

## 4 Optical Systems

**a) cardinal points**

definitions  
nodal points

**b) rigid body motion**

definitions for rotation, translation  
optical system motion

**c) stops and pupils**

entrance and exit pupils  
telecentric systems  
vignetting

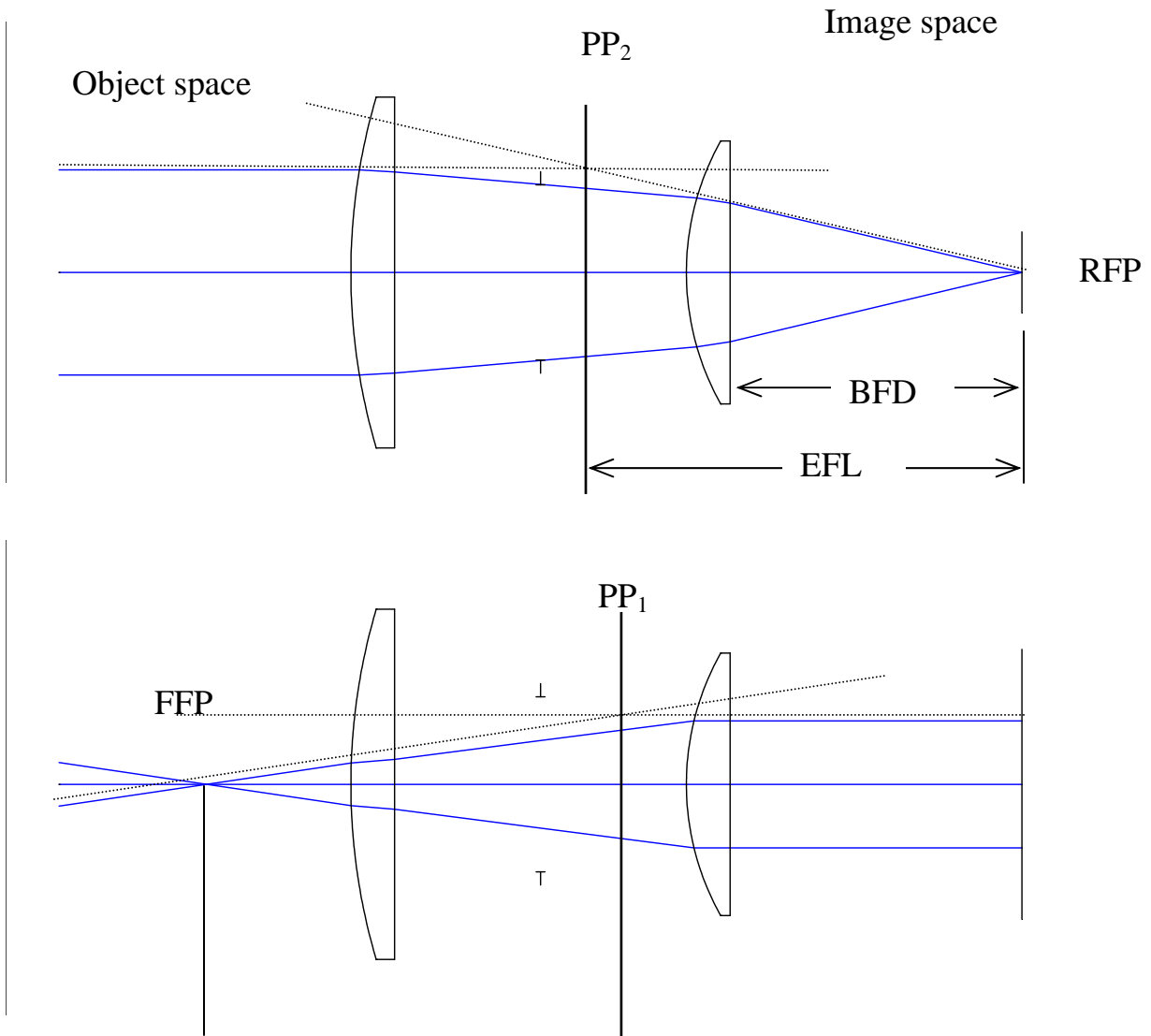
**d) afocal systems**

description  
definition of magnification  
telescopes  
beam projectors

**e) some common optical systems**

telescopes  
    Galilean, Keplerian, terrestrial (riflescope)  
    Cassegrain, Gregorian  
binoculars  
microscope

