Appendix 1

Astronomical Coordinate Systems

A basic requirement for studying the heavens is being able to determine where in the sky things are located. To specify sky positions, astronomers have developed several coordinate systems. Each system uses a coordinate grid projected on the celestial sphere, which is similar to the geographic coordinate system used on the surface of the Earth. The coordinate systems differ only in their choice of the fundamental plane, which divides the sky into two equal hemispheres along a great circle (the fundamental plane of the geographic system is the Earth's equator). Each coordinate system is named for its choice of fundamental plane.

The Equatorial Coordinate System

The equatorial coordinate system is probably the most widely used celestial coordinate system. It is also the most closely related to the geographic coordinate system because they use the same fundamental plane and poles. The projection of the Earth's equator onto the celestial sphere is called the celestial equator. Similarly, projecting the geographic poles onto the celestial sphere defines the north and south celestial poles.

However, there is an important difference between the equatorial and geographic coordinate systems: the geographic system is fixed to the Earth and rotates as the Earth does. The Equatorial system is fixed to the stars, so it appears to rotate across the sky with the stars, but it's really the Earth rotating under the fixed sky.

The latitudinal (latitude-like) angle of the equatorial system is called **declination** (Dec. for short). It measures the angle of an object above or below the celestial equator. The longitudinal angle is called the **right ascension** (R.A. for short). It measures the angle of an object east of the Vernal Equinox. Unlike longitude, right ascension is usually measured in hours instead of degrees because the apparent rotation of the equatorial coordinate system is closely related to Sidereal Time and Hour Angle. Since a full rotation of the sky takes 24 h to complete, there are (360°/24 h) = 15° in 1 h of right ascension (Fig. A.1).

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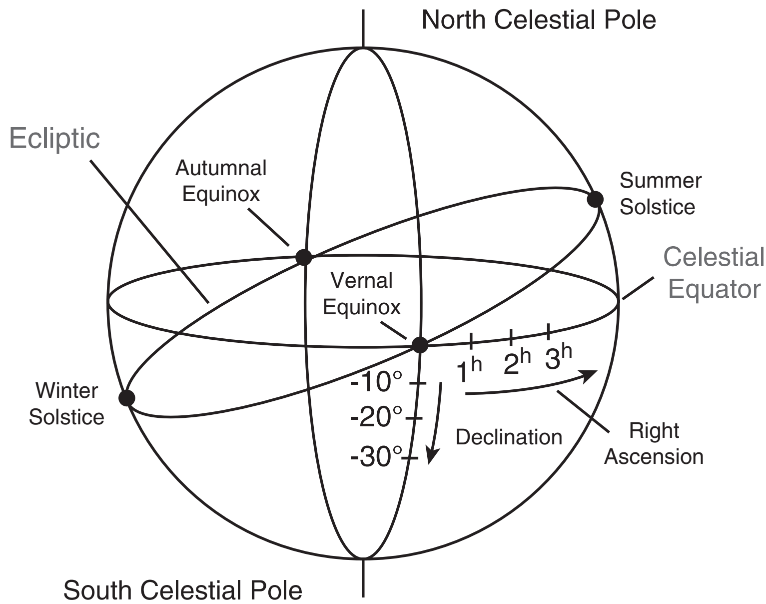

Fig. A.1 The equatorial coordinate system (Image courtesy of the author)

The Galactic Coordinate System

The galactic coordinate system has latitude and longitude lines, similar to what you are familiar with on Earth. In the galactic coordinate system, the Milky Way uses the zero degree latitude line as its fundamental plane. The zero degree longitude line is in the direction of the center of our galaxy. The latitudinal angle is called the galactic latitude, and the longitudinal angle is called the galactic longitude. This coordinate system is useful for studying the galaxy itself.

The reference plane of the galactic coordinate system is the disc of our galaxy (i.e. the Milky Way) and the intersection of this plane with the celestial sphere is known as the galactic equator, which is inclined by about 63° to the celestial equator. **Galactic latitude**, *b*, is analogous to declination, but measures distance north or south of the galactic equator, attaining +90° at the north galactic pole (NGP) and −90° at the south galactic pole (SGP).

