From L*a*b* to RGB and back

DfwG-Meeting Göppingen, October 8 – 10, 2024

Werner Rudolf Cramer

DfwG
Farbwissenschaft im Fokus

Introduction

- In recent years, interest in displaying colors in the RGB-gamut has risen sharply
- This is because the use and application of digital displays (Smartphone, Laptop, PC) has increased
- Mathematical formulas have been developed to convert measured color values La*b*/XYZ into RGB values
- These formulas refer to absorbing pigments/colors
- The measured values of interference and aluminum pigments are outside the RGB-gamut

ASTM International

- ASTM International (originally: „American Society for Testing and Materials“) is an international standardization organization based in West Conshohocken, Pennsylvania, USA

E12 - Main - Color and Appearance
E12.01 - Terminology
E12.02 - Spectrophotometry and Colorimetry
E12.03 - Geometry
E12.04 - Color and Appearance Analysis
E12.05 - Fluorescence
E12.06 - Image Based Color Measurement
E12.07 - Color Order Systems
E12.11 - Visual Methods
E12.12 - Gonioapparent Color
E12.13 - Photoluminescent Safety Markings

Formulas XYZ -> RGB

1. Bruce Lindbloom http://www.brucelindbloom.com/index.html?Eqn_RGB_XYZ_Matrix.html
   Calculated from (x, y) for red, green, blue, and D65 ref white (X, Y, Z)

```
RGB -> XYZ
+0.4124564 +0.3575761 +0.1804375
+0.2126729 +0.7151522 +0.0721750
+0.0193339 +0.1191920 +0.9503041
XYZ -> RGB (by inverting RGB -> XYZ)
+3.2404542 -1.5371385 -0.4985314
-0.9692660 +1.8760108 +0.0415560
+0.0556434 -0.2040259 +1.0572252
```

2. W3C https://www.w3.org/Graphics/Color/srgb
   EasyRGB https://easyrgb.com/en/math.php seems to use W3C, but truncated

```
XYZ -> RGB
+3.2406255 -1.5372080 -0.4986286
-0.9689307 +1.8757561 +0.0415175
+0.0557101 -0.2040211 +1.0569959
```

3. Wikipedia https://en.wikipedia.org/wiki/SRGB#Specification_of_the_transformation
   Claims to be the sRGB specification

```
XYZ -> RGB
+3.24096994 -1.53738318 -0.49861076
-0.96924364 +1.87596750 +0.04155506
+0.05563008 -0.20397696 +1.05697151
```

1966 2.1 © IEC: 1998 – 88 –

$$\begin{bmatrix} R_{sRGB} \\ G_{sRGB} \\ B_{sRGB} \end{bmatrix} = \begin{bmatrix} 3,2406 & -1,5372 & -0,4986 \\ -0,9689 & 1,8758 & 0,0415 \\ 0,0557 & -0,2040 & 1,0570 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \quad (6)$$

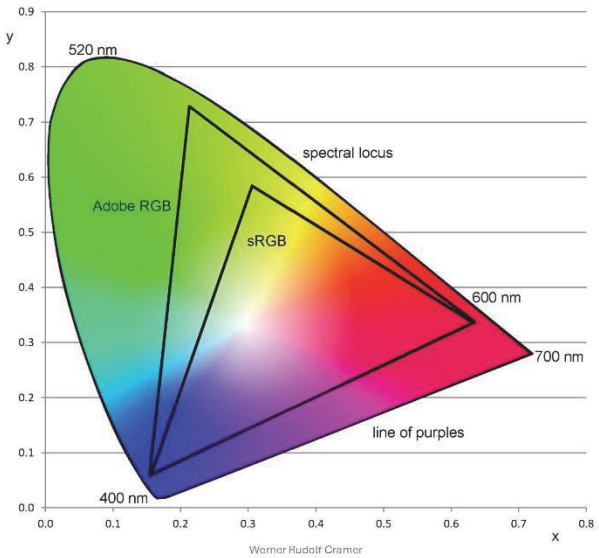
```
MATRIX_sRGB_TO_XYZ = np.array([
    [0.4124, 0.3576, 0.1805],
    [0.2126, 0.7152, 0.0722],
    [0.0193, 0.1192, 0.9505],
])
"""
*sRGB* colourspace to *CIE XYZ* tristimulus values matrix.

MATRIX_sRGB_TO_XYZ : array_like, (3, 3)
"""

MATRIX_XYZ_TO_sRGB = np.array([
    [3.2406, -1.5372, -0.4986],
    [-0.9689, 1.8758, 0.0415],
    [0.0557, -0.2040, 1.0570],
])
"""
*CIE XYZ* tristimulus values to *sRGB* colourspace matrix.

MATRIX_XYZ_TO_sRGB : array_like, (3, 3)
"""
```

