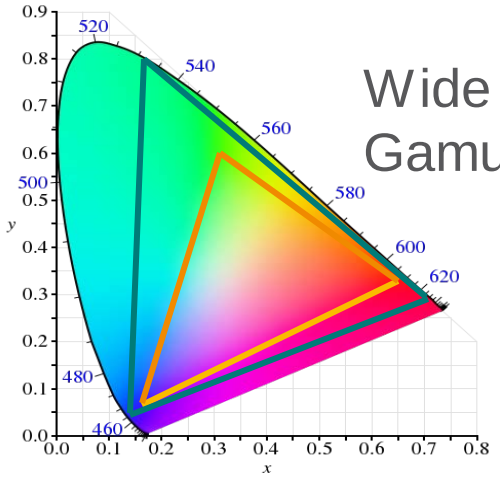
HIGH DYNAMIC RANGE MASTER CLASS

Matthew Goldman
Senior Vice President Technology, TV & Media
Ericsson

RECAP: 5 ULTRA-HD IMMERSIVE VIEWING IMAGE TECHNOLOGIES

Image Resolution



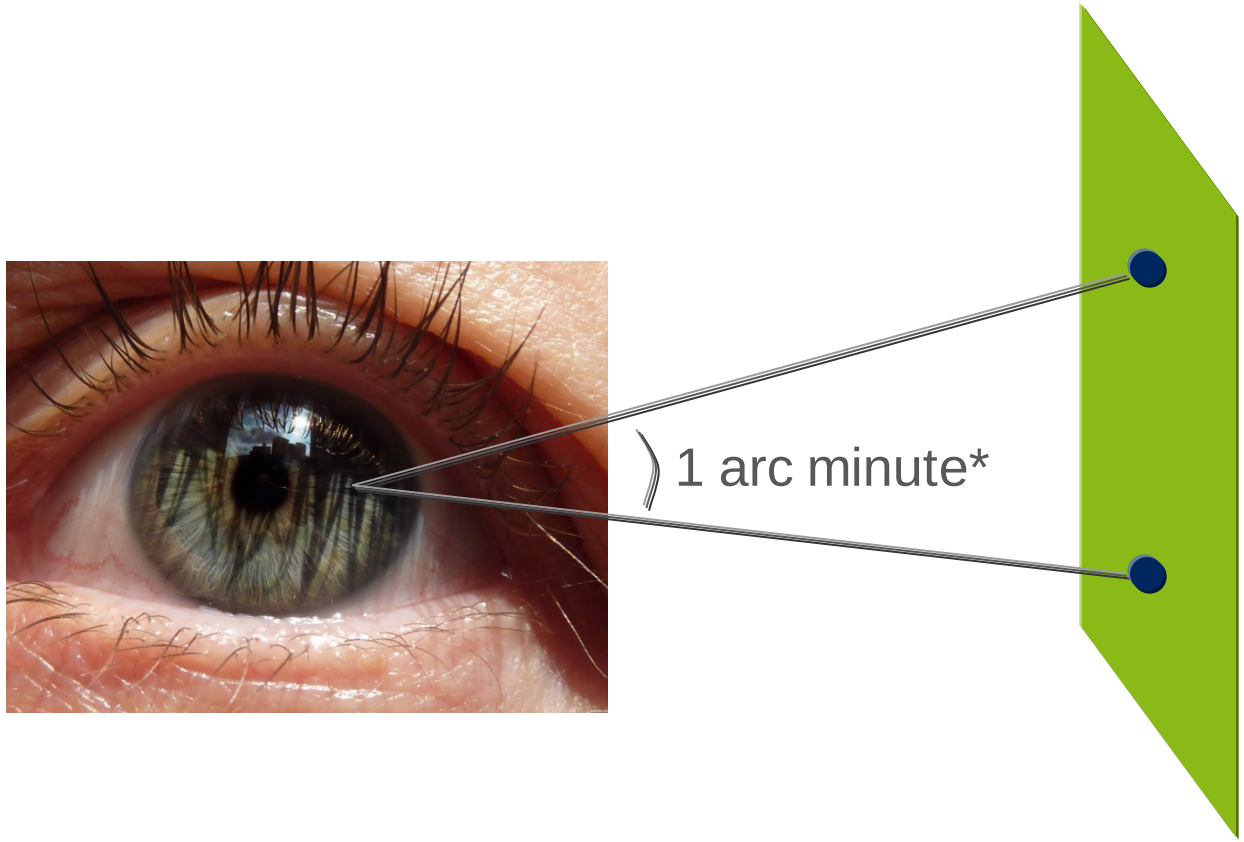
Wide Color Gamut

High Dynamic Range

10-bit Sampling

High Frame Rate

VISUAL PERCEPTION - RESOLUTION



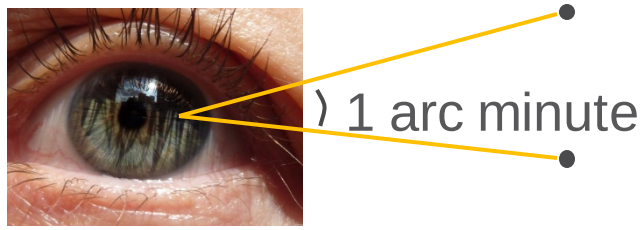
*limit of Fovea Centralis 0.5 arc minute

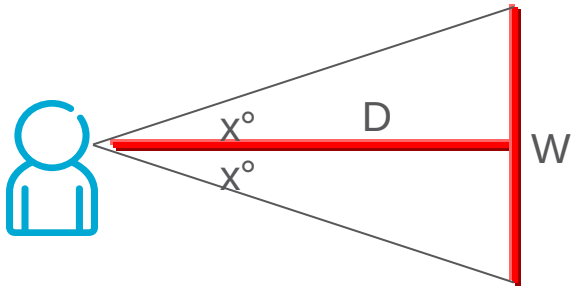
PROPER VIEWING DISTANCE
TO "SEE" SPATIAL RESOLUTION

Proper Viewing Distance (D)

