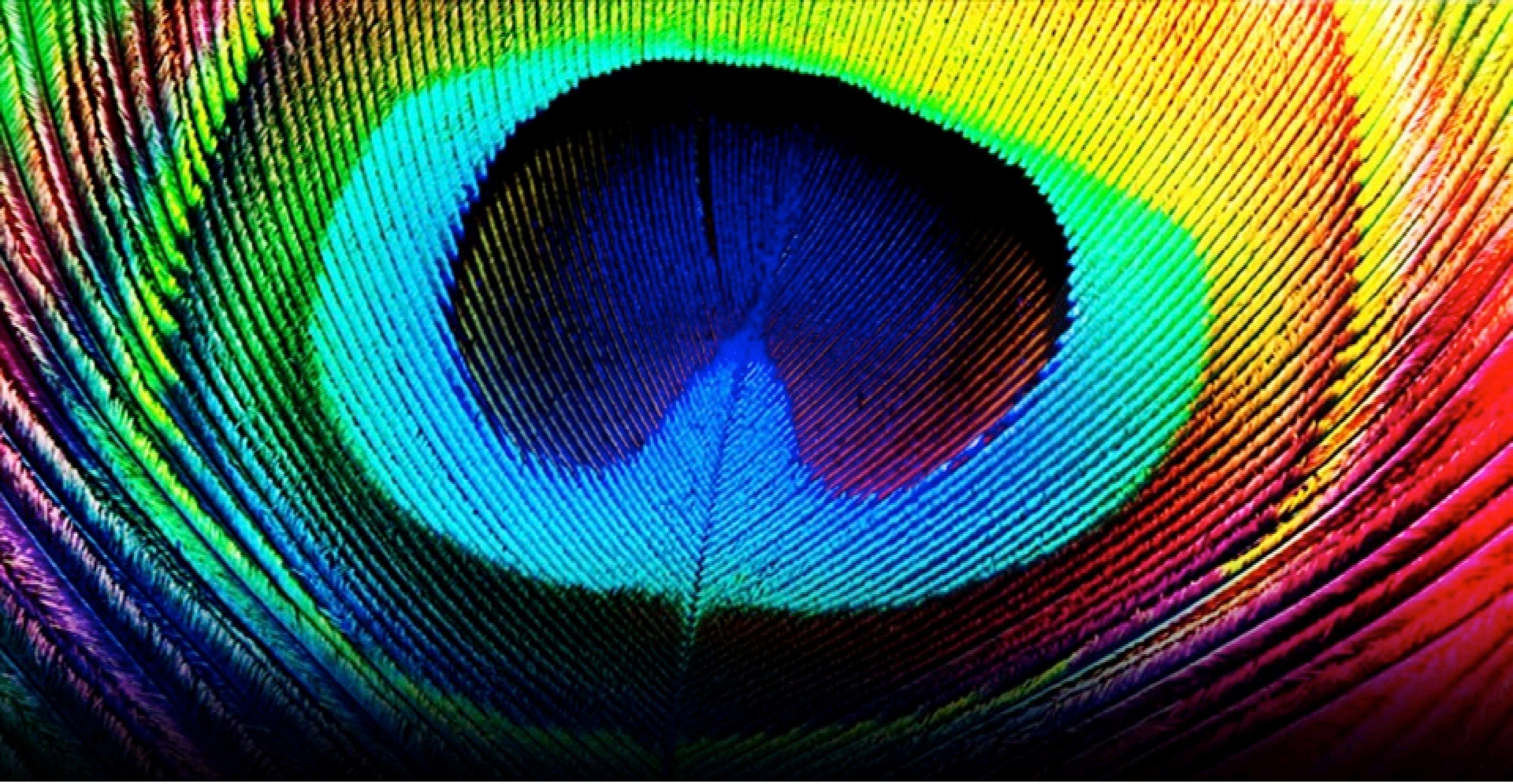


Achieving BT. 2020 Color Gamut – Quantum Dots vs. Lasers

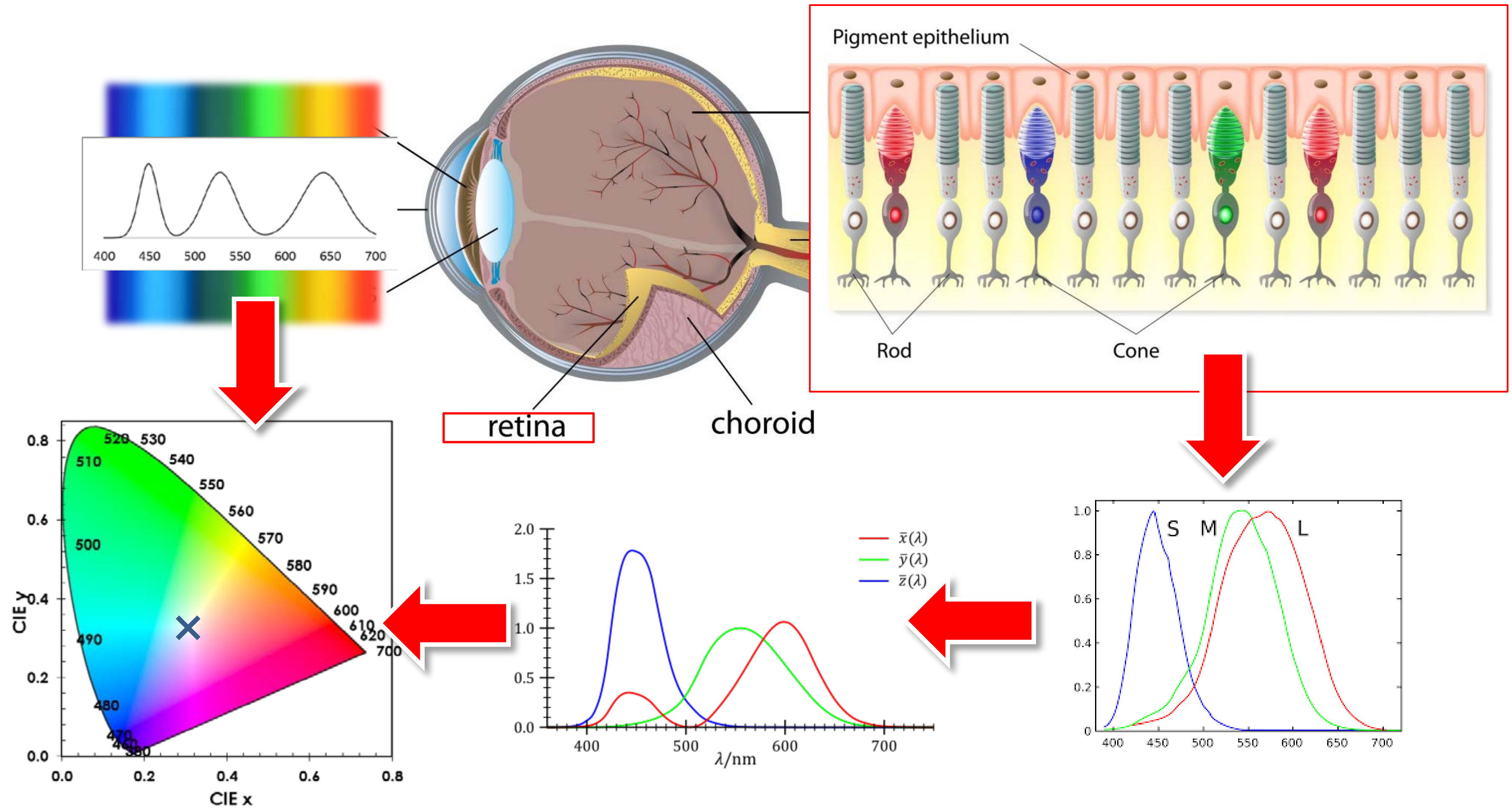
March 2016 Bay Area SID Conference

24.03.2016

Product Marketing Manager, John Ho

