Gernot Hoffmann

Color Management by ICC Profiles

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Settings for Acrobat

Edit / Preferences / General / Page Display (since version 6)
Custom Resolution 72 dpi / View by zoom 100% or 200%

Edit / Preferences / General / Color Management (full version only)
sRGB
Euroscale Coated or ISO Coated or SWOP
Gray Gamma 2.2

1. Introduction

This is an attempt to explain the workflow in ICC profiles [13], laying emphasis on white point transforms and the practical consequences. Thanks to the authors of text books and other publications (see References).

2. Color Spaces

CIE XYZ is the only device independent color space - physical colors are described by three coordinates XYZ. RGB working spaces, RGB monitor spaces, CMYK spaces, CIELu'v' and CIELab depend on some informations how the respective space is embedded in XYZ. In this sense these spaces can be considered as fictitious devices.
An emissive color is described uniquely by XYZ. A reflective surface does not have a color, but together with a light specification the reflected light has a color with three coordinates XYZ.
Light is specified by a spectrum, but often it is sufficient to know the white point X_w, Y_w, Z_w in XYZ, mostly normalized for Y_w=1 (or 100). The color temperature is always a correlated color temperatur - the value T on the locus for all color temperatures of the *Planckian* radiator, as found by the shortest distance in CIELu'v'.
CIELab is the Profile Connection Space, the intermediate source space for the conversion to CMYK.
For the sake of simplicity we are using here a D65 RGB source space and D50 proofing light for print products. ICC does not restrict color management to these cases. Furtheron we are considering working space RGB and monitor RGB as synonyms in the context of D65 white point discussions.

3. Working Space RGB to CIELab

An RGB working space is defined by the chromaticity coordinates for the primaries, the white point (WP) and additionally the Tone Reproduction Curve (TRC, gamma). The values **R**=(R,G,B) are already transformed into a linear space and normalized for RGB = 0...1. Let us assume WP D65. This means: emissive light for R=G=B is in XYZ on a line through the WP D65 and the origin of the coordinate system XYZ.

The physical source values $\mathbf{X}_s$=(X,Y,Z) in CIE XYZ for **R**=(R,G,B) are calculated by a matrix multiplication.
X and **R** are column matrices, written in text for convenience as rows.

$$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$$

The matrix $\mathbf{C}_{xr}$ uses the information about primaries and WP. Many matrices are found in [11] and [12].
CIELab is just another coordinate system. Besides the general law for the transformation we have to define the orientation of the axes L,a,b (asterisks omitted) in XYZ.
Axis (a) is aligned with X, axis (b) with -Z, but for axis (L) we have a degree of freedom: this axis points to the Reference White, here WP D50. If the viewing light is also D50, as usual for graphics art, then we have two different visual viewing white points: D65 and D50. Human adaptation is taken into account by a chromatic adaptation transform (or transformation) CAT, assuming the respective adaptation states.
This CAT is defined by a matrix **T**, which is either the *Wrong von Kries* transform $\mathbf{K}_w$, the *von Kries* transform **K** or the *Bradford* transform **B.** CAT is applied in *advance* to the CIELab conversion. The index (s) means source, (d) means destination.

$$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$$

The next step is the correction for paper white by a diagonal matrix **P**:

$$\mathbf{X}_p = \mathbf{P}\,\mathbf{X}_d$$

The conversion to CIELab is executed by two steps. First the conversion to Reference White by a matrix multiplication with $\mathbf{R}_w^{-1}$ = diag ($1/X_{w50}$, $1/Y_{w50}$, $1/Z_{w50}$):

$$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_p$$

Then we have a nonlinear transform to **L** = (L,a,b), here written without asterisks and abbreviated by three functions **F**=(F_L,F_a,F_b):

$$\mathbf{L} = \mathbf{F}(\mathbf{X}_c)$$

4. RGB to CIELab / Details

This is the complete transform, but without paper white.

Generic gamma correction, g=2.2, R=R,G,B

$$R = R'^{g}$$

sRGB gamma correction, R=R,G,B

$$R = \begin{Bmatrix} R'/12.92 & \text{if } R' \leq 0.03928 \\ ((0.055+R')/1.055)^{2.4} & \text{else} \end{Bmatrix}$$

RGB to XYZ (same white point D65, source)

$$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$$

RGB to XYZ (new white point D50, destination)

CAT, use $\mathbf{T}=\mathbf{K}_w, \mathbf{T}=\mathbf{K}$ or $\mathbf{T}=\mathbf{B}$

$$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$$

$\mathbf{X}_d$ to L*a*b* (reference white matrix $\mathbf{R}_w^{-1}$ for $\mathbf{X}_{w50}$)

$$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_d = \begin{bmatrix} 1/X_{w50} & 0 & 0 \\ 0 & 1/Y_{w50} & 0 \\ 0 & 0 & 1/Z_{w50} \end{bmatrix} \mathbf{X}_d$$

$$X_1 = \begin{Bmatrix} X_c^{1/3} & \text{if } X_c > 0.008856 \\ 7.787\,X_1 + 16/116 & \text{else} \end{Bmatrix}$$

$$Y_1 = \begin{Bmatrix} Y_c^{1/3} & \text{if } Y_c > 0.008856 \\ 7.787\,Y_c + 16/116 & \text{else} \end{Bmatrix}$$

$$Z_1 = \begin{Bmatrix} Z_c^{1/3} & \text{if } Z_c > 0.008856 \\ 7.787\,Z_c + 16/116 & \text{else} \end{Bmatrix}$$

$$\begin{aligned} L^* &= 116\,Y_1 - 16 \\ a^* &= 500\,(X_1 - Y_1) \\ b^* &= 200\,(Y_1 - Z_1) \end{aligned}$$

5.1 Chromatic Adaptation / General

Chromatic adaptation is not easily explained. This is a definition by [2]:

> The Human Color-Imaging System
> Chromatic adaptation refers to adjustments of the visual mechanism in response to the average chromaticity of the stimulus (or collection of stimuli) to which the eyes are exposed.
> For example, when exposed sufficiently long to a reddish-yellow stimulus, such as a tungsten light, the eye's longer-wavelength-sensitive receptors become somewhat desensitized and its shorter-wavelength-sensitive receptors become relatively more sensitive.
> (The white-balance adjustment of a video camera, described earlier, is an approximate emulation of this process.)
> Chromatic adaptation helps the visual system interpret objects despite changes in the color of the illuminant.
> So a white flower generally will be recognized as white, regardless of the spectral composition of the illuminant under which it is viewed.
> The adaptation may not be complete, however, depending on the type of illumination that is used, the absolute level of that illumination, the extent to which the illumination fills the visual field, and certain other factors.
> For example, light from a dim tungsten lamp will continue to appear somewhat orange, even after the observer has had ample opportunity to adapt to it.

Let us start with an experiment, the two portraits in chapter 6.1. It is assumed that the images are viewed on a calibrated monitor, D65 and near to sRGB. The upper image should look as expected: neutrally gray background and realistic skin colors, somewhat tanned. The lower image was numerically converted for a D50 background. It looks obviously too yellowish. Then blow up the lower image, remove all menue areas and wait for a while. The image will look less yellowish, but a yellow tint is still perceivable. There is adaptation, but it is not complete.

The next hypothetical test is this: an image with considerably large neutrally gray areas is edited on a calibrated monitor, D65 and near to sRGB (or color-corrected by using the monitor profil in Photoshop). It is assumed that the operator is completely adapted to D65. There is no guarantee that the adaptation state is really D65, because images can be colorful and the surround light may differ from D65 (in fact it is defined as D50 by sRGB).
The image is printed by a calibrated printer for viewing light D50, as usual. It is assumed that the observer is adapted to D50. Again - no guarantee that the adaptation state is really D50, because the print is colorful and because the environment can contain other colored objects. Nevertheless we assume complete adaptation.
Neutrally gray areas for D65 will appear neutrally gray for D50. In the whole process, the image had to be converted colorimetrically for D50, the reference white in CIELab, based on the assumption of complete adaptation.

Now we may expect that the adaptation would work as well for the colored parts. That is: the whole print under D50 should look like the monitor image for D65 (but a direct comparison is impossible). If this would be so, then it is called here a Perfect Adaptation (which contains already the complete adaptation). The necessary colorimetrical transform is called PAT, Perfect Adaptation Transform.

Tests by scientists have shown that the adaptation is not perfect. Nevertheless it is assumed that the adaptation is complete, but small color shifts have to be corrected. This correction is here called ACT, Adaptation Correction Transform.
The PAT is applied by the *Wrong von Kries* transform, using a diagonal matrix $\mathbf{K}_w$, according to the mathematics on the next page. This is entirely based on CIE colorimetry, without any further tests. It is assumed that the cones perform a perfect adaptation. Modelling the cone response functions is therefore not required (in fact these are implicitly defined by the color matching functions).
The ACT is the second part of a CAT, Chromatic Adaptation Transform. The CAT is executed either by the *(true) Von Kries* transform or by the linearized *Bradford* transform. *Bradford* is the standard for ICC profiles.

The CAT is a matrix operation, here by $\mathbf{T}$, which is the *Von Kries* matrix $\mathbf{K}$ or the *Bradford* matrix $\mathbf{B}$. The CAT matrix is found by analyzing the cone response functions (*Von Kries*) and somewhat improved by tests (*Bradford*).
Now we can decompose $\mathbf{B}=\mathbf{C}\mathbf{K}_w$ and find $\mathbf{C}=\mathbf{B}\mathbf{K}_w^{-1}$. Matrix $\mathbf{C}$ describes the Adaptation Correction Transform for the *Bradford* CAT (chapter 7.2).

The author was not able to prove the truth of the *Bradford* ACT by practical examples. A final clarification seems to be impossible, therefore we can focus our attention now to the mathematical part of the Chromatic Adaptation Transform.
This happens from $\mathbf{X}_s$ to $\mathbf{X}_d$ in CIE XYZ, where (s) stands for source image in D65 RGB and (d) for destination, e.g. for the *Bradford* CAT. In other words: the CAT has nothing to do with CIELab, but it requires already the definition of the viewing light for the paper product (more accurate: the adaptation state). This is D50 and the CIELab conversion is done for Reference White D50 as well.

5.2 Chromatic Adaptation / von Kries Hypothesis

The cones in the eye contain three different sensors: L for long wavelength, M for medium and and S for short. These are occasionally called ρ,γ,β or even R,G,B.

It is assumed that cone signals are linear functions of CIE XYZ values. As a consequence, the spectral sensitivity functions are linearly related to the color matching functions by the same matrix M_{cx}:

$$\begin{bmatrix} L \\ M \\ S \end{bmatrix} = \mathbf{M}_{cx} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

$$\begin{bmatrix} L(\lambda) \\ M(\lambda) \\ S(\lambda) \end{bmatrix} = \mathbf{M}_{cx} \begin{bmatrix} \overline{x}(\lambda) \\ \overline{y}(\lambda) \\ \overline{z}(\lambda) \end{bmatrix}$$

The *von Kries* hypothesis says that each cone type has its own gain control which depends on the adapted white. The source white is here D65, index sw. The destination white is here D50, index nw.

