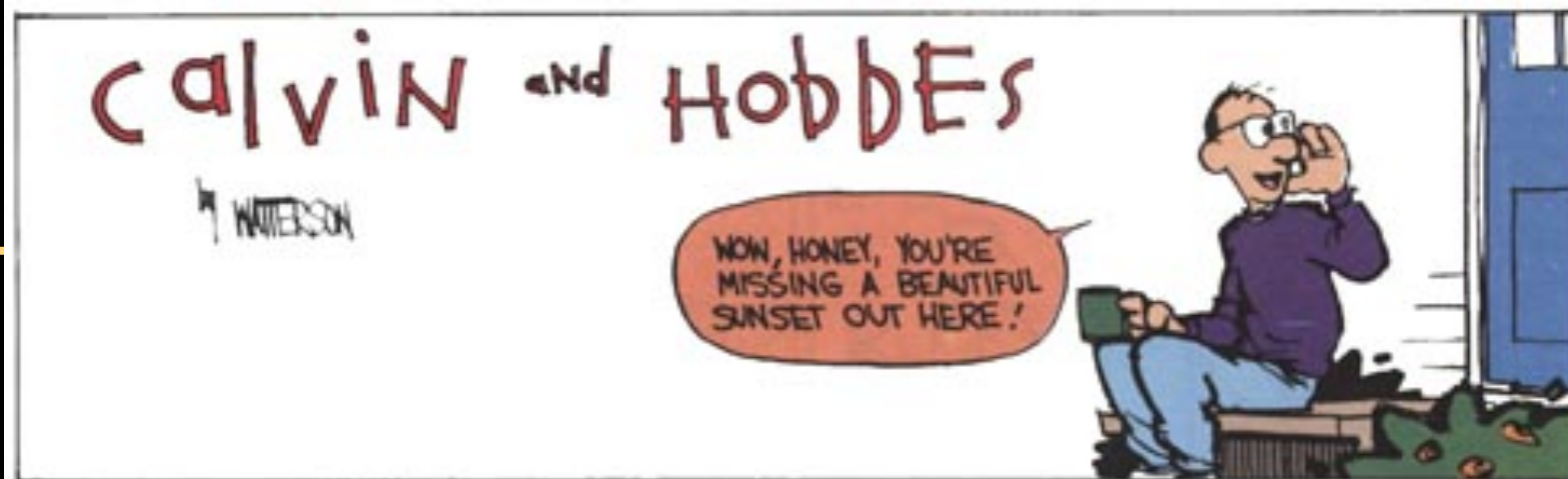


Color



-
- <https://petapixel.com/2026/05/20/youve-probably-never-seen-a-full-spectrum-color-photo/>
 - <https://www.youtube.com/watch?v=-DyrBDsKA5s>
 - <https://www.jonhilty.com/lippmann>
 -

Color



Fredo Durand
MIT EECS 6.8370/6.8371

Motivations

Color

- What does RGB really measure?
- Can RGB record all colors?
- Isn't color about wavelength anyway?
- How does this relate to human eyes?
- What are the primary colors? Red Green and Blue? Red Yellow and Blue ? Red, Green Yellow and Blue ?

Questions?

CLICK



UH OH...



THE SKY IS A DEEP ORANGE! CALVIN'S SKIN IS A PALE GREEN! YELLOW FLOWERS ARE NOW BLUE!



EVERY COLOR IS THE OPPOSITE OF WHAT IT SHOULD BE!



CALVIN HAS BEEN TRANSFERRED TO A COLOR FILM NEGATIVE!



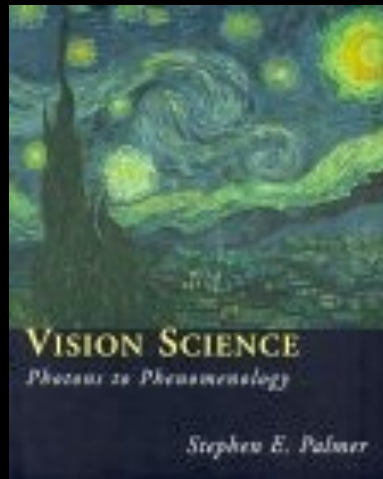
HIS ONLY HOPE IS TO BE PROCESSED BY A 1-HOUR PHOTO FINISHER! DEVELOPER! I NEED DEVELOPER!



DOGGONE IT, CALVIN! THAT'S *ANOTHER* PICTURE RUINED! CAN'T YOU LOOK PLEASANT FOR 1/500TH OF A SECOND?!



Selected Bibliography



Vision Science

by Stephen E. Palmer

MIT Press; ISBN: 0262161834

760 pages (May 7, 1999)

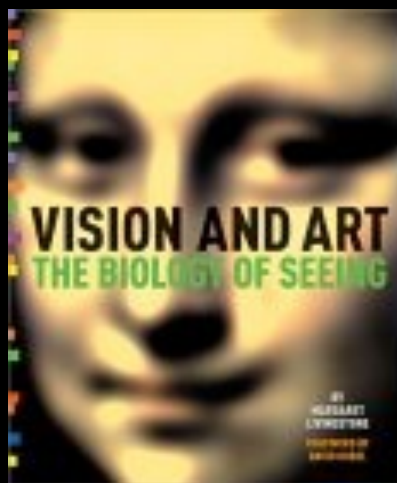


Billmeyer and Saltzman's Principles of Color Technology, 3rd Edition

by Roy S. Berns, Fred W. Billmeyer, Max Saltzman

Wiley-Interscience; ISBN: 047119459X

304 pages 3 edition (March 31, 2000)



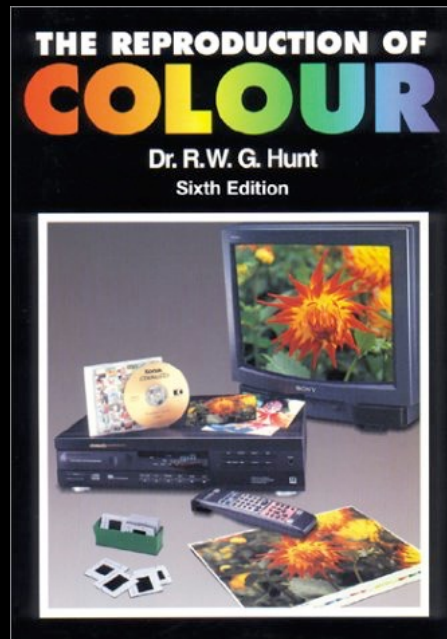
Vision and Art : The Biology of Seeing

by Margaret Livingstone, David H. Hubel

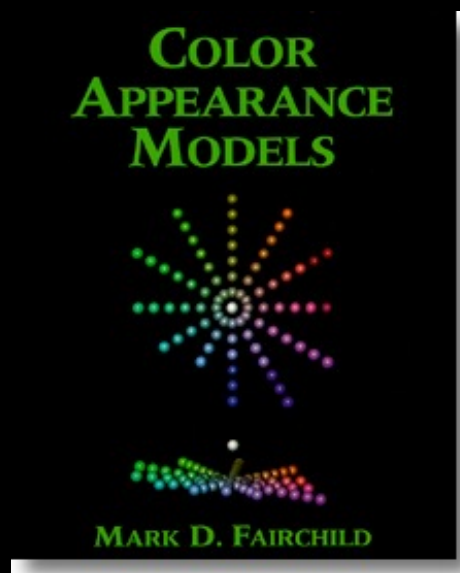
Harry N Abrams; ISBN: 0810904063

208 pages (May 2002)

Selected Bibliography

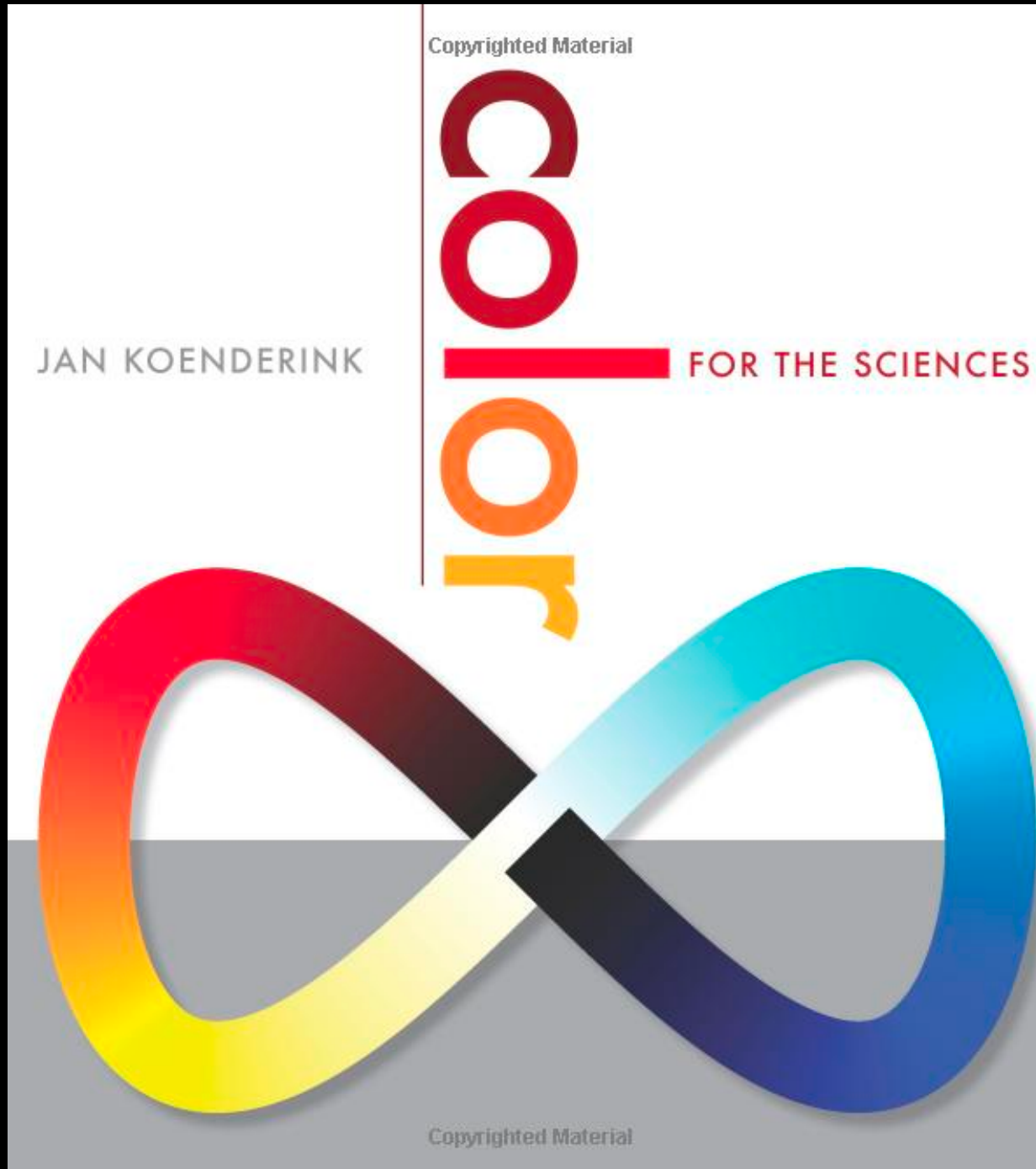


The Reproduction of Color
by R. W. G. Hunt
Fountain Press, 1995



Color Appearance Models
by Mark Fairchild
Addison Wesley, 1998

Selected Bibliography



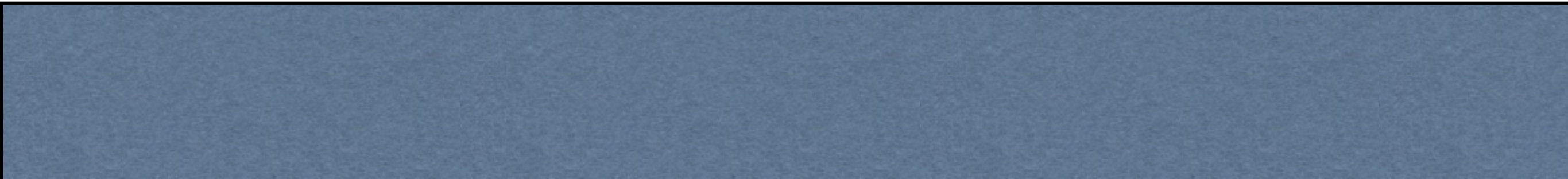
-
- <http://www.blueconemonochromacy.org/what-is-bcm/eye-retina-and-cones-2/>
 - <http://webvision.med.utah.edu/book/part-iii-retinal-circuits/s-cone-pathways/>
 - <http://www.opticsinfobase.org/josa/abstract.cfm?uri=josa-57-11-1289>
 - <http://www.cvrl.org/database/text/intros/introdens.htm>
 - <http://www.cvrl.org/database/text/density/lmintro.htm>

Check out the demo applets

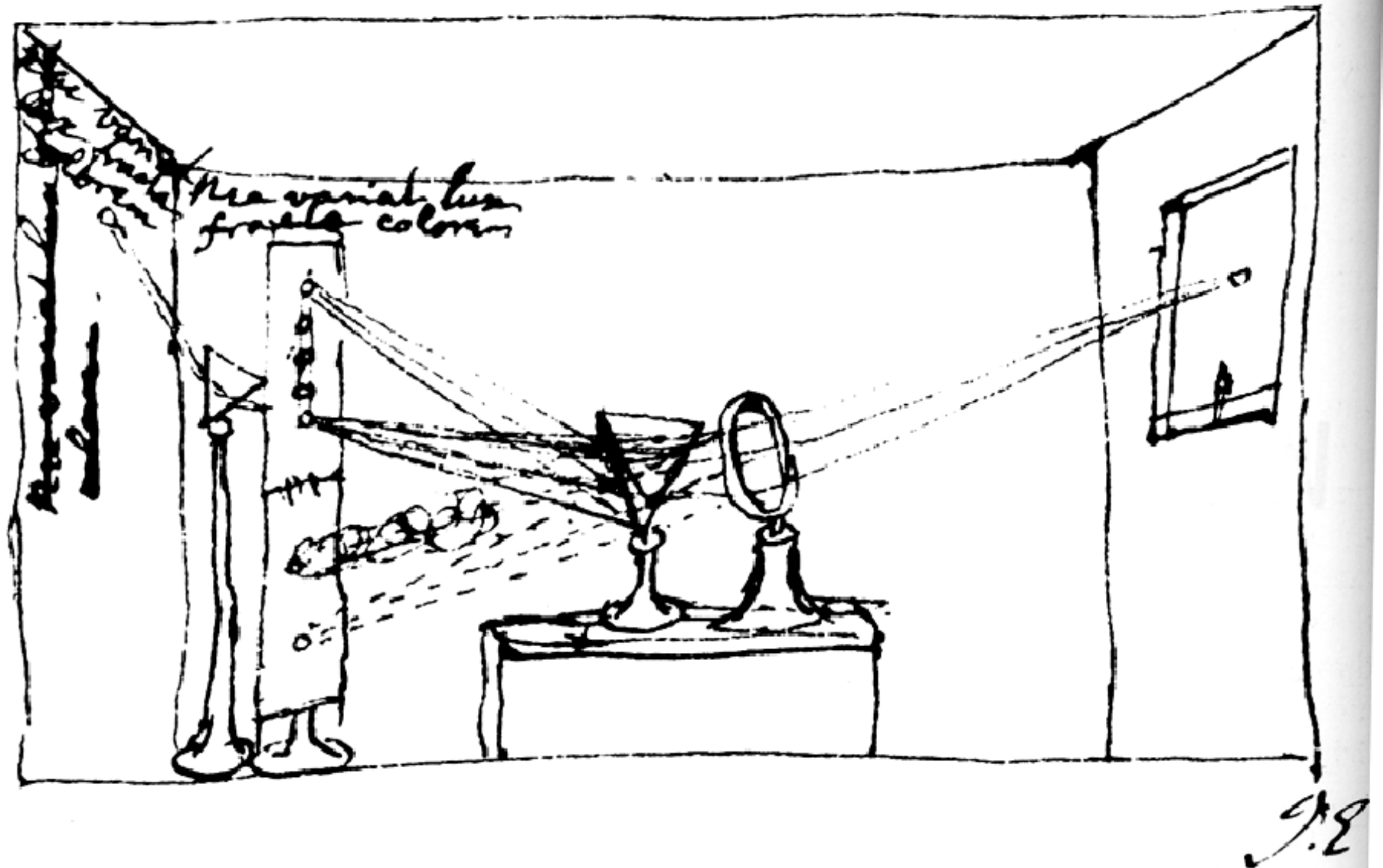
- <http://graphics.stanford.edu/courses/cs178-10/applets/locus.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/colormatching.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/threedgamut.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/gamutmapping.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/colormixing.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/gamma.html>



Physical colors: spectra



Color



4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

From Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

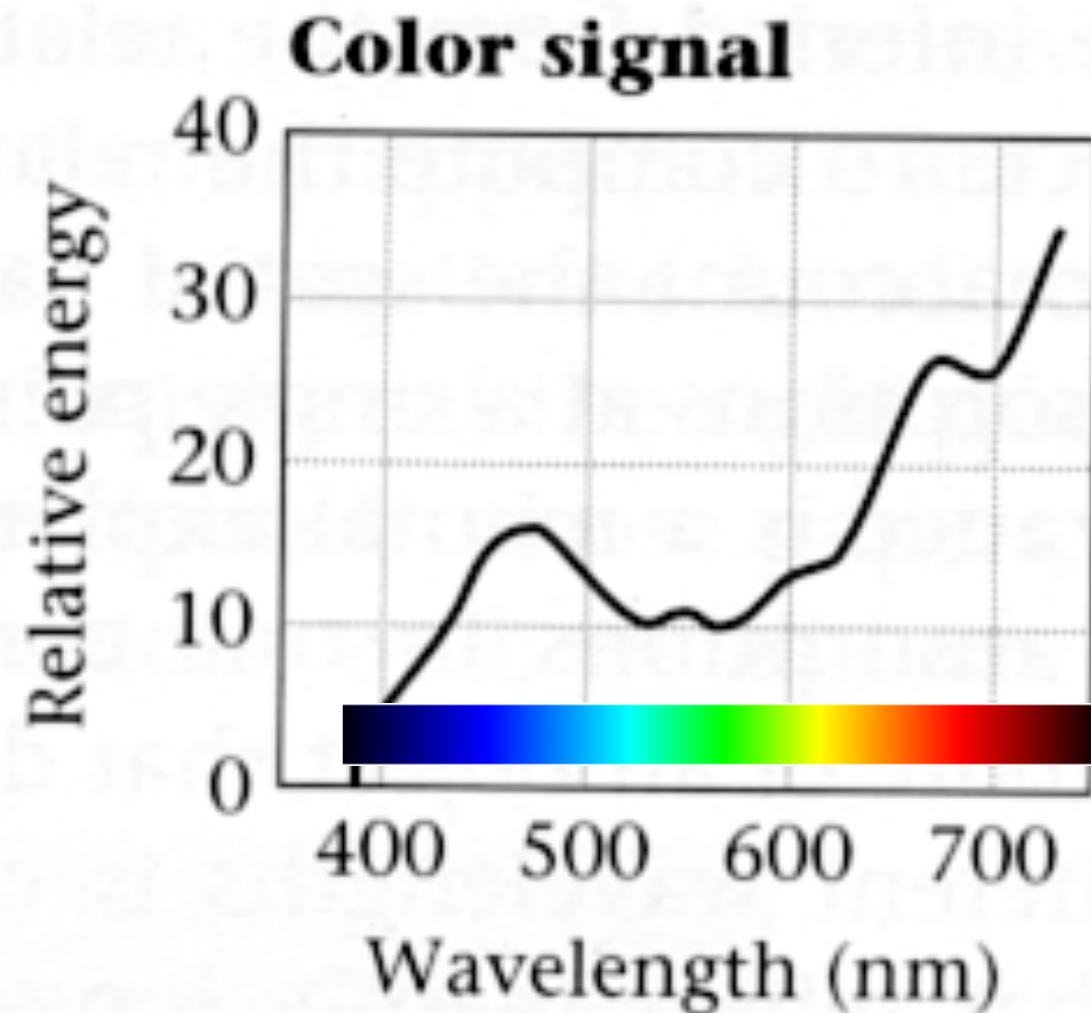
Spectrum



Light is a wave

Visible: between 450 and 700nm

Spectrum

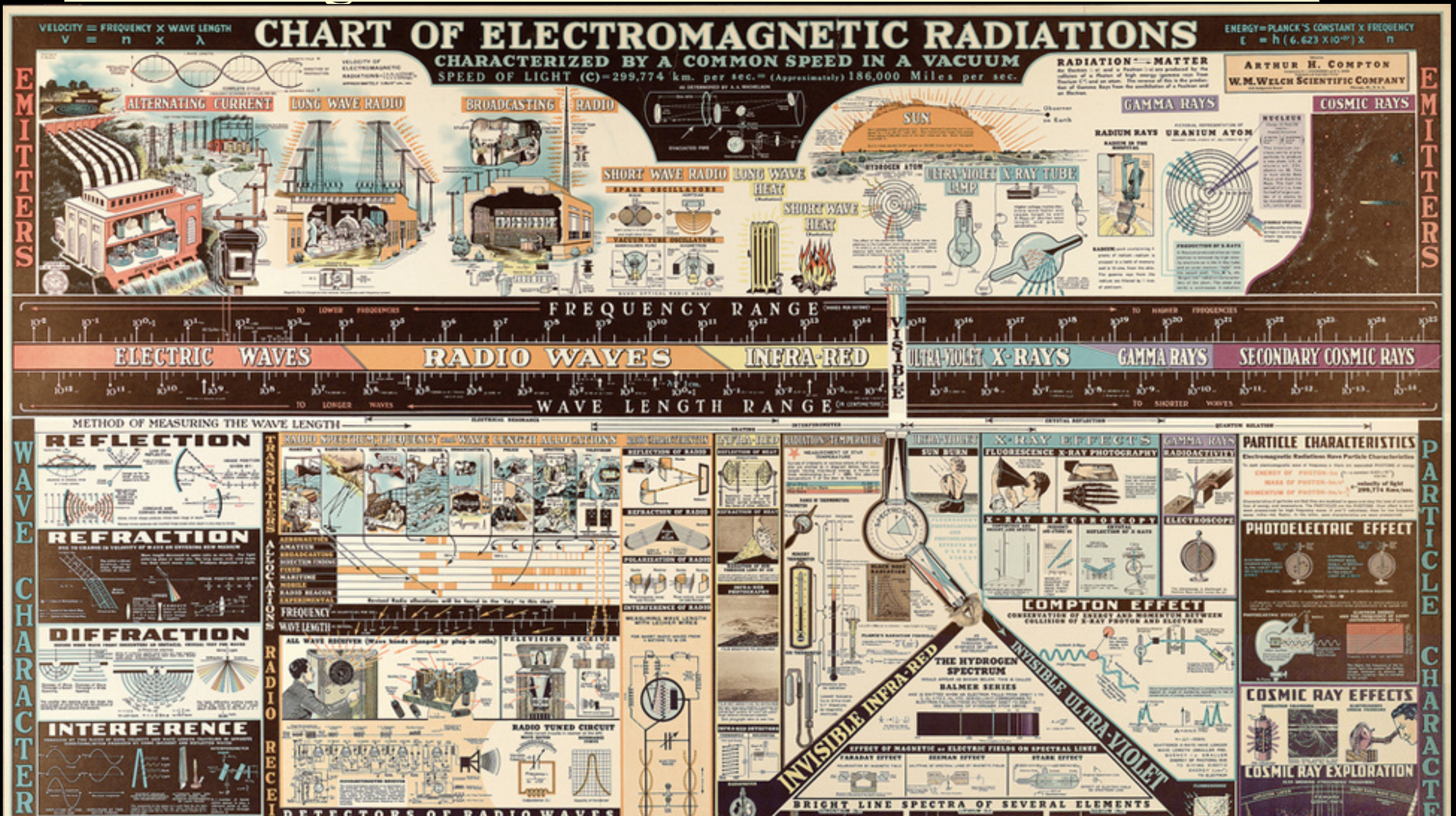


Light is characterized by its spectrum:
amount of energy at each wavelength

This is a full distribution:

one value per wavelength (infinite number of values)

- <http://gizmodo.com/a-1944-infographic-on-electromagnetic-radiation-makes-1-1019197061>



Spectrum demo

- Diffraction grating:
 - shifts light as a function of wavelength
 - Allows you to see spectra
 - In particular, using a slit light source, we get a nice band showing the spectrum
- See the effect of filters
- See different light source spectra

Figure-58 Diffraction

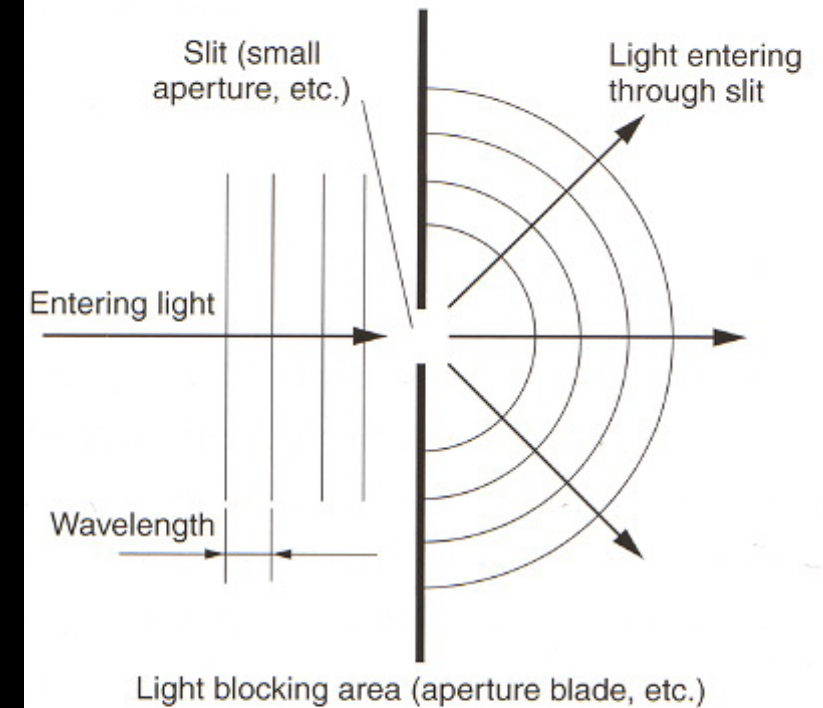
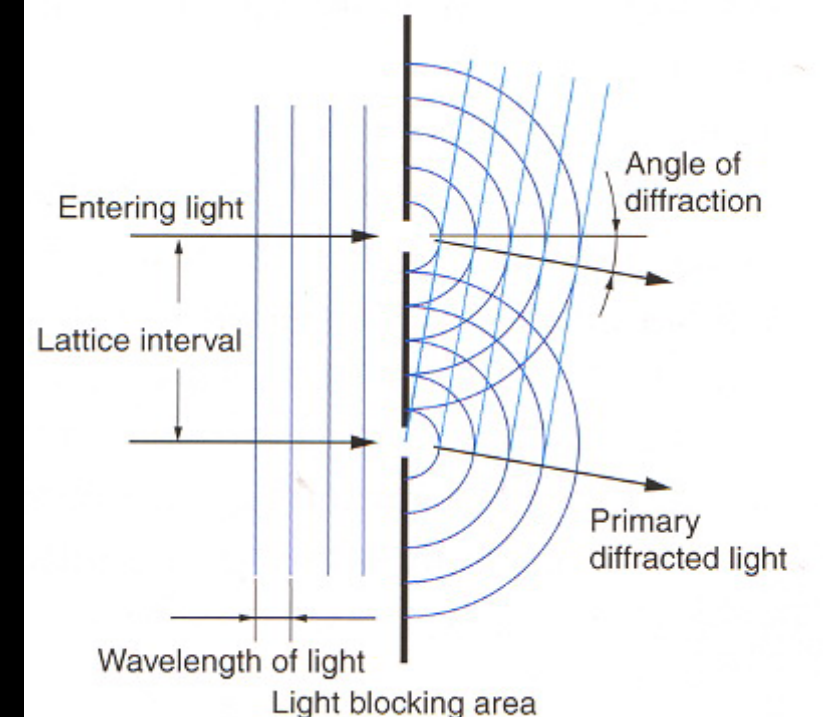
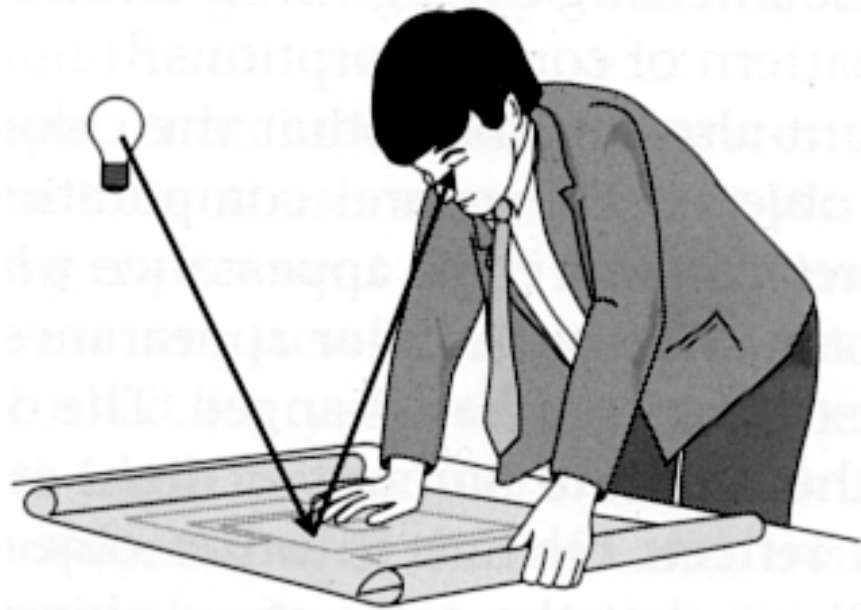


Figure-59 Principle of diffracted light generation



Source: Canon red book

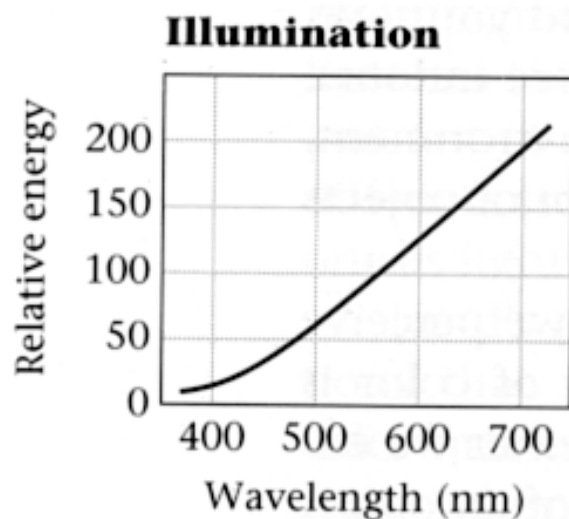
Light-matter interaction



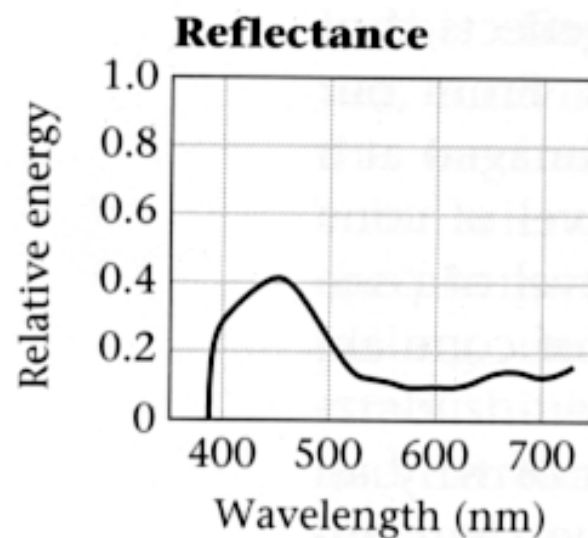
Where spectra come from:

- light source spectrum
 - object reflectance (aka spectral albedo)
- get multiplied wavelength by wavelength

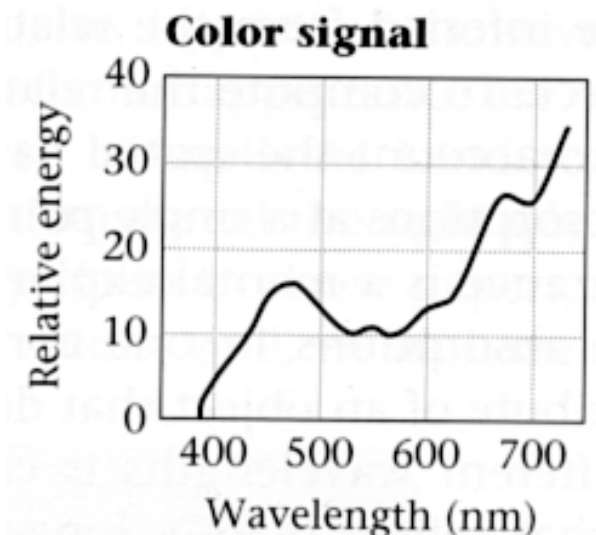
There are different physical processes that explain this multiplication
e.g. absorption, interferences



• *

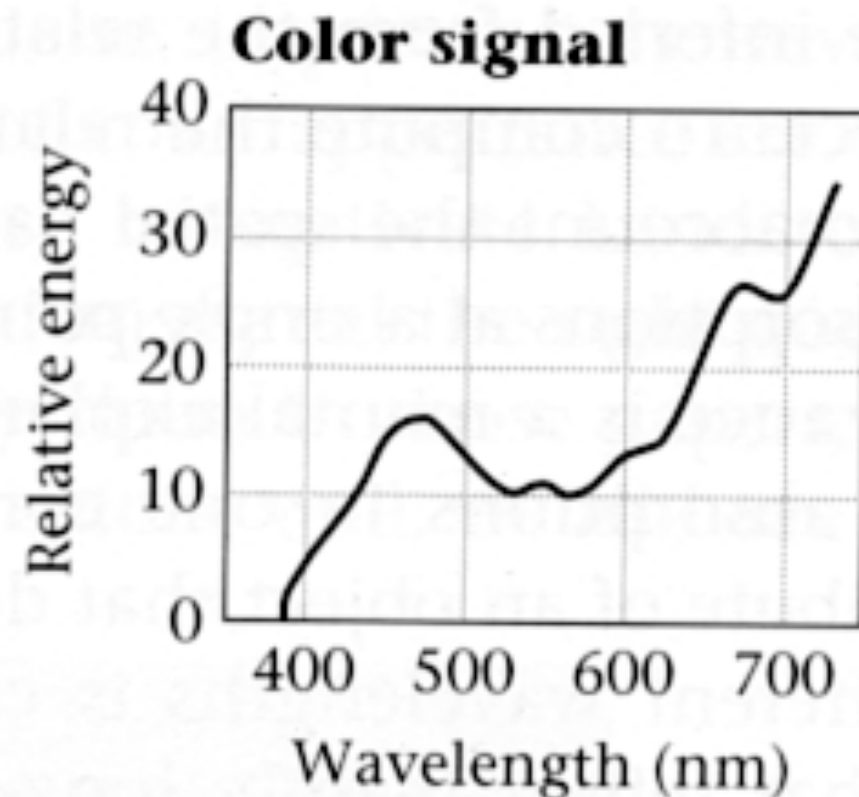


=



Questions?

