HDR workflows: ITU vs ICC

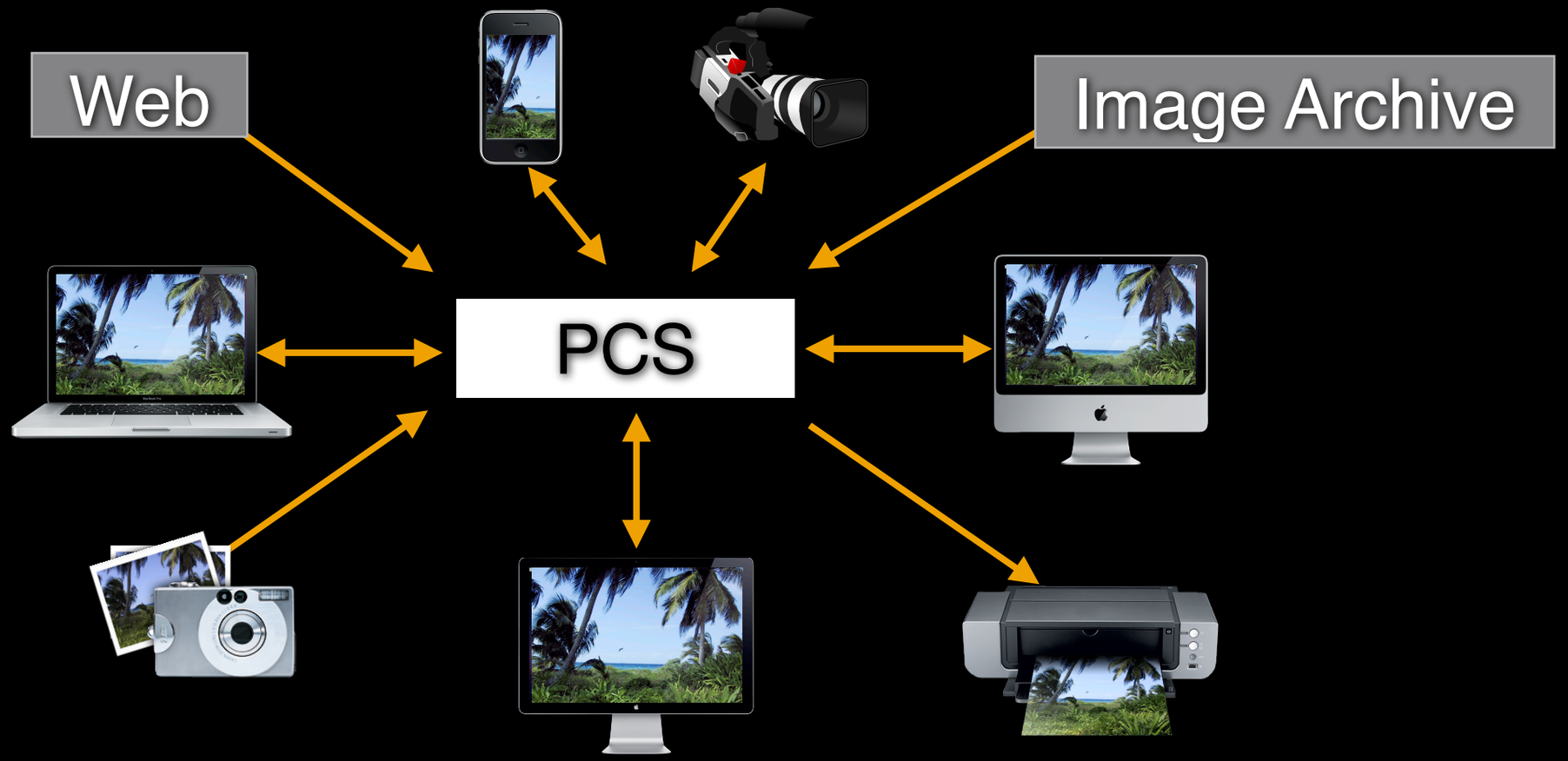
Is ICC color management model ready to embrace HDR Video workflows?

Luke Wallis
Apple Inc

ICC Color Management Workflows

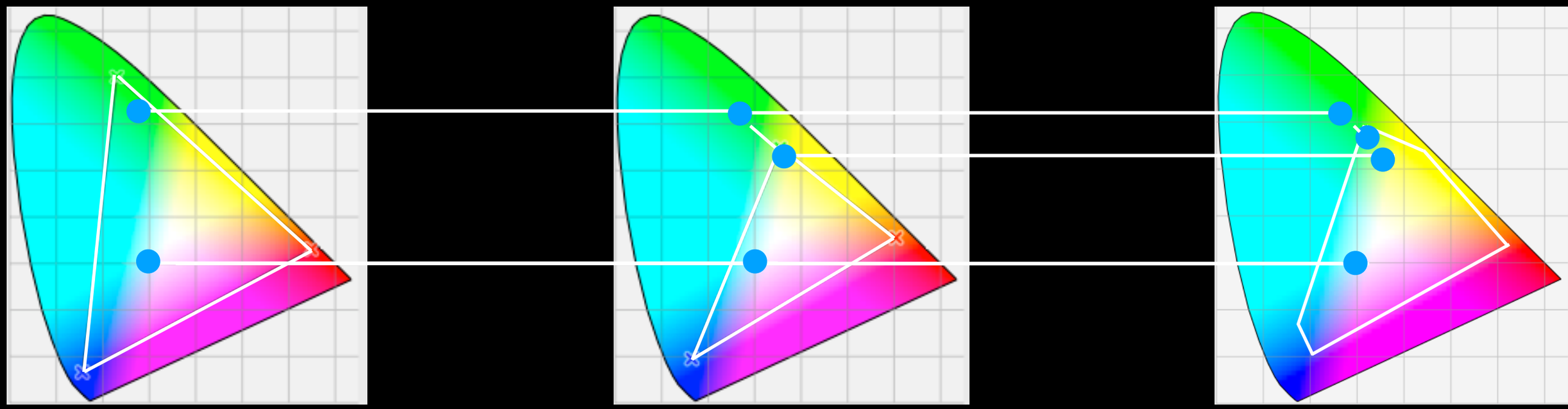
Framework for conversion between different color representation

