Wide Eyed
or too Wide?

the Dobsonian’s impact on eyepiece design

The past quarter century has witnessed a growing consensus that apparent field of view is the most important facet of any eyepiece. Amateur astronomers who observe deep sky objects with an undriven Dobson alt-az short focus Newtonian appreciate wider real fields at medium and high powers. It enables them to observe for longer whilst a nebula or star cluster drifts out of their field of vision.

Firstly for those not in the know, I ought to explain what is meant by "apparent field of view".
When you position your eye just behind the eye lens of an eyepiece held up to the open sky you see a circle of light formed by the field stop. The field stop is a circular diaphragm that limits the field of vision. The angle subtended by the field of vision is the apparent field of view. Depending on the design it ranges from a narrow 30º through a medium 55º to an ultra-wide 80º. The observed field of view is the apparent field divided by the magnification (in the absence of distortion).

Let's put a few numbers down to see what this means. Suppose I am observing with a 10-inch f/4 Dob, @ 50x magnification using a 20mm eyepiece. If the eyepiece is a Plossl, apparent field of view 50º, the real field will be 1º, but if the eyepiece is a Nagler, apparent field 82º, the real field will be 1º 36'.

Furthermore, because the Nagler is designed to compensate for the fast Newts coma, the wider real field of the ultra-wide will be sharper towards the edge. The Plossl's field will be marred by the Newts coma.

Dobs & Nags, a match made for the expanse of heaven. Nebulae and faint star clusters demand light grasp rather than raw resolving power. They do not test eyepiece resolution to the limit.

It is unfortunate that the Dob/Nag mindset has become so entrenched it now encompasses all eyepiece preferences and observing subjects. If you don't buy this argument try reading 'Astronomy Hacks' by Bruce & Barbara Thompson, which pretty well sums up the current amateur astronomy scene, particularly in North America & the UK.

So why would a planetary observer choose an eyepiece with a narrower apparent field of view when the ultra-wide angle is just as good? Since there is no such thing as a free lunch, it should come as no surprise for you to learn that the heavenly union of Dob & Nag breaks down when you try to observe fine planetary detail at high power.

A deep sky observer needs light grasp, that's aperture, the more the better. A deep sky observer also needs a very dark sky, and that for most means transportability and easy setup. For these requirements the Dob is ideal. Not so the planet observer. What we need is resolution and contrast. Telescopes optimised for hi-res viewing.

The ideal telescope for hi-res work is either a Cassegrain, Maksutov-Cassegrain, long focus Newtonian, long focus achromatic refractor or medium focus apochromatic refractor. Telescope types that have the highest quality optics, small or no central obstruction, and a focal plane largely free of coma and astigmatism.

But why wouldn't an ultra-wide be ideal for use with these telescopes at medium to high power? To answer that question I need to describe some of the qualities of eyepieces that effect the perception of low contrast detail. These are ghost images, internal reflections and scatter, and distortion.
**Ghost images & internal reflections**

There are two common causes of ghost images. Internal reflections that come to a focus at or near the eye's anterior focal plane, and a counter-reflection between the Cornea and the last lens surface facing the eye. If an air-glass surface facing the eye is concave, a ghost image may form.

The number of possible ghosts is proportional to the number of air-glass surfaces, given by the expression \( \frac{1}{2} N (N-1) \), where \( N \) is the number of air-glass surfaces.

<table>
<thead>
<tr>
<th>Number of reflecting surfaces</th>
<th>Potential Ghosts</th>
<th>Eyepiece Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>Tolles</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Steinhell Loupe</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Orthoscopic; Plössl; Galoc</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>Bertele; König</td>
</tr>
<tr>
<td>8</td>
<td>28</td>
<td>Panoptic; Nagler I;</td>
</tr>
<tr>
<td>10</td>
<td>45</td>
<td>Leitz Widefeld</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nagler II; Meade UWA</td>
</tr>
</tbody>
</table>

It must be emphasised that
\( \frac{1}{2} N (N-1) \) indicates the number of 'potential' ghosts, not the actual number. The task of the designer is to ensure that internal reflections do not focus in or near the image plane and form ghost images. But, the increase in transmission losses due to internal reflections, even if the designer can cleverly avoid the formation of ghost images becomes a big problem in complex multi-element designs.

