Color Inconstancy, Chromatic Adaptation, and Scales of Color Appearance

Mark D. Fairchild

RIT | College of Science
Munsell Color Science Laboratory

"A tree that is unbending is easily broken"

–LAO TZU

Today we're going to look at things differently…

Color Inconstancy

Why not *color constancy*?

Term: “Constancy” implies perfection.
There is no “constancy”.

Usage: Experimentation assuming “perfect” “constancy”.
Inconstancy is what happens.

Color Inconstancy — Nearly 100% of the time.
Color Constancy — Almost never.

Why not *color constancy*?

... in everyday life we are accustomed to thinking of most colors as not changing at all. This is in large part due to the tendency to remember colors rather than to look at them closely.

-Evans (1943)

All objects that are already known to us from experience, or that we regard as familiar by their color, we see through the spectacles of memory color.

-Hering (1920)

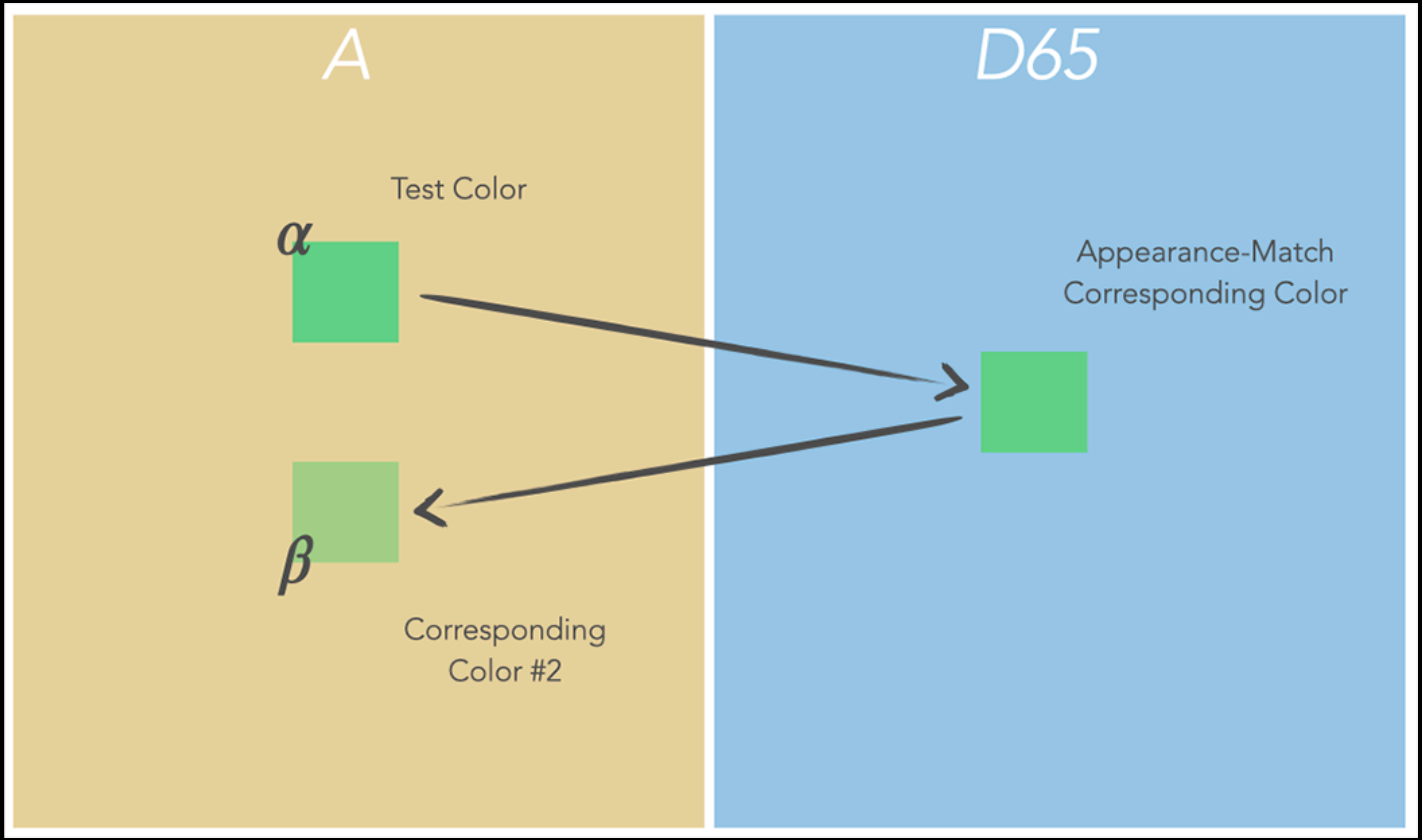
Why not *color constancy*?

- Not Mathematically Possible *(Metamerism)*
- Not Observed *(Degree of Color Inconstancy)***
- Not Useful *(Perception of Illumination Color, Weather, Time of Day, etc.)*
- Colorimetry Includes Illuminants …

- Chromatic Adaptation
- Poor Color Memory

***Karl Gegenfurtner, Nov. 2022 Optica Webinar — VR Lizards*

Corresponding Colors

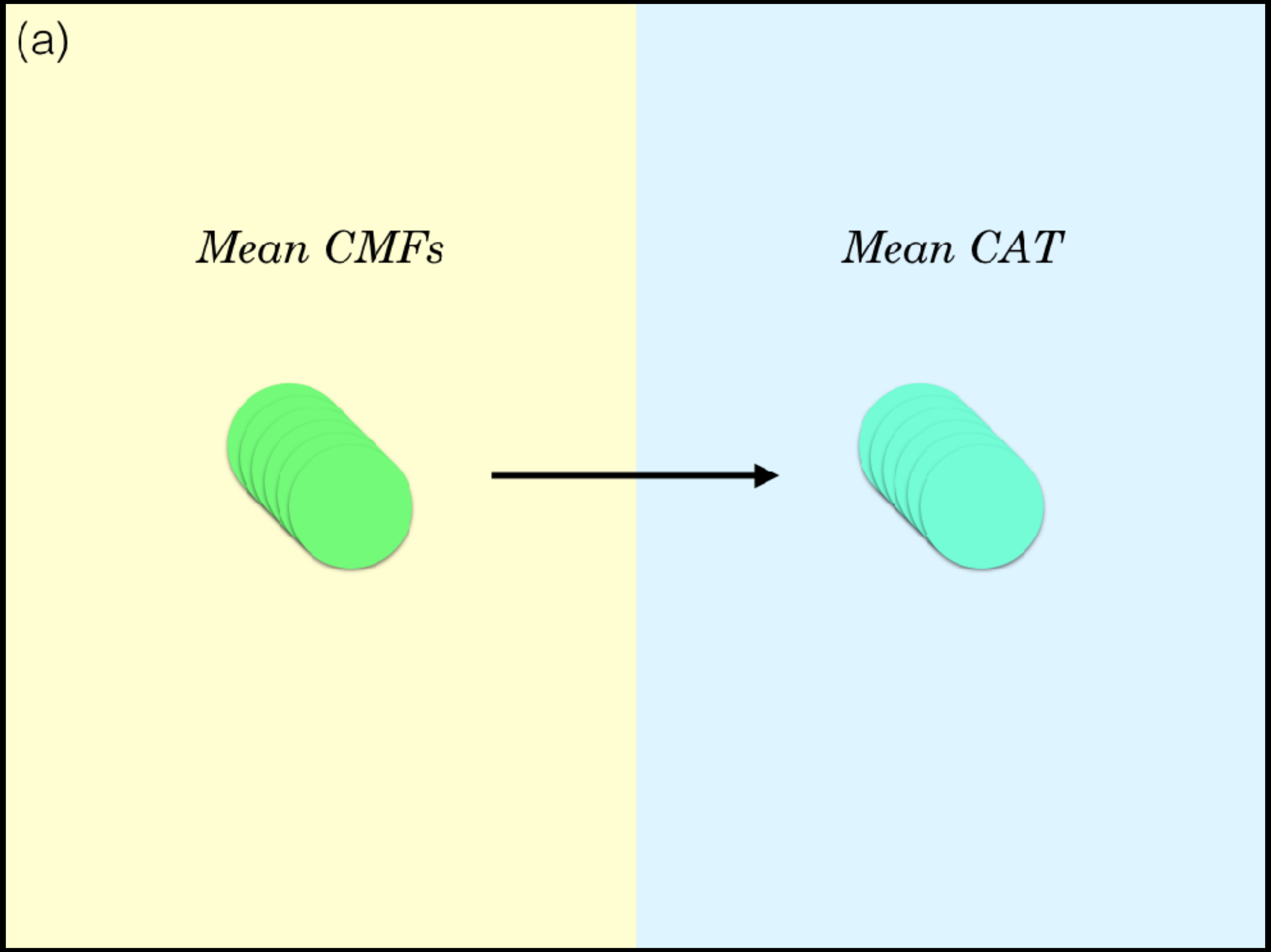


Sensory & Cognitive Chromatic Adaptation

The processes by means of which the observer adapts to the illuminant or discounts most of the effect of a nondaylight illuminant are complicated; they are known to be partly retinal and partly cortical.

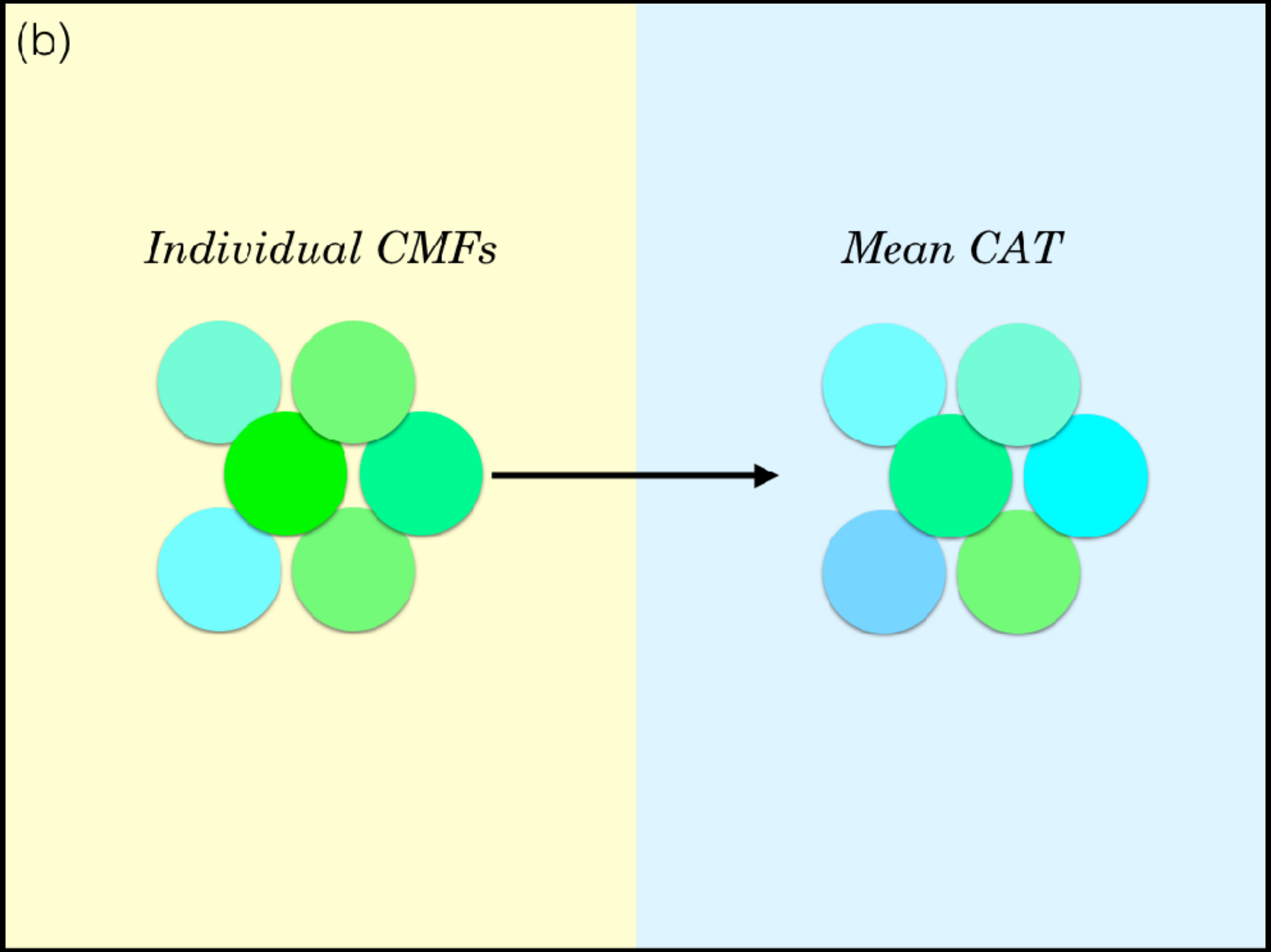
-Judd (1940)

THEORY ...



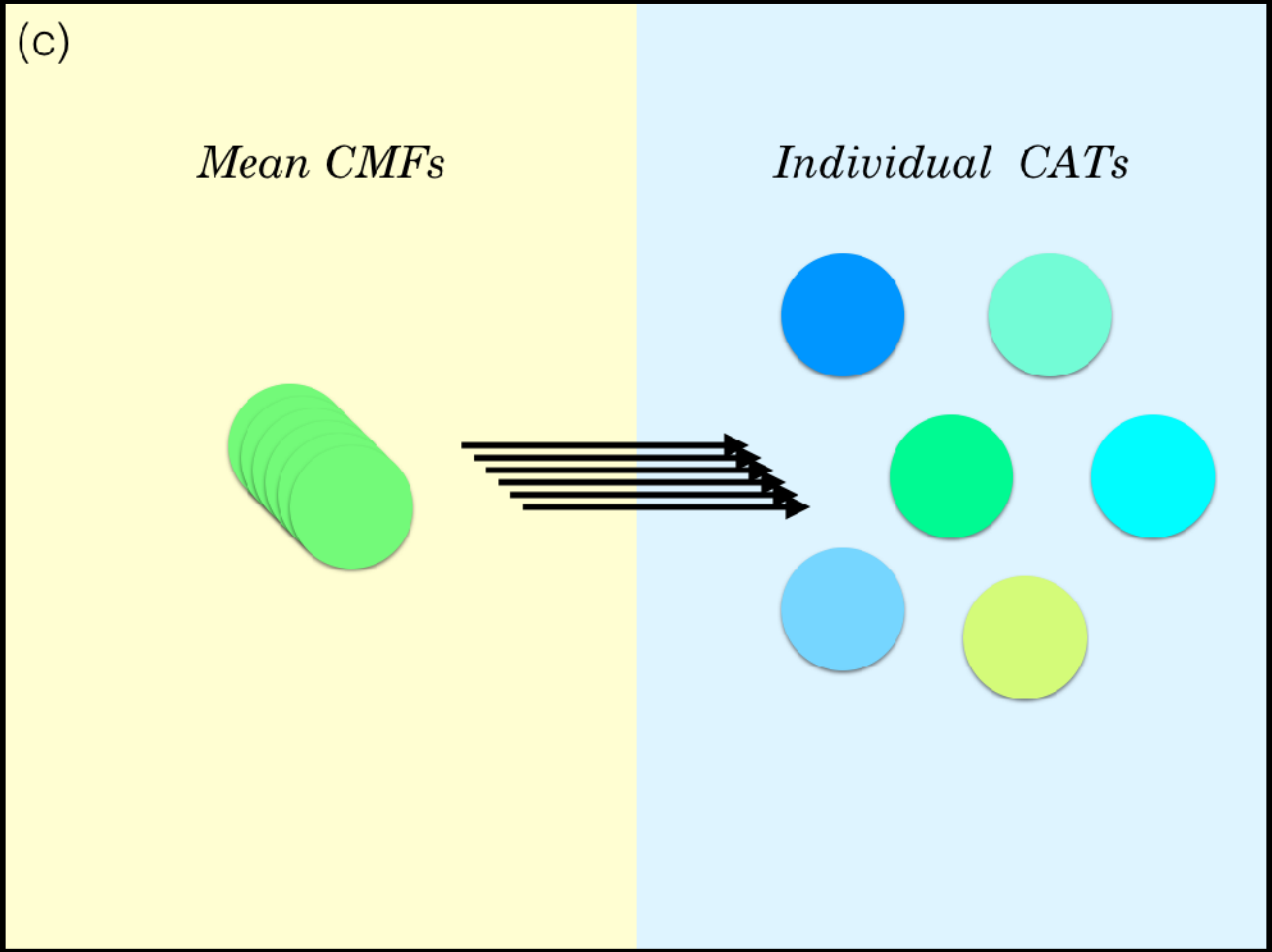
Identical Observers

THEORY ...



