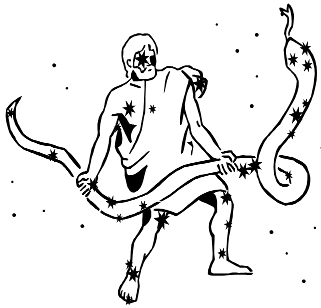
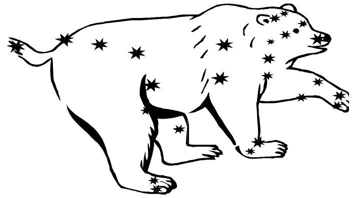
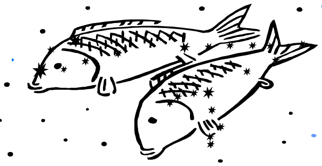
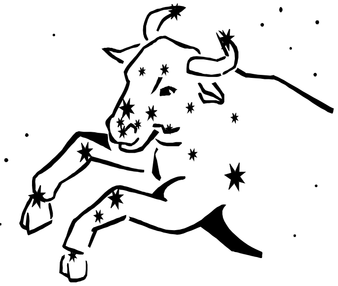





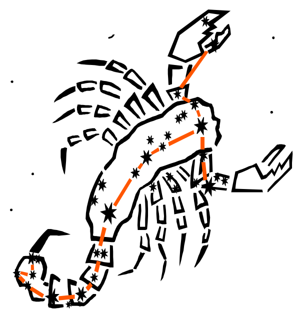
How We See The Sky

The Physics and Physiology of Visual Astronomy

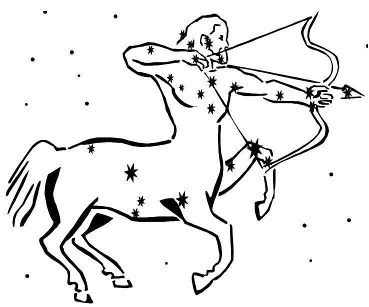
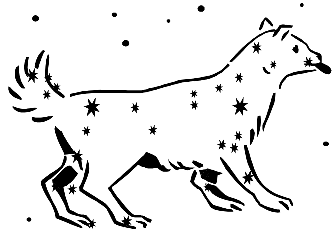


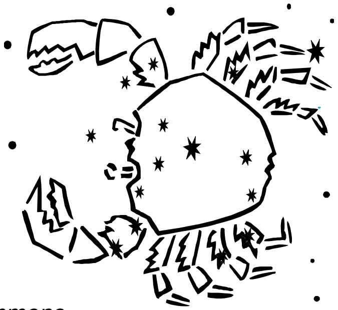





Michael W. Masters



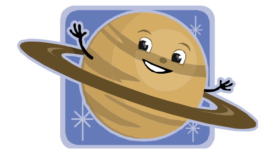
— Image source: *Wikipedia Commons*


People Ask Questions. . .

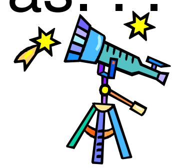


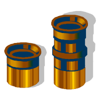
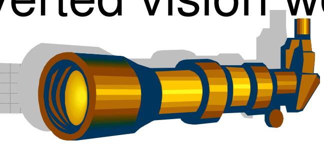





- “Hey buddy, how far can you see with that thing?”
- “I bet that thing cost a bundle, yuk, yuk!!”
- “The stars are twinkling – is it a good night?”
- “Why doesn’t your scope show colors like Hubble?”
- “My headlights didn’t bother you, did they?”
- Some comments do captures the spirit!:
  - “That isn’t Saturn! It’s a picture painted on the front of your telescope!”
- What they should be asking are questions such as. . .
  - “How faint can I see? How much detail can I see?”
  - “What is the highest power I can use? The lowest?”
  - “How long does dark adaptation take? How does averted vision work?”
  - “How do I choose a good set of eyepieces?”

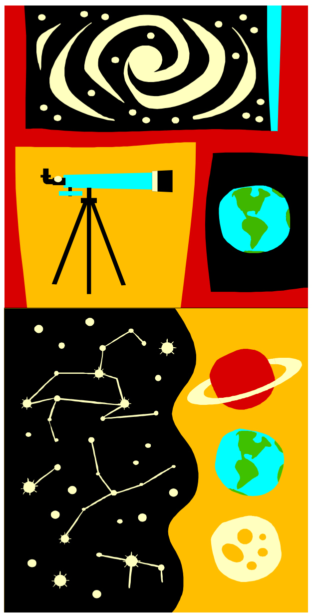




One doesn’t have to follow every technical detail to enjoy the view. But, understanding the underlying science helps us make informed choices about gear, subjects and observing technique.

Understanding the Viewing Experience

Purpose

Provide insight into the *many factors* that influence what we see when we look at the night sky through a telescope.



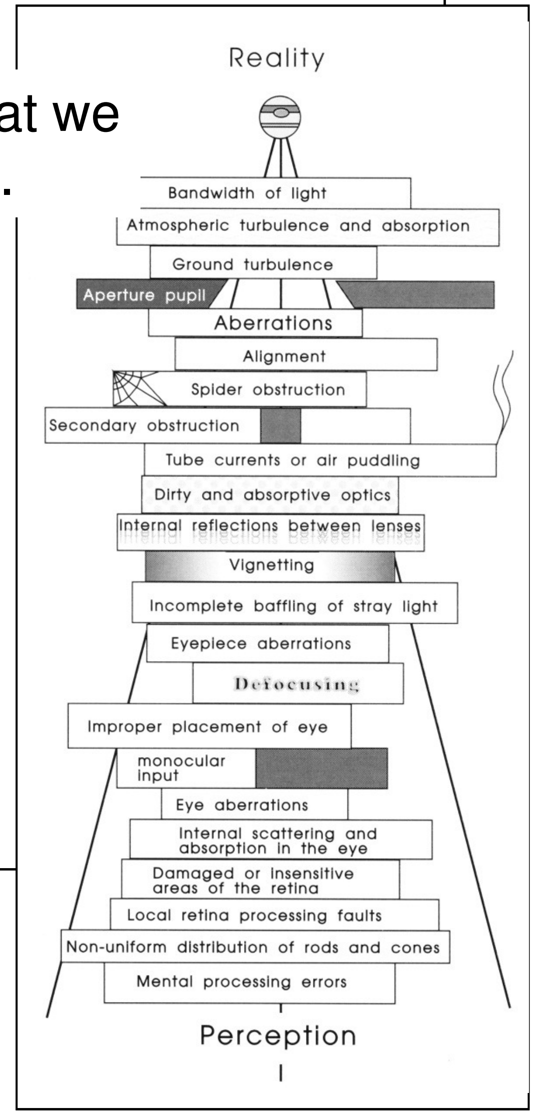
The light that reaches us

- The character of night sky objects
  - Stars
  - Moon
  - Planets
  - Faint extended objects
- The Atmosphere

How we see that light

- Telescopes
- Eyepieces
- The eye
- Accessories
- Technique
- Expectations

This talk is not about astronomy as a science; it is about the science behind observational astronomy!



— Source: *Star Testing Astronomical Telescopes,* Harold Suiter, 1994

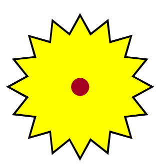
Program Notes

Content

Technical content lies between beginner and expert. Scope is visual observation only; measurement astronomy is not discussed. A bibliography is provided at the end of the talk. Different sources may differ slightly in some technical details. Equipment references are for illustration only.

Copyright Fair Use Notice

In accordance with Title 17 U.S.C. Section 107, any copyrighted material published herein is reproduced under fair use without profit or payment and is intended for the benefit of those who are interested in receiving the information for non-profit research and educational purposes only.
[Reference: http://www.law.cornell.edu/uscode/17/107.shtml]

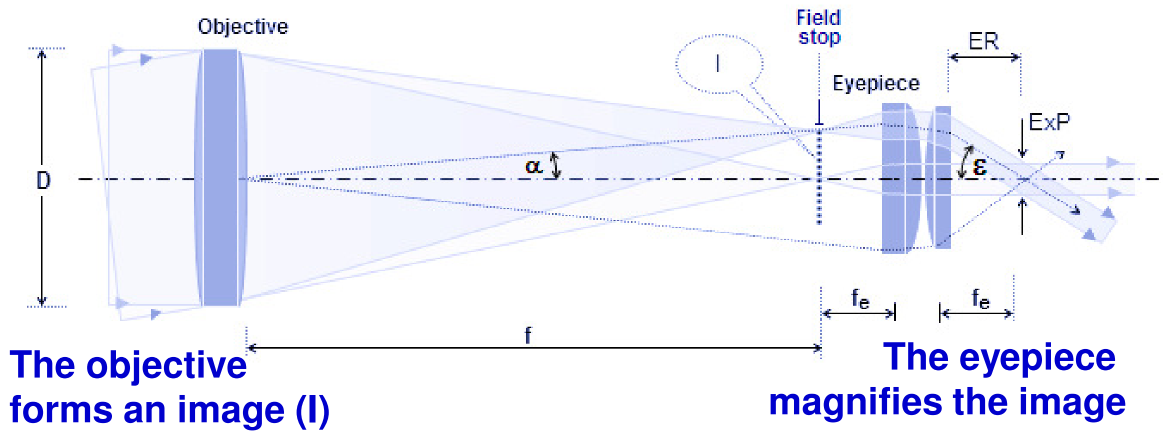


Never point a telescope at the sun
– unless it's a solar telescope, of course!!
. . .and don't look into the laser pointer either!!

Outline

- Telescope Basics
- The Eye & Vision
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

Telescope Functions & Properties



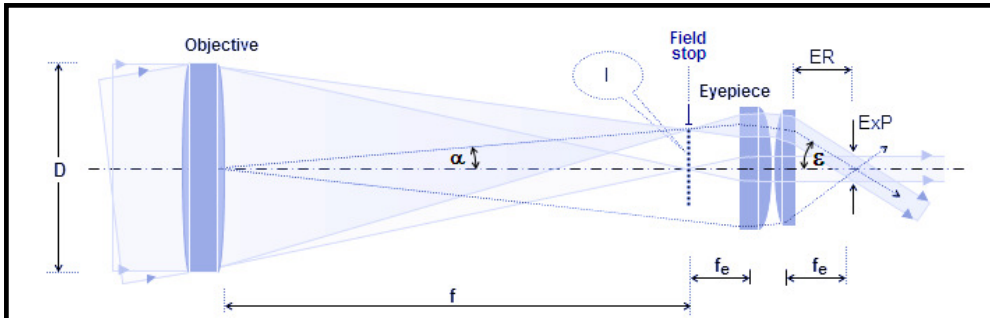
Telescope Optical Path (Refractor)

— Source: Telescope-Optics.net

- D = objective diameter
- f = objective focal length
- F = focal ratio= f ÷ D
- f_e = eyepiece focal length
- Field stop = opening located at objective focal plane
- ExP = exit pupil = f_e ÷ F
- ER = eye relief
- **ε** = apparent field of view
- **α** = true field of view

Light gathering	Proportional to area of objective — Reduced by obstructions & transmission & reflection losses
Magnification	Defined by M = f / fe — E.g. 1000mm objective / 20mm eyepiece > Mag = 50X
Resolution	Proportional to diameter of objective — Limited by diffraction as well as optical quality
Contrast	Modulation transfer function (MTF) — Quality of reproduction of information presented to the optics
Focal ratio	Defined by F = f / D — "Speed" determines exposure time for given film/sensor sensitivity — Related to ***exit pupil***, which in turn influences eyepiece choices

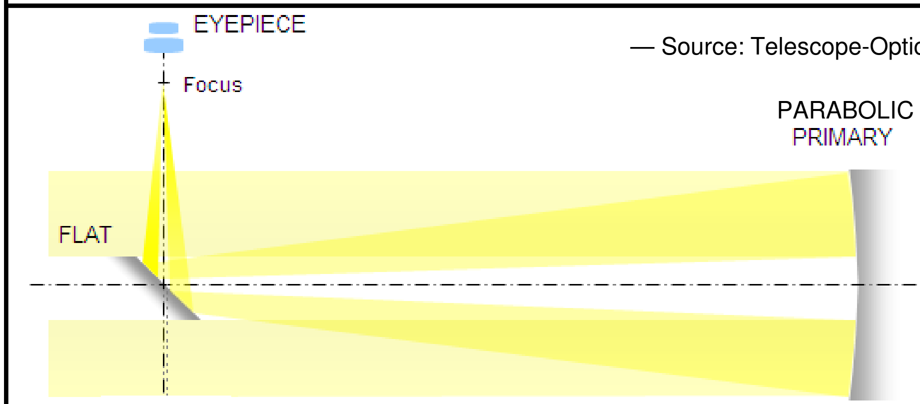
Telescope Optics



— Source: Telescope-Optics.net

Refractor (lens objective)

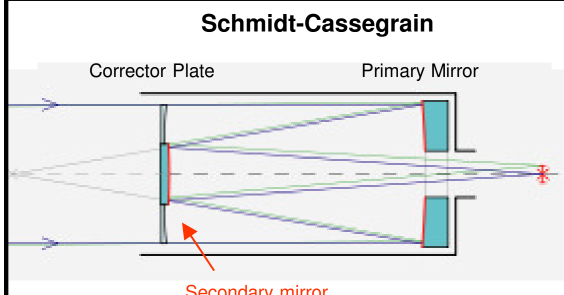
Pros	*Cons*
High quality	Most expensive type
Unobstructed	Low cost/quality models
Fast cool down	Very heavy in large sizes
Closed tube	Chromatic aberration
Low maintenance	except in apochromat

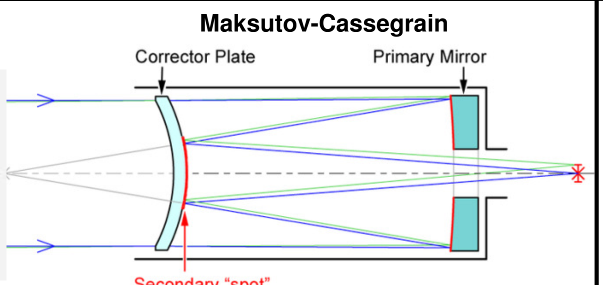


— Source: Telescope-Optics.net

Reflectors, e.g. Newtonian

Pros	*Cons*
Lowest cost/size	Slow mirror cool down
Color error free	Inherent coma aberration
Very large sizes	Secondary obstruction
Low cost mounts	Frequent collimation
(Dobsonian)	Open tube: currents, cleaning
	Mirror recoating (long term)





— Source: Wikipedia

Catadioptric (lenses & mirrors)

Pros	*Cons*
Compact	Large secondary obs.
No color error	Coma & curved focal
Closed tube	Long focus (!): slow F
Long focus	ratio, narrow FOV

Light Gathering and Magnitude

— Source: Wikipedia

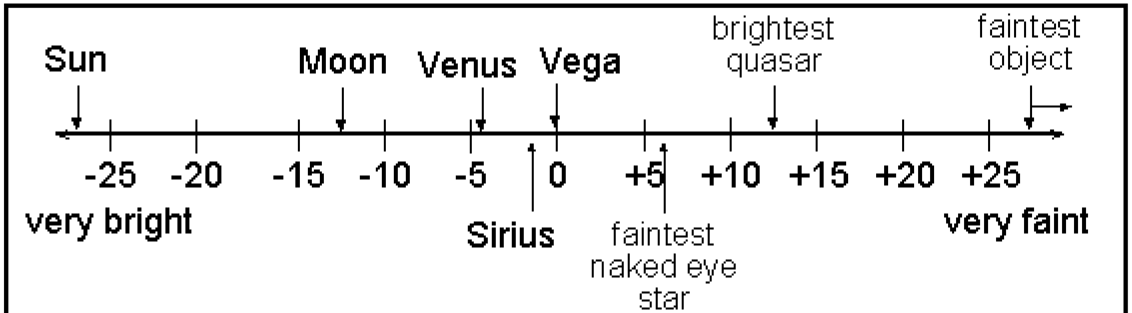
The magnitude scale was first defined by the Greek astronomer Hipparchus. He cataloged stars, defining their brightness in terms of ***magnitude*** (m), with brightest stars m=1 and faintest m=6. About 6000 stars are visible to the naked eye, more under best conditions.

— Source:Crystalinks.com

In 1856, English astronomer Norman Pogson defined a mathematical relationship for m.

$m = -100^{0.2} \log E$ (E = star luminosity)

Two stars m=1 and m=6 differ in brightness by a factor of 100. Each step in magnitude differs by a factor of $100^{0.2} = 2.512$.



Apparent brightnesses of some objects in the magnitude system.

— Source: AstronomyNotes.com

Telescope Visual Limiting Magnitude

D (in)	D (mm)	Limit	Example
0.2	5	5.6	Aged eye
0.28	7	6.3	Young eye
2	51	10.6	Typical 8x50 finder
2.6	66	11.2	William Optics ZenithStar
3.15	80	11.6	AstroTech AT80ED
4	102	12.1	Takahashi TSA-102S
5	127	12.6	TeleVue NP-127is
6.1	155	13	Astro-Physics 155 EDFS
8	203	13.6	Celestron C8
10	254	14.1	Orion 10' Skyquest
12	305	14.5	Meade 12" Lightbridge
14	356	14.8	Celestron C14
16	406	15.1	Starmaster Truss Dob
20	508	15.6	Obsession Truss Dob
25	635	16.1	Obsession Truss Dob
30	762	16.5	Starmaster Truss Dob
48	1219	17.5	Palomar Schmidt Camera
94	2388	19	Hubble Space Telescope *
200	5080	20.6	Palomar 200 inch scope
394	10000	22.1	Keck 10-meter telescope

* Limiting magnitude if inside Earth's atmosphere

9.1 + 5 log (D), where diameter D is given in inches

— Source: *Amateur Astronomer's Handbook*, Sidgwick

— Calculator: http://www.go.ednet.ns.ca/~larry/astro/maglimit.html

Light gathering power is proportional to the area of the objective

How Much Magnification?

"The answer. . .depends on the nature of eyesight, the telescope's aperture and optical design, atmospheric conditions, and even the type and size of the object looked at."

— Source: "Choosing Your Telescope's Magnification," Al Nagler, *Sky & Telescope*, May 1991

Note: this ad describes a 50mm refractor!!

— Source: Ad from Overstock.com

Barska Solid Refractor 600x Telescope

Rating 4 ★★★★☆
Read Reviews / Write a review

Online Best Price Match

Today: $53.99

Brief Description **Item#: 11103853**

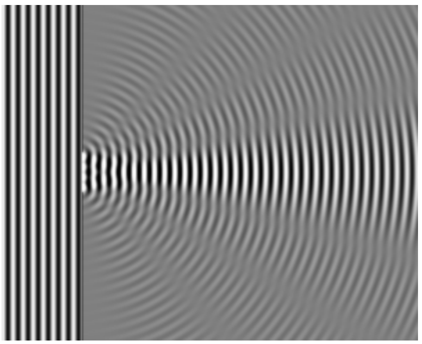
- Barska Solid refractor telescope offers all glass-coated optics for enhanced image brightness
- Get to know the outdoors with interchangeable eyepieces and a 3x Barlow lens
- Telescope features excellent for astronomy enthusiasts and professionals

In case you haven't guessed, 600X for the above scope is, in a word, preposterous!

Much more will be said about how about magnification in the segments on eyepieces and observing through the atmosphere

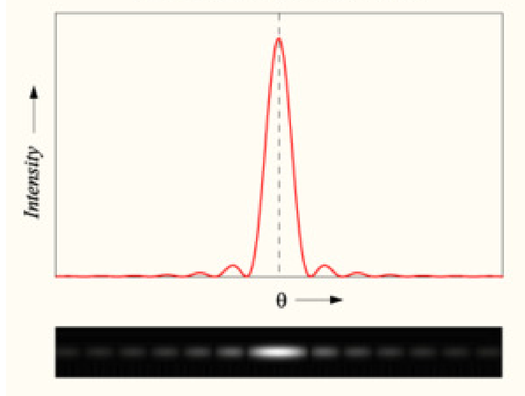
Diffraction and Resolution

Diffraction of Light by an Obstacle



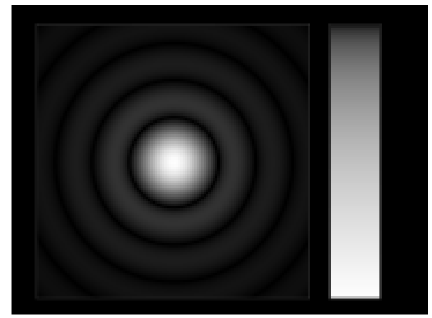
When wave fronts of light encounter an aperture (e.g. a slit) they spread out from the opening, creating a distinct pattern of reinforcement and cancellation.

Single-slit diffraction pattern



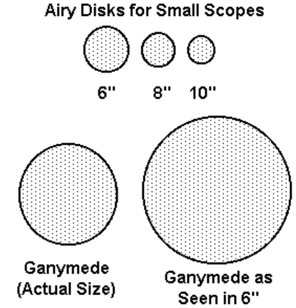
A slit produces the above pattern. A point source such as a star yields a circular diffraction pattern with a strong central peak surrounded by concentric nulls and bright rings.

Airy Disk & diffraction rings



The pattern created by diffraction of a star is called an *Airy disk*, with diameter $1.22\lambda/D$. The central disk contains about 85% of the light.

Airy Disks for Small Scopes

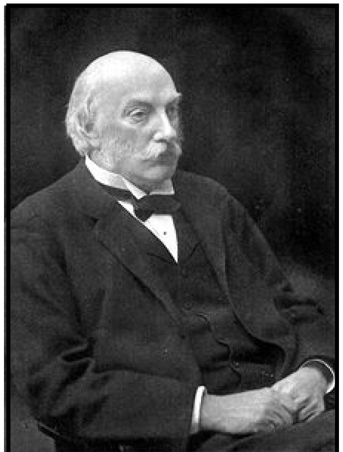


The Airy Disk diameter can be significant relative to the size of objects such as Jovian moons.

