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Color Identification of LED and Incandescent Aviation Signal Lights

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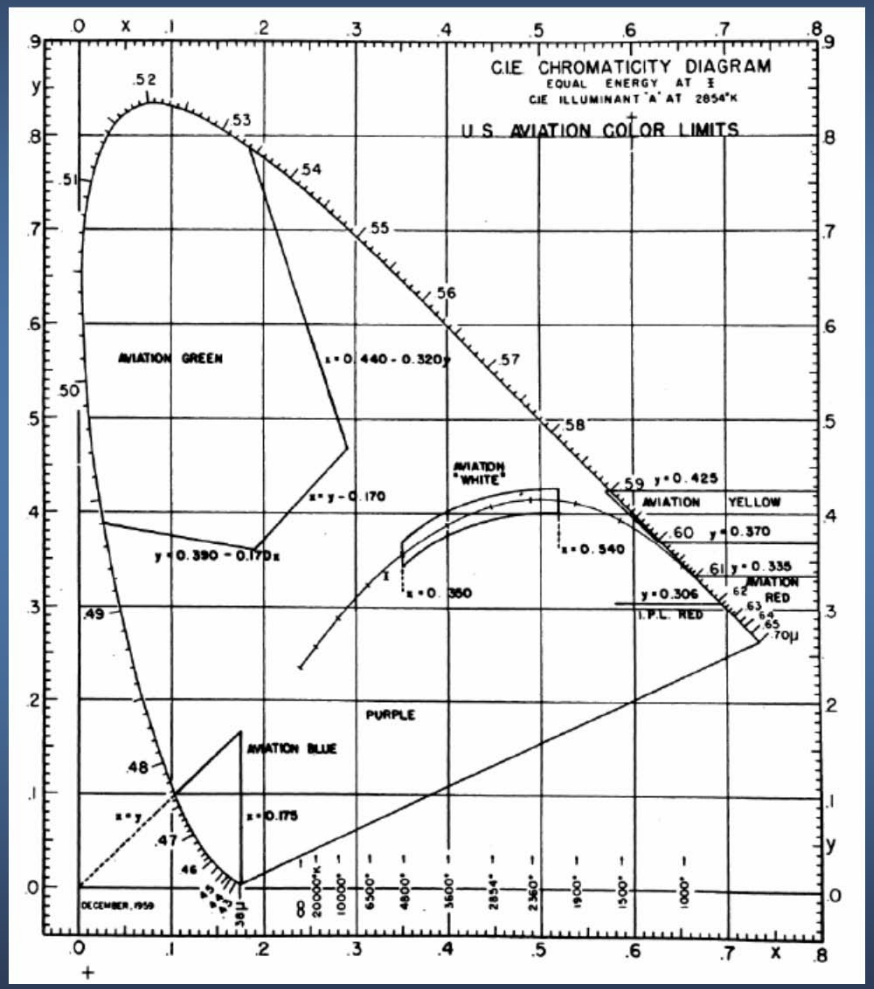
Outline

- Existing chromaticity boundaries for aviation signal lights
- Differences between LED and incandescent signal lights
  - Chromaticity
  - Intensity
- Color identification data
  - Color-normal observers
  - Color-deficient observers
- Discussion

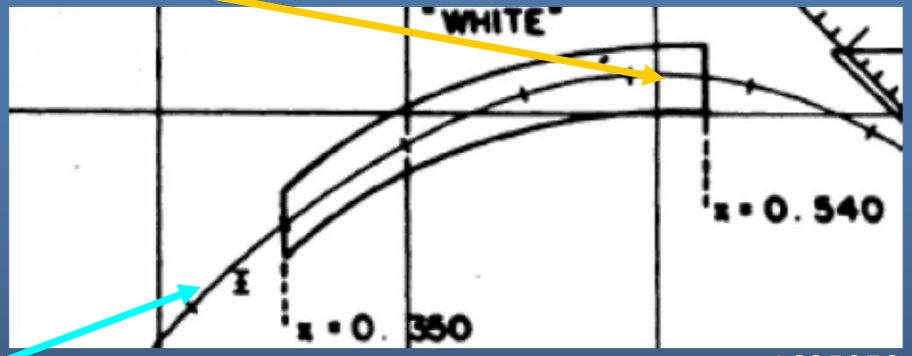
Existing chromaticity boundaries

- AS25050 from Society of Automotive Engineers (SAE 2010)



Characteristics of AS25050 chromaticity boundaries

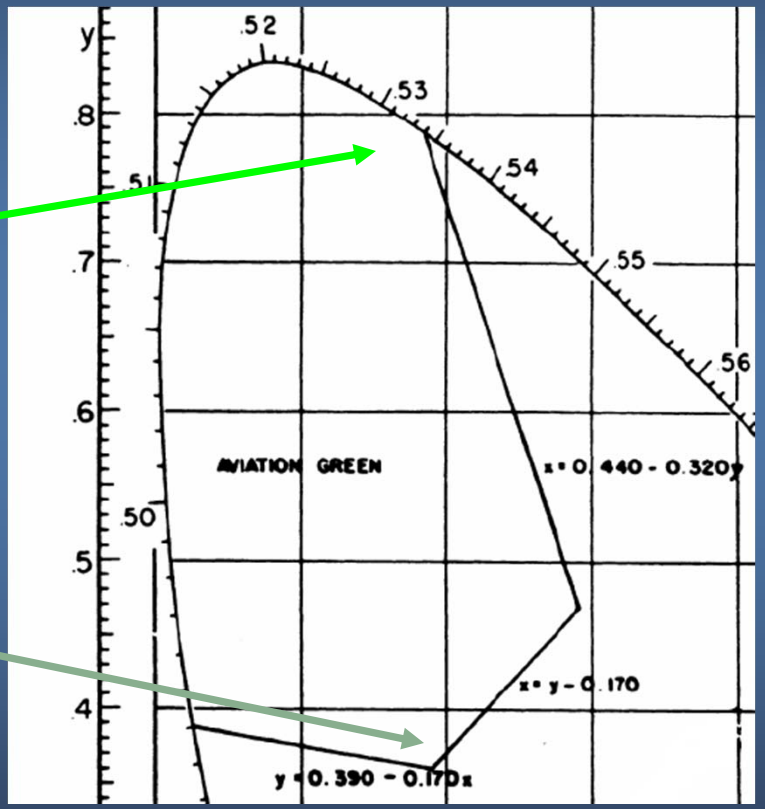
- White:
  - Extends near yellow portion of spectrum locus where many individuals identify as “yellow,” probably to accommodate dimmed incandescent sources
  - Many people identify lights beyond the left-most boundary as “white” (Bierman et al. 2009)



AS25050

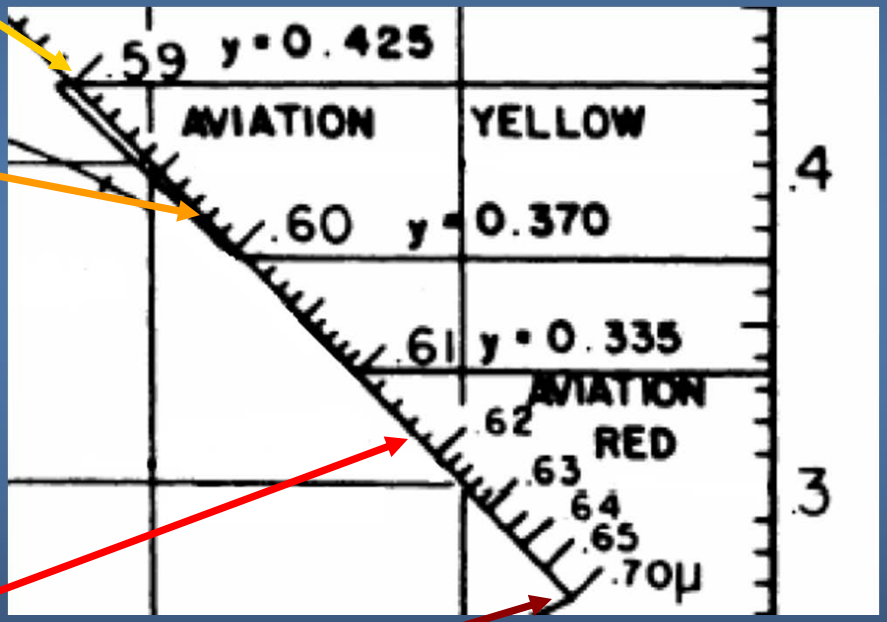
Characteristics of AS25050 chromaticity boundaries

- Green:
  - Sources nearest the "yellow" portion of the spectrum locus can be confused with yellow or red by color-deficient individuals (CIE 1994)
  - Both highly saturated and highly de-saturated colors are permitted