My formulation (here for R)

```
var_R = var_X * 3.2405 + var_Y * -1.5372 + var_Z * -0.4985
var_G = var_X * -0.9693 + var_Y * 1.876 + var_Z * 0.0416
var_B = var_X * 0.0556 + var_Y * -0.204 + var_Z * 1.057

'Calculation of R
    If (var_R > 0.0031308) Then
        var_R = 1.055 * (var_R ^ (1 / 2.4)) - 0.055
    Else
        var_R = 12.92 * var_R
    End If


sR_RGB = var_R * 255

    If sR_RGB < 0 Then

        sR_RGB = 0

    End If
```

Werner Rudolf Cramer 5

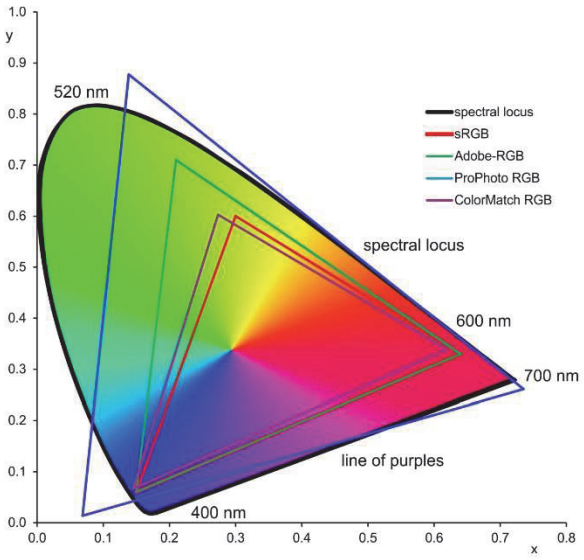
Starting position: XYZ versus RGB-gamut



Werner Rudolf Cramer 6

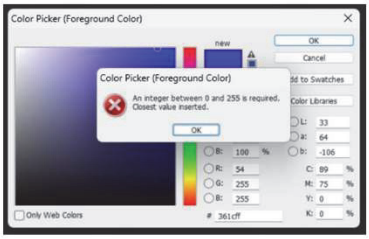
Different RGB-gamuts

d:daten\experimente\grafiken\schuhsohle.cdr



Calculations L*a*b* to RGB (plus Photoshop)

			Adobe RGB			sRGB			Photoshop		
L*	a*	b*	R	G	B	R	G	B	R	G	B
10	-40	-40	0	47	82	0	43	82	0	42	83
20	-40	-40	0	66	105	0	64	107	0	63	107
30	-40	-40	0	88	129	0	88	132	0	87	133
40	-40	-40	0	112	155	0	113	158	0	112	159
50	-40	-40	0	138	182	0	139	185	0	138	186
60	-40	-40	0	164	210	0	166	213	0	165	214
70	-40	-40	43	192	239	0	193	241	0	193	243
80	-40	-40	84	221	269	0	222	270	0	221	255
90	-40	-40	116	250	300	0	251	300	0	250	255
100	-40	-40	148	281	331	0	280	330	54	255	255
110	-40	-40	179	312	364	37	310	360			
120	-40	-40	210	345	397	105	341	392			
130	-40	-40	242	378	431	149	372	423			
140	-40	-40	274	412	466	188	403	455			
150	-40	-40	307	446	501	224	435	488			
160	-40	-40	341	482	537	259	468	521			
170	-40	-40	375	518	574	293	501	554			
180	-40	-40	410	554	612	328	534	588			



L*a*b* -> RGB (via XYZ)

L*	a*	b*	R	G	B
10	10	20	47	21	0
20	20	20	80	35	19
30	30	20	118	49	41
40	40	20	159	63	63
50	50	20	201	77	87
60	60	20	244	92	112
70	70	20	289	107	138
80	80	20	336	122	164
90	90	20	384	138	192
100	100	20	433	154	220
110	20	10	331	270	264
120	20	20	369	299	273
130	20	30	407	329	282
140	20	40	445	359	291
150	20	50	484	390	299
160	20	60	523	421	308
170	20	70	563	452	316
180	20	80	603	484	324

