Colour appearance

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Scope

- CIE Colorimetry
- Colour appearance models
- Recent developments

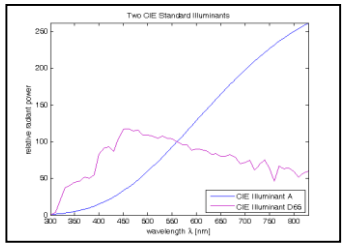
Scope

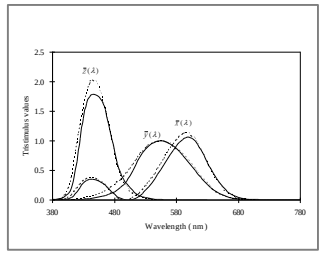
CIE Colorimetry

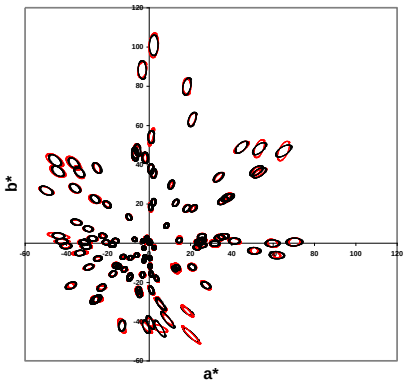
Colour appearance models

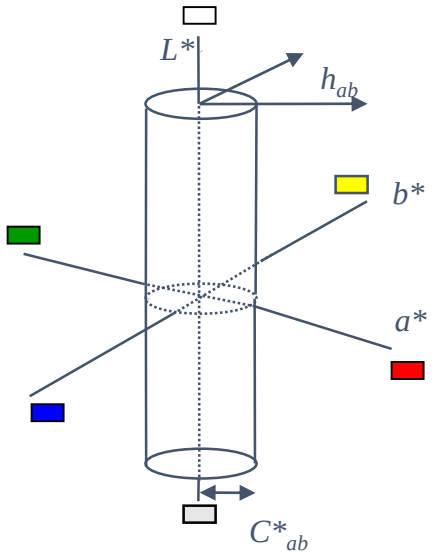
Recent developments

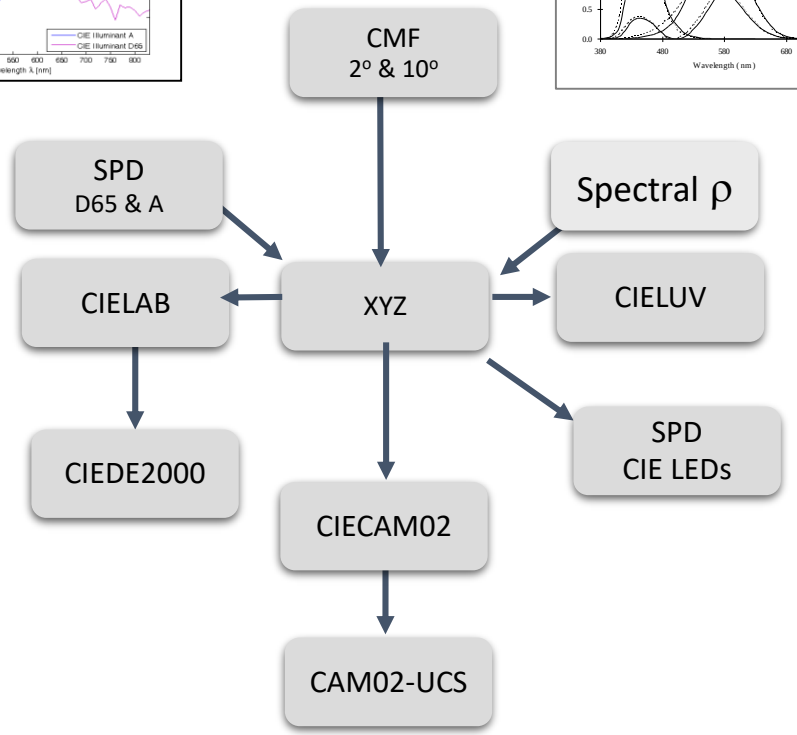
CIE 015:2018 Colorimetry 4th Edition





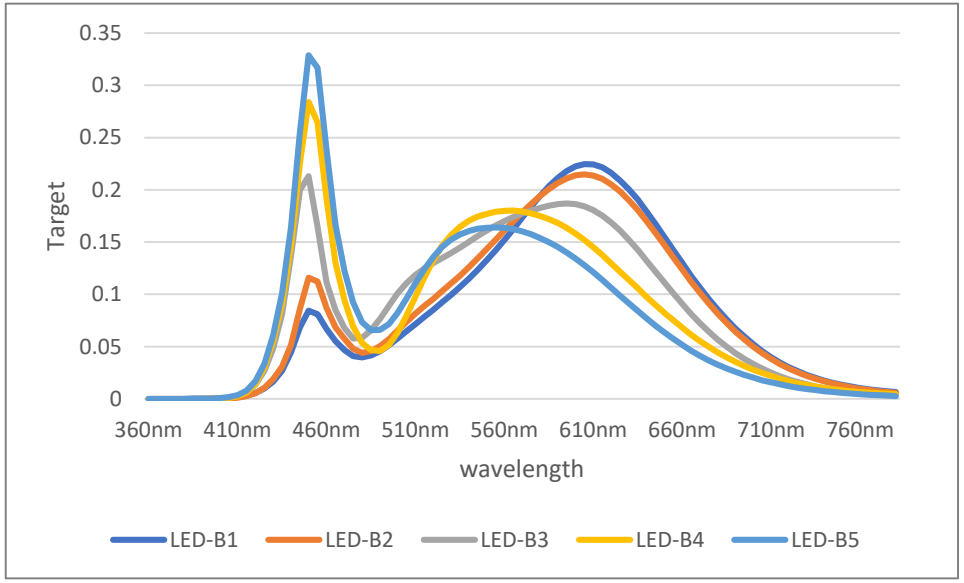


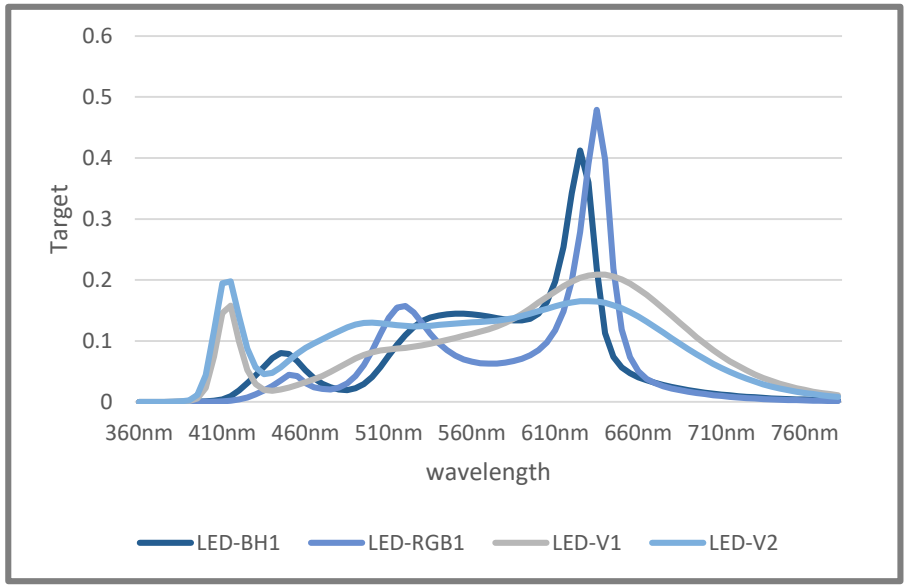




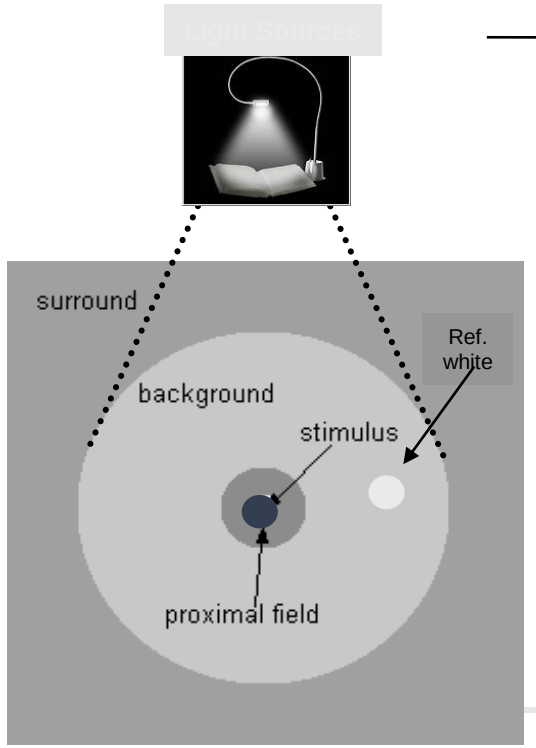
CIE 015:2018 Colorimetry 4th Edition

New CIE LED illuminants





Colour Appearance Model



X Y Z

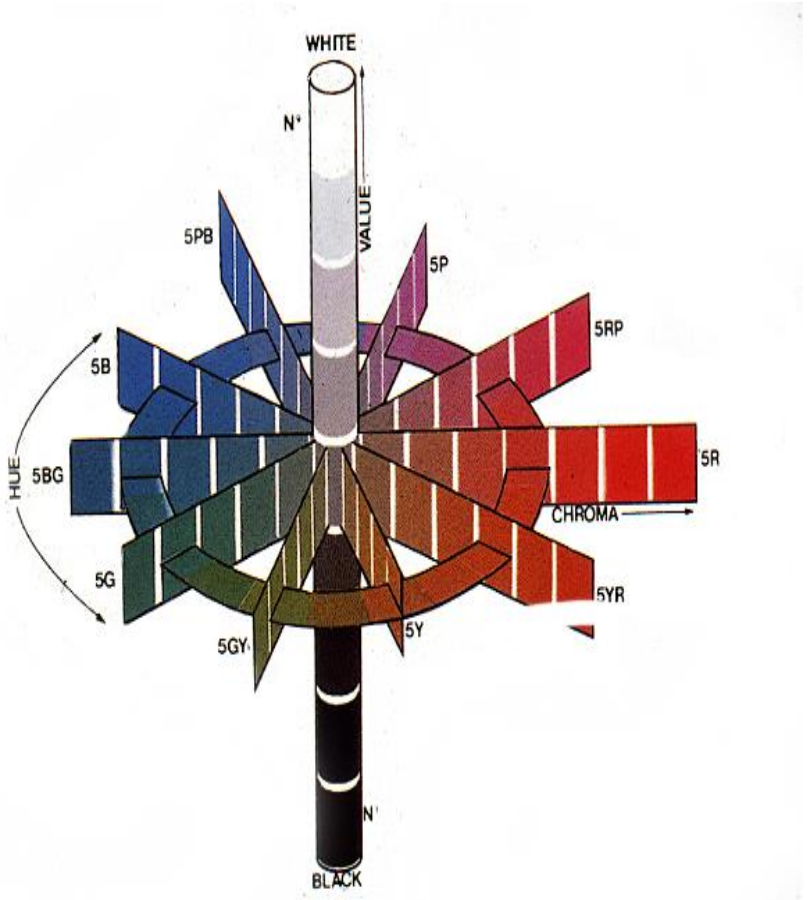
CIECAM02
(CIECAM16)

$X_w\ Y_w\ Z_w$ L_A Y_b *Surround: Average, Dim and Dark*

Lightness (J)
Redness-Greenness (a)
Yellowness-Blueness (b)
Chroma (C)
