

# Preface

As James Van Allen wrote in his foreword to this book, astronomy permeates our culture. Of all the sciences, astronomy is the one that generates the most public interest. There are hundreds of thousands of amateur astronomers, two monthly astronomy magazines with healthy circulation, and television specials about important astronomical discoveries. The demotion of Pluto from planet to dwarf planet generated headlines and editorials around the world. Part of the public interest in astronomy is surely due to the dramatic scope of the science. Part, I am sure, is because nonprofessionals not only can understand astronomical discoveries but also can make some of those discoveries. Amateur astronomers regularly carry out important astronomical observations, often with telescopes they have made themselves.

## The Goals of Astronomy: Journey to the Cosmic Frontier

I wrote this book as a text for an introductory course in astronomy for college students. I have taught such a course for many years at the University of Iowa and the University of Alabama in Huntsville. One of my main goals for those courses, and one of my main goals in this book, is to provide my students with a broad enough, deep enough background in astronomy that they will be able to follow current developments years after they finish my course. This book is current with recent developments such as the cosmological discoveries of the *WMAP* satellite and the results from the Mars rovers. But I want my students to continue to learn about astronomy long after these discoveries have been succeeded by newer, even more exciting, ones. I hope that years from now my students, and the readers of this book, will be able to read and watch stories about astronomy with confidence that they know what is going on and why the story is important. I can guarantee that future astronomical discoveries will occur at least as often as they do today, and I want my students to be prepared to enjoy future discoveries.

I hope that all the explanations and descriptions in the book will not obscure the awe and sense of wonder that all astronomers feel when they pause in their work and think about the beauty of the universe. People have felt that awe since prehistory and our wonderment has increased as we understand more about the order and underlying structure of the universe. If this book helps its readers to value both the sheer beauty of planets, stars, and galaxies and the equally beautiful principles that organize the universe, it will be a success.

I would be grateful for any suggestions and advice for improving this book. If you have any ideas to offer, please contact me at the Department of Physics, University of Alabama in Huntsville, Huntsville, Alabama, 35899, or by e-mail at [fixj@uah.edu](mailto:fixj@uah.edu).

## What's New?

**Content Updates and Additions** As stated, one of the goals of this text is to keep students up to date on current astronomical events and discoveries. In doing so, many new topics have been added to the sixth edition, and several topics from previous editions have been updated. Some of these include:

### New Topics

- Fermi gamma-ray telescope (Chapter 6)
- Recent Moon missions (Chapter 9)
- Results from the *Messenger* mission to Mercury (Chapter 10)
- The discovery of ice by the *Phoenix* Mars lander (Chapter 11)
- *Mars Reconnaissance Orbiter* images of the Martian surface (Chapter 11)
- Trans-Neptunian Objects and the history of the solar system (Chapter 13)
- *Voyagers'* encounter with the termination shock of the solar wind (Chapter 17)
- Bright gamma ray burst of March 2008 (Chapter 20)
- VLBI determination of the size and rotation of the Milky Way (Chapter 22)
- Future collision between the Milky Way and M31 (Chapter 25)
- The *Corot* and *Kepler* missions to detect transits by planets orbiting other stars (Chapter 27)

### Updated and Revised Topics

- Diffraction (Chapter 6)
- Large telescopes of the future (Chapter 6)
- Information on future eclipses (Chapter 9)
- The loss of Venus's water (Chapter 10)
- Discoveries by the *Spirit* and *Opportunity* rovers on Mars (Chapter 11)
- The climate history of Mars (Chapter 11)
- Three newly defined dwarf planets (Chapter 13)
- Icy plumes from Enceladus (Chapter 14)
- Possible future collisions of Apollo asteroids with Earth (Chapter 15)
- Brown dwarfs (Chapter 16)

- Massive black holes at the centers of galaxies (Chapter 23)
- Planets orbiting other stars (Chapter 27)

**New and Updated Images** Including images from *Hubble*, *Spitzer*, *Spirit*, *Opportunity*, *Cassini*, *Huygens*, *Mars Global Surveyor*, and *Phoenix*.

## Pedagogical Features

**Electronic Media Integration** To help better grasp key concepts, this interactive icon has been placed near figures and selections where students can gain additional understanding through the interactives on the *Astronomy Online Learning Center*.



