ICC-CMRF (2016-2017)

An Efficient Uniform Color Space for High Dynamic Range and Wide Gamut Imagery

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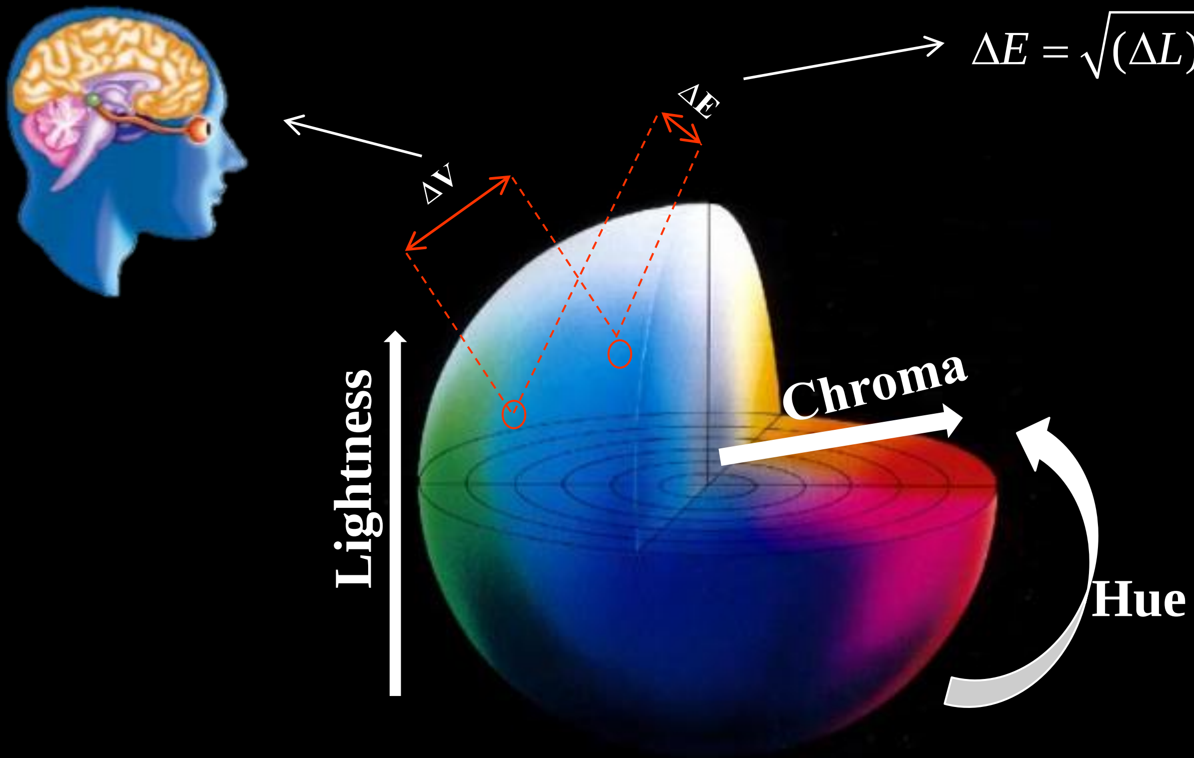
Uniform Color Space

- Predicts perceptual color difference
- No inter-dependence b/w lightness, chroma, and hue

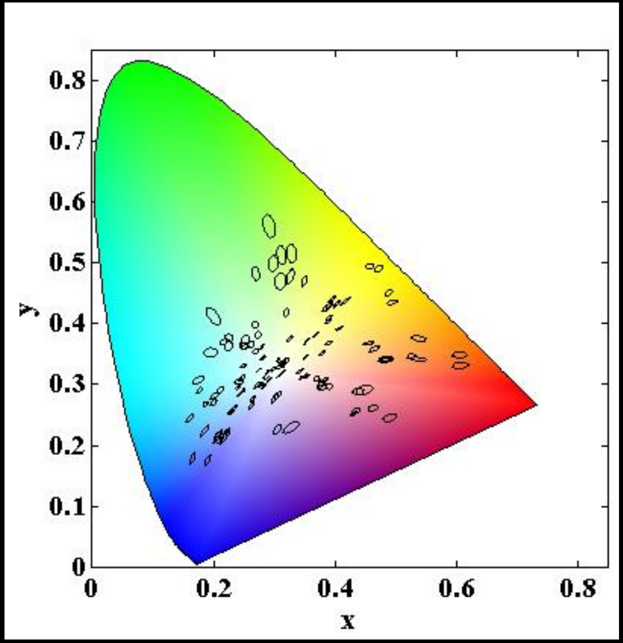


$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta C)^2 + (\Delta H)^2}$$

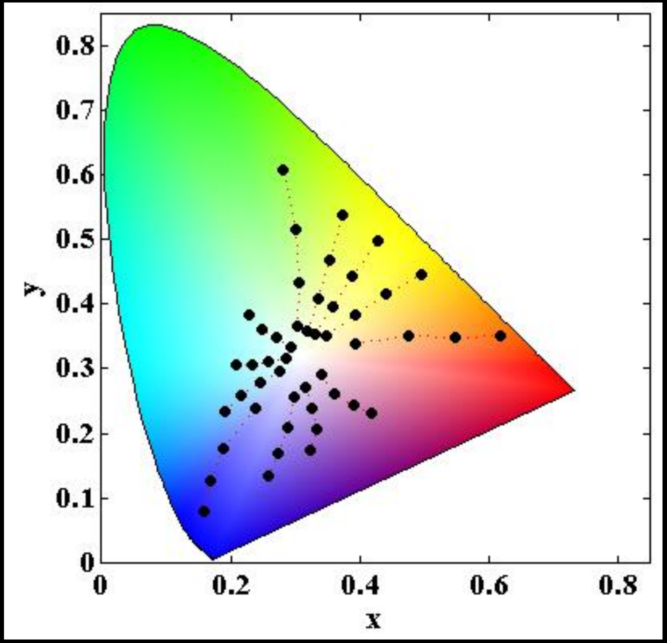
- K. A. G. Smet *et al.*, LEUKOS, 2016
- I. Lissner et al., IEEE Trans. Image Process., 2012