HD (1080p) ~= 3H

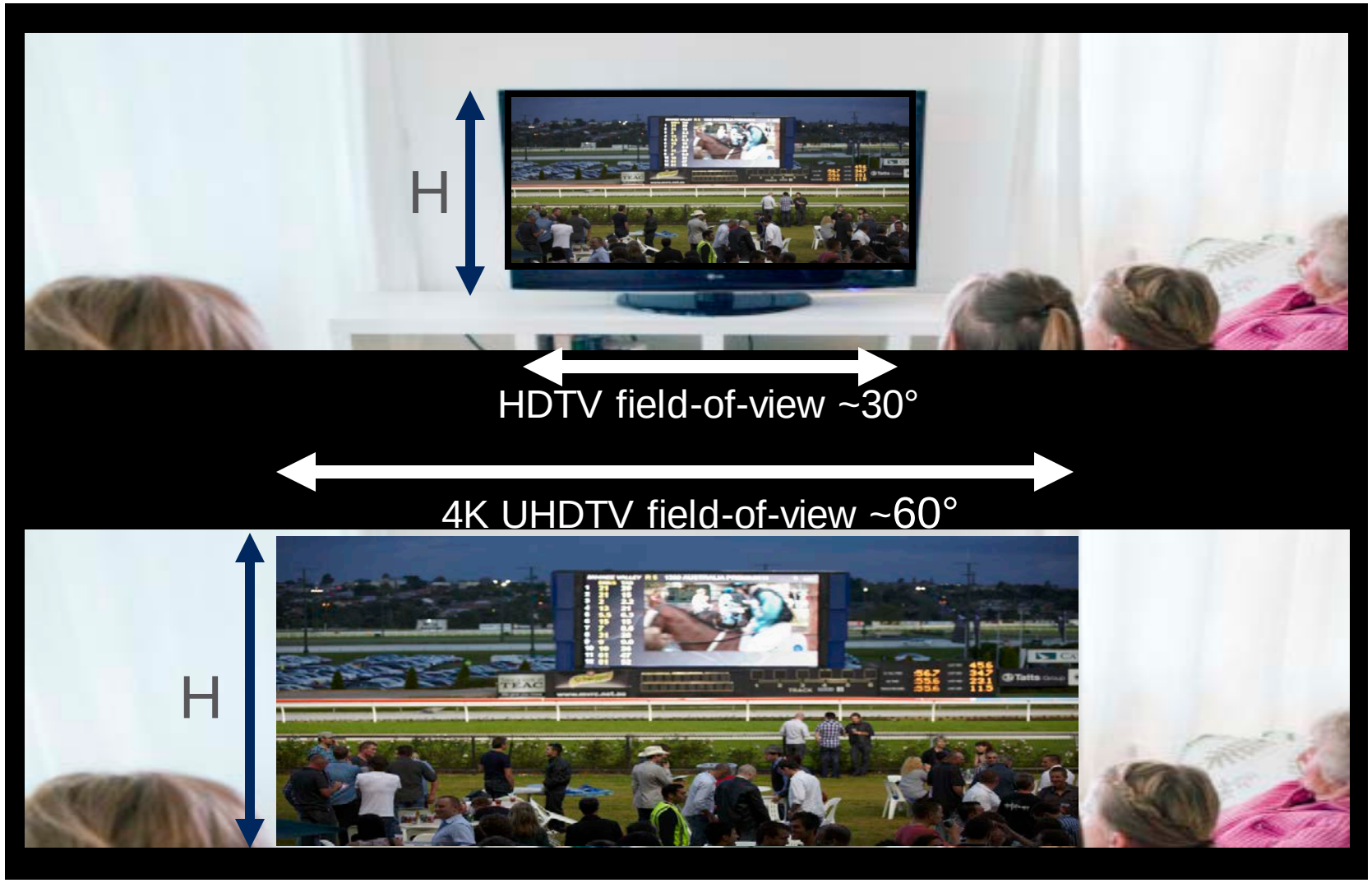
4K UHD (2160p) ~= 1.5H



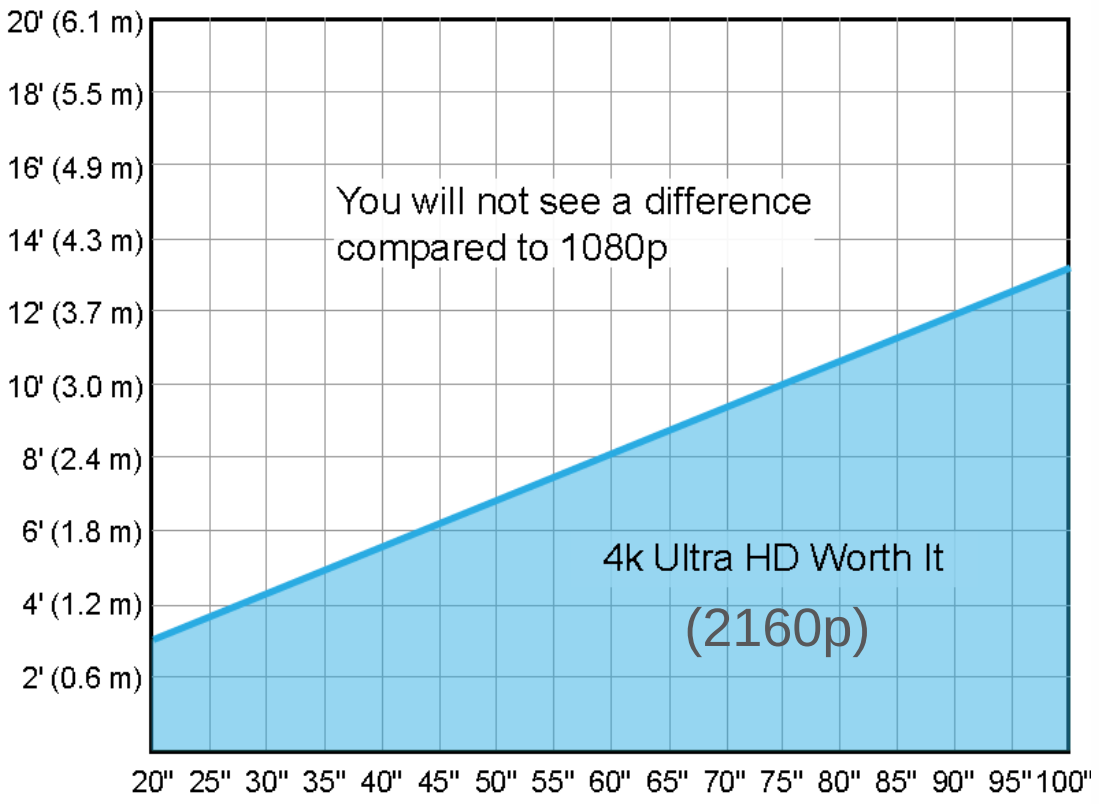


$D = (W/2)/\tan(x)$

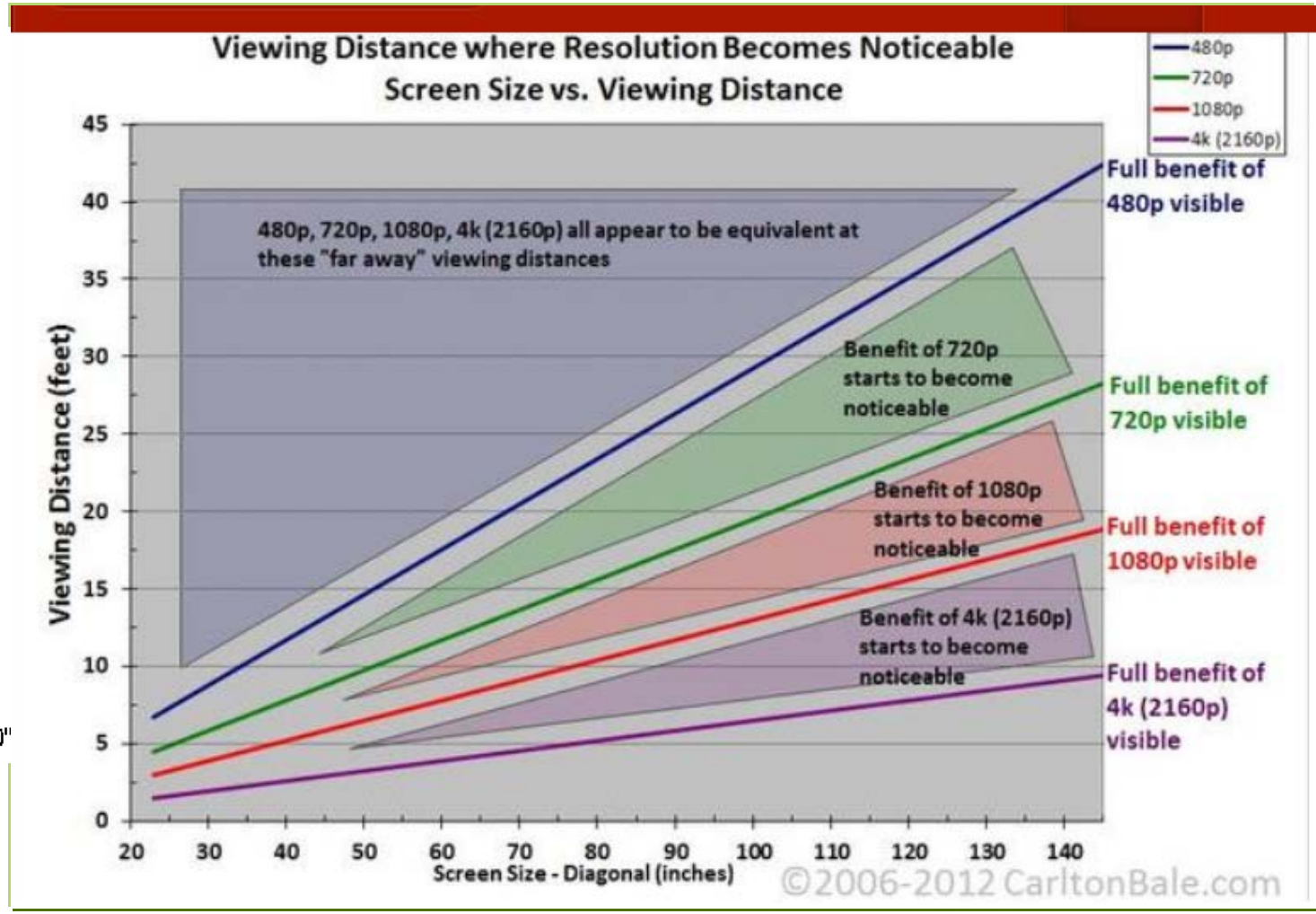
Screen size = $\sqrt{(H^2+W^2)}$



SCREEN SIZE VS. VIEWING DISTANCE



Source:
http://www.rtings.com/info/4k-ultra-hd-uhd-vs-1080p-full-hd-tvs



HIGH DYNAMIC RANGE (HDR)

- HDR immersion not limited to strict viewing distance
  - Benefits large screens (including HD) and tablets and phones

- Once you have seen HDR, you realize how much better than current TV it is

Pictures are richer, more lifelike and sharper with HDR. Seeing is believing.

HDR AND PERCEIVED RESOLUTION

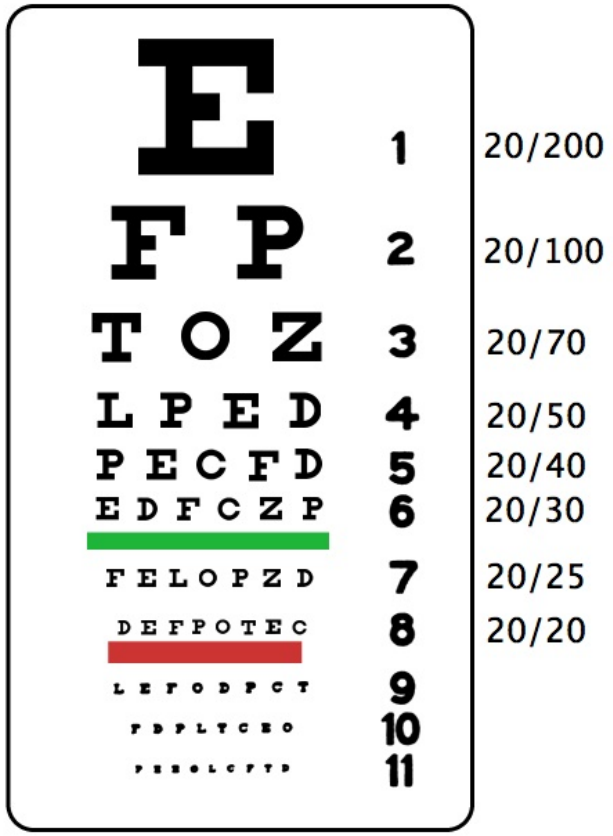
Which image has higher resolution?

HDR AND PERCEIVED RESOLUTION

Low contrast image looks ‘softer’ as some detail is harder to see

More dynamic range can reveal more detail – especially edges – and looks sharper (although the pixel resolution is the same)

CONTRAST EFFECTS ON RESOLUTION



Snellen chart:

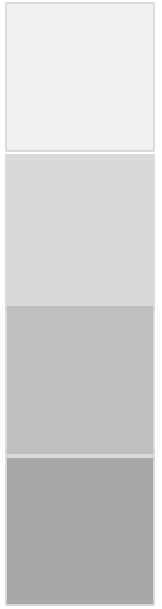
Impact of size/distance on resolution

Pelli-Robson chart:

Impact of contrast on resolution

THIS IS (SIMPLISTICALLY) HOW IT WORKS

SD/HD/4K TV Today:
Low dynamic range means subtle contrast differences in the original content (and which many cameras can capture) are not maintained – detail is missing.



HDR TV:
High dynamic range means subtle contrast differences in the original content can be captured and transmitted to the consumers, revealing previously hidden detail.

HDR IS NOT ABOUT BRIGHTER DISPLAY!

- SDR: Video generally ≤ 1.25x; Cinema generally ≤ 2.7x
- HDR: May be up to 100x

Source: Report ITU-R BT.2390

HDR: SPECULAR LIGHT IMPACT

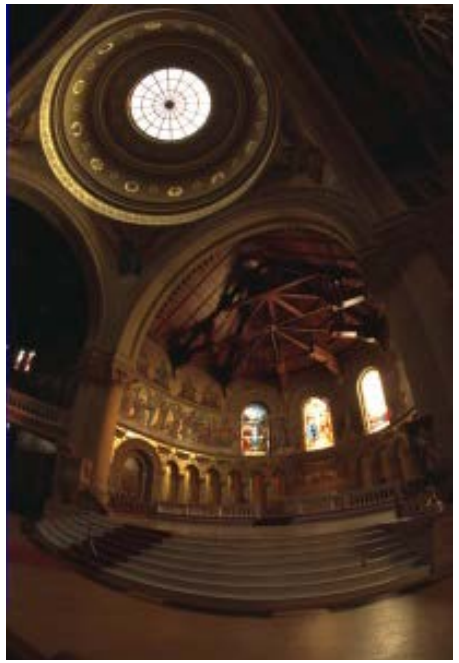
Images courtesy of Dolby Laboratories

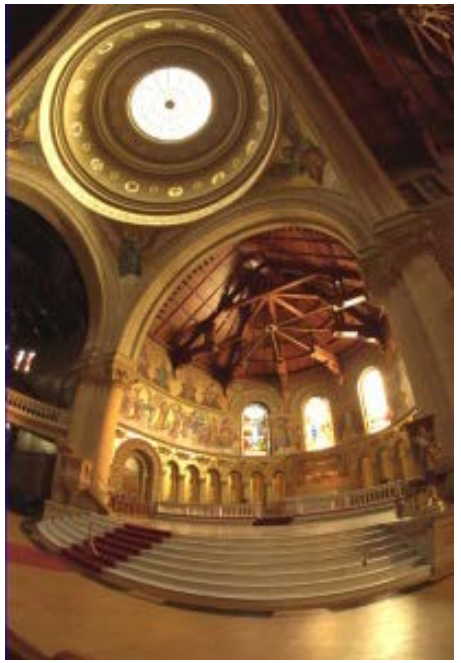
LUMINOUS INTENSITY

Candela per square meter (cd/m^2) or “nit”

Cinema today: 48 cd/m^2
- In dark viewing environment

Reference white for TV production: 100 cd/m^2
- Rec. ITU-R BT.1886
- Based on 1930s CRT!

