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Cosmic Imagery

John D. Barrow

CONTENTS

Also by John D. Barrow

Theories of Everything

The Left Hand of Creation
(with Joseph Silk)

L'Homme et le Cosmos
(with Frank J. Tipler)

The Anthropic Cosmological Principle
(with Frank J. Tipler)

The World within the World

The Artful Universe

Pi in the Sky

Perché il mondo è matematico?

Impossibility

The Origin of the Universe

Between Inner Space and Outer Space

The Universe that Discovered Itself

The Book of Nothing

The Constants of Nature: From Alpha to Omega

The Infinite Book: A Short Guide to the Boundless, Timeless and Endless

New Theories of Everything

To Brenda and Don

I can’t think of a single Russian novel in which one of the characters goes to a picture gallery

W. Somerset Maugham

Cosmic Imagery

Key Images in the History of Science

John D. Barrow

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PREFACE

'What is the use of a book,' thought Alice, 'without pictures or conversations?'
Lewis Carroll

BOOKS, ESPECIALLY BOOKS on scientific topics, generally use pictures to illustrate what they have to say. Pictures save words. They change the pace, alter the style, and make things more memorable. They are something between a thing and a thought.

This book is not intended to be like that. Its words were wrapped around the pictures and the parts they played in making a lasting and vivid contribution to our scientific understanding of the Universe. Sometimes these images recorded information in a new and impressive way; sometimes they took advantage of new ways of doing or seeing things; and at other times they simply told a story for which words alone were not enough.

Yet this is far from being a 'picture book'. The images each carry a story that is important, unusual, or simply untold. Taken together they create a wide-ranging picture of scientific progress in which there is time for history and space for geography.

The motivation for such a book grew partly out of sociological and technical changes within science itself. In just a few years, the presentation of science at all levels, from technical seminars for fellow experts to popular expositions for the general public, has become extremely visual. The ubiquity of PowerPoint, web-streamed video, digital photography, and artificial computer simulation has meant that images dominate science in a way that would have been technically and financially impossible just 20 years ago. There is a visual culture in science and it is rapidly changing.

Visuality penetrated the practice of science just as deeply as it fashioned its presentation. Small desktop computers revolutionised research and enabled complex and chaotic behaviours to be studied visually for the first time by single individuals and small research groups armed with nothing more than an inexpensive off-the-shelf box of silicon. Small science became bigger. The results of its new forms of experimental mathematics were dramatically visual and started a trend towards the investigation of emergent complexity by means of direct simulation. 'Publication' no longer meant only a paper on paper.

We have witnessd a revolution in the history of science. Not the sort of revolution that philosophers of science once believed in – they don't happen any more – but a revolution brought about by new tools, different ways of seeing, and novel ways of understanding. Nothing old needed to be overthrown to make way for the new.

The future of science will be increasingly dominated by artificial images and simulations. It will be harder for iconic images to last in the face of ever-greater technical facility. So, now is an interesting time to look backwards as well as forwards. I hope that the pictures chosen here will focus attention on the important role they played in facilitating mental pictures and guiding the way science and mathematics developed our understanding of Nature and Nature's laws.

Unfortunately, there are some special forms of complexity where pictures actually make matters worse, and the writing of this book gradually revealed itself to be one of them. Fortunately, I was helped by many people along the way who worked tirelessly to locate pictures, 'firsts', high-quality images, and copyright holders. Will Sulkin, Jörg Hensgen and Drummond Moir at The Bodley Head, Random House, played the major role in sustaining the project and transforming it from black-and-white type into the volume you are now holding. Our children, although no longer children, have maintained an unexpected interest in the final product, perhaps suspecting that there will be an accompanying video game. Elizabeth has learnt that these projects do have an end, and is especially patient on hearing continually that it is nigh. Her vital support in so many ways enabled it all to get done without too many other things remaining undone.

