

Yuteng Zhu



Yanjun Li



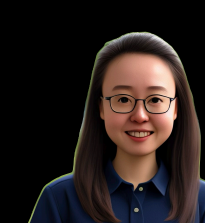
Po-Chieh Hung



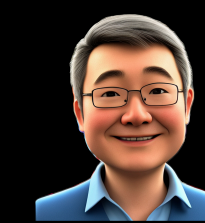
Adria Forres
Herranz



Tyler Pruitt



Yanming Li



Francisco Imai



Will Wu



Shahram Peyvandi

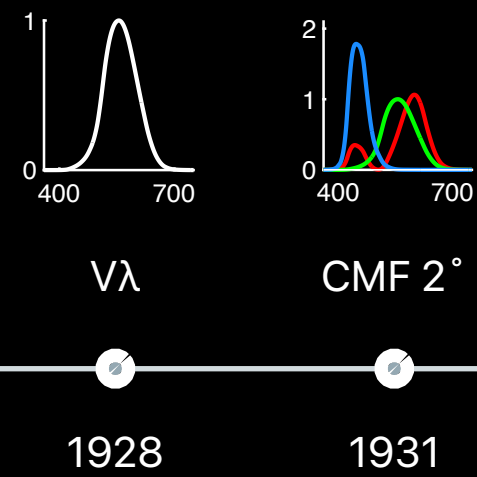
Towards Standardization for Display Color Consistency

ICC Expert Day

July 8, 2025

Vienna, Austria

Display Color Consistency | Motivation



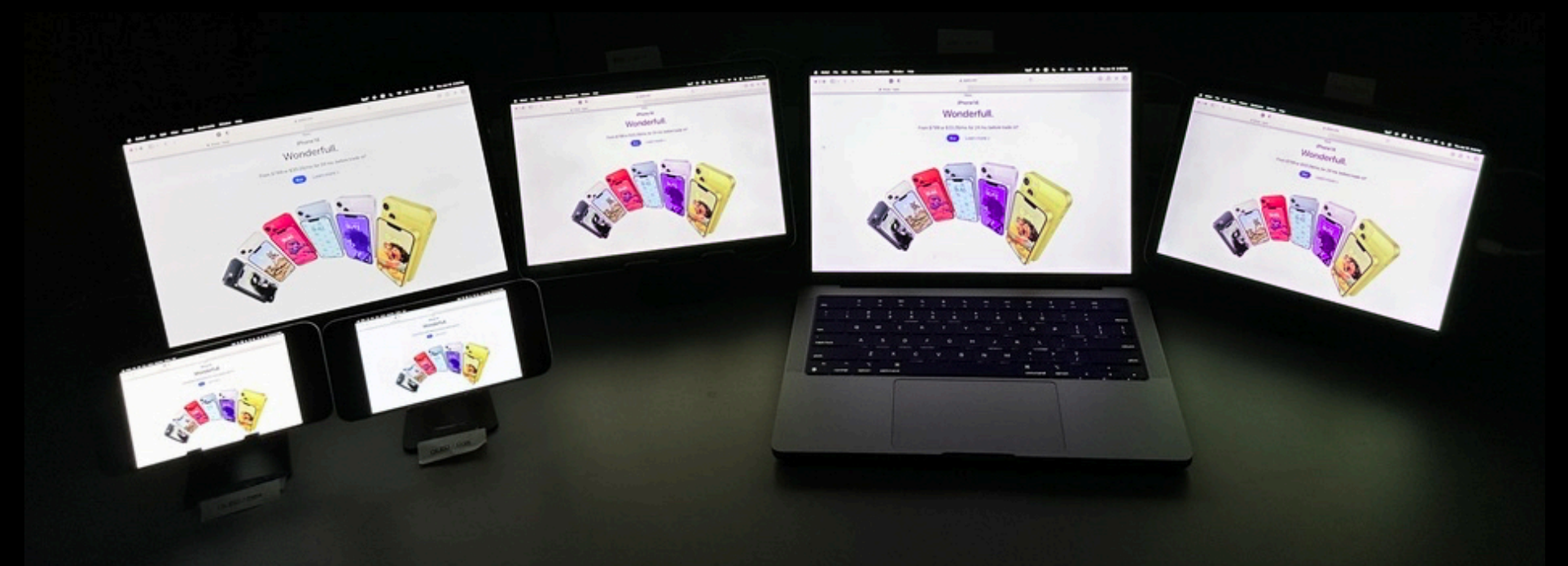
- **Issue:** Inconsistent color appearance across display technologies due to a flaw in the CIE 1931 CMF

measuring the same in CIE 1931 space, **but appear different**

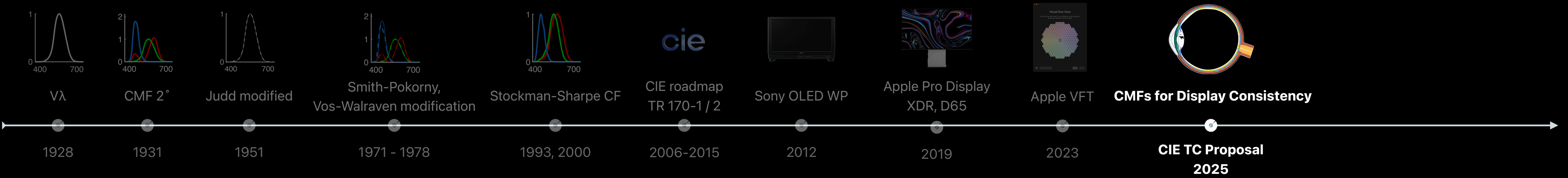


- **Goal:** New optimized CMF framework standard to improve color consistency for display industry

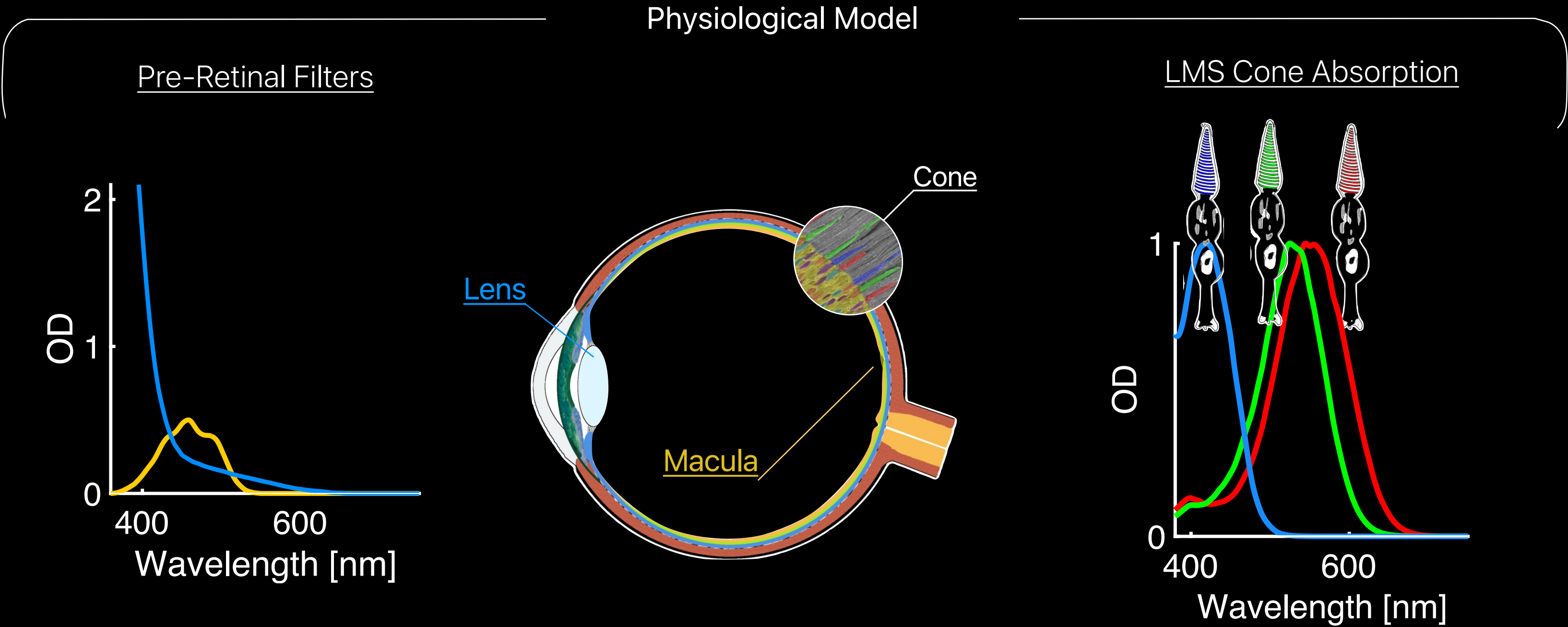
measuring the same in optimized space and **appear the same**