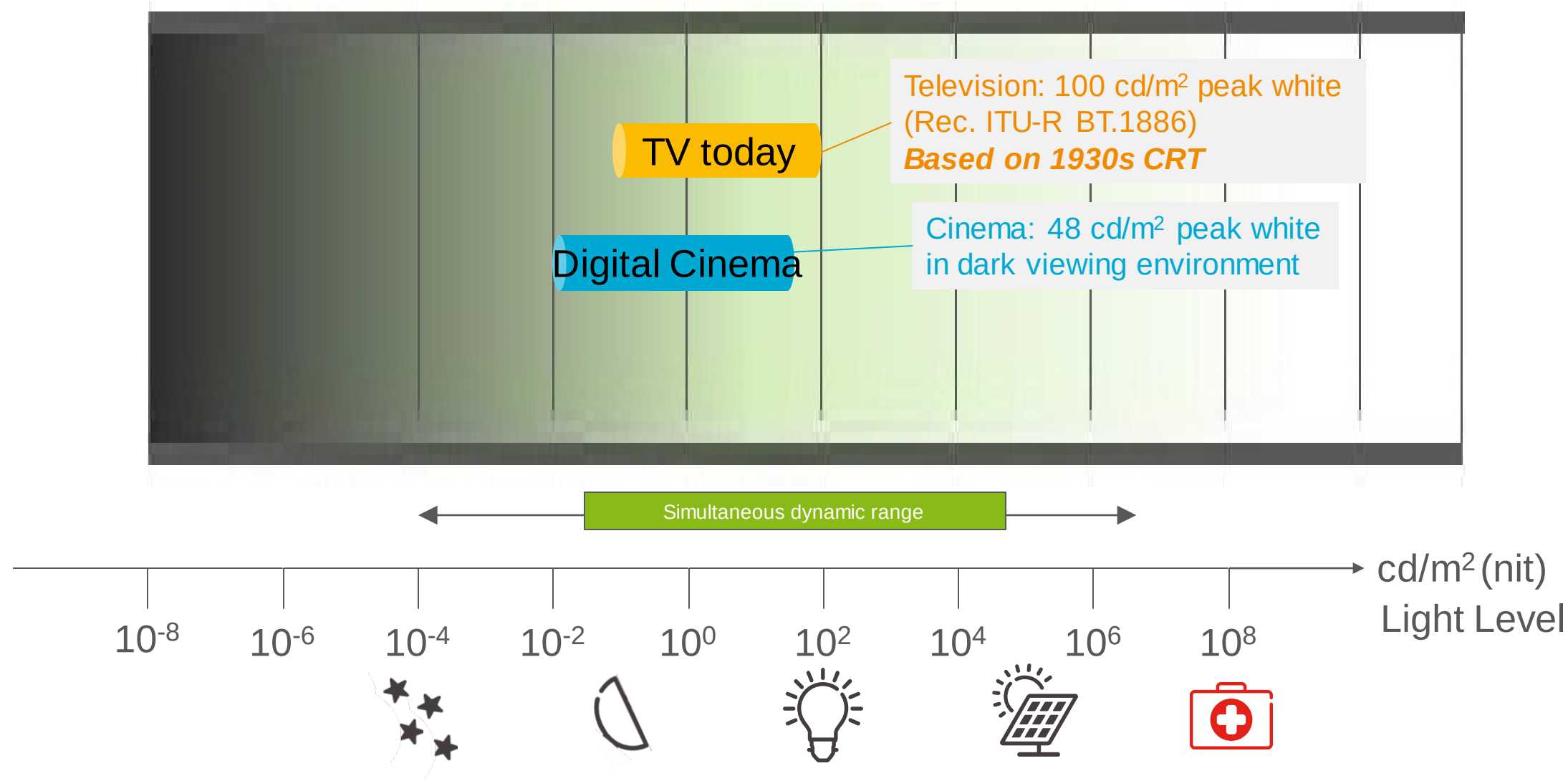




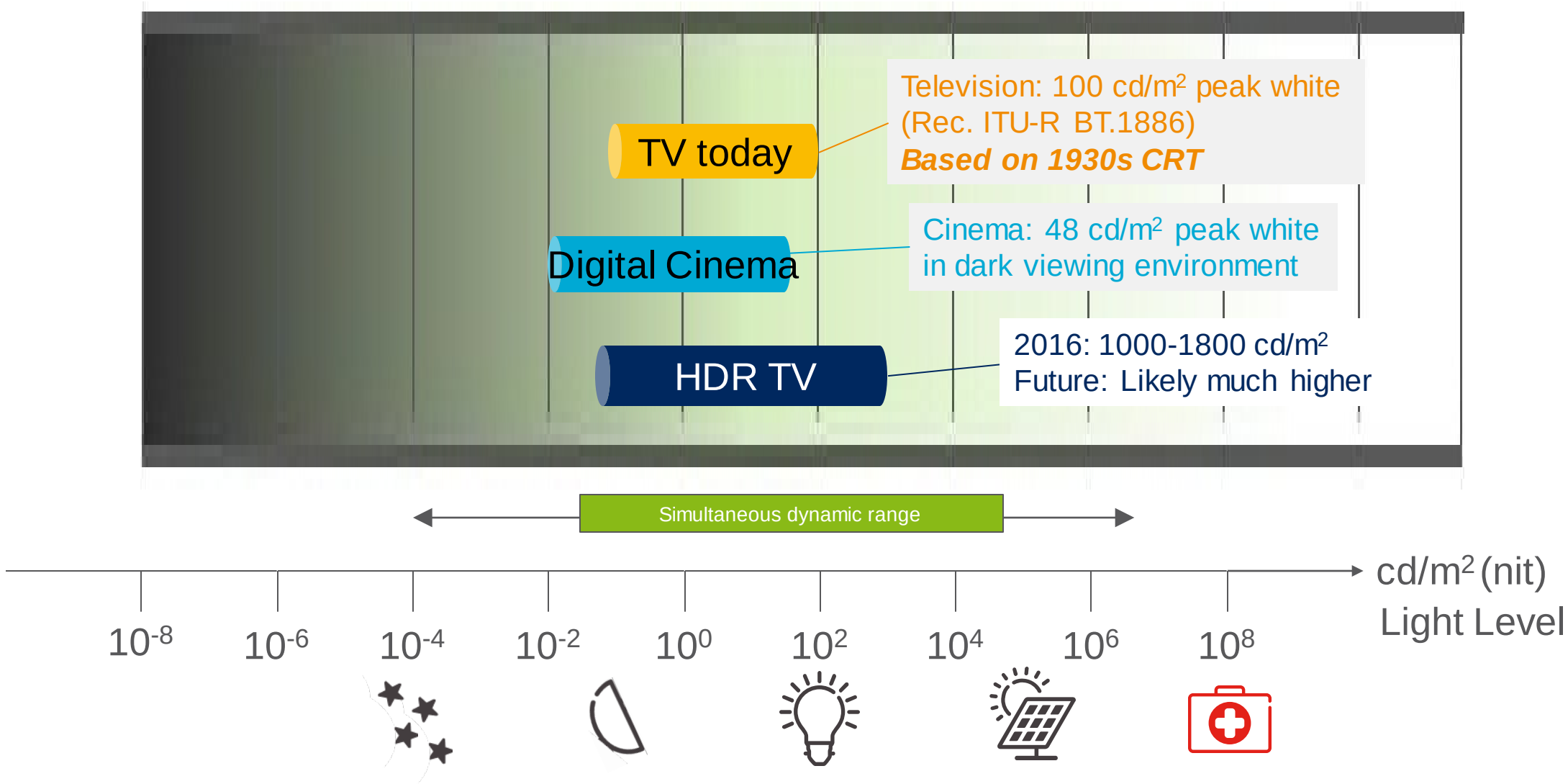
Typical LCD TV today (standard dynamic range, SDR): 300-400 cd/m^2

HDR TVs, now to future: 1,000 to 4,000 cd/m^2

HUMAN VISUAL SYSTEM CAPABILITY



HUMAN VISUAL SYSTEM CAPABILITY



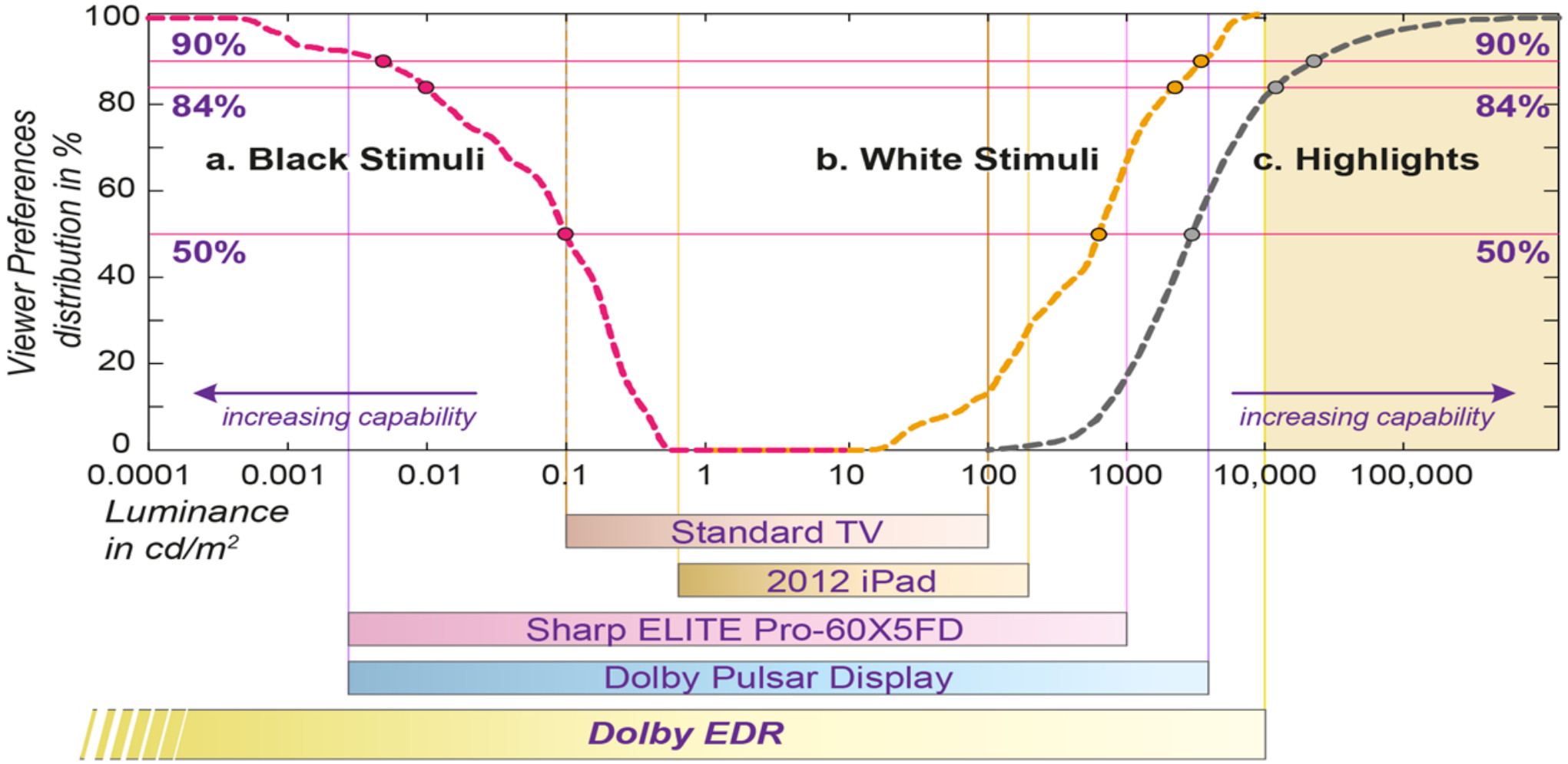
HDR LUMINANCE RANGE

- Previous HDR studies lacked a high dynamic range and high contrast ratio display
- Dolby built a prototype HDR P3 display which could create very deep black levels (0.004 nits) and up to 20,000 peak nits while maintaining a contrast of 5 million:1
- 3 preference studies were conducted to determine the preferences for
  - The Black level
  - The Diffuse White maximum
  - For the Highlights

Covers removed for photograph

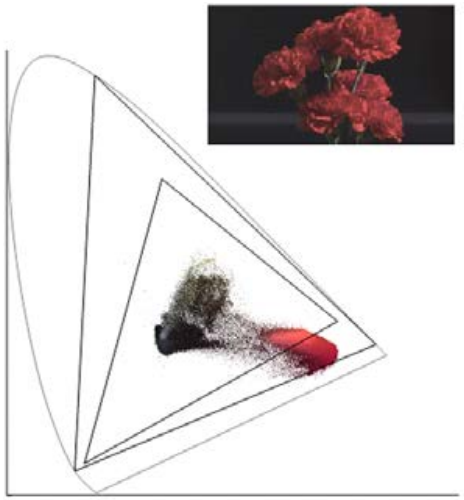
Courtesy of Dolby

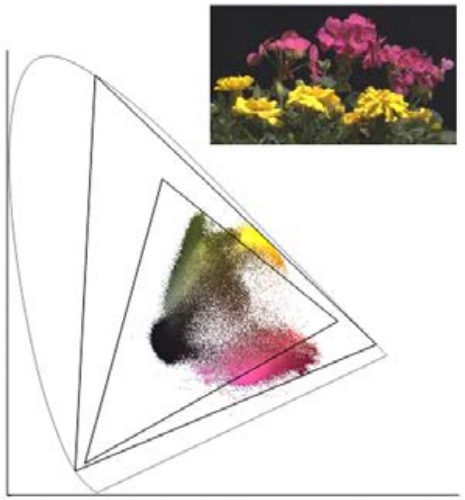
HDR STUDY (SMALL SCREEN)

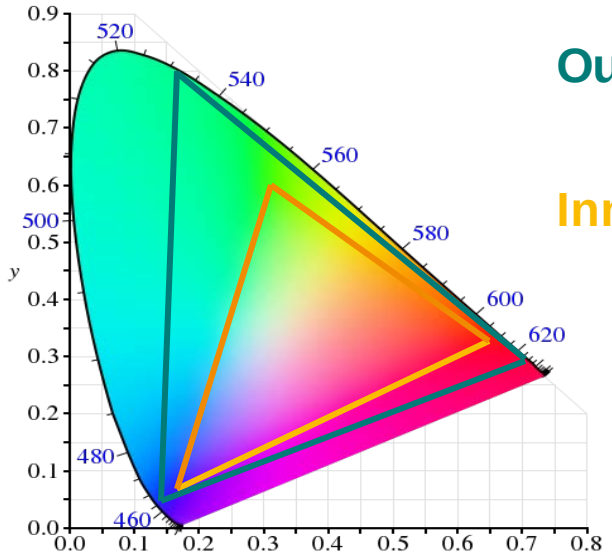


Courtesy of Dolby

WIDE COLOR GAMUT (WCG)
CAPTURE MORE OF REALITY – RICHER COLORS

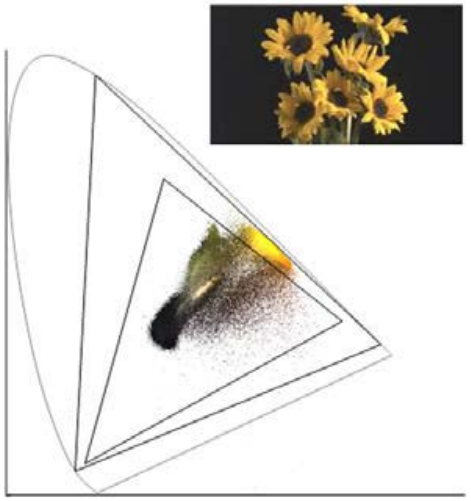


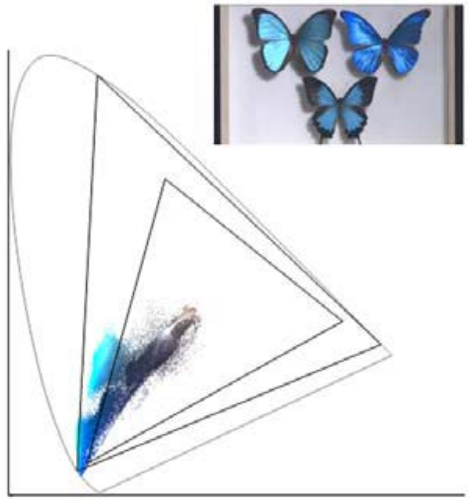


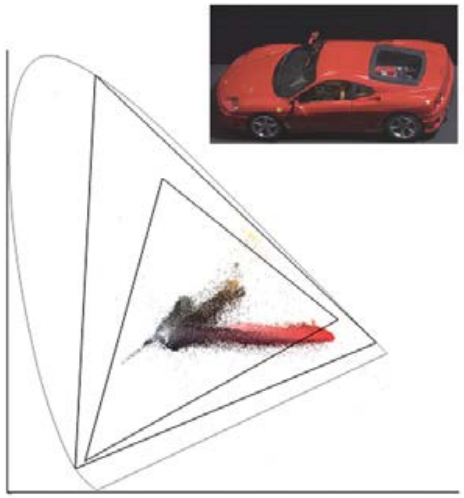


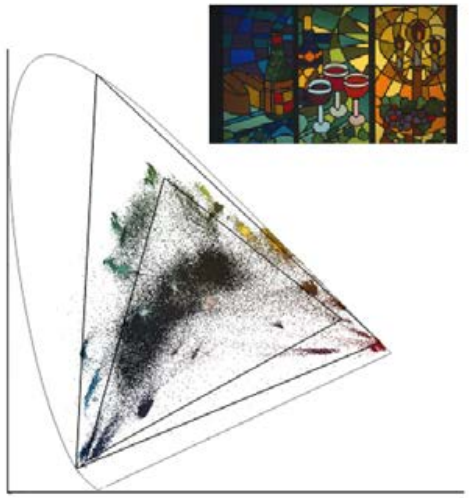
Outer triangle: UHDTV primaries
Rec. ITU-R BT.2020

