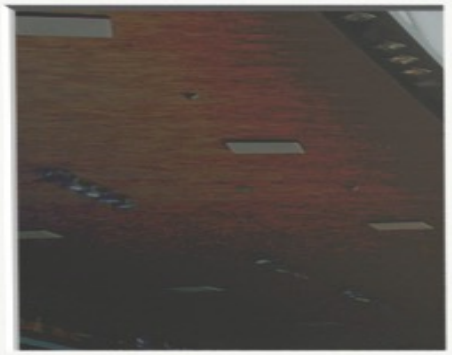
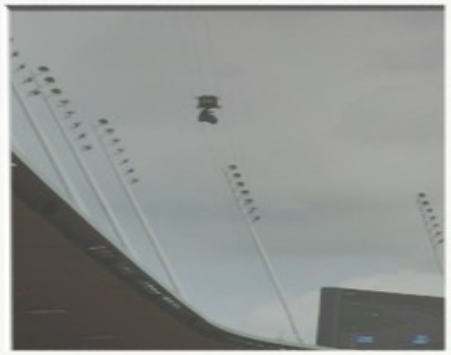
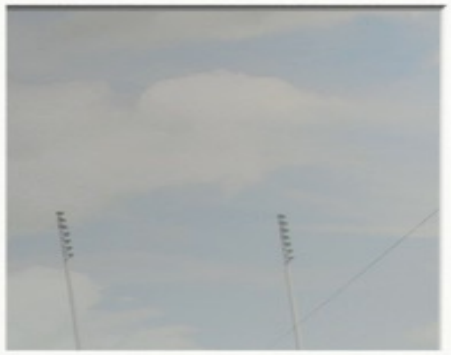
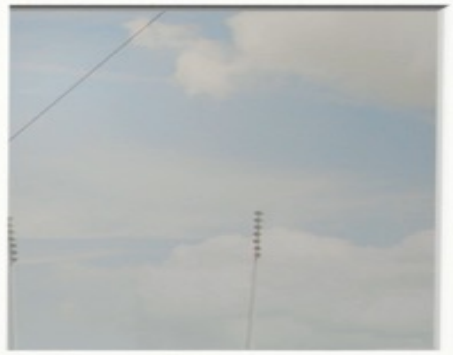
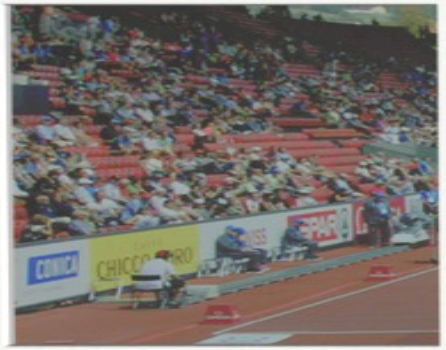
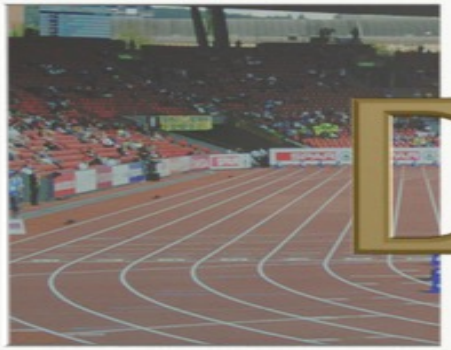
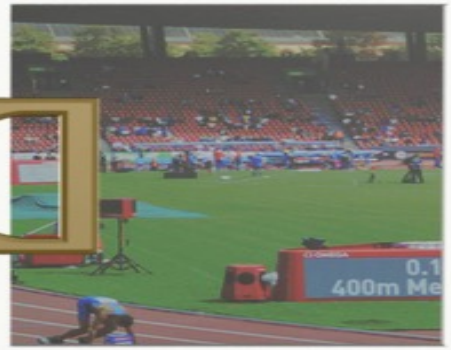
HDR and VVC: From Dream to Mainstream

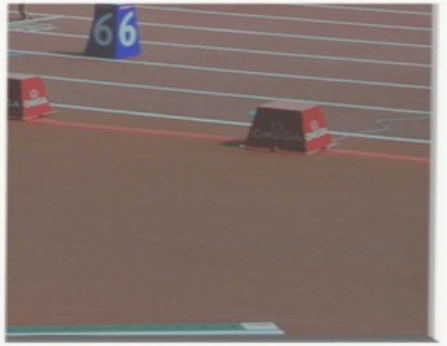
Patrick Griffis
Vice President, Technology, Standards, and Industry Engagement
Office of the CTO
Dolby Laboratories, Inc.

The Dream







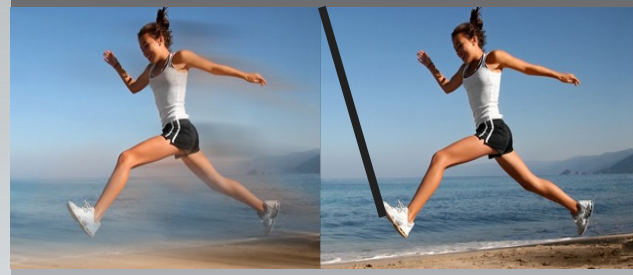
How Do We Get There?

Higher Spatial Resolution

More Pixels

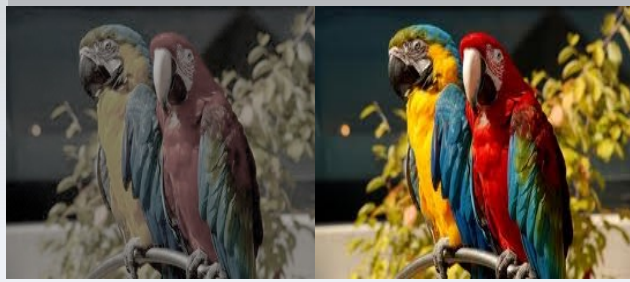
Higher Temporal Resolution

Faster Pixels



Larger Luminance Range & Color Palette

Better Pixels



MORE PIXELS

FASTER PIXELS

More and Faster Pixels Part 1- "4K"

SYSTEM CATEGORY	SYSTEM NOMENCLATURE	LUMA OR R' G' B' SAMPLES PER LINE	LINES PER FRAME	FRAME RATE (HZ)
(4K) UHDTV-1 ~8 Megapixels (3840 x 2160)	3840 x 2160/24/P	3840	2160	24
	3840 x 2160/25/P	3840	2160	25
	3840 x 2160/30/P	3840	2160	30
	3840 x 2160/50/P	3840	2160	50
	3840 x 2160/60/P	3840	2160	60
	3840 x 2160/100P	3840	2160	100
	3840 x 2160/120/P	3840	2160	120
				LEGACY
	3840 x 2160/29.97/P	3840	2160	30/1.001
	3840 x 2160/23.98/P	3840	2160	24/1.001
	3840 x 2160/59.94/P	3840	2160	60/1.001
	3840 x 2160/119.88/P	3840	2160	120/1.001

More and Faster Pixels Part 2 - "8K"

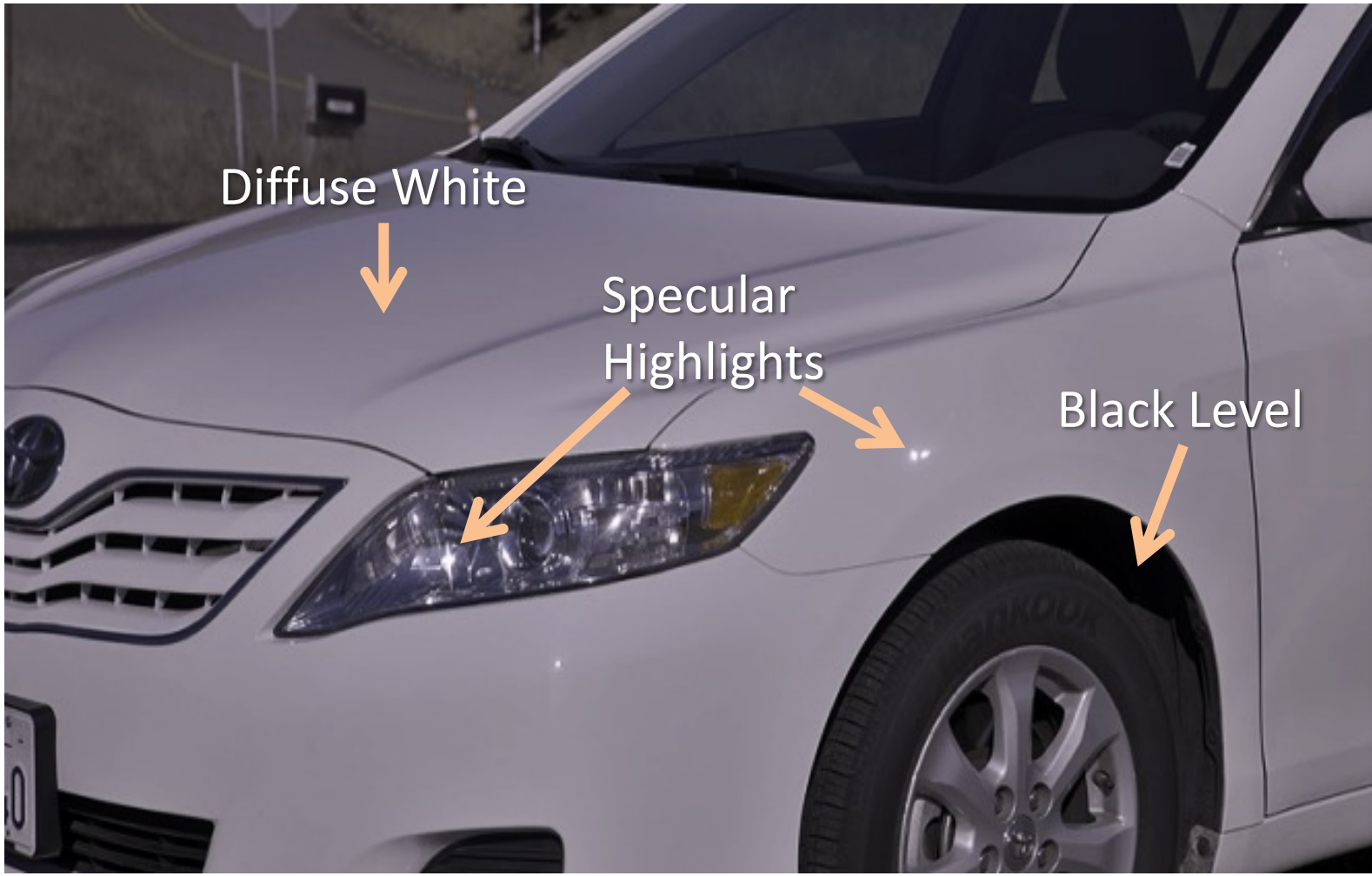
SYSTEM CATEGORY	SYSTEM NOMENCLATURE	LUMA OR R' G' B' SAMPLES PER LINE	LINES PER FRAME	FRAME RATE (HZ)
(8K) UHDTV-2 ~33 Megapixels (7680 x 4320)	7680 x 4320/24/P	7680	4320	24
	7680 x 4320/25/P	7680	4320	25
	7680 x 4320/30/P	7680	4320	30
	7680 x 4320/50/P	7680	4320	50
	7680 x 4320/60/P	7680	4320	60
	7680 x 4320/100/P	7680	4320	100
	7680 x 4320/120/P	7680	4320	120
				LEGACY
	7680 x 4320/23.98/P	7680	4320	24/1.001
	7680 x 4320/29.97/P	7680	4320	30/1.001
	7680 x 4320/59.94/P	7680	4320	60/1.001
	7680 x 4320/119.88/P	7680	4320	120/1.001

Better Pixels = HDR!