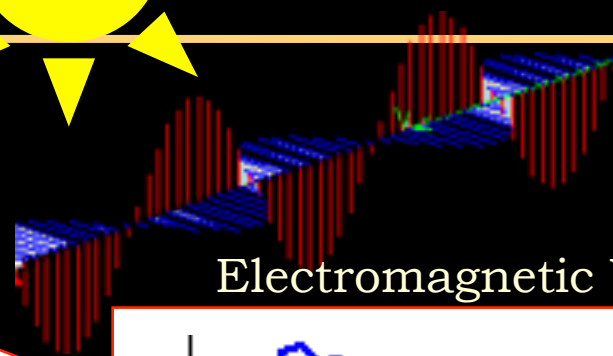
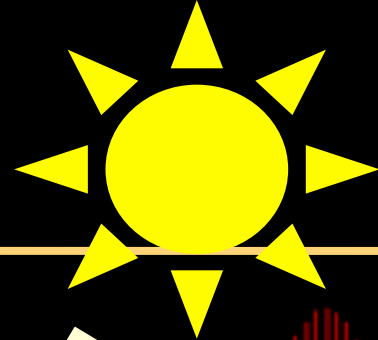
- So far, physical side of colors: **spectra**
 - an infinite number of values
(one per wavelength)



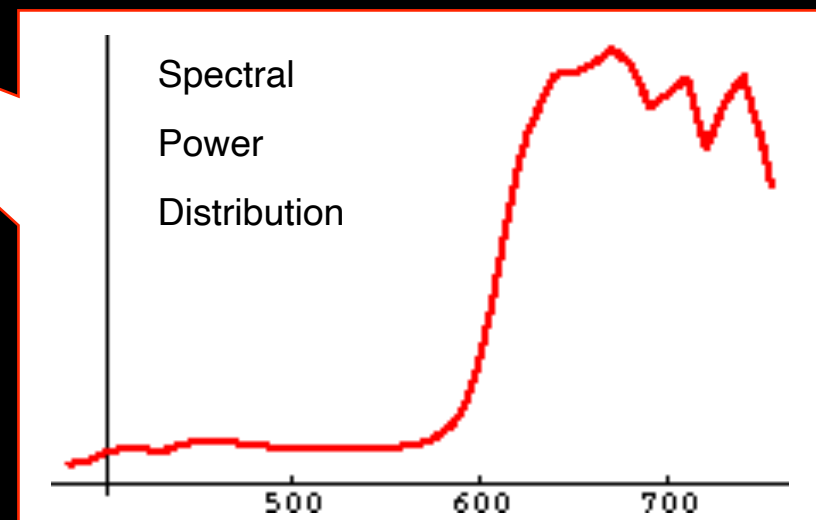
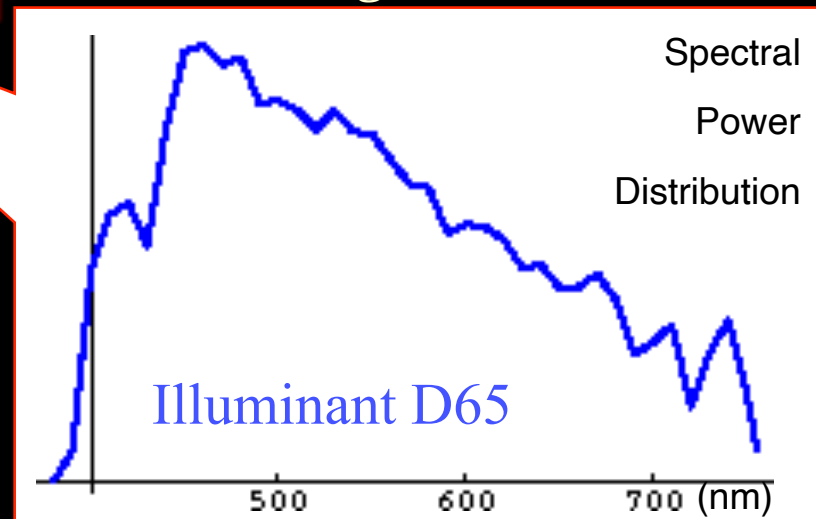
Plan

- Spectra
- **Cones and spectral response**
- Color blindness and metamers
- Color matching
- Color spaces

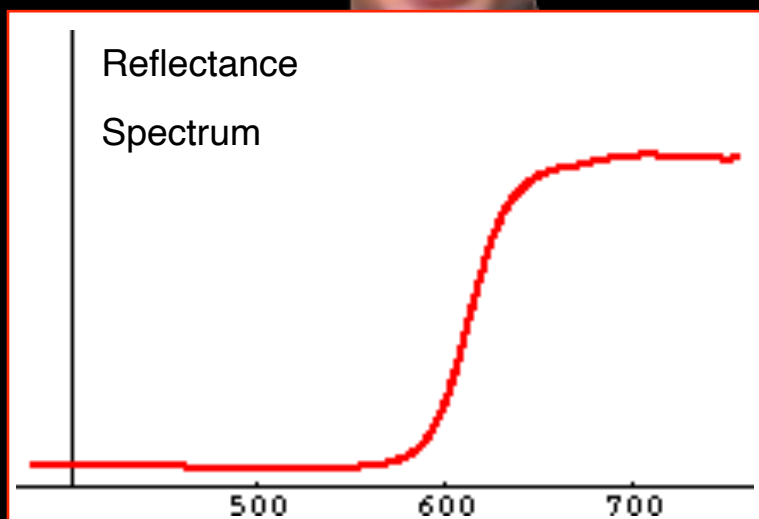
What is Color?



Electromagnetic Wave

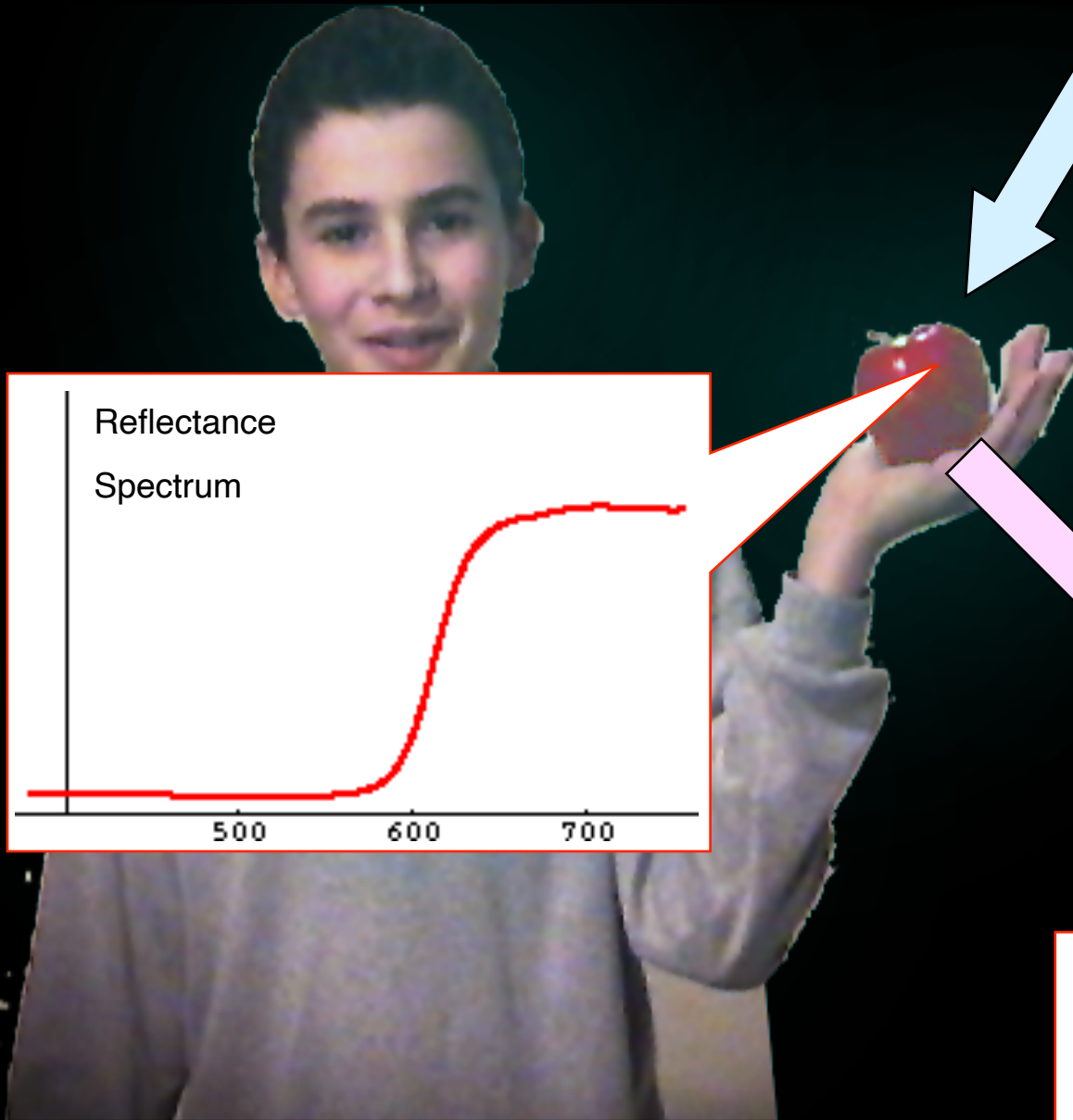


Reflectance Spectrum

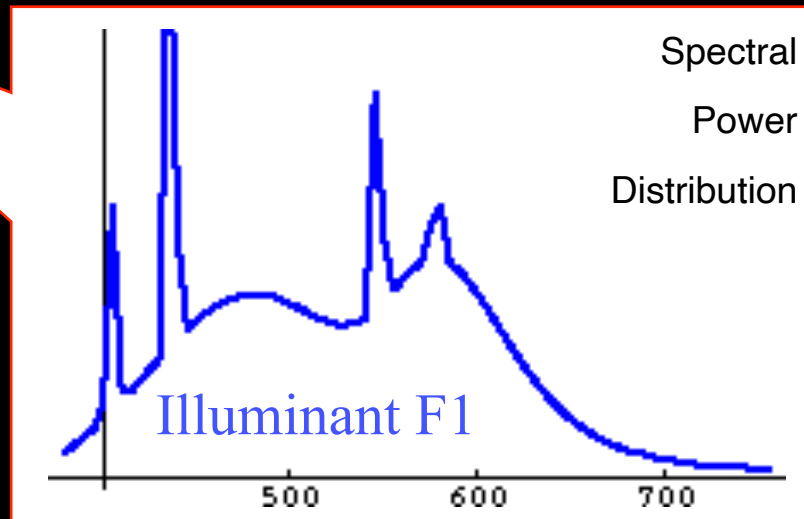
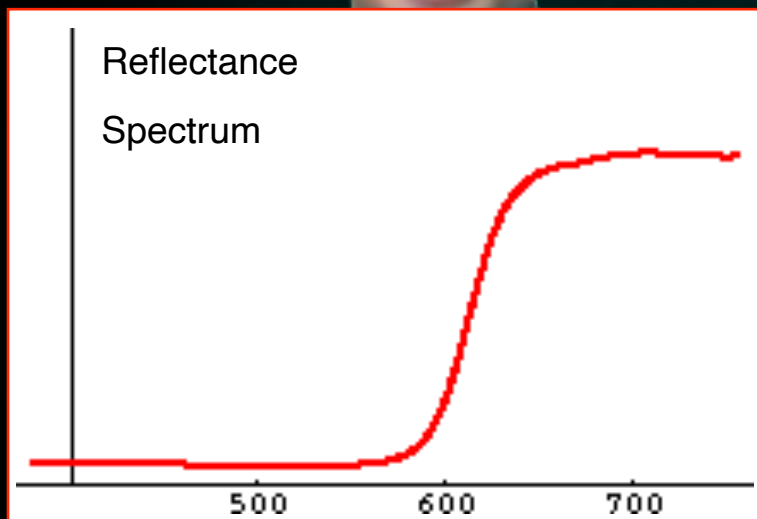


What is Color?

Neon Lamp

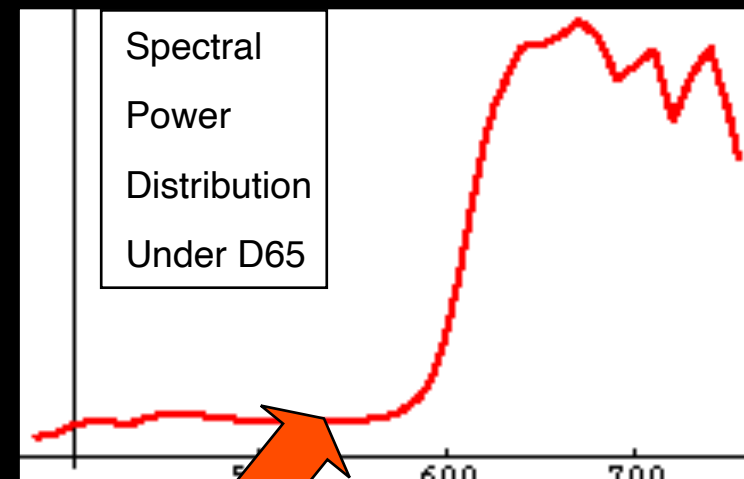


Reflectance
Spectrum

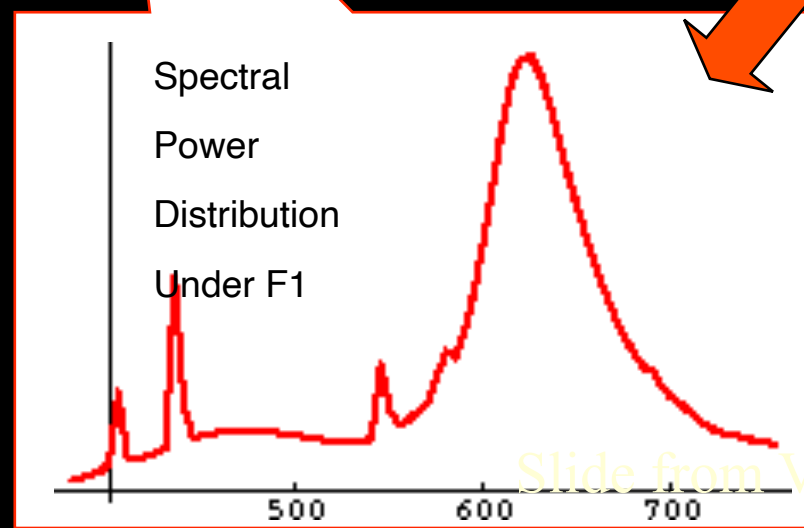


Spectral
Power
Distribution

Illuminant F1

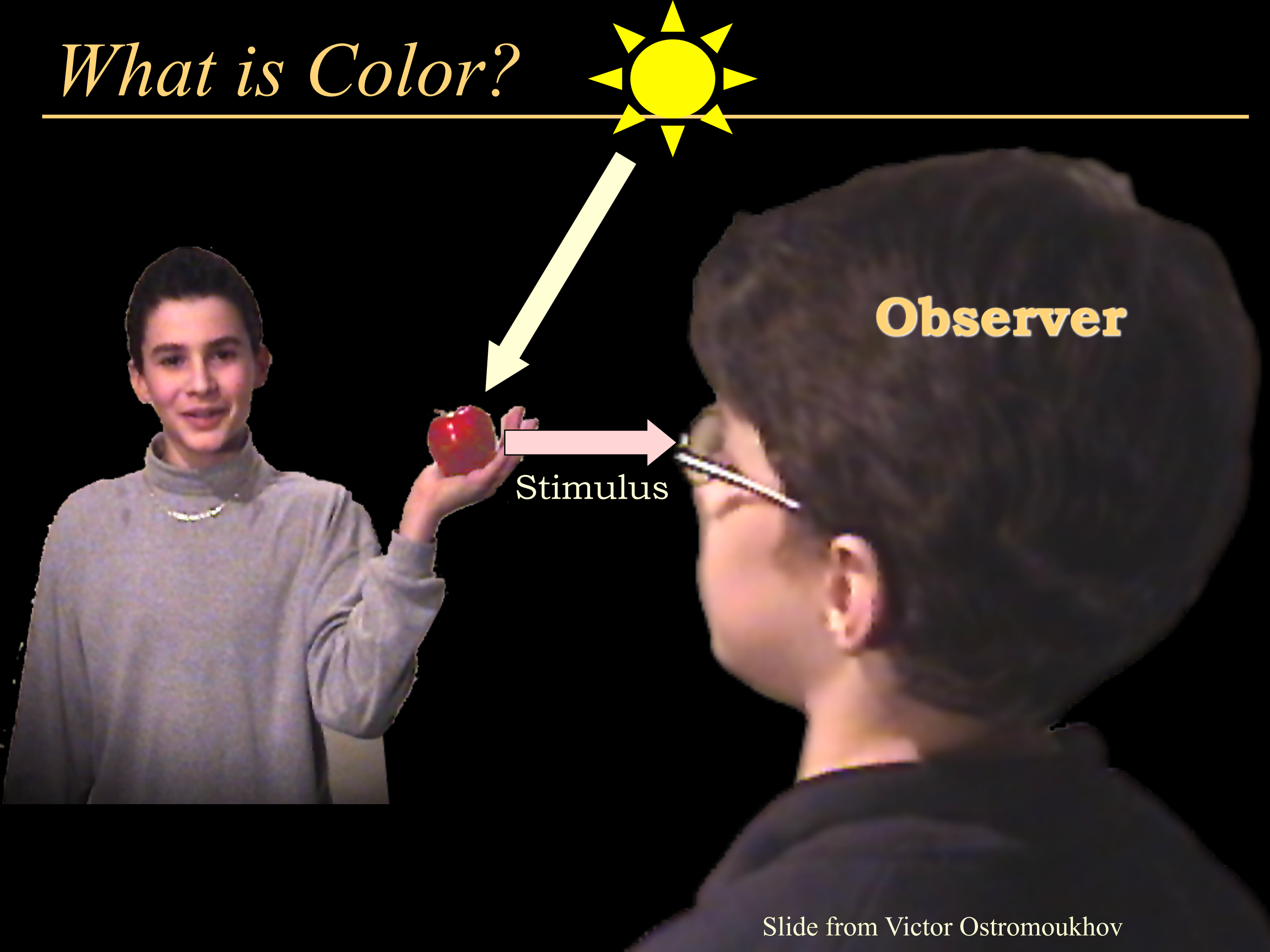


Spectral
Power
Distribution
Under D65

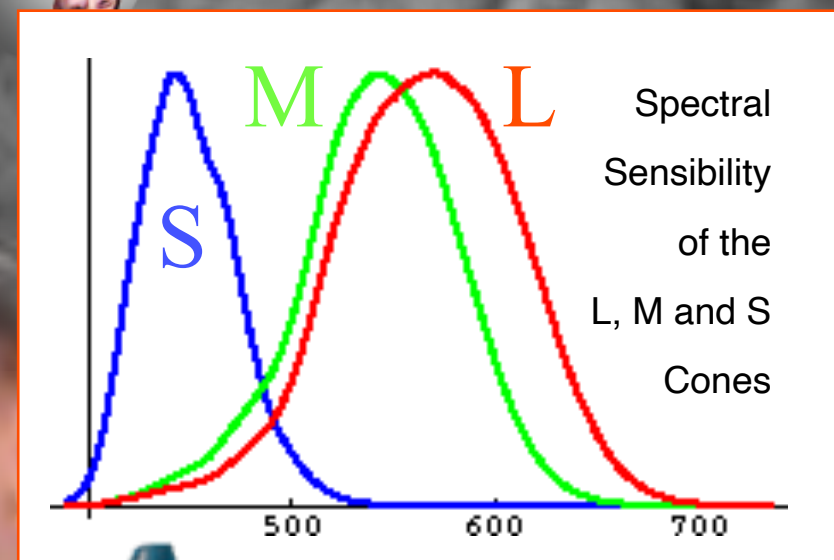
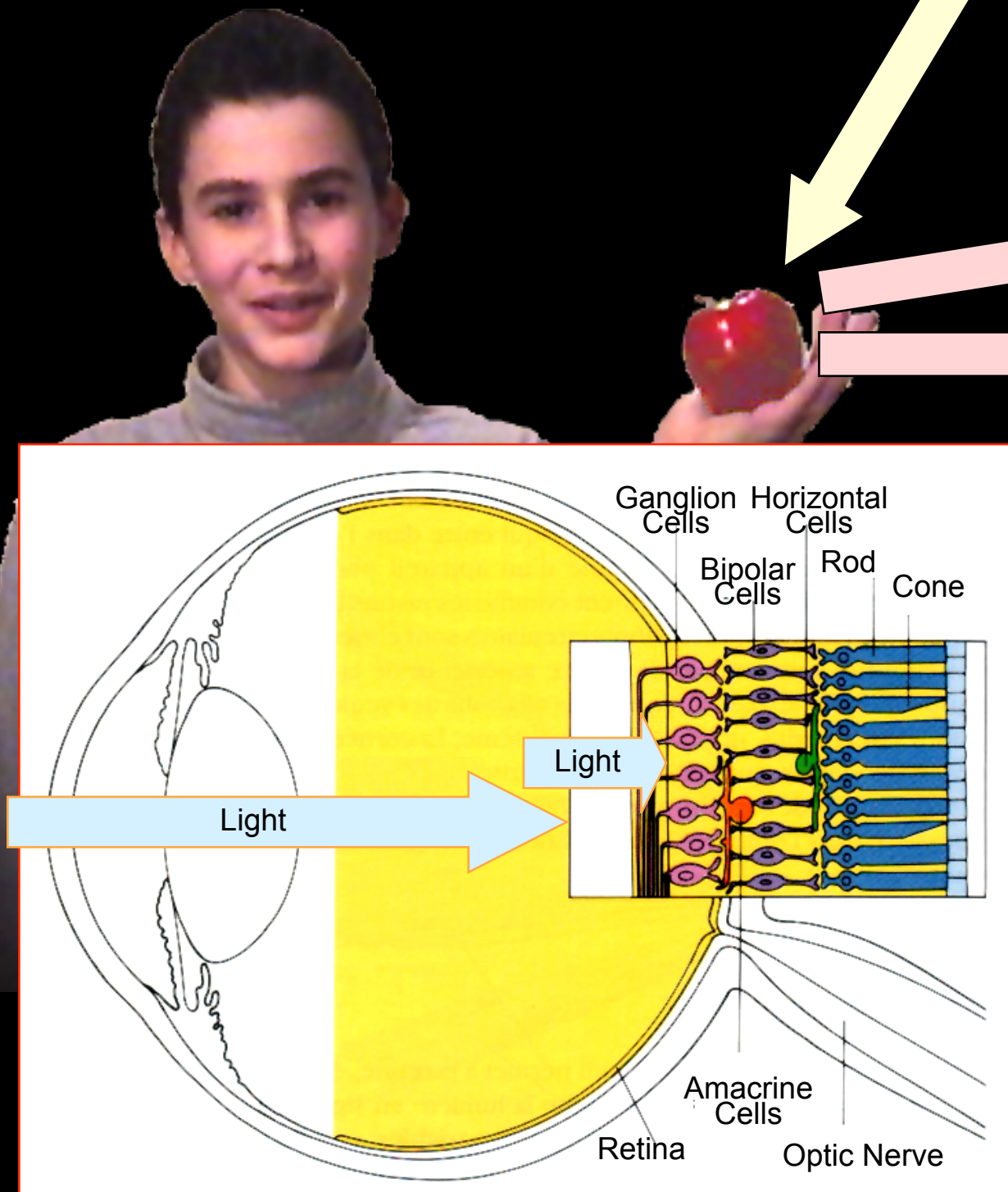
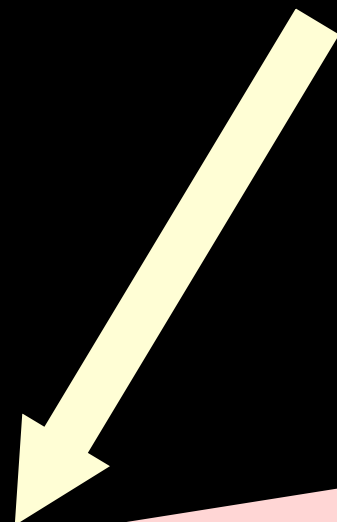
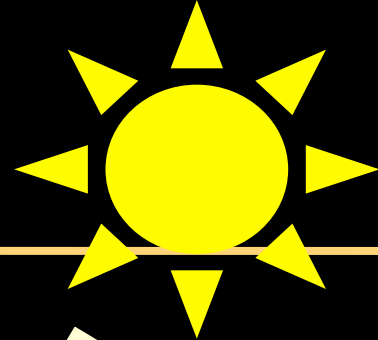


Spectral
Power
Distribution
Under F1

What is Color?

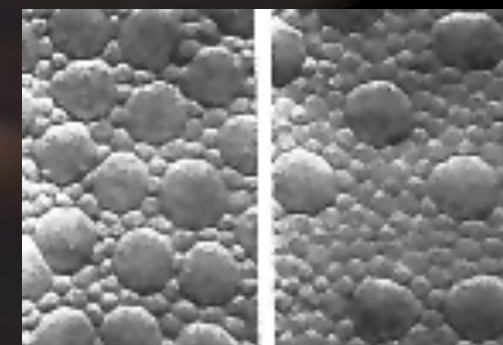


What is Color?



Rods

Cones

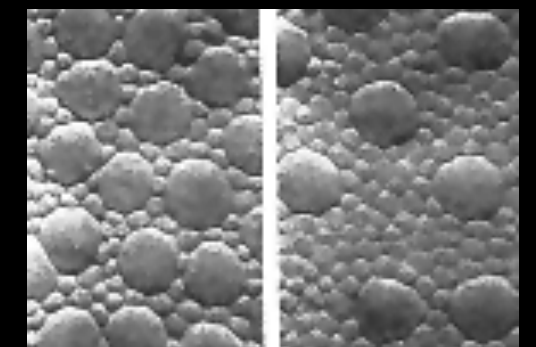
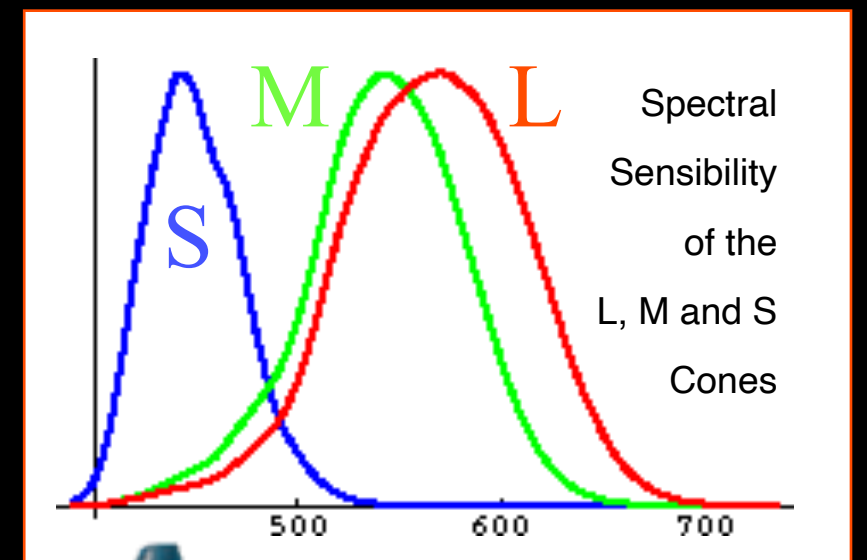
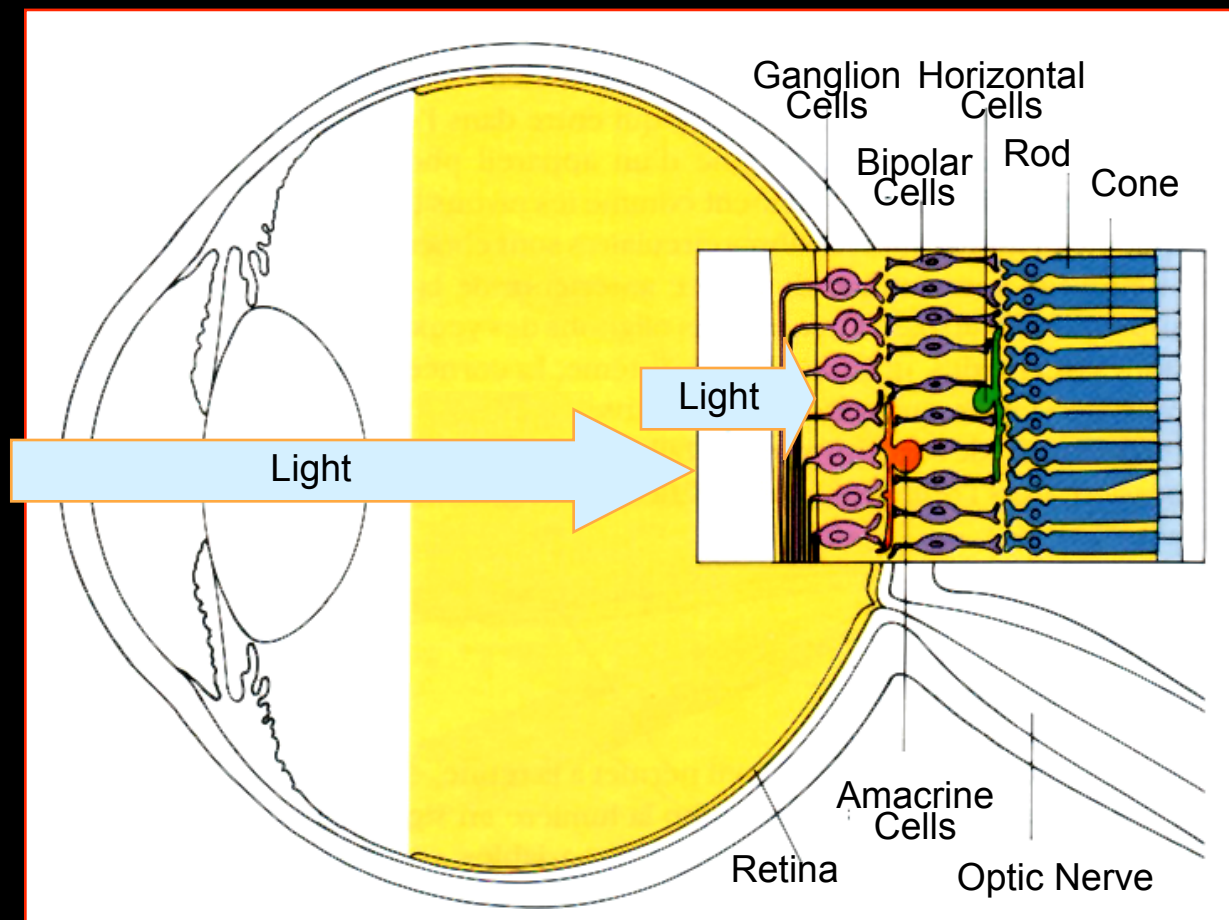


Distribution of Cones and Rods

Slide from Victor Ostromoukhov

Cones

- We focus on low-level aspects of color
 - Cones and early processing in the retina
- We won't talk about rods (night vision)



**Distribution of
Cones and Rods**

Summary (and time for questions)

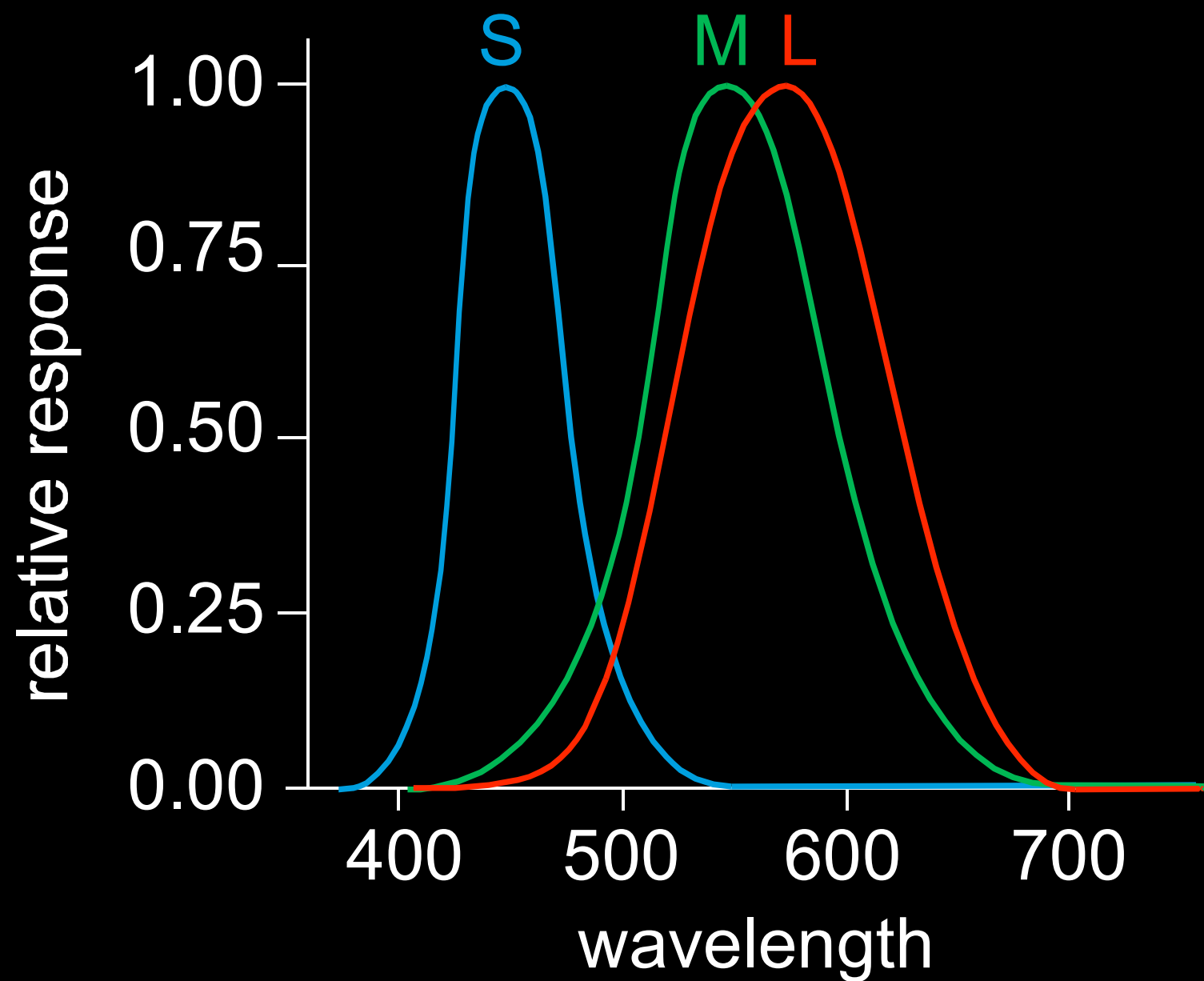
- Spectrum: infinite number of values
 - can be multiplied
 - can be added
- Light spectrum multiplied by reflectance spectrum
 - spectrum depends on illuminant
- Human visual system is complicated

