



# Color-Accurate Image Archiving of paintings with supporting spectrophotometry

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# How accurate **should** be the colors?

Two standards in cultural heritage preservation:



Federal Agencies Digitization Guidelines Initiative (FADGI)  
Technical Guidelines for Digitizing Cultural Heritage Materials

- August 2010
- September 2015 (draft)



National Library of the Netherlands  
Metamorfoze Preservation Imaging Guidelines 1.0  
(January 2012)

# How accurate **should** be the colors?



Color Encoding Error (Delta E 2000)					
Performance Level	AIM	TOLERANCE ( choose option A or B )			
		A) $\Delta E (L^*a^*b^*)$		B) $\Delta E (a^*b^*)$	
		max	avg.	max	avg.
★★★★	0	< 6	< 3	< 3	< 2
★★★	0	< 10	< 5	< 5	< 3
★★	0	< 15	< 10	< 8	< 6
★	0	> 15	> 10	> 8	> 6



	METAMORFOZE	METAMORFOZE LIGHT	METAMORFOZE EXTRA LIGHT
Color accuracy <sup>9</sup> cie 1976, Digital ColorChecker SG	Mean $\Delta E^* \leq 4$ Max $\Delta E^* \leq 10$	Mean $\Delta E^* \leq 5$ Max $\Delta E^* \leq 18$	Mean $\Delta E^* \leq 5$ Max $\Delta E^* \leq 18$

# Color accuracy by FADGI



2010



2015

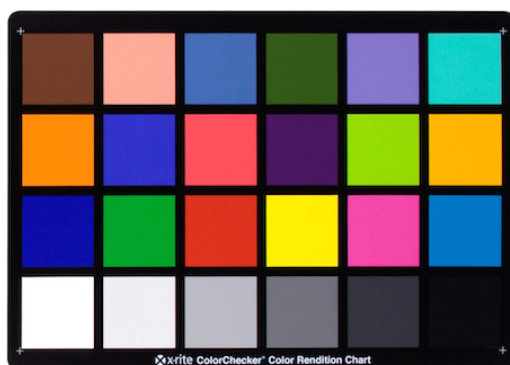
## Universal

	Mean dE2000	Max dE2000
1 star	10	15
2 star	10	15
3 star	5	10
4 star	3	6

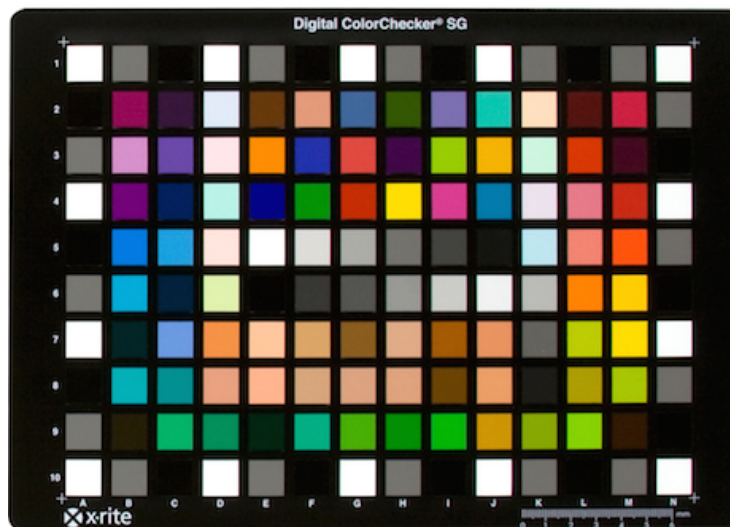
## Reproduction of Artwork

	Mean dE2000	Max dE2000
1 star	10	20
2 star	6	15
3 star	4	12
4 star	2	10

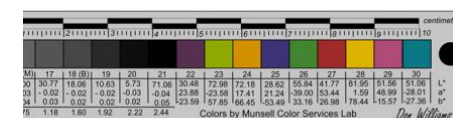
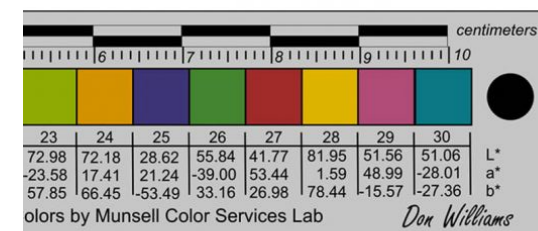
# Color charts



