HDR in ICC

Expanding Boundaries of Color Management Standards

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International Color Consortium

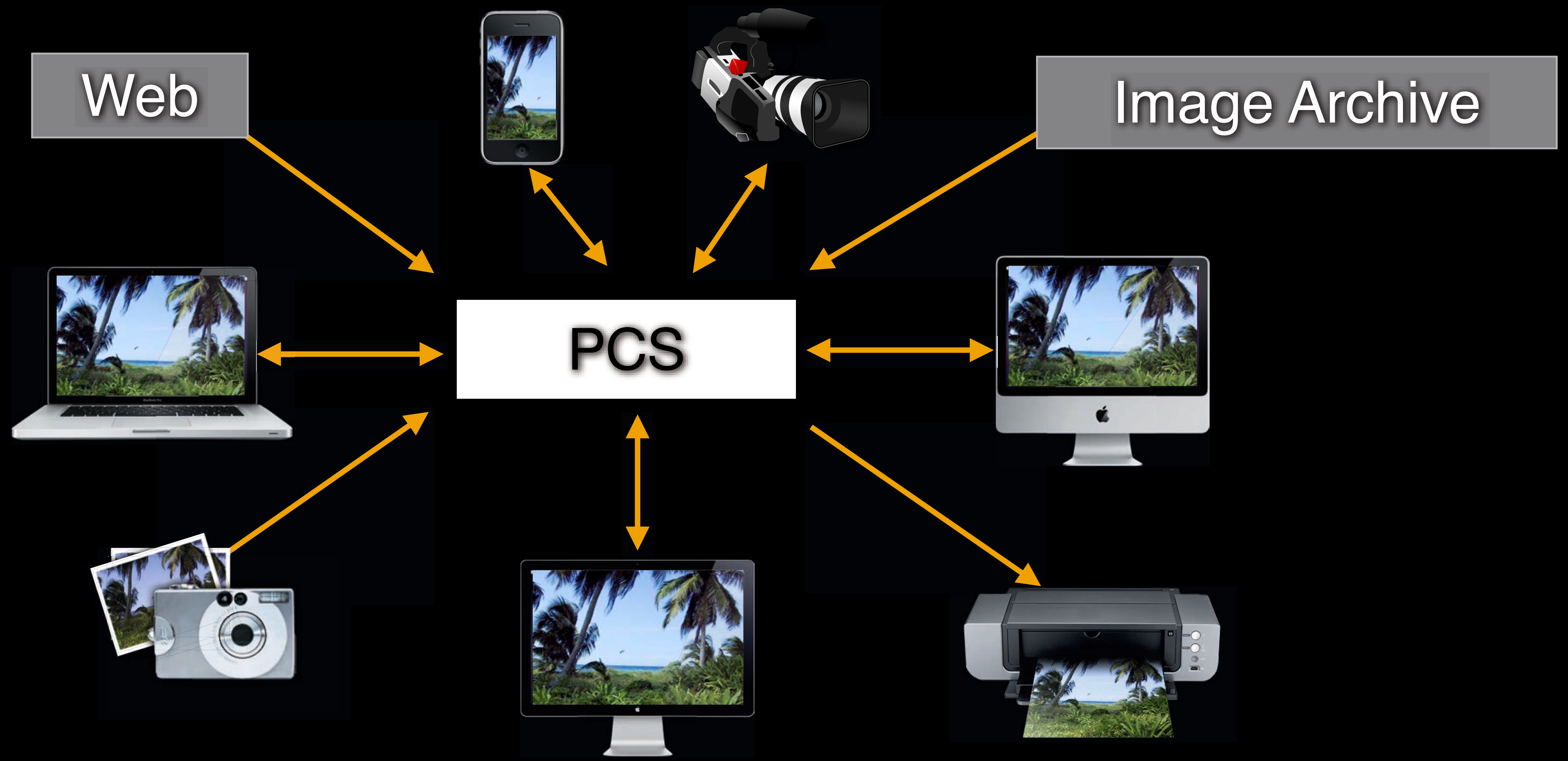
Creator of established color management standard

- Founded in 1993 by Adobe, Agfa, Apple, Kodak, Microsoft, Silicon Graphics, Sun Microsystems, and Taligent.
- The goal of ICC is to promote use and adoption of open, vendor-neutral, cross-platform color management systems.
- ICC publishes ICC profile specification. The current version published in April 2025 is 4.4.2.
- ICC profiles are the basis for consistent color appearance in color management workflows and facilitate color reproduction for display, printing or archiving of digital color content.

ICC Color Management Workflow

Framework for conversion between different color representation

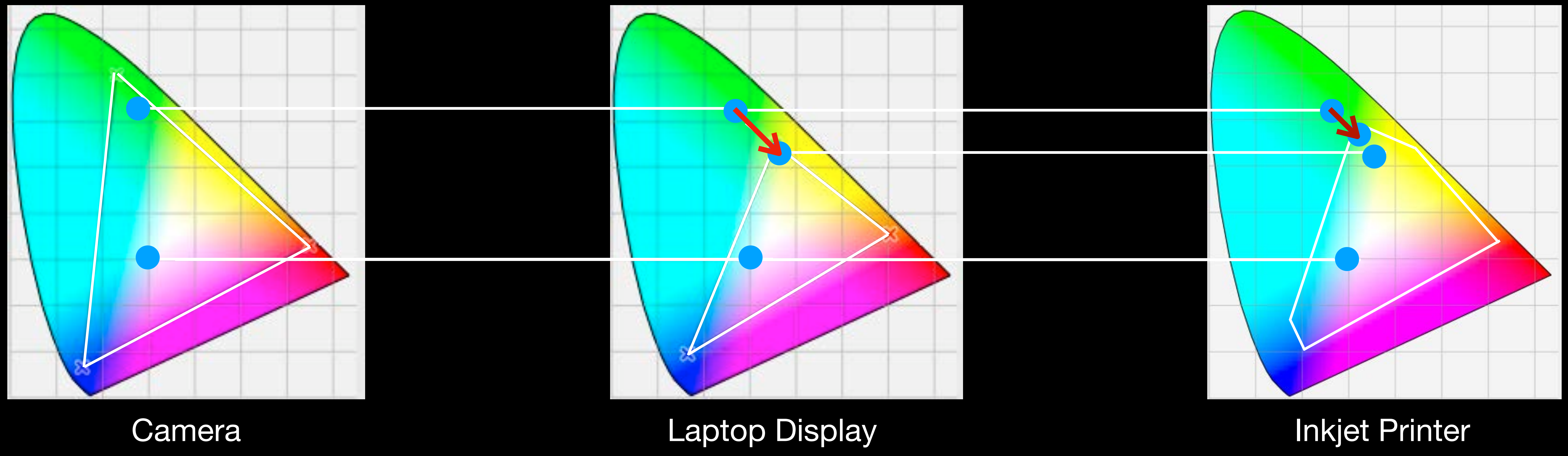
- Problem to solve: different devices have different color reproduction capabilities.
- Solution:
    - standardized device characterization - ICC profile
    - standardized processing algorithms utilizing the Reference Color Space (PCS)



