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Lecture 26:
Color and Light

not in textbook (sad but true)

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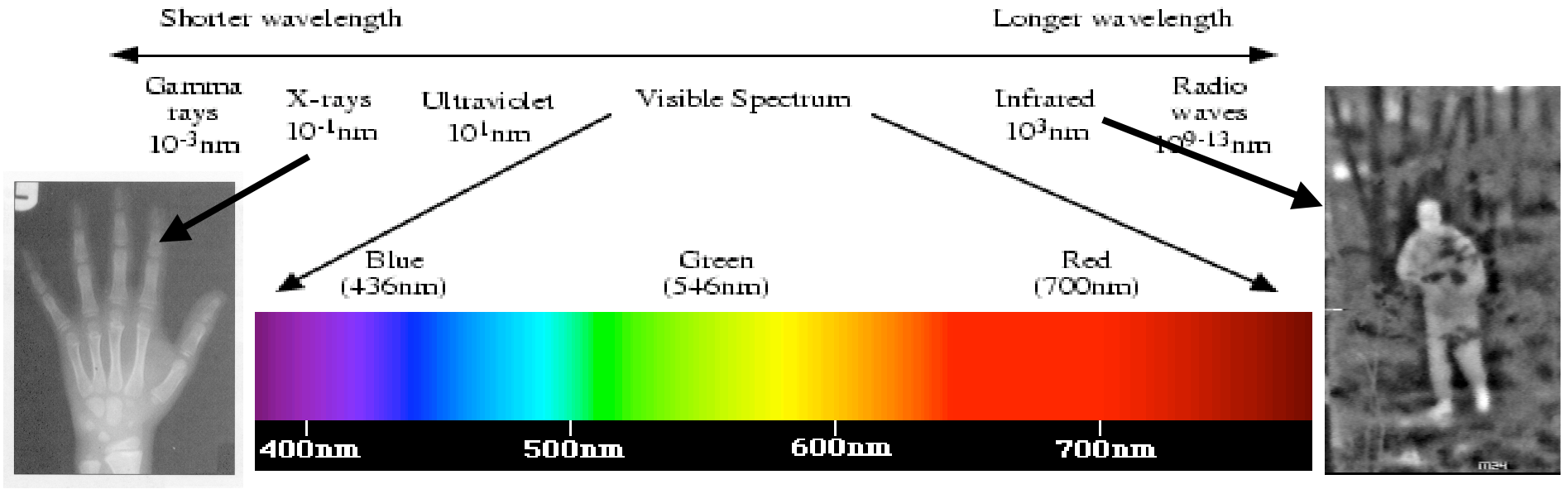
Physics of Light and Color

- Light is electromagnetic radiation
  - Different colors correspond to different ***wavelengths*** λ
  - Intensity of each wavelength specified by ***amplitude***
- Visible light: 400-700nm. range



V I B G Y O R

(ROYGBIV)

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What is Color?

- Objects don't have a "color"
- Color is a perception; what we "see"
- It is a function of
  - light source power at different wavelengths
  - proportion of light at each wavelength reflected off object surface
  - sensor response to different wavelengths

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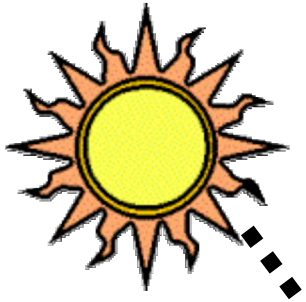
Sketch: Light Transport

Source emits photons



Photons travel in a straight line

And then some reach an eye/camera and are measured.

They hit an object. Some are absorbed, some bounce off in a new direction.

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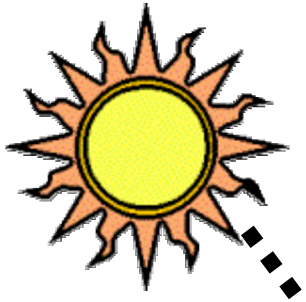
Light Transport

Source emits photons



Illumination

Photons travel in a straight line

And then some reach an eye/camera and are measured.

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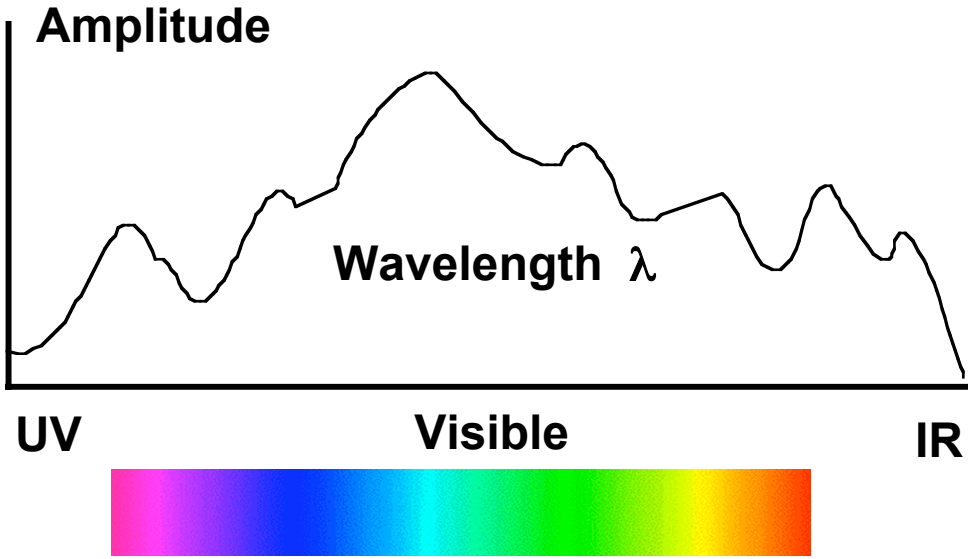
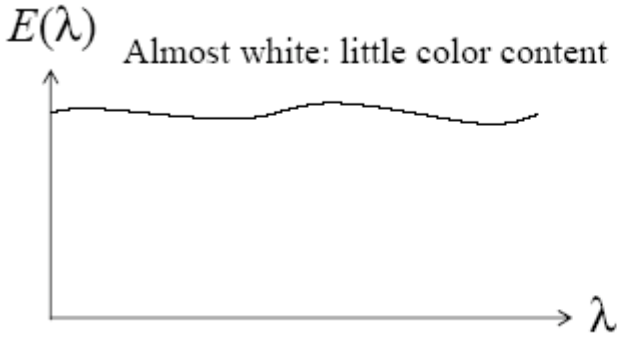
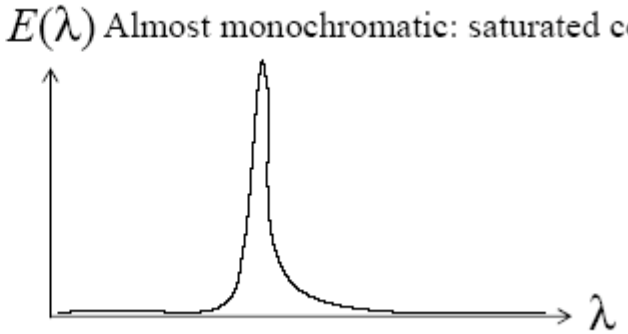
Color of Light Source

Spectral Power Distribution:

