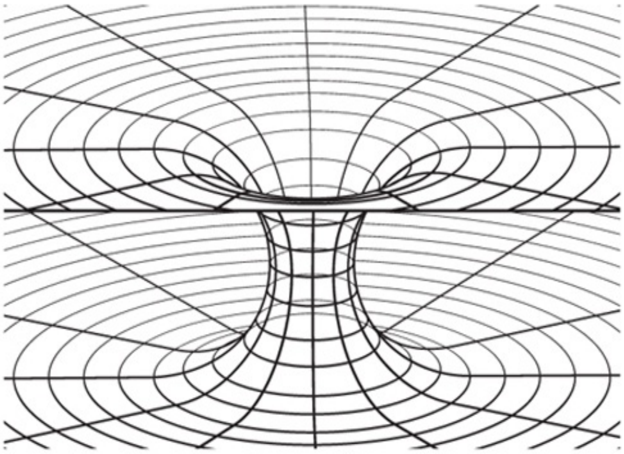
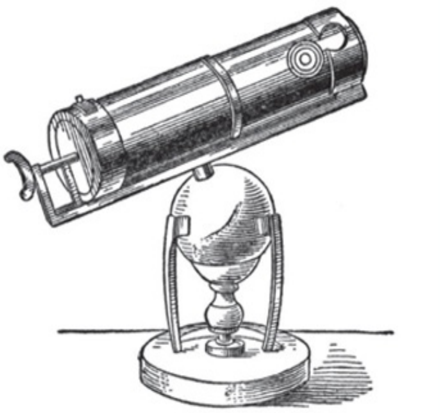
A CRASH COURSE IN THE **SCIENCE OF SPACE**

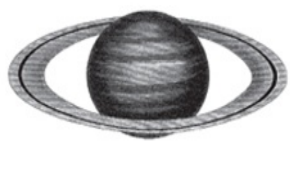
A WORMHOLE IS A HYPOTHETICAL TUNNEL THROUGH THE FABRIC OF SPACE-TIME THAT MAY ALLOW FOR PASSAGE FROM ONE SPATIAL LOCATION TO ANOTHER.



ASTRONOMY 101

FROM **THE SUN AND MOON** *TO* **WORMHOLES AND WARP DRIVE,** KEY THEORIES, DISCOVERIES, AND **FACTS ABOUT THE UNIVERSE**





THE SOLAR SYSTEM IS COMPRISED OF NUMEROUS CELESTIAL BODIES, INCLUDING PLANETS, MOONS, ASTEROIDS, AND THE SUN, A YELLOW DWARF. IT FORMED FROM A COLLAPSING MOLECULAR CLOUD BETWEEN 4.5 AND 4.7 BILLION YEARS AGO.

CAROLYN COLLINS PETERSEN

ASTRONOMY
101

FROM THE SUN AND MOON
TO WORMHOLES AND WARP DRIVE,
KEY THEORIES, DISCOVERIES, AND FACTS
ABOUT THE UNIVERSE

CAROLYN COLLINS PETERSEN

adamsmedia
Avon, Massachusetts

DEDICATION

To my many astronomy teachers. You promised me the Moon, planets, stars, and galaxies — and the universe delivered!

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INTRODUCTION

Welcome to *Astronomy 101* and one of the most fascinating sciences in the universe! Whether you're familiar with the night sky and want to learn more about what's "out there" or just beginning your cosmic journey of understanding, there's something here to teach and inspire you.

I've been "into" astronomy since I was a small child when I would go out with my parents to see what was "up out there." I grew up wanting to become an astronaut and eventually spent time in college studying a lot of astronomy and planetary science. In the early part of my career I did astronomy research (mostly into comets), and that experience taught me there is *nothing* quite so fascinating as standing (or sitting) in front of the cosmos, open to new discoveries in space! Nowadays, I spend my time communicating astronomy to the public because I want others to experience the thrill of wonder and discovery that keeps astronomers going. I often give presentations about astronomy on cruise ships and other public places, and the questions people ask about the stars and planets are always fascinating and well thought out. It shows me that the love of the stars is bred into all of us—and makes us want to know more about the cosmos.