L*	a*	b*	R	G	B
10	20	10	47	21	0
20	20	20	80	35	19
30	20	30	118	49	41
40	20	40	159	63	63
50	20	50	201	77	87
60	20	60	244	92	112
70	20	70	289	107	138
80	20	80	336	122	164
90	20	90	384	138	192
100	20	100	433	154	220
110	10	20	331	270	264
120	20	20	369	299	273
130	30	20	407	329	282
140	40	20	445	359	291
150	50	20	484	390	299
160	60	20	523	421	308
170	70	20	563	452	316
180	80	20	603	484	324

L*	a*	b*	R	G	B
10	40	40	78	0	0
20	40	40	104	4	0
30	40	40	132	36	5
40	40	40	162	62	29
50	40	40	192	88	52
60	40	40	223	114	75
70	40	40	254	140	100
80	40	40	285	167	125
90	40	40	317	195	151
100	40	40	349	223	178
110	40	40	382	253	205
120	40	40	415	282	234
130	40	40	448	312	262
140	40	40	482	343	292
150	40	40	516	374	322
160	40	40	550	406	352
170	40	40	585	438	383
180	40	40	620	471	415

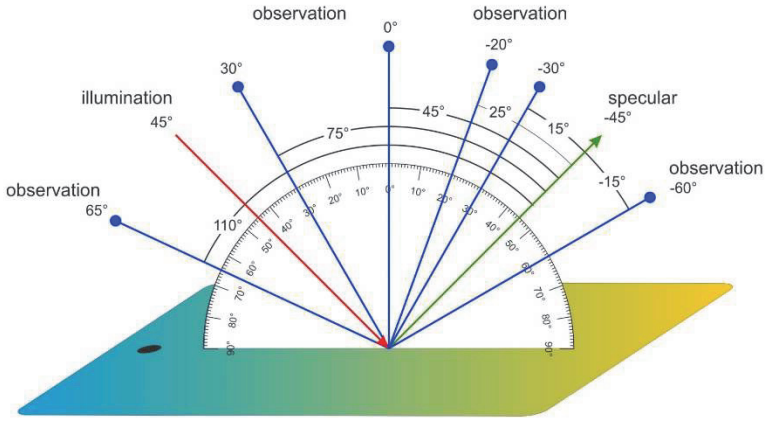
L*	a*	b*	R	G	B
10	0	0	27	27	27
20	0	0	48	48	48
30	0	0	71	71	70
40	0	0	94	94	94
50	0	0	119	119	118
60	0	0	144	145	144
70	0	0	171	171	170
80	0	0	198	199	197
90	0	0	226	227	225
100	0	0	255	255	253
110	0	0	284	285	282
120	0	0	314	314	312
130	0	0	344	345	342
140	0	0	375	376	373
150	0	0	407	407	404
160	0	0	439	439	436
170	0	0	471	472	468
180	0	0	504	505	501

L*	a*	b*	R	G	B
10	-40	40	27	27	27
20	-40	40	48	48	48
30	-40	40	71	71	70
40	-40	40	94	94	94
50	-40	40	119	119	118
60	-40	40	144	145	144
70	-40	40	171	171	170
80	-40	40	198	199	197
90	-40	40	226	227	225
100	-40	40	255	255	253
110	-40	40	284	285	282
120	-40	40	314	314	312
130	-40	40	344	345	342
140	-40	40	375	376	373
150	-40	40	407	407	404
160	-40	40	439	439	436
170	-40	40	471	472	468
180	-40	40	504	505	501

L*	a*	b*	R	G	B
10	40	-40	47	0	83
20	40	-40	72	21	107
30	40	-40	98	46	133
40	40	-40	125	70	159
50	40	-40	152	95	186
60	40	-40	179	121	214
70	40	-40	208	147	243
80	40	-40	237	174	272
90	40	-40	266	202	302
100	40	-40	296	231	332
110	40	-40	327	260	362
120	40	-40	358	289	394
130	40	-40	389	320	425
140	40	-40	421	350	458
150	40	-40	453	382	490
160	40	-40	486	413	523
170	40	-40	519	445	557
180	40	-40	553	478	590

