# Basic Optics

(Very basic)

## As applied in telescopes

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# Purpose of a telescope

The prime function of all telescopes is to collect light from a distant object and to focus an image of that object on the retina, a photographic plate or a CCD camera with as little distortion as possible.

The “little distortion” bit is what drives telescope optic design and development

# Types of telescope

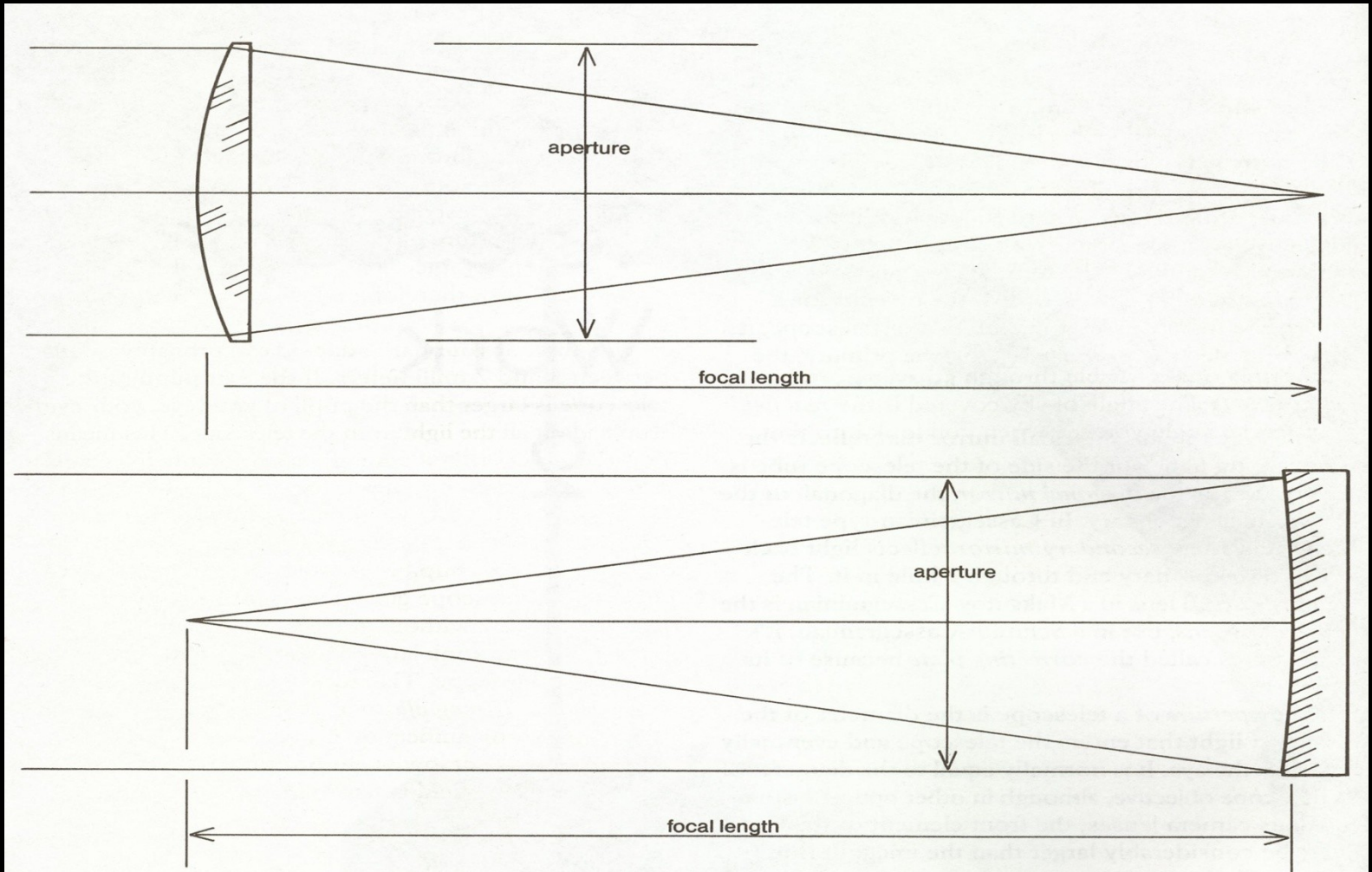
Reflecting telescopes (mirrors)

Refracting telescopes (lenses)

Catadioptric (lens-plus-mirror) telescopes

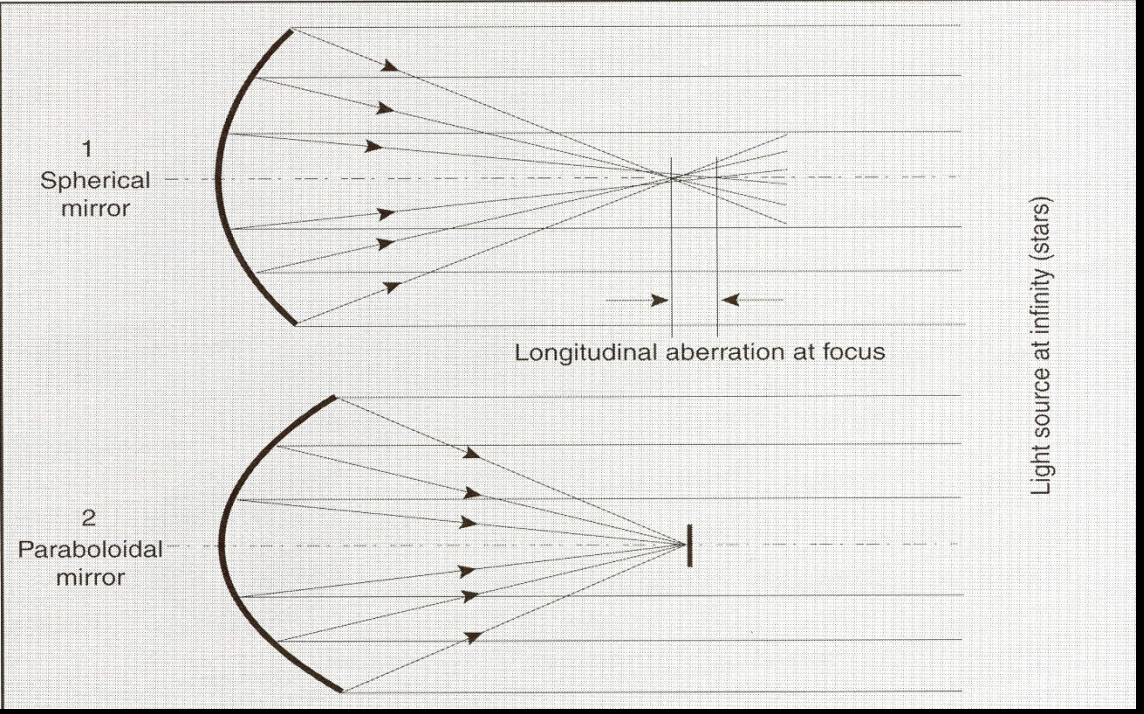
# Focal point?

## What is wrong with this picture?




For both lenses and mirrors, the focal ratio is the focal length divided by the aperture.

# Little distortions



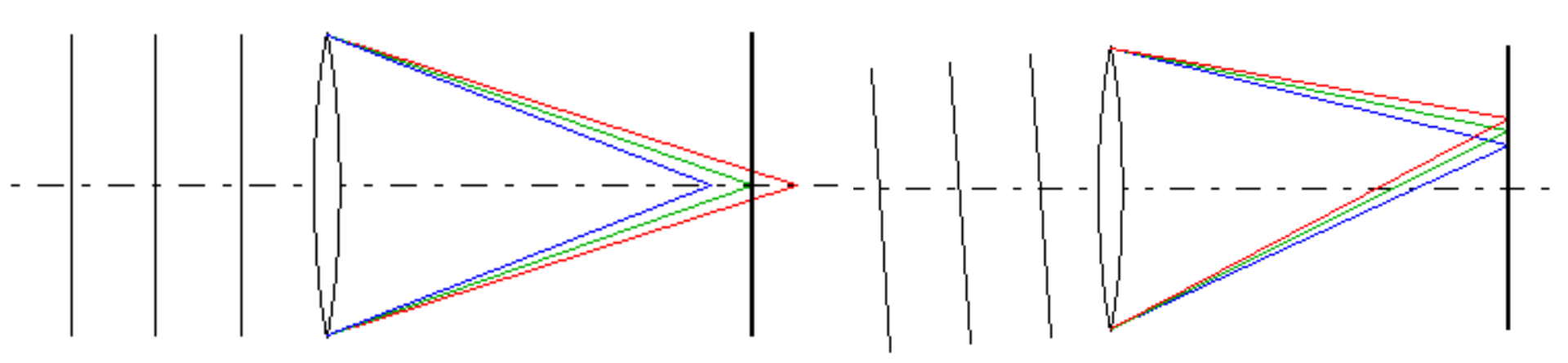

Spherical aberration

Off-Axis --- Coma

## Chromatic aberration

Longitudinal

Transverse



# Fixing little distortions

| | Focal length | | | |
|---|---|---|---|---|
| | Short | | Long | |
| Aberration | Mirror | Lens | Mirror | lens |
| Focal plane curvature | More | More | Less | Less |
| Spherical | More | More | Less | Less |
| Longitudinal colour | None | More | None | Less |
| Transverse colour | None | More | None | Little less |