Display Color Consistency | CIE -TC Proposal: Display Color Consistency



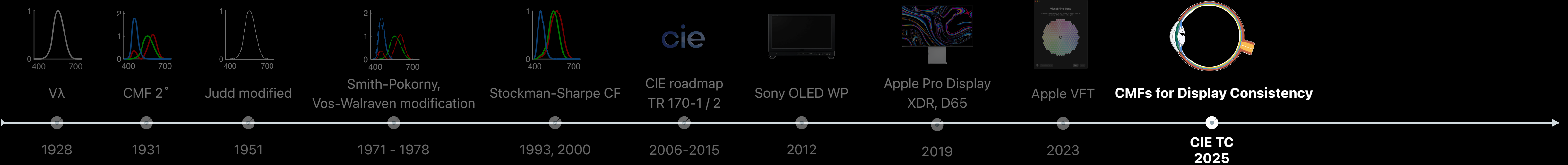
New CIE TC Proposal: Physiologically-driven optimized CMFs for Display Color Consistency



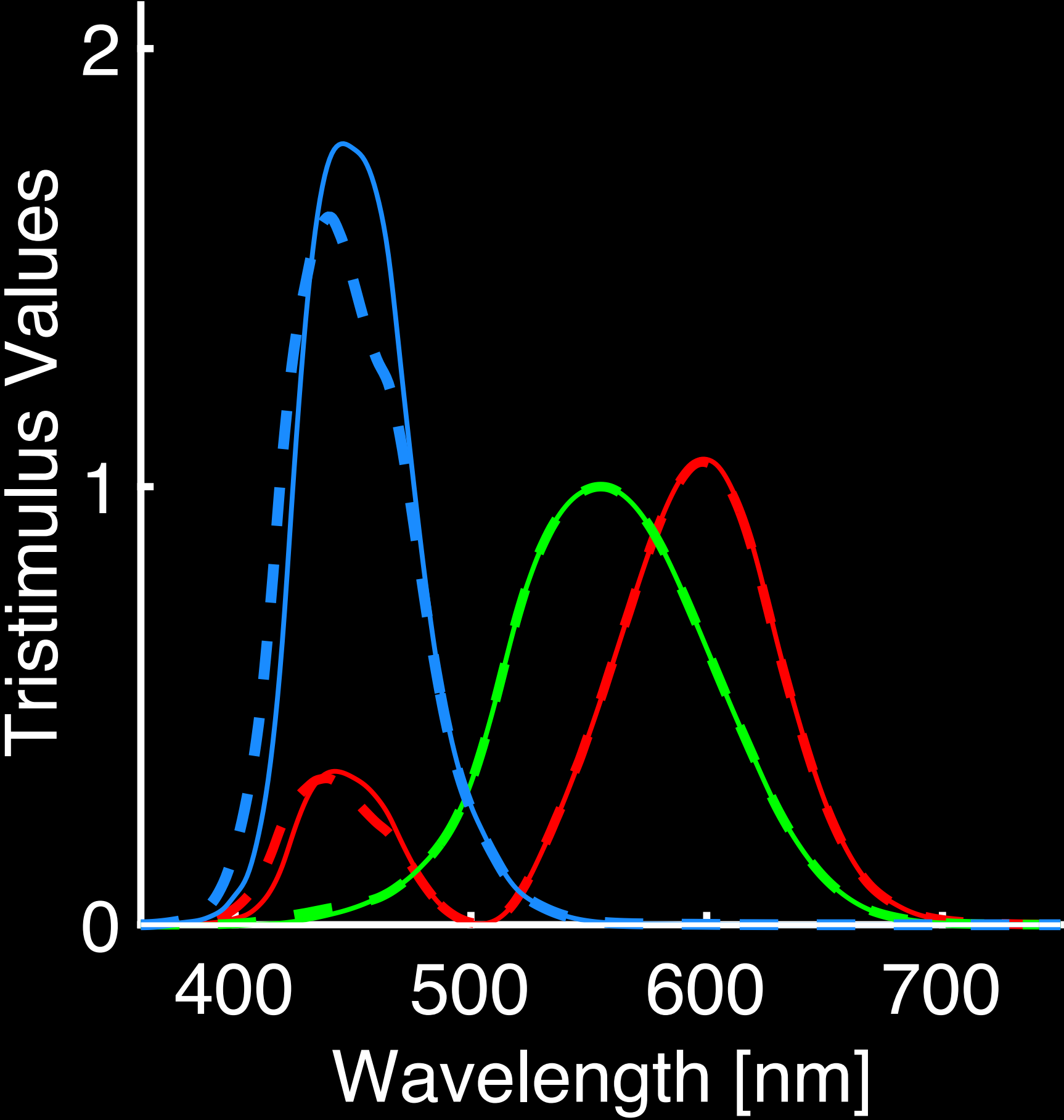
References

1. CIE Technical Report 170-1. "Fundamental chromaticity diagram with physiological axes. Part I", 2006.
2. Stockman A, Rider AT. Formulae for generating standard and individual human cone spectral sensitivities. Color Res Appl. 2023; 48(6): 818-840. doi:10.1002/col.22879
3. Shi K, Luo MR, Rider AT, Huang T, Xu L, Stockman A. A multi-primary trichromator to derive individual color matching functions and cone spectral sensitivities. Color Res Appl. 2024; 49(5): 449-464. doi:10.1002/col.22928
4. Peyvandi, S. Photon absorption, color detection, and chromatic induction. Retrieved from <https://doi.org/doi:10.7282/T3WD43HS>
5. TC 1-97 Age- And Field-Size-Parameterised Calculation of Cone-Fundamental-Based Spectral Tristimulus Values
6. CIE 254 A Roadmap Toward Basing CIE Colorimetry on Cone Fundamentals

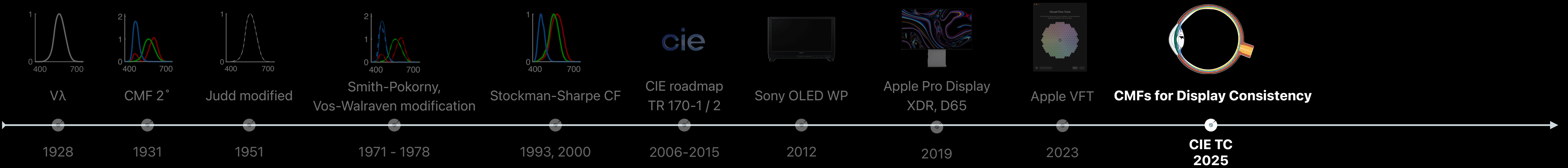
Display Color Consistency | CIE -TC Proposal: Optimized CMFs



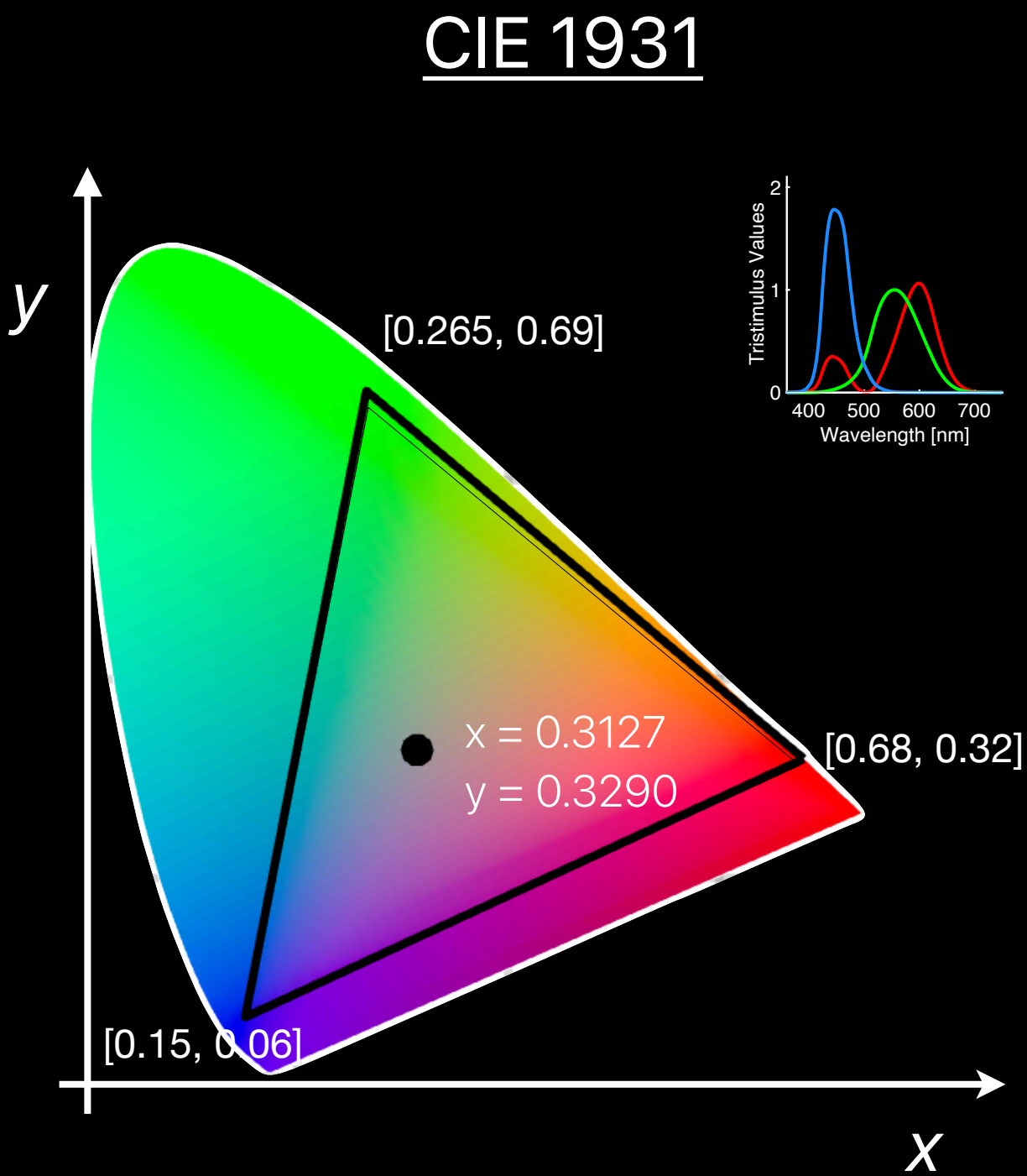
Proposal: Use of an optimized CMFs for display color consistency



