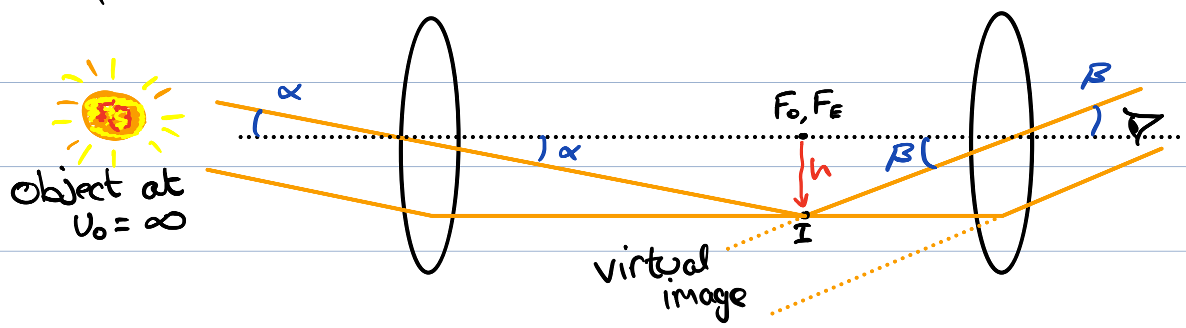
# Telescopes

There are two types of telescopes: reflecting and refracting.

## Keplerian Telescope (Refracting)

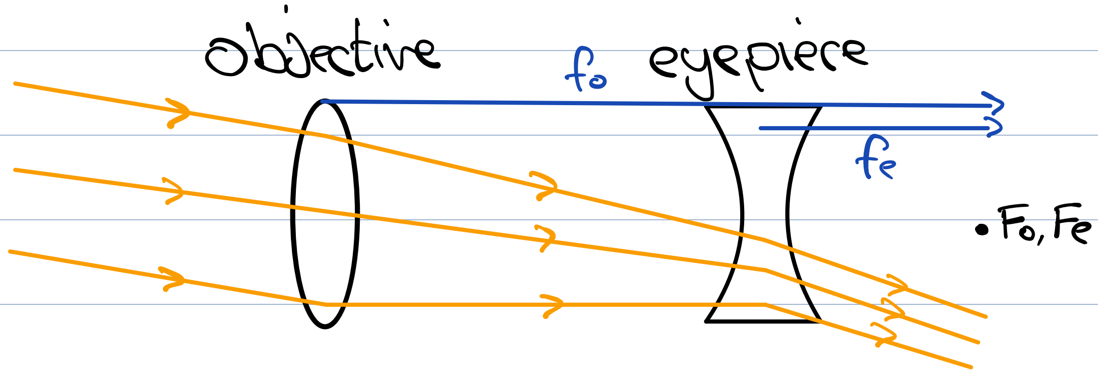
Made from two convex lenses.




The lenses must be $d = f_o + f_e$ apart. The angular magnification is $M = -\frac{\beta}{\alpha} = -\frac{f_o}{f_e}$. A high magnification telescope needs to be very long.

## Galilean Telescope (Refracting)

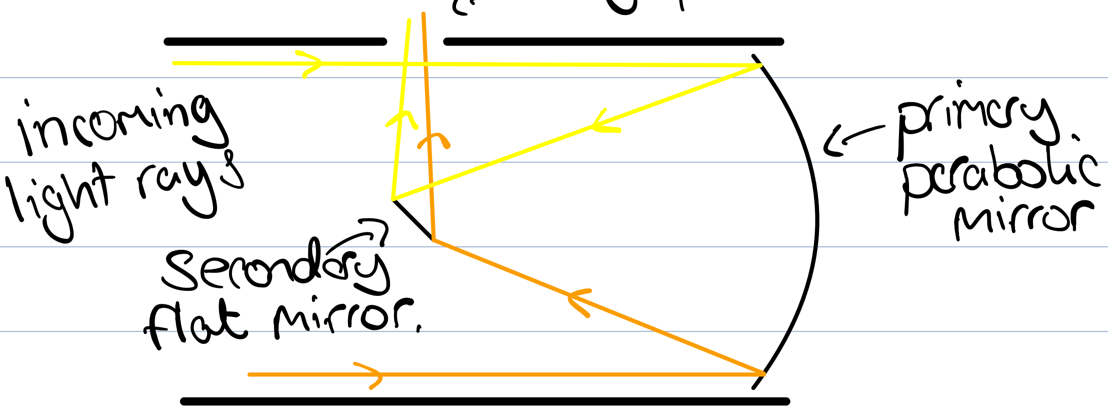
Made from one convex and one concave mirror.




