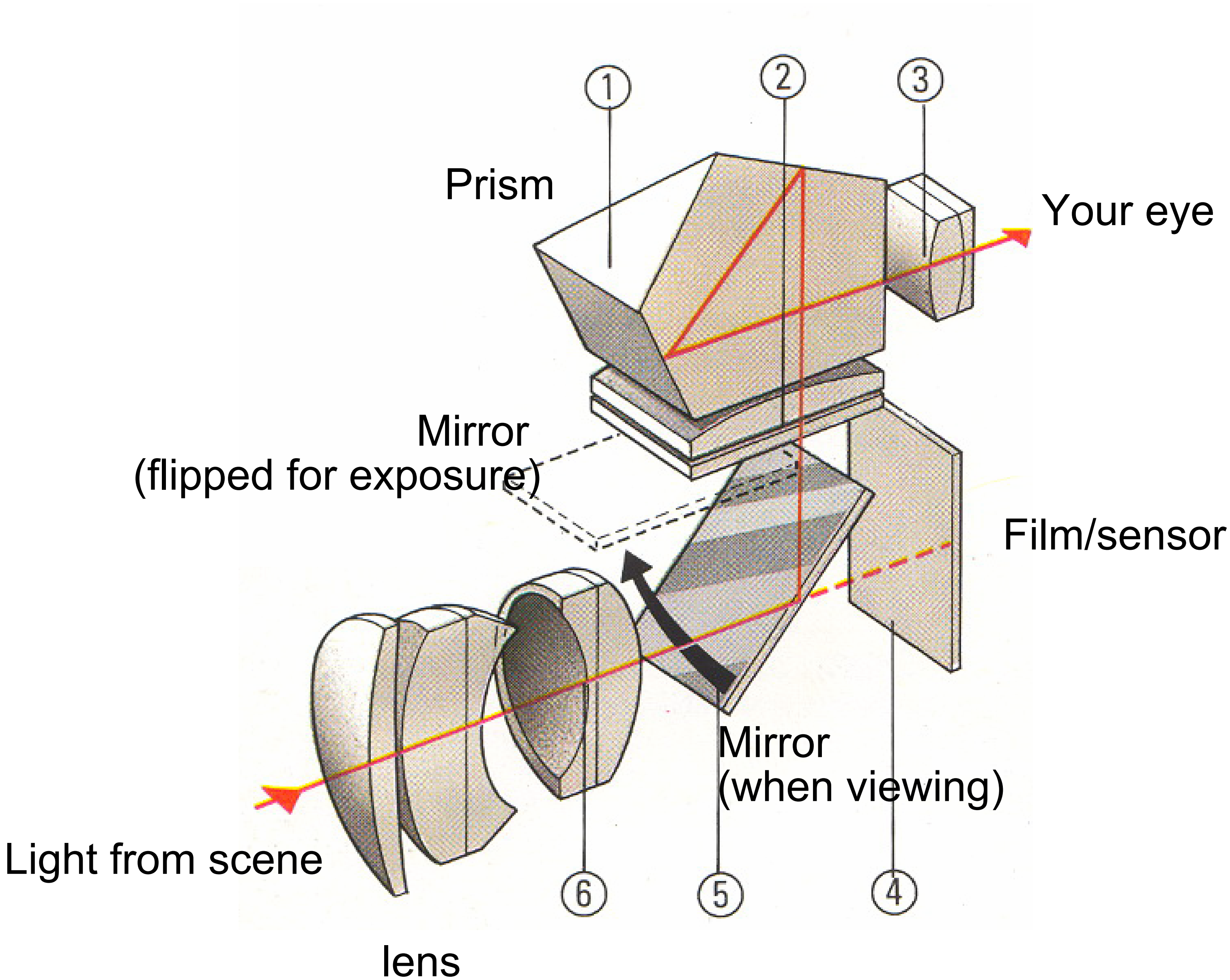
Lenses

Frédo Durand

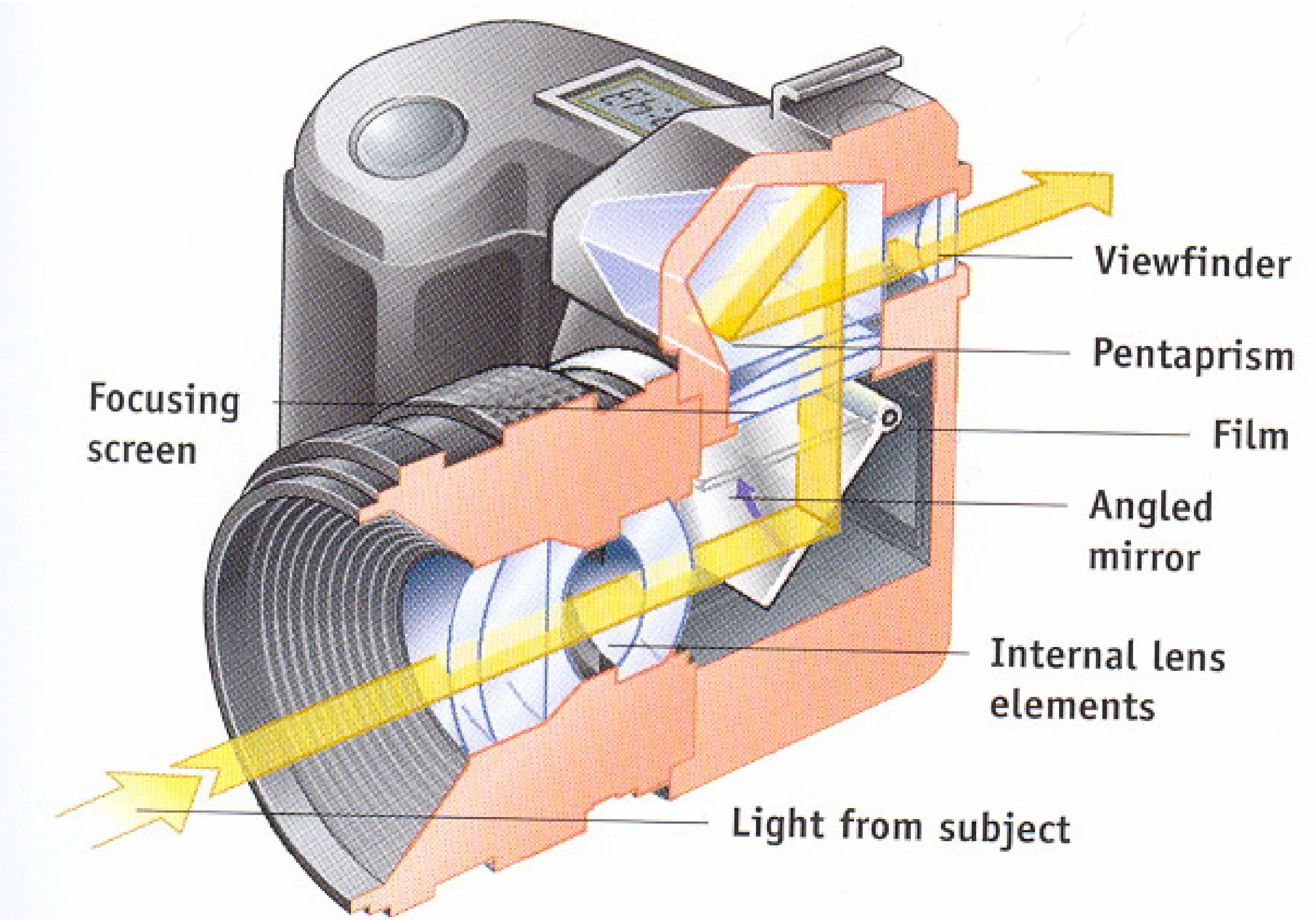
SLR view finder

- Reflex (R in SLR) means that we see through the same lens used to take the image.
- Not the case for compact cameras
- Pros and cons?

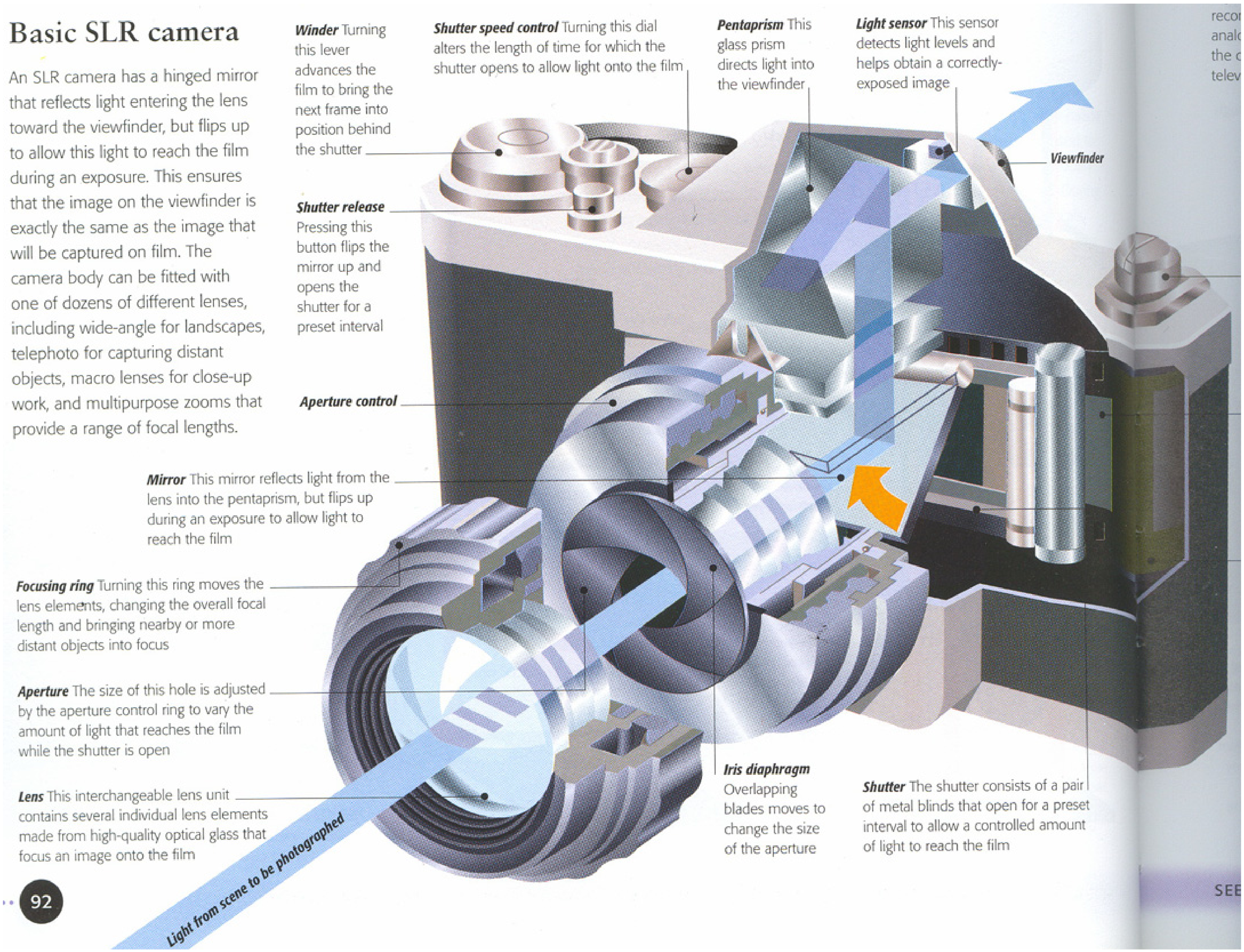
SLR view finder



SLR view finder

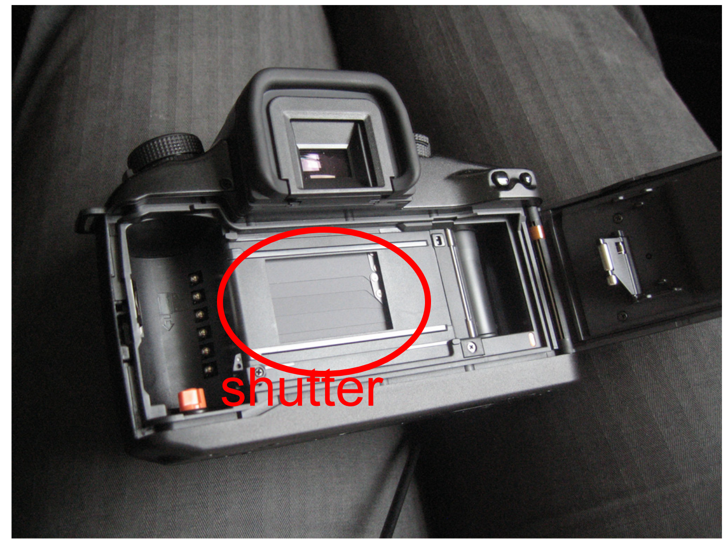


SLR anatomy


Basic SLR camera
An SLR camera has a hinged mirror that reflects light entering the lens toward the viewfinder, but flips up to allow this light to reach the film during an exposure. This ensures that the image on the viewfinder is exactly the same as the image that will be captured on film. The camera body can be fitted with one of dozens of different lenses, including wide-angle for landscapes, telephoto for capturing distant objects, macro lenses for close-up work, and multipurpose zooms that provide a range of focal lengths.
Winder Turning this lever advances the film to bring the next frame into position behind the shutter
Shutter speed control Turning this dial alters the length of time for which the shutter opens to allow light onto the film
Pentaprism This glass prism directs light into the viewfinder
Light sensor This sensor detects light levels and helps obtain a correctly-exposed image
Viewfinder
Shutter release Pressing this button flips the mirror up and opens the shutter for a preset interval
Aperture control
Mirror This mirror reflects light from the lens into the pentaprism, but flips up during an exposure to allow light to reach the film
Focusing ring Turning this ring moves the lens elements, changing the overall focal length and bringing nearby or more distant objects into focus
Aperture The size of this hole is adjusted by the aperture control ring to vary the amount of light that reaches the film while the shutter is open
Lens This interchangeable lens unit contains several individual lens elements made from high-quality optical glass that focus an image onto the film
Iris diaphragm Overlapping blades moves to change the size of the aperture
Shutter The shutter consists of a pair of metal blinds that open for a preset interval to allow a controlled amount of light to reach the film
Light from scene to be photographed
92

Shutter

- **Most of the time, the film/sensor is protected from light**
- **When we take a picture, the shutter opens and closes, thereby exposing the film.**
- **Exposure is proportional to the time the shutter is open**
- **Expressed in fraction of a second (1/60s, 1/125s, 1/250s, 1/500s, etc.)**



Two types of shutter
The two-blind system (right)
is most common

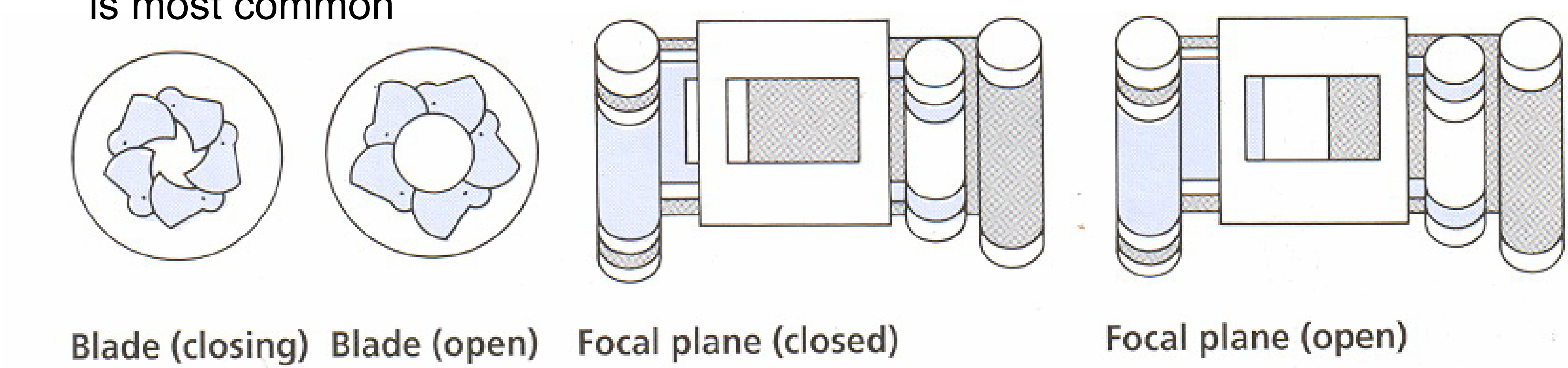
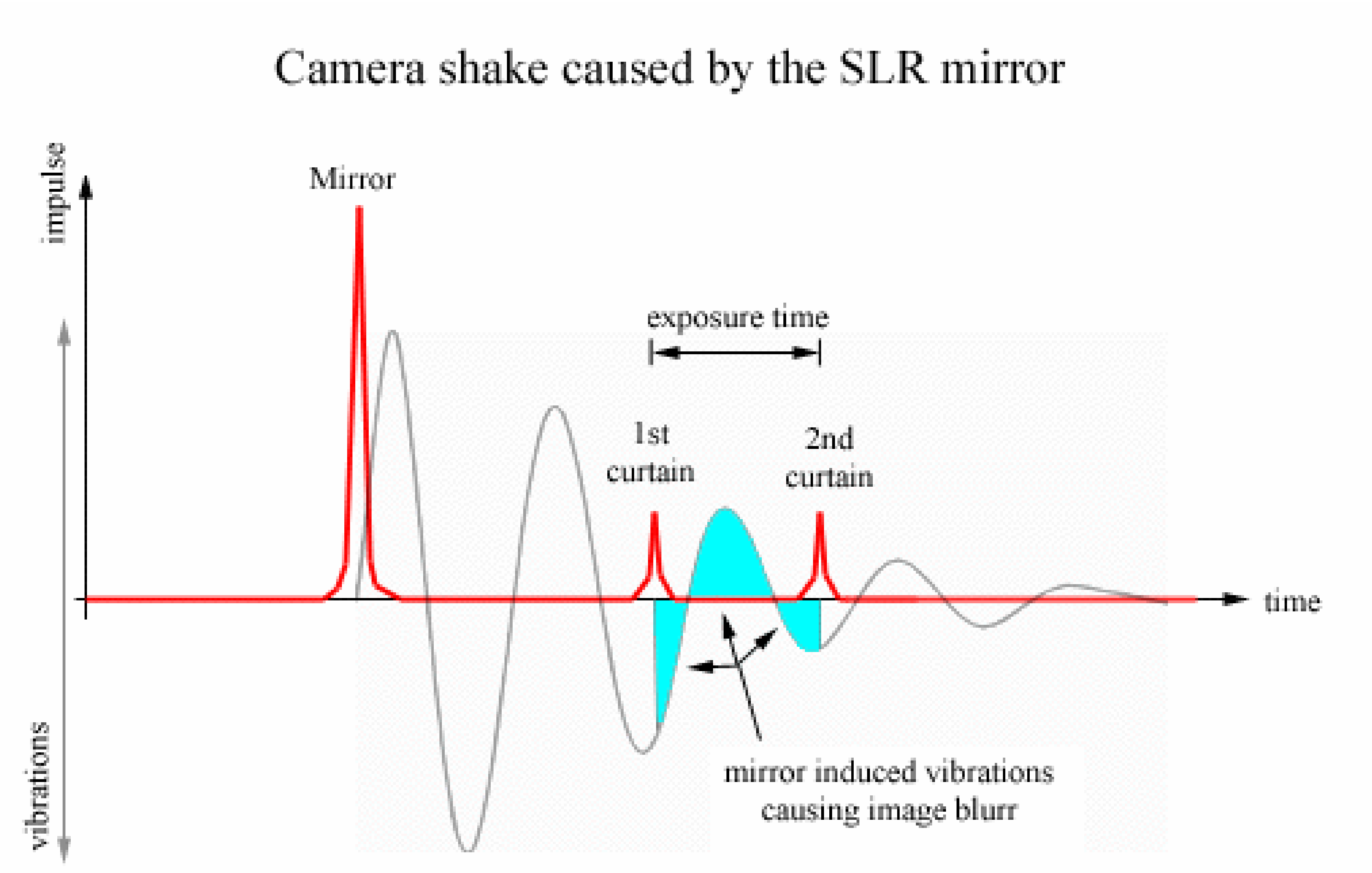


Figure 6–6. Jacques Henri Lartigue, *Grand Prix of the Automobile Club of France, 1912.* This classic photograph provides an exaggerated example of the distortion that can be caused by a focal-plane shutter. The oval shape of the automobile tire is caused by the motion of the car between the time the bottom of the tire was exposed and the top. (Remember–the image is upside-down on the negative.) The same principle caused the leaning appearance of the spectators. Lartigue turned the camera to follow the automobile (panning), and thus the image of the spectators moved at the film plane during the exposure. (Courtesy International Museum of Photography at George Eastman House.)

Mirror and camera shake

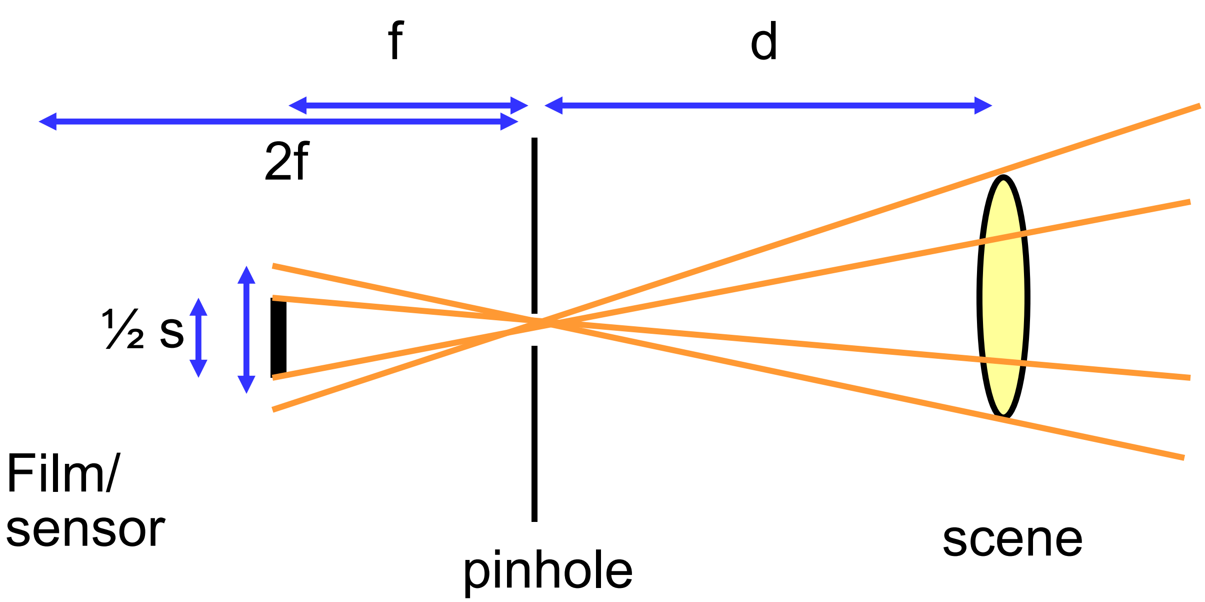
- http://www.photozone.de/3Technology/camtec2.htm



Questions?

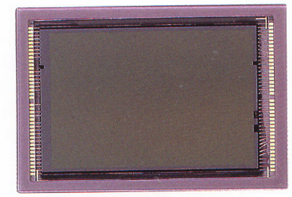
Focal length: pinhole optics

- **What happens when the film is half the size?**
- **Application:**
  - Real film is 36x24mm
  - On the 20D, the sensor is 22.5 x 15.0 mm
  - Conversion factor on the 20D?
  - On the SD500, it is 1/1.8 " (7.18 x 5.32 mm)
  - What is the 7.7-23.1mm zoom on the SD500?

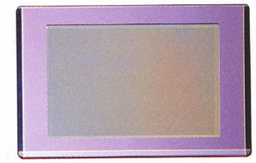


Sensor size

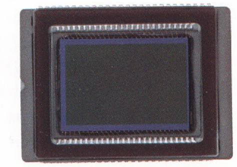
- **Similar to cropping**



EOS-1Ds : 35.8 x 23.8mm

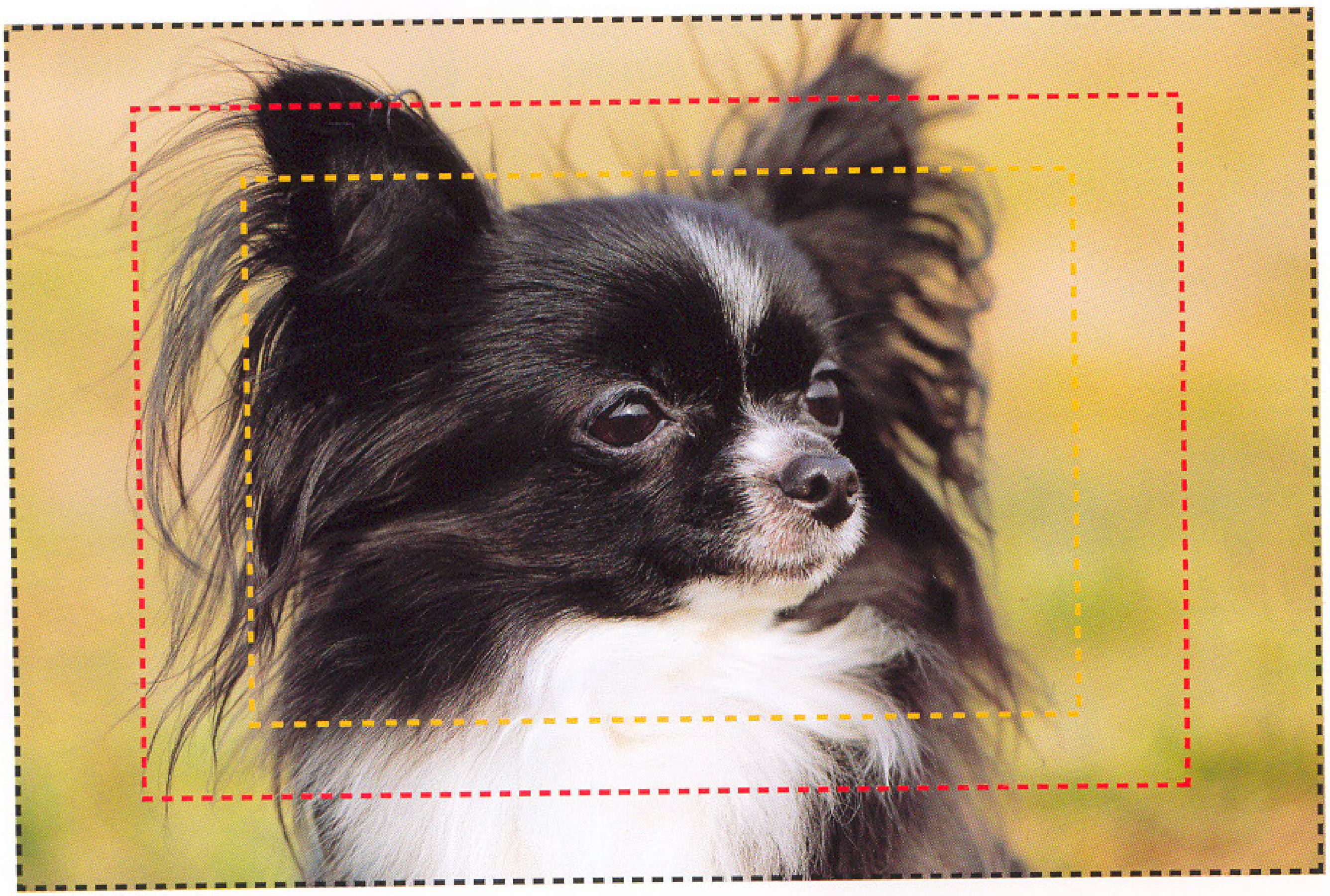


EOS-1D : 28.7 x 19.1mm



EOS 10D : 22.7 x 15.1mm

35mm full size and digital shooting range image size (picture dimensions) and lens selection



— EOS-1Ds / — EOS-1D/ — EOS 10D

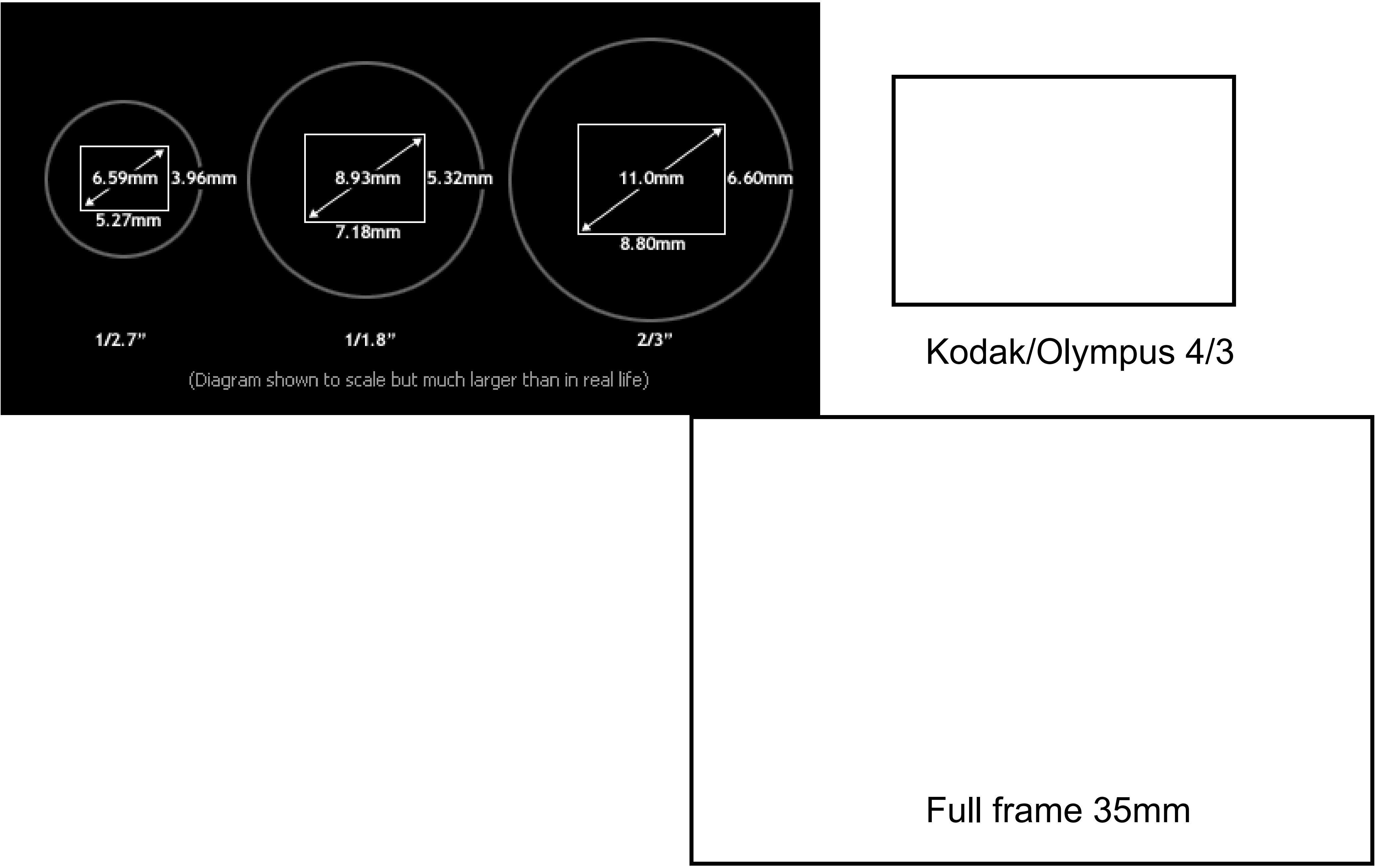
source: canon red book

EOS-1D

EOS 10D

(The EOS Kiss Digital/EOS DIGITAL Rebel/EOS 300D DIGITAL SLR camera has the same image size as the EOS 10D.)

Smaller sensors

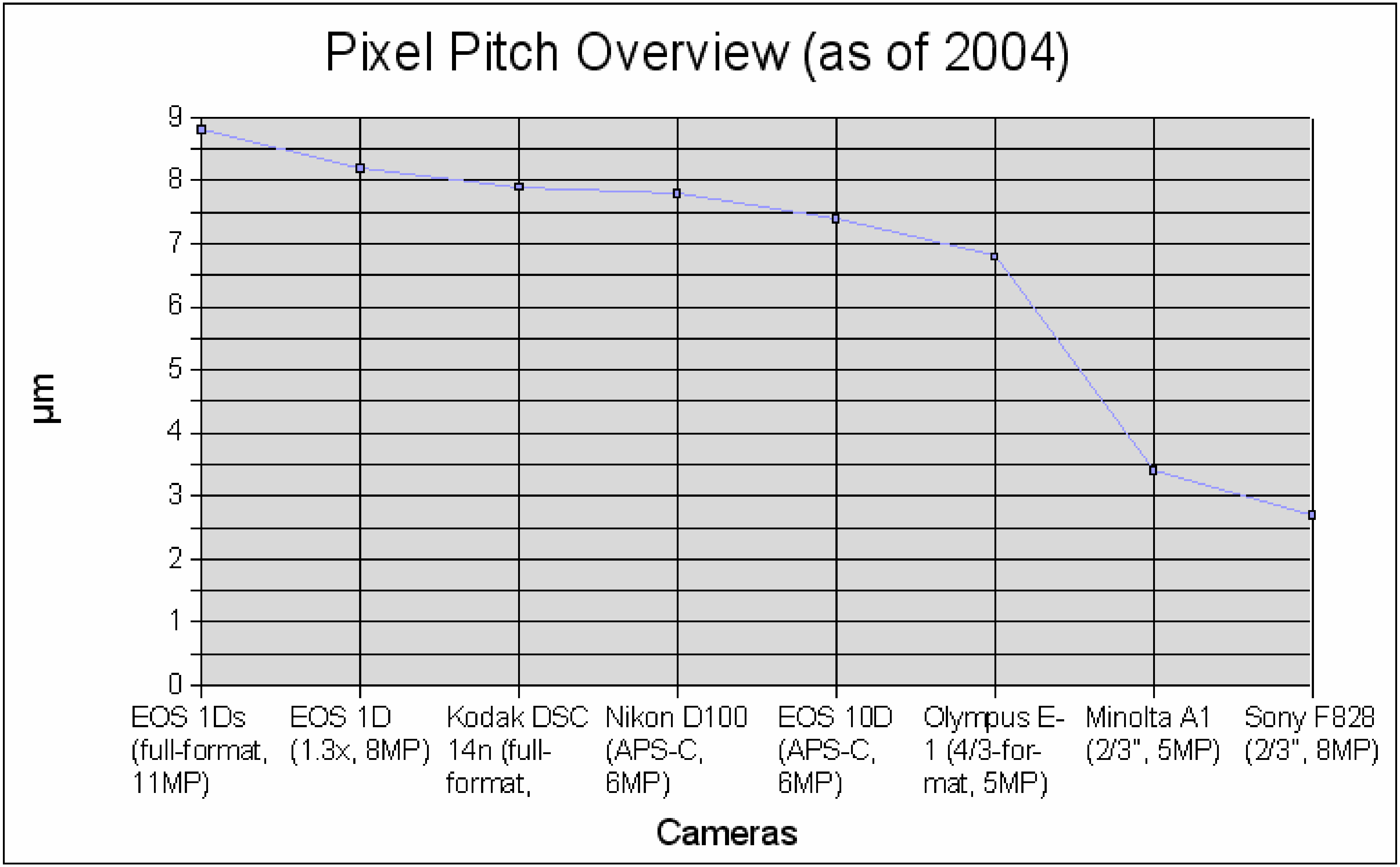


http://www.photozone.de/3Technology/digital_1.htm

edu

Pixel size

- http://www.photozone.de/3Technology/digital_2.htm



Megapixel & print size

- http://www.photozone.de/3Technology/digital_4.htm
- (pessimistic IMHO)

Megapixels & Print-Size

"How many megapixels do I really need for my purposes" - a quite common question. The following table provides an overview of megapixels in relation to common print sizes. A print resolution of 300dpi corresponds to magazine quality. "Acceptable" prints don't require 300dpi but e.g. 2MP will not scale to something like 20x30cm without a severe loss of quality.