jho@qdvision.com

Color is a Psychovisual Perception Detected By Our Eyes

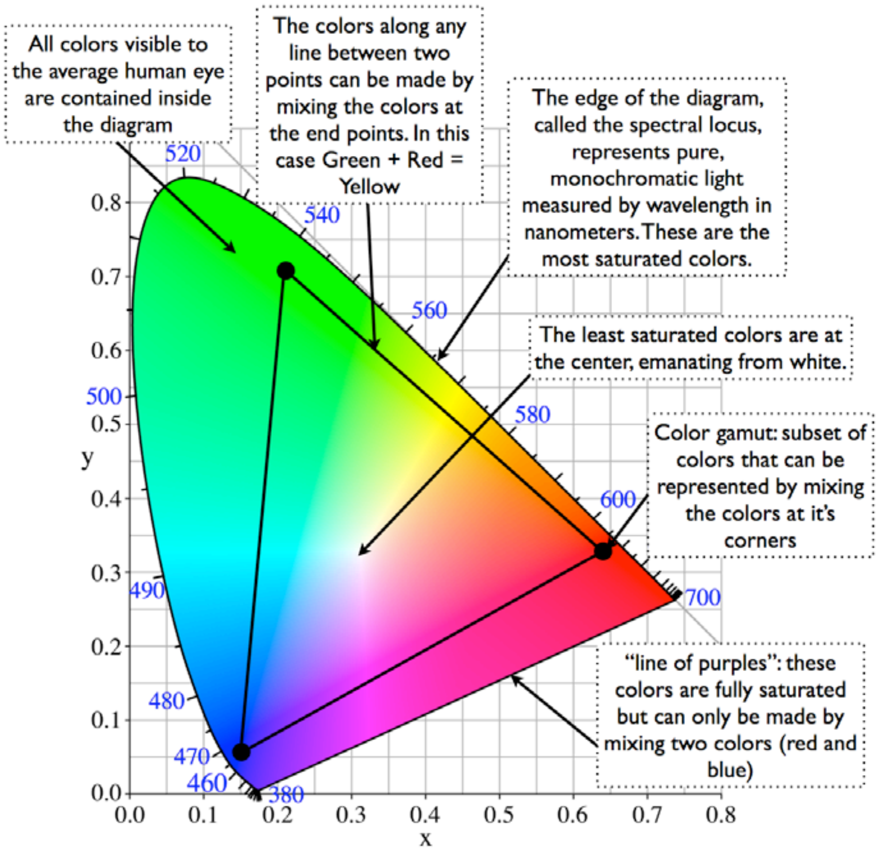


1931 CIE xyY

Color matching functions

Cone Response Curves

CIE 1931 – "The Horseshoe Diagram"