Plan

- What is color
- Cones and spectral response
- Color blindness and metamers
- Fundamental difficulty with colors

Cone spectral sensitivity

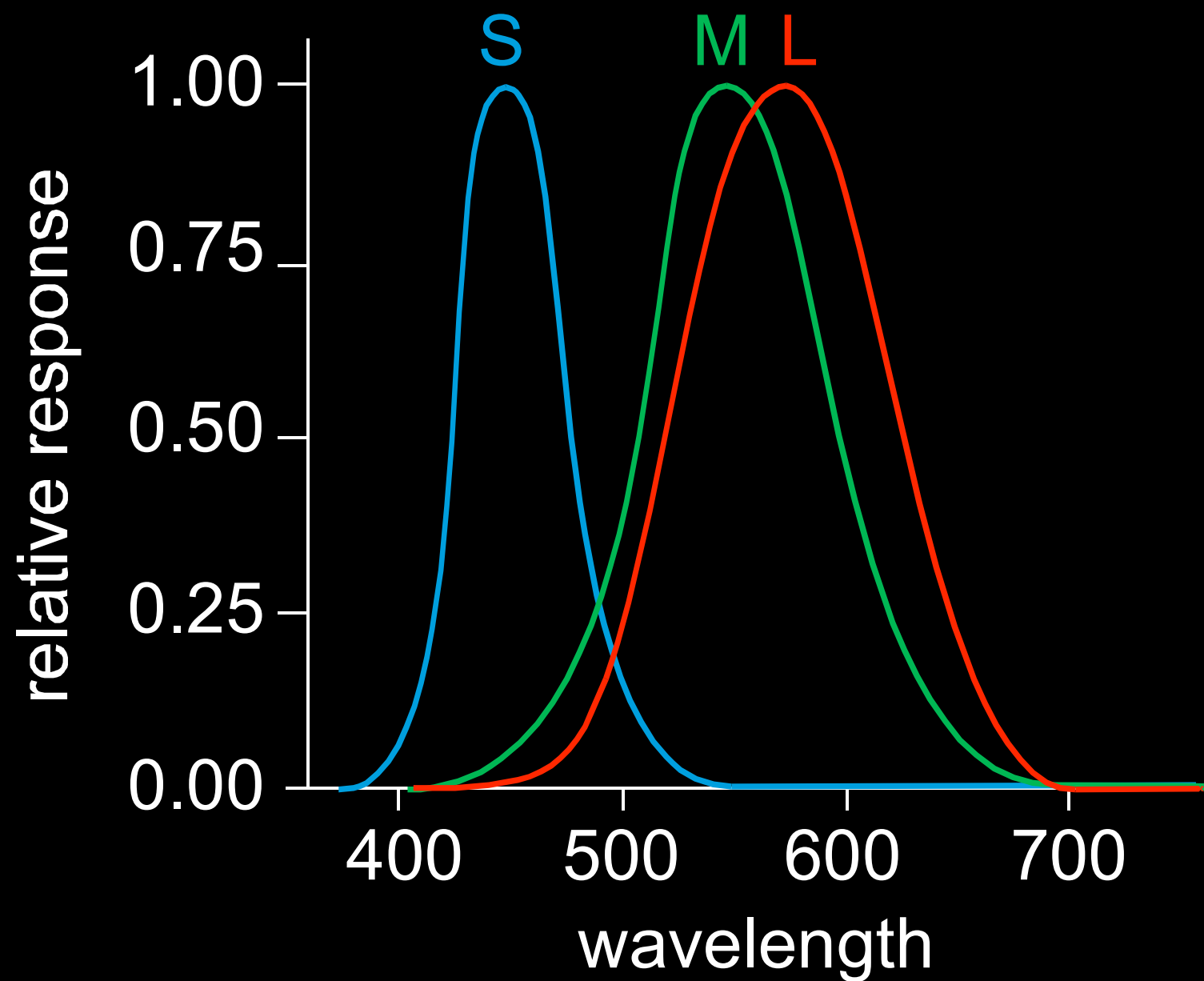
- Short, Medium and Long wavelength
- Response for a cone:



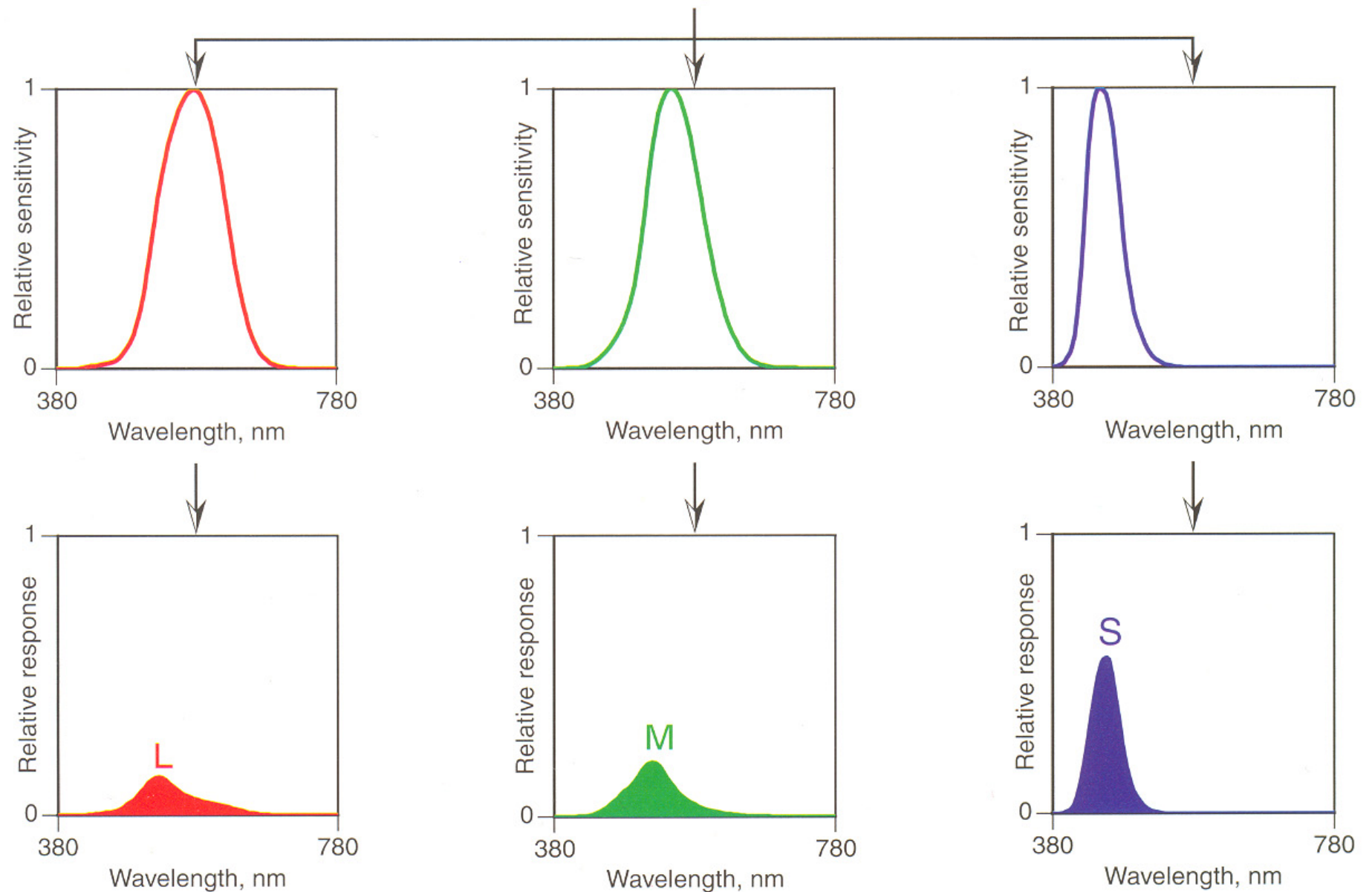
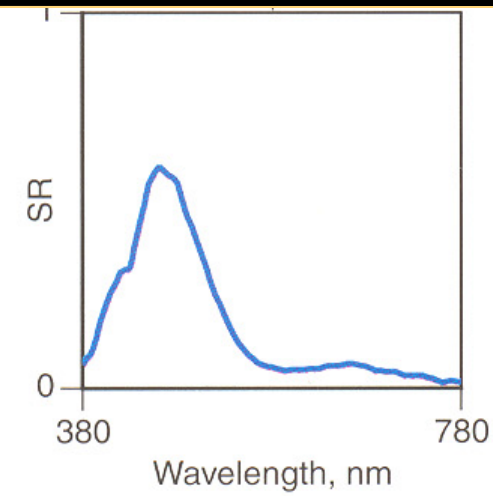
Cone spectral sensitivity

- Short, Medium and Long wavelength
- Response for a cone

$$= \int_{\lambda} \text{stimulus}(\lambda) * \text{response}(\lambda) d\lambda$$



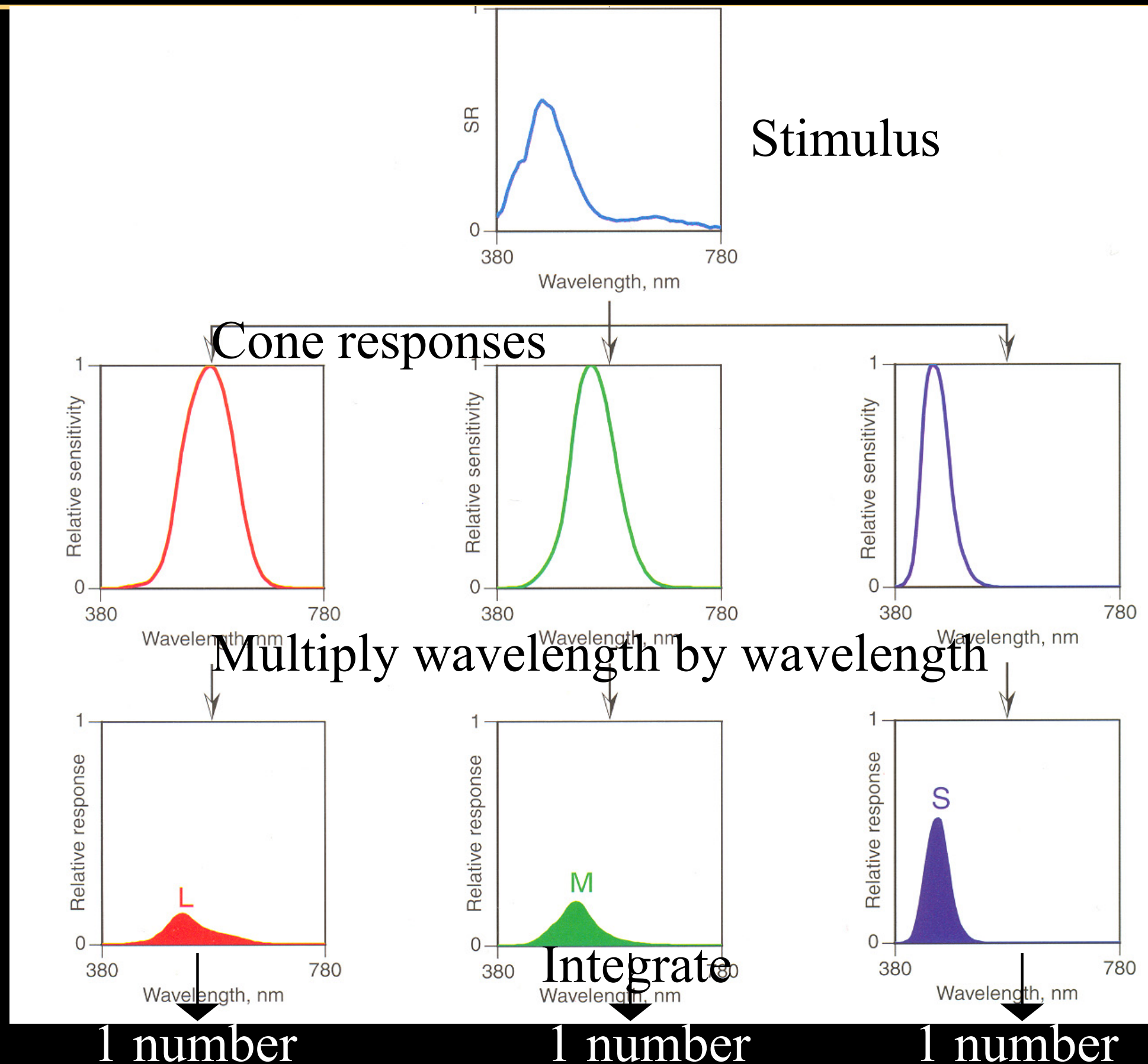
Cone response



Cone response

Start from infinite
number of
values
(one per
wavelength)

End up with 3
values (one
per cone type)

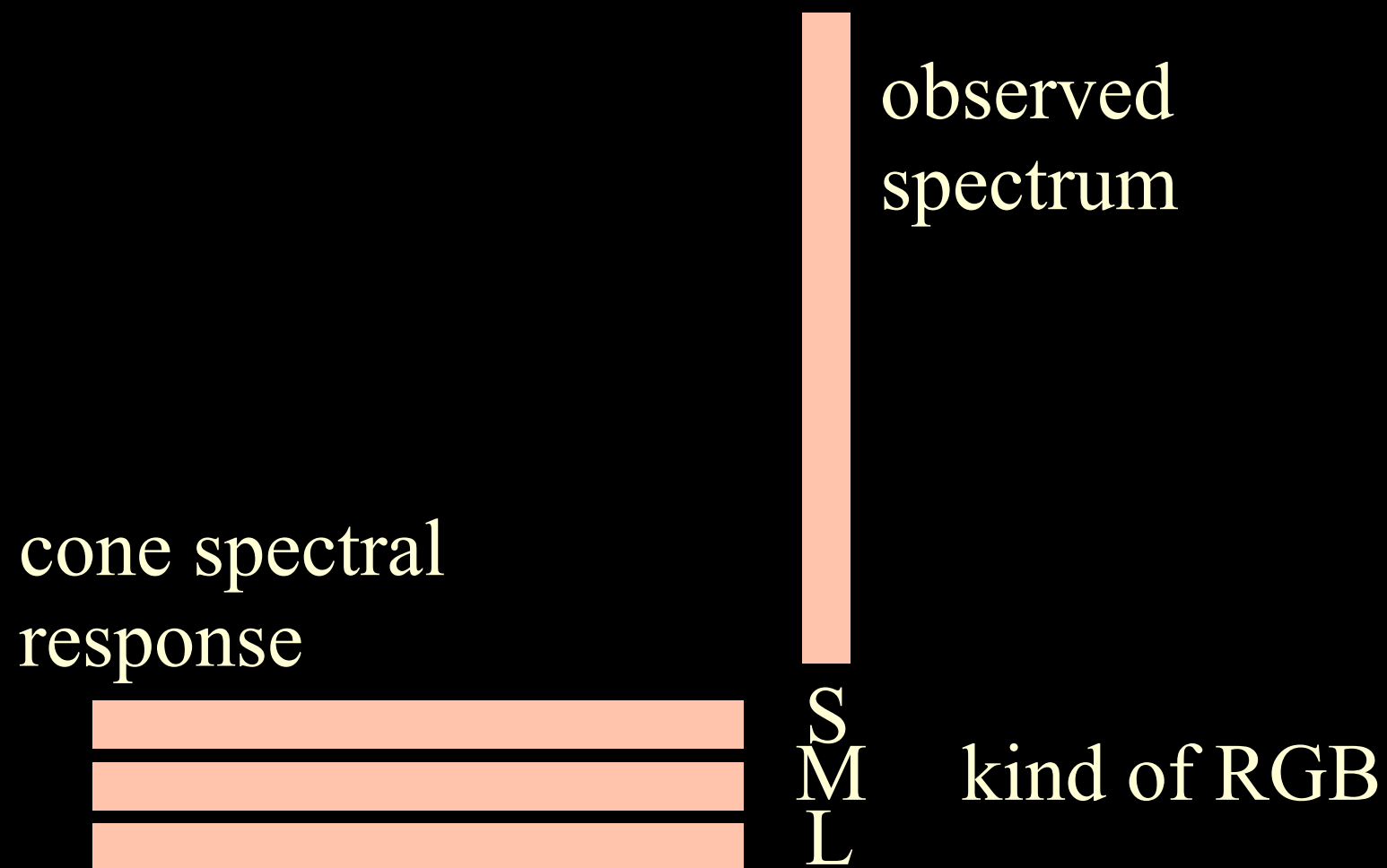


For matrix lovers

- Spectrum: big long vector size N where $N=\infty$
- Cone response: $3 \times N$ matrix of individual responses

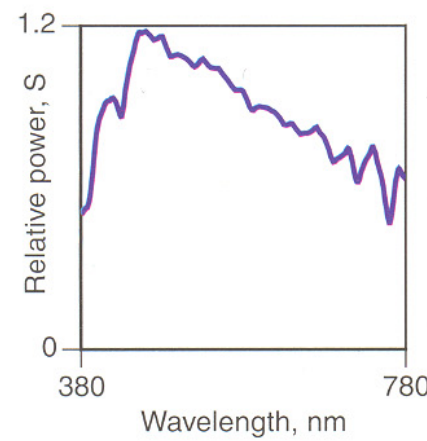
For matrix lovers

- Spectrum: big long vector size N where $N=\infty$
- Cone response: $3 \times N$ matrix of individual responses

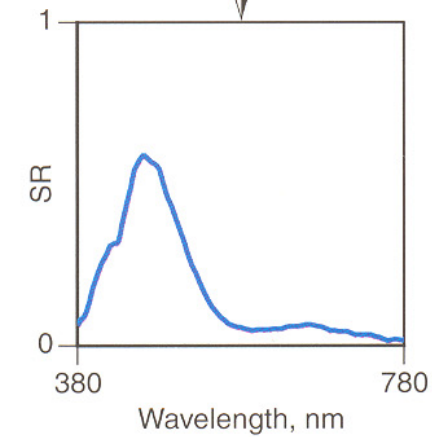
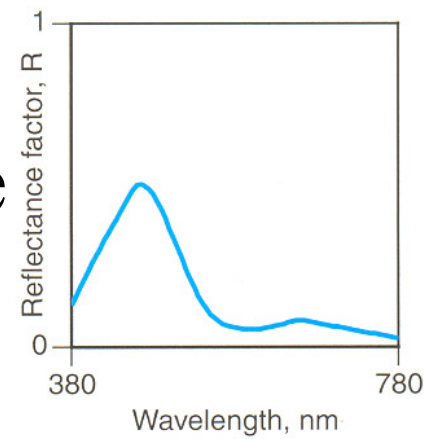


Big picture

- It's all linear!

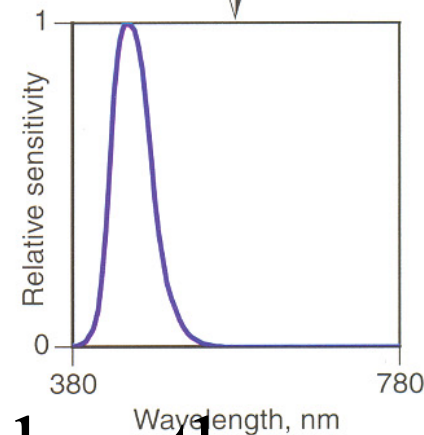
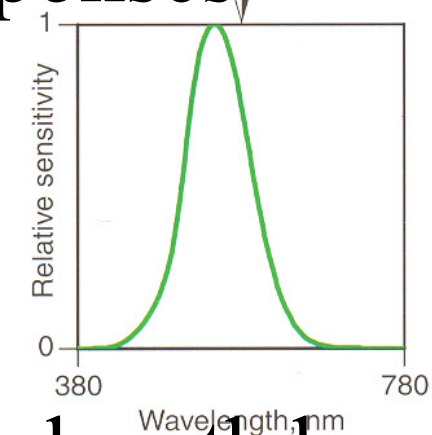
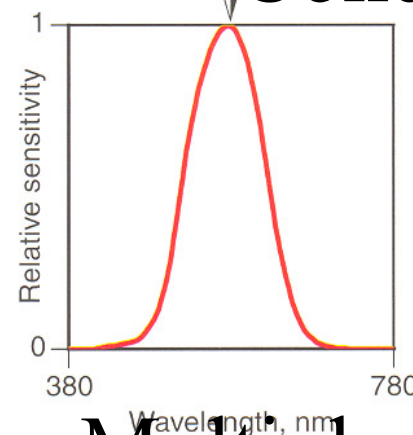


Light reflectance
multiply

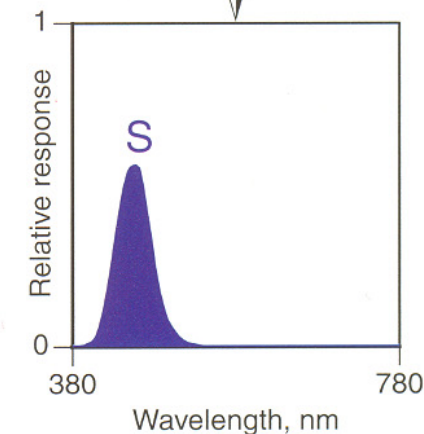
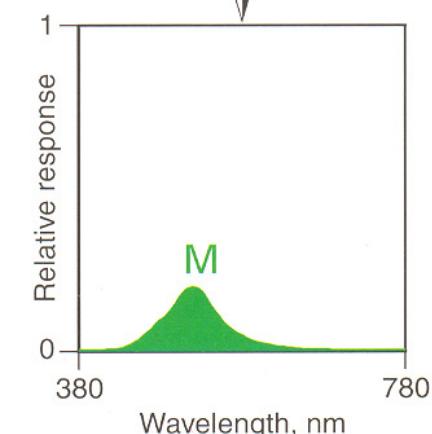
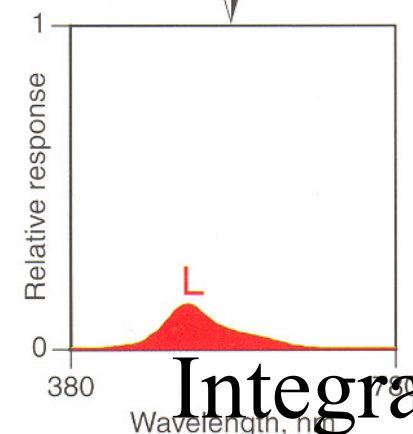


Stimulus

Cone responses



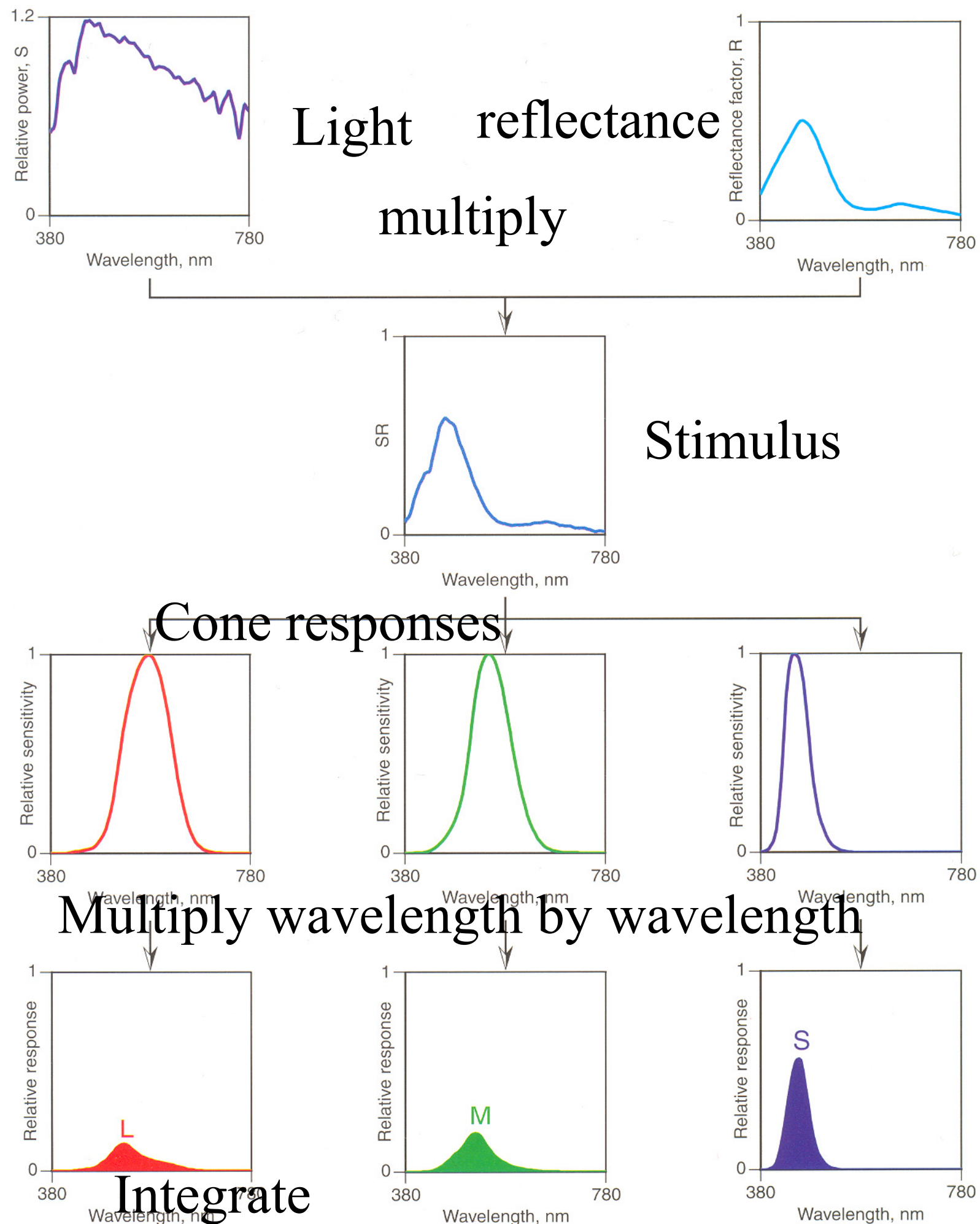
Multiply wavelength by wavelength



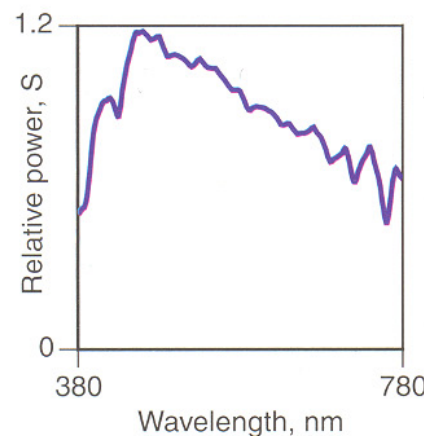
Integrate

Big picture

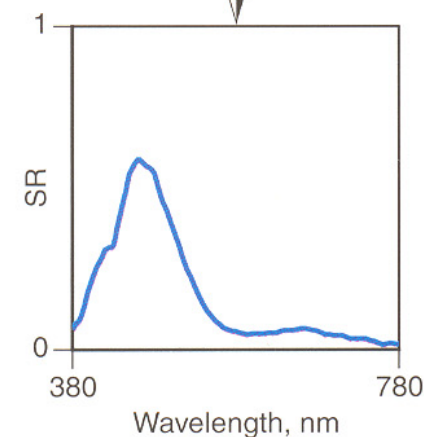
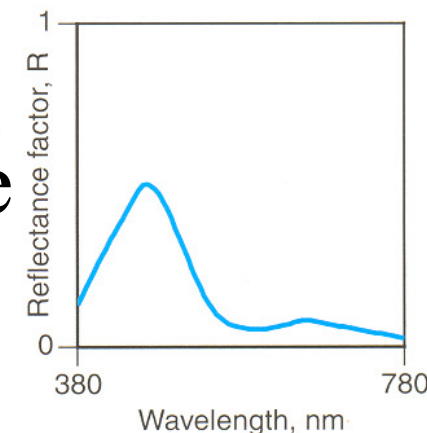
- It's all linear!
 - multiply
 - add
- But
 - non-orthogonal basis
 - infinite dimension
 - light must be positive
- Depends on light source



Questions?

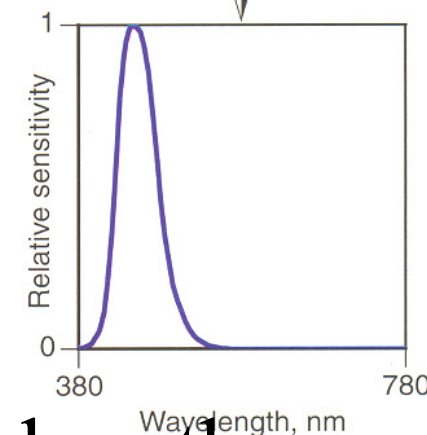
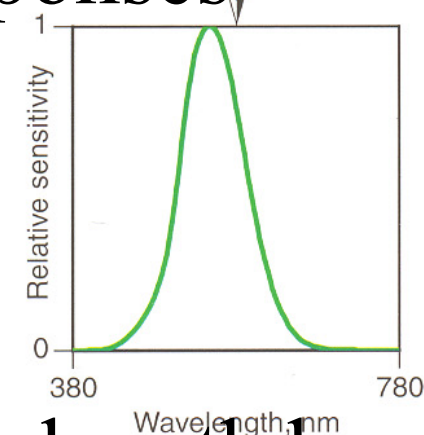
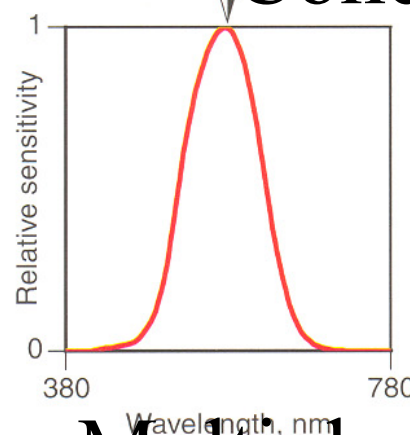


Light reflectance
multiply

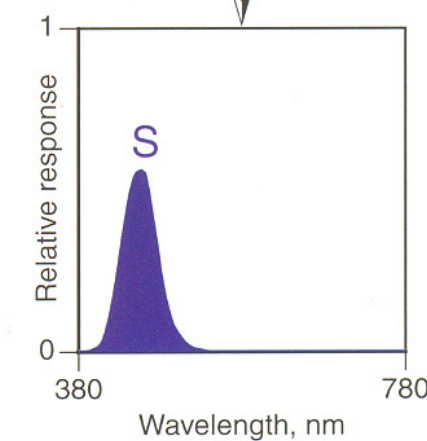
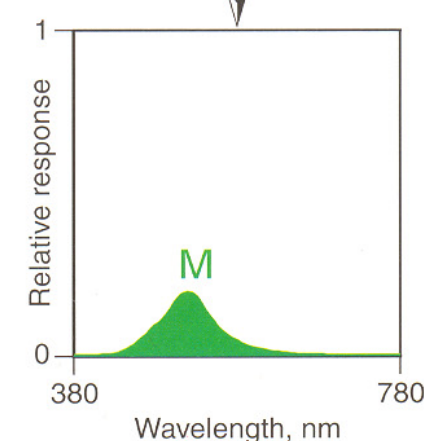
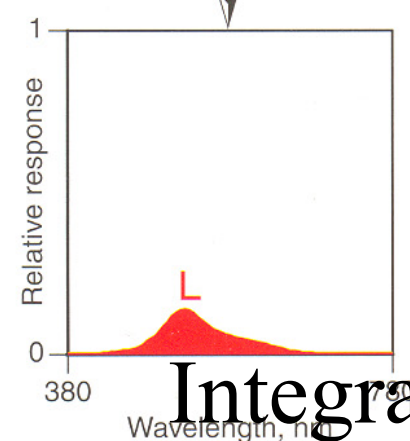