**Definition of cardinal points – project rays from object and image space**



**$PP_1$ :** Front principal point

**$PP_2$ :** Rear principal point

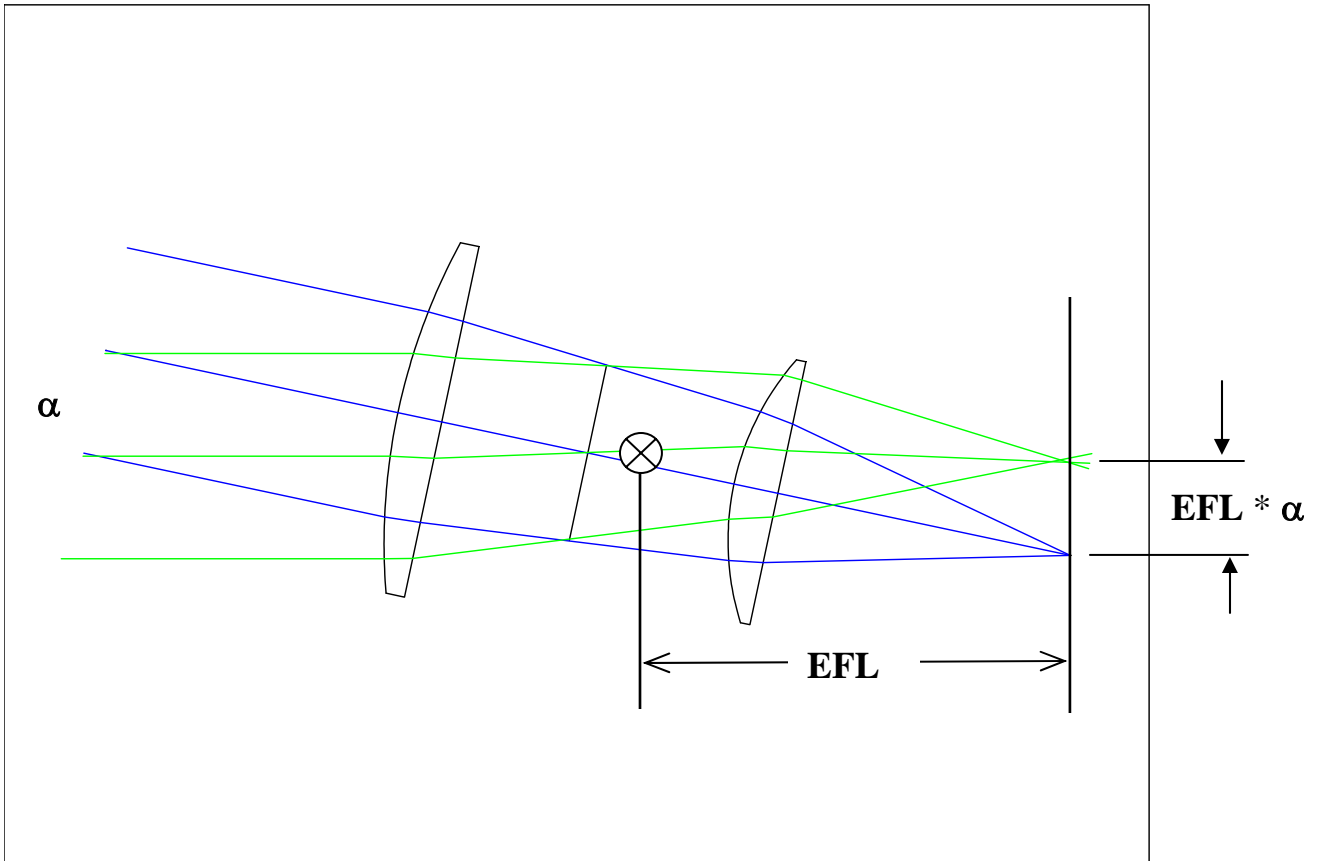
**FFP:** Front focal point

**RFP:** Rear focal point (image of object at infinity)

**EFL:** Effective focal length

**BFD:** Back focal distance

## *Nodal point at rear principal plane*



In air, object at infinity, nodal point is coincident with rear principal point

Rotation of lens system about nodal point does not move image

Simple proof (for images in air):

Object at field angle  $\alpha$  has image height of  $EFL \times \alpha$  relative to axis

Lens rotation  $\alpha$  about  $\mathbf{PP}_2$  moves system axis at focal plane by  $EFL \times \alpha$

Lens rotation  $\alpha$  causes a fixed object to shift by angle  $-\alpha$  relative to axis

