Photometry, Colormetry, and Testing

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UNEP Collaborating Centre for Energy Efficient Lighting

Content

- Introduction
- Photometry
- Colorimetry
- Testing

Introduction : Quality parameters

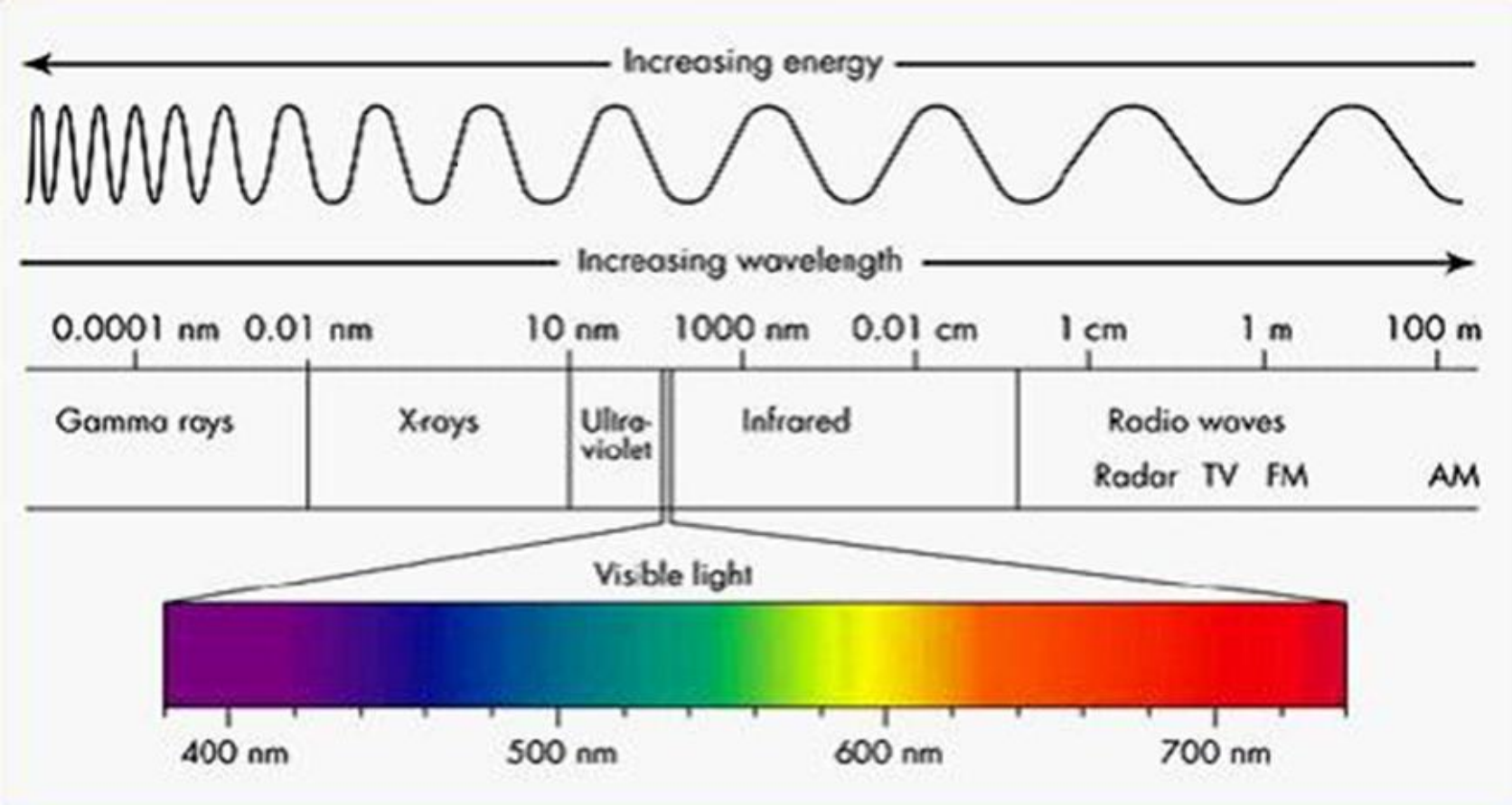
- Safety
- Performance
  - Electrical parameters
  - Photometry
  - Colorimetry

Quality parameters

- Performance

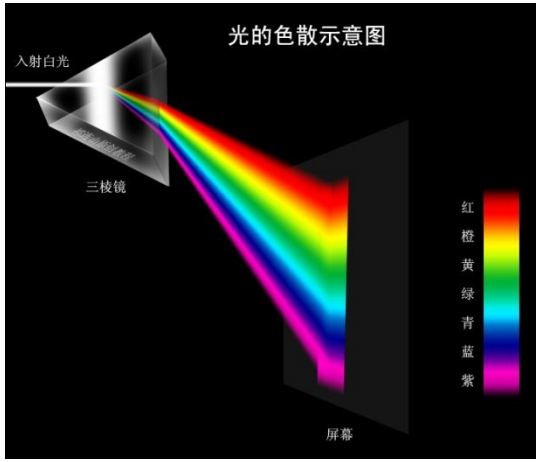
	Parameters	Conception
Photometry	Luminous flux	Amount of the light emitted
	Luminous efficiency	Efficiency for turning electricity to light
	Intensity distribution	Spacial distribution of light
	Luminance	Brightness
Colorimetry	Color coordinate	Coordinates indicating the color of the light
	CCT	Feeling related, warm, neutral, or cool
	CRI / Ra	Color rendering index, higher, more natural

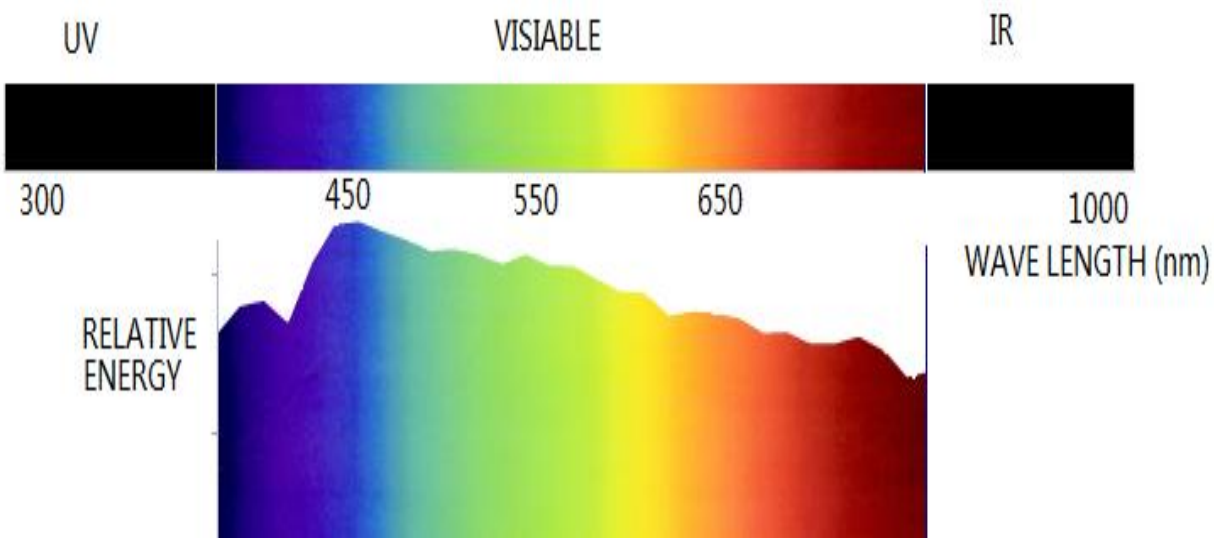
Light and radiation



Light and radiation

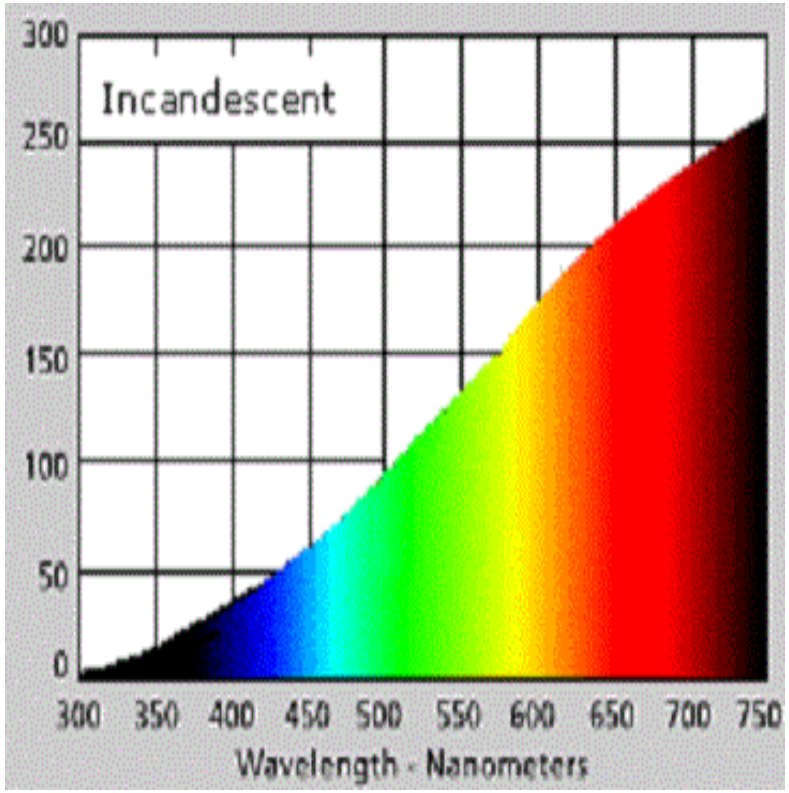
- Daylight

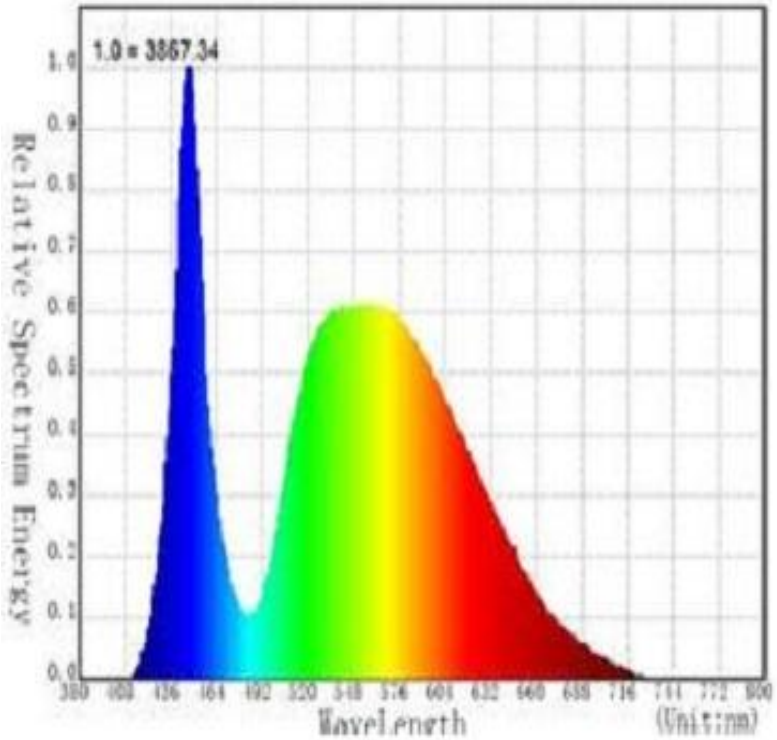




Light and radiation

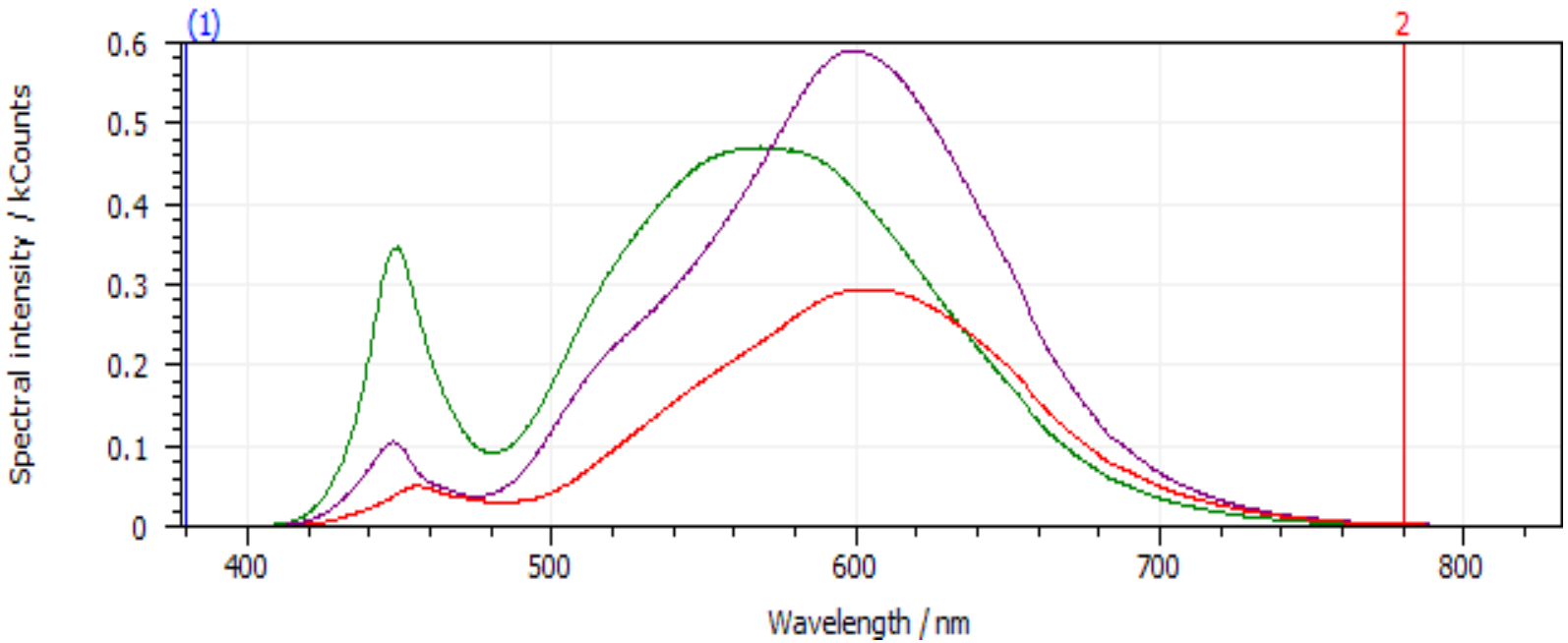
- Incandescent and LED





Light and radiation

- Typical LED SPD



Warm white , small Neutral white, big Warm white, big

Light and radiation

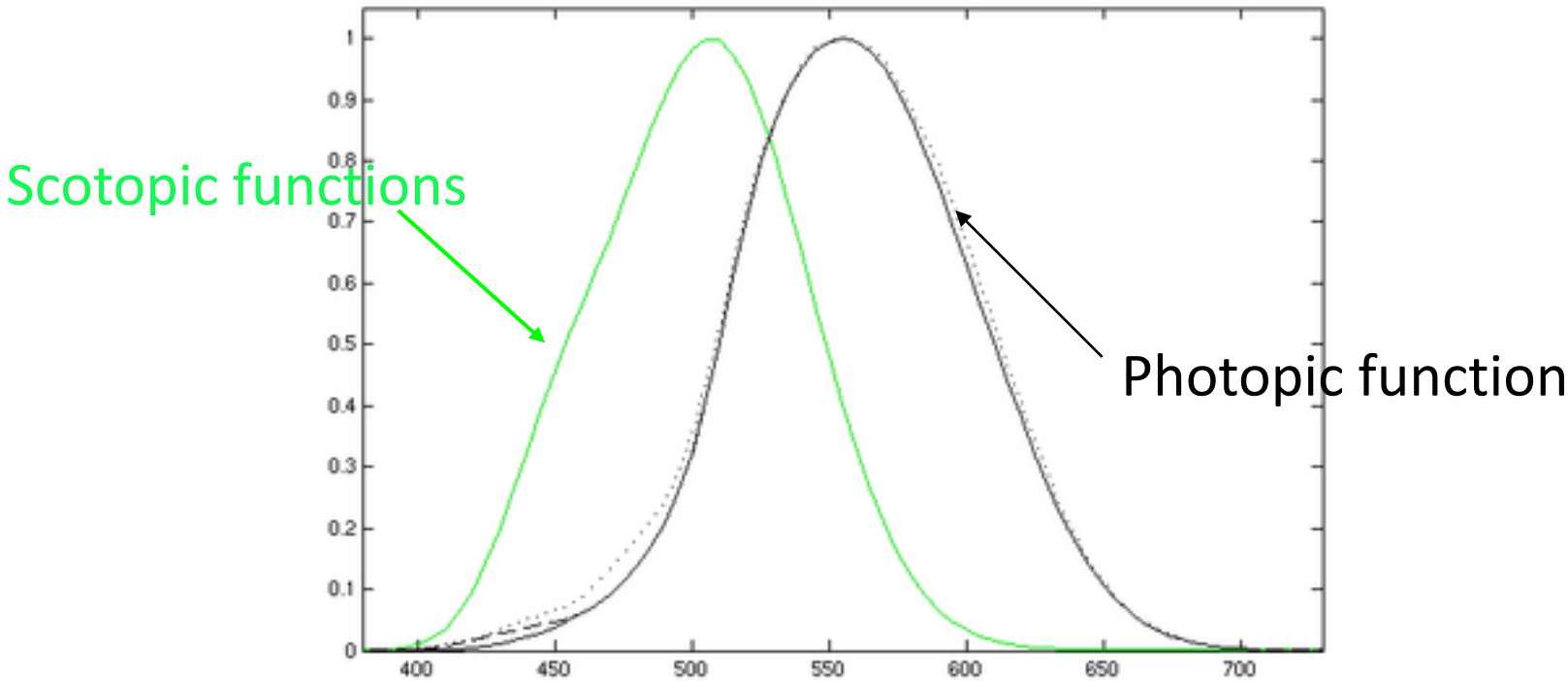
- Light and radiation
  - Photometry, colorimetry
    - To express huaman eye reception
  - Photometry
    - To express the "quantity amount" of light
  - Colorimetry
    - To express the "color feeling" of light

