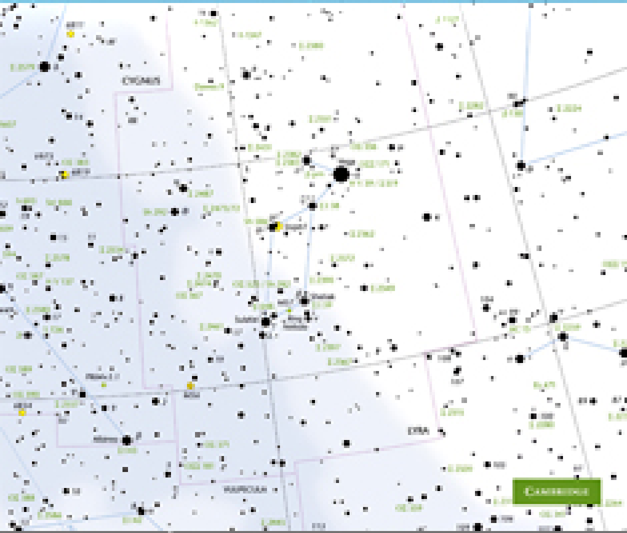
James Mullaney and Wil Tirion

THE CAMBRIDGE DOUBLE STAR ATLAS



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The Cambridge Double Star Atlas

This magnificent atlas contains the most attractive and interesting double and multiple stars for viewing with binoculars and telescopes. It is a must-have for stargazers who want to explore these fascinating objects.

The first modern star atlas devoted to double and multiple stars, it plots nearly 2,400 selected pairs, each labeled with discoverer, catalog, and/or observatory designations. A superb introduction to this important class of celestial objects, it is spiral bound and printed in red-light friendly colors, making it ideal for use in the field.

Written by experienced observer James Mullaney, and beautifully illustrated by renowned celestial cartographer Wil Tirion, this atlas provides an easy-to-use "celestial roadmap" to locate and identify double and multiple stars. Other deep-sky objects such as star clusters, nebulae, and galaxies are also included, and are color-coded for easy recognition and identification, making this an all-purpose observing reference.

JAMES MULLANEY, former assistant editor at *Sky & Telescope* magazine, is an astronomy writer, lecturer, and consultant, who has published more than 500 articles and seven books on observing the wonders of the heavens.

WIL TIRION is a full-time uranographer. He is famous for the numerous star charts he has created for astronomy books, atlases, and magazines.

THE CAMBRIDGE DOUBLE STAR ATLAS

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CONTENTS

INTRODUCTION

We are very pleased to present what is the first major modern star atlas devoted primarily to the observation of visual double and multiple stars. With the widespread growing popularity of viewing these tinted jewels of the heavens by amateur astronomers today, the need for such a work clearly exists. The one classic atlas that identified these objects, along with their discoverers and/or catalog designations, was *Norton's Star Atlas* through its first 17 editions. Sadly, all later revised and redrawn versions of this atlas – initially re-titled *Norton's 2000.0* and currently back to the original *Norton's Star Atlas* – dropped the discoverer and catalog labels (along with those of the clusters, nebulae and galaxies discovered by the Herschels) to the dismay of observers of both classes of deep-sky wonders.

It is now estimated that at least 80 percent of the stellar population exists as pairs or multiple systems of suns. Their amazing profusion, combined with a seemingly endless variety of color combinations, brightnesses, separations, and component configurations, make them fascinating objects for both leisurely viewing and serious study. Abounding as they do among the naked-eye stars, literally thousands of them are visible with even the smallest of glasses (and, in the case of the wider pairs, with binoculars as well) and on all but the very worst of nights – including those with bright moonlight, haze and heavy light pollution. So not only are these stars plentiful and easily located, but they are truly ever-fascinating sights!

While this new atlas was primarily designed with double star observation in mind, it also serves as a general-purpose guide for viewing all types of deep-sky objects, showing as it does many prominent asterisms, star clusters, nebulae, galaxies, variable stars, and the majestic Milky Way itself.