In *Astronomy 101*, you get a taste of the cosmos. Astronomy is the scientific study of objects in the universe and the events that shape them. It is one of the oldest sciences and dates back to a point in human history when people first looked up at the sky and began to wonder about what they saw. Astronomy tells how the universe works by looking at what it contains. The cosmos is populated with stars, planets, galaxies, and galaxy clusters, and these are all governed by measurable physical laws and forces.

Each topic in this book gives you a taste of the subject it covers, from planets out to the most distant objects in the universe, introducing you to some of the people who have done astronomy, and venturing into some "far out" topics, such as extraterrestrial life and the science-fiction universes familiar to TV viewers, moviegoers, video gamers, and readers. Throughout the book, I've woven in some basic concepts about astronomy and space, such as how orbits work and how to calculate distances in space.

Finally, although this isn't a "how to" book, in the final chapter, I leave you with a few thoughts about how to go about exploring the universe from your backyard and how we can all work together to mitigate light pollution—the scourge of all sky gazers.

You can read this book from start to finish, or pick and choose the topics you want to read. Each one gives you a unique insight into the endlessly fascinating universe. And, if what you read spurs you on to more investigation, the reference section at the back points you to further reading.

Why Do People Do Astronomy?

The astronomer Carl Sagan once said that modern people are descendants of astronomers. Humans have always been sky watchers. Our earliest ancestors connected the motions of the Sun, Moon, and stars to the passage of time and the yearly change of seasons. Eventually, they learned to predict and chart celestial motions. They used that information to create timepieces and calendars. Accurate knowledge of the sky has always helped navigators find their way around, whether across an ocean or in deep space.

Humanity's fascination with the sky may have begun with shepherds, farmers, and navigators using the sky for daily needs, but today that interest has blossomed into a science. Professional astronomers use advanced technology and techniques to measure and chart objects and events very precisely. New discoveries come constantly, adding to a priceless treasury of knowledge about the universe and our place in it. In addition, the tools and technologies of astronomy and space exploration find their way into our technologies. If you fly in a plane, use a smartphone, have surgery, surf the Internet, shop for clothes, eat food, ride in a car, or any of the countless things you do each day, you use technology that in some way derived from astronomy and space science.

In my childhood I was enthralled with a 1927 poem written by American writer Max Ehrmann, "Desiderata." My favorite line from it is: "You are a child of the universe, no less than the trees and the stars; you have a right to be here." That's why I draw a link between space and our DNA. All living things are a direct result of the processes that created the cosmos, built the galaxies, created and destroyed stars, and formed planets. We are, in many senses of the term, star stuff. Every atom of every living thing on Earth originated in space, and it's poetic and delightful that we evolved to look back out at the light from stars that will eventually contribute their own "stuff" to create other stars, planets, and maybe even life. That's why I can say that a love of the stars is woven into our DNA. Whether we're professional astronomers or casual sky gazers, that's what draws our attention back to the depths of space. It's where we came from.

Welcome home!

ASTRONOMY LINGO

Throughout this book I use some astro-lingo, so let's look at a few definitions that will help you understand the language.

DISTANCE

Distances in astronomy get very large very fast. Astronomers use the term *astronomical unit* (shortened to *AU*) to define the distance between Earth and the Sun. It's equivalent to 149 million kilometers (93 million miles). (Astronomy is done in metric units.) So, for distances inside the solar system, we tend to use AU. For example, Jupiter (depending on where it is in its orbit) is 5.2 AU away from the Sun, which is a distance of 774.8 million kilometers (483.6 million miles).

In interstellar space, we use other units. The *light-year* (shortened to *ly*) comes from multiplying the speed of light, 300,000 kilometers per second, by the total seconds in a year. The result is the distance light travels in a year: 9.5 trillion kilometers. The nearest star is 4.2 light-years away from us. That means that it's four times 9.5 trillion kilometers, which is a huge number. It's easier to say that the star is 4.2 light-years away.

Astronomers also use the term *parsec* (or *pc* for short). One parsec equals 3.26 light-years. The famous Pleiades star cluster is around 150 parsecs (about 350–460 light-years) away. The nearest spiral galaxy, called the Andromeda Galaxy, is about 767 kiloparsecs or 2.5 million light-years from us.

