Colour Spaces

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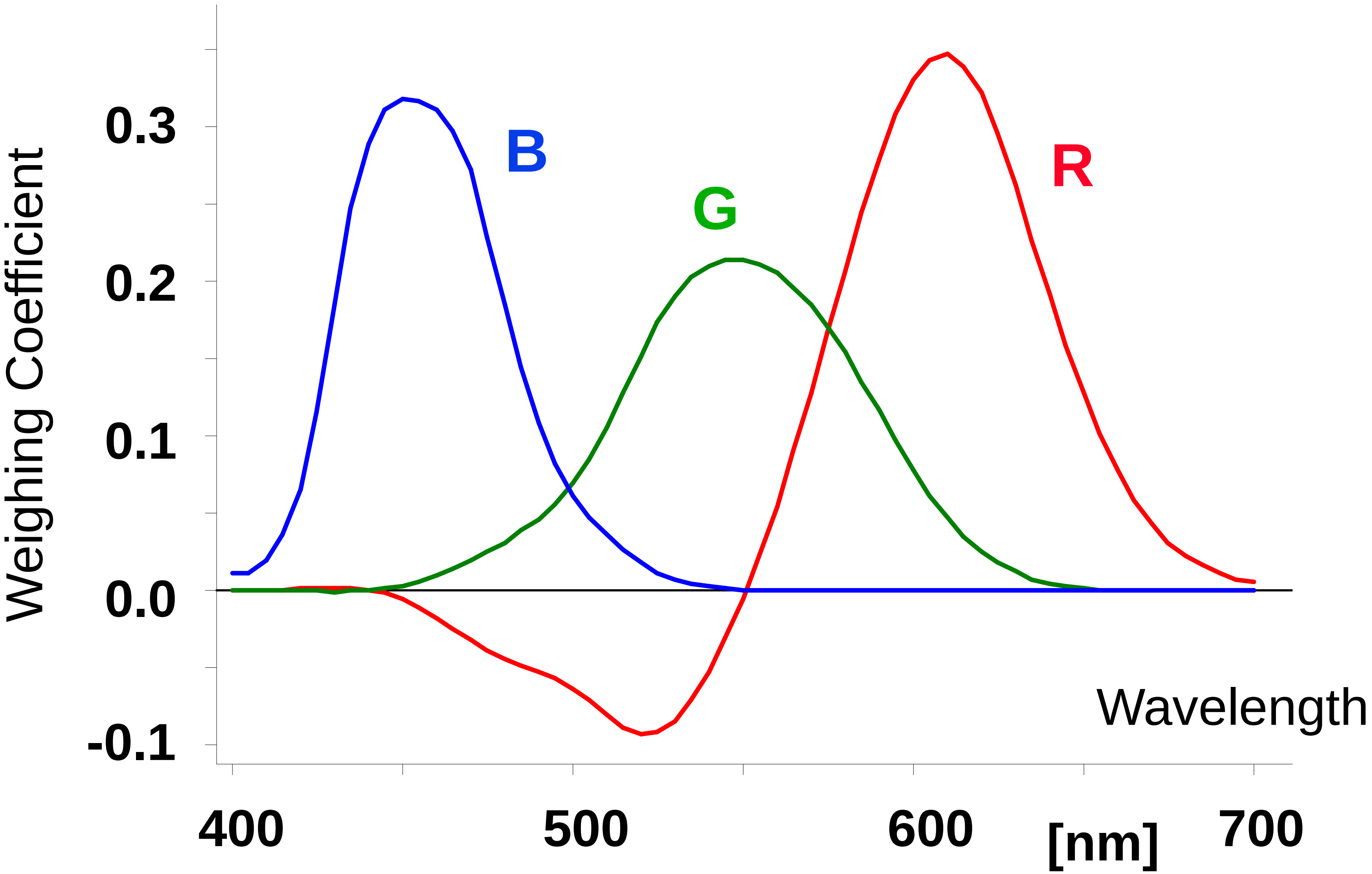