**Anti-reflection coatings**

In order to get round the difficulties in suppressing reflections off air-glass surfaces lens manufacturers resort to multiple layer films. By arranging the coatings such that the square of the outer coating's refractive index equals the adjacent coating index, and so on through to the glass index, and ensuring the external coating is durable (e.g. silicon dioxide), then reflection losses off air-glass surfaces may be reduced to almost zero across the entire spectrum. This technique is termed 'multi-coating'.

It is however impossible to reduce reflection losses at a cemented surface where there is an index gradient because the balsam cannot have precisely the same index as the different glasses either side of it! So, as long as there is an index gradient,
inevitably there is a reflection loss.

As an illustration of the seriousness of this problem, consider three different eyepieces: a single element crown lens with only two air-glass surfaces; an orthoscopic with four air-glass surfaces and two cemented surfaces where the index gradient is 0.2; a multi-element ultra-wide angle eyepiece with ten air-glass surfaces and three cemented surfaces where the index gradient is only 0.1.

Without multi-coatings on all air-glass surfaces the ultra-wide angle design would not be practicable. The table also illustrates the significance of anti-reflection coatings in maximising transmission and image contrast.

<table>
<thead>
<tr>
<th>EYEPIECE TYPE</th>
<th>REFLECTION LOSSES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Uncoated</td>
</tr>
<tr>
<td>SINGLE LENS</td>
<td>8%</td>
</tr>
<tr>
<td>ORTHOSCOPIC</td>
<td>16.8%</td>
</tr>
<tr>
<td>ULTRA-WIDE ANGLE</td>
<td>41.44%</td>
</tr>
</tbody>
</table>

Light throughput is clearly better in simpler designs. What is also evident is that a high throughput is achieved with a standard MgFl2 anti-reflection coating. Multiple layer a/r coatings widen the spectral bandwidth over which total, or almost total destructive interference of surface reflections occurs within the film layers. The reason MgFl2 a/r coated lenses look deep purple is because the coating thickness is a $\frac{1}{2}$ in the yellow-green @ 550nm. Total destructive interference of surface reflections within the film occurs only at that wavelength, and partially at other wavelengths. The greater the difference in wavelength from the central wavelength, the greater the reflection loss because of incomplete destructive interference. The light reflected back is a combination of violet and deep red, hence the deep purple tint. Anti-reflection coatings have no effect on the colour of the transmitted light.

**Scatter**

On the face of it a multiple layer a/r coating is superior to a single MgFl2 coating because reflection losses are lower across almost the entire visual spectrum. However there is a pay back. Each layer in the stack has a thickness that causes total destructive interference of a specific wavelength. Surface reflections not of that specific wavelength escape into adjacent layers. Some do get totally destroyed, but not all, because the wavelengths are infinitely variable across the visual spectrum, and the multiple layer coating can have only a certain number of layers, perhaps 9, maybe more, usually less. Light that is not destroyed by destructive interference is scattered back and forth within the stack before emerging and entering the eye. The combined effect across the visual spectrum is termed “narrow angle scatter”.

Narrow angle scatter is inconsequential at low power on either faint point sources
or faint extended and diffuse objects. It is a nuisance on bright point sources and bright extended objects at contrast boundaries, where an otherwise sharp boundary is broadened slightly.

Eyepiece designs with more than six elements would have unacceptable reflection losses, even with MgFl2 a/r coatings. These designs are only feasible because of multi-coating technology, they depend on it for the design to be practical. The Orthoscopic for instance, with its four air-glass surfaces and MgFl2 coatings on those four air-glass surfaces, has in fact a higher throughput than a multi-coated seven or eight element ultra-wide angle design. There is also no narrow angle scatter.

All that is needed in addition to eliminate all internal reflections and scattered light within the field of view is blackened lens edges, a chased and effectively blackened internal barrel wall, a sharp and blackened field stop with no bright filter thread before it, and a correctly profiled, chased and recessed eye-cup into which the eye socket can nestle, so eliminating stray light shining obliquely across the field of vision.

The one remaining source of scattered light is imperfections in surface polish and purity and homogeneity of the optical glasses used.

**Distortion**

Eyepieces always perform best on axis. If you centre the image, and can keep it centred, all that matters after that is Orthoscopy. The ideal hi-res eyepiece should have a flat, uniform, unaberrated, undistorted field of view.