Really huge distances are measured in terms of *megaparsecs* (millions of parsecs, or *Mpc*). The closest cluster of galaxies to our own Milky Way Galaxy lies about sixteen megaparsecs, or nearly 59 million light-years, away. The very largest distances are measured in units of *gigaparsecs* (billions of parsecs, *Gpc*). The limit of the visible universe lies about 14 Gpc away from us (about 45.7 billion light-years).

LIGHT

Light is the most basic property we study in astronomy. Studying the light emitted, reflected, or absorbed by an object tells a great deal about the object. The speed of light is the fastest velocity that anything can move in the universe. It is generally stated as 299,792,458 meters (186,282 miles) per second, in a vacuum. It has been measured very accurately and is the standard that astronomers and physicists use. However, as light passes through water, for example, it slows down to 229,600,000 meters (140,000 miles) per second. The letter *c* is shorthand for the speed of light.

Lightspeed does more than define distances. They help us get an idea of the age of the universe. Step out and look at the Moon. The “Moon” your eyes see is 1.28 seconds old. The Sun is 8.3 light-minutes away—you see the Sun as it was 8.3 minutes ago. The light from the next closest star, called Proxima Centauri, shows us how it looked just over four years ago. The light from a galaxy that lies 65 million light-years away left that galaxy when the dinosaurs were facing extinction. The most distant objects and events existed when the universe itself was only a few hundred thousand years old. Astronomers see them as they *were* more than 13 billion years ago. When you look out in space, you’re looking back into time. The farther across space you look, the further back in time you see. This means the telescopes and instruments we use to study the cosmos are really time machines.

Redshift and Blueshift

In several places in the book, you can read about spectra and spectroscopy. These are important tools in the astronomer's kit. They take light from an object and slice it up into its component wavelengths. The result is a spectrum. If you've ever passed light through a prism and noticed the spread of colors that come out, you've seen the principle that spectroscopy works under—except, there are more "colors" in the spectrum that we can't see. Our eyes can only detect the colors you see coming from the prism.

Visible Light

Visible light consists of the following colors: red, orange, yellow, green, blue, indigo, and violet.

Spectroscopy gives information about how fast or slow an object is moving, and helps astronomers figure out how far away it is. An object moving toward us shows lines in its spectrum that are *blueshifted*, or shifted to the blue end of the spectrum. If it moves away from us, then the lines are *redshifted* —shifted toward the red end of the spectrum. The term *redshift* is often used to indicate an object's distance, say a redshift of 0.5. Astronomers notate that as $z = 0.5$.

