CS 89.15/189.5, Fall 2015

Computational Aspects of Digital Photography

Image Formation & Camera Basics (continued)

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Dartmouth

Agenda

Pinhole optics

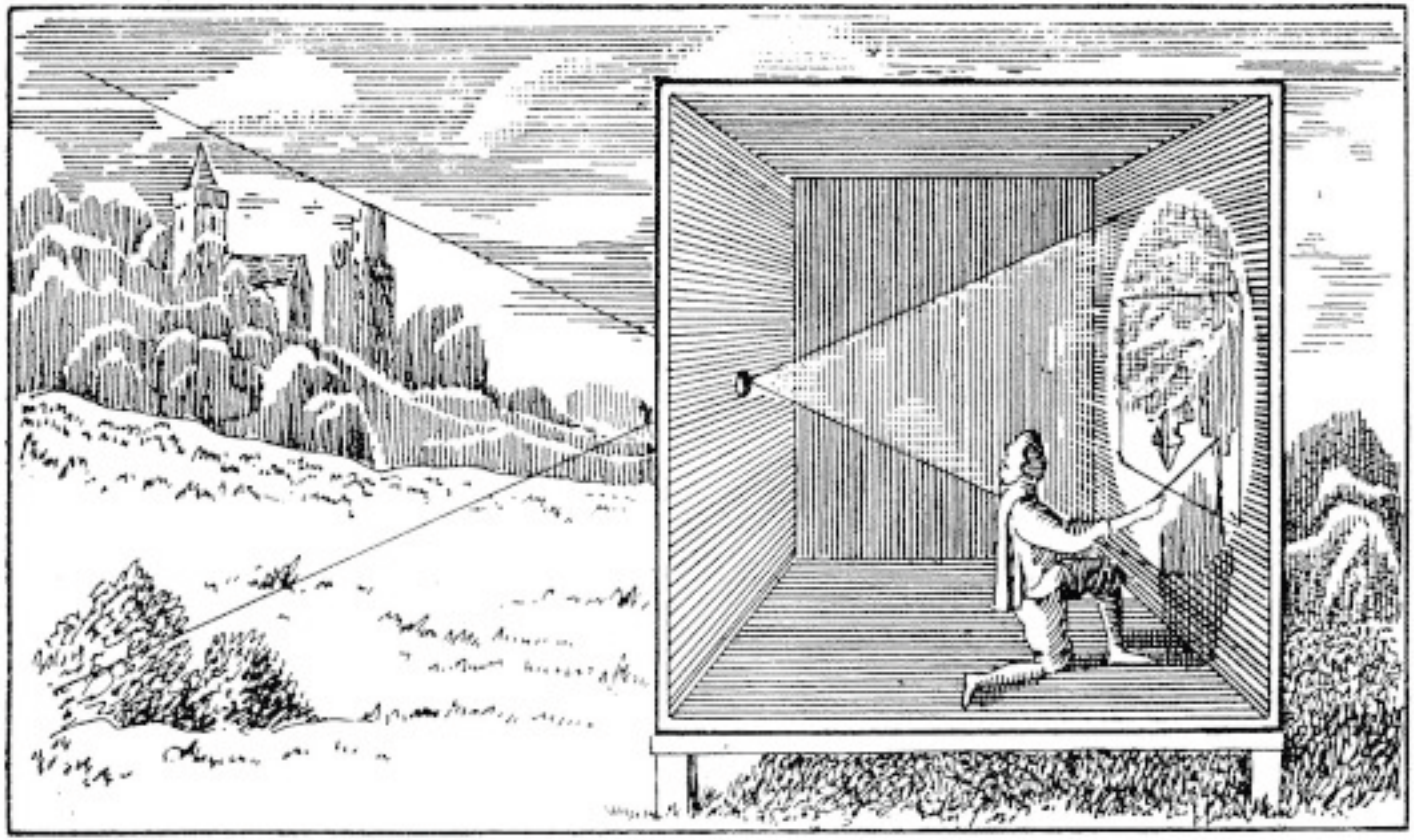
(Simplified) Lenses

Exposure

- shutter speed
- aperture
- ISO

Image processing basics

Pinhole camera / camera obscura

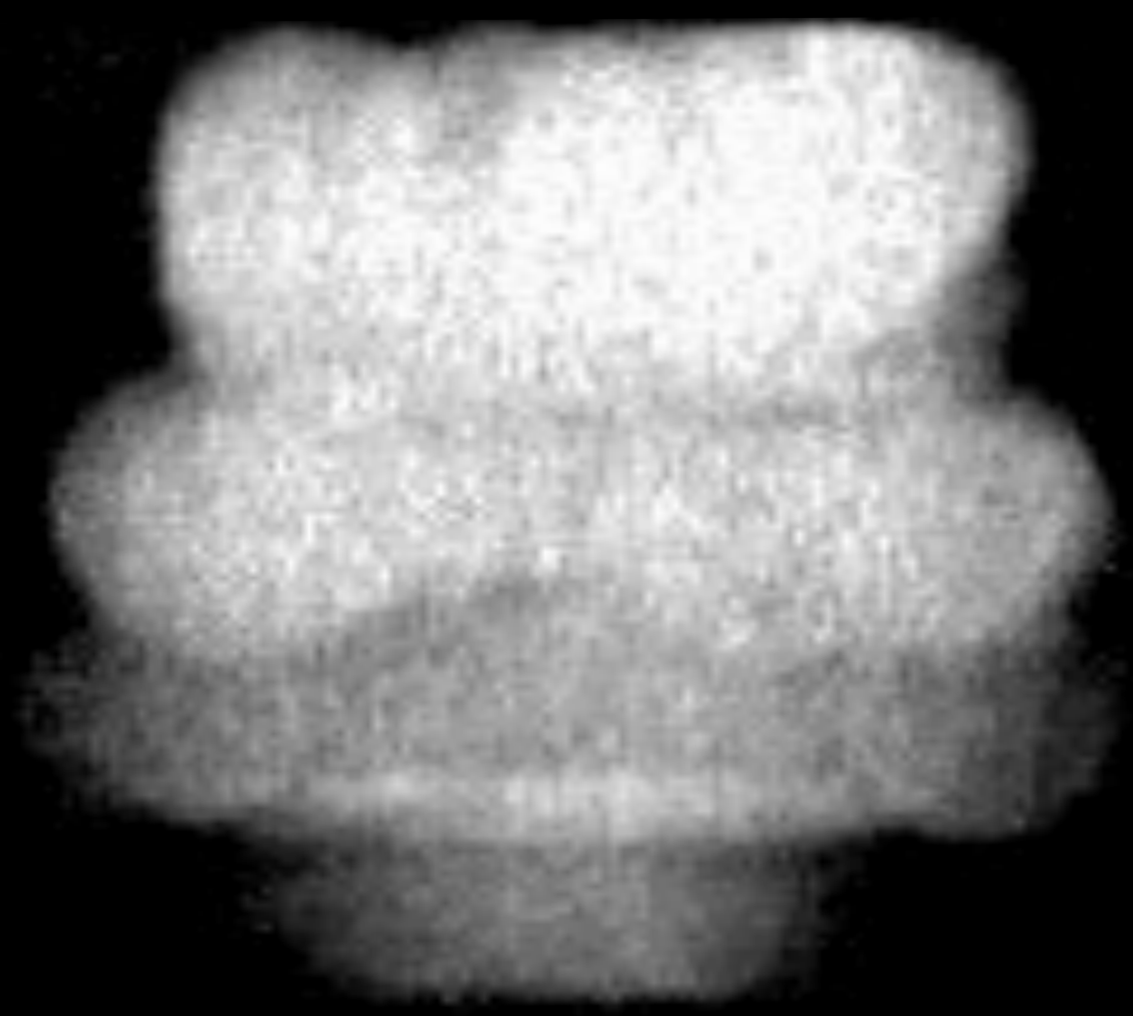


Abelardo Morell

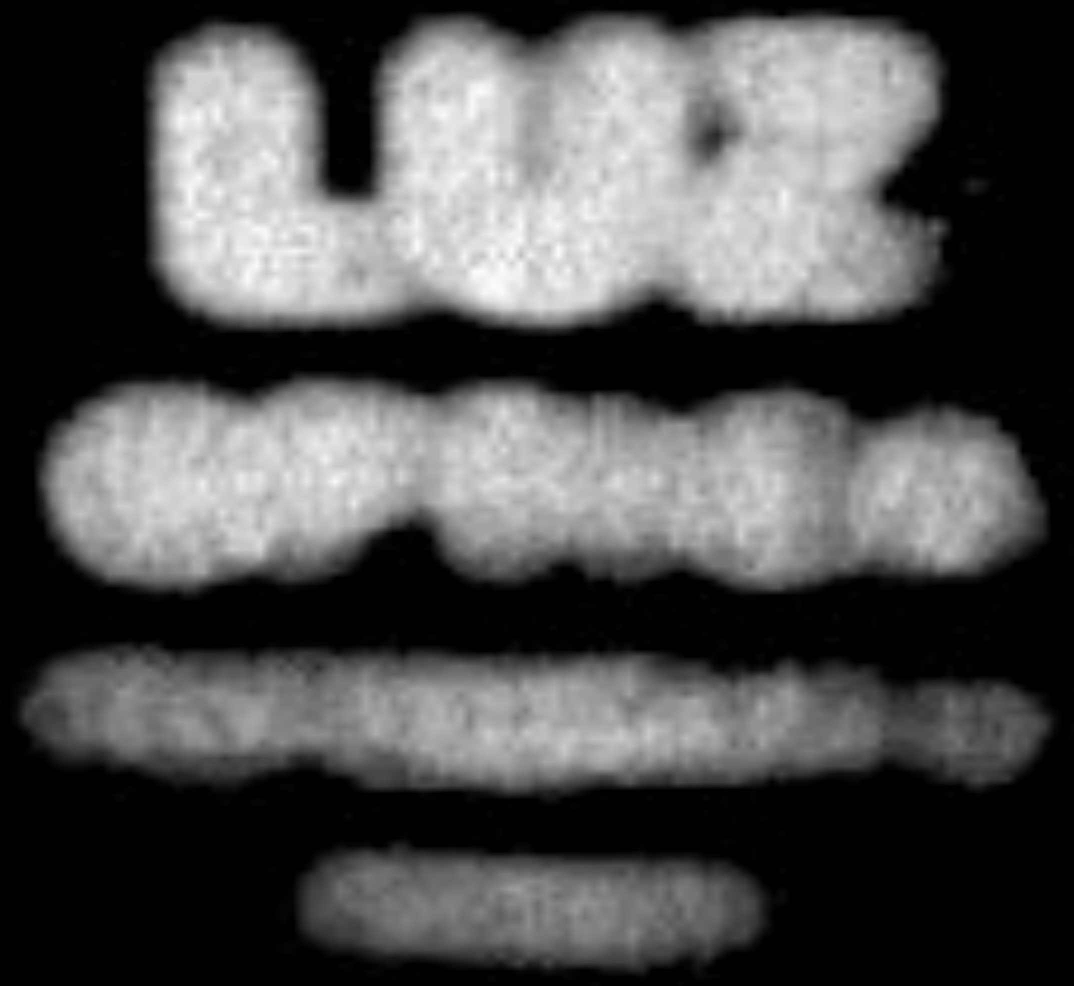
Pinhole cameras everywhere

Another way to make a pinhole camera

http://www.debevec.org/Pinhole/



2mm

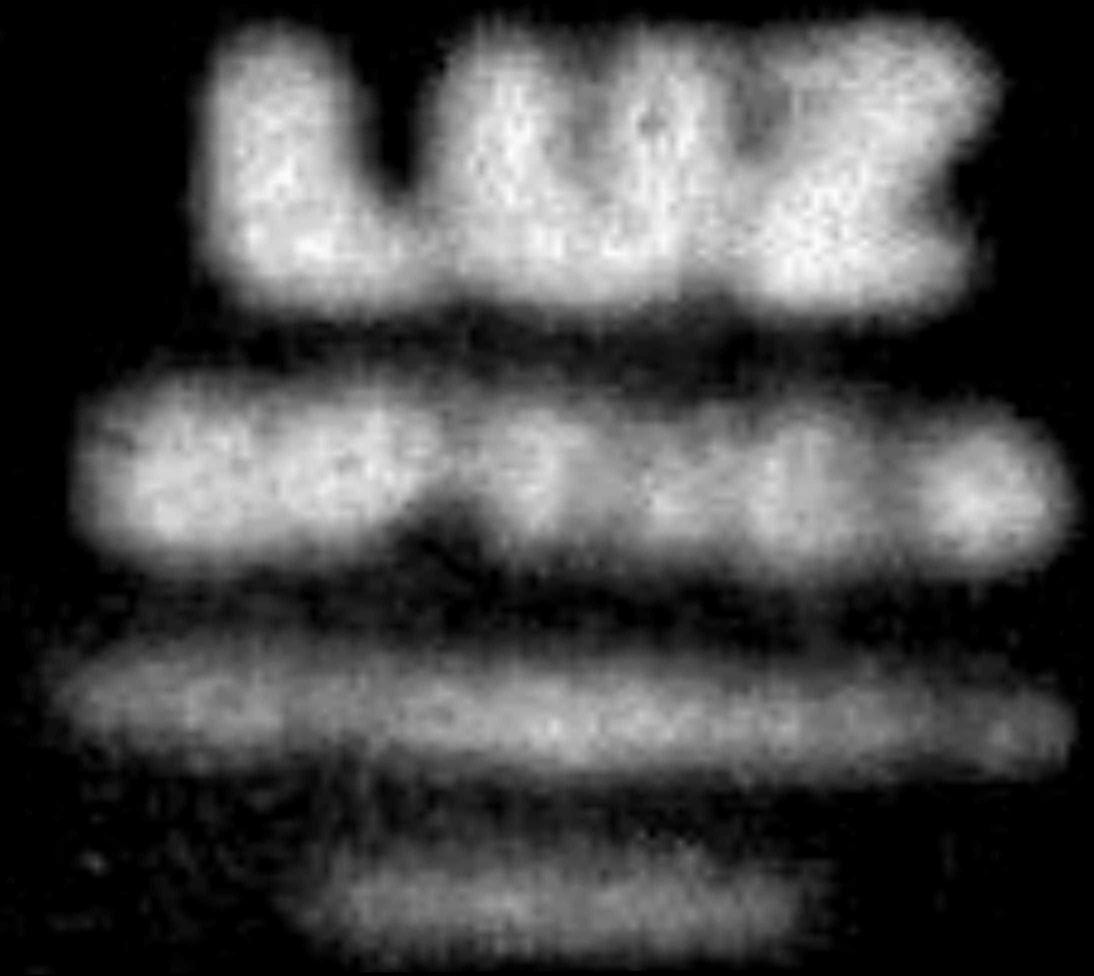


1mm

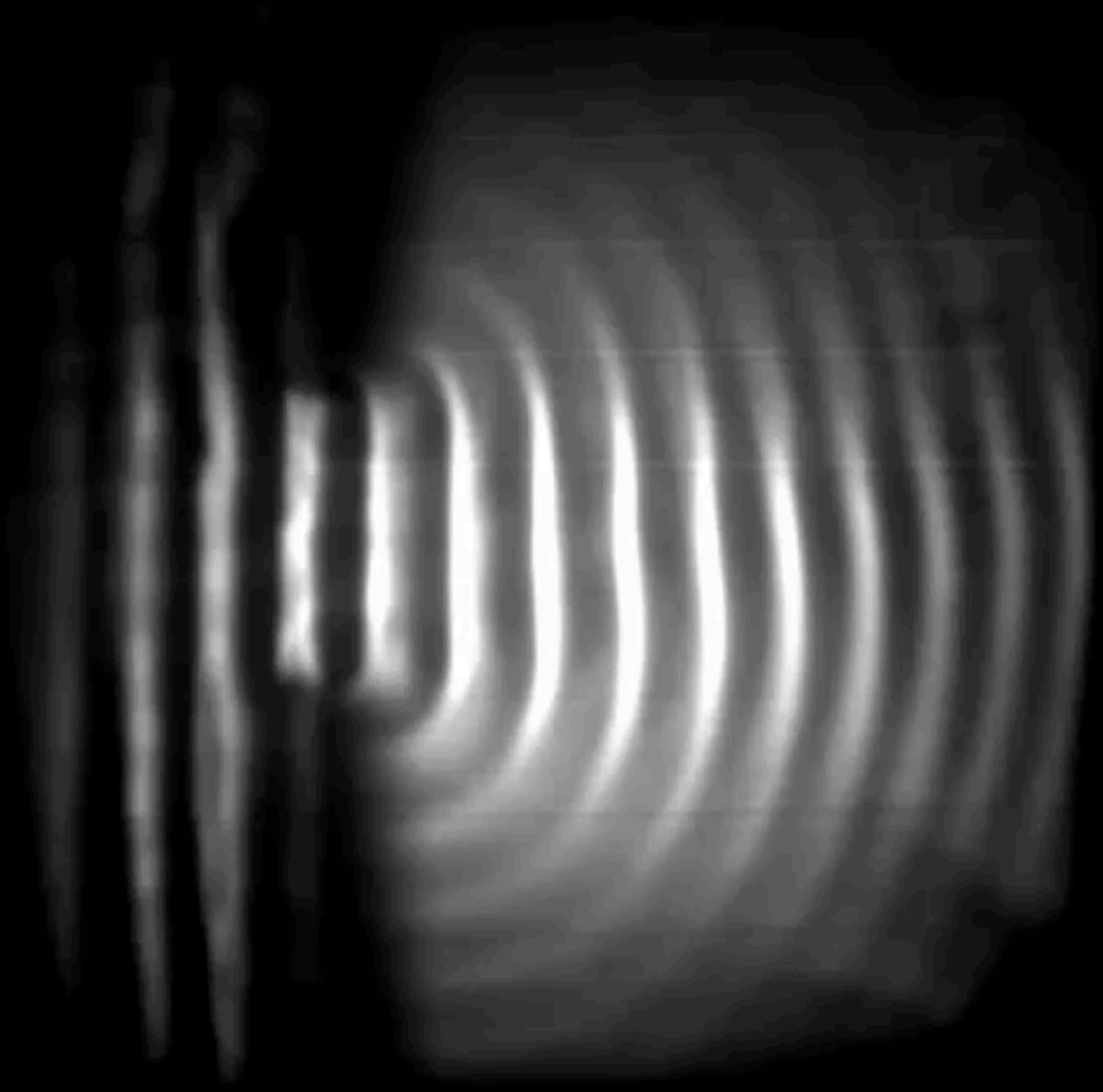
0.6mm

0.35mm

0.15mm



0.07mm



Replacing pinholes with lenses

From *Photography*, London et al.