Display Color Consistency | Problem: Standard Standard Color Space



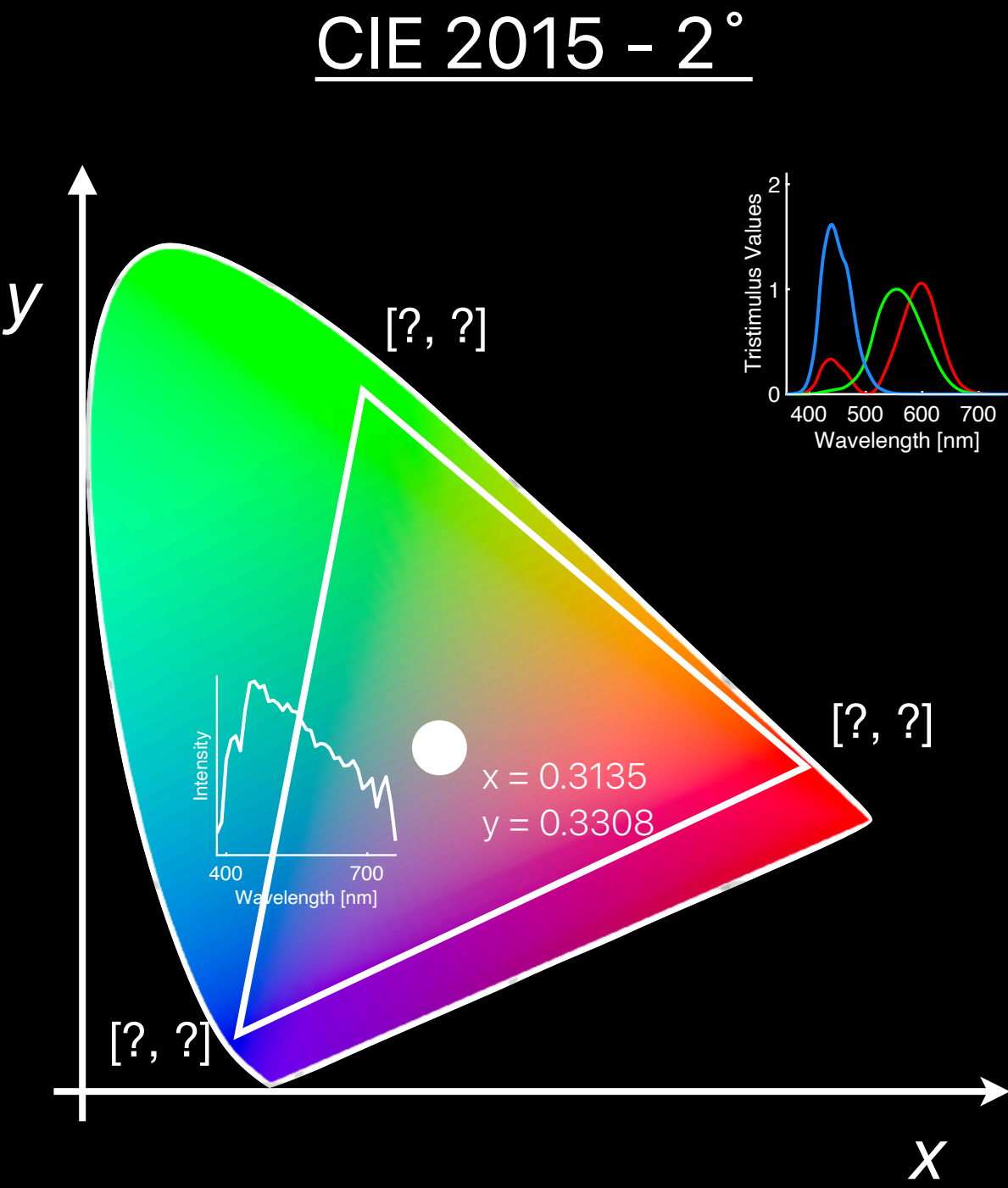
Problem: Display target color space — e.g. P3, Rec.709, ... — is defined by chromaticity coordinates in the CIE 1931 standard observer.



Submitted to CIC 2025, Under Review

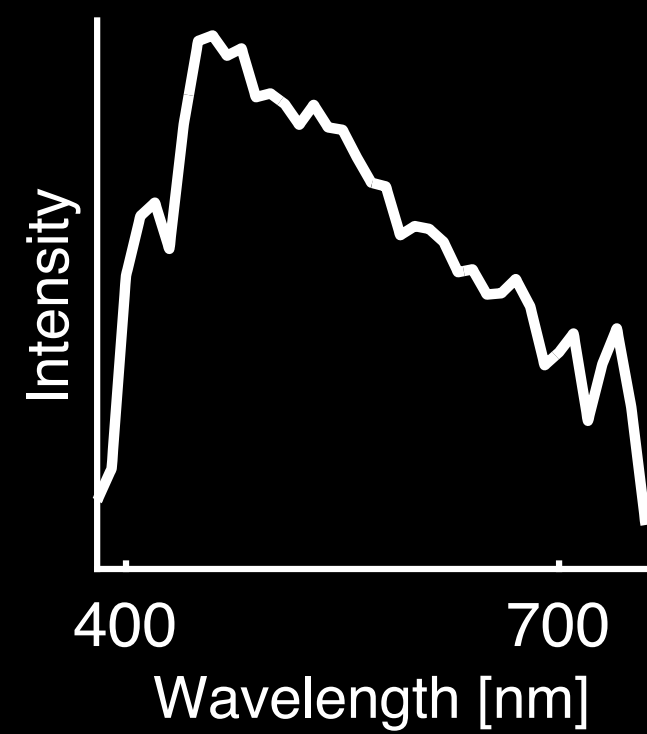
Spectral Definition of Standard Color Space Primaries for Display

Yuteng Zhu*, Yanjun Li, Po-Chieh Hung, Adria Fores Herranz, Tyler Pruitt, Yanming Li, Francisco Imai, Will Wu, Shahram Peyvandi*
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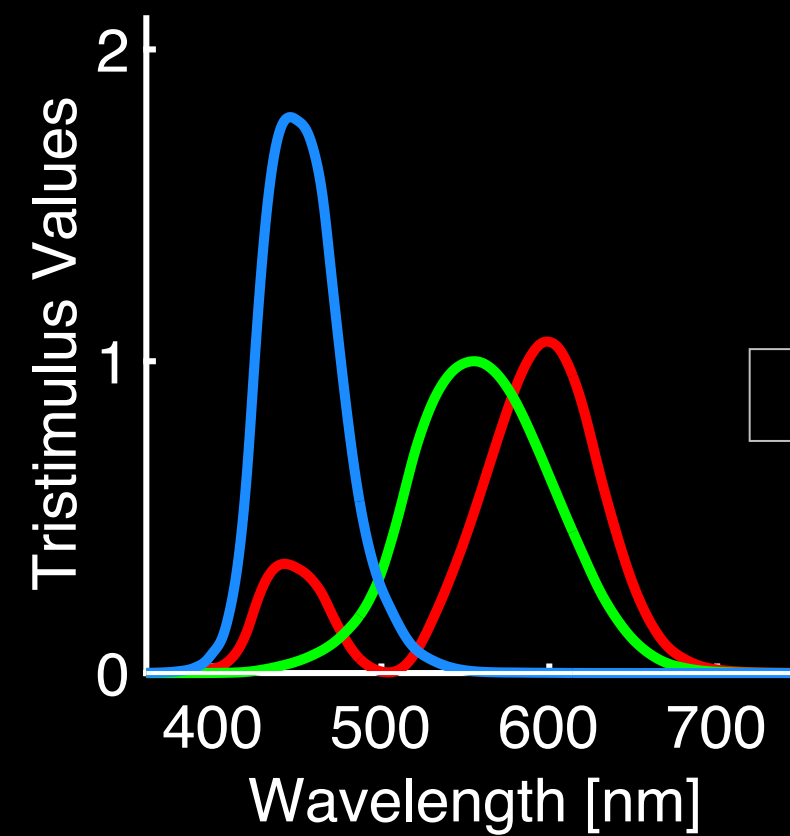


