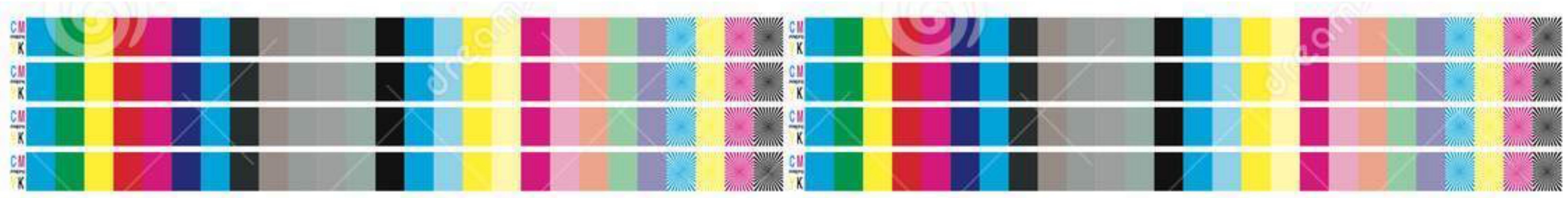
THE UNIVERSITY OF BRITISH COLUMBIA

CPSC 425: Computer Vision



Lecture 12: Color (cont)

(unless otherwise stated slides are taken or adopted from **Bob Woodham, Jim Little** and **Fred Tung**)

Menu for Today (**February 13, 2020**)

Topics:

- Trichromasity
- Colour Spaces
- Scale Invariant Feature Transform (SIFT)
- SIFT detector, descriptor

Readings:

- **Today's** Lecture: Forsyth & Ponce (2nd ed.) 5.4
  "Distinctive Image Features for Scale-Invariant Keypoints
- **Next** Lecture: Forsyth & Ponce (2nd ed.) 10.4.2, 10.1, 10.2

Reminders:

- **Assignment 3**: Texture Synthesis is due on **March 3rd @ 11:59pm**
- **Final** announced: April 17th, 7pm
- **Midterm** is everything up-to and including Color (first-half of today's lecture)

Today’s “**fun**” Example: Recognizing Panoramas

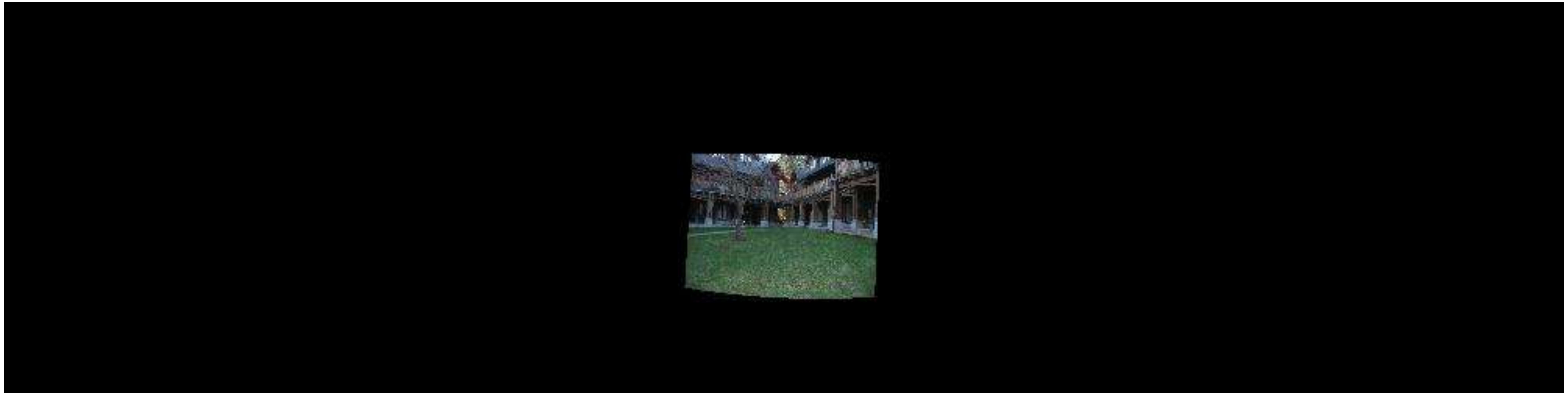


Figure Credit: Matthew Brown and David Lowe

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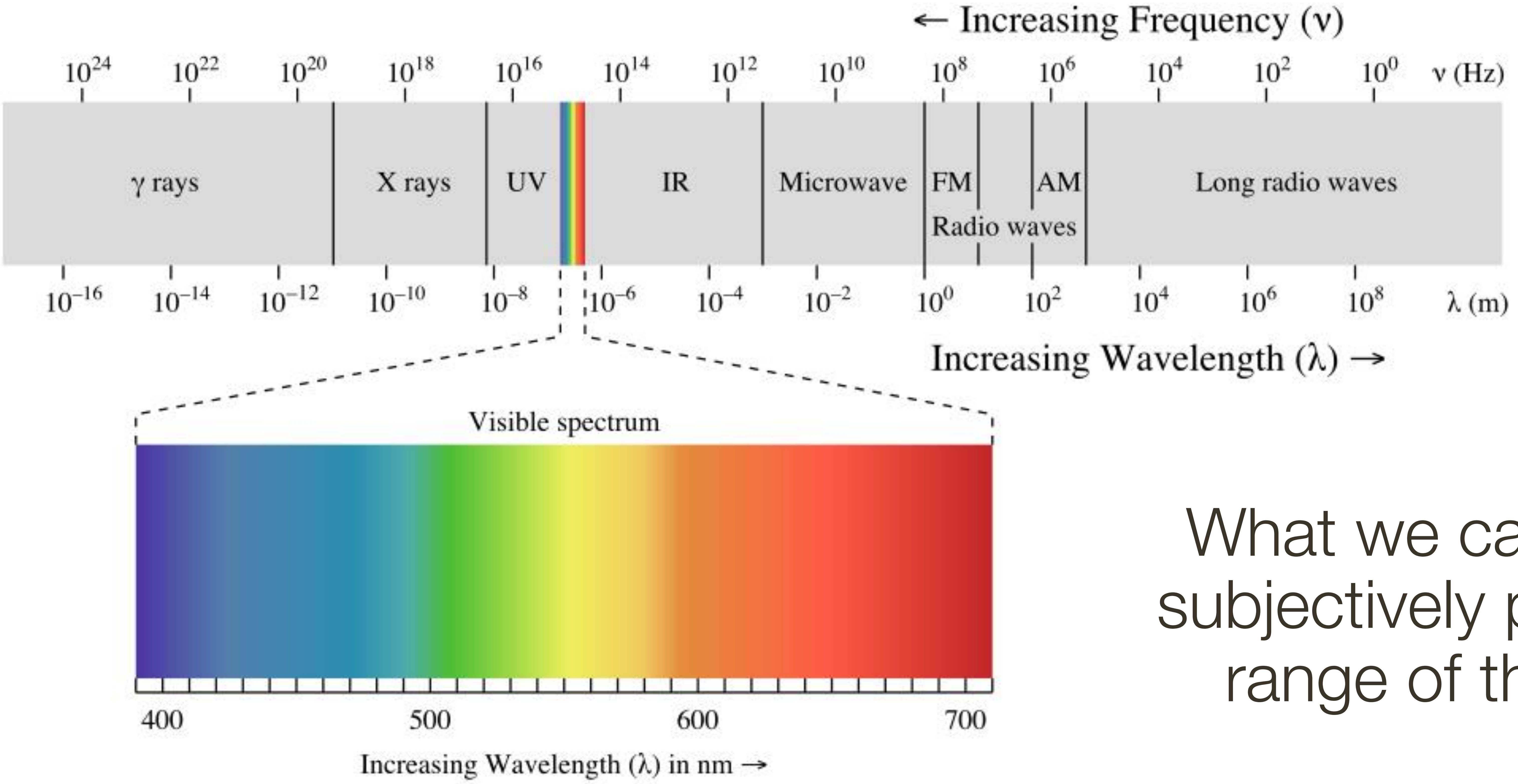
Lecture 11: Re-cap Colour

Visible colors consists of small region of electromagnetic spectrum (visible spectrum) that are perceivable by an eye and interpreted by the brain



electromagnetic spectrum

What we call “color” is how we subjectively perceive a very small range of these wavelengths.

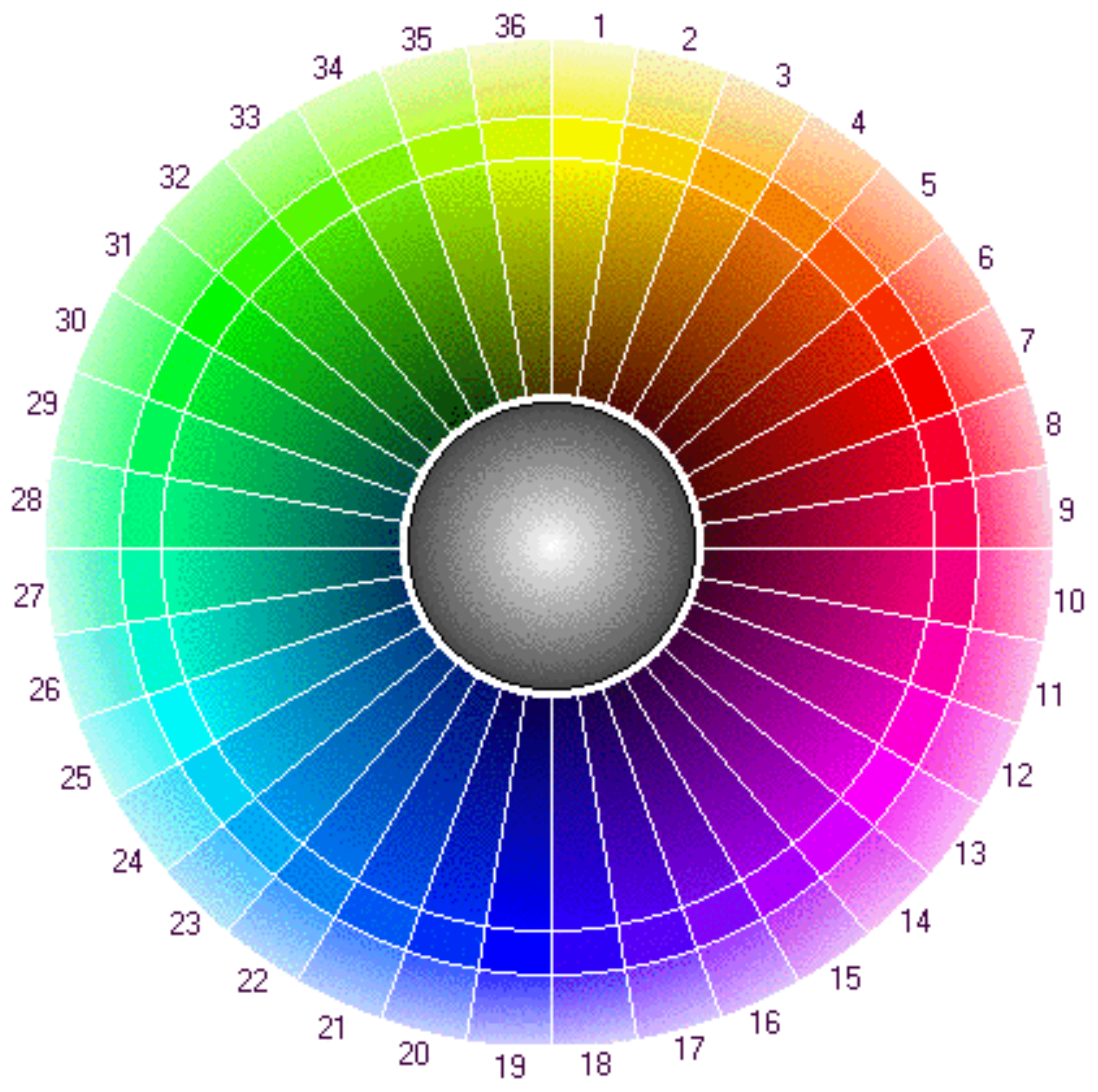
Slide Credit: Ioannis (Yannis) Gkioulekas (CMU)

