Chapter 1
Foundations, federations, and finder charts

In this book we will examine the various reasons why some celestial bodies vary their luminosities, in addition to tackling the practicalities of observing them and following their brightness changes. The names of objects and phenomena such as eclipsing variable stars, pulsating variable stars, symbiotic stars, eruptive variable stars, cataclysmic variable stars, novae, supernovae, hypernovae, X-ray bursters, γ-ray bursters, Active Galactic Nuclei, Seyfert galaxies, BL Lacertae objects, quasars, and more are our main fare. I propose the generic term *astrovariables* for them.

You might not have access to expensive equipment and only have a little of your time and the use of your eyes which you can spare. Even so, you can still make a contribution. If you doubt this, take a look at Figure 1.1 which shows the constellation of Orion. Of the main stars, the upper-left one is the red giant Betelgeuse. It is a variable and, using the techniques described later in this book, its variations of brightness can be followed by making estimates with no equipment other than the unaided eye. There are other examples.

Still, if you have or can obtain some cheap equipment then all the better because this widens the scope enormously. With very limited resources you will have a wide enough choice of objects to follow to potentially fill many lifetimes of study! If you can increase your equipment budget to a few thousand dollars then you can emulate professional astronomers and produce cutting-edge research work. Let me emphasise, though, that observing astrovariables is not the sole province of the wealthy with loads of time on their hands. You can experience a lifetime's fascination and pleasure by observing astrovariables with very limited resources – and produce scientifically valuable work while you are doing so!

Later there will be more about the astrophysics of astrovariables, and how to observe examples of each type of them. In order to use the space in the rest of this book efficiently, though, I ought to use this preliminary chapter to cover a few of the fundamentals it will be useful to have to hand. Let us begin by defining the brightness scale which is the very foundation stone of our work.

1.1 Star brightnesses

The *apparent visual magnitude* of a star is a measure of how bright it *appears* to be in our sky. The magnitude scale can cause confusion to the uninitiated because the larger positive number actually corresponds to the dimmer star.

The lovely steely-blue coloured Vega (the brightest star in the constellation of Lyra) is defined to have an apparent visual magnitude of $0^{m}.0$. There are four stars which appear brighter than Vega and so they are given negative apparent magnitudes. The brightest of these is the brilliant white Sirius, which has a magnitude of $-1^{m}.5$.

What about the other detectors we can use in astronomy? The wavelength (colour) to which they are most sensitive is a little different from detector to detector – and often very different to the response of the human eye. Star brightnesses measured with different detectors come out a little different because of this, since stars also differ in colour. This is why we make the distinction 'visual' in apparent visual magnitude, the term for a star's brightness as seen by the human eye. There is more about this in Chapter 4. In this book please assume that I am referring to visual magnitudes (as seen by the human eye, or a device which mimics the same response) unless indicated otherwise. Hence 'Sirius has a magnitude of $-1^{m}.5$' refers to its visual magnitude.

The magnitude scale is not linear (equal steps for equal brightness changes) but is instead based on ratios, with each magnitude difference corresponding to a brightness difference of 2.5 times. A difference of 5 magnitudes corresponds to a brightness difference of $2.5 \times 2.5 \times 2.5 \times 2.5 \times 2.5$ times, or 100 times (in truth the ratio is more accurately 2.512).The reason for this is that the eye appreciates brightness differences in terms of ratios and so the empirical magnitude figures that were originated by the astronomers of long ago corresponded to ratios of brightness of about this figure of 2.5.

Mathematicians define such a scale, where equal steps represent a change by a constant multiplication factor, to be a *logarithmic* scale. Looking at this from a mathematician's point of view, if we say that a number N is equivalent to another number of the form a^x (for instance $100 = 10^2$), then we can write a relationship between these numbers in terms of a logarithm. The relationship is $\log_a N = x$ (for example $\log_{10} 100 = 2$). Logarithms are an artificial construct but they do lend themselves to conveniently representing and manipulating numbers, such as those we meet in our work of measuring the brightnesses of astrovariables.

