

HDR and backlit print

ICC HDR and Spectral Imaging
Experts' Day

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Sept. 21, 2026 · NTNU in Gjøvik, Norway

HDR and backlit print – Agenda part one

Fundamentals and an overview of results obtained to date for HDR backlit prints

- **Fundamentals**

Profiling and quality assurance require color measurements – Measurement accuracy can be affected by:

- limitations of the *measurement instruments*, such as lens flare (stray light), and by temporal variations in the measured object, such as flicker
- and properties of the *devices under test (DUT)*, including spatial non-uniformities in color and luminance across the display area (e.g., backlit frames and computer displays), as well as the effects of local dimming on luminance.

- **Results**

Dynamic range of single- and multilayer HDR backlit prints

Measurement devices for HDR-luminance- and color measurement and production

Radiometric measurements:



„Measure, what we see“

! optical system (straylight)

! flickering object light

Laboratory:



Luminance meter
luminance L_v
single measurement (1 spot)



Spectro radiometer
Luminance L_v , light spectrum
single measurement (1 spot)



Light measurement camera
luminance L_v , XYZ color value
spacial measurements



Spectral light- and flicker Spectrometer
here: illuminance, flicker
single measurement (1 spot)

Production:



print calibration
reflection and transmission
single measurement (1 spot)



print calibration
reflection and transmission
single measurement (1 spot)



Display calibration
single measurement (1 spot)

Contact measurements:

