THIRD CANADIAN EDITION

ASTRO

SHOHINI GHOSE **VESNA MILOSEVIC-ZDJELAR** **ARTHUR READ** **MICHAEL REID**

THE 4LTR PRESS PROCESS

4LTR Press uses a Student-Tested, Faculty-Approved process to meet the unique needs of each course. Here are the results for the **Introductory Astronomy** course.

Students Say

They want an overview of the course concepts that illustrates their value and impact in the world. They want resources that are easy to access, either portable print texts or mobile, accessible digital solutions. They want a resource that helps them study and is easy to review for assignments and exam preparation.

Instructors Require

A text that covers current trends and topics relevant to the students taking the course. A resource that helps them engage their students, whether in print or online, and that provides support for delivering and assessing course concepts.

4LTR PRESS Delivers

An engaging experience, complete with print and digital solutions. Providing in-depth coverage of current trends, **ASTRO** is full of examples that detail how **astronomy** affects the world. Clear learning objectives, key terms, and chapter review cards help students study and prepare for course work. Easy-to-use online tools with activities, assignments, and quizzes support both formative and summative assessments, helping students learn by creating a more dynamic learning environment.

YOUR FEEDBACK YOUR BOOK

We would like to thank the following students and faculty for collaborating with us to create a more engaging solution for ASTRO, 3CE.

STUDENTS

Hailey Allegro
Julia Carsell
Ian Mack
Tanysha Stamper
Alex Robillard
Kory Pinkkinen
Carter Hayes
Rob Fox
Clarence Virtue
Siga Mathaisen
Louis-Francis Trembley
Jananee Bonello-Stauch
Kim Salazar
David Villero
Natalie Fung
Farahnaz Fallah Toosi
Sean Langton
Elisabeth Ruth Anderson

FACULTY REVIEWERS

Paul-Émile Legault, Laurentian University
Mircea Atanasiu, Mount Royal University
Mark Lubrick, University of Windsor
Robin Kingsburgh, OCAD University
William Scott, Mount Royal University
Santo D'Agostino, Brock University

SUPPLEMENT AUTHORS

Mircea Atanasiu, Mount Royal University
Matt Russo, University of Toronto

THE ASTRO SOLUTION

Print

ASTRO delivers all the key terms and all the content for the **Introductory Astronomy** course through a visually engaging and easy-to-review print experience.

Digital

CENGAGE | MINDTAP

MindTap enables you to stay organized and study efficiently by providing a single location for all your course materials and study aids. Built-in apps leverage social media and the latest learning technology to help you succeed. If your instructor has assigned MindTap, follow these simple instructions to begin.

1. Open the Access Card included with this text.
2. Follow the steps on the card.
3. Study.

CONGRATULATIONS!

You're about to unlock the content needed to ACE this course.

You only need two things to get started:

❶ The Course Link from your instructor ❷ The unique Access Code provided on this card

All set? Good! Time to get started.

❶ Visit your instructor-provided Course Link
❷ Sign in or create an account at **login.nelsonbrain.com**
❸ When prompted, enter the Access Code provided on this card.

or

Is course delivered through your campus Learning Management System?

❶ Log into your campus Learning Management System and select your instructor's course.
❷ Select the Nelson content from within your course.
❸ Sign in or create an account at **login.nelsonbrain.com** to link both accounts.
❹ When prompted, enter the Access Code provided on this card.

Did something go wrong? We can help:

My instructor didn't give me a Course Link.
Ask your instructor for the Course Link or check with him or her to see if you should be accessing your content via your campus Learning Management System. If you are not using a campus Learning Management System, visit **login.nelsonbrain.com** and enter your Access Code.

Access Code already in use?
If your Access Code came with a used book, the Access Code may have been used before. Access Codes are single use. Return to where you purchased this product for assistance.

Need Support?
Visit **nelson.com/support.**

*Learning Management System refers to a platform a campus uses to make course material available to students and instructors online. Some examples include: BlackBoard, Brightspace, Canvas, Moodle, etc.

Nelson Education Ltd. 1120 Birchmount Road Toronto ON M1K 5G4
416 752 9448 or 1 800 268 2222 email: nelson.brain@nelson.com **nelson.com**

Student Resources

- Interactive eBook
- Flashcards
- Trackable Activities:
  - — Graded Quizzing
  - — Media Quizzing
  - — Matching Exercises
- Chapter Review Questions
- Chapter Videos
- Online Glossary
- Chapter Review Cards

Students: **nelson.com/student**

Instructor Resources

- Access to All Student Resources
- Instructor Companion Site
- NETA PowerPoint® Slides
- Updated NETA Test Bank
- LMS Integration
- Image Library
- NETA Enhanced Instructor's Manual
- Quick Start Guides

Instructors: **nelson.com/instructor**

NELSON

ASTRO, Third Canadian Edition
by Shohini Ghose, Vesna Milosevic-Zdjelar,
L. Arthur Read, and Michael Reid

VP, Product Solutions, K–20:
Claudine O'Donnell

Director, Hardside Publishing:
Paul Fam

Marketing Manager:
Jessica Radford

Content Manager:
Toni Chahley

Photo and Permissions Researcher:
Kristiina Paul

Production Project Manager:
Shannon Martin

Production Service:
MPS Limited

Copy Editor:
Kelli Howey

Proofreader:
MPS Limited

Indexer:
Michael Ferreira

Design Director:
Ken Phipps

Post-secondary Design PM:
Pamela Johnston

Interior Design:
Cenveo; Pamela Johnston

Cover Design:
Courtney Hellam

Cover Image:
Alan Dyer

Compositor:
MPS Limited

Adapted from *ASTRO*, Third Edition, by Michael A. Seeds and Dana Backman, published by Cengage Learning. Copyright © 2018 by Cengage Learning.

