ASTR 2401

Telescopes

Observational Astronomy

Important Dates Coming Up

- Lab Notebooks due this Friday by 5pm
- Project Proposals due next Tuesday, October 4th in class
- Midterm Tuesday, October 11th

Labs This Week

- Observing Labs Start at 7:30
- Thursday Classroom Lab just like normal
- I need a volunteer to come at 7:00 to help me set up
- Tuesday night make sure you make a finder chart if you haven't already!
  - Thursday group, any tips for the Tuesday group?
- If observing is canceled on Thursday there will not be a classroom lab due to the football game

Optics & Telescopes

Aberrations

Telescope Characteristics

Telescope Types

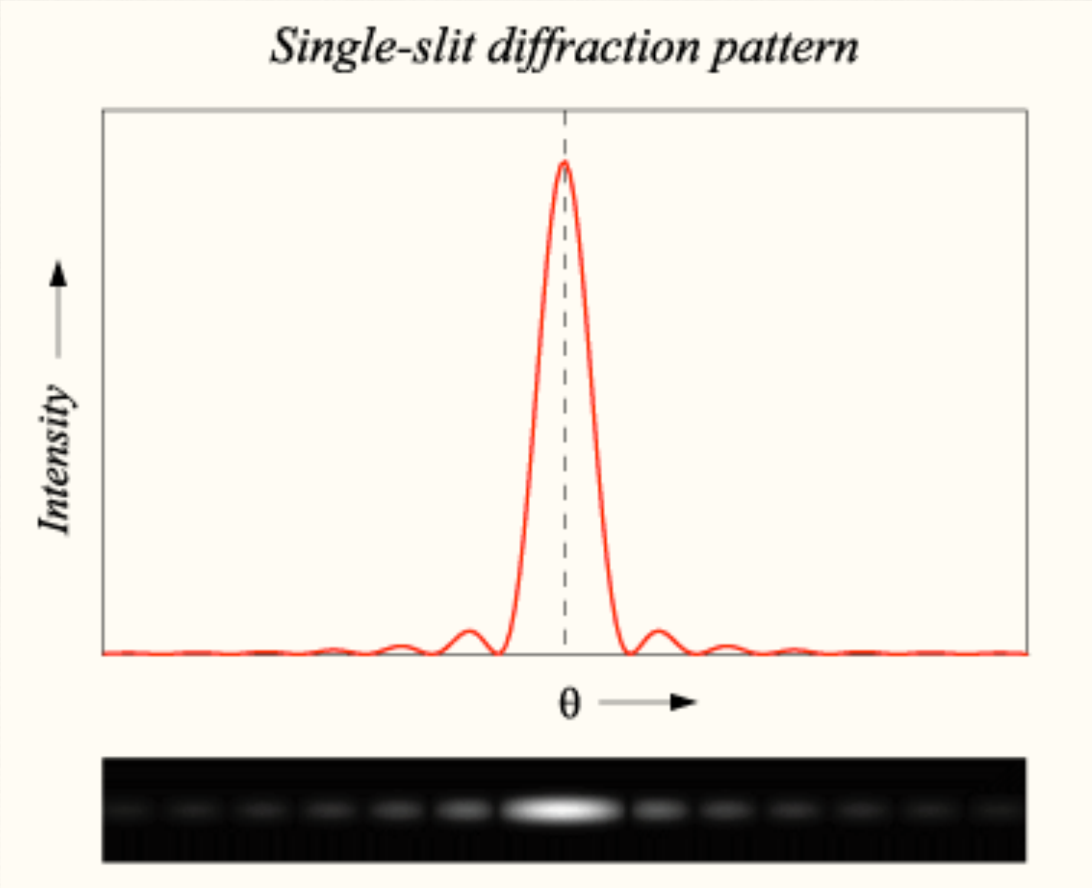
Telescope Mounts

Diffraction Limit

The maximum **resolution** that can be achieved by any optical system is set by the diffraction limit. In a sense, a telescope is the 2D analog to a single slit, and the diffraction pattern is an Airy disk. The diffraction limit is defined by the equation $\boldsymbol{\theta=1.22\ \lambda/D}$, where θ is the angle you can resolve, λ is the wavelength of the light, and D is the diameter of your objective mirror (lens).

In Focus (Airy Disc)

www.lincolnastrosoc.freeserve.co.uk/ startest.html



Diffraction Limit

In Focus (Airy Disc)

$\theta = 1.22\ \lambda/D$

Example: HST

D=2.4m

λ = 500 nm = 5x10-7 m

θ=(1.22•5x10-7 /2.4)radians • 206,265 arcsec/radian

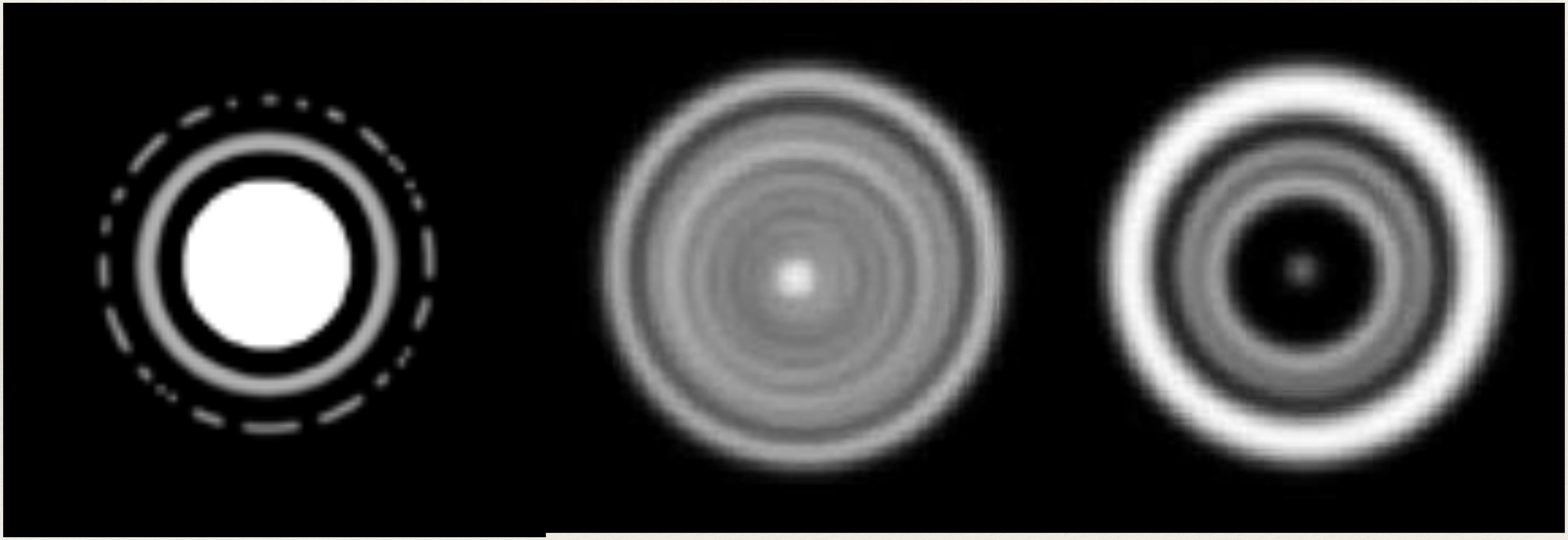
= 0.05 arcseconds.

What would the resolution be for a 24m telescope?

