The Cosmos

Astronomy in the New Millennium

FIFTH EDITION

The Fifth Edition of *The Cosmos: Astronomy in the New Millennium* provides you with the fundamentals of astronomical knowledge that have been built up over decades, with an expanded discussion of the incredible advances that are now taking place in this fast-paced field, such as New Horizons' flyby of Pluto, exoplanets, "dark matter," and the direct detection of gravitational waves by LIGO.

Written in a clear and easily understandable style, this textbook has been thoroughly revised to include (among other things) updated data and figures, new images from recent space missions and telescopes, the latest discoveries on supernovae, and new observations of the region around the four-million-solar-mass black hole at the center of our Milky Way Galaxy.

Jay M. Pasachoff, Field Memorial Professor of Astronomy at Williams College, teaches the astronomy survey course. He is also Director of the Hopkins Observatory there. He received his undergraduate and graduate degrees from Harvard and then had postdoctoral fellowships at the Harvard College Observatory and the California Institute of Technology, where he has also had recent sabbatical leaves. He now has a visiting appointment at the Carnegie Observatories.

He has observed 70 solar eclipses. He also studies occultations of stars by Pluto and other objects in the outer Solar System.

Pasachoff is Chair of the Working Group on Eclipses of the International Astronomical Union and was Chair of the American Astronomical Society's Historical Astronomy Division. He is also co-editor of *Teaching and Learning Astronomy* (2005) and *Innovation in Astronomy Education* (2008).

He received the American Astronomical Society's Education Prize (2003); the Janssen Prize from the Société Astronomique de France (2012); and the Richtmyer Memorial Lecture Award, American Association of Physics Teachers (2017). Asteroid (5100) Pasachoff is named after him.

Alex Filippenko is a Professor of Astronomy, and the Richard & Rhoda Goldman Distinguished Professor in the Physical Sciences, at the University of California, Berkeley. He received his undergraduate degree from the University of California, Santa Barbara (1979) and his doctorate from the California Institute of Technology (1984).

His primary areas of research are exploding stars, gamma-ray bursts, active galaxies, black holes, and observational cosmology. Filippenko was the only person to have been a member of both teams that revealed the Nobel-worthy accelerating expansion of the Universe. He is one of the world's most highly cited astronomers and was elected to the National Academy of Sciences (2009).

Filippenko has won many prestigious teaching awards, including the Carnegie/CASE National Professor of the Year among doctoral institutions (2006). He has appeared frequently on science newscasts and television documentaries, especially The Universe series. He received the Carl Sagan Prize for Science Popularization (2004). He enjoys world travel and observing total solar eclipses (16, all successfully).

Cambridge University Press & Assessment
978-1-108-43138-5 — The Cosmos: Astronomy in the New Millennium 5th Edition
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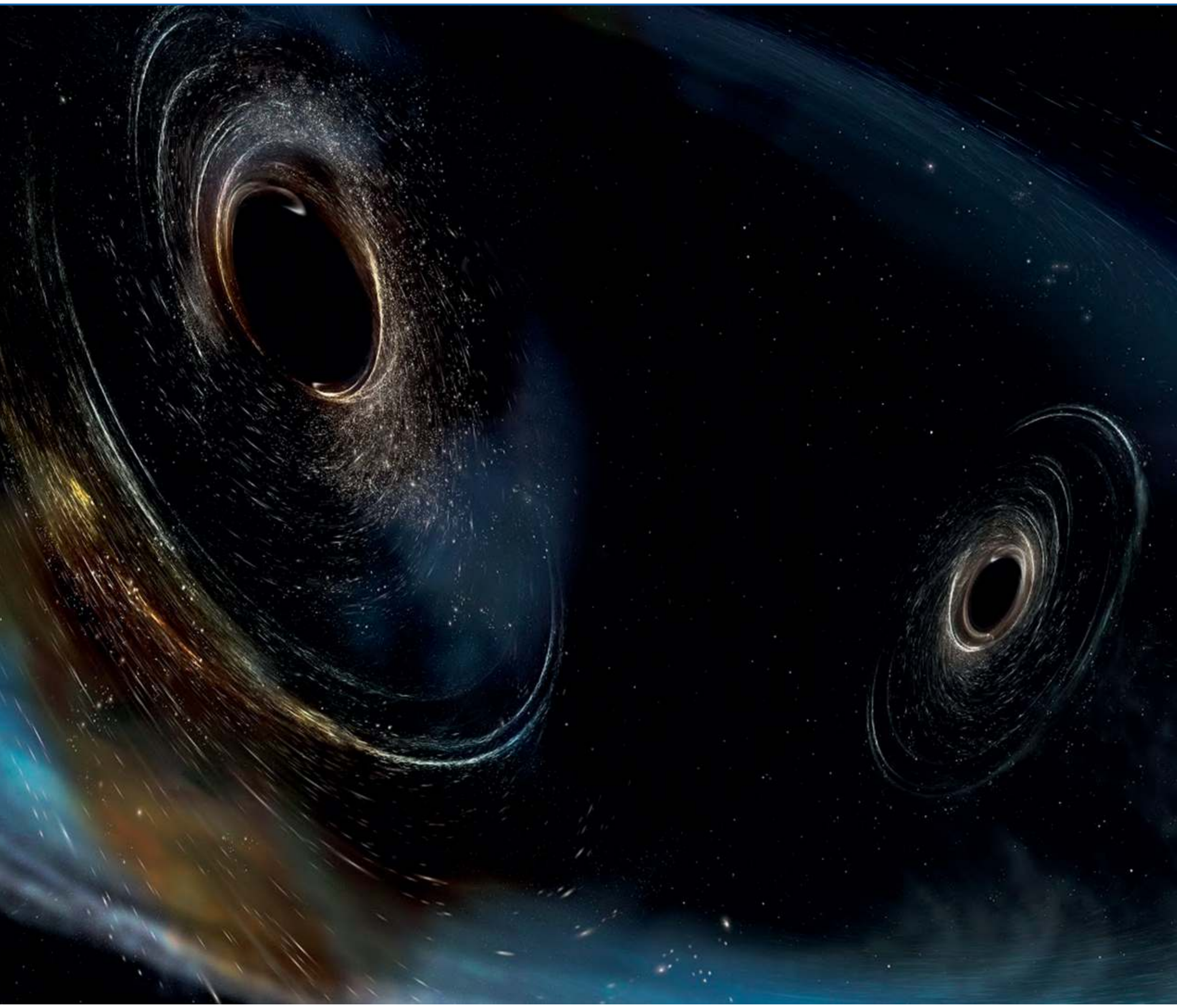

An artist's conception of two black holes, GW170104, as they merged, similar to the ones detected by the Laser Interferometer Gravitational-wave Observatory (LIGO).
Credit: LIGO/Caltech/MIT/Sonoma State (Aurore Simonnet)

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Shaftesbury Road, Cambridge CB2 8EA, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre, New Delhi – 110025, India

103 Penang Road, #05–06/07, Visioncrest Commercial, Singapore 238467

Cambridge University Press is part of Cambridge University Press & Assessment, a department of the University of Cambridge.

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www.cambridge.org
Information on this title: www.cambridge.org/9781108431385

Fourth edition published in 2013. The previous edition (*The Cosmos, 3rd Edition*) was published in 2007 by Brooks/Cole Cengage.

A catalogue record for this publication is available from the British Library

ISBN 978-1-108-43138-5 Paperback

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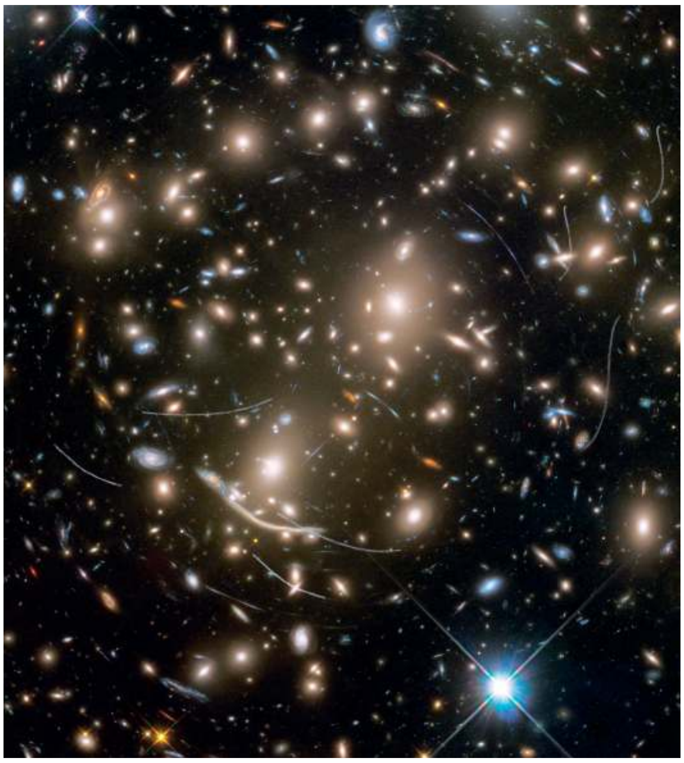
Credit: NASA, ESA, and B. Sunnquist and J. Mack (STScI). Acknowledgment: NASA, ESA, and J. Lotz (STScI) and the HFF Team

Asteroid trails, curved because of parallax across an image of a cluster of galaxies in Hubble Frontier Field Abell 370.