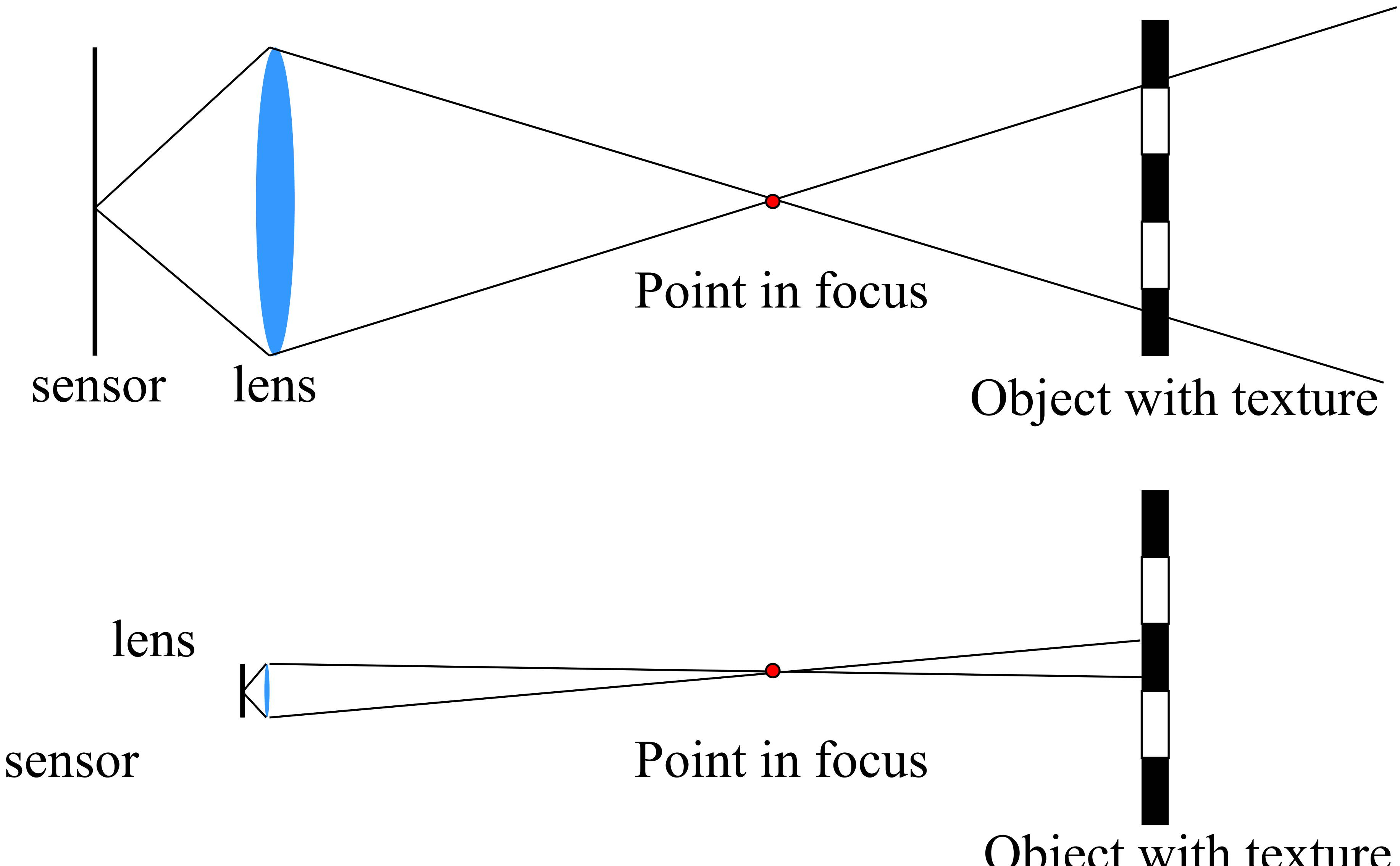
Megapixels	Resolution	common print size (rougly 300dpi)
2 MP	1600x1200	10x13cm / 4x6"
3 MP	2048x1536	13x18cm / 5x7"
4 MP	2400 x 1600	18x23cm / 6x8"
6 MP	3000x2000	20x30cm / 7x10"
8 MP	3600x2400	30x40cm / 10x14"

Sensor size does matter

- Perspective (hard to make a wide angle)
- Noise
- Dynamic range
- Depth of field

Depth of field

- **It's all about the size of the lens aperture**



http://www.outbackphoto.com/workshop/phototechnique/essay07/essay.html

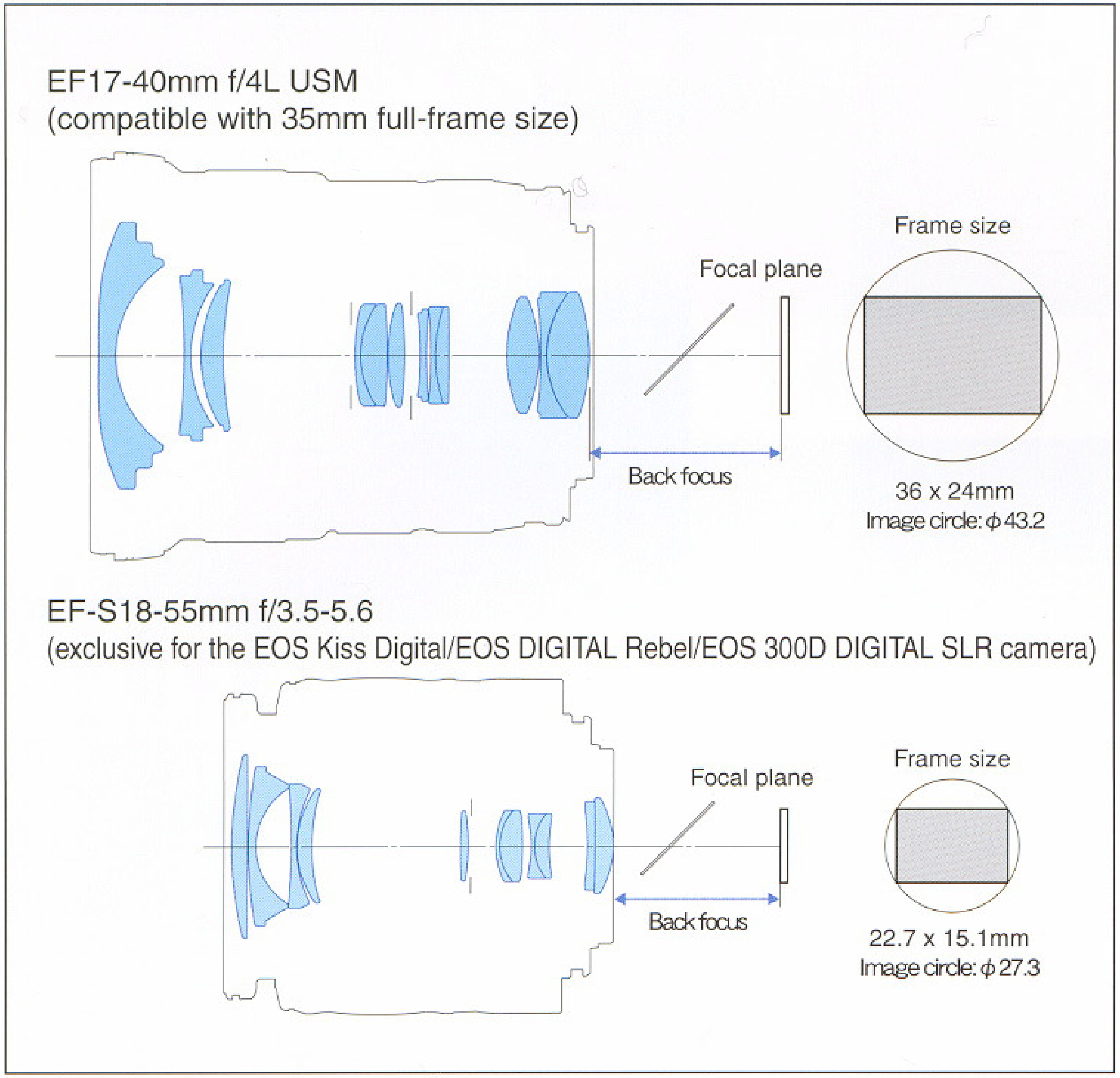
D2X (1.5x)

1DsMkII (full frame)

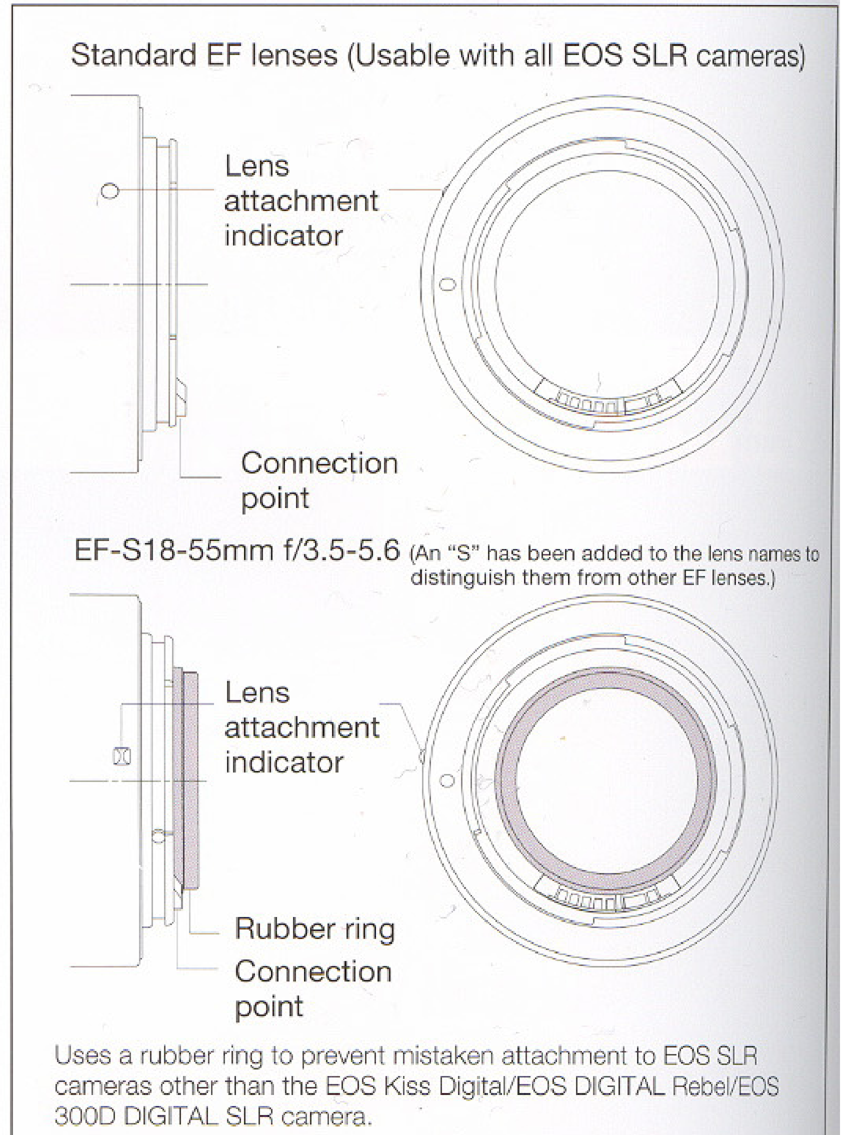
Special lenses

- **Note that small sensors on DSLRs don't use the periphery of lenses**
- **And because of the conversion factor, it's hard to get wide angle**
- **This is why manufacturers have designed special lenses**
  – Project a smaller image circle
  – Can go further back because the mirror is smaller
  – EFS for Canon, XXXX for Nikon

Design of the Short Back-Focus Lens System



Comparison of Rear Portions of Lenses

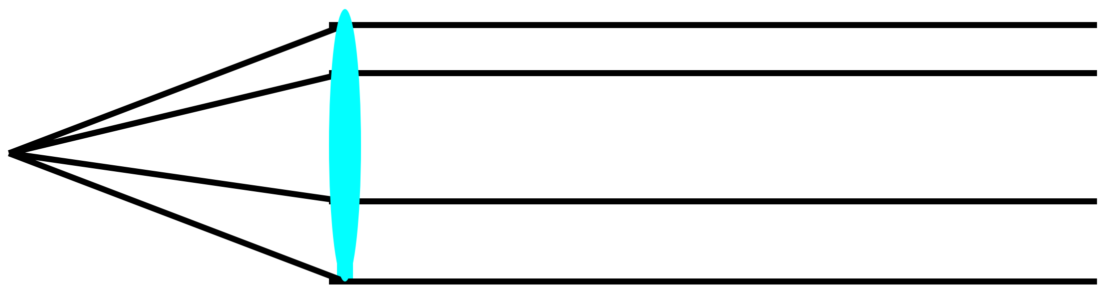


source: canon red book

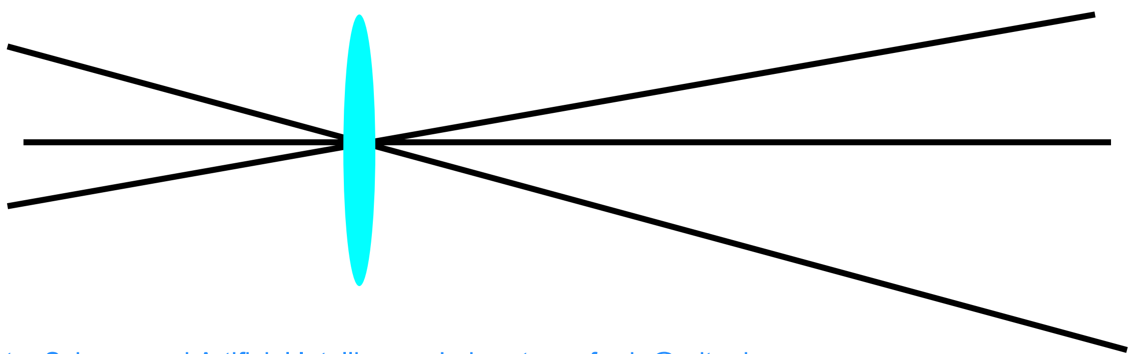
Questions?

Thin lens optics

- **Simplification of geometrical optics for well-behaved lenses**
- **All parallel rays converge to one point on a plane located at the focal lens**

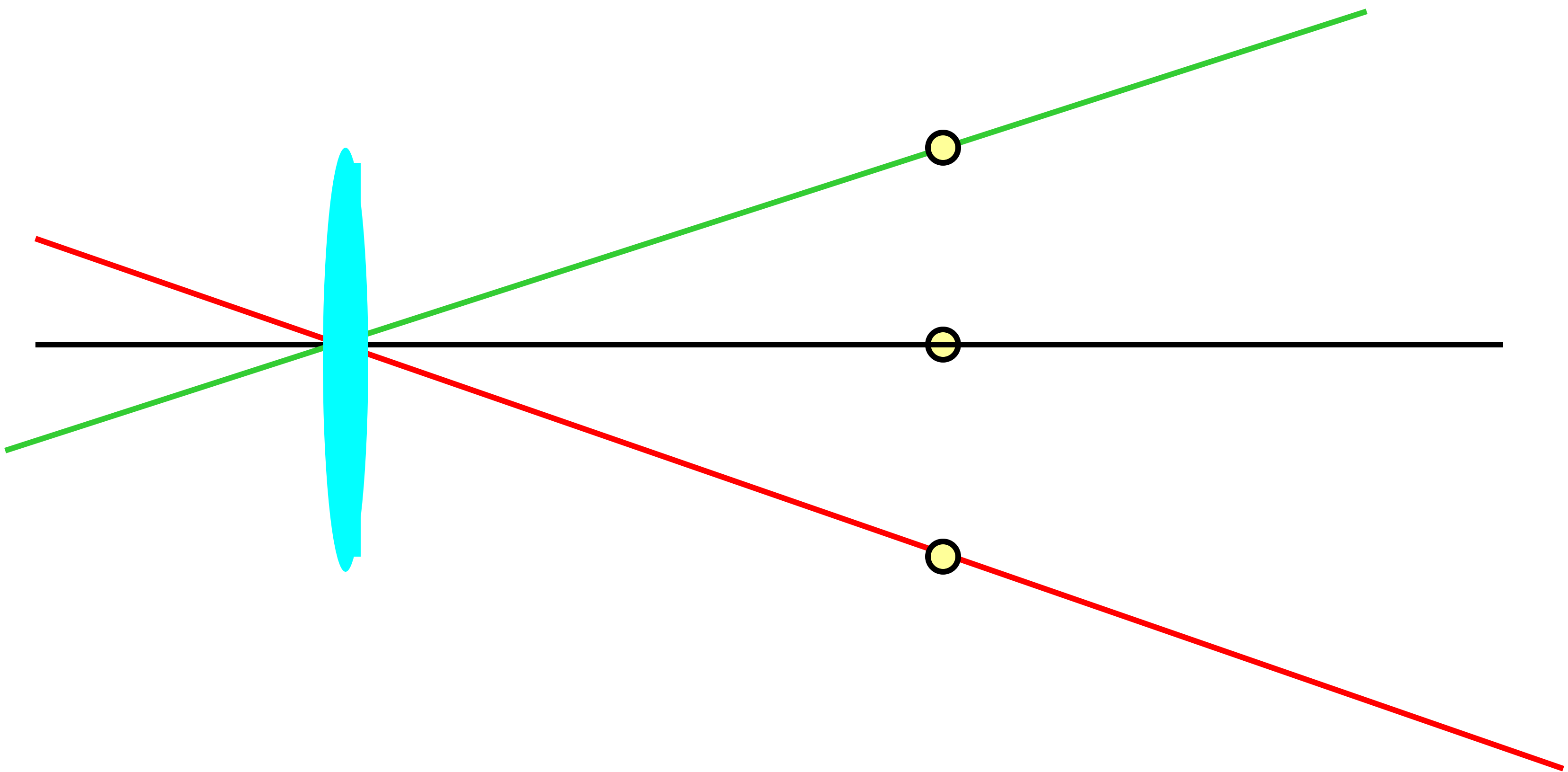


- **All rays going through the center are not deviated**
  – Hence same perspective as pinhole



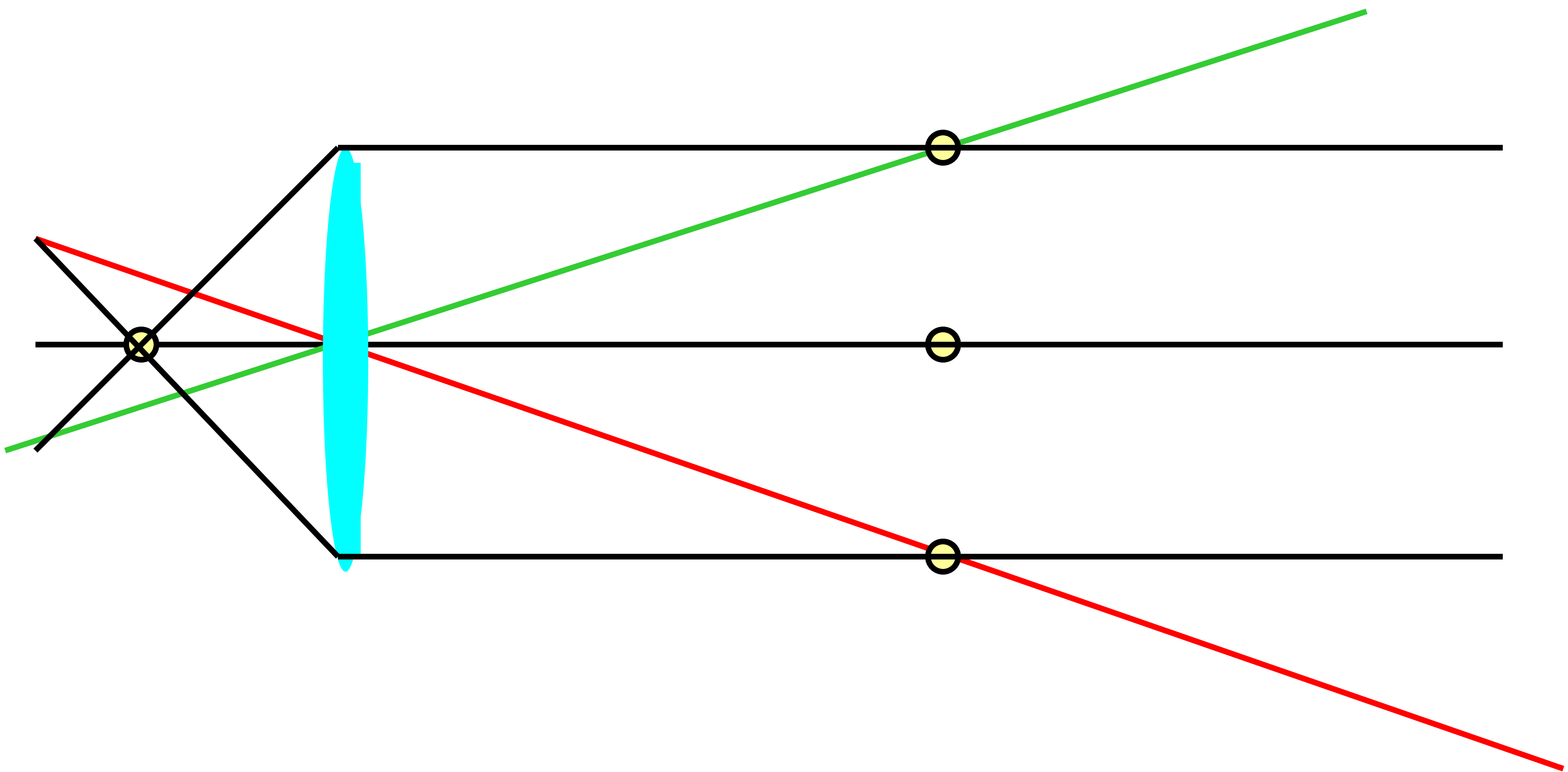
How to trace rays

- **Start by rays through the center**



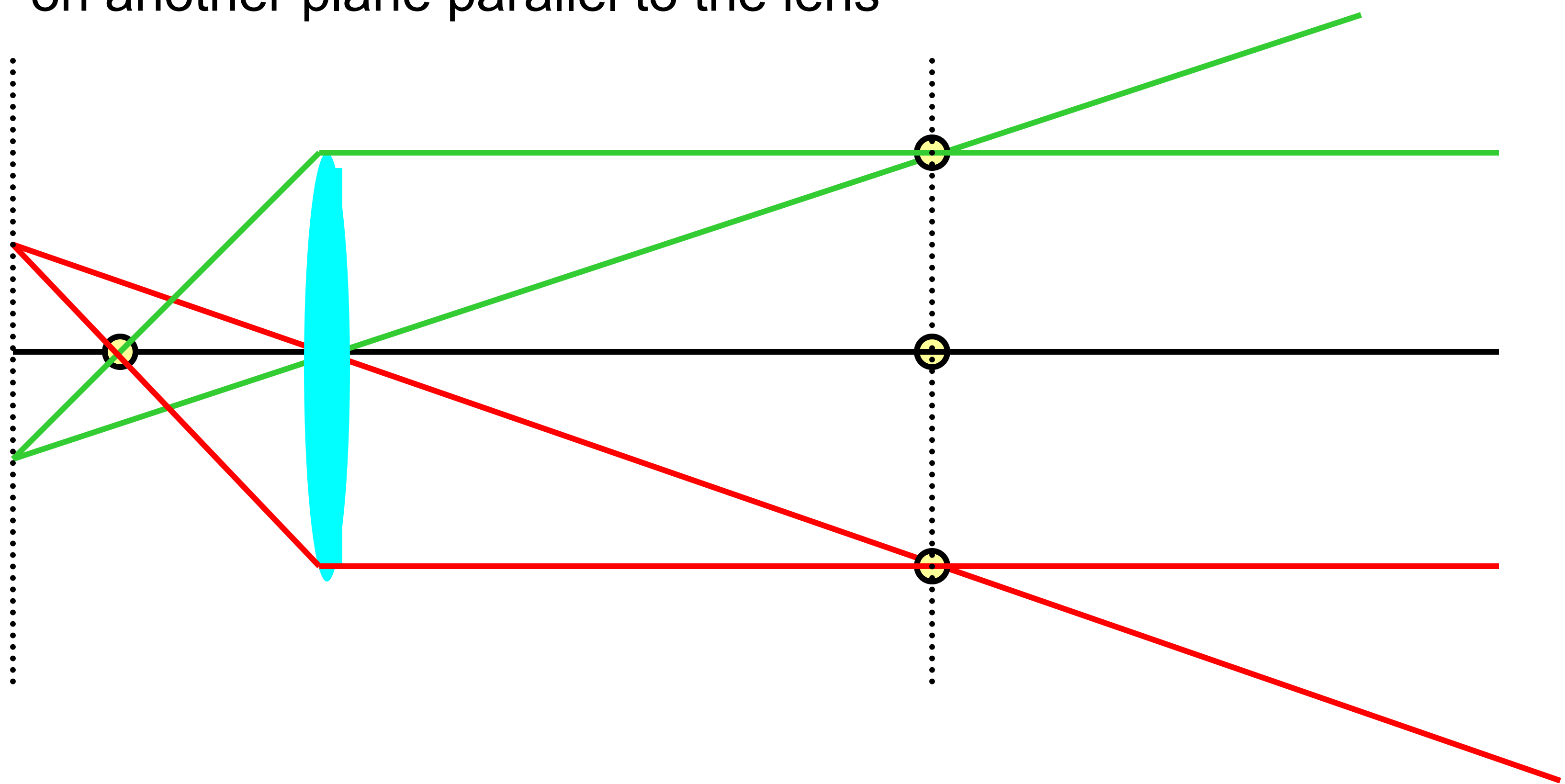
How to trace rays

- Start by rays through the center
- Choose focal length, trace parallels



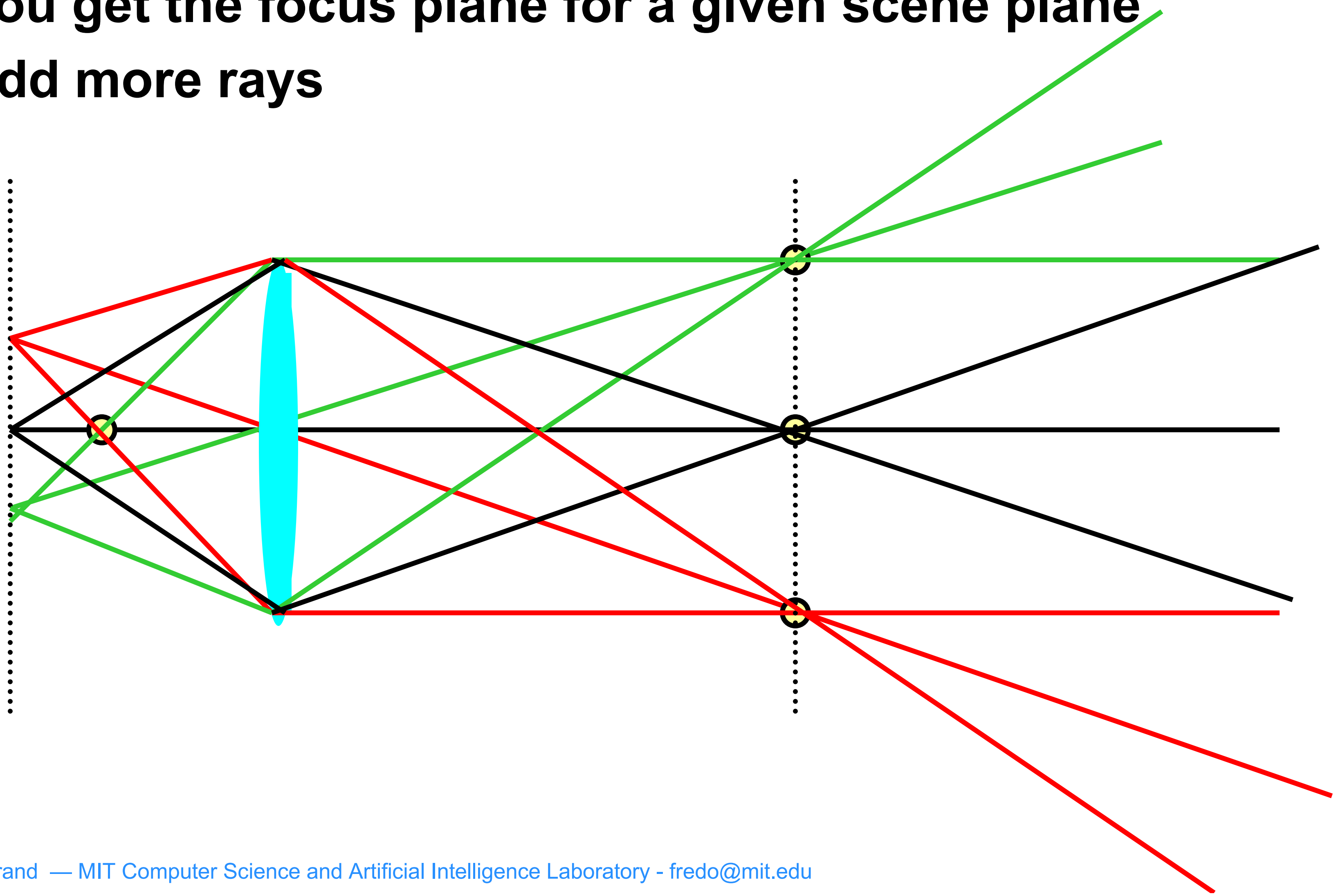
How to trace rays

- **Start by rays through the center**
- **Choose focal length, trace parallels**
- **You get the focus plane for a given scene plane**
  - All rays coming from points on a plane parallel to the lens are focused on another plane parallel to the lens



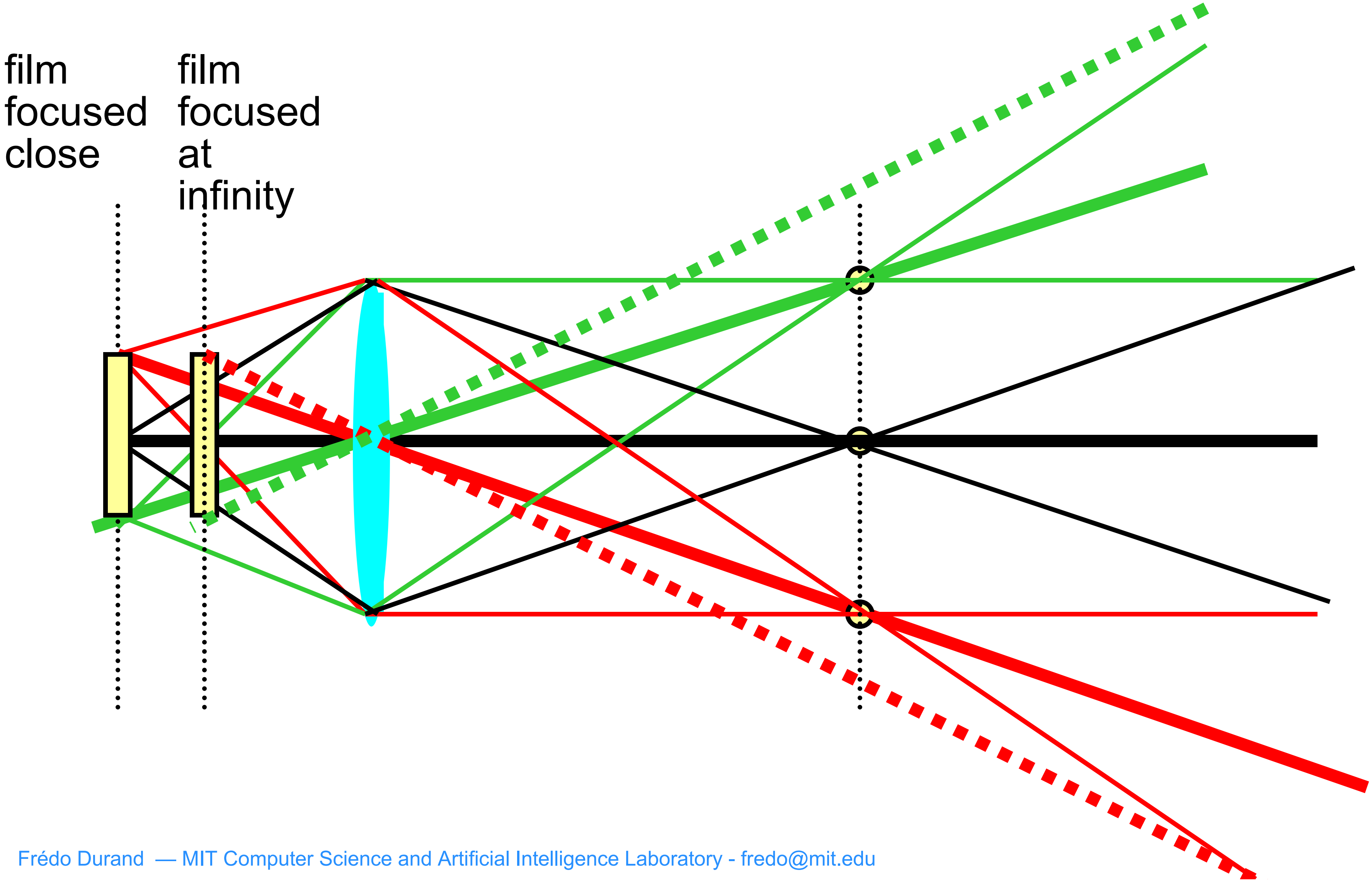
How to trace rays

- Start by rays through the center
- Choose focal length, trace parallels
- You get the focus plane for a given scene plane
- Add more rays



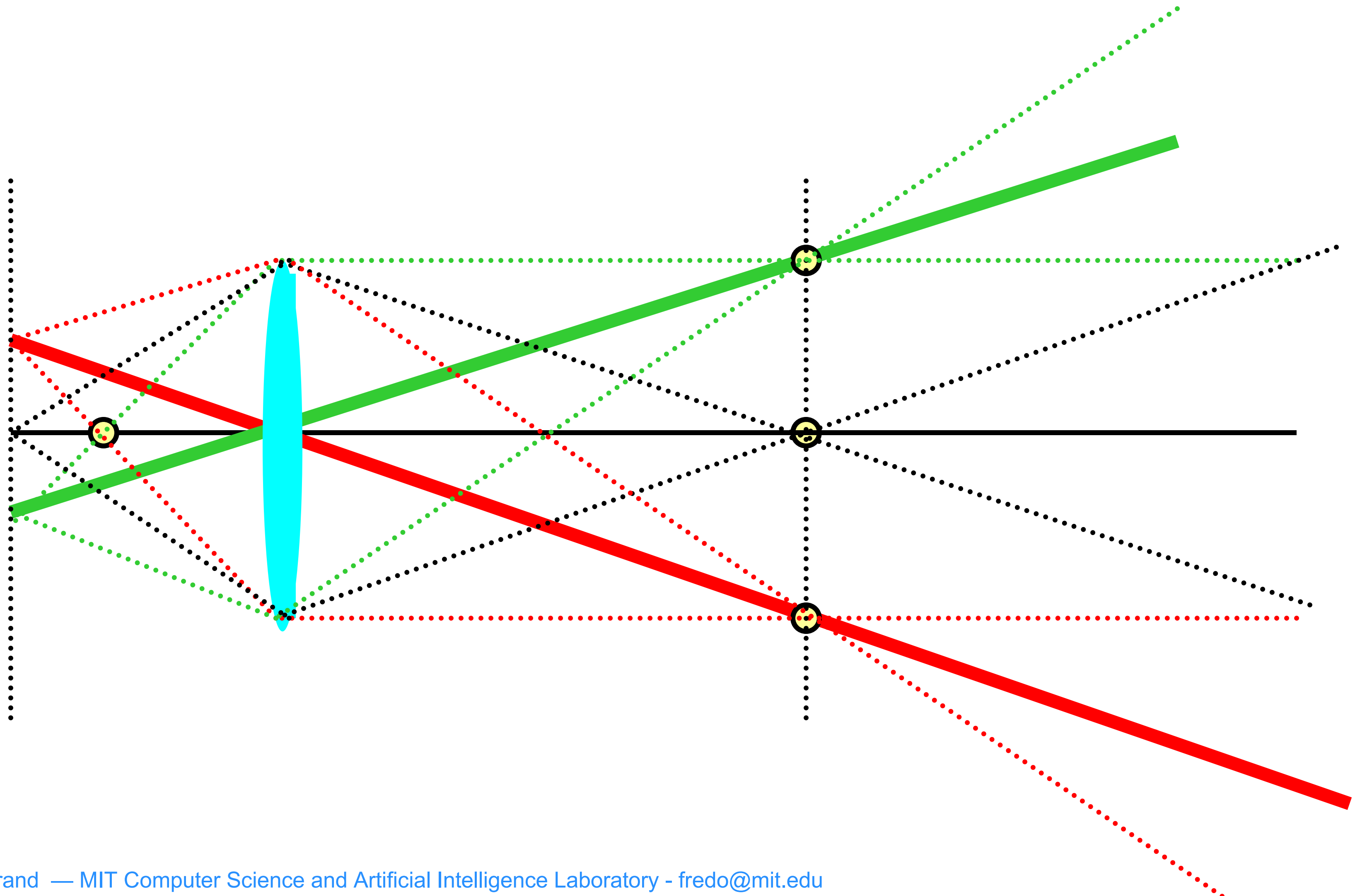
Field of view & focusing

- **What happens to the field of view when one focuses closer?**
  - It's reduced