0.6 arcsec

Taken from talk by Marc Sarazin :www.eso.org/astclim/espas/iran/zanjan

Focus



In Focus (Airy Disc) Out of focus Refractor Out of focus Reflector

www.lincolnastrosoc.freeserve.co.uk/ startest.html

Optics & Telescopes

- Aberrations
- Telescope Characteristics
- Telescope Types
- Telescope Mounts

Aberrations

Chromatic Aberration

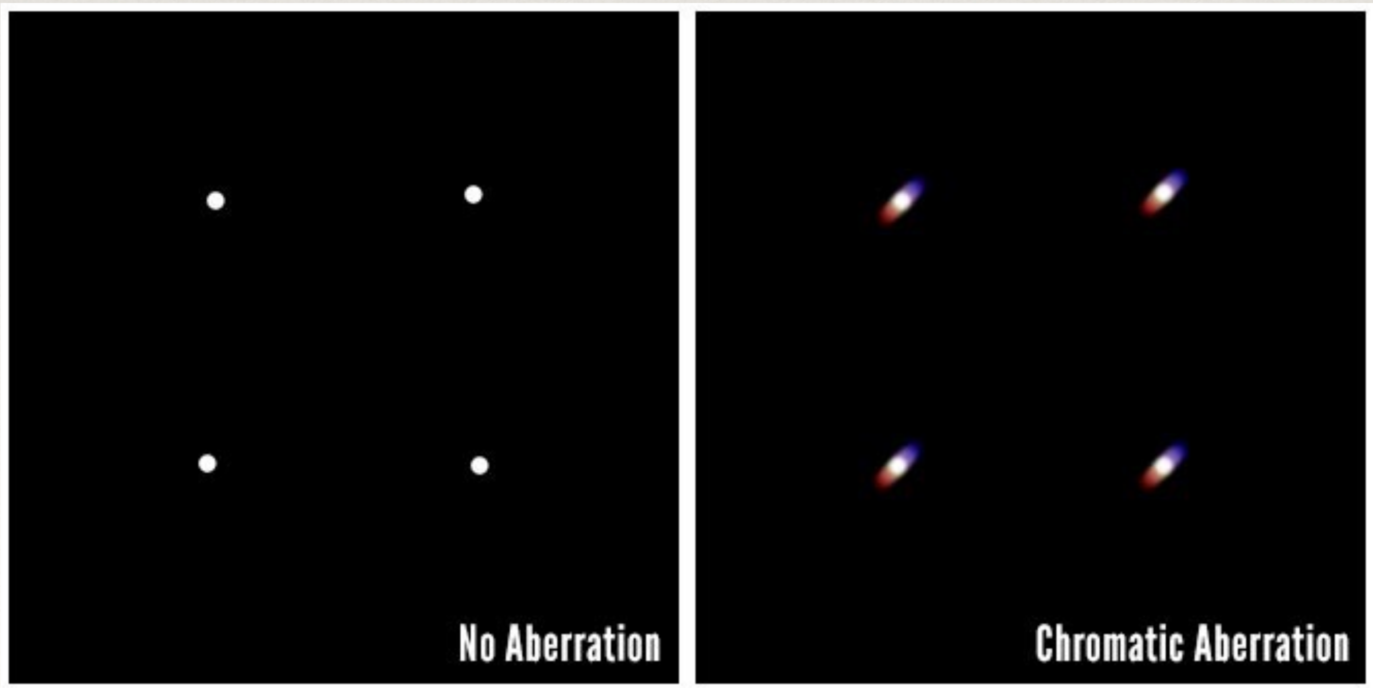
Seidel Aberrations

1. Spherical Aberration
2. Coma
3. Astigmatism
4. Field Curvature
5. Distortion

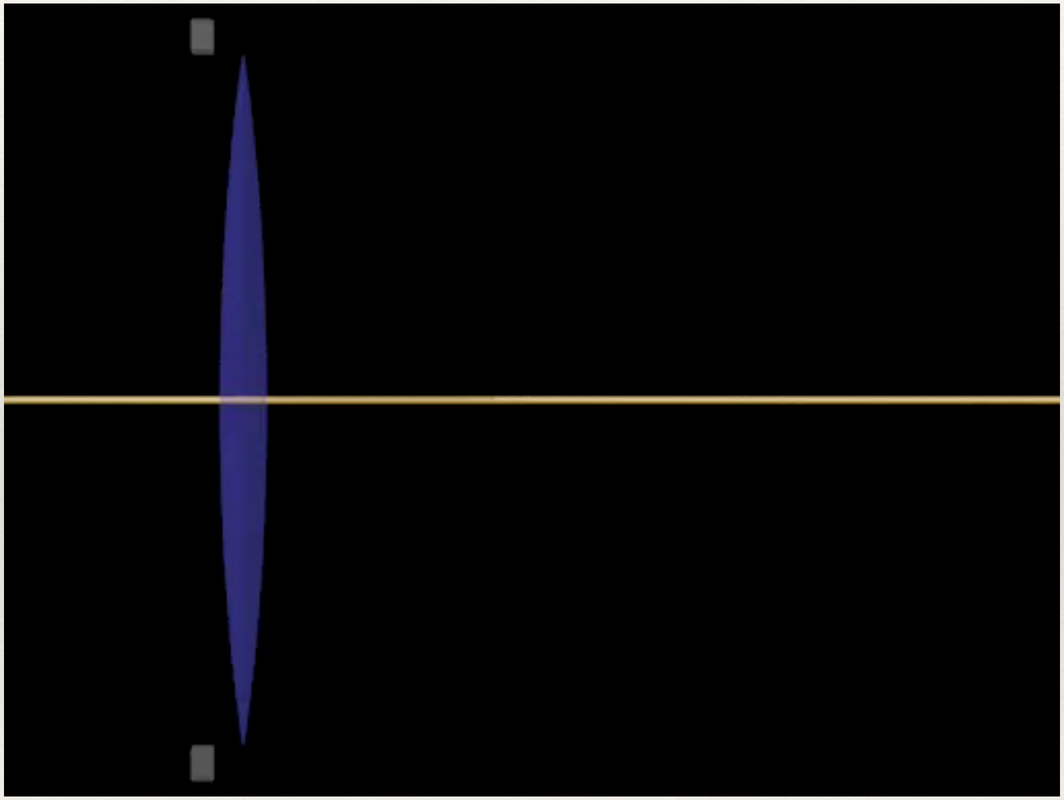
Chromatic Aberration

Chromatic Aberration

- A problem for lenses
- Caused because the index of refraction of the lenses material depends on wavelength
- Different wavelengths have different focal lengths
- Causes fringing and makes it hard to get a good focus