Map parameters and selection criteria

The 30 maps comprising the *Atlas* were planned, drawn, and labeled by Wil Tirion, widely recognized as the world's greatest celestial "cartographer" and creator of such classic works as the magnificent *Sky Atlas 2000.0*. They designate nearly 2,400 double and multiple stars suitable for viewing with typical "backyard" telescopes in the 2-inch to 14-inch aperture range. These are shown using the standard symbol of a star bisected by a bar and are labeled in green, which shows up well under the red lighting used at the telescope to maintain dark-adaptation (see below). In addition to writing this introductory guide to the *Atlas*, I selected the original target list itself (as well as the showpiece roster below) based on my personal observations of tens-of-thousands of pairs over the past 50 years using literally hundreds of telescopes of all types and sizes within the aperture range stated above. No doubt, experienced observers will have favorites that are not plotted/designated as being multiple stars. If every object that is visually double in some size of telescope were to be indicated, fully half of all the stars plotted on the maps would have bars through them! But those shown certainly are *among* the most attractive and interesting in the sky, and as such offer a well-rounded selection for surveying these fascinating stellar combos. (See Appendix C for the complete target list of pairs used in creating this *Atlas*.)

All told, some 25,000 stars are plotted in half-magnitude steps on the maps to a nominal visual magnitude limit of 7.5 (the primary star's brightness combined with that of its companion/s, the cutoff for the latter being roughly magnitude 10.5), in addition to 900 non-stellar deep-sky wonders. Angular separations range from those of tight challenging binaries reaching at least 0.5 arcseconds in their orbits such as γ Virginis and ζ Herculis out to ones wide enough to be resolved with the unaided eye – ones like the well-known combos α Capricorni, ε Lyrae and θ Tauri. Pairs wider than 180 arcseconds whose companions lie at or above the 7.5 magnitude limit are plotted as separate stars on the maps.

(These objects are typically excellent targets for viewing with binoculars.)

A number of doubles that lie somewhat below the *Atlas* limit are also plotted because they have especially striking color contrasts, and/or component configurations, as well as lying in or near striking backgrounds such as that of a cluster or nebula. In addition, a very few even fainter pairs are included for reasons other than their visual attractiveness – famous ones like Winnecke 4, notable as actually being Messier 40, and Krueger 60, a red dwarf binary flare star. And while mentioning dim objects below our limit, it's very important to point out here that many of the double and multiple stars plotted *often have one or more fainter pairs lying within the same low-power eyepiece field*! Thus, observers should always check the field of view for these unsuspected but fascinating duos in addition to scrutinizing the primary target object itself.

A magnitude scale and color-coded key to the symbols used to denote various types of deep-sky objects appears at the top of each map. Note that the edges of the maps have green-arrowed numbers indicating adjoining maps (with some overlap) in each direction, which will be very helpful in navigating the *Atlas*. Also, blue solid lines have been used to connect the principal stars in each constellation, the boundaries of which are indicated by dashed lavender lines. These so-called "stick figures" also help you find your way around the sky. Many observers today use computerized ("Go To") target acquisition, and at least some of the brighter doubles plotted – particularly those given in the showpiece roster below – can be so located by entering their designation, common name and/or coordinates on the controller's keypad. (See Appendix C for a complete list of all pairs plotted.) While these systems typically contain thousands of traditional deep-sky objects, double and multiple stars have largely been given short-shift by the programmers of their databases. And to many of us "purists," this modern technology takes away much of the fun of good old-fashioned "star hopping" to learn and find your way around the sky – which is really one of the primary purposes of a star atlas like this one.

