IN THIS CHAPTER

- Discovering the universe
- Uncovering the mystery of planets, stars, and galaxies
- Revealing the electromagnetic spectrum
- Learning about where we came from and where we're going

Chapter 1
Welcome to the Universe

Have you ever looked up at the night sky and wondered what you're seeing? How did all those dots in the sky appear? Why are some brighter than others? Have you felt that sense of awe and wonder deep in your soul, and realized that you're only a small part of something much greater? If any of these apply to you, welcome to *Astrophysics For Dummies!*

You're in good company with your pondering of the universe. Since our earliest surviving records, humans have shared this fascination with the cosmos. And, fortunately, information and knowledge about the universe are exponentially greater today than they were during the time of our ancestors.

Although simply gazing up at the heavens can be inspiring, understanding what you are looking at can make the experience mind-blowing. Gazing at the sky reveals not only other worlds in our solar system but also other stars, many of which may have planets of their own. For example, if the sky is dark enough you can see the Milky Way, the bright band of stars stretching across the sky that's actually the disk of the Milky Way Galaxy. Your knowledge of astrophysics turns a beautiful spectacle into something known but no less amazing.

TIP

With good eyesight or some binoculars and/or a telescope, you can start to see nebulae, and understand that many are clouds of gas and dust that are stellar nurseries, where new stars are being born. You can even see galaxies beyond the Milky Way, and realize that they contain billions of their own stars. Due to a fundamental property of astrophysics (the speed of light being a constant), the vast cosmic distances to these objects also means that when you see them, you are actually looking back in time. Astrophysics can then be seen as a study of time as well as of space, and it can take you all the way back to the dawn of time itself — the Big Bang, the event that created our universe.

The word *astrophysics* may seem daunting, but it's nothing more than a scientific term combining a descriptive view of the universe (that's the astronomy part) with a mathematical understanding of the theoretical basis for what you are seeing (that's the physics part). Don't worry; we bring you up to speed on the fundamentals before diving into the details of the universe. Before you know it, you'll be able to explain and understand your place in the cosmos, and know a bit more about how the world works.

Welcome to astrophysics!

The Science of Astrophysics

It's only been within the last 150 years that the field of astrophysics has really taken off as separate from either astronomy or physics. Astronomy is essentially a science of observation, whereas astrophysics is more concerned with understanding those observations. Gear up and let's dive in!

The start of astronomy

TIP

The first few thousand years of astronomy can be seen as largely descriptive. Humans around the world documented the sky, observed changes, and made up stories to explain what they saw. These stories were recorded into the names of the constellations, and they were created by cultures all around the world. People observed that although most stars had fixed patterns in the sky, there were also repeating patterns. The Sun rose and set predictably, for example. Early observers noted a few interlopers: Stars that changed position over the course of the year were later shown to be planets, and flashy visitors such as the occasional comet and meteor made their own appearances.

As time went on, astronomical observations became more rigorous as telescopes were invented and used to observe the sky in more detail. Astronomers soon discovered that there was more to the sky than sparking points of light. Although most of these objects were stars, 19th-century telescopes and the discovery of photography revealed the larger, fainter, and fuzzier objects as nebulae and galaxies. With this expanded cast, the stage was set, and interest in the cosmos was sufficiently piqued to incite an entirely new field of study, one that stretched both imaginations and creativity to the maximum.

A beautiful connection: Physics, astronomy, and astrophysics

Physics, as you might recall from high school, is the study of how the natural world works. If you drop a can of beans on your toe, that's gravity at work. Astronomy, on the other hand, is the study of everything in the sky, from planets to stars to galaxies. Astrophysics joins the party as a more quantitative study that combines the observations of astronomy ("what") with the underlying theories of physics ("how"). Put simply, astrophysics is the study of how the cosmos works from beginning to end.

TIP

Astrophysics is, in many ways, a field that focuses on studying the intangible. Astrophysicists need to come up with specific ways of gathering information about phenomena that are, quite literally, out of this world. There are several ways in which scientists can tackle this problem:

- **Observations:** Using Earth- and space-based telescopes and instrumentation, astrophysicists observe the universe at different wavelengths.
- **Laboratory work:** Specially-designed equipment allows astrophysicists to simulate certain aspects of the cosmos right here at home. Assuming your home is an advanced-science lab, of course.
- **Theory:** More than chalk on a blackboard, state-of-the-art supercomputers are used to run simulations on everything from the birth of a star to the end of the universe.