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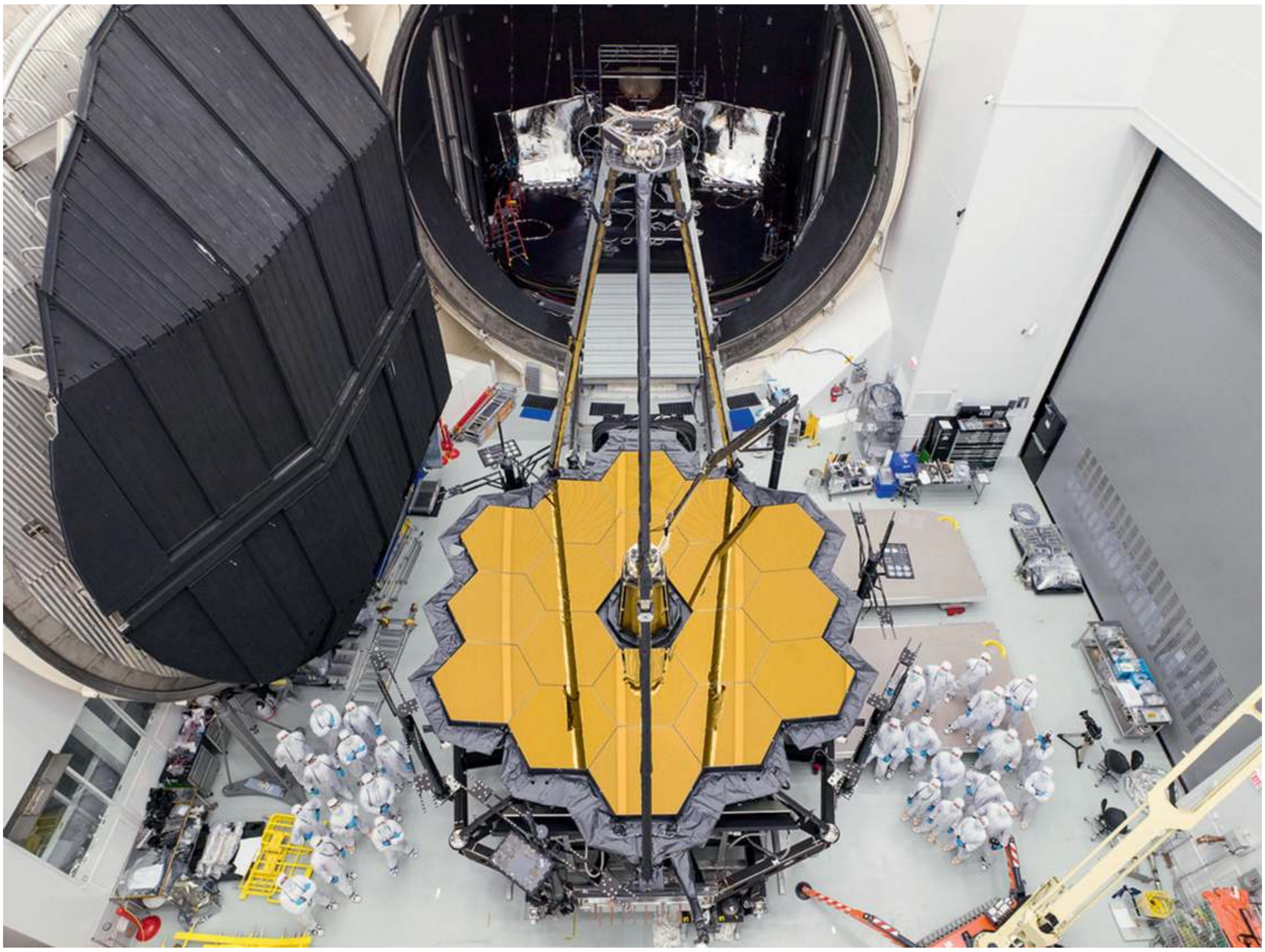
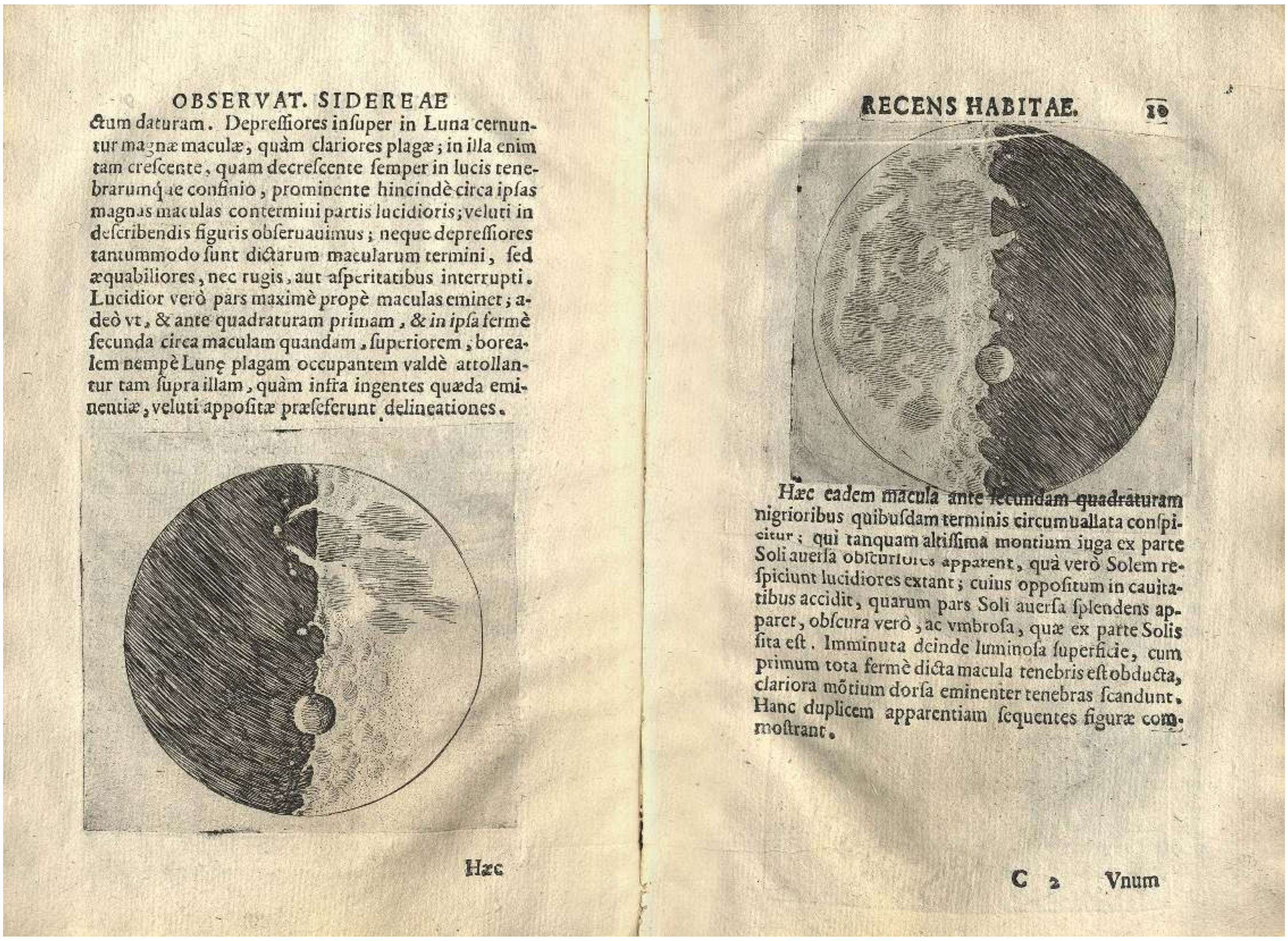


Credit: NASA

The James Webb Space Telescope being tested.

Credit: Jay M. Pasachoff and the Chapin Library, Williams College


OBSERVAT. SIDEREAE

ctum daturam. Depressiores insuper in Luna cernuntur magnæ maculæ, quàm clariores plagæ; in illa enim tam crescente, quam decrescente semper in lucis tenebrarumque confinio, prominente hincindè circa ipsas magnas maculas contermini partis lucidioris; veluti in describendis figuris obseruauimus; neque depressiores tantummodo sunt dictarum macularum termini, sed æquabiliores, nec rugis, aut asperitatibus interrupti. Lucidior verò pars maximè propè maculas eminet; adeò vt, & ante quadraturam primam, & in ipsa fermè secunda circa maculam quandam, superiorem, borealem nempè Lunę plagam occupantem valdè attollantur tam supra illam, quàm infra ingentes quæda eminentiæ, veluti appositæ præseferunt delineationes.