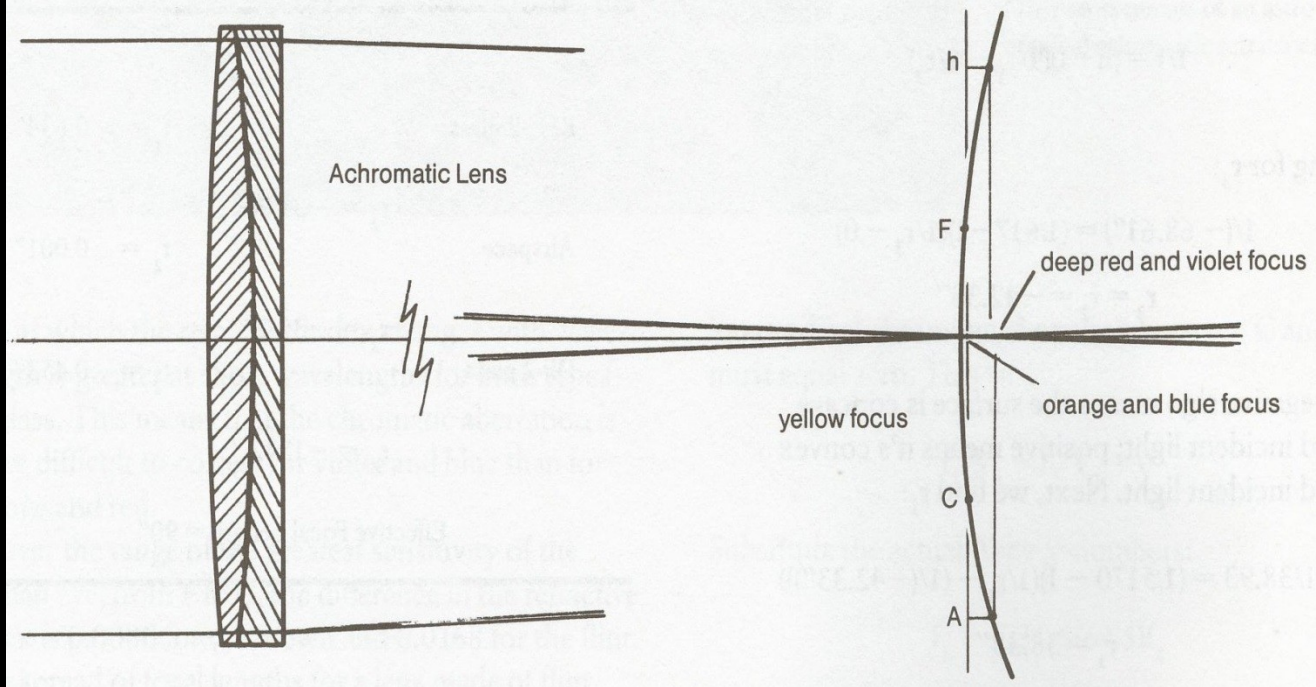
# Easy---make long telescopes

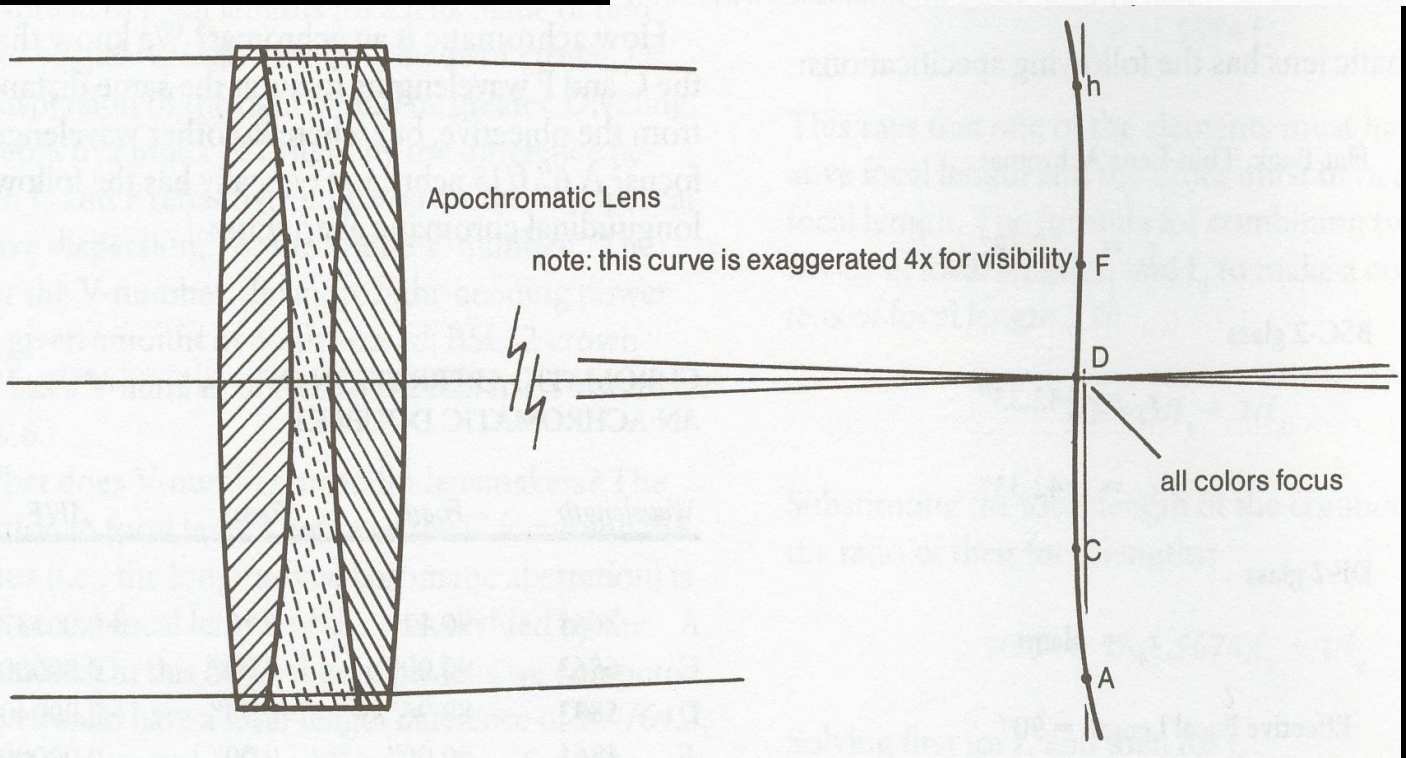
Yeah, right

Modern version of a seventeenth-century long-focus refractor in use. The aperture of the lens is 2.2″; its focal length is 168″.

Load this into your car!!!!

