Binocular Astronomy

Stephen Tonkin

Springer

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The author's name is on the spine, but no book would exist without the inspiration and support, some of it unknowing, from a host of other people.

This book was gradually inspired over several years by a number of people. In addition to the numerous people with whom I have discussed binocular astronomy over the decades at astronomical meetings, star parties, and on various Internet forums, those who deserve to be named are, in no particular order: Rob Hatch, who owned the first big binoculars through which I looked; Mike Wheatley, who showed me that 15×70s *can* be hand-holdable; Dave Strange, whose binocular chair (which looked—and felt—like some peculiar species of medieval torture instrument) got me thinking about the ergonomics of mounting systems; Bob Mizon, whose monthly Sky Notes at Wessex Astronomical Society meetings invariably exhorted people to use binoculars; Larry Patriarca of Universal Astronomics, whose superb binocular mounts make observing with binoculars a sheer pleasure; Bill Cook, who has talked opto-mechanical common sense to me for several years on the Internet; Ed Zarenski, whose work inspired me to think more carefully about rigorously testing and evaluating binoculars; and Peter Drew, whose various ingenious binocular creations at the Astronomy Centre in Todmorden, West Yorkshire, UK, are sufficient to convert the most hardened one-eyed observer.

I am grateful to the following for permitting me to use their photographs: Florian Boyd, John Burns, Canon Inc., Chris Floyd (of Starchair Engineering Pty Ltd), Jim Burr (of Jim's Mobile Inc.), Gordon Nason, Craig Simmons, and Rob Teeter (of Teeter's Telescopes). On the subject of photographs, thanks also go to my son, Tim Tonkin, for whom the consequence of a childhood of holding binoculars properly was to model the holds for the relevant photographs.

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Stephen Tonkin
Hastingleigh, Kent, UK
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Contents

Appendices

Introduction

Several years ago, a combination of age and abuse finally took its toll on my back and it became increasingly uncomfortable to use an equatorially mounted telescope for visual astronomy. I considered the option of setting up a system whereby I could operate a telescope remotely from the warmth and comfort of my study and see the resulting images on my computer screen. Almost immediately it became blindingly obvious to me that while this is a pleasurable option for many amateur astronomers, it was not one that suited me. To do so would take me more into the realms of what some call "serious" amateur astronomy, which has rapidly embraced the advances that modern microelectronic technology has to offer, enabling the serious amateur to make significant contributions to astronomical knowledge. The thought of going further down this route brought it home to me: the reason that I "do" astronomy is for pleasure and relaxation, and the option that I was considering was in danger of making it seem to me like another job.

I had always used binoculars for quick views of the sky when I did not have time to set up a telescope and for more extended observing when, for example, I was waiting for a telescope to reach thermal equilibrium. I also always keep a binocular in my car so that I usually have an observing instrument reasonably close by. Now my back injury meant that my binoculars were the only astronomical instruments that I could comfortably use. I felt as if I was resigning myself to this. I considered my options again and decided that, if I was going to be "stuck" with binoculars, I might as well at least have some good quality ones. Almost simultaneously, a large astronomical binocular was advertised for sale at an attractive price on UK Astro Ads and I took the opportunity and purchased it. This turned out to be the best decision of my astronomical life; it was like discovering visual astronomy all over again.

Why was this? First, I became less "technological." I no longer had an equatorial mount to align, computers to set up, CCD camera to focus, or power supplies to manage. Within minutes of making a decision to observe, I could be observing. Second, and there are no other words for it, I was "blown away" by what I saw through the two eyepieces of a good 100-mm binocular. The first object that I turned my new acquisition to was the Great Nebula in Orion. It was like seeing it for the first time. I began to see detail that I had never before noticed visually, and some of this disappeared if I used only one eye. The pleasure of just sweeping the skies seeing what I could find is far greater than it was with a telescope—two eyes give one the impression that one is actually out there! Lastly, I found that I had stopped wondering if I would ever discover a comet or a supernova and had stopped thinking it was about time I did some more occultation timings. I was observing *purely* for pleasure. I realized that this was something that I had not done since I was a child. I had rediscovered my astronomical roots.

There can be pressure in amateur astronomical communities to participate in observing programs, to use one's hobby to advance the status of amateur astronomers. There can also be a tangible, and not always unspoken, attitude that someone who observes only, or even primarily, for pleasure does not really deserve to be called an amateur astronomer. My one regret is that it took me so many years to realize that this is a load of nonsense. The primary purpose of a hobby is enjoyment. If people find enjoyment in "serious" amateur astronomy, then all well and good; but, I contend, it is equally legitimate to enjoy it purely for recreation. Many have found that binoculars lead one to do exactly that.

Recreational observing is not the only application of binoculars; they are also well suited to some aspects of serious astronomy. Big binoculars with their wide fields of view are excellent tools for visual comet hunters, as the names George Alcock and Yuji Hyakutaki attest. There are many variable star programs specifically for binoculars, such as that run by the Society for Popular Astronomy.

With even modest binoculars, there is sufficient in the sky to keep one enthralled for years; with good quality big binoculars, there must be sufficient for decades. This book is for those who wish to explore that further, either with binoculars as an adjunct to a telescope or, as an increasing number of us are finding, as a main instrument. Its aim is to give a thorough understanding of the optical systems you will be using and to indicate those criteria that should influence your choice of binocular. Once the choice is narrowed down, you will need to evaluate your options, and there are simple tests you can do to give a good indication as to the potential of your choice. As with any aspect of astronomy, things do not stop with the optical system itself. You will, I hope, want to mount your binoculars—even small, normally hand-held binoculars show so much more when mounted—and there are numerous accessories and techniques that can increase your observing comfort, pleasure, and efficacy. Lastly, of course, there are the objects themselves that you will observe. I have grouped these into objects suitable for medium (50-mm aperture) binoculars and giant (100-mm aperture) binoculars. Obviously, all those in the 50-mm class are observable with a larger instrument (although a few are more pleasing with the wider field of the smaller instrument), and most of those for the larger instrument can at least be detected with the smaller one. These are intended as a "taster," but there are many more available to you. For example, some observers have seen all the Messier objects with 10×50 glasses! I hope that Southern Hemisphere readers will feel that I have made sufficient effort to include a good representation from their wonderful skies. The charts are simple black on white, as that is by far the easiest to read under red light.

Whatever category of binocular observer you fall into, there is something here for you. I hope you will get out there and find the same enjoyment from your binoculars as I continue to have from mine.

CHAPTER ONE

Why Binoculars?

Amateur astronomers usually view medium aperture (50–70 mm) binoculars either as an inexpensive "entry instrument" to the hobby, or as a useful accessory to a more experienced observer's "main" instrument—a telescope. There is a great deal of justification for this. Binoculars indeed make excellent starter instruments for new observers, especially those of limited financial means. Not only is a medium aperture binocular of reasonable quality less expensive than the cheapest useful astronomical telescopes, but it is also more intuitive to use, easier to set up, more portable, and has more obvious uses outside astronomy, for example, bird watching or horse racing. It also enables the new observer to engage in useful observing programs, such as the Society for Popular Astronomy's variable star program.[1] Where the more experienced observer is concerned, the wider field of a binocular is ideal for having a preliminary scan around the sky in order to evaluate it at the beginning of an observing session, and is also useful in conjunction with the telescope's finder as an aid to hunting the objects to be observed. Additionally, there are large objects with low surface brightness, such as the Pinwheel Galaxy (M33, NGC 598), that are distinctly *easier* to see in such binoculars than they are in most telescopes of even twice the aperture.

What an increasing number of experienced observers are coming to realize is that the binocular is not limited to being an adjunct to a telescope, but is an exceptionally valuable astronomical instrument in its own right. Many of the advantages of the binocular, when used for its "beginner" or "adjunct" purpose, translate to its advanced use.

Portability

There are two facets to the portability of binoculars. The first is the compactness and weight of the instrument itself. A 10×50 binocular is possibly the most common starting binocular and adjunct binocular. It is typically about 18 cm (7 in) long and about the same width, and usually weighs a kilogram (2.2 lb) or less, considerably less in the case of lightweight models. Second, binoculars of this size and weight can easily be hand-held for moderate periods of time, so they do not need a mount to be carried with them. Even 15×70 or 16×70 binoculars, which are typically about 28 cm (11 in) long and around 2 kg (4.4 lb) in weight may be hand-held for short periods.

Of course, all binoculars will benefit from being mounted. If a mount is to be carried with this size of binocular, a reasonably sturdy photographic monopod or tripod with a pan/tilt head will suffice for binoculars up to 80 mm in aperture, or 100 mm if they are the lighter weight ones. However, it does need to be stated at the outset that the photographic tripod with pan/tilt head, although commonly used, is far from ideal as a binocular mount for astronomy (see Chapter 6).

Ease of Set-up

Binoculars of 100-mm aperture or smaller are usually trivially easy to set up. If they are to be hand-held (usually 50 mm or smaller), all that is required is that the interpupillary distance and focus are set. They do not normally require time to reach thermal equilibrium, so they can literally be regarded as "grab and go" instruments, with observations being made within a minute or so of the decision to observe!

Even larger binoculars are generally considerably simpler to set up than many telescopes. Binoculars are not generally equatorially mounted on account of the awkward position that such mounting would require of the observer's head! For this reason, binoculars are usually mounted on some form of altazimuth mount, often a photographic tripod and head. Even with 6 kg (13.5 lb) binoculars on a sophisticated parallelogram mount, I routinely find that I am observing in less than 10 minutes of having made the decision to observe.

The Binocular Advantage

It is generally acknowledged, and empirical experiments confirm, that when using two eyes, our threshold of detection of faint objects is approximately 1.4 times as good as with one eye.[2] This is a consequence of what is called *binocular summation*,[3] which is itself probably a result of at least two different phenomena:

- *Statistical summation*. For objects of a low threshold of visibility, there is a greater probability that photons from the object will be detected by at least one of two detectors (in this case, eyes) than by a single detector. If the probability of detection in one detector is just over 0.5, then the probability of detection in both is indeed approximately 1.4 times greater. For example, for a detection probability of 0.6 in one detector, the probability of detection in one of two identical detectors is given by:

$$\begin{aligned} P(\text{Both}) &= P(\text{Right})\ \textbf{OR}\ P(\text{Left}) - (P(\text{Right})\ \textbf{AND}\ P(\text{Left})) \\ &= 0.6 + 0.6 - (0.6 \times 0.6) \\ &= 0.84 \\ 0.84/0.6 &= 1.4 \end{aligned}$$

- *Physiological summation*. This is essentially an improvement of signal-to-noise ratio (SNR). The signals from each eye are added, but the random neural noise is partially canceled. If the noise is random, the resulting improvement in SNR will be $\sqrt{2}$, or approximately 1.4.

The consequence of binocular summation is that, with two eyes, we experience an improvement in both acuity of vision and in contrast. This is apparent when we have our eyes tested by an optometrist, where we notice that the eye chart is easier to read with both eyes than with one eye alone. It is easy to demonstrate this with binoculars: find an object that you can only just detect, or a double star that you can only just split, with both eyes, then cap each objective in turn. You may even notice it while reading this page! However, this is only true for well-corrected vision; if the image in one eye is sufficiently degraded, then the consequence is that binocular vision is degraded to below the performance for the good eye. This obviously has implications for when we use binoculars.

Another bonus of using two eyes is stereopsis. Although astronomical objects are obviously far too distant for them to be seen with true stereoscopic vision, when we use both eyes, there is an illusion of stereoscopic vision that enhances the aesthetic attributes of many objects. I find this effect particularly apparent with rich open clusters, especially when there are stars of obviously different colors.

Lastly, when you observe with two eyes one eye sees the small part of the field of the other eye that is obliterated by the blind spot, the location on the retina where the optic nerve enters the eye. In this sense, the binocular can be said to give a more complete view than single-eye observing.

The 5-mm Exit Pupil

Most binoculars for astronomy will give an exit pupil in the region of 3 to 5 mm. There are obvious exceptions to this. There are occasional "fashions" for using exit pupils of up to 7 mm in both medium (e.g., 7×50) and giant (e.g., 15×110, 25×150) binoculars, but there are very good reasons not to do so, as only a few objects can benefit from this even if our eyes' pupils do dilate that much. Similarly, there are some larger astronomical binoculars, usually with interchangeable eyepieces, where the exit pupil is smaller than 3 mm.

There are distinct advantages in using an exit pupil in the 3 to 5 mm range. In no particular order they are:

- Most observers' pupils do not dilate much beyond 6 mm. The eye's pupil therefore vignettes the light from the binocular.

- There is sufficient brightness to see most of the extended objects that are visible with a larger exit pupil. (Notable exceptions are the Andromeda Galaxy (M31) and the North American Nebula (NGC 7000), both of which are better with a larger exit pupil, if our eyes can accommodate it.
- It is easier to position the eyes so that the entire exit pupil is contained by the eye's pupil.
- Aberrations in the eye's lens and cornea tend, as they do in the lenses of optical instruments, to be more severe toward the periphery of the pupil than they are at the center. Many normally bespectacled observers find that they can, with smaller exit pupils, observe satisfactorily without spectacles.
- Larger exit pupils imply lower magnification. Most binocular objects are easier to resolve with greater magnification and many are easier to identify. An object is fully resolved on the retina when the exit pupil is about 1 mm, although this is impracticably small for binoculars.
- The higher magnification results in greater contrast because the sky itself is an extended object and consequently dimmed by greater magnification.
- Smaller exit pupils imply smaller real fields of view, so lateral chromatic aberration is reduced.

The obvious disadvantages are:

- Extended objects are fainter than they are with a larger exit pupil, assuming the eye can accommodate the larger pupil.
- Larger exit pupils imply lower magnifications, with consequently more relaxed tolerances for collimation between the tubes.

Small Focal Ratio and Aberrations

Most binoculars have objectives that operate at around f/4 or f/5, although there are some specialist astronomical binoculars, intended for use at relatively high magnification, that have greater focal ratios.

Most optical aberrations are exacerbated with "fast" (i.e., low focal ratio, thus photographically "fast") objectives. For a normal achromatic doublet that does not use exotic glasses, the rule of thumb is that the focal ratio must be no less than three times the diameter of the aperture, measured in inches (1 inch = 25.4 mm), for axial (longitudinal) color correction to be acceptable. This is equivalent to stating that a 50-mm objective must work at f/6 and a 100 mm at f/12, or that the limit for f/5 is 42 mm. This latter equivalent is a reason for the good reputation for optical quality of many 42 mm binoculars. If optical quality is to be maintained at greater apertures without a concomitant increase in focal ratio, either expensive exotic glasses or extra len elements or both must be employed. Several modern astronomical binoculars have slower focal ratios, such as f/7.5 or f/8. Lower focal ratios have light cones that are more obtuse; and obtuse light cones are more demanding of eyepiece quality than those that are more acute. This means that for image quality not to be compromised, better eyepieces are needed and thus greater expense is required.

Conclusion

There are many aspects of telescope astronomy that are unavailable to the binocular user. Binoculars are used almost exclusively for visual astronomy, but for sheer enjoyment of the sky, they are unparalleled!

Notes

1. See: http://www.popastro.com.
2. Dickinson, T., and Dyer, A. *The Backyard Astronomer's Guide*. Ontario: Camden House Publishing, 1991, p. 26; Harrington, Philip S. *Touring the Universe through Binoculars*. New York: John Wiley, 1990, p. 2; Salmon, T. http://arapaho.nsuok.edu/~salmonto/VSIII/Lecture11.pdf.
3. Salmon.

CHAPTER TWO

Binocular Optics and Mechanics

There are three main parts to a binocular's optical system:

- *Objective lens assembly*. Its function is to gather light from the object and form an image at the image plane.
- *Eyepiece lens assembly*. Its function is to examine the image at the image plane, rendering it visible to the observer's eyes.
- *Image orientation correction*. In modern binoculars this is usually a prism assembly. In large binoculars this may also require the eyepieces to be at 45- or 90-degree angles to the main optical tube. Binoculars are usually classified by the type of prism assembly they use (e.g., "Porro prism binocular" or "roof prism binocular") (Figure 2.1).

Astronomical observation is exceptionally demanding of optical quality; this applies equally to binoculars as to telescopes, despite the much lower magnification usually used in the former. Hence, binoculars used for anything other than casual scanning of the sky as a preliminary to using another instrument need to be of the highest optical quality you can afford. Once you have used a high-quality astronomical binocular it is very difficult to use one of lesser quality without being dissatisfied, even irritated, by it.

Objective Lens Assemblies

The objective lens consists of two or more lens elements in an achromatic or apochromatic configuration. The achromatic doublet is the most common lens in "standard" binoculars, but high-quality binoculars, particularly large astronomical

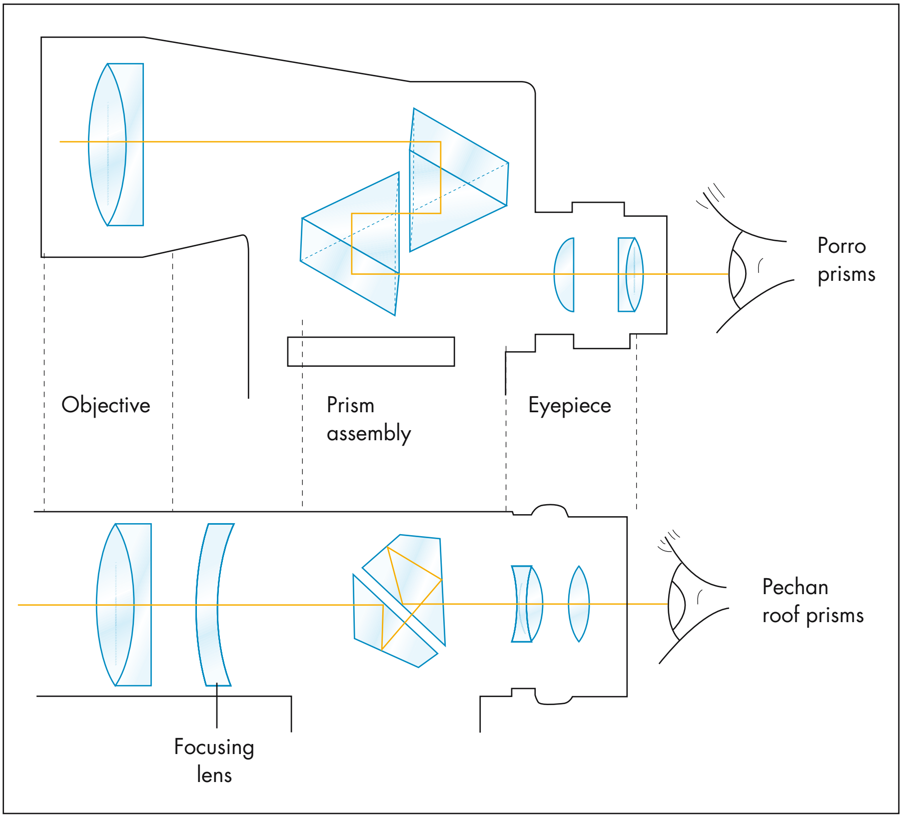

Figure 2.1. Light-path through prismatic binoculars.

binoculars, may have an apochromatic triplet. There may also be additional lenses to correct for other optical aberrations such as spherical aberration (SA), coma, or field curvature. Achromats bring two wavelengths (colors) of light to the same focus. A simple achromatic doublet would have a biconvex element of crown glass in front of a weaker diverging element of flint glass. Modern achromats may use special glasses, such as extra-low dispersion (ED) glass, in order to give better color correction. Apochromats, which bring three wavelengths of light to the same focus, may employ expensive (but brittle) fluorite glass.

Large aperture astronomical binoculars have objectives of relatively small focal ratio, often as small as f/5, and sometimes less. An achromatic doublet of 100-mm aperture with a focal ratio of f/5 will have significant chromatic aberration, especially off-axis, no matter which glasses are used. This can be particularly obtrusive on bright objects, such as the Moon or the naked-eye planets. Even a fluorite apochromat of this aperture and focal ratio will show off-axis false color on these objects.

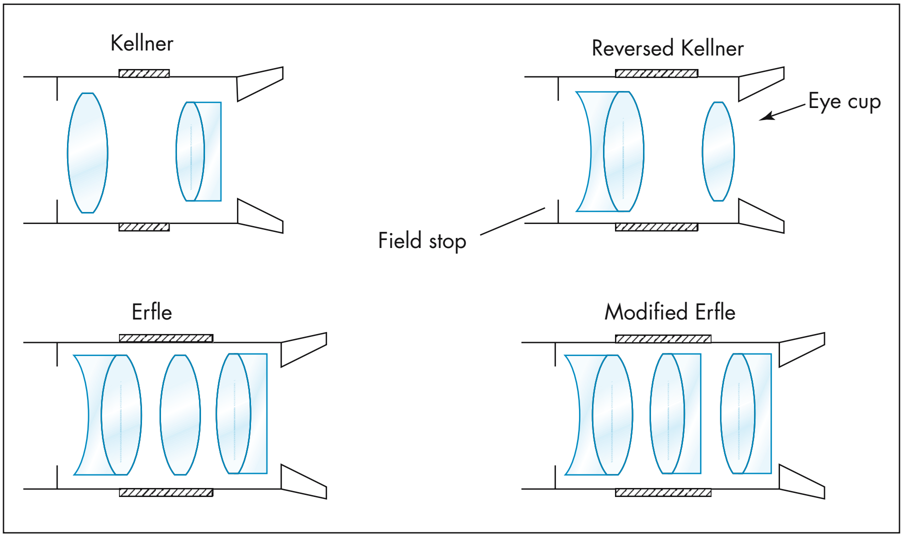

Figure 2.2. Some common binocular eyepieces.

Eyepieces

Binocular eyepieces usually consist of three or more lenses in two or more groups. The most common is the venerable Kellner configuration, a design dating from 1849 that consists of a singlet field lens and a doublet eye lens. Increasingly common are reversed Kellners, a design that was introduced in 1975 by David Rank of the Edmund Scientific Company and used in its RKE eyepieces. The field lens is the doublet and the eye lens is a singlet. The reversed Kellner has the advantages of a slightly wider field (50 degrees as opposed to the 45 degrees of a Kellner), over 50 percent more eye relief, and of working better with the short focal ratios that typify binocular objectives. Wide field binoculars usually use modifications of Erfle eyepieces. These consist of five or six elements in three groups. They can have a field of up to about 70 degrees, but eye relief tends to suffer when the field exceeds about 65 degrees (Figure 2.2).

Prisms

The prisms in binoculars serve primarily to correct the inverted and laterally reversed image that would otherwise result from the objective and eyepiece alone. A secondary effect is that they fold the light path, so that the binocular is shorter than it would otherwise be, making it easier to handle. As stated above, binoculars are often classified according to their prism type. For modern binoculars without angled eyepieces, there are two basic types: the Porro prism and the roof prism.

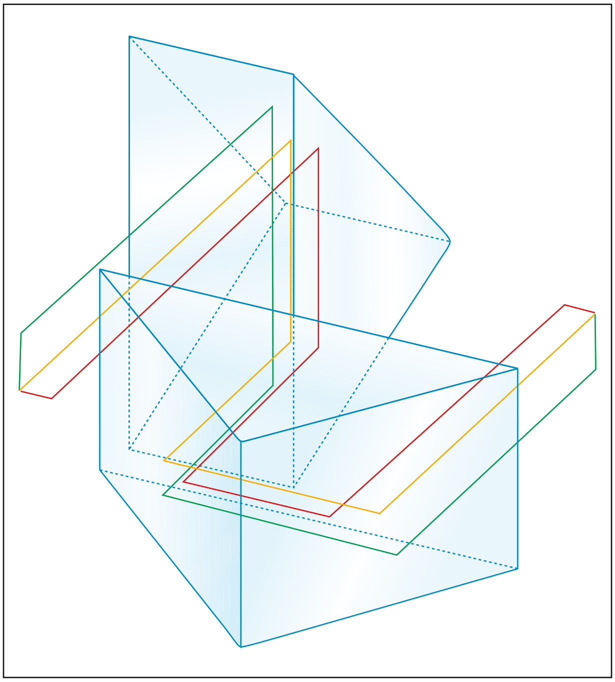

Figure 2.3. Image inversion and lateral reversal in Porro prisms.

The Porro prism assembly consists of two isosceles right-angled prisms mounted with their hypotenuses facing each other but with their long axes exactly perpendicular. This latter point is crucial; if they are not exactly at right angles, image rotation (usually referred to as "lean" when it applies to binoculars) will occur. The angle of lean is twice the angle of misalignment and opposite in direction (i.e., a clockwise misalignment of 0.5 degrees will result in an anticlockwise lean of 1.0 degree. The light path in Porro prisms is shown in Figure 2.3. There are four reflections, so the result is a right-handed image. The mutually perpendicular orientation of the prism hypotenuses results in one prism erecting the image and the other reverting it.

It is possible, especially when they are used with objectives of low focal ratio, for Porro prisms to reflect rays that are not parallel to the optical axis in such a manner that they are internally reflected off the hypotenuse of the prism (Figure 2.4a). The ray then emerges from the prism, having been reflected a third time, and contributes only optical "noise" to the image, thus reducing contrast. This extra reflection can be eliminated by putting a groove across the center of the hypotenuse (Figure 2.4b). Grooved prisms are a feature of better-quality Porro prism binoculars.

A development of the Porro prism is the Abbé Erecting System, also known as a Porro Type-2 prism (Figures 2.5 and 2.6). Its lateral offset is 77 percent that of an equivalent Porro prism assembly[1], and for this reason it is most frequently

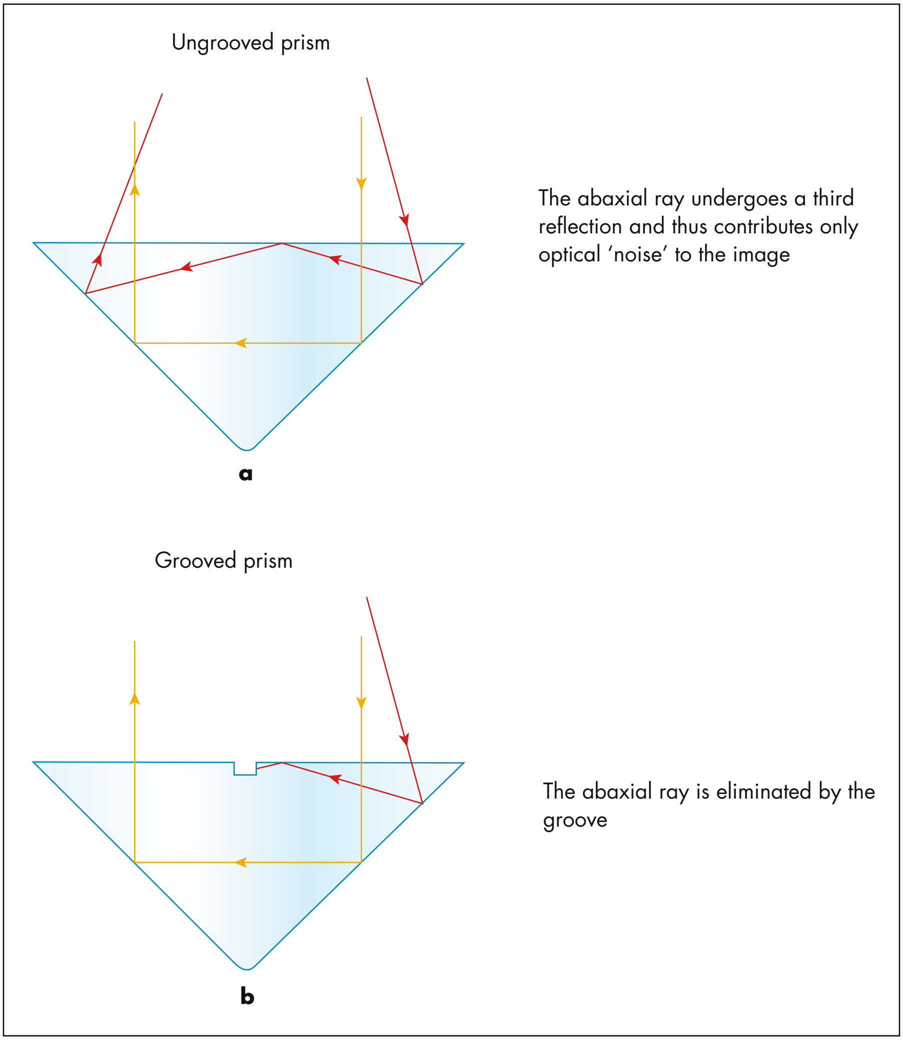

Figure 2.4. Porro prism groove.

encountered in larger binoculars. For medium-aperture binoculars, it is more common in older instruments, particularly military binoculars from the early and mid-20th Century. Abbé Erecting Systems are usually identifiable by the cylindrical prism housing, although the reverse is not true; i.e. this feature is not diagnostic of the presence of the Abbé system.

An important consideration is the glass used for the prism. Normal borosilicate crown (BK7—the *BK* is from the German *Borkron*) glass has a lower refractive index than the barium crown (BaK4—the *BaK* is from the German *Baritleichtkron*)

Figure 2.5. Abbé Erecting System, also known as a Porro Type-2 prism.

glass that is used in better binoculars. A higher refractive index results in a smaller critical angle, 39.6 degrees in BaK4 as compared to 41.2 degrees in BK7), so there is less light likely to be lost because of nontotal internal reflection in the prisms (Figure 2.7). The difference is more noticeable in wide angle binoculars with objective lenses that have a focal ratio of f/5 or less. The nontotal internal reflection of the peripheral rays of light come from the objective results in vignetting of the image. This effect can easily be seen by holding the binocular up to a light sky or other light surface and examining the exit pupil. The exit pupil of a binocular with BaK4 prisms will be perfectly round, while that of a binocular with BK7 prisms will have tell-tale blue-gray segments around it (Figure 2.8). (Note: Figure 2.8b was taken from a slight angle in order to show the nature of the vignette segments. Viewed from directly behind the exit pupil, there is a square central region with vignette segments on four sides.)

The roof prism is shown in Figure 2.9. It is a combination of a Semi Penta prism (45-degree deviation prism) (Figure 2.10) and a Schmidt roof prism

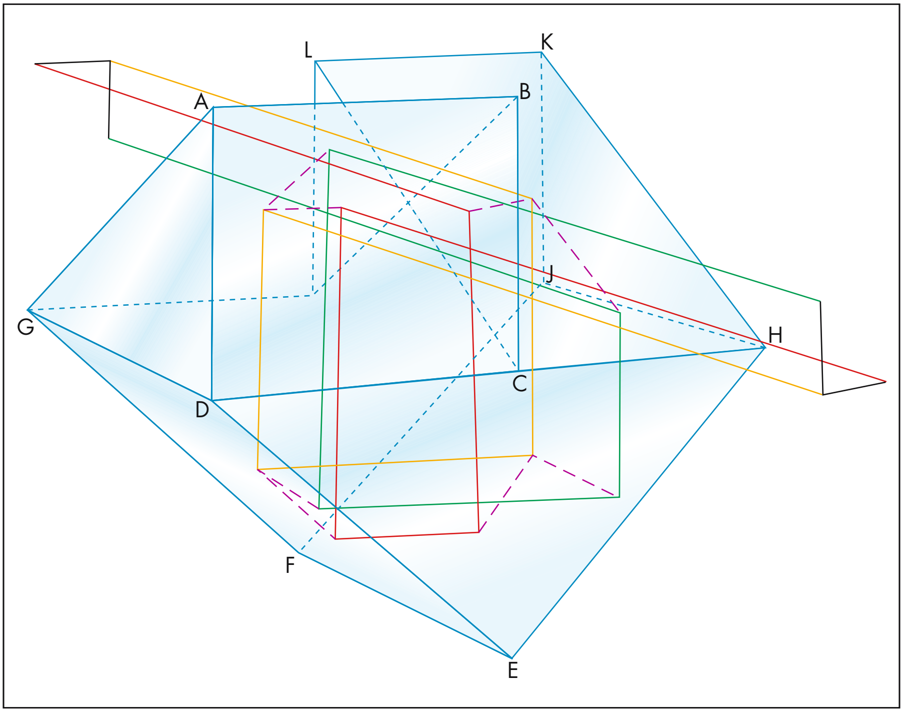

Figure 2.6. Light path in Abbe erecting system (a.k.a. Porro type-2).

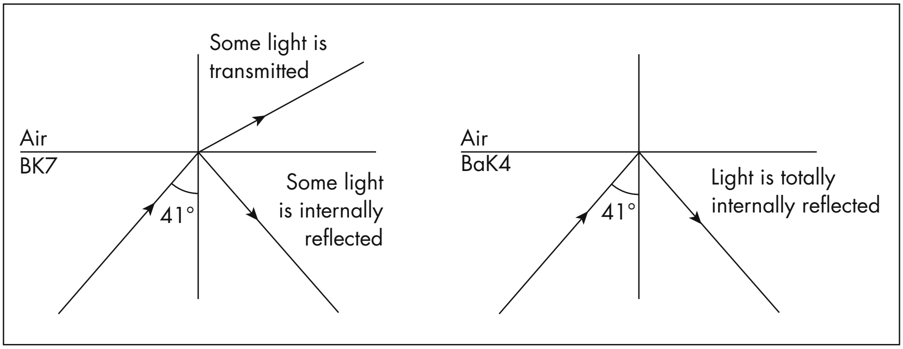

Figure 2.7. BK7 and BaK4 glass. At angles close to the critical angle of BaK4 glass, some light will be lost due to transmission in BK7 glass.

a

b

Figure 2.8. The effect of prism glass on the exit pupil. (a): BAK4 prisms. (b): BK7 prisms.

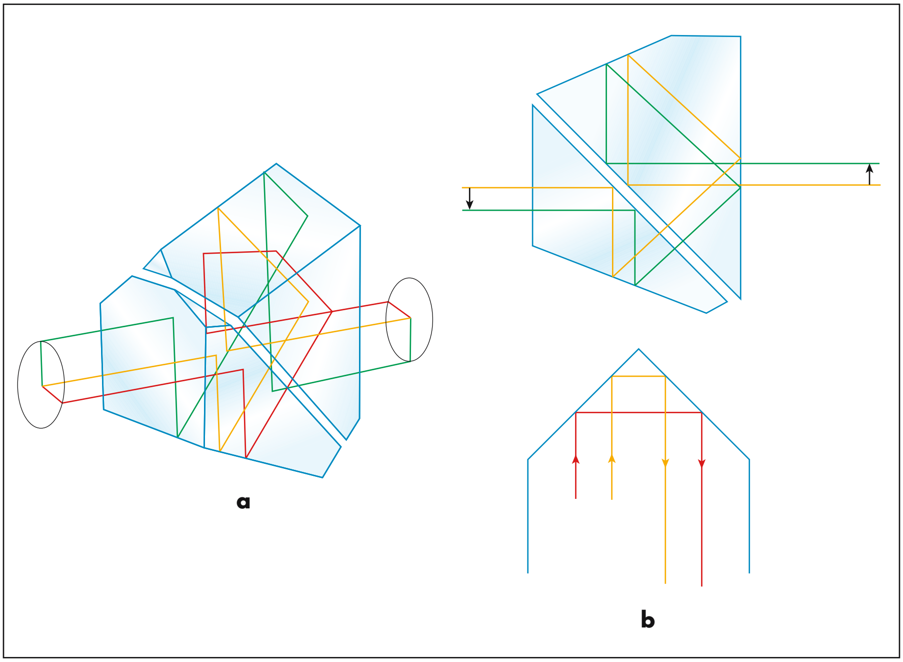

Figure 2.9. Image reversal in Pechan roof prism.

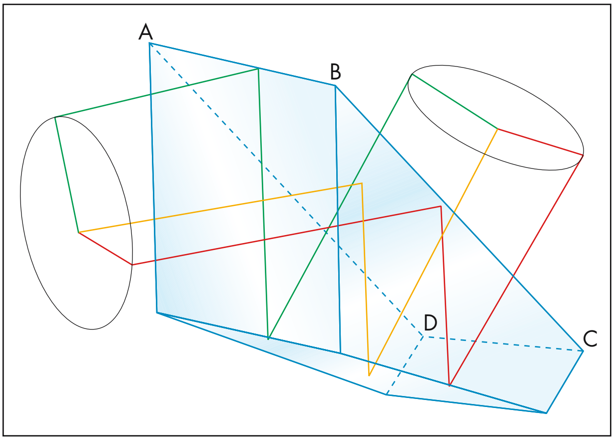

Figure 2.10. Semi penta prism (45 degree deviation prism).

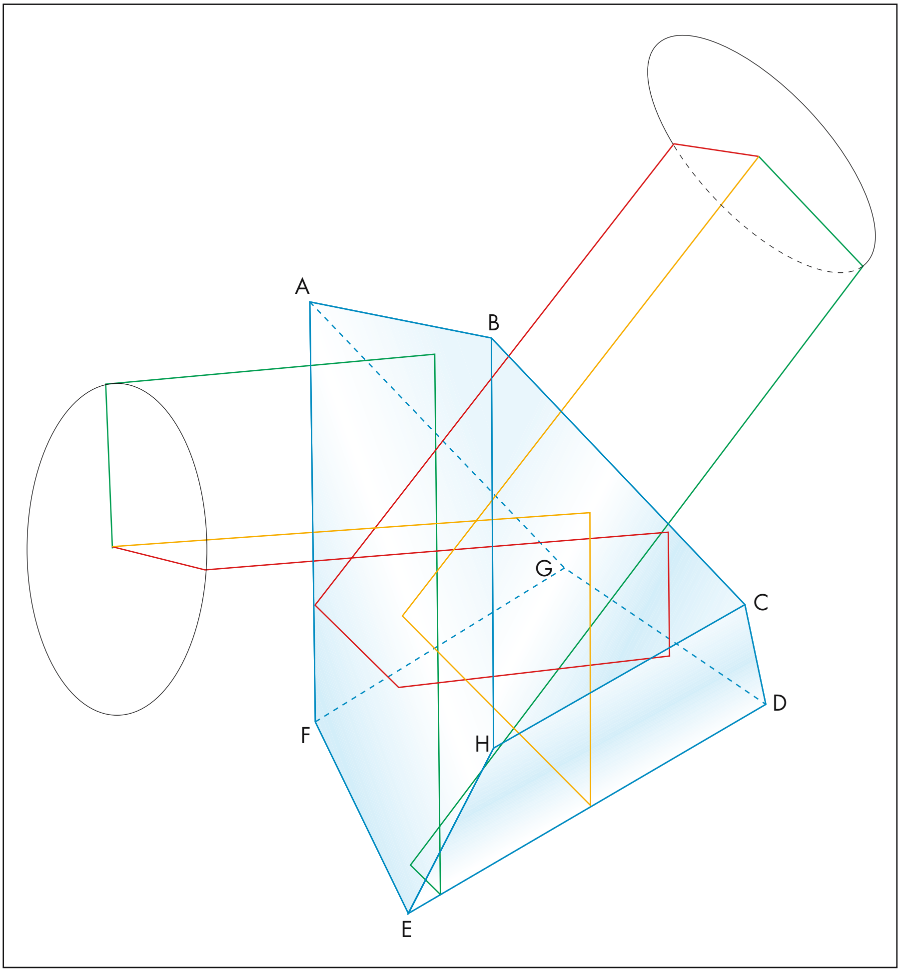

Figure 2.11. Schmidt roof prism. The image is inverted and reverted. The axis is deviated by 45 degrees.

(Figure 2.11). The combination is a compact inversion and reversion prism that results in an almost "straight through" light path. The consequence is a very compact binocular. There is, of course, a limit to the aperture of the roof prism binoculars that is imposed by the "straight through" light path because, the centers of the objectives cannot be separated by more than the observer's interpupillary distance (IPD).

Although the roof prism configuration is physically smaller and thus uses less material in its construction, it tends to be significantly more expensive than a Porro prism binocular of equivalent optical quality. This is because the prism system, particularly the roof itself, must be made to a much higher tolerance (2 arcsec for the roof) than is acceptable for Porro prisms (10 arcmin), that is, 300 times as precise! Any thickness or irregularity in the ridge of the roof will result in visible flares, particularly from bright high-contrast objects (i.e. many astronomical targets). Additionally, a result of the wave nature of light is that interference can occur when a bundle (a.k.a. pencil) of rays is separated and recombined, as happens with a roof prism. The consequence is a reduction in contrast. This can be ameliorated by the application of a “phase coating” to the faces of the roof. Binoculars with phase coatings usually have “PC” as part of their designation (see Appendix F).

As you will see from Figure 2-9, the light in a roof prism undergoes six reflections (as compared to four in a Porro prism binocular). This results in a “right-handed” image. The same is true of the Abbe-König roof prisms found in the best roof-prism binoculars. A consequence of the extra reflection and the extra lens (as compared to Porro prisms) is more light loss. In order to achieve a similar quality of image, better anti-reflective coatings need to be used.

The demand for better quality of the optical elements and their coatings in roof-prism binoculars means that they will inevitably be more expensive than Porro prism binoculars of equivalent optical quality. They do, however, offer three distinct advantages:

- They are more compact. This makes them slightly easier to pack and carry; some people (I am one) find the smaller size easier and more comfortable to hold because of the different ergonomics.
- They are usually slightly lighter. This makes them easier to carry and generally less tiring to hold.
- They are easier to waterproof because of the internal focusing. Although one does not normally do astronomy in the rain (the possible exception being the nocturnal equivalent of a “monkeys’ wedding”), nitrogen-filled waterproof binoculars are immune to internal condensation in damp/dewy conditions and will not suffer from possible water penetration when used for other purposes such as bird watching or racing.

It is a matter of personal judgment whether these advantages warrant the extra expense. I find that, on account of their relative lightness and compactness, I observe with my 10×42 roof prisms far more than I do with my 10×50 Porro prisms.

An increasing number of astronomical binoculars have 45- or 90-degree eyepieces. There are a wide variety of prism combinations that will achieve this, such as a Porro Type-2 with a Semi Penta prism for 45 degrees or with a Penta prism for 90 degrees. Another 45-degree system uses a Schmidt roof with a rhomboid.

Binoviewers use a combination of a beam splitter and a pair of rhomboidal prisms (Figures 2.12 and 2.13). The beam splitter divides the light into two mutually perpendicular optical paths. A rhomboidal prism merely displaces the axis of the light path without either inverting or reverting it. In some binoviewers pairs of mirrors perform the same function. Cylindrical light tubes may be used to ensure that the optical path length is identical on both sides. Interpupillary distance is adjusted by hinging the device along the axis of the light path from the objective lens or primary mirror.

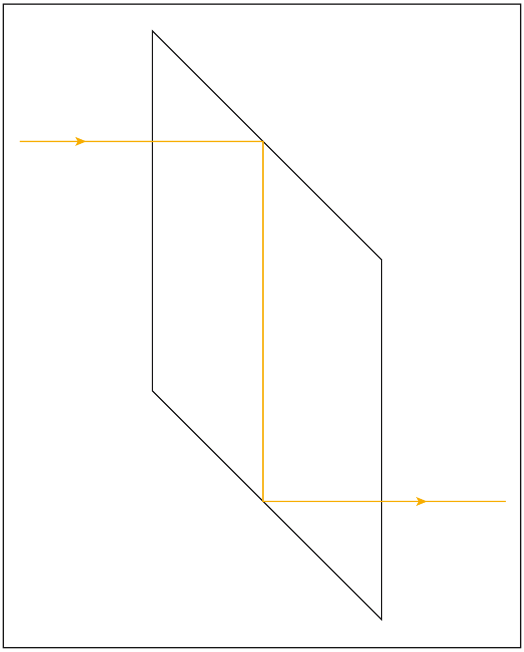

Figure 2.12. Rhomboid prism. This prism displaces the axis.

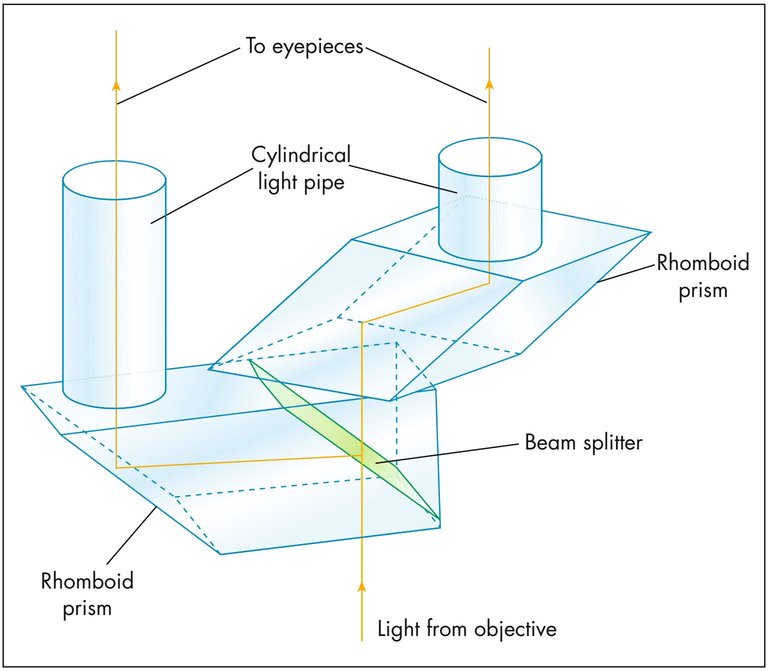

Figure 2.13. The principle of the binoviewer.

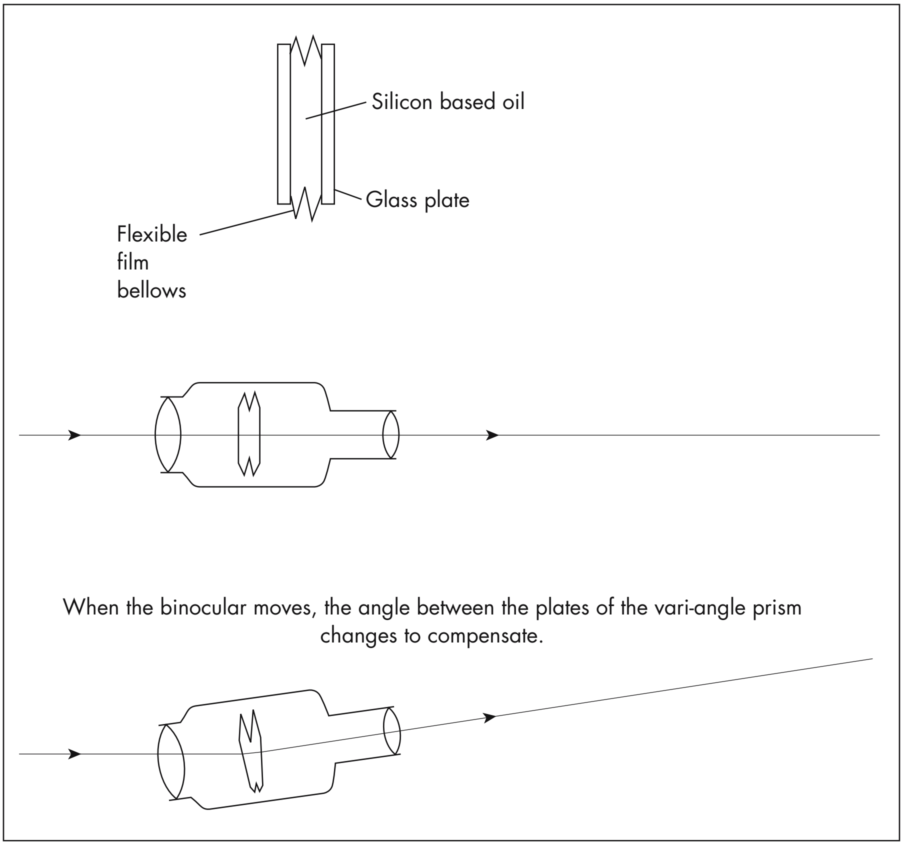

Figure 2.14. Image stabilization with Canon's vari-angle prism.

The system of image stabilization that has been most successful for astronomical purposes is that developed by Canon Inc. It employs what Canon calls a vari-angle prism (Figure 2.14), which consists of two circular glass plates that are joined at their edges by a bellows of a specially developed flexible film. The intervening space is filled with a silicon-based oil of very high refractive index. Microelectronic circuitry senses vibration and actuates the vari-angle prisms so as to compensate for the change in orientation of the binoculars.

Coatings

The most important coatings in binoculars are the antireflective coatings on the surfaces of the optical components. An uncoated glass-to-air surface will reflect about 4 percent of the light that is perpendicular to it ("normal incidence"), and even more of the light that is oblique to it. By using interference coatings, this can

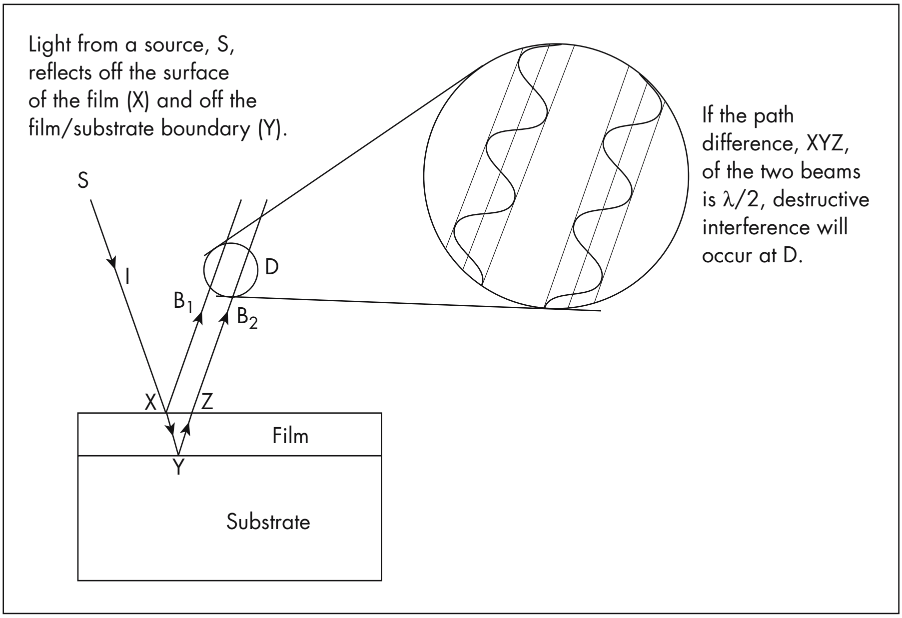

Figure 2.15. Single layer film.

be reduced to better than 0.15 percent over a very wide range of the optical spectrum. The coatings are usually optimized for a particular wavelength of light, usually in the range 510 to 550 nm. A single coating of a quarter of the wavelength of light will reflect a small proportion of the incident light. The glass behind it will reflect another small proportion. The path length of the wave reflected off the glass is half (2 × .25) a wavelength greater; the two reflected waves mutually interfere destructively, eliminating the reflection for that particular wavelength (Figures 2.15 and 2.16). At wavelengths significantly distant from the wavelength for which the coating is optimized, interference may be constructive, resulting in more reflected energy than would have occurred in uncoated glass. Additional layers of half- and quarter-wave thickness can reduce reflections at other wavelengths; this is called "multicoating" (Figure 2.17) and "broadband multicoating" (Figure 2.18). Coating is an expensive process, so there are a number of coatings that become uneconomical. It is rare to find more than seven layers on any surface in commercial binoculars.

Binocular coatings are qualitatively described as "coated," "fully multicoated," and so forth. There is no universally agreed meaning to these designations, but they are commonly held to have the following meanings:

- *Coated*: At least one glass-to-air surface (usually the outer surface of the objective) has a single layer of antireflective coating, usually MgF_2; other surfaces are uncoated.
- *Fully coated*: All glass-to-air surfaces of the lenses (but not the prism hypotenuses) have a layer of antireflective coating.

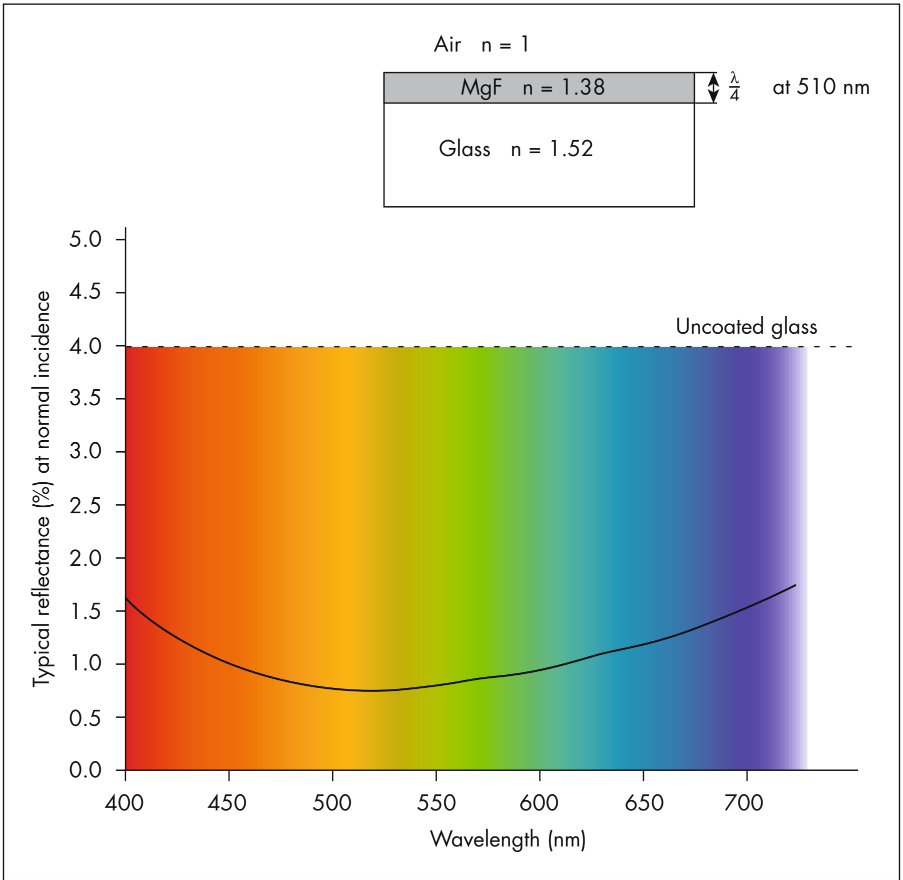

Figure 2.16. Coated optics: single layer coating.

- *Multi-coated*: At least one glass-to-air surface (usually the outer surface of the objective) has two or more layers of antireflective coating. The other surfaces may be single-layer coated or not coated at all.
- *Fully multi-coated*: All glass-to-air surfaces of the lenses (but possibly not the prism hypotenuses) have two or more layers of antireflective coating.

More recently, some binoculars coatings have been described as "broadband." Again, there is no industry-wide standard—coating can mean anything from three layers upward. Some manufacturers are more forthcoming as to the precise nature of their coatings. For example, the manufacturer of the popular Oberwerk-branded binoculars in the United States (branded as Strathspey in the U.K., Teleskop Service in Germany) provides the following information about its coatings:

- *Level I*: (Equivalent to *Fully Coated*). Single layer of MgF_2 coating on 16 glass-to-air surfaces: 4 for two objectives, 12 (6 per side) for the three optical elements in each eyepiece. The prisms are not coated.

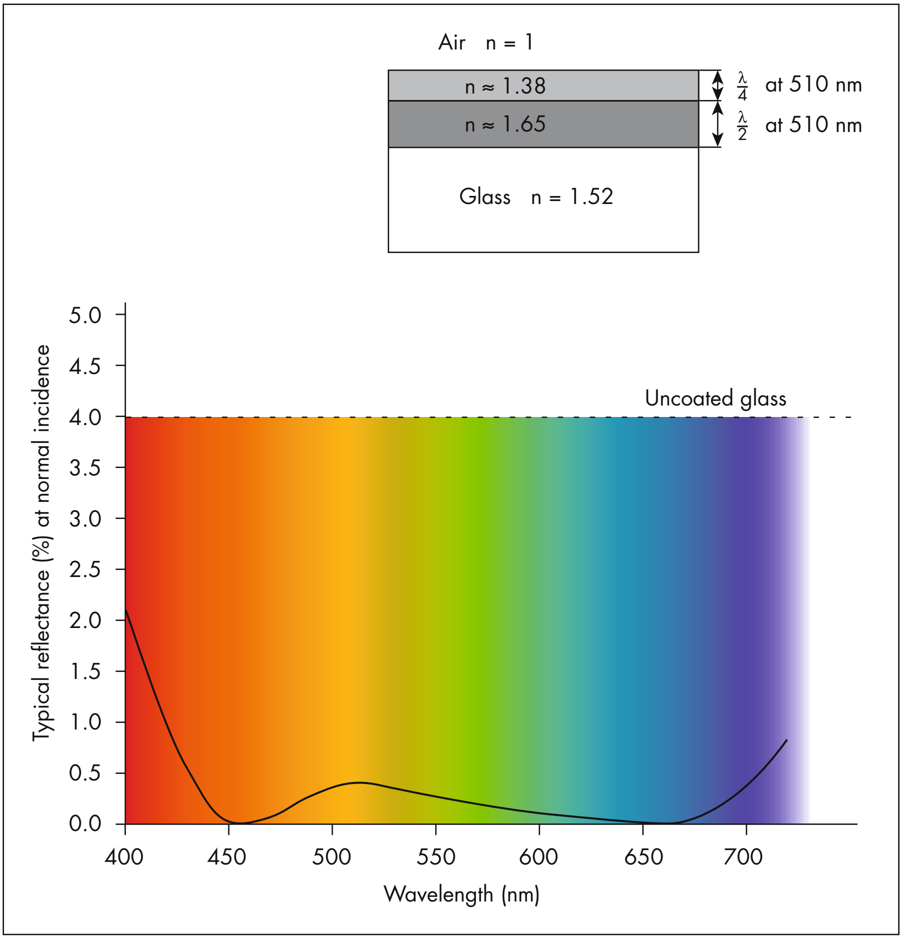

Figure 2.17. Multi-coated optics: double layer coating.

- *Level II*: (Equivalent to a blend of *Multi-Coated* and *Fully Multi-Coated*). Broadband multi-coatings of 5 to 7 layers on the 4 glass-to-air surfaces of the two objectives, and the 4 surfaces of the eye lenses of the two eyepieces. Single-layer MgF_2 coating on all other glass-to-air surfaces, including the hypotenuses of the prisms.
- *Level III*: Broadband multi-coatings on all the surfaces except the prism hypotenuses, on which there are single-layer MgF_2 coatings.
- *Level IV*: Broadband multi-coatings on all the surfaces including the prism hypotenuses. (Kunming Optical Instrument Co. Ltd.)

The effect of various coatings can be seen in the reflections of sunlight from objective lenses in Figure 2.19.

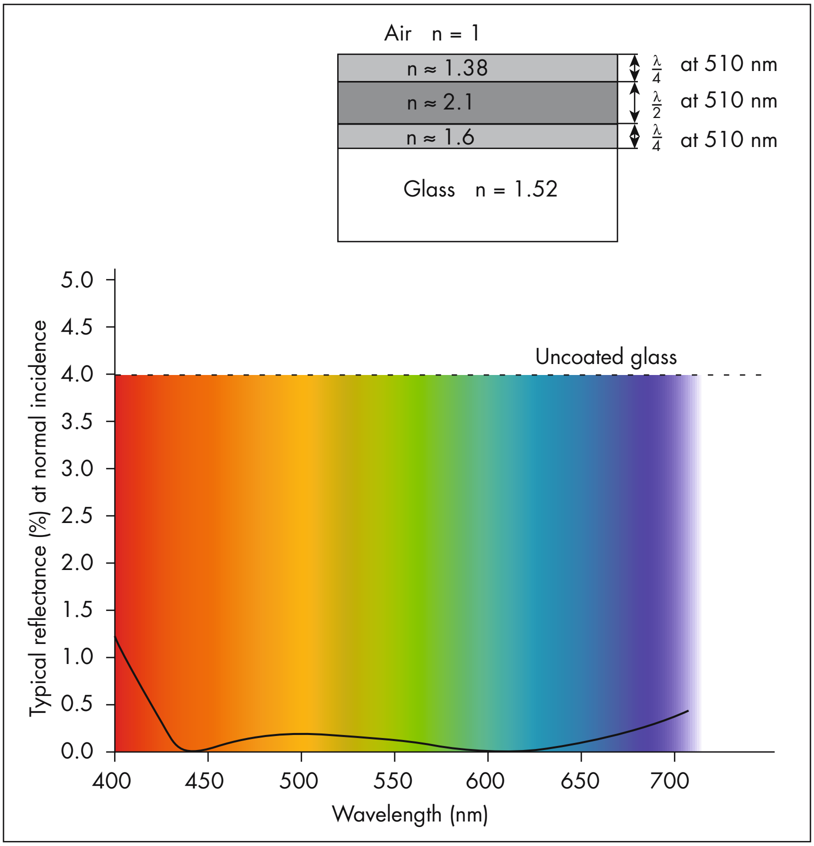

Figure 2.18. Broadband multi-coated optics: triple layer coating.

Figure 2.19. Optical coatings. Clockwise from top left: single-layer coated, broadband multicoated, multicoated, uncoated.

Aberrations

Aberrations are errors in an optical system. There are six optical aberrations that may affect the image produced by a telescope. Some affect the quality of the image, others affect its position. They are:

- Chromatic aberration: error of quality
- Spherical aberration: error of quality
- Coma: error of quality
- Astigmatism: error of quality
- Field curvature: error of position
- Distortion: error of position

Chromatic aberration is an error of refractive systems and is therefore of consideration for all binoculars. Because any light that does not impinge normally on a refractive surface will be dispersed, single converging lenses will bring different wavelengths (colors) of light to different foci, with the red end of the optical spectrum being most distant from the lens. This is *longitudinal* (or *axial*) chromatic aberration. *Lateral* chromatic aberration manifests as different wavelengths of light forming different size images. It is sometimes referred to as *color fringing*, which is descriptive of the visual effect of its presence.

Visible chromatic aberration can exist in objective lenses and eyepieces. Chromatic aberration can be reduced, but not eliminated, by using multiple lens elements of different refractive indices and dispersive powers. An achromatic lens has two elements and brings two colors to the same focus (Figure 2.20).

The choice of glass and lens design will determine not only which colors are brought to the same focus, but also the distance over which the secondary spectrum is focused. An apochromatic lens uses three elements and will bring three colors to the same focus.

Spherical aberration is an error of spherical refractive and reflective surfaces that results in peripheral rays of light being brought to different foci to those near the axis (Figure 2.21). If the peripheral rays are brought to a closer focus than the near-axial rays, the system is *undercorrected*. If they are brought to a more distant focus, the system is *overcorrected*. Spherical mirrors and converging lenses are undercorrected and diverging lenses are overcorrected.

In compound lenses, spherical aberration can be suppressed in the design of the lens by using several lenses of minimal curvature as a substitute for one of considerable curvature, by choosing appropriate curvatures for the converging and diverging elements, or as a combination of both. In Newtonian mirrors, such as those used in most reflecting binocular telescopes, the spherical aberration is corrected by progressively deepening the central part of the mirror so that all regions focus paraxial rays to the same point. The shape of the surface is then *paraboloid*, that is the surface that results from a parabola being rotated about is axis.

There are other manifestations of spherical aberration, the most common of which is zonal aberration, in which different zones of the objective lens or primary mirror have different focal lengths. Spherical aberration increases as a direct cubic function of an increase in aperture and is independent of field angle.

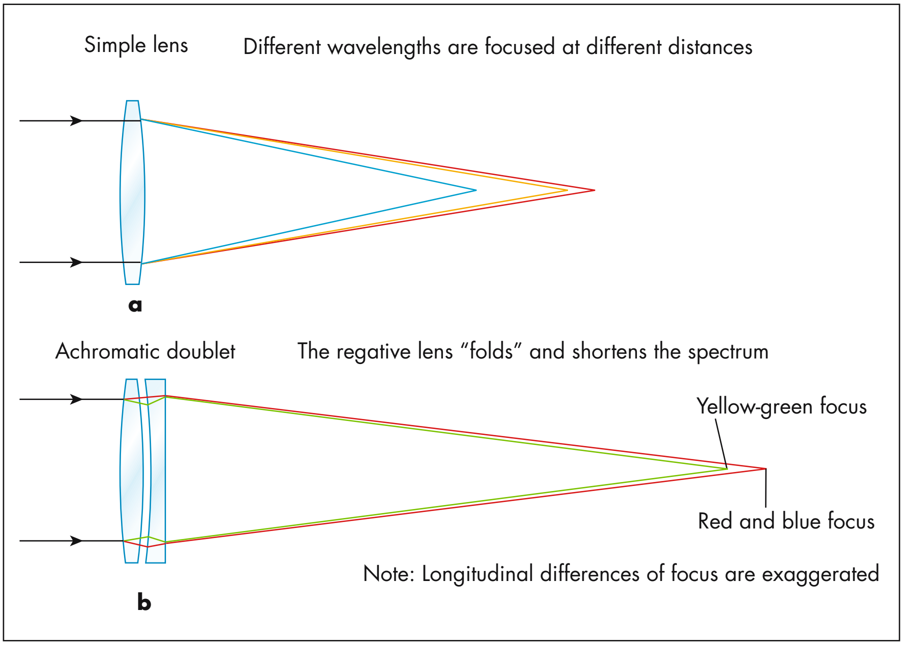

Figure 2.20. Chromatic aberration.

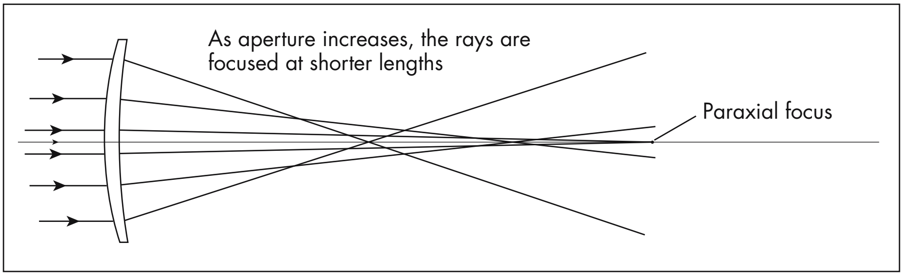

Figure 2.21. Spherical aberration in a converging lens.

Coma is a lop-sided spherical aberration. If an objective lens is corrected for paraxial rays, then any abaxial ray cannot be an axis of revolution for the lens surface and different parts of the incident beam of which that ray is a part will focus at different distances from the lens. The further off-axis the object, the greater the effect will be. The resulting image of a star tends to flare away from the optical axis of the telescope, having the appearance of a comet, from which the aberration gets its name. In objective lenses, coma can be reduced or eliminated by having the coma of one element counteracted by the coma of another. It is

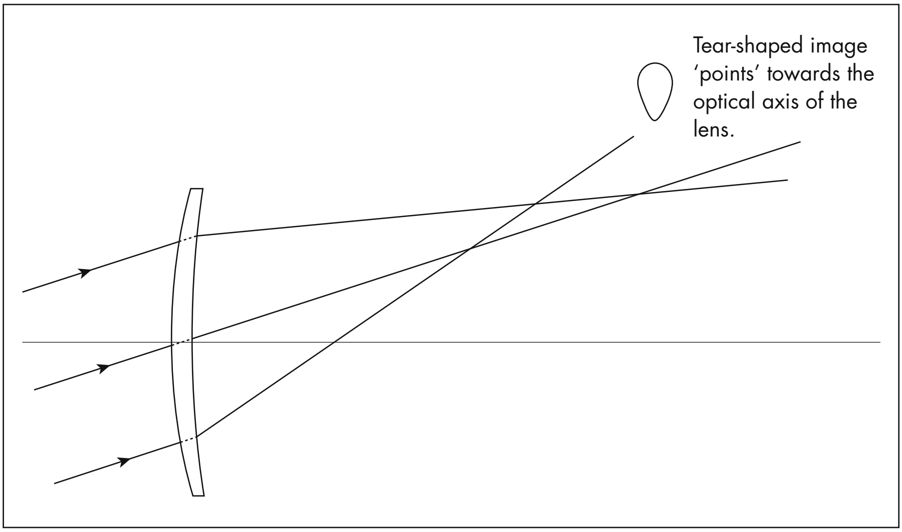

Figure 2.22. Coma in a converging lens.

usually particularly noticeable in ultrawide angle binoculars (Figure 2.22). Coma increases as direct square (quadratic) function of aperture increase and increases as a linear function of increase in field angle.

Astigmatism results from a different focal length for rays in one plane as compared to the focal length of rays in a different plane. A cylindrical lens, for example, will exhibit astigmatism because the curvature of the refracting surface differs for the rays in each plane and the image of a point source will be a line (Figure 2.23). Astigmatism will, therefore, result from any optical element with a surface that is not a figure of revolution. It can also occur in surfaces that *are* figures of revolution. Consider two mutually perpendicular diameters across a beam of light impinging obliquely upon a lens surface. The curvature of the lens under one diameter differs from that under the other, and thus astigmatism will result. Such astigmatism can be corrected by an additional optical element that introduces equal and opposite astigmatism. Astigmatism is not normally a problem in binoculars, which are primarily used for visual work, unless they have very wide fields. Astigmatism increases linearly with an increase in aperture and as a direct square (quadratic) function of an increase in field angle.

Field Curvature No single optical surface will produce a flat image—the image is focused on a surface that is a sphere tangential to the focal plane at its intersection with the optical axis (Figure 2.24). *Field curvature*, which manifests as the inability to focus the periphery of the image at the same time as the center is focused, is particularly noticeable when it is present in widefield binoculars. It can be corrected in the design of the lenses. In particular, if a negative lens can be placed close to the image plane, it will flatten the field. Field curvature increases

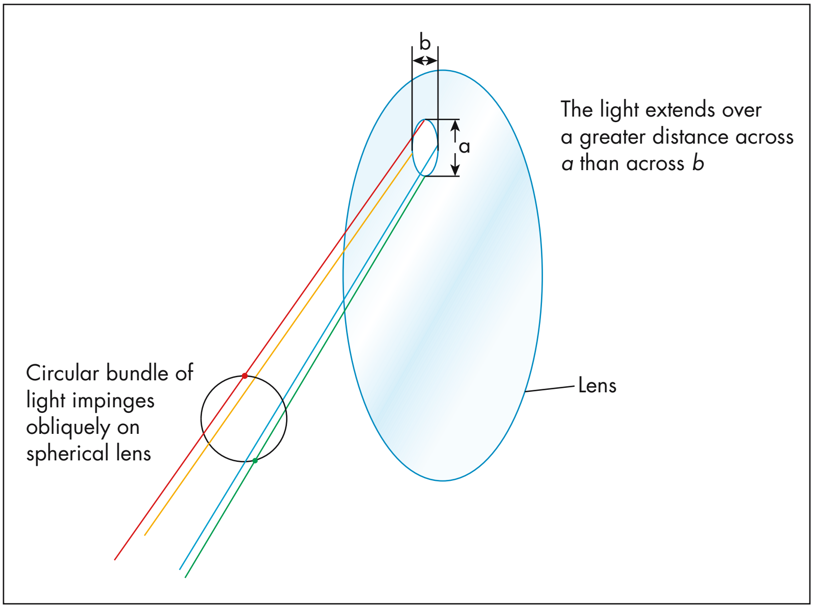

Figure 2.23. Astigmatism.

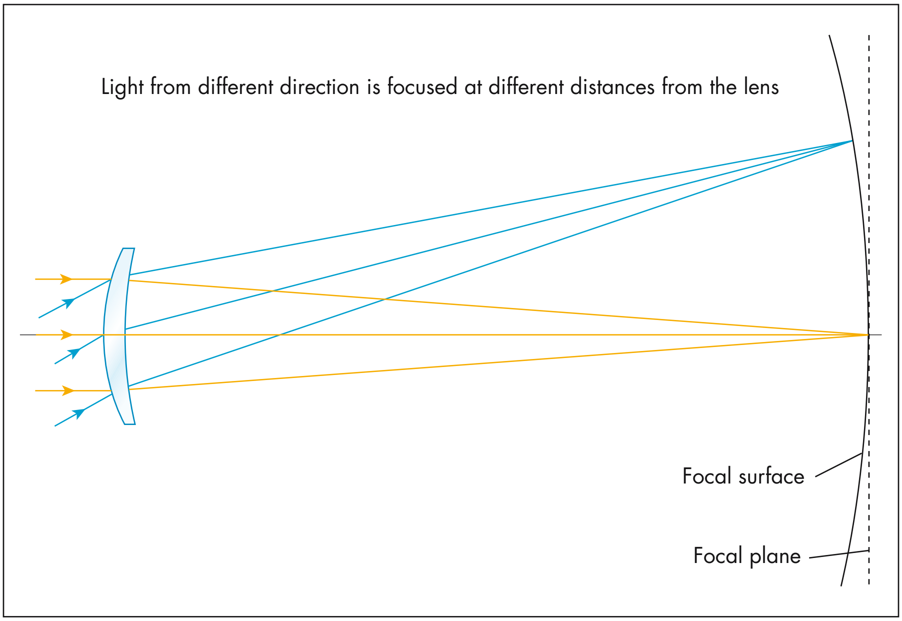

Figure 2.24. Field curvature.

