3. – Pinhole Camera

The Problem

Study the characteristics of a pin-hole camera and find the conditions for the camera to achieve optimum image quality.

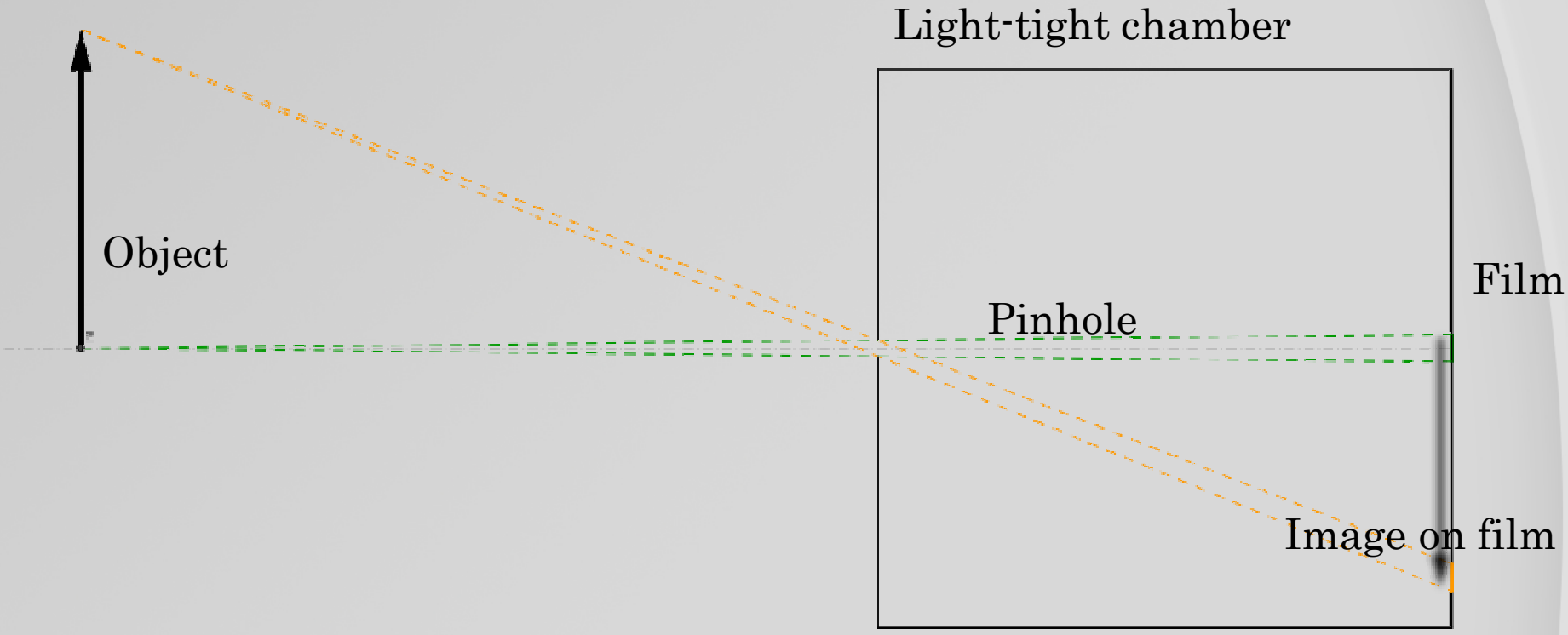
Outline

- Basic principles
  - Geometric optics
  - Diffraction
- Image quality
  - Resolution
  - Brightness
  - Measurements
- Real world usage
- Conclusion

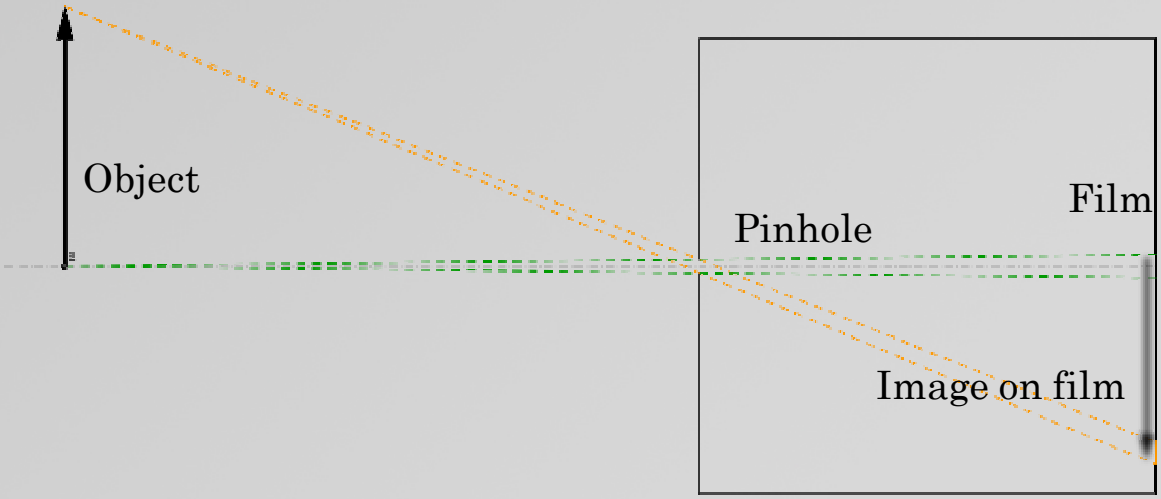
History

- Principle of the camera obscura known to ancient Greek philosophers
- Rediscovered by Arabic scientist Ibn al Haytham in the 11th century
- European renaissance - Giambattista della Porta
- 19th century – photographic film