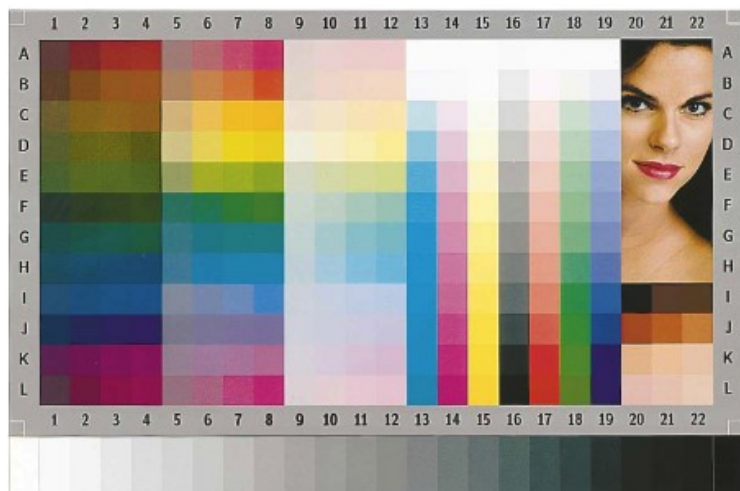
X-Rite ColorChecker Classic



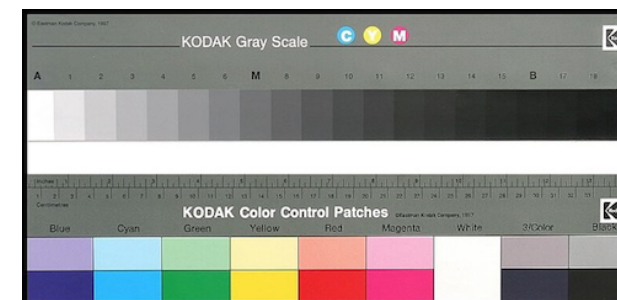
X-Rite ColorChecker Digital SG



Object-Level Targets



Kodak It8.7/2



Kodak Gray Scale & Color Control Patches

# X-Rite ColorChecker Classic



No.	Number		sRGB			CIE L*a*b*			Munsell Notation Hue Value / Chroma	
			R	G	B	L*	a*	b*		
1.	dark skin		115	82	68	37.986	13.555	14.059	3 YR	3.7 / 3.2
2.	light skin		194	150	130	65.711	18.13	17.81	2.2 YR	6.47 / 4.1
3.	blue sky		98	122	157	49.927	-4.88	-21.925	4.3 PB	4.95 / 5.5
4.	foliage		87	108	67	43.139	-13.095	21.905	6.7 GY	4.2 / 4.1
5.	blue flower		133	128	177	55.112	8.844	-25.399	9.7 PB	5.47 / 6.7
6.	bluish green		103	189	170	70.719	-33.397	-0.199	2.5 BG	7 / 6
7.	orange		214	126	44	62.661	36.067	57.096	5 YR	6 / 11
8.	purplish blue		80	91	166	40.02	10.41	-45.964	7.5 PB	4 / 10.7
9.	moderate red		193	90	99	51.124	48.239	16.248	2.5 R	5 / 10
10.	purple		94	60	108	30.325	22.976	-21.587	5 P	3 / 7
11.	yellow green		157	188	64	72.532	-23.709	57.255	5 GY	7.1 / 9.1
12.	orange yellow		224	163	46	71.941	19.363	67.857	10 YR	7 / 10.5
13.	blue		56	61	150	28.778	14.179	-50.297	7.5 PB	2.9 / 12.7
14.	green		70	148	73	55.261	-38.342	31.37	0.25 G	5.4 / 8.65
15.	red		175	54	60	42.101	53.378	28.19	5 R	4 / 12
16.	yellow		231	199	31	81.733	4.039	79.819	5 Y	8 / 11.1
17.	magenta		187	86	149	51.935	49.986	-14.574	2.5 RP	5 / 12
18.	cyan		8	133	161	51.038	-28.631	-28.638	5 B	5 / 8
19.	white (.05*)		243	243	242	96.539	-0.425	1.186	N	9.5 /
20.	neutral 8 (.23*)		200	200	200	81.257	-0.638	-0.335	N	8 /
21.	neutral 6.5 (.44*)		160	160	160	66.766	-0.734	-0.504	N	6.5 /
22.	neutral 5 (.70*)		122	122	121	50.867	-0.153	-0.27	N	5 /
23.	neutral 3.5 (1.05*)		85	85	85	35.656	-0.421	-1.231	N	3.5 /
24.	black (1.50*)		52	52	52	20.461	-0.079	-0.973	N	2 /

