WHITE PAPER

UNDERSTANDING HIGH DYNAMIC RANGE (HDR)

A Cinematographer Perspective

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Understanding High Dynamic Range (HDR) Imaging by Curtis Clark, ASC

A Cinematographer Perspective

High Dynamic Range (HDR) images vs Standard Dynamic Range (SDR) images

Defining the parameters of Dynamic Range

Dynamic range refers to the range of reproducible tonal values within a photographic image from the deepest shadow detail to the brightest highlight detail. These tonal values originate as scene luminance values that are also known as scene brightness values that can be measured with a spot photometer, either in foot-lamberts or in camera T-stops, to establish a scene contrast ratio.

Measuring Scene Luminance

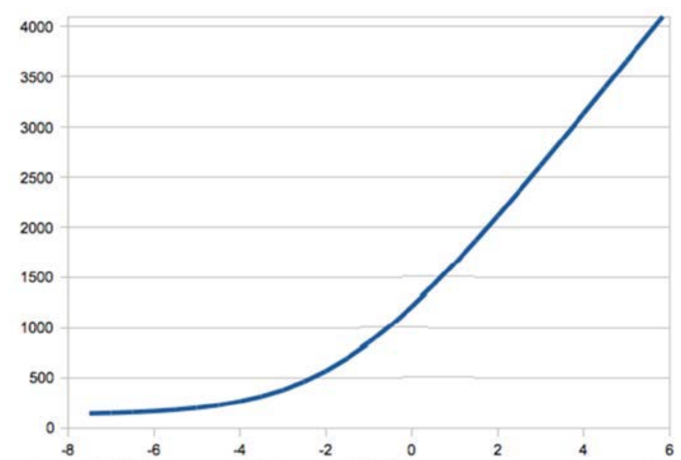
To best understand how to control exposures for both High Dynamic Range (HDR) and Standard Dynamic Range (SDR), it is important to understand how to measure scene luminance.

Motion picture images consist of variable ranges of scene luminance values (brightness vs. darkness), also known as: reflected scene tones, which can be measured photometrically in foot-lamberts (reflected foot - candles) or directly in lens T-stops using a spot photometer. The ratio of the darkest reproducible shadow detail to the brightest reproducible highlight detail can be calculated in foot-lamberts or in lens T-stops.

For example, a scene luminance with a dynamic range of .02 foot-lamberts to 80 foot-lamberts is 4,000:1 and is equivalent to a 12 stop dynamic range. Also, by way of example, a T-stop range from T-1 to T-64 represents a 12 stop dynamic range. A 13 stop range is 8,000:1; a 14 stop range is 16,000:1; and a 15 stop range is 32,000:1.

Although there is no official standard regarding the dynamic range definition of HDR, it is generally recognized that a lower threshold for HDR is 13 stops or 8000:1, advancing via 14 stops or 16,000:1 to the current de facto 'standard' of 15 stops or 32,000:1. Most of the latest generation of digital motion picture cameras are capable of capturing a 14 to 15 stop dynamic range of scene luminance without clipping maximum reproducible highlight detail or crushing minimum reproducible shadow detail. By way of comparison, modern film negatives are also capable of capturing 14 stop dynamic range.

Figure 1: Graphically Illustrating Dynamic Range of Scene Luminance Exposure Values (12-bit log image capture)



12-bit Code Values (vertical axis)

Lens T-stops or Scene Luminance (horizontal axis) 0 = 18% reflectance

A scene's dynamic range of reflected scene tones can be graphically plotted as luminance exposure values in relation to their corresponding image code values as reproduced by a digital motion picture camera's image output.

The above graphical illustration of a digital camera's dynamic range of reproducible scene tones is analogous to the D Log E characteristic curve of a film negative.