Stimulus

Cone responses



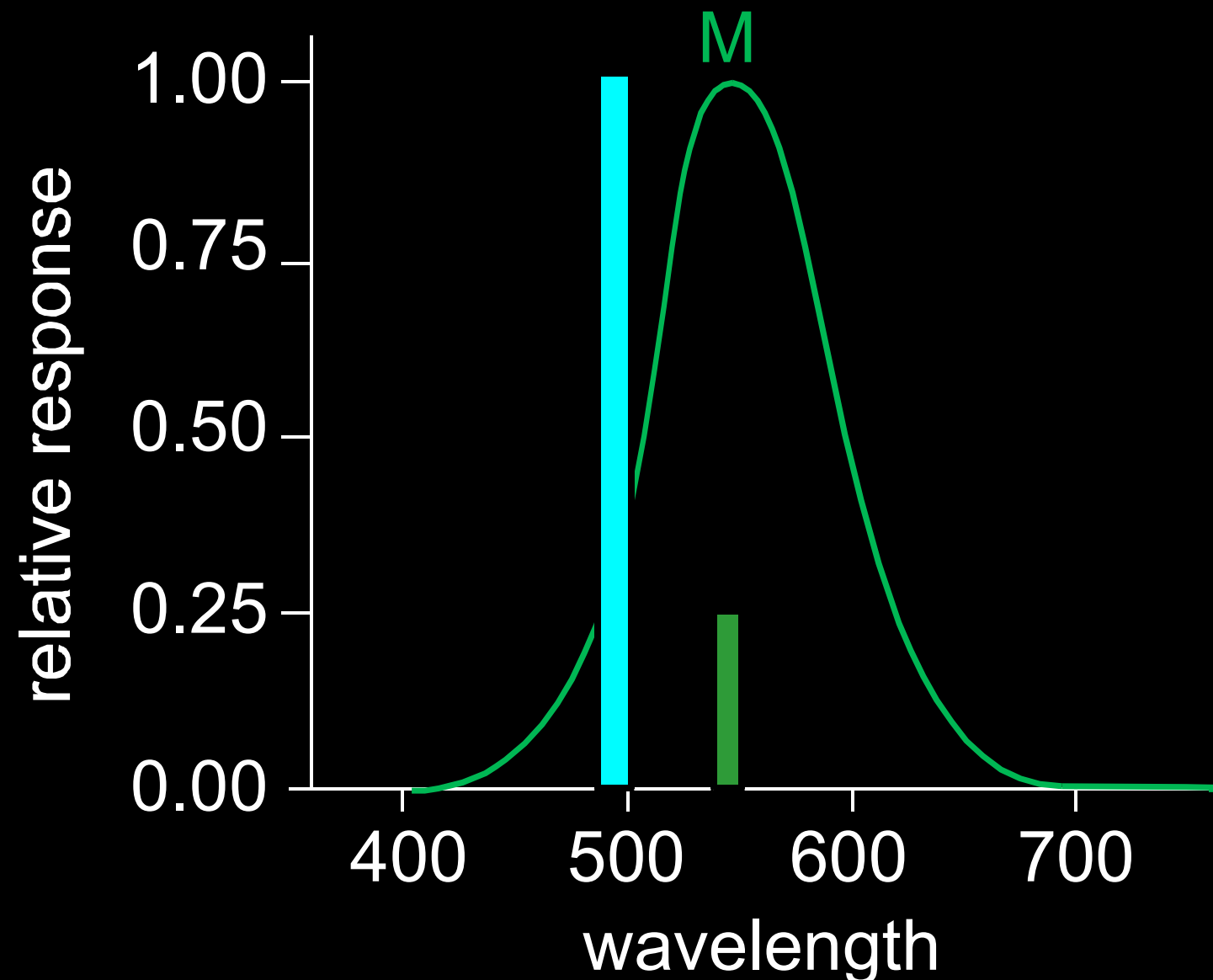
Multiply wavelength by wavelength



Integrate

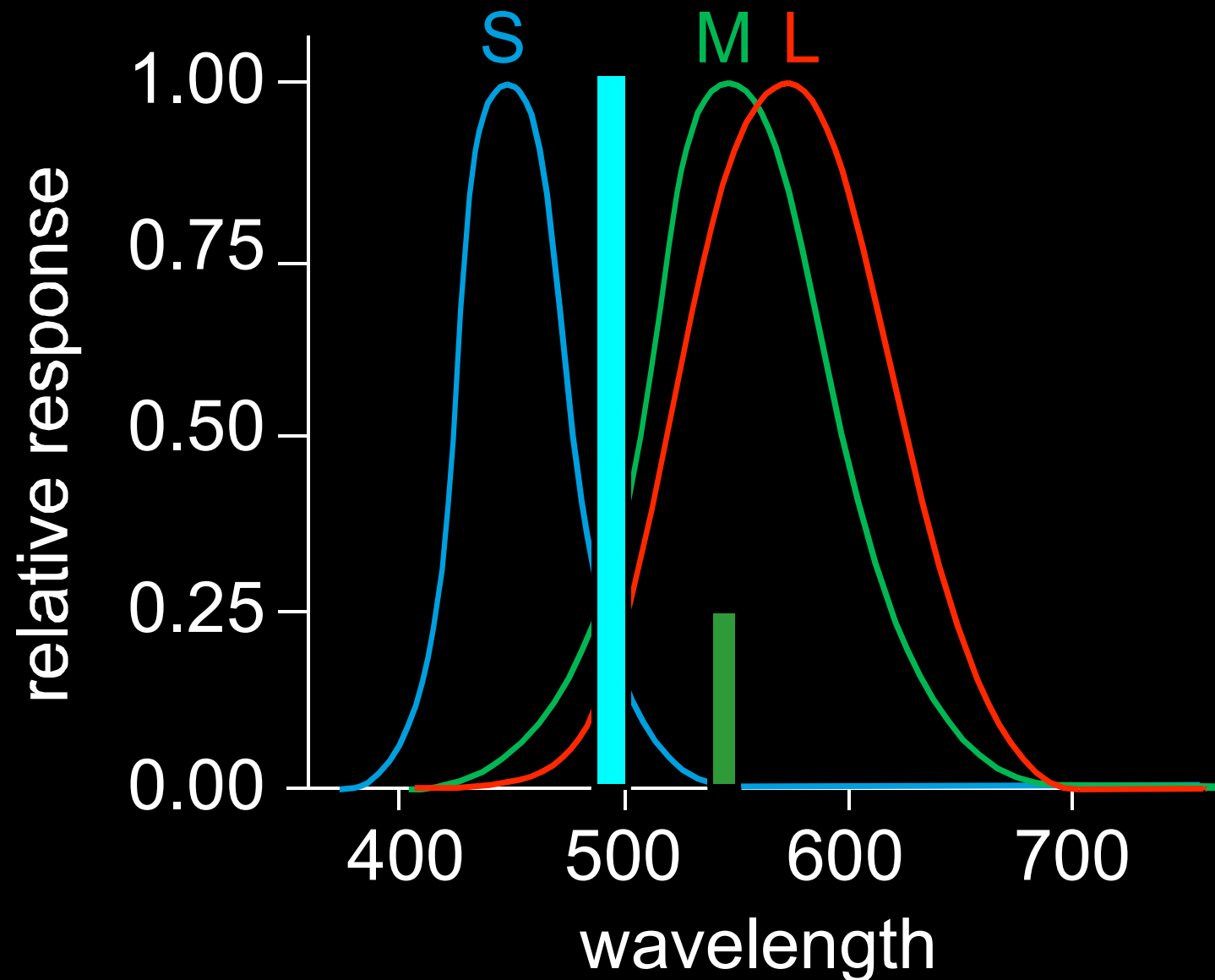
A cone does not “see” colors

- Different wavelength, different intensity
- Same response



Response comparison

- Different wavelength, different intensity
- But different response for different cones

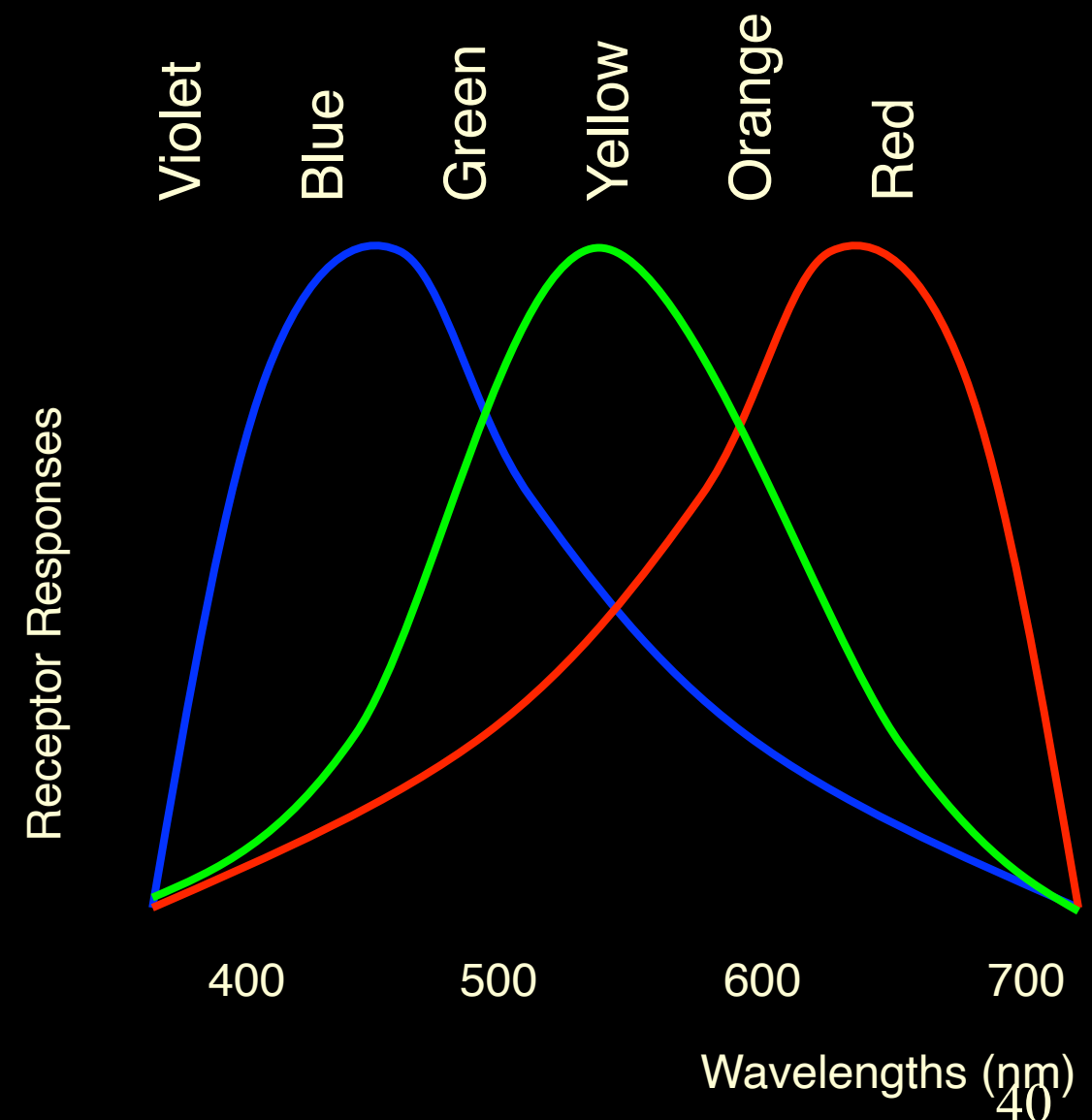


von Helmholtz 1859: Trichromatic theory

- Colors as relative responses (ratios)



- Short wavelength receptors
- Medium wavelength receptors
- Long wavelength receptors



References on different cones

- <http://hyperphysics.phy-astr.gsu.edu/hbase/vision/rodcone.html>
- <http://www.blueconemonochromacy.org/what-is-bcm/eye-retina-and-cones-2/>
- <http://webvision.med.utah.edu/book/part-iii-retinal-circuits/s-cone-pathways/>
- <http://www.opticsinfobase.org/josa/abstract.cfm?uri=josa-57-11-1289>
- <http://www.cvrl.org/database/text/intros/introdens.htm>
- <http://www.cvrl.org/database/text/density/lmintro.htm>

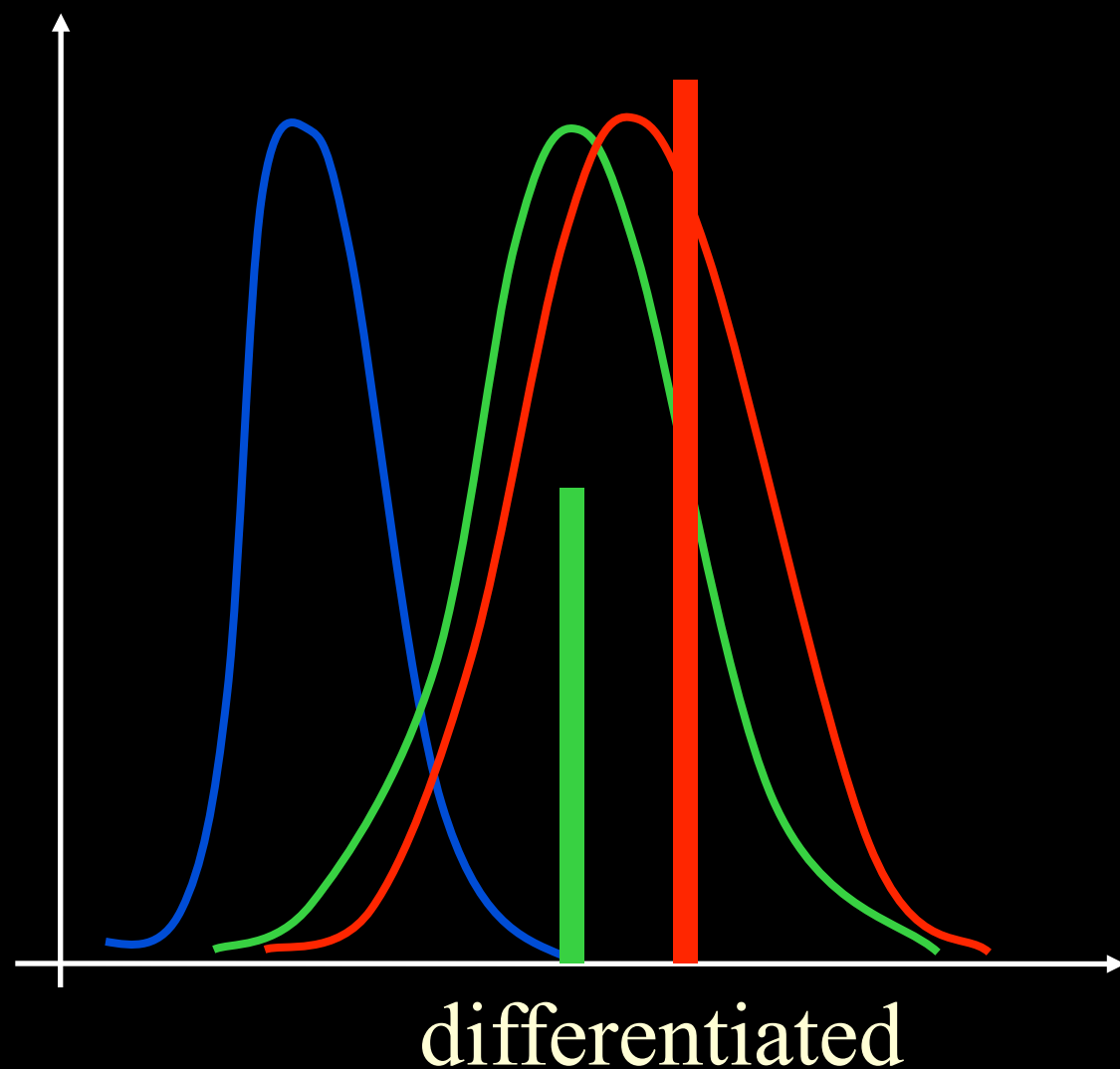
Metamers & color blindness

Plan

- Spectra
- Cones and spectral response
- **Color blindness and metamers**
- Color matching
- Color spaces

Response comparison

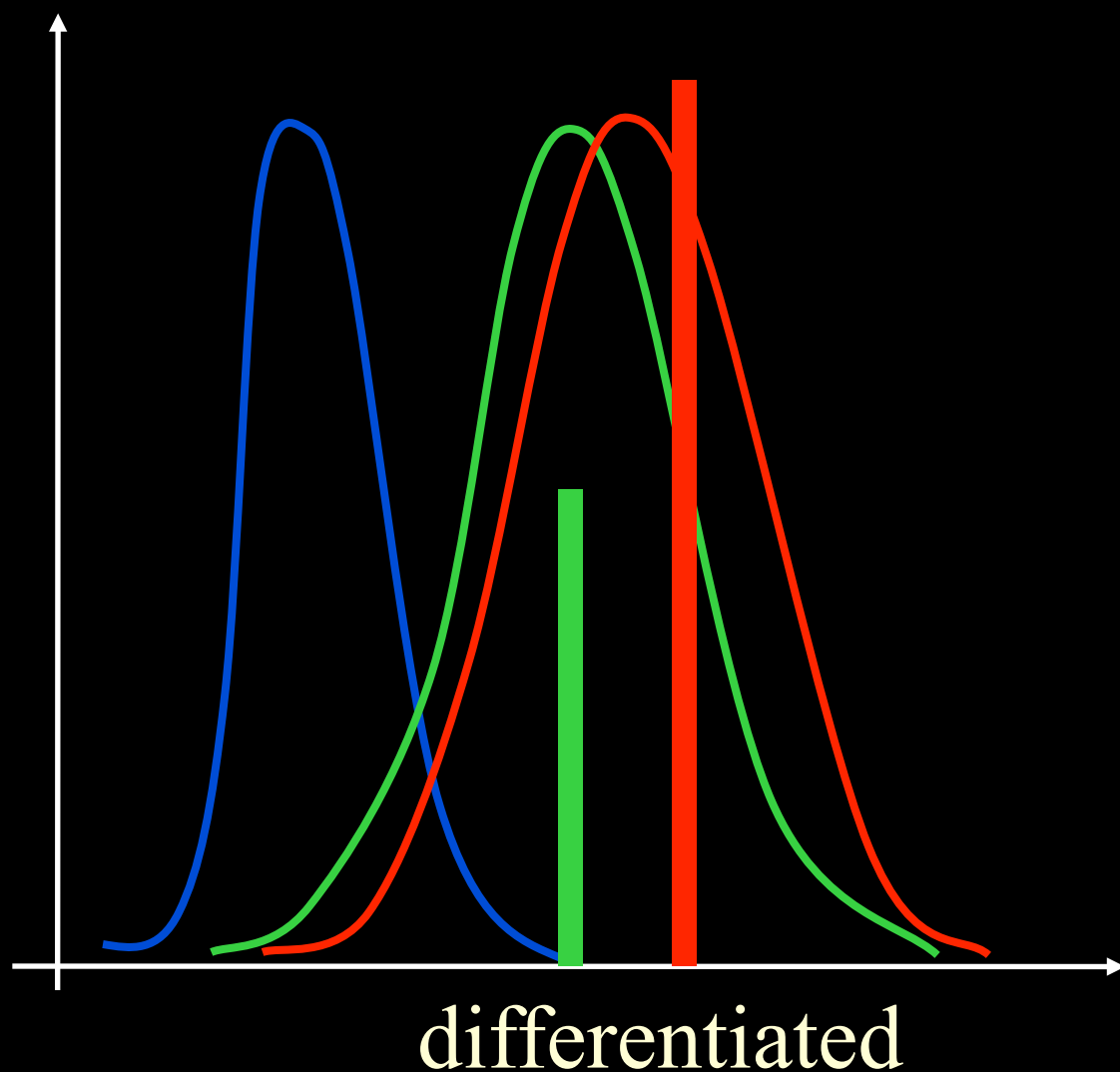
- Different wavelength, different intensity
- But different response for different cones



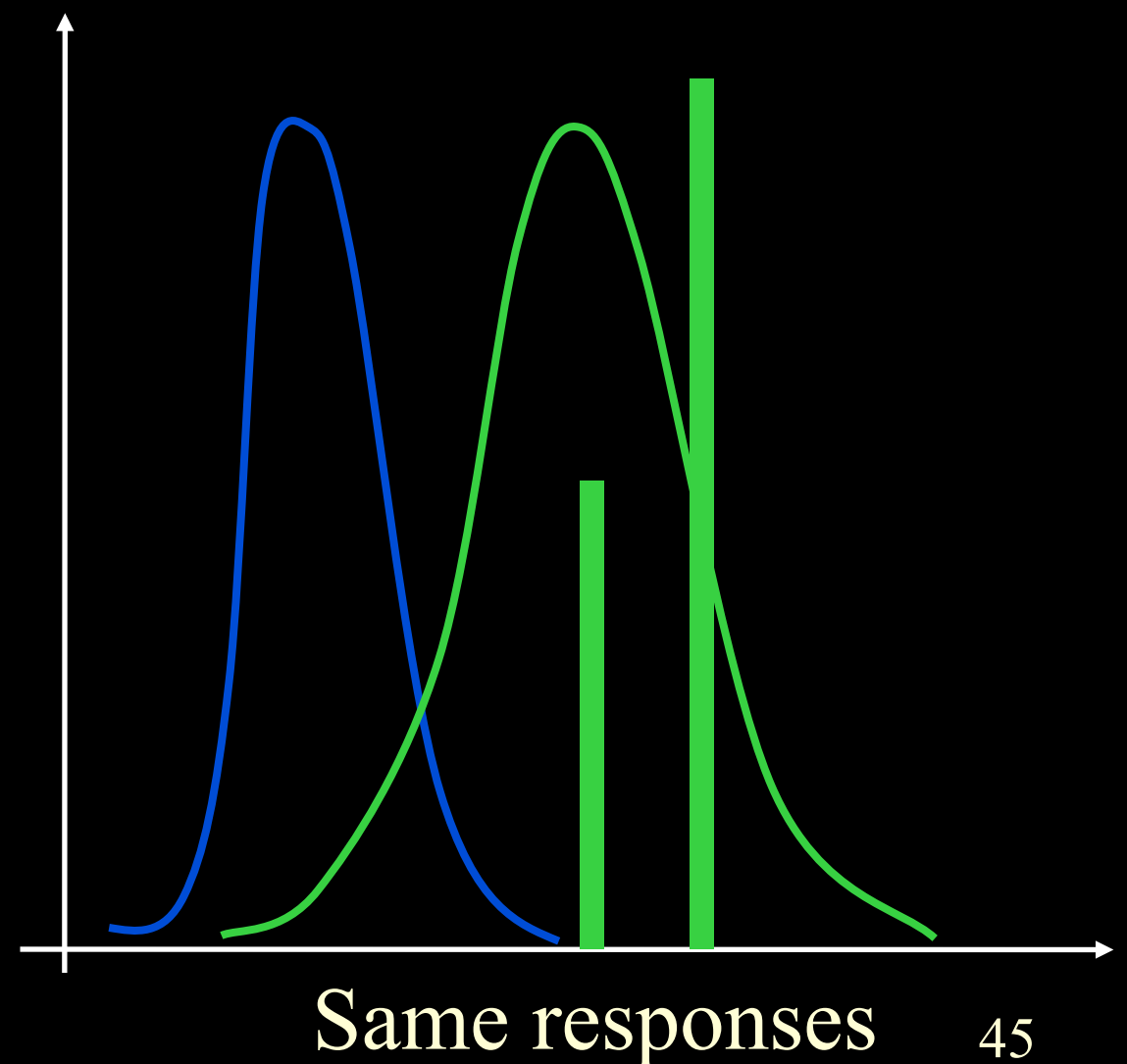
Color blindness

- Classical case: 1 type of cone is missing (e.g. M)
- Makes it impossible to distinguish some spectra

Normal observer



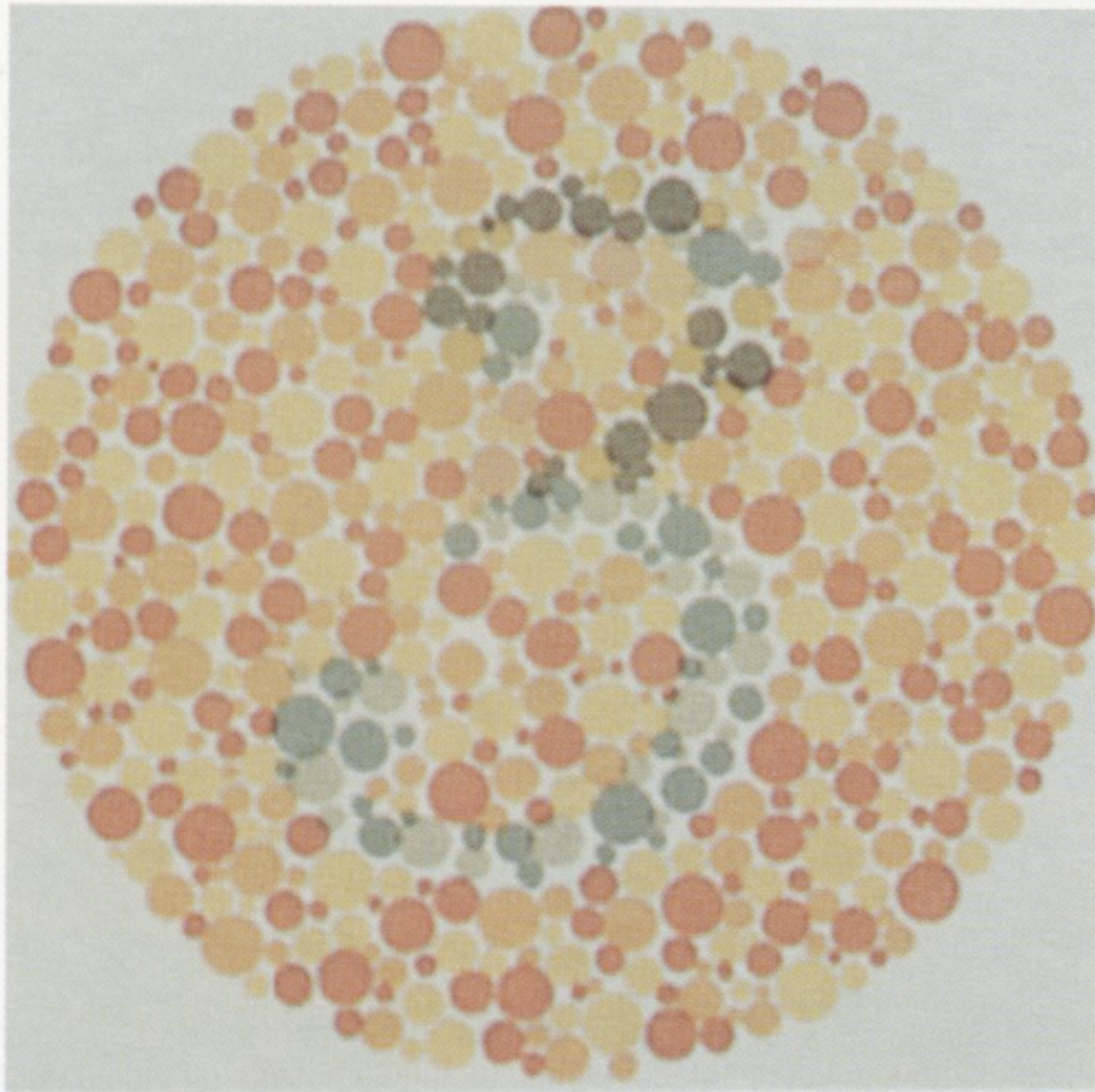
Color blind



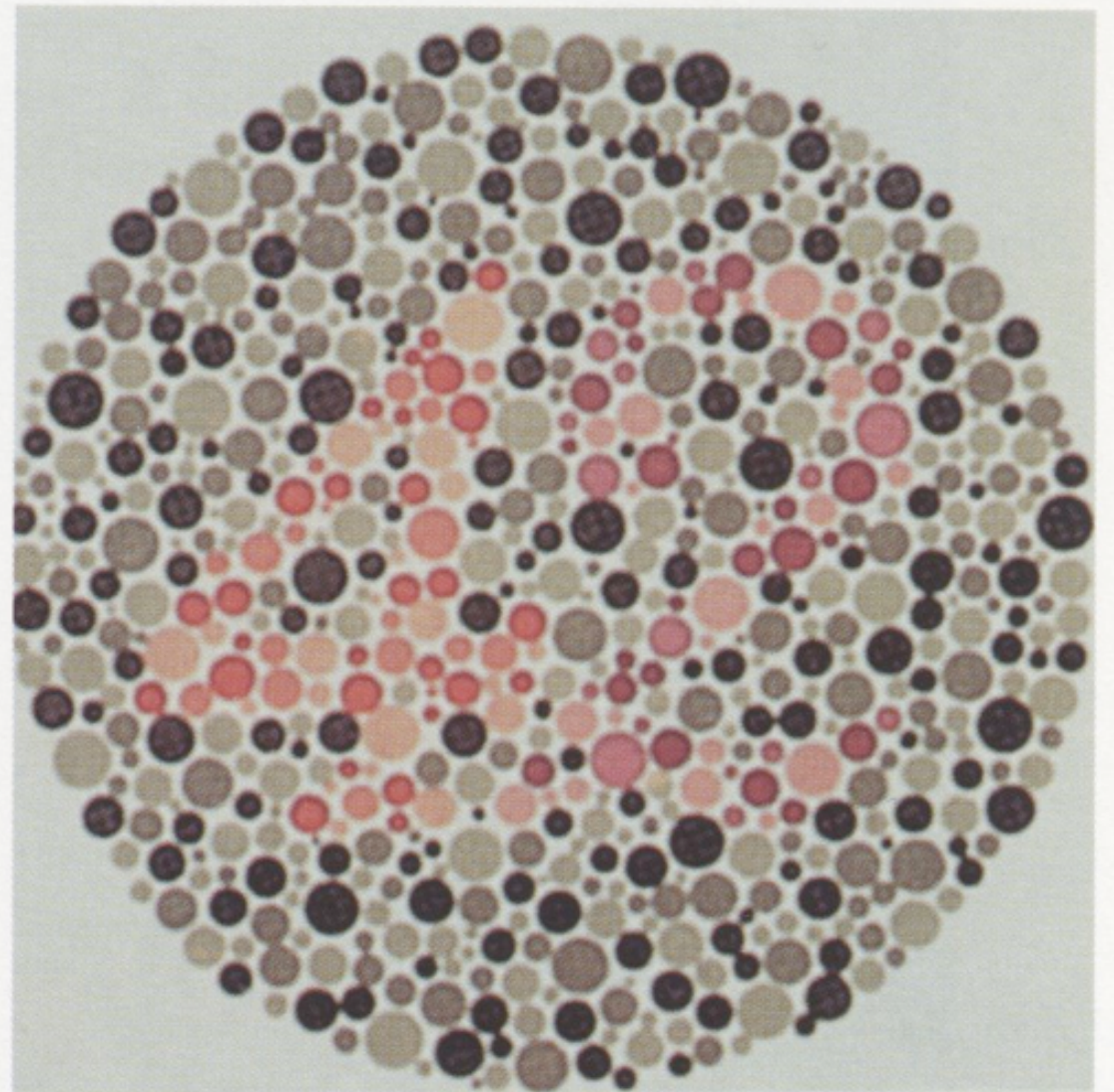
Color blindness – more general

- Dalton
- ~14%% male, 2% female
- Genetic
- Dichromate (2% male)
 - One type of cone missing
 - L (protanope), M (deuteranope), S (tritanope)
- Anomalous trichromat
 - Shifted sensitivity
- More at, e.g. http://en.wikipedia.org/wiki/Color_blindness

Color blindness test



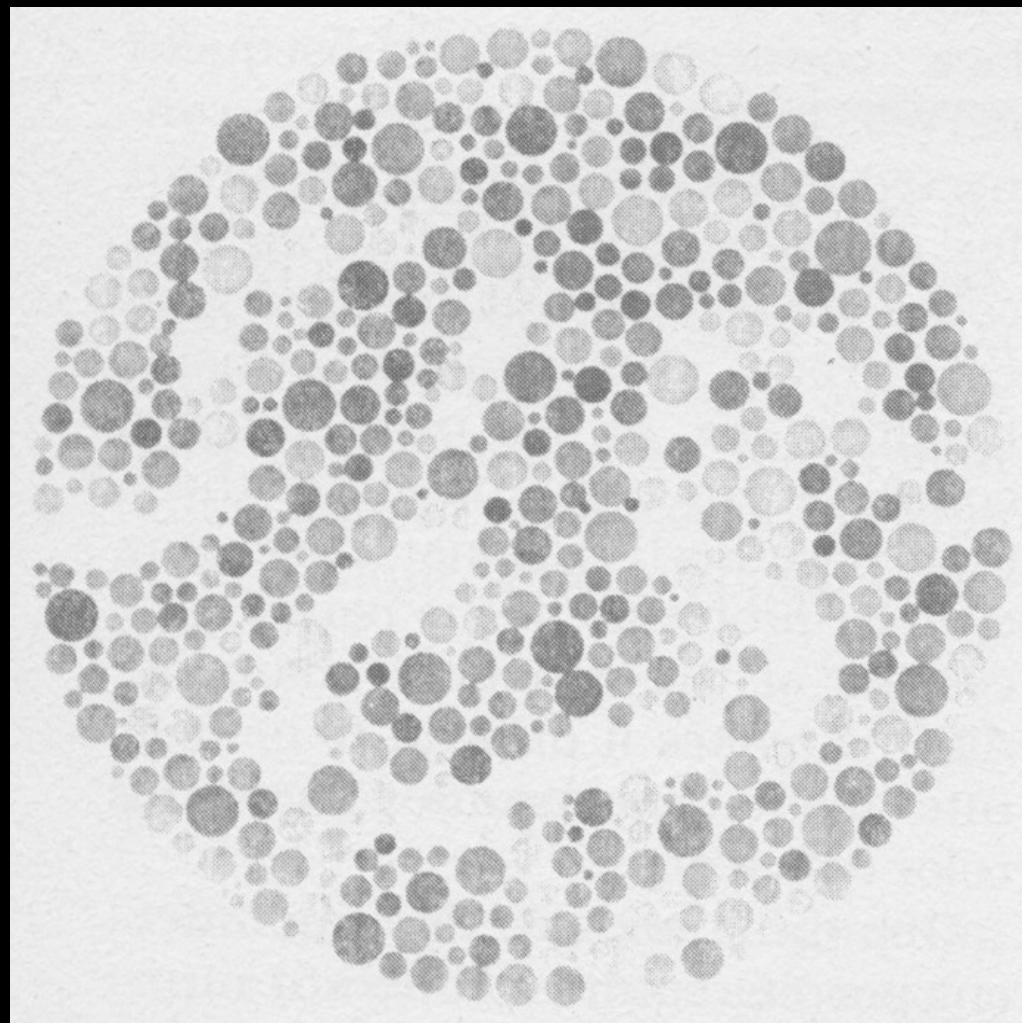
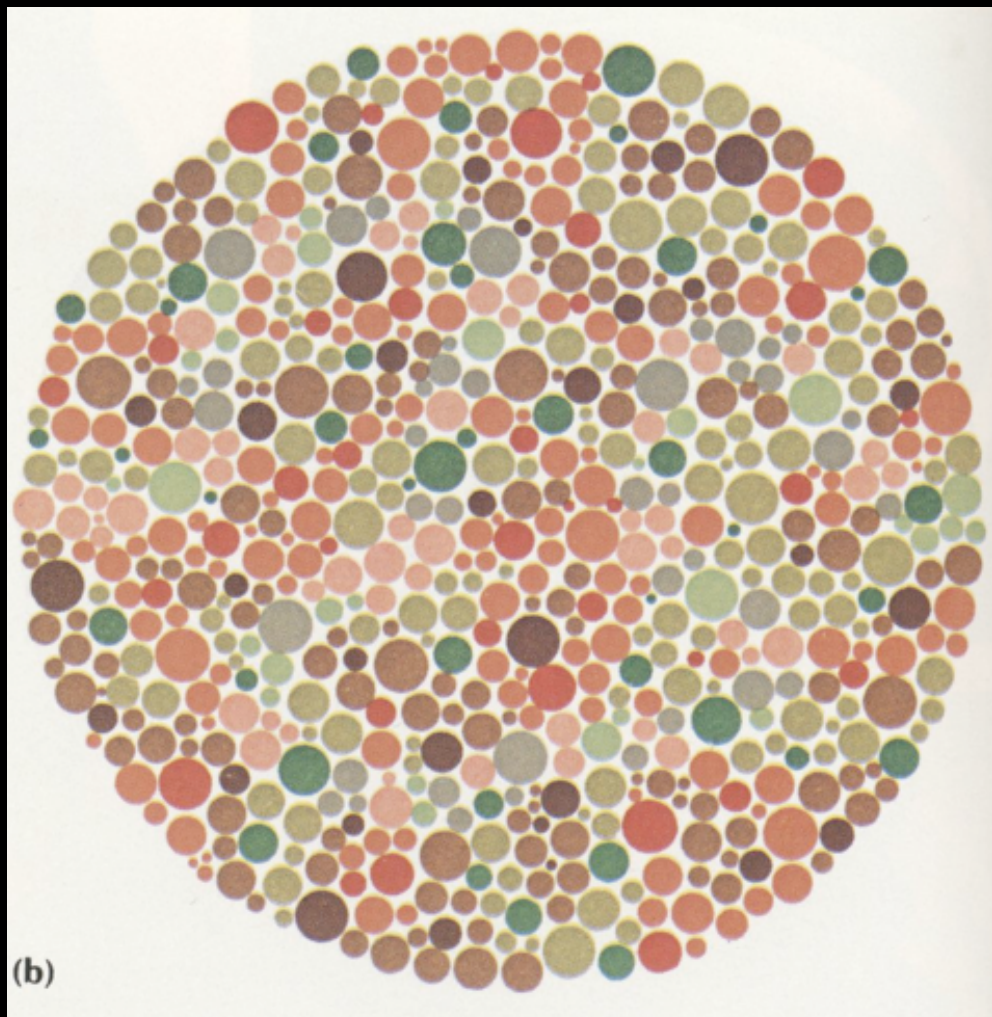
A



B

Color blindness test

- Maze in subtle intensity contrast
- Visible only to color blinds
- Color contrast overrides intensity otherwise



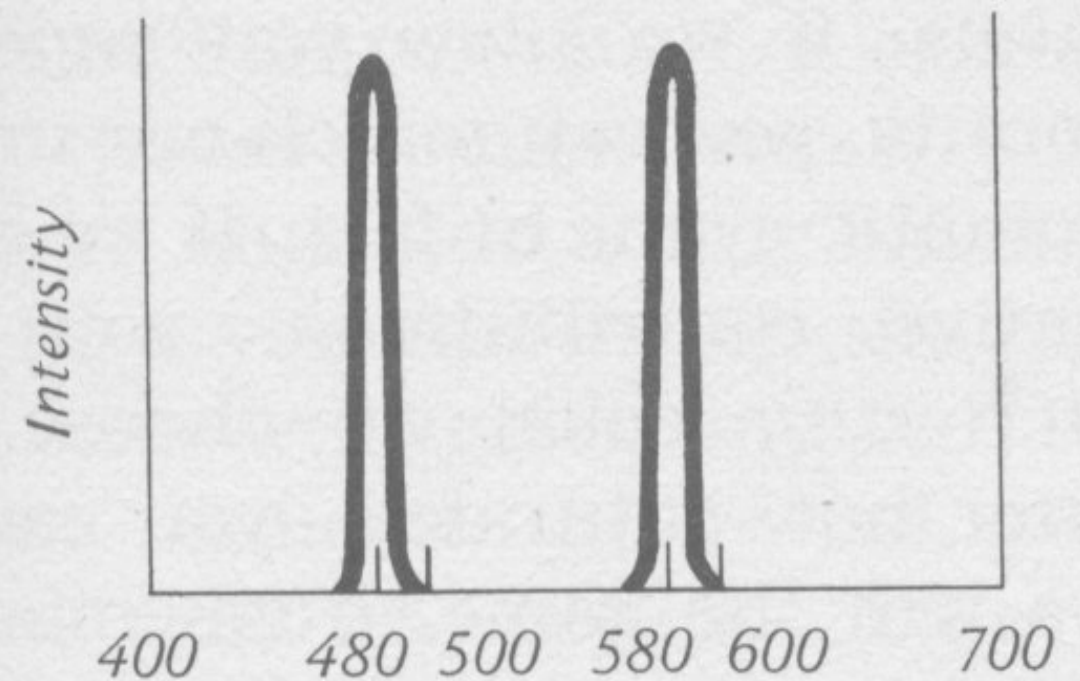
Questions?

