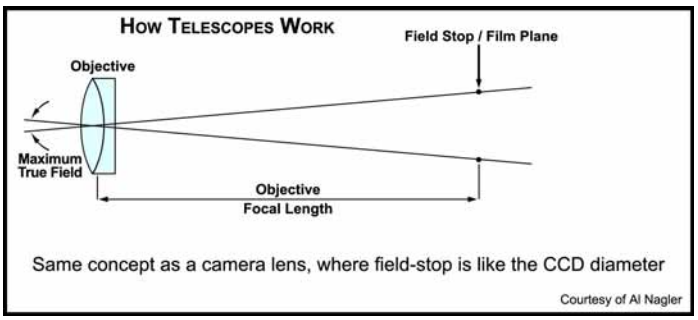
Choosing an Eyepiece - Step by Step

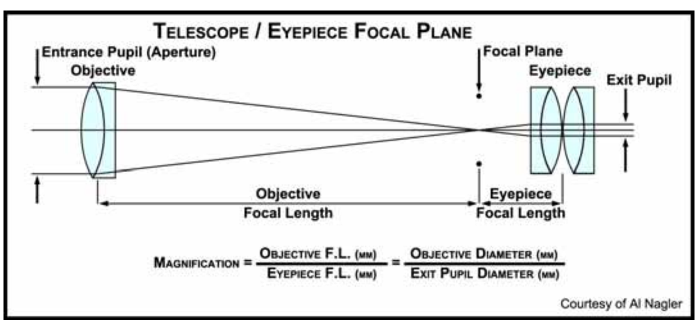
By Al Nagler, Founder, Tele Vue Optics

Many of us have met [Al Nagler](), founder of Tele Vue Optics, avid international supporter of amateur astronomy, and a friend to AAA. Born and raised in the Bronx, his path in life took him to the forefront of space exploration, developing the optics for visual simulators for the Gemini and Apollo programs. His work allowed famed astronauts like Neil Armstrong, Buzz Aldrin, Jim Lovell, Frank Borman, and so many others to train ahead of their time in space, docking modules in a hypothetical Earth orbit, and landing the LEM on the surface of the Moon.

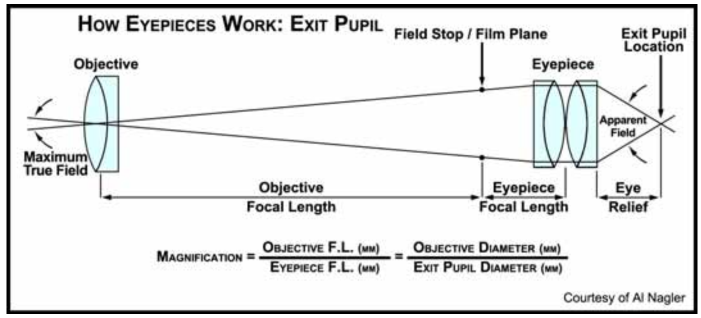
In the May and June issues of Eyepiece, Al will share his unique perspective on how to select an eyepiece for your telescopes. You will find that this is not as simple as opening a catalogue and choosing a nice looking cylinder. There is a science to collecting light at the end of a long (or short) tube, and Al explains the importance of the selection process.



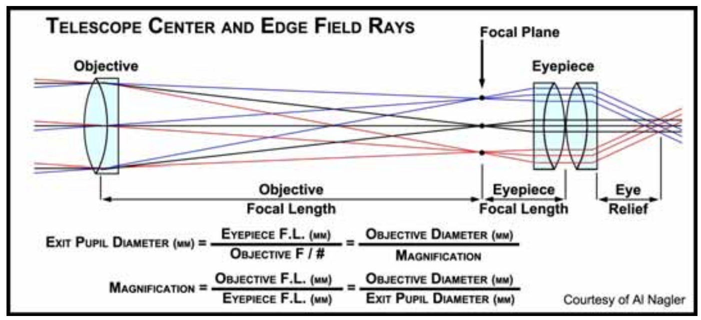
Al writes: Your telescope is like a camera lens (Figure 1 above). It produces an image at its focal plane for use with a camera body or CCD for imaging, or you can view the image with an eyepiece, acting as a magnifier. When the eyepiece focal plane coincides with the telescope focal plane, the image is in focus and is projected to infinity for visual use (Figure 2 below). The parallel beam going into the telescope ends up



parallel coming out of the eyepiece. The ratio of beam diameters or ratio of objective and eyepiece focal lengths gives you the magnification. Note that the eyepiece also views the objective itself (Figure 3 above right), and forms a small image of it outside the eyepiece. This image is called the exit pupil. If you use a reflecting telescope, and look at the exit pupil from a distance, you actually see a black disc in its center, which is