# Fixing refractors




Extra elements with different refractive indexes

# Glass is not just glass

# Reflectors -- more suitable for large aperture scopes

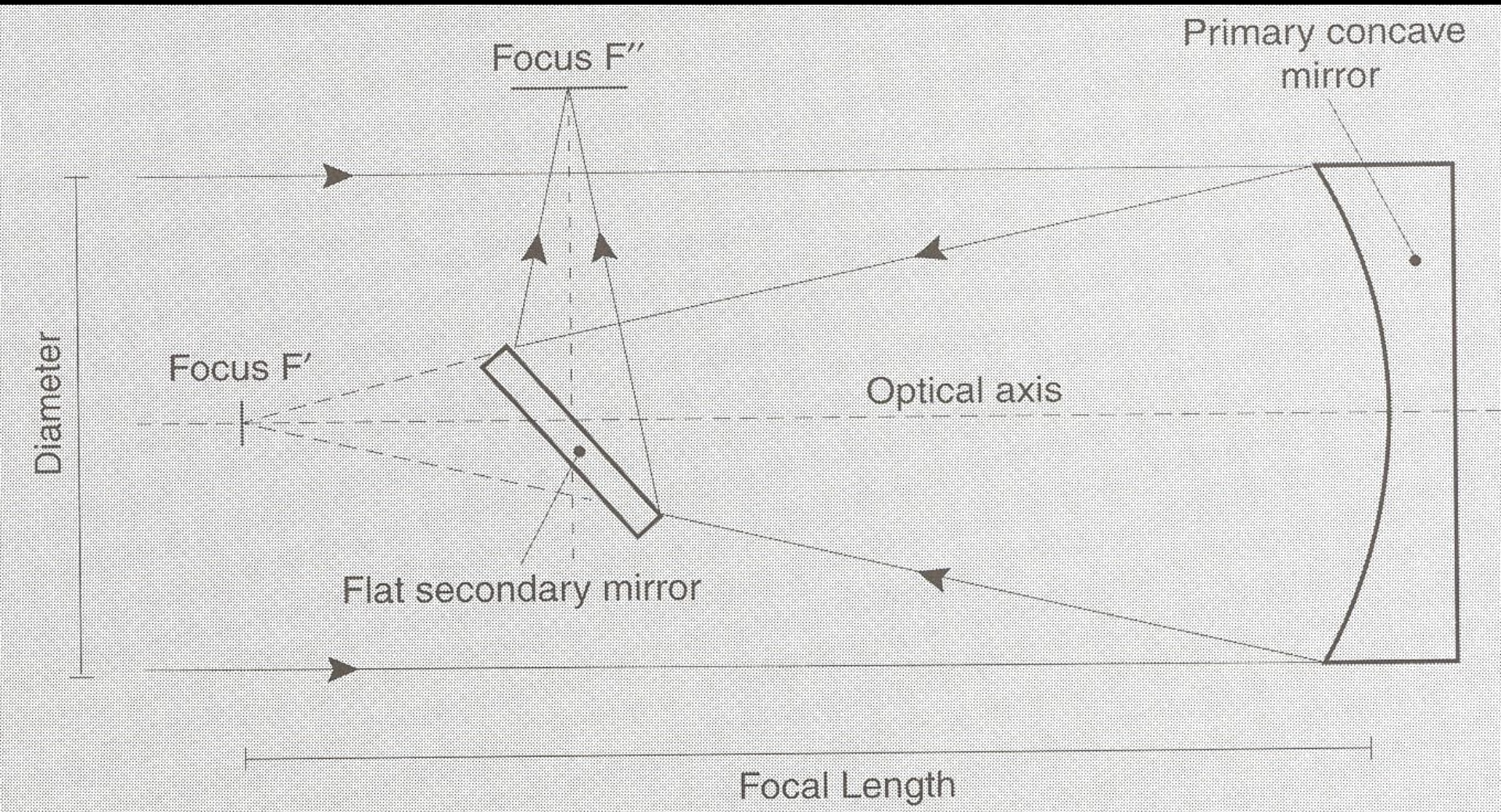
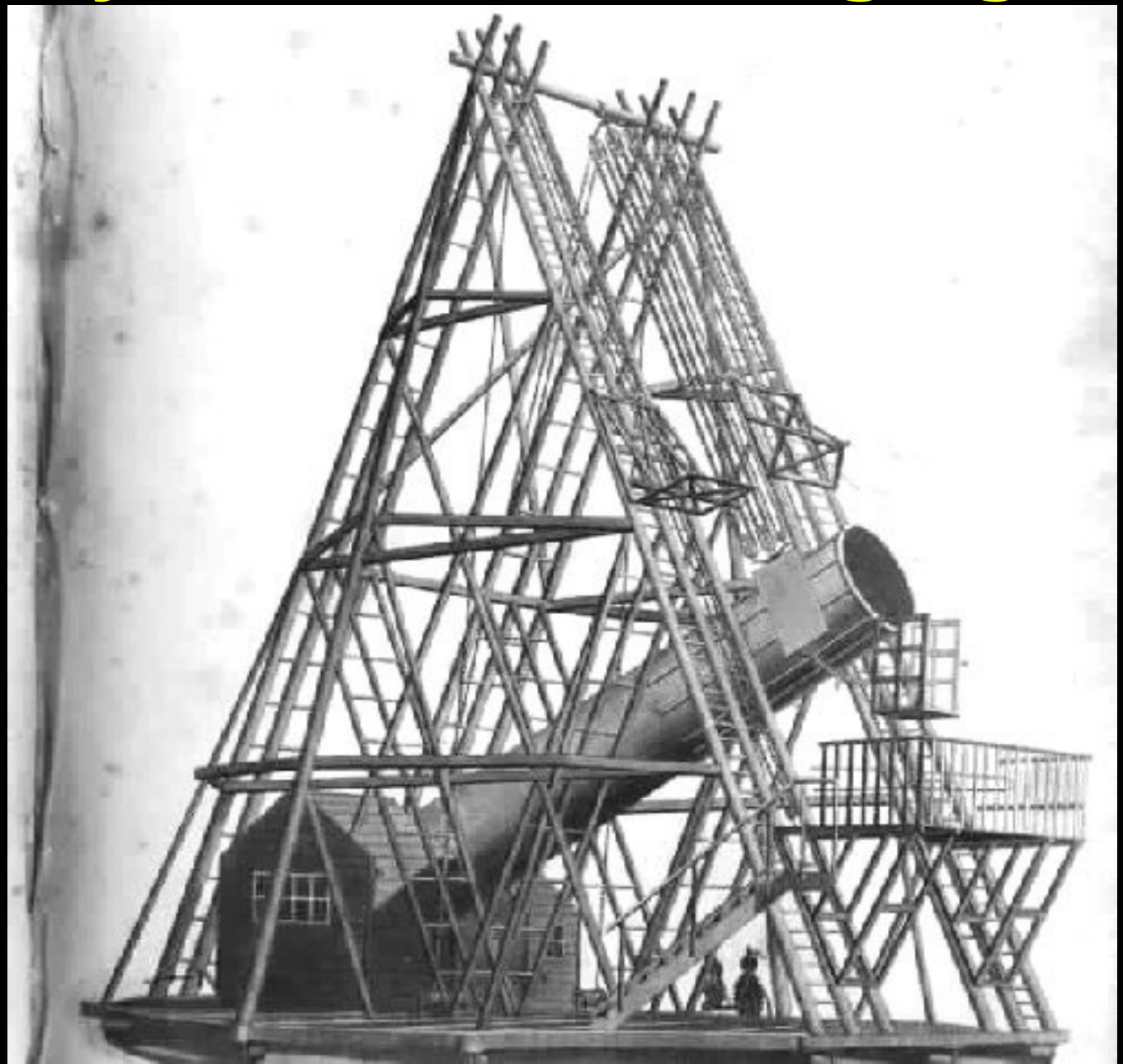
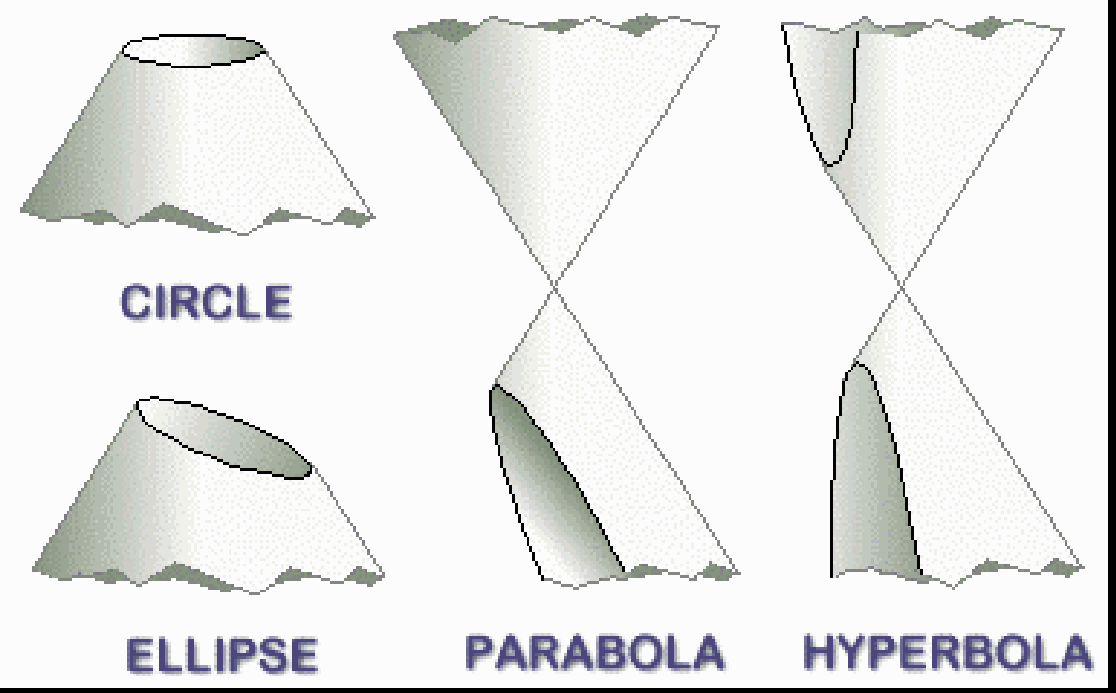
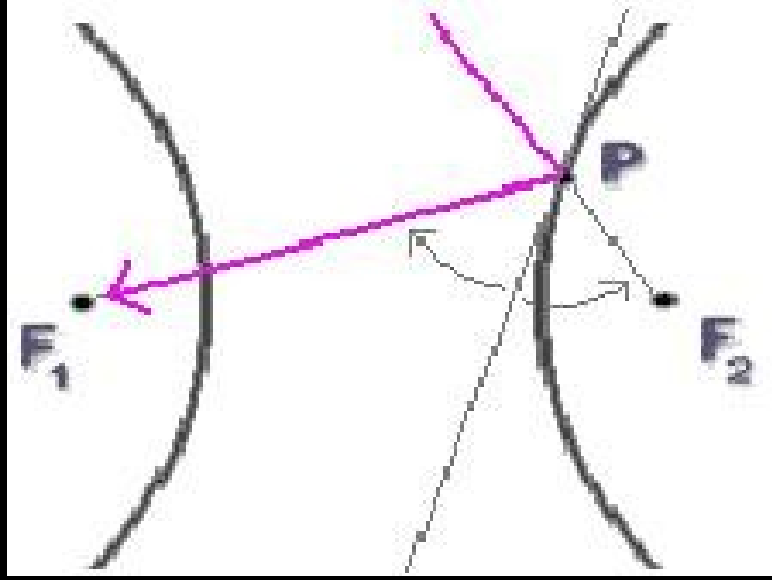