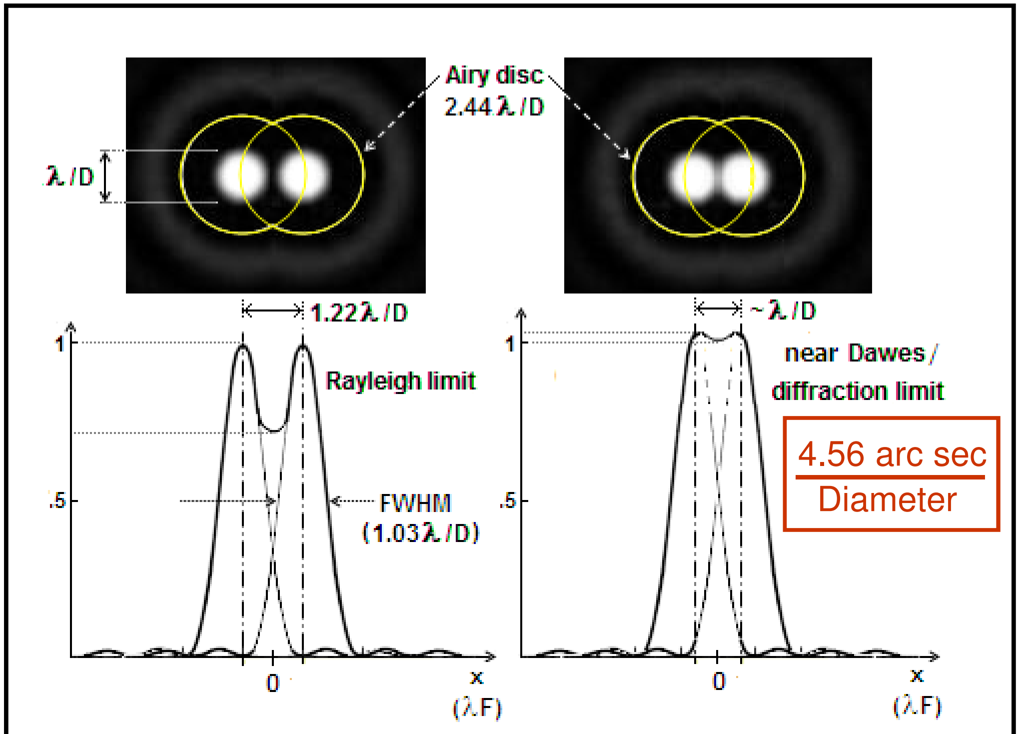
— Source: "The Limits of Telescopic Perfromance, Lenny Abbey, http://labbey.com/Articles/Limits/Limits.html

Because of diffraction, no optical system can perfectly reproduce a point source. All images, including extended objects, are degraded by diffraction.
Airy disk size is inversely proportional to objective diameter.

Diffraction and Point Source Resolution



Lord Raleigh,
English Physicist
— Source: Wikipedia



Effect of Diffraction on Double Stars
— Source: Telescope-Optics.net

William Dawes,
18th century
English Astronomer
— Source: Wikipedia

Magnifying a pair to about 2-4 arc min separation yields better viewing, see *Eye & Vision* section

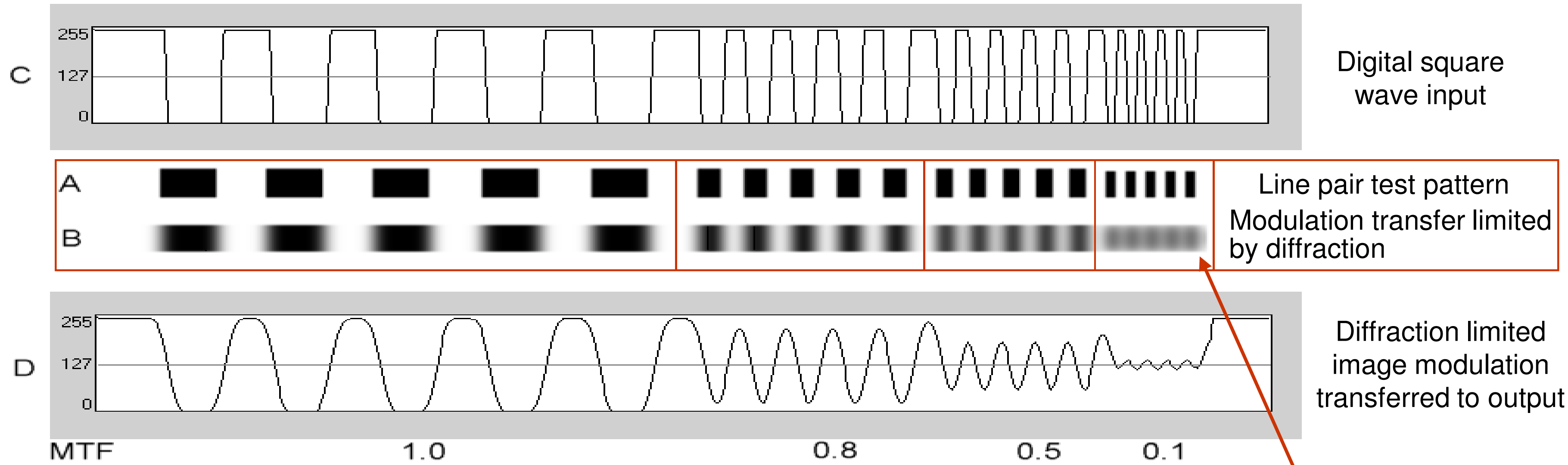
Dawes' limit applies to 2 equally bright mag 6 stars

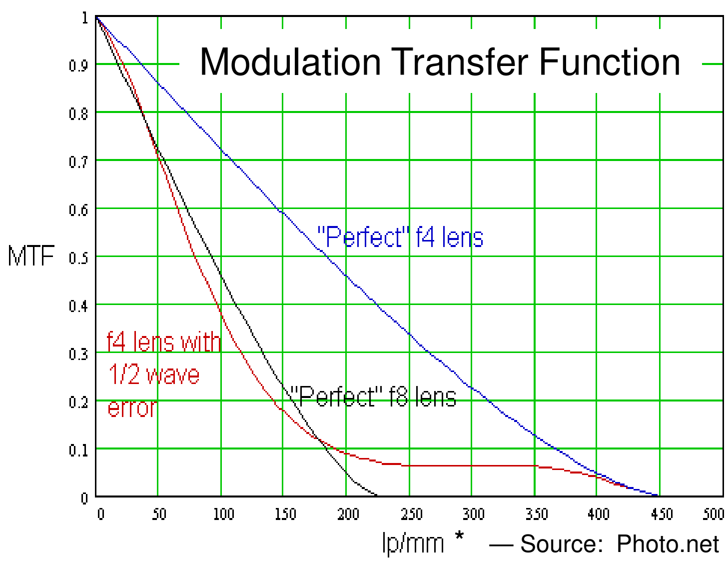
Aperture (inches)	2	3	4	5	6*	8	10	12	16	20	36
Dawes limit (arc sec)	2.3	1.5	1.1	0.9	.76	.57	.46	.38	.29	.23	.13

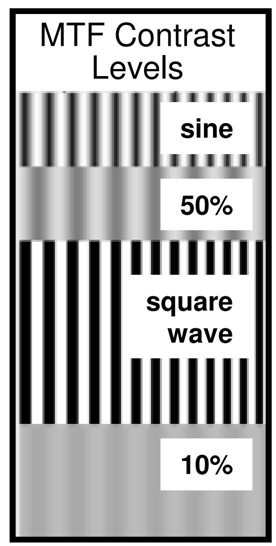
* Elongation can be detected at ~0.4 arc sec

Resolving power is proportional to the diameter of the objective

Modulation Transfer Function







— Source: NormanKoren.com

* Resolving power is sometimes expressed in line pairs per millimeter (lp/mm)

Diffraction places a limit on the **resolution** of an optical system. As detail becomes smaller, diffraction has a proportionally stronger "smearing" effect (failure to fully "transfer" scene **contrast**), diminishing the ability of the optical system to resolve fine detail.

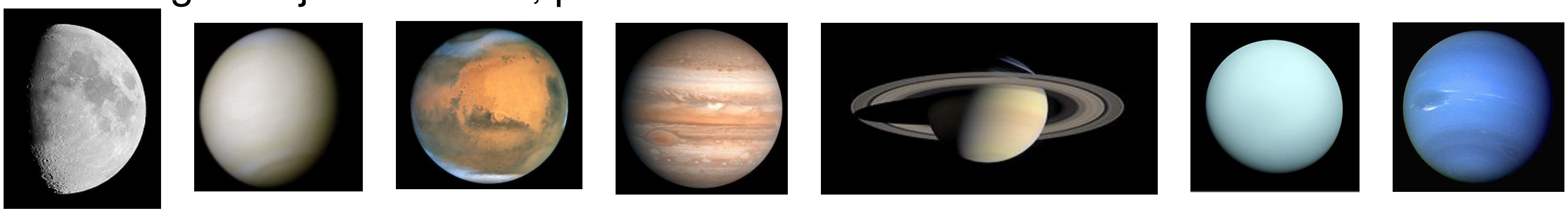
High MTF at low contrast levels helps us see subtle detail such as planetary surface features. Resolution is relevant to fine detail such as double stars.

Larger apertures are less impacted by diffraction and thus have greater resolving power*.

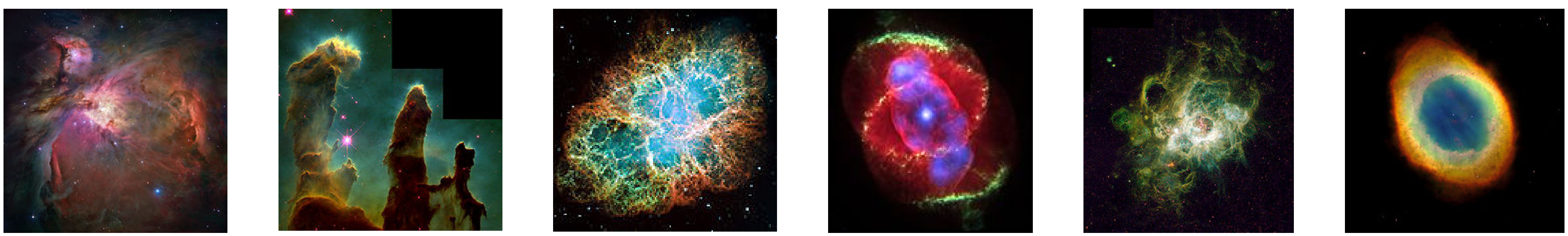
Optical **aberrations** (physics-based image quality limits) can further limit the resolving power of an optical system

Resolution of Extended Objects

- From a resolution perspective, there are two classes of extended objects
  - Bright Objects: Moon, planets



  - Faint Objects: e.g. diffuse & planetary nebulae and galaxies



- Since the eye perceives these classes differently, resolution of extended objects will be discussed later, after the eye and vision are discussed

— Source images: Wikipedia

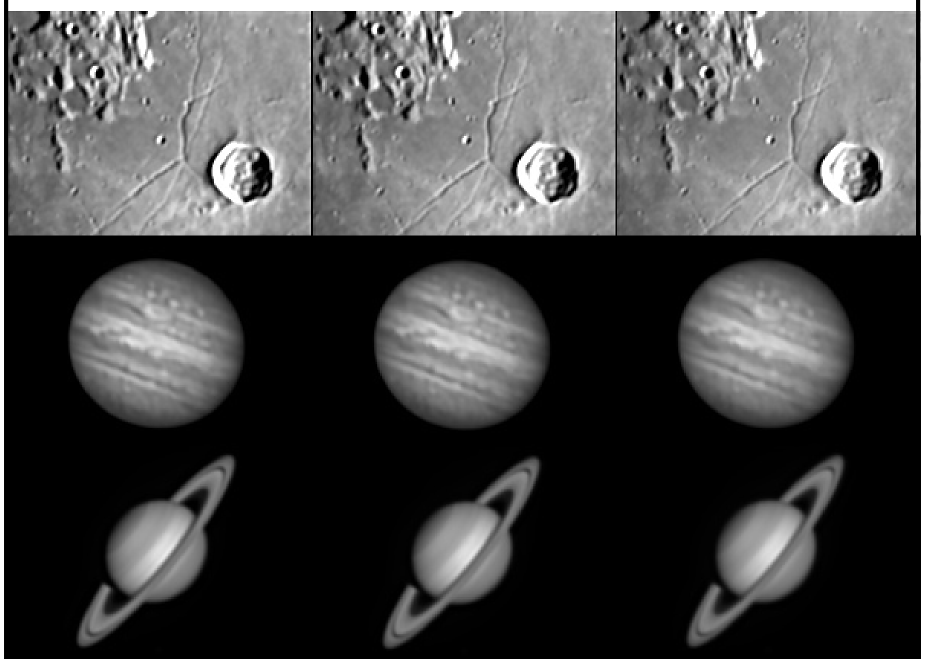
Obstructions & Coatings

Light Loss Due to Central Obstruction		
Telescope Example	Obstruction	Light Loss
8" Refractor	0%	0%
8" f/6 Newtonian	18%	3%
8" f/10 SCT	34%	11%

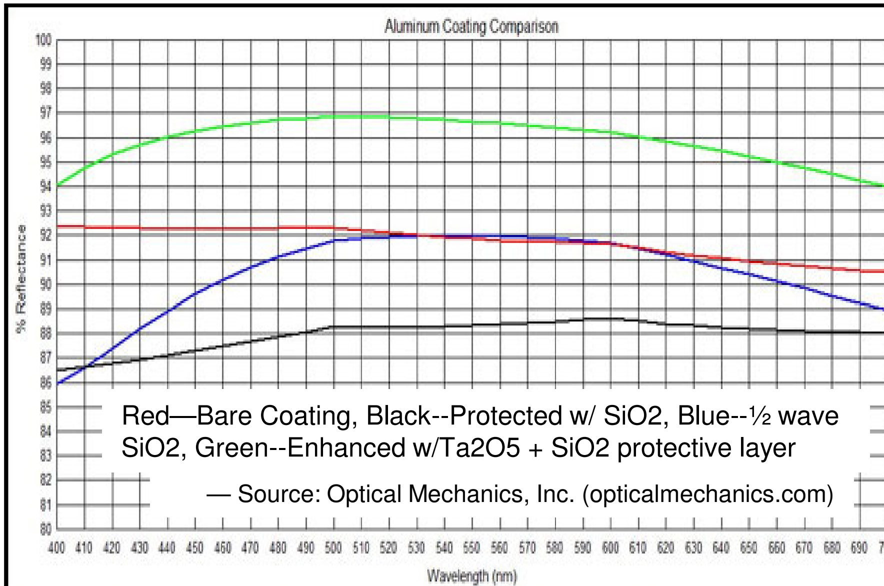
— Source: Laughton.com

150mm telescope resolution simulation

No obstruction | 20% | 33%

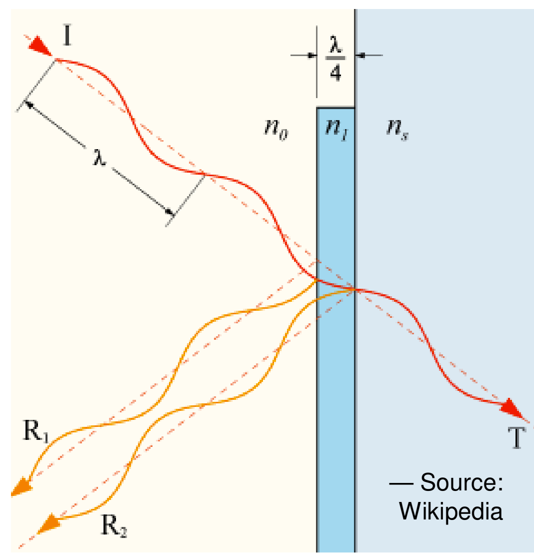


— Source: http://www.hoflink.com/~mkozma/obstruction.html



Red—Bare Coating, Black--Protected w/ SiO_2, Blue--½ wave SiO_2, Green--Enhanced w/Ta_2O_5 + SiO_2 protective layer

— Source: Optical Mechanics, Inc. (opticalmechanics.com)

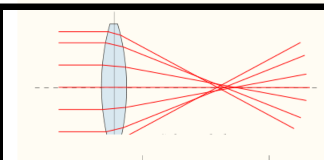
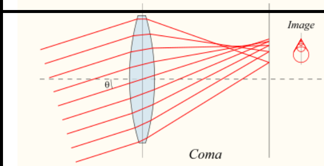
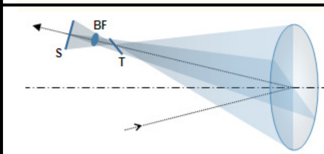
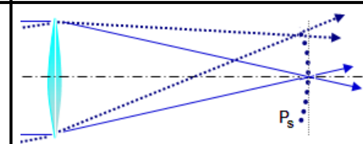
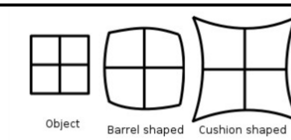
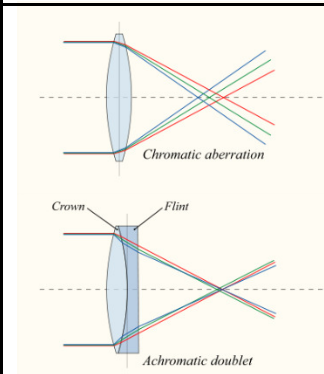


Interference in a quarter-wave anti-reflection coating

Anti-reflection coatings produce secondary phase-shifted reflections, canceling primary reflections so that virtually no light is reflected from the optical surface.

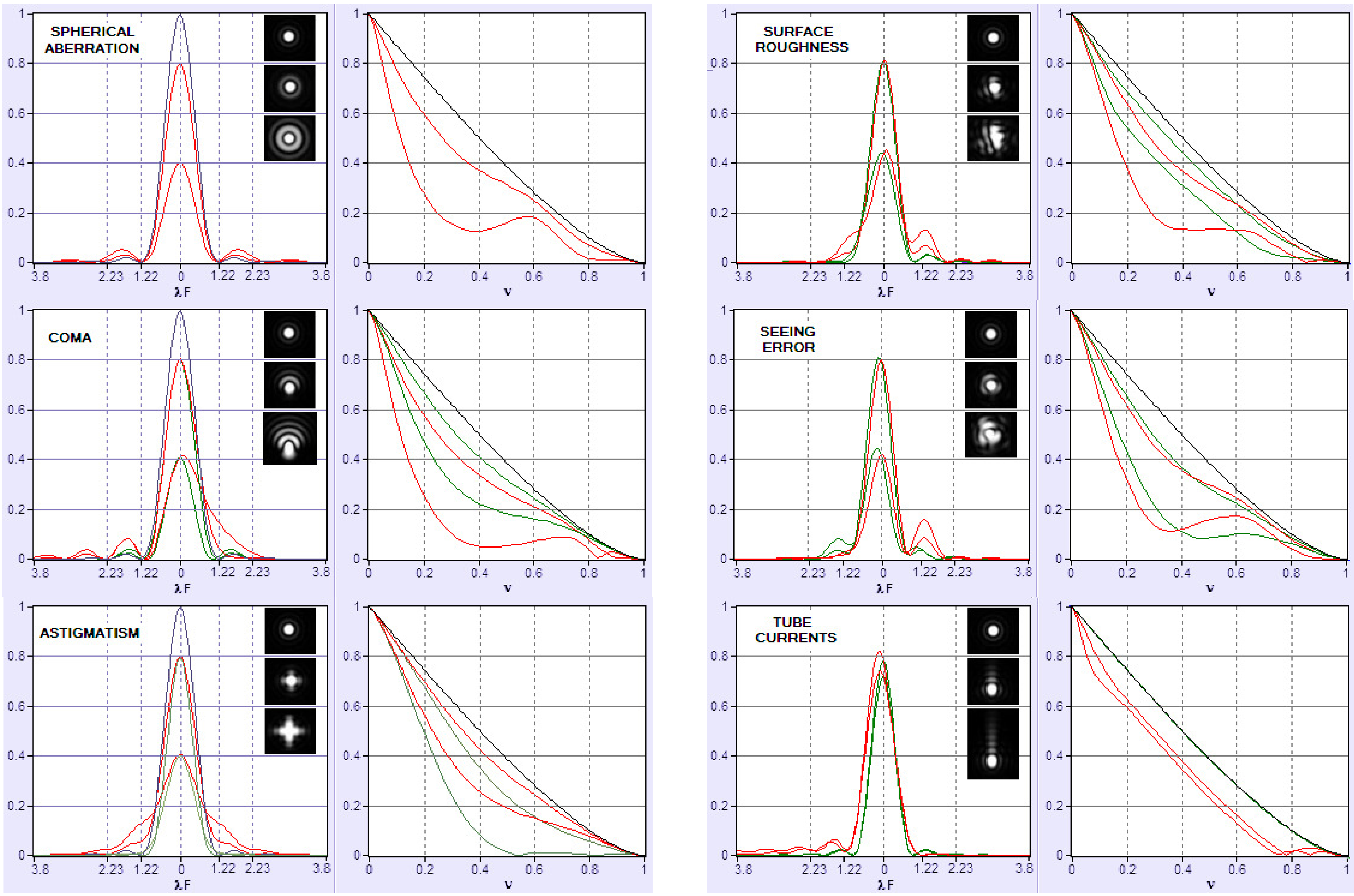
— Source: Hyper-Physics Dept, Georgia State Univ.