A large number of friends and colleagues helped. For their assistance with discussions, text, pictures, and sources, I would especially like to thank Sarah Airey, Mark Bailey, June Barrow-Green, Nadine Bazar, Alan Beardon, Richard Bright, Rosa Caballero, Alan Chapman, Pamela Contractor, Jim Council, Carl Djerassi, Richard Eden, Kari Enqvist, Gary Evans, Patricia Fara, Ken Ford, Marianne Freiberger, Sandy Geis, Gary Gibbons, Owen Gingerich, Sheldon Glashow, Edward Grant, Peter Hingley, Sharon Holgate, Michael Hoskin, Martin Kemp, Rob Kennicutt, Paul Langacker, Imre Leader, Raimo Lehti, Nick Mee, Simon Conway Morris, Andrew Murray, Dimitri Nanopoulos, Chris Pritchard, Helen Quigg, Stuart Raby, Martin Rees, Simon Rhodes, Adrian Rice, Graham Ross, Martin Rudnick, Chris Stringer, Rose Taylor, Frank Tipler, John Turner, Steven Weinberg, John A. Wheeler, Denys Wilkinson, Robin Wilson, Tracey Winwood and Alison Wright. All of them answered questions, made suggestions, or provided information or images with helpful enthusiasm.

John D. Barrow
Cambridge, 2008.

INTRODUCTION

EVERY PICTURE TELLS A STORY

'Someone who is on his way to somewhere can hardly keep company with someone who is going nowhere,' he said. 'But we can try. You can come along with me if you carry my suitcase.'

Henning Mankell[1]

WE LIKE PICTURES. They were the first things we ever saw. Our minds were not made for letters, numbers, double-entry book-keeping, musical scores, or mathematical equations – all of these are postscripts to the human story. Our senses evolved in an environment that was appreciated as something to be understood and remembered as a picture. Sensitivity to a variety of that environment's qualities was engendered in generations of survivors who discovered that they were inclined to act in ways that were safer and more enduring than those of Mr and Mrs Average.

From these humble beginnings we have inherited a liking for pictures. We find them entertaining, we find them educational, we find them memorable, and we find them inspiring. Our earliest relics of cultural anthropology reveal images of unnerving sophistication, such as those in the caves at Lascaux, that would be recognised as works of art even today. Pictures have played a role in binding primitive societies together in life-supporting ways, they have defined entire periods of human history by their style and subjects, and they have maintained tradition and social memory over long periods of time. They have focused religious emotions and contemplation, and they have invited us to ponder the inner workings of minds that use us innocently as subjects. In all these manifestations, pictures seek to represent and encapsulate something of reality in a way that has an instant impact: something that is memorable without needing to be remembered.

Every subject has its iconic images. We all know many of them in the realms of art or functional design. From the *Mona Lisa* and the Alhambra to the map of the London Underground or Tower Bridge, certain images persist and are hugely influential. They shape our memories of the world. The same is true in science. Some images have defined our steps in understanding the Universe; others have proved so effective in communicating the nature of reality that they are part of the process of thinking itself, like numbers or the letters of the alphabet. Others, equally influential, are so familiar that they appear unnoticed in the scientific process, part of the vocabulary of science that we use without thinking.

This book is about scientific imagery. We are going to look at some of the images and pictures that have played a key role in shaping our scientific picture of the world. Some of those images are so subtle that they dominate our way of practising science or describing reality without us even noticing. Others are ubiquitous icons that dominate the presentation of a whole branch of science, or our conception of its history. Others still possess an aesthetic quality but have a scientific subtext that makes them important for our story.

The use of diagrams and pictures in the practice of science and in presenting it to others is no longer an activity with an artistic imperative. The scientists who create a new form of visual representation may draw the pictures for themselves, but more often the final version will be the work of others. A technical artist (or even a computer program) will produce a prettier version from their rough sketches. What true artist would follow such a course? Scientists are trying to present information in an instantly recognisable fashion. But sometimes, as we shall see, their efforts were more enduring and more influential than they ever imagined. At other times, they were unusually controversial.

Some important scientific images are human constructions with a special purpose, but others are records of natural phenomena, the result of new instruments taking the first glimpses of a new world of the ultra small, the vanishingly faint, the stunningly explosive, or the unimaginably remote. They mark our entry into new realms that require maps because evolution never found it a worthwhile investment to equip our unaided senses to penetrate them. As we go there, we shall find that some pictures have come to play a scientific role that rivals that of words and numbers. Carefully constructed families of pictures can act as a calculus all of their own. Like any successful systems of symbols, with an appropriate grammar they enlarge the number of things that we can do without consciously thinking.