Relative amount of light energy at each wavelength







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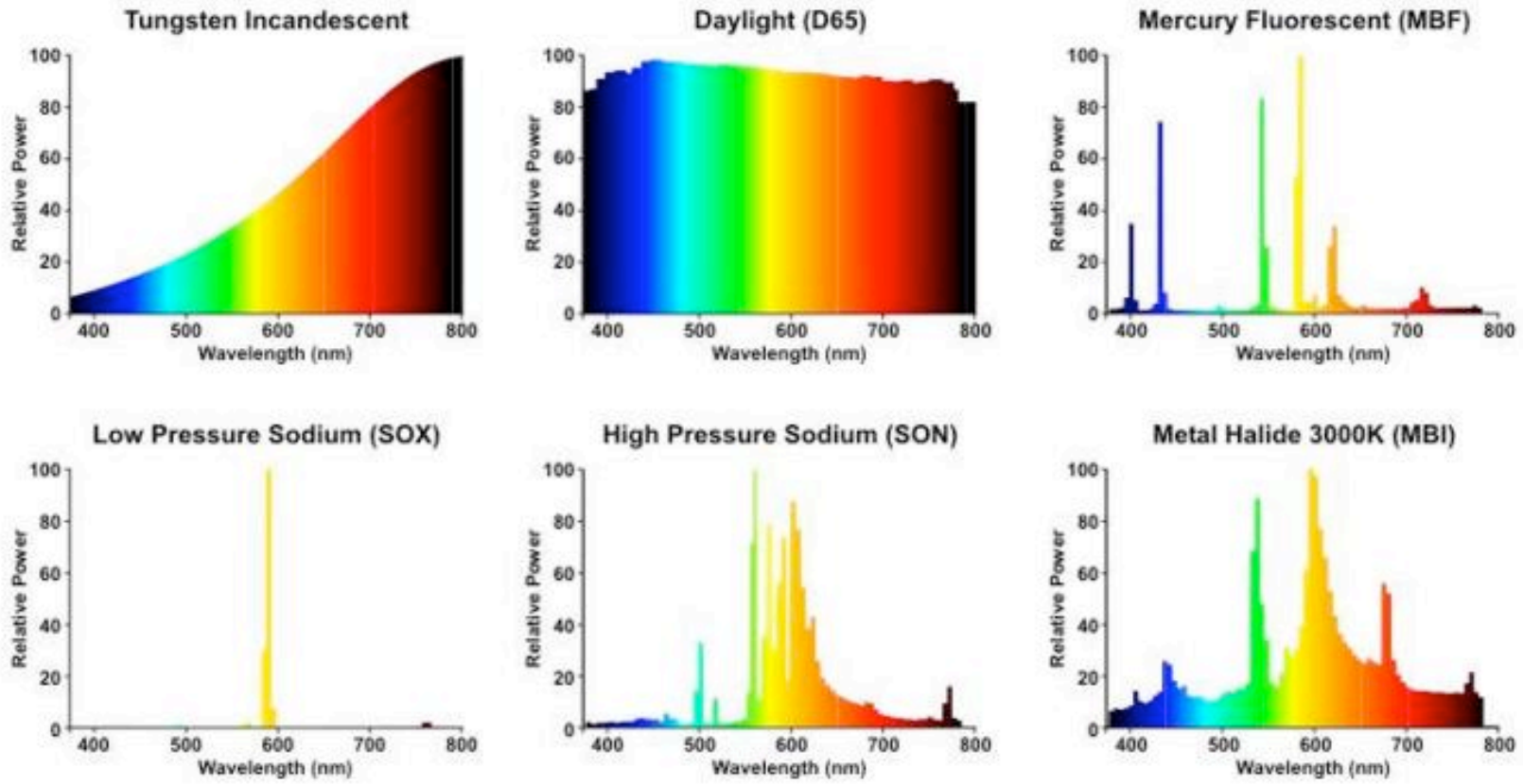
Some Light Source SPDs



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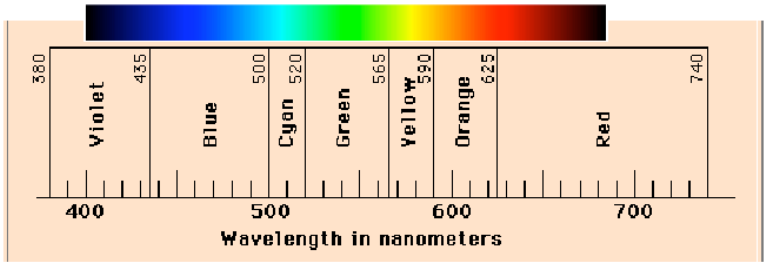
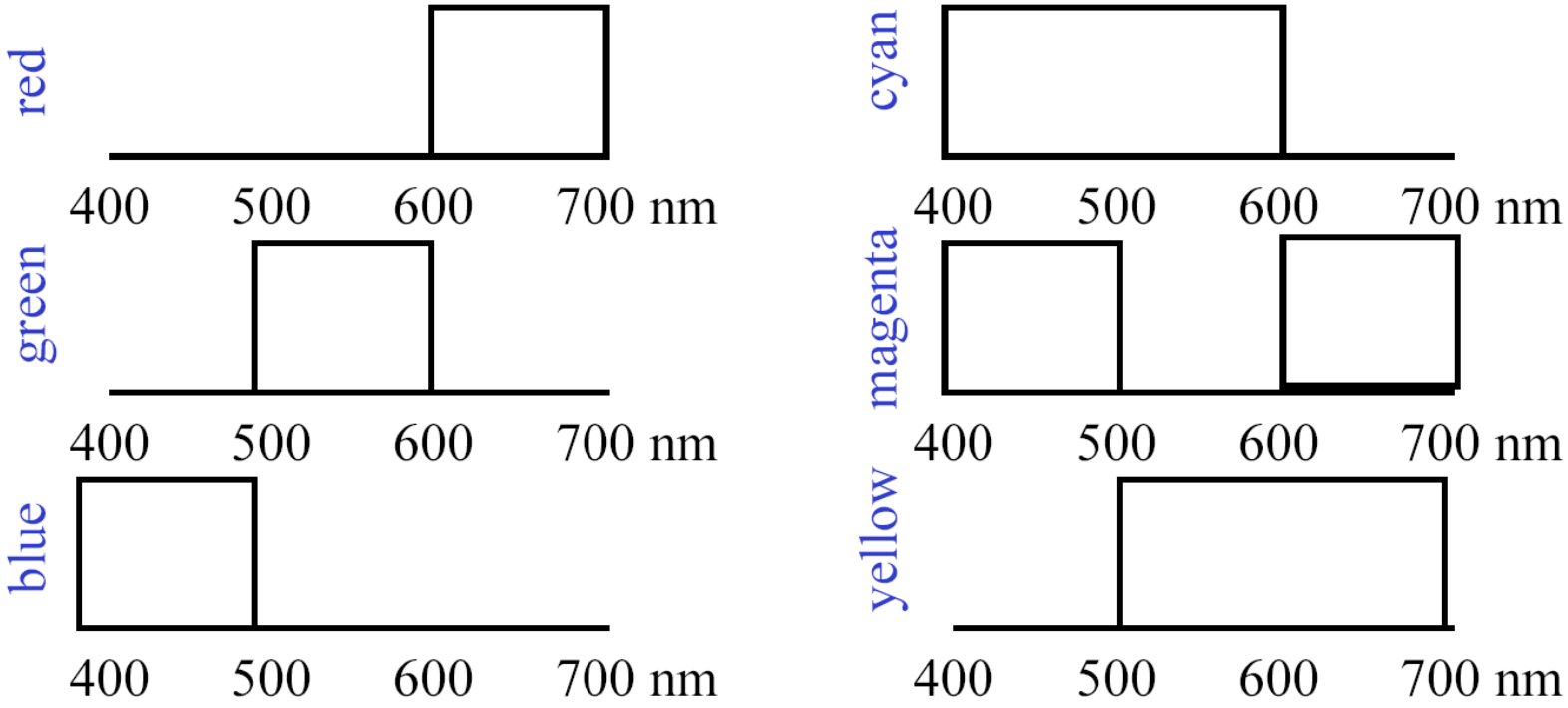
Color names for cartoon spectra





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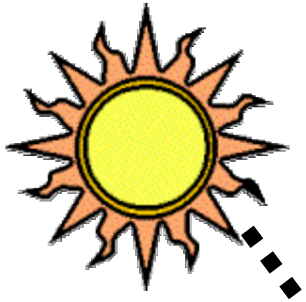
Light Transport

Source emits photons



Photons travel in a straight line

And then some reach an eye/camera and are measured.

Surface Reflection

They hit an object. Some are absorbed, some bounce off in a new direction.

