Properties of optical instruments

Visual optical systems
part 2: focal visual instruments (microscope type)

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Examples of focal visual instruments

- magnifying glass
- Eyepieces
- Measuring microscopes from the students's lab
- Study and Research Microscopes

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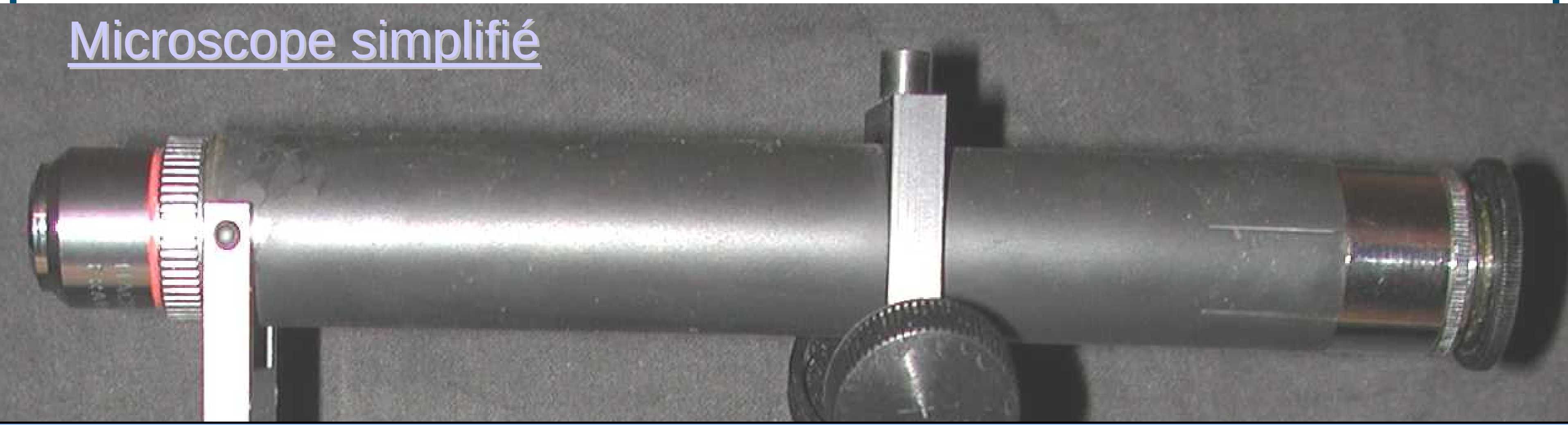
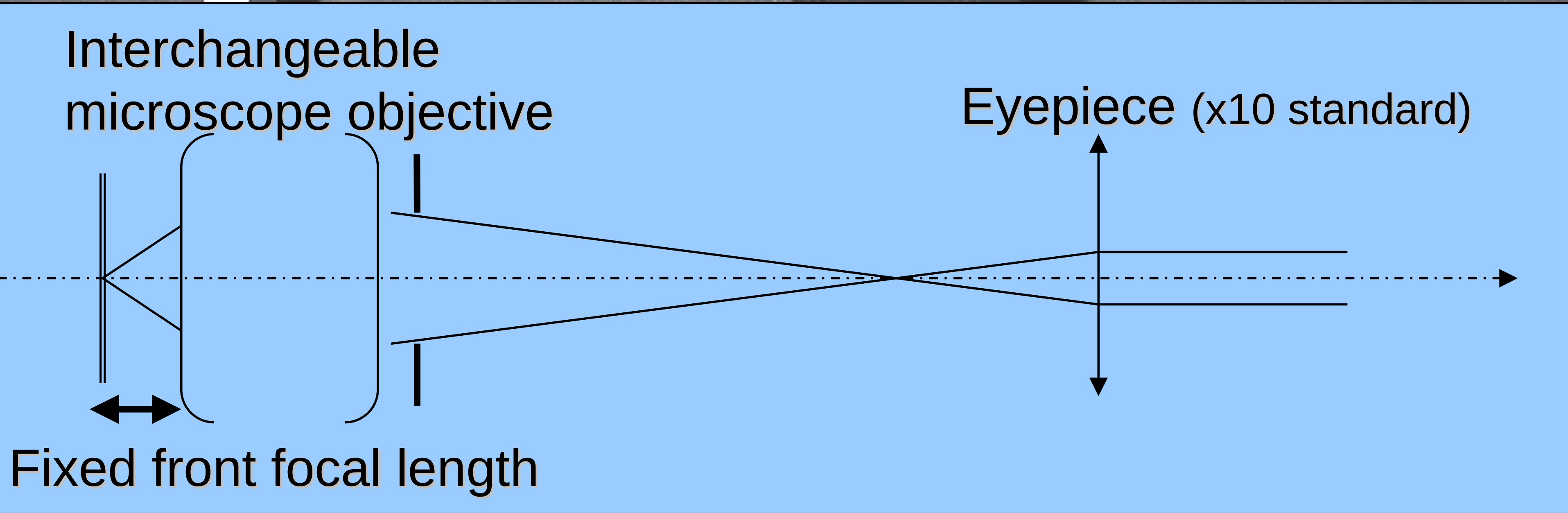
From the IO students'lab:

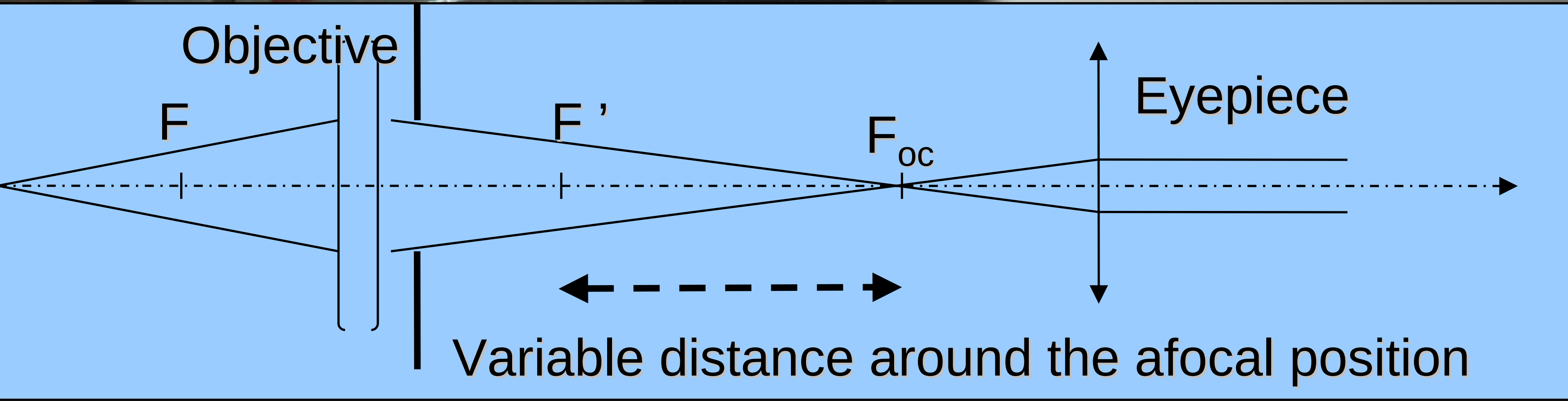
Basic microscope (viseur à frontale fixe)