Colourfulness (M)
Saturation (s)
Hue angle (h)
Hue composition (H)

Colour appearance attributes

- **Lightness**
- Brightness
- **Chroma**
- Colourfulness
- **Saturation**
- Hue angle
- Hue composition



1. M. R. Luo, et. al. Quantifying colour appearance: Part
2. M. R. Luo, et. al. Quantifying colour appearance: Part
3. M. R. Luo, et al., Quantifying colour appearance: Part
4. M. R. Luo, et al., Quantifying colour appearance: Part
5. M. R. Luo, et al., Quantifying colour appearance: Part V *CRA* **20** (1995) 18-35.

Relationship between the absolute and relative colour appearance attributes

$$Lightness = \frac{Brightness}{Brightness_{white}}$$

$$Chroma = \frac{Colourfu\ln ess}{Brightness_{white}}$$

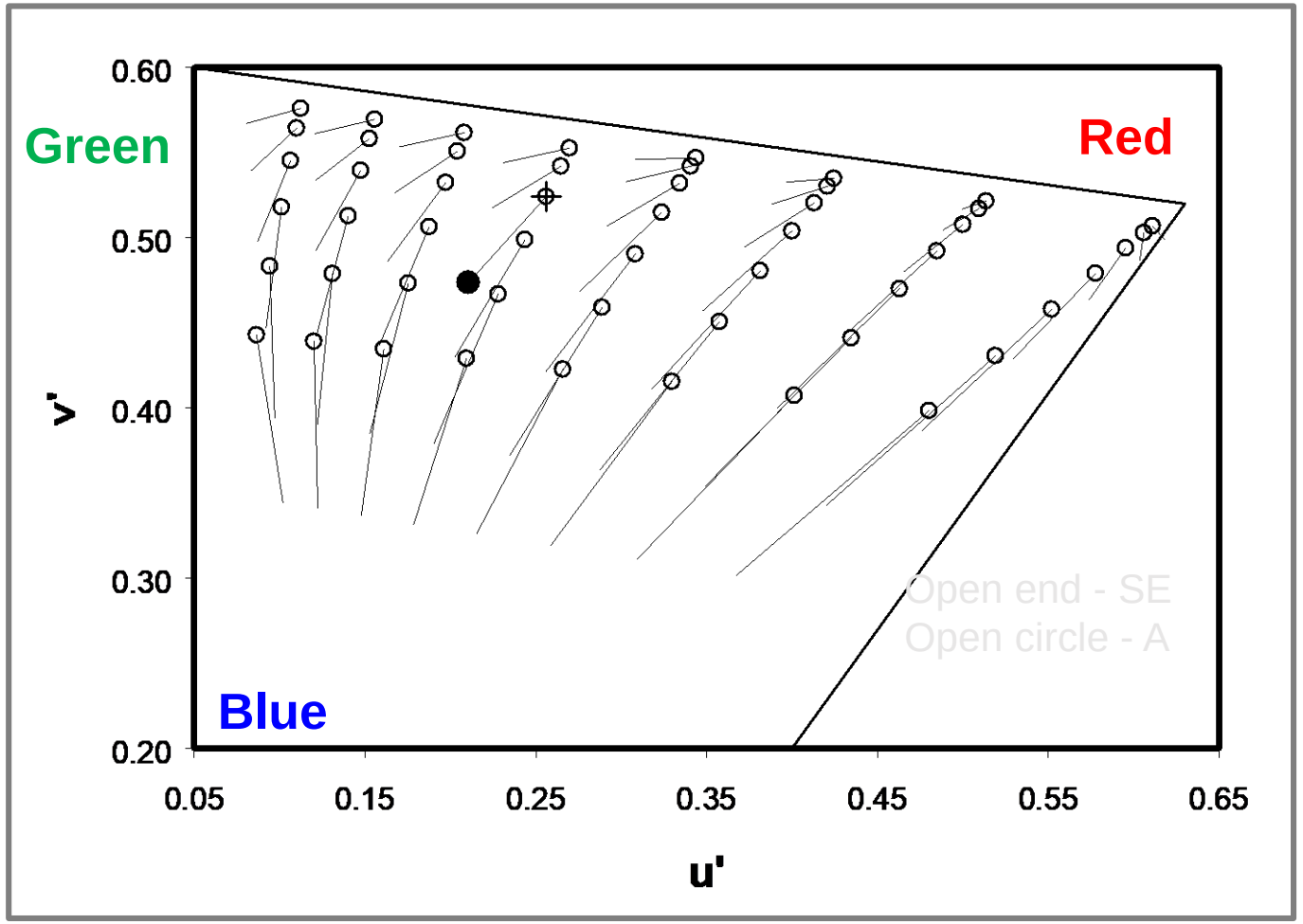
$$Saturation = \frac{Colourfu\ln ess}{Brightness} = \frac{Chroma \times Brightness_{white}}{Lightness \times Brightness_{white}}$$

