A New Way to Look at Things

Mel Bartels

I am frustrated with the inability of aperture and magnification to predict the views through the new super fast Richest Field Telescopes with extremely wide field eyepieces. New eyepieces (100-120 deg apparent FoV) and coma correctors need new criteria. Historically, criteria have changed from length (Hershel's 20 foot telescope and the Danzig 150 footer) to magnification (Galileo's 30 power telescope) to today's aperture and type (16" Dob).

My 13" f/3 with 100 degree apparent field of view Ethos eyepiece has the same field of view as my old 8" with military surplus Erfle eyepiece. Length is an insufficient criterion (40", makes scope seem too small) as is magnification (55x, says nothing about FoV) as is aperture and type (ignores compact size, FoV). Where to start?


Start with what the eye knows and doesn't know. The eye doesn't know about magnification. Pick a galaxy, vary the eyepiece's apparent FoV. The observer cannot distinguish between 200x and 300x. Magnification, just as it is disparaged in department store telescopes perhaps should be largely ignored all together.

The eye can sense two properties: apparent field of view and exit pupil (sky glow brightness).

Exit pupil is the smallest width of the cone of light entering the eye. Smaller exit pupils act to magnify the field. Sky glow brightness is proportional to exit pupil across all telescopes. Example: 10" scope needs ~35x or 1000x in area for 7mm exit pupil: 10"/7mm = ~35x or 1000x decrease, resulting in same brightness per area as unaided eye. In a dark sky this is 21.5 magnitudes per square arc-second.

Magnification and exit pupil are not the same thing. Look how exit pupil is numbered linearly but magnification greatly increases as the exit pupil shrinks. This is not the set of eyepieces that the typical amateur owns. Instead, a set that emphasizes a linear sequence of exit pupils is better. For my F3 RFT, I use 21mm, 17mm, 13mm, 10mm, 6mm and 3.7mm. This gives exit pupils of 6mm, 5mm, 4mm, 3mm, 2mm, 1mm approximately.

Eyepiece	Exit Pupil (mm)	X
21mm	6	55
17mm	5	67
13mm	4	83
10mm	3	111
6mm	2	166
3.6mm	1	333

Aperture invariably is known ahead of time but can be calculated from: apparent FoV / actual FoV * exit pupil, e.g. 100 deg / 1.8 deg * 6mm = 330mm or 13”. The problem with aperture is that it’s a linear measurement whereas the eye operates semi-logarithmically. We think that there's a difference between 4 and 6 inches of aperture and rightly so. But then we think there's a similar difference between 24 and 26 inches, and that is not the case. Additionally, aperture does not tell us what can be seen. Only after years of observing experience can one predict what will be seen in a scope of a particular size. Aperture is a relative factor, not a primary factor. I suppose we could use the square root of an aperture’s ratio to the eye’s fully opened exit pupil to compare, e.g., a 9 inch scope receives an aperture rating of ‘5.7’ while a 18 inch scope gets a rating of ‘8.1’. Notice how the numbers influence thinking. Suddenly the 18 inch scope doesn’t seem such a gigantic leap over the 9 inch. Perhaps it’s best to use limiting magnitude for stars and visual detection factor for extended objects. Here’s a series of apertures where the limiting magnitude difference is about 1 mag.

aperture	rating	high magnitude limit	low magnitude limit
6	4.7	13.7	14.7
10	6.0	14.8	15.8
16	7.6	15.8	16.8
24	9.3	16.7	17.7
40	12.0	17.8	18.8
60	14.8	18.7	19.7

An observer can detect a 0.3-0.4 magnitude difference with some scrutiny at the eyepiece; 0.2 mag. is the lower limit. The difference between 13” and 14” is not apparent at eyepiece, but the difference between 13” and 16” can be seen with some effort on star clusters. Yet aperture difference by area is ~20%: this sounds significant but is not. Amateurs compromise their designs when as little as 3% is involved, e.g., substituting a larger diagonal in an effort to flatten the illumination profile. This only results in a degradation of light across the entire field. A change of 1mm in the exit pupil makes a 0.3 mag. difference. Tests at the eyepiece show that I can detect, with some effort, a 1mm difference in exit pupil, e.g., the difference in sky background brightness between 6mm and 5mm. a half mm change in exit pupil is near impossible to detect.