The gain matrix **D** is calculated by the ratios of the destination white and source white cone values. The last equation shows for clarity the transform from D65 to D50, though the *von Kries* hypothesis is more general.

$$\mathbf{C}_{sw} = \begin{bmatrix} L_{sw} \\ M_{sw} \\ S_{sw} \end{bmatrix} = \mathbf{M}_{cx}\,\mathbf{X}_{sw}$$

$$\mathbf{C}_{dw} = \begin{bmatrix} L_{dw} \\ M_{dw} \\ S_{dw} \end{bmatrix} = \mathbf{M}_{cx}\,\mathbf{X}_{dw}$$

$$\mathbf{D} = \begin{bmatrix} L_{dw}/L_{sw} & 0 & 0 \\ 0 & M_{dw}/M_{sw} & 0 \\ 0 & 0 & S_{dw}/S_{sw} \end{bmatrix}$$

$$\mathbf{C}_d = \mathbf{D}\mathbf{C}_s$$

$$\mathbf{X}_d = \mathbf{M}_{cx}^{-1}\,\mathbf{D}\,\mathbf{M}_{cx}\,\mathbf{X}_s = \mathbf{T}\mathbf{X}_s$$

$$\mathbf{T} = \mathbf{M}_{cx}^{-1}\,\mathbf{D}\,\mathbf{M}_{cx}$$

$$\mathbf{X}_{D50} = \mathbf{T}\mathbf{X}_{D65}$$

5.3 Chromatic Adaptation / Three CATs

5.3.1 Wrong von Kries CAT

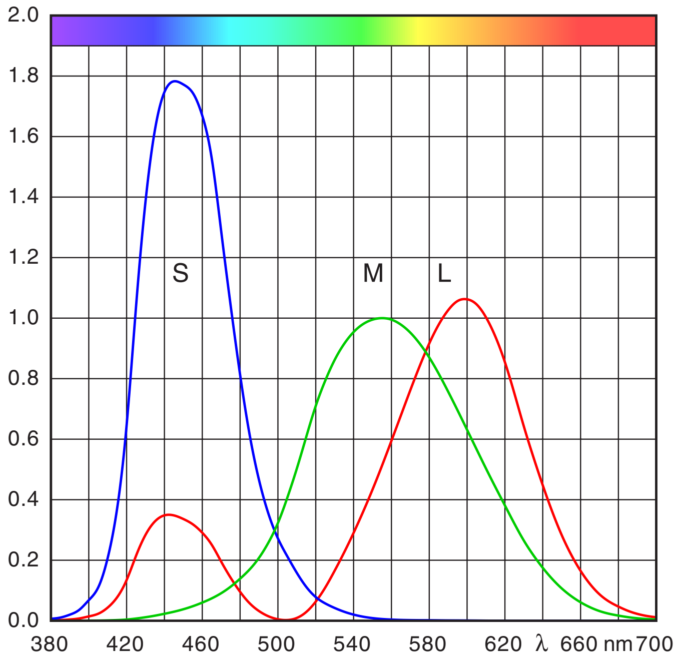
The cone sensitivities are linear combinations of the color matching functions.

The most simple assumption is $\mathbf{M}_{cx}=\mathbf{I}$, the identity matrix. The cone sensitivy functions are identical with the color matching functions.

This does not depend on real cone features. The assumption is simply that the cone gain control works perfectly.

$$\mathbf{T} = \mathbf{K}_w = \begin{bmatrix} X_{w50}/X_{w65} & 0 & 0 \\ 0 & Y_{w50}/Y_{w65} & 0 \\ 0 & 0 & Z_{w50}/Z_{w65} \end{bmatrix}$$

$$= \begin{bmatrix} 1.0146 & 0.0 & 0.0 \\ 0.0 & 1.0 & 0.0 \\ 0.0 & 0.0 & 0.7576 \end{bmatrix}$$



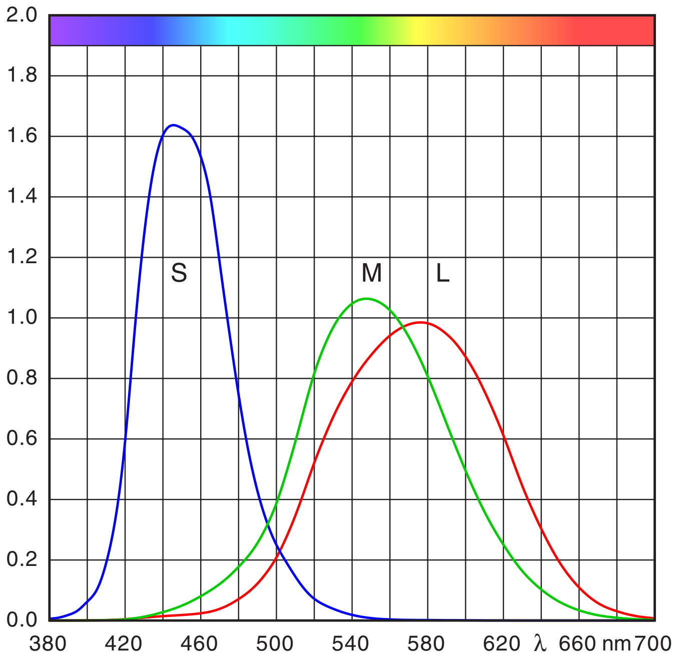
5.3 Chromatic Adaptation / Three CATs cont.

5.3.2 Von Kries CAT

The special matrix $\mathbf{M}_{cx}$ is mentioned in several books, for instance [2], [6]. It seems to be the generic *von Kries* matrix and it is used for CAT02 as well. The author was not able to find the original source.

$$\mathbf{M}_{cx} = \begin{bmatrix} +0.4002 & +0.7076 & -0.0808 \\ -0.2263 & +1.1653 & +0.0457 \\ 0.0 & 0.0 & +0.9182 \end{bmatrix}$$

$$\mathbf{T} = \mathbf{K} = \begin{bmatrix} +1.0161 & +0.0553 & -0.0522 \\ +0.0060 & +0.9956 & -0.0012 \\ 0.0 & 0.0 & +0.7576 \end{bmatrix}$$

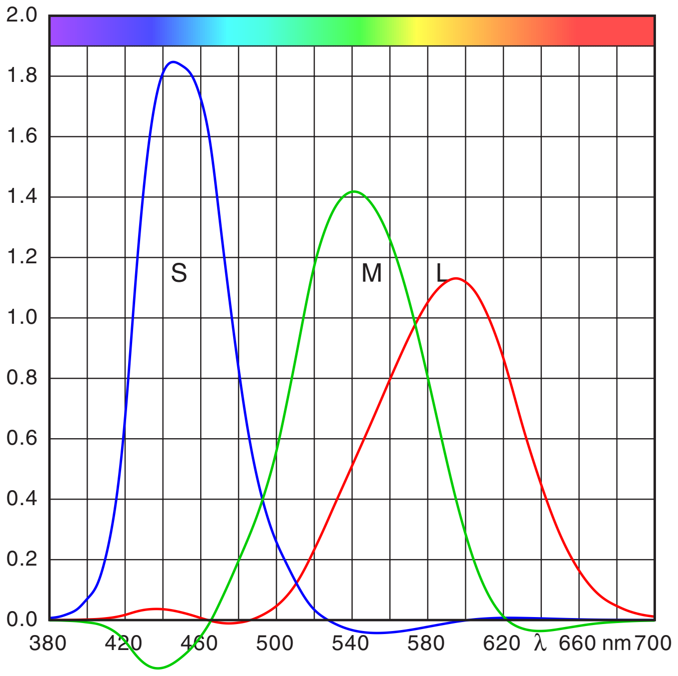


5.3.3 Bradford CAT

This matrix $\mathbf{M}_{cx}$ creates somewhat sharpened cone sensitivity functions which have partly negative values (why should these be good candidates for cone functions ?). Originally, the third channel contains a nonlinearity, and the input vector should be scaled by Y_S, [1]. Below is the linearized version, and the scaling is obsolete for $Y_S=1$ (or 100, depending on the definition)). *Bradford* CAT is the standard for ICC profiles and for CAT97, which is now replaced by CAT02.

$$\mathbf{M}_{cx} = \begin{bmatrix} +0.8951 & +0.2664 & -0.1614 \\ -0.7502 & +1.7135 & +0.0367 \\ +0.0389 & -0.0685 & +1.0296 \end{bmatrix}$$

$$\mathbf{T} = \mathbf{B} = \begin{bmatrix} +1.0479 & +0.0229 & -0.0502 \\ +0.0296 & +0.9904 & -0.0171 \\ -0.0092 & +0.0151 & +0.7519 \end{bmatrix}$$



5.4 Chromatic Adaptation / Geometrical Interpretation

Perhaps this 2D visualization can shed some light on the transforms. The nonlinearity of the CIELab conversion is replaced by simplified linear relations, visualized in XZ of XYZ.

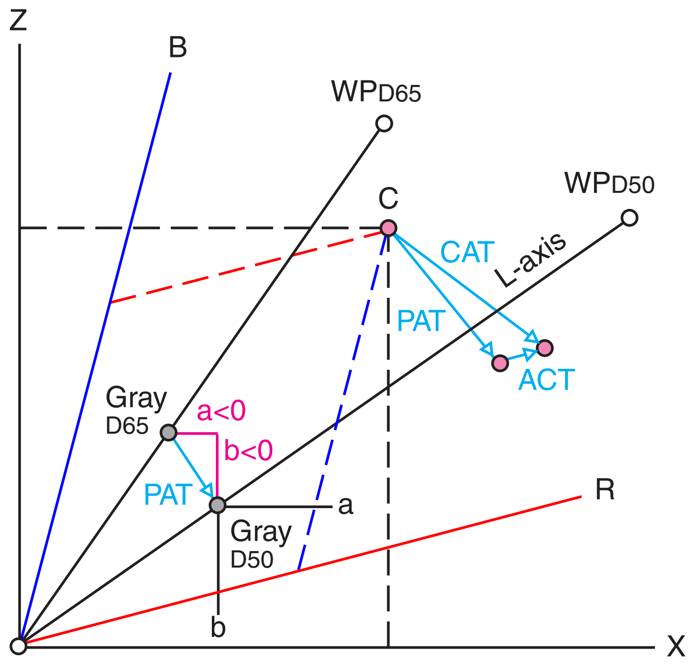
XYZ is mostly drawn as a cartesian coordinate system. RGB is then a non-orthogonal vector base in XYZ. For CIELab, the axis (a) is in X-direction. Axis (b) is in negative Z-direction. Axis (L) points into the direction of the Reference White, here WP D50 [15].

Without CAT, a monitor gray D65 for R=G=B=119 would deliver CIELab values L=50, a=-2, b=-10. This happens for rendering intent Absolute Colorimetric.

With CAT the monitor gray delivers CIELab values L=50, a=0, b=0. This is so for rendering intent Relative Colorimetric. For grays we have only a PAT as shown in the graphic.

An arbitrary color C is converted by a PAT (Perfect Adaptation Transform) and then additionally by an ACT (Adaptation Correction Transform), altogether executed by a CAT.

How is this printed? So that it looks alike the monitor image, but a direct comparison is *impossible*, because eye and brain cannot adapt simultaneously to monitor white D65 and viewing light D50.