To help better understand key concepts, this animation icon has been placed near figures and sections where students can explore additional information on the *Astronomy Online Learning Center*.



**Chapter Introduction** Every chapter begins with an introduction designed to give the historical and scientific setting for the chapter material. The overview previews the chapter's contents and what you can expect to learn from reading the chapter. After reading the introduction, browse through the chapter, paying particular attention to the topic headings and illustrations so that you get a feel for the kinds of ideas included within the chapter. Also included in the chapter introduction are questions to explore while reading the text.

**Worked Examples Boxes** This book, like my course, presumes that many of its readers are not science majors and may not have had a college-level science or mathematics course. The book provides a complete description of current astronomical knowledge, neither at an extremely technical level nor at a level that fails to communicate the quantitative nature of physical science. I have used equations where they are relevant, but follow the equations with boxes containing one or more worked examples. The examples in the boxes show how and when to use each equation and tell why the equation is important.

**Historical Emphasis** Throughout the book I have emphasized the historical development of astronomy to show that astronomy, like other sciences, advances through the efforts of many scientists and to show how our present ideas developed. In the main body of the text there are many comparisons of what was once known about a particular phenomenon to what we now know about it. These historical comparisons are used to illustrate the cycle of observation, hypothesis, and further observation, which is the essence of the scientific method of discovery.

Equations  
4.1 and  
4.2

## Running Summaries

Important concepts and facts are summarized in the body of the chapter immediately after the concept is introduced.



The epicyclic model perfected by Ptolemy used combinations of circular motions to reproduce the motions of the planets. The model could predict the positions of celestial objects with such accuracy that it was used for nearly 1500 years.

## Planetary Data Boxes

These boxes include summaries of planetary data making this information easy to access.

Table 12.1 Planetary Data	
Jupiter	
Orbital distance	5.2 AU
Orbital period	11.9 years
Mass	$318 M_{\text{Earth}} = 1.90 \times 10^{27} \text{ kg}$
Diameter	$11.2 D_{\text{Earth}} = 142,980 \text{ km}$
Density (relative to water)	1.33
Escape velocity	60 km/s
Surface gravity	2.54 g
Global temperature	125 K
Main atmospheric gases	H, He
Rotation period	9.9 hours
Axial tilt	3°
Known satellites	63
Distinguishing features	Most massive planet, conspicuous cloud features

## Sidereal and Synodic Periods

Equations 4.1 and 4.2 can be used to calculate the synodic period of a planet from its sidereal period or vice versa. Suppose there were a superior planet with a synodic period of 1.5 years. For  $S = 1.5$  years and  $P_{\text{Earth}} = 1$  year, Equation 4.1 is

$$\frac{1}{P} = \frac{1}{(1 \text{ yr})} - \frac{1}{(1.5 \text{ yr})} = \frac{(3 - 2)}{(3 \text{ yr})} = \frac{1}{(3 \text{ yr})}$$

Thus,  $P$ , the sidereal period of the planet, is 3 years. This is the hypothetical planet described in Figure 4.6. As a second example, suppose there were an inferior planet with a sidereal period of

0.25 years. For  $P = 0.25$  years and  $P_{\text{Earth}} = 1$  year, Equation 4.2 is

$$\frac{1}{(0.25 \text{ yr})} = \frac{1}{(1 \text{ yr})} + \frac{1}{S}$$

Rearranging this equation to solve for  $1/S$  gives

$$\frac{1}{S} = \frac{1}{(0.25 \text{ yr})} - \frac{1}{(1 \text{ yr})} = \frac{4}{1} - \frac{1}{1} = \frac{3}{1 \text{ yr}}$$

for which  $S = 1/3$  year.

## End of Chapter Material

**Chapter Summary** highlights the key topics of the chapter.

**Key Terms** listed here are defined in the text and in the end-of-book glossary.

**Conceptual Questions** require qualitative verbal answers.

**Problems**, involving numerical calculations, test the reader's mastery of the equations.

**Figure-Based Questions** require the reader to extract the answer from a particular graph or figure in the chapter.

**Group Activities** encourage interaction between students as they work in groups to discuss different viewpoints on chapter-related issues or to complete small group projects.