Lecture 11: Re-cap Colour

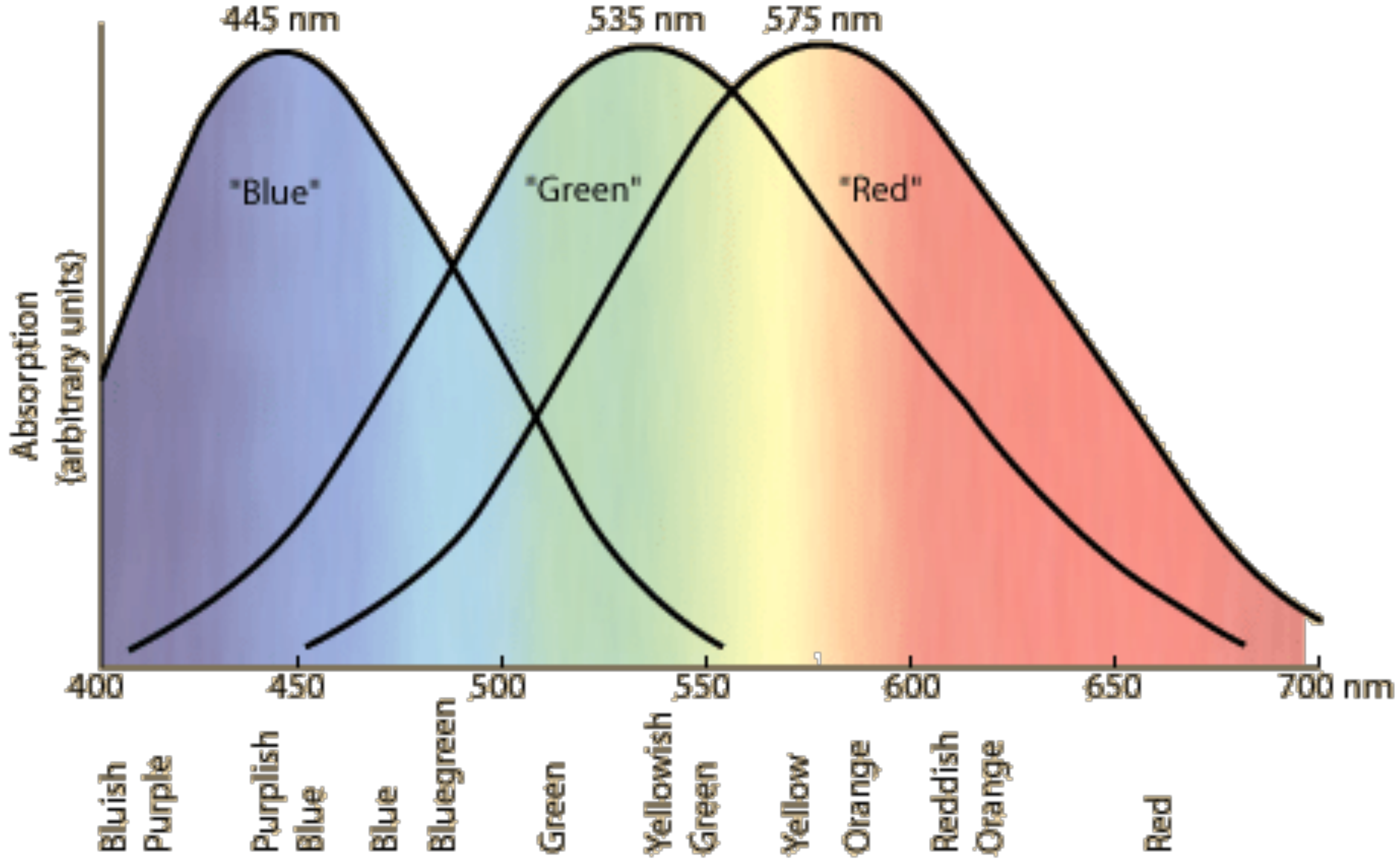
— Light is produced in different amounts at different wavelengths by each light source

— Light is differentially reflected at each wavelength, which gives objects their natural colour (**surface albedo**)

— The sensation of colour is determined by the human visual system, based on the product of light and reflectance