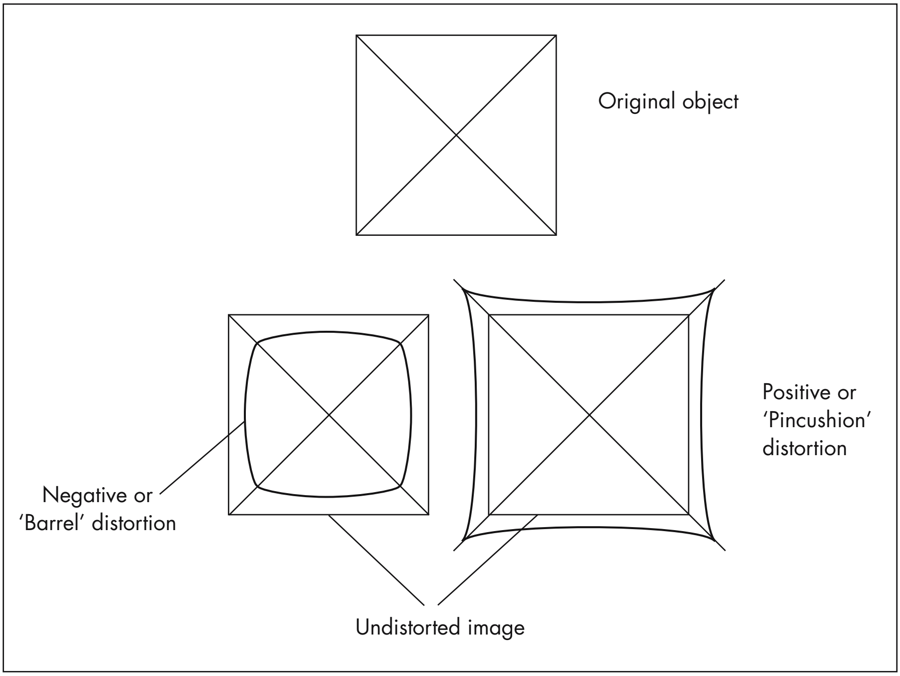

Figure 2.25. Distortion.

linearly with an increase in aperture and as a direct square (quadratic) function of an increase in field angle.

Distortion is an aberration by which a square object gives an image with either convex lines (*negative* or *barrel distortion*) or concave lines (*positive* or *pincushion distortion*). It is the only aberration that does not produce blurring of the image (Figure 2.25). It results from differential magnification at different distances from the optical axis. It almost always originates in the eyepiece, so any correction should be inherent in eyepiece design. A small amount of pincushion distortion can be desirable because it attenuates the "rolling ball" effect that results in an undistorted field of view (see Chapter 3). Distortion is unaffected by aperture and increases as a direct function of the cube of field angle.

Aperture Stops and Vignetting

Vignetting is the loss of light, usually around the periphery of an image, as a consequence of an incomplete bundle passing through the optical system. A vignetted image appears dimmer around the periphery.

Most binoculars suffer from some degree of vignetting. The exception is some binoculars designed specifically for astronomical use whose construction is based on astronomical refracting telescopes which themselves give unvignetted images.

In some, vignetting can be so severe that no part of the image is illuminated by the complete aperture. In normal daylight use, we do not notice vignetting unless it is exceptionally severe; 30 percent is common and 50 percent is sometimes deemed acceptable in wideangle systems. This is because, at any given time, only a tiny region of the image can be examined by the fovea, it is, therefore, only this region that needs to be fully illuminated. As long as the fall-off of illumination toward the periphery is smooth, it will not normally be noticed.

Binocular astronomers who, like other astronomers, echo the call for "more light!" sometimes wonder why vignetting is allowed to occur at all. To understand this, we must first understand the role of the aperture stop. An aperture stop crops the light cone and eliminates the most peripheral rays. These peripheral rays have the highest angles of incidence on the optical surfaces and undergo the most refractive bending. For these reasons they also carry with them the greatest amount of aberration. If they are permitted to pass through to your eye, they will add to the degradation of the image. Part of the process of good optical design is to assess how much of the peripheral light needs to be excluded.

If bundles of rays from all parts of the field of view fill the aperture stop, then there is no vignetting. On the other hand, if some other mechanical or optical component impedes some of this light, vignetting will occur. An unvignetted binocular requires larger optical apertures all the way through the optical system when compared to one in which vignetting does not occur. This in turn requires larger optical components (such as prisms or focusing lenses). Larger components are not only more expensive, but are also heavier. Heavier components require heavier and more robust mountings. These in turn add to the expense of the binoculars. The overall result is a heavier, more expensive, binocular. In short, vignetted systems are usually smaller, lighter, and produce better images in comparison to the equivalent unvignetted optical system. Somewhere in the design process a decision is made as to where an acceptable trade-off lies. The more discerning observer may well be prepared to accept a more expensive instrument, but the general user will almost certainly not want to pay considerably more for a hardly noticeable increase in light throughput at the periphery. Even the discerning observer may balk at an increase in weight if the binoculars are intended to be hand held.

Focusing Mechanisms

There are three different types of focusing mechanism commonly found on binoculars.

Center Focus (Porro Prism)

In the center focus Porro prism the eyepieces are connected to a threaded rod in the central hinge. An internally threaded knurled wheel or cylinder causes the rod to move, thus moving the eyepieces. The right-hand eyepiece is usually independently focusable (Figure 2.26a) to accommodate the differences in focus of the

a

b

Figure 2.26. Right eyepiece dioptre adjustment. a: Porro prism. b: Roof prism.

observer's eyes; this facility is called a "dioptre adjustment." The advantage is that the eyepieces can be focused simultaneously, which is a consideration for general terrestrial use, but not for astronomy. The disadvantages are that there is almost always some rocking of the bridge, which leads to difficulty in achieving and maintaining focus, the focusing system is difficult to seal so dirt can enter, and the optical tubes are extremely difficult to waterproof, resulting in increased likelihood of internal condensation (Figure 2.27).

Center Focus (Roof Prism)

Like the Porro prism, with the center focus system there is an external focus wheel and an independent helical focuser (dioptre adjustment) for the right eyepiece (Figure 2.26b), but the similarity ends there. The mechanism is internal, and focusing is achieved by changing the position of a focusing lens between the objective lens and the prism assembly (Figure 2.1). It has the dual advantages of permitting simultaneous focusing of both eyepieces and allowing relatively simple dust- and waterproofing. The disadvantage is that there is an extra optical element that must

Figure 2.27. The bridge rocks on this center-focus Porro prism binocular.

Figure 2.28. Roof prism center focus.

be accurately made, which absorbs a tiny amount of light, and whose movement during focusing alters the field of view slightly (Figure 2.28).

Independent Focus

Eyepieces with independent focus each have a helical focuser. This is much more robust than a center focus system and is easier to make dirt- and waterproof. The best quality astronomical (and marine and military) binoculars have independent focusing. The disadvantage is that the eyepieces cannot be focused simultaneously, but this is not an issue for astronomical observation, where refocusing is not necessary once good focus has been attained (Figure 2.29).

Figure 2.29. Independent focus—ideal for astronomy.

Collimation

Not only must the optical elements of each optical tube be collimated, but the optical axes of both tubes must be aligned. They must not only be aligned to each other, but also to the hinge or other axis about which interpupillary distance is adjusted. If this latter criterion is not met, the result is a phenomenon called *conditional alignment* in which the two optical axes are only aligned at the interpupillary distance that was set during collimation and will get progressively out of alignment for other interpupillary distances. This may be acceptable if only one person uses the binoculars.

The permitted divergence of the optical axes from true parallelism is determined by the ability of the eyes to accommodate divergence and by the magnification of the binoculars. If these limits are exceeded, either it will not be possible to merge the images from each optical tube or, if they can be merged, eye-

Table 2.1. Collimation Tolerances

Magnification	Step	Convergence	Divergence
×7	2 arcmin	6.5 arcmin	3 arcmin
×10	1.5 arcmin	4.5 arcmin	2 arcmin
×15	1.0 arcmin	3.0 arcmin	1.5 arcmin
×20	0.75 arcmin	2.25 arcmin	1.0 arcmin
×30	0.5 arcmin	1.5 arcmin	0.67 arcmin
×40	0.38 arcmin	1.13 arcmin	0.5 arcmin

strain and its attendant fatigue or headache results. Acceptable tolerances in the apparent field of view are:

- Vertical misalignment (step, dipvergence): 15 arcmin
- Horizontal convergence:[2] 45 arcmin
- Horizontal divergence: 20 arcmin

To ascertain the real tolerances, you need to divide these by the magnification to obtain the collimation tolerances listed in Table 2.1.

There are two ways in which the optical axes of the binoculars can be aligned. In almost all binoculars, the objective lenses are mounted in eccentric rings. These can be adjusted to move the optical axis in relation to the body of the binocular. In many other binoculars, the prisms are adjustable, either by grub screws (set screws) that are accessible from the outside or by being housed in a cluster whose adjustment screws are accessible by removing the cover plate on the prism housing. (See Chapter 5 for advice on how to collimate a binocular.) Collimation by eccentric rings on the objectives is preferable because tilting the prisms will result in the introduction of more astigmatism.

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Notes

1. Yoder, Paul R. *Mounting Optics in Optical Instruments*. Bellingham: SPIE, 2002.
2. There are different conventions for the use of "convergence" (and "divergence"), depending on whether the optical axes of the binocular are converging or the optical axes of the eyes are converging (to accommodate the diverging optical axes of the binocular). The usage here is the latter. It is simple to tell which convention is being used: the greater value is for converging eyes (diverging binoculars).

CHAPTER THREE

Choosing Binoculars

There is no "ideal" binocular for astronomy; the individual choice is therefore determined by the *reason* for choosing binoculars, the *purpose* to which the binoculars will be put, and the *budget*.

Binocular Specifications

Binoculars are specified by a series of numbers and letters, for example, 15×70 BIF.GA.WA. The numbers tell you the size of the binocular and the letters give additional information. The first number is the angular magnification, the second is the aperture of the objective lens in millimeters. The example therefore has a magnification ("power") of 15, an aperture of 70 mm, a body of Bausch & Lomb (a.k.a. "American") construction (B), individually focusing eyepieces (IF), rubber armour (GA), and wide-angle eyepieces (WA). There is a complete list of designation letters in Appendix F.

The numbers in the binocular specifications give rise to a variety of binocular ratings that are sometimes quoted by manufacturers and vendors. The most common are:

- *Relative Brightness*. This is the square of the diameter of the exit pupil. The exit pupil diameter is calculated by dividing the aperture by the magnification (power). For example, for 10×50, the exit pupil is 5 mm and the relative brightness is $(50/10)^2 = 5^2 = 25$. However the calculation for a 20×100 binocular, through which a great deal more can be seen, gives exactly the same relative brightness:

$(100/20)^2 = 5^2 = 25$, so this is an inadequate rating to use for astronomical binoculars. Incidentally, this is also the relative brightness that is calculated for the Mark-I eyeball (1×5) of a human being approximately 60 years old! Whereas it does give information about the surface brightness of extended objects, it says little about the overall performance. I have no doubt that I see far more in my 10×50 binoculars than I do with the naked eye, and that I see significantly more in my 20×100 binocular.

- *Twilight Index* or *Twilight Performance Factor*. This was used by Carl Zeiss International as an indication of the *distances* at which comparable detail would be seen in different binoculars. It is calculated by finding the square root of the product of the magnification and aperture. For the two binoculars above the calculations are:

$$\sqrt{(10\times 50)} = \sqrt{500} = 22.36$$
$$\sqrt{(20\times 100)} = \sqrt{2000} = 44.72$$

In this instance, the larger instrument has an index that is double that of the smaller instrument. In other words, if the smaller binocular is used to observe a target object at a given distance from the observer, the same amount of detail will be visible at double the distance in the larger instrument. This is not really applicable to visual observational astronomy where we are usually not concerned with the relative distances of objects and consider them to be effectively at the same distance.

- *Visibility Factor*. Roy Bishop devised the method to evaluate the visibility factor simply by multiplying the magnification by the aperture in millimeters. For our two binoculars above we obtain:

$$10 \times 50 = 500$$
$$20 \times 100 = 2000$$

The larger instrument has a visibility factor four times greater than the smaller one. Bishop justifies this by stating: "in the larger instrument stars will be four times brighter and extended images will have four times the area from which the eyes can glean information, with luminances being the same."[1] While this is objectively correct, I am not convinced that it reflects the subjective experience of observing through both instruments.

- *Astro Index*. Alan Adler's[2] astro index evaluates the product of the magnification and the square root of the aperture in millimeters. For our two binoculars above, we obtain:

$$10\times\sqrt{50} = 10\times 7.1 = 71$$
$$20\times\sqrt{100} = 20\times 10 = 200$$

This gives the larger instrument an astro Index of 2.8 times the smaller one; this is certainly closer to the experience of observing through them.

Others have tried to expand on these by including the effects of coatings, baffles, and other aspects of individual quality, but, although these may be more precise, they incorporate a certain amount of empirical experimental data and are not as valuable for a quick evaluation, prior to purchase, of likely performance.[3]

Field of View

In addition to the magnification and aperture, the other numerical factor that is usually stated is the field of view. This is quoted in one of three ways:

- *Degrees*. This is the most useful factor for astronomers, since it gives you an indication of the amount of sky you will be able to see. The area of sky that will be visible is directly proportional to the square of the angular field.
- *Metres at 1,000 Meters*. This factor is more useful for terrestrial use and is currently the most commonly found alternative to degrees. The approximate conversion of this to degrees is to divide by 17.5. Thus 87 m at 1,000 m ≈ (87/17.45)° = 5°. There is a conversion chart given in Appendix H.
- *Feet at 1,000 Yards*. This factor is more useful for terrestrial use and is currently most often found on binoculars intended for the U.S. market. The approximate conversion of this to degrees is to divide by 52. Thus 364 ft at 1,000 yd ≈ (364/52)° = 7°. There is a conversion chart given in Appendix H.

Most, but not all, people prefer a wide field of view for astronomy. The true field of view is dependent on the magnification and the apparent field of view of the eyepiece:

True field = Apparent field ÷ Magnification

Strictly speaking, an eyepiece can have an extremely large field of view, but this deteriorates rapidly toward the edge, so it is limited by a field stop. There is always a trade-off between field of view and edge quality. In general, a 50-degree apparent field is a "standard" field, 65 degrees and above is considered to be "wide angle," and 80 degrees and above is designated "ultrawide angle." By comparison, the field of view of the unaided eyes is approximately 45 degrees (excluding peripheral vision). Some manufacturers tend to be optimistic in their stated fields of view. In practice, 65 degrees appears to be the upper limit for an apparent field; all binoculars I have used with wider apparent fields have suffered from severe deterioration of quality and easily noticeable vignetting in the outer part of the field, and those of ultrawide angle have also appeared to have a poorer image quality even in the center of the field when compared to standard field binoculars of a similar price.

Another problem associated with some very wide field eyepieces is the effect that is colloquially called "kidney-beaning" or "flying shadows." The colloquial names are descriptive of what you see if your eyepieces are afflicted with this problem, the correct name being *spherical aberration of the exit pupil*. Different zones of the exit pupil are focused at different distances from the eyepiece, so your eye is unable to focus on the entire field at once. If your eye is slightly off center, the result is these *flying shadows* that are the shape of *kidney beans*. They tend to be worse at night when your pupils are more dilated, and some people seem to be more bothered by them than others.

While wide field views are an attraction to many people (a 7-degree field shows an area of sky twice as large as a 5-degree field), magnification is an extremely important factor for binocular astronomy, and a small cluster, nebula, or galaxy that is detectable at ×10 may appear to be stellar at ×7.

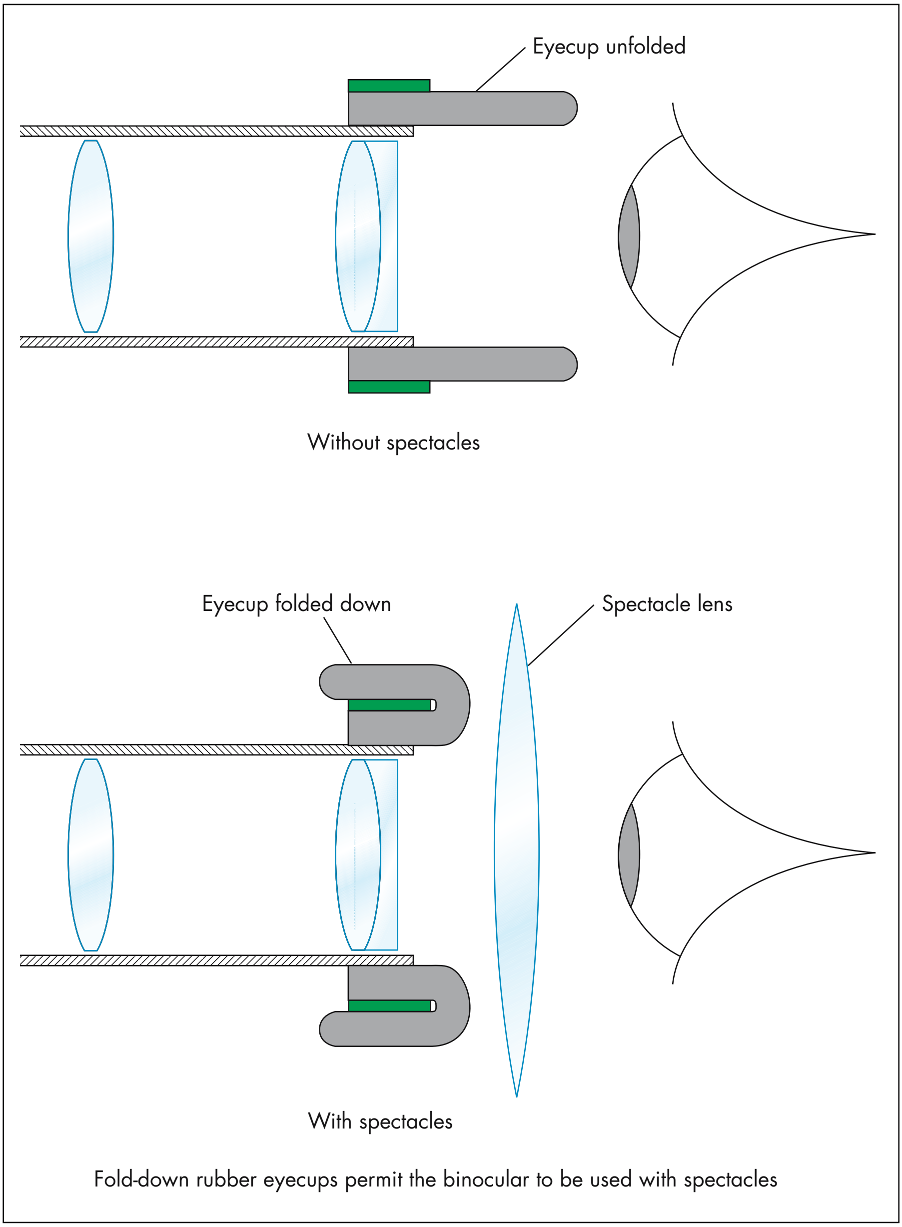

Figure 3.1. Eyecups.

Eye Relief

The *eye relief* of a binocular is the distance from the eyepiece that you need to place your eye in order for all the light from the eyepiece to pass into your eye when the exit pupil of the binocular is the same size as the pupil of your eye. It is the position of what physics textbooks call the "eye ring" and can be defined as the position of the image that the eyepiece forms of the objective lens. At this distance you will be able to see the entire field of view and will have the brightest possible image. Over the past decade manufacturers have become more aware that spectacle wearers will seek out binoculars with adequate eye relief to enable them to see the whole field of view. As with fields of view, several manufacturers tend to be somewhat "optimistic" in their quoted eye relief so, if you need to wear spectacles for observing, you should verify *in practice* that the binoculars have a suitable eye relief. So that binoculars can be used by people both with and without spectacles, they will have eye cups that are either twist-down or fold-down to enable the correct positioning of your eye (Figure 3.1). As eye relief increases, it becomes increasingly difficult to position your eye precisely behind the eyepieces. This can exacerbate the kidney bean effect if it is present.

Hand-held Binoculars

Hand-held binoculars are the choice for extreme portability, casual observing, and as a preliminary "sky-scanner" used in conjunction with a larger instrument. Almost all binoculars, including cheap plastic opera glasses, will show you more than the naked eye, but a sensible lower limit of aperture for portable astronomical binoculars is 30 mm. If extreme portability is not an issue, 40 mm is significantly better as it will admit more than 75 percent more light. As aperture increases, so does the weight of the binocular, making it increasingly difficult to hold steadily. The sensible upper limit of aperture for hand-holding is normally considered to be 50 mm. Larger apertures than this can be held for short periods, but are too tiring to use for anything other than very brief views.

For many years the commonsense view was that the limit to magnification for hand-held 50-mm binoculars was ×7. This is probably because 7×50 was, and still is, the most common size of hand-held marine binoculars. While it is true that they are easier to hold steady than, say 10×50, most of us do not do our astronomy from the moving deck of a boat. There are very few astronomical objects that are better at 7×50 than at 10×50, and it is perfectly possible to hold 10×50 binoculars sufficiently steady when our observing platform is the ground (see Chapter 6). The increased magnification of the 10×50 allows us to see more detail and generally gives more satisfying views. This is reflected in its higher rating in every performance index except relative brightness, and even this difference is reduced for those of us whose pupils do not dilate sufficiently to enable us to use the full 7-mm exit pupil of the 7×50 (Figure 3.2).

There is perennial debate on whether, if you use small or medium-sized binoculars for astronomy, you should use Porro prism or roof prism binoculars. The

Figure 3.2. Variety of 10×50 porro-prism binoculars. L to R: Older style center-focus Z-body with fixed eyecups (Zenith); Robust center-focus B-body style (Swift Newport); Modern lightweight center-focus Z-body with folding eyecups (Helios Naturesport); Robust individual focus Z-body (Strathspey Marine).

conventional wisdom is that Porro prism binoculars are better for astronomy. While it is certainly true that for the same price Porro prism binoculars tend to have superior optical quality, good quality roof prism binoculars are as optically and mechanically good as good quality Porro prism binoculars. The roof prism binoculars tend to be lighter and more compact and are therefore generally easier and more comfortable to hold. Over recent years I have found that I use my 10×42 roof prisms more than my 10×50 Porro prisms, and a side-by-side comparison shows that I see no more in the Porros when I hand-hold them, although they do show very slightly more when they are mounted. Roof prism binoculars also have the advantage that they can more easily be made waterproof, as the focusing mechanism is usually internal.

If you choose Porro prism binoculars, you may also have a choice between center-focus and independent eyepiece focus. There are no advantages to center focus if the binoculars are to be used exclusively for astronomy, but if you intend to use them for terrestrial purposes (e.g., bird watching or horse racing) then you should get center focus. My preference for astronomy is independent focusing eyepieces. They tend to be more mechanically robust, do not suffer from a rocking bridge, and modern ones tend to be waterproof and nitrogen filled, reducing the likelihood of internal fogging.

Another option for hand-held binoculars is image stabilization. This feature incorporates an electronic system that compensates for motion and vibration. Different manufacturers employ different stabilization systems, which were developed initially for military surveillance and not for astronomy. A test report in *Sky & Telescope* suggests that the best stabilization system for astronomical observation is that employed by Canon, whose optics were also superior.[4] In addition to the stabilization system, the optics are essentially a roof prism system with a field flattener (see Chapter 2) incorporated into the design. The stabilization system (see Chapter 2) compensates for shake and the result is that you can see fainter objects and more detail. A 10×30 IS binocular will show most people more than a conventional 10×50. While a 10×30 IS is sufficiently lightweight (600 g/1.25 lb) to be held for relatively long periods, the larger 15×50 IS and 18×50 IS are heavy enough to be tiring

Figure 3.3. Canon 10×30 IS image stabilized binoculars. (Photo: Canon Inc.)

to hold for extended periods. If you are considering purchasing image stabilized binoculars, you should be aware that the image stabilization mechanism requires battery power, and that the life of batteries, particularly alkaline batteries, is reduced in cold weather. Without power, the binoculars can be used as conventional binoculars (Figure 3.3).

Mounted Binoculars

All binoculars will show more if they are mounted because this eliminates the jiggles of being held. Even a small binocular will show objects a magnitude or so fainter if it is mounted. If binoculars are going to be a main observing instrument, it makes sense to acquire one of greater aperture and magnification than can be held. Big binoculars in the aperture range of 60 to 100 mm have become readily available in recent years (Figure 3.4). Once you are dealing with big binoculars, you are dealing with specialist instruments and can expect them to have features that enhance the ease and pleasure of astronomical observing. These may include:

- *Mounting Plate.* Because big binoculars necessarily have to be mounted, it is common for them to incorporate a plate, with quarter-inch threaded holes, for direct mounting to a photographic tripod or other mounting. This eliminates the need for an L-bracket, which inevitably introduces an additional potential source of instability and is yet another essential piece of equipment that has to be remembered (Figure 3.5).
- *Angled Eyepieces.* There is little to recommend in straight-through binoculars for astronomical observing. They are considerably less comfortable than those with angled eyepieces when you are observing at high elevations. Angled eyepieces also permit the use of photographic or video tripods and heads because they eliminate the need to “limbo-dance” under the tripod when you observe objects of high elevation.
- *Interchangeable Eyepieces.* If binoculars are mounted, interchangeable eyepieces become functionally useful. The ability to change magnification permits, within

the limits of the mechanical and optical precision of the binocular, the best combination of image brightness and contrast to be selected. Interchangeable eyepieces are usually friction-fit into the eyepiece holder, although some binoculars have their eyepieces turret mounted so that the unused eyepieces cannot get mislain or dropped. I am not convinced that this is a long-term advantage,

Figure 3.4. Strathspey 15×70 binocular. These Chinese binoculars, which are sold with different brand names, have become very popular in recent years. (Photo: John G. Burns)

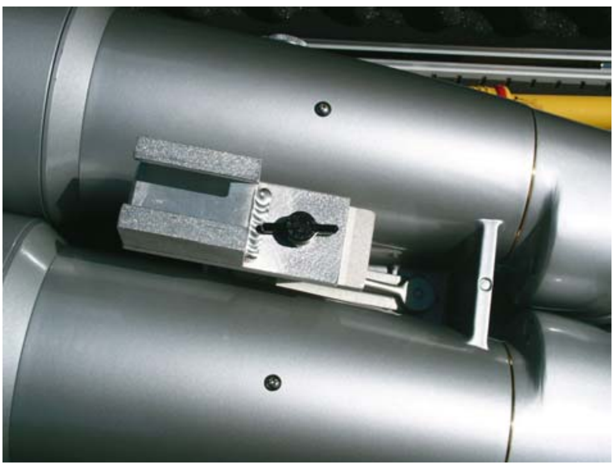

Figure 3.5. Bracket attached to mounting plate at the bottom of 20/37×100 binoculars.

because it introduces another feature that must be made to great precision and detracts from the inherent simplicity of binoculars by adding to the number of things that can go wrong. On the other hand, their advocates report this feature to be extremely useful.

Binocular Telescopes

The distinction between "binoculars" and "binocular telescopes" is fuzzy to say the least. The latter term is usually, but not exclusively, applied to binoculars larger than 150 mm (6 inch) aperture, binoculars that use Newtonian- or Cassegrainian-type optical systems, and those that are constructed from optical tubes initially intended or sold as telescope tubes, usually using eyepieces that are sold for telescopes. The majority are home constructed, but there are also commercially available models (Figures 3.6 and 3.7).

When these telescopes are home constructed, it is crucial to have a good focusing mechanism that also allows for collimation. These instruments often work at higher magnifications than equivalent binoculars, and, thus, collimation tolerances are significantly more severe. Typically, they have to be recollimated every time they are used, so ease of collimation is a must (Figure 3.8).

Figure 3.6. 250 mm (10 inch) aperture binocular telescope by JMI. The picture shows the inside of the optical tubes. (Photo: Jim's Mobile Inc.)

Figure 3.7. Binocular telescope by Peter Drew constructed from two 150 mm (6 inch) Synta telescopes.

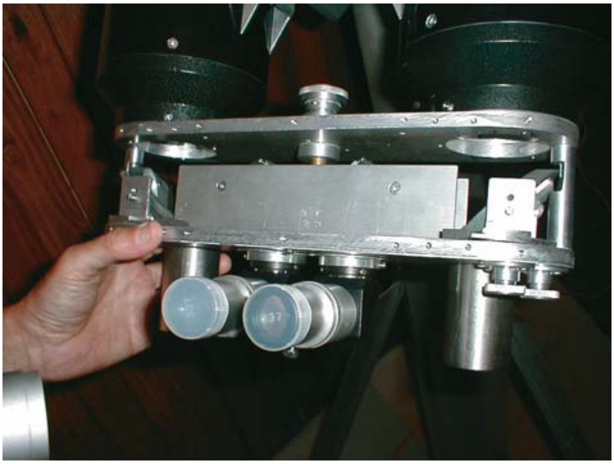

Figure 3.8. The focusing, IPD, and collimation mechanism in the Synta-based binocular telescope. Collimation is achieved by adjusting the elliptical mirrors.

Binoviewers

Binoviewers are designed to permit the use of two eyes with a single optical tube assembly (Figures 3.9 and 3.10). The rationale for their use is that they offer some of the advantages of binoculars with few attendant disadvantages. The obvious advantages are the reduction in eye strain from using two eyes, the suppression of the blind spot, and the aesthetics of false stereopsis (see Chapter 1). The obvious disadvantage is the loss of light into each eye that results from the splitting of the light into two optical paths and from the additional optical elements in each light path. While binocular summation (see Chapter 1) can compensate for some of this loss, the overall perception is that using a binoviewer is equivalent to a loss of about one third of the illumination as compared to a single eyepiece. In addition, the cost of providing matching eyepiece pairs, thus doubling the number of eyepieces required when compared to a conventional telescope, is not one that can be ignored, especially where good quality eyepieces are used. However, this is ameliorated to some extent by the development of binoviewers that incorporate the facility of multiple magnifications without changing eyepieces.

An advantage that is not common to conventional binoculars is the ability to use high magnifications without the need to collimate two optical tubes. Another is that their use with telescopes of large aperture provides an equivalent aperture that would be significantly more expensive and technologically difficult to achieve with binoculars or binocular telescopes. A less obvious advantage when they are used at high power concerns "floaters." Floaters are strands of protein that float within the transparent humors of the eye and become apparent, sometimes distractingly so, when one is observing with a small exit pupil. Users of binoviewers

Figure 3.9. Denkmeier binoviewer used with a limited edition 12.5-inch f/6 Teeter's Telescopes "Planet-Killer" telescope. (Photo: Copyright 2005, Teeter's Telescopes)

Figure 3.10. Celestron binoviewer attached to a Meade 10″ LX50. (Photo: courtesy of Gordon Nason)

report that their visibility is suppressed, often to the point of elimination, probably in the same way as they suppress the blind spot (page 3).

If you are considering a binoviewer, you should ascertain its clear aperture, as this will place a limit on the lowest power of eyepiece that you can use effectively. In cheaper units this can be as little as 20 mm, restricting the eyepieces to those with a field stop less than or equal to this. You should also ascertain whether your telescope has sufficient back focus to permit it to be used with a binoviewer; a Barlow lens in the "nose" of the binoviewer may enable this. Finally, you should consider those that have self-centering eyepiece holders as this will eliminate any miscollimation that may otherwise result from slightly undersized eyepiece barrels being held off-center by thumbscrews.

Zoom Binoculars

The question of zoom binoculars is one that inevitably arises, not least because there are good quality zoom *telescopes* and good quality astronomical zoom *eyepieces* on the market. I once made the comment that a decent zoom binocular for astronomy had yet to be invented. A vastly experienced binocular repairman, Bill Cook, retorted to the effect that my qualification "for astronomy" was redundant. The reasons for this are simple. Not only must the eyepieces zoom to within 1 percent of exactly the same rate (which means absolutely no perceptible rocking of the bridge), but a zoom binocular requires a system with moveable optical elements that must hold collimation, ideally to better than an arcminute where step (a.k.a. dipvergence, a.k.a. supravergence) is concerned if one is approaching ×30; for the ×125 that I have seen advertised for some zoom binoculars, this translates to better than 15 arcseconds! Now, consider how many good quality center-focus ×30 binoculars you know of—I don't know of any, and I am sure that part of the reason must be that it would be a feat of technological brilliance (not to say expense!) to bridge two eyepieces in such a way that they maintain collimation to within the tolerances that are required. (And remember that it is unlikely that they will have a "base tolerance" of zero error.)

According to Seyfried, zoom binoculars were developed as a "gimmick to stimulate sales" on the back of the success of zoom lenses for cameras.[5] He also asserts that the frequency with which they fail results in their being disproportionately represented at binocular repair facilities and states that he has never seen a zoom binocular that can hold collimation.

Notes

1. Bishop, R. "Binoculars." In R. Gupta, ed., *Observer's Handbook 2003*. Toronto: University of Toronto Press, 2002, pp. 50, 51.
2. Adler, A. "Some Thoughts on Choosing and Using Binoculars for Astronomy." *Sky and Telescope*, 104 (3), September 2002: 94–98.
3. Zarenski, E. How-to Understand Binocular Performance. http://www.cloudynights.com/documents/performance.pdf.
4. Seronik, G. "Image-Stabilized Binoculars Aplenty." *Sky and Telescope*, 100 (1), July 2000: 59–64.
5. Seyfried, J.W. *Choosing, Using, & Repairing Binoculars*. Ann Arbor: University Optics Inc., 1995, pp. 10ff, 47.

CHAPTER FOUR

Evaluating Binoculars

Recently, a colleague told us of a local gas station that was offering 10×22 compact binoculars for sale at under $5 each. On the reasoning that "you can't go wrong at that price," the colleague acquired a pair for his son, who was very pleased with them. Upon hearing of this, another colleague went to the gas station and bought a pair for herself. When she got home and tried them out, she found that they gave a double image, obviously a case of poor collimation. She returned them, where the sales assistant took them and, without even checking them, placed them in a box and replaced them with a new pair out of another box. My colleague was satisfied with the replacement pair and pleased with the "service" she received from the gas station.

A few weeks later, I took a group of students to see an international cricket match; one of them was the son of the first colleague, who brought his new binoculars with him. As usually happens, these binoculars were passed around among the students, most of whom had never used binoculars at a sporting event, and they were impressed with the magnified image and wanted repeated looks through the binoculars. To ease the demand, I passed around my good (but by no means superb) quality 10×42. Every student immediately noticed the difference and it was obvious that none had used binoculars of this quality before. As one put it: "These are amazing, Mr. Tonkin. They are even clearer than eyesight!" The colleague's son was, as you can imagine, a bit deflated because his binoculars seemed so inferior. I pointed out that mine had cost almost exactly a hundred times the cost of his. I showed the students how to detect the off-axis chromatic aberration and pincushion distortion in mine, and then asked them to consider if they thought that the image in mine was a hundred times better. I also pointed out that mine could not be conveniently carried in a shirt pocket. Honor was satisfied and we got on with enjoying the match, albeit with my binoculars having far more use than the budget ones.

This pair of episodes illustrates several things:

- Over the past few decades binocular manufacturing methods have improved to the extent that, without any but the most rudimentary quality control checks, binoculars of reasonable quality can be produced remarkably cheaply. Budget quality binoculars can be produced so cheaply that they are effectively disposable items.
- It is far more cost-effective for manufacturers of all but the best quality binoculars to use the customer to do the quality control. It is cheaper merely to replace the unsatisfactory (to the customer) instruments than it is to employ quality control staff.
- People will tend to be satisfied with poor quality unless they have something better with which to compare it. The consequence of this is that many instruments, which may have been rejected by effective quality control, will be acceptable to some customers, particularly if the price is right.
- Differences in optical quality can often be immediately apparent, even to "untrained" people, most of whom are capable of performing simple tests for common aberrations.
- Once you have used good quality binoculars it is difficult to be satisfied with less. However, we do become emotionally attached to our possessions and can readily justify poor quality on the grounds of price or some other comparative benefit like ultraportability.
- Optics that are entirely free of aberrations exist only in the imagination and, to a large extent, the old adage that you get what you pay for still holds true. For recreational use, the determination of whether the extra quality is worth the extra price is almost entirely a subjective one.

Hence, it is not only possible, but also very desirable, to be able to do some initial testing of binoculars in the store where they are bought. With the advent of the phenomenon that an ever increasing number of goods are bought, for reasons of cost, over the Internet or by mail, the same applies to testing upon receipt of the item. However, as you are aware, there is no substitute for the more demanding tests that astronomical use makes of binoculars, so it is important that you ensure that the vendor has a policy that will permit you to return them if they are unsatisfactory when they are used under the stars.

Preliminary Tests

A very large amount of information can be gleaned from some very basic preliminary testing. This will eliminate binoculars that are grossly unsuitable. Remember that with very few exceptions, aberrations, faults, or features that are merely irritating during initial testing will become infuriating under the stars. However, while you should not expect to find a binocular that is entirely free of all aberrations or faults, you should expect to find that they exist in lesser number and severity in more expensive instruments. What you can expect to have to accept depends to a large extent on your budget, and you may find that you are more sensitive to some aberrations or faults than to others. Your final choice must inevitably be a subjective one, but will ideally be one that is guided by a measure of objectivity. With all tests that use touch or hearing, remember that closing your eyes tends to make these senses more acute for many people.

Do not even consider fixed focus, zoom, or "quick focus" binoculars; they are unsuitable for astronomy. Here is a list of things to look for in a quality pair of binoculars:

- *Visual Overview.* Reject any binoculars that have "ruby" optical coatings, loose screws or screws with damaged heads, covering material that is not in complete close contact with the binocular housing, scuff marks anywhere, any evidence of dust or other foreign matter on the inside of the optics, or internal baffling that is not uniformly matte black.
- *Mechanical Overview.* Give the binoculars a good shake. Reject any in which you feel or hear any movement of components.
- *Focus Mechanism.* Run the focus mechanism through its full range. The feel should be uniform throughout the range and should not be too stiff or too loose. If it is stiff, it is very difficult to *find* a precise focus. If it is loose, it is difficult to *maintain* a good focus. Feel for any stiff regions or any "sloppy" regions. A different feel in different regions is indicative of poor mechanical tolerances in manufacture. Feel for any difference between dynamic friction and static friction ("stiction") by stopping the focus at various points throughout the focal range and feeling for a slight jerk or "catch" when you start to refocus. This is usually due to poor-quality lubricant and makes precise focusing difficult. On binoculars that have individual eyepiece focusing, test each eyepiece focus individually. On center-focus eyepieces, remember to test the focus ring of the right-hand eyepiece.
- *The Bridge.* The bridge is the pair of arms that connects the eyepieces to the center-post focus mechanism in Porro prism binoculars. All bridges will rock to some extent and, as they do so, they change the focus of either or both sides of the binocular. On well-made binoculars the rocking is minimal and requires considerable pressure, more than will be put on the eyepiece housing in normal use. On budget-quality binoculars there can be considerable rocking with minimal pressure. This rocking gets worse with age. To test the bridge for rocking, merely hold the binoculars by the prism housings with the eyepieces downward, then press down alternately on the eyepiece housings with the tips of the forefingers. The severity of any rocking becomes immediately apparent. If you are unsure how it will affect you, hold the binoculars to your eyes, focus on something and, by rocking the binoculars from side to side, put slight pressure alternately on each eyepiece housing with your eye socket. If the focus changes, reject the binoculars.
- *Interpupillary Distance (IPD) Adjustment.* In hand-held binoculars, the IPD adjustment is usually the central hinge. For larger binoculars, it can be either a hinge or eccentrically rotating prism housings or eyepiece turrets. If it is loose, it is difficult to maintain any given IPD. If it is very stiff, or if it is jerky, it is difficult to set the IPD. If only one person is to use the binoculars at any one time,

this need not be a significant problem. Be aware that several center-hinge binoculars need to be folded to near the minimum IPD in order to fit into the case; test if this is necessary with your IPD. Check that the IPD range accommodates all intended users. Most binoculars do not cover the entire range of IPDs for adults; this range is usually considered to be about 43 to 80 mm with a mean at around 65 mm, and about 90 percent of people have IPDs within 8 mm of the mean. Most binoculars do not deviate more than about 10 mm from the mean. If you know your IPD, the binocular IPD adjustment is easy to check merely by using a piece of card with your IPD marked on it and holding it over the binocular eyepieces. If not, you can check this when you test the binoculars for optical quality (below). Check that the eyepieces go comfortably to your eyes when the IPD is set for you. If you have narrow-set or deep-set eyes, or if your nose has a wide bridge, this may not be possible for you especially with wide-angle eyepieces, which are typically larger in diameter than "normal" ones (Figure 4.1).

- *Tripod Bush.* You will be able to see significantly more with mounted binoculars than with unmounted ones, even if you do intend to use them primarily as a hand-held instrument. Most medium-sized modern binoculars have a quarter-inch UNC (20 t.p.i.) bush in the distal end of the center-post. This bush is covered by a cap, usually made of plastic, but sometimes of metal, which unscrews. Remove it and check the quality of the bush. If possible, try an L-bracket and ensure that you can easily connect the bracket to the binocular, with the thread of the L-bracket bolt easily meshing with the thread in the bush without danger of cross-threading. Remember that you will most likely be wanting to do this in the dark, possibly with cold or gloved hands.
- *Prisms.* Hold the binoculars away from you, pointing toward something relatively bright (e.g., the sky or a light-colored wall or ceiling—*not* the Sun!), and look at

Figure 4.1. Wide-angle eyepieces (top) are of large diameter and may be unusable for people with narrow-set eyes or wide noses.

the bright circle of light in the eyepieces. If it is actually a circle, all well and good. If it is tending toward lozenge shaped, this is an indication of undersized prisms; undersized prisms are themselves indicative of cost-cutting. If there are blue-gray segments of the circle with a brighter lozenge inside, this is indicative of cheaper BK7 glass in the prisms (Figure 2.8). In both cases, the prisms will cause some vignetting of the image. With roof prism binoculars, bring them up to the eyes and carefully examine the image of the bright surface. Do you see a faint line if you defocus your eyes? If so, you are seeing the "ridge" of the roof prism. If the line is obtrusive, it will result in flaring of bright astronomical objects. This is easier to test for using a bright point of light against a dark background, but this is usually not available in the store.

- *Eye Relief.* When you look through the binoculars, the image in the eyepiece should be surrounded by the crisp dark edge of a field stop at the mutual focus of the eyepiece and objective. If there is insufficient eye relief, you cannot get your eye sufficiently close to enable this. Most modern binoculars have fold-down rubber eyecups around the eyepieces to enable their use by spectacle wearers (Figure 3.1). However, not all rubber eyecups fold down, and not all permit a bespectacled observer to get his eyes sufficiently close. Even if you do not wear spectacles, do check that the eyecups fold down. On cold or dewy night, warm moisture evaporating from your eye can condense on the eyepiece, causing it to fog. If you fold the eyecup down, air can circulate between your eye and the eyepiece, reducing the likelihood of fogging.
- *Comfort.* Comfort is particularly important if you intend to use hand-held binoculars for long periods of time. In general, lighter binoculars are less tiring to hold, but this is not always the case. A heavier binocular that is well designed from an ergonomic perspective can be less tiring than a lighter instrument that is poorly designed. There is no substitute for experiment when it comes to determining how a particular binocular suits you as an individual. When you perform the optical tests below, take your time and perform them consecutively without taking the binoculars from your eyes. Be conscious of how tired your arms become.
- *Focus.* (See also "Spherical Aberration" below.) To focus a binocular, do one optical tube at a time, with the other side covered with a lens cap on the objective side. First, set the interpupillary distance. Check by alternately shutting eyes or alternately covering objective lenses, so you have a complete field of view, surrounded by the field stop, on both sides. If the eyepieces focus independently, it does not matter in which order you do them. With center-focus binoculars, cap the right-hand objective and focus the left-hand optical tube on a distant object with the focus wheel (called "focus band" in some binocular instruction sheets). Critically examine the image to determine if it "snaps" to a good focus or if there is a range where it looks less "mushy." When you have the best focus, swap the lens cap to the left objective and, *without adjusting the focus wheel*, focus the right-hand tube with the focus ring on the right-hand eyepiece housing. Again, critically examine the focus. Remove the lens cap and again examine the focus. Then focus on a nearer object and, by alternately covering the objective lenses, verify that both sides are focused, not merely the one used by your dominant eye. Do not be tempted to use a hand instead of a lens cap or, worse, to focus

individual tubes by closing one eye; this is rarely satisfactory. The hand almost always changes the mutual orientation of eyes and binoculars from the usual observing position. This is true also when the binocular is mounted, merely because of the act of stretching the arm to a non-observing position. Closing one eye can cause the other to squint. When you do visual optical tests, you want your eyes and body to be relaxed.

- *Focal Range.* When binoculars are used for astronomy, it is not immediately apparent why one would need any focal distance other than infinity. There is, of course, the trivial case of the applicability of binoculars to terrestrial use, which often requires that you can focus them *closer* than infinity. The other case is that of eyeglass wearers who wish to observe without eyeglasses. If your eyes are hypermetropic (farsighted), there is usually no problem because the binocular adjustment is to what would be focus on a nearer object for a person with normal vision. However, if your eyes are myopic (nearsighted), to focus on an object at infinity the binocular must be adjusted to focus on what, to a person would normal vision, would be *beyond* infinity. Whereas most binoculars have some facility for this, the amount of extra focus travel varies enormously. If your eyes are myopic and you wish to observe without your eyeglasses, you should verify that the binoculars have sufficient focal range to accommodate your eyesight. You should try to focus on an object at as great a distance as possible—at least a Kilometer (about half a mile), but preferably more—away from you. Additionally, because the depth of focus of your eyes is reduced when your pupils are dilated, as they will be when the binoculars are used for astronomy, you should try to focus on a dark object without a bright background. Dark vegetation on the horizon is ideal. Be aware that you will almost certainly need a bit more "beyond infinity" travel at night time than you need during the day, so allow for this.
- *Internal Reflections.* Internal reflections, be they reflections off the interior walls or components of the binoculars, or "ghost" reflections off poorly designed or inadequately coated optical components, are both distracting and detrimental to astronomical observation. They tend to be most obtrusive when a small bright object is observed, off-axis, against a dark background (i.e., exactly the conditions that are often found in astronomical observation!). To test for this, use a bright light source (*not* the Sun), such as a recessed halogen lamp in the store ceiling or a Mini-Maglite® with the lens assembly removed, slightly off axis.
- *Chromatic Aberration.* All binoculars will exhibit some degree of chromatic aberration. In very good binoculars it may only be noticed off-axis and then only just perceptible. The purpose of this test is to compare binoculars, not to find one that is perfectly achromatic. Chromatic aberration is most obtrusive with high-contrast objects, such as many astronomical targets. Although it may not be noticeable on fainter or lower-contrast objects, if it is present it *will* degrade the image by reducing contrast. The simplest daytime test is usually to view a distant television antenna or electricity post or similar object against a bright sky. It is important to ensure that the IPD is properly set, since chromatic aberration can often be induced by moving the eye off axis. Focus the target object at the center of the field and slowly pan the binoculars so that the object moves toward the edge. Chromatic aberration will be visible as colored fringes at the interface of light and dark, usually magenta on one side and cyan on the other.

- *Spherical Aberration.* (See also "Focus" above.) Spherical aberration occurs when light from different regions of the lens is focused at different distances from the lens. It is usually well corrected for in modern binoculars, but does exist in budget ones. It is visible as a "mushy" focus (i.e., an object at the center of the field of view does not "snap" to a good focus).
- *Field Curvature.* Lenses do not focus images on a plane, but on a curved surface that is concave toward the lens. The result is that if the eyepiece is focused on an object at the center of the field of view, objects at the edge will be out of focus. This is field curvature and it is potentially present in all binoculars. In excellent binoculars it may not be noticeable at all; in budget binoculars it can be obtrusive less than halfway to the edge of the field. Unless it is severe, it is not a major problem for daytime use, where the attention is on objects at the center of the field of view, but astronomers prefer pinpoint star images right to the edge. It can be ameliorated by addition of extra lens elements, and the field of view can be limited by field stops so that it is not apparent. The extra lens elements will absorb some light and reduce contrast, an important consideration for astronomical use. In ultrawide-angle binoculars, unless they are extremely well designed, it can render most of the field of view unusable for astronomy, thus negating the perceived advantage of a wide apparent field of view. To test for it, merely focus on an object at the center of the field of view and move the binoculars so that the object moves toward the edge. If it goes out of focus but can be refocused, this is field curvature. (If it cannot be refocused, it is probably coma.)
- *Coma.* Coma is a form of off-axis spherical aberration. It is very difficult to test for during the day as it requires a point source of light. This is sometimes possible by viewing a glint of sunlight reflected off a very curved shiny object such as a metal car radio antenna. Focus the glint on the center of the field and move the binoculars so that the object moves toward the edge. If coma is present, the image of the glint will flare toward the edge of the field, giving it the appearance of a comet (hence the name coma) with its head toward the center. Coma is often present in binoculars that are not specifically designed for astronomy. This is because it is not normally visible or particularly degrading of daylight images, largely because birders, for example, use binoculars to examine birds at the *center* of the field.
- *Astigmatism.* Astigmatism is an aberration that, like coma, is very difficult to test for during the day. It manifests itself as a point object, such as a glint of sunlight, being seen as a short line when just out of best focus, that changes orientation through 90 degrees from one side of focus to the other.
- *Vignetting.* Vignetting results from the outer parts of the field of view not being illuminated by the whole of the objective lens. It manifests itself as a darkening toward the edge of the image. It is present in all terrestrial binoculars, where it is not obtrusive when they are used to examine objects at the center of the field of view, and most astronomical binoculars. Mild vignetting can be difficult to test for during daylight because the human visual system readily adapts to a very large range of illumination, but flicking the gaze back and forth between the edge and center of the field of view will usually reveal it.
- *Kidney-bean Effect.* The kidney-bean effect, also known as flying shadows, is an affliction associated with some widefield eyepieces and is a result of spherical

aberration of the exit pupil. Instead of being a flat disc, the exit pupil is curved and it is therefore impossible to focus the entire field of view at once so you have to hold the binocular slightly further from the eye to focus one zone than another. There is a position at which your iris will cut off the light from a zone between the center and the periphery and, if your eye is not perfectly aligned with the optical axis of the eyepiece, the result is these flying shadows that have the shape of a kidney bean. The effect is more pronounced in daylight, or when viewing a bright Moon, than at night, and is therefore best tested for during daylight.

- *Distortion.* Almost all binoculars will exhibit some distortion toward the edge of the field. To test for it, focus on a straight object, such as a telephone pole or a roof ridge that extends across the diameter of the field of view. Move the binoculars so that the edge of the object forms a chord near the periphery of the field. If the object curves inward toward the middle, you have pincushion distortion; if it curves outward, you have barrel distortion. A small amount of pincushion distortion can be desirable for terrestrial use, but it has no advantages—or significant disadvantages—for astronomy.

  It is a common phenomenon, even among experienced binocular users, that when they optically evaluate a binocular, they notice pincushion distortion and comment adversely on it. It is far less common (I hope that this book will go some way toward remedying this) that they know the whole reason. It is indeed true that pincushion distortion, which manifests itself as straight lines at the edge of the field of view appearing to curve in toward the middle of the field, results from increasing angular magnification away from the center of the field, but this difference in magnification is not an error, it is intended. If there is equal angular magnification, the linear magnification at the edge of the field is less than in the center, and an optical phenomenon called rolling ball effect occurs when the binocular is panned. This may not be noticeable when the binocular is used astronomically, but when it occurs in terrestrial use, it can be distinctly unpleasant and even cause nausea. A small measure of pincushion distortion eliminates this rolling effect. Different manufacturers choose different compromises between rolling ball and pincushion; the choice of which particular compromise is best is entirely subjective.

- *Collimation.* Unless miscollimation is severe, this is usually considered to be the most difficult condition for which to test. Unfortunately, it is present in a large number of lower-priced binoculars. Severe cases manifest as a double image that cannot be eliminated. Our eyes can compensate for mild miscollimation, but the price is eyestrain, which can lead to fatigue and headaches if it is prolonged. The acceptable limits for miscollimation are given in Chapter 2, but these limits are not ones that can be measured during a preliminary test. A daylight test for convergence and divergence would be to support the binoculars and focus on a *distant* vertical target such as the edge of the wall of a building or a telephone pole, and close one eye and place the target at the edge of the field of view. Alternately close your eyes and see if the image in one eye is laterally displaced from that in the other. To test for *step* (i.e., vertical shift), use a horizontal target such as the ridge of a distant roof. We are far less tolerant of step than we are of convergence or divergence, so if you detect any step at all, you should reject the binoculars.

Field Tests

If binoculars will be used for astronomy, there is no substitute for field testing them under the stars. The night sky offers the potential of objective and quantitative testing that is not easily available in daylight without relatively sophisticated optical equipment. In addition, with the exception of distortion and kidney bean, all the optical tests detailed above are easier to perform under the night sky. You will obtain better, and more easily comparable, results if you mount the binoculars. Here is a list of tests to perform at night:

- *Overall Optical Performance.* You can perform a simple and, to some extent, quantifiable test of the optical quality of your binoculars by determining the closest double stars that you can distinguish. In general, double stars, those with components of approximately the same magnitude, are easier to split than those that have components of significantly different magnitudes. The ability to separate double stars is obviously a function of magnification, so you should therefore expect binoculars with higher magnifications to routinely outperform those with lower magnifications. Because you are observing at low magnification, you should not expect to see the close separations that are discernible with telescopes of similar aperture working at high magnification. You should also be aware that differences between sky conditions at different times and places and differences in the optical acuity and observing experience of different observers restrict the objectivity of this test. It does, however, enable a single observer to compare the general optical performance of different binoculars with a high level of confidence. A table of appropriate double stars is given in Appendix A.
- *Limiting Magnitude.* The standard way of establishing the limiting magnitude of an instrument is to count the stars in a known region of sky. Some useful regions applicable to binoculars are detailed in Appendix B.
- *True Field of View.* When you are trying to find objects by star-hopping, it is essential to know what the true field of view of your binoculars is. The field of view that manufacturers state for their binoculars are not always correct, and, when wrong, they tend to err on the optimistic side. By placing stars of known separation at diametrically opposite sides of the binocular field, you can easily determine its true field of view. Similarly, if the field of view is severely degraded toward the periphery, you can determine the size of what you consider to be the usable field. A table of convenient star pairings, with relevant charts, is given in Appendix C.
- *Field of View.* Field of view is a very personal thing. Most people seem to prefer a wider field of view, such as that from an ultrawide eyepiece, giving 82 degrees or so of apparent field of view and perceive apparent fields of view of less than about 65 degrees to be akin to tunnel vision. Others find that a narrower apparent field of view helps them concentrate on the object under observation and they dislike having to "look around" to find the edges of the field of view.
- *Collimation.* Poor collimation is more obtrusive, and thus easier to test for, at night. Focus the binoculars on a reasonably bright star, then carefully move the binoculars away, keeping the image in view, until the binoculars are about 15 to 20 cm (6 to 8 in) from your eyes. If you still have a single image, the binoculars

are probably collimated within acceptable limits. If the images from each optical tube separate from each other, then the binoculars are miscollimated and will cause eye strain.

You should not expect to find a binocular that is perfect in every respect, but these simple tests should enable you to make a reasonably good assessment of the binocular in hand and to compare it to other binoculars.

CHAPTER FIVE

Care and Maintenance of Binoculars

Binoculars are generally robust and require very little maintenance if they are properly cared for. As with any other optical equipment, indeed *any* equipment, prevention and preemptive maintenance are considerably preferable to curative maintenance and repair. There are five categories of foreign matter that can threaten the well-being of binoculars. In no particular order these are:

- *Moisture*. This can invade the binocular either by condensation or from direct exposure to water.
- *User-originated grime*. This includes grease from fingers and eyelashes, spillage of food and drink, hair, and flakes of dead skin.
- *Environmental grime*. Dust is the usual culprit here, but grit can also enter the binocular in some circumstances.
- *Flora*. The usual culprits are algae and fungi.
- *Fauna*. Arthropods, especially insects and arachnids, can find ideal homes in the nooks an crannies of binoculars and their cases. William Gascoyne invented the eyepiece reticle after a spider had spun its web near the focal plane of his telescope!

Rain Guards

A rain guard is a cover for the eyepieces of a binocular. It is intended to protect the eyepieces of binoculars when they are slung from the neck in the rain or snow. As observational astronomers, we tend not to pursue our hobby in the rain, so pre-

Figure 5.1. Eyepiece rainguard. The rainguard attaches to the strap and can be slipped over the eyepieces when the binocular is not being used.

cipitation is a relatively unlikely source of moisture. Despite this, a rain guard is an invaluable addition to any binocular, particularly one that is hung from the neck. Rain guards protect the eyepieces against spillage of food and drink and against any other descending particulate matter, whatever its origin. For this reason, a rain guard is most valuable if it is of the kind that can be attached to the neck strap so that it is immediately available for use. It soon becomes second nature to put the guard over the eyepieces when you pause in observing, and the reduction in frequency with which eyepieces need to be cleaned is very noticeable (Figure 5.1).

Storage

Although moisture from precipitation does not usually affect an astronomical binocular, condensation can affect it. In terms of frequency of occurrence of damage, condensation is by far the most harmful source of deterioration of astronomical binoculars. Condensation on the external optical surfaces results in being wiped more frequently than would otherwise be necessary, with the attendant damage that all too often accompanies frequent cleaning. (To protect against condensation in use, see the section on dew prevention in Chapter 7.) Condensation on internal optical surfaces may lead to inexpert dismantling of the binoculars, which itself can lead to damage, in an attempt to gain access to and clean the affected surfaces. The water itself accelerates the corrosion of the metal parts of the binocular, especially if there are places where two different metals are in contact. This corrosion leads to stiffness in moving parts and this stiffness, allied to the corrosion, accelerates the wear of these parts. Moist surfaces are a *sine qua non* for the growth of algae and fungi; so if you keep moisture at bay, you will keep these flora at bay also.

Much of this condensation damage ultimately results from failing to cap the binoculars at the end of an observation session. The cold binocular is taken into a relatively warm and humid place, where moisture from the air condenses on the colder surfaces of the binocular. Lens caps and cases then act to hold the moisture in place. It is a good practice to bring the binoculars indoors uncapped, place them horizontally on a firm flat surface in the room in which they are to be stored until they have reached thermal equilibrium, then cap them and put them in their cases. It is an even better practice to cap them outdoors before bringing them in *unless the surfaces have been affected by dew*.

Ideally, binoculars should be stored in a cool dry place; certainly not one that is subject to great fluctuations of temperature and humidity. I store mine in a closet in an unheated part of the house. Cases and caps help to guard against arthropods that might otherwise take up residence. Multipurpose "grab-and-go" binoculars are often stored, uncased and uncapped, on interior windowsills, where they are instantly available should an object of interest be spotted. They are placed resting on their objective ends, so the objective lenses are protected to some extent. On the other hand, the eyepieces of such binoculars act as dust magnets and soon show the marks of frequent scouring. If you must store your multipurpose binoculars in this manner, at least use eyepiece lens caps or a rain guard to keep the dust at bay. Even better, store them somewhere where they are less likely to be dislodged by other household members and are less likely to have to endure the tremendous temperature ranges to which a black object on a sunny windowsill is subjected. Those who store binoculars on windowsills are second only to those who use unmounted binoculars without a neck strap in ensuring the survival of the binocular repair industry!

Desiccants

Some years ago I used to maintain a 20 × 120 naval binocular of 1940s vintage. It had two small mesh-lined inserts into which a desiccant, presumably anhydrous calcium chloride, could be placed. This would reduce the likelihood of condensation on the internal optical surfaces. Today we do not use internal desiccants, but rather fill the binocular with dry nitrogen and make it gas-tight. Nevertheless, desiccants still have their place. The currently preferred desiccant is silica gel, an amorphous form of silicon dioxide that can adsorb up to a third of its own weight of water onto its surface (of which it has about 700 m^2 per gram!). It can be regenerated by heating it in an oven to between 125° and 200°C (250° and 400°F).

Sachets of silica gel are included with a multitude of modern electronic devices, as well as with binoculars. I tape a sachet to the inside of each of my small binocular cases and also to the inside of each objective lens cap of my 100-mm binoculars. This is possibly a bit of overkill, but it seems to be a small effort to eliminate an inconvenience that may necessitate a far greater effort to remedy.

Grit

If binoculars are placed in contact with a gritty surface, it is all but inevitable that some grit will end up where it is not wanted. Sea sand is the most pernicious species of grit; even if you ensure that your hands, and anything else that touches the binocular, are meticulously clean, you can almost guarantee that wind-blown sand will find a way in. The result is that tell-tale crunching sound as the abrasion of a moving part starts to occur!

In reality, you cannot expect to keep grit entirely away from binoculars if they are actually going to be used. You can take the obvious precautions (above) to reduce the contact with grit and also try to ensure that no grease seeps from the moving parts of the binocular. Grease traps grit. It also tends to get transferred, with or without the grit for which it is often a vector, to optical surfaces. Particularly unpleasant is the grease that is used in some binoculars of Far Eastern origin; it seems to be more akin to an adhesive than a lubricant. It is important, therefore, to remove any exposed grease. This is most easily done with a paper towel or tissue, since paper tends to absorb oils and grease.

Cleaning

It cannot be overemphasised that by far the best form of cleaning of optical surfaces is to prevent the dirt from accumulating there in the first place (i.e., use rain guards, lens caps, and cases whenever appropriate). The reason for this is that it is extremely easy to damage optical surfaces by cleaning them. In reality, an optical surface has to be quite filthy before the dirt has an optical effect that is significantly noticeable during visual observation and there is a real need to clean it. The objective lenses of my binoculars go for years without being cleaned, and the eyepieces may only be cleaned once a year, although those that I use for star parties tend to need a clean after each event.

My full binocular optical cleaning kit consists of the following items (Figure 5.2):

- *Puffer Brush with Retractable Soft Bristles*. This is my first line of attack. Most dust and so forth can be blown off with the puffer alone. If it is more stubborn, I deploy the bristles and use them in conjunction with the puffer. Flick the brush quickly over the lens surface while puffing the bulb. After each stroke across the

Figure 5.2. Cleaning kit. *Top L to R*: Lens tissue, microfiber cloth. *Middle*: camel-hair brush, blower brush, Opti-Clean. *Bottom*: Lens Pen.

lens, flick any accumulated dust off the brush, while giving a sharp puff to help dislodge it. Be very careful if you use canned air as a blower—the propellant can damage lens coatings.

- *Microfiber Cloth*. I keep one of these in each binocular case. To use it, hold the binocular so that the affected lens surface is facing down, then gently flick an edge of the cloth over the lens to remove any dust. If any deposit remains, breathe on the lens to moisten it slightly, then *gently* wipe the lens from center to periphery. Microfiber is quite good at removing grease and finger prints. Never rub the lens with a circular motion and never wipe from the periphery to the center. If there are trapped particles that could scratch the optical surface, they will be trapped in the lens surround; they are relatively safe there, so don't accidentally dislodge them.
- *Lens Tissue*. Lens tissue is particularly useful on small lenses. It can be made into a swab rather like a cotton bud by folding it into a strip and wrapping it around the end of a toothpick. Dampen it in cleaning fluid and use it in light strokes from the center to the periphery of the lens.
- *Lens Pen®*. A Lens Pen incorporates a retractable soft brush and a cleaning pad that is recharged with cleaning fluid from an impregnated piece of foam in its cap. It is particularly good at removing eyelash grease and fingerprints. First, use the brush to remove any dust. When you are sure that the lens surface is clear of particles, clean the deposits with the pad, taking care not to drag any particles from the lens surround.
- *Opti-Clean*. Opti-Clean is a polymer-based cleaning product that was developed to clean silicon wafers used in the microelectronics industry and is now marketed primarily for cleaning photographic lenses. It is suitable for any glass lens. It is a transparent liquid that is applied to the lens surface. As it dries, it forms a skin. When the skin is peeled off with an adhesive tab, it pulls any grease and grime with it, leaving the lens in pristine condition. It seems expensive, but it lasts for a very long time—I have had a 5 ml vial of it for about ten years. **Note**: There are different products with the same name used for contact lenses and in dentistry.

There are other proprietary cleaning fluids available from photographic outlets. Alternatively, you can make your own. My recipe is:

6 parts distilled water
1 part pure isopropyl alcohol (IPA).
2 drops liquid detergent (e.g., mild dishwashing liquid)

Apply it to the lens with a a lint-free cotton swab or a swab made of lens tissue wrapped around the end of a toothpick. Dampen the swab and swab the lens from center to periphery, rolling the swab so as to lift any grime away from the surface. Be careful not to overmoisten the swab so you don't get liquid into the lens surround. You can dry the lens with a dry swab or with a clean lens tissue.

However you clean the lens, be careful not to rub it any more than absolutely necessary. Not only does rubbing increase the likelihood of damage to the lens surface or coatings, but rubbing with a dry cloth or tissue can cause the build-up of a static electric charge on the lens surface. This charge will attract dust or lint, and it will be extremely difficult to dislodge. If this does happen, you will need to use a water-based cleaning solution (such as the one above) to get rid of the static electric charge.

Dismantling Binoculars

In general, you should not attempt to dismantle your binocular. Unless you know precisely what you are doing, you run the risk of causing more damage than you are attempting to remedy! You would also immediately void any warranty. The single exception for the layperson is when a faulty binocular has been pronounced, by someone who is qualified to do so, unworthy of repair, either due to the extent of the damage or because the cost of repair would exceed the value of the binoculars. In these instances, there is a valuable experience to be gained.

The faults that can be relatively easily repaired are dust or flora in the binocular, prisms that have been displaced by impact, and grit or failed lubrication in moving parts. The simplest binoculars to dismantle are Porro prism varieties. If you attempt this, which you do entirely at your own risk, first prepare your work surface. I prefer to cover the work surface with plain white paper—sheets of acid-free tissue are ideal. I have a few plastic containers for components, and I ensure that any tools I use are clean. I use disposable powder-free latex gloves to handle optical components.

If the binocular has a Zeiss-type body, the objective tubes can be simply unscrewed from the binocular body (Figure 5.3), giving access to the inside surface of the objective lenses. The lower prism cover plates can then be removed, giving access to the lower prisms. These are often held in place by clips. In the Bausch & Lomb type of body, the objective cell must be removed from the tube. First remove the front protective ring—this usually simply unscrews. In this type of binocular housing, you do not gain access to the prisms from this end.

The objective lenses are held into their cells (which, in Zeiss types may be integral with the objective tubes) by a locking ring and usually a seal ring. The locking ring should be removed using a peg-spanner, but this can be done *with extreme care* with a small screwdriver with a blade that fits into the recess on the ring. The danger of scratching the lens is very great, and you should *not* attempt this unless you are willing to accept this risk. Before removing the locking ring, mark the eccentric rings with a soft pencil so they can be returned in the same orientation. If you remove the lens elements, mark the edges with a soft pencil with an arrow pointing to the front surface. Wrap them in acid-free tissue and put them safely in a container.

The dismantling of the eyepiece end and begins with the removal of the cover at the bottom of the hinge. If there is a tripod bush in the hinge, you will also need to remove this; it is slotted for a screwdriver for this purpose (Figure 5.4). This reveals a hole in the hinge, deep within which is the screw that holds the focus shaft in place. Use a flashlight to ascertain what type of head the screw has, and insert a screwdriver into this hole to undo the screw. A small amount of Blu-tac® or other similar adhesive putty on the end of the screwdriver aids the removal (and replacement) of this screw (Figure 5.5). When the screw is removed, use the focus wheel to drive out the eyepieces and bridge (Figure 5.6). The focus shaft should be

Figure 5.3. Objective barrel unscrewed. The prisms are visible under the cover plate.

Figure 5.4. Tripod bush removed. This gives access to the screw that secures the focus shaft.

Figure 5.5. Adhesive putty holds the screw to the screwdriver.

Figure 5.6. The bridge and eyepieces are lifted clear.

greasy; do not allow this grease to get on to optical surfaces or parts that may transfer it to the optical surfaces.

Once the eyepieces and bridge assembly are removed, the eyepiece guide tubes must be unscrewed (Figure 5.7). Then remove the screws that secure the top cover plate and remove the cover plate (Figure 5.8). Ensure that you store screws in such

Figure 5.7. The eyepiece guide tubes are removed.

Figure 5.8. Undo the cover-plate screws.

a way that you know which screw goes where. In Zeiss-type bodies, the upper prism will be held in place by a clamp. This may be screwed down at one end (Figure 5.9) or, in cheaper binoculars, have both ends clipped under recesses. The prism may also be protected by a shaped piece of metal or card-type composite.

In Bausch & Lomb type bodies, the prisms normally remove as a cluster (Figures 5.10 and 5.11). The screws that secure it in place are the ones immediately adjacent to the slotted-head grub screws (set screws) that are used for collimation. The prisms are secured to the cluster plate with clamps that are screwed to the plate.

Figure 5.9. Clamped prism in Zeiss-type binoculars.

Figure 5.10. Prism cluster in situ.

The eyepiece lenses are retained with a lock ring. If you decide to dismantle the eyepieces to clean the components, be sure to mark the edges of the various lenses and spaces so that you know their order of reassembly and the direction they should face. Also be aware that there may be as many as six separate lens elements.

The only time it is necessary to dismantle the hinge is when the tension needs to be adjusted. Remove the cap with the IPD scale on it and you will see a slotted brass tension screw with a locking grub screw (set screw) in it. If you need to adjust the tension, loosen the locking screw and adjust the tension screw with a screwdriver. The correct tension is achieved when it is just sufficient to prevent one side of the binocular from sagging under the effect of gravity when the binocular is held by the other side.

When you reassemble the binocular, it may be necessary to lubricate some of the mechanical parts. Use a good quality lithium grease for this. Use the minimum amount necessary and ensure that none is able to escape to the outside, where it will inevitably be transferred to the external optics. If screw threads are slightly stiff and tend to bind, you can lubricate them by running a soft graphite (lead) pencil along the thread. (Incidentally, soft pencils are also useful for lubricating stuck zippers and stiff lock mechanisms.)

Figure 5.11. Prism cluster removed.

Collimation

If miscollimated binoculars are still under warranty, return them to the supplier. The supplier should have access to a binocular repair shop that has proper collimating equipment. Proper collimation is a skilled task and miscollimation can be expensive to remedy on binoculars that are out of warranty. It can cost more than the binoculars cost in the first place and is therefore usually not worth having done on budget-priced binoculars. If your binoculars are out of warranty and you feel confident of trying to do it yourself, here is how. The methods described in this book will result in conditional alignment (i.e., the optical tubes will only be aligned at the interpupillary distance at which you perform the alignment). Binoculars can be collimated by either eccentric rings on the objective lenses or by tilting the prisms with grub screws (set screws). There is no substitute for experience in collimation. If you can, practice on an old misaligned binocular where you will not be upset if you are unable to achieve the collimation you want.

Always collimate binoculars outdoors, or indoors by looking through an open window. Window glass is usually nonuniform and can differentially affect what you see through each side of the binocular. Collimate by looking at an object at least 100 m (110 yd) away, but preferably further.

If the binoculars were once properly collimated and have suddenly lost collimation, this is most likely due to being dropped or bumped, causing a prism to shift. It is therefore worth examining the prisms to see if there is any obvious shift. Often, if a single prism has shifted, a symptom will be that the image in the affected tube will have acquired a "lean" (i.e., it will be tilted slightly to one side or the other). Prisms are held either to the body of the binocular (Zeiss or European style) or in prism housings (Bausch & Lomb or American style) by straps. A sharp jolt can move the prism, and if this has happened, it can usually be replaced. In budget binoculars there is usually no possible adjustment of the prism once it is located and secured into its recess in the binocular body (see Figure 5.9).

Prism Adjustment

If prisms are adjustable, this will be by external grub screws (set screws) that are accessible under the rubber or leatherette covering of the binocular body, usually close to the edge of the prism housing where they can be accessed by minimal shifting and stretching of the rubber. If the binocular is covered with leatherette, there are usually little tabs in the leatherette that can be lifted to permit access to collimation screws. Alternatively, the collimation screws may only be accessible by removing the cover plate. They are the slotted-head screws (Figures 5.10 & 5.12).

Remove the eyepieces and bridge, then remove the cover plate and replace the eyepieces and bridge. The collimating screws are slotted grub screws that are immediately adjacent to the cross-headed screws that secure the prism cluster to the binocular body. The screws adjust in "push-pull" pairs. The procedure is to slacken the securing screw, adjust the collimating screw, then retighten the securing screw. Adjust one pair of screws at a time and turn the collimating screw no more than an eighth of a turn and examine its effect on the image. Adjust in small increments until the images are satisfactorily aligned.

Eccentric Rings

Binoculars differ from telescopes in that collimation is achieved by lateral movement of the objectives, not by tilting them. Moving the lens one way will move the image in the eyepiece the other way. However, it is all but impossible to move an

Figure 5.12. Collimation screws.

Figure 5.13. Eccentric rings. Rotating these rings moves the lens laterally. Note that it is marked to enable its return to the original position.

objective only either laterally or vertically, and collimation with eccentric rings can be monumentally frustrating until you get the hang of it. It can be a tough test of perseverance and patience—you have been warned!

First, mark the positions of the rings (see Figure 5.13) so that if you do not manage to improve the image, you can at least set them to their original position. Next, set the rings so that there is no eccentricity (i.e., the narrowest part of the inner ring aligns with the widest part of the outer ring and vice versa). Rotate the objective lens assembly a small increment—about 10 to 15 degrees—at a time until it has made one revolution and see whether there is any movement of the image and, if so, if it is sufficient to bring the images into proper alignment. If it is not, slip the inner ring about 10 degrees and repeat the rotation of the lens assembly. Repeat this until the images are aligned as well as possible. If there is not sufficient eccentricity in the rings, you will need to adjust the prisms.