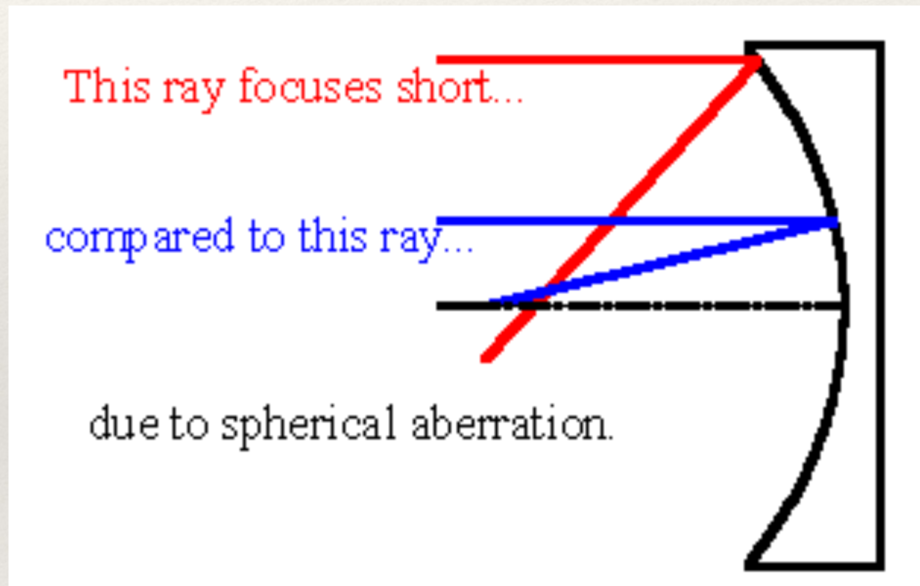
Chromatic Aberration



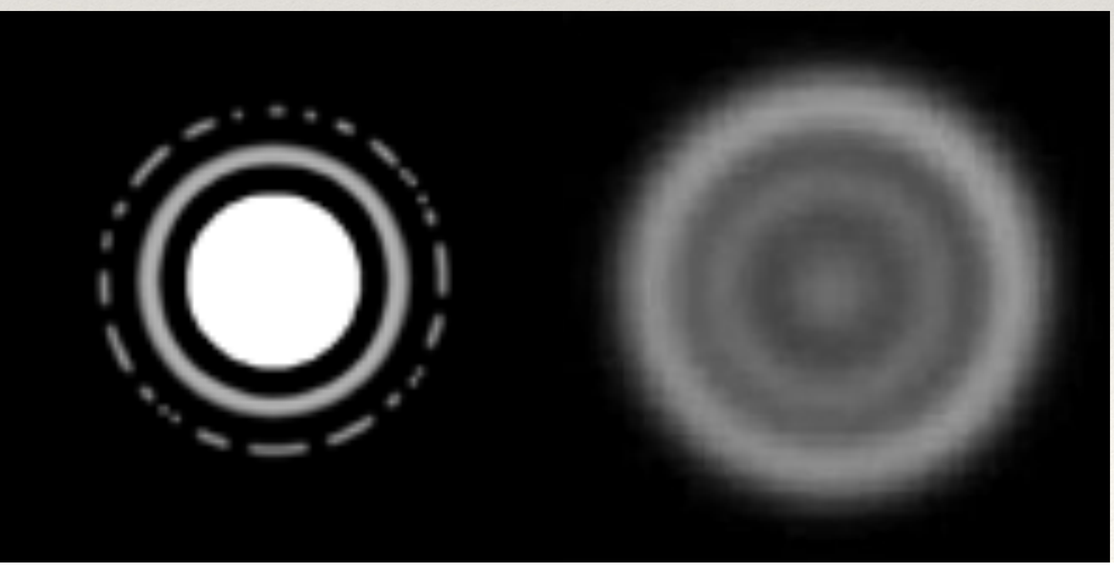
Spherical Aberration

Spherical Aberration

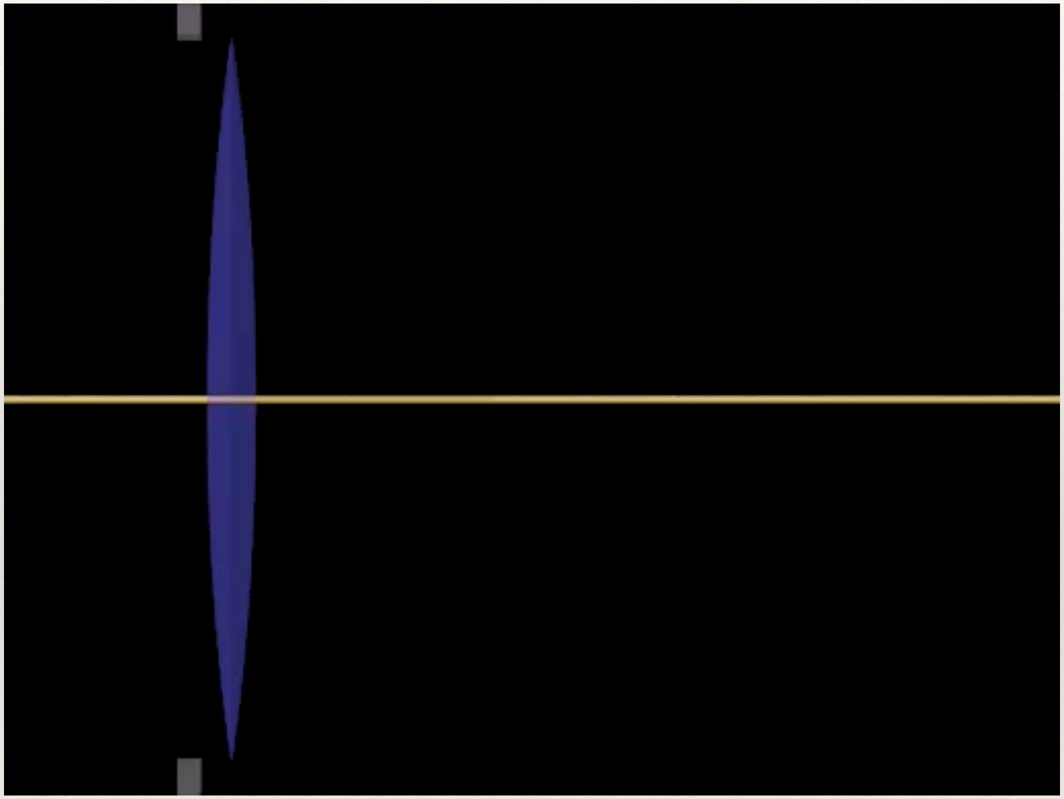
- Parallel light rays from infinity don't pass through a common focus
- True for spheres (hence the name)
- Common optics issue
- Occurs whenever optical element doesn't have desired shape
- **Net Effect: Blurry image**