$$= \frac{Chroma}{Lightness}$$

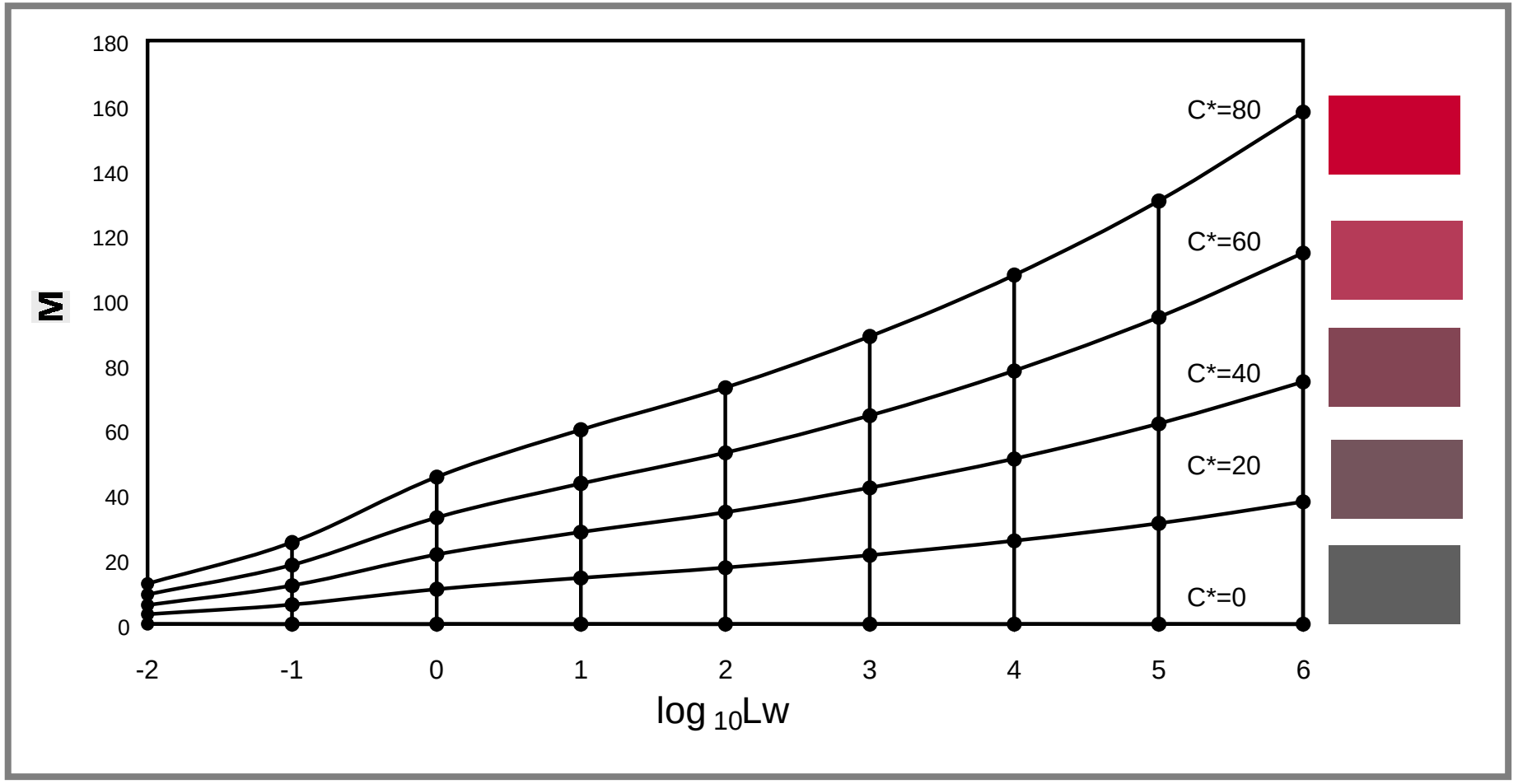
Visual Phenomena

1. Chromatic adaptation effect
2. Hunt effect
3. Stevens effect
4. Surround effect
5. Lightness contrast effect

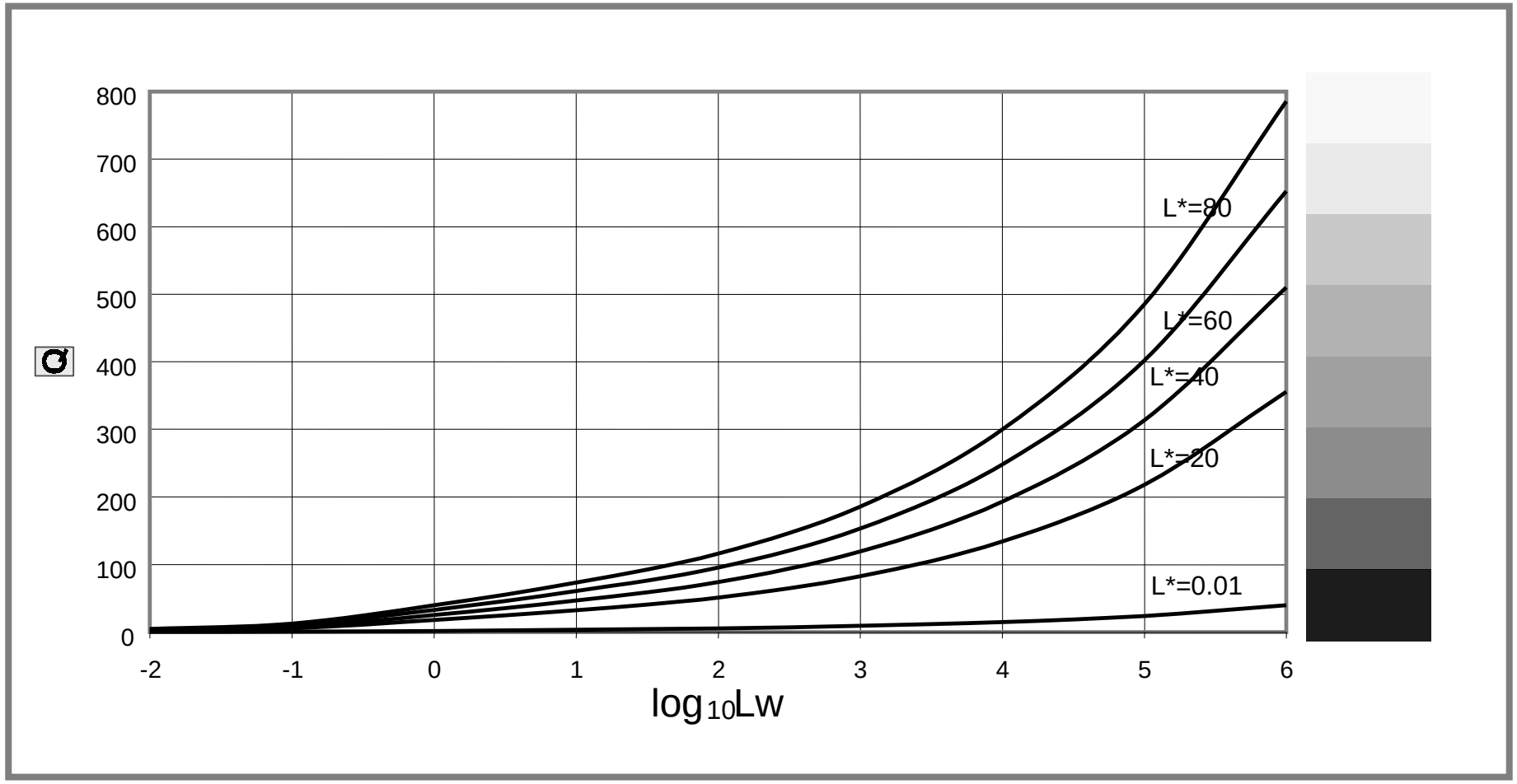
Chromatic Adaptation



Hunt Effect


180
160
140
120
100
80
60
40
20
0
M
-2
-1
0
1
2
3
4
5
6
log 10Lw
C*=80
C*=60
C*=40
C*=20
C*=0

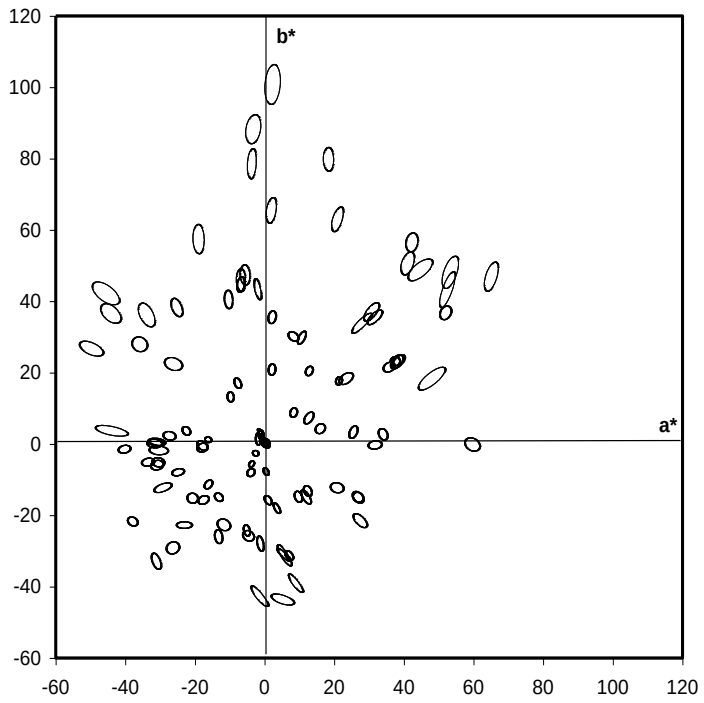
Stevens Effect



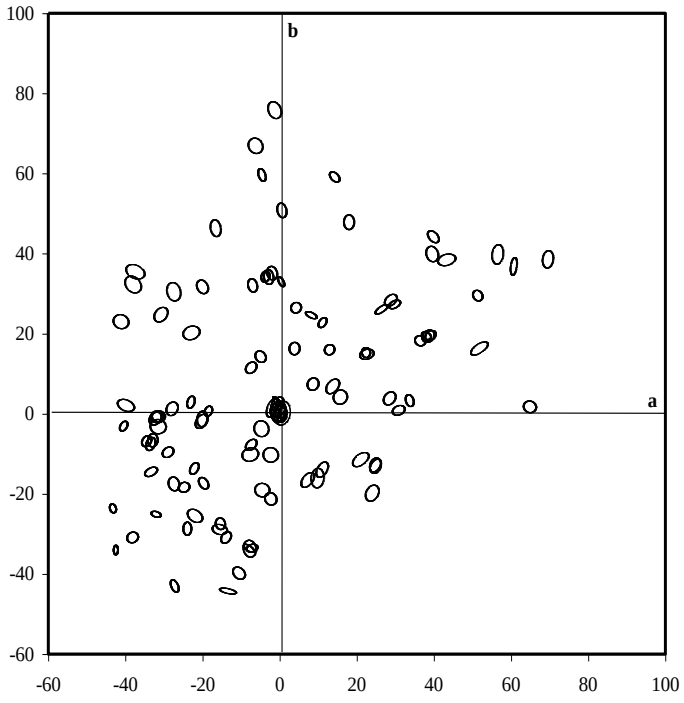
CIE Colour Appearance Models

- **CIECAM97s**
  - CIE TC1-34 *Testing colour appearance models*
  - *M. R. Luo and R. W. G. Hunt, The structures of the CIE 1997 colour appearance model (CIECAM97s), Color Res. Appl., **23** 138-146 (1998).*
- **CIECAM02**
  - CIE TC8-01 *Colour Appearance Modelling for Colour Management Applications,* Scottsdale, Arizona, USA (1998-2002)
  - *N. Moroney, M. D. Fairchild, R.W.G. Hunt, C Li, M. R. Luo and T. Newman, The CIECAM02 Color Appearance Model, CIC2002, Scottsdale, Arizona, pp23-27.*
- **CIECAM16**
  - *CIE JTC10 A new colour appearance model for colour management systems: CIECAM16, (Jiju, South Korea 2017-2020).*
  - *C. J. Li. Z. Li, Z. Wang, Y. Xu, M. R. Luo, G. H. Cui, M. Melgosa, M. H. Brill, and M. R. Pointer, Comprehensive color solutions, CAM16, CAT16 and CAM16-UCS, Col., Res. and Appl., (2017), pp42703-718.*

Uniform Colour Spaces



CIELAB



CAM02-UCS

M. R. Luo, G. Cui, C. Li, Uniform Colour Spaces Based on CIECAM02 Colour Appearance Model, Color Res. Appl. 31 (2006) 320-330.