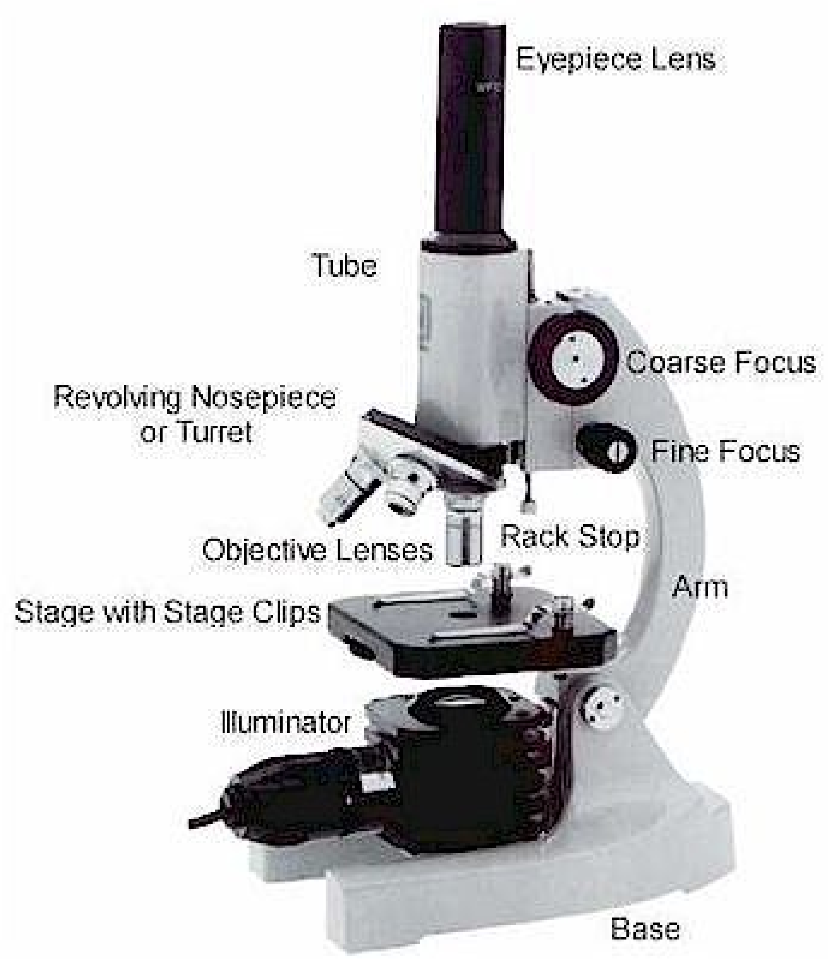


Another instrument in IO students'lab:

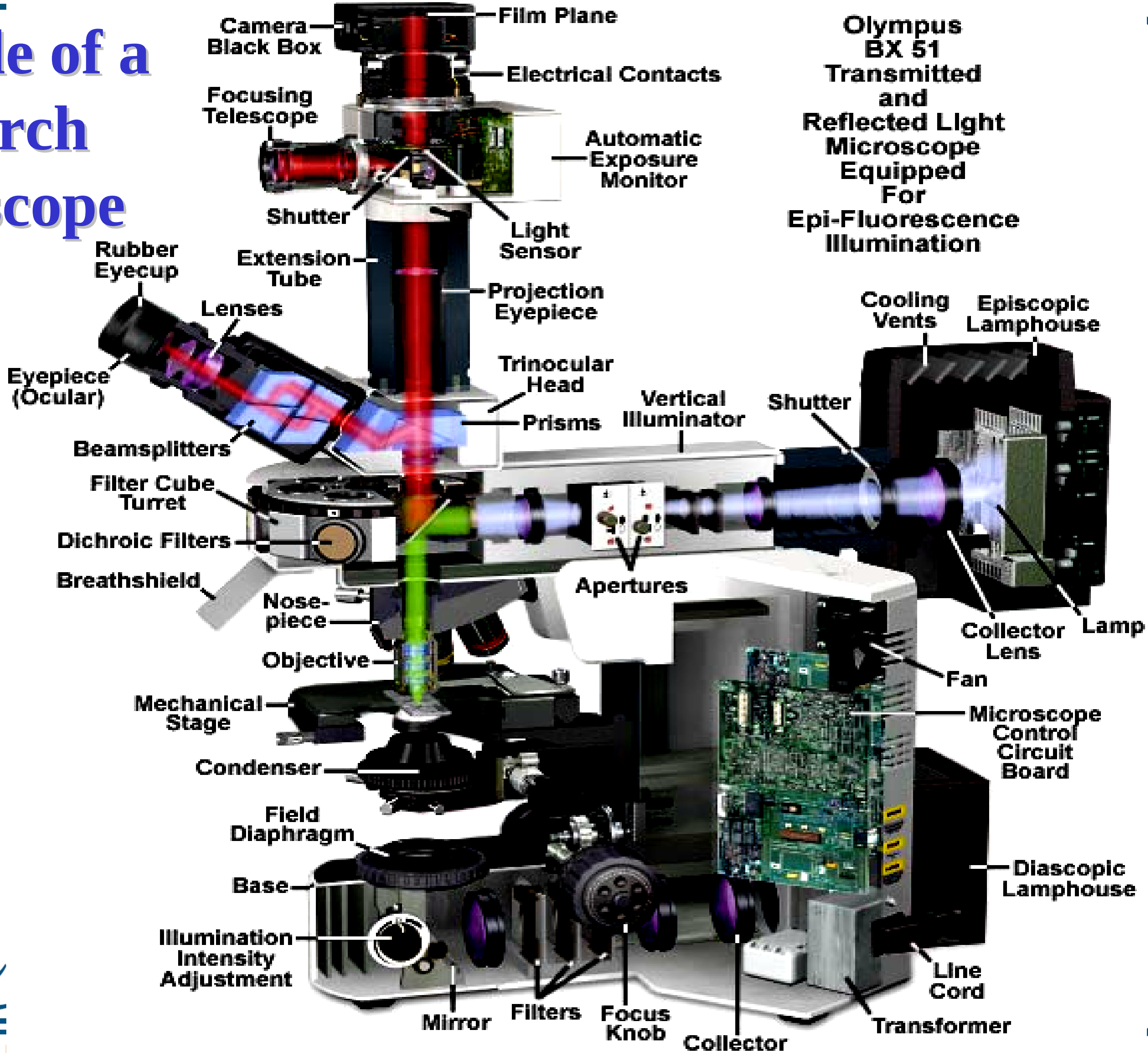
Adjustable long distance viewer (viseur dioptrique)



Example of a study microscope



Example of a research microscope



Characteristics of visual instruments

	Telescope typ instr Object at infinity	**Microscope type instr** **Object at finite distance**
Size of image (magnification)	*Angular magnification G*	Power P, magnifying power G
Aperture	***Usually entrance pupil is primary lens or mirror*** *Exit pupil adapted to eye pupil*	Numerical aperture often entrance pupil is at infinity (telecentric stop)
Resolution	*Resolution of the eye* *Diffraction, aberrations*	Transverse resolution, to compare to the naked eye
Field of view	*Internal lenses act as field stop, field lens in eyepiece adapted to eye field of view*	similar
Depth of field	*Connected with resolution by also accommodation of the eye*	similar

Size of Image for microscope type

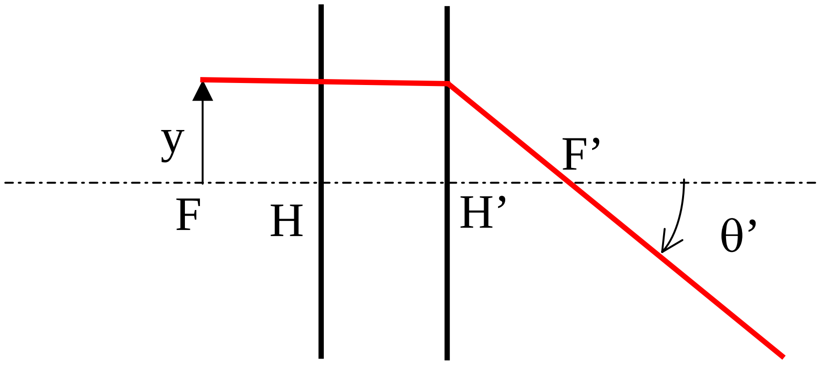
Microscope type : Object at finite distance, Image at infinity

Object with size y , Image with angular size θ'

➔ Power

$$\left|\frac{\theta'}{y}\right| = \frac{1}{f'} = P$$

Unit : diopters δ ↔ [m^{-1}]