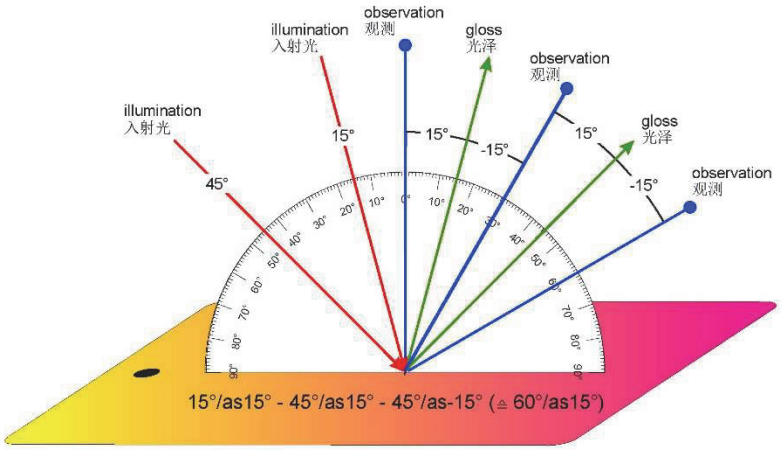
Werner Rudolf Cramer 9

Multi-angle geometries



Werner Rudolf Cramer 10

Multi-angle geometries



A color with many „eyes“

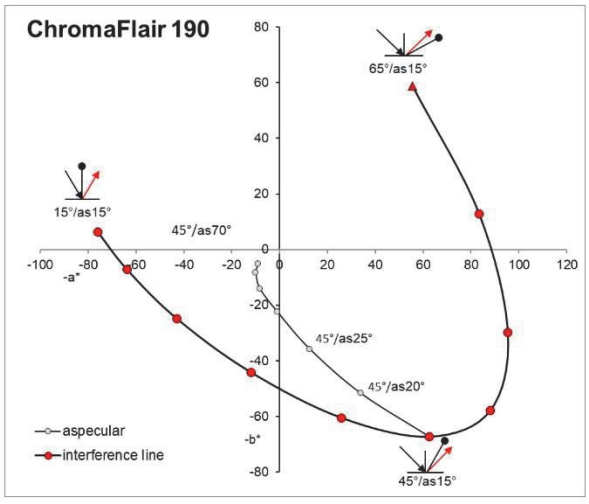
Measurement results and calculations

	1375:ChromaFlair 190L measured values			calculated RGB			calculated RGB by Photoshop		
	L*	a*	b*	R	G	B	R	G	B
45°/as15°	74.71	55.31	-64.05	204	148	299	204	148	255
45°/as25°	53.41	13.26	-41.56	110	123	194	110	123	194
45°/as45°	27.33	-19.16	-8.35	40	74	77	40	74	77
45°/as75°	12.57	-8.9	-2.47	29	41	40	29	41	40
45°/as110°	8.09	-0.42	-1.22	29	30	31	29	30	31
45°/as-15°	108.59	87.35	6.51	397	200	268	255	200	255
15°/as15°	87.34	-89.32	18.51	94	257	182	94	255	182

	re-calc with factor per geometry				re-calc with factor per all geometries				re-calc with weighted factor by L*			
	MAXRGB	R	G	B	MAXRGB	R	G	B	MAXRGB	R	G	B
45°/as15°	1.17	174	126	255	1.56	131	95	192	1.56	131	95	192
45°/as25°	1.00	110	123	194	1.56	71	79	125	1.11	99	111	174
45°/as45°	1.00	40	74	77	1.56	26	48	49	0.57	70	130	135
45°/as75°	1.00	29	41	40	1.56	19	26	26	0.26	111	157	153
45°/as110°	1.00	29	30	31	1.56	19	19	20	0.17	172	178	184
45°/as-15°	1.56	255	128	172	1.56	255	128	172	2.26	175	88	118
15°/as15°	1.01	93	255	181	1.56	60	165	117	1.82	52	141	100