Image formation



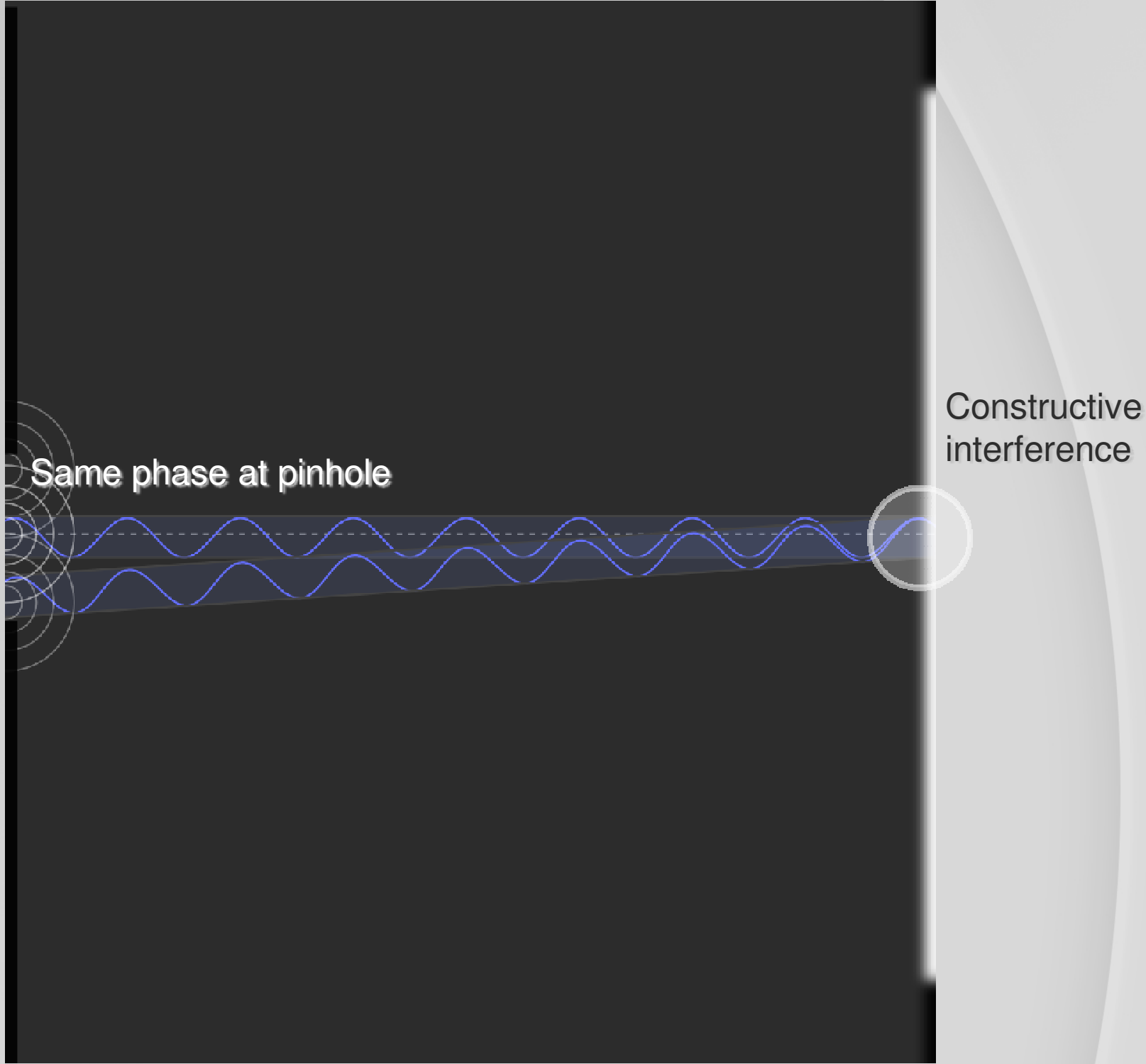
Geometric optics



- Light rays from the object pass trough the pinhole and project an image on the film
- The projection form an point on the object is approximately equal to the pinhole size for distances much larger than the diameter of the pinhole

Diffraction

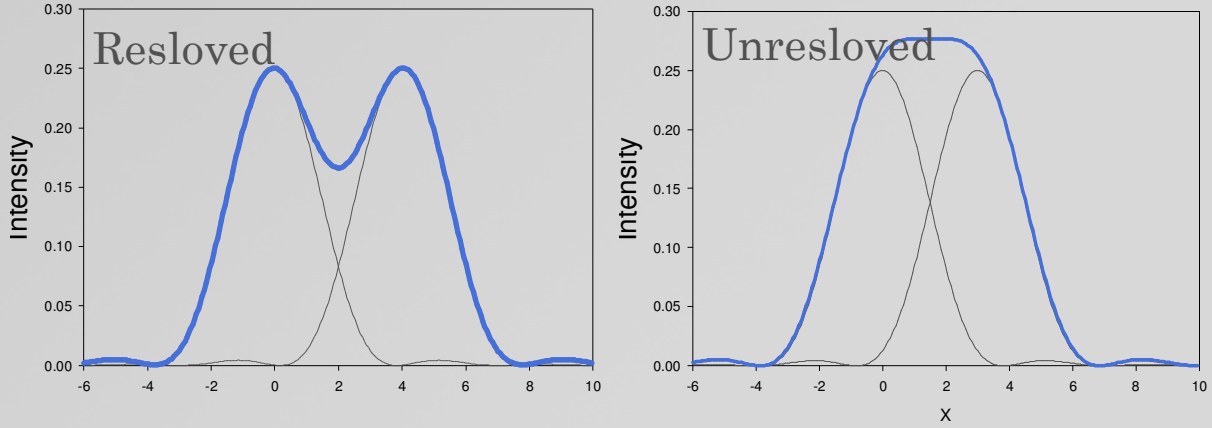
- Circular apreture analogous to narrow slit – each point on the slit a light source
- Two light rays hitting a point on the screen, one at the centre of the slit and one on the edge travel different distances
- As they reach the screen their phases are different
- Interference pattern observed


Same phase at pinhole
Constructive interference

Same phase at pinhole
Destructive interference
Airy disk

Diffraction

- Airy disk – area of constructive interference of light waves before the first minimum
- Rayleigh criterion – maximum of first patter coincides with minimum of the second



- Using mathematical analysis of Bessel functions the radius of the Airy disk can be obtained [1]

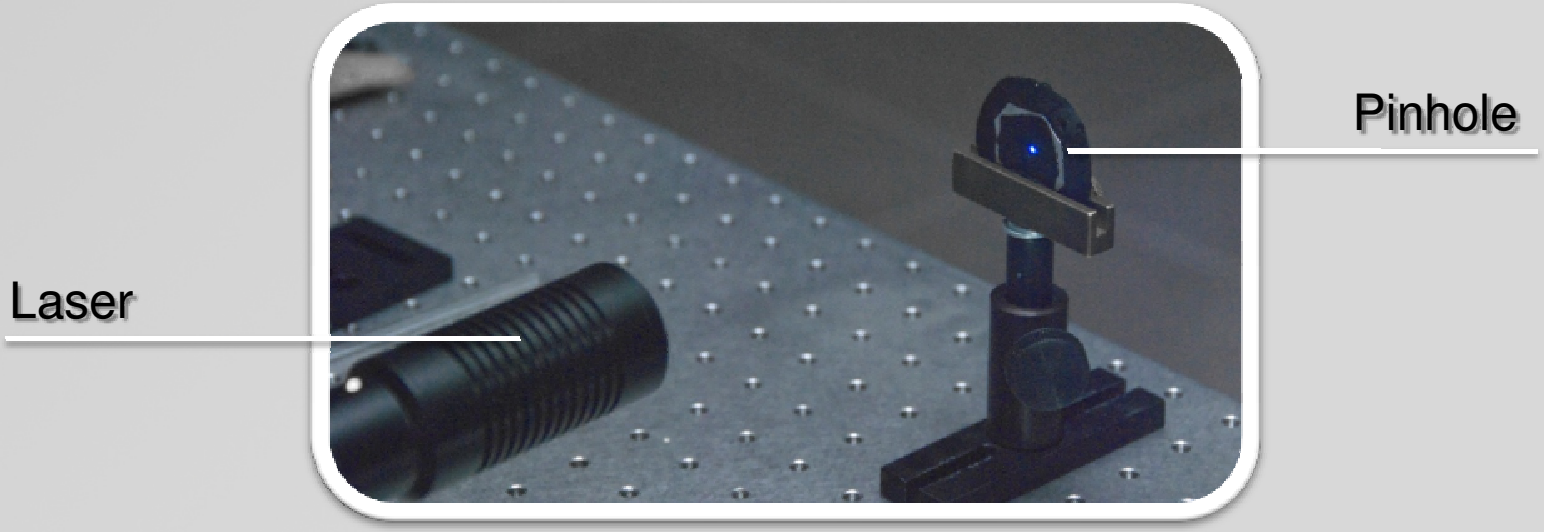
$$D_A = \frac{2.44 f \lambda}{D_p}$$

D_A – diameter of Airy disk
D_P – pinhole diameter
f – focal length
λ – light wavelength

