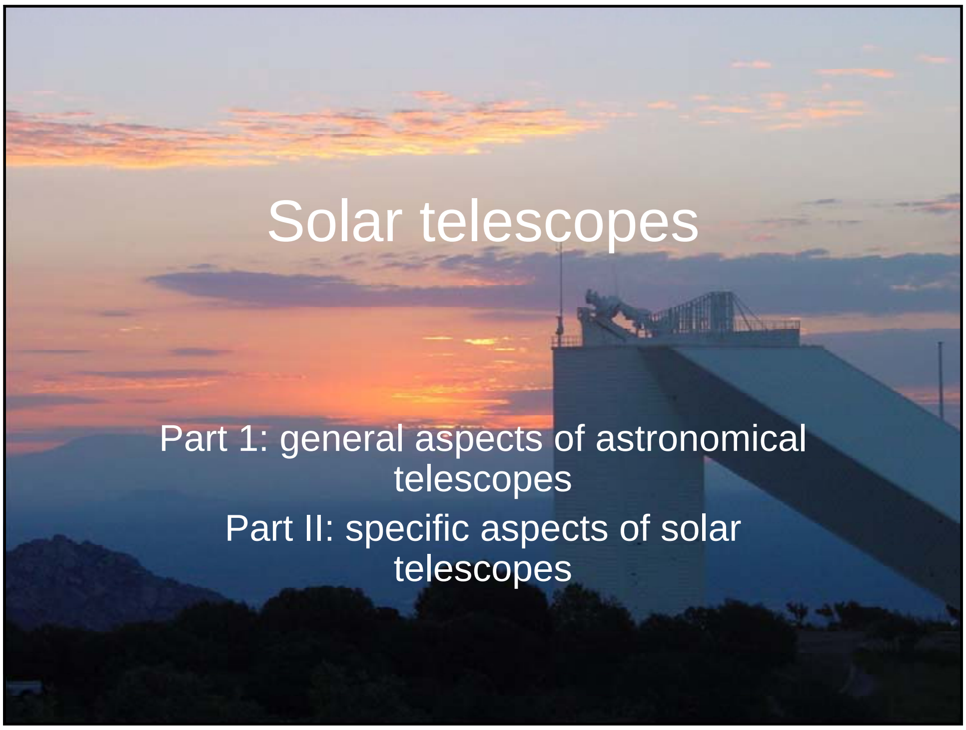
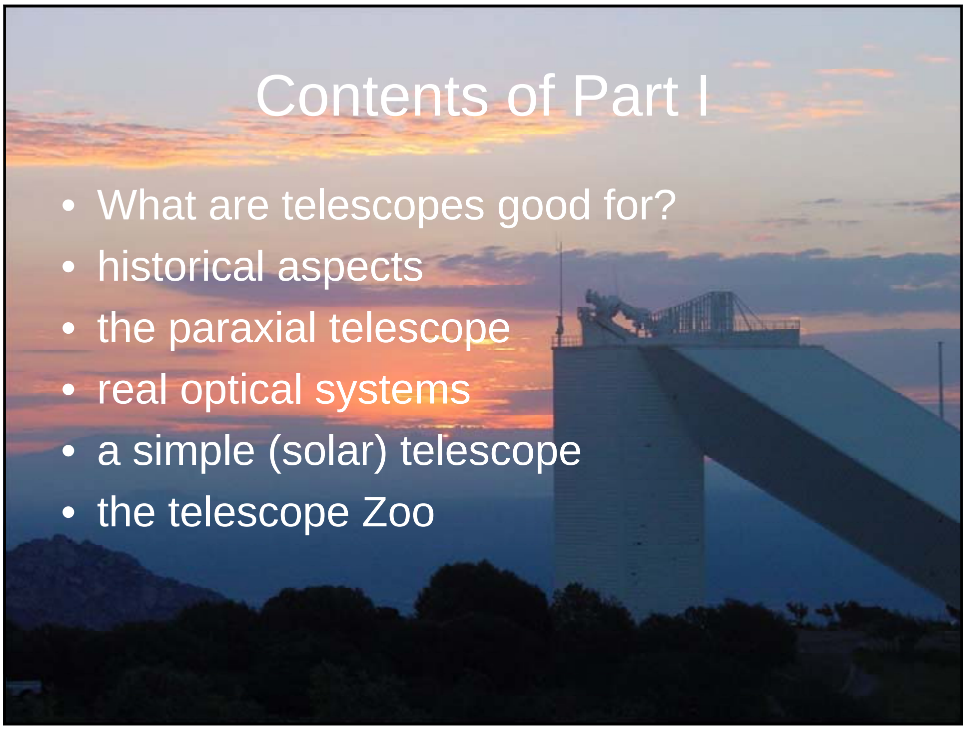
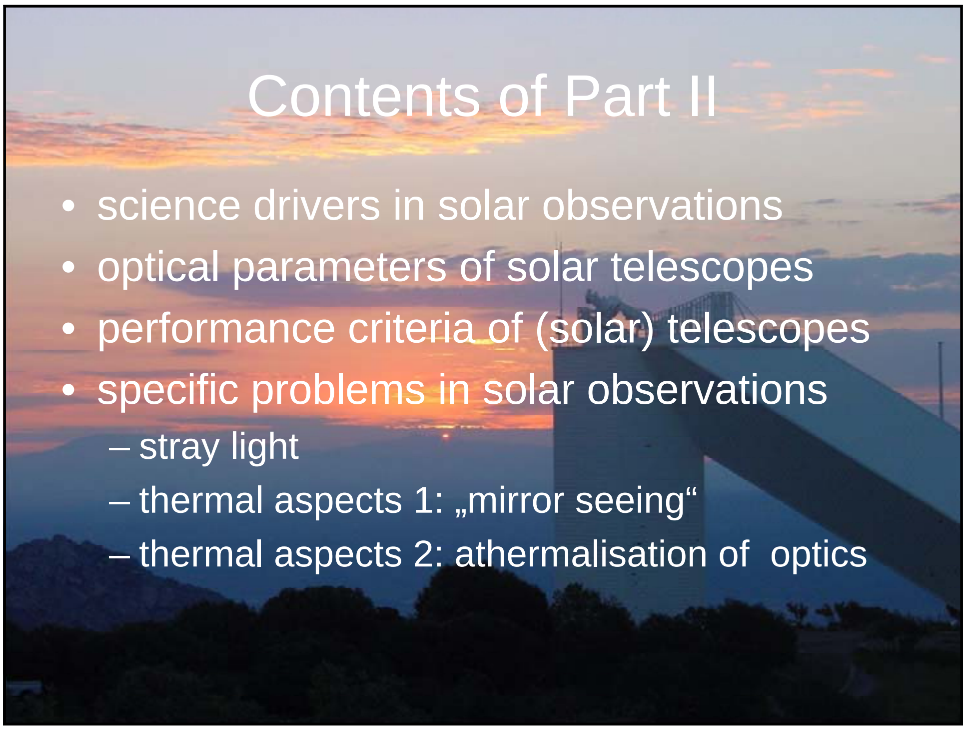

