC 4319 is simply a matter of chance.

Why does Arp question the Hubble relation? He believes that we have fooled ourselves into thinking that quasars are very far away. We base the large distances to quasars upon the assumption of cosmological redshifts. If redshifts do not reflect distance, then quasars are much closer than generally thought, and there is not a problem in identifying their source of energy. Arp has also found that quasars tend to cluster around nearby galaxies. If quasars are very distant, then we would expect them to be randomly distributed, and they certainly should not appear grouped around nearby galaxies. From these data, Arp has inferred that

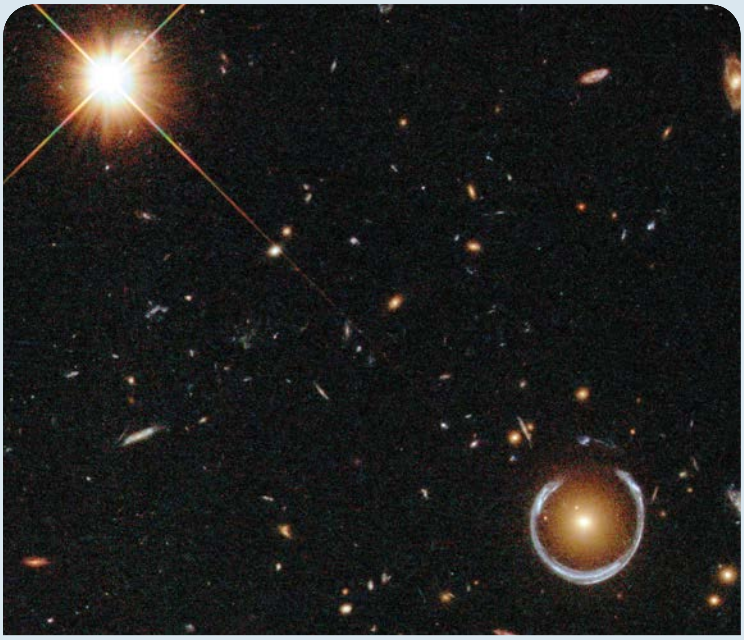

This galaxy, its image distorted by the effects of gravitational lensing, appears as a long arc to the left of the central galaxy cluster.

quasars clump around nearby galaxies. He further surmises that the central galaxies probably ejected the quasars. One problem with Arp's work is that he has not been very convincing in telling us what quasars are and why we do not see any blueshifted quasars, which we would expect to see if they are ejected from nearby galaxies.

What are the consequences if Arp is correct? It is not entirely clear. Arp does not suggest that redshifts never depend upon distance. Rather, he suggests that in at least some situations they do not. It would not be possible to determine when redshifts are cosmological and when they are not. Ultimately, the assumption of cosmological redshifts is related to the concept of an expanding universe. If the universe is not expanding, then all of the cosmology since the 1920s would appear to be invalid. Arp does not go that far. It is very clear that Arp opposes the big bang model, opting in favor of the steady state theory instead.

While most creationists applaud Arp's work, there should be a word of caution. Arp reportedly was an atheist. While creationists share his skepticism of the big bang, his beliefs and cosmology are very different from ours. It should be stressed that creationists do not endorse all of his conclusions, just as he would not endorse many of ours.

Unfortunately, Arp's story does not have a happy ending. After pursuing his work for two decades, Arp amassed some powerful opponents. In the 1980s, several of them conspired to prevent him from gaining any more telescope time to continue this work. In the estimation of many astronomers, his work had never been refuted. His opponents merely were able to silence him. Arp thought that this situation was intolerable. As a result, he took an early retirement from Cal. Tech. He soon took a position at the Max Planck Institute in Germany. Arp remained in Germany until his death.


The Cosmic Horseshoe is one of the best examples of an Einstein Ring. It also gives us a distinctive view of the Universe shortly after creation: the blue galaxy's redshift — a measure of how the wavelength of its light has been stretched by the expansion of the cosmos — is approximately 2.4.

The observed shift of lines in the spectrum of a distant object such as a galaxy or quasar is the sum of Hubble flow and Doppler motion. To determine the Hubble constant, it is important to use only the Hubble flow. Unfortunately, it is not possible to tell directly what portion of a redshift Doppler motion is and how much is due to Hubble flow. Generally, Hubble flow increases with distance, but Doppler motion probably has some random value centered on zero that is independent of distance. Note that Hubble flow is always positive, while Doppler motion can be either positive or negative. As distance increases, Hubble flow increasingly dominates the observed redshift. The result is that Doppler motions likely swamp the feeble Hubble flow of nearby galaxies. On the other hand, distant galaxies have such large Hubble flows that we can safely ignore any Doppler motions. Therefore, it is best that we use distant galaxies to determine the Hubble constant. However, the distances of faraway galaxies are difficult to measure accurately. Usually, calculations of the Hubble constant rely upon nearby galaxies, with allowances made for Doppler motions. There is some disagreement as to how to account for this, which leads to much of the uncertainty in the Hubble constant.

NGC 7727 in constellation Aquarius is believed to be the result of a clash between two galaxies. Dark energy is the mysterious force permeating the Universe and causing accelerating expansion.