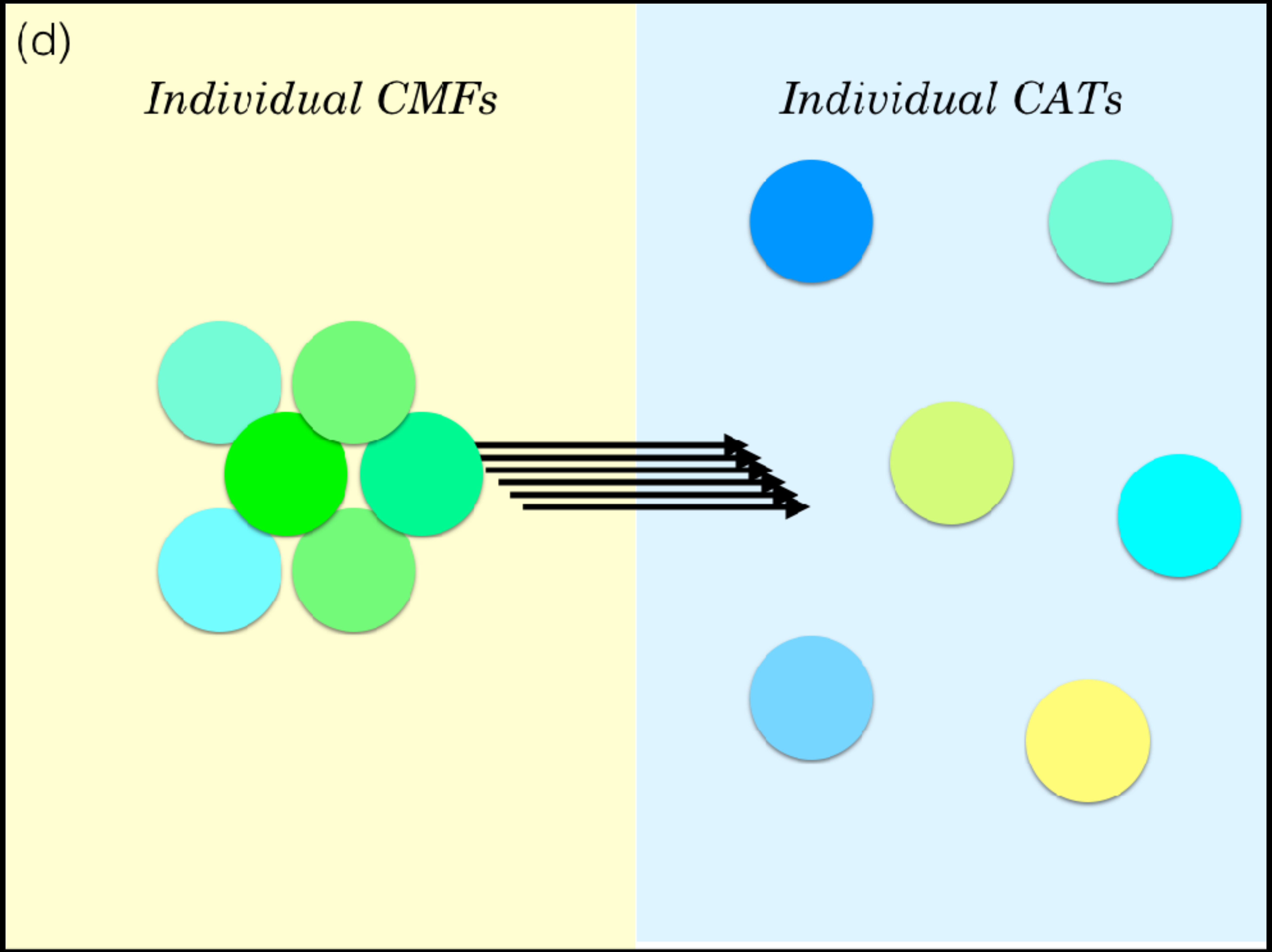
Many CMFs, Identical CATs

THEORY ...



Identical CMFs, Many CATs

THEORY ...



Many CMFs, Many CATs

The processes by means of which the observer adapts to the illuminant or discounts most of the effect of a nondaylight illuminant are complicated; they are known to be partly retinal and partly cortical.

-Judd (1940)

Very Old Degree Of Adaptation Data

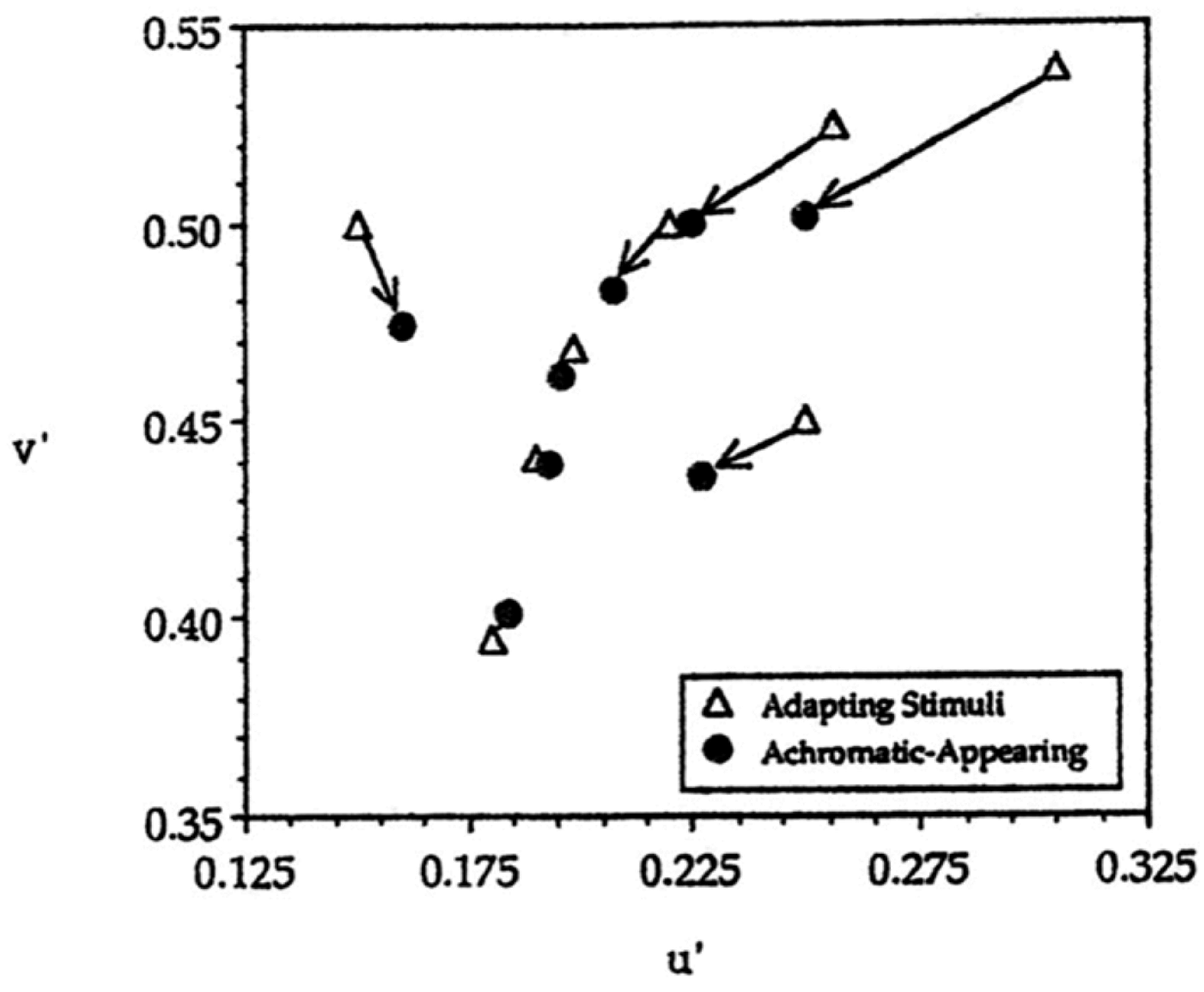
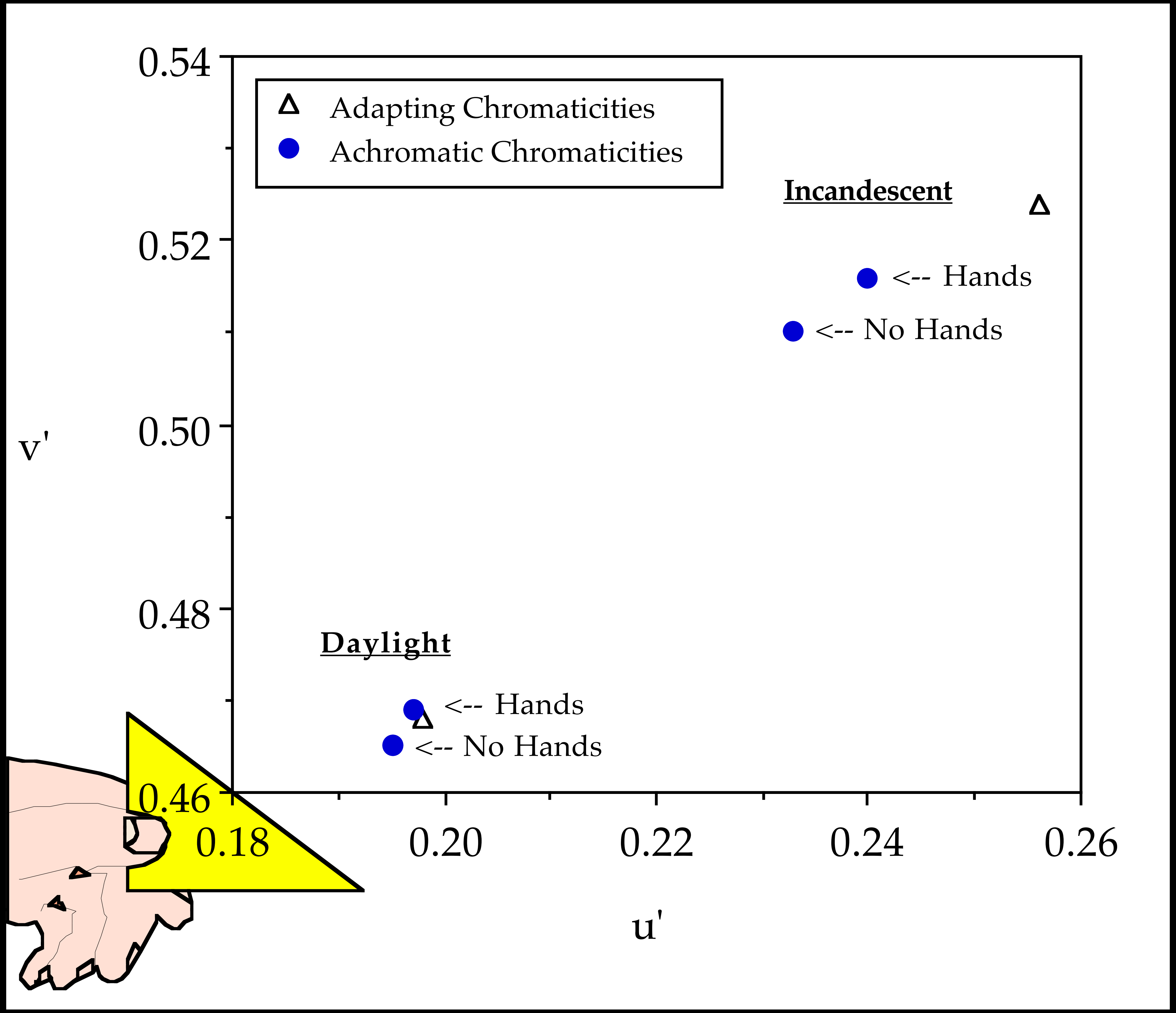
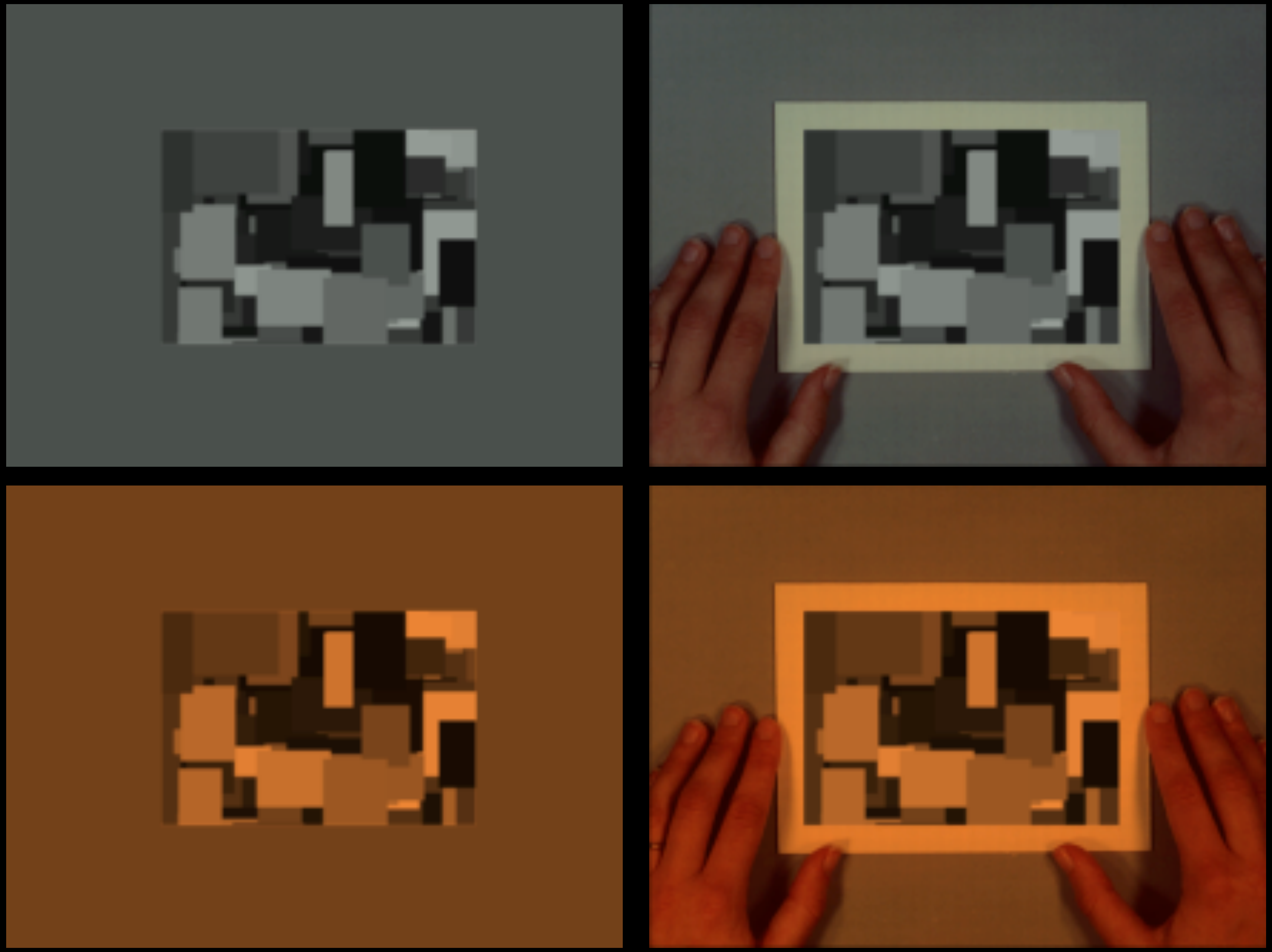


Figure 4-2. Results of experiment 5 for the average of 3 observers. Filled symbols represent achromatic-appearing stimuli under adaptation to various adapting chromaticities represented by the filled symbols. Standard errors of the mean estimates are approximately the size of the plotting symbols.