Goal: consistent color appearance across devices



Problem: different devices have different color gamuts

Solution: gamut mapping



Camera

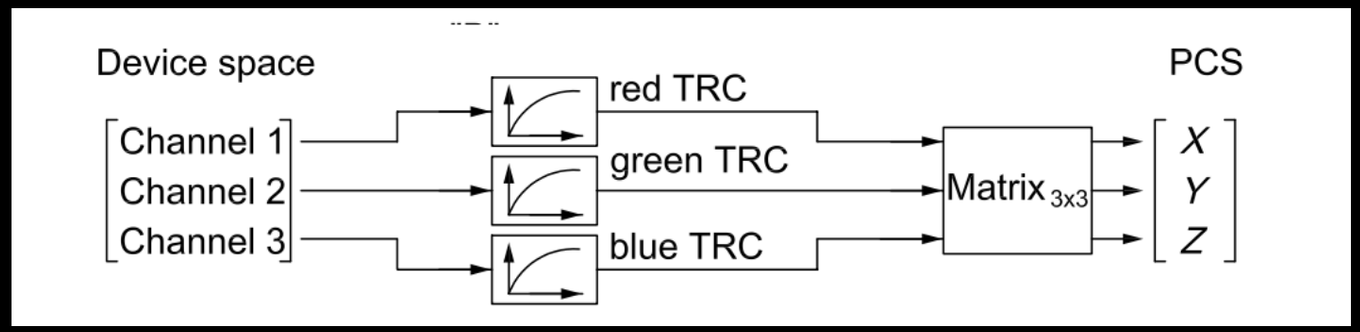
Laptop Display

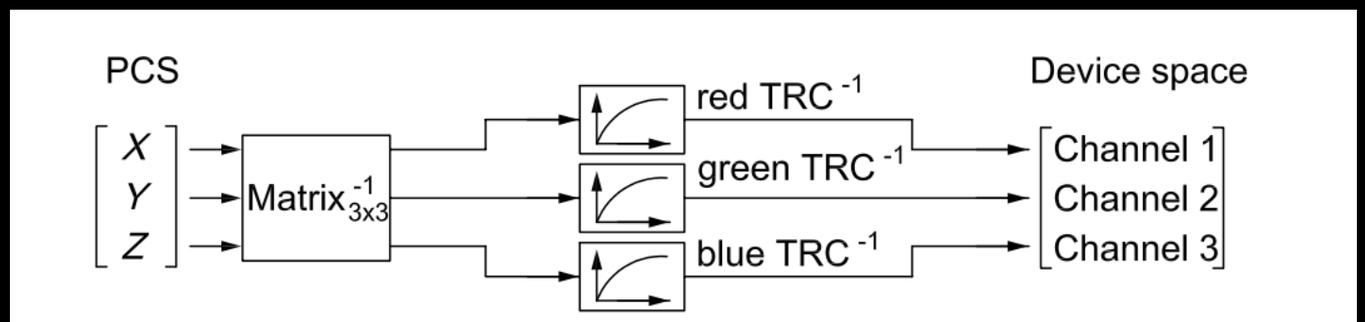
Inkjet Printer

ICC mathematical functions

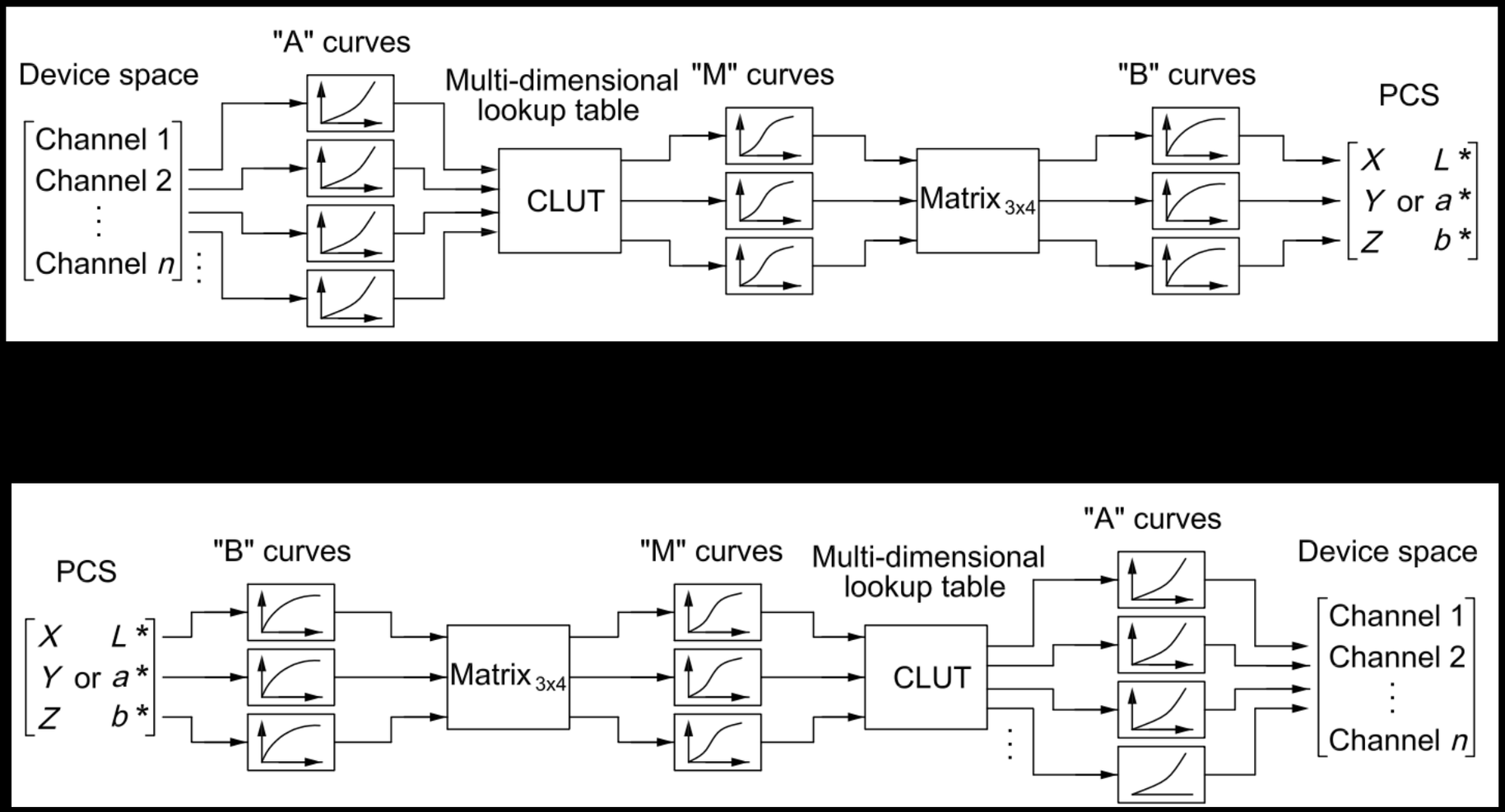
- Tone Rendering Curve
  - 1-D LUT
  - parametric: Y = (aX+b)^gamma + e [X >= d], Y = cX + f [X < d]
- Matrix
  - 3x3
  - 3x3 + 3
- CLUT
  - multi-dimensional interpolation table with N inputs and M outputs