6.1 Adaptation Illustrations / Test Images D65 / D50

D65

How to use the *lower* image by Acrobat:

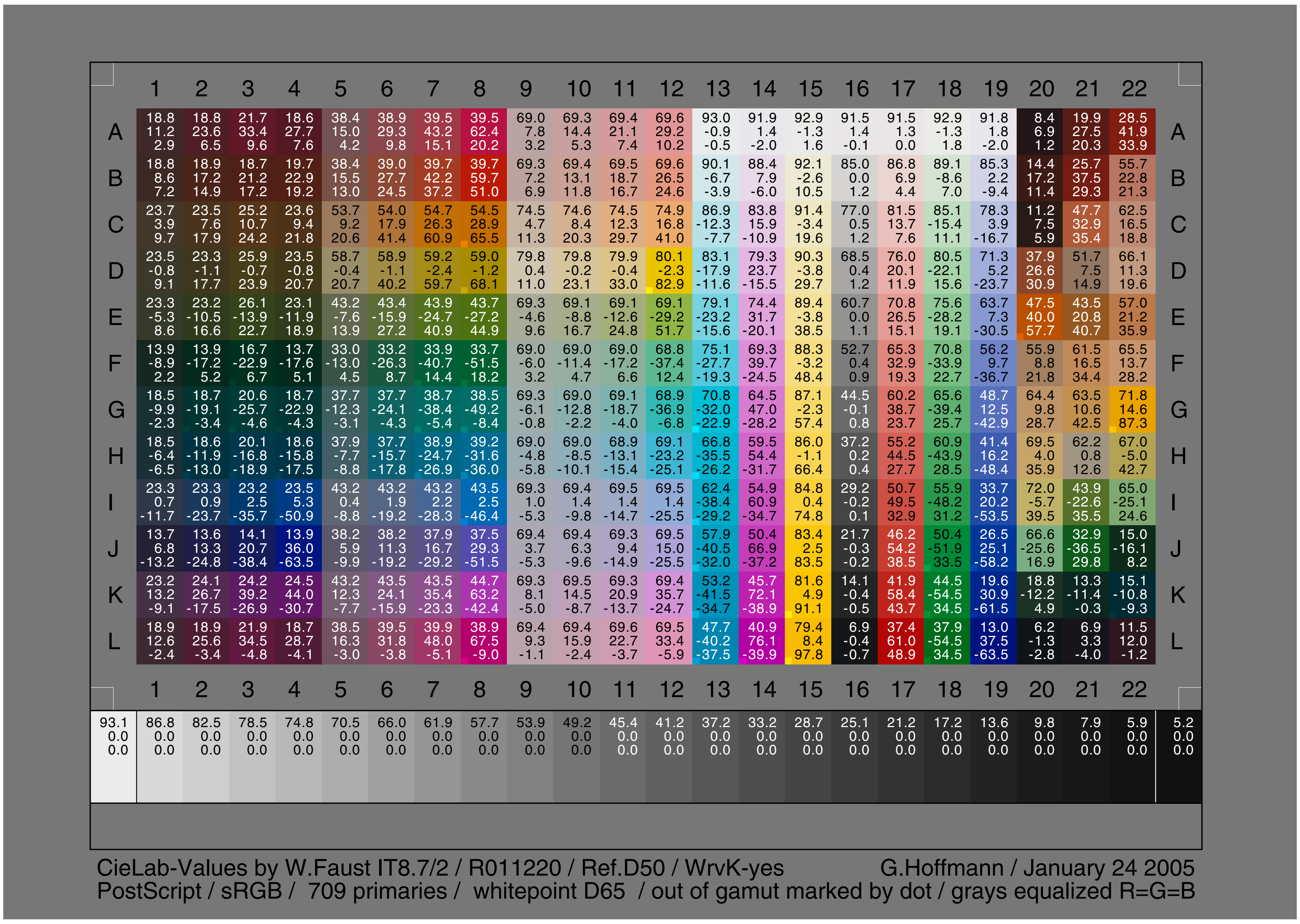
Ctrl+L Full screen
Ctrl+H Hand tool
Ctrl++ Zoom in

After a while of adaptation the image will not look as yellow

D50

6.2 Adaptation Illustrations / Comparison for CATs / Wrong von Kries

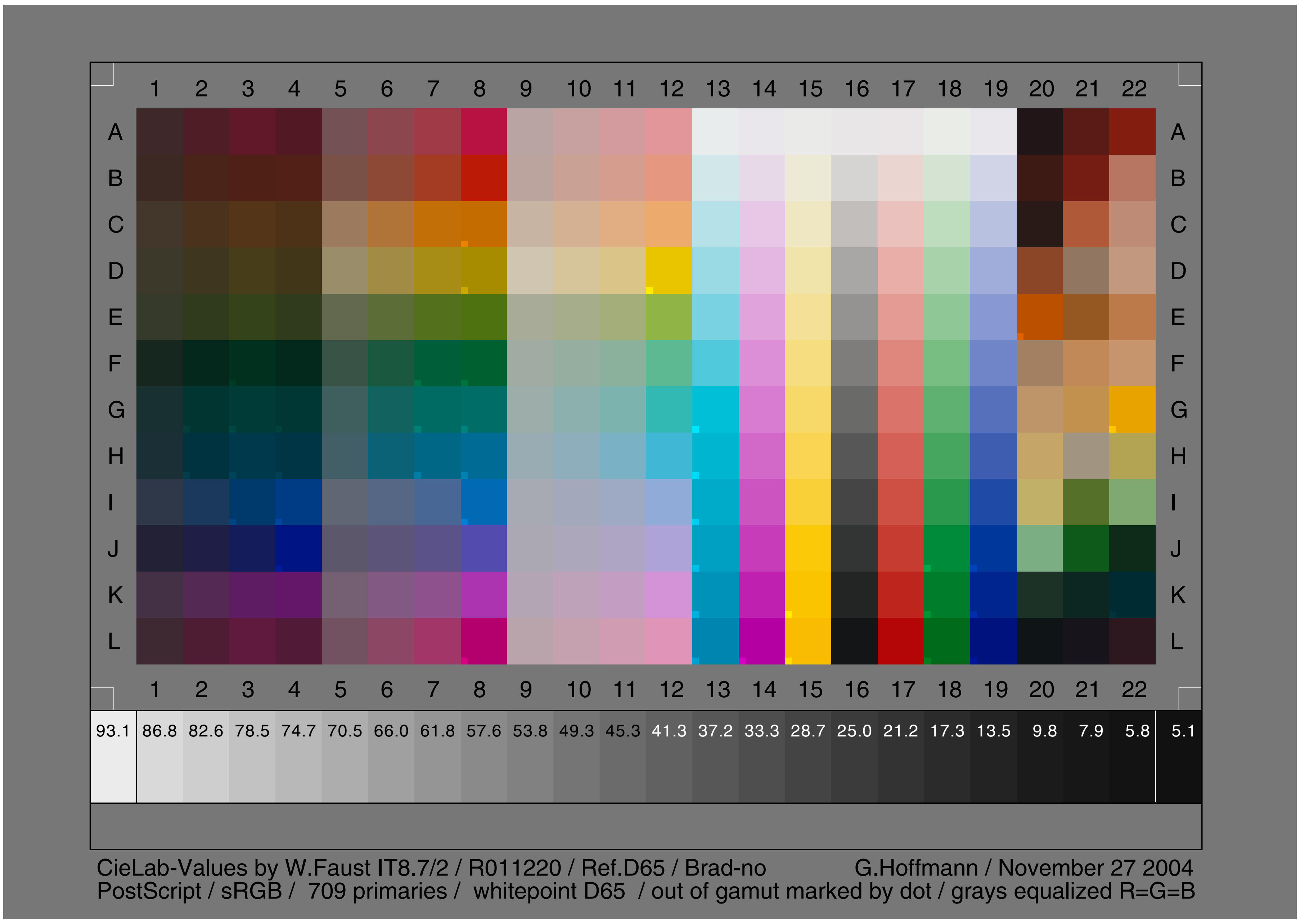
CIELab values for an IT8 target were converted to sRGB (out of gamut marked by dot). The upper image shows the result for Reference White D50 and the *Wrong von Kries* transform. The lower image for Reference White D65 without CAT. No differences in Photoshop, as expected.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
A	18.8 11.2 2.9	18.8 23.6 6.5	21.7 33.4 9.6	18.6 27.7 7.6	38.4 15.0 4.2	38.9 29.3 9.8	39.5 43.2 15.1	39.5 62.4 20.2	69.0 7.8 3.2	69.3 14.4 5.3	69.4 21.1 7.4	69.6 29.2 10.2	93.0 -0.9 -0.5	91.9 1.4 -2.0	92.9 -1.3 1.6	91.5 1.4 -0.1	91.5 1.3 0.0	92.9 -1.3 1.8	91.8 1.8 -2.0	8.4 6.9 1.2	19.9 27.5 20.3	28.5 41.9 33.9	A
B	18.8 8.6 7.2	18.9 17.2 14.9	18.7 21.2 17.2	19.7 22.9 19.2	38.4 15.5 13.0	39.0 27.7 24.5	39.7 42.2 37.2	39.7 59.7 51.0	69.3 7.2 6.9	69.4 13.1 11.8	69.5 18.7 16.7	69.6 26.5 24.6	90.1 -6.7 -3.9	88.4 7.9 -6.0	92.1 -2.6 10.5	85.0 0.0 1.2	86.8 6.9 4.4	89.1 -8.6 7.0	85.3 2.2 -9.4	14.4 17.2 11.4	25.7 37.5 29.3	55.7 22.8 21.3	B
C	23.7 3.9 9.7	23.5 7.6 17.9	25.2 10.7 24.2	23.6 9.4 21.8	53.7 9.2 20.6	54.0 17.9 41.4	54.7 26.3 60.9	54.5 28.9 65.5	74.5 4.7 11.3	74.6 8.4 20.3	74.5 12.3 29.7	74.9 16.8 41.0	86.9 -12.3 -7.7	83.8 15.9 -10.9	91.4 -3.4 19.6	77.0 0.5 1.2	81.5 13.7 7.6	85.1 -15.4 11.1	78.3 3.9 -16.7	11.2 7.5 5.9	47.7 32.9 35.4	62.5 16.5 18.8	C
D	23.5 -0.8 9.1	23.3 -1.1 17.7	25.9 -0.7 23.9	23.5 -0.8 20.7	58.7 -0.4 20.7	58.9 -1.1 40.2	59.2 -2.4 59.7	59.0 -1.2 68.1	79.8 0.4 11.0	79.8 -0.2 23.1	79.9 -0.4 33.0	80.1 -2.3 82.9	83.1 -17.9 -11.6	79.3 23.7 -15.5	90.3 -3.8 29.7	68.5 0.4 1.2	76.0 20.1 11.9	80.5 -22.1 15.6	71.3 5.2 -23.7	37.9 26.6 30.9	51.7 7.5 14.9	66.1 11.3 19.6	D
E	23.3 -5.3 8.6	23.2 -10.5 16.6	26.1 -13.9 22.7	23.1 -11.9 18.9	43.2 -7.6 13.9	43.4 -15.9 27.2	43.9 -24.7 40.9	43.7 -27.2 44.9	69.3 -4.6 9.6	69.1 -8.8 16.7	69.1 -12.6 24.8	69.1 -29.2 51.7	79.1 -23.2 -15.6	74.4 31.7 -20.1	89.4 -3.8 38.5	60.7 0.0 1.1	70.8 26.5 15.1	75.6 -28.2 19.1	63.7 7.3 -30.5	47.5 40.0 57.7	43.5 20.8 40.7	57.0 21.2 35.9	E
F	13.9 -8.9 2.2	13.9 -17.2 5.2	16.7 -22.9 6.7	13.7 -17.6 5.1	33.0 -13.0 4.5	33.2 -26.3 8.7	33.9 -40.7 14.4	33.7 -51.5 18.2	69.0 -6.0 3.2	69.0 -11.4 4.7	69.0 -17.2 6.6	68.8 -37.4 12.4	75.1 -27.7 -19.3	69.3 39.7 -24.5	88.3 -3.2 48.4	52.7 0.4 0.9	65.3 32.9 19.3	70.8 -33.9 22.7	56.2 9.7 -36.7	55.9 8.8 21.8	61.5 16.5 34.4	65.5 13.7 28.2	F
G	18.5 -9.9 -2.3	18.7 -19.1 -3.4	20.6 -25.7 -4.6	18.7 -22.9 -4.3	37.7 -12.3 -3.1	37.7 -24.1 -4.3	38.7 -38.4 -5.4	38.5 -49.2 -8.4	69.3 -6.1 -0.8	69.0 -12.8 -2.2	69.1 -18.7 -4.0	68.9 -36.9 -6.8	70.8 -32.0 -22.9	64.5 47.0 -28.2	87.1 -2.3 57.4	44.5 -0.1 0.8	60.2 38.7 23.7	65.6 -39.4 25.7	48.7 12.5 -42.9	64.4 9.8 28.7	63.5 10.6 42.5	71.8 14.6 87.3	G
H	18.5 -6.4 -6.5	18.6 -11.9 -13.0	20.1 -16.8 -18.9	18.6 -15.8 -17.5	37.9 -7.7 -8.8	37.7 -15.7 -17.8	38.9 -24.7 -26.9	39.2 -31.6 -36.0	69.0 -4.8 -5.8	69.0 -8.5 -10.1	68.9 -13.1 -15.4	69.1 -23.2 -25.1	66.8 -35.5 -26.2	59.5 54.4 -31.7	86.0 -1.1 66.4	37.2 0.2 0.4	55.2 44.5 27.7	60.9 -43.9 28.5	41.4 16.2 -48.4	69.5 4.0 35.9	62.2 0.8 12.6	67.0 -5.0 42.7	H
I	23.3 0.7 -11.7	23.3 0.9 -23.7	23.2 2.5 -35.7	23.5 5.3 -50.9	43.2 0.4 -8.8	43.2 1.9 -19.2	43.2 2.2 -28.3	43.5 2.5 -46.4	69.3 1.0 -5.3	69.4 1.4 -9.8	69.5 1.4 -14.7	69.5 1.4 -25.5	62.4 -38.4 -29.2	54.9 60.9 -34.7	84.8 0.4 74.8	29.2 -0.2 0.1	50.7 49.5 32.9	55.9 -48.2 31.2	33.7 20.2 -53.5	72.0 -5.7 39.5	43.9 -22.6 35.5	65.0 -25.1 24.6	I
J	13.7 6.8 -13.2	13.6 13.3 -24.8	14.1 20.7 -38.4	13.9 36.0 -63.5	38.2 5.9 -9.9	38.2 11.3 -19.2	37.9 16.7 -29.2	37.5 29.3 -51.5	69.4 3.7 -5.3	69.4 6.3 -9.6	69.3 9.4 -14.9	69.5 15.0 -25.5	57.9 -40.5 -32.0	50.4 66.9 -37.2	83.4 2.5 83.5	21.7 -0.3 -0.2	46.2 54.2 38.5	50.4 -51.9 33.5	26.5 25.1 -58.2	66.6 -25.6 16.9	32.9 -36.5 29.8	15.0 -16.1 8.2	J
K	23.2 13.2 -9.1	24.1 26.7 -17.5	24.2 39.2 -26.9	24.5 44.0 -30.7	43.2 12.3 -7.7	43.5 24.1 -15.9	43.5 35.4 -23.3	44.7 63.2 -42.4	69.3 8.1 -5.0	69.5 14.5 -8.7	69.3 20.9 -13.7	69.4 35.7 -24.7	53.2 -41.5 -34.7	45.7 72.1 -38.9	81.6 4.9 91.1	14.1 -0.4 -0.5	41.9 58.4 43.7	44.5 -54.5 34.5	19.6 30.9 -61.5	18.8 -12.2 4.9	13.3 -11.4 -0.3	15.1 -10.8 -9.3	K
L	18.9 12.6 -2.4	18.9 25.6 -3.4	21.9 34.5 -4.8	18.7 28.7 -4.1	38.5 16.3 -3.0	39.5 31.8 -3.8	39.9 48.0 -5.1	38.9 67.5 -9.0	69.4 9.3 -1.1	69.4 15.9 -2.4	69.6 22.7 -3.7	69.5 33.4 -5.9	47.7 -40.2 -37.5	40.9 76.1 -39.9	79.4 8.4 97.8	6.9 -0.4 -0.7	37.4 61.0 48.9	37.9 -54.5 34.5	13.0 37.5 -63.5	6.2 -1.3 -2.8	6.9 3.3 -4.0	11.5 12.0 -1.2	L
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	

