Visual Astronomy

A guide to understanding the night sky

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To Demetri J, Demetri W, Maria A, Marko W, and Zoe M
And to Shelley A for making it all possible.

Contents

Preface

Successful space missions and technological advancements in communications have, in a way, brought the Cosmos closer to us. The data from various space missions are readily available to the public, and reliable sources offer a wealth of information including coordinates, distances, magnitudes and other properties of astronomical objects. Also, a quick Internet search would show a wealth of images of astronomical objects, near and far. There are beautiful images of the Sun, of galaxies and of nebulae that have inspired many artists, and understandably so. Some of these images are artworks in their own right! In terms of backyard astronomy, technological advances bring us affordable telescopes, with cameras and software that make it very easy to point the telescope to a celestial object and observe or photograph it.

This book is intended for a general audience, with no special background in mathematics or science. The main objective of the book is to provide a concise and self-contained introduction to the basic concepts of observational astronomy. The intent is to help the reader understand the information presented in various resources, and what this information tells us about the motion patterns and appearance of the night sky.

The approach I have adopted is conceptual and mostly qualitative, and the chapters are self-contained as much as possible. Relevant quantitative aspects are included in the appendices for readers who would be interested in numerical specifics. The discussion is more focused on what is accessible to visual observation, primarily members of the Solar System and visible stars. In the case of stars, I have included discussion of absorption spectra, and made quick mention of the wealth of information that can be extracted. I believe it is important to make the reader aware of the method, at least to the level of dispelling the mystery/misconception surrounding these issues.

As is the case with books on astronomy, the distances in all diagrams are not to scale, and the numbers, including properties of nearby stars, are revised frequently. There is little one can do about the scale, other than reminding the reader. Regarding the numerical values, I have made an effort to indicate the approximate nature of the quantities listed.

This book originated from my lecture notes in introductory astronomy classes and practical observation assignments. In preparing the book I had the benefit of listening to students' questions, and learning something about their 'own universe'. In my experience as a teacher, the most encouraging sign is when the student begins to ask questions. I would consider my task successfully accomplished if, for each answer the reader finds in this book, a new question is created in his/her mind.

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Author biography

Panos Photinos

Panos Photinos is a professor of physics at Southern Oregon University (SOU), where he teaches Introductory Astronomy, Observational Astronomy and Cosmology. Prior to joining SOU in 1989 he held faculty appointments at the Liquid Crystal Institute, Kent, Ohio; St. Francis Xavier, Antigonish, Nova Scotia, Canada; and the University of Pittsburgh, Pennsylvania. He was visiting faculty at the University of Sao Paulo, Brazil; the University of Patras, Greece; Victoria University at Wellington, New Zealand; and the University of Melbourne, Australia. Panos completed his undergraduate degree in physics at the National University of Athens, Greece, and received his doctorate in physics from Kent State University, Kent, Ohio. He started naked-eye observations as a child in the Red Sea, and later upgraded to a pair of Merchant brass binoculars in Alexandria, Egypt, and in his homeland, the island of Ikaria, Greece. Ever since he has visited and stargazed from all five continents, and shared his fascination with the night sky with students of all ages. He lives near Mt Ashland where he enjoys the beautiful skies of Southern Oregon from his backyard with his wife Shelley. This is Panos' first book on Astronomy.

Chapter 1

Introduction

1.1 A brief survey of celestial objects and a sense of scale

This chapter provides a brief description of the various objects we see in the sky and some of the characteristics that distinguish them. The celestial objects that we see can be divided into two broad categories: objects within our Solar System and objects beyond our Solar System.

Objects within our Solar System include the Sun, the Moon, the planets and their satellites, asteroids, comets, meteoroids and dust particles. The Sun is by far the largest object and source of energy in the Solar System. Planets and satellites are not self-luminous. They are visible because they reflect sunlight.