Another misconception about the big bang and the expansion of the universe is that the universe must be expanding into something. It is not. The universe is merely getting larger. As space expands, it does not expand into anything. Instead, points in space merely get farther apart. The analogy to the expanding balloon probably fuels this misconception. The balloon is obviously expanding at the expense of space surrounding it. However, the surface of the balloon, a two-dimensional object, is expanding into three-dimensional space. The expanding universe is a three (or four, with time included) dimensional thing. The universe could be expanding into some other higher dimensional space, but we have no concept of that. Imagine if you were confined to the surface of the balloon. You would be restricted to two dimensions and would have no concept of the third dimension. As your balloon world expanded, you would have no idea that it was expanding into anything else.

Another misconception about the big bang is that there must have been something here before the big bang. Time began with the big bang, so there could not have been time before the big bang. In fact, the concept of "before the big bang" makes no sense. Furthermore, since the big bang marked the beginning of space, "here" did not exist prior to the big bang. In other words, here was not here then, and then was not then then either. Some Christians see the fingerprint of God in the big bang. **Feature 18.2** discusses the danger of making the big bang part of our apologetics.

FEATURE 18.2

SHOULD THE BIG BANG BE PART OF OUR APOLOGETIC?

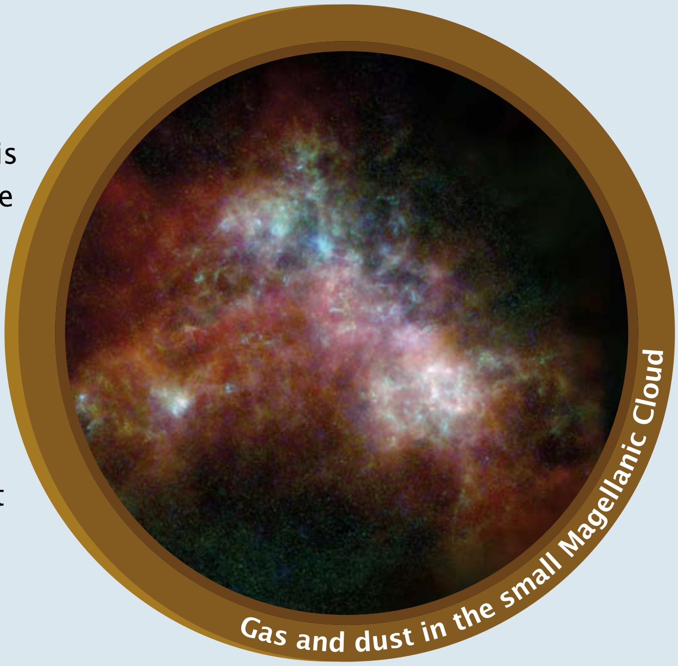
The big bang theory states that the universe and time had a beginning. This is contrary to the steady state theory and much of Western thought since the time of the Greeks. The "In the beginning…" of Genesis 1:1 suggests the beginning of all things, including space and time. Some Christians have noted the similarity of the big bang theory and Genesis 1:1 on this one point and have concluded that the two are in harmony.

If this is all the detail that the biblical creation account contained, then that may be true. However, the creation account has much more detail than that. For instance, in the big bang cosmogony, the earth formed much later than the creation of the universe, but in the biblical account, God made the earth at the very beginning. Acceptance of the big bang usually leads to acceptance of theistic evolution or progressive creation. It is impossible to harmonize either of these viewpoints with the Bible in a manner that is biblically faithful. For instance, one must use creativity to explain how plants existed before the sun, or how birds existed before land animals.

Unfortunately, reinterpreting Scripture in terms of science usually handles these and numerous other difficulties. This is a dangerous precedent, because it signals a belief that we are better to trust science to understand certain things. People who take this approach are very subtly indicating that science is of higher authority than the Bible.

It is very misleading to distill the big bang and the creation account down to one common essential, that the universe had a beginning, and then to state that this amounts to "complete harmony." There is an old saying, "the devil is in the details," that is doubly true here. To claim one common element and then liberally reinterpret one account in terms of the other amounts to deceptive advertising.

Many who teach the agreement between the big bang and the Bible argue that the big bang requires that God exist. We examine this questionable assertion in **Feature 18.3**. There is another danger missed by proponents of this apologetic. Science is a changeable thing. Much of what was scientific "truth" a century ago no longer is true. If the past is any guide, it is very likely that eventually the scientific world will discard the big bang theory. If we make the big bang an important part of our apologetic, then what will happen to our apologetic when the big bang is no longer a valid scientific theory?


Gas and dust in the small Magellanic Cloud

FEATURE 18.3

DOES THE BIG BANG PROVE THAT GOD EXISTS?

Those who believe that the big bang proves God's existence use the causality argument. The principle of causality is an ancient idea. Everything that happens is caused by something else. Conversely, every cause has an effect. Every effect is in turn a cause for a new effect, and that new effect is a cause for still another effect. Thus, there are countless seemingly never-ending chains of cause and effect through time. For instance, your parents' concern for you was the cause of them placing you in the school setting that you now find yourself. That effect was in turn the cause of you ultimately being in this class. Being in this class was the cause of you having this textbook. Having this textbook was the cause of you reading this sentence at this moment. The author had a different long chain of cause and effect that led him to write the words that you now read.

