TOPICS

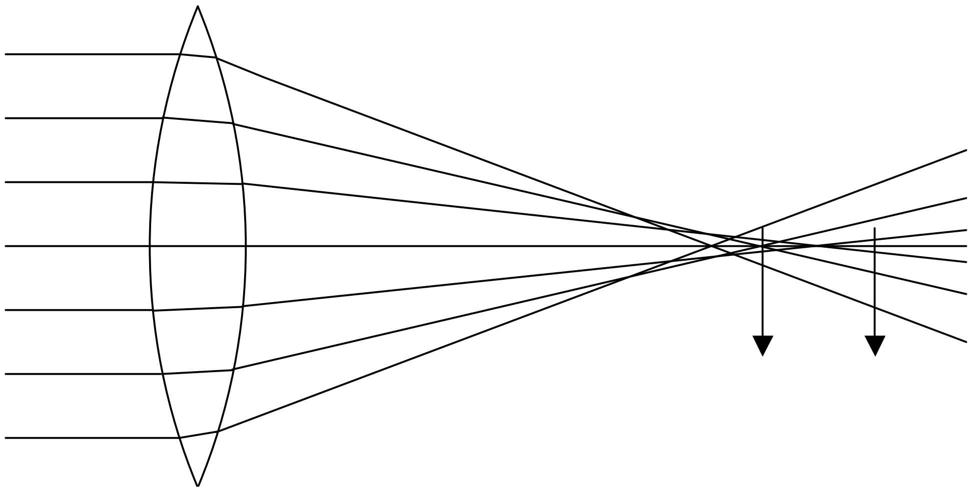
- Recap of PHYS110 *- 1 lecture*
- Physical Optics *- 4 lectures*
  - EM spectrum and colour
  - Light sources
  - Interference and diffraction
  - Polarization
- **Lens Aberrations** *- 3 lectures*
  - Spherical aberrations
  - **Coma, astigmatism, field curvature, distortion**
  - Chromatic aberrations
- Instrumental Optics *- 4 lectures*
  - Telescope, microscope
  - Stops, eyepieces
  - Instruments for the anterior eye
  - Instruments for the posterior eye

Lecture 7:

- Other monochromatic aberrations:
  - Coma
  - Oblique astigmatism
  - Curvature of field
  - Distortion
- Astigmatism in the eye
  - Cross-cylinders

