

Blackmagic Production Camera Raw Color Investigation by Spectral Analysis of Macbeth Color Charts

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Abstract

Color is an important aspect of the camera quality. Above all in a Visual Effects Pipeline (VFX) it is necessary to maintain a linear relationship of the pixel color in the recorded image to the original light of the scene throughout every step in the production pipeline. This means that the plate recorded by the camera is not permitted to be subject of changes in any way („do no harm to the plate“). Unfortunately most of the camera vendors are applying certain functions during the input step to the recorded RAW material, mostly to meet the needs of the display devices at the end of the pipeline. But they also are adding functions to establish a certain look, the camera company is associated with.

Maintaining a linear relationship to the light of the scene enables compositing artists and editors to combine imagery of varying sources (mostly cameras of different vendors). If for example an action scene is filmed using an ARRI film camera to capture the performance of the principal actors, additional imagery is derived using action cameras like the GoproHero. Also it is often desirable to have some less expensive camera at hand which can be moved around easily to take textures and imagery for example to create clean plates. A critical aspect in the production workflow is that all the imagery from the different sources can be combined

easily in editing and compositing without additional color correction.

The goal of this paper is to calculate the position of the patches of the GretagMacbeth color checker chart [1] (now X-Rite color chart) using an image recorded by the Blackmagic Production Camera and compare it to reference data sets based on those provided by the manufacturer and measured spectral data under the same lighting conditions. As a result a tendency could be obtained if the camera can be used inside the AMPAS ACES workflow.

1. The AMPAS-ACES Workflow

The Academy of Motion Picture Arts and Sciences (AMPAS) started 2004 to develop the *Academy Color Encoding System (ACES)* to gain a fully encompassing color accurate workflow with "seamless interchange of high quality motion picture images regardless of source" [2]. It is based on OpenEXR files with 16 bit half floating point accuracy and encompasses a gamut where all colors detect by the human vision system can be encoded. The color encoding system comprises four main elements (*figure 1*).

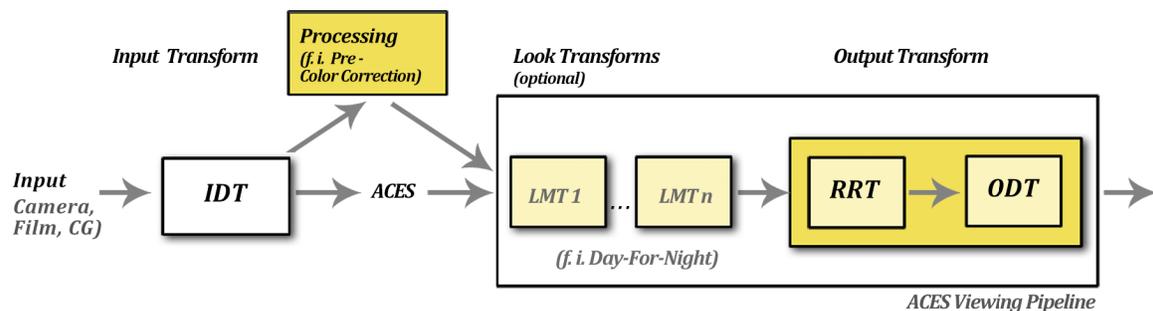


Figure 1. The AMPAS ACES workflow [3]

- IDT - Input Device Transform

Here all the functions inserted by the camera vendors like OECFs (Optical Electronic Conversion Functions) and hue shift curves to create a company look are removed. They are specified by the manufacture using ACES guidelines. The source material is then transformed into the ACES color space and encoding specifications.

- LMT - Look Modification Transform

Custom color corrections to create a certain look, but also predefined popular conversions like *Bleach Bypass* or *Day-For-*

Night can be applied. The looks are provided by LookUp Tables (LUTs).

- RRT - Reference Rendering Transform

Here the scene-referred colorimetry is converted to display-referred. This step is necessary because digital film cameras create imagery with a much wider dynamic range than 8 bit. An Arri digital film camera for example can capture a dynamic range from 0 up to 40 using the highest ISO settings compared to a dynamic range of only 0 to 1 using 8 bit sRGB images. To display these

images on a current monitor or projector a S-shaped curve like conversion function is applied to transfer the dynamic range of the imagery in a viewable form. The applied curves resemble traditional film image rendering. These conversion LUTs are applied at the final step of the production process in Digital Intermediate for delivery or are used in the production chain as a view transform without changing the source files.

- ODT - Output Device Transform

Here *Electronic Optical Conversion Functions* (EOCFs) are applied to meet the needs of the display device (film monitor, Projector, TV-set, computer display). The gamma curve exponent values ranging from 1.95 (TV) to 2.6 (film projector).

This system establishes a seamless high quality workflow from capturing to delivery and storage and is future proofed because it provides the possibility to apply color correction in later days when the quality of displaying devices may be improved.