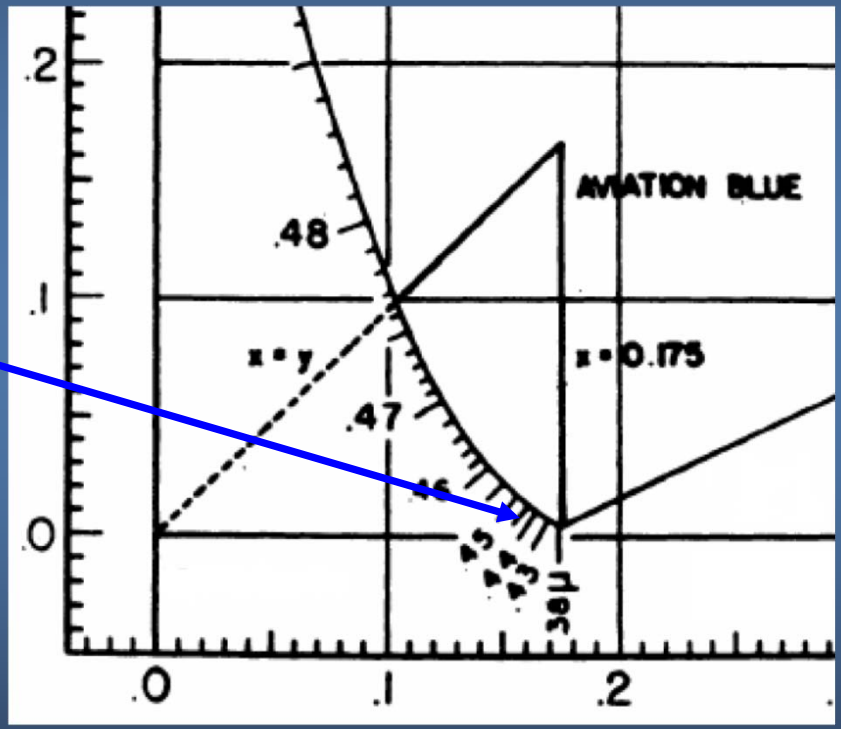
Characteristics of AS25050 chromaticity boundaries (cont'd.)

- Yellow:
  - Very close to spectrum locus
  - Yellow region is shifted toward "orange" compared to other recommendations (CIE 1994), possibly to avoid confusion with dimmed incandescent white signal lights
- Red:
  - Very close to spectrum locus
  - No long-wavelength limit



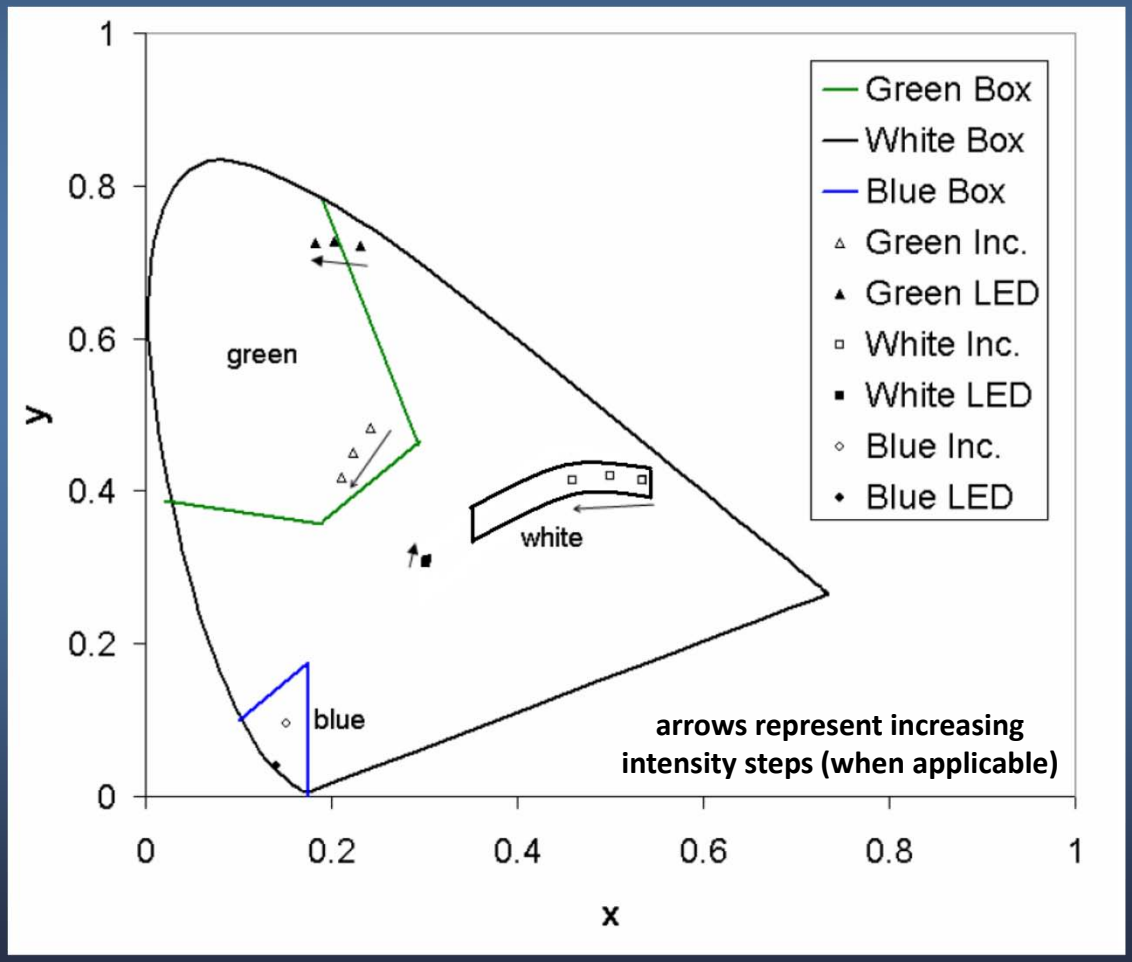
Characteristics of AS25050 chromaticity boundaries (cont'd.)

- Blue:
  - No short-wavelength limit

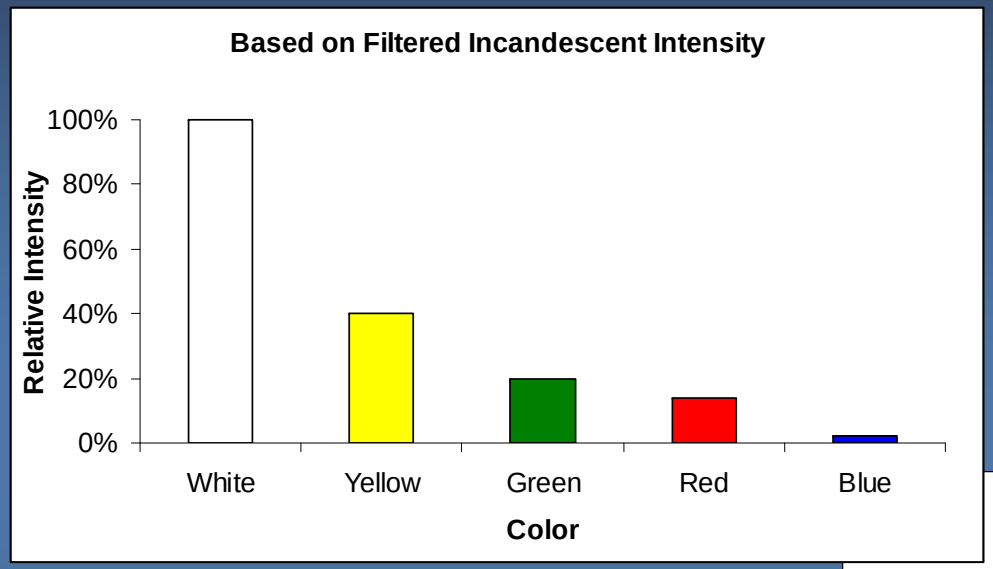


Chromaticities of several LED and incandescent aviation signal lights

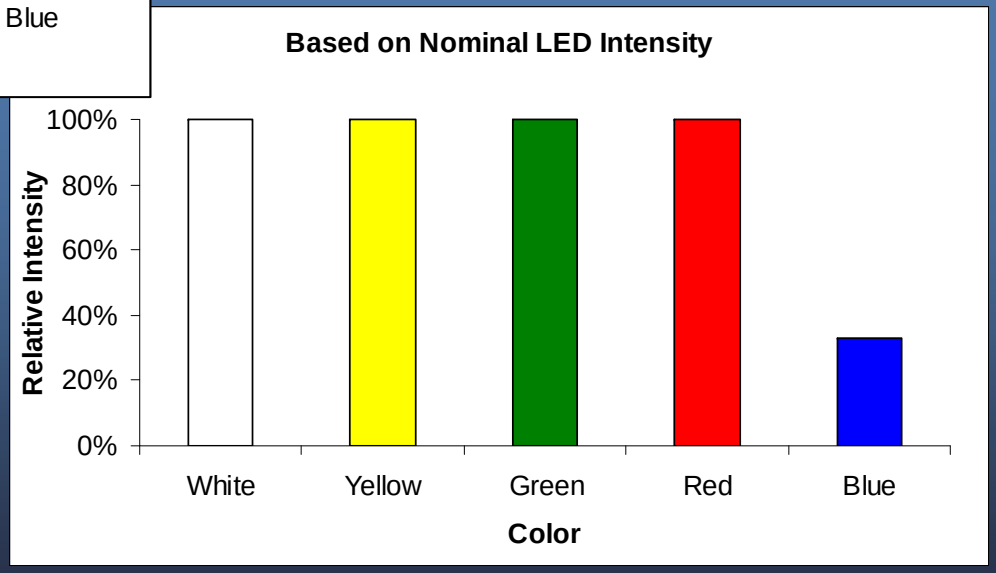
- Based on FAA-supplied data or LRC measurements of FAA-supplied units