Printed and bound in Canada
1 2 3 4 23 22 21 20

For more information contact
Nelson Education Ltd., 1120 Birchmount Road,
Toronto, Ontario, M1K 5G4. Or you can visit our
Internet site at nelson.com

Library and Archives Canada Cataloguing in Publication

Title: ASTRO / Shohini Ghose, Vesna Milosevic-Zdjelar, L. Arthur Read, Michael Reid

Names: Ghose, Shohini, author. | Milosevic-Zdjelar, Vesna, 1961- author. | Read, L. Arthur, 1941- author. | Reid, Michael, author.

Description: Third Canadian edition. | Includes index.

Identifiers: Canadiana 20190206322 | ISBN 9780176857059 (softcover)

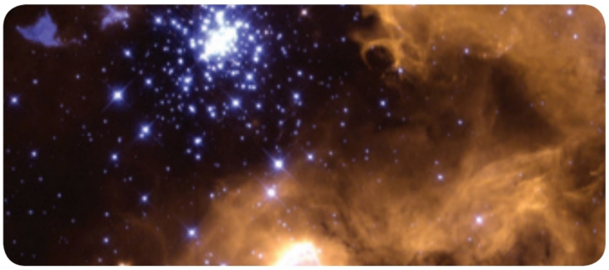
Subjects: LCSH: Astronomy—Textbooks. | LCGFT: Textbooks.

Classification: LCC QB61 .G56 2020 | DDC 520—dc23

ISBN-13: 978-0-17-685705-9
ISBN-10: 0-17-685705-2

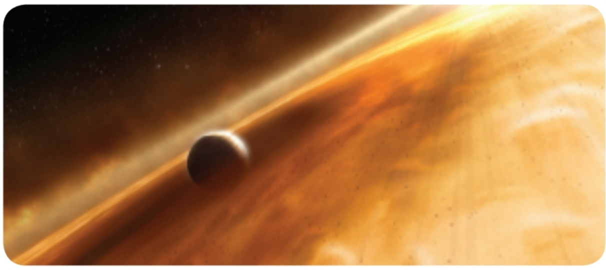
BRIEF CONTENTS

Jimmy Hu / Shutterstock.com



Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (Univ. Washington), You-Hua Chu (Univ. Illinois Urbana-Champaign), and NASA

ESO/B. Tafreshi (twanight.org)



ESA, NASA, and L. Calcada (ESO for STScI)

ESO/L. Calçada

CONTENTS

ABOUT THE AUTHORS

Shohini Ghose is a Professor of Physics and Computer Science and Founding Director of the Centre for Women in Science at Wilfrid Laurier University. She is an adjunct professor at the University of Waterloo, a member of the Guelph-Waterloo Physics Institute, and a Researcher at the Perimeter Institute for Theoretical Physics. She is a theoretical physicist who has made important contributions in the area of quantum information and computing. Her work has established new connections between chaos theory and quantum physics. Shohini has taught physics and astronomy to over 2500 students enrolled in her courses, and has developed innovative online teaching and learning tools for science. Her research and teaching has earned her numerous awards, including a WOW (Women of Waterloo) Education award and a prestigious TED Senior Fellowship. Shohini's science talks have been viewed over 4 million times online. Apart from physics she loves reading, travelling, and cricket (the game, not the insect).

Vesna Milosevic-Zdjelar, an astrophysicist from the National Observatory in Belgrade, Serbia, joined the University of Winnipeg's Physics Department in 2000. In Canada, she obtained a degree in science education and has made important contributions teaching science courses to non-science students and creating community awareness by initiating science outreach programs, for which she received Marsha Hanen award from University of Winnipeg. She initiated and co-created "Concepts in Science," a course that became the preferred science course choice for education and arts students, with enrollment increasing tenfold in just 1 year. Vesna's passion for science education came from generations of educators in her family, especially her mother Ljiljana, a nuclear physicist, whose expertise and ideas contributed to this book. Vesna has been invited to make numerous presentations at conferences and symposia for university instructors and science teachers. She teaches a broad range of courses including Astronomy, Concepts in Science, Physics for Life Sciences, and Physics of Music.

L. Arthur (Art) Read is Professor Emeritus at Wilfrid Laurier University (WLU), Waterloo. He received both his BA and MSc (Physics) from McMaster University, and his PhD (Physics) from University of Waterloo.

At WLU, Art taught physics and served in various administrative roles including Dean of Arts & Science (1983–1999), Director of the Brantford Development Project, and was subsequently appointed as the first Dean of the Laurier Brantford campus (1999–2001).