In all these considerations we recognise in the background an immediate technological impetus that provides scientists with new ways to use images. In the last twenty years we have witnessed one of the greatest innovations in human history: the Internet (with its World Wide Web) has collectivised human thinking and information retrieval in a revolutionary way and outstripped the biological capability of individuals, allowing the instant retrieval and exchange of pictures. Yet there is also something remarkably visual about the development of the modern science that has accompanied this revolution. The advent of small, inexpensive computers with superb graphics has changed the way many sciences are practised, and the way that all sciences present the results of experiments and calculations.

Long ago, computers were huge and mightily expensive – the preserve of large well-funded research groups studying block-busting problems. They built bombs, predicted the weather, or tried to understand the workings of the stars.

But the personal-computer revolution changed all that. It allowed the study of subjects such as chaos and complexity to flourish. Mathematics became an experimental subject. Individuals could follow previously intractable problems by simply watching what happened when they were programmed into a personal computer. The output was, as often as not, a sequence of pictures or movies of how a complex process developed and continued to completion. There is no simple formula that tells how galaxies end up assembling into all the shapes and sizes that we see, or how dramatic turbulence occurs when a fast-flowing river cascades through a series of rapids; these problems are too complicated to be solved exactly using pencil and paper alone. But pictures and film can reveal the crucial points in these processes by transforming the mathematical equations that control their behaviour into simulations. The rapid development of spectacular graphics has enabled almost anyone to present these conclusions in a fashion that is more visually impressive than the achievements of the movie industry just twenty years ago. The PC revolution has made science more visual and more immediate. It has enhanced the intuitive power of the human mind to appreciate the behaviour of complex patterns of behaviour from experience by creating films of imaginary experiences of mathematical worlds.

The last ten years have also seen a growing emphasis upon the visual in many areas of culture. Mass-appeal films are defined increasingly by the presence of special visual effects. Storyline is almost superfluous in the race to string together more and more cataclysmic images, some real, but most largely the products of computer simulation. When they appear on DVD we are given extra visuals and additional incestuous coverage of the making of the film. Experimental theatre introduces challenging new techniques on to the stage that make visual experience more vivid. Popular music is accompanied by the ubiquitous video or

DVD: sound is not enough. Animated films have reached new levels of sophistication and even books come with their own websites. Words are no longer enough.

The practice of science has followed a parallel course. Conference presentations and seminars used to rely on blackboard and chalk, handouts, overhead projectors, or 35mm slides. Today, scientists project data via PowerPoint, videos of computer simulations are routine, and audioclips, film, and split-screen graphics are commonplace in scientific presentations to colleagues and the general public. Even the publication of scientific research has been swept up in the technological revolution. It is now possible to publish huge quantities of colour images and video in online journals or websites associated with print journals. This would have been impossible twenty-five years ago. Importing pictures into articles is a relatively simple matter – a few mouse clicks suffice. For a great scientific expositor such as Arthur Eddington, writing in the 1930s, the inclusion of diagrams was an expensive and laborious business and, not surprisingly, you won’t find any in most of his books. Today, the opposite is true.

In this climate, it is a challenge to think about the role of images in science, not just today, but over many hundreds of years. There are definitive images, graphs, pictures, and charts that play a key role in widening our appreciation of the world. This book draws together a personal selection of these special pictures. While many such images would figure in almost anyone’s gallery of science, others are more subjectively chosen because of an importance that is not immediately obvious, or which involves something that has not been recognised at all before. Scientific pictures are often not just about science. They may be interesting because they are scientific in origin, but yet have an undeniable aesthetic quality. They may even have been primarily works of art that possess a scientific message.

Every one of the pictures we will show has a story. Sometimes that story is about its creator, sometimes it is about the scientific insight that flowed from the picture, sometimes it is about the technique of representation itself, sometimes it is that the simple image was to assume an unforeseen importance which stimulated an entirely new way of thinking, and sometimes it is simply a tale of the unexpected.