Scope

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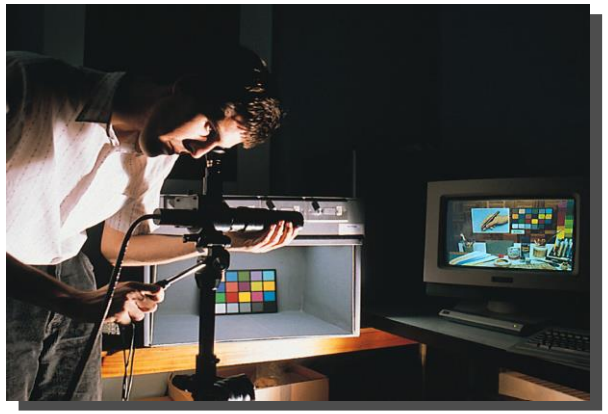
Recent developments



CIECAM

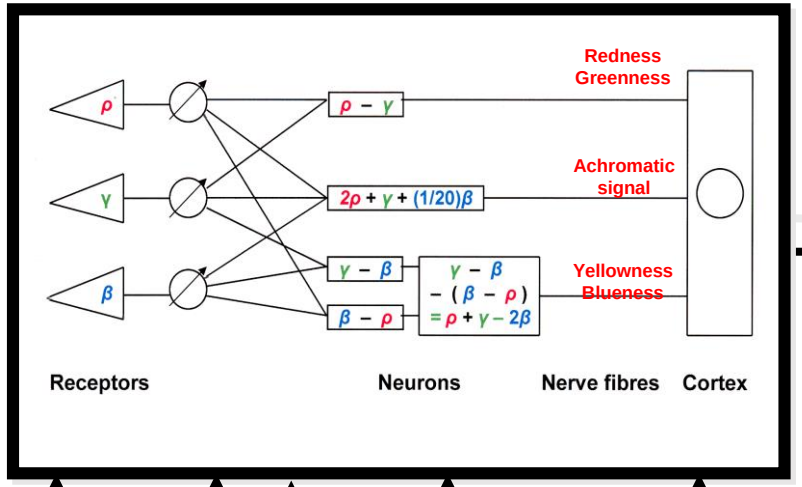
Input and output parameters

X Y Z

$$\rho_{10} = k_\rho \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{l}_{10}(\lambda)\,d\lambda$$

$$\gamma_{10} = k_\gamma \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{m}_{10}(\lambda)\,d\lambda$$

$$\beta_{10} = k_\beta \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{s}_{10}(\lambda)\,d\lambda$$



Related

Red-Green (a)
Yellow-blue (b)
Brightness (Q)
Lightness (J)
Colourfulness (M)
Chroma (C)
Saturation (s)
Hue angle (h)
Hue composition (H)

Unrelated

Brightness (Q_{un})
Colourfulness (M_{un})
White amount (W_{un})
Hue

Lightness (J')
Red-Green (a')
Yellow-blue (b')
Colourfulness (M')
Hue angle (h)
ΔJ', ΔM', ΔH, $ΔE_{J'a'b'}$

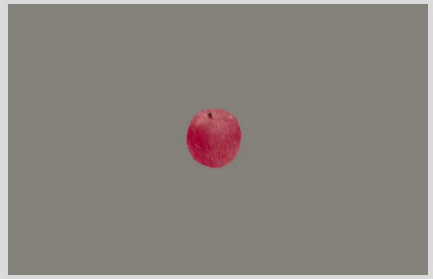
X_w Y_w Z_w ***L_A*** ***Y_b*** ***Surround: Average, Dim and Dark*** ***Angle subtense (θ)***

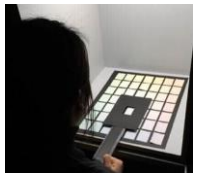
Recent developments

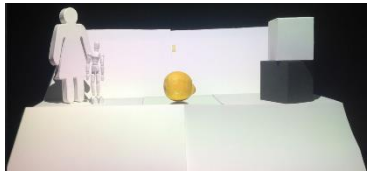
Incomplete chromatic adaptation

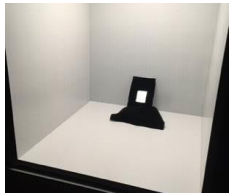
CAT02- Incomplete adaptation

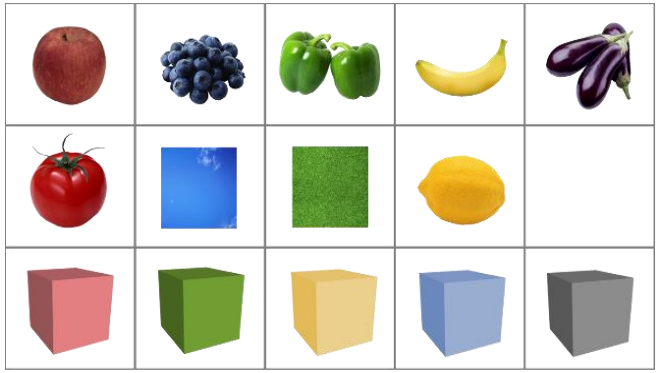
Zhai et al, OE 26(2018)7724-39
Zhu et al, CRA(DOI/10.1002/Col.22500)

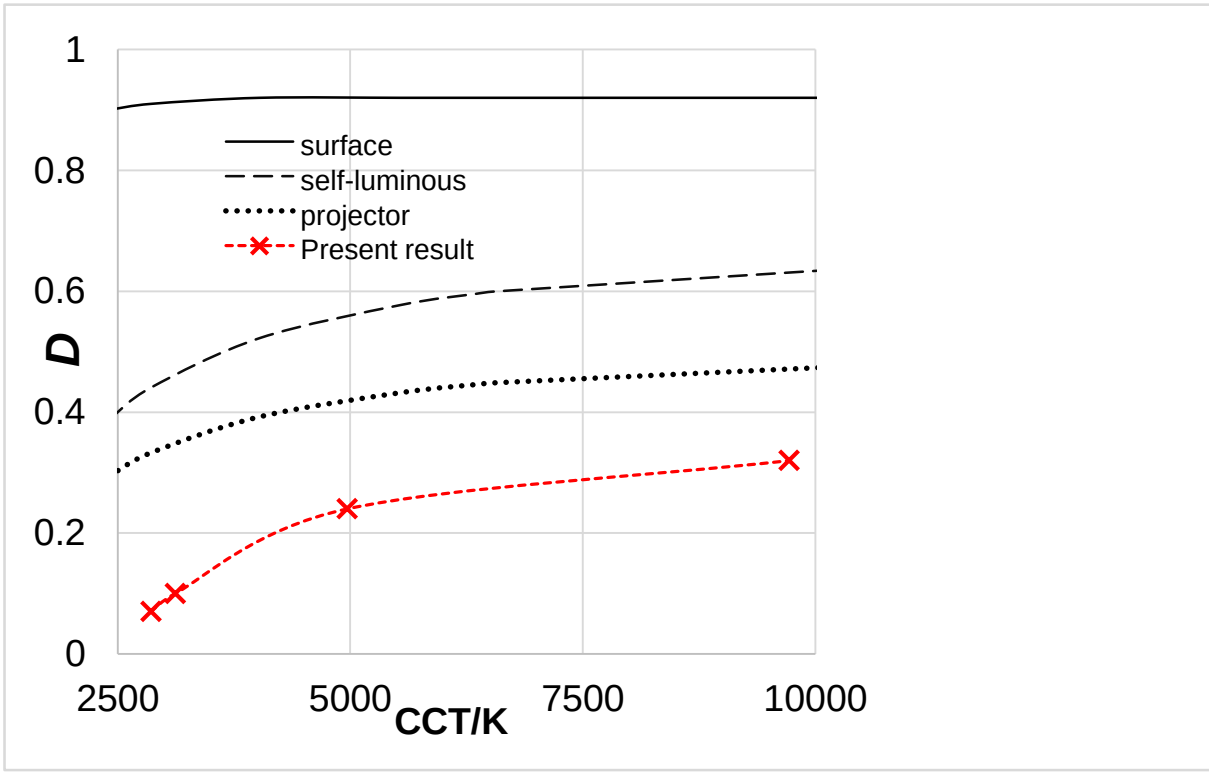












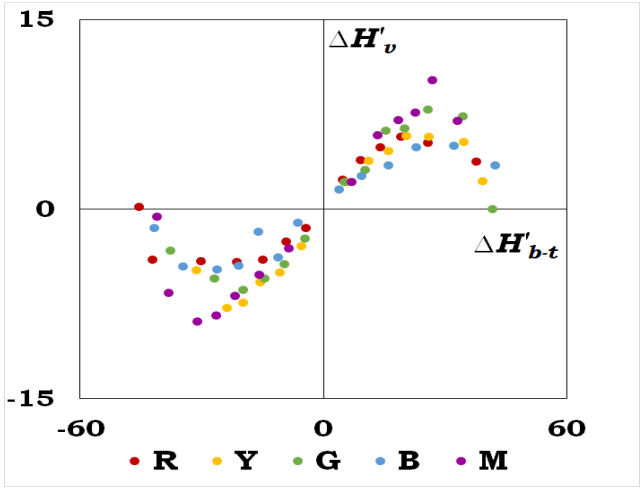
$D=F\{1-(1/3.6)e^{[(-La-42)/92]}\}$

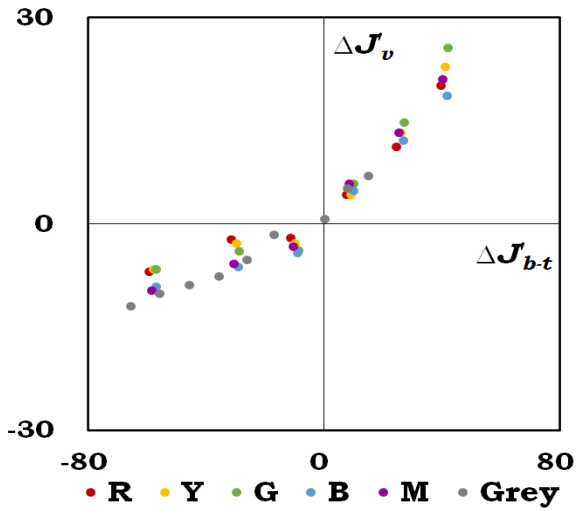
$D=a_0+a_1du'+a_2dv'+a_3sqrt(du'^2+dv'^2)$