The chain of cause and effect is interesting, but it gets more interesting when we view the chain in reverse. A cause precedes every effect. For instance, why does this textbook exist? It exists because I decided to write it. Why did I decide to write it? I realized that there was a need for such a book. There is a long chain of questions from there that goes back to how and why I became interested in astronomy and ultimately why I exist. For instance, if my parents had never met, you would not be reading this.

Medieval scholars used the causality argument to show that God must exist. Every effect is preceded by some cause, but every cause is in turn the effect of some previous cause. Medieval scholars reasoned that in the beginning there must have been some Uncaused Cause. That is, there must have been some cause that had no prior cause. This Uncaused Cause must be God.

In like fashion, many Christians today think that the universe must have had a cause. We may ask the question, "What caused the big bang?" To which the answer is "God." However, does that prove that God caused the big bang? A cause must necessarily precede its effect in time. A cause cannot occur after or at the same time that its effect does. This requirement also demands that causality work within time. If there is no time, causality does not operate. For anything to cause the big bang, that cause must exist before the big bang does. However, the big bang marked the beginning of time, as pointed out in the text. The concept of "before the big bang" makes no sense. Therefore, to insist that God must have caused the big bang is to force the use of causality where it is not valid.

It is a logical possibility that the big bang was the first, or Uncaused, Cause. If the big bang is the Uncaused Cause, then God is unnecessary. To insist that God must be the cause of the big bang simply does not follow from logic. One could respond that there is a causality principle that works apart from time, but there is no evidence of that. Some may object with the question, "What caused the big bang?" However, the atheist can reply, "Who made God?" There can be only one Uncaused Cause. We can choose between a Deity and the big bang, but logic cannot demand both. Christians who fail to see this either do not understand causality or the big bang theory, or both.

The Steady State Model: An Alternate Cosmology

While the big bang is by far the most popular explanation of the universe today, there are other possibilities. For instance, the **perfect cosmological principle** states that the universe is always homogeneous and isotropic. Under this assumption, not only does the universe look the same from every location and in every direction today, the universe must always have looked the same in the past and will look the same at all times in the future. As space expands, the universe must get less dense and cooler, so how can this be? The universe can remain homogeneous and at the same temperature as it expands only if the density remains the same. This requires that new material come into existence at a constant rate. You ought to recognize that this is a violation of the law of conservation of matter. However, the law of conservation of matter is merely a description of how we observe the world to operate. The rate of creation of new matter required to maintain a constant density as the universe expands is very small. The amount of new material introduced each year in the volume of a large room would be less than a hydrogen atom. This little bit of matter would escape our notice, so that the conservation of energy would still appear to be valid.

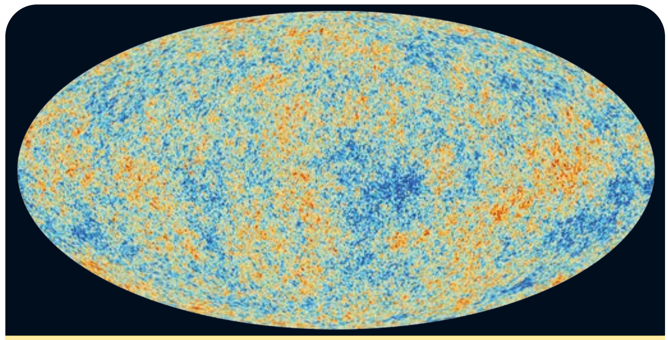
The perfect cosmological principle leads to a model where the universe never changes, so cosmologists have called this model the **steady state**. Another name is the continuous creation model, so called because it demands that the universe create new matter as we just discussed. A steady state universe never changes, so it would have no beginning or end. If the universe has neither beginning nor end, then it is eternal. For many years in the middle of the 20th century, the steady state theory was very popular, because it agreed with the eternal, infinite universe, a concept believed since ancient times. Some cosmologists claimed that the steady state theory was so beautiful that it just had to be true. Since there was no beginning of a steady state universe, there is no place for a Creator in this model. Therefore, the steady state theory is the ultimate atheistic model. Many people think that the big bang model demands that there be a Creator, but **Feature 18.2** shows that that is not the case either.