His research interests involved microwave optics and broadband molecular spectroscopy. With a keen interest in education quality and standards development, he has served as curriculum assessor for the Ontario Postsecondary Education Quality Assessment Board. He has developed and taught a variety of physics courses, including musical acoustics, analog electronics, physics for life sciences, and introductory astronomy. In his retirement, Art is currently teaching two popular online astronomy courses for Laurier.

Michael Reid is an Associate Professor, Teaching Stream in the Department of Astronomy and Astrophysics at the University of Toronto. He specializes in teaching astronomy to the widest possible cross-section of students, particularly those who aren't majoring in science. His classes range from 1500-student introductory survey courses to tiny first-year seminars. His most recent project has been developing a hands-on observational astronomy course for third-year students in the humanities. His work has garnered the Early Career and Outstanding Teaching Awards from the University of Toronto. Michael is also the Public Outreach Coordinator for the Dunlap Institute for Astronomy and Astrophysics. He coordinates events and programs to bring the thrill of astronomical discovery to tens of thousands of people every year.

PART ONE

1

The Scale of the Cosmos: Space and Time

CHAPTER OUTLINE

GUIDEPOST

You already know more about astronomy than you may think. You have enjoyed sunsets and moonrises, have admired the stars, and may know a few constellations. You have probably read about Mars rovers and the Hubble Space Telescope. That is more than most Earthlings know about astronomy. Still, you owe it to yourself to understand where you are. You should know what it means to live on a planet that whirls around a star sailing through one galaxy in a universe full of galaxies.

It is easy to learn a few facts, but it is the relationships among facts that are important. This chapter will give you the sense of scale you need in order to appreciate the vastness of the universe and to understand your place within it.

Here, you will consider important questions about astronomy:

- How is astronomy research done today through global collaborations?
- Where are you and Earth in the universe?
- How does the time span of human civilization compare with the age of the universe?
- How does science give us a way to know about nature?

The remaining chapters in this book will fill in the details, give evidence, describe theories, and illustrate the wonderful intricacy and beauty of the universe. That journey begins here.

You are about to go on a voyage to the limits of the known universe, travelling outward, away from your home on Earth, past the Moon and the Sun and the other planets of our solar system, past the stars you see in

NASA

The spectacular aurora borealis, or the “northern lights,” over Canada is sighted from the International Space Station near the highest point of its orbital path. The station’s main solar arrays are seen in the left foreground. This photograph was taken by a member of the Expedition 53 crew aboard the station on September 15, 2017.

> Space is for everybody. It’s not just for a few people in science or math, or for a select group of astronauts. That’s our new frontier out there, and it’s everybody’s business to know about space.
>
> *Christa McAuliffe,*
> *teacher and Challenger astronaut*

the night sky, and beyond billions more stars that can be seen only with the aid of telescopes. You will visit the most distant galaxies—great globes and whirlpools of stars—and continue on, carried only by experience and imagination, seeking to understand the structure of the universe. Astronomy is more than the study of planets, stars, and galaxies—it is the study of the whole universe in which you live. Although humanity is confined to a small planet circling an unremarkable star, the study of astronomy can take you beyond these boundaries and help you not only see where you are but also understand *what* you are.

Your imagination is the key to discovery; it will be your scientific space-and-time machine transporting you across the universe and into the past and future. Go back in time to watch the formation of the Sun and Earth, the birth of the first stars, and ultimately the creation of the universe. Then, rush into the future to see what will happen when the Sun dies and Earth withers.

Although you will discover a beginning to the universe, you will not find an edge or an end to space. No matter how far you voyage, you will not run into a wall. In a later chapter you will discover evidence that the universe may be infinite; that is, it may extend in all directions without limit.

Astronomy will introduce you to sizes, distances, and times far beyond your usual experience on Earth. Your task in this chapter is to grasp the meaning of these unfamiliar sizes, distances, and times. The solution lies in a single word: scale. In this chapter, you will compare objects of different sizes in order to comprehend the scale of the universe.

1.1 Astronomy: A Global Human Adventure

Like you, our ancestors viewed the night sky and attempted to make sense out of a bewildering array of white light sources or, simply, stars. Most stars appeared to remain stationary with respect to the other stars. Some were decidedly brighter than others. To a careful observer, a few even appeared faintly blue, orange, or red. A few moved quite significantly with respect to the stable background of stars—and these, initially known as wandering stars, were eventually termed planets. Of course, our ancestors also carefully monitored the comings and goings of the two brightest objects in the sky: the Sun and the Moon.

What was the human mind to make of this? For thousands of years, humans have been assembling their observations of the cosmos into stories, explanations, and models, handing these down from one generation to the next. Astronomy has long been a global effort, from the earliest natural philosophers exchanging concepts among cultures, to seafaring civilizations going on long voyages to make celestial observations, to our modern globally connected scientific community. Human beings have always been united by curiosity about our cosmic origins, and our place in space and time. Today, international coalitions of scientists and engineers come together from around the world to build grand telescopes, and collect observations, and share the results in public databases. Anyone with an Internet connection can access observations of the sky taken by telescopes from across the planet and in space.