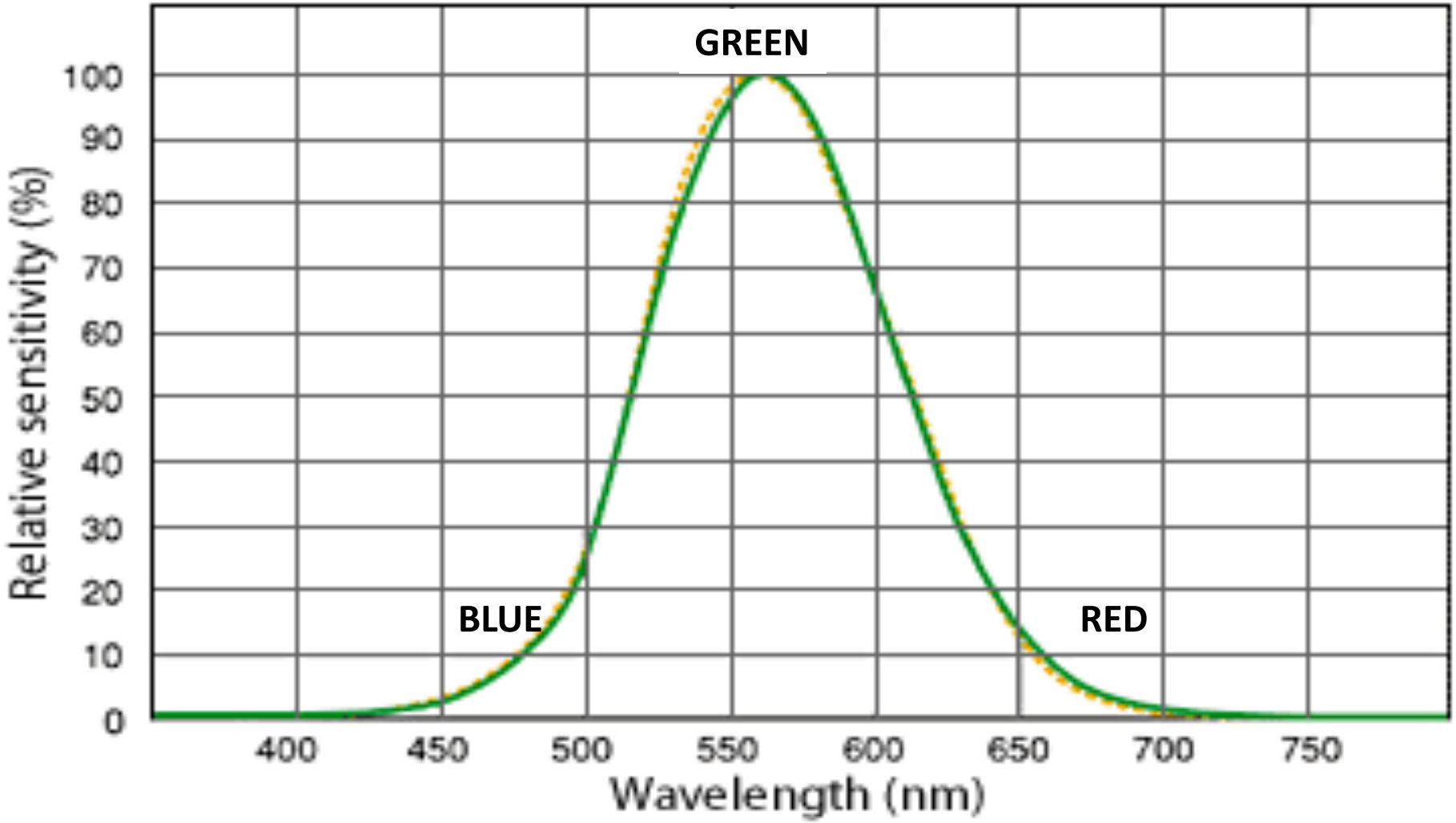
Some "Light" Nomenclature

LUMINANCE
The luminous intensity of a light source in a given direction ***weighted*** by the spectral response of the human eye for photopic (i.e. color) vision.
Measured in candela/meter squared (cd/m^2) colloquially and conveniently called **"Nits"***

* From Latin "Nitere", which means "to shine"