Werner Rudolf Cramer 13

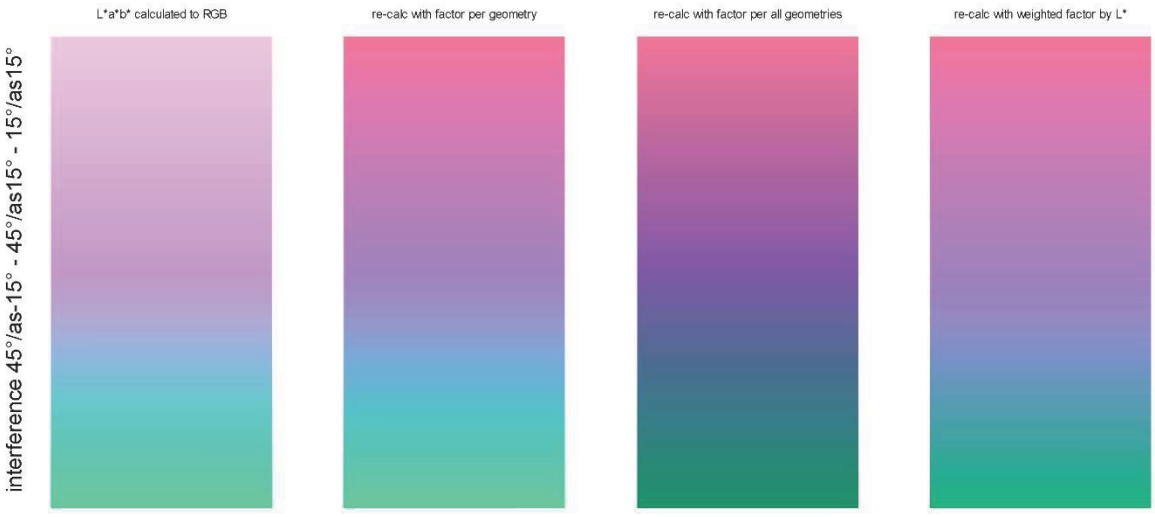
Measured results of interference and aspecular



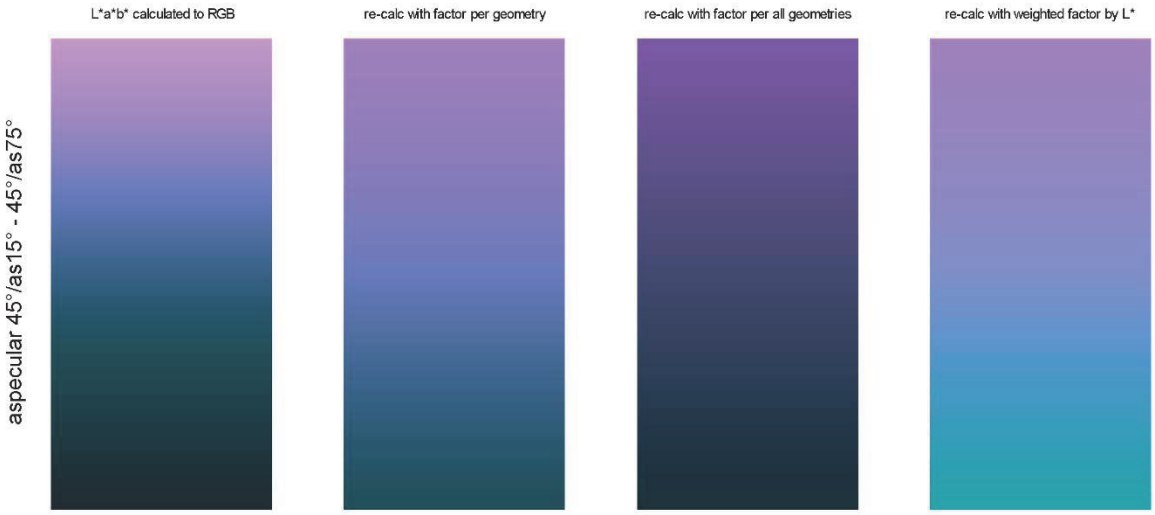
Werner Rudolf Cramer 14

Hammerfest (43°), Hamburg (60°) & Key West (89°)

Different calculations for interference (ChromaFlair 190)