Check out Chapter 4 for more information on each of these concepts.

Let there be light! The electromagnetic spectrum

The observational part of astrophysics requires — surprise! — observations.

Astrophysicists observe the universe using a variety of methods. Because we can't (yet!) travel to other stars and galaxies, these observations are all based on detectable information that distant objects send out into space. Most of this information comes in the form of electromagnetic radiation.

Electromagnetic radiation (commonly known as *light*) is a way that energy travels through space, and it's a critical concept for anyone conducting astrophysical observations. The world visible to humans comprises only a small portion of what scientists call the *electromagnetic spectrum*, a way of describing all types of electromagnetic radiation in the universe.

TECHNICAL STUFF

The electromagnetic spectrum consists of seven classes of electromagnetic waves (all defined in terms of meters):

- **Gamma rays:** Shorter than 1×10^{-11} meters
- **X-rays:** 1×10^{-11} meters to 1×10^{-8} meters
- **Ultraviolet (UV) light:** 1×10^{-8} meters to 4×10^{-7} meters
- **Visible light (optical):** 4×10^{-7} meters to 7×10^{-7} meters
- **Infrared:** 7×10^{-7} meters to 1×10^{-3} meters
- **Microwaves:** 1×10^{-3} meters to 1×10^{-1} meters
- **Radio waves:** Longer than 1×10^{-1} meters

These types of radiation are sorted by wavelength. The shorter the wavelength, the higher the energy. Gamma rays are the highest-energy type of radiation but they also have the shortest wavelength. This sorting of electromagnetic radiation in order by wavelength, is what's called the *electromagnetic (EM) spectrum;* see Figure 1-1.

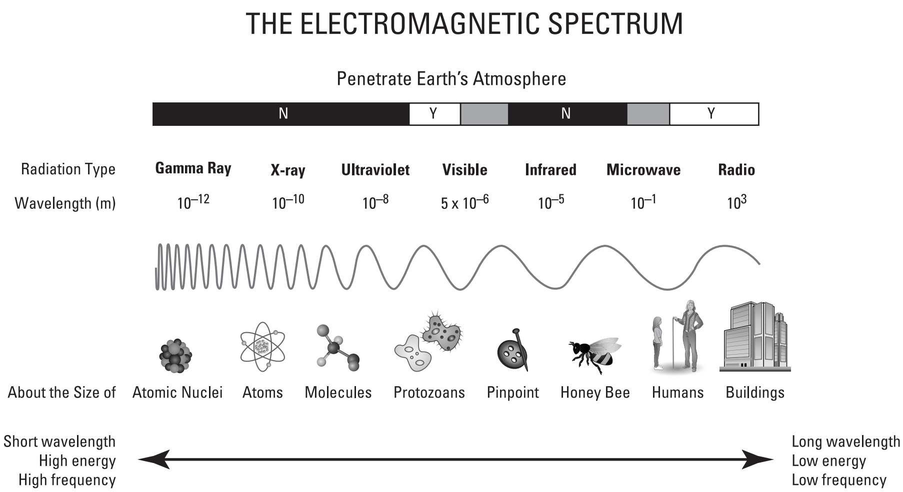

FIGURE 1-1: The electromagnetic spectrum.

Electromagnetic radiation is carried by a particle called a *photon,* and the energy and wavelength of a photon are related by this simple equation:

$$E = \frac{hc}{\lambda}$$

In this equation, E is energy, h is a constant called Planck's constant, c is the speed of light, and λ (the Greek letter lambda) is the wavelength. You can see from this equation that energy is inversely proportional to wavelength, because wavelength is on the bottom of the fraction. As wavelength shrinks, energy grows.

TIP

And what is electromagnetic radiation? It's a way that photons, in the form of electromagnetic waves, travel through space. These waves carry both energy and momentum, and they can travel through the vacuum of space and through some materials. Visible light is a kind of electromagnetic radiation, as you can see in Figure 1-1, but so are radio waves, x-rays, and other kinds of familiar radiation.