Photometry, general

- Human eye as detector
  - The huaman eye is NOT equally sensitive to different wavelength light in the visible range
- Photometry attempts to "simulate" this
  - By weighing the measured power at each wavelength with a factor that represents how sensitive the eye is at that wavelength
  - The standardized model of the eye's response to light as a function of wavelength is given by the luminosity function

Photometry, general

"Sensitive Factor"



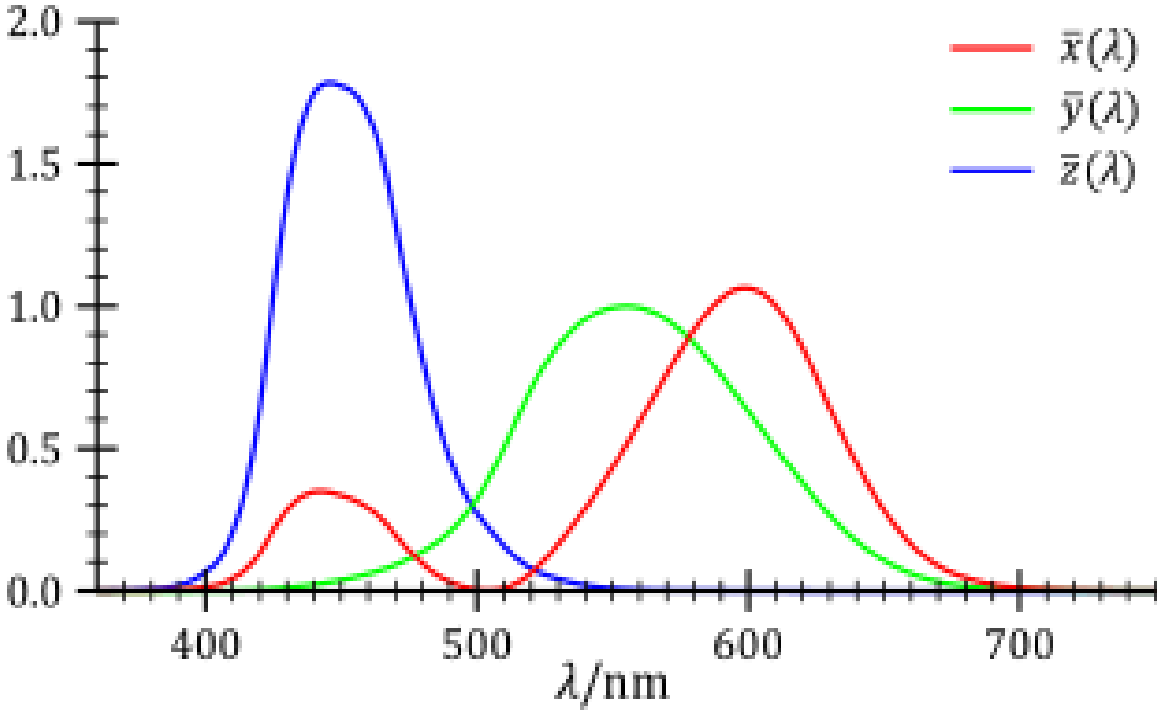
Photometry, general

- Photopic vision & Scotopic vision
  - Human eye has different responses in different light conditions
- Photometry and the vision basis
  - Based on the eye's photopic response
  - MAY NOT accurately indicate the perceived brightness of sources in dim lighting conditions
    - such as under just moonlight or starlight
    - where colors are not discernible

Colorimetry, general

- Colorimetry
  - Conception
    - Science / Technology to quantify and describe physically the human color perception
  - Expression
    - CIE 1931 XYZ color space tristimulus value, and etc.

Colorimetry, general



The CIE standard observer color matching functions

Summary

- Visible light is only a small part of electromagnetic wave
- Light emitted from a lighting source such as the sun, an incandescent lamp, though looked white, but maybe dispersed into colored light
- The "amount" of the light at each color may be different, a distribution, "total amount" also could be different
- Photometry is the "total amount" that can be seen by the eye
- Colorimetry for the relative "distribution" that can be detected by the eye

Photometry

- Parameters & definition
  - Flux, Intensity, Illuminance, Luminance
- Measurement method for total flux
  - Spacial integrating method
    - Co-ordinates systems
    - Gonio-photometers
  - Integrating sphere method
    - Principle
    - Integrating-sphere

Definition: flux

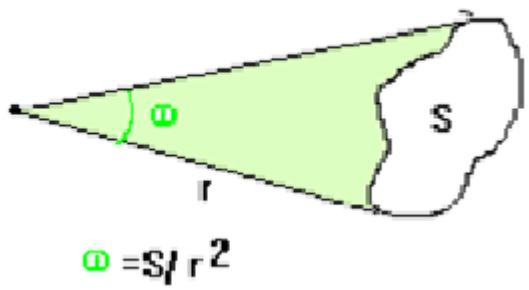
- Luminous flux
  - Quantity derived from radiant flux by evaluating the radiation according to its action upon the CIE standard photometric observer. For photopic vision is the spectral distribution of the radiant flux and is the spectral luminous efficiency
  - Unit: lm

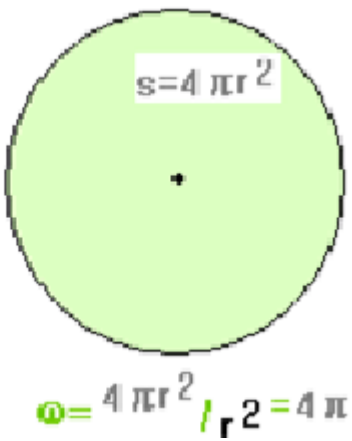
$$\Phi_v = K_m \int_{380nm}^{780nm} V(\lambda)\Phi_{e\lambda} d\lambda \begin{cases} \boxed{\Phi_v = 683 \int_{380nm}^{780nm} V(\lambda)\Phi_{e\lambda} d\lambda} \\ \Phi'_v = 1755 \int_{380nm}^{780nm} V'(\lambda)\Phi_{e\lambda} d\lambda \end{cases}$$

Definition: intensity

- Luminous intensity
  - Quotient of the luminous flux dΦ leaving the source and propagated in the element of solid angle dΩ' containing the given direction, by the element of solid angle
  - Unit: cd; lm/sr

$$I = \frac{\mathrm{d}\Phi}{\mathrm{d}\Omega'}$$

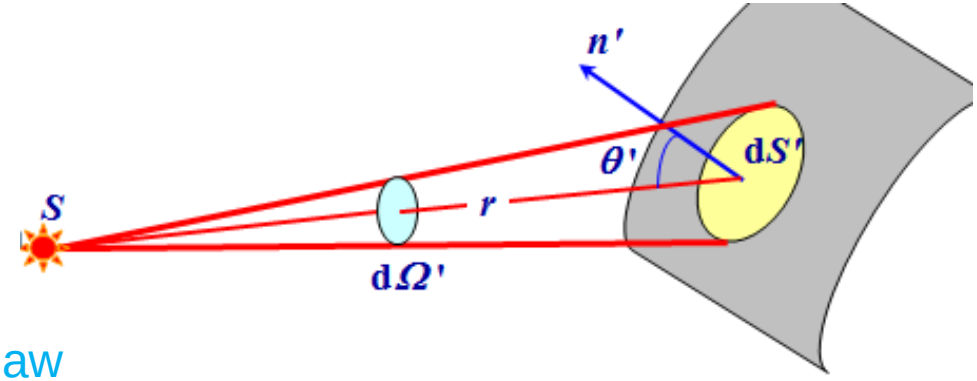




Definition: illuminance

- Illuminance
  - Quotient of the luminous flux dΦ' incident on an element of the surface containing the point, by the area dS' of that element
  - Unit: lx; lm / m^2

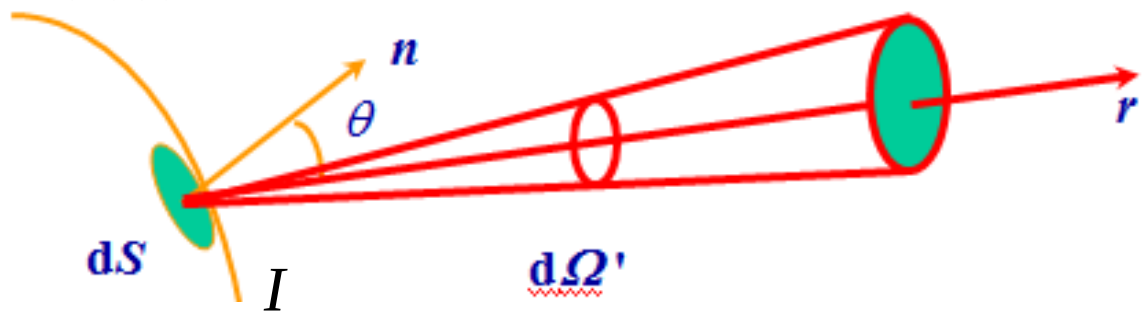
$$E = \frac{\mathrm{d}\Phi'}{\mathrm{d}S'} = \frac{I\cos\theta'}{\boxed{r^2}}$$



Inverse square law

Definition: luminance

- Luminance
  - Quantity defined by the formula where dΦ is the luminous flux transmitted by an elementary beam passing through the given point and propagating in the solid angle dΩ' containing the given direction; dS is the area of a section of that beam containing the given point; θ is the angle between the normal to that section and the direction of the beam
  - Unit: cd/m^2



$$L = \frac{\mathrm{d}\Phi}{\mathrm{d}\Omega' \cdot \mathrm{d}S\cos\theta} = \frac{I}{\mathrm{d}S\cos\theta}$$

Parameters & definitions

- Precondition
  - Suppose the light source is ideal spot light source

- Practice application
  - if the distance is no less than 5 times of the size of light source, it could be considered as a spot light
  - The longer the measuring distance, the better

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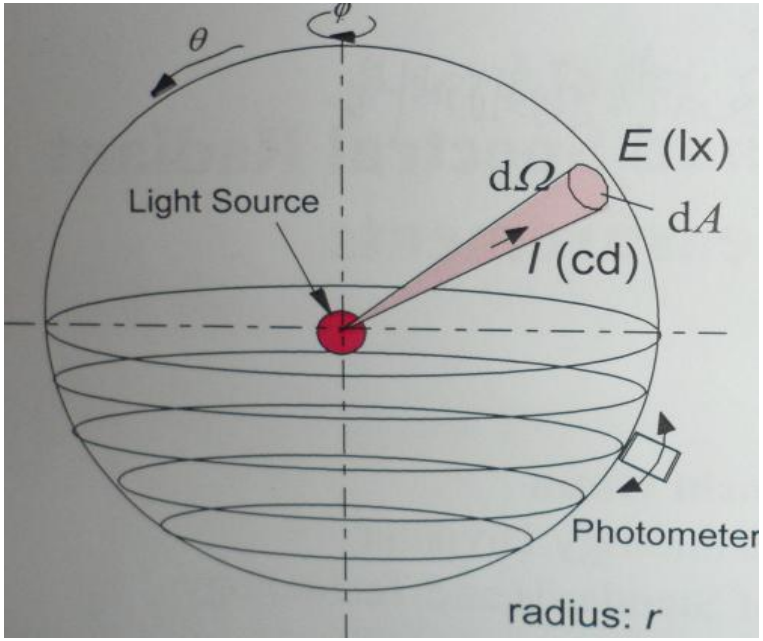
Spacial integrating

- Co-ordinates systems



Total luminous flux defined in these formula:

$$\Phi = \int_{\Omega} I d\Omega$$

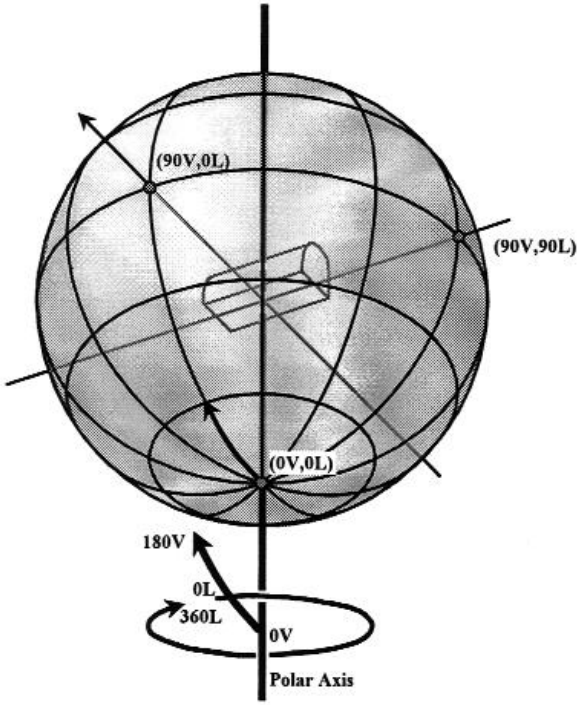
$$\Phi = \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} I(\theta,\phi) \sin\theta d\theta d\phi$$

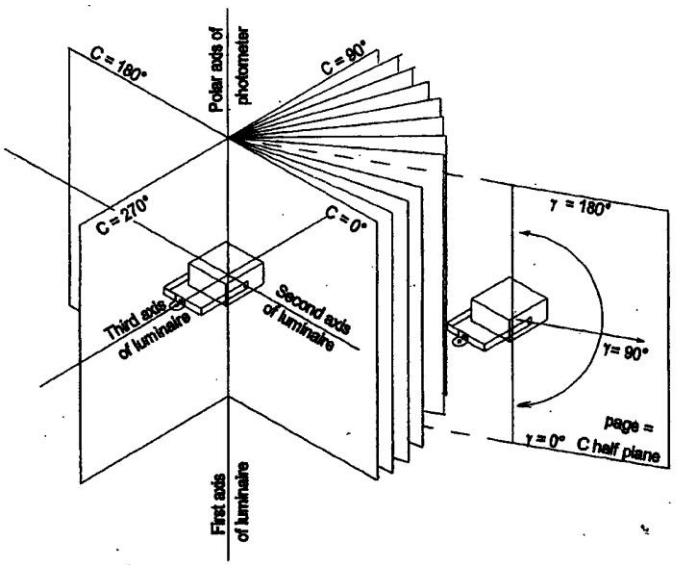
$$\Phi = \int_{A} E dA$$

$$\Phi = r^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} E(\theta,\phi) \sin\theta d\theta d\phi$$