Note: It is usually better to set the binoculars so that there is a discernible amount of divergence (i.e., so the optical paths from the binoculars are *con*verging) (see Chapter 2, note 2), and then to gradually collimate from there than it is to approach collimation from the other way. This is because the eyes are more sensitive to divergence than to convergence.

For more detailed accounts of collimation see Seyfried's *Choosing, Using, & Repairing Binoculars*, which gives a more detailed account of conditional collimation, including building bench-testing apparatus, and the Naval Education and Training Program Development Center's (NAVEDTRA) *Basic Optics and Optical Instruments*, which gives accounts of full collimation with bench test apparatus.

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CHAPTER SIX

Holding and Mounting Binoculars

When you decide how to mount your binoculars, there are two considerations that you must take into account: stability and comfort. Both of these play a significant part in determining how much you will be able to see. If the binoculars are not held in a manner that is reasonably stable, in order to eliminate shake, the amount of detail you see will be severely reduced. If you are not comfortable when you observe, you will quickly tire, and tiredness is always detrimental to observing.

Hand-held Binoculars

You will not see as much with your binoculars when you hand-hold them as you will if you mount them properly. However, if you use your binoculars for quick "grab-and-go" observing sessions, if you are using them for quick sky-scans in conjunction with a telescope, or if you are using binoculars *because* they can be hand held and are therefore the ultimate in a portable observing instrument, then you will not want to use a mount. Small and medium-sized binoculars up to about 10×50, depending on the ergonomics of the particular binocular, can be effectively held for medium periods. Slightly larger ones can be held for short periods and for "quick peeks." These periods can be extended and made more effective if ergonomic considerations are taken into account. Some people consider an extended discussion of hand-holding to be overkill, but if by understanding and applying a few simple principles you can increase the efficacy and enjoyability of your observing sessions, this discussion is worthwhile. There are four "basic" ways in which a binocular can be held: the normal hold, the triangular arm brace, the rifle sling hold, and the double-handed hold.

The "Normal" Hold

It seems to be instinctive for most people to hold Porro prism binoculars around the prism housings (Figure 6.1). The weight of the binocular is taken entirely by the arms, and the upper arms are extended forward. Although this initially feels comfortable, it is inherently tiring and unstable, especially when you are observing objects at high altitude. It rapidly results in fatigue, which, even after a few minutes, is easily noticeable, both in the limbs themselves and in the amount you can see. It is very easy to improve upon this, merely by moving your hands an inch or so closer to your face to form the triangular arm brace.

The Triangular Arm Brace Hold

Many adults feel that 10×50 binoculars have too much magnification to be hand-held. For several decades I have run astronomy clubs for youngsters and we have used 10×50 binoculars as our "standard" instrument. By teaching this way of holding binoculars, I have enabled children as young as ten years old to effectively use these binoculars for observing. If the detail they report being able to see is any indication, they are seeing noticeably more than adults using the normal hold.

Figure 6.1. The "normal" hold.

Figure 6.2. The triangular arm brace.

Hold the binocular with your first two fingers around the eyepieces and the other two fingers around the prism housing. Then raise the binocular to your eyes and rest the first knuckle of your thumbs into the indentations on the outside of your eye sockets, so that your hands are held as if you were shielding your eyes from light from the side. Rest the top knuckle of your thumb against the indent in the bone at the outside of your eye socket and the second joint against your cheekbone (Figure 6.2). Each of your arms is now locked into a stable triangle with your head, neck, and shoulder as the third "side," thus giving you a much more stable support for your binoculars. The position of your thumbs keeps the eyepieces a fixed distance from your eyes. You cannot normally reach the focus wheel on center-focus binoculars when you hold them this way (although you can with roof prisms), but you should not need to refocus during an observing session. This grip does feel unusual at first, but it is so superior to the normal way that it soon becomes second nature.

The "Rifle Sling" Hold

If you want the most stability you can get with medium-sized hand-held binoculars, use the rifle sling method. This hold is based on the way one uses a sling for rifle-range shooting, where stability of the rifle is improved if the arm is braced through the sling. Extend the binocular strap to its full extent and hold the binocular so that the strap loops down. Place both arms through the strap, so that it

Figure 6.3. The rifle sling hold.

comes just above your elbows. Hold the binocular in the most comfortable way you can and brace it "solid" by pushing your elbows apart (Figure 6.3). It initially feels a bit like getting into a medieval torture instrument, but it is remarkably effective for stability. Because it is not inherently comfortable, I do not use this method for long periods, but only for observations where I want that little bit of extra stability.

Double-handed Hold

You may sometimes wish to hold a larger binocular for short periods and find that the balance of the binocular makes the triangular arm brace method unstable. The double-handed hold uses both hands on one optical tube of the binocular. Assuming your right eye is dominant, use the triangular arm brace with your right hand and hold the right objective barrel of the binocular with your left hand (Figure 6.4). You support the left objective barrel with your left wrist—if you wear a wristwatch or bracelets, you will probably find it more comfortable if you remove them first. For extra stability, you can combine this with the rifle sling method.

An inherent source of fatigue and instability with all hand-holding methods is that your upper arms are extended in front of you. If you can support your elbows

Figure 6.4. The double-handed hold.

or upper arms, you will notice a drastic improvement in stability and reduction in fatigue. The number of possible arm rests is limited only by your imagination, including the car roof, fences, gates, boulders, height extensions to the armrests of deck chairs, and even the shoulders of a companion. If a suitable arm rest cannot be found, you can increase stability to some extent merely by leaning against something such as a wall, car, boulder, telephone pole—or the ground!

Mounting Brackets

The most commonly used binocular mount is the photo tripod and L-bracket. Most modern binoculars in the aperture range of 40 to 70 mm have, in the distal end of the center-post hinge, a bush (threaded tripod adapter) for an L-bracket. Porro prism binoculars in the aperture range of 80 to 100 mm may either have a bush for

Figure 6.5. Various mounting brackets. *Top, L-R*: Hinge clamp, Universal L-bracket, roof prism L-bracket, Proprietary (Universal Astronomics) L-bracket. *Bottom*: Bush in prism housing.

Figure 6.6. Direct mounting bush.

an L-bracket or a box for direct mounting on a tripod plate. Those of greater aperture than 100 mm almost always have a direct-mounting bush (Figure 6.5).

Some older 50-mm binoculars also have direct-mounting bushes, usually on the right-hand prism housing (Figure 6.6). Some have suggested that this arrangement can cause the optical tubes to lose alignment with each other, but I have not found this to be the case. However, if you have this type of binocular, you do need to ensure that the tripod head allows it to be mounted in such a manner that your nose does not foul the mounting plate! A tripod bush like this offers no facility for tilting the binocular side to side. Some people deem this to be an advantage.

Brackets for mounting a binocular to a tripod come in four distinct categories: hinge clamp, universal L-bracket, roof prism L-bracket, and L-bracket for roof prism. (Figure 6.5). It is important to acquire the one that is specific to your needs.

Hinge Clamp

As its name suggests, this clamps onto the center-post hinge of Porro prism binoculars. It is used when there is no mounting bush on the binocular. It may be unsuitable if the binocular has a wide focusing "band," as opposed to a narrow focusing wheel, because in the former, there is usually insufficient center-post to accommodate the clamp. As most modern binoculars have a tripod bush, this will most often be necessary on older binoculars (Figure 6.7).

Universal L-bracket

The universal L-bracket fits almost all Porro prism binoculars that have a quarter-inch mounting bush at the distal end of the central hinge. The bracket is usually merely a strip of metal that is bent into an L-shape, painted or coated, and furnished with the appropriate holes and bolts. Near the end of the upright of the L, it has a captive screw that screws into the quarter-inch mounting bush of the binocular. The foot of the L has one or two quarter-inch threaded holes for the quarter-inch screw on the tripod mounting plate. If there are two holes, use the one that offers the best balance to the binocular (Figure 6.8).

Figure 6.7. Hinge clamp.

Figure 6.8. Universal L-bracket for Porro prism binoculars.

Figure 6.9. L-bracket for roof prism binoculars.

Roof-prism L-bracket

The roof prism L-bracket is similar to the universal bracket, but it has recesses for the objective tubes of roof prism binoculars. These are closer together than in Porro prism binoculars and cannot be used with most universal L-brackets. Because the recesses have the potential to weaken the structure of the bracket, they are thicker from front to back than are universal brackets so they do not flex in use (Figure 6.9).

Proprietary L-bracket

Proprietary L-brackets work in exactly the same way as the universal bracket, except the foot of the L is adapted to fit a proprietary mounting.

Monopods

For several decades, photographers have been aware of the use of the monopod as an ultraportable and compact camera support. It also makes an ultraportable and compact support for binoculars. The mere fact that the binocular is supported confers a degree of stability that is not obtainable by hand-holding.

In order to use a monopod, you will need to obtain a suitable L-bracket or other mounting bracket for your binocular, unless it is already fitted with a mounting bush. These brackets are discussed in more detail in the section on tripod mounting below.

Monopods can be used for both standing and seated observing, but few are sufficiently long for observing high altitude from a standing position, not to mention it is extremely uncomfortable to try to observe at high elevations while you are standing unless the binoculars have angled eyepieces. In recent years it has become possible to purchase hiking poles in which the top part of the handle can be removed to reveal a camera-mounting screw.

A simple but very effective "poor-person's" alternative to a monopod is a humble broom or mop (with a clean and dry business end!). You can easily secure the binoculars to the broom- or mop-head with a bungee cord, although many people, myself included, prefer merely to rest the binocular on the head. If the mop has a telescopic pole, such as found in several designs intended for window cleaning, then its utility is increased, as these usually extend to a length that is suitable for high-altitude observing from a standing position. A mop-head with an adjustable angle is somewhat useful, but do not expect to be able to adjust the friction so as to be able to change the angle as you observe.

Photographic Tripods

Photographic tripods, used as a "normal" photographic tripod head, are usually seen as the most obvious low-cost way of mounting binoculars. Unless the binoculars have angled eyepieces, photographic tripods and heads are not ideal observing platforms because it is extremely difficult to use them for observing at high elevations. Because photographic tripods are so widely used for their intended purpose, they are mass produced and are readily obtainable at relatively low cost. However, all tripods are not equal, and one that is suitable for binocular observing should meet several criteria.

- The tripod should be high enough to permit observations of object near the zenith while you are standing. If you try to observe near the zenith from a seated or reclining position using a tripod and normal photographic head, it is a near certainty that your legs and those of the tripod will, at some stage, need to occupy the same location; the consequences are, at best, infuriating. This requirement automatically eliminates the vast majority of photo tripods.
- The height of the tripod head needs to be adjustable so that, for a single observer, the height of the eyepieces of the binocular can be changed over a range of a minimum of 150 mm (6 inches) for straight-through binoculars and 250 mm (10 inches) for those with 45-degree angled eyepieces. However, this is not the total distance through which the tripod head must move. As the binoculars are angled upward, the eyepieces get lower by an amount that is the sum of the distance from the eyepiece to the mounting bush and the distance from the mounting bush to the altitude bearing on the tripod head. To this must be added the difference in height between the tallest and shortest observer who will use this setup in a single observing session (but this latter requirement can be reduced if some sort of simple observing platform, such as an up-turned milk crate, is available for shorter observers). This height adjustment requires some form of center post. The only usable types are those with a handle and ratchet for adjusting the height; those that work on friction alone are difficult to use for our purposes.
- The tripod head needs to enable observation near the zenith. Many of the more robust heads only enable, when they are used as intended, an elevation of about

Figure 6.10. With the video head the right way around, the zenith is inaccessible.

60 degrees (Figure 6.10). However, many of them allow a *depression* of 90 degrees. If this it the case, it may be possible to use them reversed (Figure 6.11). If this is the case, any handles will also need to be reversed and you should ensure that, in doing so, they do not obstruct or interfere with any locking or friction knobs that you will need to use when you are observing.

- The altitude bearing of the tripod head must be sufficiently robust and have sufficient friction to bear the turning moment of the binoculars when they are pointed near the zenith. The great majority of photographic heads are not designed to accommodate this sort of turning moment, which is rarely encountered using a consumer compact or single lens reflex camera, and are inadequate for the task. Consequently, it is usually better to consider a robust video head with fluid motions. Test it to verify that it is sufficiently robust and has sufficient friction control to enable the binoculars to be pointed at the zenith *without changing aim when you release the handle*. All photo tripods that I have encountered that meet the previous criteria for the tripod itself have the facility to enable the heads to be interchanged, so this need not be a concern. Indeed, for most of these the tripods and heads are sold separately.

Figure 6.11. Reversing the video head makes the zenith accessible.

Even if the tripod and mount do meet all the criteria above, they can still be difficult to use, especially when you are observing near the zenith with binoculars with straight-through eyepieces (unless you are an accomplished limbo dancer). The neck-strain induced by using such a system for near-zenith observing from a standing position is extremely uncomfortable for most observers and very soon results in fatigue. The experience of keen kite flyers, who also spend long periods looking up into the sky, is that this posture can induce neck problems. Hence, it is unsurprising that many who use tripod-and-head arrangements soon seek a different solution. This brings us into the realm of proprietary binocular mounts and observing chairs.

Fork Mounts

A solution to the cantilevering of heavy binoculars that are mounted on a photo- or video head is the fork mount. It is possible to fork-mount binoculars so that they rotate in altitude about their center of mass; indeed, several large binoculars have mounting bushes in the sides of the optical tubes for precisely this purpose.

The yoke needs to be offset so that the altitude fulcrum is not above the fork's azimuth axis if it is to enable the binoculars to reach the zenith. However, this offset, and the consequent cantilevering, is constant, so it can be allowed for in the design. If necessary, it can be compensated for by the use of a counterweight system. A fork mount does not eliminate the need to raise and lower the mount for observing at different elevations.

Mirror Mounts

Over the past few decades there have been various designs of binocular mount that use a first-surface mirror arrangement to circumvent the problem of an uncomfortable observing posture. These usually need to be placed on a table or tripod and the binocular is secured to the mount. Either the binocular and mirror, or only the mirror itself, can be rotated about a horizontal axis for altitude, and the entire mount may be provided with a lazy-susan type, or other rotatable, base for azimuth adjustment. Such an arrangement is the popular Sky Window[1] and is also amenable to do-it-yourself construction (Figure 6.12).

These mounts are like Marmite—nobody seems to be ambivalent about them and observers seem to divide strongly into two diametrically opposed camps: those who extol their virtues and those who loathe them. In the interests of enabling you to assess my objectivity, I have to declare myself to be a member of the latter camp, although I have only briefly used a mirror mount and have never used Sky Window.

The advantages of mirror mounts are obvious and simple: they permit observation, particularly of higher altitudes, from a normal seated position and with the head at a range of angles for which the human body seems to be naturally designed (the "microscope position"), thus eliminating neck and back strain and the resulting fatigue. The table, if one is used, also provides a rest for the elbows. There is no doubt that, from an ergonomic point of view, they are exceptionally comfortable

Figure 6.12. A homemade mirror mount (Photo: Florian Boyd).

and are an ideal solution for those observers for whom this is a major consideration. They are also compact and relatively light, so they are relatively portable. If tables and chairs are not available at the observing location, it is no greater hardship to carry a portable/collapsible table and chair than it is to carry a tripod.

The obvious disadvantages of mirror mounts are that they provide an inverted image of the sky and that, unless they have some sort of heater, they are prone to fogging. Some observers find them difficult to aim. I have not seen any that are suitable for use with binoculars bigger than about 80-mm aperture. There are also disadvantages of using an additional optical surface. There will be some light loss, although, as long as the mirror surface is of reasonably good quality, it will not be to the extent that it will be noticed in use by most observers. The mirror will also impose a limit to the amount of magnification used, due to the difficulties and concomitant expense of making a large optically flat surface. This is not usually a problem with magnification of less than about ×15. Finally, there is the problem of cleaning. It is inevitable that such a large exposed surface will accumulate dust and debris; as with all first-surface mirrors, cleaning must be undertaken with extreme care so as not to damage the surface.

Parallelogram Mounts

Parallelogram mounts solve many of the problems inherent in the use of photographic tripods and heads:

- They move the observer away from the tripod so that its legs do not interfere with the observer's body position, especially when observing at high elevations.
- They offer easily changeable eyepiece height over a wide range and can thus accommodate different observing positions and observers of different heights. The eyepiece height can be changed without changing the aim of the binoculars, making them ideal for communal observing.
- The mounting head can be designed so that binocular's center of mass can be aligned with the altitude fulcrum, thus eliminating problems associated with a changing turning moment when objects of different altitudes are observed.
- They are amenable to home construction by moderately competent wood or metal workers.

Their disadvantages are that they are relatively bulky, they require counterweights, and the long arms mean that vibrations take longer to damp down.

The simplest incarnations of the parallelogram mount have only an altitude adjustment in the binocular mounting head, thus requiring that the observer moves in a circle around the tripod in order to change the azimuth. As more degrees of freedom of movement are introduced in the head, so more sky is observable from a single position. The epitome of this development is the Universal Astronomics[2] deluxe mounting head, which enables more than a quarter of the sky to be observed from a single position (Figure 6.13). A well-designed parallelogram mount, which has smooth motions and permits proper balancing of the weight of the binocular, almost confers the feeling that the binoculars are floating in the air in front of your eyes.

a

b

Figure 6.13A,B. A well-designed parallelogram mount allows more than a quarter of the sky to be observed without the observer having to move.

If you decide upon a parallelogram mount, you should give careful consideration to the length of the parallelogram arms. Longer arms enable a wider variety of observing postures, so you can change from standing, through sitting, to reclining without having to adjust the tripod height. Shorter arms have smaller damping times for vibrations, but require that the tripod height is adjusted for different observing postures.

Parallelogram mounts, particularly those designed for big and giant binoculars, expose the limitations of photographic tripods, particularly those with center posts. The usual solution is to use a surveyor tripod. These usually do not have leg braces, but have spiked feet that press into the ground. This is ideal, and provides an exceptionally stable platform, if you observe on a surface where this is possible. On the other hand, if you observe on a surface that is unsuitable for this, you must acquire either spreaders or leg braces (which can be retrofitted to the tripod) or an expensive accident resulting from a slipping leg is all but inevitable. Do not be tempted to rely on being able to tighten the leg hinges sufficiently to prevent this. Spreaders can be obtained from most suppliers of survey tripods, and leg braces are available from Universal Astronomics.

Observing Chairs

Some form of observing chair can enhance the comfort of astronomical observing with binoculars, as well as being extremely useful for naked-eye observation and enjoyment of the heavens. There is a variety of options, ranging from simple inexpensive garden chairs or reclining loungers, through a plethora of dedicated homemade designs, to commercially available devices that are motorized in azimuth and altitude.

If you use binoculars because of their portability, an obvious choice is a collapsible recliner that is designed for portability. They are also suitable for use with a parallelogram mount. These come in their own carrying bag, usually with a shoulder sling. Features to look for include sturdy construction, good comfortable support for your head and legs, and a continuous range of reclining positions that are easy to change by pressure of legs or shoulders, but which do not change involuntarily. It is not necessary for them to recline to a horizontal position; 30 degrees to the horizontal is adequate. Almost all of these chairs are thoughtfully provided with cylindrical mesh accessory holders in the arms; you can use these for lens caps, for eyepieces (if your binocular has interchangeable eyepieces), for spectacles (if you remove them to observe), for pencils for recording observations, for a red-light flashlight, or even for an insulated mug of warm drink or other refreshment. Some also have a pocket in the back of the seat that can act as convenient storage for observing charts or for this book. You may wish to add storage facilities to them. It is simple enough to suspend a fabric pocket for notebooks from an arm of the chair and, if you are more comfortable with a cushion under your head, a fabric pocket for this can be attached in the appropriate place, or you can merely hold a cushion in place with bulldog clips. A relative shortcoming of these collapsible recliners is that, unlike traditional garden loungers with wooden or rigid plastic arm rests, it is not simple to add extensions to raise the height of the arm rests to support your arms when you are hand-holding binoculars. However, a simple wooden frame could serve this purpose (Figure 6.14).

If you are a competent wood or metal worker, you may be attracted by the idea of making your own observing chair. There is a multitude of designs of varying complexity on the Internet. Many of these are based on materials to which the constructor has easy access, and many constructors are somewhat unobjective in their evaluation of their own designs, so you do need to exercise some thought and care

a

b

Figure 6.14a,b,c. Mac Sports recliner. This well-designed folding recliner is ideal for use with hand-held binoculars or with mounted binoculars. Note the high, padded head rest, which is a must for a recliner like this.

if you choose to copy one of these. A better option is often to adapt designs to your own specific conditions of skills and availability of tools and materials. Some Internet addresses of the better designs are given at the end of this chapter.

For the serious binocular observer, the epitome of commercial binocular observing chairs is probably the Star Chair.[3] This device is capable of supporting giant binoculars as large as 25×150, is fully motorized in azimuth and altitude, and has

c

Figure 6.14. *Continued*

Figure 6.15. Homemade observing chair. Craig Simmons's chair features a rotating base and spring counterweighting for the binoculars. Notice also how the altitude pivot axis coincides with the axis at the top of the observer's spine. (Photo: Craig Simmons).

joystick control of the orientation of the chair. Although you may think that a device such as this warrants its own observatory housing, the Star Chair is fully portable in a small car! Although it comes with a hefty price tag, it is notable that it is the only commercial motorized binocular chair that has survived more than a few years in production (Figure 6.16).

Figure 6.16. Star Chair. Superb, commercially made, computerized observing chair. (Photo: Starchair Engineering Party Ltd).

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Chairs

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Mirror Mounts

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Parallelograms

A Bino-Mount Built with Comfort in Mind: http://home.att.net/~jsstars/binomt/binomt.html

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Miscellaneous

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Notes

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2. Universal Astronomics: http://www.universalastronomics.com/
3. Starchair: http://www.starchair.com/

CHAPTER SEVEN

Observing Accessories

Finders

You can easily aim straight-through binoculars without a finder as long as the magnification is below about $\times 20$ when there is a real field of view of 2.5 degrees or more. Aiming becomes more difficult at higher magnifications and can be extremely difficult with angled eyepieces unless you are exceptionally familiar with the *binocular* view of the region of sky you are observing. Some form of finder is therefore extremely helpful in the latter cases. In order to avoid fogged optics, you should ensure that you mount the finder so that, when you use it, you are not breathing on the eyepieces of the binoculars. There are four distinct options: simple mechanical sight, reflex finders, finder scopes, and lasers.

Simple Mechanical Sight

A simple mechanical sight usually takes the form of either a sighting tube or a vee and blade sight. Both of these are amenable to do-it-yourself construction. They can be mounted to the binocular with hook-and-loop (e.g., Velcro) strip (loop on the binocular, hook on the sight) or rubber bands.

Vee and blade sights were common on large naval binoculars up until the 1950s. Of all the options for binocular finders, these are probably the simplest sight to use. You can make a simple vee and blade sight with a strip of metal approximately

25 cm by 1 cm by 3 mm (10 by .5 by .125 inch). One end has a notch filed into it and the other is either filed to a point or, preferably, twisted 90 degrees about a longitudinal axis. About 5 cm (2 inches) of each end is bent at right angles in order to form a U shape. You mount the sight on the binoculars with the vee nearer the eyepiece end. You can align it with the optical axis of the binoculars merely by bending the metal strip. If you use a vee and blade you should ensure that there is no possibility of it coming into contact with your eye!

A sighting tube is merely a straight tube of metal or plastic, about 15 to 20 cm (6 to 8 inches) long with a bore of about 1-cm (.5-inch) diameter. Such a tube will have a field of 2 or 3 degrees, depending on how far in front of your eye it is. It is therefore relatively trivial to position it so that its field is approximately the same as that of the binoculars. It may be more difficult to align it with the optical axis of the binocular, but this is usually possible with a little ingenuity through trial and error. The near end should not protrude beyond the eyepiece and, for added safety, should be edged with some soft material such as foam tape or something like a soft rubber tube pulled over it to form an eye cup. Compared to a vee and blade sight, the tube is simpler to store as it can usually be slipped into the binocular case.

Reflex Finders

Reflex finders are unit power (i.e., no magnification) devices that use a simple optical system to project the illuminated image of either a dot or a reticle of concentric circles onto the sky. The red dot finders tend to be more compact than the reticle type, and you may find that you can store it in the binocular case. Reticle finders are more bulky but are usually considered to be more useful, especially if the diameter of one of the circles is a close match to the field of view of your binoculars. Regardless of whether the circles match the binocular field, you can use the circles for precise star hopping.

Reflex finders usually include some form of aiming adjustment. In the red dot finders, this is usually achieved by ridged screws that move the finder relative to its base. In reticle finders, it is usually the orientation of the reflecting surface that is varied to change the aim. Most include a dimmer switch to alter the brightness of the dot or reticle so that it can both be seen against a bright sky and not "drown out" faint objects in a dark sky. The base of the finder slips into a mounting bracket that is attached to the binocular. Once I have established the optimum position for the finder, I fix the mounting bracket to the binocular with double-sided adhesive foam pads. Some manufacturers provide these pads with the finder but, if this is not the case, you may obtain either pads or double-sided adhesive foam tape from a good stationery or hardware store. These finders may be provided with two mounting brackets so that they can easily be swapped between instruments; alternatively, spare mounting brackets can usually be obtained via the supplier. To avoid breathing on the eyepieces and fogging them when you use the finder, if you use your right hand eye with a finder, you should mount the finder on the left tube and vice versa.

It is a common misconception that reflex finders are used only with one eye looking through it. Although this mode of use is possible with bright objects, if

Figure 7.1. *Rigel Quik-finder®* reflex sight.

you are looking through the reflecting surface all objects appear dimmer and most stars disappear entirely. The correct mode of use, as with all straight-through finders, is to begin with both eyes open. The eye that is not looking through the finder gets an unattenuated view of the sky and your brain merges the images received by both eyes, exactly as it does in "normal" use of a pair of Mark I eyeballs!

My preferred reflex finder is the Rigel Quik-finder (Figure 7.1), which is relatively compact and whose aperture stands some 75 mm (3 inches) from the body of the binocular. This sighte also has the advantage of the ability to make the illumination blink on and off at an adjustable rate; this can be a great aid when targeting a faint object when its light is obliterated by the finder illumination.

Finder Scopes

Some people prefer finder scopes to unit power finders, and some large binoculars come equipped with them. The scope need not be of high power; the scope provided with my 100-mm Miyauchi is a 3×12. If the finder is to be mounted between the optical tubes of the binocular, it should have a significant amount of eye relief if you are going to be able to avoid breathing on the eyepieces when you use the finder. The eye relief of the 3×12 (finder mentioned above) is 55 mm. This amount of eye relief is not to be found in finders intended for use with telescopes, consequently, these must be mounted to one side in the same manner as suggested above for reflex finders. On the other hand, telescopic sights designed for rifles do have adequate eye relief and have a magnification more in keeping with what is required for binoculars, although the field of view may be somewhat small. Although telescopic finders are useful in the daylight, I find them to be inferior to reflex sights for nighttime use with binoculars, but this is obviously a matter of personal preference (Figure 7.2).

Figure 7.2. 3×12 finder scope with 55-mm eye relief.

Lasers

In recent years the price of laser pointers has been decreasing and there is a growing trend of using them for astronomy, both as pointers and as finders. With the single exception of mirror mounts, for which they are the most practical type of finder, any advantage they offer over reflex finders is, in my opinion, more than offset by the combination of cost, potential danger of eye damage, and general nuisance to other astronomers. If you do use a green laser in company, you should exercise extreme care and should ascertain that none of your fellow viewers objects to its use.

Filters

The most useful filters are the UHC and O-III filters. If you only purchase one, get the UHC. A standard 31.7-mm (1.25-inch) filter sold for telescope eyepieces can be used with most large binocular eyepieces by merely holding it over the eyepiece. It is not ideal in this position, as it is designed to be placed near the focal plane, but it is certainly effective. If you have a binoviewer or a binocular telescope, then you obviously use them as intended. There is no need to acquire two—a good method of using it is to "blink" between each eyepiece, when the sought after nebula often becomes obvious. An O-III filter is especially useful for identifying those planetary nebulae that appear to be stellar at the magnification of the binocular.

Also useful, especially for solar eclipses and transits, are solar filters. These can be simply made from Baader Astro-Solar film to fit over the objective lenses. Solar-filtered binoculars are particularly useful for group viewing of solar phenomena (Figure 7.3).

Figure 7.3. Group solar observing with filtered binoculars.

Dew Prevention and Removal

In order to know how to combat dew, it is important to have some understanding of why it forms. Water vapor condenses out of the air onto any surface and simultaneously evaporates from that surface. The potential rate of evaporation is lower at lower temperatures. Below a specific temperature, the dew point, the rate of evaporation is lower than the rate of condensation and dew forms. The principles of dew reduction are then simple: reduce the amount of cooling of the optical surfaces and reduce the amount of warm moist air (especially breath!) that comes into contact with them.

Under a clear sky, objects, including optical surfaces, lose heat by radiative cooling. Outside our biosphere is space at a temperature of 2.7 K. Although the effective temperature of the sky is perhaps 100 K or so warmer than that, it is still a great deal colder than the surface of the earth. Hence, on clear nights (i.e., those good for astronomy) there will be a net loss of heat by radiation from the surface of the earth and things on it, like telescopes. As they cool, they become prone to dew (and frost) formation.

Our simplest way of reducing dew formation is to reduce the amount of sky the optical components can "see." Binocular objectives and reflex finders are among the most dew prone of all astronomical surfaces. Dew shields provide the simplest way of shielding binocular objectives from the cold sky but, of the binoculars that do have slide-out dew shields, very few are sufficiently long. To be fully effective, a dew shield should be about two and a half times as long as the aperture it is shielding. An extension of this length is unwieldy on small and medium binoculars, for which there are simpler methods for dew prevention and removal. Simple dew shields for larger binoculars can be made from stiff plastic (that from plastic folders is usually adequate) or 3-mm (.125-inch) thick polyethylene foam. These can be stored flat and can have their edges secured in use with hook-and eye (Velcro) strips.

For those who want a higher-tech solution, there are proprietary dew heaters, such as the Kendrick Dew Zapper, that are available commercially. These provide a low-level heat to the surrounding of the aperture. A do-it-yourself alternative, if you have the requisite skills, is to make a similar device using resistance wire or strings of resistors taped to the surround of the aperture. These need not impinge on the light path. Those readers with electronic capabilities will, no doubt, be able to see more sophisticated solutions.

For small and medium binoculars, the solution I use nowadays is to hang the binocular inside my jacket as soon as there is any sign of dewing and, on cold nights, when I am not actually looking through them. If you do this, you will find that they immediately dew up even worse from the warm moist air under the jacket, but they soon clear and are ready for use again. Because hand-held binoculars are usually not held to the eyes for very long periods, their objectives tend to cool less quickly, and they are not as prone to dewing as are mounted binoculars.

Eyepieces on larger binoculars offer a different problem. For obvious reasons, a long dew cap is not an option (and eye cups even make the matter worse!). The obvious thing is to avoid breathing on them, but there is another source of warm moist air: our eyes. It makes sense to dry a moist eye before putting it to an eyepiece, particularly if that eyepiece has an eye cup that will trap any moist air. On particularly cold nights, fold down or retract the eye cup. There are two obvious ways of warming eyepieces: an inside pocket or some form of electrical heating. I have never tried the latter (but there are commercially available eyepiece heaters), but I routinely swap eyepieces when I am observing in winter with my 100-mm binoculars.

Reflex finders are particularly dew-prone. A solution specific to these is to use a piece of plastic folder to make a hemicylindrical shield that covers the entire length and possibly more of the finder. This should not be of a radius that it precludes the use of both eyes with the finder. You can temporarily secure it with parcel or duct tape or tape or, once you are satisfied with it, you might use hook-and eye strips.

Figure 7.4. Twelve-volt hair drier and battery pack.

The practical alternative to dew prevention is dew removal. Several astronomical suppliers provide "dew guns." These are merely 12-volt portable hair driers that plug into the cigarette lighter socket of a car or battery pack (Figure 7.4). These are usually significantly less expensive if they are obtained from a camping store as "traveling" hair dryers.

Compass

A compass is invaluable when you are seeking twilight objects, be it Mercury at elongation or the evening objects during a Messier Marathon. A simple hiker's compass with a bezel that can be adjusted to compensate for local magnetic declination is ideal. If it has a tritium-lit luminous needle, north-point, and plate arrow, so much the better.

Charts and Charting Software

Our need, as binocular users, for sky charts, is no less than the need of telescopic astronomers, but is slightly different. Unless we are using giant binocular telescopes, we do not need charts that go as deep as those preferred by users of large telescopes. This means that our needs are usually completely met by the better "paper" charts and by most of the commonly available star-charting software. For example, the excellent Sky Atlas 2000 goes down to magnitude 8.5 and incorporates galaxies and nebulae that are fainter than this. The choice of charts is therefore a matter of preference and, often, familiarity.

If our choice to use binoculars is based to some extent on their extreme portability, we may wish to use charts or software that incorporate the same philosophy of choice. If this is the case, there is one paper chart that stands out: Collins Gem Stars (some older editions were called Collins Gem Night Sky). This little book is small enough to fit into a shirt pocket and contains sufficient information to keep the users of small and medium binoculars amused for many nights.

If you prefer to use charting software, the "extremely portable" route suggests using a hand-held computer or personal digital assistant (PDA). There are a number of excellent software options for these, depending on the operating system used by the hand-held viewer. In general, there is more astronomical software written for PalmOS than for other operating systems.

PalmOS

Of the many examples of astronomical software available for PDAs, there are three planetarium programs that stand out:

- *2Sky*: This is commercial software and is not offered as an evaluation version, but has a 30-day refund policy if you find the software to be unsuitable. The "basic" version ($25) has stars to magnitude 7 and 500 deep sky objects (DSOs), the "total" version includes stars down to magnitude 9.5 and 13, 600 DSOs from the Messier/NGC/IC catalog, and the "mega" version has stars to magnitude 11.2 and the same DSOs as the "total" version. It also comes with 2Red, which changes the entire PDA to red-screen night mode.

- *Planetarium*: This is "nagware," that is, shareware that, until you register it, reminds you when you start and/or close the program that it is unregistered. It costs $24 to register. This is my most-used astronomical software. It has a "Compass View" that shows the lunar phase and, at a quick glance, the altitude and azimuth of the Sun, Moon, major planets, and one other object of your choice. It has instantly accessible rise and set tables and twilight tables. Among its most useful features is the ease with which catalogs of your choosing can be added to its database and with which objects can be imported into a "Personal" catalog that can be exchanged with other Planetarium users. It has stars to magnitude 6.5 as standard, but there are databases that go, by increments of one magnitude, down to 11.5 (i.e., the entire Tycho2/Hipparchos catalog).
- *PleiadAtlas*: Like Planetarium, this is nagware ($10 to register). It goes down to magnitude 11.5 and incorporates the Messier, NGC, and IC catalogs.

Windows CE

There are two programs of significance for Windows CE:

- *TheSky Pocket Edition*: This is commercial software with no evaluation version. The default stellar catalog goes to magnitude 6, and this can be expanded to magnitude 9 (the SAO database). It includes the NGC and IC catalogs of deep-sky objects and can include up to a hundred comets and asteroids, but the orbital elements for these must be updated using the PC version of the program.
- *Pocket Stars*: There is no evaluation version, but there is a "no quibble" 30-day guarantee. Includes stars to just over magnitude 6 from the Bright Star catalog, and deep sky objects from the Messier and Caldwell catalogs.

If you use a PalmOS system, there is one other piece of software that is invaluable, not just for binocular astronomers: MoonDate. This piece of freeware calculates the dates of the lunar phases and inserts them into the Palm calendar, thus acting as an aid to future planning of observations.

There is one caveat to using a PDA: dark adaptation. Even if you do use a "red mode," there is still sufficient light to destroy your eyes' dark adaptation. The solution is to cover the screen with either red or neutral density (better) translucent plastic sheet. Remove it if you have an emergency need for a flashlight.

Torches (Flashlights)

First, a note on terminology, born of several misunderstandings I have encountered when communicating across the Atlantic. In U.K. English a "torch" is not the same as it is in American English. It does not mean a "flaming torch," but what is, in American English, called a flashlight. A red-light torch is a useful piece of

Figure 7.5. Small accessories. *Top L-R*: Compass, pocket star atlas, illuminated magnifier. *Middle*: Hand-held computer running Planetarium software, red LED torch (flashlight) in Nite-Ize headband. *Bottom*: White light torch (also fits in headband) for use when setting up and dismantling kit.

observing kit, not only for reading charts, but also for examining equipment when this is necessary. Torches that use red light emitting diodes (LEDs) are more than adequate for most purposes. I find that they are much more useful if they can be head-mounted, thus leaving both hands free. There is an adjustable headband called a Nite Ize that is sold for precisely this purpose (Figure 7.5).

There is, however, a potential problem with red illumination for reading charts. Red light focuses farther behind the retina than yellow light and, especially for those of us who eyes have become presbyopic with age, it can be difficult to focus the red-illuminated page. A solution, which is also applicable to people who prefer to observe without spectacles but who must use them for reading charts, is to use an illuminated magnifier. The light source can be covered with translucent red plastic or with red nail polish. The magnifier is also useful on a PDA screen. A white-light torch is useful when assembling and dismantling observing apparatus.

Storage and Transport Container

It makes sense to keep, with your binoculars, the various small items that you frequently use when observing. There are numerous options for containers and some binoculars come with very useful cases, although I have yet to find one that is ideal. A relatively inexpensive option is an aluminium camera case. If it comes with soft polyurethane foam, this should be replaced with a high-density polyethylene foam. This can easily be cut and shaped with a carving knife or a sharp chisel. Recesses in it can be made for flashlights, charts, finders, spare eyepieces, and so forth (Figure 7.6).

Cases supplied with medium and small binoculars have very little capacity for extra storage. However, in my 10×50 case I do also keep the L-bracket for tripod mounting and the solar filters (which I store on the objectives).

Figure 7.6. Binocular storage case.

Software Sources

2Sky: http://www.in2space.com/
MoonDates: http://members.aol.com/nhobbs1/
Planetarium: http://www.aho.ch/pilotplanets/
PleiadAtlas: http://astro.isi.edu/pleiadatlas/
Pocket Stars: http://www.nomadelectronics.com/
Pocket Universe 2000: http://www.stellarmetrics.com/Software/pu2000.htm
Solun: http://www.freepoc.org/solun.htm
TheSky Pocket Edition:
http://www.bisque.com/Products/TheSkyPE/TheSkyPE.asp

CHAPTER EIGHT

Observing Techniques

As any observer with any amount of experience will know, using appropriate techniques will not only increase the chances of observing difficult objects, but will also enhance the pleasure of observing.

Personal Comfort

All other things being equal, the efficacy of visual observation is usually in direct proportion to the comfort of the observer. For the binocular observer, this means three things: physical comfort, thermal comfort, and nutritional comfort.

Physical Comfort

The plethora of homemade observing aids, ranging from simple recliners to computerized observing chairs, is an indication of the degree of comfort that binocular observers seek to find. This should come as no surprise: the simple fact that one has chosen binoculars is often an indication that one has made a choice of optical comfort!

For those of us who prefer to stand whilet observing (usually restricted to those of us whose binoculars are mounted and have angled eyepieces), our comfort is relatively easy to attain. On the other hand, those of us who prefer some sort of seating or reclining may well find it considerably more difficult, owing to the differences in our backs and necks. That which perfectly suits one person may well be an anathema to another. My best advice is to try out as many options as you can and, once you have found something that suits you, acquire or make it, and then treasure it. My Mac Sports recliner is such an item, and I treat it with almost as much care as I do my binoculars themselves. If you find something close to what is ideal for you, try to adapt it. This is usually achievable by judicious use of cushioning or padding, so that your back and neck are perfectly cradled and your arms are supported but not restricted.

Thermal Comfort

Almost by definition, astronomical observing takes place during the coldest part of the day. Each of us not only has a different sensitivity to and tolerance of cold, but this individual variation itself varies from day to day and even during the course of a night's observing. Therefore, our personal insulation needs to be both adequate and adjustable; this implies layering. Furthermore, viewing through the eyepieces of the binocular is not a physically active task and, for this reason alone, we need to dress as though it were about five to ten degrees colder than it really is in order to compensate for the lack of physical activity. Those who are used to being in cold conditions will undoubtedly have their own "clothing solutions." Those who are not may find some useful ideas in the following advice, whose principles have kept me comfortable for over a decade.

- *Undergarments*: If you want to keep warm, avoid cotton; it is cold because it absorbs moisture (which is why we use it for towels) and uses our body heat to evaporate the water. If you wish to stick to natural fibres, change to wool (itchy) or silk (expensive), otherwise you need to use a synthetic "thermal" hydrophobic fabric that wicks water away from the skin without absorbing it.
- *Insulting layer*: The middle layer of clothing is the insulating layer, which needs to trap as much air as it can, because air is an excellent insulator. By far the most efficient insulating layer per unit weight, or per unit volume, is dry goose down, but the damper it gets the less effective it is. It takes ages to dry out, and it is extremely expensive. The moisture that has been wicked through the inner layer comes to the middle layer, which it will dampen unless it passes through. If you wish to stick to natural fibres, wool has the reputation for being a good insulator when it is wet, although it can be a bit heavy. Modern synthetics such as Hollofil, Thinsulate, and Polartec are excellent insulators and will wick moisture away from the body without absorbing it. It makes sense to have a zipped garment as this middle layer, so you can adjust your insulation to different conditions by opening and closing the zip. Also remember that this layer should not be too tight or be compressed by the outer layer, or its insulating properties (related to the amount of trapped air) are reduced.
- *Outer layer*: While we tend not to observe in strong winds, even a 8 km/h (5 mph) breeze can make a great deal of difference to our thermal comfort if it can get into the insulating layer. The outer layer therefore needs to be windproof, but it must also pass the water vapor that has been wicked away from our bodies by the inner layers. A windproof Polartec fleece is ideal as a combination insulator/outer.

- *Hats*: It is said that we can lose up to 40 percent of our body's heat through our heads. Even if this is as low as 25 percent, it indicates that we can regulate our body temperature by changing our headware, thereby reducing the need to deal with the insulating middle layer of clothing. "Extreme conditions" headware would follow the same pattern as our other clothing (i.e., silk or polypropylene balaclava, covered by a wool or polartec layer, covered by a windproof layer) but, for most of us, a simple fleecy hat, preferably with ear flaps, is adequate.
- *Gloves*: There is no particularly elegant solution to the need to keep the fingers warm and also have them free and sufficiently sensitive to make fine adjustments. The best solution I have found is an insulated "hunter's" glove that has a fold-back mitten over a fingerless glove as well as split thumbs. This keeps the fingers warm but enables the forefinger and thumb to easily slip out when necessary.
- *Footwear*: On clear nights the ground cools faster than the air and we lose heat rapidly to the cold ground if we wear thin soles. Ordinary thick-soled shoes worn with two layers of socks (inner "wicking" sock, outer insulating "cushion loop" sock) are sufficiently warm for most temperate zone conditions, and for the more cold-footed among us, there are alternatives such as snow boots, which have thick soles and a removable inner sock of thick felt, often combined with a sandwiched reflective layer.

Nutritional Comfort

Adequate nutrition is essential as it combats fatigue and cold. It is difficult to observe comfortably after a heavy meal and is equally difficult when we are conscious of hunger. If we are cold, we need to replace our lost energy with carbohydrates. It is usually healthier to take these in the form of starches, which release their energy slowly, than as a sugar, although those who do not have contraindicating dietary requirements may find a warm glucose-based drink to be beneficial in some circumstances. It is also essential to keep a good fluid balance. Time can pass very rapidly when we are enjoying observation, and our steamy breath on cold nights is an indication of fluid loss. Over the past decade or so, people have become more conscious of the need for adequate hydration, but there is an additional benefit that is less well known: if we maintain good hydration, even by merely sipping cold water, our extremities tend to get less cold.

Observing Sites

Where possible, choose your observing site with care. Stray light is obviously to be avoided. Also avoid observing over buildings or other sources of heat. Altitude can be an advantage as it can take you above sources of stray light and you have less (polluted) atmosphere between you and your target objects. As little as 300 m (1,000 ft) can make a noticeable difference; transparency is usually considerably better from my home on the North Downs of Kent than it is a few miles away on Romney Marsh. Conversely, if you cannot get to high ground, you may be able to observe over a sea horizon. The choice sites are those of very high altitude with a sea horizon, but few of us have access to such places.

If you observe on your own property, you can, of course prepare it. Screens can be used to block intrusive lights if they cannot be blocked by buildings or vegetation. Equally important is to prepare the ground. You cannot observe in a relaxed manner if you are in danger of tripping over objects on the ground!

If you use a site away from home, do reconnoitre it in daylight and, where appropriate, get the landowner's permission. Take personal security into account. You cannot enjoy observing if you are concerned about the potential presence of domesticated or wild animals or of antisocial people.

Observing Techniques

Once our personal comfort is attended to, we can get down to the business of actual observation. There are various ways in which this can be enhanced:

- *Dark Adaptation*: It takes at least twenty minutes to half an hour for our eyes to get properly dark-adapted, and the process of dark adaptation continues for over an hour. Some observers recommend closing your eyes for a few moments immediately before attempting a particularly difficult observation.
- *Averted Vision*: Look down toward the tip of your nose so that light from the eyepiece appears to come from the "upper outside" of the eye. Use averted vision even for things that you can see well without it as this will very often allow more detail to be seen.
- *Perfect Focus*: Ensure that your binoculars are perfectly focused. This will allow dimmer objects and more detail to be seen. Center-focus binoculars tend to get defocused more easily than those with independent eyepiece focus.
- *Keep the Binoculars Still*: If something is difficult to observe, ensure that the binoculars are firmly mounted. Keep looking and sometimes the object just appears.
- *Jiggle the Binoculars*: This seems contradictory to the advice above, but it sometimes helps, when using mounted binoculars, to examine the appropriate region with averted vision and to tap the binocular. The slight movement sometimes makes a difficult object appear.
- *Breathe*: It is a normal reaction for us to hold our breath when we are doing something critical, especially if that activity is assisted by stillness. Try to overcome this tendency if you have it: a well-oxygenated retina is more sensitive. In particular, carbon monoxide from smoke reduces the ability of the blood to carry oxygen.
- *Patience and Persistence*: These are probably the most important attributes of the successful observer. It can sometimes take several minutes to make a fleeting, difficult observation, and it may take several attempts over several nights before the various conditions are just right to allow the observation to be made. A patient, persistent observer can see more than a less patient one with better eyesight!

CHAPTER NINE

50 Deep Sky Objects for 50 mm Binoculars

The objects in this chapter are visible with medium-sized binoculars, although some are visible in much smaller instruments. Most of the objects to the far south, for example, are easily visible in 8×30 binoculars. With the exception of objects that fill the eyepiece in 10×50 binoculars, all of these objects are better viewed, in the sense that more detail can be seen, in larger instruments. Similarly, many objects in the list for 100-mm binoculars are visible—or at least detectable—in smaller instruments, but often no detail is visible. For example, under good conditions an experienced observer can see the Ring Nebula, M57, in 10×50 binoculars, but it is stellar in appearance.

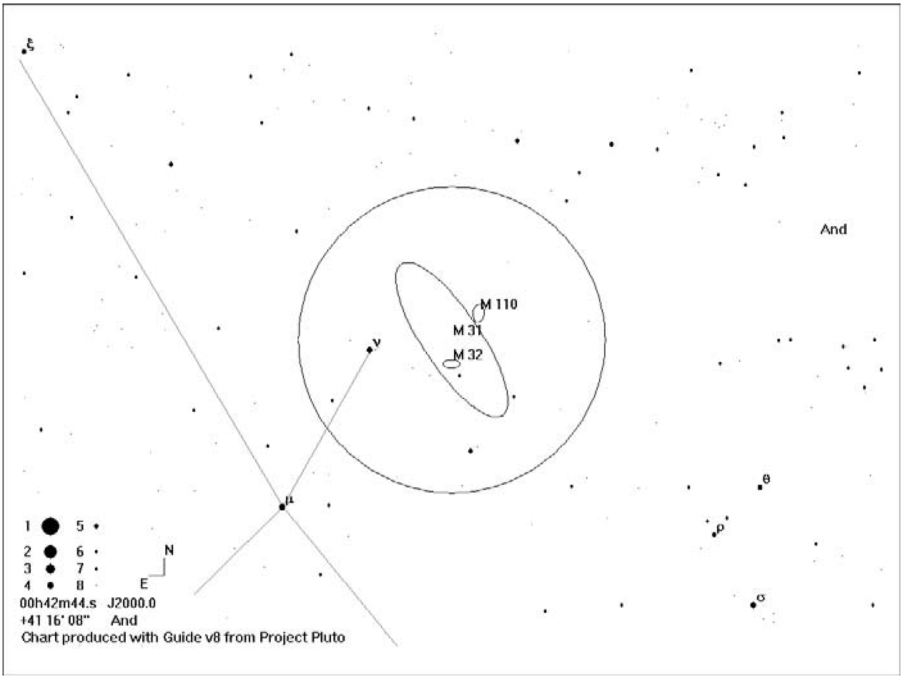
Any "best of" selection is bound to be somewhat subjective, and I acknowledge that I am particularly fond of open clusters as objects for binocular and small telescope observation. I have tried to include representative objects of all classes, but the relative ease with which open clusters can be seen, especially in nonideal sky conditions, helps to account for their apparent overrepresentation.

In addition to stars, the following classes of object are included:

- *Emission nebulae:* These consist of gas that is ionized by the energy radiated by nearby stars. The light is emitted as electrons are recaptured. They appear red in photographs, but the brighter ones may have a greenish tinge when observed by eye. They are often the sites of star formation.
- *Planetary nebulae:* So called by William Herschel because many of them appeared as discs (although only about 10 percent appear circular), that is, like planets, in his telescope. They are the debris ejected from a star as it passes through the red giant stage to become a white dwarf.

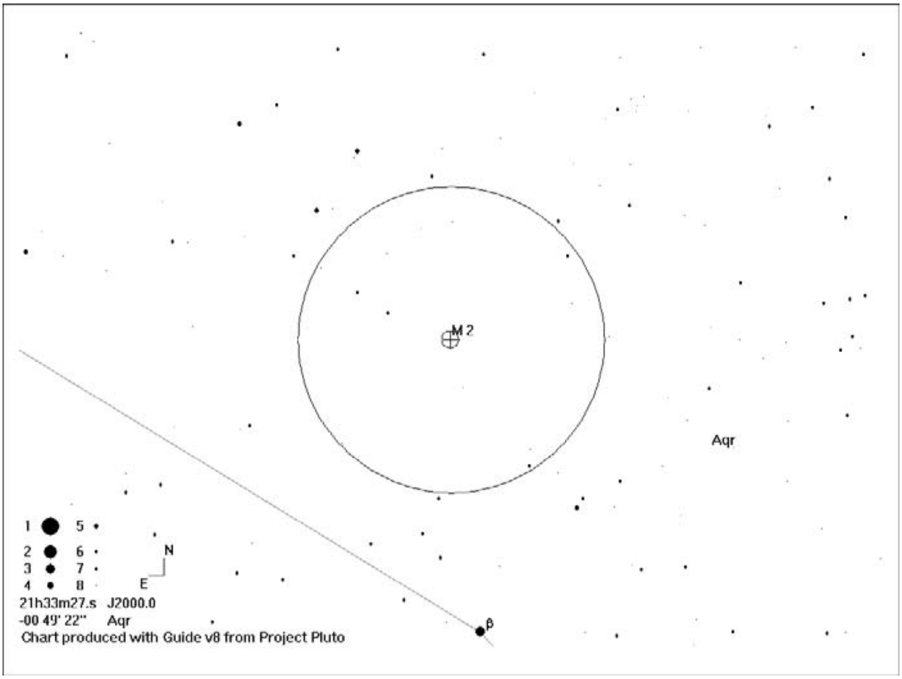
- *Reflection nebulae:* They are made visible by reflected starlight and are thus always less bright than the star that illuminates them (unless the star is attenuated by intervening dust). It is tiny dust particles, not the gas of the nebula, that reflects the light. They appear blue in photographs.
- *Galaxies:* Huge island universes of hundreds of billions of stars held together by gravity.
- *Globular clusters:* Very old dense balls of hundreds of thousands of stars, which form halos around galaxies.
- *Open clusters:* Less densely packed groups of stars than open clusters; may contain from a few dozen to a few thousand stars that recently formed in the galactic disc.

The charts (listed in alphabetical order by constellation) in this chapter show a 5-degree field of view circle. The stars are plotted to magnitude 8. North is up. The J2000 coordinates are shown.



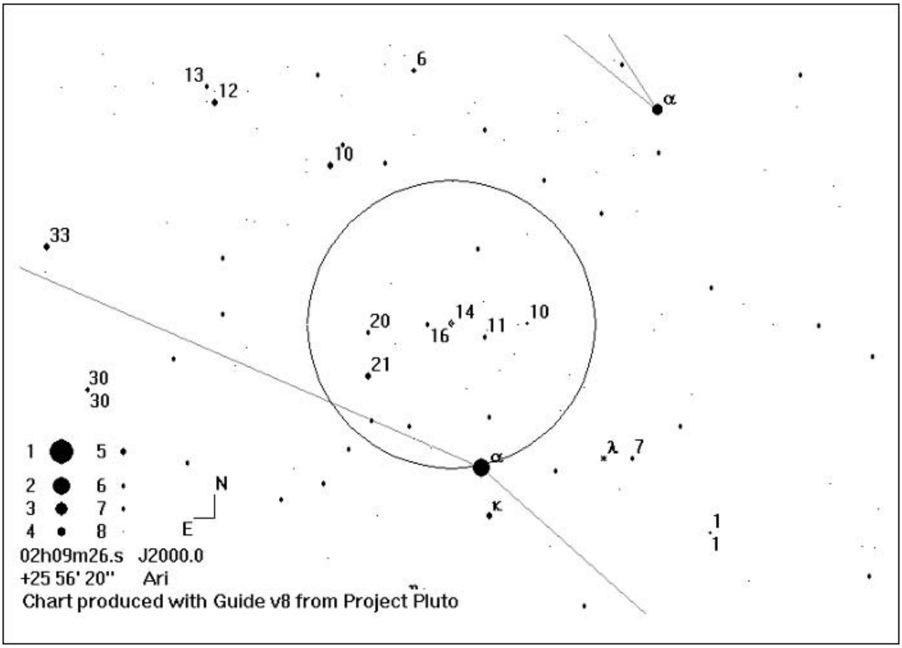
Andromeda: Galaxy: M31 (NGC 224, the *Great Andromeda Galaxy*)

The galaxy, which will be visible to the naked eye, is an easy star-hop from the yellowish *β And (Mirach)*. Place β near the SE edge of the field and find μ to the NW. Place μ where β was, and M31 will lie where μ was. You should be able to see the elongated shape of M31, which, with patience and dark skies, extends almost across the field of view. Notice the significantly brighter glow of the nucleus and how the light of the galaxy drops off more abruptly at the NW edge as a consequence of a dust lane. If you have good skies (or larger binoculars), you may be able to find the two companion galaxies. To the S of the nucleus lies M32 (NGC 221), making a right-angled triangle with two 7th magnitude stars and appearing like a large, slightly fuzzy, star in 10×50 binoculars. You may need to use averted vision to see this. Slightly more obvious in 10×50 s, and to the NW, is M110 (NGC 205).



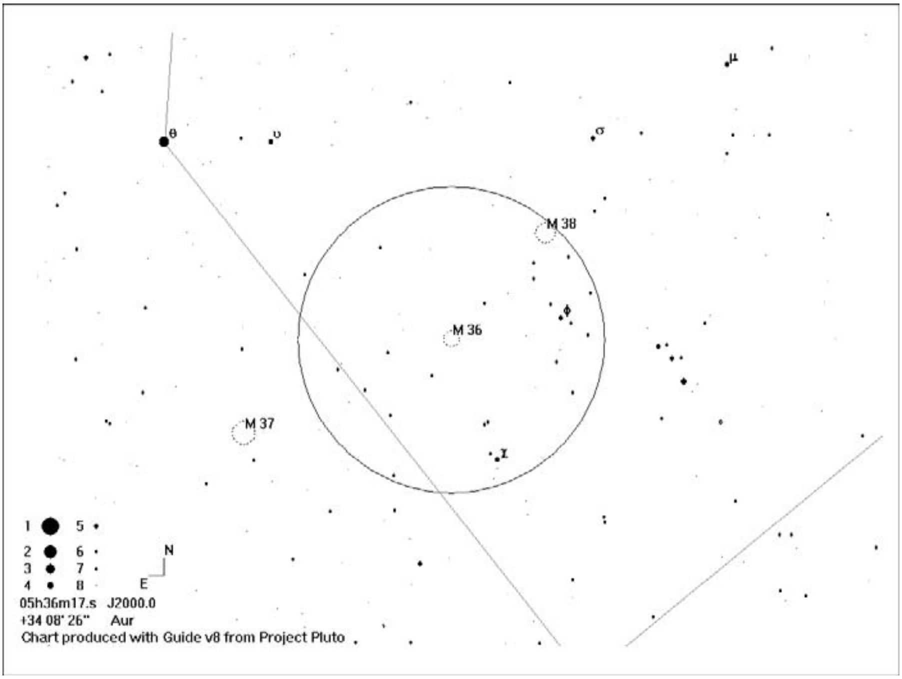
Aquarius: Globular Cluster: M2 (NGC 7089)

The cluster is about 5 degrees N of the 3rd magnitude β *Aquarii* (*Sadalsuud*). M2 is small and bright, having the appearance of a fuzzy star in 10×50 binoculars, but is visible in less than ideal sky conditions. At 50,000 light years, it is at a greater distance from us than either M13 or M5, and has a diameter of about 150 light years[1].



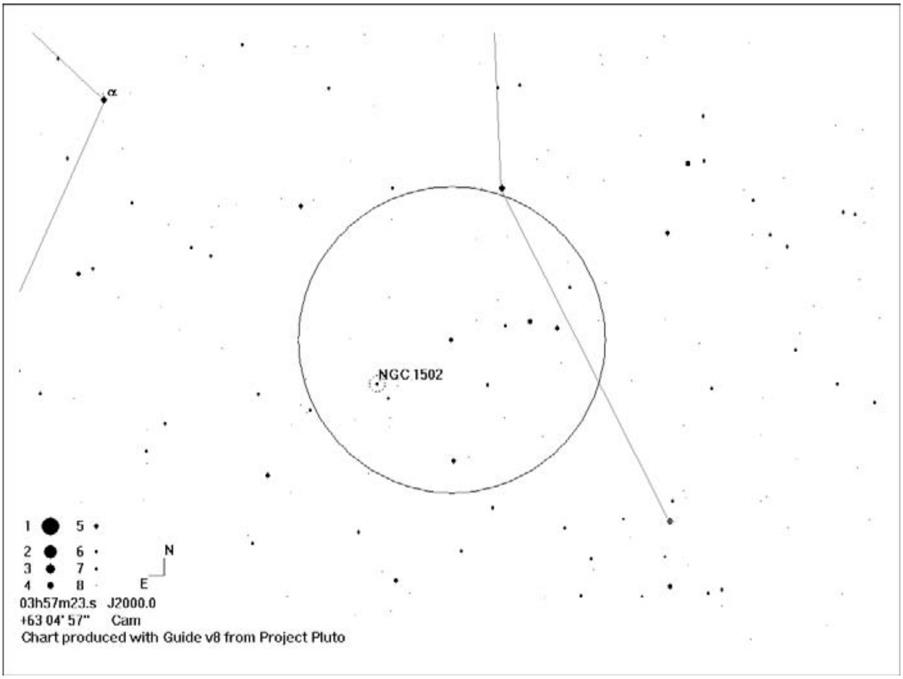
Aries: Triple Star: 14 Arietis

14 Arietis is 2.5 degrees N of *Hamal* (*α Ari*). The brighter two members (5th and 8th magnitude) are easy to distinguish and separated by 103 arcsec. The third member is considerably fainter (11th magnitude) and is 10 arsec closer to the primary. It is thus a challenge in 50-mm binoculars.



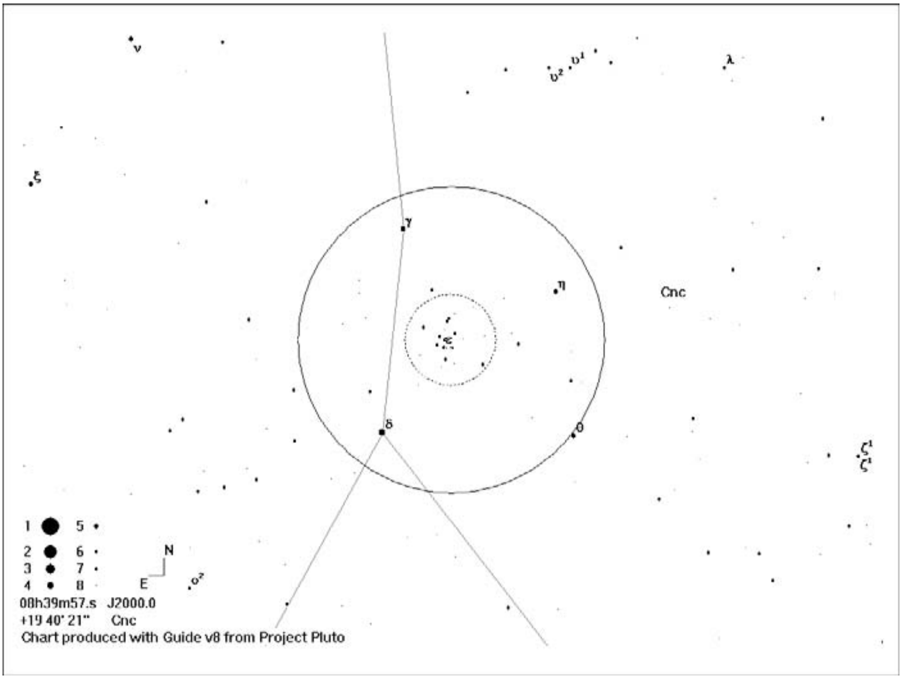
Auriga: Three Open Clusters: M36 (NGC 1960), M37 (NGC 2099), M38 (NGC 1912)

Midway between *β Tauri* (*El Nath*) and *θ Aurigae* is a slightly curved chain of three, evenly spaced, 7th magnitude stars. With this chain at the center of the field, M36 lies to the NW and M37 lies to the SE, both within the same 5-degree field. With M36 at the center of the field, M38 is at the NW edge. M36 is approximately round and about a third of the diameter of the Moon. Depending on the sky conditions and the quality of the binoculars, you may be able to resolve up to about half a dozen of the brightest stars. M37 is about twice as large as M36 and brighter overall, because it has many more stars, but the individual stars themselves are fainter. M38 is intermediate in size between M36 and M37. In good conditions, 10×50 binoculars may resolve eight or nine stars.



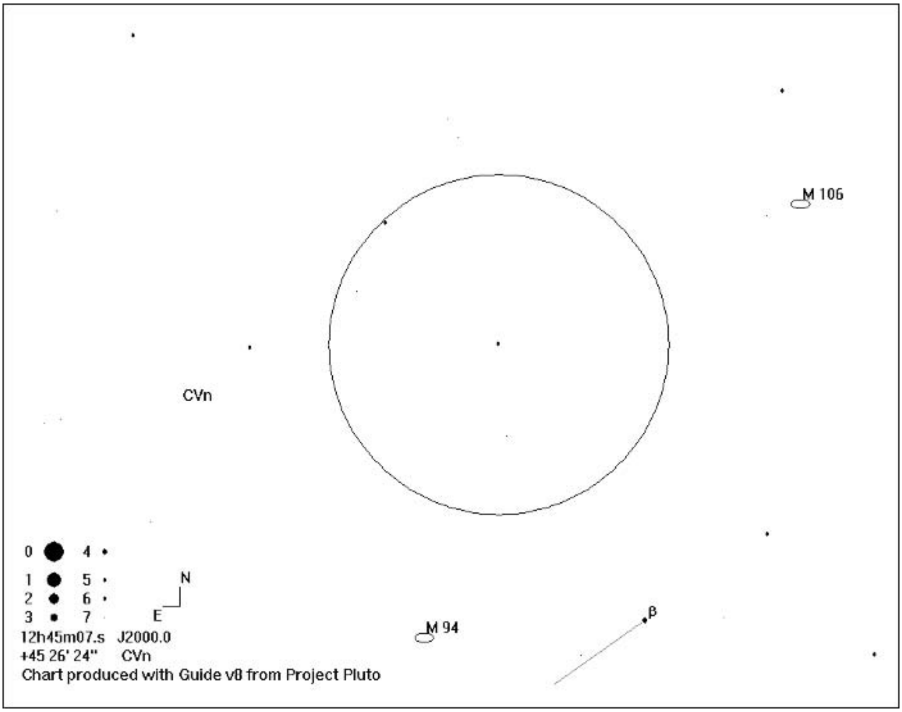
Camelopardalis: Asterism: *Kemble's Cascade*

Kemble's Cascade lies in a region of sky that is sparse of bright stars. If you are confident of identifying the 4th magnitude α *Camelopardalis* in your skies, simply find the 5th magnitude star that is a little more than half a 5-degree field to the SW, then continue the same distance to the SW. If α *Cam* is not visible or identifiable, begin at α *Persei* (*Mirfak*), and scan two and a half 5-degree fields to the NNE. This beautiful chain of stars, named for the late Canadian amateur astronomer, Fr. Lucien Kemble, is one of the northern sky's finest sights in medium-sized binoculars. It is a ribbon of stars down to 9th magnitude, more than a dozen of which can be visible in 10×50 binoculars, that extends from NW to SE across a 5-degree field, with a brighter (5th magnitude) star near the middle and the small open cluster NGC 1502 at the SE, which is the "pool" into which the "cascade" appears to "fall."



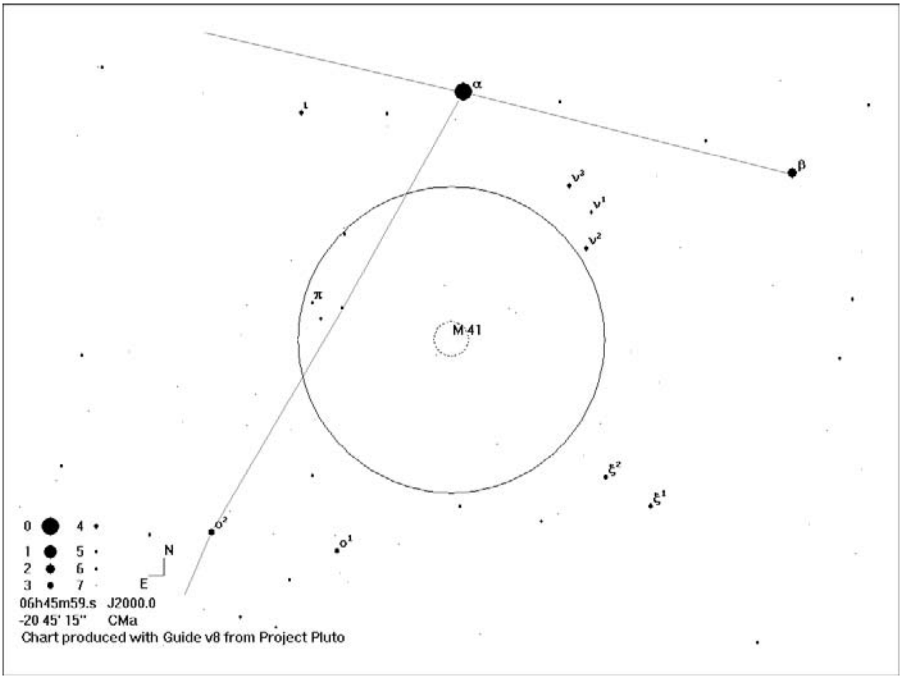
Cancer: Open Cluster: M44 (NGC 2632, *Praesepe*, the *Beehive Cluster*)

M44, which is visible to the naked eye, is in the same 5-degree field as γ, δ, and *η Cancri*, and contains *ε Cnc*. The Beehive is a very nice binocular object, in which you may be able to resolve up to twenty or so stars in 10×50 binoculars. You should also be able to resolve two binocular double stars, ADS 6915 and ADS 6921.



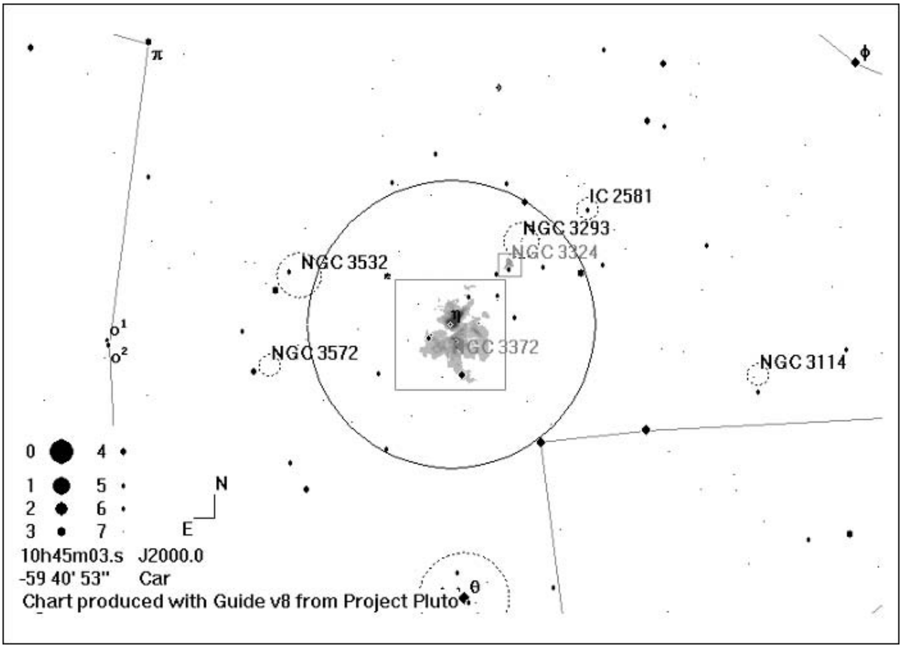
Canes Venatici: Carbon Star: Y CVn (*La Superba*)

Y Canum Venaticorum is 4.5 degrees to the NE of the 4th magnitude *β Cvn*. This 5th magnitude star was named *La Superba* by Angelo Sechii, a 19th-century Italian astronomer, as a consequence of its deep red color, which is brought out well by binoculars. *Y Cvn* is a star that is near the end of its life and shows carbon in its atmosphere. It is variable over about half a magnitude with a period of 158 days.



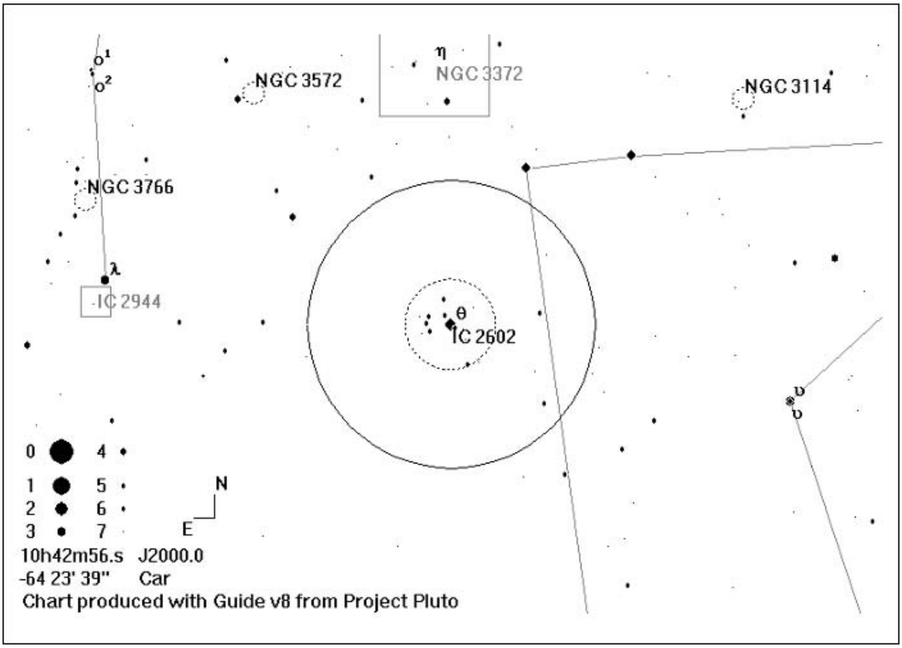
Canis Major: Open Cluster: M41 (NGC 2287)

M41 is 4 degrees south of α *Canis Majoris* (*Sirius*). This cluster is visible to the naked eye (it was noted by Aristotle) in a transparent sky. In 10×50 binoculars, half a dozen or so stars are resolved against a background glow.