Galactic longitude, *l*, is analogous to right ascension and is measured along the galactic equator in the same direction as right ascension. The zero-point of galactic longitude is in the direction of the Galactic Center (GC), in the constellation of Sagittarius; it is defined precisely by taking the galactic longitude of the north celestial pole to be exactly 123° (Fig. A.2).

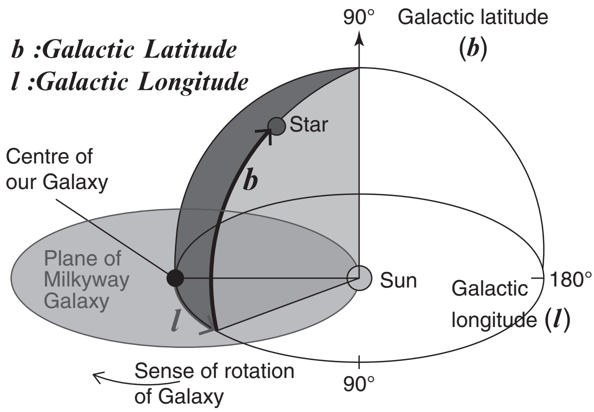

Fig. A.2 The galactic coordinate system (Image courtesy of the author)

Appendix 2

Magnitudes

The first thing that strikes even a casual observer is that the stars have different brightness – some are faint, some are bright, and a few are very bright. This brightness is called the magnitude of a star.

The origins of this brightness system are historical. All the stars seen with the naked eye were classified into one of six magnitudes, with the brightest being called a "star of the first magnitude" and the faintest a "star of the sixth magnitude". Since then the magnitude scale has been extended to include negative numbers for the brightest stars, decimal numbers used between magnitudes and a more precise measurement of the visual brightness of the stars. For instance, Sirius has a magnitude of −1.44, while Regulus has a magnitude of +1.36. Magnitude is usually abbreviated to m. Note that the brighter the star, the smaller the numerical value of its magnitude.

A difference between two objects of 1 magnitude means that the object is about 2.512 times brighter (or fainter) than the other. Thus, a first-magnitude object ($m = 1$) is 2.512 times brighter than a second-magnitude object ($m = 2$). This definition means that a first-magnitude star is brighter than a sixth-magnitude star by the factor 2.512 to the power of 5. That is a hundredfold difference in brightness. The naked-eye limit of what you can see is about magnitude 6 in urban or suburban skies. Good observers report seeing stars as faint as magnitude 8 under exceptional conditions and locations. The magnitude brightness scale does not tell us whether a star is bright because it is close to us or whether a star is faint because of its size or distance away. This classification only tells us the apparent magnitude of the object – that is, the brightness of an object as observed visually with the naked eye or with a telescope. A more precise definition is the absolute magnitude, M, of an object. This is defined as the brightness an object would have at a distance of 10 parsecs from us. It is an arbitrary distance deriving from the technique of distance determination known as parallax; nevertheless, it does quantify the brightness of objects in a more rigorous way. For example, Rigel has as an absolute magnitude of −6.7, and one of the faintest stars known, Van Biesbroeck's star, has a value of +18.6.

Of course, the explanations above assume that we are looking at objects in the visible part of the spectrum. There are several further definitions of magnitude that rely on the brightness of an object when observed at a different wavelength, or waveband, the most common being the U, B and V wavebands, corresponding to the wavelengths 350, 410 and 550 nanometers, respectively. There is

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also a magnitude system based on photographic plates: the photographic magnitude, m_{pg}, and the photovisual magnitude, m_{pv}. Finally, there is the bolometric magnitude, m_{bol}, which is the measure of all the radiation emitted from the object.[1]

Objects such as nebulae and galaxies are **extended objects**, meaning that they cover an appreciable part of the sky: in some cases a few degrees, in others only a few arcminutes. The light from, say, a galaxy is therefore "spread out" and thus the quoted magnitude will be the magnitude of the galaxy were it the "size" of a star; this magnitude is often termed the **combined** or **integrated magnitude**. This can cause confusion because a nebula with, say, a magnitude of 8, will appear fainter than an 8th-magnitude star, and in some cases, where possible, the surface brightness of an object will be given. This will give a better idea of what the overall magnitude of the object will be.