Objects beyond our Solar System include stars, nebulas and galaxies. These objects are visible because they emit enormous amounts of energy, up to billions of times more than the Sun. Most stars are actually solar systems of their own, with planets and probably satellites, asteroids, comets, etc. The following is a brief discussion of some characteristics of objects in each category, and how they could be distinguished.

Members of the Solar System are among the brightest in the sky. At their brightest, the naked eye planets (Mercury, Venus, Mars, Jupiter and Saturn) appear brighter than any of the ordinary stars. This is the result of the proximity of the planets to Earth. In addition to the high apparent brightness, the planets seem to follow paths within a narrow zone in the sky, which runs along the familiar constellations of the *zodiac*. Therefore the Sun, Moon and planets will never be seen in the Big Dipper or Southern Cross. Some of the smaller objects, e.g. comets, may stray far beyond the zodiac.

Another way that can help distinguish planets from stars is 'twinkling'. Twinkling, or scintillation, is a result of light travelling through the Earth's atmosphere. Twinkling becomes more noticeable when the apparent (not the actual) size of the object (planet/star) is smaller. The Moon does not twinkle because it has a large apparent size. Stars appear to 'twinkle' more than planets because star distances are

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so large that they appear as 'points' while planets are much closer to Earth and appear as 'disks'. Scintillation is also more noticeable if the object (planet/star) is low on the horizon because the light received by the observer travels obliquely through the atmosphere, thus the light interacts with a thicker layer of atmosphere.

Due to their orbital motion around the Sun, the distance of planets from Earth and their location relative to the Sun varies in cycles over the year(s). This variation causes noticeable changes in their apparent brightness in the night sky. The variation in brightness is particularly noticeable in the case of Venus and of Mars whose orbits bring them closer to Earth than any other planet. For smaller objects, such as comets, the variation in brightness can be noticeable over a few weeks. Meteors are bright streaks caused by comparatively small sized objects (as small as dust particles in the case of meteor showers) burning off in the Earth's atmosphere. The brightening of meteors is brief and usually spectacular.

The apparent brightness of stars can also change. For some stars the change repeats in cycles of a few days to several months. Contrary to the variation observed in planets, the variation in stars does not involve their distance to Earth. The variation of star brightness can be the result of different processes. For instance, repeated brightening can indicate the existence of a companion star. Also, repeated explosions are known to occur (the so-called *novae*) or terminal explosions marking the end of a star's life (*supernovae*) and other complicated processes that are beyond the scope of this book.

1.2 The size of objects in the Solar System

Within the Solar System, the largest and brightest object is the Sun, with a diameter of about 1.4 million km. The Earth's diameter is approximately 13 000 km. Jupiter is the largest of the planets, with a diameter approximately 11 times larger than the Earth's diameter. Asteroids, comets and meteoroids are much smaller. Ceres, the largest asteroid, has a diameter of about 960 km. Ceres is now considered a dwarf planet like Pluto. Figure 1.1 shows the Sun and the planets to scale. The smaller objects have irregular shapes, while the larger objects assume a more or less spherical shape.

According to the International Astronomical Union (IAU) the distinction between planets and dwarf planets is that planets have enough gravity to attract all nearby debris and clear the space surrounding their orbits. The term debris is used to indicate objects of irregular shape, ranging from dust sized to many kilometers. Contrary to planets, their shapes are very irregular. This is due to their smaller mass and size. Objects with a diameter smaller than approximately 500 km do not have enough gravity to compress them into a roughly spherical shape, thus smaller objects have irregular shapes.