Matrix-based RGB display profile





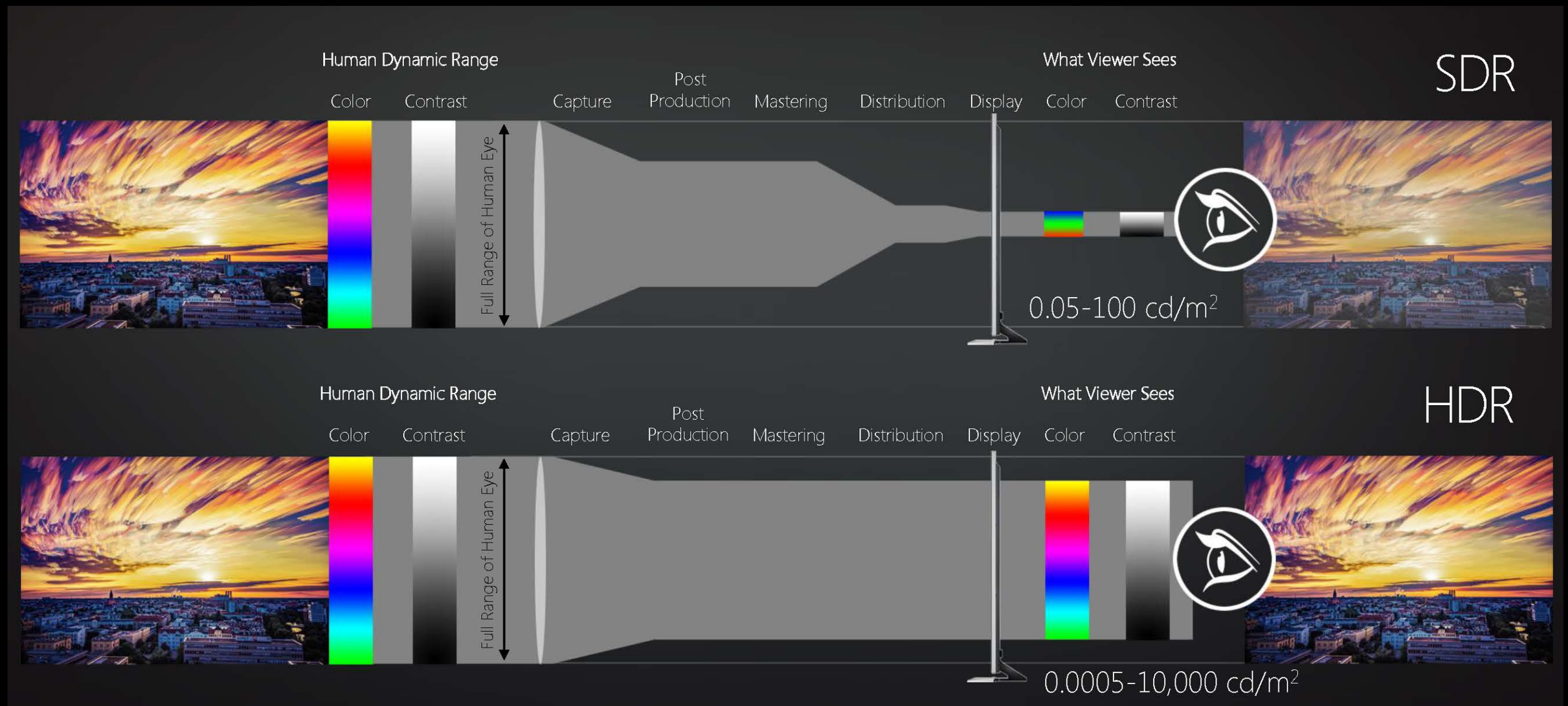
V4 Profile


Device space
Channel 1
Channel 2
Channel n
"A" curves
Multi-dimensional lookup table
CLUT
"M" curves
Matrix 3x4
"B" curves
PCS
X
Y or a*
Z
L*
b*
PCS
"B" curves
"M" curves
Multi-dimensional lookup table
CLUT
"A" curves
Device space

Notes on ICC approach

- ICC profiles describe device color gamut captured under one illuminant
- Design using PCS suitable for converting color from one gamut to another
- Predefined type and number of functions specific to the profile type
- Anonymous mathematical operations - flexible, but difficult to associate with standard functions like video transfer functions

Human Vision and Color Reproduction

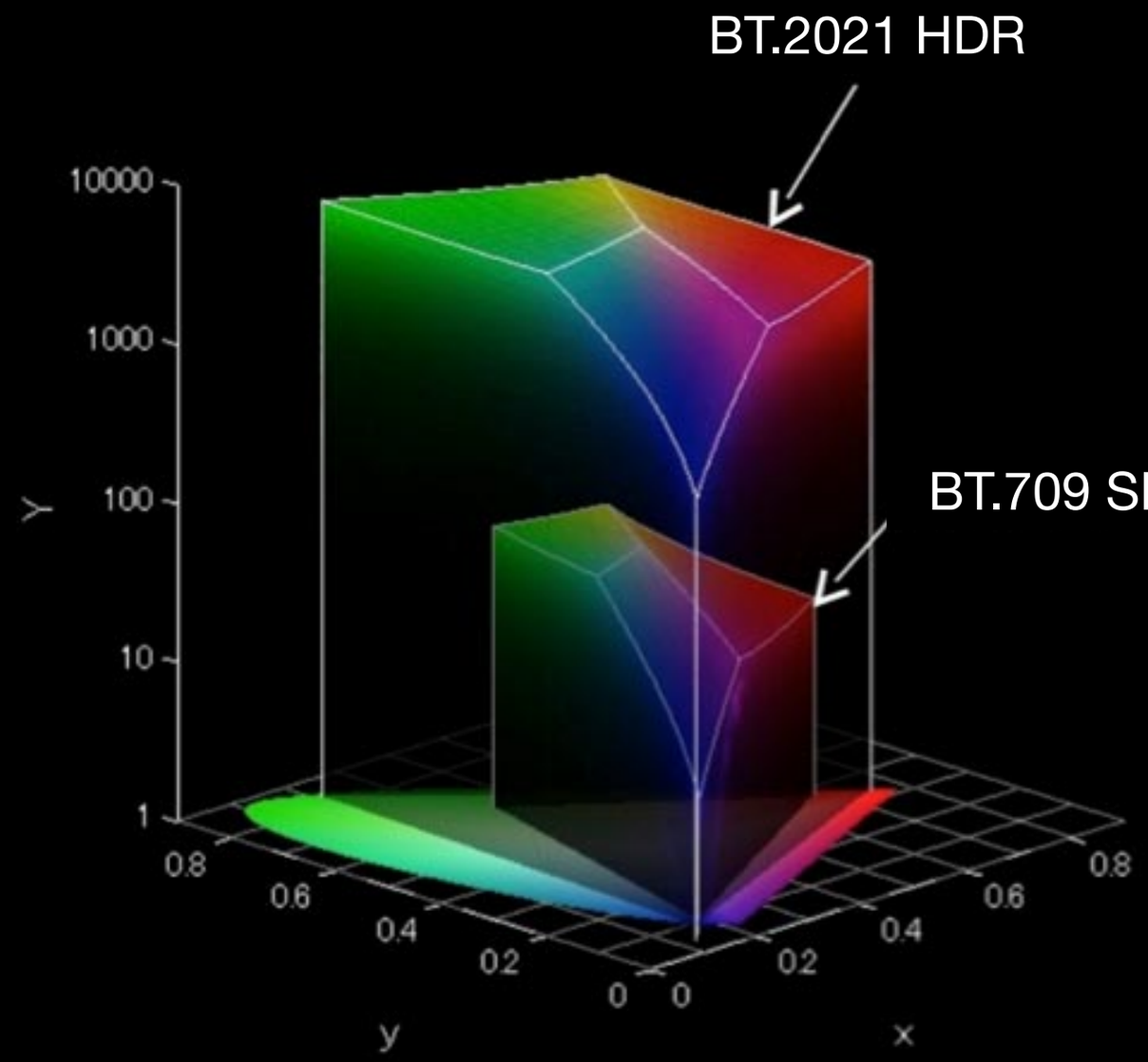


RTG Technology Summit. Under embargo until December 8, 2015, 9 a.m. EST.

