

Choosing Binoculars

By Kevin Kilburn

One of the most useful instruments for the amateur astronomer is a decent pair of binoculars. They can augment a telescope, providing wide-field views of the sky. They are helpful in locating and viewing transient astronomical objects such as comets, asteroids and the elusive planet Mercury. They can be used as the sole instrument in variable star work, allowing comparison magnitude estimates of thousands of stars, and they can be a joy on warm summer nights for sweeping the Milky Way for star clusters and nebulae from the comfort of a reclining garden chair. Indeed, as a first time instrument for the budding amateur astronomer, a pair of binoculars is to be highly recommended to help initial familiarization with the night sky whereas even a small telescope is much more difficult to manage and has such a small field of view that finding objects is almost impossible, leading to disappointment.

Which binoculars are best? As always, this depends on the sort of use to which they are going to be put. A pair of binoculars is a useful addition to any household whether or not specifically for astronomy; for bird watching, field sports, sailing, the mountains, etc., so this must be taken into account in any selection. For now, astronomy takes precedence.

Basically there are three types of binocular available: Galilean 'opera' glasses, Roof prism compact binoculars, and Porro prismatic binoculars. Each has its pros and cons:

Galilean binoculars were cheap and popular in the first two decades of the 20th century. They can often be found in second-hand shops for a few pounds and can be recognised by their characteristic 'twin-bottle' shape. Many thousands of pairs were made for theatregoers from the mid 19th century onwards and some 'opera glasses' are elegantly ornamented with mother-of-pearl inlays. They were a fashion item. Outdoor and WWI Army 'field glasses' are of the same optical design but were more ruggedly constructed and came in much bigger sizes, with up to about 60mm diameter front lenses in the case of Royal Navy issue 'night glasses', with their shark-skin or shagreen (ray-skin) finish. These type of binocular are of the 'straight through' design with the front lenses collecting light from the subject and focussing it back through simple *negative* (concave) eyepiece lenses. All Galilean binoculars are comfortable to look through and have huge eye-relief, suitable for spectacle wearers. The eyepieces are so big that unlike prismatic binoculars there is no need to adjust the interpupillary distance. There is no central hinge. The optical tubes are assembled between solid plates that span the binocular. Galileans require little in the way of focussing, but they suffer from a very narrow field of view (FoV) - like looking through a pair of cardboard toilet-roll tubes! They also have very low magnification, usually no more than x3 or x4, at best. Their optical layout is certainly not suited to wide-field astronomy although they are very collectable as antiques.



Roof prism compact binoculars are a 1960-70s, fit-in-a-pocket, development using in-line roof prisms. Modern instruments are optically very good (and can be expensive) but they are designed for daytime viewing where their compact size makes them suitable for casual use under bright conditions. Again, a straight-through design, the prisms are only there to make the image appear right way up and to shorten the instrument. Most camera shops usually stock plenty of them. Rather too small for astronomy, OGs rarely exceed 40mm, but they are top of the range for bird-watching.



Prismatic binoculars employing Porro prisms, are by far the best for all round use including astronomy. They are available in a wide choice of size and magnification to suit specific tasks and the depth of pocket. Two distinctive body shapes are available but both have the familiar zig-zag shape dictated by the Porro prism arrangement. Actually this is deliberately designed to maximise object glass (OG) separation, together with normal 72- 75mm eye separation, thus giving a maximum 3D effect on near and mid-range targets. The rather angular, multi-segmented model developed in Western Europe after WWI has separate lens tubes that screw into separate prism units. The American pattern are characterised by a more smoothly contoured aluminium all-in-one body casting that holds both the prism cages and the front lens. Both are of equally good design, the latter often being available in rubber armour that is totally waterproof and may include in-built buoyancy so the instrument floats. Both types have as a common feature optical tubes that are hinged either side of a rigid central bar connecting the prism housings but in the case of large binoculars extended to the front of the instrument to assist in keeping the heavy front lenses in collimation. In this case the bar often carries an adjustable tripod adaptor. Tripod adaptors can be bought separately to fit a range of smaller binoculars.

