

The New Cosmos

Answering Astronomy's Big Questions

Over the past decade, astronomers, planetary scientists, and cosmologists have answered – or are closing in on the answers to – some of the biggest questions about the universe. David J. Eicher presents a spectacular exploration of the cosmos that provides you with a balanced and precise view of the latest discoveries. Detailed and entertaining narratives on compelling topics such as how the Sun will die, the end of life on Earth, why Venus turned itself inside-out, the Big Bang Theory, the mysteries of dark matter and dark energy, and the meaning of life in the universe are supported by numerous color illustrations, including photos, maps, and explanatory diagrams. In each chapter, the author sets out the scientific history of a specific question or problem, before tracing the modern observations and evidence in order to solve it. Join David J. Eicher on this fascinating journey through the cosmos!

DAVID J. EICHER is Editor-in-Chief of *Astronomy* magazine, and one of the most recognized astronomy enthusiasts in the world. He has spoken widely to amateur astronomy groups and written eight books on astronomy, including *Comets: Visitors from Deep Space* and *The Universe from Your Backyard*. He is president of the Astronomy Foundation and a member of the Board of Directors for Starmus Festival. An avid observer of astronomical objects for more than 35 years, he was honored by the International Astronomical Union with the naming of a minor planet, 3617 Eicher.

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David J. Eicher
Editor-in-Chief, *Astronomy* magazine

Foreword by Alex Filippenko
University of California, Berkeley



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Now that anyone is free to print whatever they wish, they often disregard that which is best and instead write, merely for the sake of entertainment, what would be best forgotten, or, better still be erased from all books. And even when they write something worthwhile they twist and corrupt it to the point where it would be much better to do without such books, rather than having a thousand copies spreading falsehoods over the whole world.

– Niccolò Perotti (1429/30–1480)

If the Lord Almighty had consulted me before embarking on creation thus, I should have recommended something simpler.

– Alfonso X of Castile (1221–1284)

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Foreword

It's often said that we now live in a "golden age" of astronomy – and indeed, it's true.

Hardly a week goes by without a press release informing the public of a new cosmic discovery made with one or more instruments from the existing arsenal of ground-based and space-based telescopes, or through theoretical and computational studies. Sometimes, especially during national and international meetings such as those of the American Astronomical Society, several new celestial findings are announced each day.

And what amazing developments we have witnessed! Just 2 decades ago, in the mid-1990s, the evidence for "dark matter" was tantalizing but not compelling, contrary to the present situation. In a still greater turn of events, hardly anyone considered the possibility that even more mysterious "dark energy" dominates the mass-energy content of the universe and accelerates its expansion, probably dooming us to end in the Big Chill. Only the first few exoplanets had been discovered, foreshadowing the thousands that are now known or strongly suspected, and the detection of Earth-like exoplanets in the near future was considered unlikely. Given the few observed objects in the Kuiper Belt and their relatively small sizes, for another decade most astronomers would still consider Pluto to be a genuine planet. Black holes, previously popular mainly among the fertile minds of theoretical physicists and science-fiction writers, were suspected to exist but not yet detected beyond reasonable doubt.

As a long-time editor of the well-known *Astronomy* magazine, author David Eicher gained much experience in bringing celestial highlights to amateur astronomers and astronomy enthusiasts. One could learn the basics of astronomy and physics in standard textbooks, such as my own *The Cosmos: Astronomy in the New Millennium* (coauthored with Jay M. Pasachoff), but such books are not able to describe new discoveries on short timescales, and much of their volume must remain devoted to the fundamentals. Conversely, amateur astronomy periodicals generally do not provide very detailed analyses of the state of various astronomical subfields, concentrating instead on relatively brief summaries of recent developments.

Foreword by Alex Filippenko

In this book, on the other hand, Eicher synthesizes a wealth of relatively new information into an interesting, coherent, up-to-date overview of many of the most important and exciting areas of astronomy. Inspired as a youngster by the legendary Carl Sagan, and having a deep love of bringing the cosmos to the general public, he passionately shares his broad knowledge and presents the state of the art on topics ranging from our own solar system and the Milky Way Galaxy, to other planetary systems and galaxies, to the lives and deaths of stars, and to the overall composition and fate of the cosmos. Along the way, he considers the future of life on Earth, the possibility of life elsewhere, and even the meaning of life.