Dynamic Range of Color Device

- the ratio of luminance between the darkest black that can be produced and the brightest white i.e. it is device’s "contrast ratio”.
- SDR (Standard Dynamic Range): 0.05 nits - 100 nits
- HDR (High Dynamic Range): 0.0005 nits - 10,000 nits
- Human vision: can detect brightness levels as low as 0.000001 nits and as high as 100,000,000 nits.

Color Gamut vs Color Volume



HDR Video

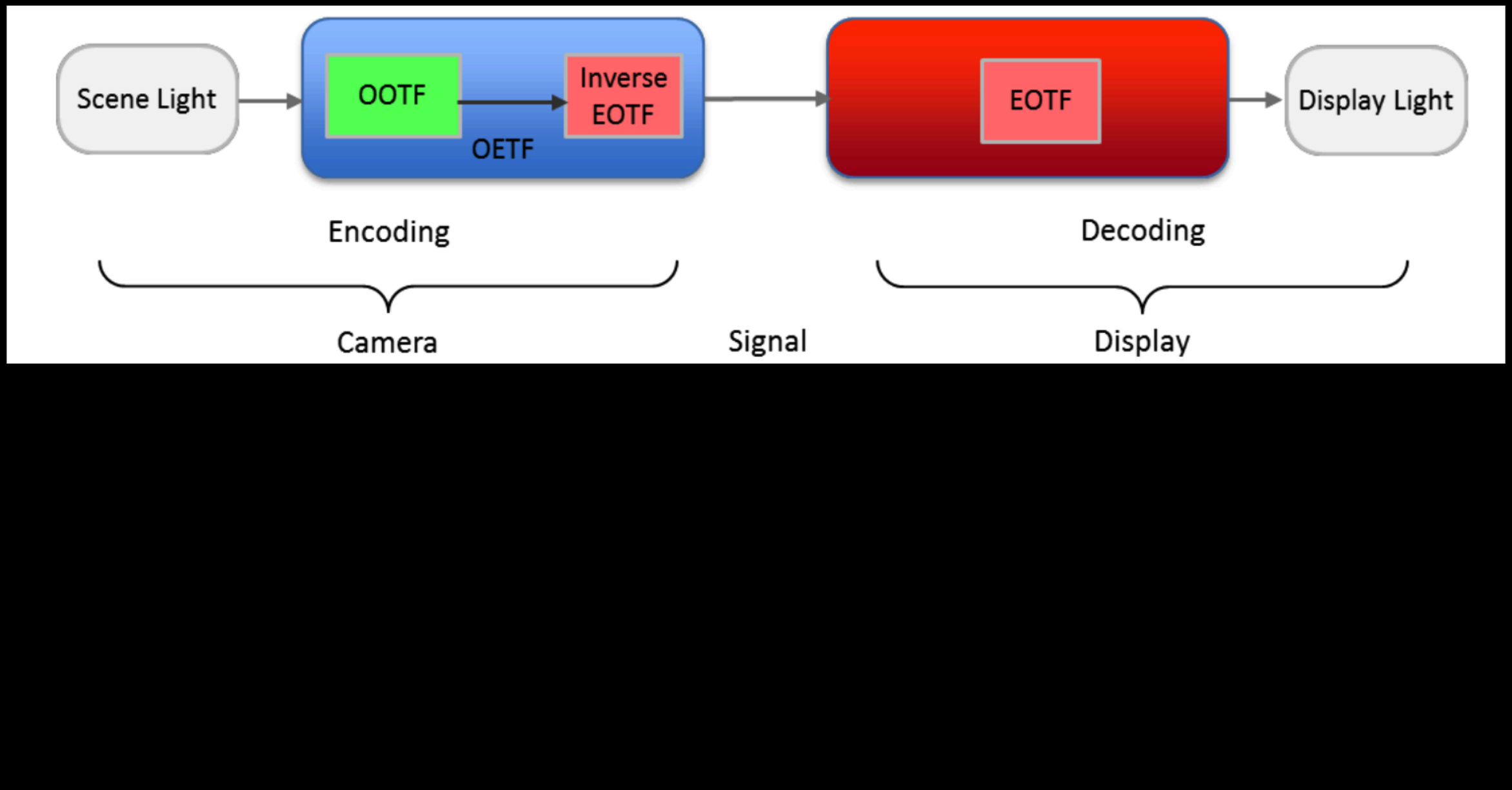
- Goal: reproduce a video experience on user's display device as close as possible to what a human being will perceive when they watch the same scene in nature.
- Two standard HDR Video systems:
    - PQ - absolute, display-referred data
    - HLG - relative, scene-referred data

Video mathematical functions

- Transfer functions describing the relationship between electrical signal, scene light and displayed light
    - OETF (opto-electronic transfer function) converting scene light into video signal
    - EOTF (electro-optical transfer function) converting video signal into the linear light the display
    - OOTF (opto-optical transfer function) converting scene light into displayed light
- Matrix
    - 3x3 color space conversion (converting primaries)