Hæc

RECENS HABITAE. 19

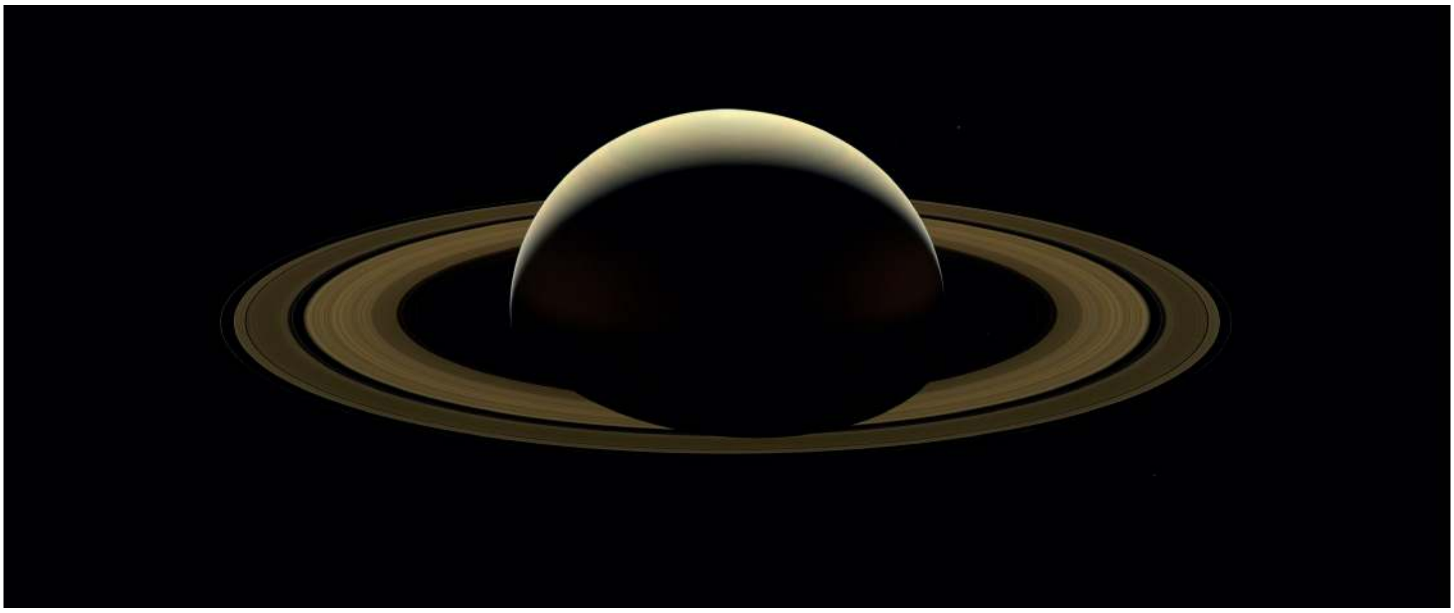
Hæc eadem macula ante secundam quadraturam nigrioribus quibusdam terminis circumuallata conspicitur; qui tanquam altissima montium iuga ex parte Soli auersa obscuriores apparent, quà verò Solem respiciunt lucidiores extant; cuius oppositum in cauitatibus accidit, quarum pars Soli auersa splendens apparet, obscura verò, ac vmbrosa, quæ ex parte Solis sita est. Imminuta deinde luminosa superficie, cum primum tota fermè dicta macula tenebris est obducta, clariora mõtium dorsa eminenter tenebras scandunt. Hanc duplicem apparentiam sequentes figuræ commostrant.

C 2 Vnum

A double page from Galileo's *Sidereus Nuncius* (1610) showing his engravings of the face of the Moon as seen through his newfangled telescope.

Credit: Jay M. Pasachoff

Mae Jemison and Sally Ride, NASA astronauts, in a 2017 LEGO™ set, in front of a Space Shuttle.



Credit: NASA/JPL-Caltech/Space Science Institute

NASA's Cassini mission farewell image of Saturn and its rings. The image is the last full mosaic taken two days before the spacecraft plunged into Saturn.

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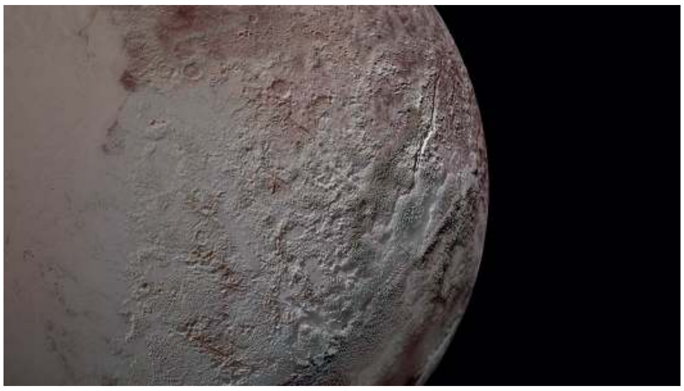
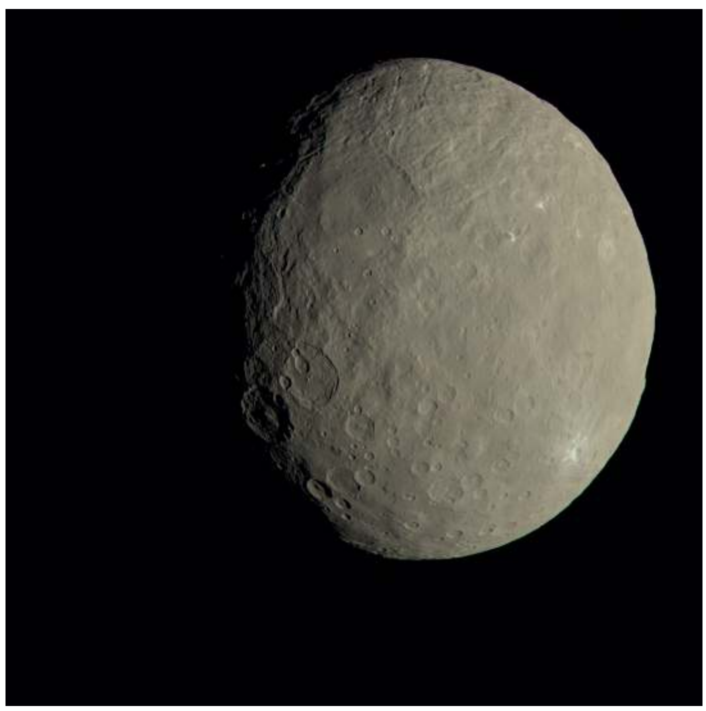


Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Terrain on Pluto, a close-up from NASA's New Horizons.

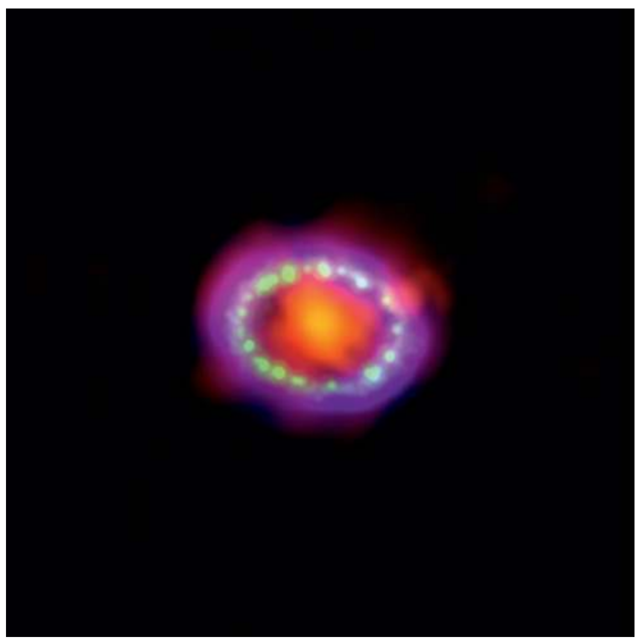


Credit: NASA/JPL-Caltech/UCLA/MPS/DLR/IDA

Asteroid and dwarf planet 1 Ceres, imaged from NASA's Dawn spacecraft that is orbiting it.