Relative luminous intensities of LED and incandescent aviation signal lights

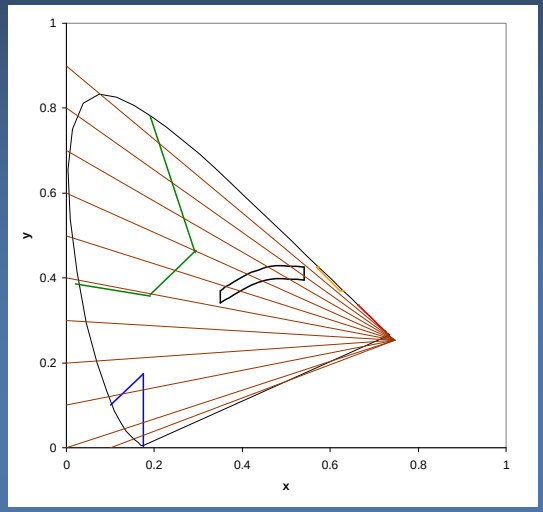


normalized for
equal input power



Implications of chromaticity and intensity differences

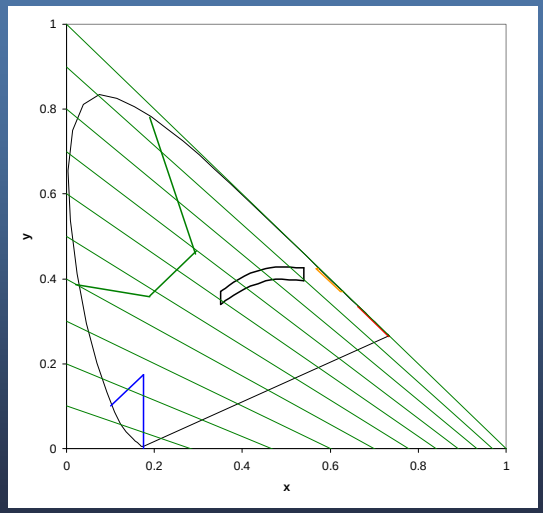
- Greater saturation → improved color identification (CIE 1994)
- Small intensity differences with LEDs of equal nominal power
  - Could provide less information to color-deficient observers who might rely on intensity differences to distinguish among colors falling along confusion lines



protans:

~2% of male population

(missing/ different "red" cone pigment)



deutans:

~6% of male population

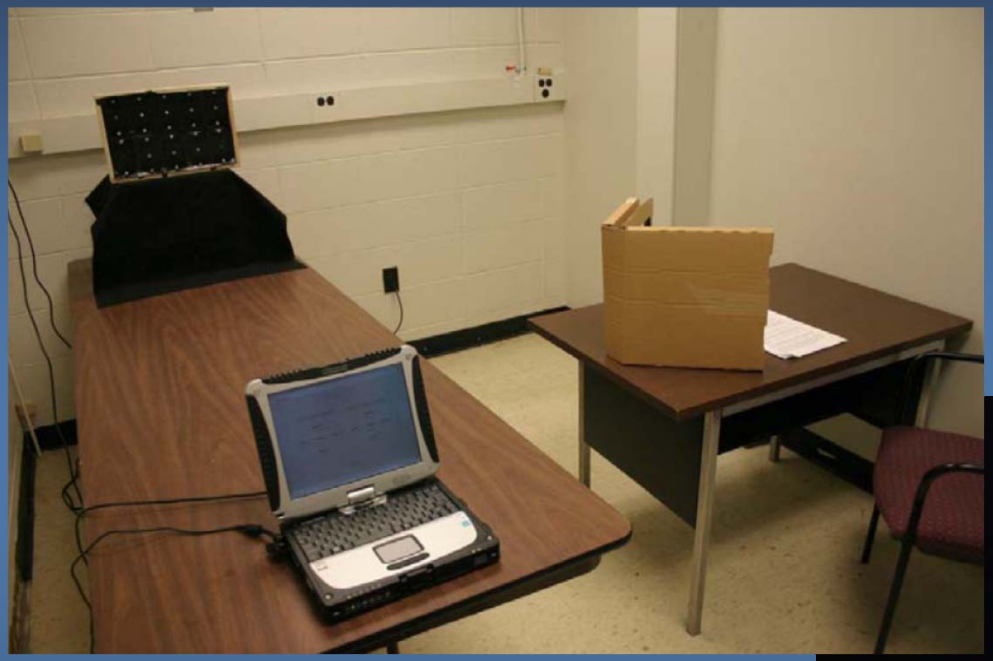
(missing/ different "green" cone pigment)

Method: Color identification study (Bullough, Skinner and Milburn 2011)

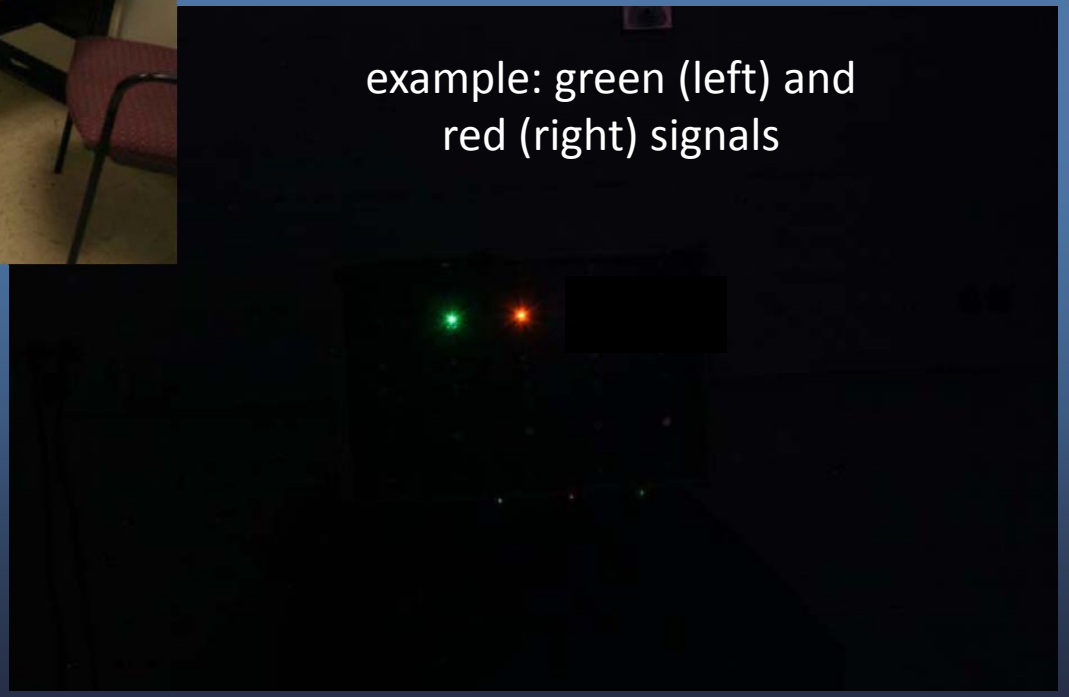
- Experimental subjects
  - Recruited through FAA Civil Aerospace Medical Institute (CAMI): ~half color-normal, ~half color-deficient
  - Color vision diagnosis provided by CAMI
  - Performance of signal light gun test as screen for color-deficient subjects (*excluded if failed*)
- Final tally: 29 color-normal (ave. age 27), 8 protan (ave. age 28), 13 deutan (ave. age 33)

Signal light gun test

Method: Color identification study (Bullough, Skinner and Milburn 2011)



Subjects viewed each color individually and in combination with each other color present, and had to identify the color of each signal presented; most subjects completed four repetitions of each color/light source combination