Aberrations of the Objective

Spherical Aberration	A difference in focal length between axial rays and edge-of-field rays. Newtonian primary mirrors are made with a parabolic curve rather than spherical in order to eliminate spherical aberration.	
Coma	A defect by which off-axis points are rendered as comet-like patches of light with fan-shaped tails. Coma is an unavoidable property of fast parabolic primary mirrors, corrected by a lens called a “Paracorr”.	
Astigmatism	The image of a point focuses differently at the sagittal and meridional foci (also called radial & tangential) creating an irregular shape. Many human eyes exhibit astigmatism.	
Field Curvature	The image lies on a curved surface instead of a plane so that all parts of the image cannot be brought into focus at the same time. For photography, field flatteners are sometimes used.	
Distortion	An optical flaw resulting in either a barrel or pincushion effect. Mild distortion is not a serious problem for deep sky observation.	
Chromatic aberration	Different colors of light are bent by different amounts as they pass through a lens, resulting in color halos around objects. CA is corrected by use of multiple lens elements. Two element objectives are called “achromatic” and two or three element lenses using glass with unusual dispersion characteristics are called “apochromatic.”	
Fabrication errors	Optical: surface roughness, ripple, zone errors, turned edge. . . Assembly: various alignment and collimation errors.	

— Source: Various, including *Visual Astronomy of the Deep Sky*, Roger N. Clark, 1990

*Effects of Aberrations on PSF and MTF **



* PSF: point spread function; MTF: modulation transfer function

— Source: Telescope-Optics.net

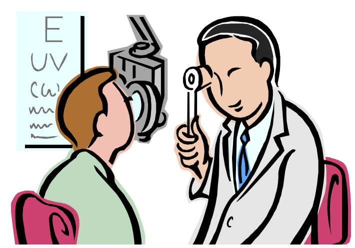
Telescope Accessories

— Sources:
Astronomics.com
Astro-Physics.com

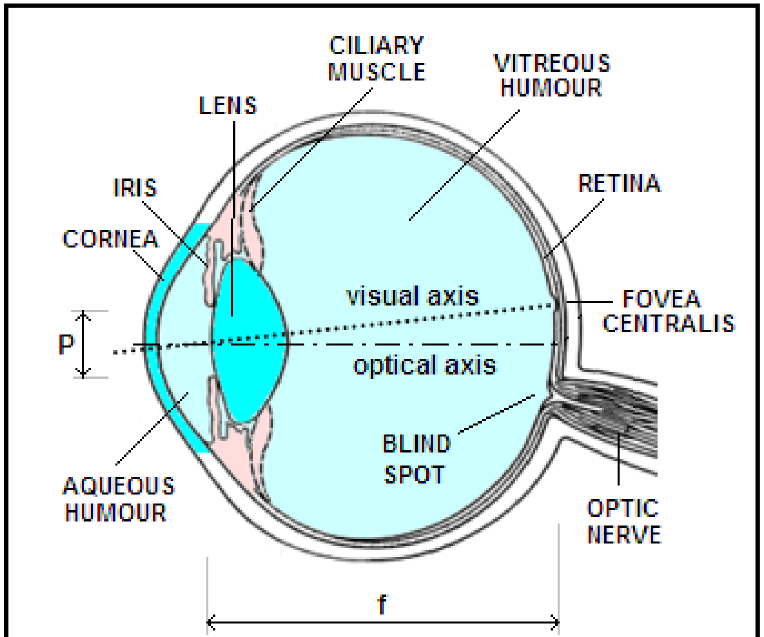
Outline

- Telescope Basics
- The Eye & Vision *
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

* The vision material herein by no means covers the extent of what is known about the eye by professionals in the field. It covers only enough to complete the story of how vision interacts with physics, optics and the atmosphere to create the experience of visual astronomy.



Anatomy of the Eye

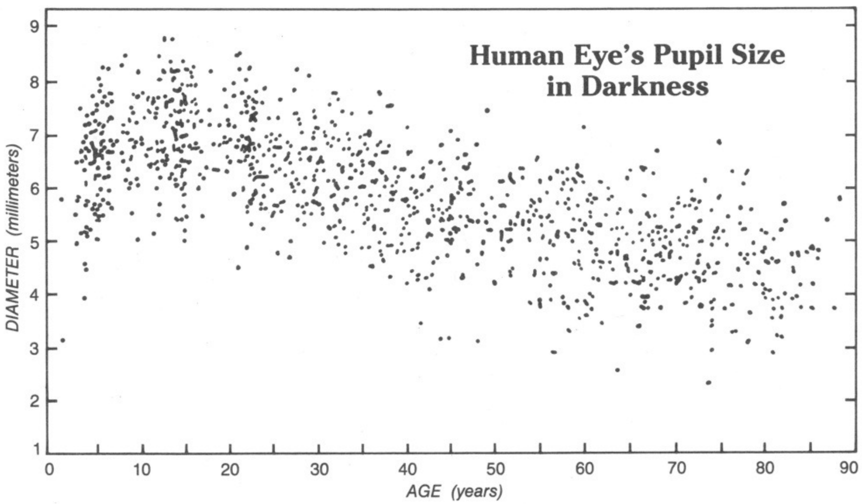


Anatomy of the eye
— Source: Telescope-Optics.net

- The iris opens and closes to control how much light reaches the retina
  - The iris opening is called the pupil, or sometimes "entrance pupil", **P** in the diagram
  - The dark-adapted pupil varies with age, ranging from a diameter of 7mm when young to less than 5mm when old
    - Pupil diameter in bright light is ~2 mm
- The lens focuses light on the retina
- The fovea is the site of maximum sensitivity to fine detail
  - The macula is an extended area of lesser sensivity around the fovea
  - Visual resolution is called "acuity"
- Maximum sensitivity to low light lies ~15-20^{o} away from the fovea

The entrance pupil of the eye (iris) determines how much light from an optical system such as a telescope enters the eye.

Eye Pupil, Age and Magnification



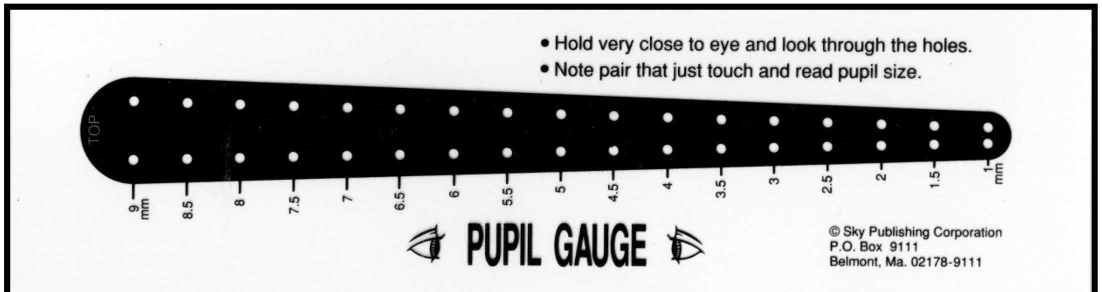
Over 1,200 people had their eyes measured to create this graph of pupil diameter versus age. Clearly, the conventional wisdom that the human eye opens to 7 millimeters in darkness is only a very rough average even for young people. Over age 50, a more realistic average is 5 mm. Which of these points would represent you? From a study by I. E. Loewenfeld published in *Night Vision* (National Academy Press, 1987).

— Source: Sky & Telescope, May 1992

Age vs. Pupil Size and Lowest Magnification
(Low power eyepieces have large exit pupils)

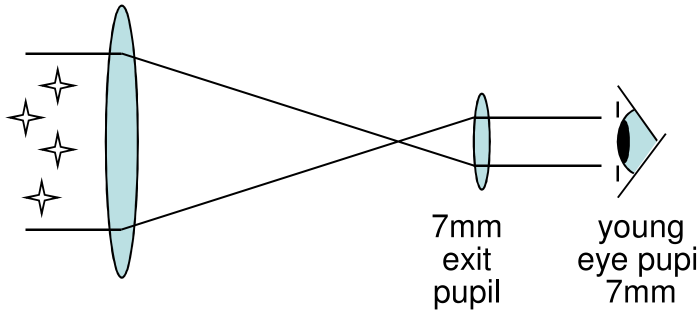
Approx. Age	Avg. Pupil Size	Lowest Effective Magnification per inch of Aperture	Lowest Effective Magnification per cm of Aperture
< 25	7	3.5	1.4
30	6.5	3.8	1.5
35	6	4.1	1.6
45	5.5	4.5	1.8
60	5	4.9	2
80	4.5	5.4	2.2

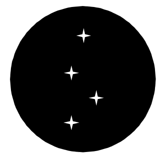
— Source: Event Horizon Newsletter, April 1996,
Hamilton Amateur Astronomers



Any eyepiece/telescope combo with a larger exit pupil than the eye's entrance pupil excludes some light from the objective. The eye pupil declines with age.

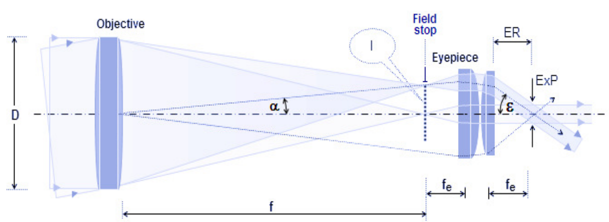
Eyepiece Exit Pupil & Eye Entrance Pupil

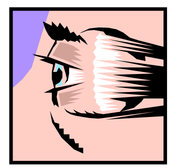


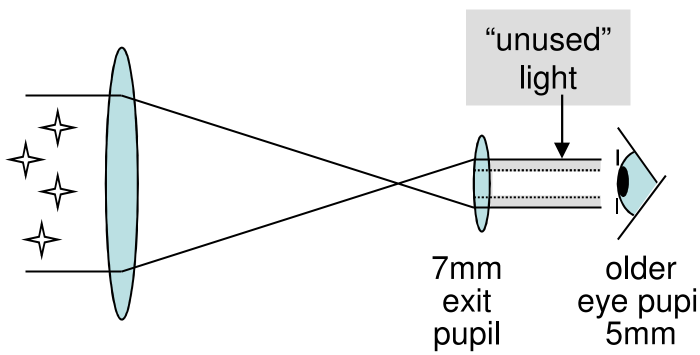


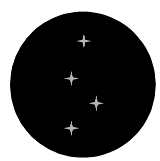
Eyepiece exit Pupil and eye entrance pupil same size → All light collected by objective is captured by eye

Exit pupil = fe ÷ F
Example Light from objective is reduced by ratio of pupil radii squared $r^2_{eye} / r^2_{eyepiece} = 51\%$ In this example, a 7” scope would deliver only as much light as a 5” scope









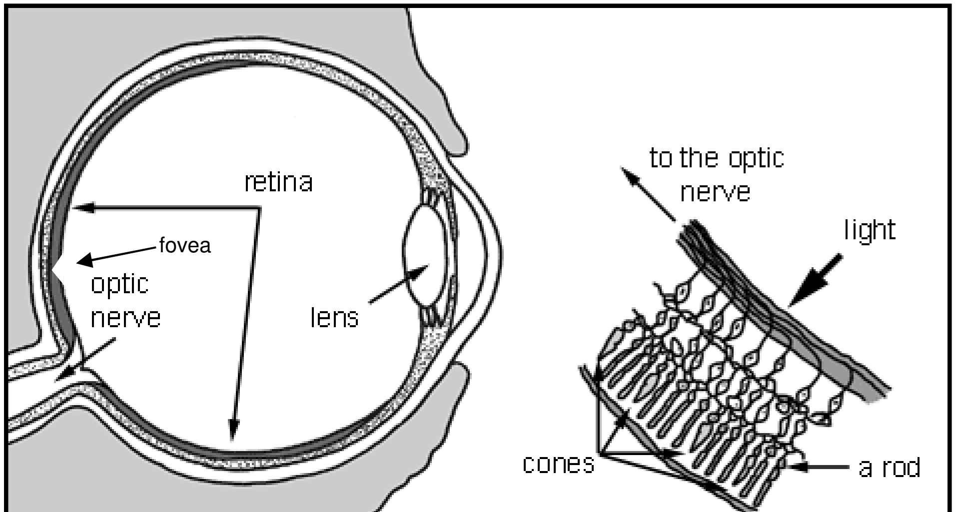
Eyepiece exit pupil larger than eye entrance pupil → Smaller eye pupil excludes some light collected by objective

Objective D = 100mm, f = 700mm => F7
Eyepiece f_e = 50mm (typical 2” Plossl)
Exit pupil = 50mm / F7 = 7.1mm

One may still want an eyepiece with a large exit pupil for the wider true field it provides – even though some light will be lost.

Rods and Cones

The retina has two types of visual receptors: rods and cones



Rods and cones

— Source: Orion-XT10.com

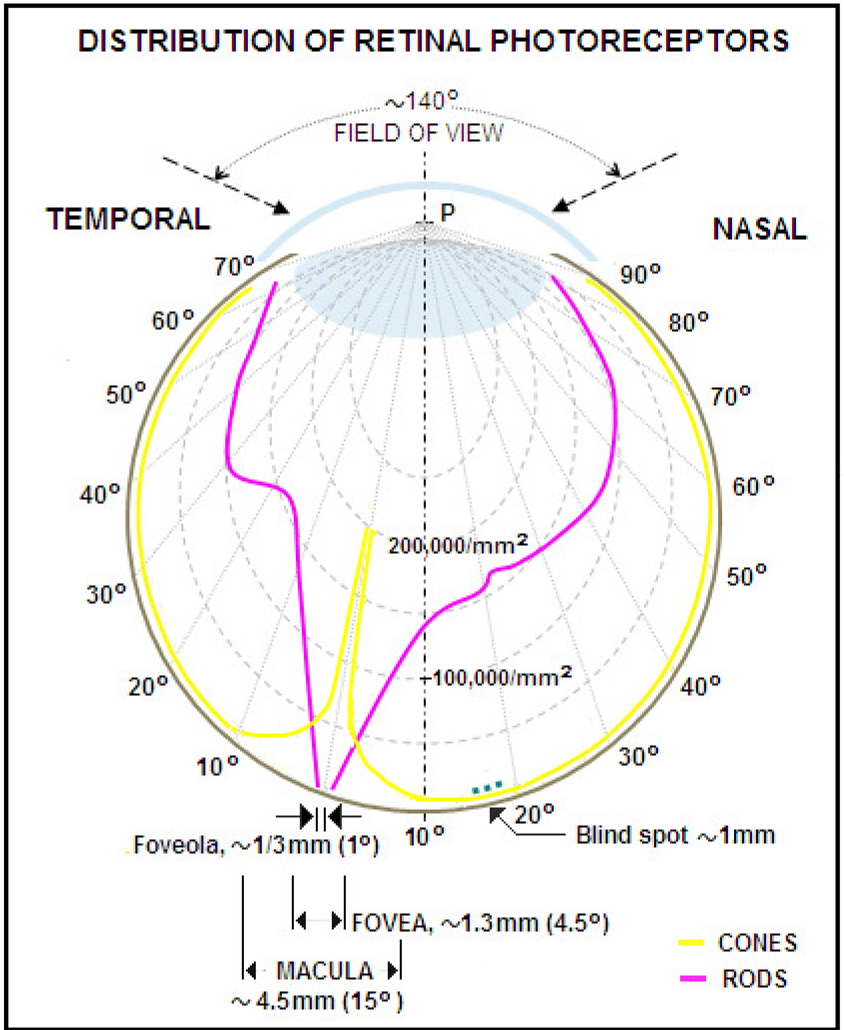
- Cones sense color & detail ("photopic vision")
  - Cones are highly concentrated at the fovea and in the surrounding macula
  - The retina contains 6-7 million cones
  - In the fovea, each cone cell has its own neural path, resulting in increased visual acuity
  - Cones begin to contribute to vision at about the level of starlight; it takes ~100 photons to elicit a cone response
  - Cones recover from bright flash stimuli in ~200ms

- Rods provide low light sensitivity ("scotopic vision")
  - Dark adaptation involves both iris dilation and rod chemical changes
    - Buildup of rhodopsin (visual purple)
  - Rods are not sensitive to color
  - A rod can detect a single photon(!) but saturates in bright light
  - The retina contains ~120M rods
  - Rods are sparce at the fovea and reach max. density ~18-20º from fovea
  - Rods recover from bright flashes more slowly than cones, in about a second
  - Several rods are "bundled" together in a single neural path, increasing low light sensitivity at the expense of acuity

— Source: *Neuroscience*, 2nd Edition, Purves, Fitzpatrick, Williams, McNamara, Augustine and Katz

Rods are not sensitive to color. We do not see color in faint, extended objects because we see them with our rods.

Distribution of Rods and Cones

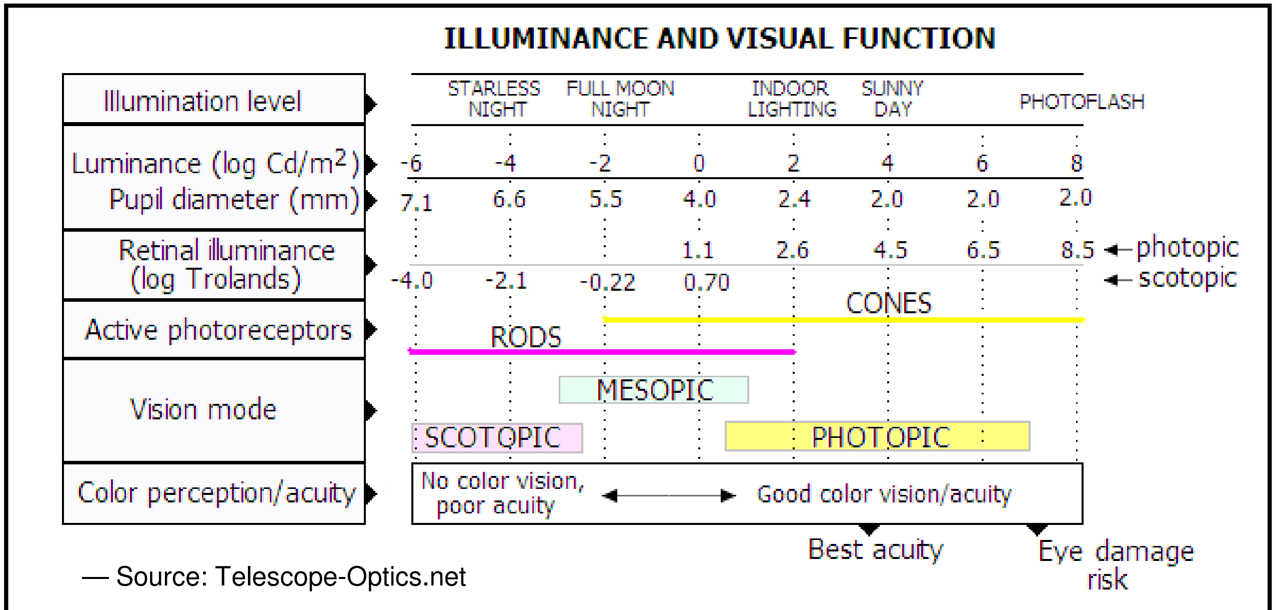


Left Eye — Source: Telescope-Optics.net

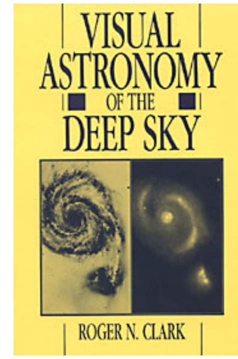
- Cones are very densely concentrated at the fovea
  - Area of greatest visual acuity
  - Less dense concentration across remainder of macula
    - Macular vision loss = blindness
- Rod density is greatest about 15-20 degrees away from fovea
  - Area of greatest low light sensitivity
    - Loss of rod function = poor night vision

Differences in rod and cone distribution leads to different strategies for seeing objects of different brightness.