The lens must be $d = f_o - |f_e|$ long - this is shorter than the Keplerian telescope. Its angular magnification is $M = +\frac{\beta}{\alpha} = \frac{f_o}{|f_e|}$. It has the same mag. as Keplerian but not inverted.

## Newtonian Telescope (Reflecting)

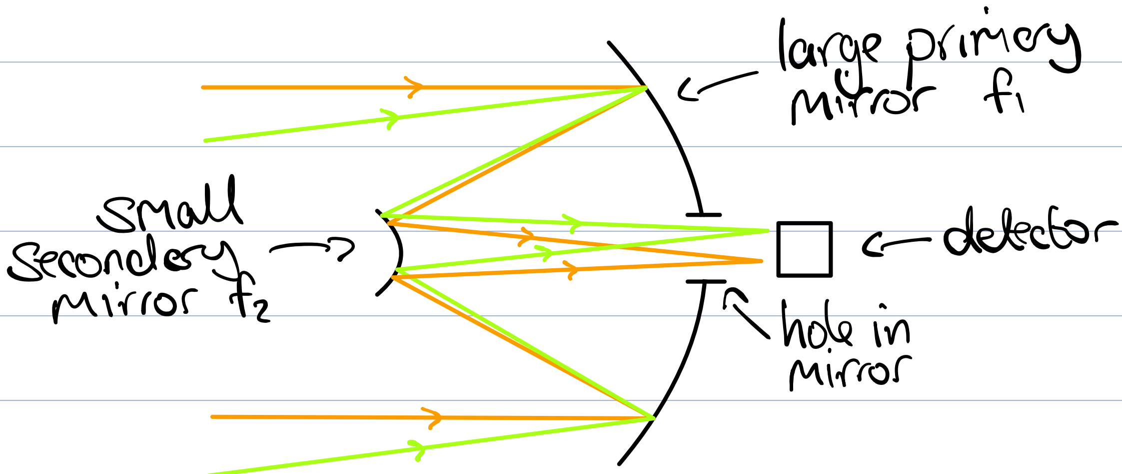
Made from one parabolic mirror and a smaller flat mirror.




Newton invented this type of telescope to solve chromatic abberation due to the lenses. Little use in present.

## Cassegrain Telescope (Reflecting)

Made from one concave and one convex mirror.




The mirrors must be $d = f_1 - |f_2|$ apart. The angular magnification is $M = +\frac{\beta}{\alpha} = \frac{f_1}{|f_2|}$. JWST

There are advantages to using reflecting telescopes.

- large diameter

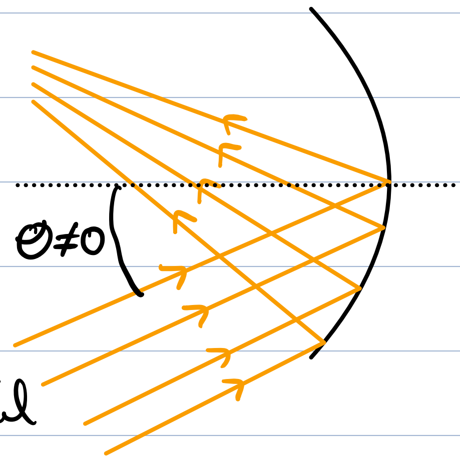
- No chromatic abberation
- can reflect visible, IR, micro + radio, lens can only do UV + visible.

## Abberations

An abberation is an error in bringing together rays to an image point, the image appears blurred. It is because the OPL is not constant.

A parabolic mirror does not suffer from chromatic abberations. However if the light entering is off-axis then we get <u>COMA</u> abberations.

Central rays near the vertex ($r \approx 0$) give paraxial image point.




Marginal rays ($r \neq 0$) miss paraxial point with increasing error.

A Cassegrain telescope is able to reduce the COMA error.