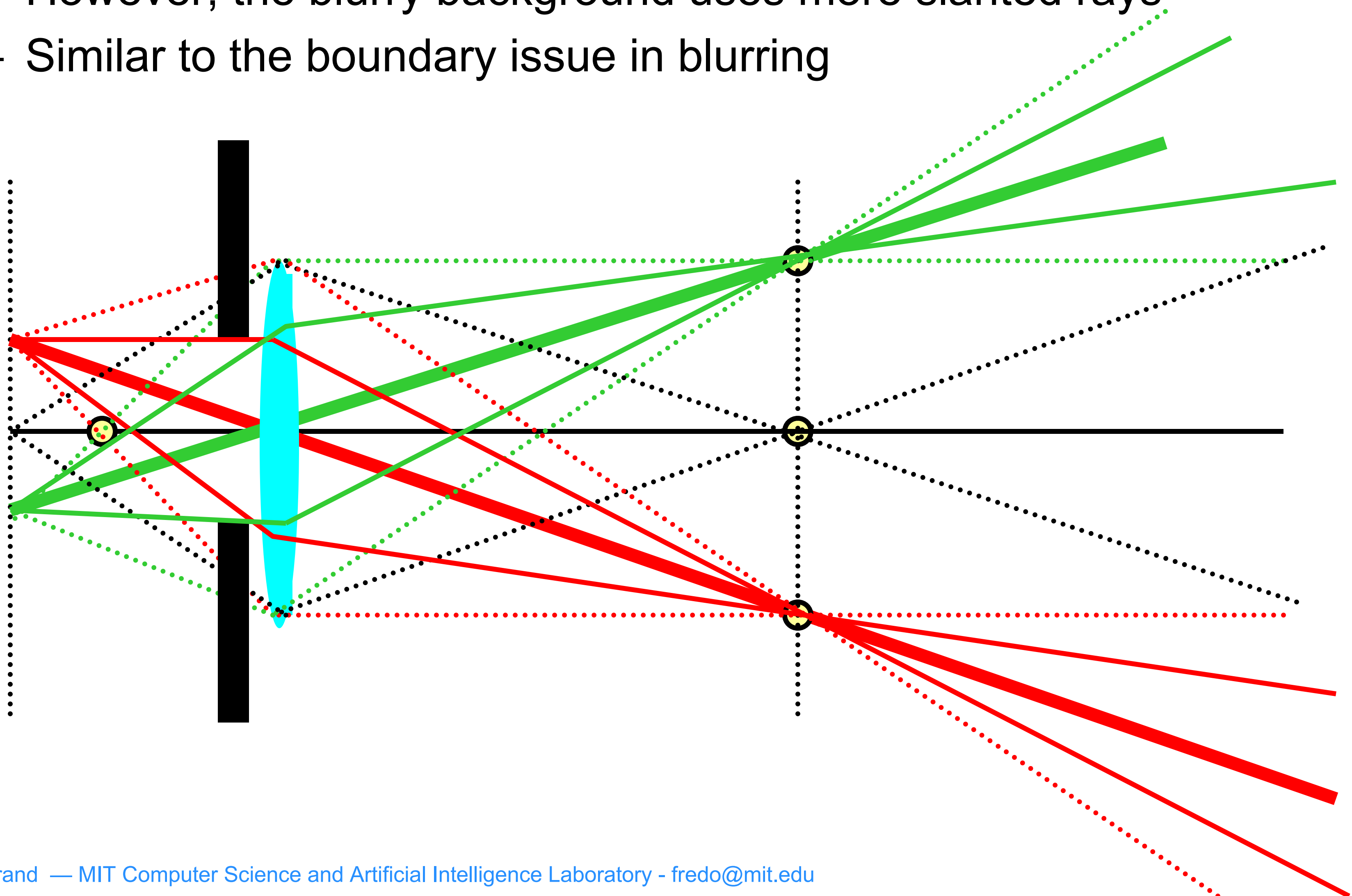
Field of view & aperture

- **Does the aperture change the field of view?**



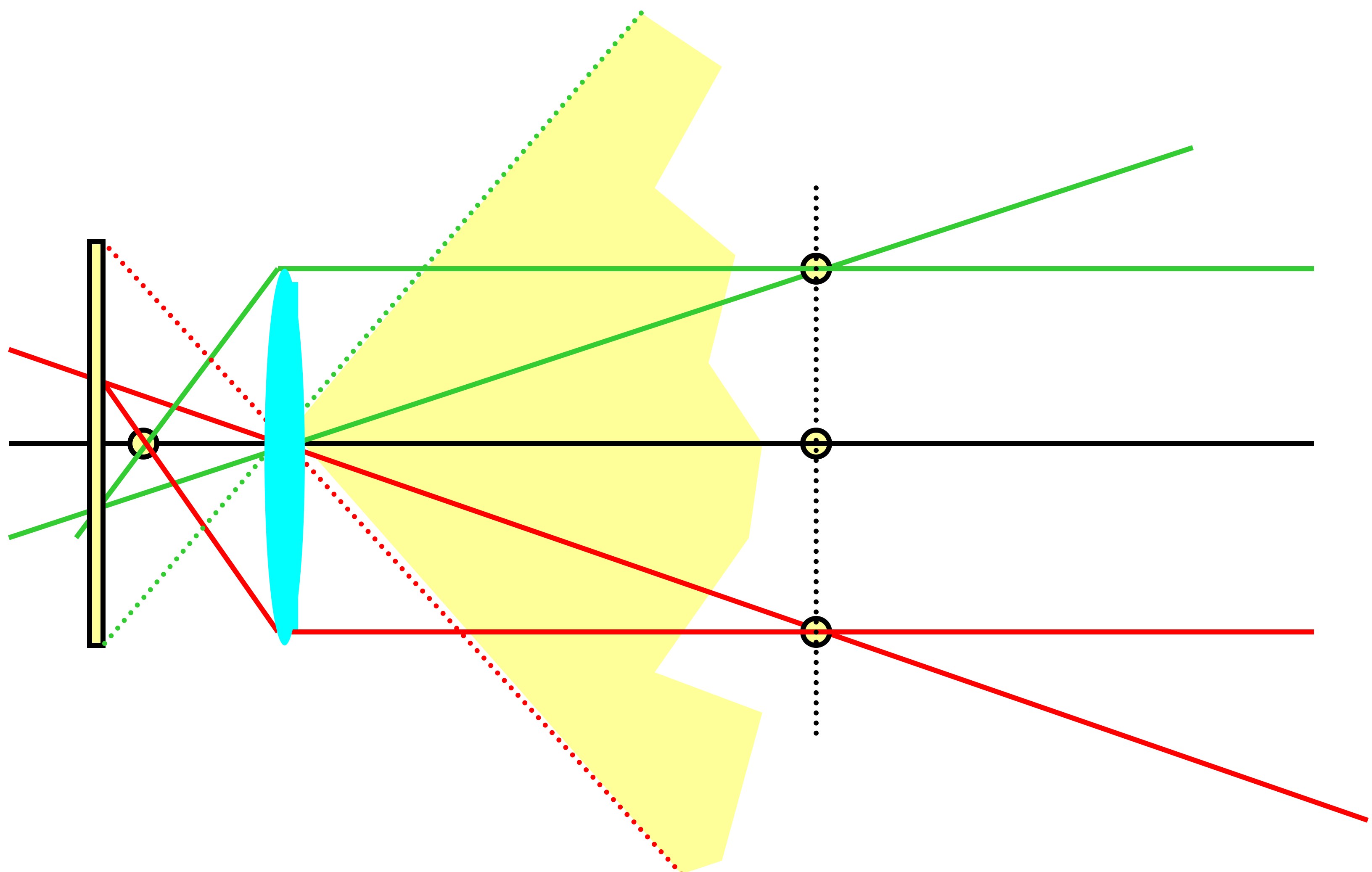
Field of view & aperture

- **Does the aperture change the field of view?**
  - No!
  - However, the blurry background uses more slanted rays
  - Similar to the boundary issue in blurring



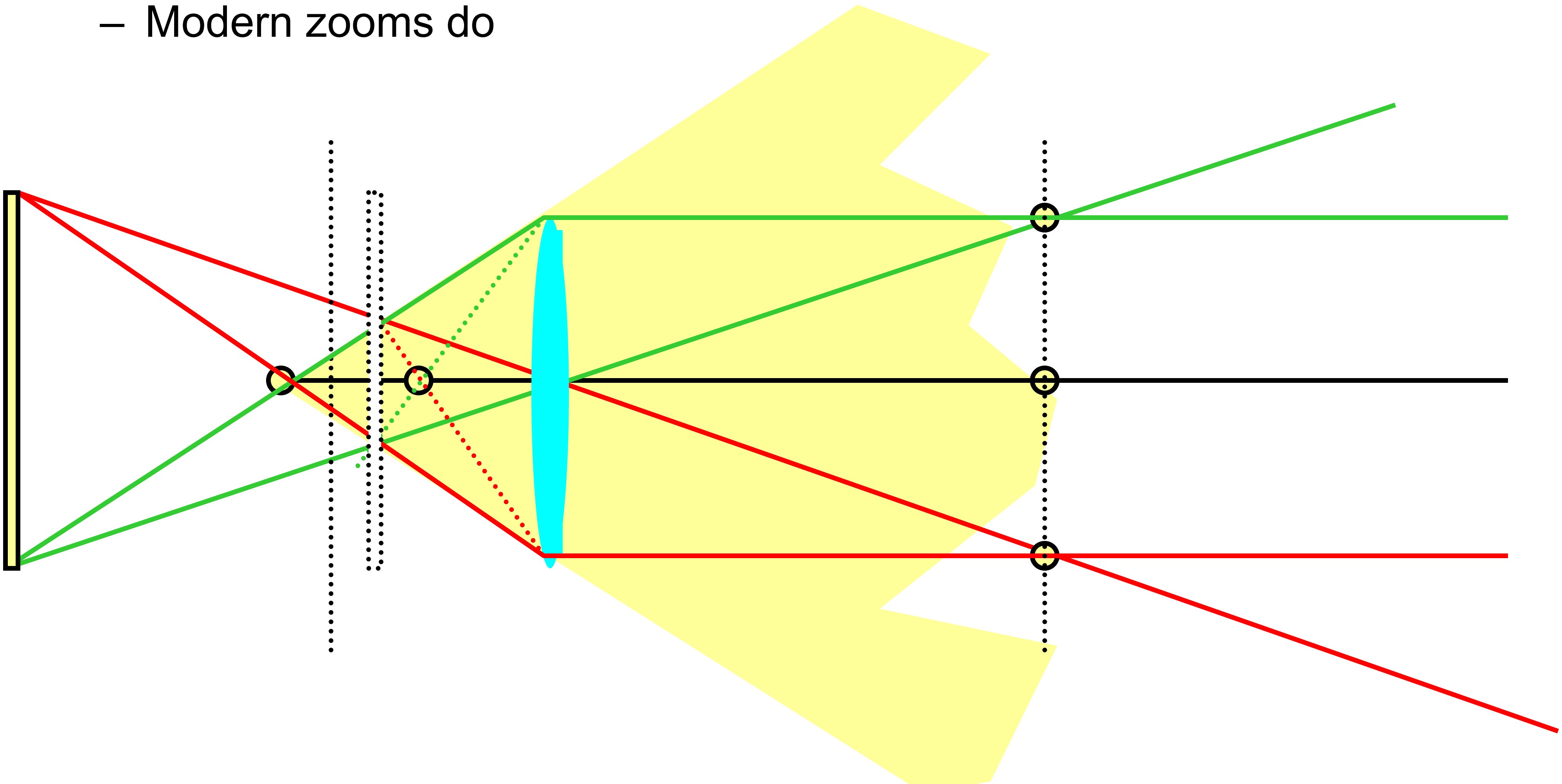
Zoom & focusing

- I replace the lens by one with longer focal length



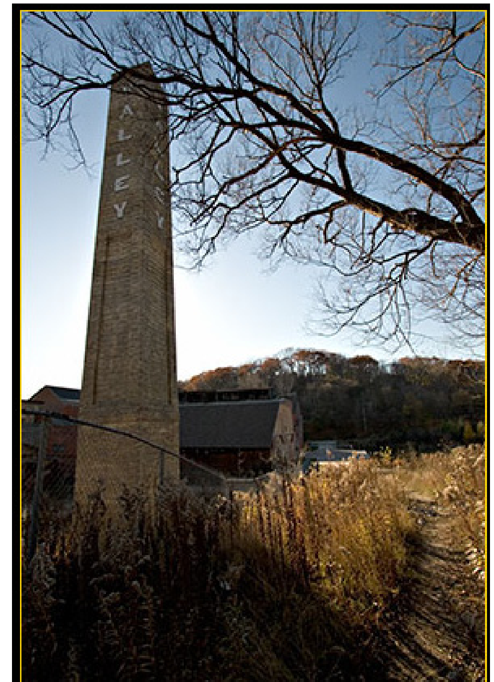
Zoom & focusing

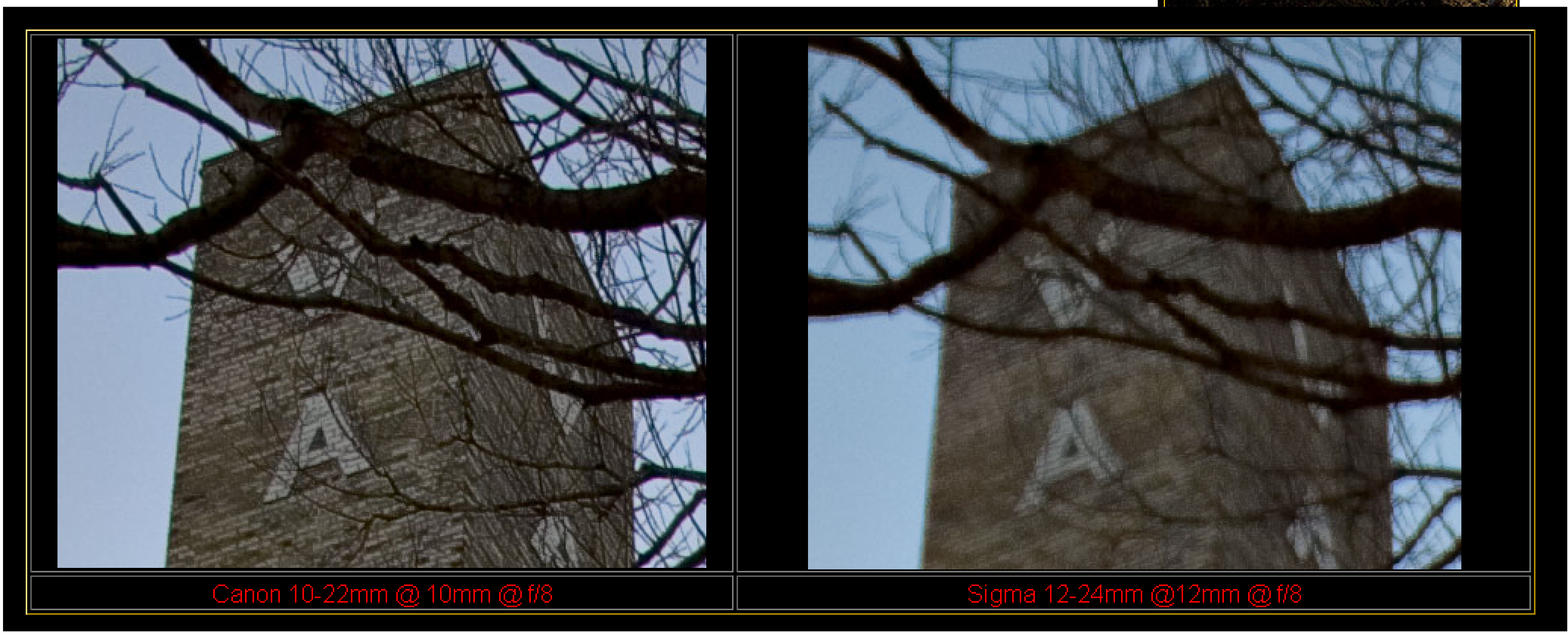
- **I replace the lens by one with longer focal length**
  - need to move much further to focus, esp. for close focusing distance
  - Basic zooms don't stay focused when you soom in/out!
  - Modern zooms do



Questions?

Lens quality varies!





source: the luminous landscape

source: the luminous landscape

Lens quality

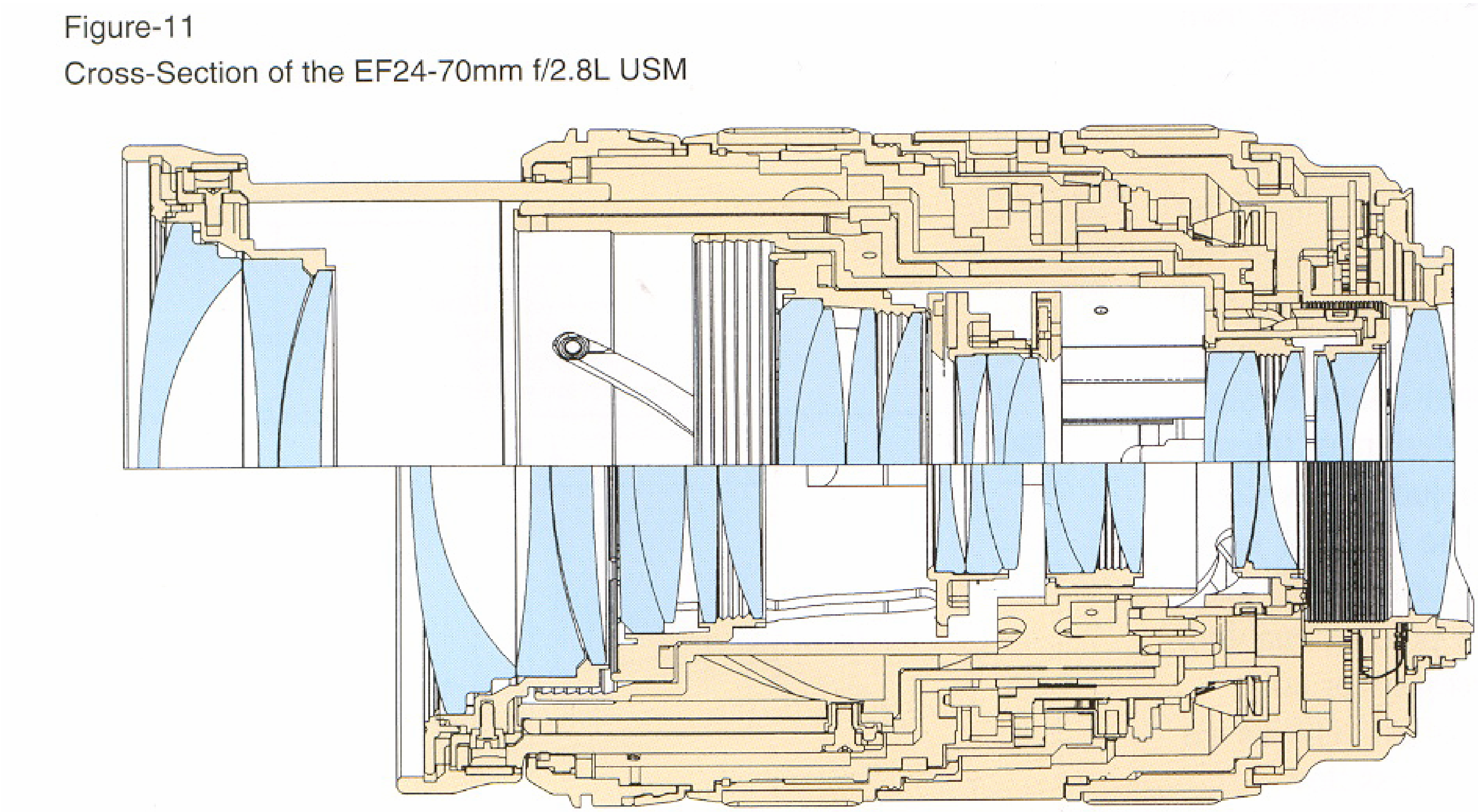
- MTF
- Sharpness
- Contrast
- Bokeh

Why are lenses so complicated?

- **Chromatic aberration**
  - Dispersion!
- **vignetting**
- **Flare**

- **Sharpness**
- **Bokeh**
- **Contrast**
- **MTF**

Lenses are complex



source: canon red book

Lens buzzwords

- UD
- Fluorite
- DO
- Aspherical
- Coating
- Apochromatic
- FTMF
- USM, HSM, Supersonic
- IS
- L series

Factors for optical quality

- **Max aperture: hard to focus all rays**
- **Min aperture: diffraction**
- **Zoom range**
  - Some zooms might be better at wide angle, some at the long end
- **Light in the frame**
  - Flare, reflection
- **Center vs. periphery**
  - Lenses are usually better in the center
- **Focusing distance**

The scene (overcast)

135mm f/2 corner (100%

70-200mm f/2.8 IS @131mm corner (100% magnification)

•http://www.outbackphoto.com/the_bag/uwe_lenses_canon_135f2/essay.html

source: digital outback

n/t

The scene (overcast)

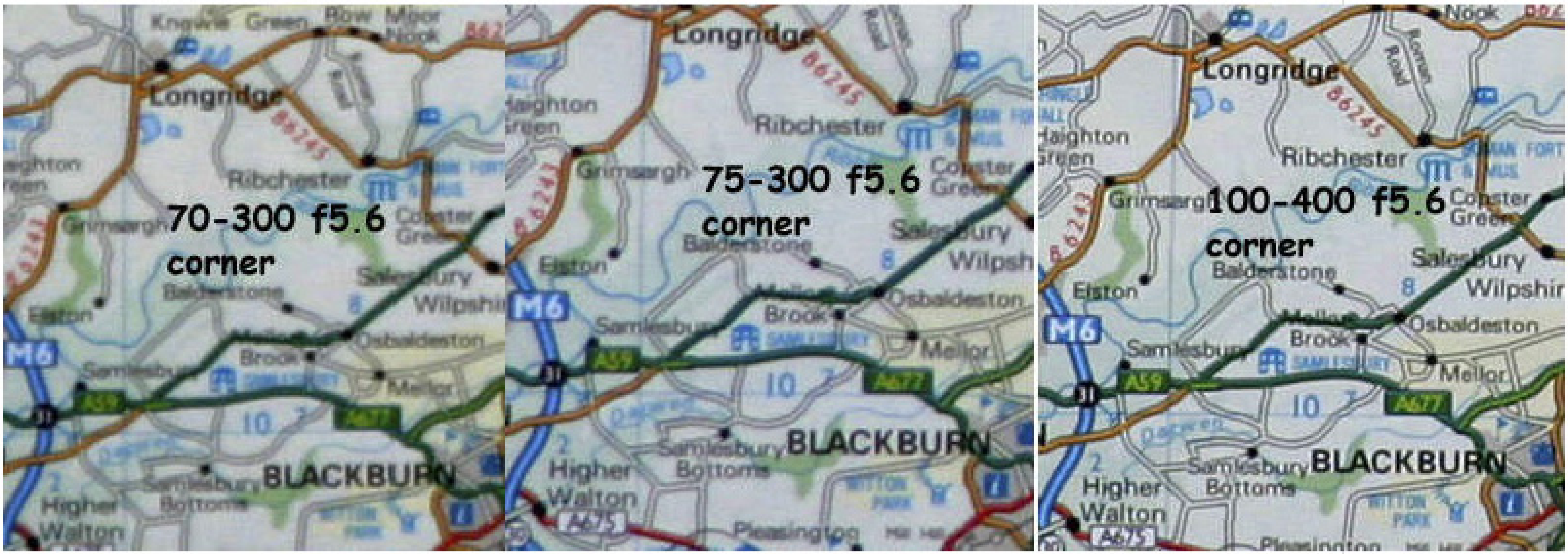
135mm f/2 (100% magnification)

70-200mm f/2.8 IS @131mm (100% magnification)

RSE sharpness 8 and detail extraction 15 (100% magnification)

source: digital outback

- http://www.photo.net/equipment/canon/70-300do_2/



250x500 pixel crops, corner of frame f5.6

- **http://www.photo.net/equipment/canon/70-300do_2/**

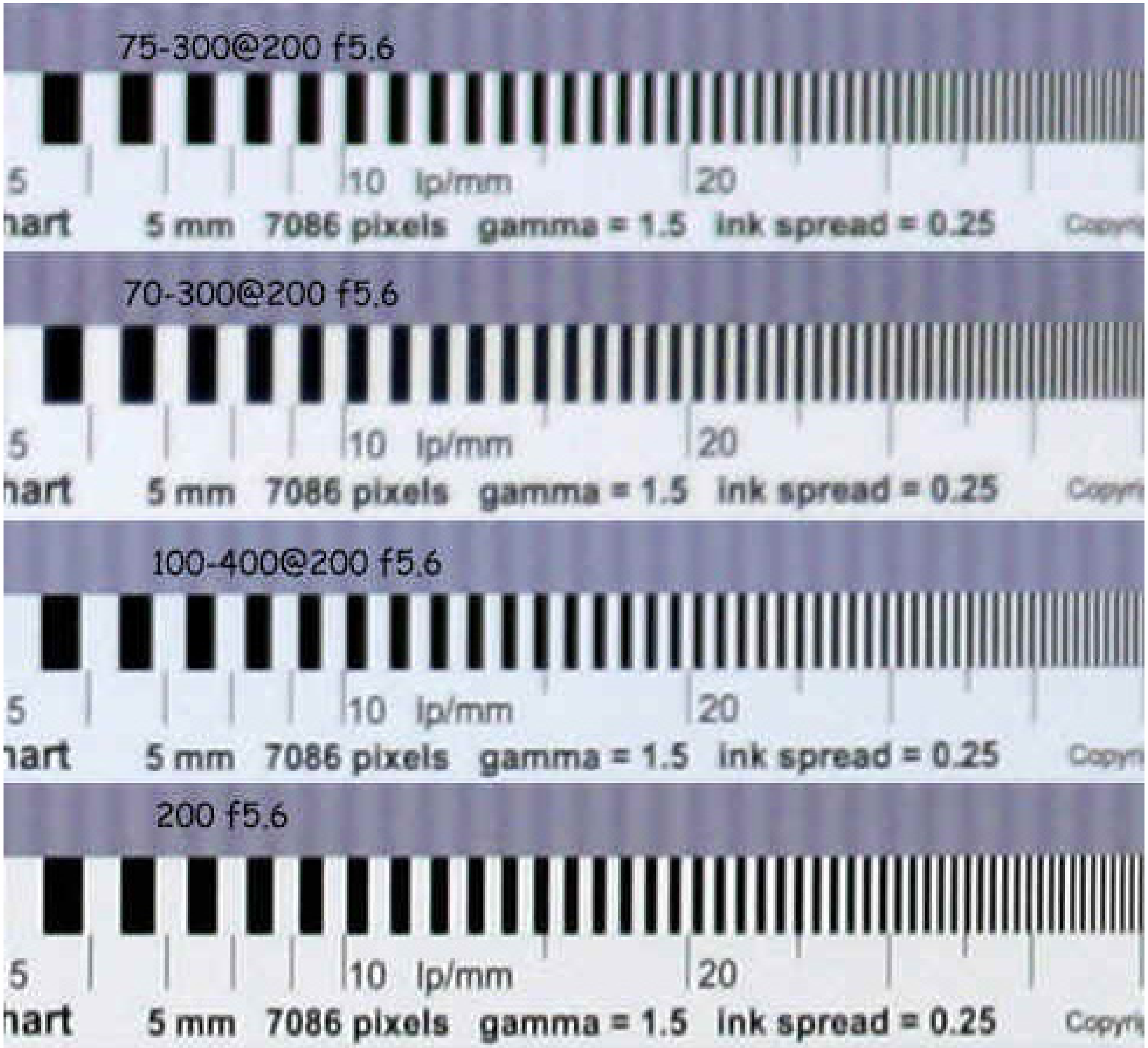
250x500 pixel crops, centre of frame f5.6

CSAIL

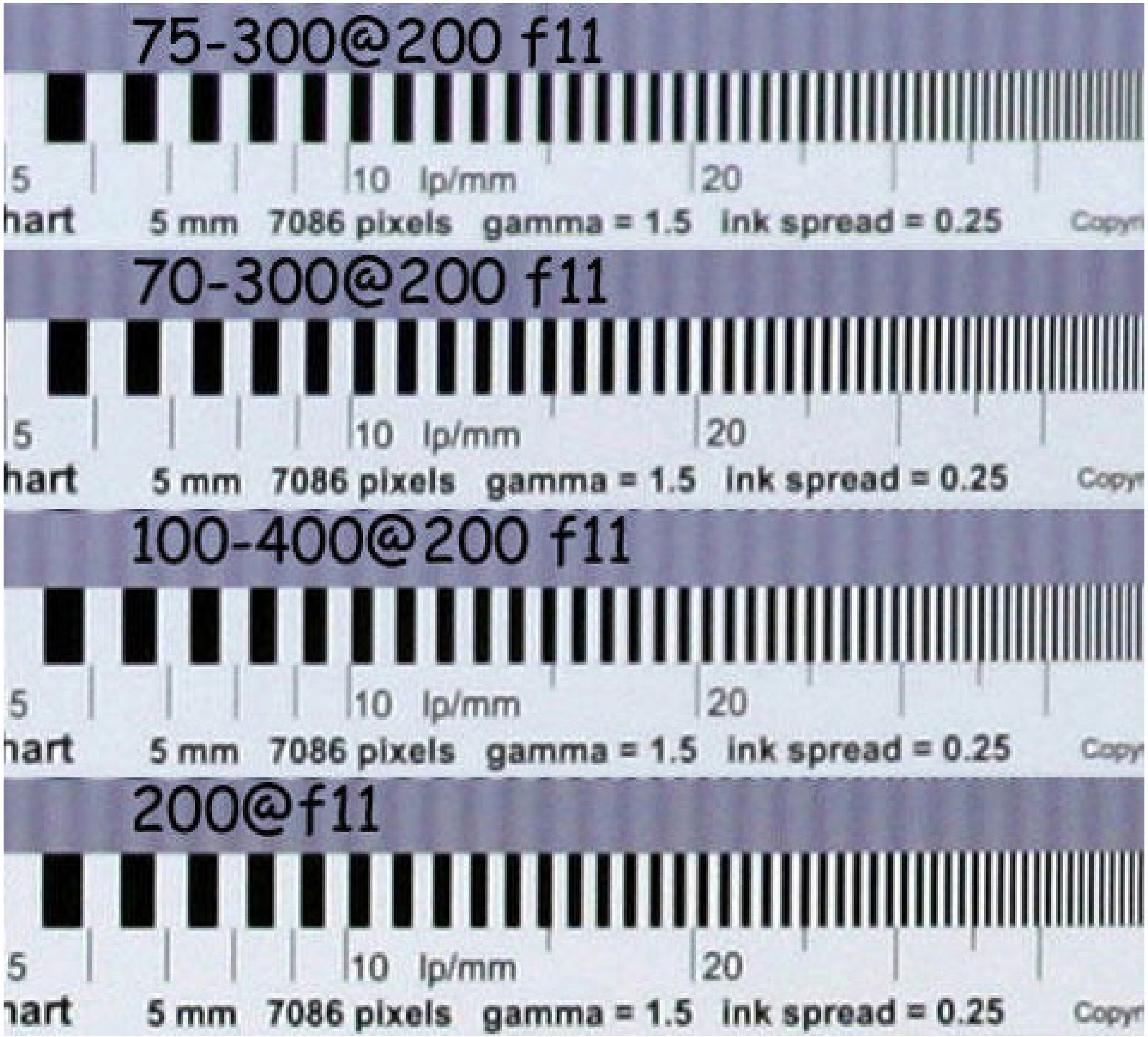
- http://www.photo.net/equipment/canon/70-300do_2/

250x500 pixel crops, centre of frame f11

- http://www.photo.net/equipment/canon/70-300do_2/



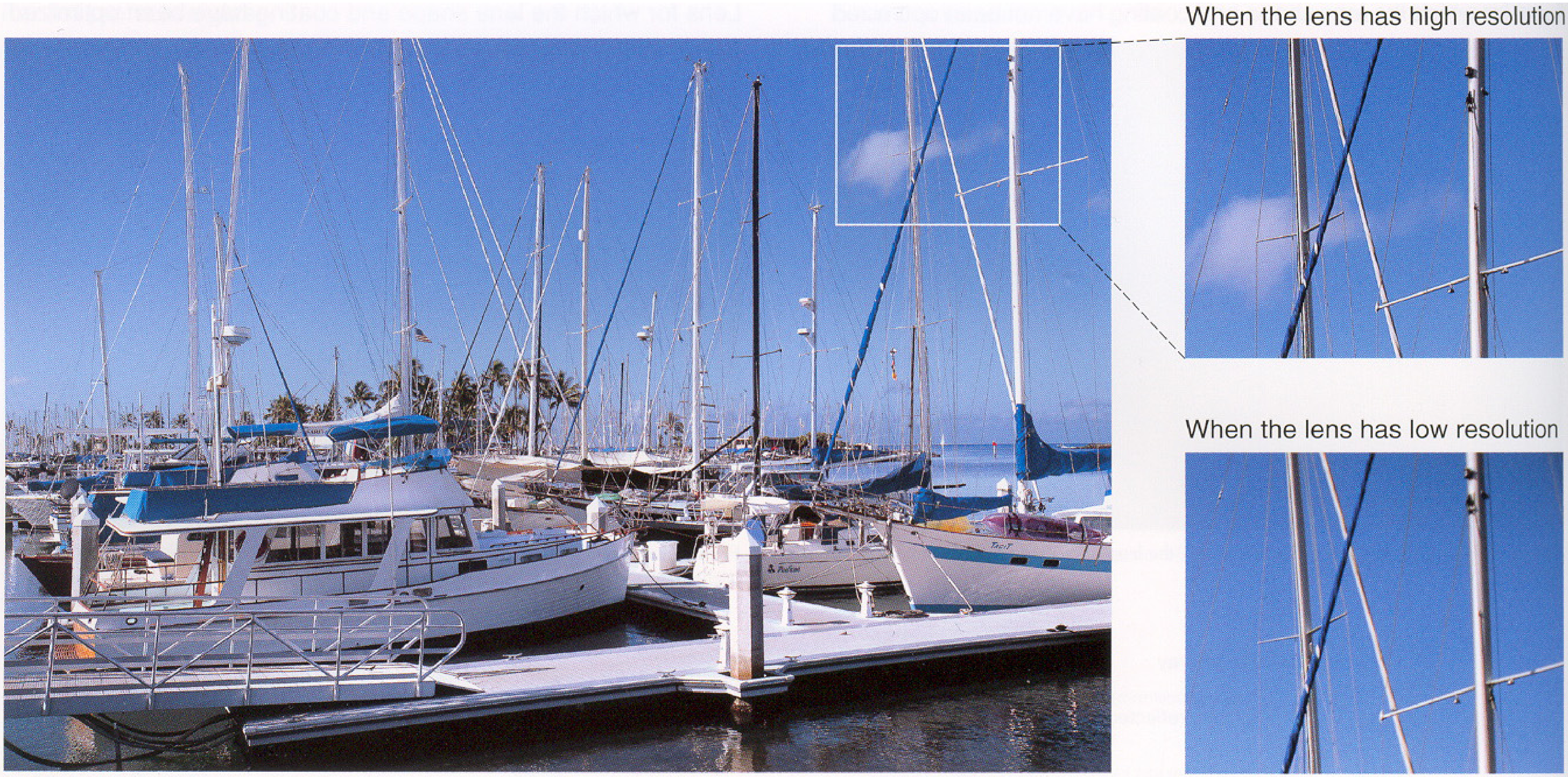
- **http://www.photo.net/equipment/canon/70-300do_2/**



- http://www.photo.net/equipment/canon/70-300do_2/

Full frame, f5.6 200mm, bottom row after auto-contrast applied

Power of lenses

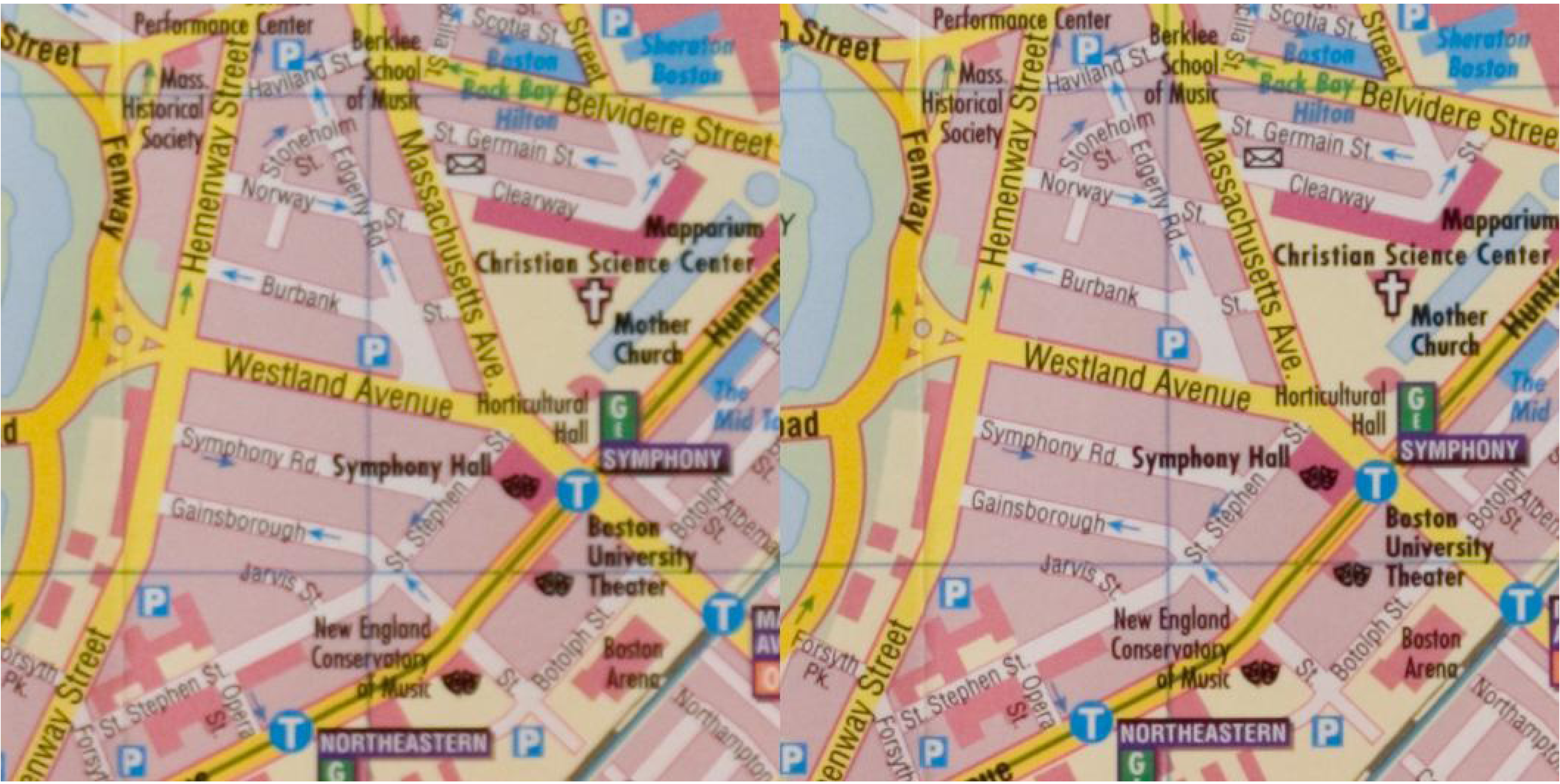


Even when combined with a digital camera, an EF lens has high potential. In this photo of a harbor crowded with yachts, high resolution reveals the fine detail in individual boats. Photographing images with detailed subject matter, such as landscapes, is possible without having to differentiate between a digital camera and a 35mm film camera.