Light Level and Visual Function

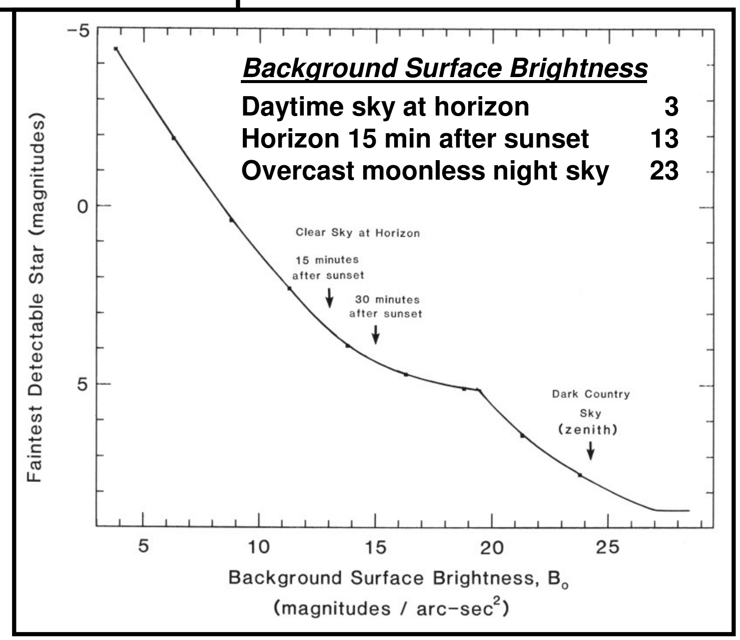


— Source: Telescope-Optics.net



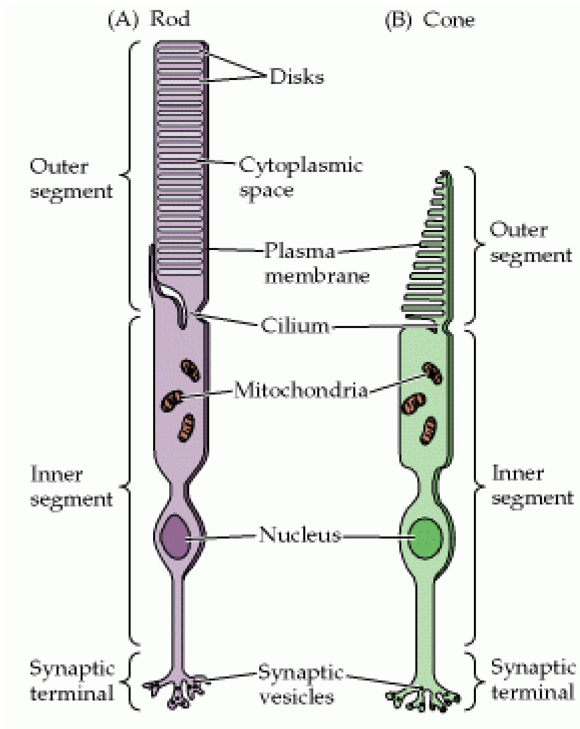
A standard measure of background brightness is magnitudes per square arc-second

- Eye detection limit: 50-150 photons arriving over a period of several seconds
- Faintest detectable star: magnitude 8.5
  - Sky brightness prevents detection at 8.5
  - Practical limit: magnitude 7 to 7.5
    - For young eyes and excellent vision under darkest skies and full night adaptation
  - *Equivalent* of mag 8.5 visible only with high magnification to darken sky background
  - Magnification darkens sky but not star

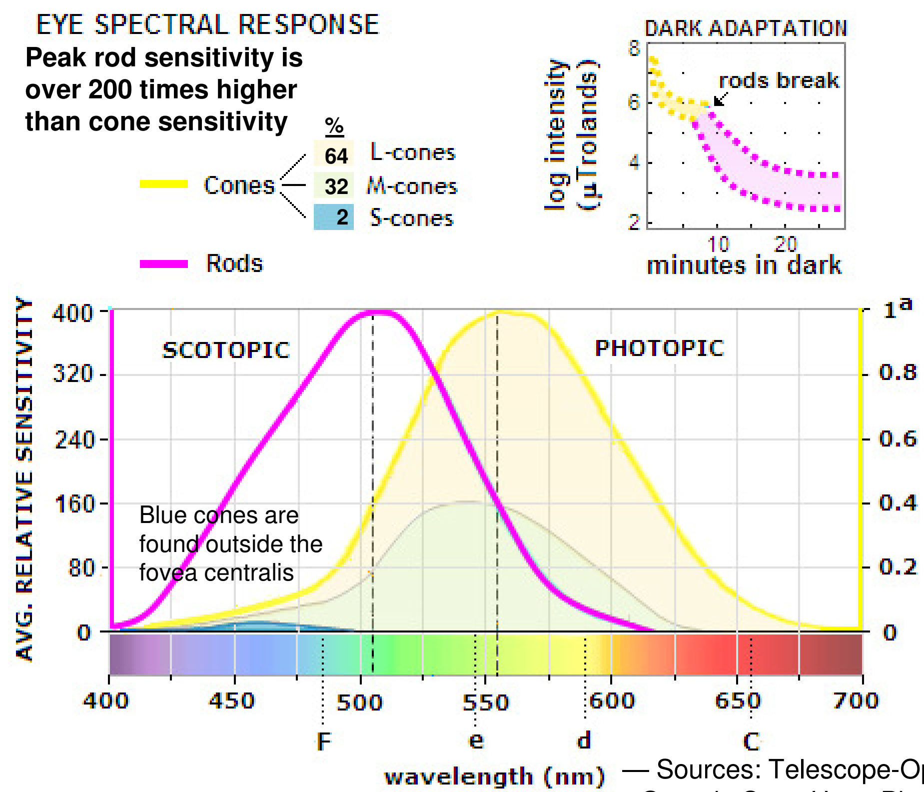


— Source: *Visual Astronomy of the Deep Sky,* Roger N. Clark, 1990

The Eye and Color Vision



— Source: *Neuroscience*, 2nd Edition, Purves, Fitzpatrick, Williams, McNamara, Augustine and Katz

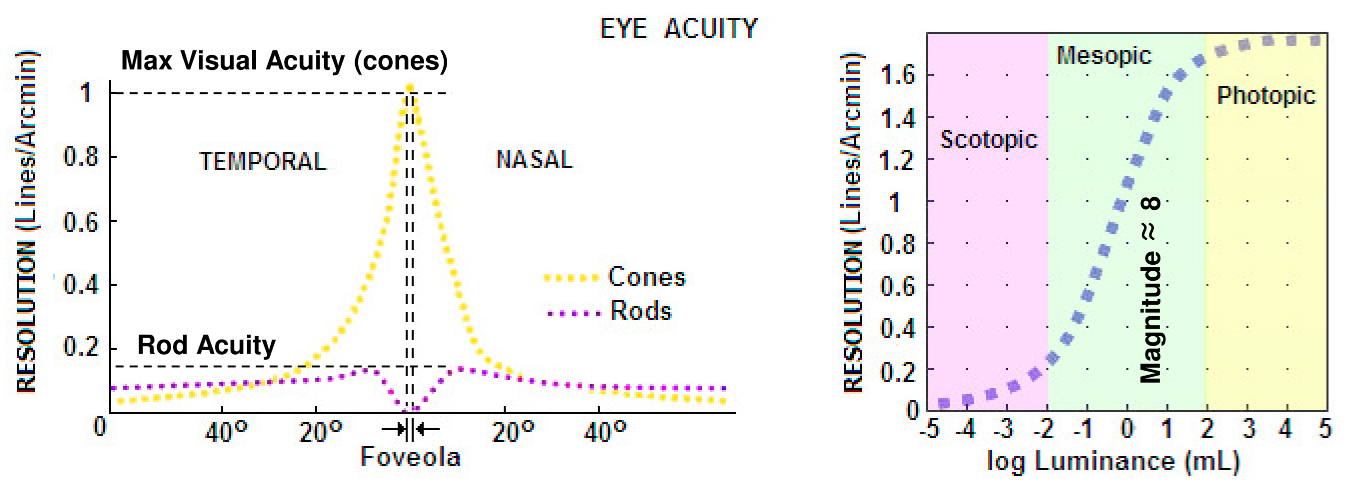


— Sources: Telescope-Optics.net & Georgia State HyperPhysics Dept.

Since rods respond to red and blue poorly, many faint deep sky objects, e.g. many planetary nebulae, are seen primarily by the green light they emit.

"The threshold of color is about 21.5 magnitudes per square arc-second.
– R. N. Clark, *Visual Astronomy of the Deep Sky*, 1990

Acuity (“resolution”) of the Eye



Resolution of rods and cones

— Source: Telescope-Optics.net

Resolution domain of bright double stars and lunar/planetary detail

Resolution domain of faint, extended deep sky objects

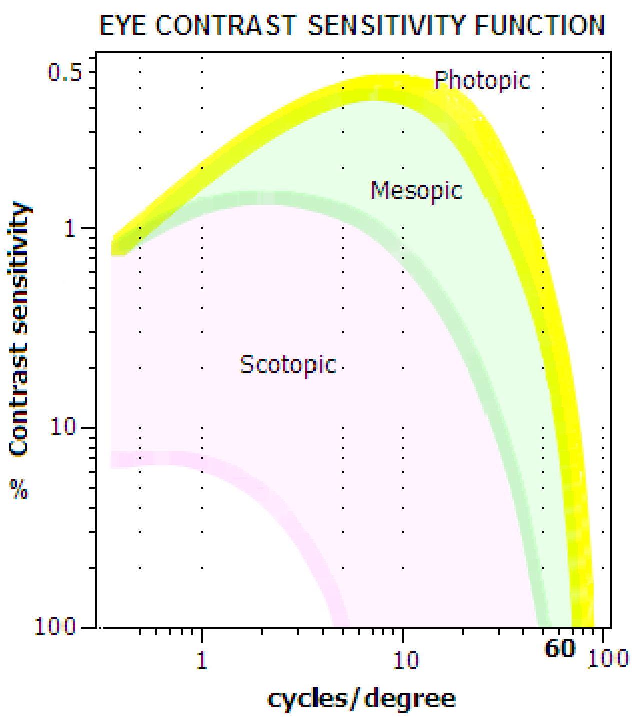
Telescopic detail must be magnified ≥ the lower limit of the eye’s visual acuity, often cited as **approximately 1 arc-minute**. Two to four times this is more comfortable

Double star pairs of equal brightness are easiest to resolve, and they should be not too bright nor too dim. Below approx. mag 8, photopic vision diminishes.

For low contrast subjects such as faint deep sky objects as well as brighter extended objects such as planets and the Moon, the eye’s ability to detect small differences in **contrast** is also a key determiner in ability to detect detail.

The eye’s ability to detect low contrast subjects will be discussed later.

Contrast Threshold



Vision contrast sensitivity
— Source: Telescope-Optics.net

During WWII, coastal defense watchers scanned the skies looking for enemy airplanes. In order to study the detectability of targets in the sky, R.H. Blackwell performed a study titled "Contrast Thresholds of the Human Eye," published in *Journal of the Optical Society of America*, v36, p624-643, 1946.

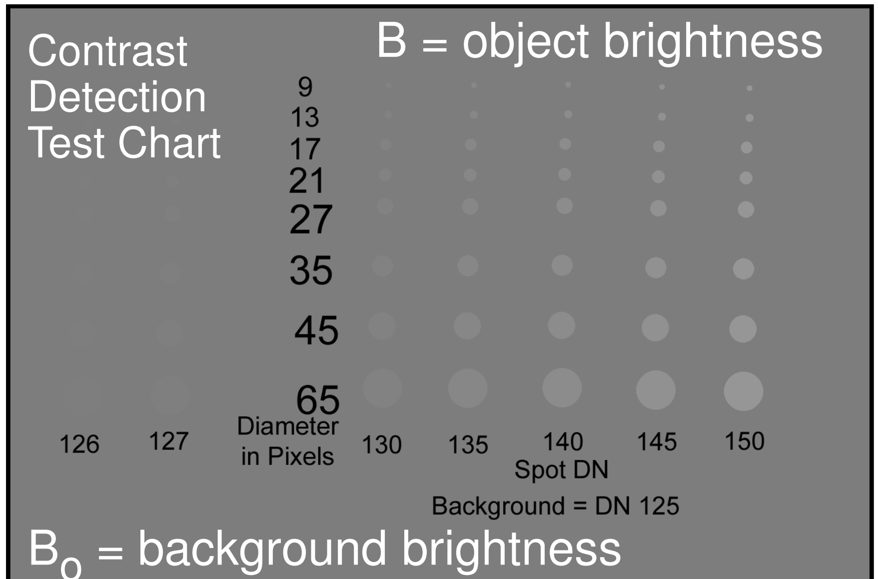
Blackwell's data was used by Roger N. Clark to study delectability of faint deep sky objects in the night sky. His results will be covered later.

Contrast is defined as:

$(B - B_o) / B_o$

B = Object brightness

B_o = Background brightness



— Source: *http://www.clarkvision.com/visastro/omva1*
& Visual Astronomy of the Deep Sky, Roger N. Clark

Dark Adaptation

- Dark adaptation is a two stage process
  - Pupil dilates to maximum diameter in a few seconds
  - Photochemical change takes 30-40 minutes and continues for up to 2 hours
    - Buildup of *rhodopsin*, also called visual purple
- Dark-adapted rod vision is up to 100,000 times more light sensitive than non-adapted cone vision
  - The eye takes up to 24 hours to recover from a day of bright sun
  - Bright white light can quickly reverse dark adaptation
  - Rods are insensitive to red, which is why red flashlights preserve night vision

— Source: Orion-XT10.com

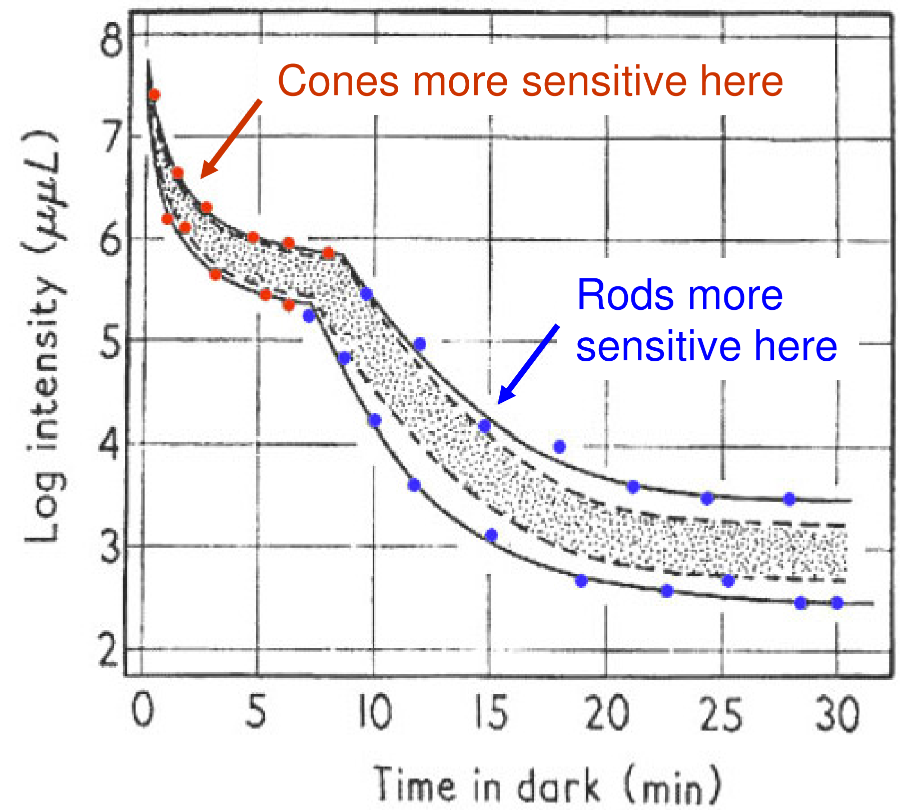
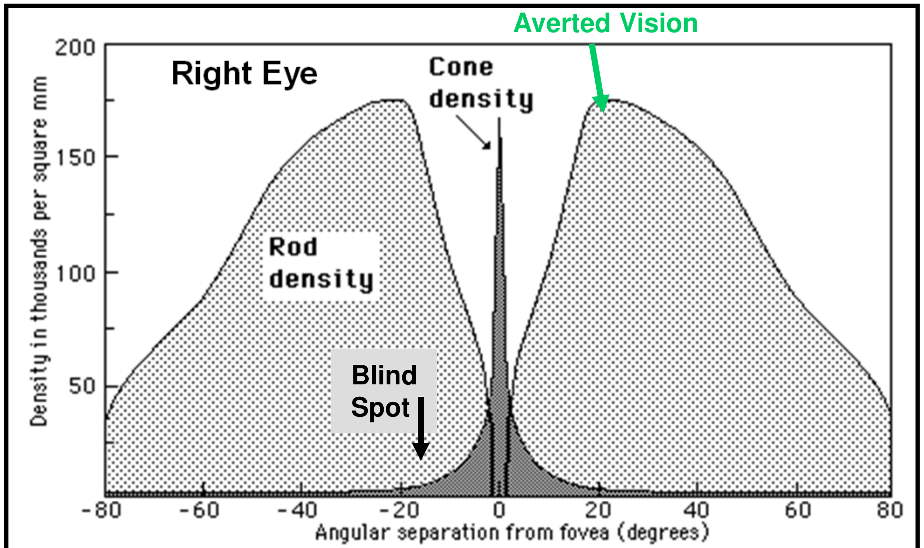


Figure 1. Dark adaptation curve. The shaded area represents 80% of the group of subjects. Hecht and Mandelbaum's data from From Pirenne M. H., Dark Adaptation and Night Vision. Chapter 5. In: Davson, H. (ed), The Eye, vol 2. London, Academic Press, 1962.

— Source: University of Utah, John Moran Eye Center

Averted Vision

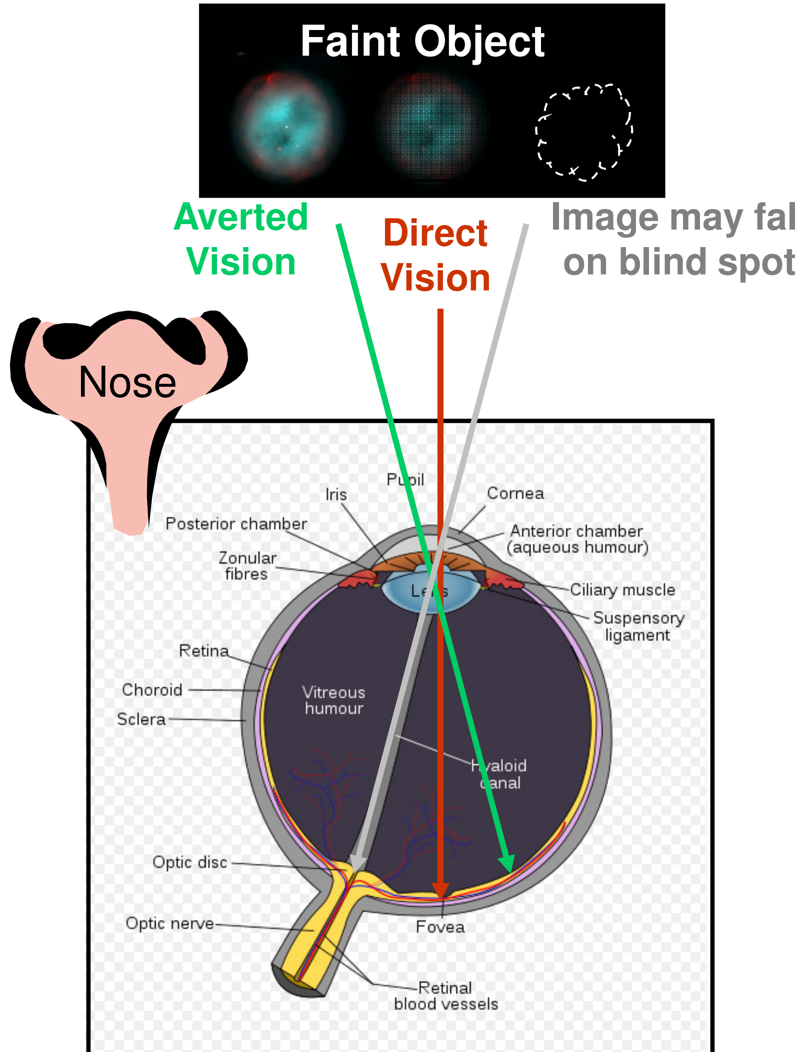


Rod and cone density on retina

— Source: Georgia State University HyperPhysics Dept.