93.1 0.0 0.0	86.8 0.0 0.0	82.5 0.0 0.0	78.5 0.0 0.0	74.8 0.0 0.0	70.5 0.0 0.0	66.0 0.0 0.0	61.9 0.0 0.0	57.7 0.0 0.0	53.9 0.0 0.0	49.2 0.0 0.0	45.4 0.0 0.0	41.2 0.0 0.0	37.2 0.0 0.0	33.2 0.0 0.0	28.7 0.0 0.0	25.1 0.0 0.0	21.2 0.0 0.0	17.2 0.0 0.0	13.6 0.0 0.0	9.8 0.0 0.0	7.9 0.0 0.0	5.9 0.0 0.0	5.2 0.0 0.0

CieLab-Values by W.Faust IT8.7/2 / R011220 / Ref.D50 / WrvK-yes G.Hoffmann / January 24 2005
PostScript / sRGB / 709 primaries / whitepoint D65 / out of gamut marked by dot / grays equalized R=G=B

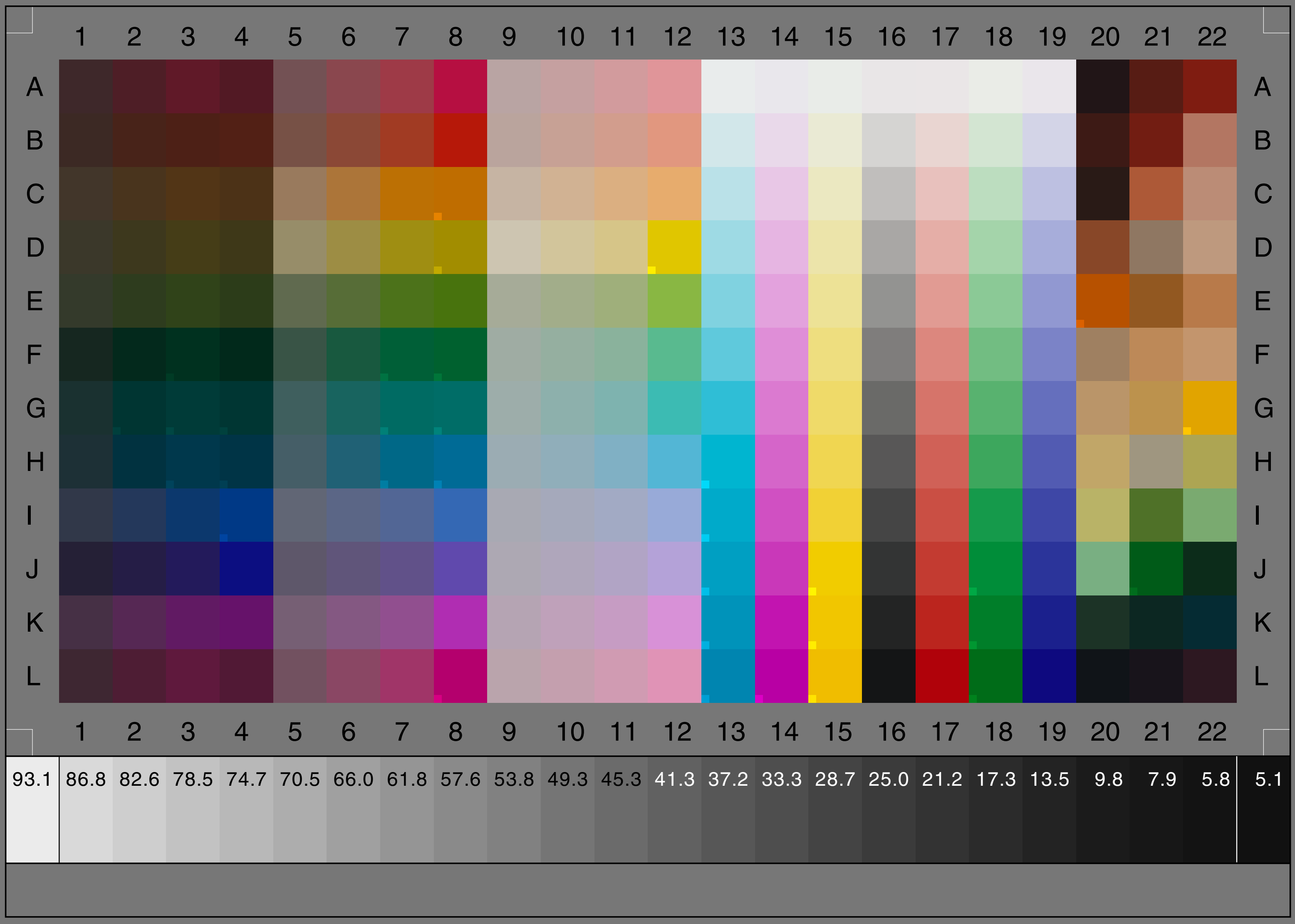


93.1	86.8	82.6	78.5	74.7	70.5	66.0	61.8	57.6	53.8	49.3	45.3	41.3	37.2	33.3	28.7	25.0	21.2	17.3	13.5	9.8	7.9	5.8	5.1

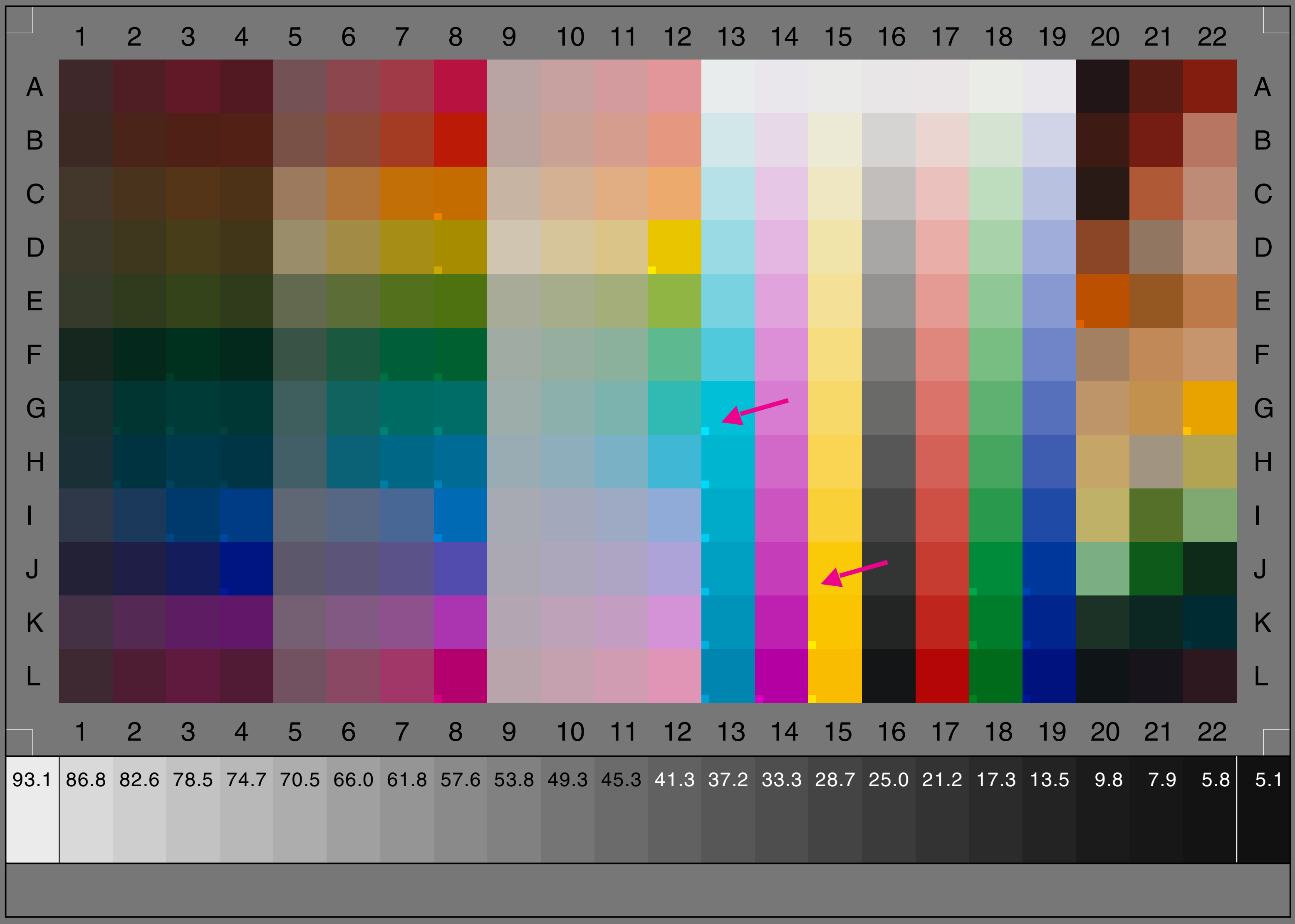
CieLab-Values by W.Faust IT8.7/2 / R011220 / Ref.D65 / Brad-no G.Hoffmann / November 27 2004
PostScript / sRGB / 709 primaries / whitepoint D65 / out of gamut marked by dot / grays equalized R=G=B

6.3 Adaptation Illustrations / Comparison for CATs / Bradford

CIELab values for an IT8 target were converted to sRGB (out of gamut marked by dot). The upper image shows the result for Reference White D50 and *Bradford* CAT. The lower image for Reference White D65 without CAT. Differences (ACT) as measured by Photoshop are very small. Bradford ACT is rather meaningless. Cyans and yellows are anyway affected by printer gamut compression.