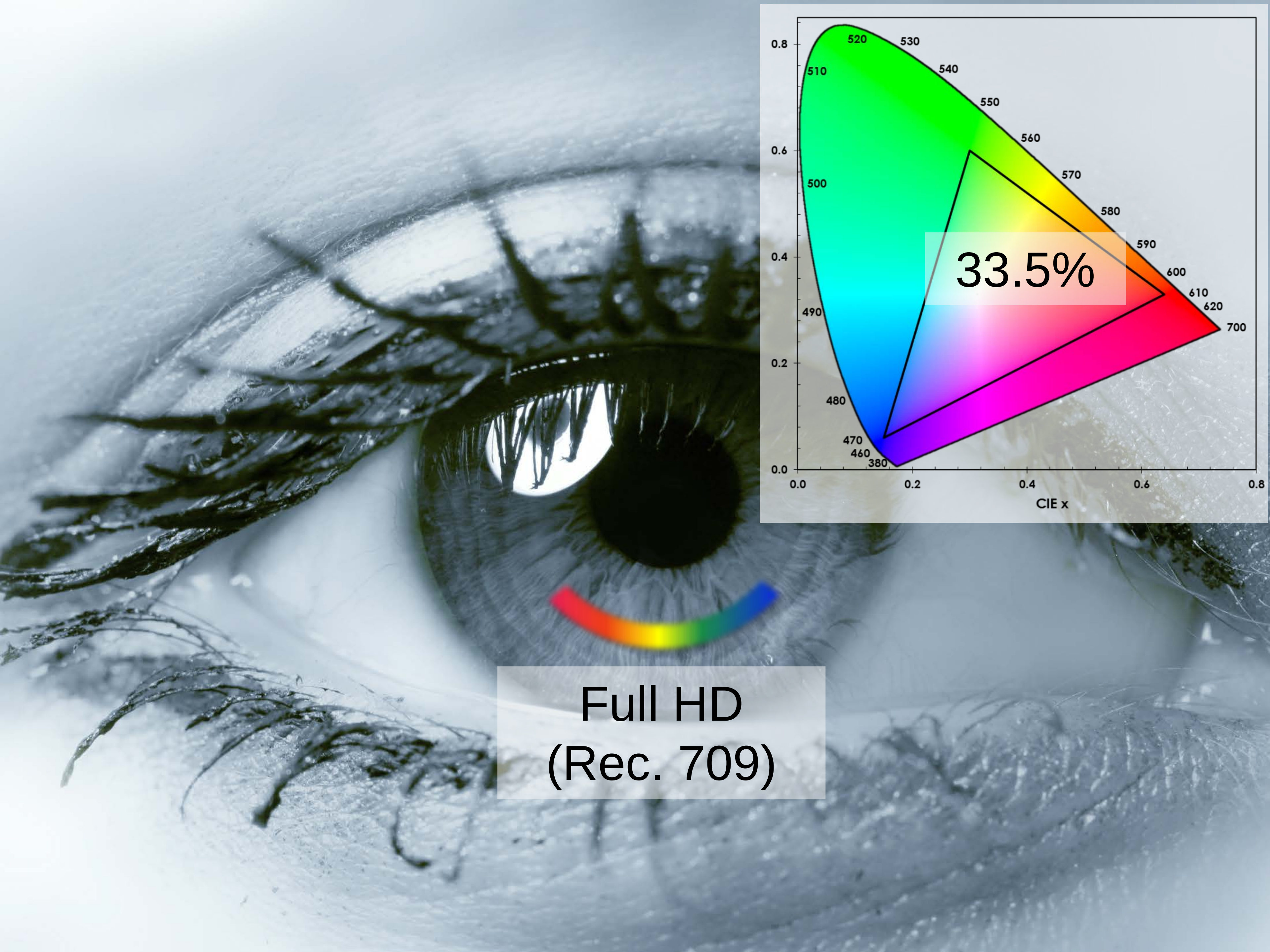


Anatomy of a CIE Chromaticity Diagram

Source: Nanosys

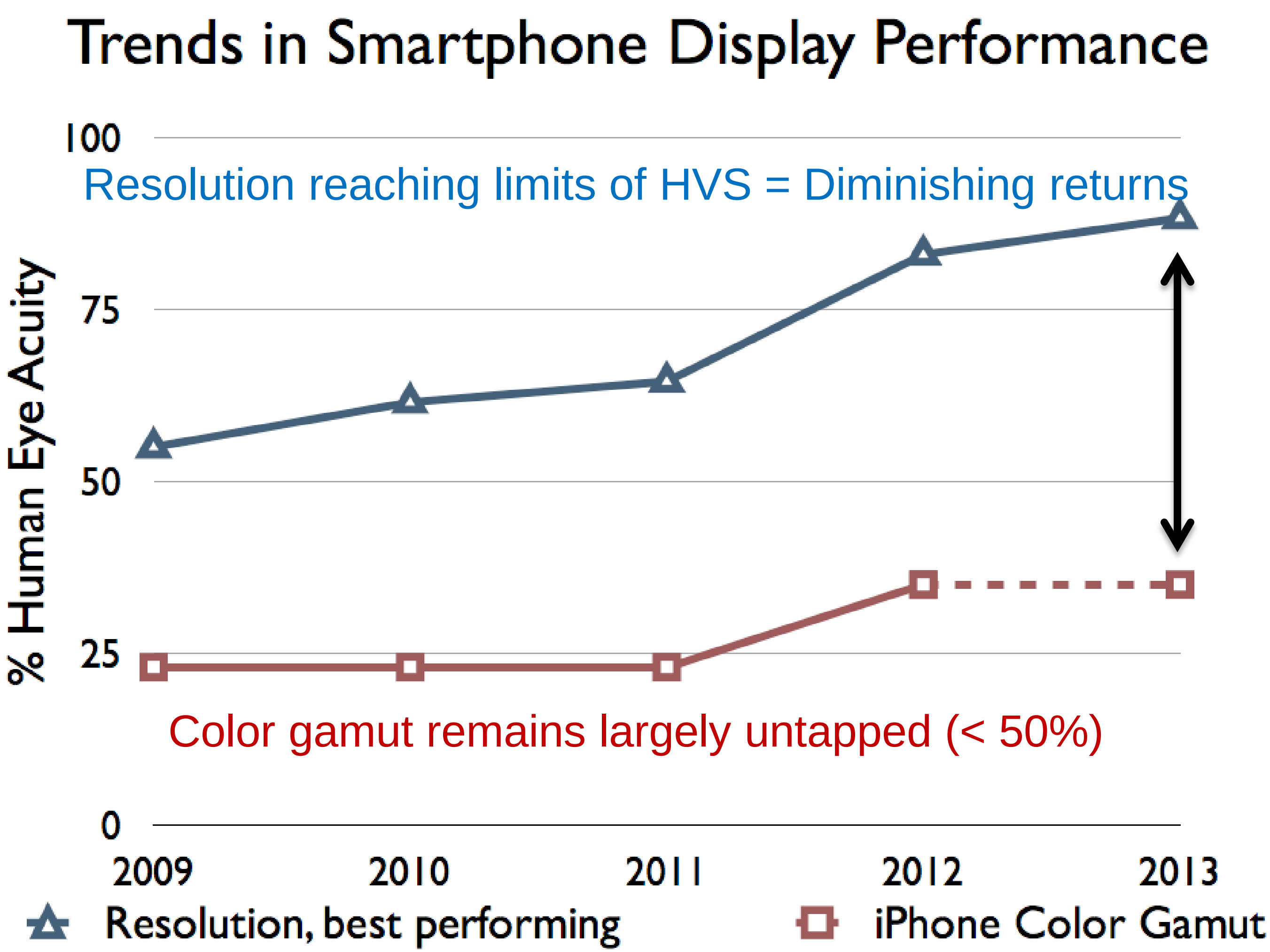
<u>Takeaways:</u>

- Represents range of human color perception
- Spectral locus, represents pure, monochromatic light (i.e. saturated colors)
- Conversely, desaturated colors are in the center of the horseshoe with white in the middle
- RGB display primaries form vertices of color gamut triangle



33.5%
Full HD
(Rec. 709)
CIE x
0.0
0.2
0.4
0.6
0.8
380
460
470
480
490
500
510
520
530
540
550
560
570
580
590
600
610
620
700