Discoverer/catalog/observatory designations

Presented below is a list of all the designations used to identify the double and multiple stars plotted on the *Atlas* in addition to their proper or common names (if any), and Bayer (Greek) letter or Flamsteed number. There are several important things to note in this regard. First, in some cases there may be a difference between a discoverer's original designation and an official catalog designation. As one example, the striking triple system β Monocerotis is widely known as "Herschel's Wonder Star" after Sir William Herschel who discovered it. But its designation (in addition to its Greek letter/constellation) shown in all listings is Σ 919, signifying that it is the 919th entry in the great double star observer Wilhelm Struve's monumental catalog containing both his and other's discoveries. Another case is the magnificent radiant binary α Geminorum, or Castor. First discovered by G. D. Cassini and later re-discovered by J. Bradley, it appears as Σ 1110 in double star lists, again in addition to its Greek letter/constellation. A third example involves one of the very first telescopic double stars ever noticed – the striking identical twin suns of γ Arietis. This double star was found accidentally by Robert Hooke in 1664 while following a comet but carries no designation by him, being officially labeled Σ 180. (The preponderance of various Struve designations for many of the objects plotted on the *Atlas* maps is a result of the famed Struve dynasty of early double star observers, who dominated that field, as did the Herschels in the discovery of clusters and nebulae.) The policy followed in this current work is to use the designation by which each pair is officially and/or best-known by double star observers.

There's also the matter of multiple designations for the same double star, some of which are shown on the maps and others of which are not. In the first case, an observer may have originally discovered the obvious duplicity of an object while another (typically later) observer may have found an additional companion (usually a less obvious, closer-in or dimmer one). These cases are shown as a dual designation with a slash between them – such as

Σ 205/O Σ 38, which is Almaak (also known as Almach), the superbly tinted bright multiple system γ Andromedae. There are even objects having *three* different designations, one example being the amazing double-double system ν Scorpii. Each close pair has a different discoverer, plus the two widely separated duos appear in a third observer's list as a "double" themselves!

In the second case involving multiple designations, only one may be shown when a pair actually has two (or, again, even more!) because the additional companion is much too close and/or faint to be seen with instruments in the aperture range stated above. There are also some instances where an object has duplicate designations by different independent discoverers, such as H V 12 = O ΣΣ 21 in Aries and Webb 2 = Piazzi 97 in Camelopardalis. And there are even cases of different numbers being mistakenly assigned to the same object by the same observer such as h 2052 in Cetus, which is the same pair as h 3373. But there's still more! There are a number of double stars – some quite bright and famous, such as α Scorpii (Antares) and α Centauri (Rigil Kent) – that have no official observer/catalog designation assigned to them, although their discoverers are known (Burg and Grant, and Richaud, respectively). This is also the case for some widely separated naked-eye pairs, such as ζ-1/2 Scorpii and μ-1/2 Scorpii, which appear much too obvious to have actually been "discovered" by anyone. Finally, in some cases, a discoverer's name will be given as an object's designation but without any number, one apparently never having been assigned to it for some reason.

Arranged alphabetically, the list that follows gives three columns of information. The first column provides standard symbols ranging from single or multiple Greek and Arabic letters to abbreviated and (in some cases) fully spelled-out names of discoverers and/or their catalogs/observatories. These are what have been used to label those double and multiple stars plotted only in this *Atlas*. (A complete listing of all known double star designations runs into the hundreds!) The second column gives the standard three-letter (and in some cases one- or two-letter) codes used in major computerized compilations such as the US Naval Observatory's massive online *Washington Double Star Catalog* (the *WDS*), which currently provides data on more than 100,000 double stars and is continually updated (typically nightly) as measurements come in! (See the reference section below.) In a majority of cases, these are the same letter codes shown in the first column but capitalized. The third column identifies the actual name of the discoverer and/or catalog/observatory represented by the symbols. Note that some of William Herschel's double star classes look very much the same as those used for his various classes of clusters and nebulae. However, they have totally different meanings!