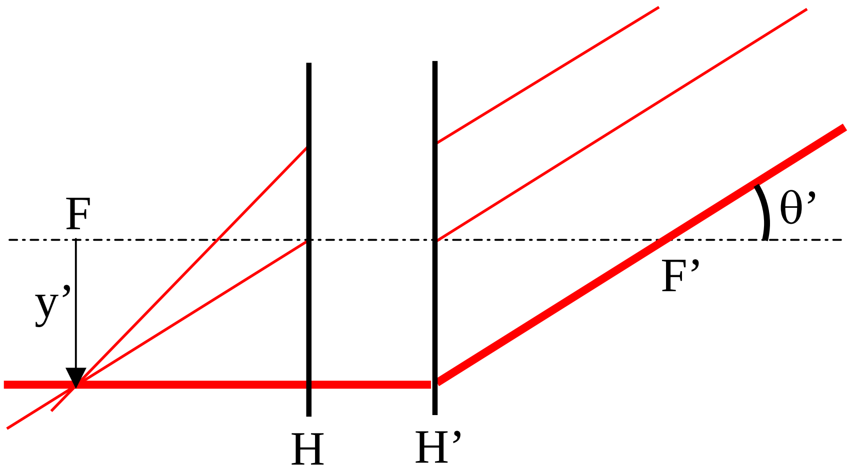


Power of a compound microscope

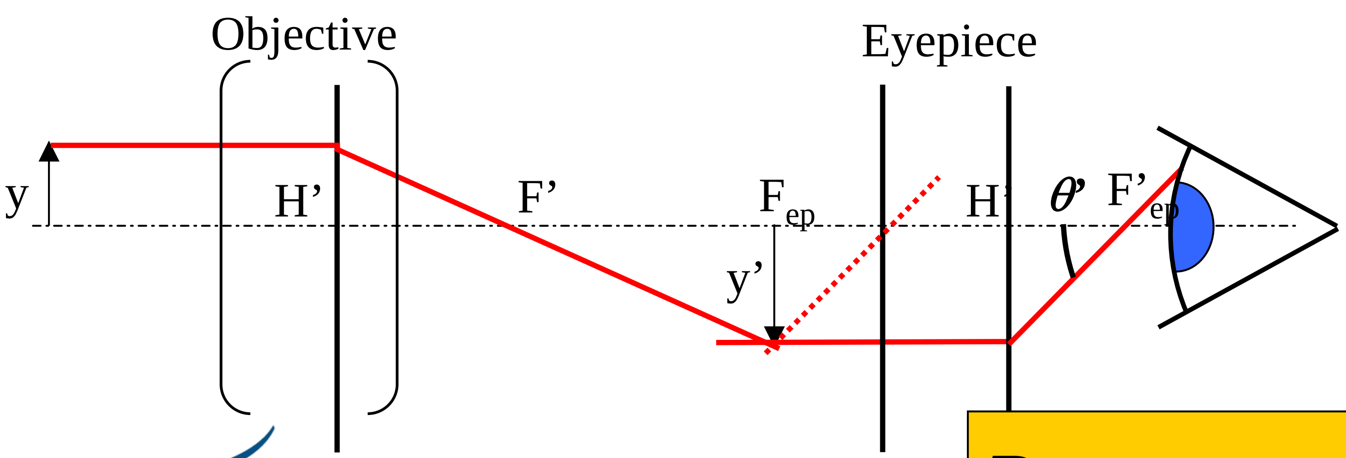
Power of the eyepiece:

$$P_{eyepiece} = \theta' / y = 1 / f'_{eyepiece}$$

in m^{-1} (diopters)



Power of the compound microscope { objective + eyepiece }



$$P_{microscope} = g_y^{objective} . P_{eyepiece}$$

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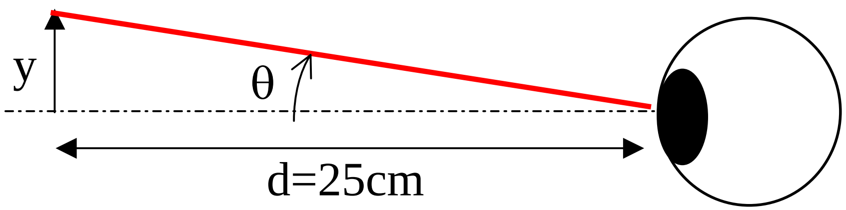
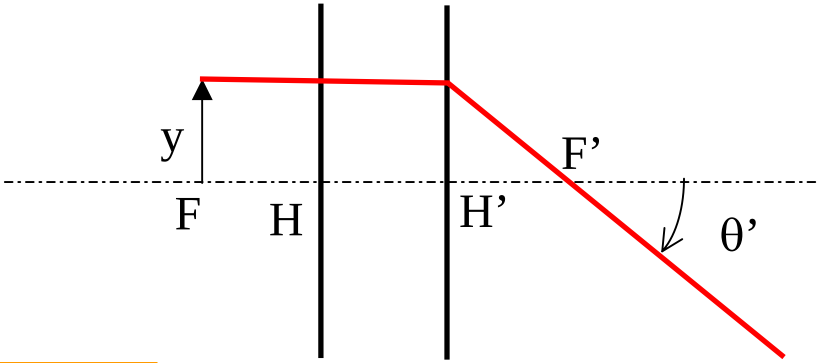
Magnification for microscope type

Comparison with angular size as seen with a naked eye





Magnification

$$G = \left|\frac{\theta'}{\theta}\right| = \frac{d}{f'} = \frac{P}{4}$$

Information given in the form (typical values):

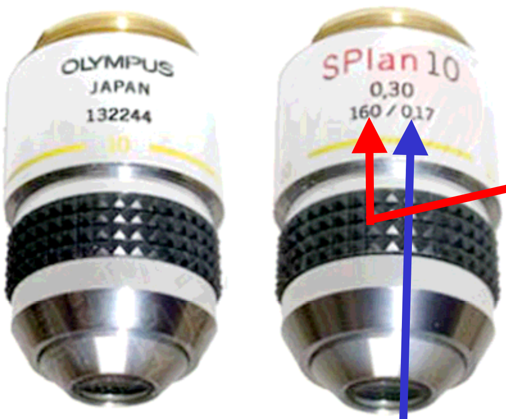
10x, 25x for an eyepiece

$$G_{microscope} = g_y^{objective} . G_{eyepiece}$$

objective 10x (g_y) associated with eyepiece 10x (P)

⇒x100 for the microscope (up to 1000)

Different types of microscope objectives



tube length 160mm

or corrected at infinity
(used with tube lens)

Transmission (corrected for glass slide 0.17mm) or reflection mode

Dry or water or oil immersion (lower or higher NA)

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Figure 1

Example of indications written on an objective :

Microscope objective
60x , 1.40 Oil , ∞ /0.17
Eyepiece : 10x

Magnification : 60

Numerical aperture in obj sp : 1,4

Designed for an object at infinity

0,17 mm coverslip over the object

Magnification of eyepiece :10

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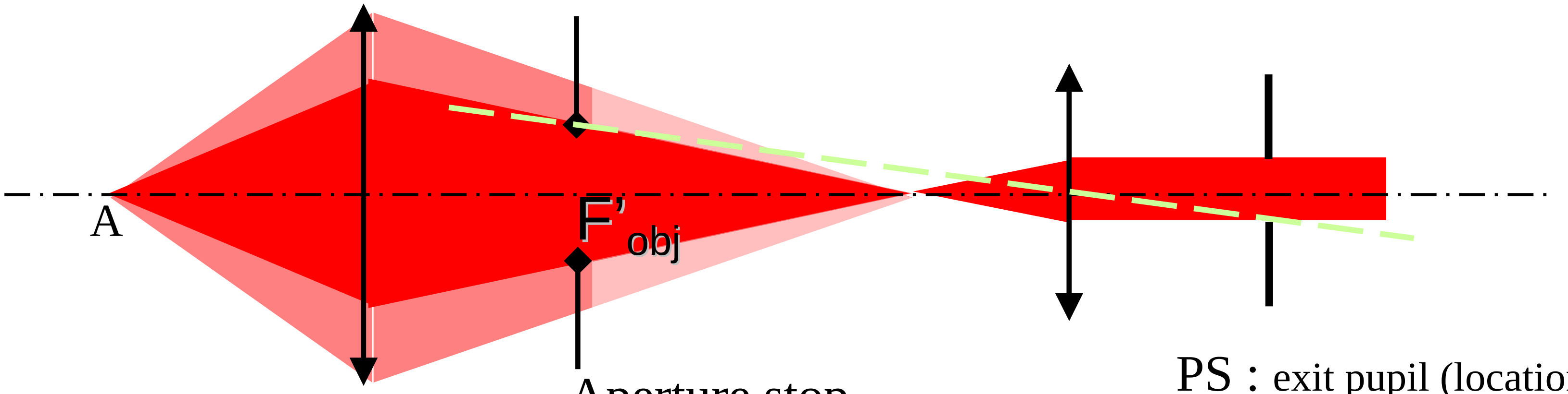
Aperture of a microscope