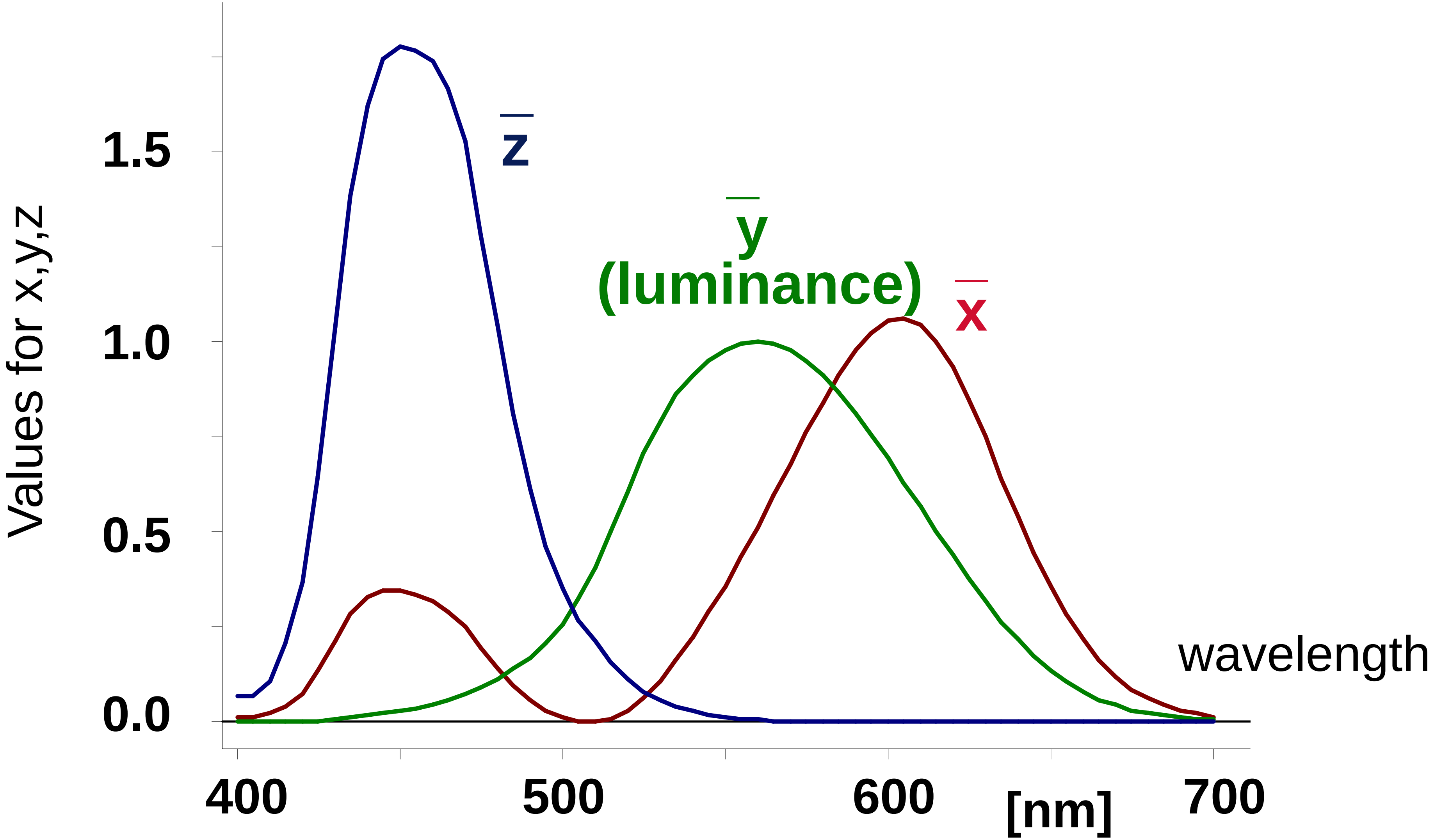
Conversion of Spectral Data