Designation	WDS code	Discoverer/catalog/observatory
β	BU	S. W. Burnham
β pm	BUP	Burnham's 1913 proper motion catalog
Δ	DUN	J. Dunlop
Σ	STF	F. G. Wilhelm Struve's 1827 Dorpat catalog
Σ I	–	Wilhelm Struve's first supplement to Dorpat catalog
Σ II	–	Wilhelm Struve's second supplement to Dorpat catalog
σ	–	Appendix to *Poulkova Observations III*
ϕ	FIN	W. S. Finsen
A	A	R. G. Aitken
AC	AC	Alvan Clark
AG	AG	*Astronomische Gesellschaft Katalog*
AGC	AGC	Alvan G. Clark

Designation	WDS code	Discoverer/catalog/observatory
Arg	ARG	F. W. A. Argelander
B	B	Willem H. van den Bos
Barnard	BAR	E. E. Barnard
BrsO	BSO	Brisbane Observatory (Australia)
CapO	CPO	Cape Observatory (South Africa)
Copeland	–	L. Copeland
CorO	COO	Cordoba Observatory (Argentina)
Cou	COU	Paul Couteau
Dawes	DA	W. R. Dawes
Dem	D	Ercole Dembowski
Dju	DJU	P. Djurkovic
Don	DON	H. F. Donner
Doo	DOO	Eric Doolittle
Edg	EDG	D. W. Edgecomb
Es	ES	T. E. H. Espin
For	FOR	L. Forgeron
Frk	FRK	W. S. Franks
Gale	GLE	W. F. Gale
GAn	GAN	G. Anderson
Gli	GLI	J. M. Gilliss
H I	H	William Herschel's 1782–1784 catalogs: I = difficult
H II	H	William Herschel: II = close but measurable
H III	H	William Herschel: III = 5″ to 15″ separation
H IV	H	William Herschel: IV = 15″ to 30″ separation
H V	H	William Herschel: V = 30″ to 1′ separation
H VI	H	William Herschel: VI = 1′ to 2′ separation
H N	H	William Herschel's 1821 catalog
h	HJ	John Herschel
HdO	HDO	Harvard Observatory (USA and elsewhere)
Hld	HLD	E. S. Holden
Ho	HO	G. W. Hough
Hooke	–	Robert Hooke
Howe	HWE	H. A. Howe
Hrg	HRG	L. Hargrave
Hu	HU	W. J. Hussey
Hzg	HZG	E. Hertzsprung
I	I	R. T. A. Innes
J	J	Robert Jonckheere
Jc	JC	W. S. Jacob
Knott	KNT	G. Knott
Kr	KR	A. Krueger
Ku	KU	F. Kustner
Kui	KUI	Gerard P. Kuiper
Lac	LCL	N. de Lacaille

Designation	WDS code	Discoverer/catalog/observatory
Lal	LAL	F. de Lalande
LDS	LDS	W. J. Luyten's 1941 proper motion survey
Lewis	L	Thomas Lewis
Mh	MH	O. M. Mitchel
Mil	MIL	J. A. Miller
MlbO	MLO	Melbourne Observatory (Australia)
Mlr	MUL	Paul Muller
O Σ	STT	Otto Struve's 1843 Pulkovo catalog
O ΣΣ	STT	Otto Struve's 1843 Pulkovo catalog supplement
Pz	PZ	G. Piazzi
R	R	H. C. Russell
Rmk	RMK	C. L.C. Rumker
Roe	ROE	E. D. Roe
Rst	RST	R. A. Rossiter
S	S	James South
Sh	SHJ	James South and John Herschel joint 1824 catalog
Se	SE	A. Secchi
See	SEE	T. J. J. See
Sei	SEI	J. Scheiner
Slr	SLR	R. P. Sellors
Smyth	SMY	W. H. Smyth
Stone	STN	Ormond Stone
Vou	VOU	J. G. E. G. Voute
Webb	WEB	T. W. Webb
WFC	WFC	*Washington Fundamental Catalogue – Astrographs*
Wg	WG	R. W. Wrigley
Wnc	WNC	F. A. Winnecke
WNO	WNO	US Naval Observatory (USA)