The Globular Star Cluster NGC 6397, one of the closest to Earth, 8,500 light years away.

ASTRONOMY IS WHAT WE HAVE NOW INSTEAD OF THEOLOGY. THE TERRORS ARE LESS, BUT THE COMFORTS ARE NIL.

John Updike[2]

NO AREA OF science is more picturesque than astronomy. The sky is a natural canvas on which to draw imaginary connections between the stars and our ideas about them. Some of humanity's earliest written records show the phases of the Moon, and tell stories that are fashioned by the appearance of the night sky. The rising and setting stars, the great circles of stars around the Celestial North Pole in the northern sky, constellations of meaning, and the eclipsing of the Moon and Sun were the greatest events that ancient humans ever witnessed. They spoke of the reliability and regularity of the Cosmos: its dark sky full of navigation beacons, their recurring movements a celestial clockwork by which to order one's life and nurture the land. We look first at some of the special pictures of the stars that were drawn and painted with great skill. Some had artistic intent, others were more prosaic. Pictures give way to diagrams. Diagrams inspire generalisations and simplifications. They replace masses of data by a compression of information. Armed with the key images that emerged from early twentieth-century astronomy, we see how the subjects of modern astrophysics and cosmology emerged, supported by early photographs and diagrams that encapsulated the diversity of the Universe and its dramatic runaway expansion. Black and white gave way to colour. The abstractions of Einstein's curved space and time gave rise to analogies and pictures that played a new explanatory role. Space and time gave way to space–time, visible light was augmented by images across the rest of the electromagnetic spectrum, and we realised that we could see back towards the apparent beginnings of time. Cosmology now gives us pictures of other universes, and makes the map of our own ever more complex.

Yet the responses that these celestial images have continually provoked tell a parallel story of equal interest. They have created a perspective of our own place in the Universe. The Universe, big and old, dark and cold, creates feelings about the relationship between life and the impersonal immensities of the cosmos. The patterns of the stars once gave rise to complicated beliefs in astrological influences upon human actions and psychologies. Astrology became astronomy, but the images of the Universe that the Hubble Space Telescope has provided have influenced us in extraordinary ways.[3] They have an aesthetic appeal that resonates with a pioneering spirit of adventure: the discovery of new vistas, spectacular events of stellar birth and death that were once the preserve of science fiction books and films.

MIDNIGHT'S CHILDREN

THE CONSTELLATIONS

Andreas Cellarius's northern hemisphere and its sky, 1660.

Lisa: Remember, Dad, the handle of the Big Dipper points to the North Star.
Homer: That's nice, Lisa, but we're not in astronomy class. We're in the woods.
The Simpsons

ONCE THE NIGHT sky was dark for everyone, everywhere. There was no artificial light, and the Moon and the stars were visible to the naked eye with a clarity that is no longer possible in modern cities. The stars were also comfortingly familiar: their positions recognised and relied upon for navigation over land and sea; their patterns a portent of disasters; their regularity and predictability the seed of human faith in a Universe that was lawful and regular rather than the plaything of temperamental deities bent upon vengeance and never-ending internecine battles. The stars were important.

The most persistent and vivid picture of the star-spangled sky has remained the map of the constellations. The stars were grouped together into collections that suggested the shapes of animals or everyday objects, perhaps to enshrine some religious or mythological association between those things and their position on the sky, or simply as an aide-memoire for reading the sky. Their slow and steady progress across the darkness, night after night, as the Moon waxed and waned, and the Earth undertook its annual orbit around the Sun, allowed time to be measured in new ways, and provided mariners with a means to navigate after nightfall. If you are travelling on land and night falls, then you can stop and wait for daylight; at sea that possibility is not always open to you.

The slowly evolving map of the constellations has played a multifaceted part in human history. It has fuelled superstition, furthered scientific astronomy, aided navigation, and created a sense of oneness with the Universe. The night sky is the oldest shared human experience. Its re-creation in pictures and illuminated manuscripts has preserved and elevated that experience in many cultures and deservedly finds a place in any gallery of great scientific images.