**Fig. 2.5 Principle of Newton's telescope.**

# Why not make it long again?

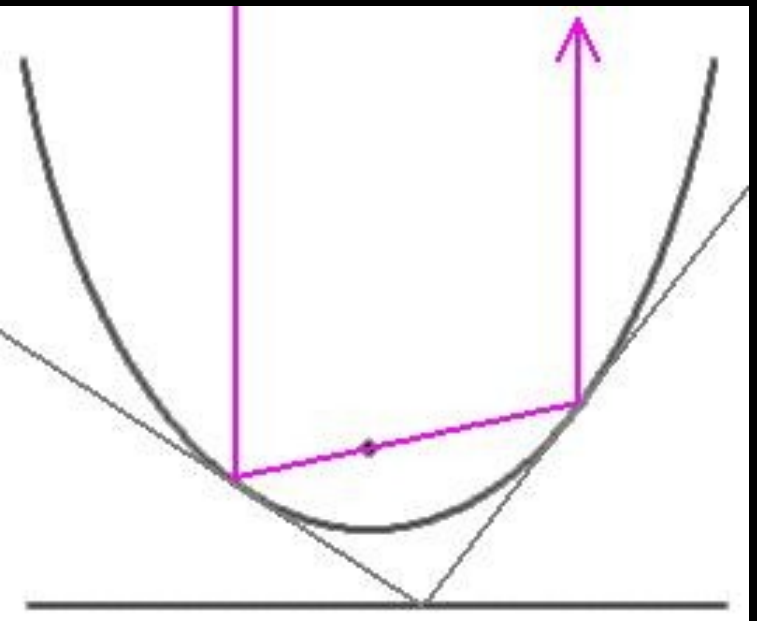




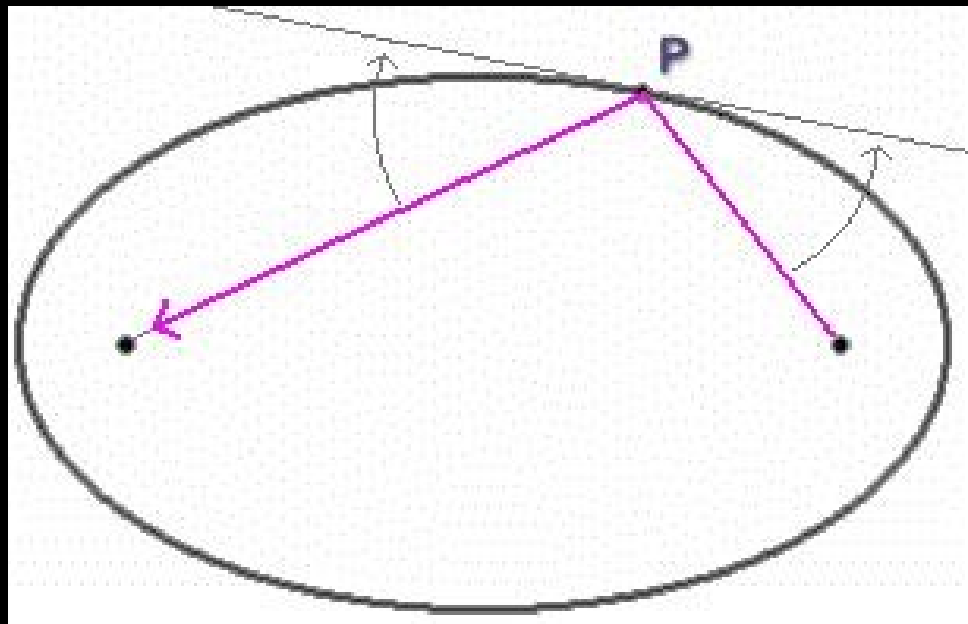




Hyperbole

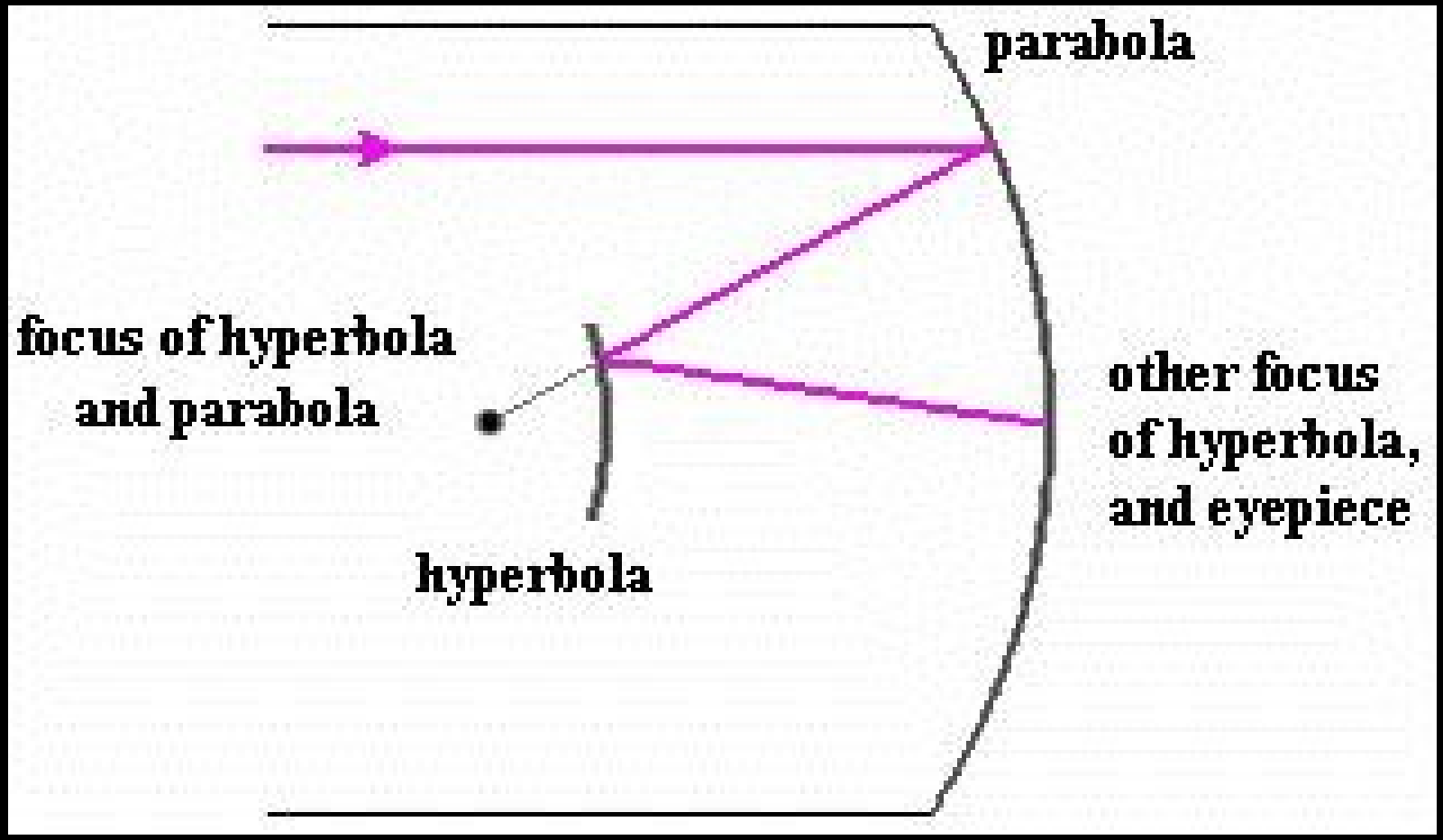
Parabola

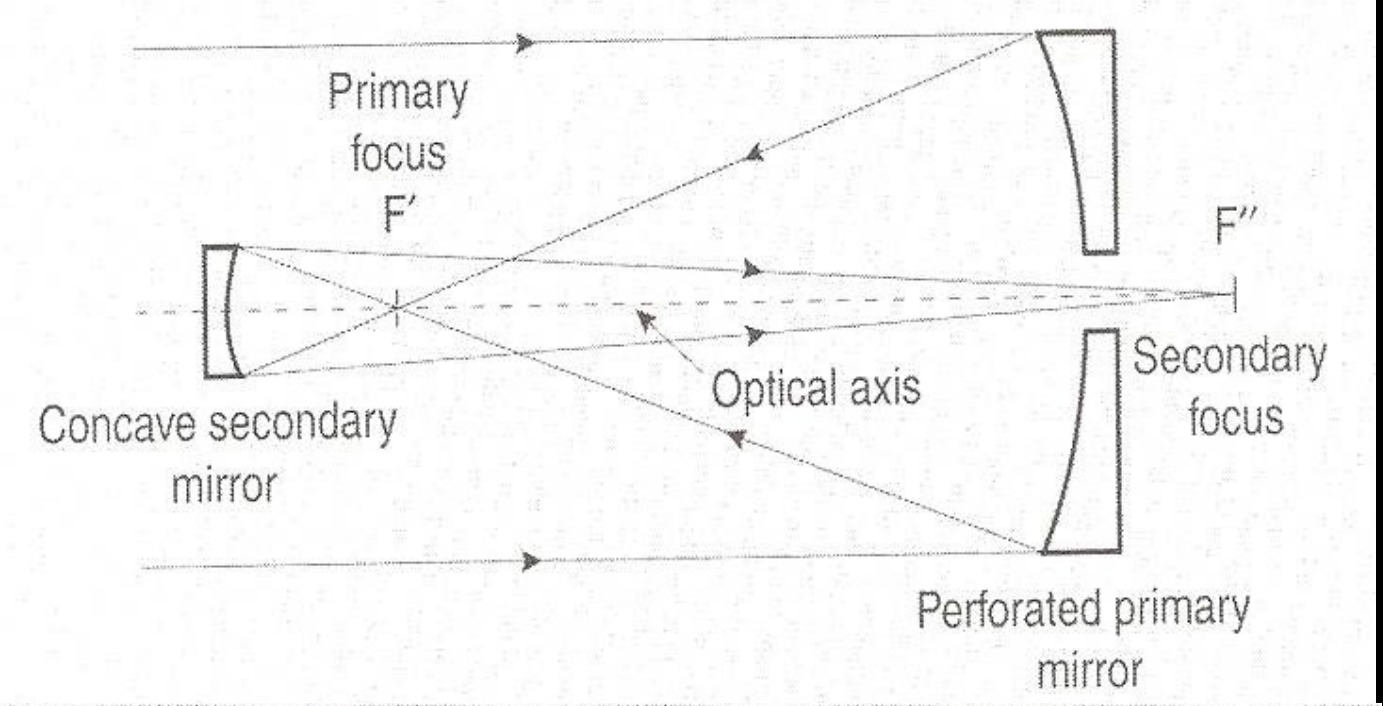


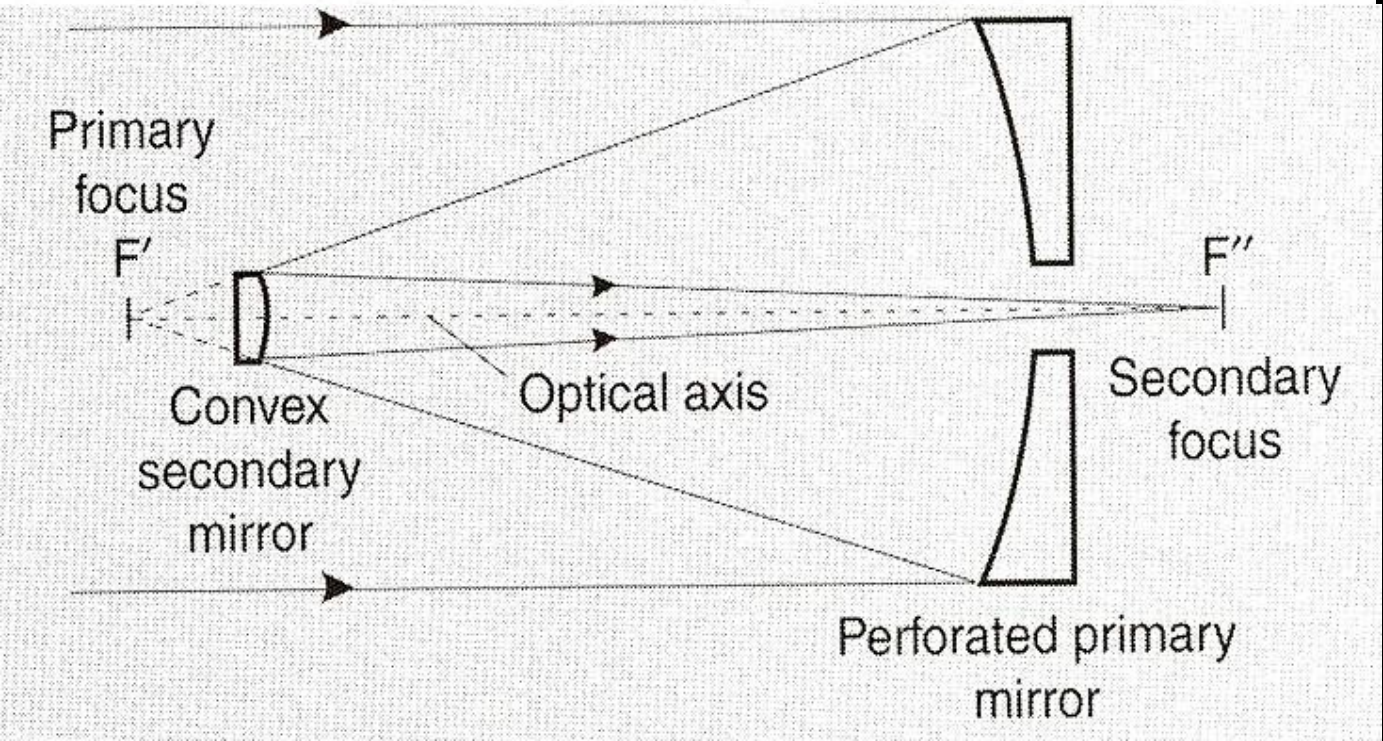
Ellipse



# Cassegrain principle






# The long and the short

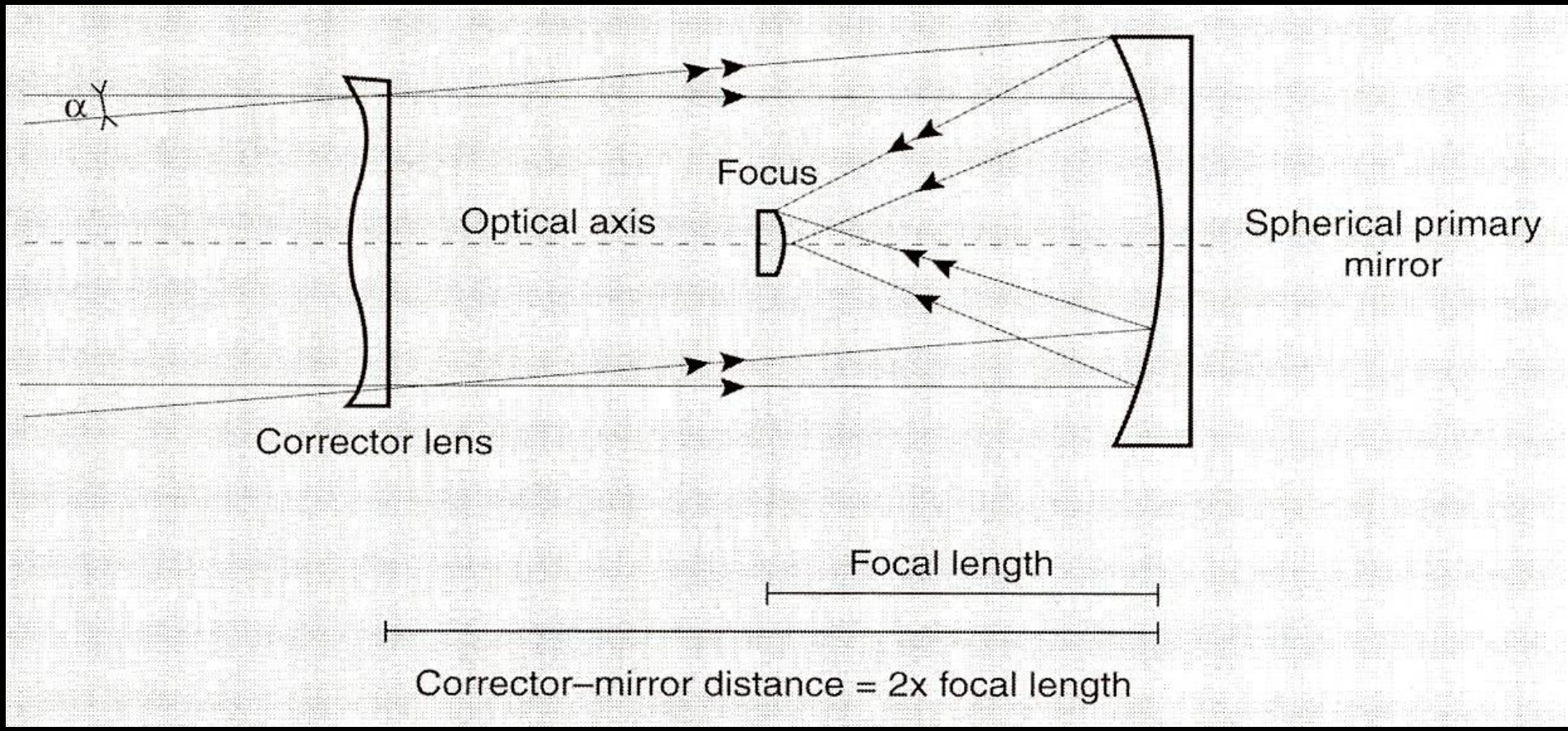
Gregorian

Coude derivative
No hole in primary
Diagonal flat in front of primary

Cassegrainians

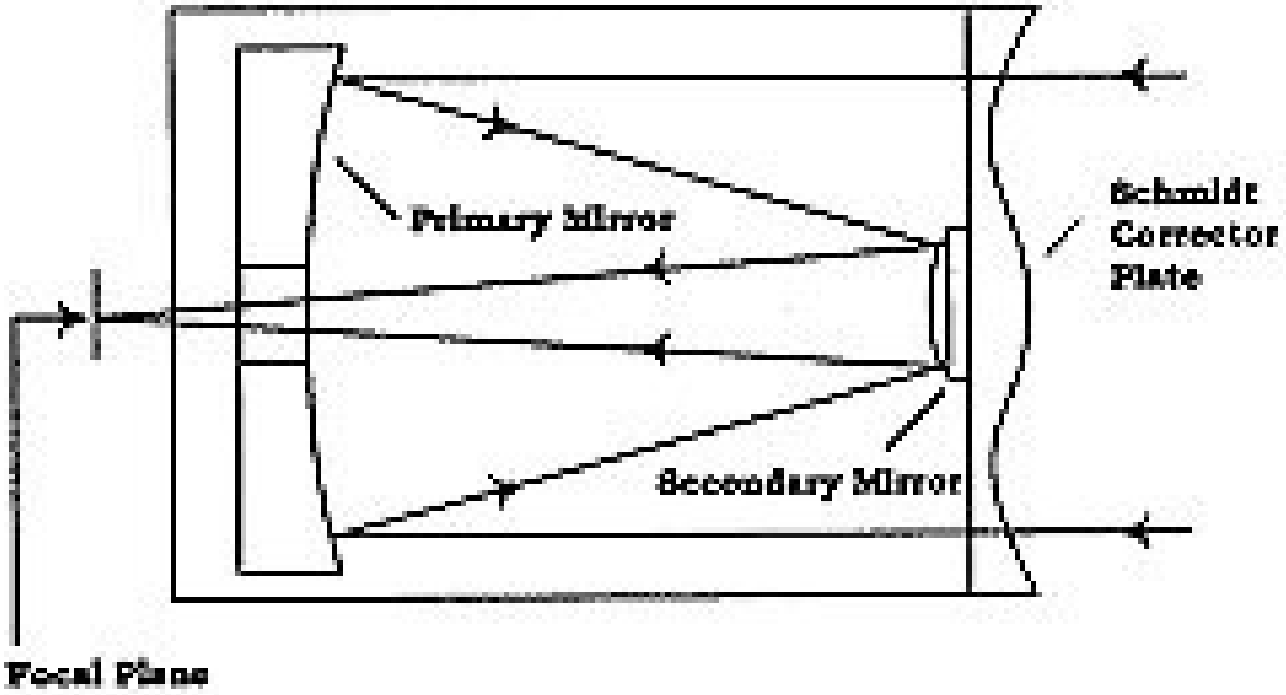
Classic
Dall Kirkham
Ritchey Chretien

# Correcting S.A. with extra optics

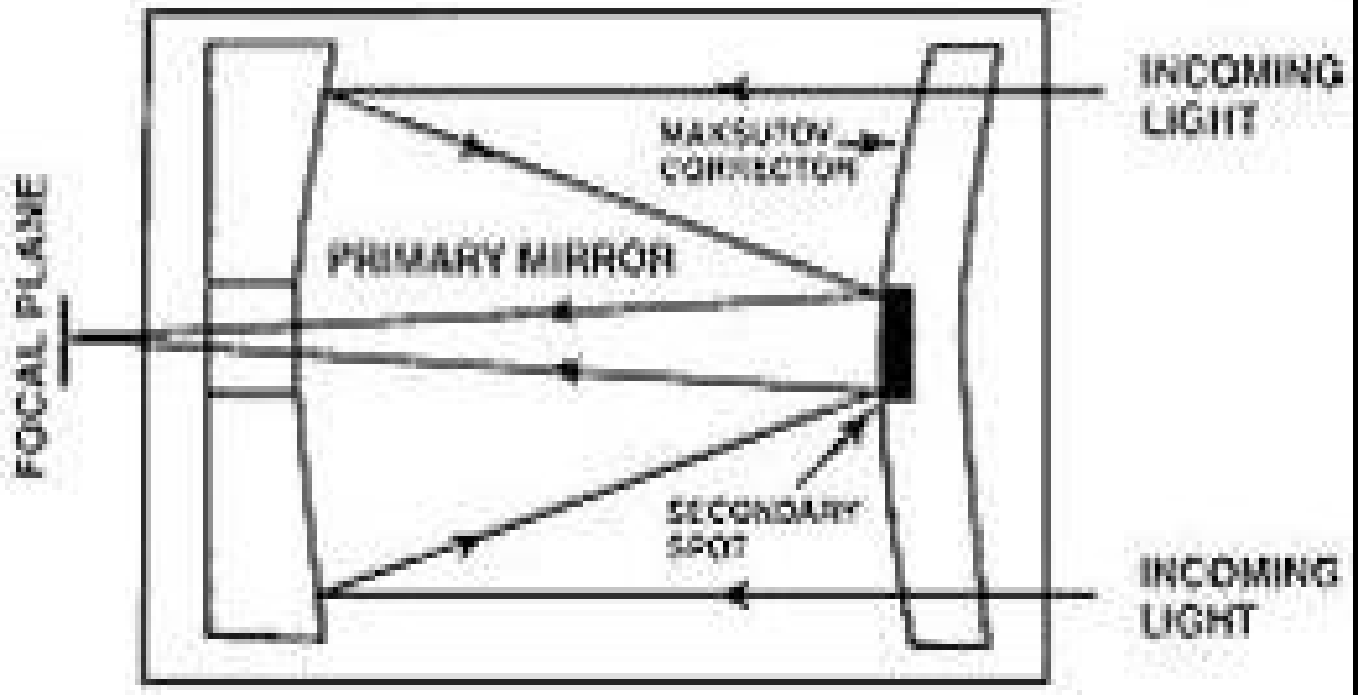