The aperture stop is usually in the second focal plane of the objective*

⇒ **Entrance pupil at infinity**

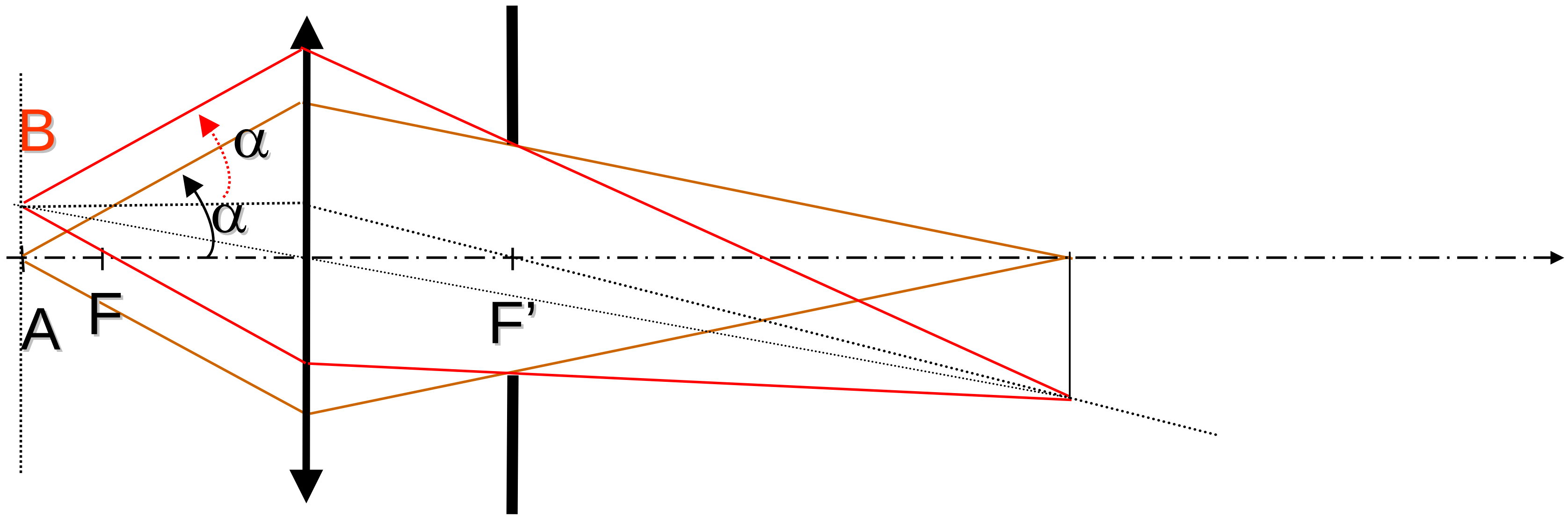
= Telecentric instrument in the object space



*except for low magnification objectives

Entrance pupil at infinity
=
Telecentric instrument in the object space

Why is it useful ?



The numerical aperture in the object space *sin* (α) stays constant for any point in the field of view.

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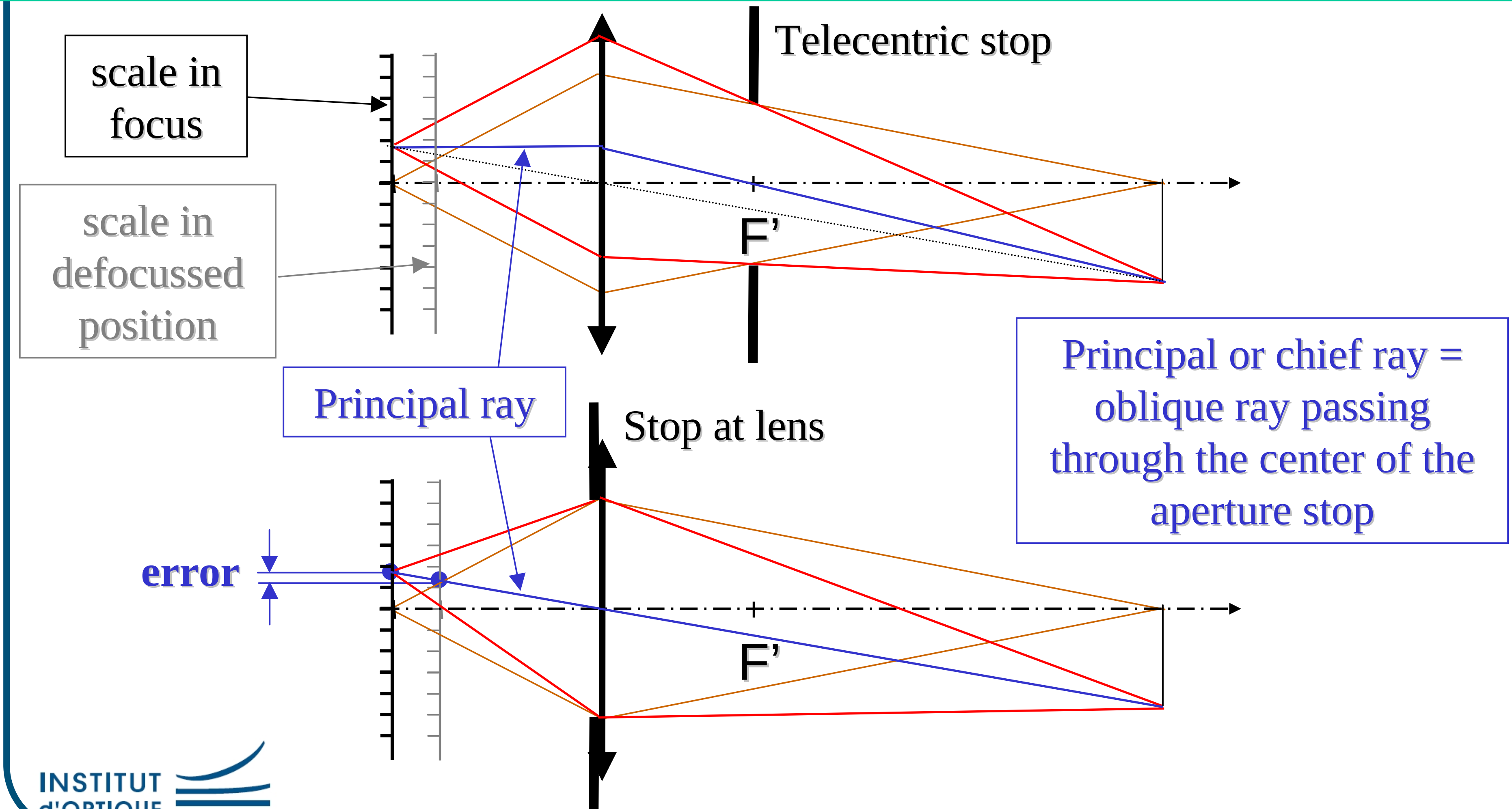
2nd advantage of the telecentric stop:

it reduces the measurement or position error caused by a slight defocusing of the system