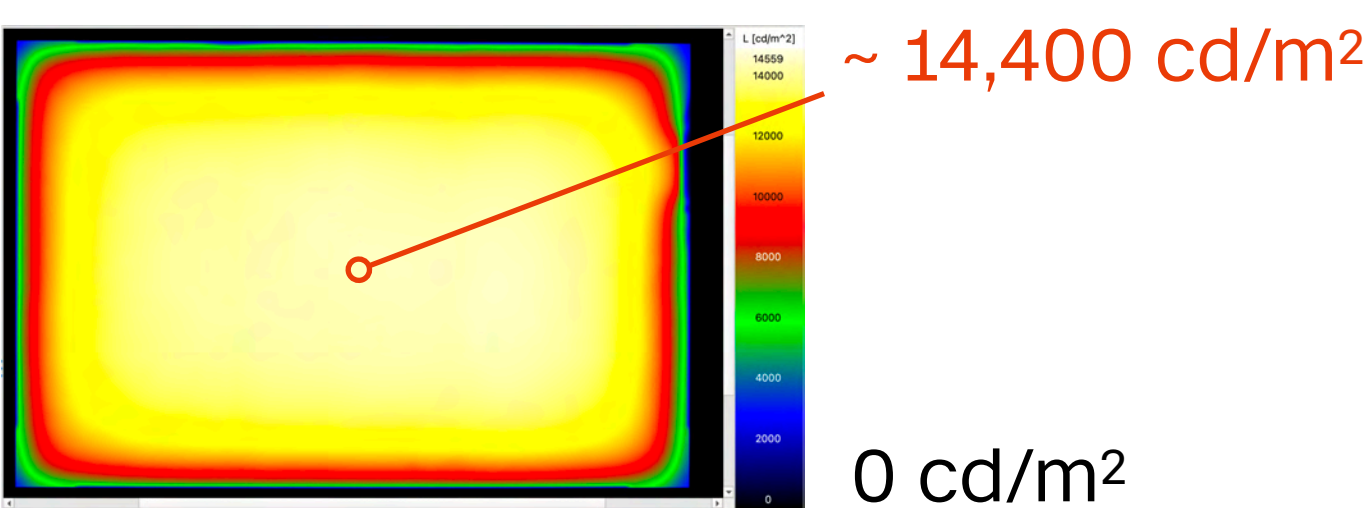
! limited dynamic range

! limited maximum brightness

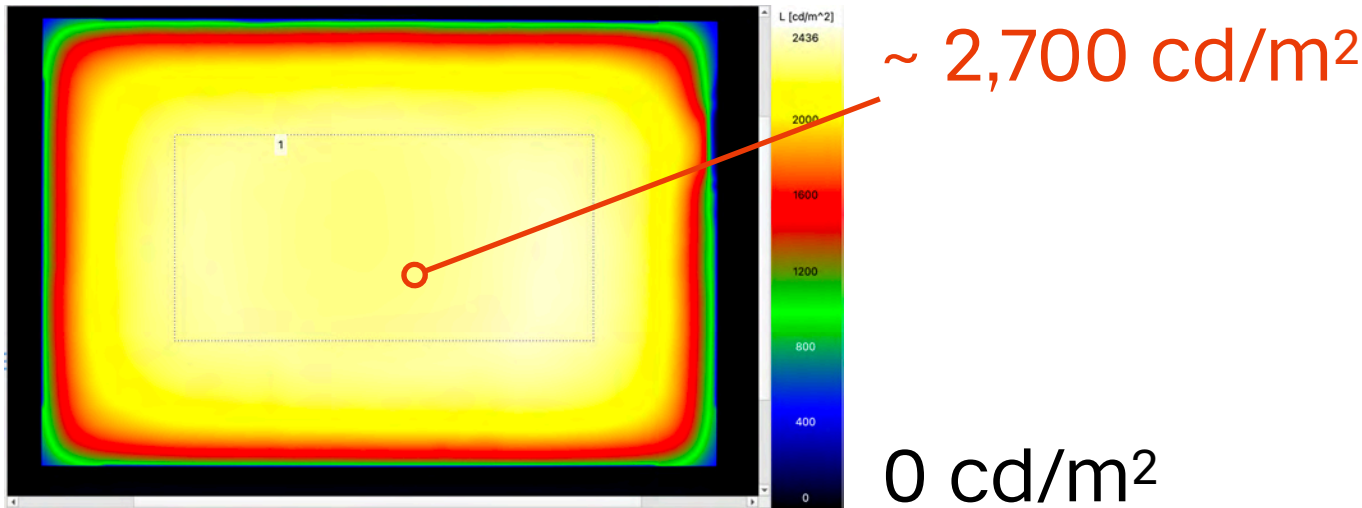
! flickering object light

Dimming (display, backlight frame) - *flicker*

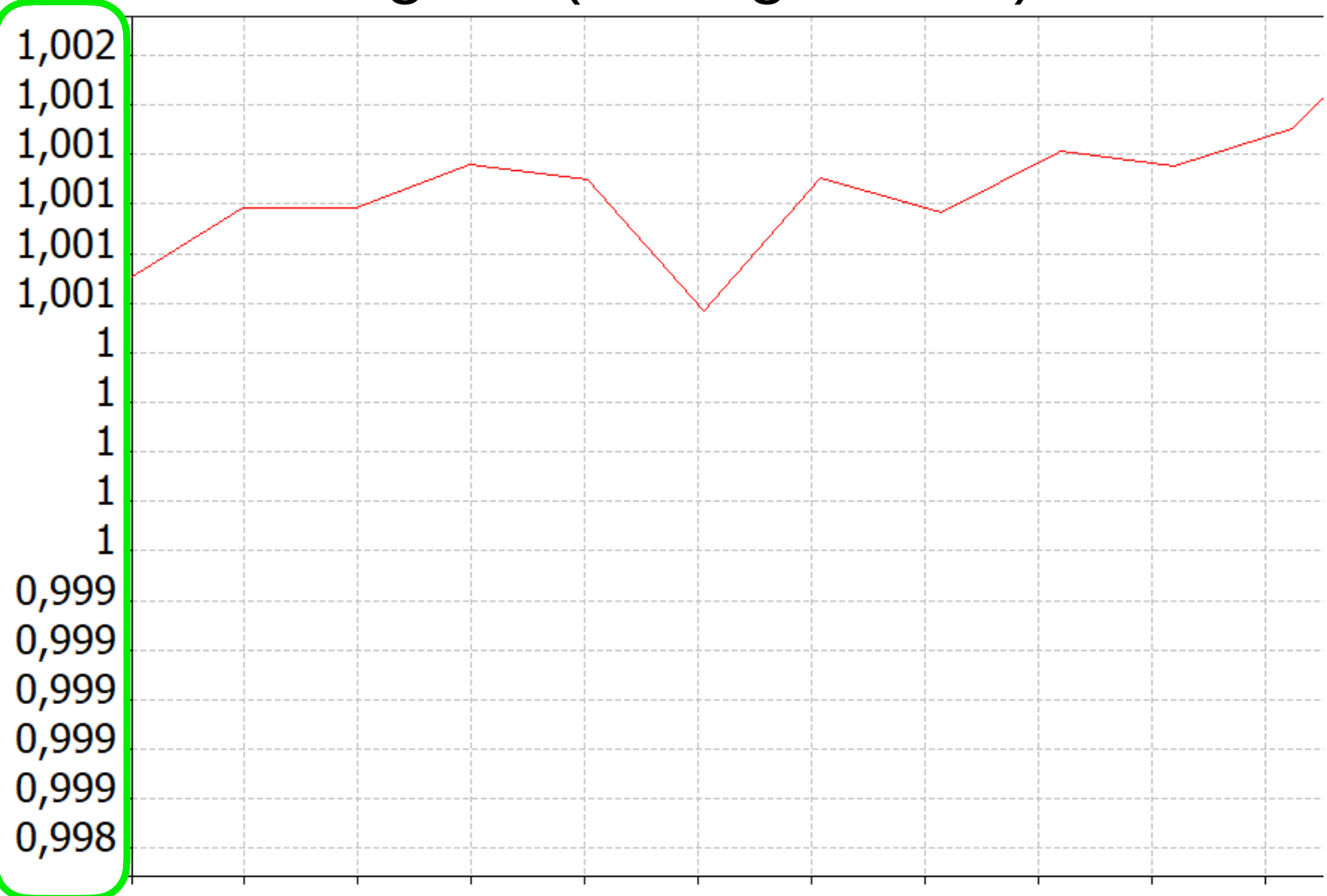
Backlight frame at *full* brightness
no flicker



