

# Photographic Technology

## PhotoTechEDU series

Lecture 2: January 24, 2007

Camera, Eye, and Color

(revised title not matching the video)

Richard F. Lyon

Google Research

dicklyon@google.com

## CHAPTER 3

### THE THEORY OF STOPS

#### Aperture stop

The diameter of the pencil of light that enters any optical system is limited actually by a physical opening called the *aperture stop*. Effectively, however, it is not limited by the dimensions of the aperture stop, but by the dimensions of a virtual image that the optical system forms

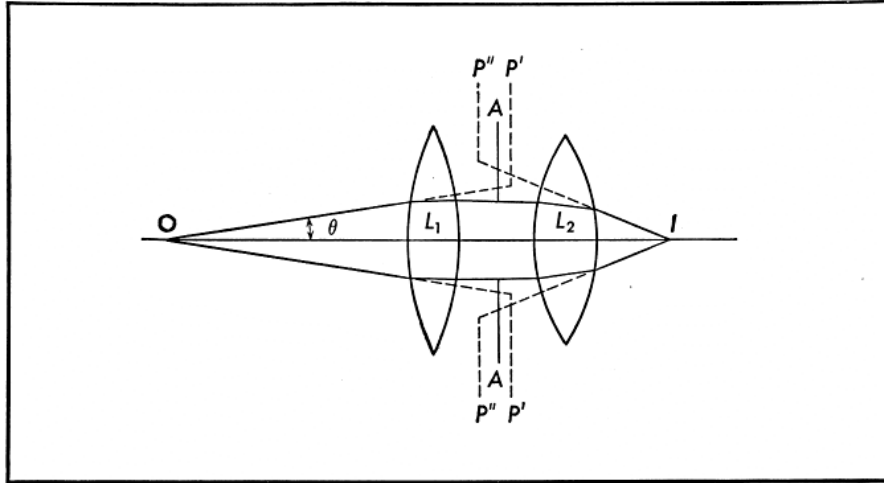


Figure 10 Entrance and exit pupils

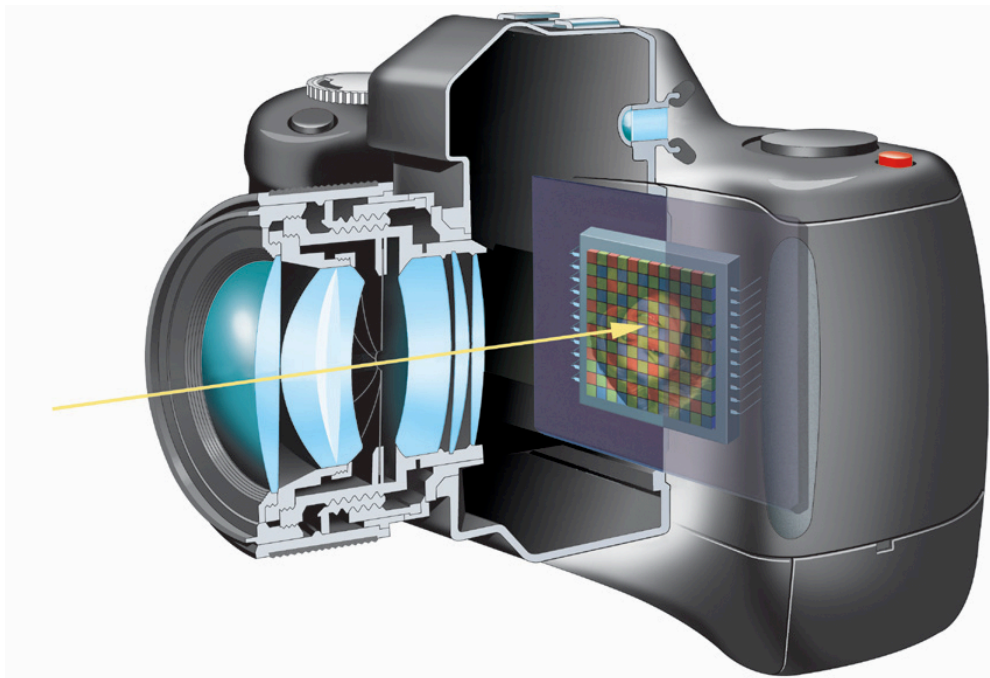
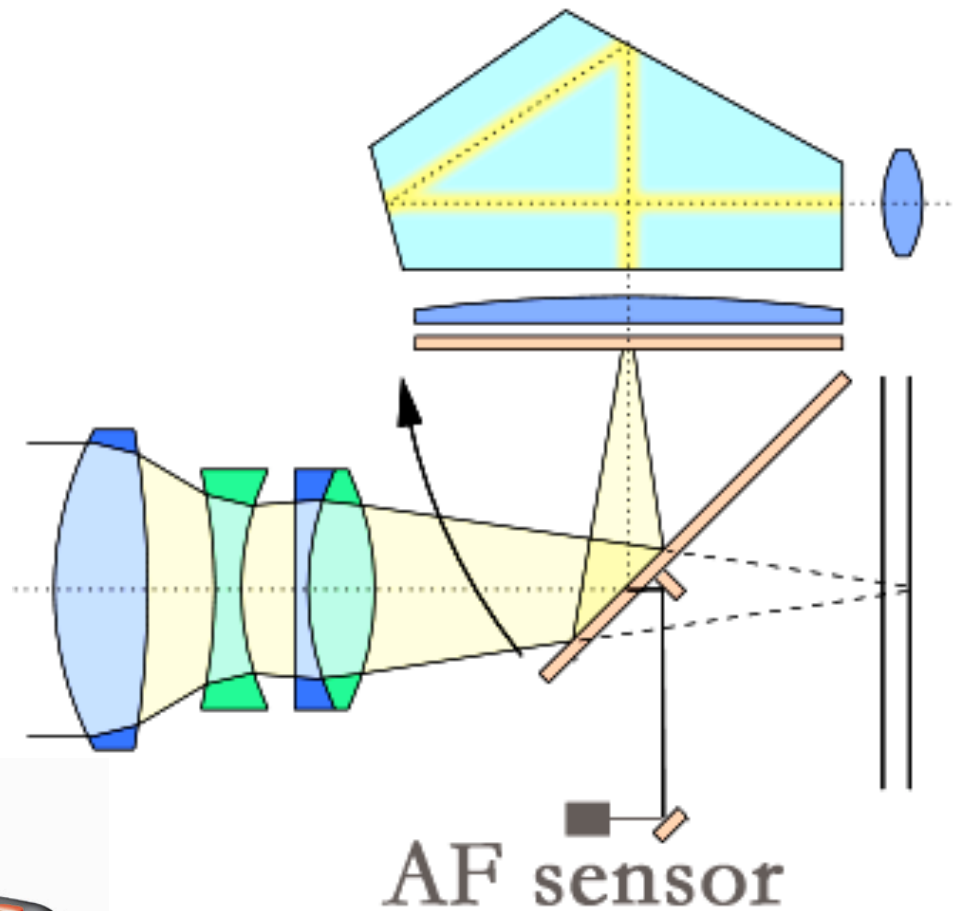
of the aperture stop. This is best explained by reference to Figure 10, in which  $O$  is an object point and  $I$  is its image formed by the compound lens system consisting of the single lenses  $L_1$  and  $L_2$ .  $A$  is the actual aperture stop or diaphragm;  $P'$  is the virtual image of  $A$  that is formed by  $L_1$ ;  $P''$  is the virtual image of  $A$  that is formed by  $L_2$ . It is evident that any ray originating at  $O$  that would pass through  $P'$  if it were not refracted by  $L_1$ , must pass through  $A$  after refraction. Therefore  $P'$  effectively limits the diameter of the entering pencil of light.