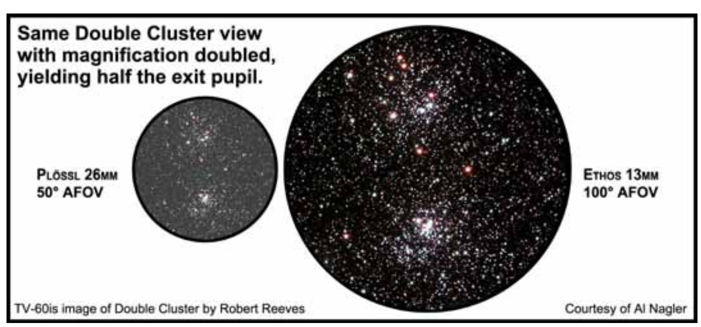
the secondary mirror or, central obscuration, for the telescope. The distance from the eye lens of the eyepiece to the exit pupil is called the "eye-relief". Also note that the maximum "true field" entering the telescope is limited by the diameter of the "field stop" at the eyepiece/objective focal plane. The "true field" is projected by the eyepiece to infinity, becoming the "apparent field" when you place your eye pupil at the exit pu-



pil. (Figure 4 composite below)

A low-power eyepiece produces a bright image. Longer focal length produces a larger exit pupil. While extended objects like the Moon, planets, and galaxies will be brightest, stars do not change their brightness as exit pupils are reduced. The higher power and resulting smaller exit pupil dims the sky background, enhancing contrast of a star field, and allowing fainter stars to be seen. If the higher power eyepiece has a similar size field stop, true field of view is maintained. Figure 5 illustrates the 50º and 100º apparent field of view (AFOV) eyepieces having the same field stop and true field sizes.

Choosing an Eyepiece (con't on Page 10)



Choosing an Eyepiece (con't from Page 9)

Getting Started - What to Look For

1. Maximize the true field of view (TFOV) by choosing an eyepiece with a large field stop (Figure 6 below). Avoid eyepiece focal lengths that yield exit pupils larger than 7mm if

STARTING YOUR EYEPIECE COLLECTION

1. Choosing Large True Field of View
A. 2" focuser permits up to 46mm field-stop
B. 1¼" focuser permits up to 27mm field-stop

2. Your Telescope Max True Field

$$\text{Eyepiece True Field (deg)} = \frac{\text{Eyepiece Field Stop (mm)}}{\text{Objective F.L. (mm)}} \times 57.3^\circ$$

3. If we neglect size, weight, cost for low-power, choose the shortest focal-length eyepiece that delivers largest true field needed for your targets.

Courtesy of Al Nagler

you have a reflector, because the black spot created in the pupil by the central obscuration may be annoying. Refractors do not have this limitation so there's no problem if lower power eyepieces with larger field stops produce larger exit pupils. Typical wide-field targets include Milky Way star clouds and:

- Open Clusters, such as the Beehive @1º, the Pleiades @2º, and the Hyades @5º
- Large Galaxies, such as the Andromeda @2 - 3º
- Nebulae, such as the North American @3º, Veil @3º, and Orion @1º

2. Maximize your high-power view for planets, double stars, planetary nebulae, etc. While you might not need a wide AFOV/TFOV for this, it helps with non-tracking scopes. (Figure 7 below).

HIGH-POWER RANGE 150X-TO-300X

1. What will the atmospheric seeing permit: 200x? 250x? 300x?

2. Also limited to 60x-per-inch of telescope aperture, up to the maximum magnification allowed by atmospheric seeing.

Remember, by choosing the lowest high-power eyepiece that reveals the detail you're looking for, you'll have a brighter, sharper appearing more contrasty image. Too high a power may reveal telescope limitations, mount shakiness and floaters in your eyes.