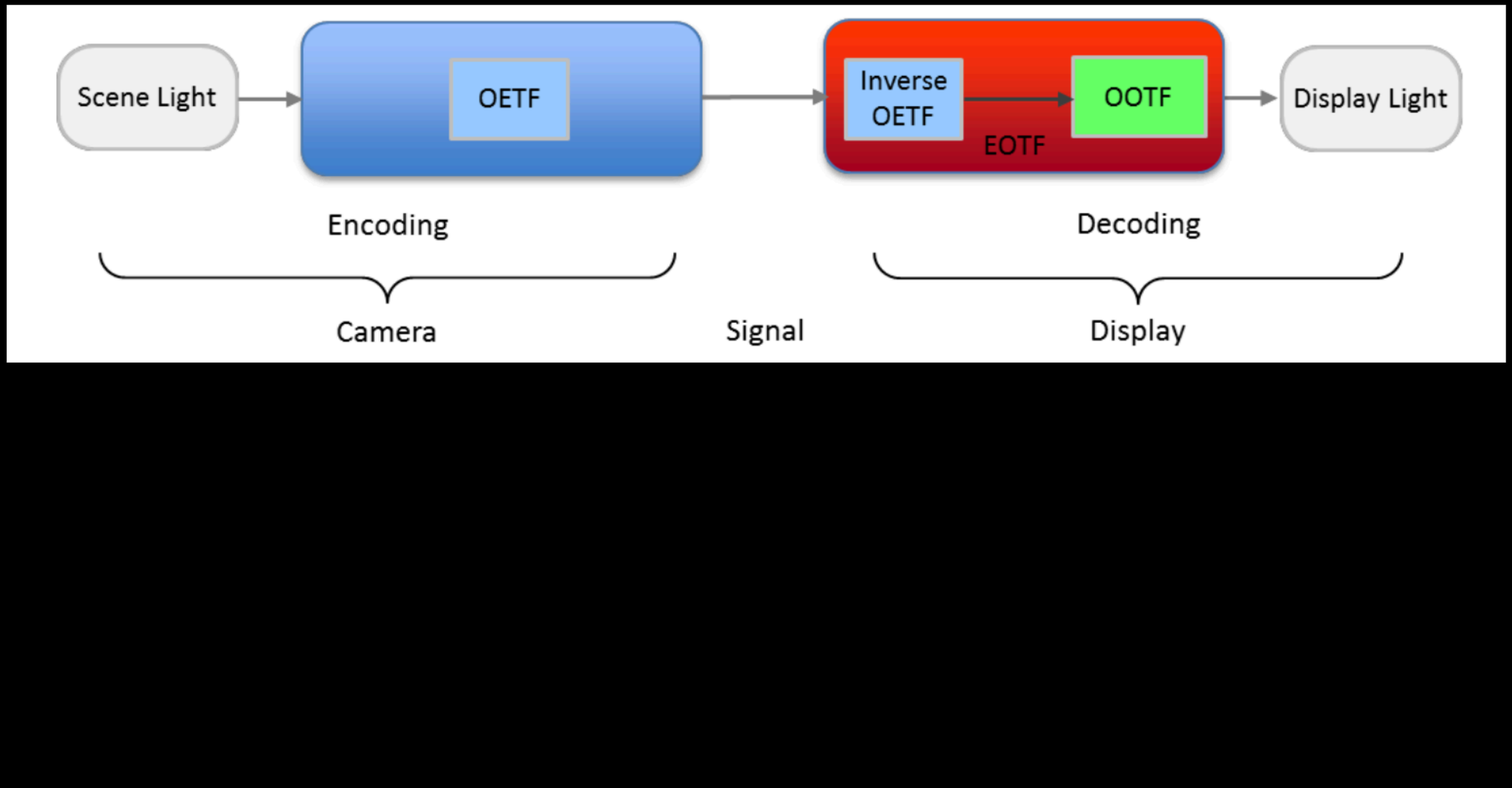
PQ architecture

Defined by Perceptual Quantizer EOTF (SMPTE ST 2084)



HLG architecture

Defined by Hybrid Log-Gamma OETF (ARIB STD-B67)

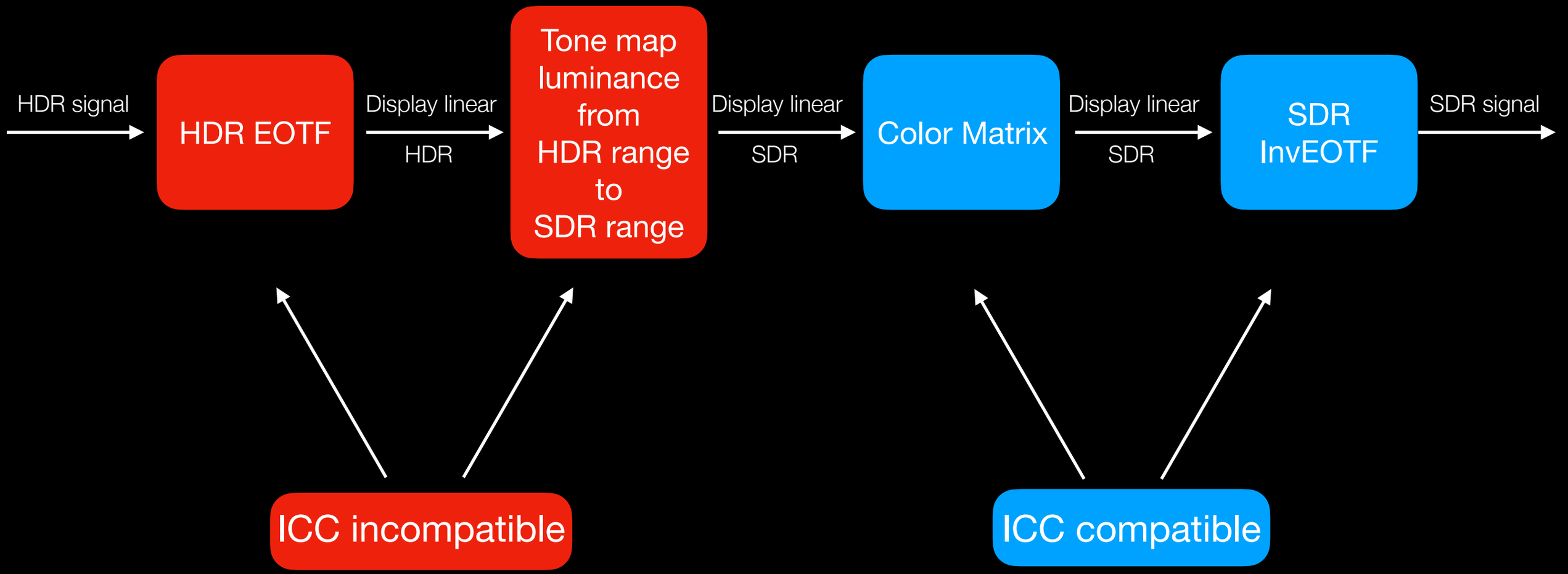


Video HDR content conversions

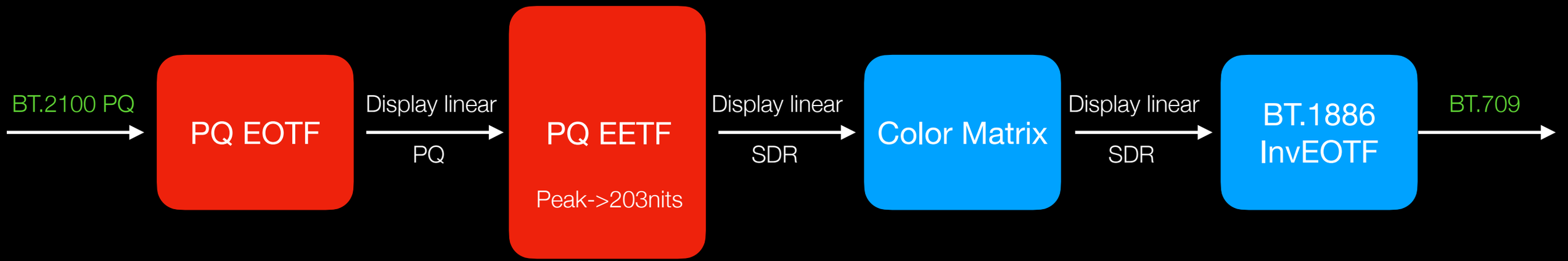
Differences and similarities to ICC workflows