Catadioptric and lenses (mixed optics) Mirrors

# Mix it up




Schmidt
Cassegrain

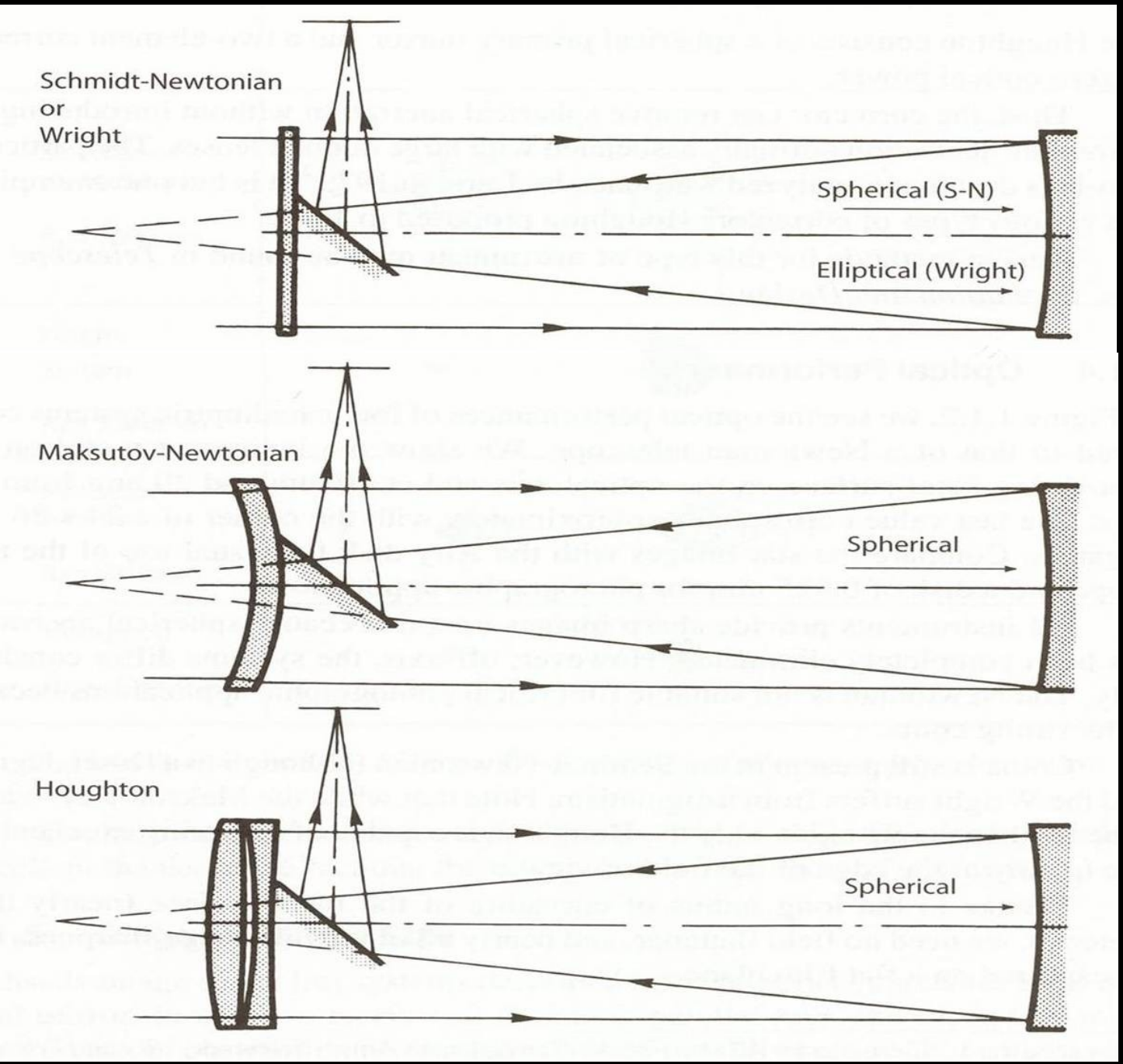



Maksutov
Cassegrain

# Summary common types

| Type | Primary | Secondary | Corrector/ Comments |
|---|---|---|---|
| Astrographic | 1 lens | | El cheapo |
| Achromatic | 2 lens | | 2 colours corrected |
| Apochromatic | 3 lens | | 3 colours corrected |
| Newtonian | concave-paraboloid | flat-diagonal | |
| Cassegrain | concave-paraboloid | convex-hyperbolic | |
| Dall-Kirkham | concave-ellipsoid | convex-spheroid | |
| Ritchey-Chretein | concave-hyperboloid | convex-hyperboloid | |
| Schmidt-Cassegrain | concave-spheroid | convex-spheroid | quadratic corrector plate (w curve) |
| Maksutov | concave-spheroid | convex-spheroid | double concentric- |

More mixing


Schmidt-Newtonian
or
Wright
Spherical (S-N)
Elliptical (Wright)
Maksutov-Newtonian
Spherical
Houghton
Spherical

Go forth and impress your friends.

Throw some names around

# Resolving power

How to get the best out of a telescope

# Perfect optical system

- Automatic iris
- Automatic focus
- Aspheric lens to match a curved image surface
- Chemical image intensifier
- Built-in washer-wiper
- Lens cover
- Stereo vision
- It is your eyes, but we still use telescopes---why?