Solar telescopes
Part 1: general aspects of astronomical telescopes
Part II: specific aspects of solar telescopes


Contents of Part I
• What are telescopes good for?
• historical aspects
• the paraxial telescope
• real optical systems
• a simple (solar) telescope
• the telescope Zoo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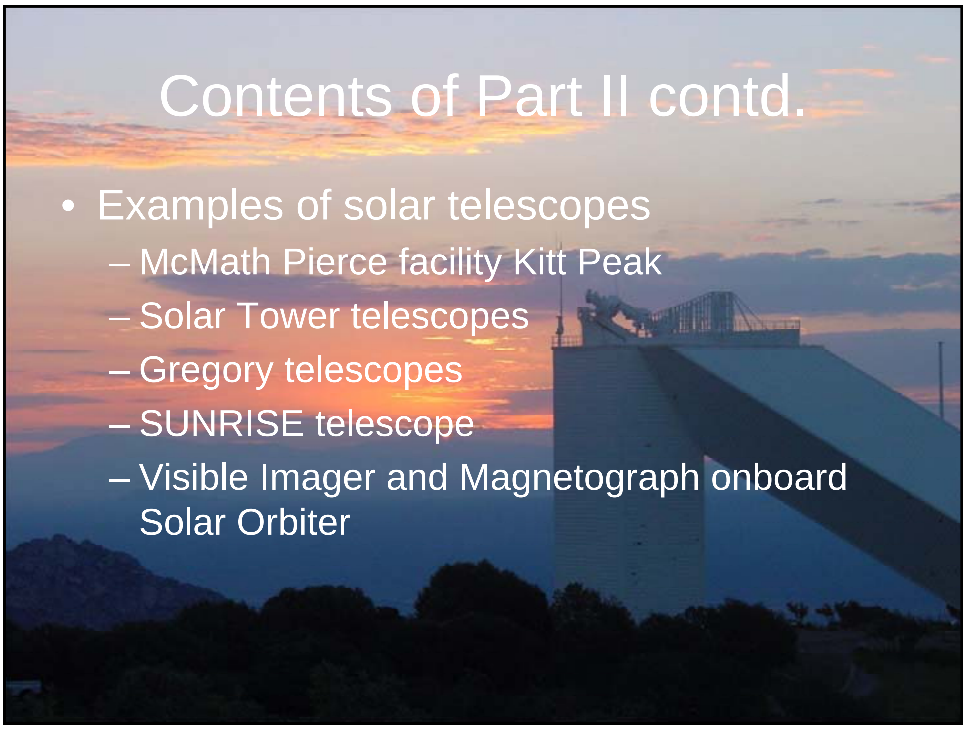
• science drivers in solar observations
• optical parameters of solar telescopes
• performance criteria of (solar) telescopes
• specific problems in solar observations
– stray light
– thermal aspects 1: „mirror seeing“
– thermal aspects 2: athermalisation of optics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• Examples of solar telescopes
– McMath Pierce facility Kitt Peak
– Solar Tower telescopes
– Gregory telescopes
– SUNRISE telescope
– Visible Imager and Magnetograph onboard Solar Orbiter

Solar Telescopes I

General aspects of astronomical telescopes

What is a telescope good for?

- instrument to map angular pattern on sky plane onto detector (object at infinite distance!) → camera
- visual magnification (historically) in direct viewing systems
- collecting photons

History

- first telescope pointed to the sky by Galileo; also the Sun is target: Sunspots seen
- Scheiner uses telescope to project an image of the Sun (safe solar viewing)
- first dedicated solar telescopes from beginning of 20th century on, first peak in the 40ies (military interest in flare forecast; very actual!)

The paraxial telescope

- optical elements represented by ideal „operators“ acting on direction of geometric light rays → „matrix optics“
- paraxial approximation: in Snell´s law replace sin x ~ x

NOTA BENE!