Inner triangle: HDTV primaries
Rec. ITU-R BT.709







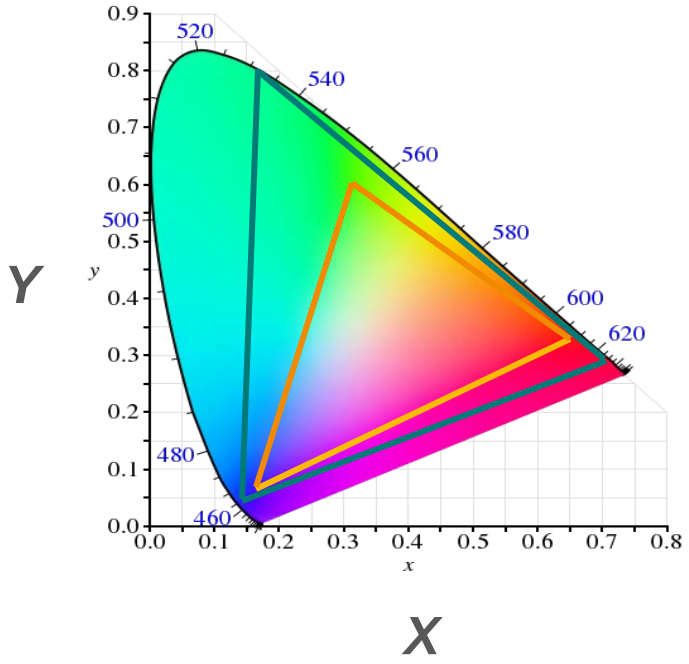


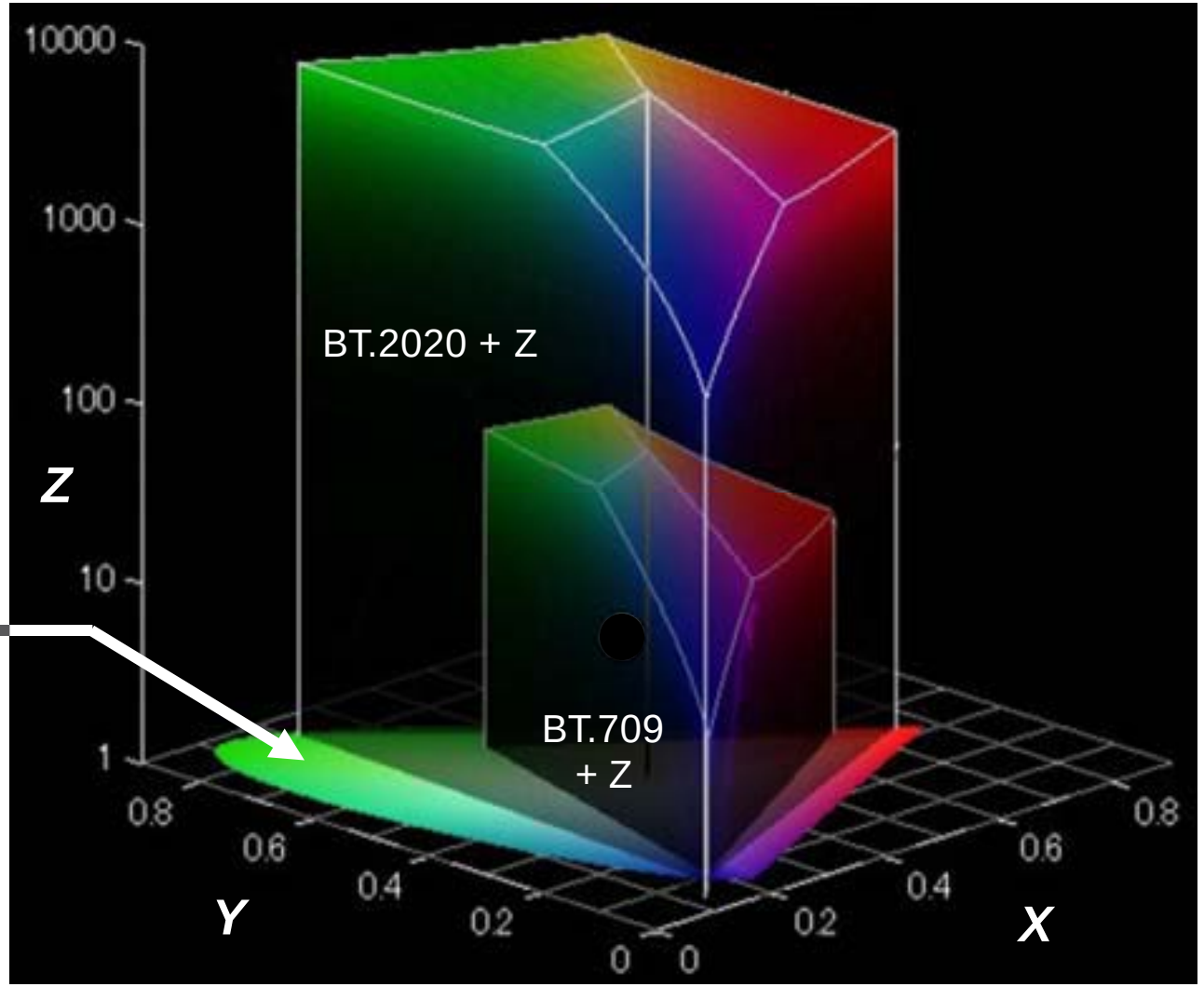
Source: Report ITU-R BT.2246

WCG & HDR ARE CLOSELY LINKED

Outer triangle: UHDTV primaries
Rec. ITU-R BT.2020

Inner triangle: HDTV primaries
Rec. ITU-R BT.709



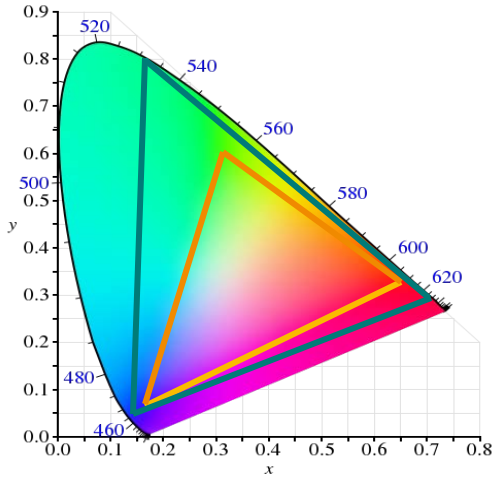


VISUAL QUALITY: SAMPLE BIT DEPTH

- Today, ***all*** direct-to-consumer digital TV uses 8-bit sampling
- Banding (posterization) with 8b, especially in plain areas
  - Sky, backgrounds, graphics, logo
  - Very noticeable with slow changes, such as fades
- Significantly improved PQ with 10-bit sample bit depth
  - No bandwidth cost in the compressed domain
  - HEVC Main-10 Profile allows 8-bit or 10-bit operation
- HDR and WCG exacerbates issues with 8-bit sampling

“HDR+” … FOR ANY IMAGE RESOLUTION

High Dynamic Range



Wide Color Gamut

10-bit Sampling

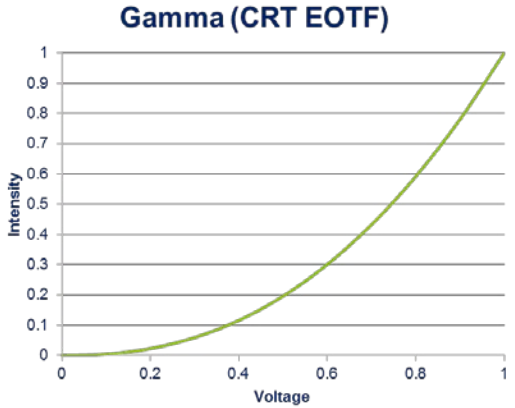
The combination of HDR, WCG and higher sample bit depth technologies – acts as a single feature!

Whether

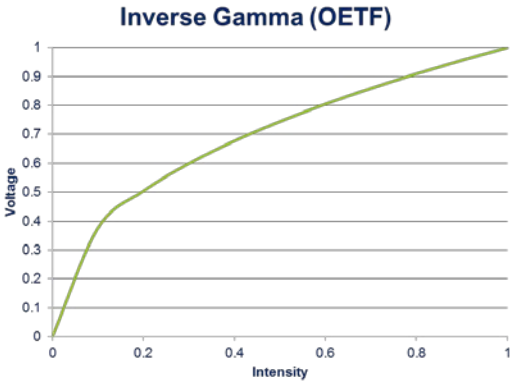
or

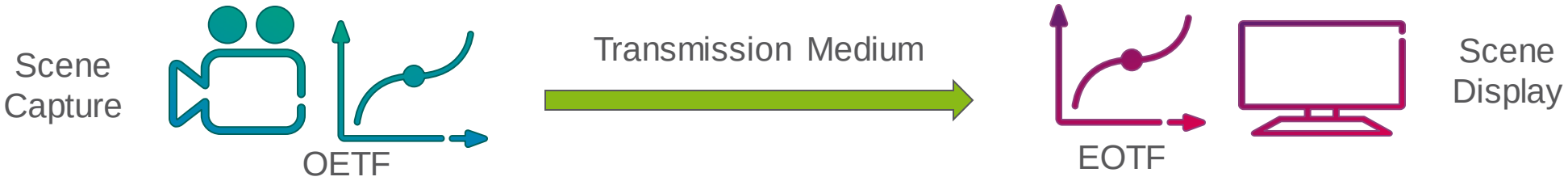
TELEVISION = *TELE + VISION*
FROM CAMERA TO DISPLAY

- To see what's happening from a far distance, the scene needs to be captured, transmitted to a remote location, then reconstituted
- Cameras convert scene light to an electrical signal, suitable of being transmitted over long distances, using an opto-electronic transfer function (OETF)
- Display convert an electrical signal back to scene light using an electro-optical transfer function (EOTF)
- For over 60 years, the cathode ray tube (CRT) was the universal display technology used
- The response of a CRT to an input signal is not linear and its EOTF is commonly known as gamma



$L = V^{\gamma}$
where $\gamma = 2.35$ for HDTV (ITU-R BT.709)