www.opticalres.com

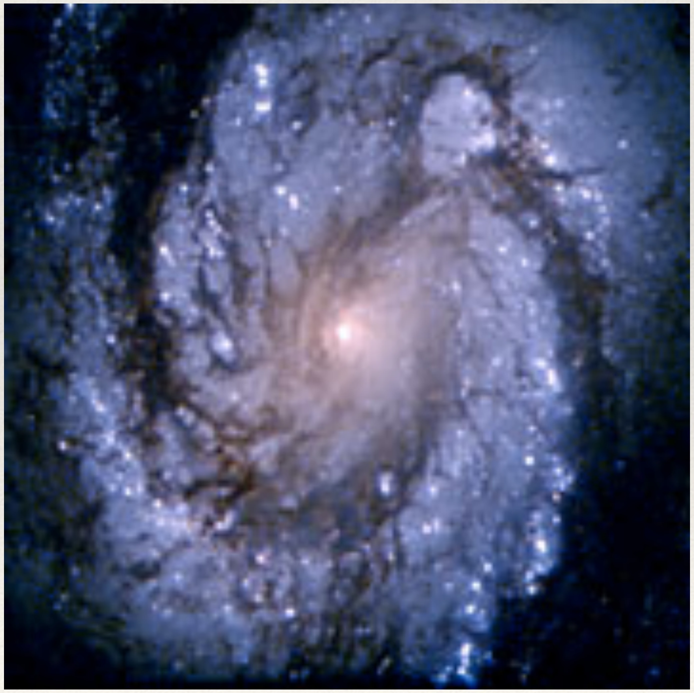


Spherical Aberration



http://phys23p.sl.psu.edu/phys_anim/optics/indexer_optics.html

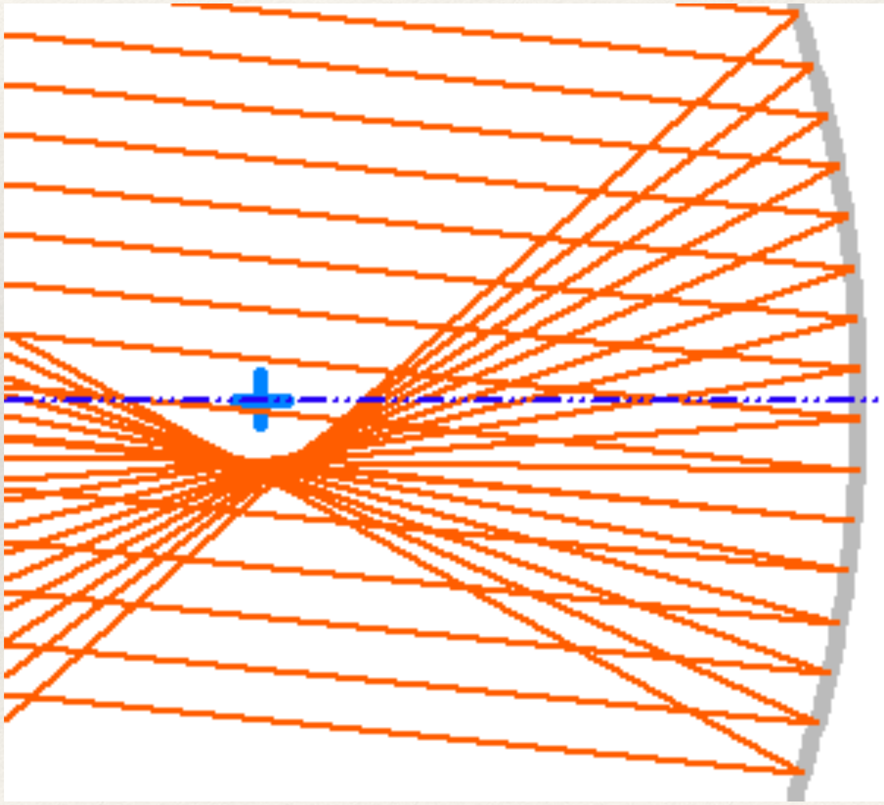
HST pre/post correction



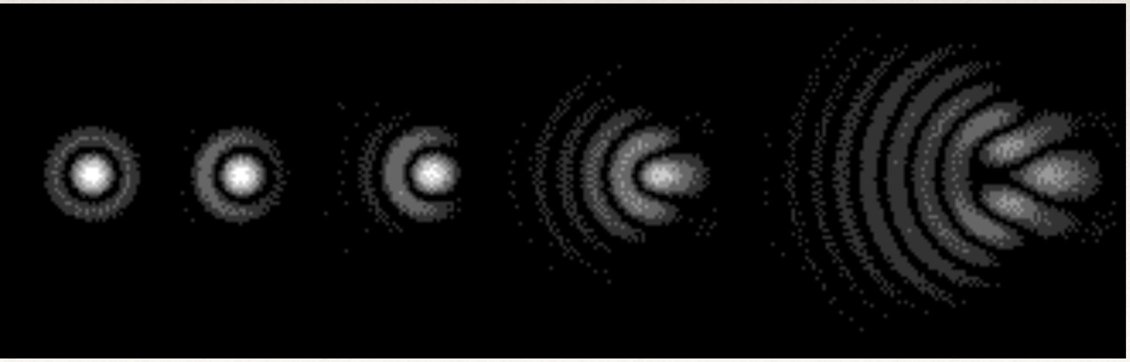
Coma

Coma

- Off-axis aberration
- Off-axis rays hitting the outer part of mirror (or lens) are focused at different points.
- Light incident at a fixed distance from the mirror(lens) is focused into a circle
- All circles together look like a comet
- **Net result: Comet like image**

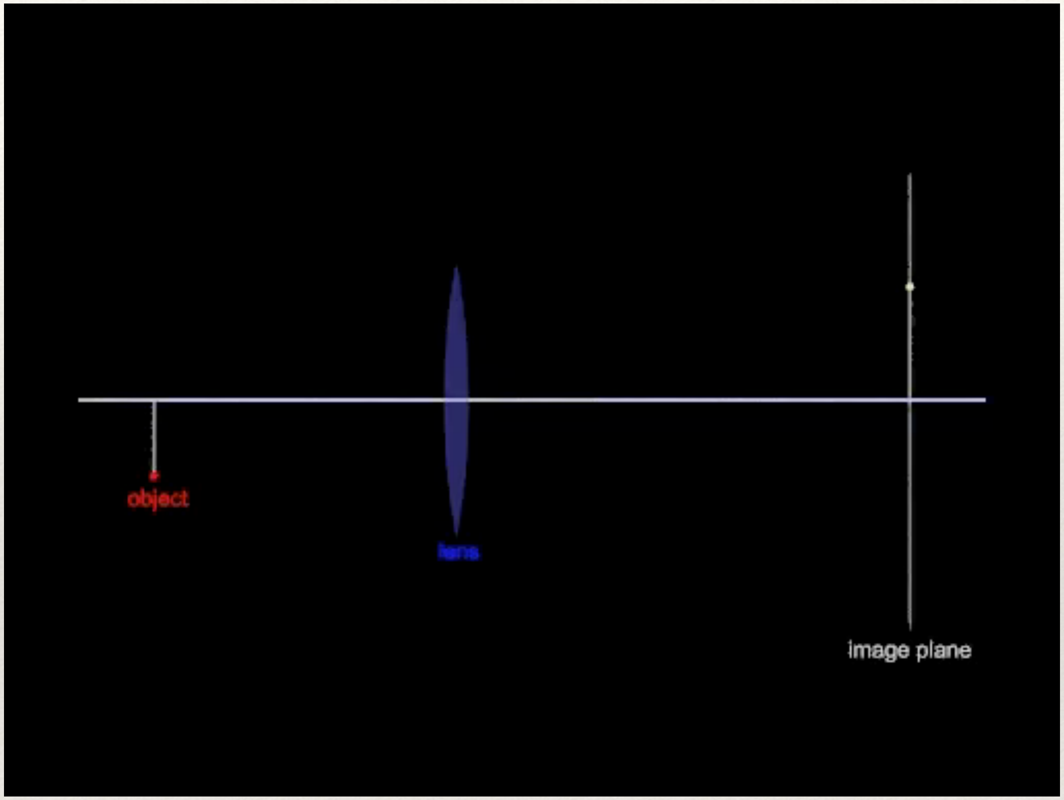


http://media4.obspm.fr/public/FSU/

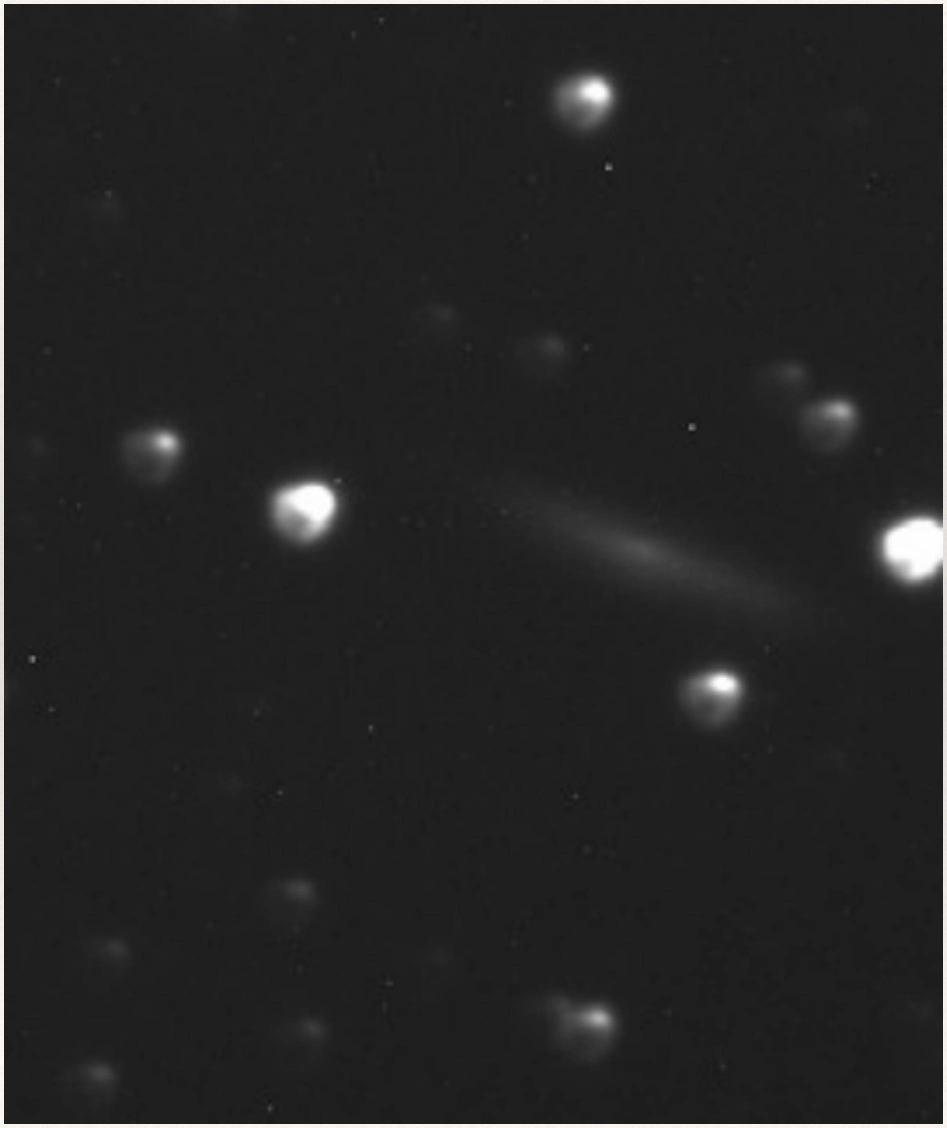


Vegaclub.com

Coma



http://phys23p.sl.psu.edu/phys_anim/optics/indexer_optics.html



RHO 30” example
of comatic aberration
(also out of focus)