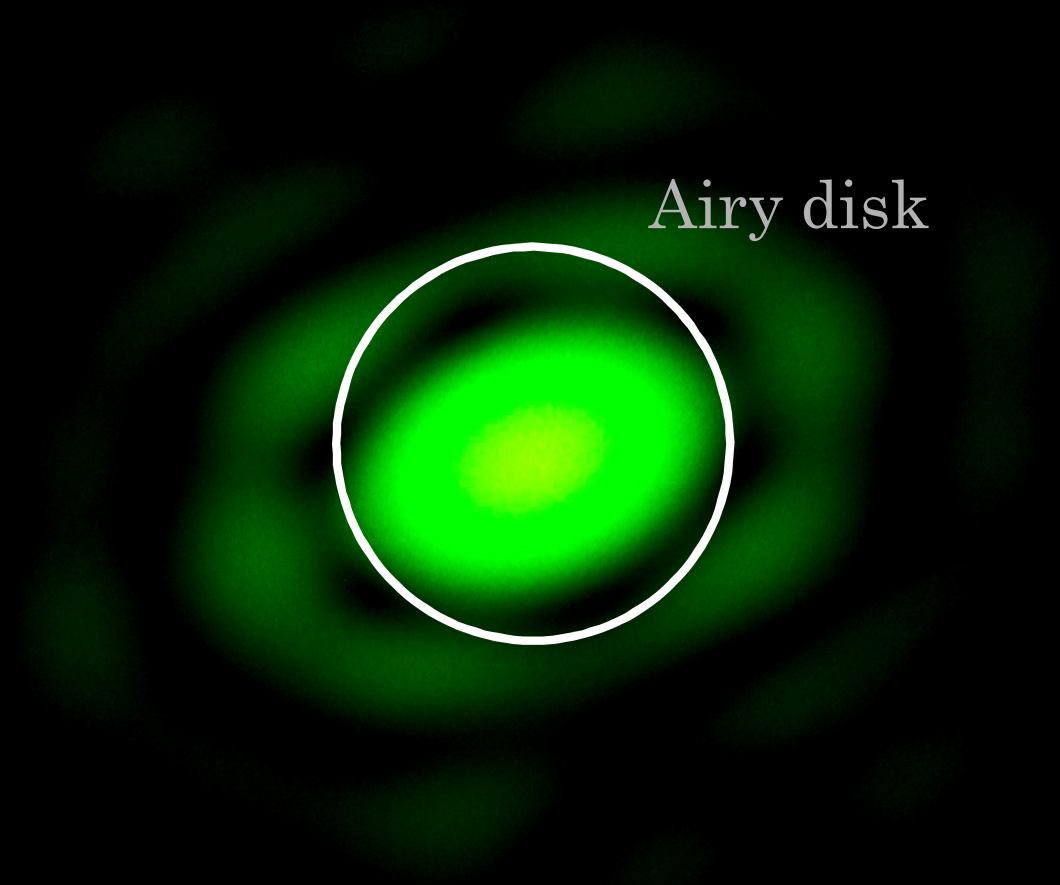
[1] Matt Young,
The Physics Teacher, December, 1989

Diffraction

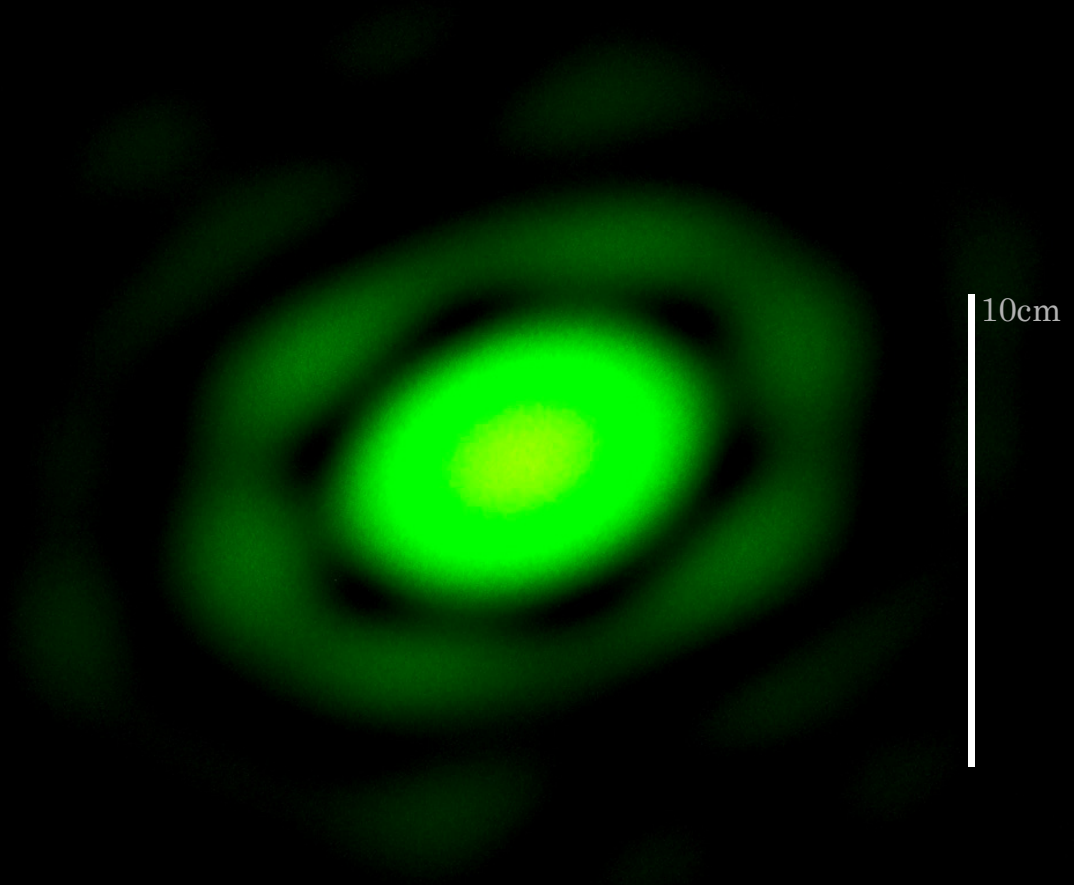
Trough 4 pinholes lasers of 4 different wavelengths (blue, green, orange and red) were aligned trough the pinhole and the diffraction pattern was photographed on a distant card