source: canon red book

Copy variation

- **Left: Addy's 100-400; Right: Frédo's**
- **(full aperture, 135mm)**



Lens quality characteristics

- Sharpness
- Contrast, color
- Uniformity center/periphery
- Flare, reflection
- Geometric distortion

Impulse response problems

- **Focusing light**
  - focus along 3D+wavelength

Color aberration

When the lens corrects the magnification color aberration

When the lens does not correct the magnification color aberration

Axial chromatic aberration (also called "chromatic difference of magnification") occurs because of variations in the wavelength or frequency of light reflected from the subject. This phenomenon not only reduces photo sharpness, but it can also create borders of color, which should not be present, at the edges of subjects in the image. EF lenses designed to counter chromatic aberration make it possible to achieve uniform sharpness and correct color reproduction from the center of a photo to its edges.

source: canon red book

Lens design, ray tracing

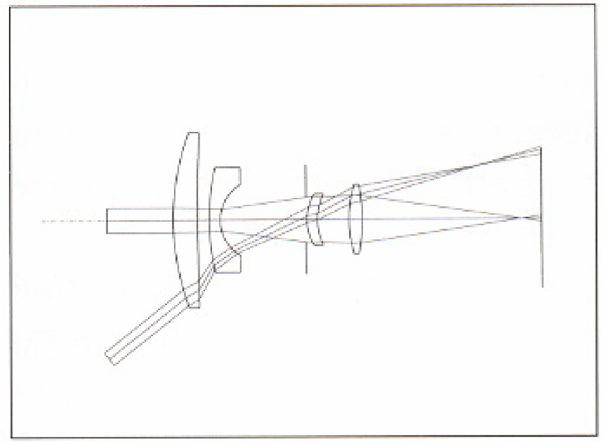


Figure-5

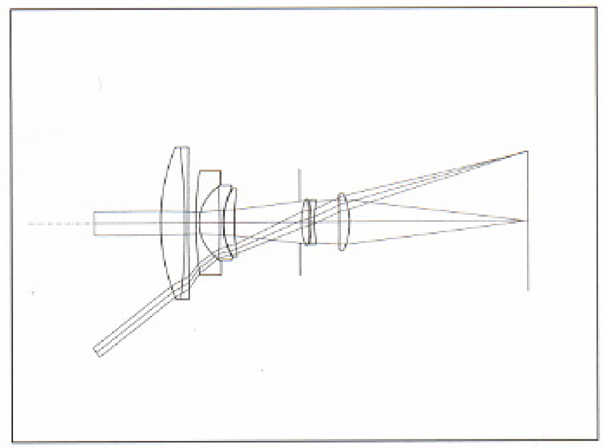


Figure-6

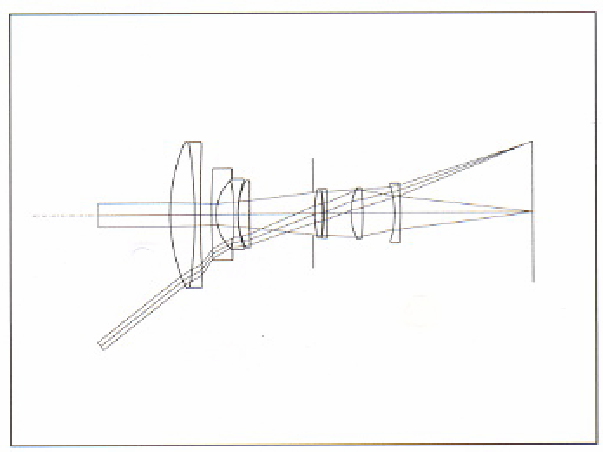


Figure-7

Spot diagram

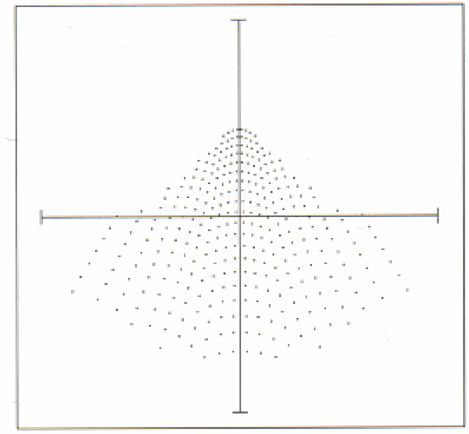


Figure-8

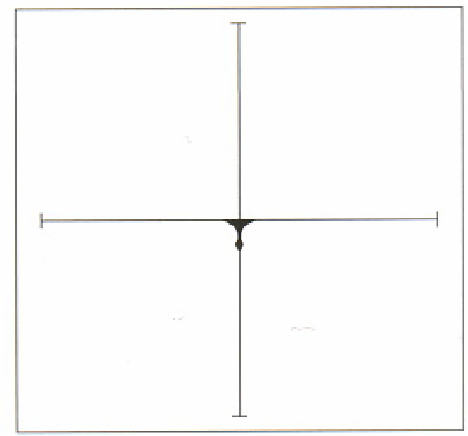


Figure-9

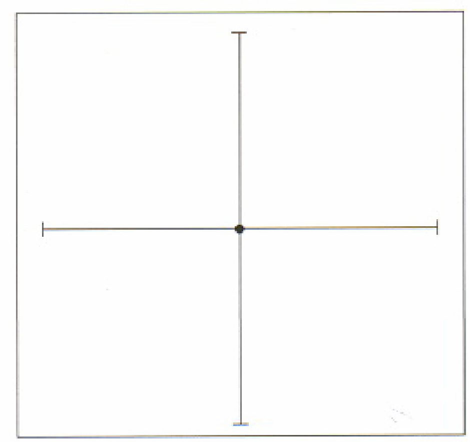


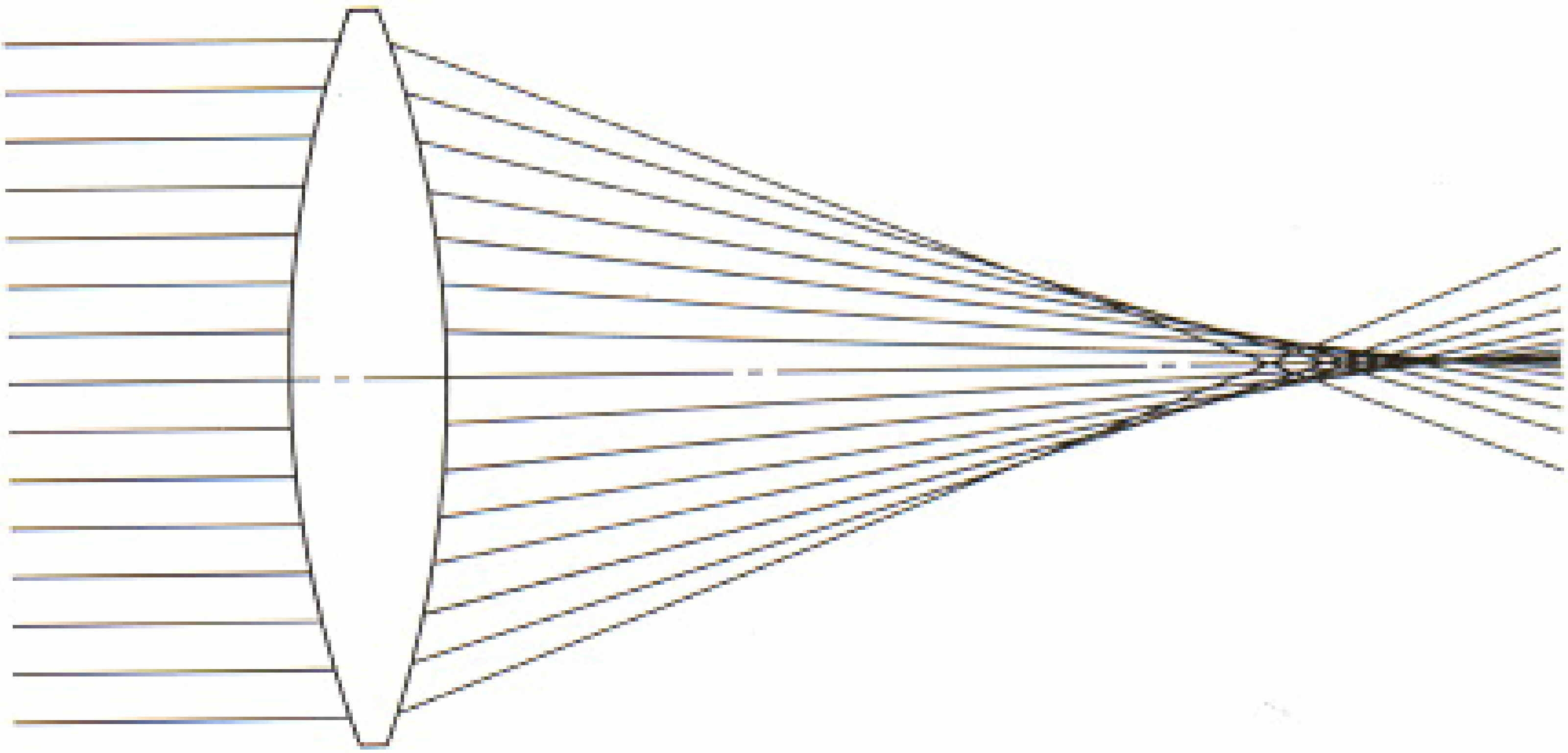
Figure-10

source: canon red book

Spherical aberration

Figure-19 Spherical Aberration

●This is the phenomenon where the focus is not concentrated on one point on the light ray but rather is offset to the front or back.
Occurrence of a halo——The image becomes flare.

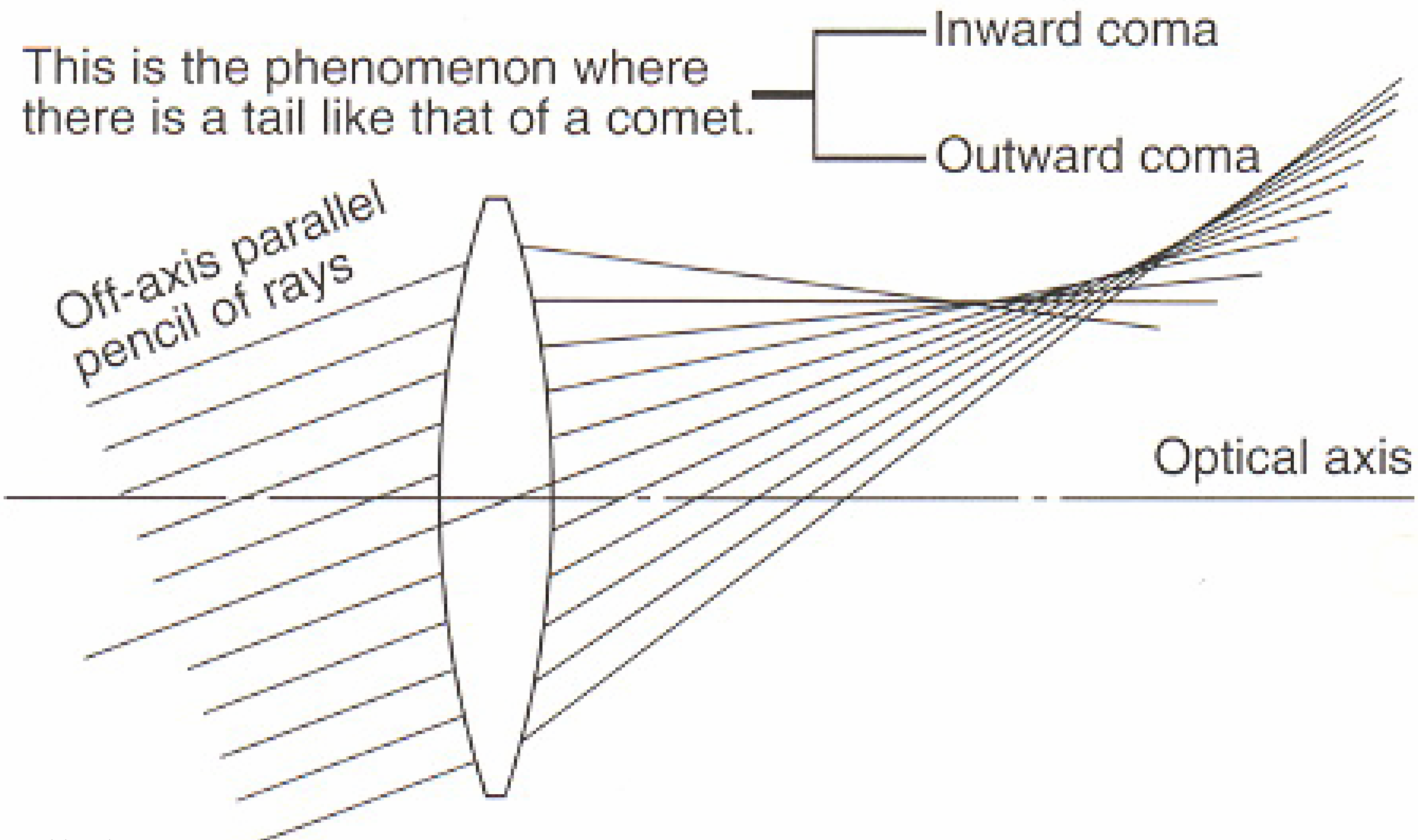


source: canon red book

Comatic aberration

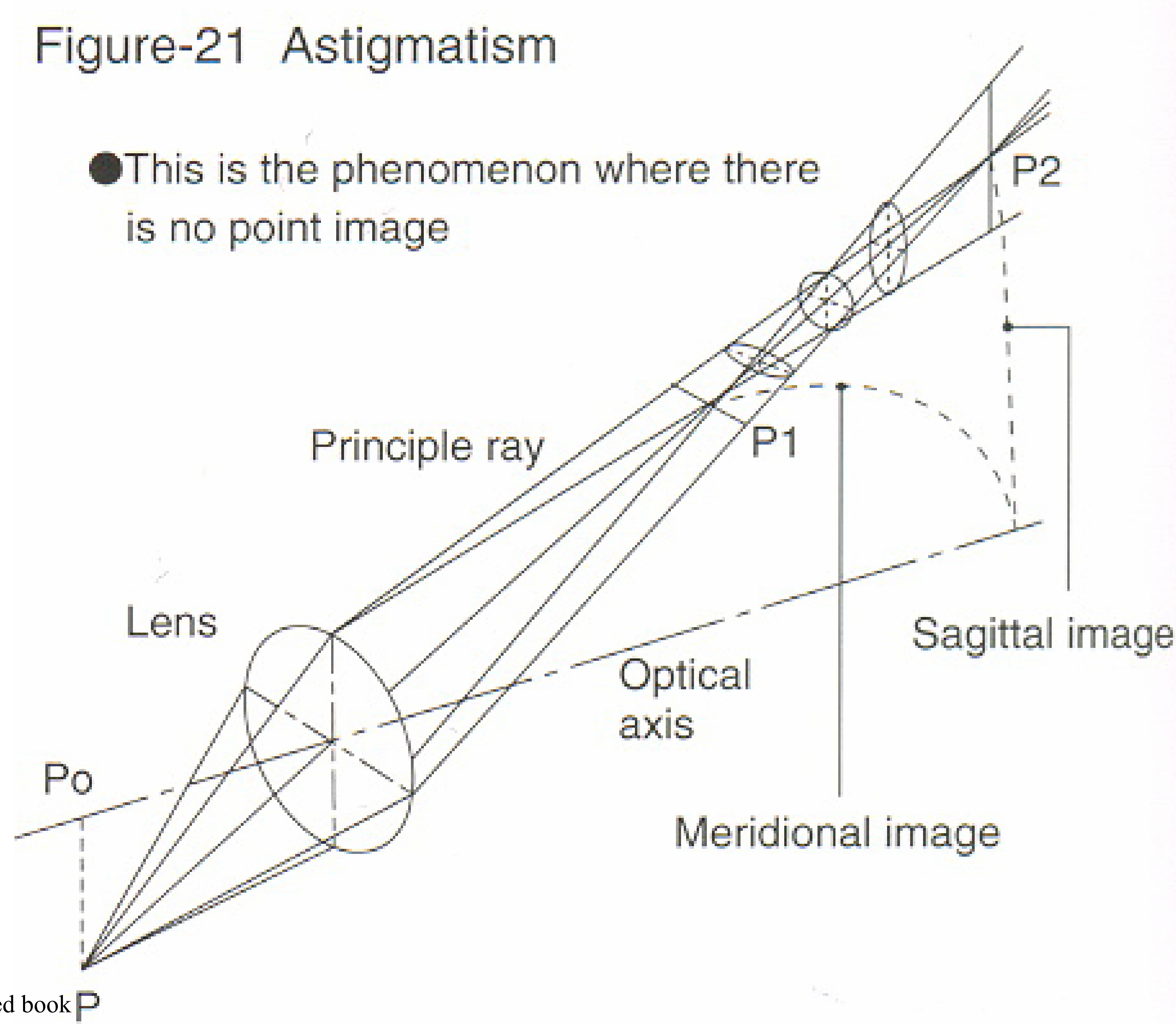
Figure-20 Comatic Aberration

- This is the phenomenon where the diagonal light rays do not focus on one point on the image surface.



source: canon red book

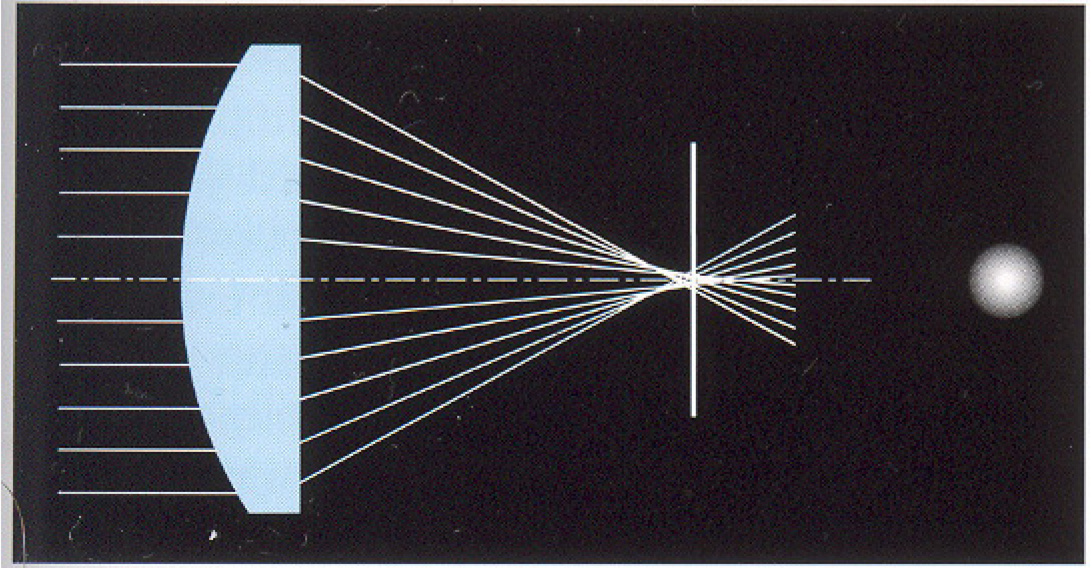
Astigmatism



source: canon red book

Aspherical lenses

Spherical aberration of spherical lens



Focal point alignment with aspherical lens

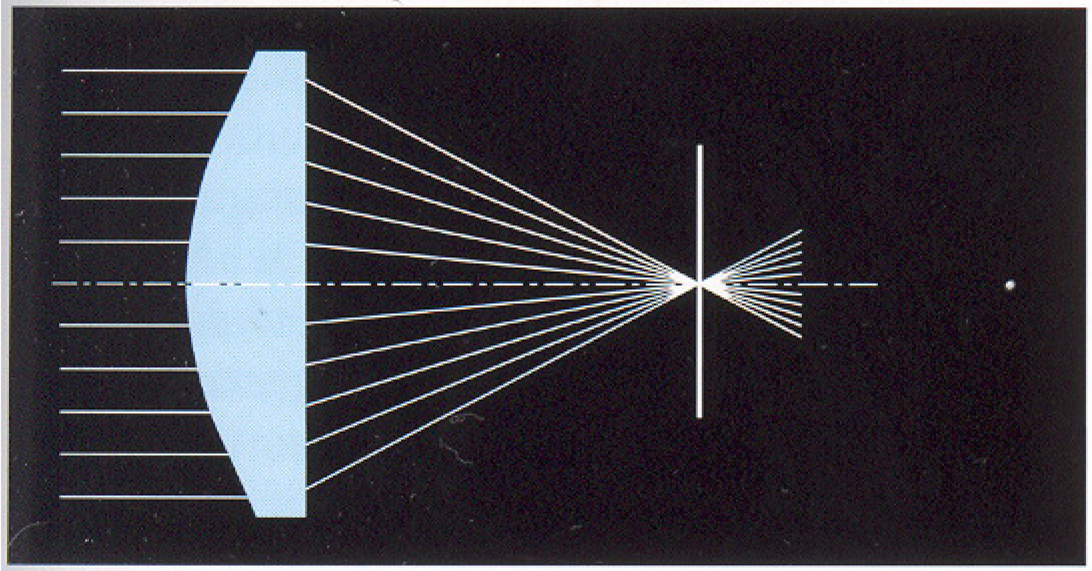


Photo-9 Spherical Lens Example

Photo-10 Aspherical Lens Example

source: canon red book

Aspherical lenses

Figure -14 EF85mm f/1.2L USM Optical System - Ray Tracing Diagram

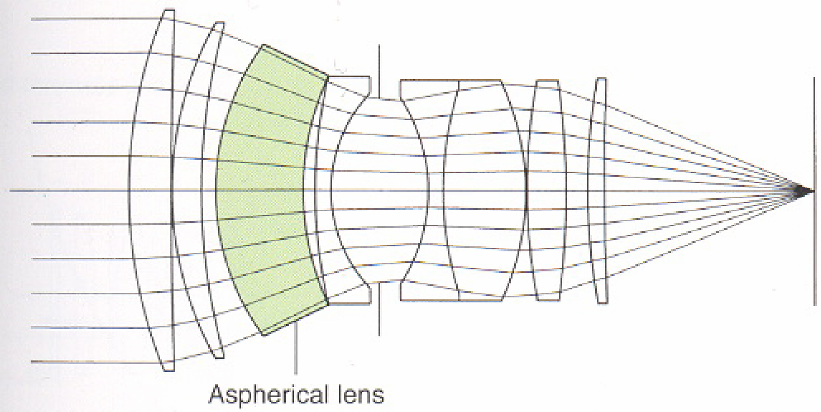


Figure-15 EF14mm f/2.8L USM Optical System - Ray Tracing Diagram

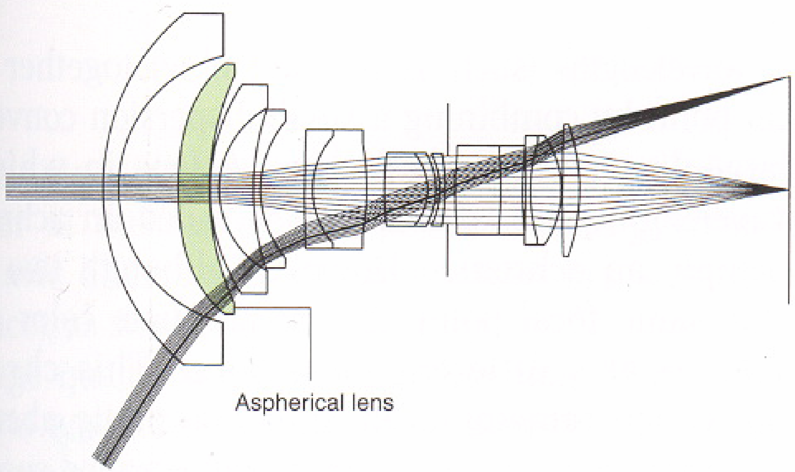
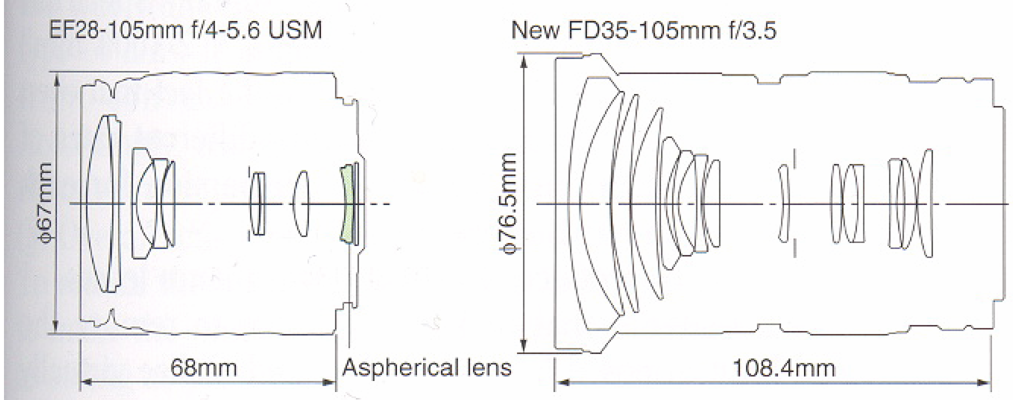


Figure-16 EF/FD Zoom Lens: Size Comparison



source: canon red book

Chromatic aberration

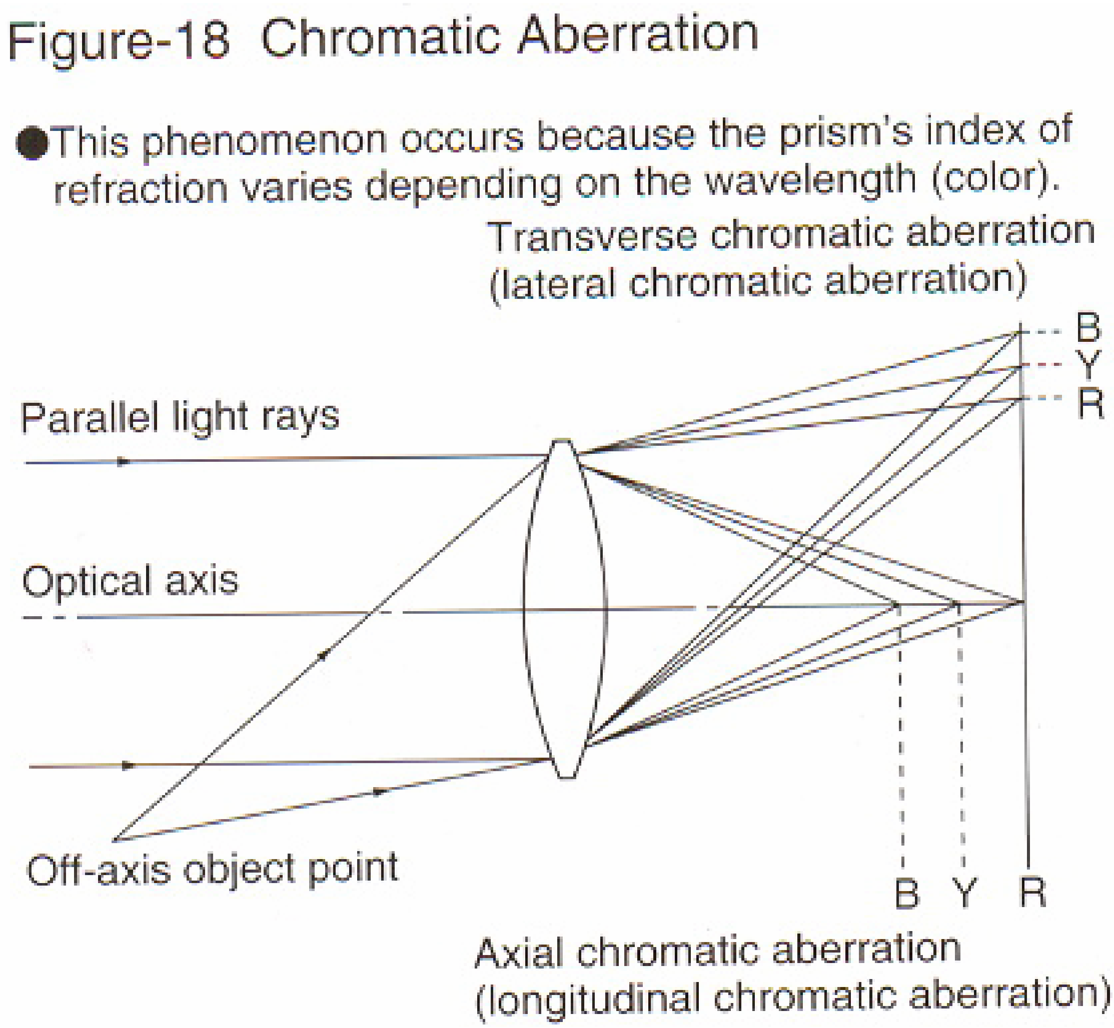


Photo-3 Axial chromatic aberration

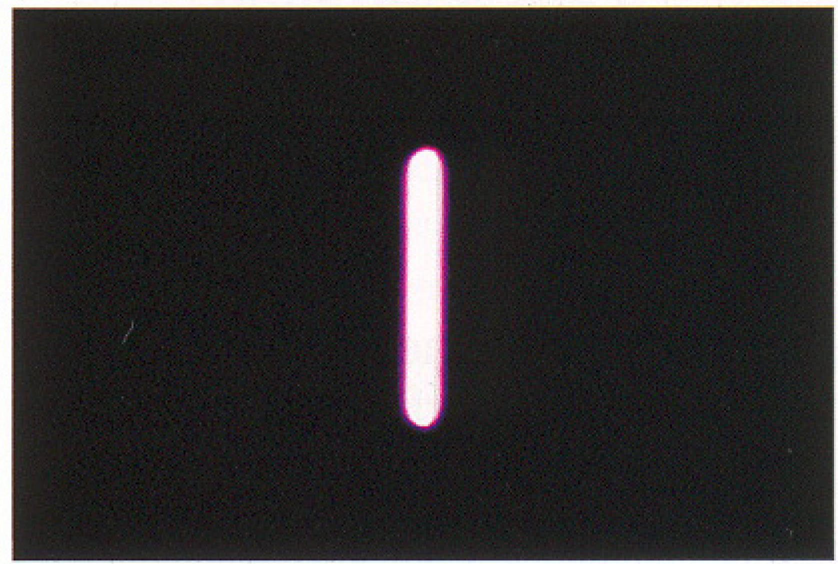
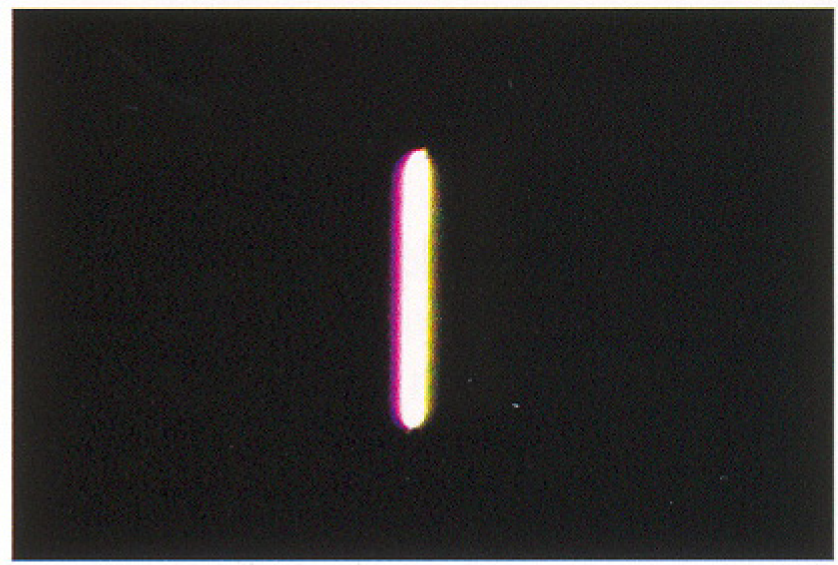


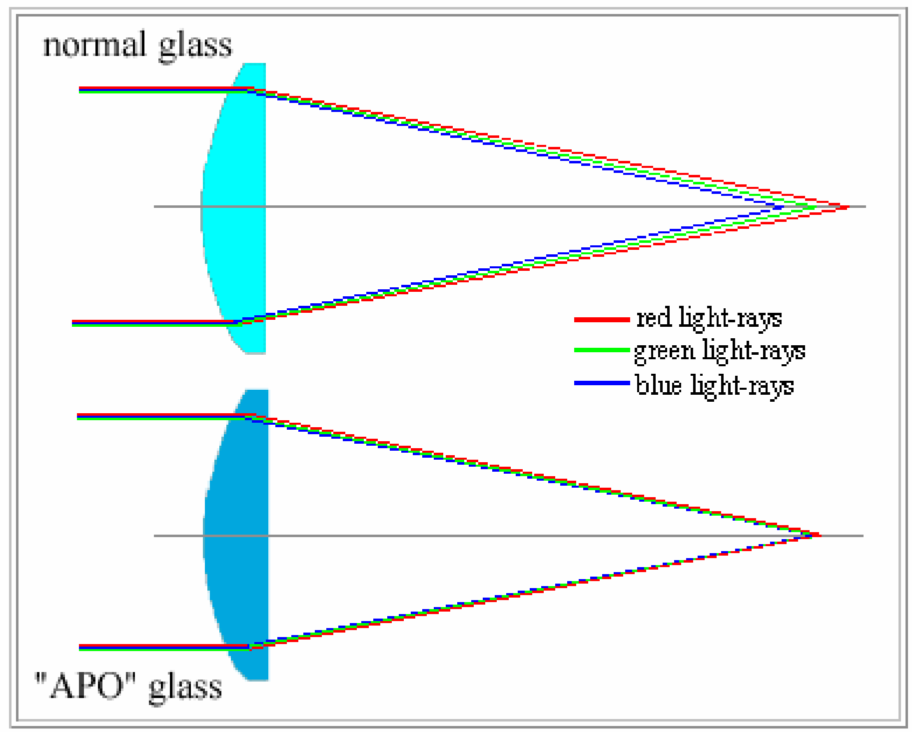
Photo-4 Transverse chromatic aberration



source: canon red book

Apochromatic glass

APO" elements (UD, SUD, CaF2, LD, SLD, ED etc.) improve contrast and sharpness by reducing chromatic aberration (color defects) that usually occur in tele lenses. These elements are able to focus different wave lengths of one light ray in one point (see picture below). These elements are quite expensive and usually not used for cheaper lenses. The problem is however that the quality of these special elements varies heavily so the effect is often downgraded to a marketing gag - this is especially true for some third-party manufacturers!
As a rule-of-thumbs a good long tele lens will always feature two or more of these special elements. Recently the first ultra-wide and wide-angle lenses emerged using APO elements besides aspericals in order to reduce problems with lateral color shifts.