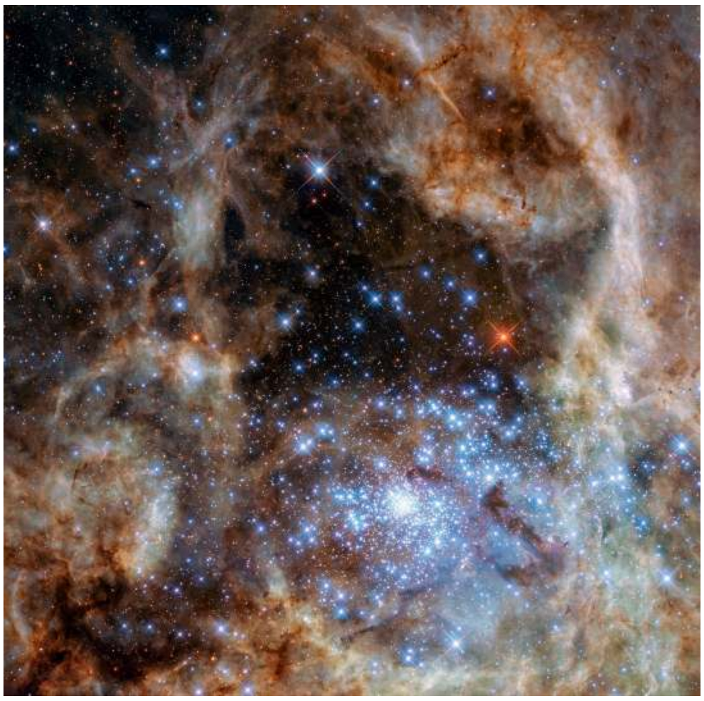
Credit: NASA, ESA, and K. Sahu (STScI)

A white-dwarf star, Stein 2051 B, only 17 light-years from Earth, seen with the Hubble Space Telescope, with a more distant star appearing below it. The white dwarf passed in front of the other star, providing a successful test of Einstein's general theory of relativity.



Credit: NASA, ESA, and A. Angelich (NRAO/AUI/NSF)
Hubble credit: NASA, ESA, and R. Kirshner (Harvard-Smithsonian Center for Astrophysics and Gordon and Betty Moore Foundation)
Chandra credit: NASA/CXC/Penn State/K. Frank et al.
ALMA credit: ALMA (ESO/NAOJ/NRAO) and R. Indebetouw (NRAO/AUI/NSF)

A multiwavelength view of Supernova 1987A, with green showing Hubble views of how the expanding shock wave from the star that exploded is colliding with material ejected previously, and the red showing dust imaged with the ALMA millimeter/submillimeter array. Blue is hot gas imaged with the Chandra X-ray Observatory.



Credit: NASA, ESA, and P. Crowther (University of Sheffield)

Star cluster R136 in the Tarantula Nebula in the Large Magellanic Cloud, imaged with Hubble.

Credit: NASA, ESA, and the Hubble Heritage Team (STScI/AURA)

The Bubble Nebula, NGC 7635, gas expanding around a massive star. The object is 7 light-years across, and is imaged here with Hubble.

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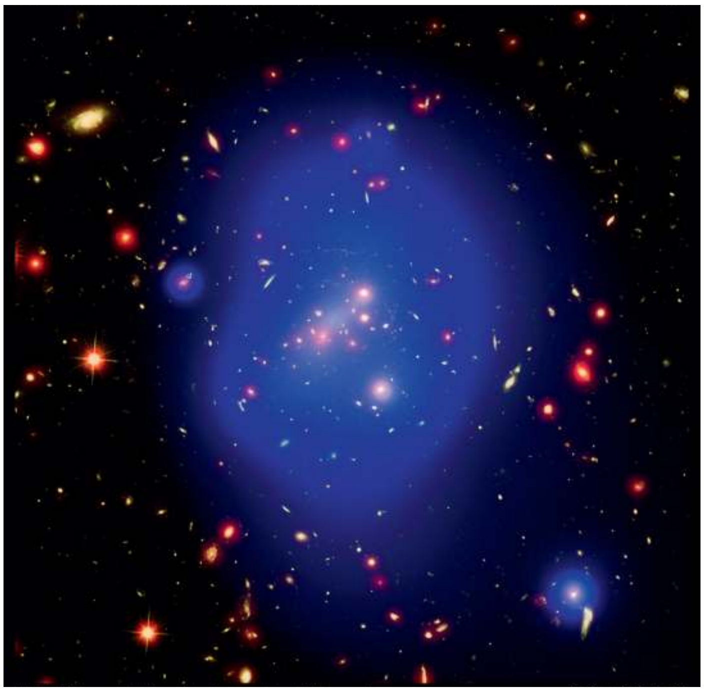
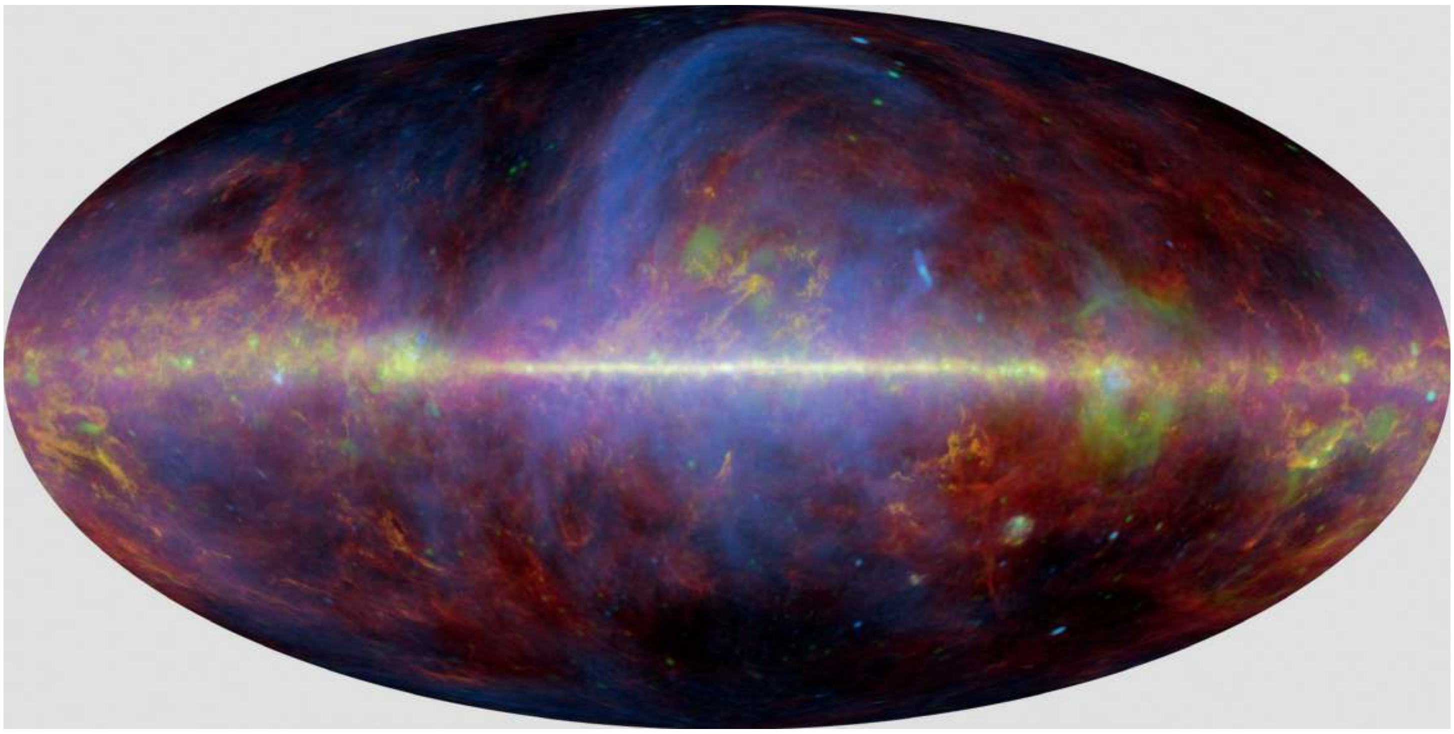
Credit: NASA, ESA, and M. Mutchler (STScI)

A pair of spiral galaxies, NGC 4302 and 4298, both about 55 million light-years away and imaged with the Hubble Space Telescope.



Credit: NASA, ESA, and M. Brodwin (University of Missouri)

A cluster of galaxies 10 billion light-years from Earth, with 500 trillion times the mass of our Sun. Hot gas in the middle, imaged with the Chandra X-ray Observatory, shows as blue-white overlaying Hubble's visible-light image in green and the Spitzer Space Telescope's image in red.



Credit: European Space Agency/Planck Consortium

An all-sky map made with the European Space Agency's Planck spacecraft, which was also used to map the cosmic background radiation. The image is a composite of magnetic-field, atomic "free-free," dust, and carbon-monoxide components.