Conventional approach

Solving Gamut Mapping Problem

- Colors from outside of destination gamut are mapped into the gamut



Conventional ICC algorithmic operations

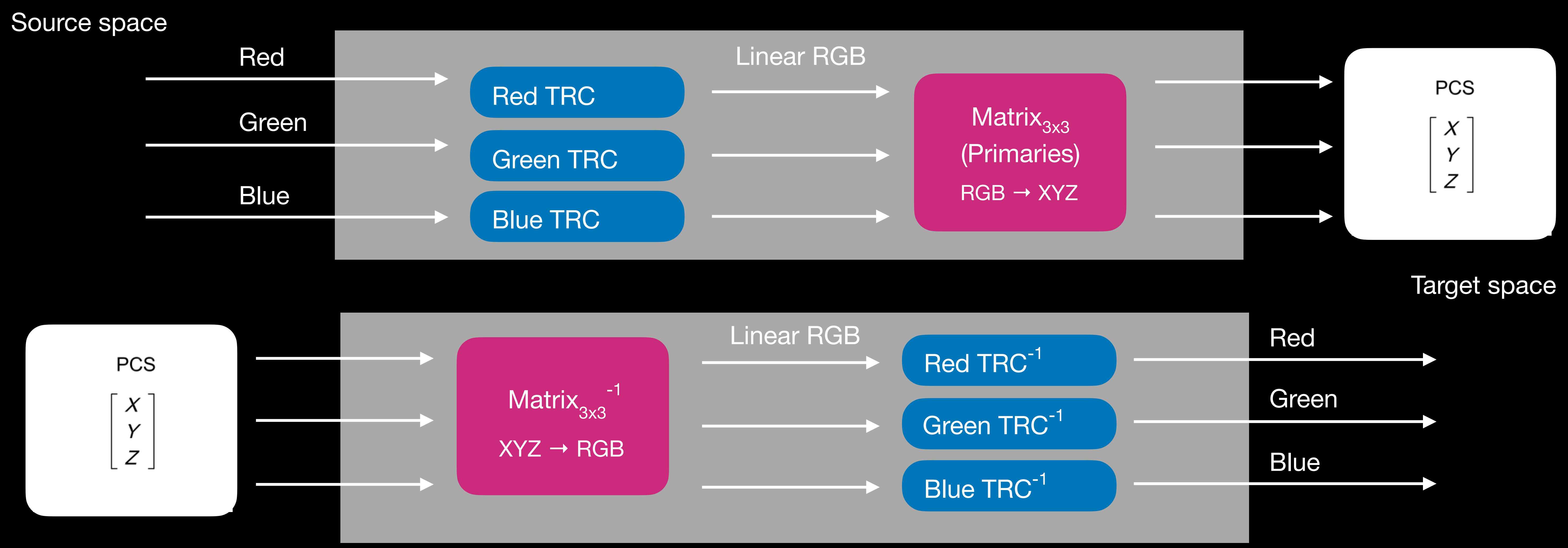
Descriptive operations defined by ICC for color conversions

- Tone Rendering Curve
  - 1-D LUT
  - parametric: $Y = (aX+b)^{\gamma} + e \; [X \geq d]$, $Y = cX + f \; [X < d]$
- Matrix
  - 3x3 with bias (3x4)
- CLUT
  - multi-dimensional interpolation table with N inputs and M outputs

Conventional ICC profile algorithmic models

Based on conventional standardized operations

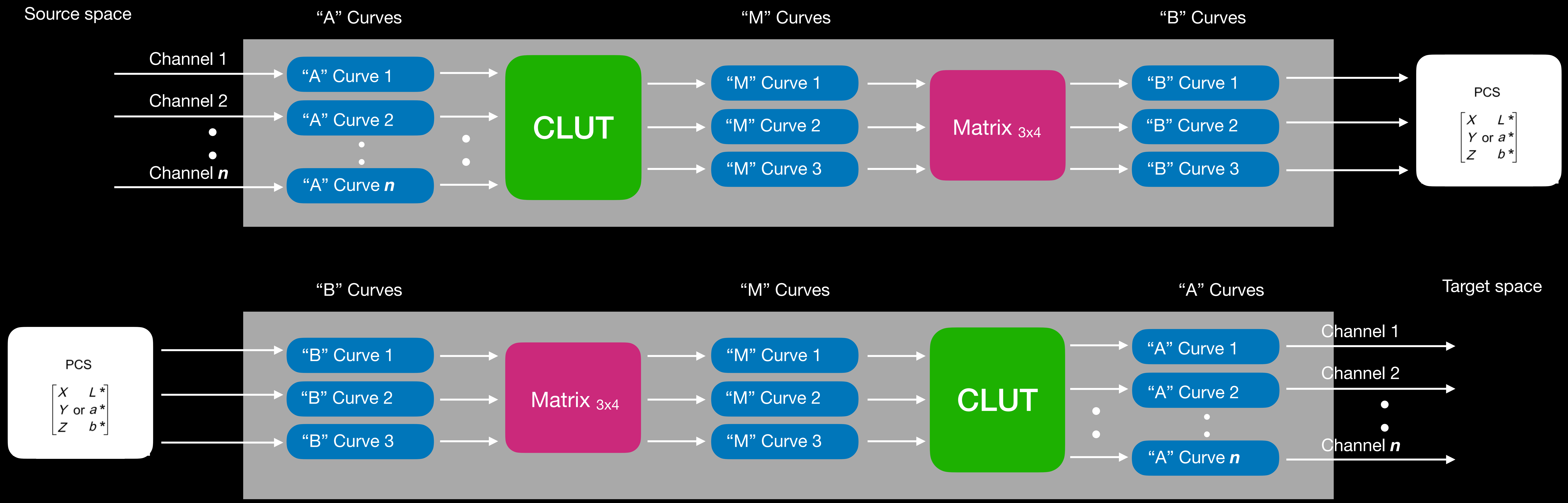
- Matrix-TRC RGB profiles
  - Examples: sRGB, Adobe RGB, Display P3, BT.2020, ProPhoto, etc…
  - Used in most of the know image file formats and display characterization