Spacial integrating

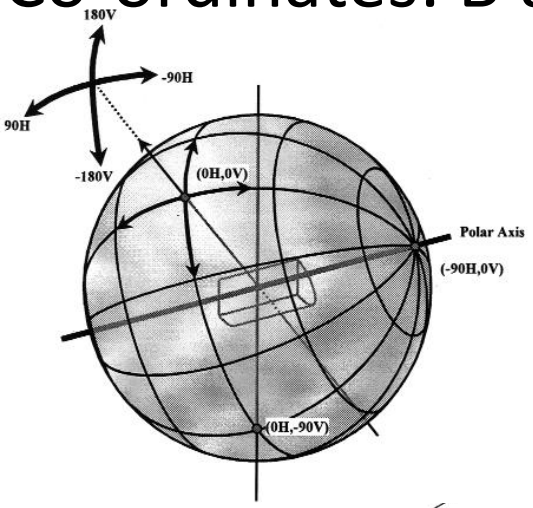
- Co-ordinates: C

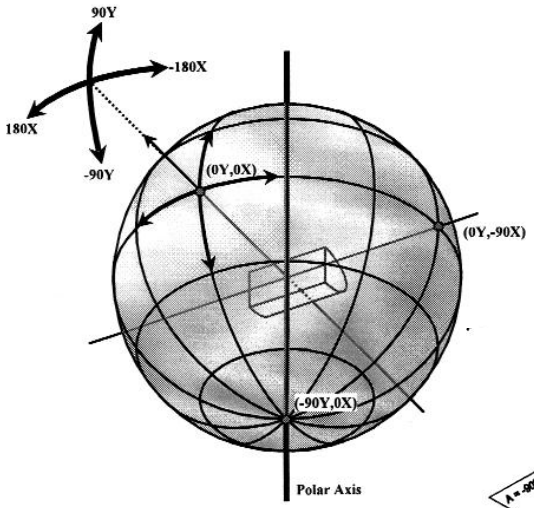


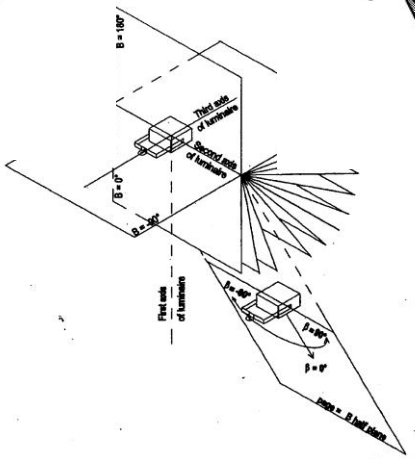


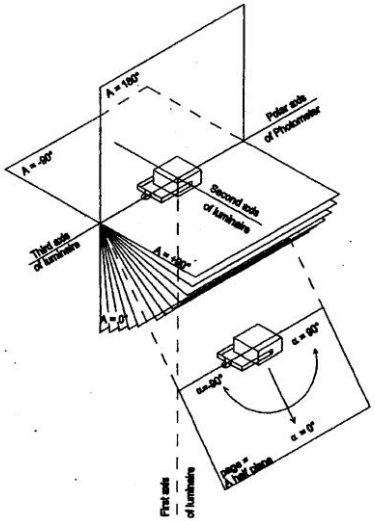
Spacial integrating

- Co-ordinates: B and A



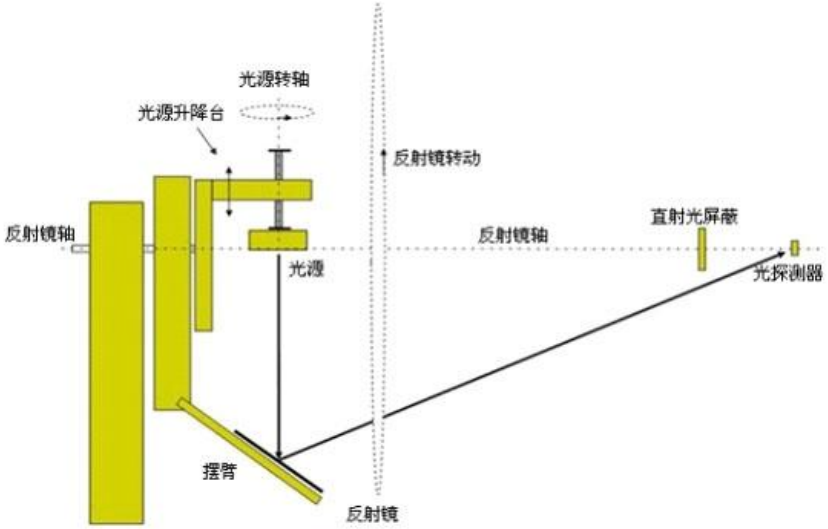






Spacial integrating

- Co-ordinate system
  - Two axes to make the detector performing "sphere surface scan"



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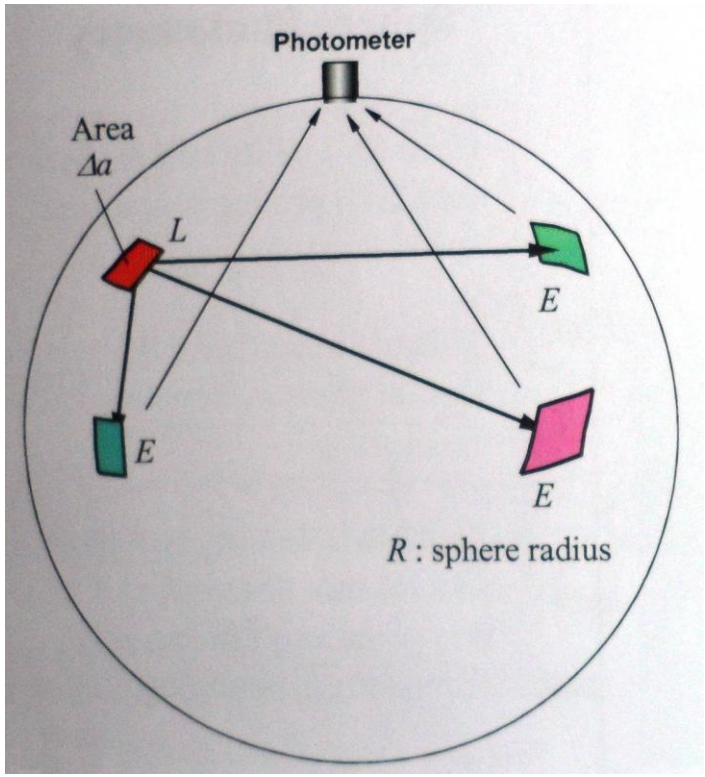
Integrating sphere

- Principal
  - Luminance L on an element Δa creates the same illuminance E all around the sphere surface: $E = L\,\Delta a / 4R^2$
  - Same amount of flux incident anywhere on the sphere wall creates an equal illuminance on the photometer port



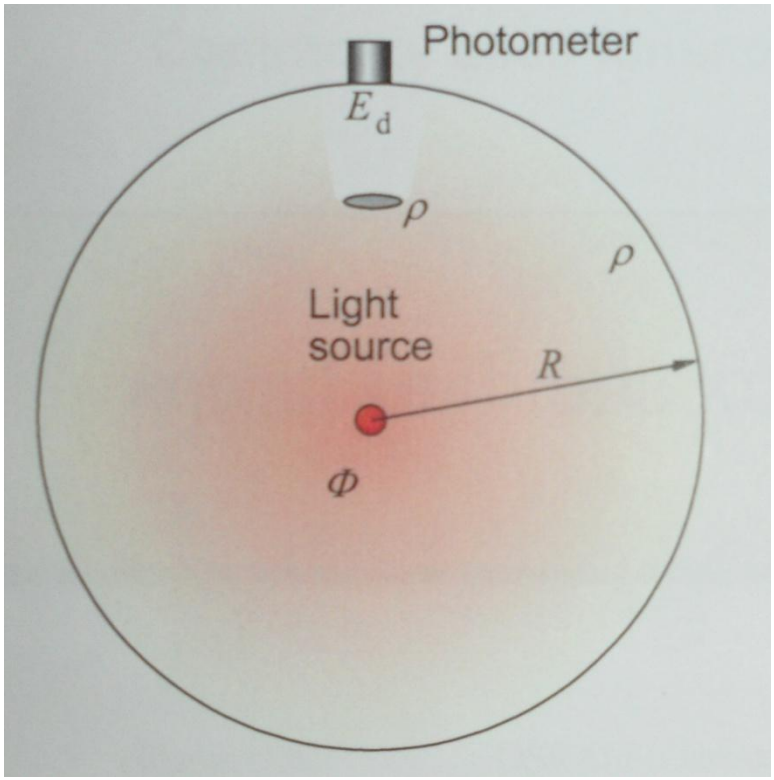
Integrating sphere

- Principal
  - Flux created by inter-reflections

$$\Phi\left(\rho+\rho^2+\rho^3.....\right)=\Phi\frac{\rho}{1-\rho}$$

  - Illuminance Ed created by inter-reflections

$$E_d=\frac{\Phi\rho}{1-\rho}\cdot\frac{1}{4\pi R^2}$$



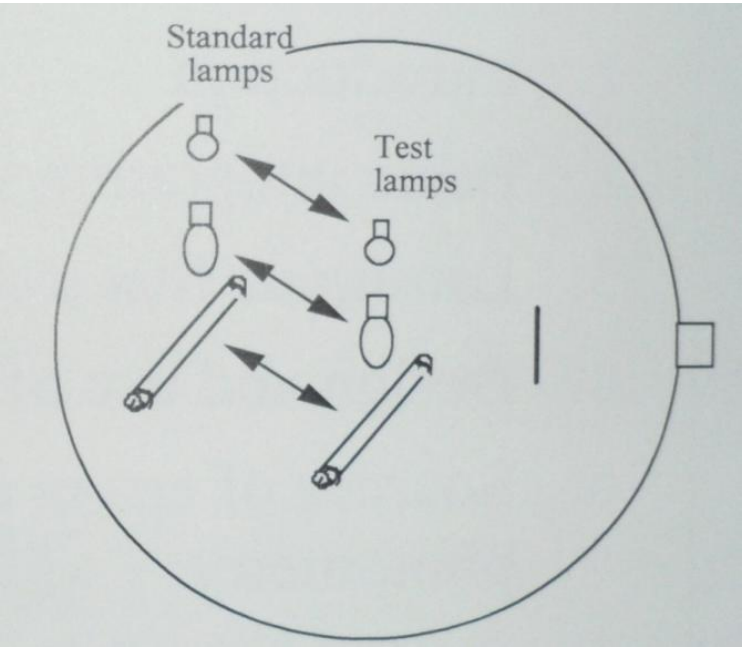
Integrating sphere

- Premises of the principal
  - The integrating sphere is perfect
  - The sphere wall reflectance is perfectly Lambertian
  - The photometer has a perfect cosine response
  - There is no objects in the sphere
- Practice
  - "ρ" changes, not easy to get the accurate value
  - "R" always not that perfect

Integrating sphere

- Integrating sphere
  - Flux standard lamp is introduced

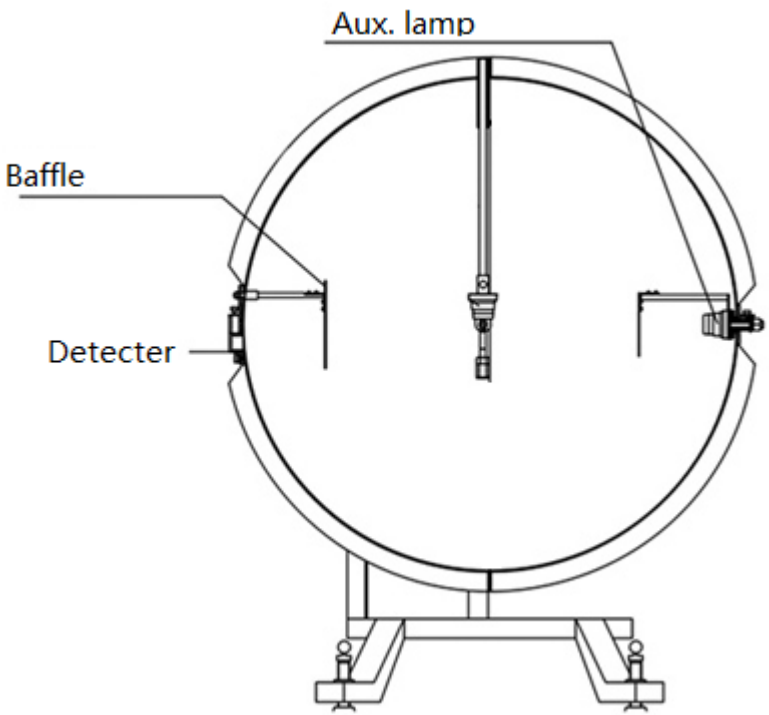
$$\Phi_T = \Phi_s \frac{E_T}{E_s}$$



Note:
Test lamp should be "similar" to the standard lamp in <u>shape, size</u>
<u>enclosure color</u>
<u>intensity distribution</u>, etc.

Integrating sphere

- Integrating sphere



Summary

- Photometry
  - amount of "light"
- system to collect the light
  - Gonio-photometer
  - integrating sphere
- Detector to receive the light
  - sensor to make photopic function of human eye

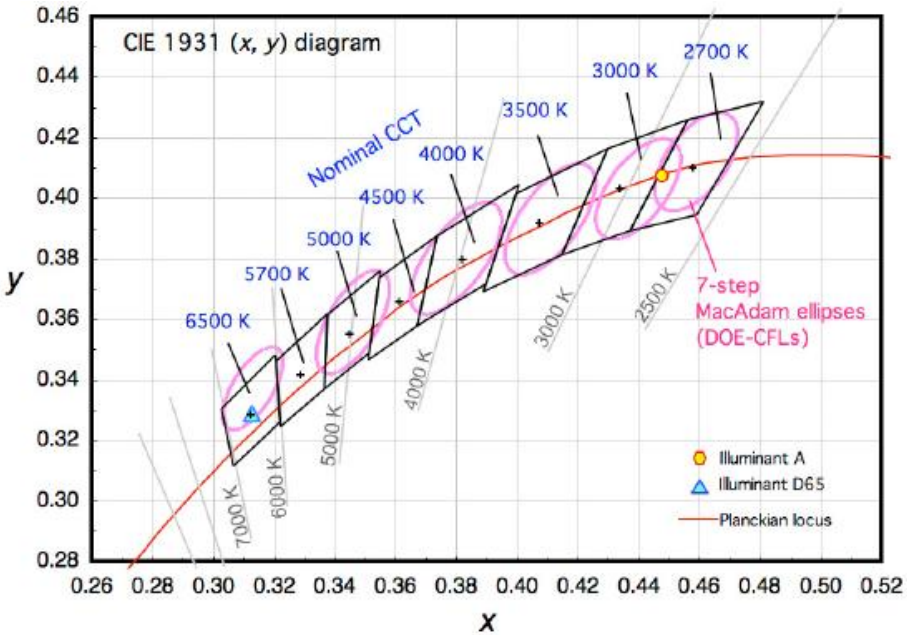
- Technical "Training"
  - Introduction
  - Photometry
  - Colorimetry
  - Testing

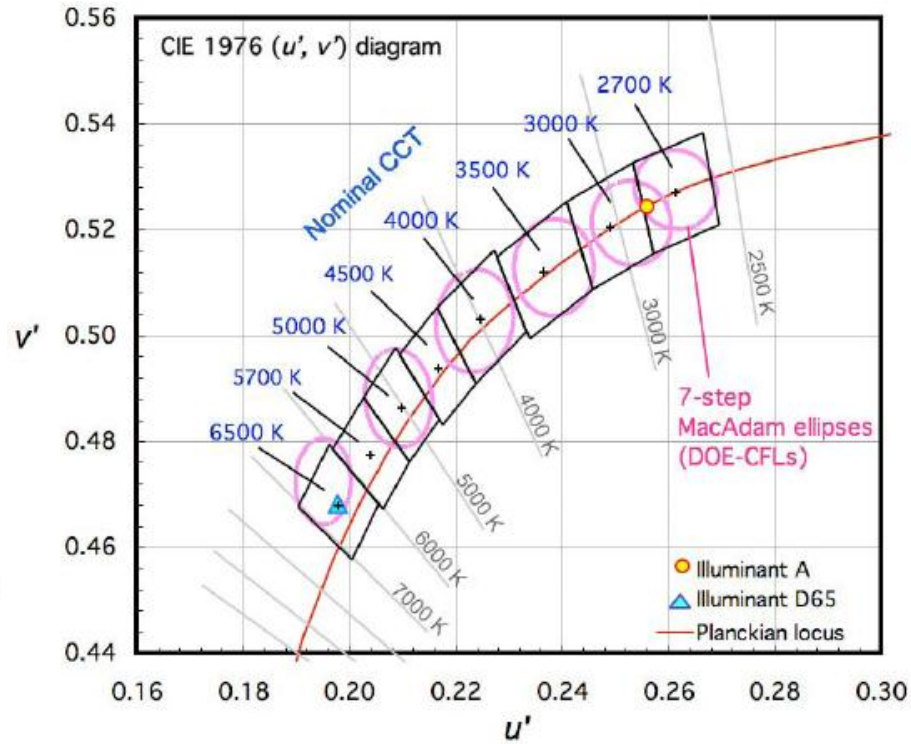
Colorimetry

- Parameters & definitions
  - Color coordinate, CCT, CRI
- Color
  - Expression & Space evolution
- "Calculation" of the Colorimetry parameters
  - Color coordinate
  - Tc & CCT
  - CRI, Ra