The absolute image motion is

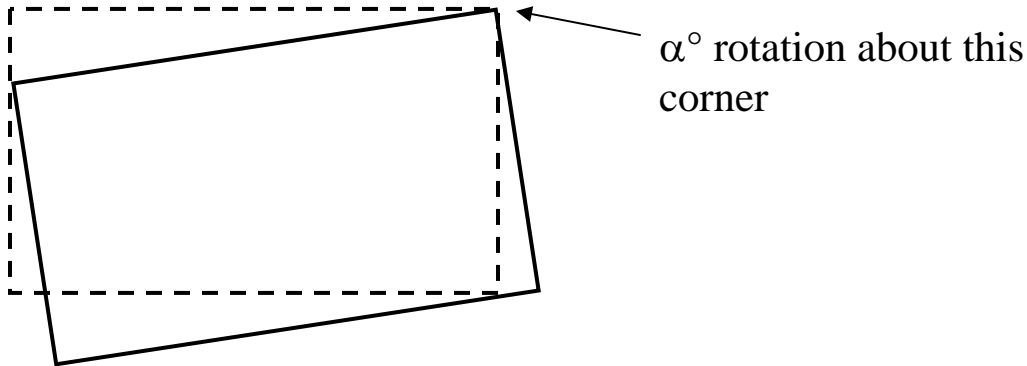
$$\frac{\text{image motion relative to lens axis} + \text{motion of lens axis}}{\text{-----}} = \frac{EFL \times -\alpha + EFL \times \alpha}{\text{-----}}$$

0, no motion

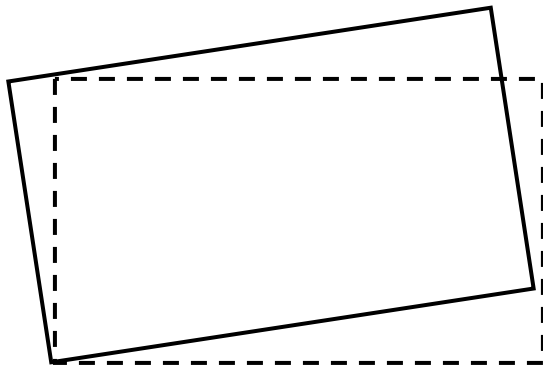
Only for the case where the system is rotated about the rear principal point.

## Rigid body rotation

Rotation about one point on an object is equivalent to rotation about any other point plus a translation.

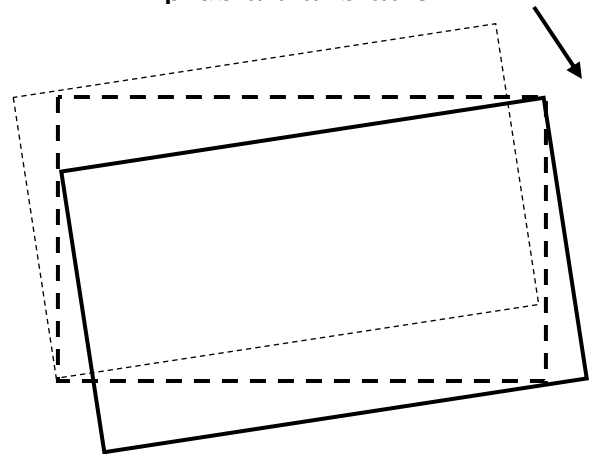


is equivalent to



$\alpha^\circ$  rotation about this corner

plus a translation



(Calculate the magnitude of the translation using trigonometry)

You can choose any point you want to rotate about as long as you keep track of the translation

To calculate effect of rotating an optical system:

1. Decompose rotation to translation of the nodal point + rotation about that point
2. Image motion will be caused only by *translation* of nodal point