Finally, many popular astronomy books will tell you that the faintest, or limiting magnitude, for the naked eye is around the 6th magnitude. This may be true for people who live in an urban location. But magnitudes as faint as 8 can be seen from exceptionally dark sites with a complete absence of light pollution. This will come as a surprise to many amateurs. Furthermore, when eyes are fully dark-adapted, the technique of averted vision will allow you to see with the naked eye up to three magnitudes fainter! Before you rush outside to test these claims, remember that to see really faint objects, either with the naked eye, or telescopically, several other factors such as the transparency and seeing conditions, as well as the psychological condition of the observer will need to be taken into consideration. Light pollution is the greatest evil here.

[1]It is interesting to reflect that *all* magnitudes are in fact not a true representation of the brightness of an object, because every object will be dimmed by the presence of interstellar dust. All magnitude determinations therefore have to be corrected for the presence of dust lying between us and the object. It is dust that stops us from observing the center of our Galaxy.

Appendix 3

Stellar Classification

For historical reasons, a star's classification is designated by a capital letter in order of decreasing temperature:

O B A F G K M L R N S

The sequence goes from hot blue star types O and A to cool red stars K, M and L. In addition, there are rare and hot stars called Wolf–Rayet stars, class WC and WN, exploding stars Q, and peculiar stars P. The star types R, N and S, actually overlap class M, and so R and N have been reclassified as C type stars – the C standing for carbon stars. A new class has recently been introduced: the L class.[2] Furthermore, the spectral types themselves are divided into ten spectral classes from 0 to 9. A class A1 star is thus hotter than a class A8 star, which in turn is hotter than a class F0 star. Other prefixes and suffixes represent additional features of stars:

emission lines	e (also called f in some O type stars)
metallic lines	m
peculiar spectrum	p
a variable spectrum	v
a star with a blue or red shift in the line	q (for example P-Cygni stars)

For historical reasons, the spectra of the hotter star types O, A and B are sometimes referred to as **early-type** stars, while the cooler ones, K, M, L, C and S, are **late-type**. F and G stars are **intermediate-type** stars.

[2]These are stars with very low temperatures – 1900–1500 K. Astronomers believe these are brown dwarves.

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Appendix 4

Light Filters

One of the most useful accessories an amateur can possess is one of the ubiquitous optical filters. They were previously only accessible to professional astronomers. They are useful, but they still have limitations. Some of the advertisements in astronomy magazines show how they will make hitherto faint and indistinct objects sometimes burst into vivid observability.

What the manufacturers do not mention is that regardless of the filter used, you will still need dark and transparent skies for the use of the filter to be worthwhile. Don't make the mistake of thinking that using a filter from an urban location will always make objects become clearer. The first and most immediately apparent item on the downside is that in all cases, the use of a filter reduces the total amount of light that reaches the eye and often quite substantially. However, the filter helps observability by selecting specific wavelengths of light emitted by an object that may be swamped by other wavelengths. It does this by suppressing the unwanted wavelengths. This is particularly effective when observing extended objects, such as emission nebulae and planetary nebulae.

For emission nebulae, use a filter that transmits light around the wavelength of 653.2 nm, which is the spectral line of hydrogen alpha (Hα) and the wavelength of light responsible for the spectacular red color seen in photographs of emission nebulae. Some filters may transmit light through perhaps two wavebands: 486 nm for hydrogen beta[3] (Hβ) and 500.7 nm for oxygen-3 [OIII], two spectral lines which are very characteristic in planetary nebula. Use of such filters will enhance the faint and delicate structure within nebulae, and, from a dark site, they really do bring out previously invisible detail. Don't forget (as the advertisers sometimes seem to) that "nebula" filters do not usually transmit the light from stars. Thus, the background will be dark with only nebulosity visible which makes them impractical for observing stars, star clusters and galaxies unless they are associated with nebulosity as can often be the case.