THE SOLAR SYSTEM
Our Neighborhood in Space

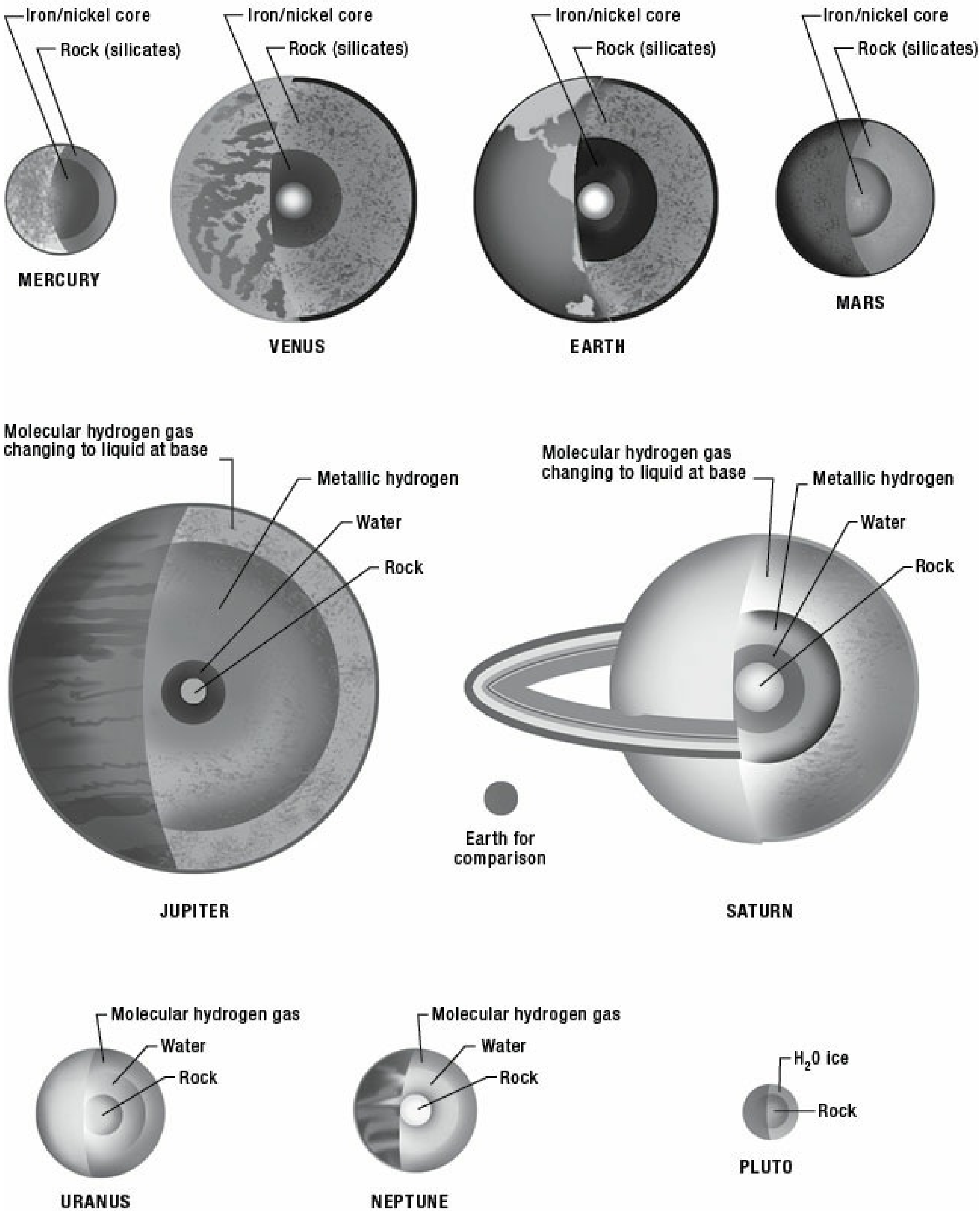
The solar system is our local place in space. It contains the Sun, eight planets, several dwarf planets, comets, moons, and asteroids. The Sun contains 99.8 percent of all the mass in the solar system. In orbit around it, in a region called the *inner solar system*, are:

- Mercury
- Venus
- Earth
- Mars

Beyond Mars, there's the Asteroid Belt, a collection of rocky objects of various sizes. The *outer solar system* is dominated by four giant planets that orbit the Sun at large distances and contain about 99 percent of the *rest* of the solar system's mass. These are:

- Jupiter
- Saturn
- Uranus
- Neptune

In recent years, planetary scientists (people who study solar system bodies) have focused much attention on a region beyond the gas giants called the *Kuiper Belt*. It extends from the orbit of Neptune out to a distance of well beyond 50 AU from the Sun. Think of it as a very distant and much more extensive version of the Asteroid Belt. It's populated with dwarf planets—Pluto, Haumea, Makemake, and Eris, for example—as well as many other smaller icy worlds.



The general compositions of the worlds of our solar system.

Inventory of the Solar System

1. 1 star
2. 8 main planets
3. 10 (and counting) dwarf planets
4. 146 (and counting) moons
5. 4 ring systems
6. Countless comets
7. Hundreds of thousands of asteroids

Planetary scientists often refer to the inner worlds of the solar system as the "terrestrial" planets, from the word *terra*, which is Latin for "earth." It indicates worlds that have a similar rocky composition to Earth. Earth, Venus, and Mars have substantial atmospheres, while Mercury appears to have a very thin one. The big outer worlds are called the "gas giants." These planets consist mostly of very small rocky cores buried deep within massive spheres made of liquid metallic hydrogen, and some helium, covered by cloudy atmospheres. The two outermost planets—Uranus and Neptune—are sometimes described as "ice giants" because they also contain significant amounts of supercold forms of oxygen, carbon, nitrogen, sulfur, and possibly even some water.