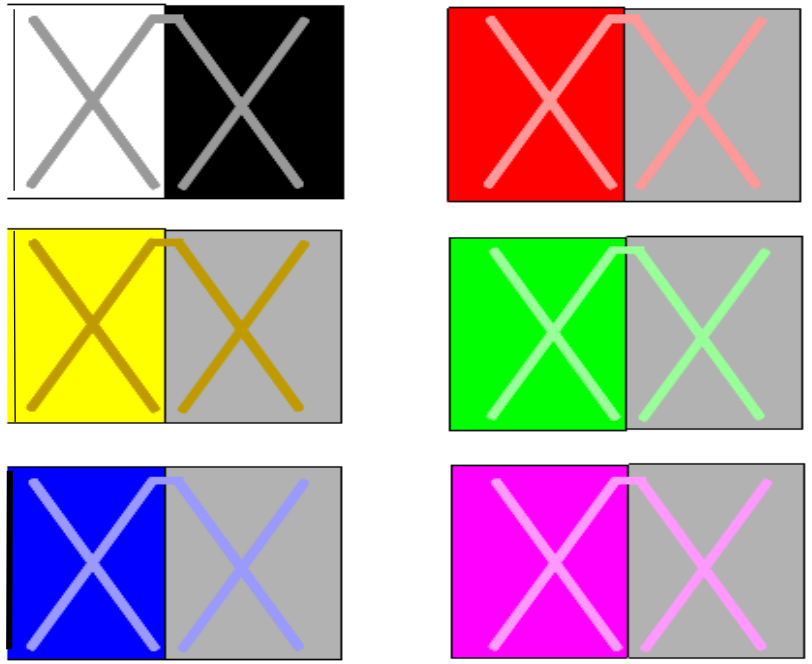
D= Function (Surround, La, [CCT, Duv] or [u'v'], Area, Time, media)

Y. Zhu, M. Wei, M. R. Luo, Effects of Adapting Chromaticities and Luminance on Color Appearance on Computer Displays Using Memory, Color Res. and Appl., 000-000

Simultaneous colour contrast

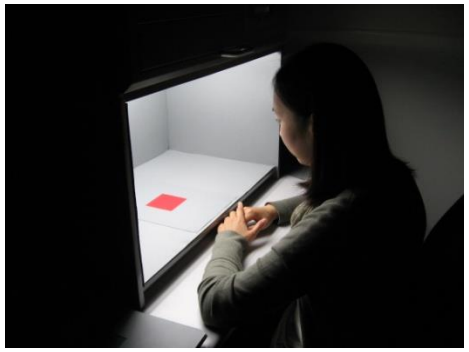


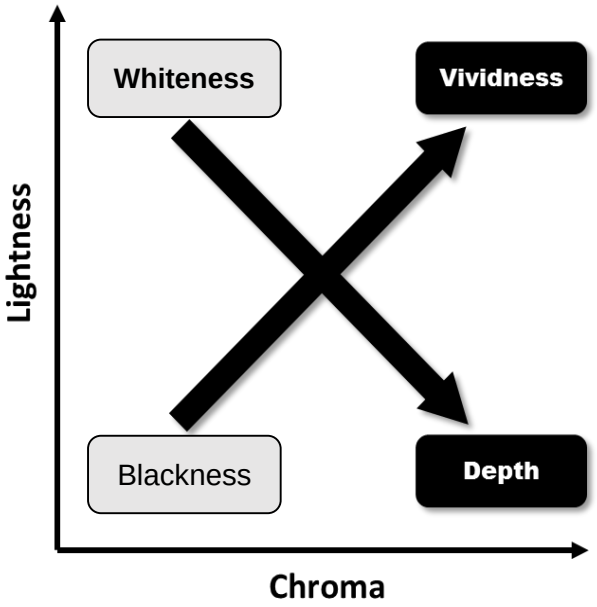




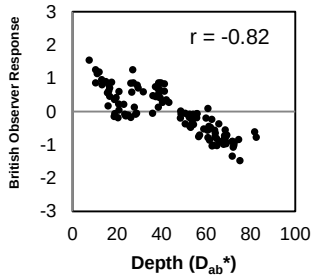
Y. Zhu and M. R. Luo, (O) Proposed Modification to the CAM16 Colour Appearance Model to Predict the Simultaneous Colour Contrast Effect, 27th Color and Imaging Conference (2019), Paris, 2019, pp190-194.

Whiteness-Depth
Blackness-Vividness

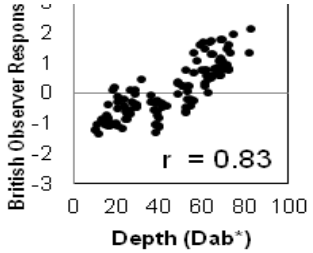




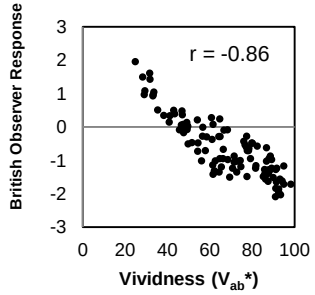
Whiteness



Saturation



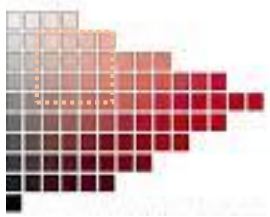
Blackness

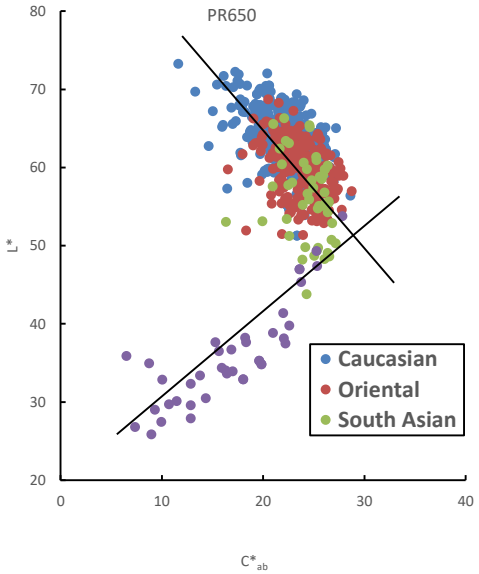


Y. J. Cho, L. C. Ou and M. R. Luo, A cross-culture comparison of saturation, vividness, blackness and whiteness scales, Color Res and Appl.,42(2017)203-215