[3]This filter can be used to view dark nebulae that are overwhelmed by the proximity of emission nebulae. A case in point is the Horsehead Nebula, which is incredibly faint, and swamped by light from the surrounded emission nebulosity.

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One kind of filter that helps in heavily light-polluted areas is the LPR (light pollution reduction filter), which effectively blocks out the light emitted from sodium and mercury street lamps, at wavelengths 366, 404.6, 435.8, 546.1, 589.0 and 589.5 nm. The filter will only be effective if the light from the object you want to see is significantly different from the light-polluting source. Light pollution reduction filters can be very effective visually and photographically, but remember that there is always some overall reduction in brightness of the object you are observing.

Whatever filters you decide on, it is worthwhile trying to use them before you make a purchase, especially because they can be expensive. Try borrowing them either from a fellow amateur or from a local astronomical society. You can then see whether the filter really makes any difference to your observing.

There is no doubt that modern filters can be an excellent purchase, but it may be that your location or other factors will prevent the filter from realizing its full potential or value for money. Most commercially available filters are made for use at a telescope and not for binoculars, so unless you are mechanically minded and can make your own filter mounts (and are happy to pay – two LPR filters could easily cost more than the binoculars), it's likely that only those observers with telescopes can benefit.

Appendix 5

Star Clusters

Open or **galactic clusters**, as they are sometimes called, are collections of young stars, containing anything from a dozen members to hundreds. A few of them, such as Messier 11 in Scutum, contain an impressive number of stars, equaling that of globular clusters (Fig. A.3.). Other, smaller groups appear little more than a faint grouping set against the background star field. Such is the variety of open clusters that they come in all shapes and sizes. Several are over a degree in size and their full impact can only be appreciated by using binoculars, as a telescope has too narrow a field of view. An example of such a large cluster is Messier 44 in Cancer. There are also tiny clusters, seemingly nothing more than compact multiple stars, as is the case with IC 4996 in Cygnus. In some cases, all the members of the cluster are equally bright, such as Caldwell 71 in Puppis, but there are others that consist of only a few bright members accompanied by several fainter companions, as is the case of Messier 29 in Cygnus. The stars which make up an open cluster are called **Population I** stars, which are metal-rich[4] and are usually found in or near the spiral arms of the galaxy.

The reason for the varied and disparate appearances of open clusters is the circumstances of their births. It is the interstellar material out of which stars form that determines both the number and type of stars that are born within it. Factors such as the size, density, turbulence, temperature, and magnetic field all play a role as the deciding parameters in star birth. In the case of **giant molecular clouds**, or GMCs, the conditions can give rise to both O- and B-type giant stars along with solar-type dwarf stars. In **small molecular clouds** (SMCs) only solar-type stars will be formed, with none of the luminous B-type stars. An example of a SMC is the **Taurus Dark Cloud**, which lies just beyond the Pleiades.

An interesting aspect of open clusters is their distribution in the night sky. Surveys show that although well over a thousand clusters have been discovered, only a few are observed to be at distances greater than 25° above or below the galactic equator. Some parts of the sky are very rich in clusters – Cassiopeia, and Puppis – and this is due to the absence of dust lying along these lines of sight, allowing us to see across the spiral plane of our galaxy. Many of the clusters mentioned here actually lie in different spiral arms and as you observe them, you are actually looking at different parts of the spiral structure of our galaxy.

[4] Astronomers call every element other than hydrogen and helium, metals.