- each „paraxial lens“ can represent complex optical systems:
  - a real lens
  - a combination of lenses
  - a mirror
  - a combination of mirrors
  - a combination of mirrors and lenses

a real lens, a combination of lenses } refractors

a mirror, a combination of mirrors } reflectors

a combination of mirrors and lenses } catadioptric systems

basic parts of an optical system

- entrance aperture
- objective lens
- focal plane (detector)
- „eyepiece“ optics (can also be a complex instrument, c.f. a spectrograph, spectropolarimeter, magnetograph, Fabry-Perot interferometer....)

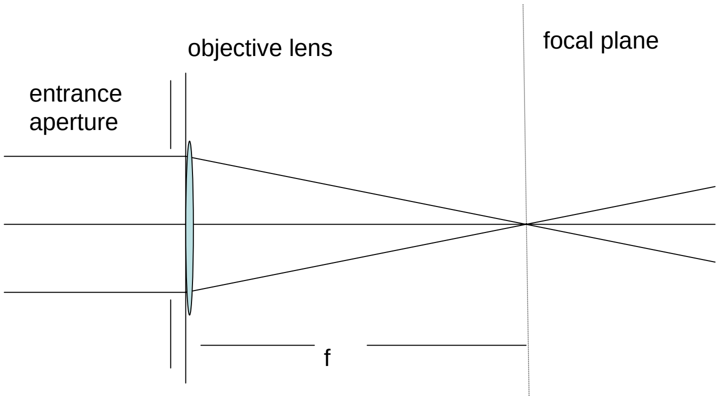
basic parameters of an optical system

- focal length
- plate scale
- entrance pupil diameter

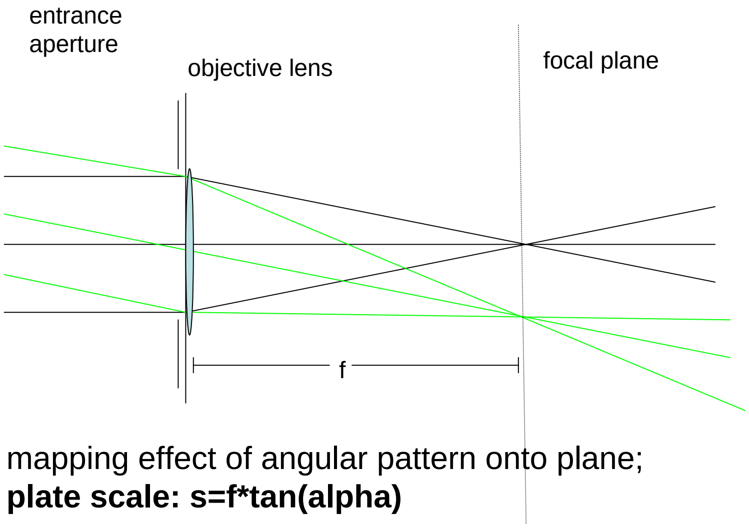
} this is what you want

- f-ratio
- exit pupil diameter
- angular magnification
- field of view

} this is what you get



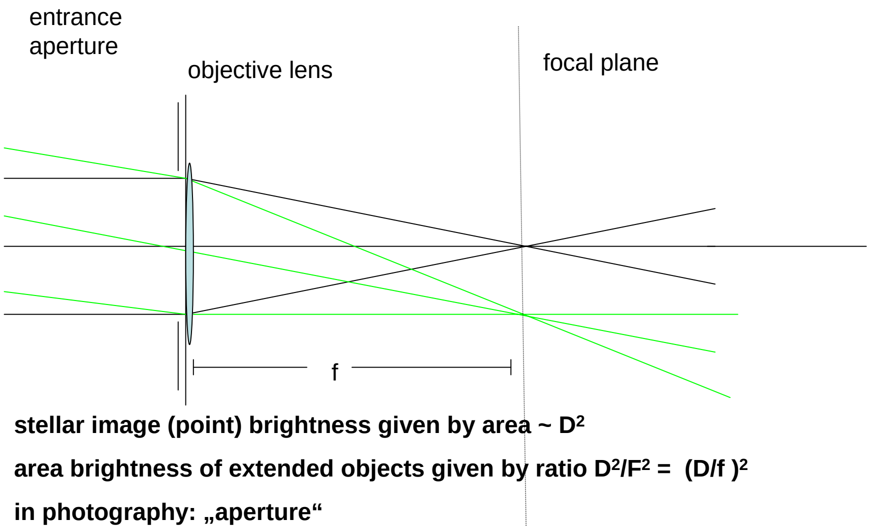
all rays coming **from 1 point on the sky** are focused in a distance f from lens



mapping effect of angular pattern onto plane;
plate scale: s=f*tan(alpha)