2. The current state of the Input Device Transforms (IDTs)

We will focus in this document on the Input Device Transform section in the ACES workflow, because it concentrates on establishing a linear relationship of the pixel value in the images to the original light of the scene. In the movie making process with a certain budget, a so called camera characterization is taking place. Hereby the positions of the patches from the X-Rite chart are recorded with a film camera and a spectral camera (see figure 2). The color of the patches in question are compared in CIE Yxy color space and a 3x3 matrix is generated to transfer the positions of the patches recorded by the digital film camera to the patches obtained from spectral data. As a result a linear relationship to the light of the scene is established with every camera on set and even influences of lenses are removed. The imagery can then easily be combined.



Figure 2. Macbeth (X-Rite) color chart and indentifiers used in the test

Additionally to this process the ACES workflow as of version 1.0.1 contains a considerable range of IDTs for the most common movie cameras to help establish a linear relationship to the light from the scene without applying the expensive camera characterization.

The aim of this document is to test out if the Blackmagic Production Camera as a consumer camera can help in this process by shooting additional material which can be combined even if no IDT is available. We focus on a practical workflow by using the built-in functionality of the most common compositing software *The Foundry NukeX v.10.4* [4].

3. The NukeX Input Interface Parameters

The Blackmagic Production Camera uses Adobe's DNG file format as a RAW container. The interpretation and conversion to a viewing environment is established by using meta data. This enables the user to convert the RAW format to a common color space.

The import of the DNG files into The Foundry's NukeX compositing software is provided by a standard *Read Node* with additional functionality implementing the DNG specifications. The parameters are shown in *Figure 4*. Supplementary to the standard functionality inside Nuke we use the also built-in OpenColor IO system developed by Jeremy Selan (Sony Picture Imagework) to gain access to the current ACES version 1.0.1. [5].

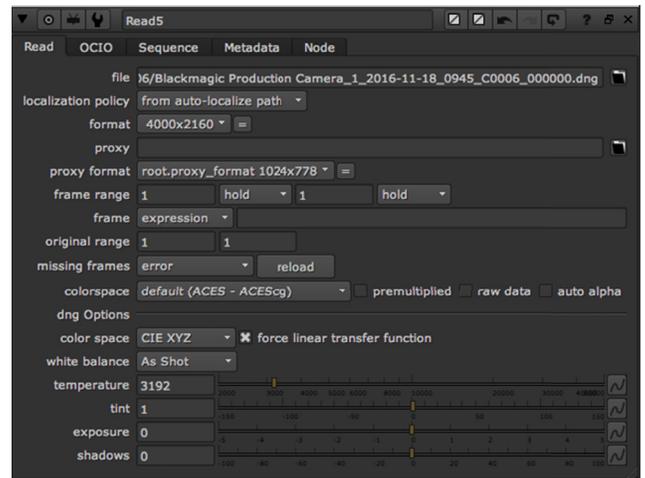


Figure 3. NukeX Read Node Parameters importing DNG files

The first parameter in the DNG read node comprises Nuke's color space. This color space is the host to all the color spaces the RAW data is converted to and should encompass all the colors of the certain target color spaces.

The default color space is ACEScg, a color space with a set of primaries which encompass a gamut smaller than the original set of primaries in ACES 2065-1, but wide enough to host all the colors of the target color spaces with the exception of some parts of the ProPhoto color space (see *figure 4*). The ACEScg color space has been developed with regard to the production workflow in the computer graphic industry, so we will use it here.

The second parameter is an option to force a linear transfer function. This is essential for VFX work and causes all OECFs (optical electronic conversion functions) to be eliminated. We use this option.

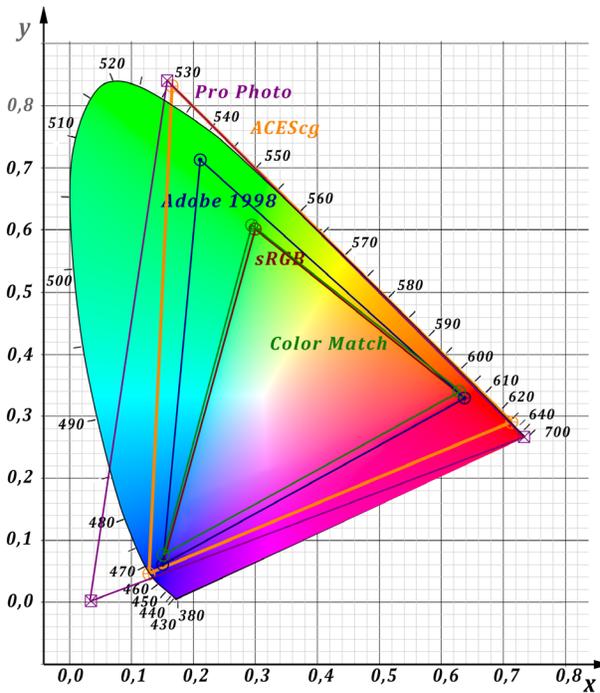


Figure 4. Gamuts of the target color spaces and the ACEScsc gamut [6]

The third parameter comprises five target color spaces - the color space the DNG SDK will debayer to [7].