The horizontal axis plots scene luminance as log exposure values (measured in foot-lamberts) or as "+" and "-" camera lens T-stops above and below 18%. The vertical axis plots their reproduced code values. By way of comparison, a film negative D Log E characteristic curve plots log exposures on the horizontal axis vs. corresponding film densities on the vertical axis.

Figure 2: Measuring Scene Luminance (example scene 1) Day interior diner scene (10-bit log image capture)

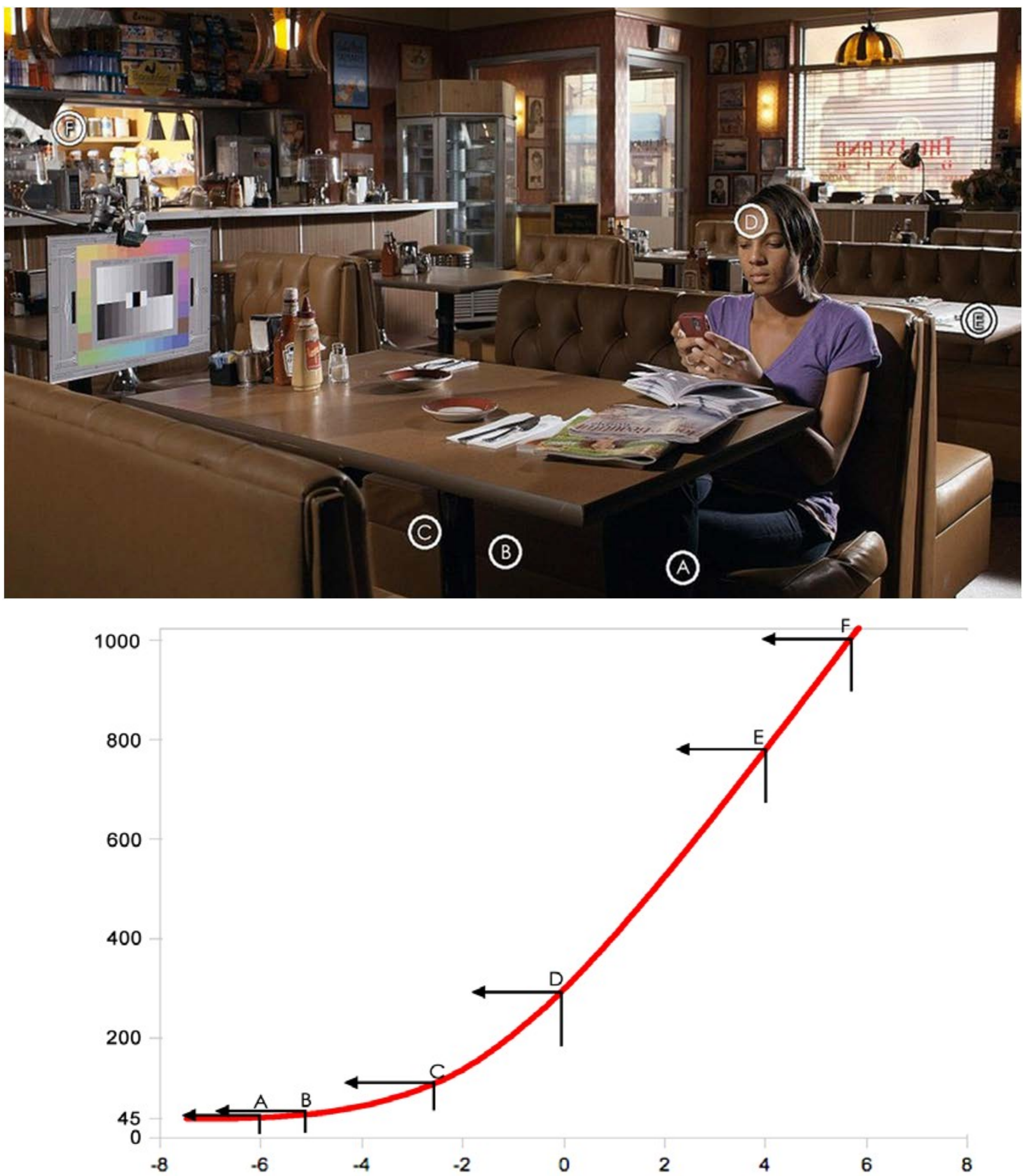
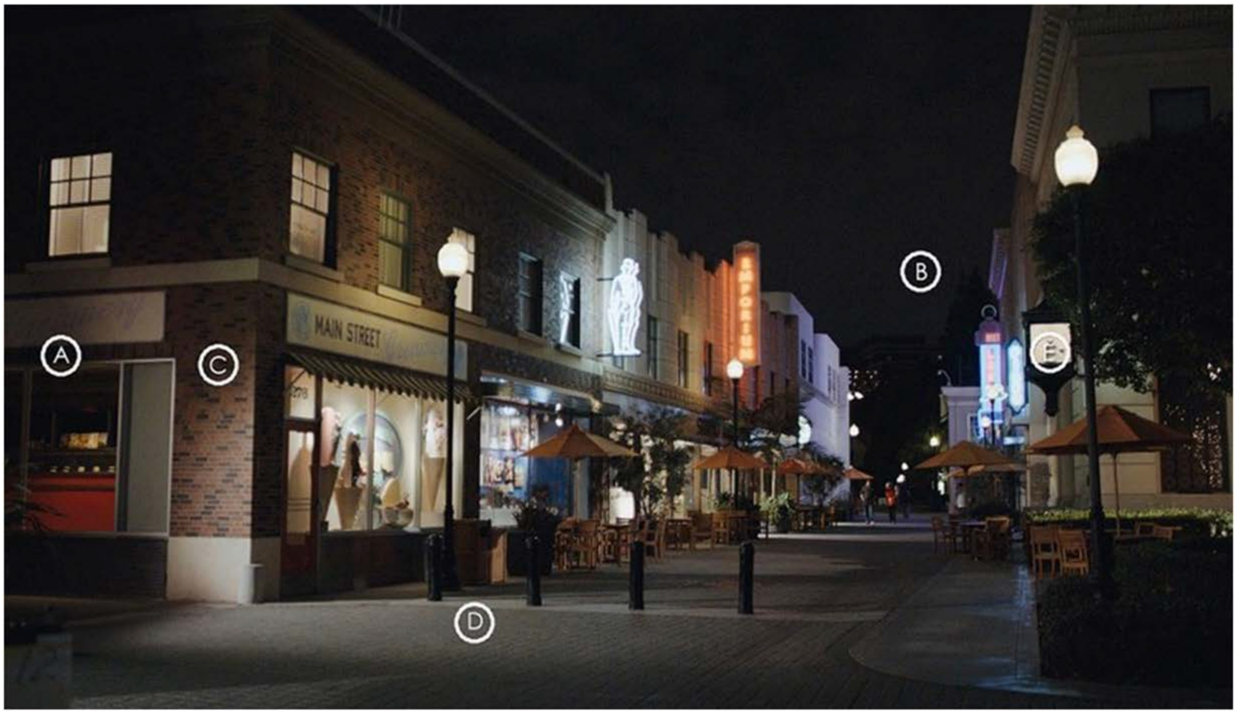
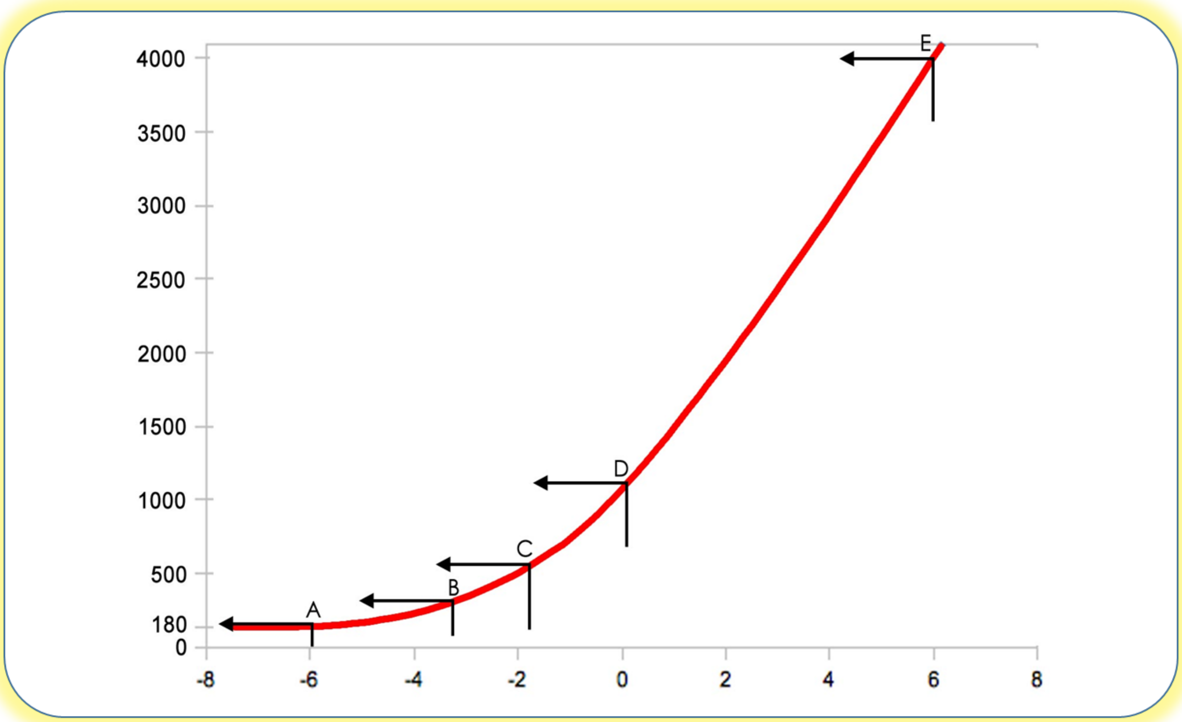