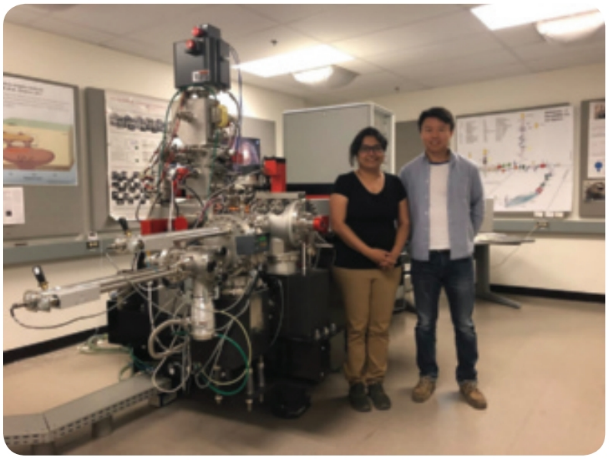
Today, we understand that we make our observations of the cosmos from a planet tucked away near the edge of just one of billions of galaxies that populate our expanding universe. We can marvel at the strength and sophistication of the human mind that has enabled us to collectively locate ourselves across vast stretches of space and time.

> People from different backgrounds approach a subject in different ways and ask different questions.
>
> *—Jocelyn Bell Burnell, discoverer of pulsars, neutron stars*

Every culture has brought a unique perspective to the search for answers to challenging questions about our place in space and time. Today scientists attempt to erase political and geographical boundaries and establish global collaborations, so that anyone can access the results of experiments and observations and test their ideas against observed data. An example of such international collaboration is the Large Hadron Collider (see **Visualizing Astronomy 11.1** and Figure 1.1), an enormous technological achievement built and used by over 10 000 scientists and hundreds of universities and laboratories, from more than 100 countries including Canada. One goal of this undertaking is to simulate the early moments of our universe and test the very nature of matter. The Large Hadron Collider has been used to discover fundamental particles in nature that make up all matter in the universe.

Mike Struik

Figure 1.1 Fabiola Gianotti, an Italian particle physicist and the Director-General of CERN (European Organization for Nuclear Research), in the ATLAS detector of the Large Hadron Collider, for which Canada contributed parts.



Maitrayee Bose/ASU, CC BY-SA

Figure 1.2 Maitrayee Bose (left) and Ziliang Jin (right) as they prepare to measure Itokawa samples.

Another international collaboration, the Event Horizon Telescope (EHT) (see Figure 4.11), has produced the first ever photograph of a black hole in a core of a distant galaxy (see Figure 10.22). The telescope consists of a planet-wide array of telescopes from Europe, Greenland, the United States, Antarctica, and Asia, connected together into a single instrument the size of Earth. Similarly, the Atacama Large Millimeter/submillimeter Array (ALMA) is a radio telescope made of 66 individual radio telescopes in the Atacama Desert in northern Chile (see the opening image of Chapter 9). This important endeavour is a colossal international collaboration involving the United States, the European Union, Canada, South Korea, Japan, and Taiwan.

You might be aware that spacecraft from different countries have been launched to explore various bodies within the solar system and in the process have discovered important details about the origin and composition of planets, moons, asteroids, and comets. The Japanese spacecraft *Hayabusa* was designed to travel to a small near-Earth asteroid (Itokawa), where it hovered close enough to its surface to collect a small sample and then returned to Earth. This journey took seven years to accomplish, and the grains of asteroidal material are now being analyzed for various molecules including water. These precious samples are now a focus of scientific study in laboratories all around the world—such as Arizona State University, where Indian and Chinese cosmochemists Maitrayee Bose and Ziliang Jin are analyzing a sample (Figure 1.2).

In 2014, India's Mars Orbiter Mission (MOM), also called *Mangalyaan*, arrived at the red planet to study its surface and atmospheric features and the effects of the solar wind on the upper atmosphere. Both the National Aeronautics and Space Administration (NASA) and the South African Space Agency provided communications and navigation and tracking support, again demonstrating global cooperation in space exploration (Figure 1.3). The orbiter continues to function as of the time of writing and plans exist for a follow-up mission, MOM-2, to arrive at Mars in the mid-2020s.

In January 2019 the Chinese spacecraft Chang'e 4 became the first moon lander to set down on the side of the Moon invisible from Earth, near the Moon's south pole. The mission's objective is to learn the age and composition of this unexplored area of the Moon called the Aitken basin, where the deep lunar crust may be exposed.

Very often observed results are more surprising than expected, and in order to test the observations, independent

Manjunath Kiran/AFP/Getty Images

Figure 1.3 Staff from the Indian Space Research Organization celebrate after their Mars Orbiter spacecraft successfully entered the Mars orbit on September 24, 2014.

teams from different parts of the world look at the same phenomena in different ways. In 1998, a team of astronomers from the Supernova Cosmology Project from Berkeley, California, set their instruments to measure the rate of slowing of the expansion of the universe. Their observations showed a surprising result. Contrary to the hypothesis that the expansion rate of the universe was slowing down, the results seemed to indicate that the universe's expansion was accelerating. In a case like this, you would not know if some systematic errors were present in the observing equipment or in the processing of the data unless another team was performing the same observation with different equipment and utilizing another methodology. Fortunately, an international collaboration of astronomers from the United States, Europe, Australia, and Chile were attempting to make the same measurement (see Figure 11.14). Their data confirmed that the surprising outcome was, indeed, correct. Astronomers were suddenly faced with the fact that our universe contains a component or force driving the expansion of the universe faster and faster. This mysterious component is now known as dark energy. You will learn more about dark energy and the beginning and end of the universe in Chapter 11.

