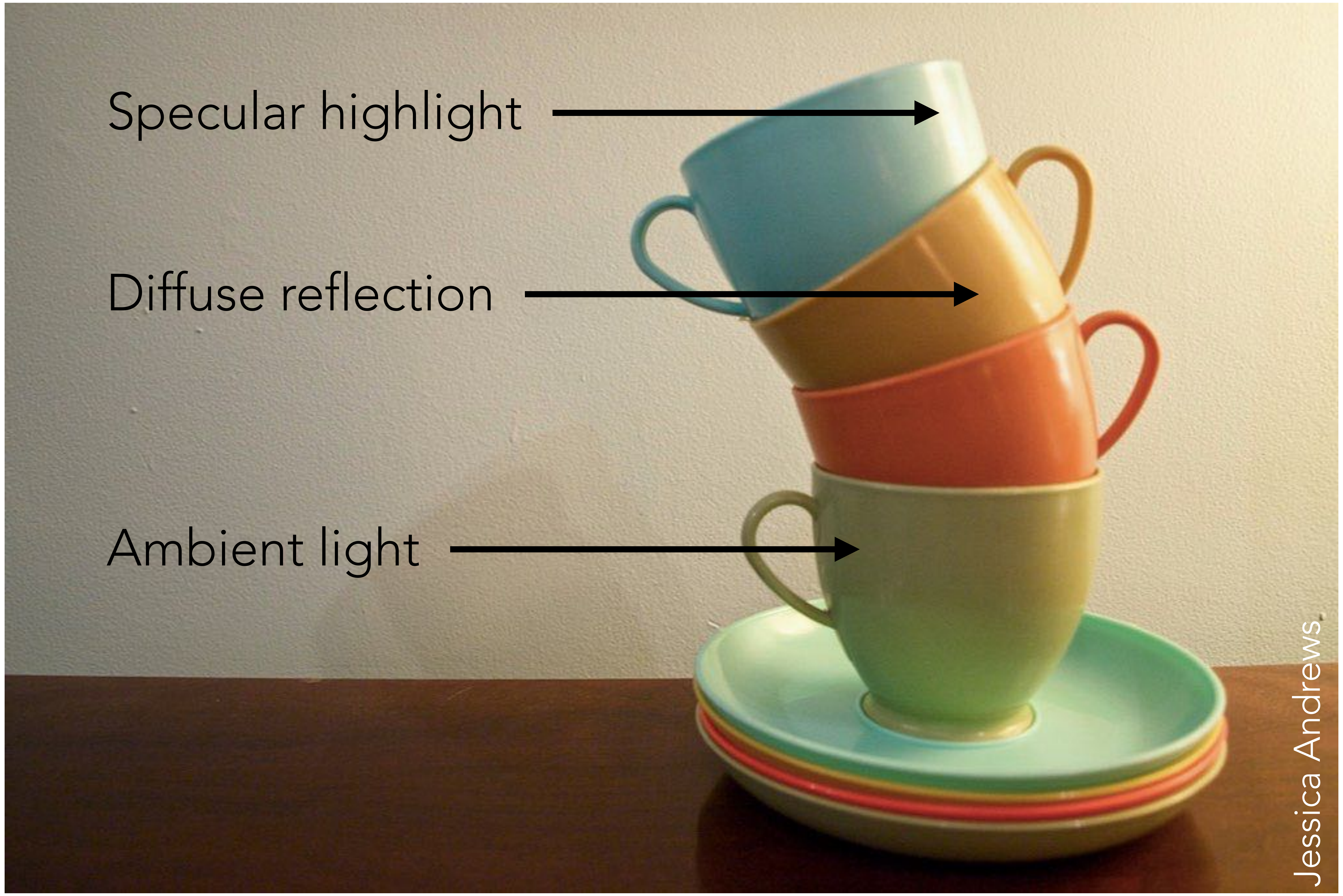
COL781: Computer Graphics

12. Shading and Colour

kitti851, pixabay.com

Recap: a very simple shading model



Diffuse reflection: Lambertian model

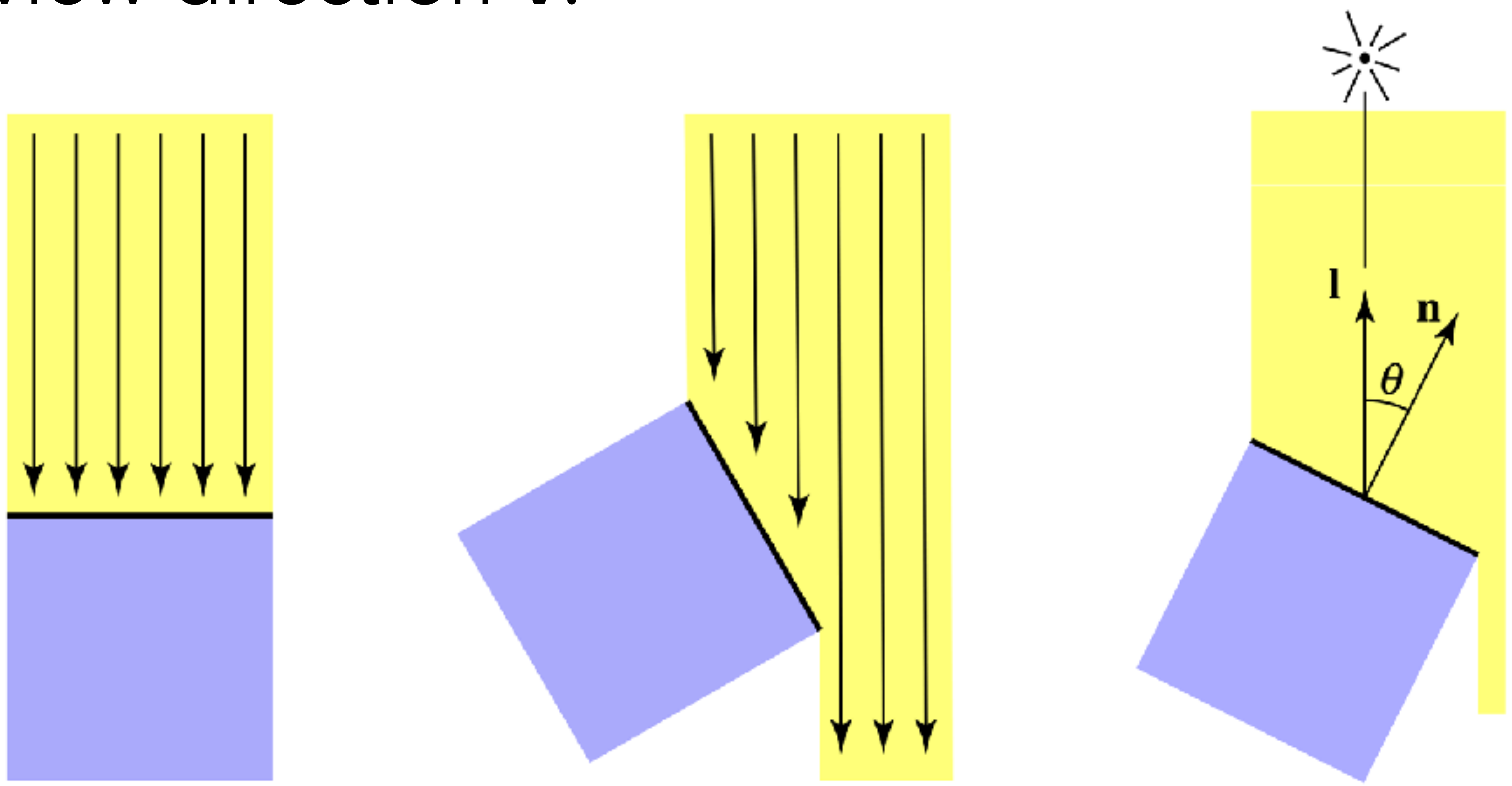
Assume the surface scatters the received light equally in all directions, i.e. the shaded colour is independent of view direction $\mathbf{v}$.

But how much light is received?
Light per unit area $\propto \cos\theta = \mathbf{n} \cdot \boldsymbol{\ell}$

So, reflected light:

$$L_d = k_d \, I \, \max(0, \mathbf{n} \cdot \boldsymbol{\ell})$$

diffuse coefficient (k_d)   incident light (I)



Both k_d and I can (should!) be RGB colours: multiplied componentwise

Specular reflection: Blinn-Phong model

Perfect mirror: Reflection is bright if and only if **v** is exactly "opposite" to **ℓ**

$$\text{bisector}(\mathbf{v}, \boldsymbol{\ell}) = \mathbf{n}$$

Shiny surface: Reflection is bright if **v** is close to being opposite to **ℓ**

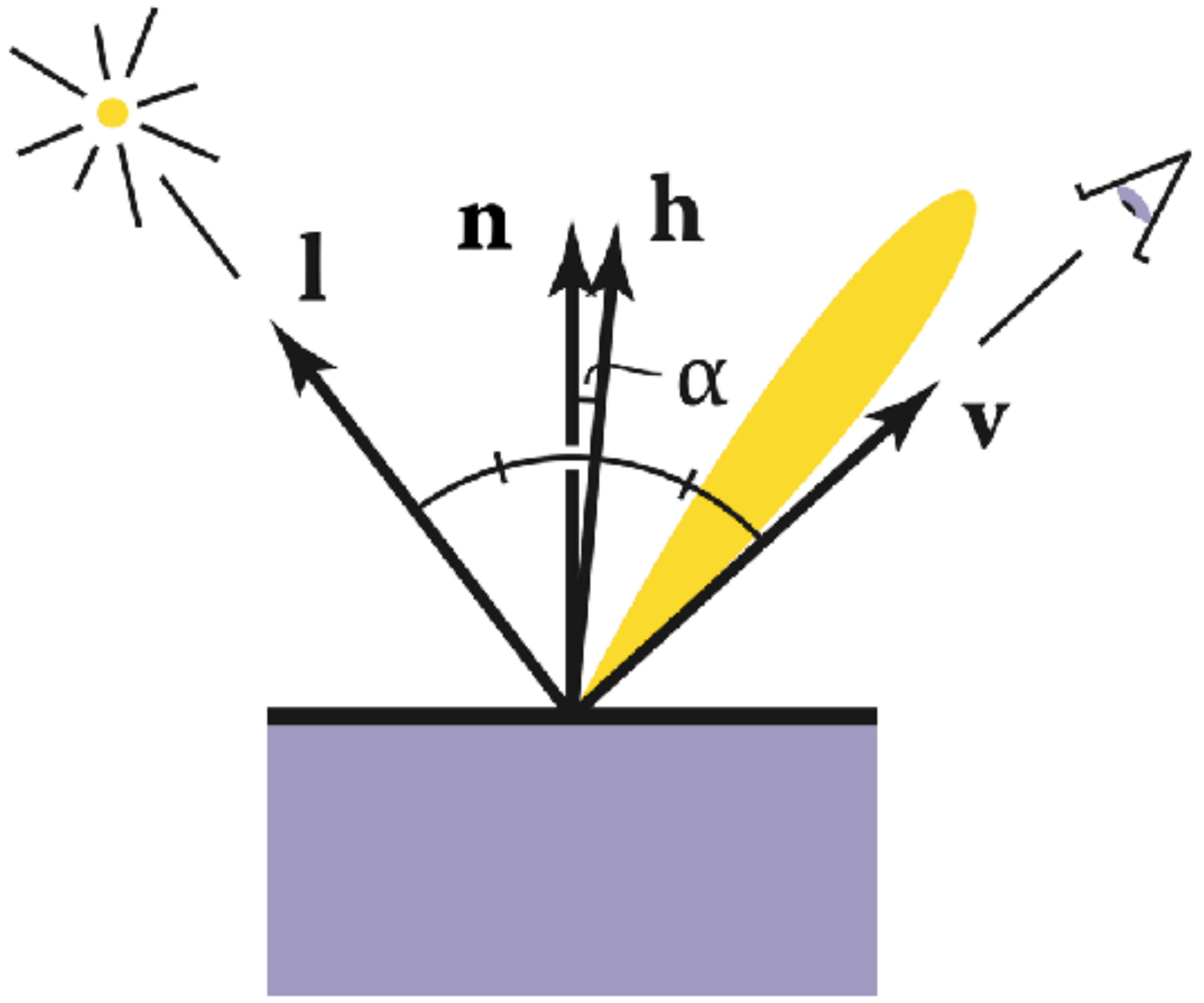
$$\mathbf{h} = \text{bisector}(\mathbf{v}, \boldsymbol{\ell}) = \frac{\mathbf{v}+\mathbf{l}}{\|\mathbf{v}+\mathbf{l}\|}$$

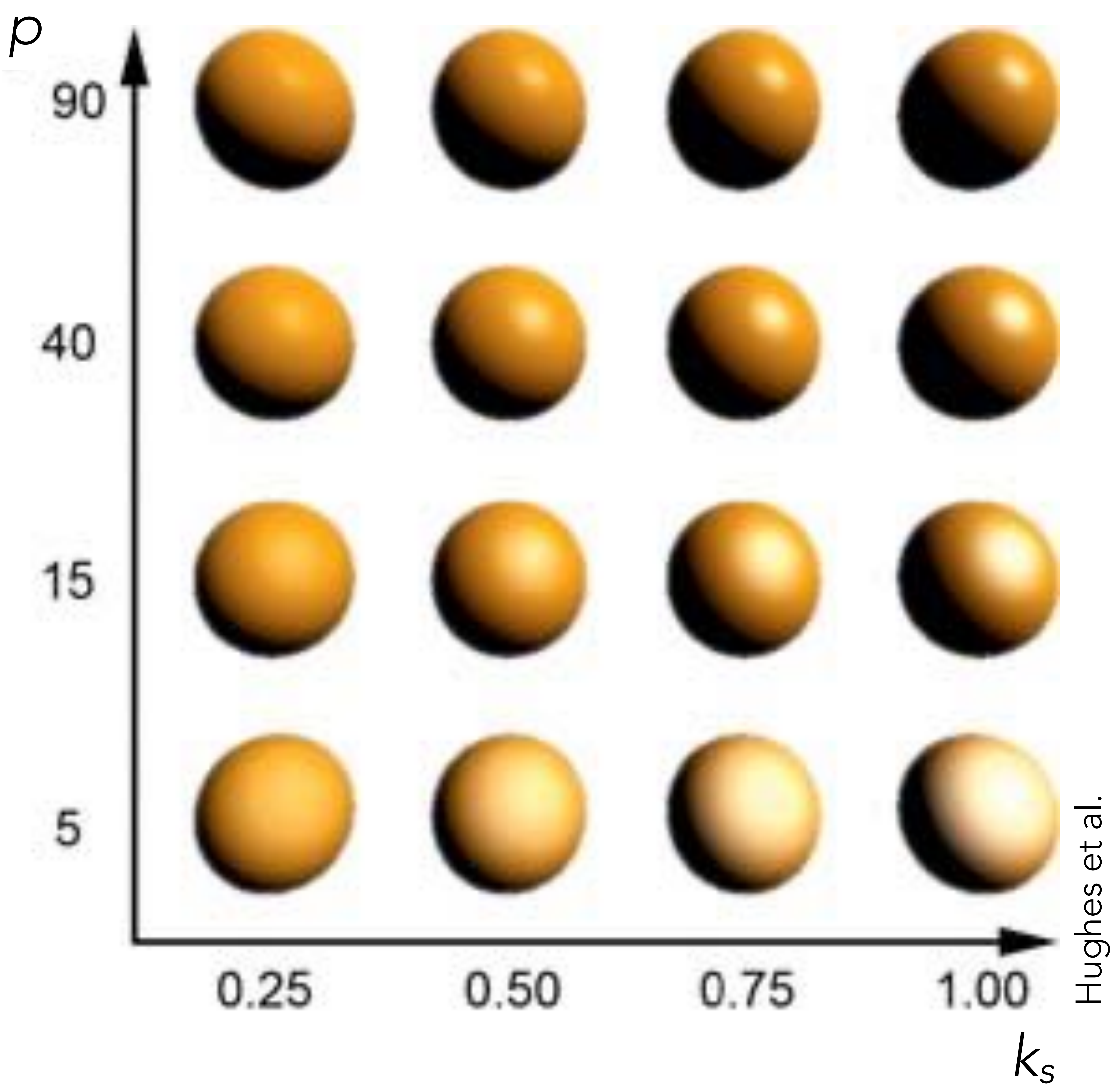
halfway vector

$$L_s = k_s\, I \max(0, \mathbf{n} \cdot \mathbf{h})^p$$

specular coefficient

Phong exponent





p
90
40
15
5
0.25
0.50
0.75
1.00
k_s
Hughes et al.