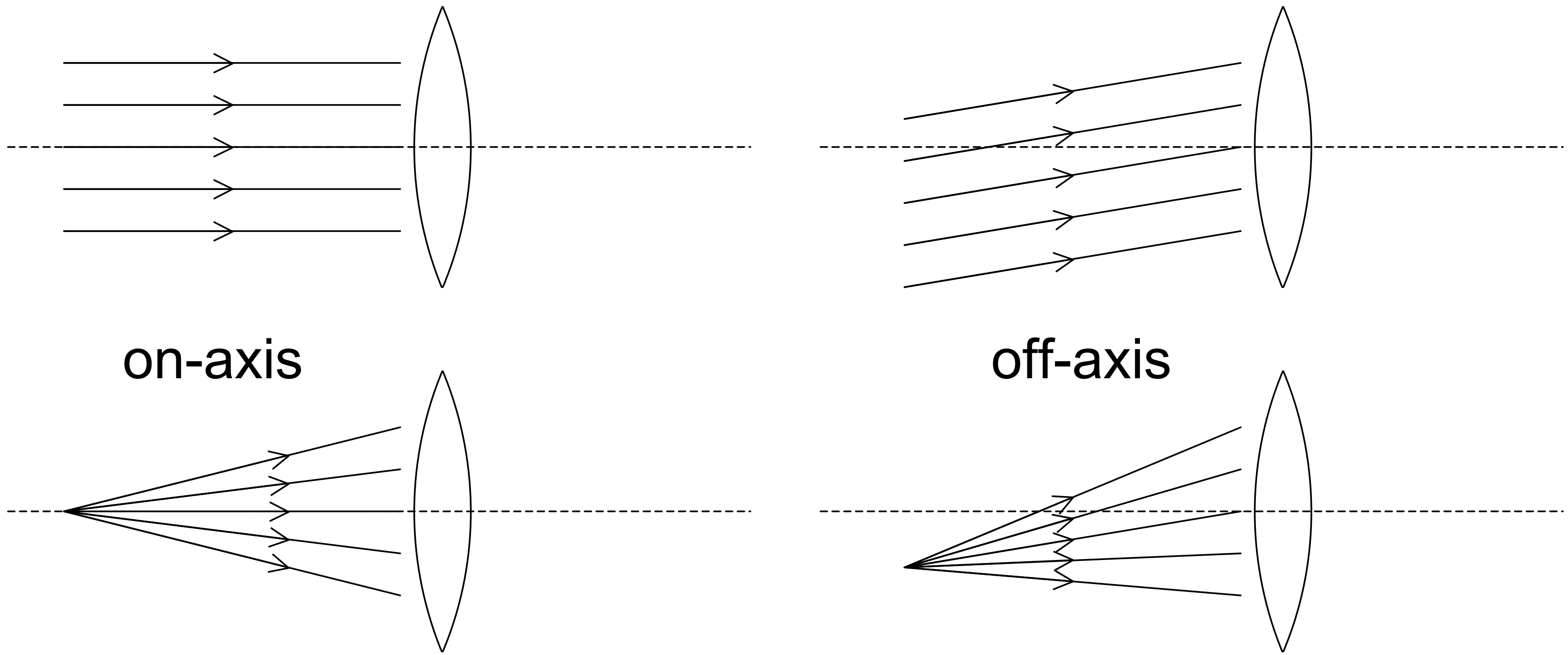
Spherical aberrations

- True bending according to Snell's law ($n_1 \sin\theta_i = n_2 \sin\theta_r$) is stronger than the paraxial approximation ($n_1\theta_i = n_2\theta_r$), in particular at large θ.
- As a result, parallel light far away from the principal axis is focused stronger than light close to the optical axis



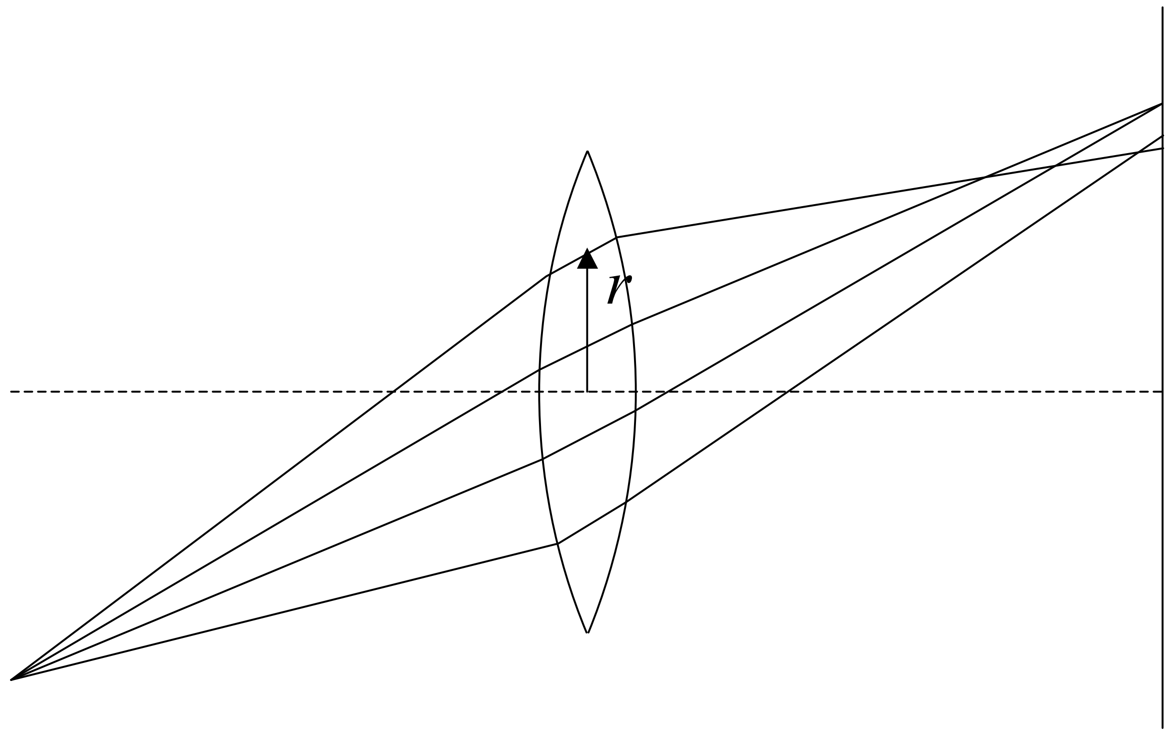
Oblique incidence

- Spherical aberrations refer to light from objects on the principal axis (on-axis).
- For light from objects not on the principal axis, (off-axis) four extra aberrations occur