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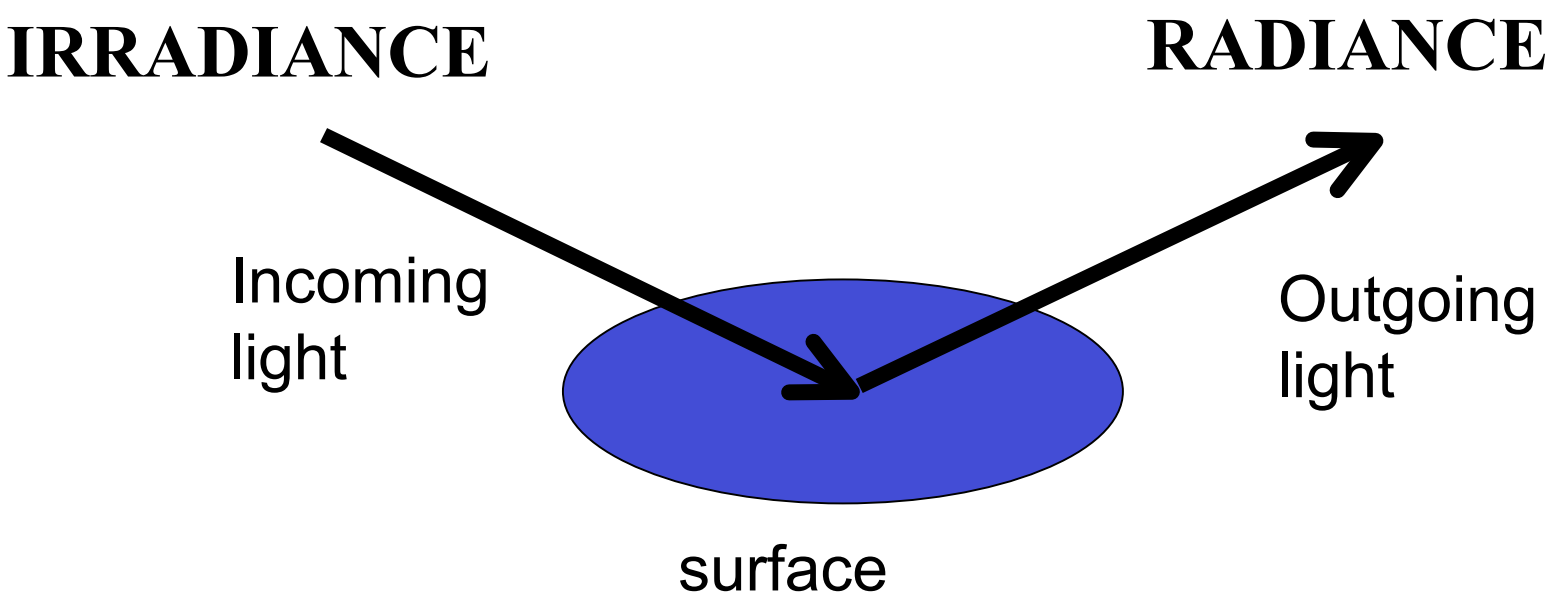
(Ir)radiance



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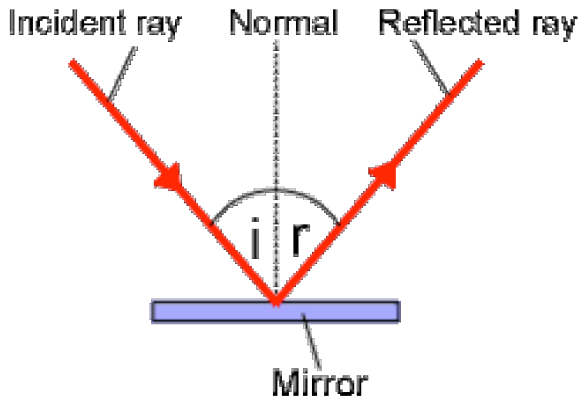
Specular Surfaces

Light rays purely reflect via Snell's law (angle of reflection = angle of incidence)

Properties:

Outgoing light has same SPD ("color") as incoming light.

If you stand in the right place you see a little picture of the light source reflected off the surface.



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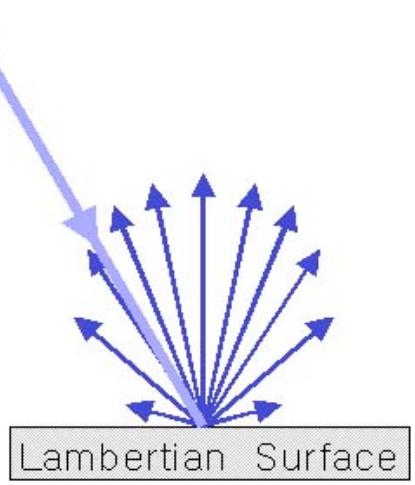
Lambertian Surfaces

Purely "matte" surface.

Properties:

Apparent brightness is proportional to cosine of angle between observer's line of sight and the surface normal (Lambert's Law)

Outgoing light has SPD that depends on spectral albedo of surface (what wavelengths get absorbed vs transmitted).



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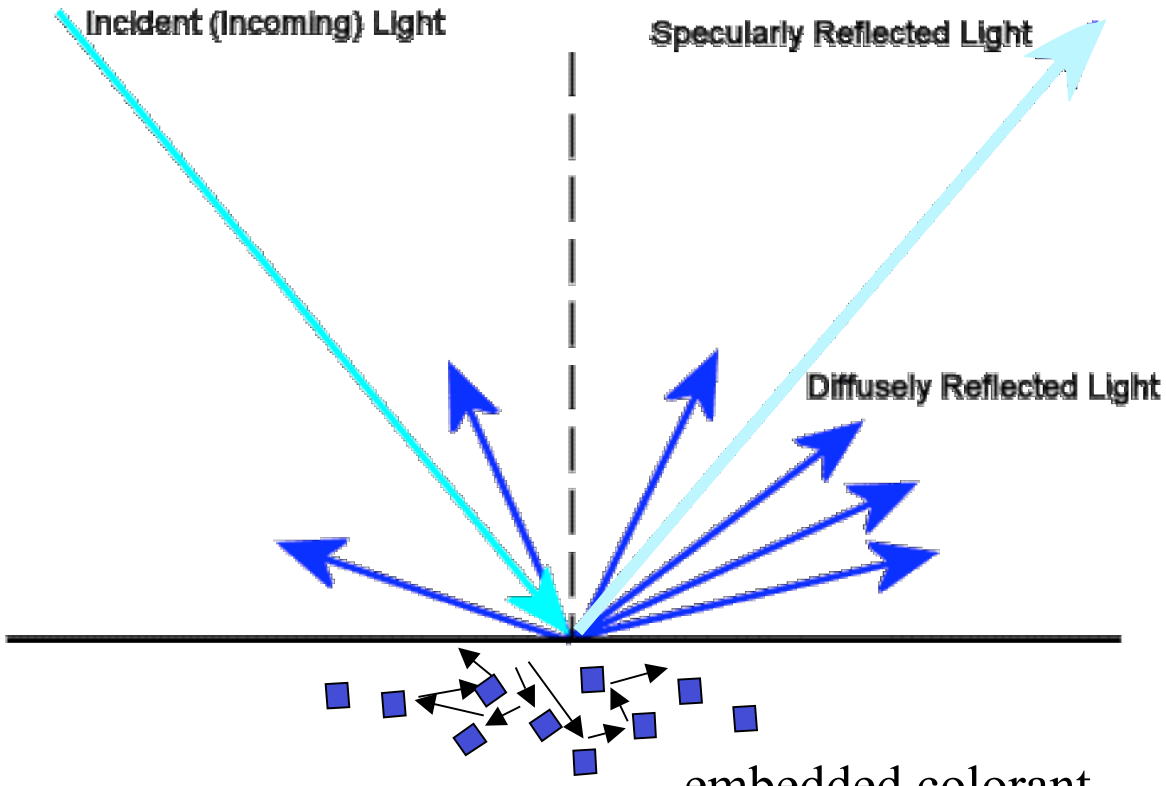
More General Surfaces

Have both a specular and diffuse reflections.