As you can see, astronomy is, and has always been, a global effort. If humanity is to unravel the secrets of the universe we must collaborate and build on observations, ideas, and technologies from all around the world. You will come to realize that the study of astronomy also incorporates important concepts from both physical and biological sciences. The story of astronomy is thus a story of collective human knowledge.

1.2 From Solar System to Galaxy to Universe

Your quest to find our place in the visible universe can start anywhere on Earth. Let's launch our journey in the Universe of Particles, a museum exhibit at the Globe of Science and Innovation at CERN (Organisation Européenne pour la Recherche Nucléaire) in Geneva (see **Visualizing Astronomy 1.1, The Scale of the Very Small and Very Large: Powers of 10**). CERN is the home of the Large Hadron Collider, the largest particle accelerator in operation today, which was designed to simulate the beginning of the universe (see also Chapter 11, **Visualizing Astronomy 11.1, The Large Hadron Collider**). Not more than 100 m under the ground from the Globe of Science and Innovation, massive detectors are looking for the first signs of the big bang, microscopic black holes, and dark matter. The results might shed light on many topics in this book, and perhaps even change a few chapters. You indeed live in exciting times, when new technology can bring us closer to our origins.

scientific notation The system of recording very large or very small numbers by using powers of 10.

field of view The area visible in an image, usually given as the diameter of the region.

Now let's use our imagination to fly out from the Globe of Science and Innovation. Along the way, study the journey described in **Visualizing Astronomy 1.1, The Scale of the Very Small and Very Large: Powers of 10**. (The following figure numbers refer to these pages.)

Your journey to the smallest realm of nature starts with the human hand on the museum exhibit (Figure 1a). To reach the scale of skin cells in your hand (Figure 1b), you have to zoom in with a microscope 100 000 times to a size that is 100-thousandth of a metre. The metre quickly becomes too large as a unit. Instead we use either prefixes (e.g., "milli," which means "one-thousandth") or **scientific notation**—the powers of 10. The information about the cell and the organism to which the cell belongs is encoded in the DNA molecule. The DNA strand shown here is a billionth of a metre thick (Figure 1c). Diving through the molecule, you encounter the main building block of matter: the atom. The size of the electron cloud surrounding the tiny nucleus of an atom is 10-billionth of a metre (Figure 1d). The nucleus of the atom is 10 000 times smaller than the atom itself. Elementary particles are roughly in the order of 10 times smaller than the nucleus. How far can we go? Large Hadron Collider achieved collisions in which a Higgs boson has been produced, on the scale of 10^{-15} m (Figure 1e). The smallest length that theoretically makes sense is the Planck length—100 billion billion times smaller than the scale of the smallest elementary particles (Figure 1f). An understanding of these building blocks of space and matter allows you to unravel the secrets of the birth and evolution of the universe.

In the following chapters you will embark on a journey from Earth to the farthest visible extent of the universe. For those distances you can use larger measures than the metre as you move outward from Earth.

You will now follow the sequence in **Visualizing Astronomy 1.1, The Scale of the Very Small and Very Large: Powers of 10**, starting again from the Globe of Science and Innovation (Figure 2a), and moving farther and farther away. Each view is made from a distance that is some power of 10 times farther away, until the distance becomes so large that we jump with higher increments. Every time you move 10 times away, your **field of view** encompasses an area 10 × 10 larger than the previous square.

Distances are first expressed in metres until they become so large that a metre becomes too small as a unit. At a distance of 10 000 m, or 10 km, the view includes about the same area as CERN's Large Hadron Collider (Figure 2b).

In the next step of the journey, you can see the entire planet Earth, which is about 13 000 kilometres in diameter. The image of Earth (Figure 2c) shows most of the daylight side of the planet, and the blurriness at the extreme right is the sunset line. The rotation of Earth on its axis each 24 hours carries you eastward, and as you cross the sunset line into darkness, we say that the Sun has set. At the scale of this image, the atmosphere on which our life depends is thinner than a strand of thread.

Next you enlarge field of view by a factor of 100 and see a region 1 000 000 km wide (Figure 2d). Earth is the small blue dot in the centre, and the Moon, with a diameter only about one-fourth that of Earth, is an even smaller dot along its orbit. If you've had a high-mileage car, it may have travelled the equivalent of a trip to the Moon, which has an average distance from Earth of 380 000 km. These numbers are so large that it is inconvenient to write them out. Astronomy is the science of big numbers, and you will use numbers much larger than these to describe the universe.