Increasing Resolution - Diminishing Returns

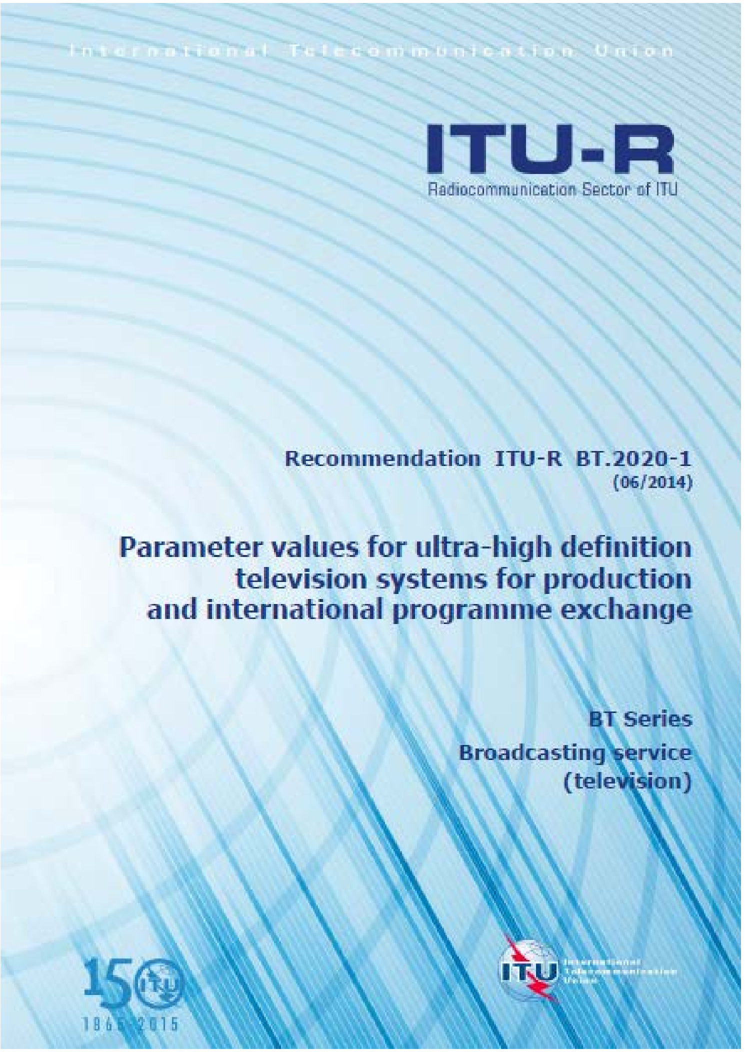


Source: Nanosys

Rec. 2020 is Happening Now: Creation, Delivery, Displays

Adobe
VESA
Walt Disney Pictures
CHRISTIE
BARCO
Visibly yours
SIGMA DESIGNS
3M
DP DIGITAL PROJECTION
NHK
ARRI
ITU
Consumer Technology Association
DIVX
Google
SONY
AVID
BBC
Canon
SHARP
ULTRA HD Blu-ray
Warner Bros. Pictures
VIZIO
DOLBY VISION
NETFLIX
MHL
UHD ALLIANCE

What is Rec. 2020?


International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R BT.2020-1
(06/2014)

Parameter values for ultra-high definition television systems for production and international programme exchange

BT Series
Broadcasting service (television)

150 ITU 1865–2015

ITU International Telecommunication Union

ITU-R Recommendation BT. 2020 (“Rec. 2020”):

- Approved in 2012 by ITU-R
- Standard for broadcast “UHD-TV”
- Picture format/container for program interchange (same as Rec. 709)
- Includes system colorimetry

TABLE 3

System colorimetry

Parameter	**Values**		
Opto-electronic transfer characteristics before non-linear pre-correction	Assumed linear(1)		
Primary colours and reference white(2)	Chromaticity coordinates (CIE, 1931)	x	y
	Red primary (R)	0.708	0.292
	Green primary (G)	0.170	0.797
	Blue primary (B)	0.131	0.046
	Reference white (D65)	0.3127	0.3290

(1) Picture information can be linearly indicated by the tristimulus values of RGB in the range of 0-1.

(2) The colorimetric values of the picture information can be determined based on the reference RGB primaries and the reference white.

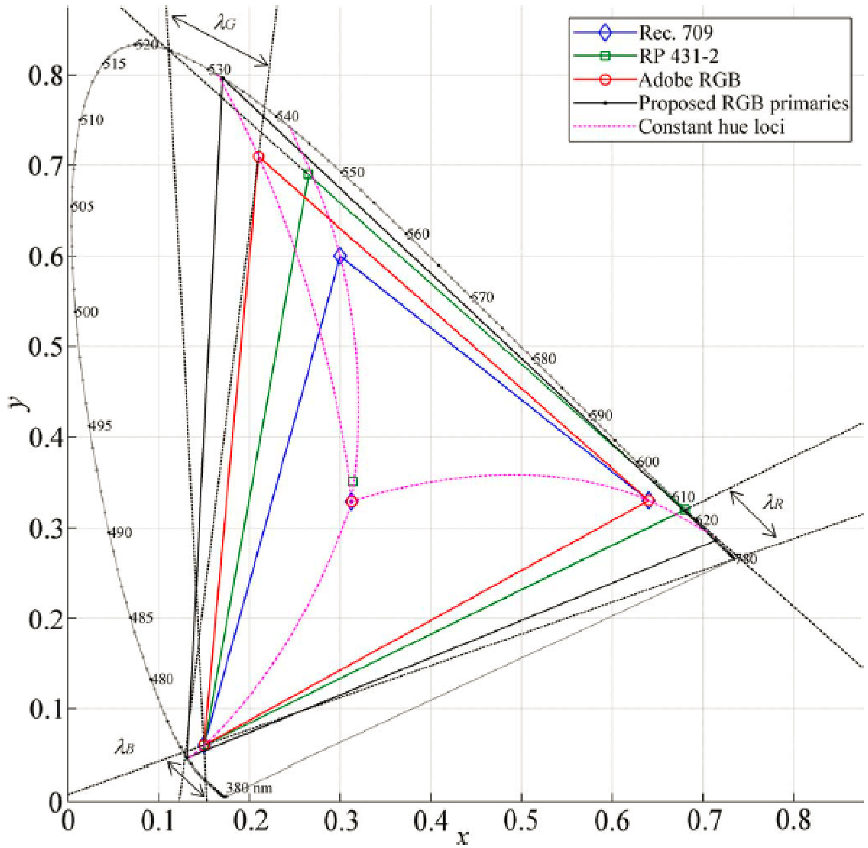
QD VISION

COLOR IQ BY QD VISION

What is Rec. 2020 color?

Rec. 2020 RGB primaries:

- Based on NHK's Super Hi-Vision
  - Preserves hue of primaries with smaller gamuts
  - Intended for RGB lasers
  - Covers ~100% of Pointer's Gamut
- The widest TV color gamut standard with physical primaries
  - RGB primaries equivalent to monochromatic light (467nm, 532nm, 630nm)
  - No imaginary or negative RGB colors

