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Jean-René Roy
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Introduction

As the dome shutters begin to close, they [coyotes] emit a high-pitched squeal that every coyote within a three-mile radius answers with a howl. Their primeval lamentations play a fitting coda to a night of solitude with the stars, the dome, and the slowly turning telescope.

Allan Sandage[1]

To learn to observe and to depict in a science is to acquire at once an ethos and a way of seeing.

Lorraine Daston and Peter Galison[2]

In one sense, that theory of the spiral nebulae to which many lines of recently obtained evidence are pointing, cannot be said to be a modern theory. There are few modern concepts which have not been explicitly or implicitly put forward as hypotheses or suggestions long before they were actually substantiated by evidence.

Heber D. Curtis[3]

How Are Images Discovery Engines?

Images of galaxies are at the core of this book (Fig. 0.1, see Plate 6.3). I set the course by showing how images have been used for discovery and to further research, with a particular emphasis on their link to knowledge and trailblazing roles in the unearthing of natural processes.

Troublesome Images

Images that we so naturally use as conveyors of information were not always accepted so easily. Walking nowadays along the streets and boulevards of bustling Istanbul in modern

1 A. R. Sandage, *Centennial History of the Carnegie Institution of Washington, Volume I: The Mount Wilson Observatory*, Cambridge: Cambridge University Press, 2004, p. 195.
2 L. Daston and P. Galison, *Objectivity*, New York: Zone Books, 2007, p. 367.
3 H. D. Curtis, Modern Theories of the Spiral Nebulae, *Journal of the Washington Academy of Sciences*, 1919, Vol. 9, p. 217.