http://www.photozone.de/3Technology/lenstec8.htm

Fluorite

Figure-23 Optical Characteristics of Optical Glass and Fluorite

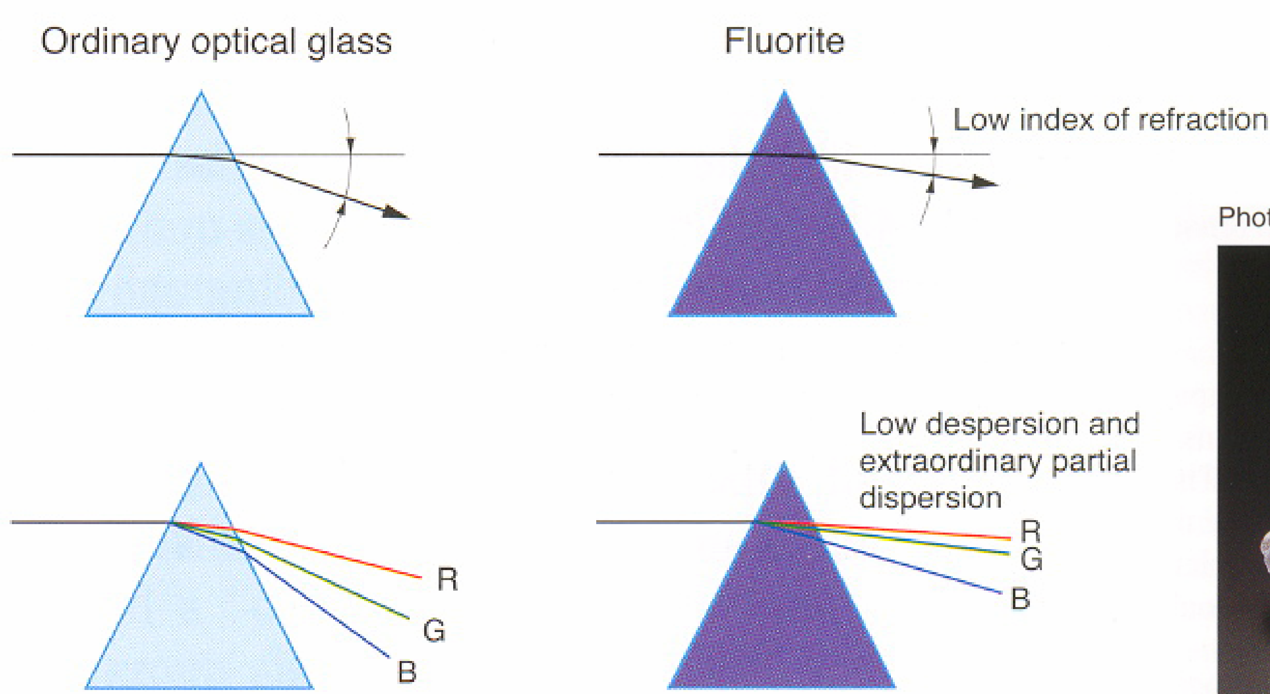
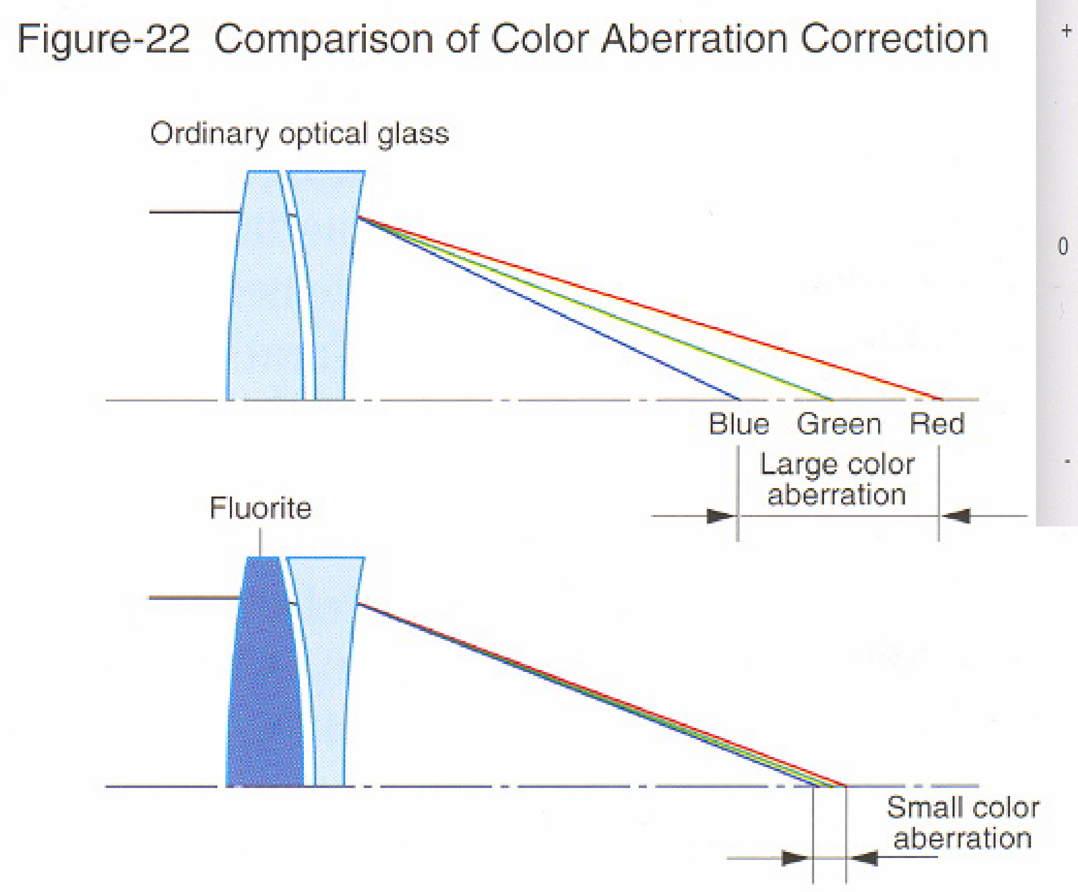
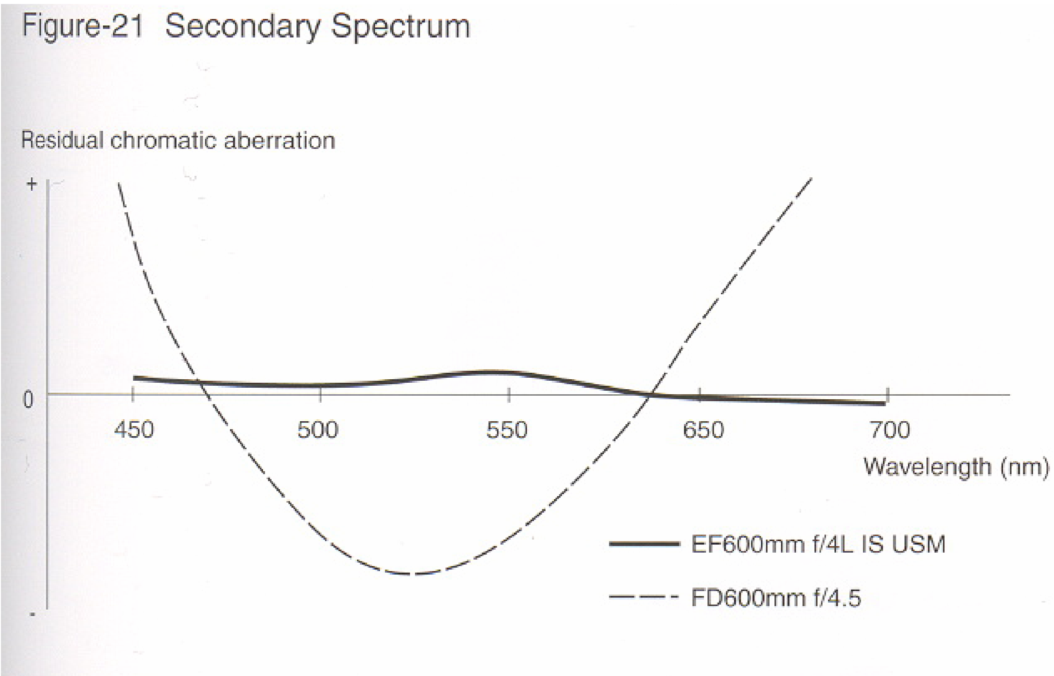


Photo-12 Artificial Fluorite Crystals and Fluorite Lenses

source: canon red book

Fluorite





source: canon red book

DO

Figure-58 Diffraction

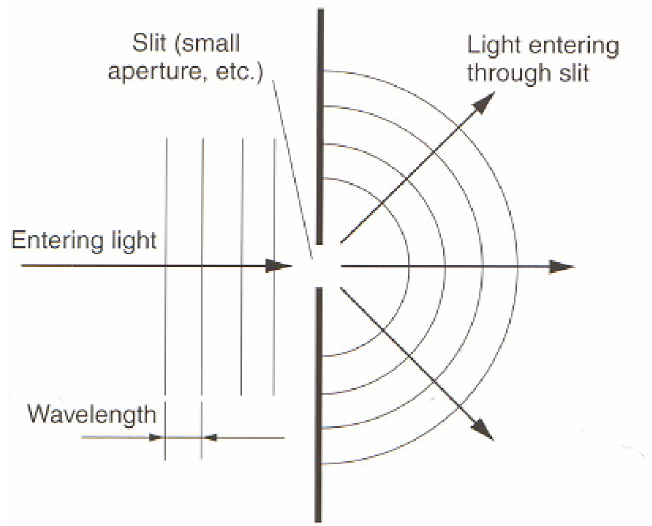


Figure-59 Principle of diffracted light generation

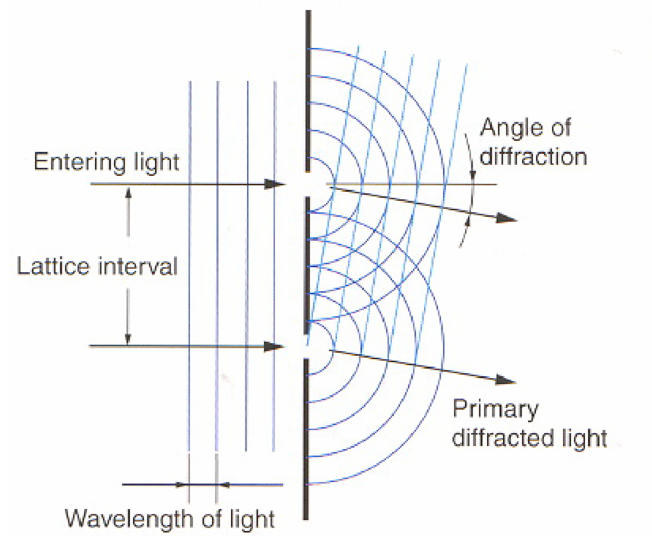


Photo-23 Multi-Layered Diffractive Optical Element (DO lens)

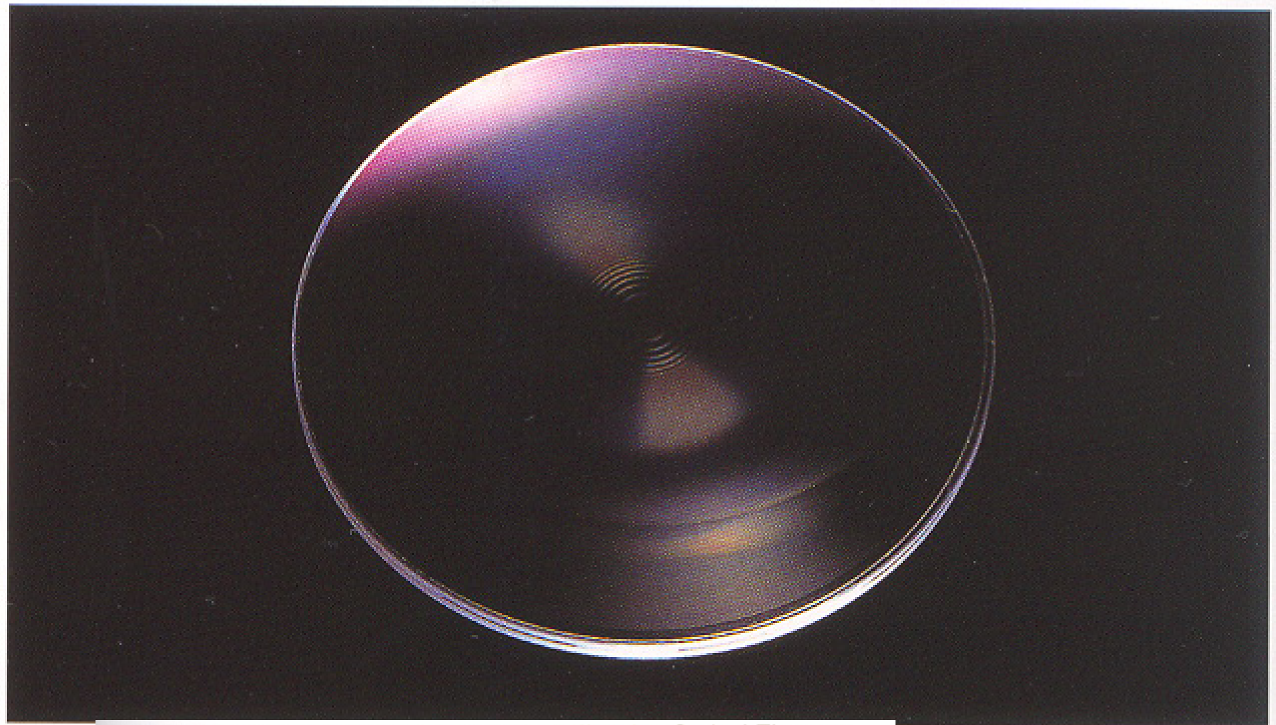
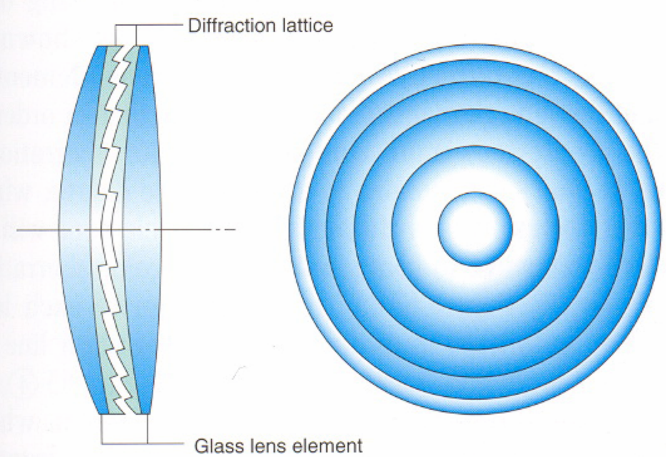


Figure-60 Construction of Multi-layered Diffractive Optical Element (illustration)



source: canon red book

DO

Figure-61 Chromatic aberration correction principal by Multi-layered Diffractive Optical Element

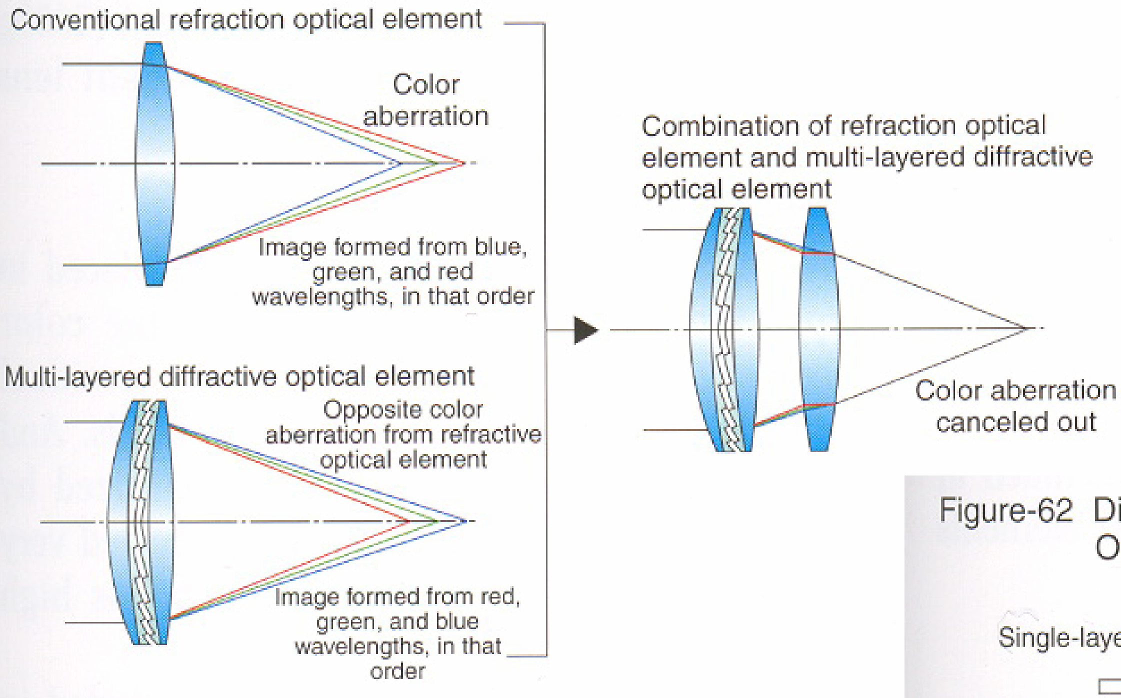


Photo-24 With DO lens installed

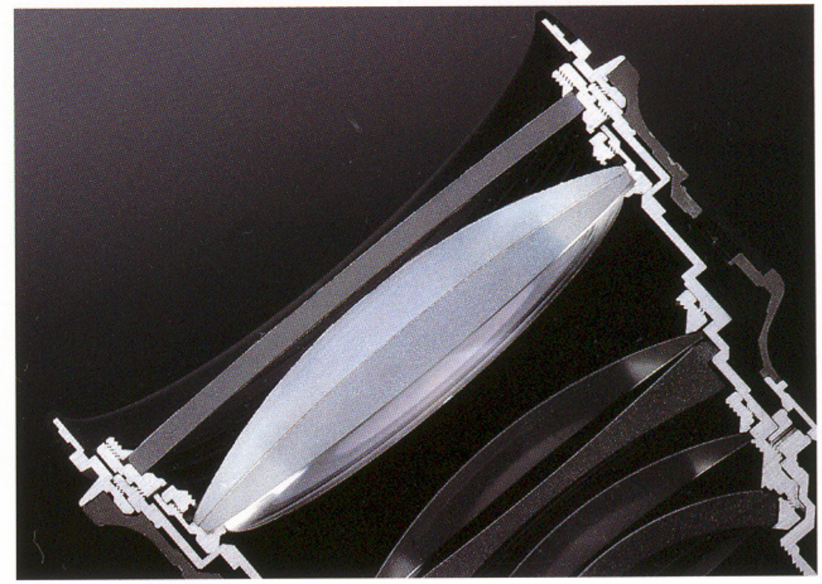
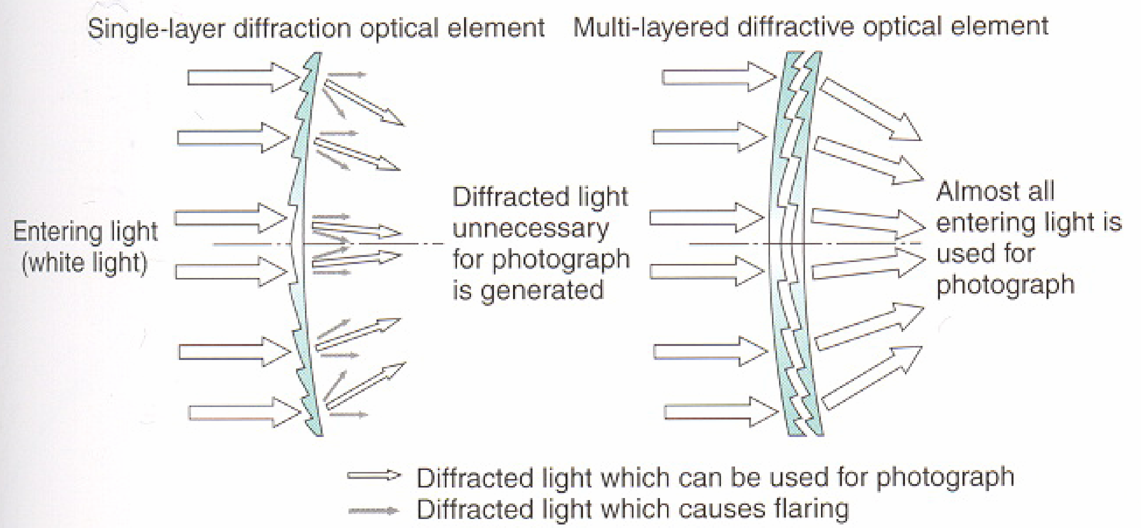
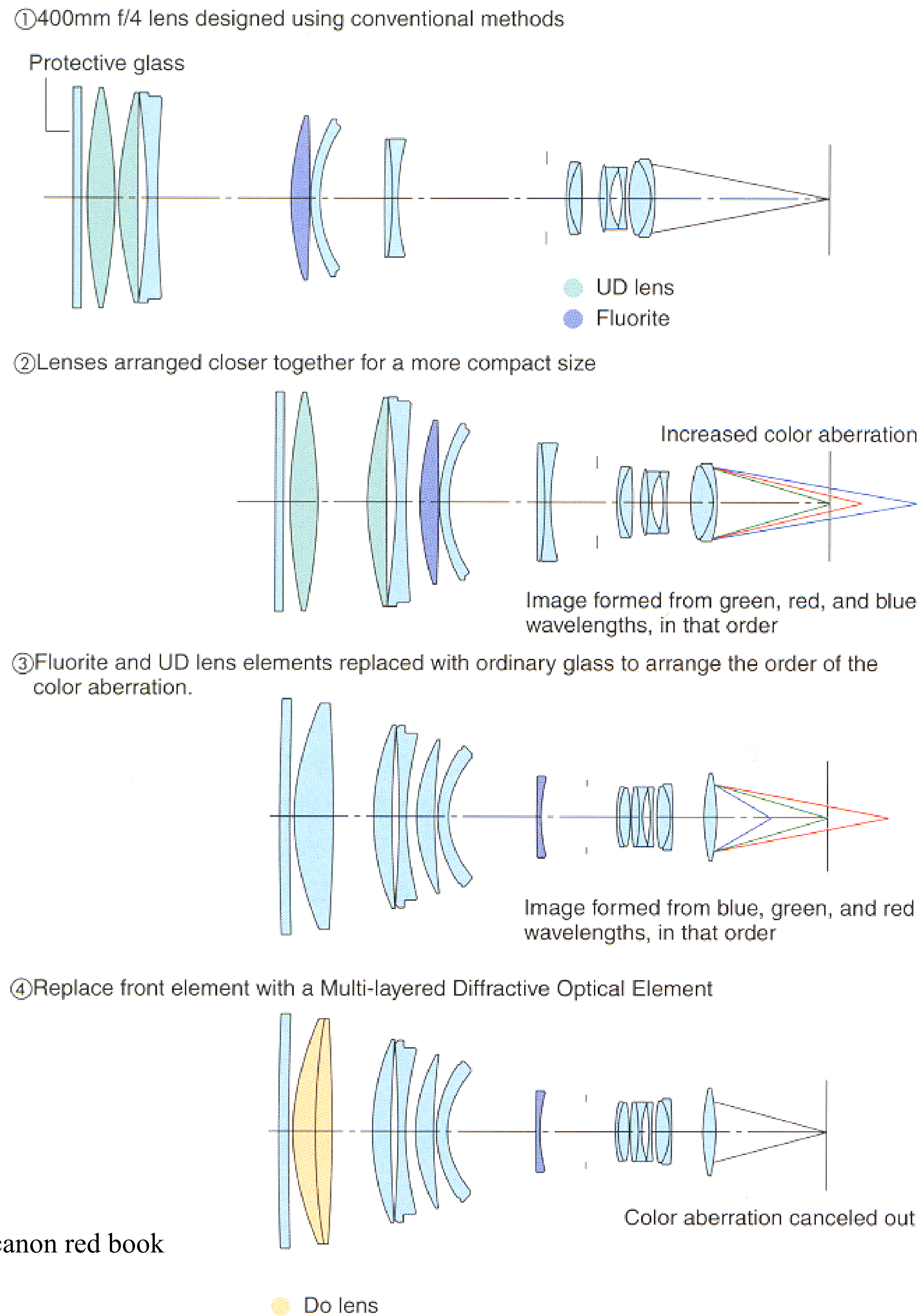


Figure-62 Difference in Diffracted Light between Single-layered Diffractive Optical Element and Multi-layered Diffractive Optical Element



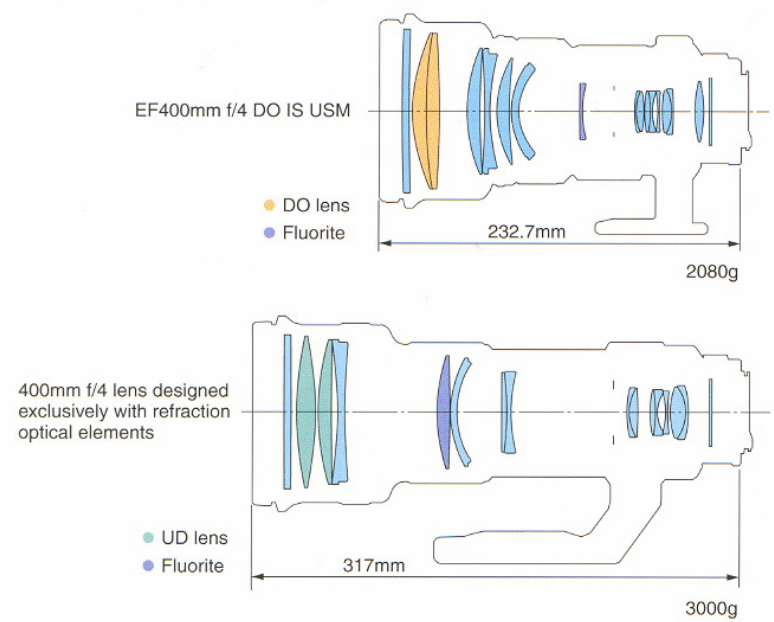
source: canon red book

Figure-63 Principle behind Smaller Optics Thanks to Multi-layered Diffractive Optical Element

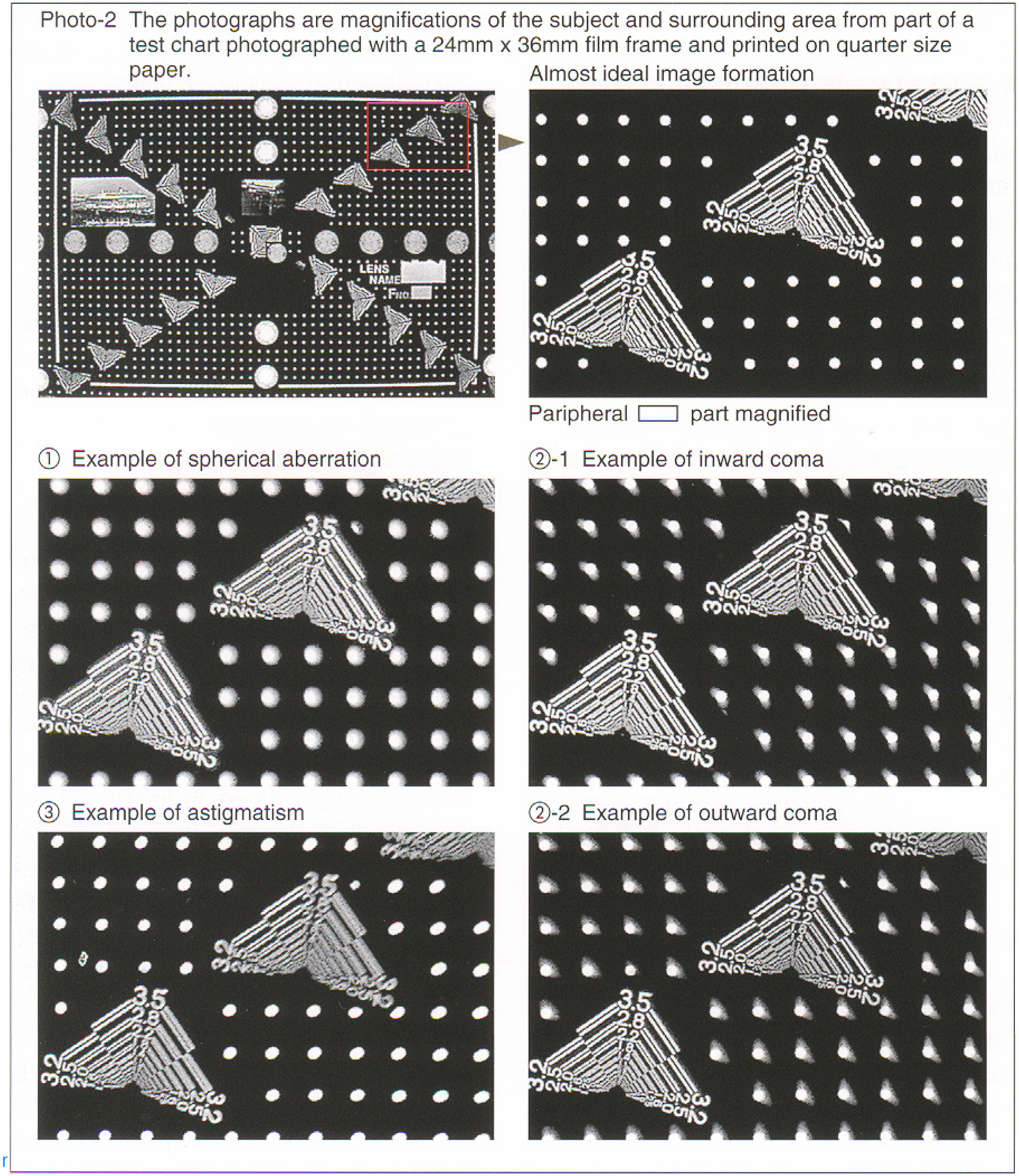


source: canon red book

Figure-64 Compact and Lightweight Lenses Thanks to Multi-layered Diffractive Optical Element



Defects



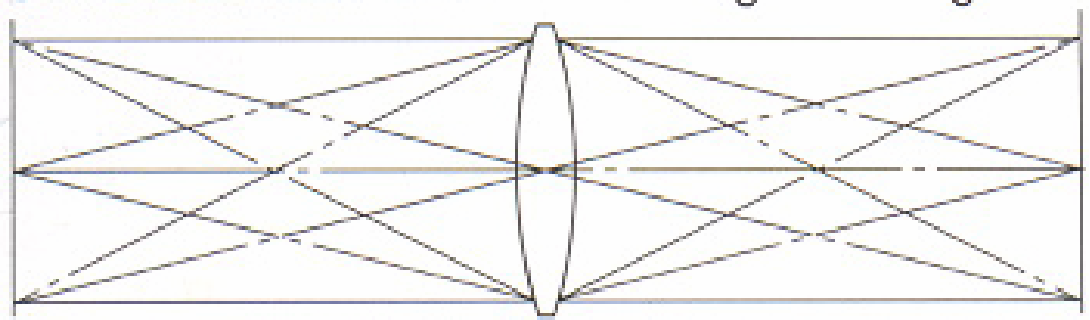
source: canon red book

Curvature of field

Figure-22 Curvature of field

This is the phenomenon where a good image focus surface is bent.

● This is an ideal lens with no image bending.

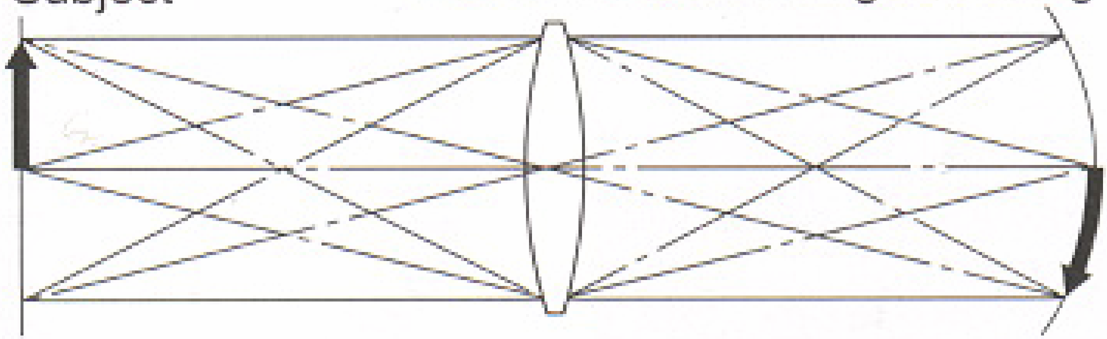


Subject surface

Focus surface

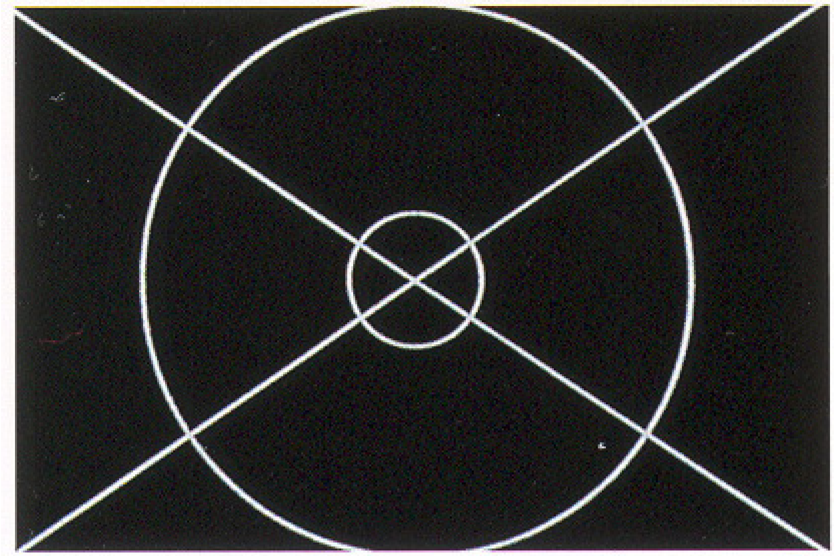
Subject

● Occurrence of image bending



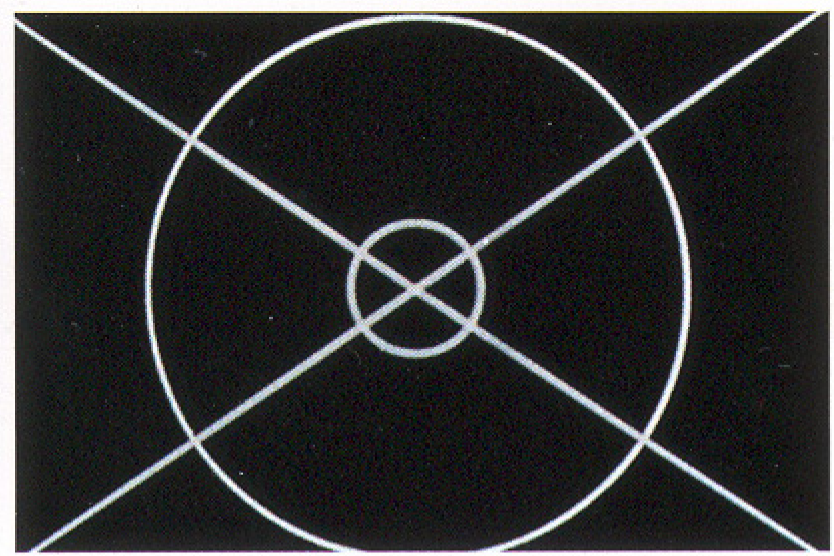
source: canon red book

Photo-5 Example of curvature of field



Focusing on center of screen causes corners to go out of focus.

Photo-6 Example of curvature of field



Focusing on corners of screen causes center to go out of focus.

Bokeh

- http://www.luminous-landscape.com/columns/sm-04-04-04.shtml

The most obvious way bokeh gets into pictures, of course, is simply as background. In Robert Harrington's cruel but beautiful picture here, for instance, most of the area of the picture is occupied by bokeh, even though it has nothing to do with the subject of the picture. The picture might be as good with a plain white or black background. Still, if you just look at the bokeh as it exists, it's hard to deny that the color and brightness of the out of focus parts contribute to the sense of a certain kind of light, and the feeling of the outdoors.

A Distracting Zoom Lens Example of Bad Bokeh

Photo Courtesy of Luis Lopez Penabad - Thank You! (see posting)

Bokeh

- **Shape of out of focus kernel**
- **http://www.kenrockwell.com/tech/bokeh.htm**

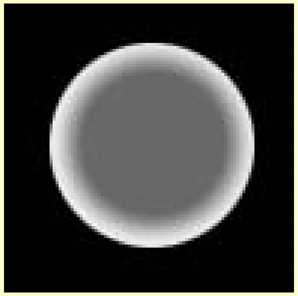


Fig. 1. Poor Bokeh. This is a greatly magnified blur circle showing very poor bokeh. Note how the edge is sharply defined and even emphasized for a point that is supposed to be out-of-focus, and that the center is dim.

Fig 2. Neutral Bokeh. This is a a technically perfect and evenly illuminated blur circle. This isn't good either for bokeh, because the edge is still well defined. Out-of-focus objects, either points of light or lines, can effectively create reasonably sharp lines in the image due to the edges of the sharp blur circle. This is the blur circle from most modern lenses designed to be "perfect."

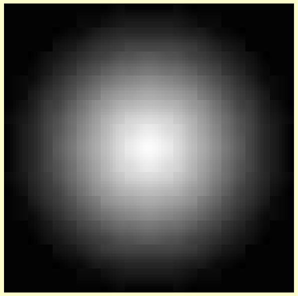


Fig. 3. Good Bokeh. Here is what we want. This is great for bokeh since the edge is completely undefined. This also is the result of the same spherical aberration, but in the opposite direction, of the poor example seen in Fig. 1. This is where art and engineering start to diverge, since the better looking image is the result of an imperfection. Perfect bokeh demands a Gaussian blur circle distribution, and lenses are designed for the neutral example shown in 2.) above.

http://www.luminous-landscape.com/essays/bokeh.shtml

Figure 2

The effect of a triangular stop can be seen clearly in this photograph. Note the downwards pointing triangles on the figure in the foreground and the upward pointing triangles on the figure in the background. It all looks rather contrived, but everything you see is 100% natural. The example suggests we should avoid triangular lens stops.

http://www.luminous-landscape.com/essays/bokeh.shtml

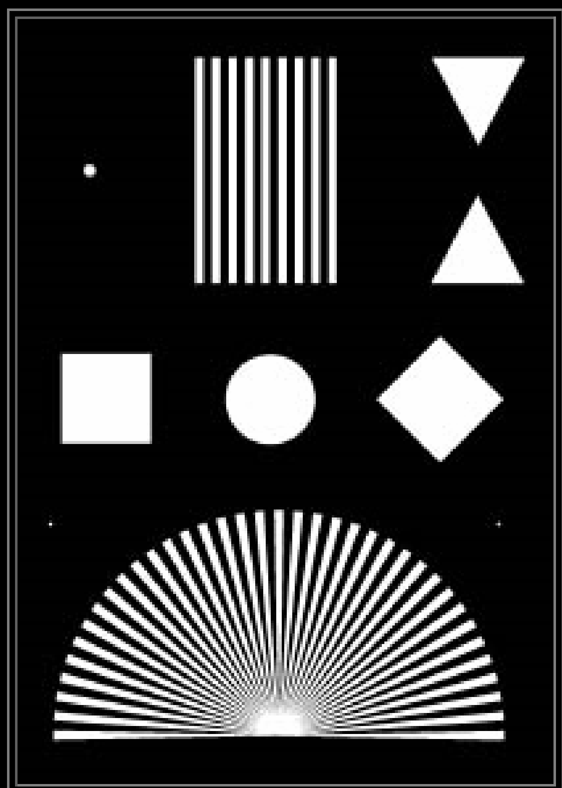


Figure 3

The simple white-on-black test pattern used to determine some of the effects of aperture shape on the out-of-focus images.