1.3 Objects beyond the Solar System

A few thousand stars are visible to the naked eye under clear sky conditions and moonless nights, and at first sight it may be difficult to discern any patterns. Starting an observation before the sky becomes completely dark (usually about 1 hour after sunset for most locations) allows the observer to see only the brightest of the stars,

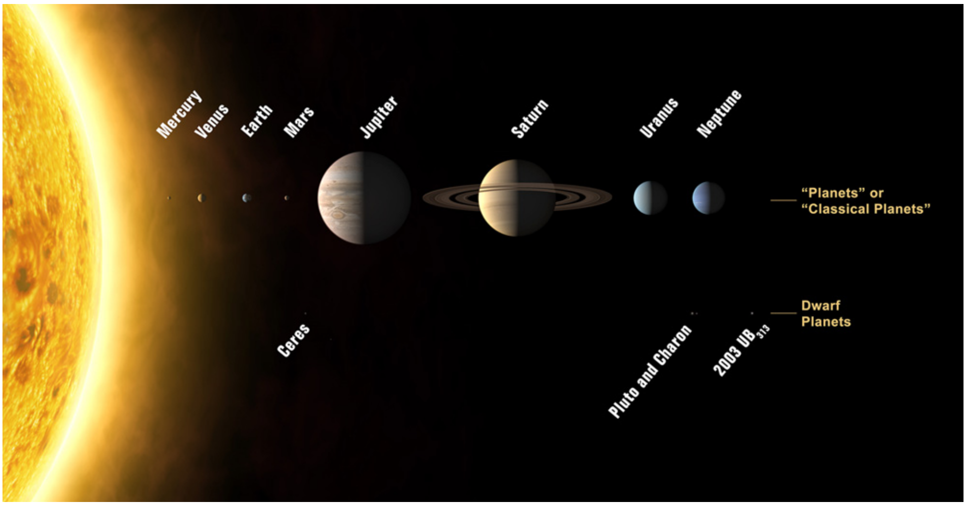

Figure 1.1. The Sun and planets. The sizes are to scale, but distances are not to scale. Credit: The International Astronomical Union/Martin Kornmesser, www.iau.org/public/images/detail/iau0603a/.

which serve as a good starting point for recognizing the usual star patterns, the familiar *constellations* and *asterisms*. These patterns can span a comparatively large area in the night sky. For example, the Pleiades or Seven Sisters (a group of stars, or asterism, in the constellation of Taurus) covers an area about two times larger than the apparent size of the full Moon. The constellation of Orion is about 50 times the apparent size of the full Moon.

The vast majority of the objects we see with the naked eye are stars. In terms of actual size, the diameter of ordinary stars is typically of the order of millions to hundreds of millions of kilometers. The use of high power telescopes reveals exotic objects, such as neutron stars, which are very small, approximately 20 km in diameter. Nebulae can be hundreds of trillions of kilometers in size. The Great Orion Nebula, visible to the naked eye, is about 120 trillion km across (about a million times larger than the Sun). Nebulae, such as the Monkey Head Nebula shown in figure 1.2, are huge star nurseries.

While vast, nebulae are still small compared to galaxies. For instance, the *Andromeda Galaxy* which is also visible to the naked eye, is roughly 10 000 times larger than Orion's nebula. By far, the largest star pattern in the sky is the *Milky Way* (MW). All the stars we see belong to our Galaxy, the MW, which appears as a faint band across the sky. It is clearly observable on moonless nights from both the Northern and Southern Hemispheres, running roughly from north–east to south–west around midnight in mid-July. Galileo was the first to report, in his pamphlet *Starry Messenger*, that the MW was actually 'nothing else but a mass of innumerable stars planted together in clusters'. The MW is a large group of stars (over 200 billion) forming a disk structure with spiral arms.

The Sun is an average sized star in the disk of the MW, closer to the edge than the center of the disk. The Sun completes one orbit around the center of the MW in about 250 million years. What we see as a band in figure 1.3 is the disk of the MW.

Figure 1.2. A portion of the Monkey Head Nebula (also known as NGC 2174), a region of active stellar formation. New-born stars are emerging from dust (center-right.) Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA), http://hubblesite.org/gallery/album/pr2014018a/.

Figure 1.3. The MW. Jupiter is above the MW. Credit: Bruno Gilli/ESO, http://www.eso.org/public/usa/images/milkyway/.