- Links:
 - Vischeck shows you what an image looks like to someone who is colorblind.
 - <http://www.vischeck.com/vischeck/>
 - Daltonize, changes the red/green variation to brightness and blue/yellow variations.
 - <http://www.vischeck.com/daltonize/>
 - <http://www.vischeck.com/daltonize/runDaltonize.php>

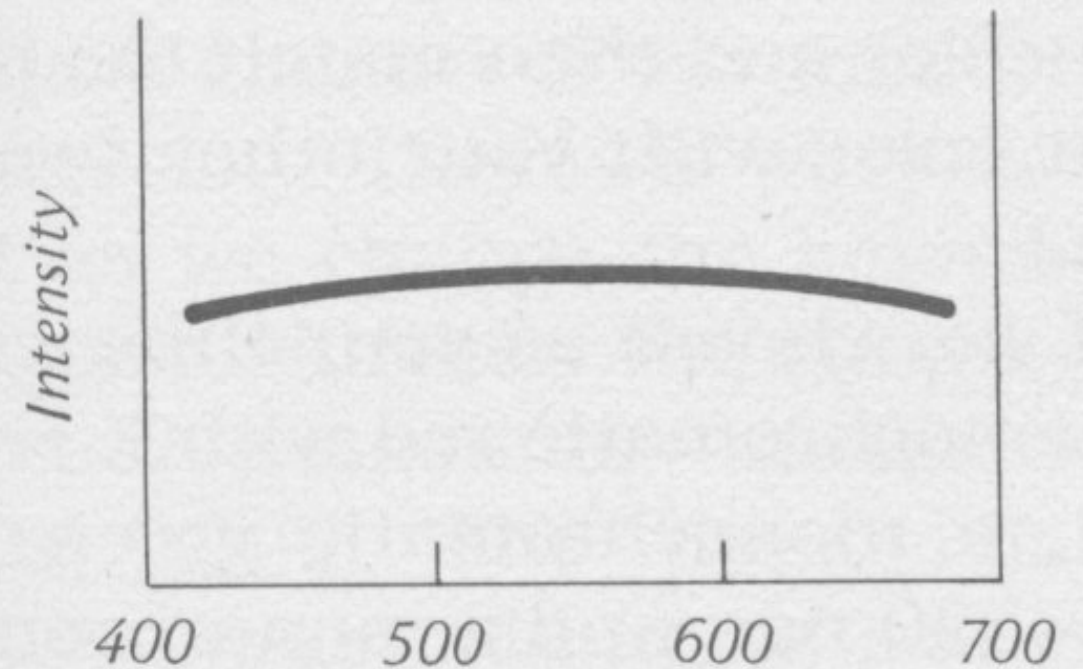
Metamers

Metamers

- We are all color blind!
- These two different spectra elicit the same cone responses
- Called metamers



(a) Wavelength (nm)

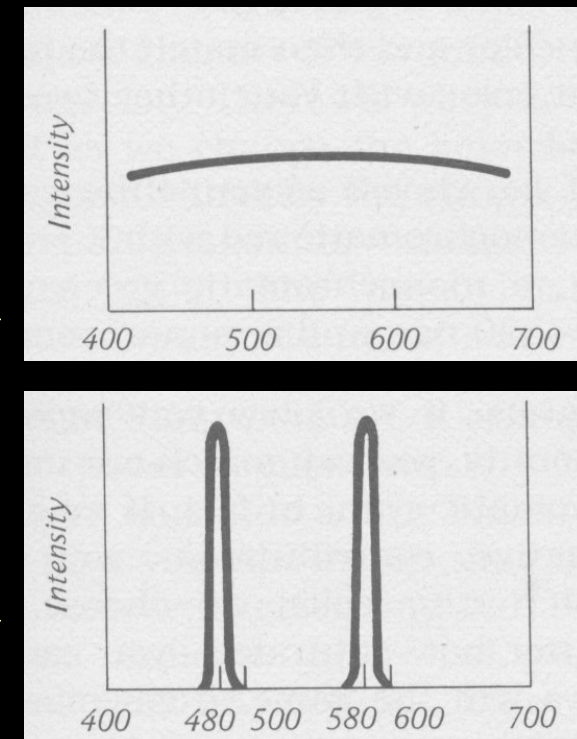
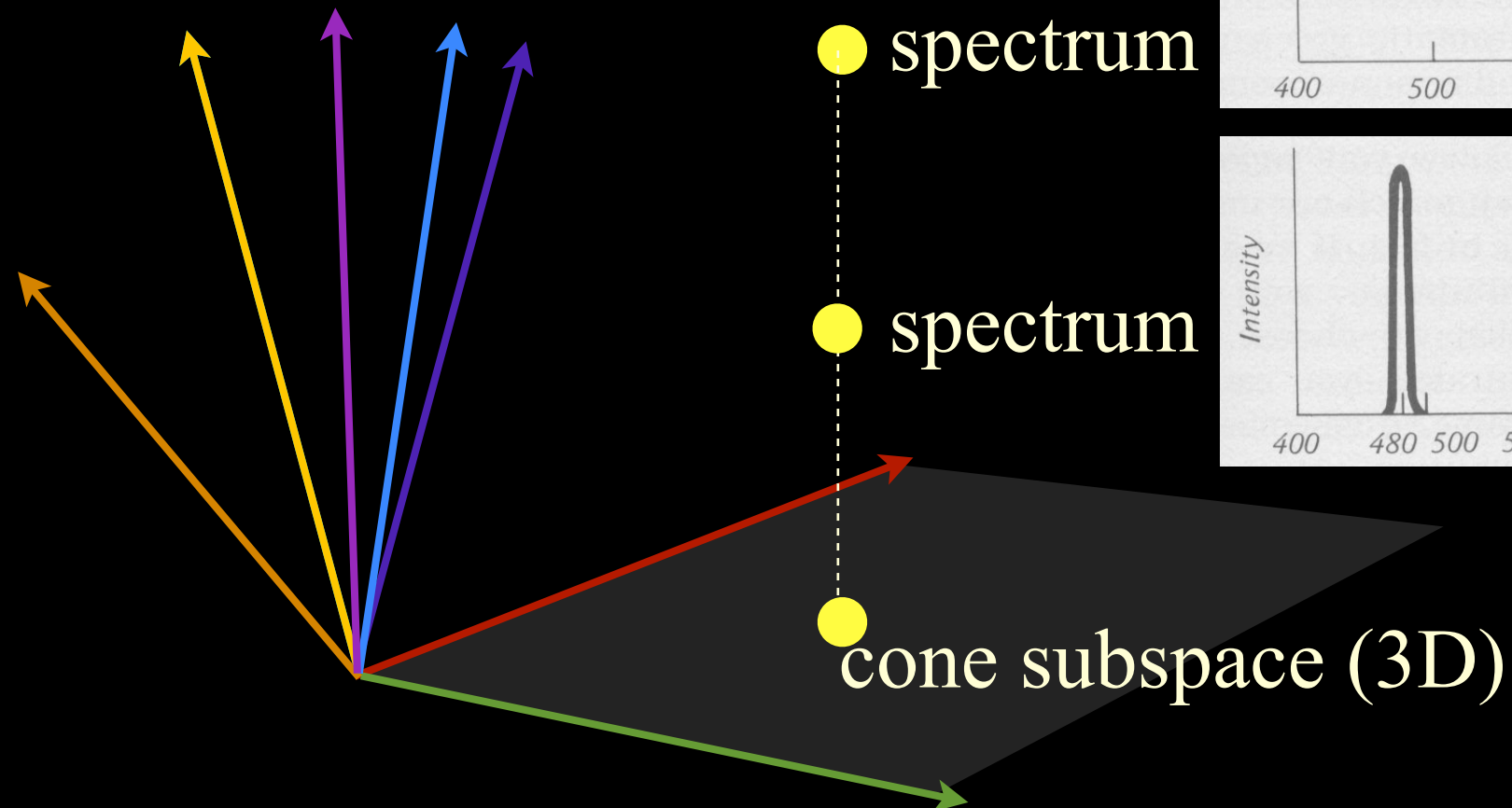


(b) Wavelength (nm)

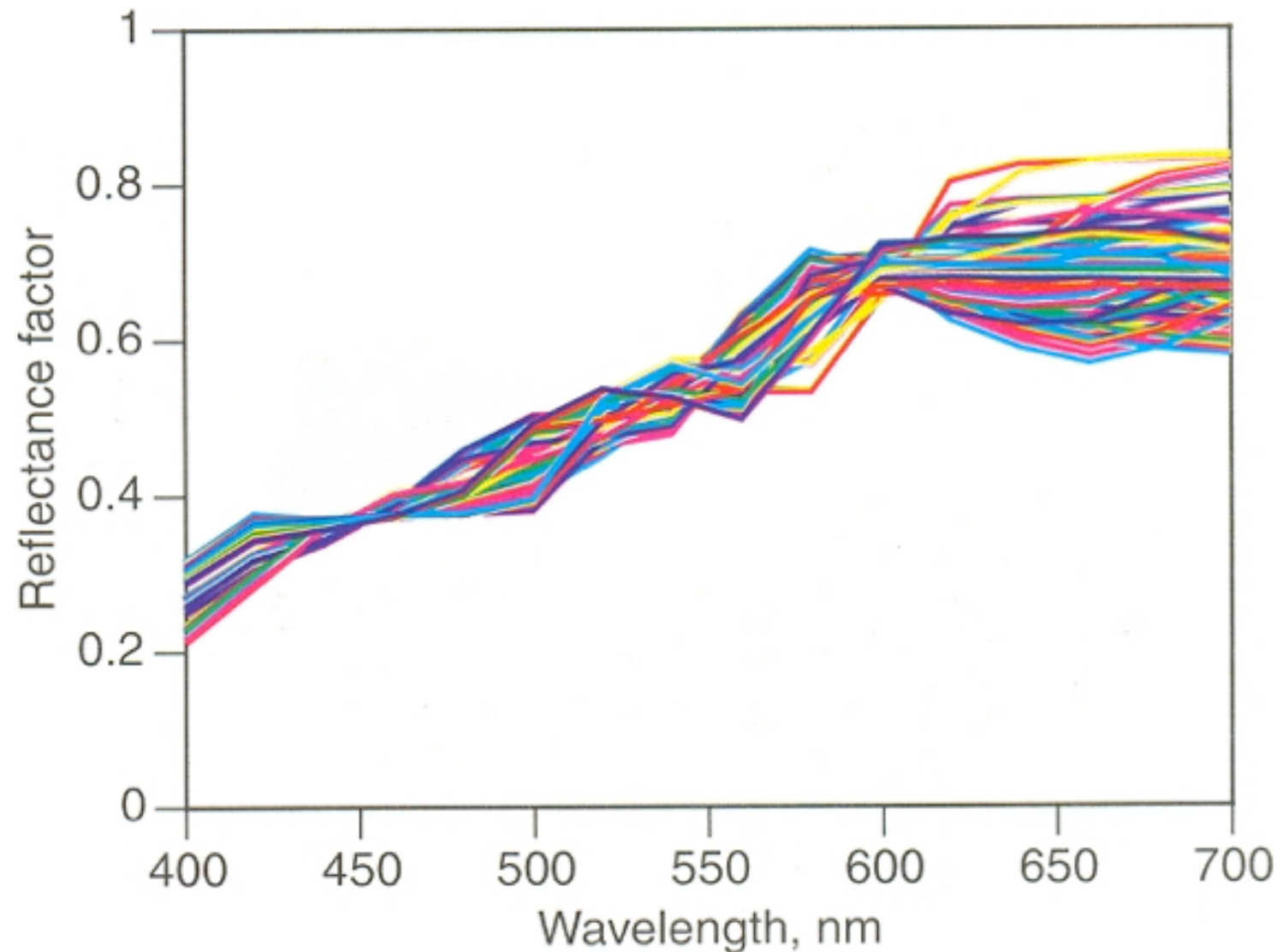
Metamers

- Essentially, we have projected from an infinite-dimensional spectrum to a 3D space:
we lose information

infinite set of bases



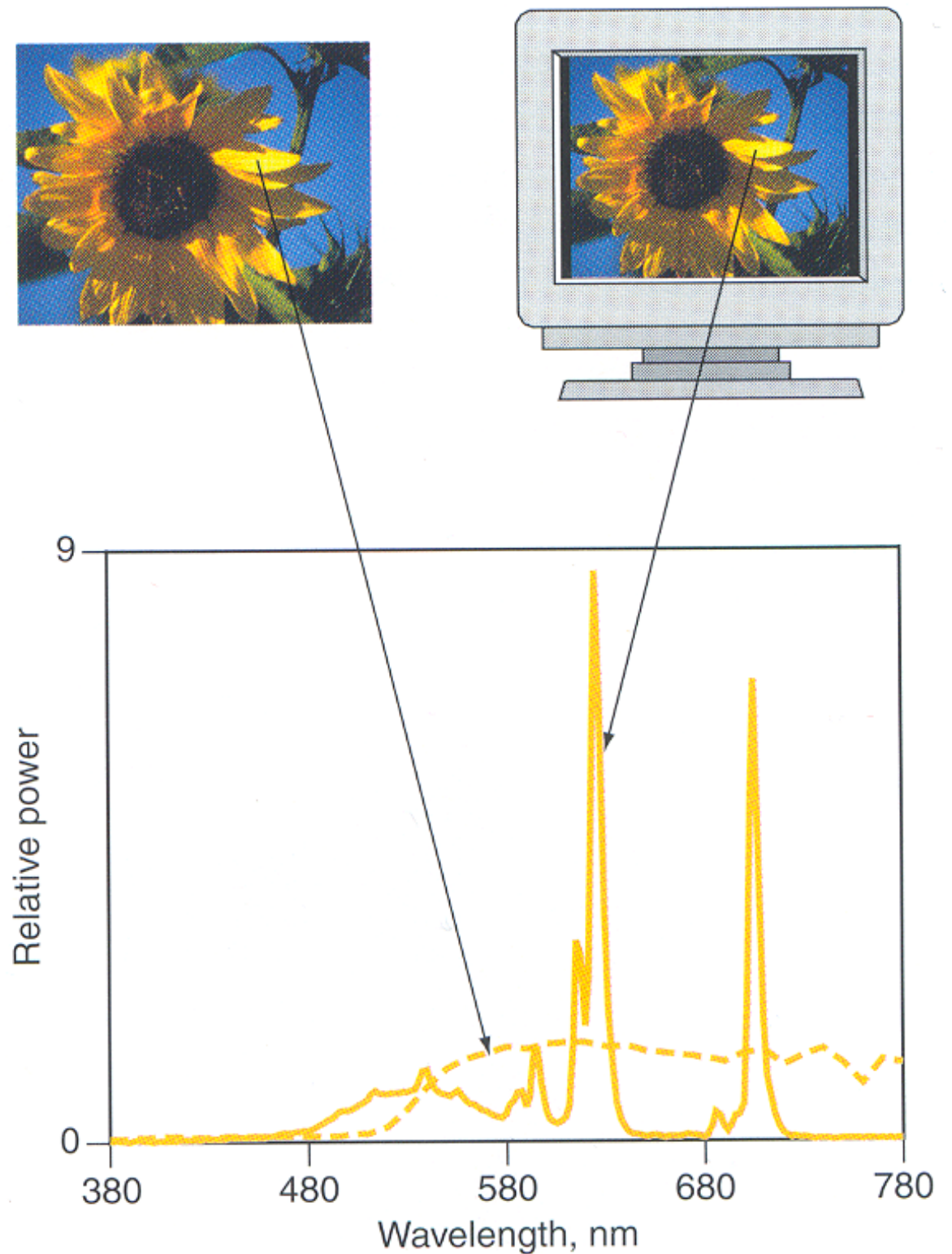
There is an infinity of metamers



Ensemble of spectral reflectance curves corresponding to three chromatic-pigment recipes all matching a tan material when viewed by an average observer under daylight illumination. [Based on Berns (1988b).]

Good news: color reproduction

- 3 primaries are (to a first order) enough to reproduce all colors



The dashed line represents daylight reflecting from sunflower petals, while the solid line represents the light emitted by a color CRT display adjusted to match the color of the sunflower.

Recap

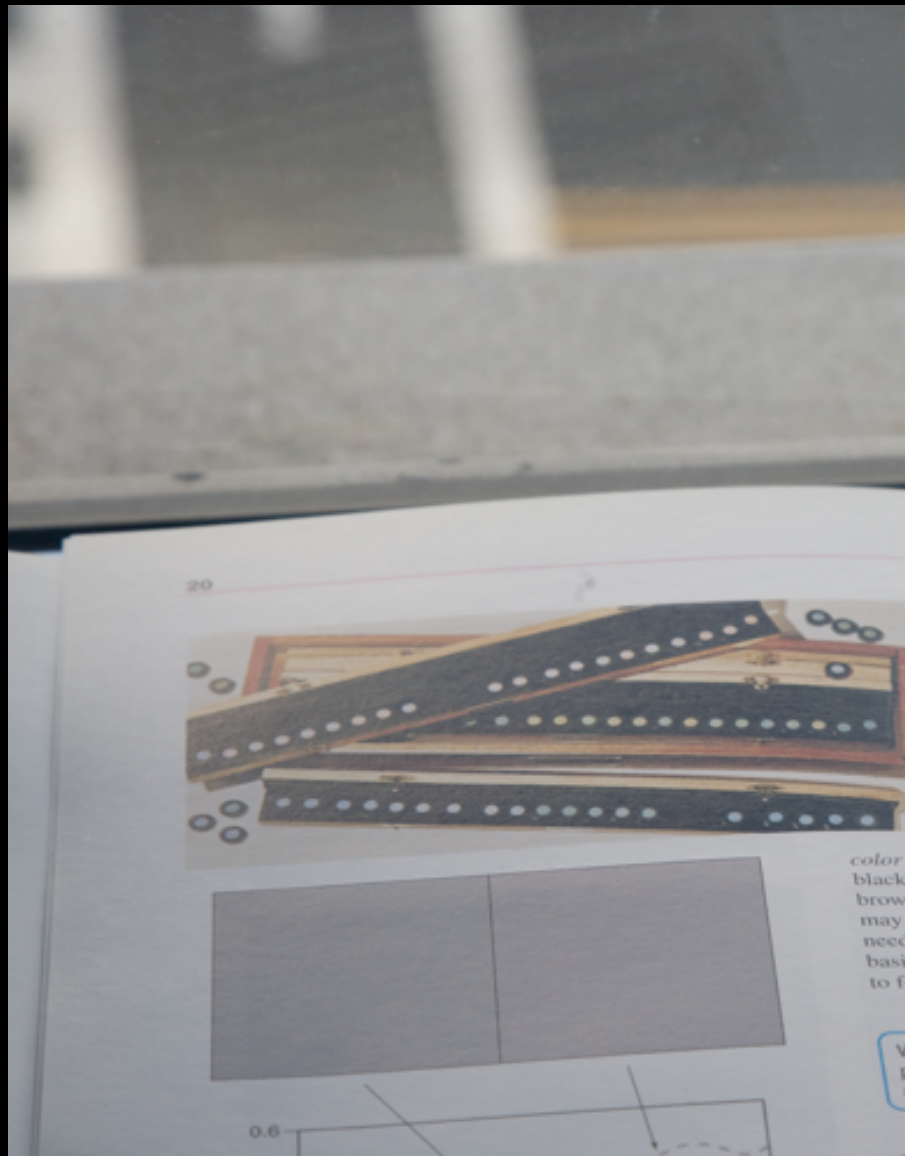
- Spectrum: infinite number of values
- projected according to cone spectral response
=> 3 values
- metamers: spectra that induce the same response
(physically different but look the same)
- Questions?

Metamerism & light source

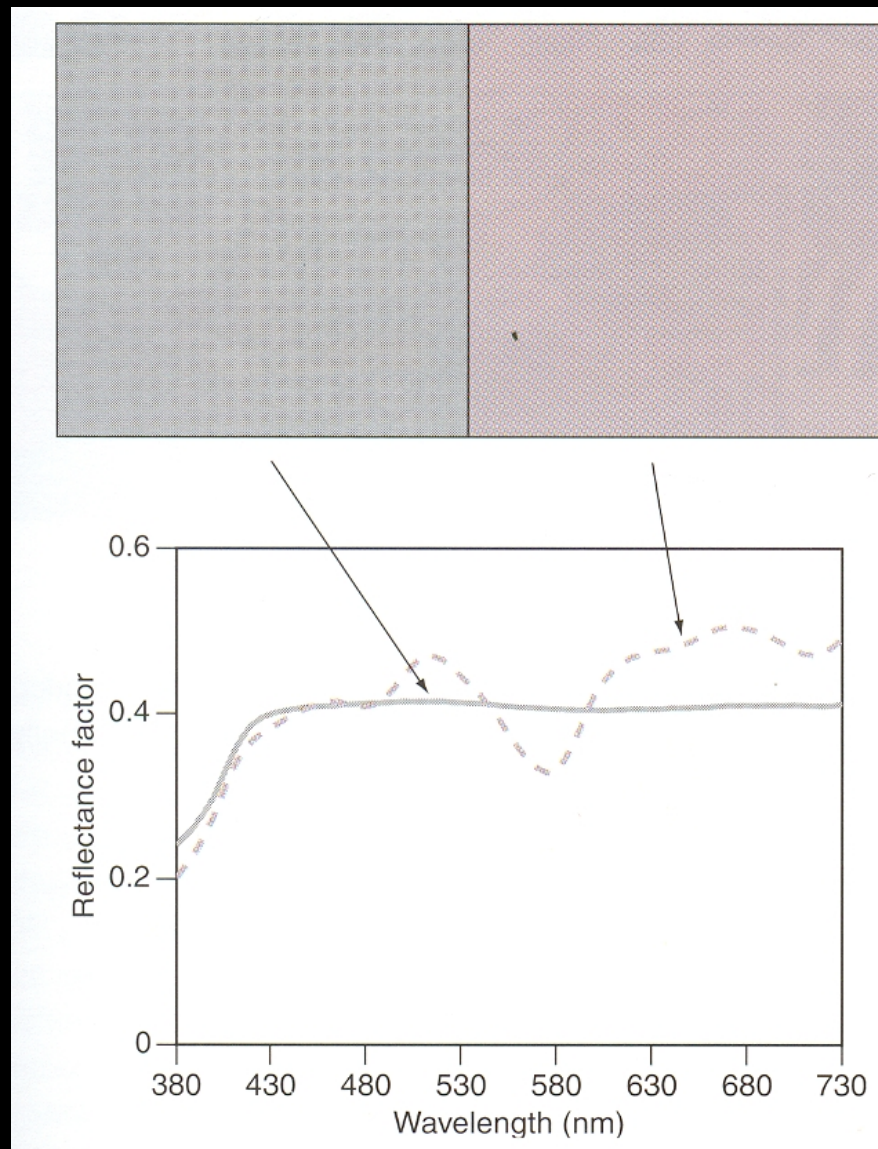
- Metamers under a given light source
- May not be metamers under a different lamp

Illuminant metamerism example

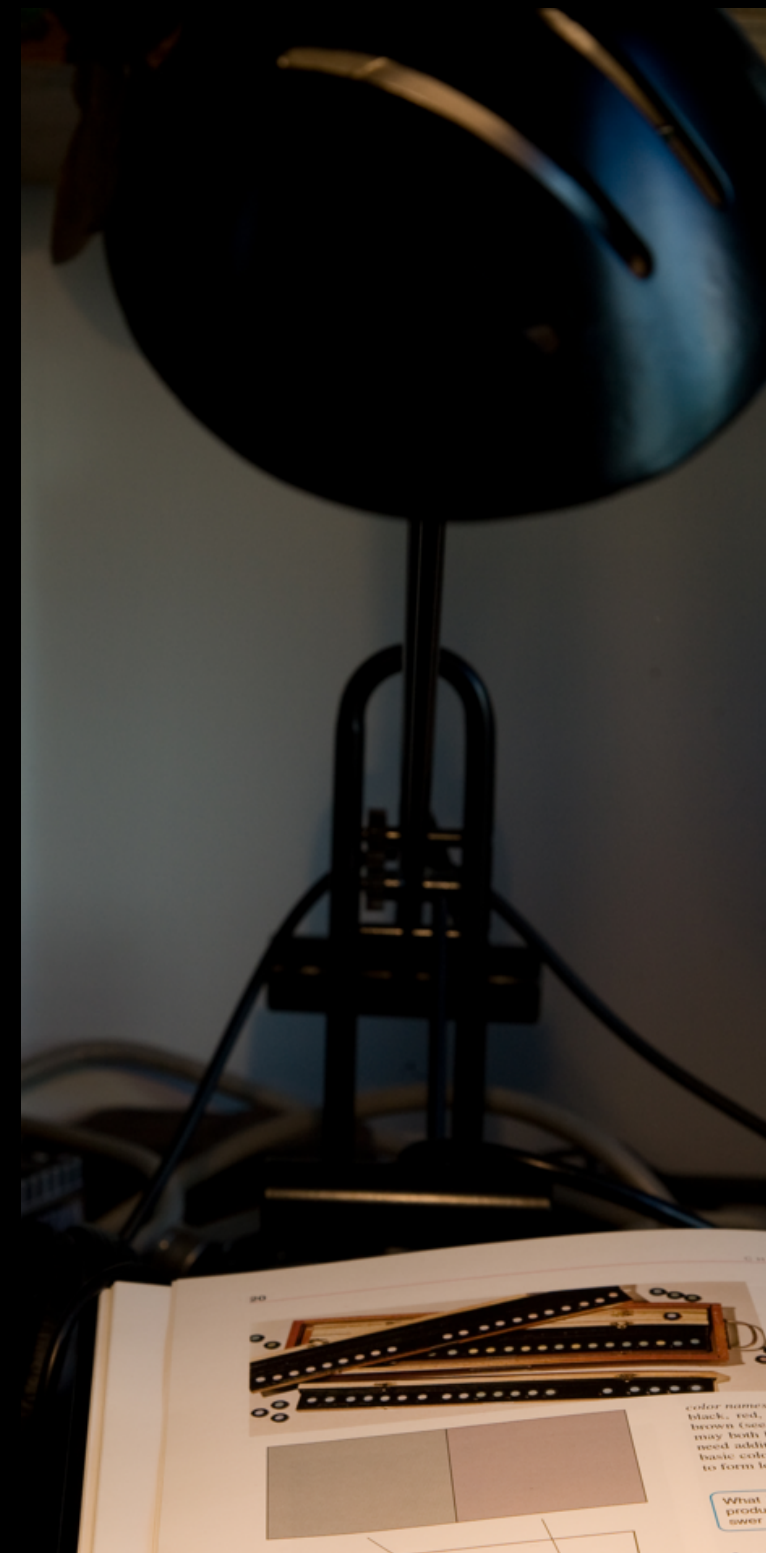
- Two grey patches in Billmeyer & Saltzman's book look the same under daylight but different under neon or halogen (& my camera agrees ;-)



Daylight



Scan (neon)



Hallogen

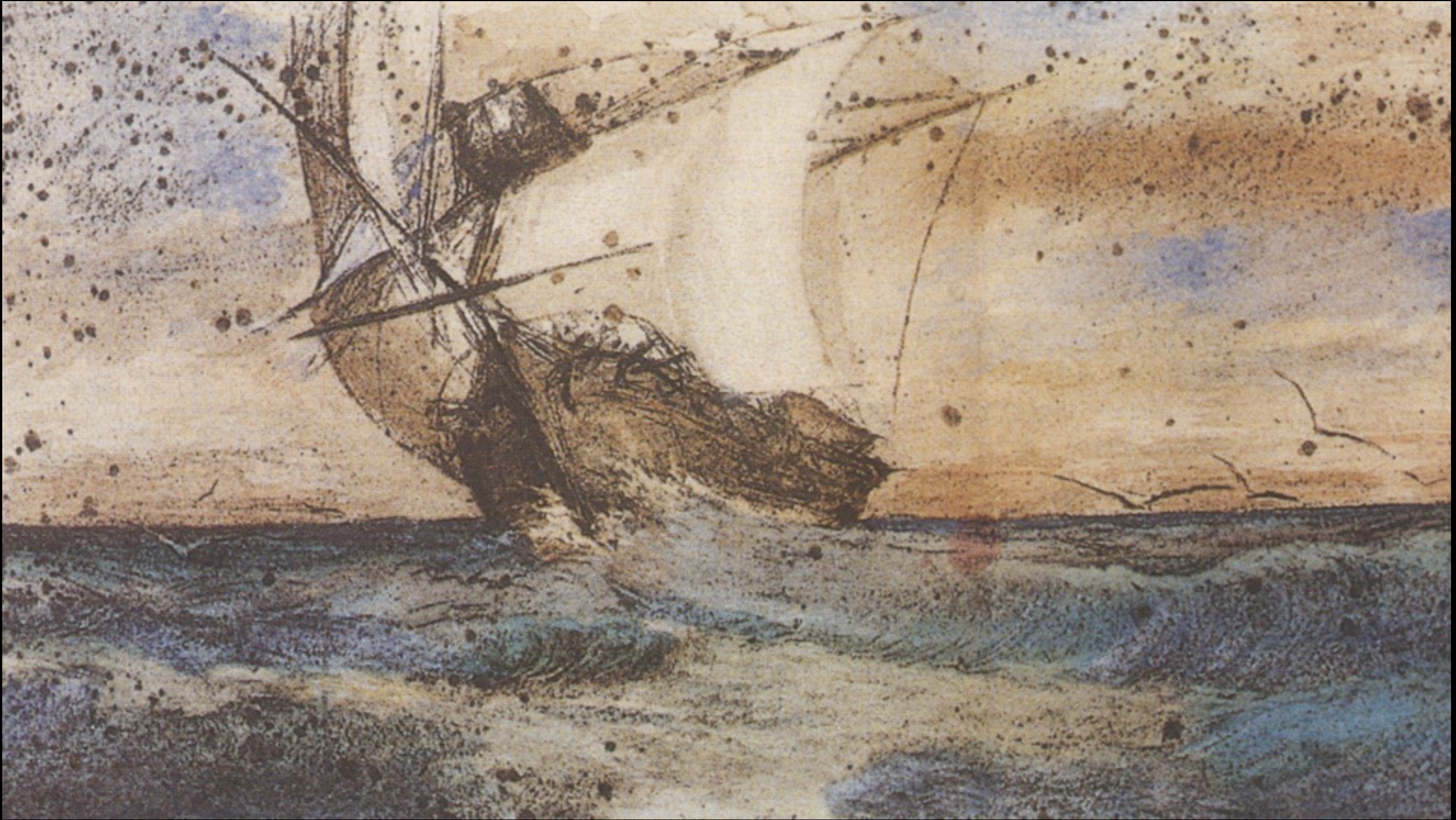
Bad consequence: cloth matching

- Clothes appear to match in store (e.g. under neon)
- Don't match outdoor

Recap

- Spectrum is an infinity of numbers
- Projected to 3D cone-response space
 - for each cone, multiply per wavelength and integrate
 - a.k.a. dot product
- Metamerism: infinite-D points projected to the same 3D point
(different spectrum, same perceived color)
 - affected by illuminant
 - enables color reproduction with only 3 primaries

Questions?