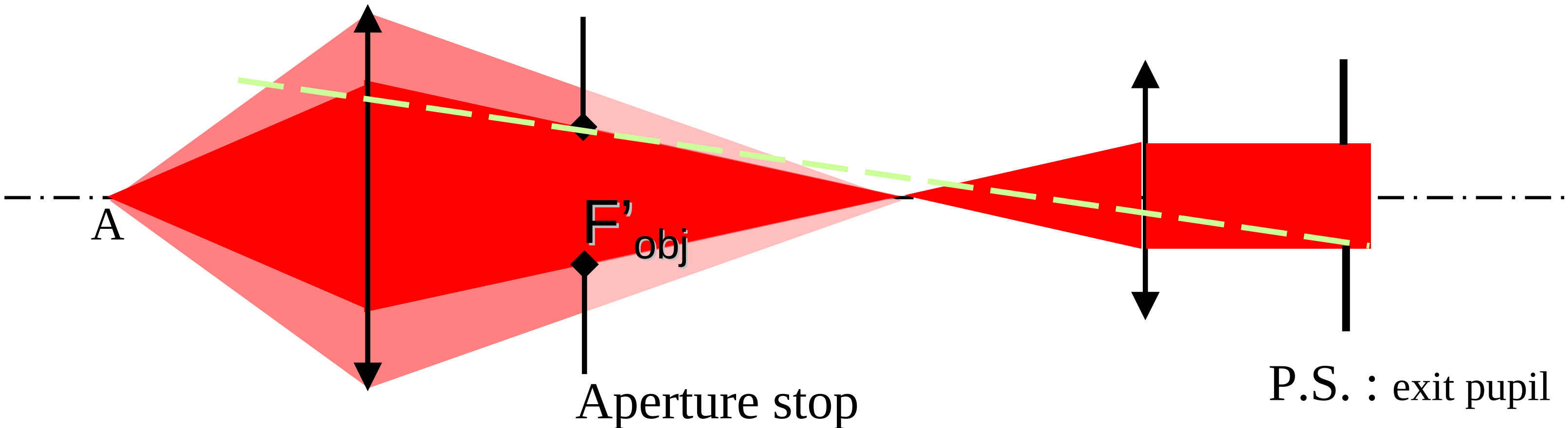


Exit pupil

The numerical aperture in the image space of the objective is given by the Abbe Sine condition

$$ny\sin(\alpha) = y'\sin(\alpha') \approx y'\alpha'$$

$$\alpha' = n\sin(\alpha)/g_y$$



Diameter of the exit pupil :

$$\Phi_{PS} = 2\alpha' f'_{ey}$$

60x Plan Apochromat Objective

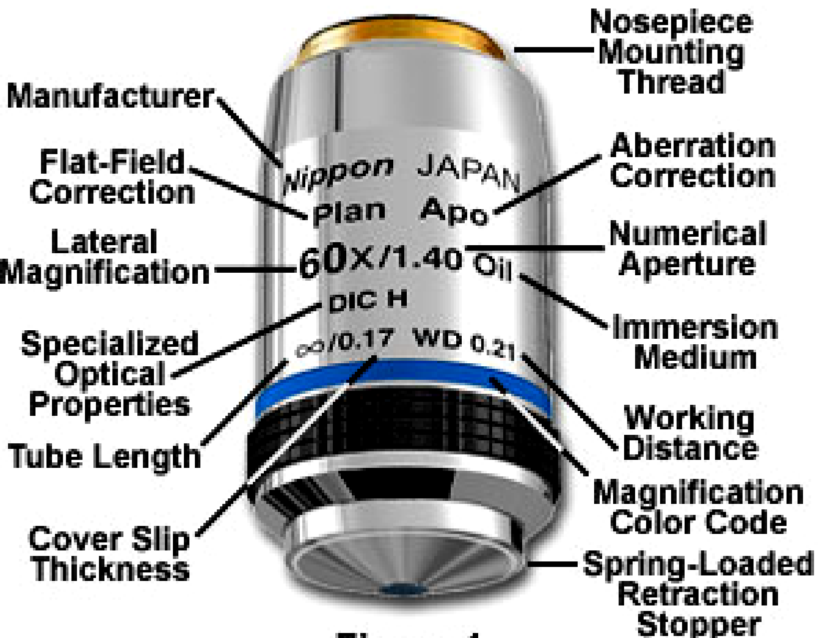


Figure 1

Example of indications written on an objective :

Microscope objective
60x , 1.40 Oil , ∞ /0.17
Eyepiece : 10x

Diameter and position of the exit pupil ?

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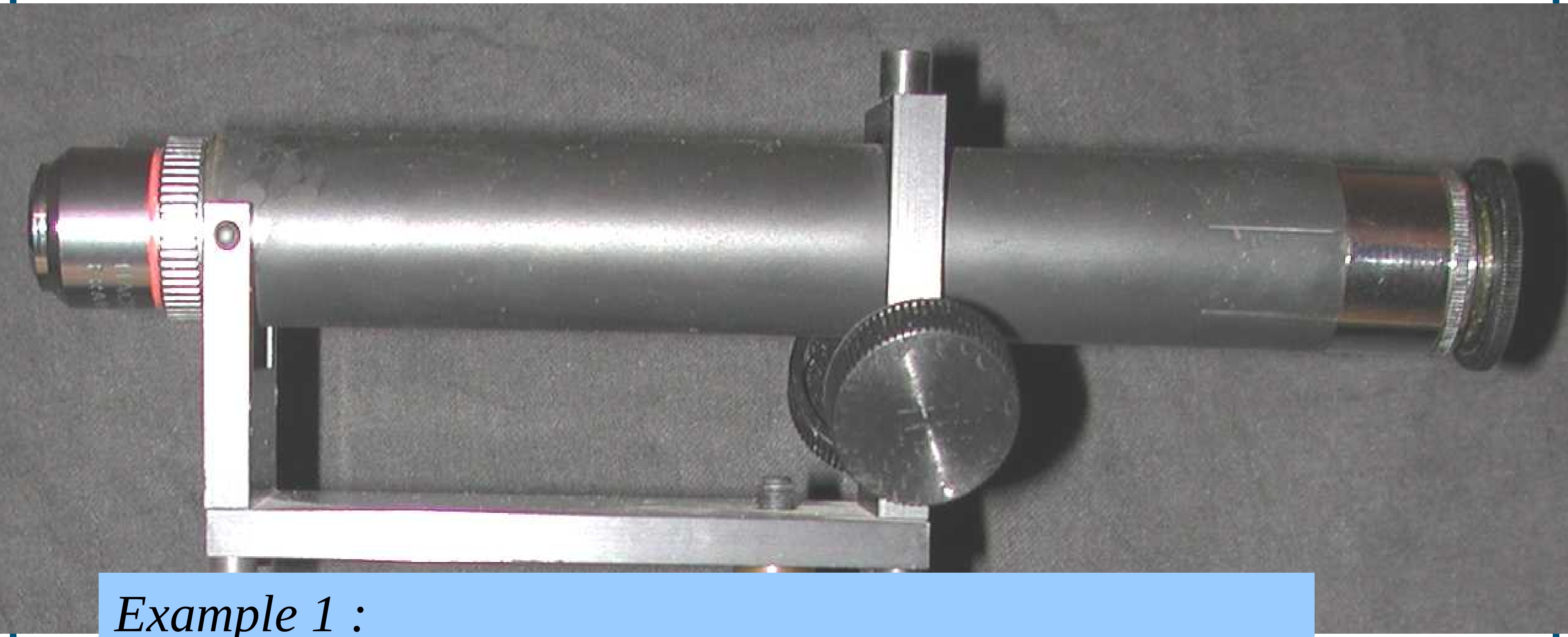
Resolution of the microscope

- Ability to separate 2 points
- should be limited by diffraction and not by the resolution of the eye

  $\Rightarrow$Exit pupil smaller than 1 mm
- Better for large NA of the objective



Example 1 :

Basic measuring microscope with objective

2.5x , 0.07, 160 /0.17

And eyepiece : 10x

Resolution of the instrument ?