Let me restate the relationship, known as the *log identity*, that defines a logarithm:

$$\text{if } N = a^x, \text{ then } \log_a N = x$$

The figure *a* is known as the *base* of the logarithm. In our work we will only be interested in logarithms of base 10 ($a = 10$). For this special case we do not need to bother to write $\log_{10}$ each time. Instead we can write Log (note the capital L).

Here is the basis of the stellar magnitude scale:

$$m = -2.5\,\mathrm{Log}\,I$$

where I is the apparent luminosity of the star, in relative units, and m is its resulting apparent magnitude.

The difference in apparent visual magnitude between one star and another, Δm, is then given by:

$$\Delta m = 2.5\,\mathrm{Log}\left(\frac{I}{I'}\right)$$

where I and I' are the relative brightnesses of the stars, I being the intensity of the brighter star (which, remember, also has the *lower*, or *more negative*, magnitude number). Can you see what the magnitude difference is between two stars where the brighter star has 1000 times the luminosity of the other? The answer is 7.5 magnitudes.

On the very best nights, if you have very keen eyesight and are sited well away from any sources of 'light pollution', you could expect to see stars down to magnitude $6^{\mathrm{m}}.5$. Of course an observer with exceptionally acute vision and access to a superior site might do better – a few observers have claimed to see stars as faint as eighth magnitude from some mountaintop locations using nothing but their unaided eyes. More prosaically, from my garden in a semi-rural English village I rarely get evenings clear enough to show stars fainter than about magnitude $5^{\mathrm{m}}.0$ without using optical aid.

1.2 Absolute magnitude and distance modulus

Since stars display a great range in their actual luminosities, the apparent magnitude of a star is by no means a reliable guide to its distance. We measure the distances of the nearby stars by the method of *trigonometrical parallax*. This is where a star's apparent position is measured with respect to several others. As the Earth moves around the Sun, so a nearby star will apparently shift its position with respect to the more distant stars. The extremes of position occur six months apart, since this is the period over which the Earth travels halfway round its orbit, providing the baseline for our changing viewpoint. Half the total angular shift of the star is the parallax.

So far no star has been found with a parallax greater than 1 arcsecond. A 1 arcsecond parallax would mean that the star was a distance of 206 265 AU from us. This is 30 million million kilometres, a distance we prefer to call 1 *parsec*. A parsec is 3.26 light years. The number of parsecs is found by taking the reciprocal of the number of arc seconds of parallax. For instance, a star that has a parallax of 0.5 arcsecond is 2 parsecs, or 60 million million kilometres from Earth.

The difficulty of measuring tiny angular movements using our Earth-based telescopes had put a limit of about 100 parsecs on the distance for which we could use parallax. However, the *Hipparcos* satellite launched into Earth orbit by the European Space Agency observed and precisely measured the positions, brightnesses, colours, and parallaxes of over a hundred thousand stars with milliarcsecond accuracy during the years 1989–1993. The distances of the stars within a hundred parsecs, or so, are now known with an accuracy of around 1 per cent and the range at which parallaxes are still useful extends about ten times as far. The data from *Hipparcos* are still having an impact on many branches of research and yet are to be bettered by many orders of magnitude by the proposed *GAIA* (*Global Astrometric Interferometer for Astrophysics*) probe, presently slated for launch sometime around 2012.

If we know how far away a star is and we measure its apparent brightness, then we can find its real luminosity. This is often expressed as its *absolute magnitude*. The absolute magnitude of a star is equal to the apparent magnitude it would have if it was set at a standard distance of 10 parsecs from Earth.

The Sun's apparent magnitude is $-26^{m}.7$, but its absolute magnitude is $4^{m}.8$, so it would appear rather insignificant if it were placed at the standard distance of 10 parsecs away. Absolute magnitude is denoted by M to distinguish it from apparent magnitude, m.