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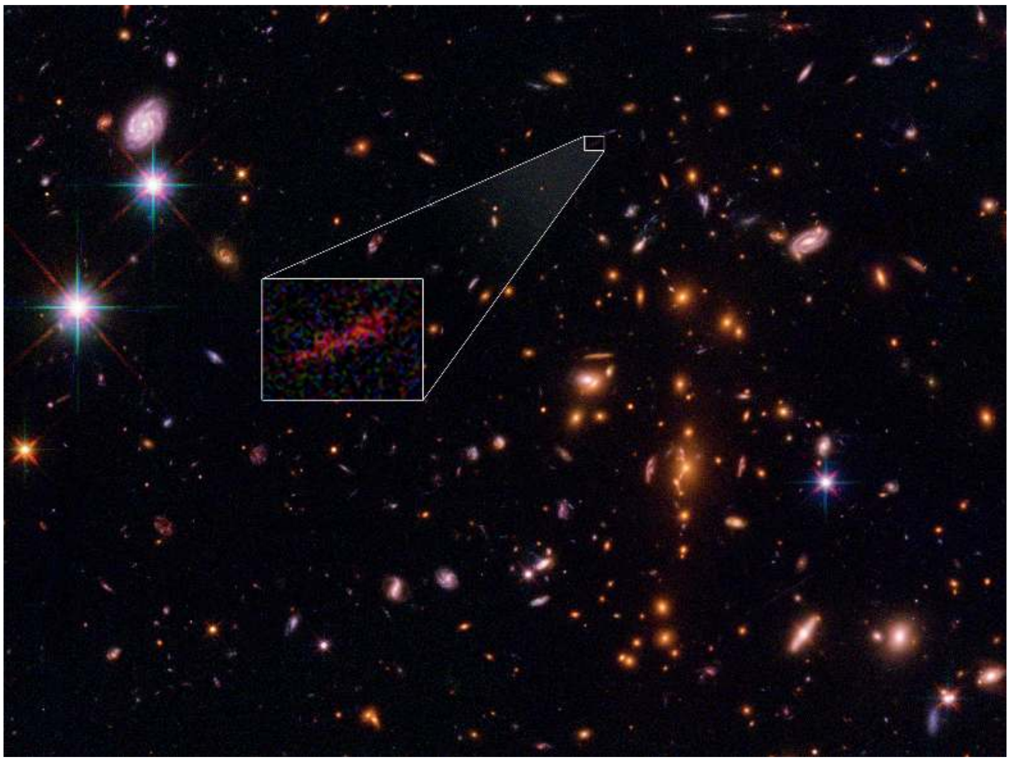
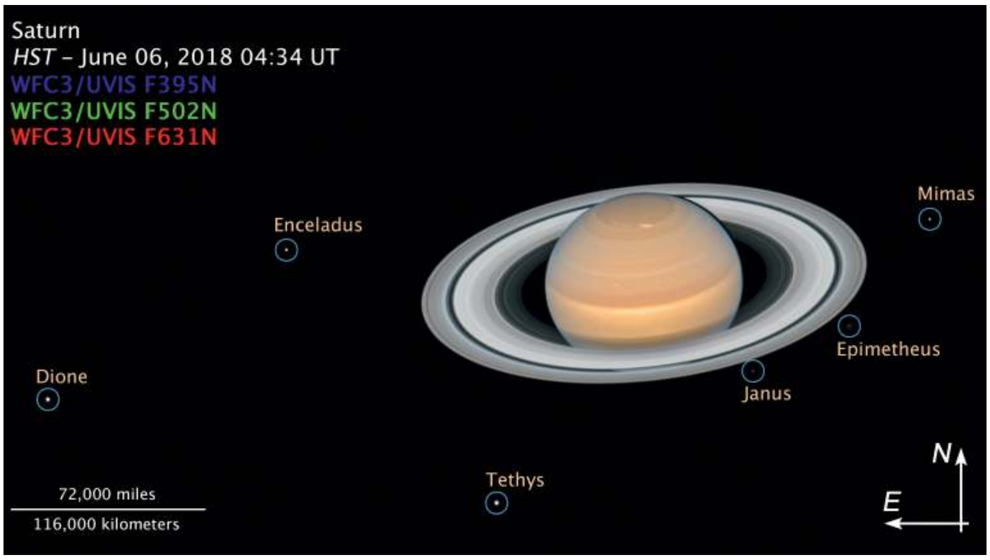


NASA , ESA, and B. Salmon (STScI)

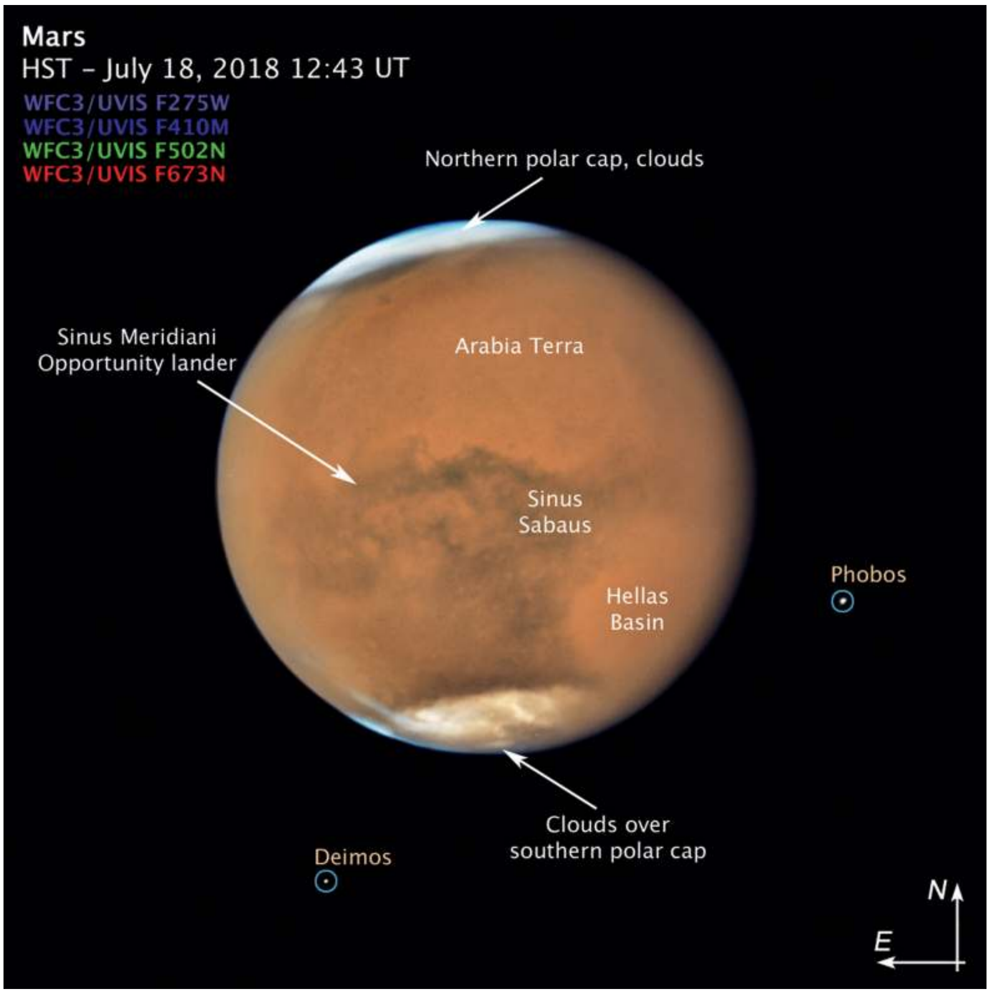
A gravitationally lensed embryonic galaxy, only half a billion years after the big bang. It is only 1% the mass of our Milky Way Galaxy, and is revealing an early stage of galaxy formation. The lensing smeared it into an arc; other galaxies about that far away and far back in time appear only as reddish dots. The image was taken with the Hubble Space Telescope.

Credit: Jay M. Pasachoff

A balloon alien, as yet unknown in reality.



NASA, ESA, and STScI

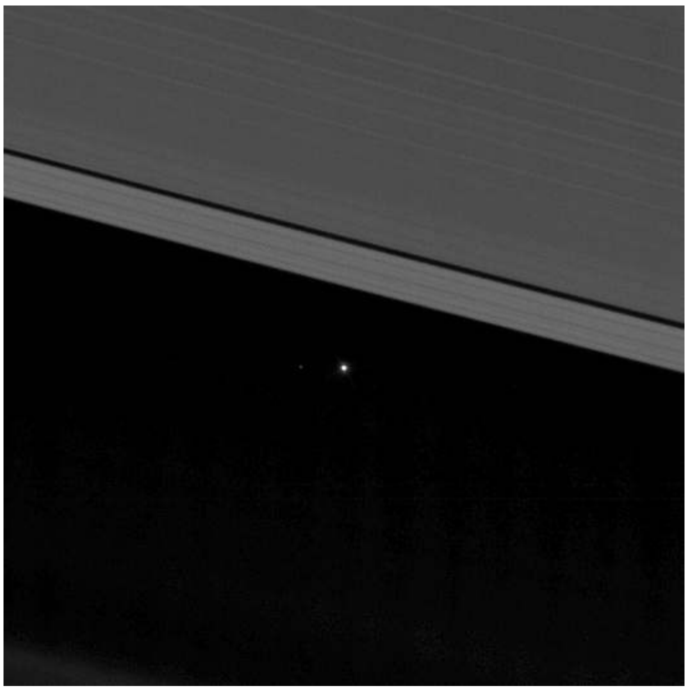


NASA, ESA, and STScI

Saturn and Mars at their closest places to Earth as they orbit, the oppositions of 2018, imaged with the Hubble Space Telescope. Saturn's northern-hemisphere summer triggered a large storm, seen here as it disintegrates near Saturn's north pole. Mars's southern-hemisphere spring triggered a huge dust storm that eventually covered the whole planet.