Light is coming from the right. Why isn't the left side totally black?

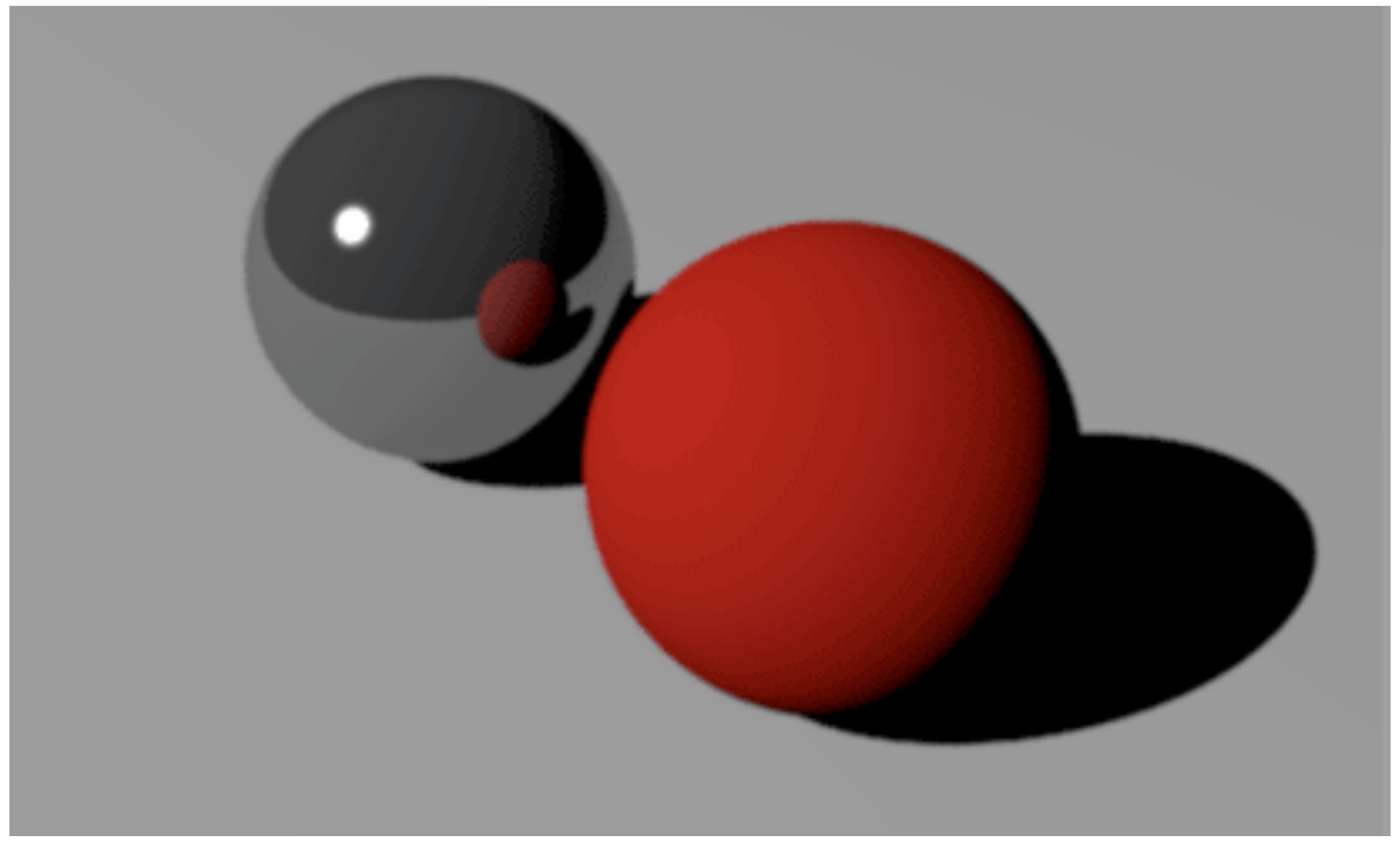
Light is coming from the right. Why isn't the left side totally black?

Ambient light

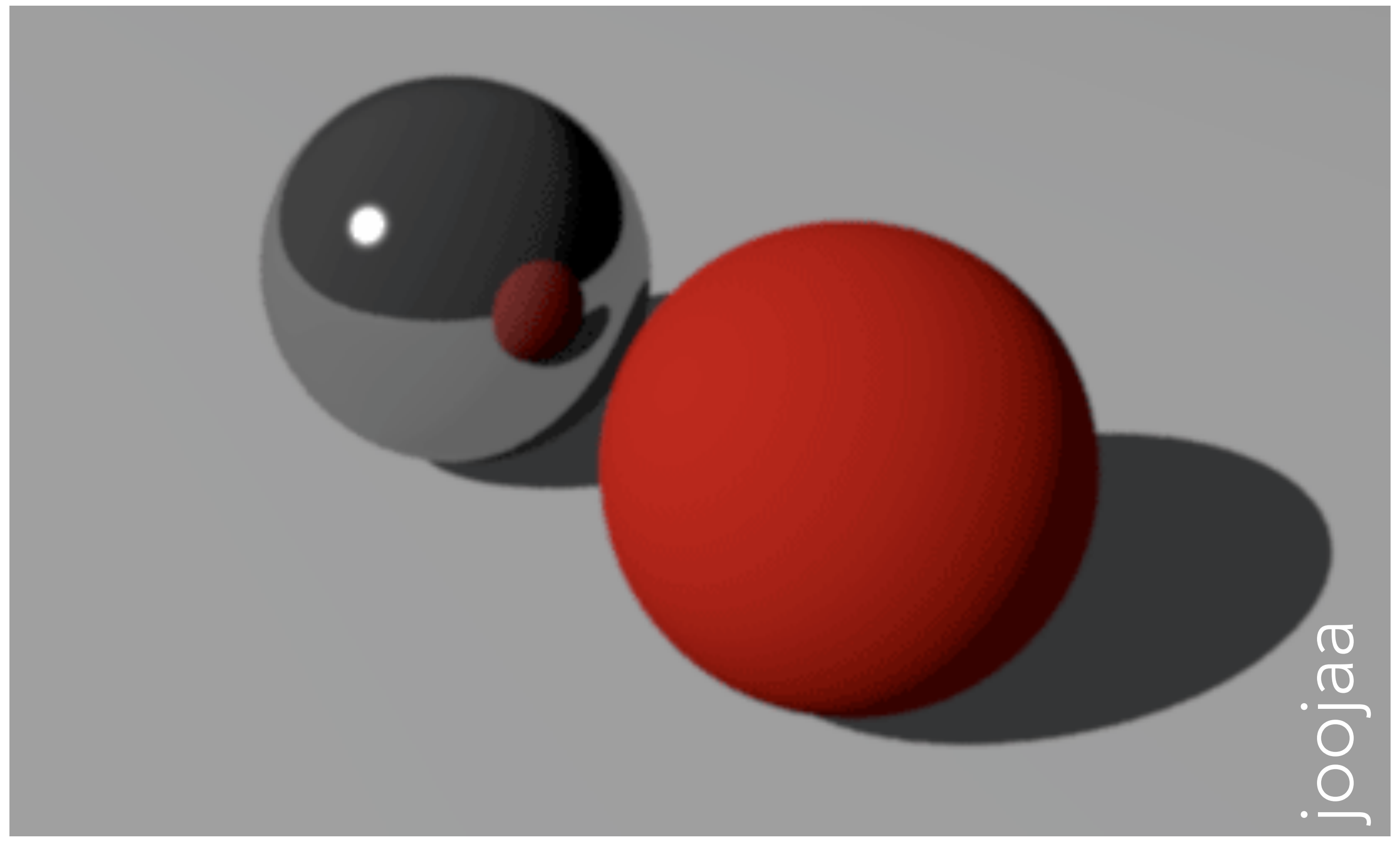
Light bounced around the scene is nonlocal: can't compute from **v**, **n**, **ℓ** only

Instead, just assume there is a constant amount of indirect lighting everywhere

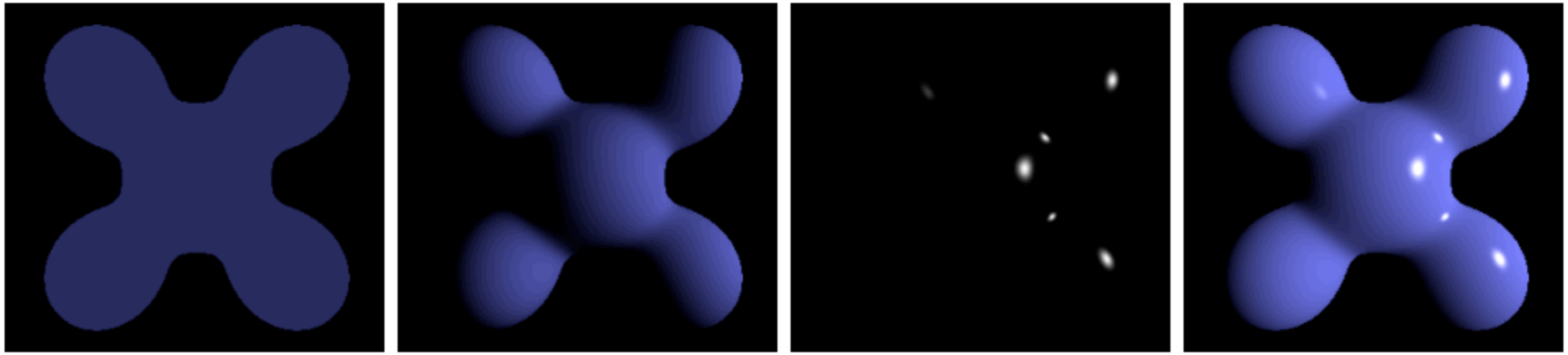
$$L_a = k_a I_a$$



Without ambient light



With ambient light



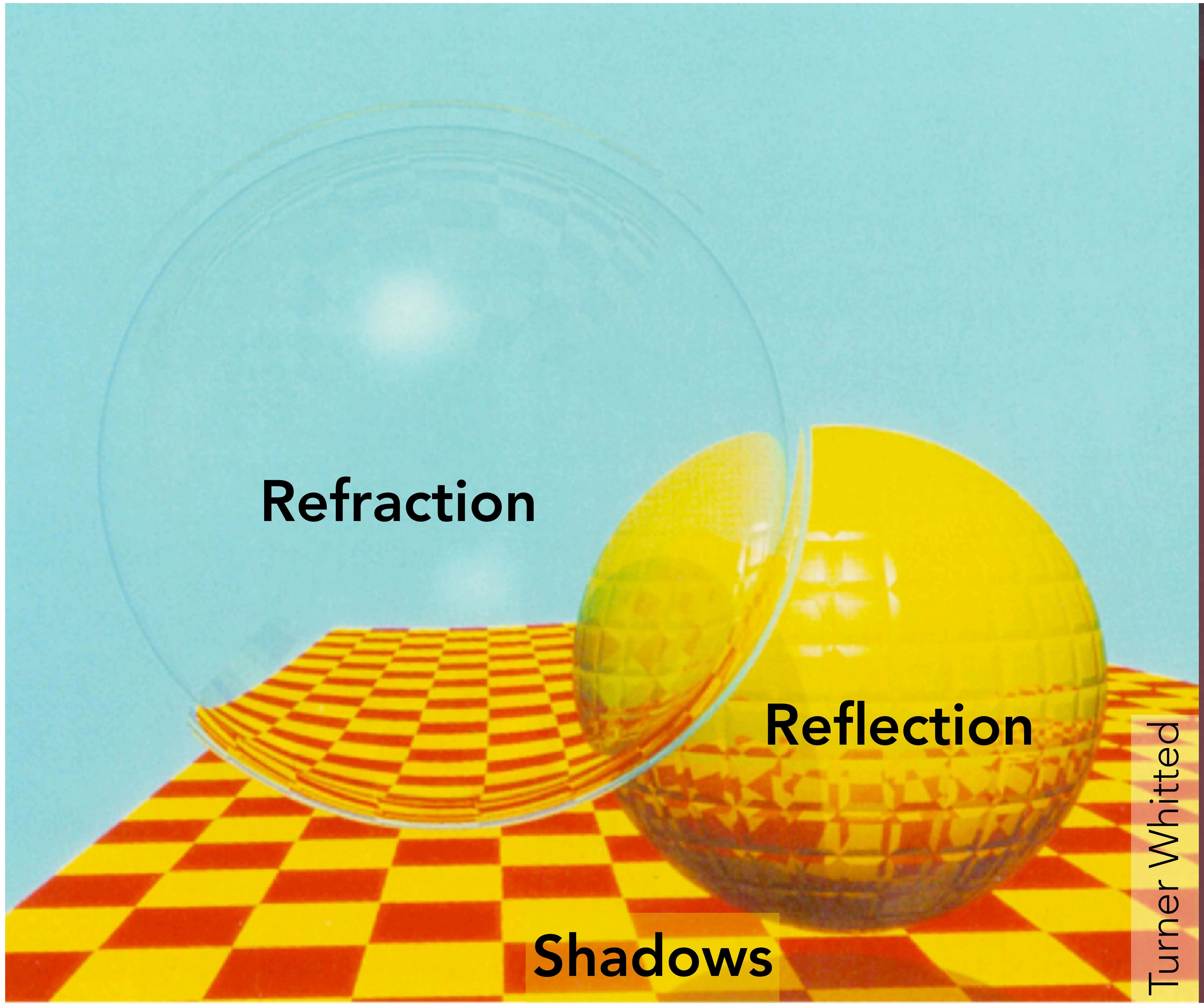
Ambient + Diffuse + Specular = **Blinn-Phong reflectance model**