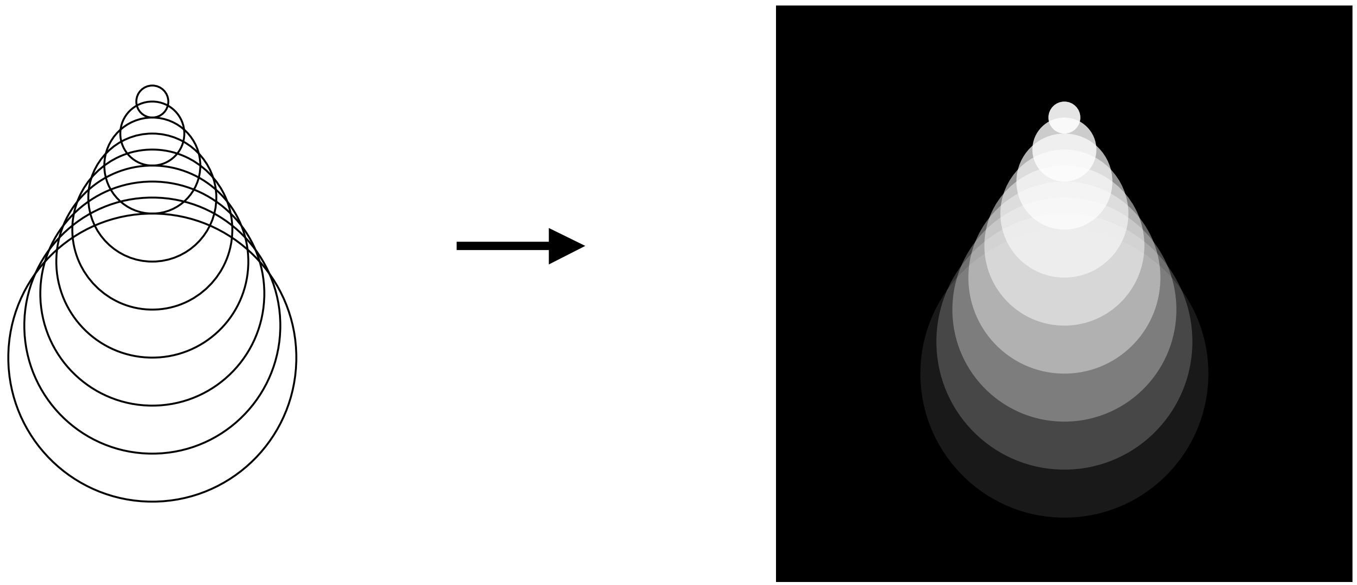
1. Coma

- Magnification and focal distance of the image depend on the distance (r) from the principle axis at the lens



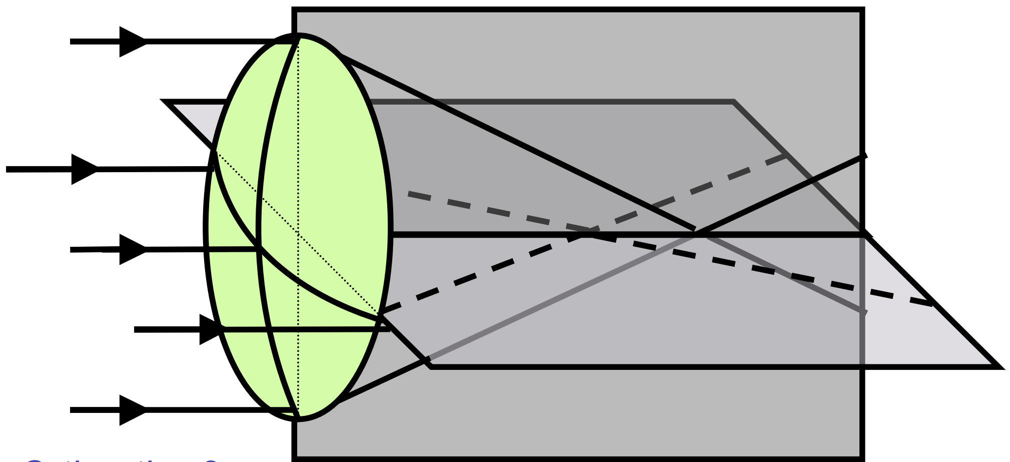
1. Coma

- The effect is that a off-axis point-like object results in an image with a comet-like shape (hence “coma”) .



2. Oblique astigmatism

- Recall: cylindrical lens
  - focuses in one plane only
- Recall: toric (sphero-cylindrical) lens:
  - Different horizontal and vertical curvature
  - Different focal strength in horizontal and vertical plane
  - Equivalent to spheric + cylindrical lens