Parameters & definitions

- Color coordinate, CCT

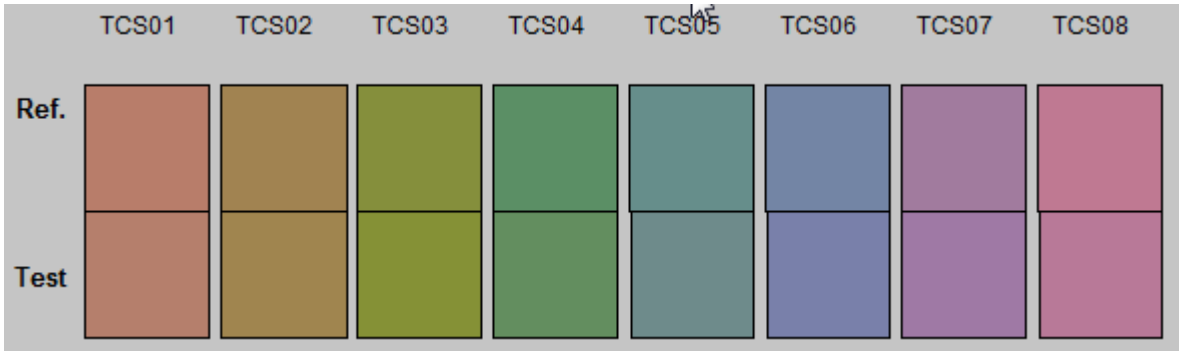


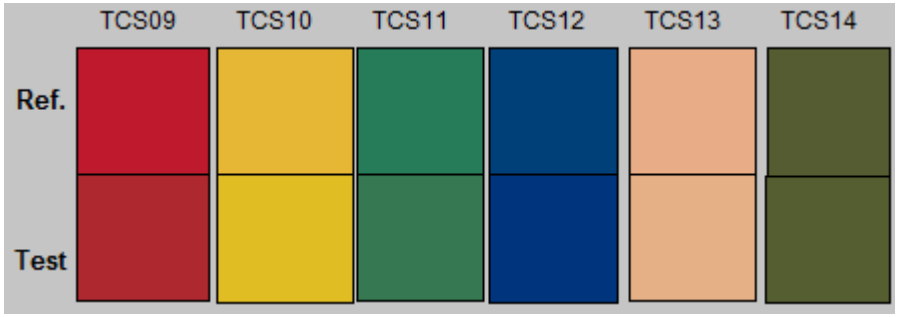


Different color space

Parameters & definitions

- CRI





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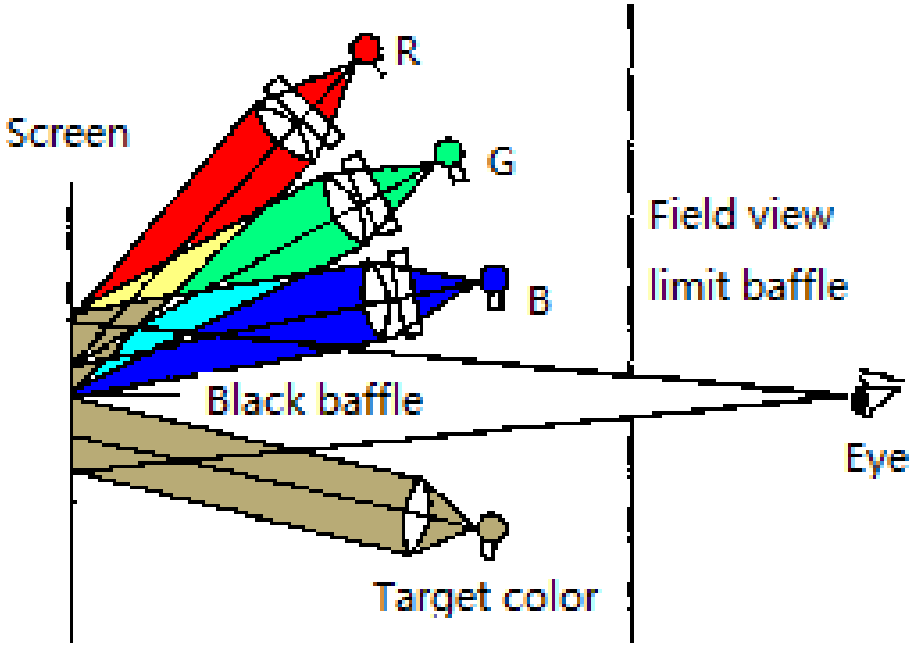
Colorimetry

- Parameters & definitions
  - Color coordinate, CCT, CRI
- Color
  - Expression & Space evolution
- "Calculation" of the Colorimetry parameters
  - Color coordinate
  - Tc & CCT
  - CRI, Ra

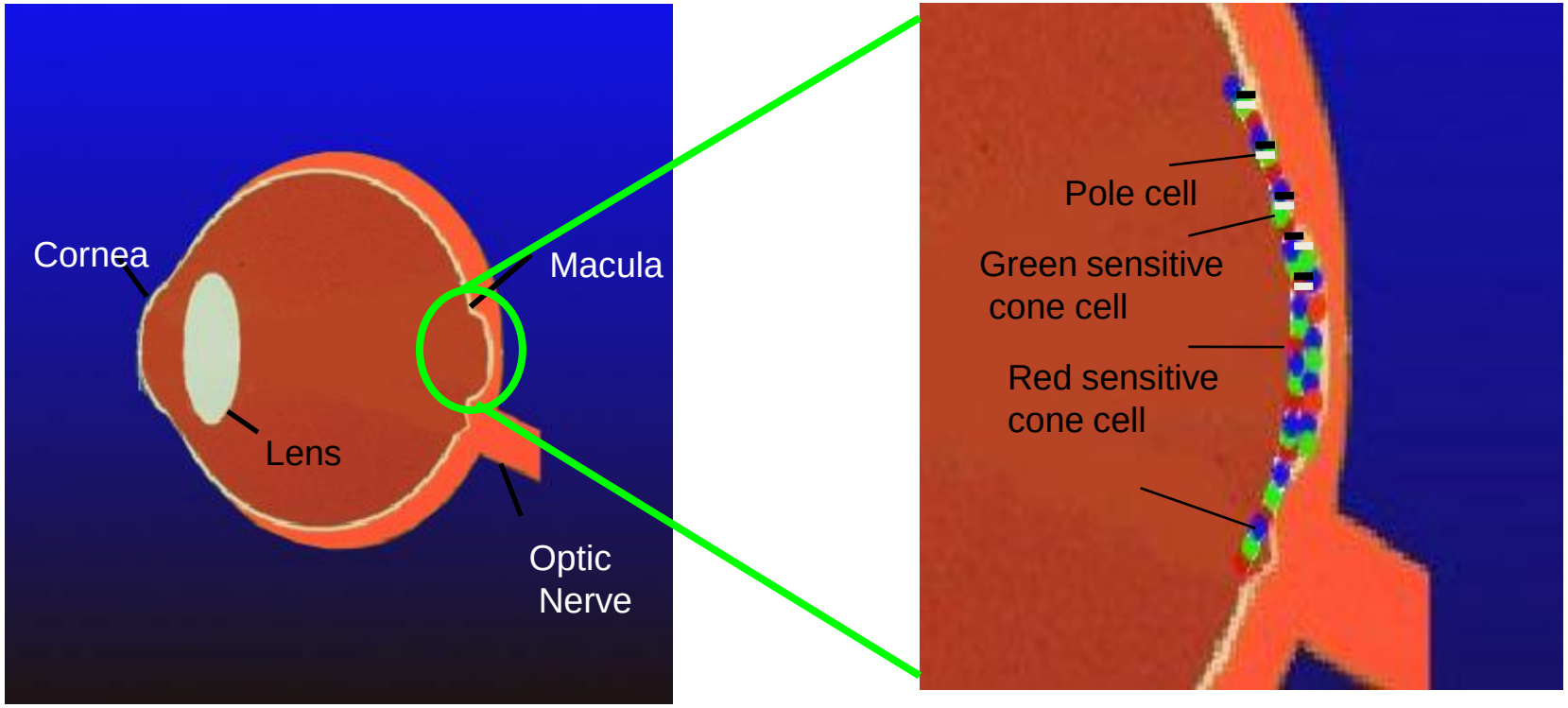
Color: Expression & Space evolution

- Expression of color
  - Color mixing principal: color matching test



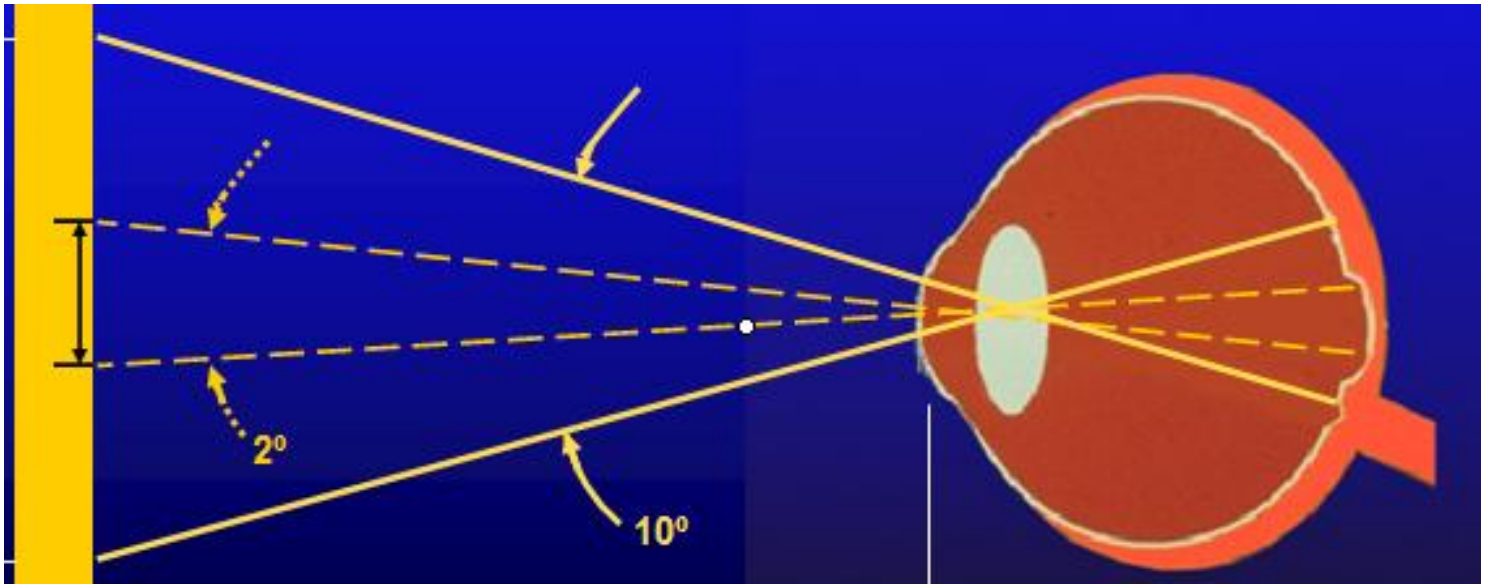
Color: Expression & Space evolution

- Detector of color: Human eye



Color: Expression & Space evolution

- Detector of color: human eye
  - The tristimulus values depend on observer's field of view
  - Color-sensitive cones resided within 2° arc of the fovea

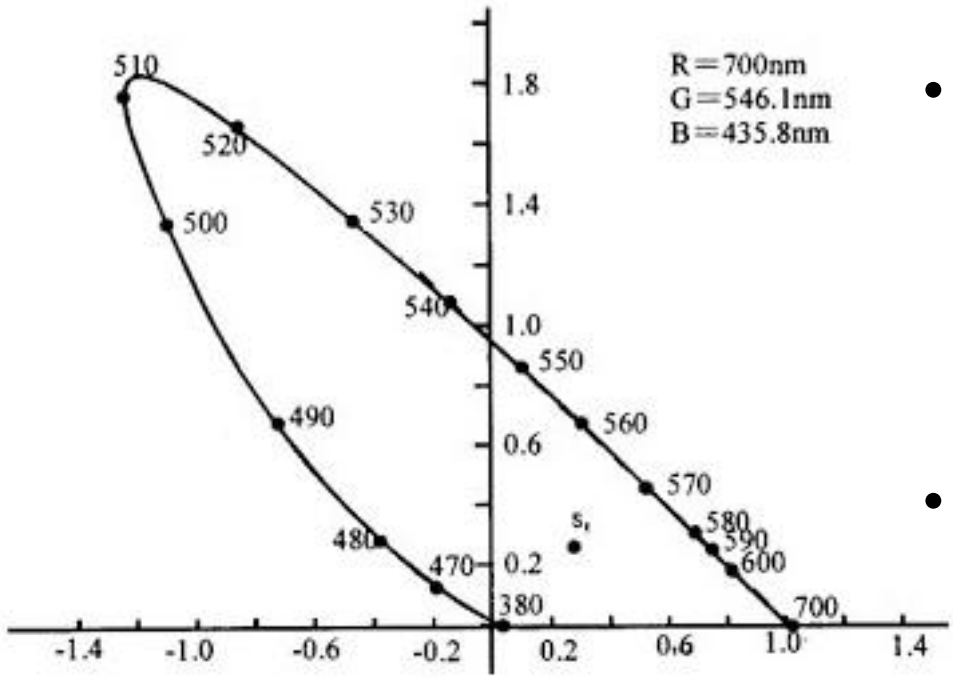


Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 RGB
  - CIE 1931 Standard (colormetric) observer
    - CIE defined color-mapping function
    - To represent an average human's chromatic response within a 2° arc inside the fovea
    - Known as the CIE 1931 2° Standard Observer

Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 RGB

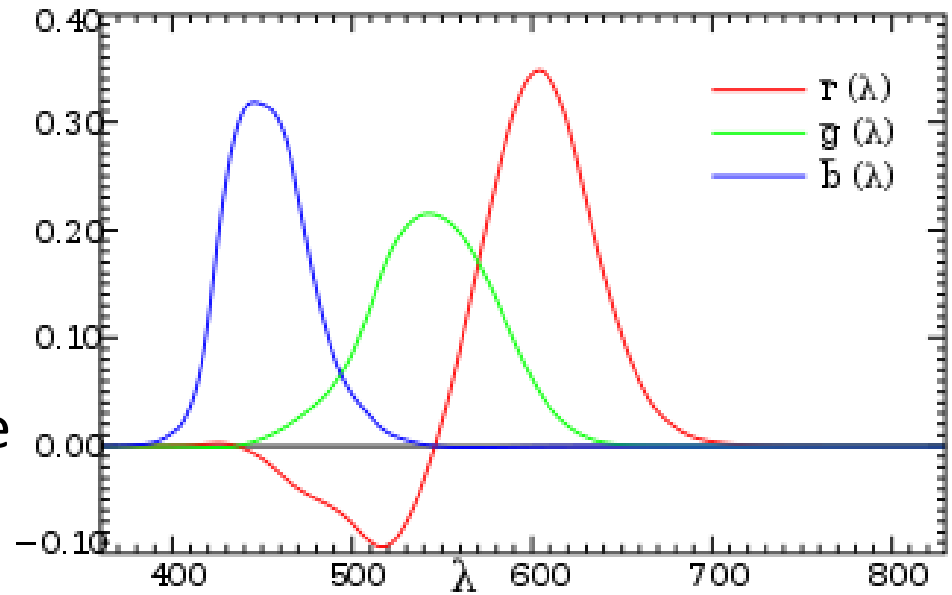


- the spectral locus passes through
  - rg=(0,0) at 435.8 nm
  - rg=(0,1) at 546.1 nm
  - rg=(1,0) at 700 nm
- the equal energy point (E) is at rg=xy=(1/3,1/3)

Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 RGB
  - Color matching functions

Amounts of primaries needed to match the monochromatic test primary at the wavelength shown on the horizontal scale



Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 RGB
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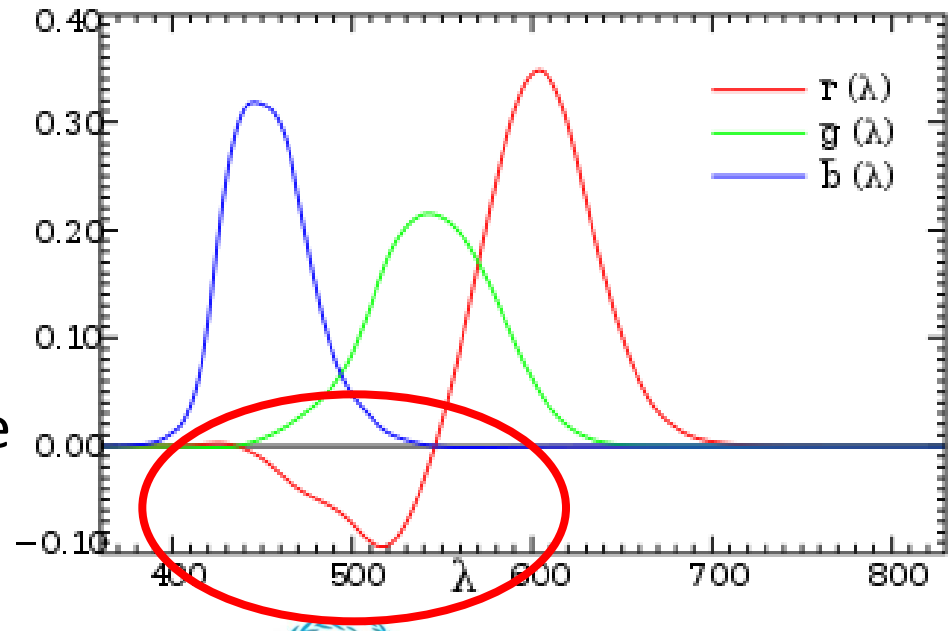
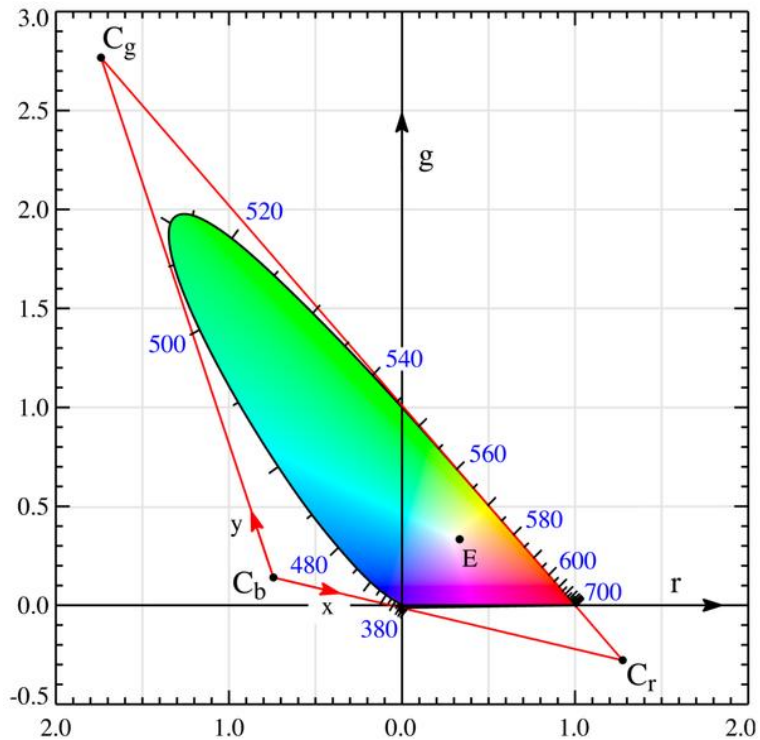


Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 XYZ
- For constant energy white point
  - $x = y = z = 1/3$
- To keep positive values of x and y
  - the gamut of all colors will lie inside the triangle [1,0], [0,0], [0,1]

Color: Expression & Space evolution

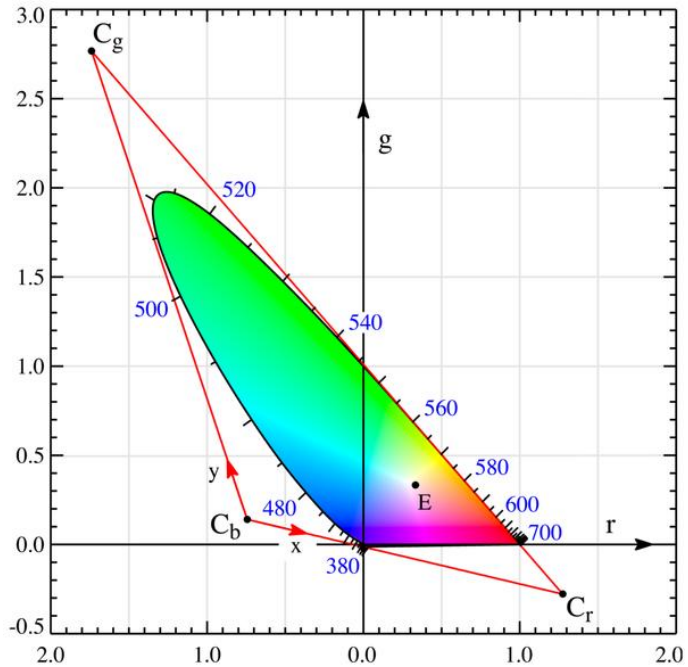
- Color space & Evolution: CIE 1931 XYZ



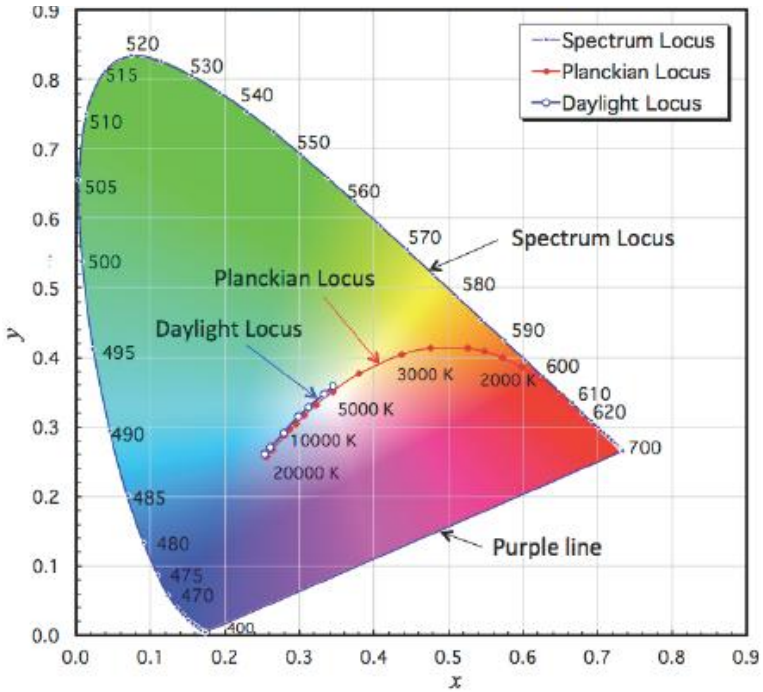
- Triangle Cb-Cg-Cr is the xy=(0,0),(0,1),(1,0) triangle in CIE xy chromaticity space
- Line connecting Cb and Cr is the alychne
- The spectral locus passes through
  - rg=(0,0) at 435.8 nm
  - rg=(0,1) at 546.1 nm
  - rg=(1,0) at 700 nm
- Equal energy point (E) is at rg=xy=(1/3,1/3)

Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 XYZ



rg coordinate



xy coordinate

Color: Expression & Space evolution

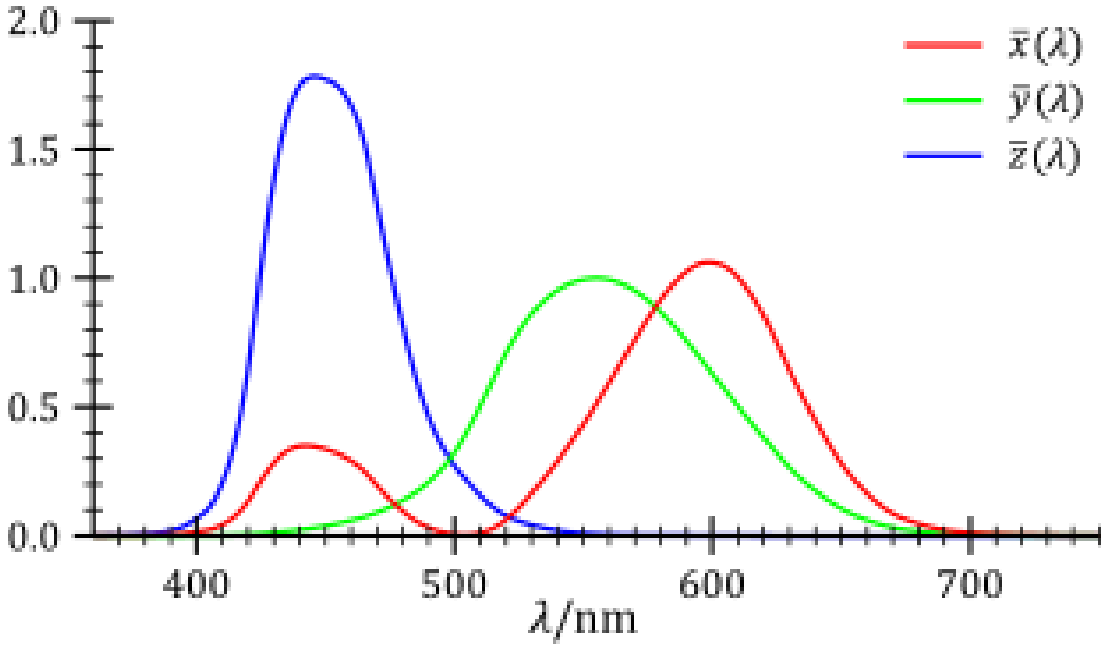
- Color space & Evolution: CIE 1931 XYZ
  - Relationship between XYZ and RGB

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.41847 & -0.15866 & -0.082835 \\ -0.091169 & 0.25243 & 0.015708 \\ 0.00092090 & -0.0025498 & 0.17860 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix},$$

Color: Expression & Space evolution

- Color space & Evolution: CIE 1931 XYZ
  - Color matching functions

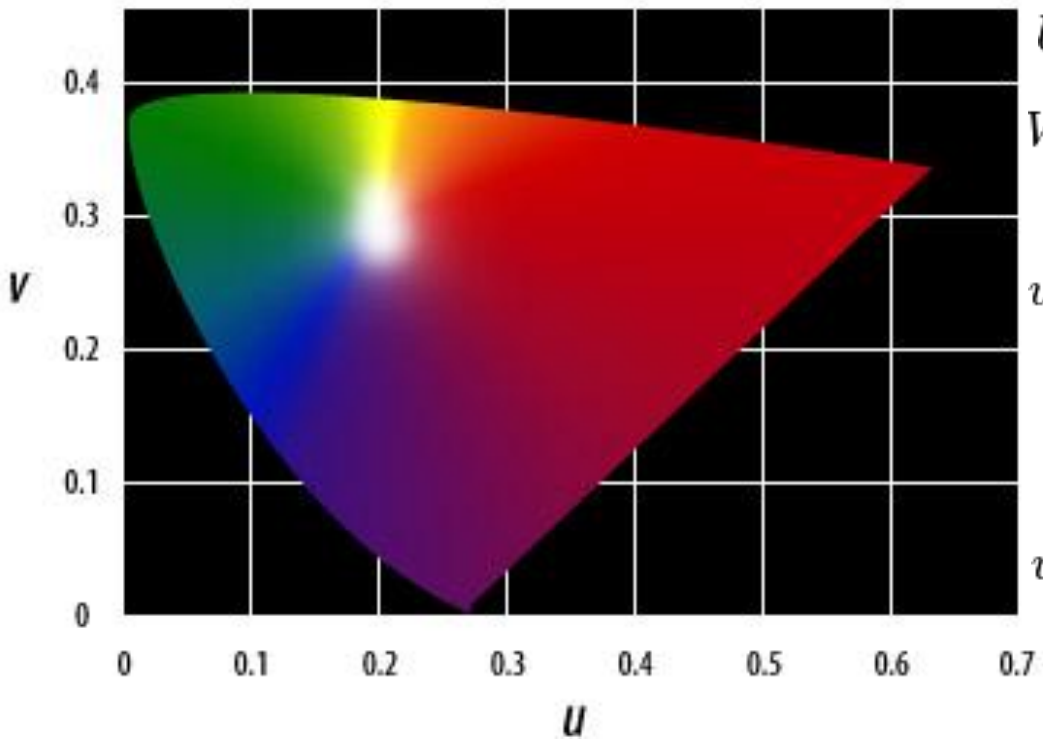


$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

Color: Expression & Space evolution

- Color space & Evolution: CIE 1960 UCS



$$U = \frac{2}{3}X \qquad V = Y$$

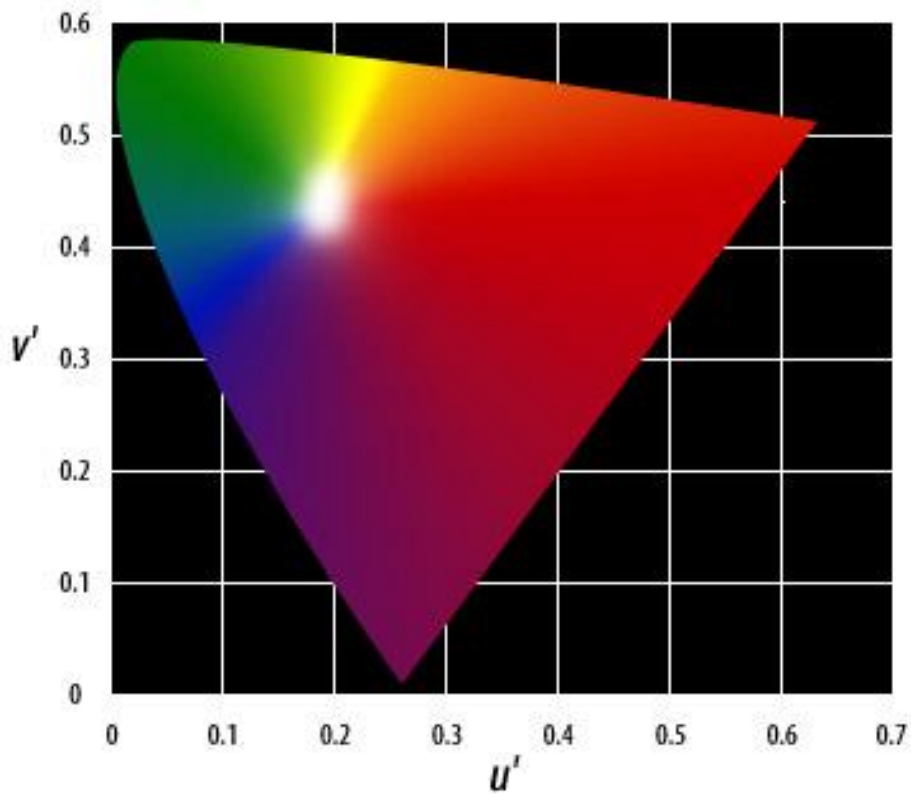
$$W = \frac{1}{2}(-X + 3Y + Z)$$

$$u = \frac{U}{U+V+W} = \frac{4X}{X+15Y+3Z} = \frac{4x}{12y-2x+3}$$

$$v = \frac{V}{U+V+W} = \frac{6Y}{X+15Y+3Z} = \frac{6y}{12y-2x+3}$$

Color: Expression & Space evolution

- Color space & Evolution: CIE 1960 LUV



$$L^* = \begin{cases} \left(\frac{29}{3}\right)^3 Y/Y_n, & Y/Y_n \le \left(\frac{6}{29}\right)^3 \\ 116\,(Y/Y_n)^{1/3} - 16, & Y/Y_n > \left(\frac{6}{29}\right)^3 \end{cases}$$

$$u^* = 13L^* \cdot (u' - u'_n)$$

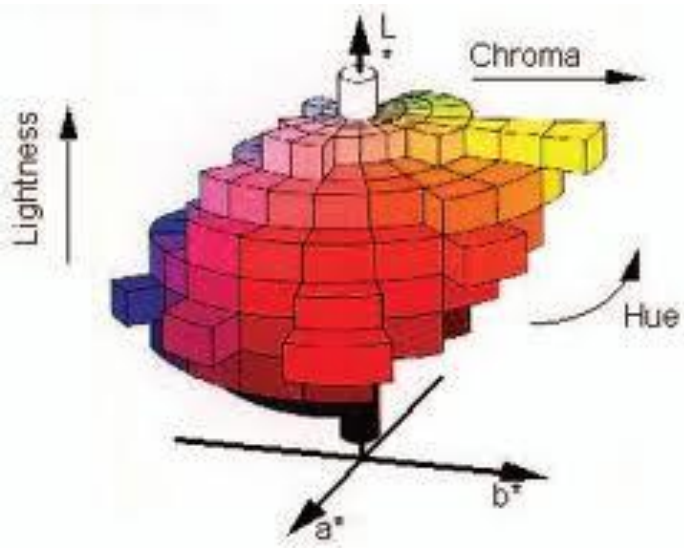
$$v^* = 13L^* \cdot (v' - v'_n)$$

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3}$$

$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{-2x + 12y + 3}$$

Color: Expression & Space evolution

- Color space & Evolution: CIE 1976 Lab



$$L^\star = 116 f(Y/Y_n) - 16$$
$$a^\star = 500\,[f(X/X_n) - f(Y/Y_n)]$$
$$b^\star = 200\,[f(Y/Y_n) - f(Z/Z_n)]$$