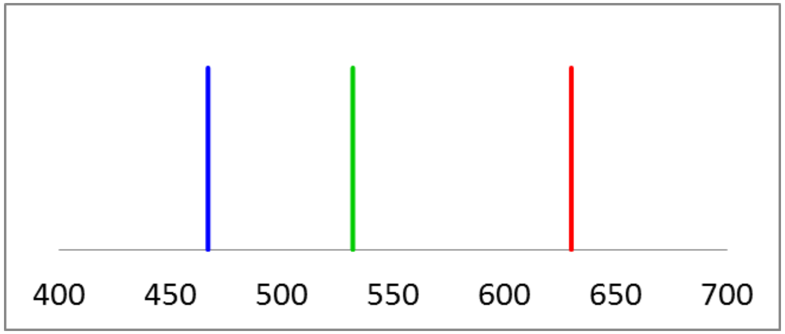


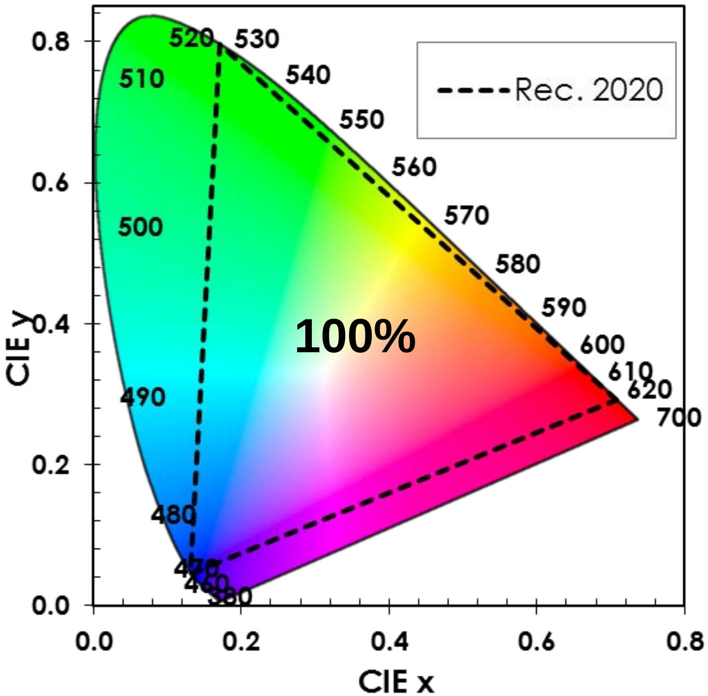
Source: Masaoka et. al., IEEE Transactions on Broadcasting, Vol. 56, No. 4, 2010

How to Achieve Maximum Overlap of Rec. 2020?

- Full gamut can only be achieved in theory
  - What does BT. 2020 compliance mean?
- Primaries originally developed by NHK:
  - Covers all existing gamut standards and real object colors
  - Compatible with potential laser wavelengths
  - Located on loci of constant hue

Theoretical Maximum

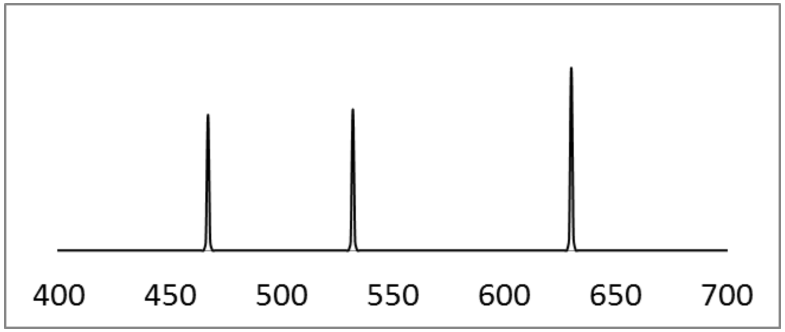


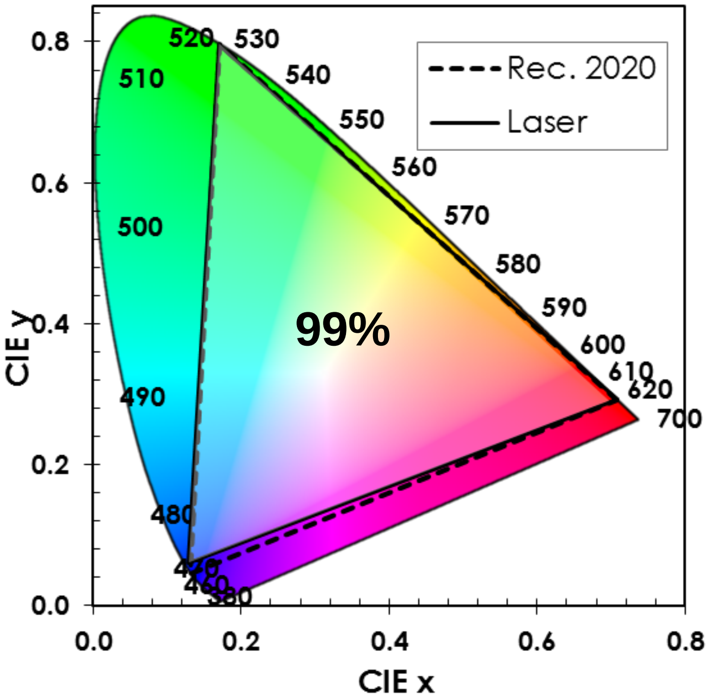


How to Achieve Maximum Overlap of Rec. 2020?

Lasers provide best performance, but are not practical

- Full gamut nearly achieved
- Speckle and observer metamerism remain key technical challenges
- Prohibitive cost/complexity

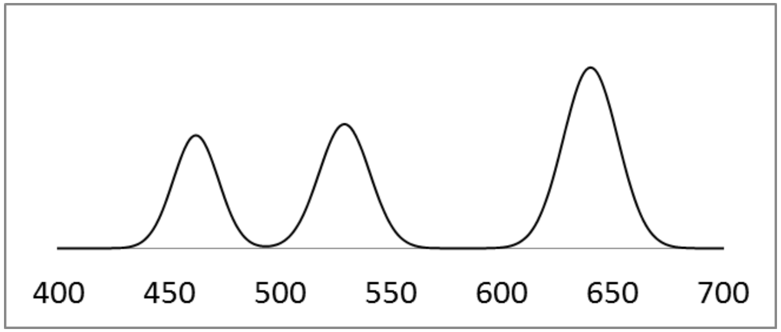


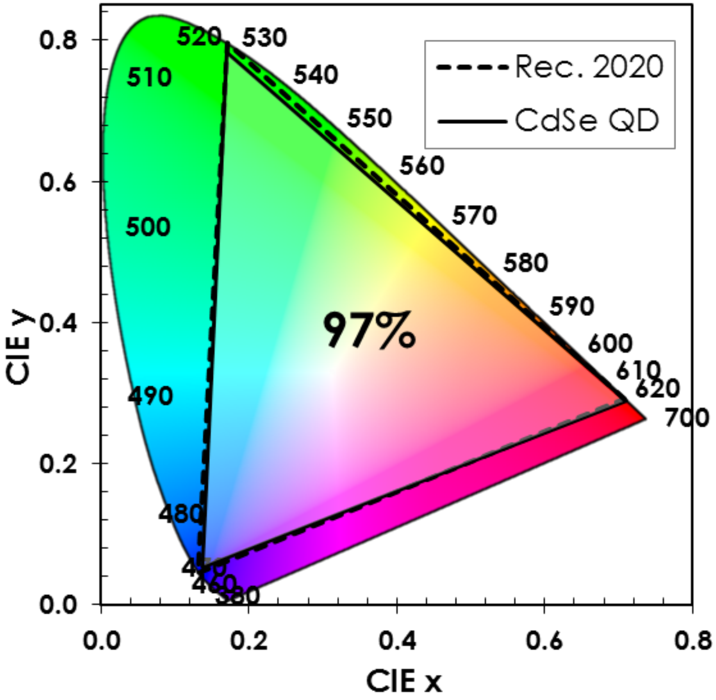


How to Achieve Maximum Overlap of Rec. 2020?