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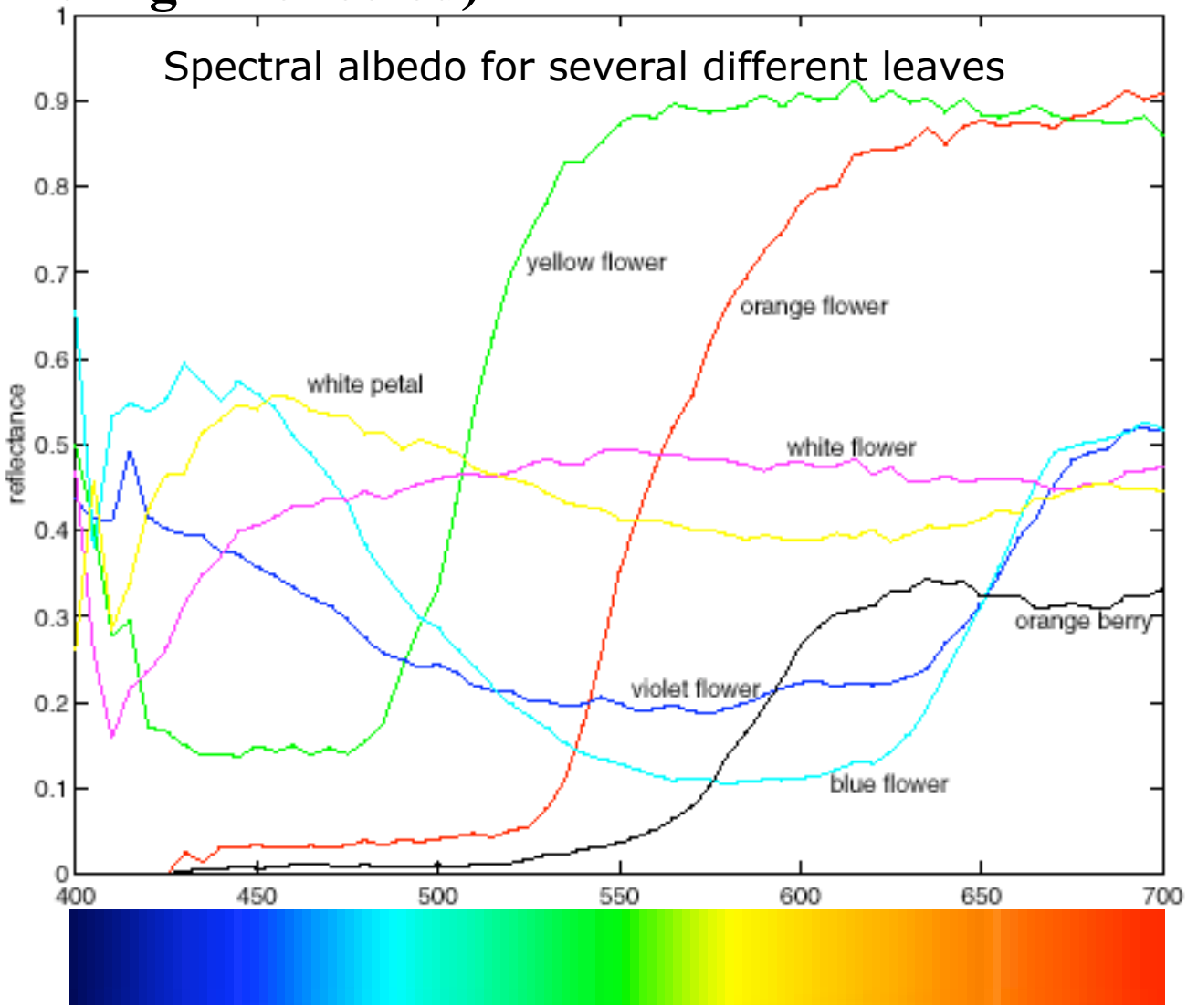
Spectral Albedo

Ratio of outgoing to incoming radiation at different wavelengths. (proportion of light reflected)



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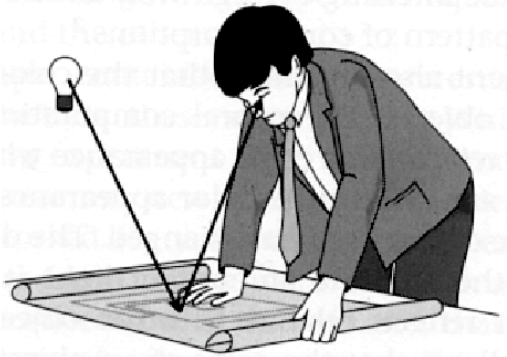
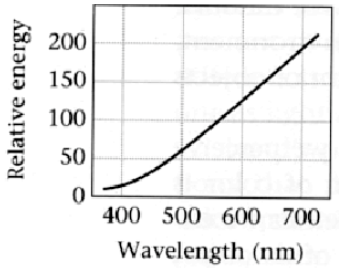
Spectral Radiance



Often are more interested in relative spectral composition than in overall intensity, so the spectral BRDF computation simplifies to a wavelength-by-wavelength multiplication of relative energies.

Spectral Irradiance



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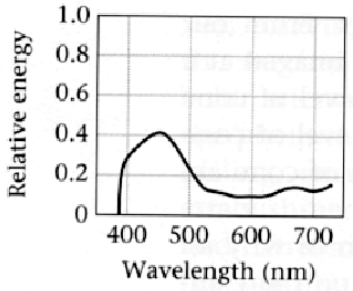
Spectral Albedo



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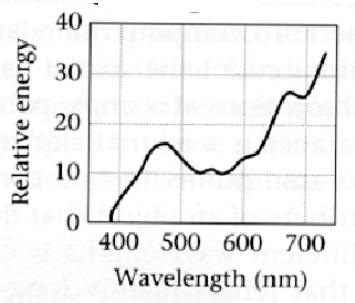
Spectral Radiance



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

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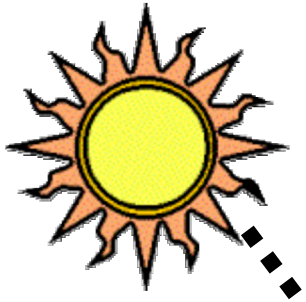
Light Transport

Source emits photons



And then some reach an eye/camera and are measured.

Sensor Response

They hit an object. Some are absorbed, some bounce off in a new direction.

Human Vision

- Human eyes have 2 types of sensors:
  - CONES
    - Sensitive to colored light, but not very sensitive to dim light
  - RODS
    - (very) Sensitive to achromatic light

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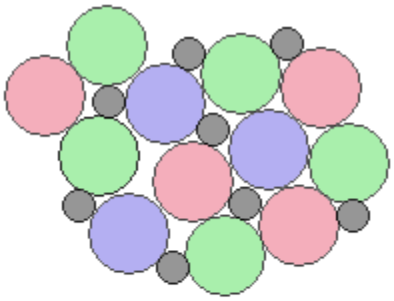
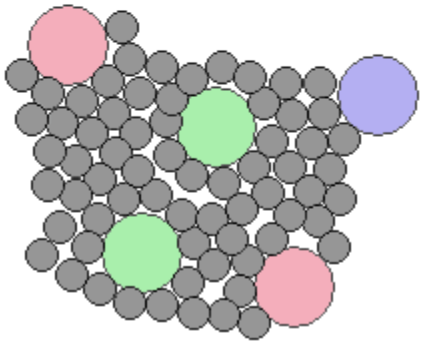
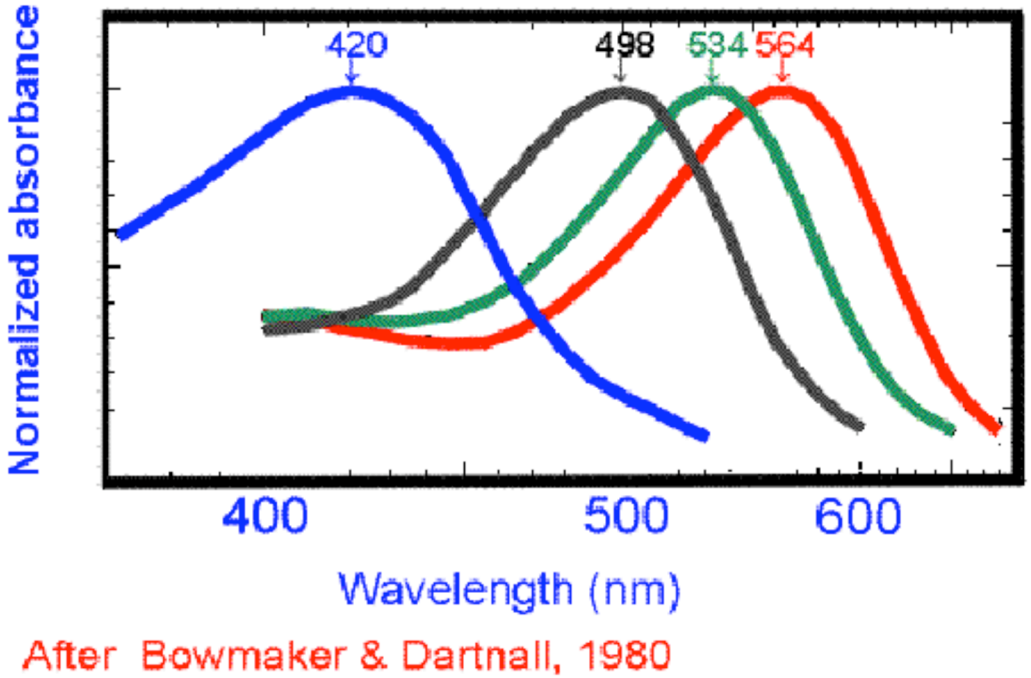
Human Eye: Rods and Cones

near fovea





near periphery



- rods (overall intensity)
- S cones (blue)
- M cones (green)
- L cones (red)