Figure 3: Measuring Scene Luminance (example scene 2) Night exterior street scene (12-bit log image capture)





Two sides of the HDR coin:

- **High Dynamic Range images** captured by digital motion picture cameras, in addition to scanned film negative, which can record:
  - 14/15 stops between minimum shadow detail and maximum highlight detail
- **Monitors and digital projectors engineered to display a High Dynamic Range of camera originated (and CGI) images** using brighter screen luminance levels than SDR displays:
  - 400 to 4000 nits – (HDR reference monitors)
  - 500 to 2000 nits – (HDR consumer monitors)
  - 108 nits (32 ft-L) – (Dolby Vision digital cinema)

HDR image capture has been part of motion pictures for decades

- **Film negative** can capture a High Dynamic Range of scene tones (14+ stops), **but**:
  - Standard Dynamic Range (SDR) display device imaging parameters for both TV monitors and cinema projection **constrain the reproduction** of HDR image capture.
    - Display a limited range of scene tones using lower screen brightness
      - 5 ft-L (17 nits) to 14 ft-L (48 nits) for projection (both film print and digital cinema) with contrast ratios between 2000:1 and 4000:1.
      - 75 nits to 250+ nits for current SDR pro and consumer monitors (average is 100 nits)
        - Excessive SDR display brightness will lift black and reduce contrast

HDR is relatively new to digital motion image acquisition and display

Until recently, professional digital video cameras had limited dynamic range (between 8 and 11 stops).

- HDR is also relatively new to both HDTV and UHDTV ('4K') professional and consumer display technologies, as well as digital cinema (laser) projection.
- HDR supports a higher dynamic range of reproducible scene tones at greater display brightness than current SDR industry norms.