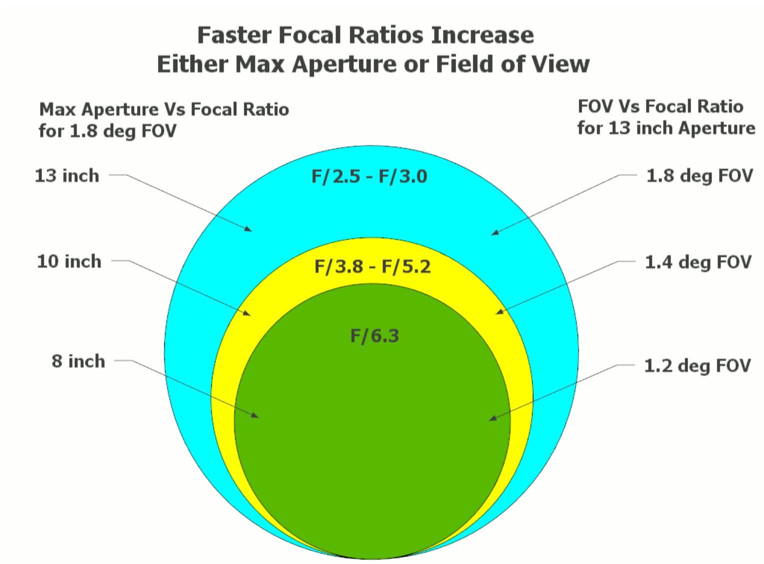
Visual detection threshold for extended objects follows same rule: a 0.2 mag. difference is noticeable. Crucially, from the perspective of visual detection, it takes a significant increase in aperture for a 0.2 mag. difference.

There's an additional factor that's very important: detail in an object. We judge an object better when the telescope increases its size so that we see more detail. About a 40% increase in size (fractal scaling) brings enough new detail into view so that we rate the object as better.

Overall then, one should jump up in aperture at least a fractal and better yet closer to double the aperture in order to make an experiential difference at the eyepiece.

Another little known factor is extinction. Looking directly overhead, we look through one atmosphere. At 10 degrees elevation, we look through five atmospheres. Each atmosphere costs 0.2 magnitude. For many of us observing in less than pristine skies, the scatter from light polluted skies increases near the horizon, making the situation much worse.

Finally, one way to increase the subjective experience is to greatly enlarge the field of view by using a super wide angle eyepiece.



Here's a list of factors that influence detection at the eyepiece.

1) Observer experience is worth 2 magnitudes (I have a series of sketches of M31 from childhood onward).

2) Observer variation is 1-2 magnitudes.

3) Age matters a magnitude: young kids can see very faint stars; as we get older, our lens yellows and ability to detect fades.

4) Knowing where to look and what to look for worth 1-2 magnitudes.

5) Did I mention averted vision, worth a magnitude or more?

6) Dark adaption continues to produce increasing benefits for hours, ultimately worth maybe a half a magnitude.

7) Field baffling is an overwhelming factor: the difference between nonexistent and fully baffled views can be worth magnitudes.

8) Covering your head with a black cloth also yields improvements, perhaps on the order of a fraction of a magnitude.

9) Time at the eyepiece is worth 1-2 magnitudes (objects gradually become recognizable or detectable over a period of time, then they fade after a prolonged period of continuous observing).

10) Comfort at the eyepiece is worth maybe a magnitude.

11) Sky transparency is such an overwhelming factor; on rare perfect nights I've seen scopes perform as if they had almost unlimited aperture; let's call superb sky transparency worth a magnitude or two.

12) Filters are worth 2 magnitudes.

13) The range of visibility, controlled as best as can be for object size and brightness, varies 1-2 magnitudes, occasionally more.

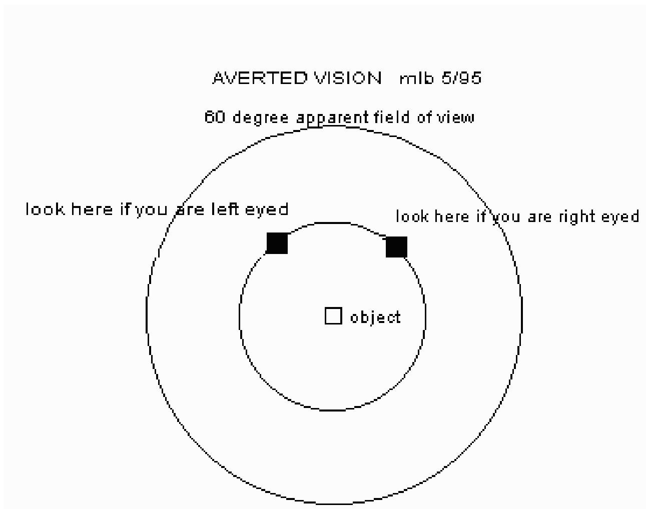
14) Visibility appears to correlate most with aperture, then apparent size (the greater the aperture, the greater the apparent size, limited by the full field of view). Review of observing books by respected authors suggest no favorite exit pupils or magnifications either; additionally there are a variety of approaches favored by experienced observers.

15) True bino viewing from unaided eye up to 22 inches yields consistent results for me: about a 80% gain in stellar limiting magnitude and about a 120% gain in visibility of extended objects; others report discordant results.

Taken in concert, these factors render any predictive tool or theoretical study's conclusions iffy - there's really no recourse in many cases except to look through the eyepiece. Perhaps it's best to operate by rules of thumb, recognizing the importance of training and telescope baffling and selecting the most pristine nights for the most difficult observations.