Fairchild (1990)

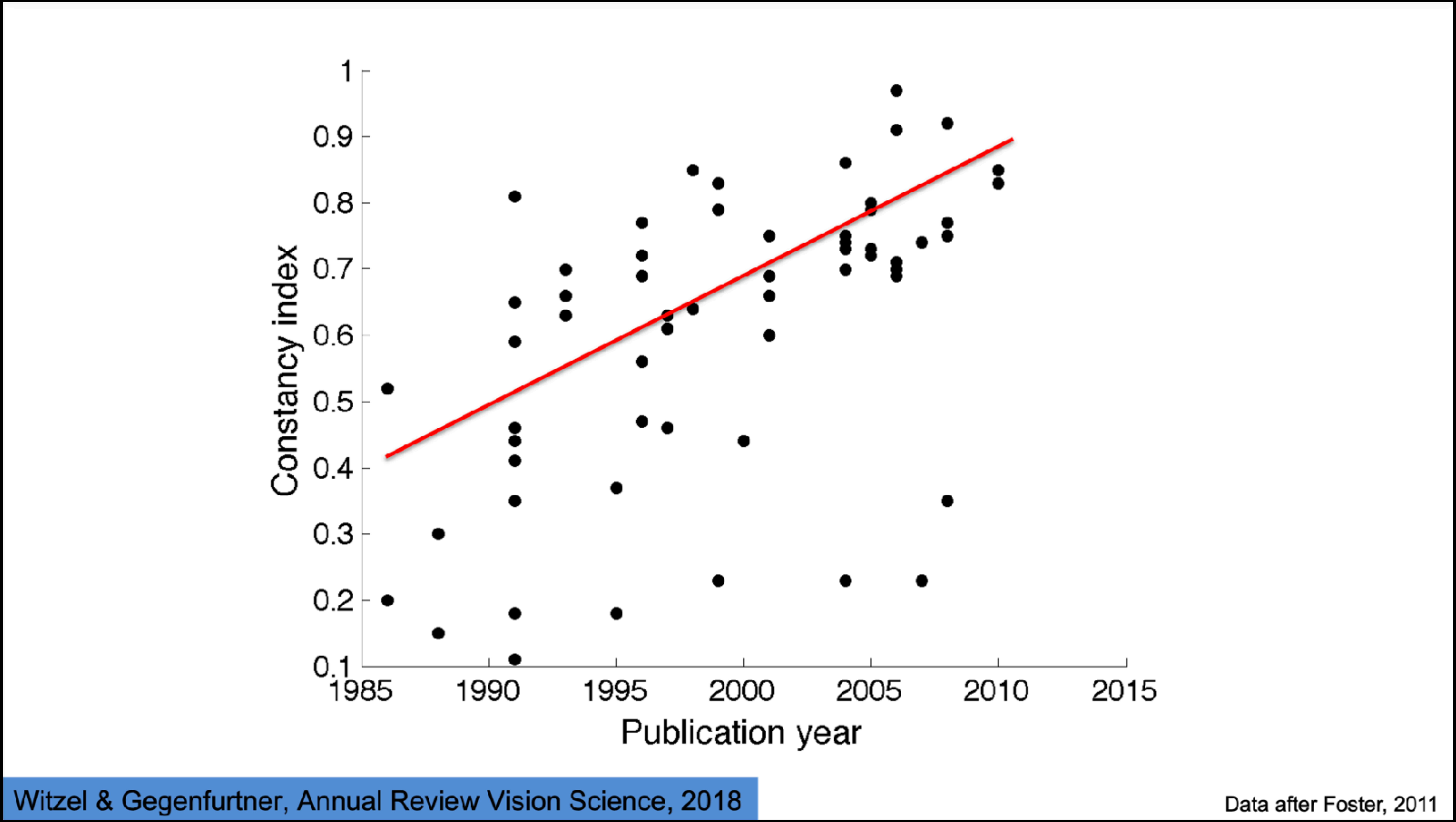
Nearly So Old Discounting Data





Fairchild, TAGA2 (1992)

Screen Capture from K. Gegenfurtner's Nov. Webinar



vK20: 15000K Reference

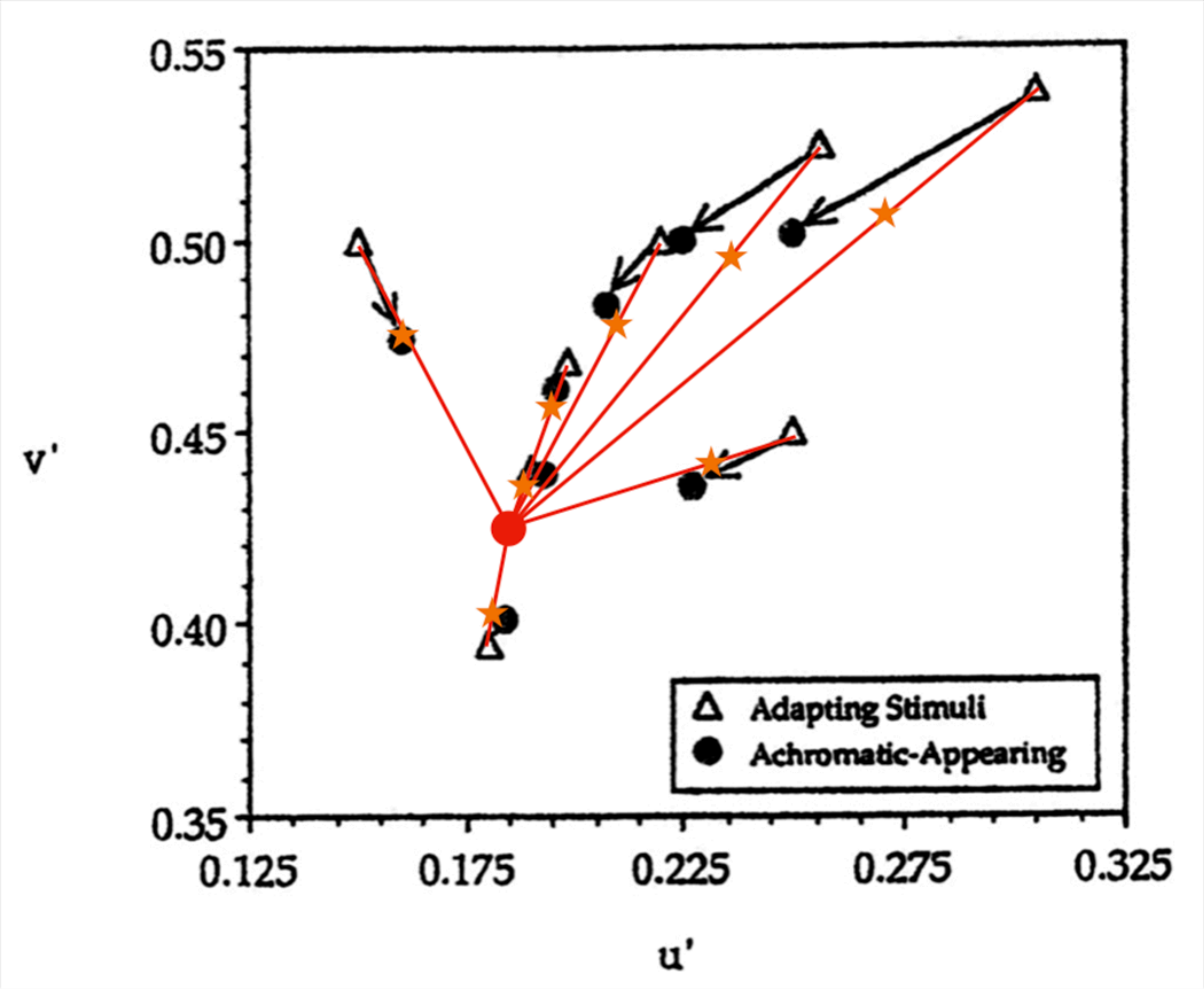
$$\begin{bmatrix} L_a \\ M_a \\ S_a \end{bmatrix} = \begin{bmatrix} \frac{1}{(D_n L_n + D_r L_r + D_p L_p)} & 0 & 0 \\ 0 & \frac{1}{(D_n M_n + D_r M_r + D_p M_p)} & 0 \\ 0 & 0 & \frac{1}{(D_n S_n + D_r S_r + D_p S_p)} \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix}$$

p allows failure of reversibility

n = current adapting white
r = reference adaptation point
p = previous adapting white

3 D-factors sum to 1.0

vK20: 15000K Reference

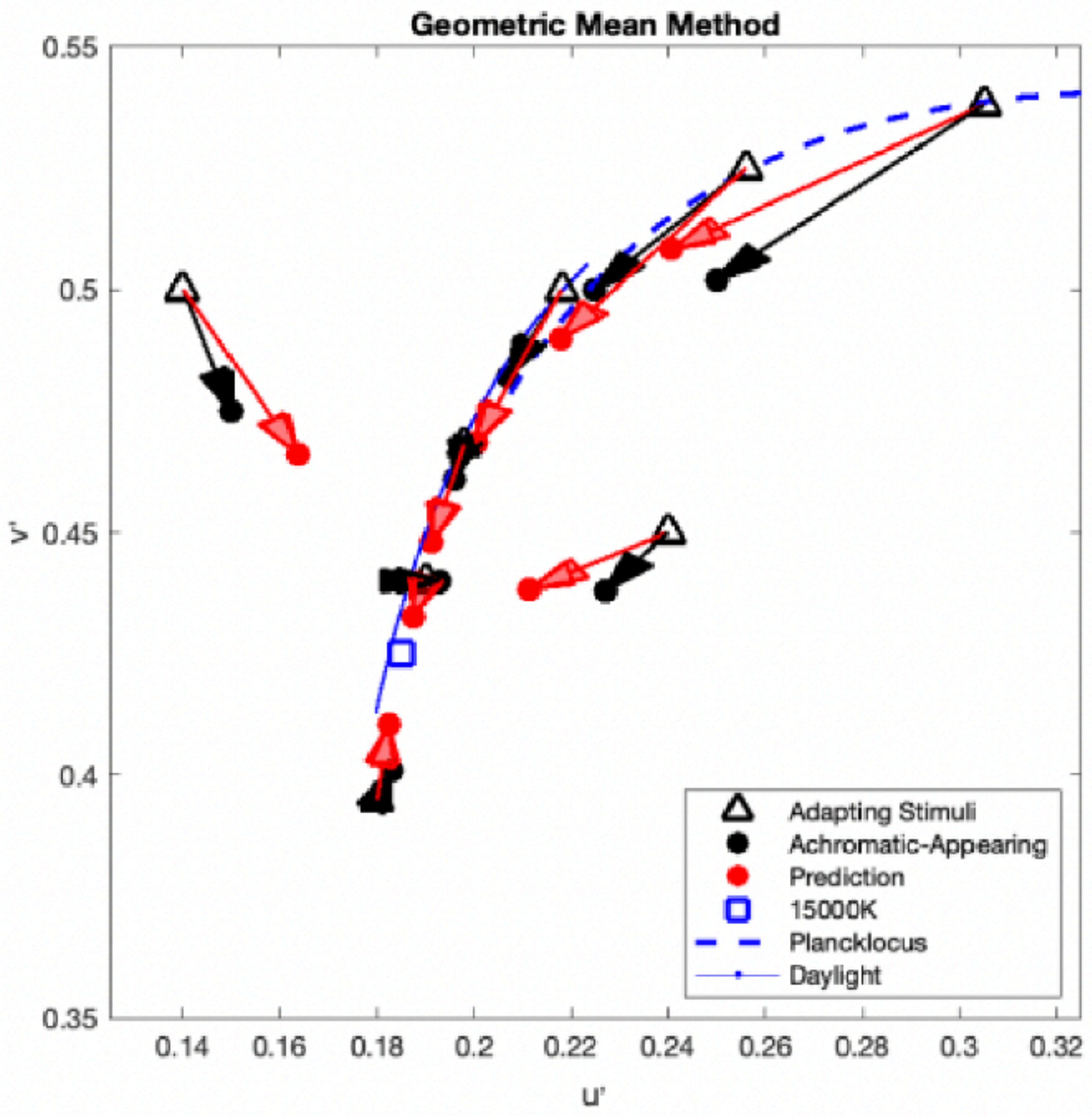


70% Adapted
***Dn,Dr,Dp* (.7,.3,0)**

Fairchild, CIC28 (2020)

Geometric Mean: WGM

$$L'M'S' = \sqrt{L_n M_n S_n \times L_r M_r S_r} \quad (5)$$



Shen & Fairchild, CIC30 (2022)

Geometric Mean: WGM

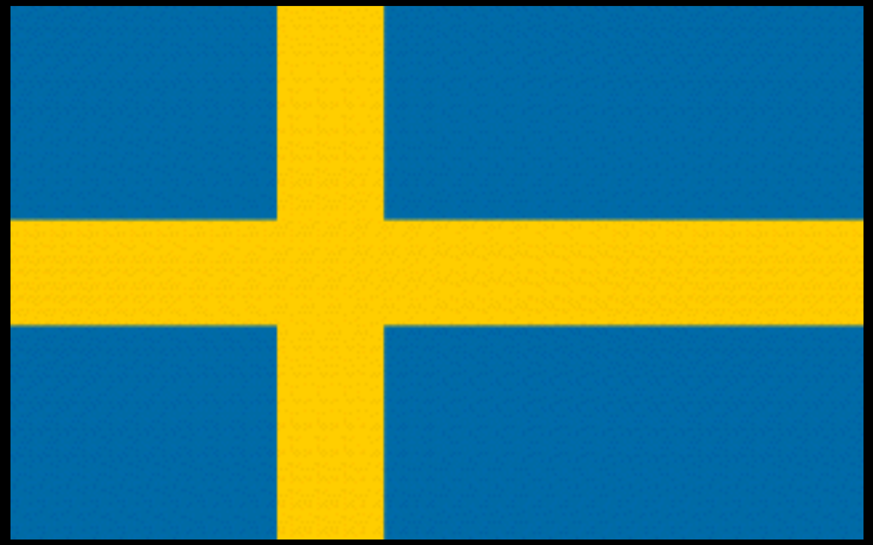
$$\begin{bmatrix} L_a \\ M_a \\ S_a \end{bmatrix} = \begin{bmatrix} \frac{1}{L_n^D \times L_r^{1-D}} & 0 & 0 \\ 0 & \frac{1}{M_n^D \times M_r^{1-D}} & 0 \\ 0 & 0 & \frac{1}{S_n^D \times S_r^{1-D}} \end{bmatrix} \begin{bmatrix} L \\ M \\ S \end{bmatrix} \quad (7)$$