Display Color Consistency | Background: Color Reproduction

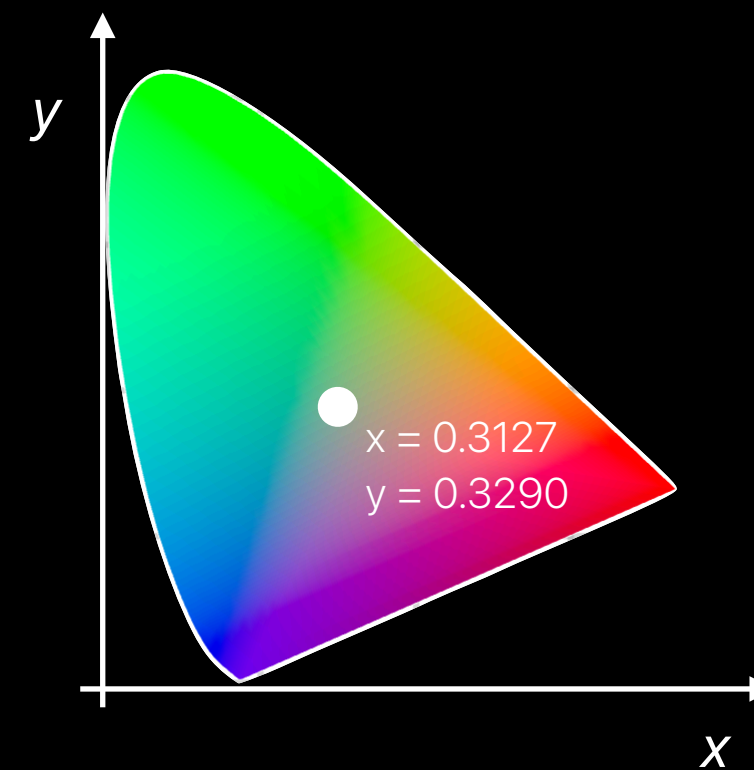
Ground Truth



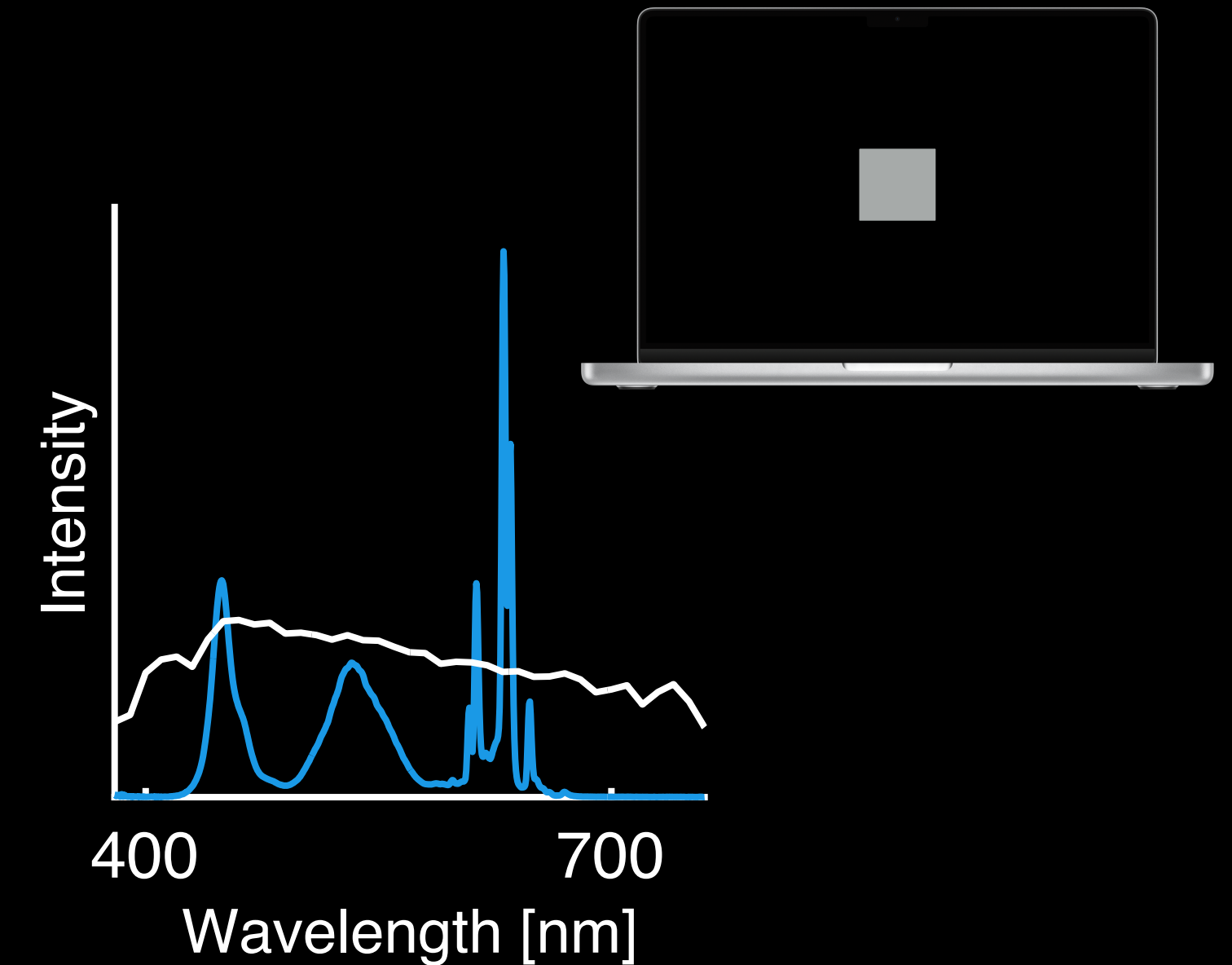
Standard Observer



Color Coordinate



Color Reproduction



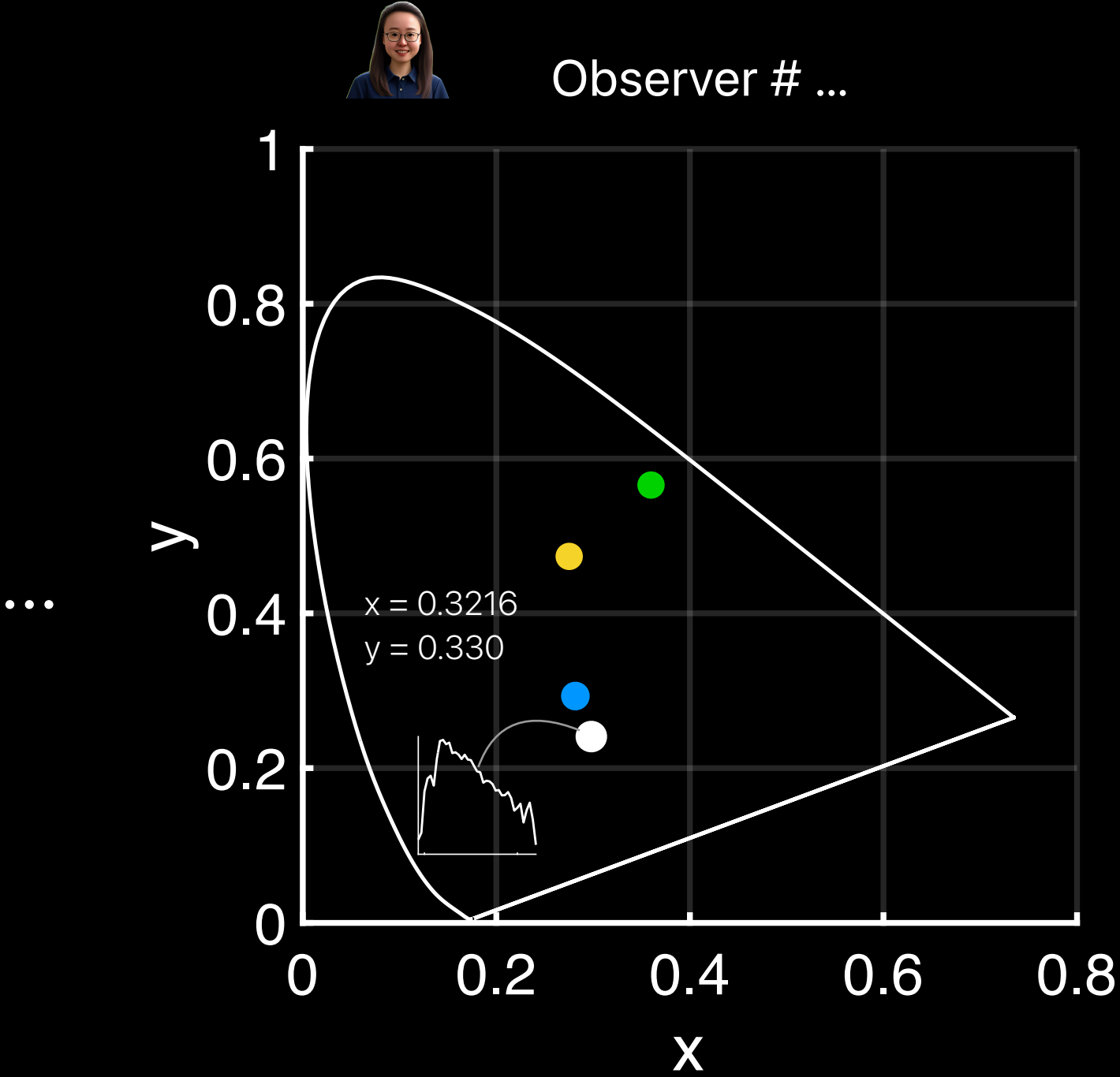
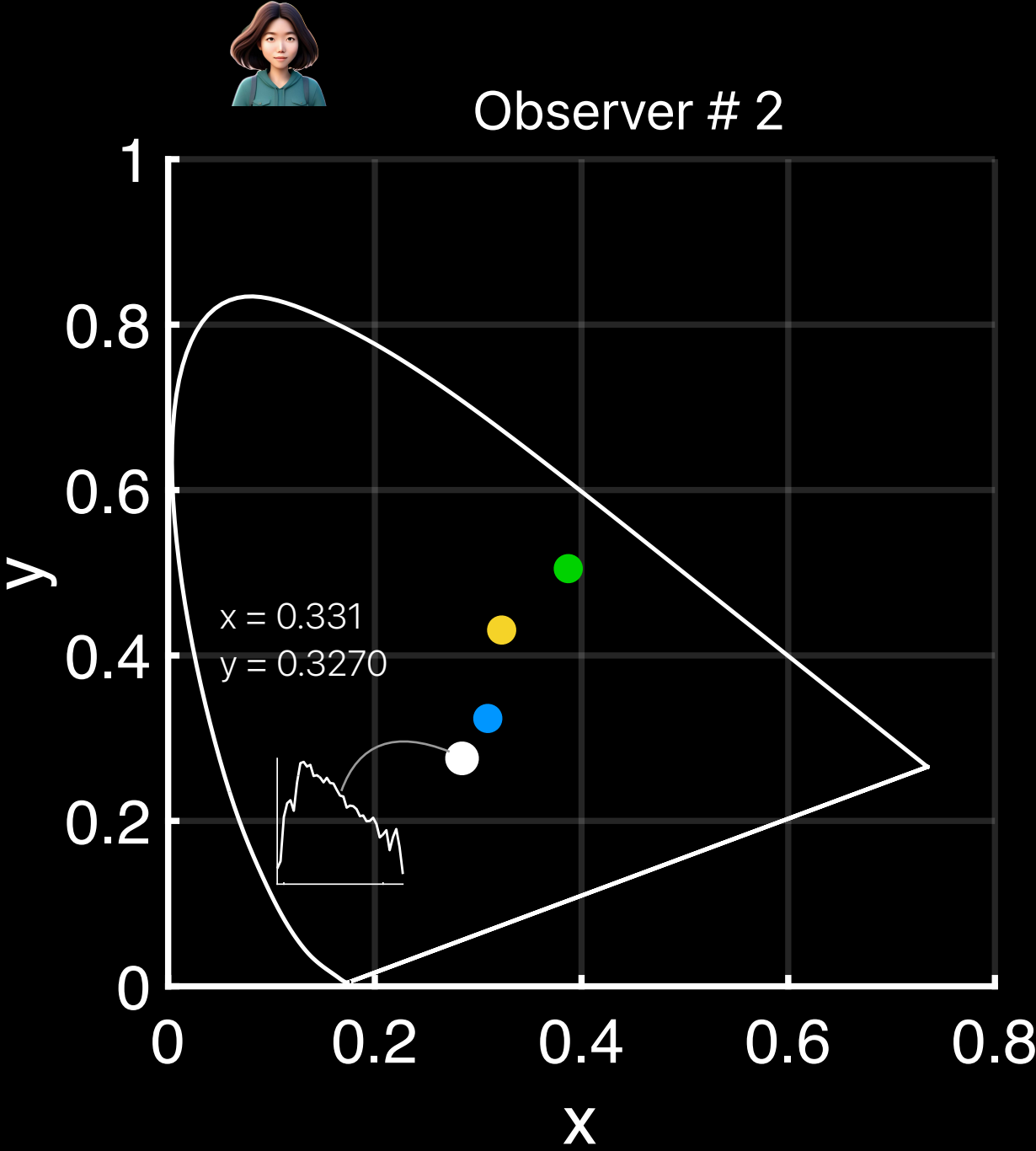
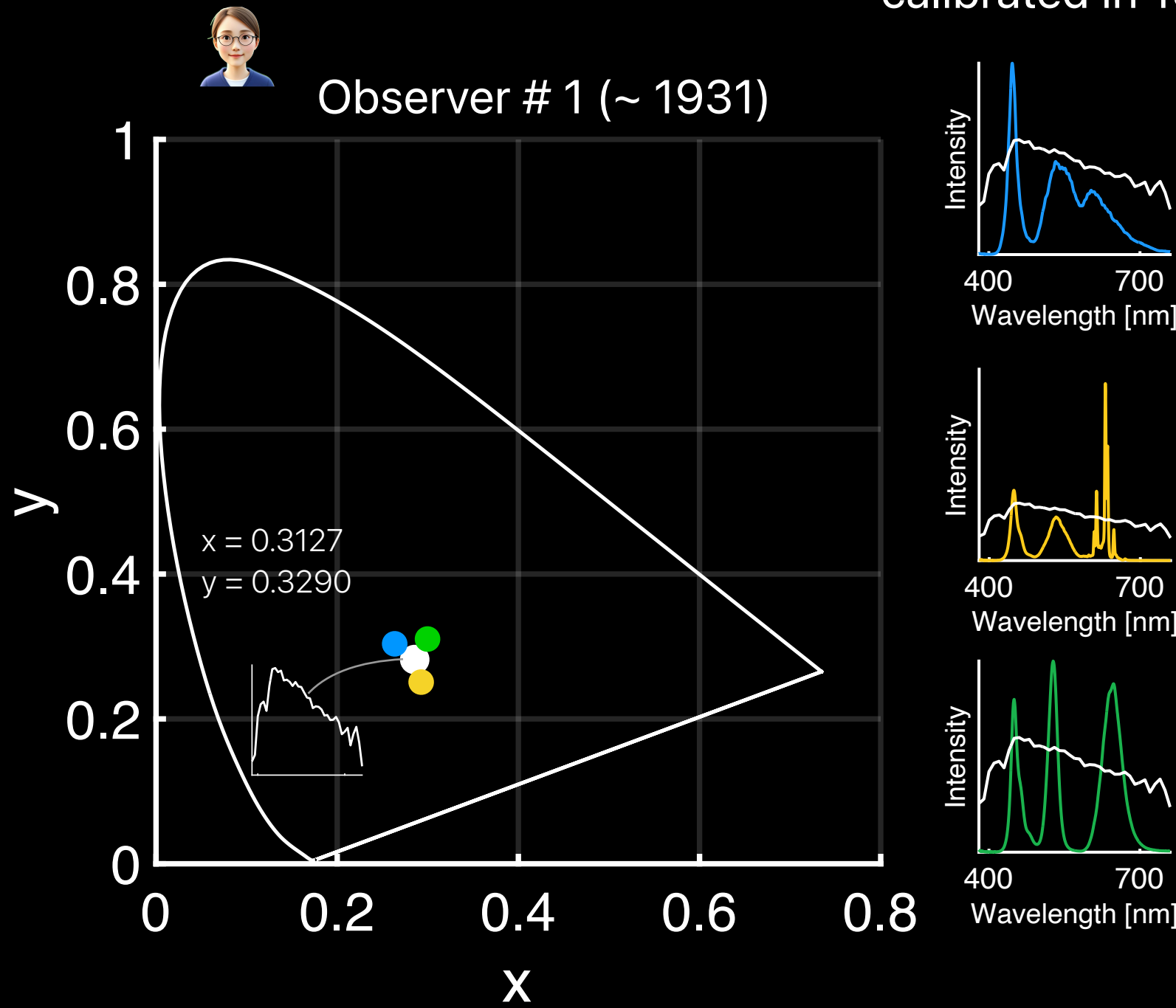
Background: Color reproduction is the process of re-producing *colors* on multiple media, e.g. digital displays

- Reproduced color and target color appear the same for *Standard Observer*

Display Color Consistency | Color Reproduction: Target Spectrum

Display Color Reproduction: Color reproduction of the CIE D65 standard illuminant on multiple displays