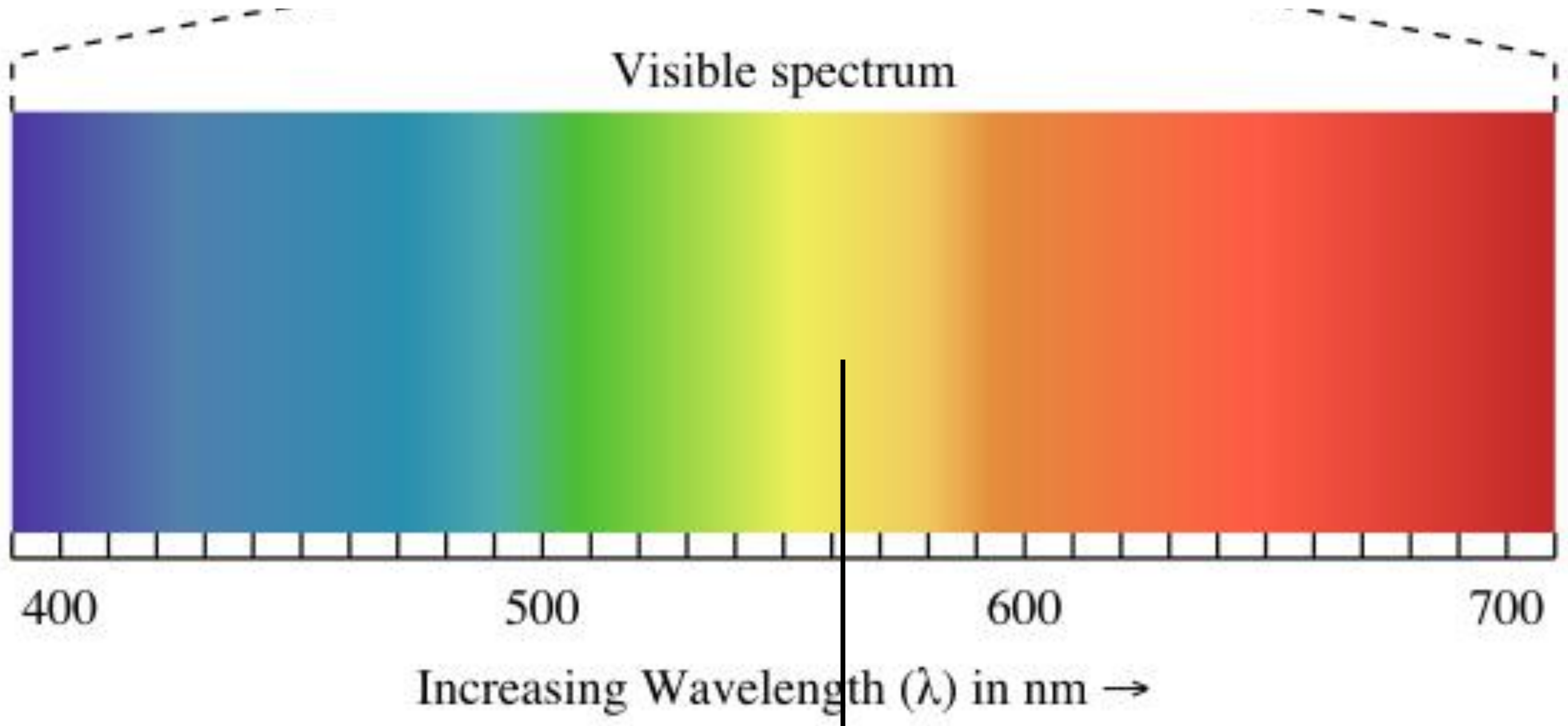


Lecture 11: Human Cone Perception

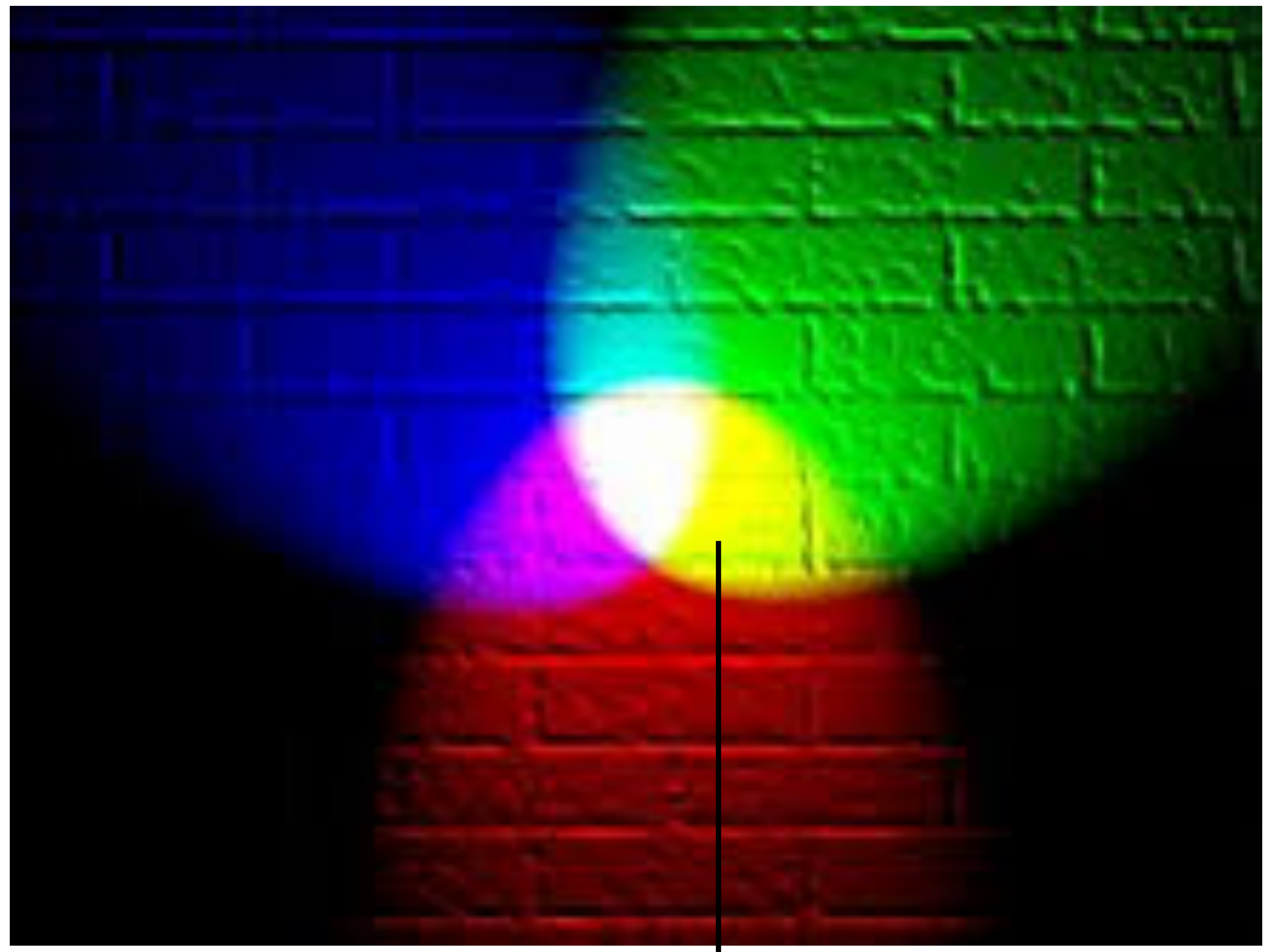


http://hyperphysics.phy-astr.gsu.edu/hbase/vision/colcon.html

Lecture 11: Color Matching



Pure Color
(580 nm)

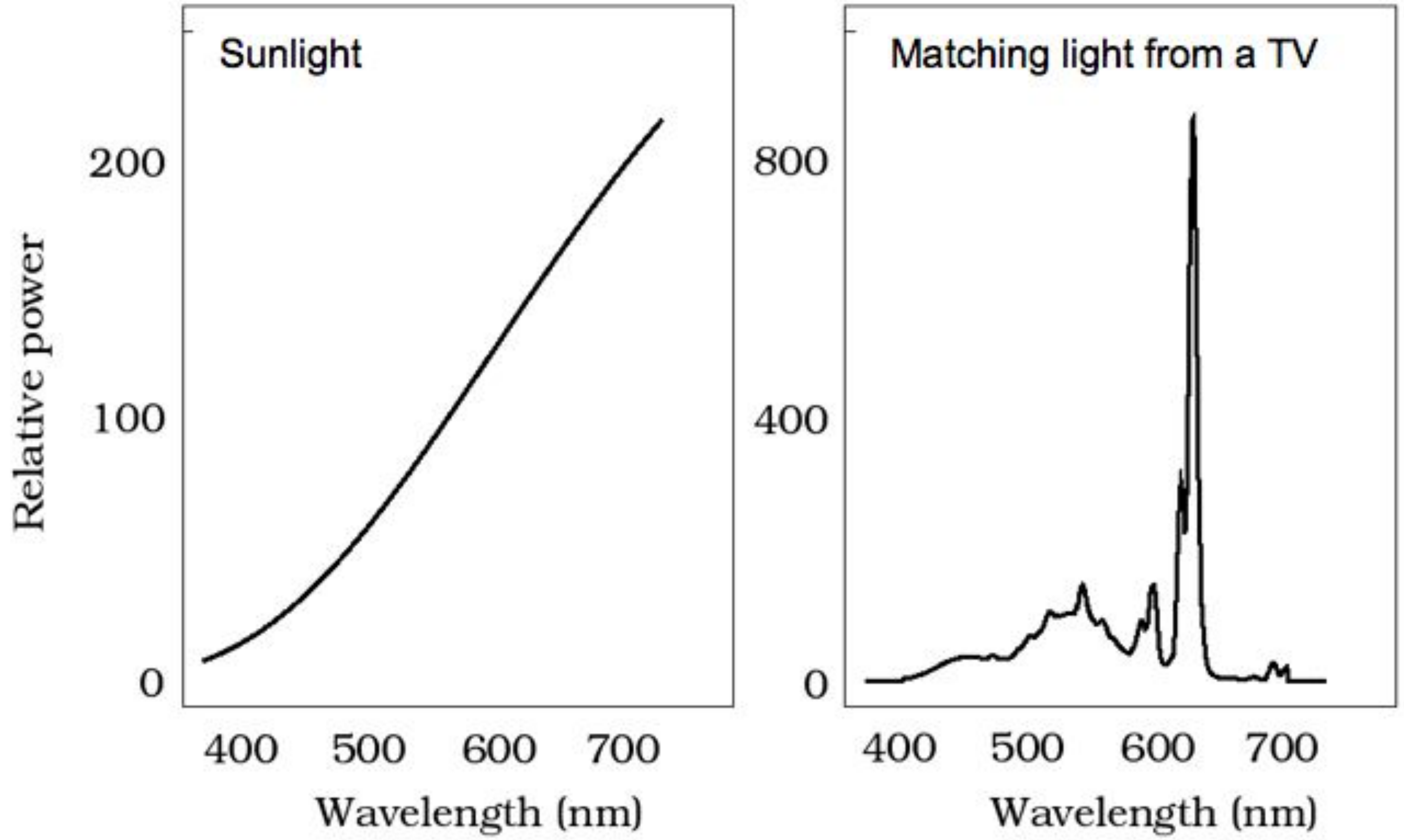


Additively Mixing
Primary Colors

Red - 700nm
Green - 546nm
Blue - 435nm

Lecture 11: Metametric Lights

Two lights whose spectral power distributions appear identical to most observers are called **metamers**.



(A) A tungsten bulb (B) TV monitor set to match (A)

Figure credit: Brian Wandell, Foundations of Vision, Sinauer Associates, 1995

Color Matching Experiments

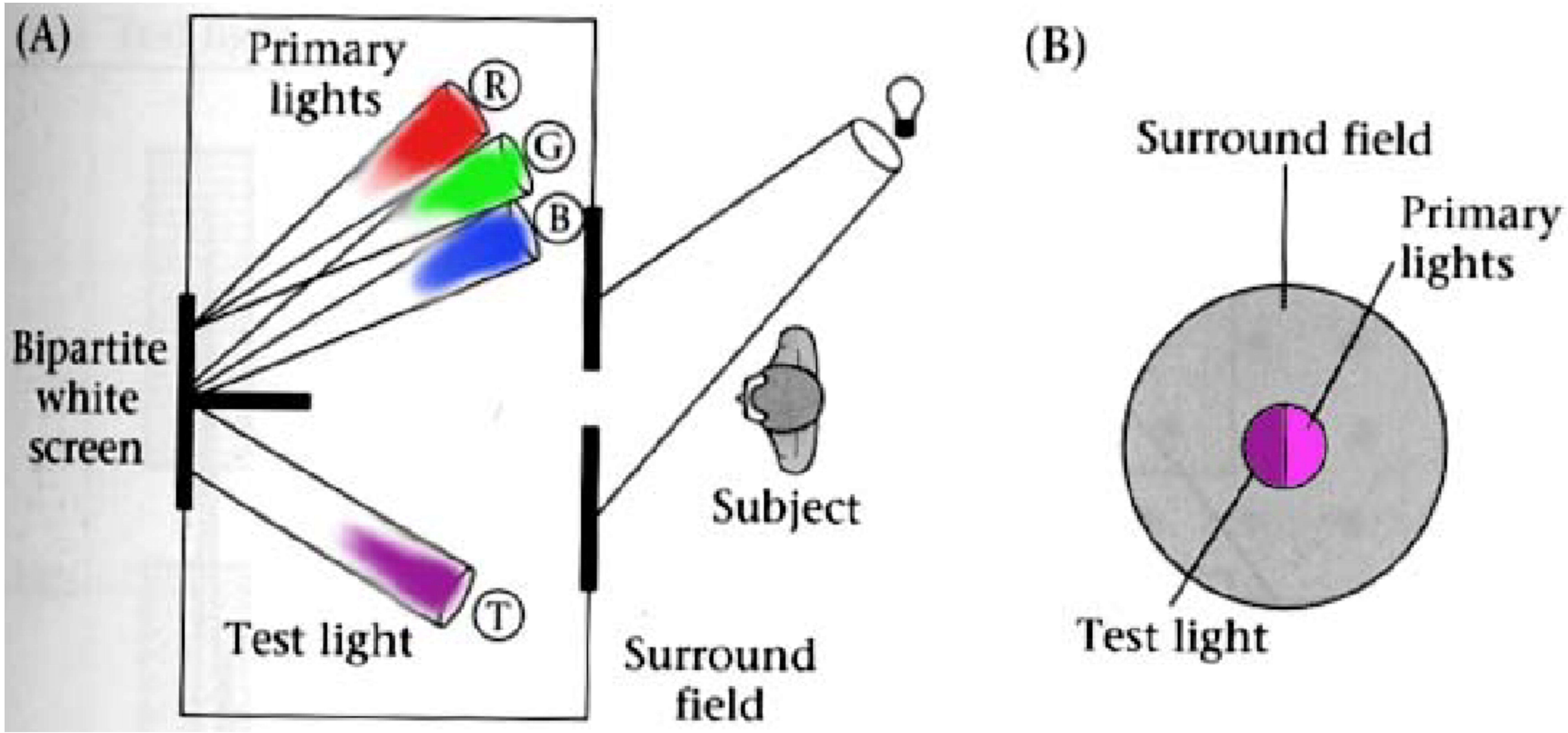


Figure Credit: Brian Wandell, Foundations of Vision, Sinauer Associates, 1995

Grassman's Laws

For colour matches:

— **symmetry**: $U = V \Leftrightarrow V = U$

— **transitivity**: $U = V \quad \text{and} \quad V = W \Rightarrow U = W$

— **proportionality**: $U = V \Leftrightarrow tU = tV$

— **additivity**: if any two of the statements are true, then so is the third

$$\begin{aligned} U &= V, \\ W &= X, \\ (U + W) &= (V + X) \end{aligned}$$

These statements mean that colour matching is, to an accurate approximation, linear.