Stops and pupils:  
what they are and why  
they matter.

Pupils are virtual  
images of the aperture  
stop. Entrance: pano  
center of rotation; exit:  
chief ray angle incident  
at sensor.

A. R. Greenleaf,  
*Photographic Optics*,  
MacMillan 1950.

# Single-lens reflex with auto-focus



# Personal but stable processing infrastructure for experimental and field work

Processes' nöthig sind, mit auf die Reise genommen werden müssen, ja noch mehr, der Photograph bedarf eines transportablen dunkeln Raumes, worin er seine lichtempfindlichen Platten präpariren kann.

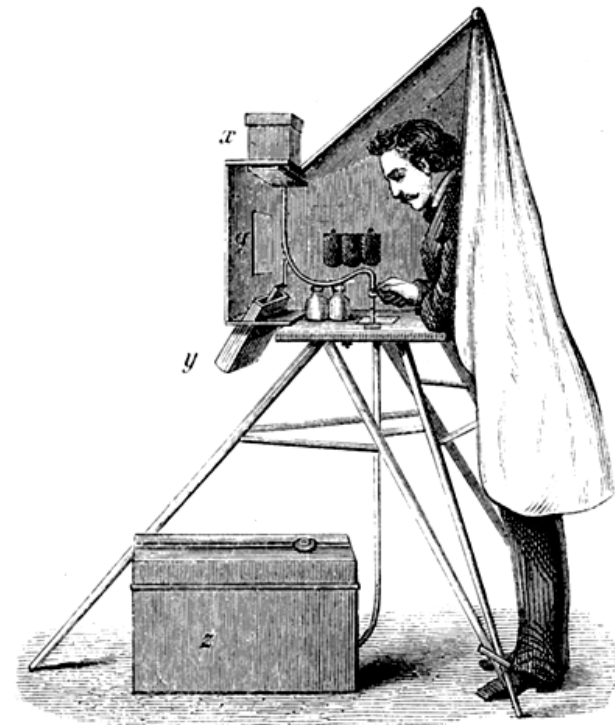


Fig. 68.

Beifolgende Figur stellt einen solchen transportablen dunkeln Raum mit dem darin arbeitenden Photographen dar. Der Arbeiter befindet sich nur mit seinem Oberkörper im Zelt, der Raum zwischen ihm und dem Zelt ist aber durch die Draperie lichtdicht verhüllt. Der Transportabilität wegen ist alles in solchem „Dunkelzelt“ auf den kleinsten Raum concentrirt. Ein gelbes Fenster *q* erleuchtet das Innere, das Silberbad steckt in einem Kasten bei *y*, das nöthige Wasser



THE   \*   \*   \*   \*  
KODAK  
\*   \*   \*   \*   CAMERA.  
=====

THIS wonderful little Camera has conquered the world. Those who are at all interested in Photography who have not made themselves the owner of one of these remarkable instruments, have missed more real pleasure than they could ever imagine possible to get out of photography. It is the only Camera that is always ready and never a burden. It is exactly what we claim for it, “**a photographic note book,**” and no larger Camera can ever take its place in its especial field.

*“You Press the Button, We do the Rest.”*

It affords the simplest and easiest means for making Photographs, and can be used by novices as well as experts.

Send for a KODAK PRIMER.

THE EASTMAN DRY PLATE & FILM CO.,

Rochester, New York.

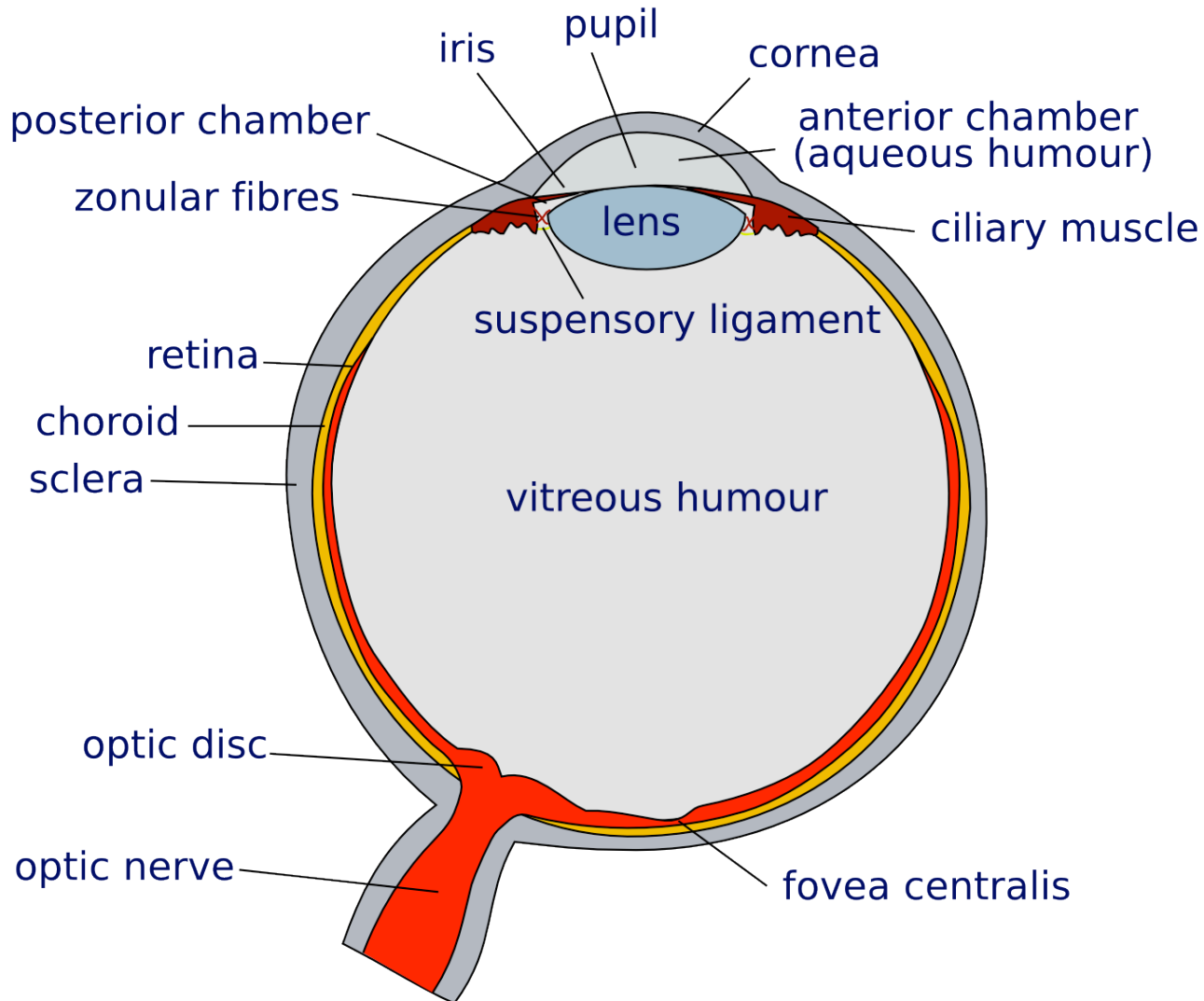
No. 115 Oxford St., London.