What Nits Measure-
Human Eye Spectral Response for Color Vision



Luminance Levels

cd/m² or ***nits***

10^{9} 1.6 Billion

10^{8} 100 Million

10^{6} 1 Million

10^{4} 10,000

10^{2} 100

10^{0} 1

10^{-2} 0.01

10^{-4} 0.0001

10^{-6} 0.000001

0 *(abs. black)*

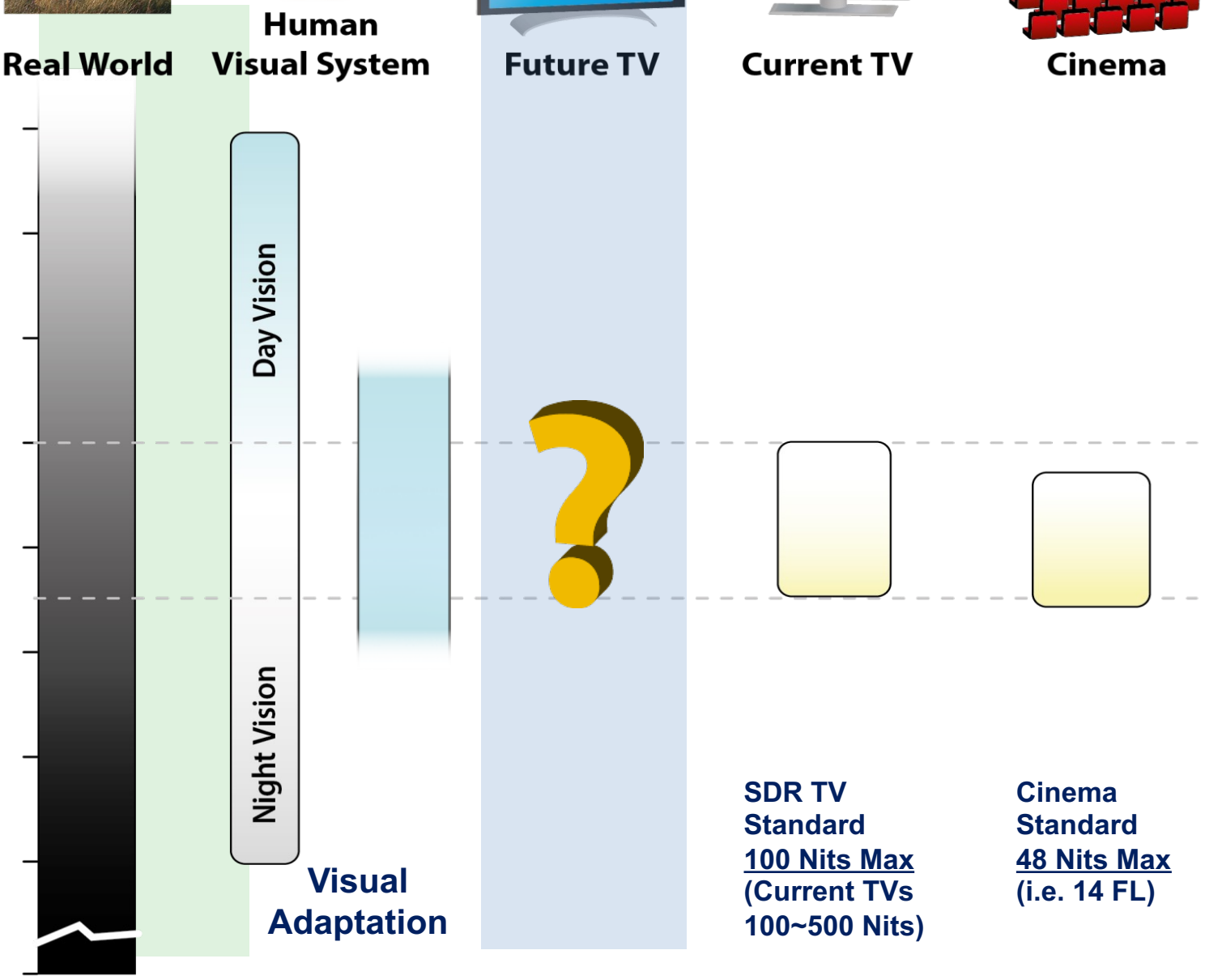
Real World

Human Visual System

Future TV

Current TV

Cinema



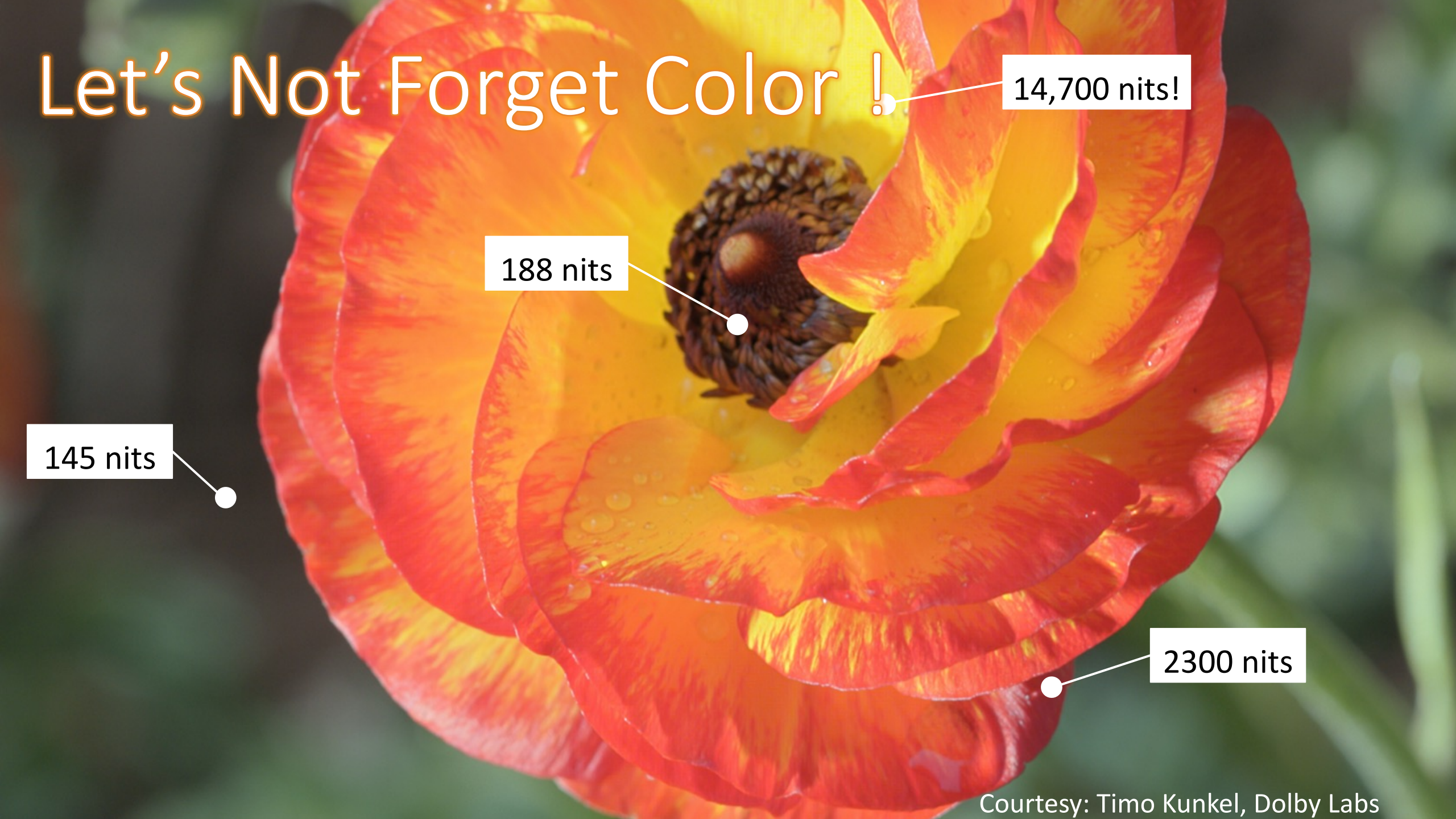
Visual Adaptation

SDR TV Standard
<u>100 Nits Max</u>
(Current TVs 100~500 Nits)

Cinema Standard
<u>48 Nits Max</u>
(i.e. 14 FL)

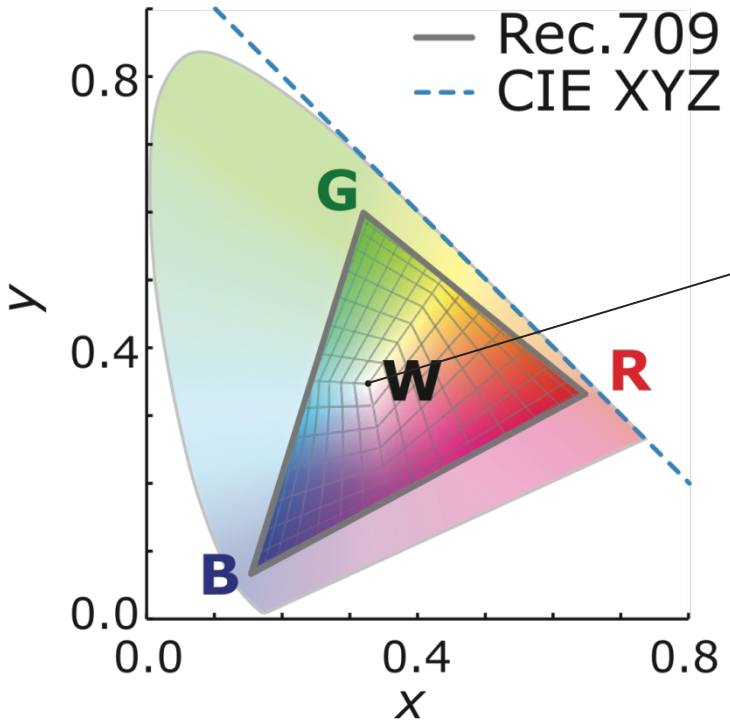
Real World Luminance Examples

Courtesy: Timo Kunkel, Dolby Labs

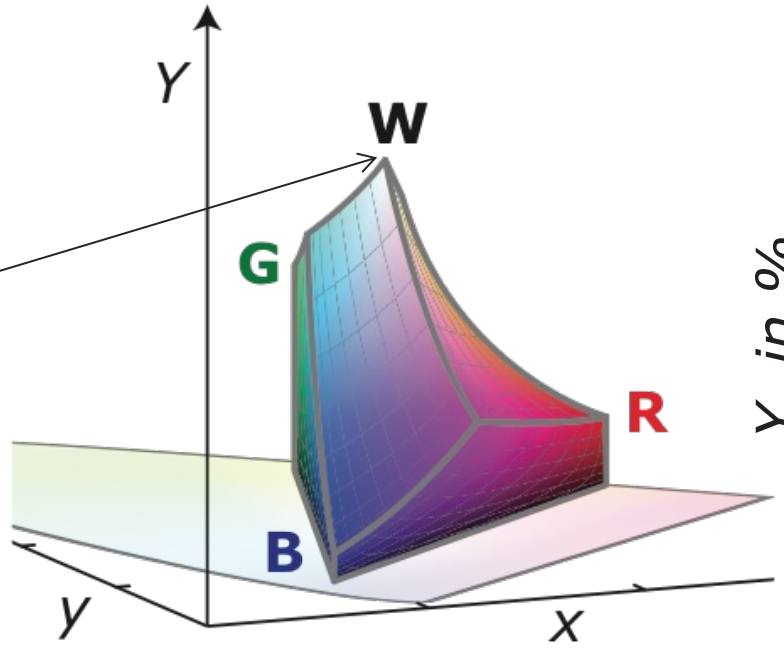

Let’s Not Forget Color !
14,700 nits!
188 nits
145 nits
2300 nits
Courtesy: Timo Kunkel, Dolby Labs

What is a “Color Volume”?