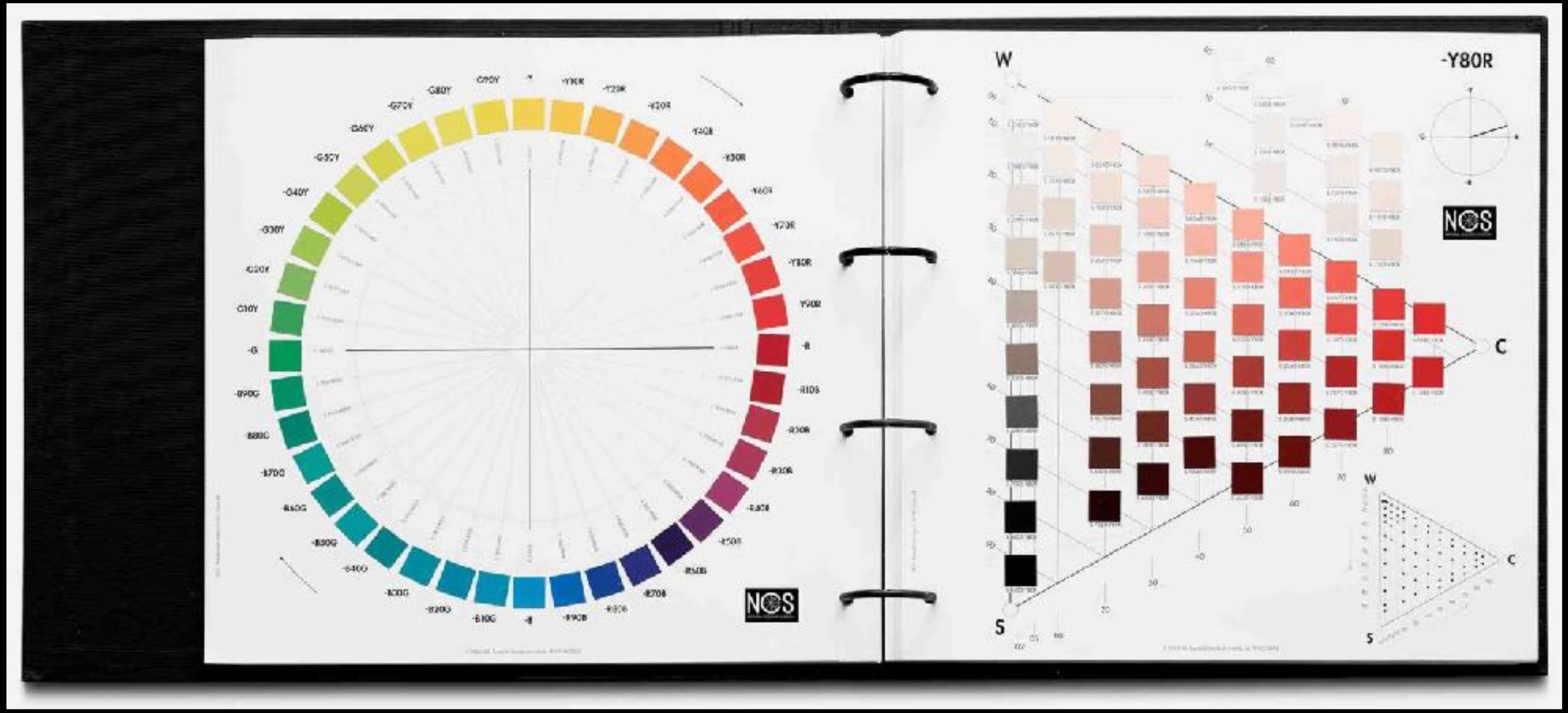
Shen & Fairchild, CIC30 (2022)

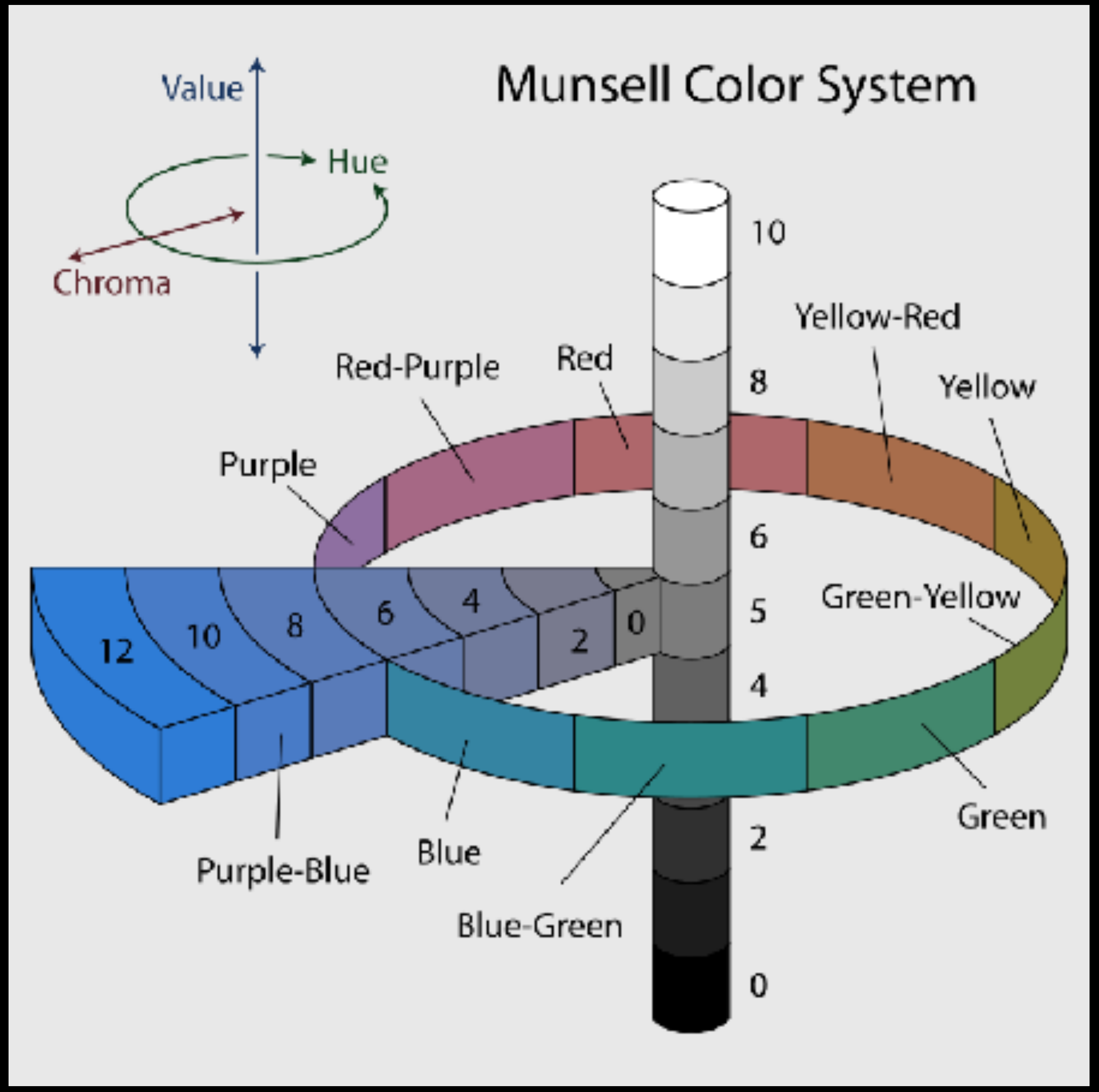
Color Space

Color Order

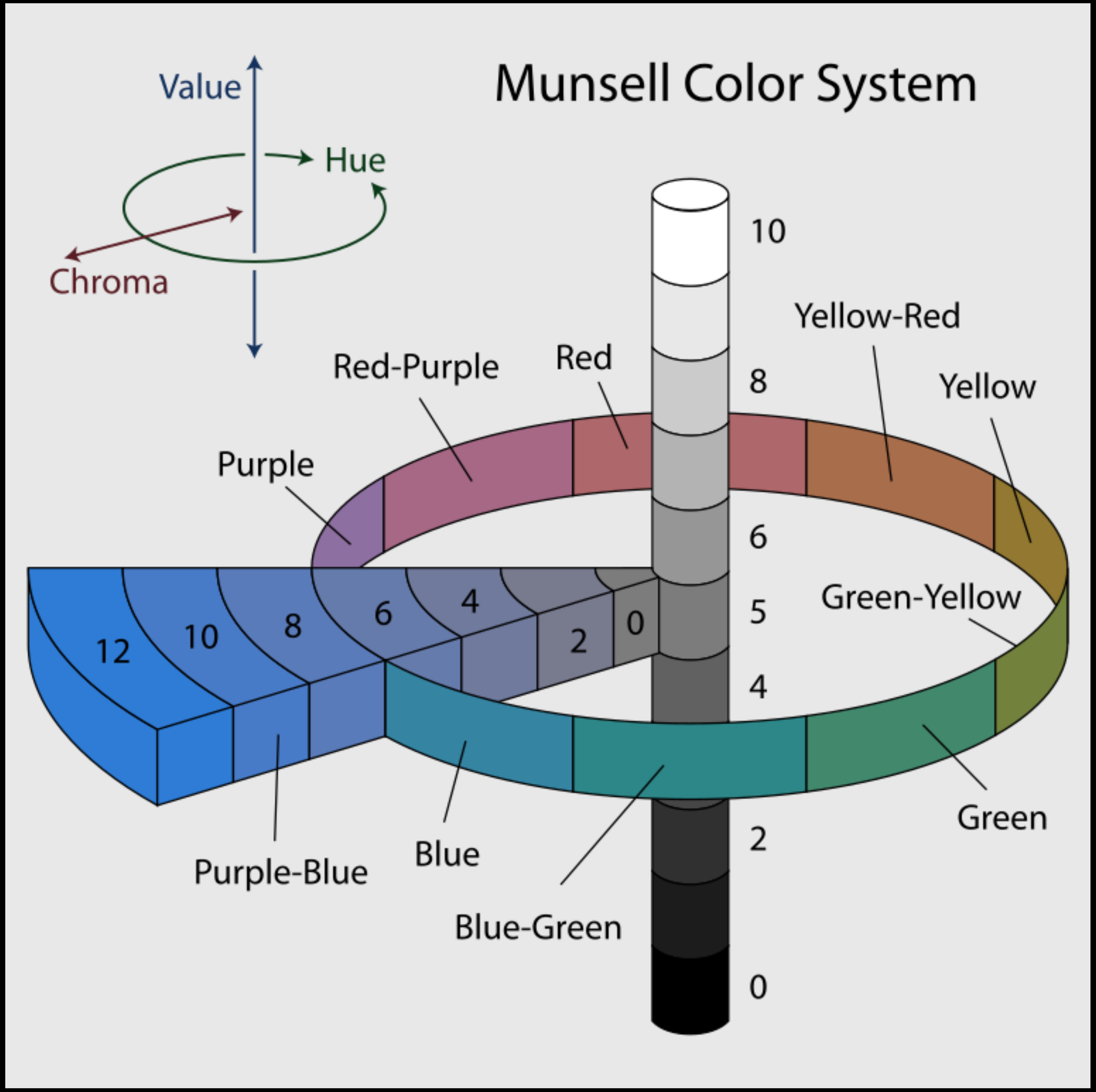
The Story of the “CIE Color Order System”







Munsell

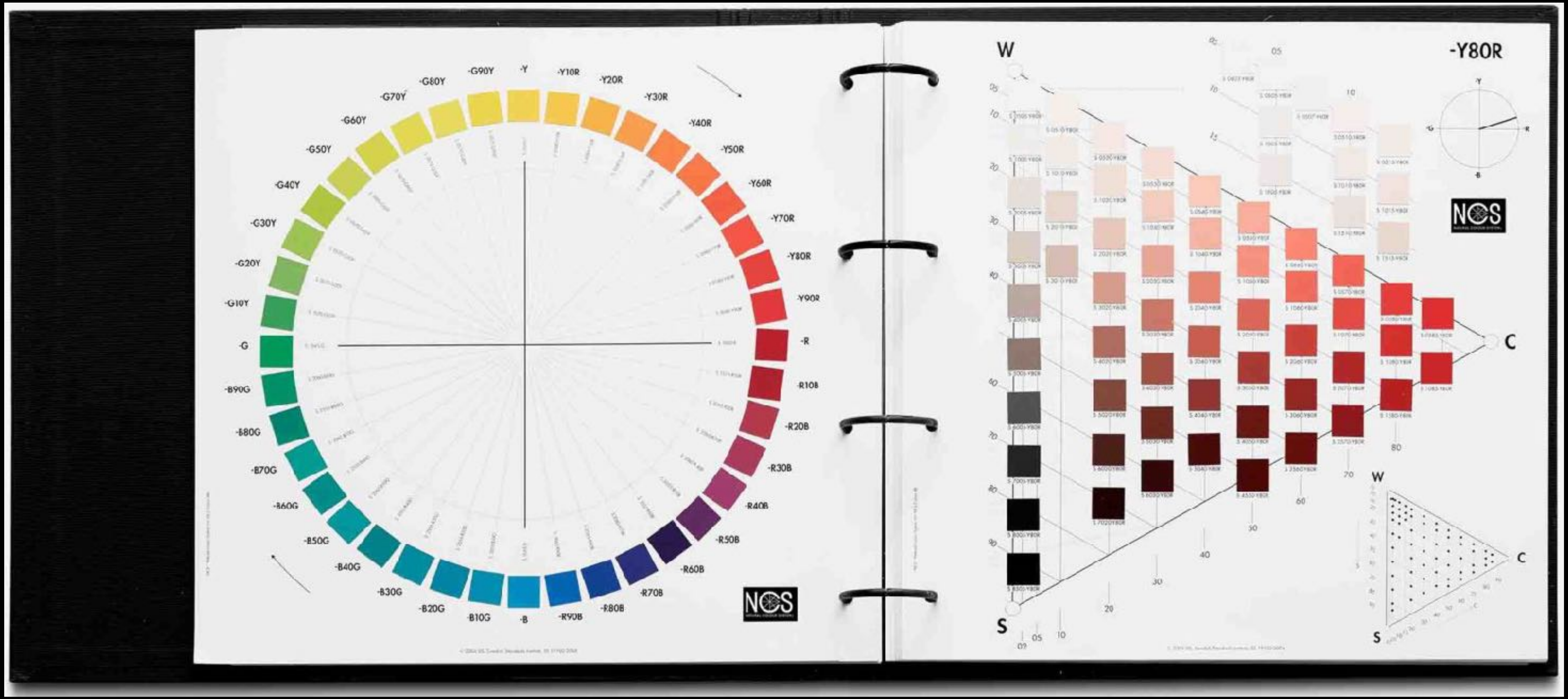


Value: Luminance Based (HK Ignored) — Not True Lightness

Chroma: True Chroma — Not Saturation

Hue: Differences — Not Appearance

NCS - Natural Color System



Blackness: Brilliance (HK Included) — True Lightness

Chromaticness: Similar to Saturation

Hue: Opponent

DIN Color System

Darkness: Brilliance (HK Included) — True Lightness

Saturation: Constant Chromaticity

Hue: Munsell Like

Dualism of 4 vs 5 Hues

Received: 19 June 2018 | Revised and accepted: 6 July 2018

DOI: 10.1002/col.22261

WILEY

RESEARCH ARTICLE

Unique hues and principal hues

Mark D. Fairchild

Program of Color Science/Munsell Color Science Laboratory, Rochester Institute of Technology, Integrated Sciences Academy, Rochester, New York

Correspondence
Mark Fairchild, Rochester Institute of Technology, Integrated Sciences Academy, Program of Color Science/Munsell Color Science Laboratory, Rochester, NY 14623, USA.
Email: mark.fairchild@rit.edu

Abstract

This note examines the different concepts of encoding hue perception based on four unique hues (like NCS) or five principal hues (like Munsell). Various sources of psychophysical and neurophysiological information on hue perception are reviewed in this context and the essential conclusion that is reached suggests there are two types of hue perceptions being quantified. Hue discrimination is best quantified on scales based on five, equally spaced, principal hues while hue appearance is best quantified using a system based on four unique hues as cardinal axes. Much more remains to be learned.