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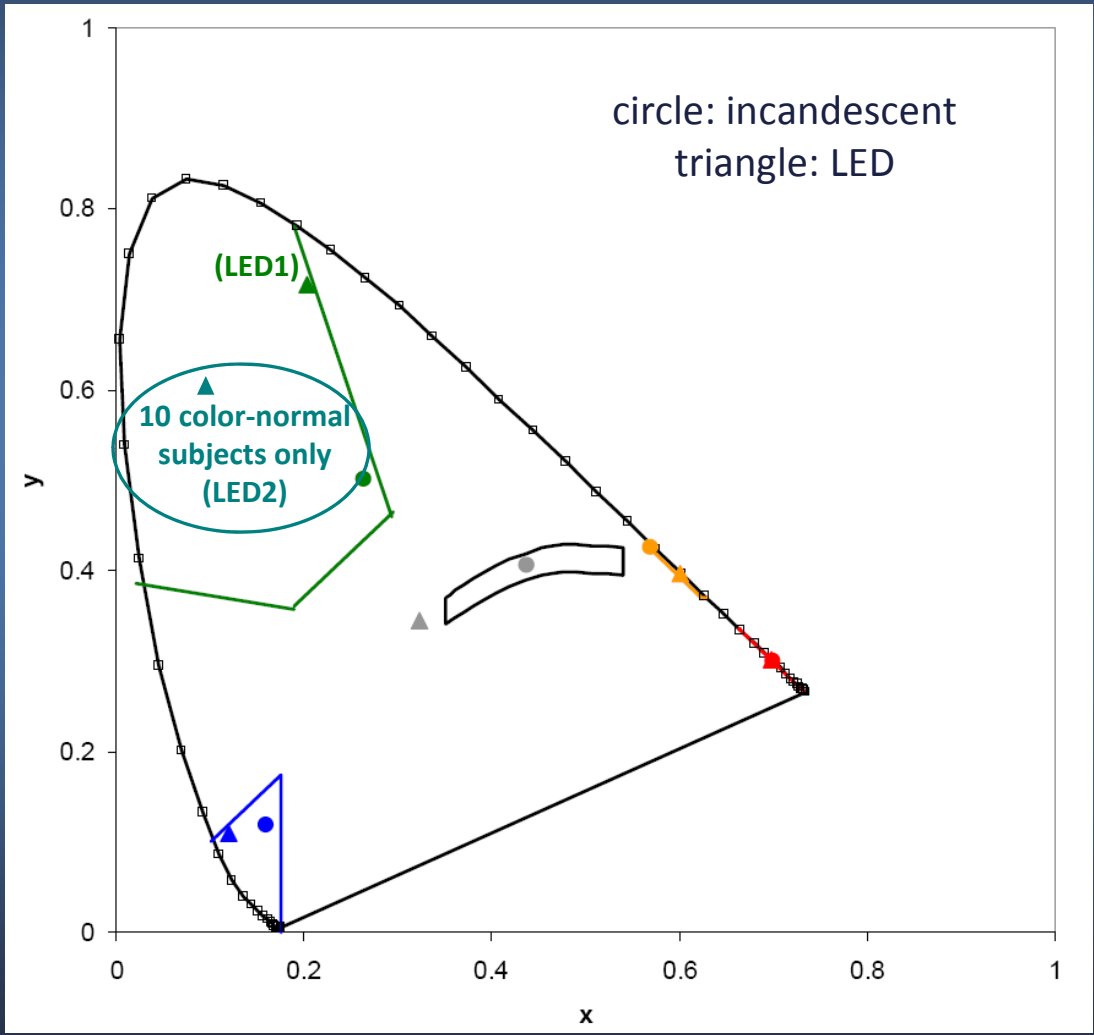
Method: Color identification study (cont'd.) (Bullough, Skinner and Milburn 2011)

Signal light chromaticities

(a second green LED chromaticity was tested for a group of color-normal observers only)



Method: Color identification study (cont'd.) (Bullough, Skinner and Milburn 2011)

Signal light intensities:

Incandescent

Color	Illuminance @ 2 m (mlx)	Equivalent Luminous Intensity @ 100 m (cd)	Equivalent Luminous Intensity @ 1 km (cd)
White	13.4	134	13,400
Yellow	5.8	58	5800
Red	1.8	18	1800
Blue	0.2	2	200
Green	2.8	28	2800

LED: Variable Drive (Incandescent Mimic)

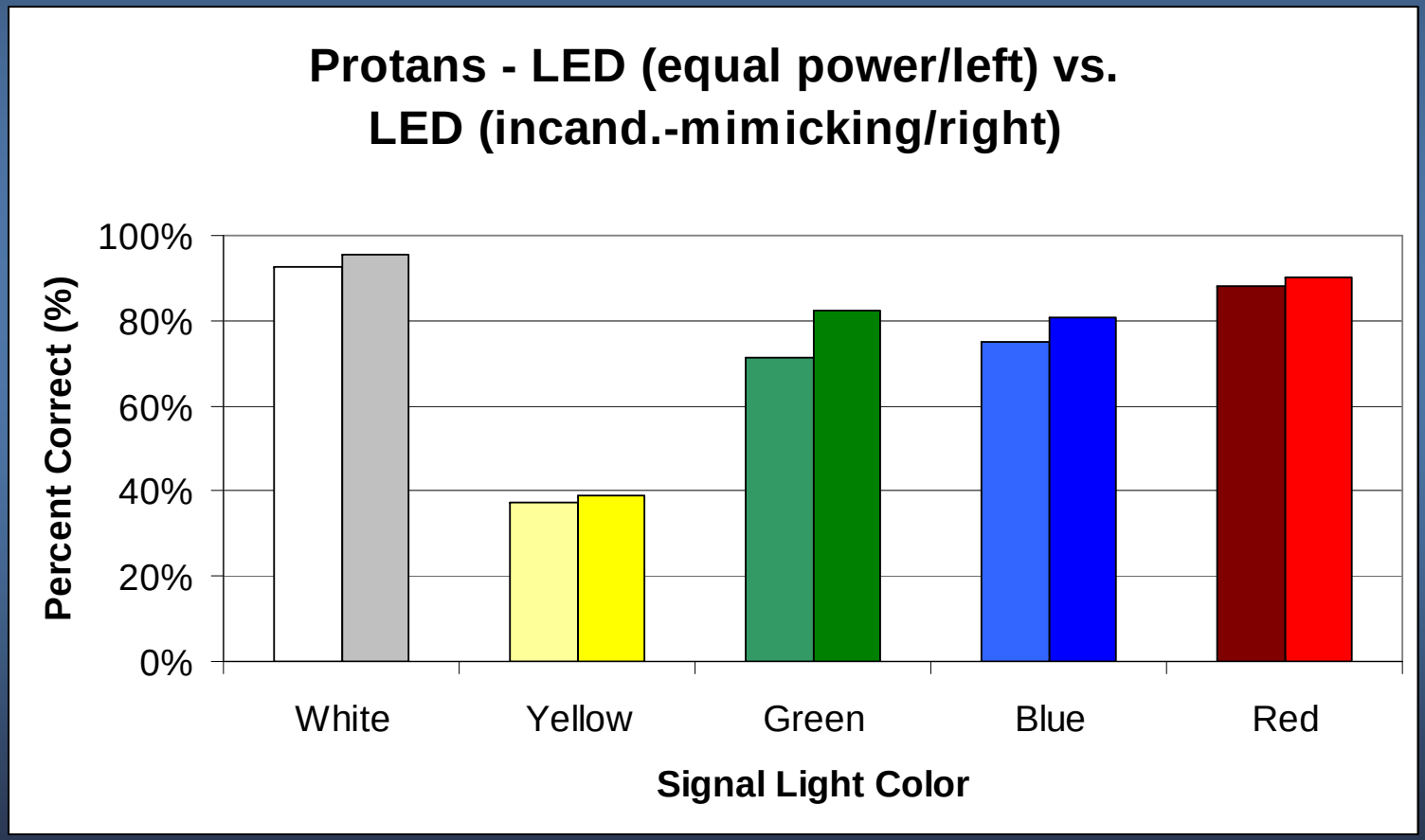
Color	Illuminance @ 2 m (mlx)	Equivalent Luminous Intensity @ 100 m (cd)	Equivalent Luminous Intensity @ 1 km (cd)
White	13.9	139	13,900
Yellow	5.6	56	5600
Red	1.9	19	1900
Blue	0.2	2	200
Green	2.8	28	2800

LED: Constant Drive

Color	Illuminance @ 2 m (mlx)	Equivalent Luminous Intensity @ 100 m (cd)	Equivalent Luminous Intensity @ 1 km (cd)
White	8.3	83	8300
Yellow	7.5	75	7500
Red	8.3	83	8300
Blue	2.8	28	2800
Green	8.3	83	8300