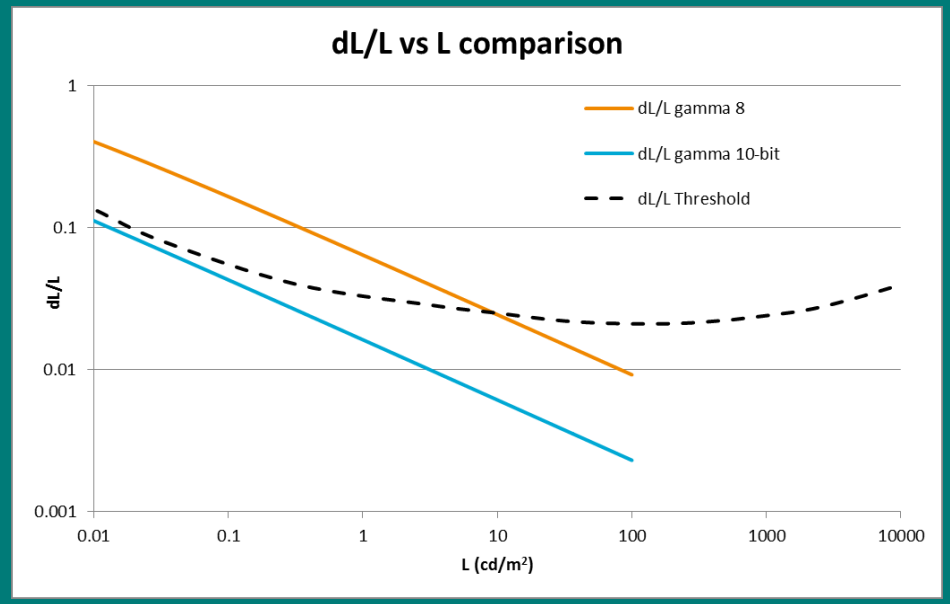




SAMPLE BIT DEPTH

0110 1001 01

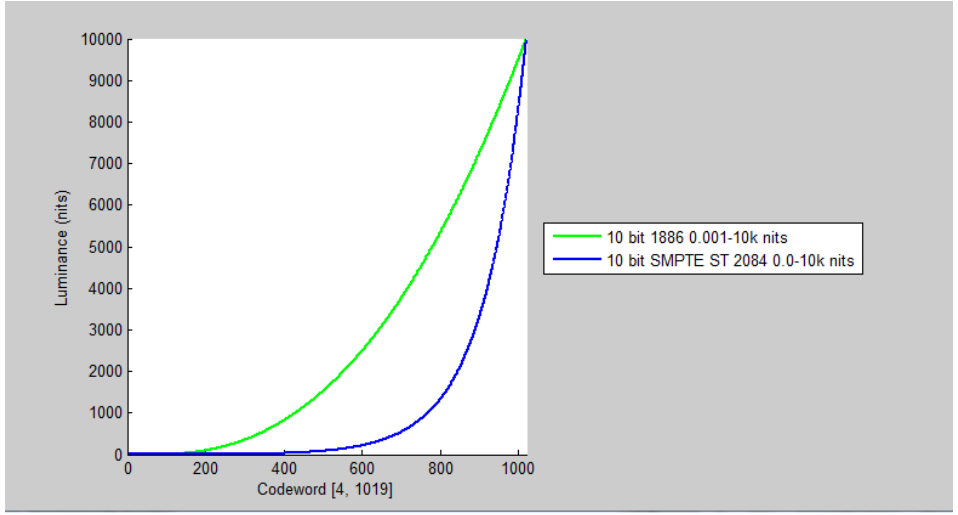
- Step size / Luminance (dL/L) is the measure of visibility
- Levels below the Barten's contrast sensitivity function (*dashed curve*) are masked from the HVS
- Mapping signal levels to display luminance (EOTF) is known as the gamma curve (*a straight line in log space*)
- 8-bit gamma-coded has large, visible steps across the range
- 10-bit gamma-coded reduces this dramatically



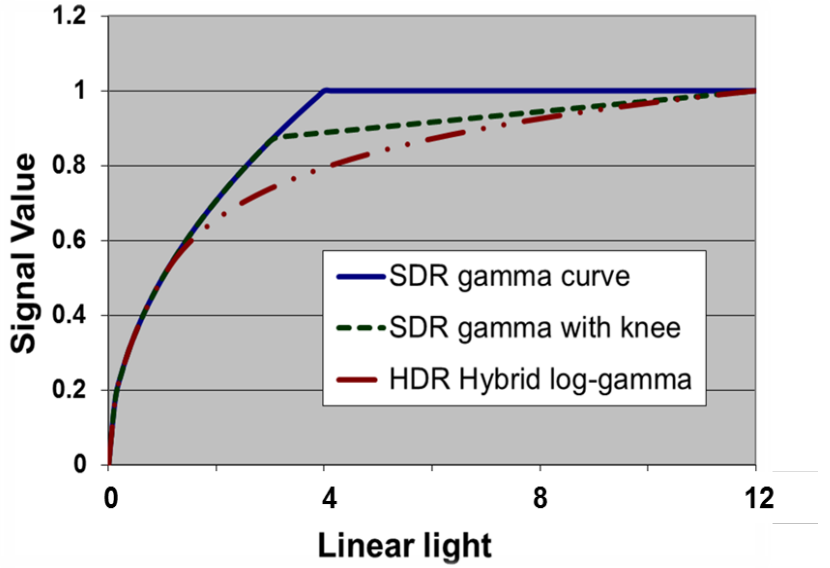
8 bit 10 bit

HDR TRANSFER FUNCTIONS

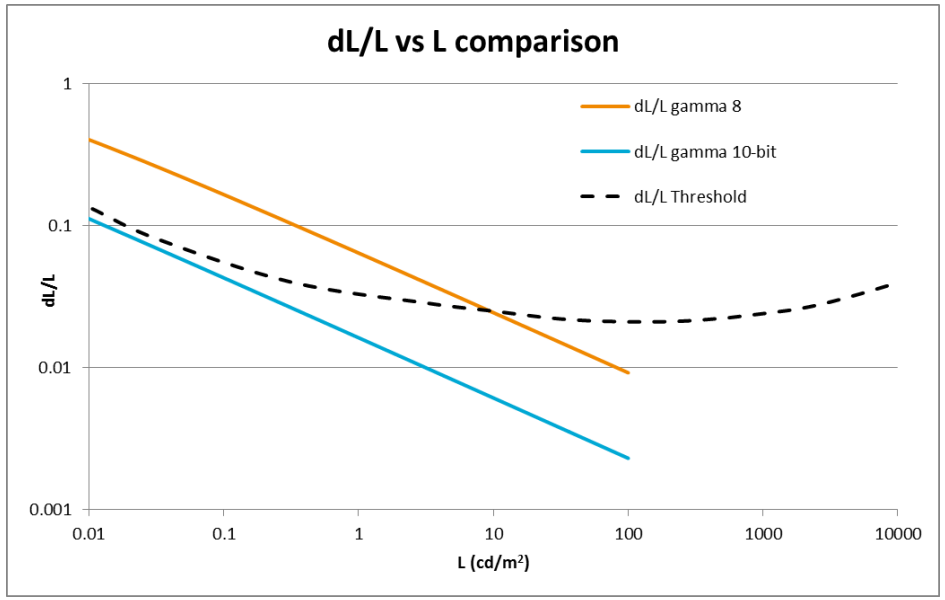
- Production reference for CRT peak white level is 100 nits
  - Now referred to as standard dynamic range (SDR)
  - SDR camera OETF comes from a desire to simplify analog TV electronics
    - Inverse of CRT gamma (EOTF)

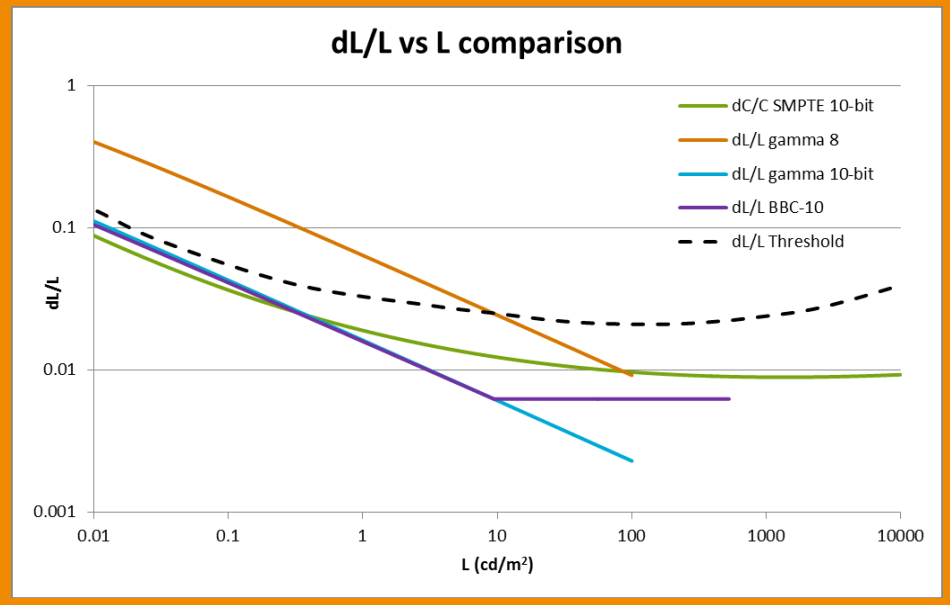


- Rec. ITU-R BT.2100 defines 2 HDR transfer functions:
  - SMPTE ST 2084 Perceptual Quantization (PQ) EOTF
  - Hybrid Log Gamma (HLG) OETF
  - **Rec. ITU-R BT.2100** – *Parameter values for high dynamic range television systems for production & international programme exchange*
  - **Report ITU-R BT.2390** – *High dynamic range television for production and international programme exchange* (companion report to BT.2100)



HDR TRANSFER FUNCTIONS



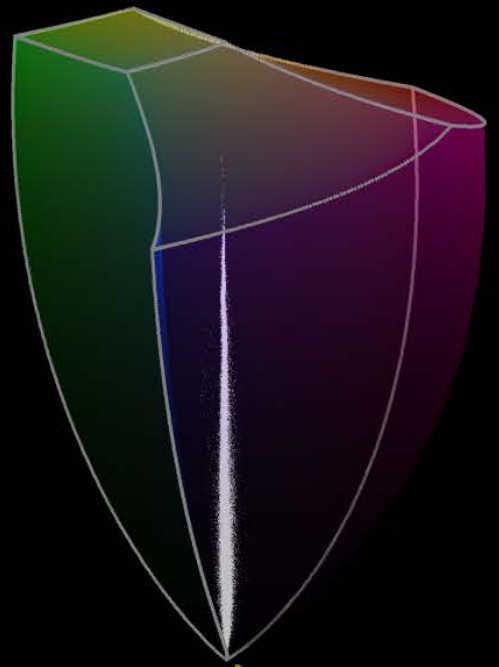


10-bit levels over wider range

ULTRA HD FORUM GUIDELINES PHASE A: PQ10, HDR10, HLG10

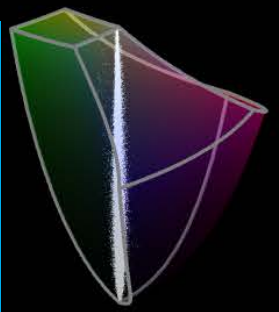
- PQ10 = SMPTE ST 2084 PQ HDR transfer function + Rec. ITU-R BT.2020 color space + 10-bit sample depth
- HDR10 = PQ10 + reference display metadata
  - Metadata = SMPTE ST 2086 HDR *static* metadata* + MaxCLL + MaxFALL
  - Specified by Blu-ray® Disc Association, DECE, CTA, UHD Alliance for pre-produced content
  - Uses HEVC Content Light Level SEI message
  - ***ST 2086:2014** – *Mastering Display Color Volume Metadata Supporting High Luminance and Wide Color Gamut Images*
    - *Specifies mastering display primaries, white point, and min/max luminance*
- HLG10 = HLG HDR transfer function + Rec. ITU-R BT.2020 color space + 10-bit sample depth
  - No metadata

STATIC CONTAINER MAPPING OF HDR TO SDR



Static Color Volume Mapping:

Container to Container



HDR Mastering Display Color Volume (SMPTE ST 2086)

SDR Display Color Volume (ITU-R BT.709)

Image courtesy of Dolby

ULTRA HD FORUM GUIDELINES FOR CONSIDERATION IN PHASE B

- Dynamic metadata system(s)
- PQ10 + frame-by-frame “Display Adaptation” metadata
- **SMPTE ST 2094-x suite –** *Content-Dependent Metadata for Color Volume Transformation of High Luminance and Wide Color Gamut Images*
  - *Specifies dynamic metadata used in the color volume transformation of source content mastered with HDR and/or WCG imagery, when such content is rendered for presentation on a display having a smaller color volume*
  - The most important elements for **live** production are:
    - Deep shadow => Min
    - Mid-tone (facial and interior) => Mid
    - Highlight regions => Max
  - Computed on a frame-by-frame basis