Modern camera: 3 variables

turn to adjust **aperture**

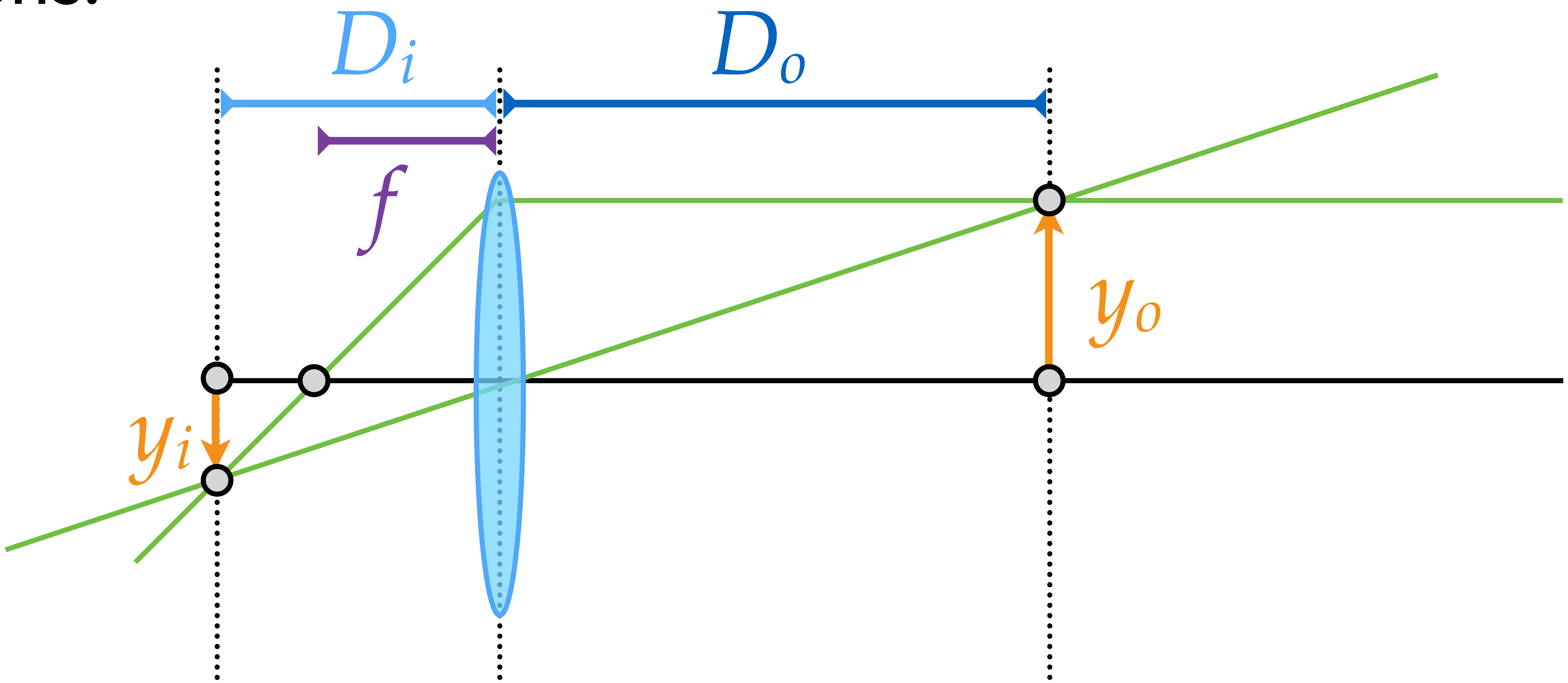
turn to **focus**

turn to adjust **shutter speed**

Thin lens formula

All rays passing through a single point y_o on a plane at distance D_o in front of the lens will pass through a single point y_i at distance D_i behind the lens.

$$\frac{1}{D_i} + \frac{1}{D_o} = \frac{1}{f}$$



Lenses gather more light, but…

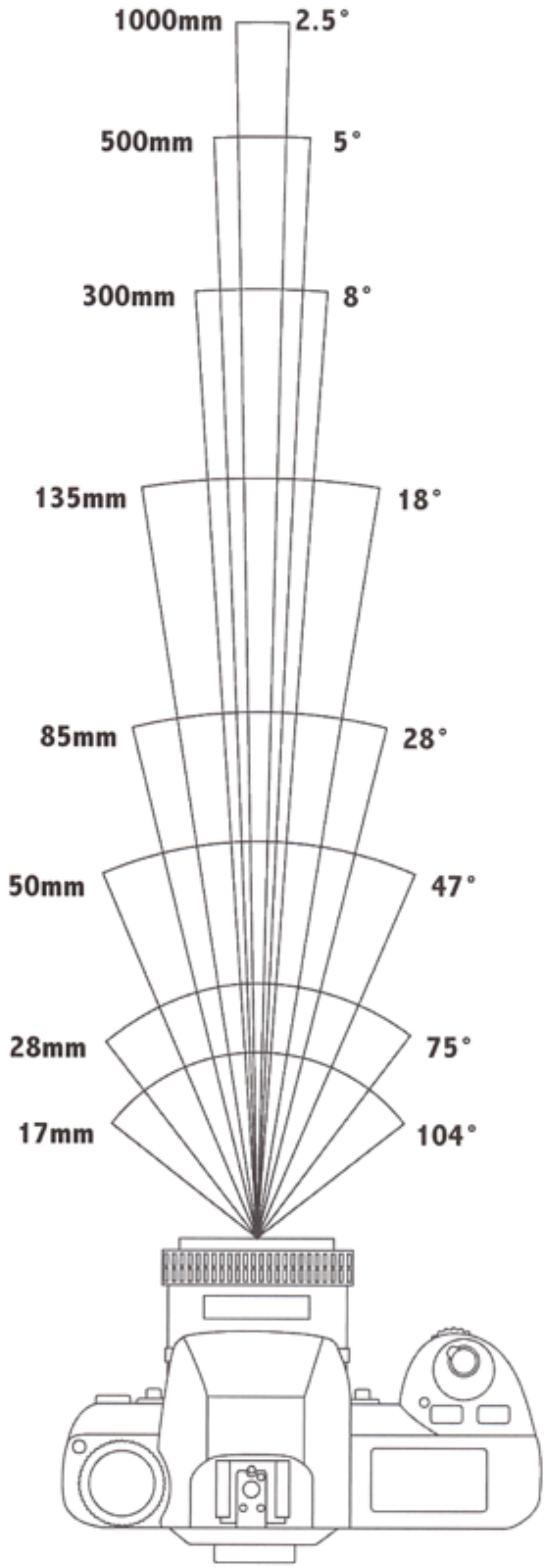
Only one plane in focus

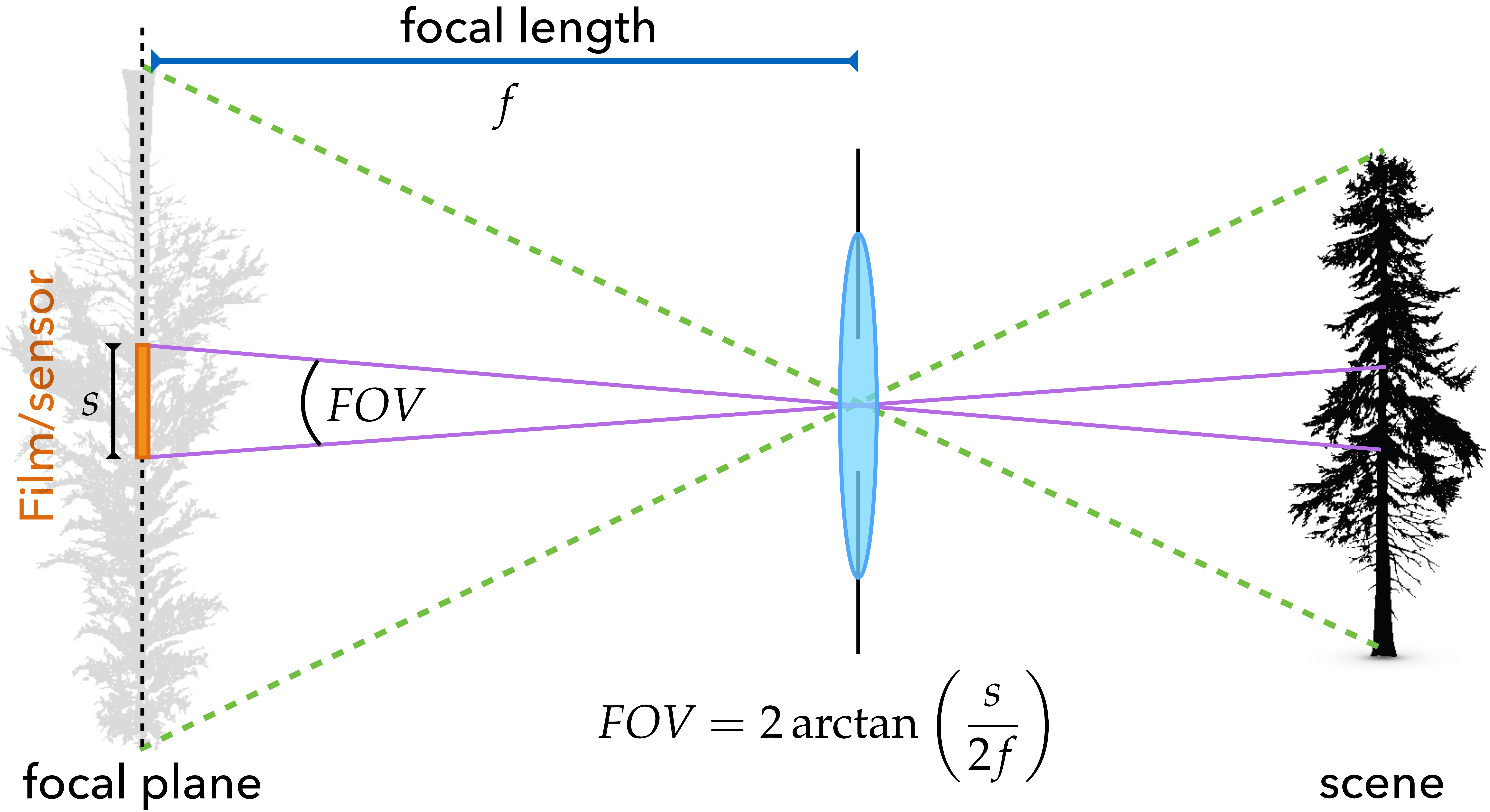
Focus by moving sensor/film

Cannot focus infinitely close


https://youtu.be/tS87bYD5kiM
24mm Focus distance & FOV (lens breathing)