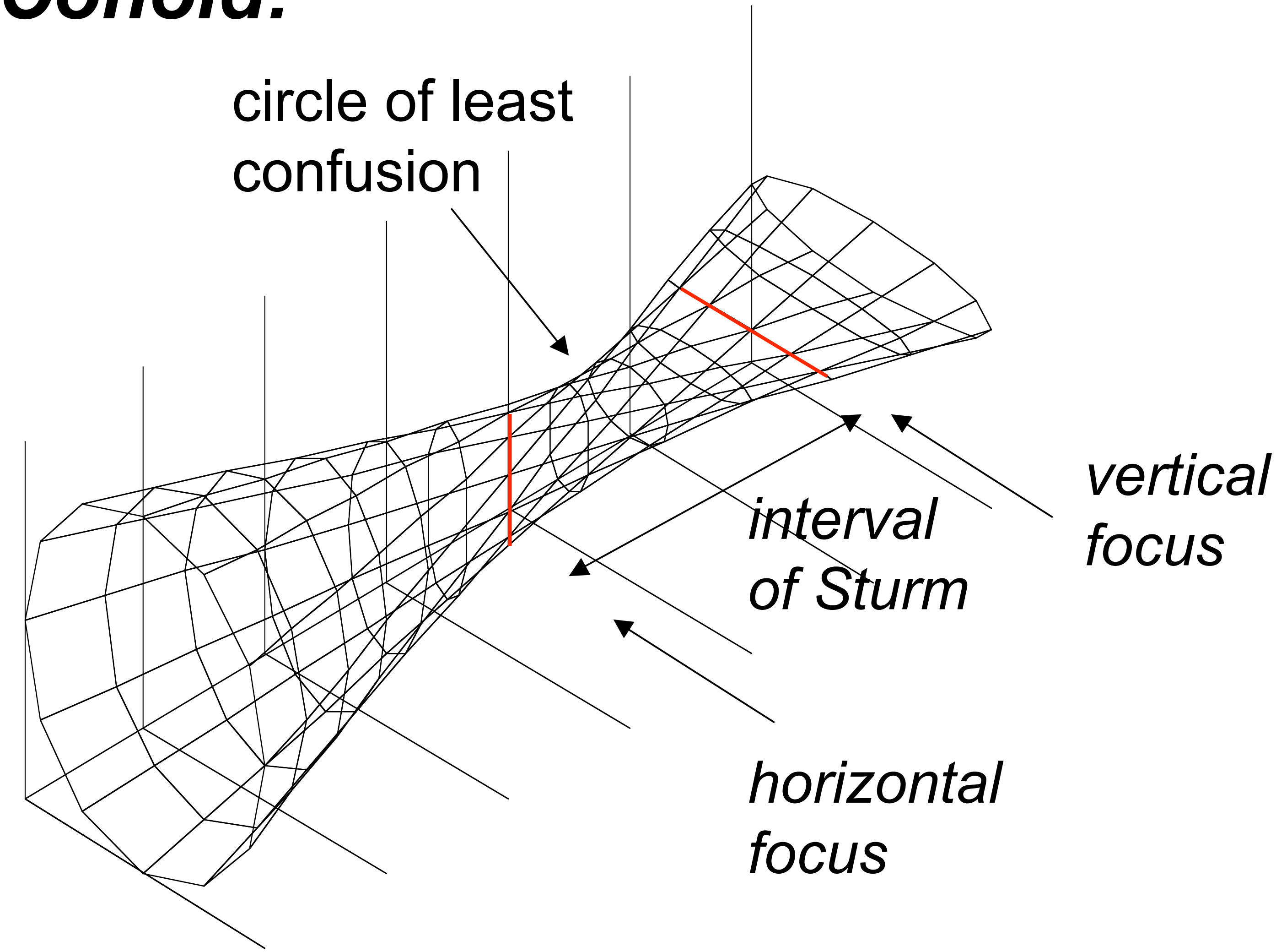


Sturm Conoid

- For a toric lens, light does not focus in a point but in two lines at right angles with each other
- The interval between the two line foci is called the ***interval of Sturm***
- The best focusing occurs somewhere inside the interval of Sturm. This point is called the ***Circle of least confusion***
- The complete envelope of the light near the Circle of least confusion is called the ***Sturm Conoid***