MACS J0454.1–0300 a galaxy cluster held together by gravity

The Cosmic Background Radiation

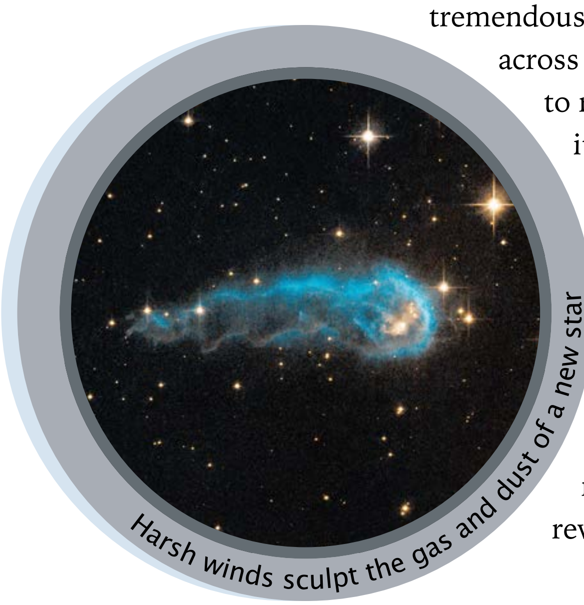
Until 1965, most astronomers probably believed the steady state model. Why? They considered the steady state model theory a simple, beautiful model. There is a bias in favor of the universe being so. But today very few people believe the steady state theory. Why? In 1964, two Bell lab scientists, Robert Wilson (b. 1936) and Arno Penzias (b. 1933), discovered the **cosmic microwave background radiation** (CMB). This discovery was so important that Penzias and Wilson received the Nobel Prize in physics in 1978. The CMB is made of many photons in the microwave portion of the spectrum coming toward us from every direction. While each photon contains little energy, there are so many of them that together they account for a significant portion of the energy in the universe. The CMB has a blackbody temperature of just under 3 K, which we can take as the temperature of the universe.

According to the big bang model, the early universe contained ionized hydrogen (protons and electrons), making the universe opaque. This opacity trapped radiation, and kept it coupled to the ionized matter. As photons were emitted, they would have traveled only a fraction of an inch before they were reabsorbed, only to be reemitted once again to repeat the process. But about 380,000 years after the big bang, the temperature of the universe would have cooled to the point that the protons and electrons would have formed stable atoms of hydrogen for the first time. This recombination of atoms would have rendered the universe transparent for the first time, allowing radiation to decouple from matter and travel great distance. Cosmologists call this alleged event the age of recombination.



The cosmic microwave background (CMB) shows tiny temperature fluctuations that correspond to regions of slightly different densities, blue is cold, red is hot.

The photons of light emitted right after the age of recombination should be visible as uniform radiation coming from all directions in space. But since this radiation would have traveled tremendous distance across the universe to reach us now, it would have undergone huge redshifts. Calculation of the conditions at the age of recombination reveals that the temperature of the universe then would have been about 3000 K. Thus, the photons ought to have a blackbody spectrum of that temperature. While the photons have traveled toward us over billions of years since the age of recombination, the universe has expanded a thousand-fold. Therefore, the photons should have experienced a thousand-fold redshift so that their temperature is now 2.73 K. A cosmologist predicted the existence of the CMB about 15 years before the discovery of the CMB. The big bang model did not predict a precise single value, but rather it predicted a range of temperature. The observed 2.73 K temperature is near the low end of that temperature range.



Harsh winds sculpt the gas and dust of a new star

The CMB is a prediction of the big bang model, but the steady state model does not predict it. This is because according to the steady state model, the universe has always been as it is today, and so there was never a time in which it had a 3000 K temperature. Since the steady state model does not predict the CMB and the big bang model does, most astronomers abandoned the steady state model shortly after the discovery of the CMB. There are some notable exceptions, such as Sir Fred Hoyle (1915–2001). Hoyle was a famous British astrophysicist who pursued work on the steady state model for decades until his death. He attempted to develop a steady state model that explained the CMB, but most astronomers do not think that he ever succeeded. Since creationists share Hoyle's rejection of the big bang theory, many creationists favor Hoyle's explanation of the CMB, though they disagree with his cosmological model.

The Big Bang and the Christian

Many Christians accept the big bang model. One feature that these Christians like about the big bang model is the fact that it clearly states that there was a beginning for the universe. This one aspect agrees with the Genesis account, unlike the steady state model. However, does this mean that the big bang model is consistent with the Genesis account of creation? There are numerous problems. One obvious problem is the time involved. The best reading of the creation account is that it took six normal days a few thousand years ago. The big bang would have happened 10–15 billion years ago.

To many Christians who have adopted the big bang model, the big bang serves as a proof for God's existence. Their reasoning is that the big bang required a cause. The only cause that they can identify is a deity. However, there is a logical fallacy in this, as discussed in **Feature 18.3**. Far from being an evidence of God's existence, the big bang is the ultimate atheistic theory.