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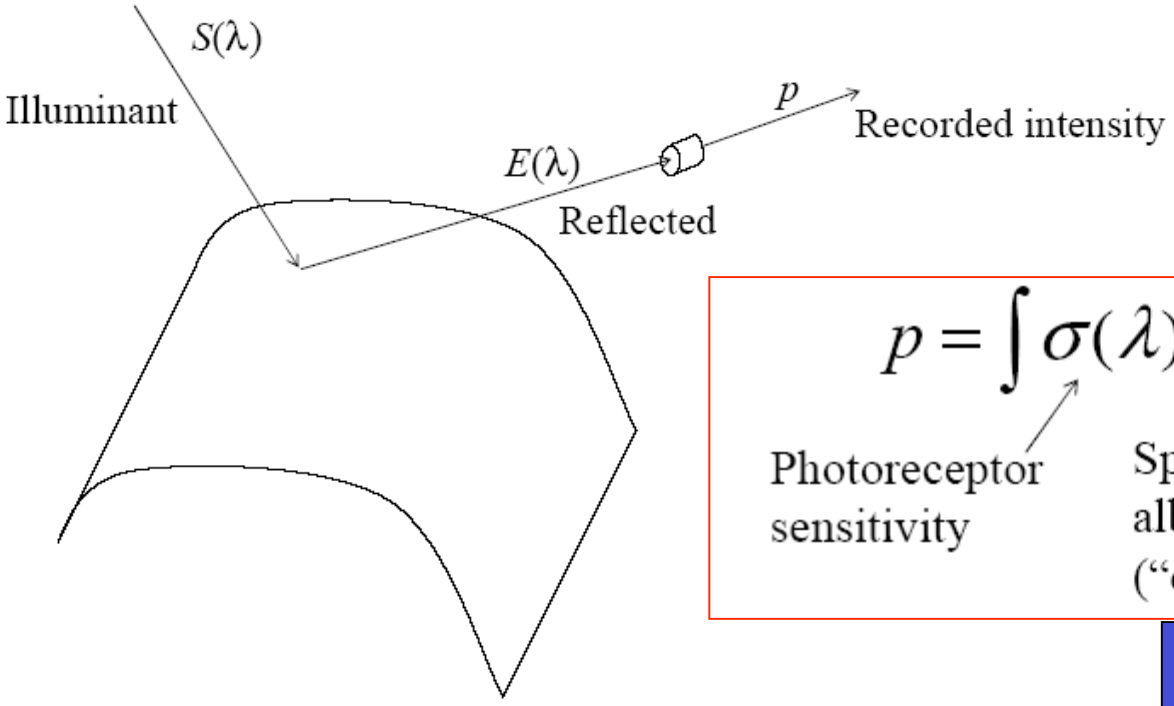
Putting it all Together = Color



$$p = \int \sigma(\lambda)\rho(\lambda)S(\lambda)d\lambda$$

Photoreceptor sensitivity

Spectral albedo ("object color")

Illuminant color

3 cones

COLOR!

$$p_S = \int \sigma_S(\lambda)E(\lambda)d\lambda$$
$$p_M = \int \sigma_M(\lambda)E(\lambda)d\lambda$$
$$p_L = \int \sigma_L(\lambda)E(\lambda)d\lambda$$

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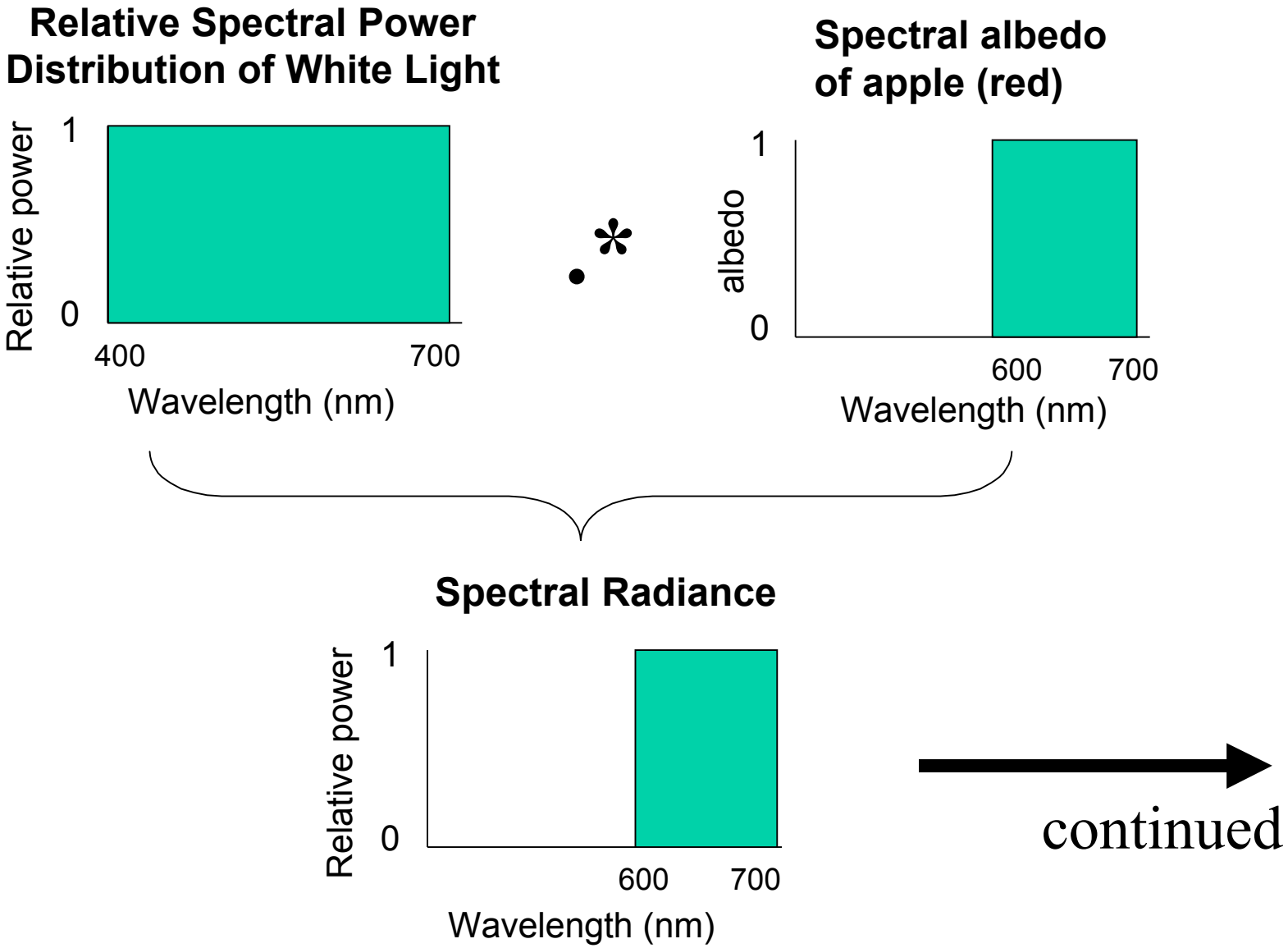
Simple Example