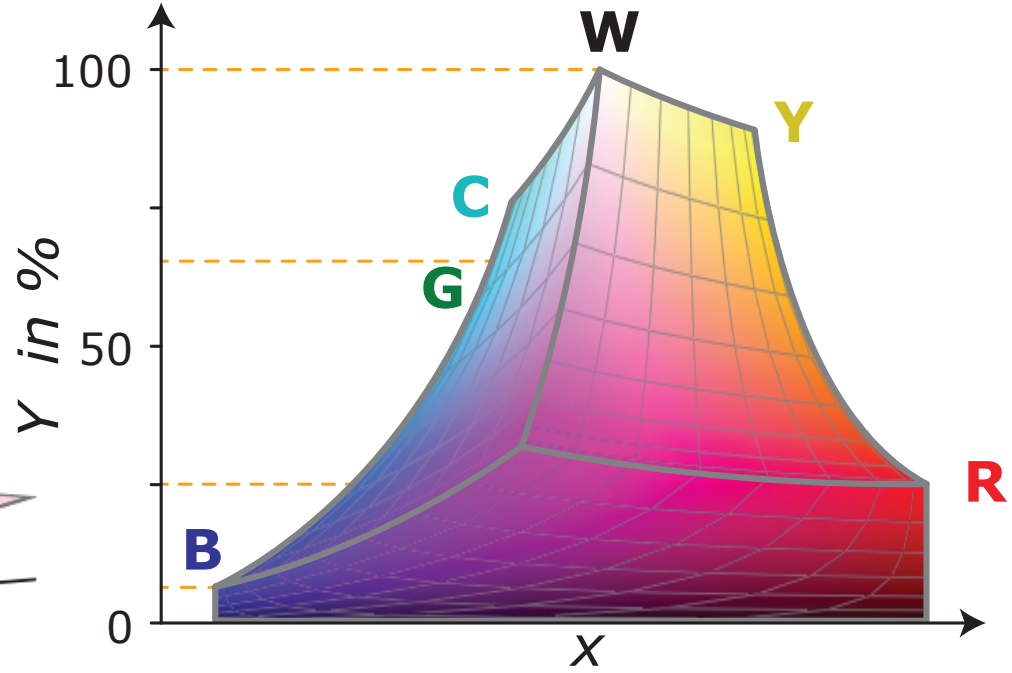
2D Chromaticity Diagram



3D **Color Volume**



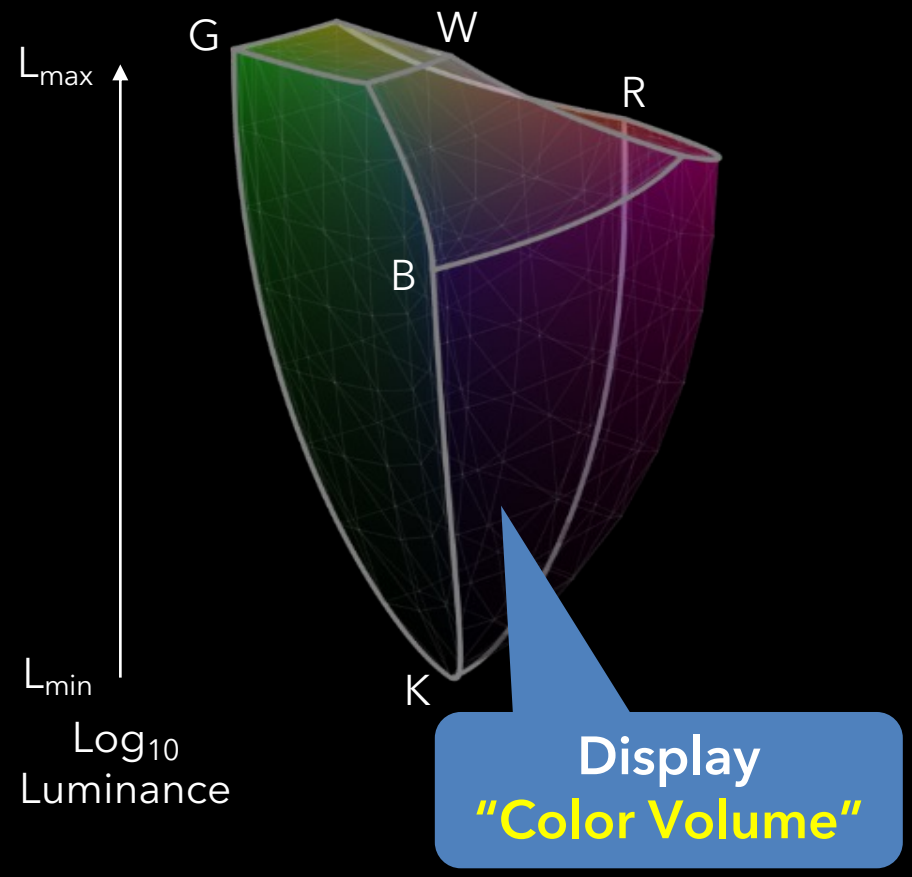
3D **Color Volume** (xY Viewpoint)

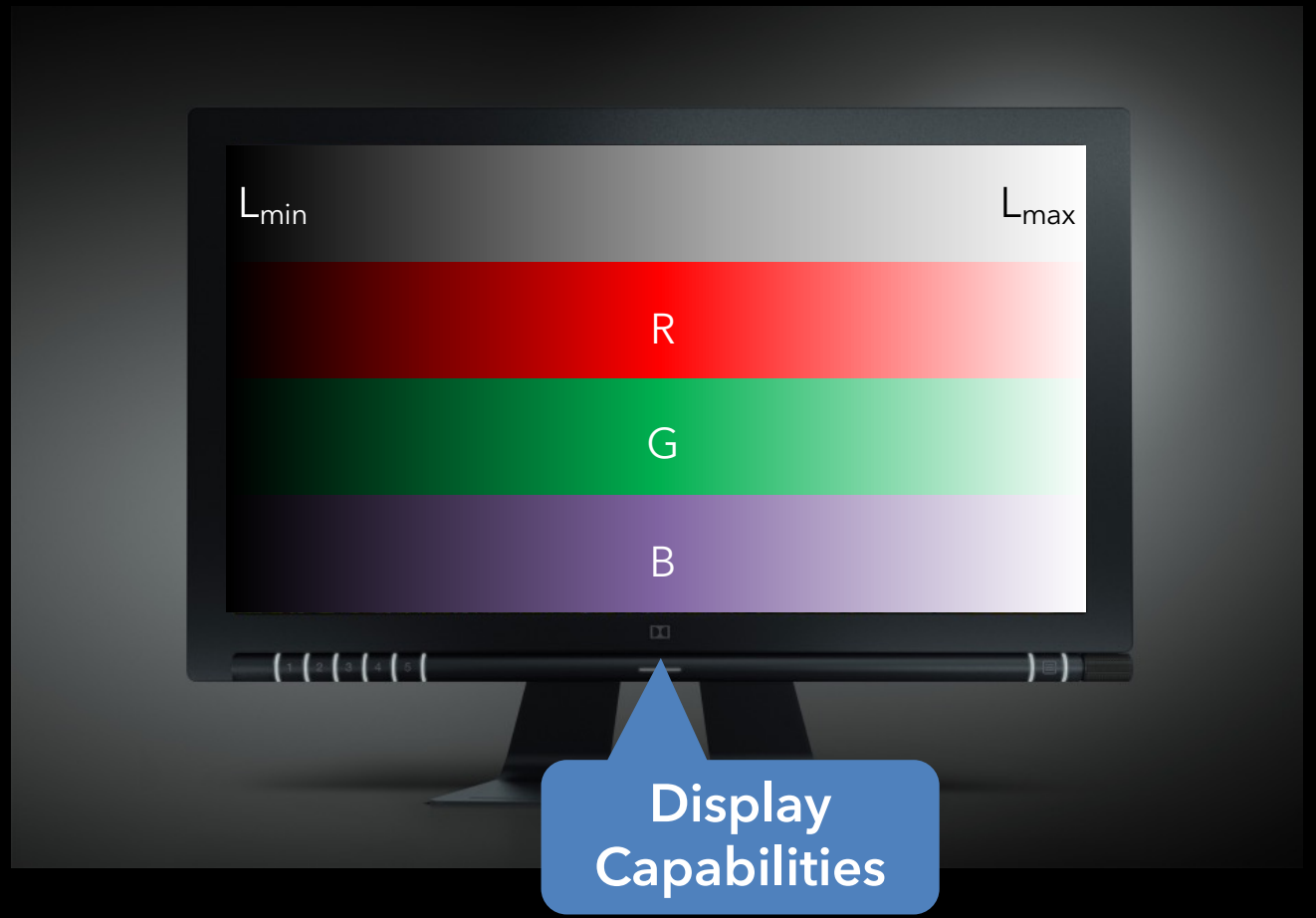


Courtesy: Timo Kunkel, Dolby Labs

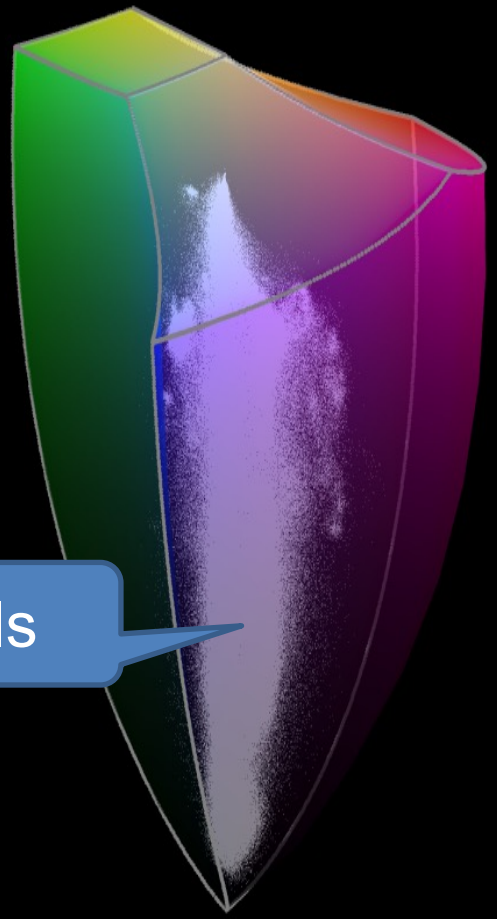
What is a “Color Volume”?

“The 3D palette of all colors that can be reproduced at all allowable intensities by a display i.e. the container for the displayed image pixels”. The Color Volume of a Mastering Display (MDCV) is standardized in SMPTE ST 2086





“Image Pixels” *The pixels that comprise the image change position on a frame by frame basis within the display color volume*

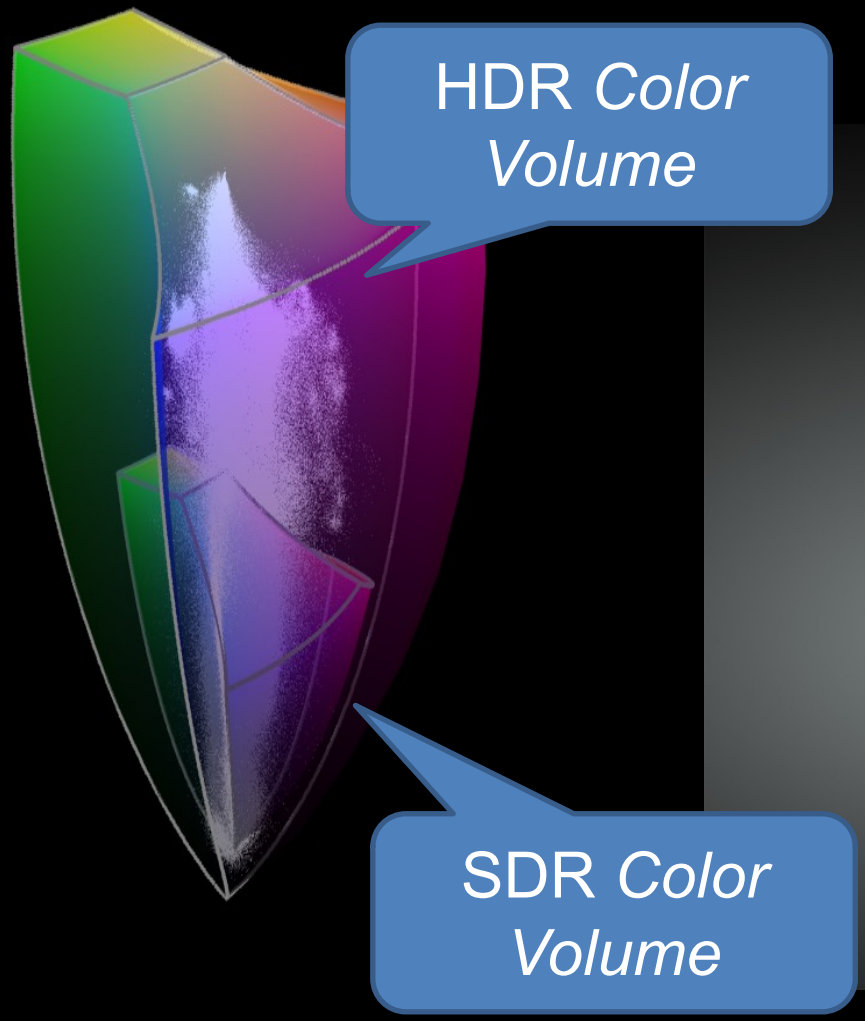


TV Image Pixels

Display
“Color Volume”