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Color: Expression & Space evolution

- Summary
  - CIE 1931 RGB was developed, based on color matching test
  - RGB transformed into XYZ, to get rid of minus stimulus value in function
  - XYZ transformed into UCS and LUV, LAB

Colorimetry

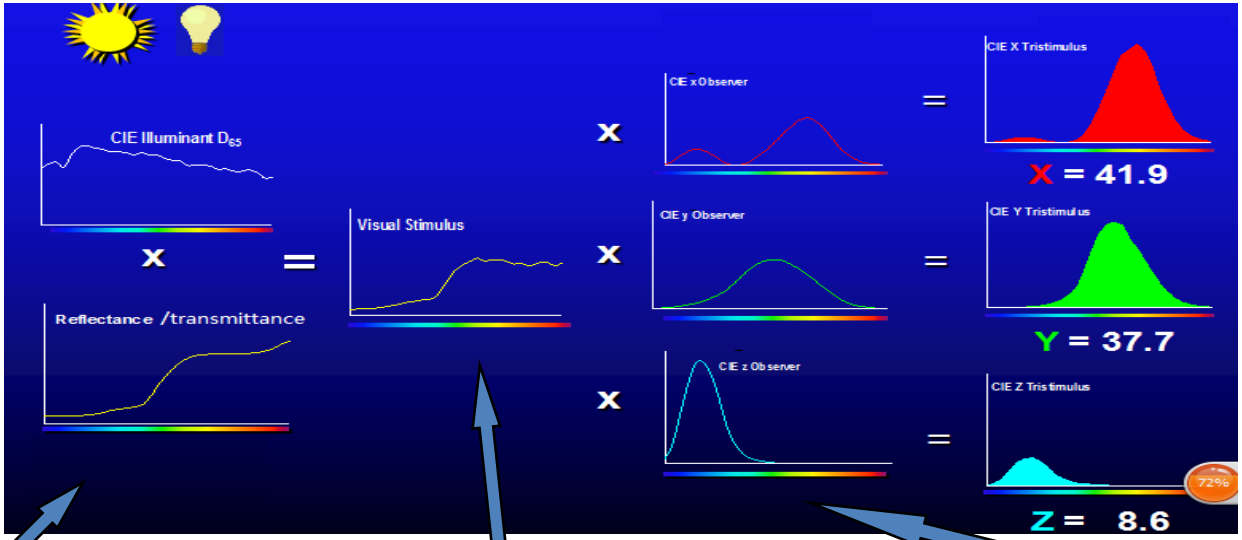
- Parameters & definitions
  - Color coordinate, CCT, CRI
- Color
  - Expression & Space evolution
- "Calculation" of the Colorimetry parameters
  - Color coordinate
  - Tc & CCT
  - CRI, Ra

"Calculation": Color coordinate

- Color coordinate
  - For light from light source / reflected / transmitted
  - For light combined
  - Metamerism
  - Dominant wavelength and purity

"Calculation": Color coordinate

- Color coordinate
  - For light from light source / reflected / transmitted

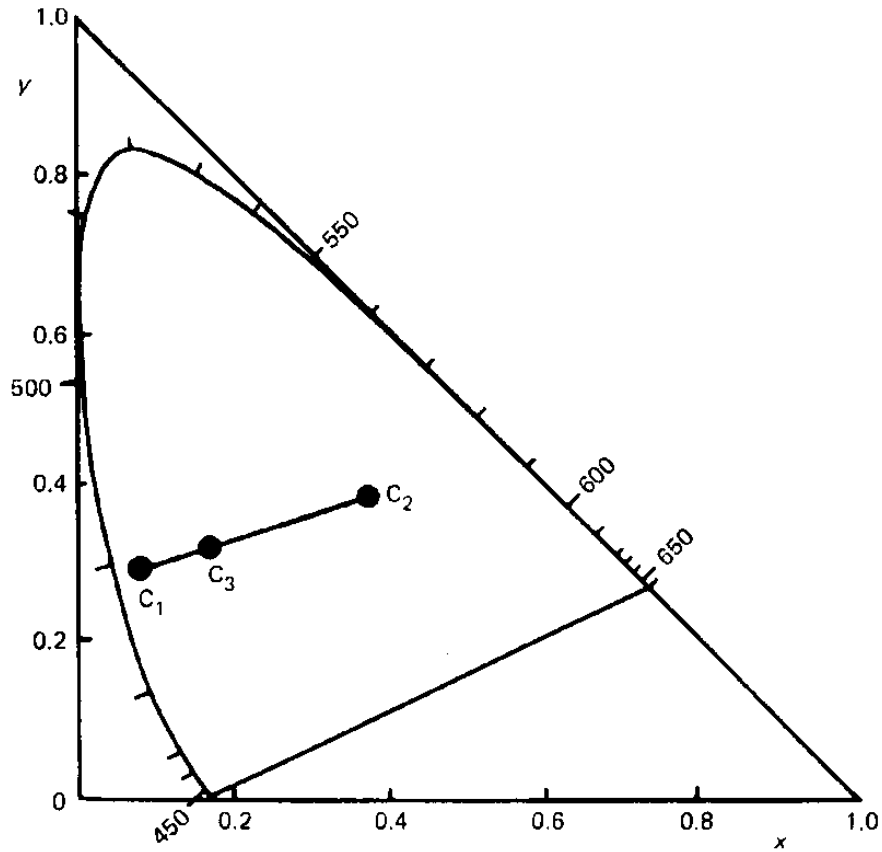


Light spectrum → Spectrum that human eye received → color mixting / separating

"Calculation": Color coordinate

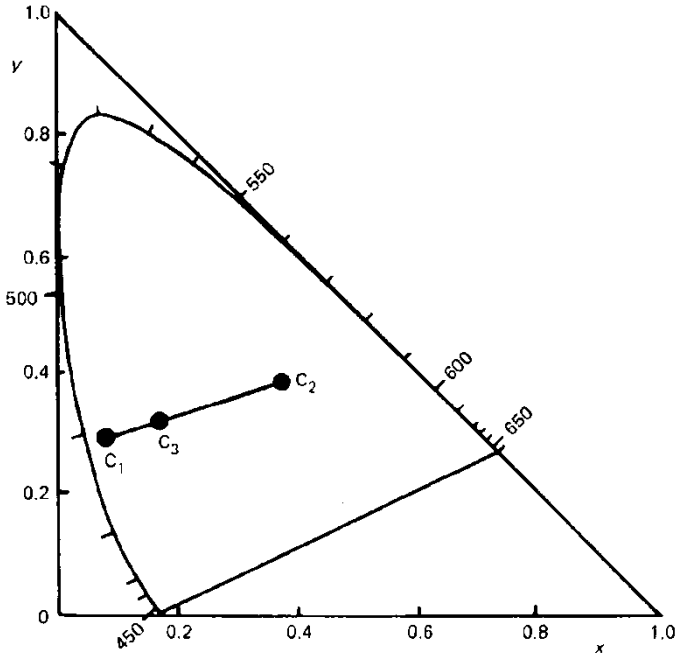
- Color coordinate
  - For light combined

- C_1 : luminance m_1; (x_1 , y_1)
- C_2 : luminance m_2; (x_2 , y_2)
- C_3 : combined light of C_1 & C_2
- 1 luminace unit= $1/L_Y$



"Calculation": Color coordinate

- Color coordinate
  - For light combined



$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

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

C_1 : $X_1 = m_1 x_1 / L_Y y_1$, $Y_1 = m_1 / L_Y$, $Z_1 = m_1 z_1 / L_Y y_1$

C_2 : $X_2 = m_2 x_2 / L_Y y_2$, $Y_2 = m_2 / L_Y$, $Z_2 = m_2 z_2 / L_Y y_2$

C_3 : $X_3 = m_1 x_1 / L_Y y_1 + m_2 x_2 / L_Y y_2$

$Y_3 = m_1 / L_Y + m_2 / L_Y$

$Z_3 = m_1 z_1 / L_Y y_1 + m_2 z_2 / L_Y y_2$

$x + y + z = 1$,

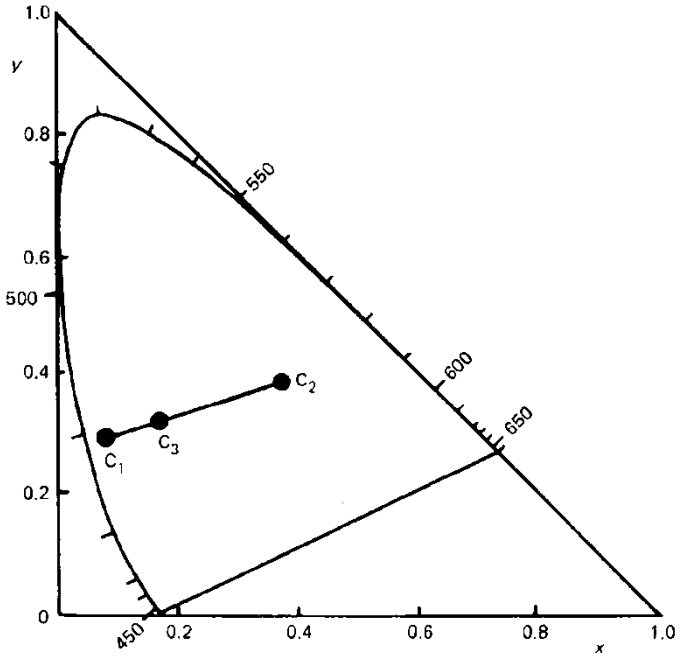
$X+Y+Z = m_1 / L_Y y_1 + m_2 / L_Y y_2$,

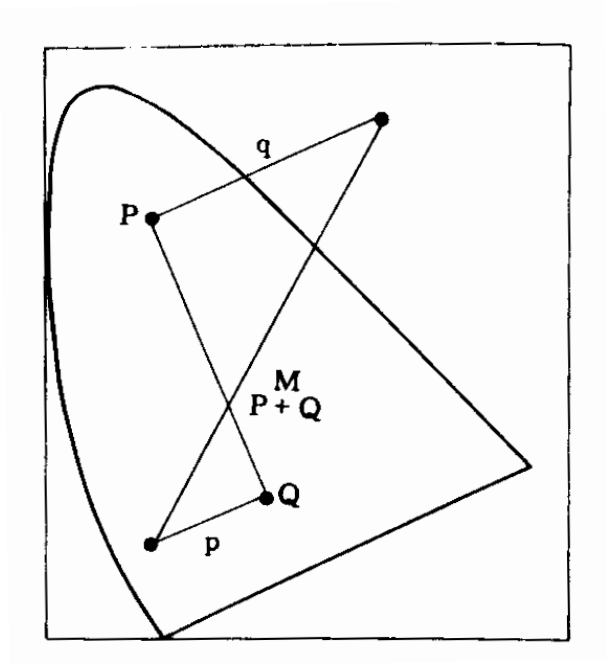
then: $x = (m_1 x_1 / y_1 + m_2 x_2 / y_2) / (m_1 / y_1 + m_2 / y_2)$

$y = (m_1 + m_2) / (m_1 / y_1 + m_2 / y_2)$

"Calculation": Color coordinate

- Color coordinate
  - For light combined





"Calculation": Color coordinate

- Color coordinate
  - Metamerism
    - Different spectral power distribution, but same color

$$X = K\int_{380}^{780} S(\lambda)\rho_1(\lambda)\bar{x}(\lambda)d\lambda = K\int_{380}^{780} S(\lambda)\rho_2(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = K\int_{380}^{780} S(\lambda)\rho_1(\lambda)\bar{y}(\lambda)d\lambda = K\int_{380}^{780} S(\lambda)\rho_2(\lambda)\bar{y}(\lambda)d\lambda$$

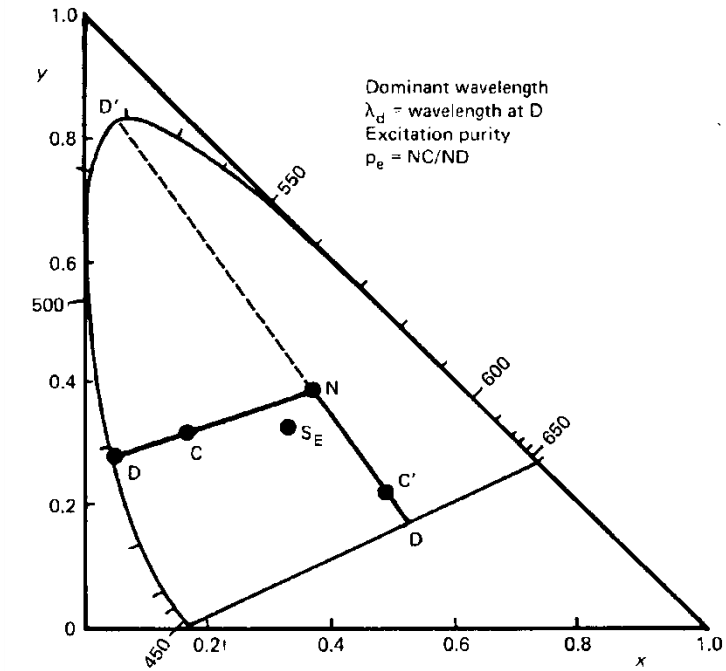
$$Z = K\int_{380}^{780} S(\lambda)\rho_1(\lambda)\bar{z}(\lambda)d\lambda = K\int_{380}^{780} S(\lambda)\rho_2(\lambda)\bar{z}(\lambda)d\lambda$$

$$\rho_1(\lambda) = \rho_2(\lambda)$$

$$\rho_1(\lambda) \neq \rho_2(\lambda)$$

"Calculation": Color coordinate

- Color coordinate
  - Dominant wavelength andpurity



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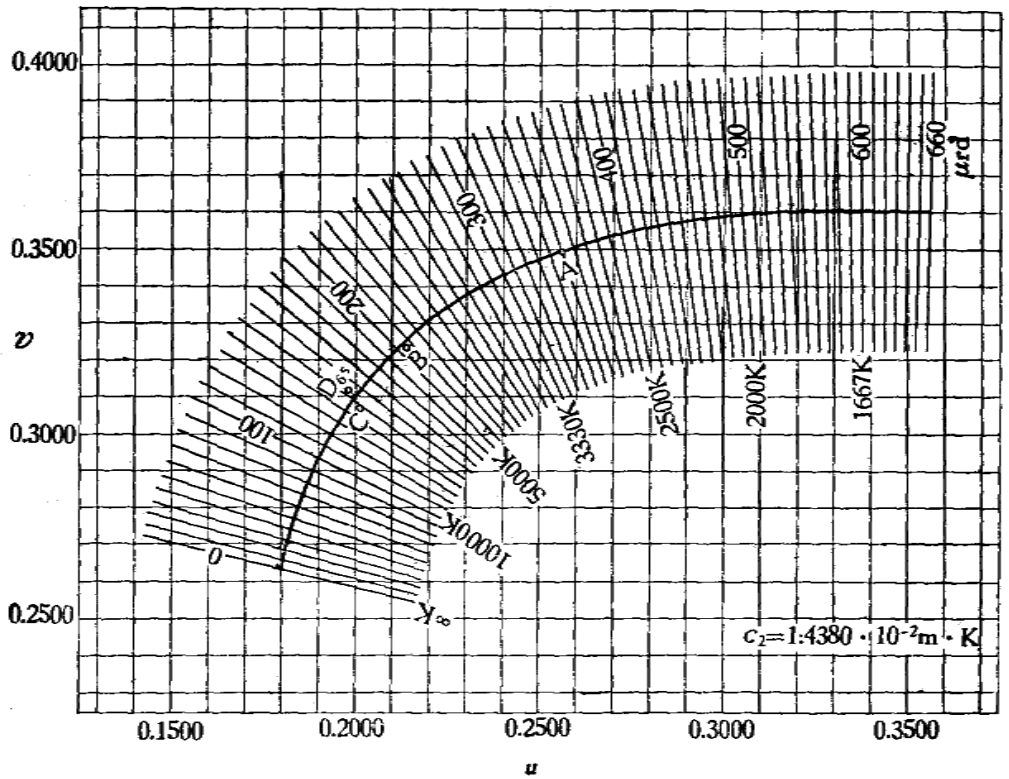
Colorimetry