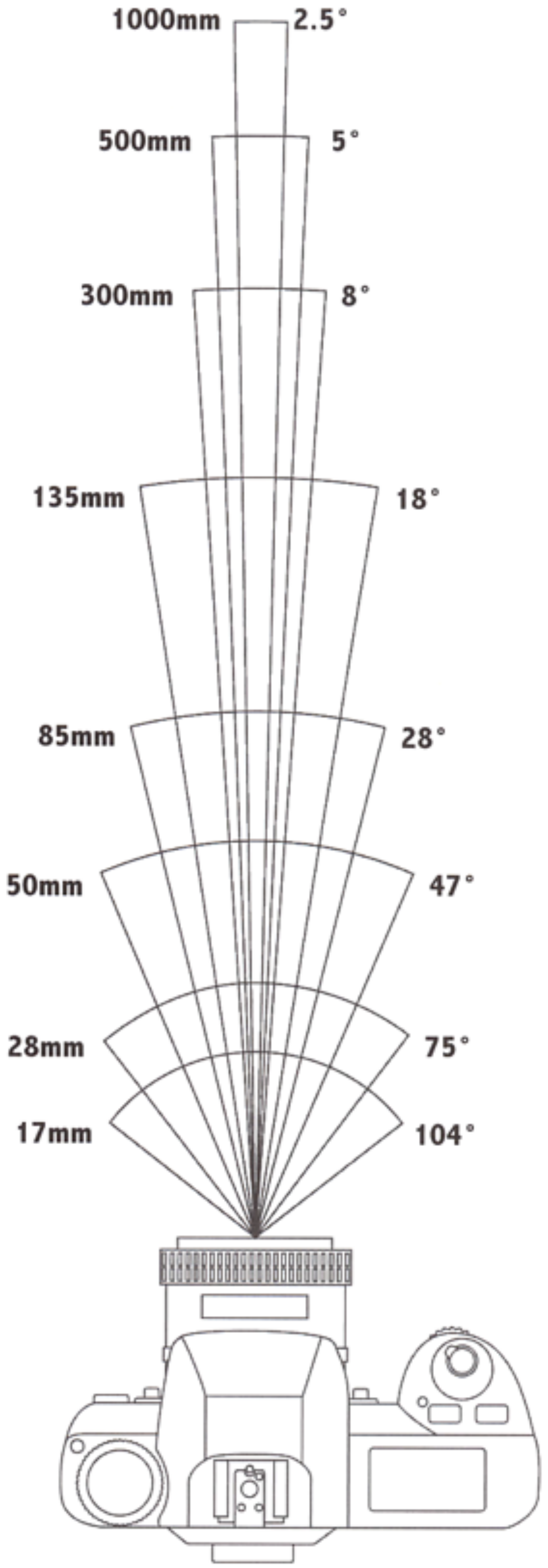
Focal length & sensor size impact FOV

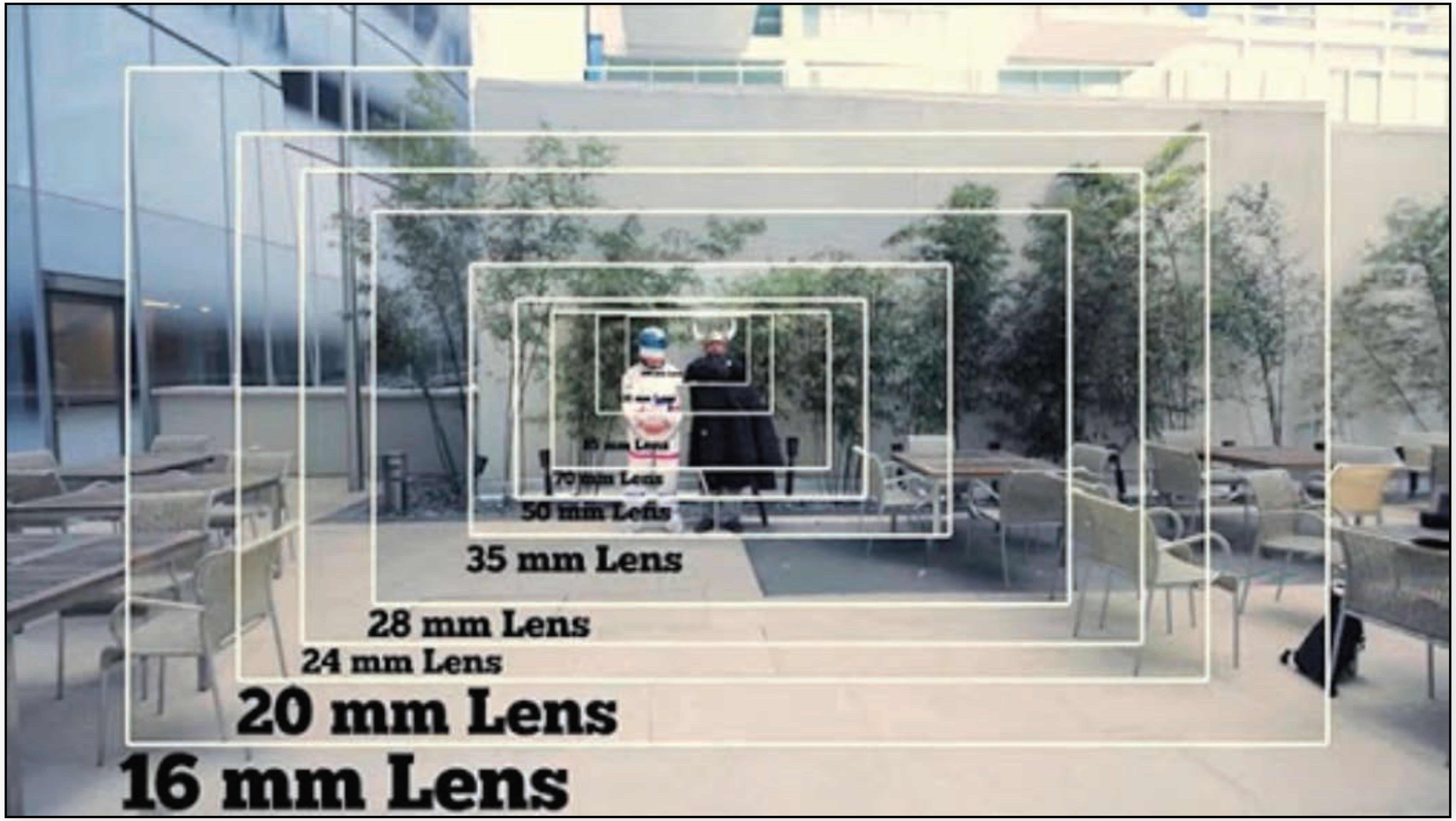




$$FOV = 2\arctan\left(\frac{s}{2f}\right)$$

Changing focal length = cropping





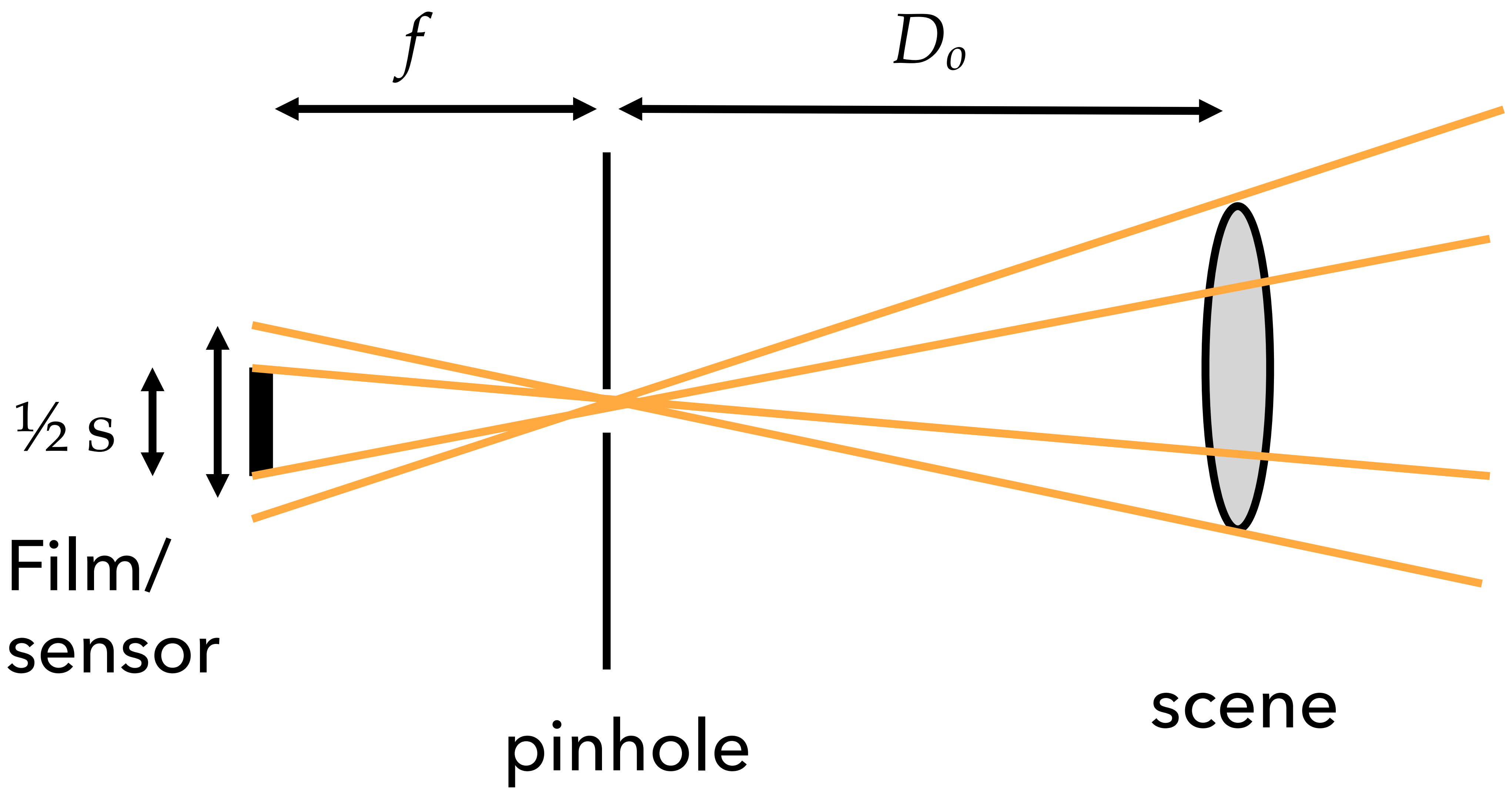
Andrew McWilliams

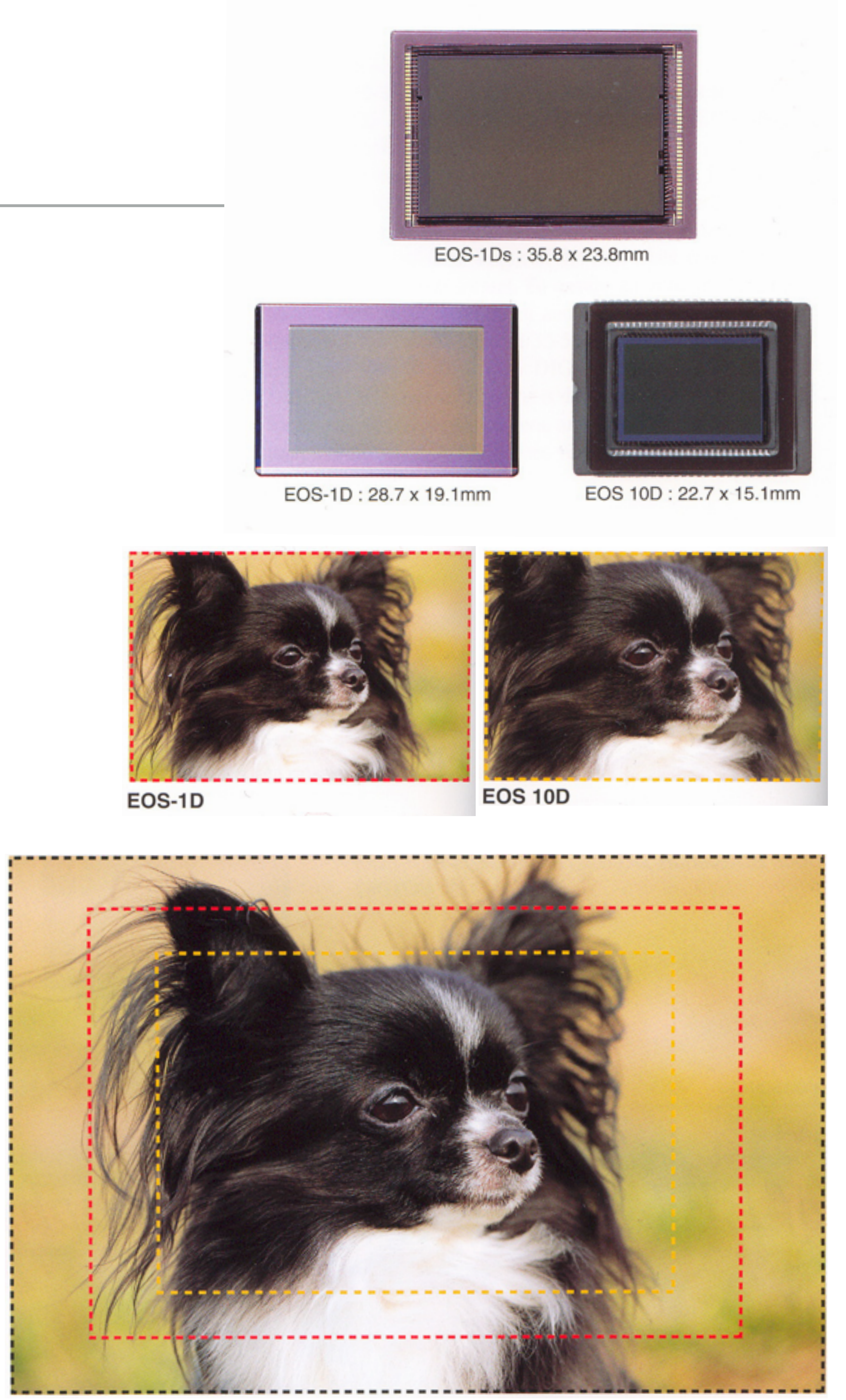
Focal length & sensor size

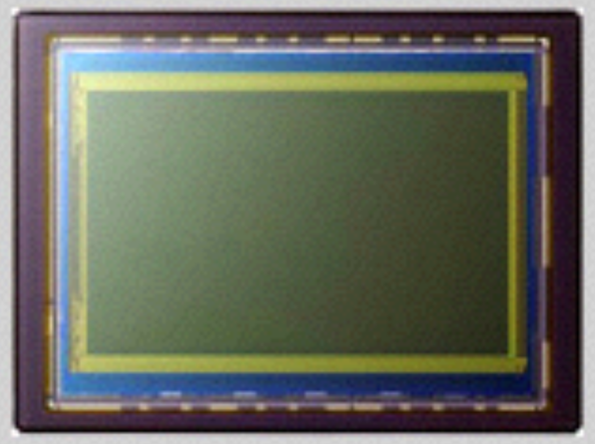
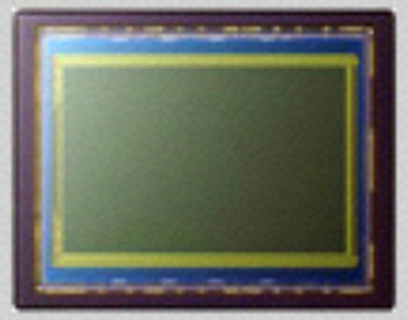
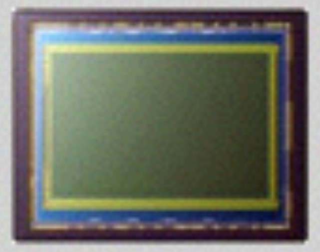
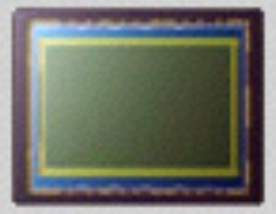
What happens when the film is half the size?

Application:

- Real film is 36x24mm
- On the 10D, the sensor is 22.5 x 15.0 mm
- Crop/conversion factor on the 10D?





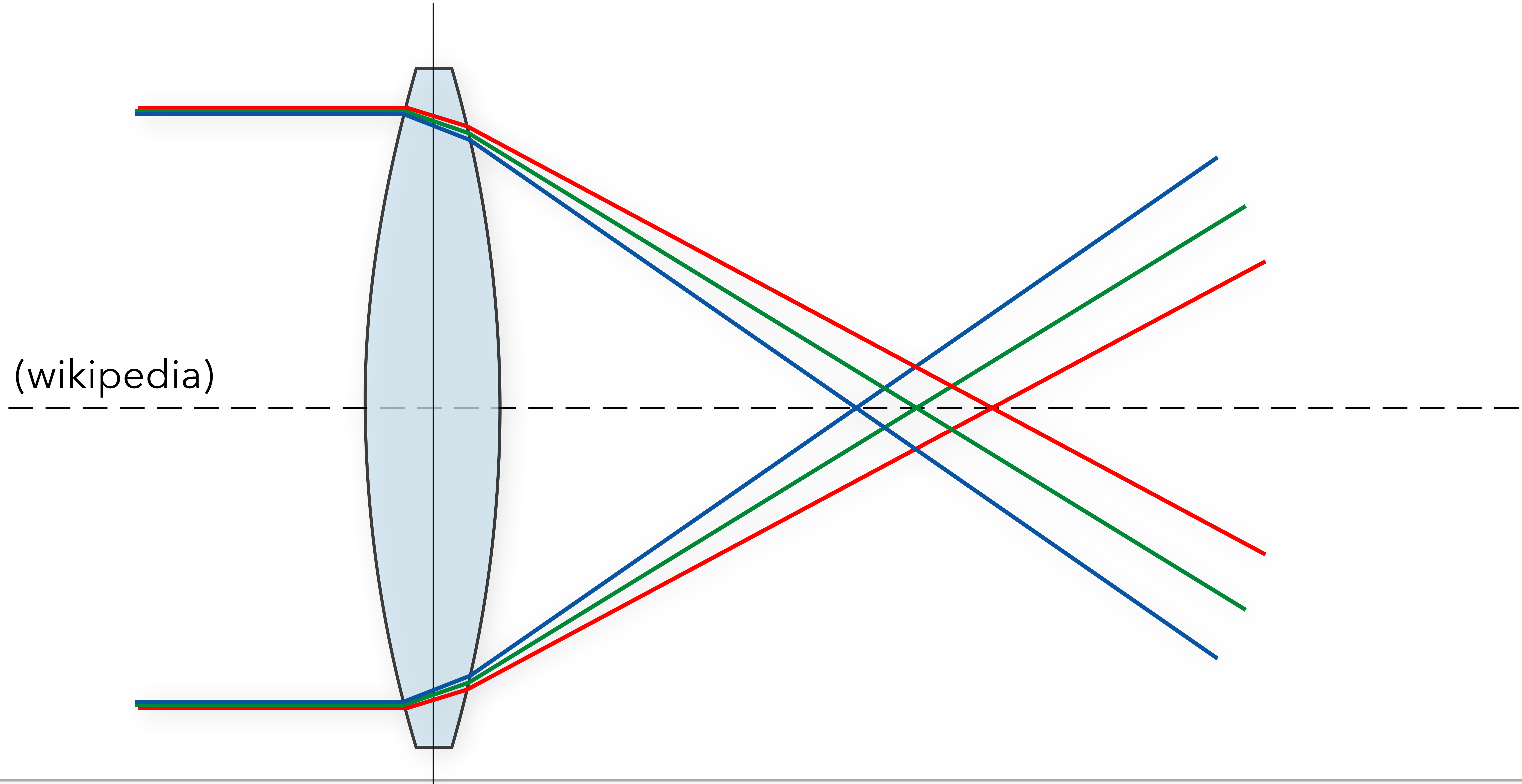
Sensor Name	Medium Format	Full Frame	APS-H	APS-C	4/3	1"	1/1.63"	1/2.3"	1/3.2"
Sensor Size	53.7 x 40.2mm	36 x 23.9mm	27.9x18.6mm	23.6x15.8mm	17.3x13mm	13.2x8.8mm	8.38x5.59mm	6.16x4.62mm	4.54x3.42mm
Sensor Area	21.59 cm²	8.6 cm²	5.19 cm²	3.73 cm²	2.25 cm²	1.16 cm²	0.47 cm²	0.28 cm²	0.15 cm²
Crop Factor	0.64	1.0	1.29	1.52	2.0	2.7	4.3	5.62	7.61
Image									
Example									

https://lensvid.com/technique/why-depth-of-field-is-not-effected-by-sensor-size-a-demonstration/

Chromatic Aberrations

Refraction angle depends on wavelength!

All colors won't converge to the same point


(wikipedia)


(wikipedia)


(wikipedia)

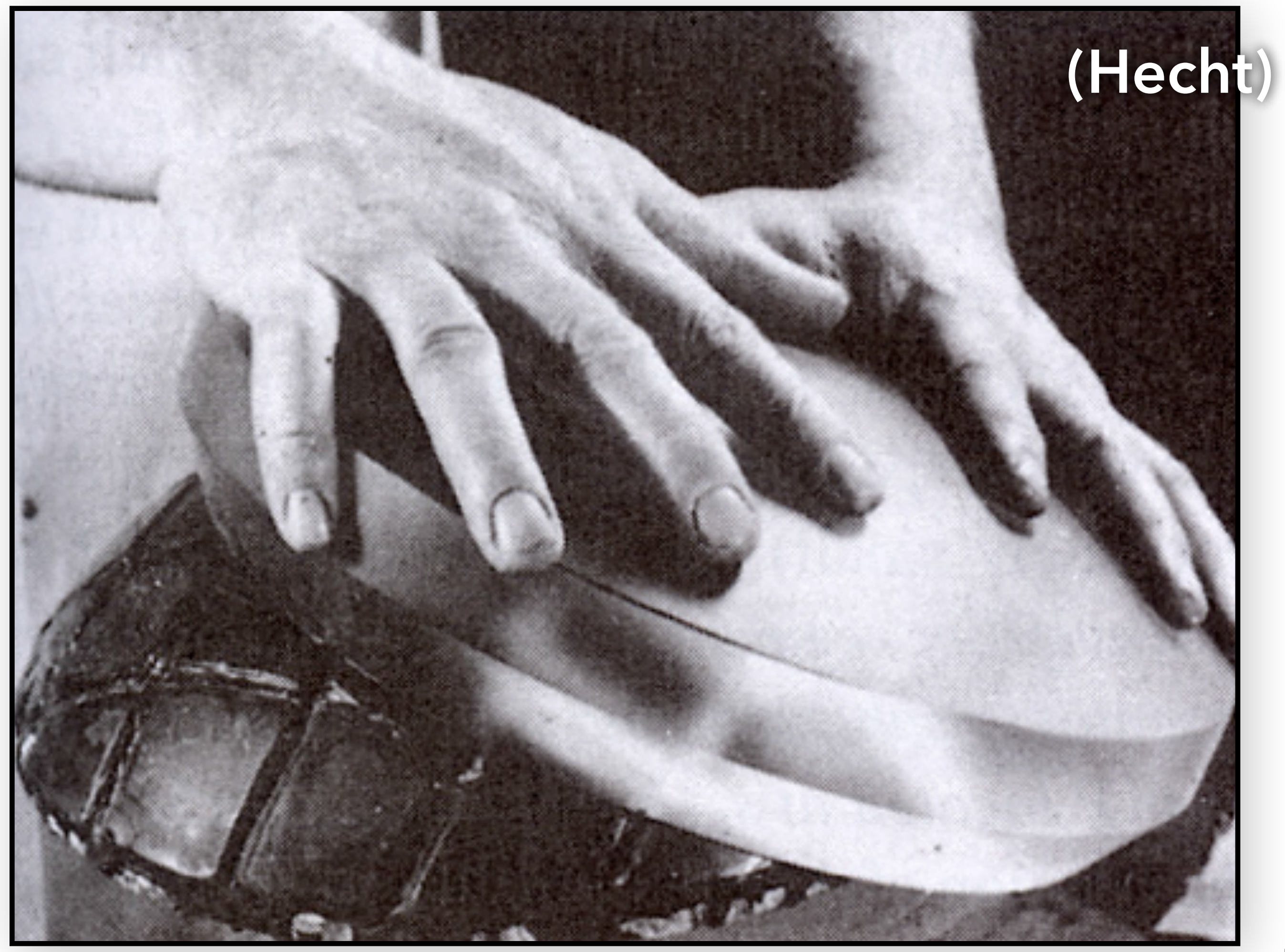

(wikipedia)