Meaningful colour appearance scales

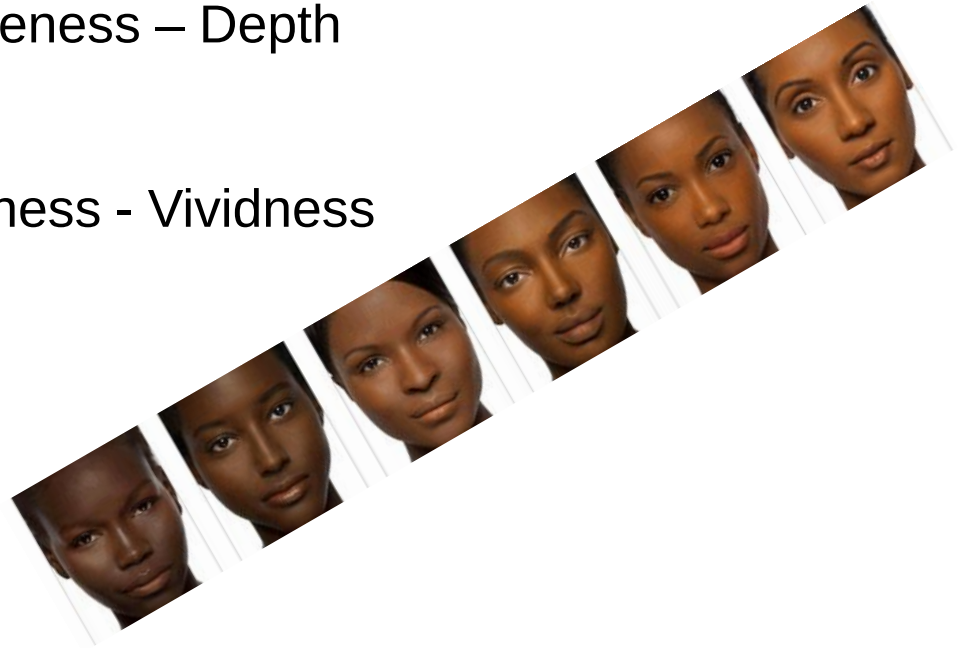
Wang and Luo, R&A, 10(2018)458-470



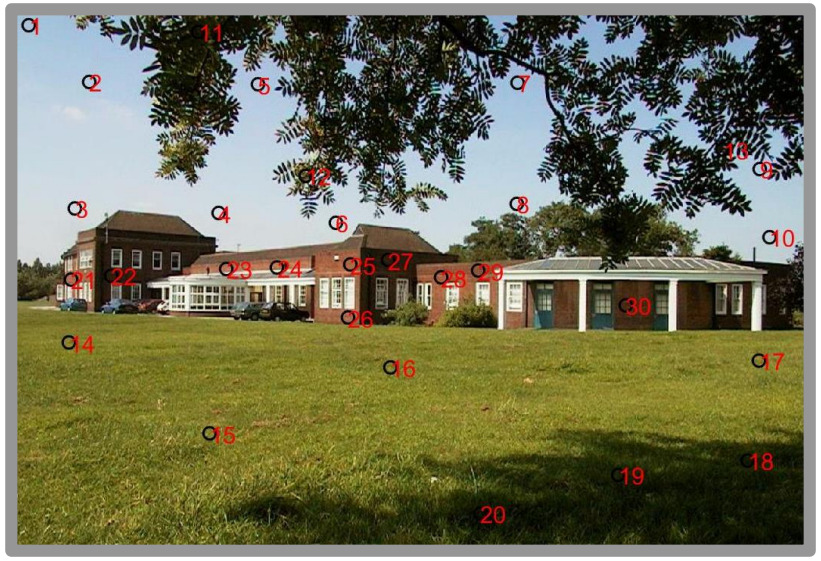


Whiteness – Depth

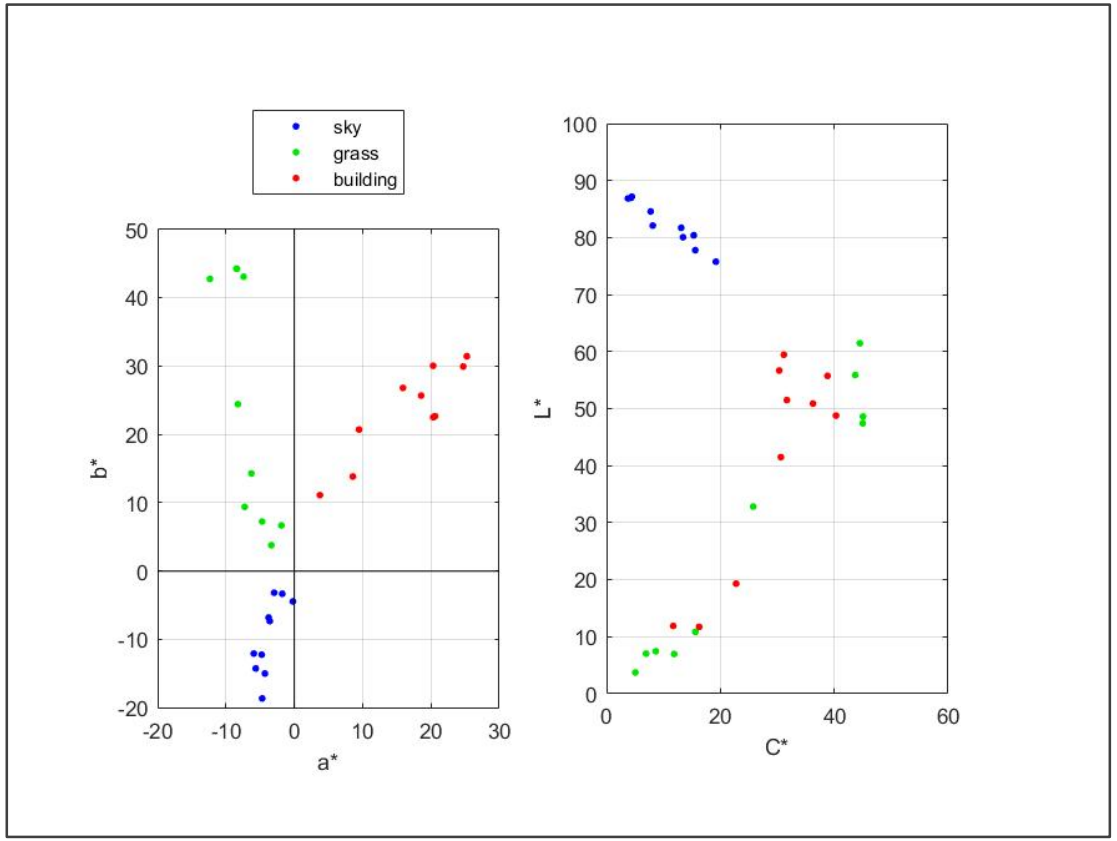
Blackness - Vividness



Back yard of CII (Derby)



Point 1~10 sky
Point 11~20 plants
Point 21~30 building



$J_zA_zB_z$ Model *for HDR/WCG*

$$\begin{bmatrix} X'_{D65} \\ Y'_{D65} \end{bmatrix} = \begin{bmatrix} b \\ g \end{bmatrix} \begin{bmatrix} X_{D65} & Y_{D65} \end{bmatrix} - \begin{bmatrix} (b-1) \\ (g-1) \end{bmatrix} \begin{bmatrix} Z_{D65} & X_{D65} \end{bmatrix} \quad (1)$$

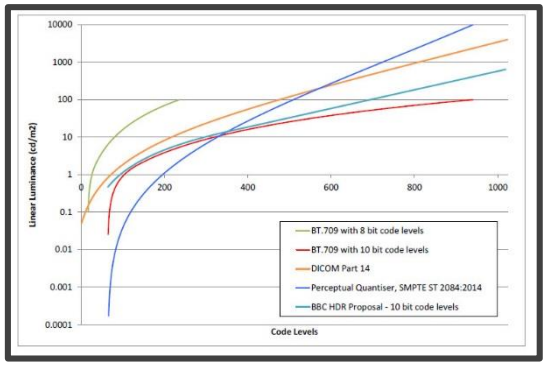
$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} 0.41478972 & 0.579999 & 0.0146480 \\ -0.2015100 & 1.120649 & 0.0531008 \\ -0.0166008 & 0.264800 & 0.6684799 \end{bmatrix} \begin{bmatrix} X'_{D65} \\ Y'_{D65} \\ Z_{D65} \end{bmatrix} \quad (2)$$

$$\{L' \quad M' \quad S'\} = \left(\frac{\left(c_1 + c_2 \left(\frac{\{L \quad M \quad S\}}{10000} \right)^n \right)}{\left(1 + c_3 \left(\frac{\{L \quad M \quad S\}}{10000} \right)^n \right)} \right)^p \quad (3)$$

$$\begin{bmatrix} I_z \\ a_z \\ b_z \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 & 0 \\ 3.524000 & -4.066708 & 0.542708 \\ 0.199076 & 1.096799 & -1.295875 \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \quad (4)$$

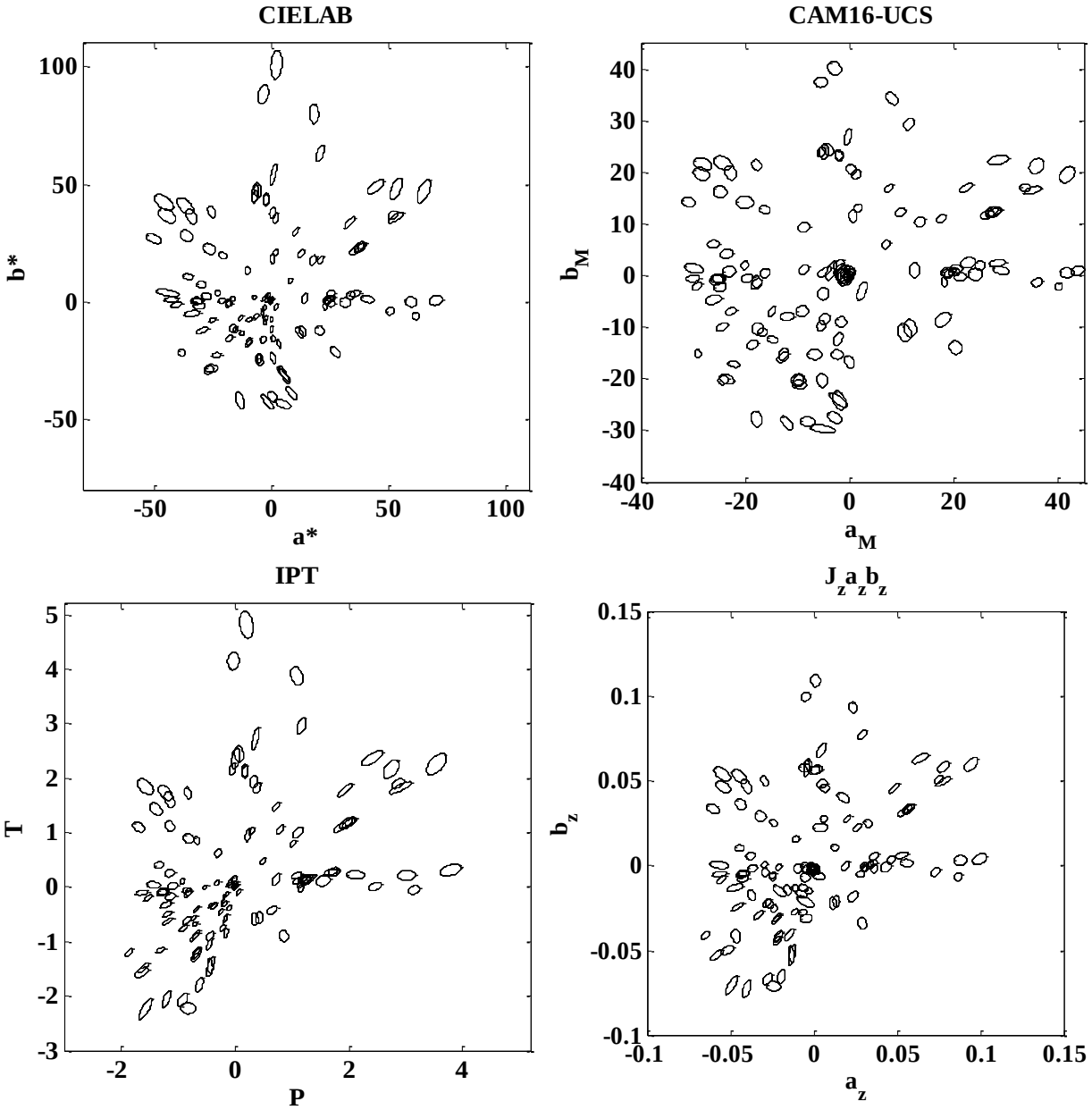
$$J_z = \frac{(1+d)I_z}{1+dI_z} - d_0 \quad (5)$$

where $b = 1.15$, $g = 0.66$, $c_1 = 3424/2^{12}$, $c_2 = 2413/2^7$, $c_3 = 2392/2^7$,
$n = 2610/2^{14}$, $p = 1.7 \times 2523/2^5$, $d = -0.56$, and $d_0 = 1.6295499532821566 \times 10^{-11}$.