DYNAMIC CONTENT MAPPING FROM HDR TO SDR

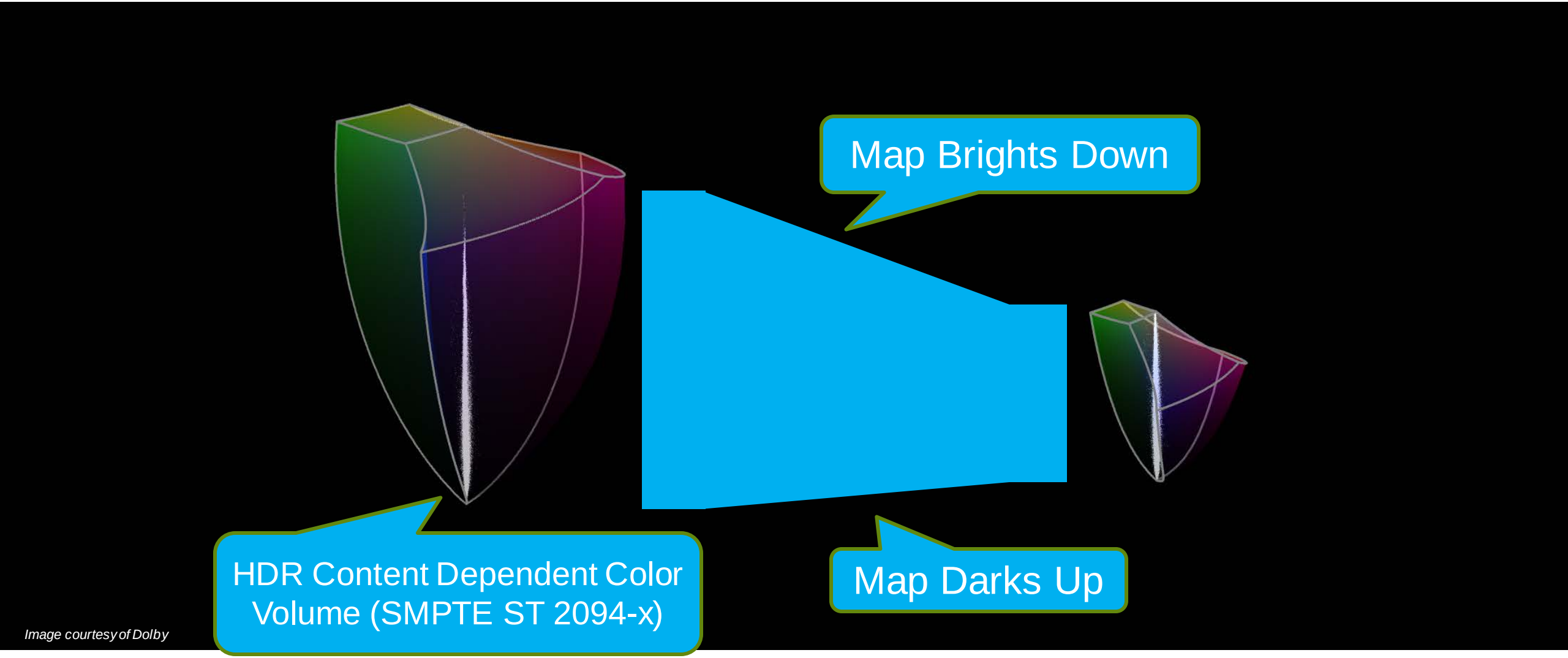


Image courtesy of Dolby

PER FRAME: MIN, MEAN, MAX

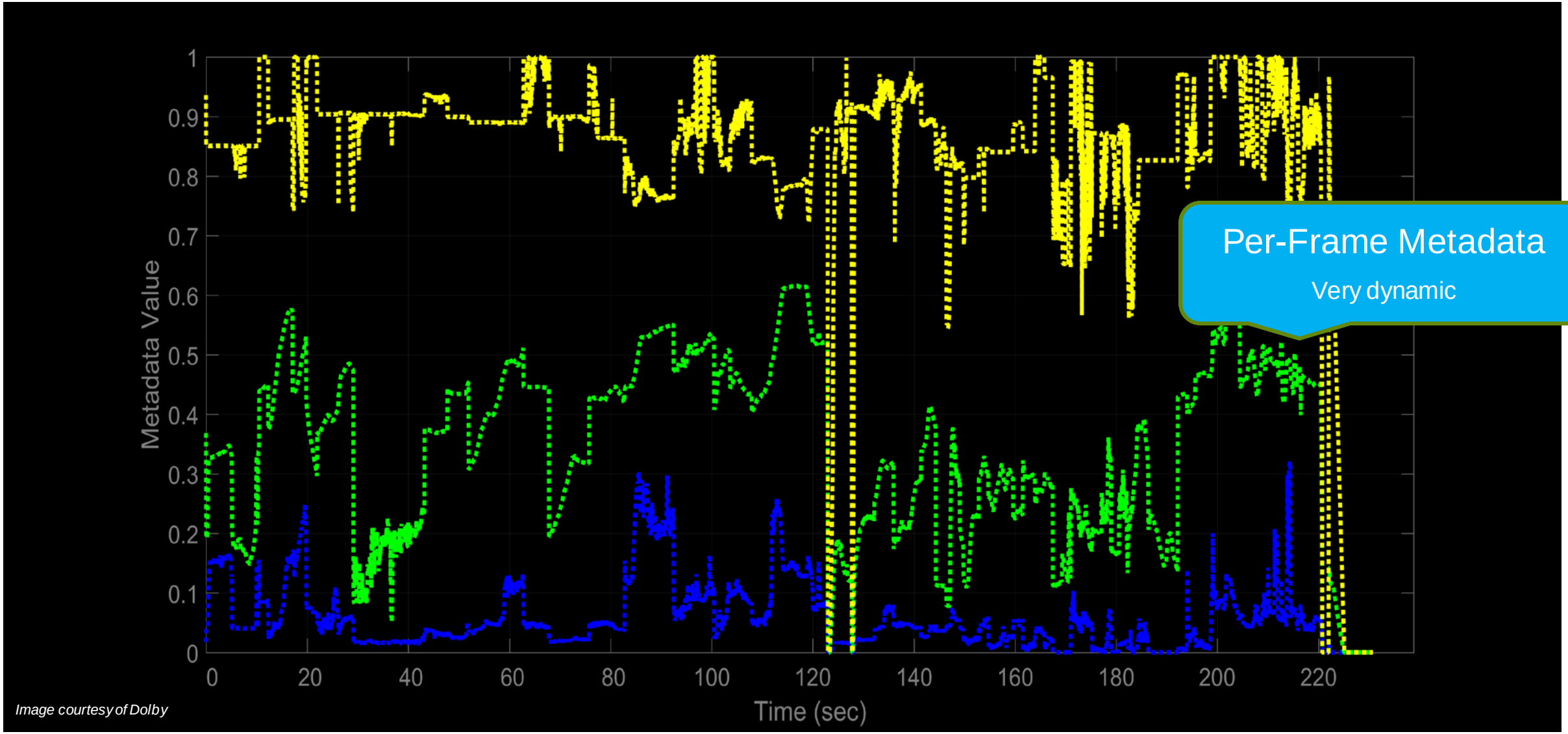


Image courtesy of Dolby

BACKWARD COMPATIBILITY TO LEGACY HD

- Dynamic range: ITU-R BT.2100 (PQ or HLG) → BT.709/BT.1886 (Gamma)
- Color space: ITU-R BT.2020 → BT.709
- Sample bit depth: 10b → 8b (for delivery-to-consumers)
- Spatial resolution: 3840x2160 → 1920x1080 or 1280x720 (as applicable)
- Temporal resolution: 50-60 fps progressive → 25-30 fps interlaced
- Video coding standard: HEVC → to AVC or MPEG-2 (for delivery-to-consumers)

- With "broadcast quality" images in both HDR and SDR formats
  - For legacy conventional HD service
  - For new Ultra HD service (1080p or 2160p HDR+)

Simulcast required unless all of these conditions are met*

**Note: the above still excludes modulation, transport, and audio BC!*

DYNAMIC METADATA APPROACHES

- Backward compatibility possible by using proprietary add-on schemes involving dual layers or single layer + “HDR enhancement” *dynamic* metadata
- Some examples
  - Dolby Vision: Dual layer, HDR baseline + “SDR reconstruction” enhancement layer
  - Dolby Vision Live: Single stream, HDR baseline + optional “Display Adaptation” metadata (SMPTE ST 2094-1 & 2094-10 HDR dynamic metadata)
    - Also optional ICtCp color space + optional closed-loop Re-shaper
  - Technicolor “SL-HDR1” (formerly “Prime”): Single stream, SDR baseline + “HDR Reconstruction” metadata (SMPTE ST 2094-1 & 2094-30 HDR dynamic metadata)
    - *Partial* “native” SDR BC → 10b, not 8b (issue with HEVC Main10 Profile)
  - Qualcomm: PQ10 + “Dynamic Range Adjustment” metadata
  - Samsung: PQ10 + optional dynamic HDR metadata

SEI MESSAGES FOR DYNAMIC METADATA: IMPLEMENTATION NOTE

- **SMPTE ST 2094-x suite –** *Content-Dependent Metadata for Color Volume Transformation of High Luminance and Wide Color Gamut Images*
- 4 different "applications" are standardized
  - 10: Dolby
  - 20: Philips
  - 30: Technicolor
  - 40: Samsung
- Unfortunately, the mapping into AVC | HEVC SEI messages is not identical
  - Application 3 (-30) has its own defined payloadType
  - The rest use the well-known user-data registered payload type of ITU-T T.35 wrapper
- There does not appear to be any coordination of how such messages are mapped
  - Each uses a different defining document, different provider code, different internal structure
  - That said, there does not appear to be any conflicts

SEI Message ST 2094-10 Dynamic Color Metadata App #1 (Dolby)

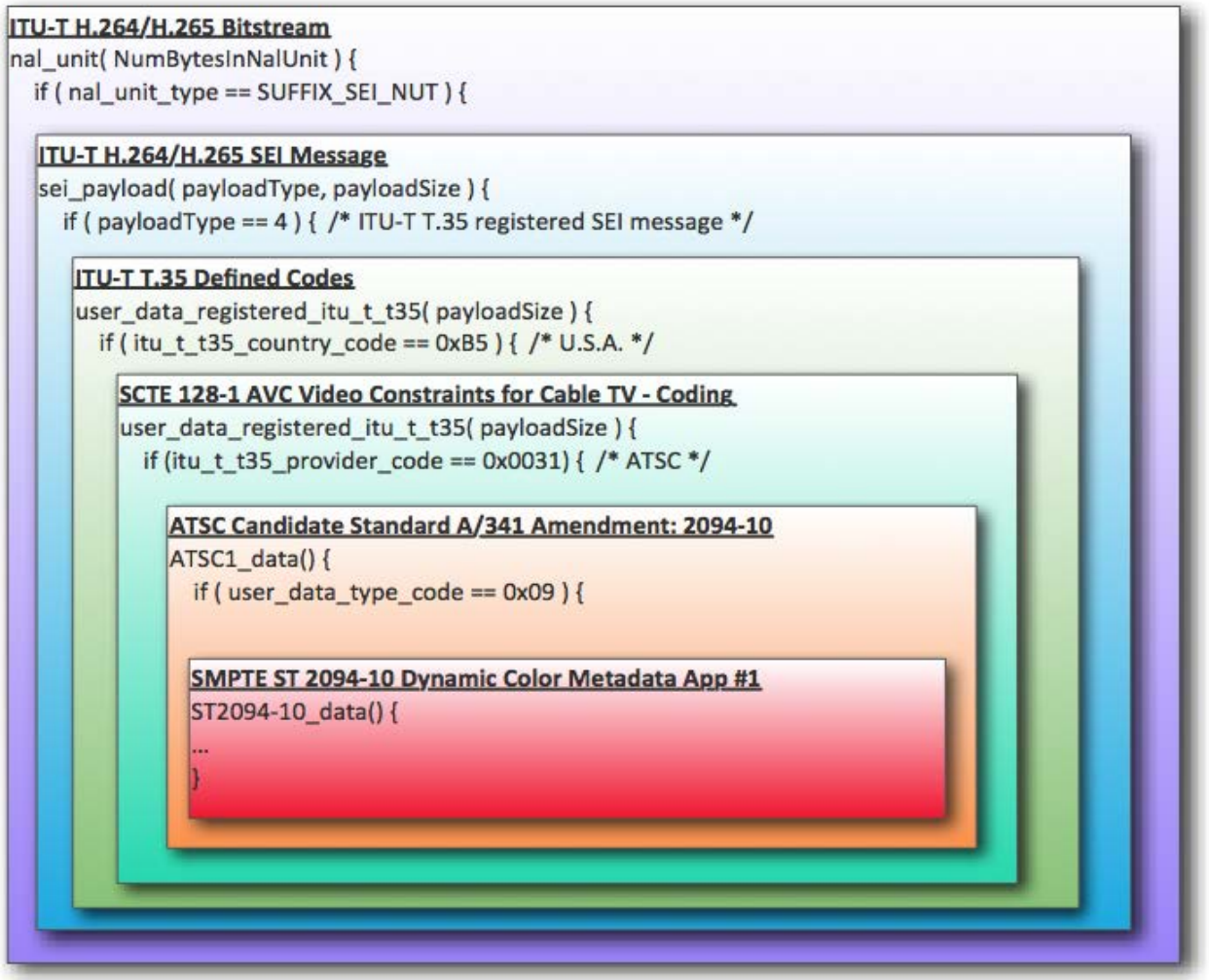


Image courtesy of Ed Reuss, Industry Consultant

SEI Message ST 2094-20 Dynamic Color Metadata App #2 (Philips)