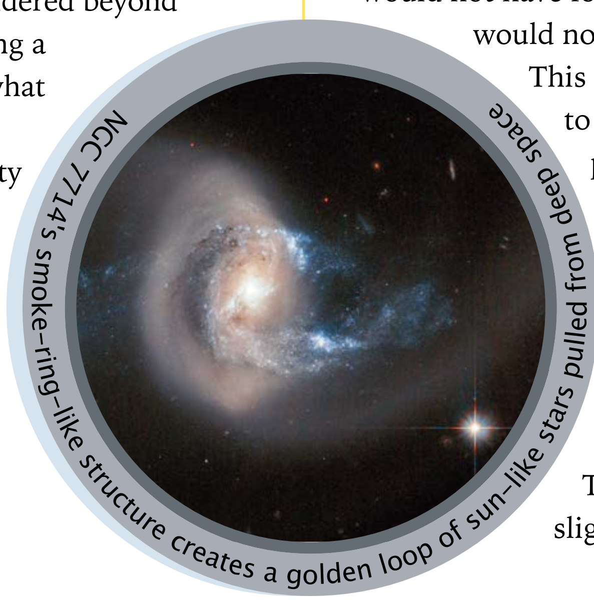
Another difficulty is that we always should keep in mind that all scientific theories are subject to later revision and even abandonment. The history of science is littered with discarded wrecks of theories that were once considered beyond doubt. If we make the big bang a key part of our apologetics, what happens to our apologetics when the scientific community abandons the big bang model?

If the big bang is not a model that is consistent with biblical creation, what is the creation model of the universe? We currently do not have a well-developed creation model. Only in recent years have creation scientists begun to develop original ideas about cosmogony and cosmology.

Problems with the Big Bang Theory

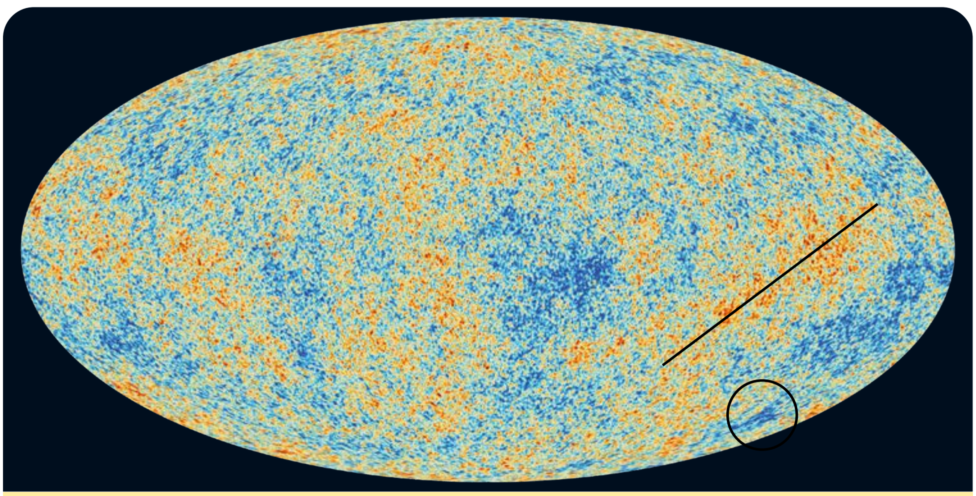
Those who support the big bang model generally give three evidences. The CMB is one proof for the big bang often cited. As previously discussed, this was a good prediction of the model. Alternate explanations generally have failed to explain adequately the CMB. However, in the next lesson we shall explore a possible explanation for the CMB within a biblical model of cosmology. While the CMB is an impressive prediction of the big bang model, there are difficulties with it.

For instance, to explain the structure that we see in the universe today (galaxies and clumps of galaxies), from the beginning of the big bang there must have been regions in the universe where the density was slightly greater than in other regions. The regions of greater density would have had greater than average gravity. The regions of greater gravity would have acted as seeds to attract matter to form the structure that we see today. Otherwise, if the universe were perfectly smooth, then galaxies, stars, and planets would not have formed. Consequently, we would not be here to see the universe. This sort of discussion can lead to what we call the anthropic principle, a topic further explored in **Feature 18.4**.


NGC 7714's smoke-ring-like structure creates a golden loop of sun-like stars pulled from deep space

These small variations in density in the early universe ought to show up as slight variations in temperature in the CMB. That is, there ought to be slightly warmer and cooler temperatures in different directions in space. Cosmologists determined that these fluctuations in temperature would be on the order of one part in 10,000. NASA designed the COBE (COsmic Background Explorer) satellite to look for these temperature fluctuations. Launched in 1989, COBE had a two-year mission during which it mapped the entire sky in the portion of the spectrum where the CMB is strongest. The two years of data collection revealed a perfectly smooth CMB, in direct conflict with the model predictions.

After some very sophisticated statistical analysis of the COBE data, a team of scientists found evidence of slight variations in the CMB in the COBE data, but on the order of about one part in 100,000 rather than the predicted one part in 10,000. Later experiments confirmed these temperature fluctuations. This was hailed as additional confirmation that the big bang model is true. Some scientists even claim that the predictions and measurements agree exactly. But how can that be, when the measured temperature fluctuations were only $\frac{1}{10}$ those predicted by the model? There indeed are temperature fluctuations, but they are far from the predicted level. Theorists altered the big bang model to fit the data. These are very loose rules for verification. Cosmologists can change the model whenever necessary to account for new data. With such rules, it is no wonder that so many people believe the big bang model.



An all-sky CMB map with the location of the Axis of Evil indicated by a line and a circle around the cold spot.