KEYWORDS

appearance, discrimination, hue, Munsell

Munsell Centennial Color Symposium

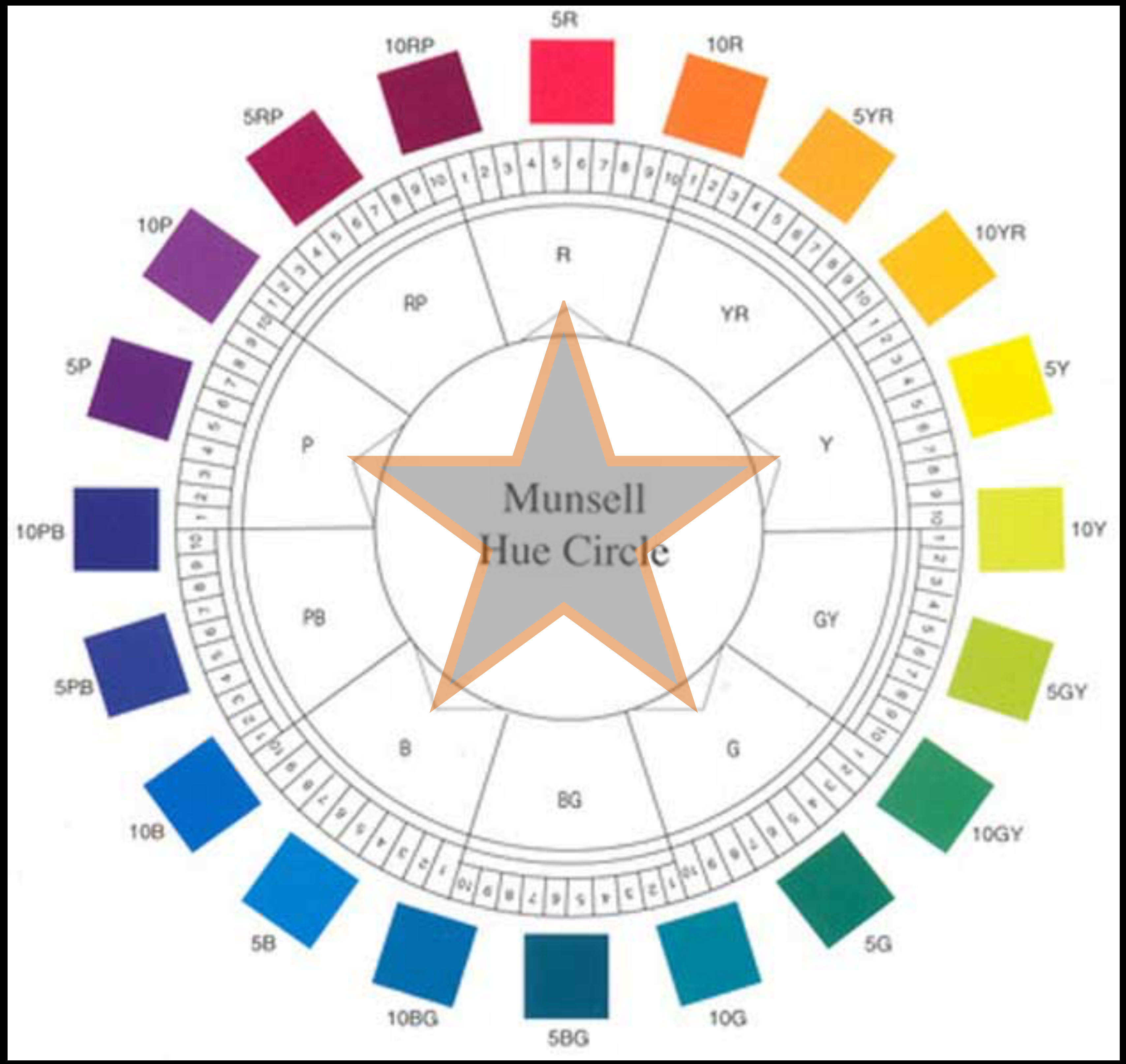
Bridging Science, Art, & Industry

June 10-15, 2018

Massachusetts College of Art and Design

Boston, MA

Munsell's 5 Principal Hues



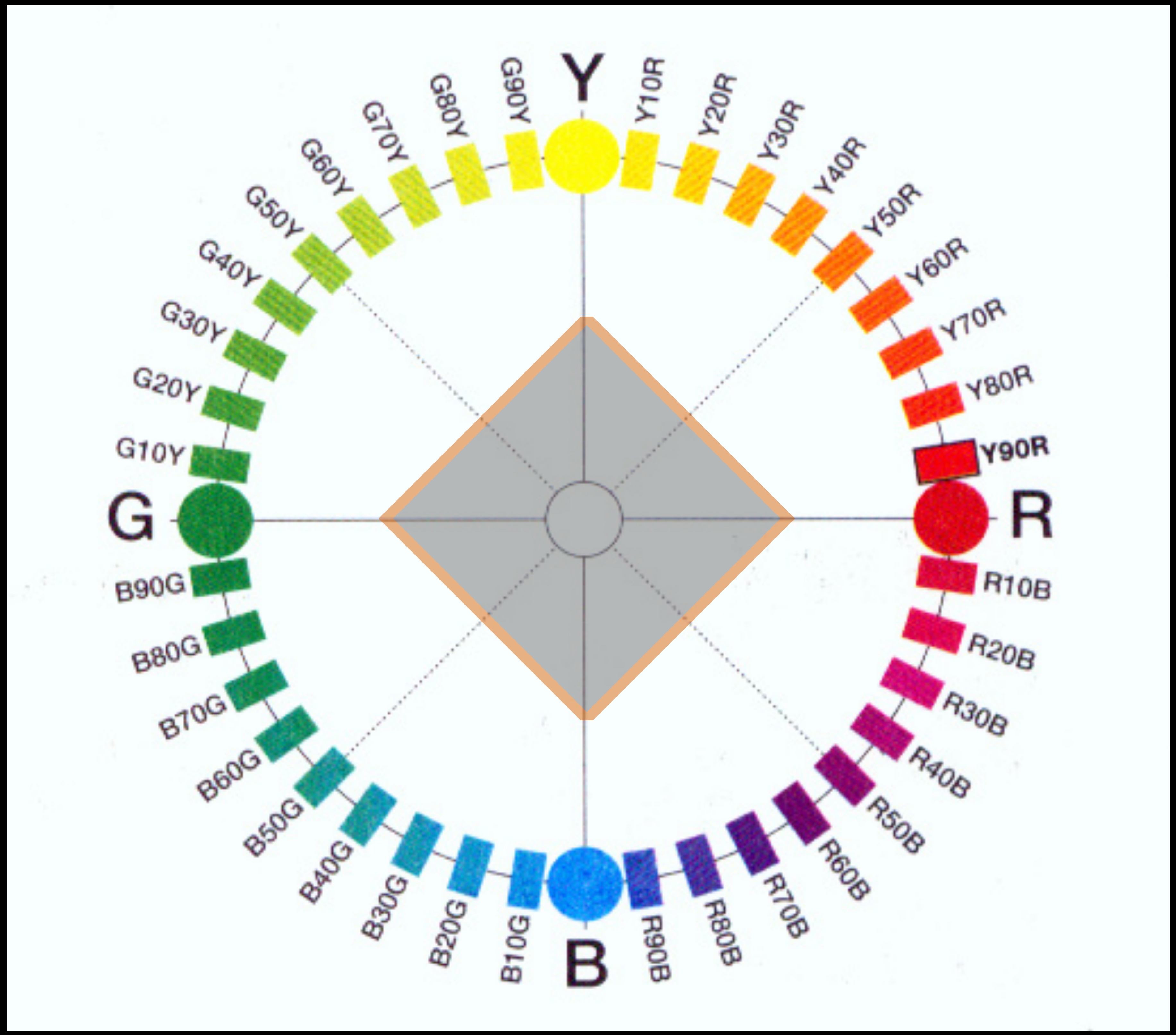
Skelton et al., PNAS (2017)
Hue Categorization

Infants: R Y G B & P

Link to Munsell?

JNDs vs. Appearance

Research Needed



Principal/Unique Hues

Munsell :

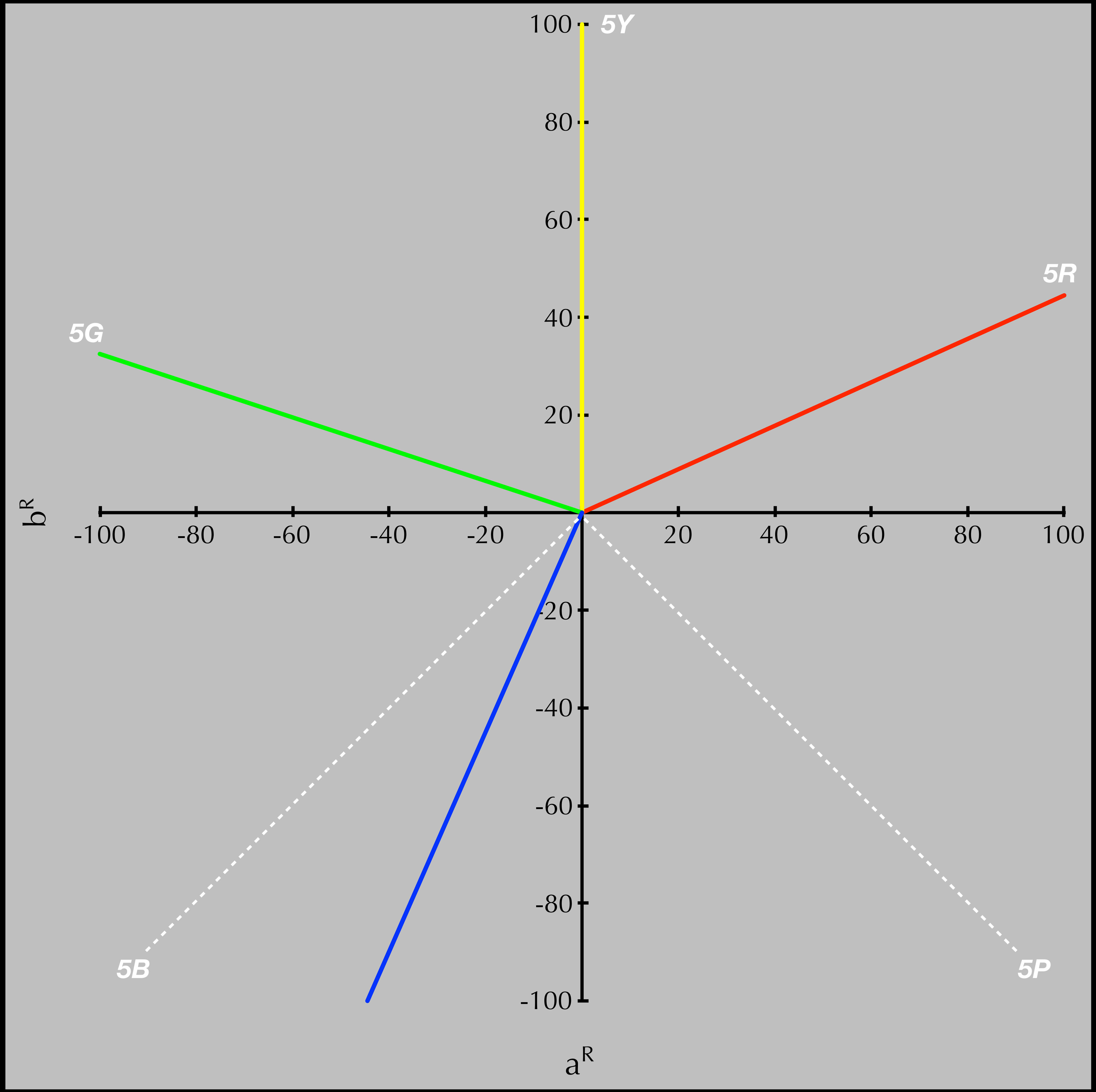
5 Principal Hues :

Based on Thresholds/Differences

NCS :

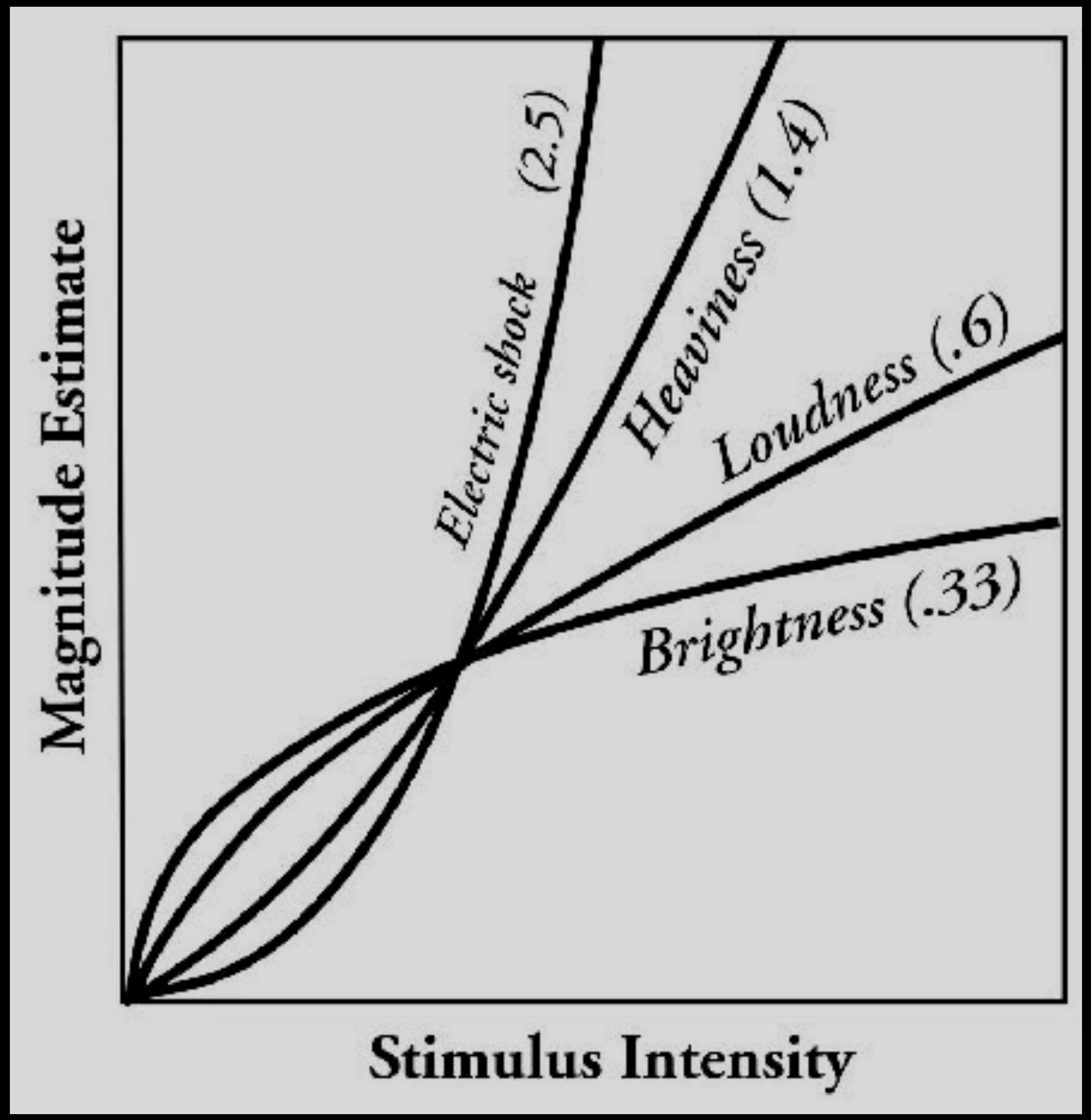
4 Unique Hues :

Based on Appearance



Going Further

Stevens: "To Honor Fechner and Repeal his Law"



Ramifications for Color "Spaces"

Thresholds vs. Scales

Differences/Tolerances vs. Appearance

Disparate Metric Dimensions

Gustav Fechner

Adding JNDs Should Make and Appearance Scale

Thresholds : $\Delta I/I = K$

Therefore Scales are Logarithmic

Stanley Stevens (and Psychophysics Thereafter …)

Scales are not Logarithmic

Power Law and Thresholds don't Add to Appearance Scales

Are Color Spaces Logical ??