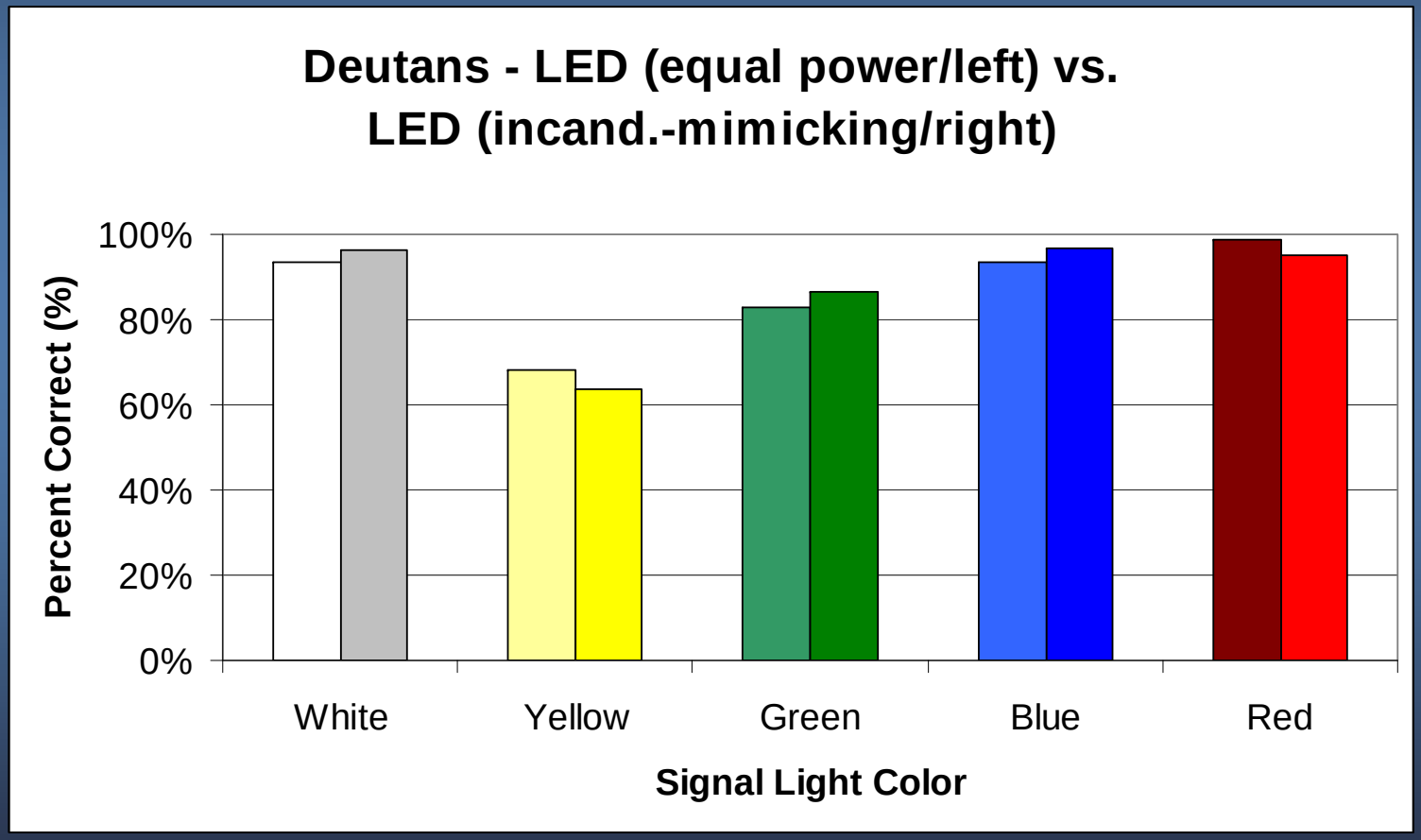
Results: Intensity differences and Protans (Bullough, Skinner and Milburn 2011)

Intensity differences made little difference for Protan observers

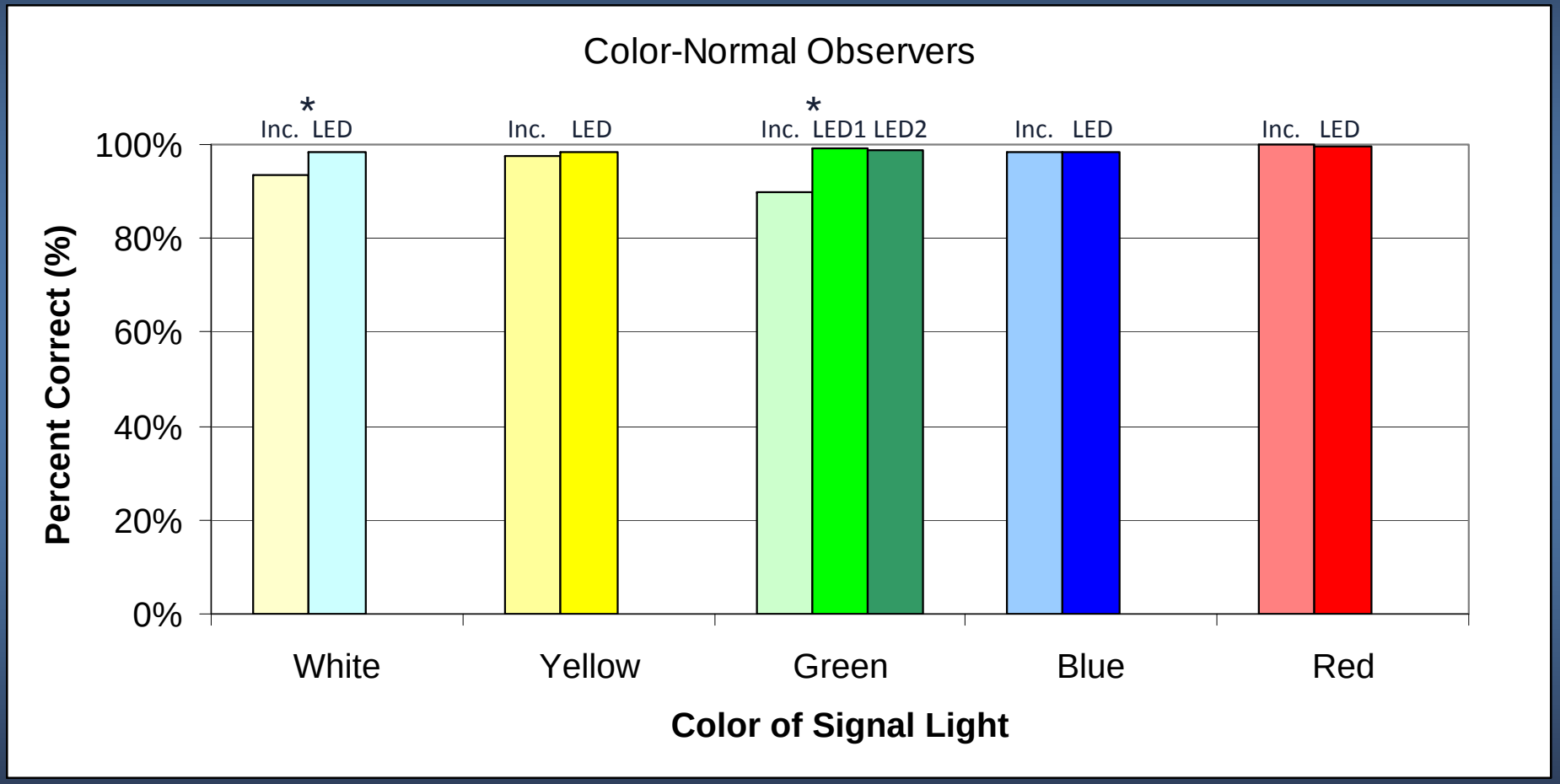


Results: Intensity differences and Deutans (Bullough, Skinner and Milburn 2011)