ICC profile algorithmic models continued

Based on conventional standardized operations

- Multidimensional LUT-based profiles
  - most typically used for printers



Notes on conventional ICC color operations

Recognized industry wide color management standard

- Designed for gamut mapping
- Device color gamut captured under one illuminant
- Prescriptive anonymous mathematical operations - flexible, but difficult to associate with descriptive specifications, like e.g.:
    - standard primaries (Rec.709, DisplayP3, DCI-P3, Rec.2020)
    - standard video transfer functions, (Rec.709 OETF, PQ EOTF, HLG OETF)
- No provisions for characterization of device dynamic range

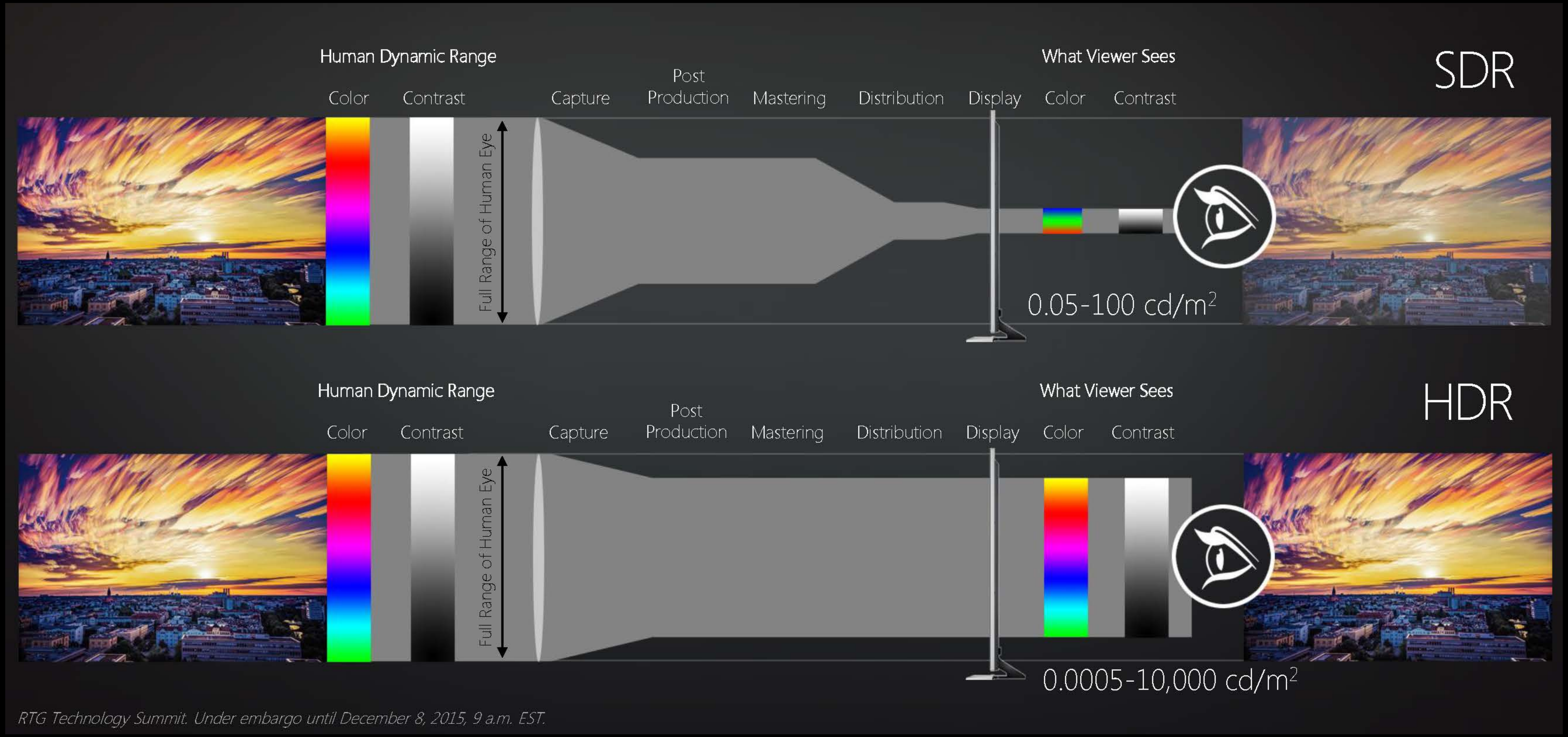
Dynamic Range of Color Device

New characteristics describing capabilities of color reproduction

- Cameras and displays capable of handling brightness exceeding diffuse white need a standardized characterization.
- Defined as the ratio of luminance between the darkest black and the brightest white that can be produced 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.