Two decades from now, it will be interesting to see how much our view of the universe will differ from what is presented here. Will we better understand the origin of the Moon, the absence of water on Mars, and the geologic history of Venus? Will we have mapped oceans and continents on exoplanets in the Goldilocks zone? Will we have directly detected exotic particles thought to be responsible for most of the dark matter in the cosmos? Will we know the true nature of dark energy and the ultimate fate of the universe?

Immersing yourself in the chapters that follow will give you a new sense of wonder at the amazing universe that we inhabit, yet simultaneously awakening both your humility as a cosmic speck of dust and your awe at our present understanding of the cosmos. And there is little doubt that this book will help inspire inquiring minds to further investigate the universe and its contents, as the human brain is restless and there is still far more to be learned.

Alex Filippenko
University of California, Berkeley

Preface

I was a child of *Cosmos*.

My youth seemed connected to Carl Sagan. When I was 14, I attended my first “star party” by accident, catching a glimpse of Saturn and other attractions in a small reflecting telescope, and that moment changed the world for me. I became active in the local astronomy club in Oxford, Ohio, a small university town where my father was a professor of organic chemistry at Miami University. The local club needed a writer on deep-sky objects – star clusters, nebulae, and galaxies – and recruited me. Soon I was so entranced with writing about these mysterious creatures of the universe beyond our solar system that I started an amateur publication, *Deep Sky Monthly*, that had its genesis on the mimeograph machine in my father’s chemistry office. It was the summer of 1977, and I was 2 months shy of 16.

During the first months of producing a publication for astronomy enthusiasts, while in high school, I wrote Professor Carl Sagan at Cornell University, letting him know about the publication and seeking career advice. He very graciously replied with the first of a number of letters. This was during his time as a celebrated astronomy figure – he periodically shared enthusiasm with Johnny Carson on *The Tonight Show* – but before his production of the legendary *Cosmos* TV program.

On June 6, 1977, Carl wrote me his first letter. His wisdom, encouragement, generosity, and positive spirit during every encounter we had from that moment on were a major factor in my pursuit of astronomy. “I am delighted to hear from a 15-year-old who is already so active in astronomy,” he wrote, and after paragraphs of advice, he closed with “With all good wishes on your career.”

My admiration for Carl Sagan grew throughout our correspondence and I beamed with pride in knowing Carl during the airing of his *Cosmos* series on PBS TV in 1980. The show premiered on Sunday, September 28, 1980, and I rushed inside after a busy day, a pleasant 72 °F in Oxford, to turn on the TV just in time for that haunting theme music by Vangelis.

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Figure 0.1 David Eicher in June 1982, 5 years after commencing publication of his amateur-produced *Deep Sky Monthly* magazine, and several years after coming under the influence of Carl Sagan, at the Eicher House in Oxford, Ohio.

David J. Eicher

"The cosmos is all there is, or ever was, or ever will be," said Carl in his opening sequence. "Our contemplations of the cosmos stir us. There is a tingling in the spine, a catch in the voice, a faint sensation as if a distant memory of falling from a great height. We know we are approaching the grandest of mysteries."

I was immediately entranced by the series, as were millions. It became one of the great success stories for PBS in an era when relatively few TV channels existed – it propelled an entire generation to discover astronomy, the stars, and the universe around us. I was particularly proud when I received a copy of the Random House *Cosmos* book in the mail, inscribed to me by Carl – "For Dave Eicher / friend of the Cosmos."

The sensational momentum of enthusiasm in my life stoked by Carl Sagan never left me. After Miami University, at age 21, I came to Milwaukee to join the staff of *Astronomy* magazine, the world's largest publication on the subject, as its most junior assistant editor, and I brought my little magazine with me, now titled *Deep Sky* and published as a quarterly. I've been at *Astronomy* for more than 32 years, and have held every editorial job, becoming the magazine's editor-in-chief in 2002. We published *Deep Sky* for 10 more years, ending it in 1992 when it became clear that if I were to progress further with *Astronomy*, I couldn't also do the smaller magazine a day or so every week.