For astronomy, light-grasp is all-important. Front lenses (objectives) range in size from 30-40mm diameter for daytime use and 50-60mm diameter for low light level applications, including astronomy. Sub-giants with 60-70mm lenses are readily available and for high-end applications, giants and even super-giant instruments, 80-125mm aperture can be bought - at a price! All quality glasses are achromatic doublets.

Merits of prismatic binoculars: They are available in a wide range of sizes and magnifications. They are relatively compact and are relatively cheap, although you get what you pay for. Disadvantages: Only one. Because binoculars are so popular there are a lot of cheap but inferior glasses on the market.

Binoculars are rated in terms of magnification and objective lens diameter. Somewhere on the body of the instrument will be a set of numbers; 7x50, 20x60 for instance. This denotes the magnification, x7 or x20, and the objective diameter, 50mm or 60mm. These numbers are the first port of call in binocular selection. They give a clear indication of how the instrument will perform for the astronomical purposes for which it is being considered.

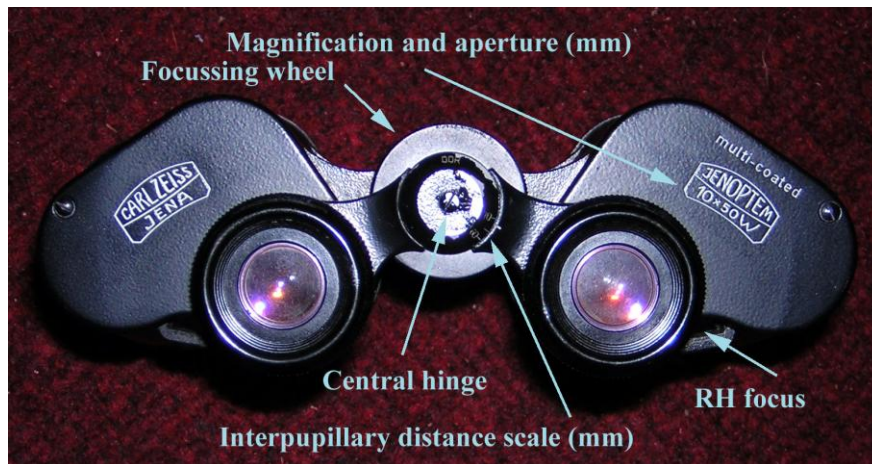


The objective diameter is the most important and dictates how much light will enter the instrument. The bigger the lens, the fainter the stars that can be seen. Star brightness, or magnitude, is a logarithmic progression. Magnitude 1 stars are brighter than mag 2...and so on. Each magnitude is about 2.52 times different in brightness than the next. The faintest star just visible to the naked eye on a very dark night is magnitude 6 and is 100 times fainter than a mag 1 star, equal to the five magnitude steps between 1 and 6 ($2.52 \times 2.52 \times 2.52 \times 2.52 \times 2.52$). To gain a single magnitude, the aperture of the bigger instrument has to collect two and a half times as much light than the smaller one in trying to see fainter stars. Its front lens collecting *area* has to be progressively 2.52x greater for each magnitude gained. Even a binocular with 25mm objectives will show stars about 3 magnitudes fainter than unaided vision because its light collecting area is about fifteen times bigger than the pupil diameter of the naked eye.

If a 25mm (1-inch) objective will just show stars of mag. 9, it will take a lens of two and a half times the *area*, 1237 sqr mm as against 491sqr mm, to reach mag.10.(Lens area is $3.142 \times \text{radius} \times \text{radius}$) This would be a 35mm lens. To gain another magnitude would require a 55mm glass and to gain yet another magnitude would require whopping 90-100mm diameter objectives. To gain three magnitudes requires glasses with about sixteen times the light collecting area of the smaller instrument! Fortunately a lot of productive astronomy can be done with a more modest binocular, somewhere in between.