Human Vision and Color Reproduction

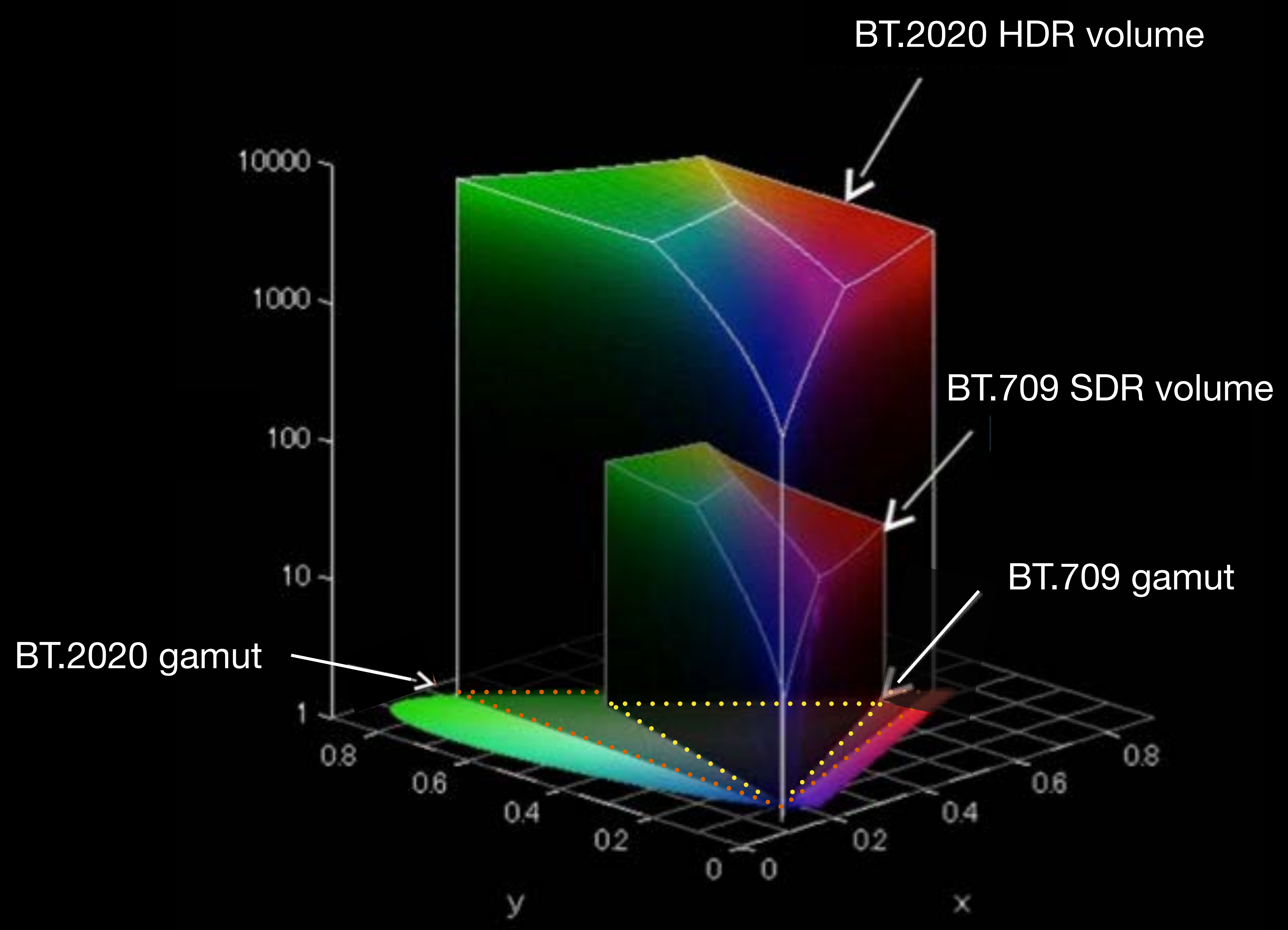
Standard Dynamic Range vs High Dynamic Range



Color Volume

Putting it all together

- Dynamic Range + Color Gamut = Color Volume



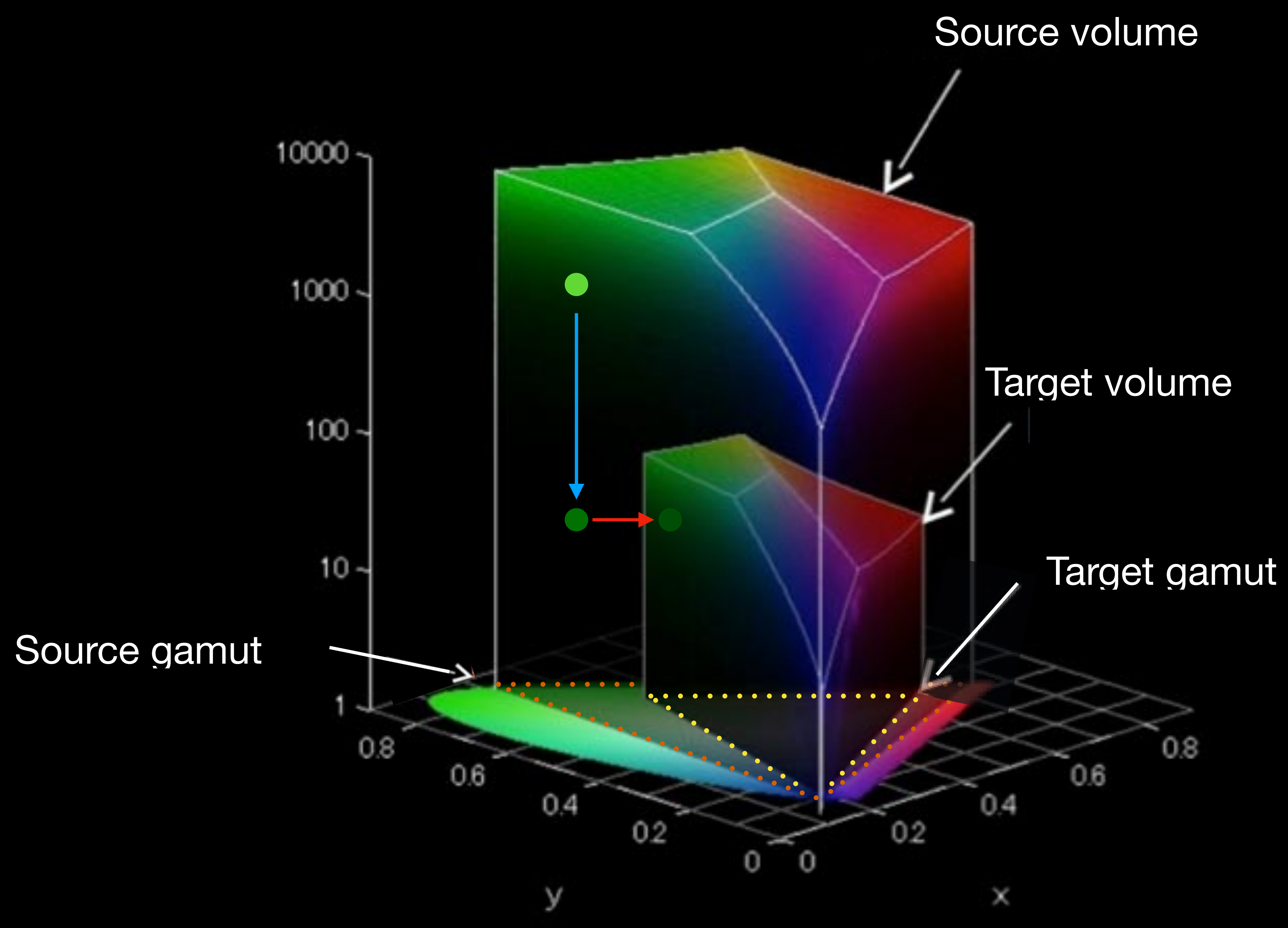
Managing Color Volumes

Luminance - new dimension in processing color

- Complete conversion between different color representations:
    1. Tone mapping
    2. Gamut mapping