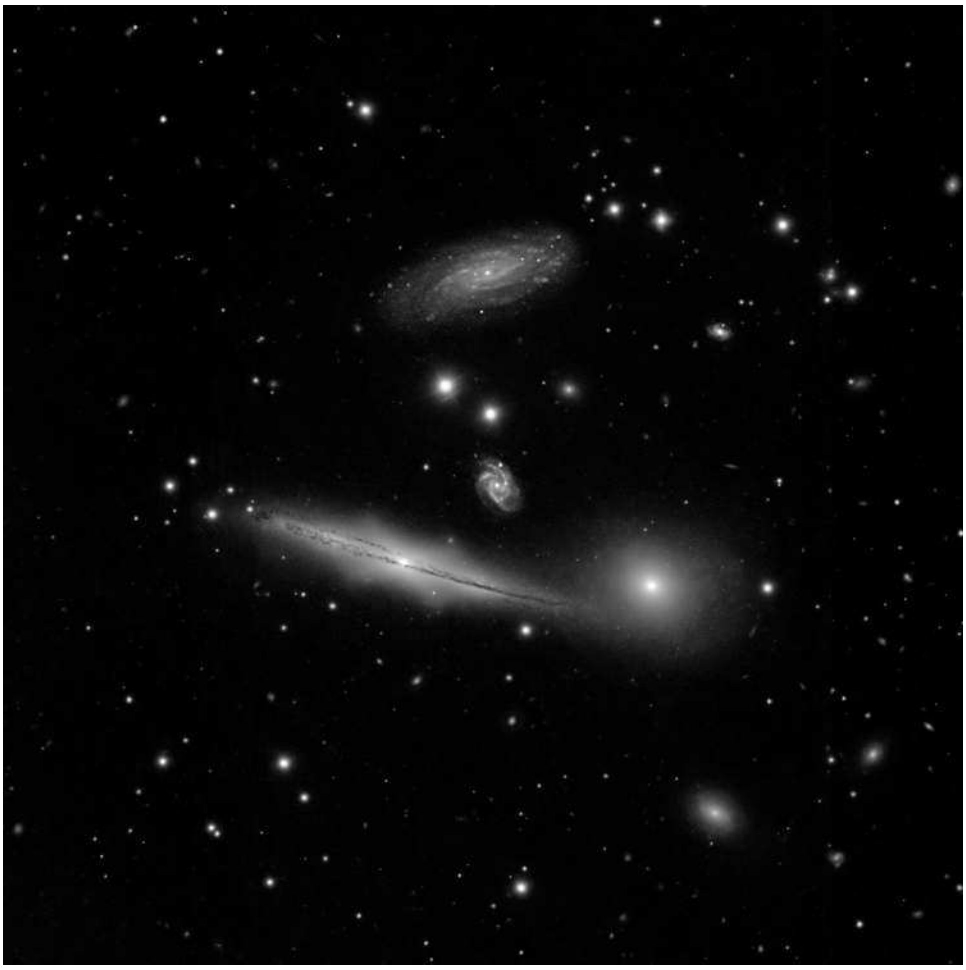

Fig. 0.1 Hickson compact group 87, about 400 million light-years away in the constellation Capricornus. The group shows the main morphological types of galaxies: spirals and ellipticals. Viewed from the same distance, the Milky Way would look like the tilted spiral at the top of this image. Credit: Gemini Observatory.

Turkey, it is hard to imagine that thirteen centuries ago a battle about images shook the ancient city to its societal underpinnings. These were the times of the iconoclasts, those who opposed religious images and who destroyed them. Anecdotal history of Byzantium reports that the first iconoclast emperor Leo III (c. 685–741) not only closed the imperial university, but also had it burnt down along with the library and its professors. Historians have shown that the rise to political power of the iconoclast regime and oligarchy in the eastern Byzantium Empire during the eighth century triggered a decadent period for Greek science. Although the burning story is considered apocryphal, it suggests that the alliance between images, knowledge and the freedom to search for knowledge have deep roots in human intellectual history. "No icons. No Science."[4]

Images of celestial objects are unlikely objects of veneration; making and studying astronomical images have rarely been controversial. Nevertheless, the association between the night sky and images runs deep. For thousands of years, humans have associated the patterns of stars in the sky with mythological figures for mnemonics and also for expressing their awe at the mysterious celestial vault. "By connecting dots with lines and parts with wholes, relations and structures appeared. This marvel had been well known since ancient times, at least ever since constellations of bears, angels, heroes, and swans were first marked out in the sky."[5] Constellations are images for the mind, and at the same time a tool to assign order in the sky while inventing personages or beasts for dreams and imagination. The perpetuity of the use of constellations and asterisms, from Antiquity to our times, is a testimony to the enduring conceptualizing power of images.

As in other fields of scientific investigation, astronomical images have generally been considered an accepted, and even required, procedure to report on the nature of things. I will show that there can be a tortuous path between seeing something and realizing what it really is or where it is. Images are a tool of discovery, but are not necessarily self-evident. The scientific apparatus used to take or reproduce images helps us to see things in new, sometimes revolutionary, ways. Scientific images are also an effective means to share information with other scientists and the public. This is a theme that has been well studied for other sciences, for example in geology by British geologist and historian Martin J. S. Rudwick.[6]

Both the discovery process and the sharing are at the root of the creation of the compendium of images, the scientific atlas.[7] In an atlas, pictures are put into a framework. As I will demonstrate, the diversity of form and morphology of galaxies allows their images to be put side by side in an organized series. As exemplified by the works of German naturalist Ernst Haeckel (1834–1919), the juxtaposition of images does not necessarily record an evolution but a continuity or transition in physical processes or environmental effects.[8] This is a theme that we will come back to in the later parts of the book.

Let us set the scene by examining the epitome of a discovery image in nineteenth-century astronomy.

Seeing Spirals

In the late eighteenth century, astronomers William and Caroline Herschel had found "nebulae" to pepper the sky in almost all directions. German naturalist and explorer Alexander

[4] E. Nicolaidis, *Science and Eastern Orthodoxy: From the Greek Fathers to the Age of Globalization*, Baltimore: Johns Hopkins University Press, 2011, pp. 40–53.
[5] O. W. Nasim, *Observing by Hand: Sketching the Nebulae in the Nineteenth Century*, Chicago: University of Chicago Press, 2013, p. 155.
[6] M. J. S. Rudwick, The Emergence of a Visual Language for Geological Science 1740–1840, *History of Science*, 1976, Vol. XIV, pp. 149–195.
[7] L. Daston and P. Galison, The Image of Objectivity, *Representations*, No. 40, Special Issue: Seeing Science (Autumn, 1992), University of California Press, pp. 81–128.
[8] O. Breidbach, *Visions of Nature, The Art and Science of Ernst Haeckel*, Munich: Prestel Publications, 2006, p. 24.