But there are other problems in the details of the CMB. The Wilkinson Microwave Anisotropy Probe (WMAP) spacecraft measured the CMB with great precision during its mission (2001–2010). Its data revealed two interesting features in the CMB — the Axis of Evil and the CMB Cold Spot. The Cold Spot is a region in the CMB that is significantly cooler than the rest of the CMB. The Axis of Evil is a long region of space that is significantly warmer than average temperature. Most interestingly, the Axis of Evil is aligned with the ecliptic. Neither the Cold Spot nor the Axis of Evil were expected from the big bang model, nor can the big bang model explain them. Furthermore, why should a cosmic radiation field have a large anomaly that is oriented with the earth's orbit around the sun?

Many scientists assumed that the CMB Cold Spot and the Axis of Evil were not real but were instead noise in the WMAP data. It was expected that both would disappear with more precise data. That opportunity came in 2009 when ESA launched Planck, a third satellite dedicated to the study of the CMB. Both the CMB Cold Spot and the Axis of Evil remain in the Planck data, indicating that both are real. There is no explanation for either in the standard big bang model.

FEATURE 18.4

THE ANTHROPIC PRINCIPLE

The Australian physicist Brandon Carter (b. 1942) coined the anthropic principle in 1973, though elements of the anthropic principle had been around far longer. The name comes from the Greek root *anthropos*, meaning "man." We get the word anthropology from the same root. The anthropic principle is the idea that there are certain characteristics about the universe that seem to demand that humans exist. The example from the text is the amount of clumping in the early big bang universe. If the early universe were too smooth, then no structures such as galaxies, stars, planets, and ultimately, people would have come into existence. On the other hand, if the early universe had been too clumped, then nearly all matter would have formed into massive black holes so that no galaxies, stars, planets, and hence people would have formed. The range in the distribution of matter in the early universe that would have led to our existence is extremely narrow. Why, then, does the universe exist as it does with people?

There are many other such examples. For instance, if the physical constants that control the structure of matter were slightly different, then certain elements would not exist as they do. If carbon were slightly different, it would not be able to form all its marvelous chemical bonds, and life would not be possible. If oxygen and hydrogen were different, would water, another essential ingredient for life, exist? All these numerous examples suggest that the universe exists as it does for our benefit. If the universe were any different from how it is, we would not be here.

To many Christians this sounds like an evidence for God's existence. However, we should be very careful. Many parts of the anthropic principle assume that the big bang, billions of years of age, and evolution are true. Creationists reject these ideas, and hence the associated anthropic reasoning. For instance, if the big bang never happened, then the smoothness of the early universe is not an issue. Some Christians accept the big bang and a vast age for the universe. To them, the anthropic principle is a very important argument for God's existence.

Scientists have explored the anthropic principle and mostly have rejected it. Their rejection is based upon a key word in the definition of the anthropic principle above and repeated here with emphasis: there are certain characteristics about the universe that *seem* to demand that humans exist. In 1988, John Barrow and Frank Tipler published *The Anthropic Cosmological Principle*, an exhaustive study of the anthropic principle. The authors concluded that the world only seemed to be designed for man. That is, no matter how contrived the world appears to be, this is the way the world is, and it could be no different.

Rather than start with what amounts to atheistic ideas of science, is it not better to begin with a creation-based approach? We should use our creation model to look for evidence in the world that suggests that it was designed and created for our benefit. There are numerous examples of design in biology, and creationists have used these for a long time. The case for design in astronomy is not as well stated, probably because of the lack of a coherent creation model for astronomy. As a creation astronomy model develops, we will have more evidence of design.

MCG+01–38–004 (the upper, red–tinted one) and MCG+01–38–005 (the lower, blue–tinted one)

A second alleged prediction of the big bang is the expansion of the universe, but this was not a prediction of the model at all. Hubble discovered the expansion of the universe long before the big bang model was developed. Indeed, the big bang theory was proposed to explain the expansion of the universe (the steady state theory was developed to explain the expansion of the universe as well). This is putting the cart before the horse. It is improper to use data that necessitated or guided the creation of a theory as evidence for the theory. To do so is an example of circular reasoning.

Circular reasoning happens when someone starts with an assumption or bit of information, develops a conclusion based upon the starting information, and then uses the starting information as "proof" that the conclusion is true. People use this sort of reasoning more frequently than we realize. It is very easy to fall into this alluring trap when we wish to establish some pet idea. Another example of this is the evidence for stellar evolution offered by H-R diagrams of star clusters as discussed in lesson 14. Please notice that while circular reasoning itself is a logical fallacy, the idea that we try to support with circular reasoning may be correct. For instance, many of the alleged proofs of God's existence are of a circular nature. Such arguments tend to confirm those who are already convinced of the conclusion but do little to convince those who are not.

The third evidence for the big bang frequently cited is the abundances of the lighter elements in the universe. The lighter elements include hydrogen, helium, and lithium and some of their isotopes. Most books about cosmology claim that the big bang theory correctly predicts the amounts of these elements in the universe. However, one can calculate different versions of the big bang. One of the things that theorists can change in big bang models is the abundances of the lighter elements. Astronomers observed the abundances of the lighter elements before the detailed big bang theory calculations. These abundances were input values in developing the big bang model. It should be no surprise then that these models "correctly predicted" these values when the models were designed to do just that. This too is circular reasoning.