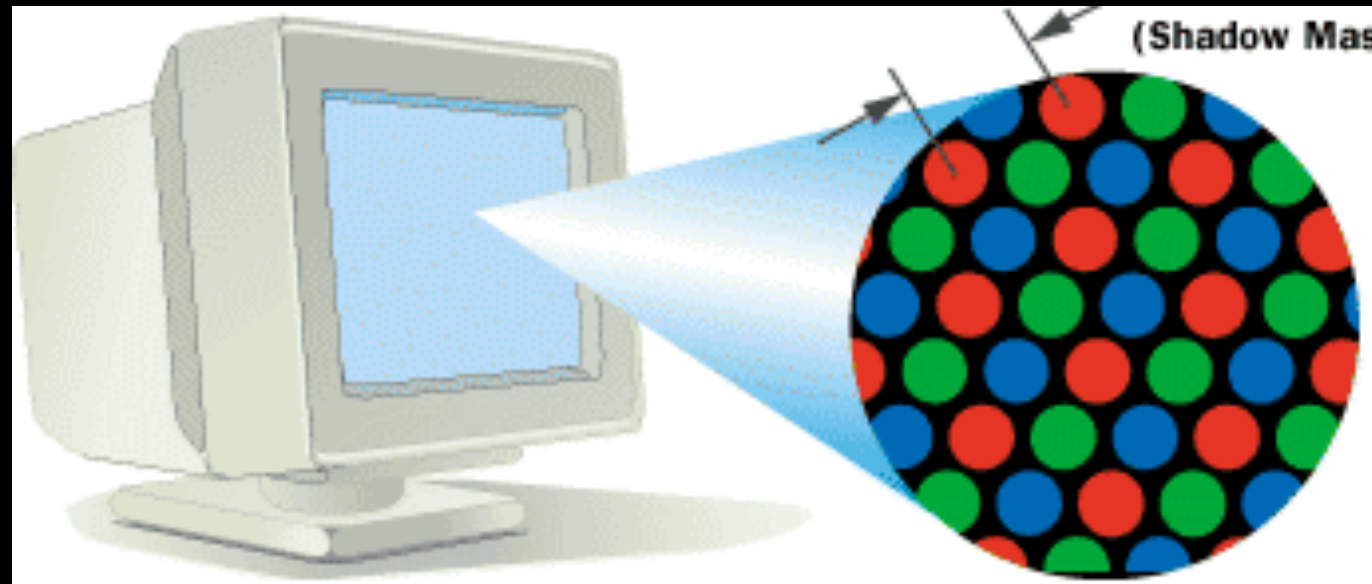


Meryon (a colorblind painter), *Le Vaisseau Fantôme*

Analysis & Synthesis

- Now let's talk about technology
- We want to measure & reproduce color as seen by humans
- No need for full spectrum
- Only need to match up to metamerism

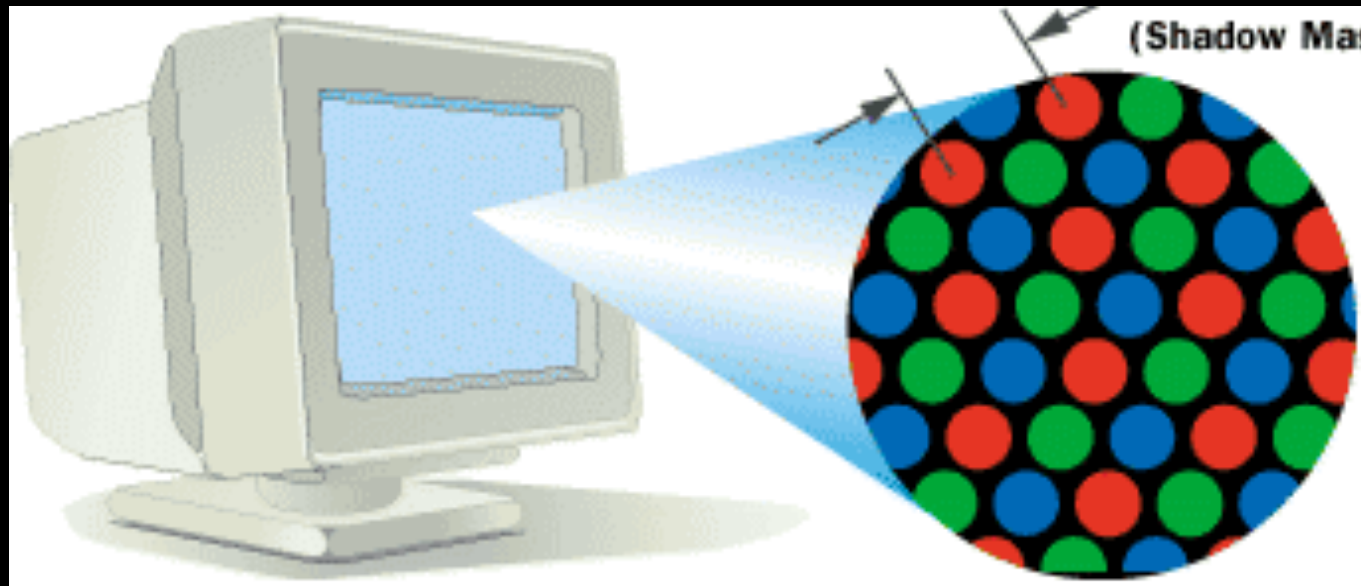
Analysis & Synthesis



<http://www.iriscam.info/PIXELS.html>

Analysis & Synthesis

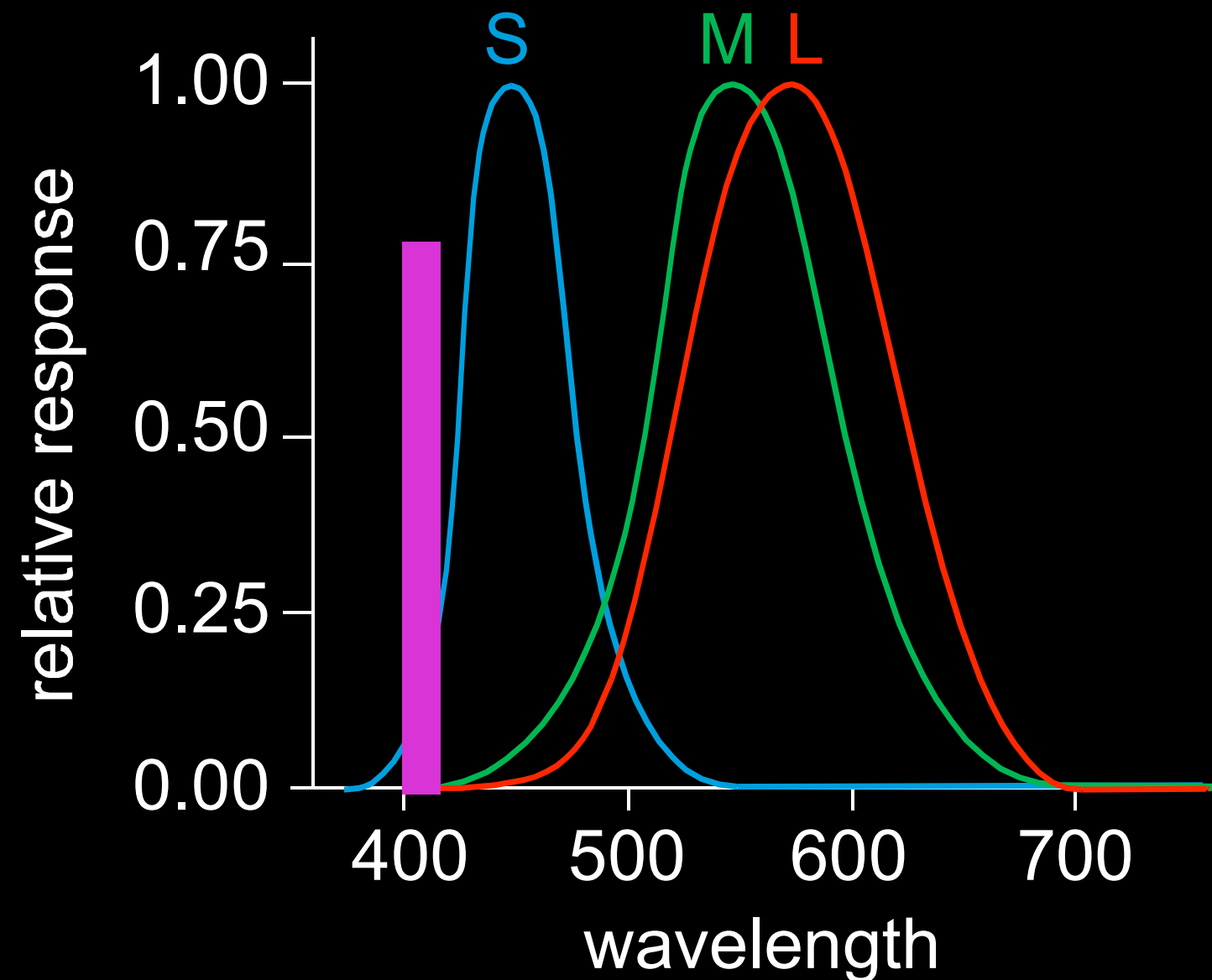
- Focus on additive color synthesis
- We'll use 3 primaries (e.g. red green and blue) to match all colors



<http://www.iriscam.info/PIXELS.html>

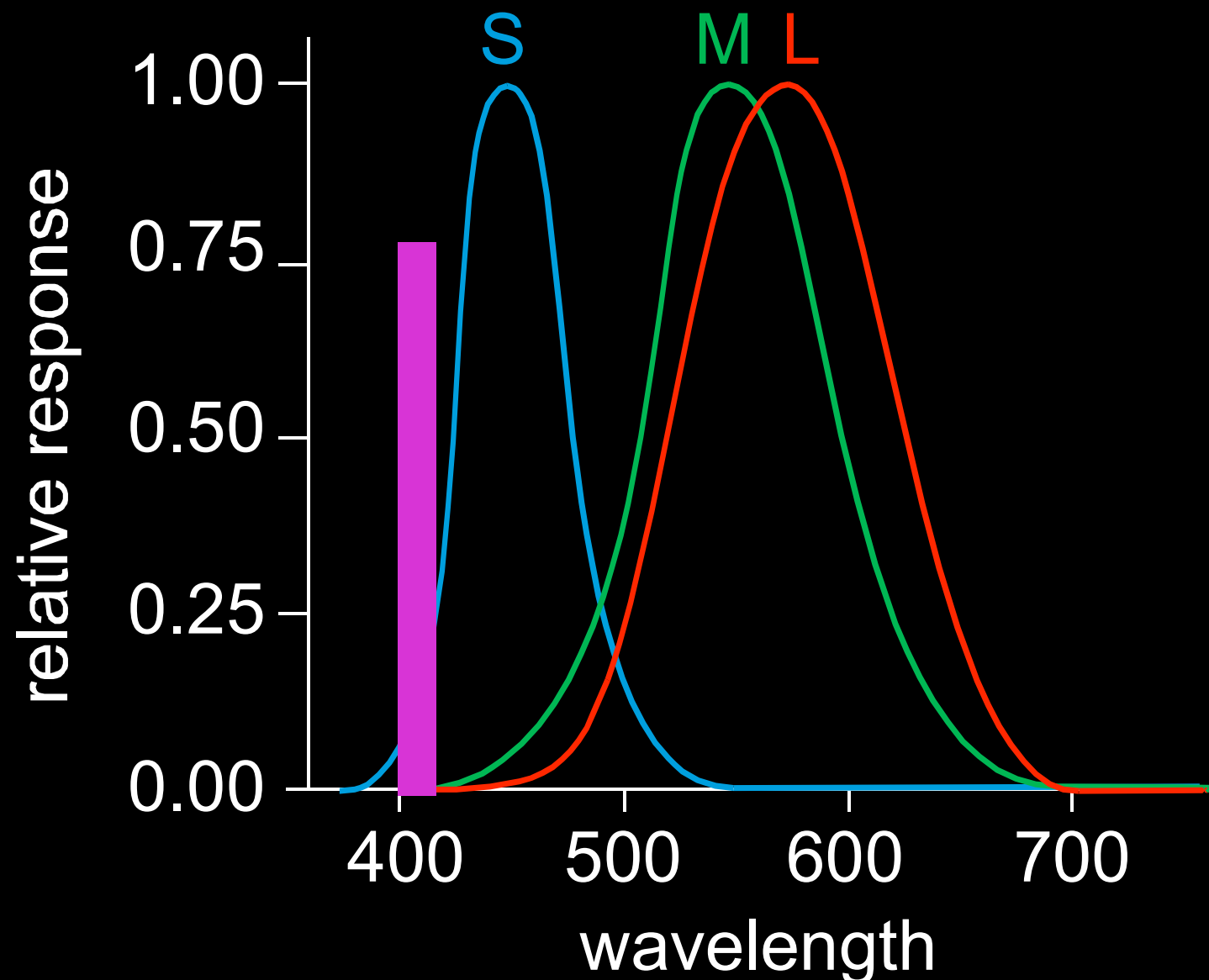
- What should those primaries be?
- How do we tell the amount of each primary needed to reproduce a given target color?

Additive Synthesis - wrong way

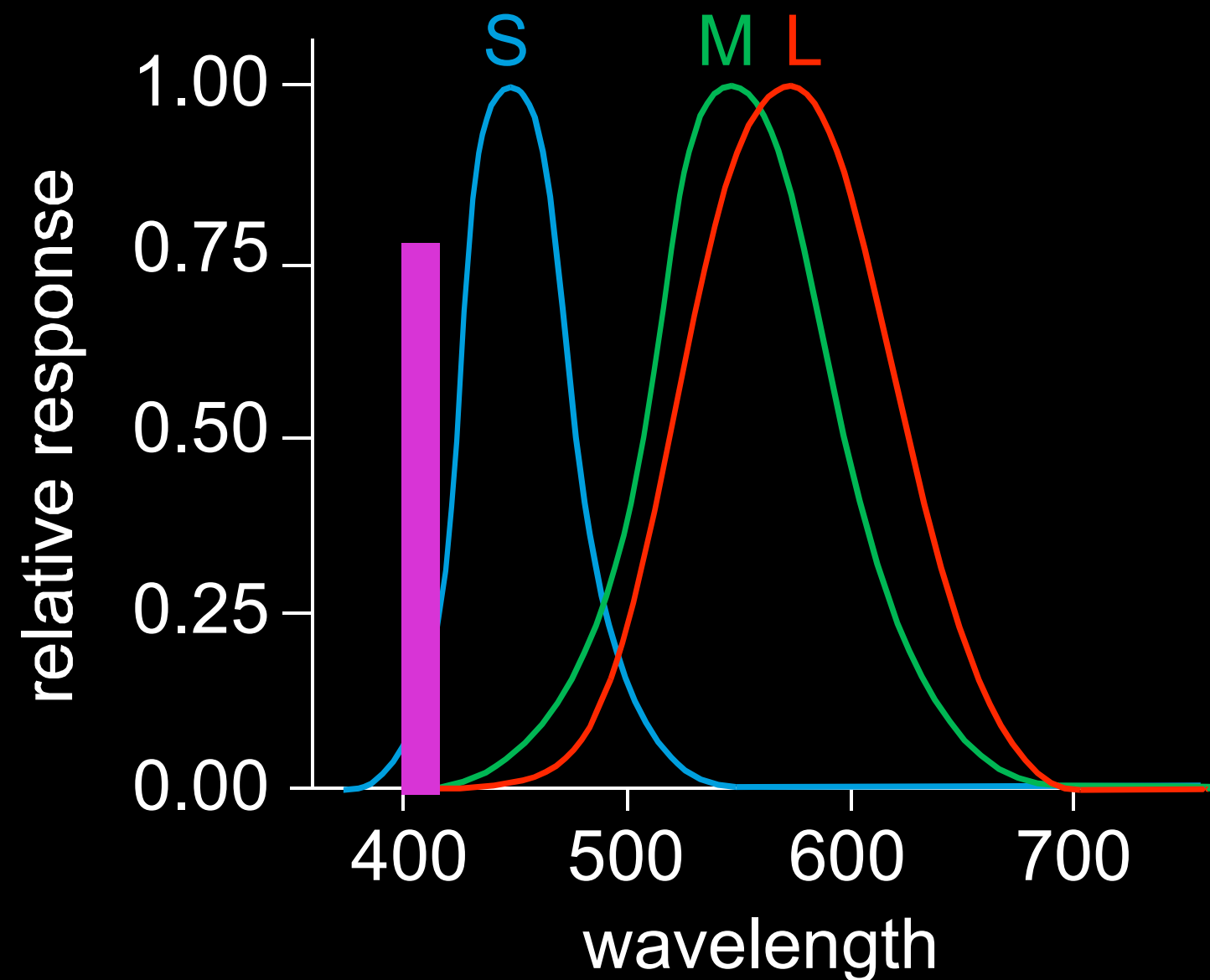


Additive Synthesis - wrong way

- Take a given stimulus and the corresponding responses s , m , l (here 0.5, 0, 0)

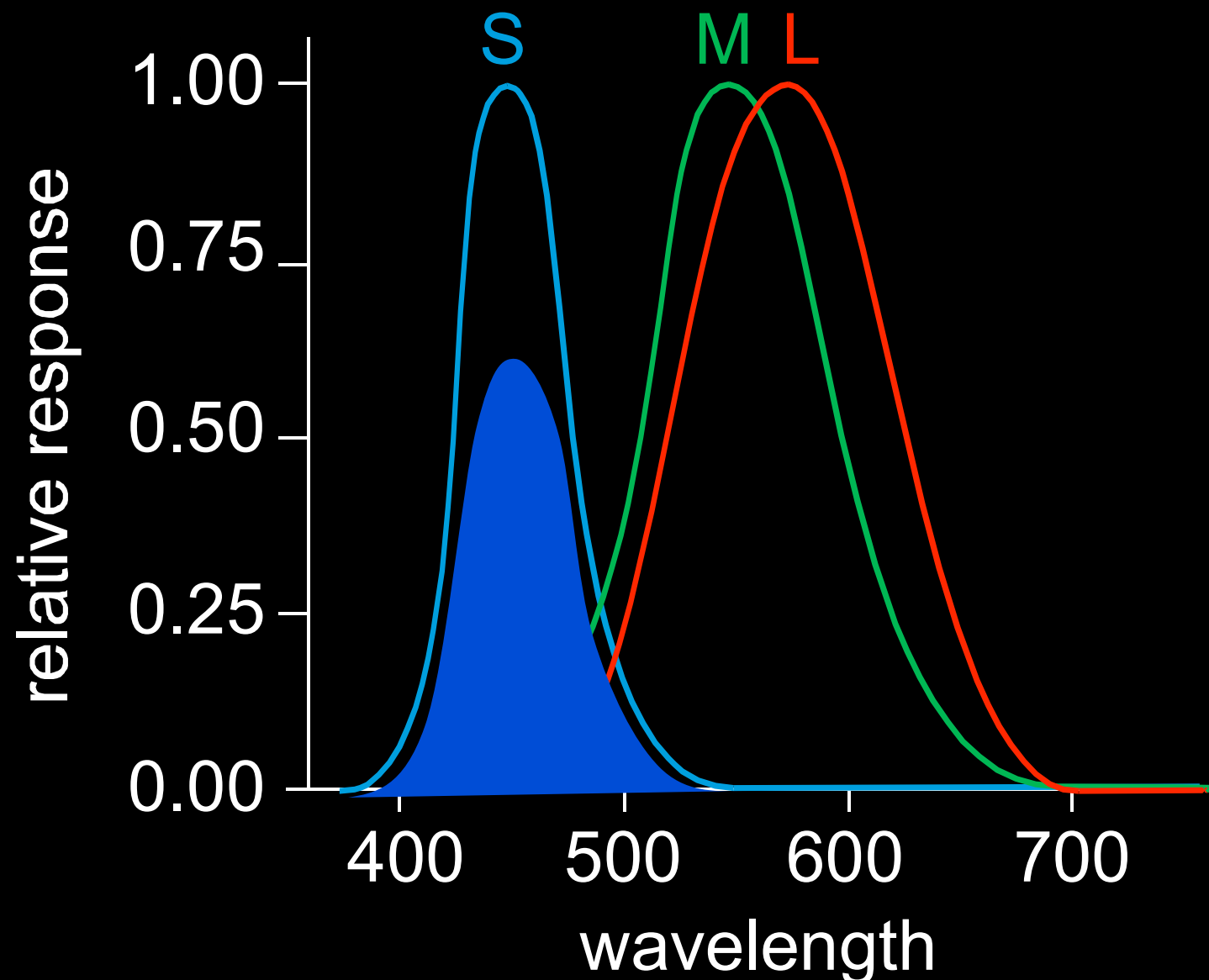


Additive Synthesis - wrong way



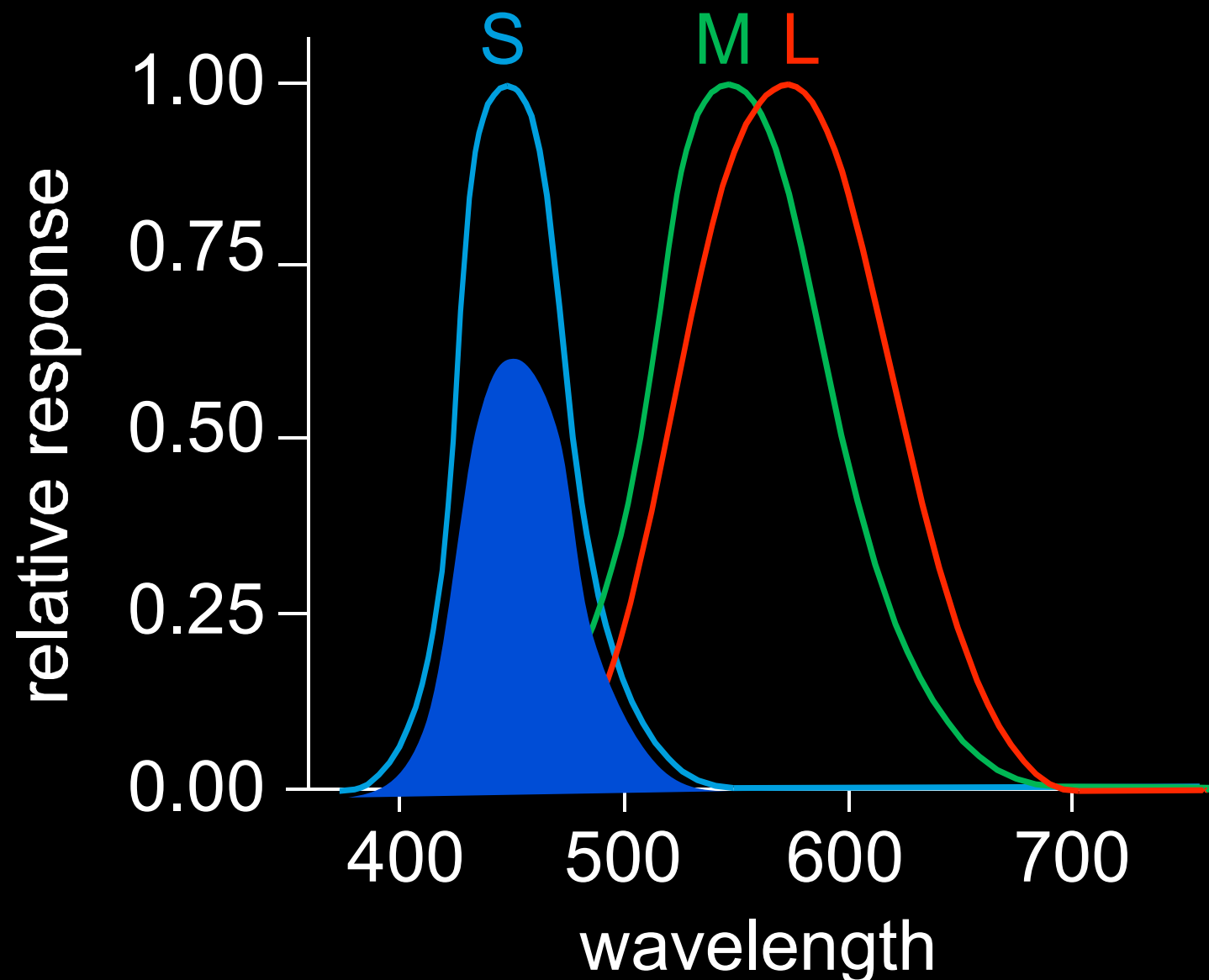
Additive Synthesis - wrong way

- Use it to scale the cone spectra (here $0.5 * S$)
- You don't get the same cone response!
(here 0.5, 0.1, 0.1)



What's going on?

- The three cone responses are not orthogonal
- i.e. they overlap and “pollute” each other



Geometry

CIE color matching

Standard color spaces

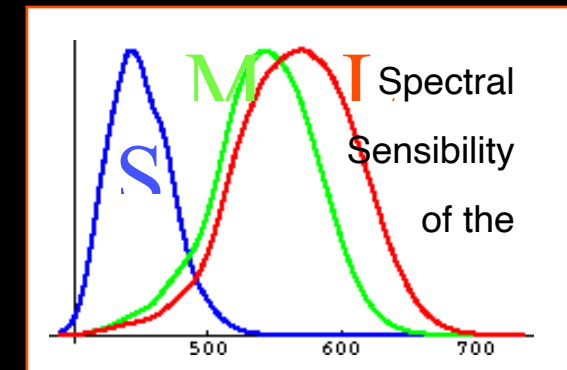
- We need a well-agreed color space
- Many possible definition
 - Including cone response (LMS)
 - Unfortunately not really used,
(because not known when colorimetry was invented)
- The good news is that color vision is linear and 3-dimensional, so any new color space based on color matching can be obtained using 3x3 matrix
 - But there are also non-linear color spaces
(e.g. Hue Saturation Value, Lab)

Overview

- Most standard color space: CIE XYZ
- LMS and the various flavors of RGB are just linear transformations of the XYZ basis
 - 3x3 matrices

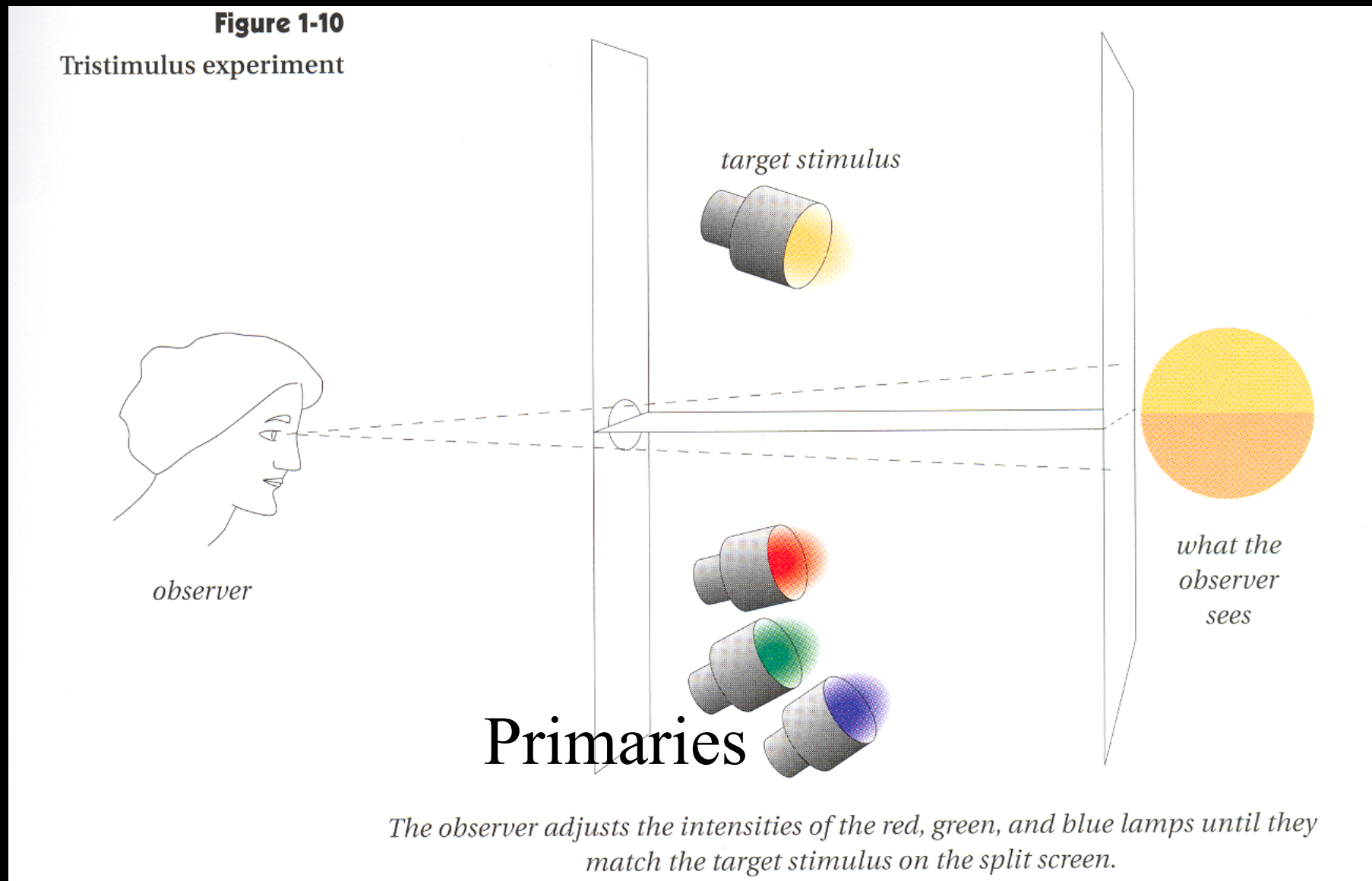
Why not measure cone sensitivity?

- Less directly measurable
 - electrode in photoreceptor?
 - not available when color spaces were defined
- Most directly available measurement:
 - notion of metamers & color matching
 - directly in terms of color reproduction:
given an input color,
how to reproduce it with 3 primary colors?
 - Commission Internationale de l'Eclairage
(International Lighting Commission)
 - Circa 1920



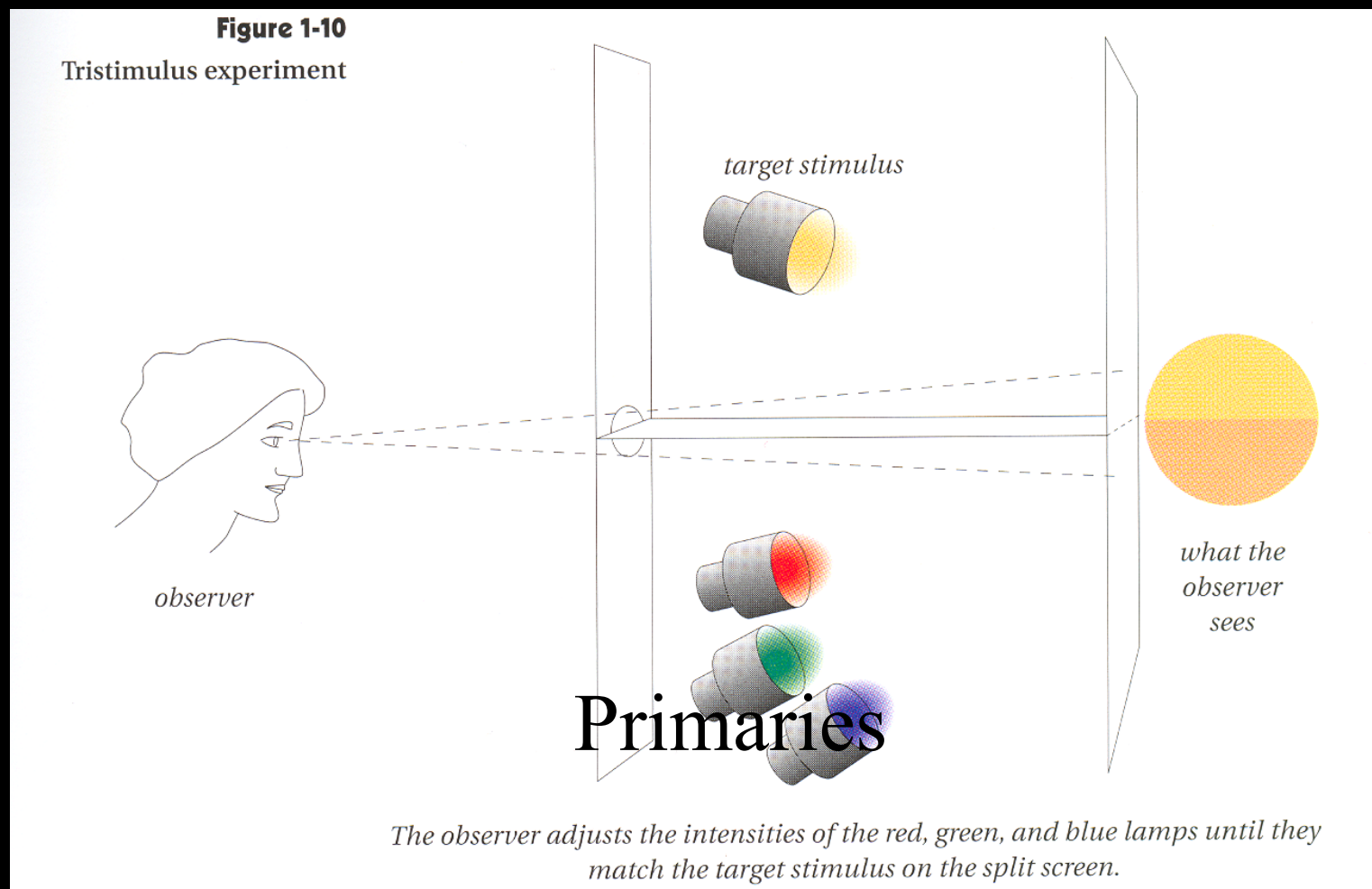
CIE color matching

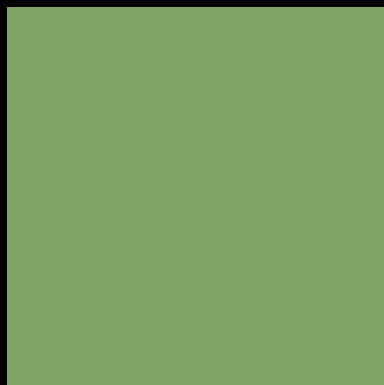
- Given an input color,
how to reproduce it with 3 primary colors?
—(Idea by Maxwell)



CIE color matching

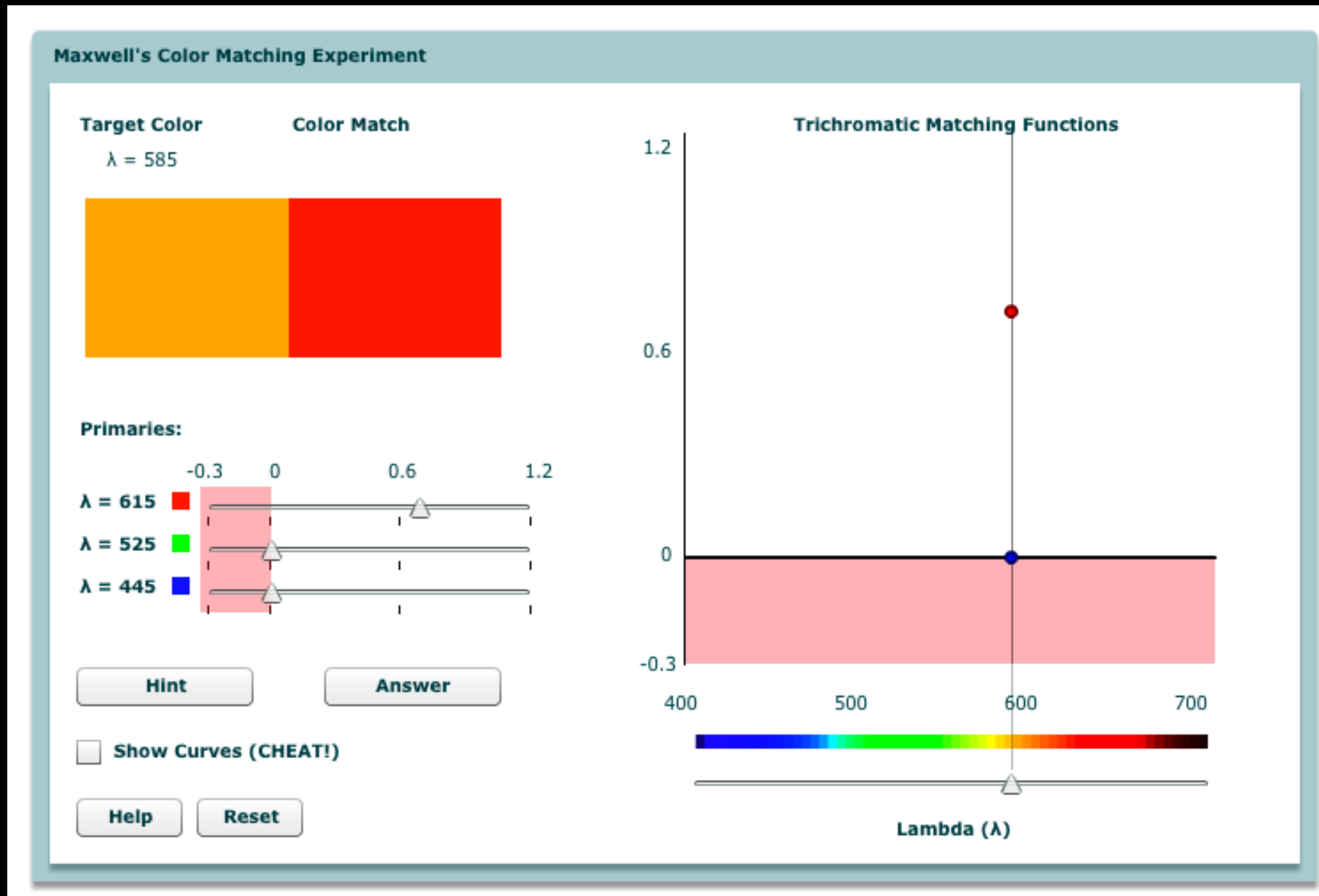
- Primaries (synthesis) at 435.8, 546.1 and 700nm
 - Chosen for robust reproduction, good separation in red-green
 - Don't worry, we'll be able to convert it to any other set of primaries (Linear algebra to the rescue!)
- Resulting 3 numbers for each input wavelength are called tristimulus values