Cie L\*a\*b\* values use Illuminant D50 2 degree observer sRGB values for Illuminate D65.



# Accuracy of color targets

No.	Number	sRGB			CIE L*a*b*			Munsell Notation Hue Value / Chroma	
		R	G	B	L*	a*	b*		
1.	dark skin	115	82	68	37.986	13.555	14.059	3 YR	3.7 / 3.2
2.	light skin	194	150	130	65.711	18.13	17.81	2.2 YR	6.47 / 4.1
3.	blue sky	98	122	157	49.927	-4.88	-21.925	4.3 PB	4.95 / 5.5
4.	foliage	87	108	67	43.139	-13.095	21.905	6.7 GY	4.2 / 4.1
5.	blue flower	133	128	177	55.112	8.844	-25.399	9.7 PB	5.47 / 6.7
6.	bluish green	103	189	170	70.719	-33.397	-0.199	2.5 BG	7 / 6
7.	orange	214	126	44	62.661	36.067	57.096	5 YR	6 / 11
8.	purplish blue	80	91	166	40.02	10.41	-45.964	7.5 PB	4 / 10.7
9.	moderate red	193	90	99	51.124	48.239	16.248	2.5 R	5 / 10
10.	purple	94	60	108	30.325	22.976	-21.587	5 P	3 / 7
11.	yellow green	157	188	64	72.532	-23.709	57.255	5 GY	7.1 / 9.1
12.	orange yellow	224	163	46	71.941	19.363	67.857	10 YR	7 / 10.5
13.	blue	56	61	150	28.778	14.179	-50.297	7.5 PB	2.9 / 12.7
14.	green	70	148	73	55.261	-38.342	31.37	0.25 G	5.4 / 8.65
15.	red	175	54	60	42.101	53.378	28.19	5 R	4 / 12
16.	yellow	231	199	31	81.733	4.039	79.819	5 Y	8 / 11.1
17.	magenta	187	86	149	51.935	49.986	-14.574	2.5 RP	5 / 12
18.	cyan	8	133	161	51.038	-28.631	-28.638	5 B	5 / 8
19.	white (.05*)	243	243	242	96.539	-0.425	1.186	N	9.5 /
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21.	neutral 6.5 (.44*)	160	160	160	66.766	-0.734	-0.504	N	6.5 /
22.	neutral 5 (.70*)	122	122	121	50.867	-0.153	-0.27	N	5 /
23.	neutral 3.5 (1.05*)	85	85	85	35.656	-0.421	-1.231	N	3.5 /
24.	black (1.50*)	52	52	52	20.461	-0.079	-0.973	N	2 /