Displays
calibrated in 1931

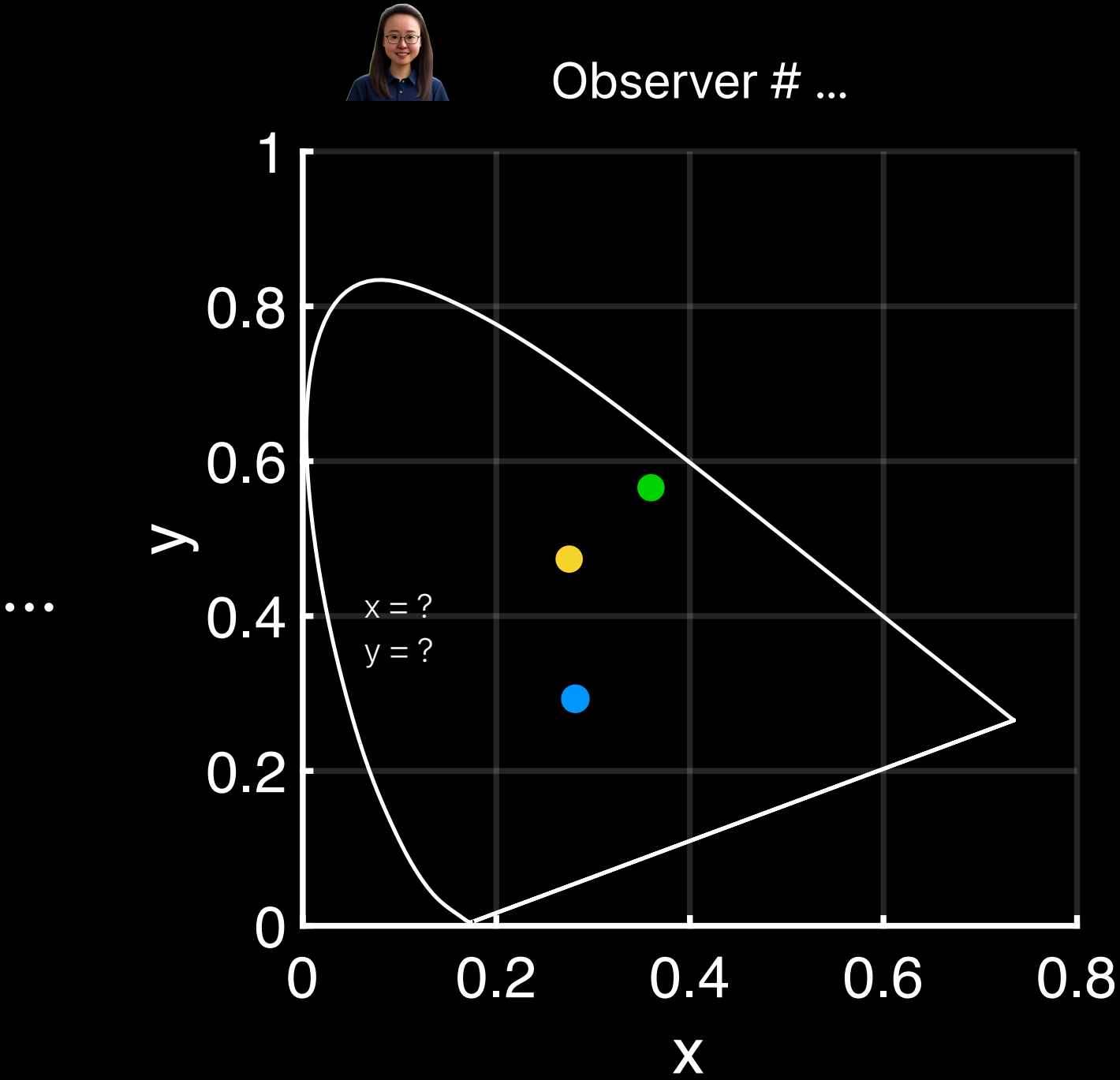
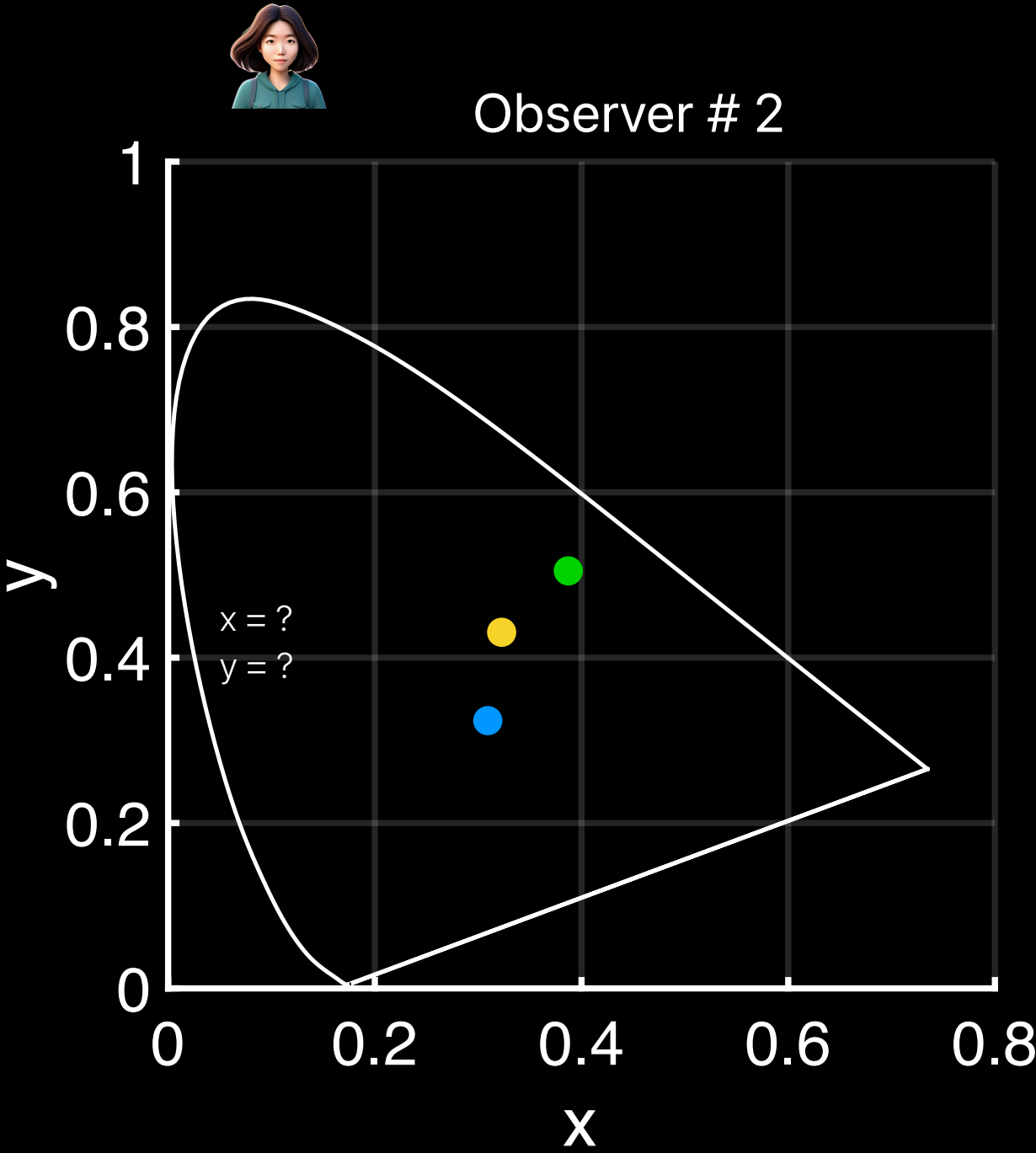
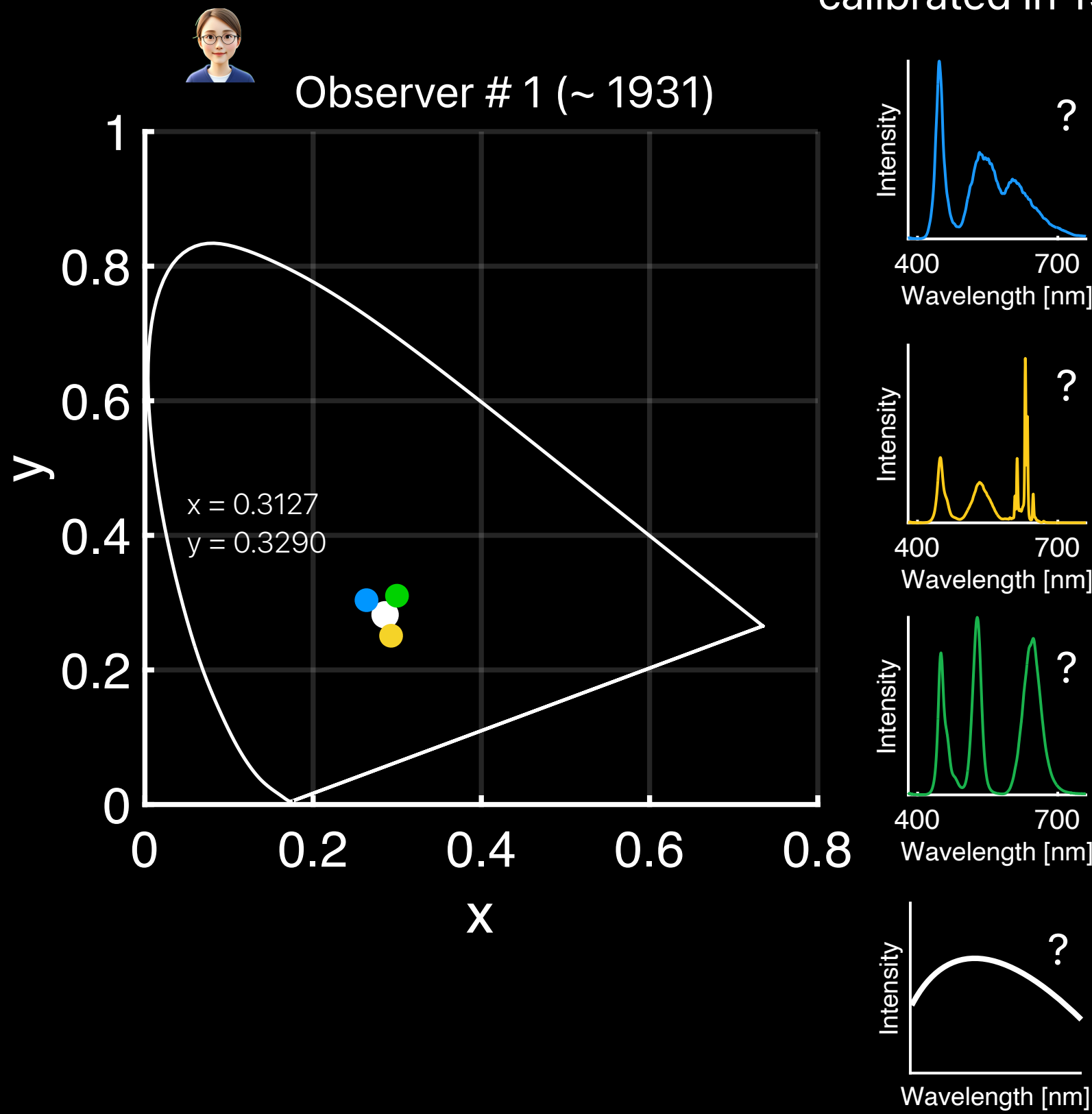


Display Color Consistency | Color Reproduction: Lack of Spectrum

Display Color Reproduction: what if the target spectrum is unknown?