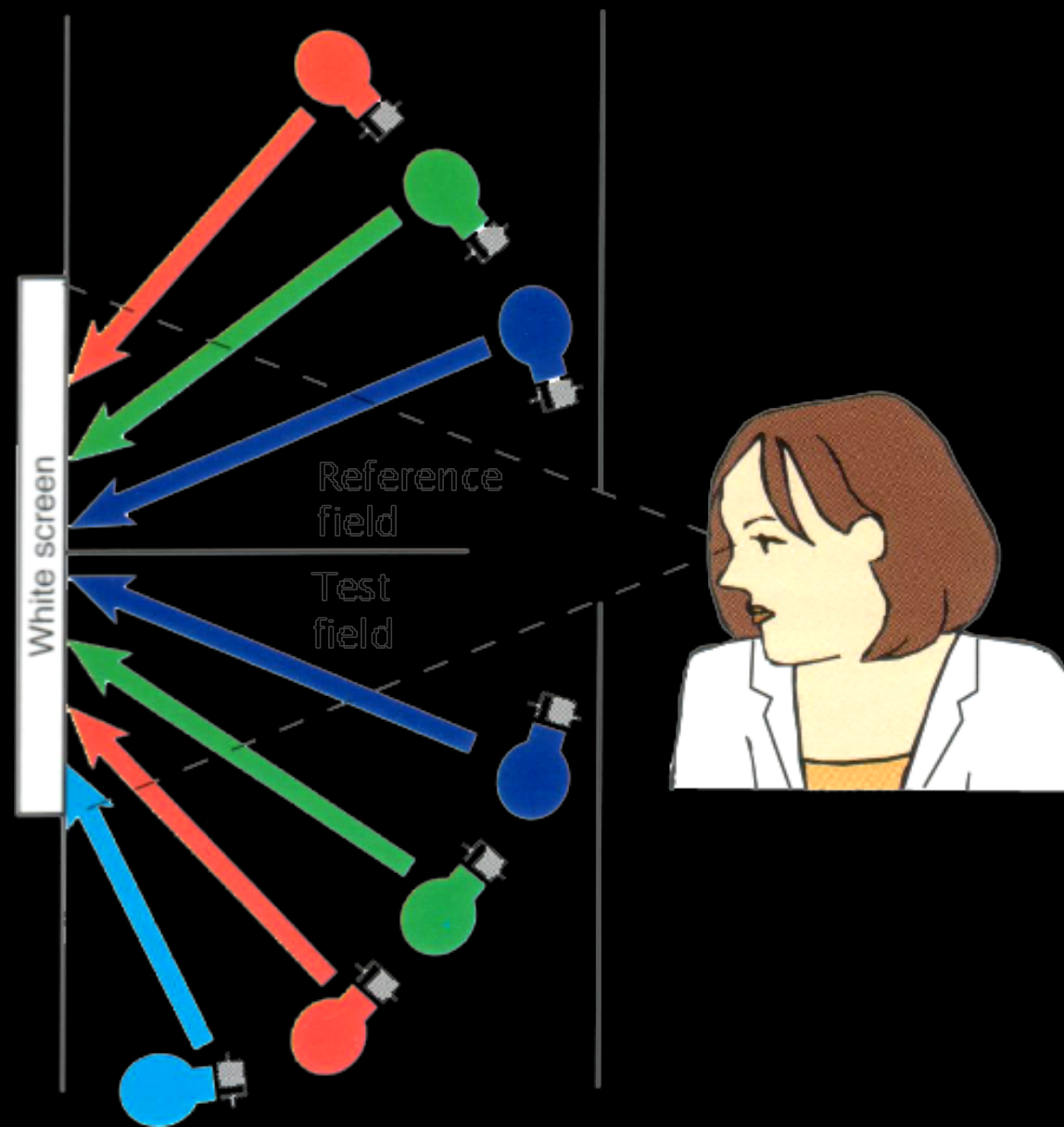
Applet

- <http://graphics.stanford.edu/courses/cs178-10/applets/colormatching.html>



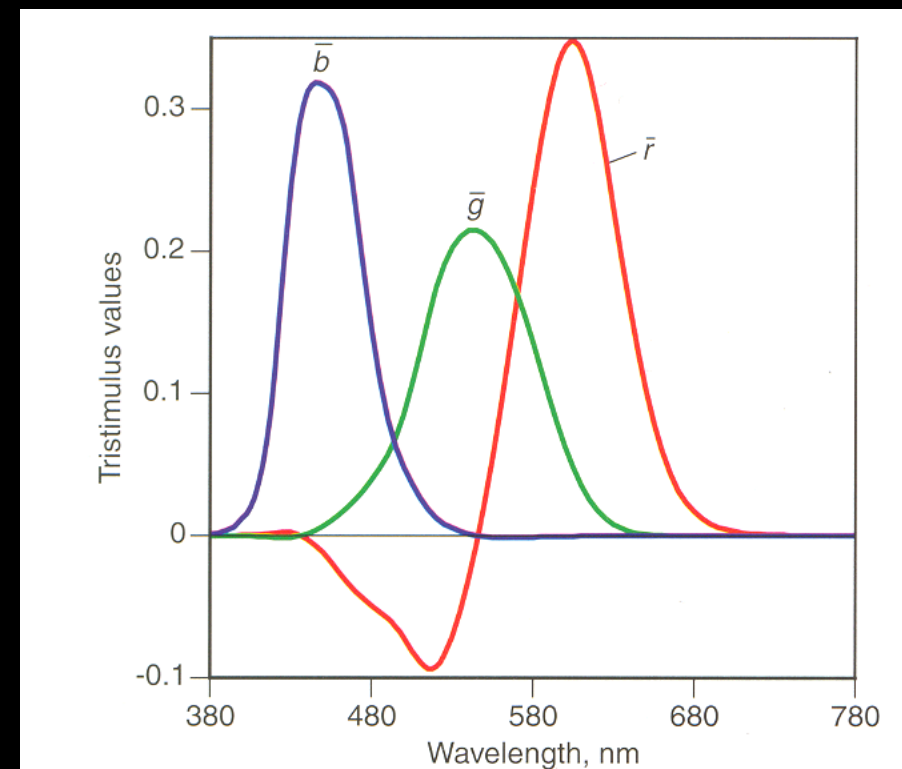
Color Matching Problem

- Some colors cannot be produced using only positively weighted primaries
- Solution: add light on the other side!



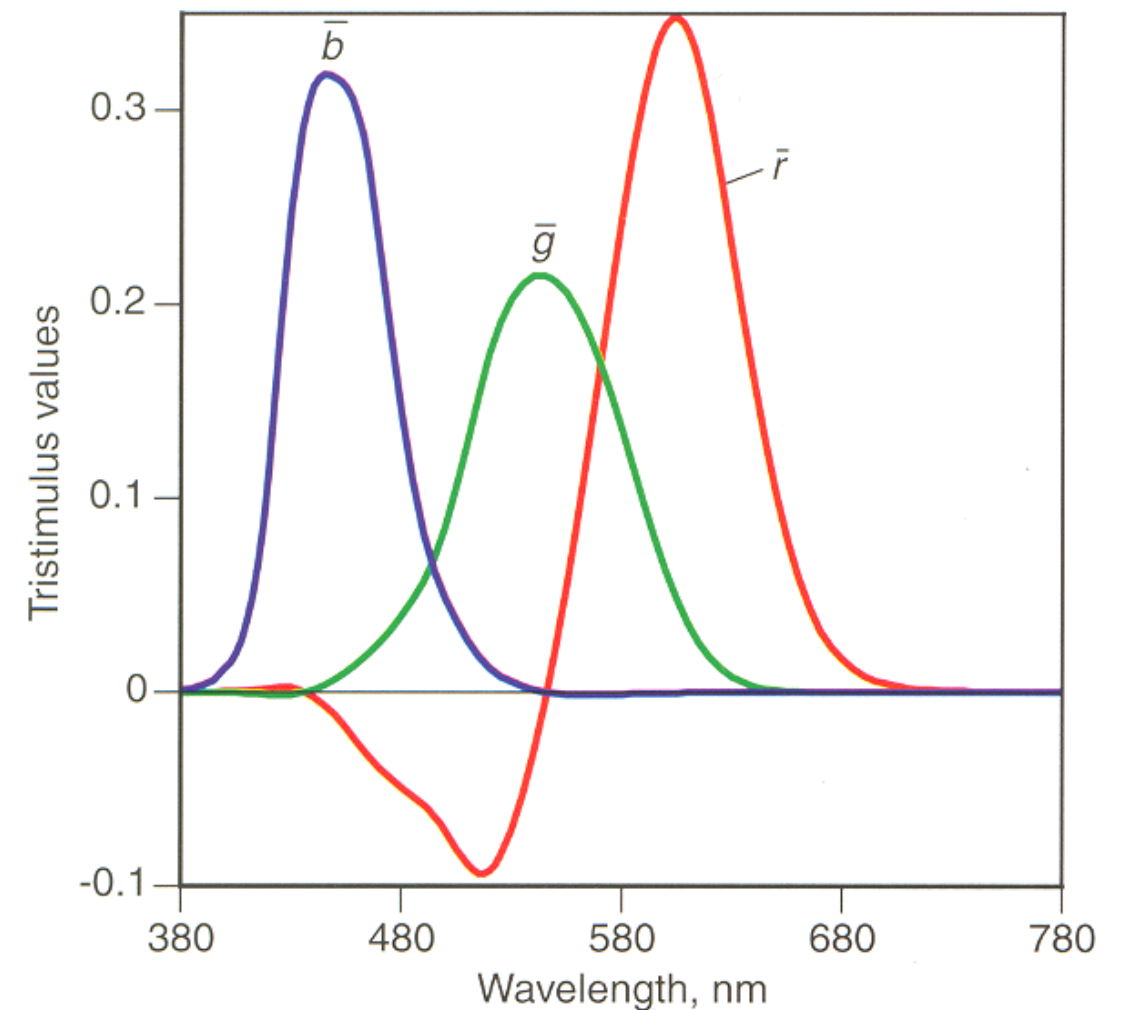
CIE color matching

- Meaning of these curves: a monochromatic wavelength λ can be reproduced with $b(\lambda)$ amount of the 435.8nm primary, + $g(\lambda)$ amount of the 546.1 primary, + $r(\lambda)$ amount of the 700 nm primary
- This fully specifies the color perceived by a human
- Careful: this is not your usual rgb



These curves are the color-matching functions for the 1931 standard observer, The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

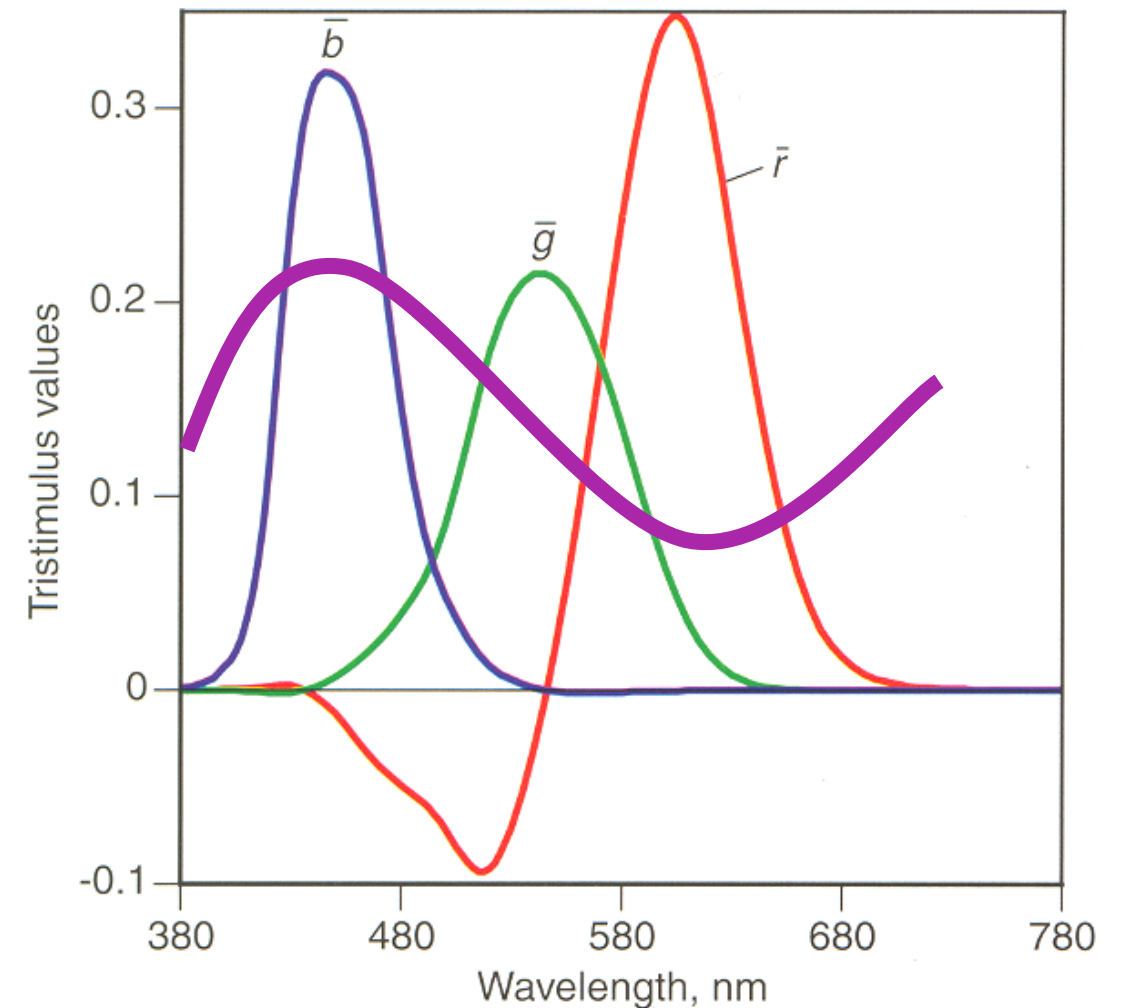
CIE color matching: what does it mean?



These curves are the color-matching functions for the 1931 standard observer, The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

CIE color matching: what does it mean?

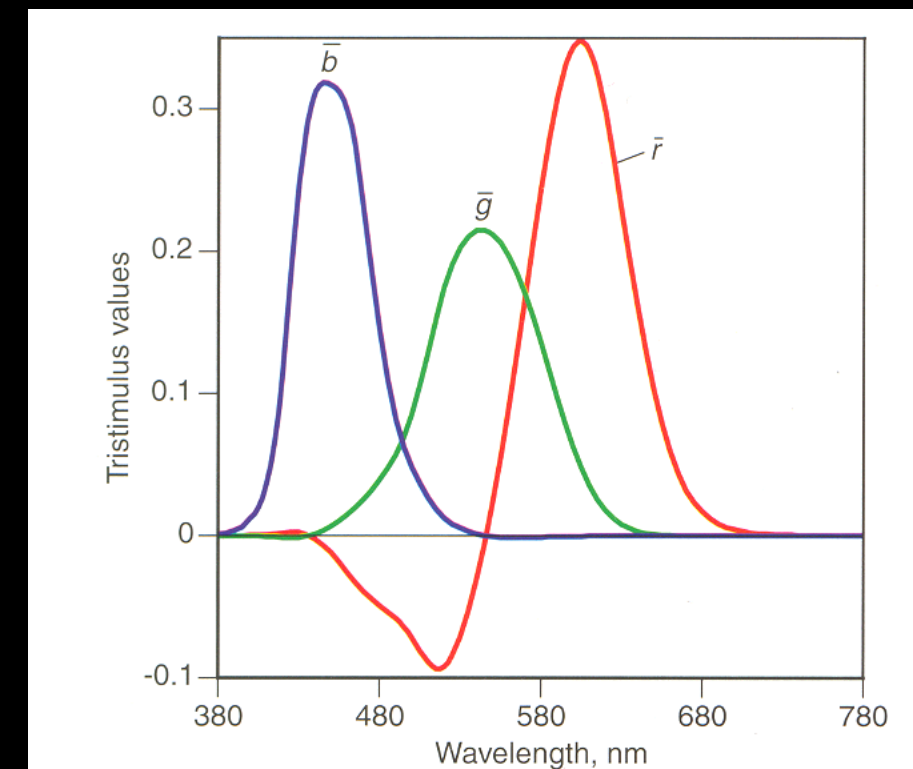
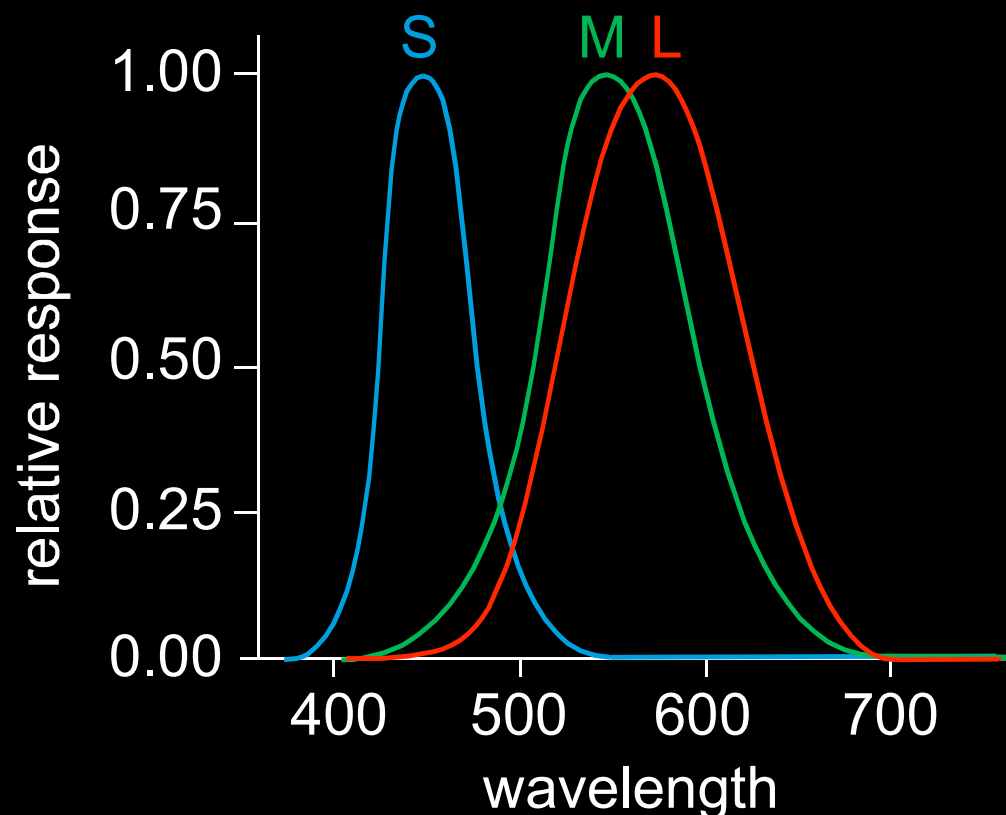
- If I have a given spectrum X
- I compute its response to the 3 matching curves (multiply and integrate)
- I use these 3 responses to scale my 3 primaries (435.8, 546.1 and 700nm)
- I get a metamer of X (perfect color reproduction)



These curves are the color-matching functions for the 1931 standard observer, The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

Relation to cone curves

- Project to the same subspace
 - $\bar{b}$, $\bar{g}$, and $\bar{r}$ are linear combinations of S, M and L
- Related by 3x3 matrix.
- Unfortunately unknown at that time. This would have made life a lot easier!



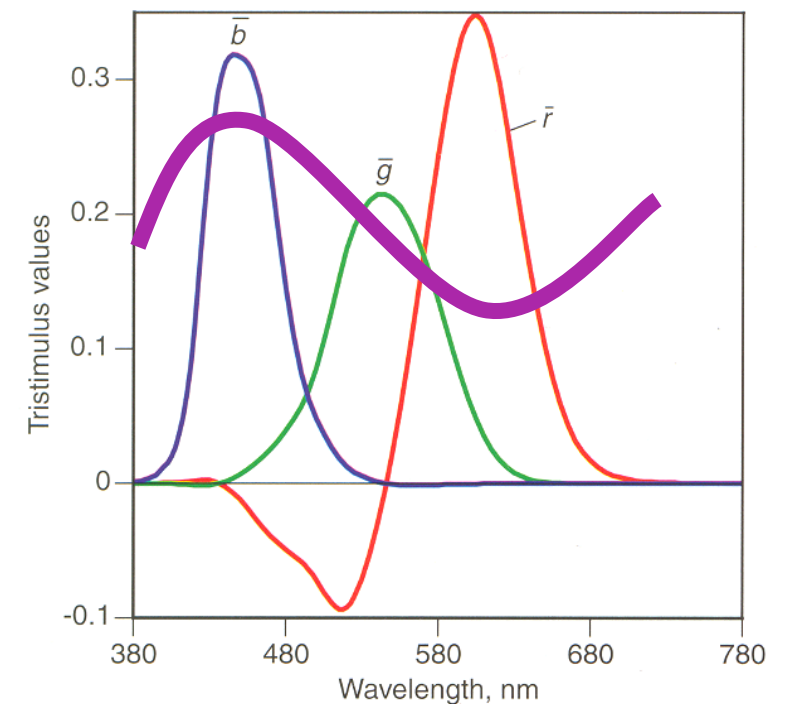
These curves are the color-matching functions for the 1931 standard observer, The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

Recap

- Spectra : infinite dimensional
- Cones: 3 spectral responses
- Metamers: spectra that look the same
(same projection onto cone responses)
- CIE measured color response:
 - chose 3 primaries
 - tristimulus curves to reproduce any wavelength
- Questions?

How to build a measurement device?

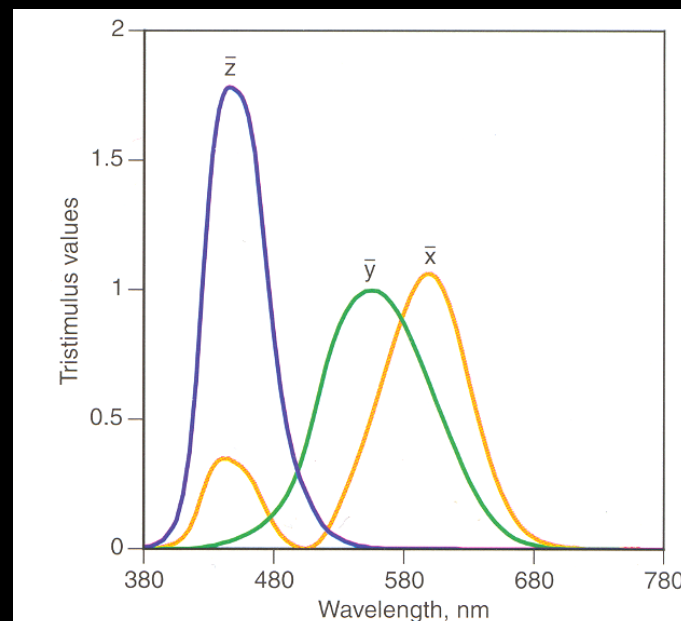
- Idea:
 - Start with light sensor sensitive to all wavelength
 - Use three filters with spectra $\bar{b}$, $\bar{r}$, $\bar{g}$
 - measure 3 numbers
- This is pretty much what the eyes do!



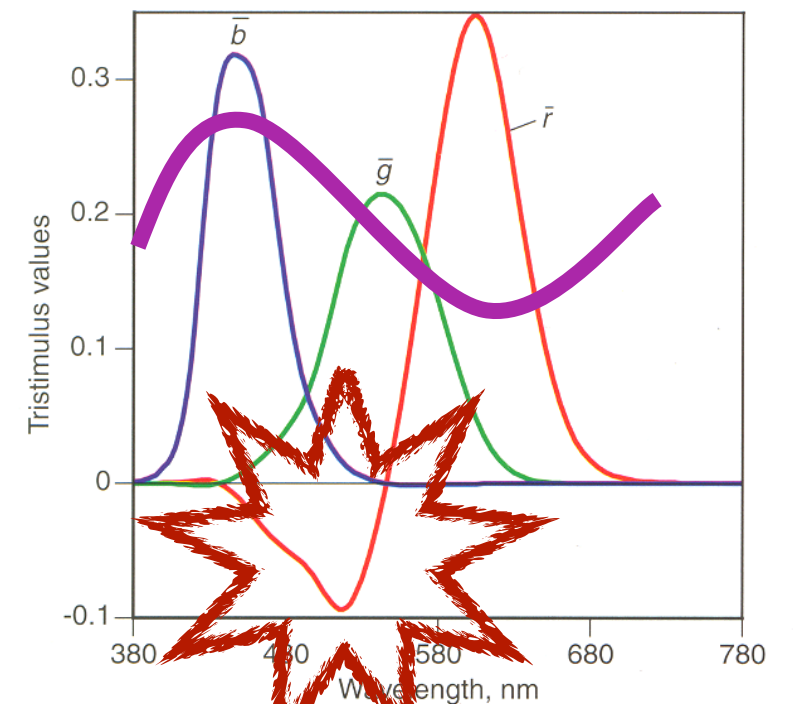
These curves are the color-matching functions for the 1931 standard observer. The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

CIE's problem

- Obvious solution:
use cone response!
 - but unknown at the time
- $\Rightarrow$ new set of tristimulus curves
 - linear combinations of b , g , r
 - pretty much add enough b and g until r is positive



The 1931 standard observer, as it is usually shown.



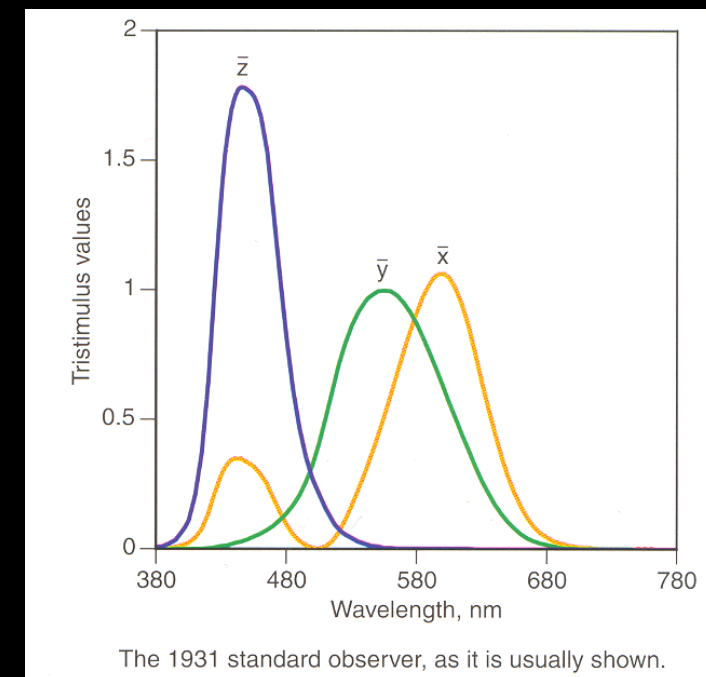
These curves are the color-matching functions for the 1931 standard observer. The average results of 17 color-normal observers having matched each wavelength of the equal-energy spectrum with primaries of 435.8 nm, 546.1 nm, and 700 nm.

CIE XYZ space

- The most standard color space
- Based on tristimulus curves
- Y corresponds to luminance/brightness
- Linear transform compared to RGE or LMS



$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.8951 & 0.2664 & -0.1614 \\ -0.7502 & 1.7135 & 0.0367 \\ 0.0389 & -0.0685 & 1.0296 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



XYZ to RGB & back

- e.g. http://www.brucelindbloom.com/index.html?Eqn_RGB_XYZ_Matrix.html

- sRGB to XYZ

0.412424	0.212656	0.0193324
0.357579	0.715158	0.119193
0.180464	0.0721856	0.950444

XYZ to sRGB

3.24071	-0.969258	0.0556352
-1.53726	1.87599	-0.203996
-0.498571	0.0415557	1.05707

- Adobe RGB to XYZ

0.576700	0.297361	0.0270328
0.185556	0.627355	0.0706879
0.188212	0.0752847	0.991248

XYZ to Adobe RGB

2.04148	-0.969258	0.0134455
-0.564977	1.87599	-0.118373
-0.344713	0.0415557	1.01527

- NTSC RGB to XYZ

0.606734	0.298839	0.000000
0.173564	0.586811	0.0661196
0.200112	0.114350	1.11491

XYZ to NTSC RGB

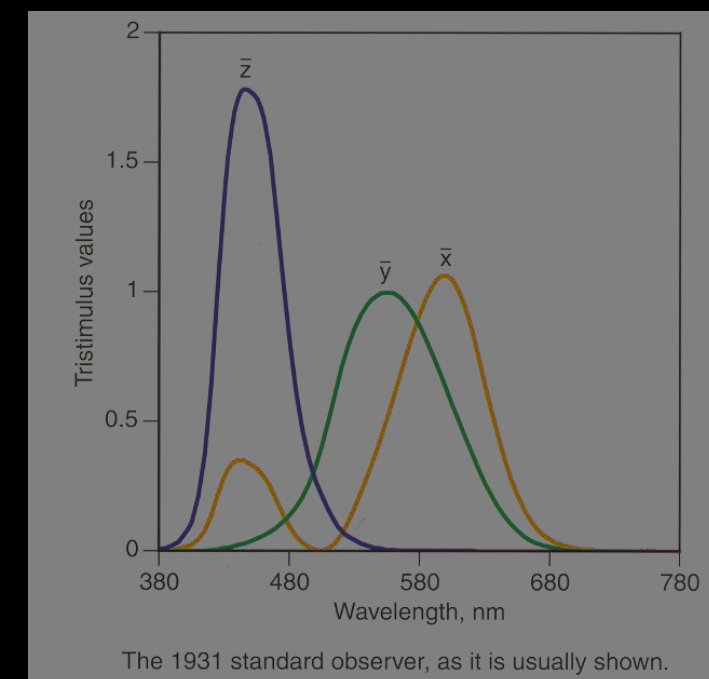
1.91049	-0.984310	0.0583744
-0.532592	1.99845	-0.118518
-0.288284	-0.0282980	0.898611

CIE XYZ space: QUESTIONS?