- Averted vision places faint objects at peak density of dark-adapted rods
  - ~15-20 deg from center of vision
  - Allow light to build up for 5-10 seconds
- The fact that rod neural paths are "bundled" increases sensitivity compared to cones
- Place faint object on the nasal side of the eye in order to avoid the retina blind spot
- Averted vision works better for faint extended objects than for bright point source objects

— Source: Orion-XT10.com



Schematic diagram of right eye

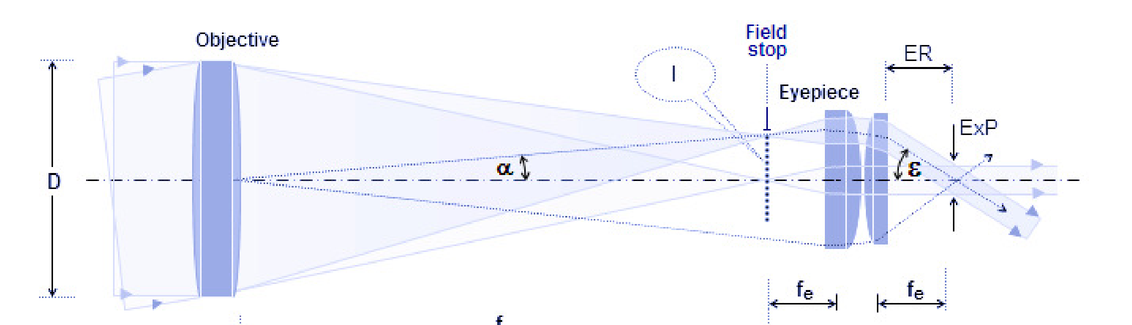
— Source: Wikipedia

— Owl Nebula Photo Credit: Robert J. Vanderbei, Wikipedia

Outline

- Telescope Basics
- The Eye & Vision
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

Eyepiece Functions & Properties



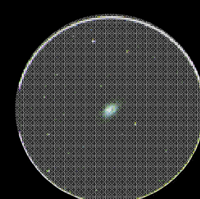
— Source: Telescope-Optics.net

D = objective diameter
f = objective focal length
F = focal ratio = f ÷ D
f_e = eyepiece focal length
ER = eye relief
ExP = exit pupil = f_e ÷ F
Field stop = opening located at objective focal plane
ε = apparent field of view
α = true field of view

Magnification	Magnify the image formed by the telescope objective — Mag = f / f_e = objective focal length ÷ eyepiece focal length
Apparent Field of View (AFOV)	Visual angle subtended by field as one looks into eyepiece — Range from < 40º (Kellner and earlier designs) to 100º (TeleVue Ethos) — True field of view approximated by AFOV ÷ magnification — TFOV = field stop diameter * 57.3 ÷ scope objective focal length
Eye Relief	Distance from eyepiece eye lens to eye of observer — Typically 10-20mm, as high as 38mm for TeleVue 55mm Plossl — 20mm is usually a comfortable eye relief for glasses wearers
Barrel Diameter	Standard sizes: 1.25” and 2.00” — Old standard 0.965” now limited to small, inexpensive eyepieces
Focus Distance	Extension of focuser tube at which eyepiece focuses — Parfocal eyepieces all focus at the same distance

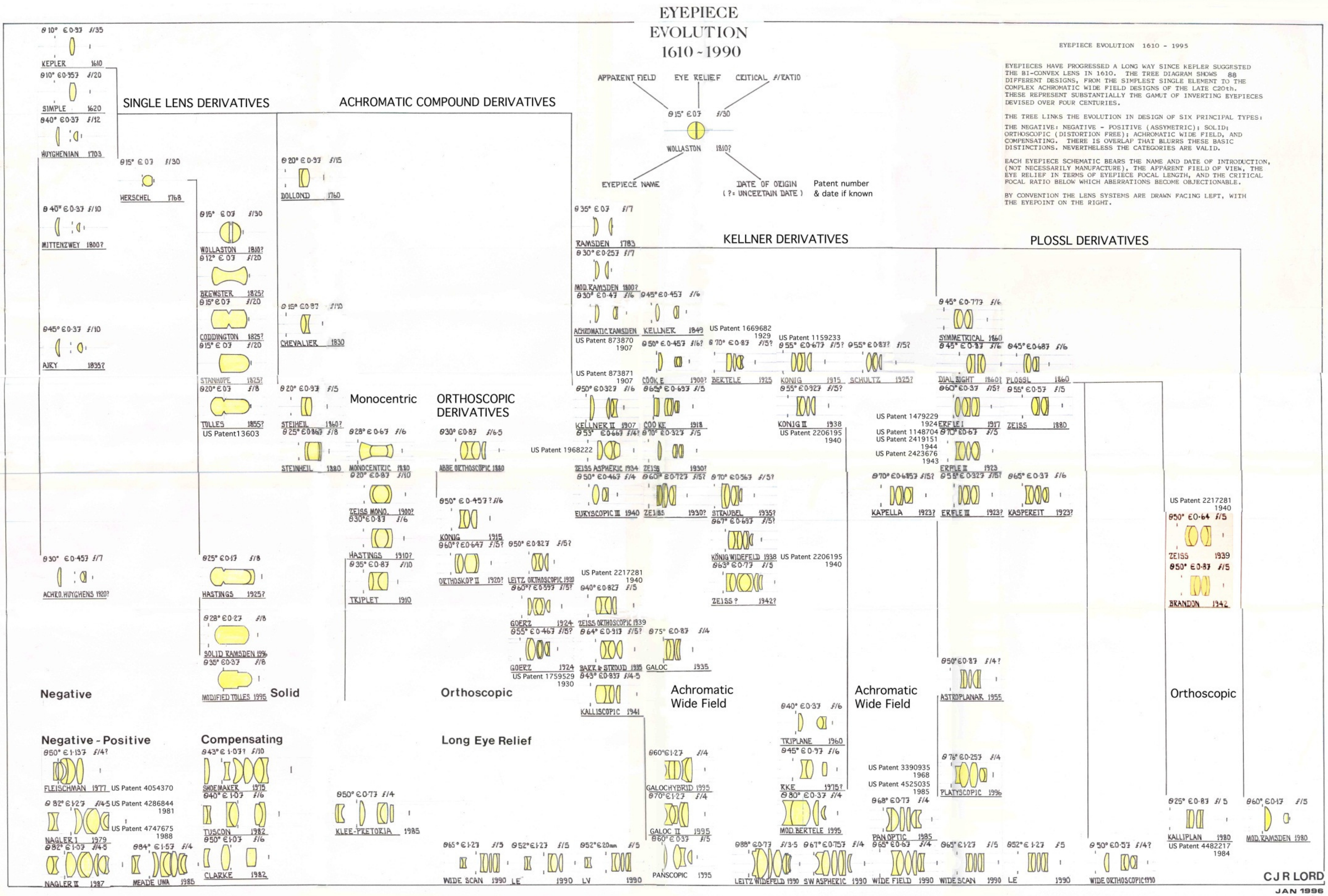
Magnification and Field of View

Useful magnification is constrained from above and below by telescope aperture, optical quality, mount steadiness, atmosphere and the eye's abilities

	Eyepiece with 50º apparent field of view		Eyepiece with 80º apparent field of view
Same focal length eyepieces yield same magnification regardless of AFOV	**Tunnel vision**  Small true field	Same power	**Ample FOV**  Large true field
Same true field of view from different AFOV eyepieces requires different magnifications	**Bright sky back-ground**  Low magnification	Same true FOV	**Dark sky back-ground**  High magnification

Eyepieces with a large apparent field of view provide a more pleasing viewing experience but are heavier and more expensive

— Source: "Choosing Your Telescope's Magnification," Al Nagler, *Sky & Telescope*, May 1991



— Source: Brayebrook Observatory, Cambridgeshire, UK

Selected Eyepiece Types

Type	Inventor	Date	Elements	AFOV °	Notes
Huygens	Huygens	17th century	2	~25	Poor quality, rarely used
Ramsden	Ramsden	18th century	2	~35	Poor quality, rarely used
Kellner	Kellner	1850	3	40	Inexpensive, still used
Plossl	Plossl	1860	4	50	Widely used, top quality
Abbe/Ortho	Abbe	1880	4	45	Good planetary/lunar
Monocentric	Stenheil	1880	3	narrow	Good planetary/lunar - TMB
Konig	Konig	1915	3-4	55-70	Very few brands
Erfle	Erfle	< 1921	5-6	60-70	Poor edge performance
Kohler *	Zeiss	1960	11	120 (!)	Military binoculars
Nagler *†	Nagler	1979	6-7	82	Large, heavy, expensive
Panoptic†	Nagler	Early 1990s	6	68	Much better than Erfle
Radian *†	Nagler	1999	6-7	60	20mm eye relief for glasses
Ethos *†	Dellechiaie	2007	?	100	Large, heavy, expensive

* Negative (Barlow-like) lens group incorporated in optical path
† TeleVue-specific designs.

Obsolete	Infrequent	Inexpensive	Good quality	TeleVue

— Sources: Various, including TeleVue, John Savard, http://www.quadibloc.com/science/opt04.htm, and Brayebrook Observatory, Cambridgeshire, UK

Aberrations of the Eyepiece

- **Spherical aberration** – causes a softness of the image in the center of the field. It is not usually a problem with eyepieces that have three or more elements unless used with very fast objectives.
- **Axial color** – is the appearance of color fringes around an object at the center of the field. It is rarely a problem with designs using three or more elements, and it is absent from some two-element eyepieces.
- **Lateral color** – is seen as color fringes around objects near the edge of the field. This is difficult to "design out" of an eyepiece and can arise from poor manufacturing as well. This aberration may persist even when the eyepiece is used with objectives of high f/number.
- **Coma** – causes comet-shaped instead of round star images near the edge of the field. It is not usually encountered in good designs.
- **Astigmatism** – causes stars to appear as lines, crosses, or squares at the edge of the field. It is the most significant problem with wide-angle eyepieces, especially with low-f/number telescopes. Using a Barlow lens with the eyepiece will often suppress astigmatism dramatically.
- **Field curvature** – prevents an image from being in focus at the center and edge of the field simultaneously.
- **Distortion** – in an eyepiece makes straight objects look curved. While some eyepieces, especially orthoscopics, are better than others in this regard, distortion is not usually a problem in astronomical viewing.

— Source: "An Eyepiece Primer," Al Nagler, *Sky & Telescope*

With eyepieces, quality costs – you get what you pay for!

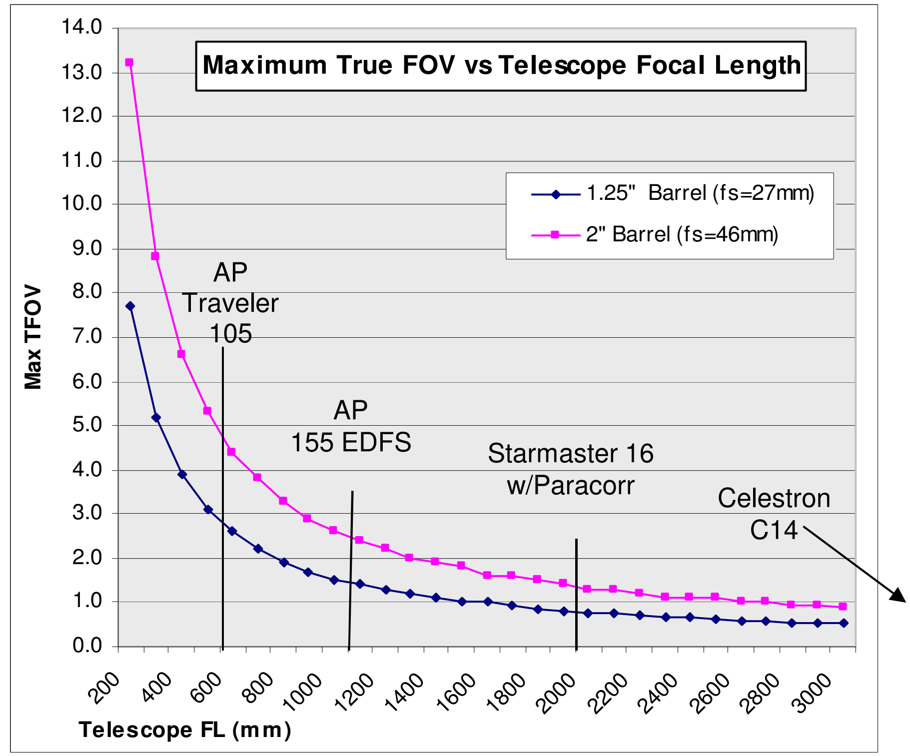
Eyepiece Manufacturers

Apparent FOV	40-45	49-55	58-60	65-72	80+
Generic type	Orthoscopic	Plossl	Plossl+, Erfle	Erfle, Wide Field	Nagler
Antares		Plossl, Elite Plossl		**Erfle, W70, Speers-Waler**	
Astro-Tech			Series 6, Paradigm	Titan, Titan II	
Baader/Zeiss	Ortho, Zeiss Abbe			Hyperion, Scopos	
Celestron		Omni Plossl, X-CEL		Ultima LX	Axiom LX
Coronado		CEMAX [1]			
Meade		4000 Plossl	5000 Plossl	**4000 QX, 5000 Super Wide**	**5000 Ultra Wide**
Orion		**Edge-On, Sirius, Epic Highlight, Ultrascopic**		Expanse, Stratus, Q70	
Pentax	XO			XL, XW	
Stellarvue		FMC Plossl		FMC Wide Field	
Takahashi		Long Eye Relief			
TeleVue		Plossl	Radian L.E.R.	Panoptic	Nagler, Ethos
TMB	Monocenetric [2]		Planetary		
University	Orthoscopic			Wide Scan 70	Wide Scan 80
Vernonscope	Brandon [3]				
Vixen	Lanthanum NLV	NLP Plossl		Lanthanum Wide LVW	
William Optics		SPL Planetary		SWAN	UWAN
Zhumel		Plossl, Super Plossl	SW Achromatic	Super Wide	

[1] WARNING: Use Coronado CEMAX eyepieces ONLY to view the Sun through Coronado solar telescopes.
[2] TMB products under review following passing of founder Thomas Back. [3] Questar markets Brandon oculars by Vernonscope.

Eyepieces with Largest True Field

- Eyepiece true field is determined by field stop diameter
  - Field stop limited by barrel diameter
    - **27mm for 1.25" eyepieces**
    - **46mm for 2.00" eyepieces**
- 1.25" eyepieces with 27mm field stop
  - 40mm TeleVue Plossl (43º AFOV)
  - 32mm TeleVue Plossl (50º AFOV)
  - 24mm TeleVue Panoptic (68º AFOV)
- 2.00" eyepieces with 46mm field stop
  - 55mm TeleVue Plossl (50º AFOV)
  - 41mm TeleVue Panoptic (68º AFOV)



- Wide apparent field eyepieces
  - Provide several benefits. . .
    - Spacious view => Wow factor!
    - Higher power darkens sky
    - Smaller exit pupil (less light loss for people with small eye pupils)
  - . . . but are expensive and bulky

Maximum True Field Examples (degrees)

Eyepiece Barrel Diameter	AP 105 Traveler 600mm	AP 155 EDFS 1100mm	Starmaster 16 w/Paracorr 2000mm	Celestron C14 3900mm
1.25"	2.5	1.4	0.8	0.4
2.00"	4.3	2.4	1.3	0.7

North America Nebula 2.0º	Double Cluster 1.0º	Moon 0.5º

Largest True Field and Exit Pupil

Type (TeleVue)	Focal **Length** fe (mm)	Barrel Diameter	AFOV (deg)	Field Stop* (mm)	Telescope Focal Ratio & Resulting Exit Pupil					
					F10	F8	F7	F6	F5	F4
Plossl	40	1.25”	43	27	4	5	5.7	6.7	8	10
Plossl	32	1.25”	50	27	3.2	4	4.6	5.3	6.4	8
Panoptic	24	1.25”	68	27	2.4	3	3.4	4	4.8	6
Plossl	55	2.00”	50	46	5.5	6.9	7.9	9.2	11	13.8
Panoptic	41	2.00”	68	46	4.1	5.1	5.9	6.8	8.2	10.2
Nagler	31	2.00”	82	42	3.1	3.9	4.2	5.2	6.2	7.8

Exit Pupil (ExP) = fe / F	
ExP less than 5mm (age 60)	5X/inch
ExP less than 7mm (age 25)	3.5X/inch
ExP greater than 7mm	<3.5X/inch

* **27mm** is largest field stop that fits in a 1.25” barrel (32mm)
46mm is largest field stop that fits in a 2.00” barrel (51mm)

Maximum True Field Examples (degrees)

Eyepiece Barrel Diameter	AP 105 Traveler 600mm	AP 155 EDFS 1100mm	Starmaster 16 w/Paracorr 2000mm	Celestron C14 3900mm
1.25”	2.5	1.4	0.8	0.4
2.00”	4.3	2.4	1.3	0.7

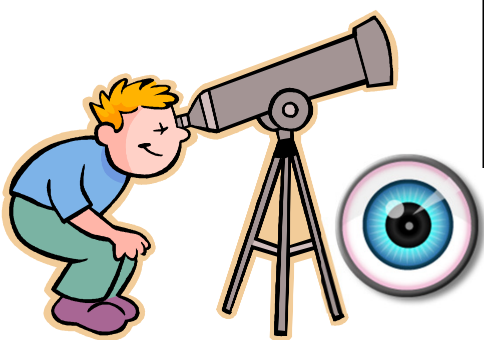
North America Nebula 2.0°	Double Cluster 1.0°	Moon 0.5°

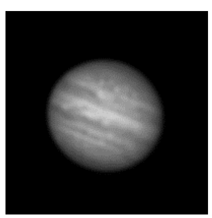
Eyepieces yielding exit pupils larger than the eye entrance pupil are still useable but some light from the telescope’s objective will be lost

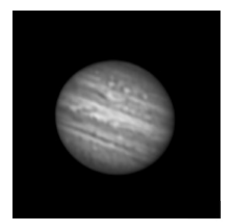
Notes for Glasses Wearers

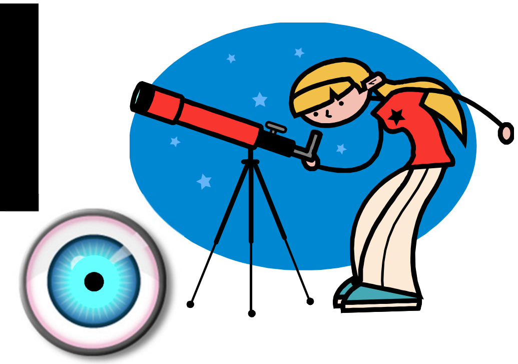
- Eye relief of ~ 20mm is needed to accommodate glasses
  - Focuser travel will accommodate distance correction provided by glasses
- Image quality of the eye depends on the diameter of the eye pupil
  - Large eye pupil diameters reveal eye aberrations such as astigmatism
  - Very small eye pupil diameters reveal defects such as floaters

- Most observers with astigmatism find they must wear their glasses when viewing at low powers and correspondingly large exit pupils.
  - Eye glasses correct for astigmatism but require long eye relief eyepieces
  - Corrective optics may also be used on the eyepiece, e.g. TeleVue Dioptrix
- Higher power eyepieces use a smaller portion of the eye, reducing the effects of astigmatism and eliminating need for glasses
  - If the eyepiece exit beam is small, only that much of the eye is used









— Source: Starizona.com web site

Choosing a Set of Eyepieces

- Range of magnifications (focal lengths)
  - Lowest power that fits in dark-adapted eye entrance pupil (3.5-5X/inch)
    - Large true field
    - Rich star fields and large star clusters
    - Large faint nebulae (w/OIII filter)
    - Low power leaves sky background bright
  - Selection of medium to high power eyepieces to fit budget (5-30X/inch)
    - Enough to darken sky but not badly impacted by atmospheric turbulence
    - Sweet spot for diffuse & planetary nebulae, globular & open star clusters, galaxies, Moon, planets, double stars
    - High power neither brightens nor dims stars because they are point sources
    - High power dims sky & extended objects
    - Renders small objects large enough to detect against background (see **OMVA**)
  - Highest power ~30-60X/inch (optional)
    - Magnify minimum resolvable detail to eye resolution threshold of > 1 arcmin
    - Moon, planets, close double stars
    - Higher powers useable for close doubles
    - Seeing usually limits maximum to 300-400X no matter how large the telescope
    - Exit pupils < 0.5mm reveal "floaters"
  - The "right" magnification is that which
    - Frames the object nicely
    - Reveals structure & detail
    - Makes faint object detectable (OMVA)

- Spacing eyepiece focal lengths
  - Fixed magnification ratio (~2.0)
    - Low cost Celestron Omni Plossl set: 32mm, 15mm, 9mm, 4mm
  - Fixed field area ratio (~1.7)
    - Expensive TeleVue Nagler set: 31mm, 22mm, 17mm, 13mm, 9mm, 7mm, 5mm, 3.5mm, 2.5mm
  - Barlow lens (typically 2X) may be used to fill in missing focal lengths
- Standard barrel diameter
  - 1.25"
  - 2.00"
- Apparent field of view
  - Wide AFOV eyepieces more pleasant but also more expensive!
- Eye relief
  - 20mm or so for glasses wearers, or. . .
  - Remove glasses for short eye relief
- Parfocal
  - Eyepieces focus at same extension of focuser drawtube
- Complex eyepieces correct aberrations on fast focal ratio telescopes
  - Paracorr may also be helpful
- Astigmatism corrector for low power eyepieces

— Sources: "An Eyepiece Primer," Al Nagler, *Sky & Telescope,* & "Choosing Eyepieces," Al Nagler, TeleVue.com

Astro-Physics 155 EDFS f7 Refractor			D = mm	F = mm	f ratio =	Faintest mag =	Airy disc = arcsec	Dawes = arcsec	Double apparent '	OTA weight	Personal eye pupil
			155	1092	7	13	1.8	0.75	4	24 lb	5
Eyepiece focal length		Power X	True field deg/min	Exit pupil mm	Effective D	Double @ Apparent	Power X / inch	TeleVue Type	Apparent field deg	Field stop mm	Eye relief mm
55	mm	20	2.4	7.9	99	12	3	Plossl	50	46	38
31	mm	35	2.2	4.4	155	6.9	6	Nagler 5	82	42	19
22	mm	50	1.6	3.1	155	4.8	8	Nagler 4	82	31.1	19
17	mm	64	1.3	2.4	155	3.8	10	Nagler 4	82	24.3	17
13	mm	84	55 '	1.9	155	2.9	14	Nagler 6	82	17.6	12
9	mm	121	39 '	1.3	155	2	20	Nagler 6	82	12.4	12
7	mm	156	31 '	1	155	1.5	26	Nagler 6	82	9.7	12
5	mm	218	22 '	0.7	155	1.1	36	Nagler 6	82	7	12
3.5	mm	312	15 '	0.5	155	0.8	51	Nagler 6	82	4.8	12
2.5	mm	437	11 '	0.4	155	0.5	72	Nagler 6	82	3.4	12

William Optics ZenithStar 66mm SD			D = mm	F = mm	f ratio =	Faintest mag	Airy disc = arcsec	Dawes = arcsec	Double apparent '	OTA weight	Personal eye pupil
			66	388	5.88	11.2	4.2	1.8	4	3.5 lb	5
Eyepiece focal length		Power X	True field deg/min	Exit pupil mm	Effective D	Double @ Apparent	Power X / inch	Type	Apparent field deg	Field stop mm	Eye relief mm
24	mm	16	4	4.1	66	15	6.2	Panoptic	68	27	15

Starmaster 16" f4.3 Reflector with TeleVue Paracorr 1.15X lens			D = mm	F = mm	f ratio w/ Paracorr	Faintest mag	Airy disc = arcsec	Dawes = arcsec	Double apparent '	Paracorr ratio	Personal eye pupil
			406	2000	4.9	15.1	0.7	0.3	4	1.15	5
Eyepiece focal length		Power X	True field deg	Exit pupil mm	Effective D	Double @ Apparent	Power X / inch	TeleVue Type	Apparent field deg	Field stop mm	Eye relief mm
55	mm	36	2.4	11.2	182	6.7	2	Plossl	50	46	38
31	mm	65	2.2	6.3	323	3.7	4	Nagler 5	82	42	19
22	mm	91	1.6	4.5	406	2.6	6	Nagler 4	82	31.1	19
17	mm	118	1.3	3.5	406	2	7	Nagler 4	82	24.3	17
13	mm	154	55 '	2.7	406	1.6	10	Nagler 6	82	17.6	12
9	mm	222	39 '	1.8	406	1.1	14	Nagler 6	82	12.4	12
7	mm	286	31 '	1.4	406	0.8	18	Nagler 6	82	9.7	12
5	mm	400	22 '	1	406	0.6	25	Nagler 6	82	7	12
3.5	mm	571	15 '	0.7	406	0.4	36	Nagler 6	82	4.8	12
2.5	mm	800	11 '	0.5	406	0.3	50	Nagler 6	82	3.4	12