The quantity $(m - M)$ is useful, as it fixes the distance of a given star. Alternatively, if the apparent magnitude and distance of the star are measured, then its true luminosity can be found. The quantity $(m - M)$ is known as the *distance modulus* of the star. The equation that relates m, M, and the distance of the star in parsecs, d, is:

$$(m - M) = (5 \operatorname{Log} d) - 5$$

1.3 Variable star nomenclature

Since there are far too many stars (and other astronomical objects) to have them all given proper names, the next best thing is to use a scheme based on the genitives of the names of the host constellations. One ingredient of this scheme (although only for the brightest stars) is an assigned Greek letter, originally devised as expressing the rank order of brightness of the star in the constellation (though certainly discrepancies exist in the stars as we see them today). Consequently Vega, the brightest star in the constellation of Lyra, is also known as α Lyrae. This can be abbreviated to α Lyr.

You will probably already be very familiar with all this but I thought it would be useful to present the constellations' names with their genitive forms and their abbreviations all together here in Table 1.1. These genitive forms themselves recur time and time again in astronomy and are the basis for the main schemes of naming astrovariables. Table 1.2 provides a listing of the Greek alphabet, also for your convenience.

Table 1.1 *Constellation genitive forms and abbreviations*

Constellation	English name	Genitive	Abbreviation
Andromeda	Andromeda	Andromedae	And
Antlia	The Airpump	Antliae	Ant
Apus	The Bird of Paradise (or the Bee)	Apodis	Aps
Aquarius	The Water-bearer	Aquarii	Aqr
Aquila	The Eagle	Aquilae	Aql
Ara	The Altar	Arae	Ara
Aries	The Ram	Arietis	Ari
Auriga	The Charioteer	Aurigae	Aur
Boötes	The Herdsman	Boötis	Boo
Caelum	The Sculptor's Tools	Caeli	Cae
Camelopardalis	The Giraffe	Camelopardalis	Cam
Cancer	The Crab	Cancri	Cnc
Canes Venatici	The Hunting Dogs	Canum Venaticorum	CVn
Canis Major	The Great Dog	Canis Majoris	CMa
Canis Minor	The Little Dog	Canis Minoris	CMi
Capricornus	The Sea-goat	Capricorni	Cap
Carina	The Keel (of the ship Argo)	Carinae	Car
Cassiopeia	Cassiopeia	Cassiopeiae	Cas
Centaurus	The Centaur	Centauri	Cen
Cepheus	Cepheus	Cephei	Cep
Cetus	The Whale	Ceti	Cet
Chameleon	The Chameleon	Chameleontis	Cha
Circinus	The Compass	Circini	Cir
Columba	The Dove	Columbae	Col
Coma Berenices	Berenice's Hair	Comae Berenices	Com
Corona Austrinus	The Southern Crown	Coronae Austrina	CrA
Corona Borealis	The Northern Crown	Coronae Borealis	CrB
Corvus	The Crow	Corvi	CrV
Crater	The Cup	Crateris	Crt
Crux	The Southern Cross	Crucis	Cru
Cygnus	The Swan	Cygni	Cyg
Delphinus	The Dolphin	Delphini	Del
Dorado	The Swordfish	Doradus	Dor
Draco	The Dragon	Draconis	Dra
Equuleus	The Foal	Equulei	Equ
Eridanus	The River Eridanus	Eridani	Eri
Fornax	The Furnace	Fornacis	For
Gemini	The Twins	Geminorum	Gem
Grus	The Crane	Gruis	Gru
Hercules	Hercules	Herculis	Her
Horologium	The Clock	Horologii	Hor
Hydra	The Sea-serpent	Hydrae	Hya
Hydrus	The Watersnake (or Small Sea-serpent)	Hydri	Hyi
Indus	The Indian	Indi	Ind

(*cont.*)