- Parameters & definitions
  - Color coordinate, CCT, CRI
- Color
  - Expression & Space evolution
- "Calculation" of the Colorimetry parameters
  - Color coordinate
  - Tc & CCT
  - CRI, Ra

"Calculation": Tc & CCT

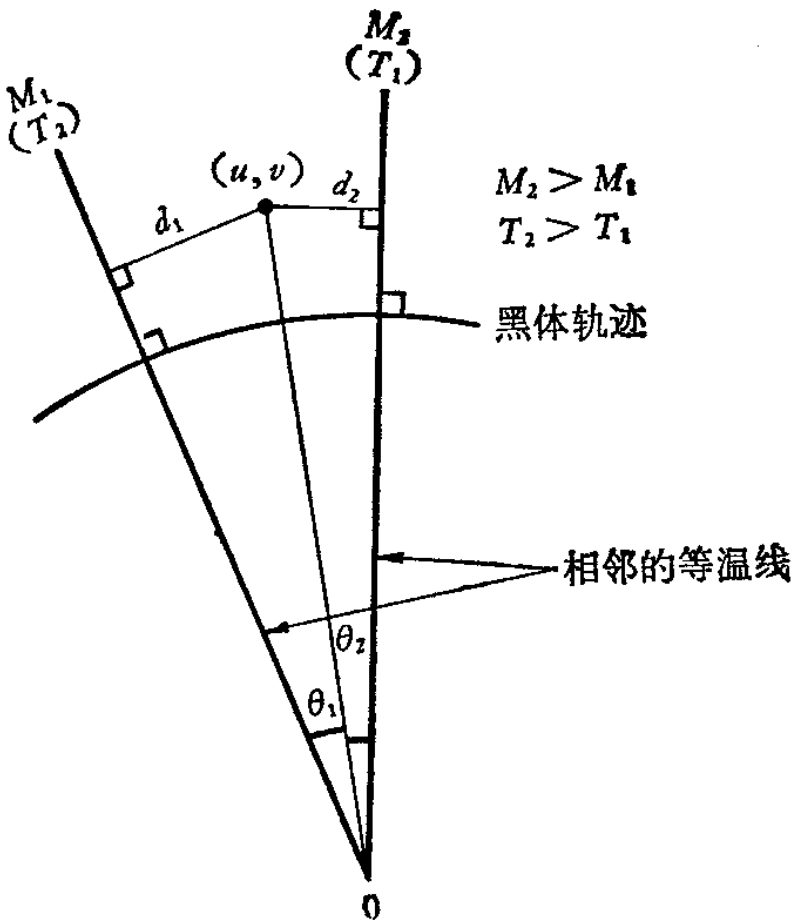
- Color temperature of a light source (Tc)
  - Temperature of an ideal black body radiator that radiates light of comparable hue to that of the light source
- Corelated color temperature (CCT)
  - Color temperature of a black body radiator which to human color perception most closely matches the light from the lamp

"Calculation": Tc & CCT



Mired lines in CIE 1960 UCS

"Calculation": Tc & CCT



$$\frac{1}{T_{C48}} \approx \frac{1}{T_1} - \left(\frac{1}{T_1} - \frac{1}{T_2}\right)\left(\frac{d_2}{d_1 + d_2}\right)$$

$T_C = 1.4388\ T_{C48} / 1.4380$

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- "Calculation" of the Colorimetry parameters
  - Color coordinate
  - Tc & CCT
  - CRI, Ra

"Calculation": CRI, Ra

- CRI
  - Definition
  - CIE standard illuminants
  - Specific "color blocks" for comparison
  - Calculation steps for Ra

"Calculation": CRI, Ra

- CRI definition
  - Effect of an illuminant on the color appearance of objects by conscious or subconscious comparison with their color appearance under a reference illuminant
  - Calculated by comparing the color rendering of the test source to that of a "perfect" source which is a black body radiator for sources with correlated color temperatures under 5000 K, and a phase of daylight otherwise (e.g. D65)
  - Chromatic adaptation should be performed

"Calculation": CRI, Ra

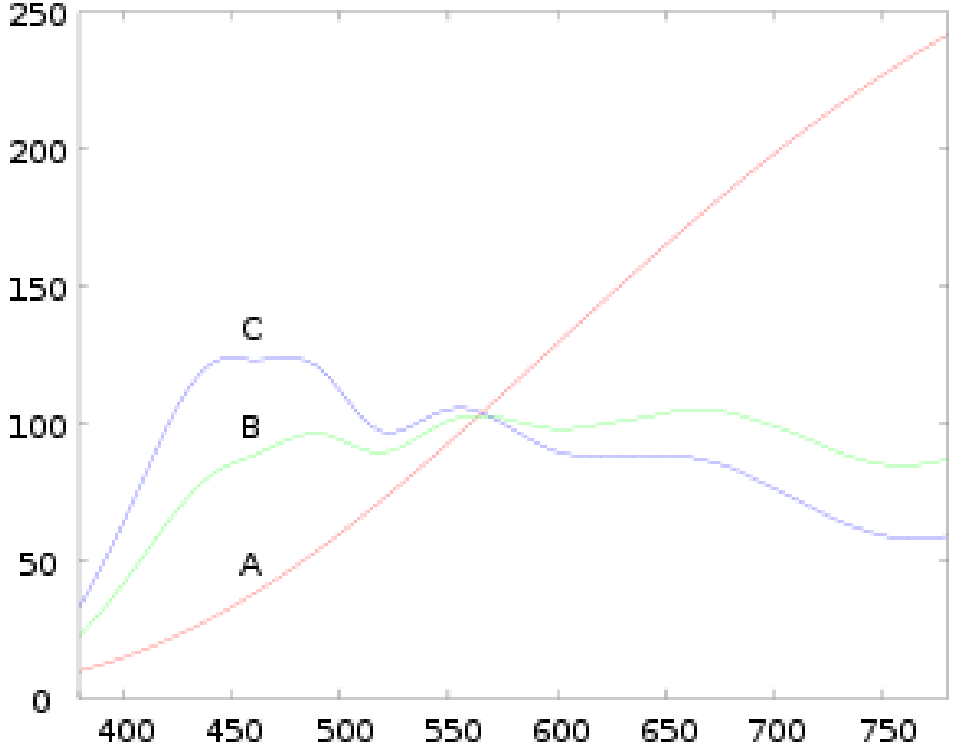
- CIE standard illuminants
  - CIE standard illuminant A
  - CIE standard illuminant B
  - CIE standard illuminant C
  - CIE standard illuminant D

"Calculation": CRI, Ra

- CIE standard illuminant A
  - Representing typical, domestic, tungsten-filament lighting
  - Relative spectral power distribution is that of a Planckian radiator at a temperature of approximately 2856 K
- CIE standard illuminant B & C
  - Daylight simulators, derived from A by using liquid filters
  - B representing noon sunlight, with CCT of 4874K
  - C representing average daylight with CCT of 6774K

"Calculation": CRI, Ra

- CIE standard illuminants A & B & C



Relative spectral power distributions (SPDs) of CIE illuminants A, B, and C from 380nm to 780nm.

"Calculation": CRI, Ra

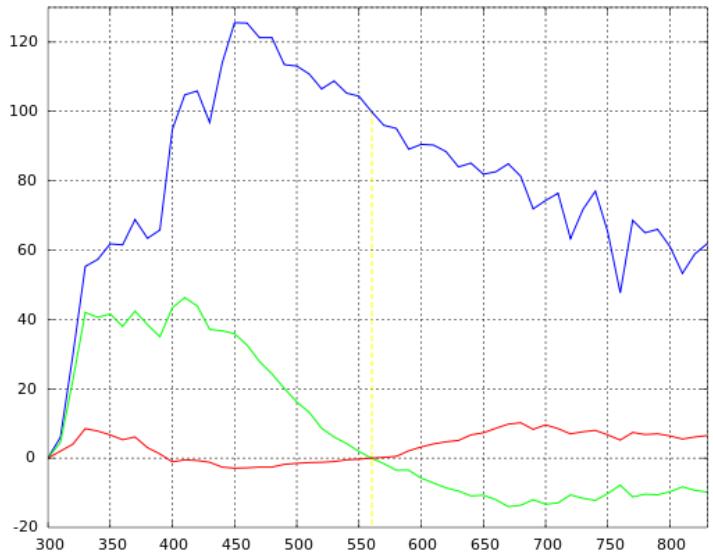
- CIE standard illuminants D
  - Constructed to represent natural daylight
    - Difficult to produce artificially
    - Easy to characterize mathematically
  - Relative SPD can be derived from its chromaticity coordinates in CIE 1931 color space

$$x_D = \begin{cases} 0.244063 + 0.09911\frac{10^3}{T} + 2.9678\frac{10^6}{T^2} - 4.6070\frac{10^9}{T^3} & 4000K \leq T \leq 7000K \\ 0.237040 + 0.24748\frac{10^3}{T} + 1.9018\frac{10^6}{T^2} - 2.0064\frac{10^9}{T^3} & 7000K < T \leq 25000K \end{cases}$$

$$y_D = -3.000x_D^2 + 2.870x_D - 0.275$$

"Calculation": CRI, Ra

- CIE standard illuminants D



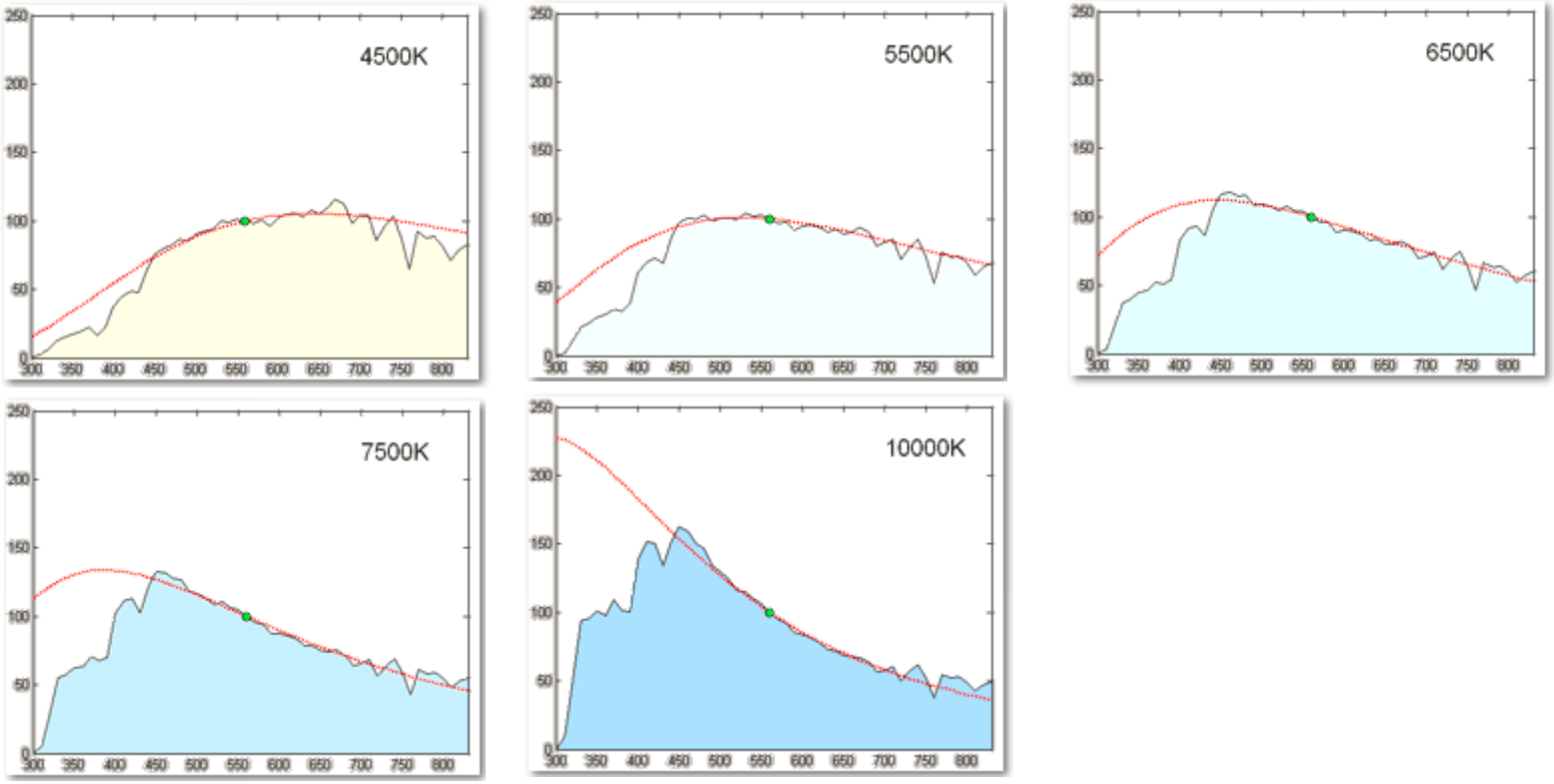
$$S(\lambda) = S_0(\lambda) + M_1 S_1(\lambda) + M_2 S_2(\lambda)$$
$$M_1 = (-1.3515 - 1.7703x_D + 5.9114y_D)/M$$
$$M_2 = (0.03000 - 31.4424x_D + 30.0717y_D)/M$$
$$M = 0.0241 + 0.2562x_D - 0.7341y_D$$

Characteristic vectors of illuminant D: component SPDs S0, S1, S2

- S0 is the mean of all the SPD samples, which is the best reconstituted SPD that can be formed with only a fixed vector
- S1 corresponds to yellow–blue variation, accounting for changes in the correlated color temperature due to presence or absence of clouds or direct sunlight
- S2 corresponds to pink–green variation caused by the presence of water in the form of vapor and haze

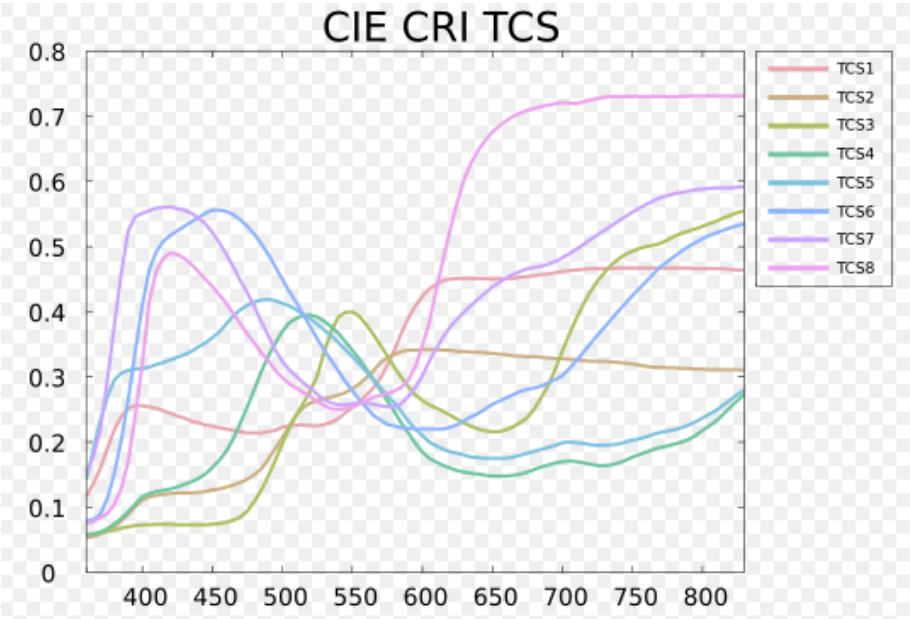
"Calculation": CRI, Ra

- CIE standard illuminants D



"Calculation": CRI, Ra

- Specific "color blocks"