Diffraction patterns

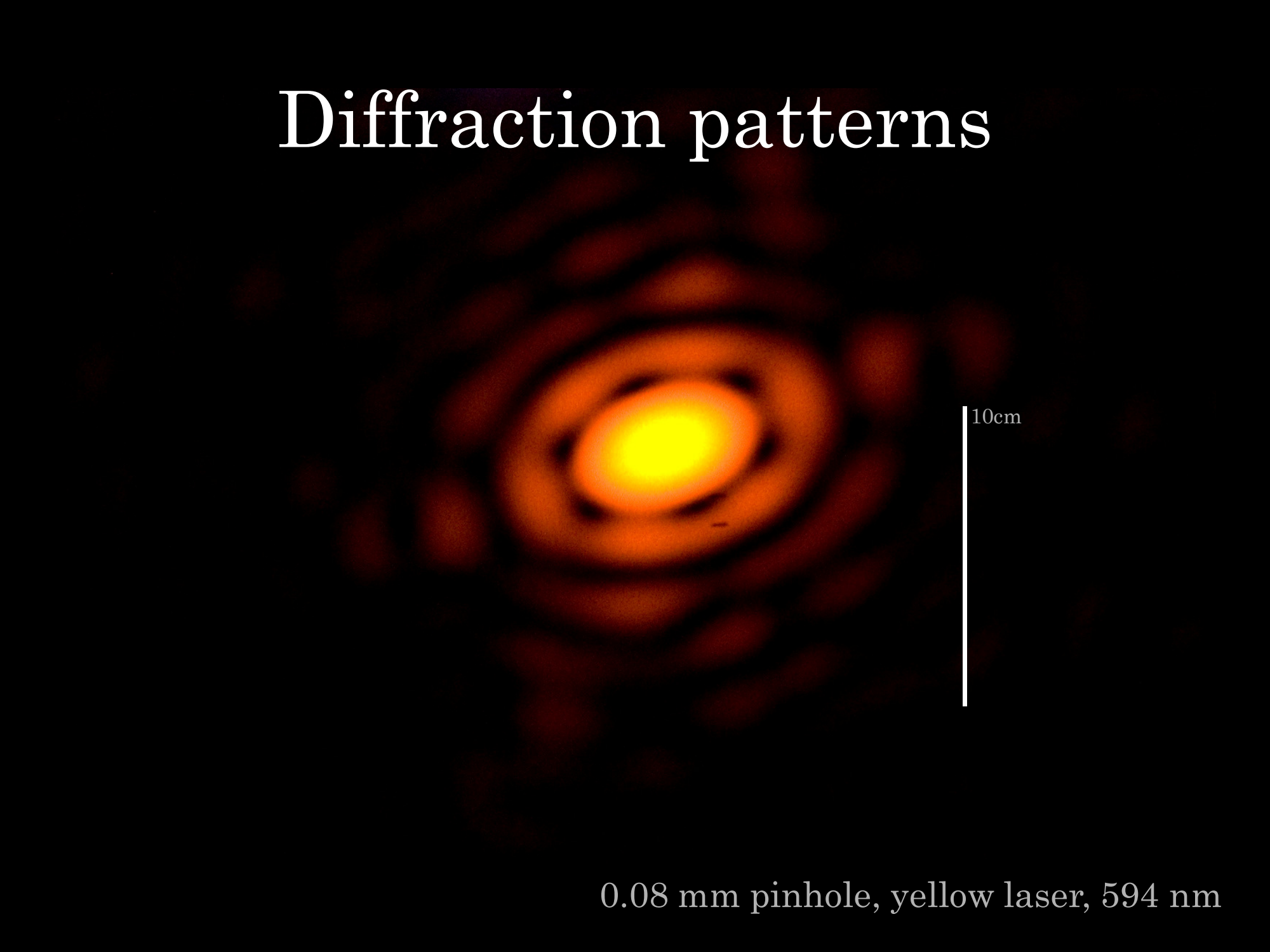


Diffraction patterns



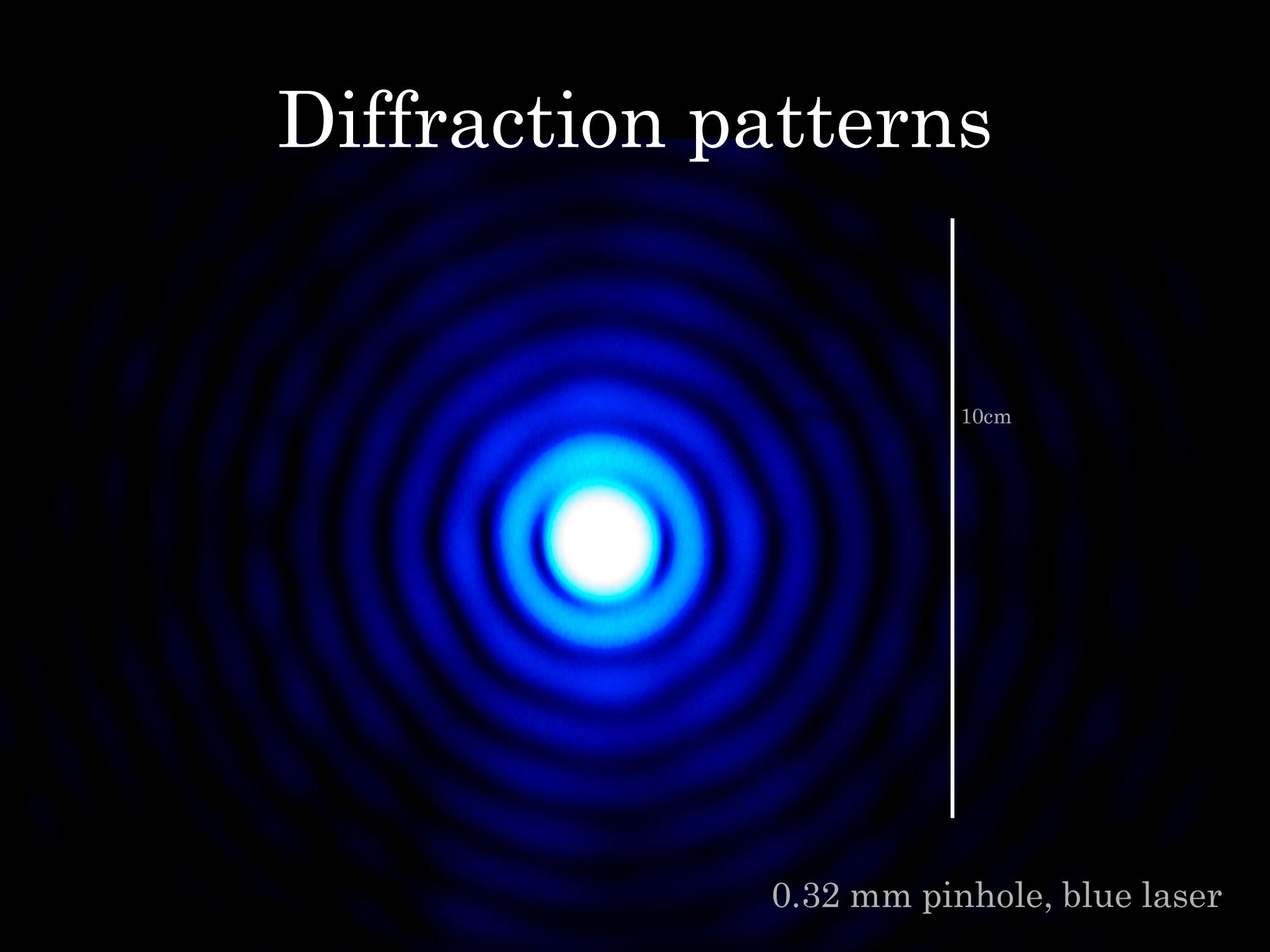
0.08 mm pinhole, green laser

Diffraction patterns



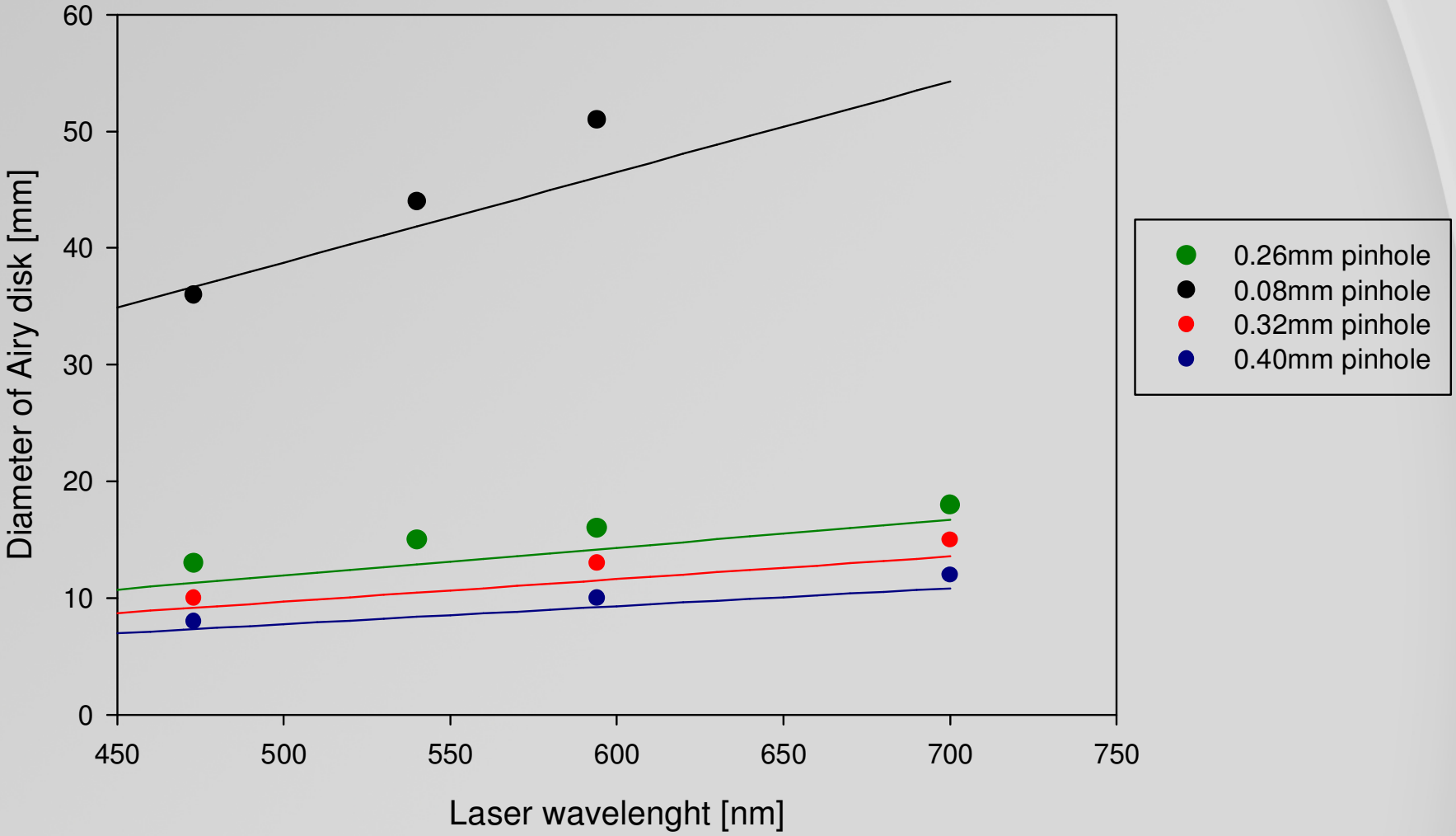
0.08 mm pinhole, yellow laser, 594 nm

Diffraction patterns



0.32 mm pinhole, blue laser

Results – airy disk diameter



Camera design

- Converted mechanical SLR camera
- Plastic adapter with pinholes
- Pinholes cut with needles in 0.1mm aluminium foil and measured using a scanner
- Extension rings for enlarging the focal length