A good starting binocular will have 50mm object glasses. Now, what about magnification? Obviously, the bigger the better... Well, not quite so!

Stars are point sources and *cannot* be magnified; lens aperture and sky brightness dictates how faint the star that can be glimpsed, as we have already seen. However, the Moon, a comet, a galaxy, or other extended object *can* be magnified and will lose surface brightness if magnified too much. Increasing the magnification spreads out what incoming light is available and makes *extended* night time objects appear fainter. To see faint ‘fuzzies’, galaxies, nebulae or comets, or for optimum terrestrial night time views, a low magnification is preferable. High magnification does however allow smaller detail to be resolved on the moon, for instance, where light is plentiful. It also has the subtle effect of reducing sky brightness without affecting star brightness, thus increasing contrast between the night sky and faint stars or asteroids. For this last reason, giant and super-giant binoculars are best for detecting faint stellar objects.



But how low a magnification is practicable? Now we hit a fundamental, physiological fact. Using the numbers on the binocular, eg 7x50, in which case 50mm is the diameter of the *incoming* beam of light, dividing the aperture by the magnification gives the diameter of the *exit pencil*, the beam of light that leaves the eyepiece and has to enter the eye. In bright daylight, the eye automatically reacts to ambient lighting conditions by adjusting the diameter of its pupil to see without being dazzled. The pupil may contract to as little as 3mm in brilliant sunlight. At night, a fully dark-adapted pupil will open to about 8mm in diameter. To fully utilise the light collected by the object glass, the *exit pencil* must not exceed the pupil of the eye, but should be as big as possible. For this reason it is often stated that 7x50 binoculars are best; 50 divided by 7 gives a 7mm exit pencil. Such binoculars are often called ‘night-glasses’ and are recommended for *young* astronomers.

Hold a pair of binoculars at arms length skywards and look at the eyepieces. You will see a bright, small, circle of light apparently floating in the centre of each lens. This is the *exit pupil/pencil*. Extended image brightness is proportional to the square of the exit pupil. Consider these three binoculars, where the front aperture is the same, 50mm, but the magnification is different:

7x50	exit pupil/pencil 7mm (50/7)	Relative image brightness $7 \times 7 = 49$	Brightest extended image
10x50	“ “ 5mm (50/10)	“ “ “ $5 \times 5 = 25$	
12x50	“ “ 4mm (50/12)	“ “ “ $4 \times 4 = 16$	Faintest extended image

This simple calculation allows other sizes of binoculars to be compared. A super-giant pair of 25x100mm binoculars will show stars only one and a half magnitudes fainter than a 50mm glass but will show a comet no brighter than a pair of 12x50's. The light collecting area of the objectives is 4 times greater but the relative image brightness of the instrument is the same! Giant binoculars are good for deep sky observing of faint stars and asteroids but may be out-performed by smaller instruments giving equal or greater image brightness, when observing comets and for wide-field views.

There is an important proviso to the general statement given above, regarding 'night glasses'. Although the maximum aperture of the iris of a young adult is about 8mm, by the age of about 30 this starts to reduce. As one gets older, it becomes impossible for a low power night glass to work effectively. Only the central part of the exit pencil will fit into the eye and the effect is exactly the same as using a smaller aperture instrument, not enough light can physically enter the eye and is wasted. For astronomy, it is therefore better to go for a slightly higher magnification, particularly for the older observer: 10x50's are a good compromise. They give reasonable magnification, with which to examine detail in an extended object, whilst retaining adequate surface brightness. Perhaps the next level would be a pair of 15x80s, with slightly greater light grasp, a greater magnification for seeing detail, and a small increase in image brightness. The increased cost of the larger instrument would, however, be disproportionately much greater.