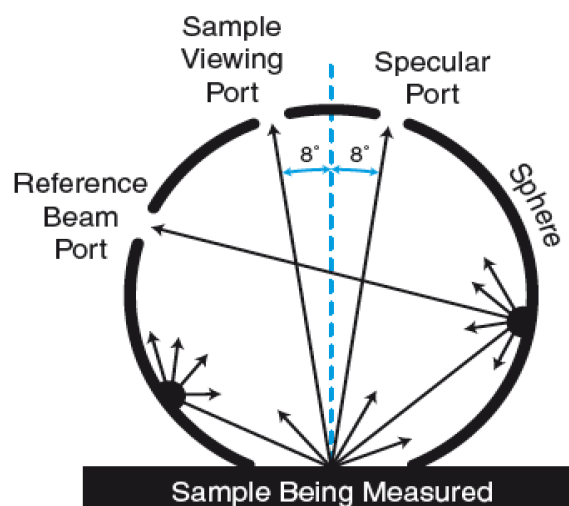
Cie L\*a\*b\* values use Illuminant D50 2 degree observer sRGB values for Illuminate D65.

	L	a	b	DE2000
1	38,76	13,73	14,47	0,71
2	65,75	20,09	17,94	1,28
3	49,68	-3,73	-21,82	1,07
4	43,68	-13,02	21,87	0,50
5	54,67	9,88	-24,54	1,37
6	69,67	-33,15	-0,05	0,82
7	63,37	36,06	58,08	0,71
8	40,45	11,54	-45,03	1,26
9	51,81	47,78	17,05	0,86
10	30,46	21,48	-20,76	0,77
11	71,85	-24,25	56,83	0,63
12	71,11	19,01	67,14	0,67
13	29,45	15,30	-50,21	0,95
14	55,76	-39,50	32,40	0,67
15	45,88	53,31	31,34	3,89
16	81,84	1,73	80,38	1,35
17	51,18	50,18	-13,58	0,88
18	49,72	-27,39	-27,86	1,42
20	95,61	-0,97	2,34	1,41
20	81,62	-0,50	0,31	0,71
21	67,26	-0,82	-0,11	0,57
22	51,07	-0,48	0,23	0,71
23	36,07	-0,82	-0,56	0,94
24	20,47	-0,13	-0,40	0,56

**AVG = 1,03**  
**MAX = 3,89**

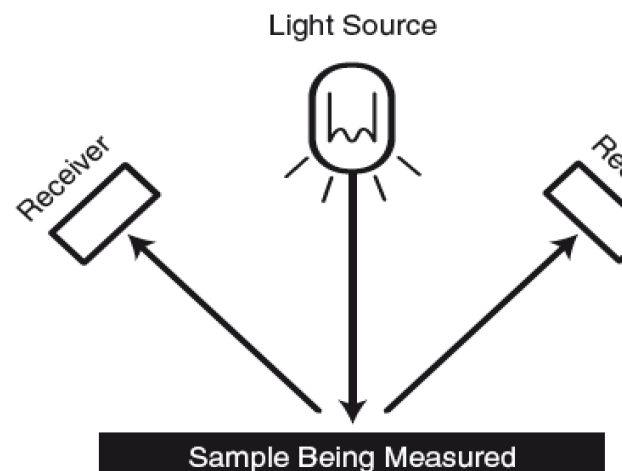
# Three primary types of spectrophotometer

## Spherical



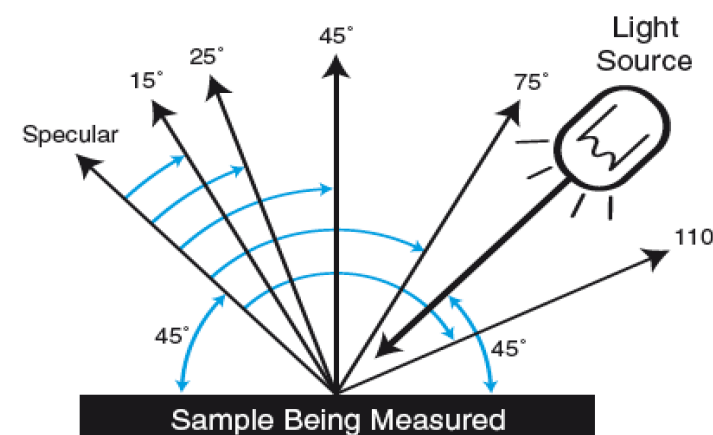
Used for measuring color that has been applied to textured surfaces such as textiles, carpets and plastics, shiny or mirror-like surfaces, including metallic inks, printing over foil, and other highly glossy surfaces.