Intensity differences made little difference for Deutan observers

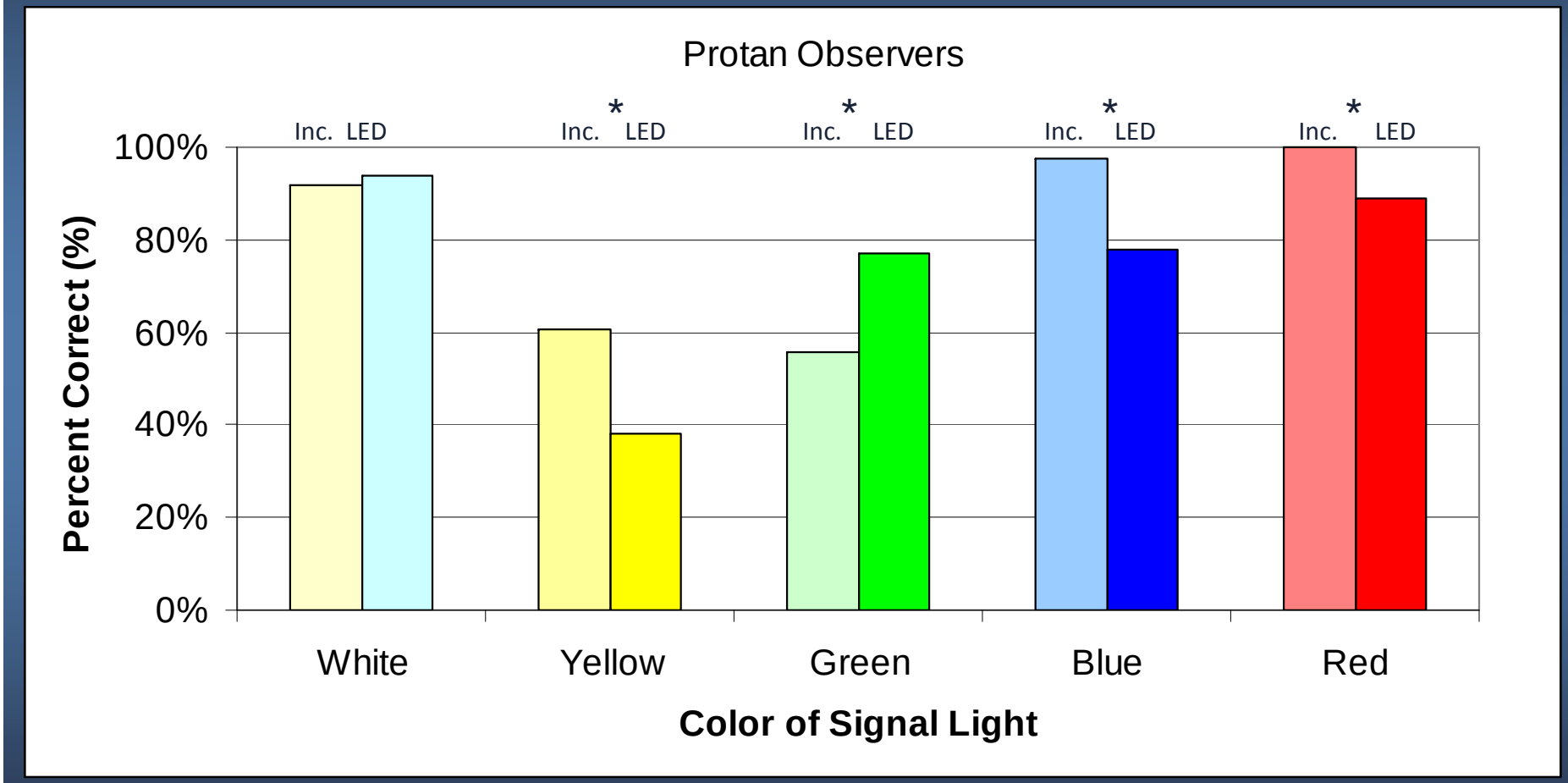


Results: LED vs. Incandescent, Color-Normal Observer (Bullough, Skinner and Milburn 2011)



**Statistically significant ($p<0.05$, Fisher's exact test) difference between incandescent and LED sources.*

Results: LED vs. Incandescent, Protan Observer (Bullough, Skinner and Milburn 2011)



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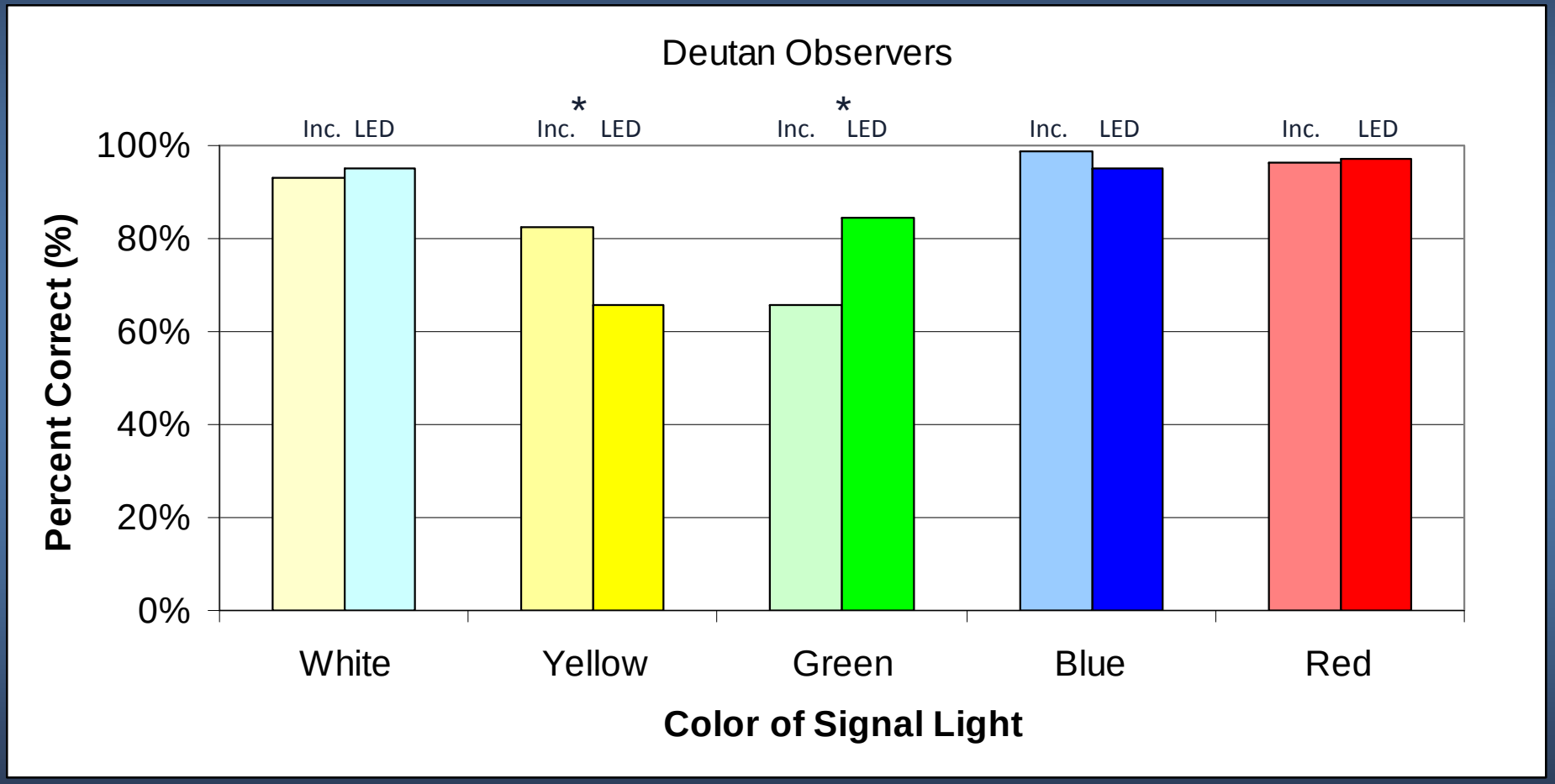
Results: LED vs. Incandescent, Deutan Observer (Bullough, Skinner and Milburn 2011)



**Statistically significant ($p<0.05$, Fisher's exact test) difference between incandescent and LED sources.*

Summary of results: Color ID study (Bullough, Skinner and Milburn 2011)

- Color-normal subjects:
  - Identification improved with white and green (and cyan) LEDs
    - White: Incandescent sometimes called “yellow”
    - Green: Incandescent sometimes called “white”
- Color-deficient subjects:
  - Identification sometimes better, sometimes worse with LEDs
    - Green: Incandescent often called “white”
    - Yellow: LED often called “red”
    - Red: LED sometimes called “yellow” by protans
    - Blue: LED sometimes called “white” by protans
  - No effect of LED intensity (nominally equal or inc.-mimicking)