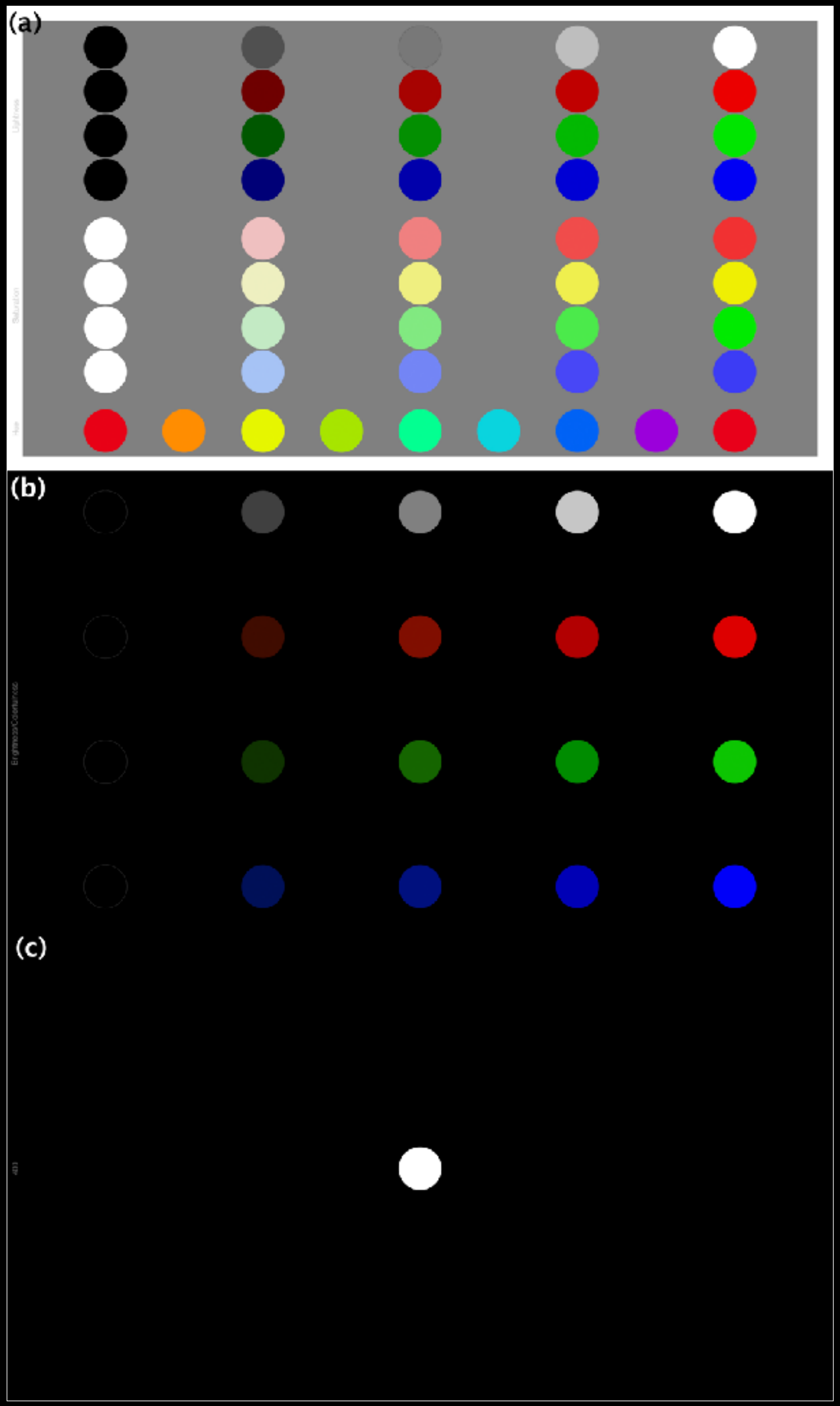
1. Maybe for Thresholds

2. Probably Not for Suprathreshold Differences

3. Almost Definitely Not for Appearance Scales

Cannot be the Same Space
(If you must have some)

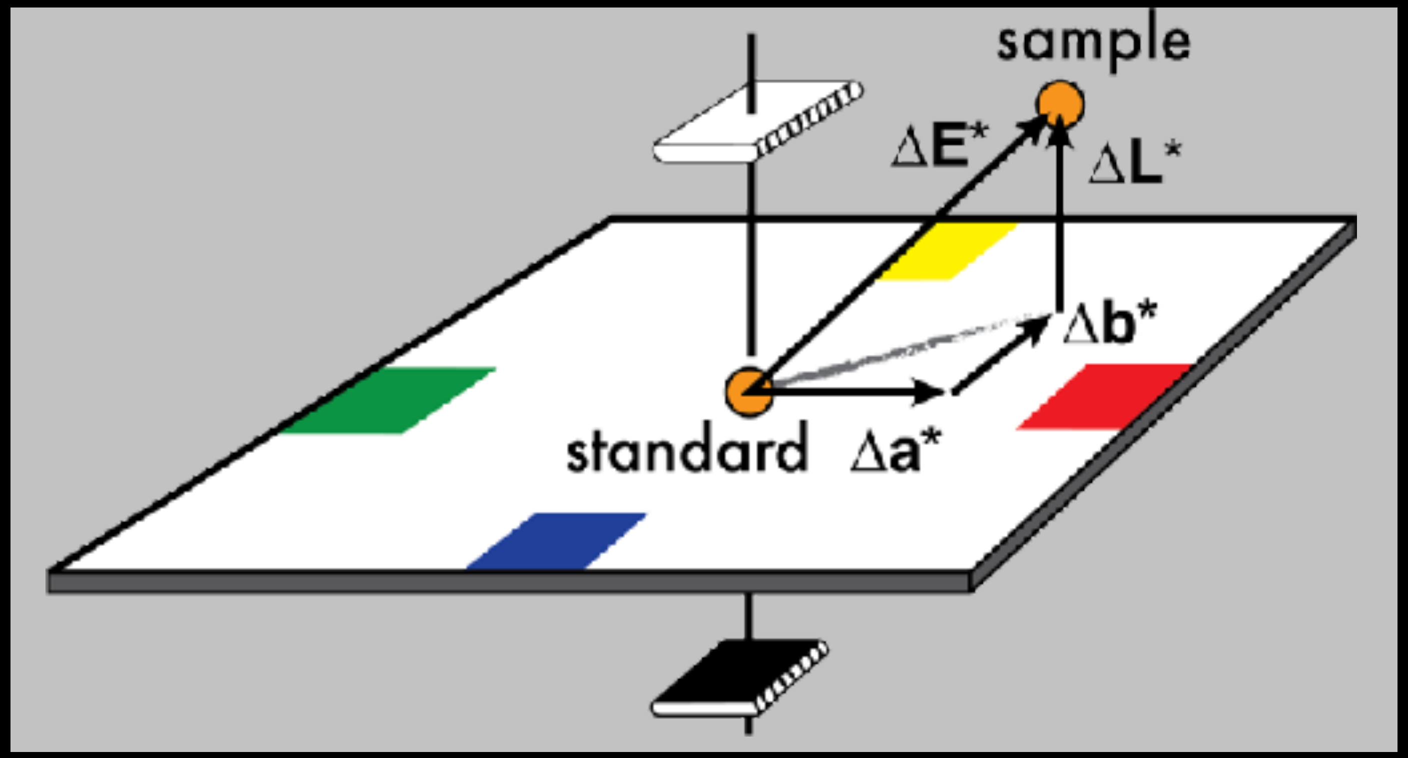
And likely not just three dimensions …



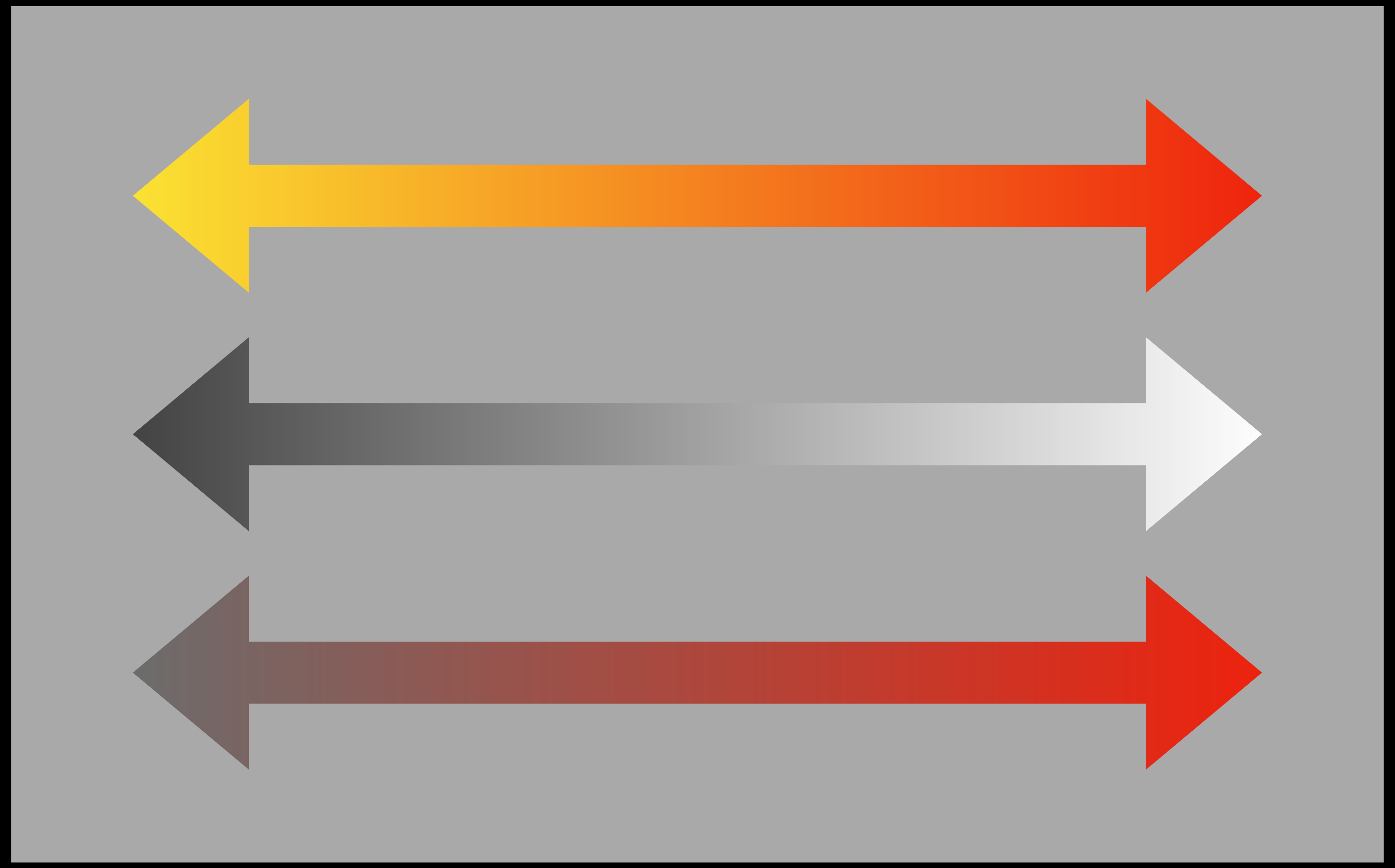
“We know dis!”

Organizing Dimensions

L*C*h
Differences / Munsell



Hue Quadrature, Brilliance, Saturation
Appearance / NCS / DIN



Color Appearance Dimensions

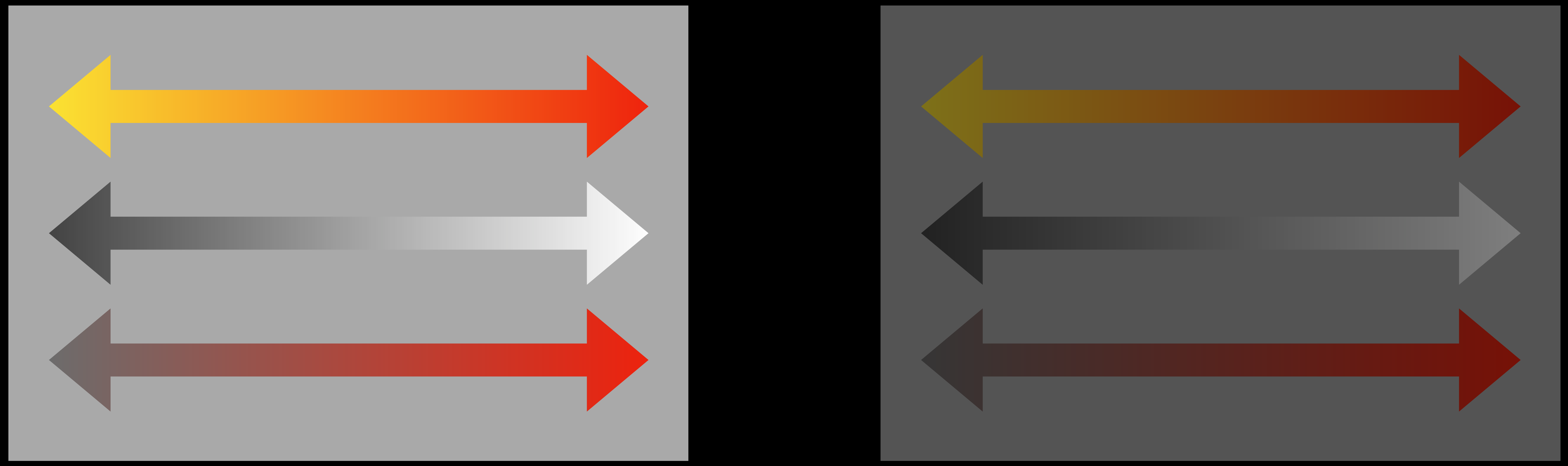
Dimensions of Color Appearance

Hue

Brightness / Lightness

Colorfulness / Saturation

Chroma



Luxo Double Checker

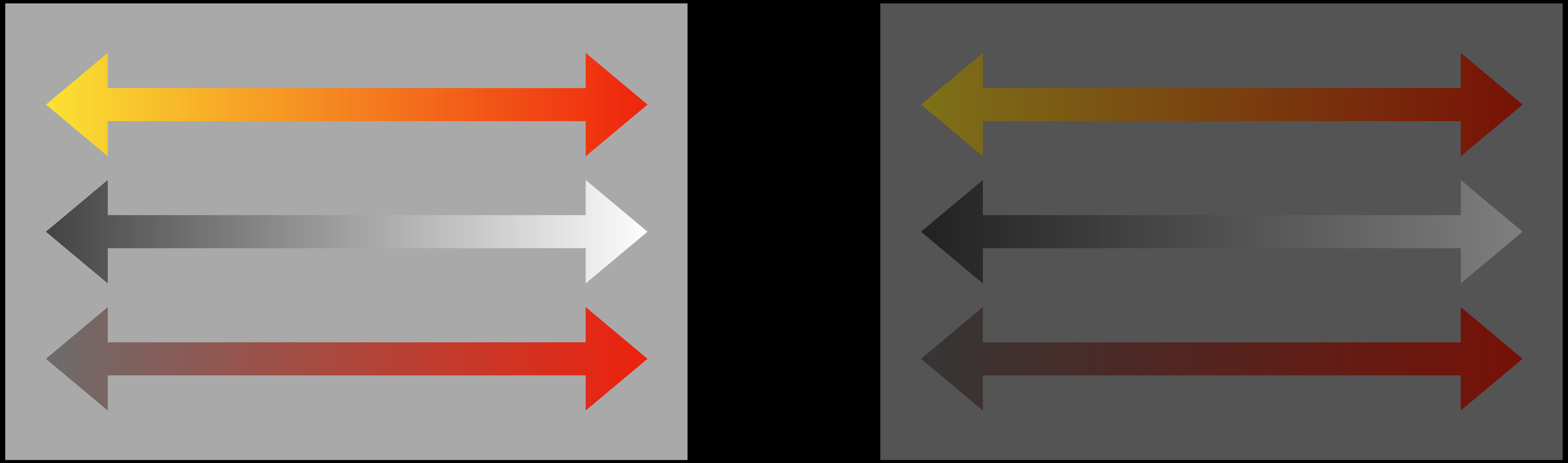
Dimensions of Color Appearance

Hue

Brightness / Lightness

Colorfulness / Saturation

Chroma



Do we need all 6 of these dimensions to describe color appearance?