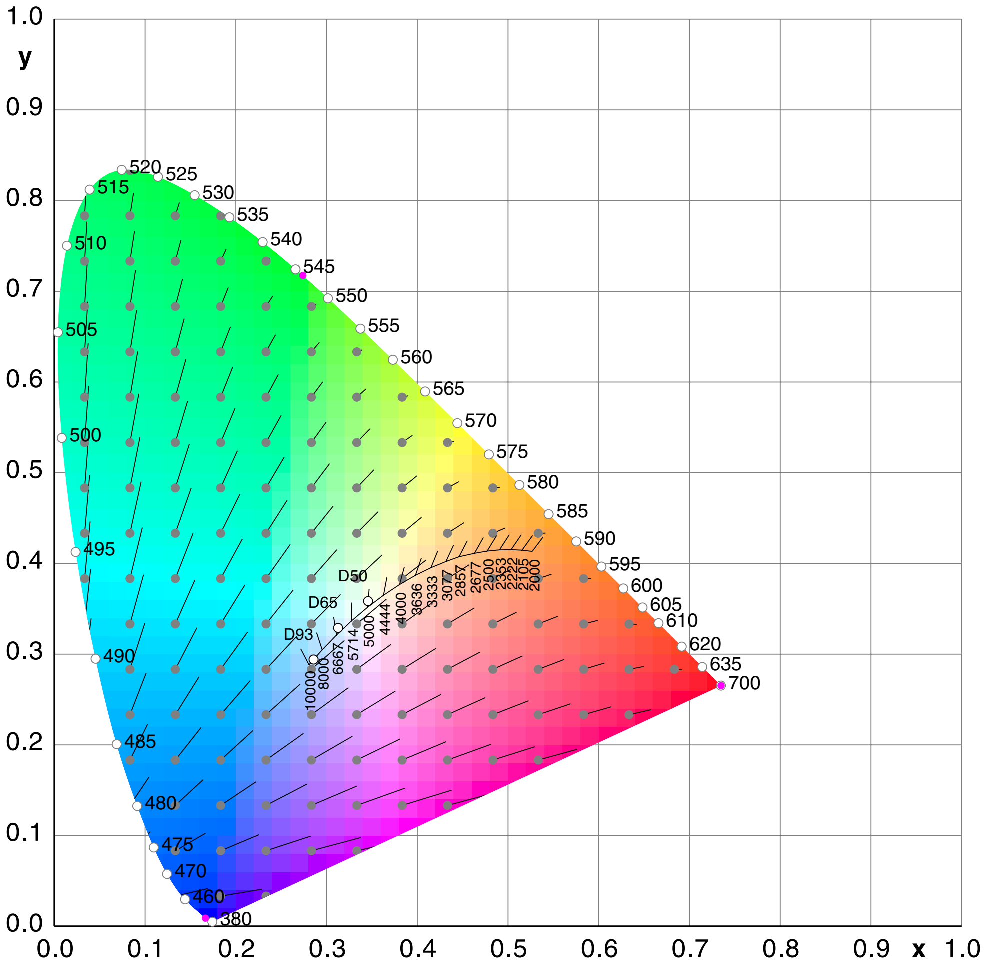
CieLab-Values by W.Faust IT8.7/2 / R011220 / Ref.D50 / Brad-yes G.Hoffmann / November 27 2004
PostScript / sRGB / 709 primaries / whitepoint D65 / out of gamut marked by dot / grays equalized R=G=B



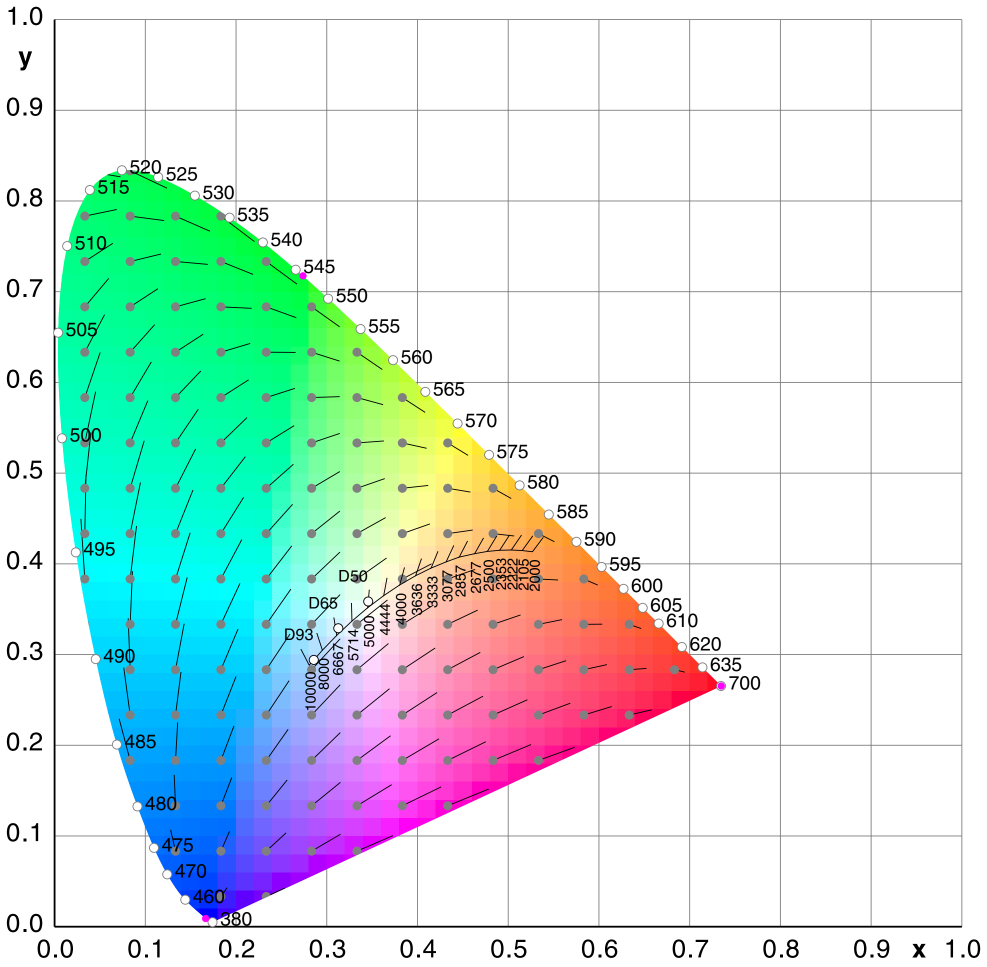
CieLab-Values by W.Faust IT8.7/2 / R011220 / Ref.D65 / Brad-no G.Hoffmann / November 27 2004
PostScript / sRGB / 709 primaries / whitepoint D65 / out of gamut marked by dot / grays equalized R=G=B

7.1 Color Shifts in the CIE Chromaticity Diagram

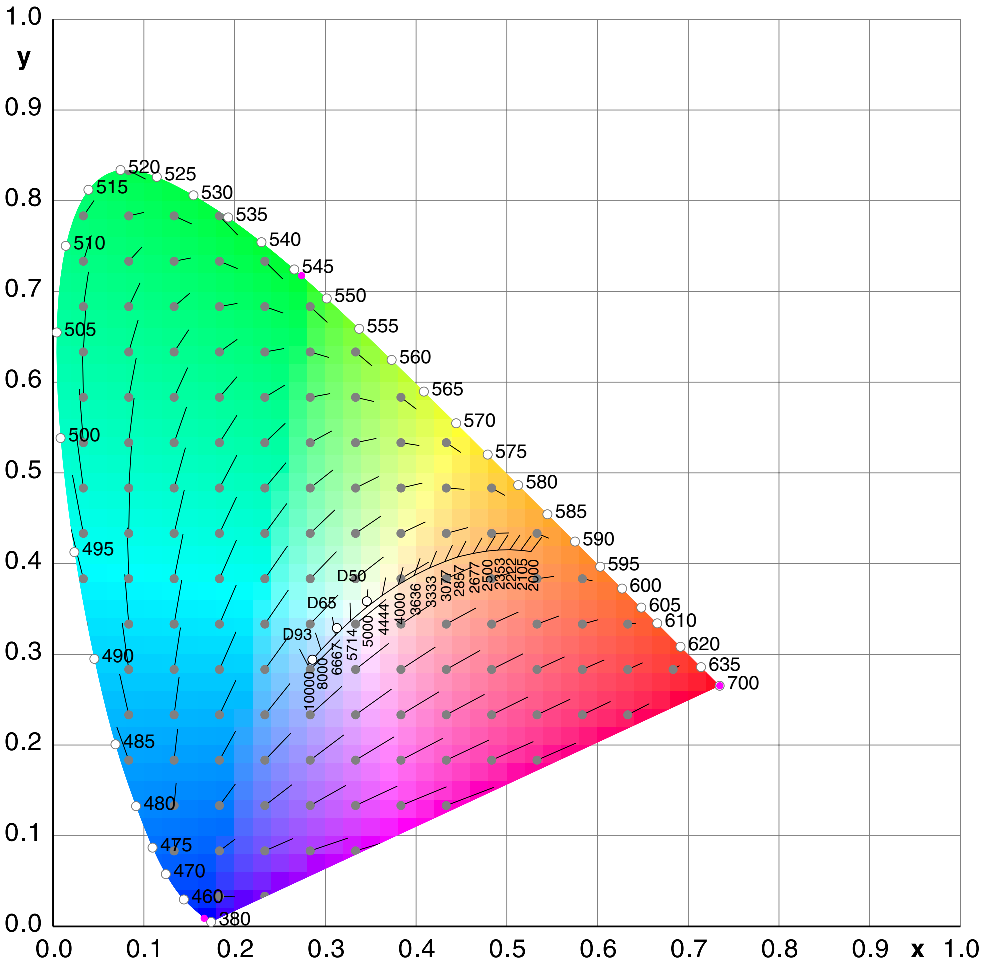
This illustration shows the color shifts for the three chromatic adaptation transforms. The dots are the values for the source $\mathbf{X}_s$. The ends of the vectors are the values for $\mathbf{X}_d$.