The key to proper HDR display is:

- Increase the luminance level of shadow detail, upper mid-tones and highlights which can add greater depth and dimensionality to image reproduction.

  While simultaneously:

- Retaining a solid black level with nuanced shadow detail, excellent contrast gradation and proper color reproduction throughout the entire dynamic range using an appropriate display gamma or electro-optical transfer function (EOTF)*,e.g., ST 2084 , which maps a high dynamic range of scene tones to their optimal reproduction within an HDR enabled display device.

Contrast of High Dynamic Range Displays is Crucial

- Good contrast of higher brightness HDR displays requires preserving black level while expanding the highlights.
  - Otherwise, perceptual contrast can be reduced if black level is lifted.
    - Sub-optimal contrast reproduction can impact dynamic range perception.
  - HDR displays should provide good contrast reproduction to be able to display the magnitude of possible tonal values from black level to brightest highlight within the high dynamic range of original scene tones.
  - Ambient light level surrounding the displayed image affects perceptual contrast.

Summary of Benefits of HDR

Image acquisition

- HDR digital image capture using RAW mode, photographically generates a more comprehensive reproduction of the original scene **including:**
  - Greater dynamic range of scene tones (luminance values) that also benefit from a wider color gamut beyond Rec.709, e.g., DCI P3, Rec. 2020.
  - ACES (Academy Color Encoding System) provides a standardized optimal framework for preserving HDR and wide color gamut throughout the production and post production workflow, from image origination using on-set HDR monitoring with look management, through editorial to final color grading.
- The choice of camera lenses can significantly impact the reproduction of the most effective implementation of HDR images. Vailing glare and lens flare have the potential to seriously reduce scene contrast thereby diminishing the maximum potential HDR scene contrast. Since lens choice should be driven by creative/aesthetic considerations that best serve narrative storytelling, it is important to conduct camera/lens testing during prep to best assess the most appropriate results that match the filmmakers' creative intent. This is especially true today with an increasing array of new digital camera sensors which need to be tested with a variety of lenses, both new and classic, to determine how they best serve creative requirements for a specific production.
  - It is vital to consider how lens performance impacts overall perception of image performance with different digital motion picture cameras. Lens characteristics such as resolution, contrast and sharpness can have an overriding determination on the reproduction of image contrast, resolution and sharpness.

Image display

- An HDR image reference display reproduces a much greater range of tonal detail with proper contrast that takes full advantage of wider color gamut **incorporating:**

- Good black level with more shadow detail enabling enhanced local contrast with added dimensionality and depth perspective.
- Brighter highlights with added dimensionality and depth perspective.
- Richer and more nuance color reproduction using wider color gamut (beyond P3 toward Rec.2020).

- Creates more natural image appearance closer to what the eye sees
  - **Facilitates a more immersive visceral experience for the viewer**

HDR enables a New Creative Canvas

HDR, in conjunction with wide color gamut and greater image resolution, provides filmmakers with an exciting new creative canvas that expands aesthetic possibilities for visual story telling.

- Cinematographers need to become proficient practitioners of this expansion oftheir photographic art.

Managing an HDR on-set workflow

There are crucial tools needed for the cinematographer and director to work effectively and efficiently with this new HDR creative canvas:

- A digital motion picture camera capable of recording a 14 to 15 stop dynamic range of scene tones preferably using camera RAW image capture, along with wide color gamut and ACES color management, e.g., the Canon EOS C700 camera, RED Weapon, Panavision Millennium DXL, Sony F65, ARRI Alexa and Panasonic VariCam.
- An on-set HDR ACES enabled 4K reference monitor capable of displaying the full dynamic range of scene tones with at least a 1000 nit peak white, along with wide color gamut captured by an HDR capable camera: e.g., the Canon DP-V2420 4K reference display, Sony BVM X300. It is important to be able to accurately monitor HDR images on-set during shooting to better evaluate creative compositional choices that make effective use of HDR in ways that best serve creative intent. An SDR proxy may constrain the enhanced aesthetic/emotional impact that is possible with the full HDR image reproduction.
- An HDR enabled waveform monitor is critical for assessing the accuracy of tone scale reproduction within an HDR scene, especially regarding reproduction of important highlight and shadow details so as to avoid unintended clipping of highlight detail and/or crushing shadow detail. The waveform does not replace but validates the cinematographer's exposure readings.