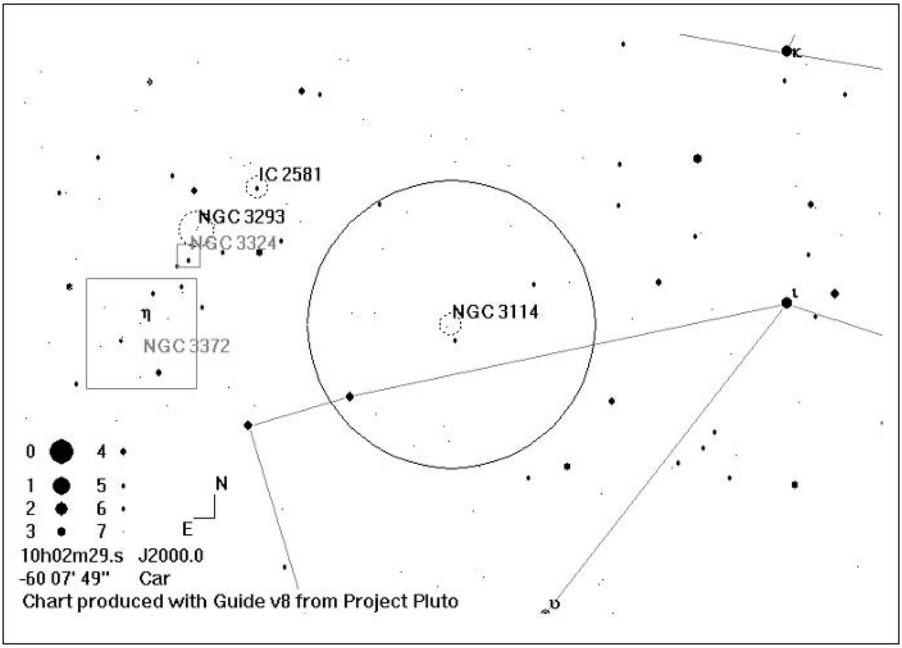
Carina: Emission Nebula: NGC 3372 (η *Carinae Nebula*)

If you place θ *Carinae* at the S of a 5-degree field, NGC 3372 will be at the N edge. The η *Carinae Nebula* is one of the stunning sights of the Southern Hemisphere. It is easily visible to the naked eye and begins to show detail even in small binoculars. It is a gas and dust shell that surrounds the enigmatic star η ***Car***, which has fluctuated in brightness from 3rd magnitude when it was first cataloged, to nearly as bright as *Sirius* in the mid-19th century (when the nebula formed), to its current status of invisible to the naked eye. The nebula and its progenitor star are 8,000 light years away, nearly a thousand times as distant as *Sirius* and five times as far as the *Great Orion Nebula*.



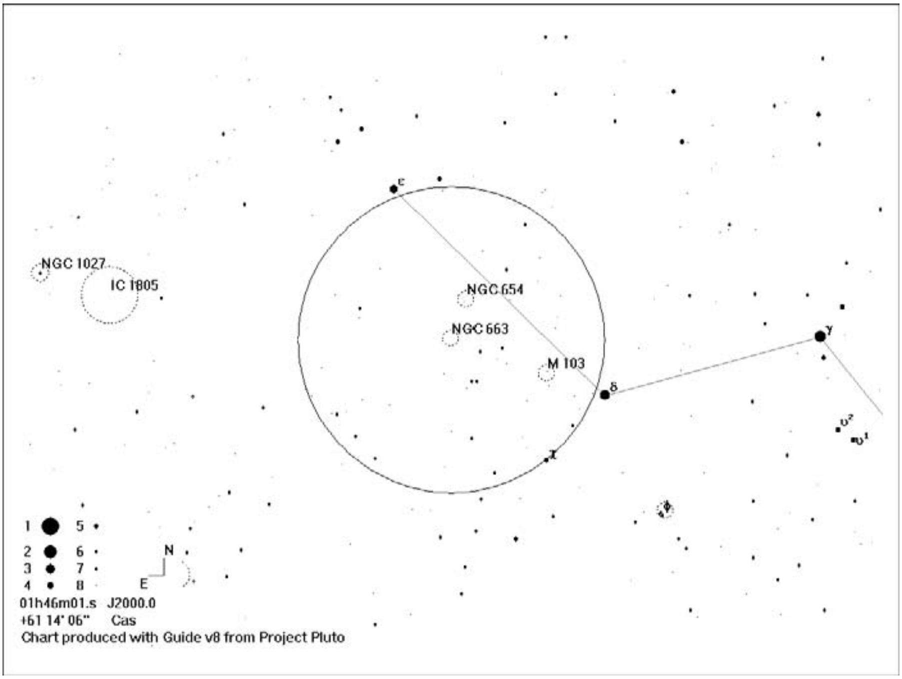
Carina: Open Cluster: IC 2602 (the *Southern Pleiades*)

IC 2602 is an easy naked-eye cluster surrounds the star ***θ Carinae***. This large cluster is similar in size and the number of bright stars as M45, thus giving it its common name. It is a particularly fine sight in 10×50 binoculars, with twenty or more stars, depending on sky conditions, being resolved.



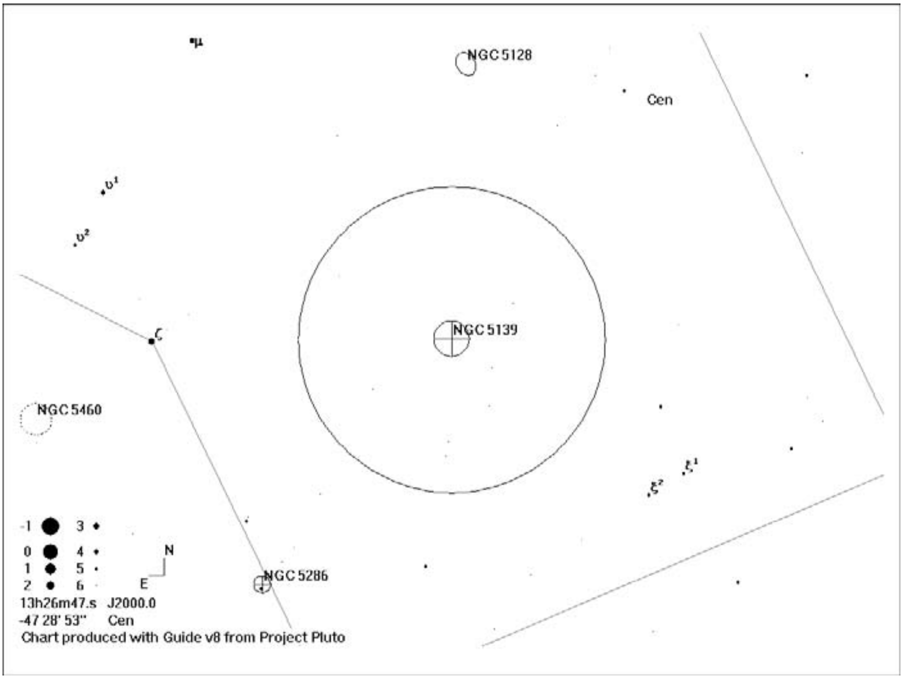
Carina: Open Cluster: NGC 3114

NGC 3114 is just visible to the naked eye and is situated just over 5 degrees W of the *η* ***Carinae*** nebula (above). NGC 3114 is a good object for 10×50 binoculars, with fifteen or so stars being resolved in a region about the same size as the Moon. It is superb in larger instruments.



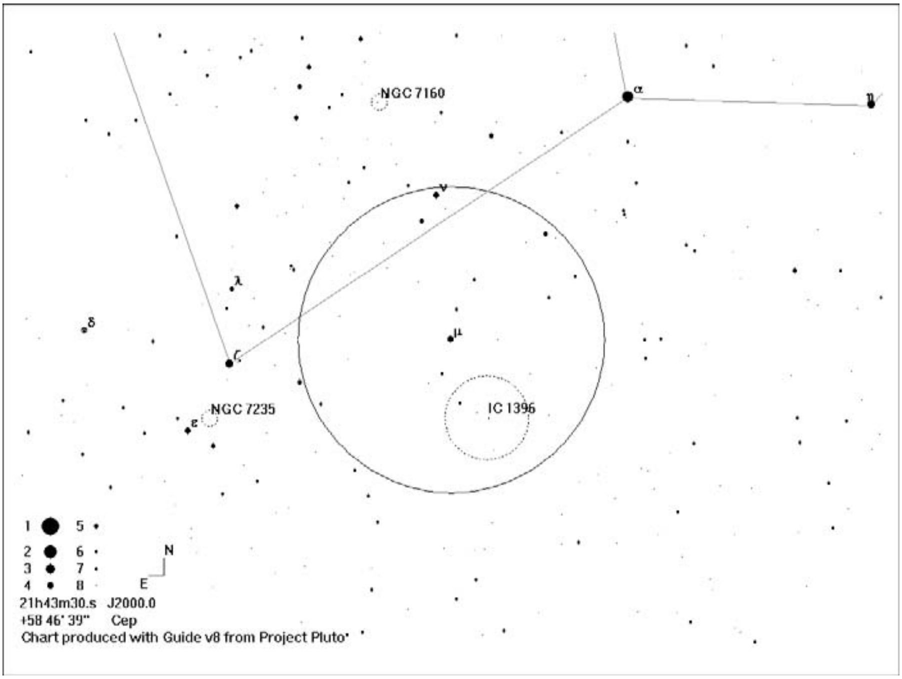
Cassiopeia: Open Cluster: NGC 663

NGC 663 is the largest of several open clusters that are visible in the same 5-degree field as δ and *ε* ***Cassiopeiae***. It is superior in every respect to the nearby M103 and, unlike M103, which appears as a small fan-shaped patch of nebulosity, some of the stars are resolvable in 10×50 binoculars.



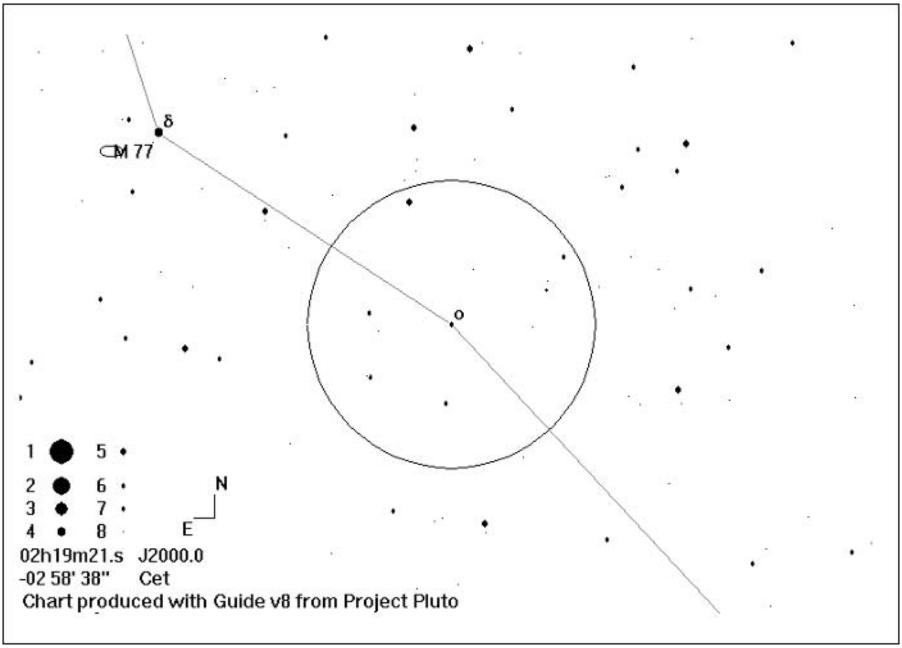
Centaurus: Globular Cluster: NGC 5139 (Omega Centauri)

This cluster is visible to the naked eye one 5-degree field to the W of *ζ* ***Centauri***. Called the "King of Globulars" for a good reason, this globular cluster is superb viewed from any instrument. It is noticeably larger than the Moon and extremely bright. It contains about a million stars.



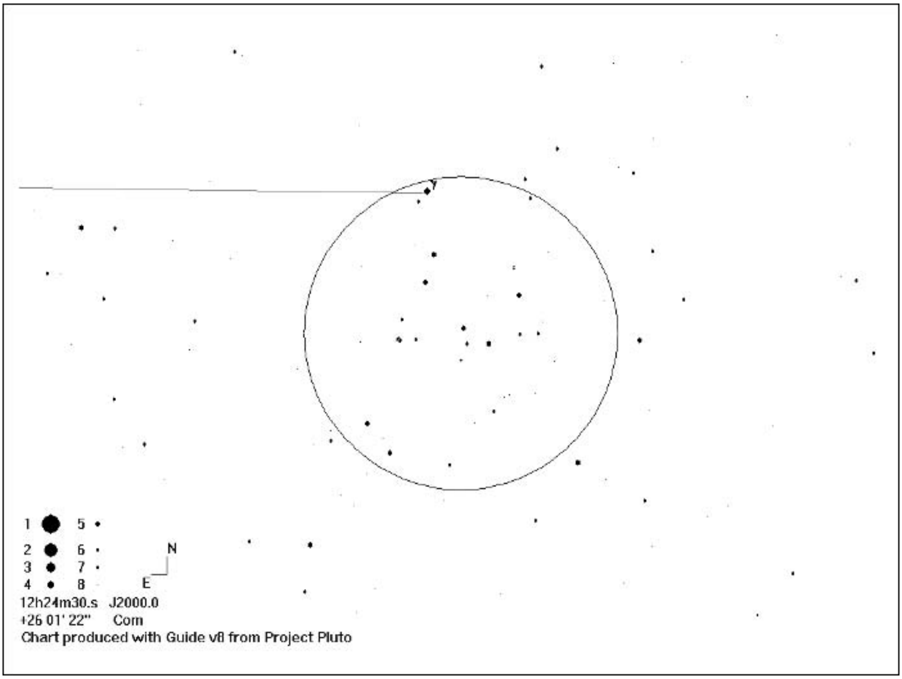
Cepheus: Red Giant: μ Cep (the *Garnet Star*)

To find the *Garnet Star*, place *α* ***Cephei*** at the NW edge of a 5-degree field and μ will be diametrically opposite. *μ* ***Cep*** is one of the reddest stars in the sky; it was named "The Garnet Star" by William Herschel. The deep orange color of this red giant is nicely brought out in 10×50 binoculars. It has a variability of a bit under a magnitude, but is usually around 4th magnitude. It is one of the largest known stars; if it replaced the Sun, it would extend well beyond the orbit of Jupiter. It is destined to become a supernova.



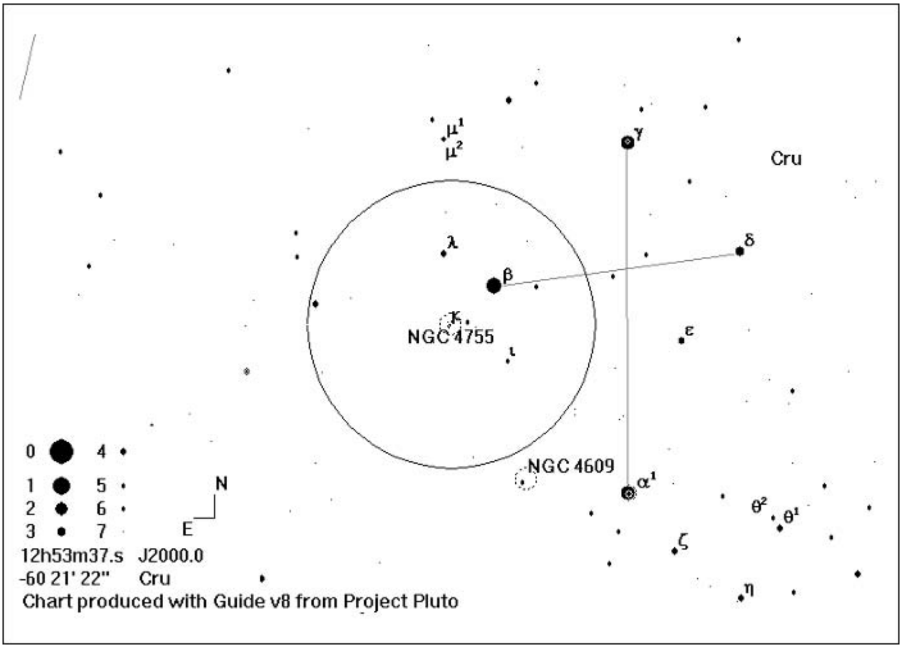
Cetus: Variable Star: o Ceti (*Mira*)

Mean magnitude range: 3.6–9.3; Mean period: 334 days; Type: Mira. *Mira* can be traced throughout most of its period with medium-sized binoculars. It is usually invisible to the naked eye, but its peak magnitude ranges from about 4th magnitude to brighter than 2nd magnitude. (William Herschel noted that the 1799 maximum that rivaled *Aldebaran* in brightness.[2]) ***Mira*** has been known to be variable since 1596, prior to the first astronomical use of the telescope. It gives its name to a class of variable red giant stars that share the same characteristic variability.



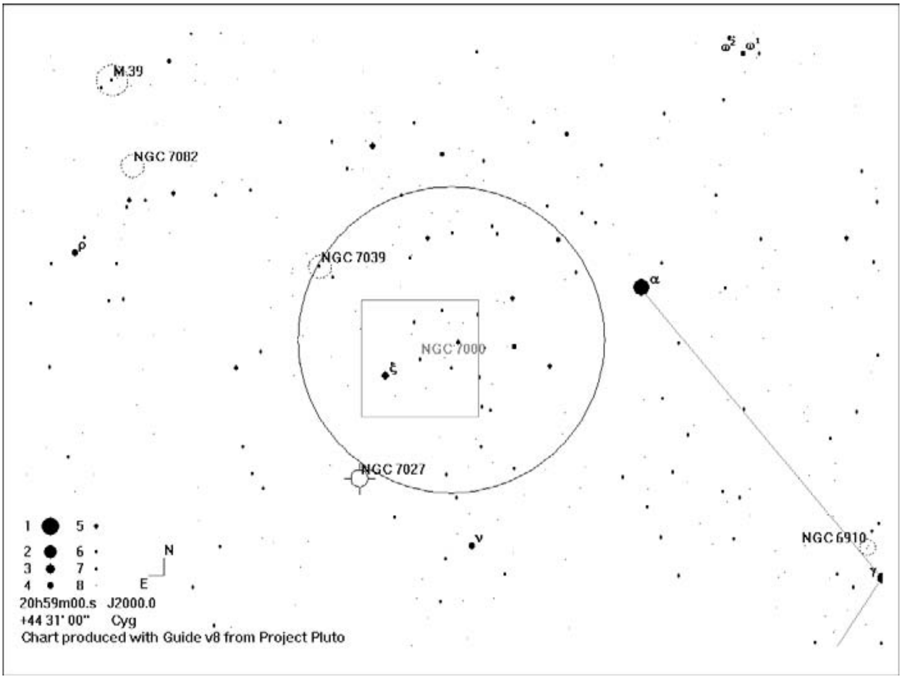
Coma Berenices: Open Cluster: Melotte 111

Melotte 111 is a large cluster of stars that includes ***γ Comae Berenices***, although it is likely that ***γ Com*** is a field star, not a true member. In a dark sky, the cluster is visible to the naked eye. It is the cluster that gives the parent constellation its name: in legend, it is the beautiful hair that Queen Berenice sacrificed to Aphrodite in order to ensure the safe return from war of her husband. This cluster, the third nearest to us, overspills a 5-degree field.



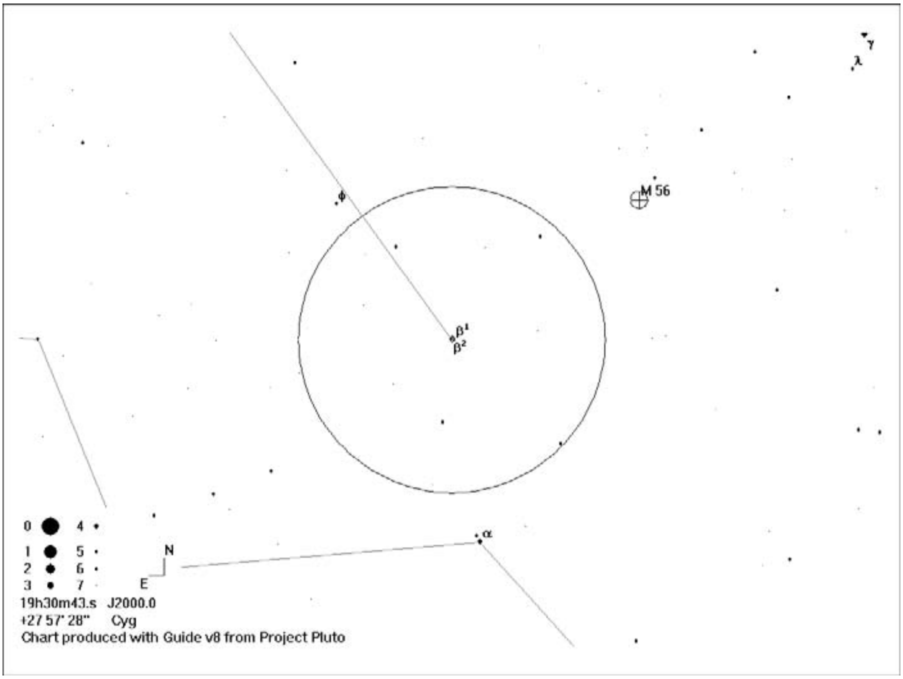
Crux: Open Cluster: NGC 4755 (the *Jewel Box*)

NGC 4755 is situated 1 degree SE of ***β Crucis*** and spans about one-third of the diameter of the Moon. It is visible to the naked eye and 10×50 binoculars will show the aptness of its common name, with several stars being resolved. With larger binoculars, you may be able to discern that one star is reddish in color.



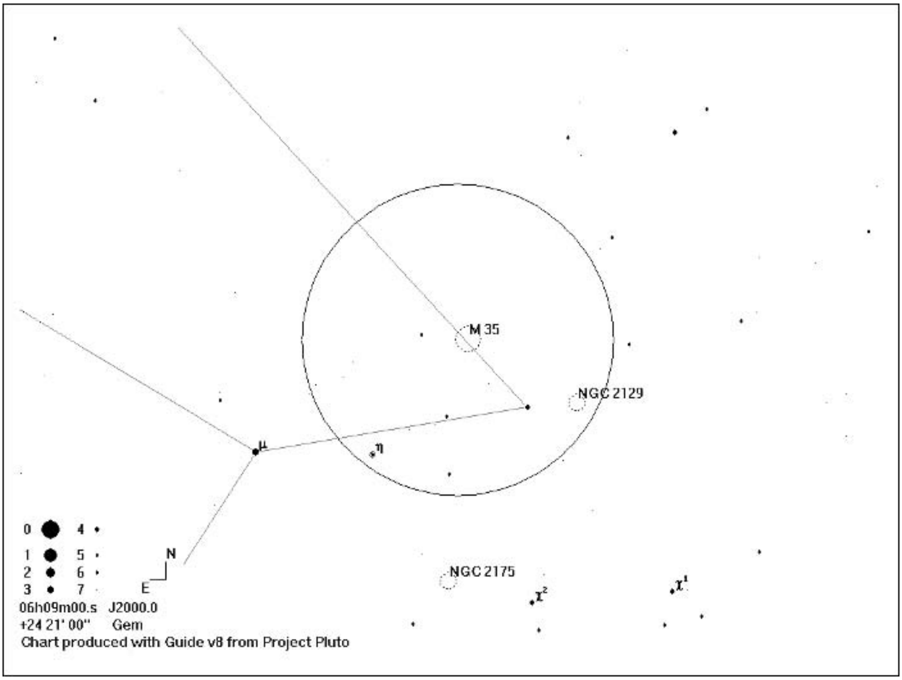
Cygnus: Emission Nebula: NGC 7000 (the *North American Nebula*)

NGC 7000 is a bright patch of nebulosity whose center is about 4 degrees ESE of ***α Cygni*** (*Deneb*). In a transparent dark sky it is visible to the naked eye with direct vision and easy with averted vision. It is extremely large, being about four times the diameter of the Moon, and is one of the few objects that is better in 7×50 binoculars than in 10×50. The characteristic shape is given to it by intervening clouds of dust.



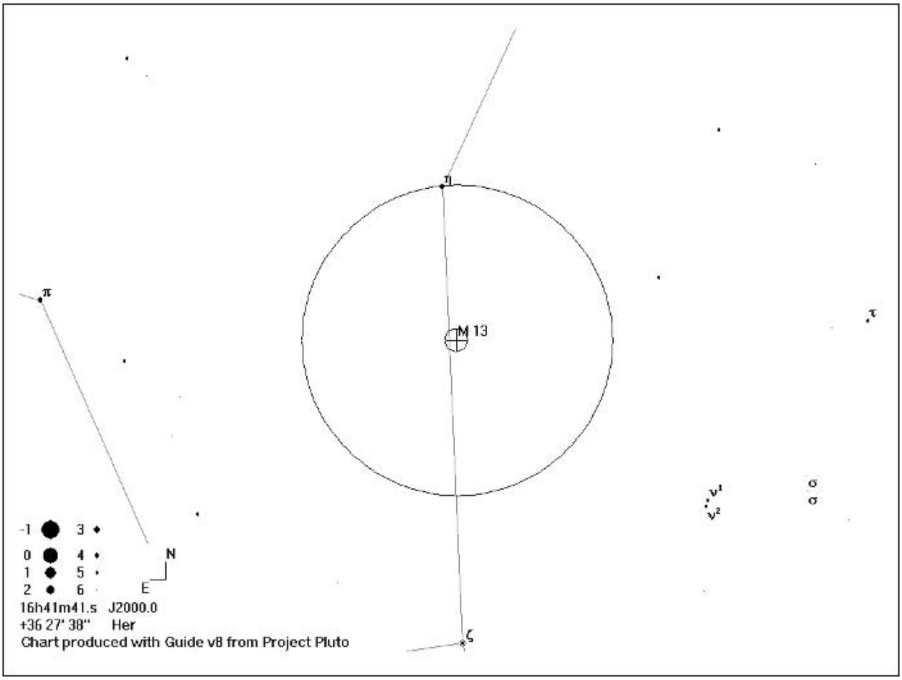
Cygnus: Double Star: β Cyg (*Albireo*)

β Cygni is the star at the head of the Swan. 10×50 binoculars show both members of this superb double star, which are separated by 34 arcsec. The primary (3rd magnitude) is a deep orange (spectral type K) and the fainter (5th magnitude) is a bright sapphire blue (spectral type B). The star is a true binary, with an orbital period of 7,270 years.



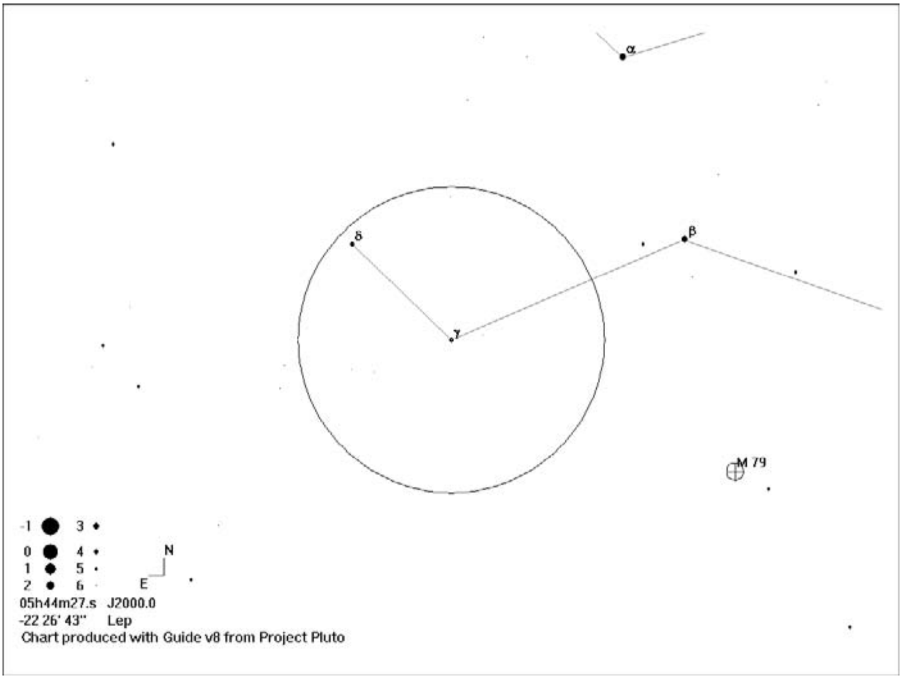
Gemini: Open Cluster: M35 (NGC 2168)

If you place ***η Geminorum*** at the SE edge of a 5-degree field, M35 will be in the center. M35 is a superb open cluster about the size of the Moon and it consists of over 300 stars, of which fifteen or so are resolvable in 10×50 binoculars. Using averted vision if necessary, see if you can glimpse two other open clusters, NGC 2158, which is half a degree to the SE, and the slightly more difficult IC 2157, which is a degree to the ESE.



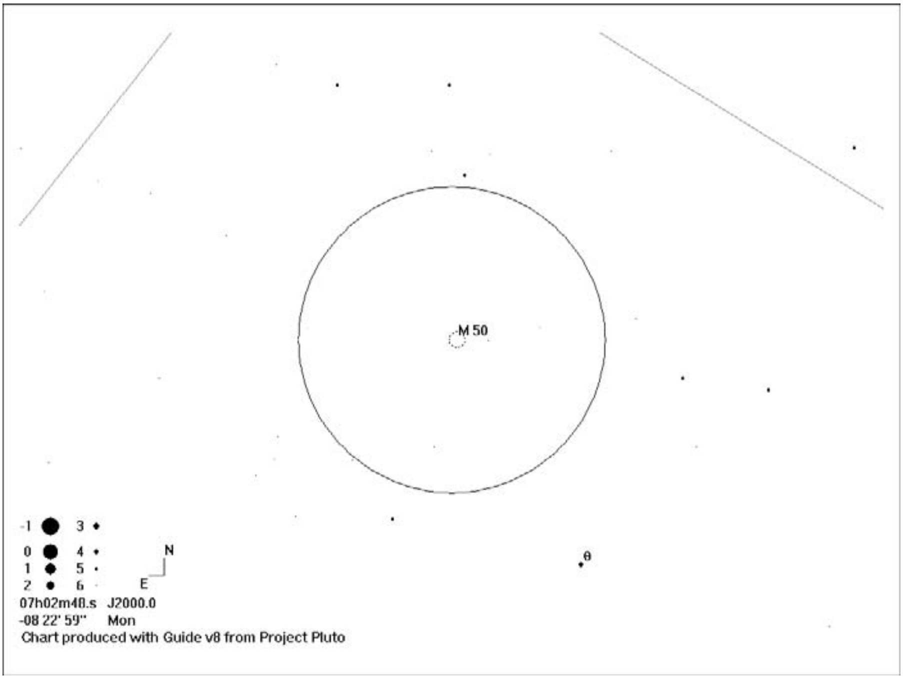
Hercules: Globular Cluster: M13 (NGC 6205)

This is possibly the easiest globular cluster to find, being very bright and lying one-third of the way from η to ***ζ Herculis***. If you place ***η Her*** at the N of a 5-degree field, M13 will lie at the center. Although 10×50 binoculars will not resolve any stars of this cluster, its bright glow should span about 20 arcmin and may be visible to the naked eye, which is how it was spotted by Edmund Halley, who was the first to record it. Using large telescopes, several tens of thousands of stars have been resolved around the periphery of the 145 light-year-wide cluster, but the stars at the core are too close together, separated by 0.1 light years or so, to be resolved.



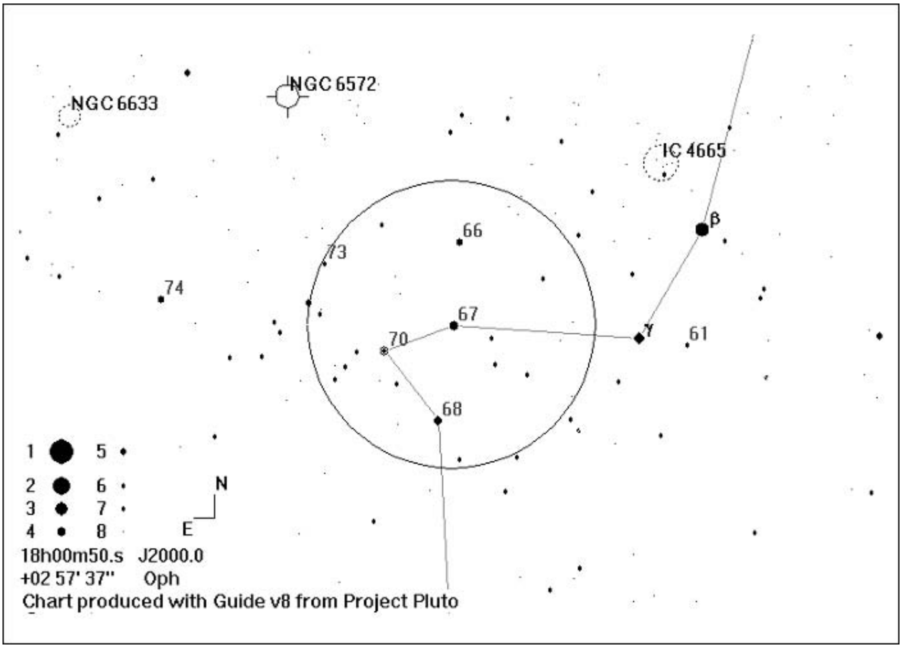
Lepus: Double Star: γ *Leporis*

The star is visible to the naked eye. The members of ***γ Leporis*** are separated by just over 1.5 arcmin. In 10×50 binoculars, the 6th magnitude fainter member is noticeably more orange (spectral type G) than the yellow (spectral type F) 3.6th magnitude primary. Also seek out M79 (NGC 1904) that is a 5-degree field to the SW; it appears as a fuzzy star.



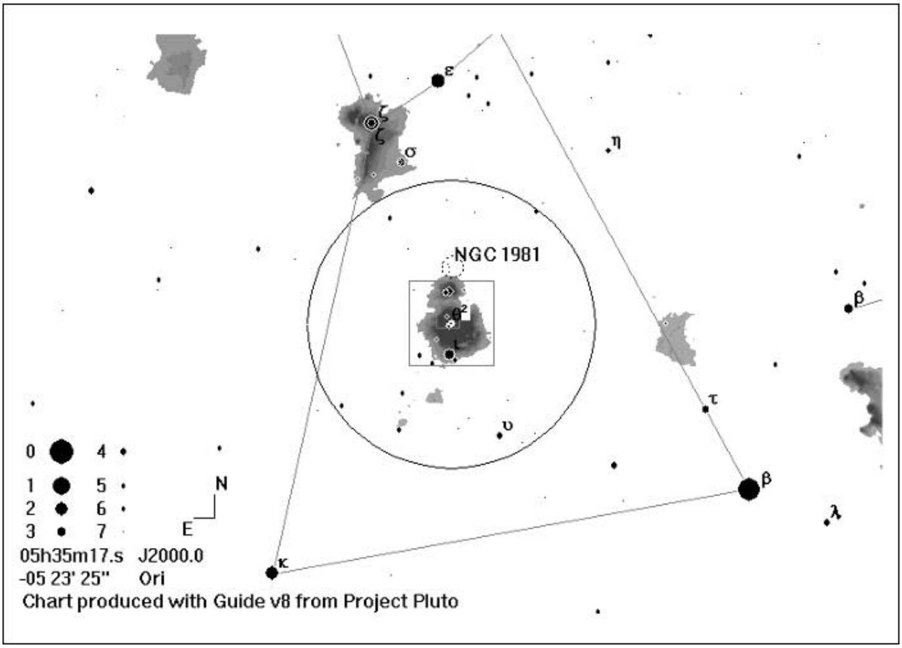
Monoceros: Open Cluster: M50 (NGC 2323)

M50 is situated 4 degrees to the NNE of the 4th magnitude ***θ Canis Majoris.*** M50 is a bright open cluster in which 10×50 binoculars will resolve a few stars against the background glow of the hundred or so stars that comprise it.



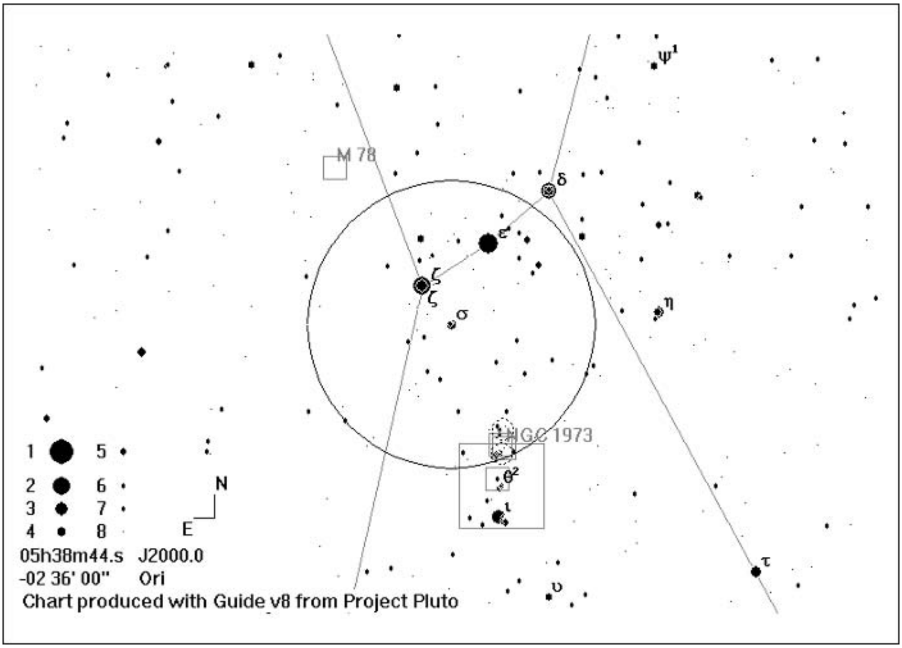
Ophiuchus: Open Cluster: Melotte 186

The region around *67 Ophiuchi* is a sparse open cluster, which is about 4 degrees in diameter and includes *66, 68,* and *70 Oph*. Look also for the smaller and denser open cluster, IC 4665, 4.5 degrees to the NW.



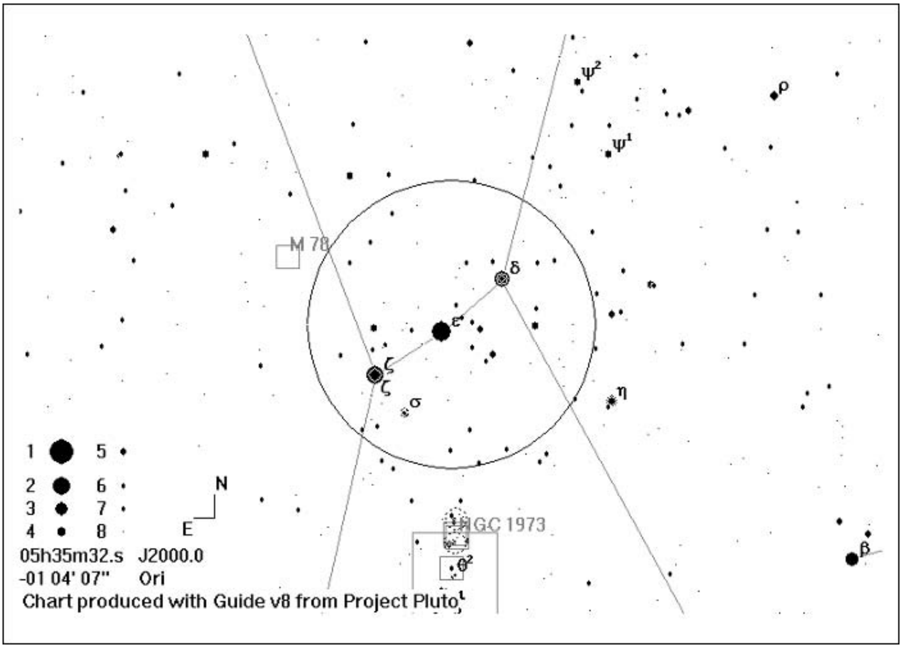
Orion: Nebulosity and Clusters: M42 (NGC 1976), M43 (NGC 1982), NGC 1973, 1975, 1977, and 1980

The Great Nebula in Orion is visible to the naked eye as the fuzzy middle star of the sword. M42 and the connected M43 benefit greatly from mounted binoculars. Even in small binoculars, a wealth of detail becomes apparent, especially if you use averted vision. Give it time: the longer you look, the more you see of the nebulosity and the cluster of stars whose light it reflects. If you have larger binoculars of higher magnification, see if you can resolve the *Trapezium* (***θ Orionis***) into separate stars. Binoculars will show that the other two "stars" of the sword are also clusters. The northern one still has some reflection nebulosity (NGC 1973, 1975, and 1977) that may hint of its presence on dark, transparent nights, but the older southern cluster (NGC 1980) has none at all. These two clusters, which are older than those associated with the star-birth region of the Great Nebula, indicate the fate of the Great Nebula itself.



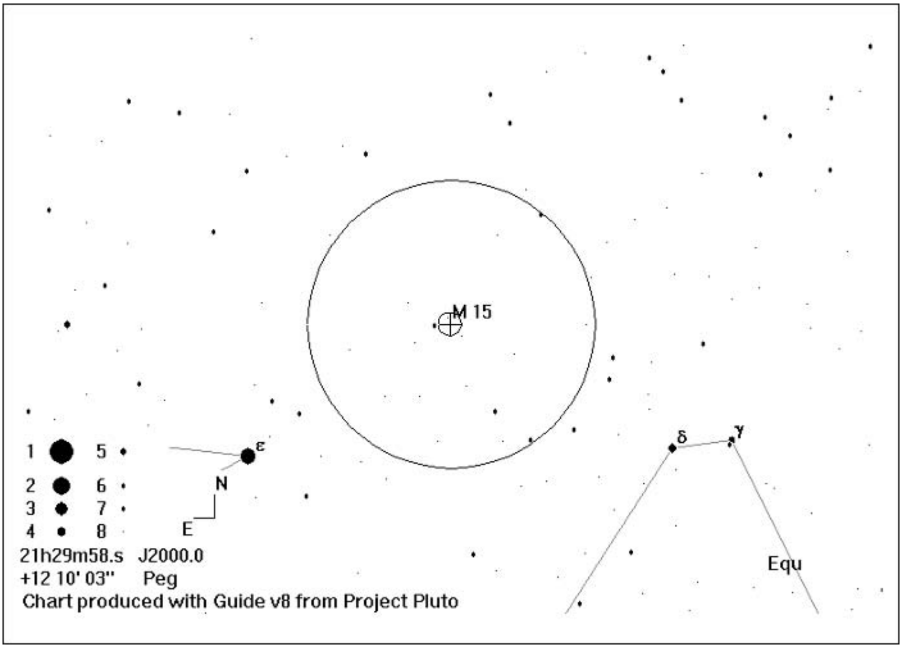
Orion: Multple Star: σ Orionis

σ Orionis is visible to the naked eye as a 4th magnitude star about a degree to the SE of the easternmost belt star (***ζ Ori***, *Alnitak*). ***σ Ori*** is, in fact, a multiple star consisting of six components. You should easily be able to split it into two components with a 10×50 binocular and see the blue 6th magnitude E component that is 43 arcsec from the white primary, but more magnification will be needed to separate the two additional components. The final visual split requires the high power of a very good telescope. The presence of a sixth member is inferred from spectroscopic radial velocity measurements.



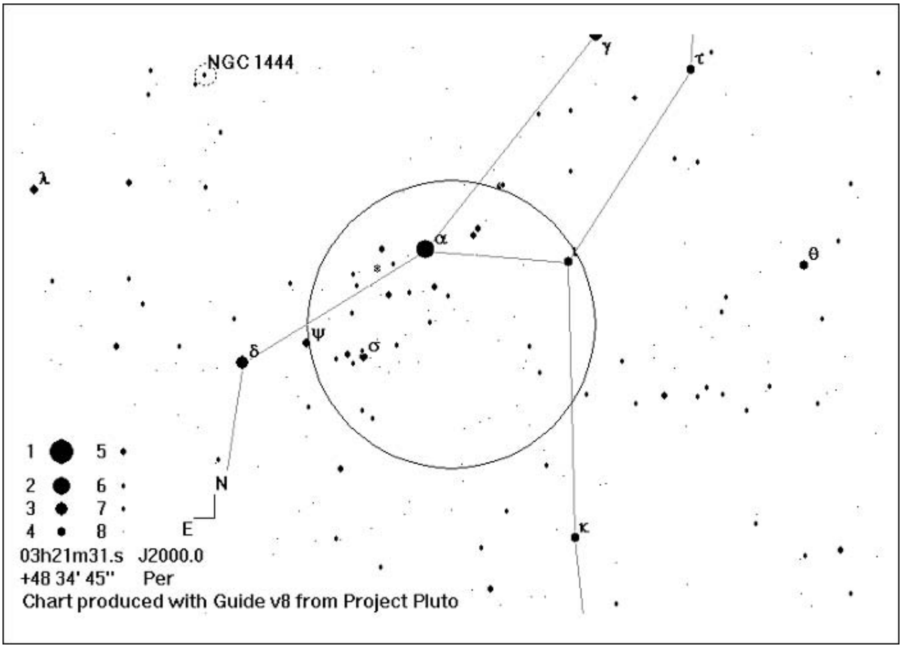
Orion: Open Cluster: Collinder 70

Collinder 70 is the cluster that almost everybody has seen and yet nobody knows! It is the cluster that includes the stars of Orion's Belt and ***σ Ori*** (above). 10×50 binoculars will reveal many tens of stars in the 3-degree expanse of the cluster, making this one of several objects that is significantly better in medium binoculars than in most telescopes.



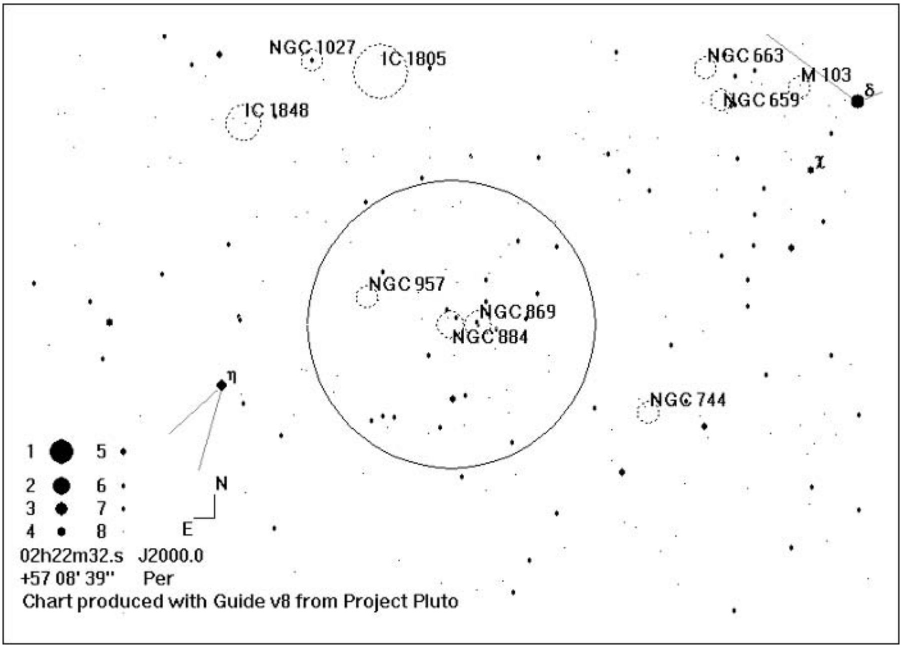
Pegasus: Globular Cluster: M15 (NGC 7078)

M15 is a little over 4 degrees to the NW of the 2nd magnitude ***ε Pegasi*** (*Enif*). Although M15 is small, with about half the apparent size of the better-known M13, it is very bright and for this reason is one of the better globular clusters for small binoculars. While you are observing in that region, go back to ***ε Peg***, which is a binocular double; the 8.6th magnitude secondary is 2.4 arcmin from the yellowish primary, in the direction of M15.



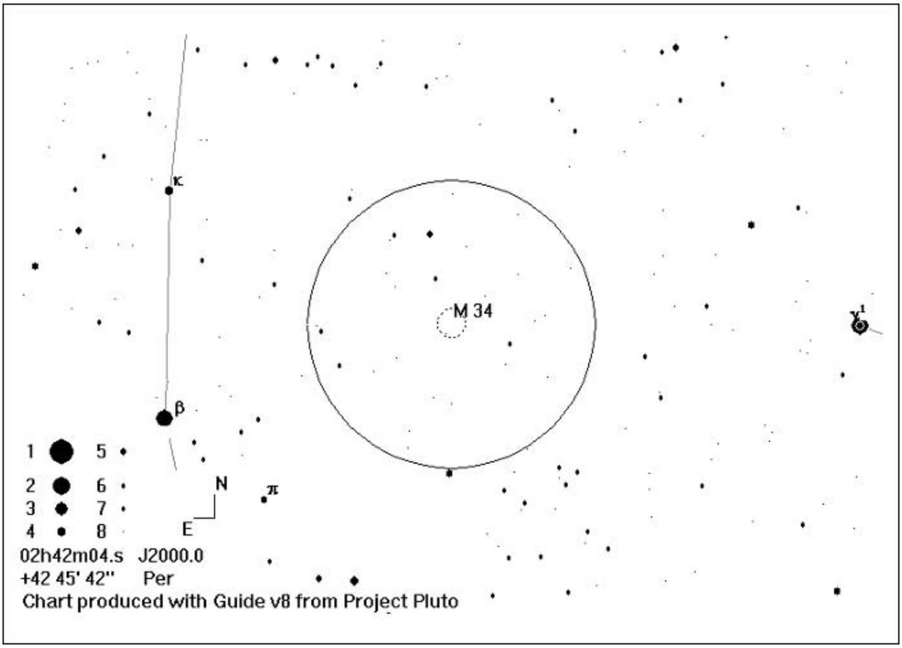
Perseus: Open Cluster: Melotte 20 (Collinder 39, the *Alpha Persei Moving Cluster*)

Melotte 20 is the cluster of stars, many of which are visible to the naked eye, around ***α Persei*** (*Mirfak*). These stars are mostly very bluish (spectral types O and B), indicating their relative youth (a few tens of millions of years). This is an ideal object for small and medium binoculars, which are able to encompass most or all of the cluster in their field of view.



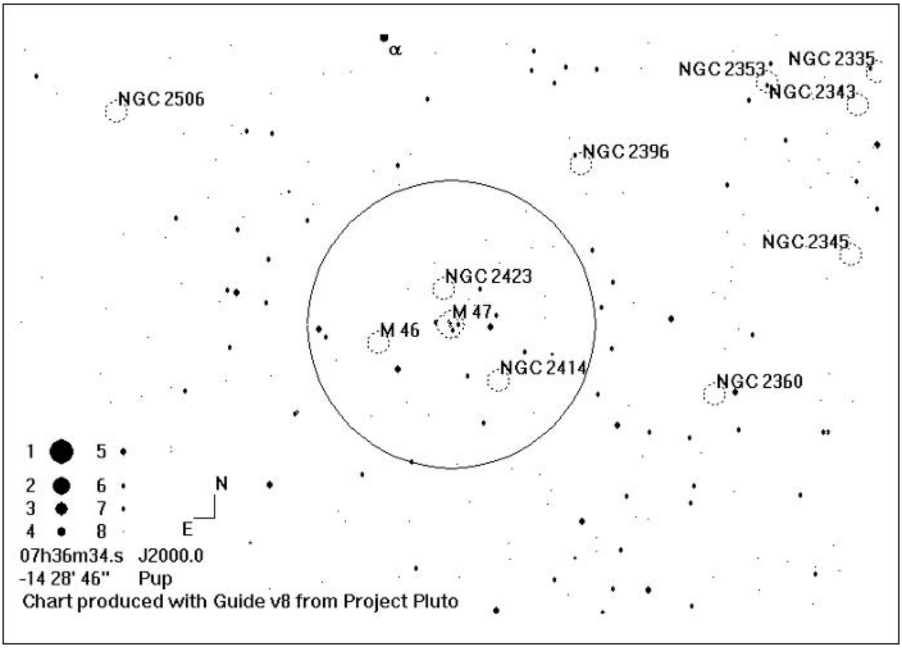
Perseus: Open Clusters: NGC 884 and NGC 869 (the *Double Cluster*)

The clusters are often visible to the naked eye but, if not, follow a line from **γ** to ***δ Cassiopeiae*** for a distance beyond ***δ Cas*** to one and a half times the distance between the stars. This pair of clusters in the sword handle of Perseus is a superb target, even with relatively small binoculars. There are several orange-red stars and these, combined with the varying brightness of the other stars, contrive to give it a three-dimensional appearance. As an aside, if our Sun was at the same distance as the *Double Cluster*, it would be too faint to be seen in 10×50 binoculars. It is worth scanning the region around the *Double Cluster*, as it is very rich in open clusters. The chain of stars to the NNW, for example, leads to ***Stock 2***, otherwise known as the *Muscleman Cluster*, on the border of Perseus and Cassiopeia.



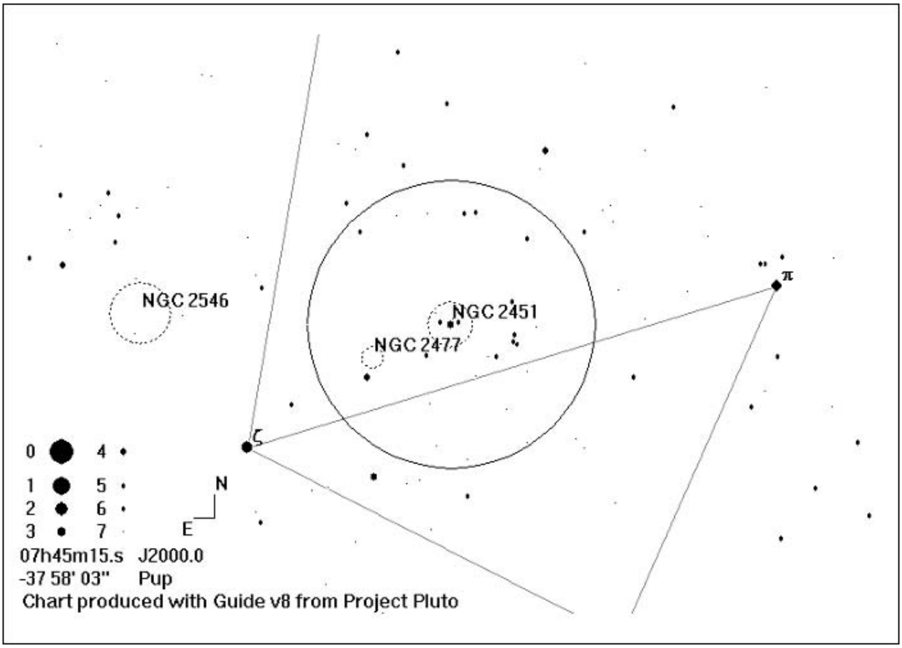
Perseus: Open Cluster: M34 (NGC 1039)

M34 is a degree NE of the midpoint of a line joining ***β Persei*** (*Algol*) to ***γ Andromedae*** (*Almaak*). It is visible to the naked eye under ideal sky conditions. This is a superb cluster for binoculars of any size, showing a dozen or more stars in a 10×50. When you observe in this region, you could also ascertain the magnitude of the ***β Per***, one of the more famous variable stars; it is an eclipsing binary star. The name *Algol* comes from the Arabic *Ras al Ghul*, meaning the demon's head. The ghoul or demon in question is Medusa.



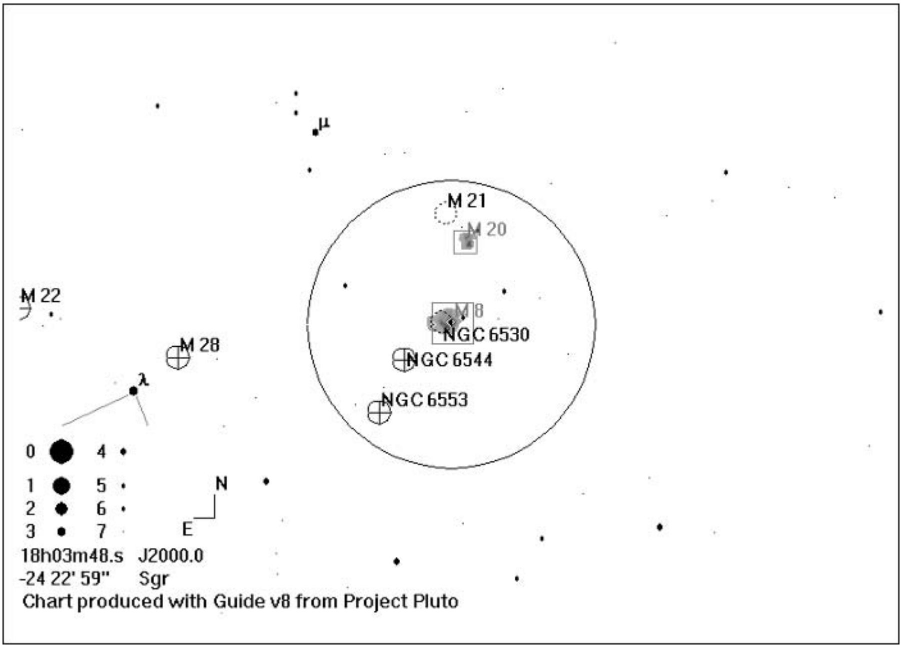
Puppis: Open Clusters: M46 (NGC 2437) and M47 (NGC 2422)

This pair of clusters lies 5 degrees to the south of α Monocerotis; alternatively, if you cannot identify α Mon, you can find the clusters by panning two and a half 5-degree fields E, then half a 5-degree field N from α CMa (*Sirius*). M46 and M47 offer, in the same field of view, a comparison between the binocular appearances of open clusters. M46 is far more compact and you may not be able to resolve any stars in 10×50 binoculars. On the other hand, M47 is much looser and over half a dozen stars can be easily resolved with the 10×50 s.



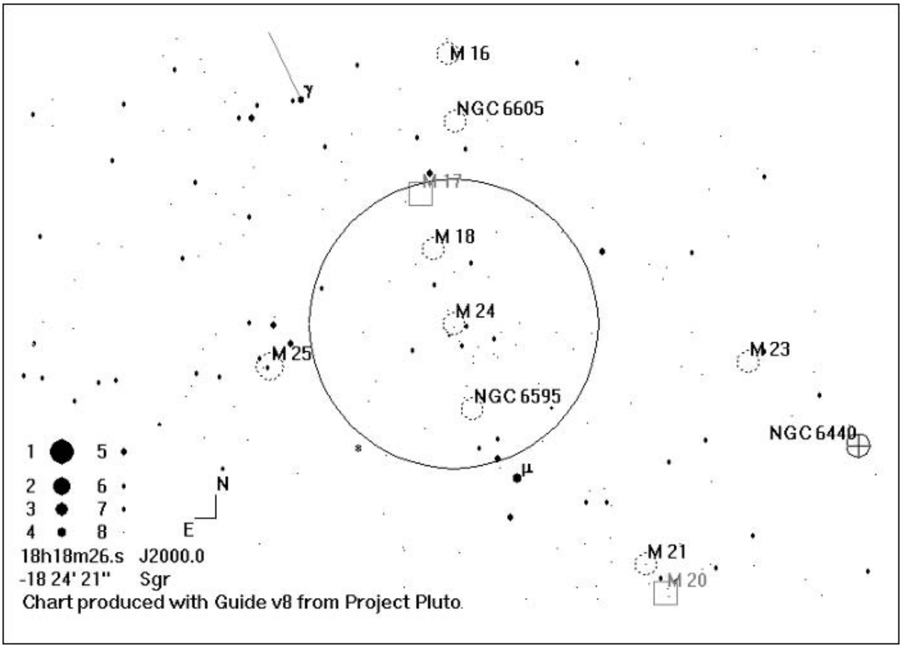
Puppis: Open Cluster: NGC 2451

NGC 2451 is 1 degree N of the center of a line drawn from *ζ Puppis* to *π Pup*. NGC 2451 is quite a sparse cluster with several relatively bright stars, which makes it a good object for binocular observation. Adding to the attractiveness of the cluster is the fact that the brightest star is orange and the surrounding bright stars are brilliant white. Six stars are particularly easy to see and a dozen or so are visible in medium binoculars under good conditions.



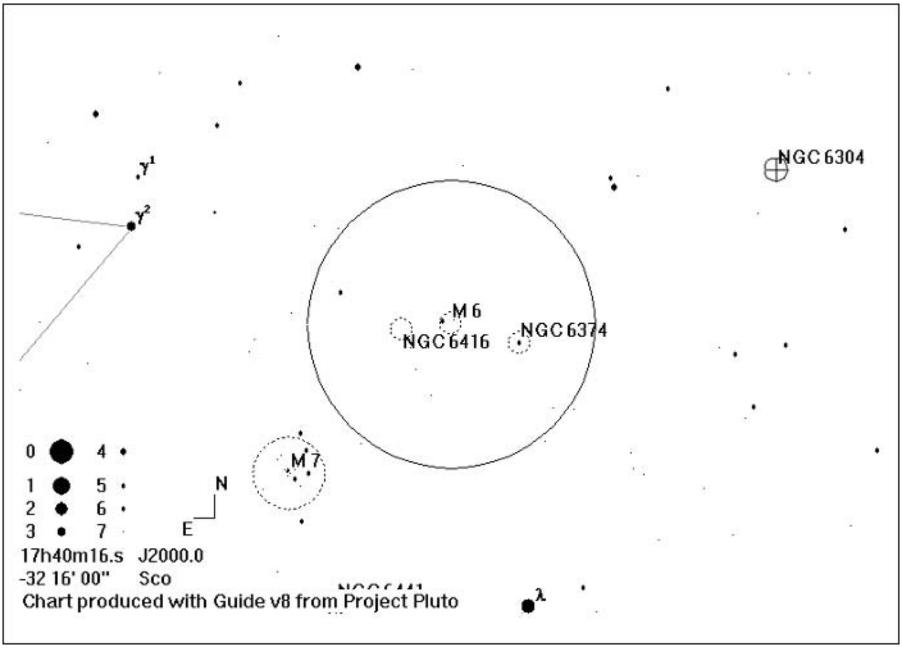
Sagittarius: Open Cluster and Nebulosity: NGC 6530 and M8 (NGC 6523, the *Lagoon Nebula*)

M8 is just over 5 degrees WNW of *λ Sagittarii*, the peak of the lid of the Sagittarius teapot asterism. The *Lagoon Nebula* is visible to the naked eye if the sky is reasonably dark and transparent. Even with compact binoculars, this stunning object will show a few stars of the associated open cluster (NGC 6530), and 10×50 s will show more than half a dozen stars and some of the surrounding nebulosity (NGC 6523) that they illuminate, as well as the denser cluster of stars to the E of the main nebulosity. The nebulosity benefits greatly from averted vision. To the N, and encompassed by the same 5-degree field of view, is the smaller and fainter M20 (NGC6514), the *Trifid Nebula*. This entire region of sky is worth scanning for other "fuzzy blobs," of which there are many that are visible in binoculars of all sizes.



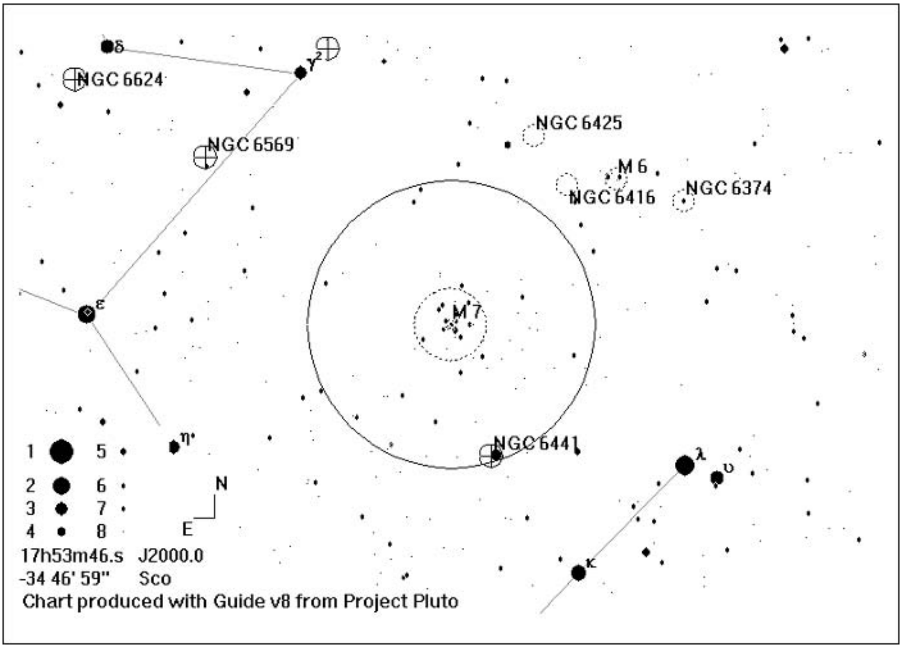
Sagittarius: Star Cloud: M24

The Sagittarius Star Cloud, M24, lies slightly more than halfway from *γ Sgr* to *μ Sgr*. M24 is a bright patch of light that is easily visible to the naked eye and, from southern England, has even been mistaken for a cloud on the horizon! Even compact binoculars begin to reveal detail, and it is a remarkably good object to view in 10×50 s. Look for the open cluster NGC 6603 (an object to which the designation M24 is often falsely ascribed) as a brighter patch in the NE of the cloud.



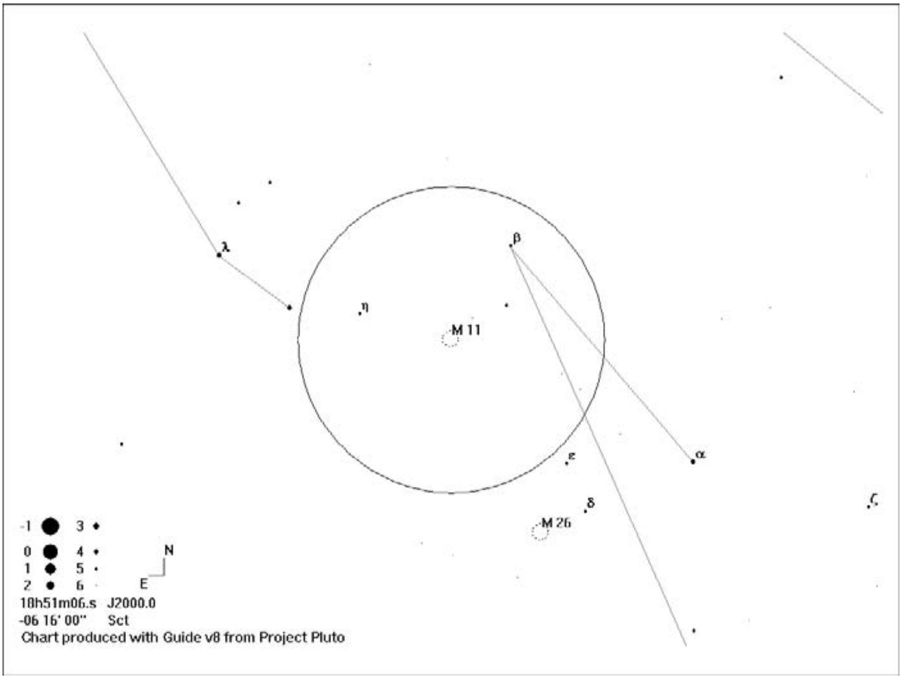
Scorpius: Open Cluster: M6 (NGC 6405, the *Butterfly Cluster*)

M6 is easily visible to the naked eye one 5-degree field N of λ *Scorpii*. While not as impressive as its neighbour, M7, M6 is a fine object in 10×50 binoculars, with half a dozen or so of the brighter stars being resolved. I find that slightly more magnification is necessary to enable the butterfly shape, from which it acquires its common name, to become apparent.



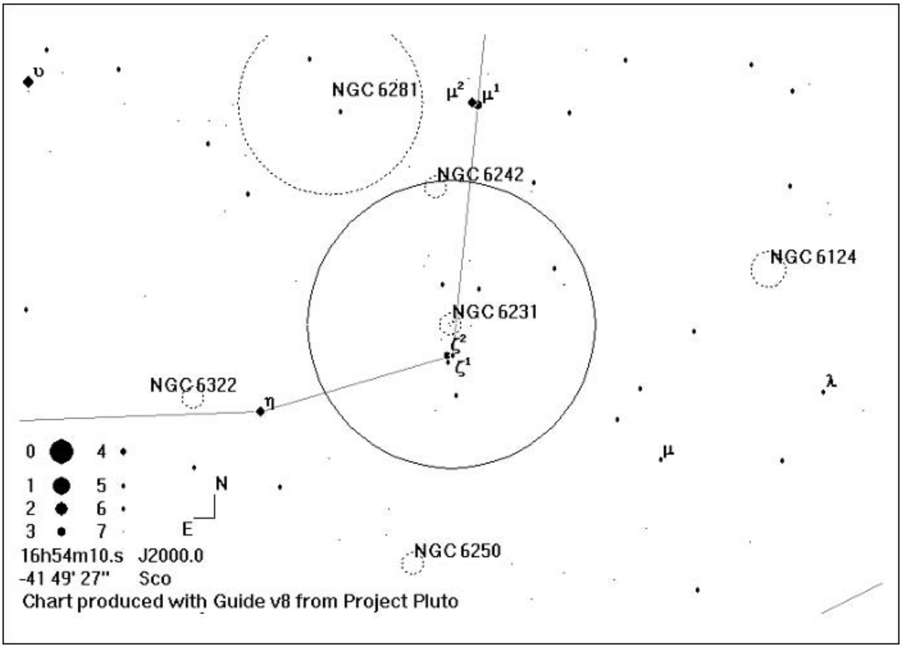
Scorpius: Open Cluster: *M7* (NGC 6475, *Ptolemy's Cluster*)

This cluster, which is visible to the naked eye as a fuzzy patch against the background Milky Way, is just over 4.5 degrees from *λ Sco* (*Shaula*), the scorpion's stinger; to the medieval Arabs it was known as the scorpion's venom. M7 is a very large, bright cluster, about two and a half times the diameter of the Moon, in which binoculars of any size will reveal individual stars, about nine of which are visible in 10×50 binoculars from a reasonably dark site, up to a dozen if the site is very dark. Greater magnification reveals more stars, about eighty of which are 10th magnitude or brighter. This fine cluster derives its common name from the observation of it by Ptolemy of Alexandria in the 1st century A.D.



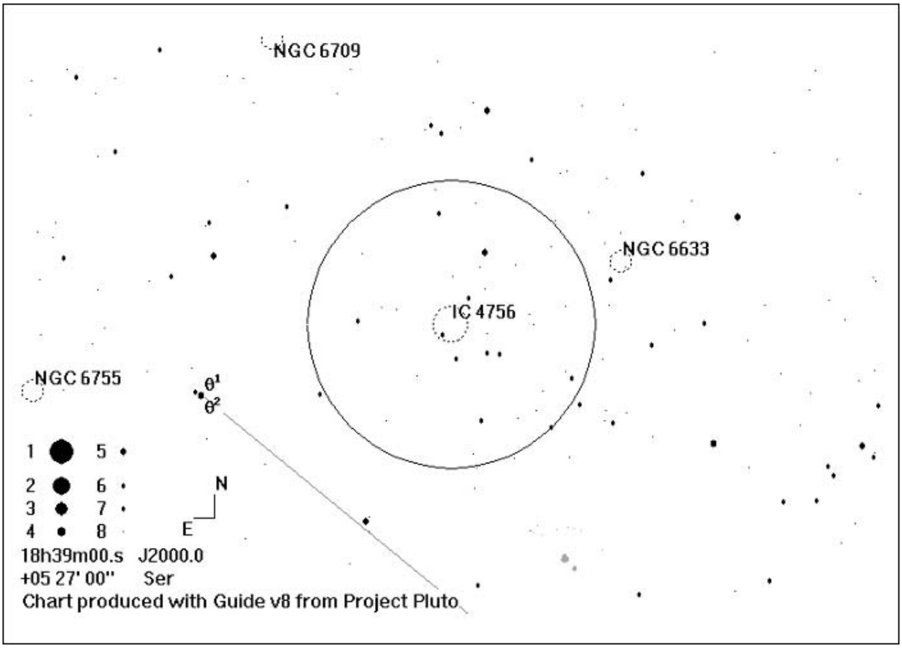
Scutum: Open Cluster: M11 (NGC 6705, *Wild Duck Cluster*)

M11 is 4 degrees to the WSW of the 3rd magnitude *λ Aquilae*. In 10×50 binoculars, the cluster is seen as a bright wedge-shaped glow of light. Although binoculars will not resolve the V-shape of brighter stars that gives this cluster of a thousand or so stars its common name, the cluster is still one of the better objects for this size of binoculars. Also worth enjoying in this region of sky is the denser part of the Milky Way that forms the *Scutum Star Cloud* as a backdrop to this cluster.