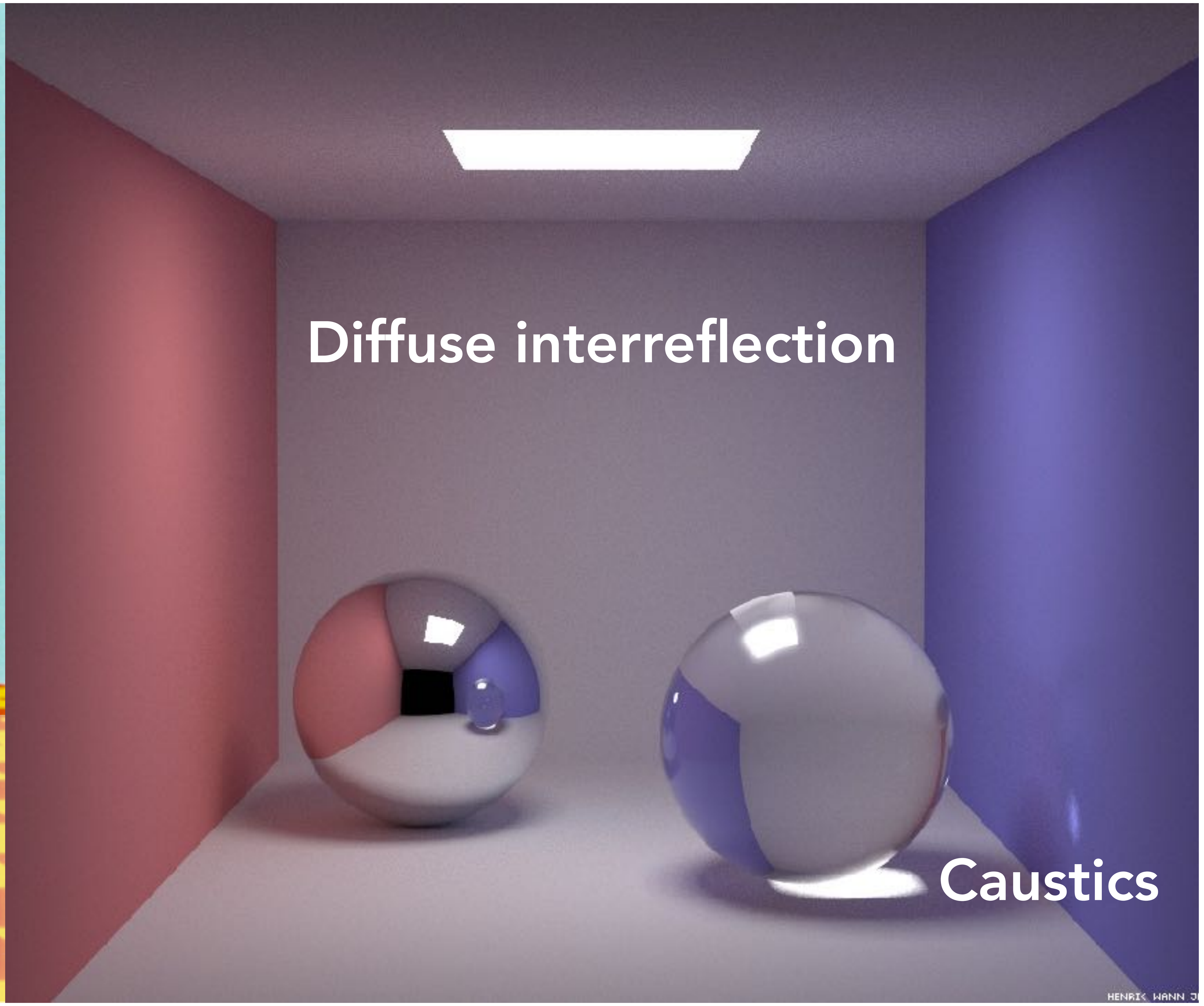
$$
\begin{aligned}
L &= L_a + L_d + L_s \\
&= k_a\, I_a + k_d\, I \max(0, \mathbf{n} \cdot \boldsymbol{\ell}) + k_s\, I \max(0, \mathbf{n} \cdot \mathbf{h})^p
\end{aligned}
$$

k_a, k_d, k_s (colours) and p (scalar) control the material's appearance

If multiple lights I_1, I_2, …: add up diffuse and specular terms for each light

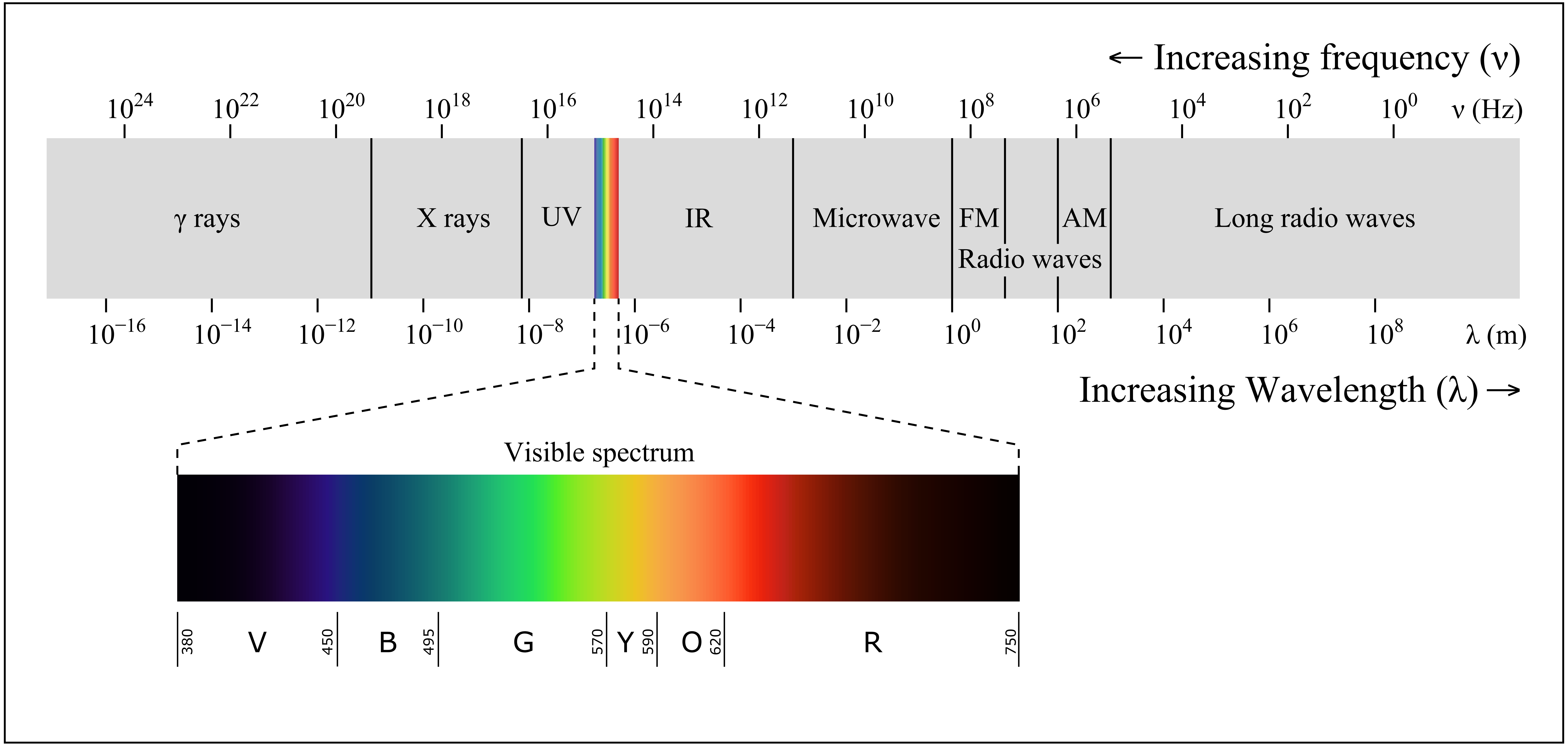
What phenomena are not captured?



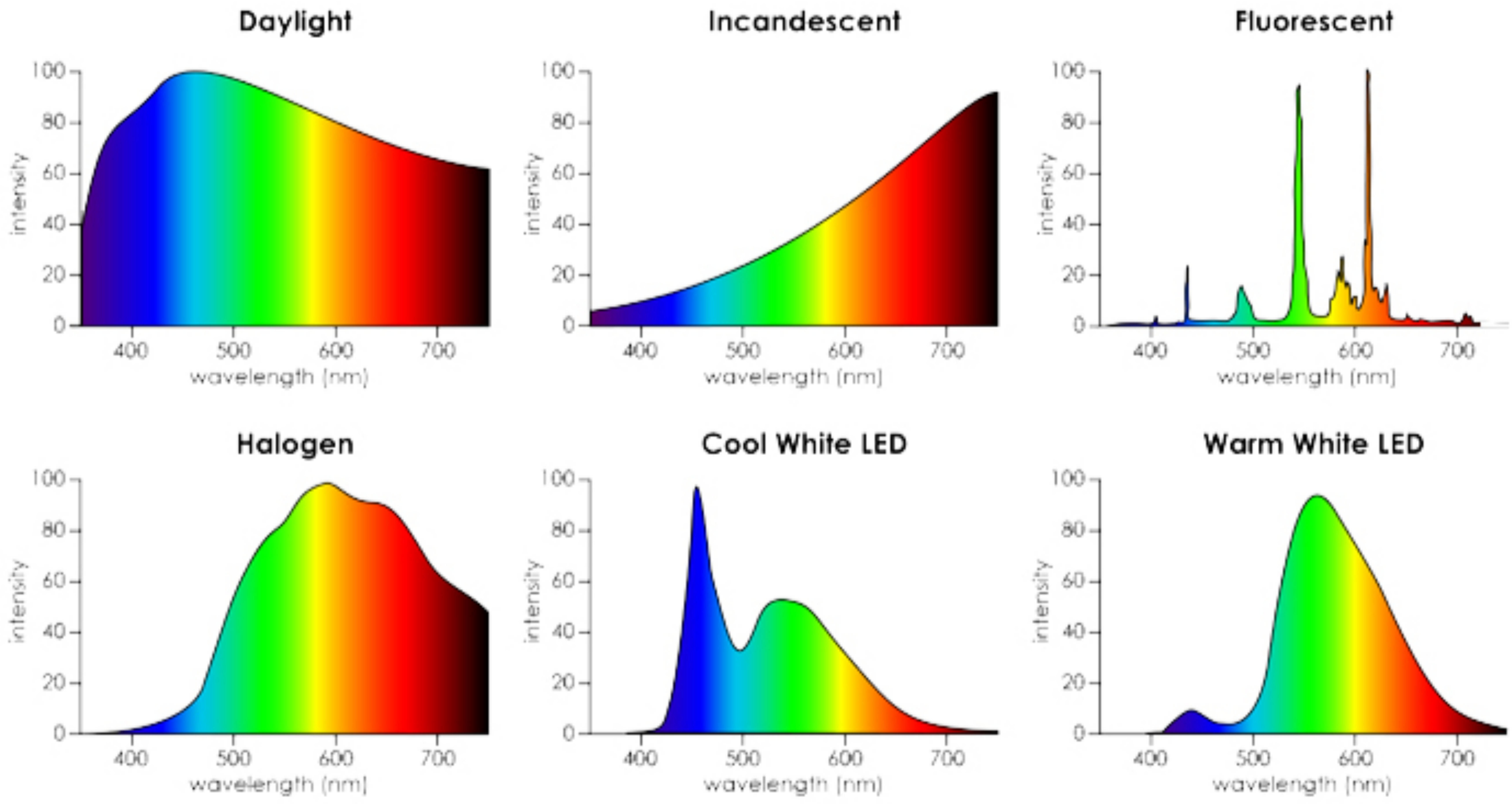


Colour

What is colour?