- PQ → SDR
- HLG → SDR
- PQ → HLG
- HLG → PQ
- SDR → PQ
- SDR → HLG

HDR → SDR

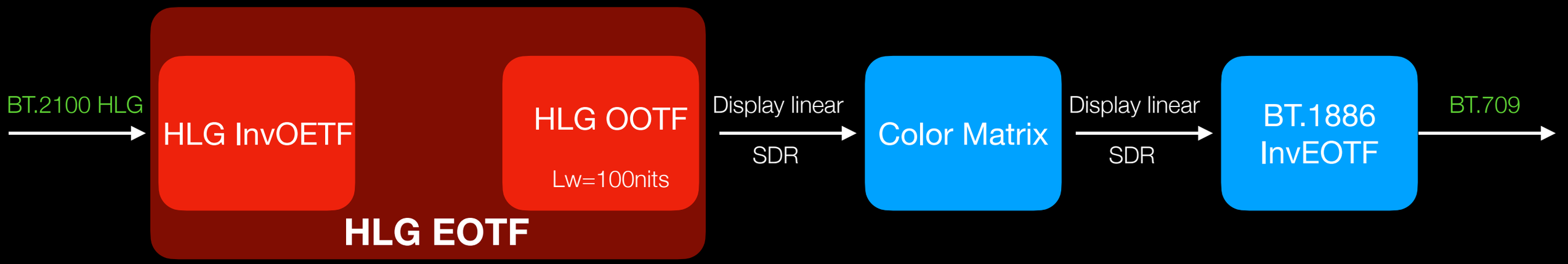

HDR signal
HDR EOTF
Display linear
HDR
Tone map luminance from HDR range to SDR range
Display linear
SDR
Color Matrix
Display linear
SDR
SDR InvEOTF
SDR signal
ICC incompatible
ICC compatible

PQ → SDR



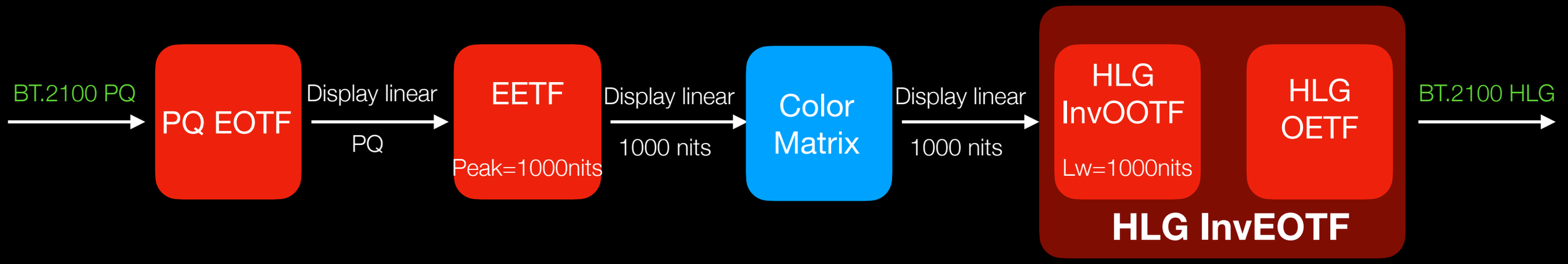
203 nits is HDR Reference White

HLG → SDR

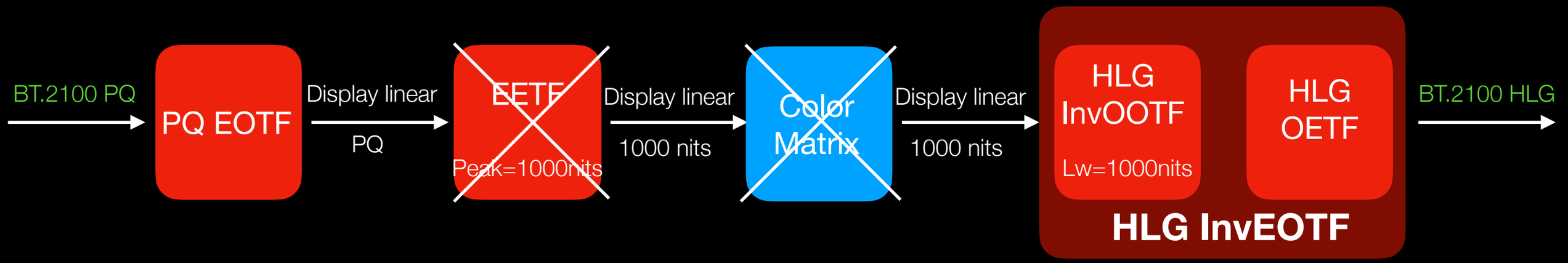


Lw is a nominal display peak luminance
which in this case is set to 100 nits.

PQ → HLG

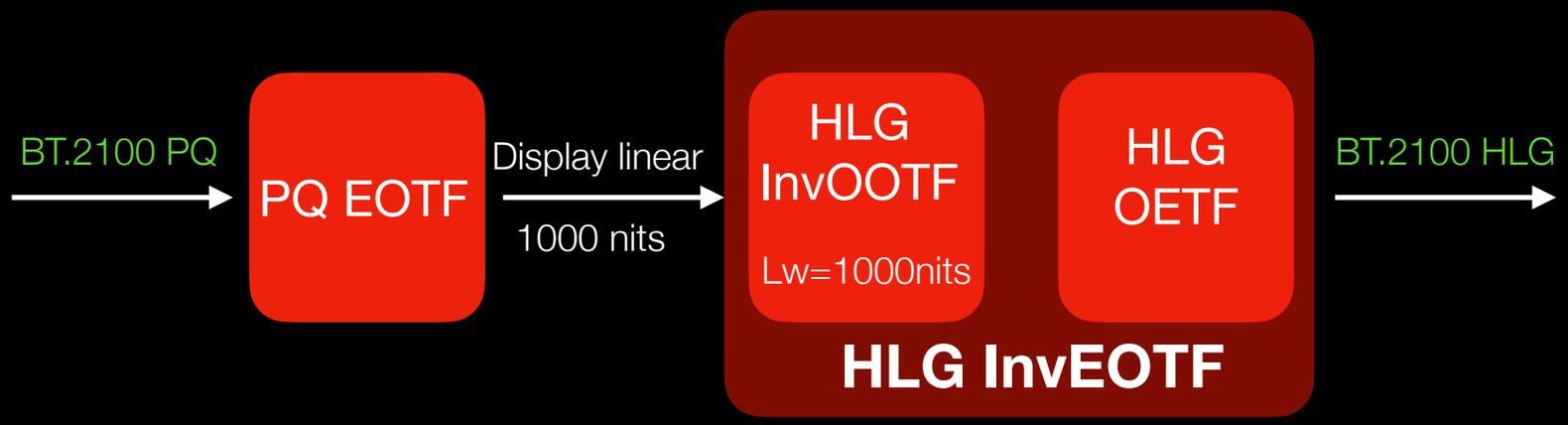

BT.2100 PQ
PQ EOTF
Display linear
PQ
EETF
Peak=1000nits
Display linear
1000 nits
Color Matrix
Display linear
1000 nits
HLG InvOOTF
Lw=1000nits
HLG OETF
BT.2100 HLG
HLG InvEOTF