Big binoculars can be difficult to manage. A pair of 25x100's may weigh over 7kg and definitely cannot be hand-held. Any instrument over 15x80 or with a magnification greater than this needs to be mounted on a tripod or a special cantilevered binocular mounting. Even 10x50's are heavy and as magnification increases there is a greater necessity to use some sort of armrest to use them in comfort. Holding the binoculars with one's elbows tucked in against the chest is another method of gaining some stability but only as a temporary measure.

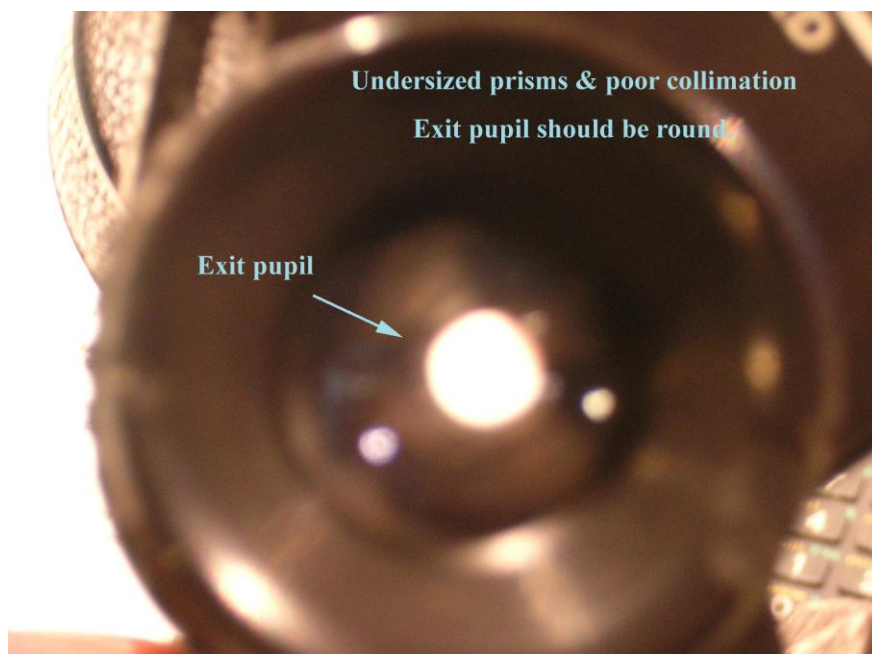
Magnification also affects the field of view. Prismatic binoculars have a fairly wide field of view (FoV); the type of eyepiece dictates this and they are designed for optimum performance. Typically, about a 45 degree *apparent* FoV is available in a good pair of prismatic binoculars, compared with perhaps only 20degrees in Galilean glasses. To see the full FoV it is necessary to put the eyepieces close to the eye. Spectacle-wearers are advised to take 'em off. The *actual* FoV is the *apparent* field divided by the magnification. For instance, a pair of 7x50's will have an actual FoV of about $45/7=6.5$ degrees. A pair of 10x50s will be a bit less. A 25x binocular will give a FoV of about 2 degrees or less; only three-four times the diameter of the full moon. A steady support becomes absolutely essential as magnification increases and in this respect a pair of 7x50 or 10x50 binoculars are preferable as an easy to hold instrument, especially for the beginner.

Variable power binoculars; incorporating zoom eyepieces, are sold for terrestrial viewing where light is not at a premium. They can be of very high magnification and are often sold on this alone. Often ex-mail order, you get what you pay for. For a combination of the reasons given above, they are not recommended for serious astronomical use.

Testing binoculars: As the name implies, binoculars are designed to be looked through using both eyes. The pair of Porro prisms that fold the light path in each side of the binocular and shorten the instrument are a critically important part of the instrument. Prism units are expensive to make and adjust. Poor quality can give rise to misalignment and miss-matching of the field of view seen in each eyepiece. Even a small misalignment can be noticeable. One way of producing cheap binoculars is to skimp on this fundamental requirement. Another way of fooling the buyer is to offer cheap Galilean optics masquerading in the body shape of a 'prismatic'...the narrow field of view easily gives this game away!