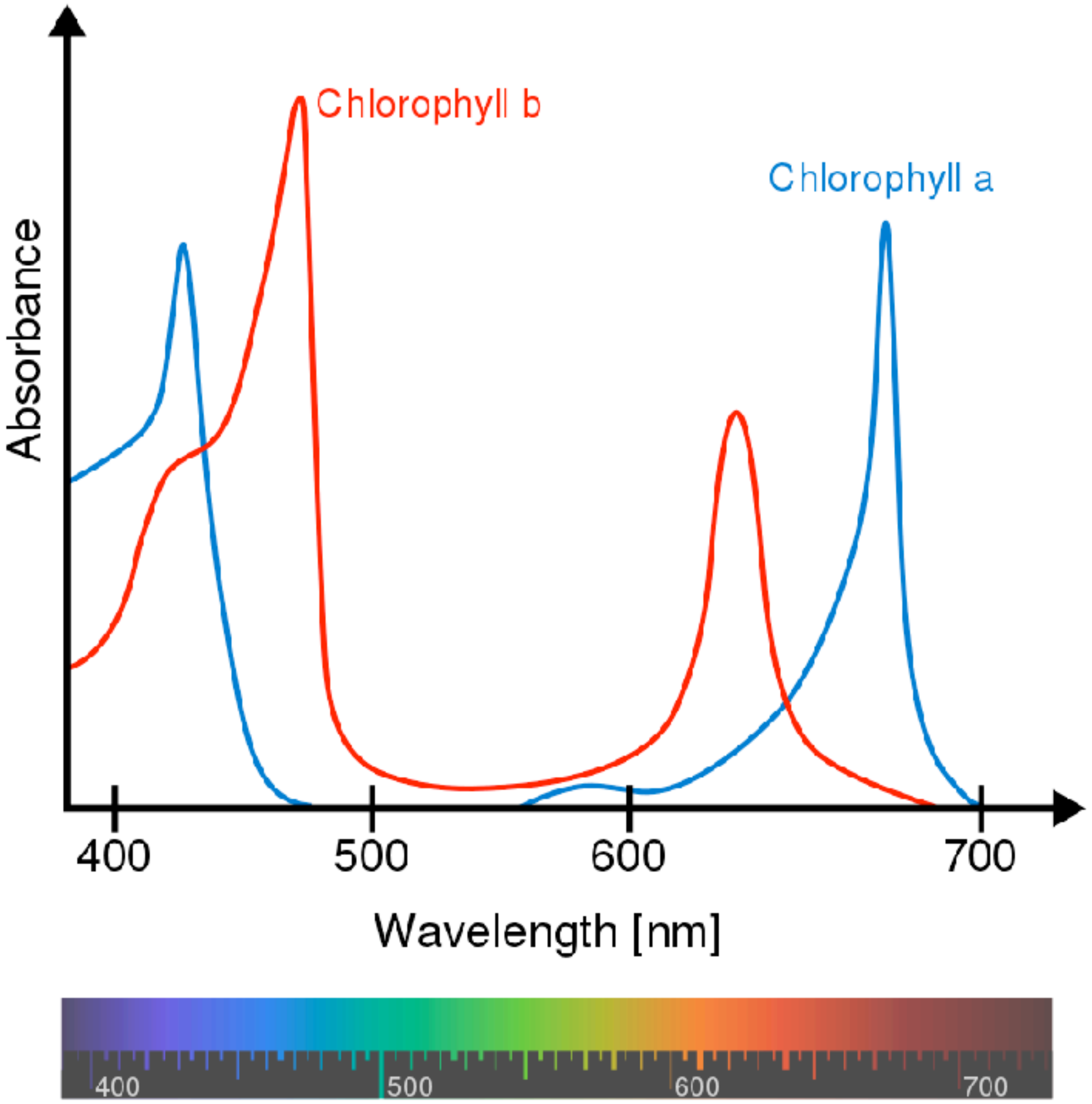


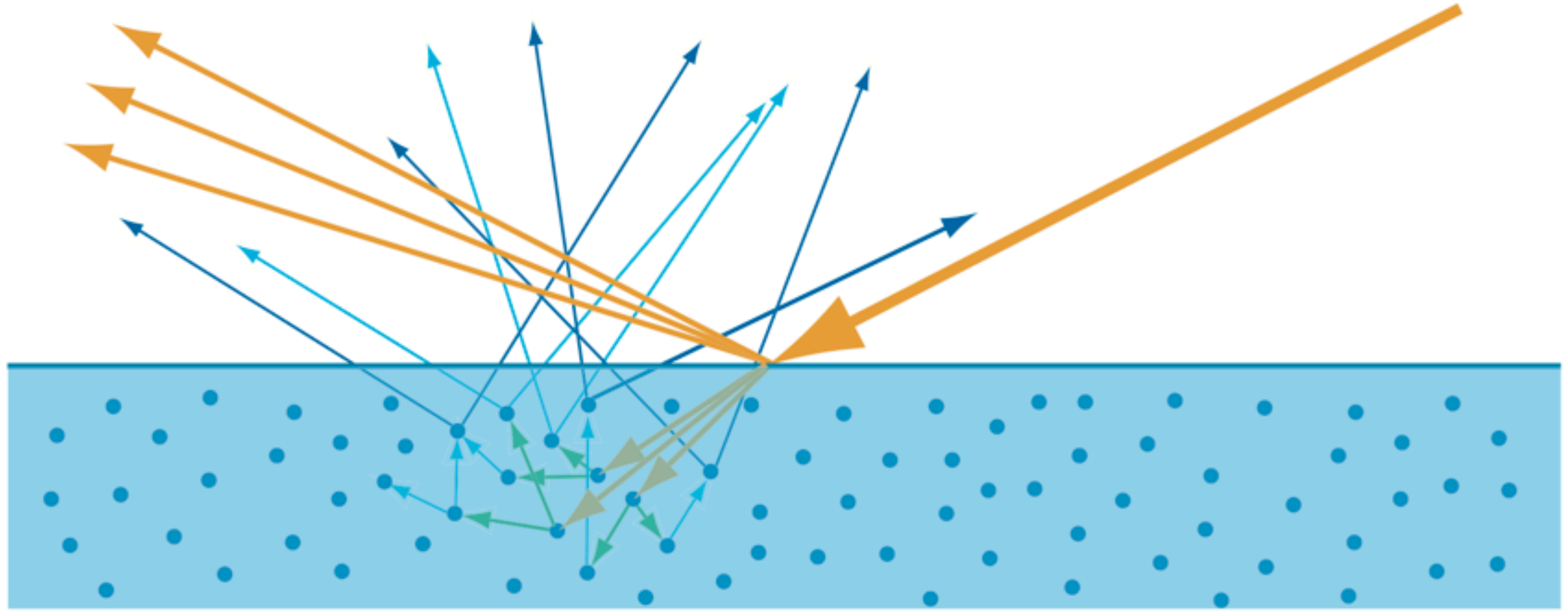
Emission spectra

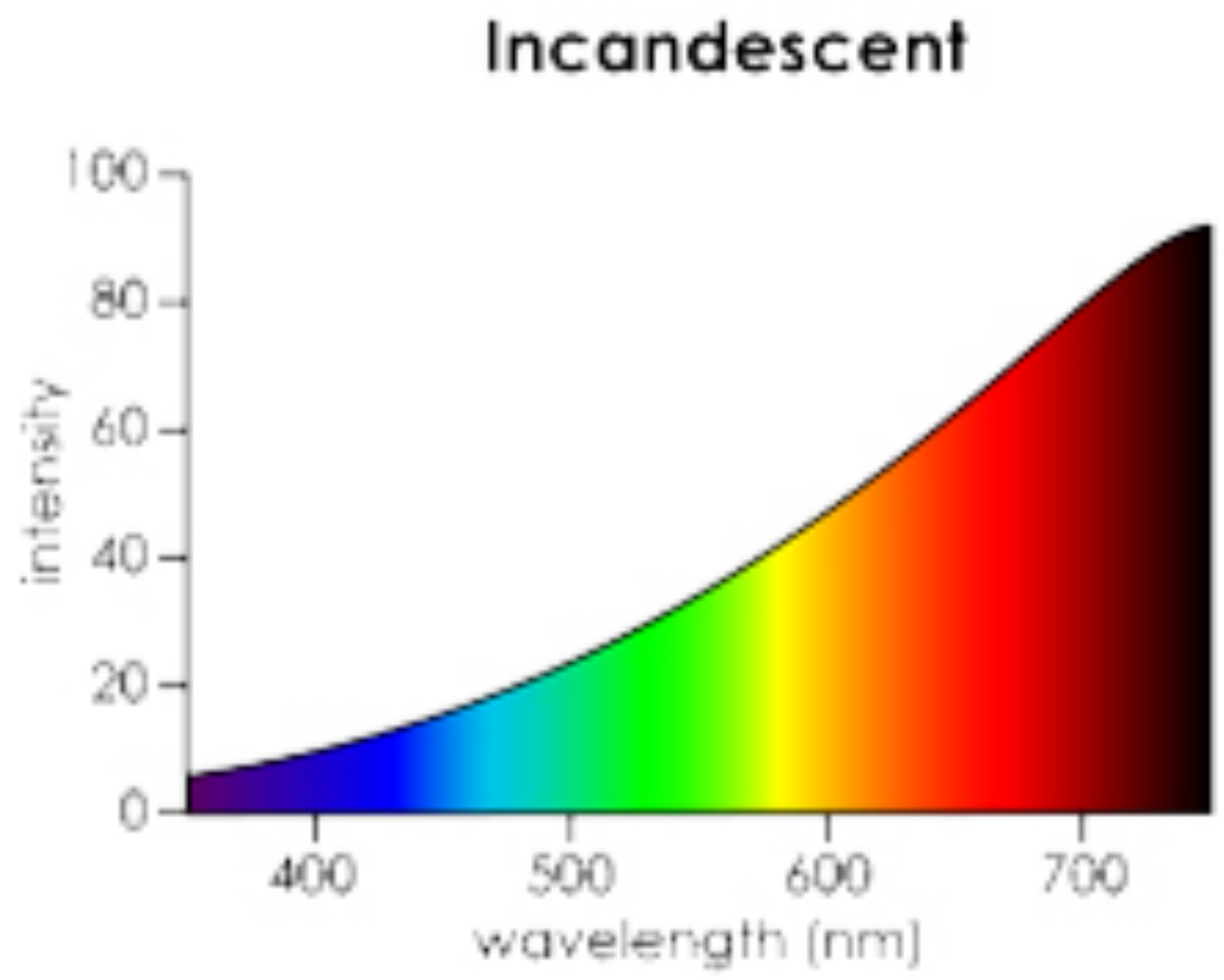


Admesy, via Ren Ng

Absorption spectra

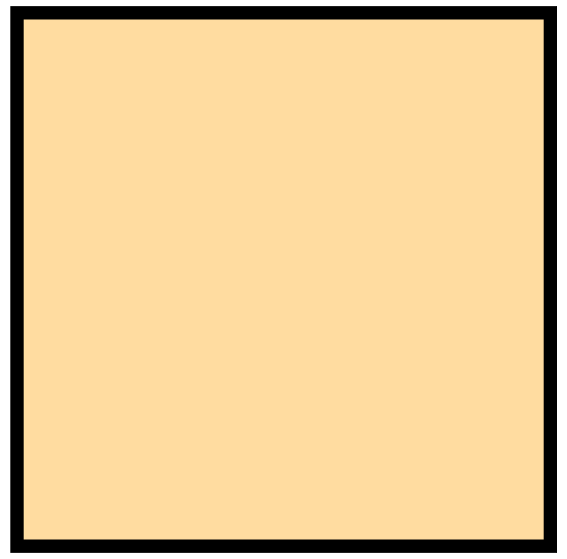






Spectral distribution

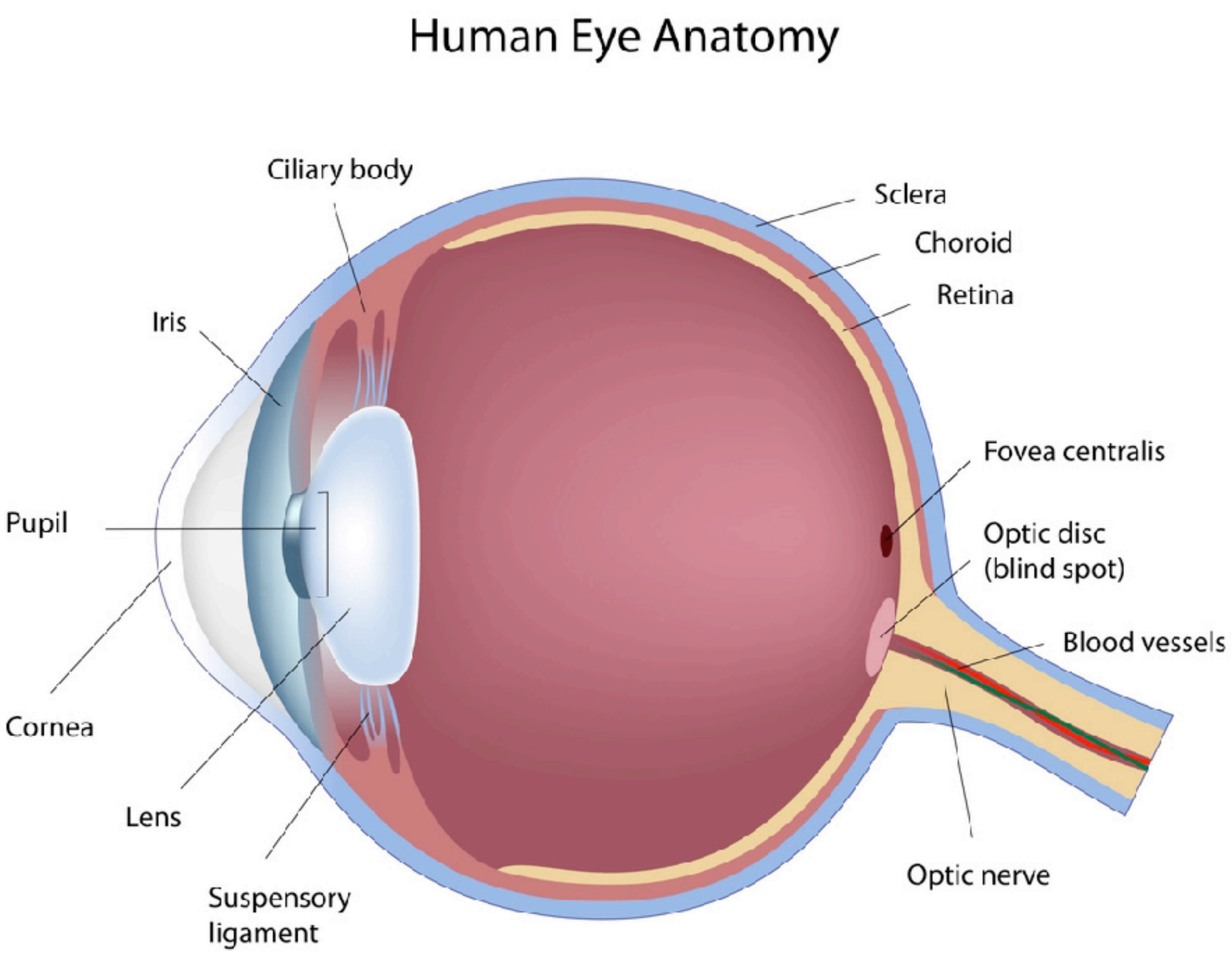
?

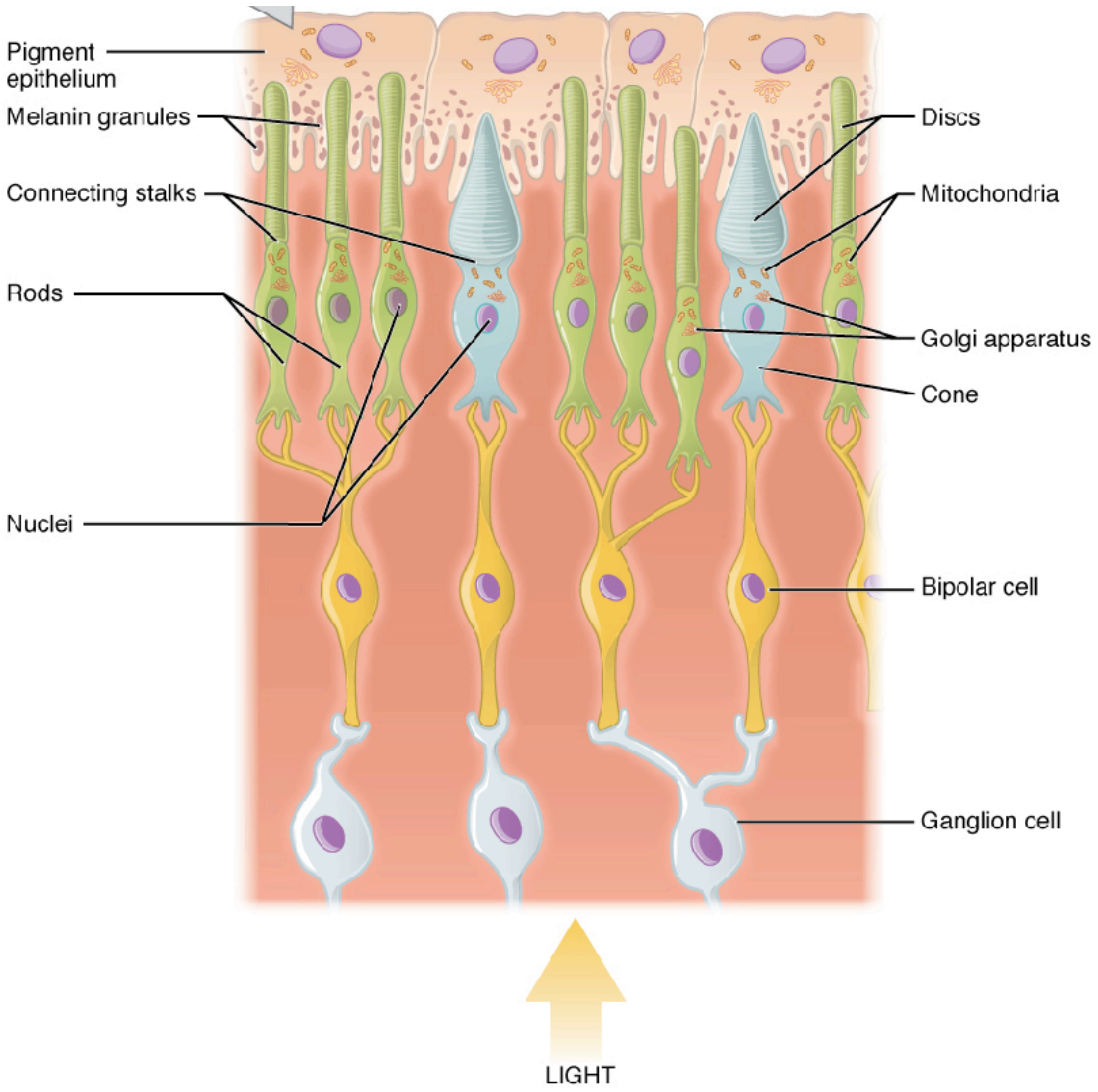


RGB (255, 220, 160)