Tone mapping luminance

Gamut mapping color components



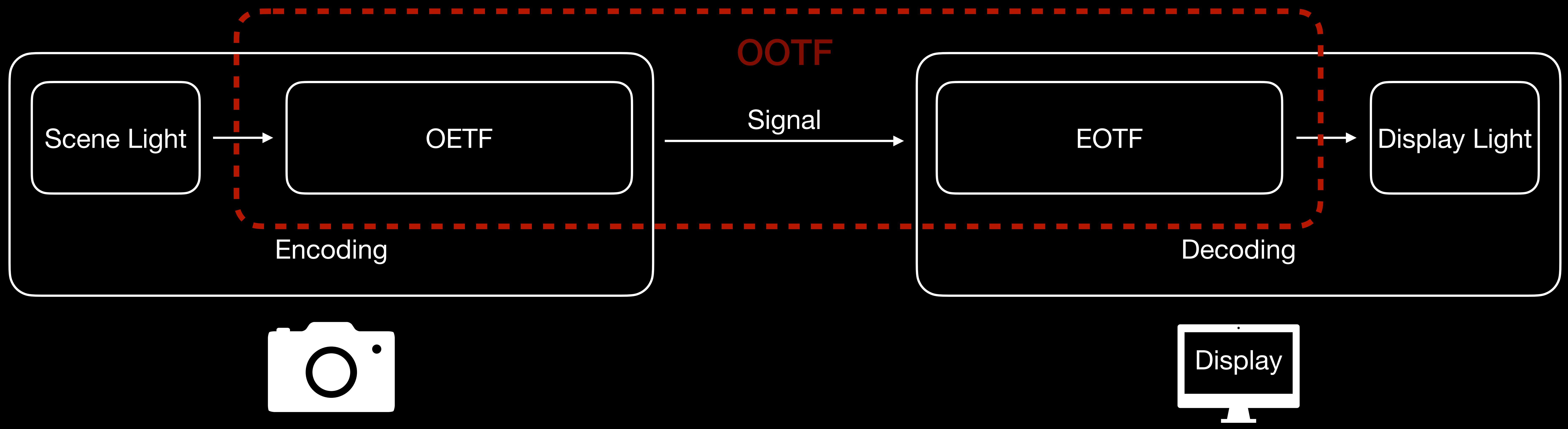
HDR Color Encodings

Digital format needed for storing and transmitting

- Purest form: unclipped floating point values in linear either scene or display referred color space.
    - Huge files, impractical for video but possible for stills in OpenEXR or TIFF
- Two industry standard HDR systems using 10-bit per component:
    - PQ - absolute, display-referred data
    - HLG - relative, scene-referred data
- Images with Gain Maps
    - Base Image + Gain Map → image specific
        - SDR + Gain Map = HDR
        - HDR + Gain Map = SDR

Capturing and Displaying Images

General Architecture



- OETF Opto Electronic Transfer Function Scene light (linear) -> Signal (non-linear)
- EOTF Electro Optical Transfer Function Signal (non-linear) -> Display light (linear)
- OOTF Opto Optical Transfer Function Scene light (linear) -> Display light (linear)

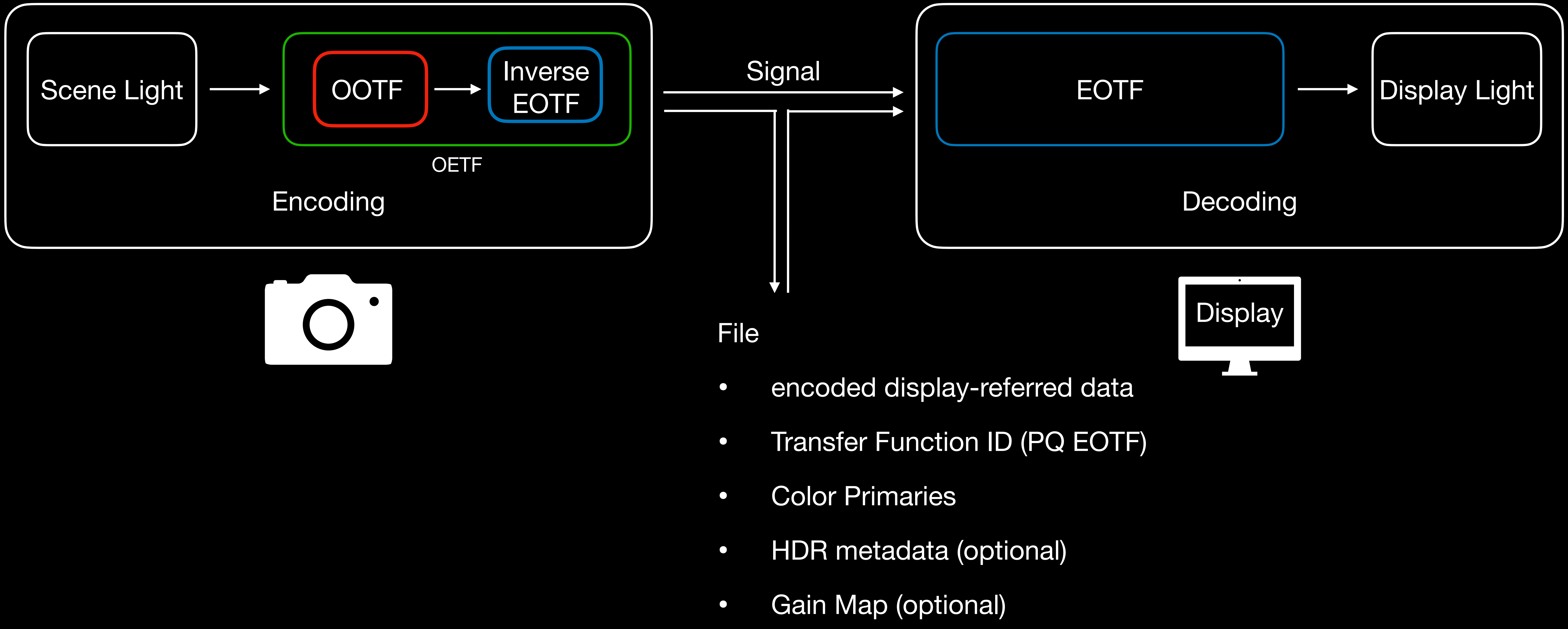
Relationship between OETF, EOTF and OOTF