Making waves

Wavelengths are what let us see colors. If you've ever looked up at the sky after a rainstorm to see a beautiful rainbow, that beautiful arch is caused by tiny droplets of water splitting visible light apart into all its different colors — the colors of the rainbow! The violet light you see has the shortest visible wavelength, green is in the middle, and red has the longest wavelength. As you'll learn in this book, the idea of colors can be extended broadly across the electromagnetic spectrum. The wavelengths of light given off or reflected by an object are related to its composition and can also be used to find its velocity and distance from us.

TECHNICAL STUFF

This simple wavelength story might be starting to make sense but like many ideas in astrophysics, it's a bit more complicated than it seems. Light in particular, and electromagnetic radiation in general, have aspects of both a wave and a particle. Light can also travel through a vacuum at the speed of light (shocking, isn't it, to hear that the speed at which light travels is the speed of light?). As it turns out, the speed of light is a fundamental, fixed constant — nothing can go faster than light, and light (which is electromagnetic radiation after all!) always travels at this speed through a vacuum.

We refer to various parts of the electromagnetic spectrum throughout this book because different celestial bodies in space make their presence known in various ways. Stars, for example, emit mostly visible light that we can easily detect, but other objects such as neutron stars emit gamma rays.

TIP

Celestial bodies emit more than one type of radiation. Figure 1-2 shows a famous cloud of gas and dust called the Crab Nebula as viewed through telescopes at five different wavelengths, from the radio to the visible to the x-ray. See the color photo section for a beautiful multi-wavelength composite version.

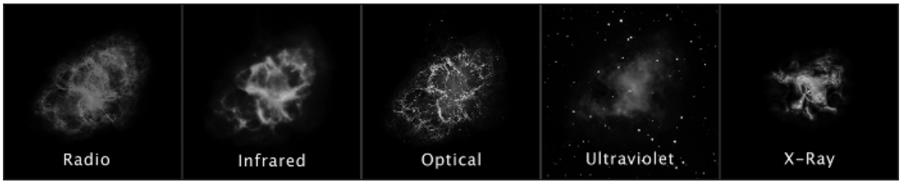

FIGURE 1-2: The Crab Nebula emitting radiation at different wavelengths.

Courtesy of G. Dubner (IAFE, CONICET-University of Buenos Aires) et al.; NRAO/AUI/NSF; A. Loll et al.; T. Temim et al.; F. Seward et al.; Chandra/CXC; Spitzer/JPL-Caltech; XMM-Newton/ESA; and Hubble/STScI

Astrophysicists use different kinds of telescopes, both on Earth and in space, to observe at wavelengths across the electromagnetic spectrum. It's often the combination of datasets taken at different wavelengths, such as in Figure 1-2, that yields new insights into how the cosmos operates.

TECHNICAL STUFF

When you get to shorter wavelengths, astronomers sometimes use frequency instead to define them. Frequency is just defined as the number of wave cycles per second, so it is inversely related to wavelength. As the wavelength increases, the frequency decreases. In fact, for light and other kinds of electromagnetic radiation that travel at the fixed speed of light, the relationship can be expressed as

$$c = \lambda \nu$$

where c is the speed of light, λ is the wavelength, and ν (the Greek letter nu) is the frequency. Wavelength is expressed in units of length (usually meters or nanometers), whereas frequency is expressed in units of Hertz (one Hertz means one cycle per second).

LIGHT VERSUS SOUND

It's not just light that comes in waves! Another highly familiar type of wave is the sound wave. Sound is a completely different process (and a completely different kind of wave) than electromagnetic radiation. The biggest difference is that sound requires a medium to move through in order to travel. Sound can be transmitted through air but also through the vibration of a musical instrument or even through the floor from your downstairs neighbor's speakers. Unlike light, however, sound can't travel through a vacuum. All those science fiction movies with ships whooshing through space are just that — fiction.

Tools of the Trade

No matter how good your eyesight may be, you'll never be able to see anything in deep space unaided. Unless you've got superpowers, you'll also have trouble seeing gamma rays, x-rays, or radio waves with the naked eye. Celestial objects such as pulsars and black hole accretion disks emit x-rays, for example, and x-rays are invisible to the human eye at the short end of the electromagnetic spectrum. There would be no realistic way to learn about these types of objects without specialized equipment. The following sections describe the most common types of observing tools astrophysicists require, and the differences between them.