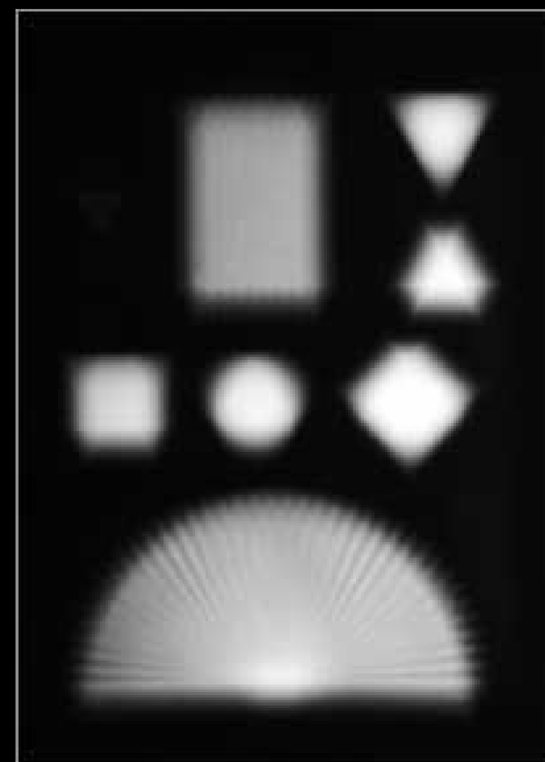


Figure 4

Here's the test target as photographed with an upwards pointing triangular lens opening and with the film too close to the lens.

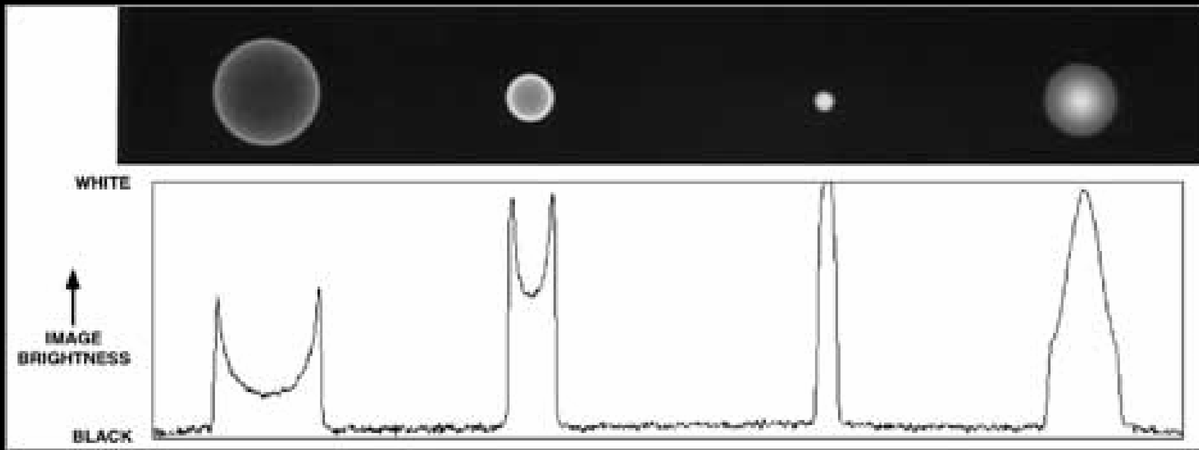


Figure 6

Here is a sequence of images of a pin hole illustrating the circle of confusion at four distances behind the Rodenstock Imagon. From left to right, the images were obtained 4 cm in front of the plane of best focus, 2 cm in front, at the plane of best focus and 2 cm behind it. Below the images is a graph showing the brightness of the image along a straight line through the centers of the circles.

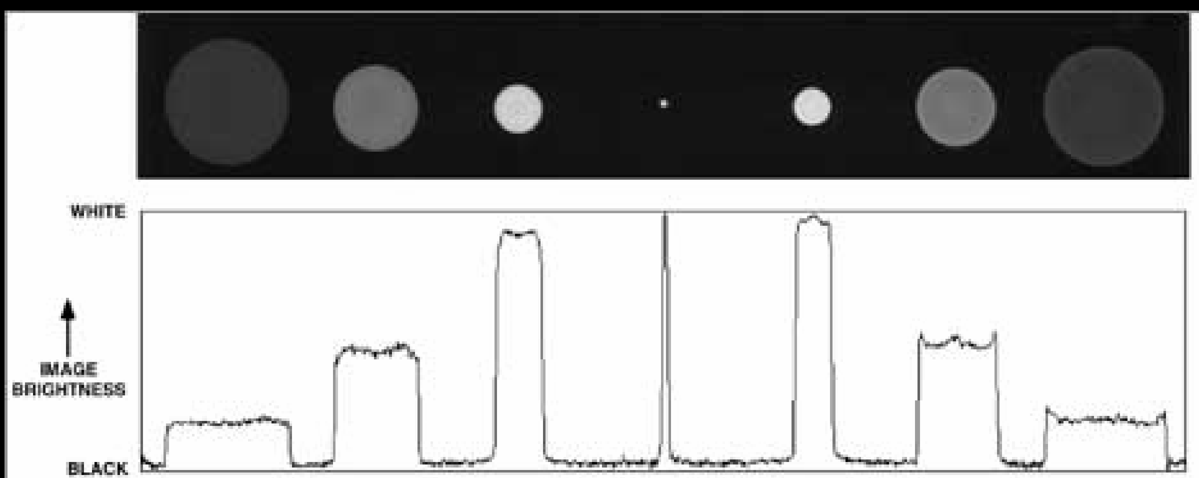


Figure 9

Here is a sequence of images of a pin hole illustrating the circle of confusion at seven distances behind the Nikkor-W. The brightness trace below shows that this lens demonstrates a 'bright ring' effect for images behind the plane of sharpest focus, while closer to the lens the trace show nicely rounded corners. The rounded corners can be expected to result in smooth, soft out-of-focus images.

Figure 10

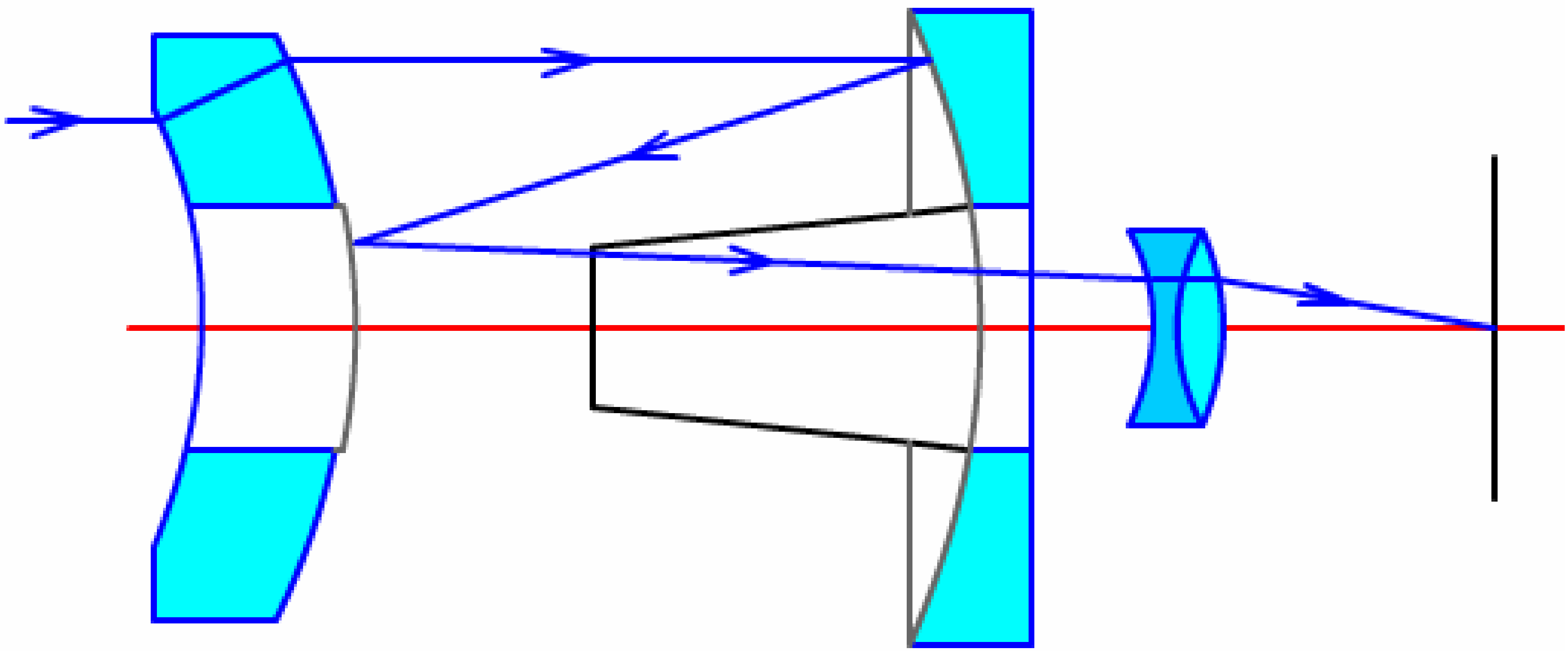
Figure 11

Here's the same scene as used for Figure 2, but this time photographed with the 180/5.6 Nikkor-W, with its standard round opening (at full aperture). We see nice soft highlights in the foreground and a slight 'bright ring' effect in the background.

Here's the scene again with the 250 Imagon, using the H=7.7 stop in place. I intended to have to outer rows of sink-strainer holes closed, but there's slight evidence here that one row of holes was open just a tiny bit. Nevertheless, the main effects seen here is the 'bright ring' out-of-focus highlights in the foreground and the 'bright core' highlights in the background.

catadioptric (mirror)

- http://www.digit-life.com/articles2/rubinar/



- http://www.telescopes.net/HOW_TO_-_Cat_Animation.gif

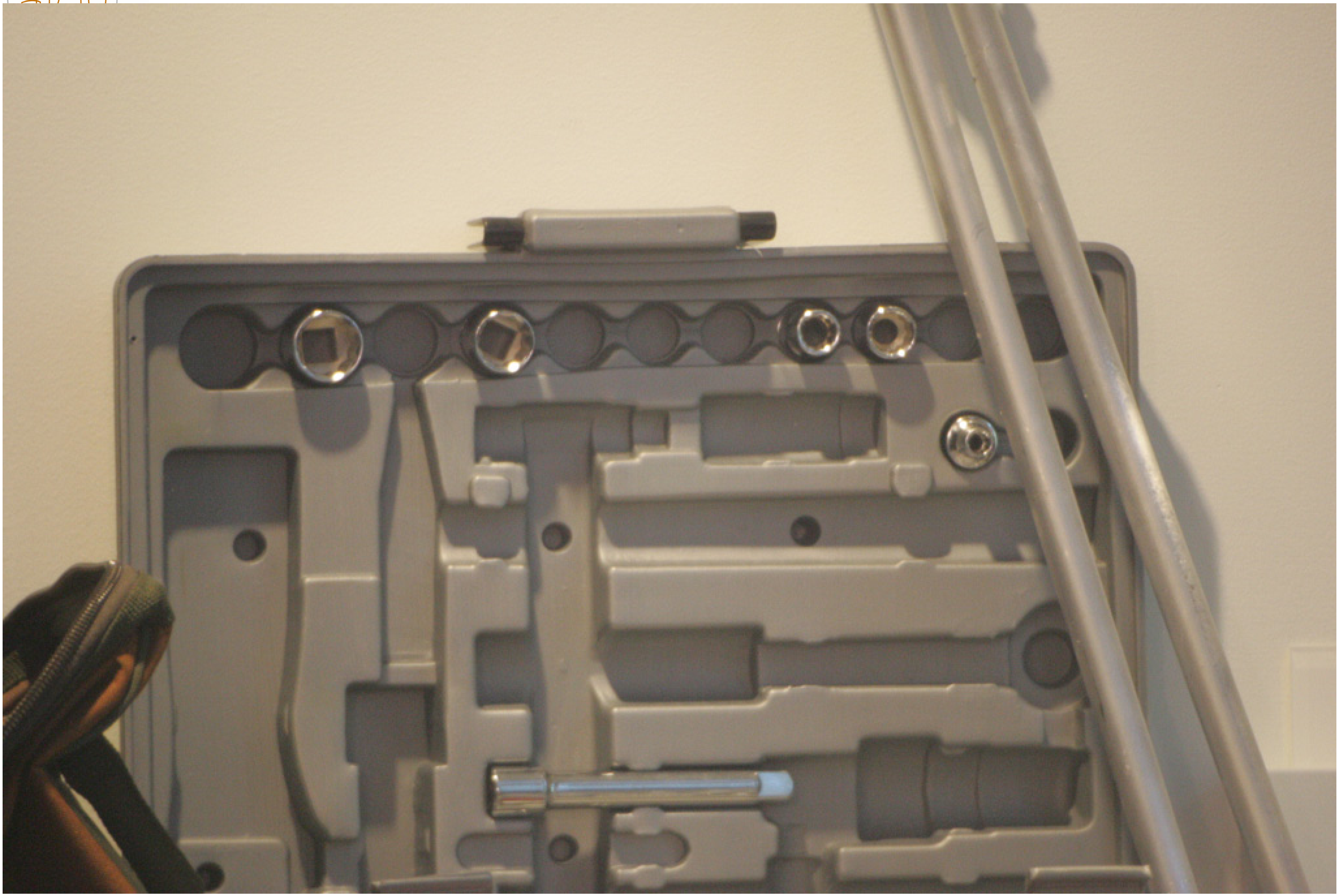
500mm vivitar ($100)

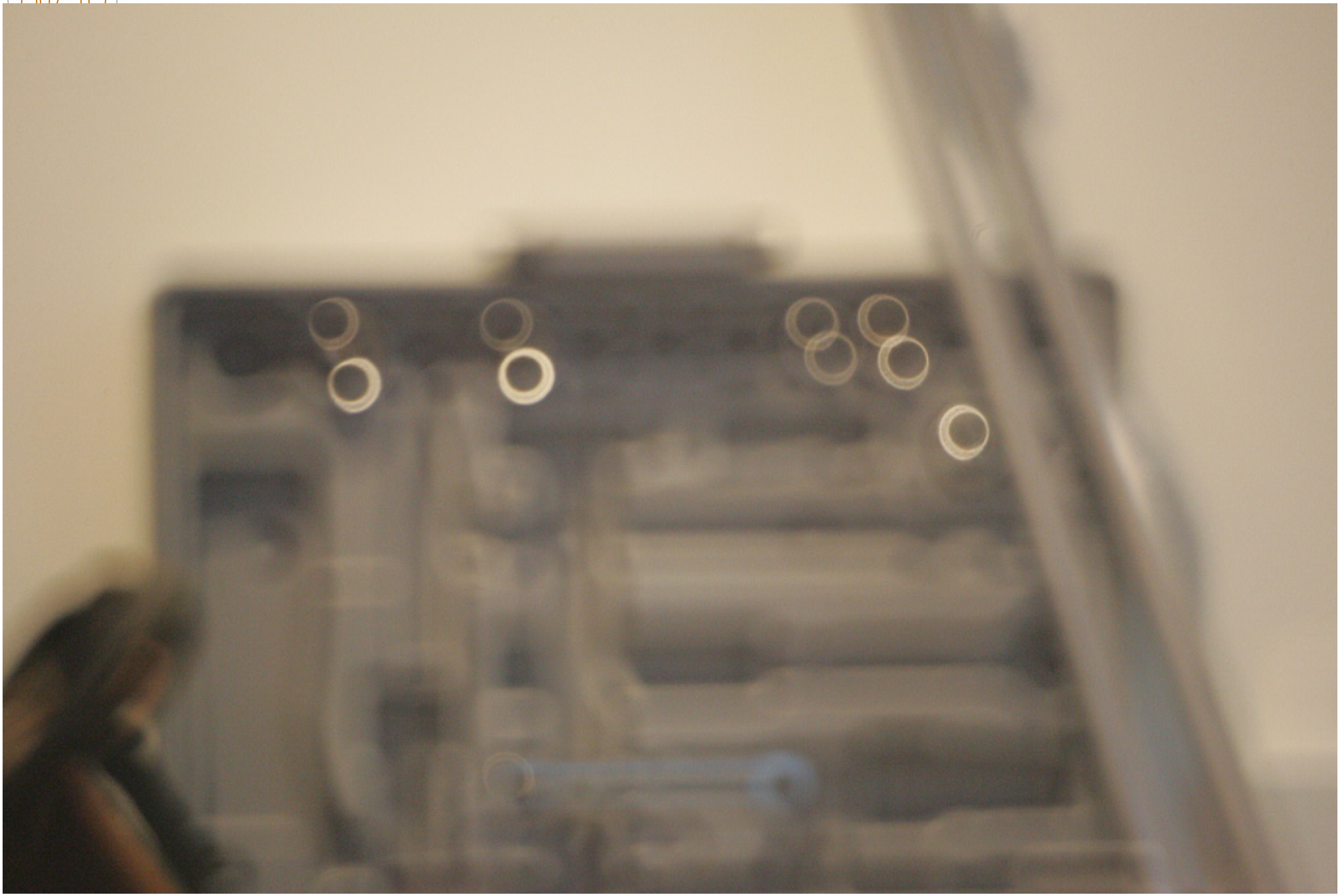
500mm Canon (5k)


rachet
rachet

Mirror lens

CSAIL





http://www.digit-life.com/articles2/rubinar/

Canon D60 + MS Rubinar - 8/500

Geometric distortion

Barrel/Pincushion

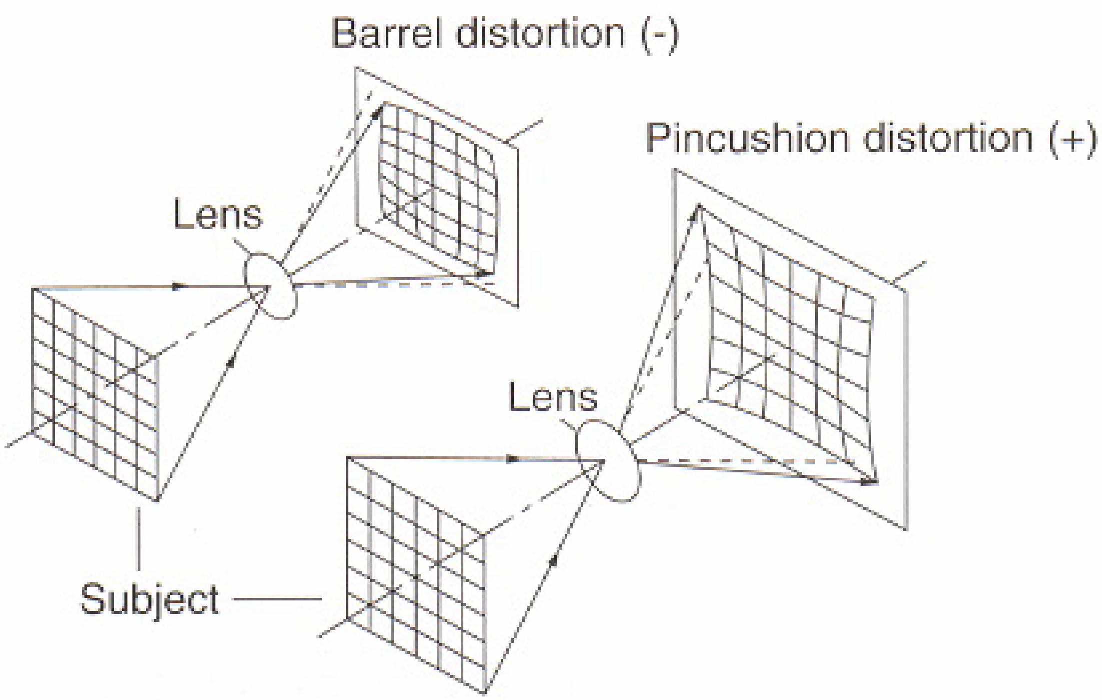
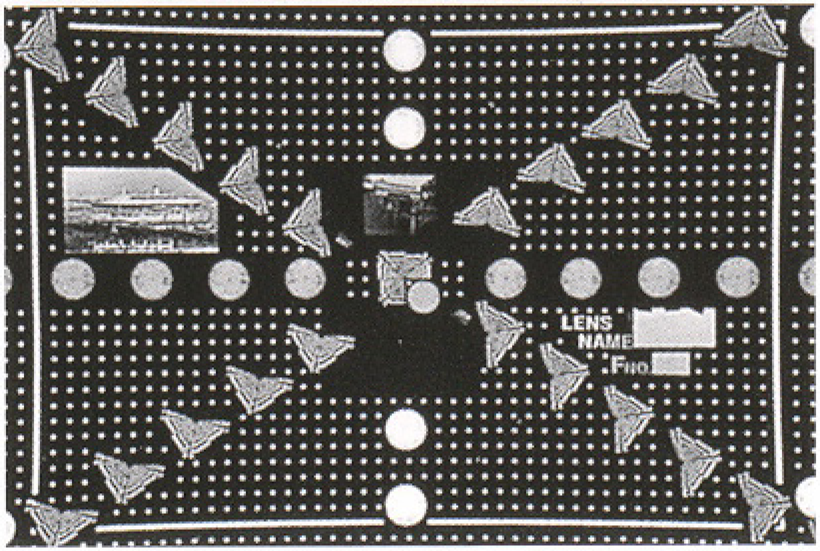
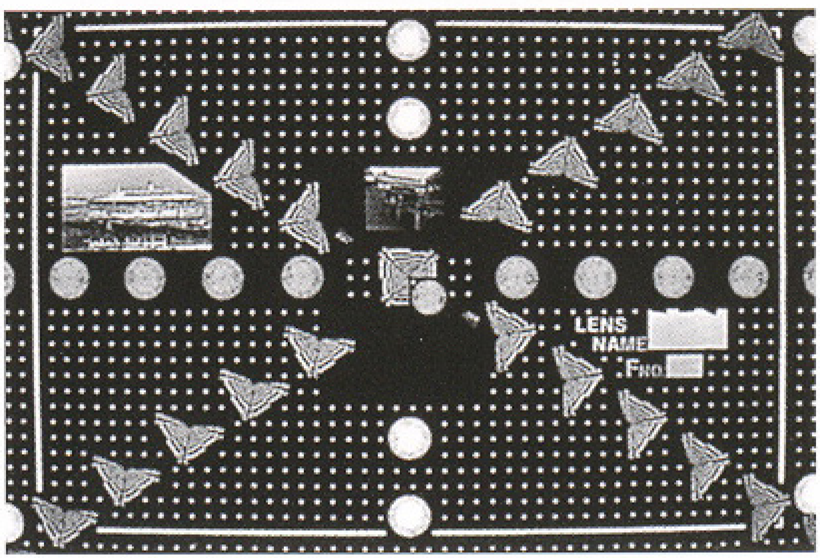


Photo-7 Example of distortion



+•Pincushion distortion

Photo-8 Example of distortion



-•Barrel distortion

source: canon red book

source digital outback

Courthouse in Santa Barbara with Leica Digilux 2

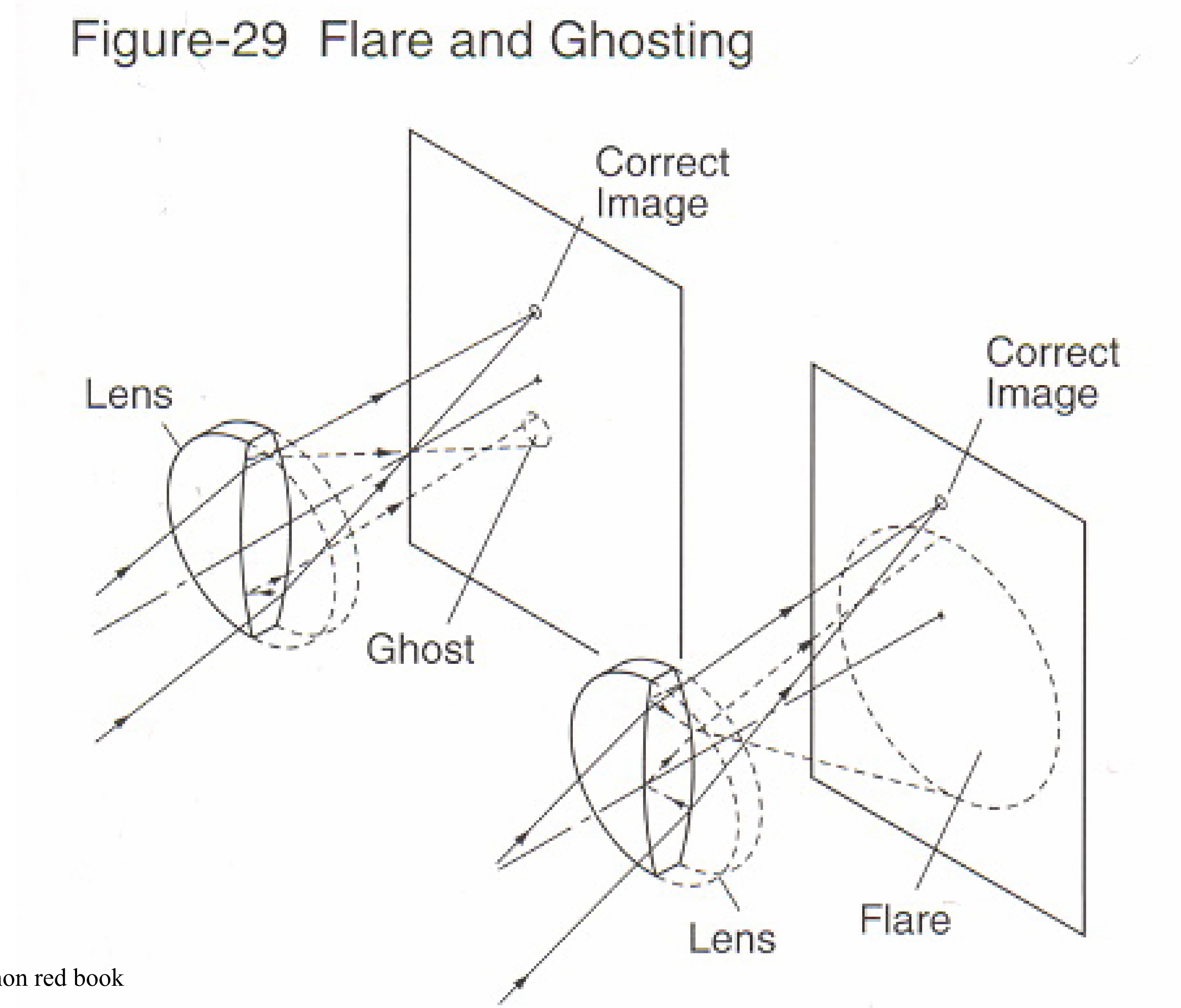
Fix with PTLens 4.1

source digital outback

Flare, reflection, vignetting

- **Use a hood!**

Flare and Ghosting



source: canon red book

Fighting reflections

Figure-34 EF300mm f/2.8L IS USM Flocked Parts to Eliminate Internal Reflections

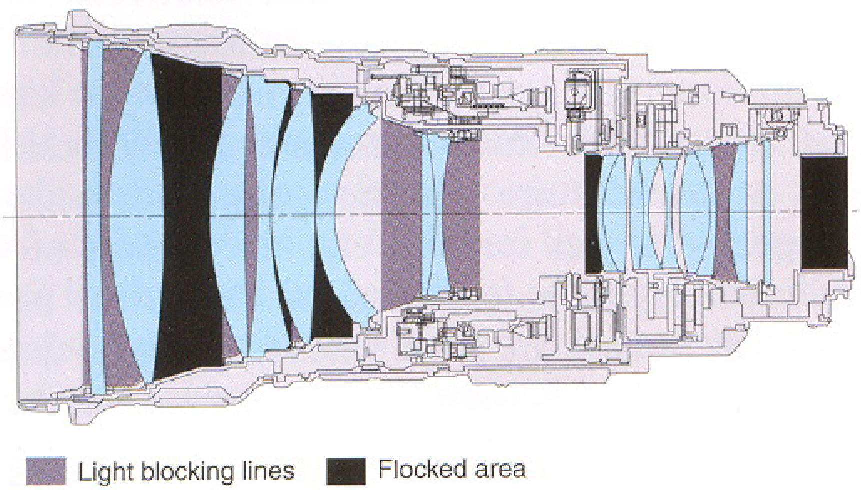


Figure-35 EF28-135mm f/3.5-5.6 IS USM flare cut moving aperture diaphragm

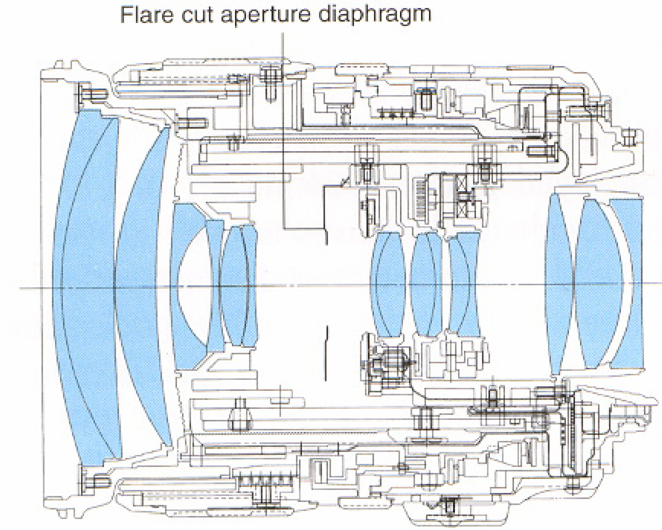
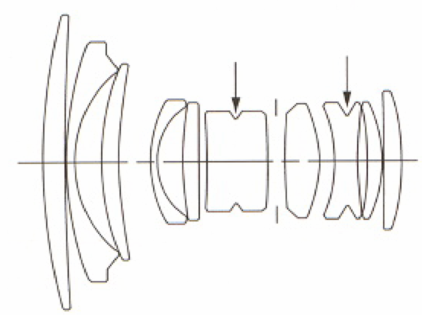


Photo-15 EF300mm f/4L IS USM Flocking Process

Figure-36 EF24mm f/2.8 Internal Light Blocking Grooves



① Anti-Reflection Coating Techniques

This method employs a special paint on angled surfaces and joining surfaces where the lens elements are held in place by the lens barrel to stop light entering the lens from reflecting from these parts. If a standard coating is used, reflections

source: canon red book

Coating

Figure-24 Surface Reflections with Non-Coated Glass

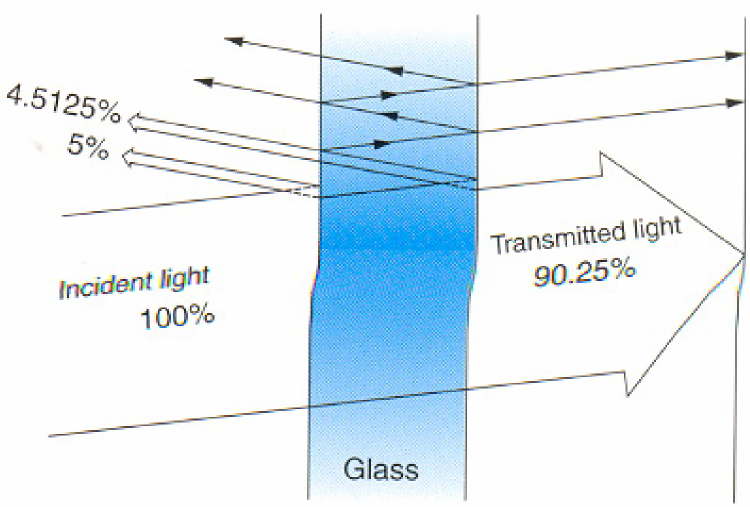
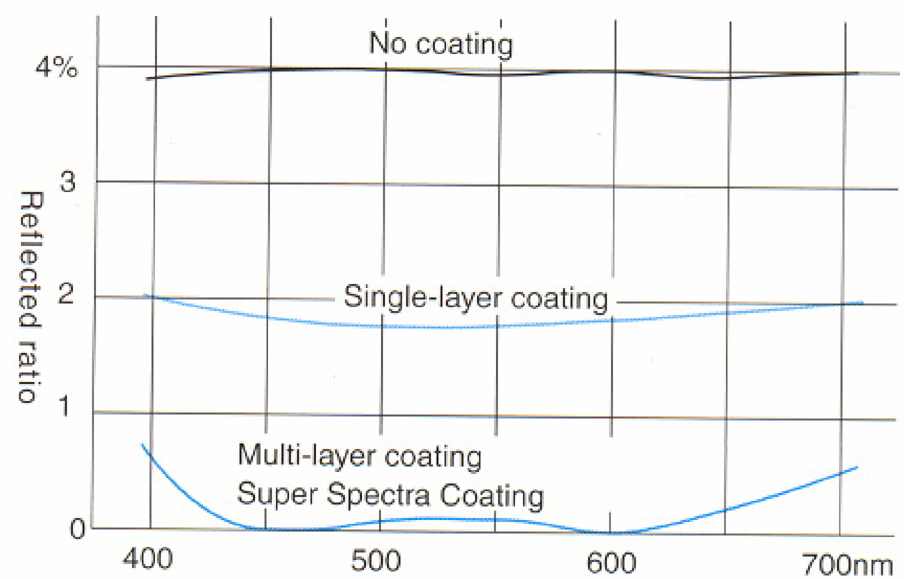


Figure-26 Super Spectra Coating Characteristics (Reflectivity)



source: canon red book

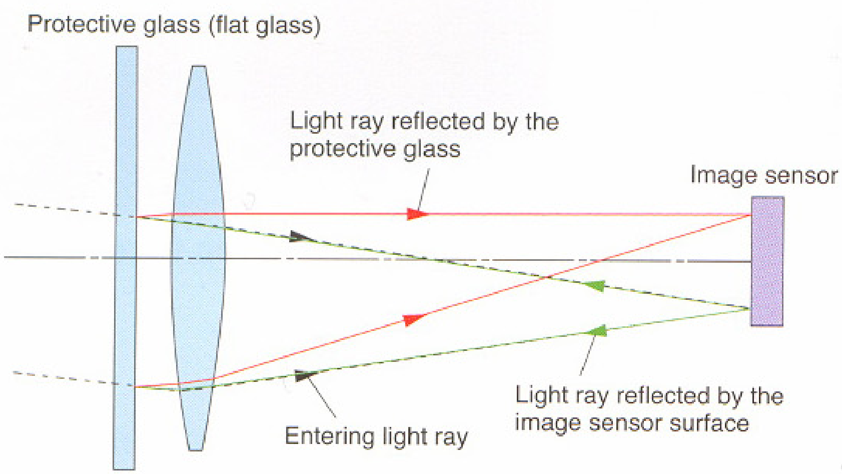
Flare/ghosting special to digital

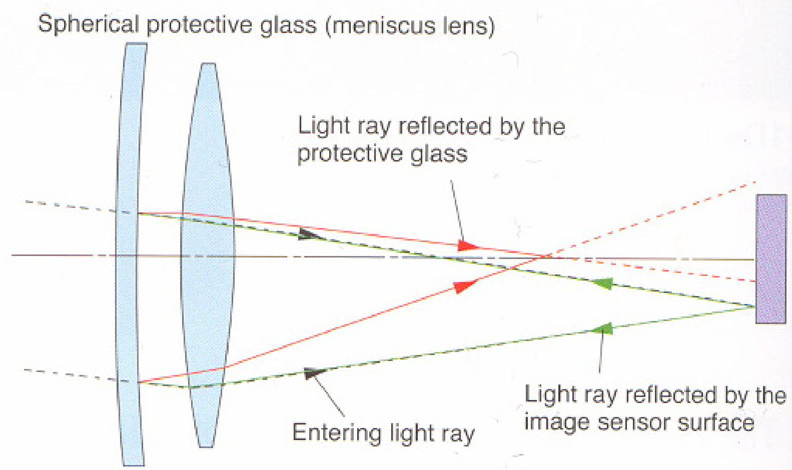
For flat protective glass

In lenses employing flat protective glass, a reflection occurs between the image sensor and the protective glass, which causes the subject to be photographed in a position different from the actual position.

For a meniscus lens

In lenses employing a meniscus lens, no reflection like that seen to the left occurs.