Under a clear sky in the Northern Hemisphere one can see another galaxy, the Great Galaxy in Andromeda (or M31), which is larger than the MW, containing an estimated one trillion stars. M31 is shown in figure 1.4. Because of its immense distance, M31 appears as a fuzzy speck of light. In the Southern Hemisphere one can observe two more galaxies, the so-called *Large and Small Magellanic Clouds* (LMC and SMC, respectively) which are roughly 100 times closer than M31. As their names suggest, the LMC and SMC, shown in figure 1.5, appear as thin clouds not

Figure 1.4. A ground based image of the Andromeda Galaxy. Credit: T Rector and B Wolpa (NOAO/AURA/NSF), http://hubblesite.org/newscenter/archive/releases/2012/04/image/c/.

Figure 1.5. The Large (top middle) and Small (top right) Magellanic Clouds from ESO's La Silla Observatory. Credit: ESO/Y Beletsky, http://www.eso.org/public/usa/images/la-silla-beletsky/.

just specks of light. Although the LMC and SMC appear more extended in the night sky than M31, they are actually much smaller than M31, each containing a few billion stars. They appear larger because they are much closer to Earth.

1.4 Distances of celestial objects

To appreciate the distances involved, we can start with our distance to the Moon, which is approximately 400 000 km (about 250 000 miles). Our distance to the Sun is approximately 400 times larger, which is about 150 million km (about 100 million miles). Compared to our distance to the Moon, the distance to the nearest star (Proxima Centauri) is 100 million times larger (about 40 trillion km). To avoid using huge numbers, astronomers use longer 'yardsticks' which will be introduced next.

Within the Solar System, it is common to use the *astronomical unit* (AU):

$$1 \text{ AU} = 150 \text{ million km.}$$

Beyond the Solar System we can use the *light year* (ly) which is the distance travelled by light in one year:

$$1 \text{ ly} = 9.4 \text{ trillion km.}$$

In terms of AU:

$$1 \text{ ly} = 63\,271 \text{ AU.}$$

The star *Proxima Centauri* is at a distance of 4.2 ly from the Sun, or 266 000 AU.

To obtain a feel for the vast distances between stars, the following comparison may be useful. It takes about 8 min for light from the Sun to reach us on Earth while it takes 4.2 years for light from Proxima Centauri to reach us on Earth. So, comparing our distance to the Sun and our distance to Proxima Centauri is like comparing eight minutes to 4.2 years.

In the above comparison we used 4.2 ly for the distance of the Sun to Proxima Centauri and also for the distance of Earth to Proxima Centauri. This interchange is legitimate because our distance to the Sun is so minute compared to our distance to Proxima Centauri. Obviously, adding or subtracting 8 min (light travel time from Earth to the Sun) to 4.2 years (light travel time to Proxima) does not make much of a difference.

The *parsec* (pc) is a commonly used unit comparable to the light year[1]:

$$1 \text{ pc} = 3.26 \text{ ly.}$$

Although the light year and parsec may appear enormous, multiples of these units are necessary to describe distances beyond our immediate stellar neighborhood in the MW. For example, the distance to M31 is about 2 million ly. This may sound like an enormous distance, but is small by cosmic standards. M31 is one of the nearest neighbors to the MW. The use of high power telescopes reveals objects at distances of billions of light years.

[1] For a definition of the parsec see appendices A and B.

Table 1.1. The distances of various objects from Earth.

Object	Distance from Earth
Moon	1.3 light seconds
Sun	8.3 light minutes
Proxima Centauri (nearest star)	4.2 light years
Sirius (brightest star in the sky)	8.6 light years
Pleiades star cluster	approximately 440 light years
Andromeda Galaxy	2.5 million light years
z8_GND_5296 (most distant galaxy at date of writing)	13.1 billion light years

Table 1.1 lists some distances from Earth that illustrate the wide range of magnitudes involved.