The nitty-gritty of telescopes and astronomical instruments

If you've ever compared your view of the night sky from a major city to the countryside or desert, you know that the darker the sky, the more stars you can see. Astronomers take the "dark sky is better" concept to the next level when they are locating observations. Although your unaided eyes, binoculars, or a small telescope are great for a preliminary tour of the sky, performing the observational science that's key to astrophysics requires using a bigger telescope.

TIP

Is bigger better when it comes to telescopes? Absolutely, because most professional telescopes gather starlight using a mirror; larger-diameter mirrors gather more starlight that in turn allows you to see objects that are fainter or farther away.

Most professional optical astronomical observatories are located on the tops of mountains, as far away from civilizations as possible, for two reasons:

- Mountains are usually some distance away from big cities. The skies are darker because there's less light pollution from city lights.
- Mountaintops are typically at higher elevations than cities (unless you're someplace like Denver, Colorado, the "Mile High City.") The atmosphere is thinner the higher you go, creating less air and stuff like water vapor between you and the stars. Because the atmosphere is constantly in motion, more atmosphere can mean blurry images, and water vapor blocks some colors of light. The less atmosphere, the better.

Some types of observatories don't actually require a long winding mountain road for access. Radio telescopes can be located at sea level. They also need to be away from civilization, though, because they're extremely sensitive to interference in the radio portion of the EM spectrum. If a scientist is observing with an optical telescope, they have to be careful to keep flashlights away from the telescopes because that light would interfere with viewing.

At a radio telescope observatory, though, cell phones are banned because the radiation they give off interferes with those radio telescopes. Solar telescopes, on the other hand, operate during daytime and don't need a dark sky location; these telescopes often use special filters to dim our Sun's intense light enough to take observations without catching our instruments on fire.

WARNING

Pro tip: Don't try to stare at the Sun without special observing glasses! The Sun's ultraviolet rays can easily burn your retinas and cause permanent damage.

REMEMBER

Also, not all observatories contain the same types of telescopes. Optical observatories use telescopes that see light in the infrared and visible portions of the EM spectrum, but millimeter-wave and radio observatories observe at longer wavelengths.

Telescopes that operate at different wavelengths look nothing like each other. For example

- Optical reflecting telescopes have reflecting mirrors to capture light.
- Optical refracting telescopes (used only in amateur astronomy today) are longer with two or more lenses connected via a tube.
- Radio telescopes use the same technology as enormous satellite dishes.

TECHNICAL STUFF

Some radio telescope observatories are even larger by virtue of having dozens (or more) of radio telescope antennae. Their signals combine using a process called *interferometry*, a technique that increases the effective baseline of the telescope array to increase its sensitivity and detect smaller objects farther out in space. You can also do interferometry at visible wavelengths — the Large Binocular Telescope Observatory (see Figure 1-3) in Arizona has twin 28-foot (8.4-meter) mirrors and can combine the two beams of light to take observations of exoplanets and distant galaxies that would otherwise require a much larger single telescope.

TIP

Try holding your cell phone up to the eyepiece of a telescope. You're using the same principle that professional astronomers use with their enormous optical telescopes. Taking astronomical observations requires that the light from an optical telescope's mirror is directed into a scientific instrument. The two main types of instruments used at professional optical observatories are

FIGURE 1-3: The Large Binocular Telescope Observatory in Arizona.

Courtesy of Large Binocular Telescope Observatory

- An instrument that focuses light from an astronomical object into an image. This can be done with a specialized digital camera that's sensitive to minute variations in brightness, and sometimes combined with filters at multiple wavelengths. Observations through different filters can be combined to make color images, or ratioed to look for compositional differences and trends.
- An instrument that splits astronomical light into its separate wavelengths. This can be done with an instrument called a spectrograph. When attached to the telescope, the spectrograph has a diffraction grating that spreads out the light into its individual wavelengths. Like a prism, this technique allows the spectrum of a star or galaxy to be recorded, providing information about its chemical composition.

Radio telescopes and other types of telescopes operate throughout the electromagnetic spectrum — check out Chapter 4 for more details.

Viewing from above: Space-based telescopes

Sometimes the top of a mountain just isn't tall enough to allow the observations astronomers need. Earth's atmosphere absorbs light from stars and galaxies at specific wavelengths of light, particularly at infrared and UV (and higher) portions of the EM spectrum. If the atmosphere is absorbing this light, it can't make it through to our telescopes. To avoid the Earth's atmosphere (who needs the atmosphere? only everything on the planet that breathes air!), astronomy must head upward into space and beyond the reach of Earth's atmosphere.