given in arcsec/mm or arcsec/px

f can be defined via plate scale: „effective focal length“



stellar image (point) brightness given by area ~ D^2

area brightness of extended objects given by ratio $D^2/F^2 = (D/f)^2$

in photography: „aperture“

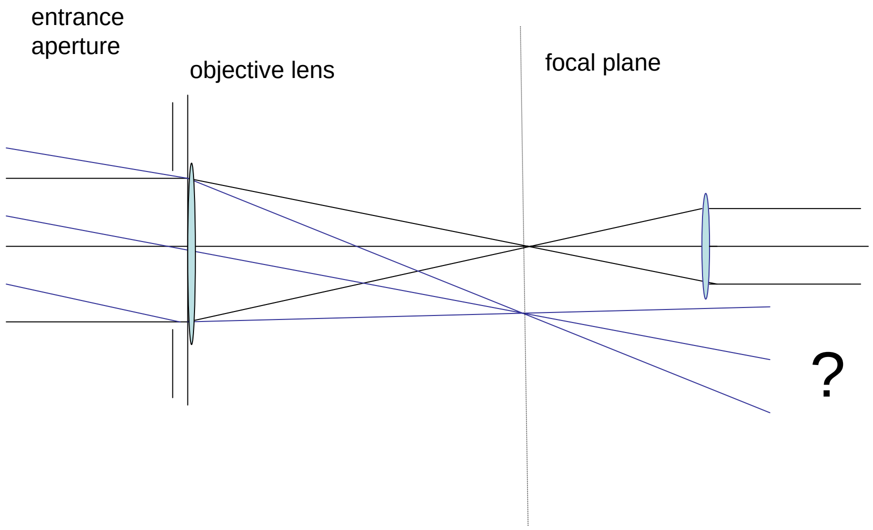
in astronomy: f-ratio or F#

high F#: slow system

low F#: fast system

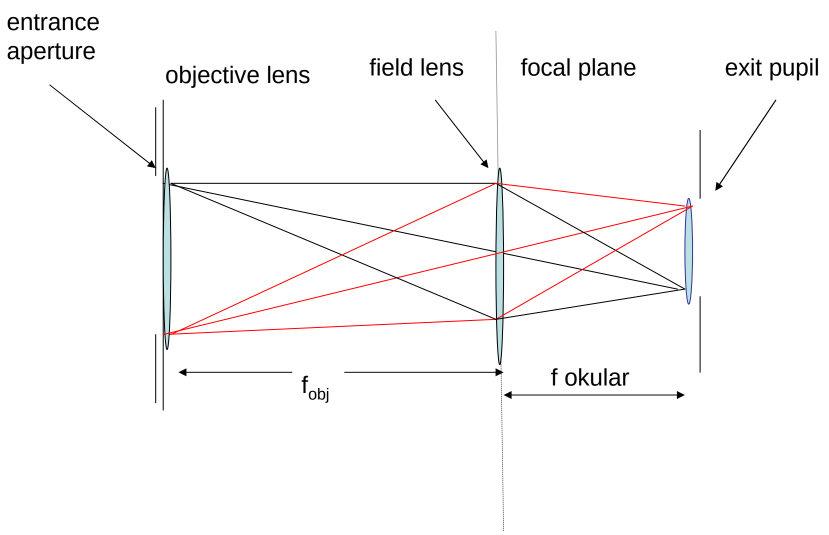
visual observations: the eyepiece

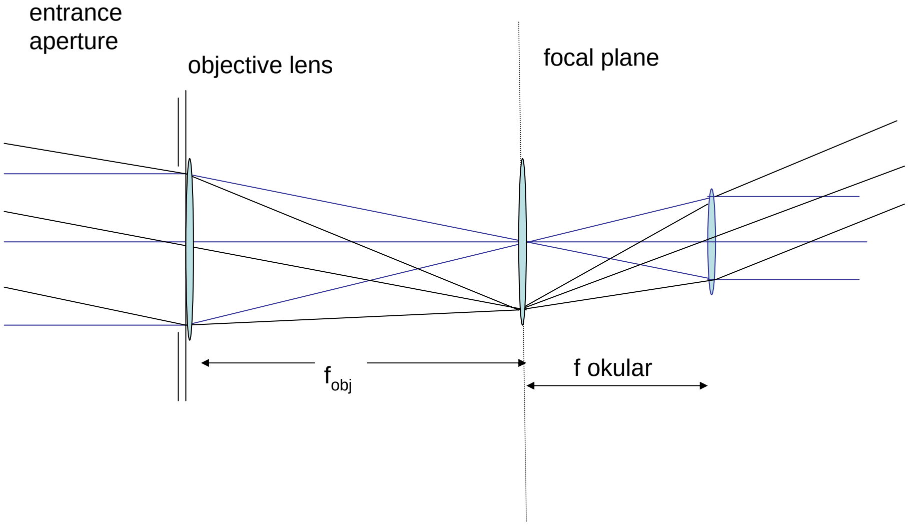
- eyepiece re-collimates the image rays („parallel light“) in order to allow „reimaging“ by the observers eye
- „the intermediate image in the telescope is seen trough a magnifying lens“
- angular magnification given by f_{obj}/f_{okular}



FOV and field lens

- how is it achieved that the light that enters the telescope can exit again???
- small size of eyepiece restricts the angular coverage in observations (FOV)
- Solution: place lens in focal plane to image the entrance pupil onto eyepiece lens
- diameter of this lens determines the useable field→ „field lens“