The color spaces are:

- sRGB
- CIE XYZ
- Adobe RGB
- ProPhoto
- Color Match

It is interesting to note that these are entirely graphic color spaces and all the video color spaces (BT.601. BT.709. BT.2020) are left out as well as film color spaces like ACES or DCI P3.

The fourth parameter comprises the white point conversion (white balance). Here verbal descriptions of CIE Illuminants (Daylight, Cloudy, Shade, Tungsten, Fluorescent, Flash and Custom) are the options to choose from. It should be mentioned that for a more professional user it would be convenient to add the illuminant's CIE name (for example Tungsten – Illuminant A) to avoid further testing and matching the verbal description to the CIE name.

Another option for the fourth parameter is *As Shot*. In our testing environment the internal camera algorithm detects a color temperature of 3192 K. In a standard usage it could be very difficult to capture the reference white with another method (for instance using spectral data), so we leave the settings as they are by using the white balance from the meta data of the recorded imagery (As shot).

4. Discussing the methods of comparing reference color to the results from the conversion process

The goal of the test is to line out a tendency, which color space – if any – is best for a linear representation of the light from the scene.

To compare the results of the encoding process from RAW imagery of the test chart with the X-Rite color checker as a given reference we use two methods. The first method derives the position of the reference patches in the CIE xy-chromaticity diagram out of a list found in the document *RGB Coordinates of the Macbeth ColorChecker* by Danny Pascale [8]. In this document coordinates of the 24 patches in the CIE xy-chromaticity diagram had been calculated using the original data given by the manufacturer and an average of 20 measurements of color checkers in use. The data is presented using CIE Illuminant D50. For comparing the position of the reference patches with the calculated positions of the test chart the positions of the reference patches have to be converted from CIE Illuminant D50 to CIE Illuminant D65.

For the second method a color checker is recorded by a *Headwall* spectral camera (see figure 5). The color chart is then recorded under the same lighting conditions by a Blackmagic Production Camera (see figure 6). The color of every patch of the X-Rite chart is converted to the CIE xyY-color space and plotted in the CIE xy-chromaticity diagram along with the position of the patches recorded by the spectral camera and the data provided from the first method. Here a custom conversion matrix has to be generated to convert data from the white point of the recording to CIE Illuminant D65, because there is no practical way to convert the recorded imagery to the original white point.



Figure 5. Test Set-up

For calculating the patch positions of the target color spaces we use the following settings inside NukeX:

- color space (Nuke): ACES - ACEScsc
- force linear transfer function: on
- white balance: As Shot
- temperature: 3192

By changing the target color space five sets of data for the 24 color patches are calculated. It should be mentioned that the usage of ACES - ACEScsg as the host color space is provided by the built-in OCIO system in Nuke 10.4 which offers access to the ACES 1.0.1 functionality.



Figure 6. Blackmagic Production Camera [9]

5. Calculating the CIE Yxy-values of the test chart

After reading in the imagery in NukeX 10.4 using the settings given above, a color conversion is established for each target color space (sRGB, CIE XYZ, AdobeRGB, ProPhoto and ColorMatch). The linear data of the test chart in conjunction with the primaries of the appropriate target color space hosted in the wide ACEScsg color space inside Nuke are then converted to CIE Yxy-color space using Nuke's *Color Space* node. We use CIE Illuminant D65 as reference to convert from. By using this white point two problems appear:

The first problem concerns the conversion from the recorded RAW imagery to CIE XYZ. The data in this process is transferred using CIE Illuminant E. To compare this data set with the others a conversion from CIE XYZ E to CIE XYZ D65 is applied.

The second problem concerns the conversion from the RAW imagery to the ProPhoto color space. This color space has the defined white point CIE Illuminant D50. So a conversion to CIE Illuminant D50 was considered, but testing led to the result that the conversion to Nuke's target color space was obviously done using CIE Illuminant D65. So we leave the settings as they are.

6. Calculating the CIE Yxy-values for the X-Rite reference (list)

The goal here is to obtain reference positions for the patches of the X-Rite chart in the CIE xy-chromaticity diagram for comparison. In the first method, we use values published in the document *RGB Coordinates of the Macbeth ColorChecker*, Table 2 [8] of this document lists the calculated position of every patch in different color spaces using the data provided by the original manufacturer GretagMacbeth as source. The white point for this data set is CIE D50 common in graphic applications. We convert it to CIE D65 using the following transfer chain:

CIE Yxy --> CIE XYZ D50 --> Bradford matrix --> CIE XYZ D65 --> CIE Yxy

The Bradford matrix used for the chromatic adaptation from CIE D50 to CIE D65 is given in formula (1).