Any two define the third one

- OETF(x) = InverseEOTF(OOTF(x))
- EOTF(x) = InverseOETF(OOTF(x))
- OOTF(x) = OETF(EOTF(x))
- InverseOETF(x) = EOTF(InverseOOTF(x))
- InverseEOTF(x) = InverseOOTF(OETF(x))
- InverseOOTF(x) = InverseEOTF(InverseOETF(x))

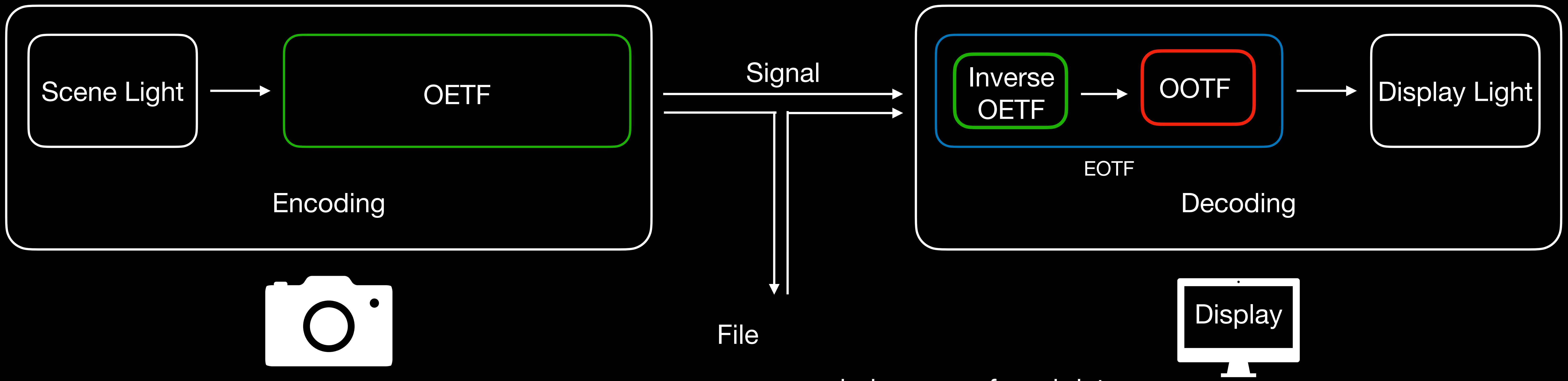
PQ Architecture

Defined by Perceptual Quantizer EOTF (SMPTE ST 2084)



HLG Architecture

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



File

- encoded scene-referred data
- Transfer Function ID (HLG OETF)
- Color Primaries
- HDR metadata (optional)
- Gain Map (optional)

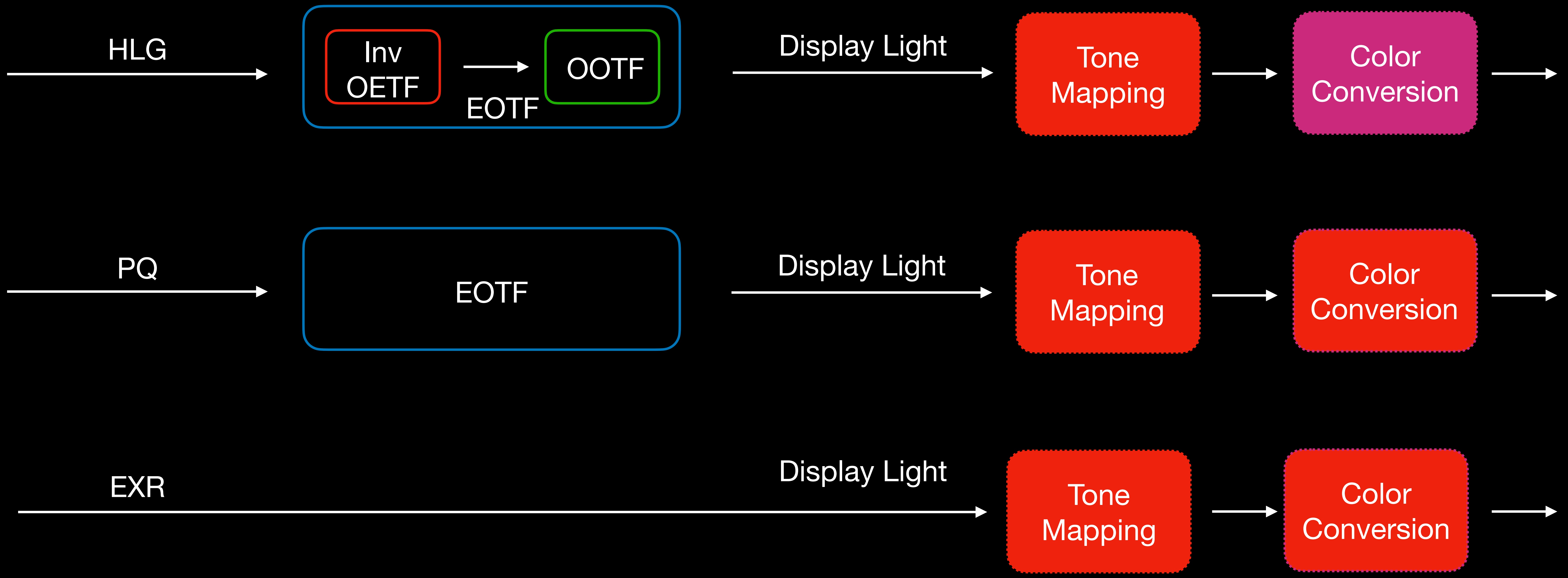
HDR Management Workflows

HDR reproduction on devices with various capabilities

- Three step process:
    1. **Decoding**
        - from encoded data to Display Light Linear space
    2. **Tone mapping**
        - Conversion to Reference Color Space (BT.2020) for consistency (e.g. HDR metadata is specified in Reference Color Space)
        - Applying Tone Mapping function:
            - Global Functions
                - ITU Recommendations
                - Global Adaptive Gain Curve
            - Image specific Functions:
                - Gain Map
                - Image Specific Adaptive Gain Curve
    3. **Gamut mapping**
        - Conversion to target color space