Give a particular night, I select for largest aperture and eyepiece apparent field of view that will frame the object. Most of the time, the object doesn't fill the field with 6mm exit pupil, so I also give smaller exit pupils or greater magnification a try, subject to seeing conditions. I typically find that higher magnification yields better results, topping off at 1 to 2mm exit pupil. Because of the variation in sky transparency alone, I almost always try again on a better night.

Averted vision works best if you know where to aim your eyes in the field of view. Here's a chart to help.



Use aperture to look up the magnitude limit and to calculate the visual detection ability. I've observed the past two years with this new way to look at things and find it much more useful. The actual field tells me how objects will fit and the exit pupil tells me the sky background brightness. Limiting magnitude both for point sources and extended objects are best calculated.

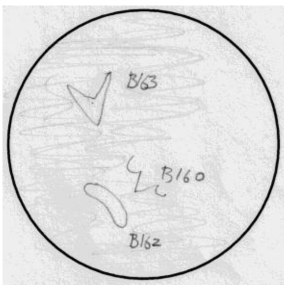
Old style of thinking: 13" telescope at 55x. New style of thinking: 1.8 degree actual field, 100 degree apparent field, 6mm exit pupi.

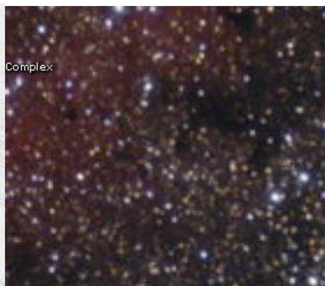
Changes in telescope design and observing approach thanks to new way of looking:

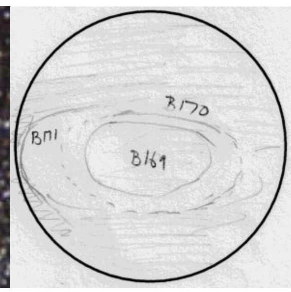
- Far better to use units of measurement that the eye understands (log scaling, apparent FoV).
- Don't optimize thereby possibly making poor compromises unless the changes approach 0.2 magnitude.
- Select a simple range of telescopes based on field of view and measurable aperture differences.
- Select a set of eyepieces that fit an equal range of exit pupils, no finer than 1mm difference. My eyepiece set: 6 mm, 4.8 mm, 3.7 mm, 2.8 mm, 1.7 mm, 1.1 mm. This is significantly different than eyepiece sets for sale today, which crowd small exit pupils and leave too big of gap at large exit pupils.
- Concentrate on the field of view: ease of finding, better context for the object(s), more 'Wow' factor.

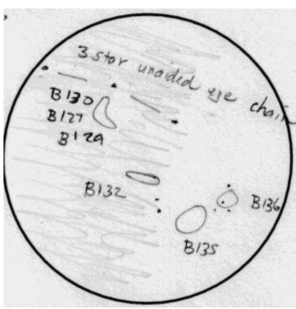
What exit pupil or magnification is best? Various experts have different opinions. Truth is, all exit pupils and magnifications work. They are all correct except when they contort themselves to say that others are wrong. The visual detection calculator shows that in light polluted skies, smaller exit pupils work a bit better and in very dark skies, larger exit pupils work a bit better. Using one of our best observers (O'Meara), I noted his comments for the 109 objects he presents in "Hidden Treasures". He often favors large exit pupils and does not hesitate to use smaller exit pupils when the object is small and is detailed.

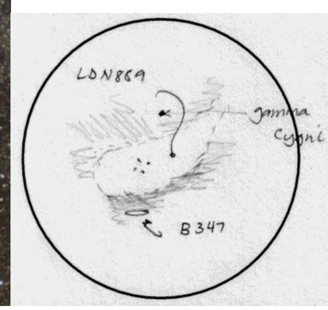
After telescope length, then aperture, it's time to take into account today's wide range of eyepiece focal lengths and apparent fields of view. The closer to the eye, the more important the factor becomes.







References

M.L. Bartels, Visual *Astronomy*. Internet <http://www.bbastrodesigns.com/visual.html>. Accessed 2012.

R. N. Clark, *Visual Astronomy of the Deep Sky*, Cambridge University Press and Sky Publishing, (book of 355 pages), 1990

N.O. Carlin, *Another interpretation of the data from Blackwell, H R (1946): Contrast Thresholds of the Human Eye*. Internet <http://www.bbastrodesigns.com/blackwel.html>. Accessed 2012.

B. Skiff, 2007, *How Dark Can the Night Sky Get?* Internet <http://www.astropix.com/HTML/L_STORY/SKYBRITE.HTM>. Accessed 2012.

Sky Quality Meter. Internet <http://unihedron.com/projects/darksky/> . Accessed 2012.