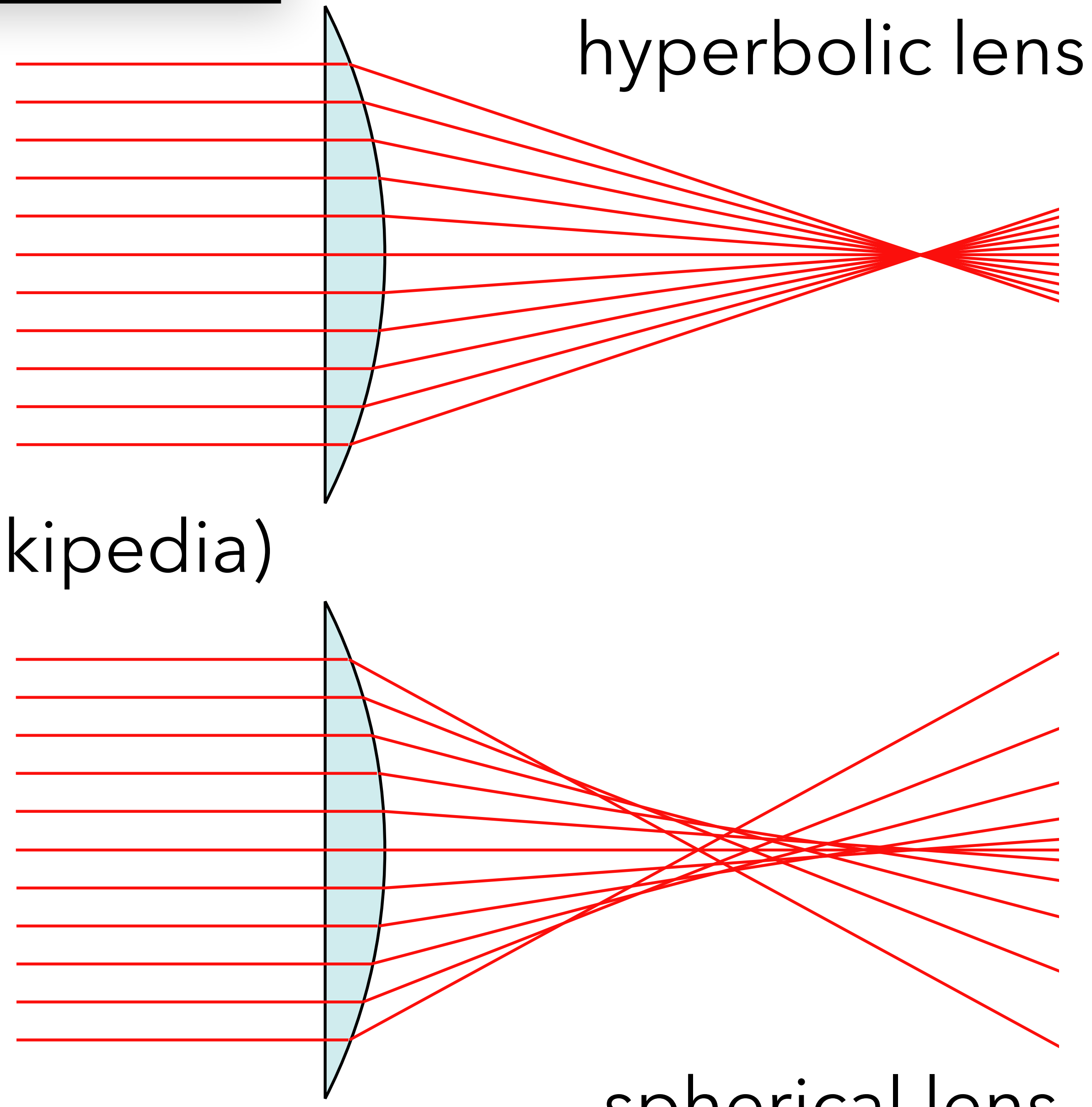
Spherical lenses

two roughly fitting curved surfaces ground together will eventually become spherical

spheres don't bring parallel rays to a point!

- this is called spherical aberation
- nearly axial rays behave best





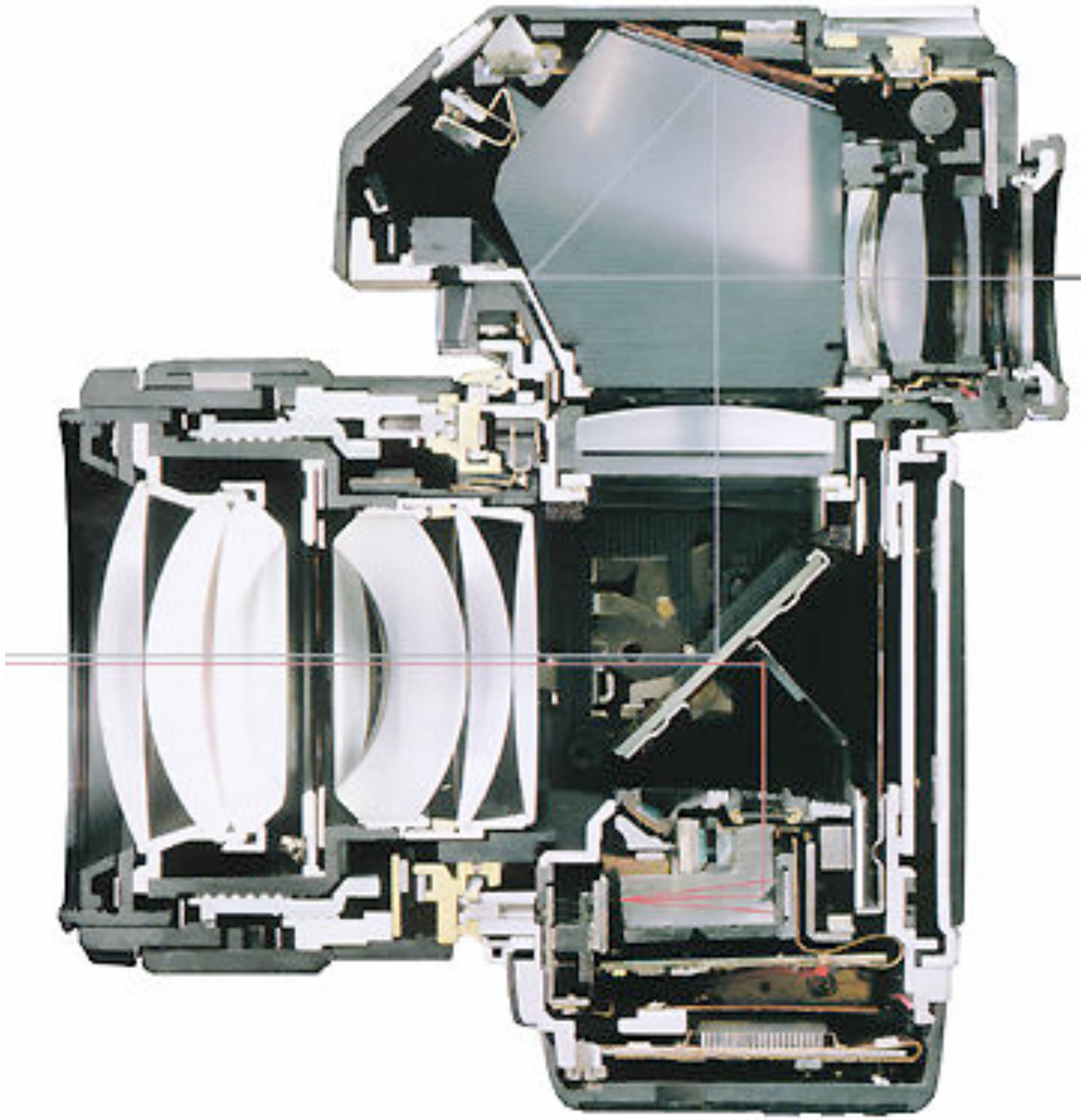
Examples of spherical aberration

(Canon)

(gtmerideth)

Canon 135mm soft focus lens

Questions?



Exposure

Get the right amount of light to sensor/film

Two main parameters:

- Shutter speed
- Aperture (area of lens)

\+ sensor/film sensitivity (ISO)

Exposure

Exposure = Irradiance x Time

Exposure time

- in seconds
- controlled by **shutter**

Irradiance

- amount of light falling on a unit area of sensor per second
- controlled by **aperture**

Shutter speed

Controls how long the film/sensor is exposed

Pretty much linear effect on exposure (until sensor saturates)

Denoted in fractions of a second:

- 1/30 s, 1/60 s, 1/125 s, 1/250 s, 1/500 s
- See a pattern?

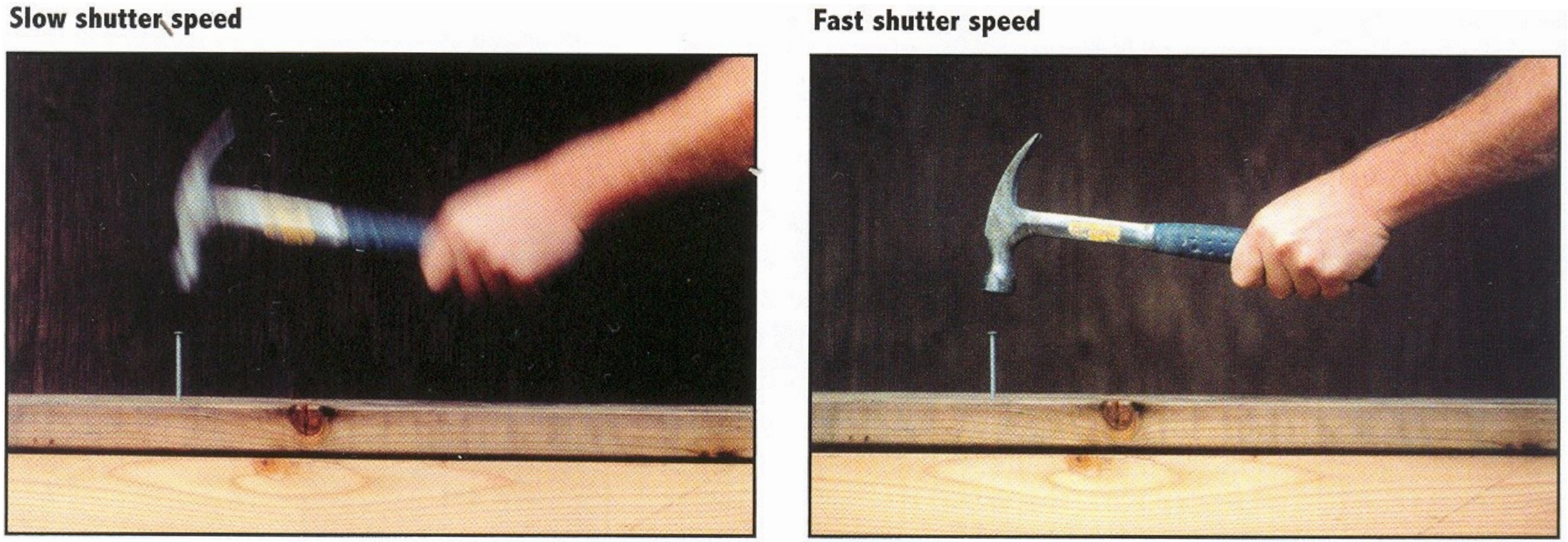
On a normal lens, normal humans can hand-hold down to 1/60

- In general, the rule of thumb says that the limit is the inverse of focal length, e.g. 1/500s for 500mm

Main effect of shutter speed

Motion blur

Doubling exposure time doubles motion blur (const. velocity)



From *Photography*, London et al.

Rolling shutter

Rich Pollet

Jonen, Wikimedia Commons

Exposure

Exposure = Irradiance x Time

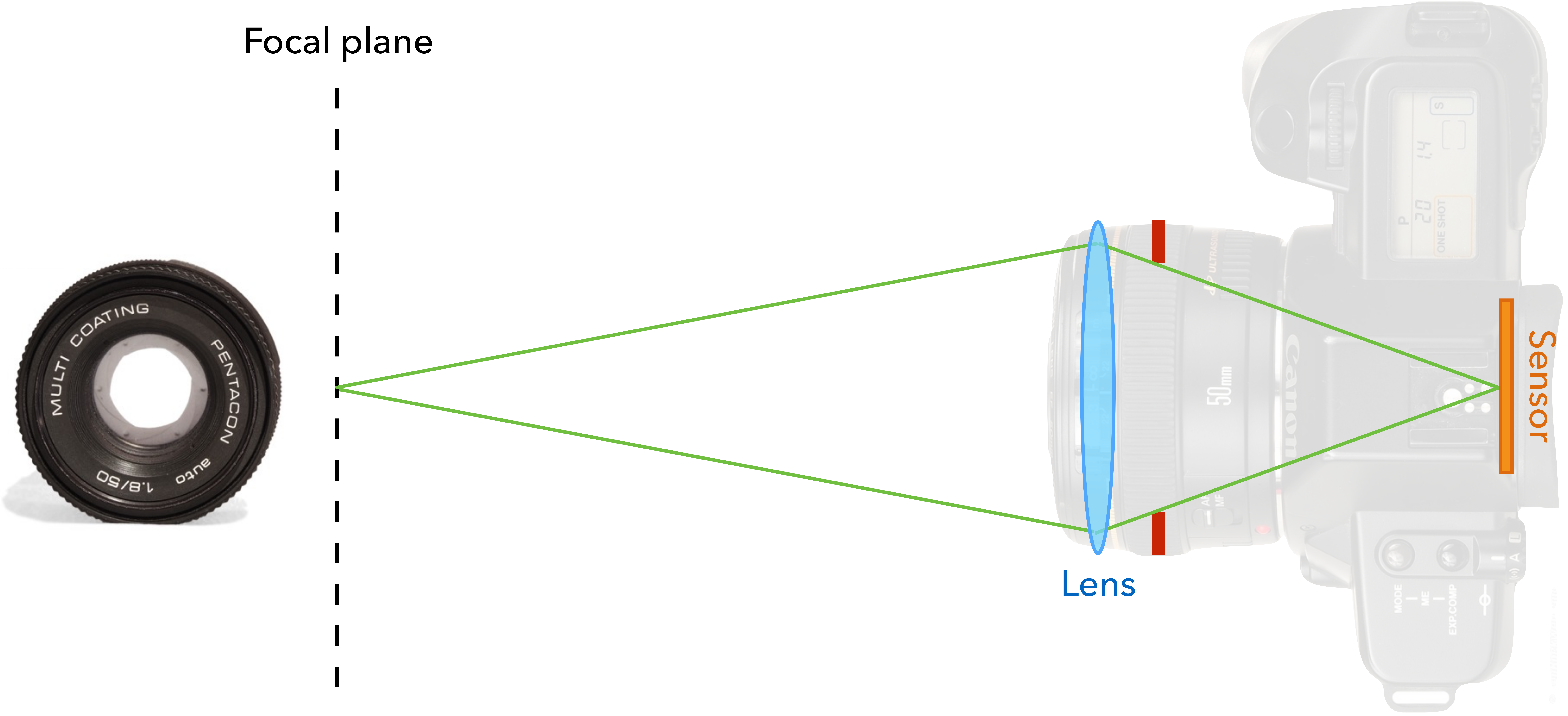
Exposure time

- in seconds
- controlled by **shutter**

Irradiance

- amount of light falling on a unit area of sensor per second
- controlled by **aperture**

Aperture



Aperture

Aperture

Diameter of the lens opening (controlled by diaphragm)

Irradiance on sensor is proportional to

- square of aperture diameter A
- inverse square of distance to sensor (~ focal length f)

As diameter A of the aperture doubles, its area (hence the light that can get through it) increases by 4x. (circle area: πA^2)

If the distance to sensor is doubled, light projects onto an area 4x larger, so light falling per unit area decreases by 4x

F-number

So that aperture values give irradiance regardless of focal length, *aperture number N* is defined relative to focal length

$$N = \frac{f}{A} \qquad A = \frac{f}{N}$$

A relative aperture size (also F-number or just N) of N=2 is denoted “f/2” to reflect the above formula.

- f/2.0 on a 50mm means that the aperture is
- f/2.0 on a 100mm means that the aperture is

low F-number with long focal length

Sigma 200-500mm F2.8 EX DG lens

What does 1600mm lens look like?

http://www.digitalpixels.net/varia/the-web/sigma-200-500mm-f28-ex-dg-lens-on-the-field/

http://dancarrphotography.com/blog/wp-content/uploads/2011/05/Canon_super_tele_comparison.jpg

F-number

Disconcerting: **small f-number = big aperture**

What happens to the area of the aperture when going from f/2.0 to f/4.0? divided by 4 (square of f-number ratio)

Typical f numbers are

- f/2.0, f/2.8, f/4, f/5.6, f/8, f/11, f/16, f/22, f/32
- See a pattern?
  - aperture area gets halved in each step (1 f-stop)
  - f-number doubles every other step

Youtube tutorial

https://youtu.be/KmNIouLByJQ

Main effect of aperture

Depth of field

From *Photography*, London et al.