What spectrum serves as the target ?

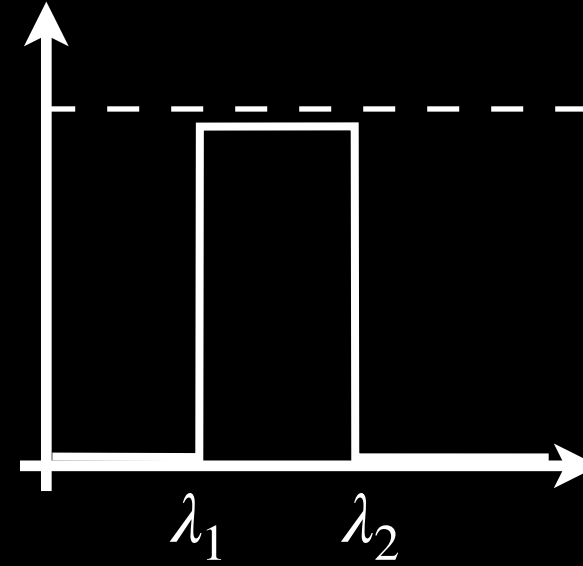
Displays
calibrated in 1931



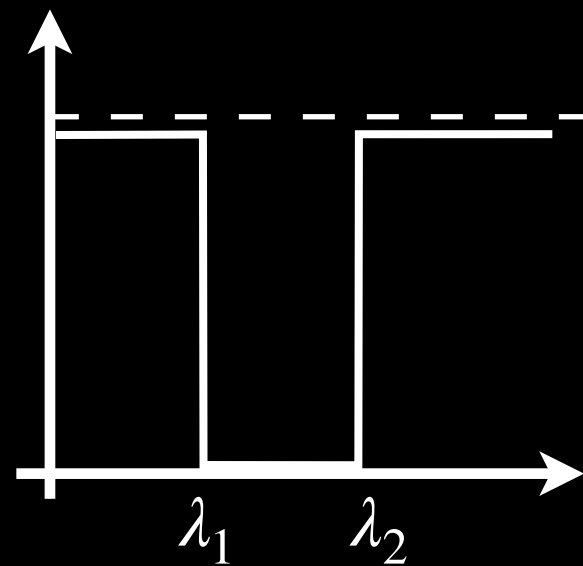
Display Color Consistency | Color Reproduction: Proposal

- Function Definition: Optimal spectral stimulus

$$\text{Type I: } f(\lambda) = \begin{cases} 1, & \text{if } \lambda_1 \leq \lambda \leq \lambda_2 \\ 0, & \text{otherwise} \end{cases}$$



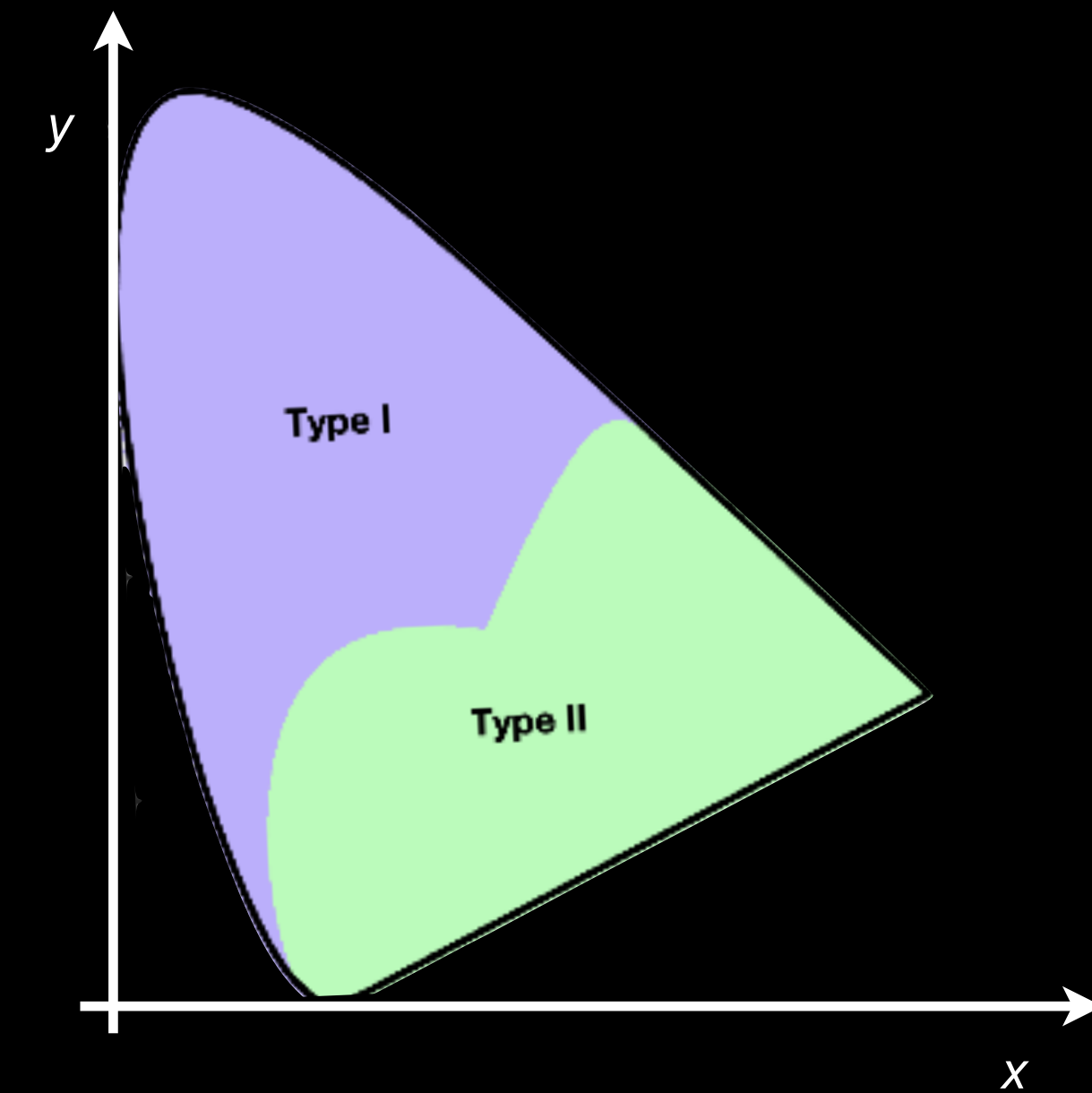
$$\text{Type II: } f(\lambda) = \begin{cases} 0, & \text{if } \lambda_1 \leq \lambda \leq \lambda_2 \\ 1, & \text{otherwise} \end{cases}$$



- Problem Definition

$$\begin{bmatrix} x \\ y \end{bmatrix} = f\left(\begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix}, CMF \right)$$

- A deterministic problem with 2 equations for 2 variables
- A **virtual** display definition: device independent



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Spectral Definition of Standard Color Space Primaries for Display

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*Corresponding authors: yuteng.zhu@apple.com, speyvandi@apple.com