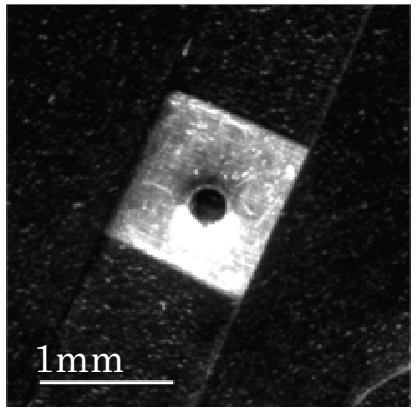




Image Quality

- Sharpness
  - Resolution
    - Linear
    - Angular
- Brightness
  - f– number
  - Brightness falloff - vignetting

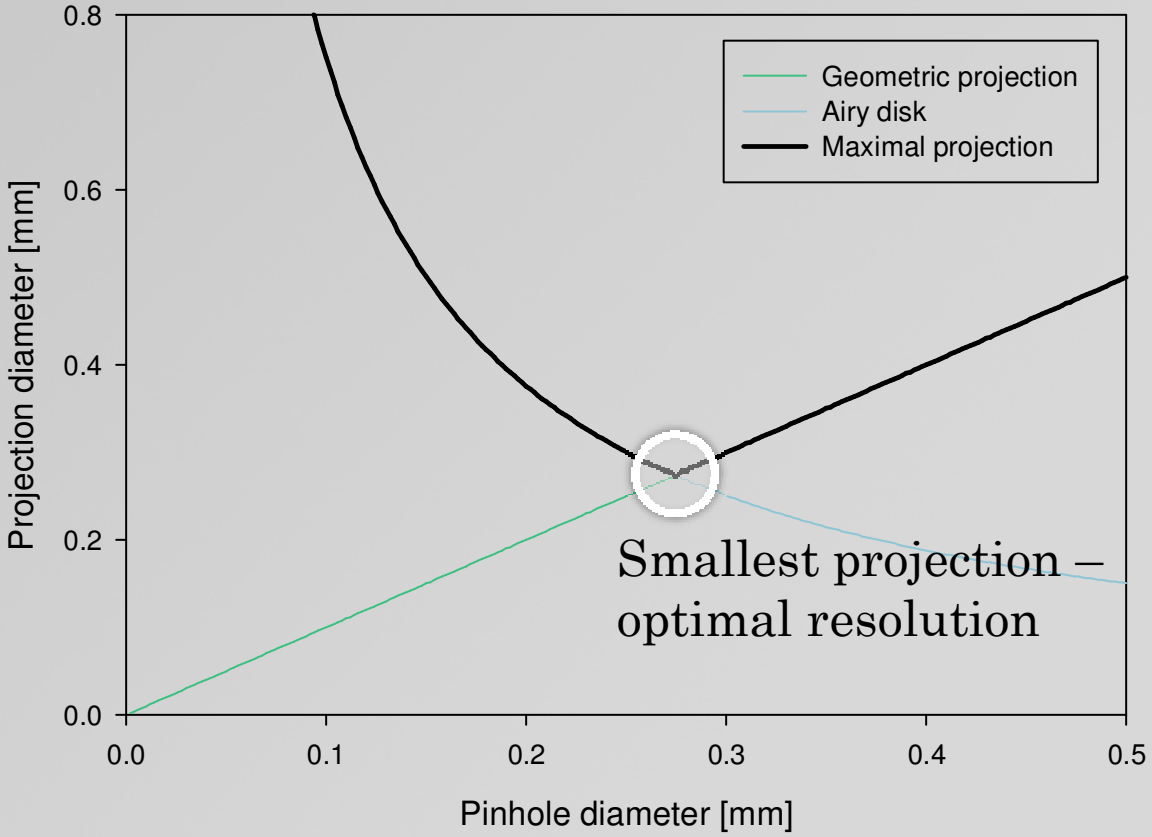
Resolution

- Sharpness – resolution
- Angular resolution – the smallest angle between two objects at which they can be resolved - different for every focal length
- Linear resolution - the smallest distance of two objects at a fixed distance at which they can be resolved
- Normalized in lines per picture width