Here, you jump to another measuring unit. You enlarge a picture not 10 times or 100 times, but 150 times in order to fit a specific distance into the picture: the average distance from Earth to the Sun. This distance is called the **astronomical unit (AU)**, which is 1.5×10^8 km, or 1.5×10^{11} m. Introducing new units is another way astronomers deal with large numbers. Using that unit, you can say, for example, that the average distance from Venus to the Sun is about 0.7 AU. At this scale you find the Sun and a few of the inner planets of our solar system (Figure 2e). The **solar system** consists of the Sun, its family of planets, and some smaller bodies, such as moons, asteroids, and comets.

Like Earth, Venus and Mercury are **planets**—small, nonluminous bodies that shine by reflecting sunlight. Venus is about the size of Earth, and Mercury is a bit larger than Earth's moon. In this figure they are both too small to be seen as anything but tiny dots. The Sun is a **star**, a self-luminous ball of hot gas that generates its own energy (Figure 1.4). The Sun is about 110 times larger in diameter than Earth, but it, too, is nothing more than a dot in this view. Earth orbits the Sun once a year.

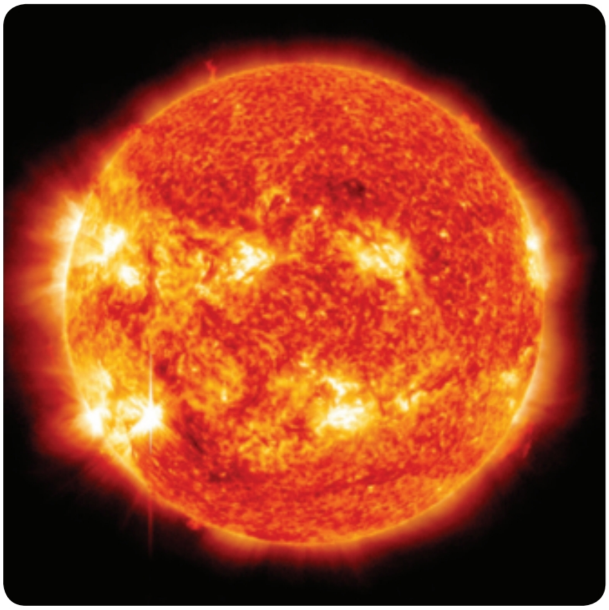

NASA

Figure 1.4 Our Star: The Sun

Now, jump 100 times farther away than the previous view, and you will see the entire solar system, all the major planets and their slightly elliptical orbits (Figure 2f). You see only the brighter, more widely separated objects as you back away. The Sun, Mercury, Venus, and Earth are so close together that you cannot separate them at this scale.

Mars, the next outward planet, is only 1.5 AU from the Sun. In contrast, Jupiter, Saturn, Uranus, and Neptune are so far from the Sun that they are easy to find in this figure. Light from the Sun reaches Earth in only eight minutes, but it takes over four hours to reach Neptune. Pluto, which orbits mostly outside Neptune's orbit, is no longer considered a major planet.

The Sun is a fairly typical star, a bit larger than average, and it is located in a fairly normal neighbourhood in the galaxy. The stars are separated by average distances about 30 times larger than this view, which has a diameter of 11 000 AU. It is difficult to grasp the isolation of the stars. If the Sun were represented by a golf ball in Vancouver, the nearest star would be another golf ball in Calgary.

At this point, our view has expanded to a diameter of about 2 million AU. The Sun is at the centre, and you see a few of the nearest stars. These stars are so distant that it is not reasonable to give

astronomical unit (AU) Average distance from Earth to the Sun; 1.5×10^8 kilometres.

solar system The Sun and its planets, asteroids, comets, and so on.

planet A nonluminous body in orbit around a star, large enough to be spherical and to have cleared its orbital zone of other objects.

star A globe of gas held together by its own gravity and supported by the internal pressure of its hot gases, which generate energy by nuclear fusion.

VISUALIZING ASTRONOMY 1.1

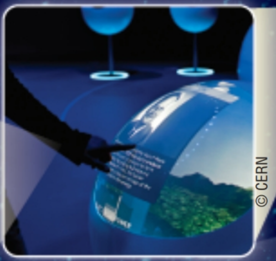
The Scale of the Very Small and Very Large: Powers of 10


© CERN

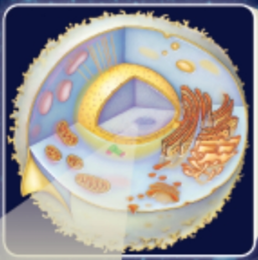
Dominionart / Shutterstock.com

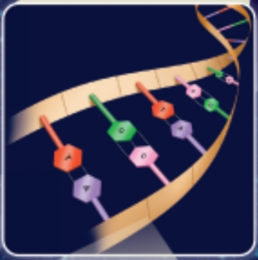
2

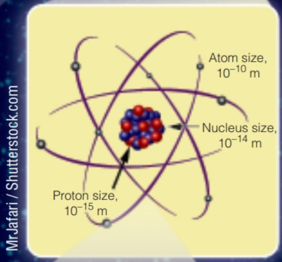
1 This view, about 20 m in diameter, is inside the Universe of Particles, a museum exhibit at the Globe of Science and Innovation at CERN (Organisation Européenne pour la Recherche Nucléaire) in Geneva (Figure 2).