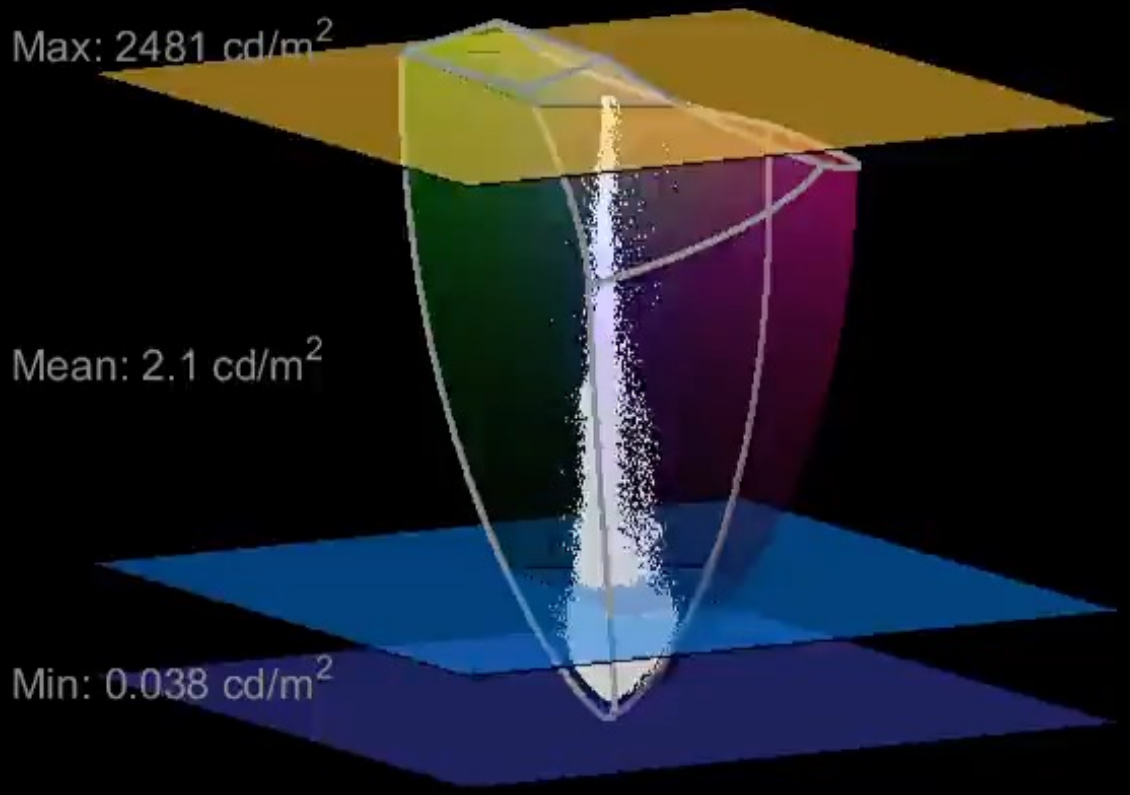
Content courtesy of the EBU

HDR Color Volume: Allows More Pixel Choice in Color and Intensity

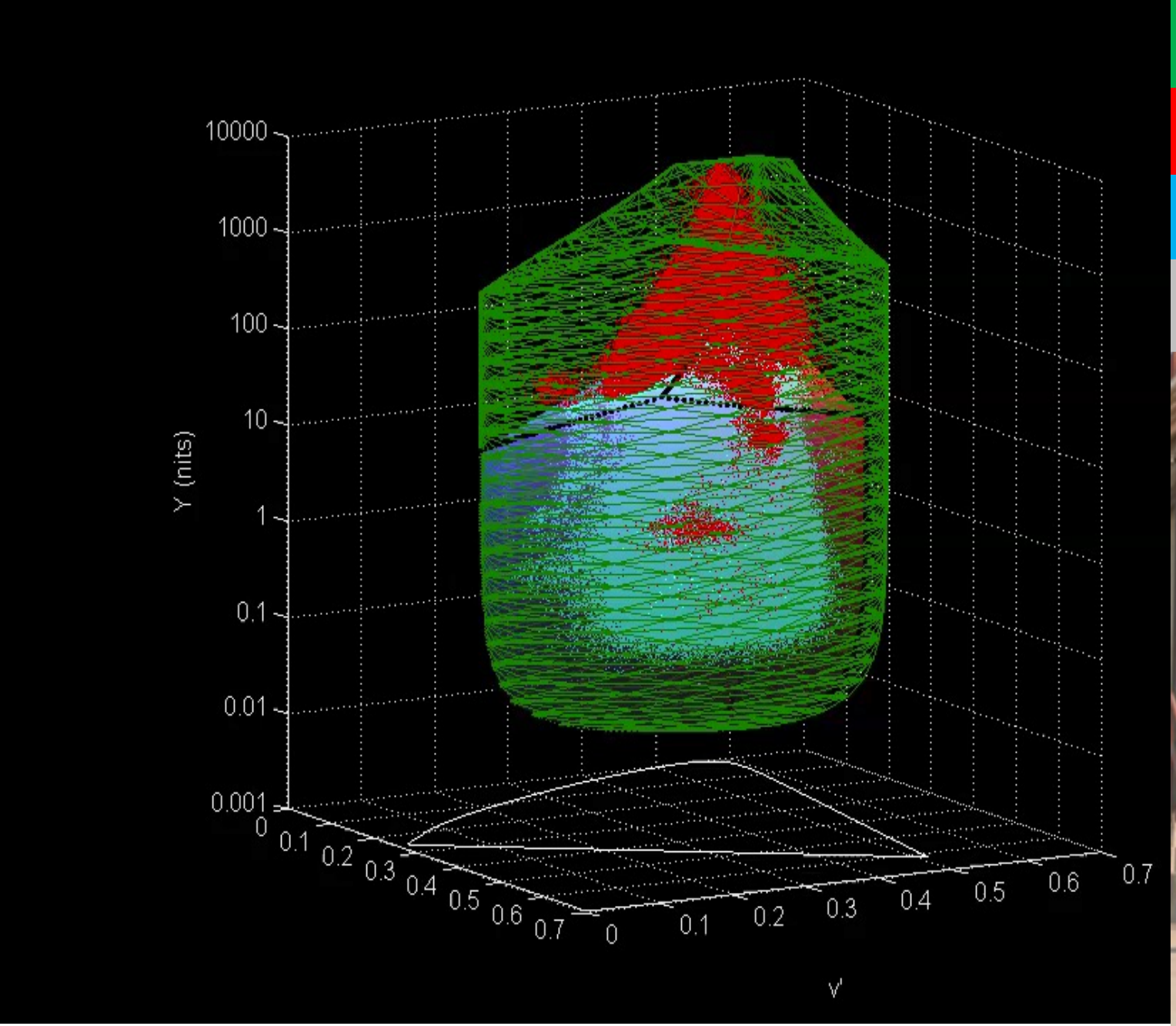


Content courtesy of the EBU

Pixels in Motion: Dynamic Content Mapping (via Dynamic Metadata)



Defined by **content image statistics, source & target display capabilities**



4000 Nit Color Volume

Pixels Outside SDR Color Volume

Pixels Inside SDR 100 Nit Color Volume

SDR Color Volume

Courtesy: Robins Atkins, Dolby Labs

How “Dark” is Black?

- Reference Video Today: ~0.01 Nit (cd/m^2)
- Reference Cinema (DCI Spec): 0.01 – 0.03 Nit
- Best consumer devices today: ~ 0.005 Nit
- “True Black” is an elusive target
  - 0.0001 Nit is **very** dark
    - Takes a minute or two to see this level after turning off lights
    - Still very dim looking even after full visual adaptation
  - ~0.00001– 0.000001 is the visual system limit (cone threshold ~0.003)
  - With long enough adaptation time, you can see handfuls of photons!!
- To deal with any possibility, assume a minimum of zero nits.

How “Bright” is White?

- Reference SDR Video Today: 80 – 120 Nits
- Reference Cinema (DCI): 48 Nits (14 foot-lamberts)
- Brightest consumer devices today: ~ 1500 Nits
- Some commercial devices today: 4000 – 5000 Nits
- 10,000 nits is easy to view & measure - a good upper limit for future proof purposes.
  - Specular highlights are much brighter than this in the real world