No!

But we need at least 5 of them …
And if you know the right 4, you can easily infer the 5th.

Model Framework

Defining Scales of Appearance

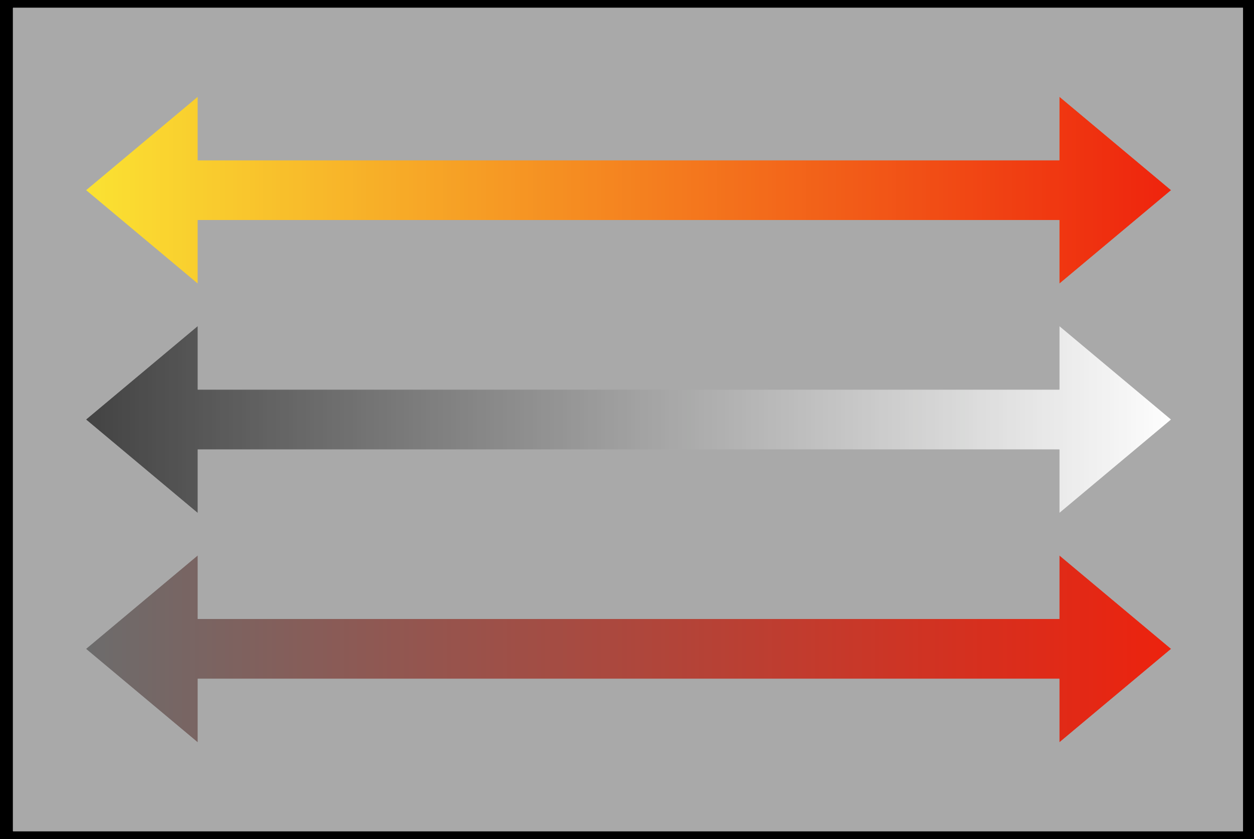
Rather than Attempting to Make a 3D Color Appearance Space *(Doomed to Failure?)*

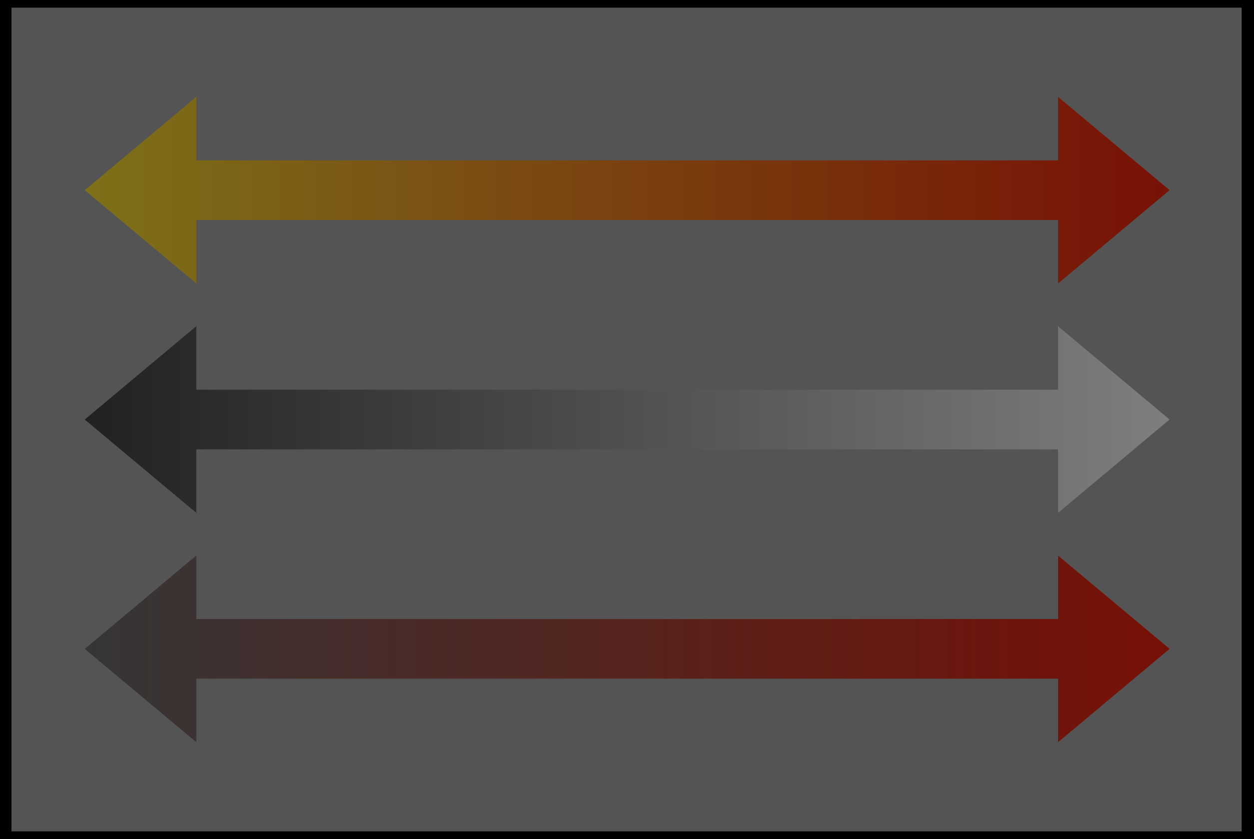
Create Four Robust, Individual, Scales of Appearance

Brightness, Brilliance *(HDR/True Lightness)*, Saturation, Hue *(Incremental & Quadrature)*