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Figure 0.2 Carl Sagan inspired a generation with books and television programs that made science accessible through his brimming enthusiasm. The astronomer’s best-known work, *Cosmos: A Personal Voyage*, ultimately reached half a billion people across the world, and won an Emmy Award.
NASA/JPL-Caltech

My life at *Astronomy* magazine has been great fun. But I’ve never forgotten the principles laid down in those letters and talks with Carl Sagan. A little more reminiscence about him, from a short piece I wrote for *Astronomy*:

My first encounter with Carl Sagan came as a teenager when I readied for a late night of observing with my telescope. I hovered over The Tonight Show before heading outside and sat, mesmerized, as this Cornell University professor made astronomy relevant, exciting, and meaningful to ordinary Americans. Sagan didn’t utter “billions and billions” on that summer night; that phrase, gently lampooning his friend Sagan, arrived later from amateur astronomer Johnny Carson.

As I looked toward a career in astronomy and started publishing Deep Sky Monthly, I sent a letter to Sagan and included copies of my little publication on observing galaxies, clusters, and nebulae. It was mid-1977. I was 15 and he was 42. Busy as he was (although this was pre-Cosmos), Sagan wrote me a long letter that I received a week or two later. It absolutely made my year and inspired me to redouble my efforts in astronomy. Filled with career advice, the letter served as an inspiration for years to come.

Through a correspondence, I got to know Carl Sagan. What struck me most was how generous he was with his time and with his wisdom. He was truly a humanist who cared about people and

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was impressed with helping them in any way he could. When Cosmos ignited interest in astronomy through the airwaves of PBS, he sent me an inscribed copy of the accompanying Random House book, signed "For Dave Eicher/friend of the Cosmos." I was awestruck.

In those days, Carl Sagan took heavy criticism from conservative or even jealous professional colleagues over his popularization of astronomy and science. To some, it was "selling out to the masses." In the world that now exists, where too few people value science and know about its details, how those elitists would sing a different tune! Sagan realized the value of the Average Joe understanding and supporting science, and did more than just about anyone else to deepen that connection between science and the public.

When I finally met Carl Sagan and spent time with him at meetings, now as an editor at Astronomy, I was even more impressed. I was struck by his height (he was 5'11" but for whatever reason seemed taller than that in person and shorter on TV), his soft-spoken, fatherly manner, his fine manner of dress, and his patient, caring gaze.

I recall how impressive it was to hear his views, in person, on a wider variety of subjects. This was no shallow TV presenter. At the "Comets and the Origin and Evolution of Life" Meeting in Eau Claire, Wisconsin, in the fall of 1991, I sat with him in the back of a meeting room. He rattled off numerous interesting questions following many of the lectures, as well versed in a whole maze of specialized research as the speakers were.

Carl Sagan wrote for Astronomy magazine many times, from the earliest issues onward. He sent me his last contribution to the magazine in 1993, and it appeared in the 20th anniversary issue of the magazine, in a story about what was coming in astronomy's future.

Three years later, we all learned he was being treated for an illness, and I called him in late 1996 when he was in Seattle at the Hutchinson Cancer Research Center. He spoke, as always, with great caring in his voice. I asked him if he would be a member of the magazine's newly forming Editorial Advisory Board, and talked about all the exciting things to come, unaware of the grave seriousness of his illness. In the most generous, compassionate way you could imagine, he simply said, "Dave, nothing would make me happier."

Two weeks later, he was gone, and we were all left stunned. Astronomy had lost its best friend and would never be quite the same again.

One of Carl's best lines from *Cosmos* was: "The cosmos is full beyond measure of elegant truths, of exquisite interrelationships, of the awesome machinery of nature."

Cosmos was produced some 35 years ago, a very short span in the history of the universe, and yet human understanding of the cosmos has changed almost unbelievably since then.