Criteria for a New UCS

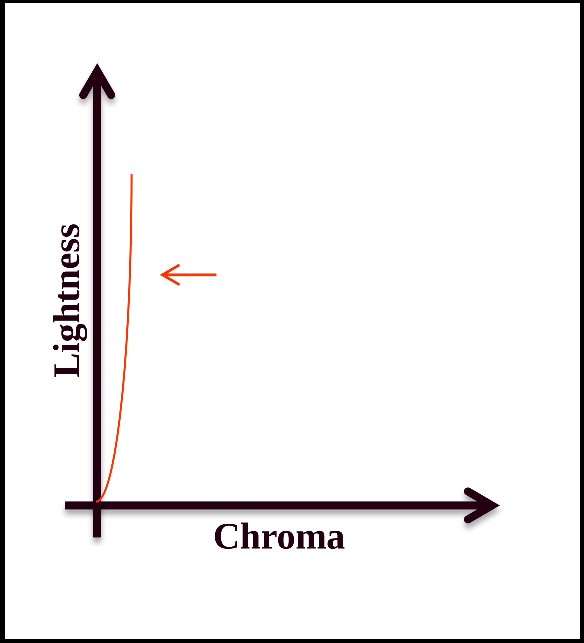
1 Uniformity (Local & Global)



2 Hue Linearity



3 Grey-scale Convergence



4 To uniformly encode high dynamic range signals e.g., 0-10,000 cd/m^2

5 To uniformly encode wide gamut image signals e.g., Rec.2020

Test Spaces

1) CIELAB — CIE/ISO standard

2) CAM16-UCS — Accurately predicts small color difference data

3) IC_TC_P — Dolby's proposal for HDR and WCG

4) $J_za_zb_z$ — Current Proposal

- CIE, Colorimetry, 2004
- C. Li *et al.*, Color Imaging Conf., 2016
- Dolby, 2016

Criteria and Visual Data

No.	Criteria	Data sets	Purpose
1	Perceptual Color Difference	i) COMBVD ii) OSA	i) Training ii) Testing
2	Perceptual Uniformity	i) COMBVD Ellipses ii) MacAdam Ellipses iii) Munsell Data	i) Reference ii) Testing iii) Testing
3	Hue Linearity	i) Hung & Berns ii) Ebner & Fairchild iii) Xiao *et al.*	i) Reference ii) Testing iii) Testing
4	Wide-range Lightness Prediction	i) RIT SL1 ii) RIT SL2	i) Testing ii) Training
5	Grey-scale convergence	Chroma-ratio metric (%)	$\text{Chroma-Ratio} = 100 \frac{3C_w}{C_r + C_g + C_b}$

- D. L. A. MacAdam, JOSA, 1942
- D. L. A. MacAdam, JOSA, 1974
- M. D. Fairchild, Electronic Imaging, 2011

Proposed $J_z a_z b_z$ space

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

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

$$\{L', M', S'\} = \left(\frac{c_1 + c_2 \left(\frac{\{L, M, S\}}{10,000} \right)^n}{1 + c_3 \left(\frac{\{L, M, S\}}{10,000} \right)^n} \right)^p \quad (3)$$

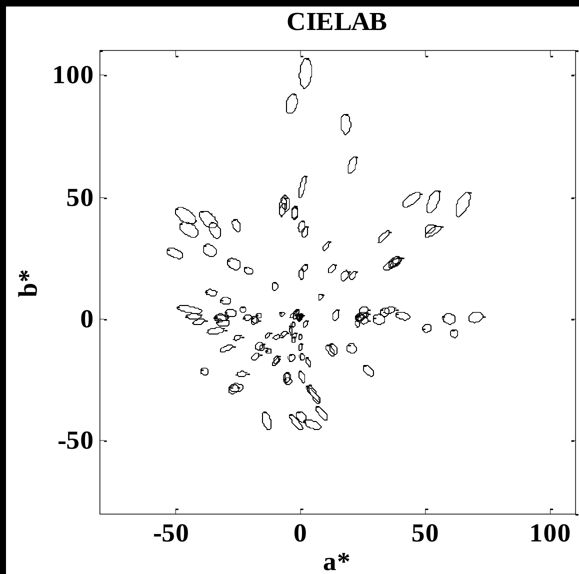
where $n = 2610/2^{14}$
$p = 1.7 \times 2523/2^5$

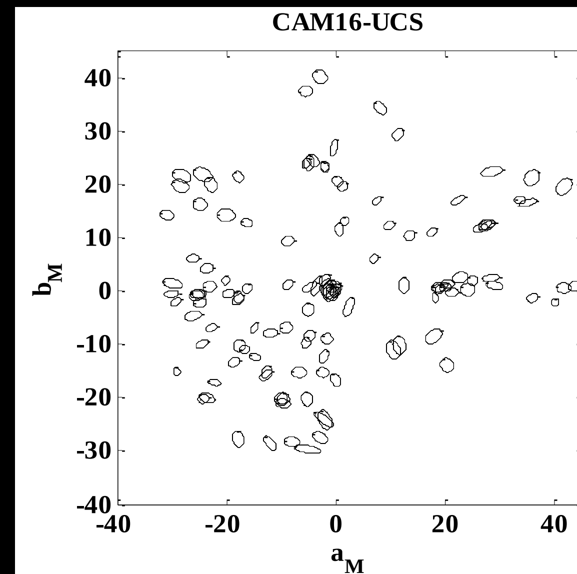
$$\begin{bmatrix} I \\ a_z \\ b_z \end{bmatrix} = \begin{bmatrix} 0.5 & 0.5 & 0 \\ 3.524000 & -4.066708 & 0.542708 \\ 0.199076 & 1.096799 & -1.295875 \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \quad (4)$$

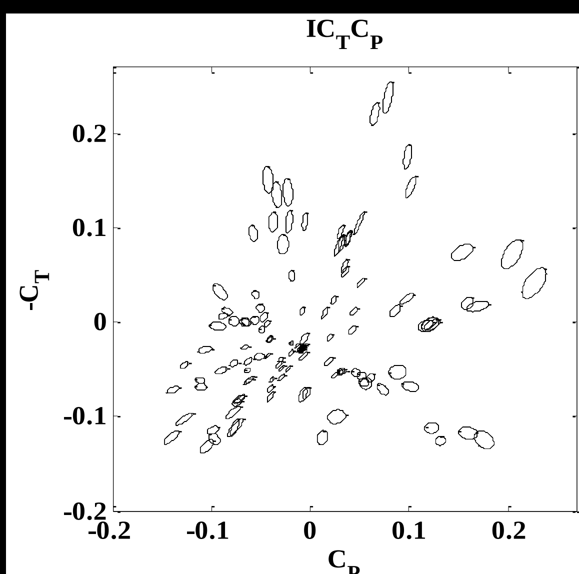
$$J_z = \left(\frac{(1+d) I_z}{1 + d I_z} \right) \quad (5)$$

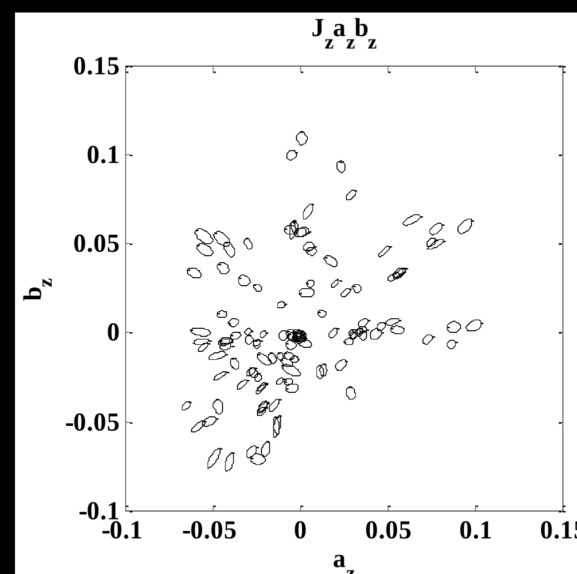
where $d = -0.56$

Results (Uniformity)

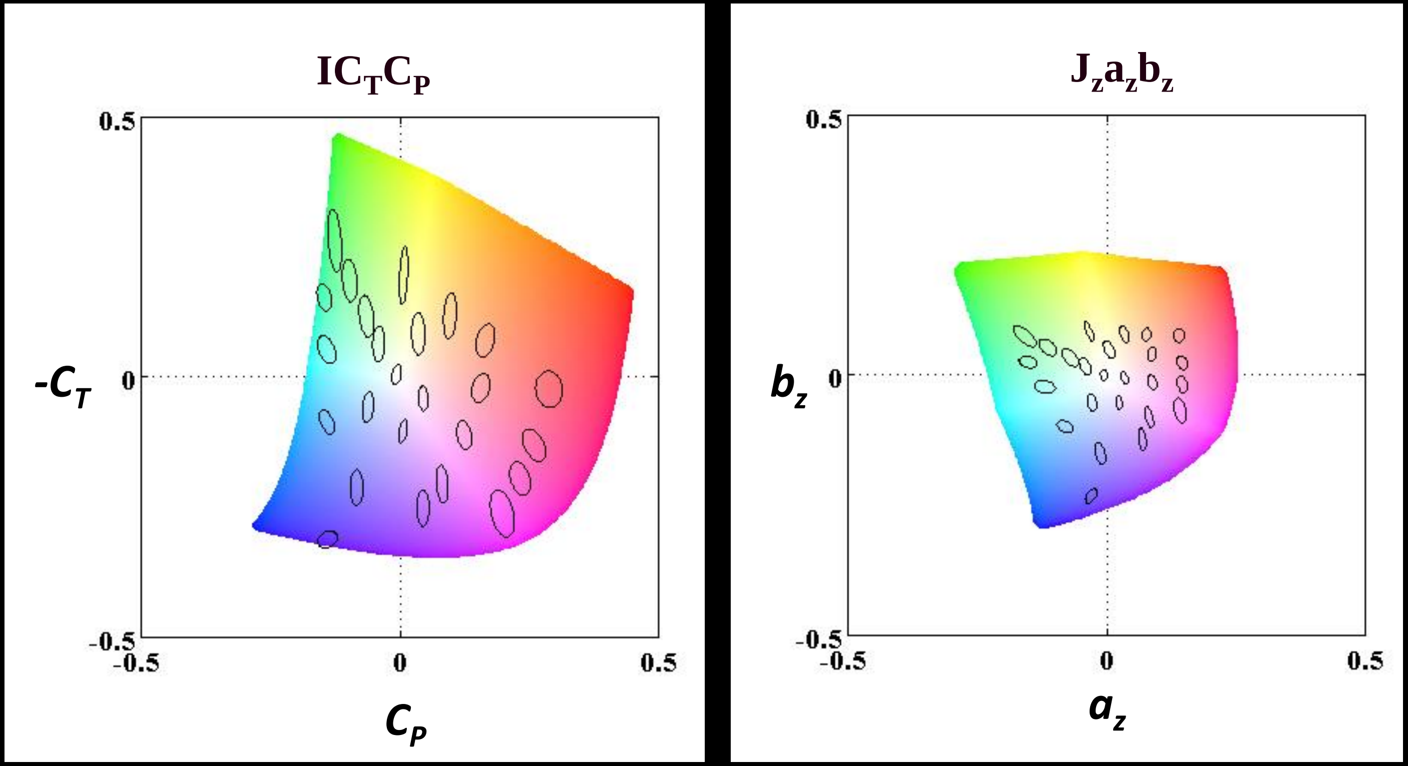




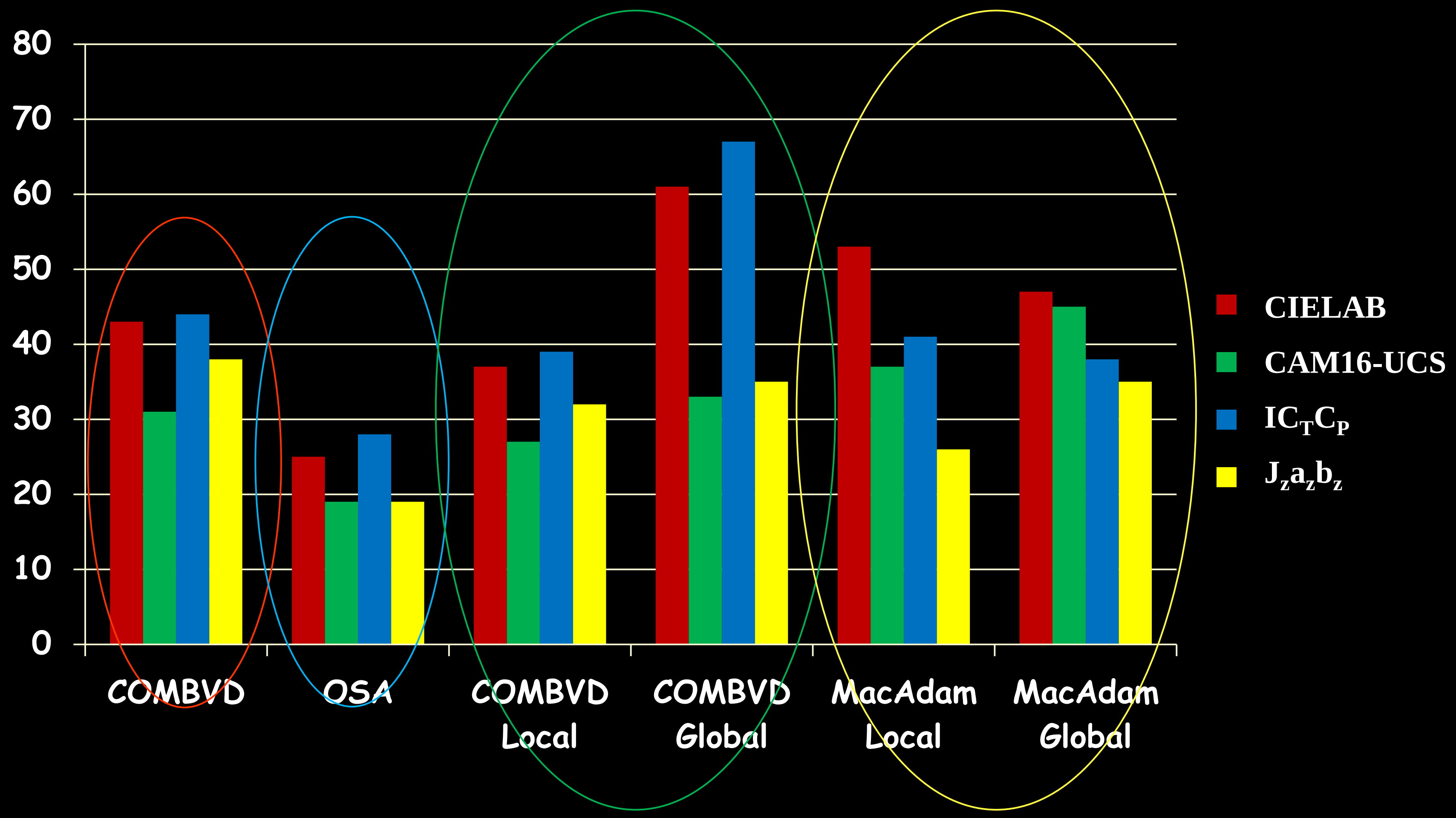




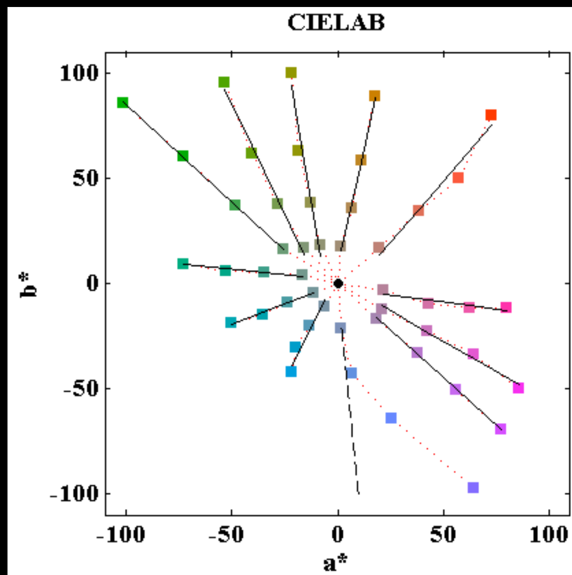
Results (Uniformity in WCG)

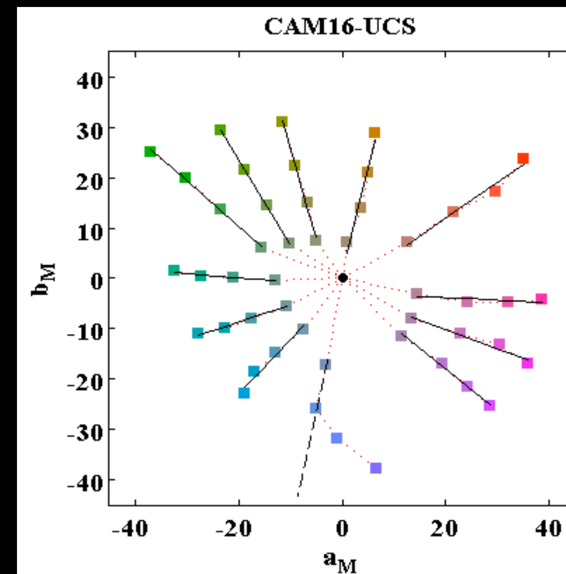


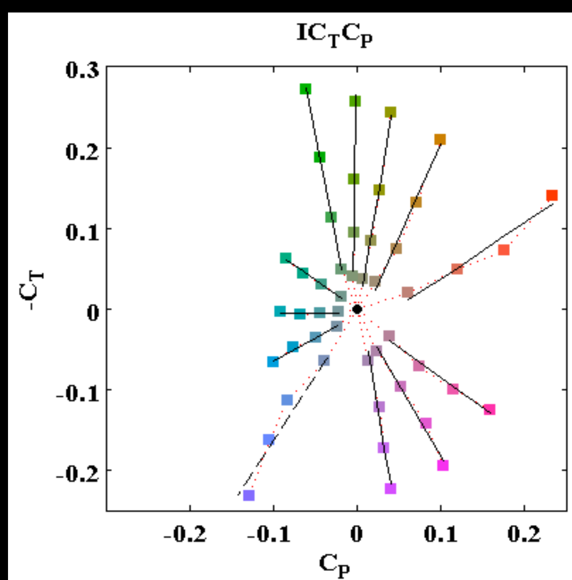
Results (Quantitative)

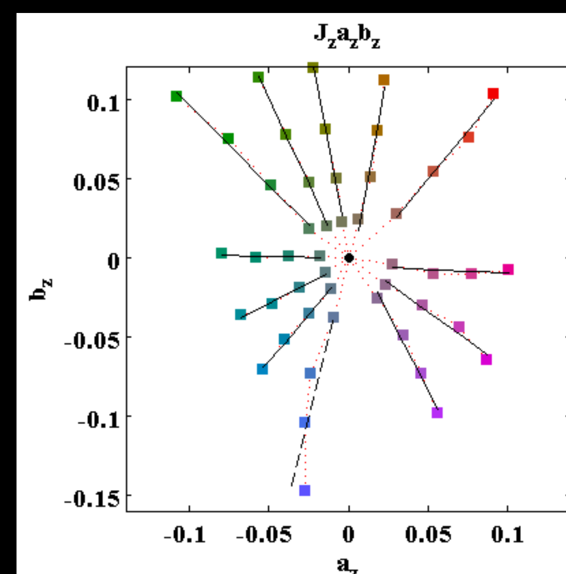


Results (Hue Linearity)

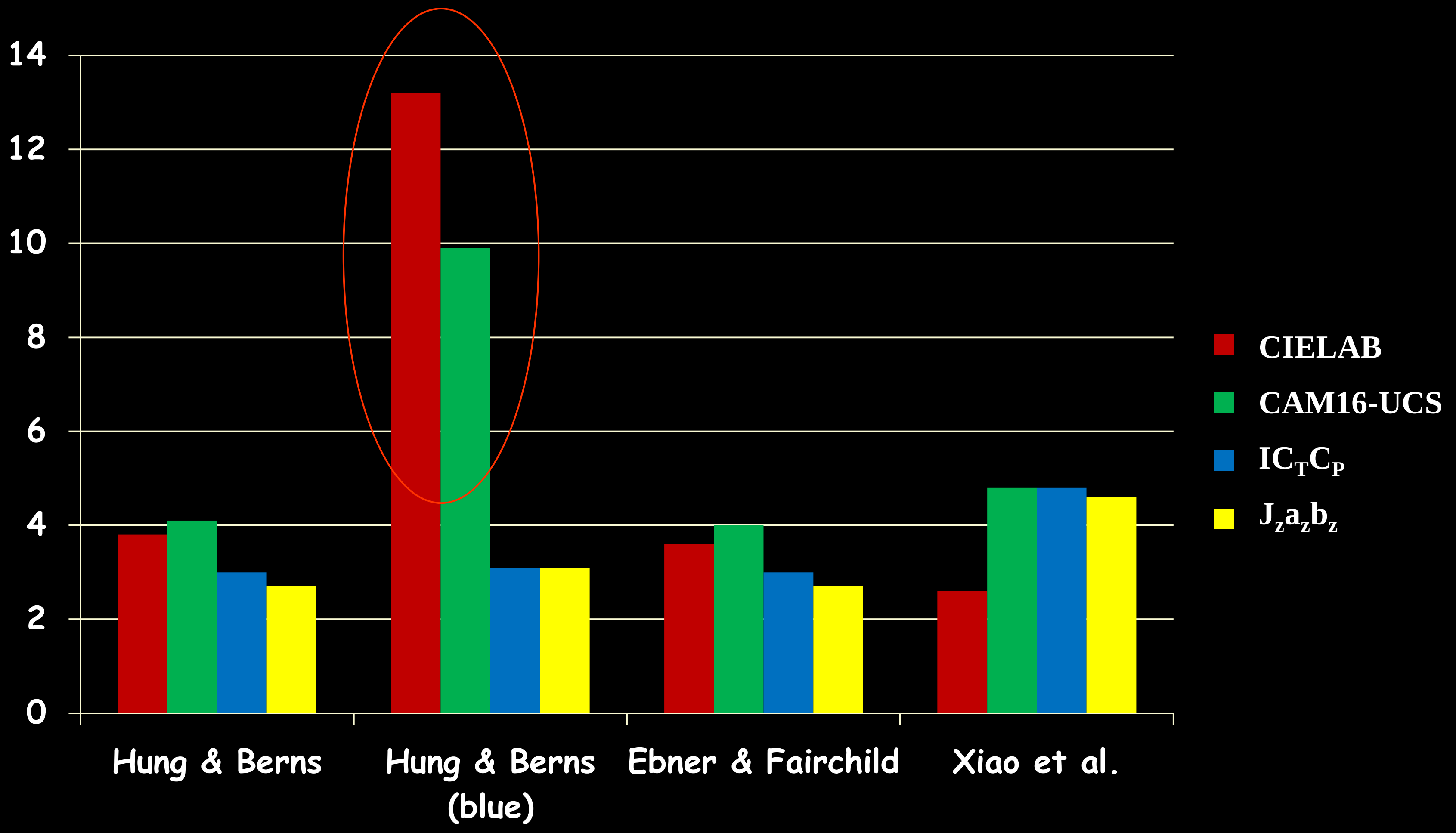




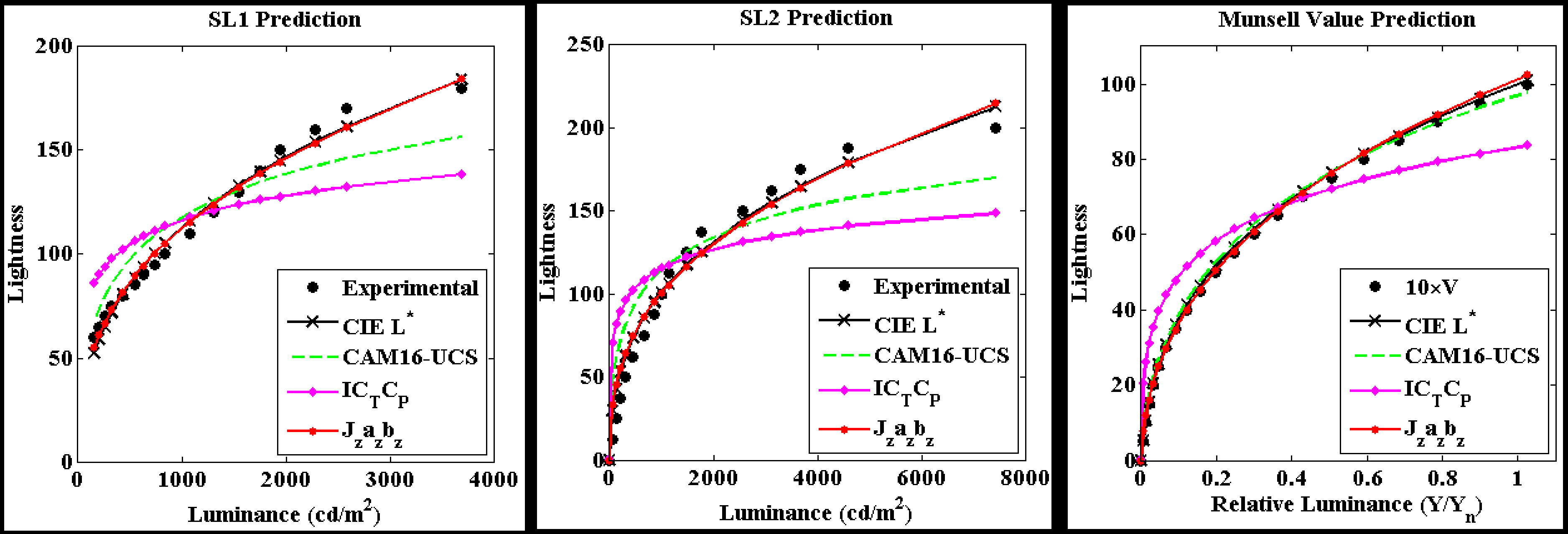




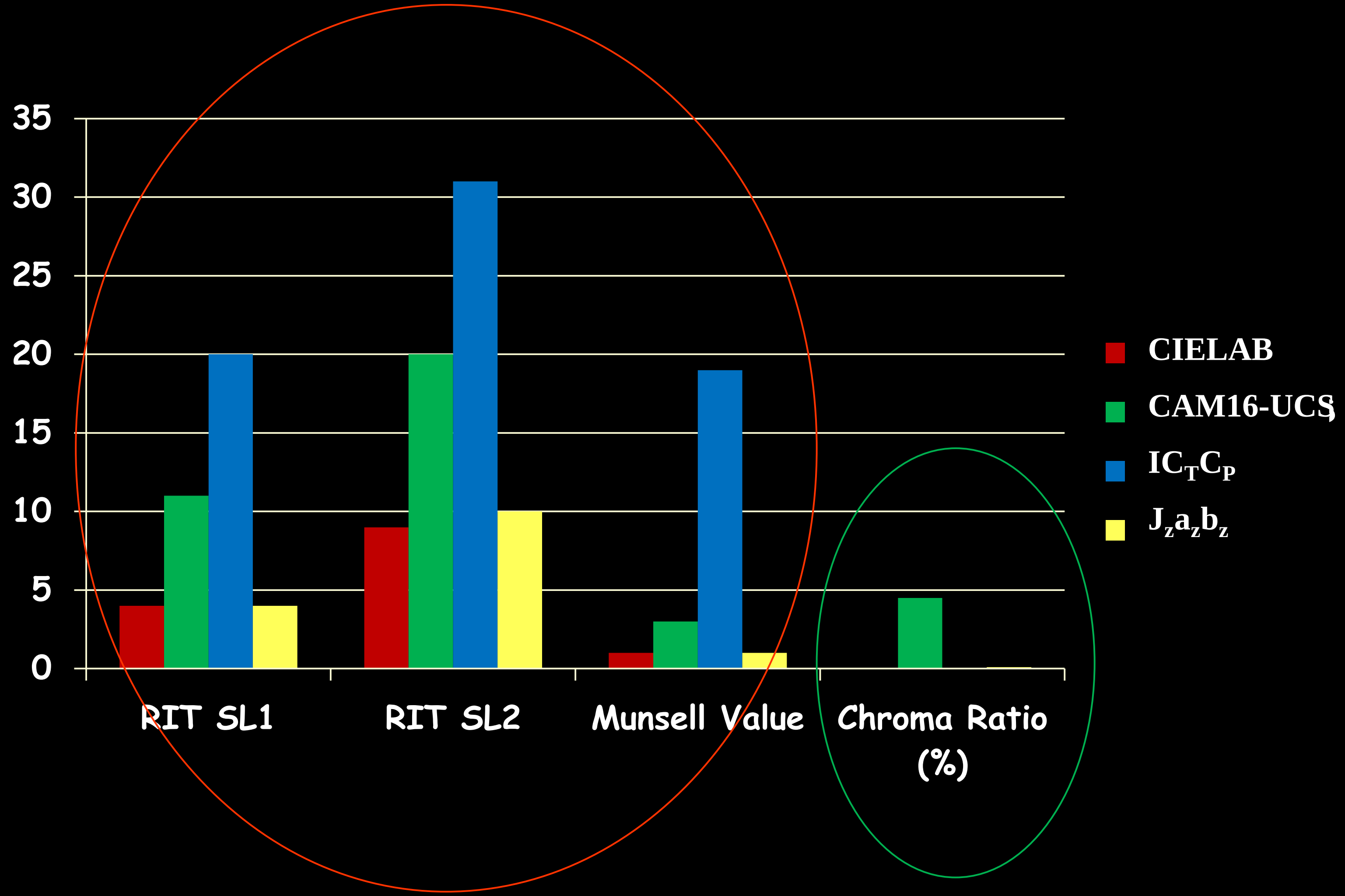
Results (Quantitative)



Results (Lightness Prediction)



Results (Lightness)



Conclusions

$J_z a_z b_z$ →

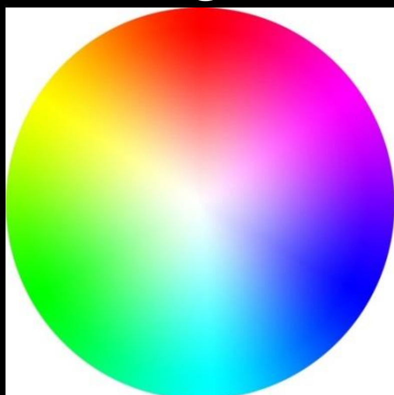
- Second best for small color difference
- Best for large color difference
- Best for wide gamut uniformity
- Best for hue linearity
- Best for wide-range lightness prediction
- Plausible grey-scale convergence

$J_z a_z b_z$ gave overall best performance and should be confidently used

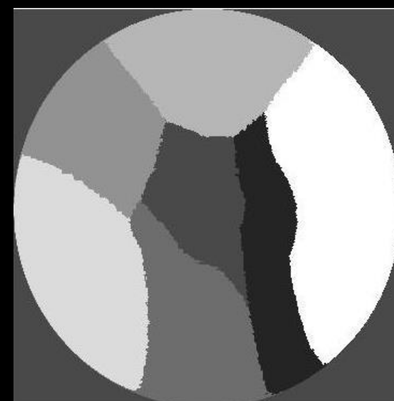
Demonstration (Image Segmentation)

Segmentation (7 regions) using K-means clustering algorithm

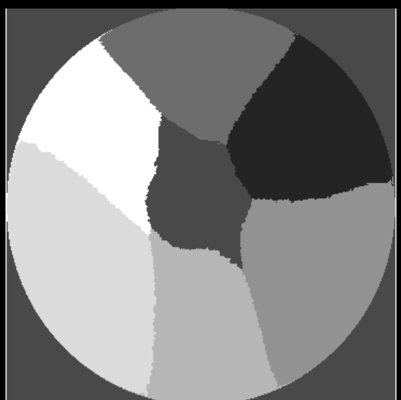
Original



CIELAB

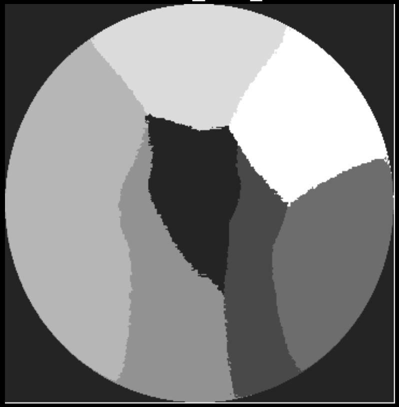


CAM16-UCS

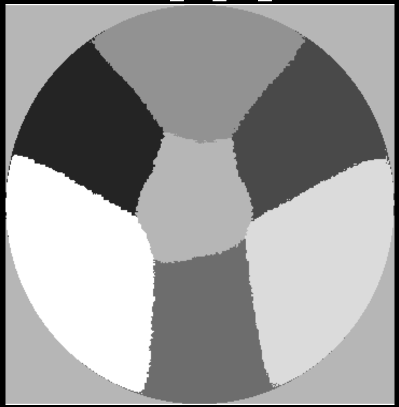


YC_bC_r

IC_TC_P



$J_za_zb_z$



Deliverables

1. Journal Paper: ***Optics Express (IF=3.3)***

https://www.osapublishing.org/oe/abstract.cfm?uri=oe-25-13-15131

2. MATLAB Code for $J_z a_z b_z$

Thank You

Any

Questions?

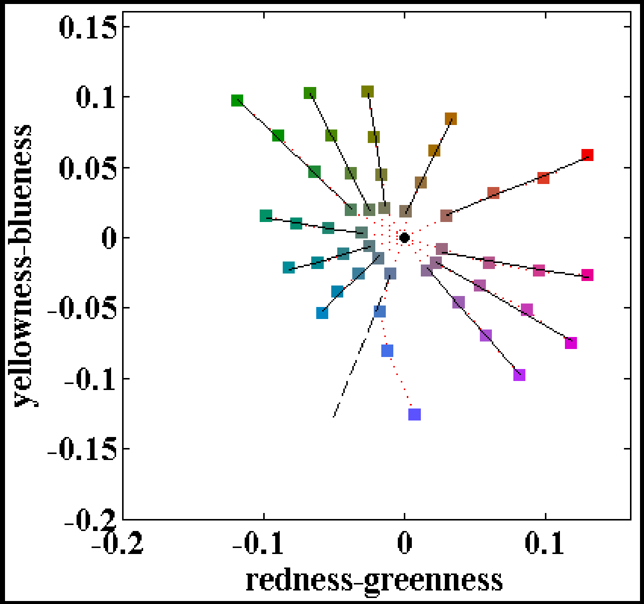
Model Development

- Initially, we start using a structure similar to IC_TC_P

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & 1-\alpha_{1,1}-\alpha_{1,2} \\ \alpha_{2,1} & \alpha_{2,2} & 1-\alpha_{2,1}-\alpha_{2,2} \\ \alpha_{3,1} & \alpha_{3,2} & 1-\alpha_{3,1}-\alpha_{3,2} \end{bmatrix} \begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} \quad (1)$$

$$\{L', M', S'\} = \left(\frac{c_1 + c_2 \left(\frac{\{L, M, S\}}{10,000} \right)^n}{1 + c_3 \left(\frac{\{L, M, S\}}{10,000} \right)^n} \right)^p \quad (2)$$

$$\begin{bmatrix} I \\ a_z \\ b_z \end{bmatrix} = \begin{bmatrix} \omega_{1,1} & \omega_{1,2} & 1-\omega_{1,1}-\omega_{1,2} \\ \omega_{2,1} & \omega_{2,2} & 1-\omega_{2,1}-\omega_{2,2} \\ \omega_{3,1} & \omega_{3,2} & 1-\omega_{3,1}-\omega_{3,2} \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \quad (3)$$



- Dolby, 20016
- M. Safdar *et al.*, Color Imaging Conf., 20016

Model Development

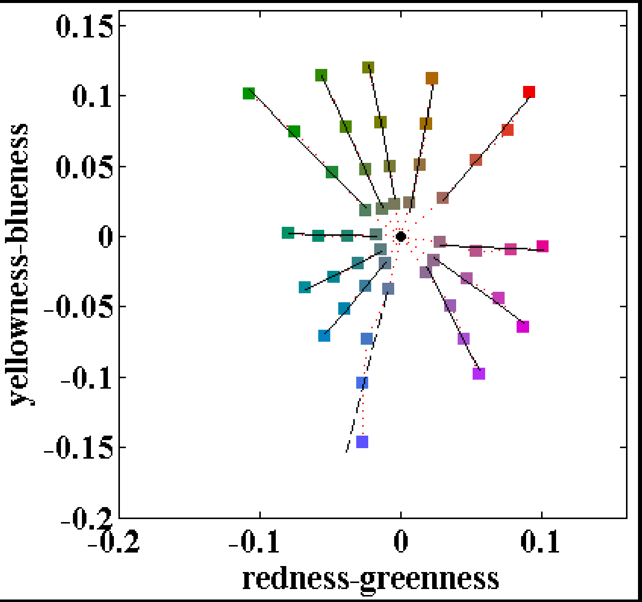
- Then we introduced a linear given below to correct hue linearity

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

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & 1-\alpha_{1,1}-\alpha_{1,2} \\ \alpha_{2,1} & \alpha_{2,2} & 1-\alpha_{2,1}-\alpha_{2,2} \\ \alpha_{3,1} & \alpha_{3,2} & 1-\alpha_{3,1}-\alpha_{3,2} \end{bmatrix} \begin{bmatrix} X'_{D65} \\ Y'_{D65} \\ Z_{D65} \end{bmatrix} \quad (2)$$

$$\{L', M', S',\} = \left(\frac{c_1 + c_2 \left(\frac{\{L, M, S\}}{10,000} \right)^n}{1 + c_3 \left(\frac{\{L, M, S\}}{10,000} \right)^n} \right)^p \quad (3)$$

$$\begin{bmatrix} I_z \\ a_z \\ b_z \end{bmatrix} = \begin{bmatrix} \omega_{1,1} & \omega_{1,2} & 1-\omega_{1,1}-\omega_{1,2} \\ \omega_{2,1} & \omega_{2,2} & 1-\omega_{2,1}-\omega_{2,2} \\ \omega_{3,1} & \omega_{3,2} & 1-\omega_{3,1}-\omega_{3,2} \end{bmatrix} \begin{bmatrix} L' \\ M' \\ S' \end{bmatrix} \quad (4)$$

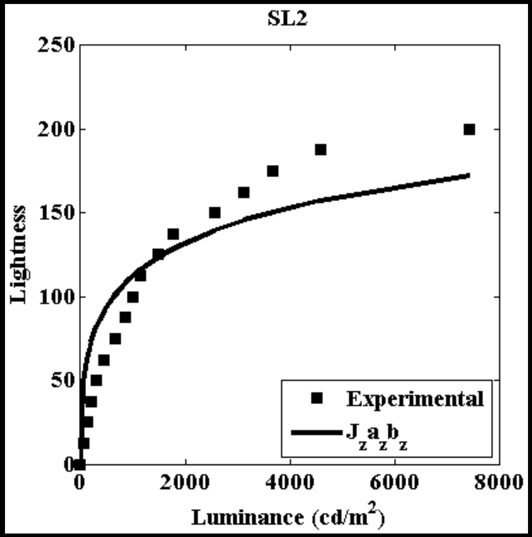


- G. Kuehni., Col. Res. Appl., 1999
- G. Cui *et al.*, Col. Res. Appl., 2002

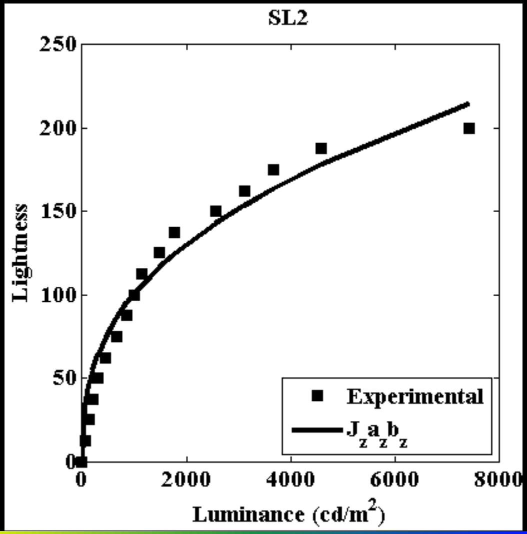
Model Development

- Another simple equation to tune perceptual lightness

$$J_z = \left(\frac{(1+d) I_z}{1 + d I_z} \right) \quad (5)$$



after Eq.5



- M. R. Luo *et al.*, Col. Res. Appl., 2006