Virtual Primary Colours X,Y,Z

- The ***Commision Internationale de l' Éclairge*** **(CIE)** in 1931 defined three virtual primaries **X, Y, Z**, the **convex combination** of which can describe all visible colours
  – X, Y, Z are defined via their spectral response curves **x, y, z** (tabulated in 1nm intervals)
- The relationship between R,G,B and X,Y,Z spaces is **linear**
  – Unambiguously defined by 3×3 matrices

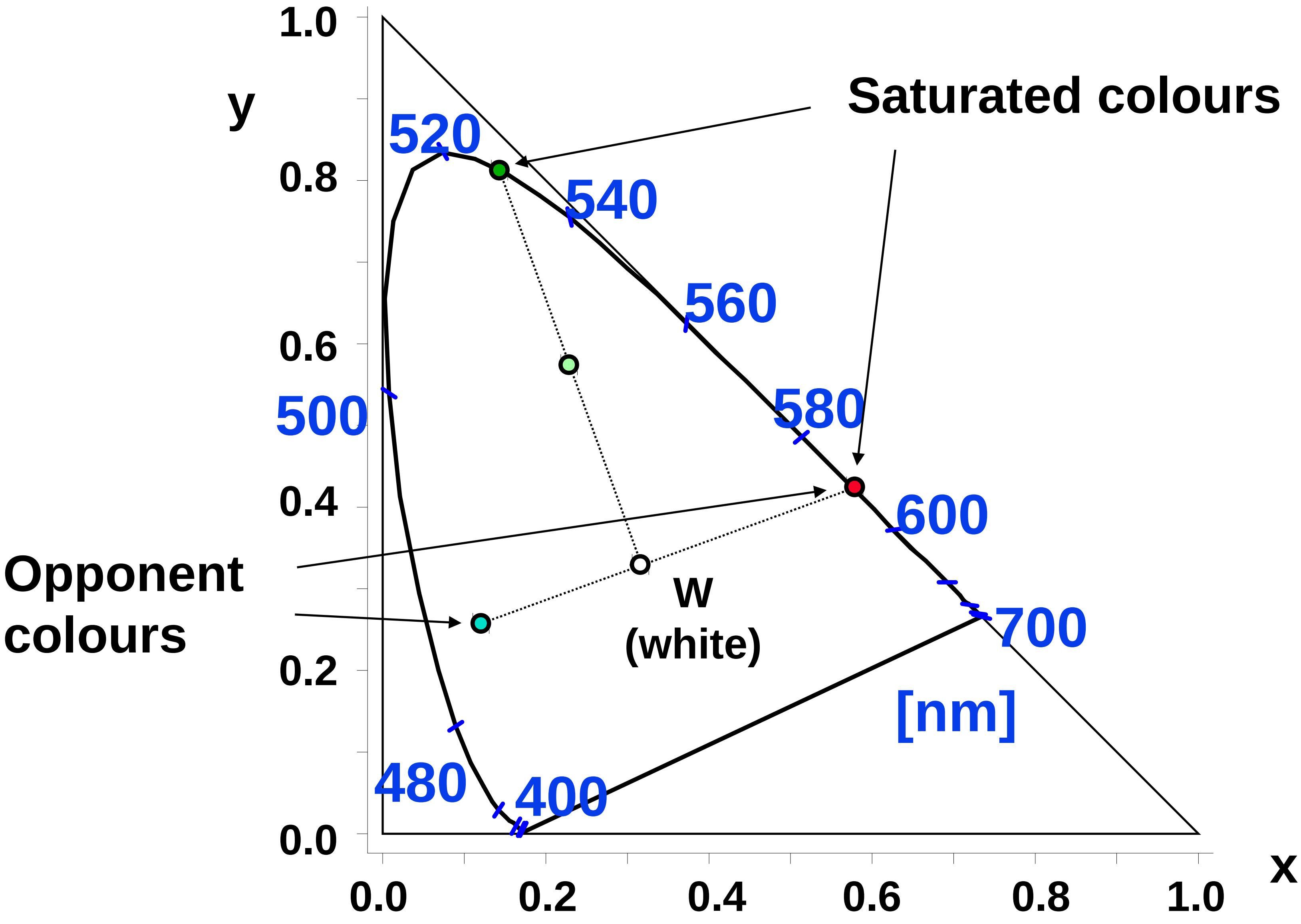
CIE XYZ Response Curves



CIE x,y Colour Space

- **Normalised colour coordinates x, y, z**:
  - **x = X/(X+Y+Z)**, **y = Y/(X+Y+Z)**, **z = Z/(X+Y+Z)**
  - **x, y, z** only carry information about hue and saturation, luminance is omitted
- The **CIE x,y** diagram does not use the **z** coordinate
  - Not independent of the others (**z = 1 - x - y**)
- The system is not **perceptually uniform** (like e.g. the uniform **CIE u,v** system)