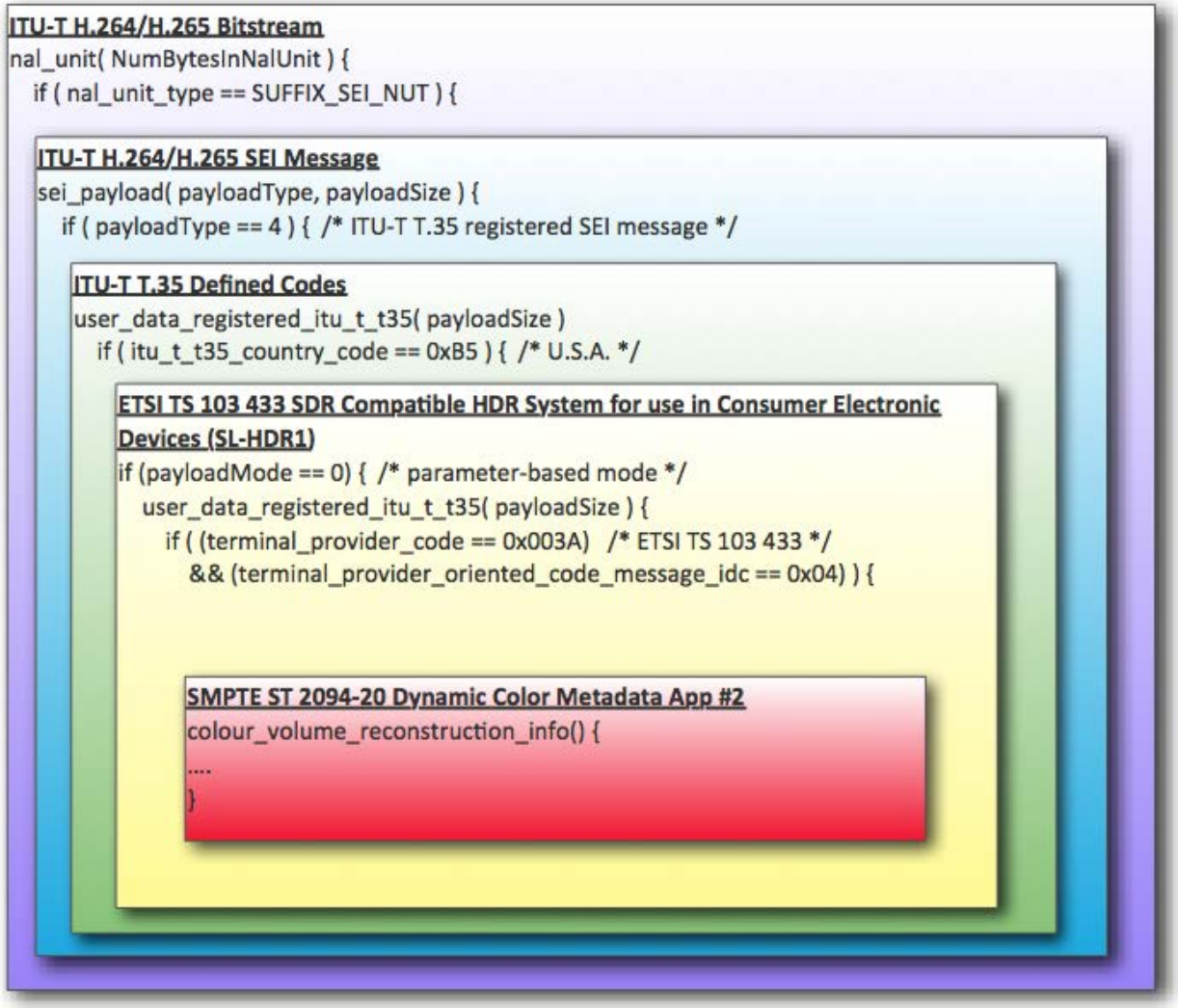


Image courtesy of Ed Reuss, Industry Consultant

SEI Message ST 2094-30 Dynamic Color Metadata App #3 (Technicolor)

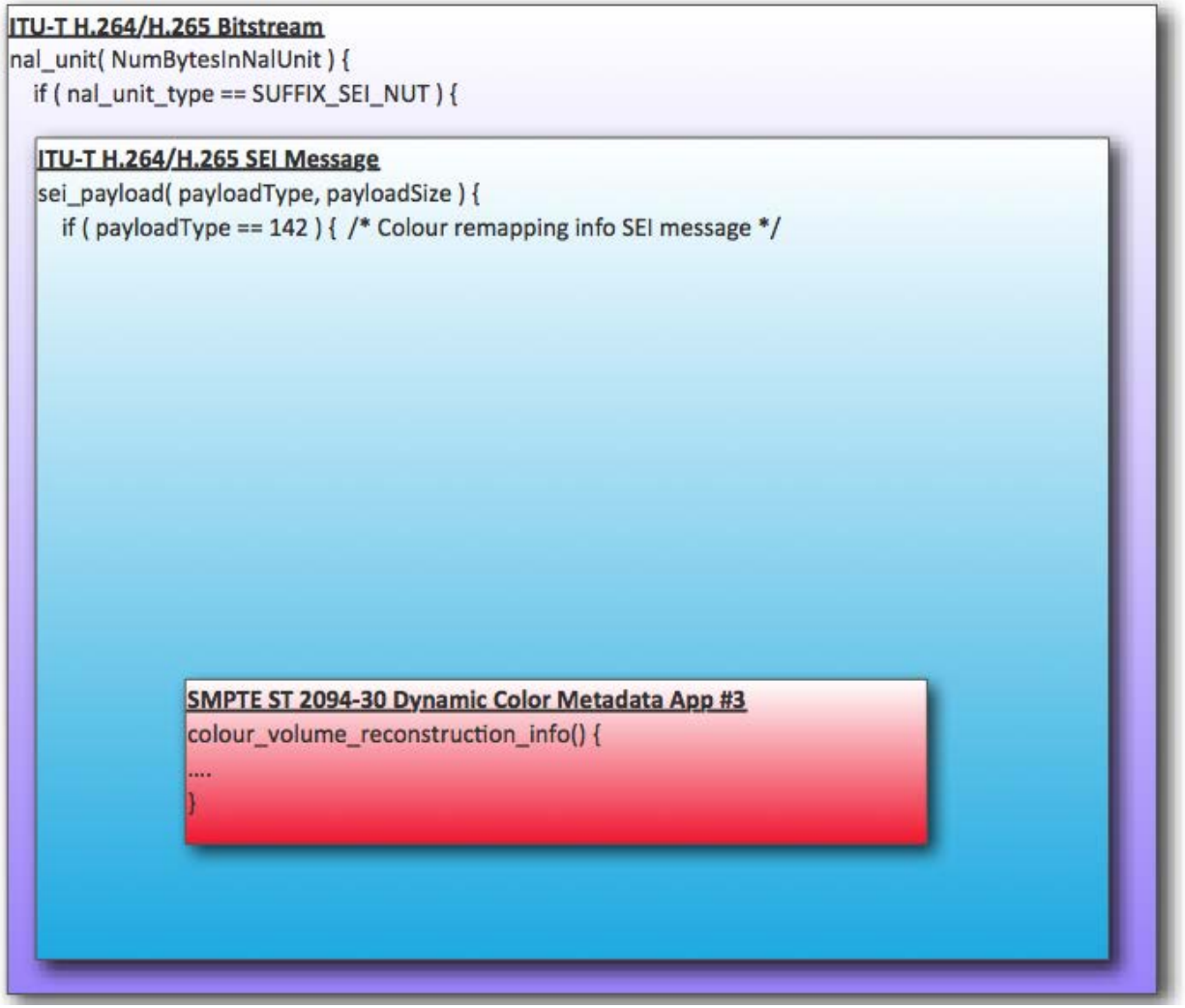


Image courtesy of Ed Reuss, Industry Consultant

SEI Message ST 2094-40 Dynamic Color Metadata App #4 (Samsung)

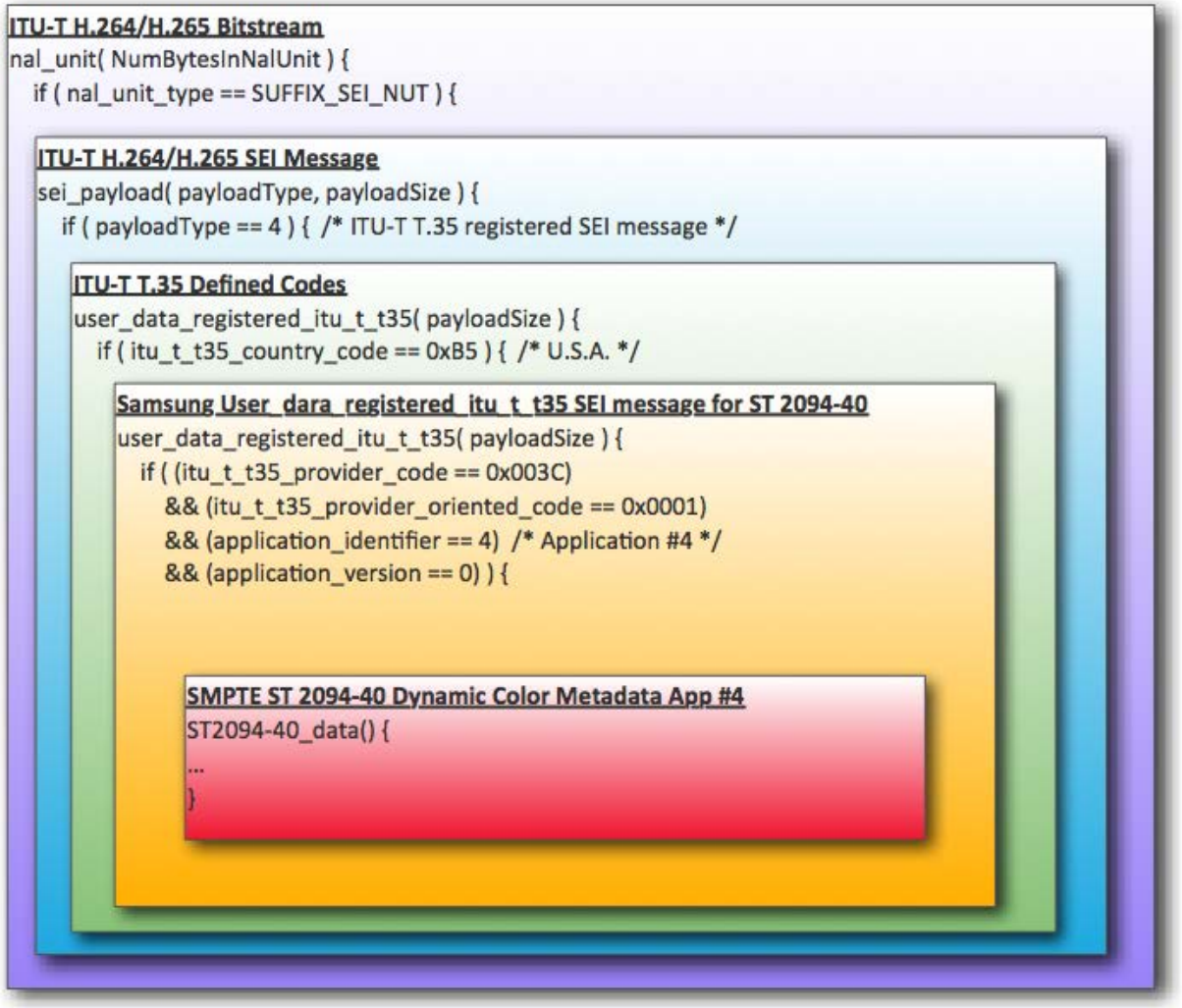


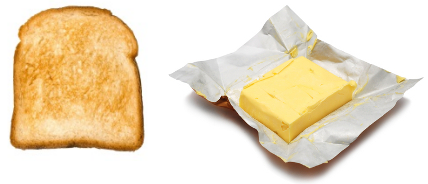
Image courtesy of Ed Reuss, Industry Consultant