Table 1.1 *(cont.)*

Lacerta	The Lizard	Lacertae	Lac
Leo	The Lion	Leonis	Leo
Leo Minor	The Little Lion	Leonis Minoris	Lmi
Lepus	The Hare	Leporis	Lep
Libra	The Scales	Librae	Lib
Lupus	The Wolf	Lupi	Lup
Lynx	The Lynx	Lyncis	Lyn
Lyra	The Lyre	Lyrae	Lyr
Mensa	Table Mountain	Mensae	Men
Microscopium	The Microscope	Microscopii	Mic
Monoceros	The Unicorn	Monocerotis	Mon
Musca Australis	The Southern Fly	Muscae	Mus
Norma	The Rule	Normae	Nor
Octans	The Octant	Octantis	Oct
Ophiuchus	The Serpent-bearer	Ophuichi	Oph
Orion	Orion (the Hunter)	Orionis	Ori
Pavo	The Peacock	Pavonis	Pav
Pegasus	The Winged Horse	Pegasi	Peg
Perseus	Perseus	Persei	Per
Phoenix	The Phoenix	Phoenicis	Phe
Pictor	The Painter	Pictoris	Pic
Pisces	The Fishes	Piscium	Psc
Piscis Austrinus	The Southern Fish	Piscis Austrini	PsA
Puppis	The Poop-deck (of the ship Argo)	Puppis	Pup
Pyxis	The Mariner's Compass	Pyxidis	Pyx
Reticulum	The Net	Reticuli	Ret
Sagitta	The Arrow	Sagittae	Sge
Sagittarius	The Archer	Sagittarii	Sgr
Scorpius	The Scorpion	Scorpii	Sco
Sculptor	The Sculptor	Sculptoris	ScI
Scutum	The Shield	Scuti	Sct
Serpens Caput	The Serpent's Head	Serpentis	Ser
Serpens Cauda	The Serpent's Tail	Serpentis	Ser
Sextans	The Sextant	Sextantis	Sex
Taurus	The Bull	Tauri	Tau
Telescopium	The Telescope	Telescopii	Tel
Triangulum	The Triangle	Trianguli	Tri
Triangulum Australe	The Southern Triangle	Trianguli Australis	TrA
Tucana	The Toucan	Tucanae	Tuc
Ursa Major	The Great Bear	Ursae Majoris	UMa
Ursa Minor	The Little Bear	Ursae Minoris	UMi
Vela	The Sails (of the ship Argo)	Velorum	Vel
Virgo	The Virgin	Virginis	Vir
Volans	The Flying Fish	Volantis	Vol
Vulpecula	The Fox	Vulpeculae	Vul

Table 1.2 *The Greek alphabet*

Alpha	α	Nu	ν
Beta	β	Xi	χ
Gamma	γ	Omicron	ο
Delta	δ	Pi	π
Epsilon	ε	Rho	ρ
Zeta	ξ	Sigma	σ
Eta	η	Tau	τ
Theta	θ	Upsilon	υ
Iota	ι	Phi	φ
Kappa	κ	Chi	χ
Lambda	λ	Psi	ψ
Mu	μ	Omega	ω

In the nineteenth century Friedrich Argelander originated the scheme we still use today for naming variable stars. In this scheme the first discovered variable star in a constellation was given the letter R followed by the genitive form of the constellation name. For instance the first variable star discovered in Cygnus was named R Cygni. It still is known by this name. The second, third, and fourth stars discovered in Cygnus are S Cygni, T Cygni and U Cygni. The ninth variable to be discovered in Cygnus is, of course, Z Cygni. When a tenth variable star was discovered in a given constellation a double letter prefix was used, for instance RR Cygni. The scheme was continued with RS Cygni, then RT Cygni, RU Cygni, and so on.

After RZ Cygni the sequence begins again with SS Cygni (*the second letter must not be earlier in the alphabet than the first – so SR Cygni is NOT permitted*), ST Cygni and onwards to SZ Cygni. After SZ Cygni comes TT Cygni, then TU Cygni and . . . you get the idea.