PQ → HLG



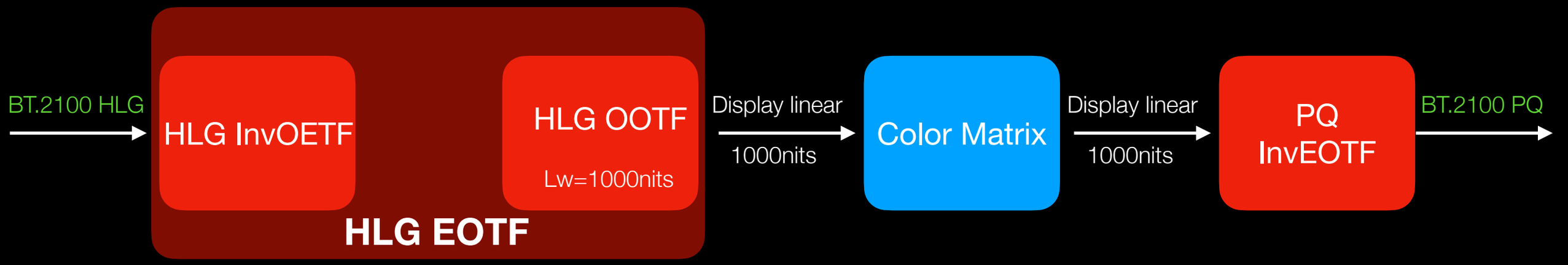
1000 nits bridge

PQ → HLG

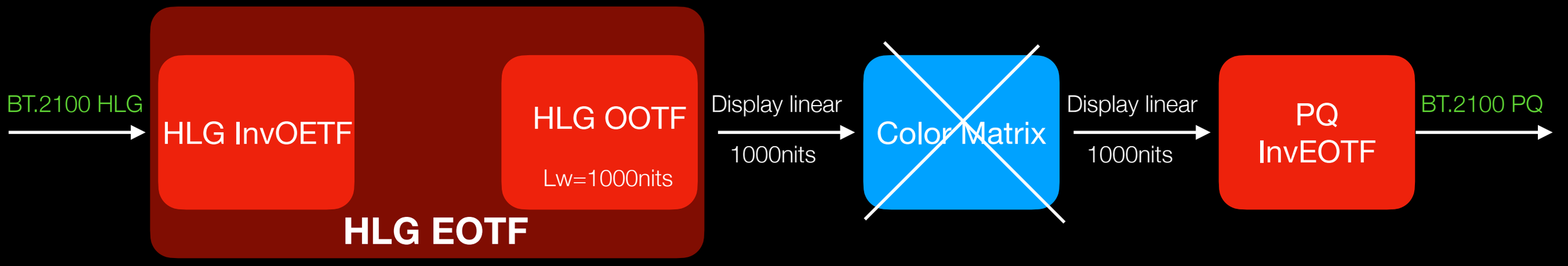


1000 nits bridge

HLG → PQ


BT.2100 HLG
HLG InvOETF
HLG OOTF
Lw=1000nits
HLG EOTF
Display linear
1000nits
Color Matrix
Display linear
1000nits
PQ
InvEOTF
BT.2100 PQ

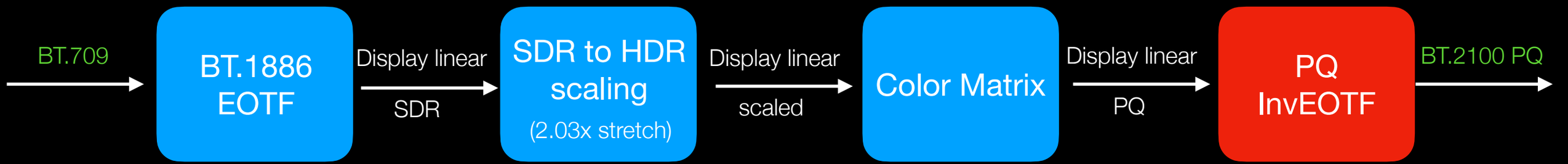
HLG → PQ


BT.2100 HLG
HLG InvOETF
HLG OOTF
Lw=1000nits
HLG EOTF
Display linear
1000nits
Color Matrix
Display linear
1000nits
PQ
InvEOTF
BT.2100 PQ

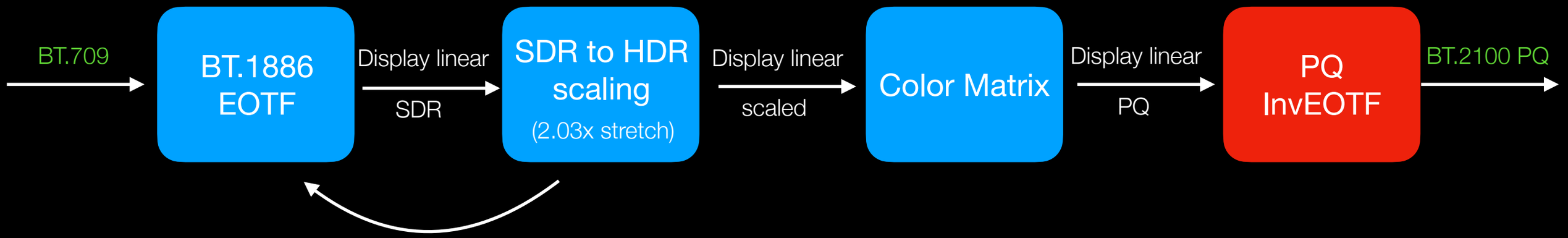
HLG → PQ


BT.2100 HLG
HLG InvOETF
HLG OOTF
Lw=1000nits
HLG EOTF
Display linear
1000nits
PQ
InvEOTF
BT.2100 PQ

SDR → PQ


BT.709
BT.1886 EOTF
Display linear
SDR
SDR to HDR scaling
(2.03x stretch)
Display linear
scaled
Color Matrix
Display linear
PQ
PQ InvEOTF
BT.2100 PQ