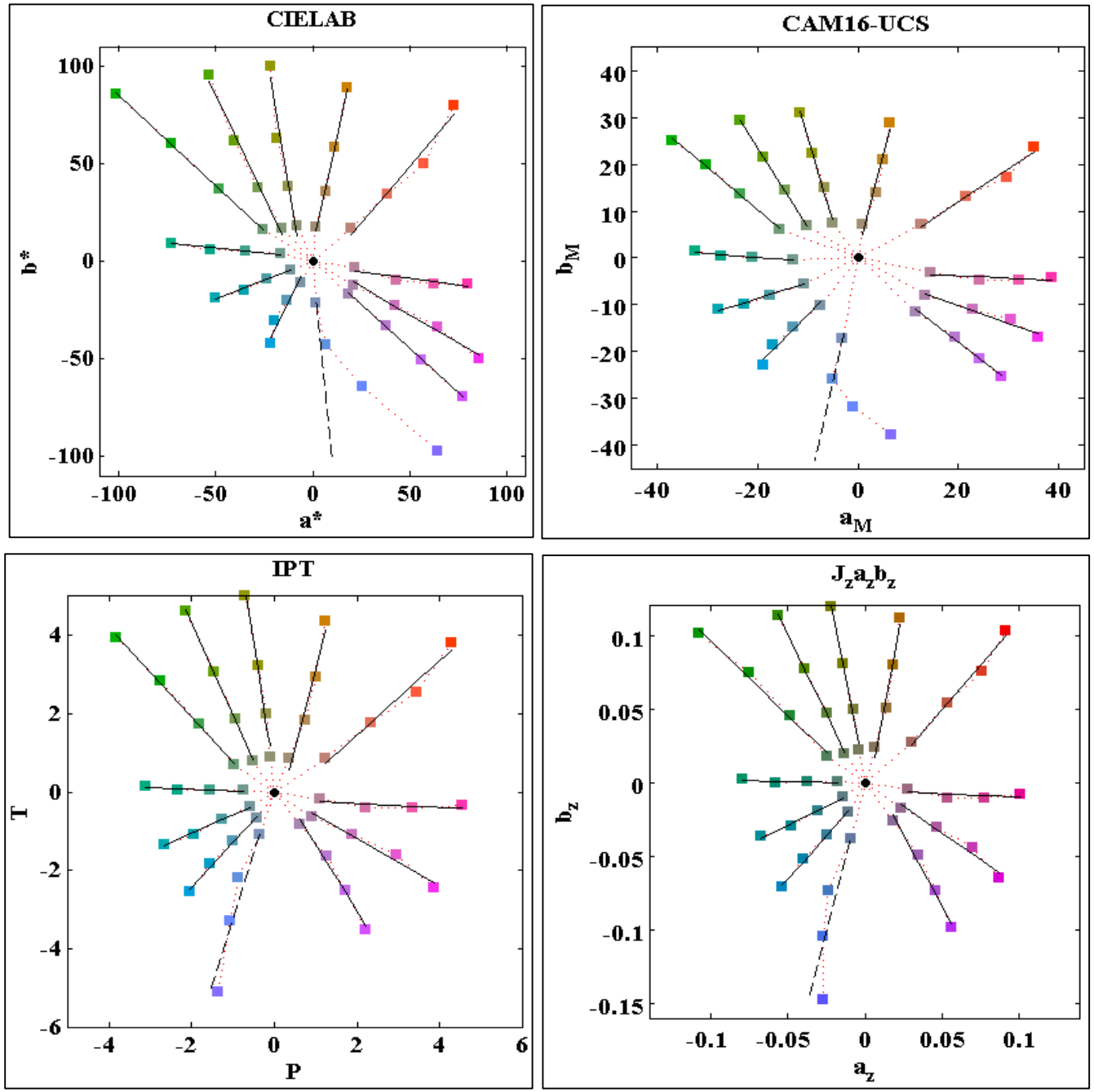


M. Safdar, G. Cui, Y. J. kim and M. R. Luo, Perceptually uniform color space for image signals including high dynamic range and wide gamut, Optics Express, 25(2017), pp15131-15151.