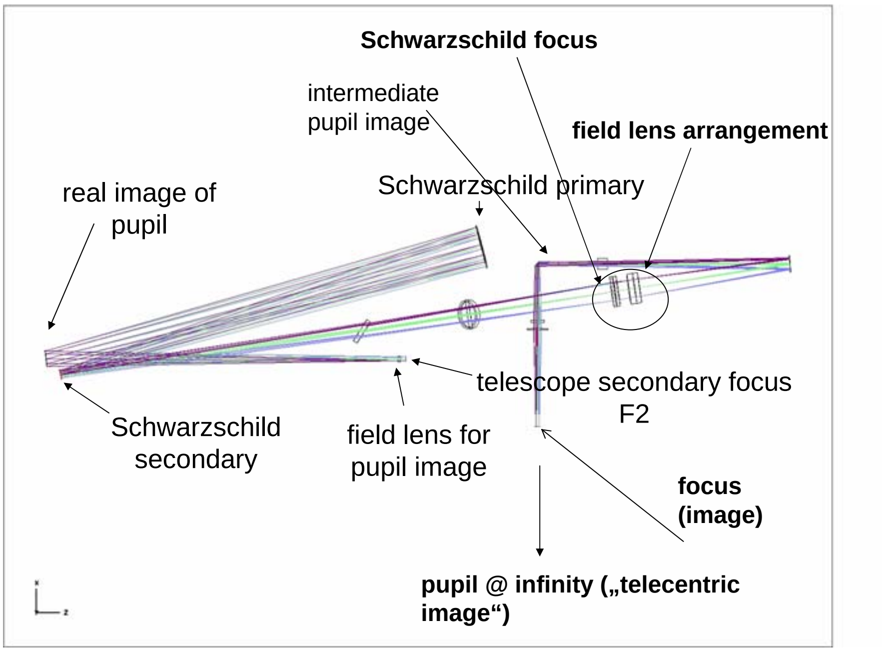


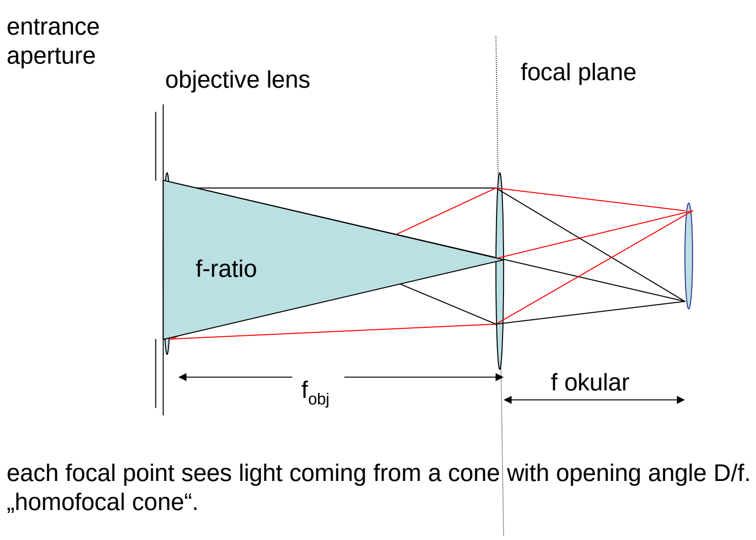


interlaced optical paths

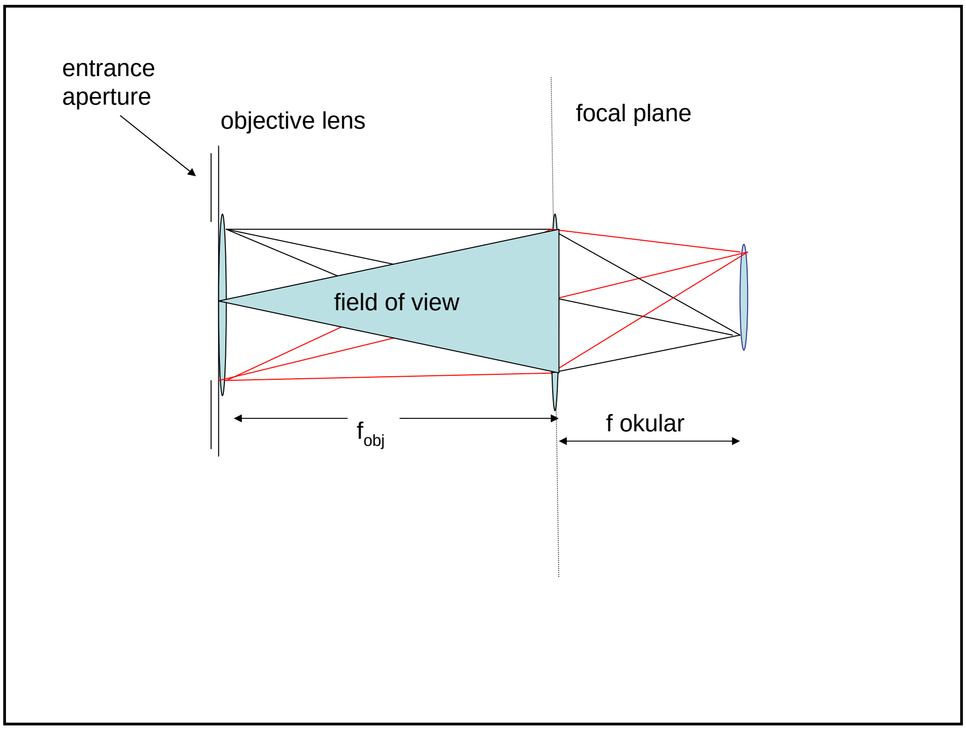
- in every optical instrument:
  image path ←→ pupil path are nested in each other !!!