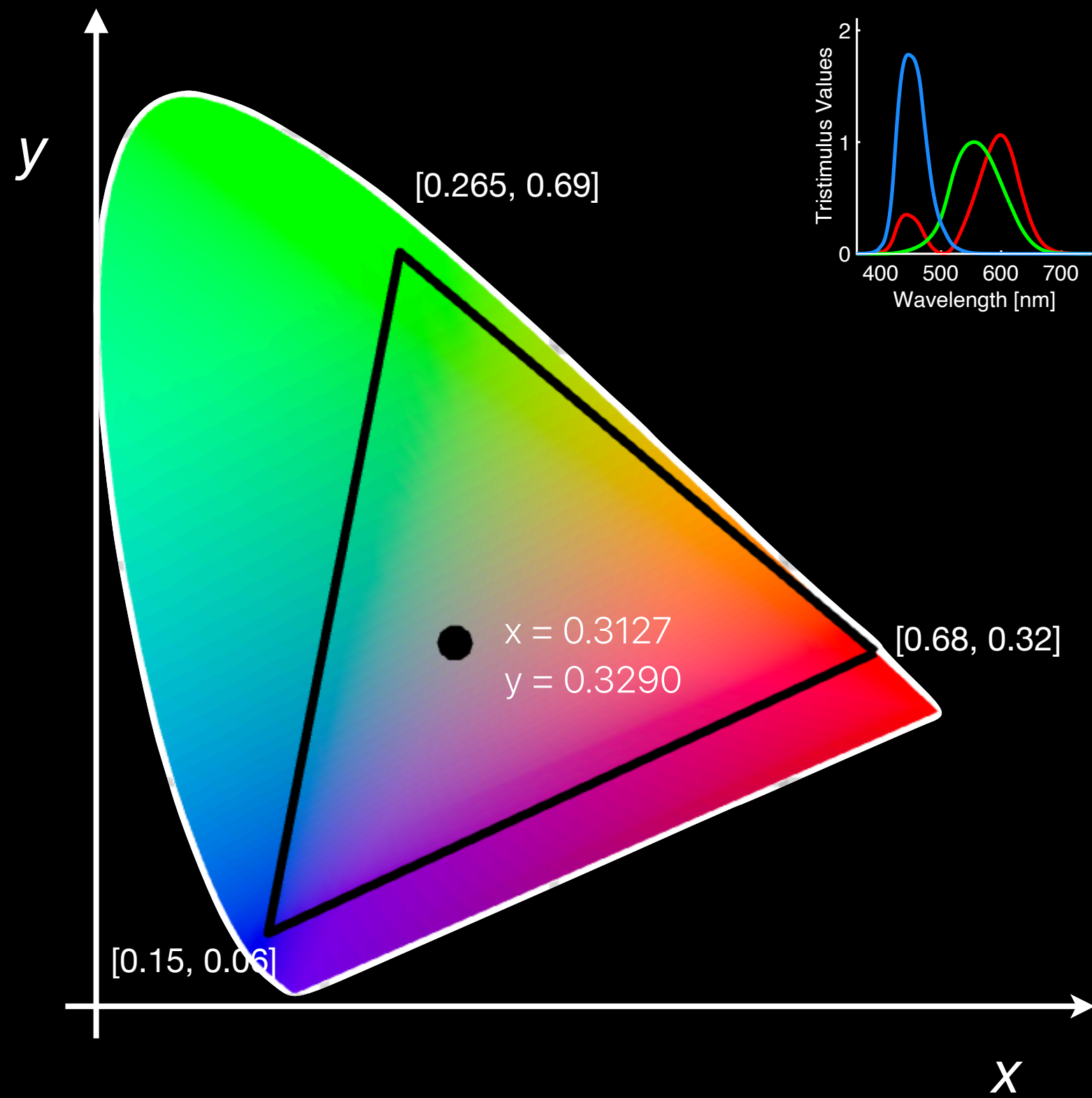
Display Color Consistency | Color Reproduction: Proposal

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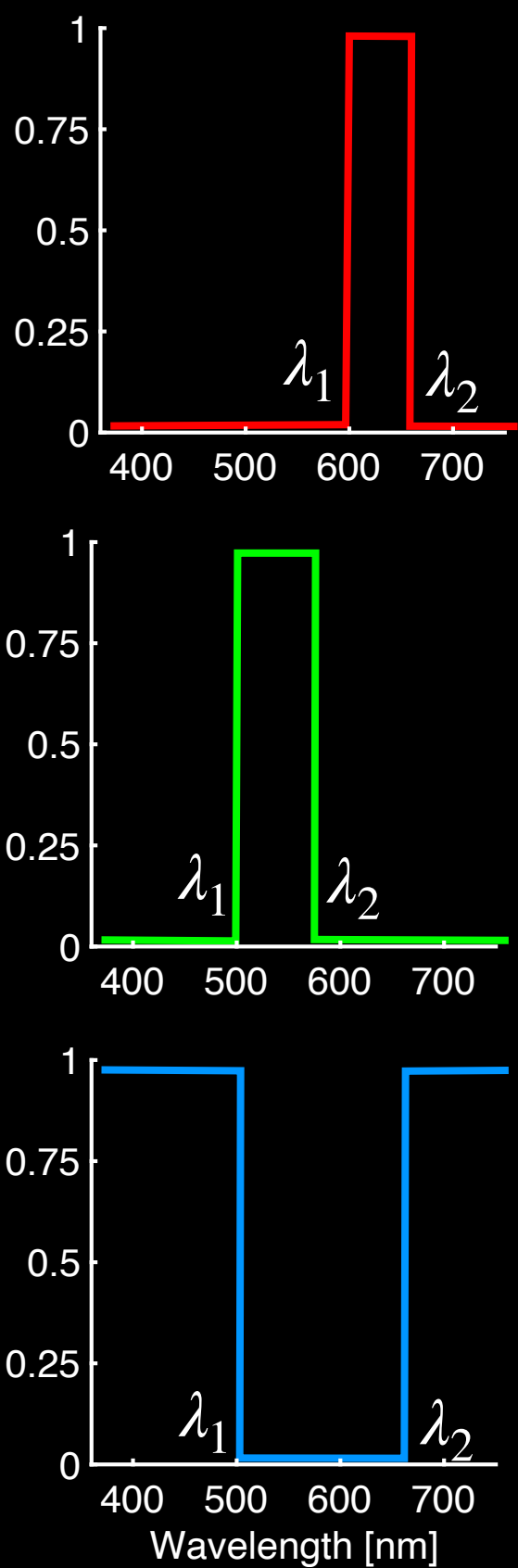
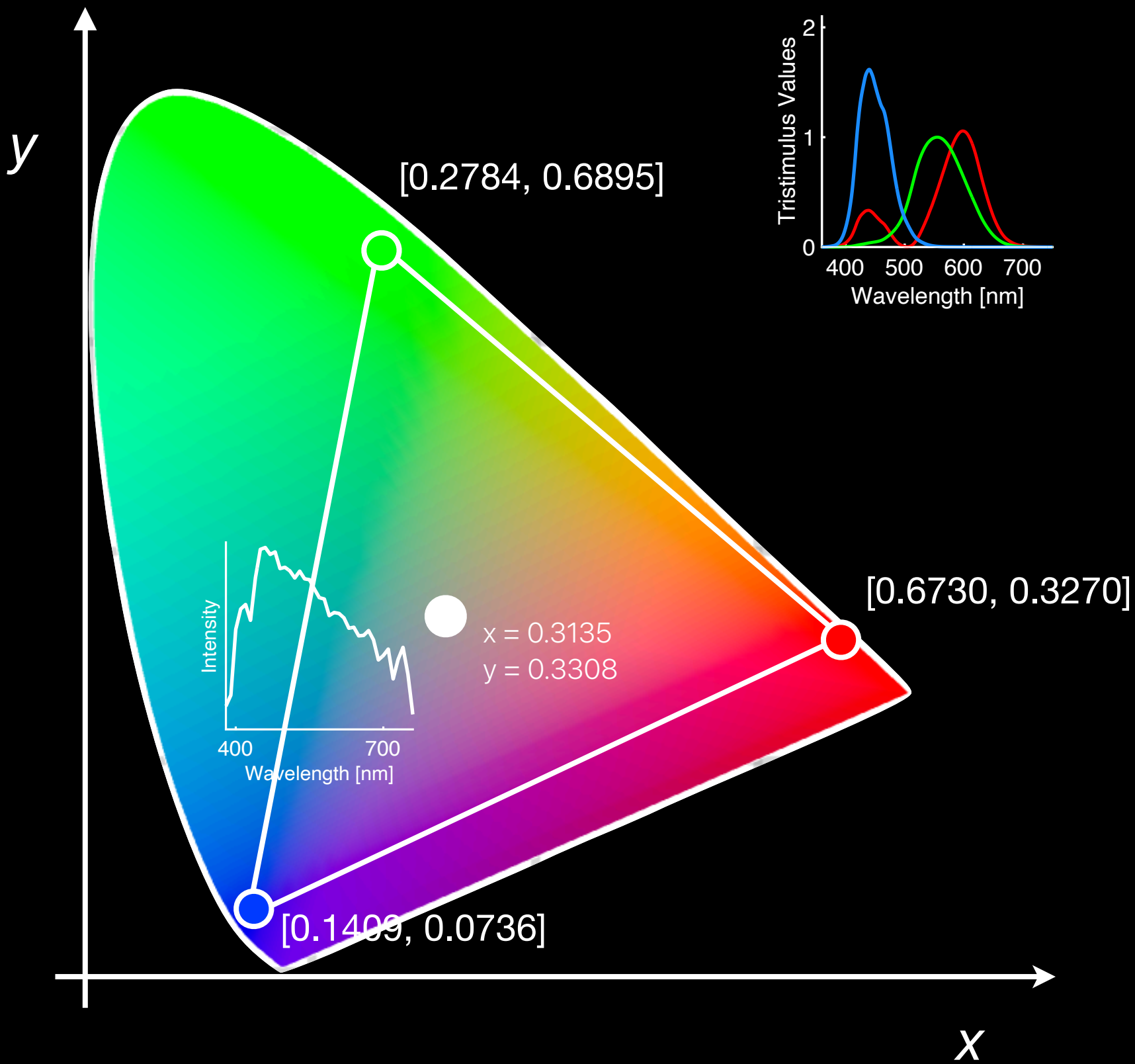
Proposal: Spectral definition of standard color space primaries for display using *Optimal Spectral Stimuli*

Optimal Spectral Stimuli

CIE 1931



CIE 2015 - 2°



Thank You