60x Plan Apochromat Objective

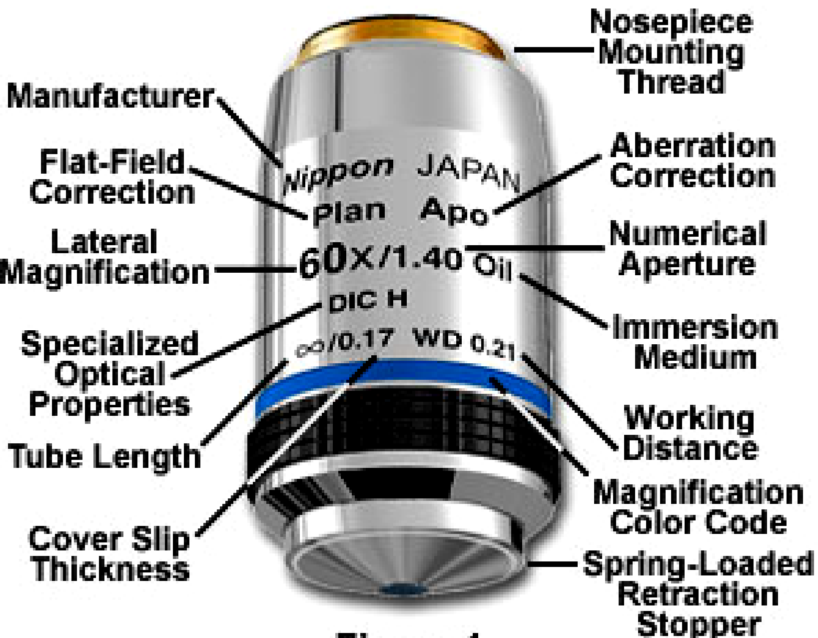


Figure 1

Example 2 :

Microscope objective

60x , 1.40 Oil , ∞ /0.17

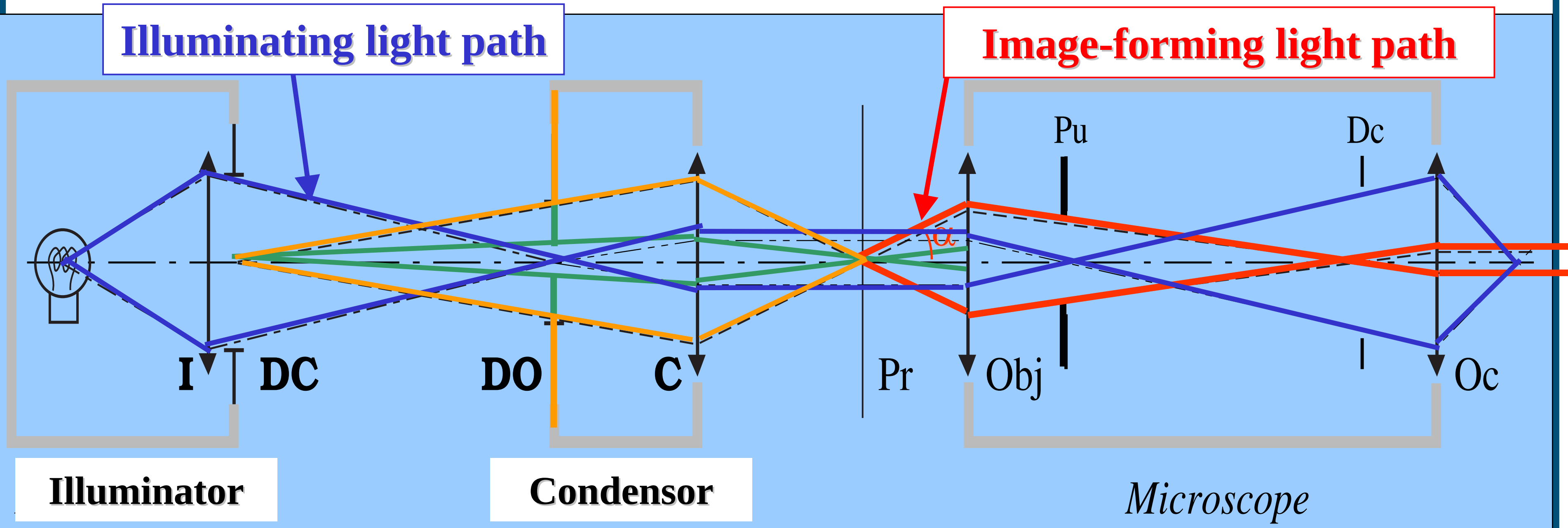
Eyepiece : 10x

Resolution ? Limited by the eye or by diffraction?

Illumination of a microscope specimen

- Uniform illumination is important to distinguish low contrast object
- Resolution is a key property in a microscope
- Spatial coherence of the illumination (aperture of the condenser) has an influence on resolution and contrast
- For good control of aperture and field, the illumination configuration is done in the Köhler configuration

Köhler illumination



Principle of the Köhler illumination

I: Illuminator optics

DC: Field stop

DO: Aperture stop

C: Condensor optics

Pr: Specimen

Obj: Microscope objective

Oc: Eyepiece

Pu: Objective pupil

Dc: Field aperture of eyepiece

Incoherent illumination

Coherent illumination

Resolution and coherence of illumination

•**Coherent illumination:** small aperture stop for the illuminating path (1st focal plane of condenser), illumination with almost parallel beam

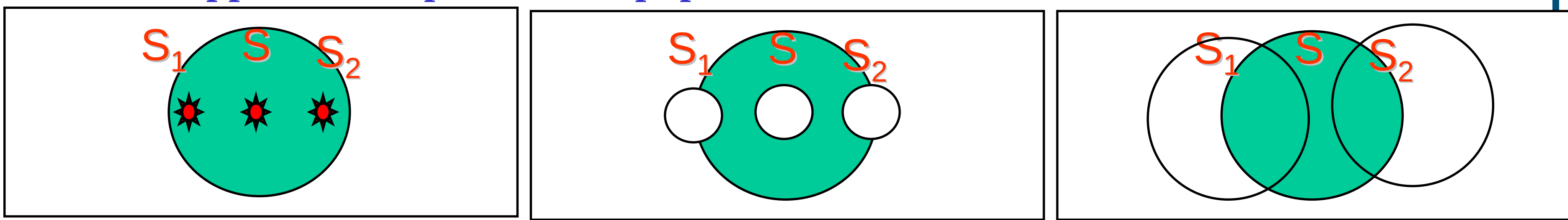
•**Incoherent illumination:** large aperture stop for the illuminating path, illumination with many different directions

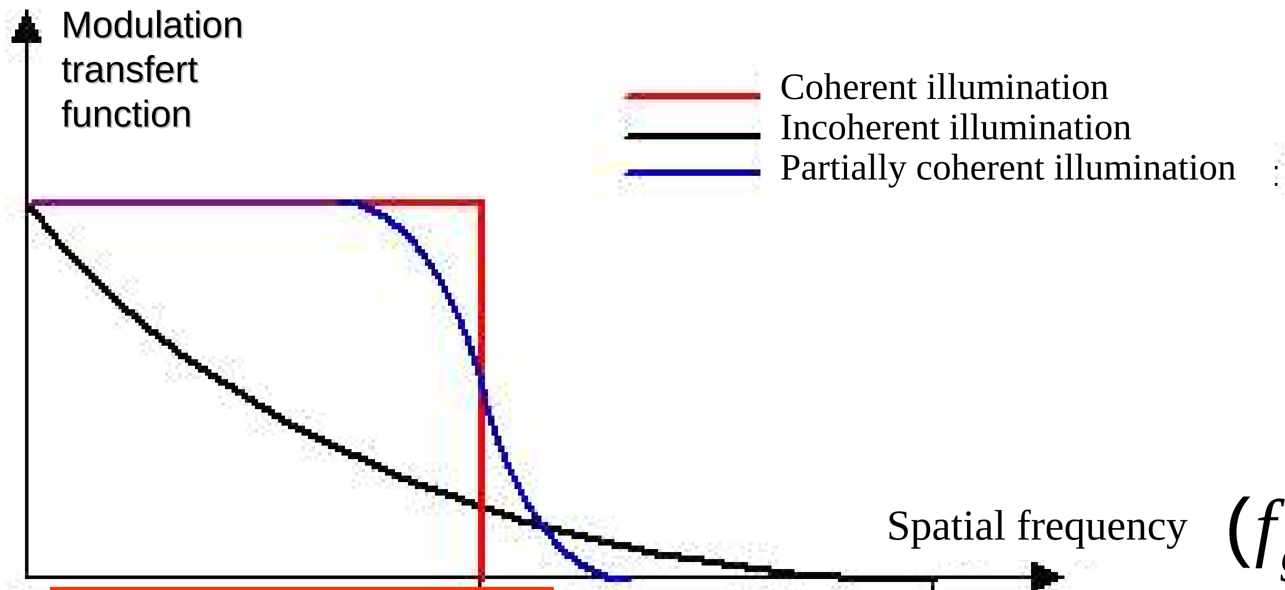
Better resolution limit for incoherent illumination