Sturm Conoid

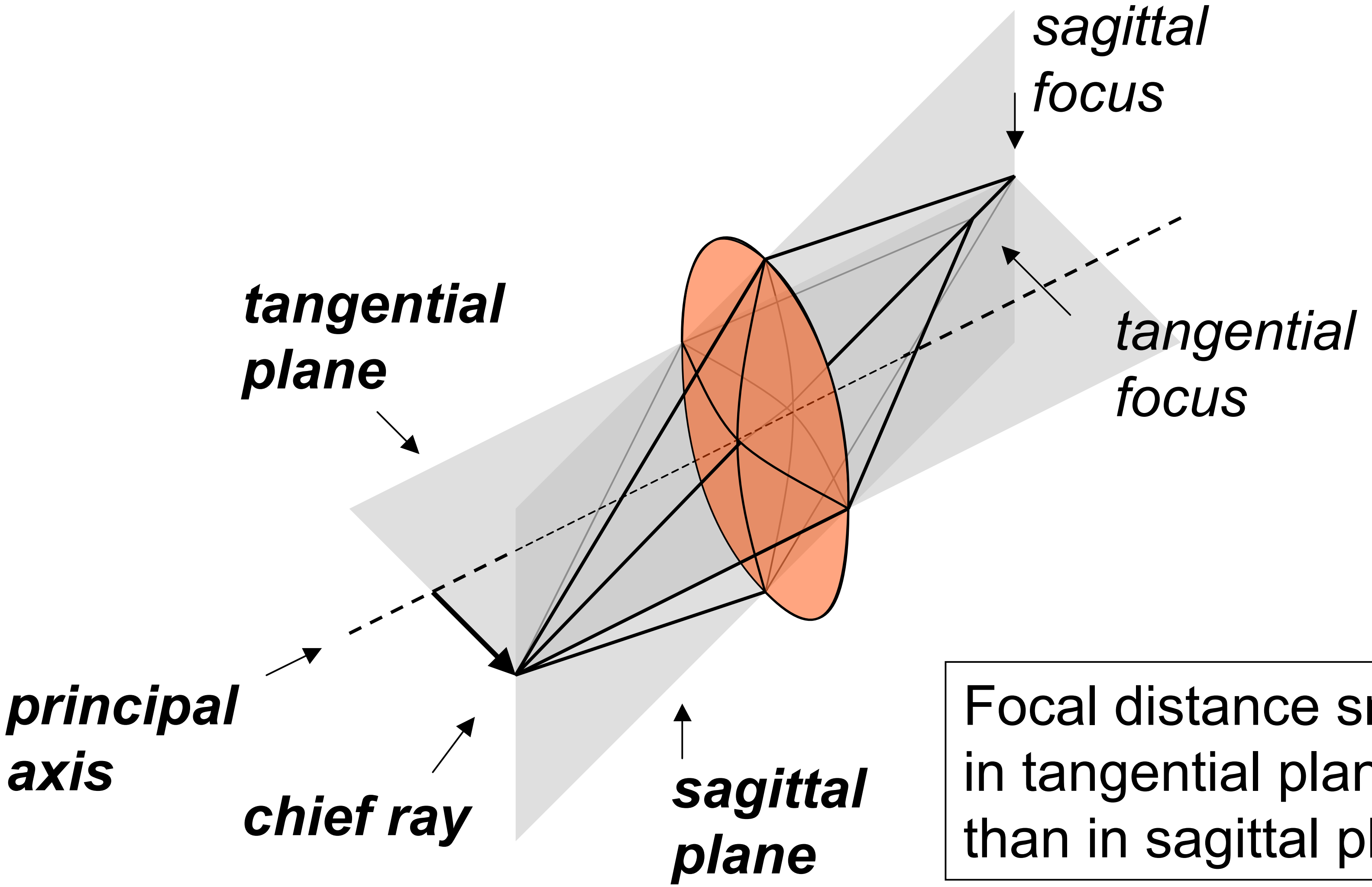
Sturm Conoid:



2. Oblique astigmatism

- A toric lens is astigmatic for all objects
- A spheric lens is astigmatic only for objects away from the principal axis (off-axis)
- This is called ***oblique astigmatism***
- A spheric lens behaves like a toric lens for off-axis objects

2. Oblique astigmatism



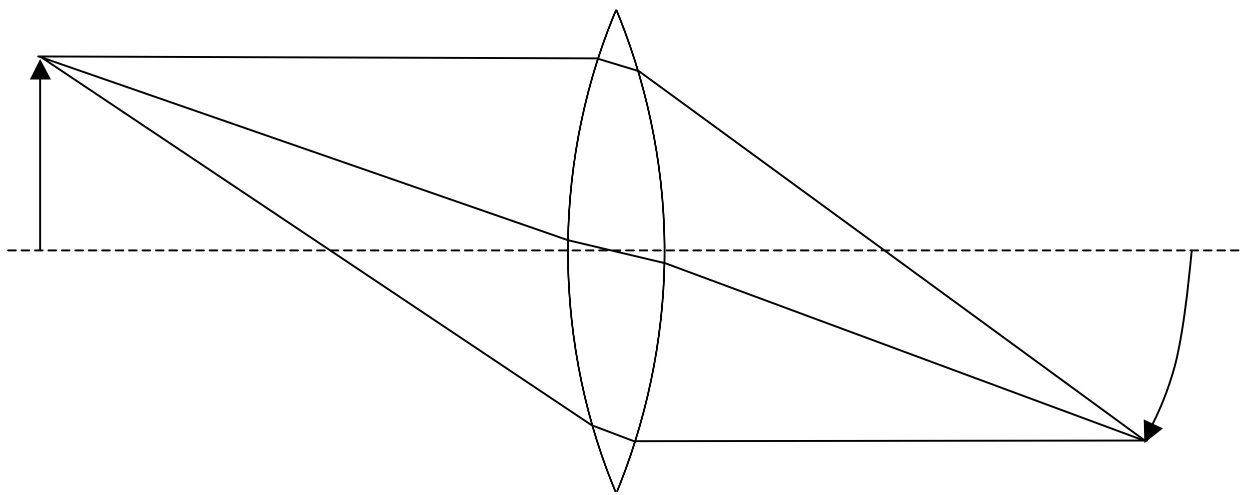
Focal distance smaller in tangential plane than in sagittal plane