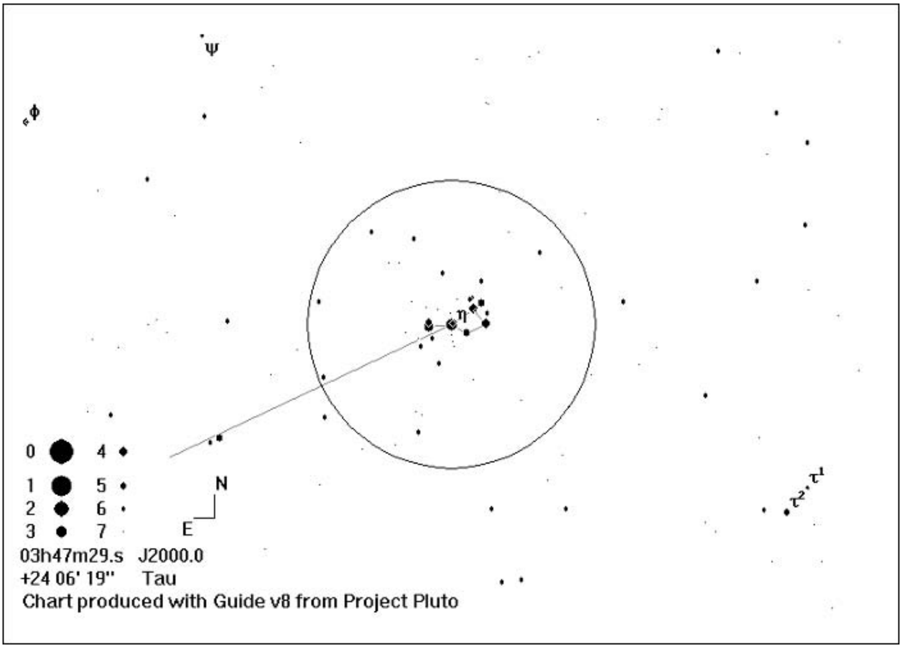
Scorpius: Open Cluster: NGC 6231

NGC 6231 is visible to the naked eye and lies half a degree north of *ζ Scorpii*. This often-overlooked cluster is a fine object in 10×50 binoculars. It is small, with a diameter about half that of the Moon, but rich in brighter stars, several of which are resolved in small and medium-sized binoculars.



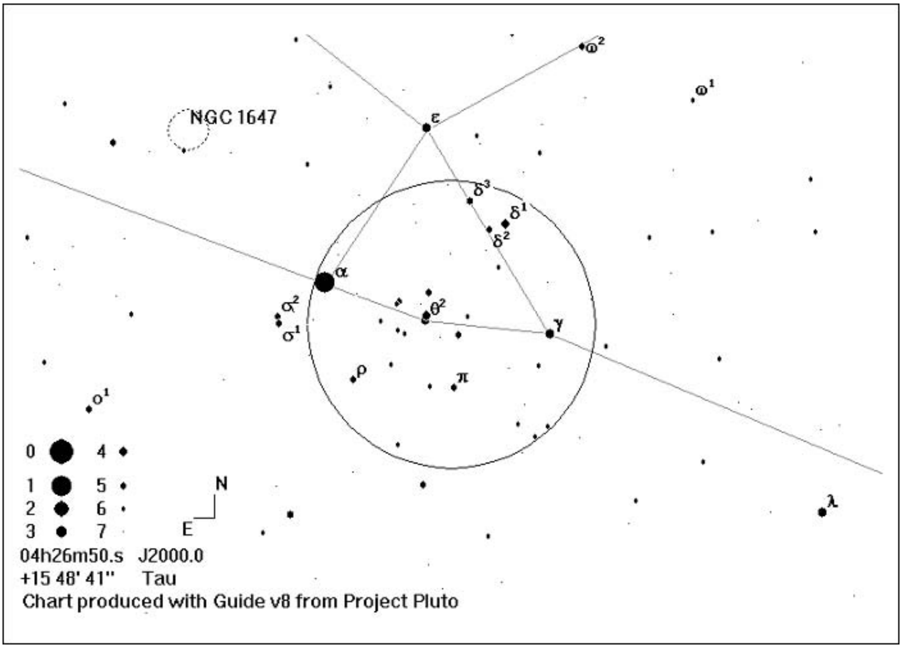
Serpens (Cauda): Open Cluster: IC 4756

IC 4756 is 4.5 degrees WNW of *θ Serpentis*. This delightful cluster, which is somewhat larger than the Moon in extent, has over a dozen members visible against a fuzzy backdrop in 10×50 binoculars. Also in the region is NGC 6633, which is smaller and less bright, but still has resolvable stars in medium-sized binoculars.



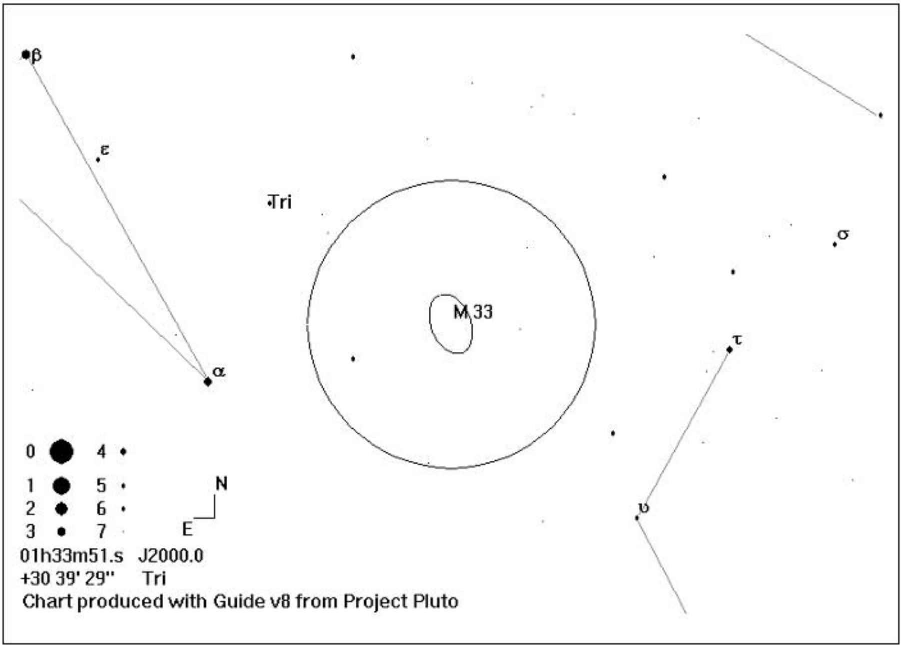
Taurus: Open Cluster: M45 (the *Pleiades*)

M45 is possibly the most stunning binocular object, one which I never fail to return to each autumn. Focusing binoculars onto it is akin to opening a box of diamonds as more of its blue-white members are revealed. Even in 10×50 binoculars it is easy to lose count of them, with several tens of stars being easily visible. In a very dark sky, good quality binoculars will give hints of the nebulosity surrounding *Merope* if you use averted vision. Larger binoculars will show more of the 300 or so stars that comprise it.



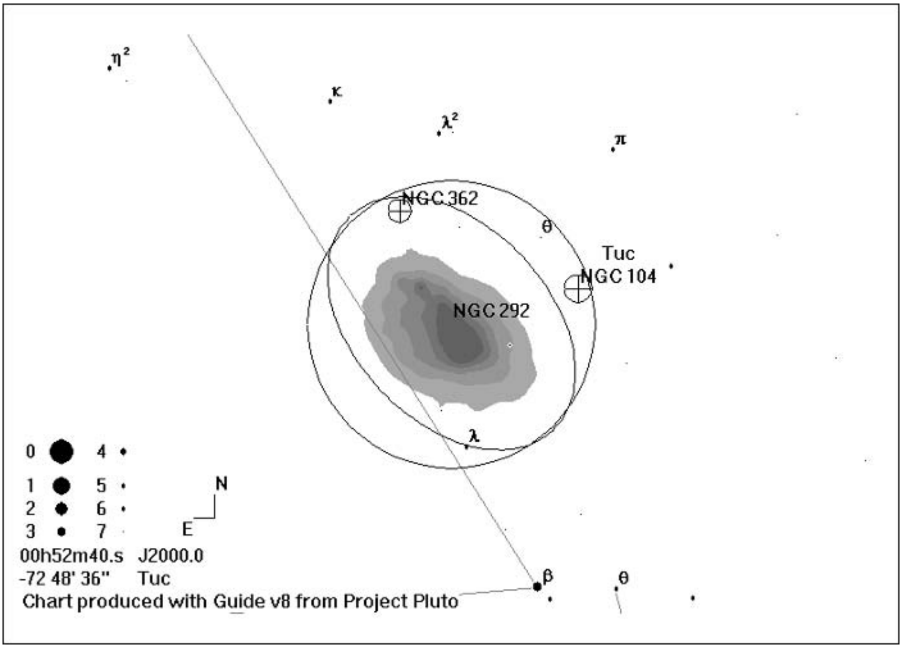
Taurus: Open Cluster: Melotte 25 (the *Hyades)*

The Hyades is the large cluster adjacent to α *Tauri* (*Aldebaran*), which is not itself a member. This cluster, the second closest to us at a distance of about 150 light years, overflows a 5 degree field of view. For this reason, it is far better viewed in binoculars than it is in a telescope. The brighter stars form the V-shape with which we are familiar as the head of the bull. The Hyades lies at the approximate center of a larger grouping of stars, the Taurus Moving Cluster, some members of which are over 45 degrees from the Hyades. Several tens of stars are revealed by 10×50 binoculars. Also worth a look is the cluster NGC 1647, which is just to the NE.



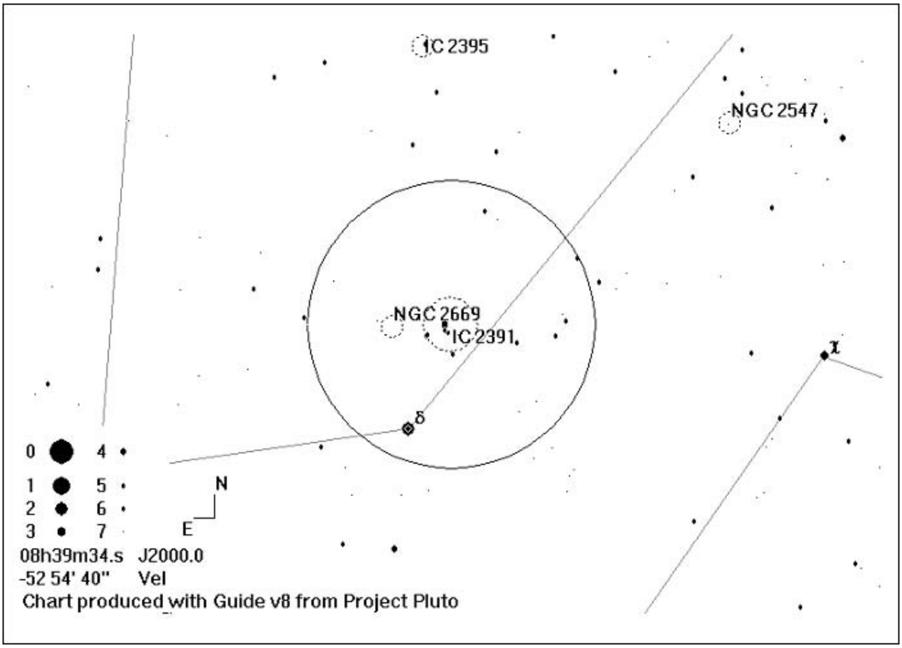
Triangulum: Galaxy: M33 (NGC 598, the *Pinwheel Galaxy*)

M33 is located a little over 4 degrees from α *Trianguli* in the direction of β *Andromedae*. M33, which has a high-integrated magnitude (and can be visible to the naked eye under ideal conditions), is a large object with a low surface brightness. It therefore requires a dark sky and low magnification, making it easier to find and see in 10×50 binoculars than in small telescopes.



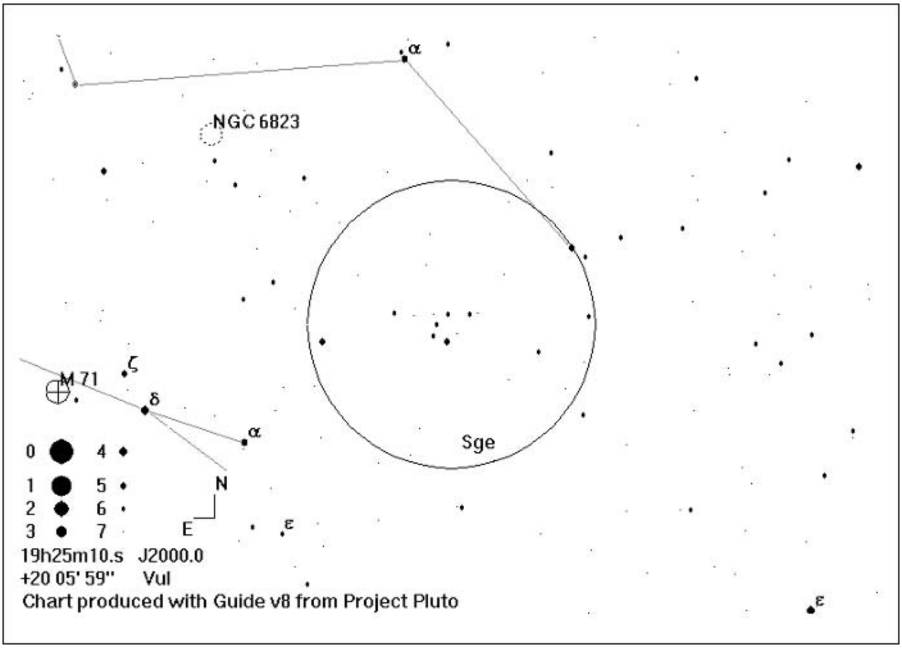
Tucana: Galaxy: NGC 292 (*Small Magellanic Cloud*)

The *Small Magellanic Cloud* is easily visible to the naked eye just over 4.5 degrees NNE of β *Hydri*. With a diameter of about 3 degrees, the *Small Magellanic Cloud* is neatly framed in a 5° field of view. It is one of the satellites to our own galaxy, at a distance of 190,000 light years. It was through studies of *Cepheid Variables* in the *Small Magellanic Cloud* that Henrietta Leavitt established their period-luminosity relationship, thus enabling their use as standard candles for measuring distances. Also visible to the naked eye is the bright globular cluster *47 Tucanae*, which is described among the 100-mm objects.



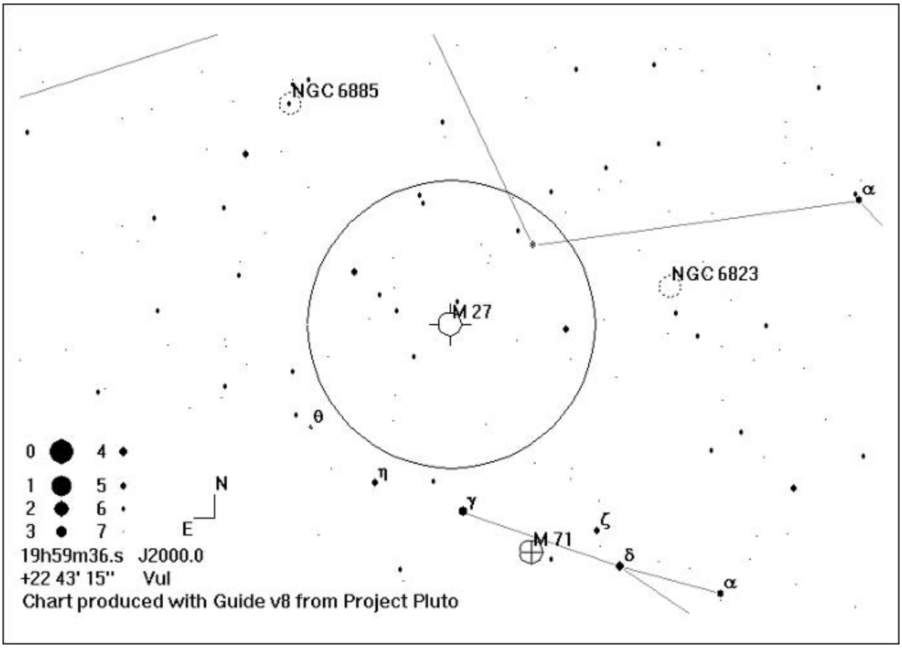
Vela: Open Cluster: IC 2391 (the *Omicron Velorum Cluster*)

IC 2391 surrounds *o Velorum*, which is 2 degrees NNW of ***δ Vel***. IC 2391 is a fairly sparse cluster, about twice the diameter of the Moon, in which ten or so stars resolve in 10×50 binoculars.



Vulpecula: Asterism: (Collinder 399, *Brocchi's Cluster*, the *Coathanger*)

Cr 399 lies 5 degrees S of *α Vulpeculae* and 4 degrees NW of *α Sagittae*. Even small binoculars will reveal the ten stars that give this asterism its common name. Because of this shape, the *Coathanger* makes a good star-party piece, with its 1.5-degree span being neatly framed within a 5-degree field of view for sufficiently long periods to permit several consecutive observations in mounted binoculars.



Vulpecula: Planetary Nebula: M27 (NGC 6853, the *Dumbell Nebula*)

If you place γ *Sagittae* at the S of a 5-degree field of view, M27 will be just N of center. Although the *Dumbell* is not the only planetary nebula that is visible in 10×50 binoculars, it is significantly easier to see than any other, but will need a larger instrument with more magnification to show some structure. The progenitor star is far too faint to be seen, even in large binoculars.

Notes

1. Burnham, R. *Burnham's Celestial Handbook*, Vol. 1, New York: Dover Publications, 1978, p. 188.
2. Levy, D. *Observing Variable Stars*, Cambridge: Cambridge University Press, 1989, p. 48.

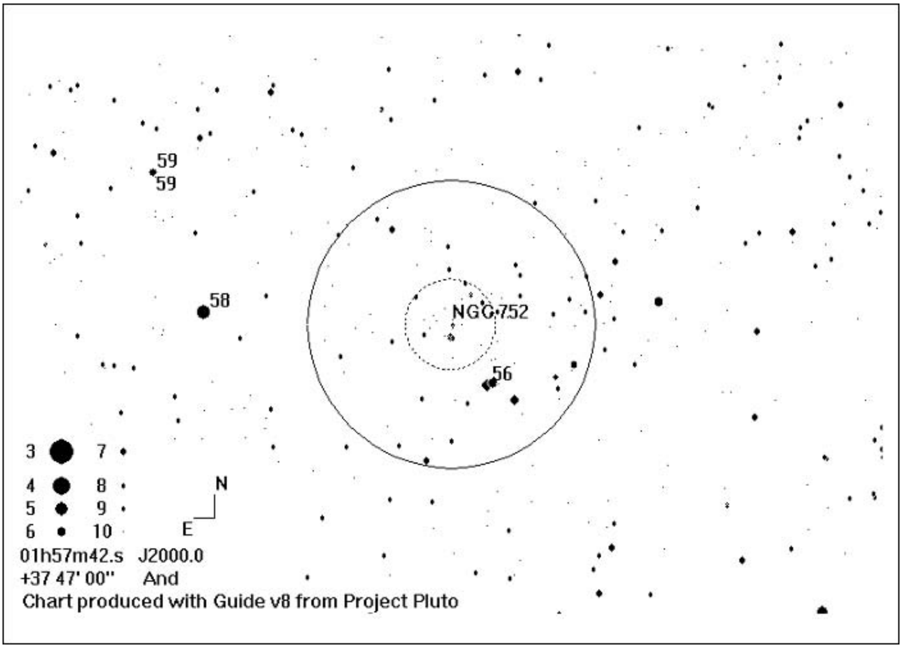
CHAPTER TEN

100 Deep Sky Objects for 100 mm Binoculars

The objects in this chapter are visible with large binoculars, although some are visible in much smaller instruments, with far less detail (or none at all) being shown. The larger aperture enables greater magnification, and together these factors enable many more fainter objects to be seen. Particular beneficiaries of this are galaxies and planetary nebulae. I usually use my 100-mm binoculars with ×37 eyepieces. A finder of some description, particularly a reflex finder with circles, is invaluable for star-hopping to objects. For objects that I can identify in smaller binoculars, I tend to use my 10×42 binoculars to locate the object, and center the finder on that location in the sky.

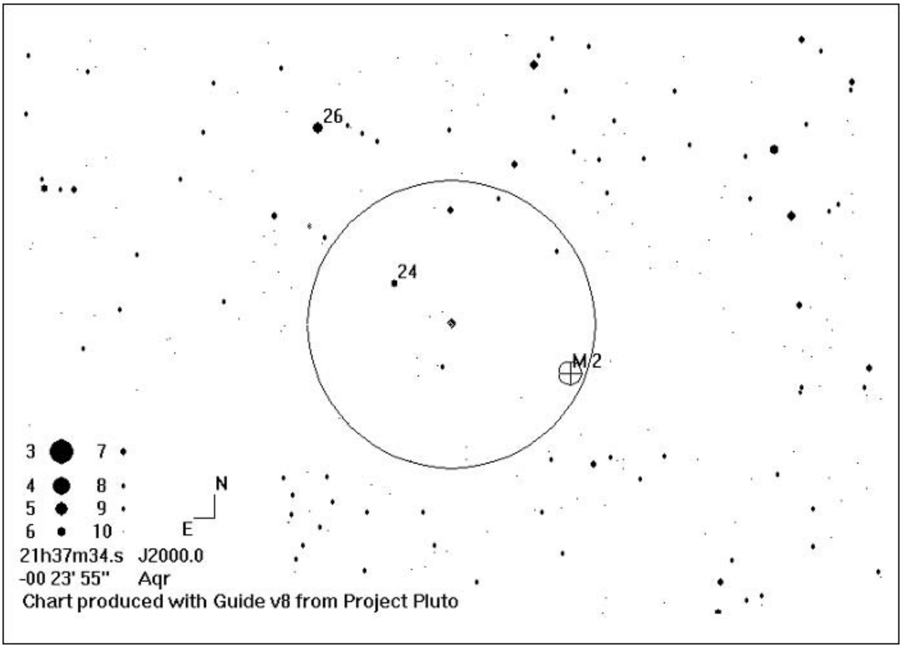
Because larger binoculars tend to be mounted, it is easier to use filters on them (Chapter seven), making otherwise difficult objects a little easier.

The charts (listed in alphabetical order by constellation) in this chapter show a 2.5-degree field of view circle, and star-hopping information is based on this field unless otherwise stated. The stars are plotted to magnitude 10. North is up. The J2000 coordinates are shown.



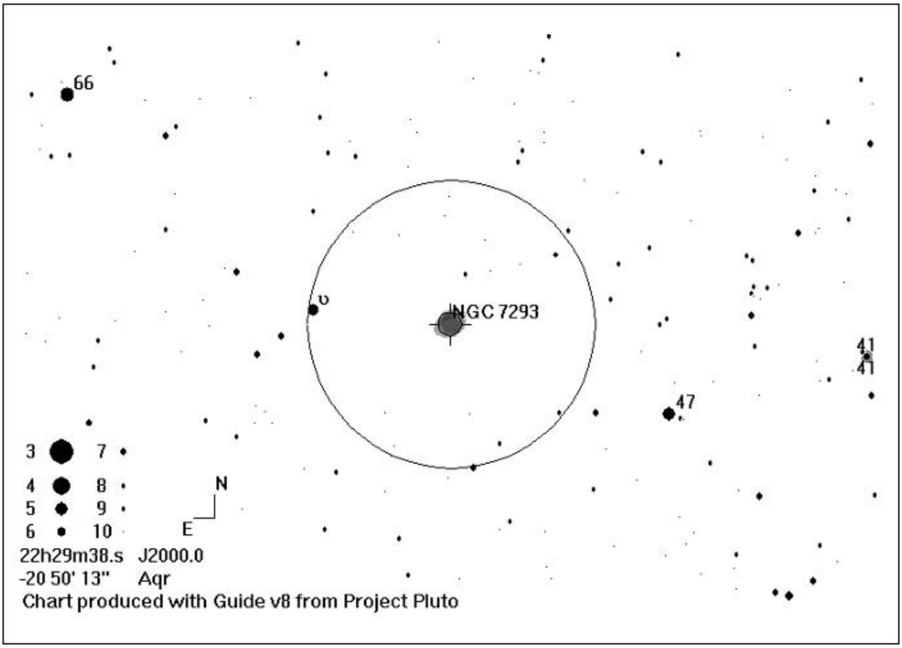
Andromeda: Open Cluster and Double Star: NGC 752 and 56 And

From *β Tri* hop 3 degrees N to *58 And*, then 2 degrees W to NGC 752, which is just NW of the double star, *56 And*. Although this cluster is visible in smaller binoculars and is often included in lists for them, it is significantly better in larger instruments. Several tens of stars (depending on sky conditions) become visible with 37×100 binoculars. *56 And* is a beautiful pair of 6th magnitude deep yellow stars separated by about 3 arcmin.



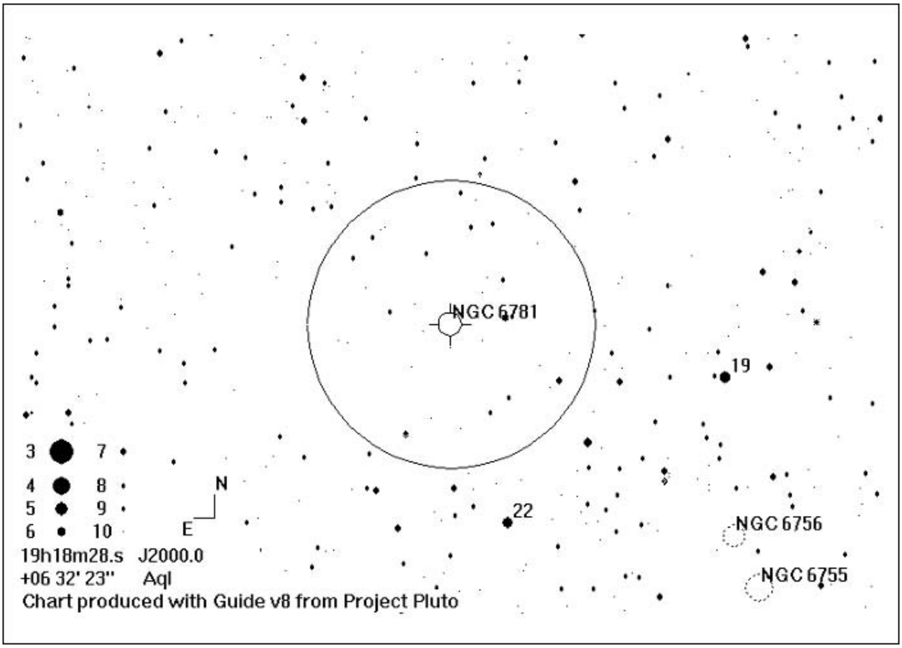
Aquarius: Double Star: Struve 2809

First locate the globular cluster M2, which is about 5 degrees N of the 3rd manitude *β Aqr (Sadalsund)*. *Struve 2809* is the nearer of the two 6th magnitude stars that form a line to the NE. This is a close pairing (31 arcsec) which can be a challenge. The stars are 6th and 9th magnitude respectively.



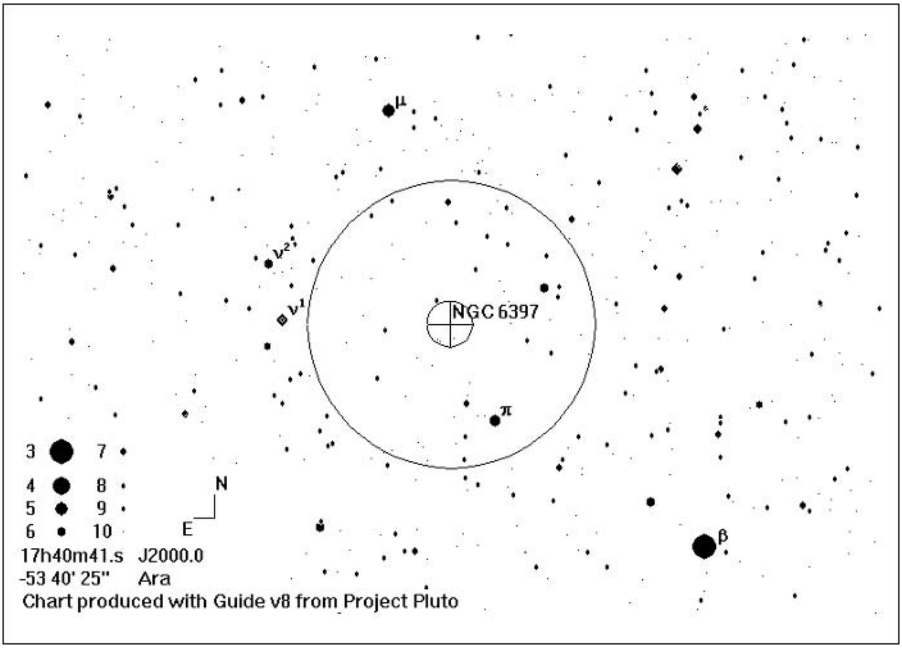
Aquarius: Planetary Nebula: NGC 7293 (the *Helix Nebula*)

Identify the 3.6th magnitude *88 Aqr* and place it on the S edge of the field or the finder ring. Sweep four fields (9.25 degrees) to the W and NGC 7293 should appear in the eyepiece. With an integrated magnitude of 6.5, the *Helix* seems as if it should be an easy object to spot. However, it is a large (about the size of the Moon) object with low surface brightness and it requires a dark sky or a UHC or O-III filter. In 100-mm binoculars I find it slightly easier to find at ×20 than at ×37. The middle of this nebula is noticeably darker than the periphery at both magnifications, particularly with a filter.



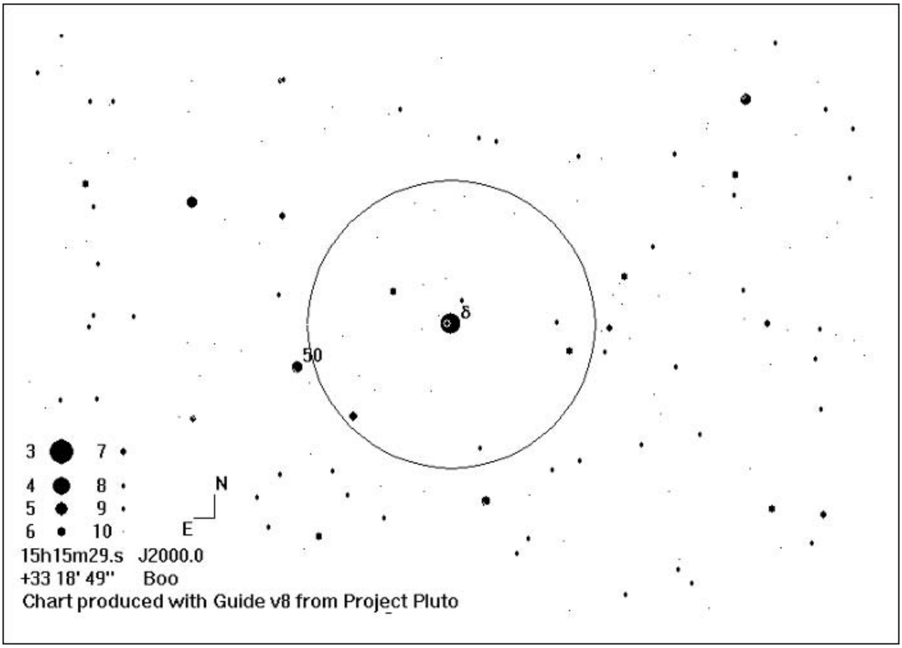
Aquila: Planetary Nebula: NGC 6781

To locate NGC 6781, begin at *δ Aql* and hop two fields in the direction of *ζ Aql*. NGC 6781 will be near the center of the second field. This 12th magnitude planetary is possibly the most challenging object in this list and requires superb sky conditions and an experienced observer. Were its position not so easy to locate, it would have no place here at all. It is considerably easier to see and identify if you use a UHC or O-III filter. With such a filter and averted vision, it appears very slightly elongated at ×37.



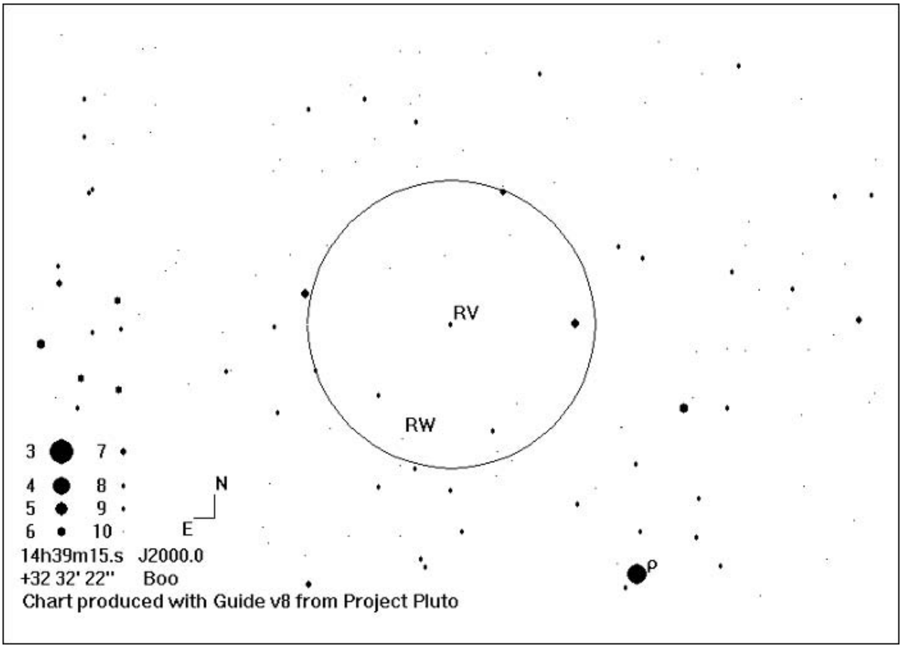
Ara: Globular Cluster: NGC 6397

One field NE of *β Ara* is the 5th magnitude *π Ara*. Place π near the S of the field and the globular should be just off center. The periphery of this large, bright globular cluster begins to resolve at ×37. It is one of the nearest globular clusters.



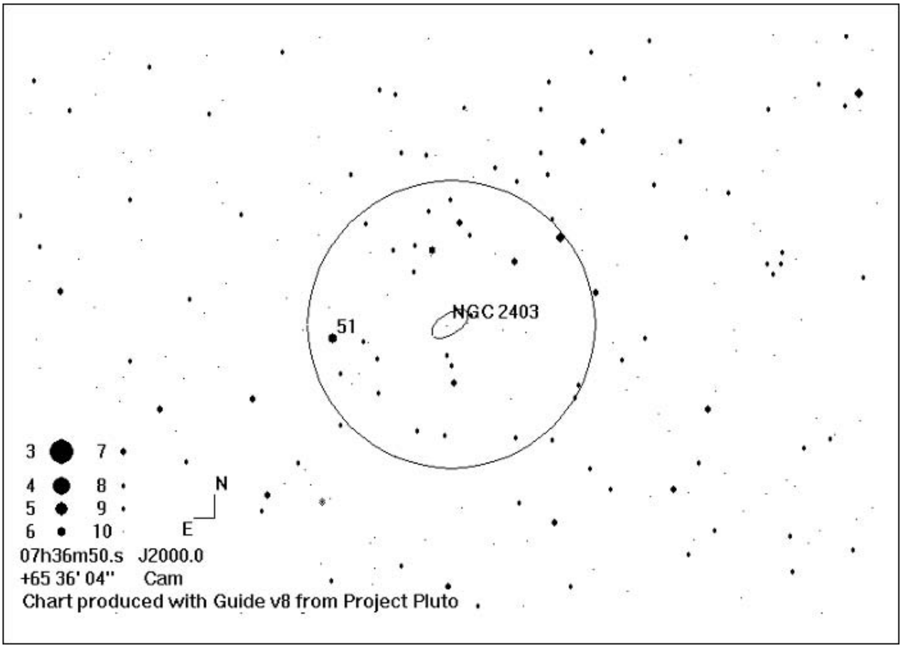
Boötes: Multiple Stars: δ Boötis and 50 Boötis

The coordinates are for *δ Boo*. *δ Boo* is a double star. The yellow-white 8th magnitude secondary is 105 arcsec from the deeper yellow *δ Boo*. Large binoculars show the color difference more distinctly. *50 Boo* is a triple star. The primary is a 5th magnitude blue-white, and the 10th magnitude members are a noticeable yellow, making a pretty trio.



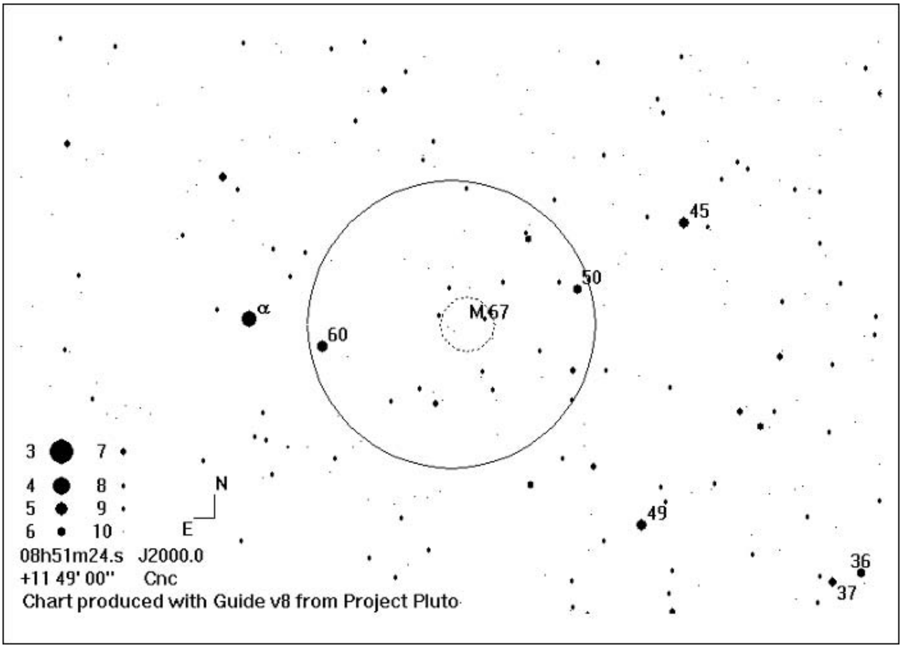
Boötes: Variable Star: RV Boötis

RV Boo is just over one field to the NE of *ρ Boo*: Mean range: 7.9–9.8; mean period: 137 days; type: semiregular. Also in the field is *RW Boo*: Mean Range: 8.0–9.5; mean period: 204 days; type: RRCrB.



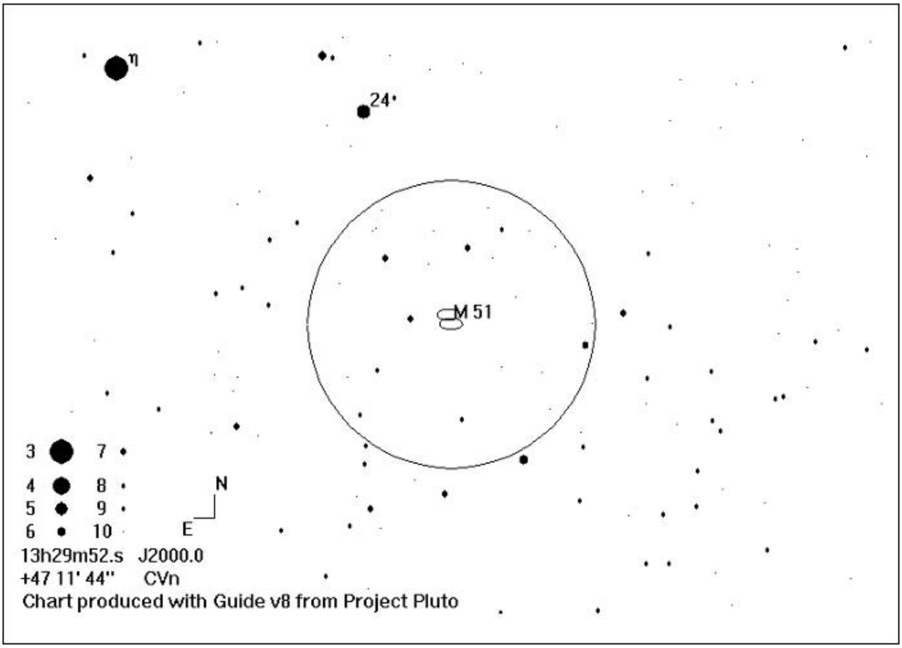
Camelopardalis: Galaxy: NGC 2403

From Mirak (*β UMa*), hop 10 degrees WNW to *υ UMa*, then a further 10 degrees to *ο UMa*. From o *UMa*, hop 7 degrees to the 6th magnitude *51 UMa* and place it on the E edge of the field of view. NGC 2403 will be near the center. NGC 2403 is an obliquely viewed spiral galaxy. It will not show any spiral structure in big binoculars, but you should detect the brighter core. It looks oblate in adequate conditions and appears more elongated (2 : 1) in darker skies.



Cancer: Open Cluster: M67 (NGC 2682)

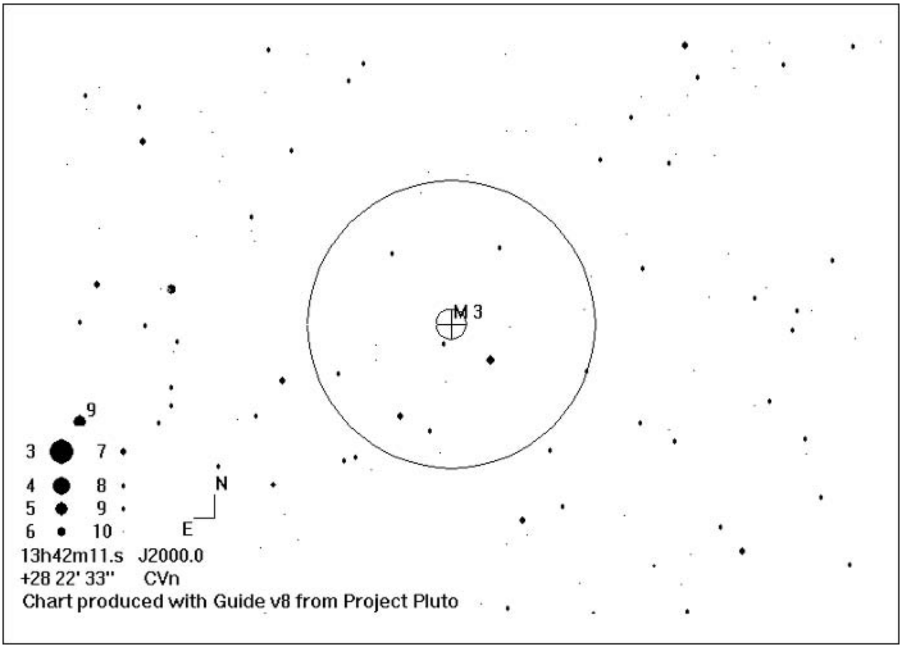
Place *Abucens* (α *Cnc*) at the E of the field of view, and M67 will appear near the W. Although relatively few stars are resolved in big binoculars, this is a large, bright cluster with many stars that are too faint to be seen but which contribute to the nebulous glow. It is a curiosity in that, at an estimated four billion years old, it is older than usual for an open cluster.



Canes Venatici: Galaxy: M51 (NGC 5194, the *Whirlpool Galaxy*)

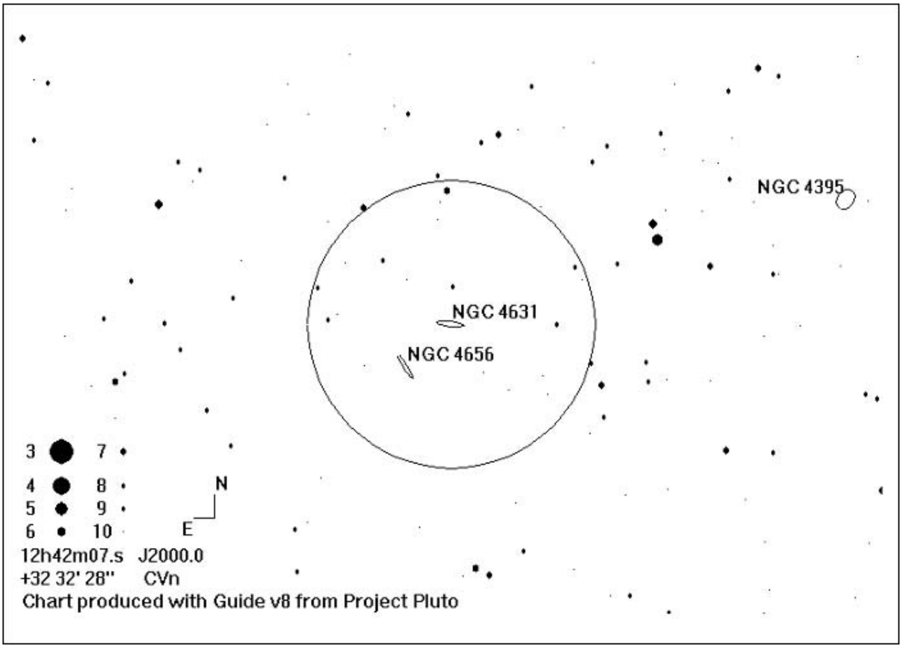
I usually find this by estimating it to be at the toe of an L whose upright is the line from *Mizar* (ζ *UMa*) to *Alkaid* (η *UMa*). If it is difficult to see, I hop one field WSW from *Alkaid* to *24 Cvn*, then 2 degrees SSW. M51 is found at the NE apex of an approximate equilateral triangle that it makes with two 6th magnitude stars.

The key to seeing the *Whirlpool* is a dark transparent sky. In good conditions, it is very obvious in big binoculars, as is its companion NGC 5195, which shares the same background glow, but do not expect to see the spiral structure that was first detected by Lord Rosse in the *Parsonstown Leviathan*.



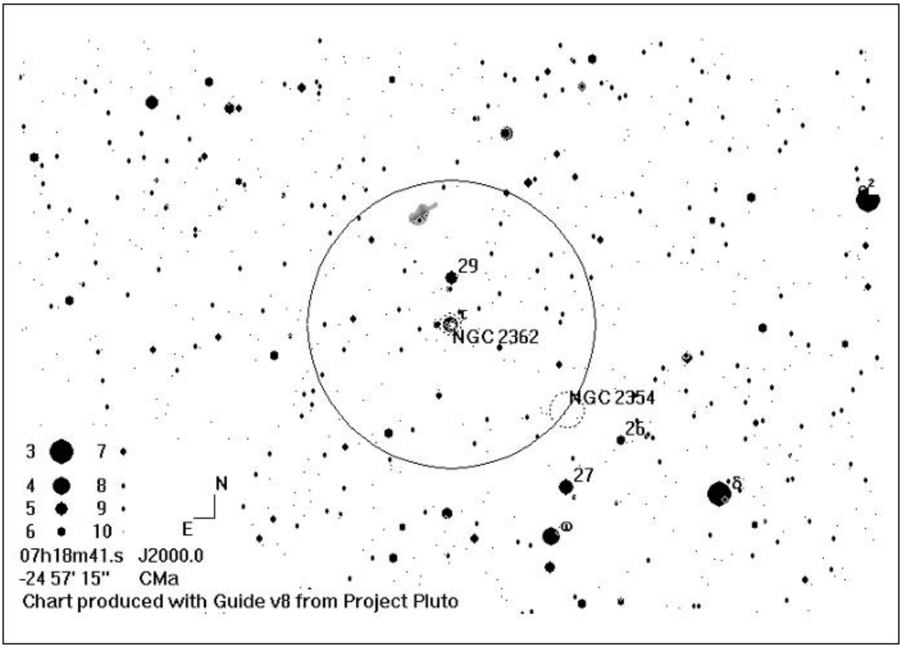
Canes Venatici: Globular Cluster: M3 (NGC 5272)

I usually find M3 by imagining the intersection of a line from *Cor Caroli* (α *CVn*) to *Arcturus* (α *Boo*) with one from β *Com* to ρ *Boo*; if M3 is not in the field, it is slightly toward *Arcturus*. Alternatively, start your hop at β *Com*. M3 is 2.5 fields E. It is a degree S of a line joining β *Com* to ρ *Boo*). Although it is not large, M3 is a bright, obvious cluster, which, at ×37, shows distinct brightening to the core. The 6th magnitude star slightly to the SW is yellowish.



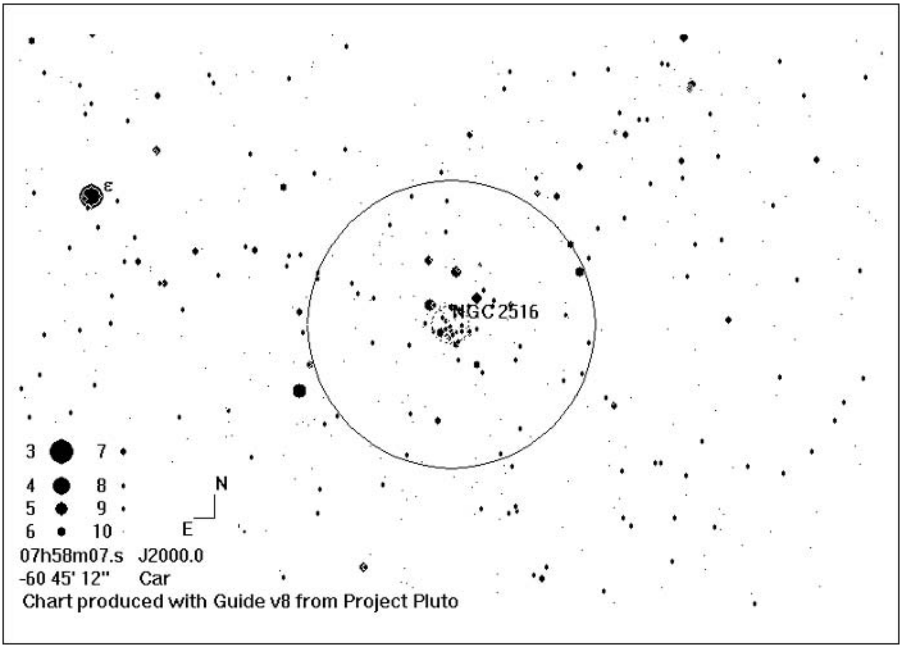
Canes Venatici: Galaxy Pair: NGC 4631 and NGC 4656

The coordinates are for NGC 4631. These galaxies are almost at the midpoint of a line from *Cor Caroli* (α *CVn*) to γ *Com*, slightly toward the latter. NGC 4631 is the easier of these two elongated galaxies, but they are both possible in 100-mm binoculars where they appear, at ×37, as a pair of short streaks of light in the sky.



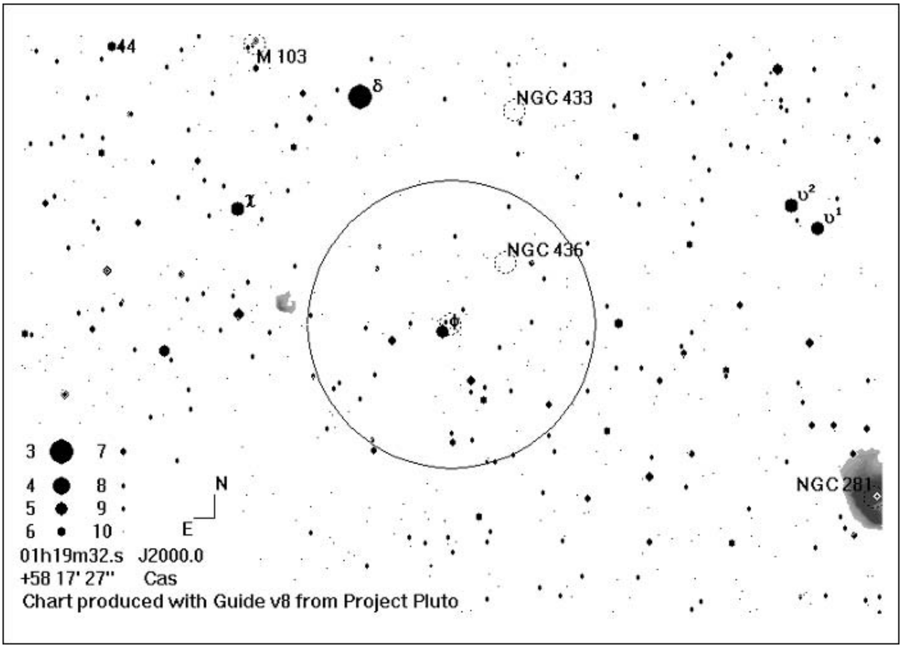
Canis Major: Open Cluster: NGC 2362

NGC 2362 surrounds the 4th magnitude τ *CMa*, which is just over one field to the NE of δ *CMa*. This is a superb cluster in big binoculars, showing about twenty stars at $\times$ 37. It contains several very blue (spectral class O) stars; the brightest star, τ *CMa*, is a brilliant bluish white.



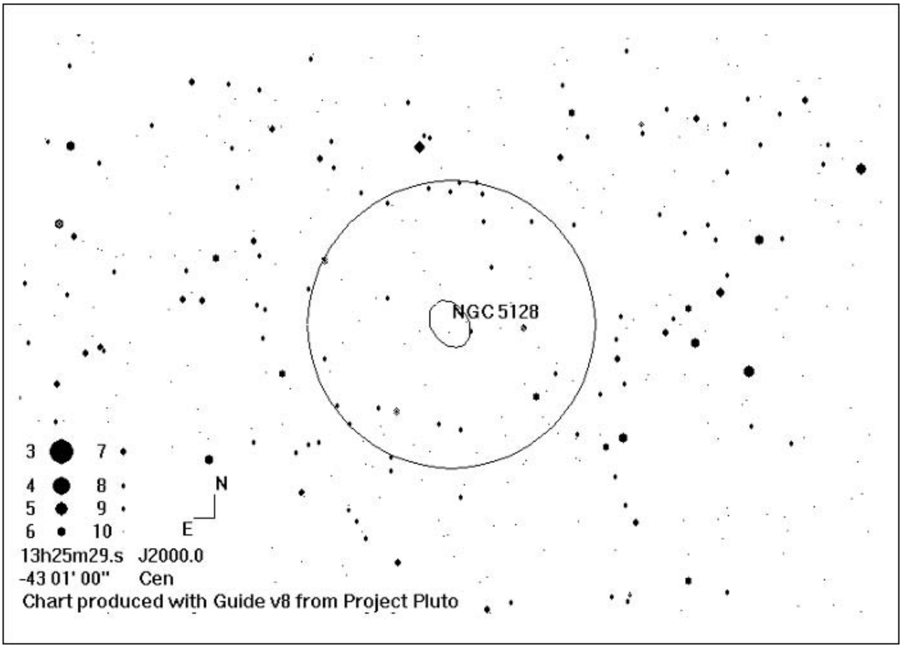
Carina: Open Cluster: NGC 2516

This easy naked-eye cluster is just over 3 degrees 1.5 fields SW of *ε Car* (*Evior*). Although this superb cluster could easily have been included among the 50-mm objects, it is so much better at 37×100 than it is at 10×50, that I consider it more appropriately placed here. Expect to see over thirty stars if the conditions are right.



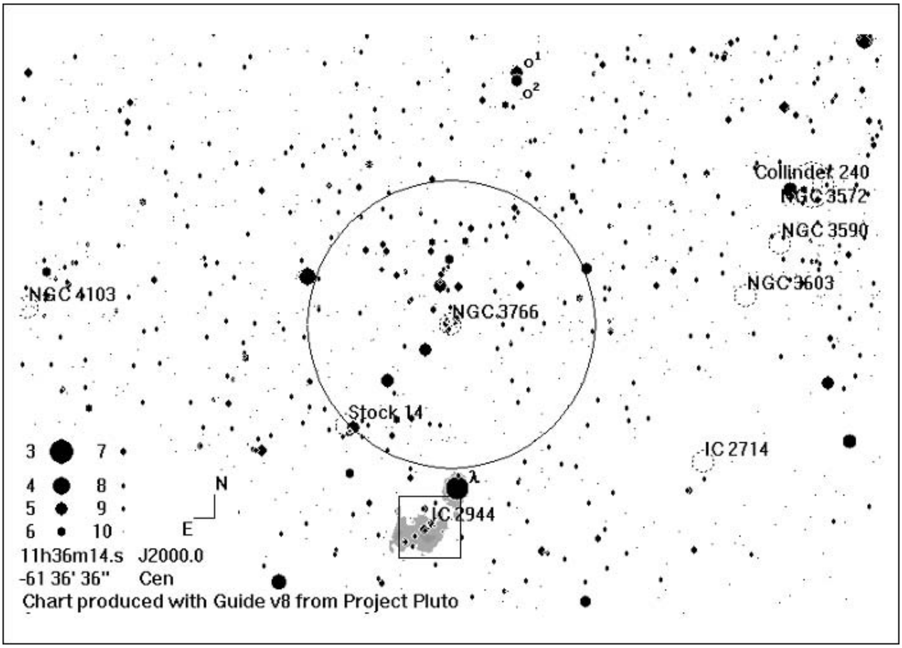
Cassiopeia: Open Cluster: NGC 457 (the *ET Cluster*, the *Owl Cluster*)

Place δ *Cas* (*Ruchbah*) at the NE of the field and the 5th magnitude ϕ *Cas* will lie diametrically opposite. Center ϕ *Cas*, which is the brightest star of this cluster, although it is not actually a member of it. NGC 457 is near the top of my list of star-party objects. The two brightest stars, ϕ *Cas* and its nearby 7th magnitude companion, appear as the glowing eyes at the SE of a stick-man asterism with outstretched arms, which, just detectable at ×37, gives this cluster one of its common names.



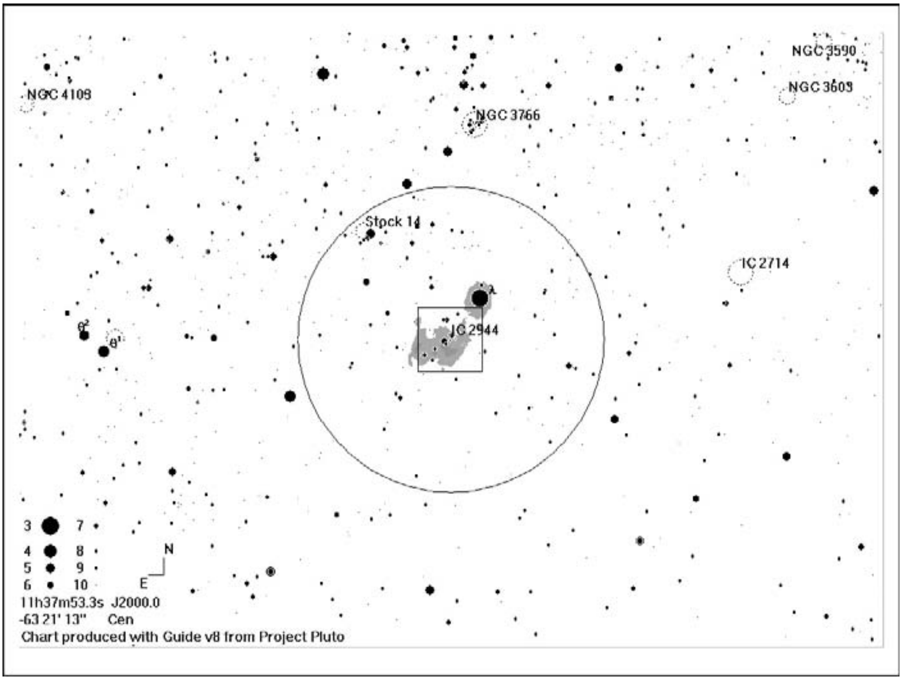
Centaurus: Galaxy: NGC 5128 (*Centaurus A*)

Sweep two fields due N of the *ω Cen* cluster (until you are due W of the more southerly of the 3rd magnitude pair μ and *ν Cen*) and this galaxy should appear almost center field. NGC 5128 is one of the better binocular galaxies, being bright and extended. It seems to elongate more with averted vision, when the dark lane that crosses it also becomes visible. It is the location of the radio source *Centaurus A* and is also a strong x-ray source. It is thought to be two galaxies in collision.



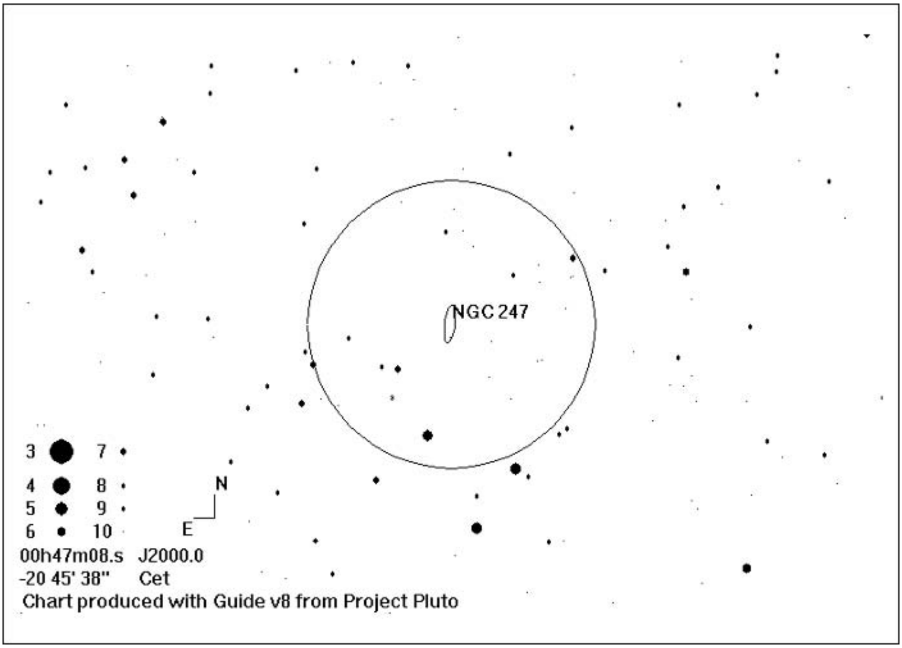
Centaurus: Open Cluster: NGC 3766

Place *λ Cen* at the S of the field and NGC 3766 will appear near the center. NGC 3766 is a superb cluster that is situated in a particularly rich region of the Milky Way. At ×37 it resolves into dozens of mostly blue stars, contrasted by a pair of deep red 7th magnitude stars that are like the ends of an arrow that pierces a heart-shaped asterism of fainter stars. Any of the other clusters shown on the chart is also worth visiting while in the region.



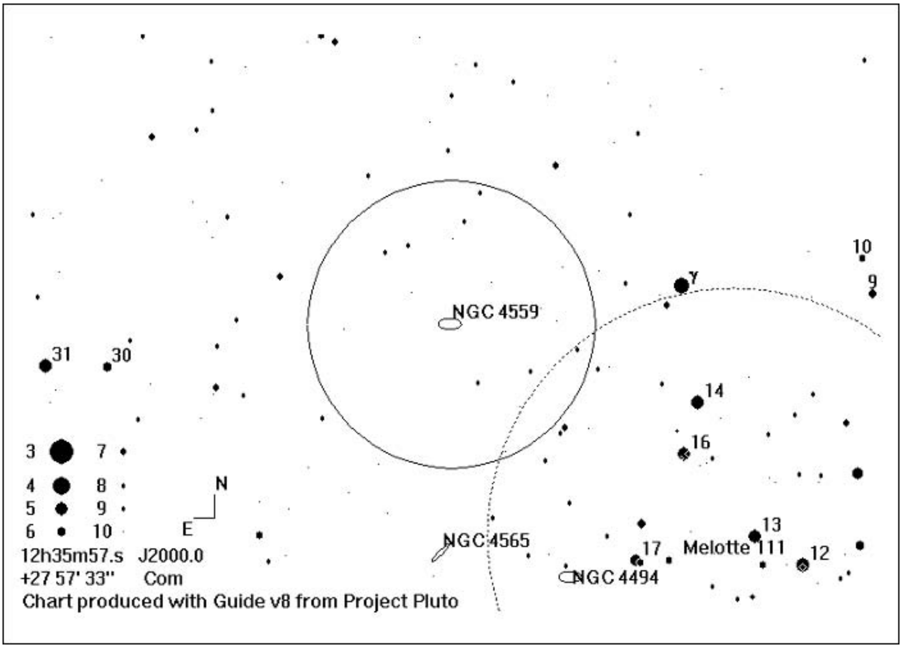
Centaurus: Open Cluster and Supernova Remnant: IC 2944 (the *Running Chicken*)

IC 2944 is located immediately to the SE of *λ Cen*, which some sources consider to be part of the object. Among the few dozen stars that comprises IC 2944 is a chain of brighter blue stars running from NW to SE. Patience, coupled with averted vision, is sometimes needed to pull the nebulosity from the rich background. A UHC or O-II filter is an obvious aid.



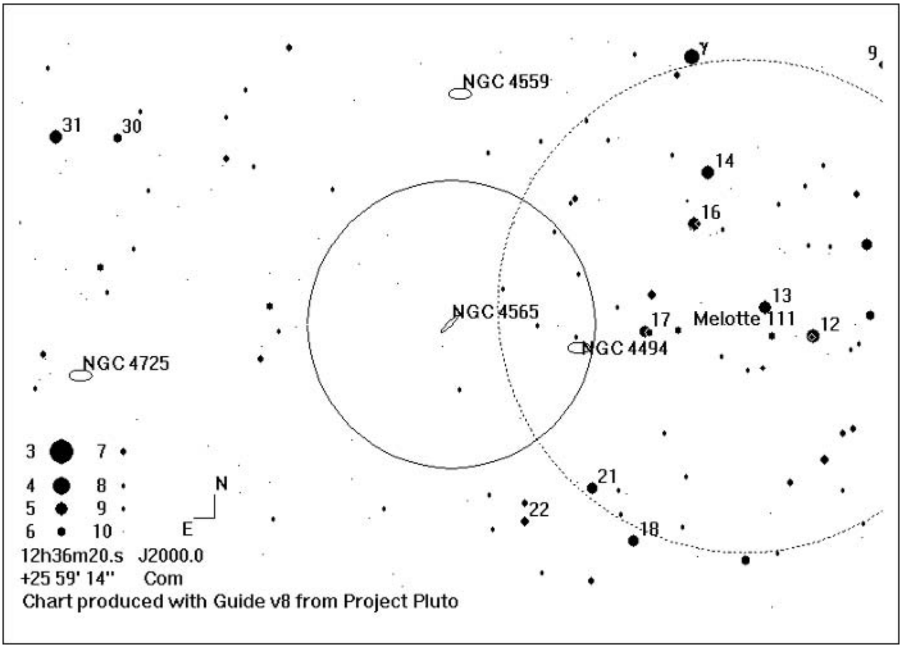
Cetus: Galaxy: NGC 247

NGC 247 is nearly 3 degrees SSE of *β Cet* (*Diphda*) and 4.5 degrees N of the considerably easier to view NGC 253. I find NGC 247 to be extremely challenging in binoculars and will not even attempt it unless sky conditions are extremely good and I am relatively fresh. It is said to have a magnitude of 9.6 but, owing to its low surface brightness, it appears to be considerably fainter. The triangle of 5.5th magnitude stars just S of it makes it easy to be certain of its location. Once there, relax, use averted vision, and, if necessary, tap the binoculars to jiggle them slightly. This is usually sufficient to tease it from the background, but I am sometimes not sure if I have *really* seen it.



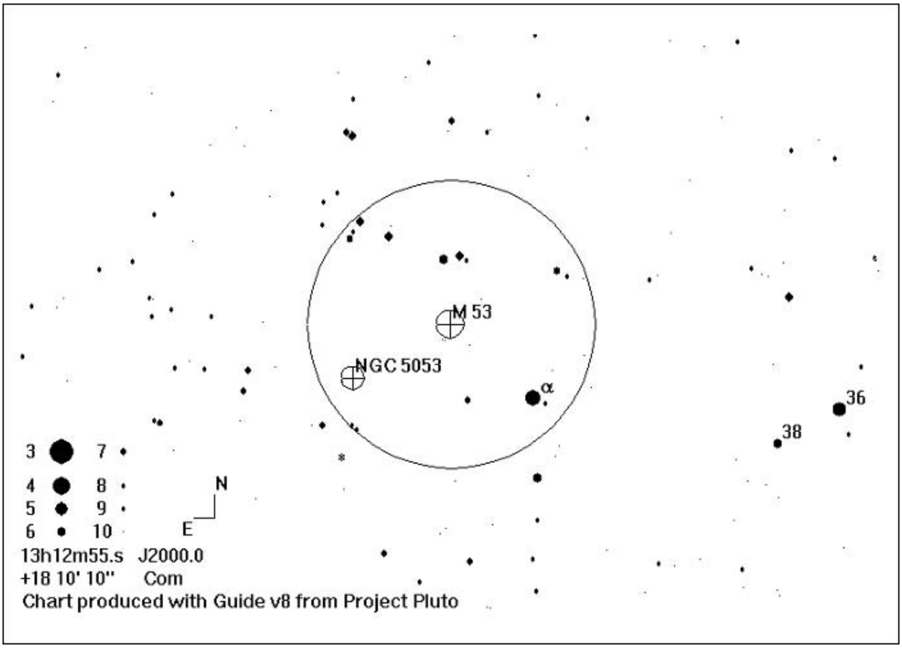
Coma Berenices: Galaxy: NGC 4559

Place γ *Com* at the W of the field and NGC 4559 will be almost diametrically opposite. NGC 4559 is visible in smaller binoculars and is an easy object at 37×100, in which it appears only slightly oblate unless the sky is very dark, when the peripheral regions become more visible and it appears to lenghten.



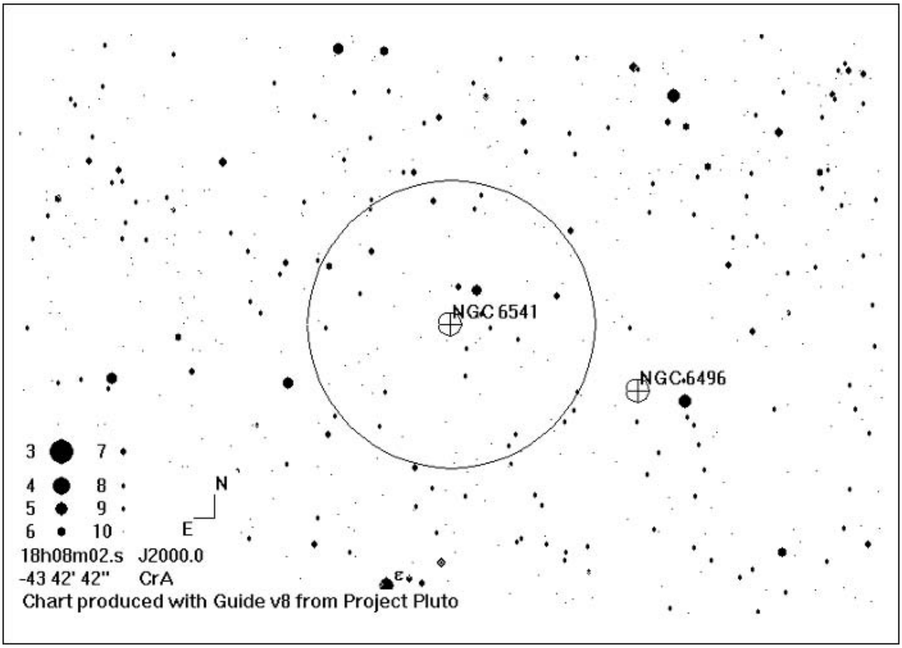
Coma Berenices: Galaxy: NGC 4565 (*Berenice's Hair Clip*)

NGC 4565 is 2 degrees S of NGC 4559 (above). NGC 4565 has a high surface brightness and is a lovely sight in large binoculars. Being a typical edge-on galaxy, to us it appears like a needle of light against the darker sky.



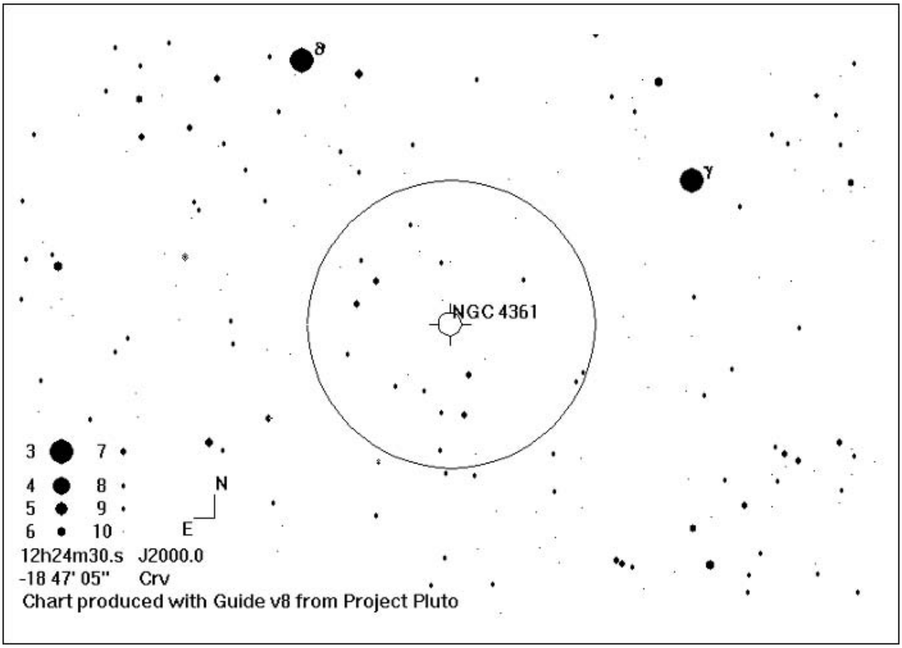
Coma Berenices: Globular Cluster: M53 (NGC 5024)

M53 lies in the same field as α *Com* (*Diadem*). This is a relatively large globular. Although it is not as bright as the "famous" ones (M13, ω *Cen*), and requires the magnification of a telescope to resolve any stars out of it, it is quite large and is easily seen as a diaphanous glow surrounding a dense core.