CdSe QD primaries yield best path to Rec. 2020 overlap

- Assumes Ideal Color Filters and 25 nm FWHM QDs
- In practice, only ~93% gamut coverage achieved due to blue and green color filter leakage
- Getting to visually indistinguishable coverage of BT. 2020 requires covering ~97% of gamut





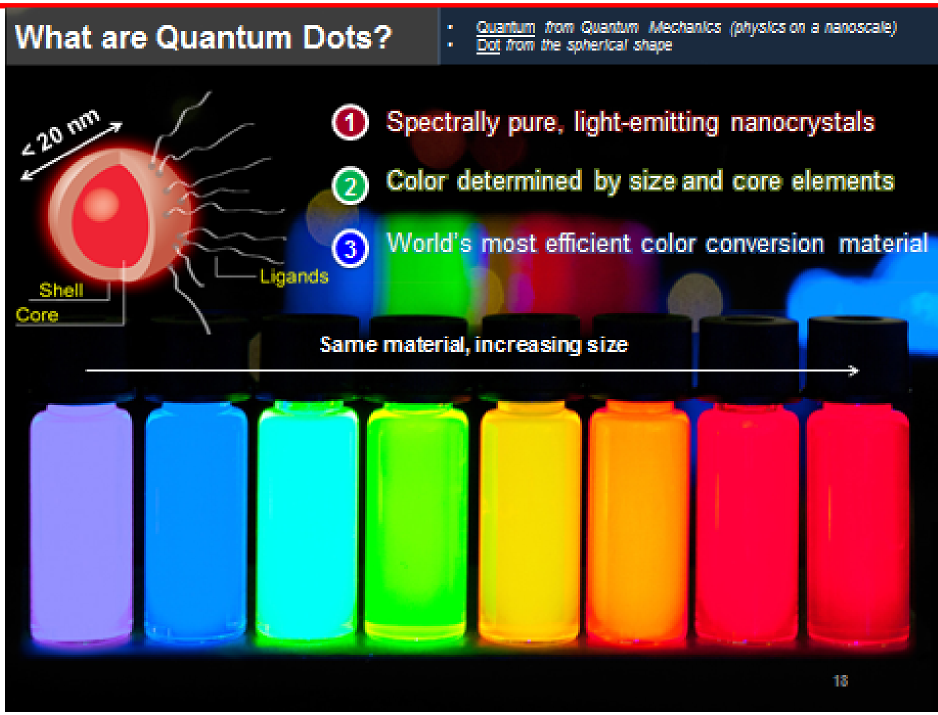
Rec. 2020 Implementations in Common Display Technology

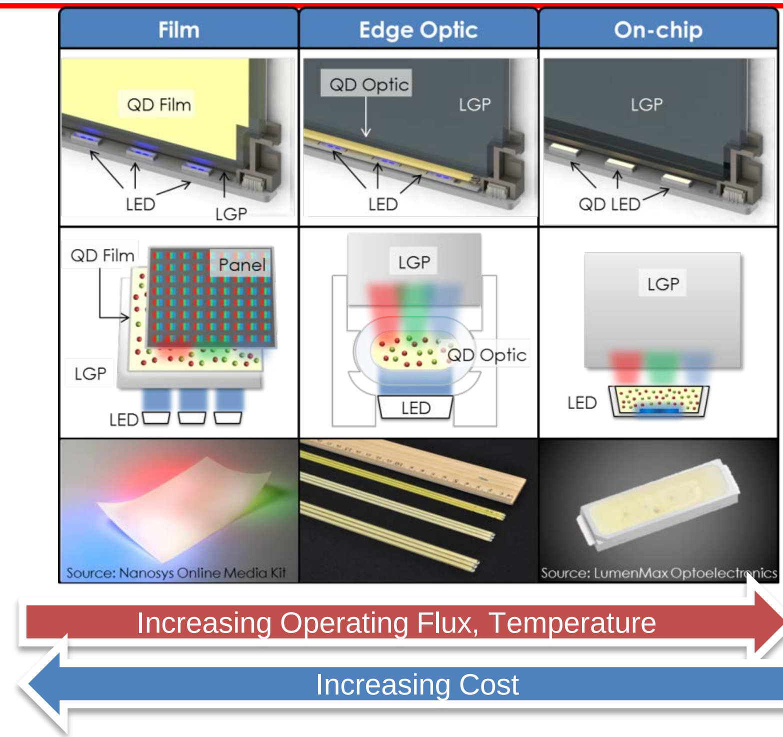
>90% Rec. 2020 requires either laser or CdSe backlight technology

			Rec. 2020			
Display Technology	**Category**	**Model**	**xy area**	**xy overlap**	**u'v' area**	**u'v' overlap**
CdSe QD	Product	TCL 65H9700	81%	81%	84%	84%
InP QD	Product	Samsung SUHD UN55JS9000	68%	68%	76%	76%
RGph	Product	AUO RS65-B2	65%	65%	72%	72%
RGph + notch filter	Product	Samsung SUHD UN55JS7000FXZA	69%	69%	75%	76%
WLED	Product	Samsung UN55HU6950	54%	54%	58%	58%
BG-Rph	Product	Dell U2713HB MNT	78%	78%	81%	82%
WOLED	Product	LG 55EC9300	62%	62%	66%	66%
R laser, Cyan LED	Product	Philips 8900 series	87%	?	?	?
CdSe QD	Demo	LG 31MU97-B MNT (modified)	**92%**	**93%**	**94%**	**94%**
RGB Laser Backlight	Demo	Mitsubishi 50" TV	**98%**	?	?	?

Reduced green and blue color filter leakage is necessary for high-spec Rec. 2020 displays

QDs and Rec. 2020





Benefits

- Most efficient down conversion material
- Spectrally narrow primaries (FWHM ~25 nm)
- Leverages existing LCD supply chain
- Cost effective
- Tunable primaries

Challenges

- *Potential for Observer Metameric Failure (OMF)*
- Regulatory barrier (Cadmium)
- Color filter materials
- Customer awareness
- Good enough color

RGB Lasers and Rec. 2020

Available Laser Primary Options

Source: Bill Beck

Color	Wavelength (nm – FWHM)	Device Type	Watts per Device	Lumens Per watt	Lumens per Device	*étendue*
	650 - 1	Diode	~1	73	73	med
	638 - 1	Diode; Bar	≤ 8	131	1,048	high
	615 - 8	DPSS + OPO	10	301	3010	low
	550 – 0.1	VCSEL SHG	2	679	1358	med
	546 - 12	DPSS wide spectrum	20-40	671	>20K	low
	532 – 0.1	DPSS; VCSEL; FL SHG	2-100	603	>60K	range
	525 - 2	Diode	1	542	542	med
	462 - 2	Diode	1	50	50	med
	445 - 2	Diode	3	20	60	med