Luminance Levels

cd/m² or nits

Sun Direct

10^{9} 1.6 Billion

10^{8} 100 Million

Sunlight

10^{6} 1 Mio

10^{4} 10,000

Indoor Lighting

10^{2} 100

10^{0} 1

Moon-light

10^{-2} 0.01

10^{-4} 0.0001

Starlight

10^{-6} 0.000001

0 *(abs. black)*

Real World

Human Visual System

Future TV

Current TV

Cinema

Day Vision

Night Vision

Entertainment Dynamic Range

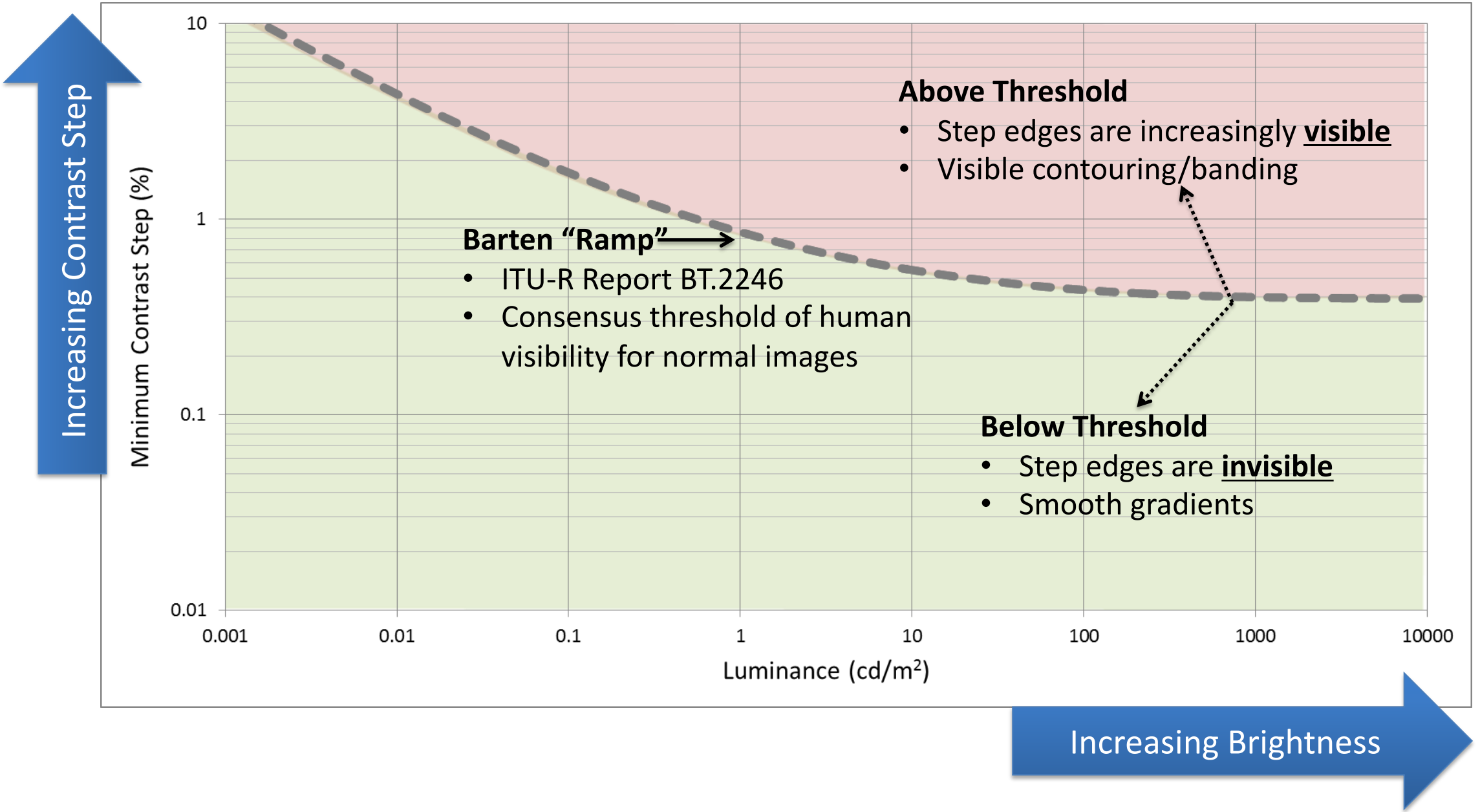
0.0 to 10k nits satisfies majority of viewers

Designing a New EOTF: SMPTE* ST-2084 (PQ)

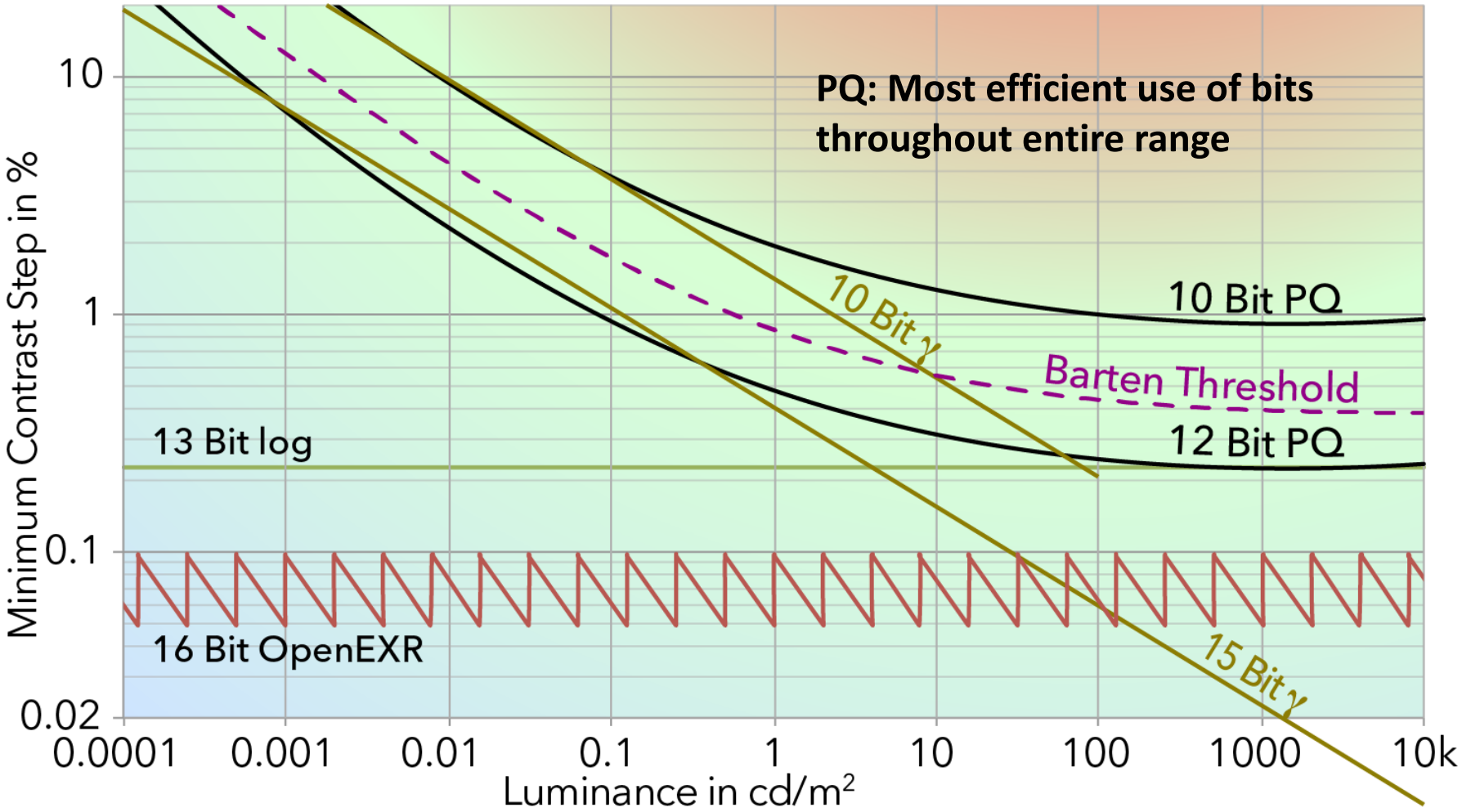
- Legacy “Electro-Optic Transfer Function” (EOTF) standard (BT-1886) based on “gamma” is typically used in a range of .1 to 100 nits
- Instead use **0 to 10,000 nits** dynamic range as a design goal to better cover preferences & provide future headroom
- Assume practical system will need to be 10 to 12 bits for sufficient precision due to infrastructure and silicon constraints
- Use Human Visual System (HVS) model based on Barten’s work which models human contrast sensitivity to determine performance
- SMPTE standard ST-2084: aka “Perceptual Quantizer” (PQ) based these criteria is now deployed in many products and services.

*__SMPTE__= SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS

Contrast Sensitivity vs. Luminance (Barten)



SMPTE ST-2084: “Perceptual Quantizer”(PQ) Performance



Legend

Artifacts Very Likely Visible

Artifacts Visible Under Some Circumstances

Barten Threshold
No Artifacts Visible - Efficient for Encoding

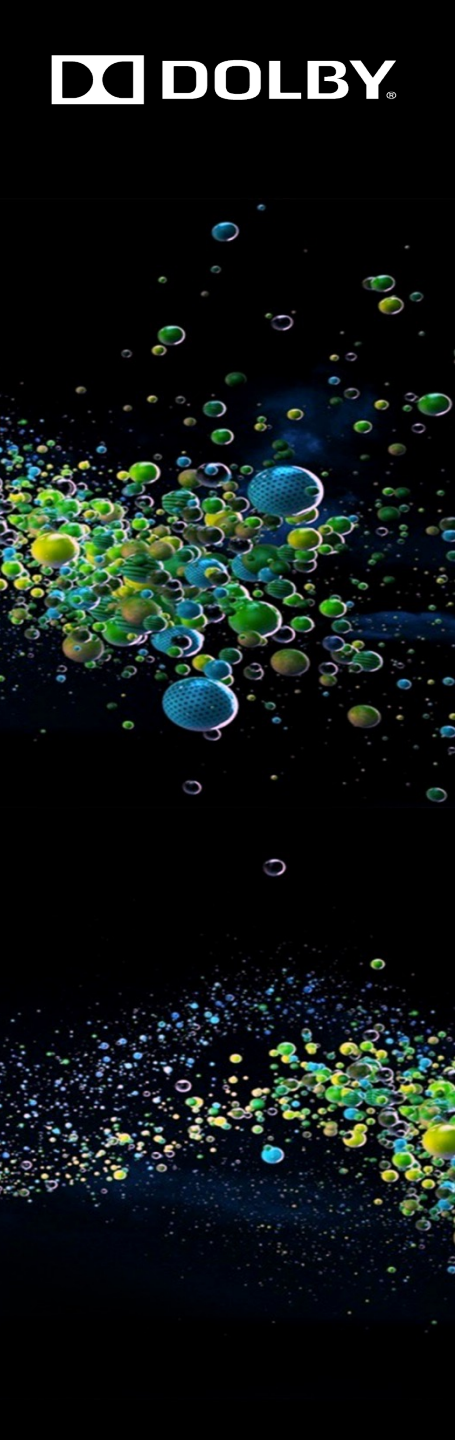
Inefficient for Encoding - Good for Post-Processing

Source: ICDM IDMS v1.1

Take Aways: Nits, Bits, and Bucks ($)

	Raw Data Rate Increase Factor	Human Visual System Acuity
Resolution: HD → 4K	400%	LOW
Frame Rate: 24 fps → 48 fps	200%	MEDIUM HIGH
Color Volume: Rec 709 →Rec 2020	125% (8→10 bits)	MEDIUM LOW
Dynamic Range: 100 nits →10,000	125% (8→10 bits)	HIGH

Source: Warner Brothers



Take Aways: Nits, Bits, and Bucks ($)

- The next generation entertainment image experience will be mix of more, faster, and better pixels **ALL** requiring more bits.

- HDR is now deployed in billions of products and multiple services. HDR has gone from dream to mainstream!