## Lens Abberations

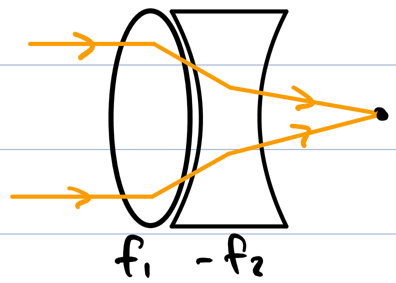
A thin lens cannot satisfy Fermat's Principle for non-paraxial angles.

Chromatic abberations occur since dispersion depends on refractive index $n(\lambda)$. $\therefore$ focal length changing with wavelength.

For a thin lens, the lens' maker equation becomes

$$\frac{1}{f(\lambda)} = [n(\lambda) - 1]\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

To correct for chromatic abberation, we can use two lenses with different refractive indexes.



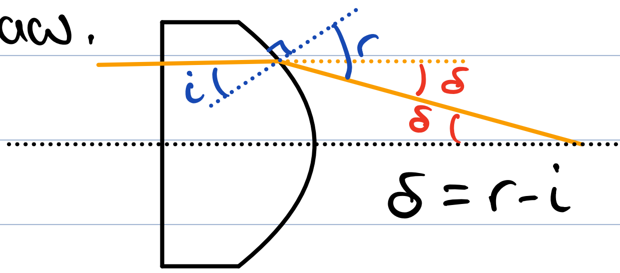

The two lenses have equal and opposite errors so OPL is roughly the same for all $\lambda$. Called an achromatic doublet lens.

## Monochromatic Abberations

- Spherical Abberation: error in imaging on-axis object for marginal rays (large $r$).
- Coma Abberation: error in imaging off-axis object (large angle $\theta$)
- Field Curvature: relative error mapping flat object plane of points to curve of points in image plane.

## Spherical Abberations

There is a significant abberation in lenses due to the nonlinearity of Snells law.




$$\delta = r - i$$

$$n_1 \sin i = n_2 \sin r$$
$$n_1 [i - i^3/3] = n_2 [r - r^3/3]$$

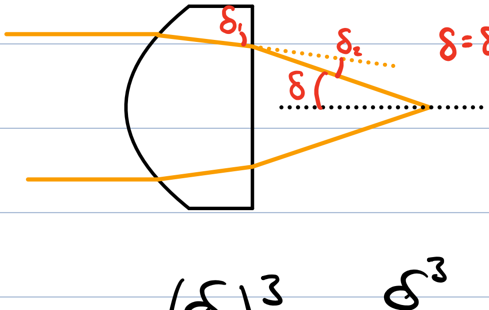
let $n_2 = 1$ & $n_1 = n$, rearranging gives

$$\delta = r - i = (n-1)\, i + \tfrac{1}{3}(r^3 - n i^3) = \delta + \Delta\delta$$

This gives the paraxial deviation $\delta = (n-1)\, i$ and the abberation $\Delta\delta \approx \frac{1}{3}(r^3 - n i^3) \propto \delta^3$.

This leads to spherical abberations, even if the lens is parabolic.

To reduce spherical abberations we should reduce the angle that light enters the lens. For a plano-convex lens, placing the convex part first reduces the error $\approx 4\times$.




$$\delta = \delta_1 + \delta_2$$

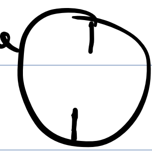
$$\delta_1 \approx \delta_2 \approx \frac{\delta}{2} \qquad \Delta\delta \propto 2 \cdot \left(\frac{\delta_0}{2}\right)^3 = \frac{\delta^3}{4}$$

More surfaces $(n)$ is better. $\Delta\delta \propto n \cdot \left(\frac{\delta}{n}\right)^3 = \frac{\delta^3}{n^2}$ which can make the error negligible.

When the object is distant but the image is near use a planoconvex lens.

When object and image distances are similar use a biconvex lens.

A spherical ball lens is able to limit Coma and spherical abberations. It has a principle axis for all ray angles and an aperture in centre can stop marginal rays. However it doesn't stop field curvature.



A camera lens set-up also stops chromatic abberations (different material) and a final lens solves field curvature.

In the human eye, the curvature of the retina solves field curvature

When a lens has been designed so well to eliminate all abberations it becomes diffraction limited.