A wide apparent field of view is the least important facet of a hi-res eyepiece. This is just as well because it is optically impossible to design an eyepiece with spherical lens surfaces that is truly Orthoscopic when the apparent field of view exceeds a radian.

There are two types of distortion, angular magnification, and rectilinear. Astronomical eyepieces are designed to give a uniform magnification across their apparent field of view. Binocular and military eyepieces, intended for terrestrial viewing, are designed to keep straight shapes, straight, whether at the field centre or the field edge.

Angular magnification distortion is a function of the field radius angle. Rectilinear distortion is a function of the tangent of the field radius angle. Because the tangent of an angle cannot equal the angle itself (the angle expressed in radian measure - 1 rad ≈ 57°.3 ), if the lenses have spherical surfaces, it is impossible to correct for both at the same field radius angle.

If you restrict the eyepiece design to spherical surfaced lenses, then the only way to maintain true Orthoscopy (freedom for either angular magnification or rectilinear
distortion), is to restrict the apparent field of view to less than a radian.

It matters not how many elements the eyepiece has, how many lens groups, or what type of optical glasses are used. If the lens surfaces are all spherical, distortion will appear when the apparent field is wider than a radian. You either have to correct for angular magnification distortion and put up with rectilinear distortion, or vice versa.

When you correct for either type of distortion, the correction entails an optical trade off. Distortion is measured across the field radius. But an eyepiece designed for an astronomical telescope is by definition supposed to be interchangeable. It is designed to match a flat telescope focal plane. When either type of distortion is minimized, what the designer is doing is forcing the eyepiece's focal surface away from the ideal flat surface, onto a curved surface. In a binocular design this would be the objective’s Petzval surface. The designer cannot do this with an astronomical eyepiece because it is intended for use on a wide range of focal ratios and Petzval field curvatures. The designer is obliged to force the focal surface onto either the sagittal or tangential field surface or somewhere in between. The consequence of making this compromise is astigmatism.

Strictly speaking Orthoscopy is correction for the "Offence against the Sine Condition" - OSC. It includes correction for spherical aberration and coma, not astigmatism. An optical system that is Orthoscopic is also aplanatic. An optical system that is both Orthoscopic and free from astigmatism is termed Anastigmatic. However it is generally understood that an Orthoscopic eyepiece is also free from field curvature and the astigmatism associated with field curvature.

**Ideal telescope, eyepiece and mounting for hi-res work**

So, to return to my question, why wouldn't an ultra-wide be ideal for hi-res work at medium to high power. I have shown that ultra-wides come with three drawbacks. Lower throughput and narrow angle scatter due to more glass and multi-coatings on all those extra air-glass surfaces. Distortion, usually negative or pincushion.

I have also shown that eyepiece types with few elements and air-glass surfaces offer the greatest potential for high contrast views of faint planetary detail. The TMB Super Monocentric, Zeiss or UO Abbe Orthoscopic, Brandon Orthoscopic, Clave or TeleVue Plossl, Takahashi HI LE Ortho, are amongst several Orthoscopic types I would choose in preference to an ultra-wide for planet observing.
None of these eyepieces possess apparent fields wider than 50°, and if we put a few numbers together to provide an example of a typical planetary 'scope's real field of view the following scenario ensues.

TEC140APO, 140mm f/7 triplet and 5mm TMB Super Mono afov 30° power 196x real fov 9' 11".
If the telescope was undriven the planet would drift across the field in about 36 seconds. The only way to effectively observe a planet with the envisaged setup is to put the telescope on a driven mount. The telescope is also being pushed near its optical performance limit (x40 per inch). The mounting also needs to be very stable. My personal preference is a heavy duty German equatorial, but an equally well made driven alt-az would serve equally well.

**Conclusion**

The increasingly held notion that the only good eyepiece is an ultra-wide angle eyepiece is a prejudice that has arisen within the Dob deep sky community. Those of us who prefer to observe hi-res objects; the planets, the Moon, the Sun in H-alpha, and close double stars, do not need ultra-wides, or a Dob. Light pollution is not really a problem for the hi-res observer. So a permanently mounted hi-res telescope such as a medium aperture apo or a Mak or a long focus Newtonian, on a heavy duty driven mount should be the hi-res observer's goal. And as for the eyepiece? Take your pick of the Orthoscopics, but stick to a 40º to 50º apparent field, and less than 6 elements.
10-inch f/10 Newtonian on German Equatorial by George Calver c1894