Name	Appr. Munsell	Appearance under daylight	Swatch
TCS01	7,5 R 6/4	Light greyish red	
TCS02	5 Y 6/4	Dark greyish yellow	
TCS03	5 GY 6/8	Strong yellow green	
TCS04	2,5 G 6/6	Moderate yellowish green	
TCS05	10 BG 6/4	Light bluish green	
TCS06	5 PB 6/8	Light blue	
TCS07	2,5 P 6/8	Light violet	
TCS08	10 P 6/8	Light reddish purple	
TCS09	4,5 R 4/13	Strong red	
TCS10	5 Y 8/10	Strong yellow	
TCS11	4,5 G 5/8	Strong green	
TCS12	3 PB 3/11	Strong blue	
TCS13	5 YR 8/4	Light yellowish pink	
TCS14	5 GY 4/4	Moderate olive green (leaf)	

"Calculation": CRI, Ra

- Calculation steps

1. Using the 2° standard observer, find the chromaticity co-ordinates of the test source in the CIE 1960 color space

2. Determine the correlated color temperature (CCT) of the test source by finding the closest point to the Planckian locus on the (u,v) chromaticity diagram
   - If the test source has a CCT<5000 K, use black body for reference
   - otherwise use CIE standard illuminant D

3. Ensure that the chromaticity distance (DC) of the test source to the Planckian locus is under 5.4×10^{-3} in the CIE 1960 UCS

$$DC = \Delta_{uv} = \sqrt{(u_r - u_t)^2 + (v_r - v_t)^2}$$

"Calculation": CRI, Ra

- Calculation steps

4. Using the 2° standard observer, find the co-ordinates of the light reflected by each sample in the CIE 1964 color space

5. Chromatically adaption for each sample by a von Kries transform

$$u_{c,i} = \frac{10.872 + 0.404(c_r/c_t)c_{t,i} - 4(d_r/d_t)d_{t,i}}{16.518 + 1.481(c_r/c_t)c_{t,i} - (d_r/d_t)d_{t,i}}$$

$$v_{c,i} = \frac{5.520}{16.518 + 1.481(c_r/c_t)c_{t,i} - (d_r/d_t)d_{t,i}}$$

$$c = (4.0 - u - 10.0v)/v$$

$$d = (1.708v - 1.481u + 0.404)/v$$

In the formulas subscripts *r* and *t* refer to reference and test light sources, respectively

"Calculation": CRI, Ra

- Calculation steps

6. For each sample, calculate the Euclidean distance between the pair of co-ordinates

7. Calculate the special (i.e., particular) CRI using the formula

$$R_i = 100 - 4.6\Delta E_i$$

8. Find the general CRI (Ra) by calculating the arithmetic mean of the special CRIs

Color: "Calculation"

- Summary
  - Based on spectrum power distribution
    - each wavelength light then expressed in RGB / XYZ
  - Specific color space is used
  - For Ra, standard illuminant is used
  - For Ra, standard color blocks is used

Summary

- Colorimetry
  - Color cooridinate, CCT, Ra is widely used
  - Based on spectrum power distribution
    - each wavelength light then expressed in RGB / XYZ
  - Specific color space is used
  - For Ra, standard illuminant is used
  - For Ra, standard color blocks is used

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Measurement method of SPD

- SPD
- Principle to measure SPD
- Procedure to measure SPD
- key elements to consider during this process
- CFLs and LED
- Comparison of lab's equipments and operation

Measurement method of SPD

- SPD
- Principle to measure SPD
- Procedure to measure SPD
- key elements to consider during this process
- CFLs and LED
- Comparison of lab's equipments and operation

Measurement method of SPD

- SPD
  - Visible light is actually the combination of each wavelength light, expressed as SPD
  - Photometer to receive SPD
    - Mimic the photopic function of human eye, and discard color information
    - Received signal is the amount of light, total flux
  - Spectroradiometer to receive SPD
    - Received signal is SPD
    - Make photopic function calculation to get total flux
    - Make XYZ calculation to get the colorimetric parameters

Measurement method of SPD

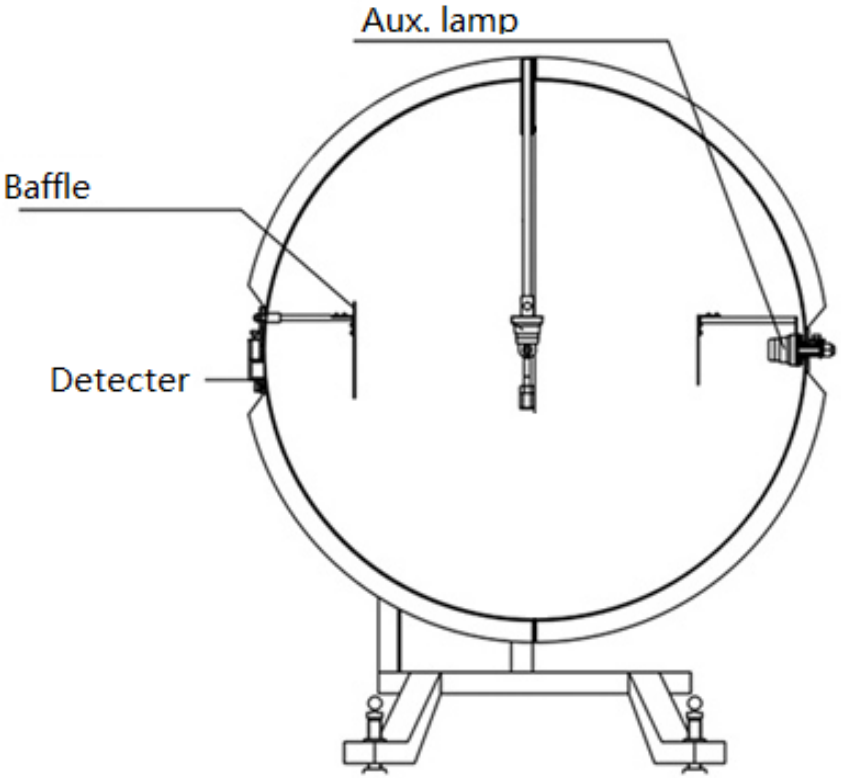
- SPD
- Principle to measure SPD
- Procedure to measure SPD
- key elements to consider during this process

Measurement method of SPD

- Principle to measure SPD
  - Use spectro-radiometer instead of photometer
  - Gonio-spectroradiomter
    - Similar function with gonio-photometer
    - to get the spacial information in each direction
    - make spacial integrating / weighting
  - Integrating sphere
    - Similar funtion with sphere-photometer
    - Integrated / weighted SPD is got

Measurement method of SPD

- Procedures to measure SPD
  - Comparative method
    - Keep regular calibration of standard lamp for traceability
    - Use standard lamp to calibrate the system
    - Make measurement
    - Perform corrections as self-adsorption correction

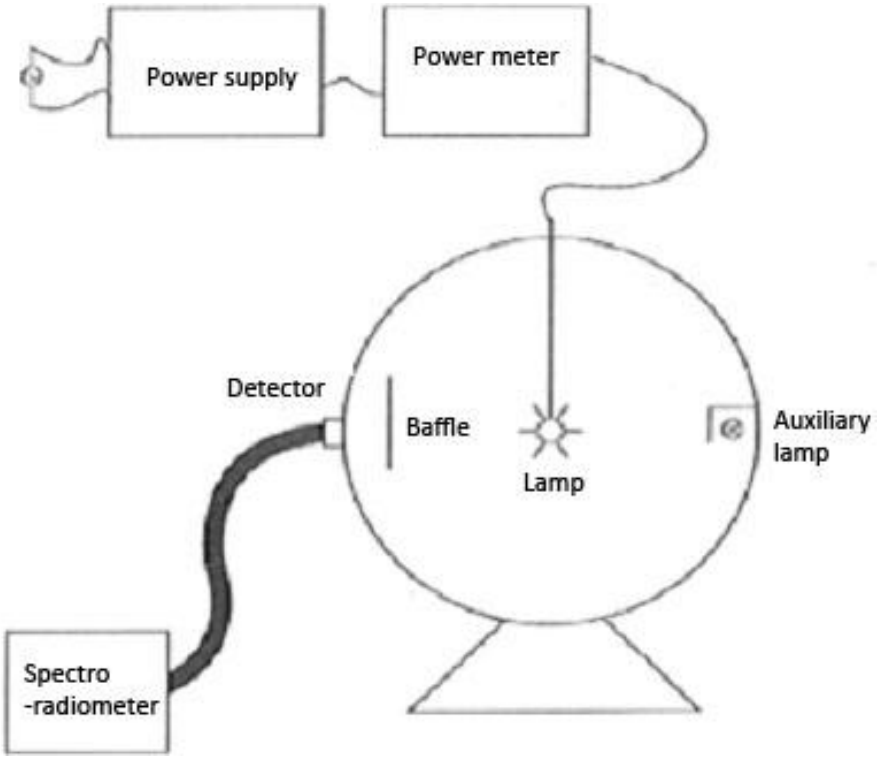


Measurement method of SPD

- Key element to consider during this process
  - Preparation
    - Good understanding in theory, equipment and sample;
    - Strictly controlled environment conditions
    - Standard lamp in good condition and traceability
    - Equipments in good condition and calibration
  - Operation
    - Careful operation of the std. lamp, such as mounting, burning, and storing
    - Sufficient warming up for samples and equipment
    - Properly setting of equipment parameters

Measurement method of SPD

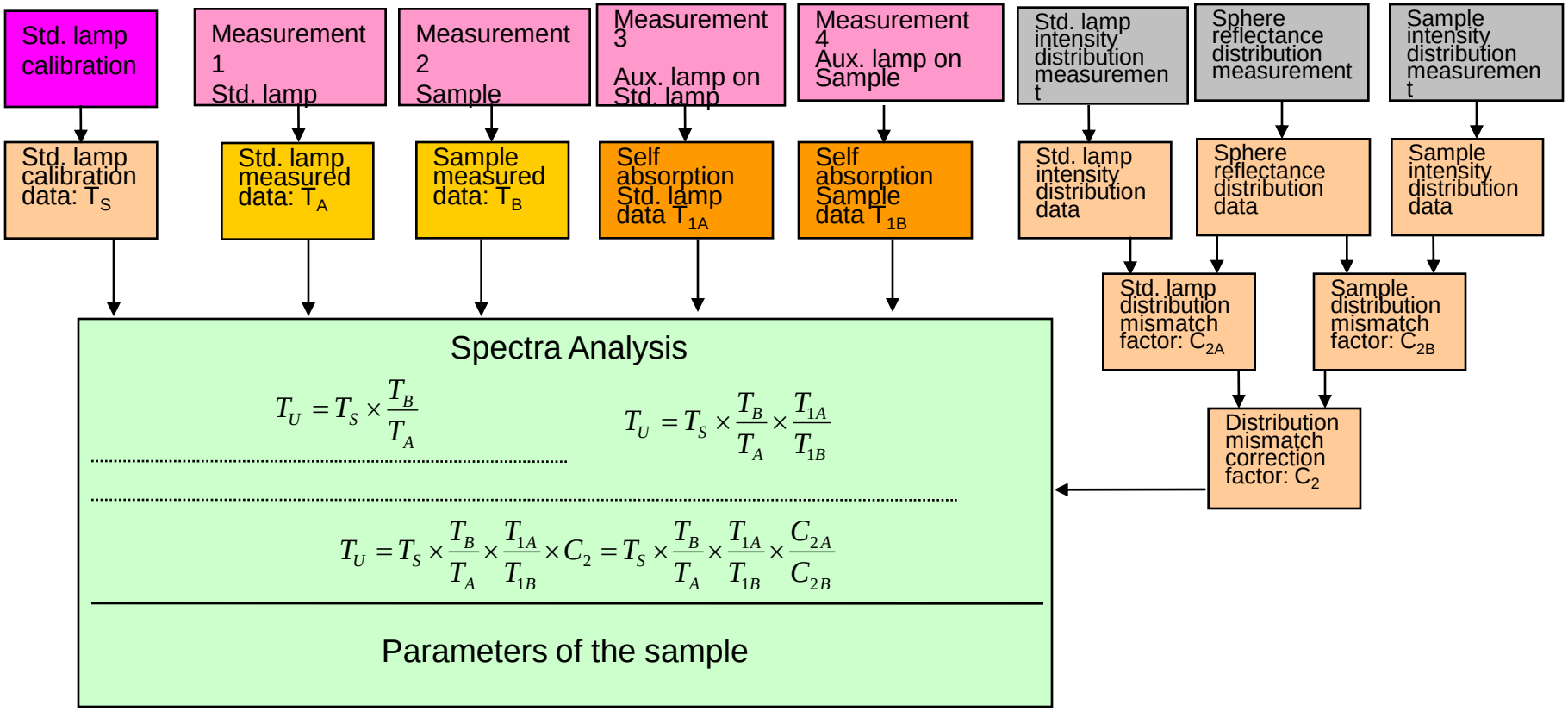
- Comparison of lab's equipments and operation
  - Equipments
    - –Source
    - –Input
    - –Circuit
    - –Detector
  - Procedures
    - –Testing
    - –Correction
    - –Characteristics of sample



Test method

- Measure the SPD of the lamp.
- Use spectroradiometer instead of photometer.
- Use total radiant flux standard lamp instead of total luminous standard lamp. Spectral energy should be used.
- To get spacial distribution information, gonio-spectroradiomter should be used.

Keys in sphere-spectroradiometer system



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- Good understanding of the theory, method, equipment and sapmle;
- Reliable tracing data, such as std. lamp, power-meter;
- Strict control of the environment, such as the input power noise, ambient;
- Careful operation of the std. lamp, such as mounting, burning, and storing
- Sufficient warming up for samples and equipment.
- Properly setting parameters of equipment， such as Integration time， average times

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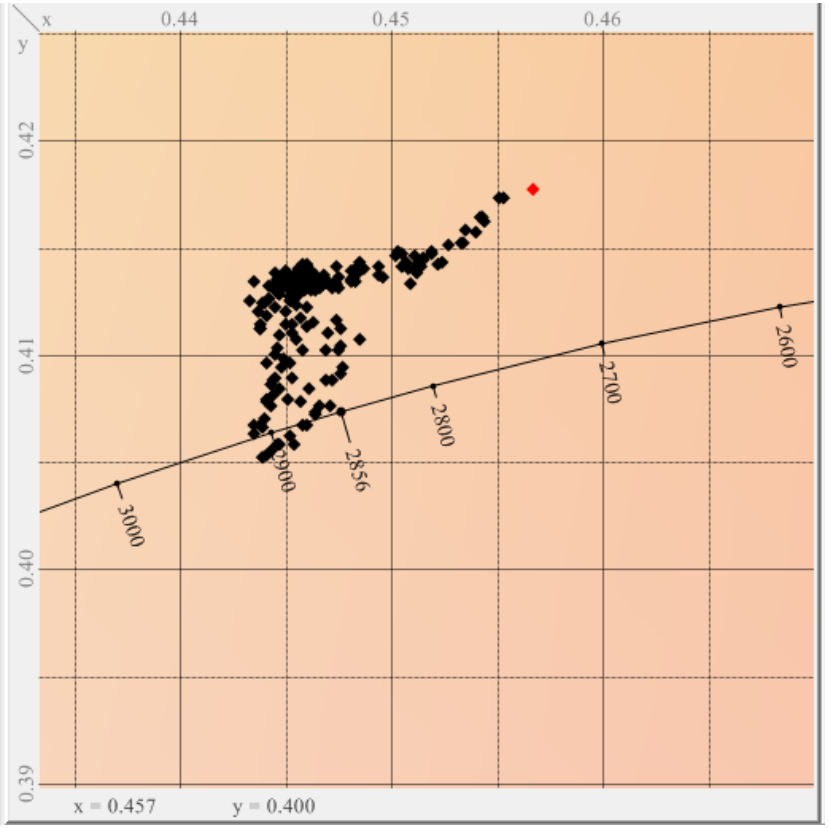
Color distribution in space



Global Efficient Lighting Centre

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Thank you for your attention

National Lighting Test Centre China