Eventually all the designations up to ZZ were used and so astronomers reverted to using double letters in the first part of the alphabet: AA to AZ, then BB to BZ, then CC to CZ, and so on. The letter J was never used in case it might be confused with the letter I when written.

The foregoing schemes allowed the designation of 334 stars in any given constellation, the last being QZ (remember, RR to ZZ were already used up). Eventually still further variables stars were discovered. For these a V is used followed by a number and the constellation name. For instance, the 335th variable star in Orion is V335 Orionis, while the next one discovered is V336 Orionis.

Other schemes for naming stars are also in vogue. For instance, *Harvard Designations* (*HD*) are also commonly used. In this scheme the star is given a six-digit number which represents its co-ordinates for epoch 1900. The first two digits give the number of hours of right ascension (00 to 24) and the second two give the remaining number of minutes (00 to 59). The final pair of digits give the declination of the star (and these are in italics for negative declinations).

As an example, the Harvard Designation for the star R Cygni is HD 193408 because its co-ordinates were $\alpha = 19^h\ 34^m$, $\delta = +08^\circ$ on 1 January 1900. To take another example, the Harvard Designation of the star R Centauri is HD 140959 because its co-ordinates on 1 January 1900 were $14^h\ 09^m$, -59°.

In the cases where you know both the Harvard and Argelander designations of variable stars, it is a good idea to give both when reporting observations as this will minimise the risk of misidentifying the star to which your observation corresponds.

For example, writing 193408 R Cygni confirms to the recipient of your observations which star your observed magnitude corresponds to. If you referred to a particular star as 200938 R Cygni he/she would be alerted that there is a problem. He/she could ask you to check and you would find that you should have written the star as 200938 RS Cygni. Without the Harvard Designation as a check your value of the observed brightness of the star RS Cygni would have been assigned to the star R Cygni!

There are many more star catalogues I could mention. In due time you will undoubtedly encounter stars with designations beginning HIP (from the catalogue created from the *Hipparcos* database) and SAO (the important catalogue issued by the Smithsonian Astrophysical Observatory in 1966), along with many others but I will stop here. The Argelander and Harvard Designations are the main schemes of use to us and it would only use up precious space in this book, and maybe even confuse matters, to delve into the others. This is enough to get you underway – and it is my intention throughout this book to present you with enough useful information to get you started, while not including so much as to mire you in minutia.

1.4 Variable star classification

I wish I could say that the classification scheme for variable stars was easy, simple, and straightforward. Unfortunately I cannot. When we get down to the really fine detail I cannot even say that it is entirely permanent! Please do not allow yourself to become too bogged down with how variable stars are classified. After all, it is the stars themselves that really matter. I think it will be of the greatest help to you at this juncture if I present a broad picture of the way variable stars are classified and then introduce specific cases as we come to them in the course of this book.

The classification of variable stars can be thought of as existing in layers. In the first layer we can divide all variable stars into just two types: *intrinsic variable stars* if their brightness varies due to some internal cause and *extrinsic variable stars* if it varies due to some external agency

In the next layer we can divide the same stars this time into seven groups: *eruptive variable stars*; *pulsating variable stars*; *rotating variable stars*; *cataclysmic variable stars*, *eclipsing binary systems*; *optically variable X-ray sources*; and '*other miscellaneous variables*'. I choose these seven groups but some authorities would insist that the entire population of variable stars ought to be divided up in different ways. Just as one instance *symbiotic stars* could be considered as distinct from cataclysmic variable stars. I could go on but I am sure you get the idea. I think that the seven groups I have already stated are sufficient to cover all bases, each group being considered a ‘broad church’ itself containing diversity in its members.

There is a particular reason why I am promoting these seven categories as standards we should accept – and that is because it is the scheme adopted by the very important *General Catalogue of Variable Stars (GCVS) Research Group*, based at the Sternberg Astronomical Institute of Moscow, in Russia. This scheme has been developed by the expert members of the group, incorporating advice from a number of specialists. I have more to say about this group in the next section, suffice it to say here that I recommend you adopt this group’s classifications when starting out in your own researches.