## 0°/45° or 45°/0°



The most common spectrophotometer, can exclude gloss. They are used for measuring color on smooth or matte surfaces.

## Multi-Angle



Views the color of a sample as if it is being moved back and forth, just as you would twist a sample to see the color at various angles. Used for specially coated pigments and special effect colors with additives such as mica and pearlescents, such as nail polish and automotive coatings.

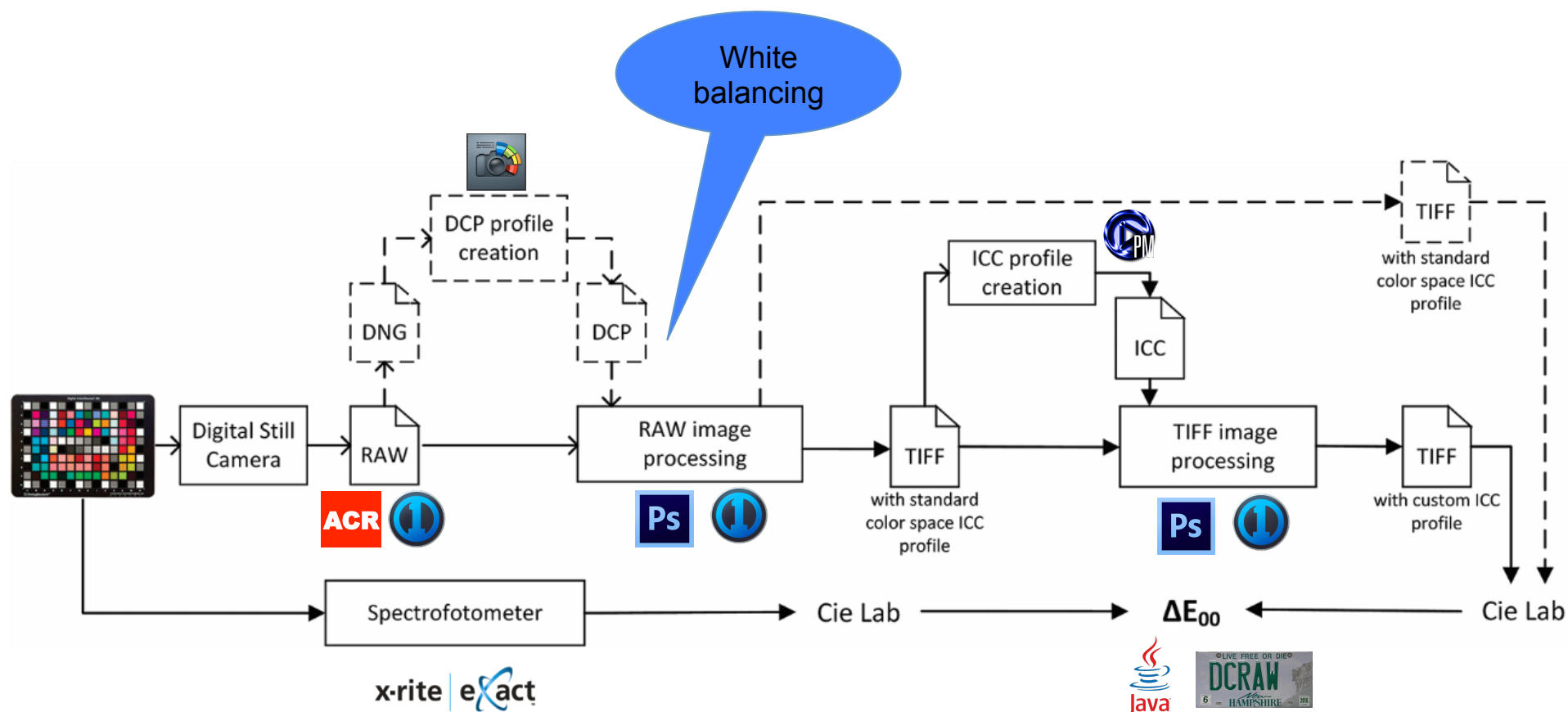


# Measuring modes according to ISO 13655:2009

ISO 13655-2009: Spectral Measurement and Colorimetric Computation for Graphic Arts Images defines “M” series of measurement conditions:

	M0	M1(1)	M1(2)	M2	M3
Illumination	CIE Illuminant A	CIE Illuminant D50	CIE Illuminant D50	Not specified	Not specified
Measure effect of OBAs (optical brightening agents)		YES	YES		
Measure ink fluorescence		YES			
Cut the effect of OBAs				YES	YES
Cut first surface reflections					Polarizing filter

# Color image reproduction workflow



Korytkowski, P., A. Olejnik-Krugły (2016) Precise capture of colors in cultural heritage digitization, Color Research & Application, in press

# Our spectrophotometer: X-Rite eXact Advanced



Measurement Geometry	45°/0° ring illumination optics, ISO 5-4:2009(E)
Inter-Instrument Agreement	Average: 0.25 $\Delta E_{ab}$ , Max: 0.45 $\Delta E_{ab}$ (for M3: 0.55 $\Delta e_{ab}$ )
Light Source	Gas filled tungsten (illuminant type A) and UV LED