Additive vs. **Subtractive** Mixing

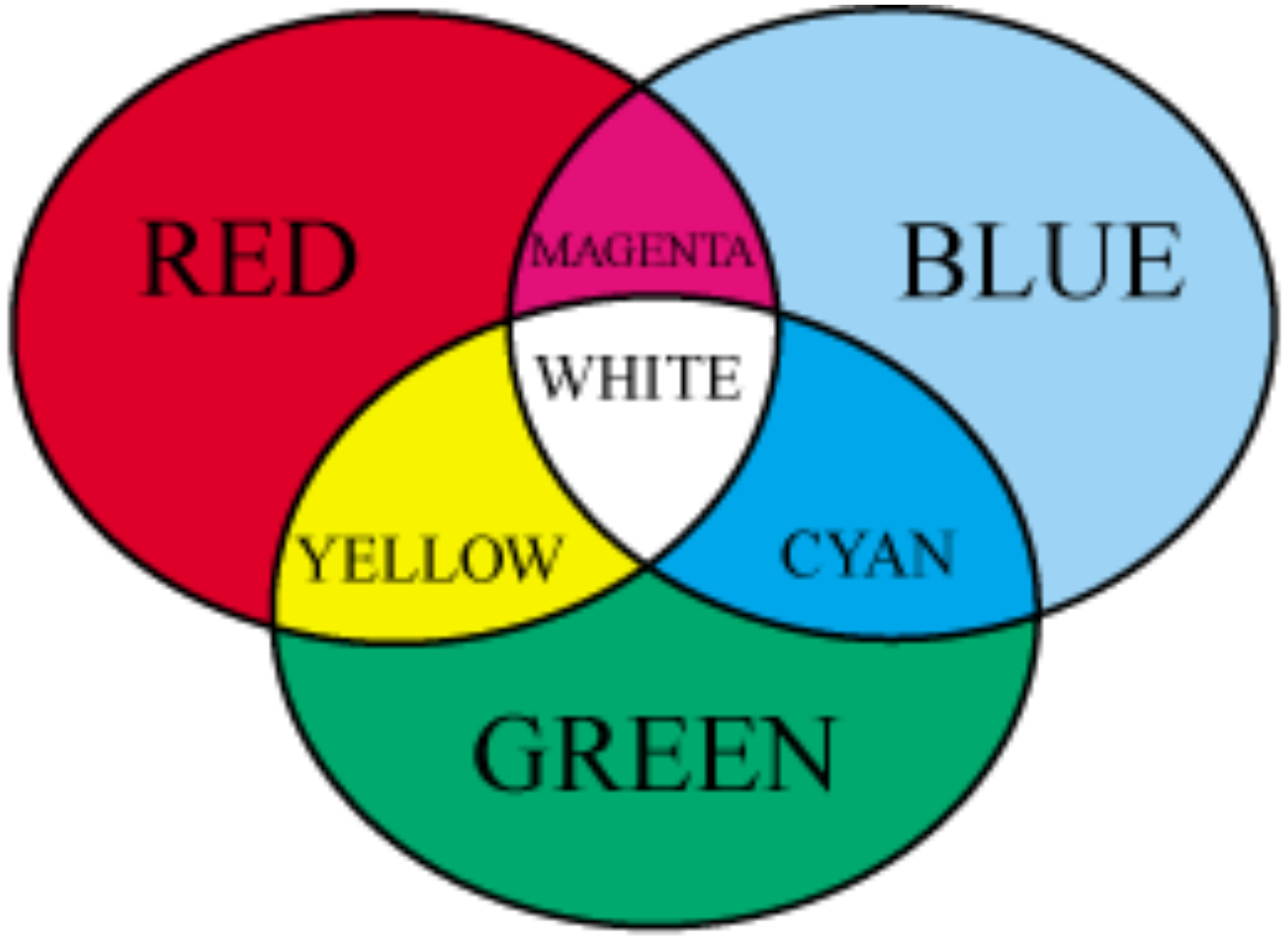


Fig. 2.4.3a - Additive Mixing

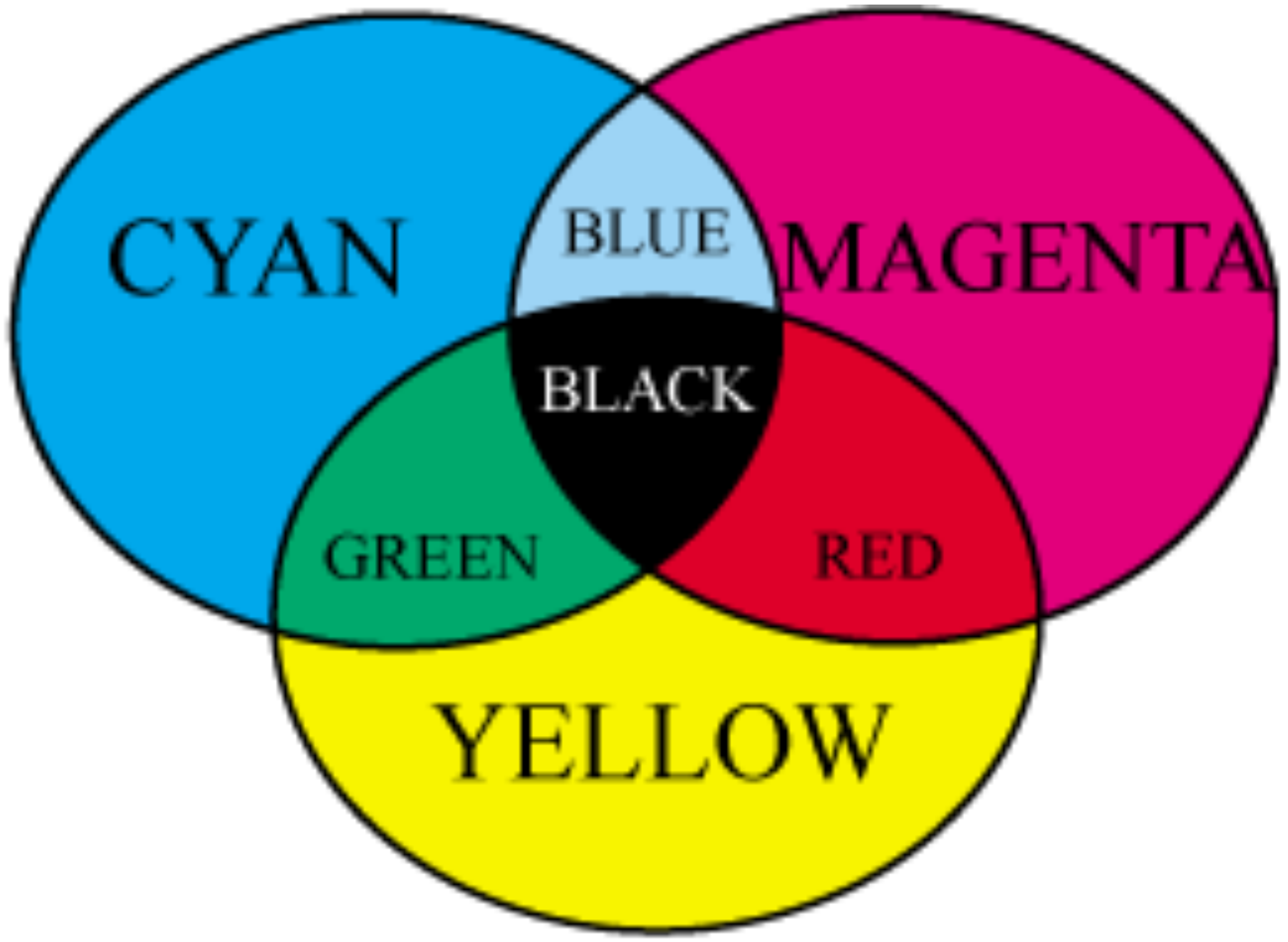


Fig. 2.4.3b - Simple Subtractive Mixing

Representing Colour

— Describing colours accurately is of practical importance (e.g. Manufacturers are willing to go to a great deal of trouble to ensure that different batches of their product have the same colour)

— This requires a standard system for representing colour.

Linear Color Spaces

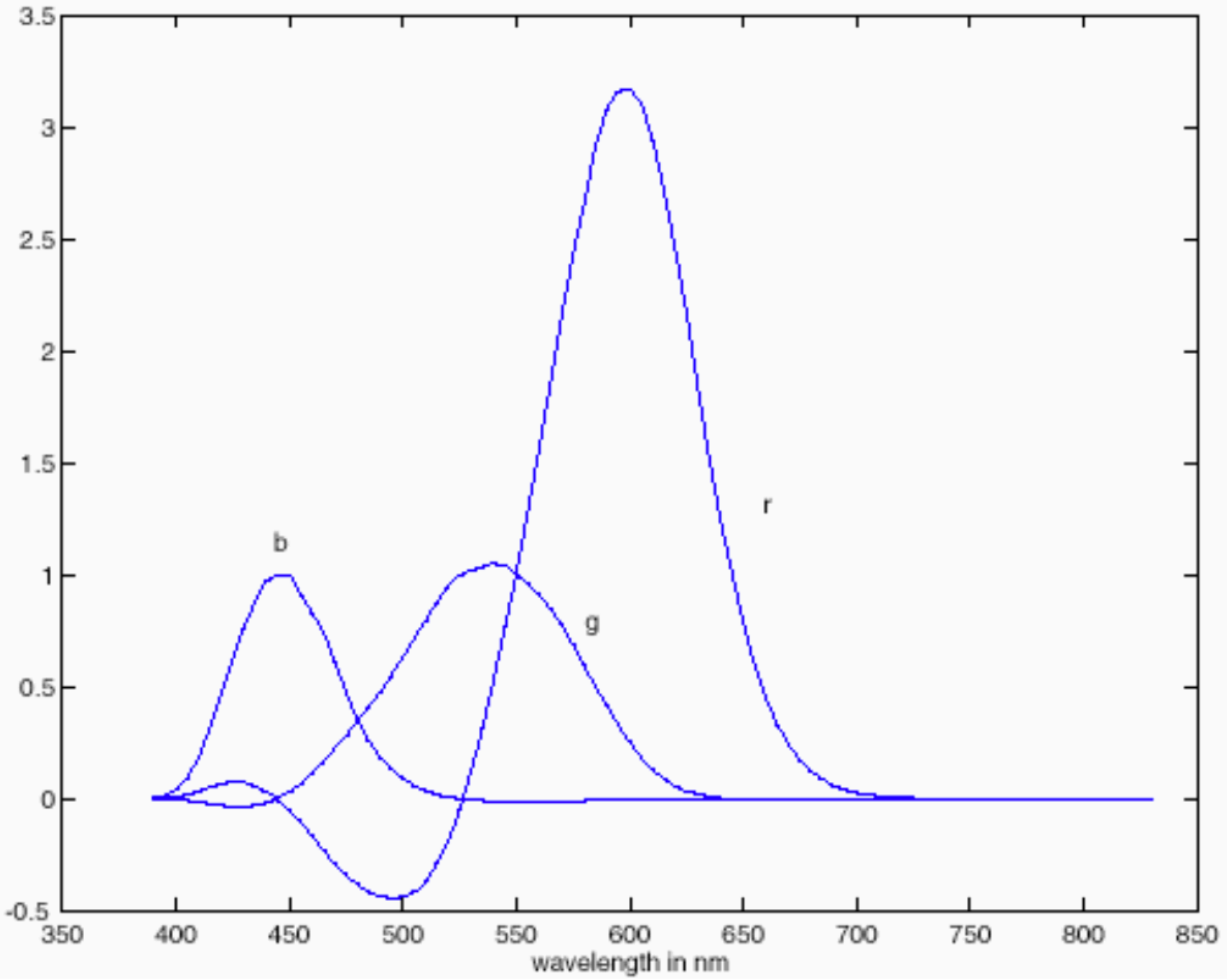
A choice of primaries yields a linear colour space
— the coordinates of a colour are given by the weights of the primaries used to match it

Choice of primaries is equivalent to choice of colour space

— **RGB**: Primaries are monochromatic energies, say 645.2 nm, 526.3 nm, 444.4 nm

— **CIE XYZ**: Primaries are imaginary, but have other convenient properties. Colour coordinates are (X , Y , Z), where X is the amount of the X primary, etc.