Automated  
back-end  
processing  
pipelines:

*“You Press the  
Button, We do  
the Rest.”*

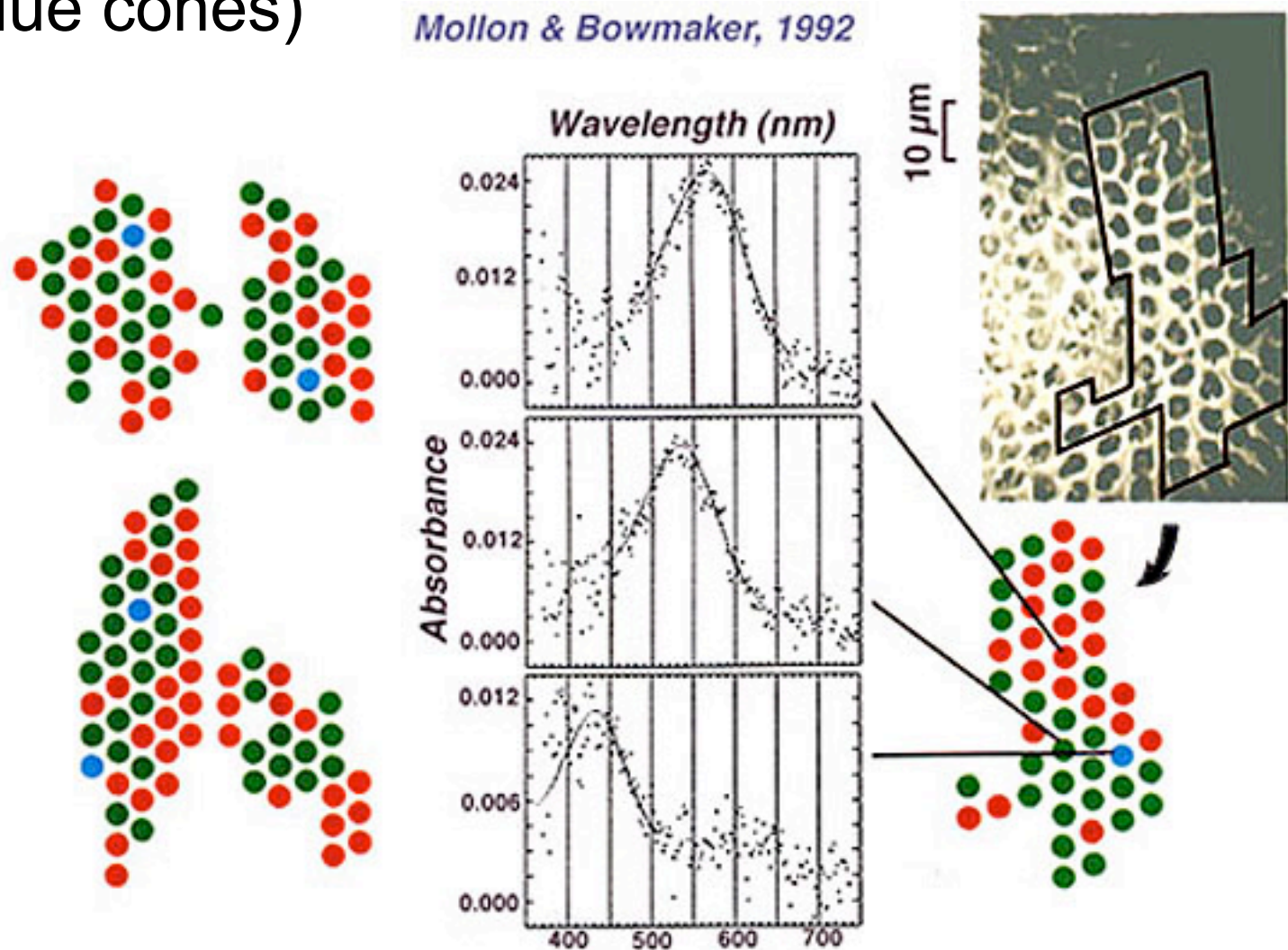
Fig. 9. An advertisement from the *American Annual of Photography* for 1890.

# Human eye as a camera: has lens, pupil, iris, sensor, etc.



# How do Humans See Color?

- Packed mosaic of cones in the *fovea centralis* (few blue cones)



# Maxwell's 1860 color-matching functions: three sensations, not independently stimulatable

Fig. 6.

VOL. I. PLATE VI. (1)

Fig. 7.

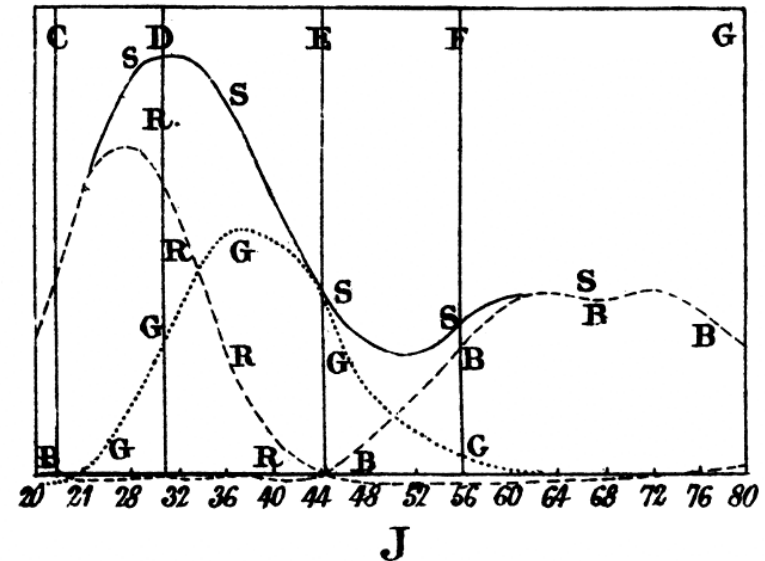
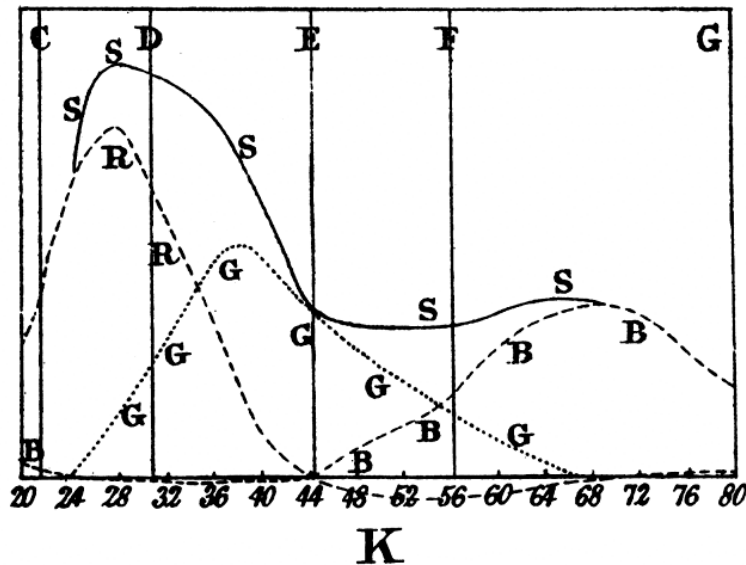
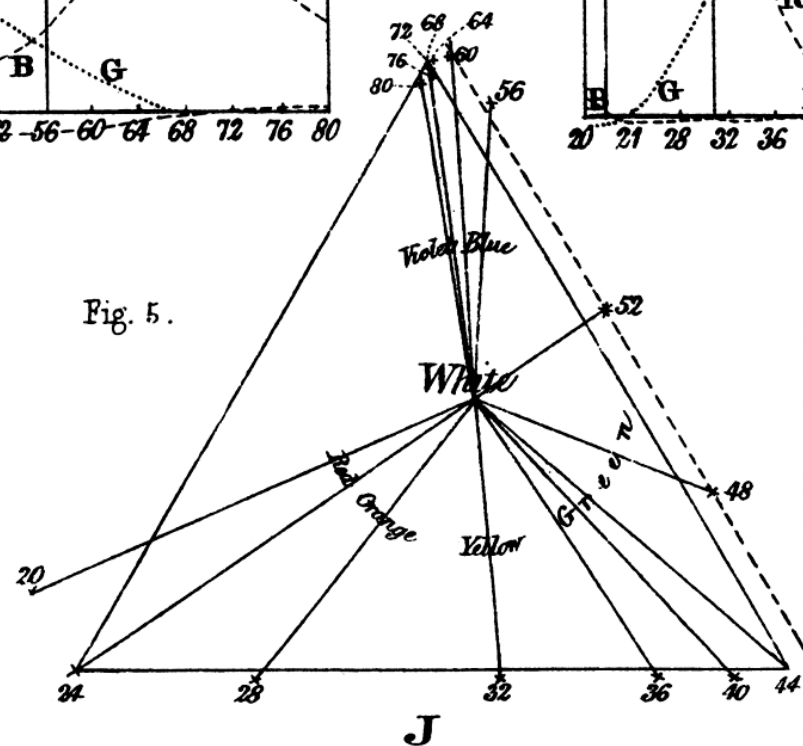


Fig. 5.