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0.95316124 & -0.02660489 & 0.02389283 \\ -0.03826641 & 1.0288533 & 0.00941316 \\ 0.00260979 & -0.00303776 & 1.08934474 \end{bmatrix} \cdot \begin{bmatrix} X_E \\ Y_E \\ Z_E \end{bmatrix} \quad (1)$$

7. Calculating the CIE Yxy-values for the X-Rite reference (spectral data)

In this method we use the data from the recordings provided by the spectral camera. The CIE color matching functions we use in this process are published in [10]. We are using *Standard Observer 1976* with sampling points every 5 nm. After applying the CIE color matching functions patch a2 is used as reference and we normalize the recorded relative light energy of the Y parameter to a value of 60 (roughly the reflectance of patch a2). This results in the following values for patch a2:

	X	Y	Z
Wp rec.	58.053	60.00	24.763
Wp D65	95.047	100	108.88
			3

Table 1. Coordinates of the recorded white point and CIE D65 in CIE XYZ

To convert from the white point of the recording to D65 (60%) for patch d2, we generate a matrix using simplified XYZ scaling. The recorded spectral data (XYZ) is then normalized using formula 2 and 3.

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} X_{src}/X_{tgt} & 0 & 0 \\ 0 & Y_{src}/Y_{tgt} & 0 \\ 0 & 0 & Z_{src}/Z_{tgt} \end{bmatrix} \cdot \begin{bmatrix} X_{rec} \\ Y_{rec} \\ Z_{rec} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} X_{D65} \\ Y_{D65} \\ Z_{D65} \end{bmatrix} = \begin{bmatrix} 0,982397933 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 2,635328762 \end{bmatrix} \cdot \begin{bmatrix} X_{rec} \\ Y_{rec} \\ Z_{rec} \end{bmatrix} \quad (3)$$

The converted CIE XYZ data of every reference patch is then converted to CIE Yxy. The energy distribution along the visible spectrum of the reference patch d2 with an estimated temperature of 3192 K is shown in figure 7.

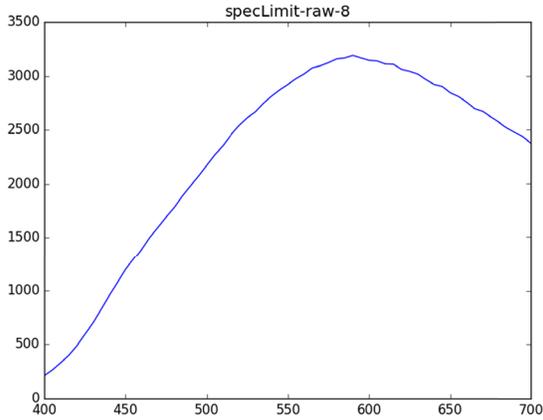


Figure 7. White point of the spectral data

The position of the white point of the recorded spectral data is off the black body line where all CIE Illuminants are placed. This and the problems in calculating the chromatic adaptation in the tungsten area leads to offsets between the position of the two sets of reference patches. We will discuss this in the summary section, but leave the spectral data as additional reference to obtain a tendency.

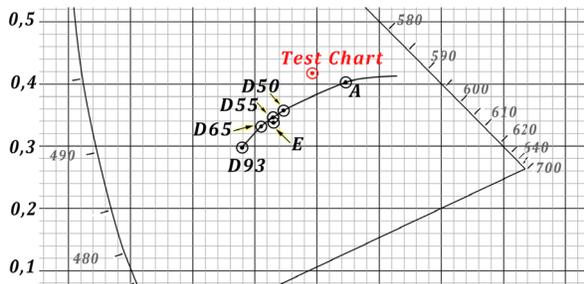


Figure 8. White point of the spectral data in CIE Yxy [11]

7. Discussing the results

The data sets obtained using the methods described in section 4 to 6 are listed in Table 2. For comparing purposes we also calculate the differences between the values of the X-Rite source and the values of the target color spaces for every patch (Table 3). The patches with the largest differences (a1, a2, a6, b1) along with the patches associated with the first primaries and second primaries (c1-c6) are plotted in the following figures. For better reading we use the term image patches for the result of the appropriate color space conversion using the camera recordings, X-Rite patch for the listed position of the patches in [8] and spectral patch for the calculated position using the spectral data.

7.1. Patch A1 (dark skin)

The positions of the five image patches are close together but the offset from the X-Rite positions (list and spectral) is considerably. This is obviously due to the wide spread convention of camera manufacturer who tend to shift skin tones towards a

warmer color. It is interesting to note that the spot where the image patches are placed is close to the position of the reference X-Rite patches using CIE Illuminant D50 which produces an image which is much warmer (more yellows and reds) than using CIE D65.

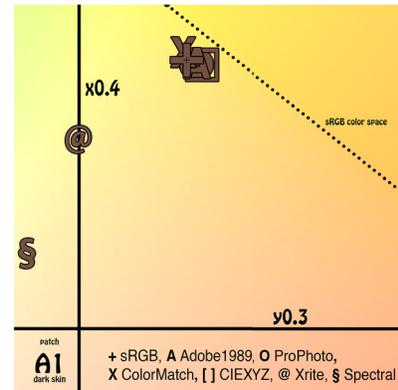


Figure 9. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch a1 (dark skin)

7.2. Patch A2 (light skin)

The positions of the five image patches are close together and the offset from the X-Rite positions (list and spectral) is mediocre.