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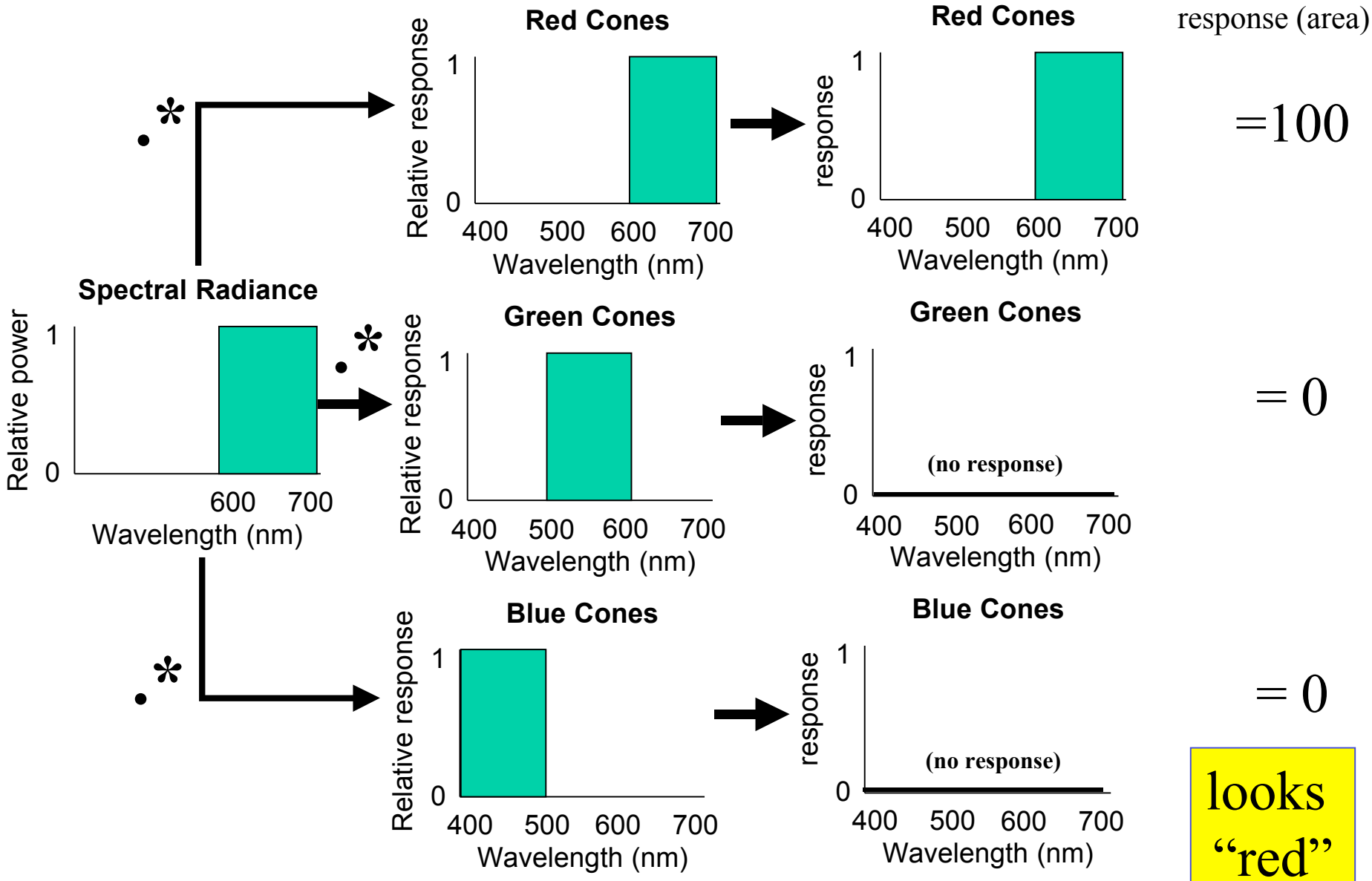
Simple Example (continued)



relative numeric response (area)

= 100

= 0

= 0

looks "red"

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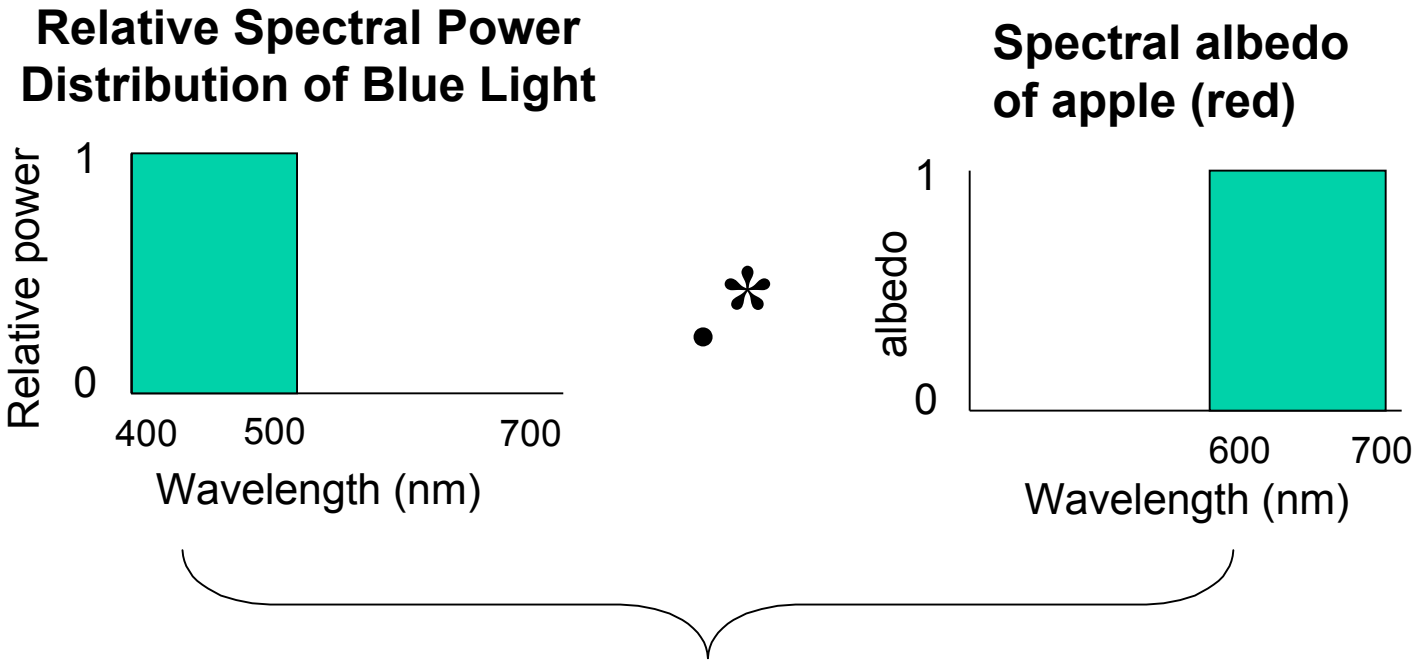
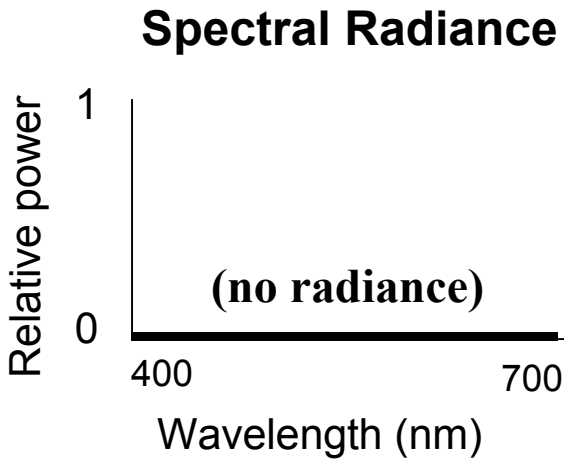
Simple Example