A significant difference between objects of the Solar System and stars is that due to the enormous distances involved, stars and other objects beyond the Solar System do not appear to move relative to each other. As a result, within a human lifetime, the star patterns in the night sky (what we generally call asterisms and constellations) appear unchanging. The star patterns that we see today appear similar to what the early Assyrian and Babylonian observers saw.

The fact that the star patterns appear unchanging does not mean that stars do not move. In fact the stars forming each constellation/asterism move independently of each other, typically with speeds of tens or hundreds of kilometers per second (tens or hundreds of thousands of kilometers per hour). To understand the situation it is important to recognize that what we perceive is not the relative distance of the stars, but the direction of our line of sight to the stars. The situation is analogous to comparing a high-flying jet plane traveling at 1000 km per hour and a bird flying at 10 km per hour. The plane appears to move much more slowly than a bird. Obviously the jet travels a larger distance than the bird each second, but our line of sight to the airplane shifts much more slowly because the airplane is much further away.

Because the distances to the stars are so immense the angle formed by our line of sight to a pair of stars does not change noticeably in the span of a human lifetime. Due to the Earth's rotation, the entire sky appears to move. But the relative positions of the stars with respect to each other remain the same and, as a whole, the star pattern appears unchanging.

Planets are much closer to the Earth than the stars, so their locations in relation to each other and to the stars shift noticeably. For the nearest planets (Venus, Mars and Mercury) the shift can be noticeable in a span of a few days. Being much closer than the planets, the shift of the Moon relative to the stars is noticeable over a few hours. In summary, the more distant the object, the smaller is its apparent shift in the sky.

Full list of references

Appendix E

A detailed and easy to follow stargazing guide for the entire sky can be found in:Moore P 2001 *Stargazing: Astronomy without a Telescope* 2nd edn (Cambridge: Cambridge University Press)

Constellation maps, figures, coordinates and transit times and other details useful in observational work are contained in:Bakich M E 1995 *The Cambridge Guide to the Constellations* (Cambridge: Cambridge University Press)

More advanced discussion of coordinate systems and spherical trigonometry equations can be found in:Roy A E and Clarke D 2003 *Astronomy: Principles and Practice* 4th edn (London: Taylor and Francis)

Birney D S, Gonzalez G and Oesper D 2006 *Observational Astronomy* (Cambridge: Cambridge University Press)

Introduction to the celestial sphere, Kepler's laws, the solar system, the physical properties of planets and stars, in a very accessible level of discussion can be found in:Chaisson E and McMillan S 2013 *Astronomy Today* 8th edn (Reading, MA: Addison-Wesley)

Koupelis T 2014 *In Quest of the Universe* 7th edn (Jones and Bartlett)

Arny T T and Schneider S E 2013 *Explorations: Introduction to Astronomy* 7th edn (New York: McGraw Hill)

For a more advanced introduction, see:Roy A E and Clarke D 2003 *Astronomy: Principles and Practice* 4th edn (London: Taylor and Francis)

Holliday K 1999 *Introductory Astronomy* (John Wiley & Sons)

Optics of telescopes and imaging, as well as an introduction to methods of analysis, in a level suitable for students intending to pursue a major in astronomy are discussed in:Kitchin C R 2013 *Telescopes and Techniques* 3rd edn (Berlin: Springer)

Birney D S, Gonzalez G and Oesper D 2006 *Observational Astronomy* (Cambridge: Cambridge University Press)

An interesting and enjoyable account of the development of calendars and measuring time is given in:Steel D 1999 *Marking Time: The Epic Quest to Invent the Perfect Calendar* (John Wiley & Sons)

Two classic works of popularized astronomy:Rudaux L and De Vaucouleurs G 1962 *Larousse Encyclopedia of Astronomy* (Prometheus Press)

Flammarion C 1964 *The Flammarion Book of Astronomy* (Simon & Schuster)

A scholarly work on the origin and meaning of star names is the re-edition of the classic work: Allen R H 1963 *Star-names and Their Lore and Meaning* Dover Edition