LEDs, color boundaries, and identification

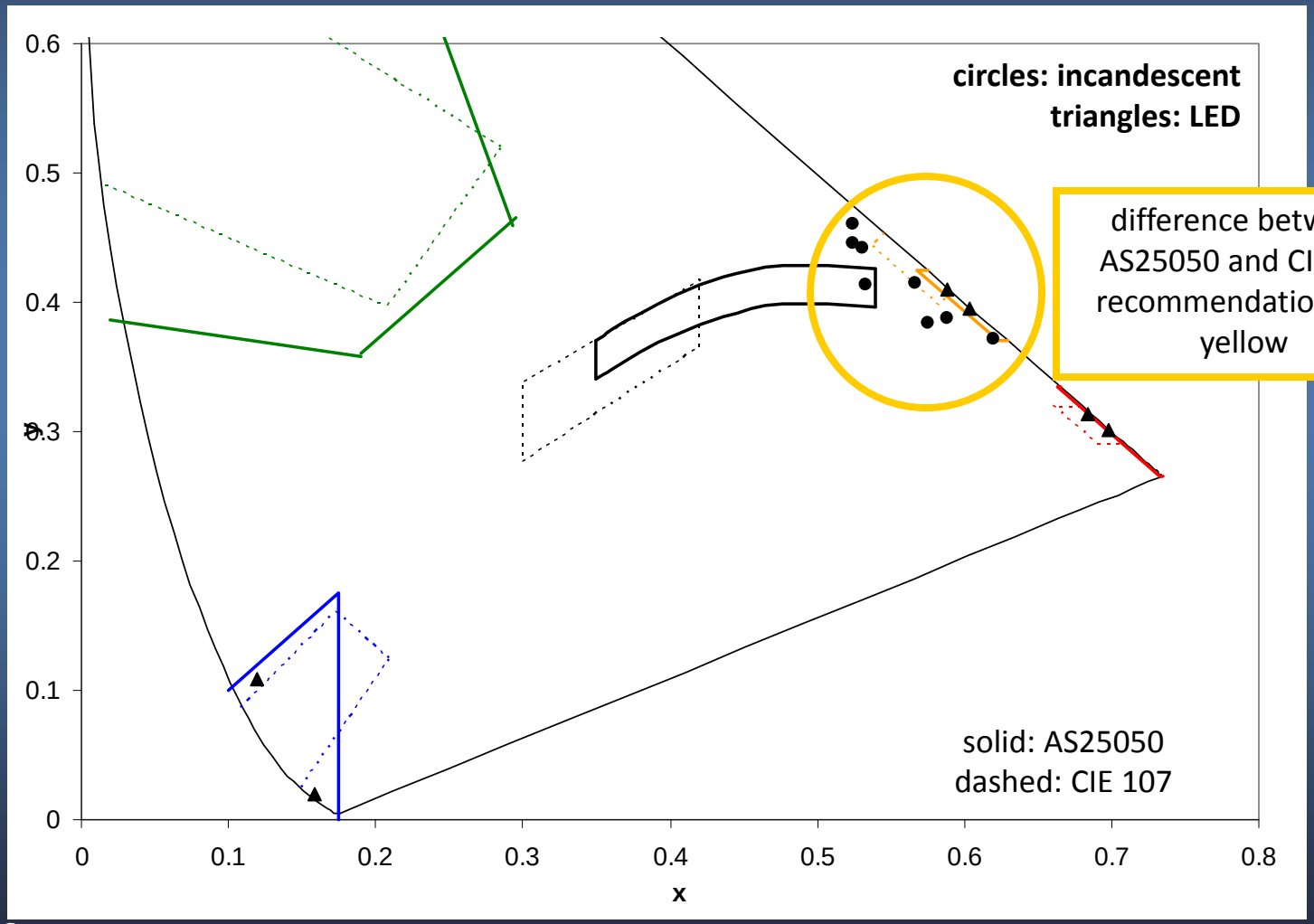
- White
  - Results confirm findings from Bierman, Skinner and Narendran (2009) suggesting white boundary can be extended toward “blue” without penalty
- Green
  - “Green” (~525 nm) or “cyan” (~505 nm) LEDs are available
  - “Cyan” LEDs are further from yellow-red confusion lines
  - Results confirm that “cyan” LEDs are reliably identified by color-normal observers

LEDs, color boundaries, and identification

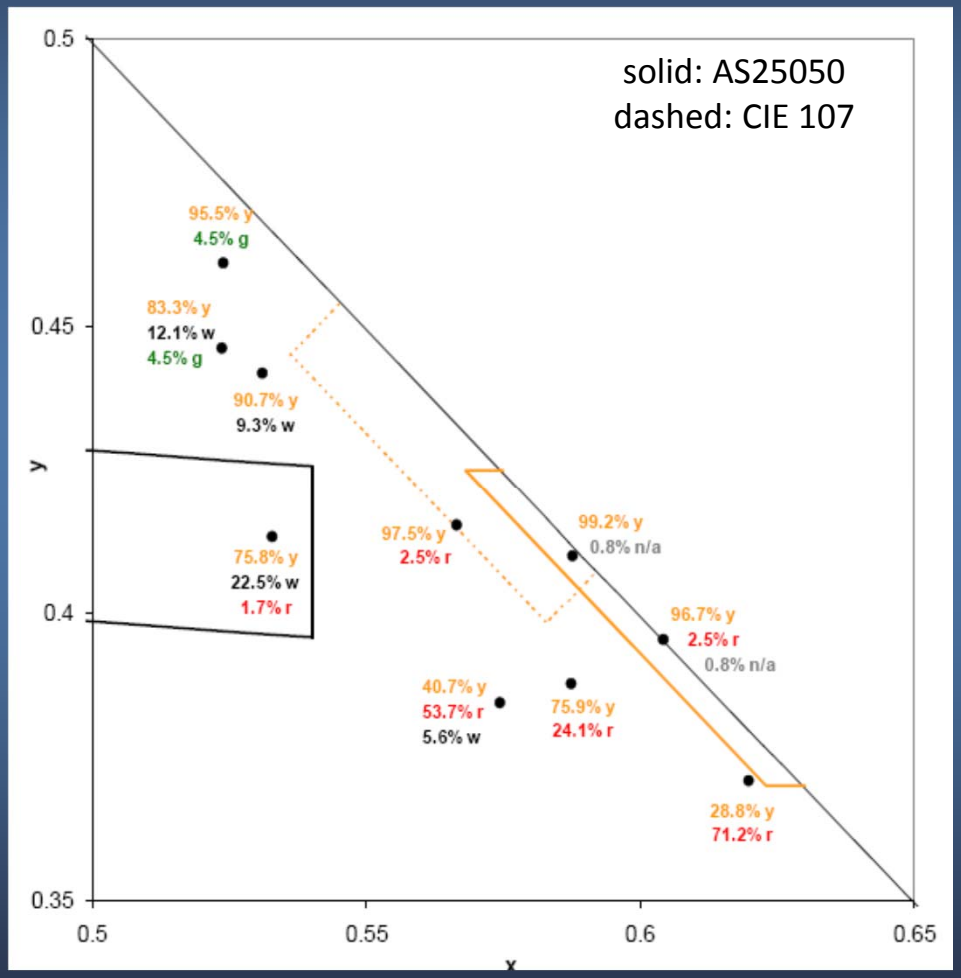
- Red
  - “Red” (~630 nm) or “red-orange” (~615 nm) LEDs are available
- Blue
  - “Blue” (~470 nm) or “royal blue” (~450 nm) LEDs are available
- Yellow
  - Longer-wavelength yellow seems more prone to mis-identification as “red”
  - AS25050 yellow box is shifted toward “orange” compared to CIE (1994) recommendations and ICAO (2009) requirements

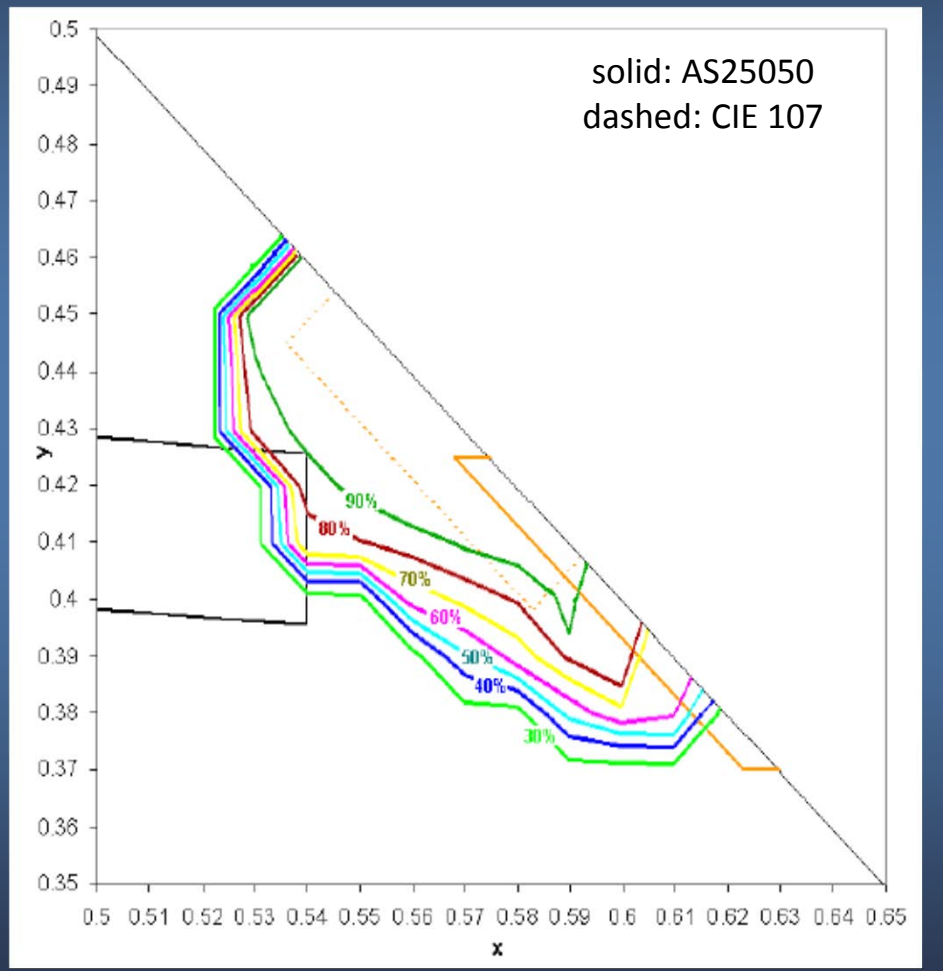
Method: Red/yellow/blue LED study (Bullough, Skinner and Taranta 2011)

Same apparatus as previous experiment; 20 color-normal subjects (ave. age 45)