Wrong von Kries



Von Kries



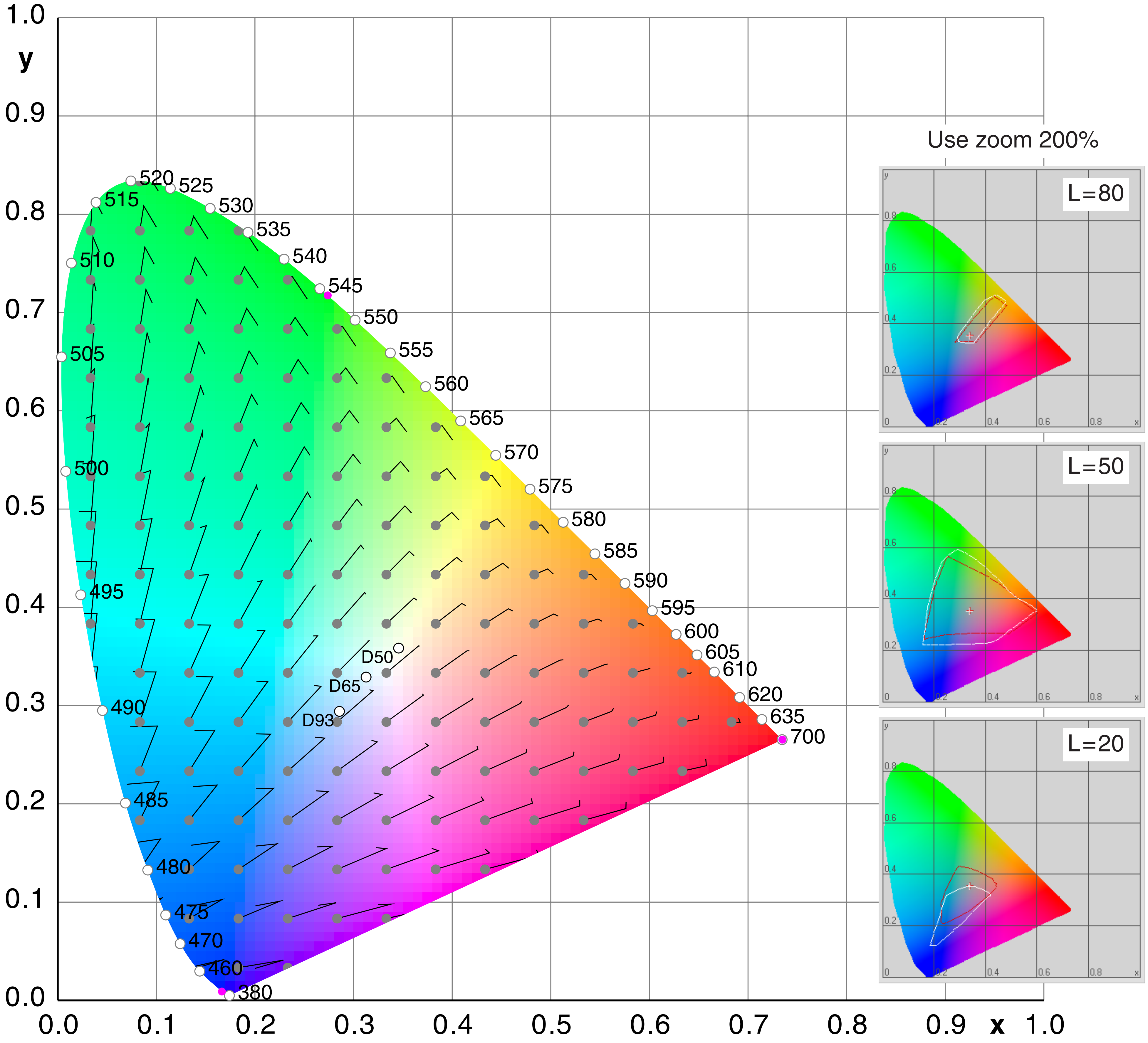
Bradford

7.2 Color Shifts in the CIE Chromaticity Diagram

This illustration shows the color shifts for the *Bradford* transform by two steps: first a *Wrong von Kries* transform by matrix $\mathbf{K}_W$ and then a correction transform by $\mathbf{C}$, using $\mathbf{B}=\mathbf{C}\mathbf{K}_W$ with $\mathbf{C}=\mathbf{B}\mathbf{K}_W^{-1}$.

$$\mathbf{C} \;=\; \begin{bmatrix} +1.0328 & +0.0229 & -0.0663 \\ +0.0292 & +0.9904 & -0.0226 \\ -0.0091 & +0.0151 & +0.9925 \end{bmatrix}$$

The first step by *Wrong von Kries* performs the white point shift, here called Perfect Adaptation Transform PAT. Only the correction shift - indicated by the second part of the vector - is a *true* chromatic adaptation transform, called Adaptation Correction Transform ACT.
It seems that this correction is hardly of great importance for common printing spaces, as shown by the small images by GMB ProfileMaker for ISO Coated (red) and for a high end inkjet (white), for L=20,50 and 80.



8. ICC CMYK to CIELab

CMYK values can be converted to CIELab by version C or D of these table systems. Most likely version C with explicit tables Ac and Bc is used. These nonlinear tables deliver a better resolution for the more relevant part of the CLUT.
lutAtoBType means Device to PCS (profile connection space, here CIELab)

A.	IN3	-									Bc	-	Lab
B.	IN3	-					Mc	-	Ma	-	Bc	-	Lab
C.	CMYK	-	Ac	-	CLUT	-					Bc	-	Lab
D.	CMYK	-	Ac	-	CLUT	-	Mc	-	Ma	-	Bc	-	Lab

IN3	Arbitrary three inputs
CMYK	Input **C**
Ac	A-Curves: 4 one-dimensional input tables or parametric curves, possible if CLUT is used
CLUT	Multi-dimensional table *lutAtoBType* with 4 inputs and 3 outputs
Mc	M-Curves: 3 one-dimensional tables or parametric curves
Ma	3x4 Array for a 3x3 matrix and an offset The first 9 elements are multiplied by the input, the last 3 elements are added as offsets
Bc	B-Curves: 3 one-dimensional output tables or parametric curves
Lab	Output **L**

CLUT	AtoB0	Perceptual Rendering Intent (page 20 in [10])
CLUT	AtoB1	Media-Relative and ICC-Absolute Colorimetric
CLUT	AtoB2	Saturation Rendering Intent

9. ICC CIELab to CMYK

CIELab values can be converted to CMYK by version C or D of these table systems. Most likely version C with explicit tables Bc and Ac is used. These nonlinear tables deliver a better resolution for the more relevant part of the CLUT.
LutBtoAType means PCS (profile connection space, here CIELab) to Device.

A.	Lab	-	Bc	-									OUT3
B.	Lab	-	Bc	-	Ma	-	Mc	-					OUT3
C.	Lab	-	Bc	-					CLUT	-	Ac	-	CMYK
D.	Lab	-	Bc	-	Ma	-	Mc	-	CLUT	-	Ac	-	CMYK

Lab	Input **L**
Bc	B-Curves: 3 one-dimensional input tables or parametric curves
Ma	3x4 Array for a 3x3 matrix and an offset The first 9 elements are multiplied by the input, the last 3 elements are added as offsets
Mc	M-Curves: 3 one-dimensional tables or parametric curves, possible if Ma is used
CLUT	Multi-dimensional table *lutBtoAType* with 3 inputs and 4 outputs
Ac	A-Curves: 4 one-dimensional output tables or parametric curves , if CLUT is used
CMYK	Output **C**
OUT3	Arbitrary 3 outputs

CLUT	BtoA0	Perceptual Rendering Intent (page 20 in [10])
CLUT	BtoA1	Media-Relative and ICC-Absolute Colorimetric
CLUT	BtoA2	Saturation Rendering Intent

On page 18 of [13] we find the Header Rendering Intent coding, which is slightly different (mostly the header indicates Perceptual, which is either not complete or even wrong for RGB profiles):

0	Perceptual
1	Media-Relative Colorimetric
2	Saturation
3	ICC-Absolute Colorimetric

10. ICC Rendering Intents

Four different Rendering Intents are mostly available:

ICC Absolute
Media-Relative
Perceptual
Saturation

Rendering Intents concern four topics:

White point mapping CAT
White point mapping PWT
Gamut compression
Dynamic range compression

11. ICC-Absolute Colorimetric Rendering Intent

No CAT, no PWT.

$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$ as usual

$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$ **T** is identity matrix

$\mathbf{X}_p = \mathbf{P}\,\mathbf{X}_d$ **P** for Paper White Transform PWT. **P** is identity matrix

$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_p$ Reference White for RW D50

$\mathbf{L} = \mathbf{F}(\mathbf{X}_c)$ as usual

No gamut compression.
All out-of-gamut colors are clipped to nearest color in CIELab.
Gamut clipping depends on the specific software (choice of the direction in CIELab).
No dynamic range compression.

ICC-Absolute uses the table system for Media-Relative.
Reference White for CIELab is practically always D50.

If the working space is defined for D50 as well (like WideGamutRGB) and an image is optimized on a D50 monitor, then the print would look correctly under D50 viewing light.

If the working space is defined for D65 (like sRGB) and an image is optimized on a D65 monitor, then the print would look too blue-ish unter D50 viewing light.

Absolute Colorimetric does not make any sense for practical printing if the data sources are defined in a D65 working space.

It can be used for proof printing for the workflow RGB -- CMYK1 -- CIELab -- CMYK2.

For instance, CMYK1 is an offset space like ISO Coated and CMYK2 is an inkjet space.
The first conversion RGB -- CMYK1 is done by Perceptual or by Media-Relative Colorimetric rendering intent (the latter preferably with Blackpoint Compensation, which is not a feature of ICC profiles).
The second conversion by CMYK1 -- CIELab -- CMYK2 by Absolute Colormetric would try to simulate the appearance of the offset print by the inkjet print. If the inkjet paper should be more blue-ish than the offset paper, then the inkjet would put yellow ink onto plain paper areas and correct the other regions as well.

12. Media-Relative Colorimetric Rendering Intent

Uses CAT and PWT white point mapping.

$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$ as usual

$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$ $\mathbf{T}=\mathbf{B}$ is the Bradford matrix

$\mathbf{X}_p = \mathbf{P}\,\mathbf{X}_d$ **P** for Paper White Transform PWT. See below

$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_p$ Reference White for RW D50

$\mathbf{L} = \mathbf{F}(\mathbf{X}_c)$ as usual

No gamut compression.
Out-of-gamut colors are clipped to nearest color in CIELab.
Gamut clipping depends on the specific software (choice of the direction in CIELab).
Dynamic range compression.
Mostly, L*=100 is mapped to paper white.
Mostly, L*= 0 is not mapped to the darkest printable black.
Mapping L*= 0 to the darkest printable black is called Blackpoint Compensation (BPC).
This is not a feature of ICC profiles but of application programs like Phoshop or RIPs.

A PWT needs two media:

1. Reference Medium, here the perfect diffuser/absorber, therefore not explicitly used
   White Lab=100/0/0
   Black Lab=0/0/0
2. Actual Medium, Measuring Mode Absolute under D50, e.g.
   White Lab=93/0/-4 delivers X_{pw}, $Y_{pw}=1$, Z_{pw}
   Black Not specified

$\mathbf{P} = \mathrm{diag}\,(X_{D50}/X_{pw},\ Y_{D50}/Y_{pw},\ Z_{D50}/Z_{pw})$ with $Y_{D50}=1$

The author is meanwhile not sure about the handling of paper white.

Media-Relative with BPC is the *recommended* default Rendering Intent for photos, though not *intended* for this purpose.The gamut clipping is mostly not perceivable. The colors can easily look dull if Perceptual is used.

Media-Relative is mostly used for printing D65 working space data and it can be used for proof printing for the workflow CMYK1(offset) -- CIELab -- CMYK2(inkjet).
If the inkjet is more is blue-ish than the offset paper, then Media-Relative would leave white or light gray areas as they are.
It is assumed that the observer is adapted to paper white, therefore the paper does not (should not) appear blue-ish.

13. Perceptual Rendering Intent

Uses CAT and PWT white point mapping.

$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$ as usual

$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$ $\mathbf{T}=\mathbf{B}$ is the Bradford matrix

$\mathbf{X}_p = \mathbf{P}\,\mathbf{X}_d$ **P** for Paper White Transform PWT. See below

$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_p$ Reference White for RW D50

$\mathbf{L} = \mathbf{F}(\mathbf{X}_c)$ as usual

Gamut compression.
Out-of-gamut colors are mapped to the nearest color in CIELab.
Gamut compression and mapping depend on the specific software.
All colors are simultaneously shifted.
Dynamic range compression.
Mostly: L*=100 is mapped to paper white.
L*= 0 is mapped to the darkest printable black.