Observer, atmosphere and instrument

It has often been stated that the person behind the eyepiece of a telescope is far more important than the size or type or quality of the instrument itself. The truth of this adage has been proven time and again – a typical example being that of a skilled observer using a small telescope seeing vastly more detail on a planet like Mars than an inexperienced one using a much larger aperture. The fact is that the eye does not work alone, but rather in conjunction with the most marvelous "image processor" known – the human brain! It was Sir William Herschel, the greatest visual astronomer that ever lived, who said that "seeing" is an art and that as observers we must properly educate our eyes to *really see* what it is that we are looking at in the eyepiece. And so this section is aimed at helping you get the most out of your nightly explorations of the heavens, especially the observation of double stars.

Training the eye

There are several distinct areas in which the human eye/brain combination can be educated to see better. Let's begin with that of visual acuity – the ability to see or resolve fine detail in an image or in splitting close double stars. There's no question that the more time you spend at the eyepiece, the more detail you will eventually see! Even without any real purposeful training plan in mind, the eye/brain combination will learn to search for and find ever-finer detail in what it is viewing. But this process can be considerably accelerated by a simple exercise repeated daily for a period of at least several weeks. On a piece of white paper, draw a circle – say, 3 inches in diameter. Then using a soft pencil, randomly place various markings within the circle, ranging from broad patchy shadings to fine lines and points. Now place the paper at the opposite side of a room at a distance of at least 20 feet or so, and begin drawing what you see using the unaided eye. Initially, only the larger markings will be visible to you, but as you repeat this process over a period of time, you'll be able to see more and more of them. Tests have shown improvements in overall visual acuity of a factor of 10 using such procedures! Not only will you see more detail on the Sun, Moon and planets as a result, but you'll also be able to resolve much closer double stars than you were able to previously.

A second area of training the eye/brain combination involves the technique of employing *averted* (or side) *vision* in viewing faint celestial objects. This makes use of the well-known fact that the outer portion of the retina of the eye – that containing the receptors called *rods* – is much more sensitive to low levels of illumination than is the center of the eye containing the receptors known as *cones*. (See the discussion below involving color perception by the latter.) This explains the common experience of driving at night and objects seen out of the corner of your eye appearing brighter than they actually are if you turn and look directly at them. While this is especially useful in viewing low-surface-brightness targets like nebulae and galaxies (where increases in apparent brightness of 2 to 2.5 times have been reported!), averted vision is also helpful in detecting faint companions to doubles by looking to one side or the other of the primary star (above or below also works).

A third important area involving the eye/brain combination is that of color perception. At first glance, to the unaided eye the stars all appear to be white. But, upon closer inspection, differences in tint among the brighter ones reveal themselves. The lovely contrasting hues of ruddy-orange Betelgeuse and blue-white Rigel in the constellation Orion is one striking example in the winter sky. Another can be found in the summer sky by comparing blue-white Vega in Lyra, orange Arcturus in Bootes and ruddy Antares in Scorpius. Indeed, the sky is alive with color once you've been trained to see it! While the rods in the edge of the eye are light sensitive, they are essentially colorblind. Thus, for viewing the tints of stars (whether single, double or multiple) direct vision is employed – making use of the color-sensitive cones at the center of the eye. Stare directly at an object to perceive its color (and off to the side to see it brighter – unless it's already bright like a planet or brilliant star!). Many of the lovely color combinations reported for double stars are a result of contrast effects between the primary and its companion/s. However, in other cases these are very definitely real! A star's color is primarily an indication of its "surface" temperature: ruddy ones are relatively cool and bluish ones are quite hot, while yellow and orange suns fall in between these extremes. And there are even some green stars, such as the striking emerald-green companion of Antares (α Scorpii) and the sea-green or aquamarine companion of Almaak (Almach), γ Andromedae.