The work of the astronomer Halton Arp (1927–2013) is described in **Feature 18.1**. For years, Arp called into question whether red shifts are always cosmological. Arp has offered many examples of quasars and galaxies for which he thinks most astronomers have incorrectly assumed that red shifts give distances. Many creationists like Arp's work. They reason that if Arp is correct, then we could never be sure when a red shift tells us distance. If we have doubts about the Hubble relation, then can we say with confidence that the universe is indeed expanding? If the universe is not expanding, then the big bang did not happen. But this misunderstands Arp's work. Arp never doubted that the universe is expanding. Rather, he questioned whether all large redshifts are cosmological. Of course, red shifts are real, so if they do not result from the expansion of the universe, then there must be some other explanation for the red shifts. Arp and others have offered several alternate explanations for high redshifts, but all seem to suffer from some difficulties.

Since the mid 1970s, an Arizona astronomer named William Tifft has noticed that red shifts do not fall over a continuous range of values. Instead, red shifts seem to lie near certain values, particularly multiples of 72 $\frac{\text{km}}{\text{s}}$. When we find measurements of a variable that clump near certain values, we say that the variable is quantized. A similar thing happens to energy values in very small systems such as atoms. Energy quantization in small systems forms the basis of quantum mechanics. What does the quantization of galaxies, some of the largest things known, mean? No one knows yet. While most astronomers are suspicious of quantized red shifts, they have not been able to discredit the data. If anything, the data become stronger with time. However, it may be that quantized redshifts are the result of our looking through the clumps of matter in the universe, a subject that we already discussed.

If real, then red shift quantization is a difficulty for the big bang. If red shifts are cosmological, then red shift quantization could mean that we are in the center of a series of shells of galaxies. This would invalidate the cosmological principle, upon which the big bang depends. It would also suggest that the universe has a center, which most versions of the big bang do not allow. Even worse, we are at or very near the center of the universe! This means that we have a very favored place in the universe. If we are the result of random events, what is the probability that we ended up so close to the center of the universe? This not only threatens the big bang theory, but all evolutionary thinking as well. In the next chapter, we will discuss creation-based cosmologies that place the earth near the center of the universe. Thus, while the big bang model may not explain quantized red shifts, this creation cosmology can.

The evidence of the big bang is far less than many people think. The only good evidence for the big bang is the existence of the CMB, though the detail of the CMB does not offer real proof for the big bang. Other so-called "proofs" of the big bang are circular arguments. There are other features of the universe that are difficult, if not impossible, for the big bang theory to explain.


Galaxy clusters merging and releasing X-ray energy

There are other problems with the big bang model, such as the lack of antimatter in the universe. You probably have heard of antimatter in the context of science fiction, but antimatter is real. When matter and its counterpart of antimatter meet, they annihilate one another in a burst of energy (following Einstein's famous $E = mc^2$ equation). The big bang model requires that the universe began with equal amounts of matter and antimatter, but clearly the universe is dominated by matter, so what happened to the antimatter? There is no satisfactory solution to this problem.

By the 1970s, cosmologists understood that there were two other problems with the big bang model — the horizon problem and flatness problem. In the 1980s, cosmologists invoked cosmic inflation to solve these problems. Inflation is a hypothetical rapid expansion that began and ended in the early universe, before the universe was 10^{-32} seconds old. Inflation supposedly was far faster than the speed of light. No one knows what caused inflation, or what caused it to stop. Nor is there any evidence for inflation. However, cosmologists and astronomers generally believe inflation happened, or else the universe that we know wouldn't be here. It doesn't occur to most of them that perhaps the big bang model is wrong.

Age, Origin, and Fate of the Universe

Within the big bang theory, cosmologists use the Hubble constant, H, to estimate the age of the universe. To a first approximation, the age of the universe is the reciprocal of H. We call this the Hubble time, $T_H = \frac{1}{H}$. Notice that H has the units $\frac{\frac{km}{s}}{Mpc} = \frac{km}{s}$ Mpc. Since both km and Mpc are units of distance, then H has units of reciprocal time. Therefore, the reciprocal of H has the units of time. To determine the value of the Hubble time, we must convert km to Mpc or Mpc to km. Since the Hubble time is so large, it helps to convert T_H from seconds to years as well. If $H = 50 \frac{\frac{km}{s}}{Mpc}$, then $T_H = 20$ billion years. If $H = 100 \frac{\frac{km}{s}}{Mpc}$, then $T_H = 10$ billion years. The currently accepted value of H is $70 \frac{\frac{km}{s}}{Mpc}$, which results in a Hubble time of 14.3 billion years.

Assuming a big bang universe that has been expanding at the same rate since its beginning, then the Hubble time is the age of the universe. However, there are reasons to believe the expansion rate has not been constant. For instance, the universe contains matter, which produces gravity. As the universe expands against gravity, the expansion slows. This is like an object launched upward from the earth. As the object climbs, it gradually slows. Most objects move slowly enough that gravity eventually reverses their upward motion. This can happen to the universe as well, but most cosmologists consider this unlikely. If we factor in the effect of gravity, we find that the universe was expanding more rapidly in the past. This means that if we find the Hubble time using the current value of H, our T_H will be too large. In other words, the Hubble time is an upper limit to the age of the universe.