© CERN

1a **1 m from museum exhibit**

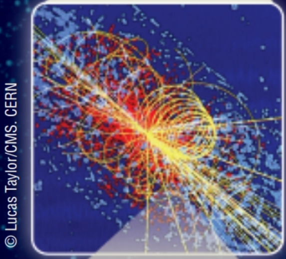

1b **Body cell, 10^{-5} m**


1c **Thickness of DNA, 10^{-9} m**

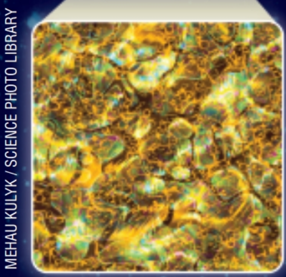


MrJafari / Shutterstock.com

1d **Atom size, 10^{-10} m**


© Lucas Taylor/CMS. CERN

1e **Computer simulation of particle traces from a Large Hadron Collider collision in which a Higgs boson is produced, 10^{-15} m**


MEHAU KULYK / SCIENCE PHOTO LIBRARY

1f **Planck length, 10^{-35} m**

Each area of astronomy and related multidisciplinary sciences (such as astrobiology and astrochemistry) explores a different realm of nature, from the smallest structures in the universe to the largest. The study of the production of energy in stars involves the study of an atomic nucleus, while cosmology studies the structure and evolution of the universe on the largest scale. To understand the vast range of sizes and distances on our journey to understanding nature, we have to adopt symbols for very small and very large numbers. It is not convenient to express the size of an atom as 0.0000000001 m or the far distance observed in the universe as 100 000 000 000 000 000 000 000 000 m. Instead, we use either **prefixes** (e.g., "kilo," which means "one thousand") or **scientific notation** (i.e., powers of 10). Here are some examples:

1 billionth of a metre (**nano**metre, nm) = 0.000000001 m = 10^{-9} m
1 millionth of a metre (**micro**metre, μm) = 0.000001 m = 10^{-6} m
1 thousandth of a metre (**milli**metre, mm) = 0.001 m = 10^{-3} m
1 hundredth of a metre (**centi**metre, cm) = 0.01 m = 10^{-2} m
1 thousand metres (**kilo**metre, km) = 1000 m = 10^{3} m
1 million (**mega**) metres = 1 000 000 = 10^{6} m
1 billion (**giga**) metres = 1 000 000 000 = 10^{9} m

Dominionart / Shutterstock.com

2a

100 m from CERN's Globe of Science and Innovation

Imagery ©2014 TerraMetrics. Map data ©2014 Google

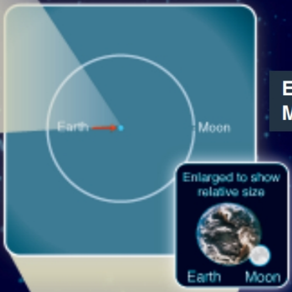
2b

CERN site aerial view, 10^4 m = 10 km

NASA

2c

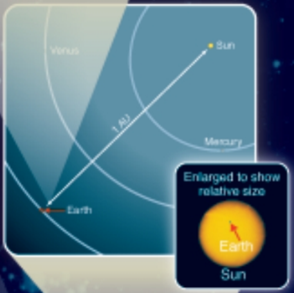
Earth, 10^7 m = 10^4 km



NASA

2d

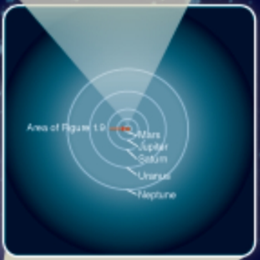
Earth with the Moon, 10^6 km



NASA

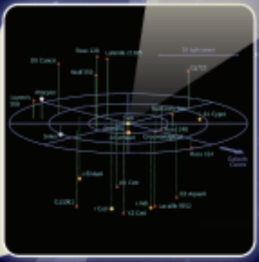
2e

Solar system inside Earth's orbit, 1.5 × 10^{11} m. This distance is called the **astronomical unit**.



2f

Orbits of solar system, 150 AU, about 10^{13} m

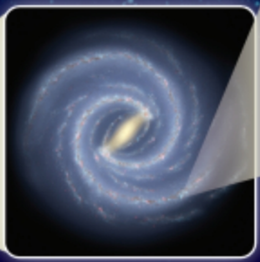


ESO/R.-D.Scholz et al. (AIP)

2g

Some closest stars to our Sun within 30 ly, 3 × 10^{17} m

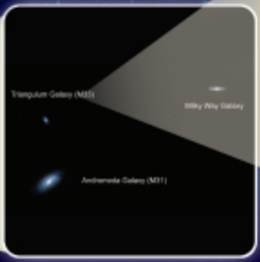
NASA/JPL-Caltech/ESO/R. Hurt



2h

Milky Way, our galaxy, 10^5 ly, 10^{21} m

NASA. Screen capture of http://svs.gsfc.nasa.gov/30955. Frank Summers (STScI), Gurtina Besla (Columbia University), and Roeland van der Marel (STScI)

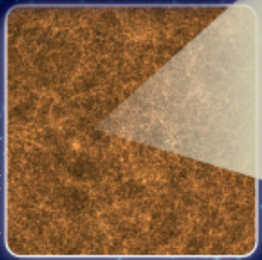


2i

Local Group of galaxies, 4 × 10^6 ly, 4 × 10^{22} m

2j

The view with a diameter of 1.7 billion light-years. This image is a fragment of an all-sky survey created by SDSS (Sloan Digital Sky Survey), capturing a quarter of a billion stars and a quarter of a billion galaxies. It shows clusters of galaxies connected in a vast network.