In 1980, we knew nothing of dark energy, and far less than we do now about dark matter. The nature of black holes was still mostly conjecture. We did not know the intricate details of how the Sun will die, or what will happen when life comes to an end on Earth. We did not yet have a good idea of how the Moon formed. We utterly lacked an understanding of the nature of martian or venusian geological history. Pluto was still safely considered a planet. We had no evidence for numerous planets orbiting stars near us in the galaxy.

We erroneously believed the Milky Way was a normal spiral galaxy. We did not know about the future collision of the Milky Way and Andromeda galaxies.

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We lacked detailed evidence for the exact nature of the Big Bang and the cosmic microwave background radiation (beyond its mere detection). We had only hazy notions of the universe's size, age, and fate. And we did not know enough about the origin of life on Earth or the number of stars in the universe to speculate meaningfully about the potential existence of life elsewhere in the cosmos.

All of these major areas were in a very primitive state just 35 years ago, when *Cosmos* first aired, and thus the reason for putting all this stuff together in a big book like *The New Cosmos*.

From the earliest days, as humans looked skyward, they no doubt wondered about the twinkling lights spread across the sky. For thousands of years, myths and imaginations carried the day as culture slowly leaned forward toward rational observation and empirical science. Astrologers dreamed up ideas; philosophers imagined answers. And then, in the autumn of 1609, Galileo climbed to the roof of his house in Padua, Italy, and – after looking at the steeple of the nearby church with his new telescope – slid the field of view over to the Moon. He became the first to see and share with the world a magnified view of the lunar surface, with craters, dark “seas,” and mountains. In making this first shared telescopic observation, Galileo ignited a new era of astronomy.

For centuries thereafter, astronomy was, like the other sciences, mainly an exercise in classification. Whether they contemplated stars, minerals, butterflies, plants, or fish, scientists categorized what they observed in nature as a first gross step in understanding it. Then, in nineteenth-century astronomy, a revolution in astrophysics arrived. Photography, spectroscopy, and other tools led to a new wave of understanding the cosmos. Suddenly, astronomers began to understand the physical nature of the universe in a more enlightened way.

But another revolution has taken place, one that is far more fast-paced and remarkable. Over just the past decade, astronomers, planetary scientists, and cosmologists have answered, or are closing in on the answers to, some of the biggest questions about the universe.

This revolution is rapidly recasting what we know about the cosmos around us. Given this flood of new findings and new ways to understand nature, we can now say that we live in a place redefined by our fresh knowledge – a new cosmos.

These include questions about the universe's origin, its fate, its size, its shape, and its age. We now know about the relative numbers of planets around us in nearby parts of the Milky Way Galaxy. We know about the barred spiral structure of the Milky Way and about its future collision and merger with our neighbor in Andromeda. We know about the ubiquitous nature of black holes in galaxies. We know about the cosmic distance scale of the galaxy, about the vast stretches of space that surround us inside the Milky Way and beyond it.

Planetary scientists also pursue answers to big questions that are hotly evolving. These include such key questions as the formation of the Moon, the transformation of Mars' climate, the strange case of Venus turning itself inside

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out, arguments over what makes a planet and what is merely a dwarf planet. We also know what will happen to the Sun, how our solar system will look 5 billion years from now, and how long life will be able to exist on Earth before the oceans will boil away, ending our existence.

Answers to questions of cosmology lag behind a bit, given their enormous complexity, but astronomers have made huge recent strides that hint toward resolution. Studies are narrowing the gap on questions about the nature of dark matter, dark energy, the fate of the universe, the abundance of life in the universe, and the number of civilizations it may hold.

This book is my attempt to assemble 16 of the really big ideas in astronomy, planetary science, and cosmology that have exploded in terms of understanding over the past generation.

I hope that you enjoy it and know that we are still early in the game, despite these huge recent advances, in really knowing the vastly huge universe that surrounds us.

Carl Sagan used to lament that, “ninety-nine percent of people on Earth are born, live their lives, and die without realizing their place in the cosmos.” I hope that this book helps to decrease that percentage just a little, and bring about the majestic wonder of the universe to more people on our little blue planet.

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This book was originally inspired by Carl Sagan, many years ago, a friend and supporter whom we lost way too soon.

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