RGB Colour Matching Functions



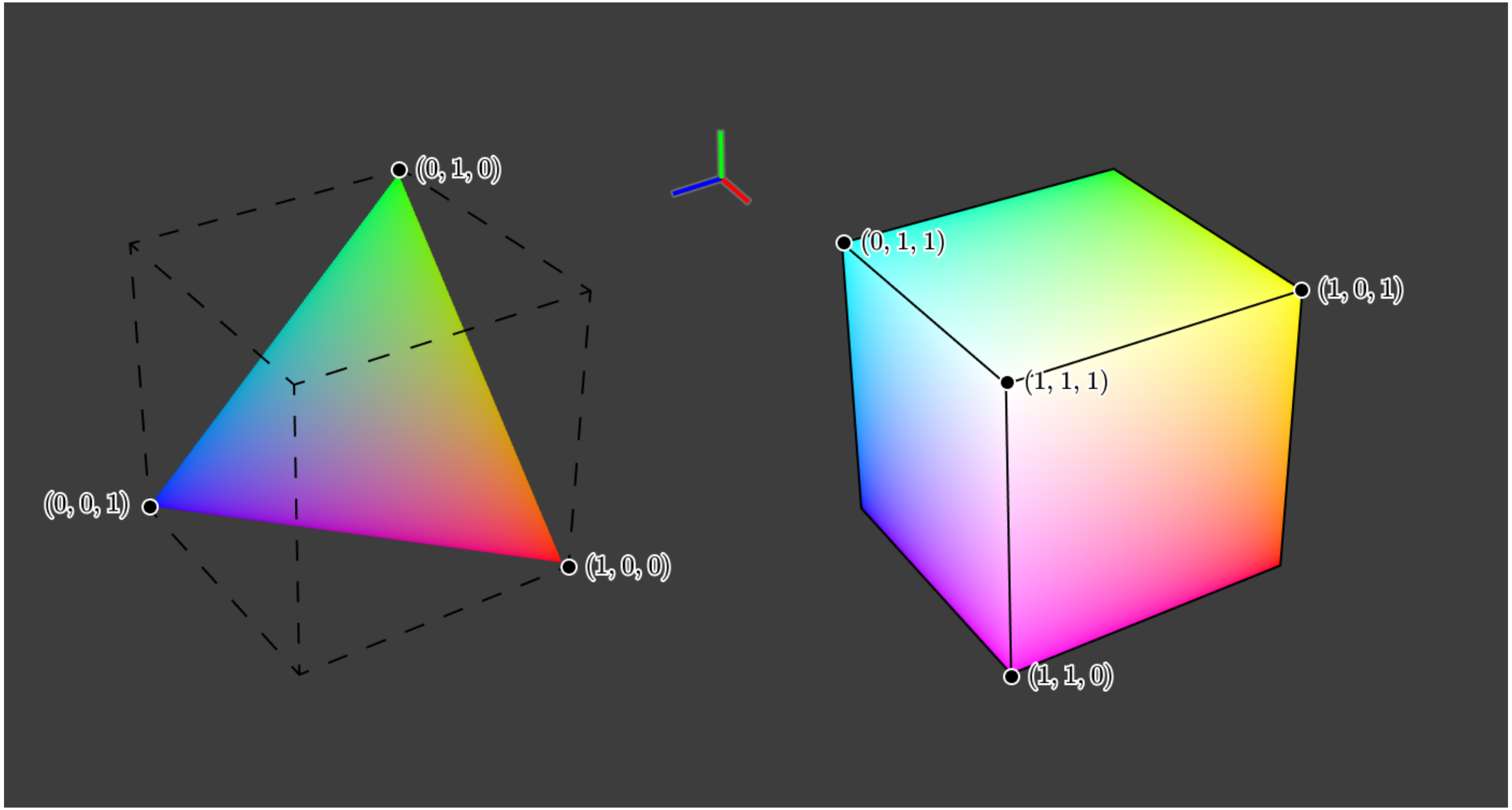
Forsyth & Ponce (2nd ed.) Figure 3.9

— Primaries monochromatic

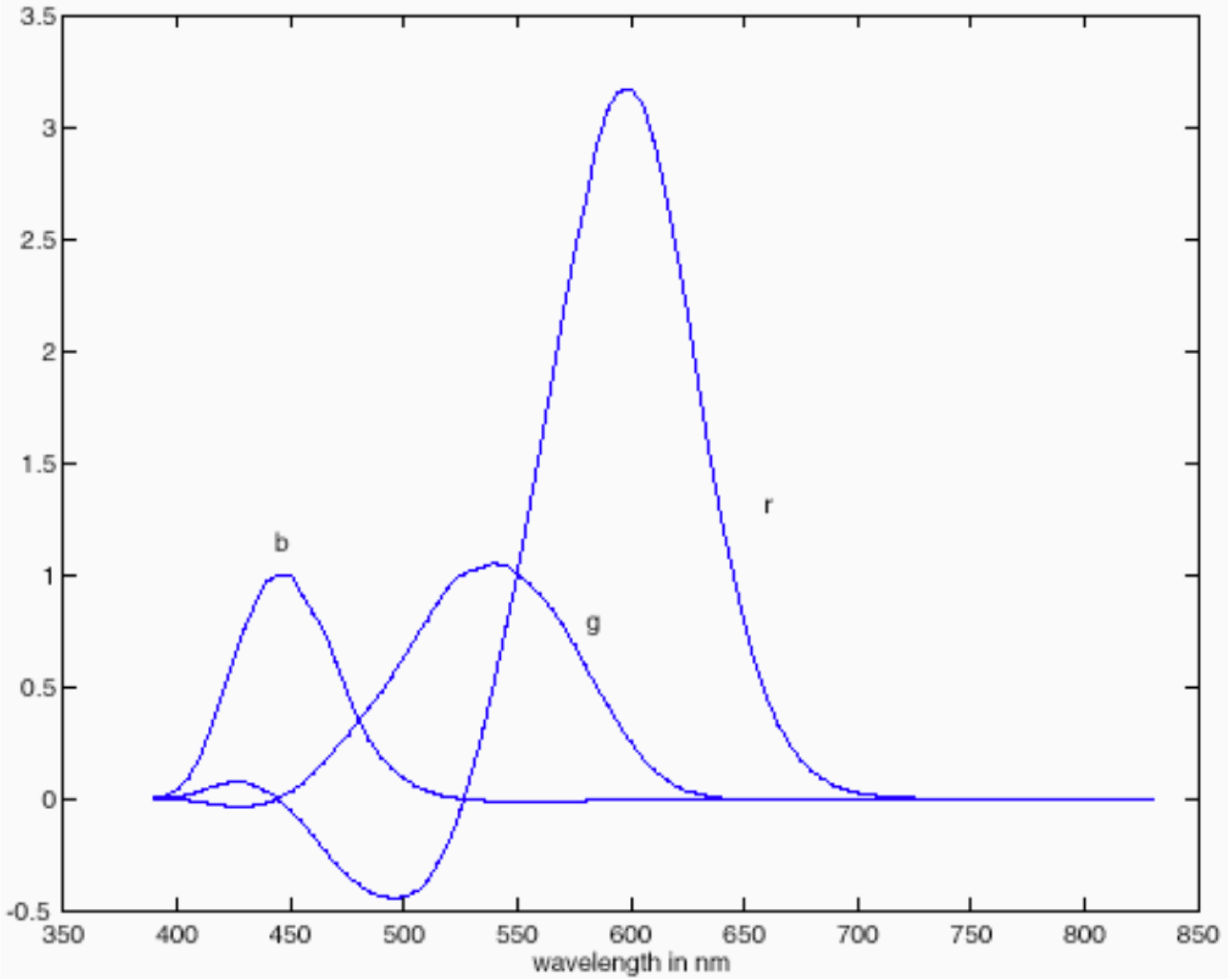
— Wavelengths 645.2, 526.3 and 444.4 nm

— Negative parts means some colours can be matched only subtractively

RGB Color Space



RGB Colour Matching Functions



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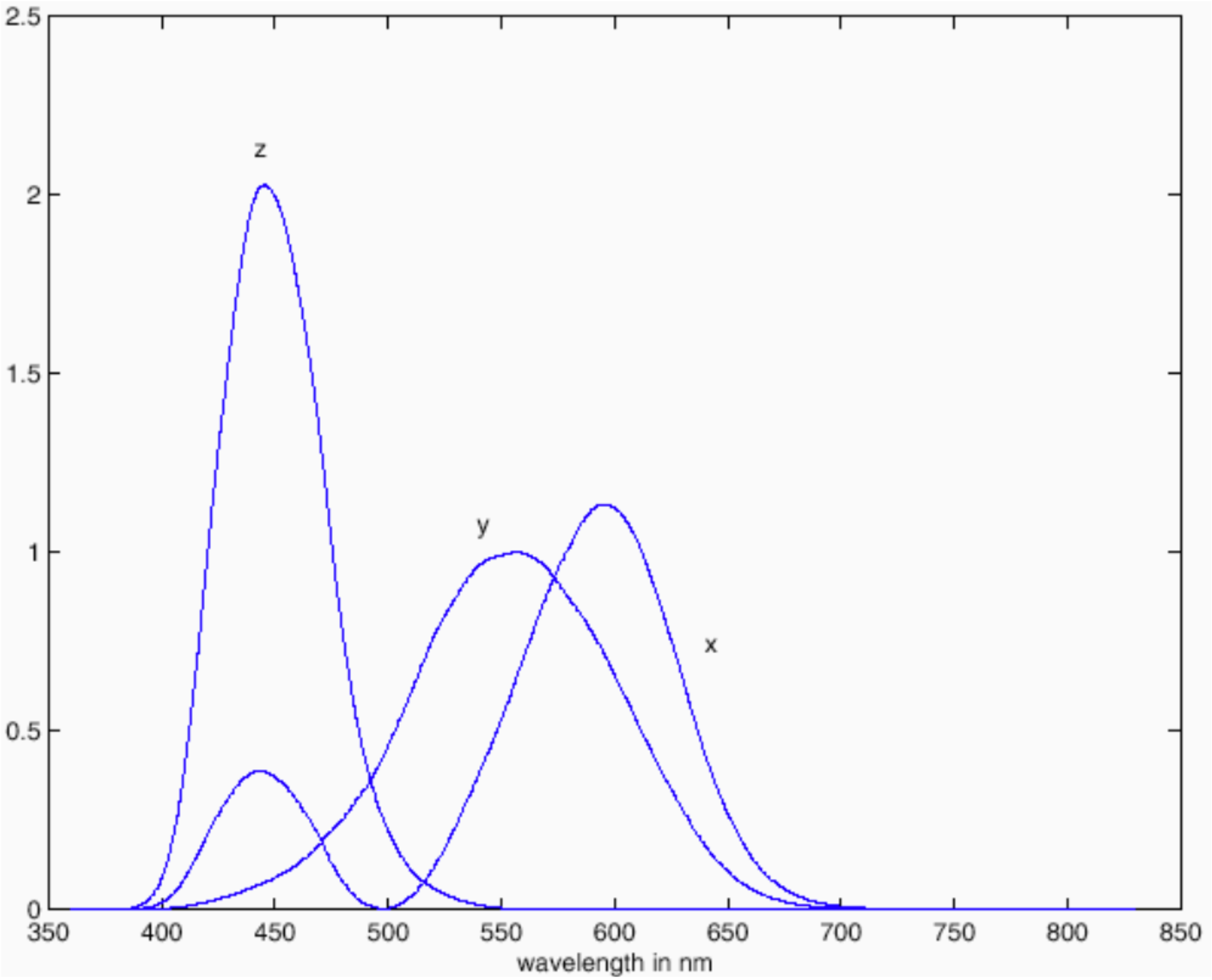


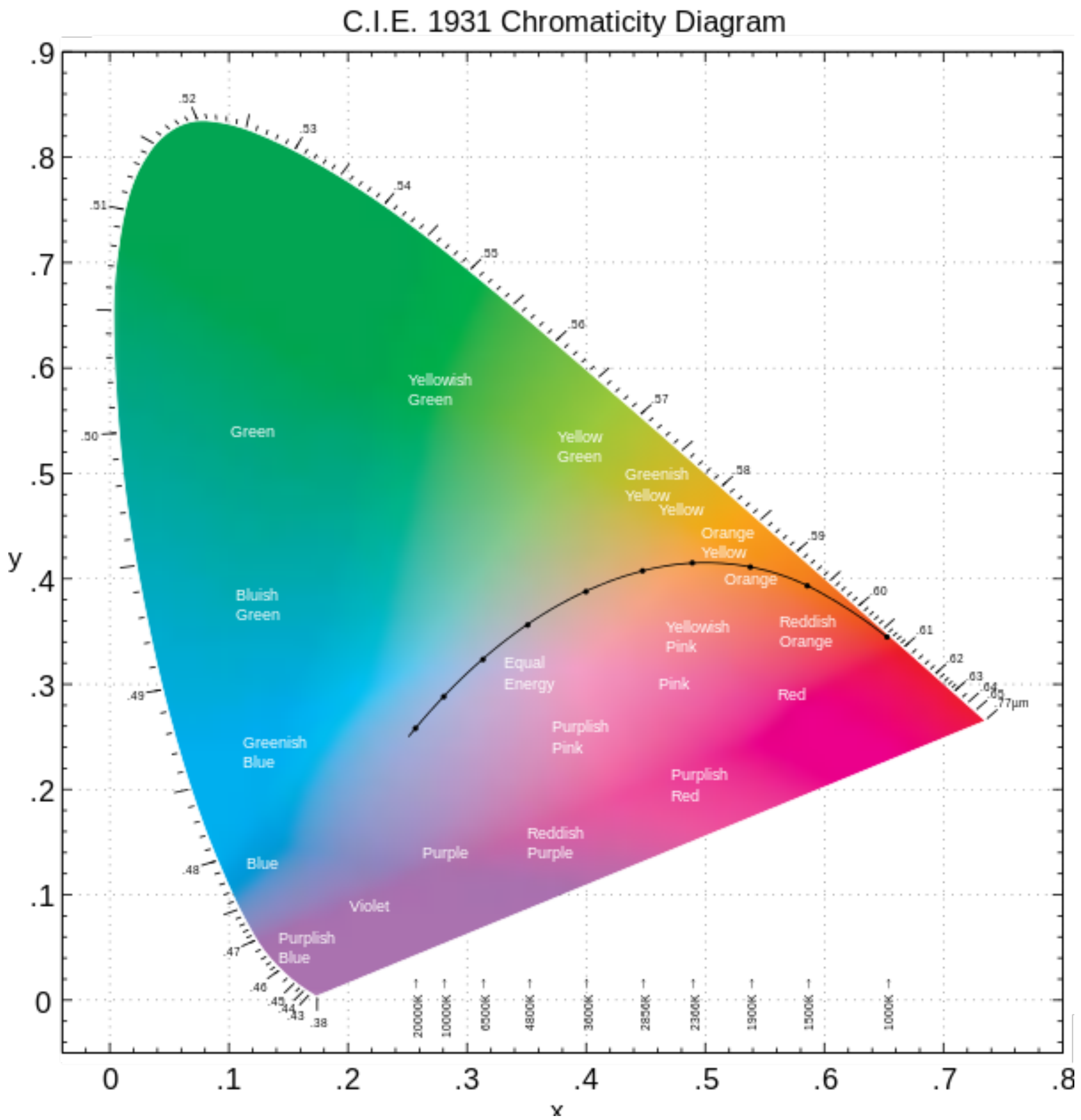
Forsyth & Ponce (2nd ed.) Figure 3.8