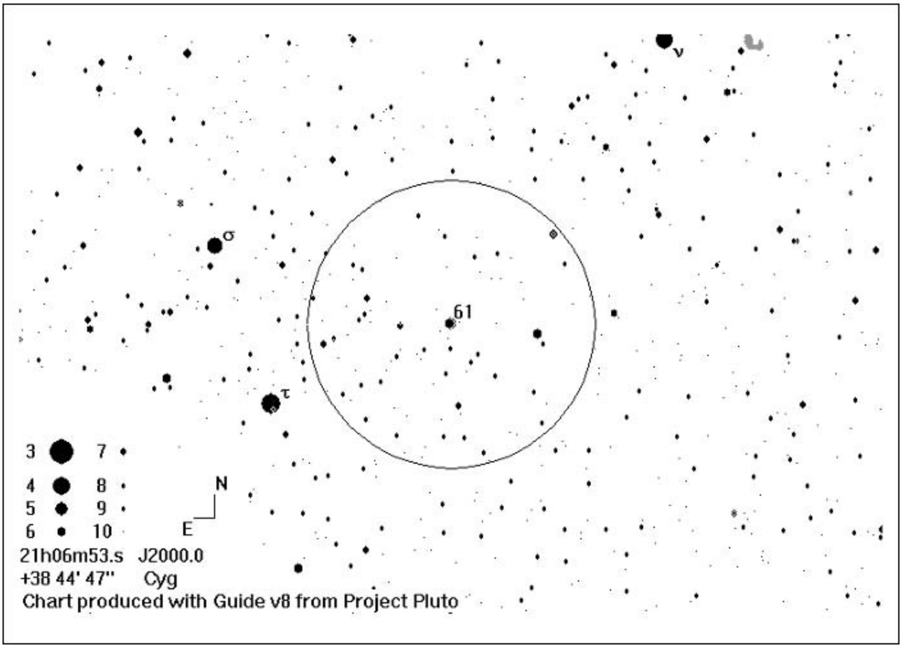
Corona Australis: Globular Clusters: NGC 6541 and NGC 6496

NGC 6541 is about a quarter of a field S of the point where a line from θ *CrA* to θ *Sco* crosses a line from *θ Tel* to θ^1 *Sco*. NGC 6541 is a large, bright object that is easy to view in all binoculars. More of a challenge is the nearby NGC 6496, nearly 2 degrees to the WSW, which is about half the size and a quarter of the brightness. The 5th magnitude star nearly half a degree to the WSW of the fainter cluster can be an aid to locating it when sky conditions are less than ideal.



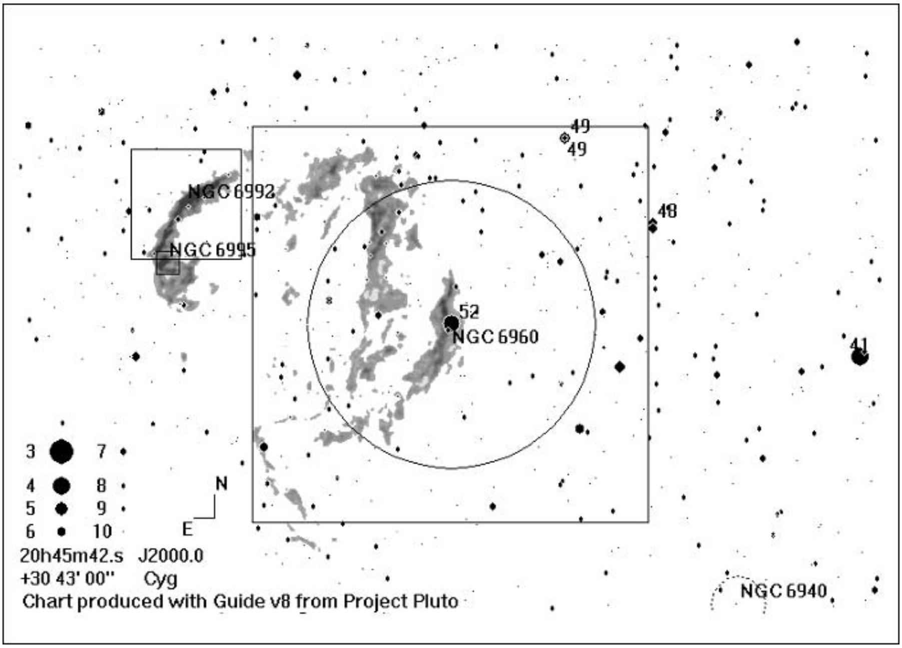
Corvus: Planetary Nebula: NGC 4361

NGC 4361 is located one field diameter to the SE of γ *Crv*. This compact, 10th magnitude planetary nebula is a difficult object from the latitude of southern Britain, owing to its low altitude of culmination, but it is considerably easier from the latitude of the Mediterranean. As with all objects of this type, it benefits from a UHC or O-III filter and averted vision. The 12th magnitude progenitor star is also visible at ×37.



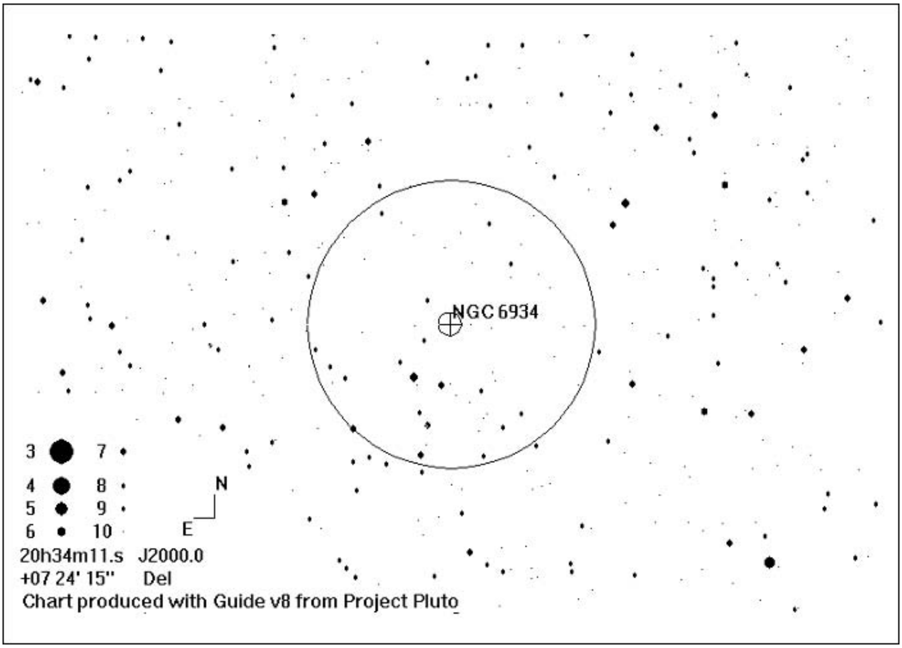
Cygnus: Double Star: 61 Cygni

61 Cyg is situated to the WNW of *τ Cyg*, in the same field. Every astronomer should observe *61 Cyg*! Not only was this star the first to have its distance measured (by F.W. Bessel in 1838), but it is also the naked-eye star with the greatest proper motion (5.22 arcsec/yr), although some claim this for the star Groombridge 1830, which is at magnitude 6.4 and is visible from very dark sites (7.06 arcsec/yr). It is at a distance of 11.4 light years (Bessel measured it at 10.3). *61 Cyg* has a combined magnitude of 4.8, but binoculars show it to be a pair of orange-red stars (both spectral type K) with magnitudes of 5.2 and 6.0. They have an orbital period of 659 light years.



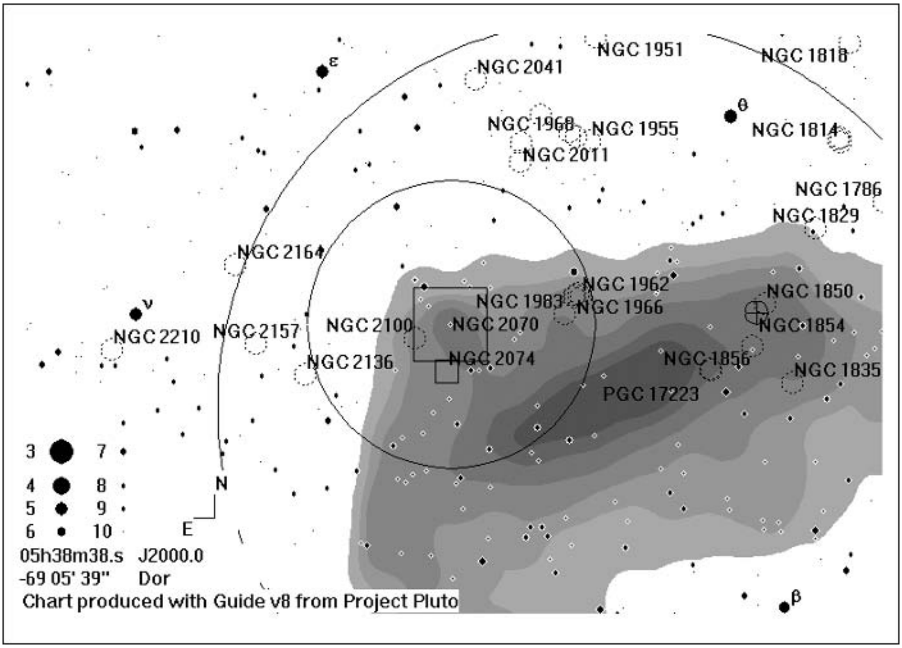
Cygnus: Supernova Remnant: *Veil Nebula* (NGC 6960, NGC 6992 and 6995)

The western part of the *Veil* (NGC 6960) is a background to *52 Cyg*, which, if the sky is dark enough to see the *Veil*, will be visible to the naked eye 3 degrees S of *ε Cyg*. The *Eastern Veil* (NGC 6992 and 6995) can be found by scanning one field to the NE. If you have a UHC or O-III filter, this object is a must. It is nothing less than superb in big binoculars in either of these filters. The first time I saw the Eastern portion with an O-III, my immediate reaction was that the binocular had *shrunk* the Milky Way! In a good sky you will realize that even the field of the binoculars cannot contain the entire *Western Veil*, as small detached clumps of it come into view with averted vision.



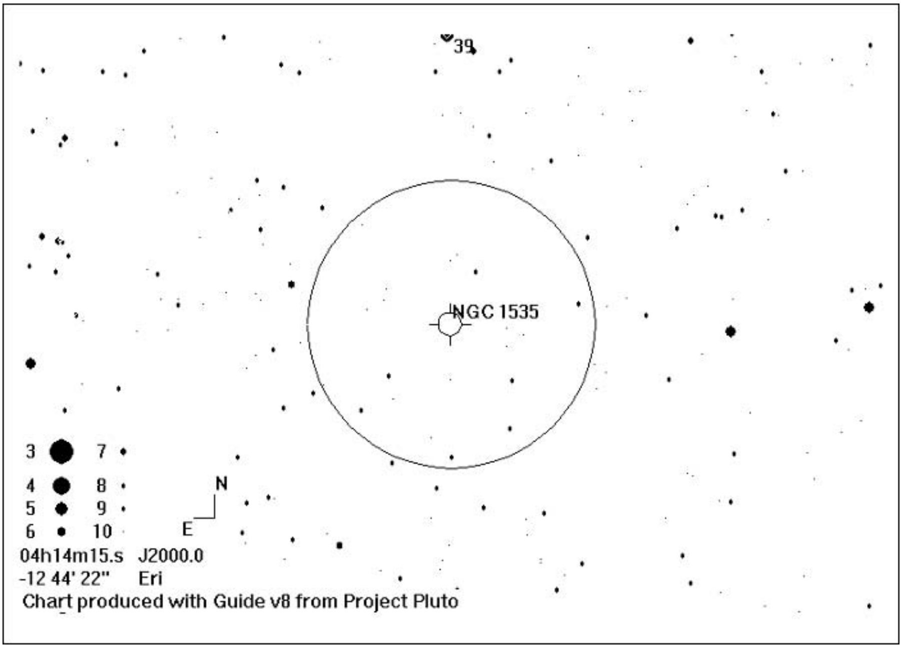
Delphinus: Globular Cluster: NGC 6934

Scan two fields to the S of *ε Del*, and NGC 6934 will be obvious to the E of center of the second field. NGC 6934 is a very easy object to view, even with 8×30 binoculars. There is a phenomenon that is common to almost all largeish globular clusters in 100-mm glasses at ×37: they appears to get larger as transparency improves. NGC 6943 displays this phenomenon in a more pronounced degree than any other globular which I have tested.



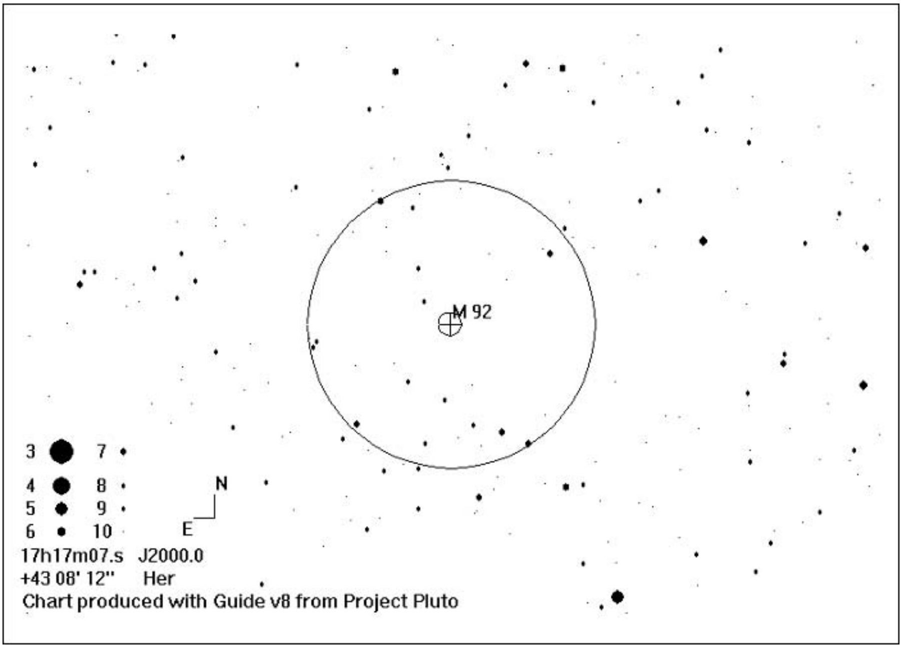
Dorado: Galaxy and Emission Nebula: *Large Magellanic Cloud* and NGC 2070 (*Tarantula Nebula, Loop Nebula*, 30 Doradus)

The chart is centered on NGC 2070. The *Large Magellanic Cloud* (*LMC*) is easily visible to the naked eye. The *Tarantula* is situated within the *LMC* and makes an approximate equilateral triangle with ν and ε *Dor*. Binoculars of any size give a breathtaking view of the *LMC*, which is the brightest of our companion galaxies. The *Tarantula* is very bright, being distinguishable to the naked eye if sky conditions permit. It is the largest known emission nebula and, if it were situated at the same distance as M42 in Orion, it would be sufficiently bright to cast shadows.[1] The structure, some of which is visible in binoculars, gives it its common names, but it requires a larger aperture and more magnification to reveal significant detail.



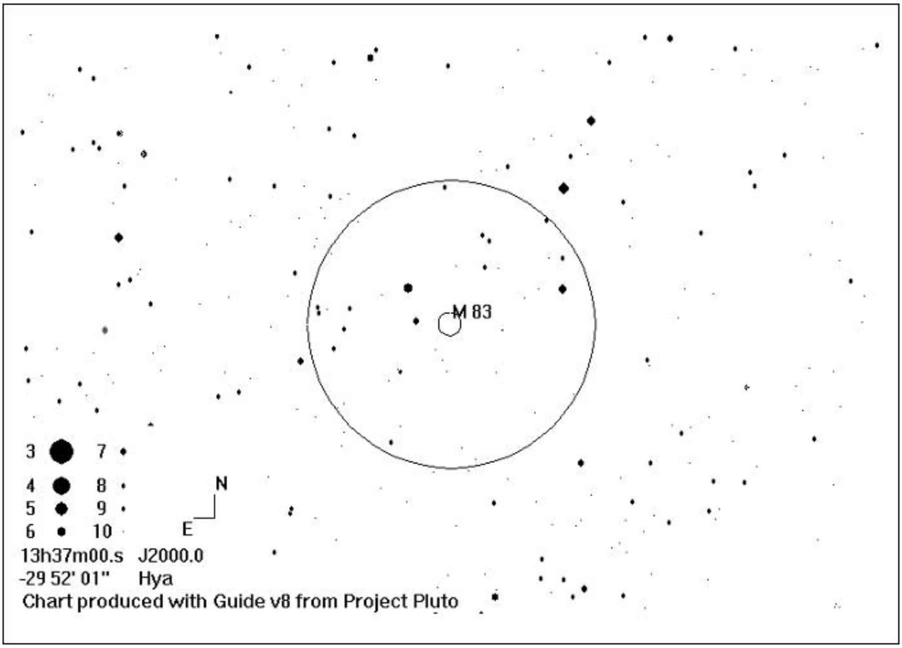
Eridanus: Planetary Nebula: NGC 1535

NGC 1535 is located 4 degrees ENE of γ *Eri*. This small, 10th magnitude planetary nebula is a moderately easy object to view at 37×100 as long as the sky is transparent and free of light pollution. However, this magnification shows no structure.



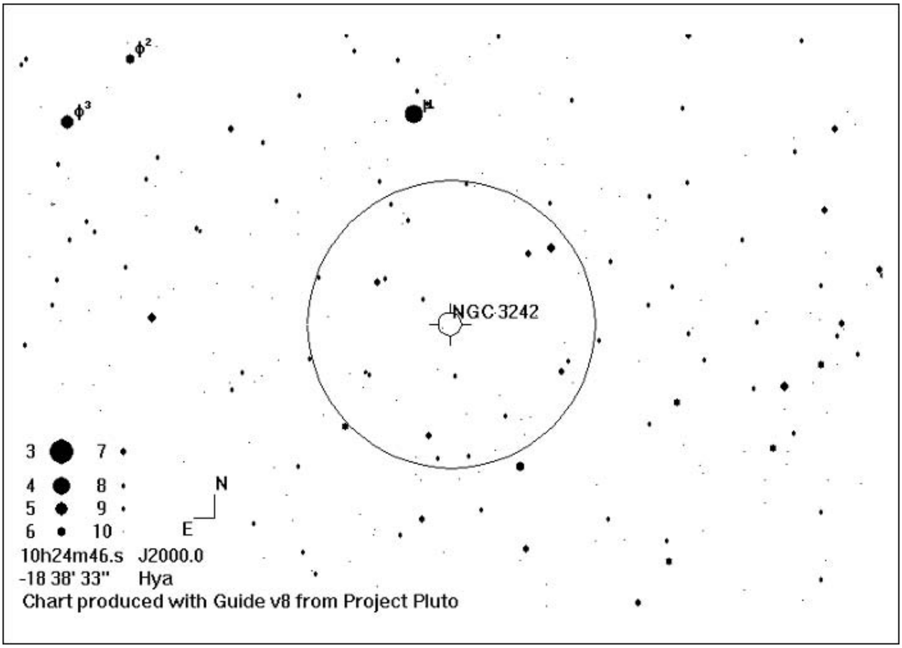
Hercules: Globular Cluster: M92 (NGC 6341)

M92 lies two-thirds of the way from η to *ι Her*. M92 is an object that would be far better known, and more often observed, were it not for its famous neighbor, M13. It is a superb globular cluster in its own right, very bright with edges that begin to resolve at ×37.



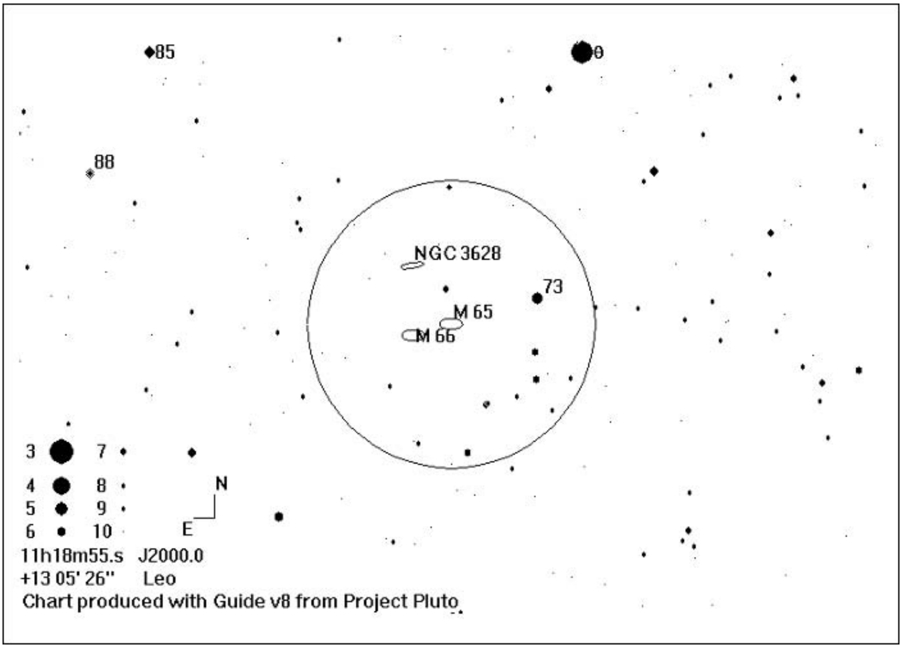
Hydra: Galaxy: M83 (NGC 5263)

This galaxy is situated in a star-sparse region of sky. A relatively simple star-hop is available to observers whose location is sufficiently far south for θ *Cen* to be available. Starting at *θ Cen*, go 1.5 fields NW to *2 Cen*. Place *2 Cen* at the SSE of the field and locate *1 Cen* about three-fourths of the way across the field. Continue this line for a further 1.5 fields and M83 should be visible. For those of a more northerly location such as most of Britain, M83 will be a difficult object owing to its low transit altitude. Start at γ *Hya* and go just over half a field SSE to a 7th magnitude star. A whole field SE of this is another star of similar brightness. A further field to the SSE brings us, via yet another star of similar brightness, to a 6th magnitude star. Continue this line for a further half field between two more 6th magnitude stars and M83 should be visible just E of center. M83 is a relatively bright galaxy that is almost face on. In binoculars it appears as a circular glow. It is of interest in that it has been a somewhat prolific source of supernova, hosting no fewer than six during the 20th century, several of which have been within the range of big binoculars.



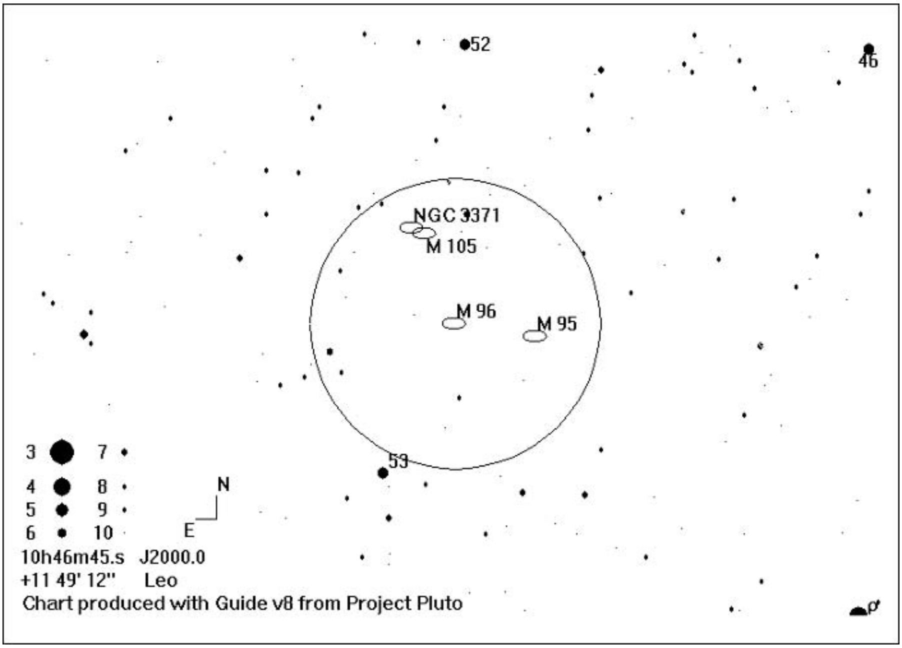
Hydra: Planetary Nebula: NGC 3242 (the *Ghost of Jupiter*)

Place the 4th magnitude *μ Hya* at the N of the field and NGC 3242 should appear about halfway to the edge on the opposite side. If you have trouble identifying it, flash a UHC or O-III filter across an eyepiece. The *Ghost of Jupiter* appears stellar in smaller binoculars, but is distinctly nonstellar at 37×100, although I have not been able to detect the oblateness that gives it its common name in these.



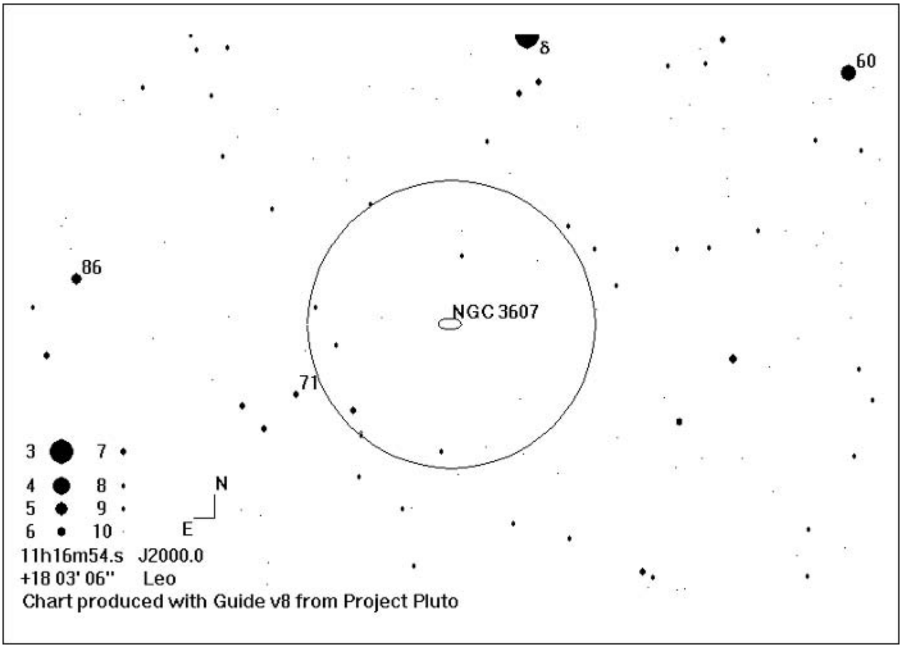
Leo: Galaxy Trio: M65 (NGC 3623), M66 (NGC 3627 and NGC 3628)

Coordinates are for M65. Put θ *Leo* (*Chort*) at the N of the field and find *73 Leo* 2 degrees to the S. Place *73 Leo* at the W of the field and the galaxies should be visible near the middle. These galaxies are nicely framed in a 2.5-degree field. Although they are visible as flecks of light in 10×50 binoculars, they are distinctly better at ×37 and the difference in shape of NGC 3628 becomes apparent.



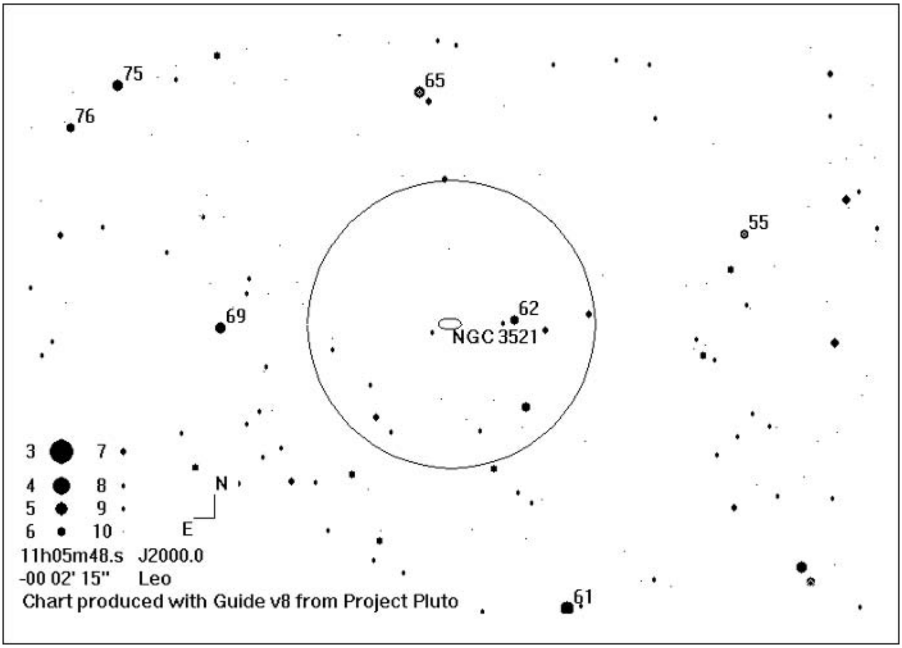
Leo: Galaxy Trio: M95 (NGC 3351), M96 (NGC 3368), and M105 (NGC 3379)

The coordinates are for M96. The galaxies are to be found two fields to the NE of *ρ Leo*. This is another galaxy trio that is neatly framed in the field of big binoculars. The two companion galaxies to M105 (NGC 3371 and NGC 3373) are tricky, but possible, bringing the total in one field to five galaxies.



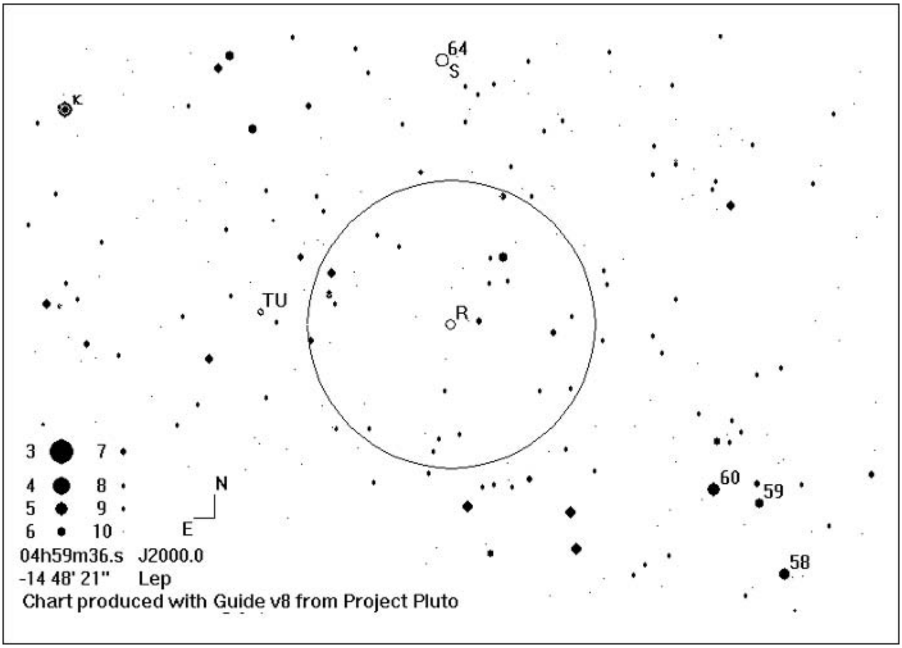
Leo: Galaxy: NGC 3607

NGC 3607 is located just over 2.5 degrees SSE of δ *Leo*. This 11th magnitude galaxy is almost spherical. It is small and compact and therefore relatively easy to see. It is the central galaxy of a tight group of three; the northern one is possible but challenging at ×37, but I have never seen the more southerly one in binoculars.



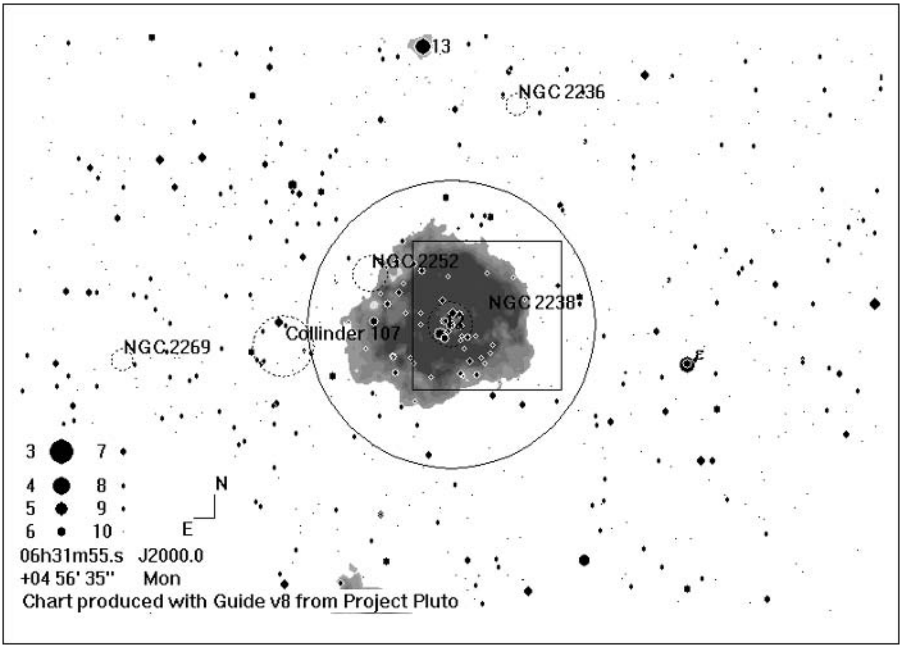
Leo: Galaxy: NGC 3521

Midway between β *Vir* and β *Sex* identify the white 5th magnitude *69 Leo* and then the deep yellow *62 Leo*. NGC 3521 is half a degree E of *62 Leo*. This bright (10th magnitude) galaxy is often overlooked as a binocular object owing to its location away from the bright stars by which the constellation of Leo is recognized. It is considerably larger than, for example, any of the M95/96/105 trio and is as bright as M96. It is clearly elongated along a SSE to NNW axis.



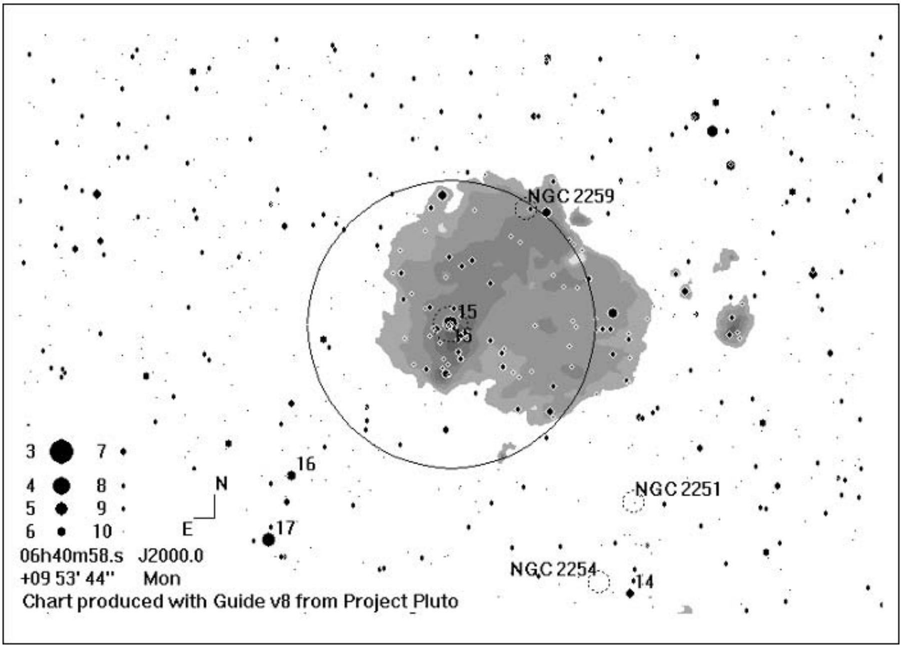
Lepus: Variable Star: R Leporis (*Hind's Crimson Star*)

Mean magnitude range: 5.9–10.5; mean period: 427 days. Follow the line from α *Lep* to μ *Lep* a further 1.5 fields, where *R Lep* should be visible and identifiable by its color. *R Lep* is a Mira-type variable, but is not included for this reason, but because of its color. It is a candidate for the reddest visual star, hence its common name. Its color is obviously most impressive when it is near maximum.



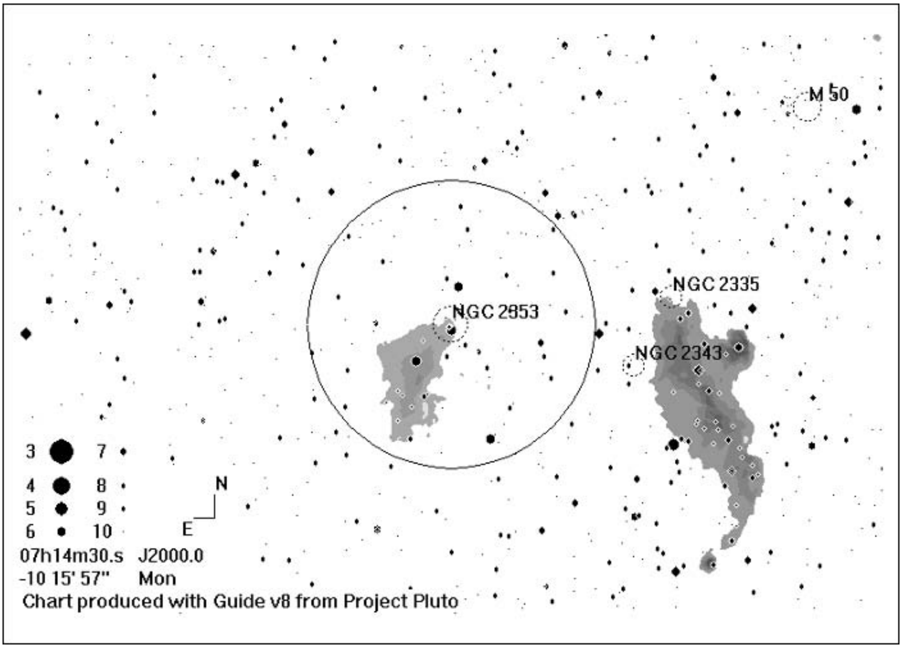
Monoceros: Open Cluster: NGC 2239 (NGC 2244)

There are no bright stars in the immediate region. Possibly the simplest star-hop is to follow the line from *λ Ori* through *Betelgeuse* (*α Ori*) for a further three 2.5-degree fields until you come to *ε Mon*. Just under one field E of *ε Mon*, NGC2239 (also designated NGC 2244) is the cluster of stars that appears around *12 Mon*, which is a foreground object, not a member of the cluster. Although NGC 2239 is often given in lists for 50-mm binoculars, it comes into its own with larger glasses, where the yellow-orange *12 Mon* stands out against the predominantly blue-white stars of the cluster. Under ideal conditions, and with averted vision, it is possible to glimpse the surrounding *Rosette Nebula* as a slight brightening of the sky background.



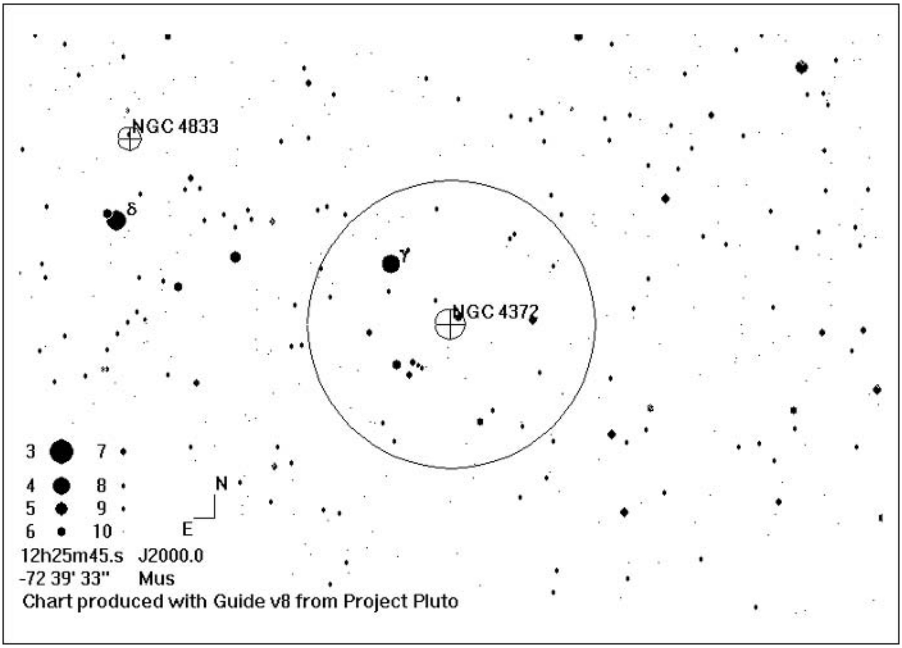
Monoceros: Open Cluster: NGC 2264 (the *Christmas Tree Cluster*)

This cluster is most easily found with the aid of a reflex finder or low-power, wide-field binoculars. Find the center of a line joining *Betelgeuse* (α *Ori*) to β *CMi* and offset 2 degrees in the direction of γ *Gem* (*Alhena*). The cluster surrounds the star *15 Mon*. This bright cluster has a characteristic wedge shape from which it derives its common name. The paucity of faint stars is thought to be due to a significant amount of interstellar dust in the region. The surrounding nebulosity of the *Cone Nebula* is not normally visible, but can be teased out with the aid of a UHC filter.



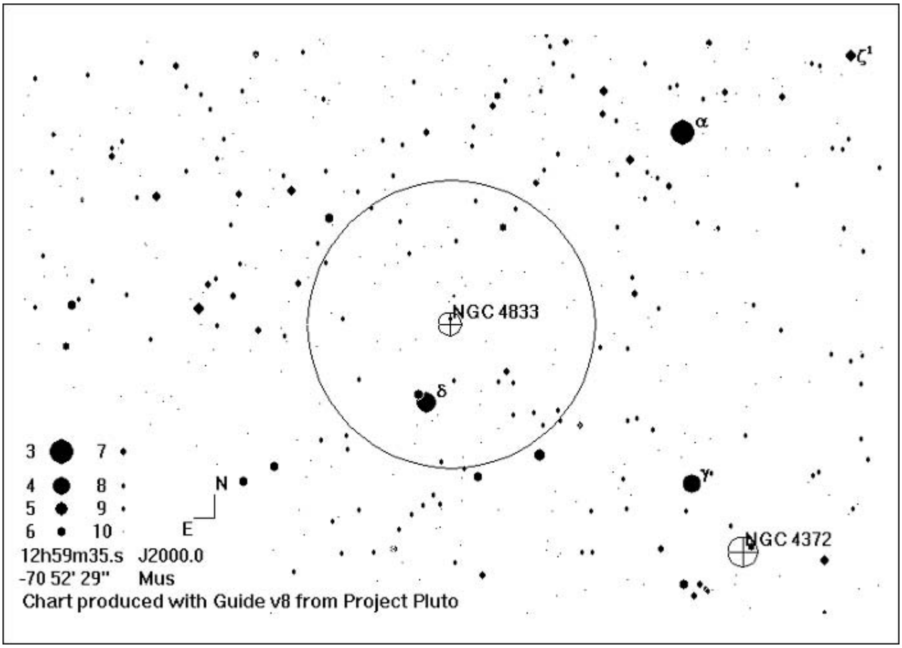
Monoceros: Open Cluster: NGC 2353

NGC 2353 can be found by hopping two and a half fields W of α *Mon*. NGC 2353 is a particularly fine cluster in binoculars at ×37, in which several stars are resolved. It is not particularly dense, permitting the appreciation of the stars that become visible.



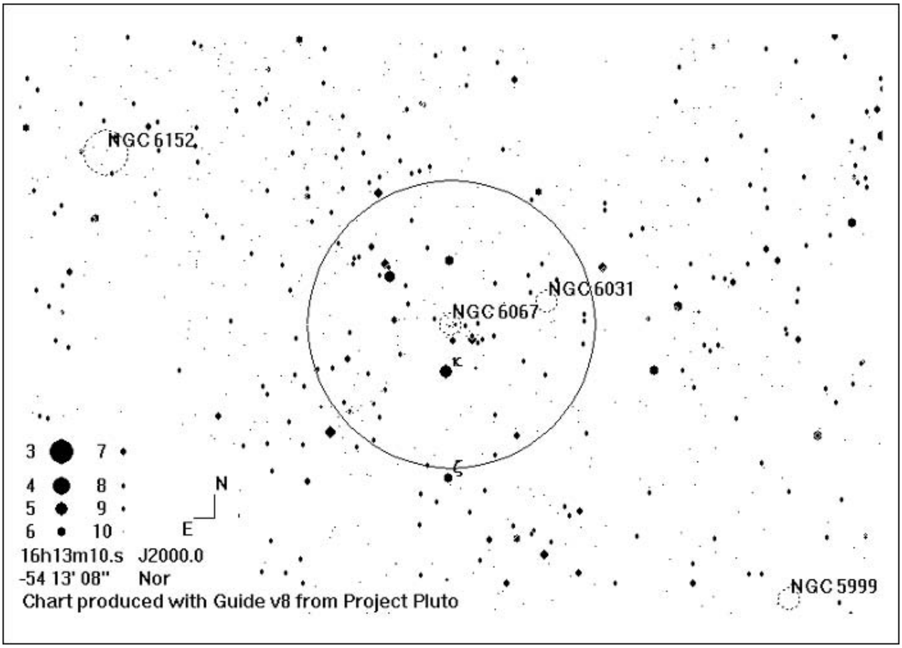
Musca: Globular Cluster: NGC 4372

NGC 4372 is located in the same field of view as γ *Mus*, just S of the star. NGC 4372 is large (18.6 arcmin) but of relatively faint surface brightness. Hence, it benefits from a dark, transparent sky.



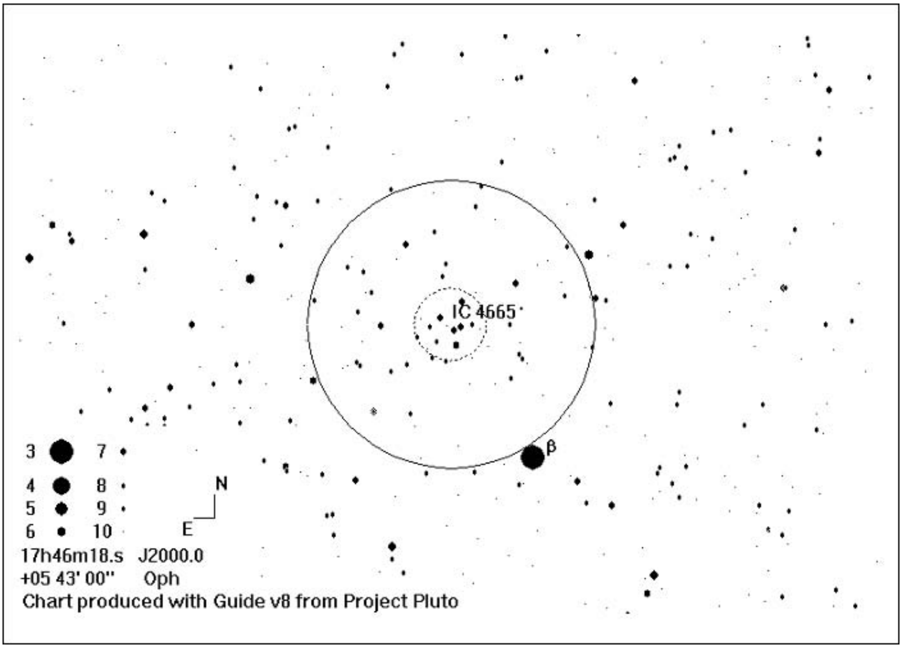
Musca: Globular Cluster: NGC 4833

NGC 4833 is to the NNW of *δ Mus*, in the same field. NGC 4833 is both smaller and brighter than the nearby NGC 4372 (above). It is therefore a little easier to locate and observe, especially if sky conditions are less than ideal. It is in a rich star field on the edge of the Milky Way.



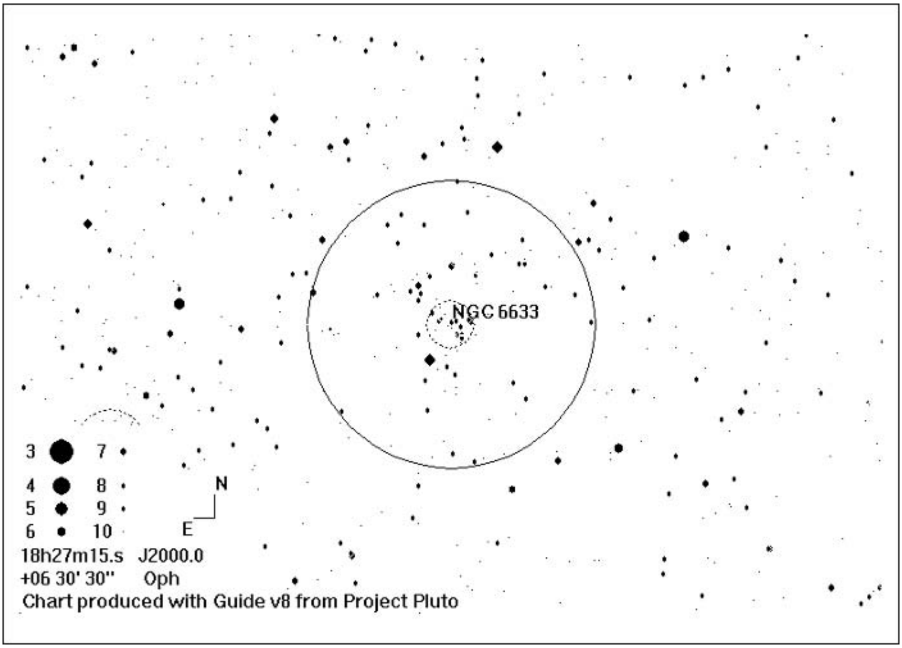
Norma: Open Cluster: NGC 6067

NGC 6067 is a Moon diameter N of *κ Nor*. Situated in a rich part of the Milky Way, this is a very impressive cluster in big binoculars, showing distinctly different colors among its brighter stars.



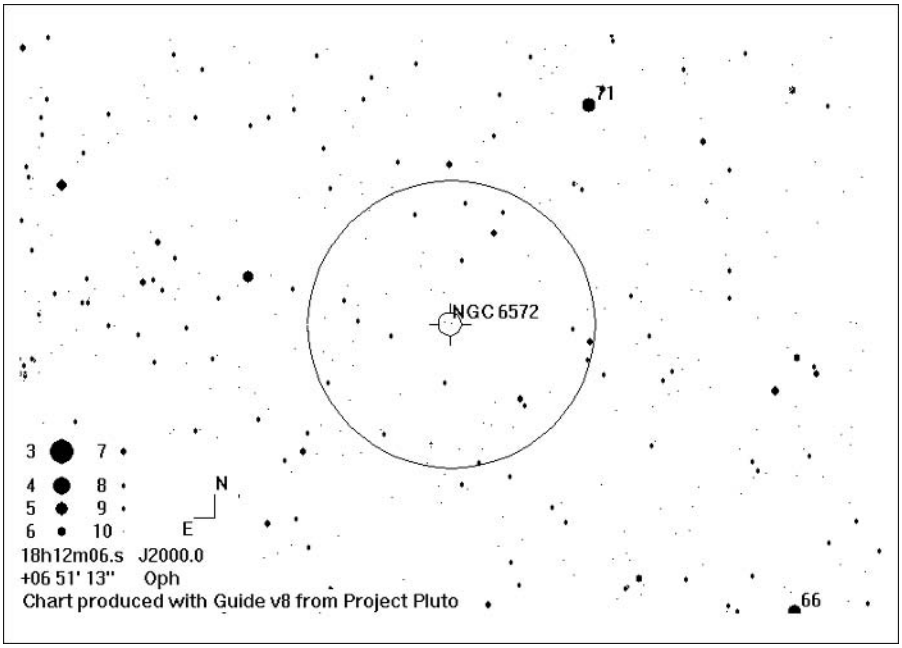
Ophiuchus: Open Cluster: IC 4665

IC 4665 is half a field to the NNE of *β Oph*. This large cluster is another object that is frequently given in lists for smaller binoculars but which benefits tremendously from larger apertures and the higher magnification that permits more stars to be revealed. Particularly attractive is a curved chain of bright white stars.



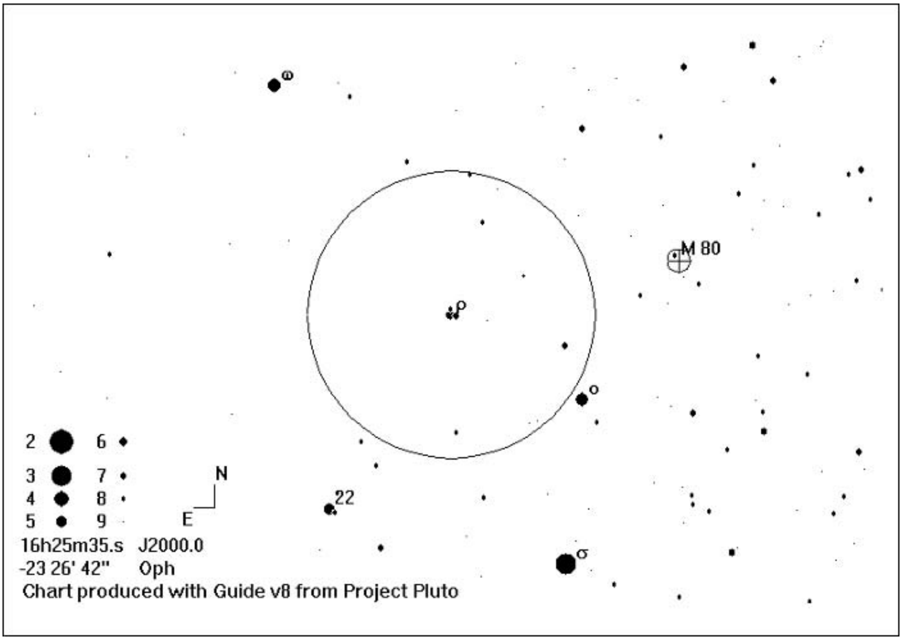
Ophiuchus: Open Cluster: NGC 6633

This superb cluster is often overlooked and excluded from binocular lists because it can be tricky to find. Just over 8 degrees ESE from *Rasalhague* (α *Oph*) is the 4th magnitude *72 Oph* with the slightly dimmer *71 Oph* a degree to the S of it. From *71 Oph*, carefully pan one and a half fields to the SE and find a yellowish star that is about half the brightness of *71 Oph*. Place this star on the NW periphery of the field and the cluster should be visible toward the SE edge. The stars in this cluster are older, and therefore more yellow, than those in many open clusters. Over twenty of these are easily resolved at ×37.



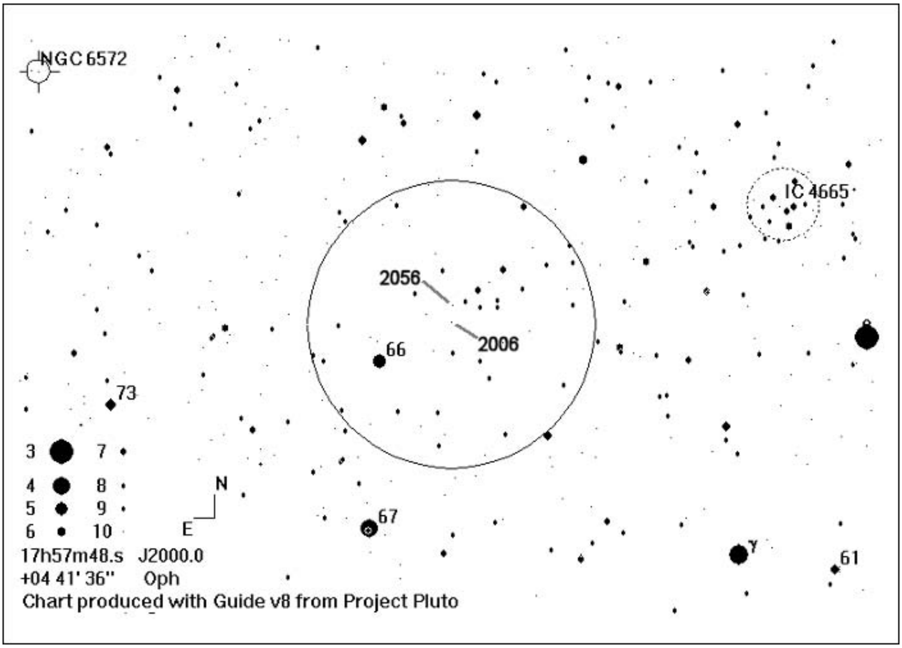
Ophiuchus: Planetary Nebula: NGC 6572

The easiest hop to this object begins at *β Oph*. Pan three fields to the E, then one field N, where you should be able to identify the star field. This tiny planetary appears stellar in nature, but is distinguished by the beautiful green color that warrants its inclusion in this list. It is probably the greenest object that is visible with binoculars of this size.



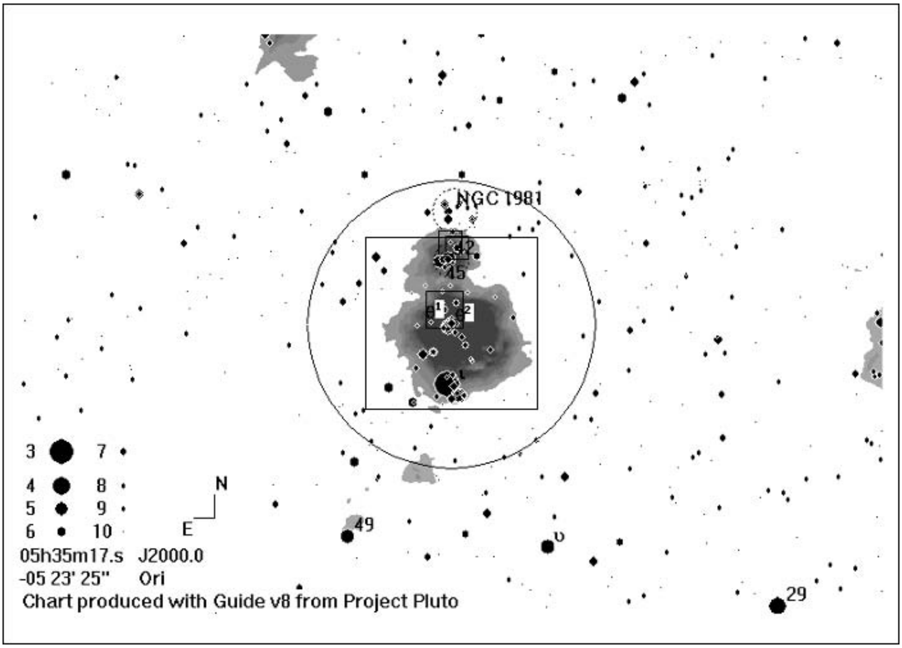
Ophiuchus: Triple Star: ρ Ophiuchi

ρ Oph is one field to the NNE of *σ Sco* (the direction of *ω Oph*). This 5th magnitude star is one of a visual triple star, whose 7th magnitude comites are situated 2.5 arcmin to the N and W respectively. Can you see the slightly bluer color of the W comes?



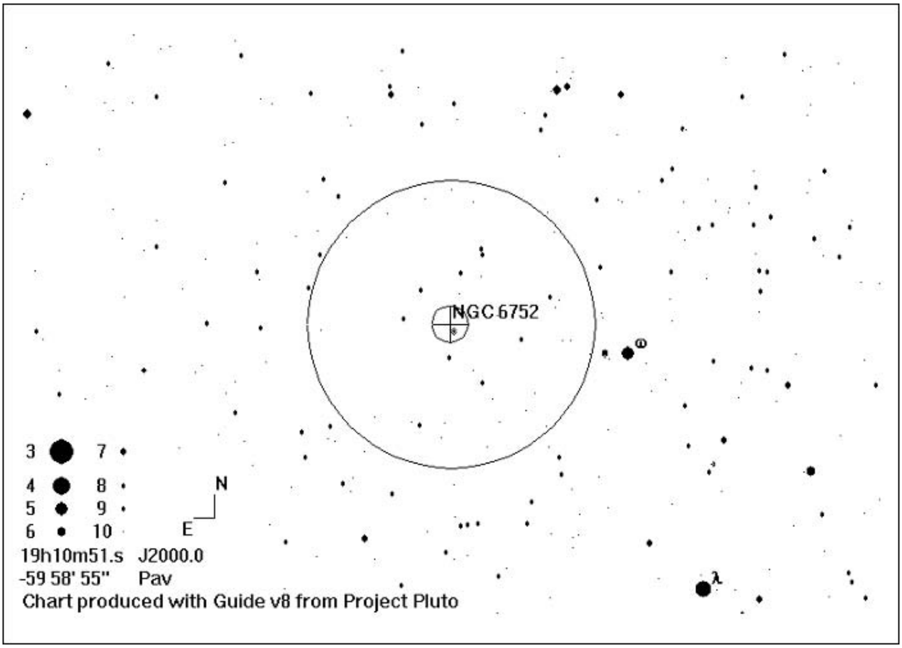
Ophiuchus: Star: *Barnard's Star*

Barnard's Star is the star with the greatest known proper motion (10.28 arcsec/yr). The chart gives its position for January 1 in 2006 and 2056 respectively. The large proper motion was discovered by E. E. Barnard in 1916. If you observe this 9.5th magnitude star in company, be sure to take the opportunity to dispel the notion that it has planets. This notion was the result of some shortcuts in data reduction taken by Peter van der Kamp in the 1960s and 1970s and, although modern methods have shown it to be in error, it has gained some renewed currency on the Internet.



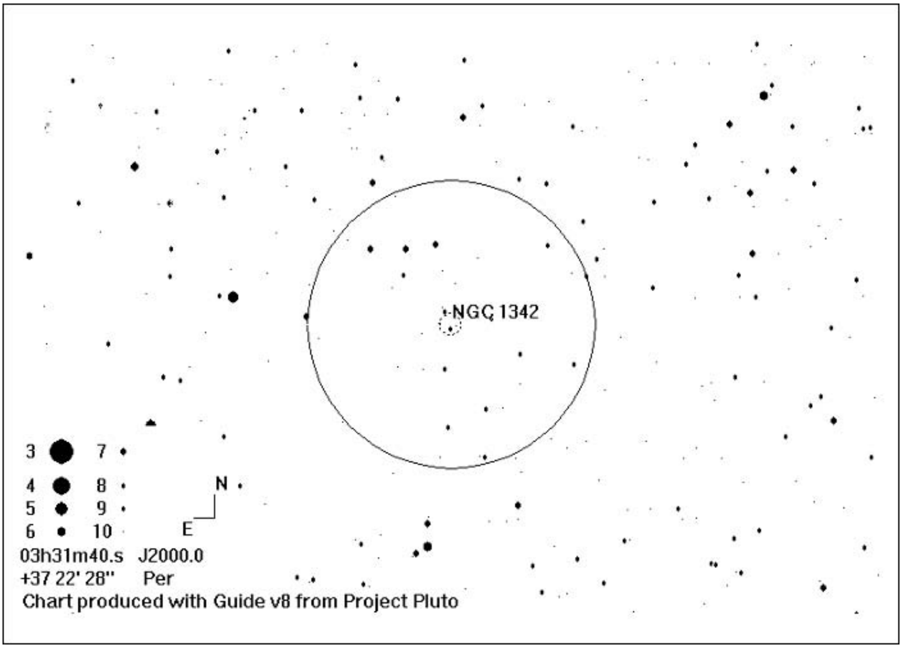
Orion: M42 (NGC 1976, The *Great Orion Nebula*)

This naked-eye object is found in the middle of Orion's sword. The *Great Nebula* is listed separately among the objects for 50-mm binoculars, but double the aperture and triple or quadruple the magnification, and it is almost like looking at a different object, especially on a transparent dark night. In big binoculars, far more fine detail becomes visible; it seems that the longer you look, the more you see, and a false stereopsis emerges. Look for structure around the "fish-mouth" and in the "wings." The *Trapezium* (*θ Ori*) becomes resolvable and can be resolved into four stars with good optics and steady seeing. This showpiece of the northern winter skies is one to be enjoyed over and over again.



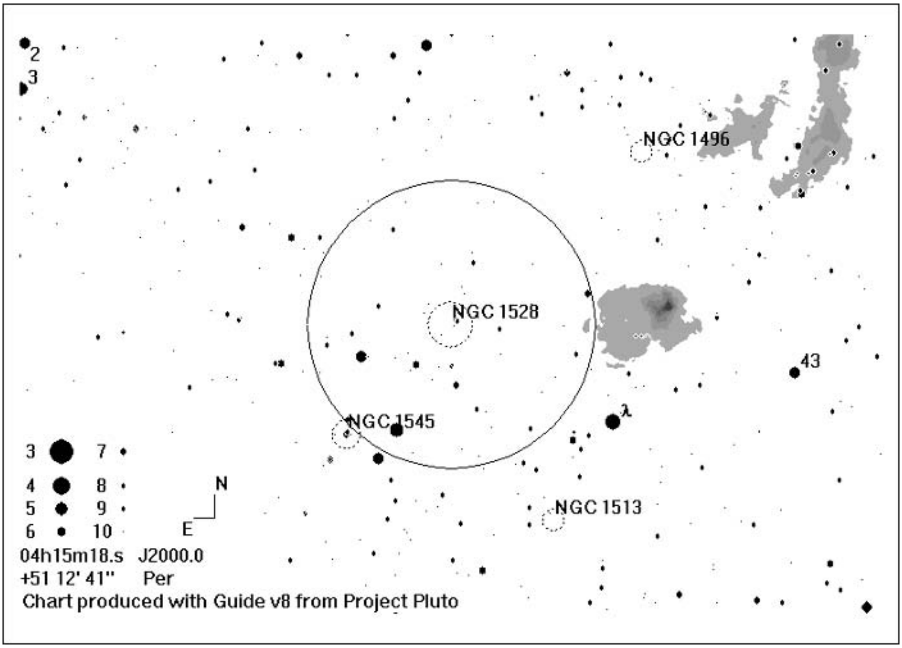
Pavo: Globular Cluster: NGC 6752

NGC 6752 is 1.5 degrees from *ω Pav* in the direction of *α Pav*. For Northern Hemisphere observers, it may be easier to start at *α Pav*, from which you go four fields W and then one field S. NGC 6752 is a large (19 arcmin) fairly loose globular that is one of the best of this class of object for large binoculars. It is bright (magnitude 5.4) and is worth looking for from any location south of the Tropic of Cancer.



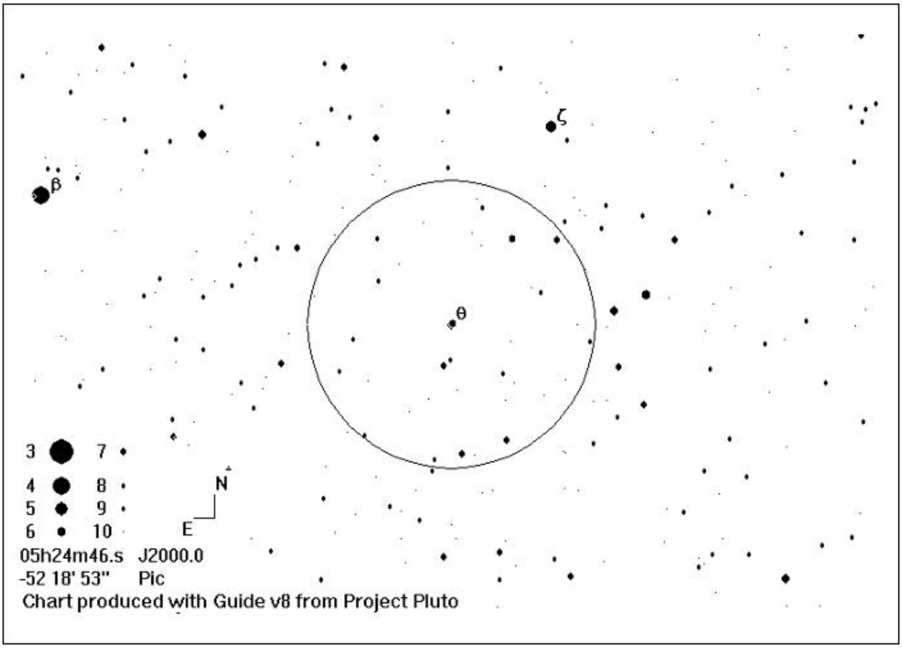
Perseus: Open Cluster: NGC 1342

This cluster is best located with the aid of either a reflex finder or with wider field binoculars. If you aim at a spot halfway between *Algol* (β *Per*) and ζ *Per*, NGC 1342 will be in the field, slightly toward *Algol*. This is a rather sparse cluster that is partially resolved in large binoculars. I find it of interest as it only has a few stars in each magnitude band.



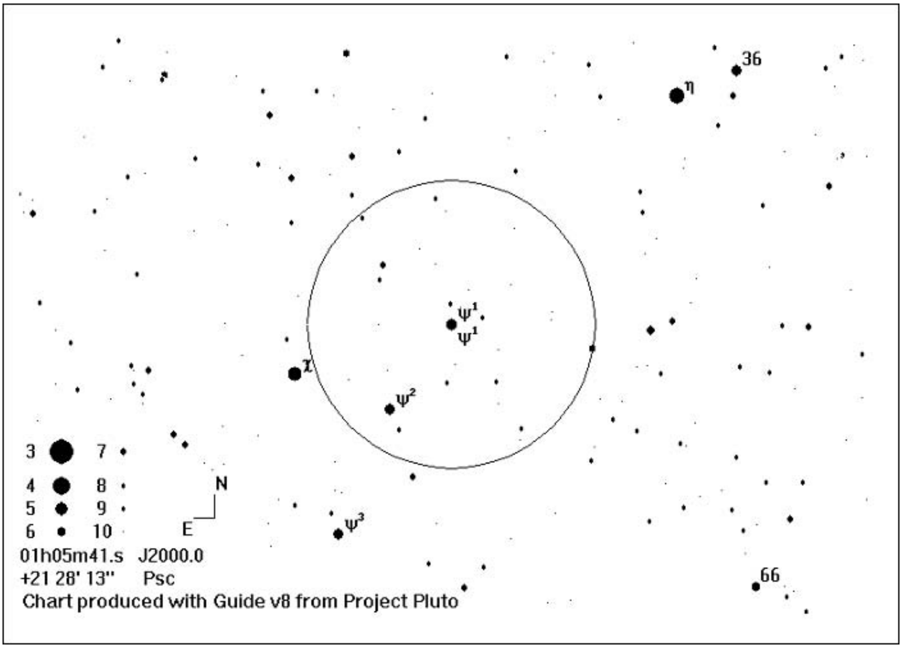
Perseus: Open Cluster: NGC 1528

From *δ Per*, scan two fields to the NE to find *λ Per*. Place *λ Per* near the SW of the field and NGC 1528 will appear as a misty patch to the NE. Only a few stars are resolved in this bright cluster, which still appears mostly as a misty patch even in big binoculars. It is one of several objects that could easily have been in Messier's catalog of cometlike objects. Also look at NGC 1545 to the SE, which can fit into the same field. By comparison, this is a rather poor cluster, being sparser and smaller.



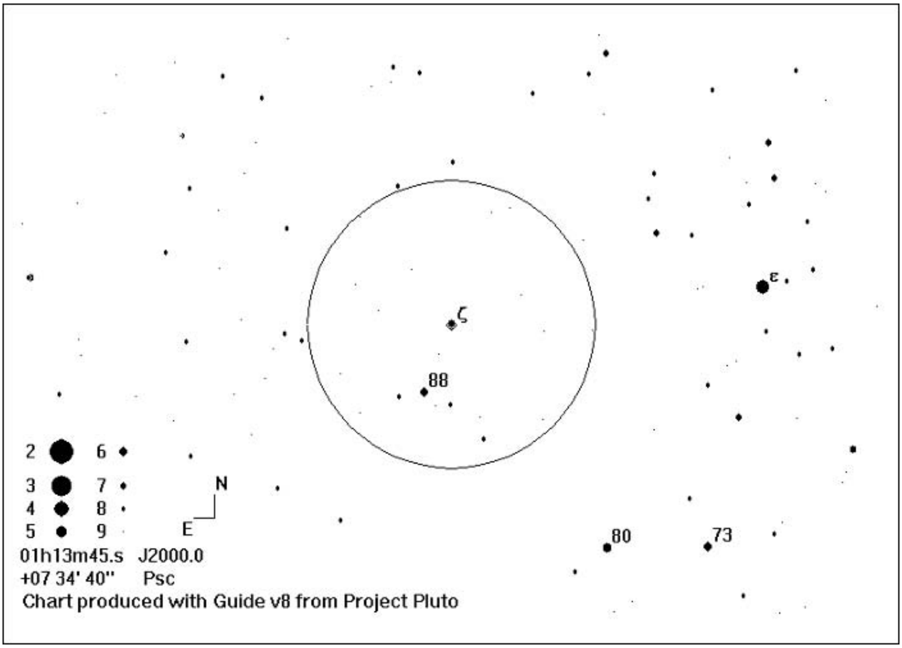
Pictor: Double Star: θ Pictoris

θ Pic makes the right angle of the right triangle that has β and *ζ Pic* at its other apexes. Pictor is a constellation that is unremarkable to the naked eye, but which comes into its own with binoculars. *θ Pic* is a pair of almost equal brilliant white stars (just fainter than 6th magnitude) that are separated by 38 arcsec.