Before buying a binocular it is worth carrying out simple tests to ensure that the prisms are correctly sized, aligned and the instrument is fully collimated. Do the checks in the following order. The first tests are to examine each side of the binocular as though it was a self-contained monocular. The second tests are a bit more complicated and aim to confirm that each side is collimated with respect to the other.

1. To check the prism size, hold the binoculars angled downwards, towards the floor, at arms length and look at the exit pupil. It must be fully round. Any suggestion of a fuzzy-edged, or even squared off exit pupil is a sure sign of undersized prisms or prisms made from cheap BAK-7 glass rather than the high refractive-index BAK-4 glass used for the prisms of higher quality binoculars. Oval, or 'cats-eye' exit pupils indicate prism misalignment, and is less of a problem but should not be present in a new instrument. It is usually seen in one side of the binocular, rarely in both. Binoculars sometimes do get misaligned and can be professionally re-collimated. It is not a job for the amateur. If the binoculars you are contemplating buying show this defect, don't buy them but ask to see another pair. They may simply have become misaligned enroute from the manufacturer to the shop, perhaps by being dropped.



2. Now, look through the binoculars at a distant scene and adjust the inter-pupillary distance, by moving one side with respect to the other on the hinged bar that separates them, until a **circular** fused image is seen. Binoculars should not show the figure-of-8 outline to the field of view so beloved by cartoonists! It is recommended that spectacle-wearers should remove them so that the eyes can be brought closer into the eye-cups of the eyepieces. Rubber eye-cups can be bought separately and may assist viewing comfort. They do however have the tendency to fall off and get lost.

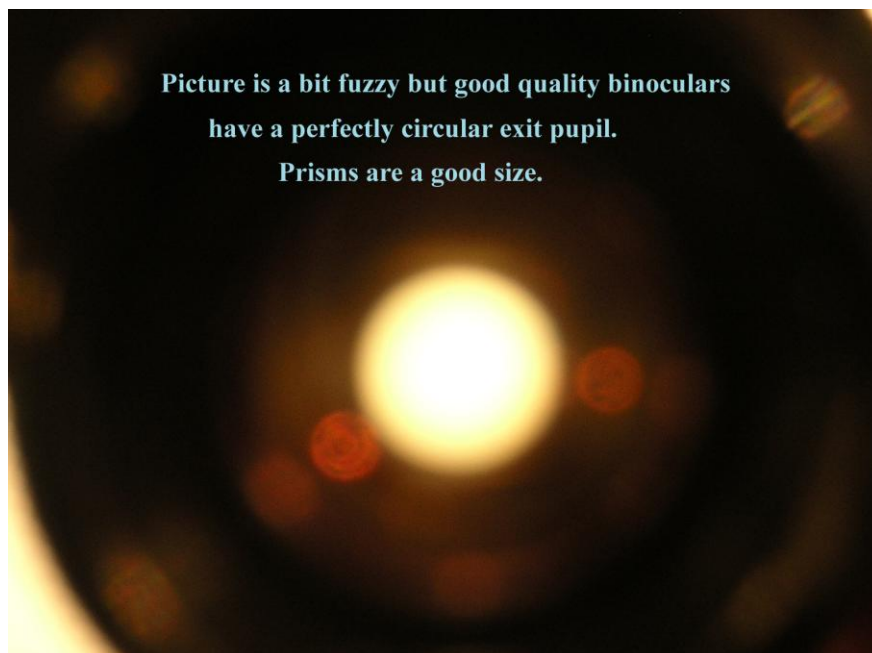
NB: If you know that you have eye astigmatism, spectacle-wearers may have to keep them on and make do with a somewhat restricted FoV. Without prescribed corrective lenses that are purpose made to go over the eyepieces, astigmatism cannot be corrected for the binocular user.