**Chapter Summary**

A white dwarf is a planet-sized star supported by degenerate electrons. Massive white dwarfs are smaller than low-mass white dwarfs. The Chandrasekhar limit, the greatest mass that a white dwarf can have, is about  $1.4 M_{\odot}$ . (Section 20.1)

A white dwarf keeps a constant size as it evolves. It radiates away its heat and grows cooler and dimmer simultaneously. After billions of years, a white dwarf becomes so dim it is difficult to detect. (20.1)

White dwarf stars evolve from the cores of asymptotic giant branch stars that have lost their outer layers as cool winds. A star like the Sun will produce a white dwarf of about  $0.6 M_{\odot}$ . The most massive white dwarfs originate in main sequence stars of about  $8 M_{\odot}$ . (20.1)

A type II supernova is the result of the collapse of the core of a massive star. As the core collapses, its protons and electrons combine to form neutrons. The inner core becomes a neutron star. Infalling matter rebounds from the neutron star and produces a shock wave that moves outward rapidly through the star. After a few hours, the shock wave expands the surface of the star and produces a great brightening. (20.2)

Supernova 1987A, in the Large Magellanic Cloud, a nearby galaxy, was the first supernova visible to the naked eye in nearly 600 years. Neutrinos, which were detected almost a day before the supernova brightened, marked the time of core collapse and confirmed the idea that type II supernovae result from the collapse of the cores of stars. (20.2)

Gamma ray bursts are brief blasts of gamma rays that originate in distant galaxies. Most gamma ray bursts are probably produced by the collapse of cores of massive stars. (20.2)

The blast of gas ejected from a supernova sweeps up the surrounding interstellar gas (20.2)

A luminous supernova remnant. High-energy electrons in the supernova remnant emit synchrotron radiation, which makes a supernova remnant visible using radio telescopes. After about 10,000 to 100,000 years, the supernova remnant merges into the interstellar gas. (20.2)

Neutron stars, about 10 km in radius, are supported by degenerate neutrons. Like white dwarf stars, the more massive neutron stars are the smallest. The greatest mass that a neutron star can have is estimated to be between  $1.5$  and  $2.7 M_{\odot}$ . A newly

formed neutron star spins very rapidly and has a large magnetic field. (20.2)

Pulsars are rotating neutron stars that emit beamed radiation. The rotation of the neutron star can be seen to sweep past the Earth, causing us to see pulses of radiation as often as one thousand per second. (20.2)

The beamed radio emission from pulsars is produced by energetic electrons in regions near magnetic poles, which are tipped with respect to the rotation axis of a pulsar. Pulsars lose their energy as time passes and, after perhaps 10<sup>4</sup> years, slow to periods of a few seconds. Many are highly magnetized neutron stars that produce gamma ray bursts. (20.2)

The rotation of the magnetic field of a pulsar produces low-frequency electromagnetic radiation carried off the rotational energy of the pulsar. The radiation energies electrons, which emit synchrotron radiation that fills in the center of the supernova remnant. (20.2)

Spacetime is the combination of three space axes and one time coordinate that locates any event in space and time. A geodesic, the shortest distance between two points, is a straight line in flat space but a curved path in curved spacetime. Geodesics, such as the sum of the angles of a triangle, depend on the curvature of spacetime. (20.3)

According to general relativity, gravity is a sequence of the curvature of spacetime by objects and light follow geodesics in curved time near massive objects. We cannot see spacetime is curved, so we have invented the idea of gravity to account for the motion of objects in curved spacetime. (20.3)

A black hole forms as a result of the collapse of a star when the core is too massive to be a neutron star. The black hole is bounded event horizon, through which nothing can escape even light. The Schwarzschild radius, the radius of the event horizon, is 3 km times the mass of the black hole in solar masses. (20.3)

All that we can ever learn about a black hole is its mass, angular momentum, and electric charge. We can detect the presence of black holes, however, by looking for the strong gravity influence that they have on their immediate surroundings. (20.3)

**Key Terms**

black hole 489	gravitational redshift 488	Schwarzschild radius 489	supernova remnant 478
Chandrasekhar limit 471	magusar 483	spacelike trip 486	synchrotron emission 478
event horizon 489	neutronization 474	spacetime 484	timelike trip 486
gamma ray bursts 477	neutron star 474	spacetime diagram 485	type II supernova 478
geodesic 486	pulsar 481	supernova 473	white dwarf star 478