COMBVF Ellipses

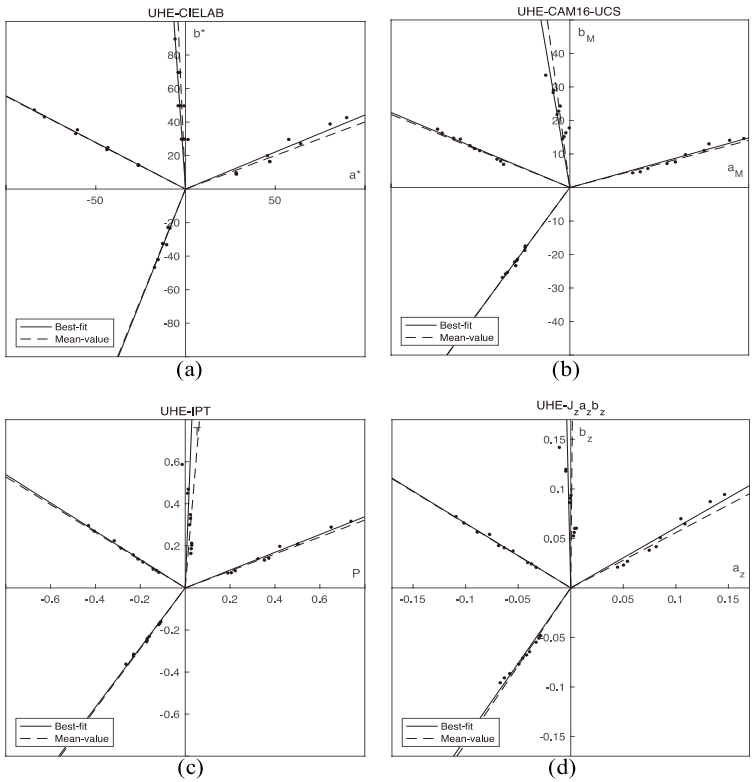


Hung & Berns Data

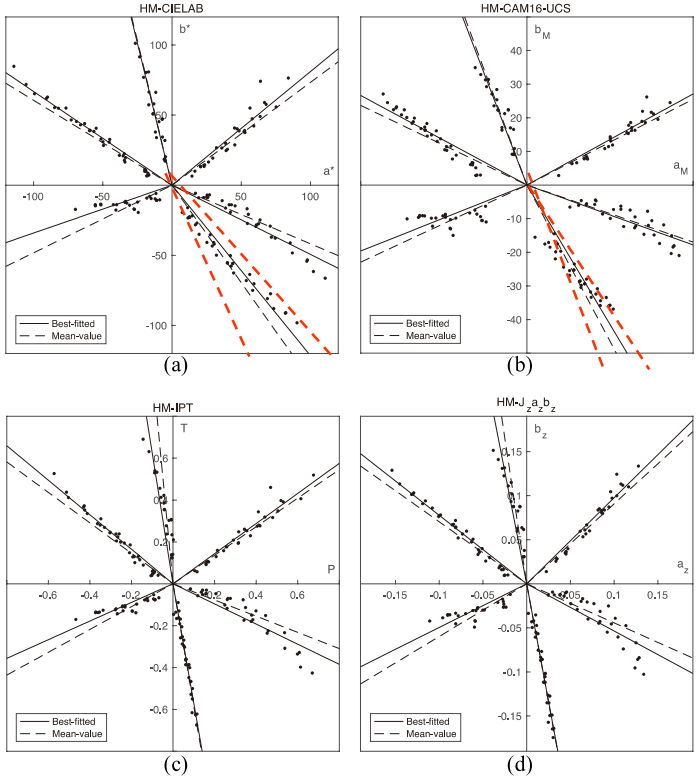


Hue Linearity - WCG

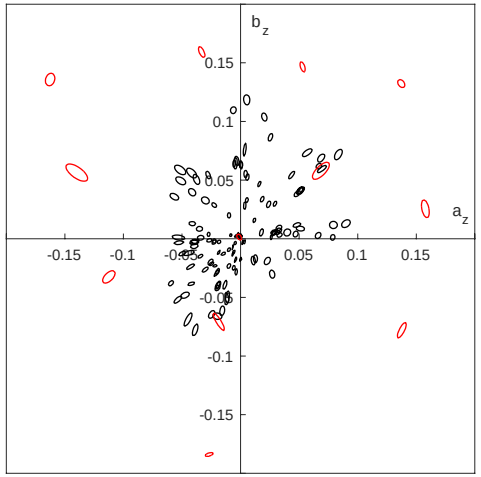
Unitary Hue Data

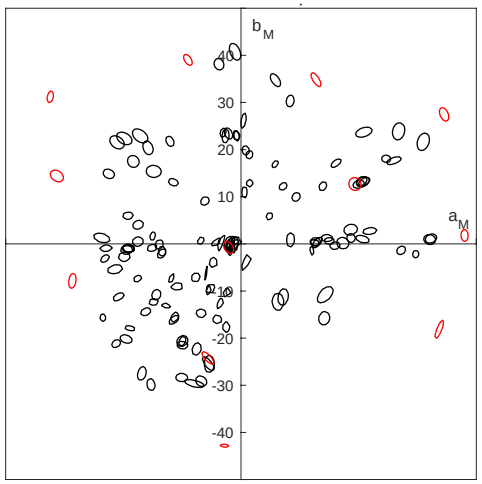


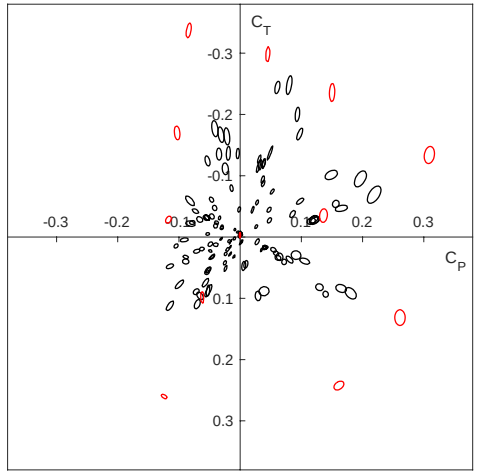
Other Hue Data

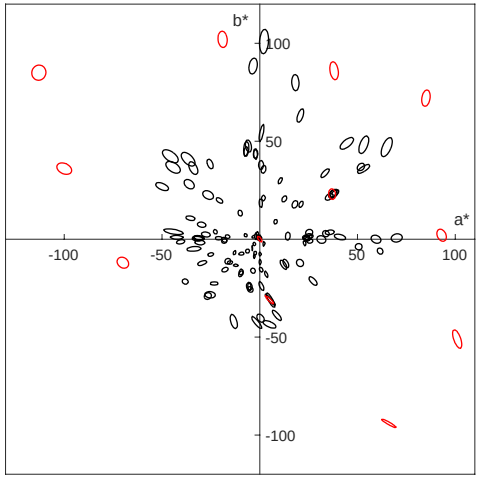


UCS's performance





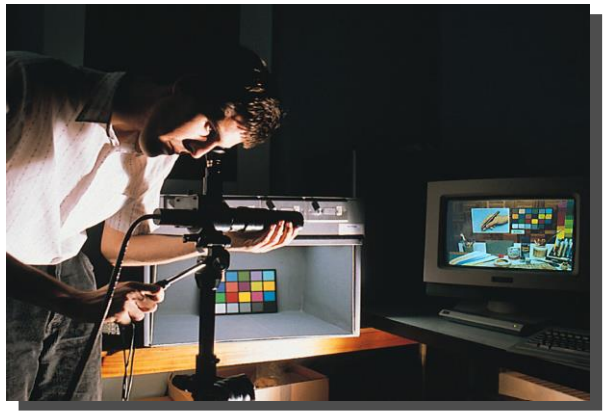




$$\boldsymbol{Local} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{A_i}{B_i} - 1\right)^2}}{1} \times 100\% \quad (8)$$

$$Global = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(S_i - \bar{S}\right)^2}}{\bar{S}} \times 100\% \quad (9)$$

Colour Spaces	Local (%)	Global (%)
CIELAB	222	48
CAM02-UCS	138	31
IC_TC_P	175	59
$J_za_zb_z$	160	67



CIECAM

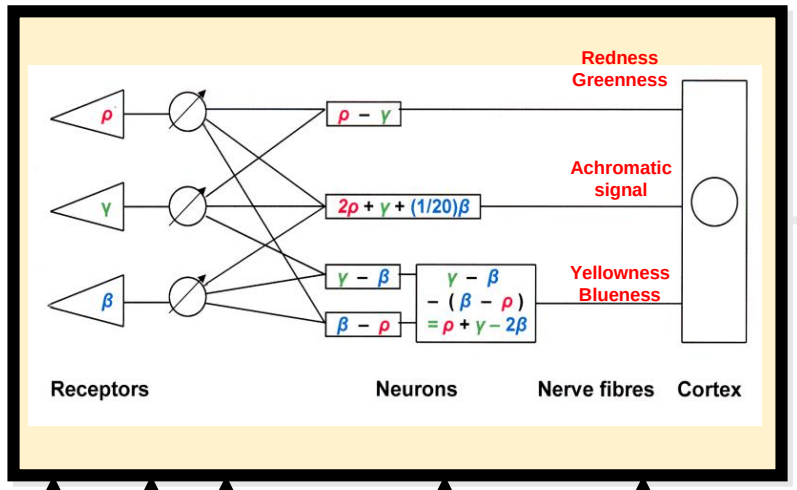
Input and output parameters

X Y Z

$$\rho_{10} = k_\rho \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{l}_{10}(\lambda)\,\mathrm{d}\lambda$$

$$\gamma_{10} = k_\gamma \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{m}_{10}(\lambda)\,\mathrm{d}\lambda$$

$$\beta_{10} = k_\beta \int_{390}^{830} L_{e,\lambda}(\lambda)\bar{s}_{10}(\lambda)\,\mathrm{d}\lambda$$



X_w Y_w Z_w — **L_A** — **Y_b** — ***Surround:* *Average, Dim and Dark*** — ***Angle subtense* *(θ)***

1D-scales

Related
Brightness (Q)
Lightness (J)
Colourfulness (M)
Chroma (C)
Saturation (s)
Hue angle (h)
Hue composition (H)

UCS

Lightness (J')
Colourfulness (M')
Hue angle (h)
ΔJ', ΔM', ΔH, $ΔE_{J'a'b'}$

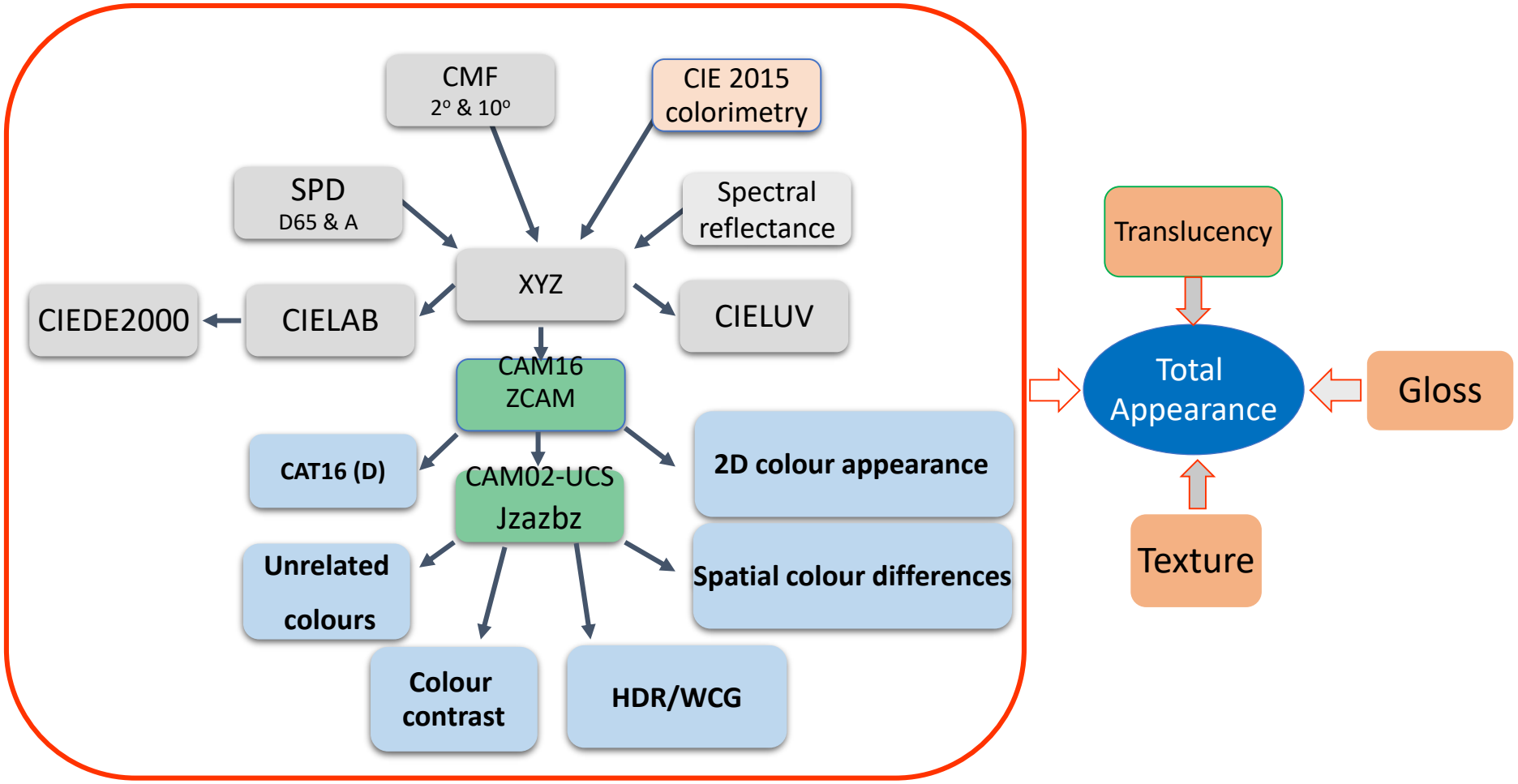
2D-scales

Vividness (V)
Depth (D)
Saturation (s)
Blackness (K)
Whiteness (W)
Clarity (Cl)

Colou reproduction

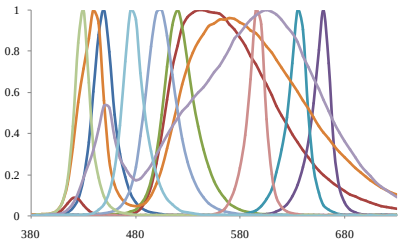
- **Spectral** ***(R%)***
- **Relative Colorimetric** ***(XYZ)***
- **Absolute Colorimetric** ***(X_L Y_L Z_L)***
- **Appearance** ***(JCh, QMh)***
- **Preference** ***(JCh, QMh)***

Go beyond colour!



Conclusions

- **Colour appearance models**
  - viewing parameters, Correlates, Visual phenomena
- **Recent developments**
  - CAT-D
  - Colour contrast
  - 2D-colour appearance scales
  - $J_z a_z b_z$ UCS
  - HDR and WCG applications
    - Hue linearity



Thanks for your attention!

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