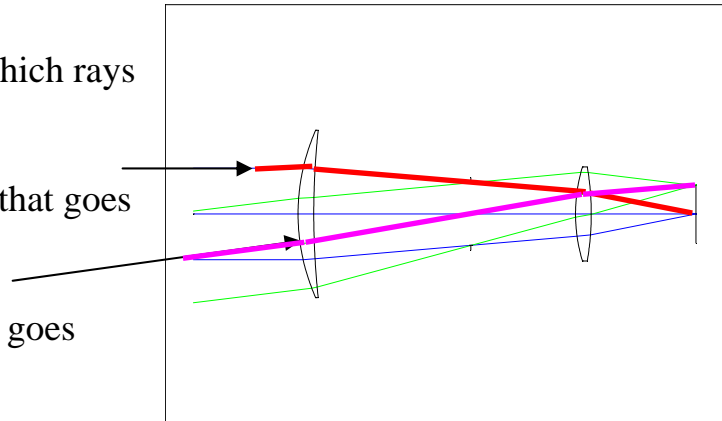
## Definition of pupils

### Aperture stop

Actual “hole” that defines which rays get through the system

**Marginal ray** – on axis ray that goes through edge of stop

**Chief ray** – off axis ray that goes through center of stop

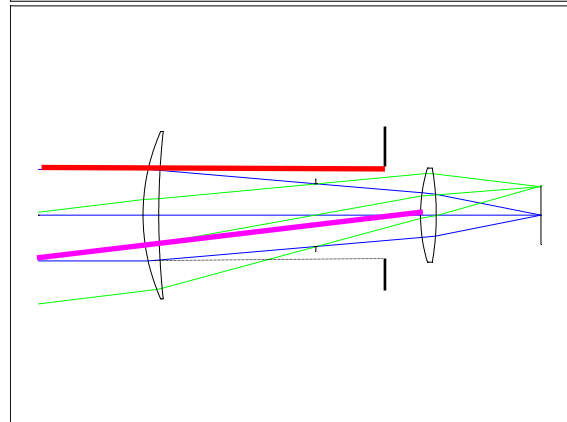


### Entrance pupil

Image of the stop in object space