**Conceptual Questions**

- Describe the main difference between the mass-radius relationship for main sequence stars and the mass-radius relationship for white dwarf stars.
- A  $2 M_{\odot}$  core of a star contracts after using its nuclear fuel. Explain why we can be sure that the star will not become a white dwarf.
- Suppose two white dwarf stars have the same surface temperature. Why is the more massive of the two white dwarfs less luminous?
- Describe the evolution of a star after it becomes a white dwarf.
- Main sequence stars of  $5 M_{\odot}$  are thought to evolve into  $1 M_{\odot}$  white dwarfs. What happens to the  $4 M_{\odot}$  that do not become part of the white dwarf?
- What is the relationship between the central stars of planetary nebulae and white dwarf stars?
- Suppose AGB stars did not lose mass through cool winds. What effect would this have on the number of white dwarf stars in the galaxy?
- What is the difference between the spectra of type I supernovae and those of type II supernovae?
- The core of a massive AGB star consists of iron and nickel surrounded by shells of successively lighter elements. What does this structure have to do with the history of consumption of nuclear fuels by the star?
- Why does the process of neutronization reduce the ability of the degenerate electrons in the core of a massive AGB star to support the weight of the star?
- What are the processes that reverse the infall of matter during a type II supernova explosion and blast material out of the star?
- What is the ultimate origin of the energy released in a type II supernova?
- How do we know that most gamma ray bursts originate far beyond the Milky Way?
- What is thought to be the relationship between gamma ray bursts and supernovae?
- Only a small percentage of the energy of a type II supernova is carried away by radiation and the shell of matter blasted outward. What happens to the rest of the energy released in the explosion?
- Why are many supernova remnants bright in the radio part of the spectrum?
- Why does the expansion of a supernova remnant as time passes?
- What effect do supernova explosions have on chemical makeup of interstellar gas?
- What are the similarities and differences between mass-radius relationships of white dwarfs and main sequence stars?
- What does the concept of conservation of angular momentum have to do with the rapid rotation of neutron stars?
- Why was it possible to reject the idea that pulsars were rotating white dwarfs, pulsating white or pulsating neutron stars?
- Why would no pulses be observed from a neutron star if its magnetic axis and spin axis are aligned?
- What happens to the rotation rate of a pulsar as it passes?
- Why don't we see any pulsars with periods longer than a few seconds?
- Why are all pulsars not found within supernova remnants?
- How many coordinates are used in spacetime?
- Why is a stationary body represented by a vertical line rather than a point in a spacetime diagram?
- Why can't a body move horizontally in a spacetime diagram?
- What is the difference between spacelike trip and timelike trip?
- Suppose you lived in a two-dimensional world. Describe a way you could use geometry to determine whether your world was flat or curved.
- Suppose you make a triangle in your backyard using a stretched string to make three geodesics from the sides of the triangle. You then use a tractor and found that the sum of the angles of the triangle was  $180^{\circ}$ . You know that the surface of Earth is curved, so why didn't your triangle of more than  $180^{\circ}$ ?

**Problems**

- A black hole has a Schwarzschild radius of 25 km. How much mass is contained in the black hole?
- How large is the Schwarzschild radius of a black hole containing a mass equal to that of the Earth?
- The visible light from a gamma ray burst has an apparent magnitude of 8.0. The distance of the galaxy in which the burst occurred is 3 billion pc. Find the absolute magnitude of the visible light. How does this compare with the absolute magnitude of the Sun? (Use Equation 16.3.)

**Figure-Based Questions**

- Use Figure 20.3 to estimate the radius of a  $0.9 M_{\odot}$  white dwarf star.
- A white dwarf star has a radius two-thirds as large as the Earth's. Use Figure 20.3 to find the mass of the star.
- Use Figure 20.5 to find the mass of the white dwarf star that results from the evolution of a  $6 M_{\odot}$  main sequence star.
- Use Figure 20.9 to find the brightness (relative to its maximum brightness) of a type II supernova 100 days after the time of maximum light.
- Use Figure 20.17 to estimate the radius of a  $0.5 M_{\odot}$  neutron star.