CIE XYZ: Colour matching functions are positive everywhere, but primaries are imaginary. Usually draw x, y, where

$$x = X/(X + Y + Z)$$
$$y = Y/(X + Y + Z)$$

Overall brightness is ignored

Geometry of Colour (CIE)



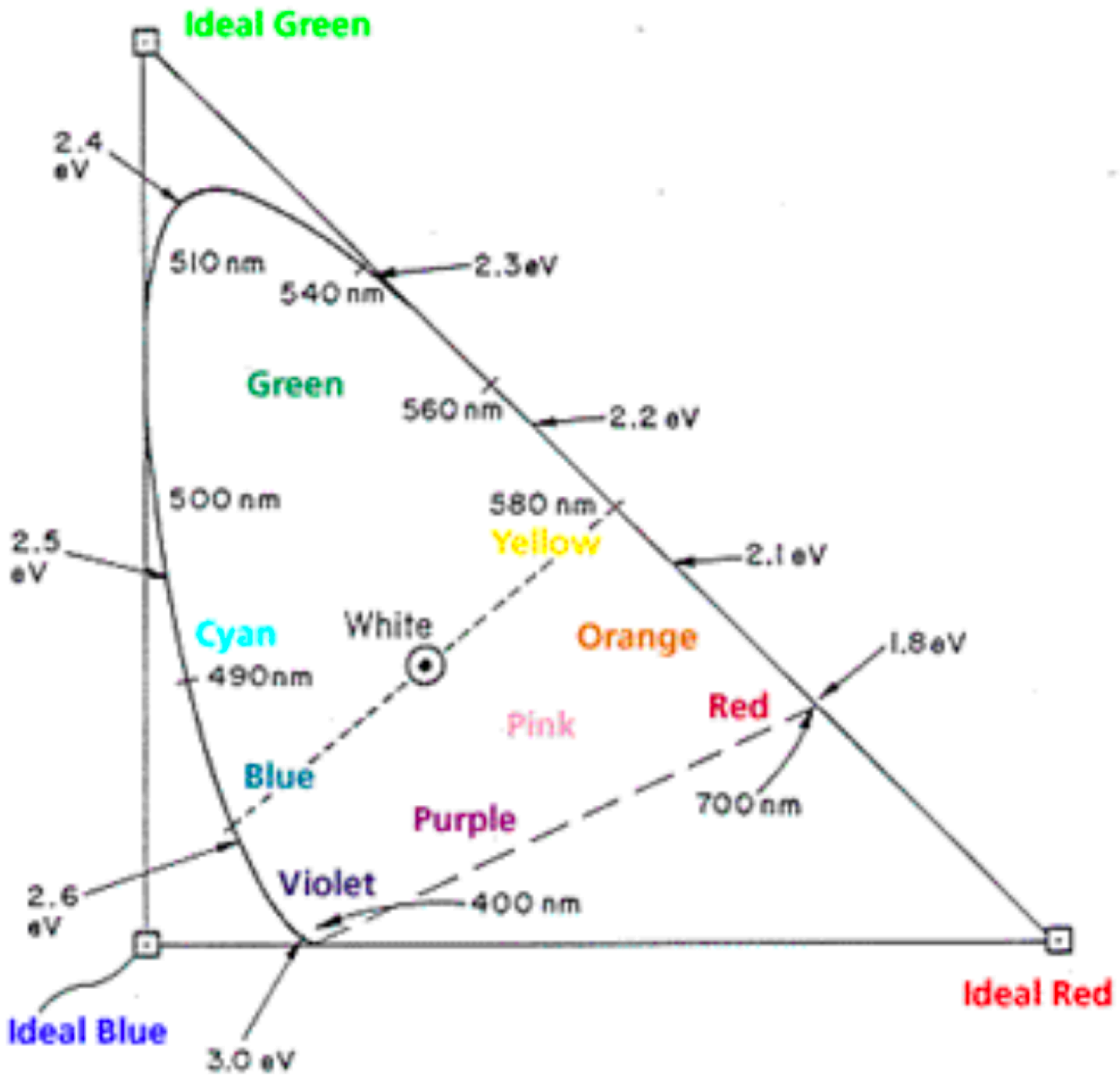
— White is in the center, with saturation increasing towards the boundary

— Mixing two coloured lights creates colours on a straight line

— Mixing 3 colours creates colours within a triangle

— Curved edge means there are no 3 actual lights that can create all colours that humans perceive!