HDR Availability

Displays

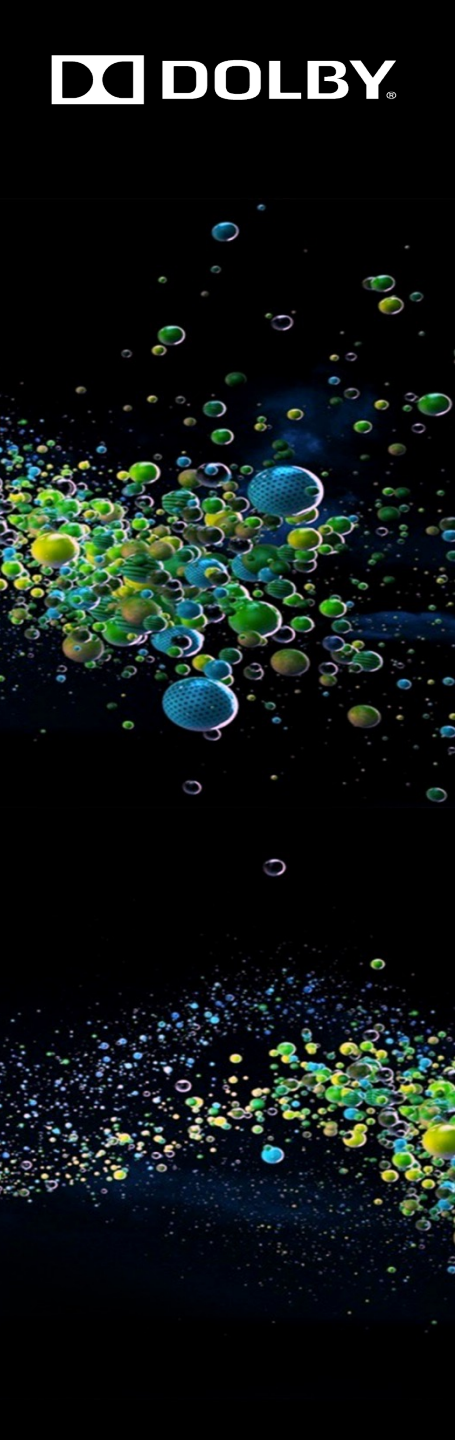
Of **225 million TVs** sold globally in **2020:**

- **58% included HDR** functionality
- **10% even provided 500 cd/m²** peak luminance or higher *(Source: OMDIA)*
- Many also support **dynamic metadata**-enabled HDR formats.

HDR supported on PCs, mobile phones, tablets, as well as gaming platforms

HDR Content

- **Widely Available** in Cinema, OTT, Blu-ray, Broadcast, UGC, & Gaming



HDR and VVC (H.266) (Versatile Video Coding)

VVC was designed from the start with both SDR and HDR in mind. *“HDR is now a first-class citizen”*

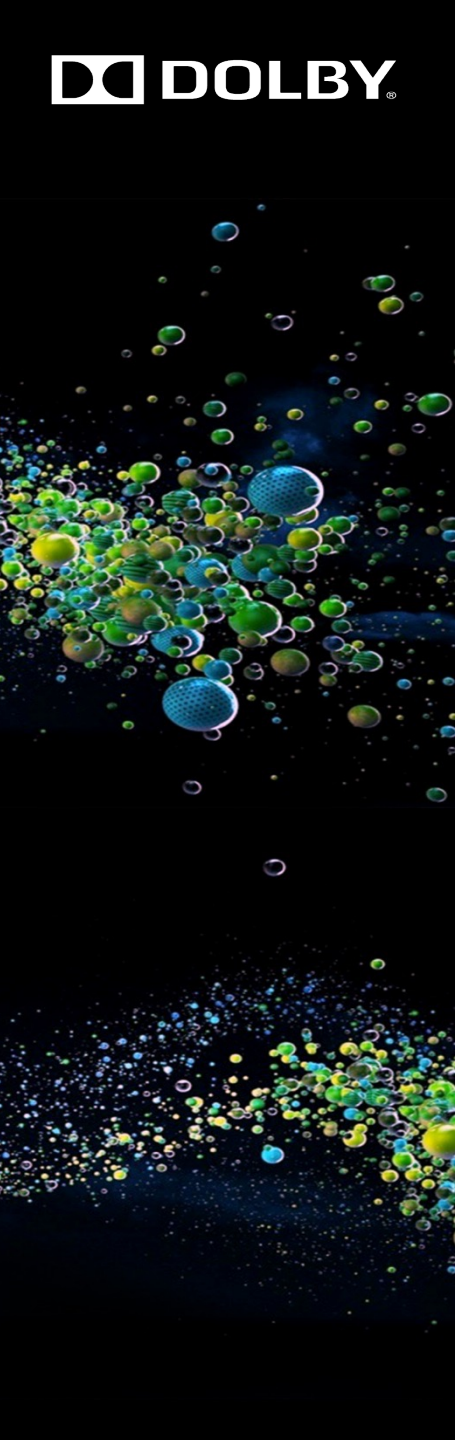
Revised Recommendation ITU-T H.266 (V2)

Versatile video coding

Summary

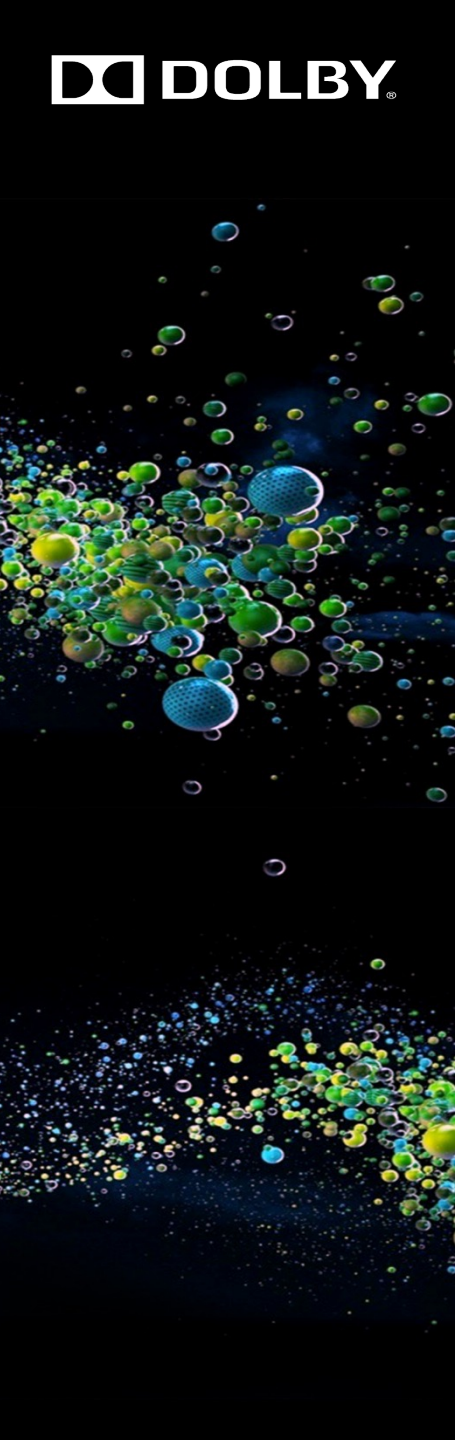
Recommendation ITU-T H.266 specifies a video coding technology known as *Versatile Video Coding* and it has been designed with two primary goals. The first of these is to specify a video coding technology with a compression capability that is substantially beyond that of the prior generations of such standards, and the second is for this technology to be highly versatile for effective use in a broadened range of applications than that addressed by prior standards. Some key application areas for the use of this standard particularly include ultra-high-definition video (e.g., with 3840×2160 or 7620×4320 picture resolution and bit depth of 10 bits as specified in Rec. ITU-R BT.2100), video with a high dynamic range and wide colour gamut (e.g., with the perceptual quantization or hybrid log-gamma transfer characteristics specified in Rec. ITU-R BT.2100), and video for immersive media applications such as 360 omnidirectional video projected using a common projection format such as the equirectangular or cubemap projection formats, in addition to the applications that have commonly been addressed by prior video coding standards.

This Recommendation was developed collaboratively with ISO/IEC JTC 1/SC 29 and corresponds with ISO/IEC 23090-3 as technically aligned twin text.



HDR and VVC (H.266) (Versatile Video Coding)

AVC	HEVC	VVC
Maximum compression efficiency compatible with widespread use	Maximum compression efficiency compatible with widespread use	Maximum compression efficiency compatible with widespread use
Target use case: HD	Target use case: UHD	Target use case: HDR 360-degree UHD 8k Unified codec

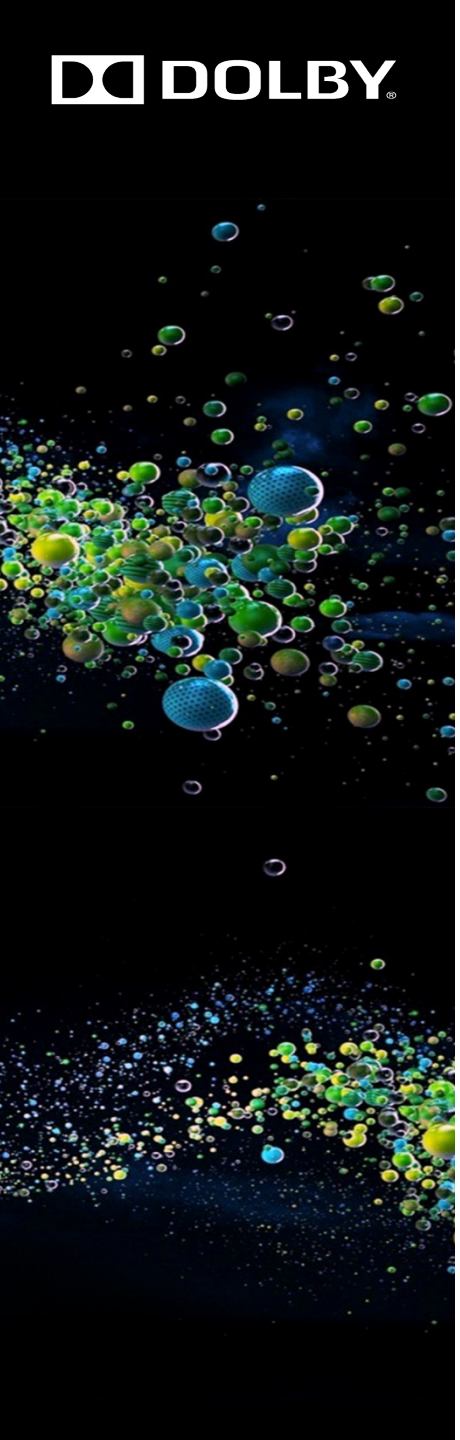


HDR and VVC (H.266) (Versatile Video Coding)

- New coding tools in VVC were motivated by HDR applications but have since been shown to also benefit SDR applications (e.g. SMPTE ST 2086 “Mastering Display Color Volume” (MDVC))

- Transfer characteristics for HDR are fully mature and completely specified across all standards (AVC, HEVC, VVC, VSEI, CICP, etc.)