HDR Management Workflows

HDR reproduction on devices with various capabilities



ICC Support for HDR

Extending standards and provide backward compatibility

- HDR Working Group created in 2019
  - works closely with other standards organization: ISO TC-42, SMPTE
- Results: new HDR oriented new tags
  - CICP tag approved on October 1st, 2021
  - ADGC tag approved on April 17th, 2025
  - HDR metadata in ICC Metadata Registry: MDCV, CCV, CLL and CRWL
- Emphasis on Backward Compatibility
  - v4 A2B0 tag provides conversion from HDR to SDR for older CMMs

CICP tag

First descriptive ICC tag for processing data

- CICP i.e. “Coding-independent code points” for data identification
  - primaries and transfer functions are identified as per ITU T-REC-H.273
    - CMM needs to know how to interpret primaries and transfer function IDs
  - ITU T-REC-H.273 contains identifiers for PQ EOTF and HLG OETF

CICP tag example

ProfileWithAdaptiveGainCurve.icc

#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'mluc'	148	Multi-localized description strings
2	'cprt'	'mluc'	80	Multi-localized strings
3	'wtpt'	'XYZ '	20	Media white-point tristimulus
4	'A2B0'	'mAB '	6,412	Intent-0, device to PCS conversion
5	'B2A0'	'mBA '	6,412	Intent-0, PCS to device conversion
6	'chad'	'sf32'	44	Chromatic adaptation matrix
7	'cicp'	'cicp'	12	Coding-independent code points
8	'hdgm'	'gmap'	242	Adaptive Soft Clip Curve
9	'lumi'	'XYZ '	20	Tristimulus value

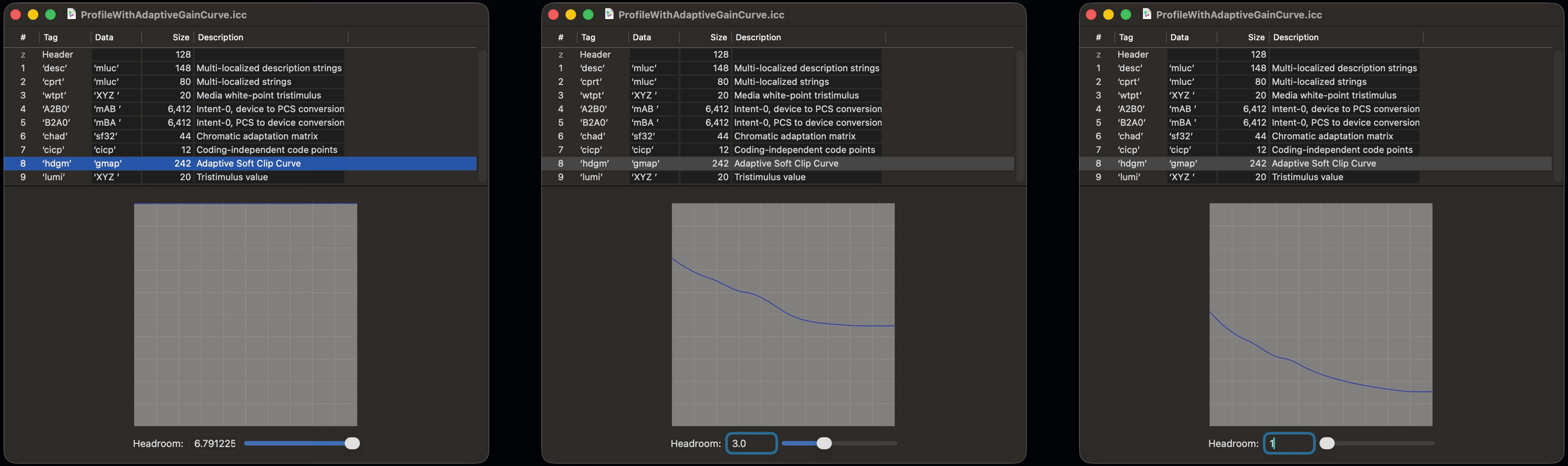
Color Primaries: 12 P3-D65
Transfer Characteristics: 16 PQ
Matrix Coefficients: 0 R'G'B'
Video Full Range Flag: 1

ADGC tag

Powerful and versatile tone mapping method

- ADGC i.e. “Adaptive Gain Curve”
  - Specifies a gain-based global tone mapping curve, adaptive to varying headroom, for conversion between HDR and SDR representations of the image
  - Defines 3 stages: Input Evaluator, Gain Evaluator and Output Evaluator
    - Input Evaluator allows for choice of all or individual color components with various weights as an input.
    - Gain Evaluator is expressed as a piecewise cubic curve:
      F(x) = C3*x3 + C2*x2+ C1*x + C0
    - Output Evaluator calculates values for output components based on desired target headroom.

Adaptive Gain Curve tag example



HDR metadata tag example

ProfileWithAdaptiveGainCurve.icc

#	Tag	Data	Size	Description
z	Header		128	
1	'desc'	'mluc'	148	Multi-localized description strings
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9	'lumi'	'XYZ '	20	Tristimulus value
10	'meta'	'dict'	556	Profile Metadata

Profile Metadata

Content Light Level
Average Light Level: 113.500000
Max Light Level: 454.000000
Primaries: 12