One final note concerning preparation of the eye to see better is that of *dark-adaptation*. It's an obvious fact that the eyes need time to adjust to the dark after coming out of a brightly lit room. Two factors are at play here. One is the dilation of the pupils themselves, which begins immediately upon entering the dark and continues for several minutes. The other involves the actual chemistry of the eye, as the hormone rhodopsin (often called "visual purple") stimulates the sensitivity of the rods to low levels of illumination. The combined result is that night vision continues to improve noticeably for perhaps half an hour or so. This explains why the sky looks black on first going outside, but later looks gray as you fully adjust to the dark. In the first instance, it's a contrast effect and in the second the eye has become sensitive to stray light, light-pollution and the natural airglow of the sky itself that were not seen initially. Double stars themselves are generally so bright that they can be seen to advantage almost immediately upon going to the telescope (making them ideal "warm-up" targets before viewing other types of deep-sky wonders). Exceptions are faint pairs and dim companions to brighter stars (where the radiance of the primary often destroys the effect of dark-adaptation). White light causes the eye to lose its sensitivity but red light preserves it, making it standard practice to use red illumination for reading star maps and making notes at the eyepiece.

Sky conditions

A number of atmospheric and related factors affect the visibility and appearance of celestial objects in the telescope. In the case of double and multiple stars, the most important of these is atmospheric turbulence or seeing, which is an indication of the steadiness of the image. On some nights, the air is so unsteady (or "boiling" as it's sometimes referred to) that star images appear as big puffy, shimmering balls, and detail on the Moon and planets is all but non-existent. This typically happens on nights of high transparency – those having crystal-clear skies in which the air overhead is in a state of rapid motion and agitation. On other nights, fine detail stands out on the Moon and planets like an artist's etching, and star images are nearly pinpoints showing virtually no motion, with even close double stars revealing themselves easily. Such nights are often hazy and/or muggy, indicating stagnant tranquil air over the observer's head.

One of the most dramatic and revealing examples of the impact of changing seeing conditions upon the visibility of celestial objects comes from the great double star observer, S. W. Burnham, in the following classic account of the famed pair Sirius (α Canis Majoris): "An object glass of 6-inches one night will show the companion to Sirius perfectly: on the next night, just as good in every respect, so far as one can tell with the unaided eye, the largest telescope in the world will show no more trace of the small star than if it had been blotted out of existence."

Various "seeing scales" have long been employed by observers to quantify the state of atmospheric steadiness. One of the most common of these uses a 1-to-5 numerical scale, with 1 indicating hopelessly turbulent blurred images, 5 stationary razor-sharp ones, and 3 average conditions. Others prefer a 1-to-10 system, with 1 again representing very poor and 10 virtually perfect seeing, respectively. (In some schemes, the numerical sequence is reversed, with lower numbers indicating better and higher numbers poorer seeing.) Casual double star observing can be done in all but the worst of seeing conditions, but projects like that of micrometer measurements of the angular separations of close binary systems require the very best seeing possible.

Among other factors affecting telescopic image quality is that known as "local seeing" or the thermal conditions in and around the telescope itself. Heat radiating from driveways, walkways and streets, houses and other structures (especially on nights following hot days), plays a significant role. This is why observing from grassy areas away from buildings gives the best results. The cooling of the telescope's optics and tube assembly is especially critical to achieving sharp images. Depending on the season of the year, it may take up to an hour or more for the optics (especially the primary mirror in larger reflectors) to reach equilibrium with the cooling night air. During this cool-down process, air currents within the telescope tube itself can play absolute havoc with image quality, no matter how good the optics and atmospheric seeing are. (This is less of a concern using refractors with their closed tubes, which in smaller apertures at least are essentially ready for immediate use.) Surprisingly, even the heat radiating from the observer's body can be a concern here, particularly with reflecting telescopes that have open-tubed truss designs.