Better contrast for coherent illumination

Influence of the coherence of the illumination on the quality of the images

What happens in the plane of the pupil?





$$(f_{grating})$$

$$f_{grating} < \frac{n \sin\alpha}{\lambda}$$

$$f_{grating} < \frac{2n \sin\alpha}{\lambda}$$

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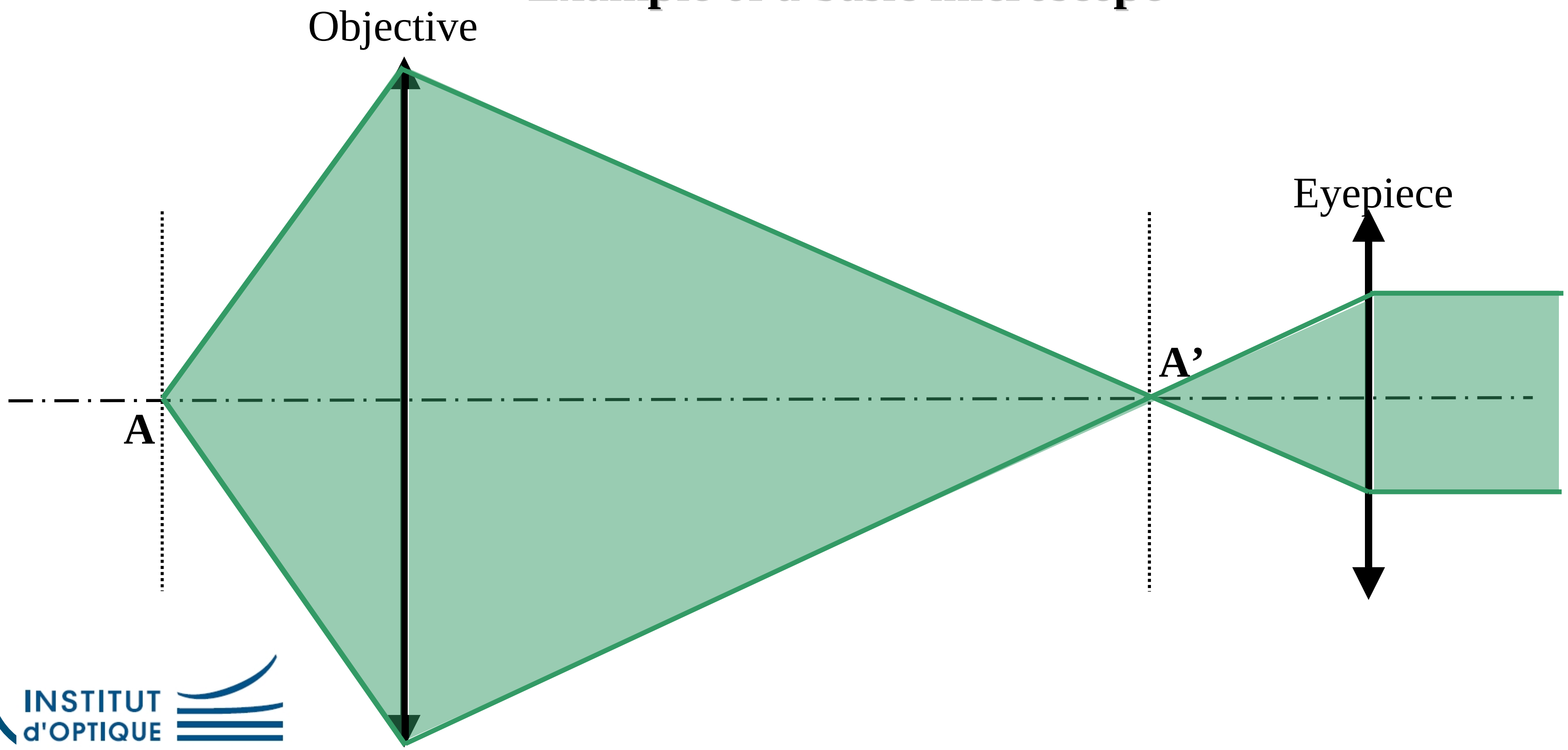
Field of view of a microscope

What happens when we moves away from the axis ?