CIE x,y Chroma Diagram



RGB Primaries

- Corresponds to **three types of phosphors**:

  R = [0.628, 0.346]

  G = [0.268, 0.588]

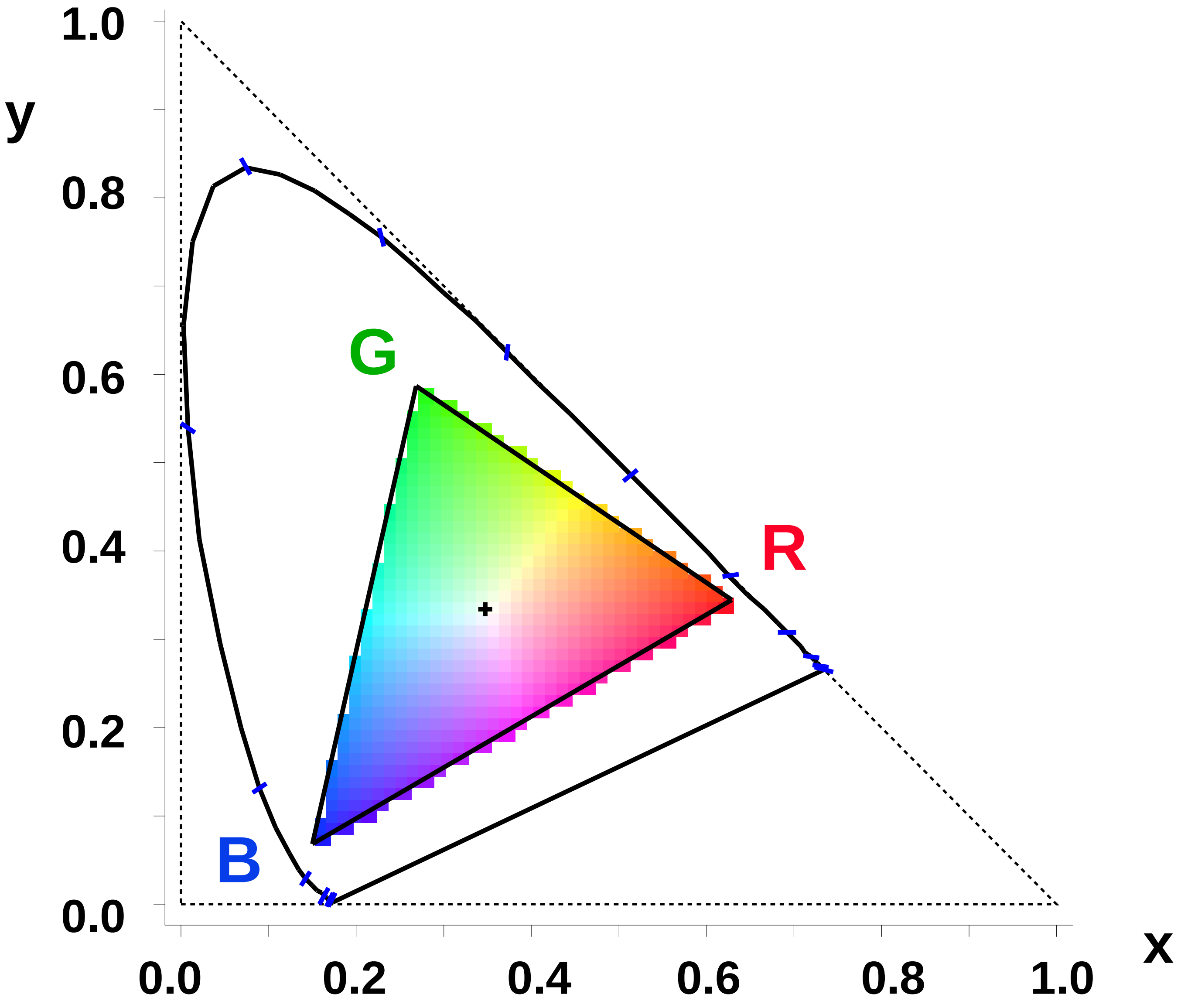
  B = [0.150, 0.070]