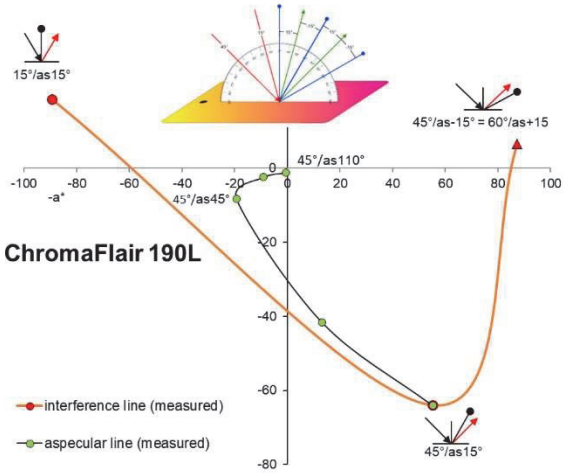


Different calculations for aspecular (ChromaFlair 190)



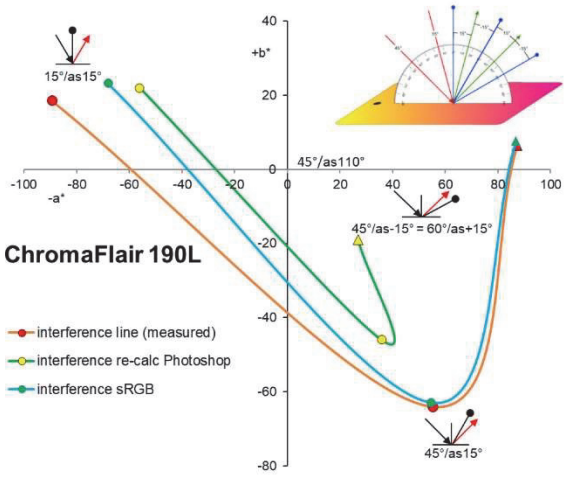
Werner Rudolf Cramer 17

Measured results with actual geometries



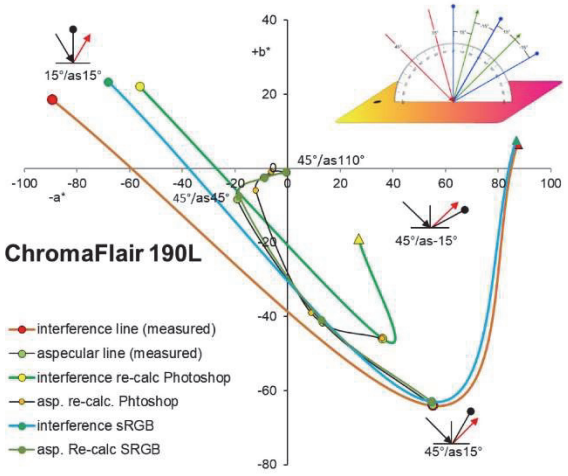
Werner Rudolf Cramer 18

Measured results and re-calculation



Werner Rudolf Cramer 19

Measured and calculated results



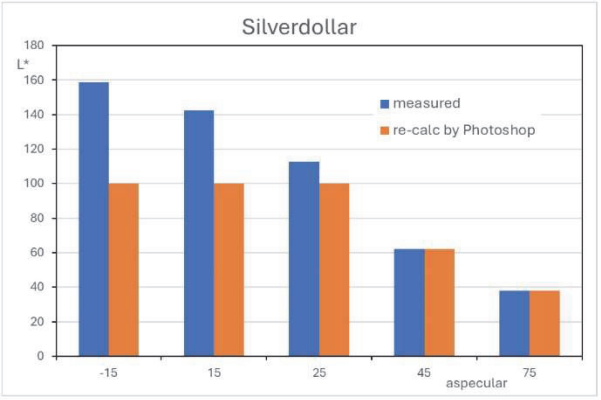
Werner Rudolf Cramer 20

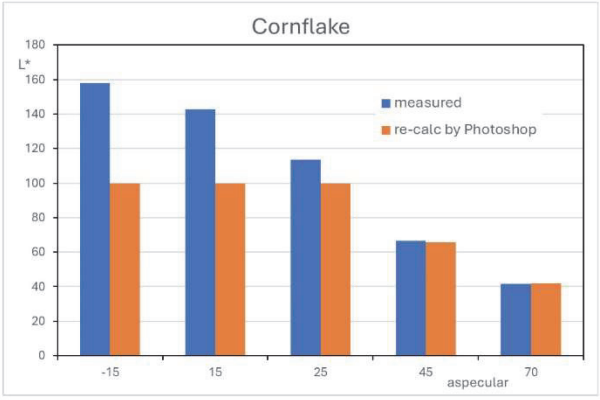
Examples of aluminums (cornflake & silverdollar)