A PWT needs two media:
1. Reference Medium , here a realistic white and black printed good paper.
   White Lab=89.0/0/0
   Black Lab=3.1373/0/0 , X_0=0.00336, Y_0=0.00347, Z_0=0.00287, perceptual black point
2. Actual Medium, Measuring Mode Absolute under D50, e.g.
   White Lab=93/0/-4 delivers X_{pw}, Y_{pw}=1, Z_{pw}
   Black Lab=Not specified

$\mathbf{P} = \mathrm{diag}\,(\, X_{D50}/X_{pw},\ Y_{D50}/Y_{pw},\ Z_{D50}/Z_{pw}\,)$ with $Y_{D50}=1$

The author is meanwhile not sure about the handling of paper white.

Perceptual can be used for photos with a significant content of out-of-gamut colors, in order to preserve the relation of colors relative to each other. In many cases the global color shift is not perceived as pleasant, therefore practicians prefer often Media-Relative.
Should be used for scanned transparencies because of the large dynamic range.

It was assumed that the observer is adapted to D50 surround light. Now it is additionally assumed that the observer is adapted to paperwhite.
It is well known that the adaptation to white on a *large* image is based on the appearance of areas with neutral grays. The adaptation is *not* based on the color of paperwhite in highlights [2] .

Nevertheless, the ICC Perceptual Rendering Intent is based on the wrong assumption that the observer adapts additionally to paperwhite.

14. Saturation Rendering Intent

This Rendering Intent is ill defined. Perhaps it can be handled like Media-Relative with different gamut mapping.
Uses CAT white point mapping.

$\mathbf{X}_s = \mathbf{C}_{xr}\,\mathbf{R}$ as usual

$\mathbf{X}_d = \mathbf{T}\,\mathbf{X}_s$ **T** is not defined

$\mathbf{X}_p = \mathbf{P}\,\mathbf{X}_d$ **P** is identity matrix

$\mathbf{X}_c = \mathbf{R}_w^{-1}\,\mathbf{X}_p$ Reference White for RW D50

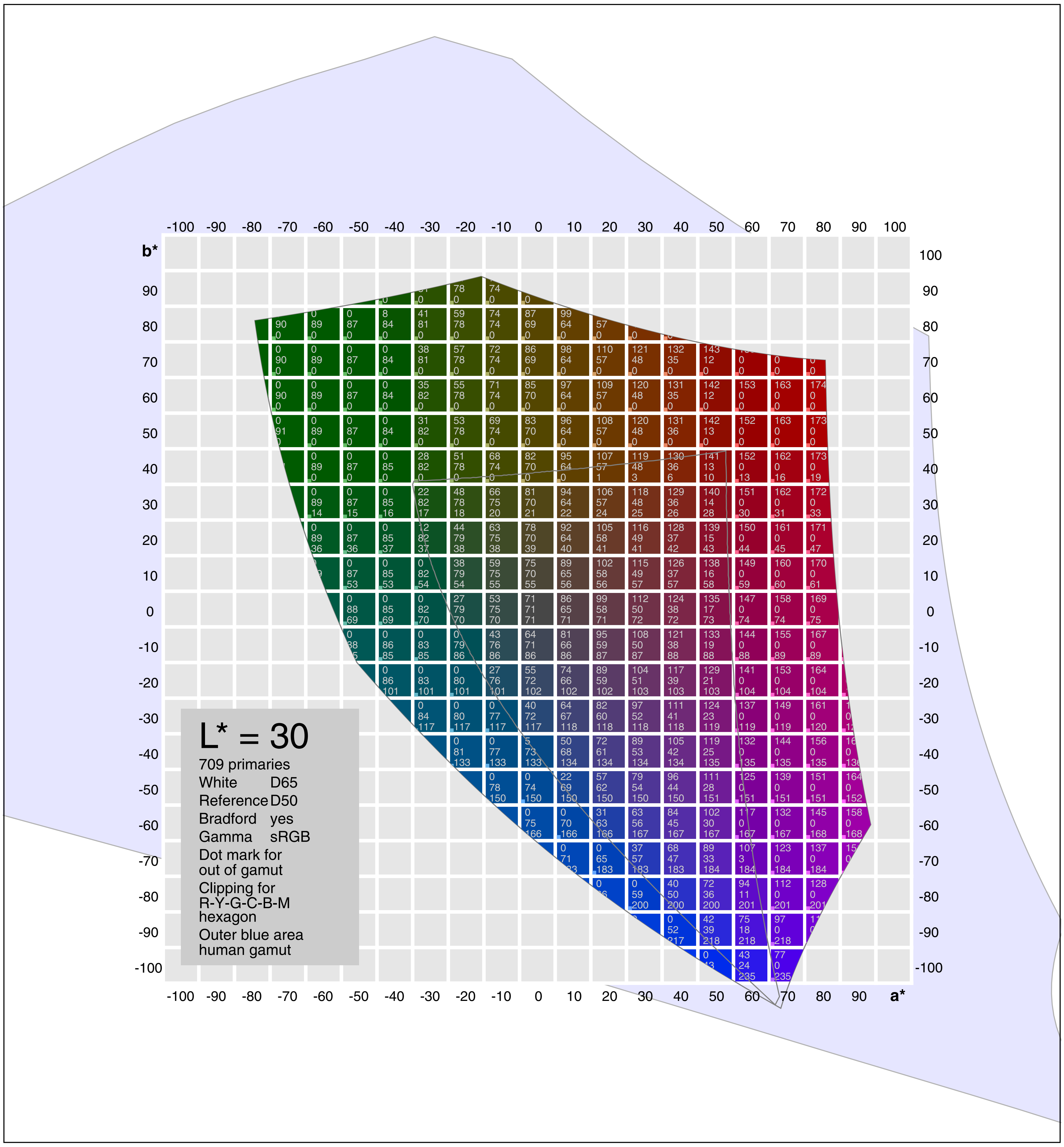
$\mathbf{L} = \mathbf{F}(\mathbf{X}_c)$ as usual

Maps many colors to in-gamut values, preserving saturation, though not necessarily the hue.
Can map some colors to more vibrant printer colors.
Remaining out-of-gamut colors are clipped to nearest color in CIELab.
Dynamic range compression (not accurately specified).

Saturation is used for presentation graphics.
Colors should be vibrant, accuracy cannot be expected.

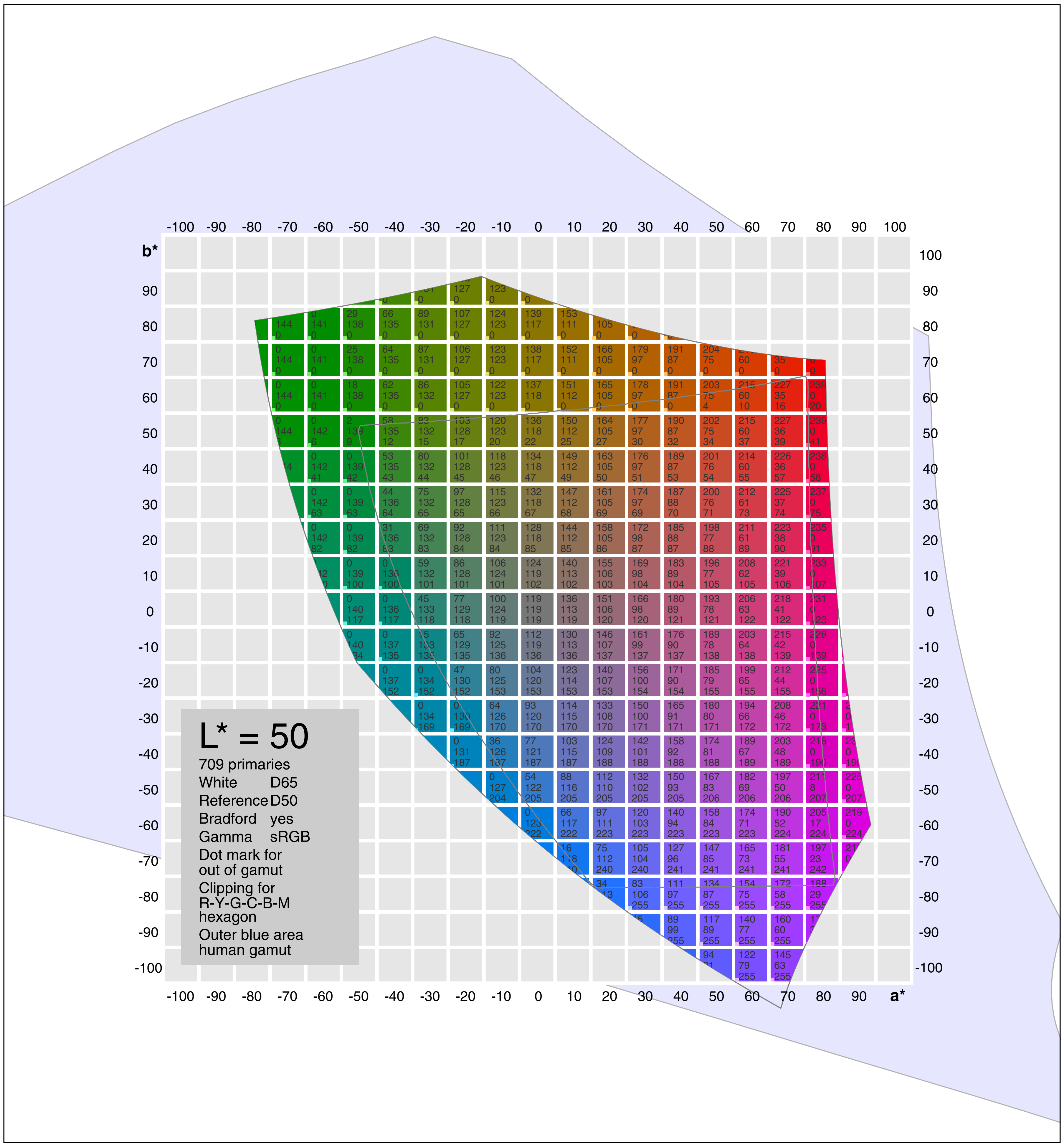
15.1 CIELab and sRGB, L*=30

The graphic shows the CIELab diagram, the sRGB gamut boundary and for [0...255] clipped sRGB values. An RGB set is out-of gamut if any value is less than 0 or greater than 255.
The values cannot be shown without clipping because the inverse gamma correction, a power function, is not defined for negative arguments.