Courtesy of Al Nagler

3. Choosing eyepiece powers between 125x - 150x for globular clusters is one good choice. For an eyepiece collection with similar AFOV (e.g. 50º Plössls, 82º Nagler or 100º Ethos) noted observer/eyepiece guru/dealer, Don Pensack suggests a non-linear focal length range yielding 50x, 100x, 150x, 200x, and 250x for typical astronomical scopes. Note that the magnification step ratios illustrate that smaller steps are more valuable at the higher planetary magnifications (primarily to optimize for limits due to atmospheric turbulence). One implication to meet this requirement is to consider zoom eyepieces such as 8 - 24mm, 3 - 6mm, or 2 - 4mm models with appropriate focal length telescopes). Note in Don's series, if 50x yields a 5mm pupil, as with a 10" telescope, the pupil steps are 5mm, 2.5mm, 1.67mm, 1.25mm & 1mm – a logical range.

4. Number of eyepieces needed. As Don Pensack also notes, 5 eyepieces are useful, for example with a 10" f/5.5 telescope (1270mm focal length Dobsonian), which suggests approximate focal lengths of 25.4mm, 12.7mm, 8.5mm, 6.35mm, 5.1mm for this instrument. However, it might be more effective to consider fewer eyepieces, expanding the true field at low and mid-powers, while gaining flexibility at high power. For example, a 21mm 100º AFOV Ethos yields a 60.5x, 4.2mm exit pupil, and 1.63º true field in the sky. Or as an alternative, a 31mm, 82º AFOV Nagler yields a 44x, a 6.2mm exit pupil, and 1.9º true field in the sky. Next, a 13mm 100º AFOV Ethos yields 98x, a 2.6mm exit pupil, and a 1º true field in the sky. Next, an 8mm 100º AFOV Ethos yields 159x, a 1.6mm exit pupil, and a 0.6º true field in the sky. Finally, a 3 - 6mm Nagler Zoom yields 212x - 424x.

For an SCT, such as a 10" f/10, the combination of 31mm Nagler and 13mm Ethos yields nearly a 1º TFOV and maximum power (82x and 195x respectively) with only 2 eyepieces. I call this combo my "dyslexic duo". A nearly ideal range, however, can be had with just three eyepieces: 41mm Panoptic giving the maximum TFOV of 1.04º at 62x, 17mm Ethos with 0.67º at 150x, and 12mm Delos at 212x.

Adam Evans 2013

Andromeda galaxy, visible with binoculars, but better with a telescope. Comet PANNSTARS at upper right, in green

For a fast, wide-angle refractor such as a 5", f/5.2 NP127 with a 660mm effective focal length, up to five eyepieces might be required to maximize its wide-field and high power potentials. The 31mm Nagler yields a 3.6º TFOV at 21x with a 6mm exit pupil, the 13mm Ethos yields 1.94º TFOV at 51x with a 2.5mm exit pupil, and a 6mm Ethos yielding a 0.9º TFOV at 110x, with a 1.2mm exit pupil. Next, needing a wide-field for mid-range open cluster viewing, a 4.7mm 110º Ethos at 140x still gives a 0.78º TFOV. For planetary and globular cluster viewing at higher power, the Nagler 2 - 4mm Zoom gives a continuous magnification range from 165x - 330x.

Part 2 of Al Nagler's "Choosing an Eyepiece - Step by Step" will continue next month, discussing the myriad of available eyepiece options.

Choosing an Eyepiece - Step by Step (Part 2)

Professional Advice from Al Nagler, Founder, Tele Vue Optics

Al Nagler, staunch supporter of AAA and recent recipient of the AAA Amateur Astronomers Medal at this year's annual membership meeting, has generously shared his unique perspective about how to choose an eyepiece. This is the second installment of his two-part article, bringing clarity to those of us who have always wanted to know the true specifics behind optics, and how to select those eyepieces that will enhance our observing capabilities.

Exploring Your Choice Options

Among my goals at Tele Vue is to make choosing eyepieces a simple process. A few years ago, I tried to develop an "artificial intelligence" method of doing this, however, I gave up due to the variety of technical, ergonomic, cost, and telescope application factors involved. Perhaps one of you might take up the cause.

Meanwhile, Tele Vue developed an online "eyepiece calculator" to aid in balancing choices in magnification, TFOV, eye relief, and exit pupil with any option of telescope focal length, aperture, and use with various Barlow-type lenses (Figure 8 below).

EYEPIECE CALCULATOR

Eyepiece Calculator can return a table of eyepieces with telescope-specific information such as: mag., exit pupil, and true field.