							Adobe-RGB			re-calc. by Photoshop		
Cornflake	illumination	observation	aspecular	L*	a*	b*	R	G	B	L*	a*	b*
x0780	45	150	-15	158.19	-0.28	1.11	444	445	439	100	0	0
x0780	45	120	15	142.83	-0.43	0.63	391	392	388	100	0	0
x0780	45	110	25	113.5	-0.46	-0.53	295	297	295	100	0	0
x0780	45	90	45	66.61	-0.5	-1.1	159	161	161	66	-1	-1
x0780	45	65	70	41.78	-0.64	-0.98	97	99	99	42	-1	0
							Adobe-RGB			re-calculated bei Photoshop		
Silverdollar	illumination	observation	aspecular	L*	a*	b*	R	G	B	L*	a*	b*
x0513	45	150	-15	158.82	-0.89	0.27	445	447	443	100	0	0
x0513	45	120	15	142.34	-0.43	-1.03	388	391	390	100	0	0
x0513	45	110	25	112.74	-0.87	-0.42	292	295	293	100	0	0
x0513	45	90	45	62.18	-0.41	-0.60	148	149	149	62	0	0
x0513	45	60	75	38.01	-0.67	-1.01	89	90	91	38	0	-1

Werner Rudolf Cramer 21

Photoshop sets L*-values higher than 100 down to 100





Werner Rudolf Cramer 22

Viola Fantasy + color_01

9001	01.07.2002	Viola Fantasy	100	2.50	color_01	0
9002	01.07.2002	Viola Fantasy	95	2.38	color_01	5
9003	01.07.2002	Viola Fantasy	90	2.25	color_01	10
9004	01.07.2002	Viola Fantasy	80	2.00	color_01	20
9005	01.07.2002	Viola Fantasy	60	1.50	color_01	40
9006	01.07.2002	Viola Fantasy	40	1.00	color_01	60
9007	01.07.2002	Viola Fantasy	20	0.50	color_01	80
9008	01.07.2002	Viola Fantasy	0	0.00	color_01	100

MUSTER	DATUM	ZEIT	BEL_W	BEOB_W	DIFF_W	FILTER	X	Y	Z	L*	a*	b*
9001	25.07.2002	8:34	45	120	15	2	217.58	211.59	202.11	132.92	17.61	9.84
9002	25.07.2002	8:38	45	120	15	2	158.3	168.95	173.76	122.16	-2.34	3.41
9003	25.07.2002	8:41	45	120	15	2	108.12	118.52	128.31	106.76	-6.76	-0.56
9004	25.07.2002	8:48	45	120	15	2	63.69	77.43	87.87	90.52	-21.22	-3.4
9005	25.07.2002	8:51	45	120	15	2	29.46	37.74	44.31	67.83	-22.69	-4.35
9006	25.07.2002	8:58	45	120	15	2	14.29	18.86	22.65	50.53	-20.65	-4.35
9007	25.07.2002	9: 2	45	120	15	2	5.58	7.27	9.01	32.41	-14.2	-4.07
9008	25.07.2002	9: 5	45	120	15	2	0.3	0.25	0.54	2.3	2.32	-3.9

Aluminum + blue

9115	A552	100	2.82			
9519	55-552	80	1.96	55-silber	20	0.56
9520	55-552	60	1.47	55-silber	40	1.12
9521	55-552	40	0.98	55-silber	60	1.68
9522	55-552	20	0.49	55-silber	80	2.25
9523	55-silber	100	2.81			

Panel	illumination	oberservation	aspecular	L*	a*	b*
9115	45	120	15	3.87	14.07	-24.07
9519	45	120	15	75.63	-40.09	-52.08
9520	45	120	15	99.3	-46.03	-54.77
9521	45	120	15	116.03	-43.41	-47.38
9522	45	120	15	135.29	-31.42	-31.92
9523	45	120	15	162.11	-0.48	-0.27

To take away

- For interference and aluminum pigments, special features must be observed for the RGB gamuts
- The color and brightness values of these pigments are significantly higher than those of absorbing chromatic pigments
- The conversion of L*a*b*/XYZ values into RGB values refers to absorbing colored pigments
- When converting L*a*b*/XYZ values of interference and aluminum pigments to sRGB or AdobeRGB, restrictions must be observed
- Brightness values L* above 100 (often above 70) are automatically reduced
- Calculated RGB-values above 255 are reduced to 255