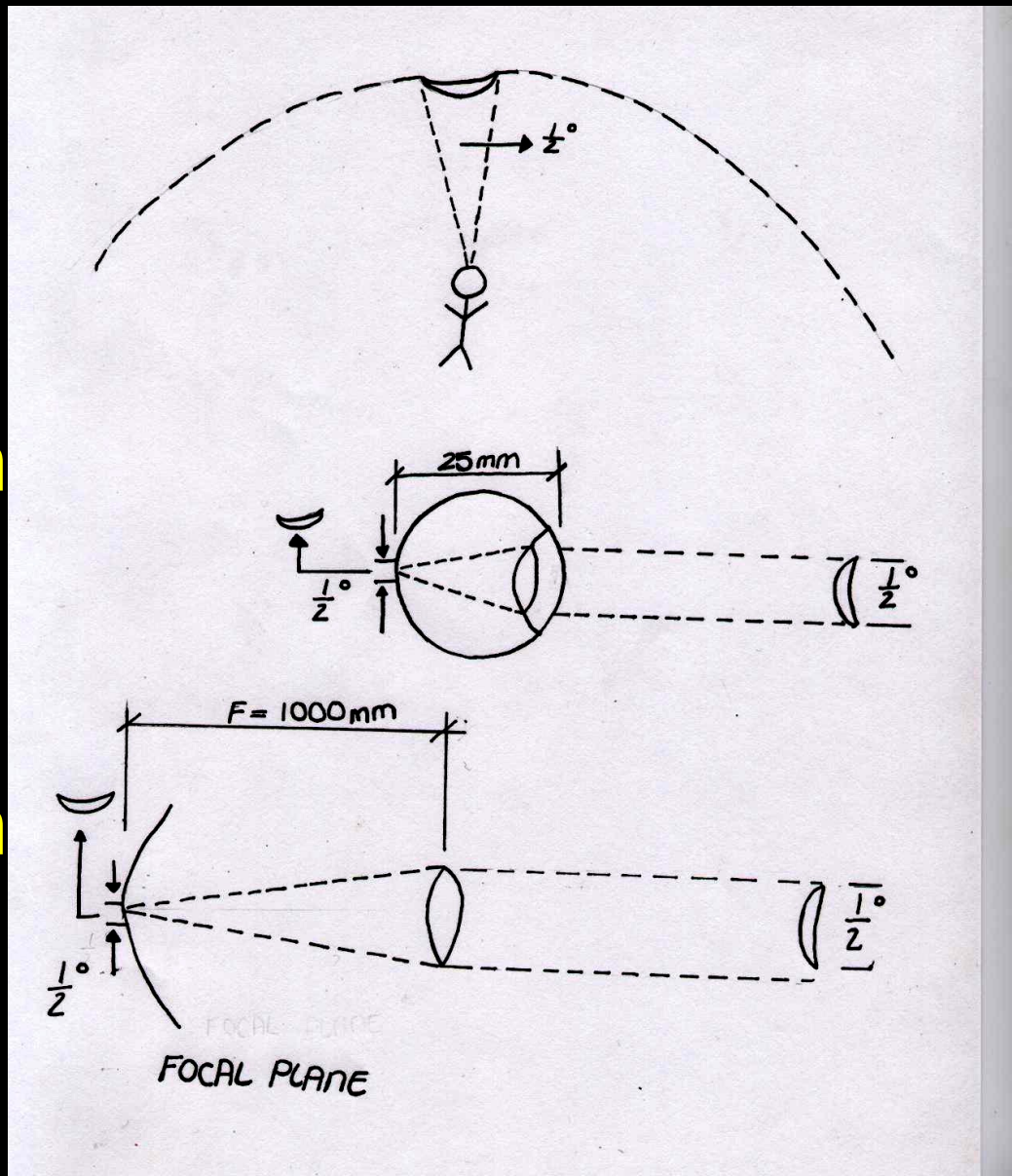
# Magnification

- Focal length
- ½ ° image

- F = 25 mm
- Image = 0.2182 mm

- F= 1000 mm
- Image = 8.7266 mm

- 40 x larger

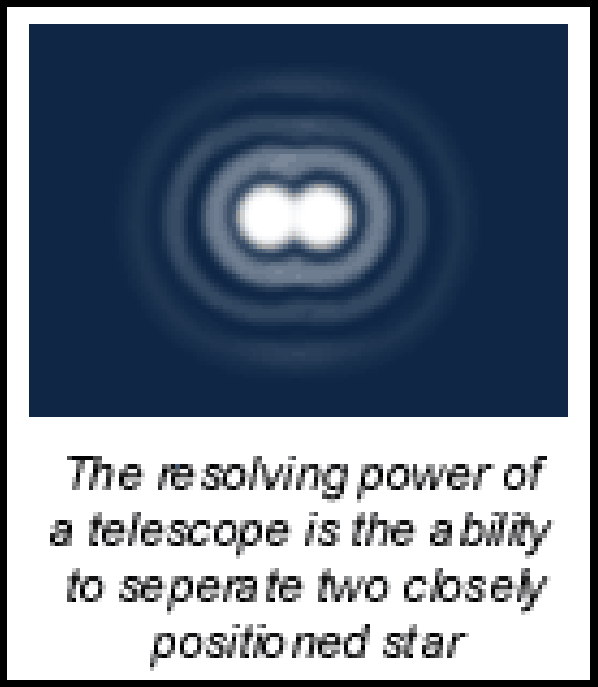


# Focus of lens or mirror.

- Smallest image possible = Airy disk
- Airy disk diameter d = 2.44 * W * (F / D)
- F/ D = Focal ratio
- Image is made up of lots of Airy disks.
- Airy disk for F8 = 0.0099552 mm
- Airy disk for F4 = 0.0049976mm
- Low F ratio = brighter photographic image
- Visually = virtually no effect on brightness

# Airy disk

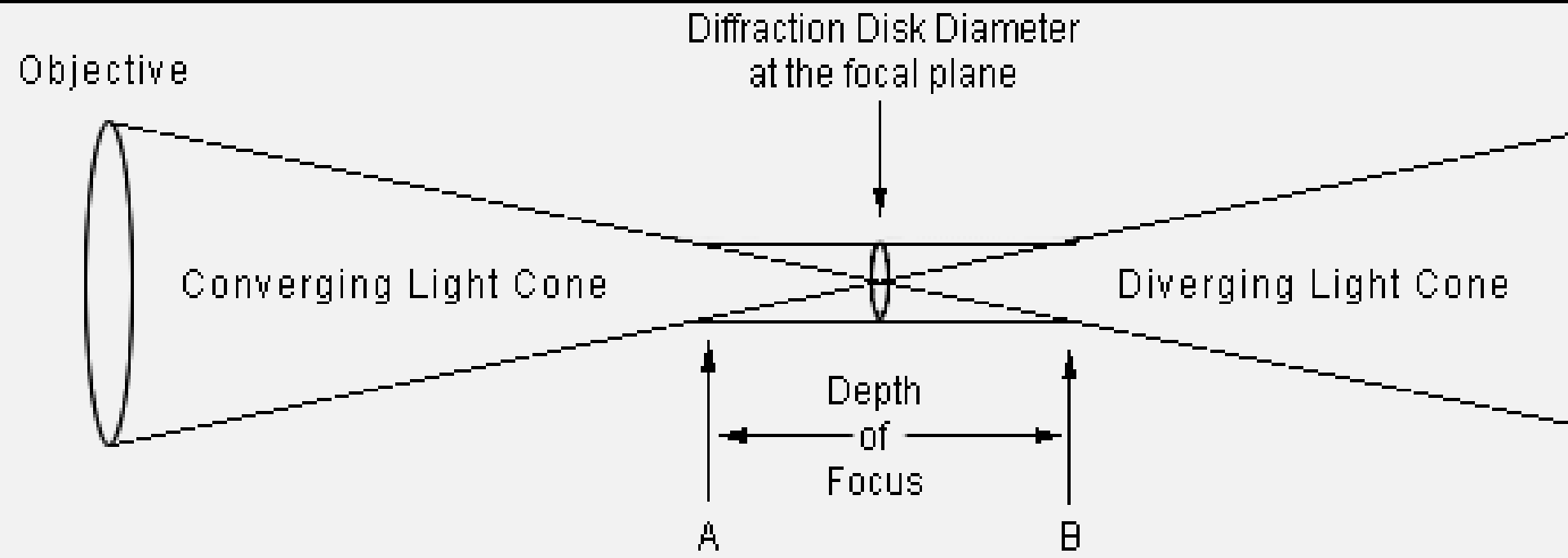
- Caused by diffraction of circular opening
- Ideal 84% in central dot
- Central obstruction brightens outer rings
- Brighter outer rings decreases contrast



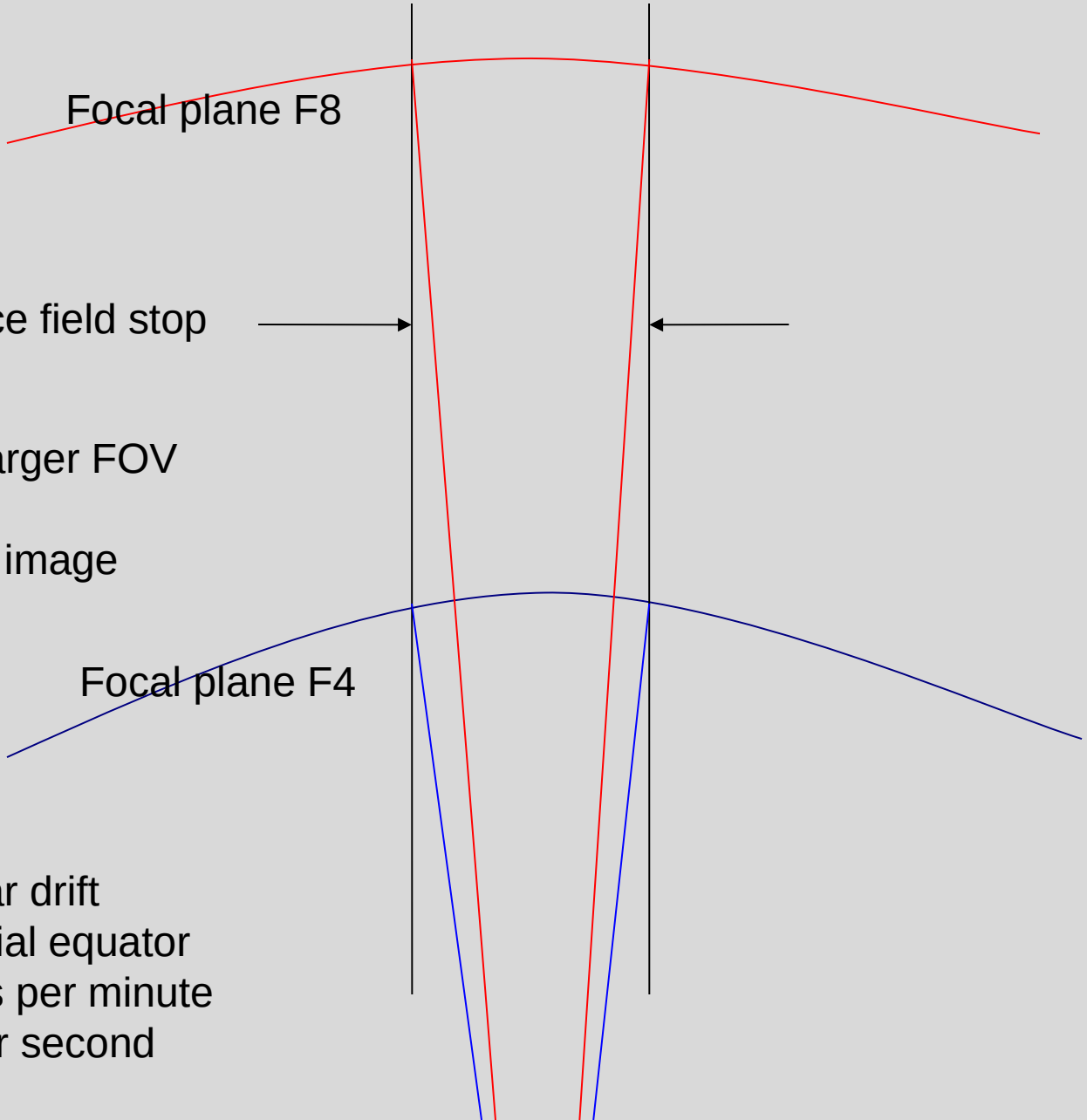
*The resolving power of a telescope is the ability to seperate two closely positioned star*

# How does the Airy disk affect focus

- Focus range = 2 * F/D * d (Airy disk diameter)
- F8 range = 0.203008 mm
- F4 range = 0.050752 mm
- F8 has 3.53 times more “range”



# Field of view




Shorter focal length = larger FOV
Lower magnification
Automatically “brighter” image

Determine FOV by star drift
Choose star on celestial equator
Drift at 15 Arc minutes per minute
Or 15 Arc seconds per second

# Ability to see small detail

- Angular resolution
- Θ ¨ = 4.9 / D (inches) or Θ ¨ = 120 / D (mm)
- D = diameter of objective
- Your eye,  Θ ¨ = 30¨
- 30¨ = R1 coin at 137,5 Meters
- 6 Inch telescope = 0,8167 ¨ -- 30 times better.
- Moon D = 3476 Km or ½ ° on 400 000 Km
- Eye can resolve 58 Km
- 6 inch telescope resolves 1.58 Km

# To see the lunar Landers

- Assume Lander is 5 Meters in diameter
- At 400 000 Km it is 0.00258¨
- You need a 45 Meter mirror
- And, atmosphere has 1¨ lim
- 1¨ = R1 coin at 4,125 Km.
- 1¨ = Golf ball at 10 Km.
- Do not even try to find them

# Resolution (Resolving power)

- **The relationship of magnification of extended objects to resolution:**
- Angular resolution defines the angular size of diffraction disk.
- Smaller aperture = coarser dot structure of image
- Small aperture – do not use high magnification.
- Maximum recommended M = 50 x aperture in inches.
- or 2 x Aperture in mm.
- **Resolution as it applies to diffraction disks:**
- Size of diffraction disk defines the minimum angular separation that can be resolved.
- Larger aperture = smaller diffraction disk.
- Lower F-ratio = smaller diffraction disk.
- Fast telescopes with high magnification – best to resolve double stars

# Contrast and definition

- The contrast of an image is dependent upon the amount of light which is contained in the central disk versus the surrounding rings.