TECHNICAL STUFF

Placing a telescope into space requires launching it from a rocket on Earth. Think of a space-based telescope as a satellite that is also a telescope. A satellite in this context is any celestial body or piece of equipment that orbits the Earth. Space-based telescopes use specialized equipment to point toward a desired portion of the sky and record data. This data is then transmitted back to Earth using radio waves. Scientists analyze the data and may use it to create those famous images you've seen, for example, from the Hubble Space Telescope. Chapter 4 has more on space telescopes, and Chapter 18 contains a summary of 10 important space missions for astrophysics.

Stars, Galaxies, and Their Cosmological Friends

You're up to speed with how astrophysicists observe the sky, and have a baseline for the tools they use to make those observations. Next up: a brief tour of what's out there.

TIP

The objects visible from Earth in the night sky are at a huge range of distances, from close to very far away, but many of those objects are separated from you in time as well as in distance. For example, shooting stars — or meteors — are tiny flecks of cosmic dust that burn and glow in Earth's atmosphere as much as 100 km up. These are some of the closest objects to Earth. A larger space rock may make it down to the ground and land in your backyard as a meteorite, but that happens only rarely.

You may also see a satellite in the sky, perhaps the International Space Station or a communications satellite several hundred or thousand miles up. These human-made objects are orbiting the Earth and are farther away than shooting stars, because they're outside of the Earth's atmosphere. Also orbiting the Earth but even farther away is our Moon. It's about 239,000 miles (384,000 km) away from us but looks bigger and brighter than any star in the sky. Why? It's farther out past our atmosphere than a satellite but it's much larger; although the Moon is smaller than a planet or star, it's still significantly closer to us.

Beyond the Moon lie the planets of our solar system. Venus, Mars, Jupiter, and Saturn are the easiest to see due to their combinations of size and distance (Jupiter and Saturn are far but huge, and Mars and Venus are both near neighbors). Tiny Mercury is hard to see but can be seen with your eyes. Uranus and Neptune, however, are so far away that they require telescopes to catch. The Sun is the closest star to the Earth. We're 93 million miles (150 km), or 1 astronomical unit (AU), away from it, but the Sun is so big and bright that it dominates our daytime sky.

TECHNICAL STUFF

What about the rest of the stars that are so pervasive in the night sky? They're stars, just like our Sun, but farther away and appear dimmer. The closest star to us, besides our Sun, is Proxima Centauri at 25 trillion miles (40 trillion km) away. All of the individual stars in the sky are part of our Milky Way Galaxy. Our solar system is located in one arm of its spiral structure. With a telescope, you can see other faint and somewhat fuzzy objects in the sky. Some are nebulae within our own galaxy, but others are different galaxies, each of which can contain billions of stars.

TECHNICAL STUFF

Because light has a maximum speed (the speed of light, *c*, is 186,000 miles per second or 300,000 km/sec), light from these distant stars and galaxies can take thousands or even billions of Earth years to reach us. Cosmic distances like this are often measured in light-years — a light-year is the distance light can travel in one year through a vacuum, or about 5.9 trillion miles (9.5 trillion km). The distance to Proxima Centauri, for example, is about 4.3 light-years. It takes light 4.3 years to reach the Earth from Proxima Centauri, meaning that the light you see was actually given off 4.3 years ago. 4.3 years may not seem like much, but Proxima Centauri is relatively close. When you see distant galaxies, you're seeing light that was given off millions to even billions of years ago.

TIP

Every time you see pictures of a distant galaxy or star, you're looking back in time. Astrophysicists use these types of observations to peer through the cosmos all the way to the beginning of time itself, to the events surrounding the Big Bang. Between viewing ancient galaxies and detecting high-energy astronomical phenomena such as black holes and quasars, astrophysics works to solve a bit of a detective story of the universe.

Ready to dive into astrophysics? This book will take you on a ride through the universe, piecing together the elements (literally!) that make up stars, galaxies, and the universe — and, coincidentally, humans like yourself. Learn what you are seeing, how to see it, and what it all means, and then you'll be ready to learn about how the universe got here in the first place, and where it all might end.