Tristimulus values

The human eye

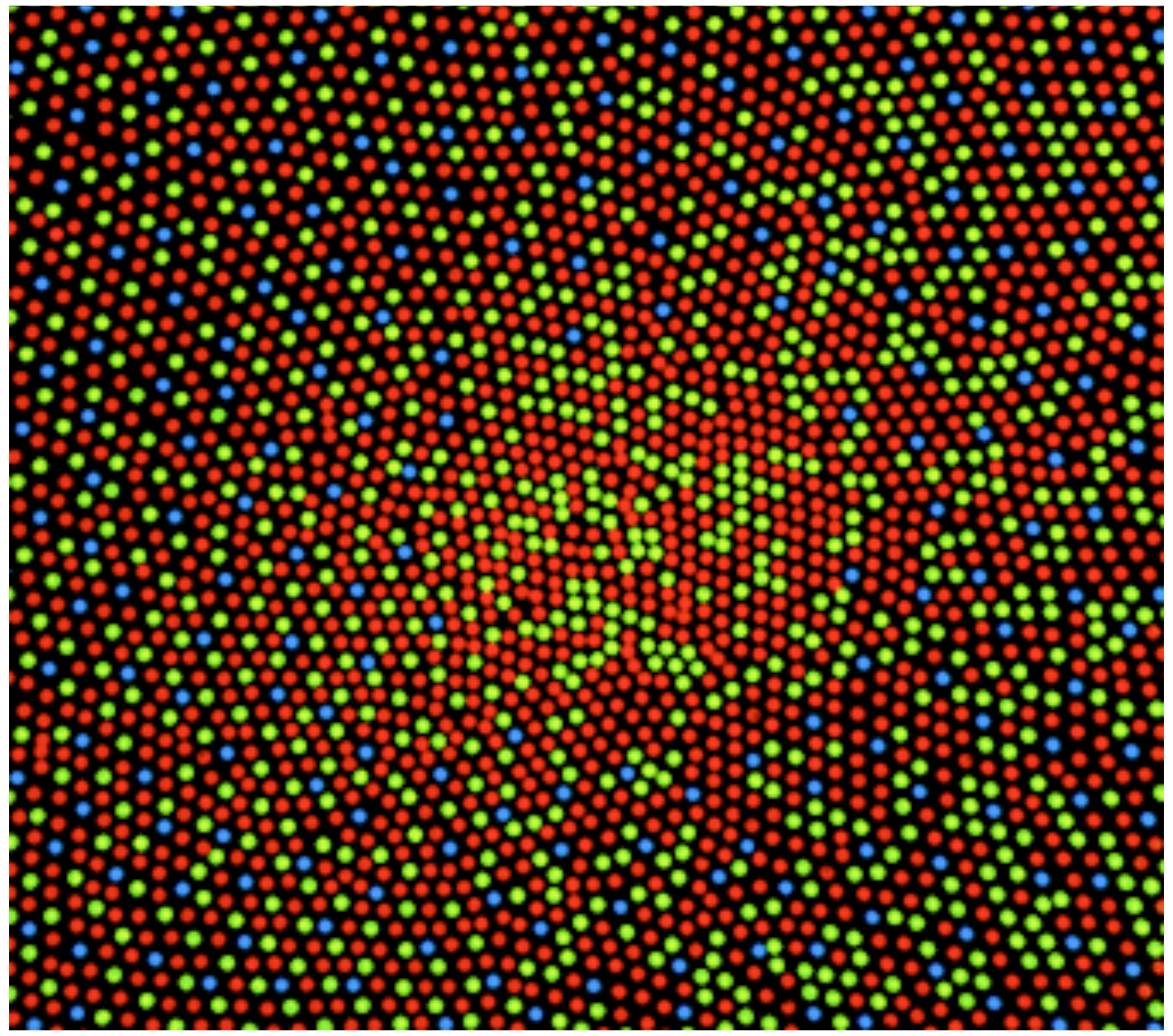


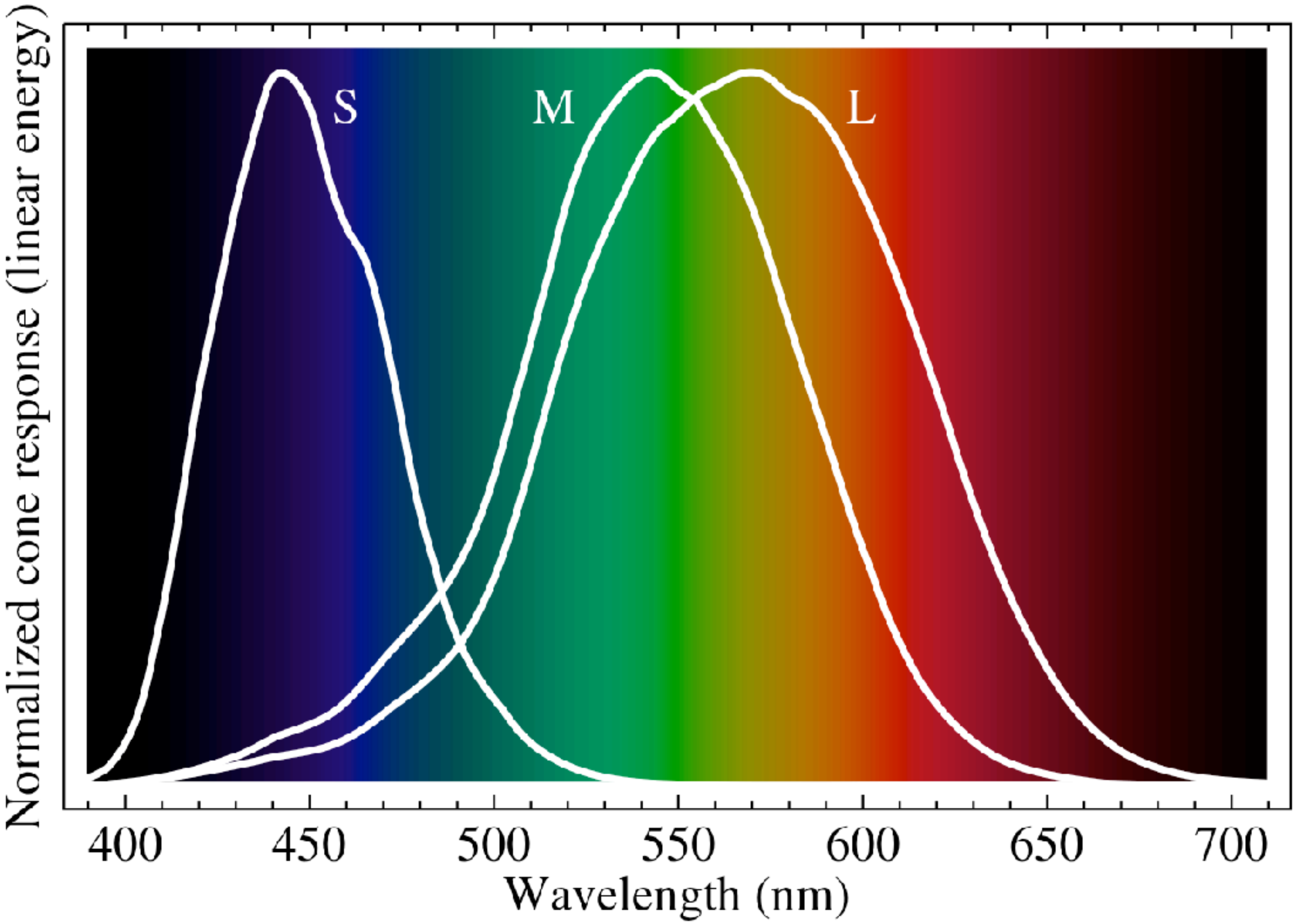


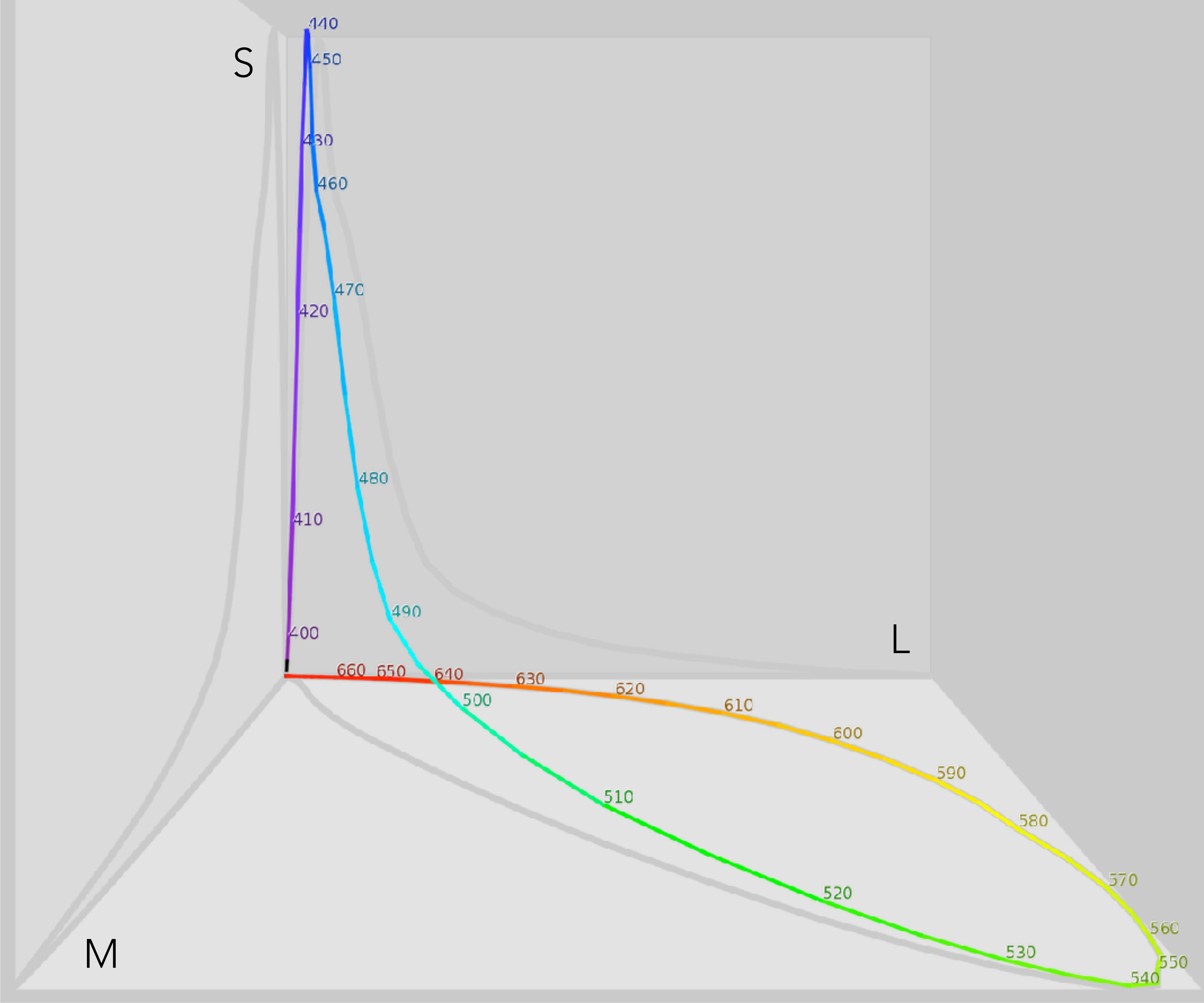
Cone cells

Three types of cone cells: sensitive to long, medium, and short wavelengths

(not red, green, and blue!)