The annual path of the Sun, viewed from our terrestrial perspective, traces out on the celestial sphere a great circle on the sky. In ancient times this was divided into twelve signs, or 'houses', of the zodiac by the twelve constellations through which the Sun passed in sequence on its (apparent) annual journey around the Earth.[4] These twelve signs are still those used credulously today in the astrology columns of many magazines and newspapers around the world. Actually, the signs of the zodiac (which means literally 'circle of animals') differ from the constellations of the zodiac, even though they share similar names. The constellations are groups of adjacent stars that formed some discernible and suggestive pattern. The signs of the zodiac,[5] by contrast, consist of twelve equal zones of 30 degrees in length, or one hour on a clock face, giving a total of an entire circle of 360 degrees around the sky. Conventionally, the constellations are each taken to be 18 degrees wide in extent on the sky. At first the signs and their synonymous constellations were closely related, but gradually more and more ancient constellations were named and they soon greatly outnumbered the signs. Since the signs were only used for astrological purposes they could remain twelve in number, but the constellations were crucial for navigation and so navigators in different parts of the world needed different markers and lines in the sky, hence the continual additions to the menagerie of constellations to ensure adequate sky coverage. Most people still know their star sign and astrology is still peddled in some quarters as a way of predicting human personality and behaviour by means of the character traits traditionally associated with individuals born under a particular star sign.

Another fascinating feature of the oldest constellation maps has enabled astronomers to speculate about the place and the time of their original creation. When the Earth rotates it wobbles slightly, just like a precessing top, so that its axis of rotation (currently almost, but not quite, the same as the axis through the North and South magnetic Poles) does not always point in the same direction in the sky but traces a circle that takes about 26,000 years to complete. At present, our northern rotational axis points conveniently towards a star that we have dubbed the ‘Pole Star’, or ‘Polaris’, but far in the past or the future the celestial North Pole would have pointed, or will point, in a different direction, either at another star or at no star at all. For example, in 3000 BC the Pole Star would have been Alpha

Draconis, but when Shakespeare has Julius Caesar say he is 'constant as the northern star',[6] this is a complete anachronism: there would have been no northern star in Caesar's day.

This precession of the celestial North Pole means that the sky looks different in significant ways to observers located at different latitudes on the Earth and at different times in history. Most interesting of all, an ancient astronomer observing from a latitude of, say, L degrees north would have been unable to see a disc of the sky centred on the south celestial pole and spanning an angle of $2L$ degrees on the sky. By looking at maps of the ancient constellations, several nineteenth-and twentieth-century astronomers have claimed to locate the latitude of the earliest known constellation mappers close to 35 degrees north from the angular extent of the empty zone in their maps of the southern sky.

This 35-degree line of latitude runs through the Mediterranean Sea, intersecting the Minoans, the Phoenicians (modern-day Lebanon) and the Babylonians (modern-day Iraq). Then by locating the centre of that empty zone it is possible to extrapolate the history of the precession backwards to find out when the South Pole was at the centre of the empty zone. This gives an interval of time between about 1800 and 2500 BC for when the ancient constellations were laid down.[7]

The reasons for their suggestive shapes and names are lost. But if we assume that the inventors were Mediterranean navigators then many of the animal shapes make good sense, tracing the rising of stars on the sky and permitting the setting of a sailing course at night. They also took on a wider significance. Maps symbolise a human desire to understand and be in control of our surroundings. To map a territory was tantamount to possessing it. Maps of the heavens offered an ultimate reassurance that all was well in the Universe, that we were at a focal controlling point within it, and had a special part to play in its unfolding story.