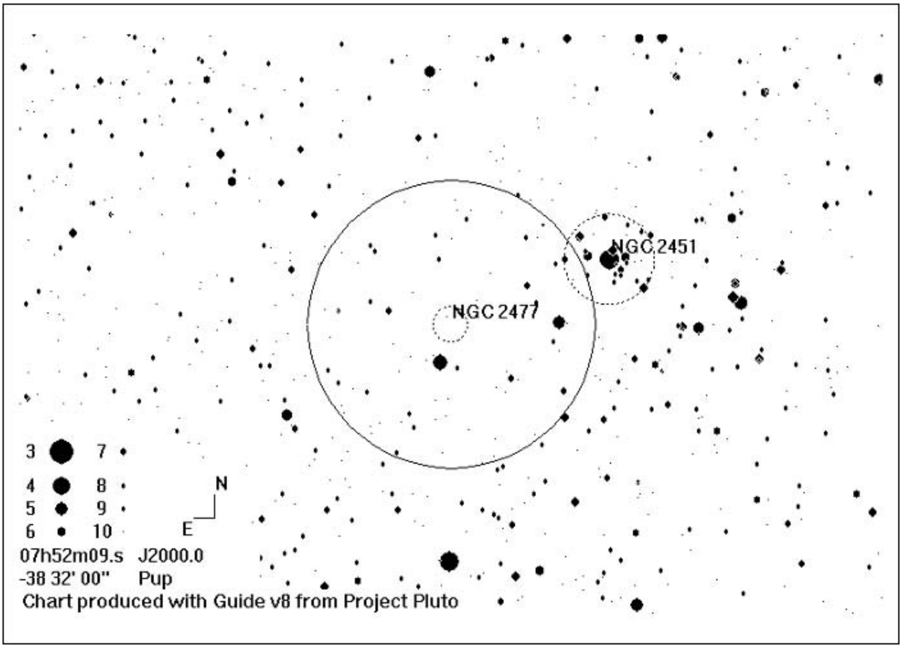
Pisces: Double Star: ψ1 Piscis

ψ1 Psc lies in the northern branch of the Pisces asterism, a degree and a half from *χ Psc* in the direction of *ν Psc*. This is a delightful double of two brilliant white 5th magnitude stars separated by 30 arcsec.



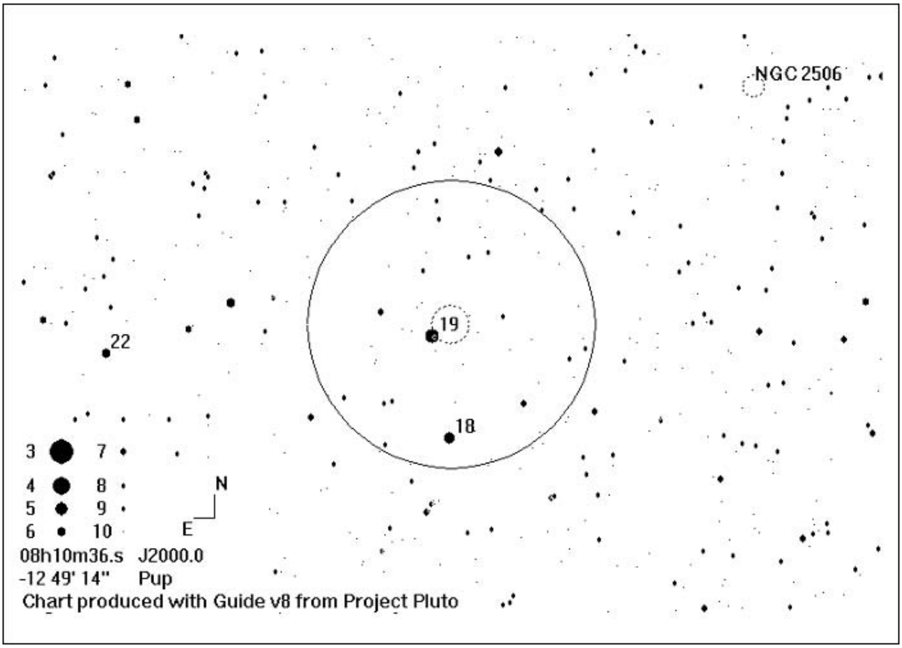
Pisces: Double Star: ζ Piscis

ζ Psc lies on the southern "branch" of the constellation, just over one field E of the brighter *ε Psc*. This is a very pretty pair of 5th and 6th magnitude separated by 23 arsec.



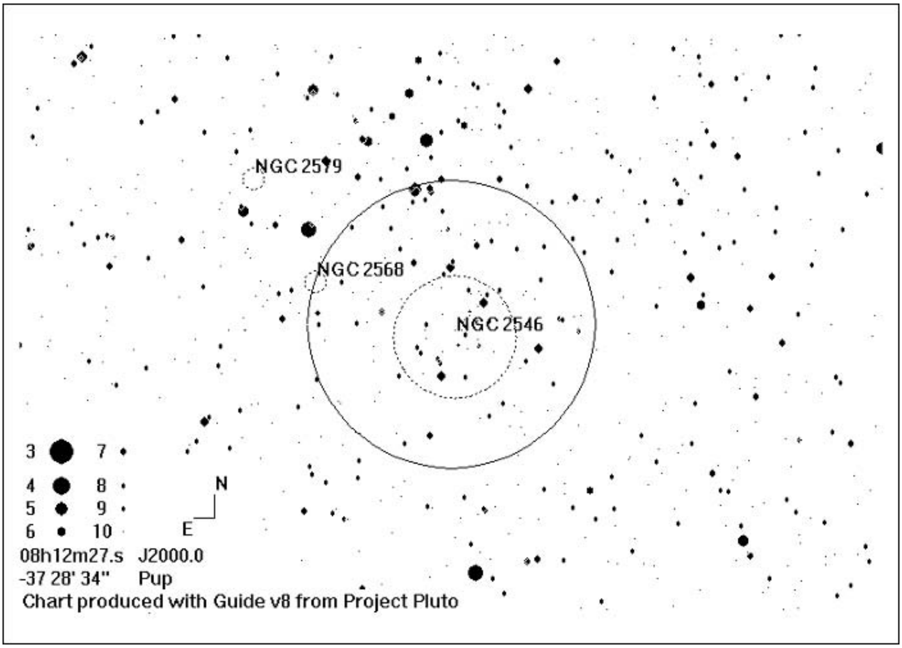
Puppis: Open Cluster: NGC 2477

NGC 2477 is a very slightly more than one field NW of *ζ Pup*. This is an absolutely superb cluster. Only a handful of stars are resolved in big binoculars, but the hundreds of unresolved stars provide a beautiful backdrop to those few. Compare it to the sparser NGC 2451, which can be included in the same field and is described in the list of 50-mm objects.



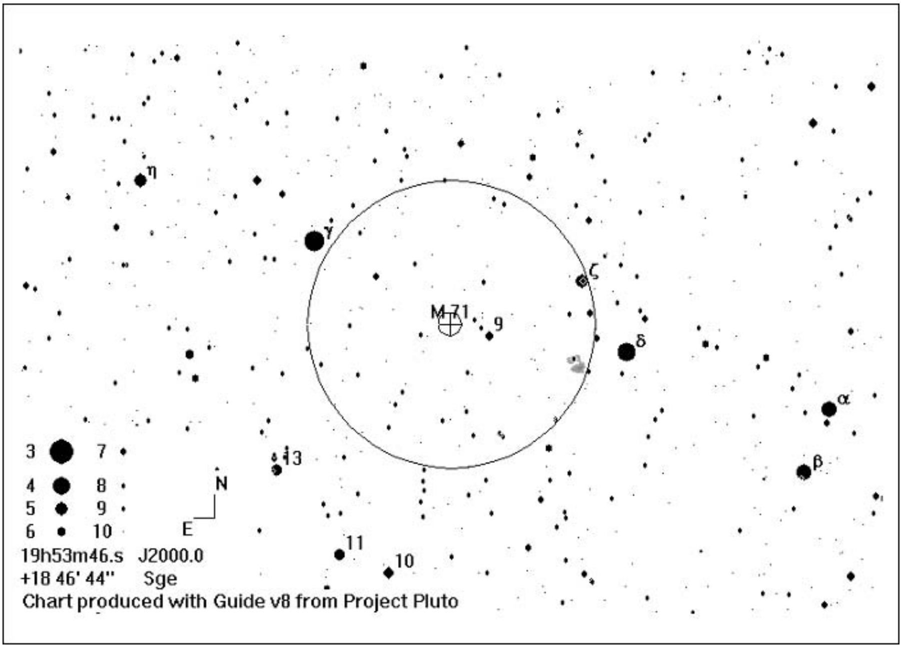
Puppis: Open Cluster: NGC 2539

NGC 2539 is adjacent to the 5th magnitude *19 Pup*, which itself is 8 degrees SE of *α Mon*. NGC 2539 is a challenging object to locate, but relatively easy to identify. It requires good sky conditions, which, owing to its declination, is rare from the latitude of Britain. I find the surrounding star field confusing for star-hopping and my usual method of location is to scan the region with 10×42 binoculars, in which it appears as a faint misty patch, and find the location with these in order to point the larger instrument in the same direction. It appears in the larger instrument merely as a larger misty patch, but one that is attractive for its delicacy.



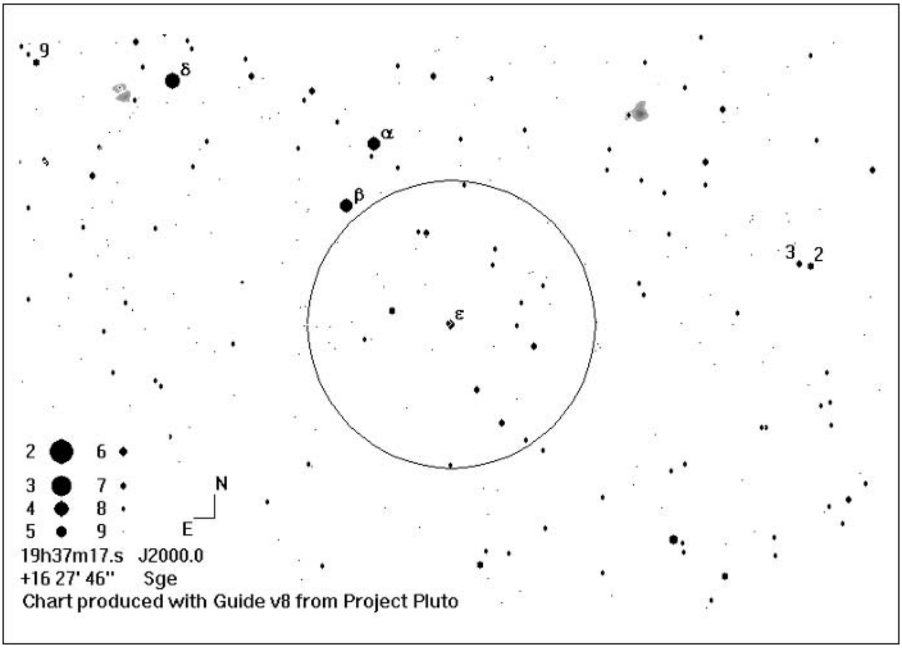
Puppis: Open Cluster: NGC 2546

NGC 2546 is located 3 degrees to the NE of ζ *Pup*. This huge, sparse cluster is a fine sight in big binoculars, which reveal the varied colors of some of the brighter stars. It lies in a lovely star field and is altogether a delightful object.



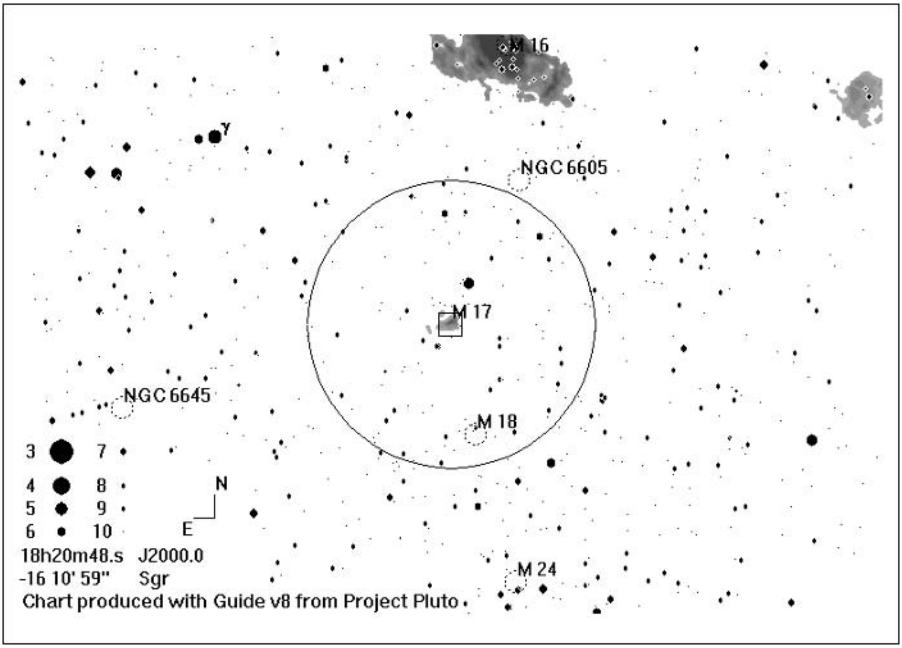
Sagitta: Cluster: M71 (NGC 6838)

M71 is marginally south of the midpoint of a line joining ψ and δ *Sge*. It is easy to distinguish this small cluster from the background Milky Way in big binoculars at ×37. There is some dispute as to its nature, and it has been variously described as a compact open cluster and a loose globular cluster, with the latter having the most recent favorability. It is included because of this somewhat enigmatic nature, as it is otherwise a fairly banal object in binoculars.



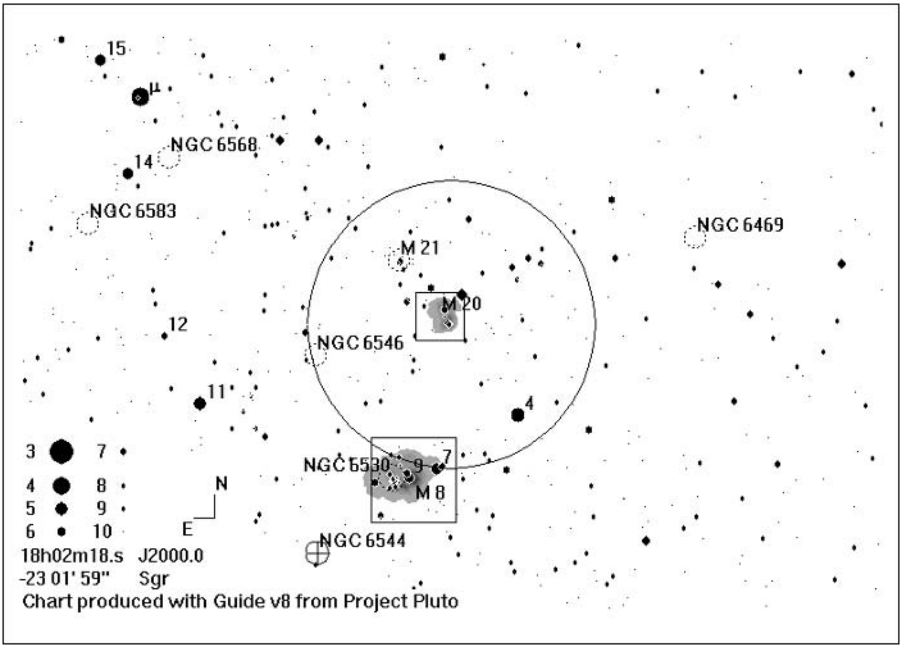
Sagitta: Double Star: ε Sagittae

ε Sge is located about 1.5 degrees SW of *α* and *β Sge*, the fletch end of the arrow. *ε Sge* is a beautiful colored pair with the 8th magnitude blue secondary 88 arcsec from the 6th magnitude yellow primary.



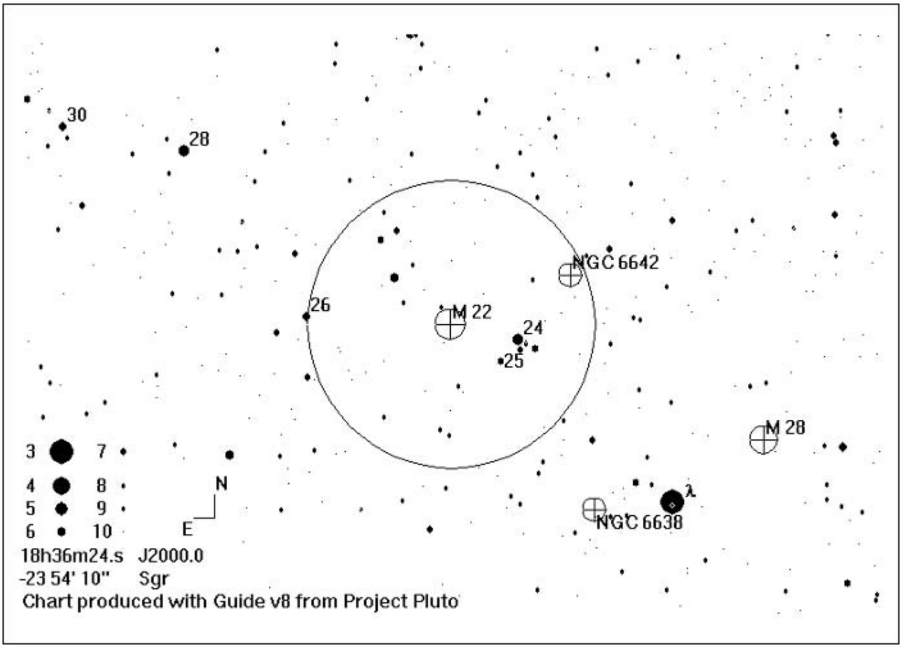
Sagittarius: Emission Nebula: M17 (NGC 6618, the *Omega Nebula* or *Swan Nebula*)

The *Omega Nebula* forms forms the southern apex of an equilateral triangle with γ *Sct* and M16 (below) as its other apexes. The initial impression is of an elongated glimmer of grayish light. Under examination with averted vision (or a UHC filter) an extension appears to the SW of the glimmer, giving the nebulosity the appearance of a checkmark rather than an omega or a swan. Also in the region is the somewhat unimpressive M18. About fifteen stars are visible in this rather sparse open cluster. The other open cluster shown in the chart, NGC 6605, is even less impressive: it is entirely nonexistent. It is one of several objects in the NGC catalog that does not actually exist. The *Eagle Nebula*, M16, shows over a dozen stars embedded in a distinct nebulosity. The nebulosity is enhanced by a UHC filter. This is the region of the famous "Pillars of Creation" image from the Hubble Space Telescope.



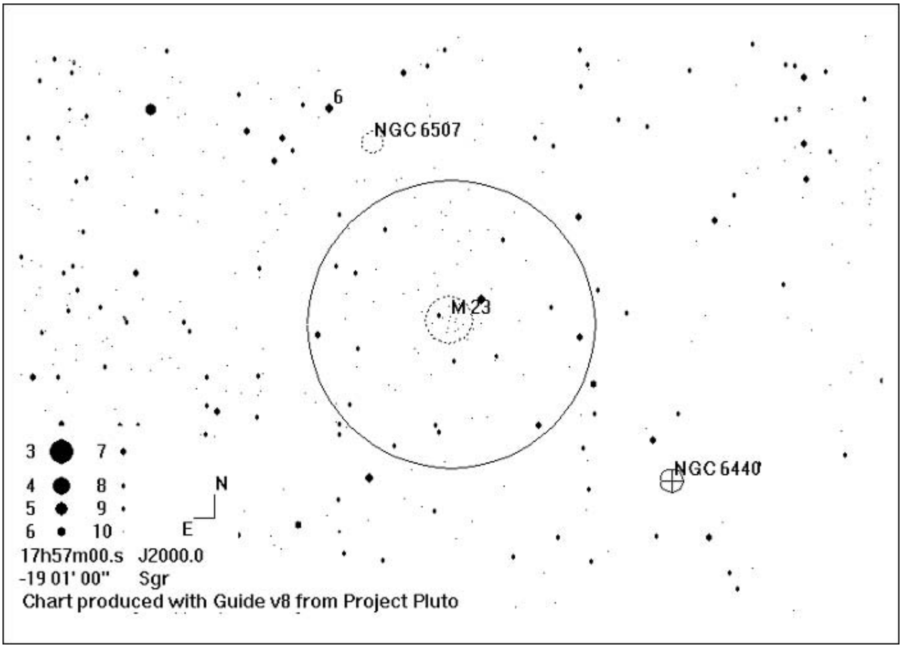
Sagittarius: Emission Nebula: M20 (NGC 6514, the *Trifid Nebula*)

First, find the *Lagoon Nebula* (M8, NGC 6523), which is just over 5 degrees (two fields) WNW of *λ Sgr*, the "peak" of the lid of the Sagittarius "teapot" asterism. Place the *Lagoon* at the S of the field and the *Trifid* should appear near the center. In size, the *Trifid* (so called, not because of any relation to John Wyndham's sentient plants, but because of its division into three parts by dark dust lanes) is dwarfed by M8 to the S, but it is otherwise an impressive object. Big binoculars will resolve a handful of stars against the bright nebulosity. If it is high up in a dark sky, you may detect a greenish tinge to the nebulosity.



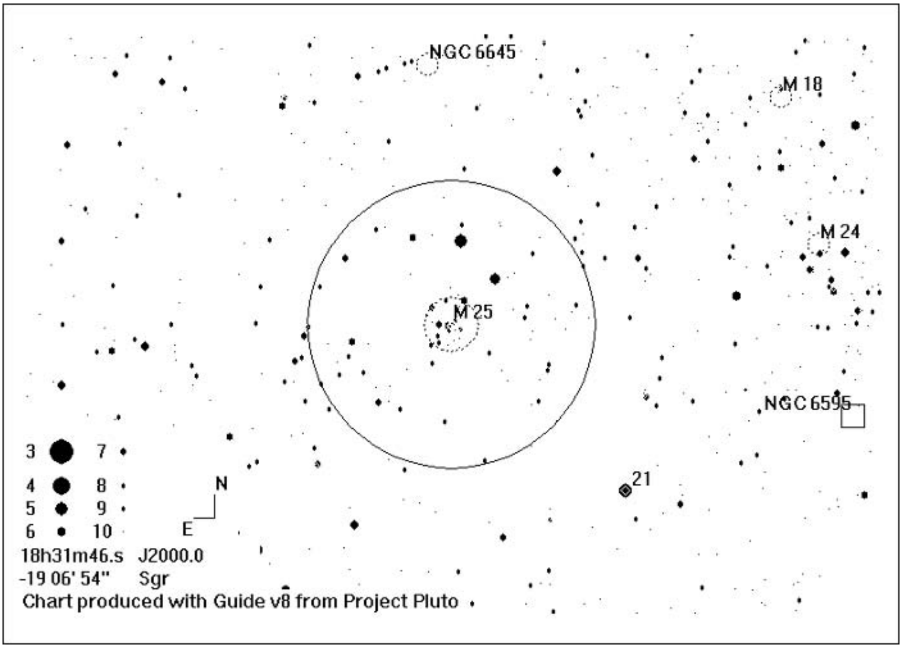
Sagittarius: Globular Cluster: M22 (NGC 6656)

M22 is one field to the NE of *λ Sgr*, the "peak" of the "teapot lid" asterism. This is a beautiful globular cluster at ×37, where it shows a very much brighter core, very much like the nucleus of a comet. This makes it very clear why Charles Messier compiled his catalog of objects that were not to be confused with comets. It is the third largest of the Southern Hemisphere globular clusters and, despite this accolade usually being given to M13 (which is easier to observe), is the largest globular that is visible from the United Kingdom.



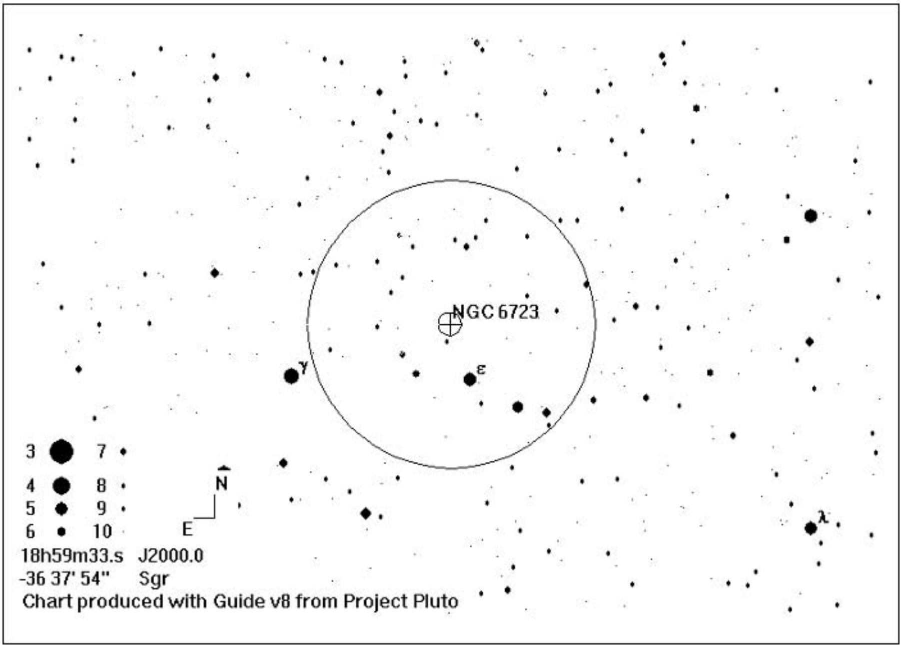
Sagittarius: Open Cluster: M23 (NGC 6494)

Scan SE four fields from *ζ Ser*, in the direction of *μ Sgr*. M23 should lie near the middle of the fourth field. This large bright cluster is an exquisite object in large binoculars and shows over a dozen stars at ×37. To me it appears that the brighter stars form a lower case alpha (α).



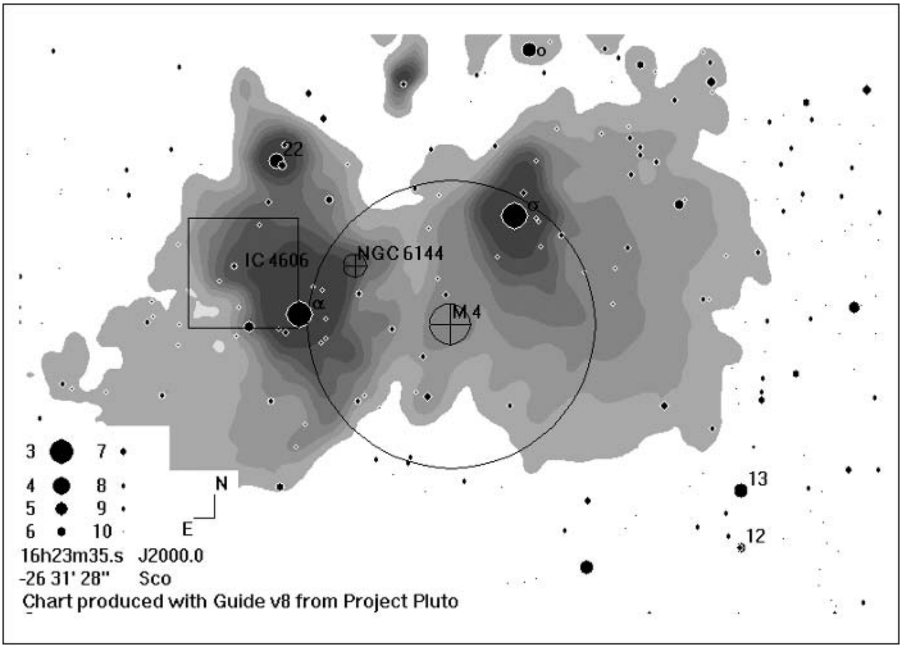
Sagittarius: Open Cluster: M25 (IC 4725)

If you place *γ Sct* on the W edge of the field and scan S for two fields, you will find M25 showing distinctly against the background Milky Way. This bright rich cluster is unusual for open clusters in that it has few blue-white stars. Of the dozen or so stars that are resolved in big binoculars, note the triangle of deep yellow 7th magnitude stars to the N of the Cepheid variable, *U Sag*, which has a mean magnitude range of 6.3 to 7.1 over a period of 6.7 days.



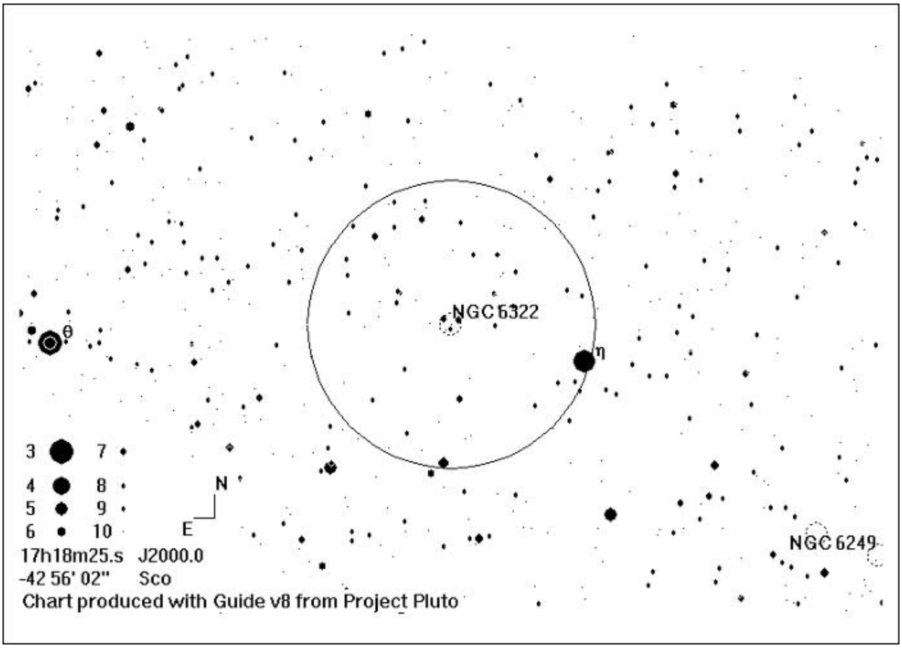
Sagittarius: Globular Cluster: NGC 6723

NGC 6723 is to the N of *ε CrA*, at the right-angled apex of a triangle that has its other apex at *γ CrA*. With a diameter of 11 arcmin and a magnitude of 7, NGC 6723 is another of those large bright southern globulars. It is fairly loose at its extremities and looks as though it is about to resolve at ×37.



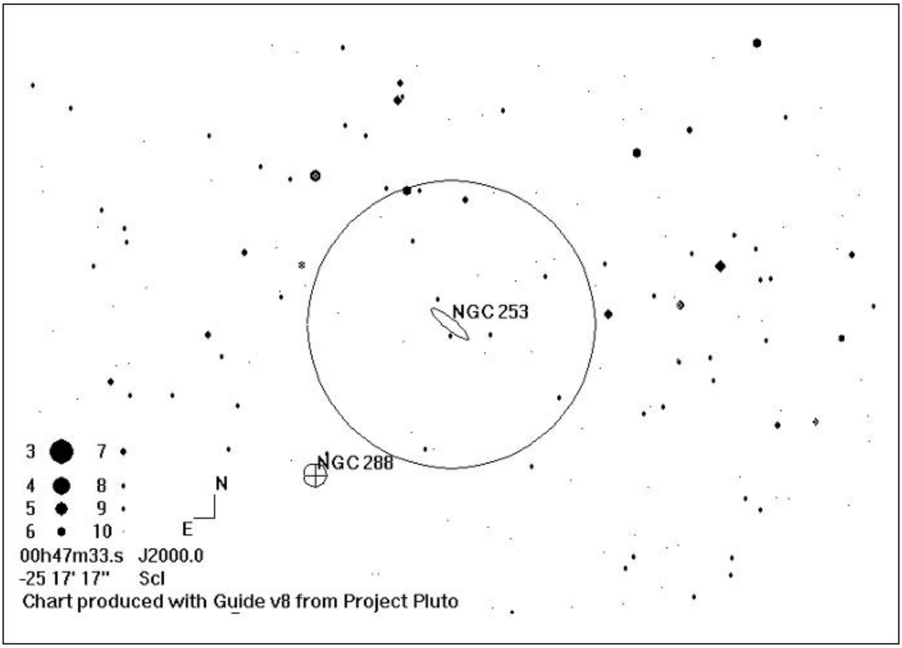
Scorpius: Globular Cluster: M4 (NGC 6121)

M4 has to be the easiest globular cluster to find. Simply place *Antares* (α *Sco*) on the E of the field and M4 will lie at the center. M4 is easy to identify in any binoculars. It is relatively close to us (7,000 light years) for a globular cluster; indeed it is closer than some open clusters. Owing to its proximity, it appears as a rather loose cluster that begins to reveal detail in 37×100 binoculars. It would be even more spactacular were it not for intervening dust. It is in a beautiful star field that I find easier to appreciate with binoculars than with a telescope.



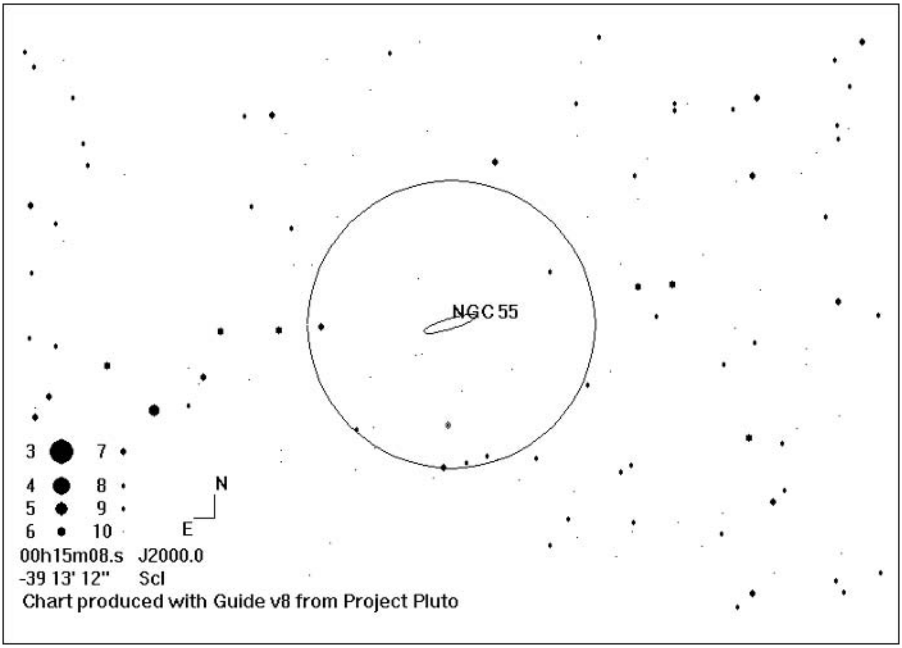
Scorpius: Open Cluster: NGC 6322

Place *η Sco* near the W edge of the field and NGC 6322 will appear near the center. The stars of this pretty cluster are framed by a near-equilateral triangle of stars of about magnitude 7.5.



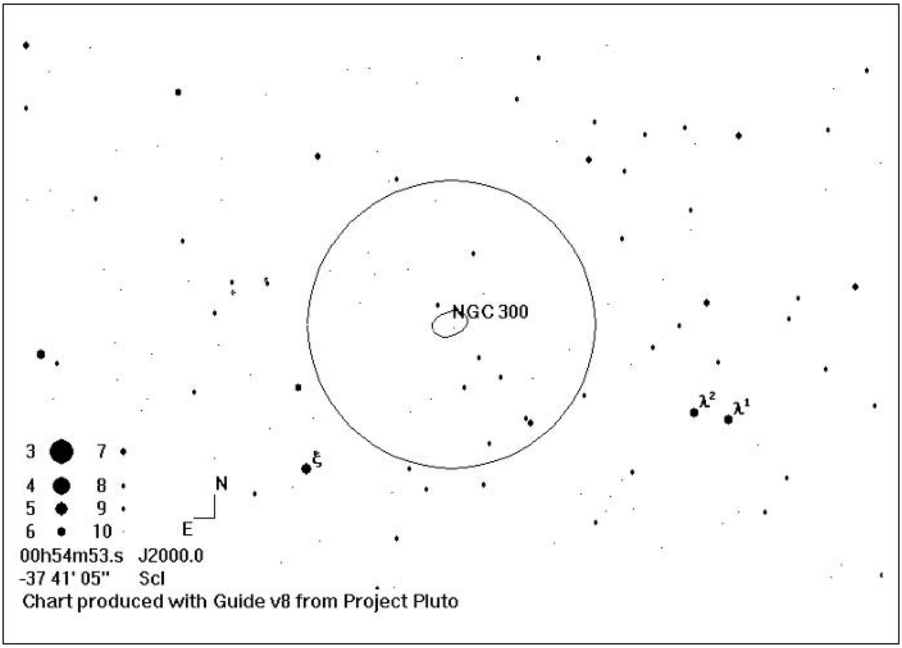
Sculptor: Galaxy and Globular Cluster: NGC 253 and NGC 288

Two fields to the S of *Diphda* (*β Cet*) find a triangle of 5th magnitude stars. NGC 253 is just over one field to the S of the most southerly star of this triangle. This bright galaxy shows as an elongated glow with a brighter middle. It is a relatively easy object, even from the latitude of Britain, despite its low transit altitude. It is so bright and large (over 20 arcmin long) that it is possible to find and identify, even in smaller binoculars. A good southern horizon is, of course, essential from this latitude. The globular cluster NGC 288, which lies three-quarters of a field to the SE, is another easy object, showing as a dim circular glow with about half the diameter of the galaxy's length.



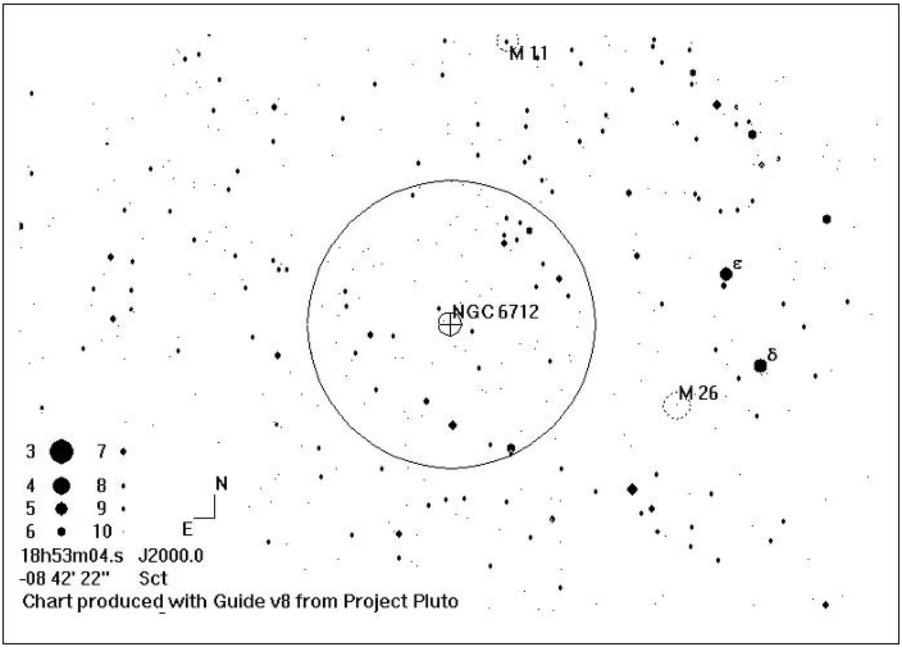
Sculptor: Galaxy: NGC 55

NGC 55 is located one and a half fields to the NW of *α Phe*. This Sculptor galaxy is not visible from the latitude of Britain. It is slightly dimmer than NGC 253, but is noticeably longer and thinner. It is neatly framed in a 2.5-degree field, making it a very nice binocular object.



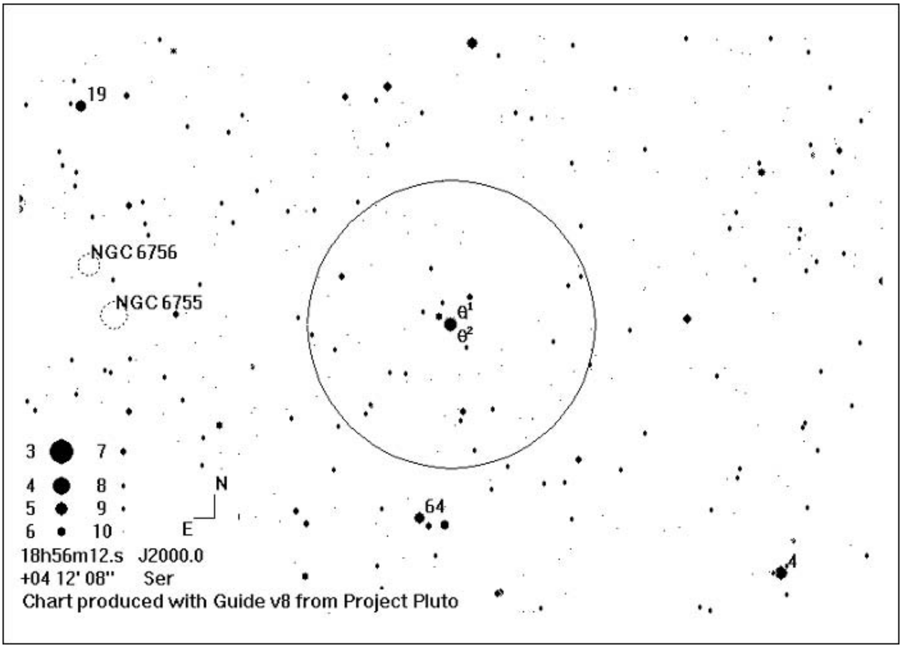
Sculptor: Galaxy: NGC 300

NGC 300 makes the slightly obtuse apex of an isosceles triangle with *υ Scl* and *λ2 Scl* as the base angles. Imagine a mini version of M33 and you have NGC 300. It is to the 37×100 binocular what the Messier galaxy is to a 10×50 binocular. It is apparently 9th magnitude, but is of extremely low surface brightness. It is difficult to view from northern temperate latitudes and is far better seen from the tropics or southern latitudes.



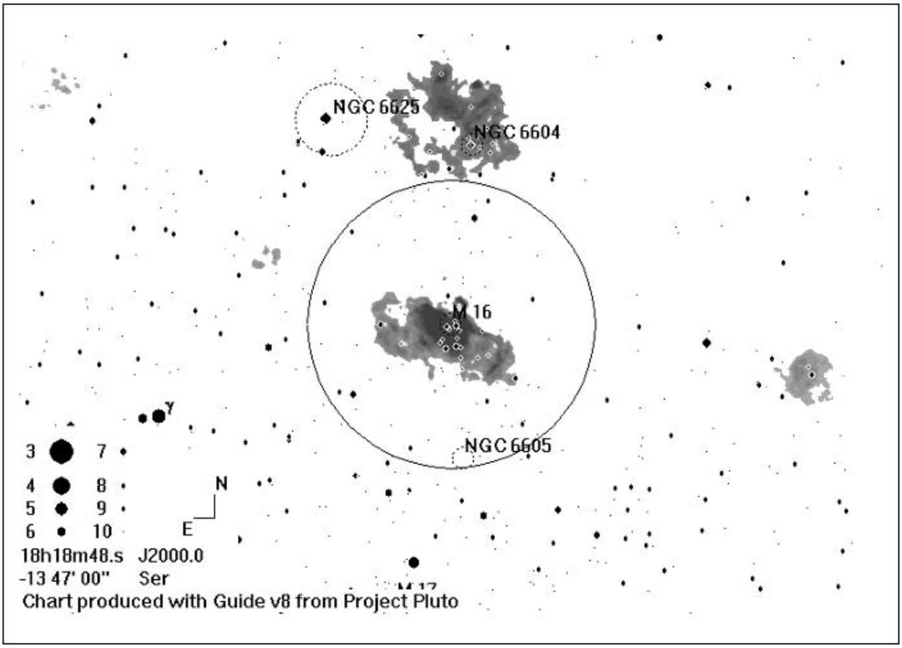
Scutum: Globular Cluster: NGC 6712

NGC 6712 is one 2.5-degree field E of *ε Sct*. This 8th magnitude globular cluster is an easy object, about 5 arcmin in diameter. It is in a particularly beautiful star field. In particular note the various colors of the stars in the little equilateral triangle of 7th and 8th magnitude stars at the NW of the field.



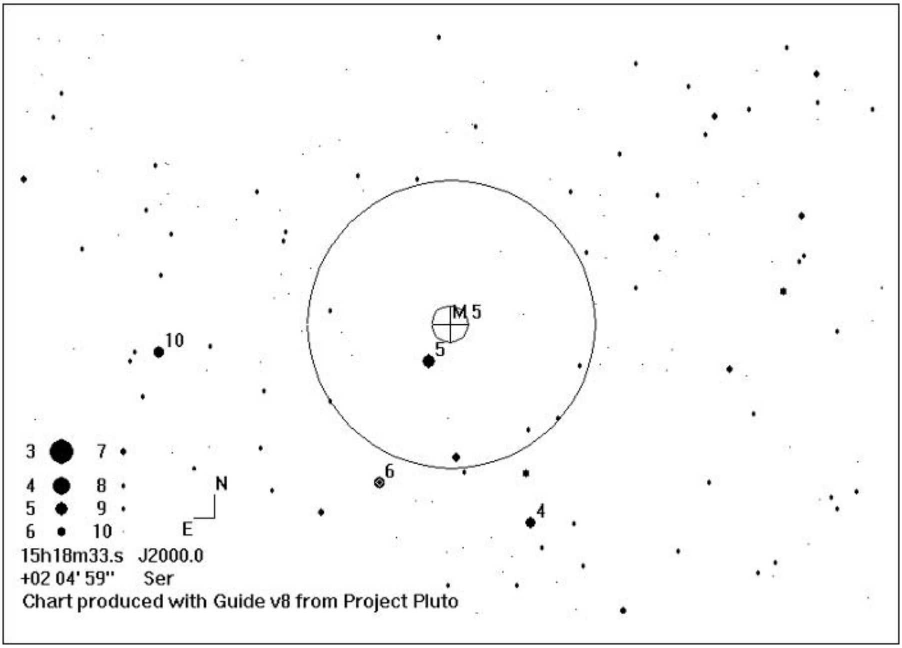
Serpens: Double Star: θ Serpentis

θ Ser is the tip of the tail of the snake. It is three fields to the W of *δ Aql*. *θ Ser* is a pair of 5th magnitude stars of spectral type A5 separated by 22 arcsec. It is easily split at ×37 and, owing to the approximate equality of brightness of its components, is a good test of 10×50 binoculars.



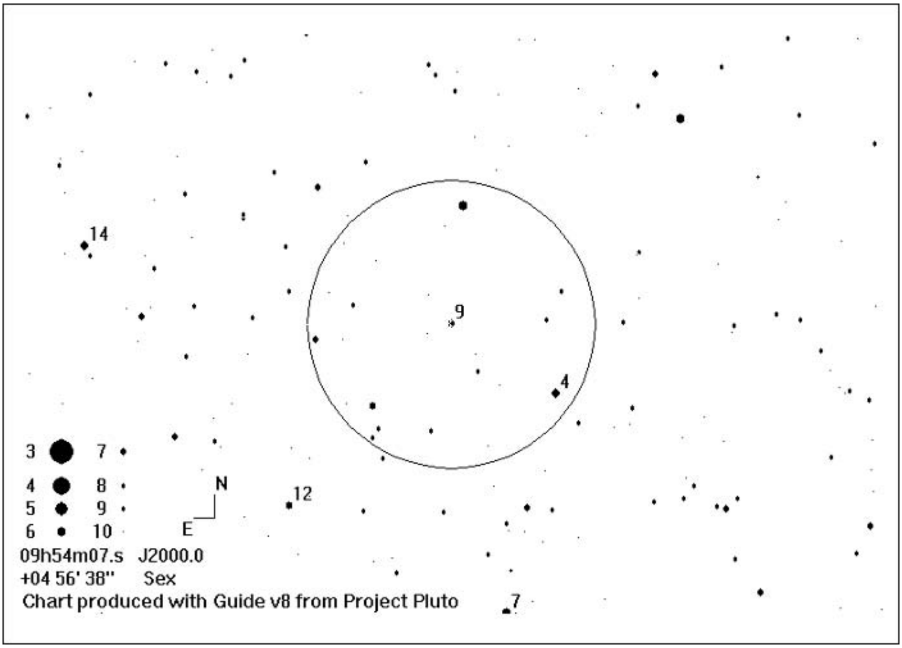
Serpens: Emission Nebula and Cluster: M16 (NGC 6611, the *Eagle Nebula*)

Identify *γ Sct*, place it at the S of the field of view and pan one and a half fields to the W. The cluster associated with M16 should be visible near the center of the field. Unless skies are very good, you may only be able to see the cluster in an unfiltered view. A UHC filter will bring the nebulosity into prominence, and you should be able to identify in its form the wings and tail from which it gets its common name.



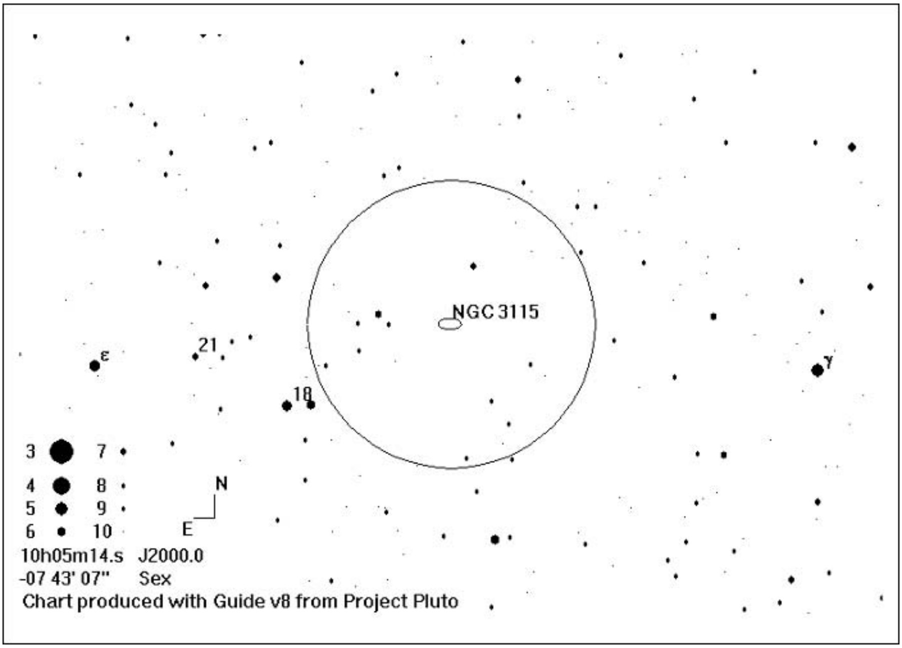
Serpens: Globular Cluster: M5 (NGC 5904)

Find M5 by panning just over three fields from α *Ser* in the direction of μ *Vir*. M5 is one of the better globulars to view with binoculars. Although it does not seem as bright as M13, it appears slightly larger.



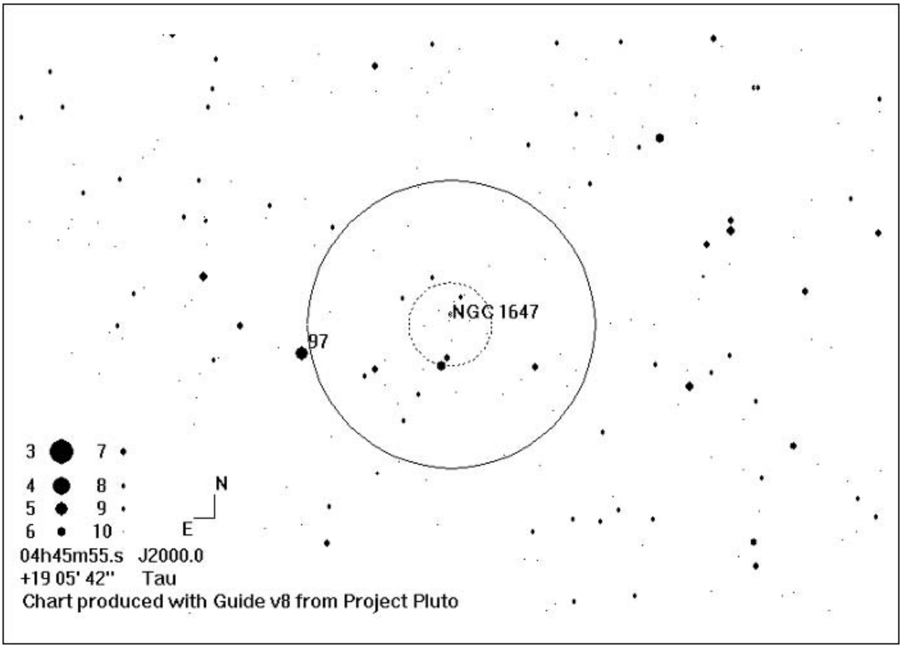
Sextans: Double Star: 9 Sextantis

9 Sex is 8 degrees SW of *α Leo* (*Regulus*). It is in the direction of *ι Hya*, and the hop is aided by *π Leo*, which is just over halfway from *α Leo* to the double. *9 Sex* is a widely viewed (53 arcsec) pair of 6th and 9th magnitude stars. The primary is noticeably red.



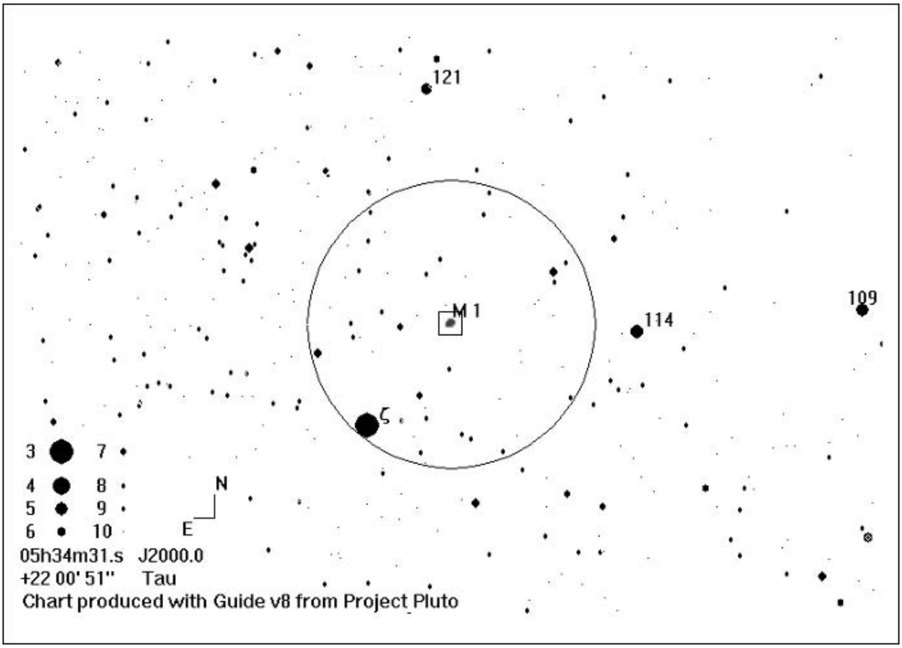
Sextans: Galaxy: NGC 3115 (the *Spindle Galaxy*)

Identify the 5th magnitude *γ Sex*, which is 6 degrees E of *α Hya* (*Alphard*). NGC 3115 is one and a half fields farther E from *γ Sex*. 100-mm binoculars at ×37 will show clearly how this bright galaxy got its name. It is extended about five times its width on a NE to SW axis.



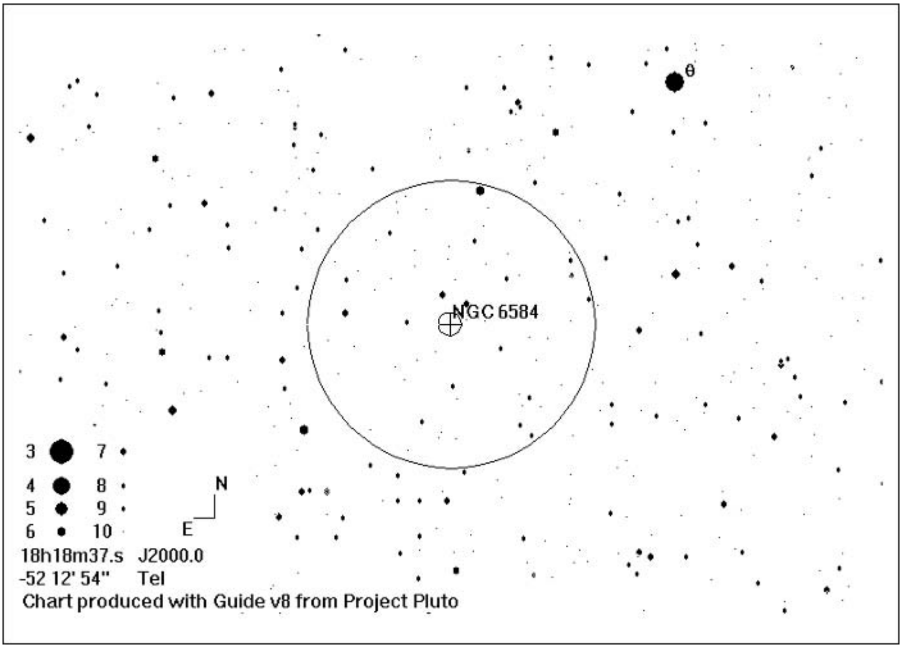
Taurus: Open Cluster: NGC 1647

NGC 1647 is one and a half fields NE of *Aldebaran* (*α Tau*). This is a cluster that deserves to be far better known. It is underobserved because of its proximity to its illustrious neighbors, the *Pleiades* and the *Hyades*. This big, somewhat sparse, grouping of stars is much better viewed in binoculars than it is in a telescope, where it does not always appear to be an obvious cluster.



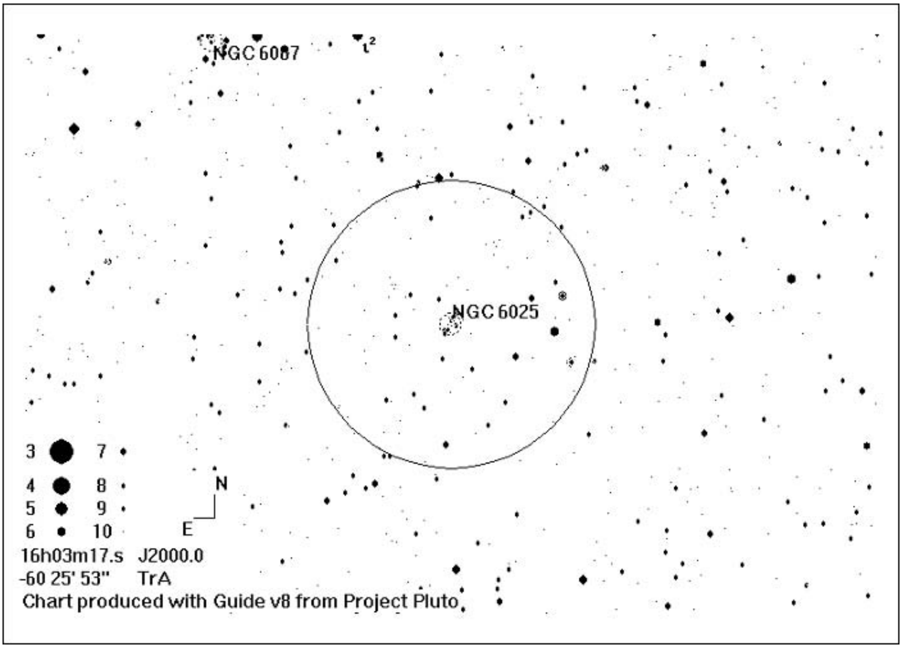
Taurus: Supernova Remnant: M1 (NGC 1952, the *Crab Nebula*)

Place *ξ Tau* at the SE edge of the field, and M1 will appear in the middle. On the night of August 28, 1758, a young assistant at the Naval Observatory at the Hotel de Cluny in Paris discovered what appeared to be a comet in the constellation of Taurus. This young man had been charged by the observatory director (Joseph Nicholas Delisle) to find Halley's Comet, the return of which had been predicted for that year. The assistant was unable to observe again for two weeks and, when he did, his new "comet" had not moved. This object in Taurus became the first object in the young Charles Messier's catalog of "fuzzy blobs" that should not be mistaken for comets, and thus he sowed the seeds for many sleepless nights, around the end of March and beginning of April, for amateurs who attempt his eponymous "marathon" of observing the entire catalog between dusk and dawn. The object in Taurus was later found to be the remnant of a supernova of 1054, which was visible for two years and was even briefly a daylight object. For all that illustrious past, M1 is a fairly boring object to observe with binoculars; it shows as nothing except a small fuzzy patch, which is difficult to see unless the sky is very dark.



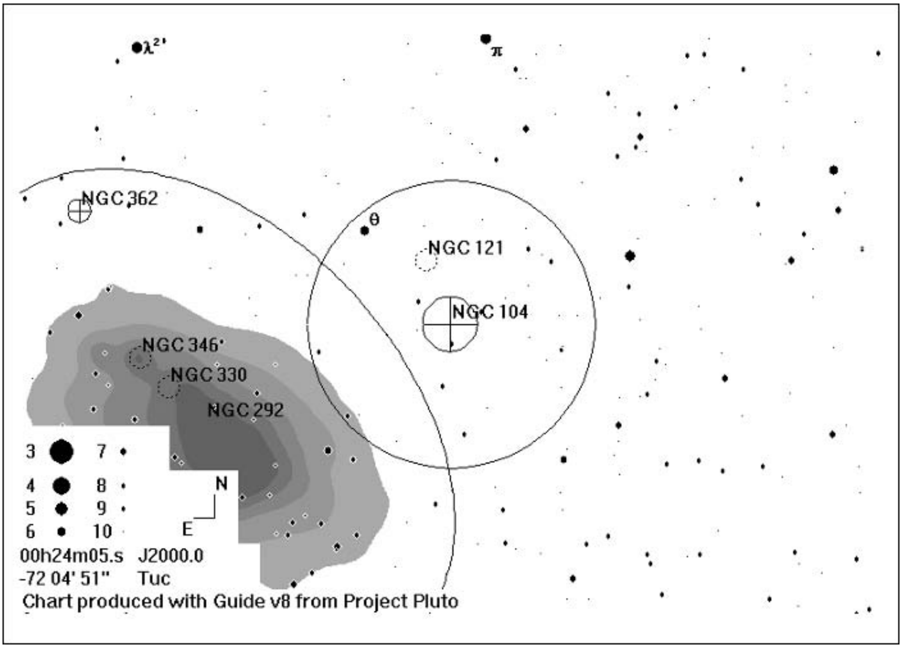
Telescopium: Globular Cluster: NGC 6584

NGC 6584 is just over one field to the SE of the distinctively blue *θ Ara*. NGC 6584 is a relatively small (8 arcmin), but distinctively bright globular cluster. It is entirely unresolved at ×37, but is one of those binocular objects that seems as though just a little more magnification will start to reveal its secrets.



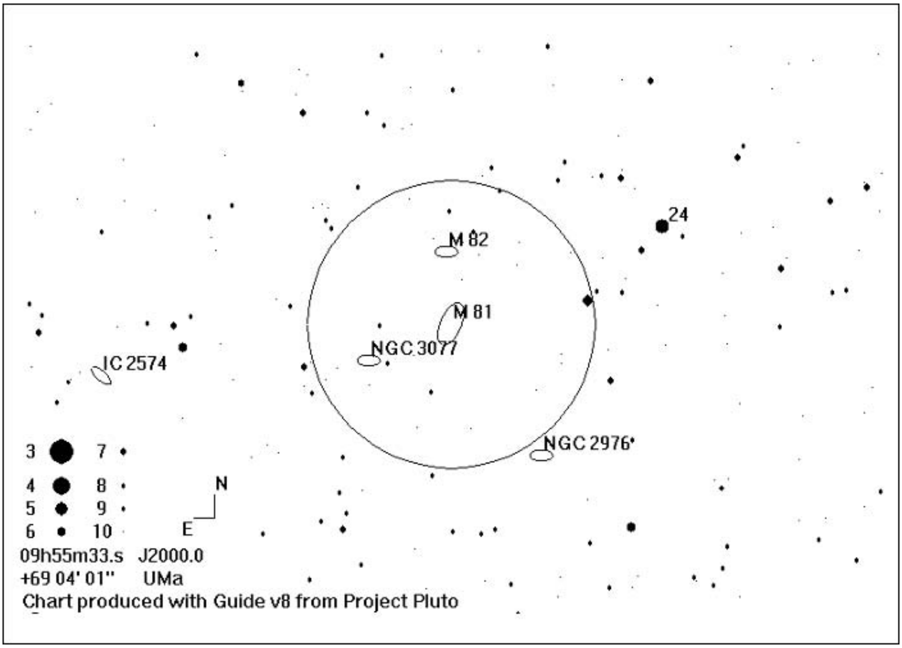
Triangulum Australe: Open Cluster: NGC 6025

Follow the line that joins γ to ε to β *TrA* a further 3 degrees and NGC 6025 will be easily visible. This bright cluster resolves into a dozen or more stars in big binoculars. The brighter members are a distinct brilliant diamond-white against a delicate glow.



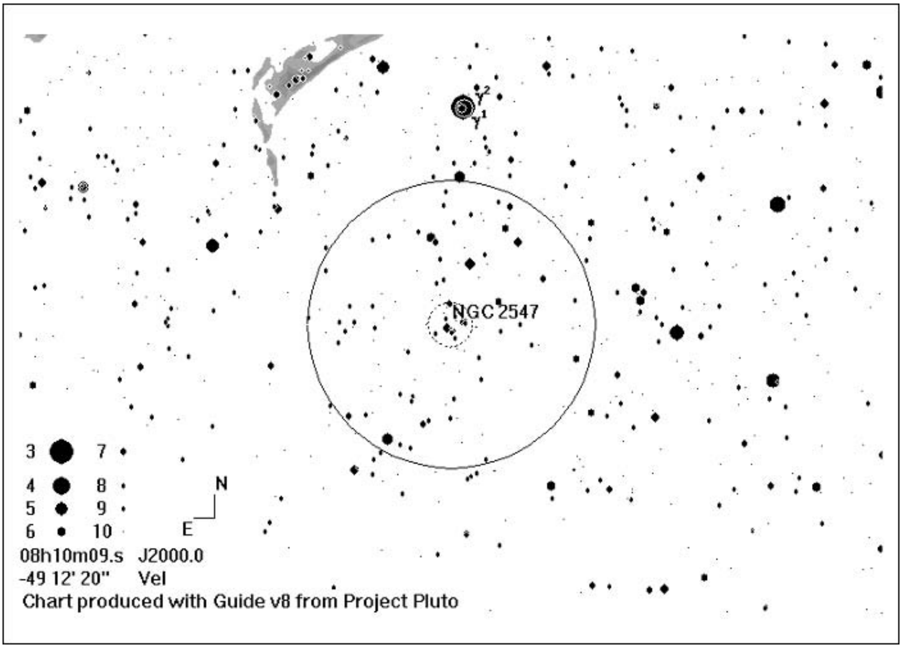
Tucana: Globular Cluster: NGC 104 (47 Tucanae)

47 Tucanae is an easy naked-eye object to observe about a degree to the NW of the *Small Magellanic Cloud* (*SMC*). This is an absolutely superb object in binoculars of any size. Big binoculars begin to resolve its outer regions. Although it is not quite as large or bright as its rival, *ω Cen*, I find that it seems to resolve a bit better. Also visible in binoculars is the otherwise fine, somewhat less impressive, globular, NGC 362, which lies on the N edge of the *SMC*.



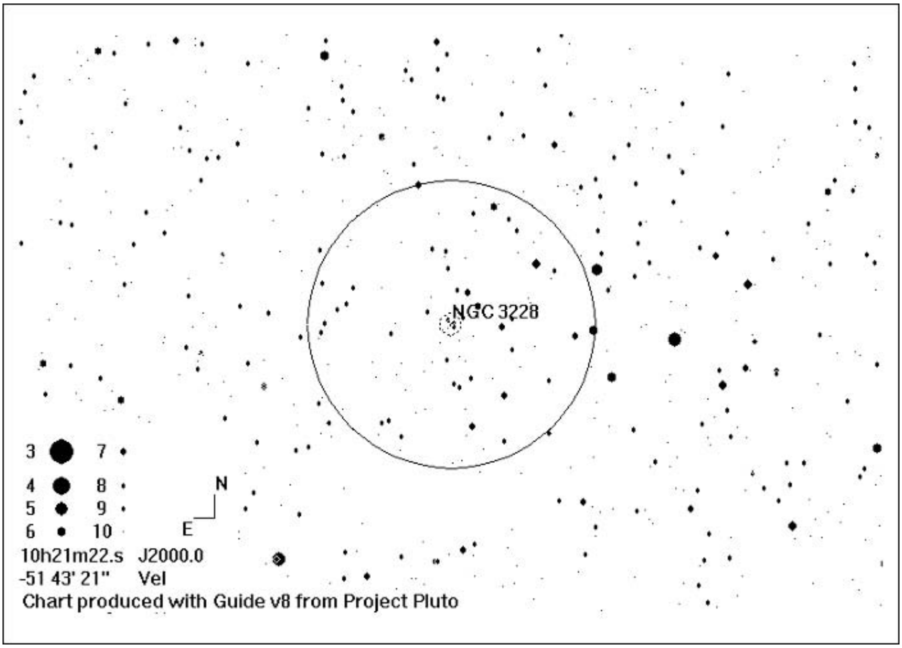
Ursa Major: Galaxy Pair: M81 (NGC 3031) and M82 (NGC 3034)

I usually find this pair with the aid of a reflex finder. Extend a line from *Phecda* (γ *UMa*) through *Dubhe* (α *UMa*) the same distance beyond *Dubhe*. From this point, the galaxies are a degree or so in the direction of *Polaris* (α *UMi*), adjacent to the 4.5th magnitude *24 UMa*. M81 is the easier of the pair to view with small glasses, but both are easy objects at 37×100, with M81 showing a hint of nucleus. Their difference in orientation is obvious.



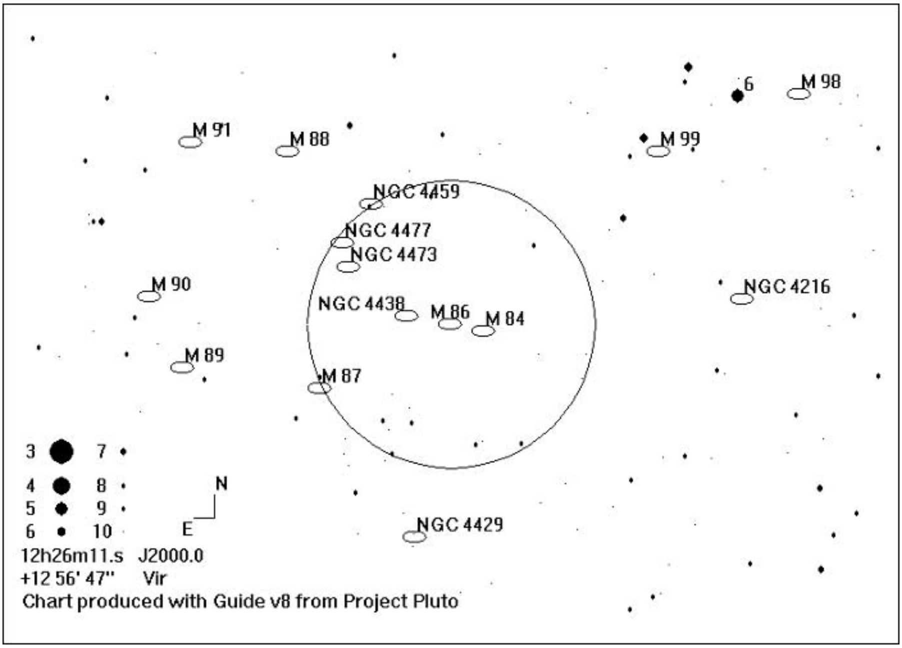
Vela: Open Cluster: NGC 2547

NGC 2547 is 2 degrees S of the 2nd magnitude γ *Vel*. NGC 2547 is a fine cluster, nearly the same apparent diameter as the Moon, that shows over thirty stars at ×37, sky conditions permitting.