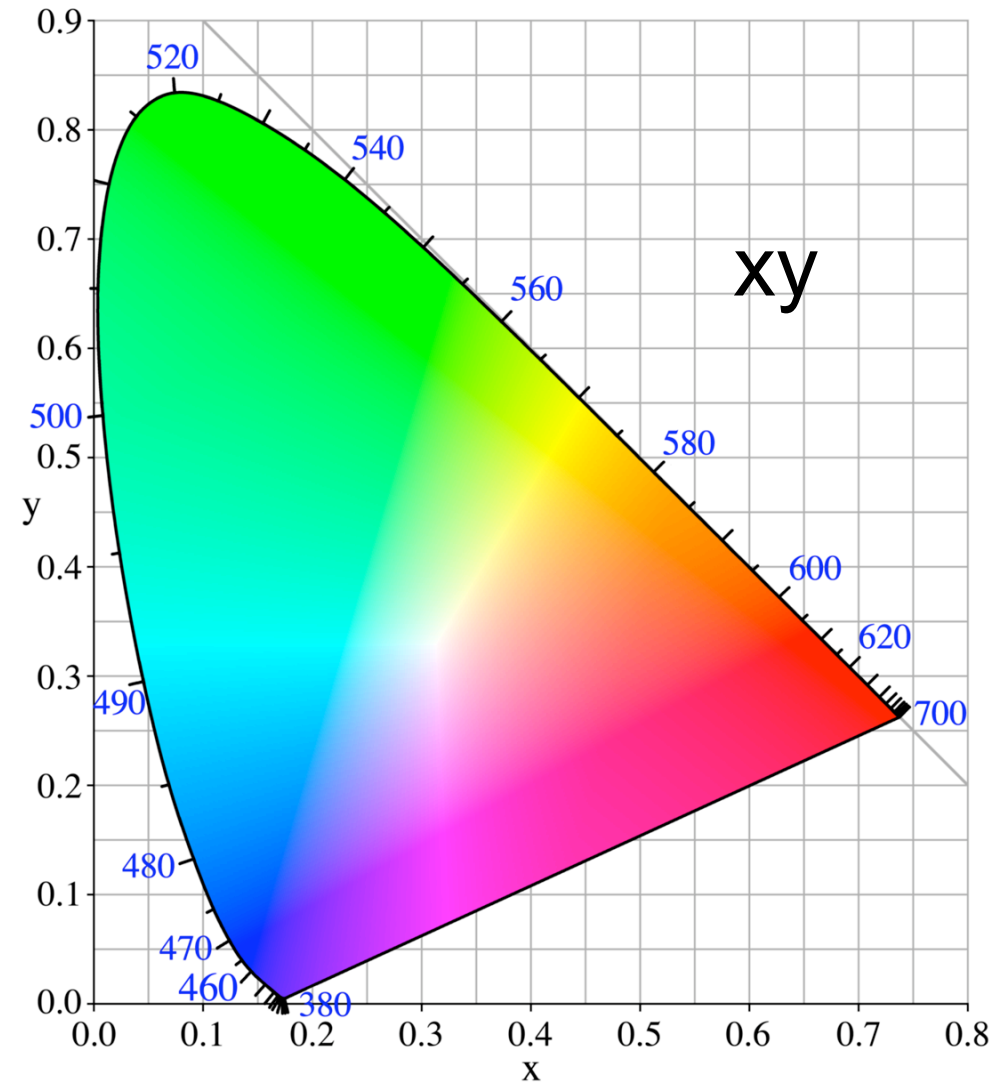
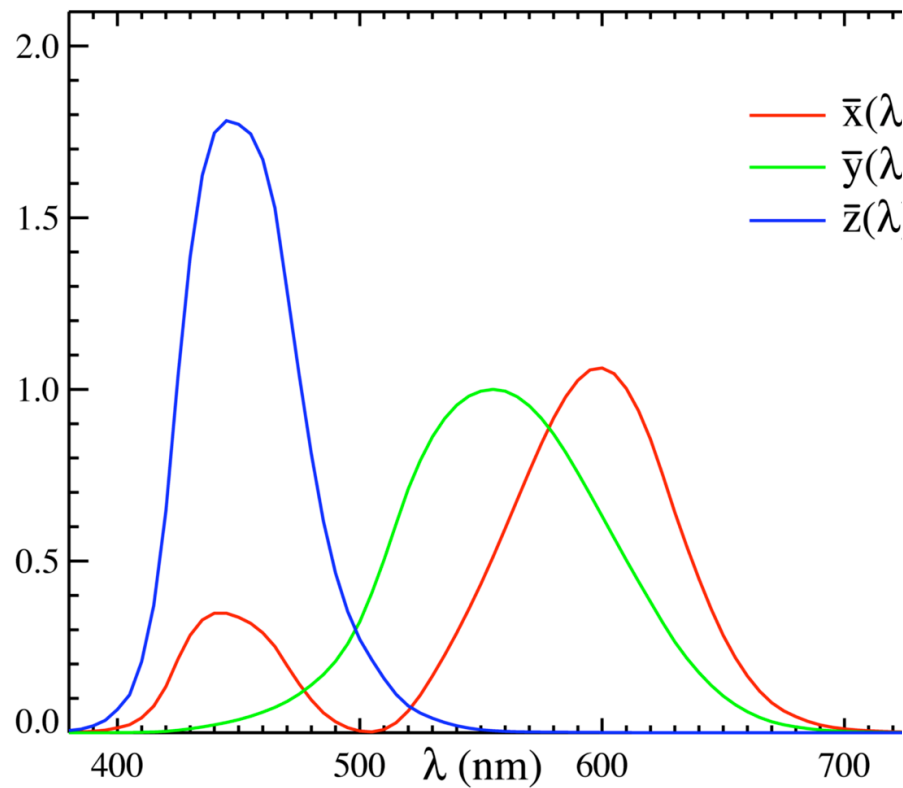