Measurement Conditions	M0, M1 (part 1) , M2, M3
Spectral Interval	10 nm
Spectral Range	400 nm to 700 nm

# Testing environment

## Cameras:

1. Phase One 645DF+ with P65+ digital back,
2. Canon EOS 5D Mark II,
3. Nikon D7100.



## Lights:

- Continuous light, a simulation of D50 generated by SpectraLight QC Light Booth, CCT=5002K,
- Continuous tungsten A light generated by SpectraLight QC Light Booth, CCT=2861K,
- Flashed light, CCT=4820K.



Korytkowski, P., A. Olejnik-Krugły (2016) Precise capture of colors in cultural heritage digitization, Color Research & Application, in press

# How accurate **can** we capture the colors?

Camera			Nikon				Canon				Phase One	
Light			D50		A		Flash		Flash		D50	
Color Space	Profile		avg.	max	avg.	max	avg.	max	avg.	max	avg.	max
1 ProPhoto RGB	ICC		1.66	4.26	3.09	12.29	1.85	5.32	2.43	6.21	1.87	6.19
2 AdobeRGB	ICC		1.85	5.41	3.60	14.85	2.47	7.08	2.4	6.24	2.03	4.75
3 eciRGBv2	ICC		2.09	8.62	3.81	13.68	1.93	6.30	2.18	5.69	1.88	4.73
4 ProPhoto RGB	DCP		3.83	9.77	6.65	19.51	7.02	15.71	4.24	10.77	3.7	9.79
5 AdobeRGB	DCP		3.85	9.79	5.46	14.42	7.03	15.74	4.31	10.80	3.32	9.56
6 ProPhoto RGB	DCP+ICC		1.92	5.12	3.14	9.84	2.96	7.57	2.61	6.45	2.38	5.91
7 AdobeRGB	DCP+ICC		2.04	6.21	3.71	14.44	2.74	6.64	2.7	7.83	2.18	8.23

**4 star** according to FADGI 2015

Korytkowski, P., A. Olejnik-Krugły (2016) Precise capture of colors in cultural heritage digitization, Color Research & Application, in press



# Further analysis

Original (X-Rite eXact)