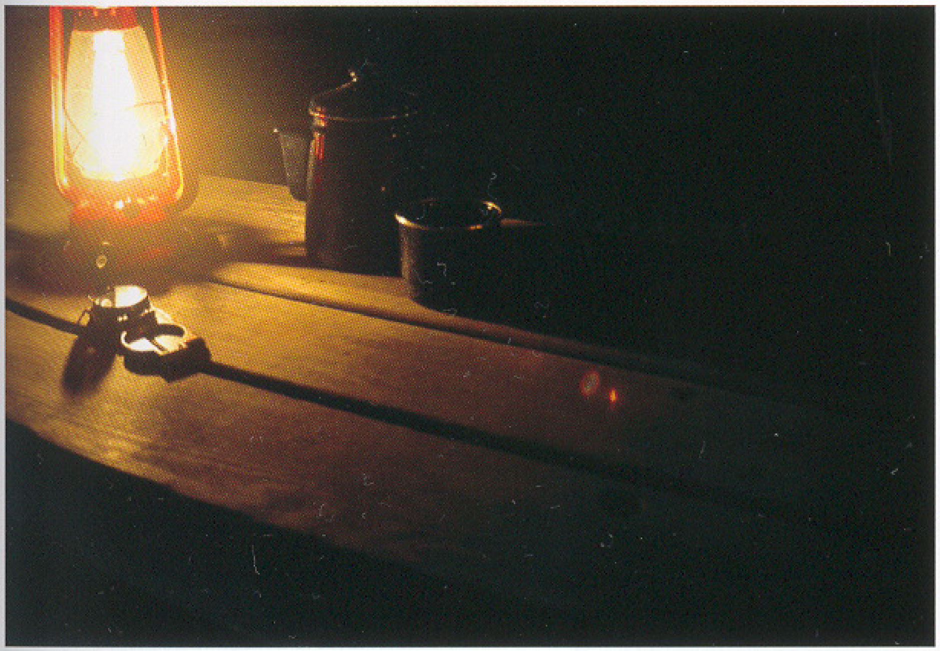




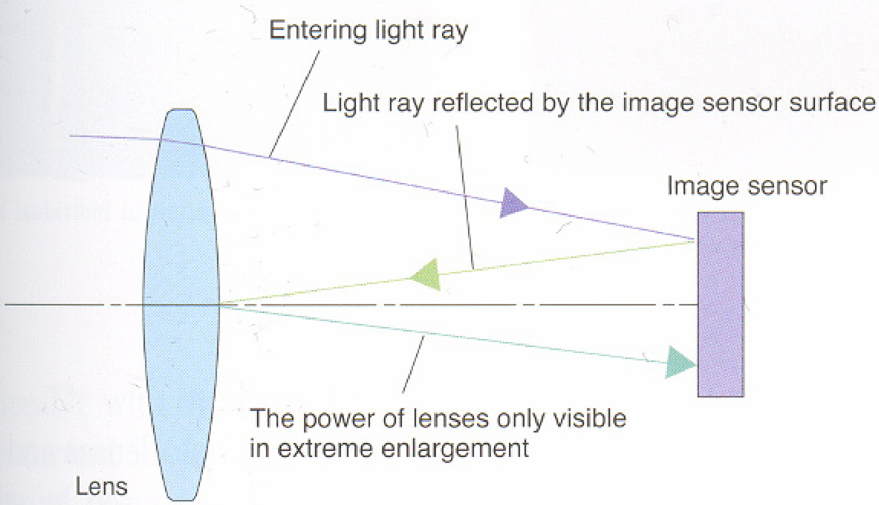
source: canon red book

Coating for digital

Lens for which the lens shape and coating have not been optimized

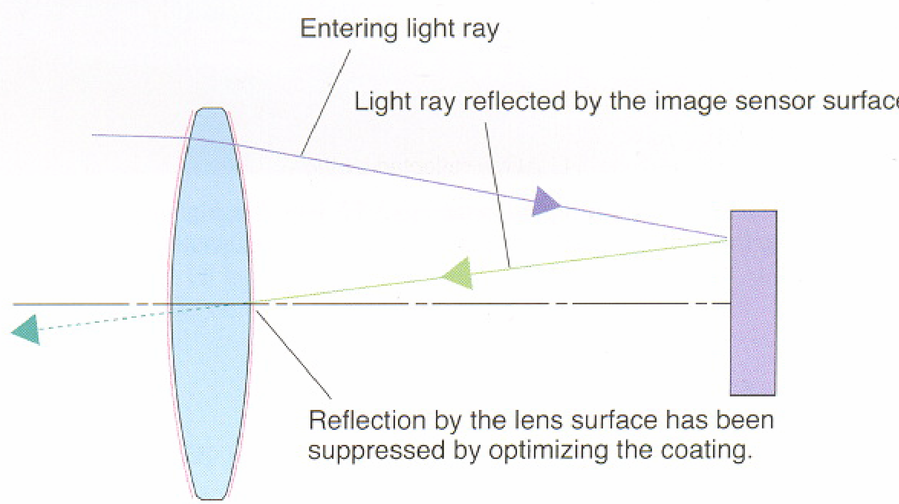


Flaring and ghosting occurs with lens for which the lens shape and coating have not been optimized.



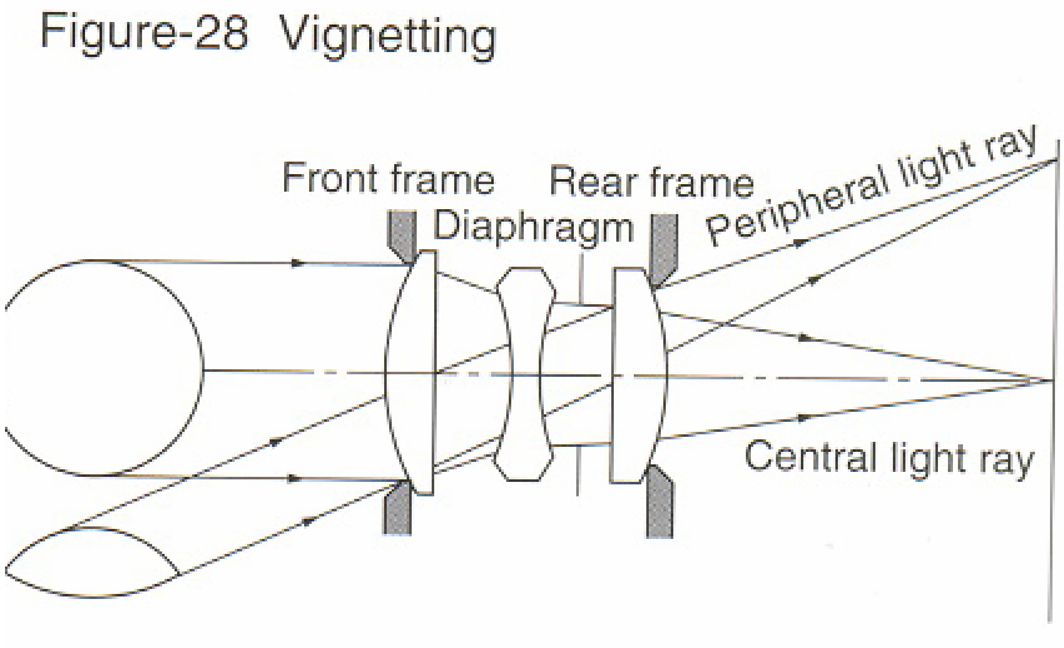
Lens for which the lens shape and coating have been optimized

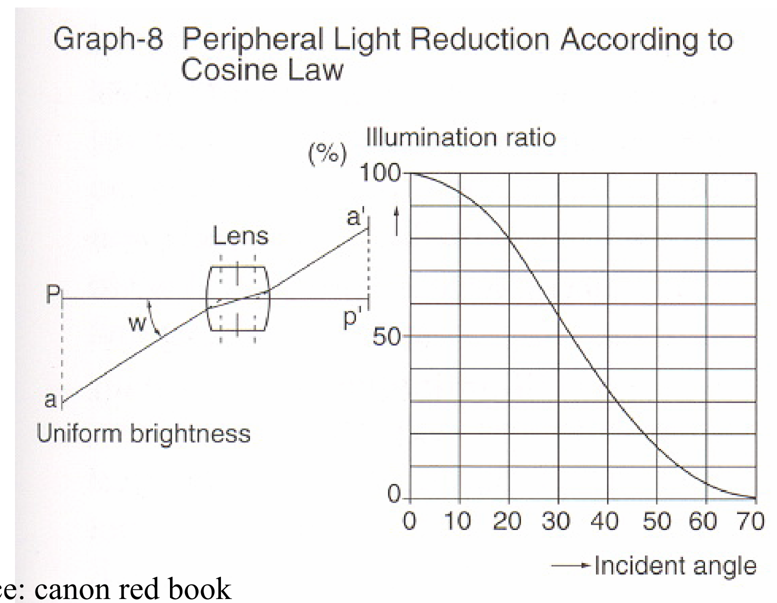
Flaring and ghosting are suppressed with lens for which the lens shape and coating have been optimized.

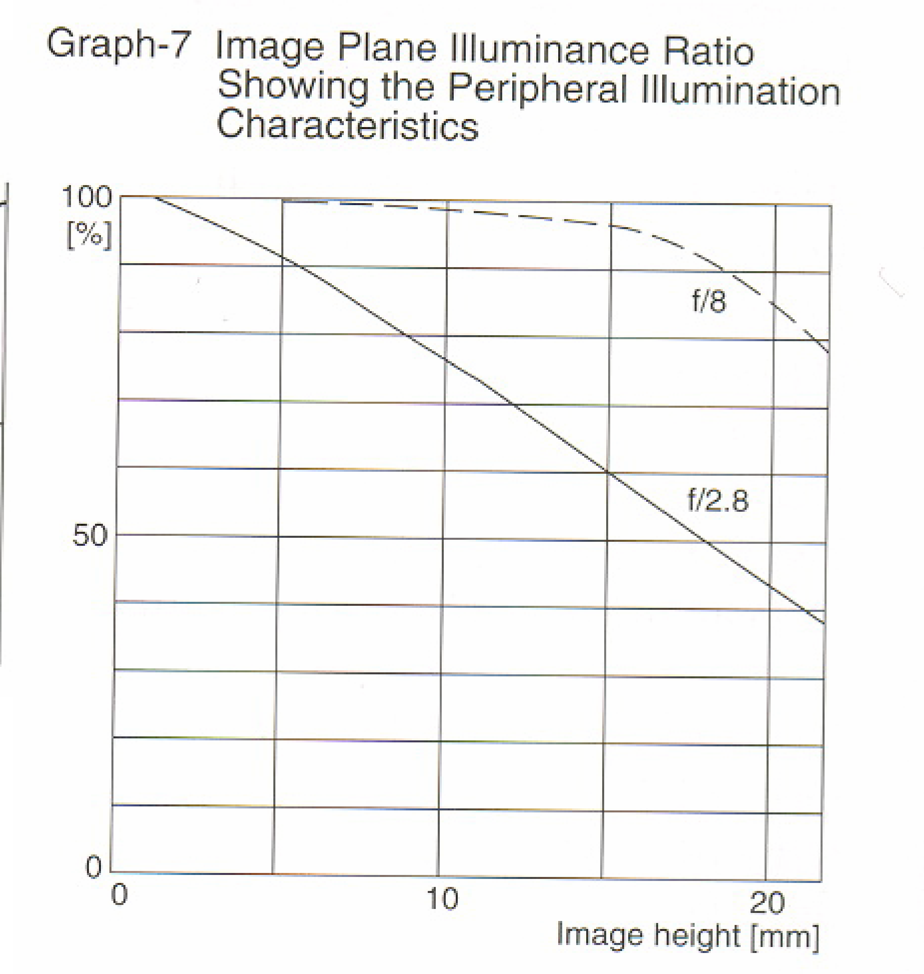


source: canon red book

Vignetting







source: canon red book

Vignetting

- http://www.photozone.de/3Technology/lenstec3.htm

vignetting

no vignetting

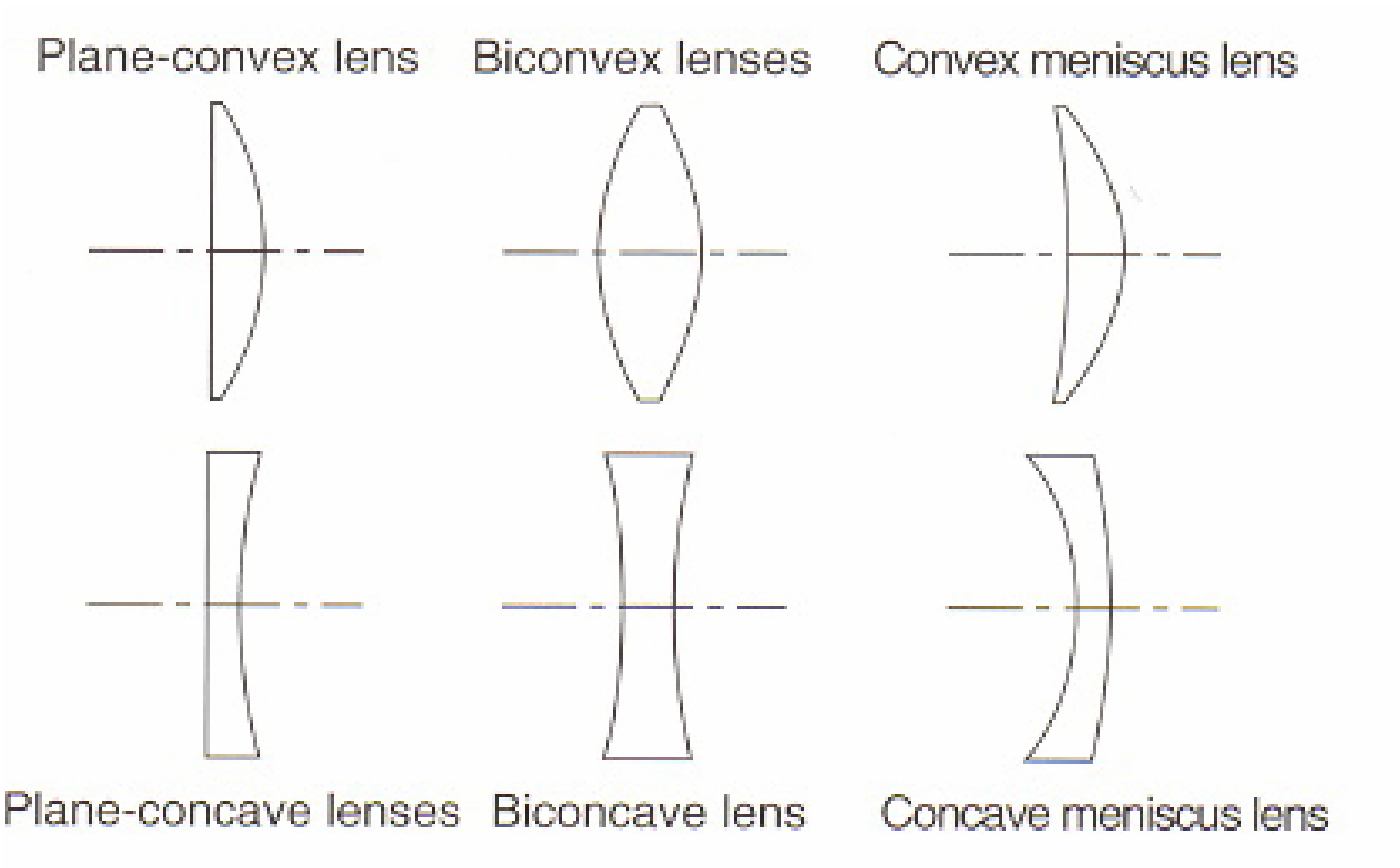
CSAIL

Old — 28mm f/2.8

New — 28mm f/2.8

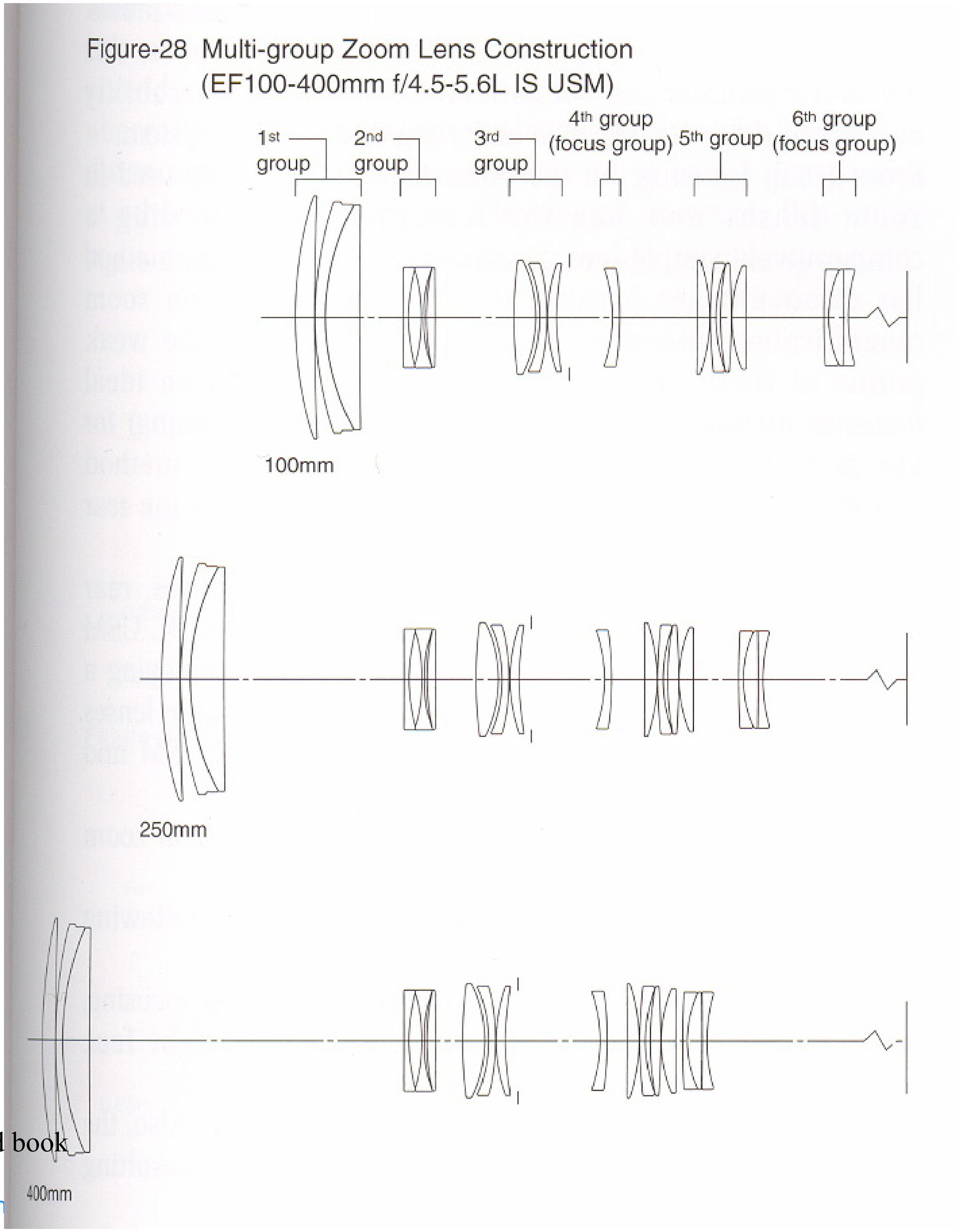
Lens design, focusing, zooming

Lens shapes



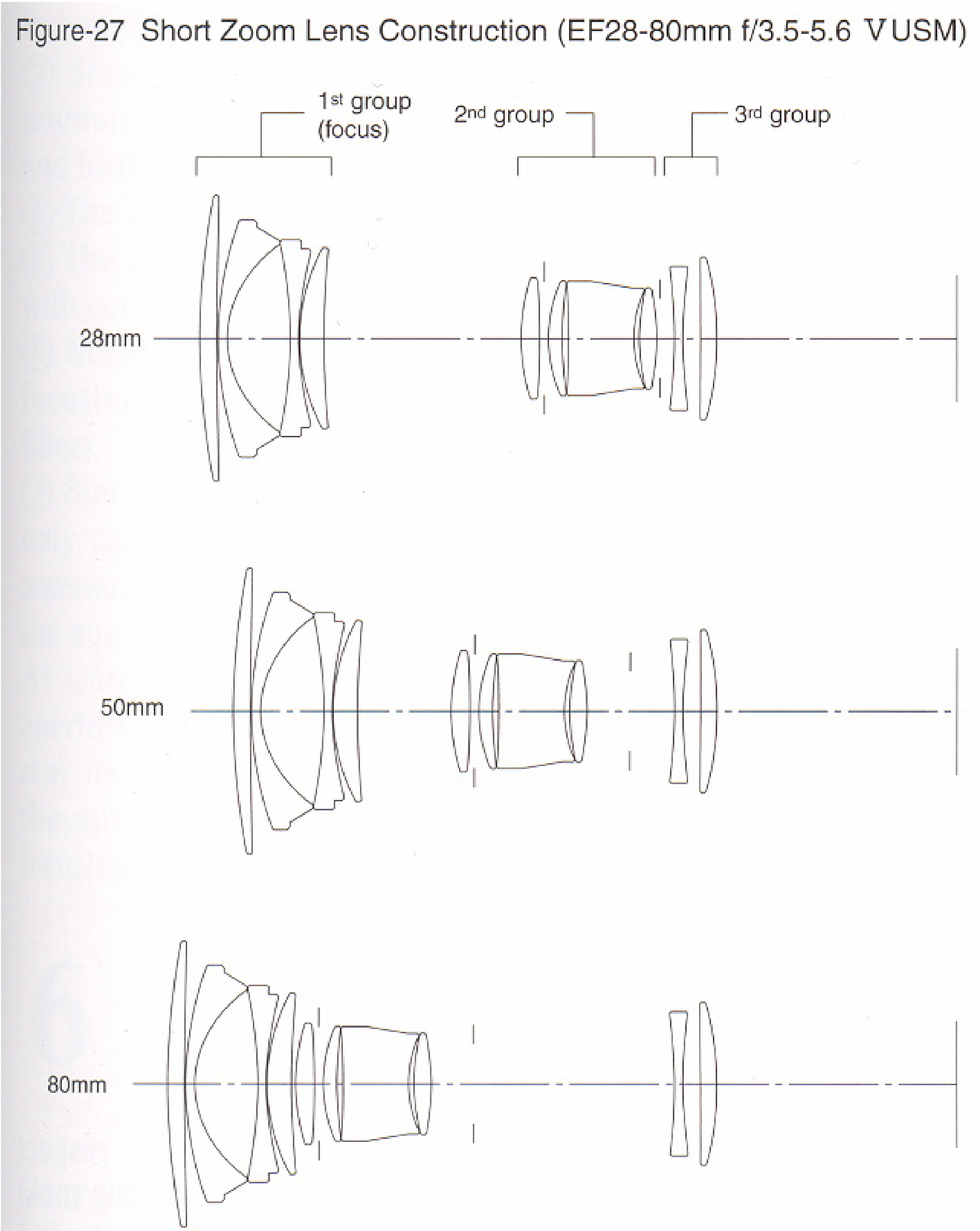
source: canon red book

Multi group construction



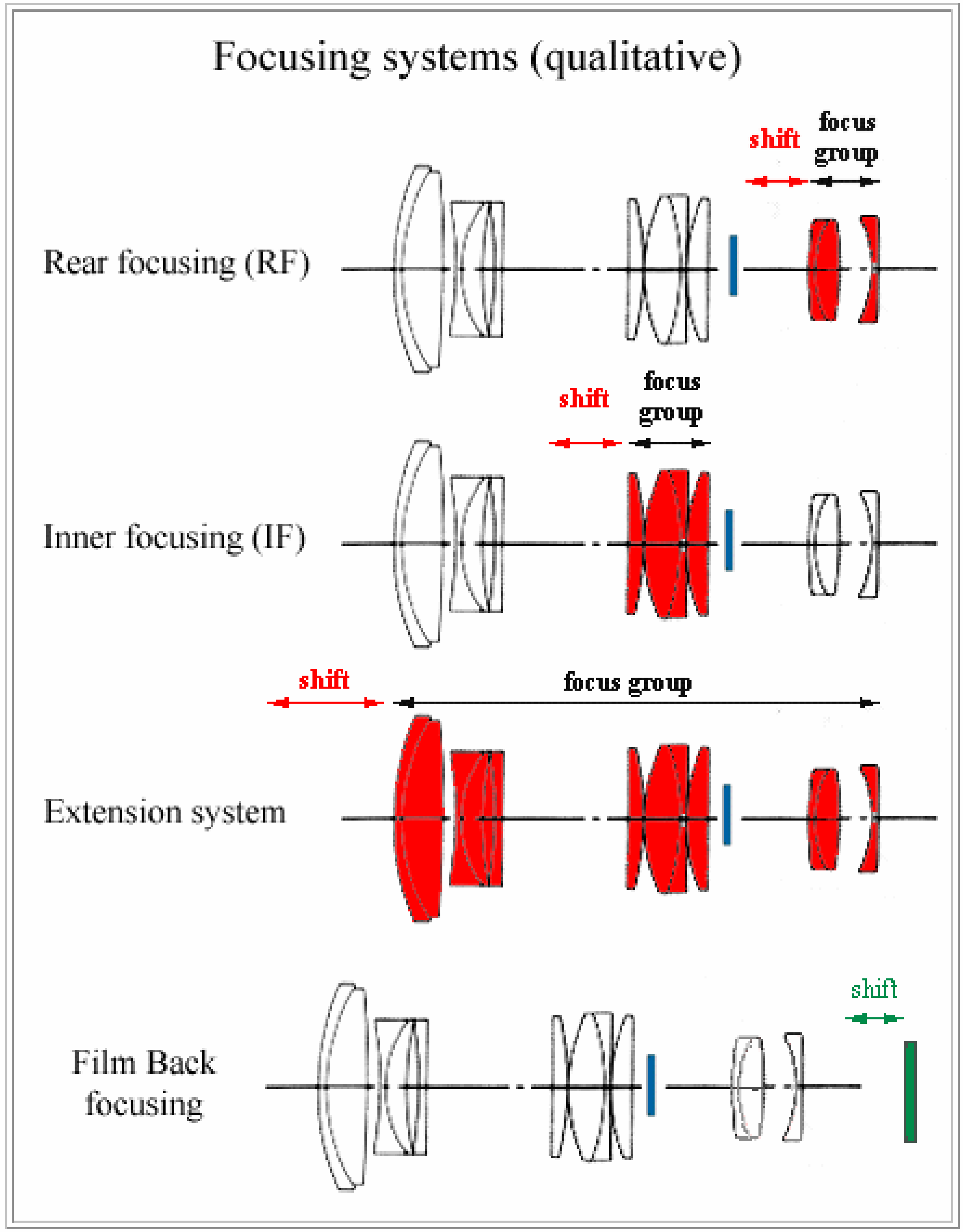
source: canon red book

Short zoom construction

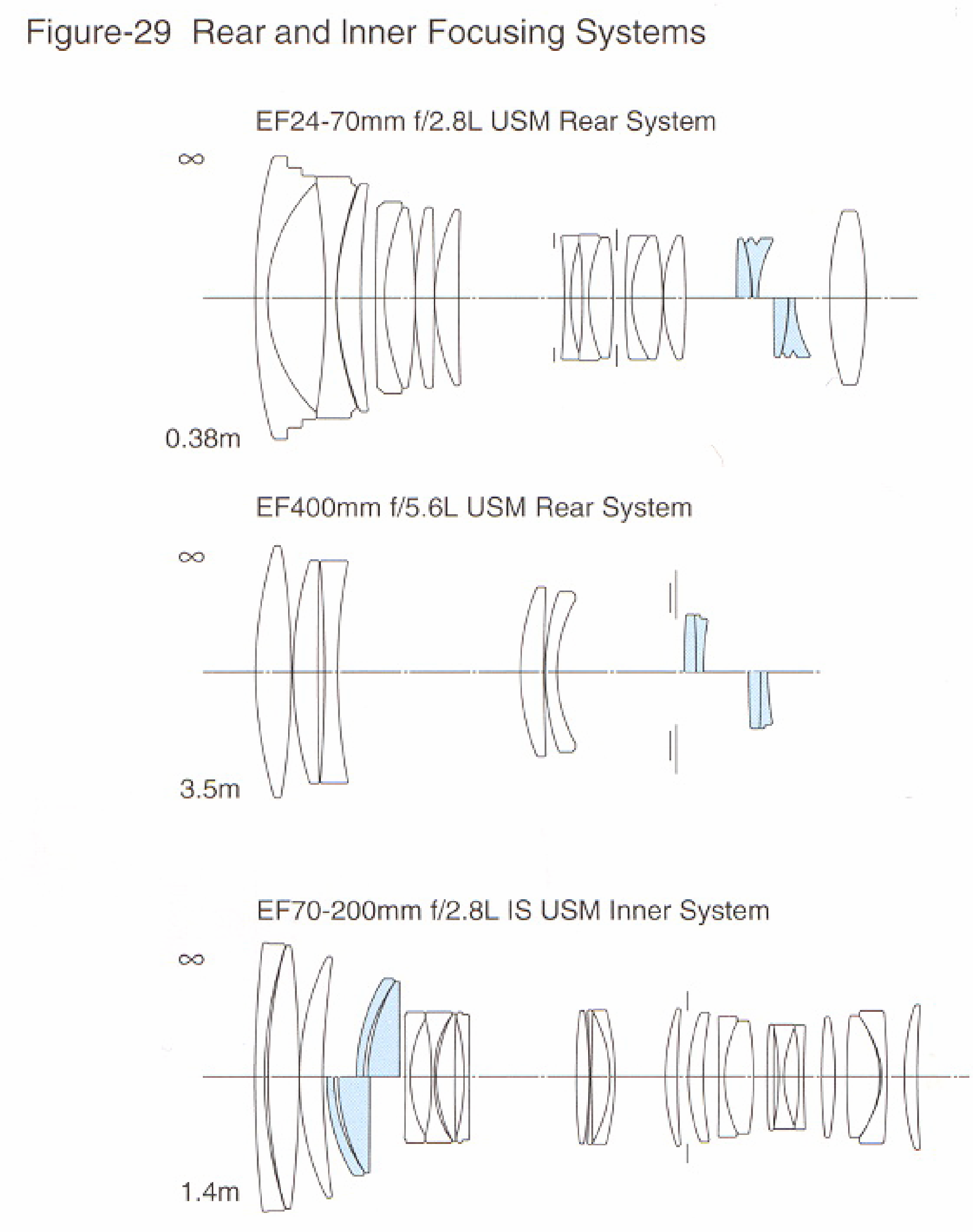


source: canon red book

- **http://www.photozone.de/3Technology/lenstec7.htm**



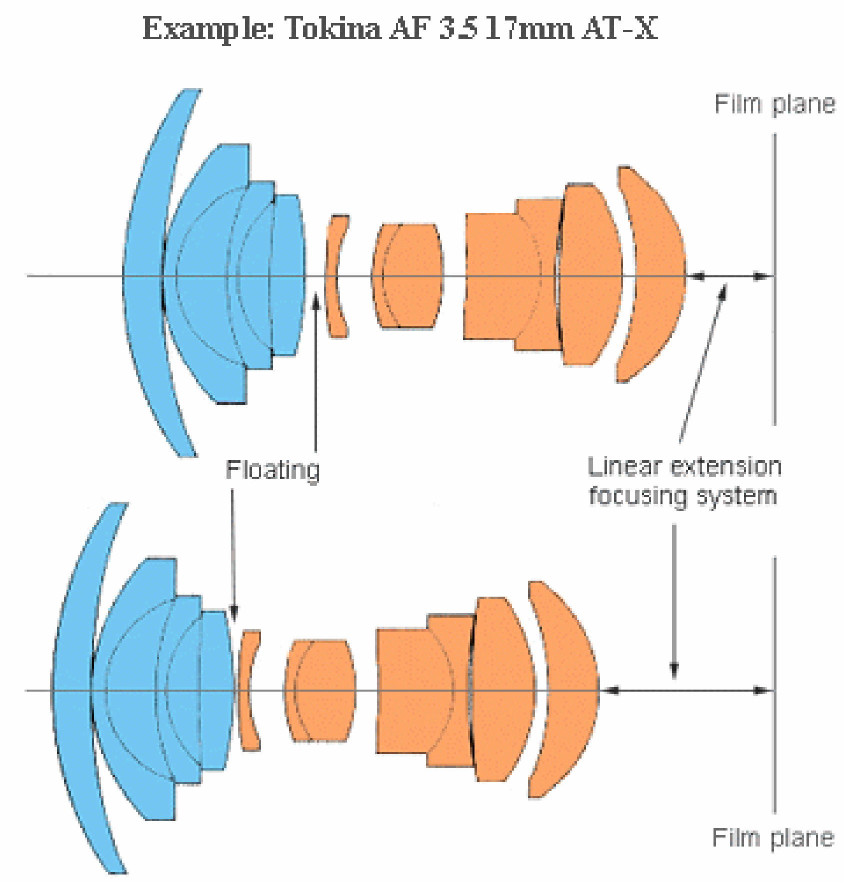
Rear and inner focus



source: canon red book

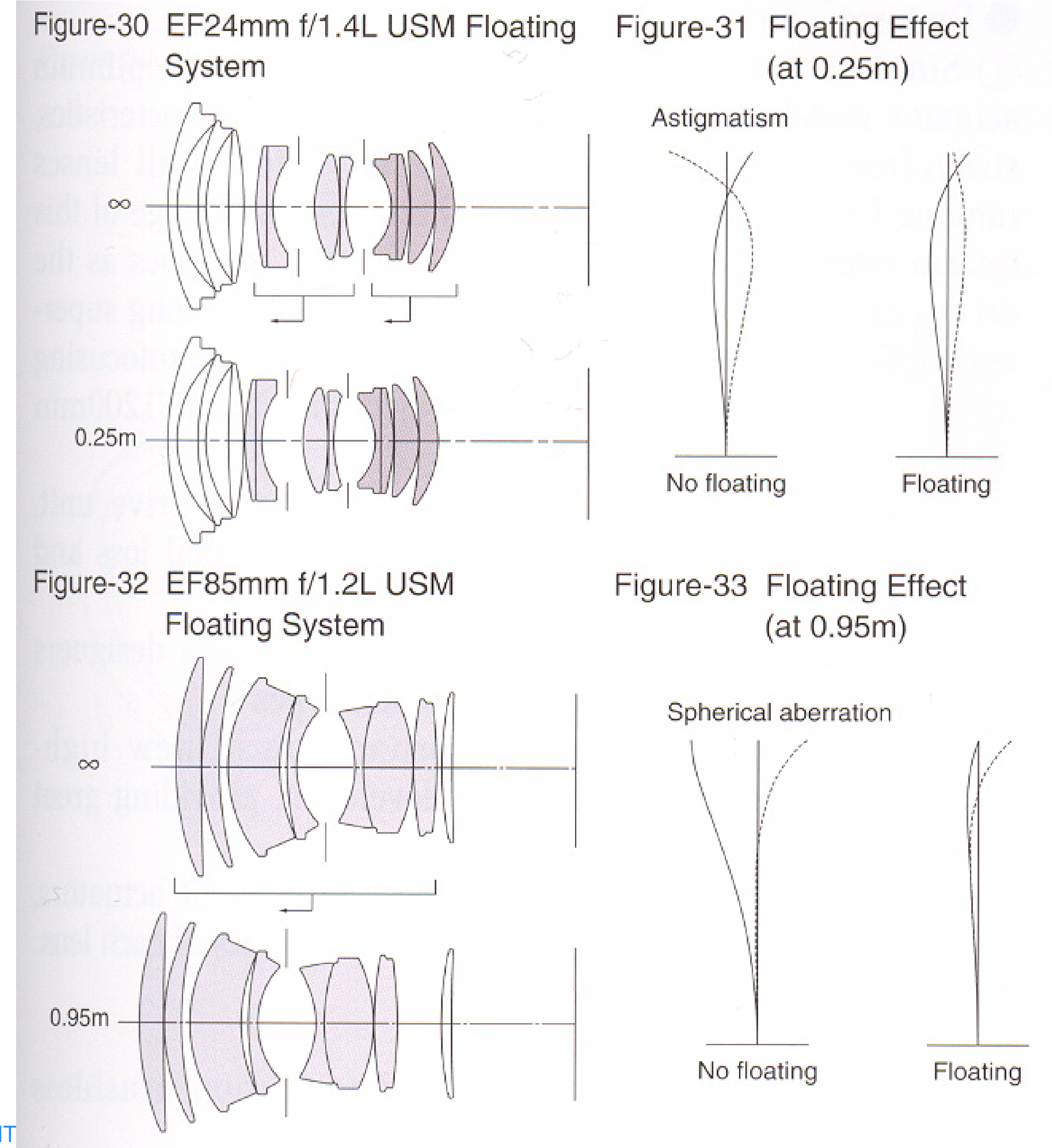
Floating elements

- On of the most underestimated effect on image quality is the performance deterioration towards closer focus distances. Curvature of field becomes significantly pronounced here and reduce the sharpness towards the image borders. The same goes for large aperture lenses that suffer from increased spherical aberrations here. Normal lenses shift just a single group of elements for focusing. Additional floating elements (see picture below) can improve the close-focus performance significantly. However, the vast majority of all lenses does not feature this mechanism. Many ultra-wide and virtually all true macro lenses (e.g. 50/2.8macro, 100/2.8macro, 200/4macro) have FEs though.