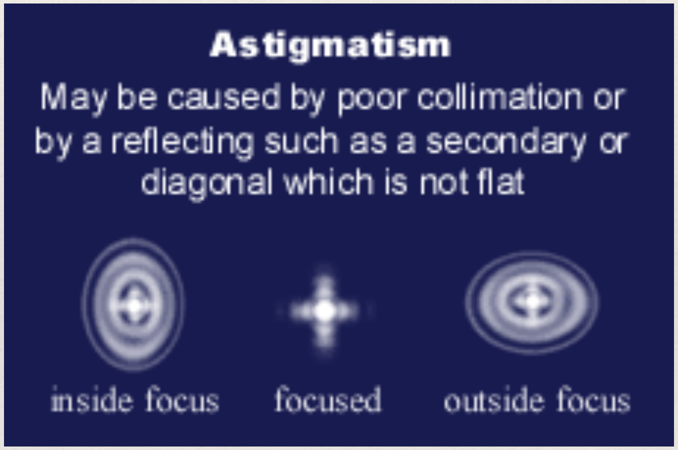
Aberrations

Astigmatism

- Mirror (lens) asymmetric about center
- Stars focus to cross rather than point

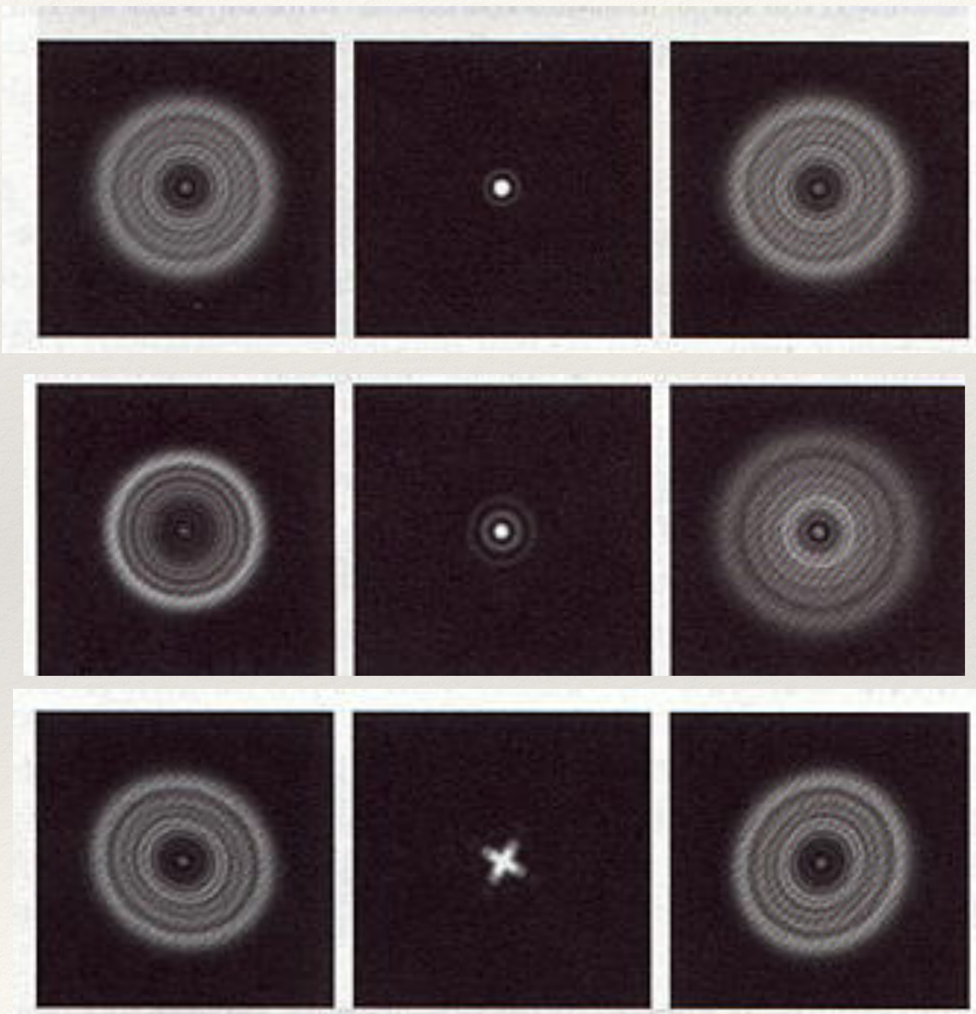
points.

- With typical seeing, may only notice the ellipses.
- **Net result: Cross pattern; ellipses when out of focus.**



www.skywatchertelescope.net

Aberrations



Inside Focus Focus Outside Focus

No defect

Spherical Aberration

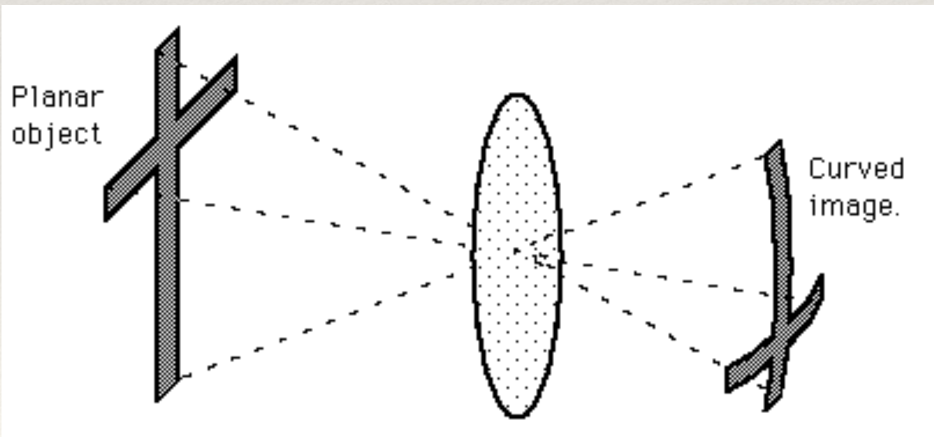
Astigmatism

http://www.robertvincent.freeserve.co.uk/testing.html

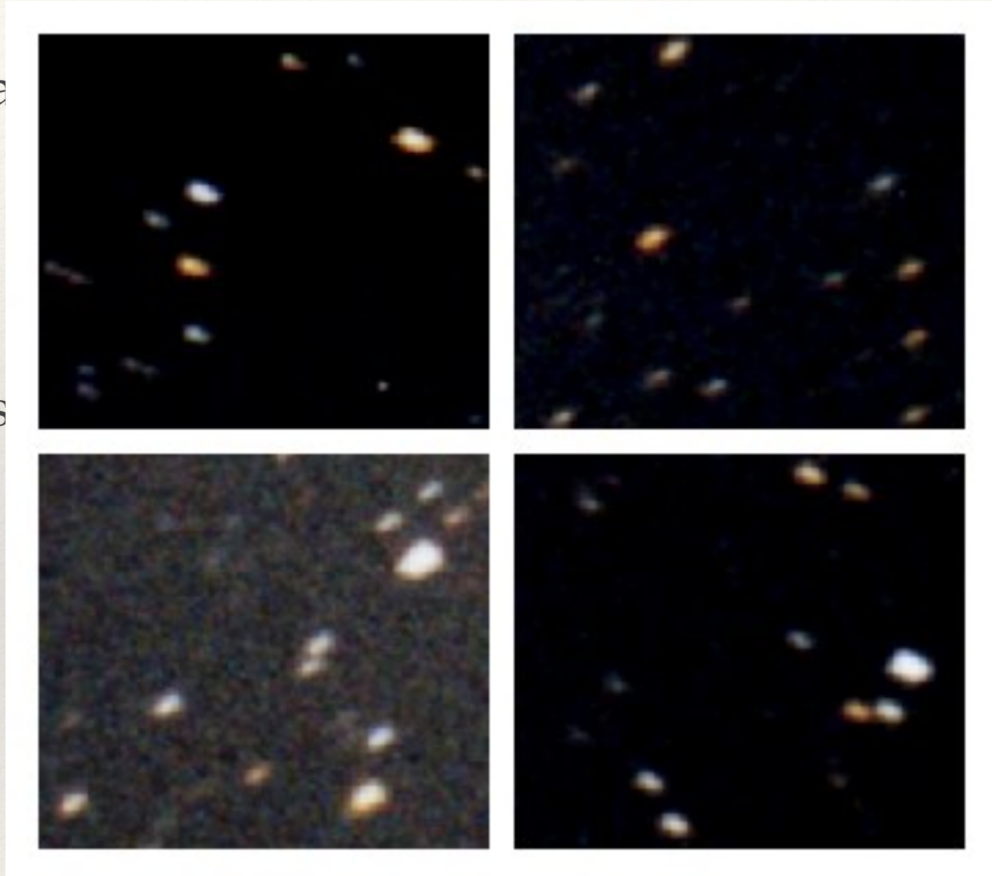
Aberrations

Field Curvature

- Light is focused on a curved surface ra
 a plane
- Flat detector (CCD) will therefore see
 distortion because it is not in focus at
- Gets worse the further you get off-axis