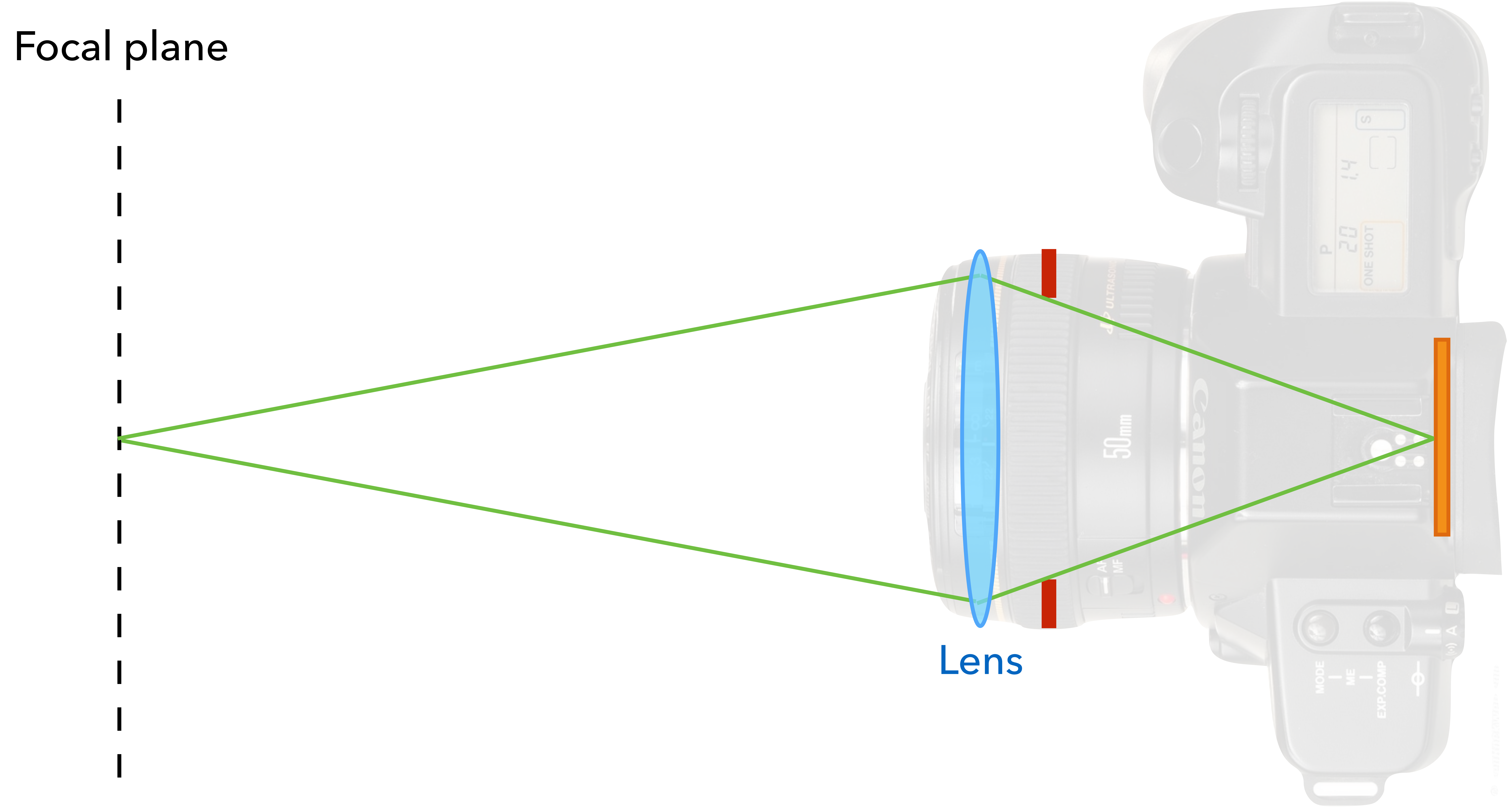
Large aperture opening

Small aperture opening

Depth-of-Field

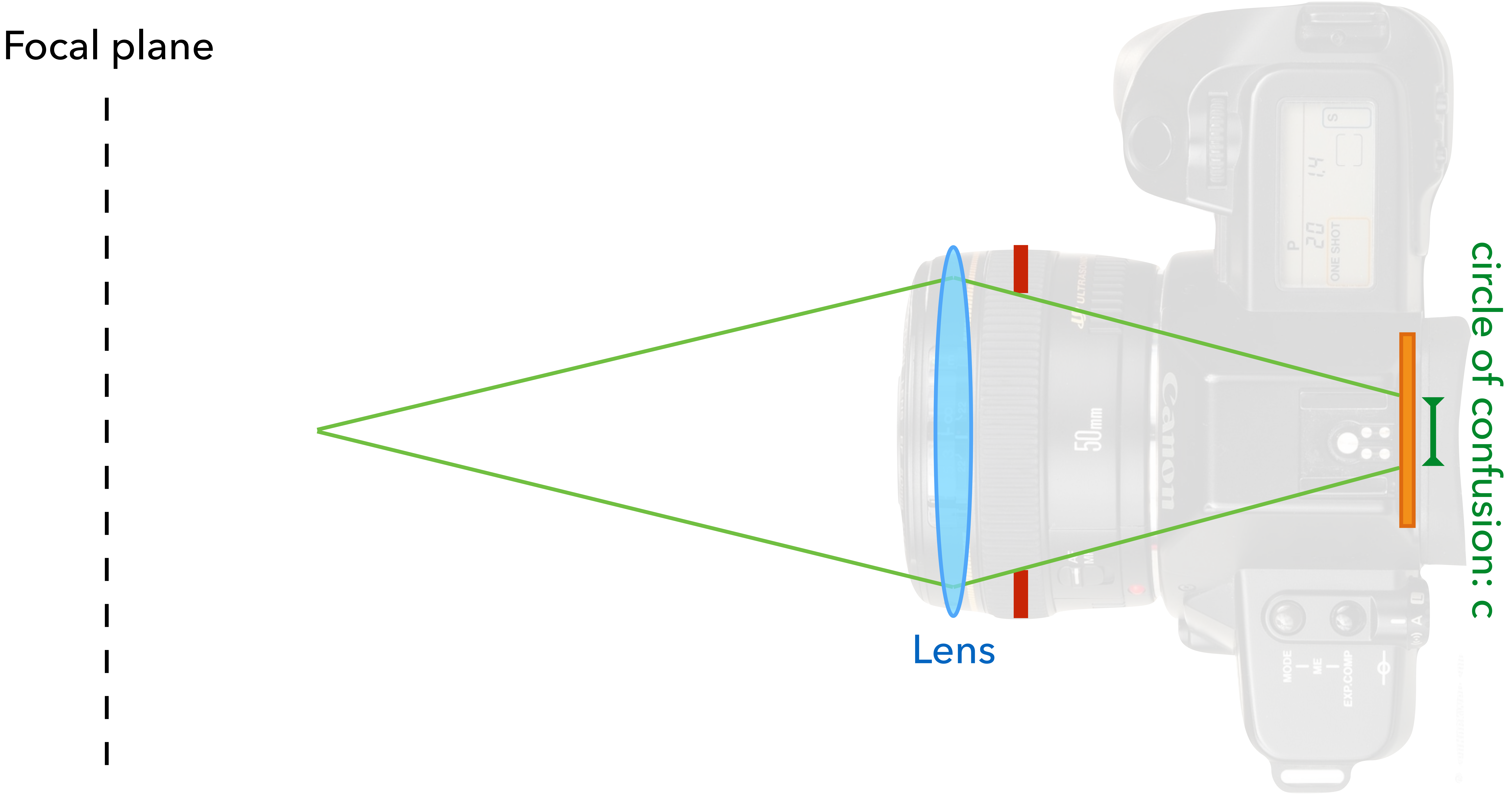
source: flickr

In focus



Out-of-focus blur

http://en.wikipedia.org/wiki/Circle_of_confusion



Out-of-focus blur

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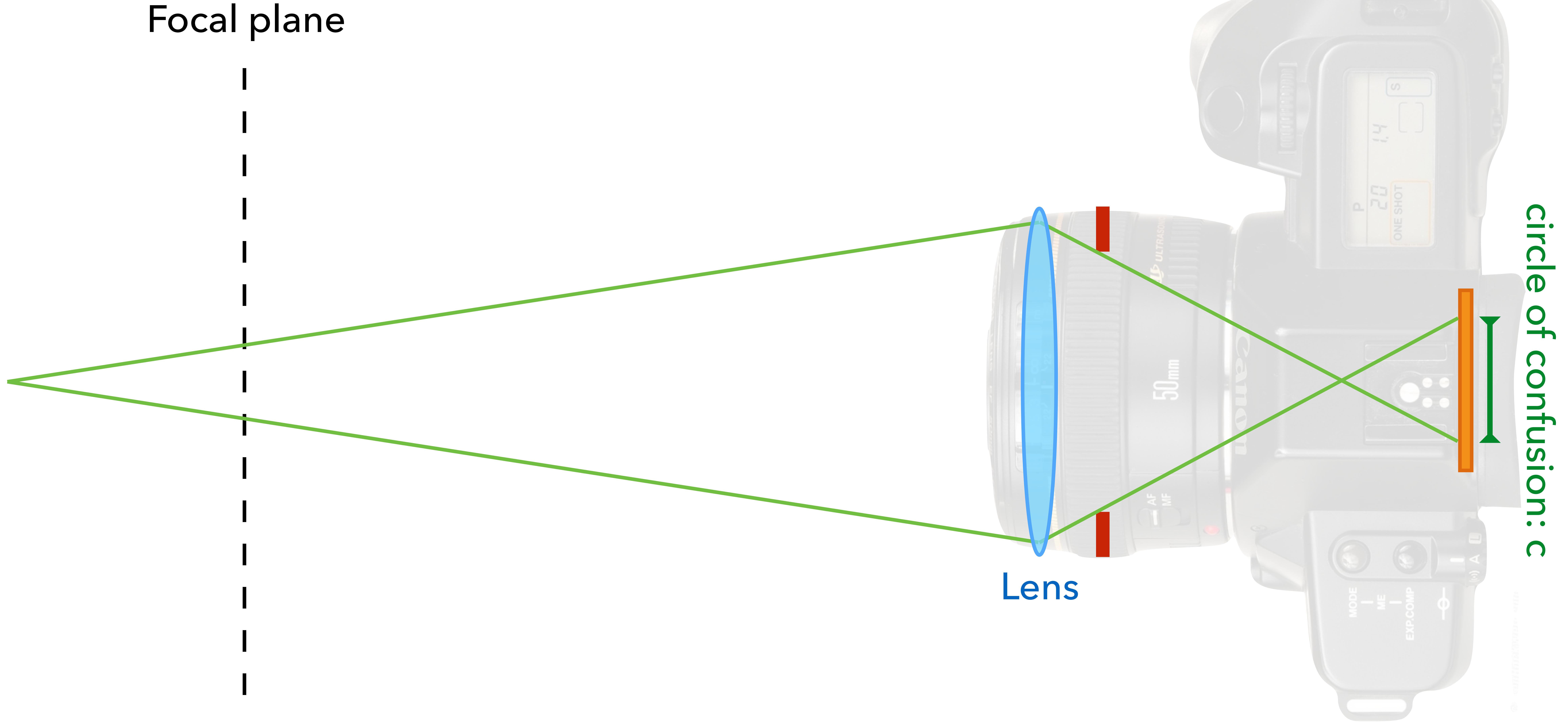
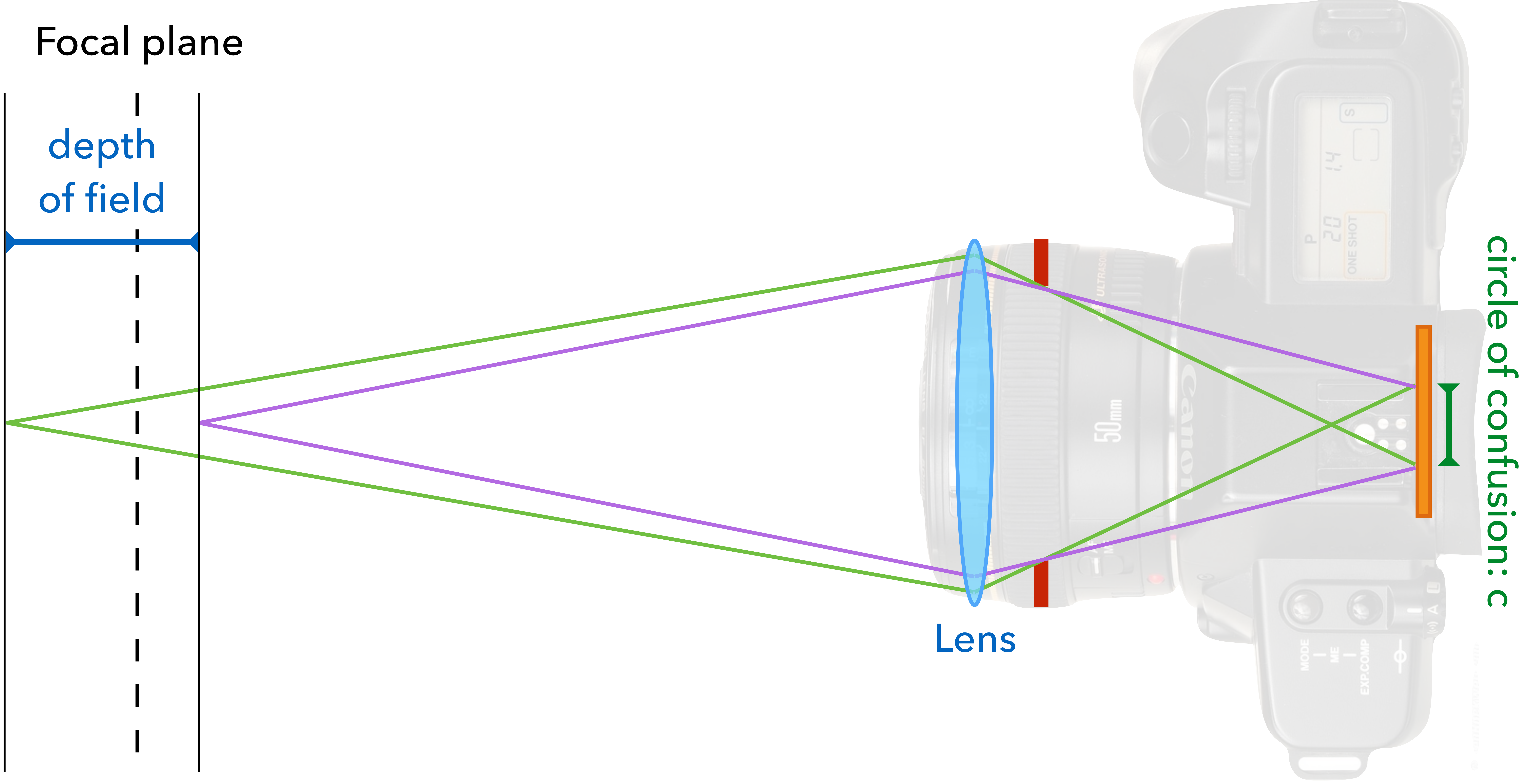