von Humboldt (1769–1859) was a visionary scholar. Commenting on the nature of these "nebulae," he boldly coined the expression "island-universes," a magnificent and visually evocative concept.[9] In his view, the Milky Way was a giant system of stars that seen from a great distance would just appear like one of the many "nebulae" reported by astronomers. The concept had already been explored in 1755 by his fellow countryman, philosopher Immanuel Kant (1724–1804), who mused over the existence of other universes just like our Milky Way (Chapter 5).[10] Both men were fantasizing: neither Kant nor von Humboldt had any scientific basis for their daring concept. As per Heber Curtis's quote at the start of this introduction, it was a hypothesis explicitly put forward long before it was actually substantiated by evidence.

About a century after Kant proposed his hypothesis, an Irish gentleman was about to make a giant leap in probing the "islands" of the cosmic sea. He did it by producing stunning hand-drawn portraits of the numerous and then still mysterious foamy patches popping up across the whole sky. On a cool and clear night in the spring of 1845, there may have been some howling wolves, and certainly some squealing wheels moving the new cantankerous machine at Birr Castle, Ireland. William Parsons, the Third Earl of Rosse, was using a new giant telescope he had just built and put into operation. Parsons had been observing a "nebula" in the constellation of Canes Venatici. The sidereal cloud he was examining was already known as listing 51 in the catalogue of French comet chaser Charles Messier. Carefully looking through his powerful instrument, Parsons noticed this time something very peculiar: the "nebula" had an overall pattern that appeared like a set of winding arms, "an arrangement of curved branches, which cannot well be unreal, or accidental."[11]

Scrutinizing what we now know to be a large galaxy located at about 23 million light-years, Parsons had come across a fundamental shape of galaxies. That night he had discovered a spiral structure (Fig. 0.2). British science historian John North (1934–2008) remarked that Parsons "did not fully appreciate what he had found for some time."[12] However, when Rosse presented his drawings to the British Association for the Advancement of Science, John Herschel made a big deal of them; it must surely have excited the lord. Today, we know that spirality betrays a pattern of subtle motions generated by a dynamic instability of stars and gas clouds orbiting in the gravitational potential of large disk-shaped galaxies.

During the following 30 years, William Parsons and Birr Castle's skillful observers catalogued thousands of "nebulae." The drawings of "nebulae" executed by the Parsonstown's observers have made history (Chapter 2). Astrophotography later showed that most of their hand-made sketches or portraits were generally correct depictions of the cosmic objects they viewed through the eyepiece of the Leviathan (Chapter 3). Yet neither the Earl of Rosse nor his observers had even the slightest idea of what these objects really were. They were also unaware that, soon following in their footsteps, astronomers would enlarge the size of the universe by unimaginable proportions.

[9] A. von Humboldt, *Cosmos: A Sketch of the Physical Description of the Universe*, New York: Harper & Brothers, 1866.
[10] I. Kant, *Universal Natural History and Theory of the Heavens* (translated by Ian Johnston), Arlington: Richer Resources Publications, 2008.
[11] C. Parsons (editor), *The Scientific Papers of William Parsons, Third Earl of Rosse 1800–1867*, London, 1926; Cambridge: Cambridge University Press, 2011, p. 116.
[12] J. North, *Cosmos: An Illustrated History of Astronomy and Cosmology*, Chicago: University of Chicago Press, 2008, p. 592.

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Fig. 0.2 Early sketch of spiral "nebula" Messier 51 made by William Parsons in April 1845 (compare with Fig. 2.10a). The Whirlpool Galaxy is located at about 23 million light-years. Courtesy of Wolfgang Steinicke.