http://hyperphysics.phy-astr.gsu.edu/hbase/geoopt/aber3.html

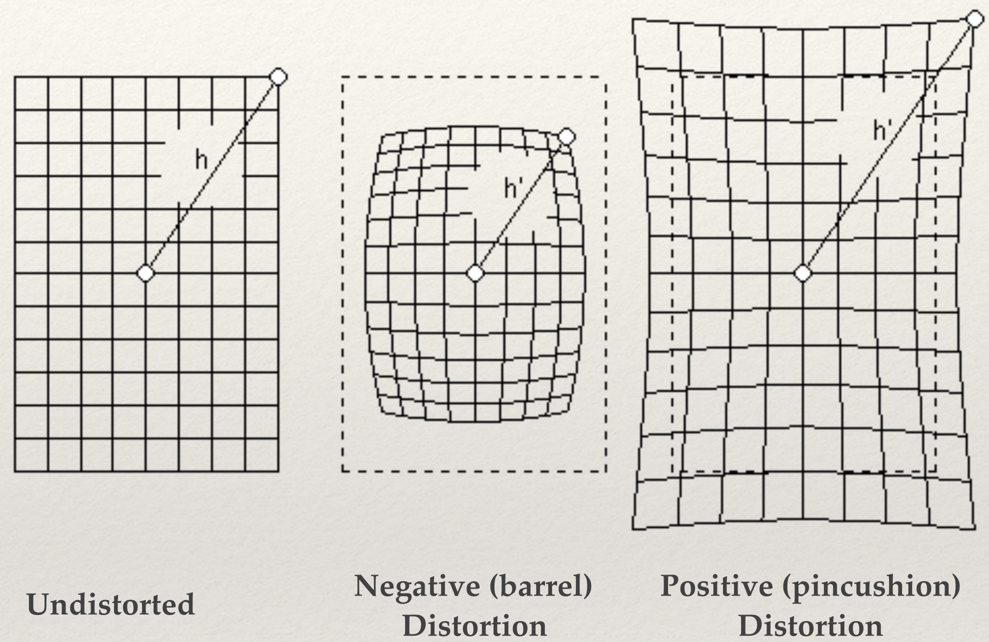


Each image above shows a small region at the four edges of the photograph. The stars are distorted in radial direction, this is caused by the curved focal plane of the fast f/6.5 refractor. (http://astro.nightsky.at/)

Distortion

Distortion

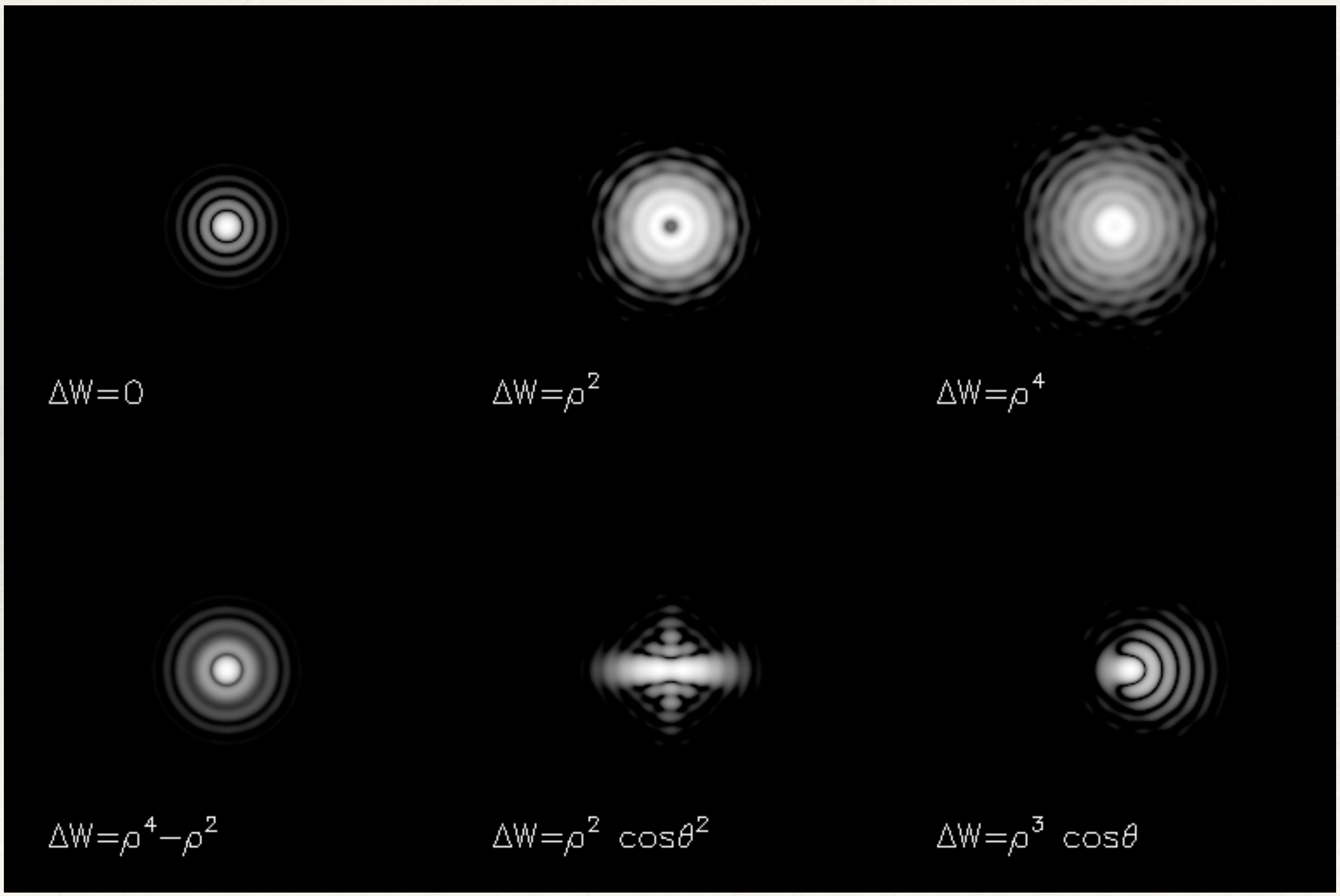
- Image differs geometrically from the object.
- Can have positive or negative distortion
  - Familiar example of distortion is image on an old-style computer monitor