Eyepiece Accessories

2” Barlow Lens with
1.25” Adapter

Focal Reducer &
Field Flattener
(photography)

TeleVue Paracorr
Coma Corrector
(fast Newtonians)

Adapter to use 1.25”
Eyepieces in 2” Focuser

2” Mirror Diagonal with
Dielectric Coatings

Eyepiece Diopter Corrector
for Eye Astigmatism
(low power eyepieces)

Filters
(discussed
separately)

Binoviewer

— Sources: TeleVue.com
Astronomics.com

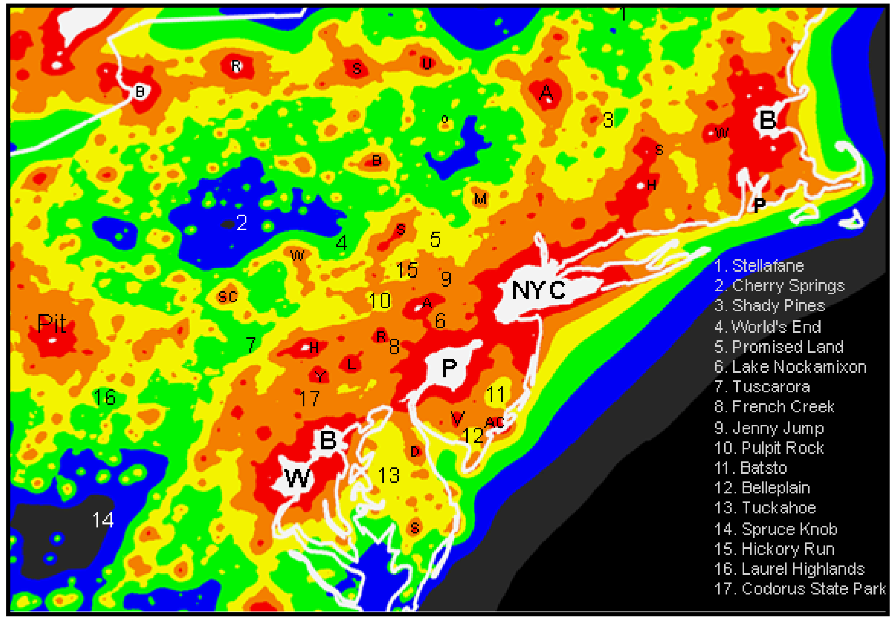
Outline

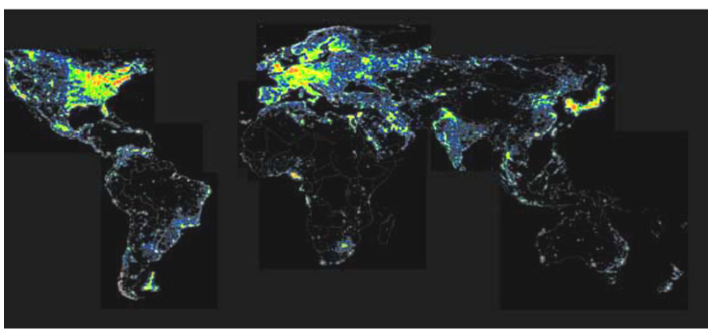
- Telescope Basics
- The Eye & Vision
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

Night Sky Background Brightness

Night Sky Brightness	$(m/a\text{-}s^2)$
Moon surface	3.4
Mars surface	3.9
Horizon, overcast	5.0
Jupiter surface	5.2
Saturn surface	6.8
Heavy daytime overcast	8.0
Horizon 15 min after sunset	13.0
Earthshine on Moon	14.5
Flagstaff AZ (full moon)	18.0
Mount Wilson	19.8
Lowell (Mars Hill, AZ)	20.5
Palomar Mountain	21.5
Siding Spring (Australia)	21.8
Darkest night sky at zenith	22.0

– Source: “How Dark Can the Night Sky Get,” Brian Skiff, 1996-2001; “Measurements Of The Surface Brightness Of The Earthshine . . .”, Pilar Montanes-Rodriguez, Enric Palle and P. R. Goode, *The Astronomical Journal*, Sept 2007; R.N. Clark; *Visual Astronomy*





– Image Credits: P. Cinzano, F. Falchi (University of Padova), C. D. Elvidge (NOAA National Geophysical Data Center, Boulder). Copyright Royal Astronomical Society. Reproduced from the *Monthly Notices of the RAS* by permission of Blackwell Science.

“Yellow indicates an artificial sky brightness equal to the natural so that the total sky brightness is doubled.

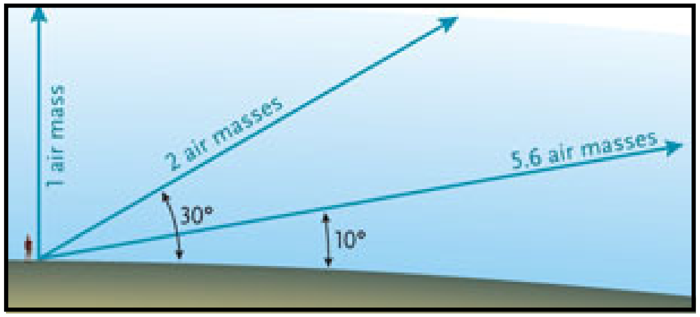
Orange level indicates areas where the milky way is invisible or quite difficult to see by an average observer in normal clear nights.

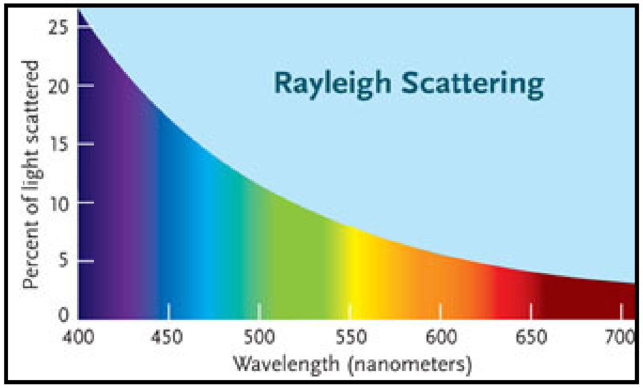
Red areas indicates zones where very approximately one hundredth of stars, or few more, is visible over 30 degrees of elevation.

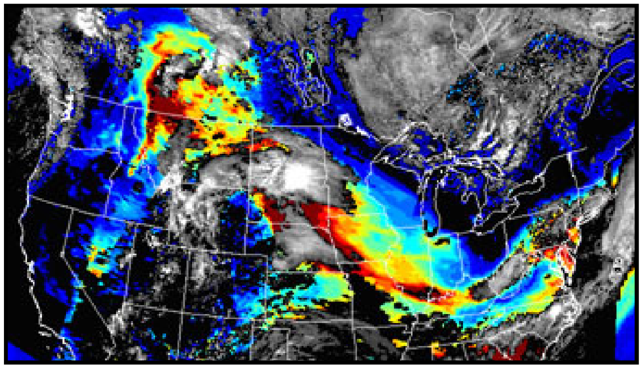
Blue border indicates artificial sky brightness over 10% than the natural brightness which is the definition of ‘light polluted sky’.”

Atmospheric Transparency

- Atmospheric light loss is reported in terms of loss per "airmass"
  - One airmass is the amount of air over a sea level observer looking straight up
  - Away from zenith but not near horizon, total airmass ≈ 1/sin(altitude)





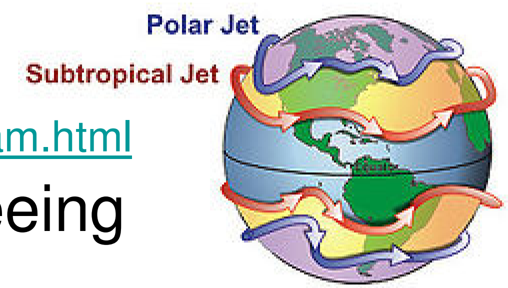


— Source: "Transparency and Atmospheric Extinction" Tony Flanders and Phillip J. Creed, *Sky & Telescope*, June 10, 2008

- Light loss due to three types of phenomena
  - Rayleigh scattering, which also brightens the sky
    - Reduces brightness of star directly overhead by 0.145 magnitude per air mass at 510nm
  - Absorption by ozone
    - Ozone reduces by 0.016 magnitude per air mass
  - Absorption by aerosols, e.g. water vapor, smoke, pollen, smog, etc.
    - Aerosol optical depth (AOD) varies from < 0.1 (excellent) to 0.5 (hazy and very bad)
    - For AOD =0.2 (OK night in Eastern US), brightness loss is 0.24 per air mass
  - Total loss from all sources (Eastern US example): 0.145 + 0.016 + 0.24 = 0.4 magnitude per air mass
  - Downloadable Excel spreadsheet calculator at http://media.skyandtelescope.com/documents/Stellar-Extinction-Model-V3.0.xls

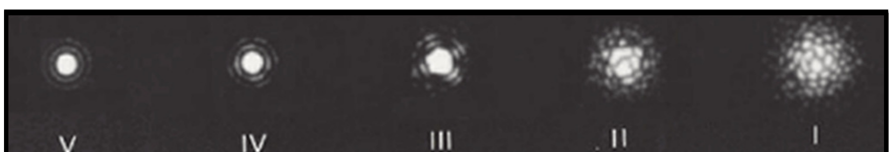
Atmospheric Seeing

- Seeing is perturbations in the atmosphere due to high frequency temperature fluctuations and mixing of air parcels of different temperatures and densities.
  - Low altitude (0-300ft): local convection currents from natural and artificial sources (telescope cooling also disturbs images)
  - Mid-altitude (300ft-1 mile): turbulence caused by topography upwind from observing site
  - High altitude (>1 mile): jet stream effects
    - http://www.wunderground.com/US/Region/US/JetStream.html



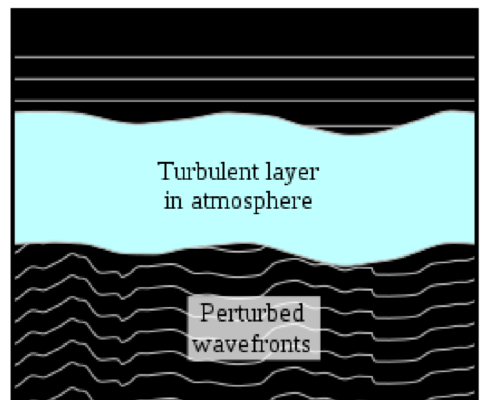
- Heavily twinkling of stars indicates poor seeing
  - Seeing is worse when a cold front passes through
  - Seeing is worse in winter and better in summer
    - Transparency is usually just the opposite
  - Seeing is worse in periods of high wind

– Source: "The Atmosphere & Observing," Damian Peach, *Astronomy Now*, 2003



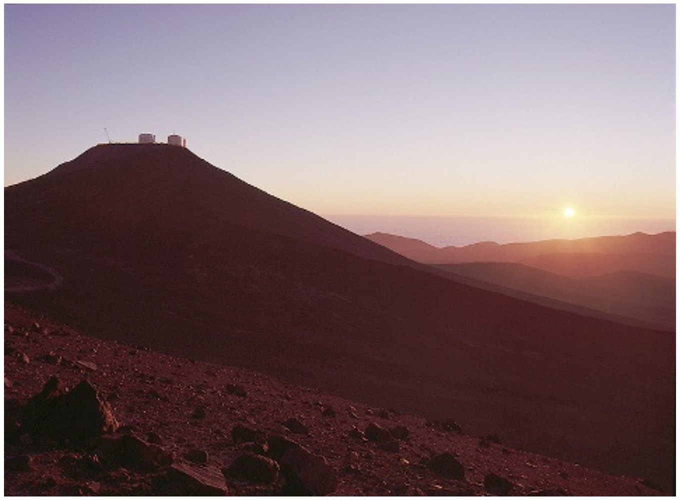
Seeing on a scale of 1 to 5

— Source: Gary Ayton Photography

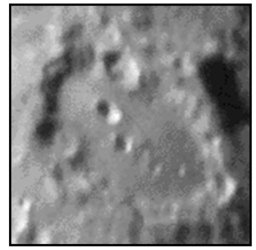


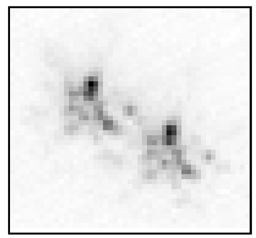
– Source: Wikipedia

Seeing Examples

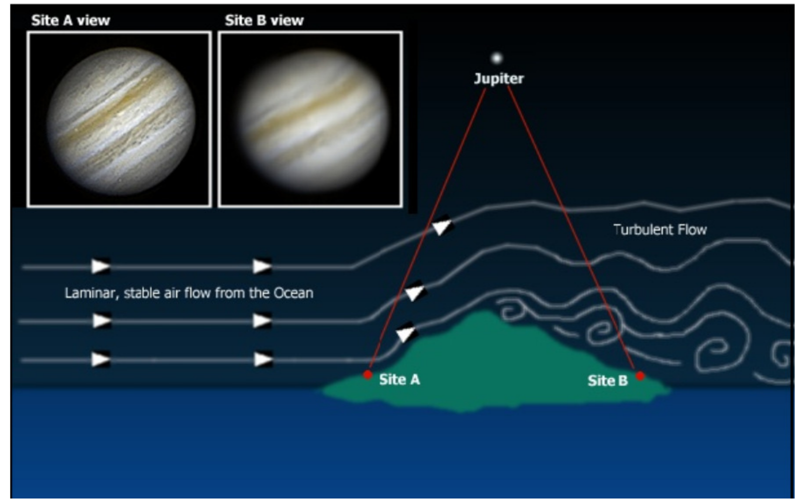


– Cerro Paranal, "The Atmosphere & Observing," Damian Peach

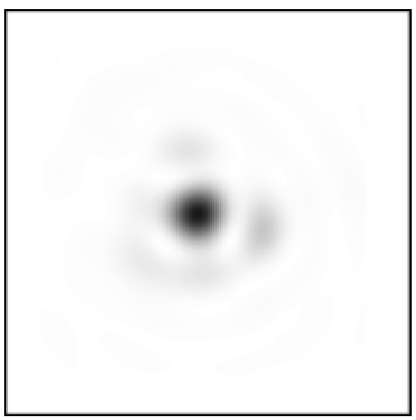




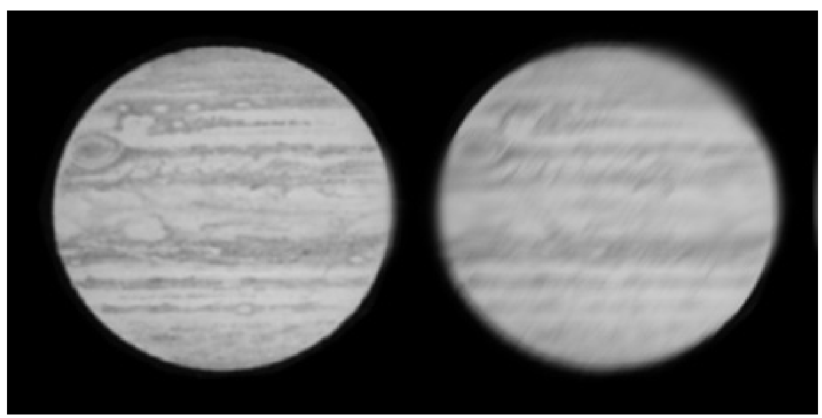
– Source, Wikipedia



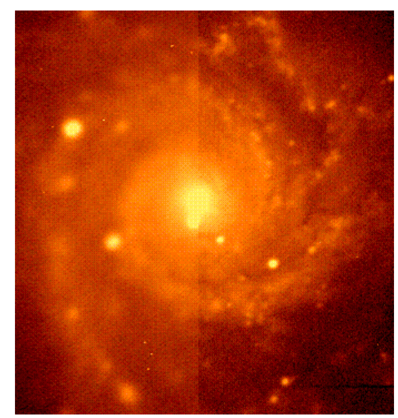
– "The Atmosphere & Observing," Damian Peach



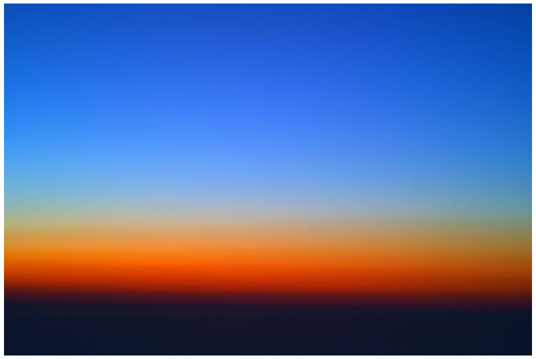
– Source, Wikipedia



– "The Atmosphere & Observing," Damian Peach



Atmospheric Phenomena



Rayleigh scattering – the scattering of light by particles smaller than the wavelength of light. It makes the sky blue.

Aurora – a phenomenon produced by collision of charged particles with the earth's outer atmosphere.

Green flash – a phenomenon seen at sunrise or sunset, produced by refraction of different frequencies of light by different amounts.

Sun Dogs (parhelion) – an optical effect resulting from refraction of sunlight by ice crystals in cirrus or cirrostatus clouds; located at 22 degrees from the sun.

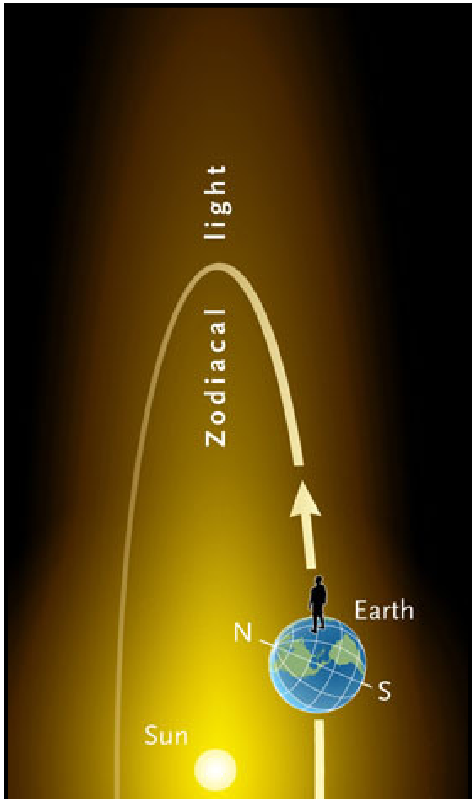
Moon Dogs, or ring around the moon – similar to sun dogs. On rare occasions a second halo can be seen at 46 degrees.

– Source, Wikipedia

Circumhorizon arc – an optical effect caused by refraction of sunlight by thick flat ice crystals in cirrus clouds. Can be observed only beyond ±55 deg latitude.

Zodiacal Light and Gegenschein

The ***zodiacal light*** is a faint, roughly cone-shaped, whitish glow seen in the night sky which appears to extend up from the vicinity of the sun some 20-30 degrees along the ecliptic or zodiac, best seen about two hours before sunrise (fall) or after sunset (spring).



Zodiacal light is caused by dust particles in the plane of the ecliptic.
– Source: Sky & Telescope

First explained by Cassini in 1683, it is caused by sunlight reflecting off dust particles in the plane of the ecliptic, extending out beyond the orbit of Mars.

The zodiacal light can approach the brightness of the Milky Way. Accompanying it is a far fainter complete ring around the ecliptic, the ***zodiacal band***.


Zodiacal light in the eastern sky before the beginning of morning twilight.
– Source: Wikipedia

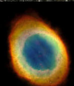
There is also a very faint, slightly increased counterglow opposite the Sun called the ***gegenschein***.

— Source: Space.com

Outline

- Telescope Basics
- The Eye & Vision
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

Seeing the Night Sky. . .