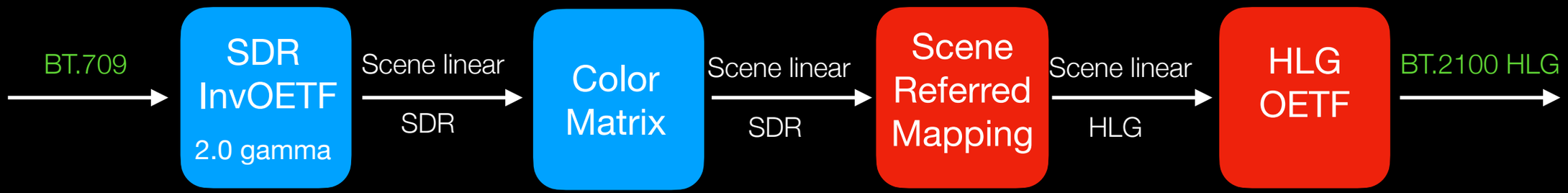
SDR → PQ


BT.709
BT.1886 EOTF
Display linear
SDR
SDR to HDR scaling
(2.03x stretch)
Display linear
scaled
Color Matrix
Display linear
PQ
PQ InvEOTF
BT.2100 PQ

SDR → PQ


BT.709
BT.1886 EOTF with (2.03x stretch)
Display linear
scaled
Color Matrix
Display linear
PQ
PQ InvEOTF
BT.2100 PQ

SDR → HLG



ITU-R BT.2087 derives inverted SDR OETF from ITU-R 1886 as gamma = 2.0

Scene Referred Mapping to match content from BT.709 and BT.2020 SDR cameras with HLG cameras

Differences and similarities to ICC workflows

Similarities :

- Transfer functions = Parametric Curves
- Matrices to convert primaries (concatenation of RGB->XYZ & XYZ->RGB)

Differences :

- HDR parametric transfer functions not in ICC spec
- Parametric 3D tone mapping functions not in ICC spec
  - Neither can be approximated by 1-D or 3-D LUTs
- Overall conversion depends on both source and destination

Resolving differences

Two potential approaches:

1. HDR parametric transfer functions and 3D tone mapping functions added to ICC spec.
2. Add HDR identifier tag, i.e. reference to relevant ITU-R.

CICP tag

Coding-independent code points (CICP) for video signal type identification.

- CICP tag provides linking of the color space encoding represented by an ICC profile with an equivalent video signal type identification (CICP) used in video equipment compliant with ITU-T H.273 and ITU-T H.265 as defined by the International Telecommunication Union (ITU) or as defined by SMPTE Universal Labels.

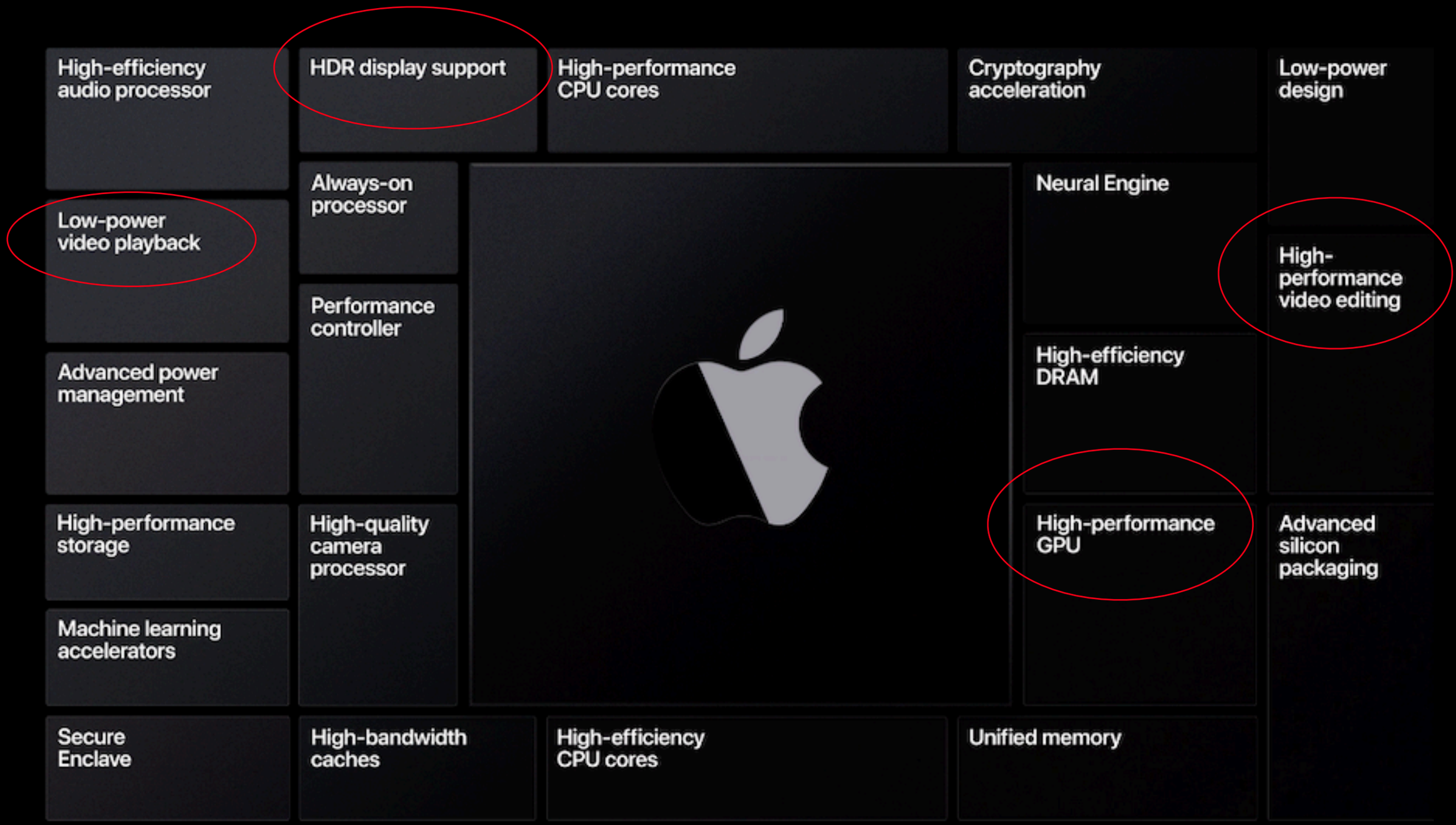
ICC HDR profile (as of now)

ICC profile provides an approximate color rendering (typically display-referred) for non-video equipment, while the CICP tag provides the mapping back to the original video space.

CICP tag will enable updated CMMs to process video as per respective ITU-R specifications.

HW support to create conversion workflows

HDR and SDR function identifiers needed!



References

ITU-R BT.2100-2 Image parameter values for high dynamic range television for use in production and international programme exchange
ITU-R BT.2390-7 High dynamic range television for production and international programme exchange
ITU-R BT.2408-2 Guidance for operational practices in HDR television production
ITU-R BT.2087-0 Colour conversion from Rec. ITU-R BT.709 to Rec. ITU-R BT.2020
ITU-R BT.1886 Reference electro-optical transfer function for flat panel displays used in HDTV studio production
ITU-R BT.2446 Methods for conversion of high dynamic range content to standard dynamic range content and vice-versa