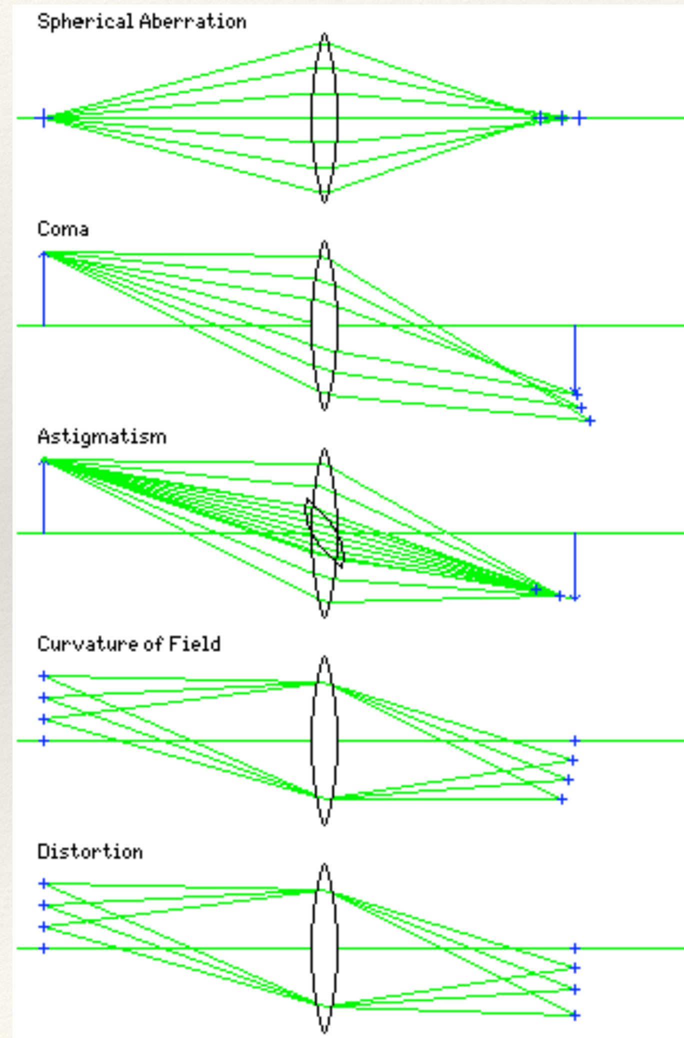


http://www.vanwalree.com/optics/distortion.html

Aberrations

Functional form of Seidel Aberrations





quadibloc.com/science/opt0505.htm

Telescopes

For any telescope, there are four quantities to keep in mind that together characterize the performance of the telescope.

1. Focal ratio
2. Image Scale
3. Field of view
4. Light gathering power

Focal Ratio

1. Focal ratio - the ratio of the focal length to the aperture **(f/D)**. For telescopes of the same aperture D the size of the image (image scale) depends on the focal length. Doubling the focal length (and hence the f-ratio) doubles the linear size of an extended image and therefore the light is spread over four times the area. Thus the speed with which one can image extended objects with a telescope is inversely proportional to the square of the f-ratio.

Most modern observatories use relatively fast optical designs

Examples:

Keck (f/1.75, 10m diameter aperture)	$\Rightarrow$	focal length = 17.5m
GTC (f/1.59, 10.4m diameter aperture)		16.5m
RHO (f/4, 0.76m diameter aperture)		3m

Image Scale (plate scale)

2. Image Scale (plate scale) - The conversion between the size of the image in the focal plane (usually measured in mm) and the corresponding angular size subtended on the sky. The relation between the two is

$$\mathbf{d = f \cdot \theta}$$

Where f is the focal length and θ is in arcseconds. If f is measured in meters, then the relation

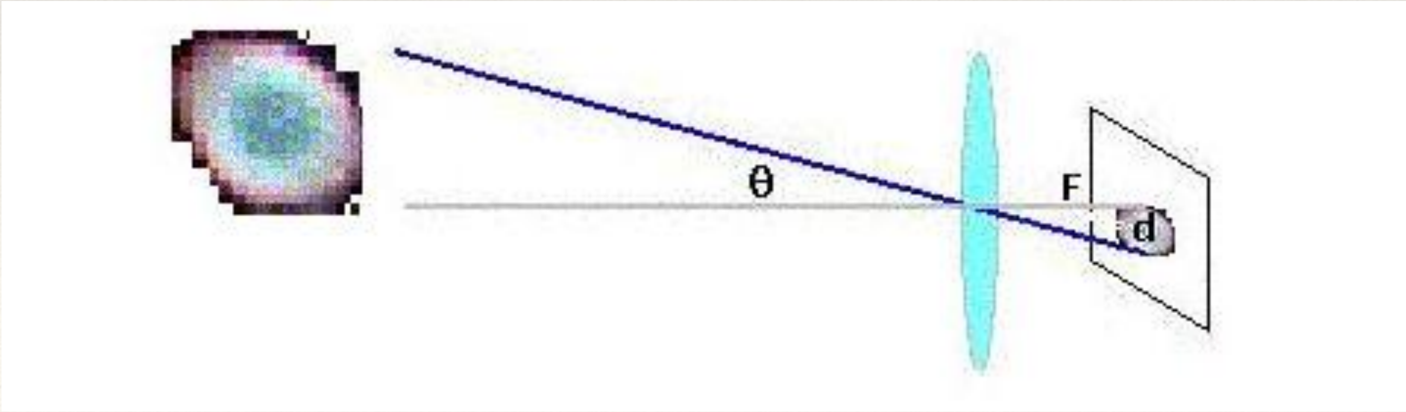
$$\mathbf{s = f/206.25}$$

gives the plate scale in mm/arcsec.

Example: A 4m, f/5 telescope

$f = 4 \cdot 5 = 20m \quad \Rightarrow \quad s = 0.097$ mm/arcsec, or $1/s = 10.31$ arcsec/mm

The plate scale is an important consideration in telescope/instrument design. You need to have the pixels on your detector be at least a factor of two smaller than the expected seeing.



Field of view

3. Field of view - Effective angular extent over which telescope can produce quality images. There are two factors that drive the effective field of view:

Size of the Aperture Stop - how large is the angular extent of light that makes it all the way to the focal plane?

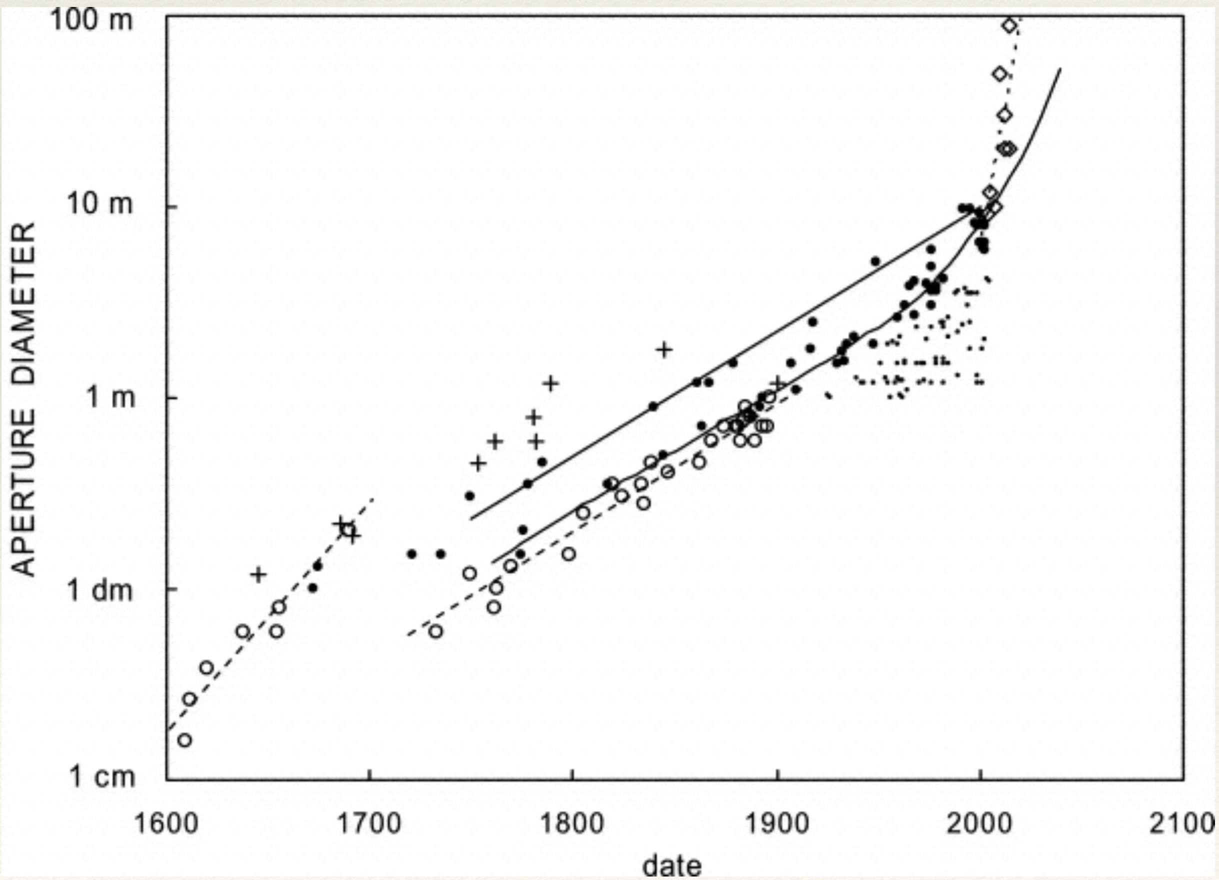
Off-Axis Aberrations - how far away from the center of the focal plane can you go before the images get distorted?