The Oort Cloud

The entire solar system is surrounded by a shell of frozen bits of ice and rock called the Oort Cloud. It stretches out to about a quarter of the way to the nearest star. Both the Kuiper Belt and the Oort Cloud are the origin of most of the comets we see.

Moons and Rings

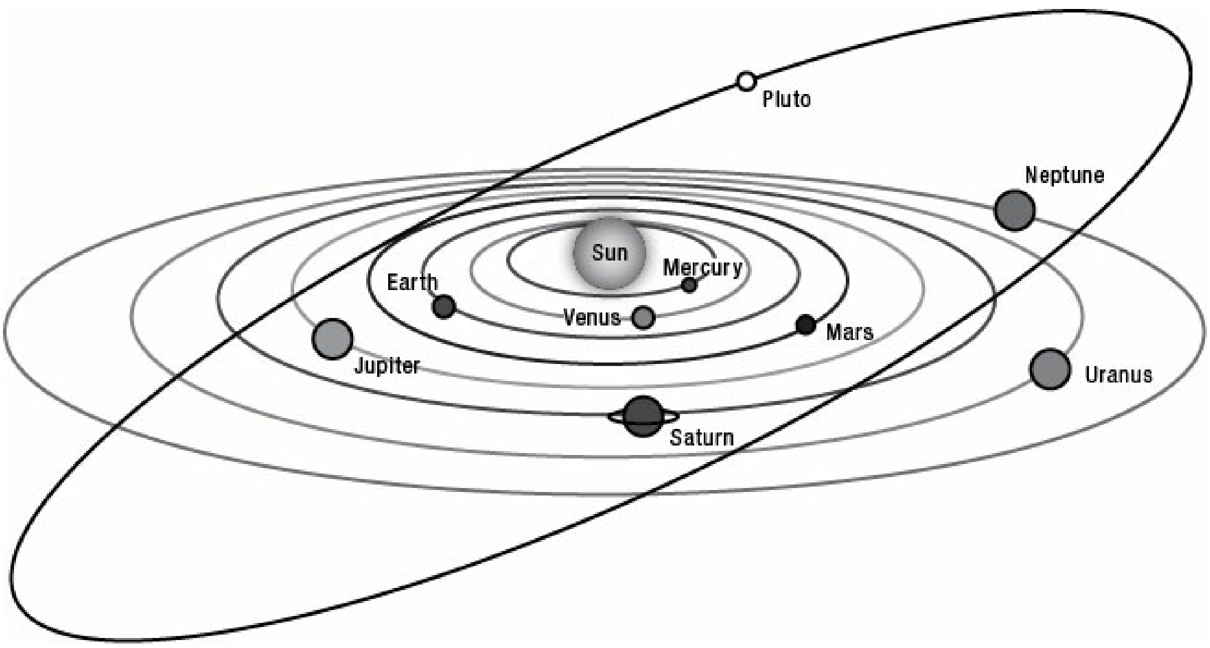
Nearly all the major planets, some of the dwarf planets, and some asteroids have natural satellites called moons. The one we're most familiar with is Earth's Moon. The lunar (from the name Luna) surface is the only other world on which humans have set foot. Mars has two moons, called Phobos and Deimos, and Mercury and Venus have none.

The gas giants swarm with moons. Jupiter's four largest are Io, Europa, Ganymede, and Callisto, and they're often referred to as the Galileans, honoring their discoverer, astronomer Galileo Galilei. Over the past few decades, at least sixty more have been discovered orbiting Jupiter. Saturn, Uranus, and Neptune also sport dozens of smaller icy worlds. Out in the Kuiper Belt, dwarf planet Pluto has at least five satellites, while Eris has at least one.

Each gas giant planet has a set of rings. Saturn's is the most extensive and beautiful. It's possible Earth had a ring in its early history, and planetary scientists now look at rings as somewhat ephemeral (short-lived) objects.

Orbiting the Sun

All the planets of the solar system travel around the Sun following paths called orbits. Those paths are defined by Kepler's Laws, which state that orbits are elliptical (slightly flattened circles), with the Sun at one focus of the ellipse. The farther out an object orbits, the longer it takes to go around the Sun. If you connect a line between the Sun and the object, Kepler's Law states that this line sweeps out equal areas in equal amounts of time as the object goes around the Sun.