S
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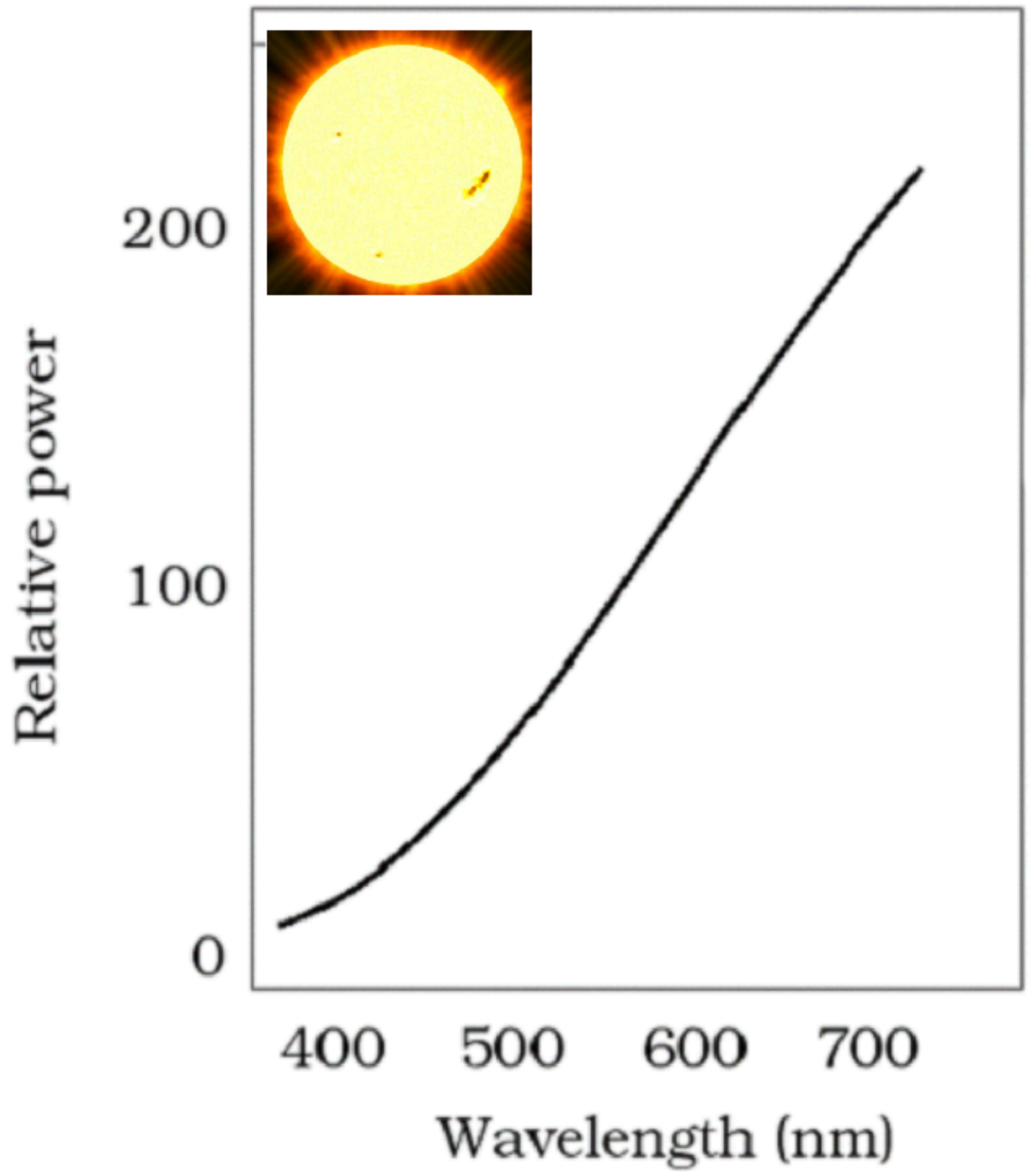
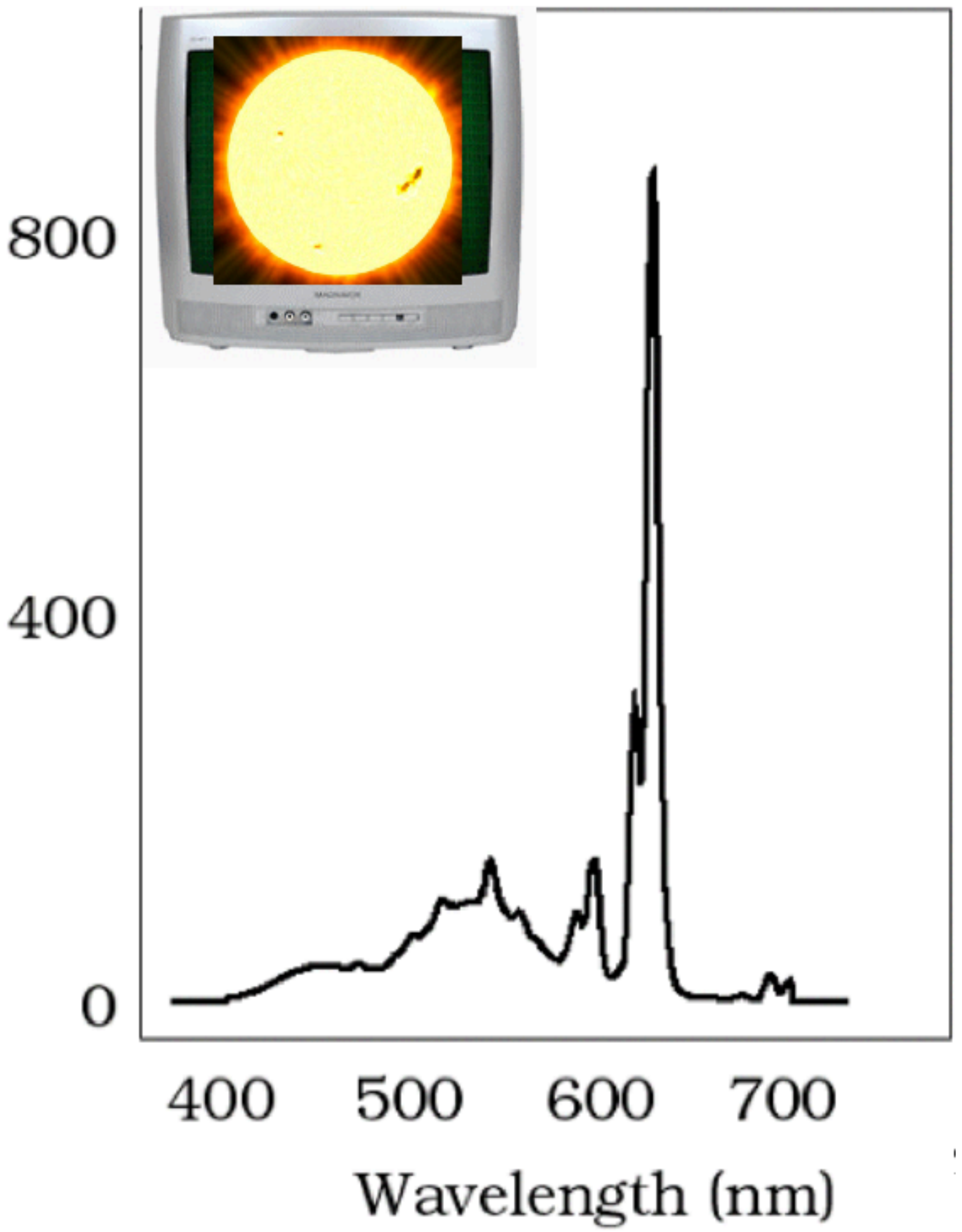
520
510
500

Metamers

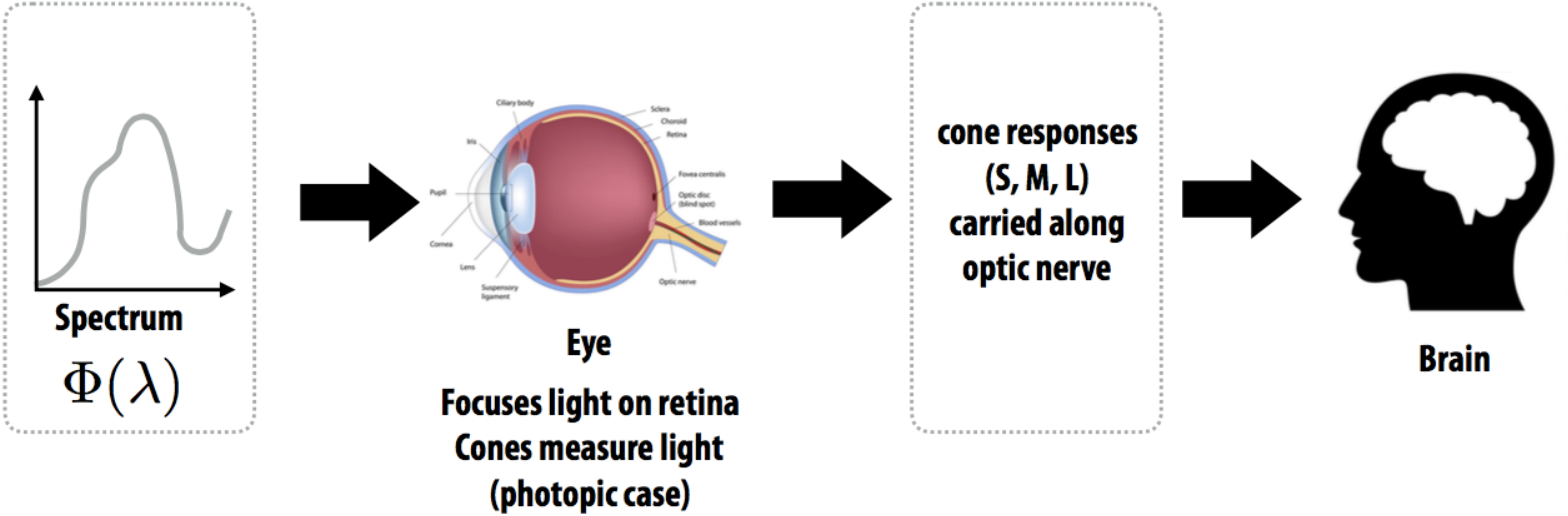




Brian Wandell

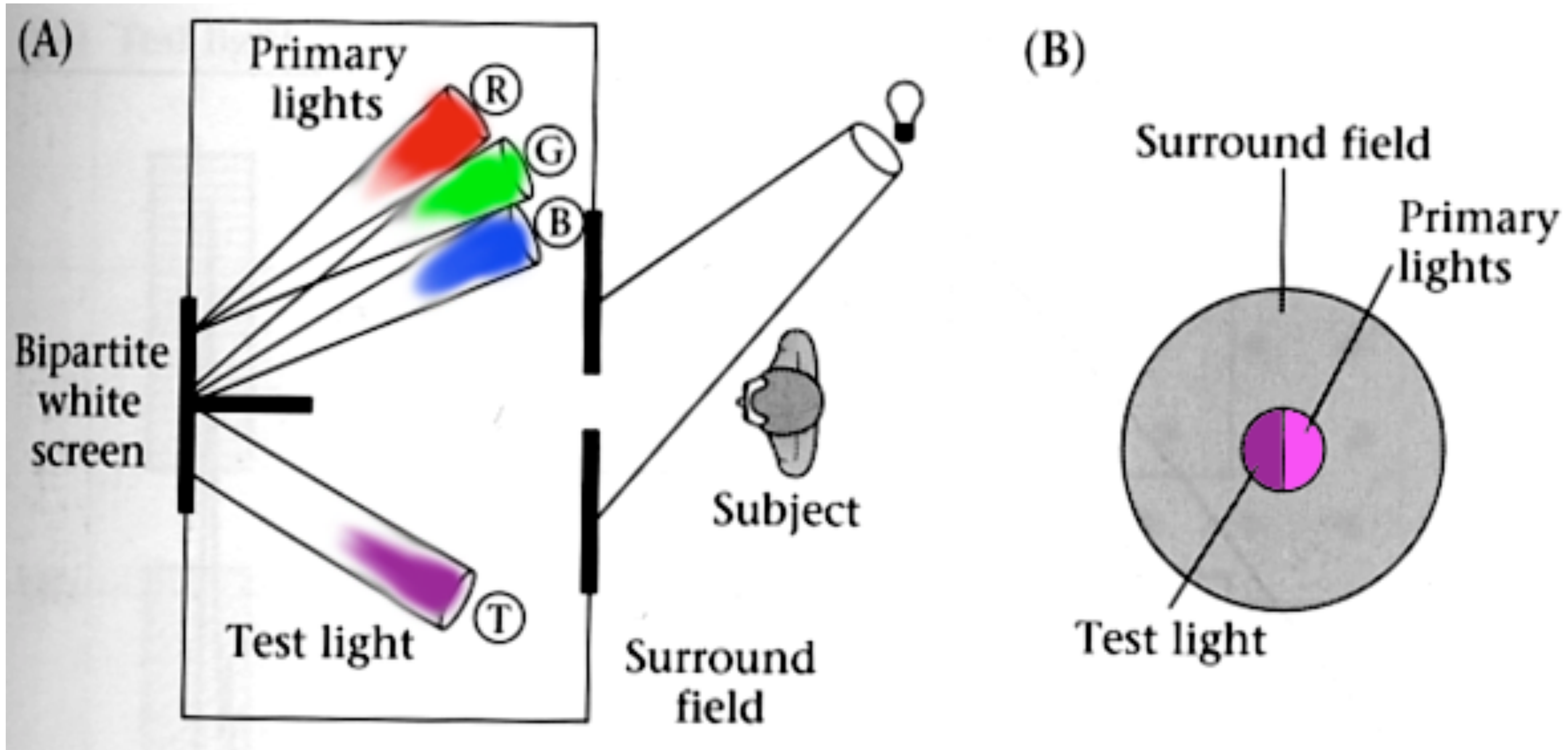
Colours are entirely a product of the human visual system!

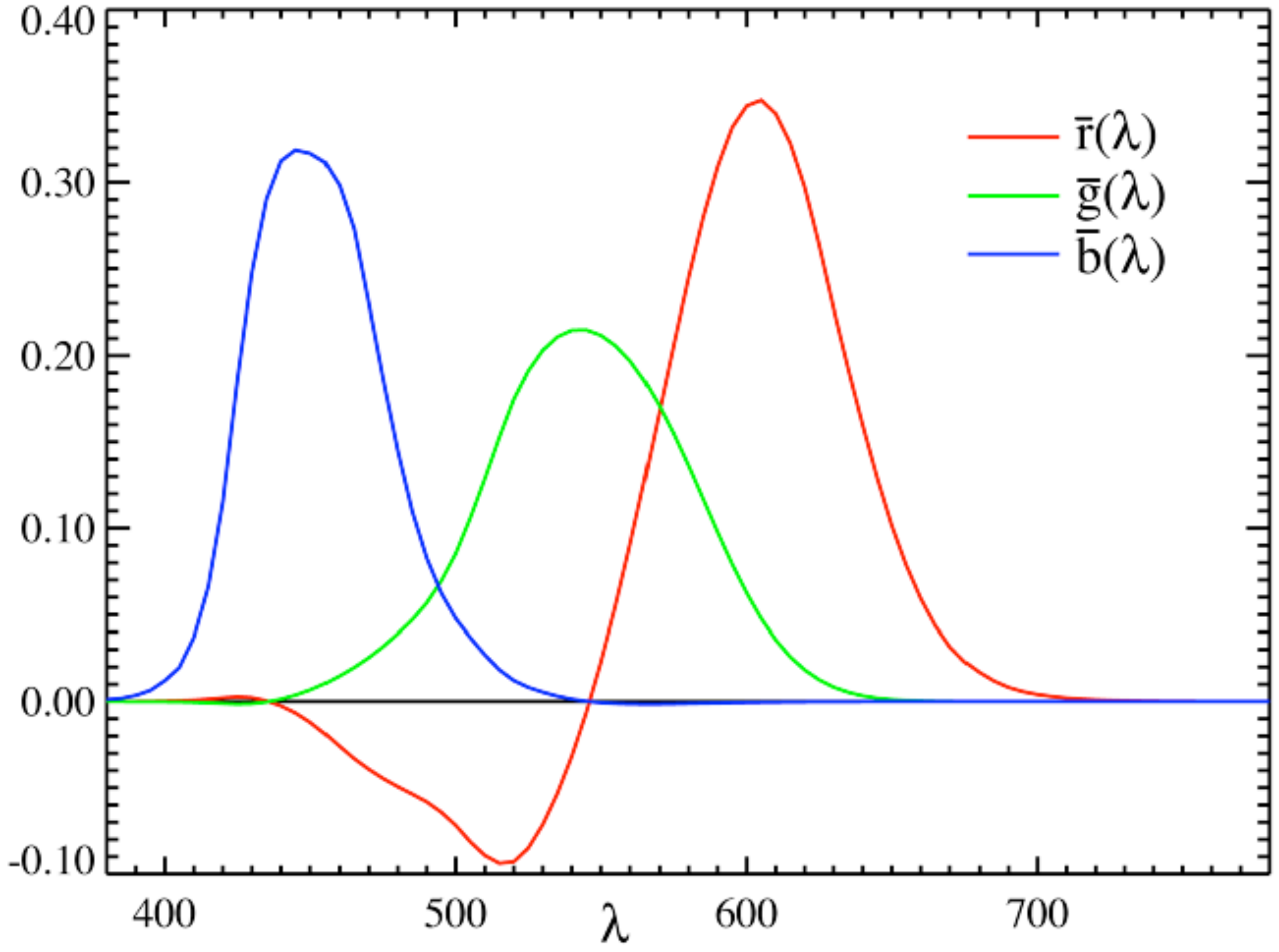
Physically, only spectra exist.