Located where chief ray cross the axis in object space

Sized by marginal ray height of pupil image in object space

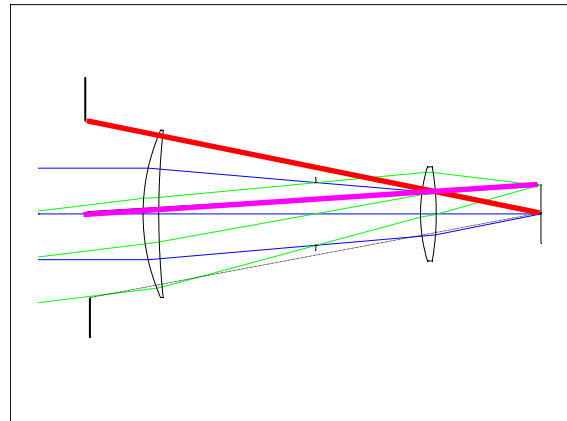


### Exit pupil

Image of the stop in image space

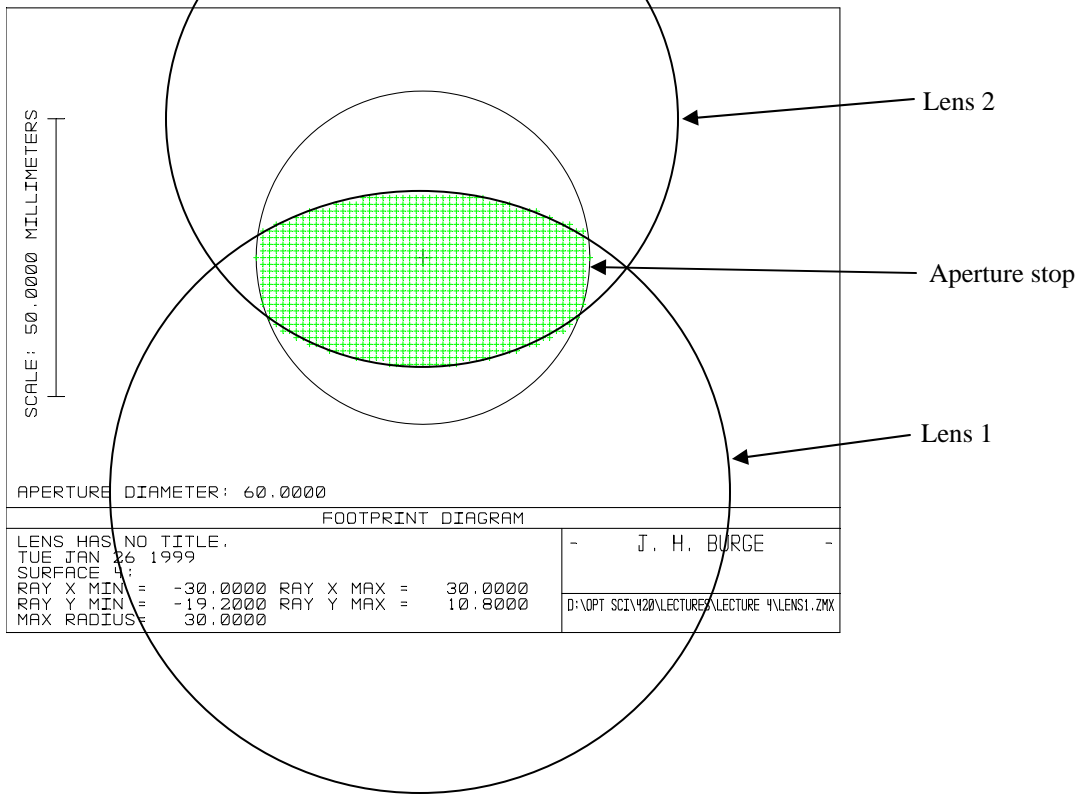
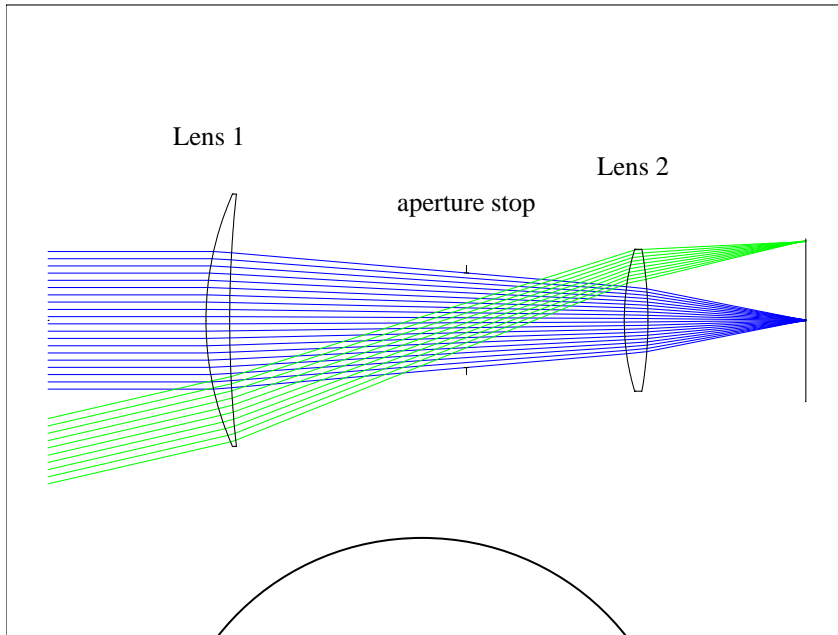
Located where chief ray cross the axis in image space