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An open cluster presents a perfect opportunity for observing star colors (see Appendix 7: Star Colors). Many clusters, such as the ever and rightly popular Pleiades, are all a lovely steely blue color. On the other hand, Caldwell 10 in Cassiopeia has contrasting bluish stars along with a nice orange star. Other clusters have a solitary yellowish or ruddy orange star along with fainter white ones, such as Messier 6 in Scorpius. An often striking characteristic of open clusters is the apparent chains of stars that are seen. Many clusters have stars that arc across apparently empty voids, as in Messier 41 in Canis Major. Another word for a very small, loose group of stars is an **asterism**. In some cases, there may only be 5–6 stars within the group.

The previous section on open clusters dealt with groups of stars that were usually young, have an appreciable angular size and may have a few hundred components. **Globular clusters** are clusters that are very old, compact and may contain up to a million stars, and in some cases even more. The stars that make up a globular cluster are called **Population II** stars. These are metal-poor stars and are usually found in a spherical distribution around the galactic center at a radius of about 200 light years. Furthermore, the number of globular clusters increases significantly the closer one gets to the galactic center. This means that particular constellations that are located in a direction towards the Galactic bulge have a high concentration of globular clusters within them, such as Sagittarius, and Scorpius.

The origin and evolution of a globular cluster is very different from that of an open or galactic cluster. All the stars in a globular cluster are very old, so any star earlier than a G or F type star has already left the main sequence and is moving toward the red giant stage of its life. In fact, new star formation no longer takes place within any globular clusters in our galaxy, and they are believed to be the oldest structures in our galaxy. The youngest of the globular clusters is still far older than the oldest open cluster. The origin of the globular clusters is a scene of fierce debate and research with the current models predicting that the globular clusters may have been formed within the proto-galaxy clouds that eventually made up our galaxy.

There are about 150 globular clusters ranging in size from 60 to 150 light years in diameter. They all lie at vast distances from the Sun and are about 60,000 light years from the galactic plane. The nearest globular clusters, for example, Caldwell 86 in Ara, lie at a distance of over 6000 light years, and thus the clusters are difficult objects for small telescopes.

Appendix 6

Double Stars

Double stars are stars that look like a single star, but will resolve into two stars using either binoculars or a telescope. Many stars may appear as double due to them lying in the same line of sight as seen from the Earth, and this can only be determined by measuring the spectra of the stars and calculating their red (or blue) shifts. Such stars are called **optical doubles**. It may well be that the two stars are separated in space by a vast distance. Some, however, are actually gravitationally bound and may orbit around each other over a period of days or even years.

Many double stars cannot be resolved by even the largest telescopes, and these are called **spectroscopic binaries**, the double component only being fully understood when the spectra are analyzed. **Eclipsing binaries**, such as Algol (β Persei), are where one star moves in front of its companion during orbit, thus brightening and dimming the light observed. A third type is **astrometric binaries,** such as Sirius (α Canis Majoris), where the companion star may only be detected by its influence on the motion of the primary star.

The brighter of the two stars is usually called the **primary** star, whilst the fainter is called the **secondary** or **companion**. This terminology is employed regardless of how massive either star is, or whether the brighter is in fact the less luminous of the two in reality, but just appears brighter as it may be closer.

Perhaps the most important terms used in double star work are the **separation** and **position angle** (PA). The separation is the angular distance between the two stars, usually in seconds of arc, and measured from the brightest star to the faintest. The position angle is the relative position of one star, usually the secondary, with respect to the primary, and is measured in degrees, with 0° at due north, 90° at due east, 180° due south, 270° at due west, and back to 0°. This is shown in Fig. A.3. with the double star γ Virginis, which has components of magnitude 3.5 and 3.5, a separation of 1.8″ (arcseconds) and a PA of 267° (epoch 2000.0). Note that the secondary star is the one always placed somewhere on the orbit, while the primary star is at the center of the perpendicular lines. The separation and PA of any double star are constantly changing, and should be quoted for the year observed. When the period is very long, some stars will have no appreciable change in PA for several years; others, however, will change from year-to-year.