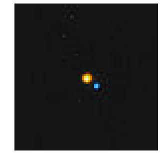
Image	Object	Brightness	Vision	Contrast	Resolution	Power
	Moon	Bright	Photopic	Mostly High	High	High
	Planets	Bright	Photopic	Low	High	High
	Comets	Faint	Scotopic	Low	Low	Low - Med
	Double stars	Bright	Photopic	High	High	High
	Rich star fields	Faint	Scotopic	Medium	High	Low
	Open clusters	Bright-Faint	Photopic - Scotopic	High	Low - High	Low - Med
	Globular clusters	Faint	Scotopic	Med - High	High	High
	Planetary nebulae	Faint	Scotopic	Low	Low	Med - High
	Diffuse nebulae	Faint	Scotopic	Low	Low	Low - Med
	Dark nebulae	Dark	Scotopic	Very low	No detail	Low - Med
	Galaxies	Faint	Scotopic	Low	Low	High

— Source images: Wikipedia

Observing Double Stars

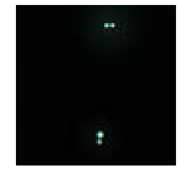
- Double stars were once very popular but have fallen out of favor except for spectacular pairs such as:
  - Mizar, a naked-eye double for sharp-eyed observers
  - Albireo, a spectacular orange and blue pair
  - Epsilon Lyra, the famous “double-double”
  - Trapezium, in the Great Nebula of Orion, M42

Mizar-Alcor



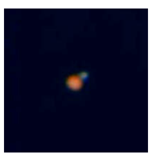
Albireo

Trapezium

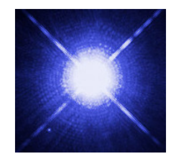


Epsilon Lyra (not to scale)

- Nevertheless, they are fun and great tests of visual acuity
- Suggestions for observing double and multiple stars
  - Pick a night when diffraction rings are stable and well defined
  - Nearly equal magnitude doubles are easier to split
    - Very bright primaries make companion difficult to see
  - Be prepared to use high magnification for close doubles
    - Dawes limit is realistic under ideal conditions for equal mag = 6 pairs
    - Even closer doubles can show “elongation”
      - Try to estimate position angle before checking data
    - Below about mag = 8, vision begins to transition from photopic to scotopic and eye resolution ability drops

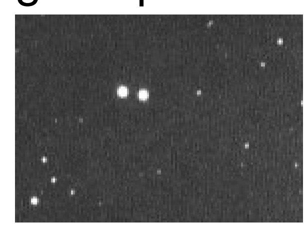


Gamma Andromedae



Sirius

Airy Disk



Messier 40

— Source images: Wikipedia

Observing Star Clusters

- Open clusters are among the most beautiful and easiest to observe of deep sky objects
  - Open clusters form from a single initial molecular nebula and consist of a dozen or so to a few hundred stars, often still in nebula
  - They are only loosely bound gravitationally and eventually dissipate
  - The best magnification is that which frames the cluster while leaving some space around it
- Globular clusters are among the most spectacular!
  - Globular clusters contain from several thousand to a million or more stars and are among the oldest objects in the galaxy
  - The Milky Way contains about 200, mostly in the galactic halo
  - The magnification guideline is similar to that for planets – use the highest magnification that the atmosphere allows

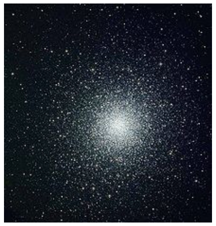
M45 Pleiades

M 11

NGC 346

M15

M 13

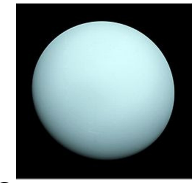


M92

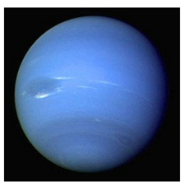
M80

— Source images: Wikipedia

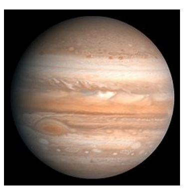
Observing the Planets



- Even though planets are relatively bright, seeing surface detail is surprisingly difficult
  - Much of the detail is low contrast and/or small in size
    - Detail is at the limit of contrast discrimination and eye resolution
  - Seeing detail requires high magnification, which stresses optics
  - Detail is especially subject to disruption by atmospheric turbulence
- Suggestions for planetary observing



  - Use high enough power to “comfortably” resolve available detail
    - Usually at least 150X for scopes big enough to use it
  - Use the highest power that the atmosphere allows
    - Rarely more than 300-400X no matter how big the telescope

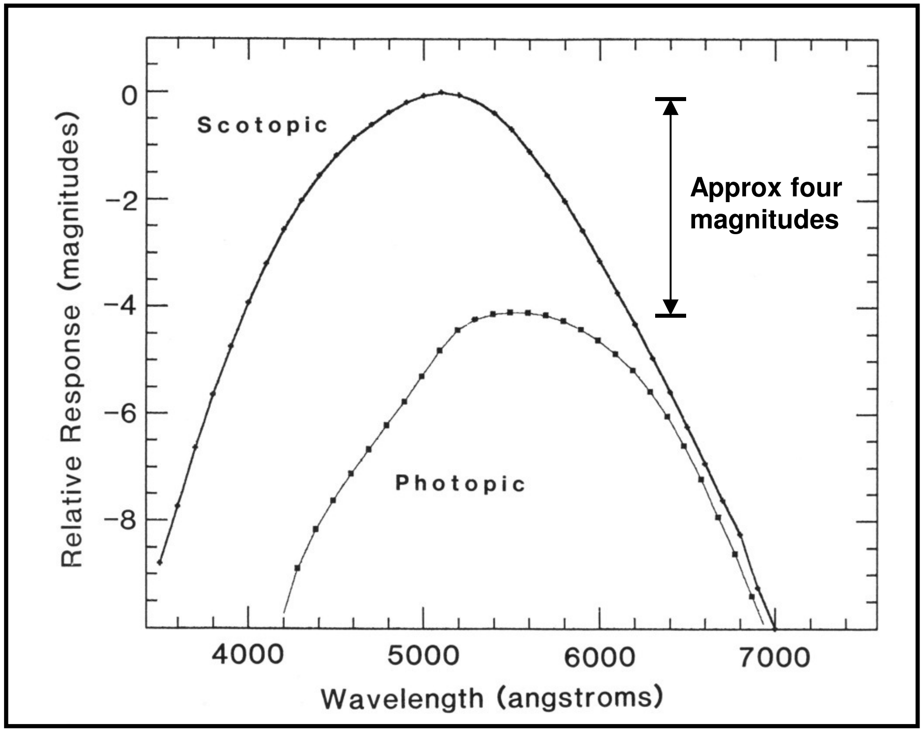


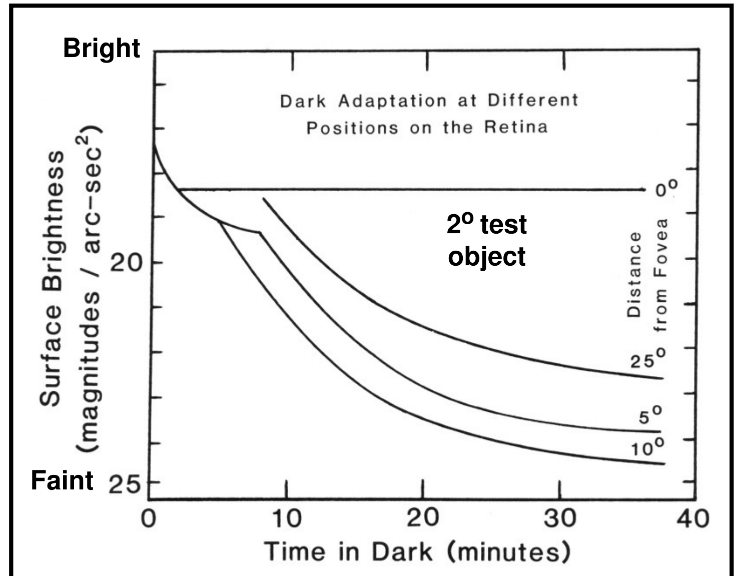
  - View planets with patience over a long time
    - Wait for those rare moments when the atmosphere steadies down
    - Views are often best in summer and on hazy nights

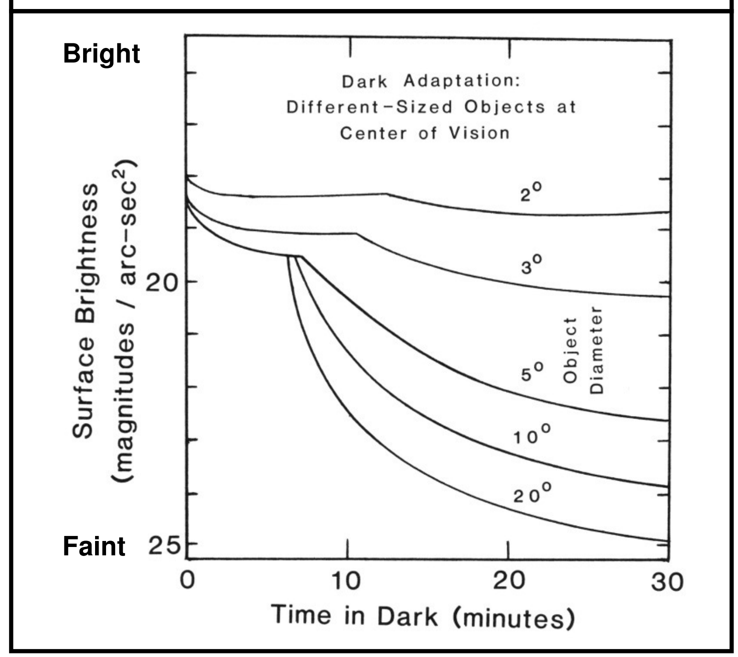
  - Try color and planetary bandpass filters
    - They probably won’t help much – but they might!!
  - Buy a refractor or a bigger scope!

— Source images: Wikipedia

More on Seeing Faint Objects







<u>*Conclusions*</u>

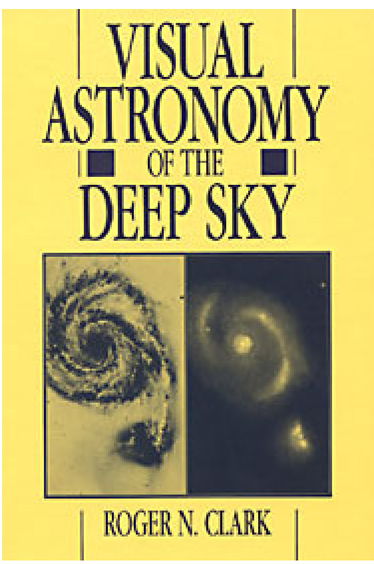
- Rods more sensitive to low light by 4 magnitudes
- Greatest sensitivity occurs at 8-16º from fovea
- Eye dark adapts to large objects better than small
- Factors that influence visibility of faint objects
  - Background brightness, object brightness, apparent size, dark adaptation, location of image on retina

— Source: *Visual Astronomy of the Deep Sky,* Roger N. Clark, Cambridge University Press, 1990, from Crossier & Holway (1939); Middleton (1958); Hecht et al (1935) after Bartley (1951)

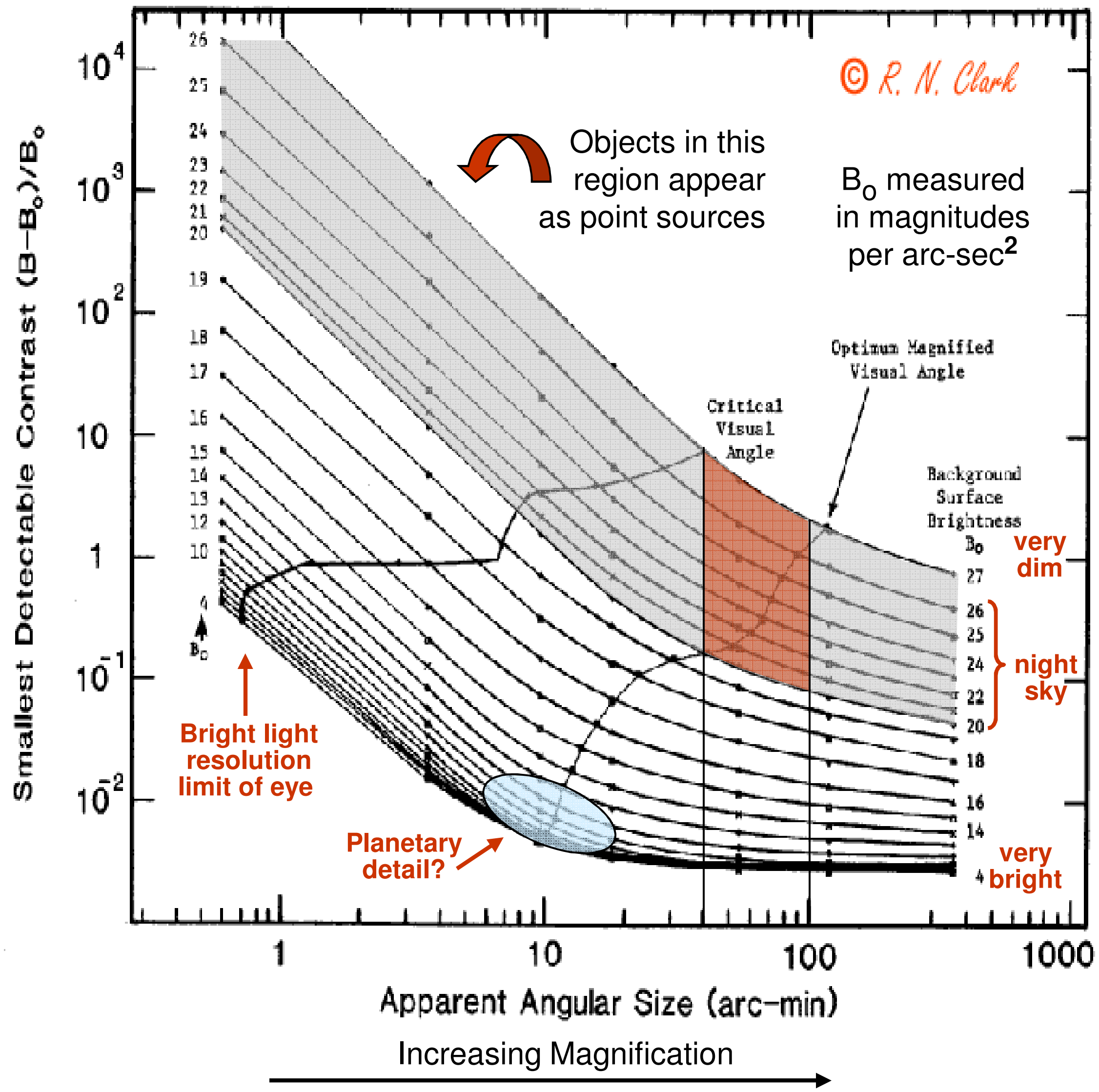
Optimum Magnified Visual Angle

Based on Blackwell's research, Roger N. Clark states in *Visual Astronomy of the Deep Sky* that there is an ideal magnification for visual detection of faint objects, defined by what Clark calls the **optimum magnified visual angle.**

"The OMVA for very faint objects is on the order of 0.5 to 1.5 degrees. . .more than 100 arc-min at the faint end."



"Against the very dim night-sky background seen in a telescope (fainter than 25 magnitudes per square arc-sec), a large object must have a contrast of nearly 1.0, and a small object more than 100, to be *detected."*

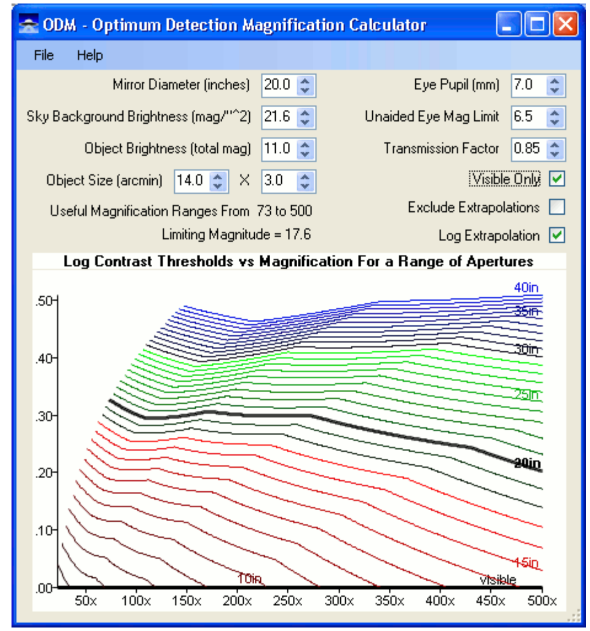


— Source: *Visual Astronomy of the Deep Sky,* Roger N. Clark, 1990
& *http://www.clarkvision.com/visastro/omva1*

Optimum Detection Magnification

Comparisons	Typical 8"	12.5" f/5 Obsession	15" f/4.5 Obsession	18" f/4.5 Obsession	20" f/5 Obsession	20" f/4 Obsession	25" f/5 Obsession	25" f/4 Obsession
Light gathering power over typical 8" Schmidt-Cassegrain	-	2.5X	4X	5X	6X	6X	10X	10X
Limiting stellar magnitude:	14.0	15.0	15.5	16.0	16.5	16.5	17	17
Rayleigh Resolution Limit:	0.68 arc seconds	0.38 arc seconds	0.36 arc seconds	0.31 arc seconds	0.27 arc seconds	0.27 arc seconds	0.22 arc seconds	0.22 arc seconds
Contrast limit: (minimum diameter before a nebular object fades from view)	11 arc minutes	6.0 arc minutes	5.7 arc minutes	4.8 arc minutes	4.3 arc minutes	4.3 arc minutes	3.4 arc minutes	3.4 arc minutes

— Source: Obsession Telescopes web site



Optimum Detection Magnification Calculator

— Source: Mel Bartels, http://www.bbastrodesigns.com/dnld/odm.zip

Magnification for detection of faint deep sky objects			
Aperture	Small Low Surf. Bright.	Small High Surf. Br.	Large
Example	Galaxies	Planetaries	Diffuse nebulae
Mag. Rule	Moderate power	High power	Low power
6"	150-250x	400-600x	25-40x
8"	100-200x	300-500x	30-50x
12"	80-150x	200-400x	45-60x

— Source: Starizona.com web site

Note that the recommended power for small objects in small scopes is well beyond the normally quoted 50X per inch maximum magnification

Klein Visibility Class

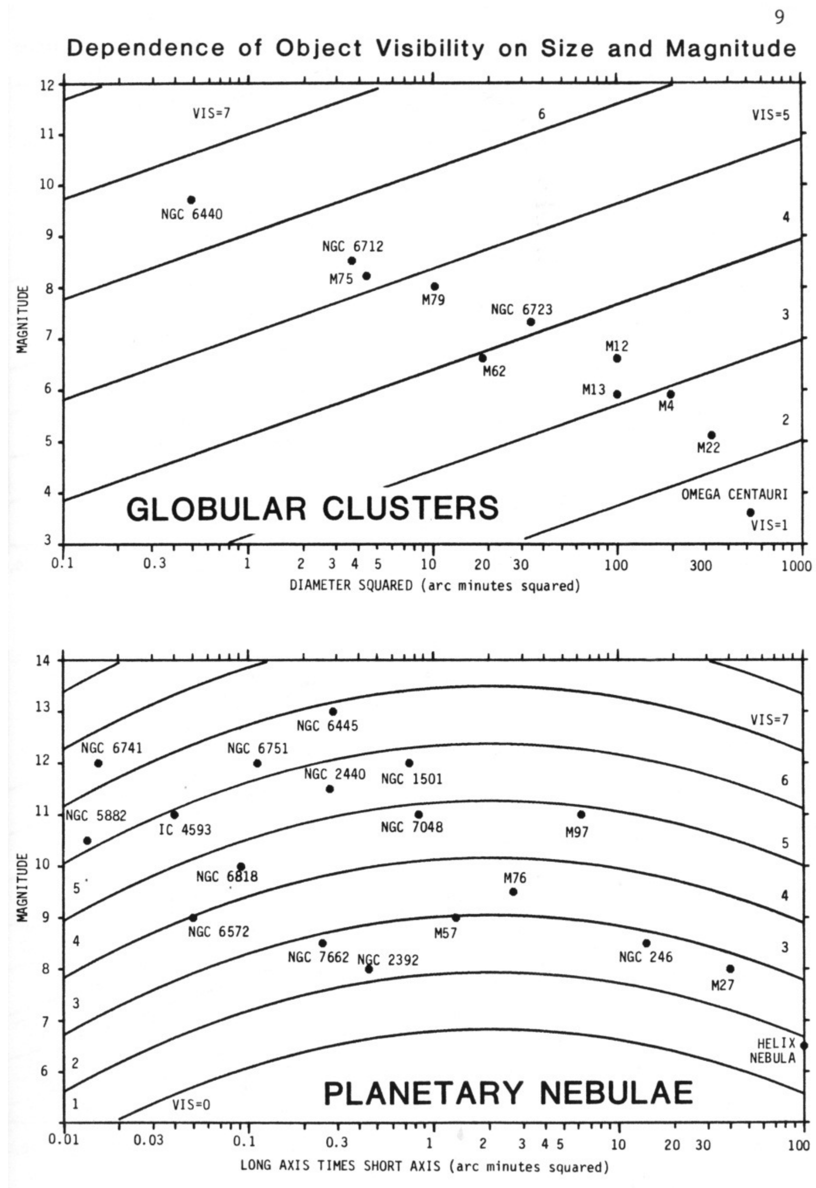
Visibility Class (V) of Night Sky Objects

Galaxies	V = 1.156 m – 8.30 + 0.928 log AB
Diffuse Nebulae	V = 1.140 m – 8.62 + 1.430 log AB
Globular Clusters	V = 0.510 m – 1.39 + 1.300 log AB
Open Clusters	V = 0.500 m – 2.50 + 0.840 log AB
Planetary Nebulae	V = 0.900 m – 5.15 + log AB – 0.3
Red Stars	V = 0.5 m – 1.00
Double Stars	Relates log (sep) vs mag diff squared

A, B = long, short dimensions of object (arc-min)