Each religious tradition embraced the zodiac and the constellations in its own way. Julius Schiller produced a Christianised picture of the constellations in which the strange pagan symbols were replaced by names from the Old and New Testaments. But the greatest draughtsman and artist of all those who strove to represent the constellations was the Dutch-German mathematician and cosmologist Andreas Cellarius. His *Celestial Atlas of Universal Harmony*, the *Atlas Coelestis seu Harmonica Macrocosmica* of 1660, is one of the most beautiful books ever created. The hand-coloured engravings are the Sistine Ceiling of the map-maker's art, combining vivid colours and exuberant figures within the geometrical constraints of a sky map of the constellations.[8]

The oldest image of the ancient constellations available to us today is one that is enshrined in stone rather than on paper and associated with a very different type of 'atlas'. In the National Archaeological Museum of Naples, famed for its ancient Egyptian remains, is the Farnese Atlas, a second-century AD Roman statue of the bearded figure of Atlas bearing a white marble globe of the constellations on its shoulders. The statue, standing more than two metres tall, is bending on one knee and is partly covered by a cloak. The celestial globe it bears is 65 cm in diameter and is damaged only by a hole through the top that cuts through the constellations of Ursa Major and Minor. In all, forty-one constellations are shown drawn in positive relief; no single stars are shown. The equator, the two tropics, the colures,[9] and the polar circles are shown as coordinate lines in relief around the sky on the surface. The globe is laid out with remarkable precision and the positions of defining points on the sky are accurate to about 1.5 degrees. In 2005, Bradley Schaefer[10] of the University of Louisiana re-analysed the layout of the constellations shown on the Farnese globe and showed that with high probability they are an image of the long-sought lost star catalogue of Hipparchus of Rhodes, the greatest astronomer of the ancient world. One of Hipparchus' many accomplishments, made possible by the extraordinary precision of his observations, was the discovery of the 26,000-year precession of the Earth's rotation axis that we discussed above. By studying the locations of the constellations and the blind spots in the sky coverage alone, Schaefer dated the constellation map shown on the Farnese globe to 125 BC with an uncertainty of only about fifty-five years either way. Hipparchus created his star catalogue in 129 BC but it vanished in antiquity and has remained unknown until now except for references to it by others.[11] Ironically, Hipparchus' own discovery of the precession was the key tool in dating the globe that bears an image of his map.

Yet, the constellations have created one strange mystery of history. The trick of using the Earth's precession history in conjunction with empty regions of ancient sky maps to date and locate the creators of the knowledge those maps contain was first exploited by a little-known Swedish amateur astronomer, Carl Swartz, who in 1807 published a book[12] on the subject in Swedish and French, with a second edition in 1809. From the maps available to him, he deduced that the original constellation map-makers probably lived around 1400 BC near a latitude of 40 degrees north and he suggested the city of Baku, on the coast of Armenia, as their likely home. Subsequently, other astronomers, such as the Astronomer Royal, Edward Maunder,[13] in 1909, and Michael Ovenden[14] in 1965 (neither of whom seemed to know of Swartz's book), narrowed the map-makers' latitude down to around 36 degrees north and their epoch to the range 2500–1800 BC. Ovenden believed (unjustifiably in the minds of many historians)[15] that the Minoans were the prime candidates because they were seafarers with an advanced culture at the target latitude who suddenly disappeared owing to a natural disaster in about 1450 BC. But he noticed a strange historical conundrum. One of the most useful records of ancient astronomical knowledge is contained in a long and detailed prose poem by Aratus of Soli,[16] which is entitled the *Phaenomena* (*The Appearances*) and was published in about 270 BC. He listed forty-eight constellations and their relative positions on the sky in his poetic tribute to the great Greek astronomer and mathematician Eudoxus of Cnidus,[17] who lived between 409 and 356 BC. Ancient literature talks of 'the sphere of Eudoxus' and it is generally believed that he possessed a celestial globe, but nothing more is known about it or about his astronomical writings and maps. Fortunately, Aratus used Eudoxus' now-lost writings to create his poetic description of the sky and so he gives us a constellation-by-constellation guide to Eudoxus' sky. But when Hipparchus studied the poem 150 years later he was puzzled. The sky according to Aratus and Eudoxus was not one they could ever have seen. Taking precession into account, they included constellations that were not visible to them when and where they lived, and they omitted some of the constellations that were visible. Ovenden's analysis of the poem indicates that it describes a sky that would have been visible at latitudes between 34.5 and 37.5 degrees north at a time between about 3400 and 1800 BC – very similar to the time and place we have deduced from the ancient constellation maps as well.[18]