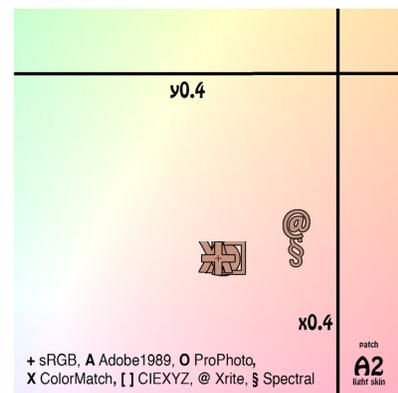


Figure 10. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch a2 (light skin)

7.3. Patch A4 (foliage)

This patch features the most dramatic shift and offset to the reference positions. The image patch positions are close together as well, but the offset to the reference positions and especially to the spectral references is considerably. This may be an indication that the camera manufacturer tries to increase the green tones as part of the company look.

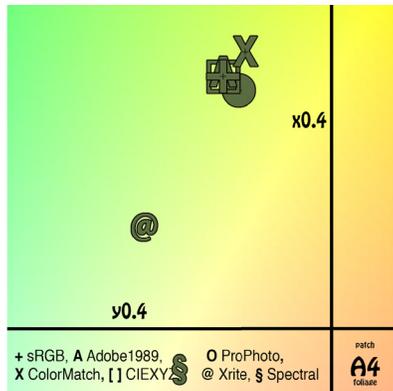


Figure 11. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch a4 (foliage)

7.4. Patch B1 (orange)

The image patches are spread out moderately along the boundaries of the sRGB color space. Whereas the positions of the AdobeRGB, ProPhoto, and CIE XYZ patches with a wider color space are located slightly outside the sRGB color space and the sRGB and ColorMatch patches with a smaller color space are directly located directly on the border. Notably is a shift towards orange obviously to produce a warmer tone in the image.

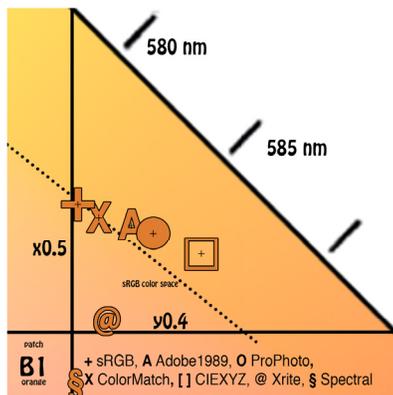


Figure 12. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch b1 (orange)

7.5. Patch C1 (blue)

The distribution of the image patches feature a moderate shift towards a more saturated blue outside the sRGB color space for AdobeRGB, ProPhoto, and CIE XYZ slightly outside the sRGB color space. The offset from the reference positions is moderate and aims to a slightly bluer appearance.

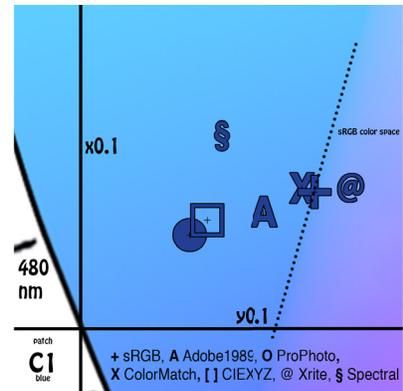


Figure 13. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c1 (blue)

7.6. Patch C2 (green)

For the green patch the calculated positions of the image patches and the X-Rite patch are close together. Only the spectral patch is slight off towards yellow (Figure 14).

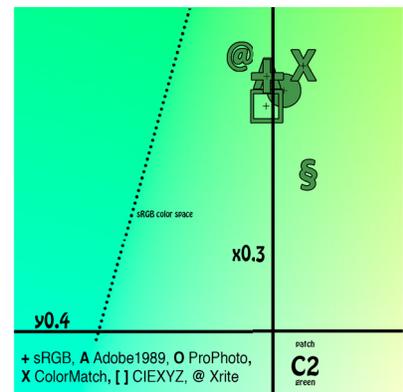


Figure 14. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c2 (green)

7.7. Patch C3 (red)

The slots for the image patches are clearly moved towards a more saturated red position. The offset is considerably larger to the spectral patch (Figure 15).

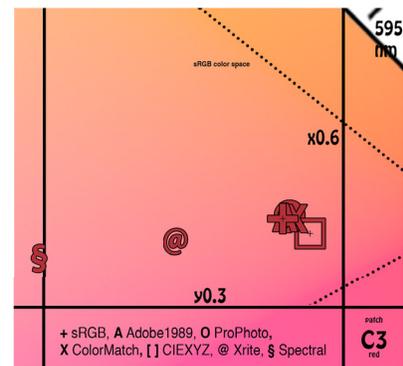


Figure 15. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c3 (red)

7.8. Patch C4 (yellow)

The image patches associated with a larger color space (CIE XYZ, ProPhoto) are located at the boundary of the sRGB color space at the same spot as the X-Rite patch. The sRGB, AdobeRGB, and ColorMatch patches are shifted slightly toward a yellowish green. The position of the spectral patch is located in a more reddish area (Figure 16).