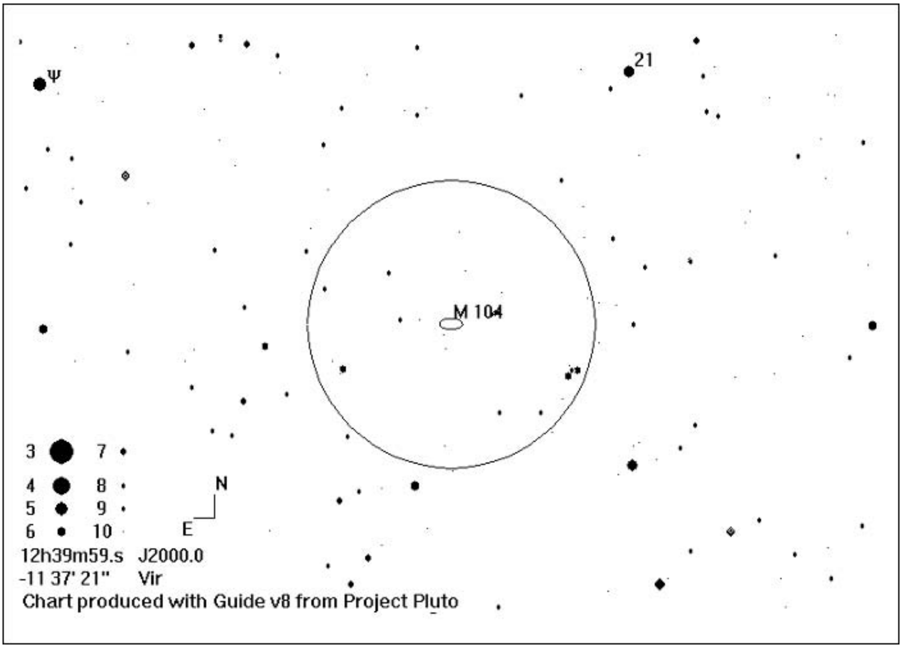
Vela: Open Cluster: NGC 3228

NGC 3228 is situated about half a degree to the NW of dead center of an imaginary line joining ϕ *Vel* and μ *Vel*. NGC 3228 is a small (5 arcmin) cluster of mainly white stars, of which nine are easily visible. It is a Southern Hemisphere version of the sort of binocular cluster that is in great abundance in the Perseus-Cassiopeia region of the Northern Hemisphere.



Virgo: Galaxy Chain: NGC 4374 (M84), 4406 (M86), 4438, 4473, 4477, and 4459 (*Markarian's Chain*)

The coordinates are for M86, the brightest galaxy in the chain. *Markarian's Chain* lies almost exactly halfway between *β Leo* and *ε Vir*; a reflex finder is ideal for placing you in the correct location. The problem in this region of the sky is not finding galaxies, but in sorting them out. There are tens of galaxies available to big binoculars in this region, the *Virgo/Coma* cluster. *Markarian's Chain* is a string of a dozen or so galaxies that extend over nearly 2 degrees from Virgo into Coma. The brightest members are M84 and M86, both of which are easy objects to view. The chart shows the six brightest members of this chain, and you should be able to see all of these if the sky is reasonably dark. More fainter members will become visible under ideal conditions. It is worth exercising patience (and averted vision) to tease the fainter members into visibility. While you are in the locality, it is worth panning around and seeing what other galaxies you can see—and identify!



Virgo: Galaxy: M104 (NGC 4594, the *Sombrero Galaxy*)

M104 is located a little over two fields NNE of *δ Crv*. The *Sombrero* is distinctly elliptical with a central bulge and brighter nucleus at ×37. In ideal conditions, and with averted vision, the dust lane that appears in photographs is suspected.

Bibliography

Moore, P., ed., *Philip's Astronomy Encyclopedia*. London: Philip's, 2002.

Note

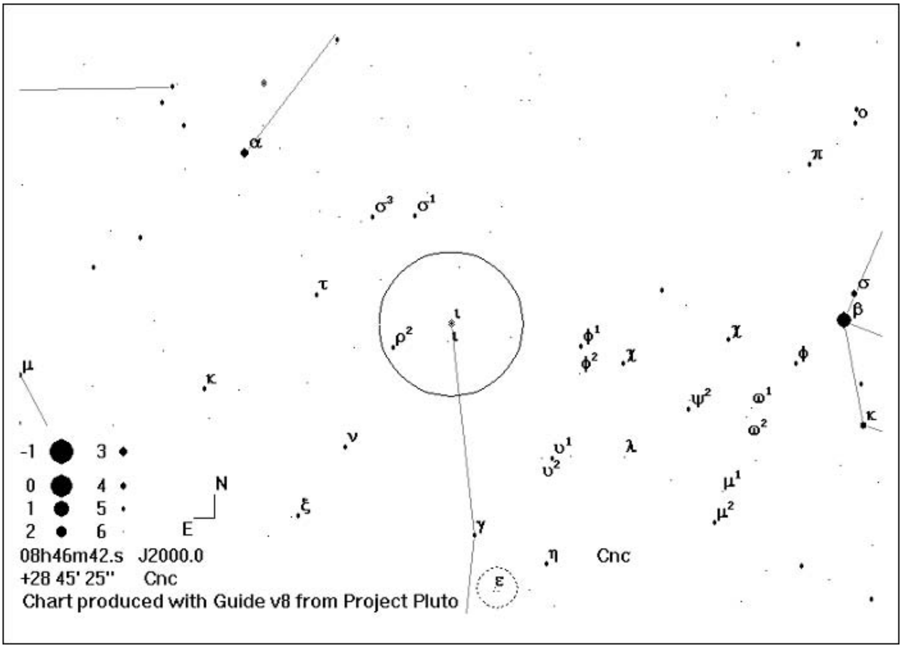
1. Moore, P. *Exploring the Night Sky with Binoculars*. Cambridge: Cambridge University Press, 1986, p. 96.

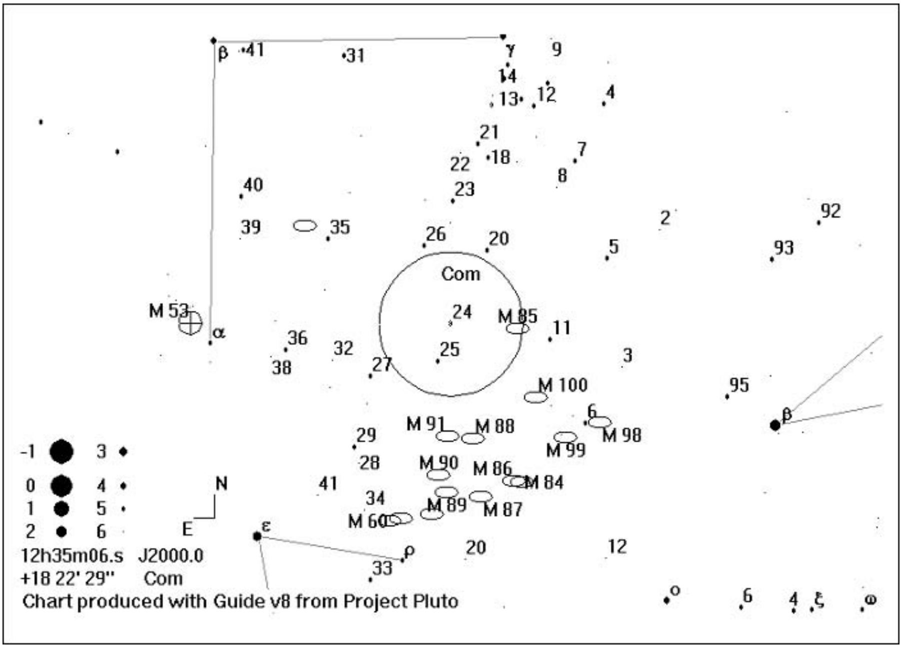
APPENDIX A

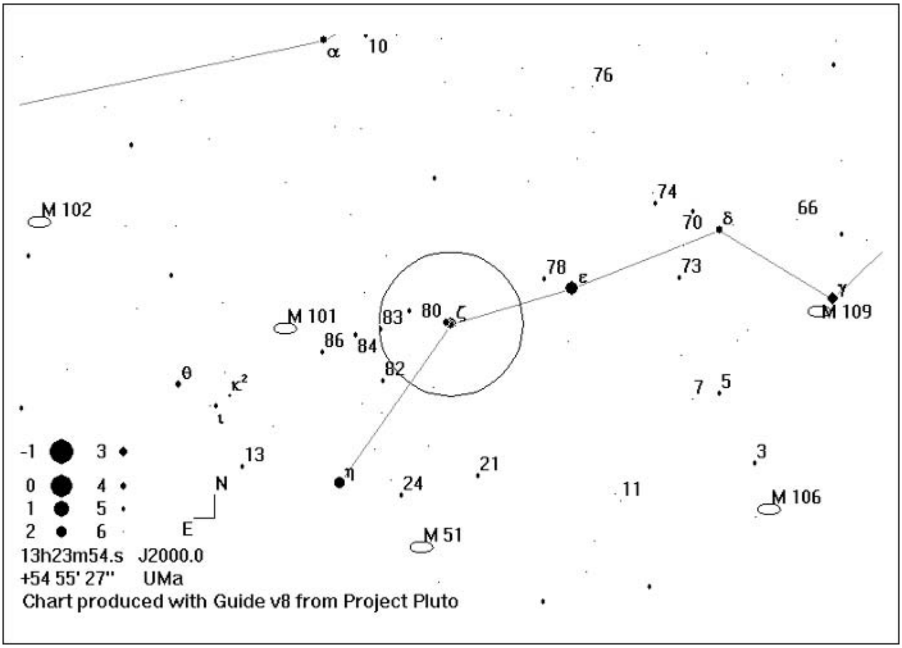
Double Stars for Indicating Resolution

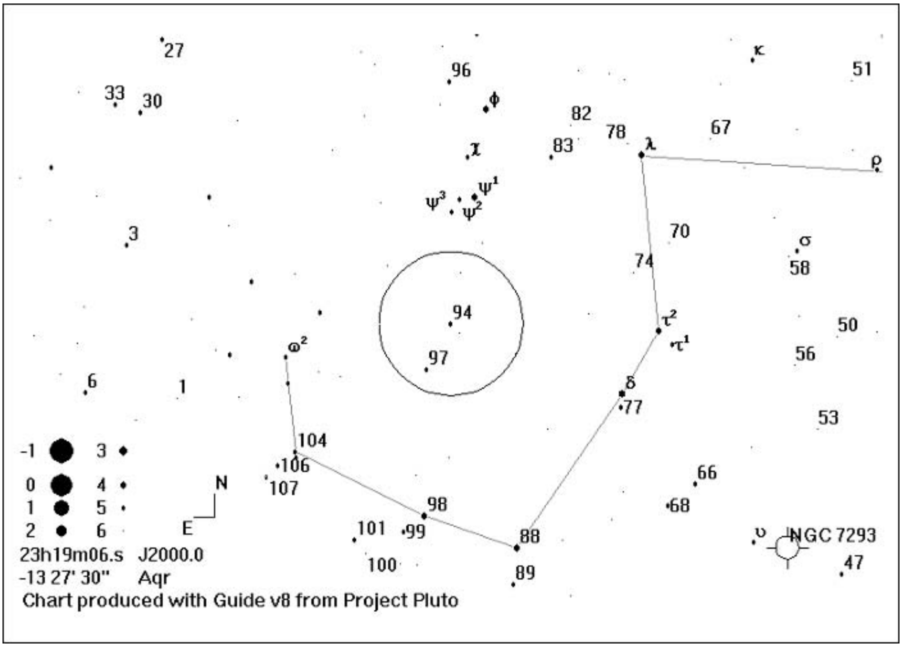
The following list of double stars can be used, in addition to those given in the observing lists, as an aid for comparing binocular performance and indicating resolution.

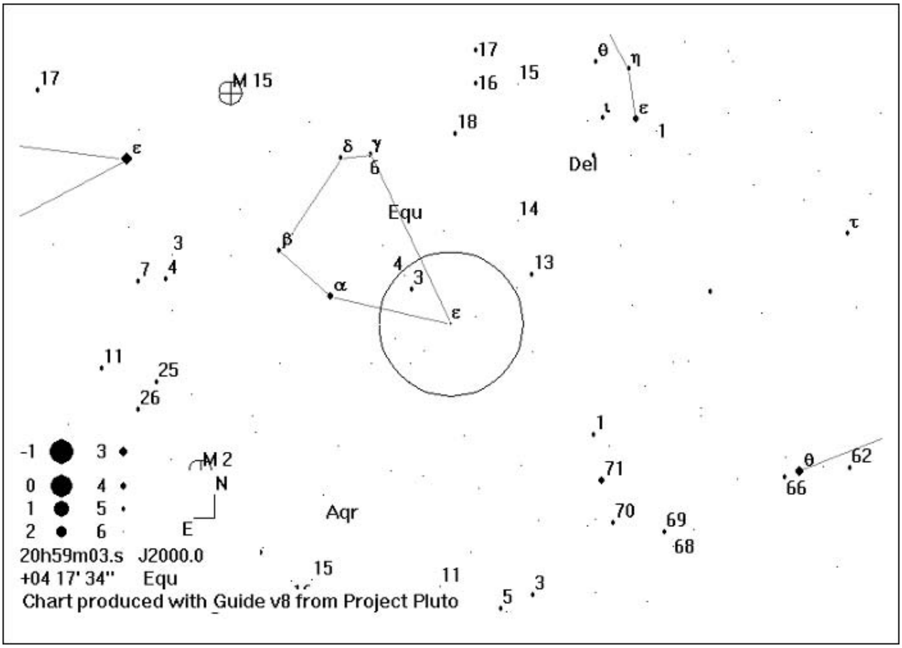
Separation (arcsec)	Star
31	ι Can
20	24 Com
15	ζ UMa
14.4	94 Aqr
11	ε Equ
10	γ Del
7.5	γ Ari
6.5	54 Leo
6	ζ Can

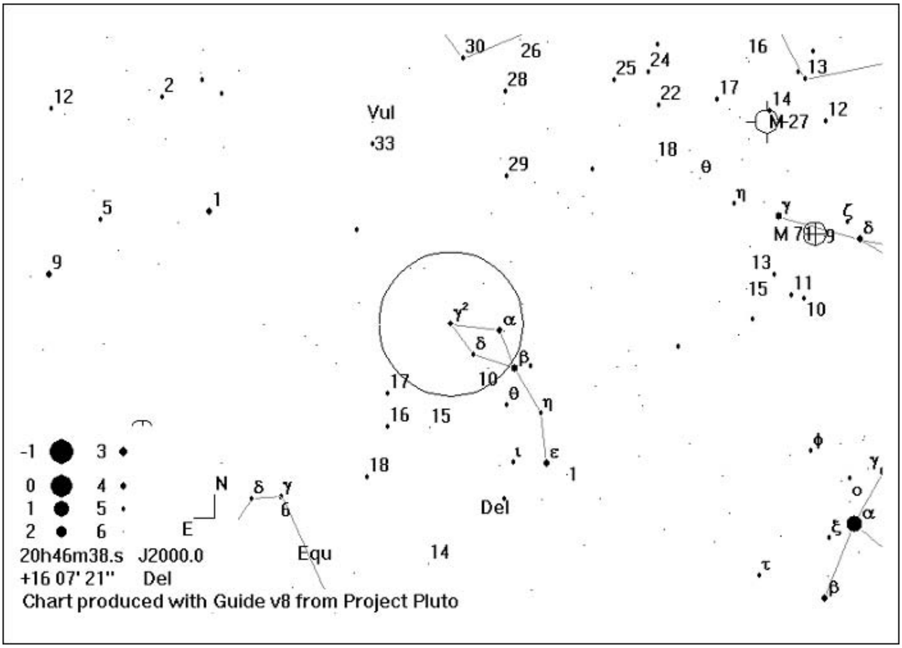

08h46m42.s J2000.0
+28 45' 25" Cnc
Chart produced with Guide v8 from Project Pluto

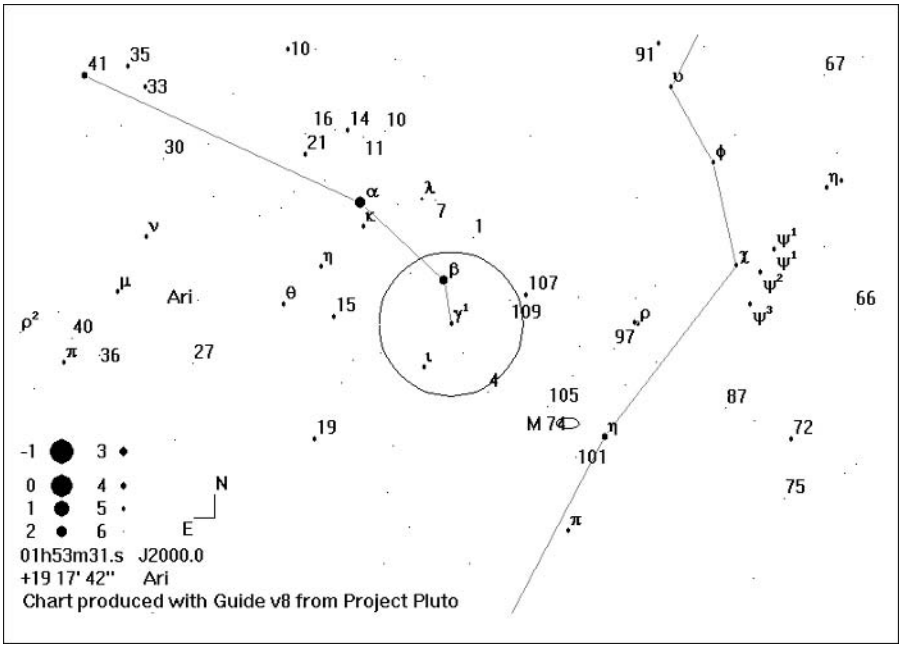

12h35m06.s J2000.0
+18 22' 29" Com
Chart produced with Guide v8 from Project Pluto

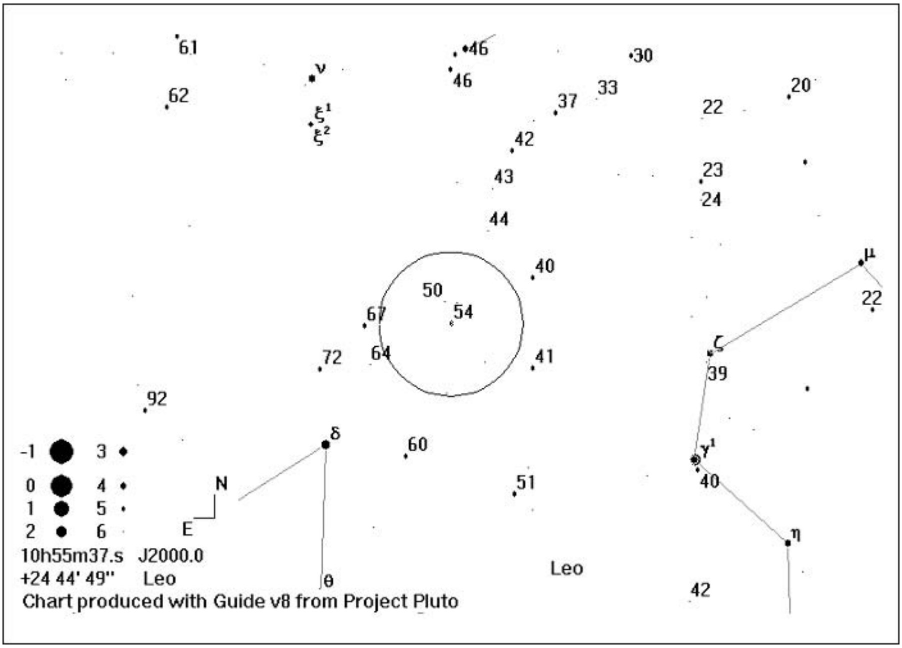

α
10
76
M 102
74
70
δ
66
78
ε
73
γ
M 101
83
80
ζ
M 109
86
84
82
θ
κ²
7
5
ι
13
3
η
24
21
11
M 106
M 51
N
E
-1 3
0 4
1 5
2 6
13h23m54.s J2000.0
+54 55' 27" UMa
Chart produced with Guide v8 from Project Pluto

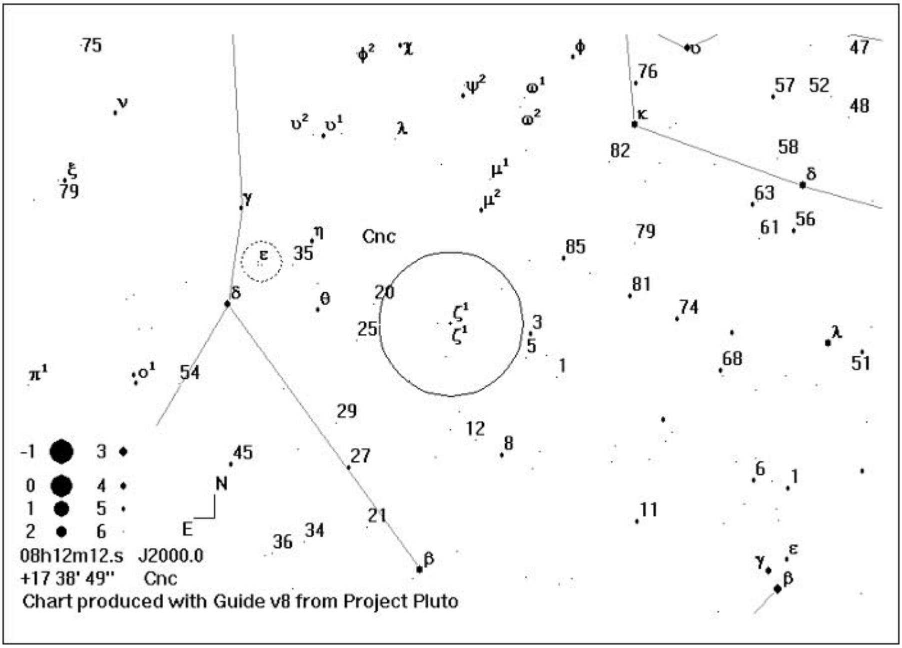

27
96
κ
51
33
30
φ
82
78
67
83
λ
χ
ρ
ψ³
ψ¹
ψ²
3
70
σ
74
58
94
τ²
50
ω²
τ¹
97
56
6
1
δ
77
53
104
106
66
107
98
68
101
99
88
υ
NGC 7293
100
89
47
N
E
-1 3
0 4
1 5
2 6
23h19m06.s J2000.0
-13 27' 30" Aqr
Chart produced with Guide v8 from Project Pluto


M 15
Equ
Del
Aqr
M 2
N
E
-1 0 1 2 3 4 5 6
20h59m03.s J2000.0
+04 17' 34" Equ
Chart produced with Guide v8 from Project Pluto


Vul
M 27
M 71
Del
Equ
N
E
-1 0 1 2 3 4 5 6
20h46m38.s J2000.0
+16 07' 21" Del
Chart produced with Guide v8 from Project Pluto


41
35
33
10
16
14
10
21
11
30
α
κ
λ
7
1
ν
η
β
μ
Ari
θ
15
γ¹
107
109
ρ²
40
π
36
27
ι
4
91
υ
67
φ
η
ψ¹
ψ¹
χ
ψ²
66
ρ
97
ψ³
105
87
M 74
η
72
19
101
75
π
-1
0
1
2
3
4
5
6
N
E
01h53m31.s J2000.0
+19 17' 42" Ari
Chart produced with Guide v8 from Project Pluto


61
46
46
30
ν
62
37
33
22
20
ξ¹
ξ²
42
43
23
24
44
40
μ
50
54
67
22
ζ
72
64
41
39
92
δ
60
γ¹
40
51
η
-1
0
1
2
3
4
5
6
N
E
10h55m37.s J2000.0
+24 44' 49" Leo
θ
Leo
42
Chart produced with Guide v8 from Project Pluto


08h12m12.s J2000.0
+17 38' 49" Cnc
Chart produced with Guide v8 from Project Pluto
Cnc
N
E

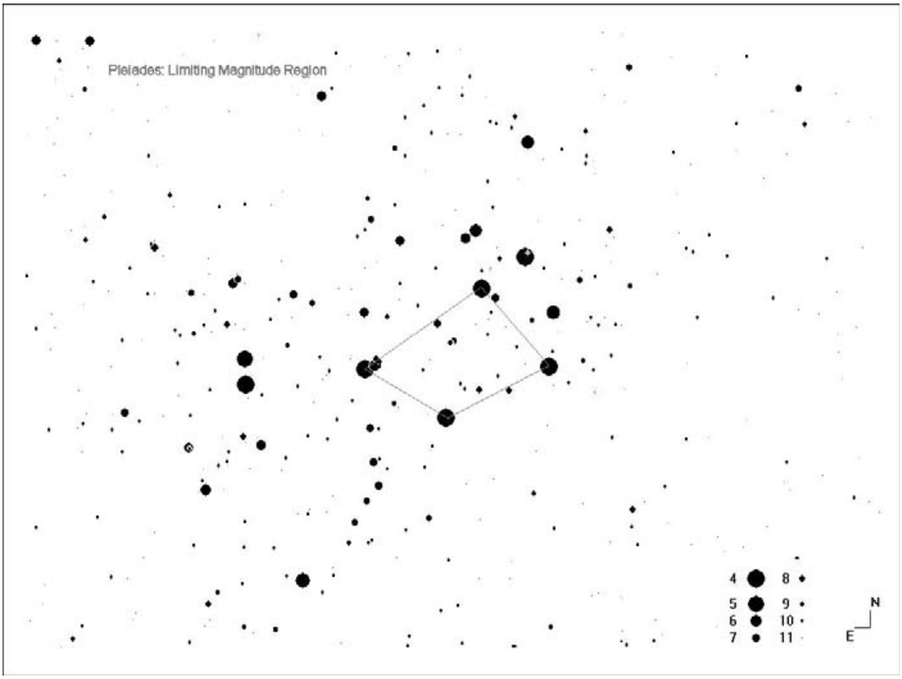
APPENDIX B

Limiting Magnitude

Limiting magnitude may be determined by finding the magnitude of the faintest star observable or by counting the stars in a known region of sky. In addition to the optical quality of the instrument, the limiting magnitude will depend upon sky conditions, the experience of the observer, and the altitude of the objects being observed.

M45: The Pleiades

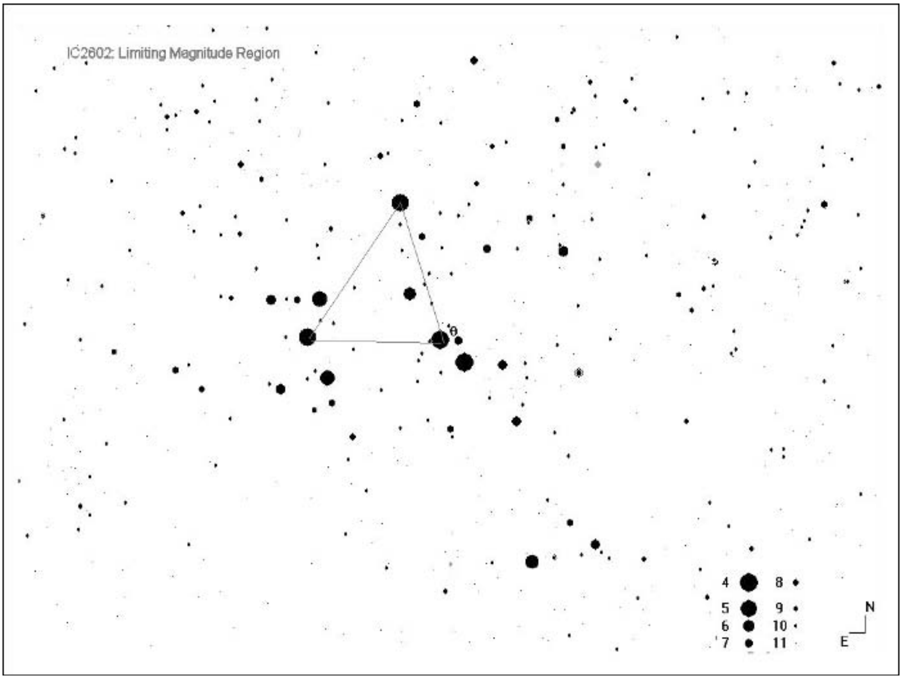
The region to be counted is that bounded by (but not including) Alcyone, Maia, Electra, and Merope.



Number of Stars	Limiting Magnitude
6	9.0
7	9.5
9	10.0
12	10.5
15	11.0
18	11.5
22	12.0
25	12.5
31	13.0

IC 2602 (the *Southern Pleiades*)

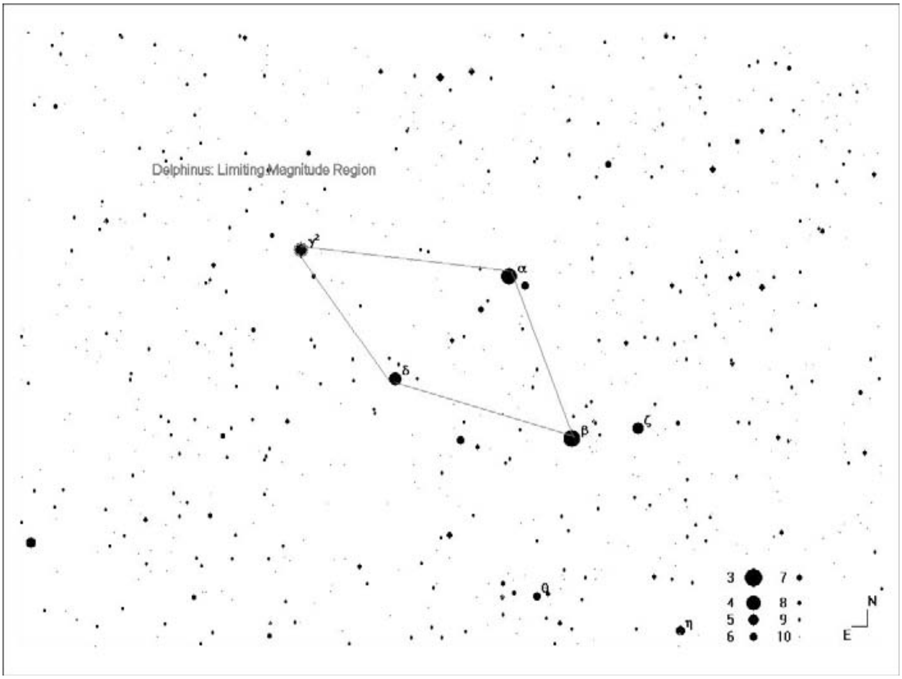
The region to be counted is a triangle bounded by (but not including) θ *Carinae* and two 5th magnitude stars.



Number of Stars	Limiting Magnitude
2	9.5
4	10.0
7	10.5
12	11.0
13	11.5
17	12.0
28	12.5
36	13.0

Delphinus

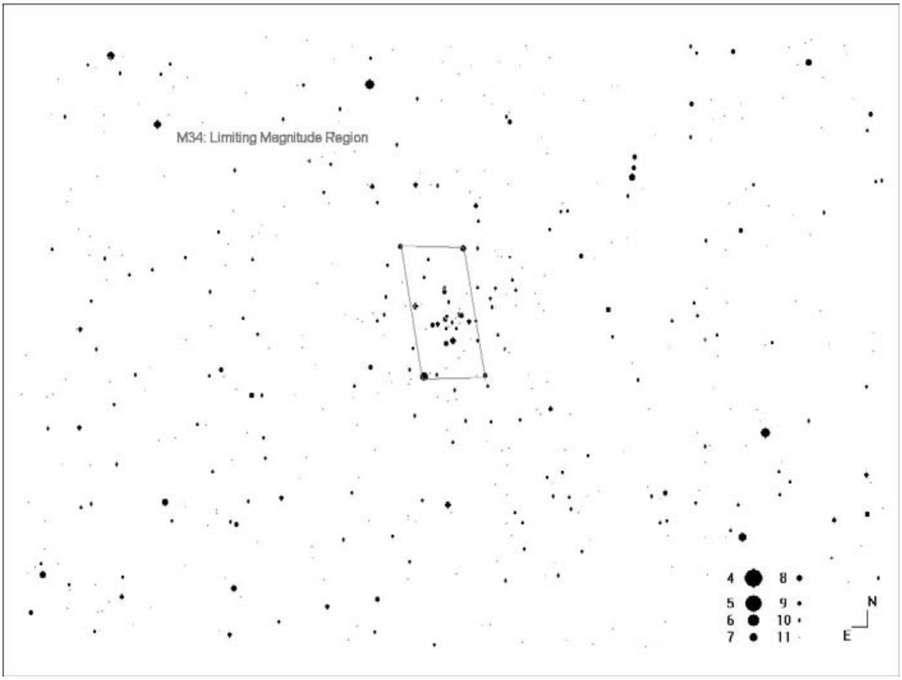
The region to be counted is the "kite" bounded by (but not including) α, β, γ, and δ *Delphini*. Suitable for smaller binoculars.



Number of Stars	Limiting Magnitude
6	8.5
9	9.0
14	9.5
24	10.0
38	10.5

M34

The region to be counted is that bounded by (and including) the parallelogram of 8th magnitude stars. There are a number of optical doubles in this region, so users of larger binoculars (100 mm and above) will get more reliable results at higher magnifications.



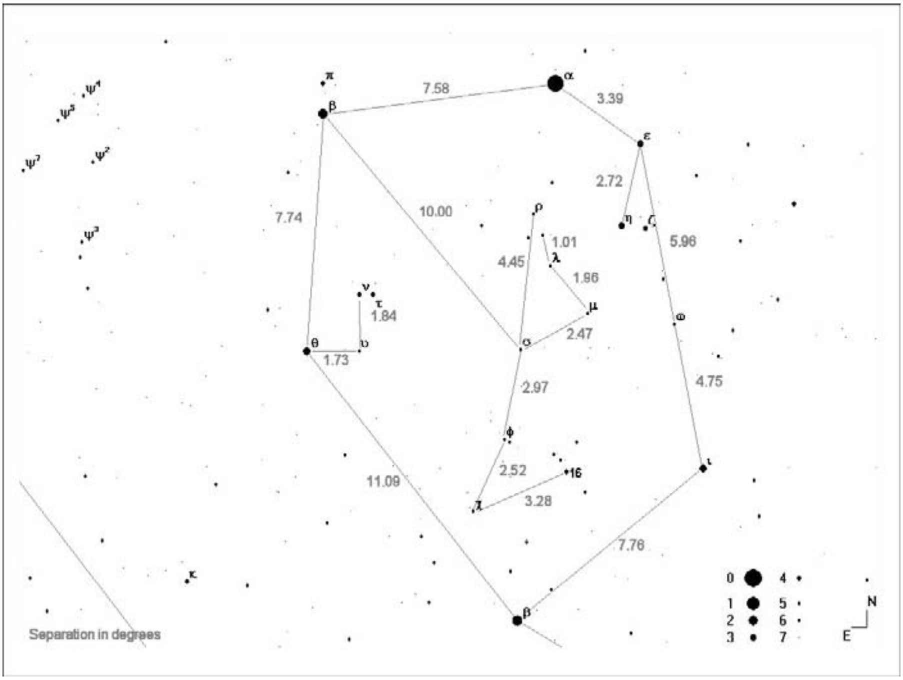
Number of Stars	Limiting Magnitude
6	8.5
10	9.0
12	9.5
16	10.0
18	10.5
26	11.0
33	11.5
40	12.0
50	12.5
61	13.0

APPENDIX C

True Field of View

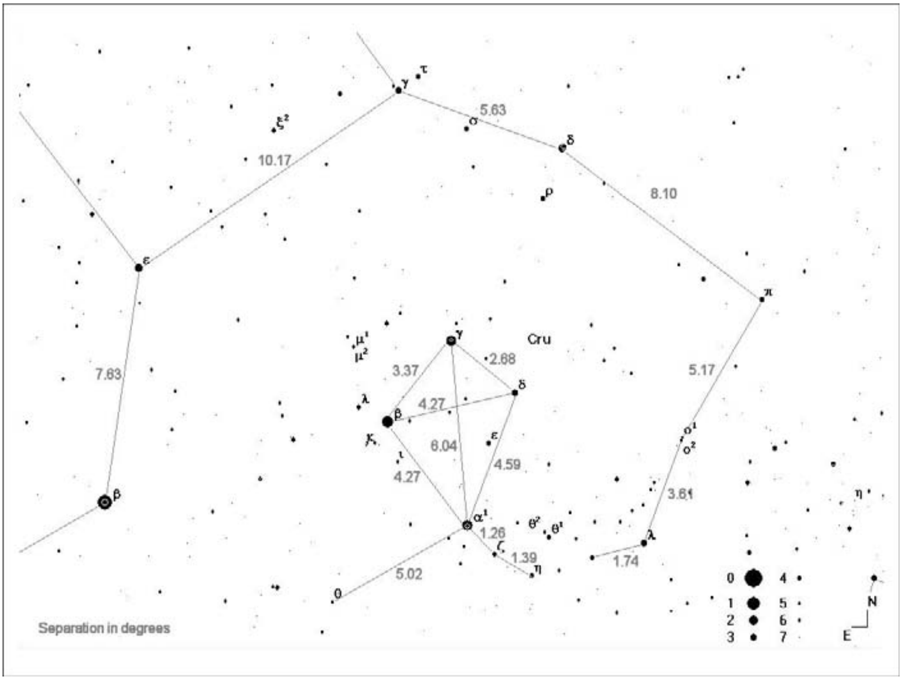
The charts and tables in this section can be used to help establish the true field of view of binoculars. It is arranged in alphabetical order by the constellation at the center of the field. Each chart shows a 28-degree by 20-degree area of sky.

Auriga



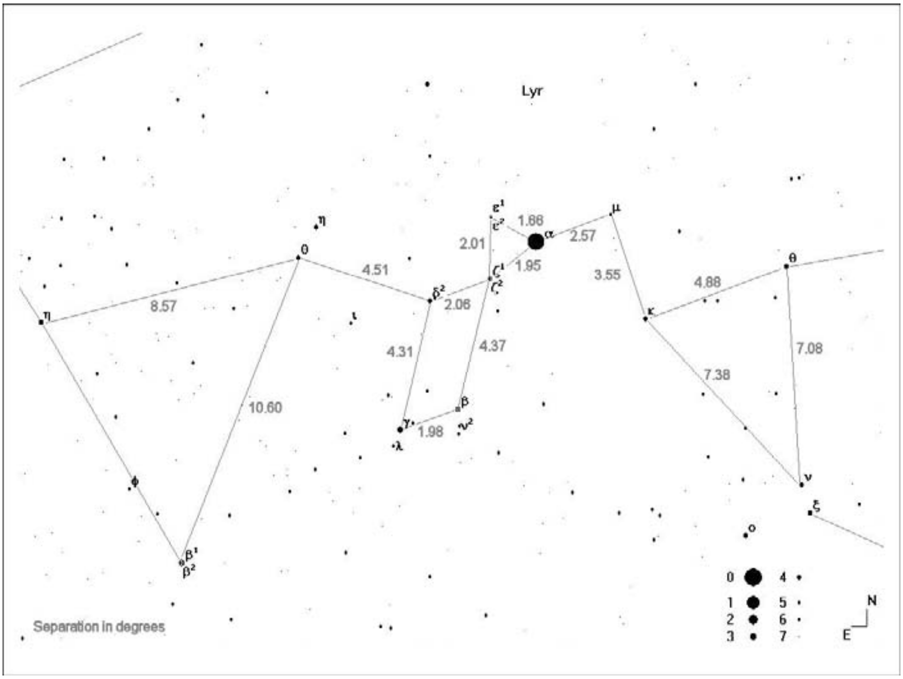
Separation	1st Star	2nd Star
11.09°	β Tauri	θ Aurigae
10.00°	β Aurigae	σ Aurigae
7.76°	β Tauri	ι Aurigae
7.74°	θ Aurigae	β Aurigae
7.58°	β Aurigae	α Aurigae
5.96°	ε Aurigae	ω Aurigae
4.75°	ω Aurigae	ι Aurigae
4.45°	σ Aurigae	ρ Aurigae
3.39°	α Aurigae	ε Aurigae
3.28°	χ Aurigae	16 Aurigae
2.97°	ϕ Aurigae	σ Aurigae
2.72°	ε Aurigae	η Aurigae
2.52°	χ Aurigae	ϕ Aurigae
2.47°	σ Aurigae	μ Aurigae
1.96°	μ Aurigae	λ Aurigae
1.84°	υ Aurigae	ν Aurigae
1.73°	θ Aurigae	υ Aurigae
1.01°	λ Aurigae	BSC 1738

Crux, Centaurus, Musca



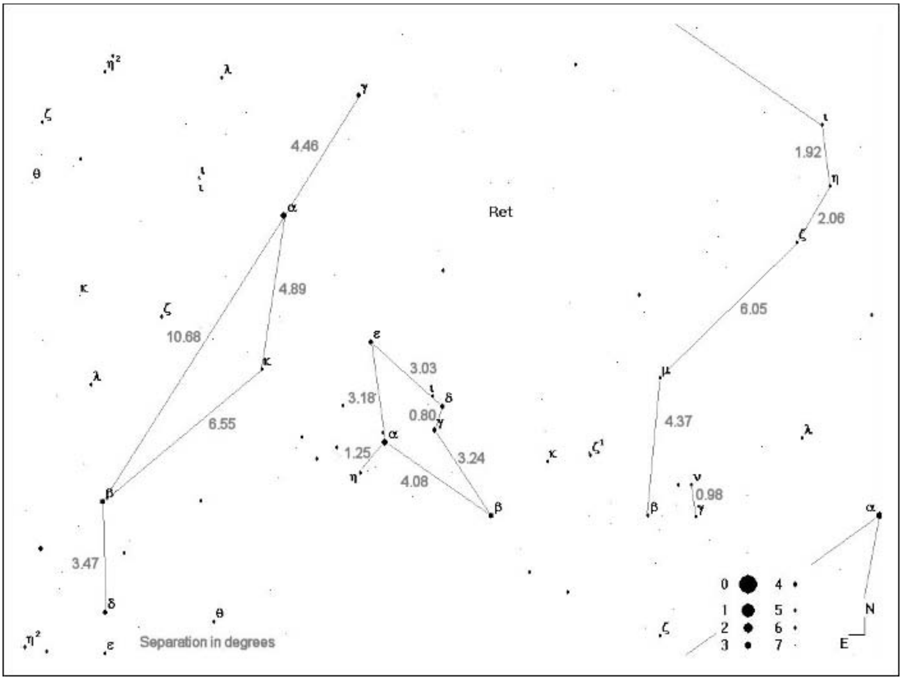
Separation	1st Star	2nd Star
10.17°	ε Centauri	γ Centauri
8.10°	δ Centauri	π Centauri
7.63°	β Centauri	ε Centauri
6.04°	α Crucis	γ Crucis
5.63°	γ Centauri	δ Centauri
5.17°	π Centauri	o^1 Centauri
5.02°	α Crucis	θ Muscae
4.59°	α Crucis	δ Crucis
4.27°	β Crucis	δ Crucis
4.27°	β Crucis	α Crucis
3.61°	λ Centauri	o^1 Centauri
3.37°	β Crucis	γ Crucis
2.68°	γ Crucis	δ Crucis
1.74°	λ Centauri	BSC 4537
1.39°	η Crucis	ζ Crucis
1.26°	α Crucis	ζ Crucis

Lyra, Cygnus, Hercules



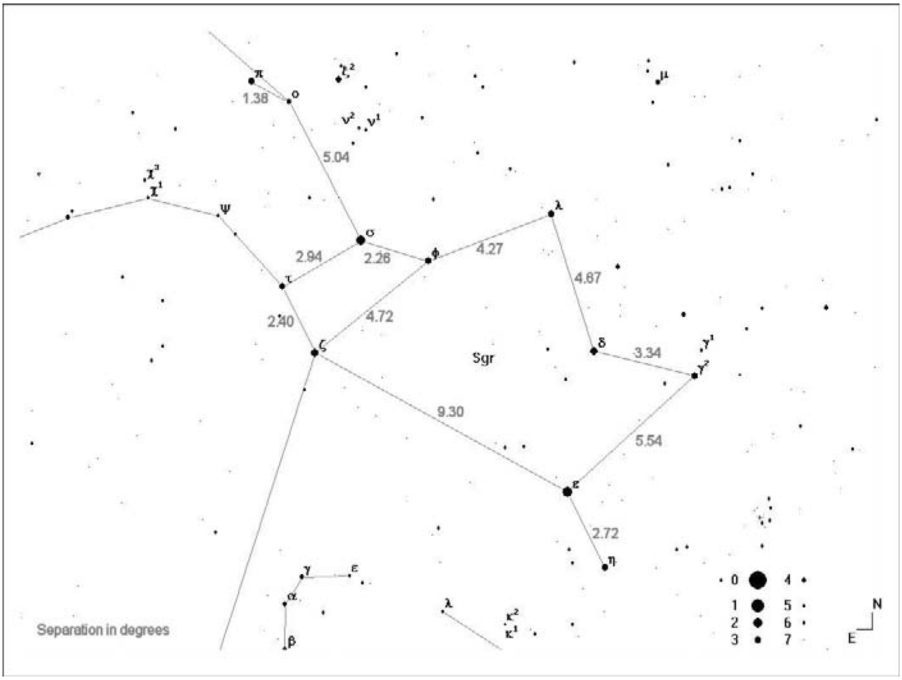
Separation	1st Star	2nd Star
10.60°	θ Lyrae	β^1 Cygni
8.57°	θ Lyrae	η Cygni
7.38°	κ Lyrae	ν Herculis
7.08°	η Herculis	θ Herculis
4.88°	θ Herculis	κ Lyrae
4.51°	θ Lyrae	δ^2 Lyrae
4.37°	β Lyrae	ζ^1 Lyrae
4.31°	γ Lyrae	δ^2 Lyrae
3.55°	κ Lyrae	μ Lyrae
2.57°	α Lyrae	μ Lyrae
2.06°	δ^2 Lyrae	ζ^1 Lyrae
2.01°	ε^2 Cygni	ζ^1 Lyrae
1.98°	γ Lyrae	β Lyrae
1.95°	α Lyrae	ζ^1 Lyrae
1.66°	α Lyrae	ε^2 Cygni

Reticulum, Dorado, Horologium



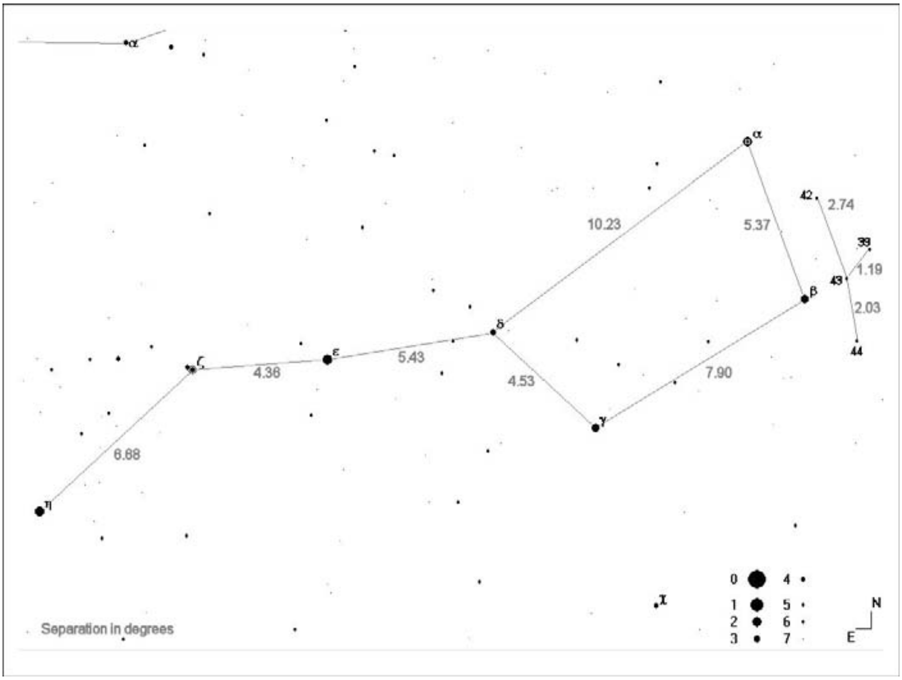
Separation	1st Star	2nd Star
10.68°	β Doradus	α Doradus
6.55°	β Doradus	κ Doradus
6.05°	ζ Horologii	μ Horologii
4.89°	α Doradus	κ Doradus
4.46°	α Doradus	γ Doradus
4.37°	μ Horologii	β Horologii
4.08°	α Reticuli	β Reticuli
3.47°	β Doradus	δ Doradus
3.24°	β Reticuli	γ Reticuli
3.18°	α Reticuli	ε Reticuli
3.03°	δ Reticuli	ε Reticuli
2.06°	ζ Horologii	η Horologii
1.92°	η Horologii	ι Horologii
1.25°	α Reticuli	η Reticuli
0.98°	γ Horologii	ν Horologii
0.80°	δ Reticuli	γ Reticuli

Sagittarius



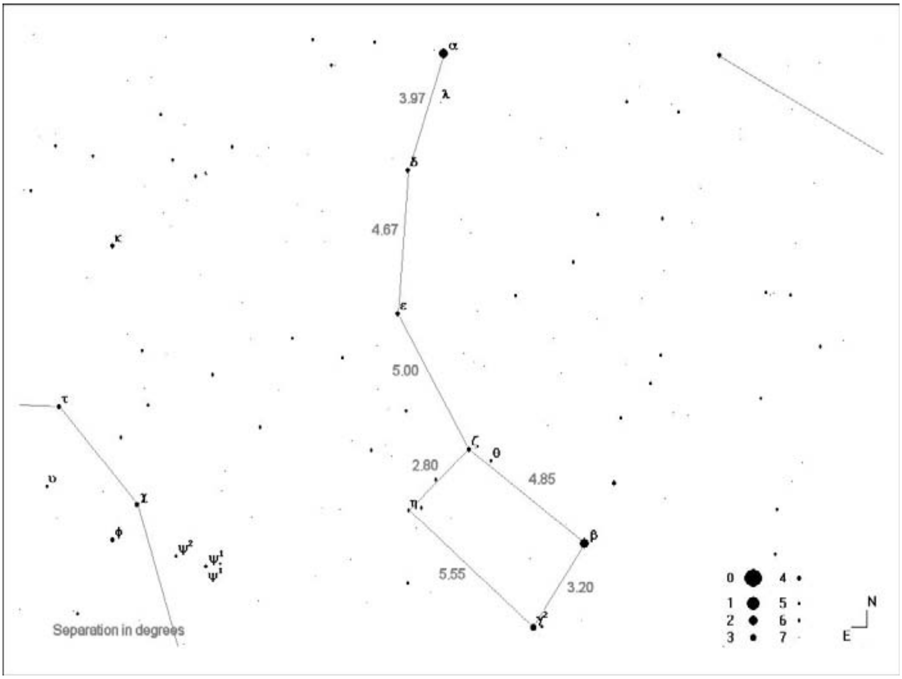
Separation	1st Star	2nd Star
9.30°	ζ Sagittarii	ε Sagittarii
5.54°	ε Sagittarii	γ^2 Sagittarii
5.04°	σ Sagittarii	ο Sagittarii
4.72°	ζ Sagittarii	φ Sagittarii
4.67°	λ Sagittarii	δ Sagittarii
4.27°	λ Sagittarii	φ Sagittarii
3.34°	δ Sagittarii	γ^2 Sagittarii
2.94°	σ Sagittarii	τ Sagittarii
2.72°	ε Sagittarii	η Sagittarii
2.40°	τ Sagittarii	ζ Sagittarii
2.26°	σ Sagittarii	φ Sagittarii
1.38°	ο Sagittarii	π Sagittarii

Ursa Major



Separation	1st Star	2nd Star
10.23°	α Ursae Majoris	δ Ursae Majoris
7.90°	β Ursae Majoris	γ Ursae Majoris
6.68°	η Ursae Majoris	ζ Ursae Majoris
5.43°	ε Ursae Majoris	δ Ursae Majoris
5.37°	α Ursae Majoris	β Ursae Majoris
4.53°	γ Ursae Majoris	δ Ursae Majoris
4.36°	ζ Ursae Majoris	ε Ursae Majoris
2.74°	42 Ursae Majoris	43 Ursae Majoris
2.03°	43 Ursae Majoris	44 Ursae Majoris
1.19°	43 Ursae Majoris	39 Ursae Majoris

Ursa Minor



Separation	1st Star	2nd Star
5.55°	η Ursae Minoris	γ^2 Ursae Minoris
5.00°	ζ Ursae Minoris	ε Ursae Minoris
4.85°	ζ Ursae Minoris	β Ursae Minoris
4.67°	δ Ursae Minoris	ε Ursae Minoris
3.97°	α Ursae Minoris	δ Ursae Minoris
3.20°	β Ursae Minoris	γ^2 Ursae Minoris
2.80°	ζ Ursae Minoris	ϕ Ursae Minoris

APPENDIX D

Useful Addresses

Manufacturers

Canon Inc.
http://canon.com/

Carl Zeiss GmbH
http://www.zeiss.de/de/bino/home_e.nsf

Fujinon Inc.
http://fujinon.com/

Kunming Optical Instruments Co., Ltd.
http://www.binocularschina.com/index.html

Miyauchi Optical
http://www.miyauchi-opt.co.jp/

Nikon Corporation
http://www.nikon.com/

Starchair
http://www.starchair.com/

Universal Astronomics
http://www.universalastronomics.com/

Suppliers

UK

Monk Optics Ltd
Wye Valley Observatory
The Old School
Brockweir
Chepstow
NP16 7NW
Phone: +44 (0)1291 689858
Fax: +44 (0)1291 689834
Web: http://www.monkoptics.co.uk

Optical Vision Ltd
Unit 2b, Woolpit Business Park
Woolpit
Bury St. Edmunds
Suffolk IP30 9UP
England
Phone: +44 (0)1359 244 200
Fax: +44 (0)1359 244 255
Email: info@opticalvision.co.uk
Web: http://www.opticalvision.co.uk/

Opticron
Unit 21, Titan Cort
Laporte Way
Luton
Bedfordshire, LU4 8EF
UK
Phone: +44 (0)1582 726522
Fax: +44 (0)1582 723559
Email: info@opticron.co.uk
Web: http://www.opticron.co.uk/

Strathspey Binoculars
Robertland Villa Railway Terrace
Aviemore
PH22 1SA
Scotland, UK
Phone: +44 (0)1479 812549
Email: john@unixnerd.demon.co.uk
Web: http://www.strathspey.co.uk/

USA

The Binoscope Company
3 Wyman Court

Coram, NY 11727
Phone: 631-473-5349
Fax: 631-331-8891
Email: astrojoe@optonline.net
Web: http://www.binoscope.com/

Jim's Mobile Incorporated
8550 West 14th Avenue
Lakewood, CO 80215
Phone: 303-233-5353
Fax: 303-233-5359
Email: info@jmitelescopes.com

Oberwerk Corporation
75-C Harbert Dr.
Beavercreek, OH 45440
Phone: 937-426-8892
Email: info@oberwerk.com

Orion Telescopes and Binoculars
89 Hangar Way
Watsonville, CA 95076
Phone: 831-763-7000
Email: support@telescope.com
Web: http://www.telescope.com/

Universal Astronomics
6 River Ct.
Webster, MA 01570
Phone: 508-943-5105
Fax: 707-371-0777
Email: Larry@UniversalAstronomics.com
Web: http://www.universalastronomics.com/

Binocular Repair

UK

Action Optics
16 Butts Ash Gardens
Hythe
Southampton
SO45 3BL
Phone or Fax: 023 8084 2801
Mobile: 079 77 88 1482
Email: richard@actionoptics.co.uk
Web: http://www.actionoptics.co.uk/Index.htm

USA

Captains Nautical Supplies, Inc.
2500 15th Avenue West
Seattle, WA 98119
Phone: 206-283-7242, Toll-free in the USA and Canada 800-448-2278
Fax: 206-281-4921
Email: sales@captainsnautical.com

Suddarth Optical Repair
205 West May St.
Henryetta, OK 74437
Phone: 918-650-9087
Email: binofixer@aol.com

APPENDIX E

Internet Resources

Astromart Astronomy Classifieds:
http://www.astromart.com/

Astronomy Centre:
http://www.astronomycentre.org.uk/

Binocular Astronomy Resource Page:
http://www.uvaa.org/binocularresources.htm

BinoSky:
http://www.lightandmatter.com/binosky/binosky.html

Cloudy Nights Binoculars Forum:
http://www.cloudynights.com/ubbthreads/postlist.php?Cat=0&Board=binoculars

Telescopes and Astronomy Supplies in Australia
http://www.quasarastronomy.com.au/shops.htm

UK Astro Ads:
http://www.astronomy-uk.co.uk/

APPENDIX F

Binocular Designations

There is a potentially bewildering array of letters that manufacturers use to give further information about binoculars in addition to the magnification and aperture. There is not an industry-wide standard of these, but here are most of those in recent and current use:

A: Armored, usually with rubber (see **GA**).

AG: Silver coating on reflective surfaces of roof prisms (from *argentum*, the Latin for *silver*, whose chemical symbol is similar: *Ag*)

B: Depends on context and/or source of binoculars.

(a) Usual American, Chinese, and Japanese usage. A Porro prism binocular with each optical tube of one-piece construction (Bausch & Lomb or American style).

(b) Usual European usage: Long eye relief, suitable for eyeglass wearers (from *brille*, the German for *spectacles*).

C: Depends on context.

(a) Compact binocular (usually a small roof prism binocular).

(b) Coated optics.

CF: Center focus. Usually combined with another letter, such as, BCF: Bausch & Lomb style center focus.

D: Roof prism binocular (from *dach*, the German for *roof*).

F: Flat-field technology.

FC: Fully coated optics.

FL: Fluorite lenses.

FMC: Fully multicoated optics.

GA: Rubber armored (from *gummi*, the German for *rubber*).

H:	H-body roof prism binocular.
IF:	Individual focusing eyepieces. Usually combined with another letter, such as, ZIF: Zeiss style individual focus.
IS.	Image stabilized.
MC:	Multicoated optics.
MCF:	Mini-center-focus (“delta” Porro prism binoculars, with the objectives closer together than the eyepieces).
N:	Nitrogen filled.
P or **PC:**	Phase-corrected prism coatings (on roof prisms).
P*:	Proprietary (to Zeiss) phase coatings.
SMC:	Fully multicoated optics.
T*:	Proprietary (to Zeiss) antireflective coatings.
W, **WA**, or **WW:**	Wide angle.
WP:	Waterproof.
Z:	Porro prism binocular with each optical tube of two-piece construction, with the objective tube screwing into the prism housing (Zeiss or European style).

APPENDIX G

Glossary of Terms

Abaxial rays: Rays that are distant from the optical axis.
Abbé prism: A roof prism.
Aberration: An optical effect that degrades an image.
Absolute magnitude: The *apparent magnitude* that an object would possess it if were placed at a distance of 10 *parsecs* from the observer. In this way, absolute magnitude provides a direct comparison of the brightness of stars.
Accomodation: The ability of the eyes to focus on both near and distant objects. The normal range is from about 120 mm (4.5 inches) to infinity.
Achromatic: Literally "no color." A lens combination in which *chromatic aberration* is corrected by bringing two colors to the same focus.
Airy disc: The bright central part of the image of a star. It is surrounded by diffraction rings and its size is determined by the aperture of the telescope or binocular. About 85 percent of the light from the star should fall into the airy disc. You will not see the disc and rings unless you have a binocular telescope or binoculars that operate at unusually high magnifications.
Altazimuth: A mounting in which the axes of rotation are horizontal and vertical. An altazimuth mount requires motion of both axes to follow an astronomical object, but is simpler to make than an *equatorial mount* and can, in some forms, be held together by gravity.
Albedo: The proportion of incident light which a body reflects in all directions. The albedo of Earth is 0.36, that of the Moon is 0.07, and that of Uranus is 0.93. The true albedo may vary over the surface of the object so, for practical purposes, the mean albedo is used.
Altitude: The angle of a body above or below the plane of the horizon—negative altitudes are below the horizon.

Amici prism: A right angled prism whose hypotenuse face has been formed into a roof. It is used to erect images.

Anastigmat: An optical system that is corrected for *astigmatism* in at least one off-axis zone and for which it has tolerable correction for the intended purpose over the rest of the field.

Angle of incidence: The angle between the *normal* to an optical surface and the incident ray.

Angle of reflection: The angle formed-between the *normal* to an optical surface and the reflected ray.

Angle of refraction: The angle formed-between the *normal* to an optical surface and the refracted ray.

Aperture: The diameter of the largest bundle of light that can enter an optical system. It is usually the diameter of objective lens or primary mirror.

Aperture stop: A physical aperture that restricts the size of the bundle of light passing through an optical system.

Aphelion: The position in a heliocentric orbit at which the orbiting object is at its greatest distance from the Sun.

Apoapsis: The position in an orbit at which the orbiting object is at its greatest distance from the object about which it is orbiting.

Apochromatic: A lens combination in which *chromatic aberration* is corrected by bringing three colors to the same focus. The term is used by some manufacturers to describe *achromatic* doublets whose false color is approximately equivalent to that of an apochromatic triplet lens.

Apogee: The position in a *geocentric* orbit at which the orbiting object is at its greatest distance from Earth.

Apparent field (of view): The angular size of the entire image (see also *true field (of view)*).

Apparent magnitude: The brightness of a body, as it appears to the observer, measured on a standard *magnitude* scale. It is a function of the *luminosity* and distance of the object, and the transparency of the medium through which it is observed.

Arcminute: One sixtieth of a degree of arc.

Arcsecond: The second division of a degree of arc. One sixtieth of an arc minute (1/3600th of a degree).

Astigmatism: An optical *aberration* resulting from unequal magnification across different diameters.

Axial rays: Rays that originate from a distant object on the optical axis.

Azimuth: The angular distance around the horizon, usually measured from north (although it is sometimes measured from south), of the *great circle* passing through the object.

Back focus: The distance between the exit aperture of an optical tube and the position of the image plane. Binoviewers in particular require a significant amount of back focus.

Baffle: An opaque barrier that is positioned so as to reduce or eliminate the effects of stray light in an optical system. In binoculars these often take the form of machined ridges or screw threads in the objective tubes.

BaK4: Barium crown glass. This is a glass of high optical density that is used for the prisms of good quality binoculars.

Barlow lens: A diverging lens that has the effect of increasing (usually doubling) the effective focal length of the telescope.

Binocular vision: See **Stereopsis.**

Binoviewer: A device that splits equally the single light cone from a telescope into two light cones to enable the observer to use both eyes for observation.

BK7: Borosilicate glass. Cheaper and less dense than **BaK4**, it is commonly found in cheaper binocular prisms.

Blind spot: The position where the optic nerve enters the retina. It can become noticeable when using optical instruments, but its effect is ameliorated by the use of both eyes.

Catadioptric: A telescope whose optics, not including the eyepiece, consists of both lenses and mirrors. The most common examples of these are the Schmidt-Cassegrain telescopes, whose "lens" is an aspheric corrector plate, and the Maksutov-Cassegrain telescopes, whose "lens" is a deeply curved meniscus.

Cells: The part of an optical instrument that holds the lenses or mirrors.

Chromatic aberration: An *aberration* of refractive optical systems in which light is dispersed into its component colors, resulting in false color in the image. There are two distinct manifestations of it: longitudinal chromatic aberration: Light of different wavelengths is brought to different foci, and lateral chromatic aberration: Light of different wavelengths forms images of different sizes.

Collimation: 1. The act of bringing of the optical components of a telescope into correct alignment with each other. 2. The act of making the optical axes of the optical tubes of the binocular parallel to each other and, where appropriate, to the central hinge. (See also *conditional alignment*).

Coma: 1. The matter surrounding the nucleus of a comet—it results from the evaporation of the nucleus. 2. An optical *aberration* in which stellar images are fan-shaped, similar to comets.

Comes (pl. comites): The faint companion of a double star.

Concave: Curving inward at the center.

Convex: Curving outward at the center.

Conditional alignment: An incomplete *collimation* of a binocular in which the optical axes are parallel to each other but not to the central hinge. The optical axes are therefore only parallel at a specific *Interpupillary distance*.

Culmination: An object is at culmination when it reaches the observer's meridian. It is then at its greatest altitude.

Declination: The angle of an object above or below the celestial equator. It is part of the system of equatorial coordinates.

Depth of field: The range of distances from the objective lens for which objects appear to be in focus when the binocular (or other optical system) is focused on an object within that range.

Dialyte: A double lens in which the inner surfaces have different curvatures and which cannot therefore be cemented.

Diffraction limited: A measure of optical quality in which the performance is limited only by the size of the theoretical diffracted image of a star for a telescope of that aperture.

Distortion: An *aberration* in which the periphery of the field undergoes a different magnification to the center of the field. There are two major types: barrel distortion: the center is magnified more than the periphery, and pincushion distortion: the periphery is magnified more than the center.

Dobsonian: Named after John Dobson, who originated the design. An *altazimuth* mount constructed usually of plywood or medium density fiberboard suited to home construction. Also refers to a telescope or binocular telescope so mounted.

Elongation: The angular distance between the Sun and any other solar system body, or between a satellite and its parent planet.

Equatorial mount: A mounting in which one of two mutually perpendicular axes is aligned with Earth's axis of rotation, thus permitting an object to be tracked by rotating this axis so that it counteracts Earth's rotation.

Exit pupil: The position of the image of the aperture formed by the eyepiece. It is the smallest disc through which all the collected light passes and is therefore the best position for the eye's pupil. Also known as an *eye ring* or a Ramsden disc.

Eyepiece: The lens combination that is closest to the eye.

Eye relief: The distance from the eye lens of the eyeglass to the *exit pupil*. Eyeglass wearers require sufficient eye relief to enable them to place the eye at the exit pupil.

Eye ring: An alternative name for the *exit pupil*.

Field of view: The maximum angle of view through an optical instrument.

f-number, f-ratio: The ratio of the focal length to the aperture.

Focal plane: The plane (usually this is actually the surface of a sphere of large radius) where the image is formed by the main optics of the telescope. The eyepiece examines this image.

Focuser: The part of the telescope that varies the optical distance between the objective lens or primary mirror and the eyepiece. This is usually achieved by moving the eyepiece in a drawtube, but in some catadioptric telescopes it is the primary mirror that is moved.

Fork mount: A mount where the telescope swings in declination or in altitude between two arms. It is suited only to short telescope tubes, such as Cassegrains, and variations thereof. It requires a *wedge* to be used equatorially.

Galilean moons: The four Jovian moons first observed by Galileo (Io, Europa, Ganymede, and Callisto). They are observable with small binoculars.

German equatorial mount (GEM): A common *equatorial mount* for small and medium-sized amateur telescopes, suited to both long and short telescope tubes. The telescope tube is connected to the counterweighted declination axis, which rotates in a housing that keeps it orthogonal to the polar axis. Tracking an object across the meridian requires that the telescope be moved from one side of the mount to the other, which in turn requires that both axes are rotated through 180 degrees, thus reversing the orientation of the image. This is not a problem for visual observation, but is a limitation for astrophotography.

Granulation: The "grains of rice" appearance of the Sun's surface, which results from convection cells within the Sun.

Great circle: A circle formed on the surface of a sphere by the intersection of a plane that passes through the center of the sphere. A great circle path is the shortest distance between two points on a spherical surface.

Image plane: A plane, perpendicular to the optical axis, where the image is formed.

Inferior conjunction: The *conjunction* of Mercury or Venus when they lie between Earth and the Sun.

Inferior planets: Planets (i.e., Mercury and Venus) whose orbits lie inside Earth's orbit.

Infinity: The distance at which rays from an object are indistinguishable from parallel. It has the symbol ∞.

Interpupillary distance: The distance between the pupils of the eyes when the observer is viewing a distant object, or between the exit pupils of a binocular. The latter needs to be adjustable so as to match the former.

Inverted: Upside down.

Light bucket: Slang term for a telescope of large aperture.

Light year: The distance traveled by light in one year: 9.4607×10^{12} km or 63,240 AU or 0.3066 *parsecs*.

Limb: The edge of the disc of a celestial body.

Luminosity: The amount of energy radiated into space per second by a star. The bolometric luminosity is the total amount of radiation at all frequencies; sometimes luminosity is given for a specific band of frequencies (e.g., the visual band).

Magnitude: The brightness of a celestial body on a numerical scale. See also *absolute magnitude* and *apparent magnitude*.

Meridian: The *great circle* passing through the celestial poles and the observer's *zenith*.

Minor planets: Another term for asteroids.

Night glass: A binocular (or telescope) with an *exit pupil* of 7 mm or more.

Normal: Perpendicular to an optical surface.

Normally: Impinging perpendicularly on an optical surface.

Occultation: An alignment of two bodies with the observer such that the nearer body prevents the light from the farther body from reaching the observer. The nearer body is said to occult the farther body. A solar eclipse is an example of an occultation.

Off-axis: At an angle to the optical axis.

Opposition: The position of a planet such that Earth lies between the planet and the Sun. Planets at opposition are closest to Earth at opposition, and thus opposition offers the best opportunity for observation.

Optical axis: The "line of optical centers" of the elements of an optical system. It is the line of the principal axes of these optical elements and, when they are curved, it is the line passing through their centers of curvatures.

OTA: Abbreviation for optical tube assembly. It is normally considered to consist of the tube itself, the focuser and the optical train from the objective lens (refractor), primary mirror (reflector), or corrector plate (catadioptrics) up to, but not including, the eyepiece.

Paraxial rays: Rays that are close to and parallel to the optical axis.

Parfocal eyepieces: Eyepieces sharing the same focal plane. They can be interchanged without refocusing.

Parsec: The distance at which a star would have a parallax of 1 arcsecond (3.2616 *light years*, 206,265 astronomical units, 30.857×10^{12} km).

Pechan prism: A prism, consisting of two air-spaced elements, that will revert an image without inverting it.

Periapsis: The position in an orbit at which the orbiting object is at its least distance from the object about which it is orbiting.

Periastron: The position in an orbit about a star at which the orbiting object is at its least distance from the star.

Perigee: The position in a geocentric orbit at which the orbiting object is at its least distance from Earth.

Perihelion: The position in a heliocentric orbit at which the orbiting object is at its least distance from the Sun.

Phase: The percentage of illumination, from the observer's perspective, of an object (normally planet or moon).

Phase coating: A coating used on *roof prism* binoculars to increase contrast by correcting a differential phase shift.

Planisphere: The projection of a sphere (or part thereof) onto a plane. It commonly refers to a simple device that consists of a pair of concentric discs, one of which has part of the celestial sphere projected onto it, the other of which has a window representing the horizon. Scales about the perimeters of the disc allow it to be set to show the sky at specific times and dates, enabling its use as a simple and convenient aid to location of objects.

Porro prism: An isosceles right-angled prism that reflects the light, by total internal reflection, off both shorter faces, giving a combined angle of reflection of 180 degrees.

Prism: A transparent body with two or more optically flat surfaces that are inclined to each other. Light is either refracted or reflected at these surfaces.

Proper motion: The apparent motion of a star with respect to its surroundings.

Quadrature: The position of a body (Moon or planet) such that the Sun-body-Earth angle is 90 degrees. The *phase* of the body will be 50 percent.

Rayleigh criterion (Rayleigh limit): Lord Rayleigh, a 19th-century physicist, showed that a telescope optic would be indistinguishable from a theoretical perfect optic if the light deviated from the ideal condition by no more than one quarter of its wavelength.

Reflector: A telescope whose optics, apart from the eyepiece, consist of mirrors.

Refractive index: A measure of the relationship between the angles of incident and refracted rays.

Refractor: A telescope whose optics consist entirely of lenses.

Resolution: A measure of the degree of detail visible in an image. It is normally measured in *arcseconds*.

Reticle: A system of engravings in a transparent disc, or of wires or hairs, placed at the focal plane of the eyepiece so as to superimpose a grid or other pattern over the field of view.

Reverted: Laterally reversed.

Rhomboidal prism: A reflecting prism that has two parallel reflecting surfaces and two parallel transmitting surfaces. It is used to offset an image without changing its orientation. Pairs of rhomboidal prisms are used to adjust the *interpupillary distance* in *binoviewers* and some binocular telescopes.

Right Ascension (RA): The angle, measured eastward on the celestial equator, between the First Point of Aries and the hour circle through the object.

Roof prism: A prism in which one face has been formed into a "roof" with a right-angled apex.

Scintillation: The twinkling of stars, resulting from atmospheric disturbance.

Spherical aberration: An optical *aberration* in which light from different parts of a mirror or lens is brought to different foci.

Stereopsis, stereoscopic vision: Three-dimension vision that results from the spacing of the eyes, each eye seeing the object from a slightly different angle.

Superior conjunction: The conjunction of Venus and Mercury when they are more distant than the Sun.

Superior planets: Those planets whose orbits lie outside Earth's orbit.

Terminator: The boundary of the illuminated part of the disc of a planet or moon.

Transit: 1. The passage of Mercury or Venus across the disc of the Sun; 2. The passage of a planet's moon across the disc of the parent planet; 3 The passage of a planetary feature (such as Jupiter's Great Red Spot) across the central *meridian* of the planet; 4. The passage of an object across the observer's meridian (see also *culmination*).

True field (of view): The angular size of the entire object. It is the angle of the cone of rays at the aperture that is transmitted as a usable image.

Umbra: 1. The shadow that results when a bright object is completely occulted. A total eclipse of the Sun occurs when the observer is in the Moon's umbra; 2. The dark inner region of a sunspot.

Vignetting: The loss of light, usually around the periphery of an image, as a consequence of an incomplete bundle of rays passing through the optical system.

Visual axis: A line from the object, through the node of the eye's lens, to the fovea.

Wedge: The part that fits between the tripod or pillar and the fork of a fork-mounted telescope, which enables the fork to be equatorially aligned.

Zenith: The point on the *meridian* directly above an observer.

Index