Dailies and Editorial workflow

With the exception of FotoKem's Next Lab, FilmLight's Prelight On-Set, Colorfront's On-Set Express Dailies and MTI Film Cortex Dailies, many on-set digital dailies systems currently do not yet routinely support HDR with down conversion to SDR, especially from RAW camera image output. For current production workflow, creating an SDR version of dailies is mandatory for distribution to production personnel who generally don't have easy access to HDR monitors for viewing. This usually involves on-set look and data management that can generate conventional SDR dailies, or alternatively send the original HDR camera image data to a post facility where a colorist will color grade the footage to accommodate both HDR and an SDR down conversion. The post facility colorist can run a comparative HDR reference check to better manage SDR down conversion (e.g., using the Dolby Vision CMU: Content Mapping Unit), thereby creating companion HDR/SDR grades that can be viewed with appropriate HDR/SDR monitors. Dolby Vision effectively manages the conversion from HDR to SDR using their CMU (Content Mapping Unit) which optimally and efficiently maps the color graded HDR camera original content to SDR images. Without effective and efficient down conversation from HDR to SDR, colorists may need to do a separate color grade for SDR.

Demand for HDR image monitoring, from on-set through post, will start to ramp up as more productions choose to take advantage of HDR's expanded creative palette as their primary platform. This may include HDR editorial support for Avid, Final Cut Pro and Adobe Premier, as well as HDR VFX support for CGI compositing applications. HDR editorial, as well as on-set HDR generated dailies will become progressively available as filmmakers' demands increase, thereby justifying the essential upgrades needed to support these systems. ACES, of course, should be included as the color management system and image interchange framework throughout the production/postproduction workflow.

HDR Final Color Grading for TV and Digital Cinema

It is essential to use a master grading HDR reference monitor capable of displaying a 15 stop dynamic range with at least 1000 nits, along with support for wide color gamut (DCI P3 and Rec. 2020) using ACES color management: e.g., the Canon DP-V2420 4K Reference Display; Sony BVM X300; Dolby PRM 4200 Pulsar (4000 nits).

HDR digital cinema exhibition is still in its infancy, largely due to a limited number of cost effective HDR laser projector installations in general release theaters. Also, there are currently a limited number of digital intermediate post finishing facilities that have HDR projectors for color grading an HDR master. Due to a more rapid advance and commercial availability of large screen UHD (4K) TVs that are HDR enabled, along with the recent introduction of the new Ultra HD Blu-ray (4K HDR Wide Color Gamut), the home theater is currently the primary driver advancing the demand for HDR. In addition, over-the-top content (OTT) steaming services like Netflix are actively promoting HDR for their productions, thereby exploiting a potential marketing advantage over the currently prevailing SDR digital cinema.

HDR and SDR will coexist for an indeterminate time until an inflection point is reached in consumer adoption of HDR that may further accelerate momentum toward a more ubiquitous adoption of HDR. This will then make HDR the primary platform for both home entertainment and cinema exhibition.