**Group Activity**

Borrow a "chalk globe" from your instructor. Working with your group, make a triangle on the chalk globe by picking three points not too far apart and connecting the points with geodesics. You can make the geodesics by stretching a piece of string tight between a pair of points. Use a protractor to measure the angles of the triangle. Find the sum of the angles. Repeat the measurements using three points located fairly far apart on the chalk globe. Have the group discuss how the sum of the angles in your triangles compares with the sum of the angles in a plane triangle.

**For More Information**

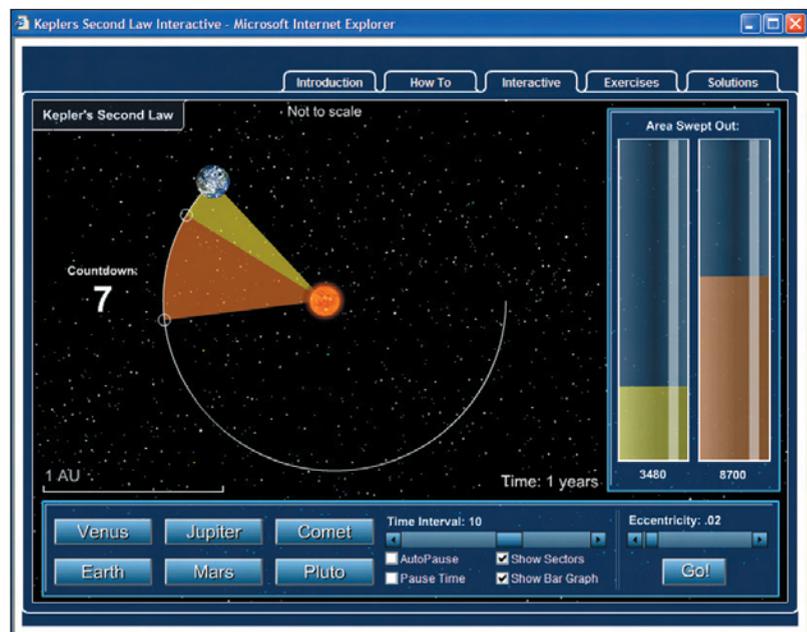
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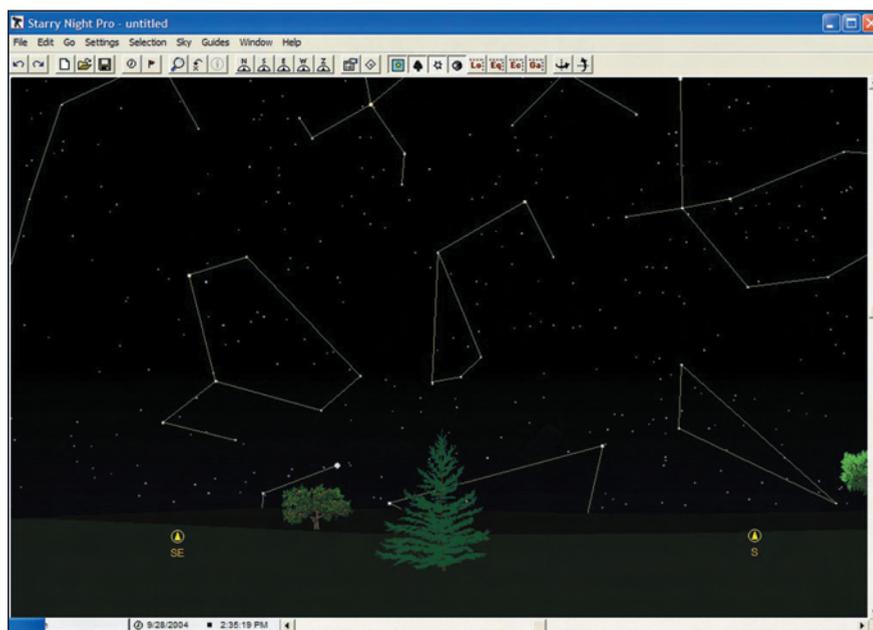
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**William A. Hollerman** University of Louisiana at Lafayette  
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## Reviewers of Previous Editions

The following astronomers and physicists reviewed previous editions of the book. Their comments and advice greatly improved the readability, accuracy, and currency of the book.

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