See Calculator at TeleVue.com

Courtesy of Al Nagler

(EXAMPLE FOR 540MM, F/5.4)

Design	Focal Length (mm)	Apparent Field (°)	Eye Rel. (mm)	Barrel Size	Mag. (x)	Exit Pupil (mm)	True Field (°)	True Field @ 1000 yards (feet)	Mag. w/2x Barlow (2x)
Nagler 5	31	82	19	2"	17.4	5.8	4.5	233.3	--
Ethos	21	100	15	2"	25.7	3.9	3.8	201.1	--
Nagler 5	26	82	16	2"	20.8	4.9	3.7	194.4	--
Nagler 4	22	82	19	2"	24.5	4.1	3.3	172.8	--
Ethos	17	100	15	2"	31.8	3.2	3.1	164.4	--
Nagler 5	20	82	12	2"	27.0	3.7	2.9	152.2	--
Nagler 4	17	82	17	2"	31.8	3.2	2.6	135.0	--
Ethos	13	100	15	2" & 1¼"	41.5	2.4	2.4	123.9	83.1
Nagler 5	16	82	10	1¼"	33.8	3.0	2.3	122.8	67.5
Delos	17.3	72	20	1¼"	31.2	3.2	2.2	117.8	62.4
Ethos	10	100	15	2" & 1¼"	54.0	1.9	1.9	98.3	108.0
Nagler 6	13	82	12	1¼"	41.5	2.4	1.9	97.8	83.1
Delos	14	72	20	1¼"	38.6	2.6	1.8	96.1	77.1
Nagler 4	12	82	17	2" & 1¼"	45.0	2.2	1.8	95.0	90.0

Beyond the pure numbers, to generate a collection of eyepieces, consider all factors (Figure 9, center panel, below).

Given the telescopes you own or plan to own, what are your major areas of interest? For example, deep sky would likely be served by eyepieces with a very wide AFOV, planets less so, and birding somewhere in between.

The atmosphere always limits the usefulness of very high magnification, due to turbulence. Typically, this limits resolution to about ½ arc second. Transparency and steadiness are often mutually exclusive: Dark, clear winter skies with brilliant twinkling stars versus steady hazy summer skies for better planetary viewing. (Of course, if you attend the Winter Star Party in the Florida Keys, you can get steadiness and transparency without pollution).

CONSIDER ALL THE FACTORS

A. Your Targets (Deep Sky, Planets, Birds)

B. The Atmosphere (Steadiness, Transparency, Pollution)

C. Your Telescope (Aperture, Focal Length, Type)

D. Your Eyepieces (Type, Focal Length, Apparent FOV, Eye-Relief)

E. Your Eyesight (Do you wear eyeglasses and why?)

Courtesy of Al Nagler

Your telescope speed (f/#) impacts whether you're best served with eyepiece types that retain full field sharpness or less expensive models with aberrations that are masked with f/8 or slower scopes. Faster telescopes, for a given aperture, have greater true field potential, desirable for deep sky or nature viewing. Some telescopes, such as Newtonian (Dobsonian) reflectors also benefit from coma correctors, such as the Paracorr. By correcting the telescope's coma, the full-field sharpness can be obtained, whether visually or for imaging.

Consider the eyepiece qualities that are important to you. Personal factors such as eye-relief, AFOV preference, and ergonomics should enter into your decision. Often there is a balance between aspects like the need to wear eyeglasses versus the visual impact of wide angle (AFOV) "spacewalk" views (up to 110+°). Or, the cost balance between wide AFOV, eyepieces compared with designs that minimize AFOV, for cost savings.

Long eye-relief eyepieces may permit the use of eyesight astigmatism correction with a "Dioptrx™" lens, an optically better alternative to wearing eyeglasses.

Other Considerations (Figure 10 at right)

There are "cost-no-object" eyepieces available to obtain the

Choosing an Eyepiece (con't on Page 10)

GENERAL CONSIDERATIONS

- **Cost**
- **Parfocality**
- **Binoviewing**
- **Barlow / Powermates**
- **Zooms**
- **Weight**
- **Filters**
- **How Many Eyepieces Do You Need?**
- **Transmission, Coloration**
- **Aberrations**

Courtesy of Al Nagler

Choosing an Eyepiece (con't from Page 9)

clearest, widest, most natural view possible. Consider the value of a lifetime of great experiences, and that you only need a few eyepieces of this caliber for viewing the most important objects you enjoy. Moderate cost eyepieces can also trade-off characteristics such as wide AFOV while retaining excellent sharpness and contrast. Even lower cost eyepieces these days perform nicely, particularly with slower telescopes.