# The Young–Helmholtz tri-chromatic color theory by James Clerk Maxwell

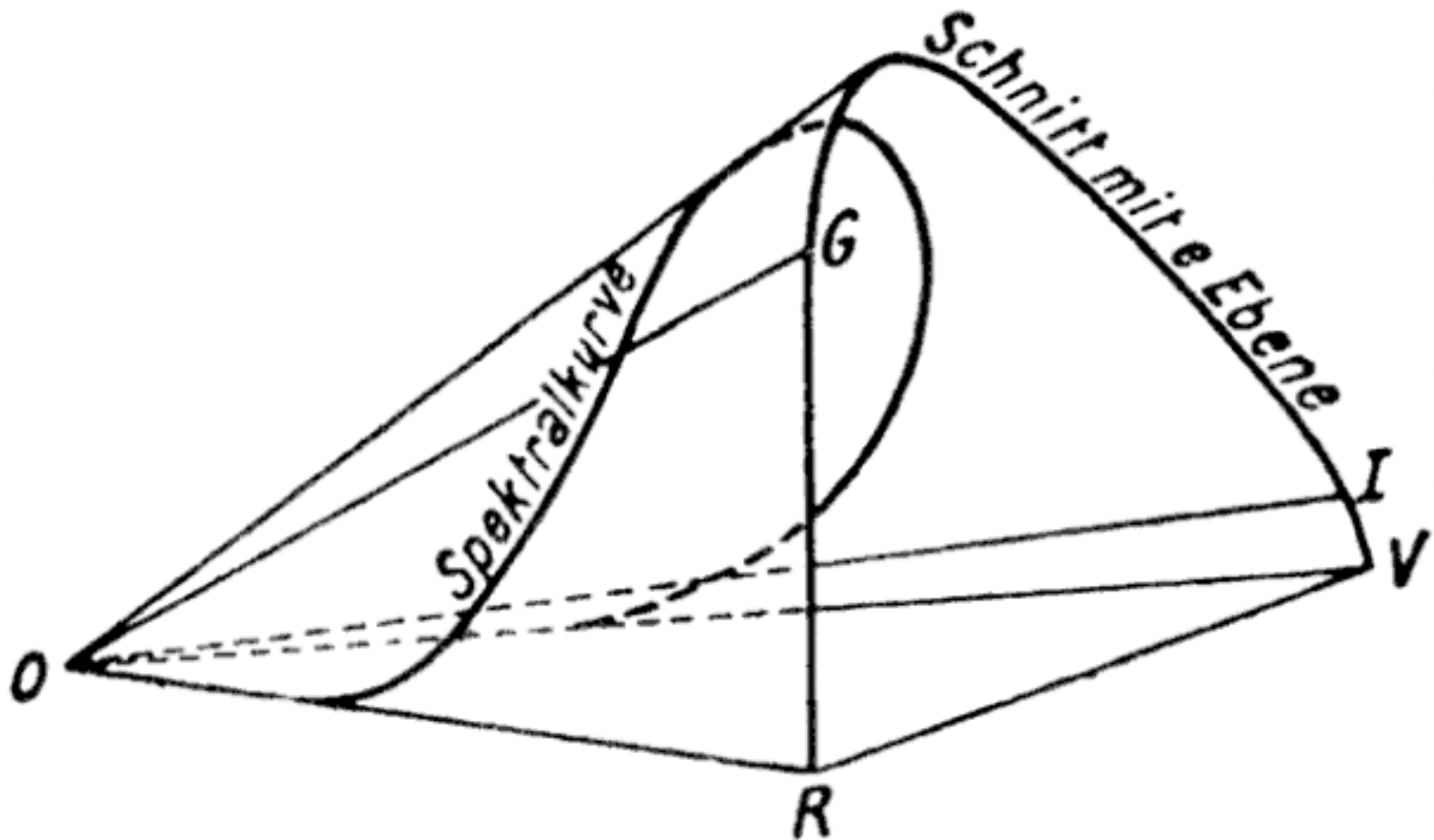


First color photo:  
additive three-  
projector  
reconstruction

# CIE 1931 XYZ color-matching functions and XYZ color space

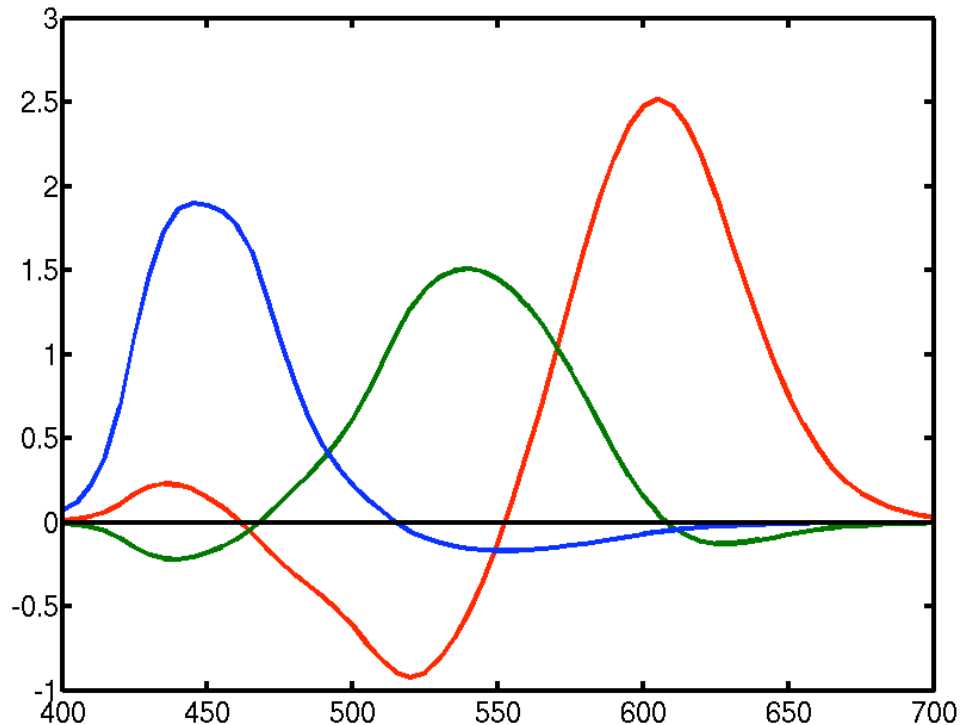


# Erwin Schrödinger's 1920 *Farbenmetrik*

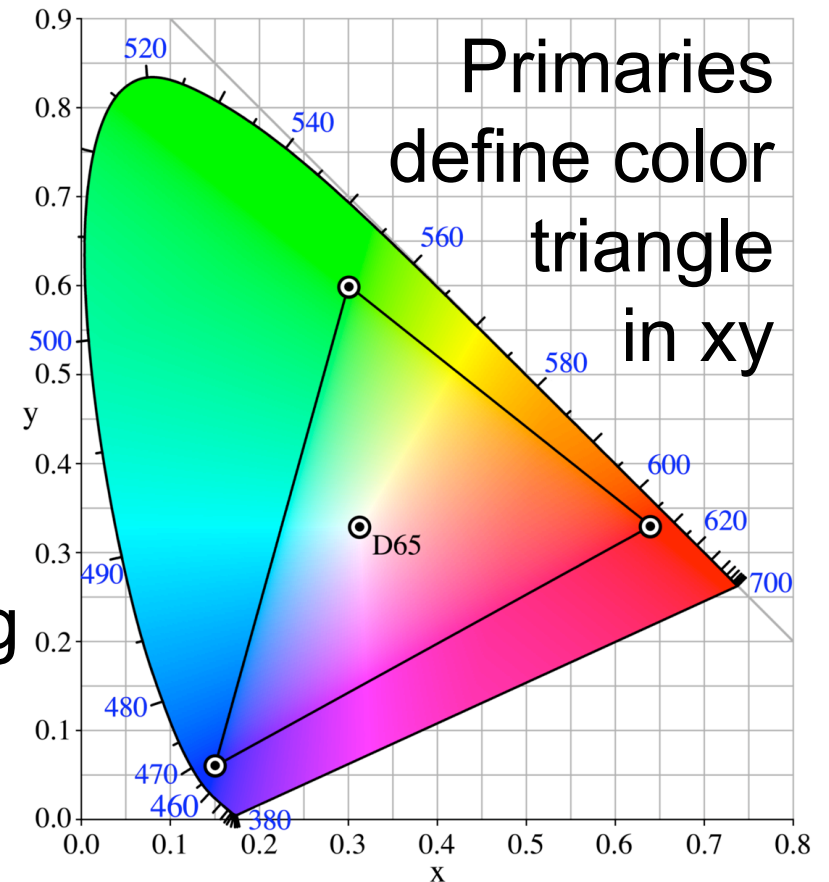
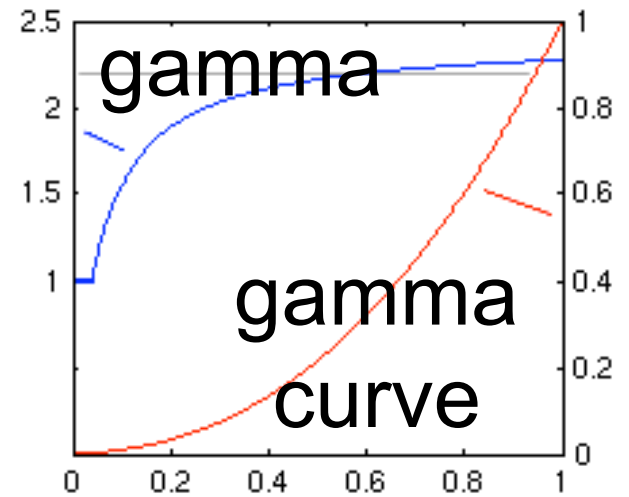