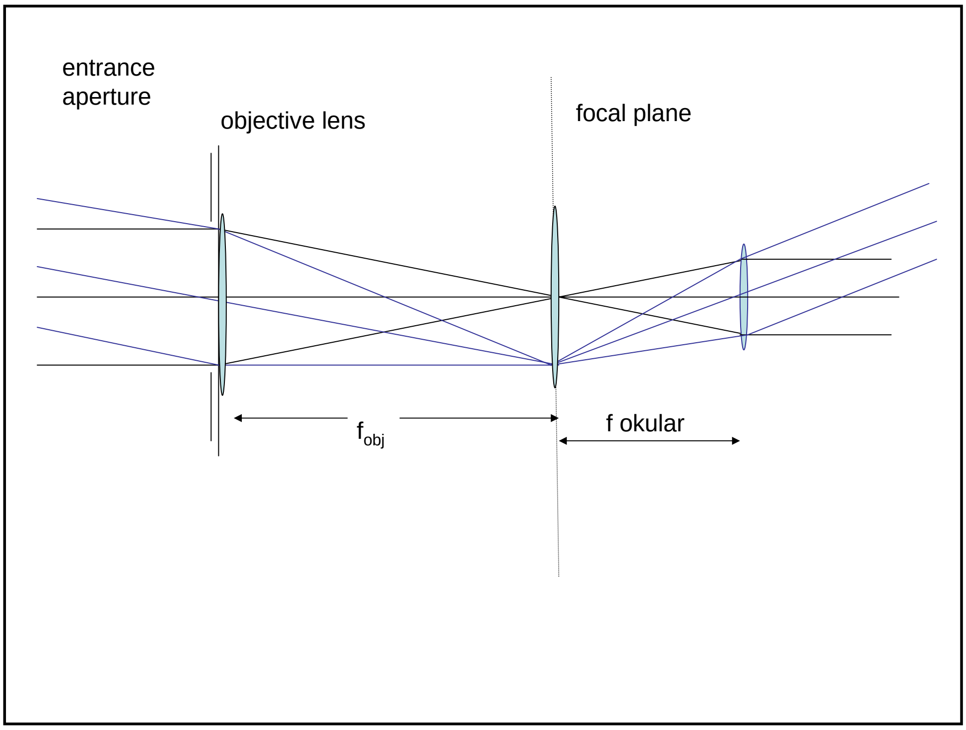
Example: SUNRISE ISLID reimager:





each focal point sees light coming from a cone with opening angle D/f.
„homofocal cone".

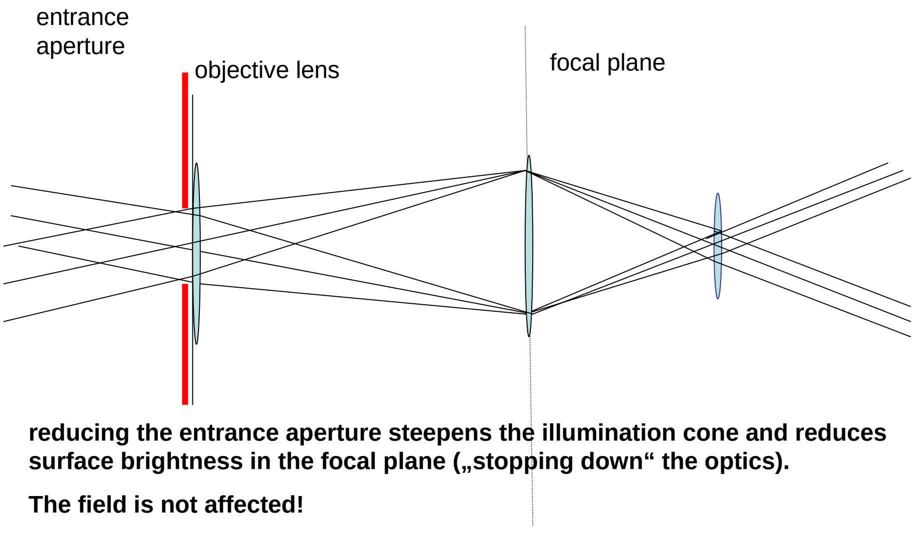

entrance
aperture
objective lens
focal plane
field of view
f obj
f okular


entrance
aperture
objective lens
focal plane
f obj
f okular

Fieldstops, apertures, obscurations, spiders, vignetting..

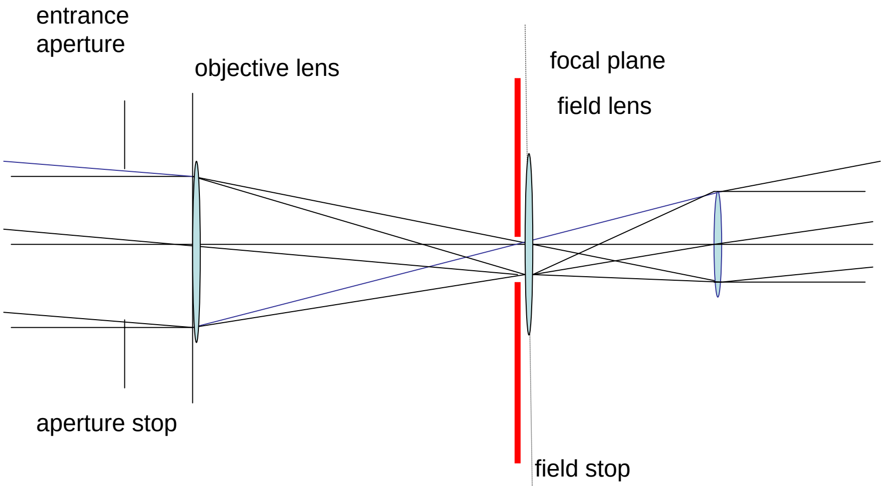
- light rays propagate until they hit an optical surface or a wall....