Michael Blanton and the Sloan Digital Sky Survey (SDSS) Collaboration their distances in AU. Astronomers have defined a new larger unit of distance, the light-year. One **light-year (ly)** is the distance that light travels in one year, roughly 10^{13} km, or 63 000 AU. In the diagram of the nearby stars in relation to the Sun (Figure 2g), the diameter of our view is 30 ly. The nearest star to the Sun, Proxima Centauri, is 4.2 ly from Earth. In other words, light from Proxima Centauri takes 4.2 years to reach Earth.

Although these stars are roughly the same size as the Sun, they are so far away that you cannot see them as anything but points of light. Even with the largest telescopes on Earth, you still see only points of light when you look at stars, and any planets that might circle those stars are much too small and faint to be visible. Of course, no one has ever journeyed thousands of light-years from Earth to look back and photograph the Sun's neighbourhood.

The space between the stars is filled with thin gas. Although those clouds of gas are thinner than the best vacuum produced in laboratories on Earth, it is those clouds that give birth to new stars. The Sun formed from such a cloud about 5 billion years ago.

Expanding your view by a factor of 3000, you see our galaxy (Figure 2h). A **galaxy** is a great cloud of stars, gas, and dust bound together by the combined gravity of all the matter. In the night sky, you see our galaxy from the inside as a great, cloudy band of stars ringing the sky as the **Milky Way**, and our galaxy is called the **Milky Way Galaxy**. Of course, no one has photographed our galaxy, but astronomers have evidence that the galaxy image in Figure 2h is similar to our own. Our Sun would be invisible in such a picture, but if you could see it, you would find it about two-thirds of the way from the centre to the edge. Our galaxy contains over 100 billion stars, and, like many others, has graceful **spiral arms** winding outward through the disk. You will discover in a later chapter that stars are born in great clouds of gas and dust as they pass through the spiral arms.

The visible disk of our galaxy is roughly 100 000 ly in diameter, but the most recent data from large international surveys of stars in the Milky Way Galaxy indicate the size of the disk to be much larger. Only a century ago, astronomers thought it was the entire universe—an island universe of stars in an otherwise empty vastness. Now we know that the Milky Way Galaxy is not unique; it is a typical galaxy in many respects, although larger than most. In fact, ours is only one of many billions of galaxies scattered throughout the universe.

light-year (ly) Unit of distance equal to the distance light travels in one year.

galaxy A large system of stars, star clusters, gas, dust, and nebulae orbiting a common centre of mass.

Milky Way The hazy band of light that circles our sky, produced by the glow of our galaxy.

Milky Way Galaxy The spiral galaxy containing our Sun, visible in the night sky as the Milky Way.

spiral arms Long spiral pattern of bright stars, star clusters, gas, and dust. Spiral arms extend from the centre to the edge of the disk of spiral galaxies.

supercluster A cluster of galaxy clusters.

Continuing our journey from the very small to the very large, we move away 40 times farther, and our galaxy appears as a tiny luminous speck surrounded by other specks in a region 4 million ly in diameter. Notice that our galaxy is part of a cluster of a few dozen galaxies called the Local Group (Figure 2i). Galaxies are commonly grouped together in clusters, and some of these galaxies have beautiful spiral patterns like our own galaxy but others do not. In a later chapter you will investigate what produces these differences among the galaxies.

The image of a fragment of an all-sky survey created by SDSS (Sloan Digital Sky Survey) captures a quarter of a billion galaxies and represents a diameter of 1.7 billion light-years (Figure 2j). It shows clusters of galaxies connected in a vast network. Clusters are grouped into **superclusters**—clusters of clusters—and the superclusters are linked to form long filaments and walls outlining voids that seem nearly empty of galaxies. These filaments and walls appear to be the largest structures in the universe.

If we expanded our view frame one more time, we would probably see a uniform fog of filaments and voids. As we puzzle over the origin of these structures we are at the frontier of human knowledge. The sequence of figures ends here because it has reached the limits of possible observation of the universe. It is not possible to see any distance larger than 13.8 billion light-years. If the universe is 13.8 billion years old, the light from distances farther away than this would not have had the time to reach us. You will learn more about cosmology in Chapter 11.

A problem in studying astronomy is keeping a proper sense of scale. Remember that each of the billions of galaxies contains billions of stars. Many of those stars probably have families of planets like our solar system, and on some of those billions of planets liquid-water oceans and protective atmospheres may have sheltered the spark of life. It is possible that some other planets are inhabited by intelligent creatures who share our curiosity, wonder at the scale of the cosmos, and are looking back at us when we gaze into the heavens.

How could anyone possibly know these secrets of nature? Science gives us a way to know how nature works (see **How Do We Know? 1.1** and **How Do We Know? 1.2**). As you explore the universe in the chapters that follow, notice not only *what* is known but also *how* it is known.