# Color-matching functions and color spaces



sRGB: defined by color matching functions or primaries, and whitepoint and gamma curve





# Color one-shot three-plate cameras

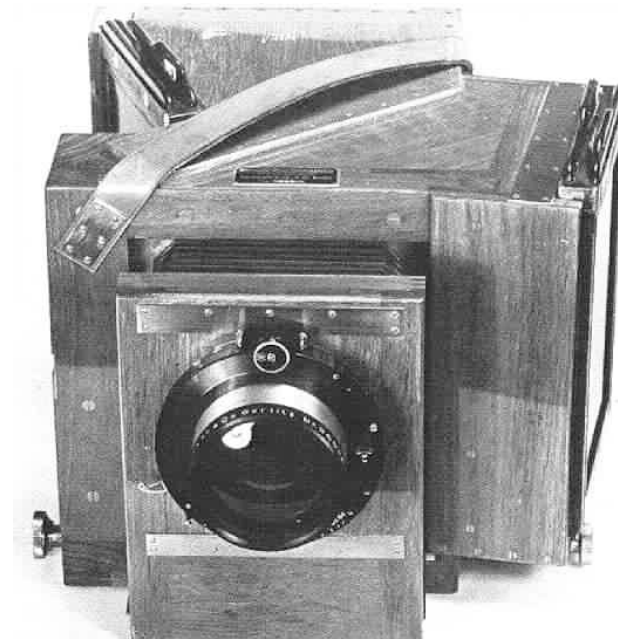
1932

Devin Tri-Color



Fig. 16. — Louis Ducos du Hauron (1).

Louis Ducos du Hauron  
1873



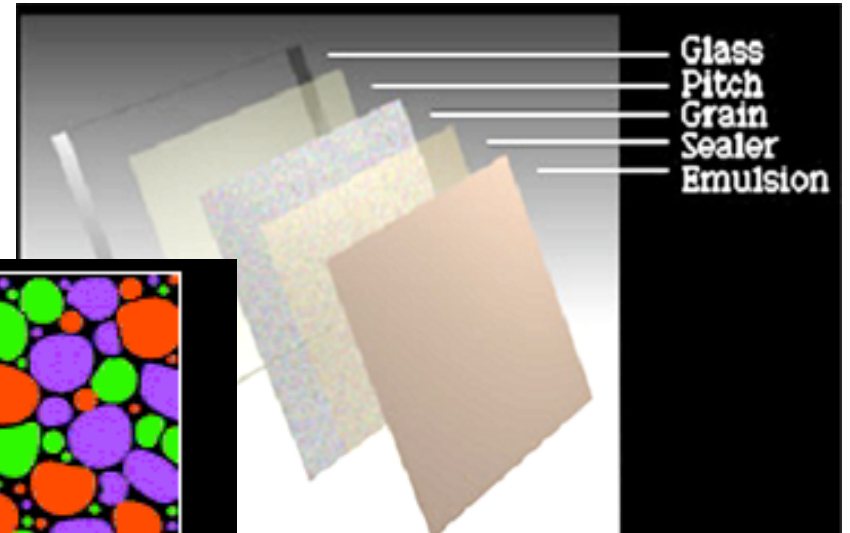
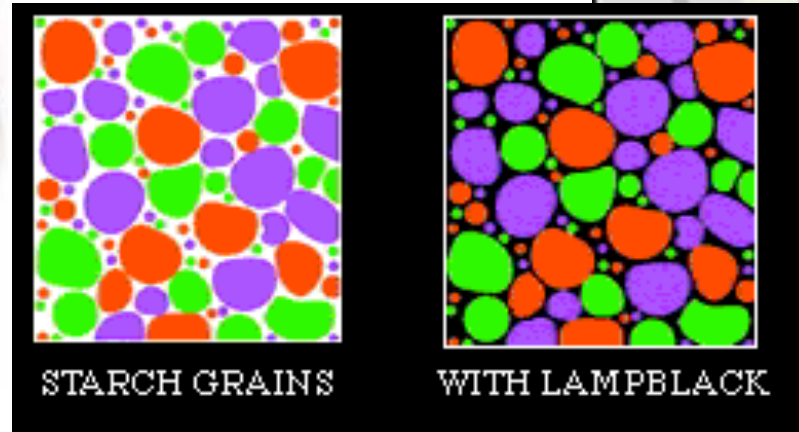




L. DUCOS DU HANON. 1877.



# Auguste and Louis Lumière



1906: Autochrome, a photographic transparency plate patented by the Lumière brothers of Lyons, France.

Grains of potato starch dyed orange, green, and violet.

This screen of grains worked as a filter mosaic, exposing a panchromatic emulsion. The exposed plate was then reversal processed resulting in a transparency, and was viewed through the same filter grains.

# Autochrome – Color Filter Mosaic



[http://www.ilford.com/html/us\\_english/autochrome/auto86.jpg](http://www.ilford.com/html/us_english/autochrome/auto86.jpg)



# Three-shot color



<http://www.loc.gov/exhibits/empire/gorskii.html>



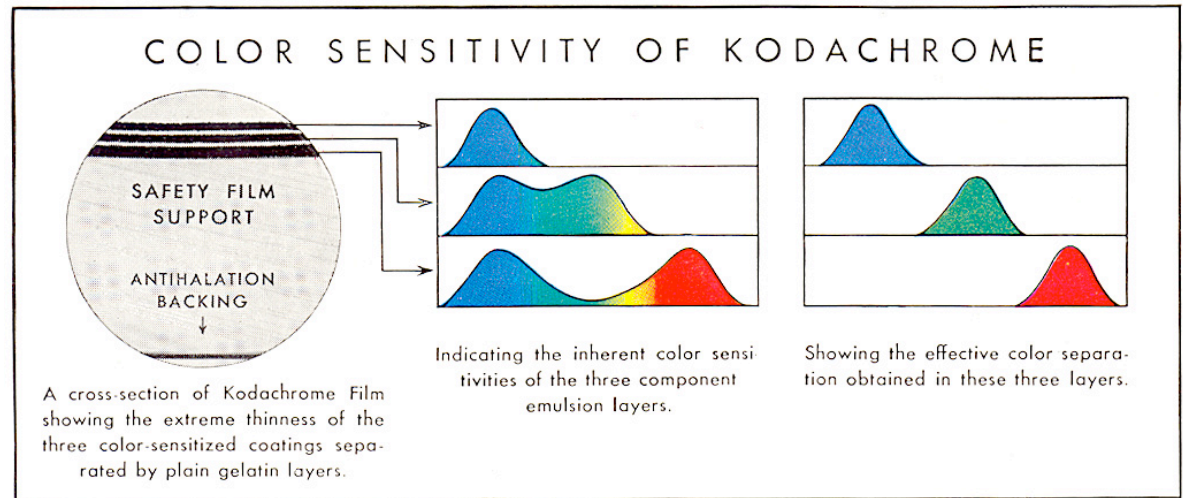
Sergei  
Mikhailovich  
Prokudin-  
Gorskii:  
Photographer  
to the Tsar  
1908–1915

Austro-  
Hungarian  
Prisoners of  
World War I

# The Silver Solution: Kodachrome



Leopold Mannes and  
Leopold Godowsky, Jr.  
of Eastman Kodak Co.