A Rapidly Expanding Universe

Coming 2,000 years after Greek astronomer Aristarchus of Samos (c. 310–230 BC), Polish astronomer and mathematician Nicolaus Copernicus (1473–1543) had blown away the size of the Ptolemaic universe by proposing the heliocentric model for the solar system. Copernicus was attempting to solve the inconsistencies of the Ptolemaic model that had placed the Earth at the center of the universe. Instead, Copernicus had the Earth rotating on itself, the Moon circling it, and the tandem in revolution around the Sun along with the five other visible planets. Like Aristarchus, he positioned the fixed stars as other suns at such great distances that they appeared to us as just faint points of light. While the Ptolemaic universe had a size 10,000 times the size of the Earth, Copernicus had it at least billions of times larger.[13]

During the first decades of the twentieth century, our cosmological perspective was again dramatically overturned in the wake of the works of several European and American astronomers. Unlike Copernicus, these astronomers were not trying to solve tricky celestial mechanics issues. Working collectively and competitively Heber Curtis (1872–1942), Ernst Öpik (1893–1985), Knut Lundmark (1889–1958), Vesto Slipher (1875–1969), Harlow Shapley (1885–1972), Edwin Hubble (1889–1953) and Milton Humason (1890–1972)

[13] A. Van Helden, *Measuring the Universe*, Chicago: University of Chicago Press, 1985, pp. 28–40.

were trying to determine the distance to intriguing celestial 'foamy patches' (Chapter 5). In doing so, they unveiled the world of galaxies in a sequence of stunning observational findings derived mainly from images obtained with a new generation of powerful telescopes.

By bringing out the world of galaxies, modern astronomers exploded the volume of the Copernican universe by at least 10^{15} times, or one million billion times. The distances to island-universes were found to be colossal, measured in millions, even billions of light-years, millions of times further away than any of the stars we see at night. The light-year is a commonly used unit of astronomical distance, not of time as its name might suggest. It is the distance travelled by light in one year at the velocity of 299,792,458 meters per second; this is equivalent to 9.46×10^{12} km. The new cosmological findings congealed rapidly during the first decades of the twentieth century through a succession of other unexpected observations. It was realized that the universe was not only gigantic but also almost empty. Indeed, if one took all the matter of the observable universe and collapsed it into a pancake-shaped disk with the density of water, the thickness of this flat universe would be only one millimeter! As French mathematician and writer Blaise Pascal (1623–1662) wrote in *Pensées* of 1670, "Through space the universe grasps me and swallows me up like a speck; through thought I grasp it."

More surprises came. The biggest one: the universe is expanding (Chapter 5). Moreover, one strange property does not come up alone. During the 1930s, astronomers found out with puzzlement that the dominant form of matter in the universe is invisible. Galaxies are decoys for something that is unseen but more pervasive, which is weaving the fabric of cosmic space. Because this invisible mass does not emit or absorb light, it was named dark matter. I will show how images help unravel these surreal discoveries.

These latest developments came about very quickly, resulting from observations by inquisitive minds using a succession of ever more powerful telescopes. However, the discovery of galaxies has been an amazing odyssey. Again, images were the bonfires lighting the path.

Tools of Vision and of Measurements

The appearance of vision in living organisms and the evolution of the eye have been remarkable processes. The retina of the human eye is the surprising achievement of some billions years of life evolutionary processes. Seven hundred million years ago, animals developed the light-sensitive protein opsin, which captures light. Since then, vision has taken multiple forms and provided animals of all kinds with a most efficient advantage.[14,15] Aeons later, humans find themselves equipped with a liquid ball, a flexible soft lens, and 125 million photosensitive cells feeding a brain powerfully adapted for vision. Vision has provided us with an added capacity to adapt and survive, as well as to be creative and innovative enough to find stars, nebulae and explore the extragalactic universe. All this because we have eyes

14 R. Dawkins, *The Blind Watchmaker*, New York: W. W. Norton & Company, 1996.
15 Extinct trilobites had solid eyes made of calcite. See L. Browers, Animal Vision Evolved 700 Million Years Ago, *Scientific American Blogs*, November 20, 2012.

assisted by a powerful brain to process the optical signals and the billions of photons that continuously hit the retina.

We observe, astronomers observe. A simple statement attributed to the American baseball player Yogi Berra (1925–2015) is most relevant: "You can observe a lot by just watching." Historians of science Lorraine Daston and Peter Galison set this out in more scholarly words: "Perceptions, judgments, and, above all, values are calibrated and cemented by the incessant repetition of minute acts of seeing and paying heed."[16]