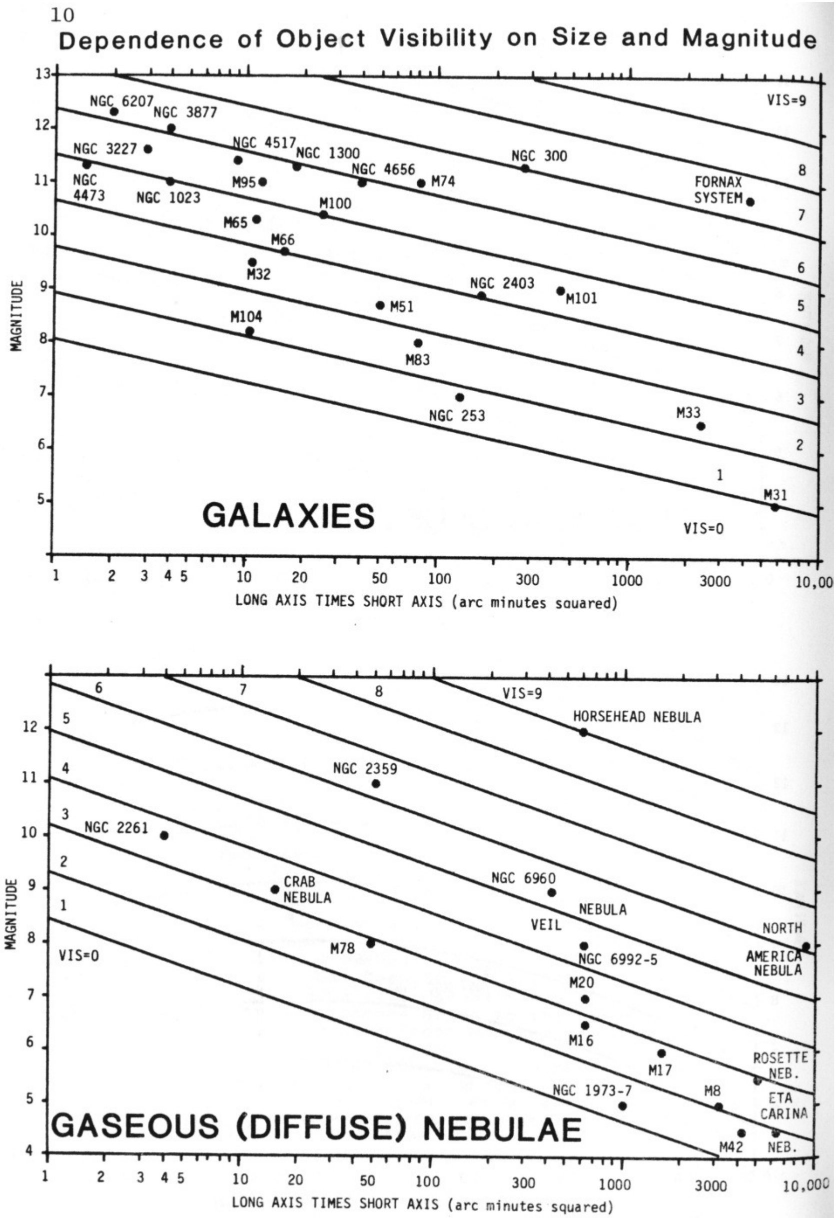
V = 0 - 2	Very easy
V = 3 - 4	Easy
V = 5 - 6	Moderate
V = 7 - 8	Difficult
V = 9	Very difficult

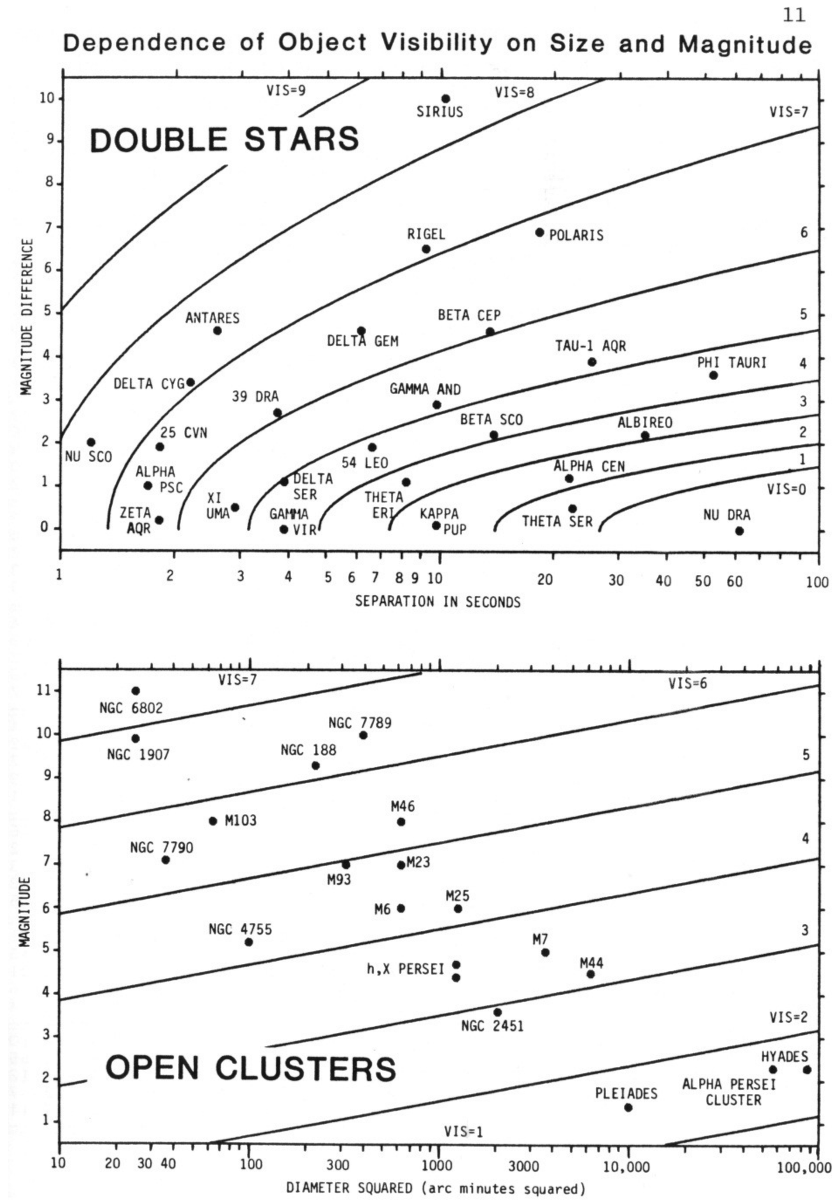
— Source: *The Visibility of Deep Sky Objects,* Fred Klein, 1981; Expanded from an article by Peterson, *Sky & Telescope*, Nov. 1980



Klein visibility class combines deep sky object magnitude and area, creating a function of surface brightness which is then “binned” into a number between 0 and 9 for simplicity.

Klein Visibility Class (cont.)





— Source: *The Visibility of Deep Sky Objects,* Fred Klein, 1981

Bandpass and Attenuating Filters

Filters limit admitted light to a selected frequency range. They reduce the amount of transmitted light and thus object brightness. However, they increase object visibility by darkening the sky background more than the objects for which they are designed or by increasing contrast.

Nebula Filters

Optimum Exit Pupil for Nebula Filters				
Filter Type	**Deep Sky**	**UHC**	**OIII**	**H-Beta**
Bandpass	90nm	22-26nm	10-12nm	8-10nm
Light-polluted sky	0.5-2mm	1-4mm	2-5mm	3-7mm
Dark sky	1-4mm	2-6mm	3-7mm	4-7mm

— Source: Lumicon.com

Color Filters
(Lunar and Planetary)
— Source: Lumicon.com

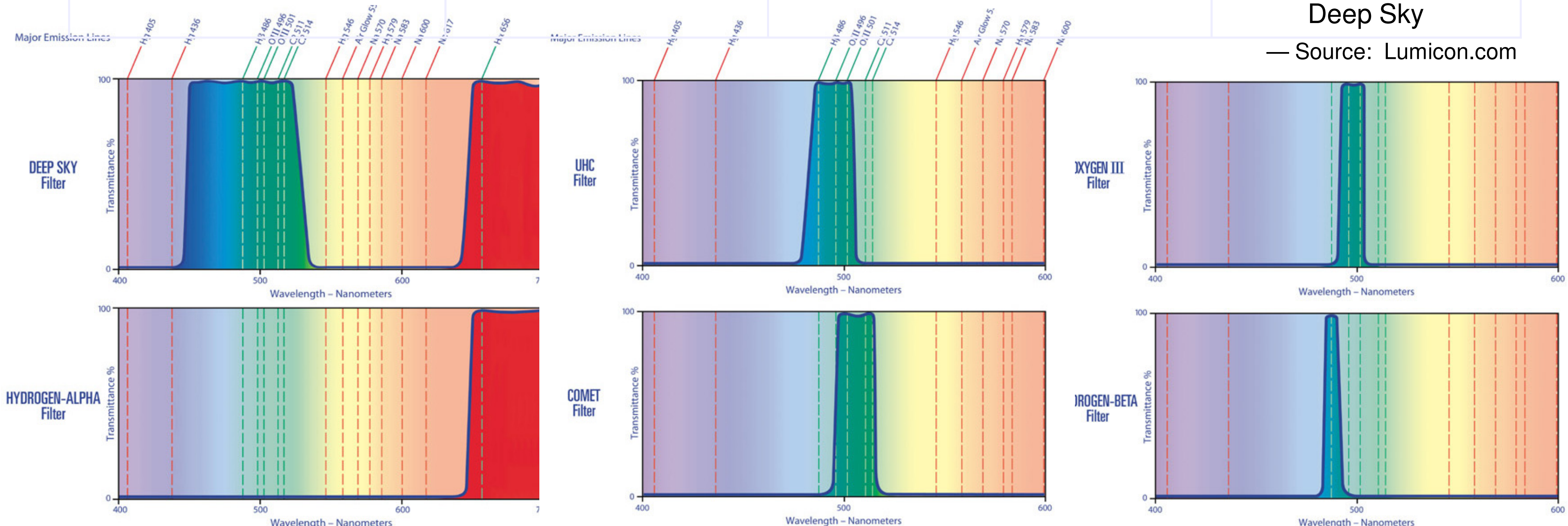
White Light Solar Filters (Mylar)
— Source: KendrickAstro.com

Solar H-Alpha Telescopes and Filters
— Source: CoronadoFilters.com

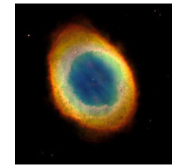
Bandpass Filter Characteristics

Objects	Examples	Best Filter for Viewing	Best Filter for Photography
Stars & Star Clusters	M13, M11	None	Deep Sky
Diffuse Nebulae	Lagoon, Swan	OIII (light polluted sky) Deep Sky, UHC (dark sky)	Deep Sky
Planetary Nebulae	Dumbbell, Ring	OIII (light polluted sky) Deep Sky, UHC (dark sky)	Deep Sky
Faint Planetary Nebulae	NGC 7293, Abell 33	OIII	Deep Sky
Reflection Nebulae	Pleiades, Trifid	Deep Sky	Deep Sky
Spiral Galaxies	M33, M101	None	Deep Sky
Faint Nebulae	Veil, Rosette, N. American, Pelican	OIII (light polluted sky) Deep Sky, UHC (dark sky)	Deep Sky
Extremely Faint Nebulae	California, Horsehead	H-Beta	Night-Sky H-Alpha Deep Sky

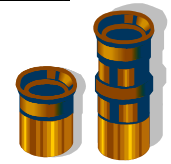
— Source: Lumicon.com



Observing Faint Extended Objects



- Use magnification consistent with Roger Clark's OMVA
  - High power magnifies object enough for detection: 0.5° to 2.0°

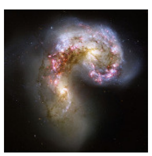


- Wait until eyes are fully dark adapted
  - 30-40 minutes for photo-chemical changes
  - Use eye patch or keep eye in darkness for several minutes

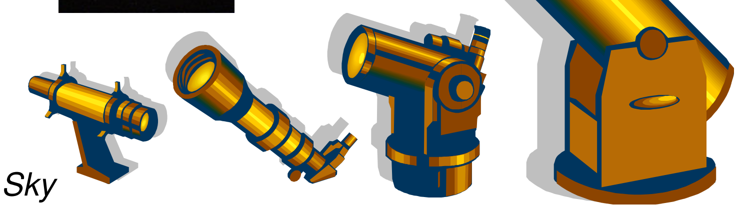
- Use averted vision
  - Place object 15-20° from center on nasal side
  - Allow light to build up for 5-10 seconds

- Use filters
  - LPR filter for light polluted skies
  - OIII filter for large faint nebulae & some planetaries
  - H-Beta filter for California, Horsehead and Cocoon Nebulae

Nebula Filters



- Get a bigger telescope!!
  - When it comes to faint fuzzies, aperture fever rules for a good reason!



Outline

- Telescope Basics
- The Eye & Vision
- Eyepiece Essentials
- Atmosphere & Sky
- Observing the Sky
- Sources & References
- Questions & Answers

Sources and References

- *Visual Astronomy of the Deep Sky,* Roger N. Clark, 1990, Cambridge University Press
  - http://www.clarkvision.com/visastro/omva1 —science of observing faint deep sky objects
- *Amateur Astronomer's Handbook*, Sidgwick Extensive discussion of optics and seeing
- "How Dark Can the Night Sky Get," Brian Skiff, *Sky & Telescope*, 1996-2001
- Sky & Telescope Magazine, May 1992 — eye pupil and age
- *Event Horizon Newsletter*, April 1996, Hamilton Amateur Astronomers — eye pupil
- http://labbey.com/Articles/Limits/Limits.html — "The Limits of Telescopic Performance
- http://www.opticalmechanics.com/technical_articles/coating_primer.html — mirror coatings
- http://www.orion-xt10.com/dark-adapted-averted-vision.html — averted vision
- http://en.wikipedia.org/wiki/Fovea — description of the eye
- http://hyperphysics.phy-astr.gsu.edu/hbase/vision/rodcone.html — rods & cones
- http://amateurastronomy.org/EH/Apr96.PDF — Exit pupil vs age
- http://www.ayton.id.au/gary/Science/Astronomy/Ast_viewing.htm — good outline
- http://www.mapug-astronomy.net/AstroDesigns/MAPUG/VisualDet.htm — more on OMVA
- http://www.bbastrodesigns.com/visual.html — Mel Bartels on deep sky
- http://www.bbastrodesigns.com/blackwel.html — Nils Olaf Carlin on deep sky
- http://www.cityastronomy.com/contrast.htm — contrast transfer
- http://www.normankoren.com/Tutorials/MTF5.html — Norman Koren, Understanding image sharpness
- http://www.astropix.com/HTML/L_STORY/SKYBRITE.HTM — Sky brightness Brian Skiff
- http://starizona.com/acb/basics/equip_telescopes_makcass.aspx — scope types
- http://www.go.ednet.ns.ca/~larry/astro/maglimit.html — mag limit calculator
- http://www.ncbi.nlm.nih.gov/books/bv.fcgi?call=bv.View..ShowSection&rid=neurosci.section.751 — neurology of the eye, *NeuroScience*, 2nd Edition, Dave Purves, David Fitzpatrick, Mark Williams, James McNamara, George Augustine, Lawrence Katz
- http://www.skyandtelescope.com/howto/visualobserving/19712459.html — "Transparency & Atmospheric Extinction," Sky & Telescope, June10, 2008

References and Sources

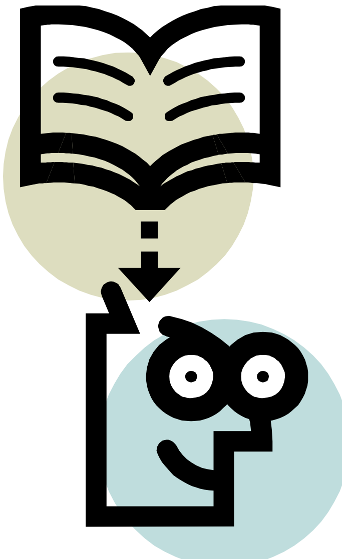
- http://photo.net/learn/optics/mtf/ — Photo.net on MTF
- http://www.normankoren.com/Tutorials/MTF.html — Norman Koren on MTF
- http://www.company7.com/books/products/testing.html
  - Harold Suiter, *Star Testing Astronomical Telescopes*
- http://www.telescope-optics.net/index.htm — extensive discussion of optics
- http://webvision.med.utah.edu/ — John Moran Eye Center, University of Utah
- http://www.hoflink.com/~mkozma/obstruction.html — central obstruction
- http://www.laughton.com/paul/rfo/obs/obs.html — central obstruction
- http://members.csolutions.net/fisherka/astronote/astromath/ueb/Unequalbinaries.html — double star resolution
- http://www.quadibloc.com/science/opt04.htm — many eyepiece schematics!
- http://www.brayebrookobservatory.org/BrayObsWebSite/HOMEPAGE/BRAYOBS%20PUBLICATIONS.html — history of eyepieces!
- http://televue.com/engine/page.asp?cat=2 — TeleVue eyepiece articles
  - "An Eyepiece Primer" and "Choosing Eyepieces" (from *Sky & Telescope),* Al Nagler
- http://Starizona.com — astronomy with eyeglasses
- http://www.skyandtelescope.com/howto/visualobserving/19712459.html — transparency and atmospheric extinction
- http://www.dustymars.net/Observing_Mars_8.html — seeing & transparency
- http://homepage.ntlworld.com/dpeach78/seeing2002.htm — seeing conditions
- http://www.damianpeach.com/seeing1.htm — seeing conditions
- www.starlight-theatre.ca/WHIZ-DOC.PDF -- surface brightness of planets, etc.
- *The Visibility of Deep Sky Objects,* Fred Klein, 1981
- http://solar.njit.edu/preprints/montanes1375.pdf "Measurements Of The Surface Brightness Of The Earthshine With Applications To Calibrate Lunar Flashes," Pilar Montanes-Rodriguez, Enric Palle and P. R. Goode, *The Astronomical Journal*, Sept 2007

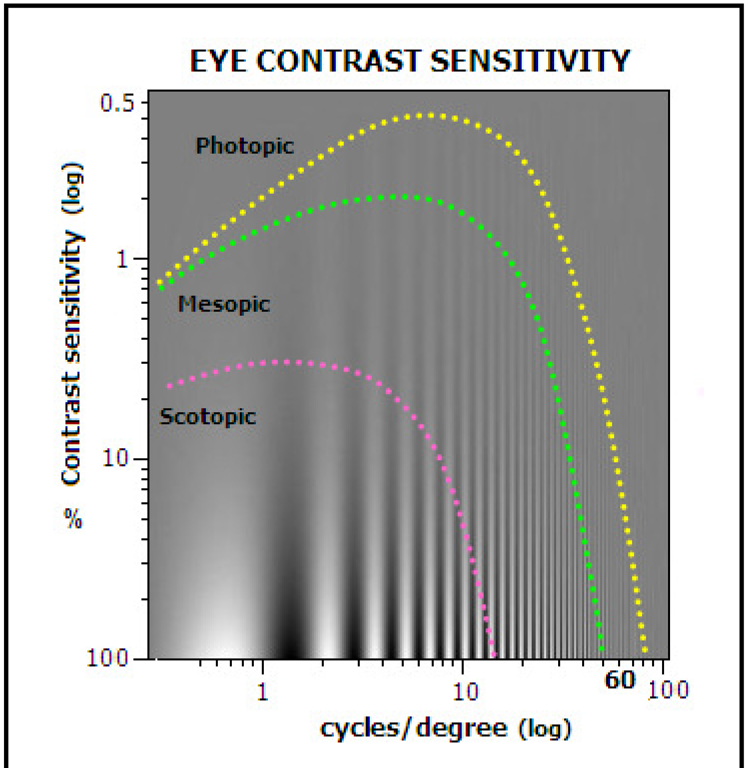
Final Thoughts

The key to enjoyment is to learn the sky, your scope and your personal capabilities. Even a modest telescope of less than outstanding quality can give a lifetime of enjoyable service.

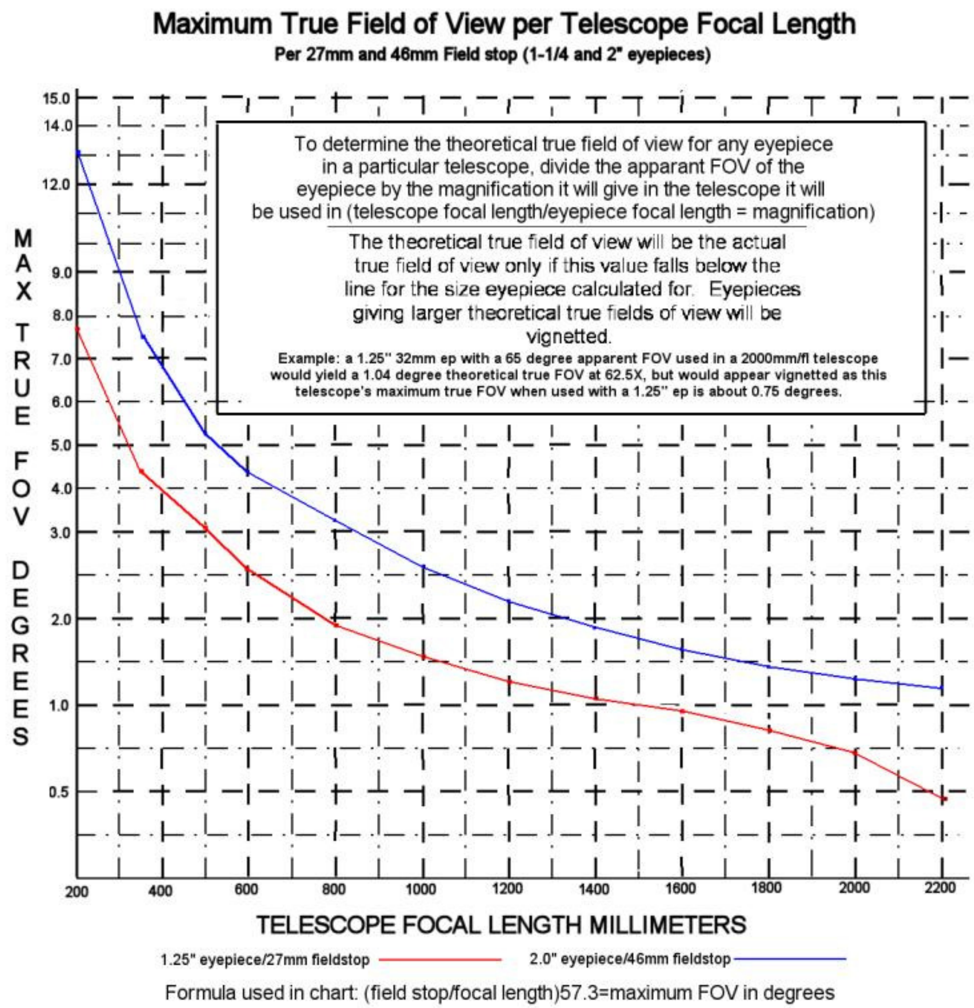
Star parties are a great place to share information and get hands-on help with learning the sky and how to use your scope and accessories.

Questions & Answers





Eye contrast sensitivity
— Source: Telescope-Optics.net



— Source: Whitepeak Lunar Observatory