Sized by marginal ray height of pupil image in image space

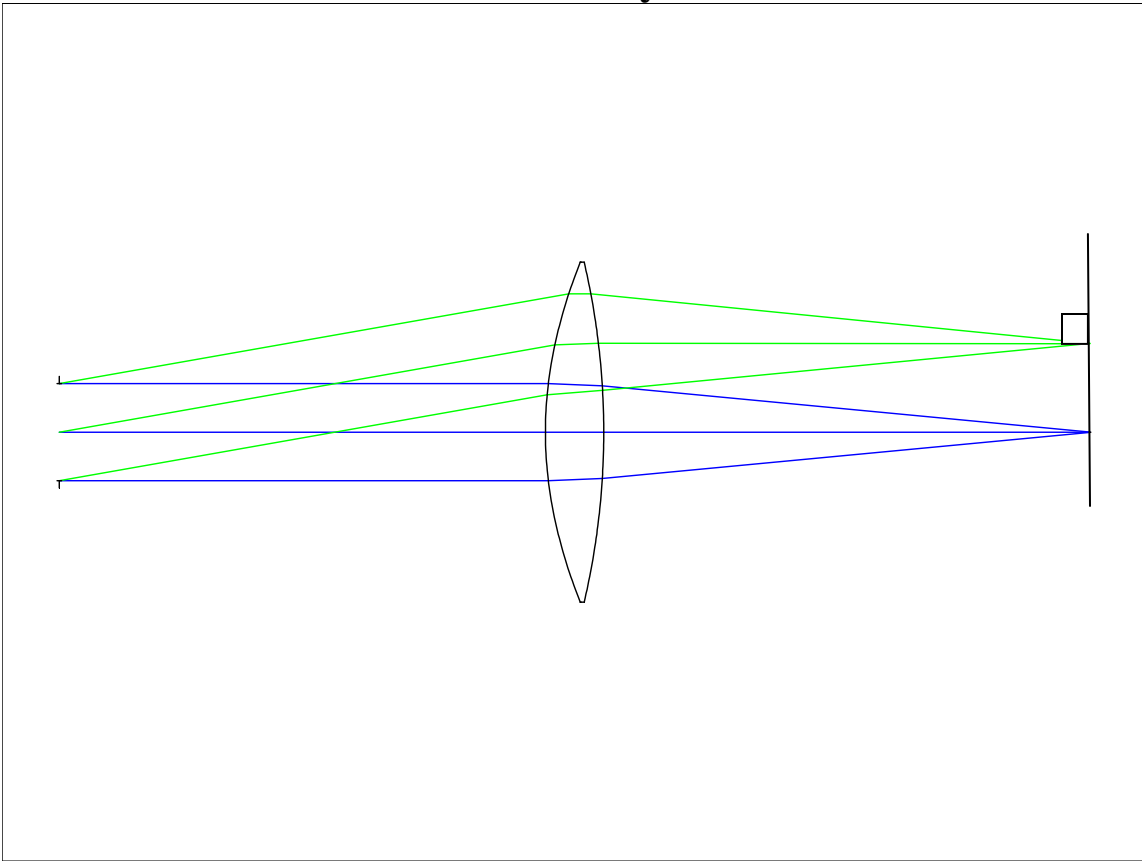


## Vignetting

When something other than the aperture defines which rays get through. Leads to loss of light.



## Telecentric system



Telecentric in image space  
Exit pupil at infinity  
Chief ray is normal to image plane

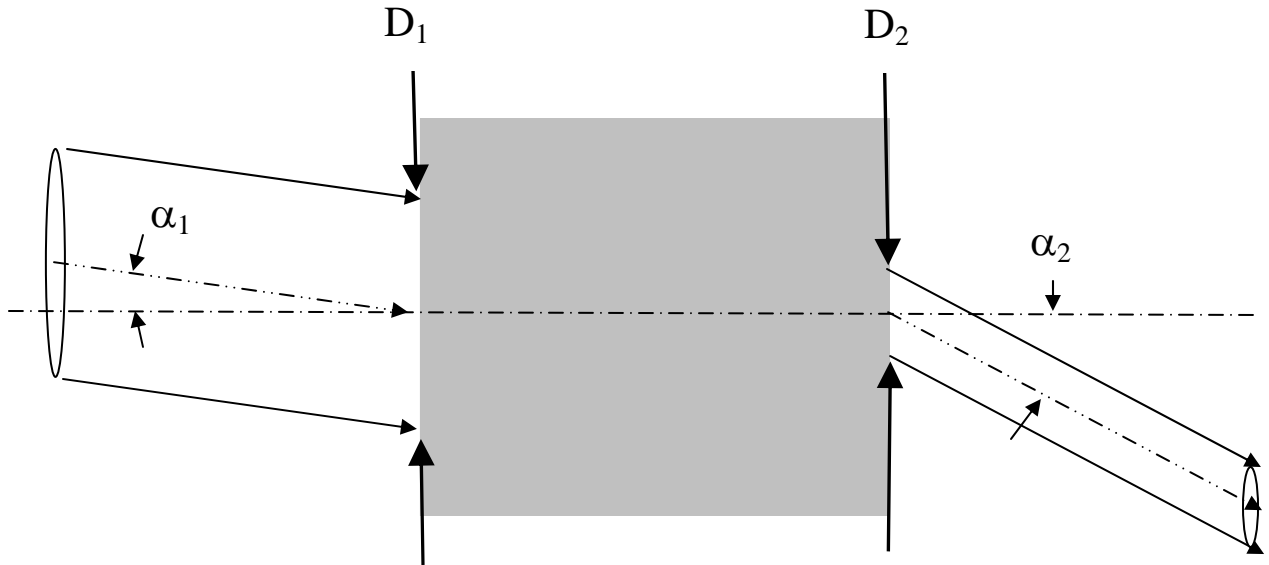
Telecentric in object space,  
Entrance pupil at infinity  
Chief ray is normal to object plane

Why do we care?

- Going through focus, image does not shift
- Provides uniform illumination across the field
- Some detectors are highly directional (fiber optic bundles)

## Afocal systems

Do not create a real image -- object at infinity, image at infinity



$D_1$  = Entrance Pupil

$D_2$  = Exit pupil

It makes stuff appear larger – magnifying power

$$MP = \frac{\alpha_2}{\alpha_1}$$

LaGrange Invariant requires  $D_1\alpha_1 = D_2\alpha_2$

Examples:

Galilean, Keplerian telescope, laser beam projector

Binoculars