  – white **W(D_{6500}) = [0.313, 0.329]**

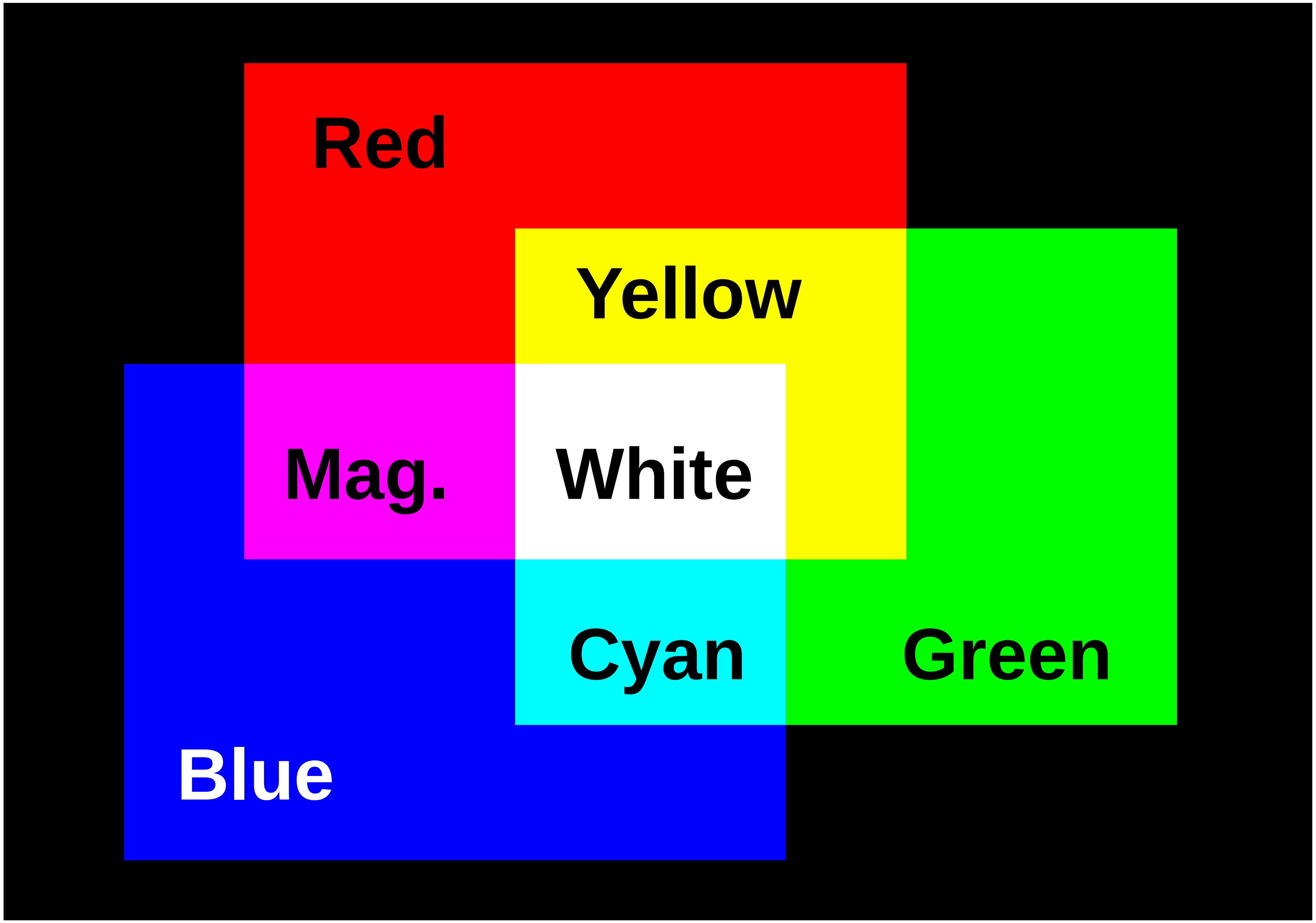
- **Equal energy white W** has the coordinates **[1/3, 1/3]**