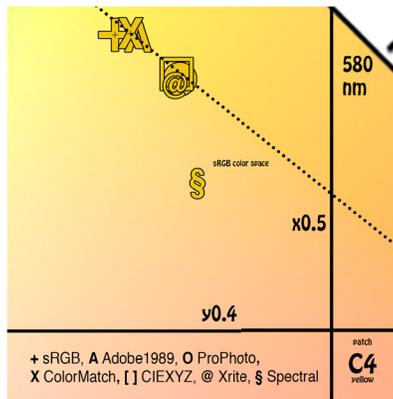


Figure 16. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c4 (yellow)

7.9. Patch C5 (magenta)

Here the position of all patches with the exception of the X-Rite patch are clustered close together.

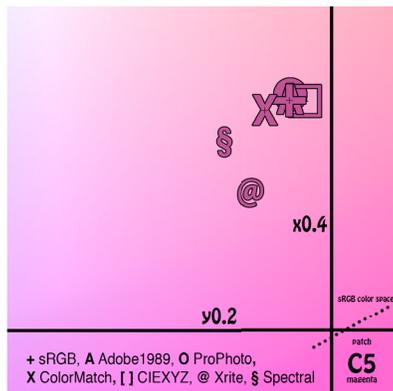


Figure 17. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c5 (magenta)

7.10. Patch C6 (cyan)

The slots of all patches are clustered close together. This is the most accurate converting for all the values.

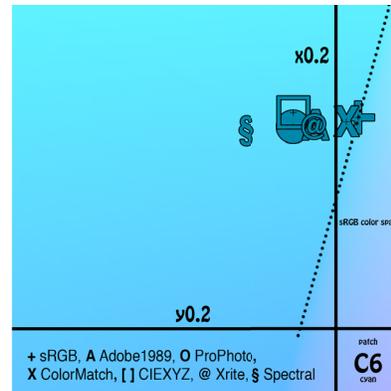


Figure 18. Positions of the X-Rite color patches in the CIE xy-chromaticity diagram for patch c6 (cyan)

8. Summary

The results of the investigation reveal that the colors conversion from the DNG RAW files to the target color spaces leads to considerably offsets mostly in the red/green/orange area whereas the offsets in the cyan/blue/magenta area could possibly be tolerated (figure 20). This behavior makes it difficult to insert the Blackmagic Production Camera in a VFX pipeline where the linear relationship to the light of the scene is critical. Most camera vendors try to overdrive the orange-yellow-green colors or position them in another place in the CIE xy-chromaticity diagram to create a pleasant look. In the *Red Color* space (figure 19) the same offsets are noticeable.

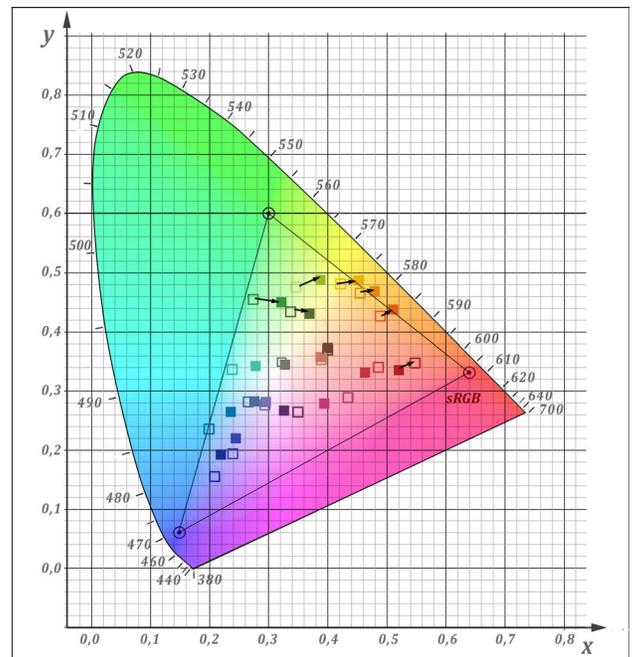


Figure 19. Positions of the RED camera Red Color space patches (full square) to the spectral positions in an other test [14]

But contrary to the RED cameras, where the Camera RGB [14] color space gains access to the internal wide camera color

space, there is obviously no access to the internal CameraRGB wide gamut color space for the Blackmagic Production Camera using this conversion system. The access is necessary because this is the step in the color conversion system where the debayered RAW data is available without hue shift curves applied to establish the company look.

Also desirable would be a possibility to leave the data using the white point of the recording position, id est without conversion to a common white point. This would help to compare the color checker positions to the spectral data. But this possibility is also hard to find with any other camera manufacturers.