Preface

Astronomy continues to flourish, with huge discoveries such as the one that pairs of giant black holes merge, sending ripples through space-time – so-called gravitational waves – that we can pick up on Earth. Even the merger of a pair of neutron stars has been detected not only from the gravitational waves – let's say by ear, given the "chirp" of detection – but also with ordinary telescopes, the eyes of the Universe. So, as of 2018, we have the eyes and the ears of the Universe working together.



NASA/JPL-Caltech/Space Science Institute

The dot between two of Saturn's rings is Earth, our planet. NASA's Cassini spacecraft orbited in the Saturn system through 2017, when it was directed to plunge into Saturn's atmosphere to safely destroy it without risking contaminating any of Saturn's moons with terrestrial life-forms.

The Universe's expansion – which was long thought to be slowing down – is, astonishingly, accelerating, presumably as a consequence of mysterious "dark energy." We have discovered thousands of planets around other stars – other solar systems abound! A generation of large optical telescopes has been built on mountaintops, and arrays of dozens of radio telescopes such as the Atacama Large Millimeter/submillimeter Array (ALMA) at an extremely high-altitude site explore their part of the spectrum at high resolution. Still larger telescopes are being planned or built, including the Thirty Meter Telescope, the Giant Magellan Telescope, and the European Extremely Large Telescope, all for optical and near-infrared studies, and the Daniel K. Inouye Solar Telescope in Hawaii for detailed studies of the Sun. The Hubble Space Telescope, with its latest updated set of cameras, sends down exciting data all the time, and we anticipate the launch in 2021 of the James Webb Space Telescope with its mirror much larger than Hubble's. The latest space observatories transmit images made with gamma rays, with x-rays, and with infrared radiation. The overall structure of the Universe is being mapped and analyzed, with catalogues of millions of objects being compiled. Cosmology has become an observationally rich science.

In Solar System studies, NASA's Curiosity rover triumphantly travels around Mars, bearing instruments to investigate Mars's past habitability. The Cassini spacecraft that orbited Saturn for 13 years plunged into its surface in 2017, to protect Saturn's moons from being contaminated with terrestrial microbes. Spacecraft recently orbited the asteroid and dwarf planet Ceres and a comet. Another spacecraft flew right by Pluto and its moons and is now en route to a tiny object beyond them. Moreover, new electronic instruments and computer capabilities, new space missions to Solar-System objects, and advances in computational astronomy and in theoretical work will continue to bring forth exciting results.

In this latest edition of *The Cosmos: Astronomy in the New Millennium*, we describe the current state of astronomy, both the fundamentals of astronomical knowledge that have been built up over decades and the incredible advances that are now taking place. We want simply to share with students the excitement and magnificence of the Universe.

We try to cover all branches of astronomy without slighting any of them; each teacher and each student may well find special interests that are different from our own. One of our aims in writing this book is to educate citizens in the hope that they will understand the value and methods of scientific research in general and astronomical research in particular.

In writing this book, we share the goals of a commission of the Association of American Colleges, whose report on the college curriculum stated:

> A person who understands what science is recognizes that scientific concepts are created by acts of human intelligence and imagination; comprehends the distinction between observation and inference and between the occasional role of accidental discovery in scientific investigation and the deliberate strategy of forming and testing hypotheses; understands how theories are formed, tested, validated, and accorded provisional acceptance; and discriminates between conclusions that rest on unverified assertion and those that are developed from the application of scientific reasoning.

The scientific method permeates the book.

What is science? The following statement was originally drafted by the Panel on Public Affairs of the American Physical Society, in an attempt to meet the perceived need for a very short statement that would differentiate science from pseudoscience. This statement has been endorsed as a proposal to other scientific societies by the Council of the American Physical Society, and was endorsed by the Executive Board of the American Association of Physics Teachers:

> Science is the systematic enterprise of gathering knowledge about the world and organizing and condensing that knowledge into testable laws and theories. The success and credibility of science is anchored in the willingness of scientists to:
>
> Expose their ideas and results to independent testing and replication by other scientists; this requires the complete and open exchange of data, procedures, and materials;
>
> Abandon or modify accepted conclusions when confronted with more complete or reliable experimental evidence. Adherence to these principles provides a mechanism for self-correction that is the foundation of the credibility of science.

Our book, through the methods it describes, should reveal this systematic enterprise of science to the readers.

Because one cannot adequately cover the whole Universe in a few months, or even a year, we have had to pick and choose topics from within the various branches of astronomy, while trying to describe a wide range, to convey the spirit of contemporary astronomy and of the scientists working in it. Our mix includes much basic astronomy and many of the exciting topics now at the forefront.

Two examples are the currently hottest topics in astronomy: the discovery of thousands of planets around other stars (so-called exoplanets) and the discovery of gravitational waves from merging black holes and neutron stars. Our exoplanet coverage brings the discoveries and the new techniques and spacecraft being used up to 2018, with a graph of the Kepler spacecraft's discoveries, mention of the K2 version of the spacecraft including an image with its fields of view overlain, and a discussion of new instruments, such as NASA's Transiting Exoplanet Survey Satellite (TESS), launched in 2018.

For the fantastic discovery of gravitational waves from collisions of black holes over a billion light-years away, which was honored with the 2017 Nobel Prize in Physics, we have expanded our previous coverage of the Laser Interferometer Gravitational-wave Observatory (LIGO). We include the latest update to the graph of spiraling neutron stars that led to an indirect verification of the existence of gravitational waves, which was recognized with the 1993 Nobel Prize in Physics. Moreover, we discuss LIGO's August 2017 detection of two such neutron stars merging, and the result not only of the gravitational waves themselves but also of concomitant gamma rays, visible light, and other forms of electromagnetic waves.

For the 2017 total solar eclipse whose path crossed the United States, we have the latest imaging and a discussion of why such observations were scientifically important.

Anyone choosing an astronomy textbook should consider the following:

- Readability. Our prose is extremely clear and readable.
- Scientific accuracy. Our book is written by experts in the field and has the various chapters checked by other experts.
- Up to date. Our book has sunspot numbers up to date to show the current phase of the sunspot cycle; exoplanet lists and diagrams up to the current situation; the latest on the Cassini mission to Saturn and to Curiosity roaming around on Mars; images of the corona at the 2017 total solar eclipse; a discussion of the Hubble constant and the expansion of the Universe, with slightly different values coming from an overall measurement of the cosmic background radiation from the Planck spacecraft compared with the latest values of the Universe's expansion and acceleration from supernova observations; and more.
- Features like *A Closer Look, Figure It Out*, and *Star Party* that help this book be useful for astronomy survey courses of one semester or of those that spread the material out over two or more semesters.

NEW IN THIS EDITION

- Updated data (such as sunspot numbers showing the current minimum of the sunspot cycle) and figures throughout the text, as well as new images from recent space missions (such as the Cassini mission to Saturn as well as Curiosity roaming around on Mars) and ground-based telescopes (such as images of the corona at the 2017 total solar eclipse).
- Expanded discussions of the hottest current topics, such as New Horizons' flyby of Pluto (Chapter 8), the latest on exoplanets (Chapter 9) and dark matter (Chapter 18), and the direct detection of gravitational waves by LIGO (Chapter 14).
- The latest discoveries on supernovae, including pictures of the first known strongly gravitationally lensed supernova (showing five separate images of that supernova).
- New observations of the 4-million-solar-mass black hole at the center of our Milky Way Galaxy.
- The latest progress on precision measurement of the Hubble constant for the expansion of the Universe.
- Additional end-of-chapter questions and updated summaries and glossary.

ORGANIZATION

The fifth edition of *The Cosmos: Astronomy in the New Millennium* is generally organized in an Earth-outward approach. Chapter 1 gives an overview of the Universe. Chapter 2 presents fundamental astronomical concepts about light, matter, and energy, while Chapter 3 summarizes the various types of telescopes used to explore the electromagnetic spectrum. In Chapter 4, we discuss easily observed astronomical phenomena and the celestial sphere. Some professors prefer to cover that material at the very beginning of the course or at other points, and there is no problem with doing so.

Chapter 5 examines the early history of the study of astronomy. Chapters 6 through 8 cover the Solar System and its occupants, although a thorough discussion of the Sun is reserved for later, in Chapter 10. Chapter 6 compares Earth to the Moon and Earth's nearest planetary neighbors, Venus and Mars. Based largely on the Voyager, Galileo, and Cassini data, Chapter 7 compares and contrasts the Jovian gas/liquid giants – Jupiter, Saturn, Uranus, and Neptune. Chapter 8 looks at the outermost part of the Solar System, including Pluto and its moon, Charon, as well as other Kuiper-belt objects still farther out; the chapter also spotlights comets and meteoroids, the Solar System's vagabonds. Chapter 9 discusses the formation of our own Solar System and describes the exciting discovery of thousands of exoplanets and exoplanet candidates around other stars.