Tangential / sagittal planes

- The tangential plane contains the off-axis object and the principal axis
  - In the tangential plane the object is furthest off-axis
- The sagittal plane contains the chief ray and is perpendicular to the tangential plane
  - In the sagittal plane the object is on-axis
- The chief ray is the ray of light from the off-axis object and passing through the centre of the lens

3. Curvature of field

- Objects on a plane perpendicular to the principal axis give rise to a curved image:

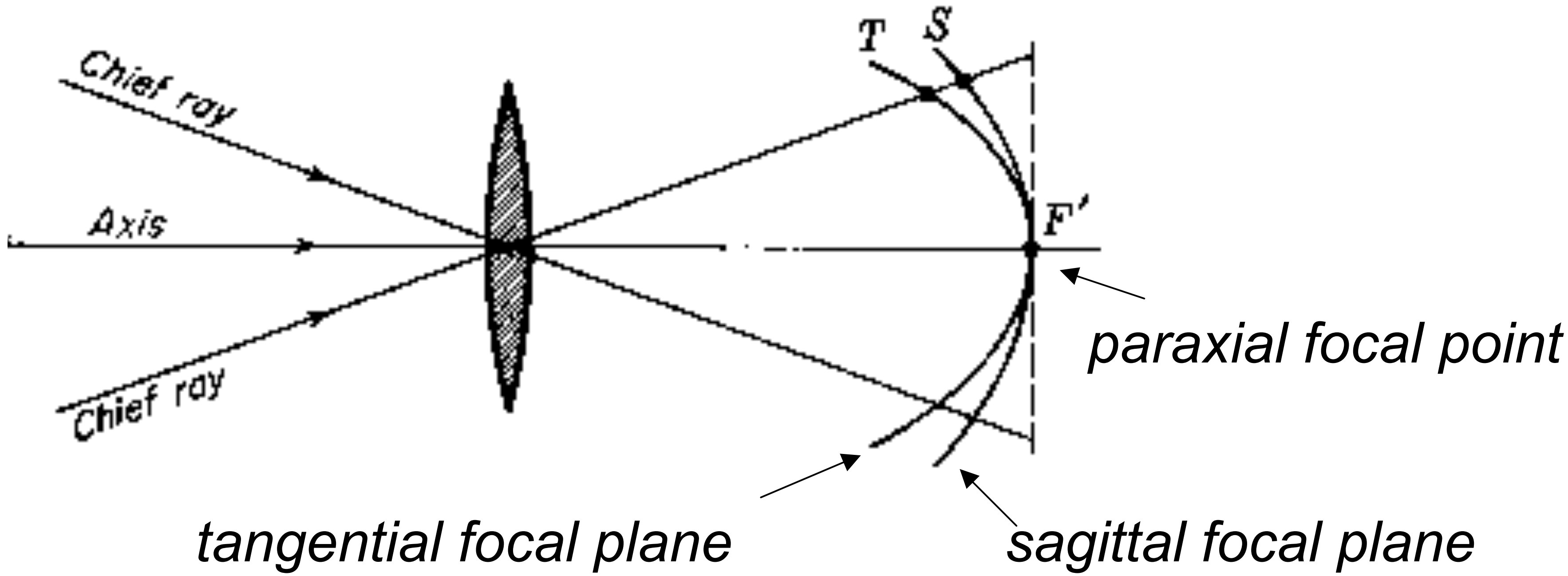


3. Curvature of field

- The effect is to blur the off-axis points when imaging on to a plane, as for example in a camera lens
- It is not important in the eye, because the curvature of the retina compensates for the curvature of field.