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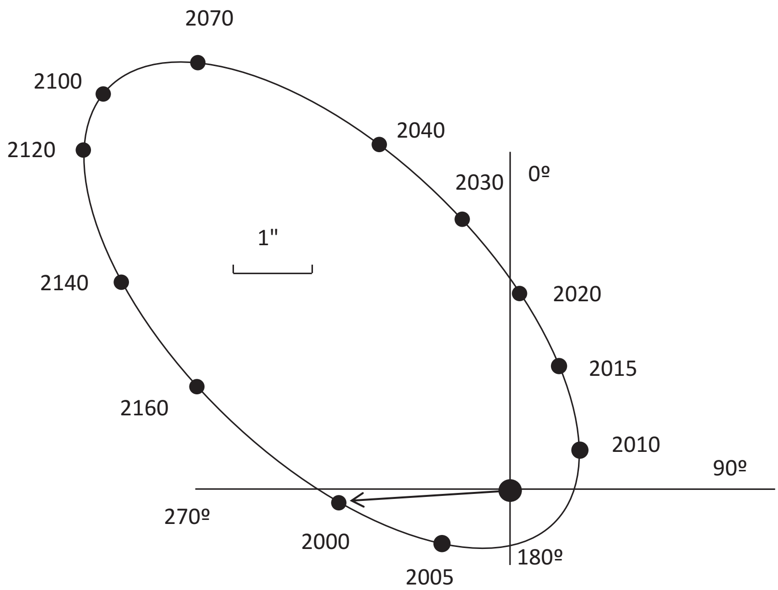

Fig. A.3 The motion of γ Virginis (Image courtesy of the author)

Appendix 7

Star Colors

The most important factor that determines the color of a star is you: the observer! It is purely a matter of both physiological and psychological influences. What one observer describes as a blue star, another may describe as a white star or one may see an orange star, whilst another observes the same star as being yellow. It may even be that you will observe a star to have different color when using different telescopes or magnifications, and atmospheric conditions will also have a role to play. The important thing to remember is that you should record the color you observe.[5]

It may seem to a casual observer that the stars do not possess many bright colors, and only the brightest stars show any perceptible color. Betelgeuse can be seen to be red, and Capella, yellow, whilst Vega is blue, and Aldebaran has an orange tint, but beyond that, most stars seem to be an overall white. To the naked eye, this is certainly the case, and it is only with some kind of optical equipment that the full range of star color becomes apparent.

However, what is meant by the color of a star? A scientific description of a star's color is one that is based on the stellar classification, which depends upon the chemical composition and temperature of a star. In addition, a term commonly used by astronomers is the color index. This is determined by observing a star through two filters, the B and the V filters, which correspond to wavelengths of 440 nm and 550 nm respectively, and measure a star's brightness. Subtracting the two values obtained gives B – V, the **color index**. Usually, a blue star will have a color index that is negative, i.e., −0.3. Orange-red stars could have a value greater than 0.0, and upwards to about 3.00 and greater for very red stars (M6 and greater). But as this is an observationally based book, the scientific description will not generally apply.

As mentioned above, red, yellow, orange and blue stars are fairly common, but are there stars which have, say, a purple tint, or blue, or violet, crimson, lemon, and the ever-elusive green color? The answer is yes, but it depends on how you describe the color. A glance at the astronomy books from the last century and beginning of the twentieth century will show you that star color was a hot topic, and descriptions such as Amethyst (purple), Cinereous(wood-ash tint), Jacinth (pellucid orange), and Smalt (deep blue), to name but a few, were used frequently. Indeed, the British

[5] An interesting experiment is to observe a colored star first through one eye, and then the other. You may be surprised by the result!

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Astronomical Association even had a section devoted to star colors. But today, observing and cataloguing star color is just a pleasant past-time. Nevertheless, under good seeing conditions, with a dark sky, the keen-eyed observer will be able to see the faint, tinted colors from deepest red to steely blue and all the colors in between.