Look at a **distant** brick wall (not less than 30metres), first through one eye and then the other. Focus the **left eye** using the centre-wheel focussing. Now focus the **right eye** using the independent adjustable focus on the RH eyepiece. Some large binoculars have independent focussing on each eyepiece and do not have a central focusing wheel.

Both images should be crisply defined in each eye. A small amount of combined focus 'twiddling' with the centre wheel should then produce a crisp, comfortable image in both eyes. This is used to adjust the focus for intermediate distances to different targets. Identifiable courses of bricks must not appear to be displaced either horizontally or vertically with respect to one another. The two superimposed images should also match with no apparent rotation of one side with respect to the other. The fused image must be clear and comfortable to view, without any feeling of eye-strain. If there is any discomfort with the instrument or it is blatantly obvious that the two sides are not in collimation, reject the binocular immediately.

Quality instruments will easily pass all of the above tests, cheap ones often fail one or some of them, but you may be lucky!

NB: The above method of focussing should be done every 10-15 minutes when observing with binoculars at night. A dark-adapted eye soon loses its natural ability to focus when ambient light levels are low.



A good pair of binoculars will last a lifetime. Many still survive from WWII and yet are still perfectly serviceable. If a bargain is available, even old binoculars can be professionally cleaned, re-collimated and put back into useful work at about half the cost of a new pair. In the very worst scenario, lenses will be chipped or cracked and then nothing can be done. New binoculars, particularly from a recognised manufacturer or distributor such as Zeiss, Nikon, Pentax or Meade and Celestron (there are others) will not be cheap but are a very good investment and should carry a lifetime guarantee. At the time of writing, 2010, expect to pay around £150-£200 (\$220-300) for good 10x50 glasses. Other less expensive makes can be good value but may show a degree of variable quality control, even within the same brand although the Russian Helios binoculars and some Chinese imports are now of very high quality and are gaining in popularity. You get what you pay for. Some instruments are definitely better than others but even then, the simple tests suggested above will separate the wheat from the chaff.

Monoculars: these are one half of a binocular. They are usually available in small sizes, up to about 40mm, and are very portable. Because of their shape, they can be awkward to aim, especially at astronomical targets.

Image-stabilized binoculars: a fairly recent Japanese development in which the light collected by the object lenses passes through prism units that are free to move, at the press of a button, thus remaining more or less steady even though the observer's hands are shaking with cold. They are an expensive option. Buy them if you don't mind the cost. The Russian approach has interesting possibilities; stabilize the binoculars, rather than the image, by incorporating fast-spinning gyroscopes! This does however make for a very heavy and cumbersome instrument.

Anti-reflection coatings. Uncoated glass reflects about 3% of incident light and there are a lot of air-glass surfaces in a binocular. This can waste a lot of light, perhaps as much as 25%. This is the reason why it is difficult to put an exact figure on the faintest star magnitude that can be seen through binoculars of ever-larger size. To improve optical transmission and thereby increase image brightness and contrast, magnesium fluoride coatings have been employed for many years to reduce reflectance. All modern binoculars have some degree of anti-reflection coating on their optical surfaces. Look out for these descriptions:

Coated optics: one or more surfaces are coated.

Fully coated: all air-glass surfaces are coated.

Multi coated: one or more glass surfaces are multi-coated.

Fully multi-coated: All air-glass surfaces are multi-coated.

Anti-reflectance coatings impart characteristic colours to the appearance of binocular lenses. This is an optical interference effect depending on the thickness of the coating and to some extent is a trademark of various manufacturers. Many are blue-green, some are yellow and a few, perhaps the highest quality, are red. The best binocular optics have fully multiple AR coatings (FMC) on all optical surfaces, reducing individual surface reflection to about 0.25%, whether or not they are immediately visible; lenses, prisms and eyepieces. Overall transmission is better than 95%. As always, you get what you pay for.

Good observing.

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