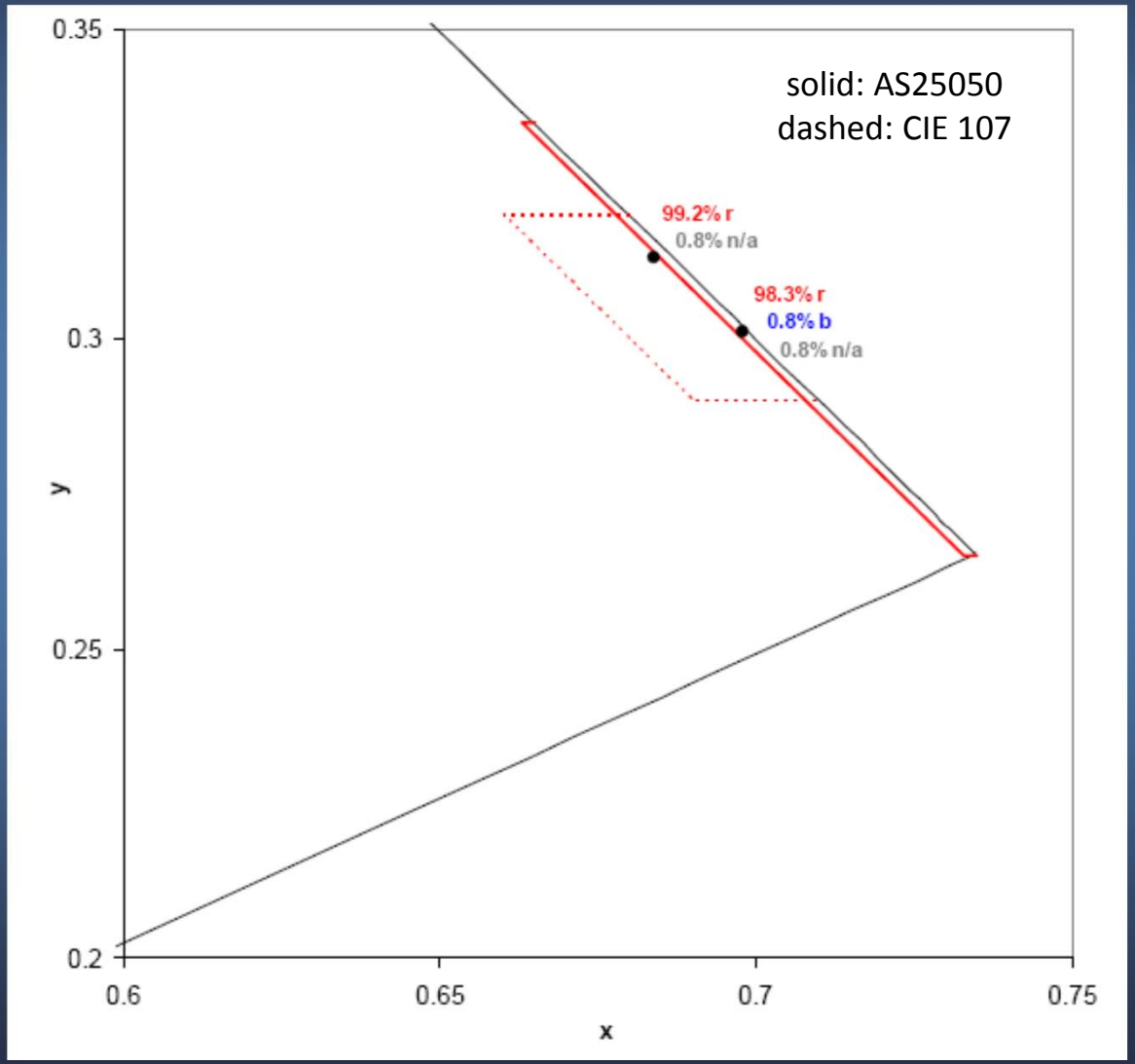


Results: Yellow color identification (Bullough, Skinner and Taranta 2011)

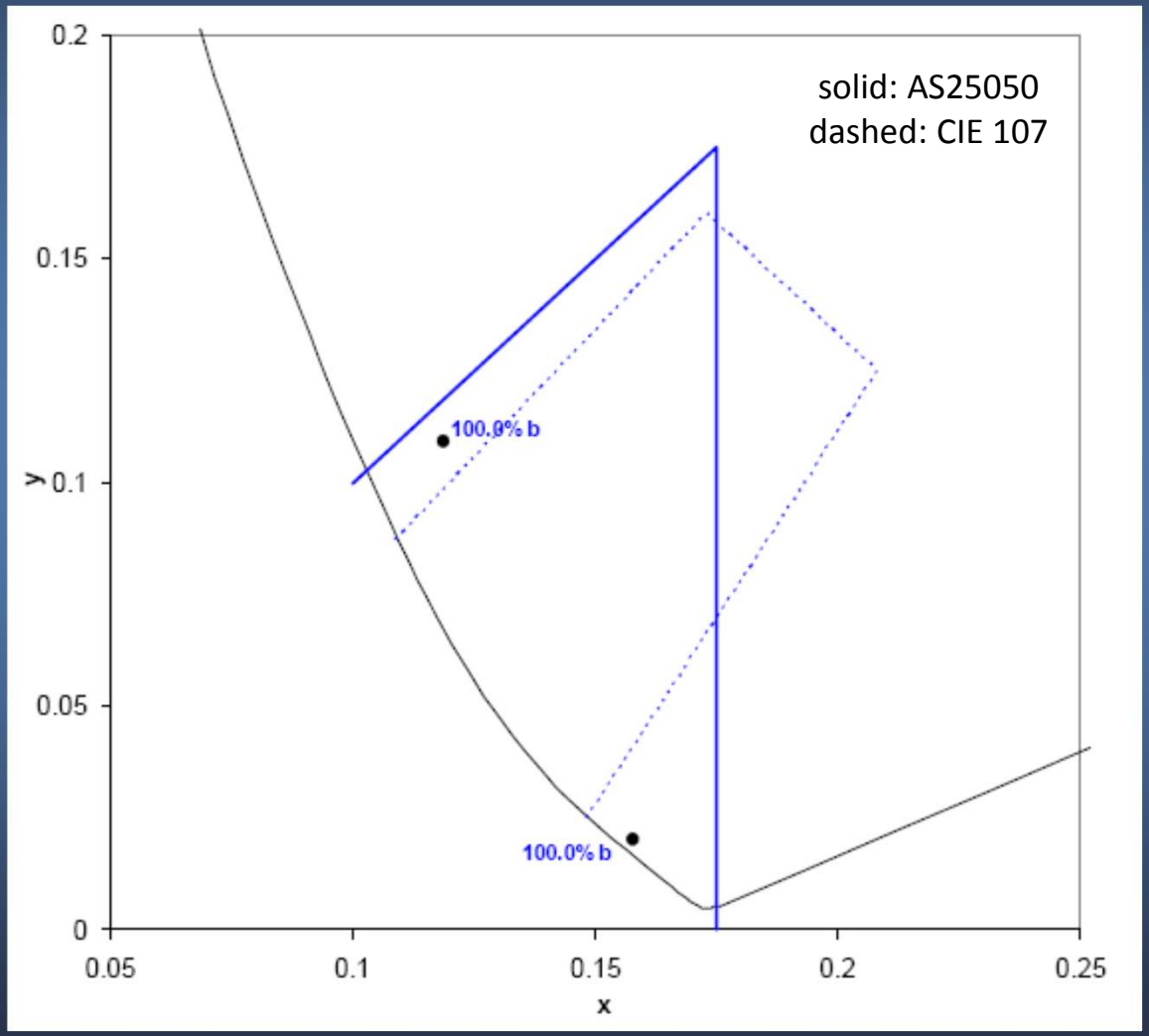




Results: Red color identification (Bullough, Skinner and Taranta 2011)



Results: Blue color identification (Bullough, Skinner and Taranta 2011)



Summary: Yellow/red/blue study (Bullough, Skinner and Taranta 2011)

- Long-wavelength portion of SAE AS25050 yellow chromaticity region may be prone to identification as red
  - If shift toward “orange” is to minimize confusion with dimmed white incandescent, LEDs do not require such a shift
- No issues found with red (~630 nm) or red-orange (~615 nm) LEDs, nor with blue (~470 nm) or royal-blue (~450 nm) LEDs

Discussion

- LEDs do not present any problems for color-normal observers
  - Color identification is improved for white and green/cyan LEDs and never worse for any other color
- White and green LEDs also improve color identification for color-deficient observers
- Intensity differences are relatively unimportant for color identification by color-deficient observers
- Long-wavelength yellow lights may be problematic for color-normal and color-deficient observers

Discussion

- Both “red” and “red-orange” LEDs fall within AS25050, CIE 107 and ICAO Annex 14 recommendations, and are reliably identified as red
  - Extending red boundary region beyond ~650 nm seems unnecessary
- “Blue” and “royal blue” fall within AS25050 and ICAO Annex 14 (but not CIE 107) boundaries, and are reliably identified as blue
  - Extending blue boundary region shorter than ~450 nm may not provide any additional benefit

Acknowledgments

- Studies sponsored by Federal Aviation Administration (FAA): FAA/05-C-AT-RPI and 2010-G-013
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Thank you.