Curiously, the topic of scientific observation itself has not received that much attention from historians of science. Hence the fine collection of essays assembled by Lorraine Daston and Elizabeth Lunbeck is quite unique and most enlightening. The essays show the evolution of the meanings and practices of observing and experimenting from antiquity to the early twentieth century.[17] Learning to observe and to depict meant to acquire an ethos and a new way of seeing, as Daston explained. The methods of scientific observations as we know and understand them are relatively recent. Even during this period, they have evolved significantly, going initially from long lists and tabulations to include, with time, more details on set-ups, environments and conditions, bringing us finally to the modern-day metadata system. "By the turn of the eighteenth century, 'observation' had become an essential practice in almost all of the sciences, not just astronomy, meteorology, and medicine – and the complement and supplement of 'experiment'."[18] As I will show, the opening of the world of galaxies benefited from this maturing process and pushed the cognitive demands of observing. Images, obtaining and interpreting them, played a crucial role in the deep transformation of astronomical observing, from the time of Galileo telescopic viewing to modern-day 'machine' science.

Working Objects

As finely described and analyzed by Harvard University historian Peter Galison, scientists have been very creative at developing and using a whole arsenal of machines. In his monumental *Image and Logic*, Galison contrasts the visual and logical approaches of the scientific method. One tradition aims at producing "images of such clarity that a single picture can serve as evidence for a new entity or effect."[19] Against imaging, Galison contrasts the "logic tradition" where electronic devices, amassing signals, act as counting machines instead of picturing machines. In all fields of science, quantitative measurements are an essential basis for assembling factual data in order to identify processes, reconstruct behaviors and establish trends. The two approaches complement each other.

In the battery of tools for observing and measuring, images and the ways to record them are outstanding. "Part of the *déformation professionnelle* of scientific observers is a

[16] L. Daston and P. Galison, *Objectivity*, New York: Zone Books, 2007, p. 367.
[17] L. Daston and E. Lunbeck (editors), *Histories of Scientific Observation*, Chicago: University of Chicago Press, 2011.
[18] L. Daston, The Empire of Observation, 1600–1800, in *Histories of Scientific Observation*, L. Daston and E. Lunbeck (editors), Chicago: University of Chicago Press, 2011, p. 85.
[19] P. Galison, *Image and Logic: A Material Culture of Microphysics*, Chicago: University of Chicago Press, 1997, p. 19.

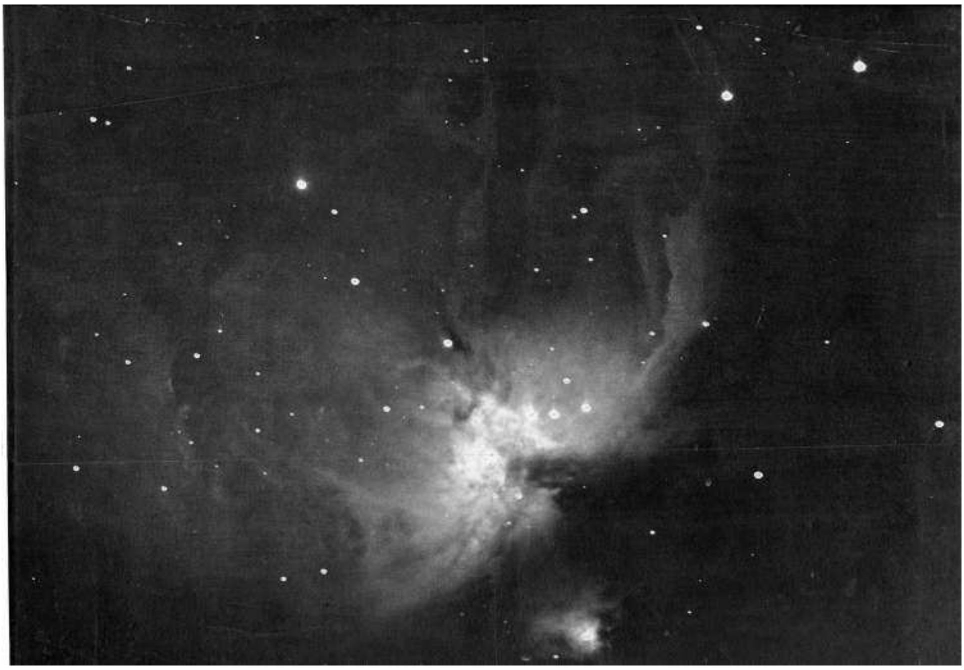

Fig. 0.3 Orion Nebula photographed with the 36-inch telescope by Andrew Common in 1883. Credit: Institute of Astronomy, University of Cambridge.