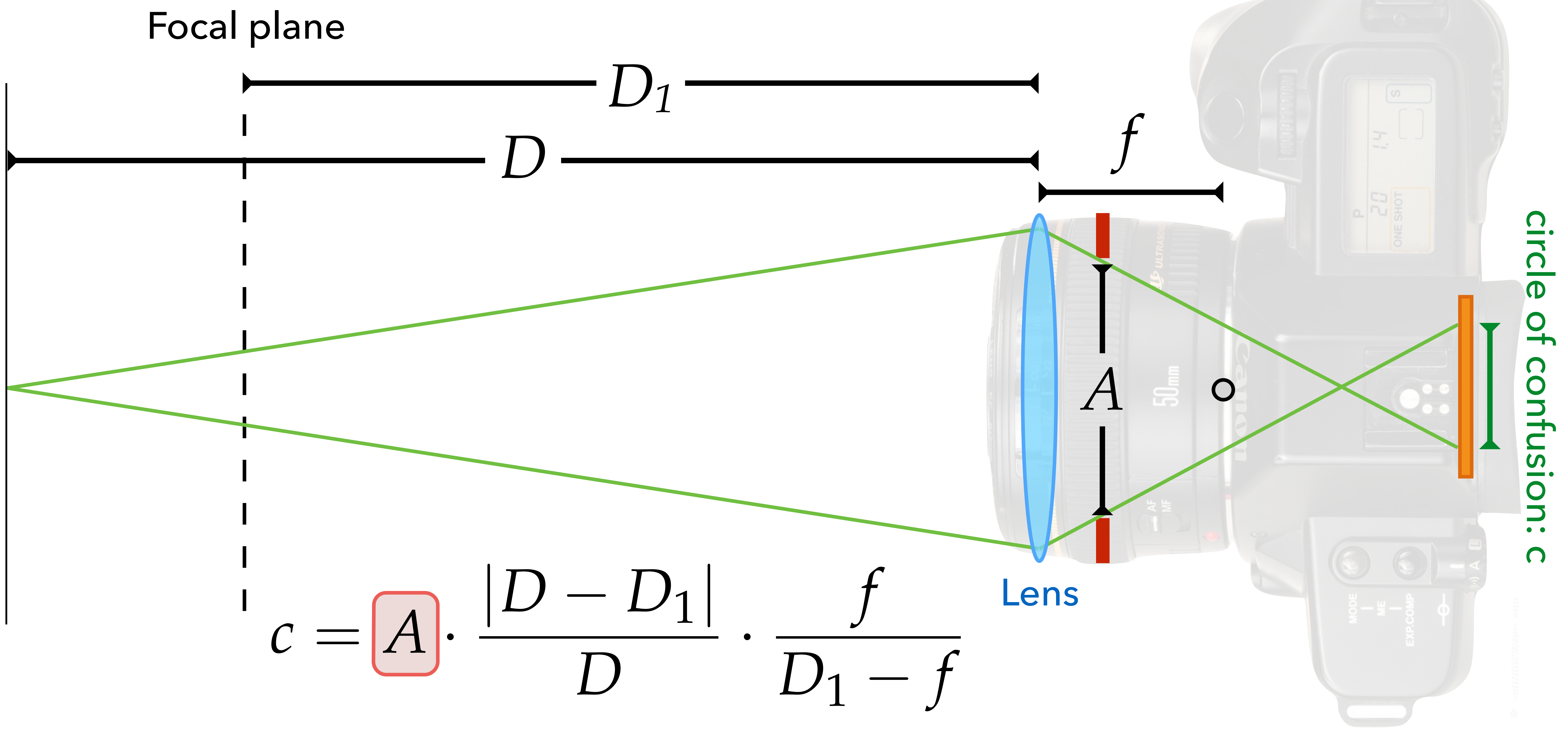
Depth of field

http://en.wikipedia.org/wiki/Circle_of_confusion



Circle of confusion

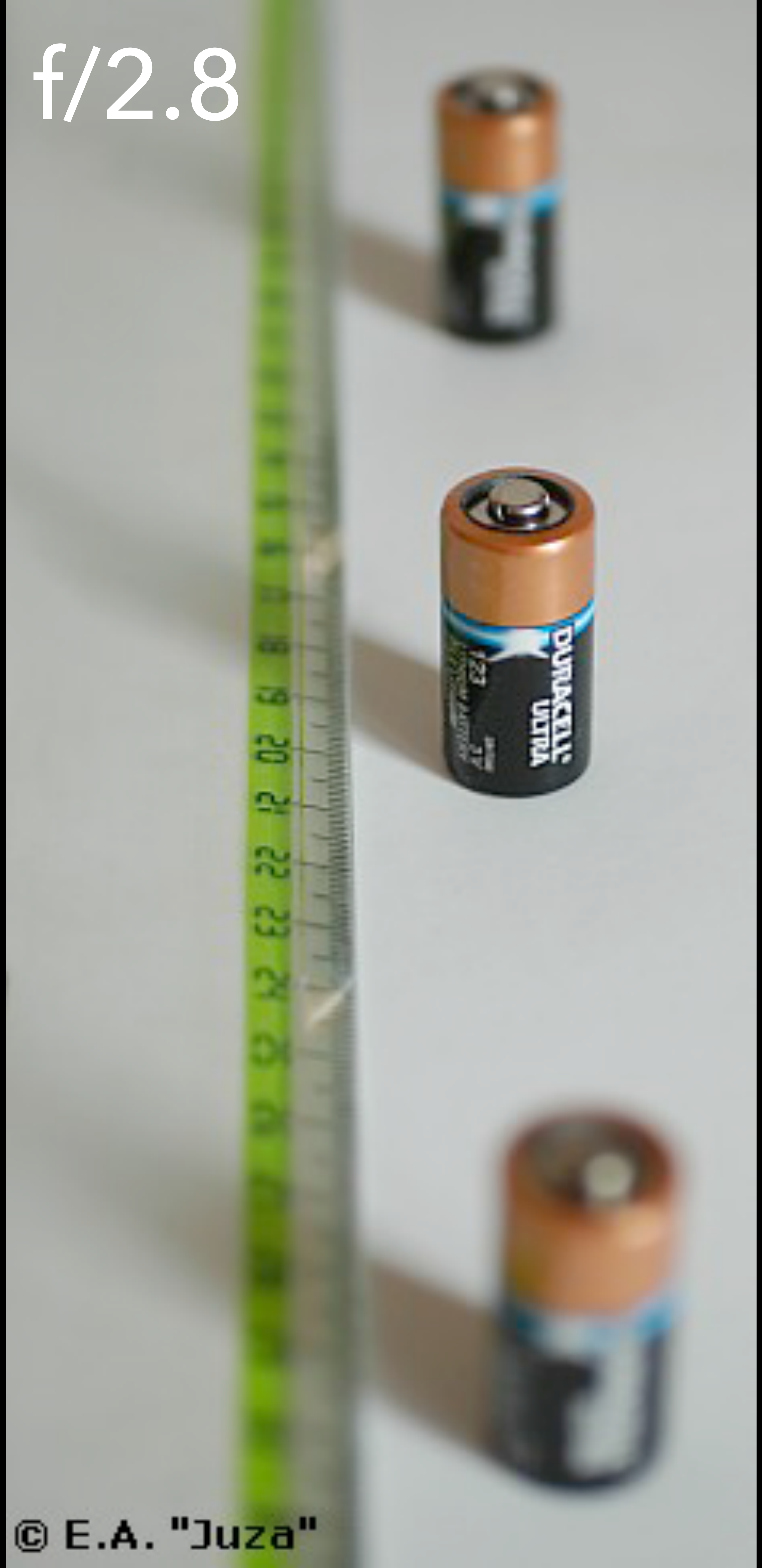
http://en.wikipedia.org/wiki/Circle_of_confusion

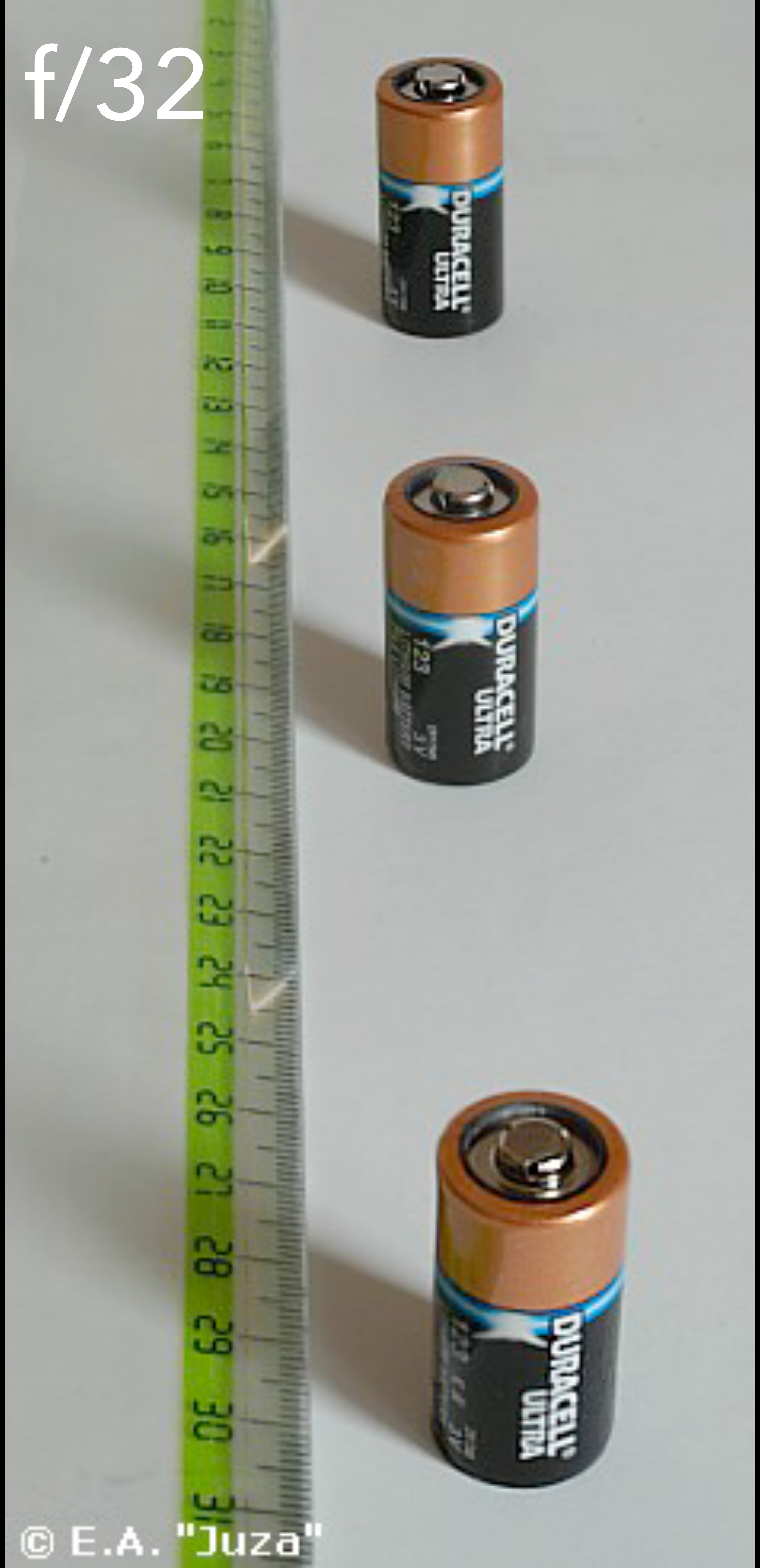


$$c = \boxed{A} \cdot \frac{|D - D_1|}{D} \cdot \frac{f}{D_1 - f}$$

CoC is linear with aperture diameter

DoF is linear with F-number





source: onebigphoto.com

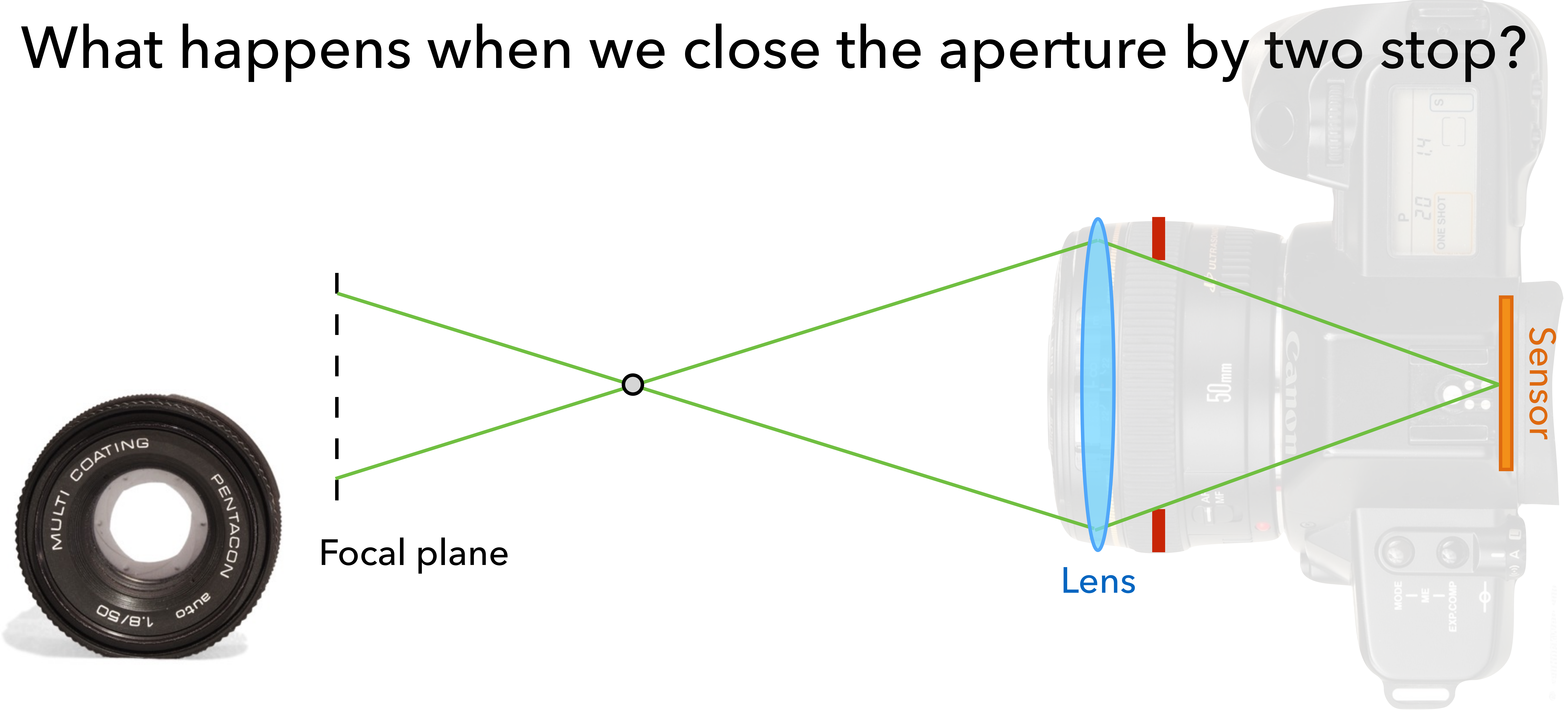
Why does this look like a miniature?

F-number of the Human Eye?

http://www.petapixel.com/2012/06/11/whats-the-f-number-of-the-human-eye/

Depth of field

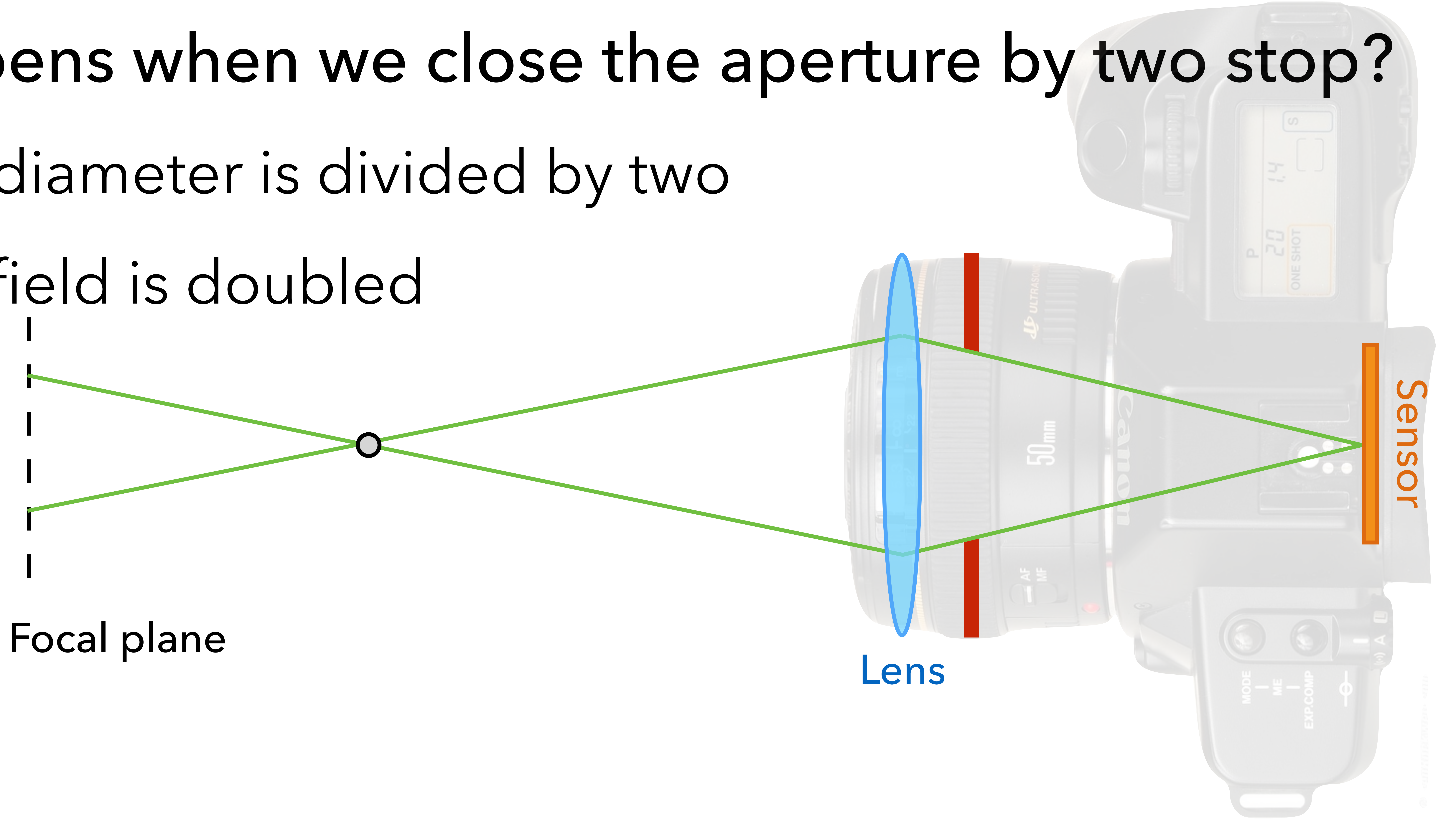
What happens when we close the aperture by two stop?



Depth of field

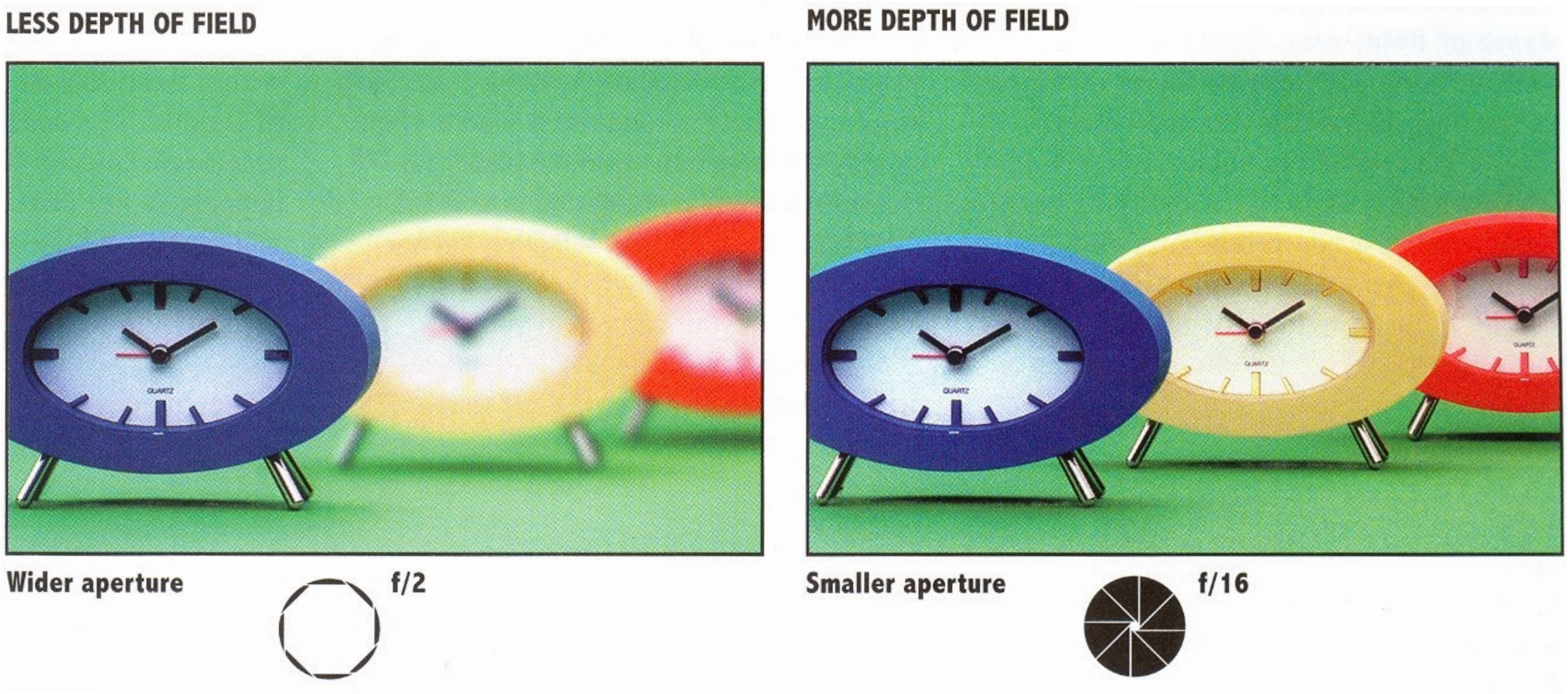
What happens when we close the aperture by two stop?