## Senses colors in layers

- one shot
  - no motion problems
- all colors at all locations
  - no sampling artifacts
- one piece of film
  - no registration problem



# Three-Shot Color Photography with Vidicon TV Tube



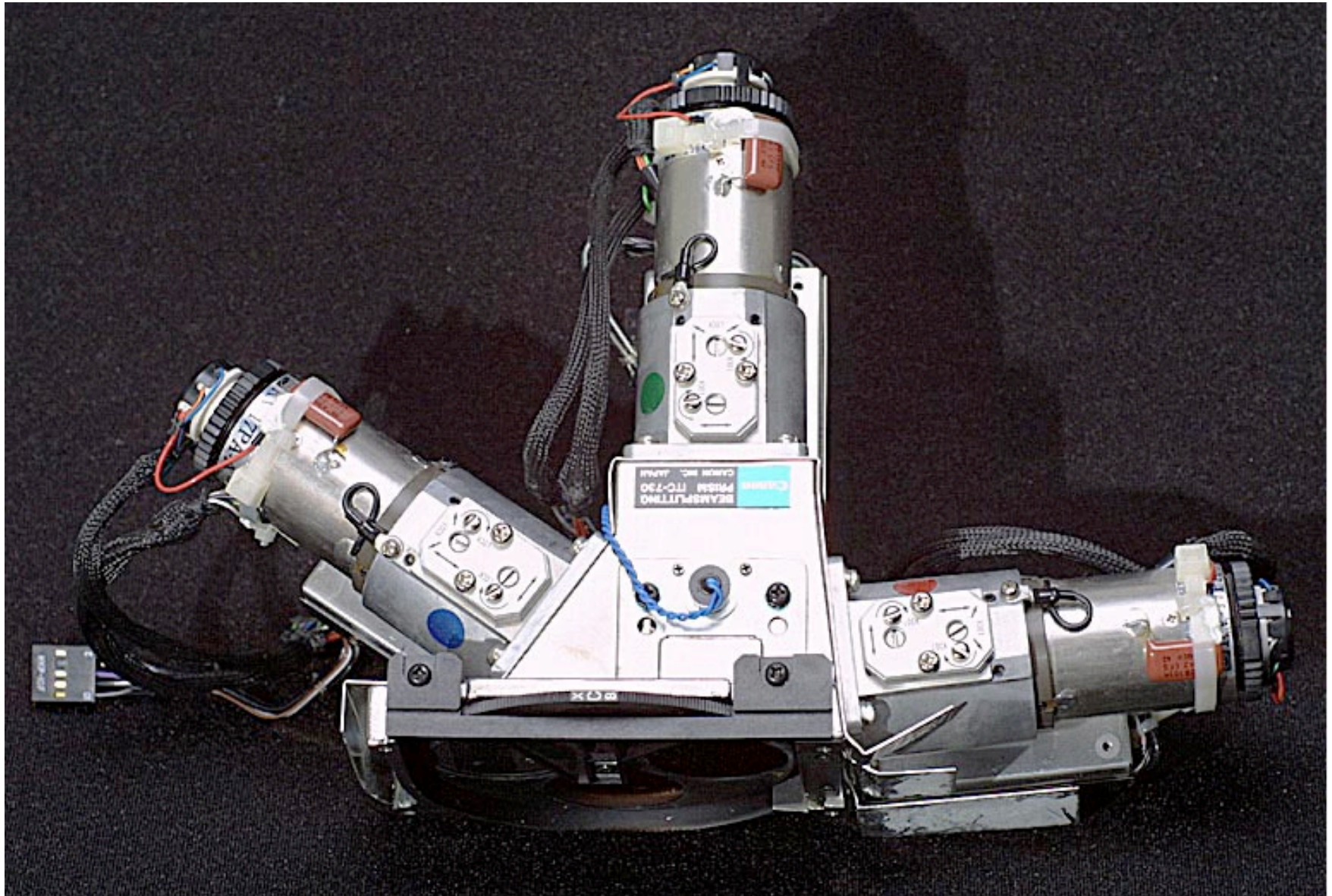
## Surveyor 1 – 1966

<http://history.nasa.gov/SP-168/section2b.htm>

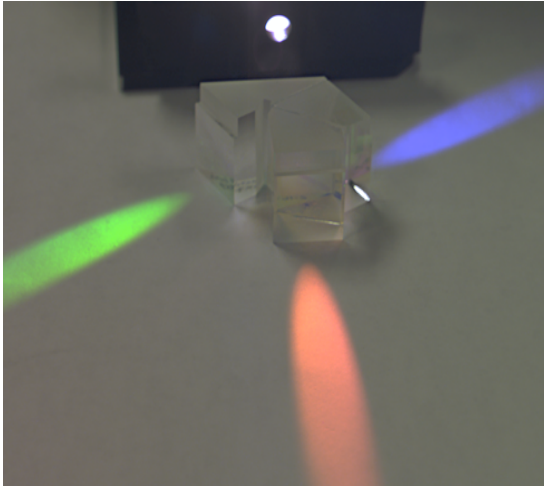
<http://nssdc.gsfc.nasa.gov/database/MasterCatalog?sc=1966-045A&ex=1>