Geometry of Colour (CIE)



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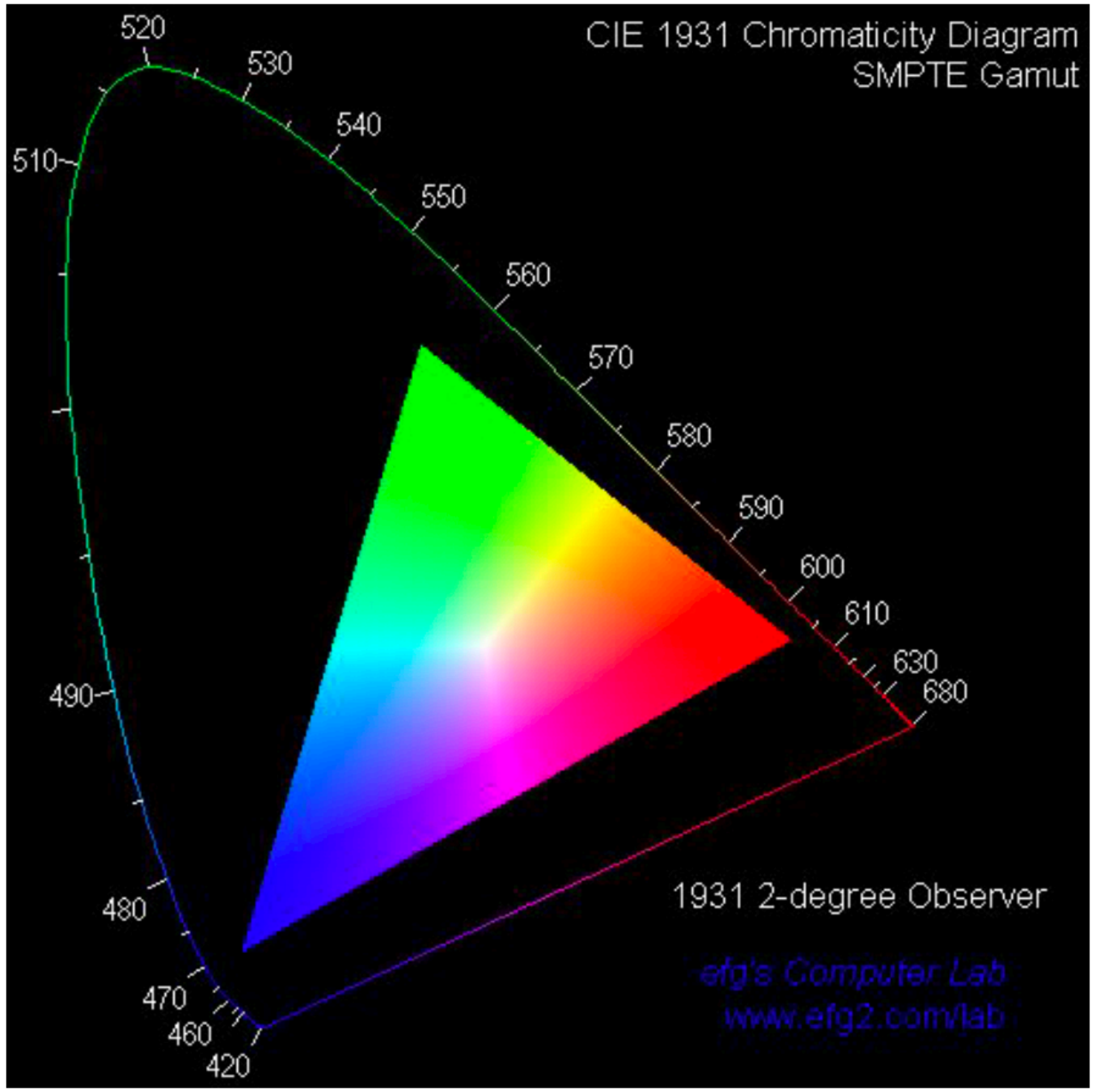
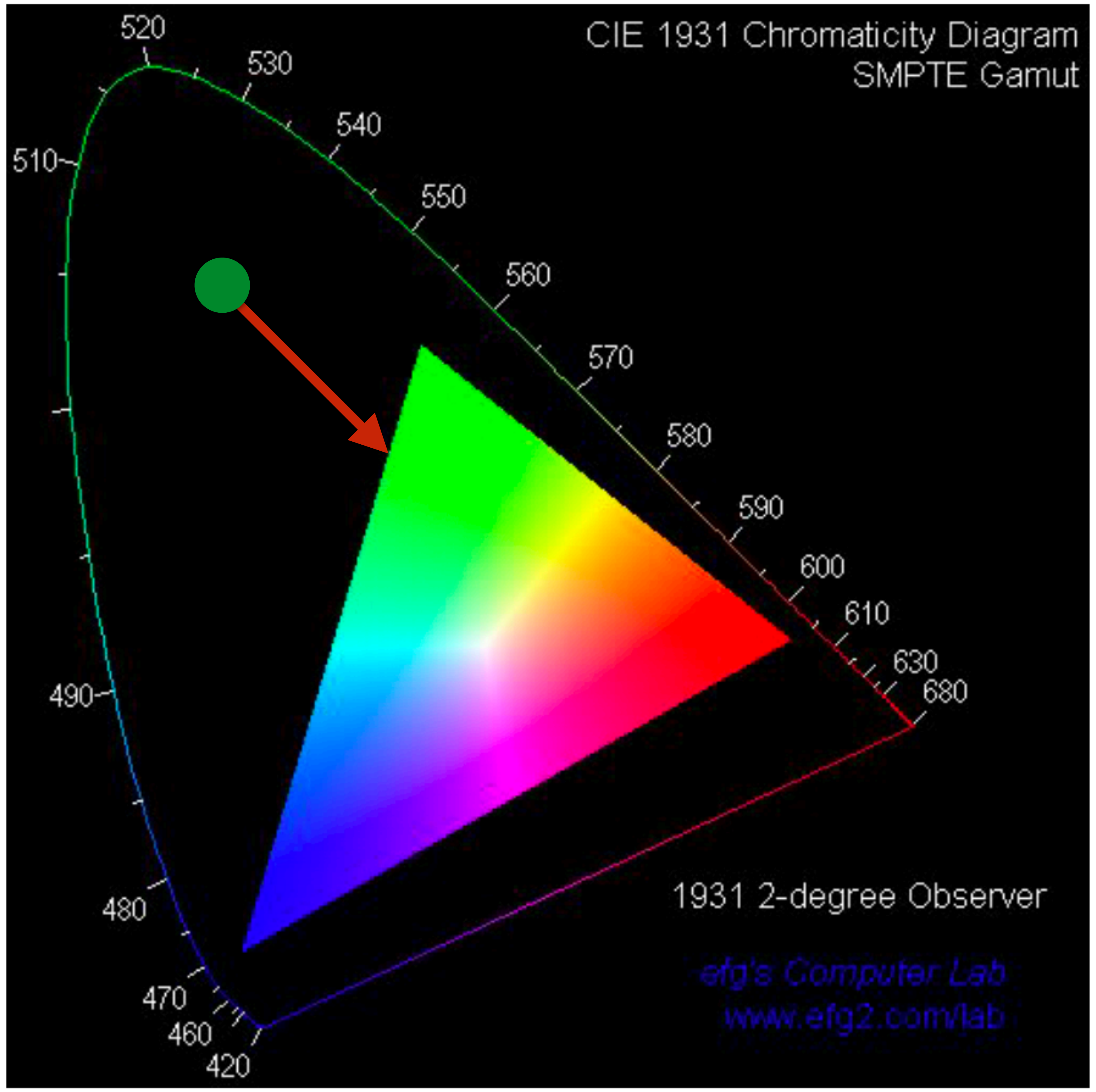
RGB Colour Space



The sub-space of CIE colours that can be displayed on a typical computer monitor (phosphor limitations keep the space quite small)

RGB Colour Space



Adding **red** to the green color outside of the region brings it back to where it can be matched by **green** and **blue** RGB primaries