- White **R** for the **NTSC** TV norm: **[0.31, 0.316]**

Monitor Gamut in CIE x,y



Additive Colour Mixing (RGB)



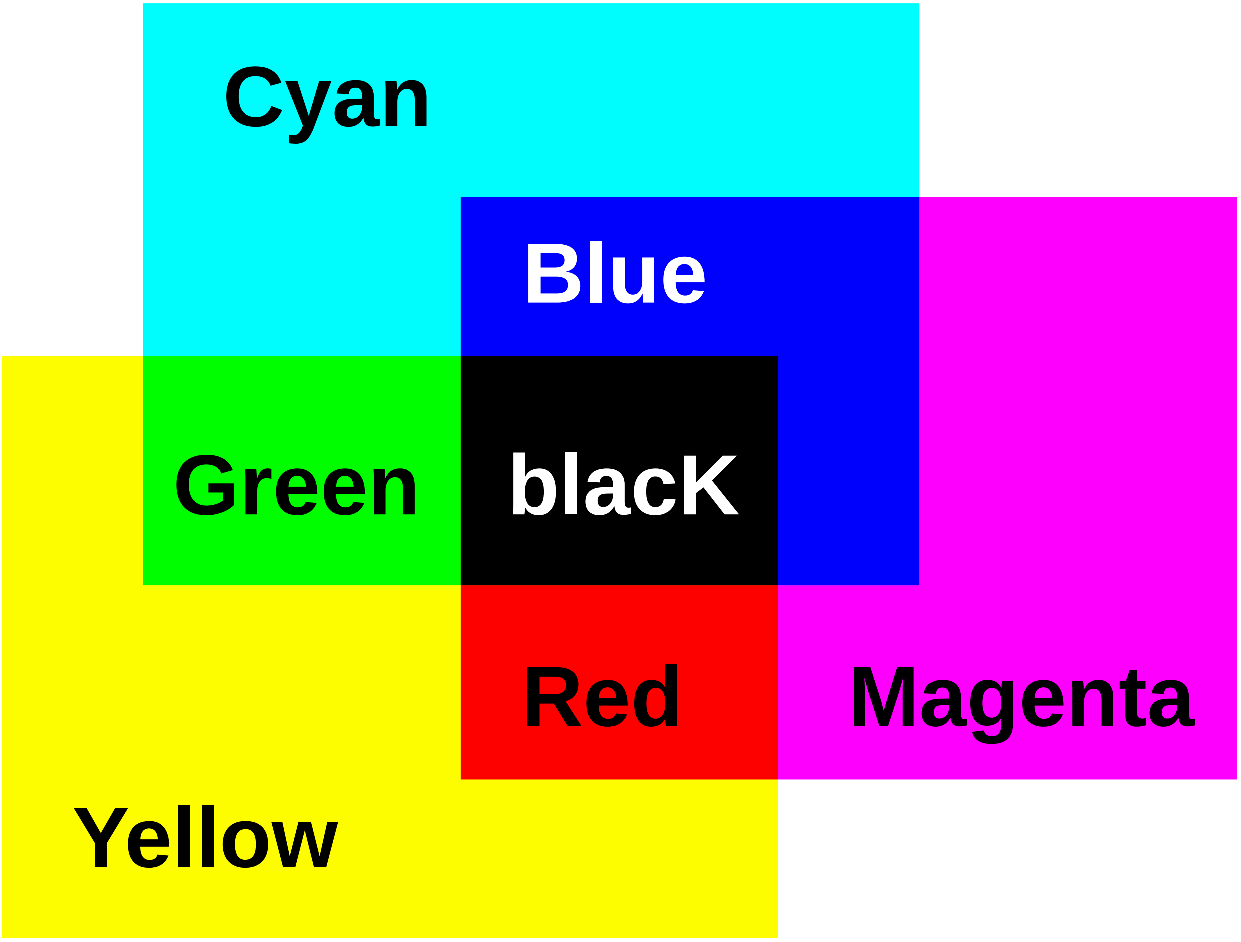
The CMY(K) Colour System

- Used in **2D/3D print** (and chemical photography)
  - Everywhere, where controlled absorption of light is used to determine object appearance