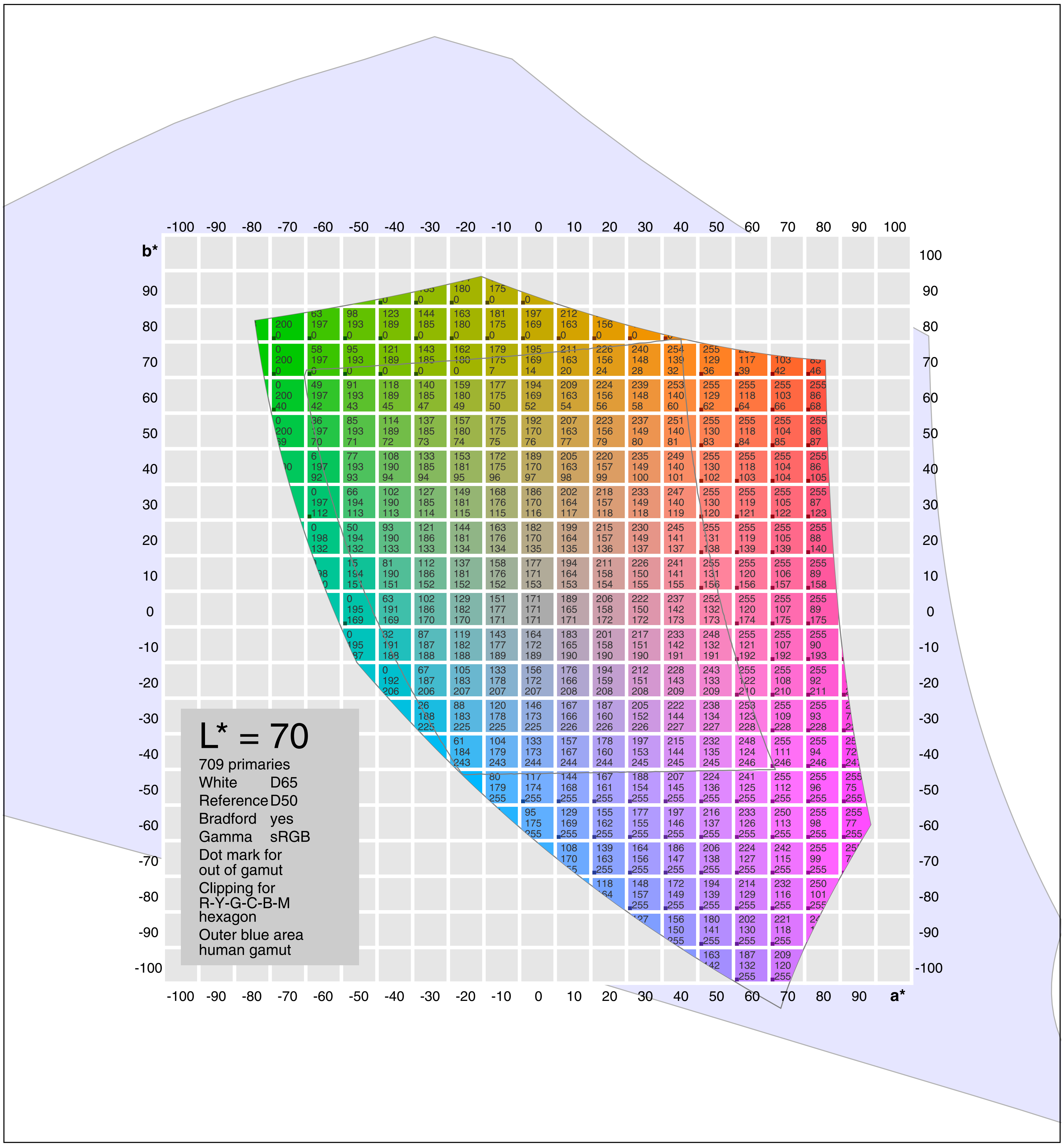
15.2 CIELab and sRGB, L*=50

The graphic shows the CIELab diagram, the sRGB gamut boundary and for [0...255] clipped sRGB values. An RGB set is out-of gamut if any value is less than 0 or greater than 255.
The values cannot be shown without clipping because the inverse gamma correction, a power function, is not defined for negative arguments.



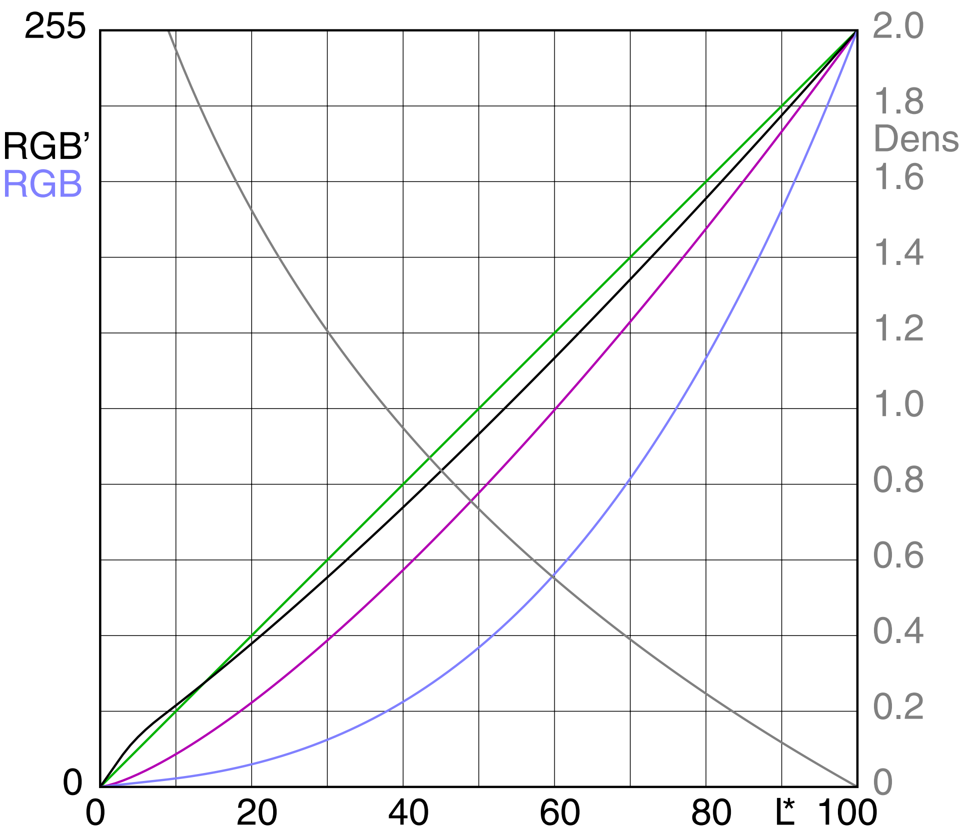
15.3 CIELab and sRGB, L*=70

The graphic shows the CIELab diagram, the sRGB gamut boundary and for [0...255] clipped sRGB values. An RGB set is out-of gamut if any value is less than 0 or greater than 255.
The values cannot be shown withot clipping because the inverse gamma corection, a power function, is not defined for negative arguments.



16. CIELab and sRGB Grayscale

The upper numbers in the swatches are CIELab values $L^*=0$ to 100.
The lower numbers are the sRGB values C’=R’=G’=B’= 0.0 to 255.0.
The RGB’ values in the file are rounded.

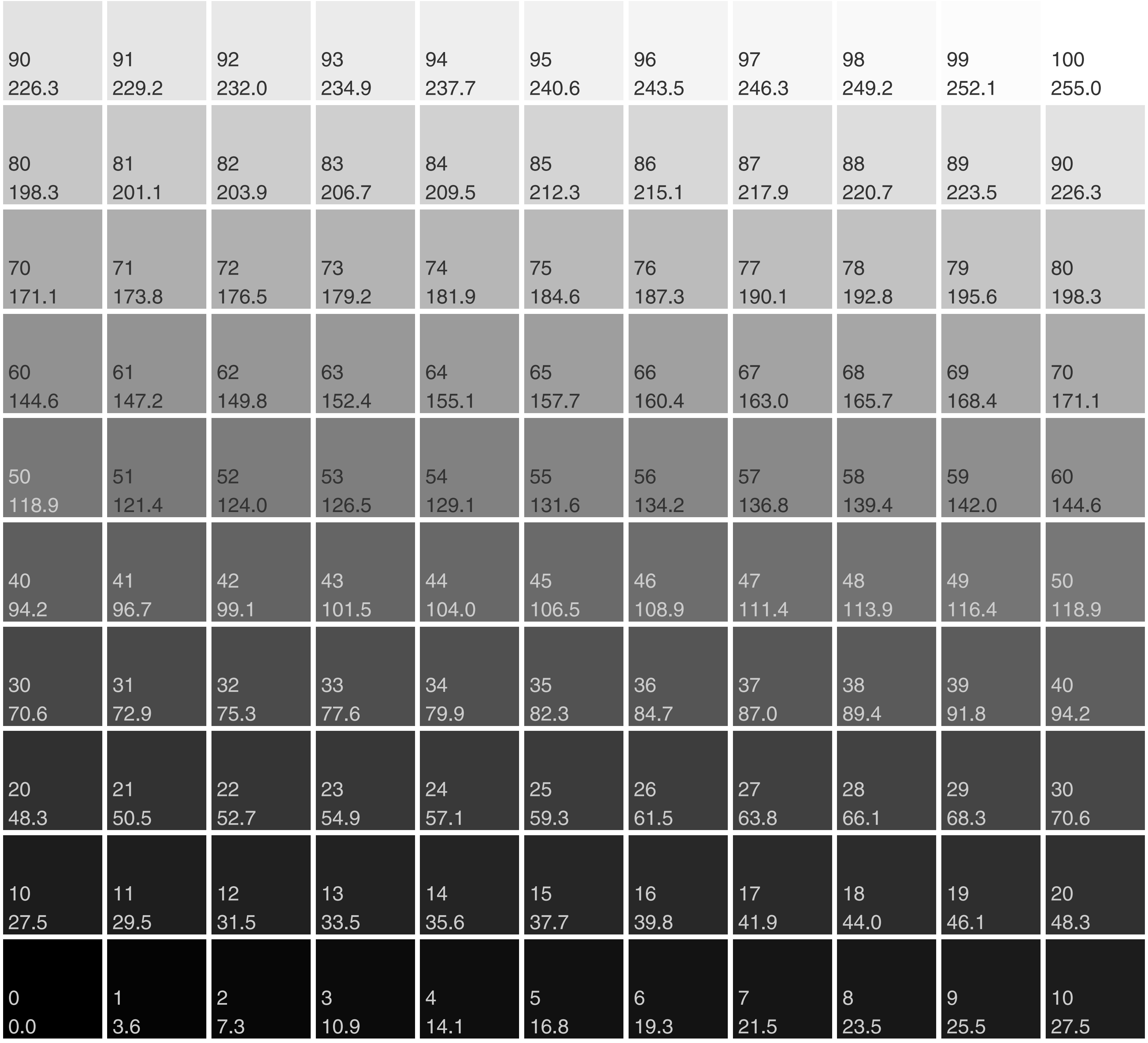


The Tone Reproduction Curve from L^* to C’ is surprisingly nearly linear

Black	Actual Curve for sRGB
Green	Linear

Normalized Curves 0..1

Magenta	$C'=L^{*3/2.2}$
Blue	$C=L^{*3}$
Gray	Density



90 226.3	91 229.2	92 232.0	93 234.9	94 237.7	95 240.6	96 243.5	97 246.3	98 249.2	99 252.1	100 255.0
80 198.3	81 201.1	82 203.9	83 206.7	84 209.5	85 212.3	86 215.1	87 217.9	88 220.7	89 223.5	90 226.3
70 171.1	71 173.8	72 176.5	73 179.2	74 181.9	75 184.6	76 187.3	77 190.1	78 192.8	79 195.6	80 198.3
60 144.6	61 147.2	62 149.8	63 152.4	64 155.1	65 157.7	66 160.4	67 163.0	68 165.7	69 168.4	70 171.1
50 118.9	51 121.4	52 124.0	53 126.5	54 129.1	55 131.6	56 134.2	57 136.8	58 139.4	59 142.0	60 144.6
40 94.2	41 96.7	42 99.1	43 101.5	44 104.0	45 106.5	46 108.9	47 111.4	48 113.9	49 116.4	50 118.9
30 70.6	31 72.9	32 75.3	33 77.6	34 79.9	35 82.3	36 84.7	37 87.0	38 89.4	39 91.8	40 94.2
20 48.3	21 50.5	22 52.7	23 54.9	24 57.1	25 59.3	26 61.5	27 63.8	28 66.1	29 68.3	30 70.6
10 27.5	11 29.5	12 31.5	13 33.5	14 35.6	15 37.7	16 39.8	17 41.9	18 44.0	19 46.1	20 48.3
0 0.0	1 3.6	2 7.3	3 10.9	4 14.1	5 16.8	6 19.3	7 21.5	8 23.5	9 25.5	10 27.5

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This doc:
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February 05 / 2013:
Conversion from PageMaker to InDesign
May have caused minor layout bugs