Chapter 10 concentrates on the Sun, our nearest star, exploring its various components and the solar activity cycle. Moving outward, Chapters 11 through 14 examine all aspects of stars. Chapter 11 begins by presenting observational traits of stars – their colors and types – and goes on to show how we measure their distances, brightnesses, and motions. It also discusses binary stars, variable stars, and star clusters, in the process showing how we derive stellar masses and ages. Chapter 12 answers the question of how stars shine and reveals that all stars have life cycles. Chapter 13 tells what happens when stars die and describes some of the peculiar objects that violent stellar death can create, including neutron stars and pulsars. Black holes, the most bizarre objects to result from star death, are the focus of Chapter 14. We end the chapter by describing how the Laser Interferometer Gravitational-wave Observatory (LIGO) detected, several times, the tiniest possible variation in the length of a light beam, with the waves interpreted as coming from the merger of two black holes each containing 10–30 times as much mass as the Sun. And in August 2017, LIGO even detected the merger of two neutron stars simultaneously with telescopes around the world and in space seeing the event in ordinary, electromagnetic radiation. We are in the era of "Multi-Messenger Astronomy," as NASA has recently put it: "photons, gravitational waves, and particle astrophysics."

As we explore further, Chapter 15 describes the parts of the Milky Way Galaxy and our place in it. Chapter 16 pushes beyond the Milky Way to discuss galaxies in general, the fundamental units of the Universe, and evidence that they consist largely of dark matter. Ways in which we are studying the evolution of galaxies are also described. Chapter 17 looks at quasars, distant and powerful objects that shine because gigantic black holes are swallowing gas in the central regions of galaxies.

Chapters 18 and 19 consider the ultimate questions of cosmological creation by analyzing recent findings and current theories. Evidence that the expansion of the Universe is currently speeding up with time (probably propelled by a mysterious "dark energy"), possibilities for the overall geometry and fate of the Universe, ripples in the cosmic background radiation, the origin and early exponential growth of the Universe, and the idea of multiple universes are among the fascinating (and sometimes very speculative) topics explored. Lastly, Chapter 20 discusses the always-intriguing search for extraterrestrial intelligence.

FEATURES

The Cosmos: Astronomy in the New Millennium offers instructors a concise overview of a wide range of astronomical topics. An early discussion of the scientific method stresses its importance in the verification of observations. The text presents up-to-date coverage of many important findings and theories as well as the latest images, including observations of Jupiter and Saturn from the Cassini–Huygens mission (including the landing on Titan), close-up observations of Mars, images of stars in formation and of gas near them from the largest telescopes in space, and coverage of recent total solar eclipses and of the pair of transits of Venus – the like of which will not be seen on Earth until the year 2117, in the twenty-second century.

We provide, as well, a sampling of the many significant findings from the Hubble Space Telescope. Numerous images from the Chandra X-ray Observatory, the Spitzer Space Telescope, the Planck spacecraft that studied the cosmic background radiation, and the Gaia spacecraft that is mapping a billion of the nearest stars, also appear, as do results from the Swift spacecraft that is monitoring gamma-ray bursts, among the most powerful and violent phenomena in the Universe (the origin of one type of which is now proven by observations of the merging neutron stars). Of particular interest is the recent advance in our understanding of the age and expansion of the Universe, both through better measurements of the current expansion rate and through the discovery that the Universe's expansion is now speeding up with time. We also present the recent exciting measurements that allow astronomers to determine the overall geometry of the Universe and the early appearance of large-scale structure through detailed observations of the cosmic background radiation.

PEDAGOGY

1. **Chapter opener**. Each chapter includes the following features:
   - Origins. NASA has chosen Origins as one of its major themes for the organization of its missions and has several spacecraft in the Origins program. Inspired by this choice, each chapter piques the reader's interest with some of the discoveries, tools, and theories behind our effort to understand the Universe and its relationship to us.
   - Chapter introduction, summarizing the main topics discussed in each chapter and how these fit into the rest of the book.
   - Aims, setting out what students should expect to learn from the material that follows.
2. **Star Parties**. An occasional feature that shows students how to find things in the sky. These include observing exercises and links to the star maps that appear on the inside covers of the book. For example, *Star Party 5.1* explains how to sketch the position of Mars or Jupiter in relation to the stars near them, repeating this exercise every 6–9 days over the course of 2–3 months. Students examine their results to see the planets in their prograde and retrograde motions, which are important to understand in order to

properly comprehend the work of Copernicus and how it superseded the model of Ptolemy.

3. **Figure It Out**. In some astronomy courses, it may be appropriate to elaborate on equations. Because we wrote *The Cosmos: Astronomy in the New Millennium* to be a descriptive presentation of modern astronomy for liberal-arts students, we kept the use of mathematics to a minimum. However, we recognize that some instructors wish to introduce their students to more of the mathematics associated with astronomical phenomena. Consequently, we provide mathematical features, numbered so they can be assigned or not, at the instructor's option. *Figure It Out* 5.1, for example, gives a mathematical treatment of Kepler's third law that can be included in a course in a way that is easy to mark on a syllabus; similarly, *Figure It Out* 5.2 gives professors the option of introducing Newton's formulation of Kepler's third law to find masses.
4. **Lives in Science**. These boxes provide biographies of important historical figures like 5.1 Copernicus, 5.2 Tycho, 5.3 Kepler, 5.4 Galileo, and 5.5 Newton. *Lives in Science* 10.1 discusses Albert Einstein.
5. **A Closer Look**. Using these boxes, students can further explore interesting topics, such as size scales in the Universe, observing with large telescopes, various celestial phenomena, mythology, and naming systems. For example, we are pleased to supply some exciting new close-up views of Mars from NASA's Curiosity rover that is now on its surface in *A Closer Look* 6.5, whereas in *A Closer Look* 5.1 we specifically define the main features of the Ptolemaic system: deferent, epicycle, and equant.
6. **Key words and glossary**. New vocabulary is boldfaced in the text and in the expanded summaries that are given at the end of each chapter, and defined in the glossary.
7. **Chapter summary.** Each chapter includes the following features:
   - Concept Review, summarizing the main topics discussed.
   - Questions. An expanded set of end-of-chapter questions covers a range of material and includes some that are straightforward to answer from the text and others that require more thought.
   - Topics for Discussion. A list of themes and questions aimed at engaging students in deeper explorations of the material discussed in each chapter.
8. **Appendices for additional coverage**. Appendices at the end of the book provide additional information on planets, stars, constellations, and nonstellar objects.
9. **Sky Maps**. Inside the covers of the book, students will find the exceptionally beautiful sky maps by Wil Tirion to help them find their way around the sky when they go outside to observe the stars.

ONLINE RESOURCES

Adopters of *The Cosmos*, 5th edition, can access a rich array of teaching and learning resources at http://thecosmos5.com. The website (together with the authors' personal website http://www.solarcorona.net) is regularly updated to include the latest discoveries and photographs from various sources. It features the following:

- Multiple-choice self-tests and other useful information such as lists of typographical errors, updates to various new scientific discoveries since the publication of the textbook, and links to websites such as those with new discoveries as yet unknown at the time of this printing.
- "Misconceptions." Recent educational research has shown that students often need to unlearn incorrect ideas in order to understand the correct ones. A list of these misconceptions – as well as the correct alternatives – is available on our website.
- Links to relevant websites on a wide variety of astronomical material, such as http://photojournal.jpl.nasa.gov for planetary images; http://sidc.oma.be/silso for the latest sunspot cycle plots; http://spaceweather.com for the latest on daily sunspots or auroras; and http://hubblesite.org for a wide range of new Hubble Space Telescope observations.
- People in Astronomy. A series of interviews presenting a famous contemporary astronomer engaged in conversation about a variety of topics, such as: current and future work in astronomy, what led that person to study and pursue astronomy as a career, and why learning about astronomy is an important scientific and human endeavor. We interviewed a diverse set of astronomers – diverse both personally and in astronomical field of study. We discussed Saturn with Carolyn Porco, the head of the Saturn imaging team on the Cassini spacecraft; brown dwarfs and exoplanet astronomy with Gibor Basri and how he got interested in astronomy; space astronomy with Jeff Hoffman, a former astronaut who helped upgrade the Hubble Space Telescope in orbit; and Sandra Faber about galaxies. We hope that students enjoy reading their comments as much as we enjoyed speaking with them and learning about their varied interests and backgrounds.

STAR CHARTS

Pasachoff's *Peterson Field Guide to the Stars and Planets* is a suggested accompaniment for those wanting monthly star maps, star charts, and other detailed observing aids; see http://www.solarcorona.com. Quarterly star maps, improved and redrawn for us for *The Cosmos: Astronomy for the New Millennium* by the foremost celestial cartographer, Wil Tirion of The Netherlands, appear on the inside covers in *The Cosmo*s, 5th edition.

ACKNOWLEDGMENTS

The publishers join us in placing a heavy premium on accuracy, and we have made certain that the manuscript and past editions have been carefully read and considered. As a result, students will find that the statements in this book, brief as they are, are authoritative.