Resolution and magnification

Much has been written in the literature of double star observation over the years about the resolution capabilities of various size apertures, the best-known of which is *Dawes' Limit*. Derived from observations with several excellent refractors of various sizes, it states that $R = 4.56/A$, where R is the resolution in arcseconds and A is the telescope's aperture in inches. (If expressing the aperture in millimeters rather than inches, the relationship becomes $R = 116/A$.)

But this formula holds strictly true only for pairs of equal brightness and of about the 6th-magnitude. For brighter, fainter, and especially unequal pairs, Dawes' Limit departs markedly from actual results at the telescope (values as great as $36/A$ having been reported in the case of a 6th-magnitude difference between a primary and its companion!). Another resolution relationship is the *Rayleigh Criterion*. Here $R = 5.5/D$, where R is again the resolution in arcseconds and D is the diameter (or aperture) of the telescope in inches. This theoretical relationship is based on the wave nature of light and gives a somewhat less stringent and (according to many observers) a more realistic result. Part of the difference involves what is actually meant by the "resolution" of two stars. Dawes' Limit considers this to be when the first dark ring of one star's diffraction pattern intersects the other star's central disk – which means a notched or partially merged image of the pair. The Rayleigh Criterion considers a pair to be split when the outer edge of each star's diffraction disk is separated by a space equal to the width of the first dark ring – in others words, fully separated images. There's also the *Markowitz Limit* which states that for a pair to show disks just in contact $R = 6/D$, giving a yet more realistic value of what's actually seen at the eyepiece. (A more recent innovative approach to the subject of double star resolution has been developed by Christopher Lord of the Brayebrook Observatory in Britain, including an amazingly comprehensive nomogram for determining the resolution of unequal binaries. Those interested in exploring this topic further should go to www.brayebrookobservatory.org and click on "Publications.")

So the primary factors at play in determining if a given telescope will split a particular double star (aside from atmospheric conditions) are the magnitude difference and separation of its components. In achieving optimum results here, in addition to very steady seeing, the telescope must be used at what is known as its "resolving magnification." This is typically given as 25× per inch of aperture or more. But, for casual observation of double stars in general, the rule-of-thumb is to use the lowest power that just nicely separates the pair. And again, as previously mentioned above, be sure to check the field of view for any additional pairs (or fainter companions to the primary target) that may be present but that lie below the magnitude cutoff of our selections. Also, it's much more fun and "exploratory" to look at objects shown as double stars on the *Atlas* maps to see if they can be resolved, the number of companions visible and what colors if any are present *before* checking lists like those in the showpiece roster and reference sections below for what you should have seen but may have missed!

Optical quality and collimation

For the casual observation of double stars, even a telescope of mediocre optical quality can provide acceptable views, but for more demanding work – such as resolving close pairs or making micrometer measurements as some observers do – high optical quality is essential. The condition of a telescope's optics and its all-important optical alignment can readily be determined by a simple test using a star itself. Known as the extrafocal image test, this involves looking at the image of a star, both inside and outside of focus, using a medium-to-high-power eyepiece. An ideal target for this purpose is 2nd-magnitude Polaris (α Ursae Minoris), which is neither too bright nor too faint, and has the great added advantage of not moving in the eyepiece as the Earth rotates!

A telescope having first-class (or "diffraction-limited") optics in perfect alignment (or collimation) will show identical circular disks of light with a pattern of faint concentric interference rings on either side of focus as the eyepiece is racked in and out. These rings should be uniformly spaced and of even intensity; if not, this indicates zones in the optical figure – a condition known as "spherical aberration." A "shaggy" look to the rings indicates a rough polish to the glass rather than the desired smooth one. If the extrafocal images are triangular rather than circular, this shows that the objective lens or mirror is pinched in its cell. Elliptical-shaped images that rotate 90 degrees on either side of focus are the most to be feared, since they reveal the serious optical defect known as "astigmatism" or a warping of the glass itself. However, both astigmatism in the