Effects affecting image sharpness

- Geometric optics – "shadow" (projection) of the pinhole on the imaging plane
  - Diameter of the projection equal to the pinhole diameter as the distance of the object to the pinhole >> pinhole diameter
- Diffraction
  - Diffraction pattern trough a circular aperture – *Airy disk*

Effects affecting image sharpness



$$D_A = D_p$$

$$D_p = \frac{2.44 f \lambda}{D_p}$$

$$D_p = \sqrt{2.44 f \lambda}$$

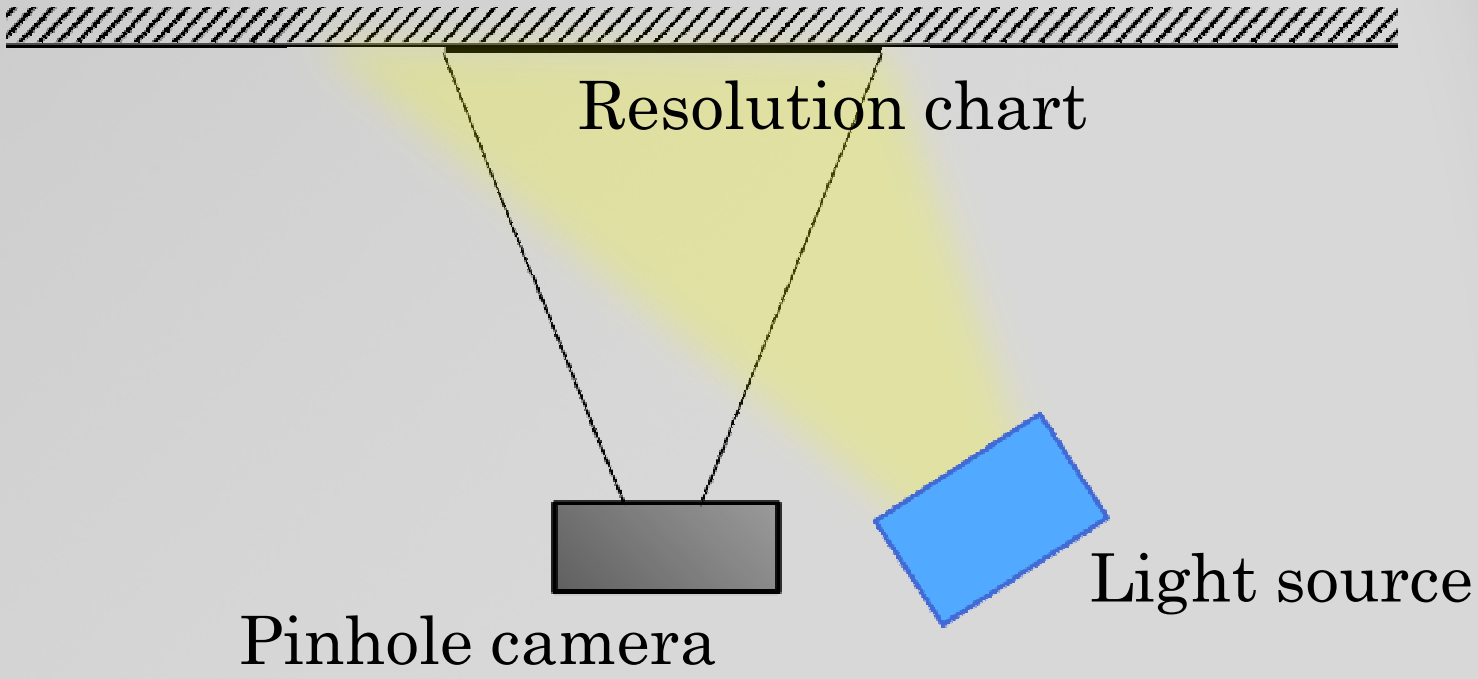
D_A – diameter of Airy disk
D_P – pinhole diameter
f – focal length
λ – light wavelength

Graph showing the diameter of the two projections – blue – Airy disk, red – pinhole "shadow"

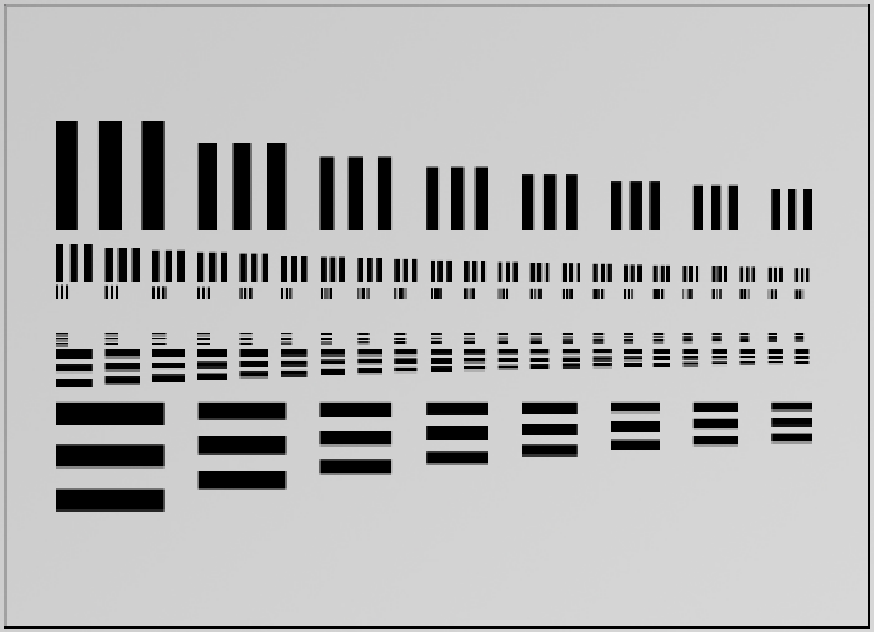
Measurements

- Resolution measurements
  - Costum designed test pattern
  - Camera set at a distance when the full chart is covered for each focal length
  - Exposure time measured using a grey card with another camera and calculated from the f number of the pinhole camera
  - The resulting film scanned and analyzed on the computer