HDR+ FOR ON-DEMAND ASSETS

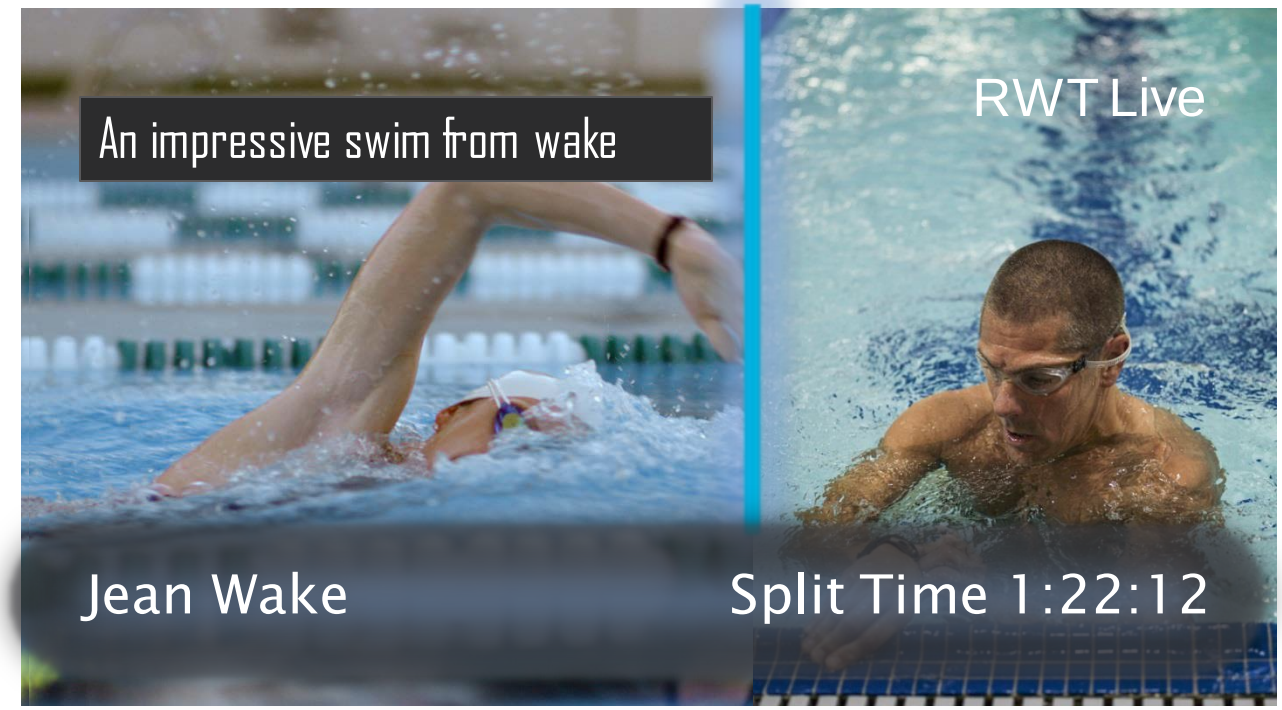
- Fewer constraints than live production
  - Post-production can produce for just that specific content
  - Knows about pictures “in the future”
  - A much more controlled environment
- Could exist in multiple formats if needed
  - Although more economical if there is only 1 format for all

LIVE TV CHALLENGES

- Live TV ecosystems have special needs
- To get on-air in early adoption (2017-2019?), must keep the solution simple and “forgiving”, to work as best as possible with existing live workflows
- Some proposed HDR schemes ***require*** metadata or dual layer streams
  - This information may get dropped until the HDR Live TV ecosystem matures (islands of implementations always occur in technology displacements)
  - For early Live TV workflows, use HDR schemes that do not require metadata or dual layers so that if lost/missing/not produced, renderer is still able to produce “broadcast quality” HDR images
- “Bread & butter” will be conventional HD for a long time
  - Simulcast likely required in early deployments



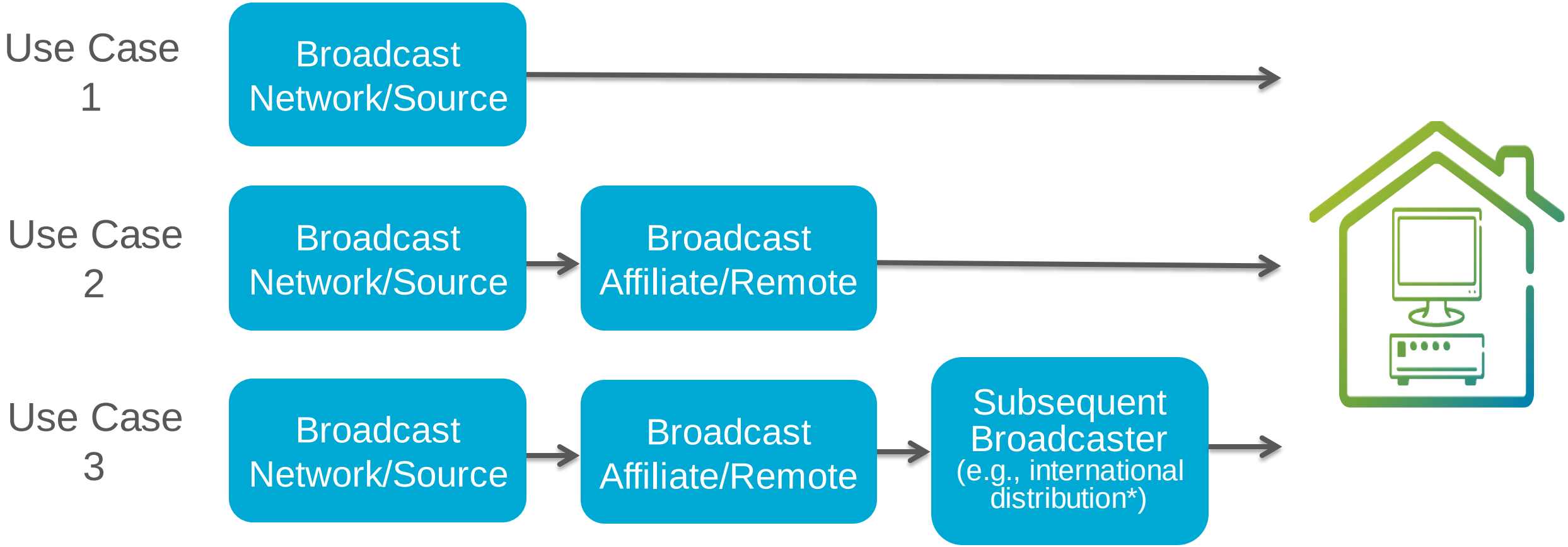
LIVE TV CONTENT DELIVERY IS NOT LIKE ON-DEMAND, BLU-RAY, OR CINEMA



Several HDR+ schemes had been proposed, based on discussions with Hollywood studios / Blu-ray Disc Association / display manufacturers. ***None of which, however, produce Live TV programming!***

"JUST INSERT AT THE FINAL ENCODE"

In Live TV, what/where is the "final encoder"?



**or MVPD (Cable or Satellite Provider) in some regions*

SDR CONTENT IN LIVE HDR BROADCASTS: THE CHALLENGE

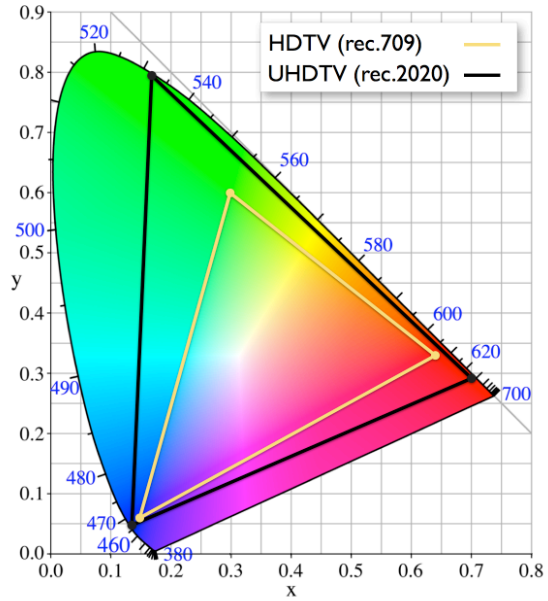
- Early HDR Live TV will have a limited amount of HDR content
- Unlike with On-Demand service, SDR content is likely to be mixed with HDR content during an HDR broadcast
  - Mix of live SDR and HDR sources
  - SDR interstitials in a HDR service
  - No post-production workflow stage like with On-Demand

SDR-TO-HDR CONVERSION: THE PROBLEM

- HDR content visualized on an HDR screen recreates the real world more faithfully than SDR content viewed on a conventional SDR display
- Since there is a great amount of legacy content which has been recorded, color graded and stored in SDR formats, it needs to be converted for correct visualization on HDR displays
- Inverse Tone Mapping (ITM) is a process performed on the original SDR source to create its HDR depiction, to match real-world luminance values as faithfully as possible
  - However, accurate reconstruction of real-world luminances is an impossible task, because information is lost due to data acquisition (sensor noise, dynamic range, saturation), data processing (quantization, conversion, clipping) and artistic manipulations (color grading, applying artistic vision)

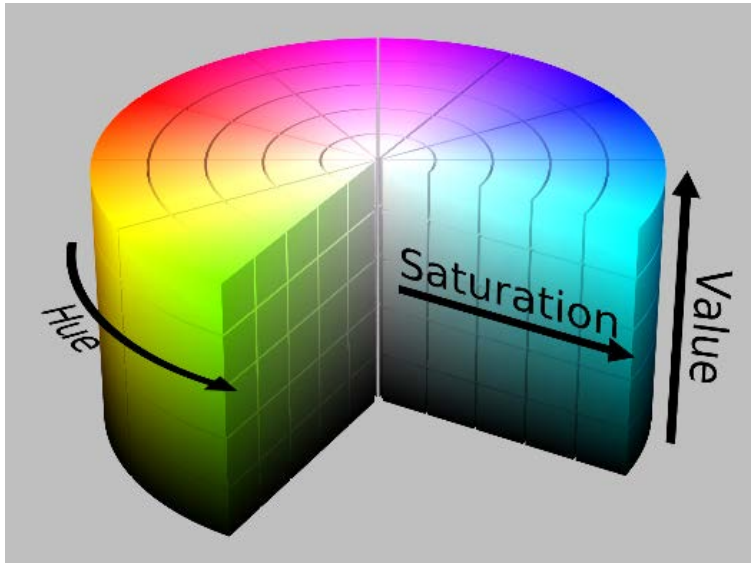
SDR-TO-HDR UPCONVERSION

- One cannot “create” HDR from SDR (despite some claims) as the SDR content has no HDR information
  - Subtle differences in HDR greyscale are missing and the SDR color space is smaller



UHDTV vs HDTV Color Gamuts

- However, one can “balance” SDR hue saturation and luma values, so that it looks correct on a HDR TV, running in HDR mode



WHY THIS IS IMPORTANT

HDR

SDR

SDR

HDR

WHY THIS IS IMPORTANT

HDR

SDR

SDR

HDR

HDR

SDR

SDR

HDR

VIDEO “LOUDNESS”!

› Remember audio loudness issues?

VIDEO "LOUDNESS"!

- Advertisers may use the opportunity to grab attention by introducing huge steps in light levels

BANDWIDTH IMPACTS

	Uncompressed	Compressed (consumer-grade)
4K (2160p) vs. 1080i HD	400%	circa 250%
“HDR+” (HDR+WCG+10bit)	25-30%	circa 0-20%
HFR (50-60fps → 100-120fps)	200%	circa 30%

In some cases, bandwidth also required to simulcast legacy HD bitstreams in addition to new UHD HDR+ bitstreams

SO WHAT ABOUT 1080P HDR?

- If bandwidth constraints prevent a broadcaster from offering all of the new technologies, then focus on the **“best bang for the bit”**
  - 1080p50/60 HDR
- Take advantage of all modern displays’ ability to up-convert 1080p to 4K (2160p)
  - Of course, HDR support required to render HDR

THINGS STILL TO DO

- Signaling of transfer functions and carriage of HDR metadata, end-to-end … *almost there!*
  - Production side (SMPTE standards): Both SDI and Pro Media over IP
    - Payload ID signaling added: Pre-FCD ST 292-1 (1.5G single-link), DP ST 372 (1.5G dual-link), DP ST 425-1 (3G single-link), FCD ballot ST 2036-3 (10G), Pre-DP ST 2081-10 (6G single-link), Pre-DP ST 2082-10 (12G single-link)
      - Harmonization planned with PDNR Rec. ITU-R BT.1120 Digital interfaces for studio signals with 1920 × 1080 image formats
    - WD SMPTE ST 2108 Extended HDR/WCG Metadata Packing & Signaling for SDI
    - FCD SMPTE ST 2110-40 Transport of SMPTE Ancillary Data
  - Consumer side completed:
    CTA / HDMI Forum – CTA 861-G, minimum HDMI 2.0b

OTHER THINGS STILL TO DO

- Recommended practice for HDR/HDR or HDR/SDR transitions
  - Address potential "Video Loudness" issues!
  - Matching light levels before mixing
  - Being considered by ITU-R, ATSC, DVB, SCTE, others
- Live TV workflows present many challenges to overcome
  - True backward compatibility?: The "Holy Grail"
  - What is the final (emissions) encoder?:
    Accepting that one doesn't own the entire real-world live workflow
  - What about mixing standard and high frame rates?

ERICSSON