  the effect of an obstacle depends on its location in the optical system



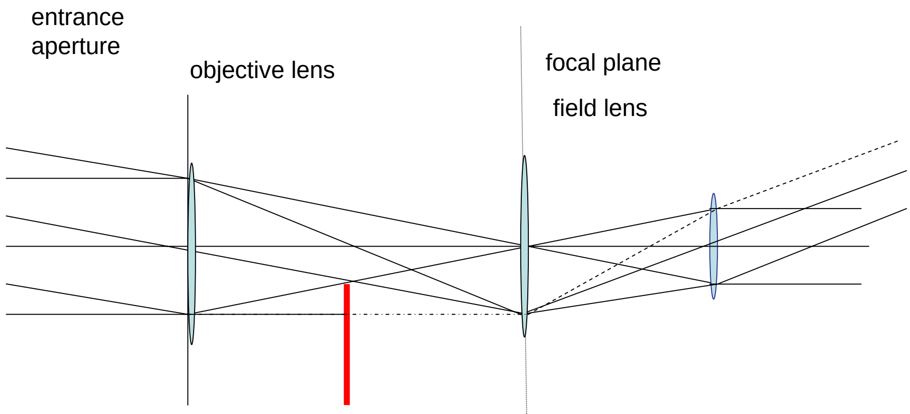
reducing the entrance aperture steepens the illumination cone and reduces surface brightness in the focal plane („stopping down“ the optics).

The field is not affected!



A field stop restricts the useable field of view

It has no influence on the brightness of the image! Note: During a solar eclipse the moon acts as a field stop! Highest danger for the retina, since surface brightness on retina unchanged!

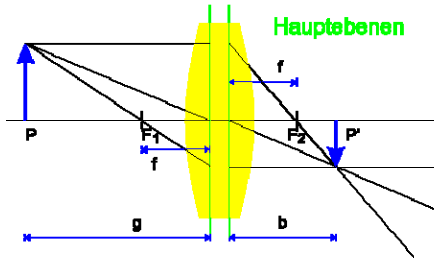


Vignetting : a mechanical obstacle between aperture and focal plane leeds to a reduced brightness in parts of the field of view.

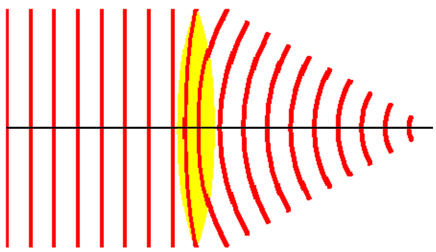
:

real optical systems

- geometric optics: light represented by rays; rays obey Snell´s law



- wave optics: concept of wave fronts; optical surfaces deform wave fronts by influencing optical path lenght



aberration theory

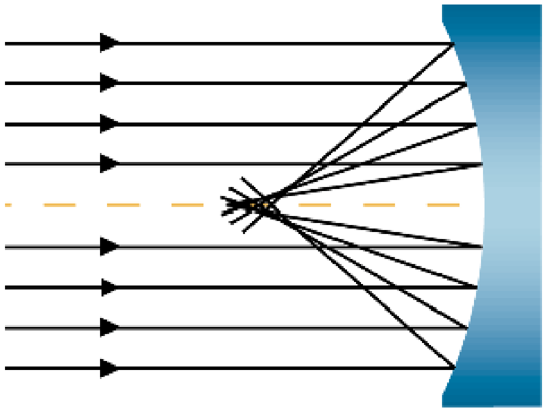
- paraxial approximation not valid for real optical elements → optical aberrations
- purely geometric aberrations: no impact on quality of point image, but on its location
  - image curvature
  - image tilt
  - distortion
- not regarded here

chromatic aberrations

- refractive index (optical path length in glass) depends on frequency (wavelength),
- „dispersion“ effects: lateral and axial colour
- inherent to refractive optics (Refractors)
- can be disregarded for mirror optics (Reflectors)

a simple (solar) telescope

- the spherical mirror:



spherical aberration

- spherical aberration limits the useful aperture of a sperical mirror (lens), and hence the f-ratio (german name: „Öffnungsfehler")
- for f# >40 spherical aberration becomes negligeable
- remark: independent on field angle → sherical mirrors ideal for wide angle systems → Schmidt camera

excurs: The Schmidt camera

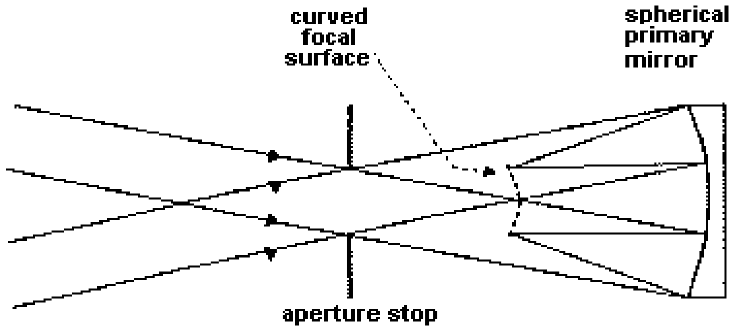
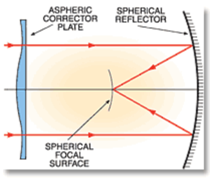


Figure 1. The optical layout of the lensless Schmidt camera.