Measurement setup



Resolution chart



Computer generated target

- resolution lineary increasing with every square



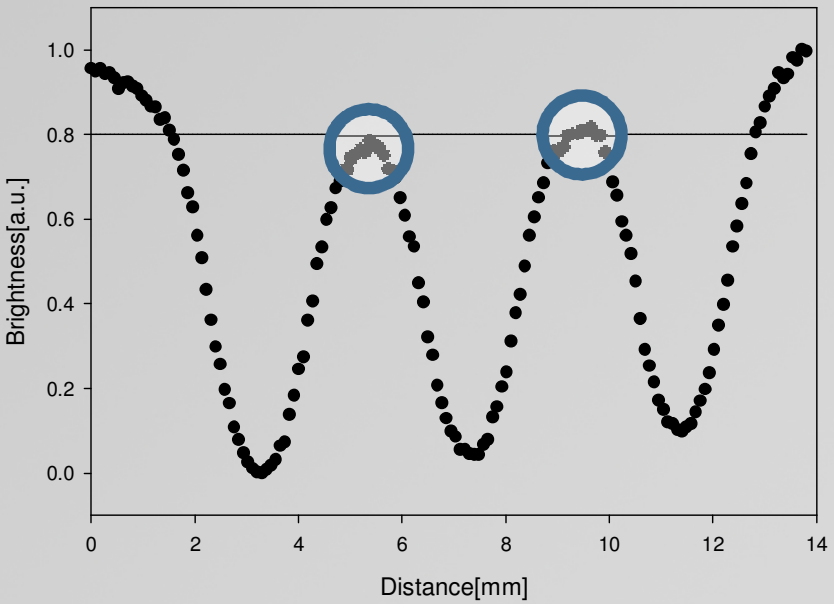
The photographed target

Data analysis

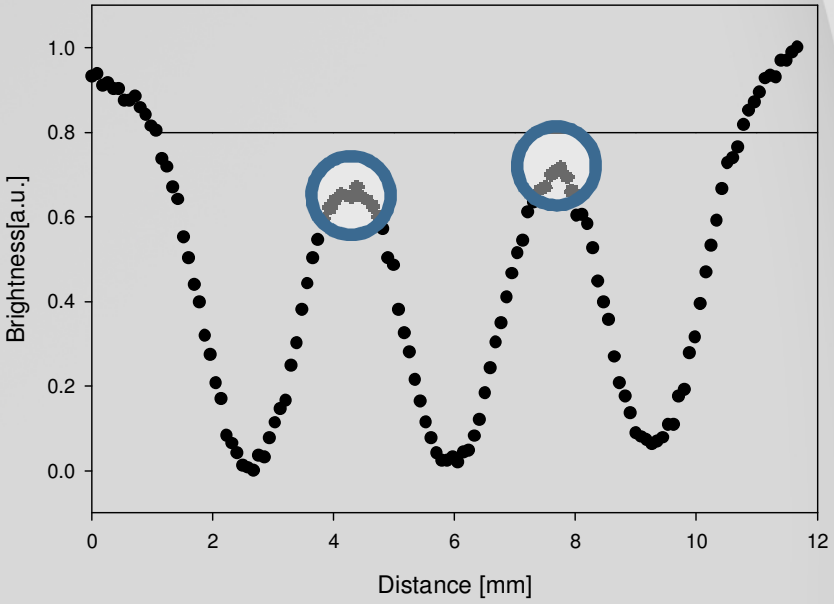
- Pixel brightness profile plot over each resolution square
- Lines are resolved whet the intermediate maximums are no darker than 0.8 difference between maximum and minimum

Data analysis

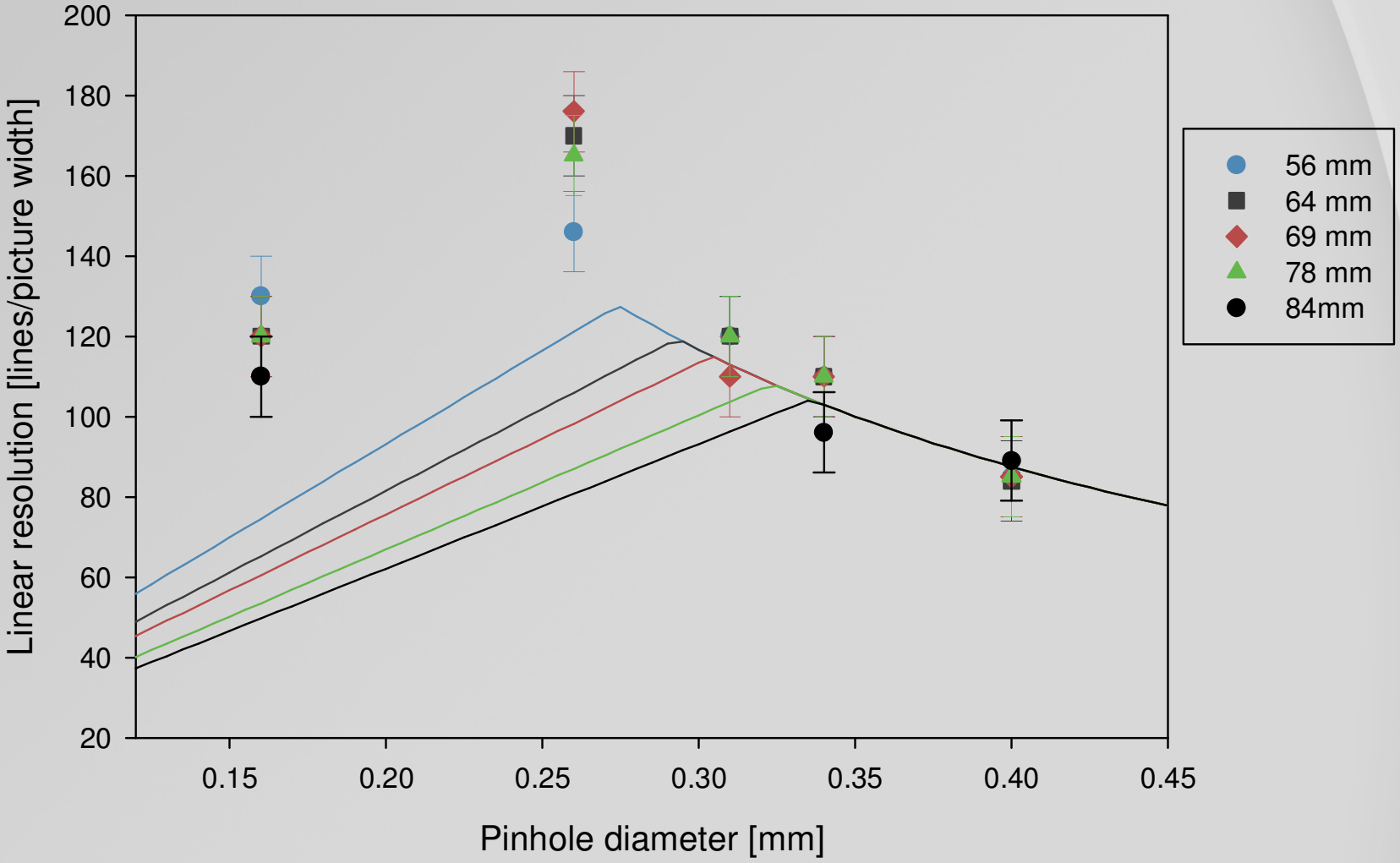
Resolved



Unresolved



Results


Linear resolution [lines/picture width]
200
180
160
140
120
100
80
60
40
20
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Pinhole diameter [mm]
56 mm
64 mm
69 mm
78 mm
84mm