- The optical perfection of the system: The lower the quality, the lower the contrast.
- The size of an obstruction in the optical path of a telescope reduces contrast.

- Definition is a function of the optical accuracy of the system. The more precise the optical accuracy, the finer the definition will become.

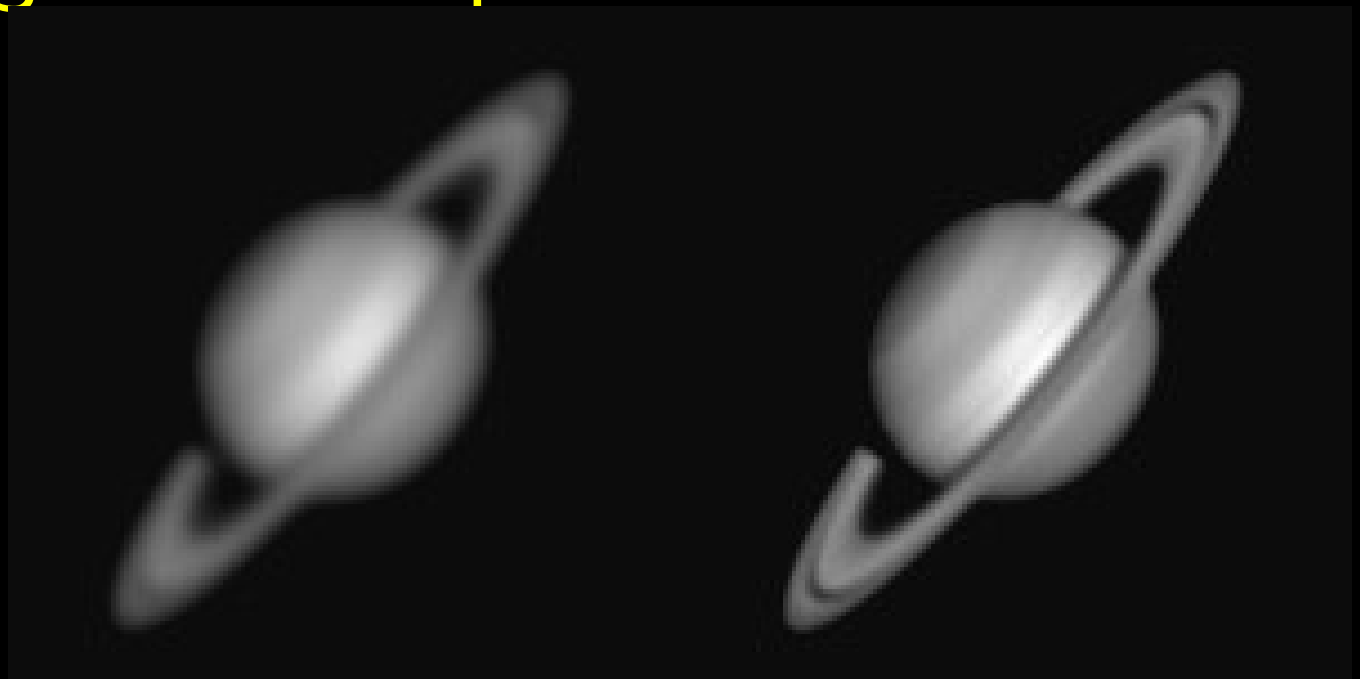
- A good quality 2 inch refractor will give exceptional contrast and definition, but can only resolve 2.28 seconds of arc.

- A large optically flawed instrument will give poor contrast and definition but will be fairly adequate in resolution.

# What affects seeing

- Atmospheric conditions


- Optical misalignment
- Biggest telescope killer



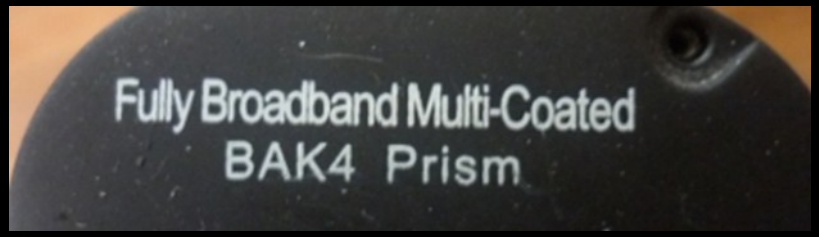
# General rules

- **Low power viewing:**
- Use the highest power that frames the subject
- **High power viewing:**
- Use the lowest power that reveals the detail you're looking for.

# Guidelines to practical magnifications

| | |
|---|---|
| Minimum useful magnification | 0.13*D (or 0.2*D for better contrast) |
| Best visual acuity | 0.25*D |
| Wide views | 0.4*D |
| General viewing | 0.5*D to 1.0 *D |
| Normal high power, double stars | 1.2*D to 1.6*D |
| Close doubles | 2.35*D |
| Maximum useful magnification | 2.0*D |
| Messier objects, general viewing | 0.8*D |
| Sweet spot | 0.5*D |

# The minefield of binoculars




Tells you exactly nothing about these, in no particular order:

Quality of internal light-baffling.
Type and quality of eyepieces.
Prism housings.
Field curvature.
Spherical aberration.
Crispness of focus.
Edge distortion.
Amount of vignetting.
Size of fully illuminated field of view.
Chromatic aberration.
Mechanical build quality.
Smoothness of focus.
Manufacturer's quality control.

# But the prisms are good?

- "**BAK4**" glass used for the prisms of Chinese binoculars is not the same as **Schott BaK4**
- It's not even Barium Crown, which is what **BaK** stands for!
- It is a phosphate crown glass with a lower refractive index and dispersion than **Schott BaK4** (but higher than **BK7**).
- It also potentially has a higher "bubble count"; this is noticeable as a slight milkiness to the image when compared with good quality glass.

| Glass Type | Refractive Index | Critical Angle | Dispersion |
|---|---|---|---|
| Schott BaK4 | 1.5688 | 39.6° | -0.0523 $\mu m^{-1}$ |
| Chinese BaK4 | 1.5525 | 40.1° | -0.0452 $\mu m^{-1}$ |
| Schott BK7 | 1.5168 | 41.2° | -0.0418 $\mu m^{-1}$ |

# Neither does BAK 4 tell you:

- Is the prisms are under-sized? If they are, they will cut out some light.
- The precision with which the flat surfaces of the prism have been polished
- Is the prisms hypotenuses grooved? Grooved prisms reduce spurious reflections.
- Is the prism sides blackened? Prevents non-image-forming light entering the prism.
- Is the reflective surfaces of the prisms shielded? Prevents non-image-forming light entering the prism.
- How the prisms are secured into their housings?
- There's an enormous difference between glue and a properly constructed prism cage.


BK7
BaK4
Fully Broadband Multi-Coated

# At least the coatings are good?

***There is no industry-wide standard for the term "Fully Multi-Coated"***.

It could mean that all glass-to-air surfaces of the lenses in the objectives and the eyepieces, and the transmissive faces of the prisms, all have 7 layer interference coatings (properly applied).

Or it may mean that just the glass-to-air surfaces of the lenses have 2 layer interference coatings.

You have no way of knowing.

# Magnification and aperture is good?

They can lie:
The top one is actually a 10 x 50.


The lower one is actually a 15 x 22!!!!
Advertised as as being "*Day and Night Vision Binoculars*"?

Beware

Measure the diameter of the objective lens, you may find it is indeed 50mm.

So, is it a 10×50?
Well, not really.

If you measure the exit pupil, it should be 5mm (50mm ÷10), but it isn't.
It's 4.2mm.

That means it's effectively a 10×42.

A 50mm transmits nearly 1½ times as much light as a 42mm.

# WHY?

If you stop it down to 42mm, you can get away with smaller prisms.

Smaller prisms require smaller housings and less robust fixing.

Stopping it down to 42mm increases the effective focal ratio from around f/3.5 to around f/4.2.

This makes much less demand on eyepiece quality and improves colour correction and edge performance

So much easier to do than by using better quality optics!

# Try before you buy

What is printed on a binocular cover plate does not necessarily tell you *anything* about the binocular.

I have yet to see a Fully Multi-coated budget 10×50 with BAK4 prisms that gives images of the quality or brightness of a genuine Zeiss (Jena) 10×50 (single-layer coatings and BK7 prisms);

Maybe now you know why.

# Remember this slide?

| | |
|---|---|
| Minimum useful magnification | 0.13*D (or 0.2*D for better contrast) |
| Best visual acuity | 0.25*D |
| Wide views | 0.4*D |
| General viewing | 0.5*D to 1.0 *D |
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# Using exit pupil

Confused?

Not to worry

Me too