The worlds of the solar system shown on their orbital paths. Most of the planetary paths are close to being circular except for Pluto's orbit, which is very elongated.

Solar System Worlds and Orbits

PLANET	AVERAGE DISTANCE FROM SUN (KM)	ORBITAL PERIOD (EARTH YEAR/EARTH DAYS)
Mercury	57,900,000	0.24 Earth year (88 Earth days)
Venus	108 million	0.62 Earth year (226.3 Earth days)
Earth	149 million	1 Earth year (365.25 days)
Mars	227 million	1.88 Earth years (686.2 Earth days)
Jupiter	779 million	11.86 Earth years (4,380 Earth days)
Saturn	1.425 billion	29.5 Earth years (10,767.5 Earth days)
Uranus	2.85 billion	84 Earth years (30,660 Earth days)
Neptune	4.5 billion	165 Earth years (60,225 Earth days)
Pluto	5.06 billion	248 Earth years (90,520 Earth days)

View a text version of this table

What's a Planet?

Early Greek sky gazers used the word *planetes* (wanderer) to refer to starlike objects that wandered through the sky. Today, we apply the word *planet* to eight worlds of the solar system, excluding Pluto. In 2005, when planetary scientists found Eris, which is larger than Pluto, it forced them to think hard about what *planet* means. In the current definition (which will probably get revised again), a planet is defined by the International Astronomical Union (IAU) as a celestial body that has its primary orbit around the Sun, has sufficient mass for its own gravity to mold it into a round shape, and has cleared the neighborhood around its orbit by sweeping up all the planetesimals, which means that it's the only body of its size in its orbit. This complex definition excludes comets, asteroids, and smaller worlds that aren't rounded by their own gravity. The IAU also defined another class called *dwarf planets*. These are objects that meet the first two criteria for planets but have not yet cleared their orbits. Pluto, along with Ceres (discovered in 1801 and long known as a minor planet) and the more recently discovered worlds of Eris, Makemake, and Haumea, is now classified as a dwarf planet.

Forces That Sculpt Worlds

Several processes have an effect on the surfaces of worlds.

Volcanism is when volcanoes spew mineral-rich lava. This happens on our own planet, Venus, and Jupiter's moon Io. It has occurred in the past on Mercury and Mars.

Cryovolcanism, where icy material erupts from beneath the surface, occurs mostly on the frozen moons of the outer solar system.

Tectonism warps the surface layers on a planet or moon, driven by heat from below. On Earth, tectonism stems from the motions of rock plates that jostle around underneath our planet's crust. Tectonism may have occurred on Mars; it appears to have affected Venus; and a form of it occurs on some of the icy moons in the outer solar system.