Benefits

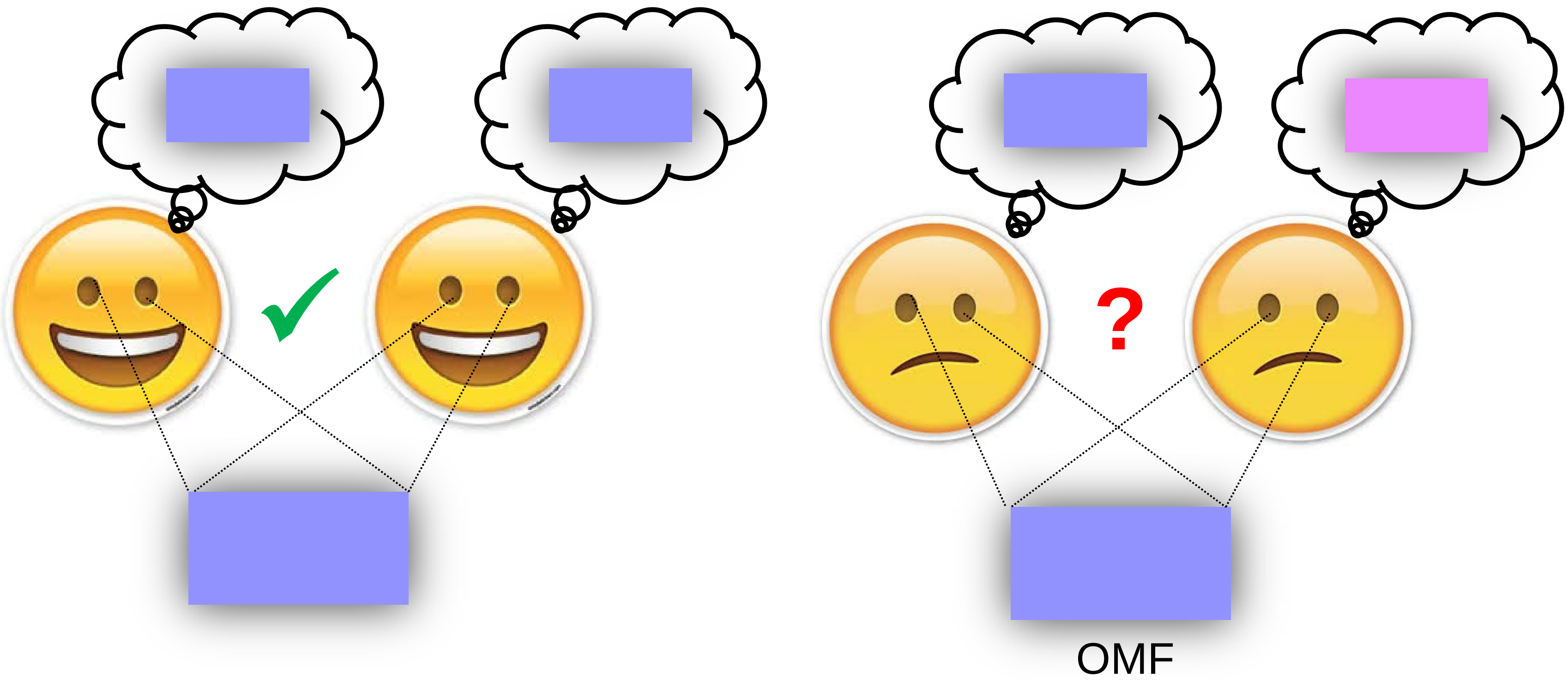
- Efficient, high powered light sources
- Near-monochromatic primaries (FWHM < 1 nm)
- Can be used in backlight or projection mode

Challenges

- *Potential for Observer Metameric Failure (OMF)*
- Speckle
- Étendue (i.e. beam quality)
- Available wavelengths
- Regulatory barrier (laser safety)
- Prohibitive cost
- Differential aging

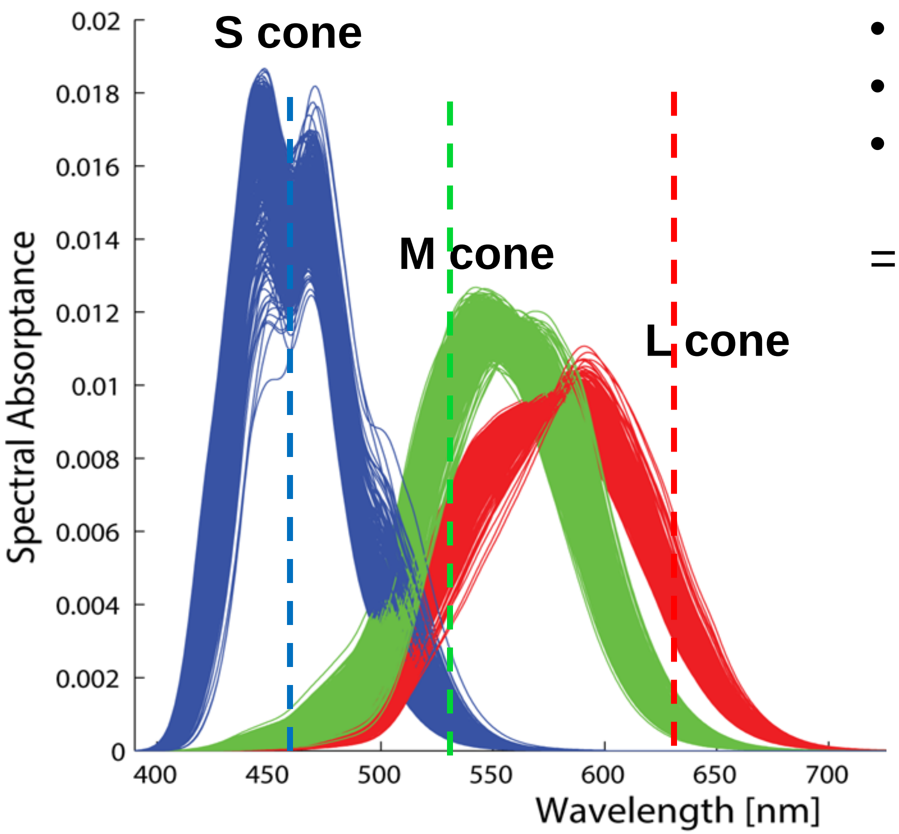
Do You See What I See?