It is worth noting that several distinctly colored stars occur as part of a double star system. The reason for this may be that although the color is difficult to see in an individual star, it may appear more intense when seen together with a contrasting color. Thus, when I discuss double and triple stars, there are descriptions of many beautifully colored systems. For instance, in the following double star systems, the fainter of the two stars in η Cassiopeia has a distinct purple tint; whilst in γ Andromadae and α Herculis, the fainter stars are most definitely green.

Appendix 8

Books, Magazines and Astronomical Organizations

I have selected a few of the many fine astronomy and astrophysics books in print. You do not have to buy, or even read them all, but I recommend checking at your local library to see if they have some of them.

Star Atlases and Observing Guides

Norton's Star Atlas & Reference Handbook, I. Ridpath (Ed.), Longmans, 1999, Harlow, UK.
Sky Atlas 2000.0, W. Tirion, R. Sinnott, Sky Publishing & Cambridge, University Press, 1999 Massachusetts, USA.
Millennium Star Atlas, R. Sinnott, M. Perryman, Sky Publishing, 1999, Massachusetts, USA.
Uranometria 2000.0 Volumes 1 & 2, Wil Tirion (Ed), Willmann-Bell; Virginia, 2001, USA.
Observing Handbook and Catalogue of Deep-Sky Objects, C. Luginbuhl, B. Skiff, Cambridge University press, 1990, Cambridge, USA.
Observer's Guide To Star Clusters, M. D. Inglis, Springer, 2013.
Deep-Sky Companions: The Messier Objects, S. O'Meara, Cambridge University Press, 1999 Cambbridge UK.
Observing the Caldwell Objects, D. Ratledge, Springer-Verlag, 2000, London, UK.
Burnham's Celestial Handbook, R. Burnham, Dover Books, 1978, New York, USA.
Amateur Astronomer's Handbook, J. Sidgwick, Pelham Books, 1979, LONDON, UK.

Astronomy and Astrophysics Books

Field Guide to the Deep Sky Objects, M. D. Inglis, Springer, London, 2012.
Astrophysics Is Easy, M. D. Inglis, Springer, 2015
The Milky Way, Bart & Priscilla Bok, Harvard Science Books, Massachusetts, 1981
Voyages Through The Universe, A. Fraknoi, D. Morrison, S. Wolff, Saunders College Publishing, 2000, Philadelphia, USA

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Introductory Astronomy & Astrophysics, M. Zeilik, S. Gregory, E. Smith, Saunders College Publishing, 1999, Philadelphia, USA
Galaxies and Galactic Structure, D. Elmegreen, Prentice Hall, 1998, NEW JERSY
Stars, J. B. Kaler, Scientific American Library, 1998, New York, USA
Stars, Nebulae and the Interstellar Medium, C. Kitchin, Adam Hilger, 1987, Bristol, UK

Magazines

Astronomy Now UK
Sky & Telescope USA
New Scientist UK
Scientific American USA
Science USA
Nature UK

The first three magazines listed are aimed at a general audience and the last three are intended for the well-informed lay person. In addition, there are many research level journals that can be found in university libraries and observatories.

Organizations

The Federation of Astronomical Societies.
http://fedastro.org.uk/fas/

Society for Popular Astronomy
http://popastro.com

The *American Association of Amateur Astronomers*
http://astromax.com

The Astronomical League
http://www.astroleague.org/

The British Astronomical Association
https://britastro.org

The Royal Astronomical Society
https://www.ras.org.uk

The Webb Society
http://webbdeepsky.com

International Dark-Sky Association
http://www.darksky.org/

Campaign for Dark Skies
http://www.britastro.org/dark-skies/

Appendix 9

The Greek Alphabet

The following is a quick reference guide to the Greek letters, used in the Bayer classification system. Each entry shows the uppercase letter, the lowercase letter, and the pronunciation.