continued

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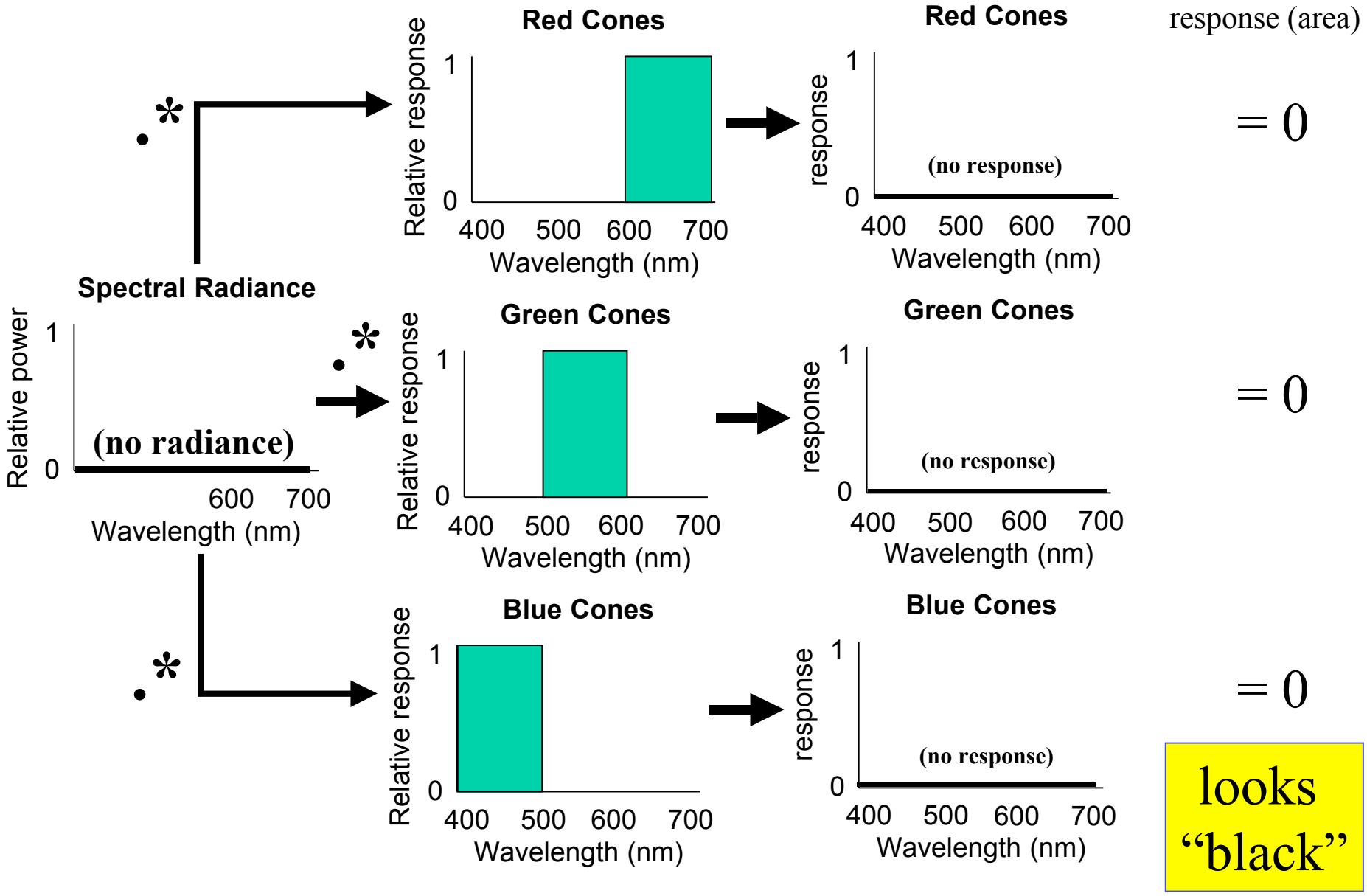
Simple Example (continued)



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The Abyss Clip

“One-way ticket” clip from DVD

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What is Going On in This Clip?

Under yellowish green light, both the blue/white wire and the black/yellow wire look identical.

Now for the spectral explanation of why this happens…

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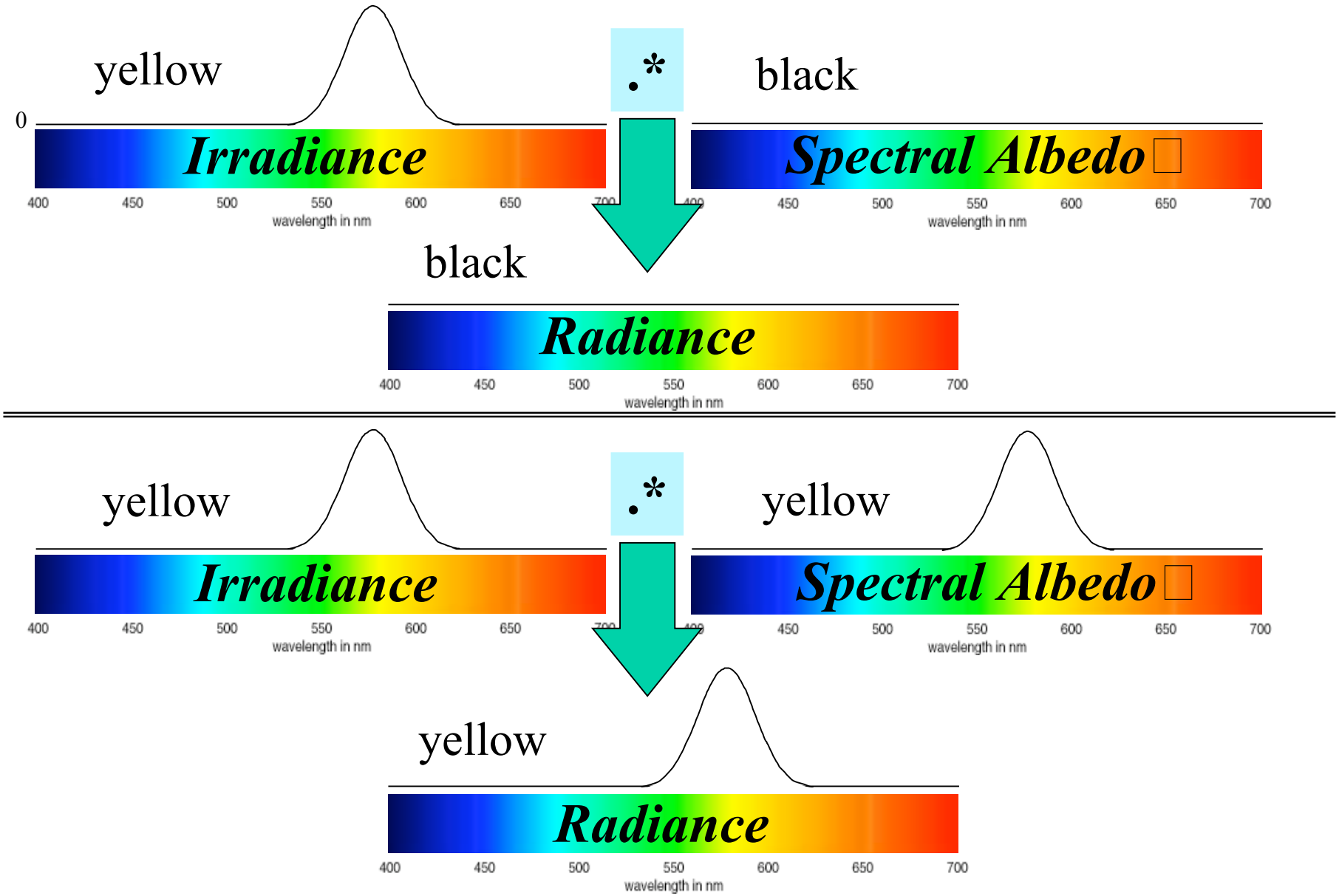
Black/Yellow under Yellow Light