- Colours are mixed **subtractively**

- Basic colours are **C** (cyan), **M** (magenta), **Y** (yellow)
  These match the classical print primaries
  - **C, M, Y** are counterparts to **R, G, B**

Subtractive Colour Mixing (CMY)



The CMY(K) Colour System

- Conversion between **CMY** and **RGB**:
  - **C = 1 - R**, **M = 1 - G**, **Y = 1 - B**
- In addition to **C**, **M**, **Y** there is also frequently a **black component K**:
  - Composite black is not as deeply black as genuine K
  - Black ink is cheaper than the coloured ones

K’ ≈ min(C,M,Y), **C’ ≈ C−K**, **M’ ≈ M−K**, **Y’ ≈ Y−K**

The YIQ Colour System

- Used for **TV broadcasts and signals**
  - Defined by the **NTSC** in 1953
  - Compatible with black and white TV sets

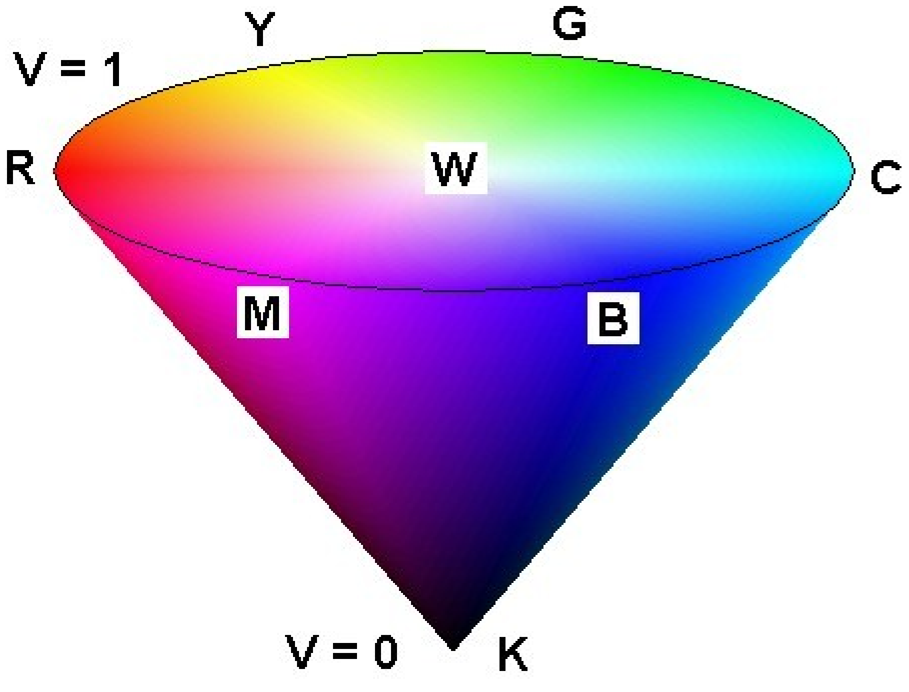
$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.528 & 0.311 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