- The most standard color space
- Based on tristimulus curves
- Y corresponds to luminance/
brightness
- Linear transform compared to RGE
or LMS



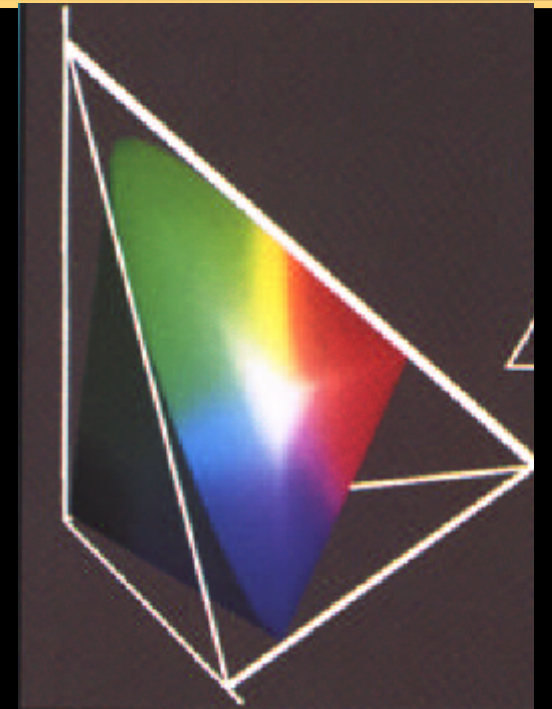
$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.8951 & 0.2664 & -0.1614 \\ -0.7502 & 1.7135 & 0.0367 \\ 0.0389 & -0.0685 & 1.0296 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$



Chromaticity diagram

Chromaticity diagrams: motivation

- 3D space are tough to visualize
- Chrominance is our notion of color, as opposed to brightness/luminance
- Recall that our eyes correct for multiplicative scale factors
 - discount light intensity

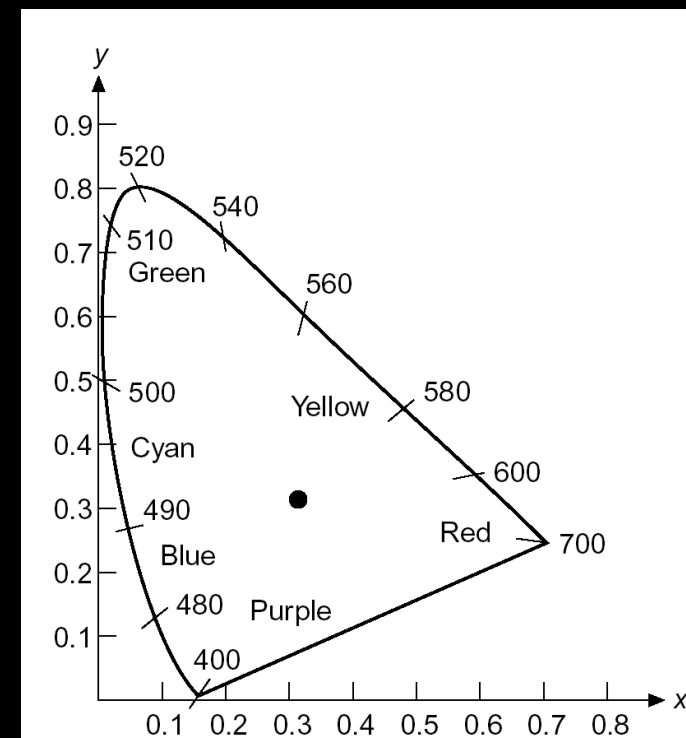


Chromaticity diagrams

- Project XYZ to 2D
- normalize against by $X + Y + Z$:

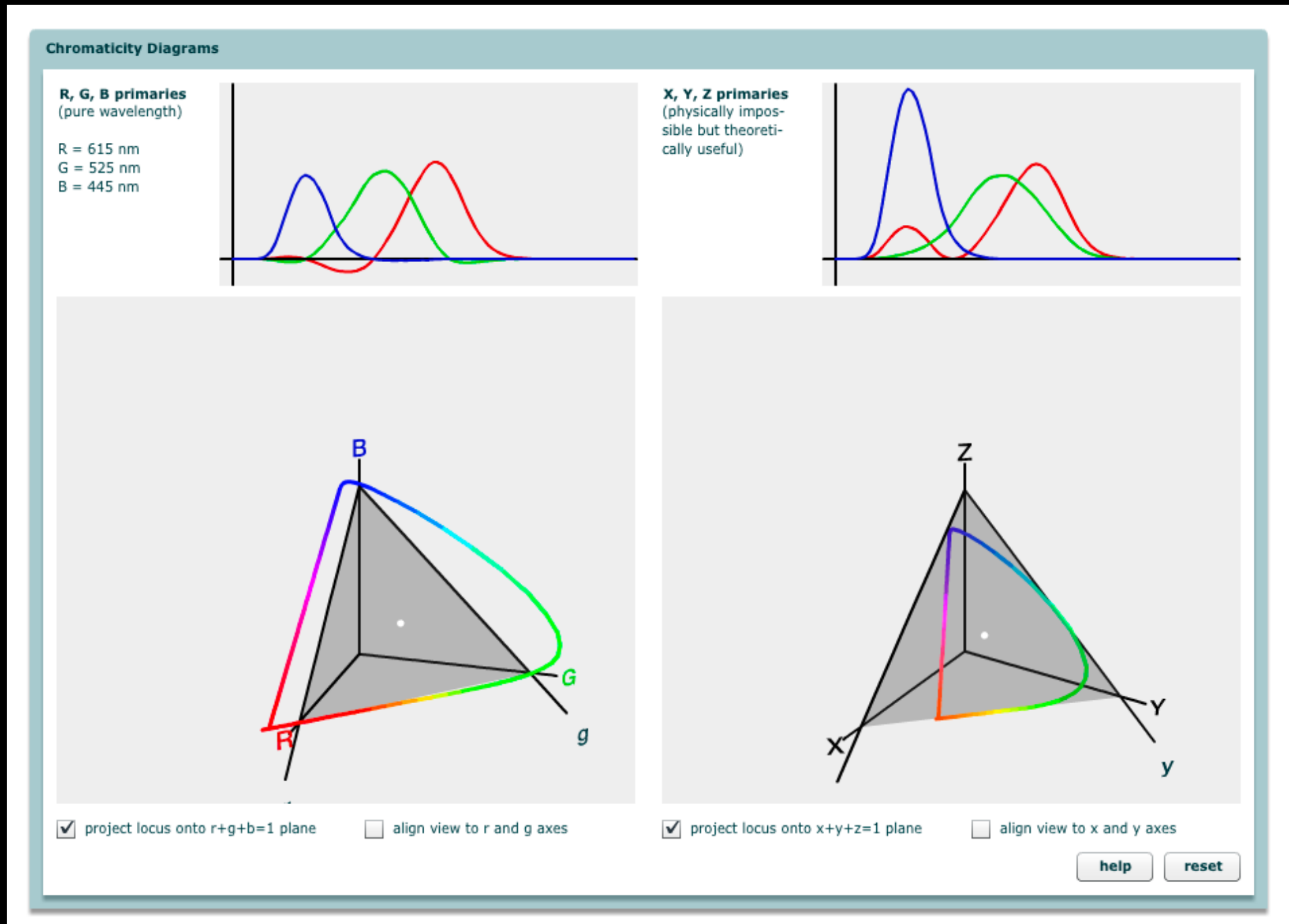
$$x = \frac{X}{X+Y+Z}; \quad y = \frac{Y}{X+Y+Z};$$

—equivalent to perspective projection to plane $X+Y+Z=1$



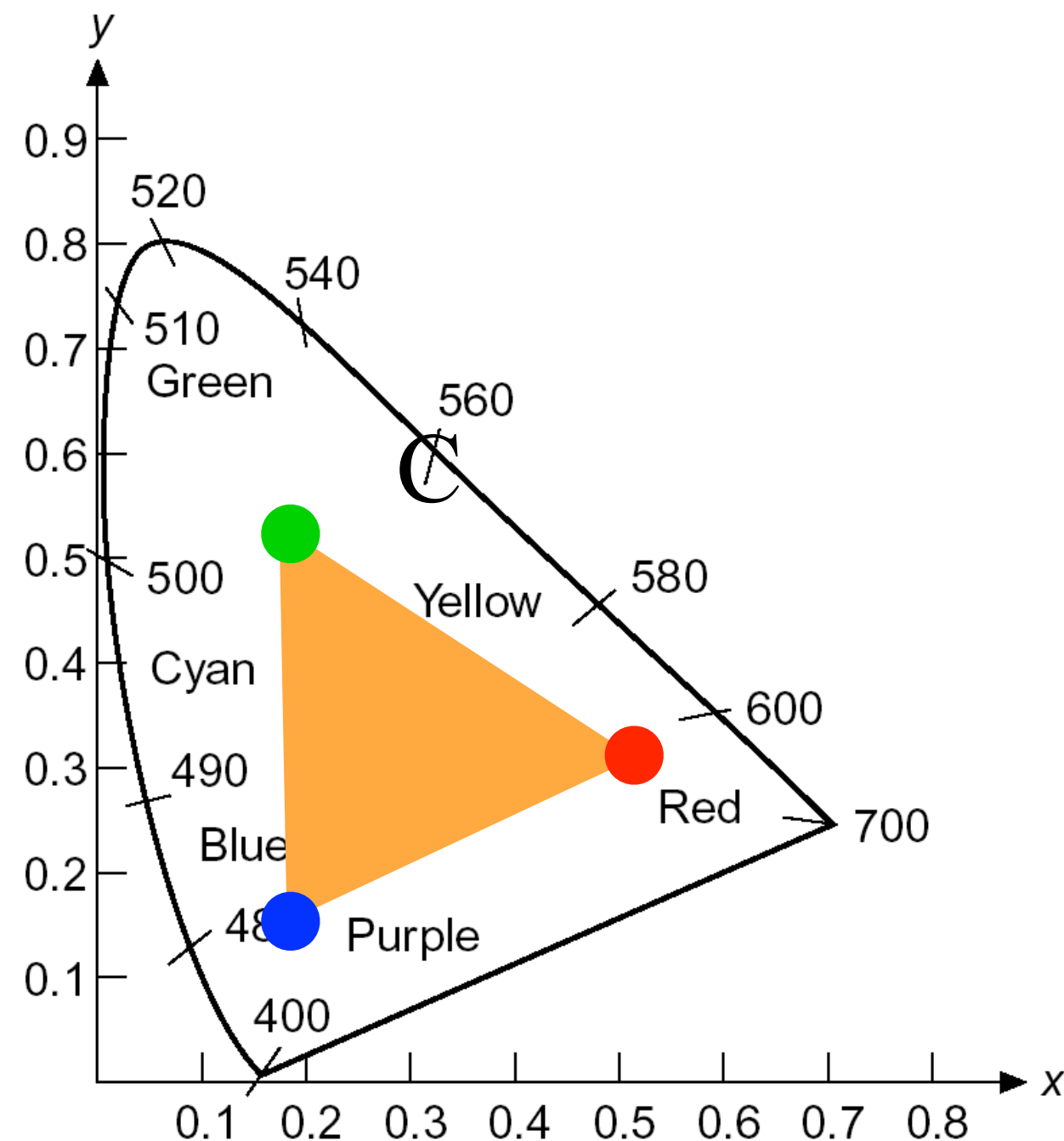
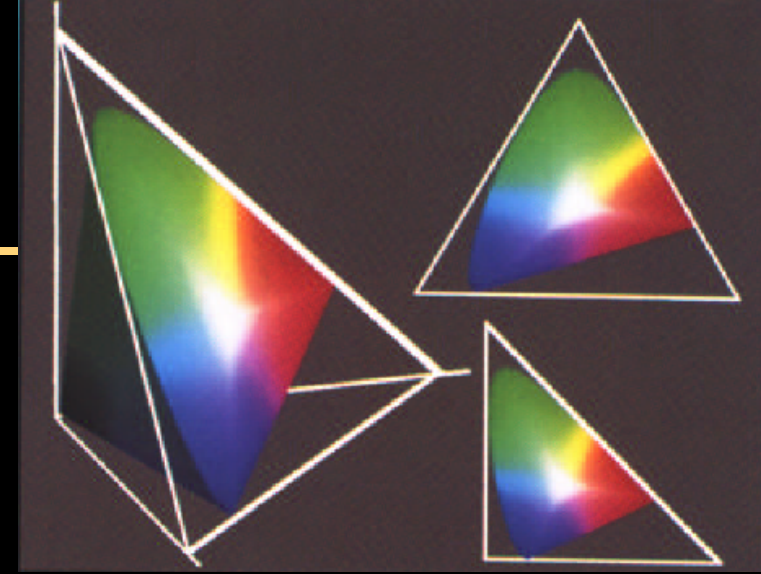
Applet

- <http://graphics.stanford.edu/courses/cs178-10/applets/threedgamut.html>



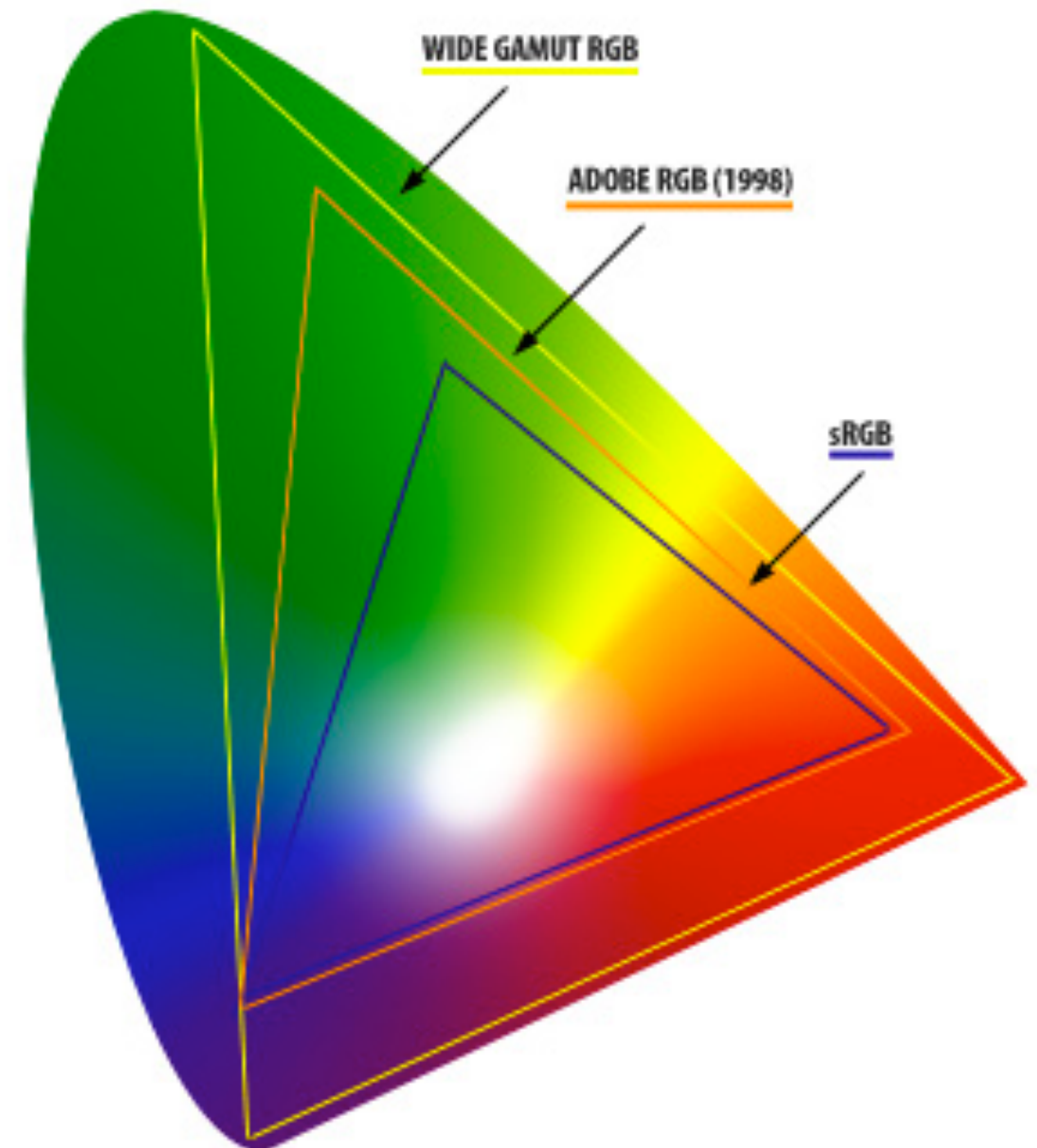
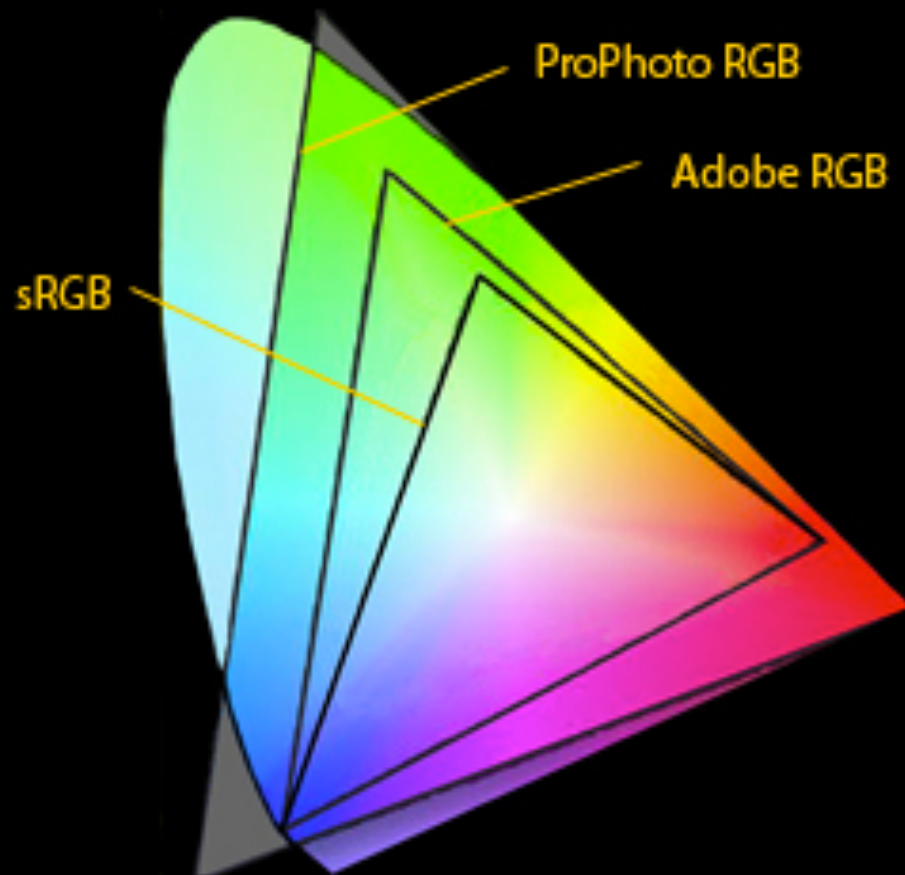
Color gamut

- Given 3 primaries
- The realisable chromaticities lay in the triangle in xy chromaticity diagram
- Because we can only add light, no negative light



RGB limitations

- http://dba.med.sc.edu/price/irf/Adobe_tg/manage/images/gamuts.jpg
- <http://www.petrvodnakphotography.com/Articles/ColorSpace.htm>



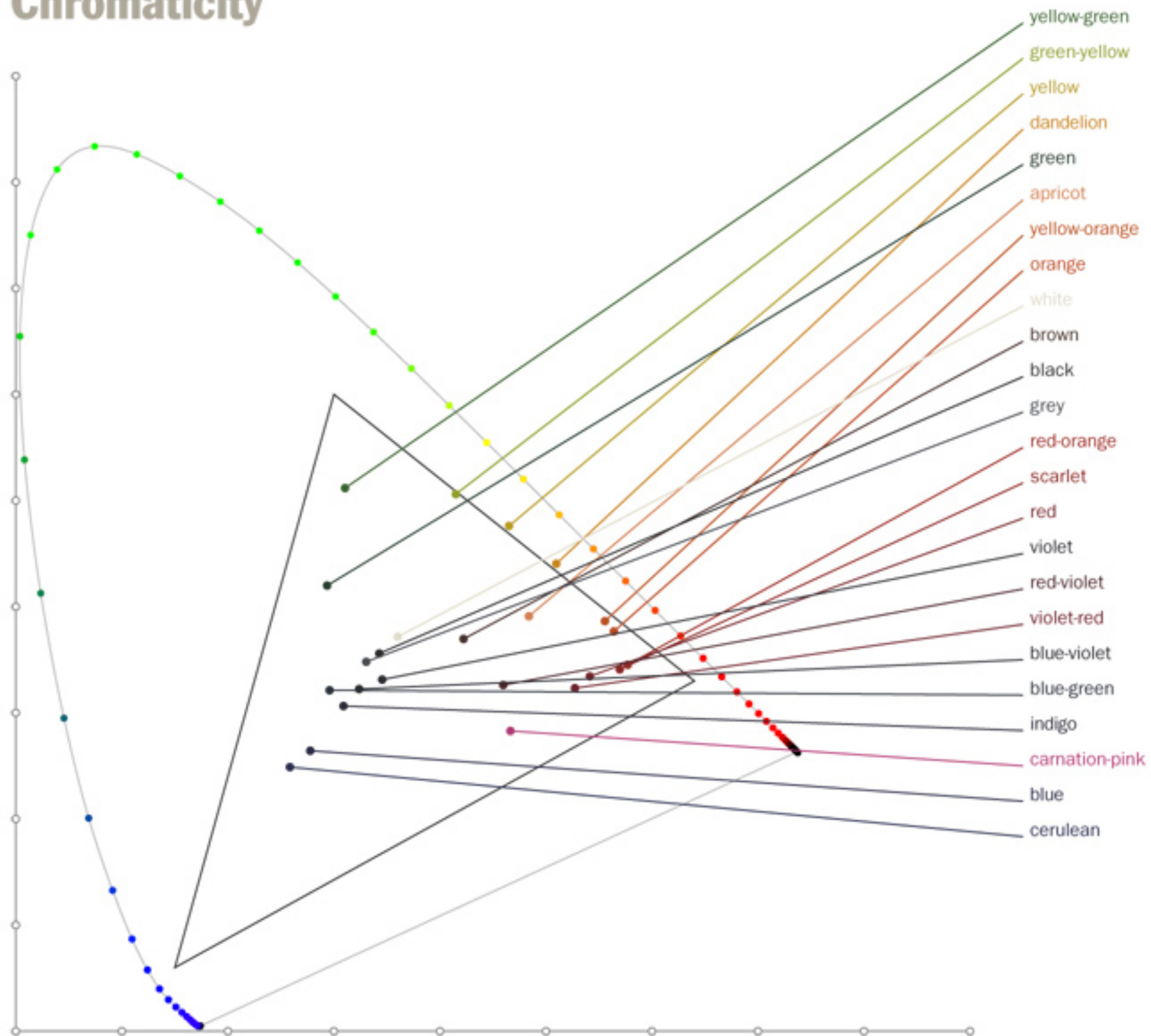
Recap

- Metamers enable color reproduction
- CIE defined XYZ using color matching experiments
- Linear transform to/from RGB or LMS
- Chromaticity diagram: 2D version,
remove luminance
- Lack of negative numbers makes life hard

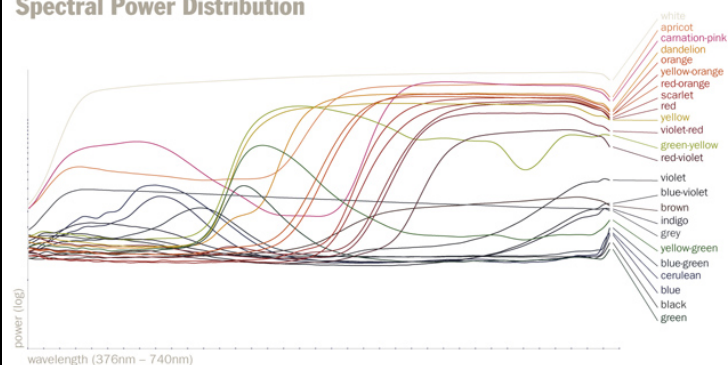
Questions?

- Chromaticity of crayons
- <http://www.photomark.com/notes/2011/sep/20/crayon-colors/>

Chromaticity

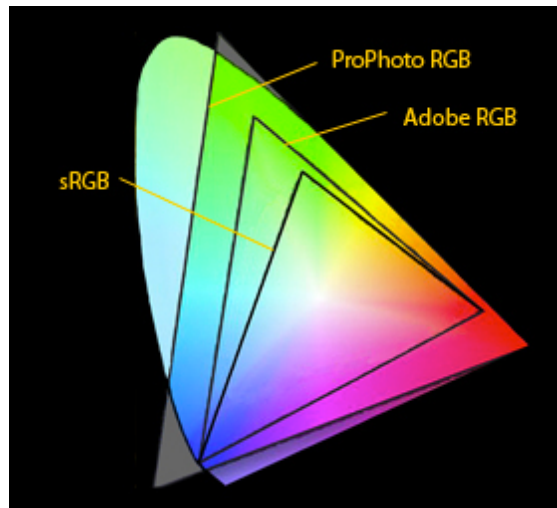


Spectral Power Distribution



Take home message

- Cone spectra are non-orthogonal
- Analysis spectrum (camera, eyes) cannot be the same as synthesis one (display)
- Impossible to encode all possible colors without something negative
 - CIE XYZ only needs positive coordinates, but would need primaries with negative light
 - RGB can use physical (non-negative) primaries, but needs negative coordinates for some colors



Warning: Tricky thing with color

- Spectrum for the stimulus / synthesis
 - Light, monitor, reflectance
- Response curve for receptor /analysis
 - Cones, camera, scanner

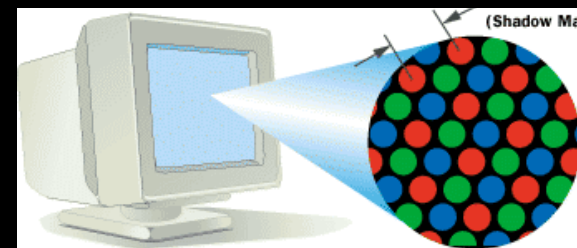


Warning: Tricky thing with color

- Spectrum for the stimulus / synthesis
 - Light, monitor, reflectance
- Response curve for receptor /analysis
 - Cones, camera, scanner

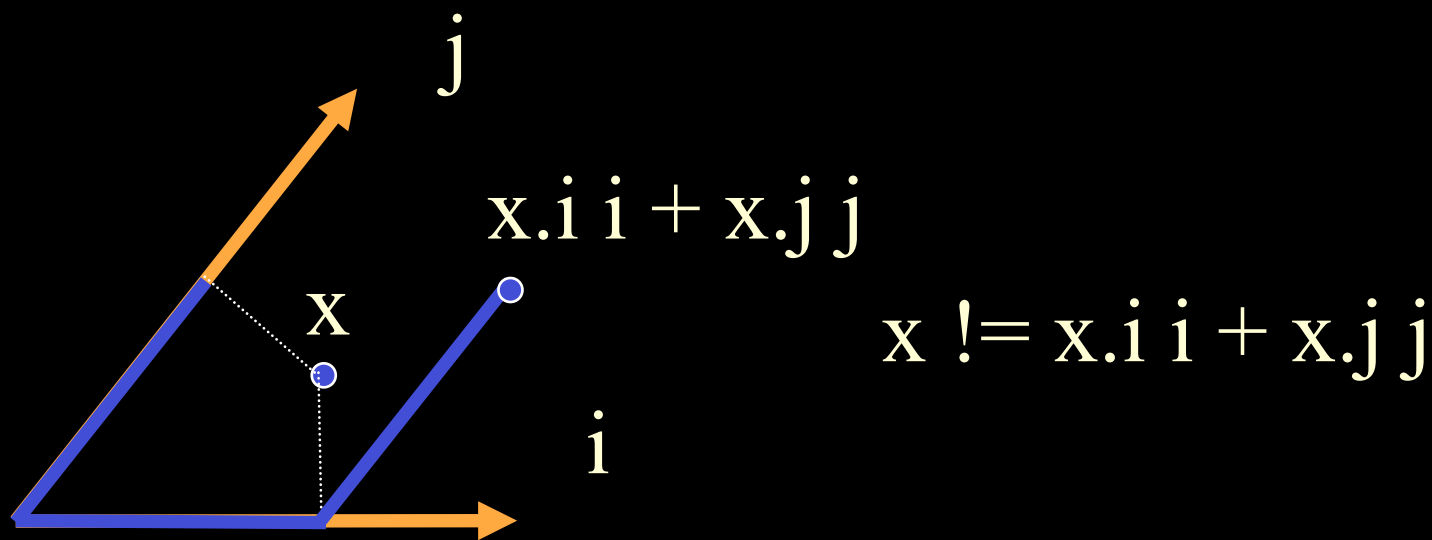
Usually not the same

Because cone responses are not orthogonal



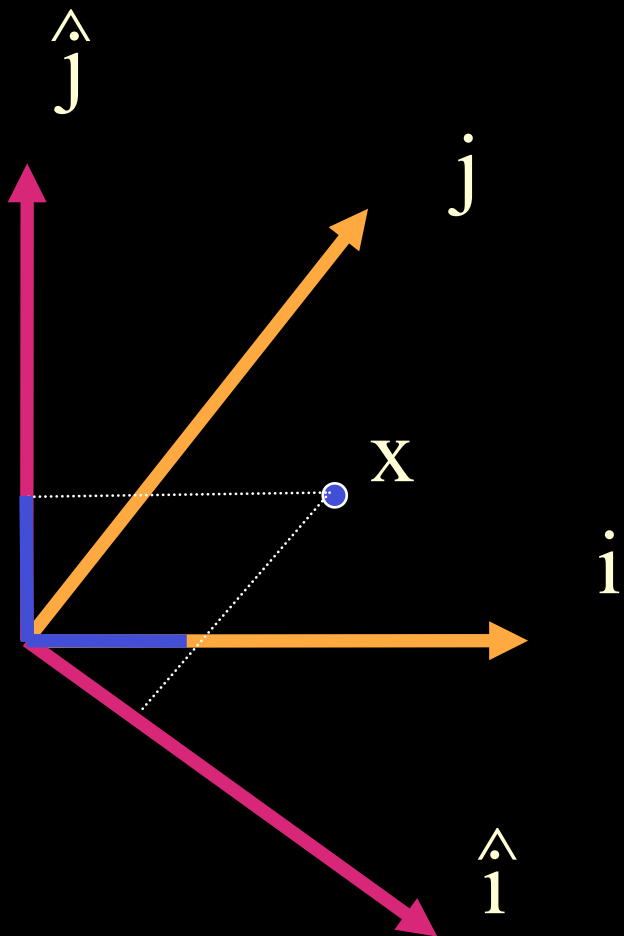
Same as non-orthogonal bases

- Non orthogonal bases are harder to handle
- Can't use dot product on same vector to infer coordinates
 - Same problem as with cones, the i & j components pollute each other



Same as non-orthogonal bases

- Non orthogonal bases are harder to handle
- Can't use dot product on same vector to infer coordinates
- Need a so-called dual basis
 - Same for color: different basis for analysis/ synthesis



$$x = x.\hat{i} \hat{i} + x.\hat{j} \hat{j}$$

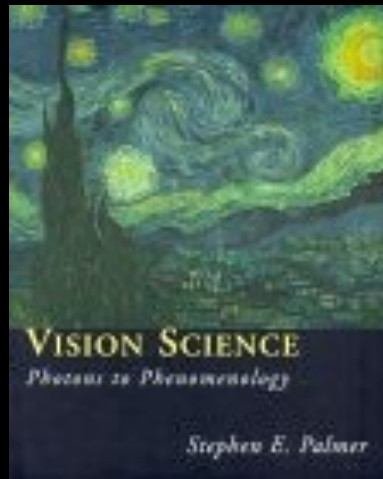
Note that $\hat{i}$ has negative coordinates

Fundamental problems

- Spectra are infinite-dimensional
- Only positive values are allowed
- Cones are non-orthogonal/overlap

Questions?

Selected Bibliography



Vision Science

by Stephen E. Palmer

MIT Press; ISBN: 0262161834

760 pages (May 7, 1999)

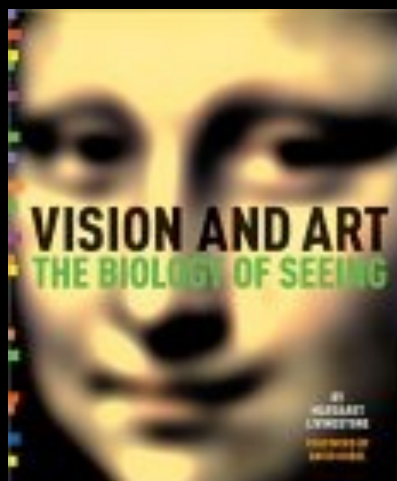


Billmeyer and Saltzman's Principles of Color Technology, 3rd Edition

by Roy S. Berns, Fred W. Billmeyer, Max Saltzman

Wiley-Interscience; ISBN: 047119459X

304 pages 3 edition (March 31, 2000)



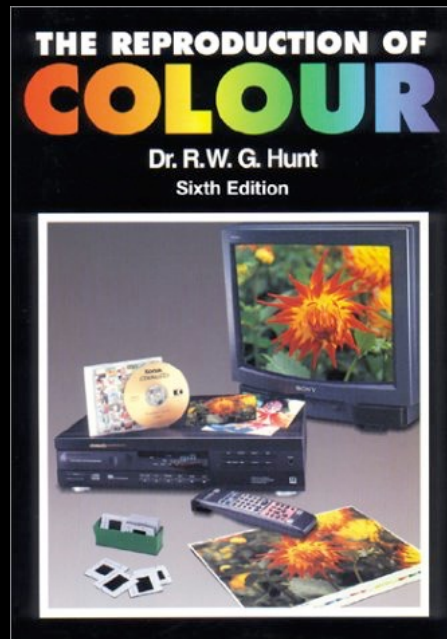
Vision and Art : The Biology of Seeing

by Margaret Livingstone, David H. Hubel

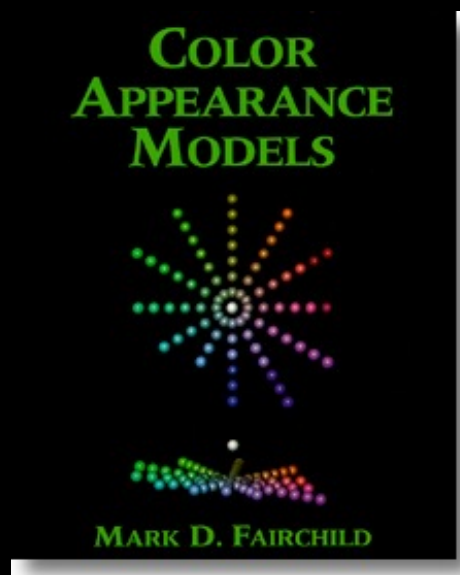
Harry N Abrams; ISBN: 0810904063

208 pages (May 2002)

Selected Bibliography

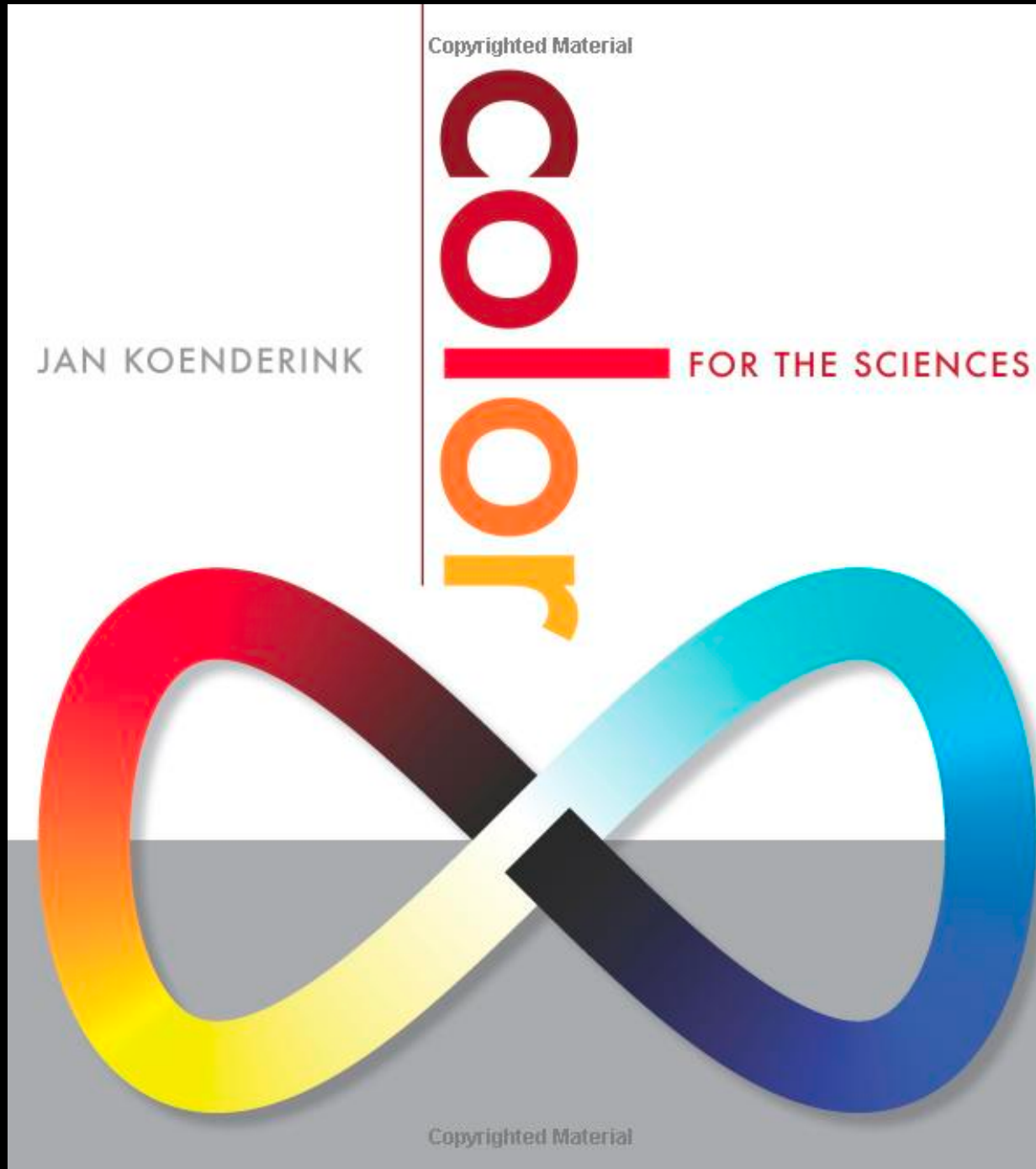


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Questions?

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 - <http://webvision.med.utah.edu/book/part-iii-retinal-circuits/s-cone-pathways/>
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 - <http://www.cvrl.org/database/text/intros/introdens.htm>
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Check out the demo applets

- <http://graphics.stanford.edu/courses/cs178-10/applets/locus.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/colormatching.html>
- <http://graphics.stanford.edu/courses/cs178-10/applets/threedgamut.html>
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