This fifth edition of *The Cosmos* benefited from new and updated photographs and comments on text from Seth Shostak (SETI Institute)

on SETI, Daniel Wertheimer (University of California, Berkeley) on SETI, Lynn Cominsky (Sonoma State University) on gamma-ray astronomy, Leon Golub (Harvard-Smithsonian Center for Astrophysics) on heliophysics, Joel Weisberg (Carleton College) on gravitational waves from the double pulsar, Richard Manchester (CSIRO, Australia) on pulsars, Rosemary Killen (NASA's Goddard Space Flight Center) and Carl Schmidt (University of Virginia) on Mercury, Augustin Sanchez Lavega (Valencia) on the winds of Jupiter and Saturn, Laura Brenneman (Harvard-Smithsonian Center for Astrophysics) on future x-ray missions, Alan Guth (MIT) and Adrienne Erickcek (University of North Carolina) on the inflationary universe, and Eric Nash (NASA's Goddard Space Flight Center) on the ozone hole. We also thank William Graham for useful comments. The fourth edition of The Cosmos benefited from the advice and special images provided by Lynn Cominsky (Sonoma State University), Leon Golub (Harvard-Smithsonian Center for Astrophysics), Joel Weisberg (Carleton College), Daniel Seaton (Royal Observatory of Belgium), John Johnson (Harvard-Smithsonian Center for Astrophysics), Robert Simmon (NASA's Goddard Space Flight Center), Richard McCray (University of Colorado), Richard Manchester (CSIRO, Australia), Daniel Stern (Jet Propulsion Laboratory), Daniel Mortlock (Imperial College, London), Matthew Templeton and Arne Hernden (AAVSO), Stefan Fichtel (Ixtract), Federica Bianco (Las Cumbres Observatory Global Telescope Network and the University of California, Santa Barbara), Gareth Williams (Harvard-Smithsonian Center for Astrophysics), Lorne McKee (National Resources Canada), Jens Vellev (Aarhus University), Gerard van Belle (Lowell Observatory), Geoff Marcy (University of California, Berkeley), Wayne Hammond (Chapin Library of Williams College), and Axel Mellinger (Central Michigan University).

At the time of proof for the fifth edition, we benefitted from additional consultations with Gerald Williger (U. Louisville; currently a Fulbright Scholar at Konkoly Observatory) on the full set of chapters; Mark Showalter (SETI Institute), Jupiter's moons; Carolyn Porco (Southwest Research Institute), Cassini/Saturn; Imke de Pater (U. California, Berkeley), outer planets; Lindy Elkins-Tanton (Arizona State U.), lunar minerals and water; Beatriz Garcia (Pierre Auger Observatory, Argentina), cosmic rays; David Ehrenreich (U. Geneva), exoplanets; Bruce Elmegreen (IBM) and Clare Dobbs (U. Exeter), M51 modeling; Mansi Kasliwal (Caltech), Palomar Transient Factory and Zwicky Telescope Facility; Doug Gies (Georgia State U.), CHARA; Howard Bond (Penn State and STScl), V838 Cygni; Lorenzo Reynard (South African Radio Astronomy Observatory), Square Kilometer Array; Marek Demianski (Williams College and University of Warsaw), supernovae and cosmology; Alan Stern and Cathy Olkin (SwRI), Dale Cruikshank (NASA Ames), Rick Binzel (MIT), Bill McKinnon (Washington U.), Pluto; and Eric Mamajek (NASA's JPL-Caltech), planetary and stellar data and names.

For her extensive editorial consulting, we thank Madeline Kennedy in Williamstown. For additional assistance, we thank Michele Rech in Williamstown.

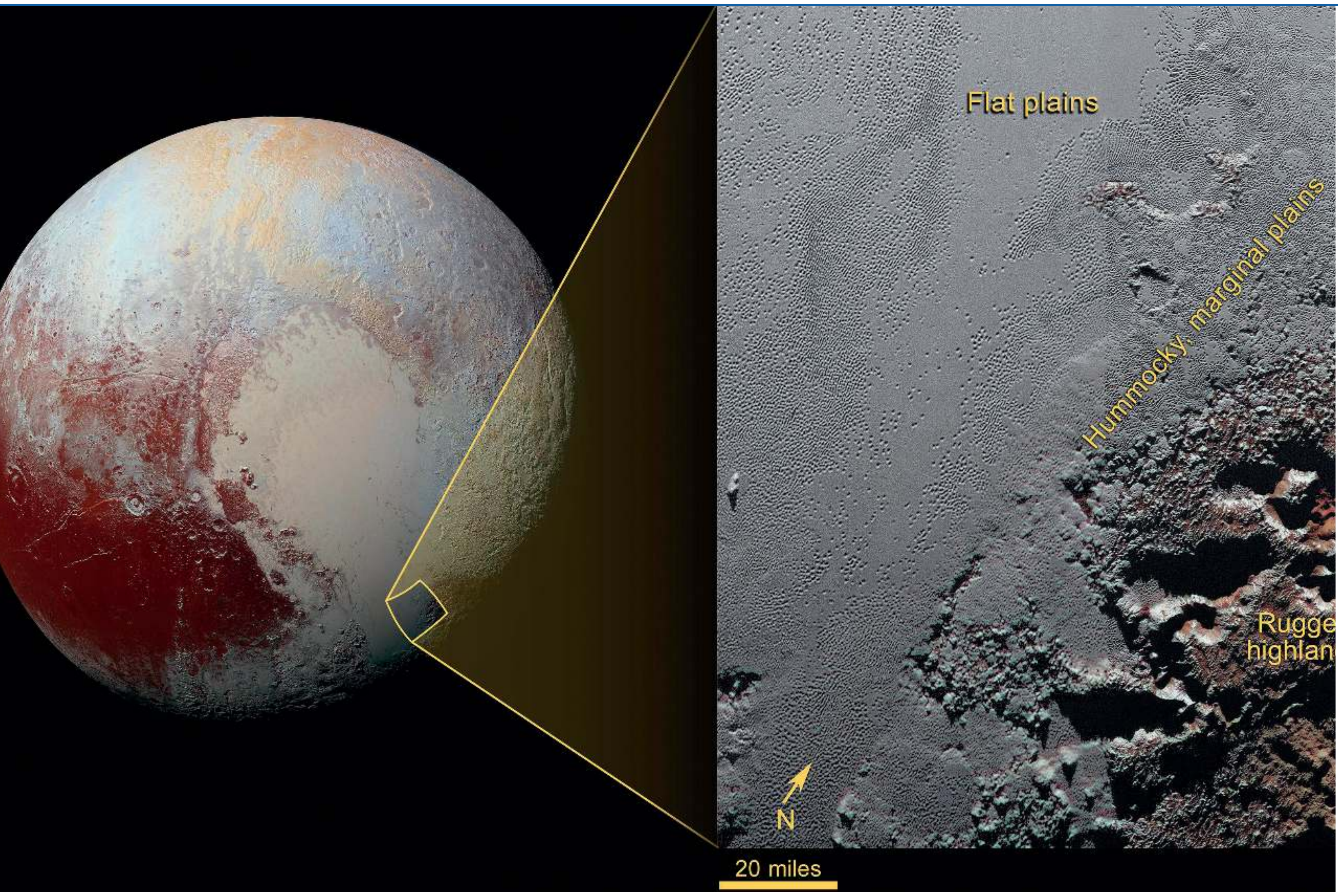
At Cambridge University Press, we thank our commissioning editor Vince Higgs, and Ilaria Tassistro and her editorial team, as well as Charlie Howell and his production team.

J.M.P. thanks various members of his family, who have provided vital and valuable editorial services in addition to their general support. His wife, Naomi, has always been very helpful both personally and editorially. He is grateful for the family support of Deborah Pasachoff/Ian Kezsbom/Lily Kezsbom/Jacob Kezsbom/Xander Kezsbom and of Eloise Pasachoff/Tom Glaisyer/Samuel Glaisyer/Jessica Glaisyer.

A.F. thanks his children, Zoe, Simon, Caprielle, and Orion Filippenko, for the long hours they endured while he was busy working on this book rather than spending time with them; they mean the universe to him. A.F. also thanks his wife, Noelle Filippenko, for her incredible patience, advice, and support; he could not have succeeded without her, and he looks forward to sharing more of the wonders of the cosmos with her.

We are extremely grateful to all the individuals named above for their assistance. Of course, it is we who have put this all together, and we alone are responsible for the content. We would appreciate hearing from readers with suggestions for improved presentation of topics, with comments about specific points that need clarification, with typographical or other errors, or just to tell us about your astronomy course. We invite readers to write to us, respectively, at Williams College, Hopkins Observatory, 33 Lab Campus Drive, Williamstown, MA 01267–2565, eclipse@williams.edu, and Department of Astronomy, University of California, Berkeley, CA 94720–3411, alex@astro.berkeley.edu, or through the book's websites. We promise a personal response to each writer.

Jay Pasachoff
Alex Filippenko



A close-up view of the surface of dwarf planet Pluto, taken as NASA's New Horizons spacecraft flew by on July 14, 2015, along with a full-disk view taken as the spacecraft approached. The heart-shaped region is Sputnik Planitia. At bottom right, in enhanced color, we see features that rise 1.5 miles high, scarred by clusters of pits 5–8 miles across and up to 1.5 miles deep, deeper than our Earth's Grand Canyon.

NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute