Welcome to

ICC Chiba Color Expert's Day 2013

February 1st, 2013

Keyaki Kaikan, Chiba University

Research and Education for Vision, Color and Image Sciences in Chiba University

Hirohisa Yaguchi

Contents

- History of Image Science at Chiba University
- Education of Image Science at Chiba University
- Current researches at Yaguchi-Mizokami Labo (Vision Labo)
    - Simulation of color appearance for anomalous trichromats with multispectral images

History of Imaging Engineering in Chiba University

- 1920: Dept. of Graphic Arts, Tokyo Polytechnic College
- 1951: Dept. of Graphic Arts

  Dept. of Photographic Engineering, Chiba Univeristy
  - 1964: Institute of Natural Color Engineering
  - 1995: Center for Environmental Remote Sensing
- 1976: Dept. of Image Science
- 1989: Dept. of Information Science
- 1998: Dept. of Information and Image Sciences
  - 2003: Center for Frontier Medical Engineering
- 2008: Dept.of Informatics and Imaging System

  Dept. of Image Sciences

  Dept. of Medical System Engineering

Education of Vision, Color and Imaging

- Faculty of Engineering (undergraduate students)
  - Visual Information Processing (Prof. Yaguchi)
  - Processing and Analysis of Color Image (Prof. Tominaga)
  - Digital Image Processing (Prof. Tominaga)
  - Image and Human Sensitivity (Prof. H.Kobayashi)
  - Human and Images (Prof. H.Kobayashi)
  - Image Recording Engineering (Prof. Kitamura)
  - Computer Graphics (Assoc. Prof. Tsumura)
  - Fourie Transform for Information and Image Sciences (Assoc. Prof. Horiuchi)
  - Medical Image Processing (Prof. Haneishi)
  - Remote Sensing Technology (Prof. Kuze)
  - Psychophysics (Assoc. Prof. Aoki)
  - Fundamentals of Image Science (Prof. Yaguchi et.al.) for JPAC (Japan Program at Chiba for foreign students)
  - Development of Imaging Technology (Visiting Prof. Kuwayama)
  - Digital Imaging System (Visiting Prof. Kurosawa)
  - Design and Evaluation of Image Quality (Visiting Prof. Inui)
  - Image Electronics (Visiting Prof. Nakaya)

Education of Vision, Color and Imaging

- Graduate School of Advanced Integration Sciences
  - Visual Science (Prof. Yaguchi)
  - Color Reproduction (Prof. Yaguchi)
  - Image Kansei Engineering (Prof. Kobayashi)
  - Image Evaluation and Analysis (Assoc. Prof. Tsumura)
  - Electronic Imaging (Prof. Tominaga)
  - Medical Image Engineering (Prof. Haneishi)
  - Application of Remote Sensing Engineering (Prof. Kuze)
  - Pattern Recognition (Assoc. Prof. Horiuchi)
  - Image Analysis (Visiting Prof. Po-Chieh Hung)
  - Comparative Cognition (Prof. Jitsumori)
  - Form Perception (Prof. Kimura)
  - Cognitive Processing (Assoc.Prof. Ichikawa)

Vision Research Group in Chiba University

- Dept. of Information and Image Sciences, Faculty of Eng.
  - color vision, multispectral imaging, computer graphics, KANSEI engineering
- Dept. of Design, Faculty of Eng.
  - environmental humanomics, ergonomics
- Dept. of Architecture, Faculty of Eng.
  - lighting engineering, environmental design
- Dept. of Medical System Eng., Faculty of Eng.
  - brain imaging, fMRI, physiological optics, retina
- Div. of Behavioral Sciences, Faculty of Letter
  - cognitive and information sciences, psychology, comparative cognition

Current Research Projects in Yaguchi-Mizokami Labo

- Spatiotemporal aspects of color discrimination
- Color recognition and visual attention
- Color appearance in mesopic vision
- Color discrimination for color deficiencies and color universal design
- Analysis of image difference
- Measurement of contrast sensitivity functions
- Color rendering evaluation of solid state light sources
- Color appearance and discomfort glare of automotive headlamps
- Color appearance of human skin
- Perceived quality of wood image
- Natural environment and development of human color vision
- Color constancy and naturalness

Color Universal Design

How color deficiencies see color?

Normal

Protanope
(missing L cone)

Deuteranope
(missing M cone)

Tritanope
(missing S cone)

Simulation based on
Hans Brettel, Françoise Viénot, and John D. Mollon ,
Computerized simulation of color appearance for dichromats,
JOSA A, Vol. 14, Issue 10, pp. 2647-2655 (1997)

Why color appearance for anomalous trichromat?

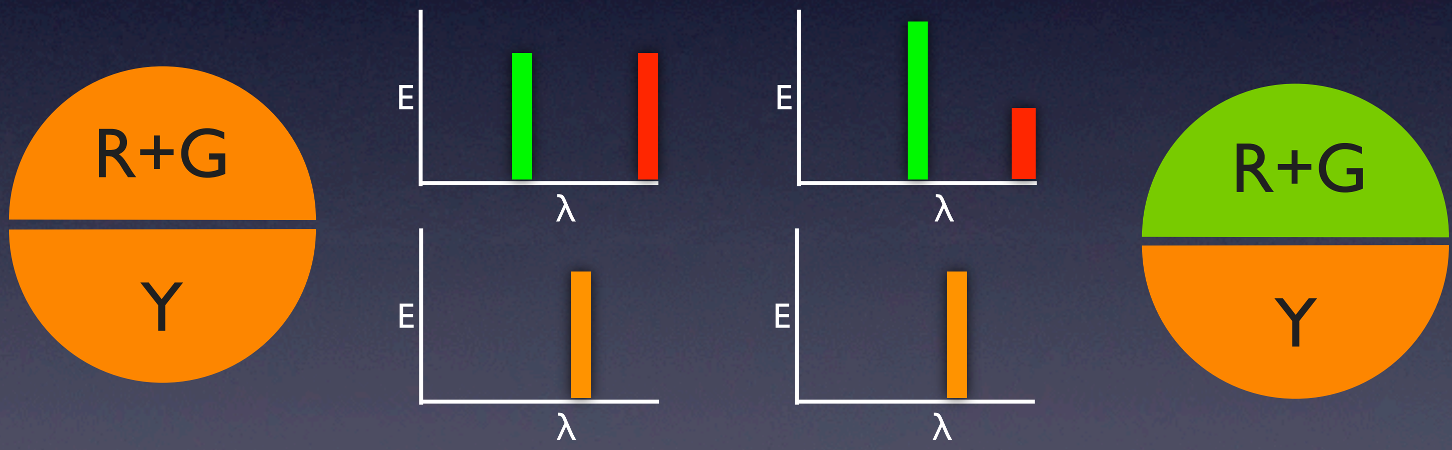
Main types of inherited color vision defects with approximate proportions of appearance in the population.

Conditions	Percent (%) in UK	
	Male	Female
Protanopia	1	0.02
Protanomaly	1.5	0.03
Deuteranopia	1	0.01
Deuteranomaly	5	0.4
Tritanopia and tritanomaly	Very small	

(R.Fletcher and J.Voke, Defective colour vision, fundamentals, diagnosis and management, Adam Hilger Ltd, 1985)

Rayleigh color match

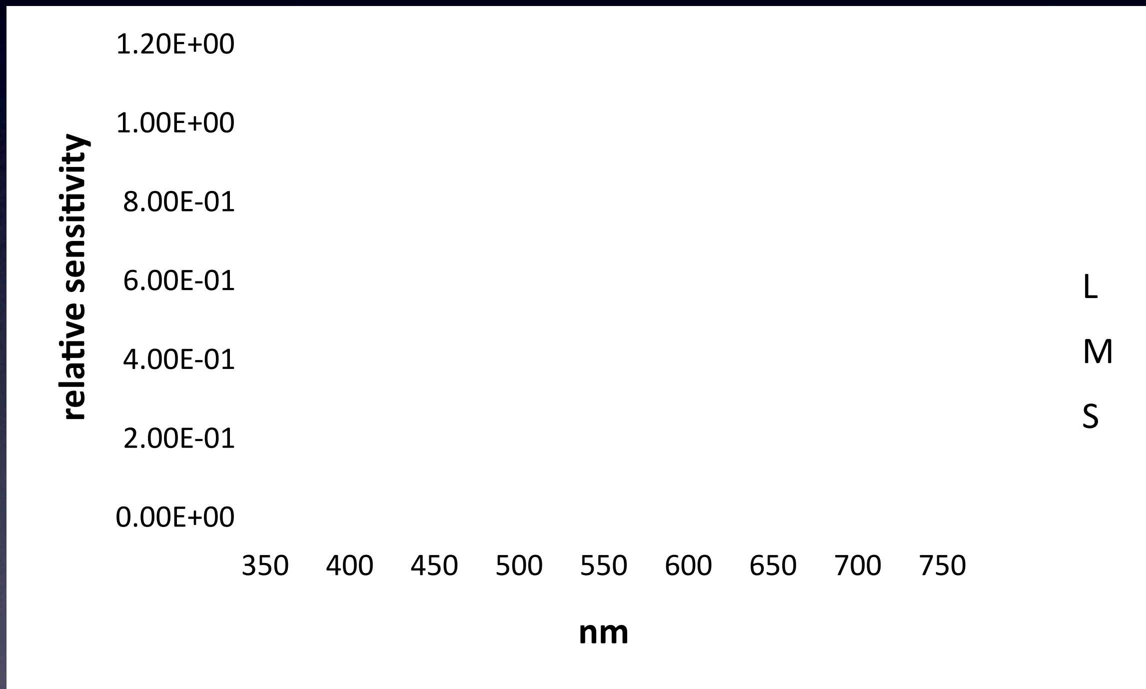
- Anomaloscope are used for classification of color deficiency types.
- In the anomaloscope, observers make color match between narrow-band yellow (590nm) and a mixture of narrow-band red (690nm) and green (545nm), so called Rayleigh match.
- Normal trichromat and anomalous trichromats make color matches with different R/G ratio with each other (Observer metamerism).



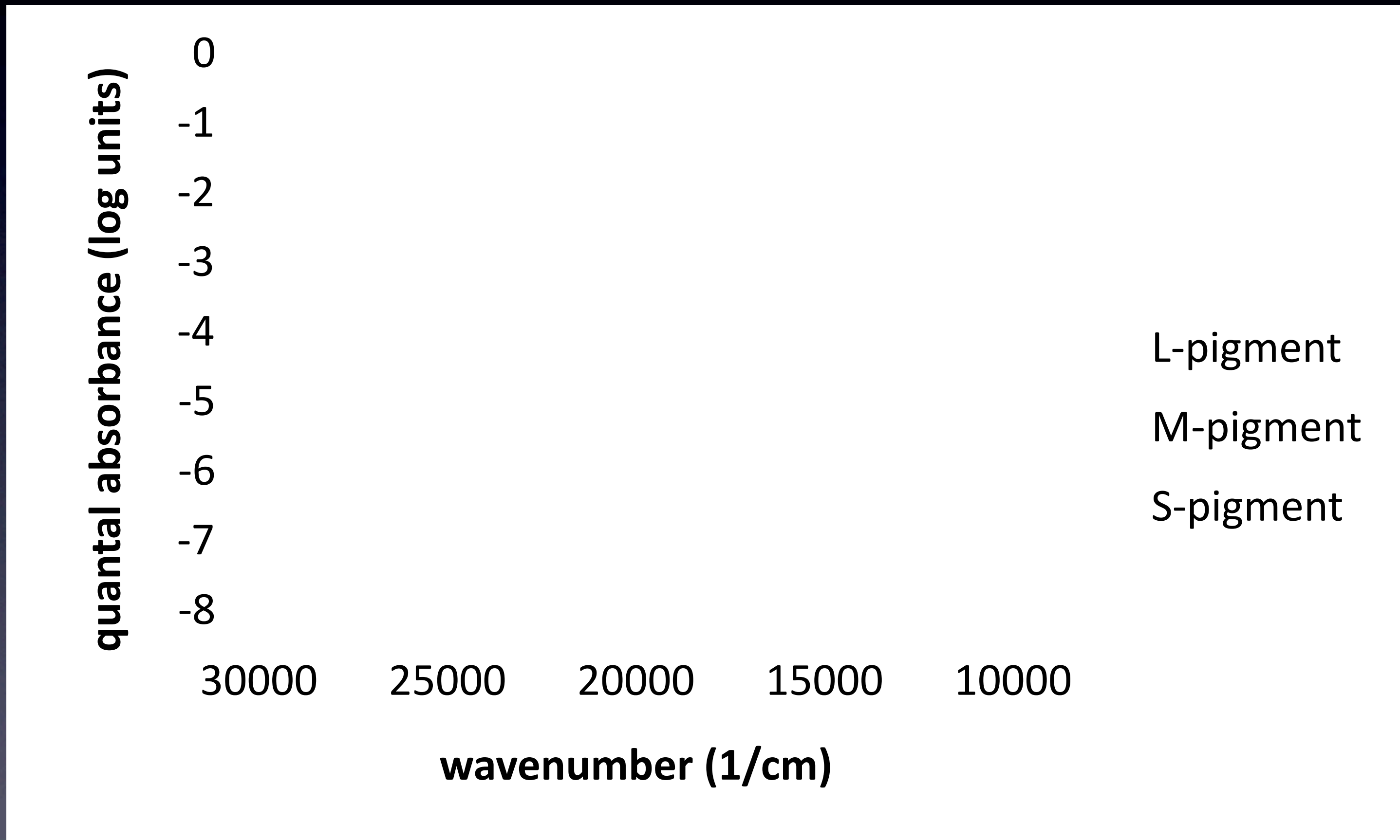
Normal

Normal trichromat's view of deuteranomalous color matching

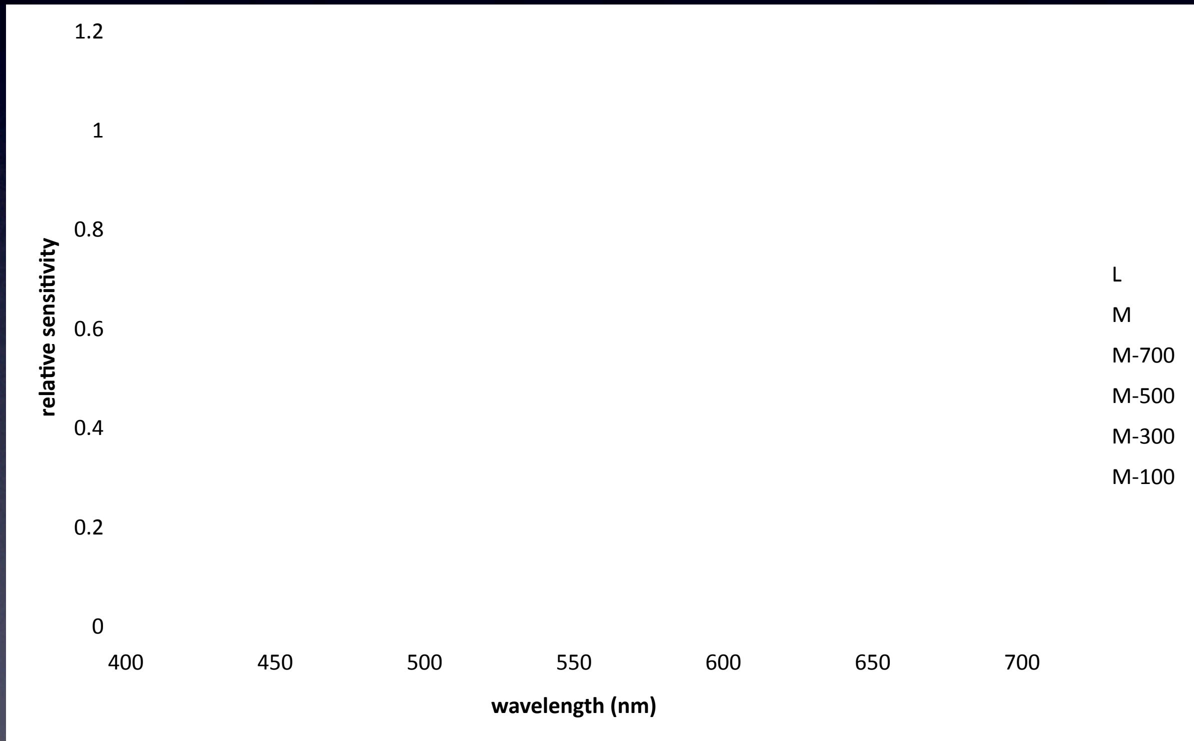
L-, M-, S-cone spectral sensitivities (CIE2006)



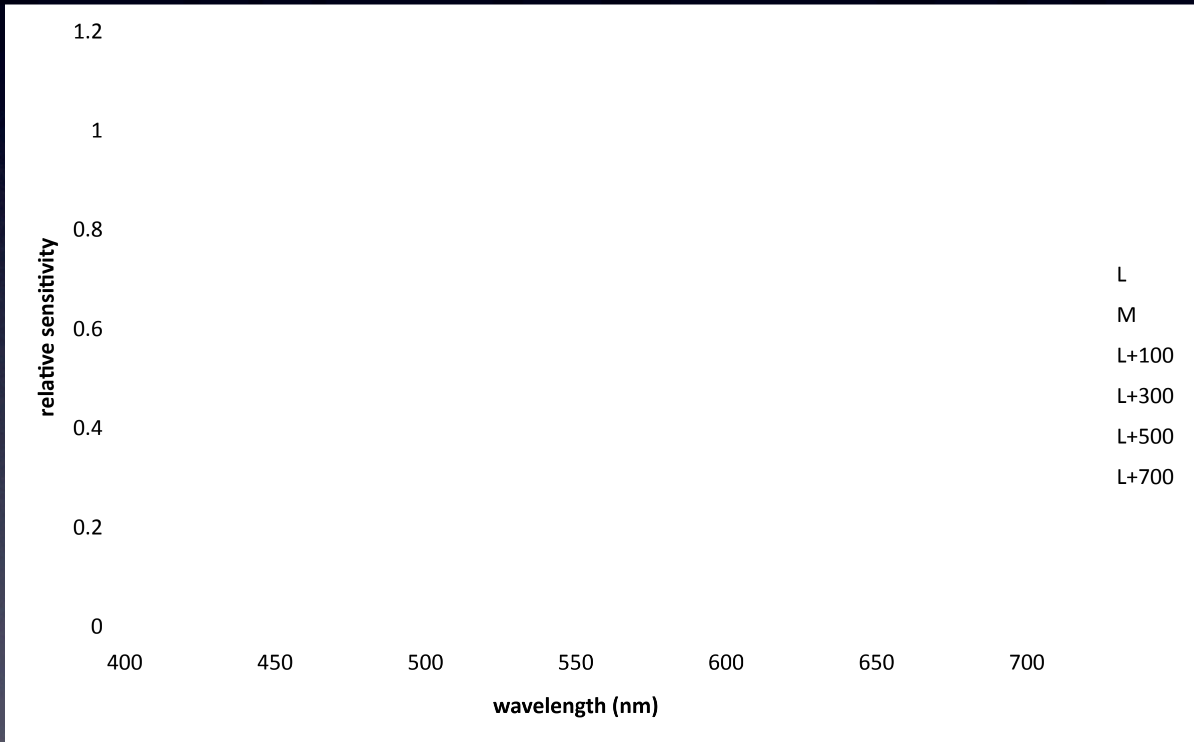
Log quantal absorbance of cone pigments as a function of wavenumber



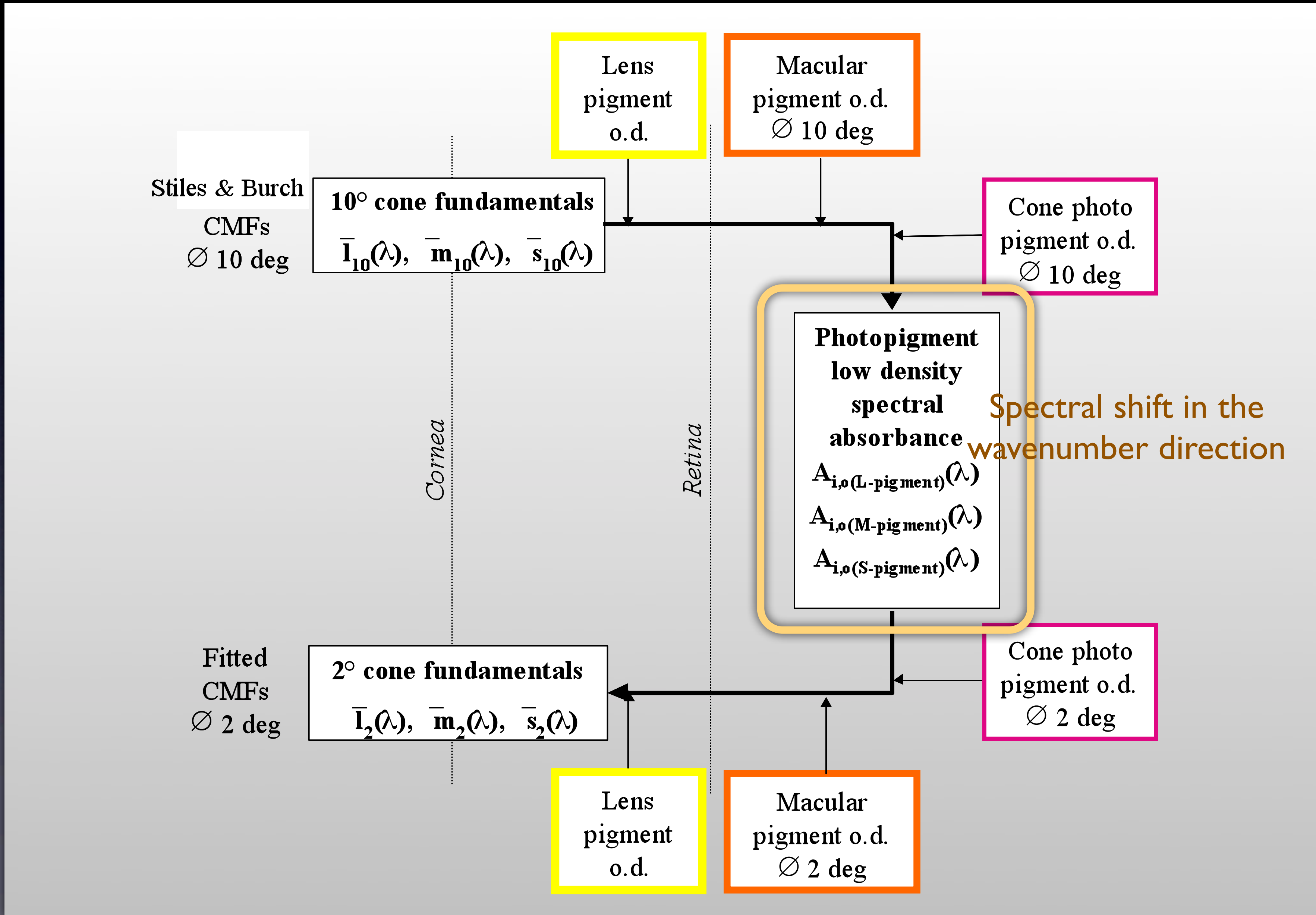
Spectral sensitivities of M' (hybrid)-cones (Deuteranomalous trichromat)



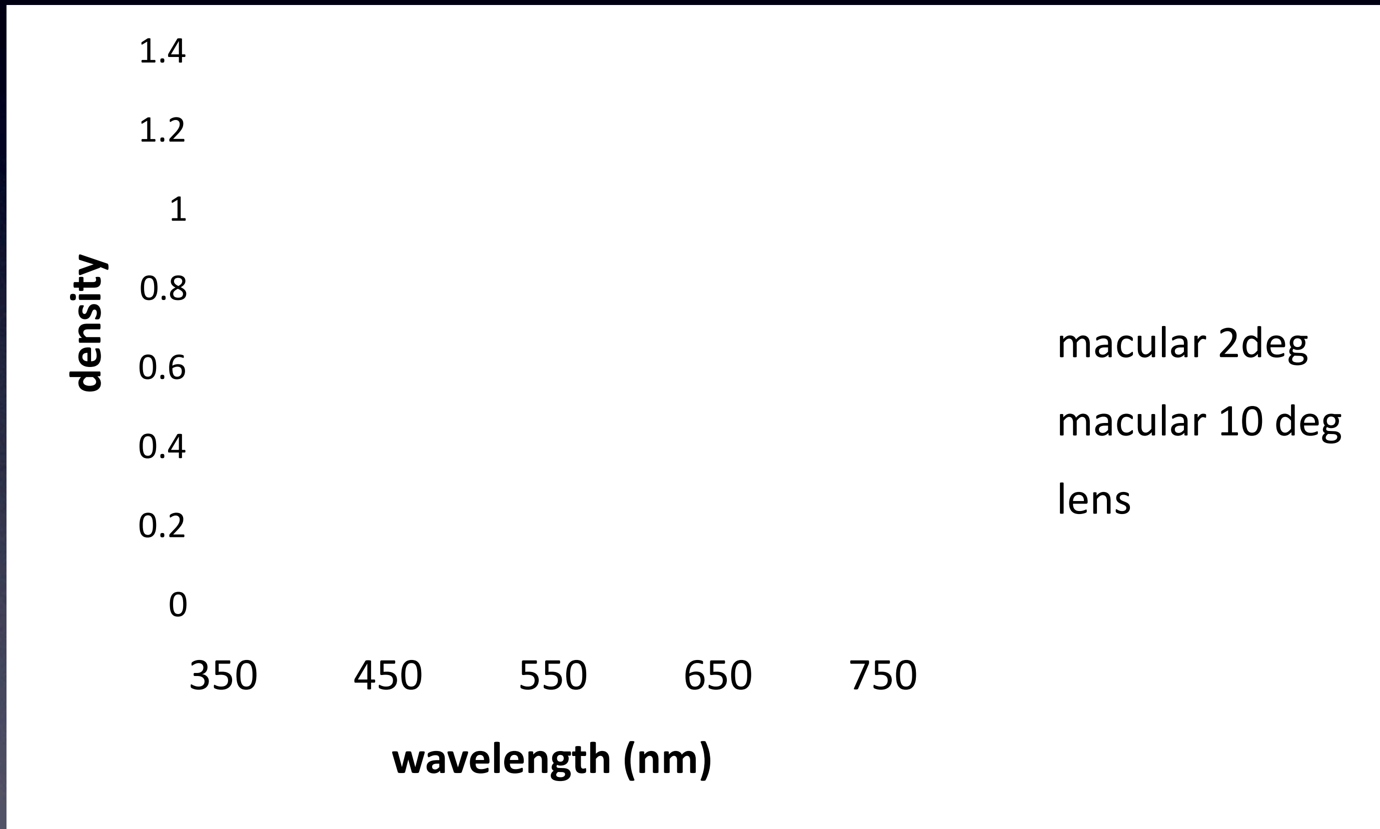
Spectral sensitivities of L' (hybrid)-cones (Protanomalous trichromat)



Derivation of the 2° cone fundamentals from the 10° cone fundamentals (CIE170-1)



Ocular density



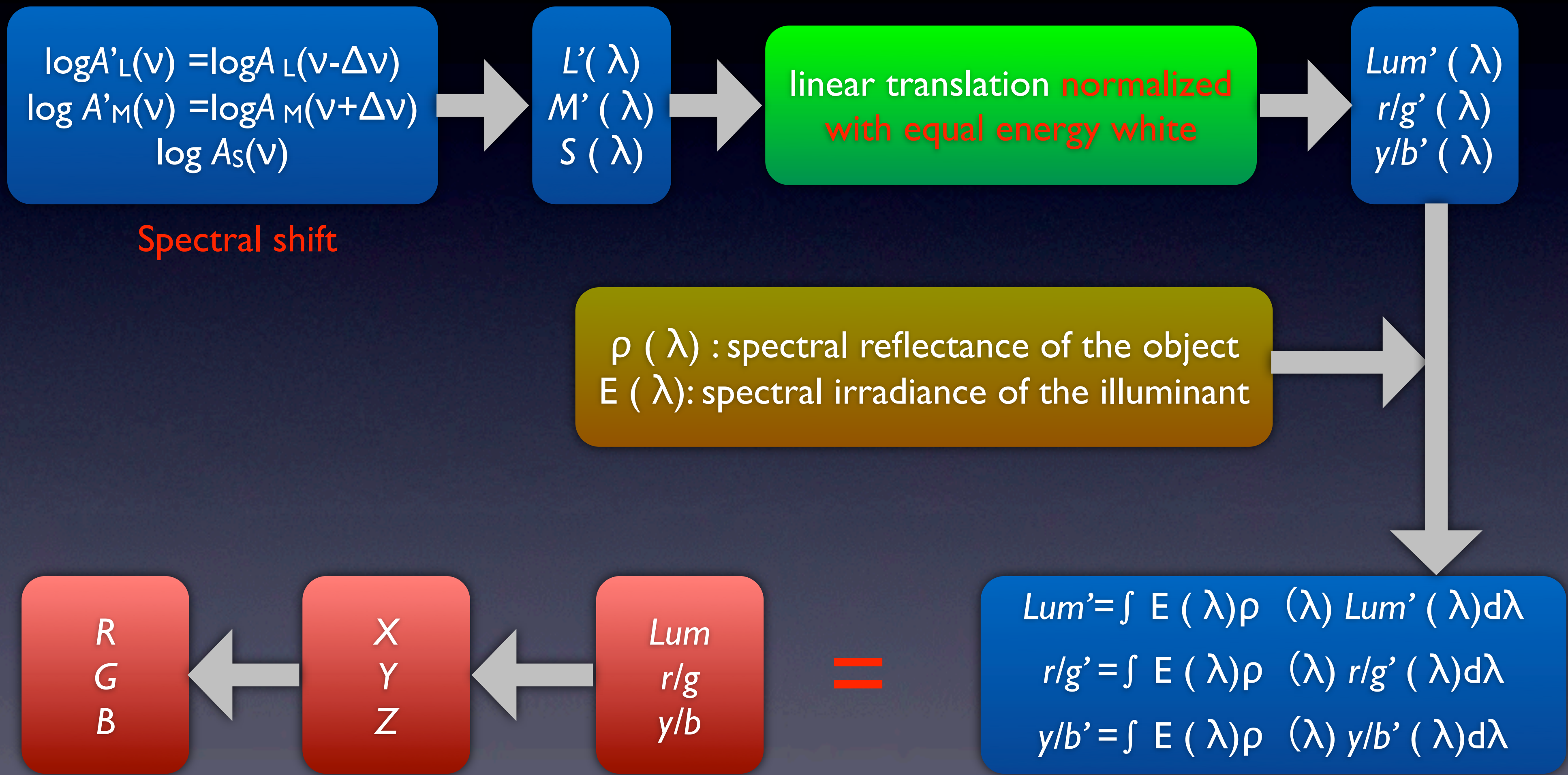
The reconstructed cone fundamentals for the 2 deg observer

- The cone absorptance spectra in terms of quanta (Self-screening)
  - $\alpha_{i,l}(\lambda) = 1 - 10^{[-0.5 A_{i,0(\text{L-pigment})}(\lambda)]}$
  - $\alpha_{i,m}(\lambda) = 1 - 10^{[-0.5 A_{i,0(\text{M-pigment})}(\lambda)]}$
  - $\alpha_{i,s}(\lambda) = 1 - 10^{[-0.4 A_{i,0(\text{S-pigment})}(\lambda)]}$
- The cone fundamental spectral sensitivity in terms of quanta
  - $L_q(\lambda) = \alpha_{i,l}(\lambda)\, \tau_{macula}(\lambda) \tau_{ocul}(\lambda)$
  - $M_q(\lambda) = \alpha_{i,m}(\lambda)\, \tau_{macula}(\lambda) \tau_{ocul}(\lambda)$
  - $S_q(\lambda) = \alpha_{i,s}(\lambda)\, \tau_{macula}(\lambda) \tau_{ocul}(\lambda)$

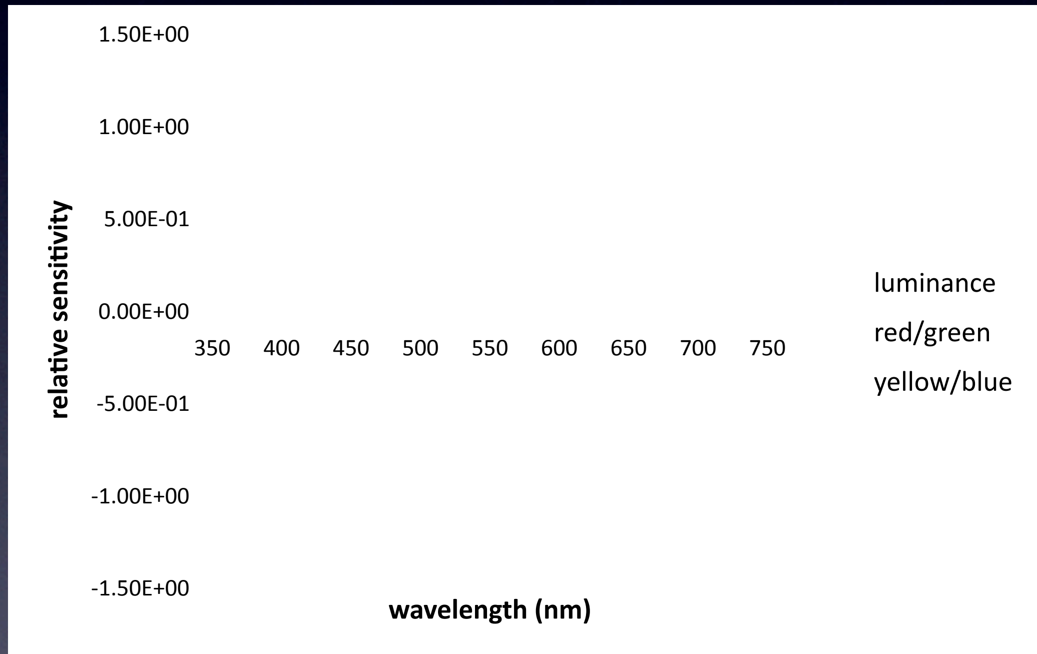
Assumptions

- Spectral absorption of L-, M-cones are getting close.
  - Protanomalous: $\log A'_L(\nu) = \log A_L(\nu - \Delta\nu)$
  - Deuteranomalous: $\log A'_M(\nu) = \log A_M(\nu + \Delta\nu)$
- L-, M-, S-fundamentals specified with CIE170-1 (2006), Stockman and Sharp
- Transfer matrix of LMS to XYZ, CIE170-2 (2013)
  - $X = 1.94735469L - 1.41445123M + 0.36476327S$
  - $Y = 0.68990272L + 0.34832189M$
  - $Z = 1.93485343S$
- Second stage
  - luminance $Y = k_l L + k_m M = 0.68990272L + 0.34832189M$
  - $r/g = \alpha_l L - \alpha_m M = 0.838812974L - 1.025975198M$
  - $y/b = \beta_y Y - \beta_s S = 0.516835014Y - S = 0.356565882L + 0.180024949M - S$
  - $r/g = y/b = 0$ *for equal energy white* $(X=Y=Z)$
- Color appearance would be reproduced from the second stage
  - Y, r/g, y/b to XYZ then to RGB

Simulation flow



Spectral sensitivities at the second stage (Normal observer)



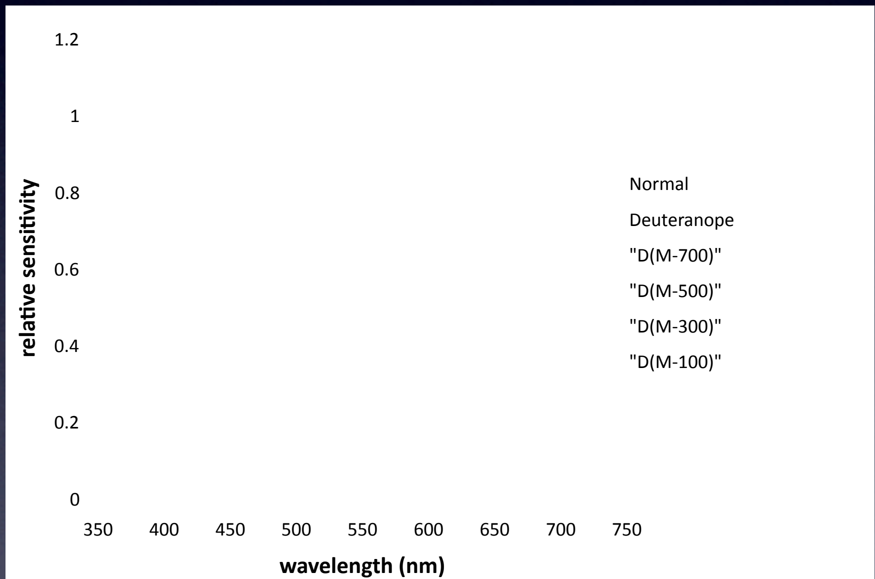
- luminance $Y = 0.69L + 0.35M$
- $r/g = 0.84L - 1.03M$
- $y/b = 0.36L + 0.18M - S$
- *$r/g = y/b = 0$ for equal energy white ($X=Y=Z$)*

Opponent color response

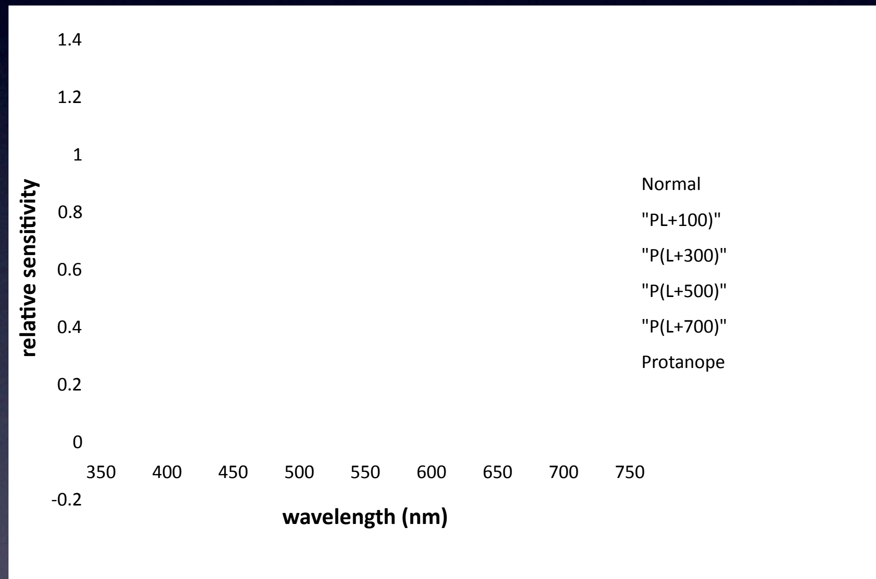
- luminance $Y' = k_l\,(L_{EW}/L'_{EW})\,L' + k_m(M_{EW}/M'_{EW})\,M'$
- $r/g' = \alpha_l\,(L_{EW}/L'_{EW})\,L' - \alpha_m(M_{EW}/M'_{EW})\,M'$
- $y/b' = \beta_y Y' - \beta_s S = k_l\,(L_{EW}/L'_{EW})\,L' + k_m(M_{EW}/M'_{EW})\,M' - S$
- $r/g' = y/b' = 0$ for the equal energy white ($X=Y=Z$)

Achromatic spectral sensitivities of anomalous trichromats

Deutan



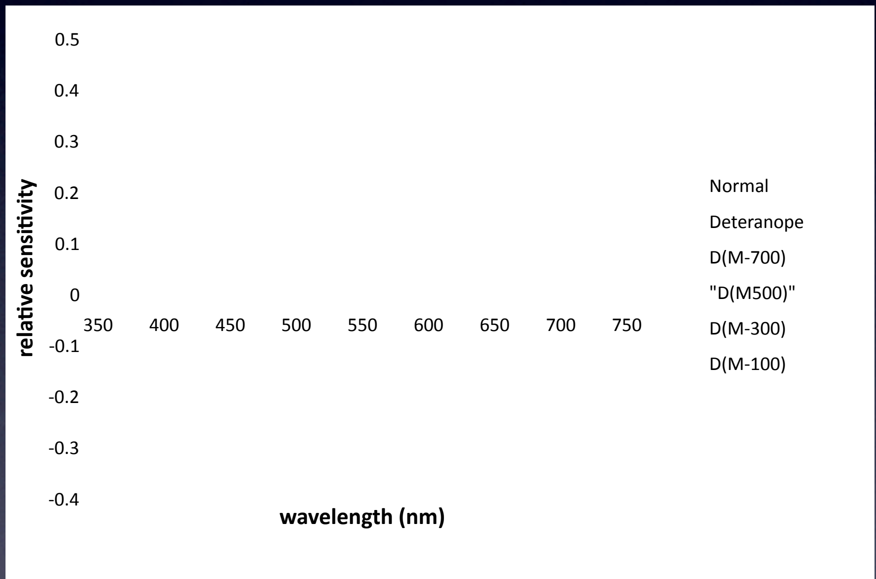
Protan



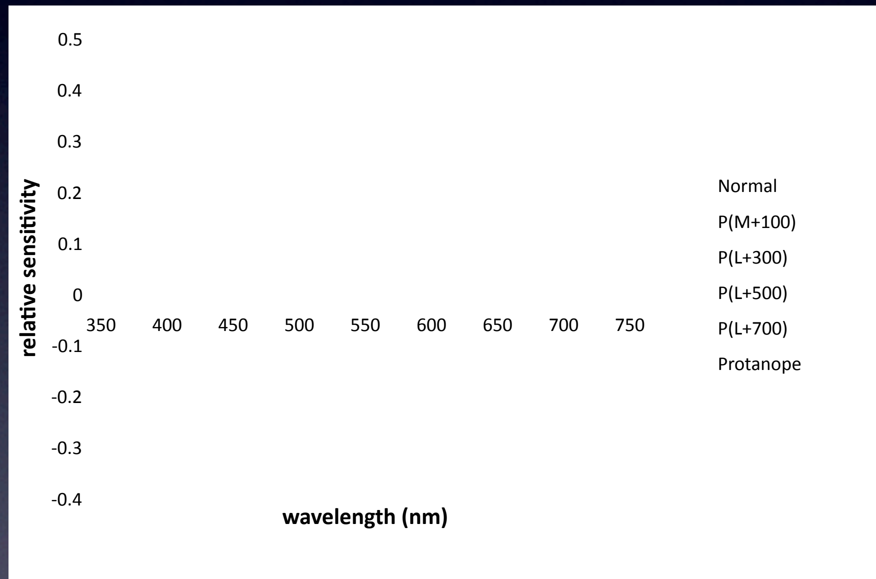
*normalized with the equale energy white (same luminance)

Red/green spectral sensitivities of anomalous trichromats

Deutan



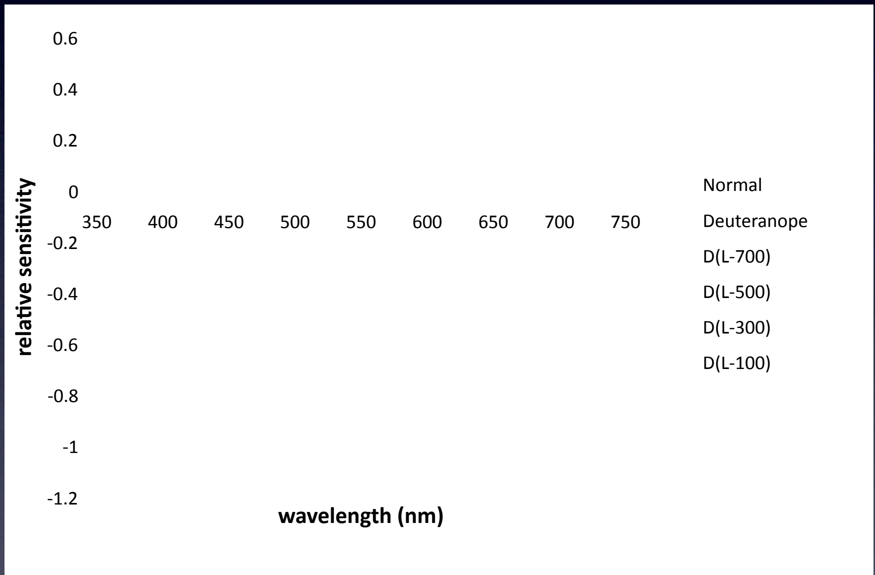
Protan



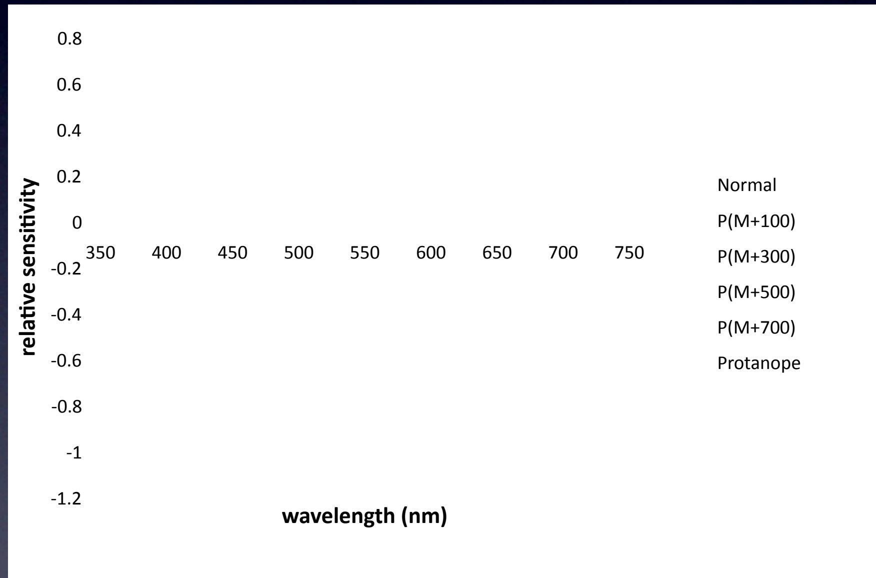
*normalized with the equale energy white (r/g = 0)

Yellow/blue spectral sensitivities of anomalous trichromats

Deutan



Protan



*normalized with the equale energy white (r/g = 0)

Transfer matrix of XYZ to LMS (CIE170-2, 2013)

- X = 1.94735469L - 1.41445123M + 0.36476327S
- Y = 0.68990272L + 0.34832189M
- Z = 1.93485343S
- L = 0.21057582X + 0.855097643Y - 0.039698265Z
- M = -0.417076374X + 1.177261096Y + 0.078628251Z
- S= 0.516835014Z

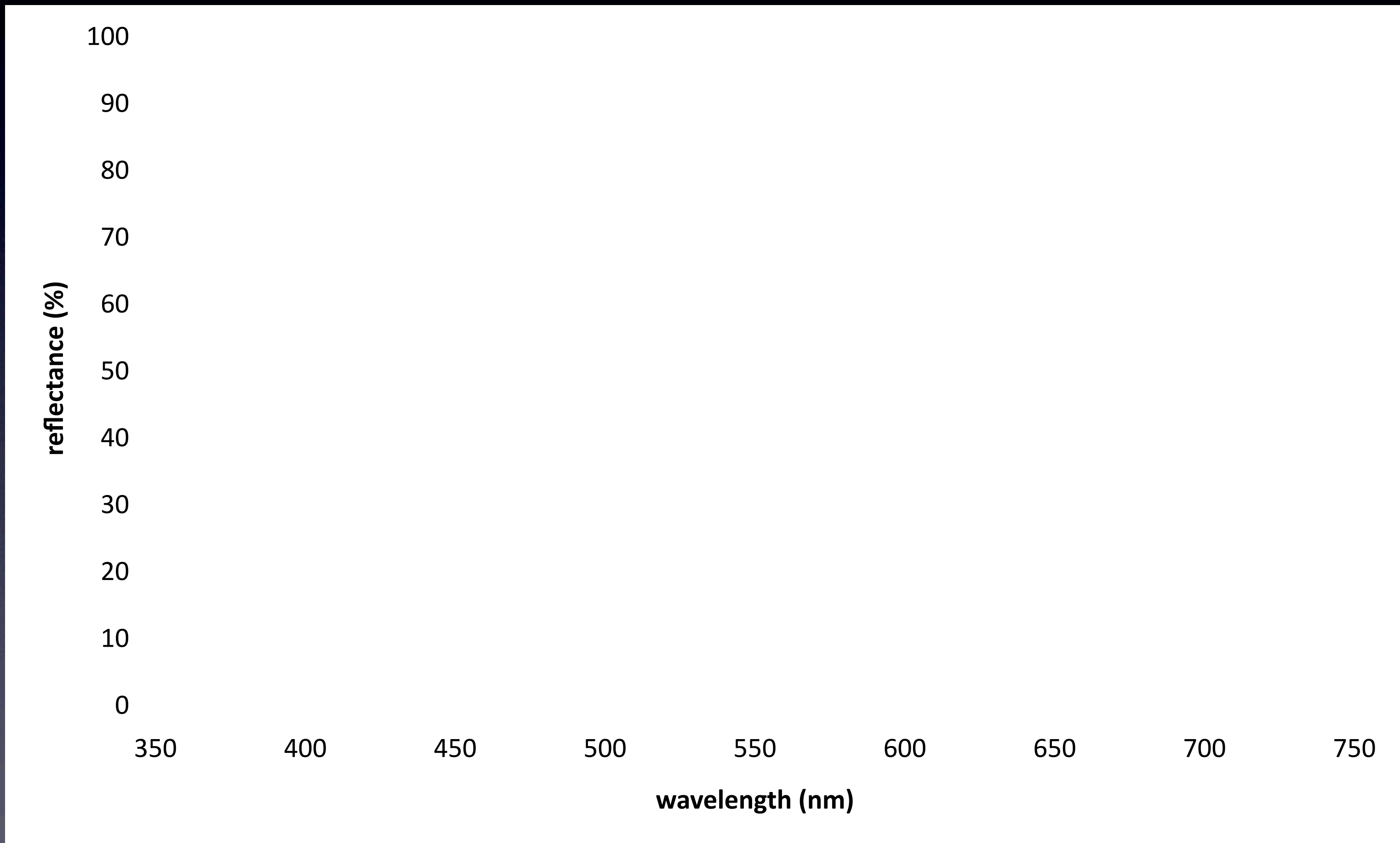
Second stage to XYZ

- $X = A + 1.654140017 r/g - 0.36476327 y/b$
- $Y = A$
- $Z = A - 1.93485343 y/b$

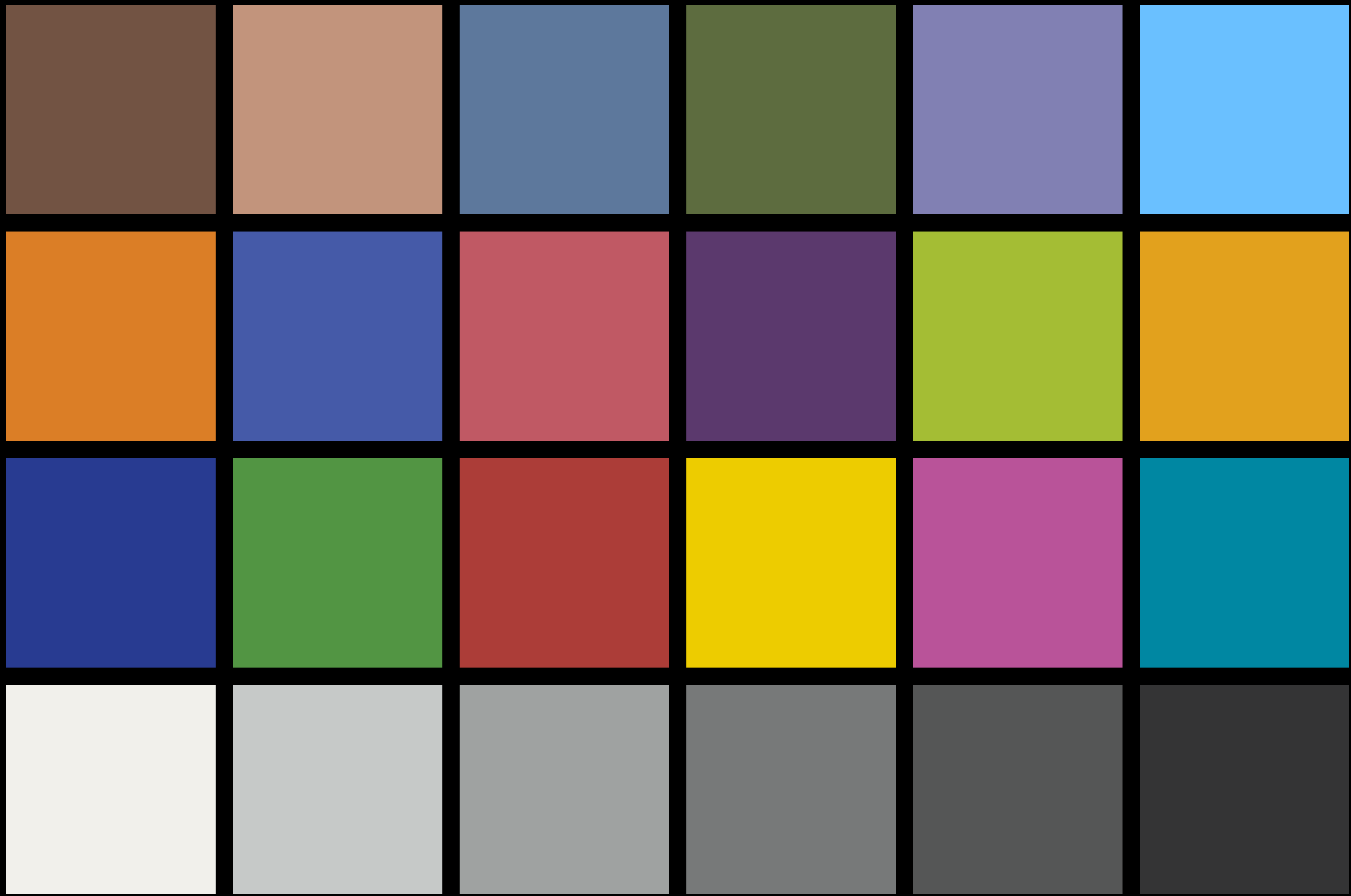
XYZ to sRGB

- $R = 3.2406X - 1.5372Y - 0.4986Z$
- $G = -0.9689X + 1.8758Y - 0.0415Z$
- $B = 0.0557X - 0.2040Y + 1.0570Z$
- $R_{8\text{-bit}} = R^{1/\gamma}$
- $G_{8\text{-bit}} = G^{1/\gamma}$
- $B_{8\text{-bit}} = B^{1/\gamma}$

Spectral reflectance of Macbeth Color Checker

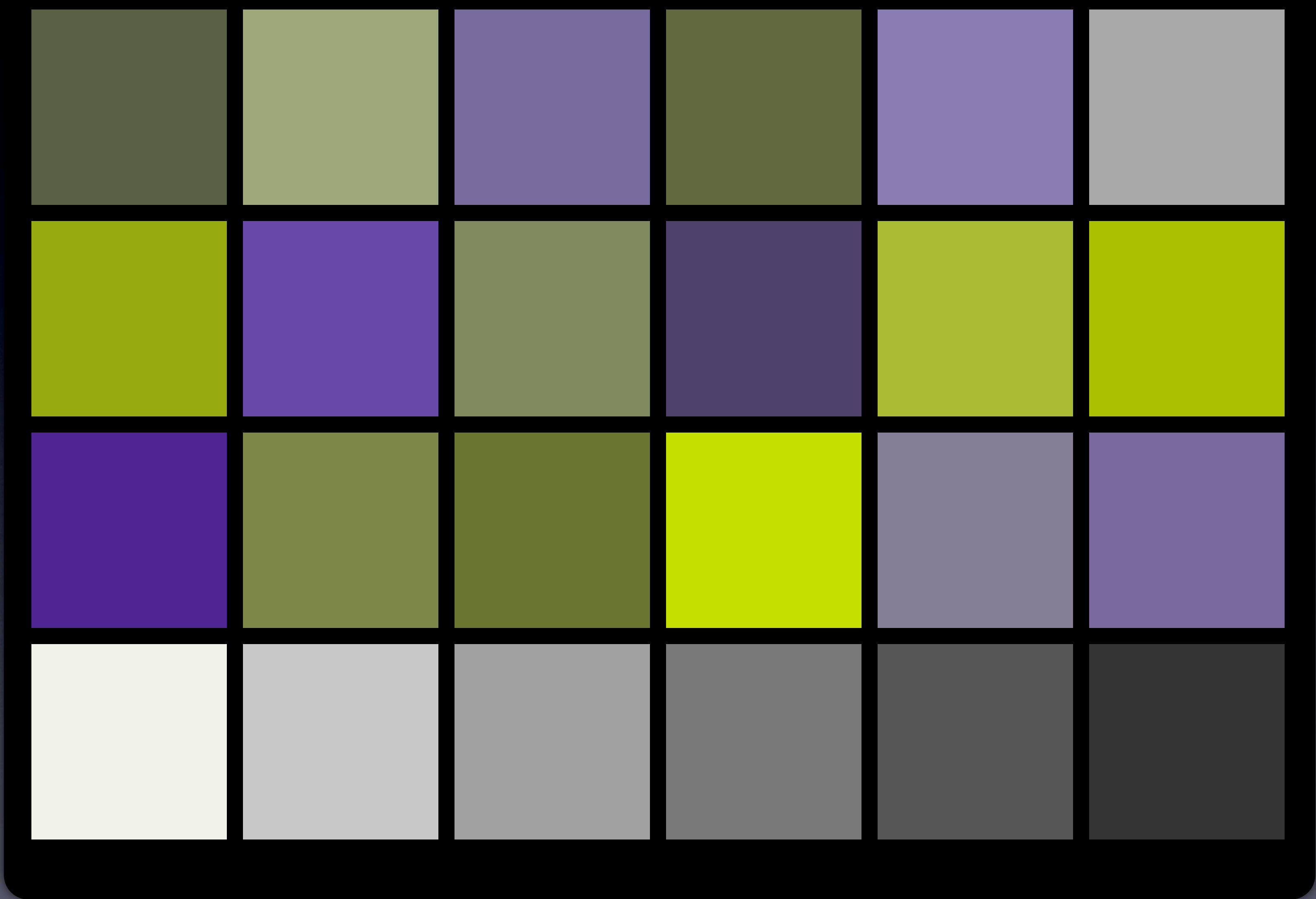


Normal trichromat (γ=1.8)

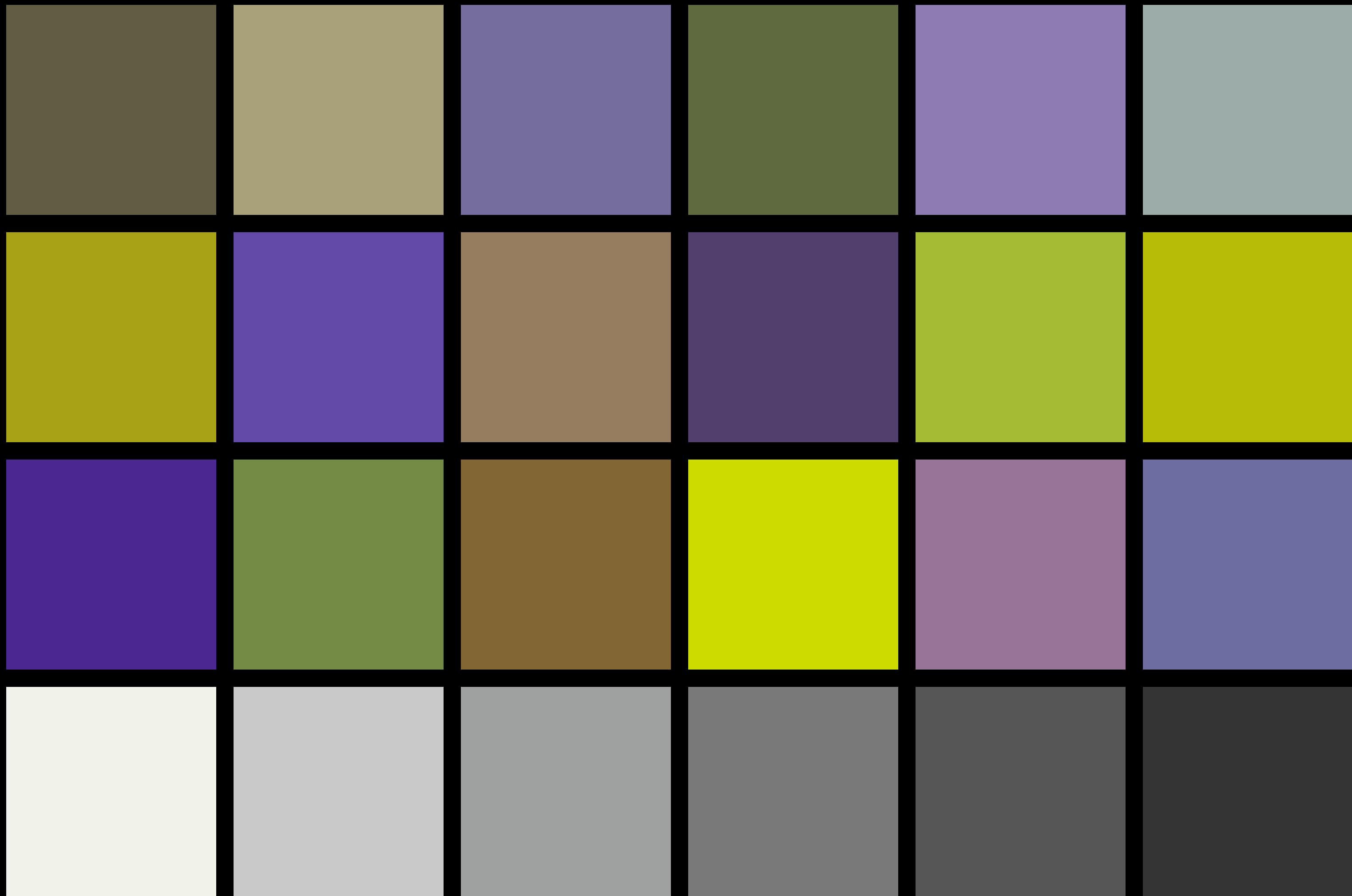


Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Deuteranope (γ=1.8)

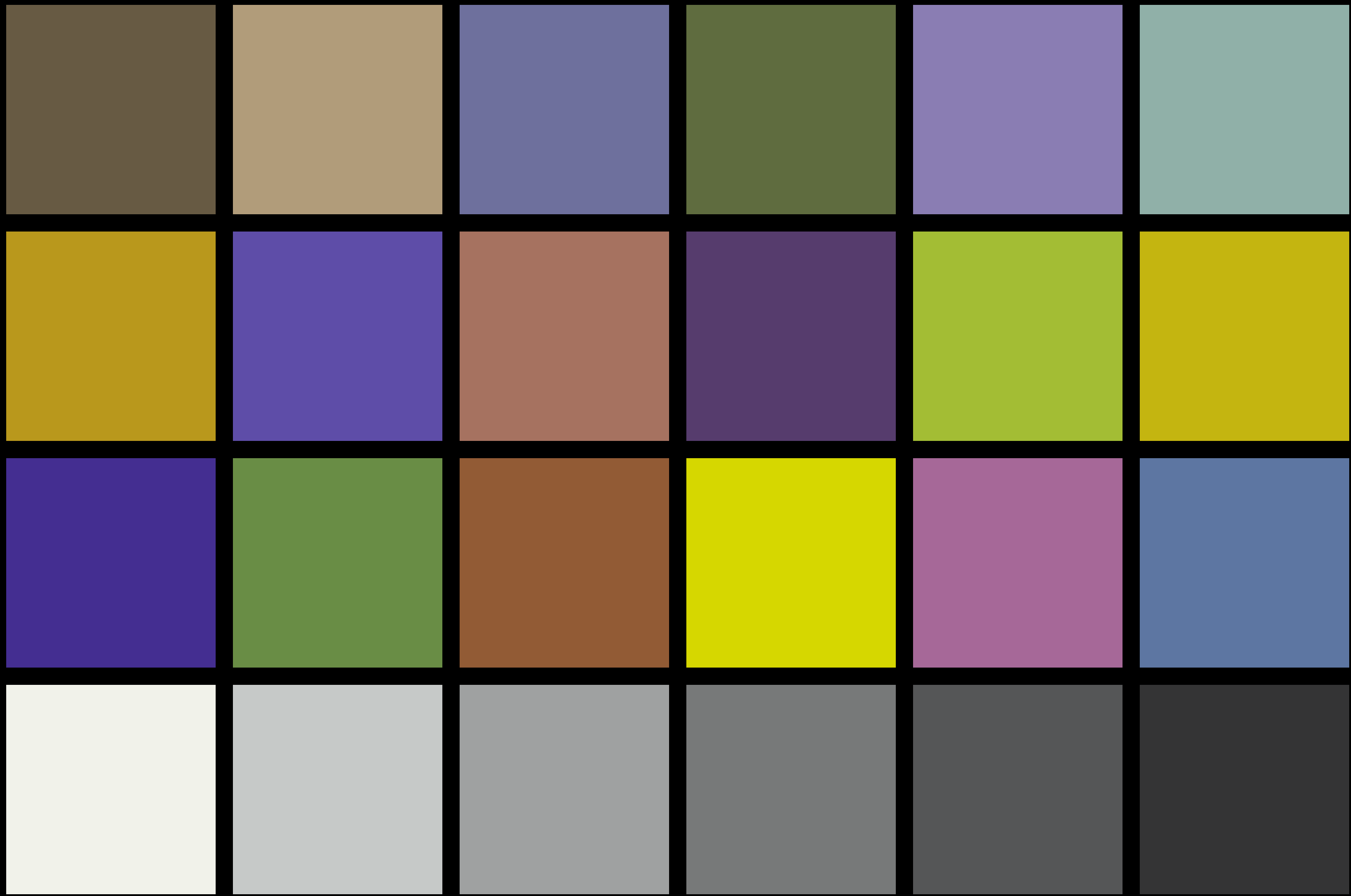


Deuteranomalous(M-700cm^{-1}) (γ=1.8)



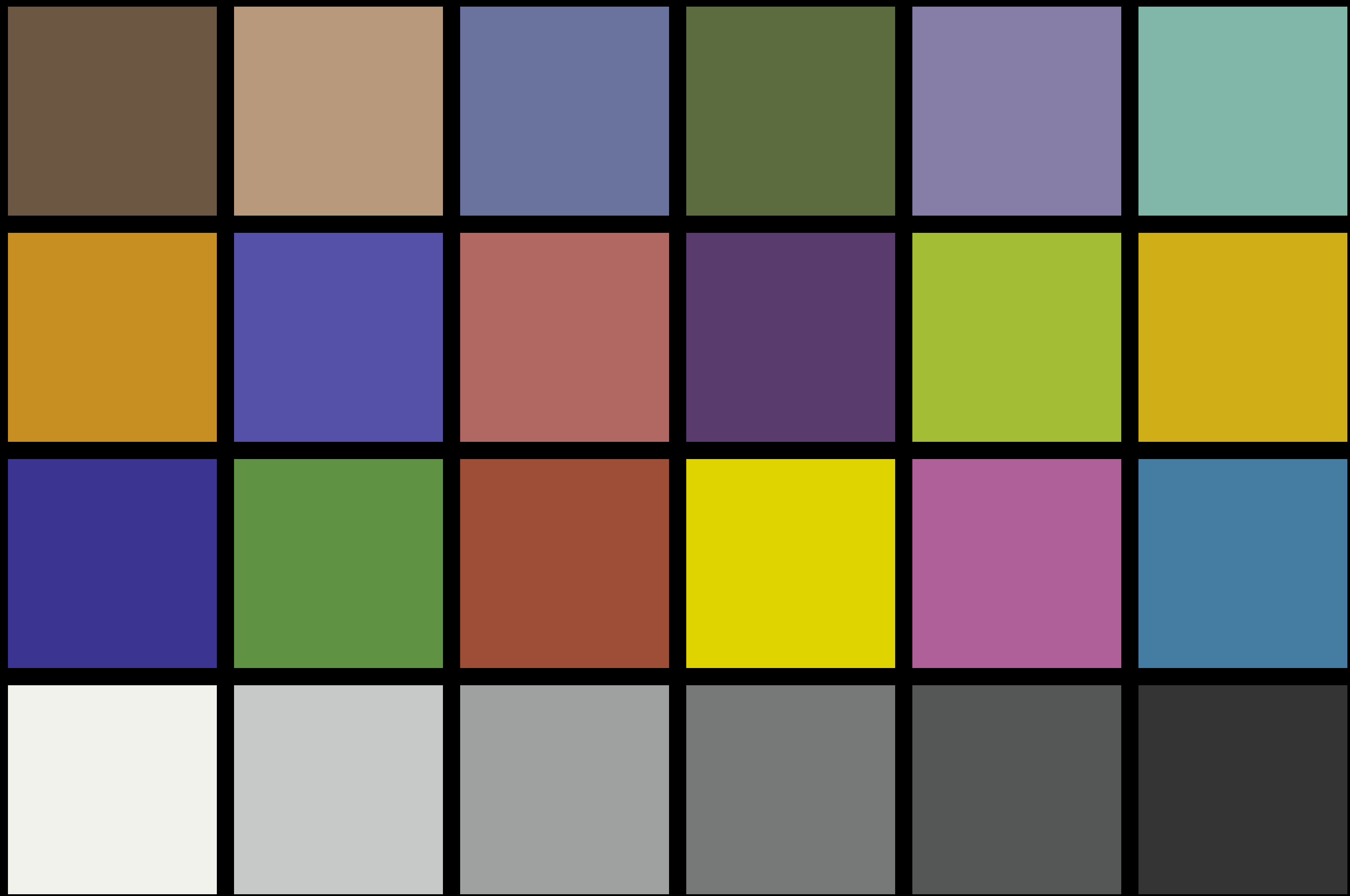
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Deuteranomalous(M-500cm^{-1}) (γ=1.8)



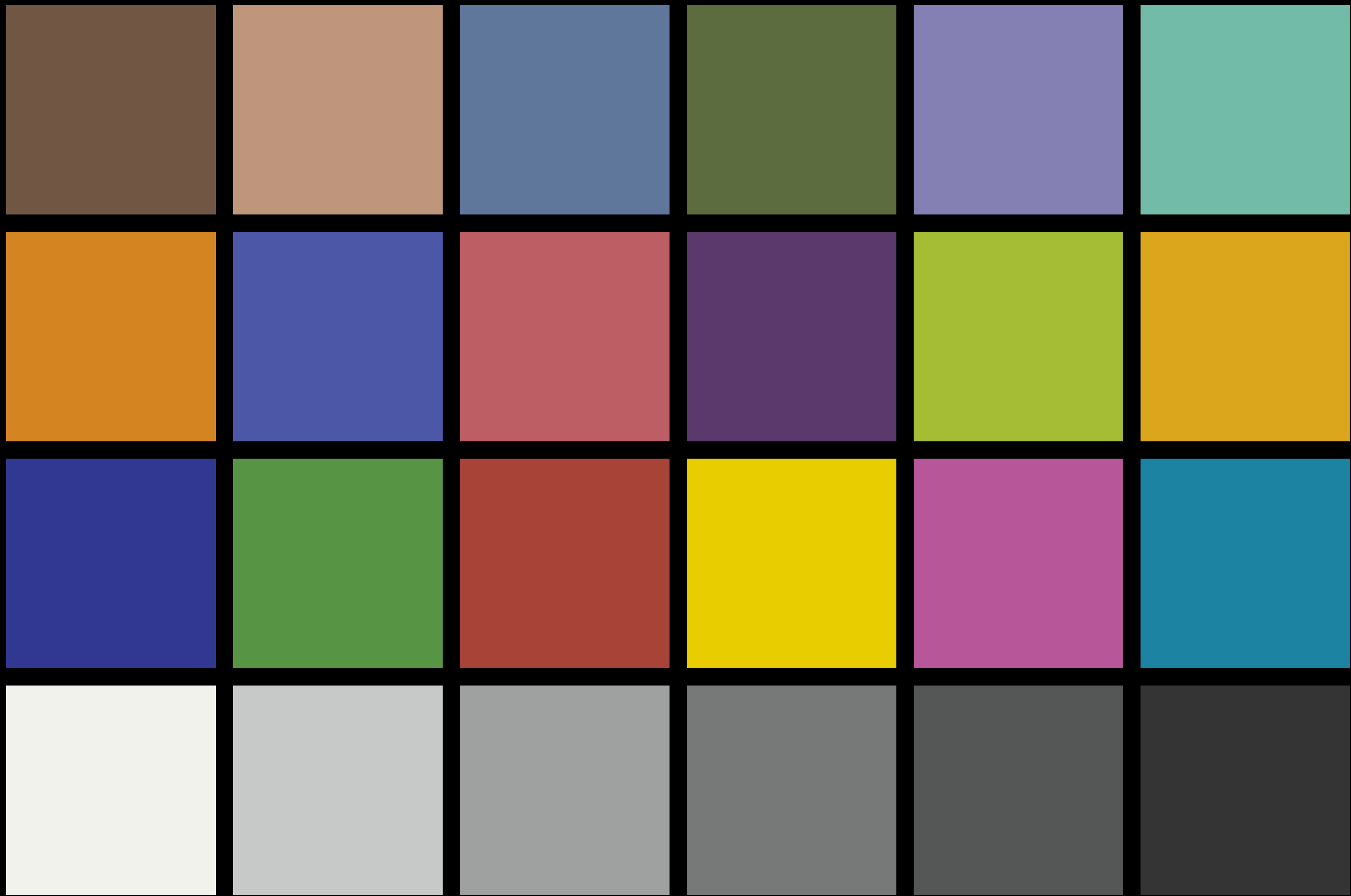
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Deuteranomalous(M-300cm^{-1}) (γ=1.8)



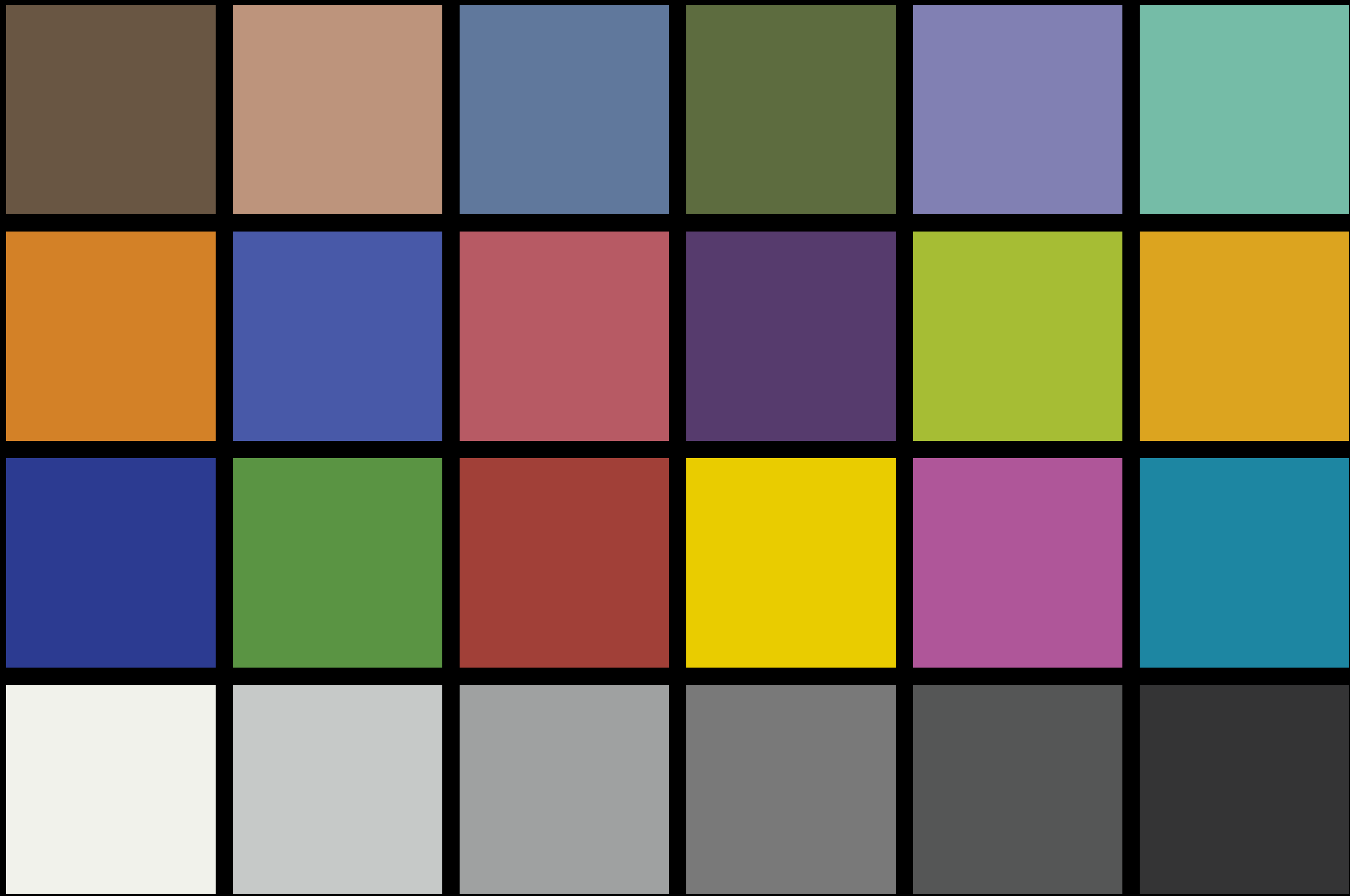
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Deuteranomalous(M-100cm^{-1}) (γ=1.8)



Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Protanomalous (L+100cm^{-1}) (γ=1.8)

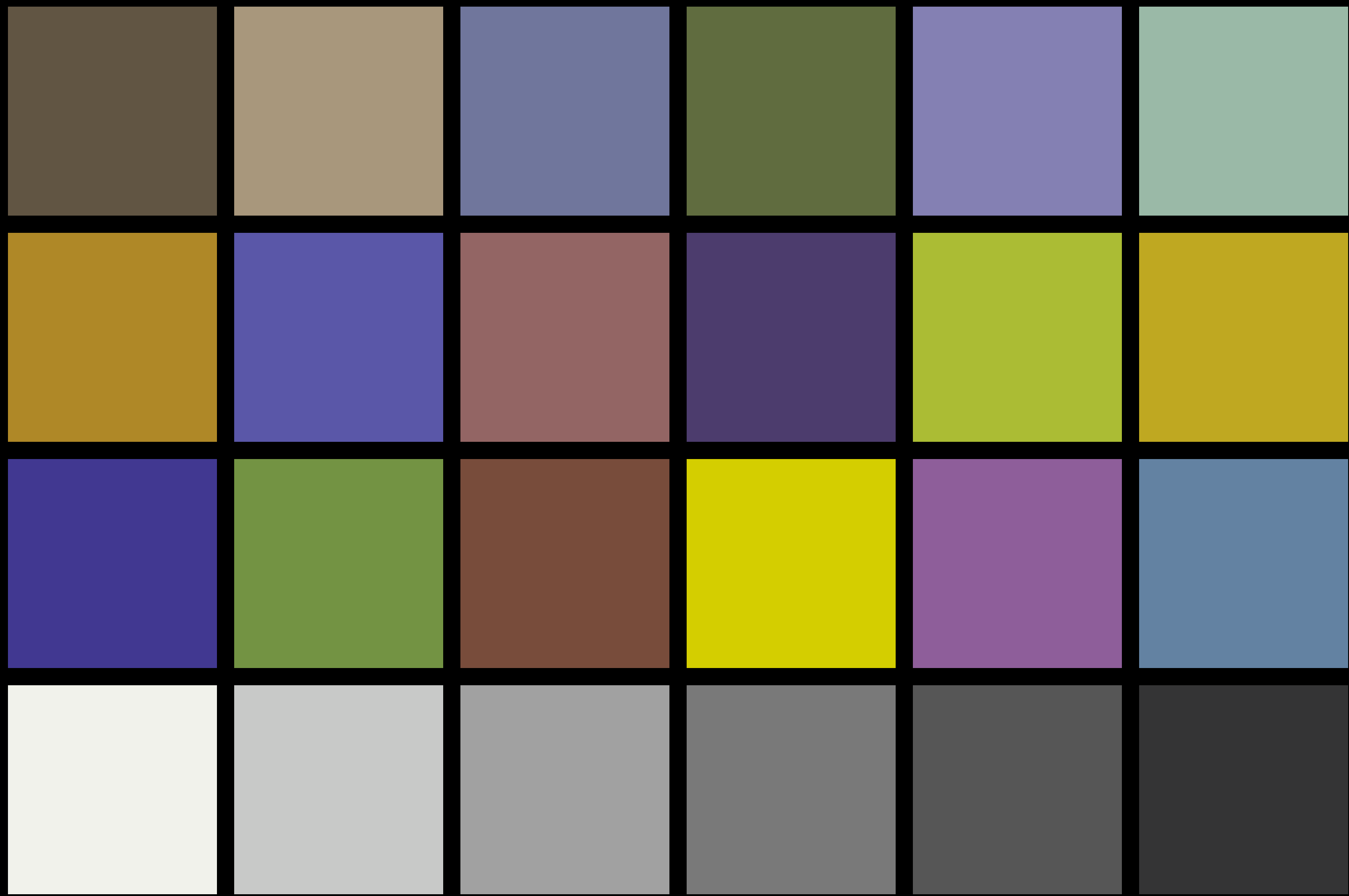


Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Protanomalous (L+300cm^{-1}) (γ=1.8)

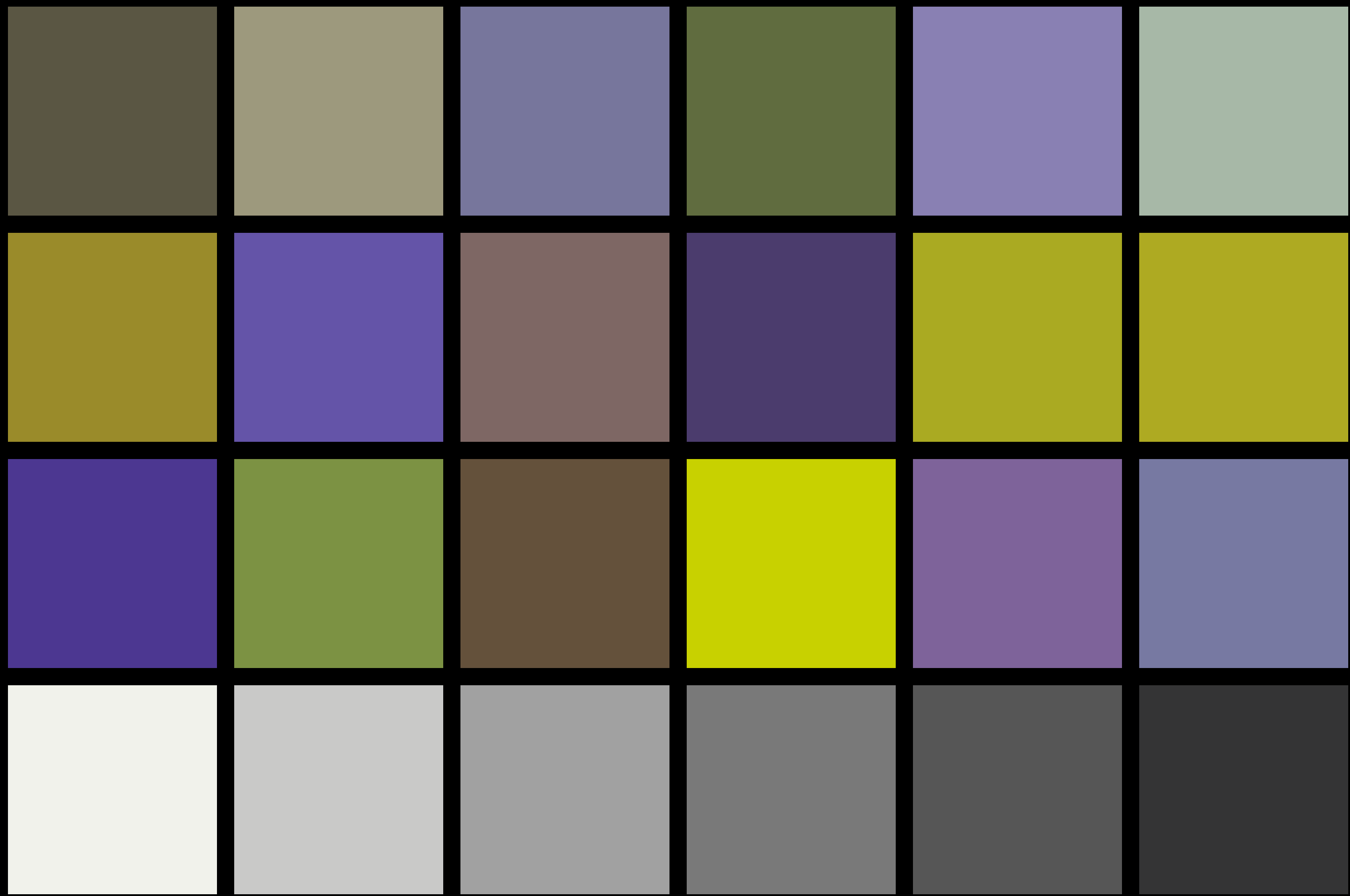
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Protanomalous (L+500cm^{-1}) (γ=1.8)



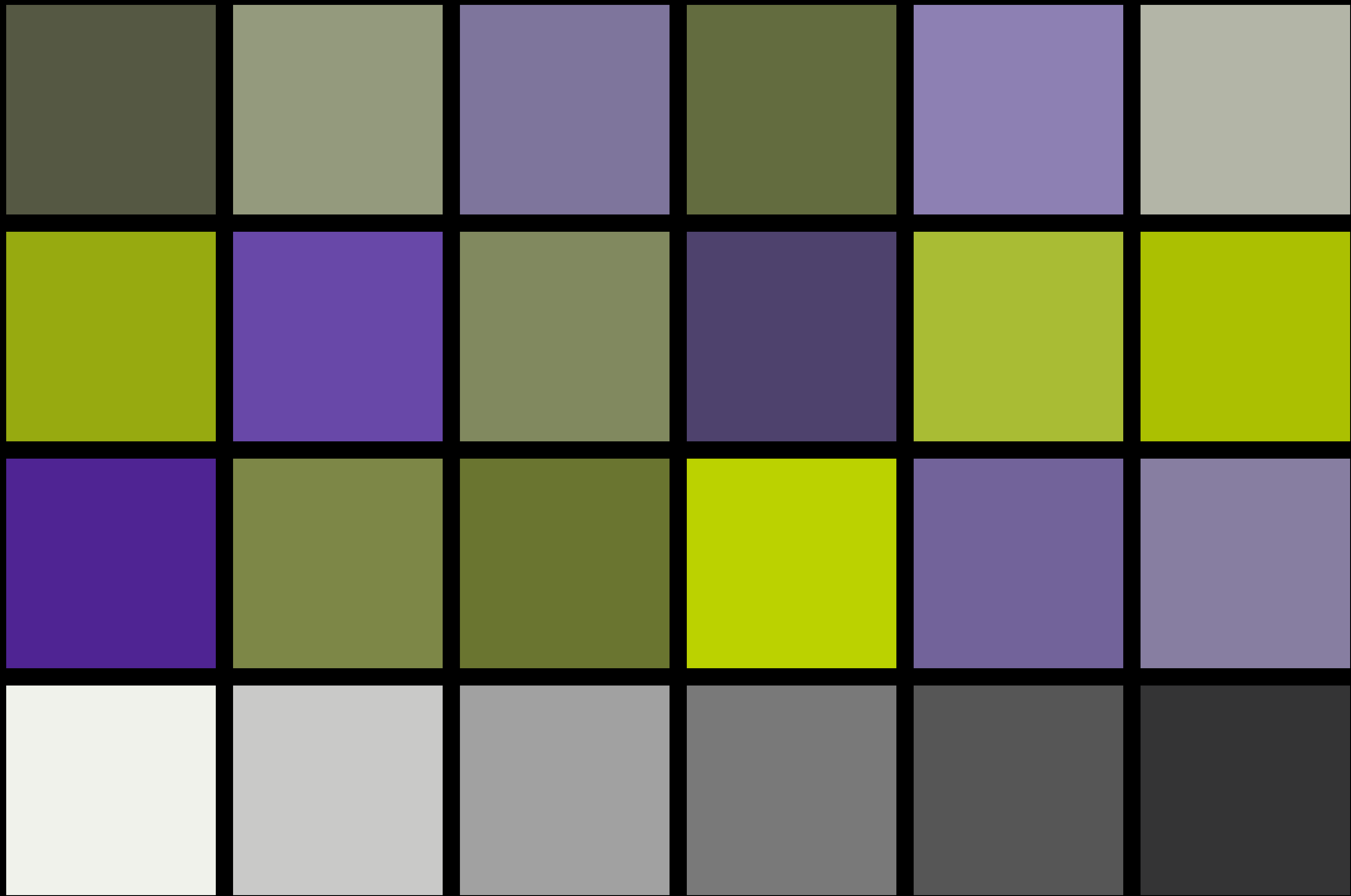
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Protanomalous (L+700cm^{-1}) (γ=1.8)



Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

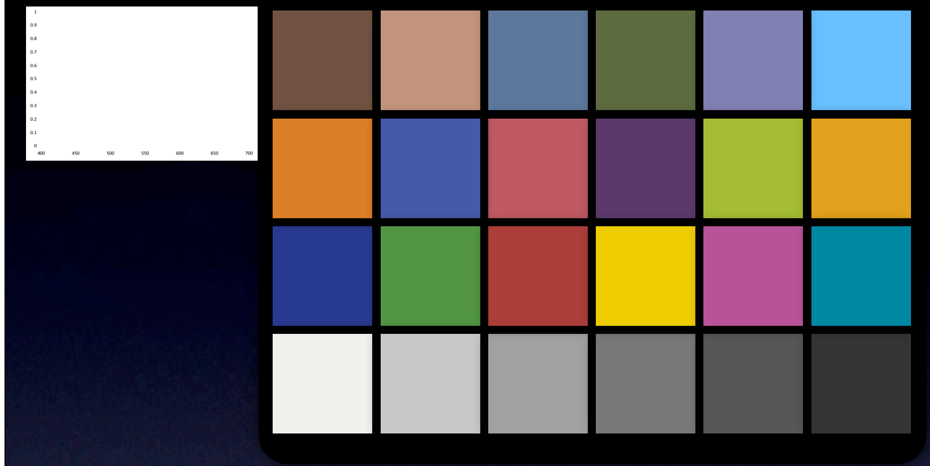
Protanope (γ=1.8)



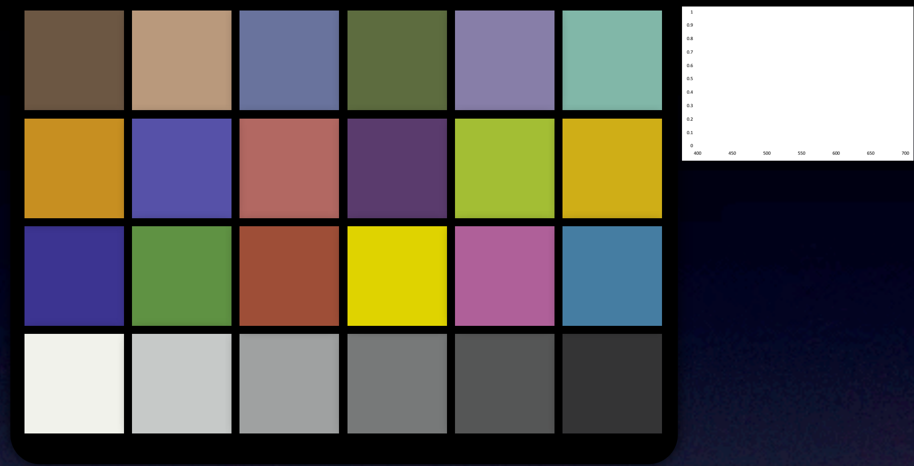
Macbeth ColorChecker Color Rendition Chart simulated with anomalous trichromat by Yaguchi method

Color appearance for Deutan

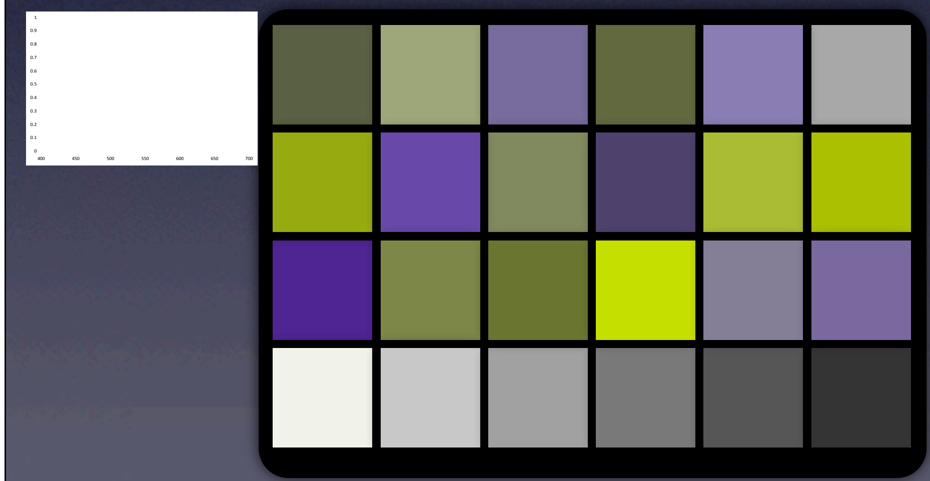
Normal



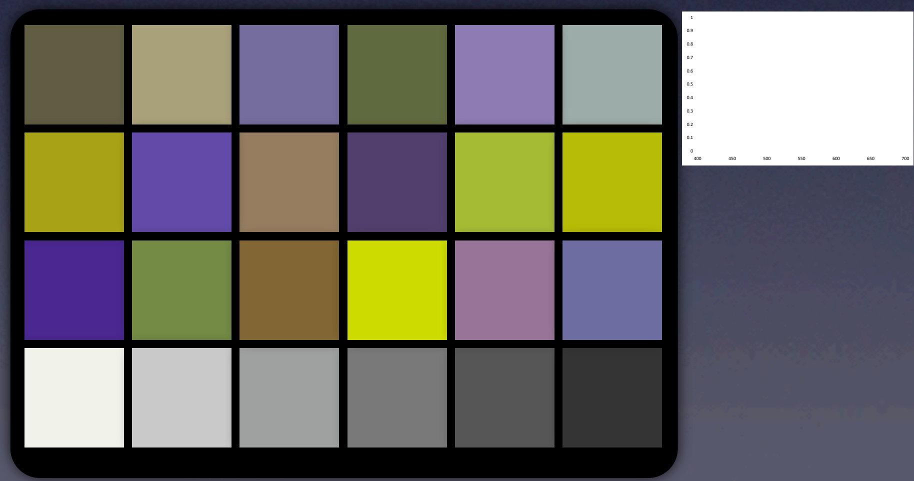
Deuteranomolous (M-300)



Deuteranope

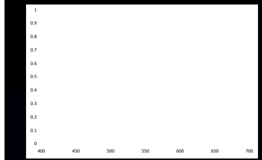


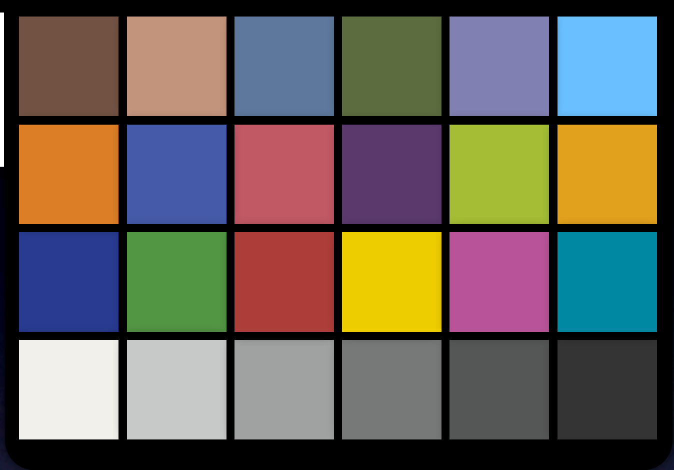
Deuteranomolous (M-700)



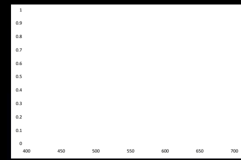
Color appearance for Protan

Normal

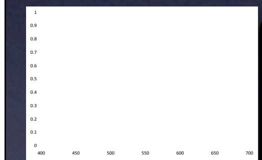


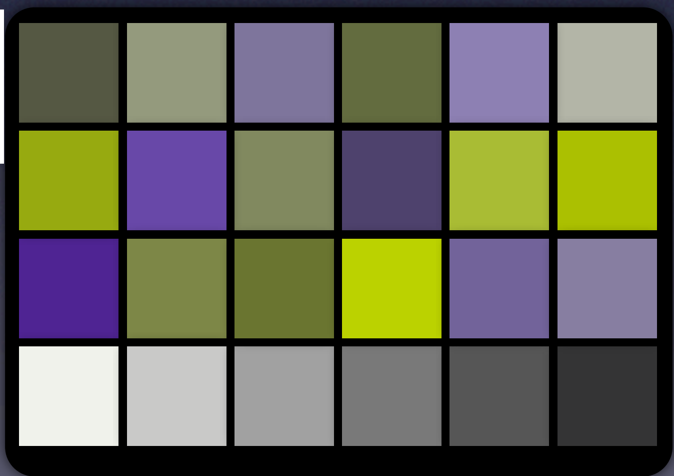


Protaanomolous (L+300)

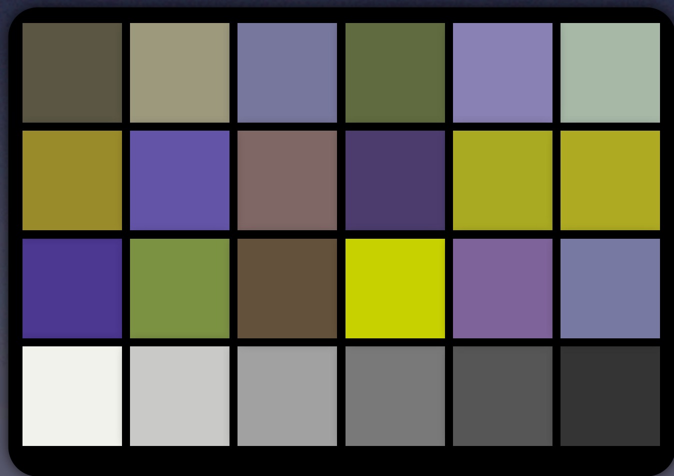


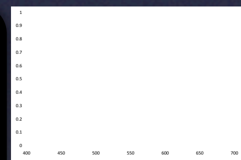
Protanope



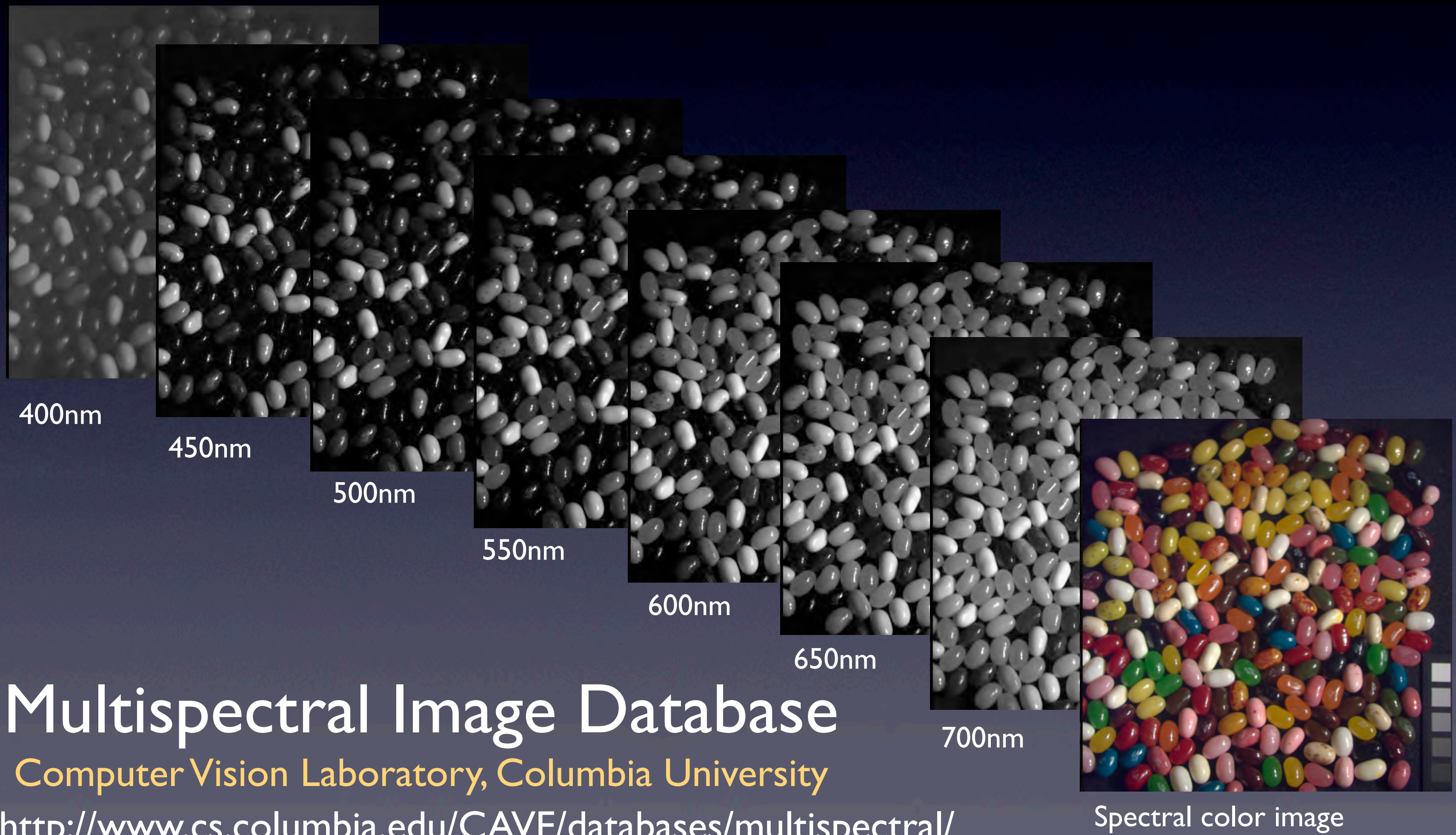


Protaomolous (L+700)





Multispectral images are needed for a real simulation of color appearance for anomalous trichromats



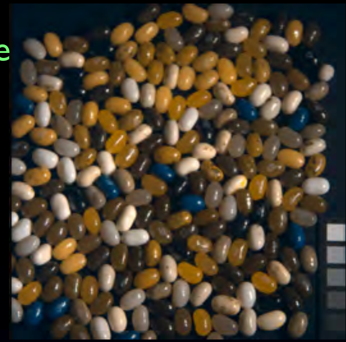
Multispectral Image Database

Computer Vision Laboratory, Columbia University

http://www.cs.columbia.edu/CAVE/databases/multispectral/

Simulation of color appearance for anomalous trichromats

Deuteranope



Deuteranomalous trichromats

M-100

M-300

M-500

M-700

Normal

L+100

L+300

L+500

L+700

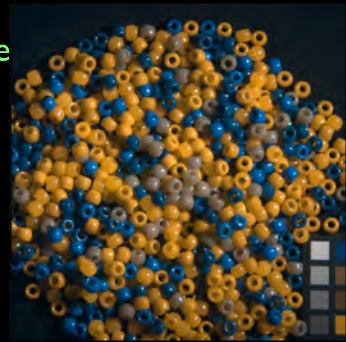
Protanomalous trichromats

Protanope

jelly beans

Simulation of color appearance for anomalous trichromats

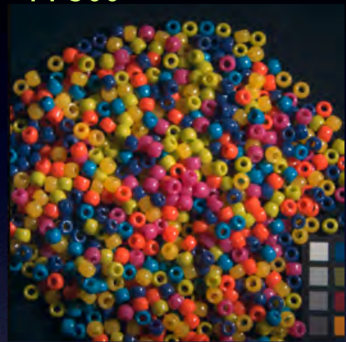
Deuteranope



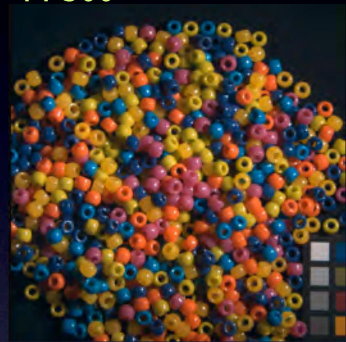
Deuteranomalous trichromats

M-100

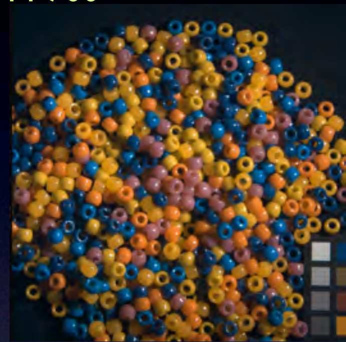
M-300



M-500



M-700

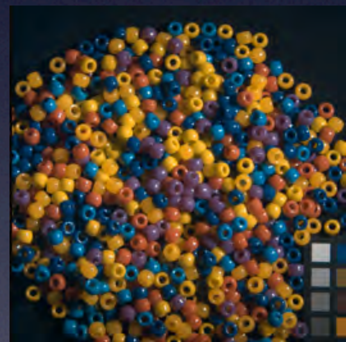


Normal

L+100

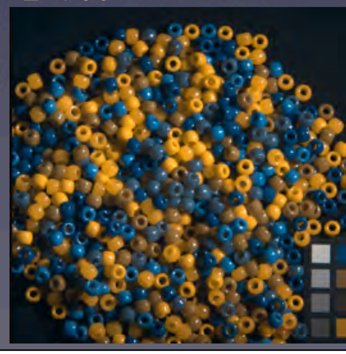
L+300

L+500



L+700

Protanomalous trichromats



Protanope

beads

Simulation of color appearance for anomalous trichromats

Deuteranope

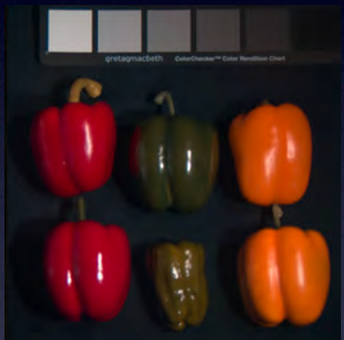
Deuteranomalous trichromats

M-100

M-300

M-500

M-700



Normal

L+100

L+300

L+500

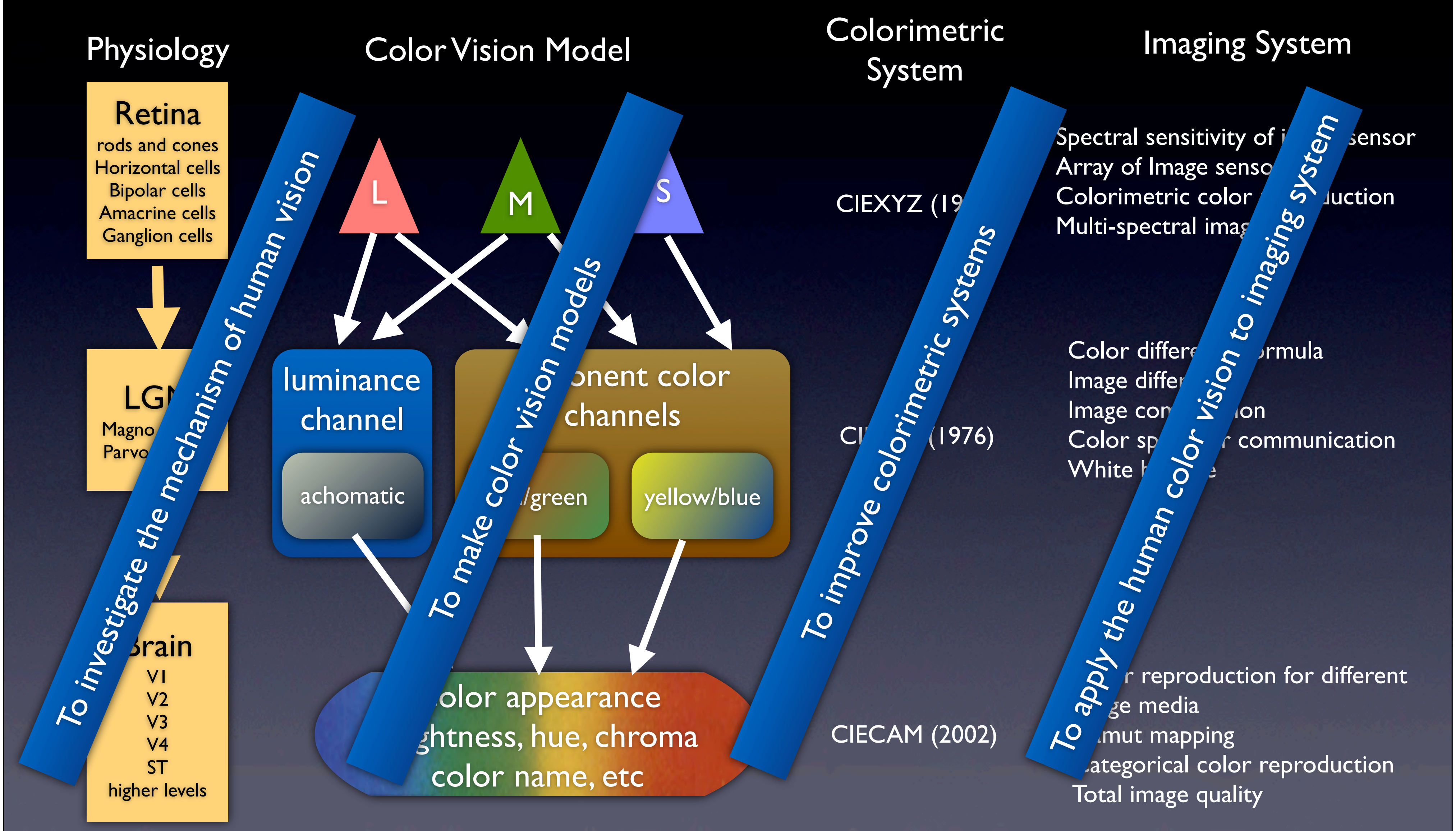
L+700

Protanomalous trichromats

Protanope

fake and real peppers

Color Vision and Application to Imaging Science



Color and Image

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