You must, though, be prepared for variations in the way different authors and authorities treat and classify astrovariables. For instance, they can also be divided up into groups based on the way their brightnesses vary with time. So some authorities speak of *irregular variable stars* and *semi-regular variable stars*, *long-period variable stars*, *novae*, *dwarf novae* and *recurrent novae, and flare stars*.

So, all variable stars can be classified into groups according to either scheme. The third layer of classification involves grouping stars into those that show similar behaviour, tempered by our understanding of their physical nature and the processes in operation causing their variability. In other words, we group stars together according to their characteristics. Each of these groupings we give a designation based on a chosen star that exemplifies the group.

For example, one class of very young variable stars are known as *FU Orionis stars*. All FU Orionis stars behave like and, as far as we can at present deduce, are physically very much like FU Orionis itself. These stars undergo irregular surges in brightness and so would be considered as members of the broader set of stars known as eruptive variables. Of course that also makes them irregular variables under the alternative scheme.

Again, I wish to promote the classifications issued by the GCVS group as the standards we should adopt. The GCVS variable groupings are often written as abbreviations. Hence FU Orionis stars are denoted as FU.

At this point I want to introduce you to the CD-ROM that accompanies this book. It is full of resources to help you. If all the files were printed out, the volume of material on the CD-ROM would fill this book several times over – which is why it is presented on the CD-ROM and not in these printed pages!

Once it is started on your computer you just click on the ‘Index’ icon and you will see a menu. One of the items listed under ‘Miscellaneous’ is a text file called ‘GCVS variability types’. Click on this and you will see displayed a partially updated document first written by Dr Nikolai N. Samus and Dr O. V. Durlevich in 1998 (and reproduced by special permission). You will see it contains a full and detailed listing, with explanations, of the classification scheme adopted by the GCVS Research Group. The listing includes the abbreviations for each type.

Please do be aware that even this set of designations is not itself fixed and constant. At present there are over ninety groupings named after ‘prototype’ stars but the number keeps on growing as smaller and smaller distinctions are being recognised. There are even subdivisions to some of these.

Please also do be aware that some of the groupings are known by alternative names, especially by other authorities. For example, the stars that used to be known as β Canis Majoris stars are now fashionably called β Cephei stars and BL Boo stars can also be referred to as ‘anomalous Cepheids’. It is also true that as a variable star’s light variations and other physical parameters become increasingly refined with continued observation this sometimes leads to the star being reclassified from one type of variable to another.

Personally, I think that the classifying of variable stars has evolved into something of a headache – and this is also a reason why the classifications of such a major and important body as the GCVS Research Group ought to be adopted as standard. All I can say is don’t have bad dreams about it yourself. Watch for inconsistencies between authors and be especially careful when you are reading older literature on this subject.

I will, in the course of this book, introduce the main GCVS groupings and subtypes of variable stars as we come to them. However, I have no intention of even trying to be complete in this respect. This book is to help you get started in your study of variable stars – but most particularly concerns how to actually observe them. Learning all the types of variable stars and their particular characteristics is something that you can take your time doing. It may be that eventually you will develop a special interest in one class of variable stars at the expense of all others. You might then not be interested in the other types at all. However, please do remember that the GCVS classification document is on the CD-ROM for you to refer to whenever you need it.

Incidentally, the end part of the ‘GCVS variability types’ document also contains a listing of the numbers of objects (of the original 35 148 objects listed in 1998) that fall into each designation. You will see that a great many of the specific variable types are extremely thinly represented, some having just one member!

1.5 The *General Catalogue of Variable Stars* (*GCVS*)

As well as covering practical matters involved with making observations, this book includes introductions to the various types of variable object and how they fit into the grand scheme of things. Along the way I consider particular examples. However, I can only cover so much in the available space and you certainly will not want to limit yourself to studying just the examples I give. You will find further examples of astrovariables to study in various magazines and journals and you should ask for advice on the current programmes carried out