ACES

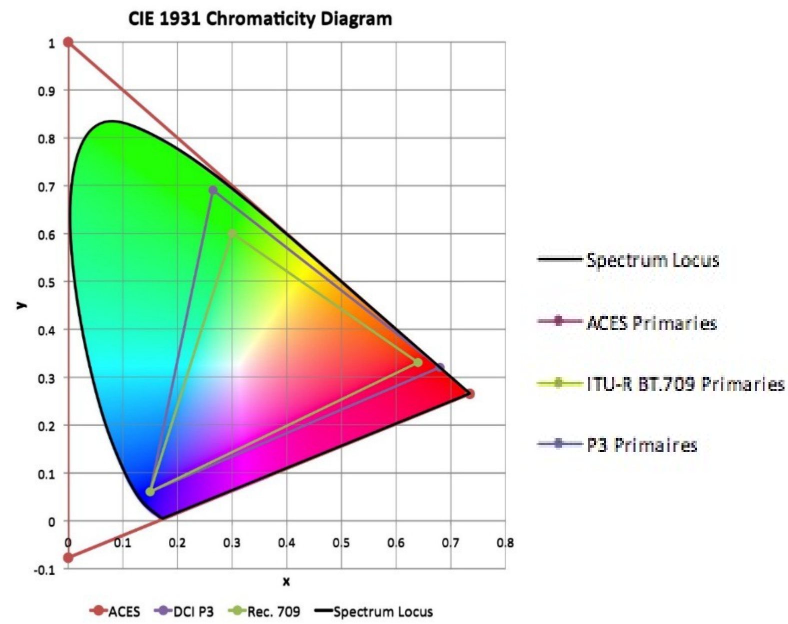
- **ACES** (**Academy Color Encoding System**) is both a standards based color encoding system and an image interchange framework within production and post production workflows. It has been created and is maintained by the Academy of Motion Picture Arts and Sciences (AMPAS).
    - **ACES** includes **encoding**, **rendering** and **output display specifications**, **transforms**, **file formats** and recommended practices that enable the creation and processing of high fidelity images while ensuring image integrity within the workflow.
    - The **Academy Color Encoding Specification**, also **"ACES,"** defines a high precision (16 bit floating point) RGB wide color gamut image encoding appropriate for both photographed and computer-generated images.

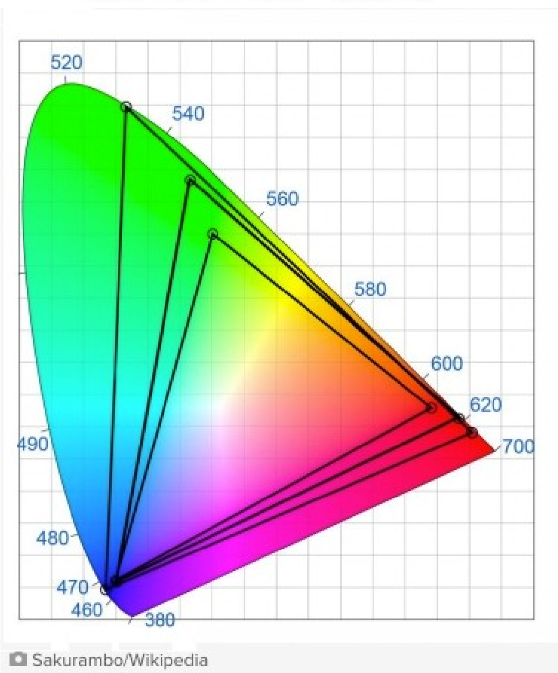
For important information on ACES, here is a link to ACES Central website maintained by AMPAS
http://acescentral.com/t/list-of-aces-productions/23

Chromaticity

Below are two chromaticity diagrams that illustrate comparative color space/color gamut differences between ACES, Rec.2020, DCI P3 and Rec.709 in relation to the Spectrum Locus of human vision.

Figures 4 and 5: Chromaticity Diagrams





- smallest is **Rec 709**, the current video standard
- medium is **DCI P3**, the current digital projection standard
- largest is **Rec 2020**

* See link to SMPTE *Newswatch* article by Michael Goldman regarding status of EOTF standards:

https://www.smpte.org/publications/newswatch