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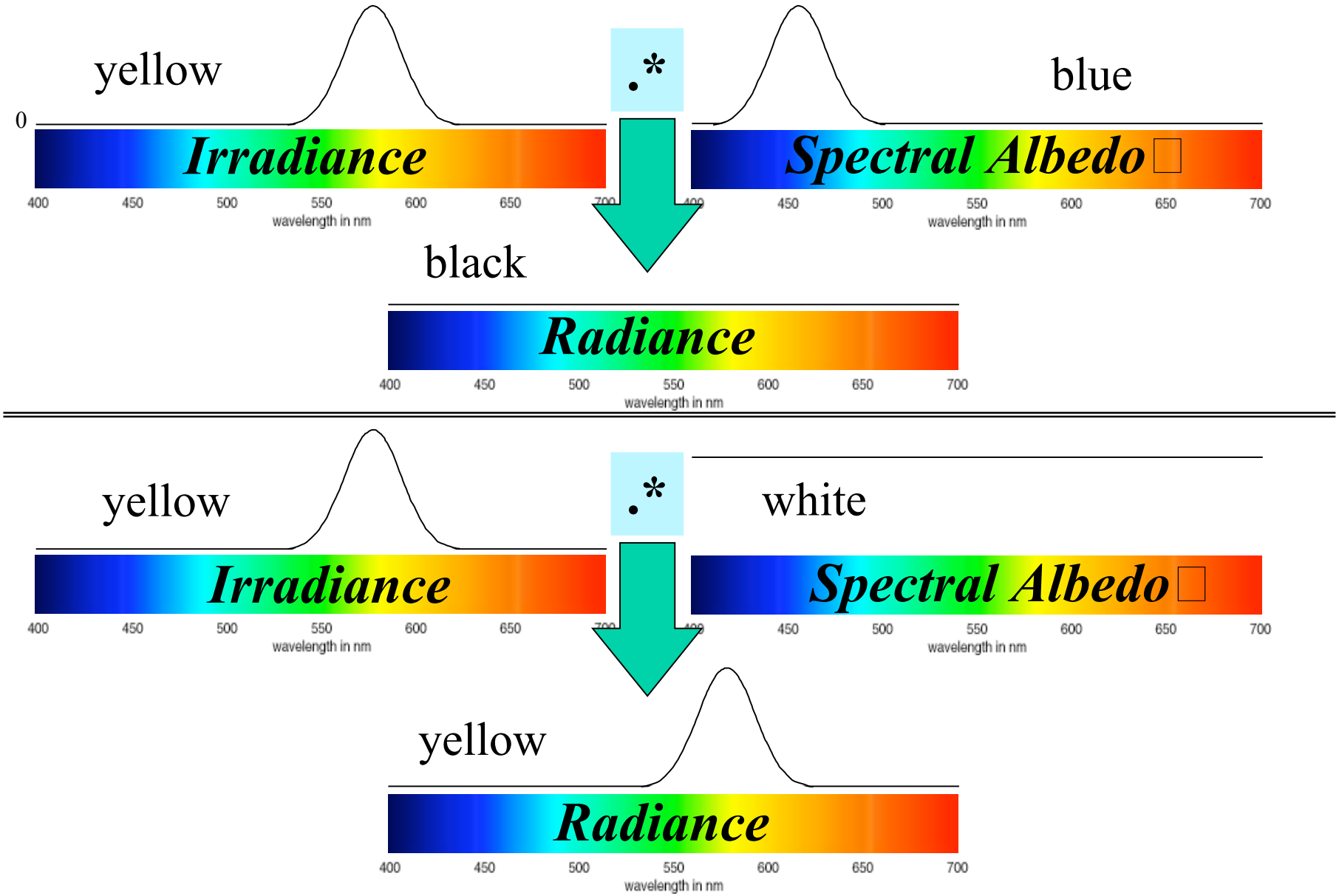
Blue/White under Yellow Light



Lesson Learned

Surfaces materials that look different under white light can appear identical under colored light.

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Metamers

Definition: two different spectral reflectances that appear indistinguishable to a given observer under given illumination conditions.

Illumination metamerism: two color distributions look the same under a given illumination

Observer metamerism: two color distributions look the same to a given observer.

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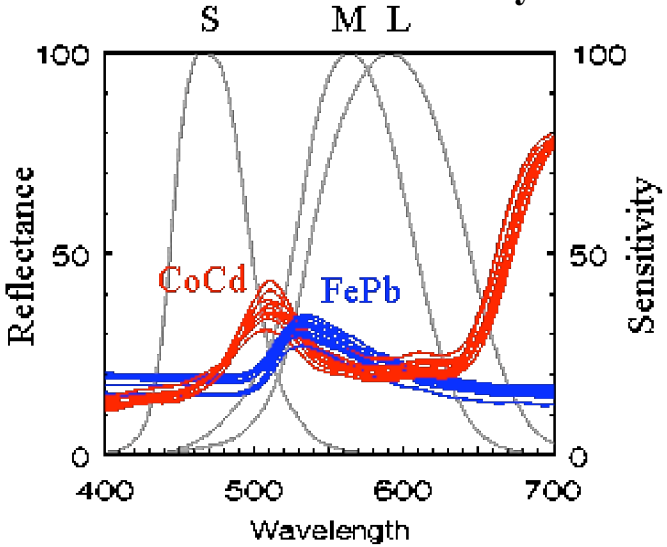
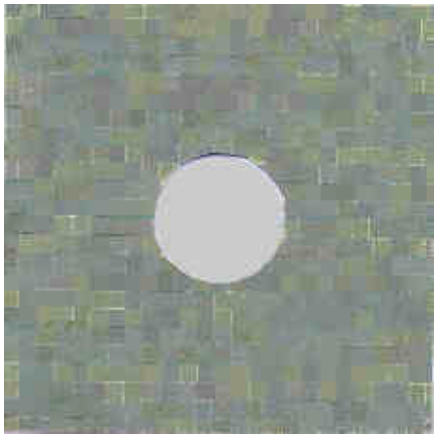
Sample Metamers

Metameric curves for human eye under daylight

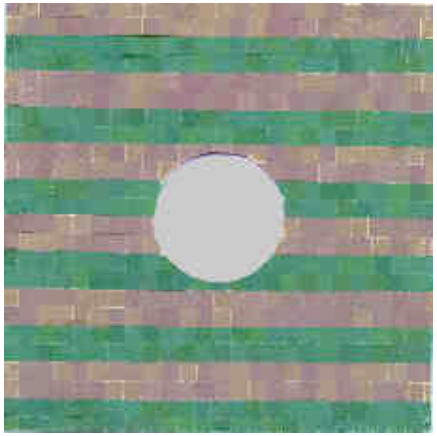


Test pattern viewed under daylight



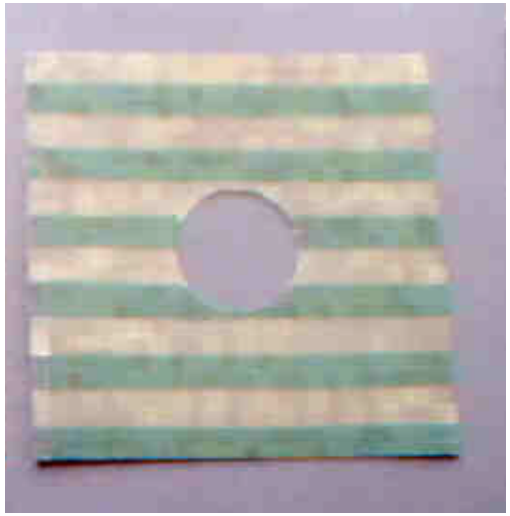
Overcoming metamerism by viewing under different illumination

Viewed under incandescent lighting



Overcoming metamerism by having a different observer

Viewed by camera with more sensitive red response than human eye



From http://www.iitp.ru/projects/posters/meta/

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Metamers

To further explore observer metamerism, see the interactive metamer applet at:

http://www.cs.brown.edu/exploratories/freeSoftware/catalogs/color_theory.html

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Perception: Color Constancy

Humans are very good at recognizing the same material colors under different illumination. Not clear how this is achieved in the general case.

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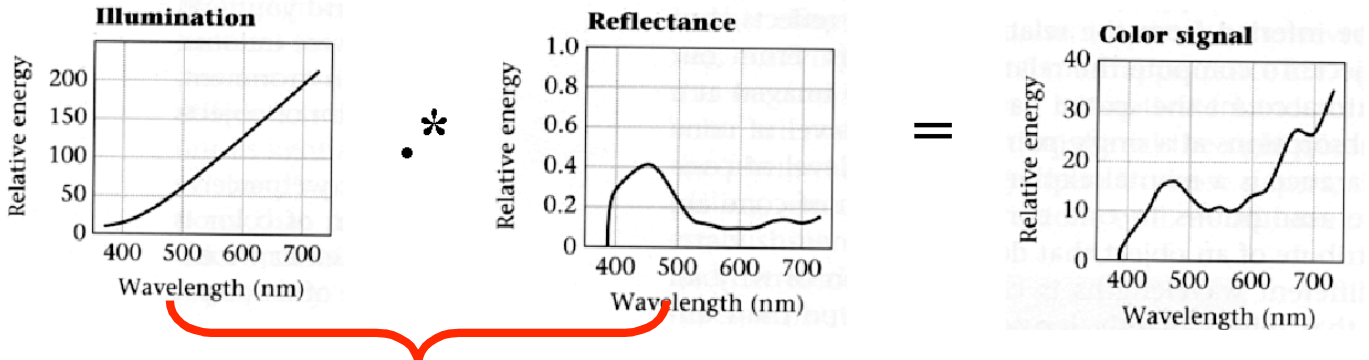
Why is Color Constancy Hard?



Want to factor this signal into these two components. Need prior knowledge!

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Color Blindness

Normal color perception

Red/Green color blindness