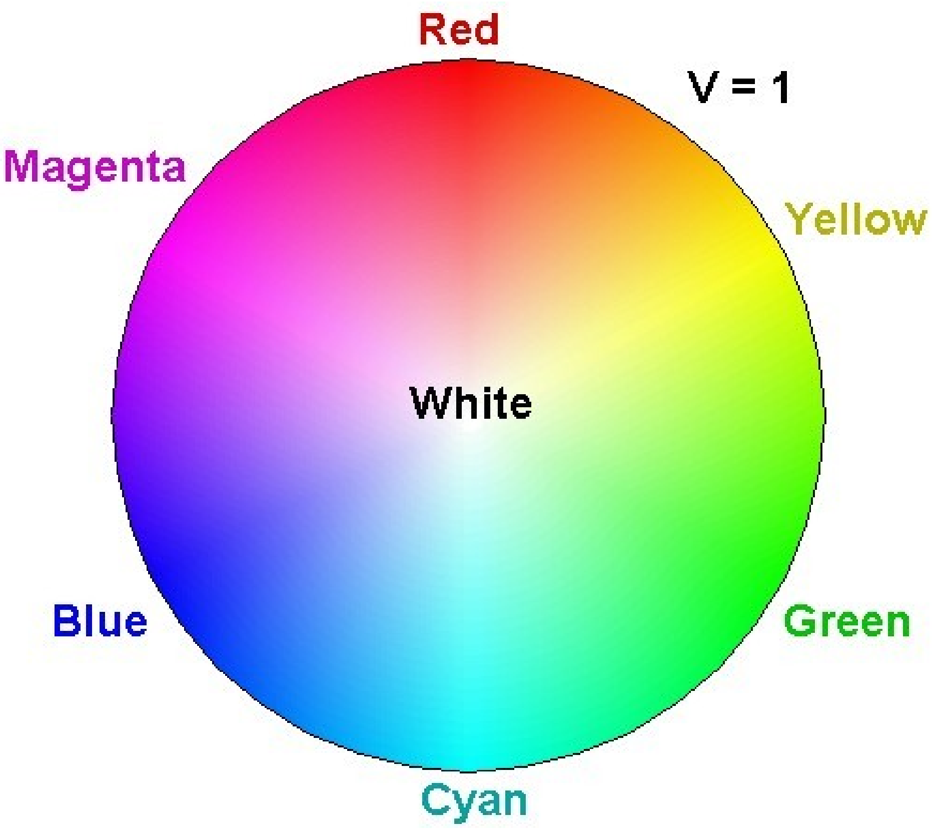
- The (**I**,**Q**) signals are perceptually less important
  - Consequence: these signals are allocated less bandwidth

The HSV Colour System

- **User-oriented**
  - Intuitive parameters: „hue”, „saturation”, and „value”
- Description of the components:
  - **H**: main hue, range **0°** to **360°**
  - **S**: saturation, range from **0** (white) to **1** (spectral colour)
  - **V**: luminance, range **0** (black) to **1**

Colour Circle





Translation RGB → HSV

```
procedure RGB2HSV ( R,G,B : real; var H,S,V : real );
var min, max, delta : real;
begin
  min := minimum(R,G,B); max := maximum(R,G,B);
  V := max; delta := max - min;
  if max <> 0.0 then S := delta/max
              else S := 0.0;
  if delta <> 0.0 then
    begin                { chromatic case }
      if R = max then H := (G - B)/delta else
      if G = max then H := 2 + (B - R)/delta
                 else H := 4 + (R - G)/delta;
      H := H * 60.0;     { conversion to degrees }
      if H < 0.0 then H := H + 360.0;
    end;
end;
```

Translation HSV → RGB

```
procedure HSV2RGB ( H,S,V : real; var R,G,B : real );
var i, f, p, q, t: real;
begin
  if S = 0.0 then
    begin                     { achromatic case }
      R := V; G := V; B := V;
    end      else
    begin                     { chromatic case }
      if H = 360.0 then H := 0.0;
      H := H/60.0;            { 0 <= H < 6 }
      i := trunc(H);          { number of slices: 0 <= i <= 5 }
      f := H-i;               { 0 <= f < 1 }
      p := V * (1.0 - S);
      q := V * (1.0 - S*f);
      t := V * (1.0 - S*(1.0 - f));
      ...
```

Translation HSV → RGB

```
      ...
      case i of          { six options: }
        0: (R,G,B) := (V,t,p);  { short for 3x “:=“ }
        1: (R,G,B) := (q,V,p);
        2: (R,G,B) := (p,V,t);
        3: (R,G,B) := (p,q,V);
        4: (R,G,B) := (t,p,V);
        5: (R,G,B) := (V,p,q);
        end;
    end;                 { chromatic case }
end;
```

Other Colour Systems

- **HLS** („hue”, „lightness”, „saturation”)
  - Similar to **HSV**, double cone
- Company standards
  - e.g. **TekHVC** (Tektronix)
- Colour systems and atlases:
  - **PANTONE®** (Pantone Inc.)
  - **Munsell Book of Colour**
  - **Ostwald system** (1931)

Literature

- **G. Murch**: ***Human Factors of Color Displays***, in Advances in Computer Graphics II, Springer, 1986, 1-27
- **J. Foley, A. van Dam, S. Feiner, J. Hughes**: ***Computer Graphics, Principles and Practice***, 579-599

End

Further information:

- Lecture A. Wilkie: ***Introduction to Colour Science*** (NPGR025)