Kayvon Fatahalian

Colour matching experiments





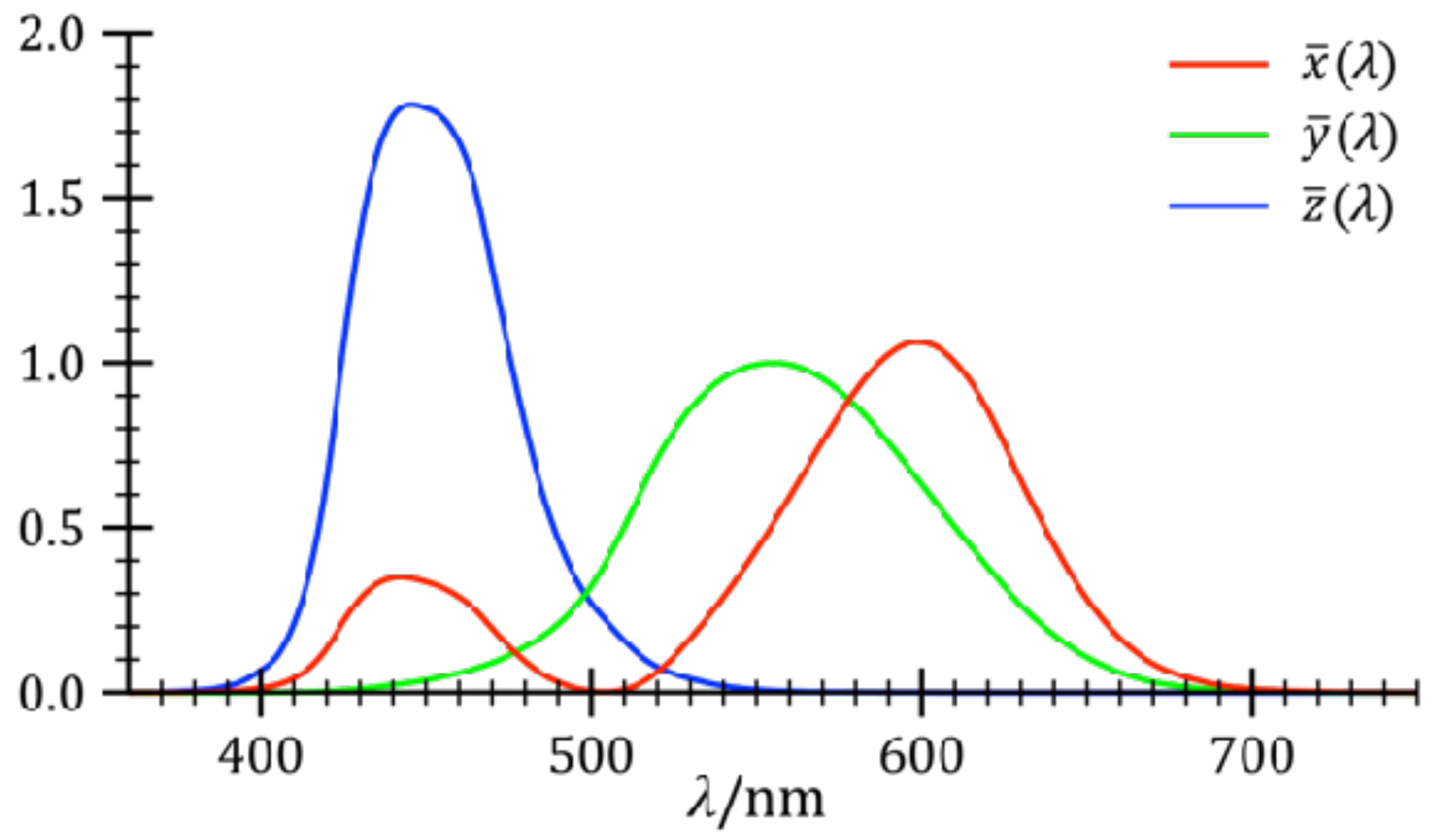
Primaries: 700 nm (red),
546.1 nm (green), 435.8 nm (blue)

Colour spaces

A **colour space** is a choice of coordinate system for the 3D space of colours.

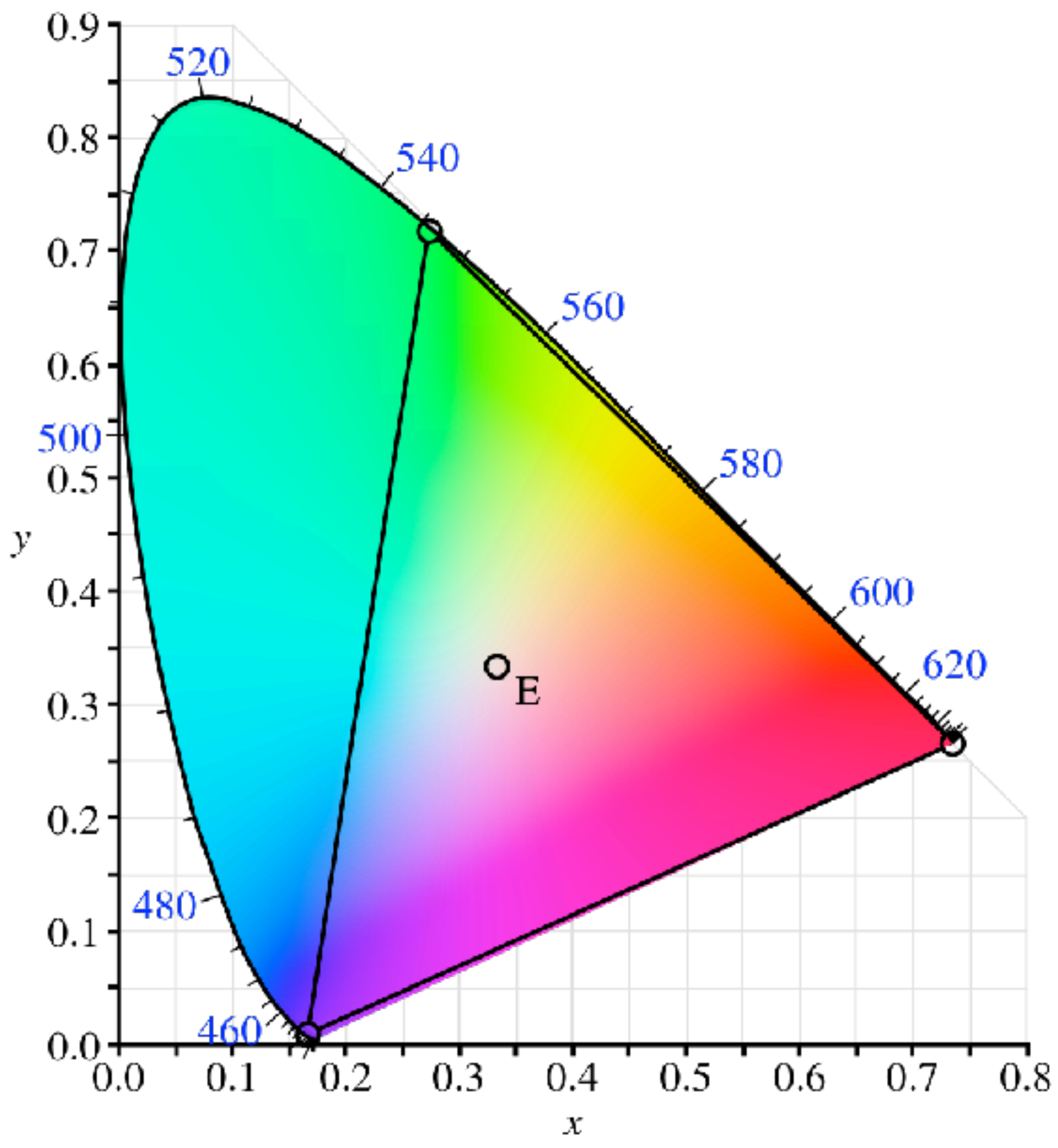
CIE 1931 XYZ colour space:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490\,00 & 0.310\,00 & 0.200\,00 \\ 0.176\,97 & 0.812\,40 & 0.010\,63 \\ 0.000\,00 & 0.010\,00 & 0.990\,00 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



Chromaticity diagram

vs. $(x, y) = \dfrac{(X, Y)}{X + Y + Z}$



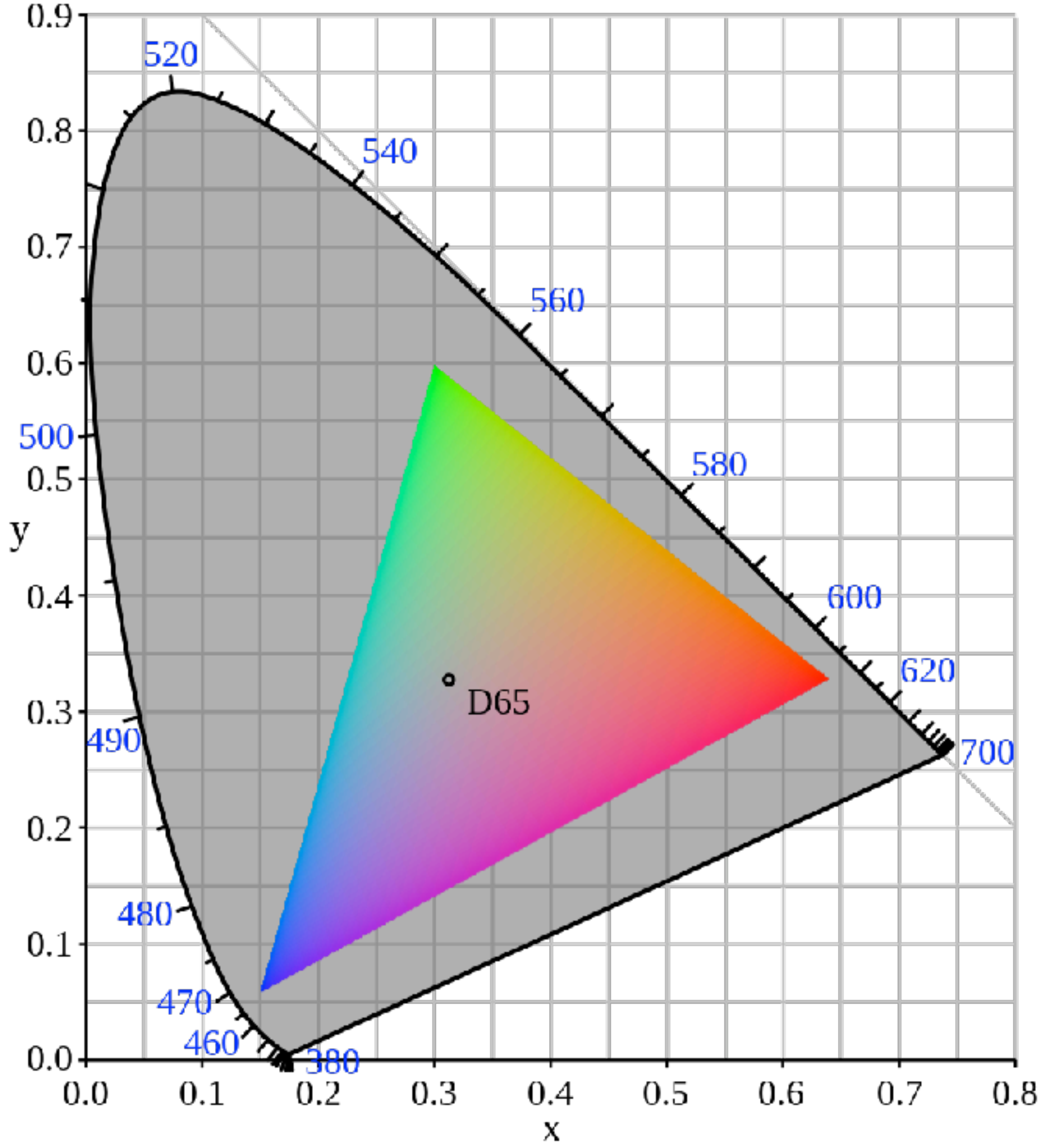
sRGB

Standard colour space for most monitors, printers, and the web

$$\begin{bmatrix} R_{\text{lin}} \\ G_{\text{lin}} \\ B_{\text{lin}} \end{bmatrix} = \begin{bmatrix} +3.2406 & -1.5372 & -0.4986 \\ -0.9689 & +1.8758 & +0.0415 \\ +0.0557 & -0.2040 & +1.0570 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

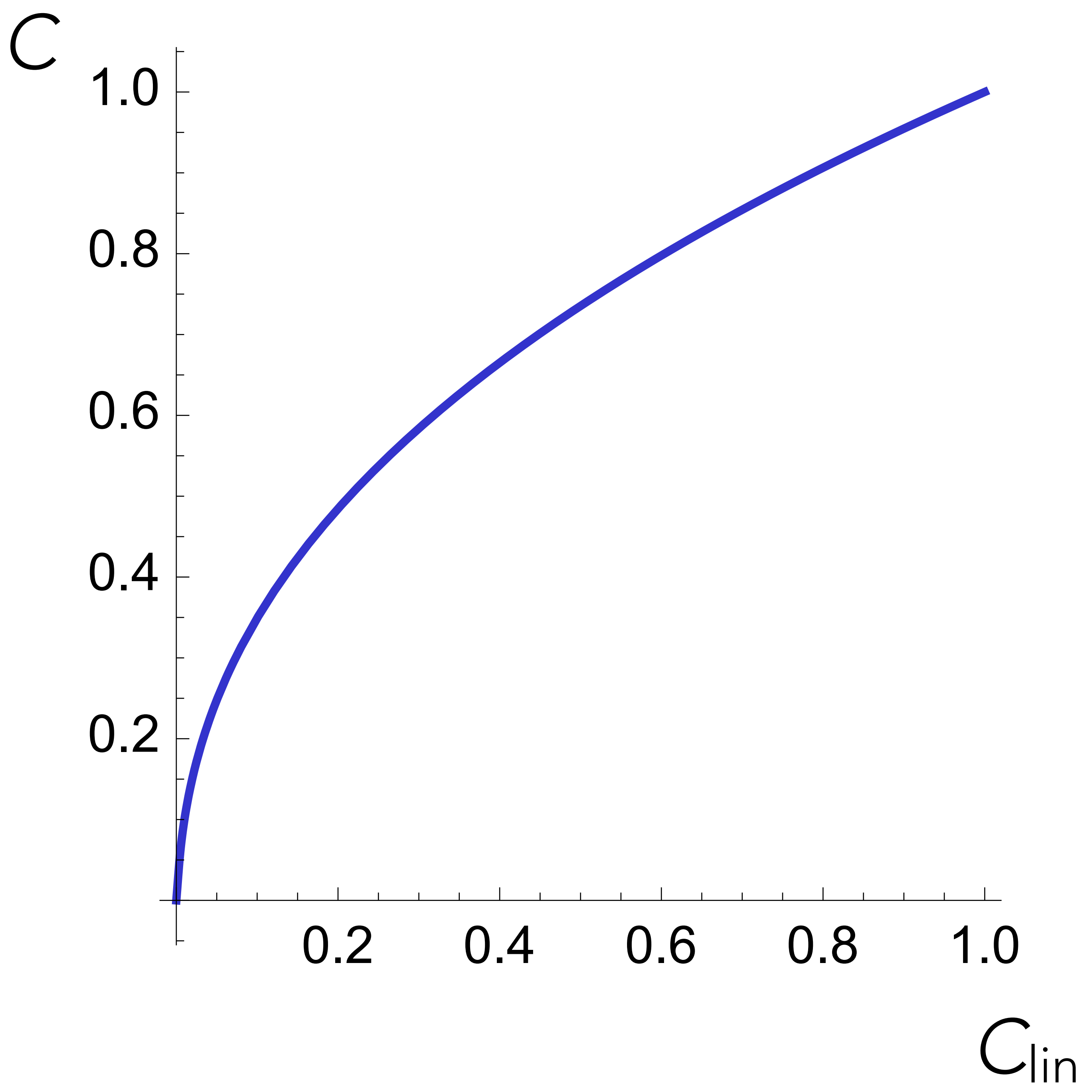
Then for $C = R, G, B$:

$$C = \begin{cases} 12.92 C_{\text{lin}}, & C_{\text{lin}} \leq 0.0031308 \\ 1.055 C_{\text{lin}}^{1/2.4} - 0.055, & C_{\text{lin}} > 0.0031308 \end{cases}$$



$$C = \begin{cases} 12.92 C_{\text{lin}}, & C_{\text{lin}} \leq 0.0031308 \\ 1.055 C_{\text{lin}}^{1/2.4} - 0.055, & C_{\text{lin}} > 0.0031308 \end{cases}$$