Telescope	Diam(m)	Field of View (arcmin)
Gott 12”	0.3	12 (CCD f/10)
HST	2.4	3 (ACS)
CFHT	3.6	40 (CFH12K)
SUBARU	8.1	34 (SuprimeCam)
Keck	10	17 (DEIMOS)

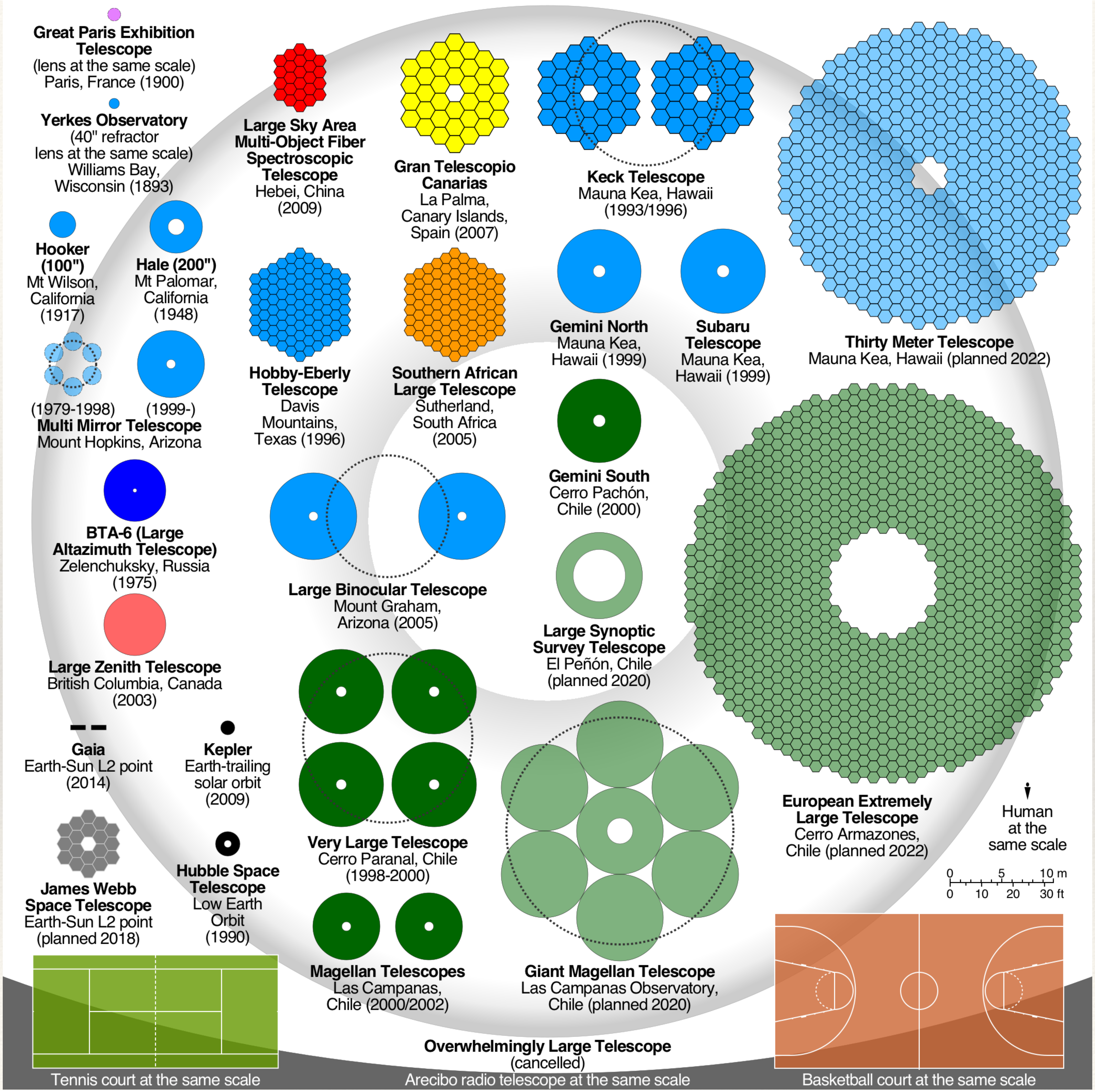
*FOV values are approximate and are quoted for specific instruments on these telescopes

Light gathering power (collecting power)

4. Light gathering power (collecting power) - The total light collected per unit time. This is directly proportional to the aperture of the telescope (or D^2 for a circular mirror/lens). The larger the collecting area, the quicker you can image an object.



Racine 2004, PASP



Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor
lens at the same scale)
Williams Bay,
Wisconsin (1893)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China
(2009)
Gran Telescopio Canarias
La Palma,
Canary Islands,
Spain (2007)
Keck Telescope
Mauna Kea, Hawaii
(1993/1996)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
Hooker (100")
Mt Wilson,
California
(1917)
Hale (200")
Mt Palomar,
California
(1948)
Hobby-Eberly Telescope
Davis
Mountains,
Texas (1996)
Southern African Large Telescope
Sutherland,
South Africa
(2005)
Gemini North
Mauna Kea,
Hawaii (1999)
Subaru Telescope
Mauna Kea,
Hawaii (1999)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
Gemini South
Cerro Pachón,
Chile (2000)
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia
(1975)
Large Binocular Telescope
Mount Graham,
Arizona (2005)
Large Synoptic Survey Telescope
El Peñón, Chile
(planned 2020)
Large Zenith Telescope
British Columbia, Canada
(2003)
Gaia
Earth-Sun L2 point
(2014)
Kepler
Earth-trailing
solar orbit
(2009)
Very Large Telescope
Cerro Paranal, Chile
(1998-2000)
European Extremely Large Telescope
Cerro Armazones,
Chile (planned 2022)
Human
at the
same scale
0 5 10 m
0 10 20 30 ft
James Webb Space Telescope
Earth-Sun L2 point
(planned 2018)
Hubble Space Telescope
Low Earth
Orbit
(1990)
Magellan Telescopes
Las Campanas,
Chile (2000/2002)
Giant Magellan Telescope
Las Campanas Observatory,
Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

Telescopes

For any telescope, there are four quantities to keep in mind that together characterize the performance of the telescope.

3. Field of View
4. Collecting Area

These two quantities are often combined into a single number, called entendue, which is a product Area and Field of View. Entendue (AΩ) is what matters if you want to perform a wide-area, deep sky survey.

Some example entendues:

Telescope	**Diam(m)**	**Ω(deg²)**	***A*Ω (m² deg²)**
SDSS	2.5	3.9	6.0
CFHT	3.6	1	8.0
SUBARU	8.1	0.2	8.8
Pan-STARRS	3.6	7	60
Nominal LSST	6.7	9.6	336

Entendue

Collecting Area and Field of View are often combined into a single number, called entendue, which is a product Area and Field of View.

Entendue (AΩ) is what matters if you want to perform a wide-area, deep sky survey.

Some example entendues:

Telescope	Diam(m)	Ω(deg^2)	AΩ
USAF Linear	1.0	2.0	1.5
SDSS	2.5	3.9	6.0
CFHT	3.6	1	8.0
SUBARU	8.1	0.2	8.8
Pan-STARRS	3.6	7	60
Nominal LSST	6.5	9.6	190

(from Pan-STARRS web page)

Telescopes

Magnification with an eyepiece (relevant for amateur astronomy)

Magnification is relevant when one is using an eyepiece, placed outside the focal plane (since you want your eye to bring the light to a focus).

$$m = f_{scope} / f_{eye}$$

Typical eyepieces are 25 mm, 12.5 mm, and 6 mm. With a telescope of 1 meter focal length these eyepieces would give magnifications of about 40x, 80x, and 170x power. This means that objects such as the moon would appear 40, 80, or 170 times larger in diameter (and hence they would appear to be 40, 80, or 170 times closer).

The magnification of a telescope is only useful for extended objects (e.g. the moon, planets, nebulae, galaxies), not unresolved objects such as stars (though magnification does apply to the angular separation of two stars).