near-obsessive preoccupation with their objects of inquiry."[20] What is captured in an image can often be measured and put into graphic forms, or non-representational pictures, to summarize and convey information as effectively as possible (Chapter 4).[21] Commenting on Ernst Haeckel's experience of nature, Olaf Breidbach writes, "The very act of looking at nature was the best way of understanding it. Illustrations were not simply images of nature – they were the very embodiments of scientific knowledge. And a scientist was someone who illustrated his observations of nature in such a way as they could be shared by those not in a position to carry out discoveries for themselves."[22] The illustrations become scientific working objects.

"Working objects can be atlas images, type specimens, or laboratory processes – any manageable, communal representative of the sector of nature under investigation. No science can do without standardized working objects, for unrefined natural objects are too quickly particular to cooperate in generalizations and comparisons."[23] In astronomy, examples of working objects are archetypal objects such as the Orion Nebula (Fig. 0.3), the "great galaxy" in Andromeda (Fig. 0.4, Plate 1.1), the Omega Centauri globular cluster (Fig 0.5),

[20] L. Daston, On Scientific Observation, *ISIS*, March 2008, Vol. 99, No. 1, pp. 97–110, p. 107.
[21] E. R. Tufte, *The Visual Display of Quantitative Information*, Cheshire CT: Graphics Press, 1983.
[22] O. Breidbach, *Visions of Nature, The Art and Science of Ernst Haeckel*, Munich: Prestel, 2006, p. 20.
[23] L. Daston and P. Galison, *Objectivity*, New York: Zone Books, 2007, p. 19.

Fig. 0.4 Messier 31, the Andromeda Galaxy, imaged with the Spitzer Infrared Space Telescope. The image shows the galaxy at a wavelength of 24 microns in the mid-infrared. Credit: NASA/JPL-Caltech/Karl Gordon.