Another problem is the lack of the possibility converting the color directly to a film color space used in film production pipelines, like DCI P3 or ACES. So a graphic color space has to be used as an intermediate color space and then a second conversion must be performed. Here the AdobeRGB color space is recommended because it exhibits the least deviation error compared to the X-Rite patches. Additional testing using conversion possibilities to Apple ProRes files should be taking place.

Further testing is also recommended in some ways. First nearly all camera vendors are applying two data sets for their imagery, one in the tungsten area (CIE Illuminant A) and one in the daylight area (CIE Illuminants D). The results of the calculation using both data sets can cause offsets between the spectral data sets [12][13]. So the behavior of the camera in the daylight area should be investigated as well, because comparing results is easier in this color temperature range.

In a second test scenario the results of this test could be compared not only with the spectral data but also with the results using digital film cameras (ARRI, RED, Sony etc.).

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Author Biographies

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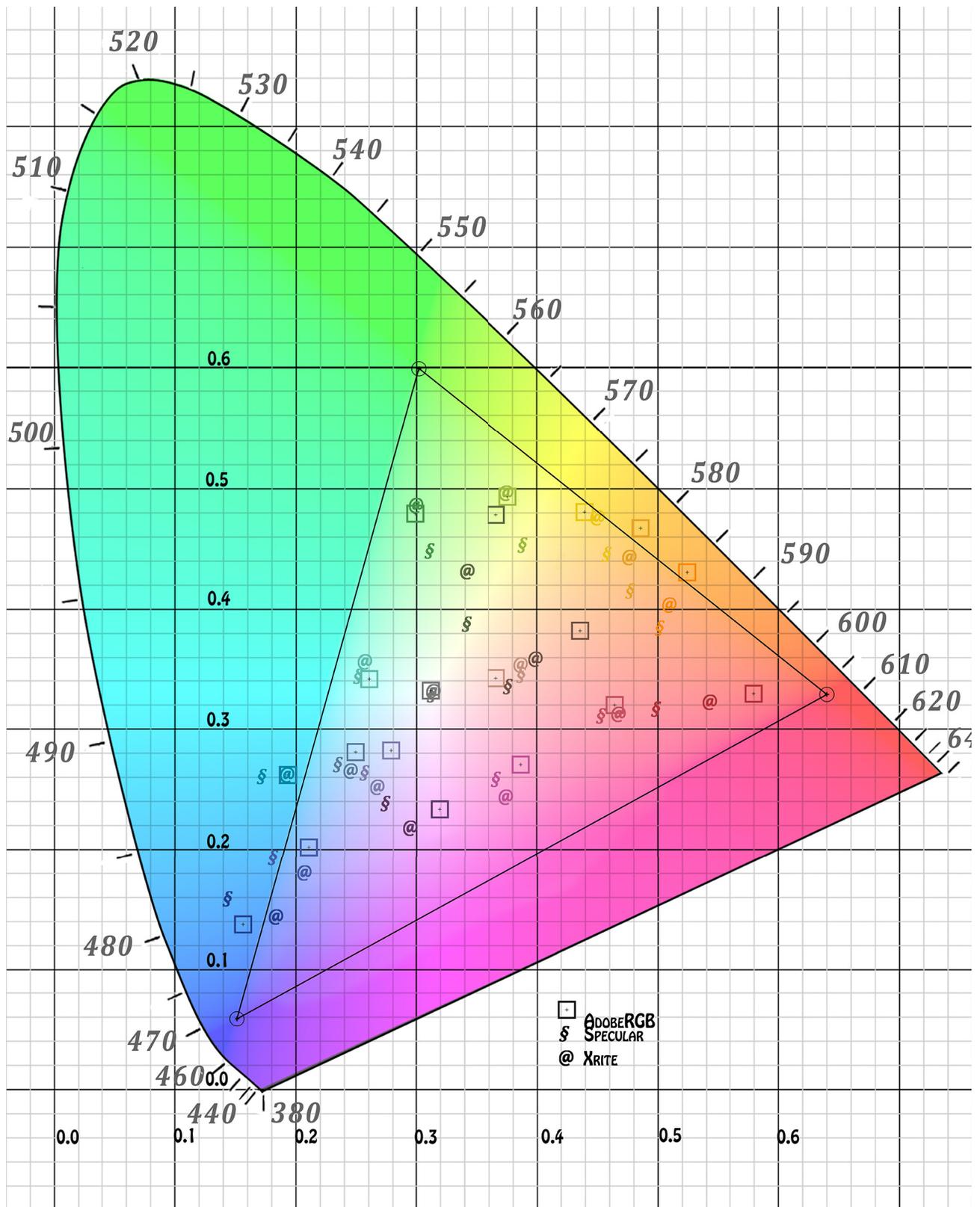


Figure 20. Positions of the AdobeRGB patches, the X-Rite color patches and the spectral patches,