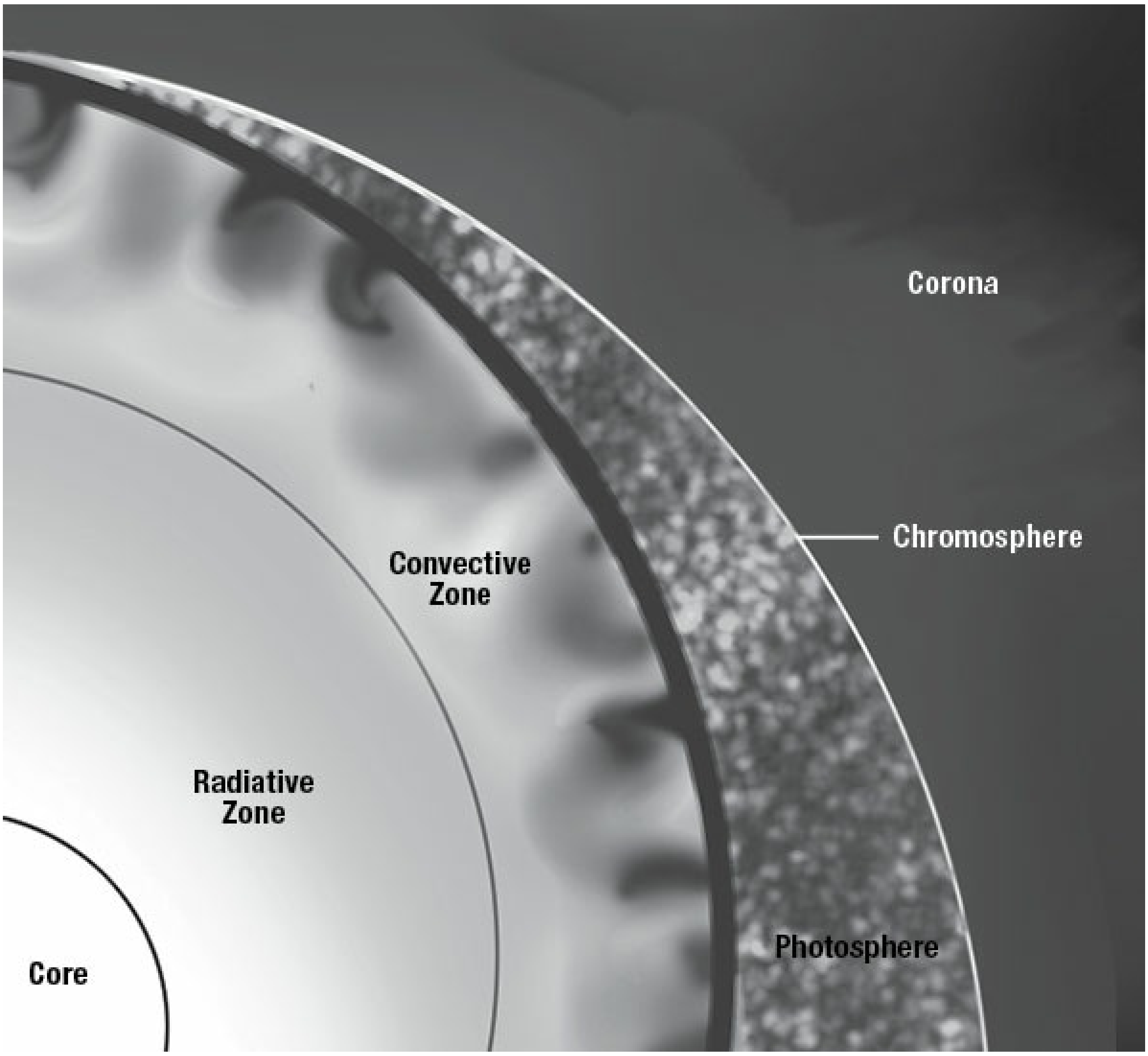
Weathering and erosion also change surfaces. On Earth, wind-driven sand can sculpt the landscape, and running water erodes the surface. This also occurs on Mars, where winds blow dust and sand across the surface. Extensive evidence shows that water once flowed across Mars's surface or existed in shallow seas and lakes.

THE SUN
Living with a Star

The Sun is a star and the biggest source of heat and light in our solar system. It's one of at least several hundred billion stars in the Milky Way Galaxy. Without it, life might not exist, and that makes it very important to us. To early people the Sun was something to worship. Ancient Greeks venerated Helios as the sun god, but they had insatiable scientific curiosity about it. They had lively debates over the true nature of this bright thing in the sky. In the 1600s, Italian astronomer Galileo Galilei (1564–1642) speculated about what the Sun could be. So did Johannes Kepler (1571–1630) a few decades later. In the 1800s, astronomers developed scientific instruments to measure the Sun's properties, which marked the beginning of solar physics as a scientific discipline.

Solar Physics

The study of the physics of the Sun is called solar physics and is a very active area of research. Solar physicists seek to explain how our star works and how it affects the rest of the solar system. They measure the Sun's temperatures, figure out its structure, and have assigned it a stellar "type" based on their measurements. Their work allows us to learn more about all stars by studying our own.



A cutaway view of the Sun, showing the core, the radiative zone, the convective zone, chromosphere, and corona.

Structure of the Sun

The Sun is essentially a big sphere of superheated gas. An imaginary voyage into its heart shows its structure.

- First, we have to traverse the outer solar atmosphere, called the corona. It's an incredibly thin layer of gas superheated to temperatures well over a million degrees.
- Once we're through the corona, we're in the chromosphere. It's a thin, reddish-hued layer of gases, and its temperature