Parfocality means not having to significantly refocus when changing eyepieces. (For various reasons, a slight touch-up in focus may be needed for nominally parfocal designated eyepieces).

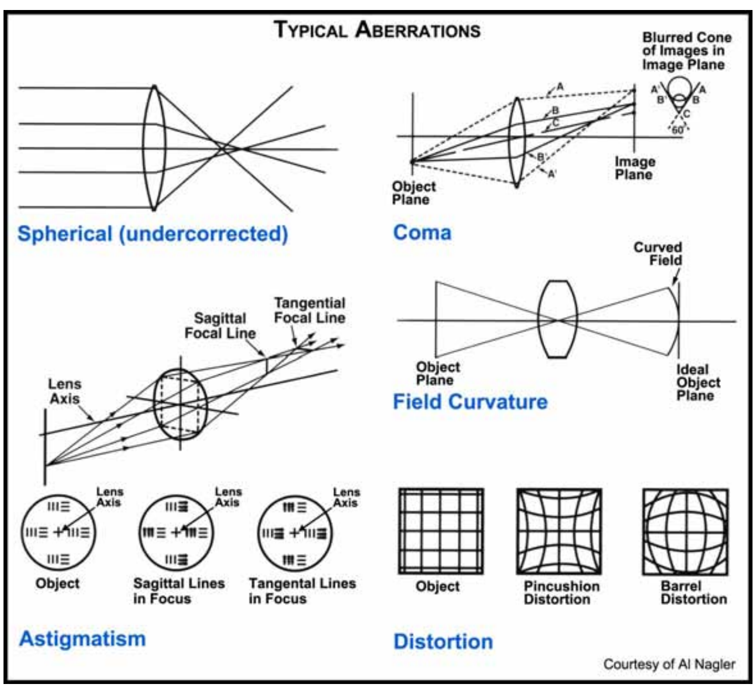
Binoviewing takes natural viewing to the maximum. Although splitting the incoming light to two optical paths reduces brightness, if the contrast is maintained, using both eyes seems to overcome the impression of brightness loss, except for the very faintest stars and nebula details. Contrast is enhanced, floaters in your eyes are less noticeable, and you get a dimensional impression that can be startling, as with the Moon, planets, and star clusters (especially globulars). If you have any doubts, close one eye right now and then see how much more you enjoy the comfort of viewing with both eyes. Or try the experiment with a pair of binoculars. Theoretically a binocular viewer presents the same image to both eyes, so since astronomical objects do not have parallax, like close objects, why do they still seem dimensional? My theory, somewhat corroborated by questioning at star party viewing, is that the eyepiece field stop is interpreted by the brain as a "window" seemingly around two or three feet away, through which the brain "interprets" the sky as much farther away.

While some telescopes, like SCTs, can be refocused to compensate for the typical 5-inch optical path length of a binocular viewer, most need the help of using a Barlow to achieve focus. The Tele Vue 2x amplifier/corrector compensates for all the aberrations of the binoviewer prisms, so that a 500mm f/5 telescope becomes an equal quality 1000mm f/10 when using a binoviewer.

Barlows or Powermates (a 4-element version that maintains magnification at different path lengths, and offers improved use in imaging) allow gaining higher magnifications with your eyepiece collection while maintaining eye-relief, in most cases. While certainly saving cost, and permitting a simpler eyepiece collection (three eyepieces can act like six), they may be cumbersome to constantly change and handle. Personally, I prefer having one or two more eyepieces, especially if parfocal, as a more elegant solution, with less weight and optical complexity. Zoom eyepieces are especially convenient, although most are not parfocal through their range and have reduced AFOVs at lower power. Exactly the opposite of what you would want. For planetary viewing at high magnification, Nagler 3 – 6mm or 2 – 4mm zooms, are considered alternatives to high performance simpler eyepieces, because they avoid the above limitations. They allow easy optimization of magnification to atmospheric limits, and also have click-stop settings for convenience. Eyepiece size and weight might impose limits on smaller instruments, and make storage more difficult. If your telescope can be moved in its cradle, or has a sliding counterweight on its tube, it's less of an issue, and of course a scope on a tracking mount with R.A. and DEC axes locked has little issue.