- Aperture diameter is divided by two
- Depth of field is doubled



Depth of field

$$N = \frac{f}{A} \qquad A = \frac{f}{N}$$



lower N means a wider aperture & less depth of field

 From *Photography*, London et al.

Depth-of-Field (Bokeh)

source: wikipedia

Depth-of-Field (Bad Bokeh)

source: wikipedia

Depth-of-Field (Bokeh)

source: pptbackgrounds.net


Bokeh (Cat’s Eyes)
source: flickr

Bokeh (Cat's Eyes)

source: flickr

Cat's Eyes

Questions?

Exposure

Two main parameters:

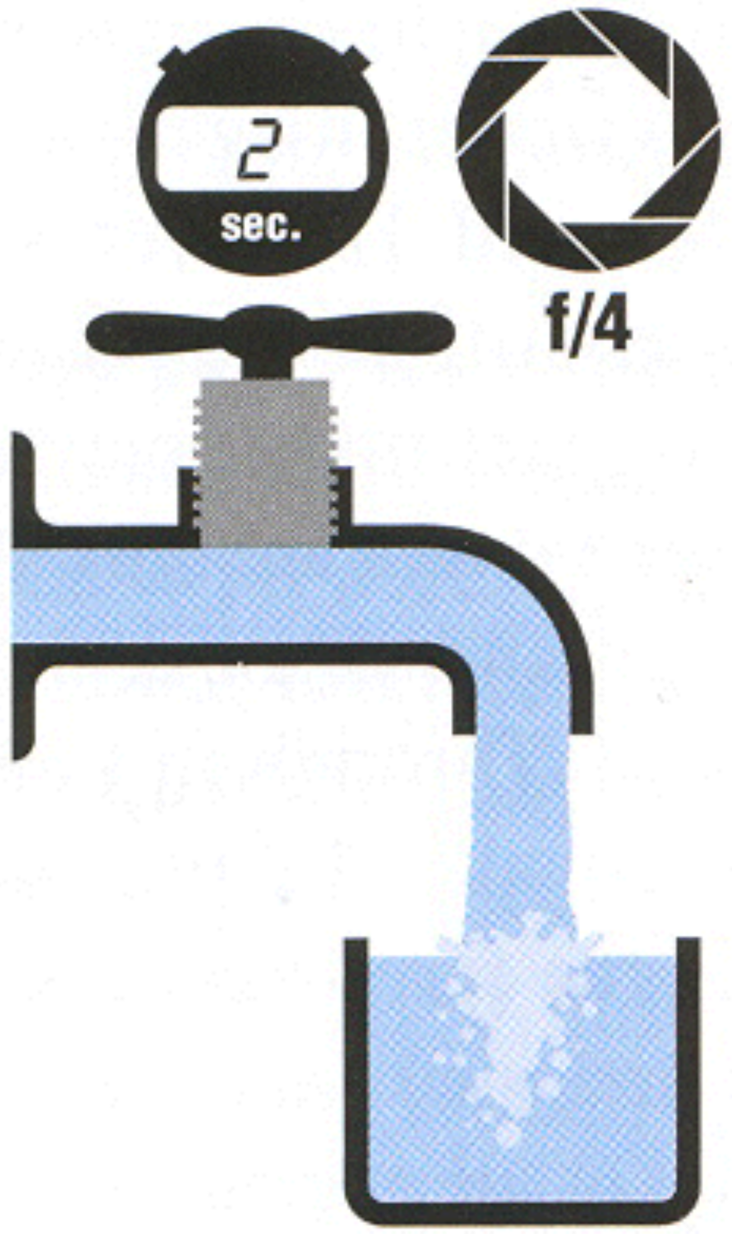
- Aperture (in f stop)
- Shutter speed (in fraction of a second)

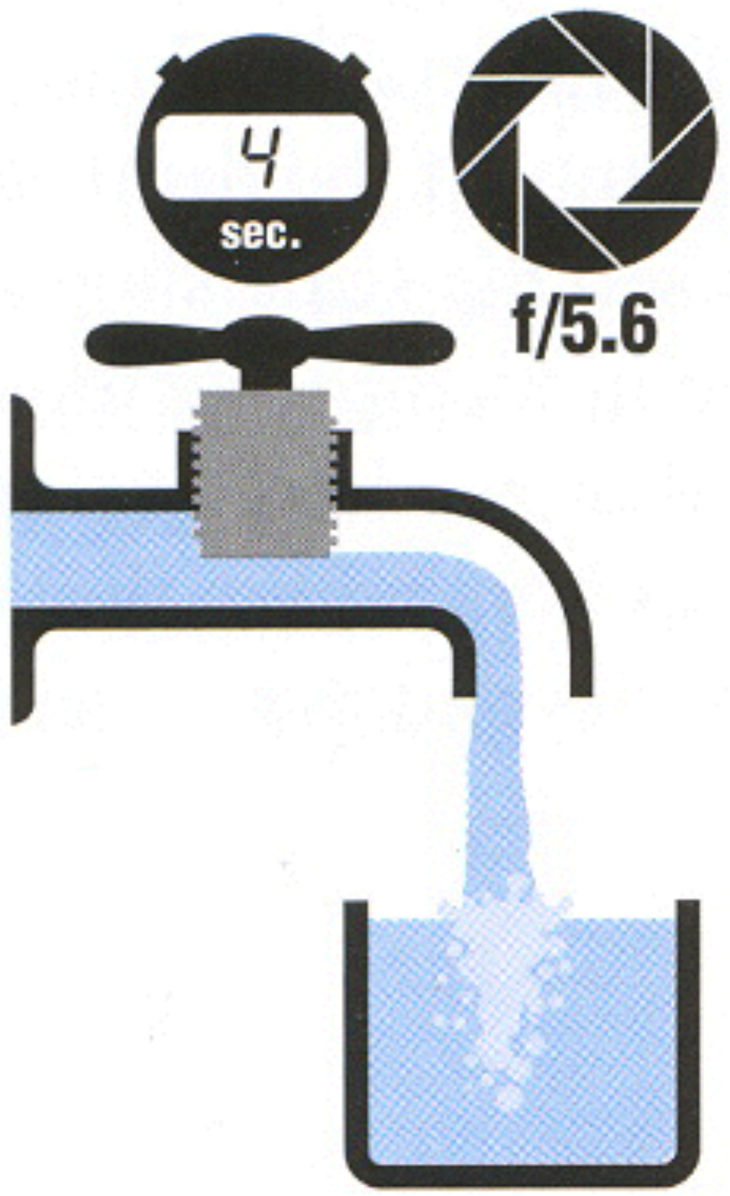
Reciprocity

- Amount of light captured stays the same if exposure is doubled and aperture *area* is halved (or vice versa)

Hence square-root of two progression of f stops vs. power of two progression of shutter speeds

Reciprocity can fail for very long exposures



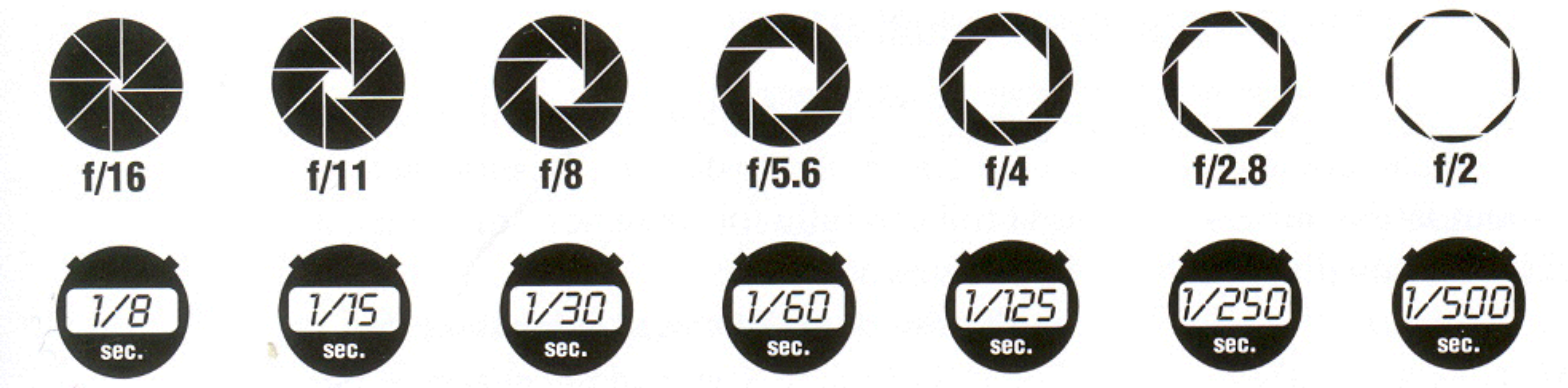


From *Photography*, London et al.

Reciprocity

Assume we know how much light we need

We have an infinite choice of shutter speed/aperture pairs

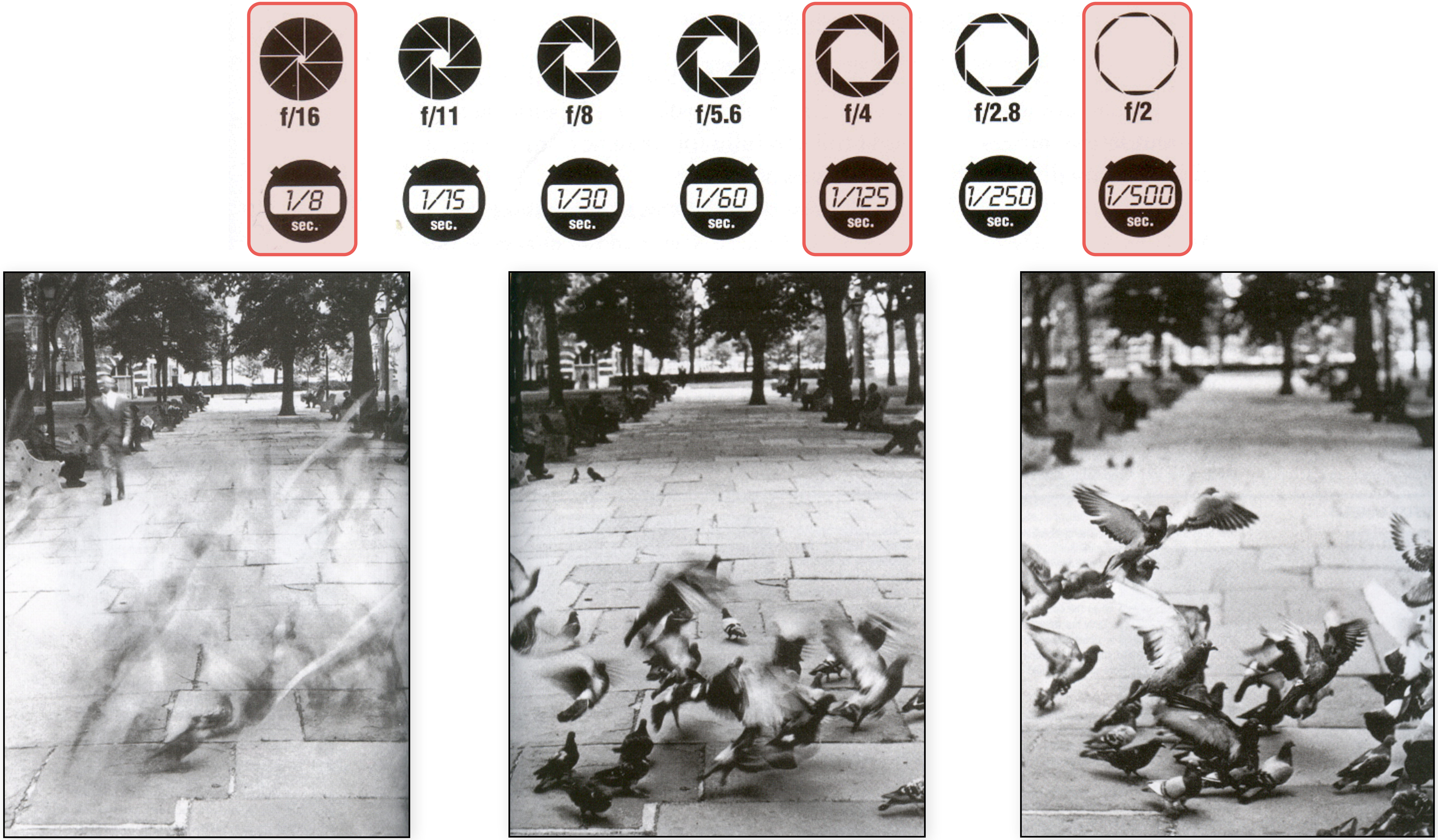


What will guide our choice of a shutter speed?

- Freeze motion vs. motion blur, camera shake

What will guide our choice of an aperture?