Example of a basic microscope



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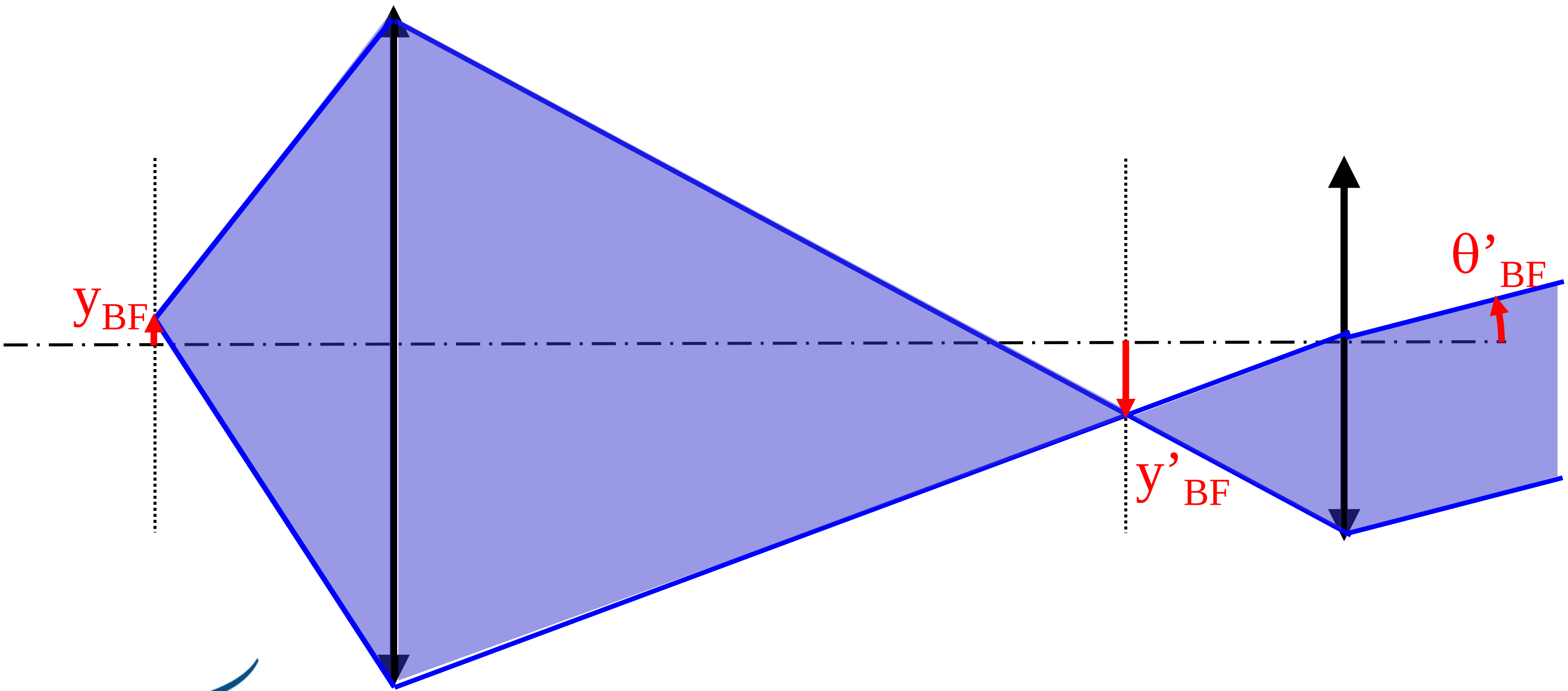
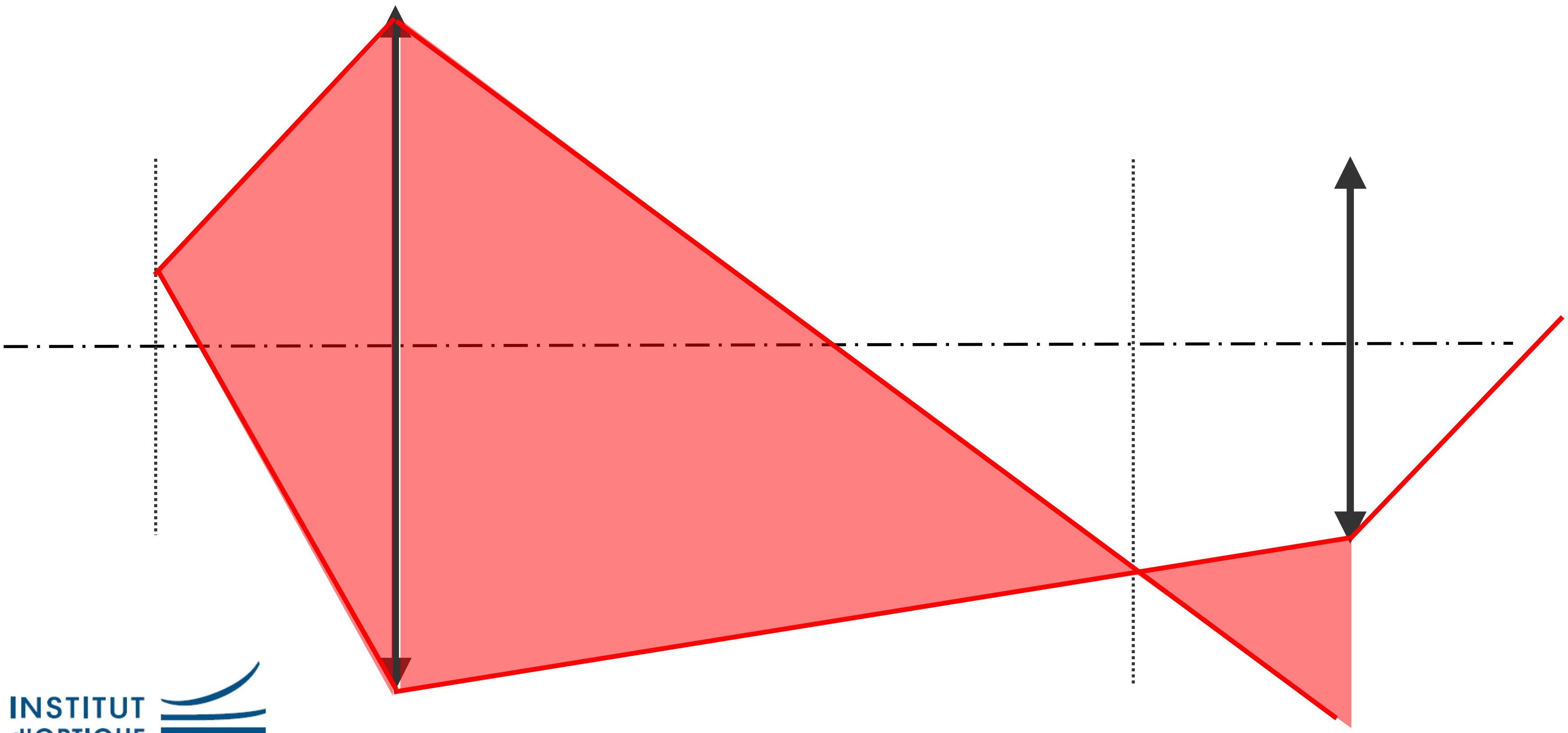
➔ Edge of bright field

Max distance from axis when rays entering through the entrance pupil all exit through the instrument

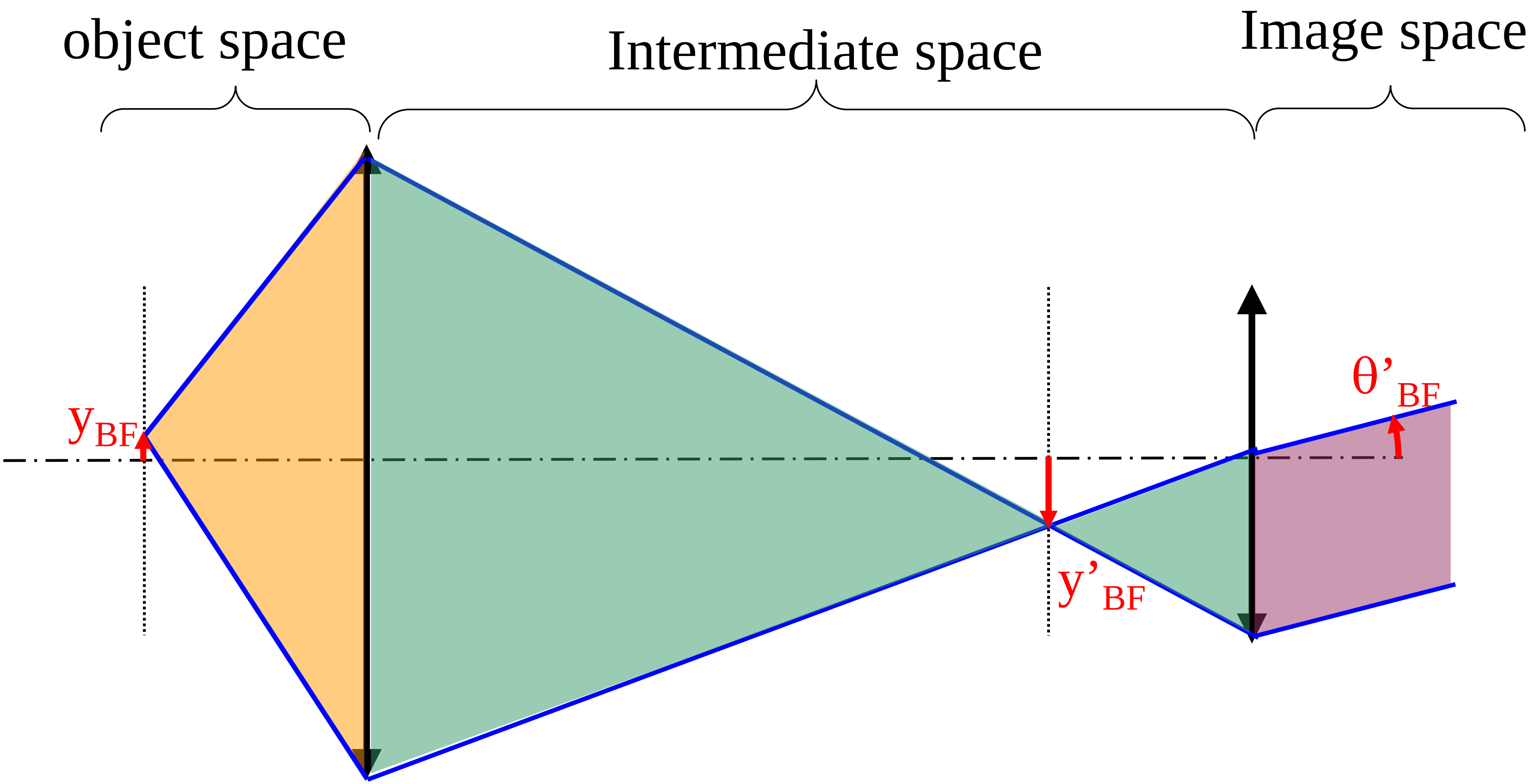


➔ Edge of total field

Maximum distance from axis when NO MORE ray entering the entrance pupil exit through the instrument



Method for calculation



Calculation in one of the spaces

Through conjugation, it is equivalent to calculate the FOV

- in the object space (y_{BF}, y_{TOT})
- in the intermediate space (y'_{BF}, y'_{TOT})
- in the image space (θ'_{BF}, θ'_{TOT})

➔ Choose the space where the calculation is simpler !

➔ Then deduce the FOV in the other spaces using conjugation formulas

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Requires practising on problems