Both Colorfulness and Chroma Are Derivative

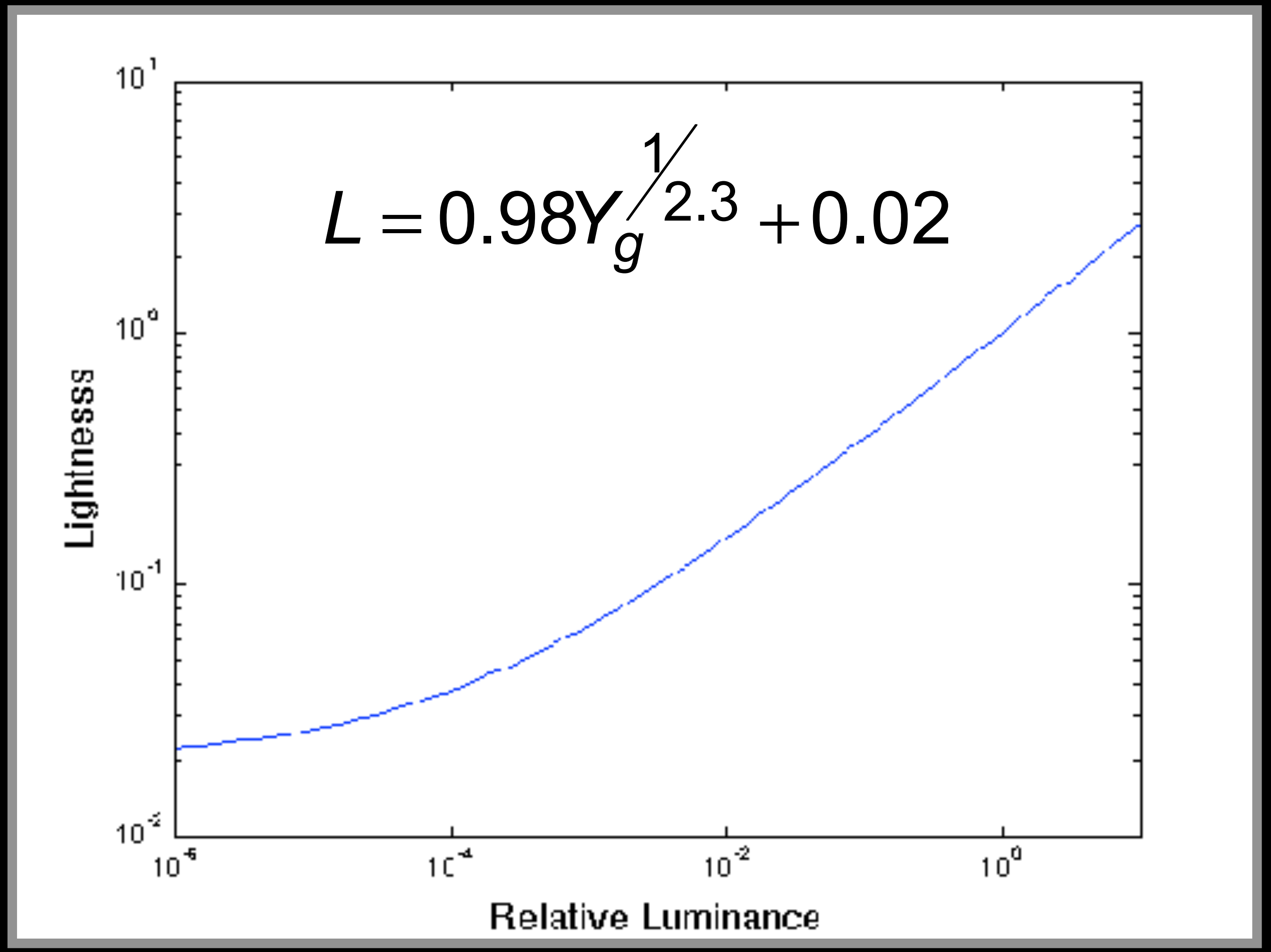
Work in Progress

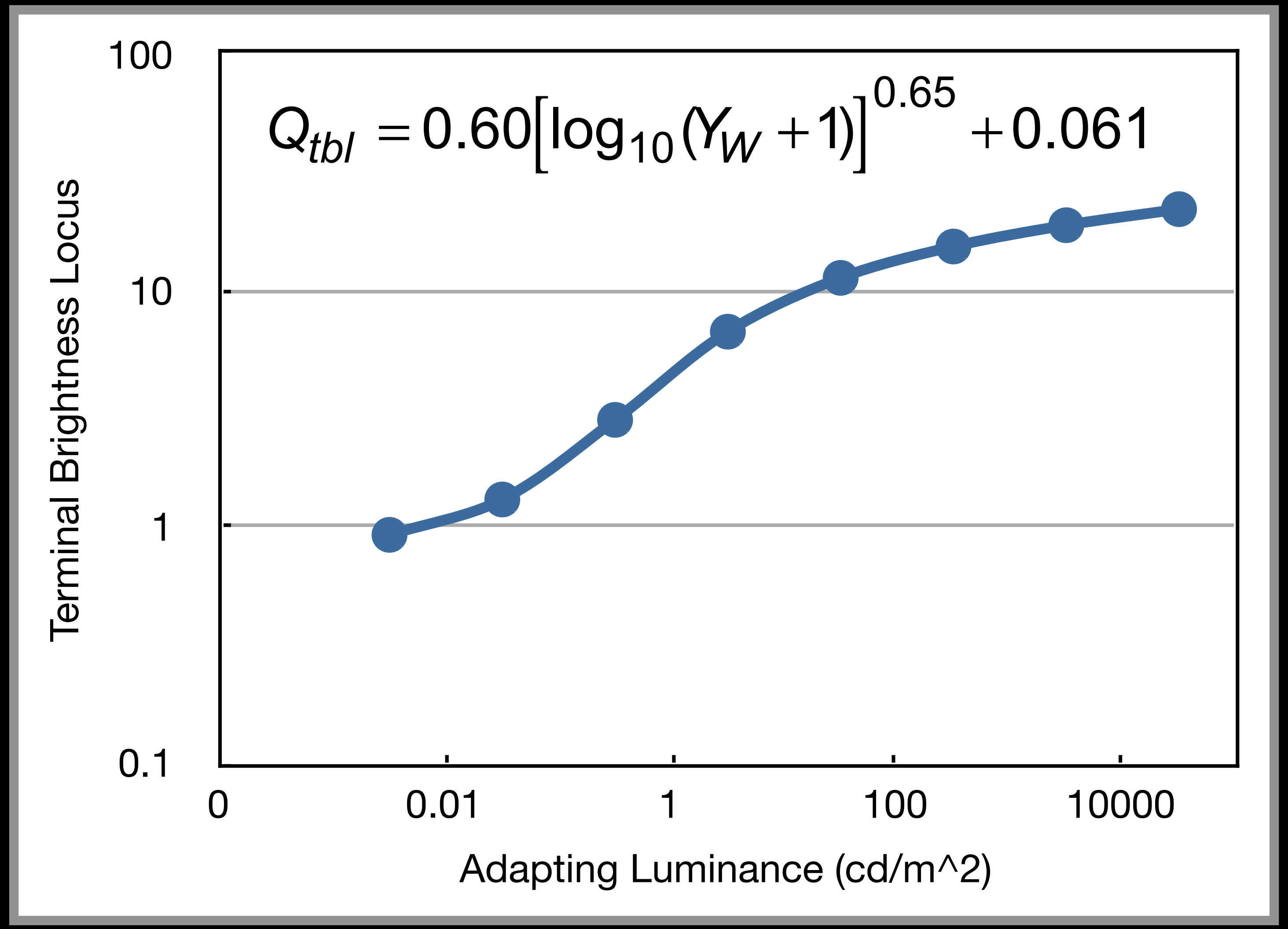




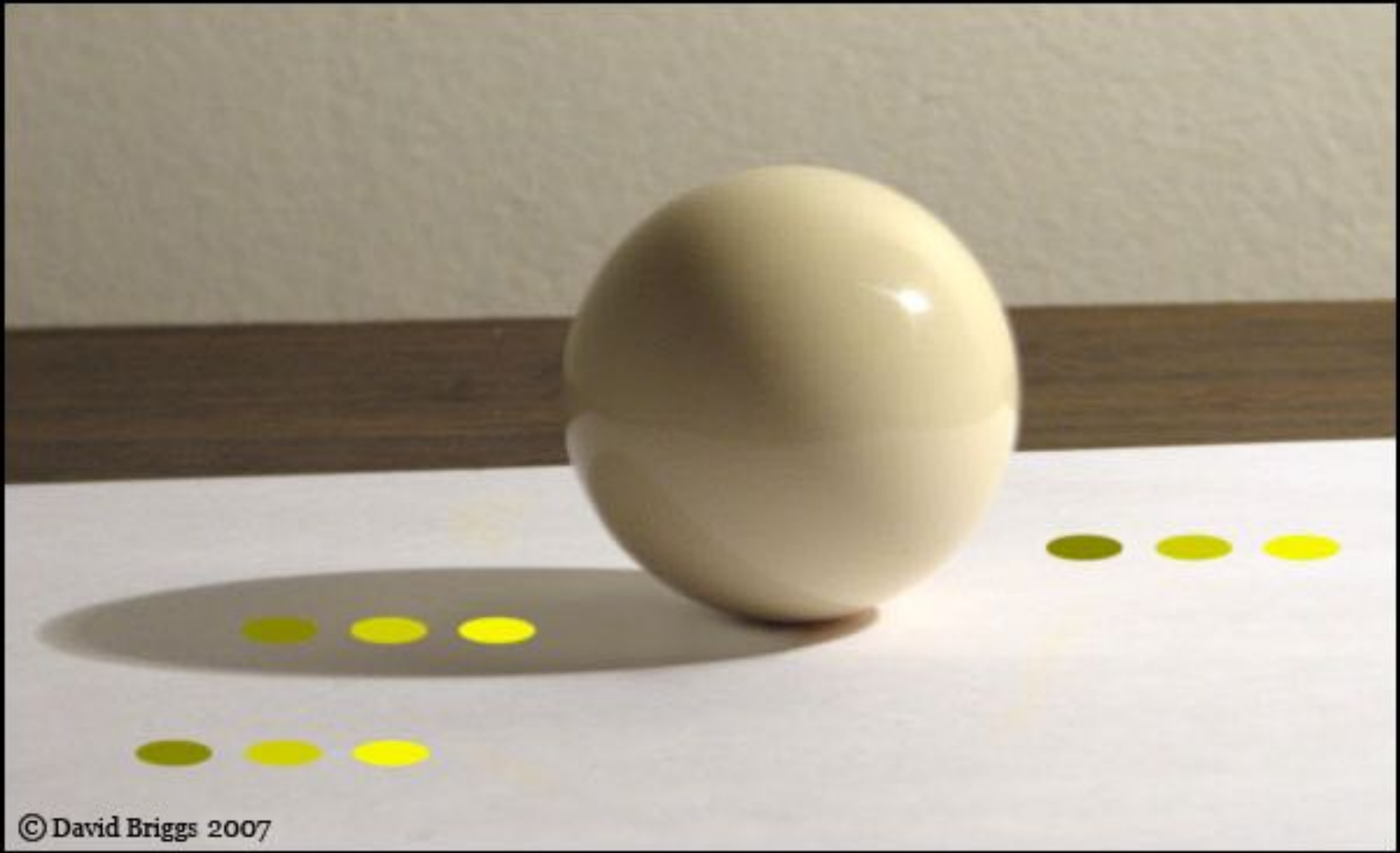
Brilliance: Brightness and Lightness

- Evans' G0
- Lightness is Scaled Relative to G0, Not Diffuse White
- Nonlinear with Luminance
- Lightness (0-100), Brightness (Scale with Terminal Brightness Function)



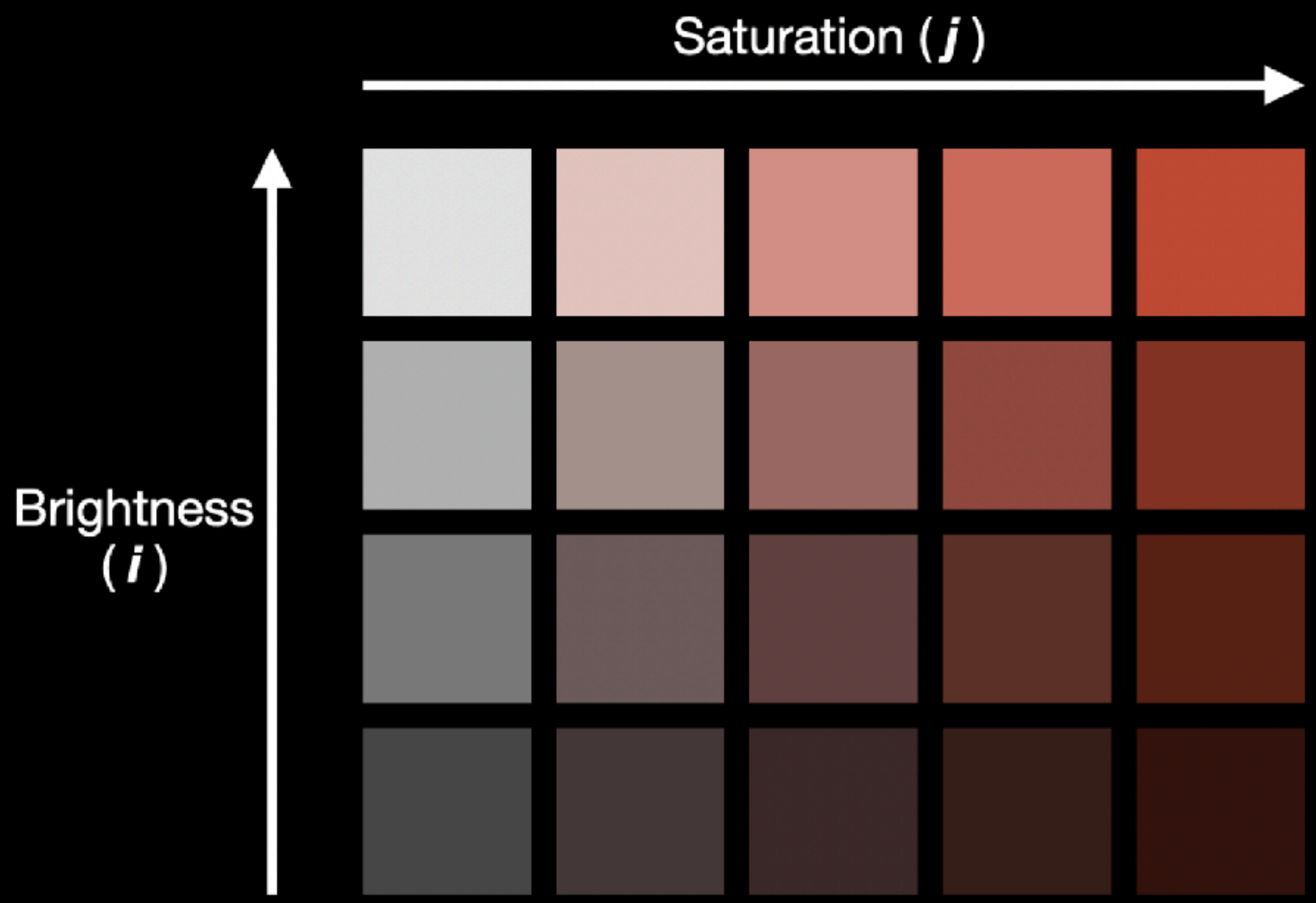


Brilliance, G0



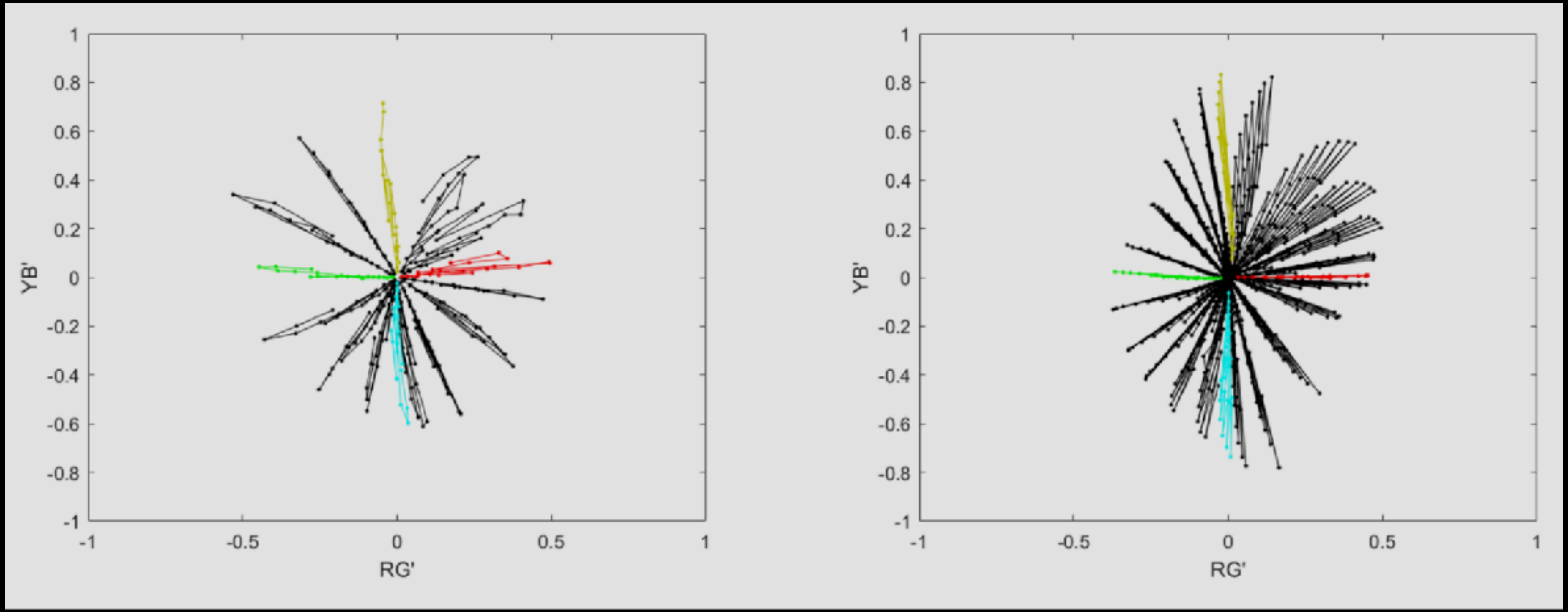
Saturation

- Excitation Purity in Fundamental Chromaticities
- Supported By Psychophysics
- Uncertainty Very Large



Hue

- Individual Cone Fundamentals: *LMS*
- Simple Linear Opponent Transformation
- Individual Unique Hues: *RGYB*
- Two Hue Scales: FHS_h, FHS_H

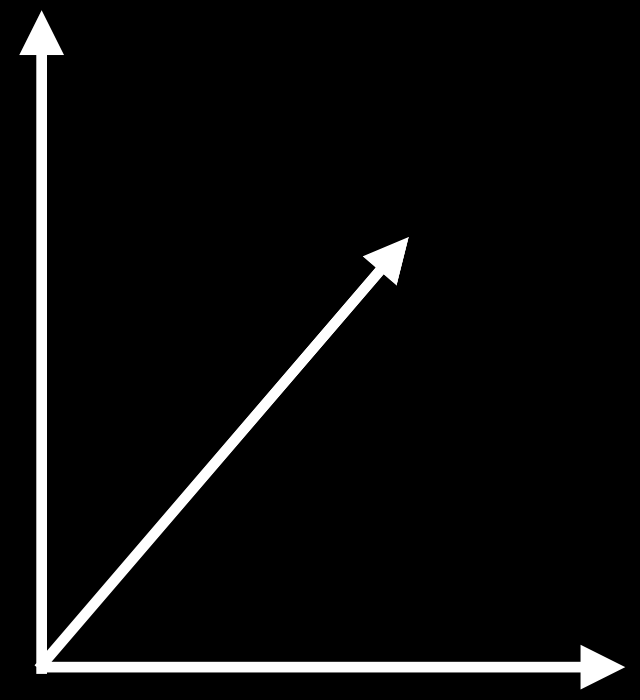


“Space” — an Afterthought

Assess wine and plot three dimensions of perceived acidity, perceived floral aroma, and hue as a “space”.

Does that really have any meaning as three orthogonal dimensions? *(Multi-modal)*

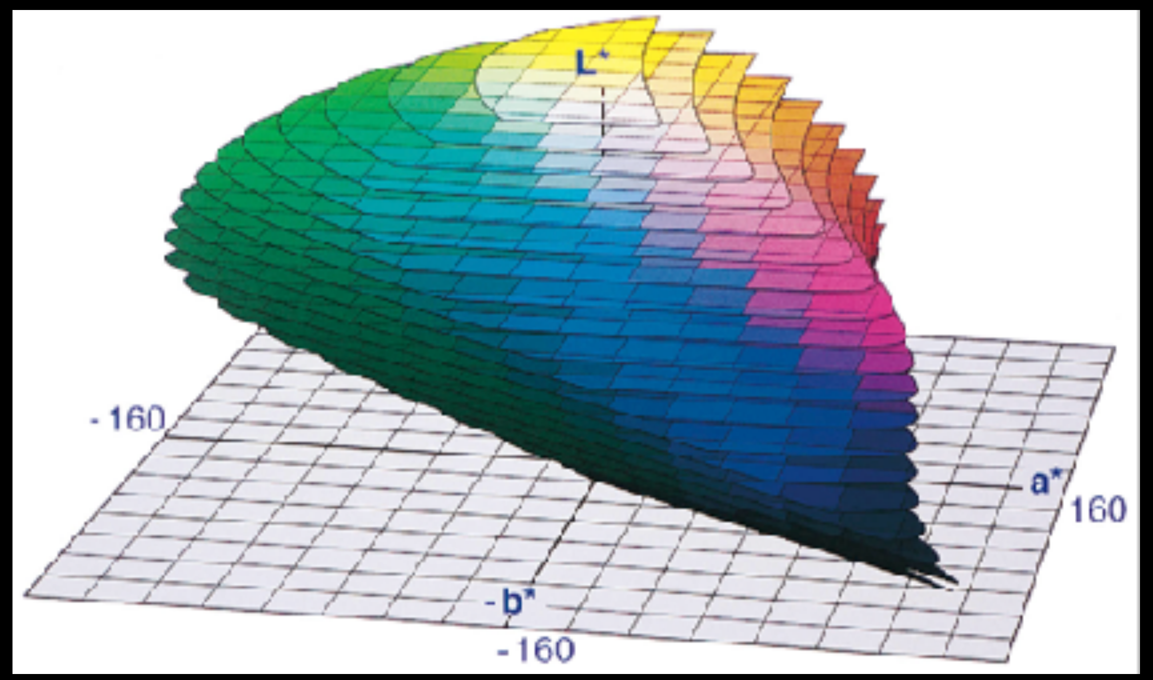
Why do we think that Hue, Brilliance, and Saturation should make a 3D metric space???



Non Euclidean

Convenience for Visualization

Not an Internal Representation



Optimal Colors in CIELAB ….
These have an ecological meaning;
CIELAB probably does not.

Conclusions

Color Appearance: Inconstancy, Adaptation, Scales

Scales Need Not Be Constrained By Spaces

I left the woods for as good a reason as I went there. Perhaps it seemed to me that I had several more lives to live, and could not spare any more time for that one.

-Henry David Thoreau

Thank You …

Questions / Comments / Suggestions …

mark.fairchild@rit.edu