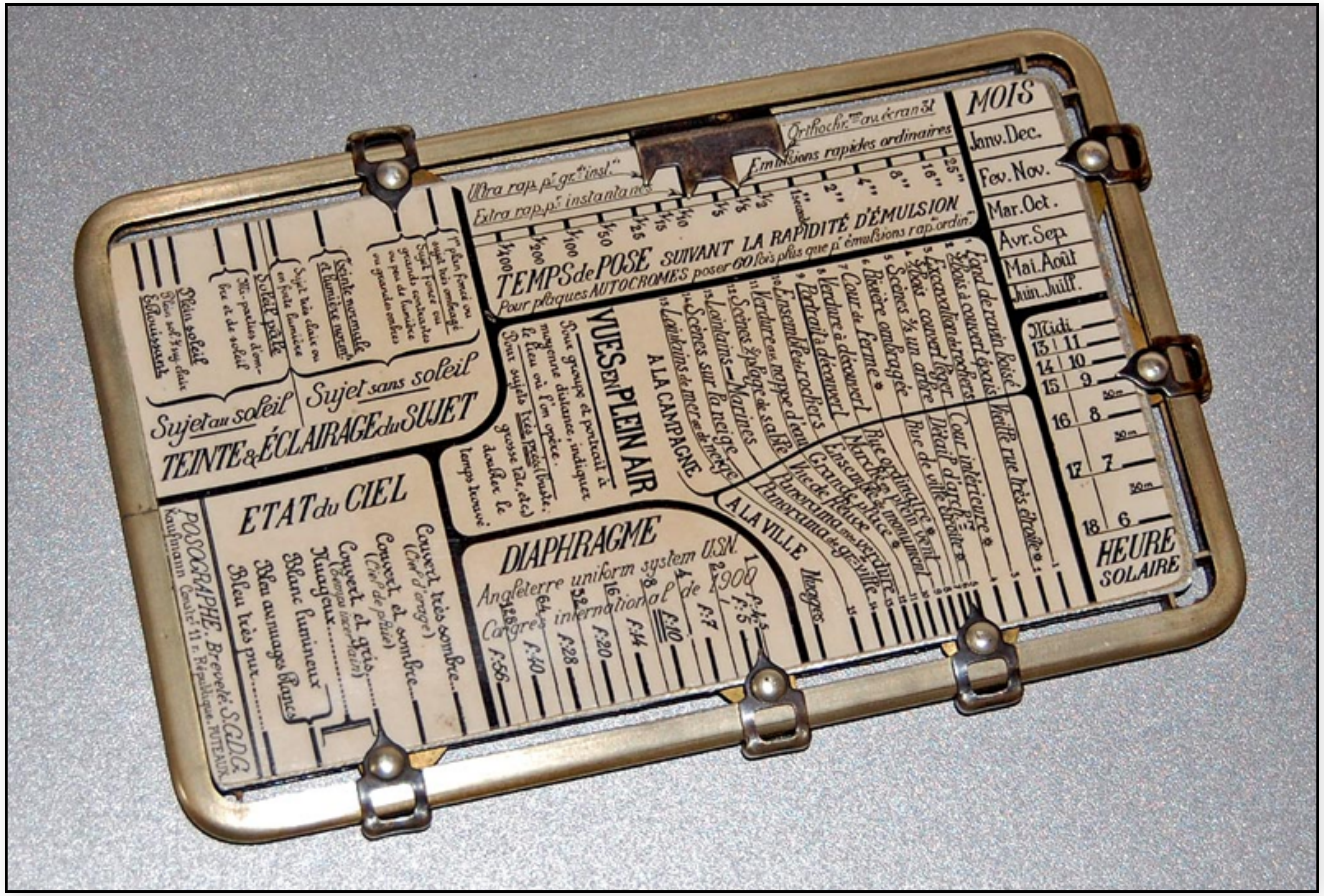
- Depth of field, diffraction limit

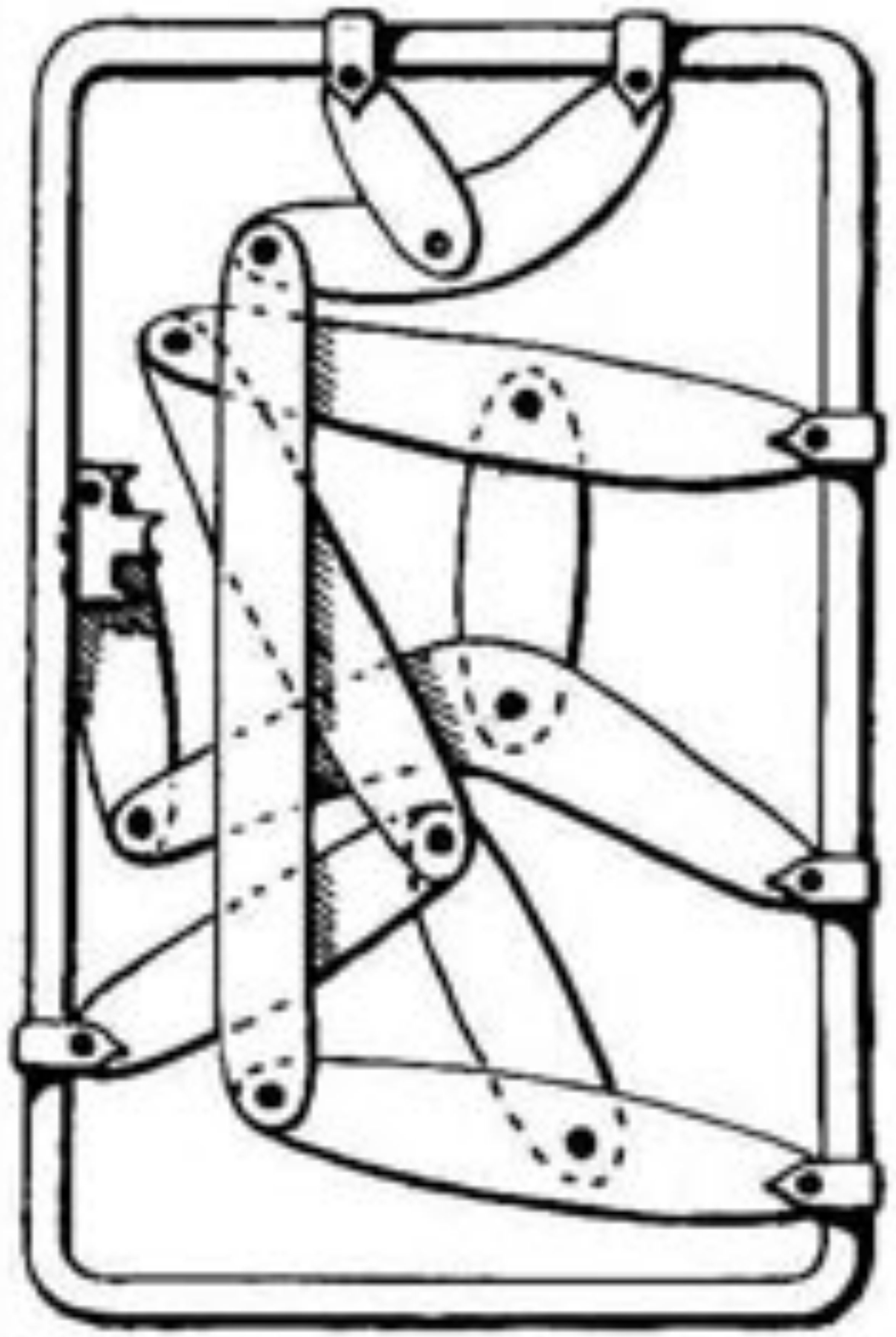


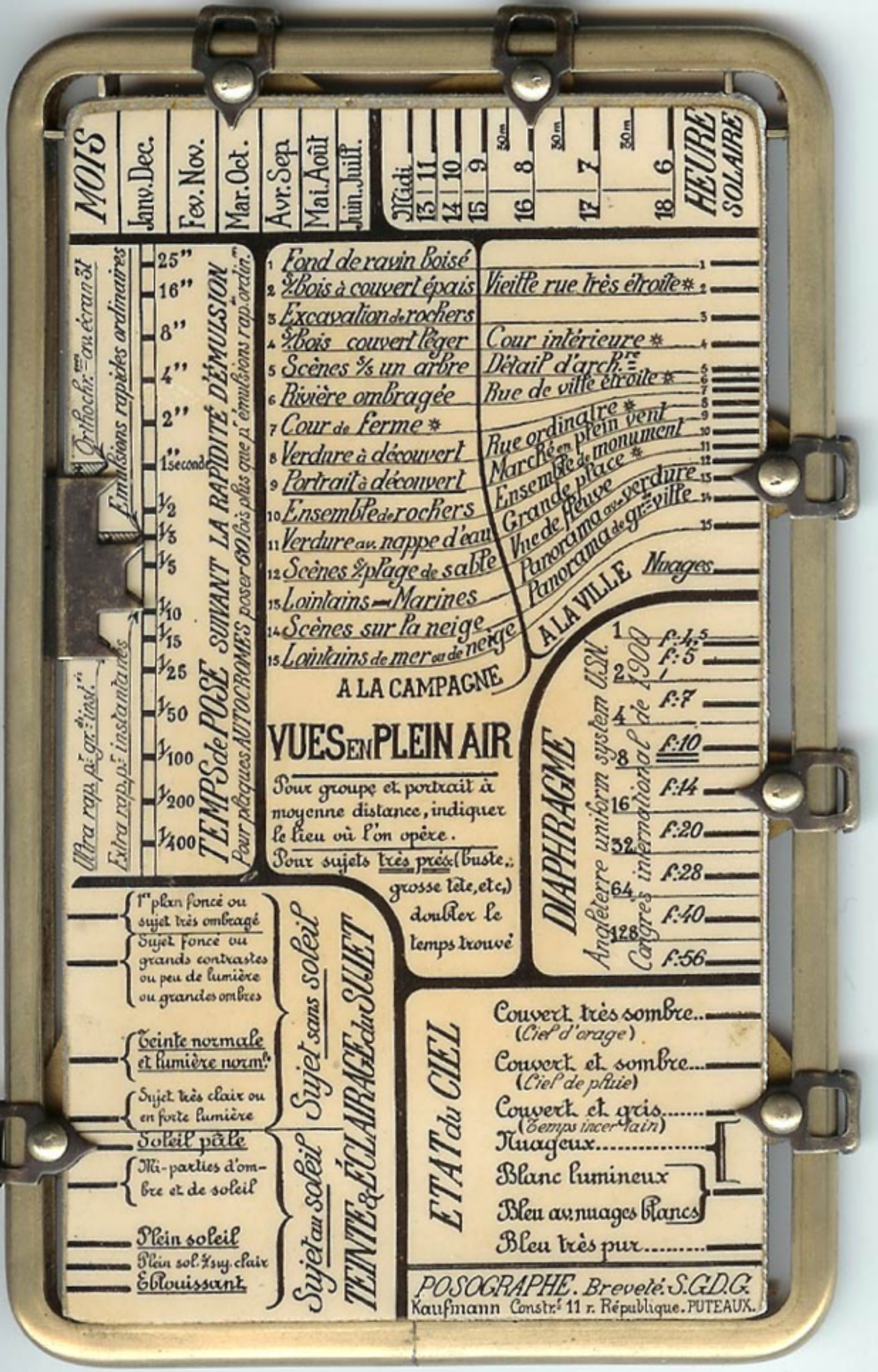
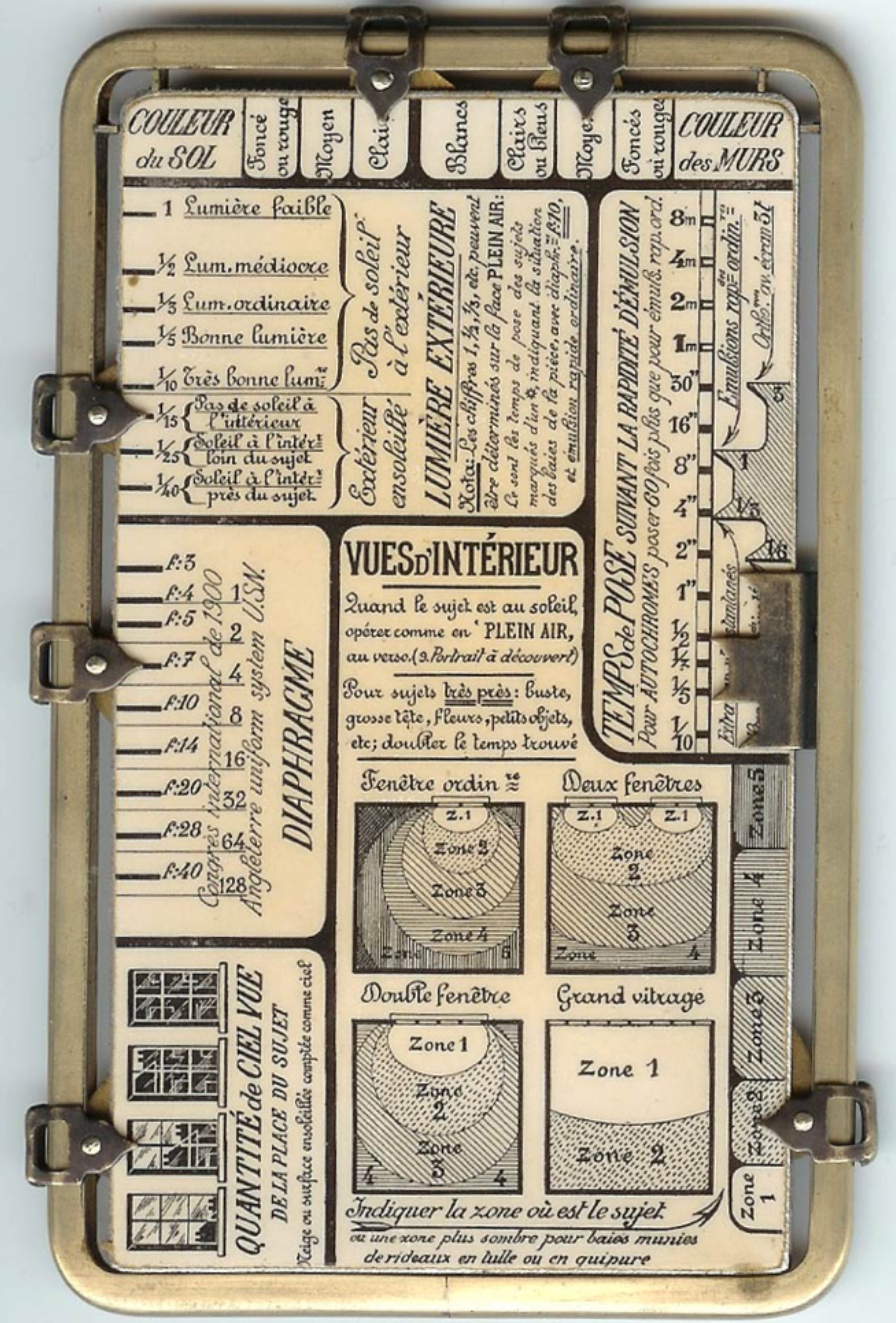
From *Photography*, London et al.

Analog

http://www.nzeldes.com/HOC/Posographe.htm






MOIS
Janv. Dec.
Fev. Nov.
Mar. Oct.
Avr. Sep.
Mai Août
Juin Juil.
Midi
HEURE SOLAIRE
TEMPS de POSE SUIVANT LA RAPIDITÉ D'ÉMULSION
Pour plaques AUTOCHROMES poser 60 fois plus que p. émulsions rap. ordin.
Orthochr. ou écran 3t
Émulsions rapides ordinaires
Ultra rap. p. gr. inst.
Extra rap. p. instantanés
1 Fond de ravin boisé
2 Bois à couvert épais
3 Excavation de rochers
4 Bois couvert léger
5 Scènes s/s un arbre
6 Rivière ombragée
7 Cour de ferme
8 Verdure à découvert
9 Portrait à découvert
10 Ensemble de rochers
11 Verdure au nappe d'eau
12 Scènes s/plage de sable
13 Lointains - Marines
14 Scènes sur la neige
15 Lointains de mer ou de neige
A LA CAMPAGNE
Vieille rue très étroite
Cour intérieure
Détail d'arch.
Rue de ville étroite
Rue ordinaire
Marché en plein vent
Ensemble de monument
Grande place
Vue de fleuve ou verdure
Panorama ou verdure
Panorama de gr. ville
Nuages
A LA VILLE
VUES EN PLEIN AIR
Pour groupe et portrait à moyenne distance, indiquer le lieu où l'on opère.
Pour sujets très près (buste, grosse tête, etc.) doubler le temps trouvé
DIAPHRAGME
Angleterre uniform system U.S.N.
Congrès international de 1900
f:4.5
f:5
f:7
f:10
f:14
f:20
f:28
f:40
f:56
1er plan foncé ou sujet très ombragé
Sujet foncé ou grands contrastes ou peu de lumière ou grandes ombres
Teinte normale et lumière norm.
Sujet très clair ou en forte lumière
Soleil pâle
Mi-parties d'ombre et de soleil
Plein soleil
Plein sol. & suj. clair
Éblouissant
Sujet au soleil
Sujet sans soleil
TEINTE & ÉCLAIRAGE du SUJET
ETAT du CIEL
Couvert très sombre
(Ciel d'orage)
Couvert et sombre
(Ciel de pluie)
Couvert et gris
(Temps incertain)
Nuageux
Blanc lumineux
Bleu av. nuages blancs
Bleu très pur
POSOGRAPHE. Breveté S.G.D.G.
Kaufmann Constr. 11 r. République. PUTEAUX.

COULEUR du SOL
Foncé ou rouge
Moyen
Clair
Blancs
Clairs ou bleus
Moyen
Foncés ou rouges
COULEUR des MURS
1 Lumière faible
1/2 Lum. médiocre
1/3 Lum. ordinaire
1/5 Bonne lumière
1/10 Très bonne lum.
Pas de soleil à l'extérieur
1/15 Pas de soleil à l'intérieur
1/25 Soleil à l'intér. loin du sujet
1/40 Soleil à l'intér. près du sujet
Extérieur ensoleillé
LUMIÈRE EXTÉRIEURE
TEMPS de POSE SUIVANT LA RAPIDITÉ D'ÉMULSION
Pour AUTOCHROMES poser 60 fois plus que pour émuls. rap. ord.
Émulsions rap. ordin.
Ortho. ou écran 3t
VUES D'INTÉRIEUR
Quand le sujet est au soleil, opérer comme en "PLEIN AIR, au verso. (9. Portrait à découvert)
Pour sujets très près: buste, grosse tête, fleurs, petits objets, etc; doubler le temps trouvé
DIAPHRAGME
Congrès international de 1900
Angleterre uniform system U.S.N.
f:3
f:4
f:5
f:7
f:10
f:14
f:20
f:28
f:40
Fenêtre ordin.
Deux fenêtres
Double fenêtre
Grand vitrage
Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
QUANTITÉ de CIEL VUE DE LA PLACE DU SUJET
Indiquer la zone où est le sujet
ou une zone plus sombre pour baies munies de rideaux en tulle ou en guipure

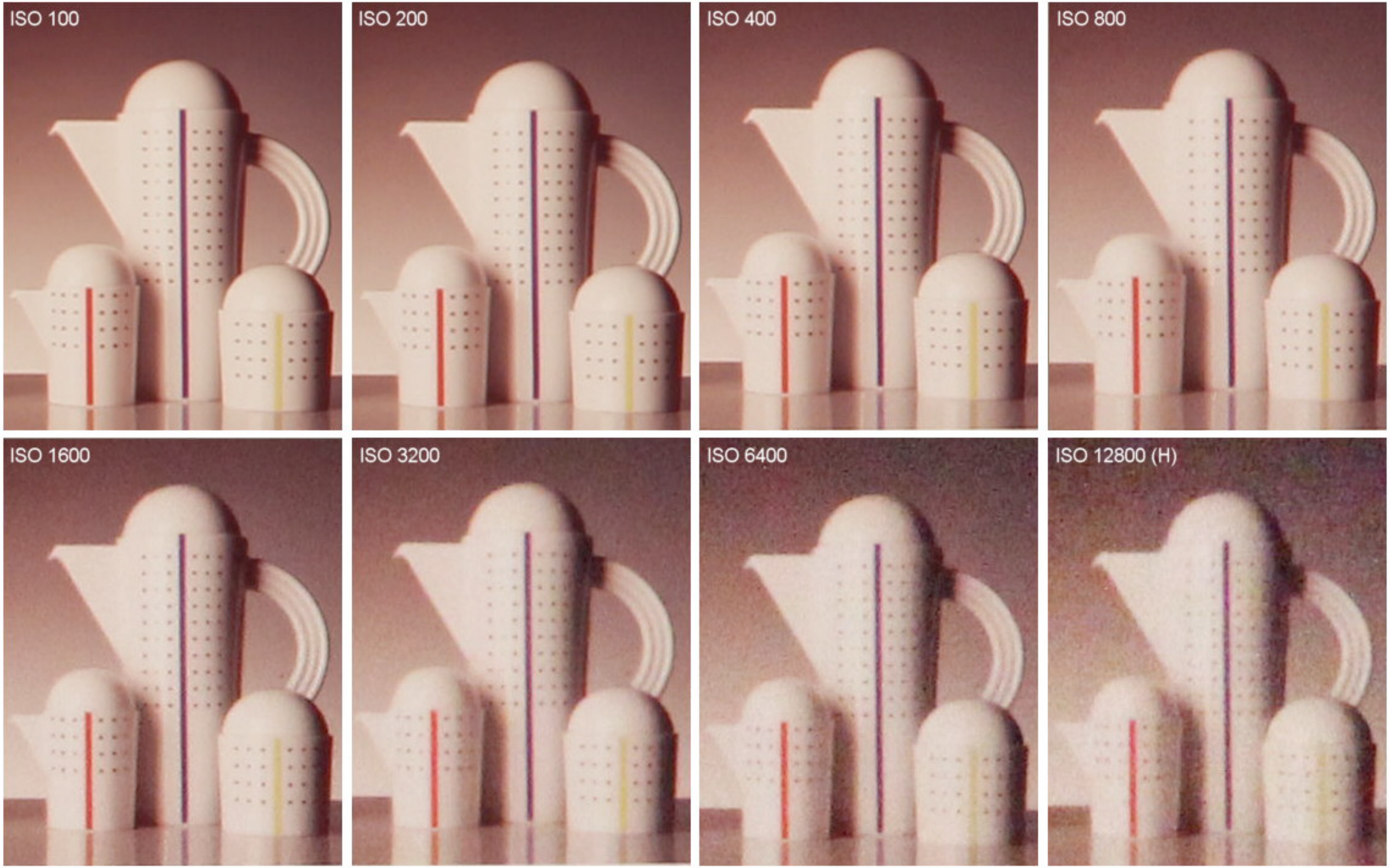
Sensitivity (ISO)

Third variable for exposure

Linear effect (200 ISO needs half the light as 100 ISO)

Film: trade sensitivity for grain

Digital: trade sensitivity for noise


ISO 100
ISO 200
ISO 400
ISO 800
ISO 1600
ISO 3200
ISO 6400
ISO 12800 (H)

Conclusions

Simple camera model

- Thin lens, aperture, shutter, sensor

Photographs often have undesired artifacts

- Distortions, color artifacts, blur, noise, under/overexposure

Goal: develop algorithms to remove artifacts after image is captured

Slide credits

Steve Marschner

Alyosha Efros

Frédo Durand

Marc Levoy

Matthias Zwicker

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