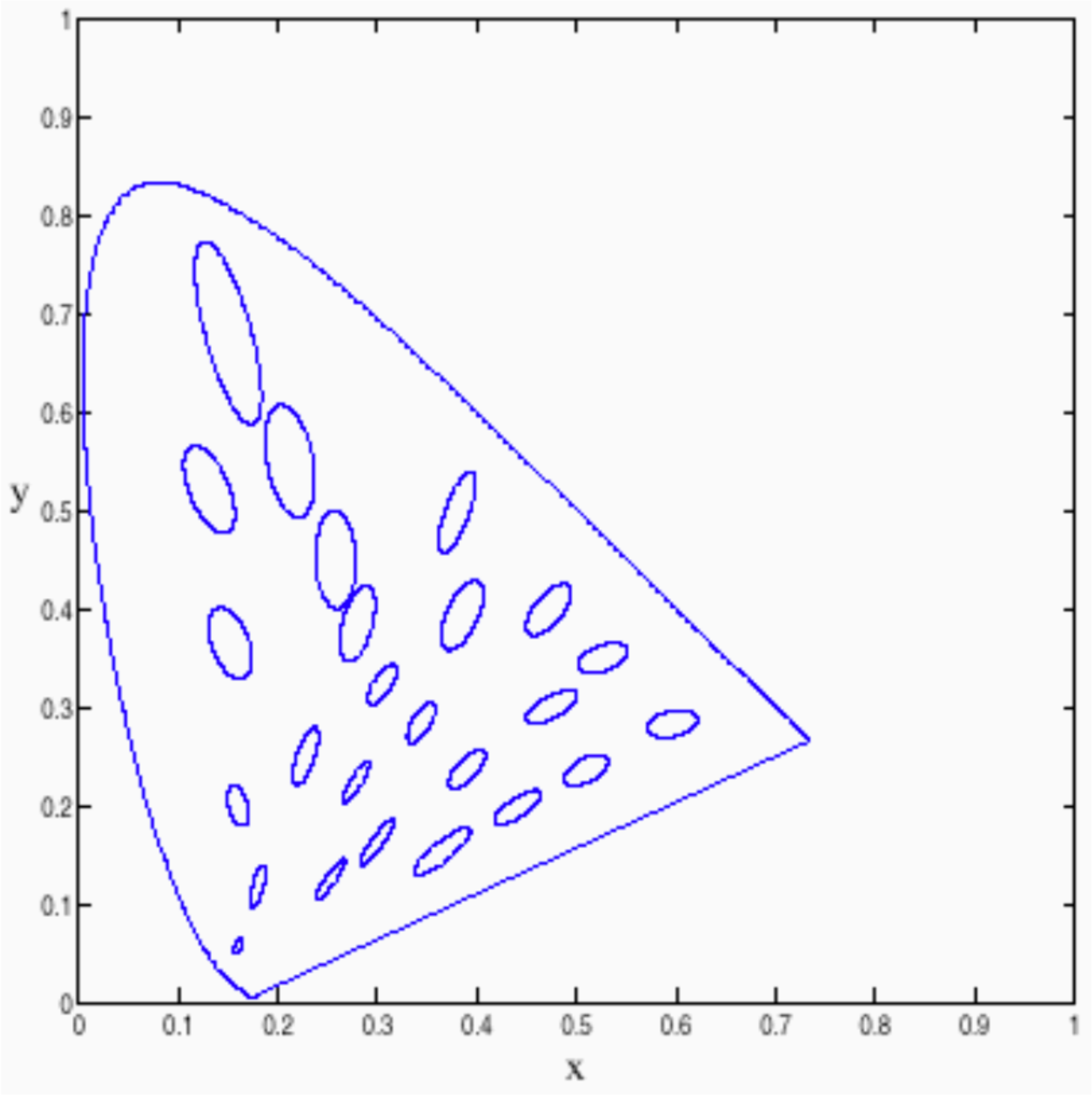
Uniform Colour Spaces

Usually one cannot reproduce colours exactly

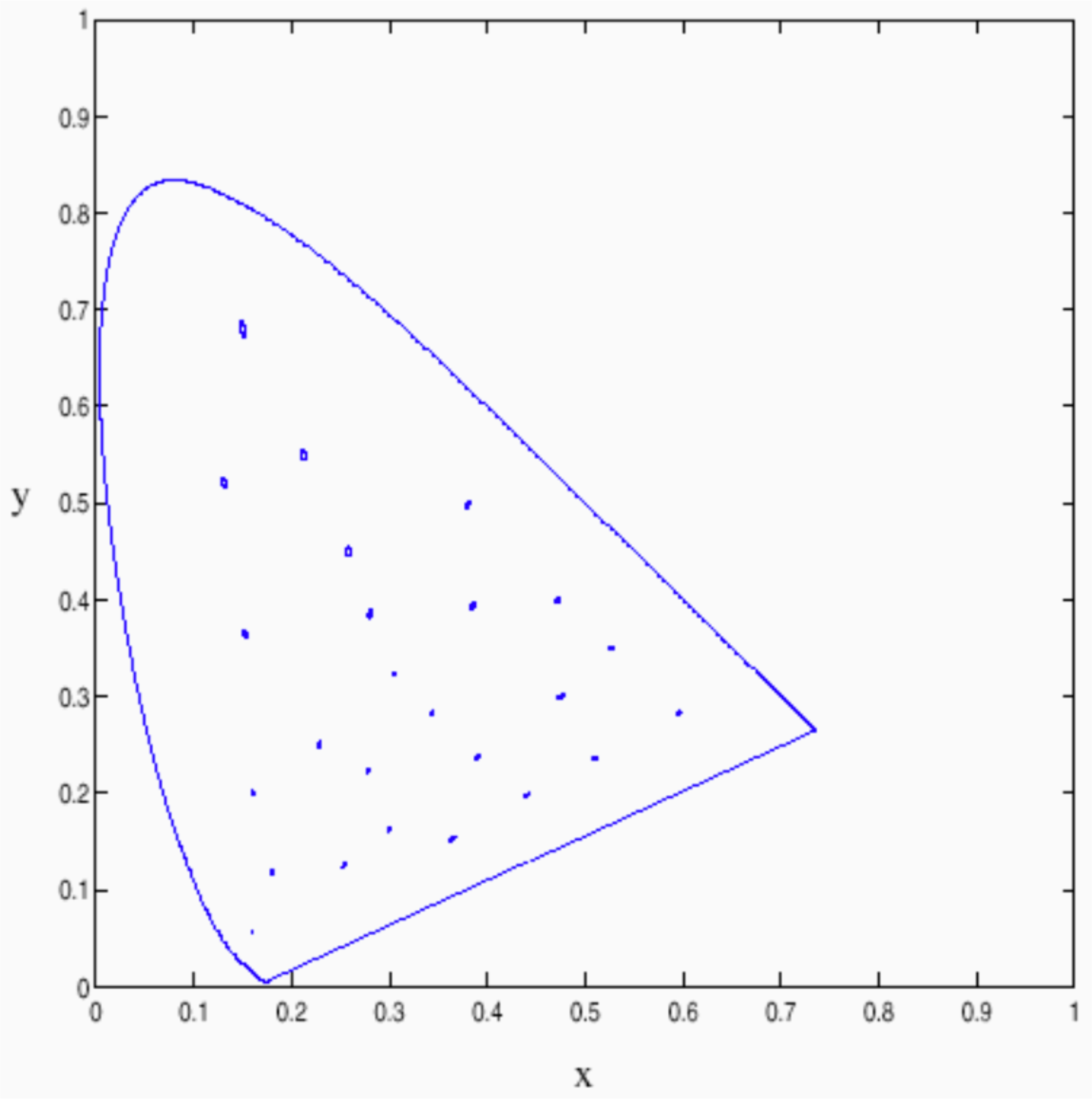
This means it is important to know whether a colour difference would be noticeable to a human viewer

Uniform Colour Spaces

McAdam Ellipses: Each ellipse shows colours perceived to be the same



10 times actual size



Actual Size

Forsyth & Ponce (2nd ed.) Figure 3.14

Uniform Colour Spaces

McAdam ellipses demonstrate that differences in x , y are a poor guide to differences in perceived colour

A **uniform colour space** is one in which differences in coordinates are a good guide to differences in perceived colour

— example: CIE LAB

HSV Colour Space

The coordinates of a colour in a linear space like RGB or CIE XYZ may not necessarily...

— encode properties that are common in language or important in applications

— capture human intuitions about the topology of colours, e.g. hue relations are naturally epxressed in a circle

HSV Colour Space

More natural description of colour for human interpretation

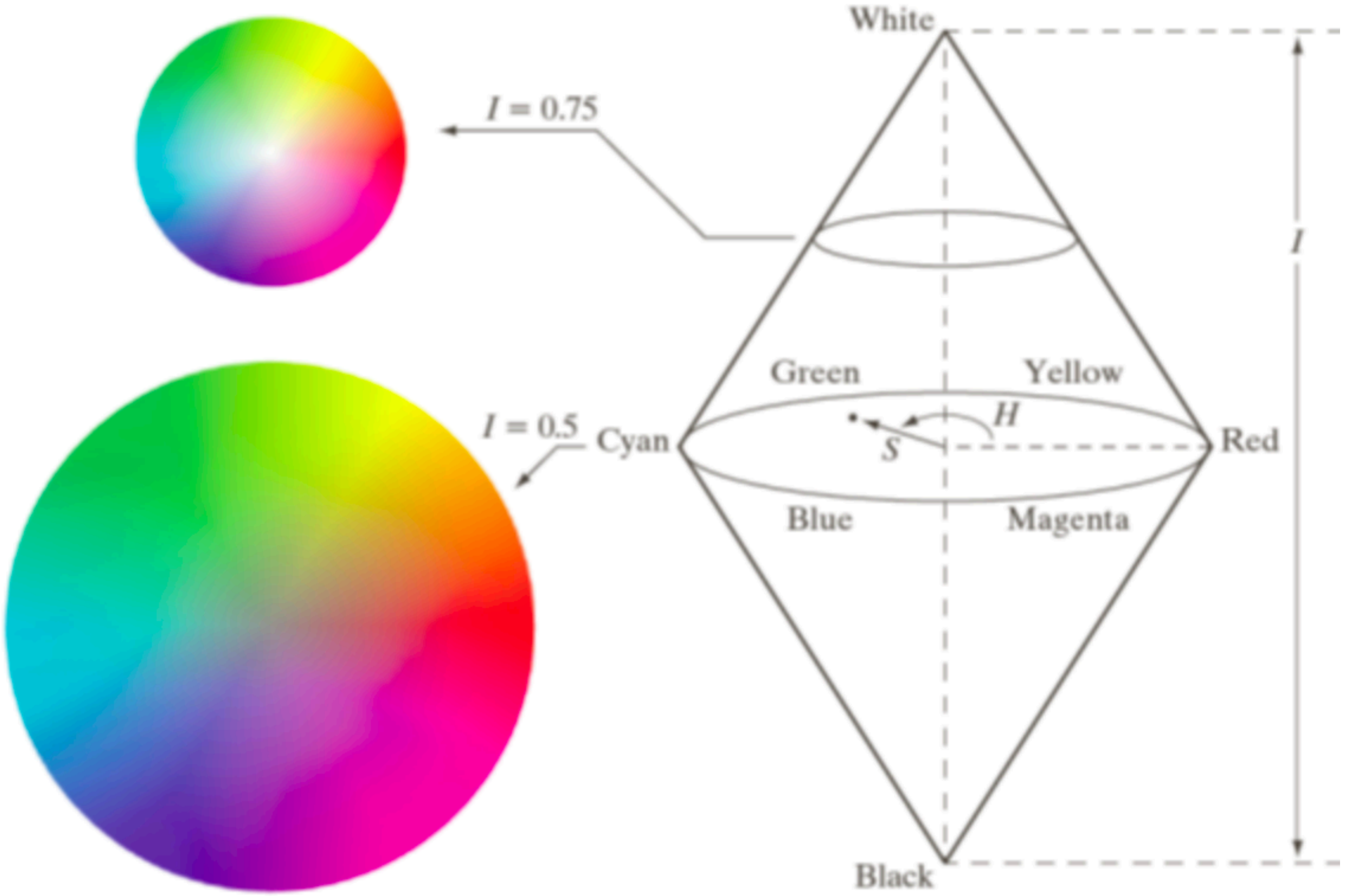
Hue: attribute that describes a pure colour
— e.g. ’red’, ’blue’

Saturation: measure of the degree to which a pure colour is diluted by white light
— pure spectrum colours are fully saturated

Value: intensity or brightness

Hue + saturation also referred to as **chromaticity**.

HSV Colour Space



Gonzalez and Woods, 2008

Colour **Constancy**

Image colour depends on both light colour and surface colour

Colour constancy: determine hue and saturation under different colours of lighting

It is surprisingly difficult to predict what colours a human will perceive in a complex scene
— depends on context, other scene information

Humans can usually perceive
— the colour a surface would have under white light

Colour **Constancy**

A classic experiment by Land and McCann

Environmental Effects

Chromatic adaptation: If the human visual system is exposed to a certain colour light for a while, colour perception starts to skew

Contrast effects: Nearby colours affect what is perceived

Summary

— Approaches to texture exploit pyramid (i.e. scaled) and oriented representations

— Human colour perception

- — colour matching experiments
- — additive and subtractive matching
- — principle of trichromacy

— RGB and CIE XYZ are linear colour spaces

— Uniform colour space: differences in coordinates are a good guide to differences in perceived colour

— HSV colour space: more intuitive description of colour for human interpretation

— (Human) colour constancy: perception of intrinsic surface colour under different colours of lighting