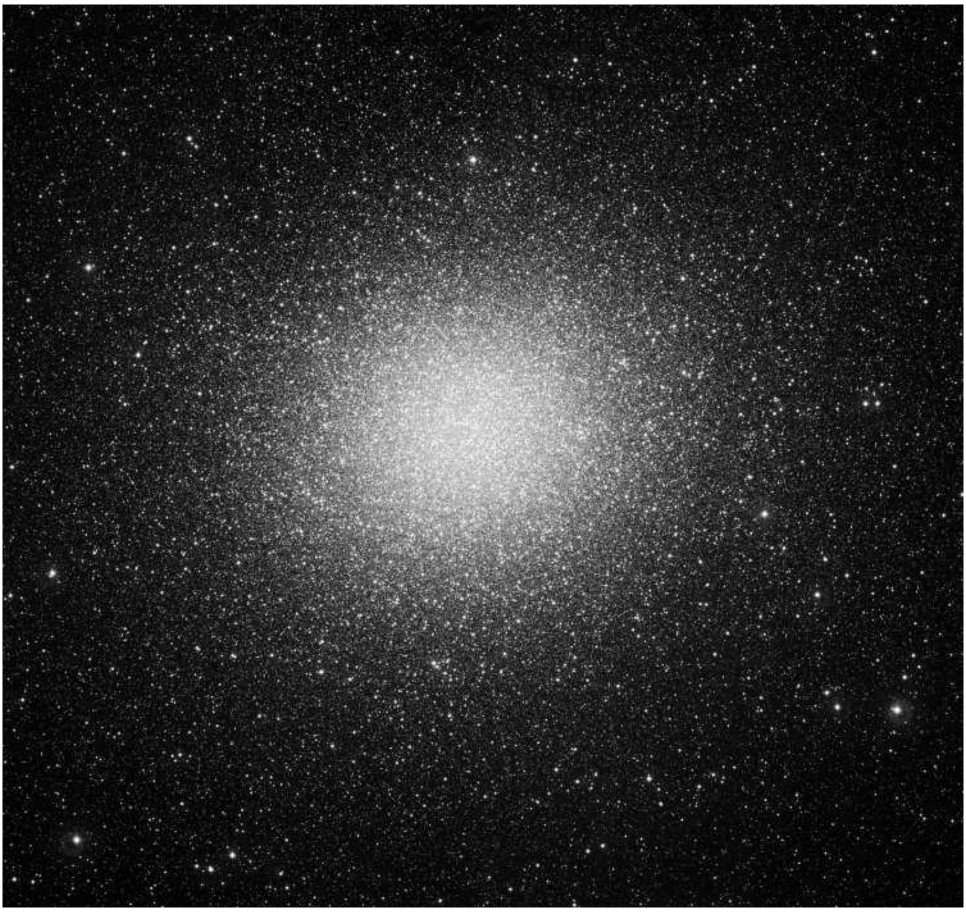

Fig. 0.5 Center of globular cluster Omega Centauri. The cluster is about the size of the full Moon in apparent size. Credit: ESO.

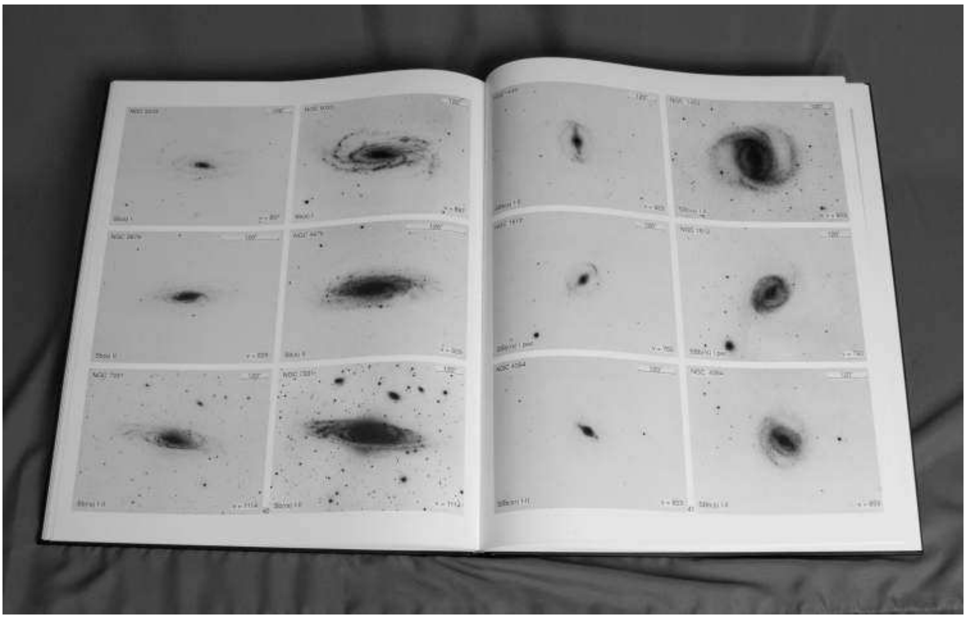

Fig. 0.6 Two pages of the NASA *Atlas of Galaxies* by Sandage and Bedke (1988). Courtesy of NASA Scientific and Technical Information Division.

the Sun and several other objects of the northern and southern celestial hemispheres. Image compendia, in particular atlases of galaxies, are other forms of working objects (Fig. 0.6). Non-representative images can also be working objects. Hertzsprung–Russell diagrams, which distribute stars of different luminosities as a function of their colours, have been powerful working objects to help understand the evolution of stars. Comparable diagrams have been created to describe and separate classes of galaxies. Working objects are the material from which concepts are developed and applied to broader classes of objects.

Images at Work

The image tradition is the center of our attention. Several groundbreaking images helped to unravel the world of galaxies, showing evidence for a new entity or effect. As a conducting thread of the book, I will present several noteworthy images. Transformational images, like Lord Rosse's first drawing of Messier 51, or the photographic plates obtained by Edwin Hubble identifying variable stars in the Great Andromeda Nebula, are not necessarily spectacular from an "aesthetic" viewpoint. Actually they are often quite bland to the unfamiliar eye. Furthermore, what appears on an image may not be at all obvious; instead it may act as evidence for something thus far unknown or poorly understood, for example the map of the distribution of galaxies in the Coma cluster and Virgo cluster of galaxies, first by William Herschel in 1785, then by Fritz Zwicky 150 years later. Only a trained eye will notice the unusual concentration and relative symmetry of these systems of galaxies.