The 2" and 1¼" eyepieces accept filters of all kinds, of course. If you have a filter slide, or use a 2" diagonal to screw in your 2" filters, you can then use 2" or 1¼" eyepieces without needing any 1¼" filters on the eyepieces themselves.

The number of eyepieces you need or want is a very personal decision, but as long as you can take advantage of the maximum field and maximum planetary power your telescope and atmosphere permit, you can fill in with a few steps between, with factors of field-stop ratios of 1.7 – 2.0 at lower powers, and 1.3 – 1.5 at higher powers (or use zooms). See previous detailed suggestions, or call knowledgeable dealers or manufacturers to help (we're happy to). If you have eyesight astigmatism, you'll need long eye-relief (at least 17mm) to be comfortable with eyeglasses, or use our Dioptrx™ options. Eyepieces with variable height eye guards might be particularly effective.



Transmission with most modern eyepieces is quite high when using multicoated lenses. Depending on both coatings and glass types, some eyepieces may have a slightly warmer or cooler tone, with the most recent models cooler. However, visual differences are usually inconsequential in normal observing.

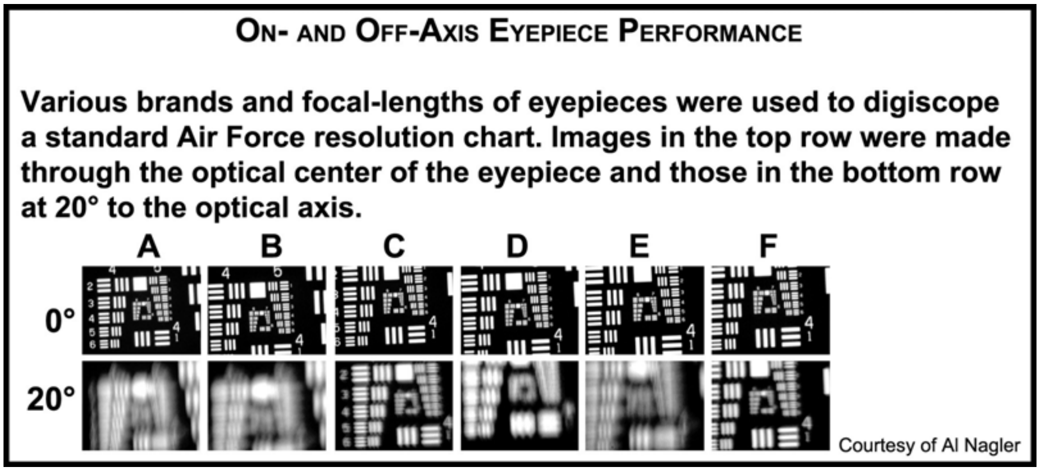
Aberrations (Figure 11 at left)

Eyepiece aberrations are strictly due to eyepiece design, not manufacturing. Aberrations such as spherical aberration are rarely seen in eyepieces. This means that at the center of the field, sharpness differences between different models will likely not be detectable. On page 11, Figure 12 at the top displays a test set-up that used a highly corrected flat field f/5.5 refractor. Note that just 20º off-axis, differences are dramatic. This is a very sensitive test to define differences, and magnified normal viewing would not show this degree of difference at 20º of-axis. However, at larger fields off-axis, especially with faster telescopes, degrada-

Choosing an Eyepiece (con't on Page 11)

Choosing an Eyepiece (con't from Page 10)