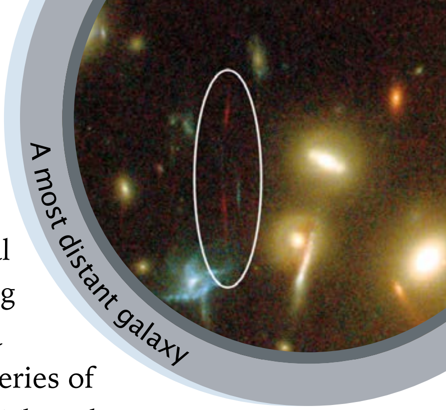
There may be other factors at work. We previously discussed why Einstein introduced the cosmological constant, an idea that soon was discarded, only to be revived at the end of the 20th century and rechristened *dark energy*. Both the cosmological constant and dark energy would cause the space of the universe to repel itself, resulting in accelerated expansion. Dark energy has the opposite affect that gravity has upon the age of the universe. Whereas gravity makes the universe younger than the Hubble time, dark energy makes the universe older than the Hubble time. The current thinking is that gravity has the stronger effect, shortening the age of the universe from the Hubble time. In 2004, a group of researchers concluded that the most probable age of the universe is 13.7 billion years (± 1%). However, a few years later this was revised to 13.8 billion years, the currently believed age for the universe. This value almost certainly will change again.

What is the origin of the big bang universe? As we discussed elsewhere in this chapter, some people see God in the origin of the big bang. However, most cosmologists attempt to explain the universe in terms of some sort of natural phenomenon. One explanation is that the universe began in a quantum fluctuation. Quantum fluctuations are small, hypothetical violations of the conservation of energy that happen for very short intervals of time. This is the result of the uncertainty principle in quantum mechanics, the physics of the smallest systems, such as atoms. The larger the violation of the conservation of energy, the shorter time that the violation can last. Presumably, if the energy involved is identically equal to zero, then the violation could last forever. There is much energy in the universe, so how could the energy of the universe be zero? Theorists have devised ways (all hypothetical) that the total energy of the universe might be zero. If the universe has zero total energy, then they reason that the universe merely could be a quantum fluctuation, an accident. As one theorist quipped, "The universe is just one of those things that happens from time to time."

There are other attempts to explain the universe physically. One suggestion is that there are many universes, a *multiverse*, if you will. From time to time, each universe within the multiverse gives rise to new universes. Therefore, our universe was spawned by some pre-existing universe of which we have no knowledge, just as our universe produces new universes of which we have no knowledge. The great British astrophysicist Stephen Hawking (1942–2018) has suggested that our universe is unbound in time. By this, he means that the universe has always existed. The big bang is just the most recent step in the evolution of the universe. However, we cannot probe beyond the limit of the big bang in the past.

You may find these suggestions humorous, but make no mistake — their proponents are very serious. These attempts to explain the origin of the universe illustrate several things. First, they illustrate that the ultimate question about the origin of the universe is not a scientific question. Indeed, the origin of the universe has no physical explanation, so we cannot study it scientifically. Second, they illustrate the atheistic philosophy that most big bang theorists adopt. Some scientists who are Christians claim that the supposed science of the big bang ultimately leads to God. However, the desperate attempts of cosmologists to explain the universe apart from the supernatural show otherwise.

What is the fate of the big bang universe? Theoretically, there are two basic possibilities. One possibility is that the universe eventually will slow its expansion and reverse into contraction. Some have suggested that the contraction will end in a "big crunch," from which the universe will rebound into a new big bang. This represents a complete return to the eternal universe, because then our big bang universe might be just a single episode of an infinite series of expansions and contractions. The other possibility is that the universe will expand forever, gradually getting cooler and less and less dense.



A most distant galaxy

Which scenario for the future of the universe is correct? Cosmologists think that they can determine which one is true by studying the universe. One critical factor is the amount of matter in the universe. If the universe contains at least a certain critical density, then the universe will eventually contract. If the universe contains less than this critical density, the universe will expand forever. Since about 1960, astronomers have measured the density to be less than that required to re-collapse the universe. Recent measurements of dark matter have increased the amount of matter, but it still is less than the critical density. If one adds dark energy, the chance of re-collapse is even more remote. Therefore, the best evidence is that the universe will expand forever.

As the universe expands, stars will gradually die out. The universe will expand until the density and temperature fall toward absolute zero. This is a very bleak outlook for the universe. The universe may have been born in a big bang, but it apparently will end in a whimper. Of course, this is in stark contrast to the Bible. While many Christians see the big bang in the Genesis creation account, many, including the author of this book, do not. Furthermore, the Bible, as in 2 Peter 3:10 speaks of the heavens passing away rapidly and violently. Instead of a gradual heat death, we know from the Bible that the universe will end in judgment, but that God will replace it with a more glorious new heaven.