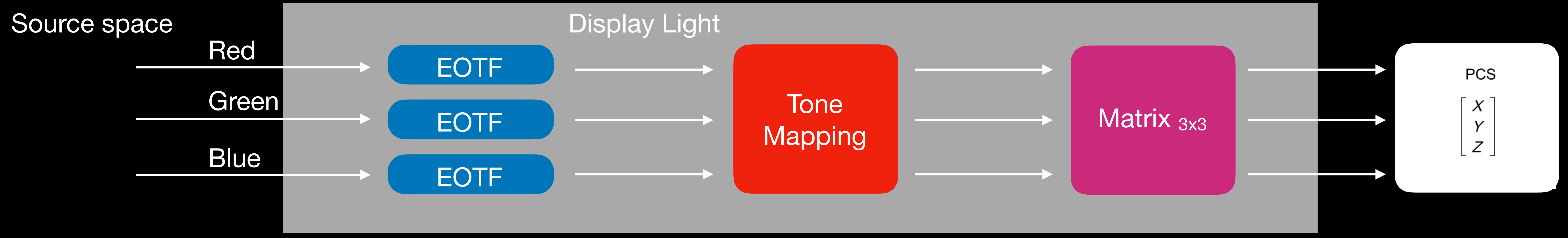
Content HDR Reference White Luminance
Reference White: 203.000000

Mastering Display Color Volume
Max Luminance: 1600.000000
Min Luminance: 15.000000
Primaries: 12

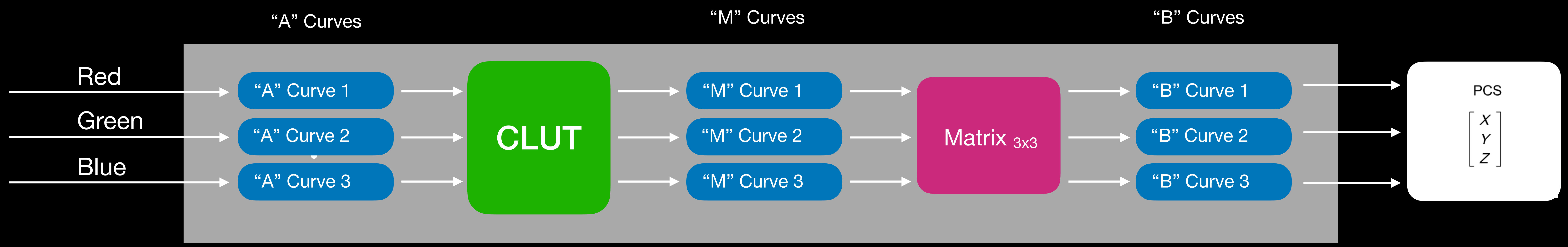
ICC HDR profile

Algorithmic model

- HDR path



- Backward compatibility path



Sample Images

Adaptive Gain Curve

A2B0 based on Adaptive Gain Curve

Sample Images

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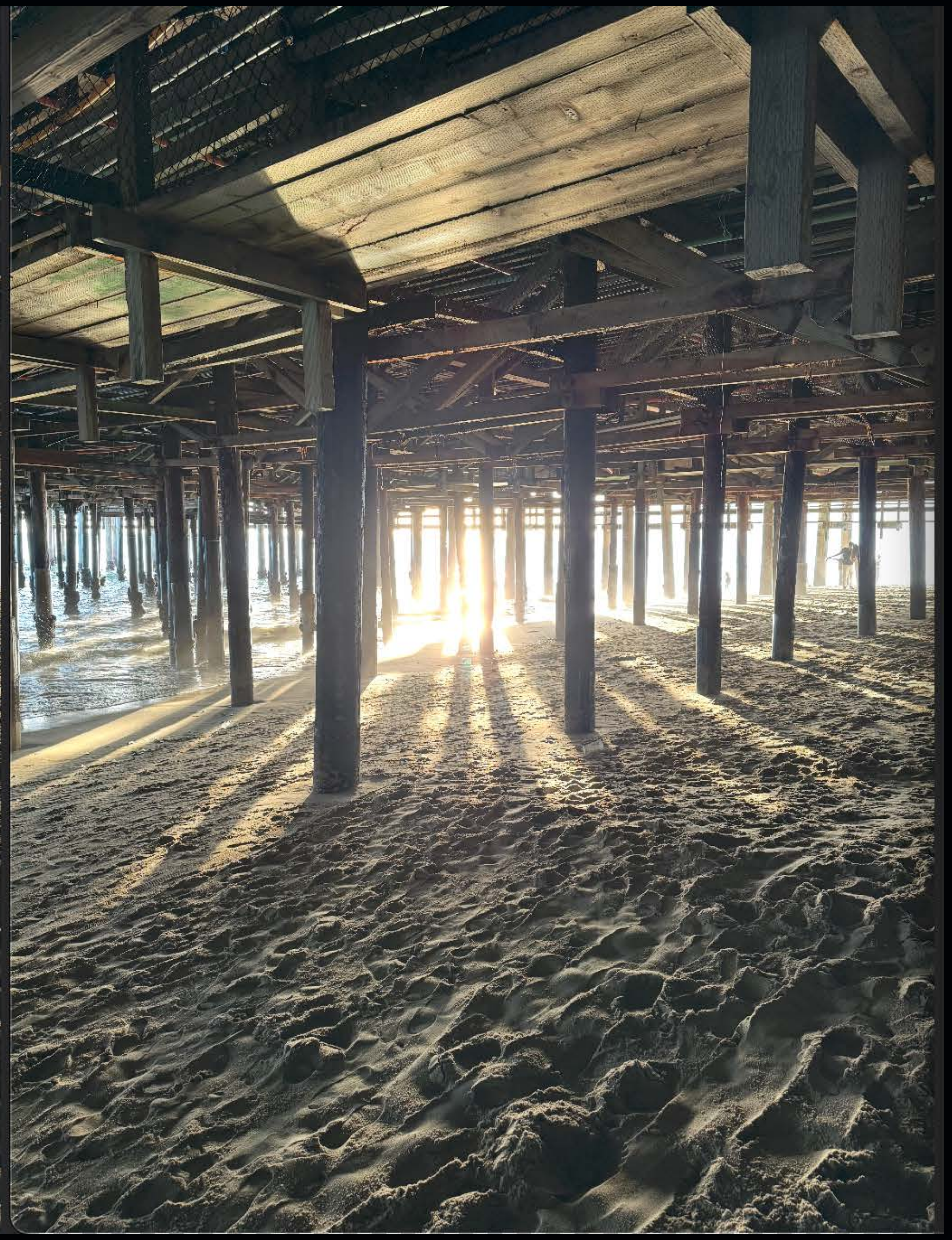

A2B0 based on Adaptive Gain Curve

Sample Images

Adaptive Gain Curve

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