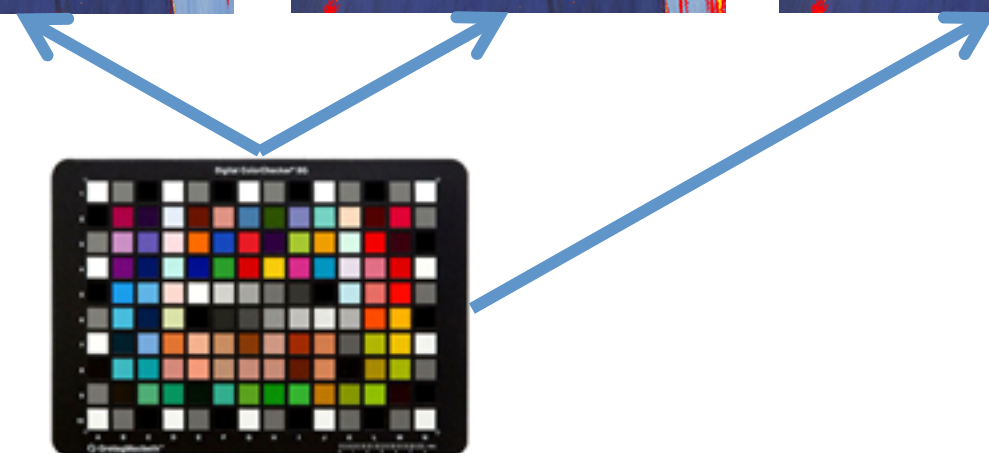
Profoto



ICC profile



ICC profile + 8 spot colors



$dE_{00} > 10$

$dE_{00} > 5$

$dE_{00} > 3$

# Further analysis

Original (X-Rite eXact)

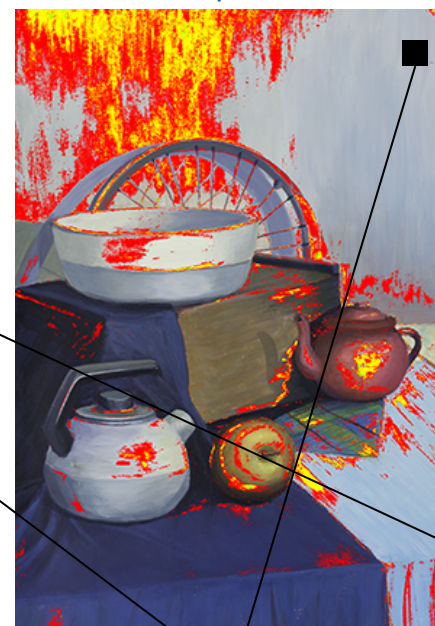


Profoto



$dE_{00} = 4,16$

ICC profile



$dE_{00} = 1,3$

ICC profile + 8 spot colors



$dE_{00} = 1,3$

- $L = 76, a = -6, b = -7$
- $L = 81, a = -4, b = -7$
- $L = 77, a = -5, b = -7$
- $L = 77, a = -5, b = -7$

$dE_{00} > 10$

$dE_{00} > 5$

$dE_{00} > 3$



- Is a new color management system.
- Flexibility in the selection of illuminant and color matching functions.
- Spectral communication of color information through an optional spectral PCS.
- Supports the use of color appearance processing in the PCS, with the facility to store appearance attributes in a v5 profile.
- Emulation of goniochromatic effects (angular dependent color impression) with use of Bidirectional Reflection Distribution Function (BRDF).
- The iccMAX specification was approved by the ICC on 29 July 2016.
- Future ISO 20677-1: Image technology colour management — Extensions to architecture, profile format, and data structure.



## Conclusions

- With current photography technology (even semi-professional lines) and an appropriate workflow it is possible to achieve FADGI 4 stars color accuracy level.
- Although it could be a challenge to stay below mean  $dE_{00}$  2, we got 1.66 – 1.93.
- Building ICC profiles with additional spot colors do not improve color accuracy (exceptions would be very saturated colors)
- Further improvements in color capture accuracy we would seek in spectral methods.
- Current color management could not address all challenges of Cultural Heritage.
- iccMAX is a promising solution.

Thank you for your attention!

Dziękuję za uwagę!