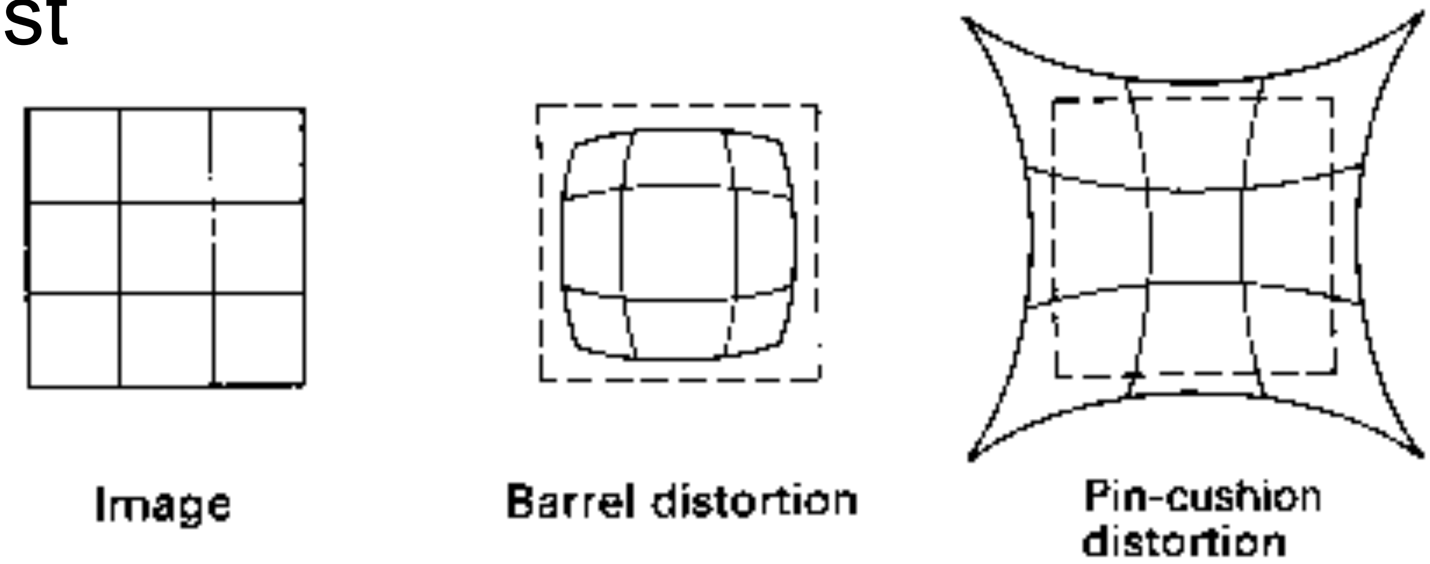
Oblique astigmatism + curvature of field

- The combined effect of oblique astigmatism and curvature of field is two curved focal planes:



4. Distortion

- Distortion arises because the magnification of the lens varies across the image.
- In the absence of other aberrations, all points are perfectly imaged as points.
- For a square grid, the corners are displaced the most



Summary of monochromatic aberrations

- All are caused by **large incidence angles** of light on the air-glass interface and the consequent **breakdown of the paraxial approximation**
- **On-axis** objects only suffer from **spherical** aberrations
- **Off-axis** objects suffer from **four additional aberrations**:
  - **Coma**: unequal magnification and focal distance through different lens zones
  - **Oblique astigmatism**: shorter focal length for rays through tangential than sagittal plane
  - **Curvature of field**: plane objects give rise to curved images
  - **Distortion**: uneven magnification of the object
- Affect both convex and concave lenses

Reducing monochromatic aberrations

- In general, similar techniques that reduce spherical aberrations are valid to reduce the other monochromatic aberrations:
  - aspheric lenses
  - aperture stop
  - distributed bending
  - thin lenses of high refractive index
  - using doublets