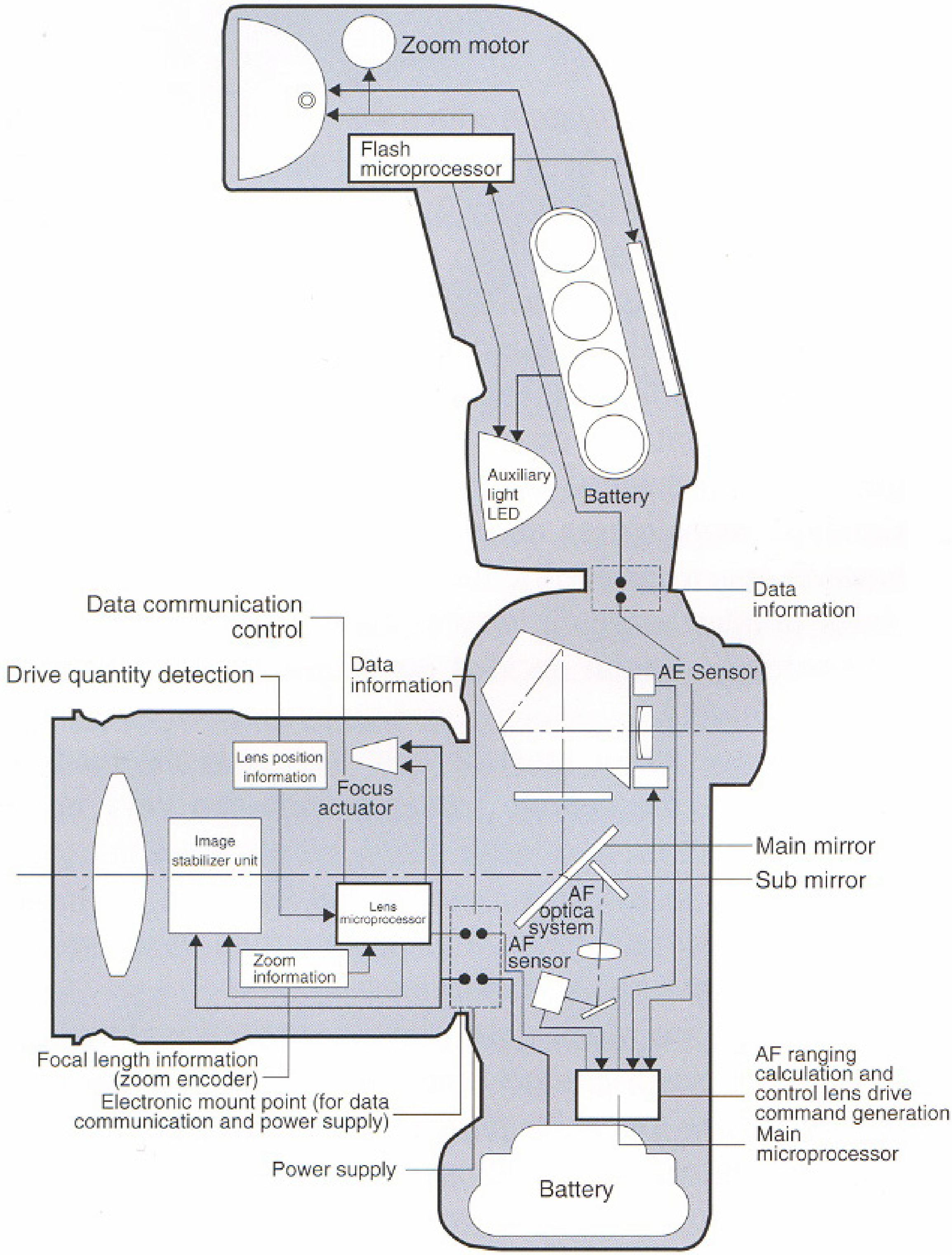
http://www.photozone.de/3Technology/lenstec7.htm

Floating elements



source: canon red book

Lens electronics

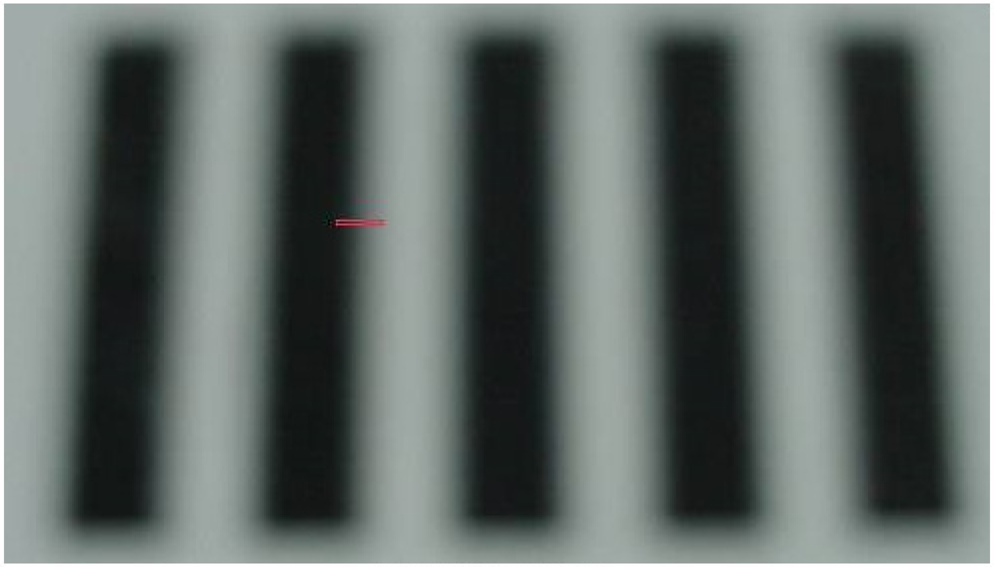


source: canon red book

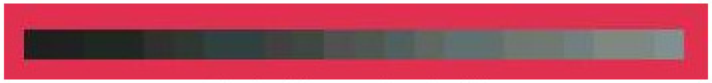
Active autofocus

- **Compact cameras**
- http://electronics.howstuffworks.com/autofocus2.htm

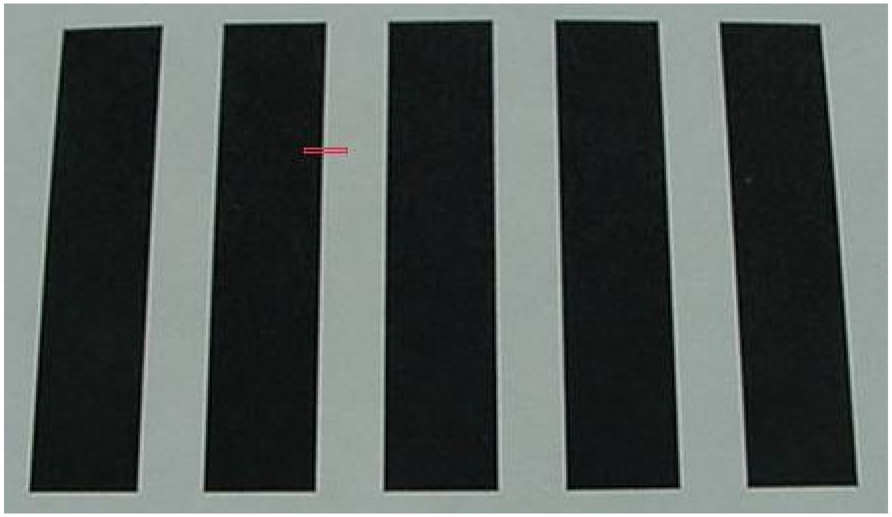
- http://electronics.howstuffwor



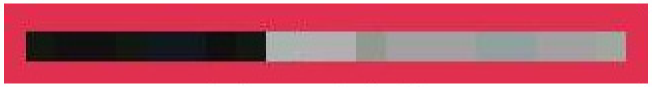
Out-of-focus scene



Out-of-focus pixel strip



In-focus scene



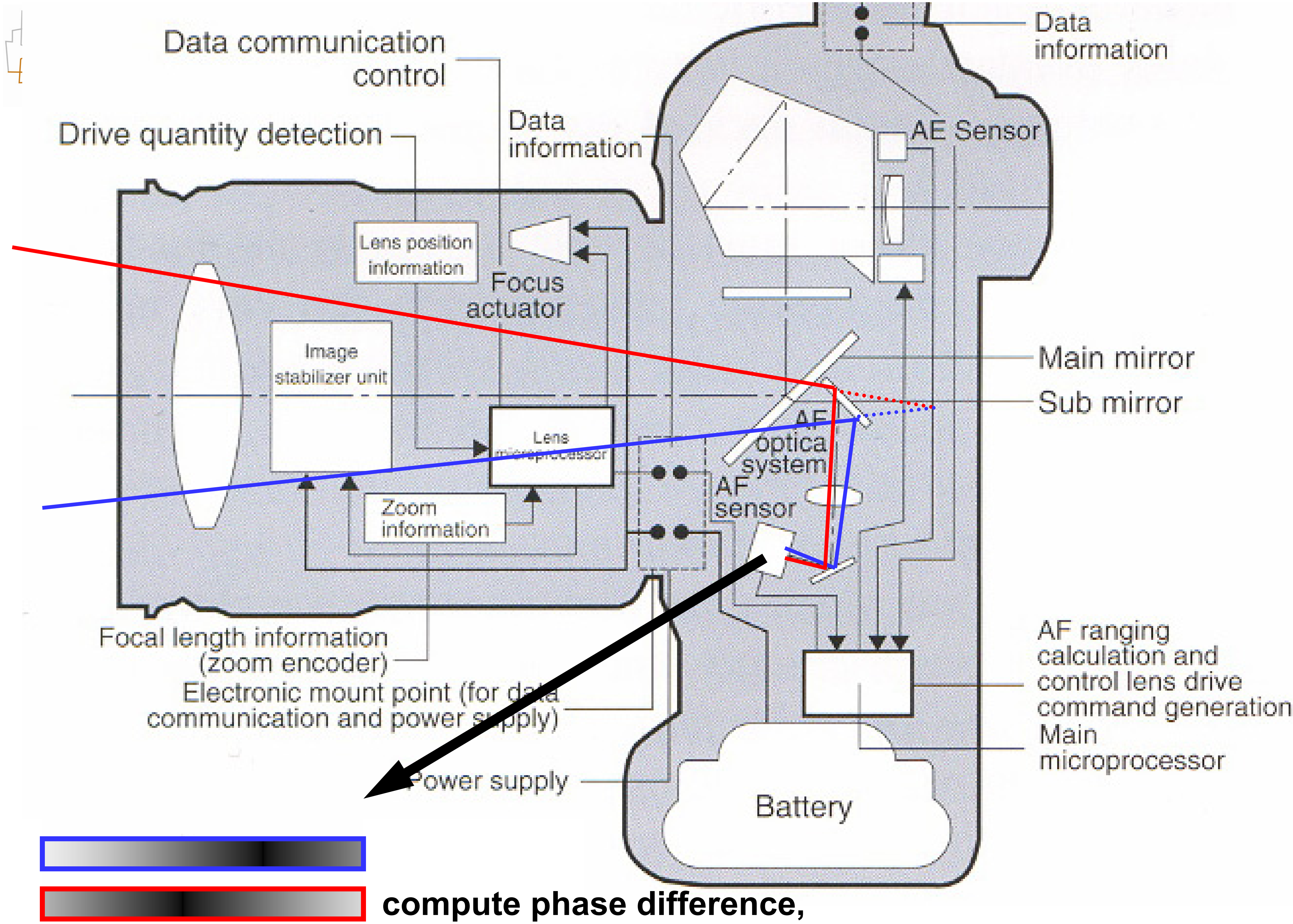
In-focus pixel strip

Autofocus

- http://www.fredmiranda.com/forum/topic/241524
- When you half-press the shutter release, the activated AF sensor "looks" at the image projected by the lens from two different directions (each line of pixels in the array looks from the opposite direction of the other) and identifies the phase difference of the light from each direction. In one "look," it calculates the distance and direction the lens must be moved to cancel the phase differences. It then commands the lens to move the appropriate distance and direction and stops. It does not "hunt" for a best focus, nor does it take a second look after the lens has moved (it is an "open loop" system).

  If the starting point is so far out of focus that the sensor can't identify a phase difference, the camera racks the lens once forward and once backward to find a detectable difference. If it can't find a detectable difference during that motion, it stops.

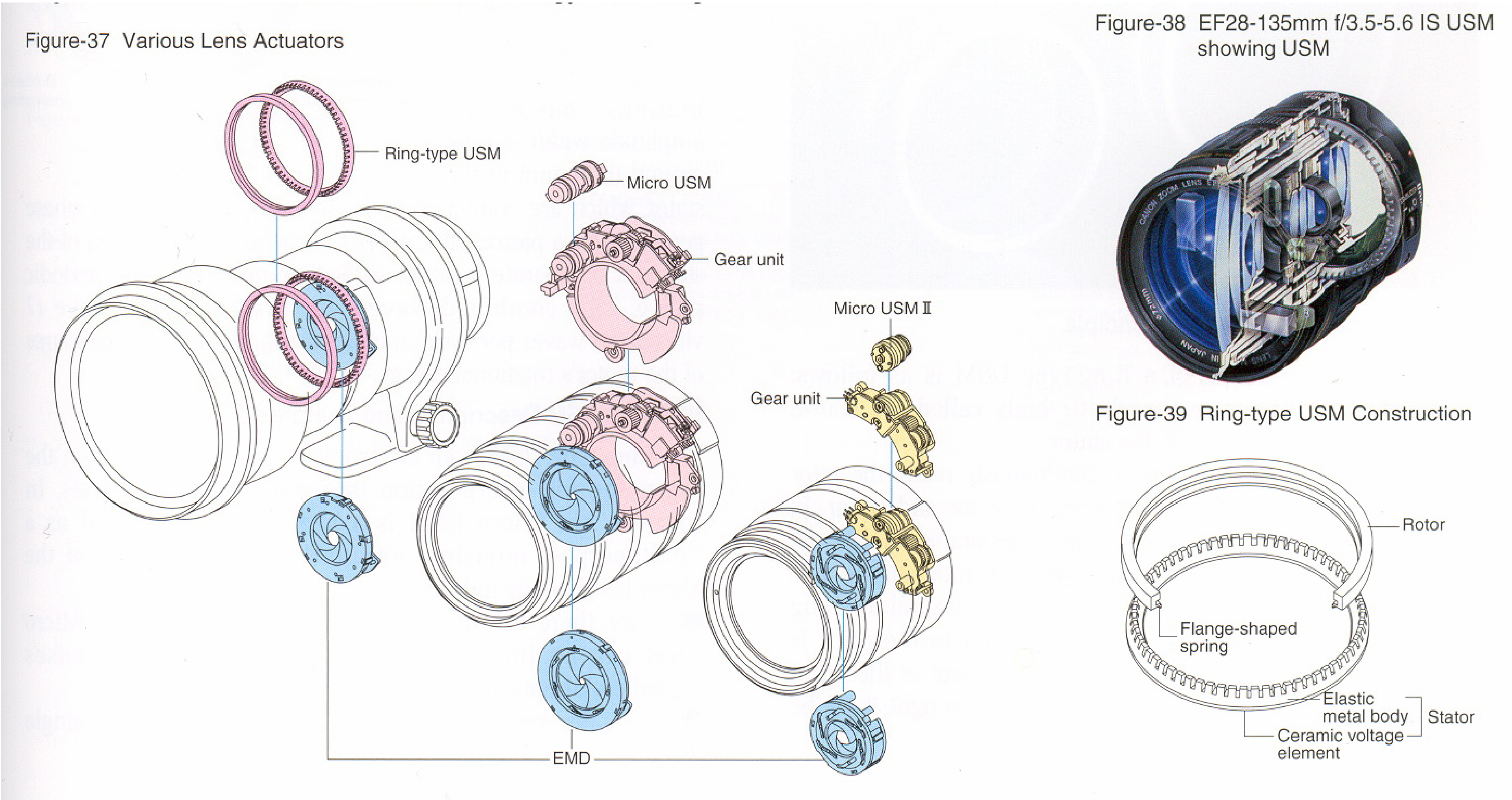
  Although the camera does not take a "second look" to see if the intended focus has been achieved, the lens does take a "second look" to ensure it has moved the direction and distance commanded by the camera (it is a "closed loop" system). This second look corrects for any slippage or backlash in the lens mechanism, and can often be detected as a small "correction" movement at the end of the longer initial movements.



compute phase difference, deduce distance

source arthur morris

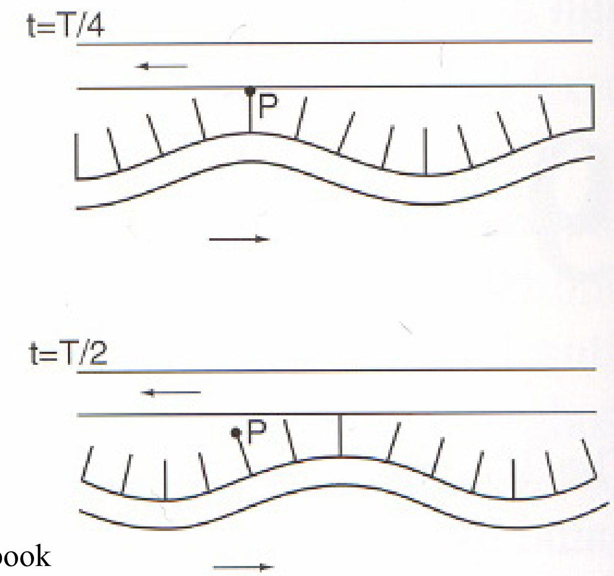
Lens actuators



source: canon red book

USM

Photo-16 Ring-type USM



T: Period of flexural traveling wave

source: canon red book

Figure-41 Vibrations Generated by Piezoelectric Ceramic Element

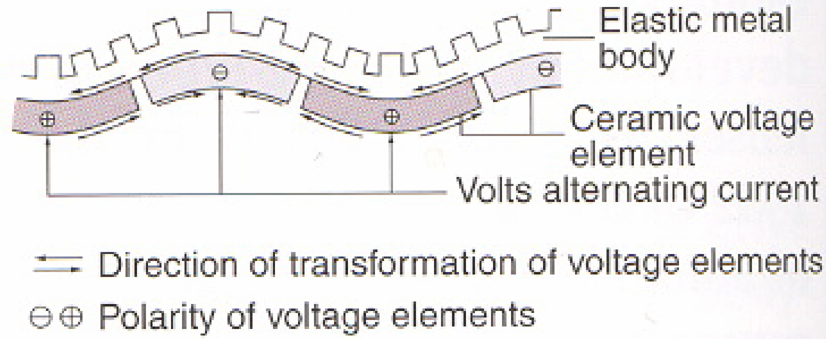


Figure-42 Piezoelectric Ceramic Element Layout (bottom of stator)

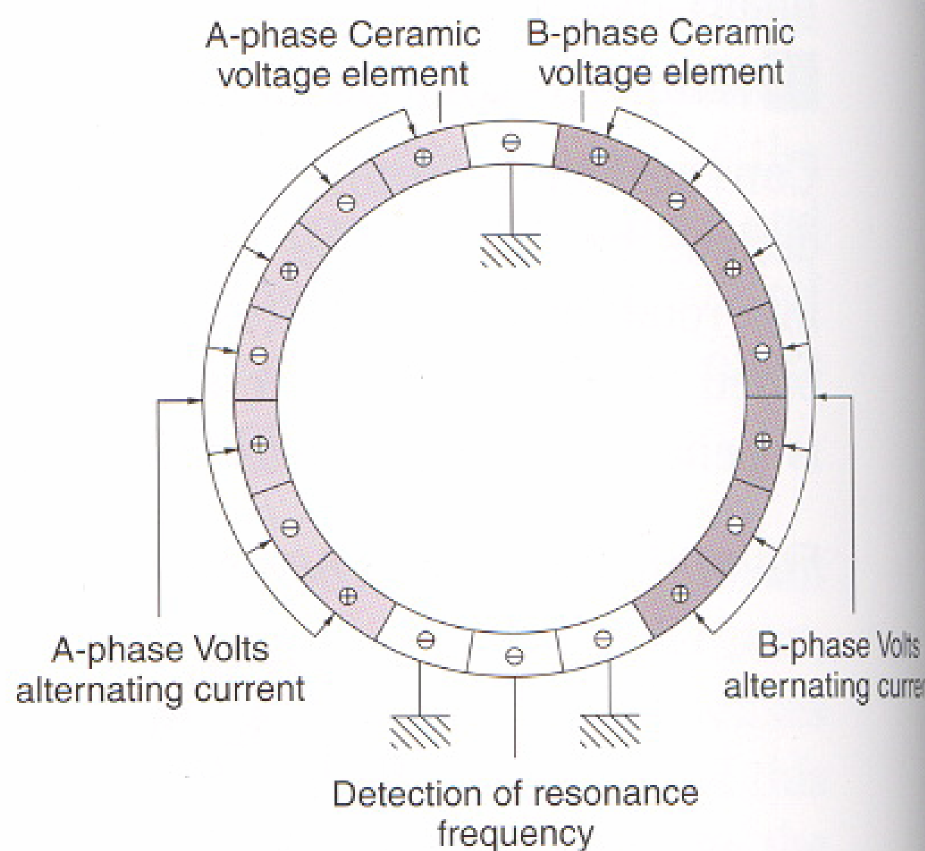
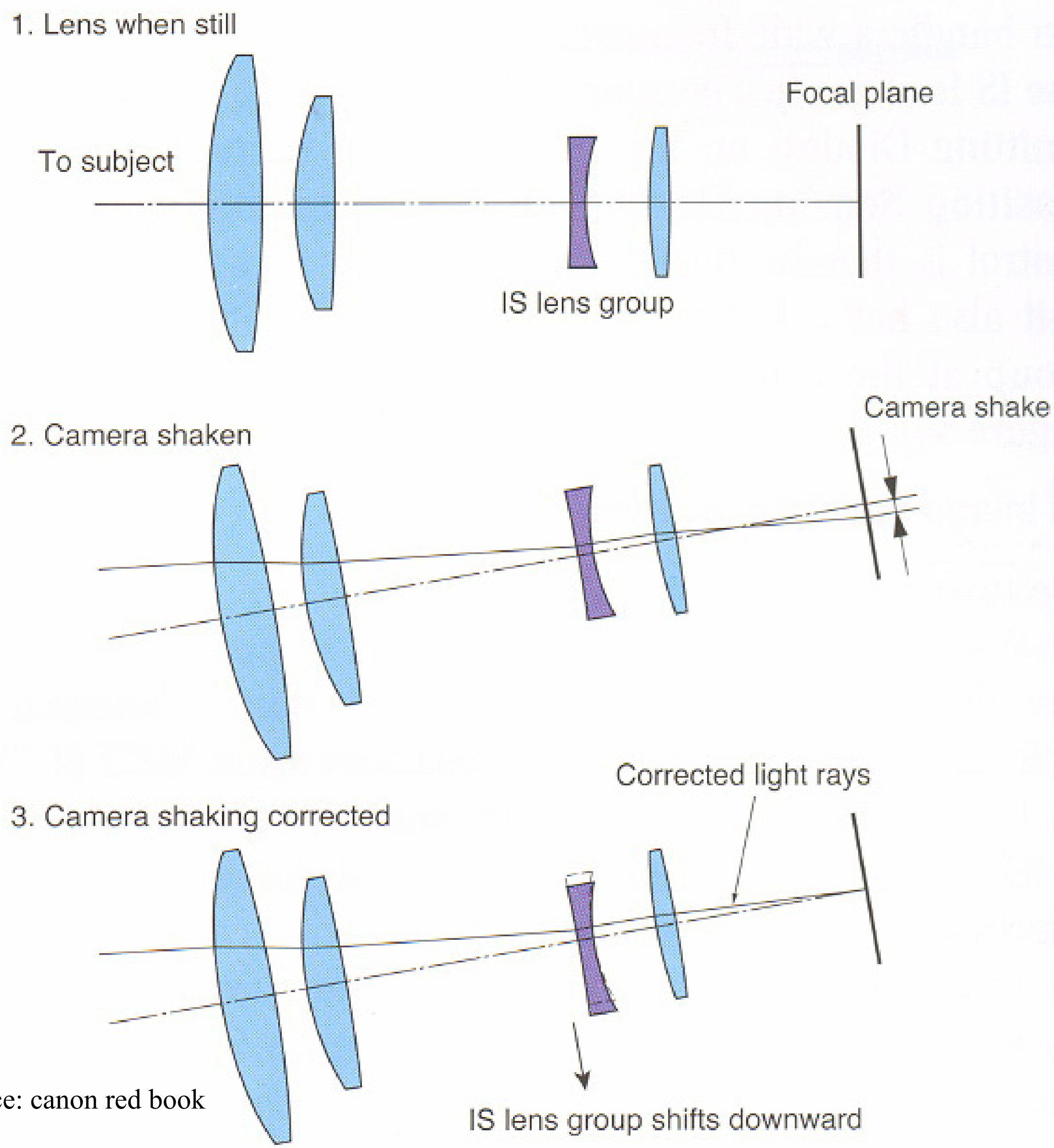


Image stabilization



source: canon red book

Photo-21 Shake-detecting gyro sensor

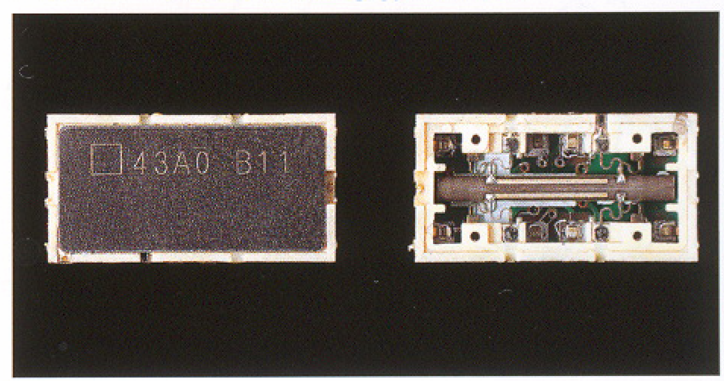
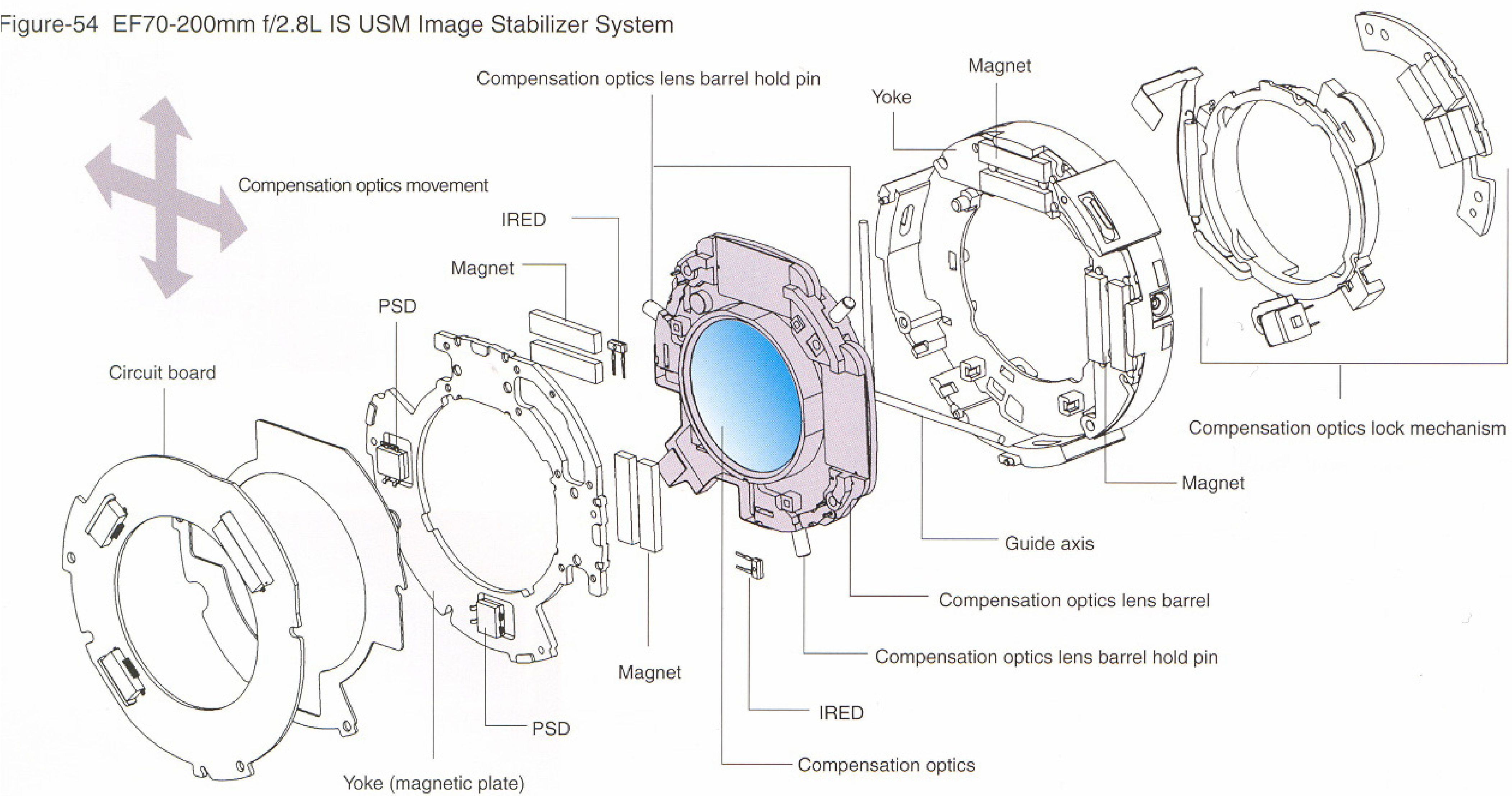
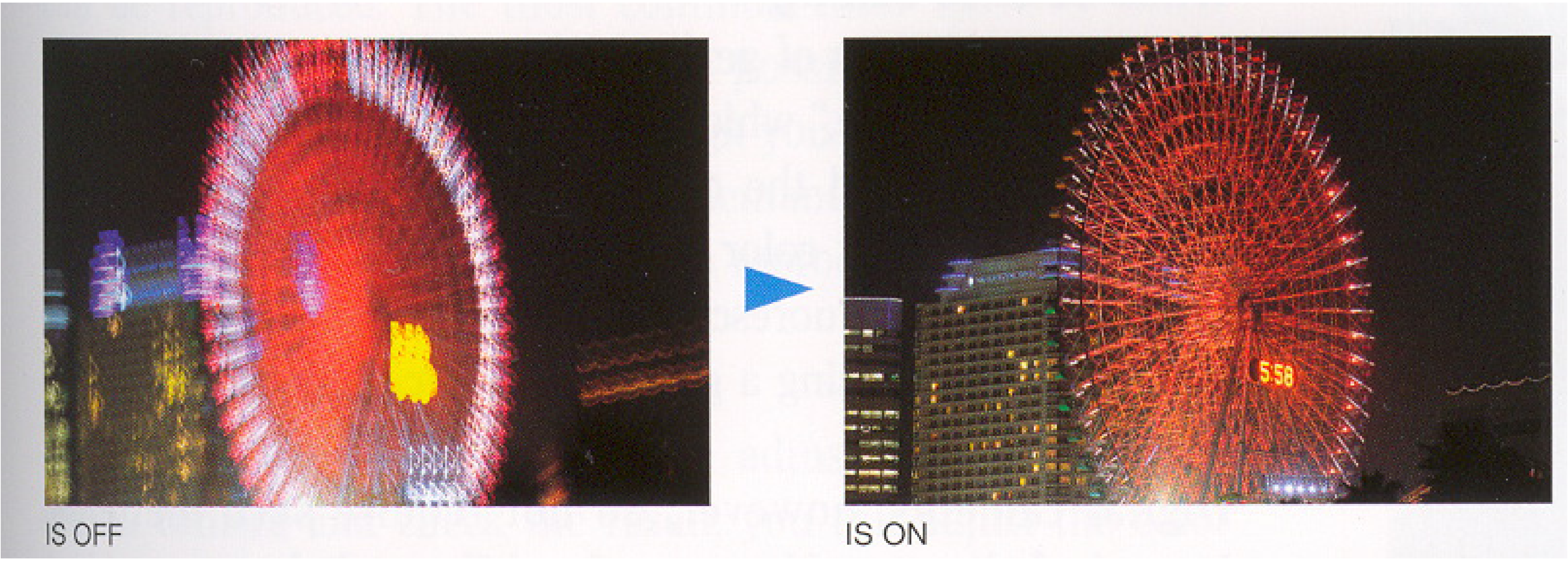


Image stabilization



source: canon red book

Image stabilization



source: canon red book

1000mm, 1/100s, monopod, IS

Frédo Durand — MIT Computer Science and Artificial Intelligence Laboratory - fredo@mit.edu

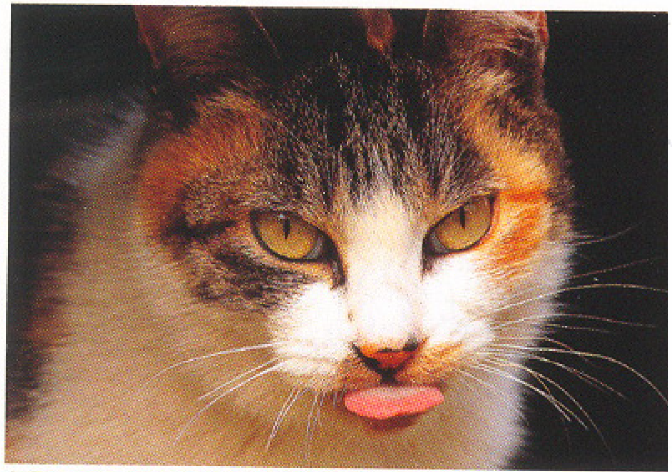
70mm 1/25s IS (iso 1600, f/5)

CSAIL

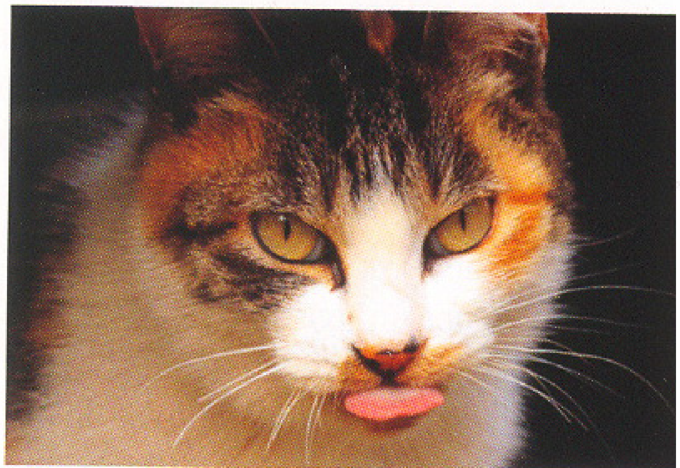
70mm 1/25s IS (iso 1600, f/5)

CSAIL

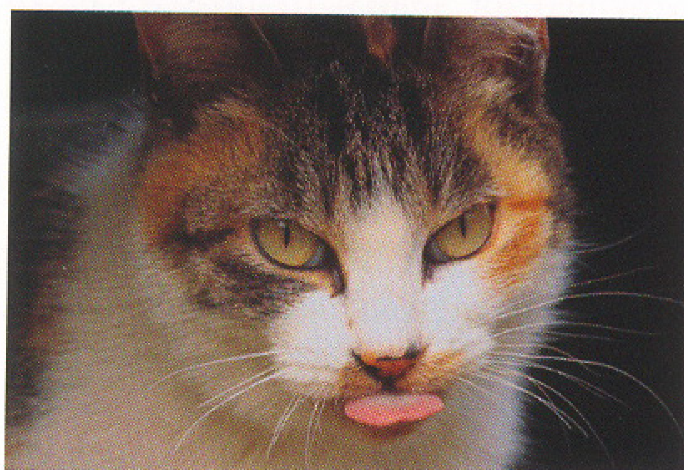
- **MTF**



A:Resolving power and contrast are both good



B:Contrast is good and resolving power is bad

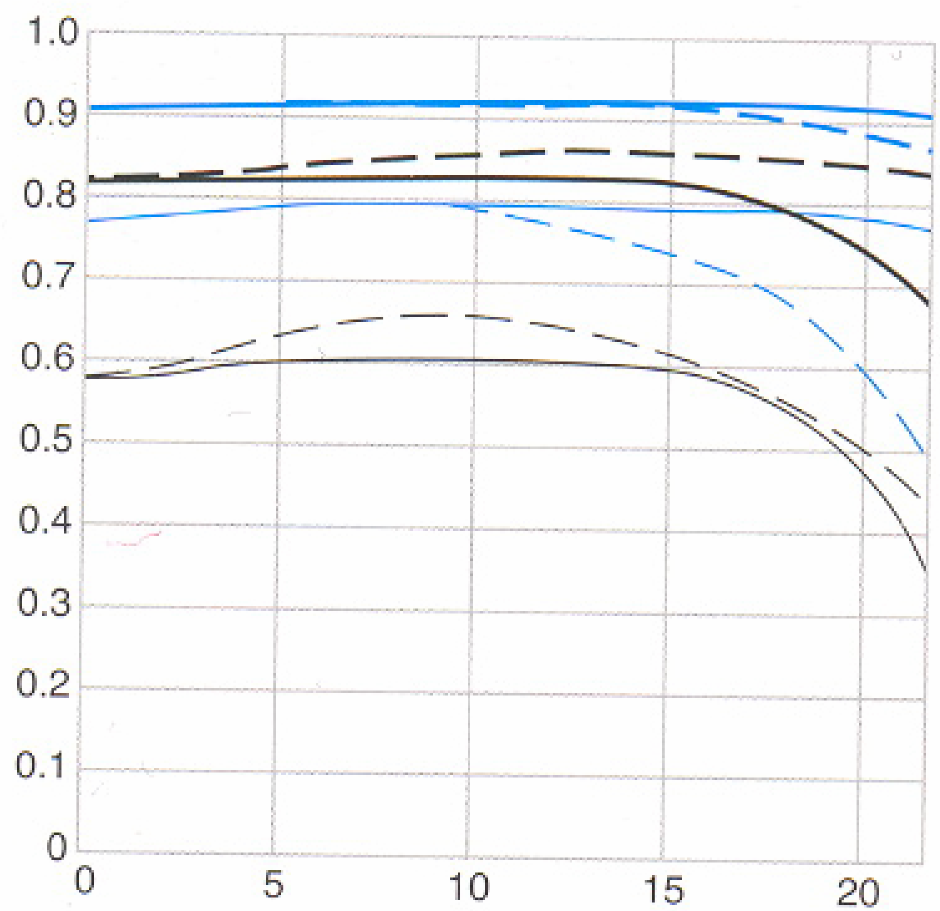


C:Resolving power is good and contrast is bad

Table-3

Spatial frequency	Maximum aperture		F 8	
	S	M	S	M
10 lines/mm	━━━ (thick black)	━ ━ ━ (thick black)	━━━ (thick blue)	━ ━ ━ (thick blue)
30 lines/mm	─── (thin black)	─ ─ ─ (thin black)	─── (thin blue)	─ ─ ─ (thin blue)

Graph-5 MTF Characteristics



source: canon red book

New blur index based on Photoshop!

- **100 macro:** http://www.slrgear.com/reviews/showproduct.php/product/157/sort/2/cat/10/page/1
- **50mm f/1.4** http://www.slrgear.com/reviews/showproduct.php/product/140/sort/2/cat/10/page/2
- **16-35mm** http://www.slrgear.com/reviews/showproduct.php/product/142/sort/2/cat/11/page/1
- **55-200** http://www.slrgear.com/reviews/showproduct.php/product/141/sort/2/cat/11/page/1
- **28-135** http://www.slrgear.com/reviews/showproduct.php/product/139/sort/2/cat/11/page/1
- **18-55** http://www.slrgear.com/reviews/showproduct.php/product/137/sort/2/cat/11/page/1
- **17-85** http://www.slrgear.com/reviews/showproduct.php/product/136/sort/2/cat/11/page/1
- **10-22** http://www.slrgear.com/reviews/showproduct.php/product/135/sort/2/cat/11/page/1

Bottom line

- http://www.photozone.de/3Technology/lenstec4.htm
- **Yes, you can get a cheap & razor sharp high-quality lens: look for a prime in the 35-100mm range**
  - e.g. Canon 85mm f/1.8, 50mm f/1.8