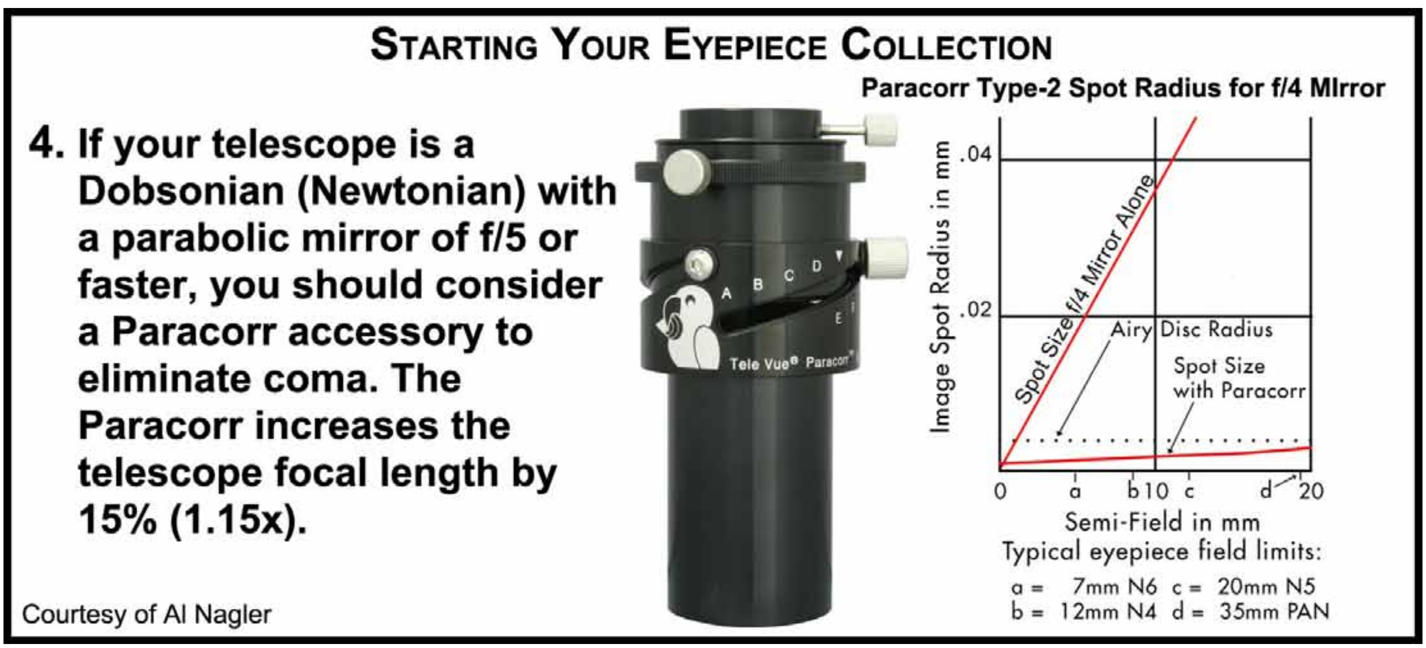
tions mainly due to astigmatism will be seen in less well-corrected eyepieces. Field curvature is due both to eyepiece and telescope design, and may add or cancel, depending on the eyepiece/telescope combination. My personal philosophy favors flat field eyepieces and telescopes so that when the focal surfaces match up, you have the potential of sharp star images over the entire field, regardless of telescope speed. Distortion is sometimes erroneously called field curvature, because the field grid pattern can be either "barrel" or "pincushion". This aberration is a function of the eyepiece alone, and usually more noticeable with larger AFOV eyepieces. It has no connection with sharpness or other aberrations, and if a star field is stationary, it will probably never be noticed. The level of aberration correction, along with coating technology today, gives the potential of what I like to think of, as "spacewalk" views, as seen in last month's article in Figure 5. One aberration that's a consequence of using paraboloidal mirrors in Newtonians or Dobsonian telescopes is coma, which usually dwarfs any coma in eyepieces. Who wants to see comets all over the outer field of fast Dobsonians, no matter how perfect the eyepiece? Figure 13 below shows how a coma corrector can reduce the "spot size" of star patterns to make an almost perfect wide field large aperture reflector that will challenge the perfection of the best eyepieces.



Courtesy of Al Nagler

Note in the chart illustration below, how star images start degrading at just 1mm off the center of the field, degrading dramatically across the field for an f/4 mirror, but the coma corrector preserves the center field excellence over the entire field.

While choosing eyepieces seems like a complicated process, learning the basics is a helpful start. I've spoken to many customers who have too many eyepieces, and too many high-power eyepieces. You can find a number of advice articles on our website TeleVue.com, and you might find the "eyepiece calculator" particularly helpful, since it gives magnification, true field, exit pupil with a wide range of eyepieces for your specific telescope aperture and focal length. Of course try, if possible, to use different eyepieces and telescopes at local star parties, and of course you can call me or my staff at 845-469-4551 for personal advice.



Courtesy of Al Nagler

Thank you, Al, for sharing your vast knowledge about eyepieces in this interesting and informative two-part series, and for being such an active part of AAA. We look forward to seeing you at future membership and public events. – ES