# 3-Tube Color TV Camera



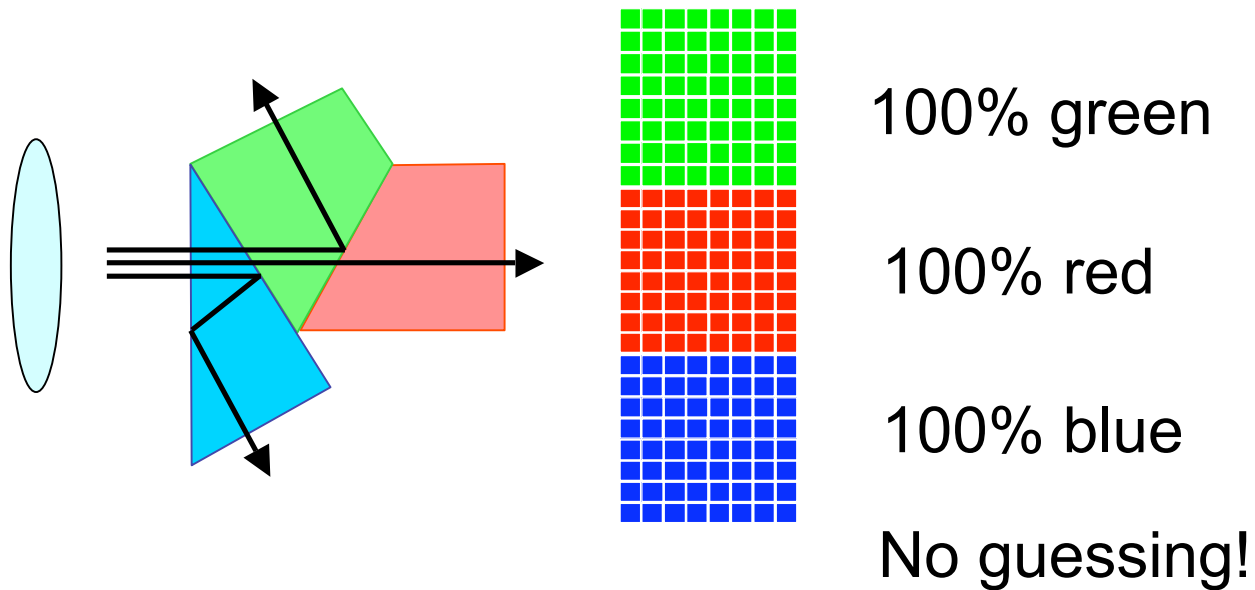




# Prism-based Color Camera

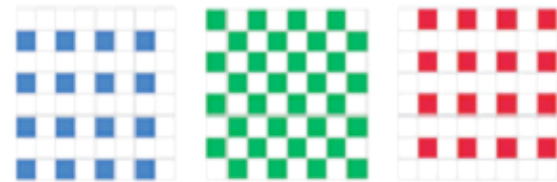
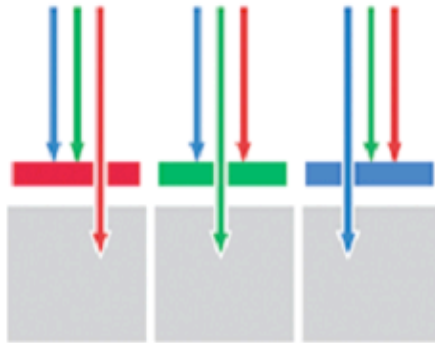
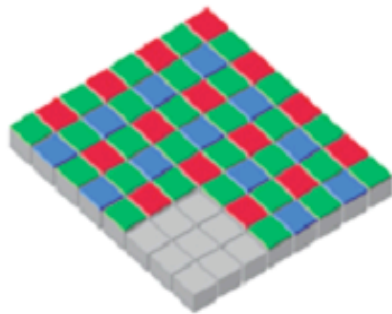


2000 – Foveon II

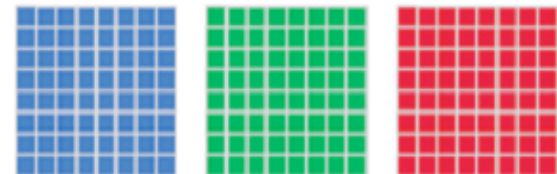
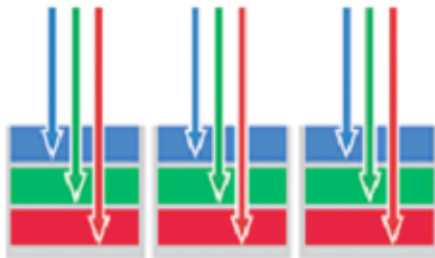
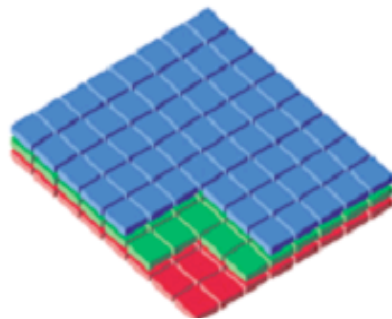


# One-chip color image sensors

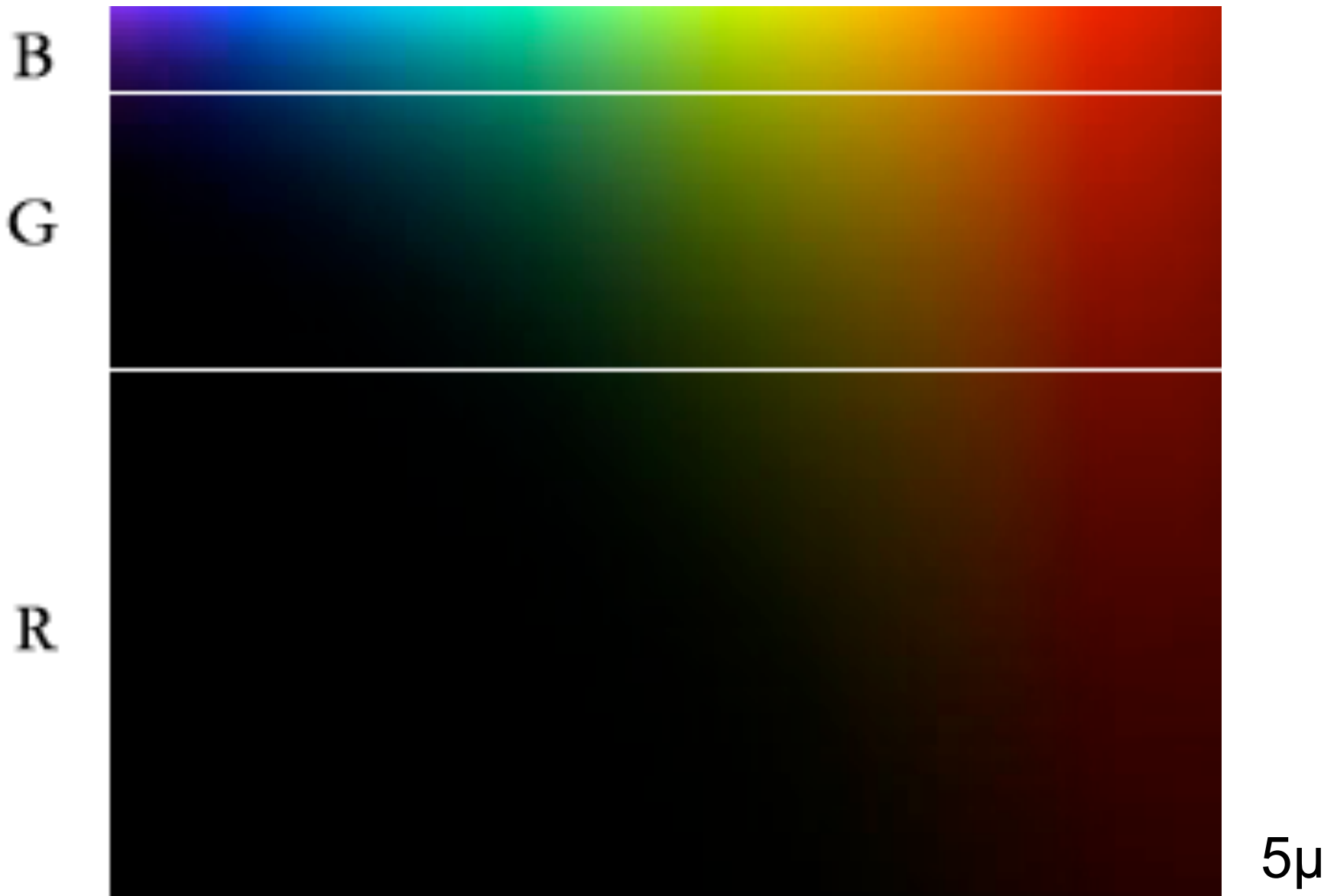
Mosaic Capture



Foveon® X3 Capture



# Absorption of light in Silicon, and depth regions that absorb mostly Blue, Green, and Red





GretagMacbeth  
ColorChecker  
(and me)  
with first  
Foveon X3  
sensor  
prototype  
(2k x 2k x 3)