Appendix A

Colorspace D65 -> xyY														
nuke color space: ACEScg														
force linear transfer function: on														
color space debayered to:														
Patch	CIE XYZ		sRGB		AdobeR		ProPhoto		ColoMat		Xrite		Spectral	
	D65				GB				ch					
	x	y	x	y	x	y	x	y	x	y	x	y	x	y
1 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 a	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 b	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 c	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 d	0	0	0	0	0	0	0	0	0	0	0	0	*	*
2 d	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3 d	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4 d	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5 d	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6 d	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Difference values: X-Rite - Color space				
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Table 2 Positions of the image X-Rite color patches in the CIE xy-chromaticity diagram

Nuke color space: ACEScg													
force linear transfer function: on													
color space debayered to:													
Patch	CIE XYZ		sRGB		AdobeRG		ProPhoto		ColorMatc		Sum		
	D65				B				h				a
	x	y	x	y	x	y	x	y	x	y	x	y	bs
1 a	0.0381	0.0226	0.0334	0.0242	0.0364	0.0229	0.0364	0.0229	0.0323	0.0265	0.1766	0.1191	0.2957
2 a	0.0211	0.0107	0.0243	0.0109	0.0243	0.0109	0.0228	0.0111	0.0264	0.0105	0.1189	0.0541	0.1730
3 a	0.0006	0.0182	0.0027	0.0154	0.0027	0.0154	0.0012	0.0155	0.0057	0.0150	0.0129	0.0795	0.0924
4 a	0.0263	0.0462	0.0242	0.0462	0.0242	0.0474	0.0292	0.0419	0.0312	0.0538	0.1351	0.2355	0.3706
5 a	0.0113	0.0328	0.0114	0.0306	0.0114	0.0306	0.0096	0.0309	0.0121	0.0300	0.0558	0.1549	0.2107
6 a	0.0023	0.0111	0.0042	0.0145	0.0042	0.0147	0.0031	0.0149	0.0099	0.0144	0.0237	0.0696	0.0933
1 b	0.0295	0.0206	0.0085	0.0361	0.0147	0.0271	0.0268	0.0231	0.0011	0.0320	0.0806	0.1389	0.2195
2 b	0.0025	0.0230	0.0036	0.0214	0.0036	0.0214	0.0057	0.0203	0.0063	0.0226	0.0217	0.1087	0.1304
3 b	0.0042	0.0078	0.0149	0.0094	0.0033	0.0101	0.0011	0.0109	0.0085	0.0093	0.0320	0.0475	0.0795
4 b	0.0264	0.0174	0.0243	0.0158	0.0243	0.0158	0.0215	0.0165	0.0175	0.0132	0.1140	0.0787	0.1927
5 b	0.0031	0.0051	0.0009	0.0029	0.0010	0.0029	0.0063	0.0093	0.0085	0.0046	0.0198	0.0248	0.0446
6 b	0.0240	0.0305	0.0074	0.0227	0.0089	0.0236	0.0238	0.0306	0.0023	0.0203	0.0664	0.1277	0.1941
1 c	0.0446	0.0099	0.0112	0.0013	0.0270	0.0077	0.0500	0.0145	0.0151	0.0002	0.1479	0.0336	0.1815
2 c	0.0018	0.0046	0.0017	0.0062	0.0017	0.0062	0.0030	0.0111	0.0095	0.0036	0.0177	0.0317	0.0494
3 c	0.0449	0.0042	0.0358	0.0092	0.0362	0.0092	0.0381	0.0102	0.0411	0.0093	0.1961	0.0421	0.2382
4 c	0.0013	0.0034	0.0182	0.0155	0.0107	0.0146	0.0023	0.0019	0.0129	0.0157	0.0454	0.0511	0.0965
5 c	0.0168	0.0279	0.0120	0.0281	0.0121	0.0282	0.0123	0.0299	0.0043	0.0251	0.0575	0.1392	0.1967
6 c	0.0060	0.0041	0.0139	0.0018	0.0008	0.0002	0.0066	0.0006	0.0103	0.0009	0.0376	0.0076	0.0452
1 d	0.0013	0.0025	0.0013	0.0025	0.0013	0.0025	0.0013	0.0025	0.0013	0.0025	0.0065	0.0125	0.0190
2 d	0.0011	0.0049	0.0007	0.0039	0.0007	0.0039	0.0008	0.0038	0.0010	0.0039	0.0043	0.0204	0.0247
3 d	0.0017	0.0096	0.0011	0.0080	0.0011	0.0080	0.0013	0.0079	0.0017	0.0082	0.0069	0.0417	0.0486
4 d	0.0012	0.0180	0.0002	0.0156	0.0002	0.0156	0.0007	0.0153	0.0013	0.0160	0.0036	0.0805	0.0841
5 d	0.0006	0.0266	0.0015	0.0234	0.0015	0.0234	0.0011	0.0230	0.0004	0.0239	0.0051	0.1203	0.1254
6 d	0.0091	0.0329	0.0078	0.0299	0.0078	0.0299	0.0093	0.0307	0.0093	0.0307	0.0433	0.1541	0.1974
Sum	0.3198	0.3946	0.2652	0.3955	0.2601	0.3922	0.3143	0.3993	0.2700	0.3922			

Table 3 Differences between the position of the color space conversions and the positions of the X-Rite color checker