Roughly, $C_{\text{lin}} \approx C^{\gamma}$, $C \approx C_{\text{lin}}^{1/\gamma}$ where $\gamma = 2.2$

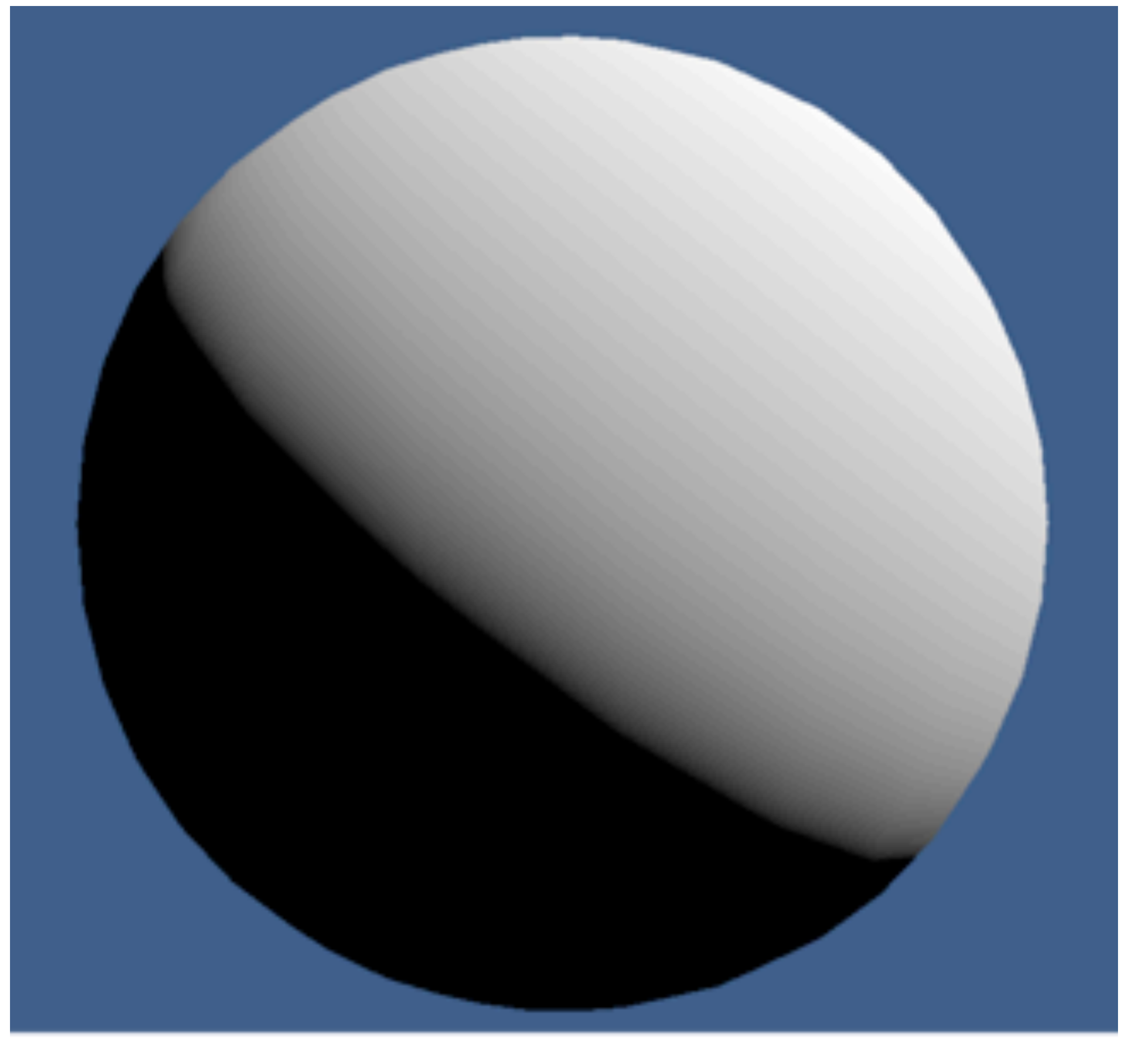


Gamma correction: component values are transformed by a nonlinear function (roughly a power law)

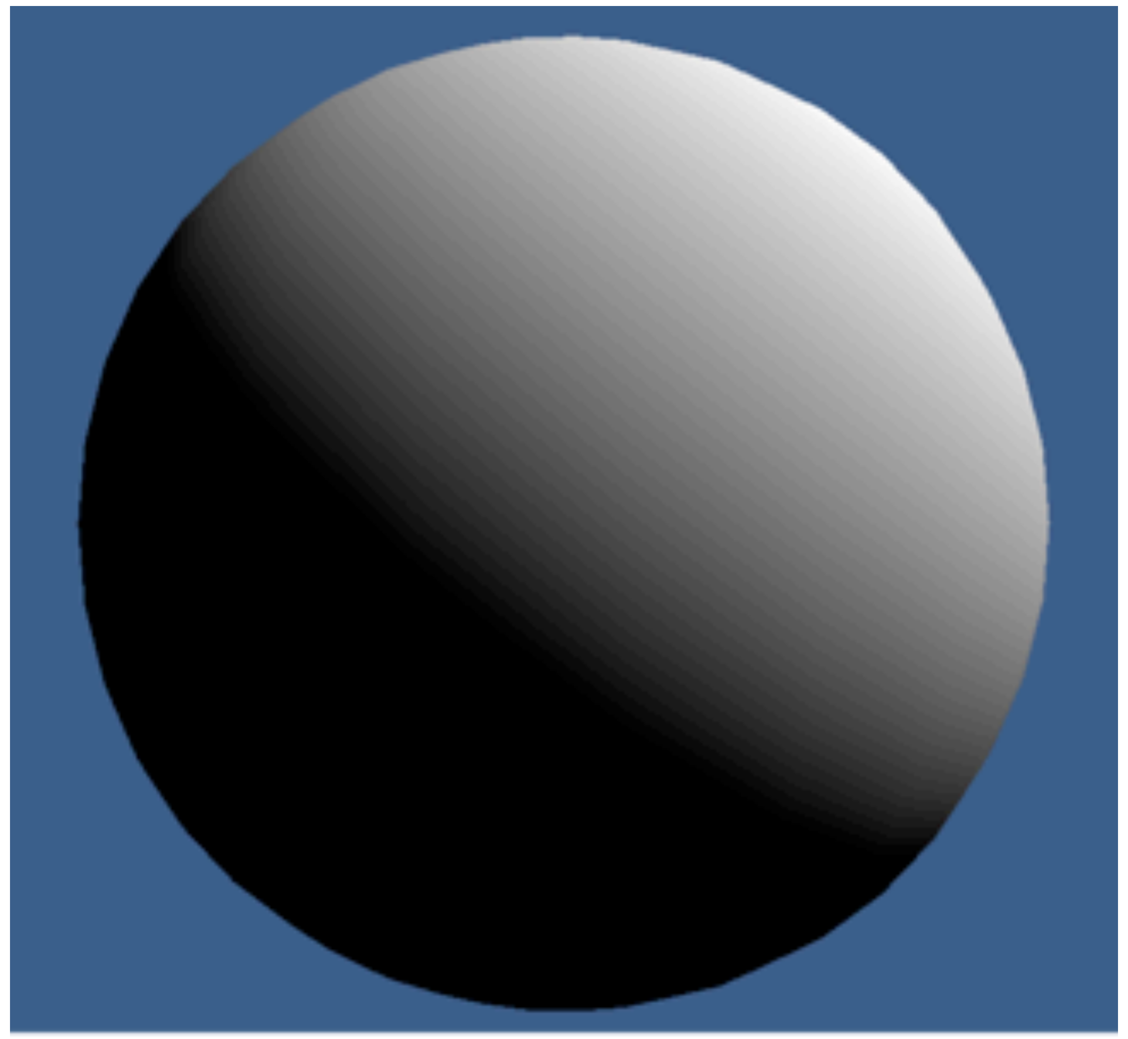
- **Historical reason:** Compensate for CRT displays' nonlinear response to input voltage
- **Current reason:** Better quantization of dark values

What does this mean for graphics?

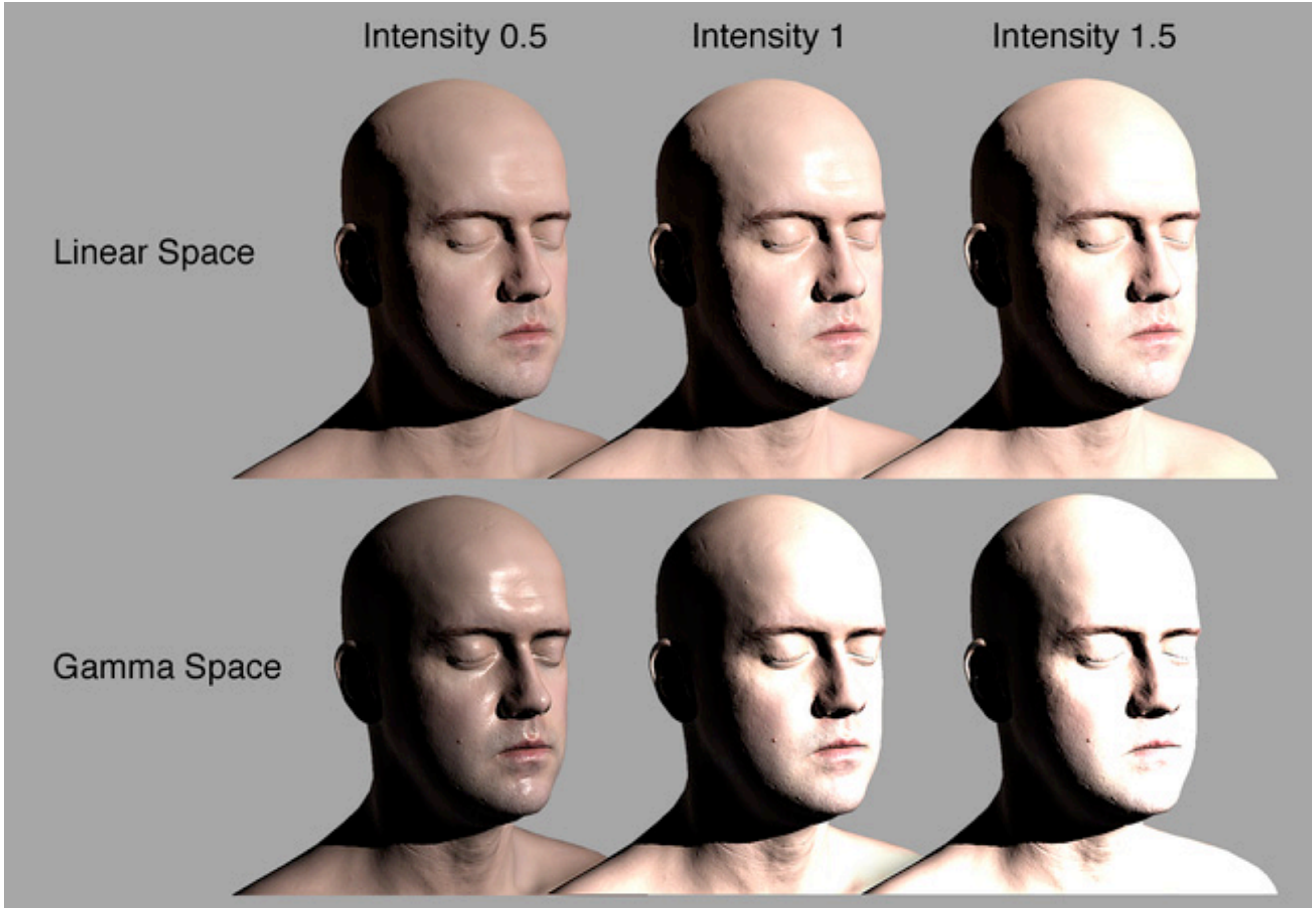
- Colours from user input, texture images, etc. are in "gamma space" C
- Shading computations should be done in linear space $C_{\text{lin}} \approx C^{\gamma}$
- Output image should store colours in gamma space again, $C \approx C_{\text{lin}}^{1/\gamma}$



Linear Space



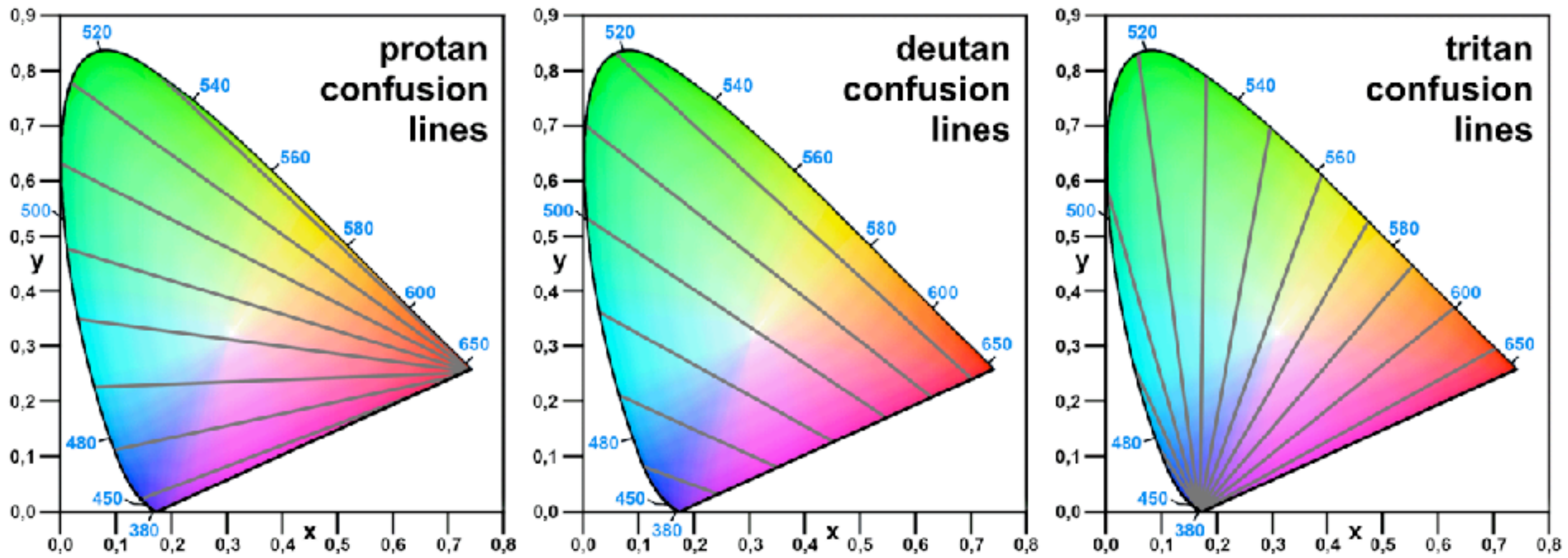
Gamma Space



Unity

Colour blindness

Reduced or no functionality in one (or more) of the three types of cones



Normal vision

Deuteranopia

Tritanopia

Next week: Ray tracing