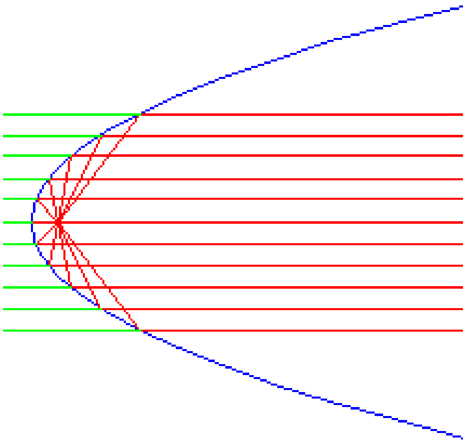
how to make a Schmidt camera faster

- put corrector plate in entrance aperture (center of the spherical mirror) to correct for spherical aberration (Schmidt plate)

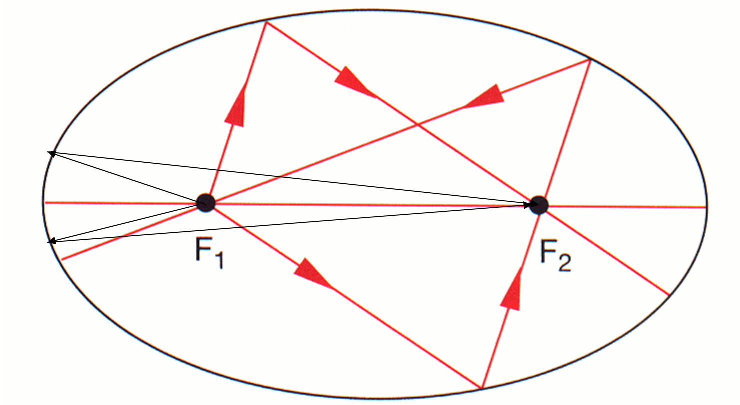


- → asphérisation („aspheric optics“, aspheric lens; hard to manufacture)

aspheric optics: parabola

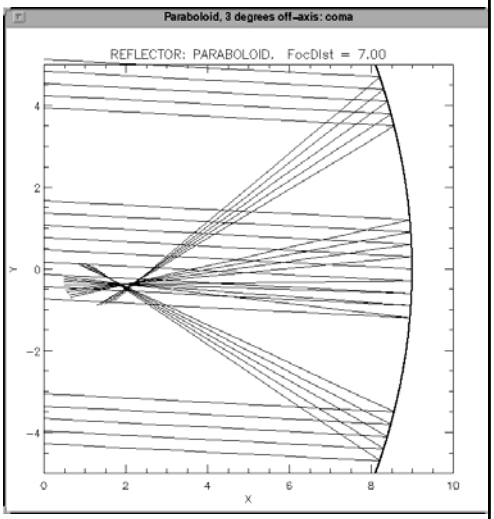


aspheric optics: ellipsoid



aberrations of aspheres

- aberration free focus only „on axis“; deviation from rotational symmetry (edges of FOV) causes aberrations:
- (astigmatism)
- Coma



selecting a mirror

- for large f# a spherical mirror is the best choice (easy to manufacture, very insensitive to alignment errors: shift compensates tilt!)
- prime focus solar telescopes with f# > 40 use spherical mirrors
- example: McMath-Pierce facility on Kitt Peak (f# 54, 1.5m diameter, 86m (!) focal length, observation in prime focus)

arguments against prime focus telescopes

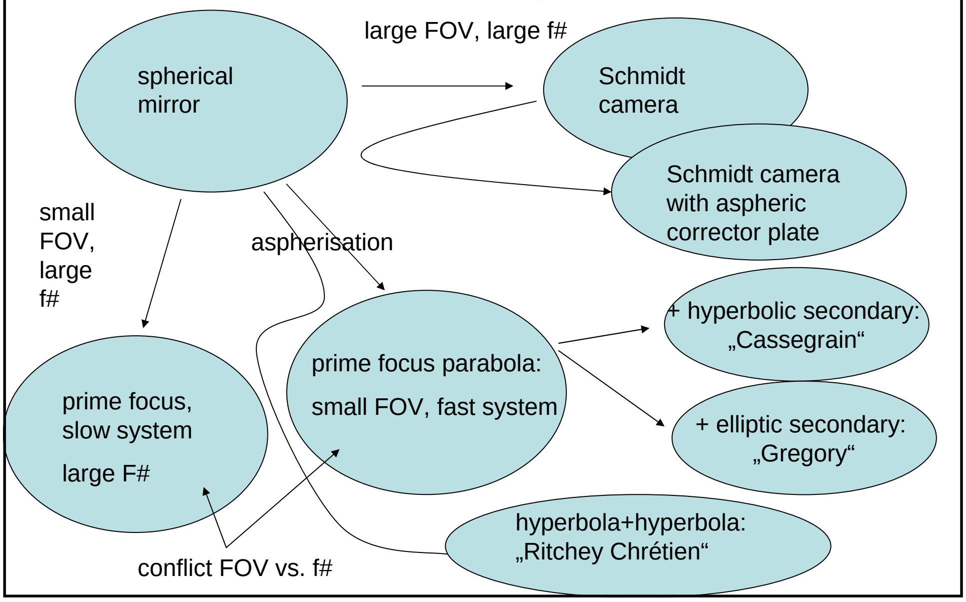
- high angular resolution requires large effective focal length (non-vanishing pixel size!)
- in prime focus:

effective focal length = focal length = length!

telescopes with short primary focal length

- compact telescopes consist of short primary focal length + internal magnification
- observation in secondary (tertiary) focus
- folded designs
- 2nd mirror can be used to compensate for primary aberrations („optical systems“)

the telescope Zoo



NOTA BENE!

- compensating optical aberrations of surfaces by adding more surfaces must be done extremely carefully, otherwise you risk to fight fire with fire..