- Signaling of HDR-related metadata using SEI messages is fully mature and completely specified across all standards



VVC (H.266) HDR Support

The VVC standard primarily specifies the syntax, semantics, and decoding processes required for conforming video decoders.
Information about how video is intended to be post-processed, displayed, or otherwise used is **specified mainly via the VSEI standard**.

- **VSEI (H.274)** (**Versatile Supplemental Enhancement Information** messages for coded video bitstreams).
  While the core of VVC provides the tools for compressing the bits, **VSEI provides the tools for how the result is displayed.** VSEI specifies **Video Usability Info (VUI), Supplemental Enhancement Info (SEI) ,** and points to **CICP**.

- **CICP (H.273)** (**Coding Independent Code Points** for video signal type identification)
  VSEI points to CICP as a way of specifying key VSEI syntax elements needed for HDR. This includes transfer characteristics (PQ, HLG, etc.), color primaries, matrix coeffs, etc..

Standards Adoption of VVC*

ARIB ISBD (Japan)

Investigating VVC Main 10 and Multilayer Main 10 profiles for its next generation digital video broadcasting system.

ATSC

Specifying VVC for inclusion in the ATSC 3.0 suite of standards.

CTA WAVE

Added VVC profile to Web Application Video Ecosystem (WAVE) Content Specification in 2021.

DASH-IF

Added VVC profile to DASH-IF Interoperability Points in 2022.

DVB

Adopted VVC as Next Generation Video Codec into its codec toolbox in 2022.
DVB set several performance-related **Commercial Requirements** to be met by next generation video codecs which VCC exceeded:

- Efficiency gains over HEVC for live of at least 27% and for offline streaming of at least 30%.
- Support for 8K video over legacy broadcast multiplexes.
- 5x 4K services in a 40Mbps multiplex (vs 3X for HEVC).

SBTVD (Brazil)

Selected VVC as the sole video base layer codec in 2021. Specification drafting is ongoing.
In **SBTVD** evaluation, VVC technology was tested on variety of content test cases and compression gains of >30% were reported for:

- Spatial resolutions from 720p to 4320p for HDR HLG and HDR PQ.
- 1080p SDR content with different frame rates.
- Sign language video in portrait mode (540x960 and 360x640)

SCTE (Cable)

Adopted VVC into SCTE 281-1 and 281-2 in March 2023.

** Based on publicly available information*

VVC Deployment Status

Encoding

- Real-time commercial VVC encoders with 15-30% performance gains over HEVC using the same or comparable HW (1-1.5x).
- Offline commercial VVC encoders with >30% performance gains over HEVC integrated into cloud-based encoding, transcoding and mobile OTT services.

Software Decoding

- HD playback on Android and iOS mobile platforms.
- UHD/4K playback on laptop/desktop grade processors.
- UHD/8K playback on AMD EPYC and Intel Xeon based servers.
- Web browser playback with WebAssembly with Edge, Firefox and Chrome browsers.

Open-source and Commercial Developer Tools

- VVC encoder or decoder integration plugins available for FFMPEG, VLC, GPAC,..
- VVC conformance testing specification developed by JVET, VVC Verification and Validation bitstreams developed by DVB.
- Commercial test bitstreams and bitstream analyzers.

Hardware Decoding

- 8Kp120 VVC decoder IP core.
- 4Kp60 SoC decoder for STB.
- 4Kp120 and 8Kp120 SoC decoders for TVs.
- New TV models supporting VVC announced for 2023.

JVET maintains up to date list of VVC deployment, document available from JVET repository: jvet-experts.org
See: https://jvet-experts.org/doc_end_user/documents/30_Antalya/wg11/JVET-AD0021-v7.zip for deployment updates

VVC Deployment Guidelines:

Media Coding Industry Forum (MC-IF)

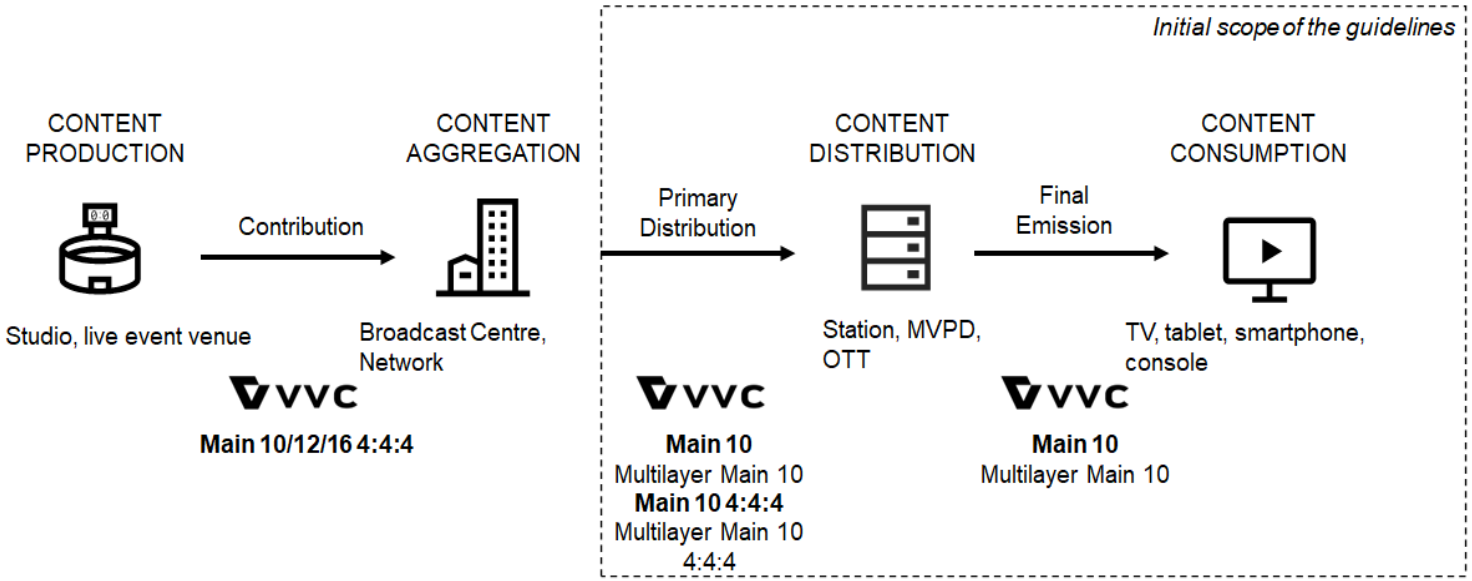
The **Media Coding Industry Forum** (MC-IF) (https://www.mc-if.org) is developing VVC technical guidelines for video broadcast and streaming and includes a number industry leaders:

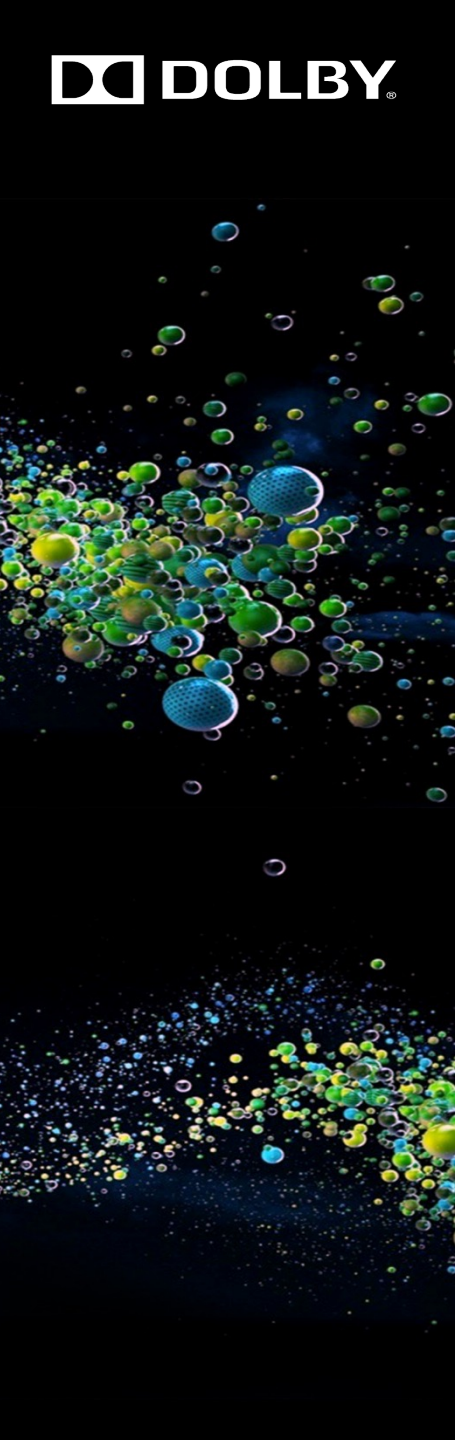
First version of the VVC Guidelines is under development and currently planned for a release at end of Q2 2023.

The guidelines aim to:

- Cover best practices of VVC configuration for industry relevant VVC-based profiles
- Provide up to date information on VVC operating bitrate ranges
- Provide information on the usage of VVC with accompanying technologies such as VSEI standard
- Advocate interoperability and seek commonality of VVC usage

Get updates at: https://www.mc-if.org/broadcast-streaming-guidelines/





Take Aways: Nits, Bits, and Bucks ($)

- The next generation entertainment image experience will be mix of more, faster, and better pixels **ALL** requiring more bits.
- HDR is now deployed in billions of products and services. HDR has gone from dream to mainstream!
- VVC is no longer a dream and poised to go mainstream!

Questions?