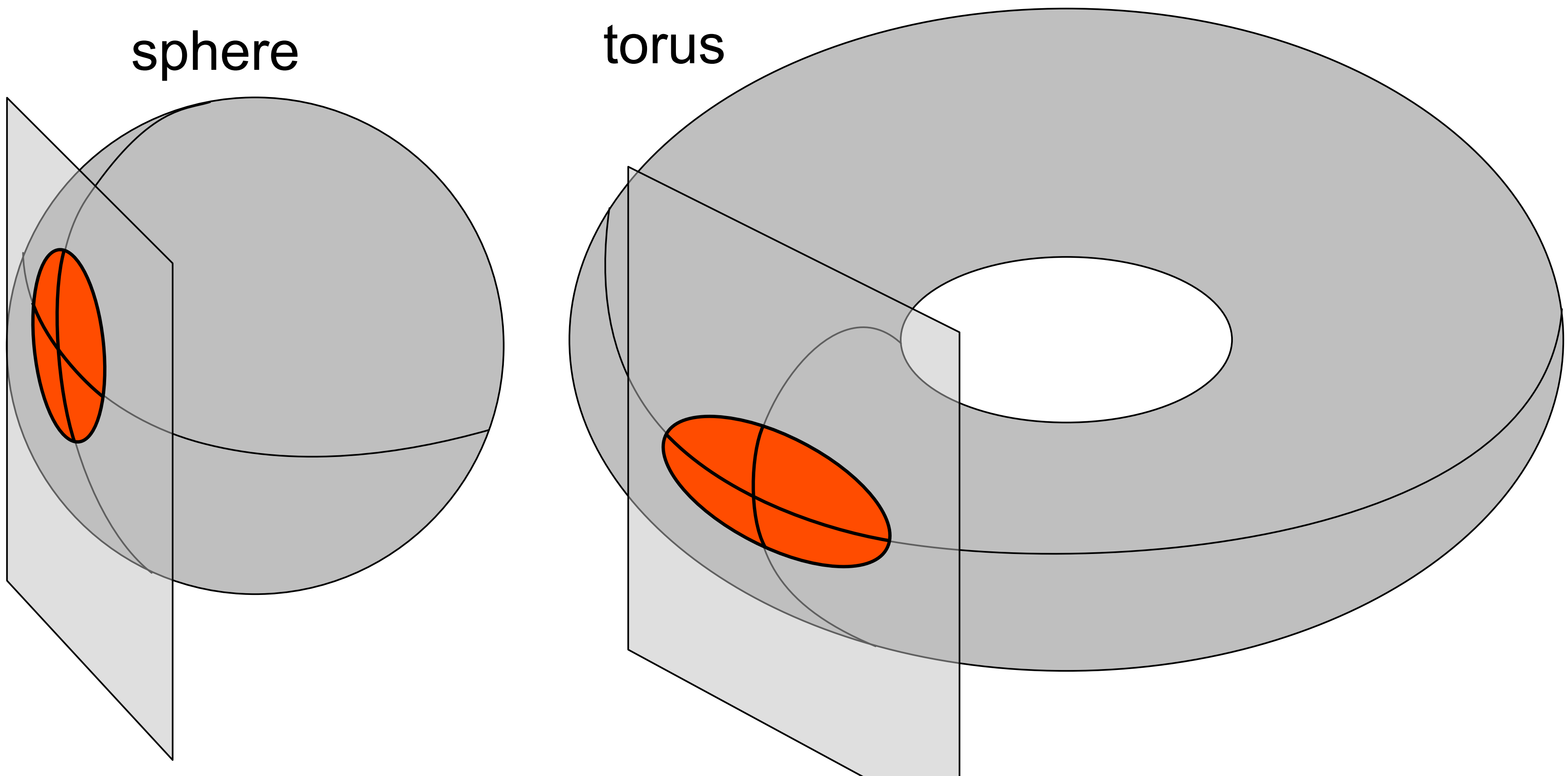
Monochromatic aberrations in the eye

- Spherical aberrations are reduced by
  - The aspheric cornea
  - The graded-index lens
  - The iris as an aperture stop
  - The directional sensitivity of the cones
- The four other monochromatic aberrations are not very relevant for the eye because they apply to off-axis objects only
  - The eye only has high-resolution vision in the central part (macula)
- Curvature of field is no problem for the eye because the retina is curved

Astigmatism in the eye

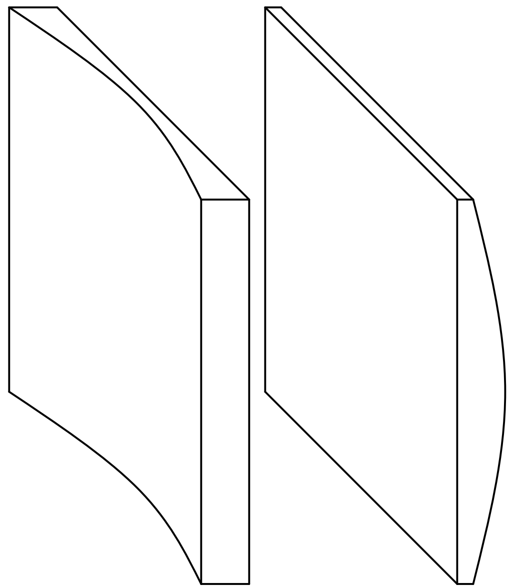
- If the refractive power of the eye varies in different meridians, this is called astigmatism
- Astigmatism is caused by an irregularly shaped cornea or lens
- It can be corrected with a cylindrical lens
- It is often necessary to correct for myopia or hypermetropia as well
- This can be done by combining a spheric and a cylindrical lens into a toric (sphero-cylindrical) lens

Toric lens surface



Cross-cylinders

- Used to detect astigmatism and find the axis of astigmatism of the eye
- Combination of a negative and positive cylinder of equal strength (usually 0.5D) mounted at an angle of 90 degrees



- In practice combined into one piece of glass

Cross-cylinders

- For the non-astigmatic eye, introducing cross-cylinders will deteriorate the view independent of the orientation
- For the astigmatic eye, the view will be best when the axis of the cross-cylinders is aligned with the axis of astigmatism
- Patient is asked which orientation gives the best view
- If astigmatism is detected, a cylinder is introduced until the view is independent of the rotation of the cross-cylinders