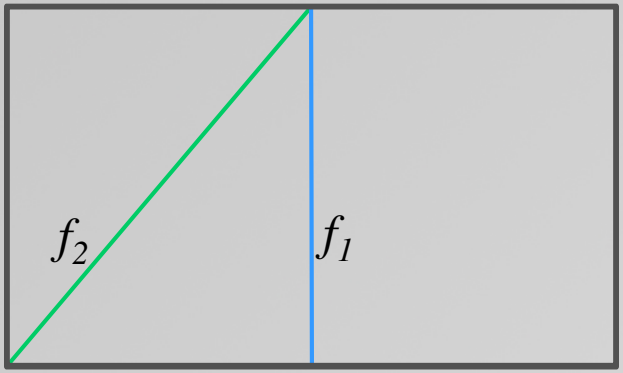
Brightness

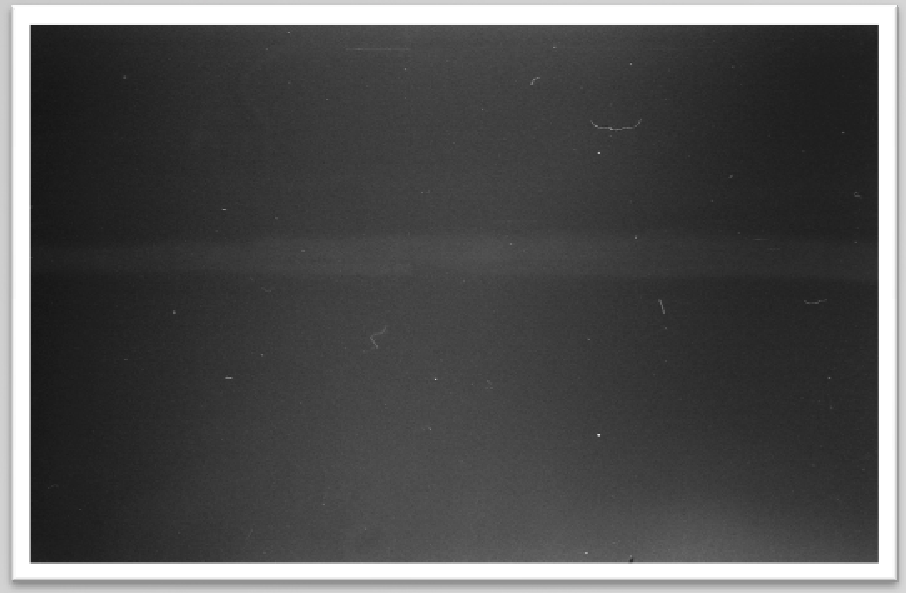
- Brightness of an imaging instrument (lens or otherwise) is stated as its *f*-number
- *f* number is the ration of the focal length and aperture diameter $f_n = \frac{f}{D}$
- Exposure time proportional to $\Delta t \propto \frac{1}{f_n^2}$
- Lens cameras - $f_n \approx 8$
- Pinhole camera - $f_n \approx 200$

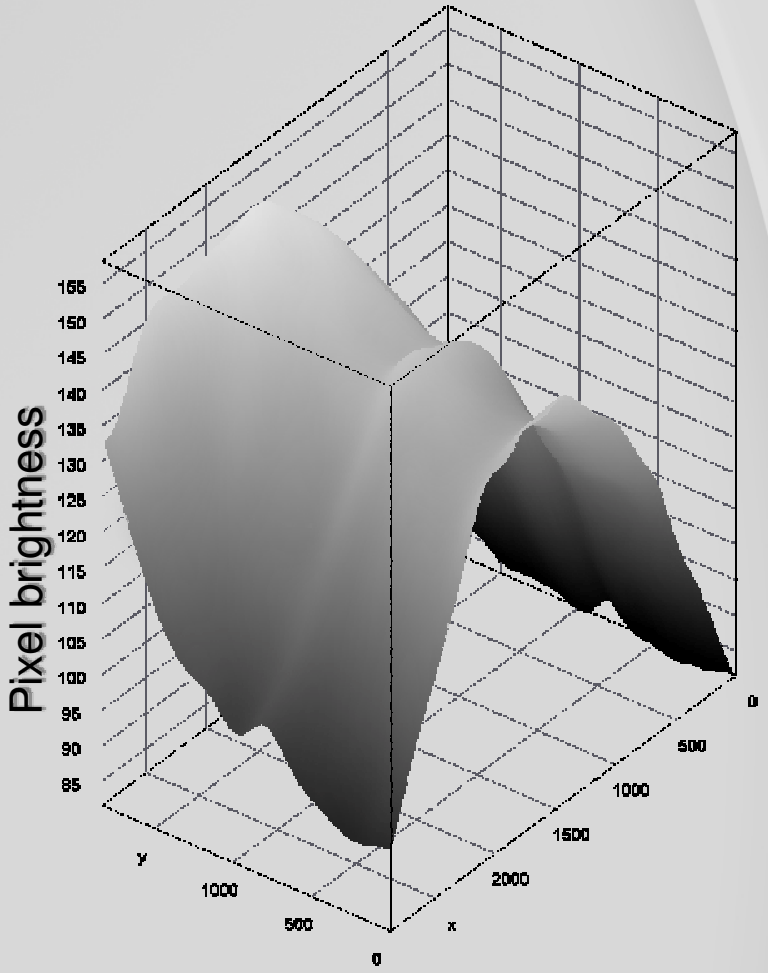
Brightness fallof (vignetting)

- The f - number increases from the center to the edge of the film
- The camera was aligned close to an evenly lit LCD display and underexposed

Brightness falloff

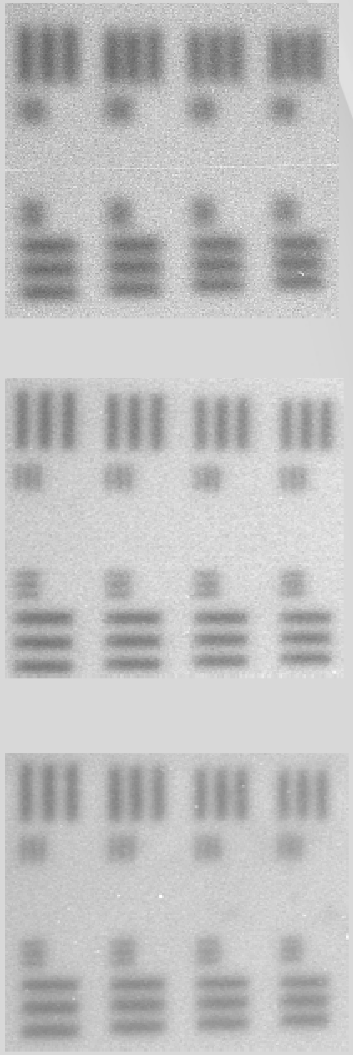






Real world usage

- Advantages
  - Cheap
  - Very wide angles posible
  - No geometric distortion
  - Large depth of field
- Disadvantages
  - Low resolution
  - Long exposure times









Conclusion

- Effects investigated
  - Diffraction
  - Geometric optics
- Measurements
  - Diffraction of circular apretures (pinhole)
  - Pinhole camera resolution
  - Brightness falloff

Conclusion ctd.

- Ideal parameters determined experimentally and theoreticaly
- Picures taken with optimal camera configuration for normal field coverage focal distance 56mm - 50° coverage, 0.26 mm pinhole