- Observer Metamerism: When two observers experience the same light source as different hues
- Potential for OMF increases with narrow RGB primary sources
  - Careful selection of peak wavelengths necessary to minimize this effect



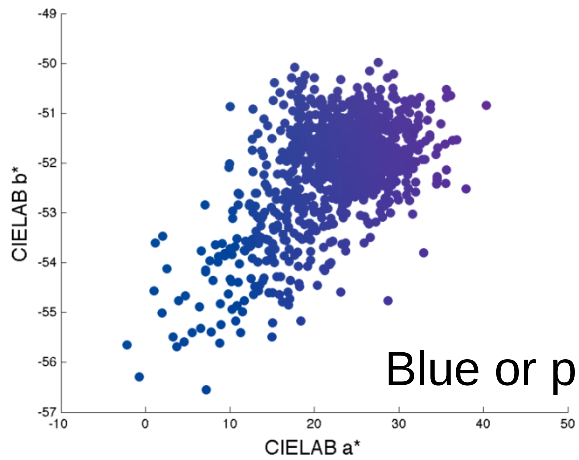
How Does Observer Metamerism Occur?

A Representative Population of 1,000 Human Observers



- Genetic Differences
- Yellowing of lens with age
- Macular pigment spectral density

=> No standard observer!



Blue or purple?

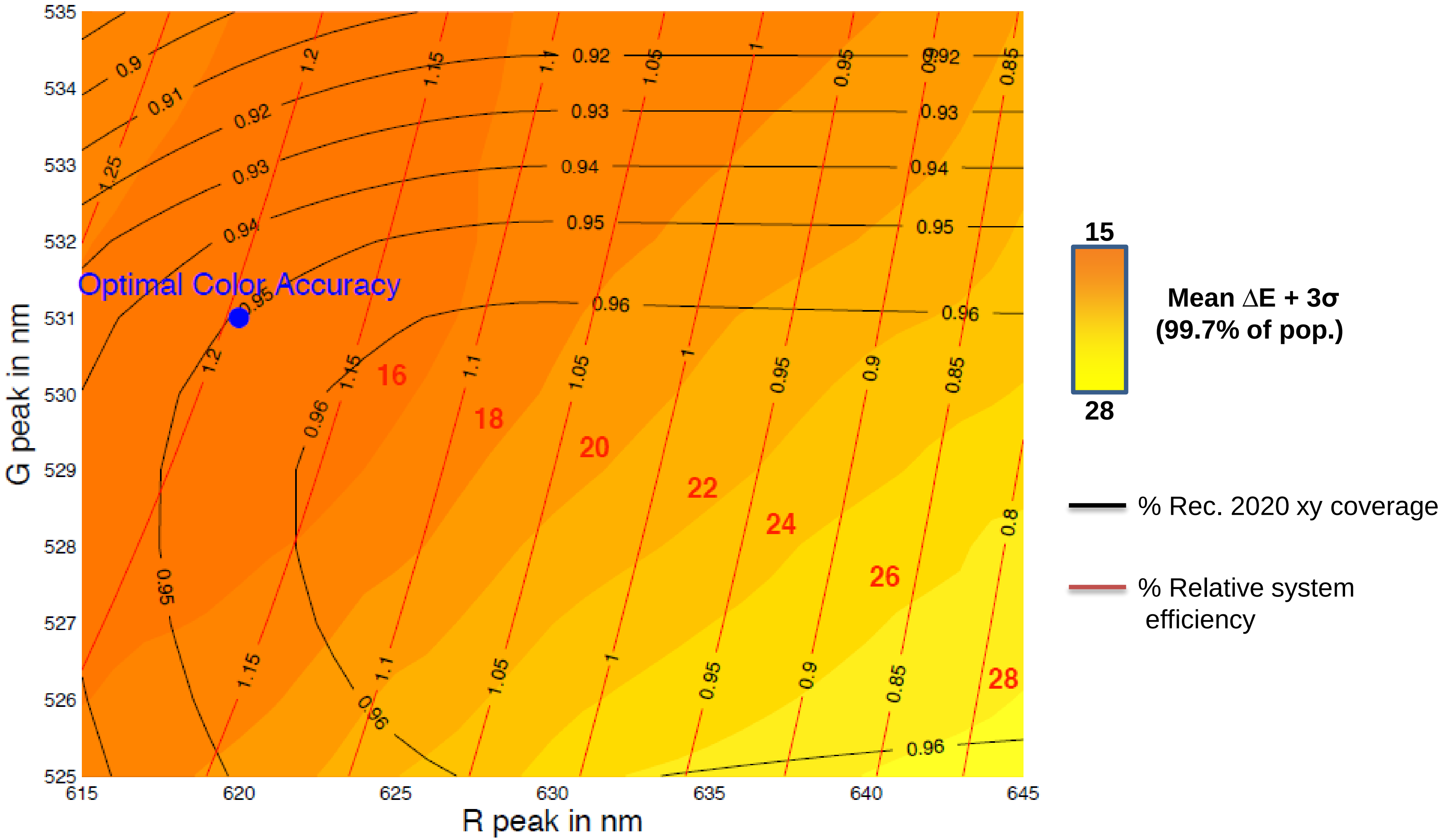
Source: M.D. Fairchild and R.L. Heckaman, Measuring observer metamerism: The Nimeroff approach, *Color Research and Application*, in press / early view DOI: 10.1002/col.21954 (2015)

Assessment of Rec. 2020 Implementations

Technology6	Model	Rec. 2020 xy Coverage [%]	Rec. 2020 u'v' Coverage [%]	Relative Efficiency [%]	Mean DeltaE	Mean DeltaE + 3Sigma
Rec.2020 Primaries		100	100	100%	5	24
Laser*	Avail. Tech.	98.0	97.2	93%	4.6	24
QD	TCL 55H9700 (modified)	88.8	90.0	85%	4.4	24
CFL	Apple LCD	55.9	55.3	113%	4.3	24
CRT	NTSC	46.0	47.7	101%	3.8	22
WOLED	LG 55EC9300	59.6	60.8	93%	3.8	22
RGB LED	HP DreamColor	83.6	87.9	102%	3.7	19
Y Phosphor LED	Samsung 55" UHD TV	52.0	54.7	112%	3.5	20
RG Phosphor LED	AUO 65"	58.5	62.6	83%	3.4	17
Optimal Monochromatic Primaries**	Simulation	95.1	91.6	120%	2.5	15
Optimal 30nm FWHM QD Primaries	Simulation	87.8	89.0	108%	2.8	15

*Available laser technology (462 nm, 532 nm, 638 nm) and FMHW=0.1nm
**Simulated monochromatic primaries (450 nm, 530 nm, and 620 nm) and FMHW=0.1 nm

RGB Primary Tunability Is A Key Advantage



Summary

- Rec. 2020 colorimetry establishes the widest TV color gamut, requiring monochromatic RGB primaries
- Rec. 2020 adoption is widespread and continues to grow
- 100% Rec. 2020 is not physically achievable => need to define compliance
- QDs and lasers can achieve >95% Rec. 2020 coverage
- Potential for OMF increases with narrower primaries => location matters
- Only QDs offer tunable primaries to optimize for gamut, OMF, and system efficiency

Thanks!