Α α Alpha	Η η Eta	Ν ν Nu	Τ τ Tau
Β β Beta	Θ θ Theta	Ξ ξ Xi	Υ υ Upsilon
Γ γ Gamma	Ι ι Iota	Ο ο Omicron	Φ ϕ Phi
Δ δ Delta	Κ κ Kappa	Π π Pi	Χ χ Chi
Ε ε Epsilon	Λ λ Lambda	Ρ ρ Rho	Ψ ψ Psi
Ζ ζ Zeta	Μ μ Mu	Σ σ Sigma	Ω ω Omega

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Appendix 10

Astrophotography Web Sites

Matt BenDaniel – http://starmatt.com/
Mario Cogo – www.intersoft.it/galaxlux
Bernhard Hubl – http://astrophoton.com
Dr. Jens Lüdeman – http://www.ias-observatory.org/IAS/index-english.htm
Axel Mellinger – http://home.arcor-online.de/axel.mellinger/
Thor Olson – http://home.att.net/~nightscapes/photos/MilkyWayPanoramas/
Harald Straus (Astronomischer Arbeitskreis Salzkammergut) – http://www.astronomie.at/
Chuck Vaughn – http://www.aa6g.org/Astronomy/astrophotos.html
http://www.seds.org/~spider/ngc/ngc.html

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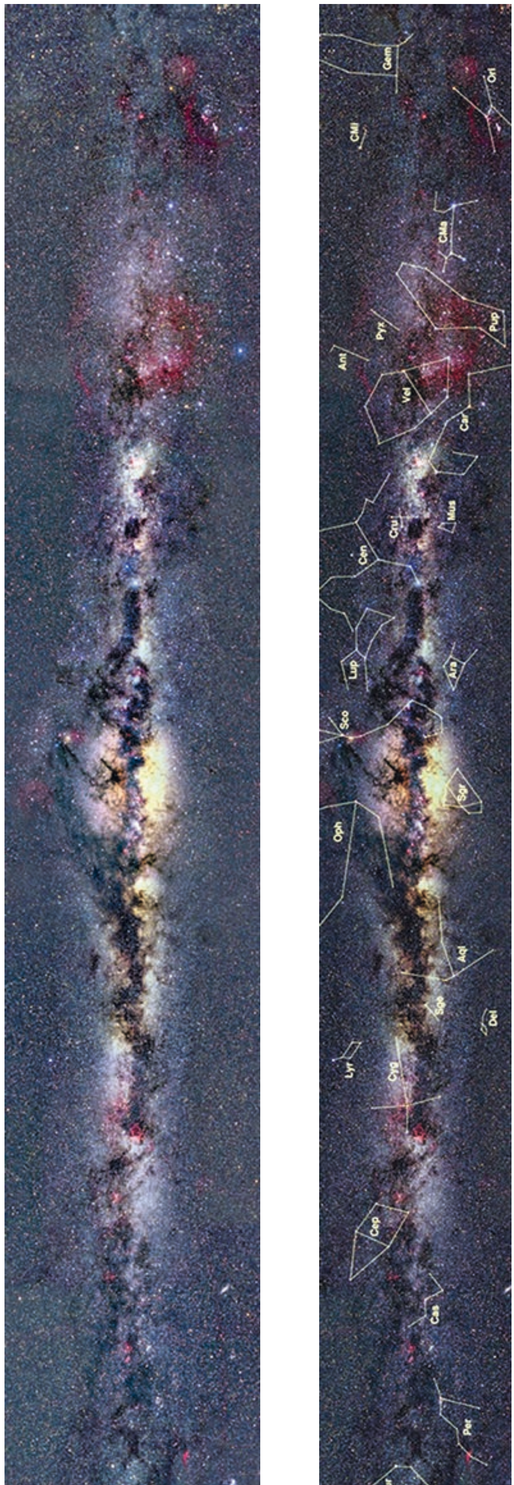
Gem
Ori
CMi
CMa
Pup
Pyx
Ant
Vel
Car
Mus
Cru
Cen
Ara
Lup
Sco
Sgr
Oph
Aql
Sge
Del
Lyr
Cyg
Cep
Cas
Per
Aur