Backlight frame at *dimmed* brightness
flickering light!



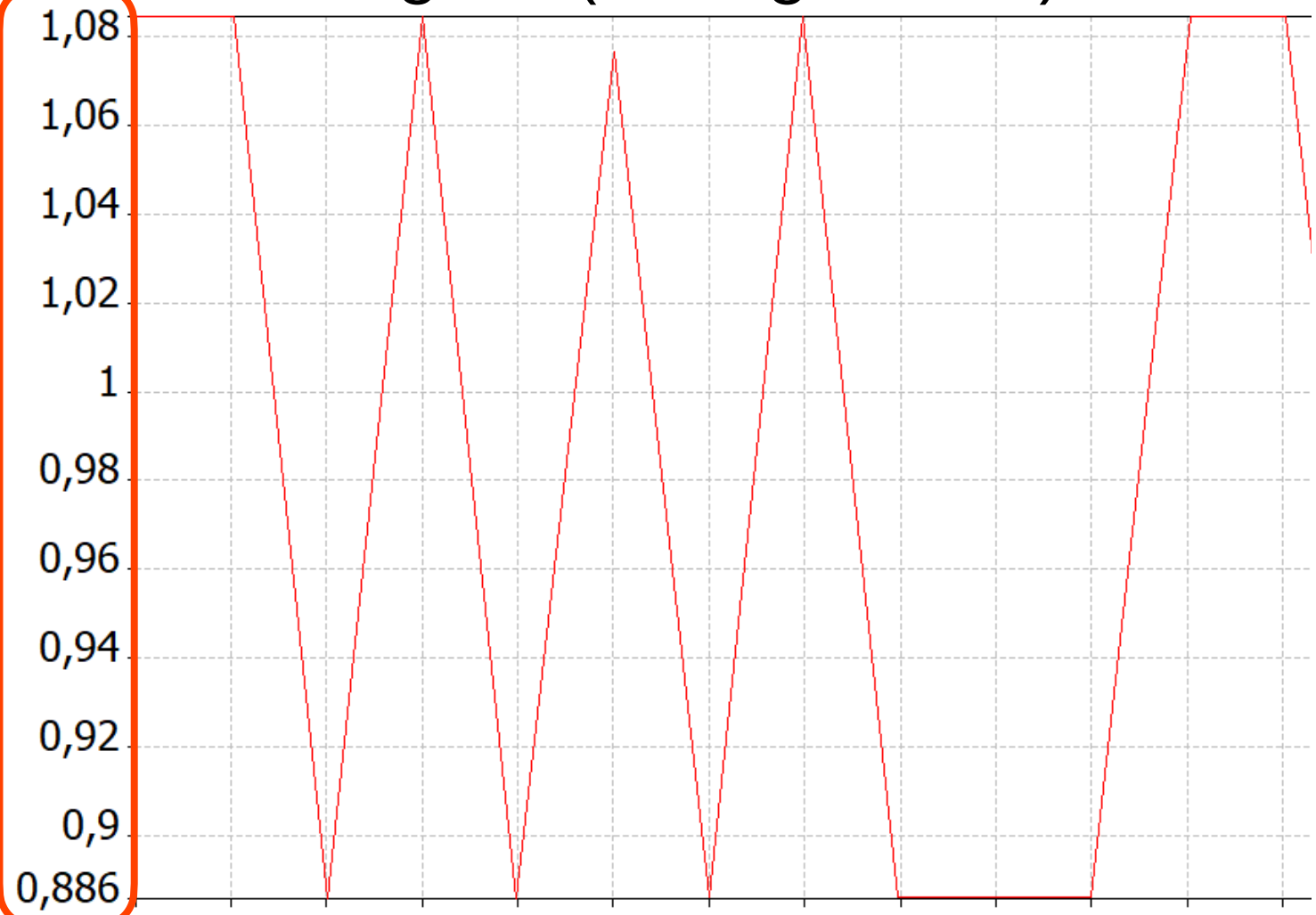
Time diagram (average Lv = 1)



not flickering light frame:
→ reliable measurement values

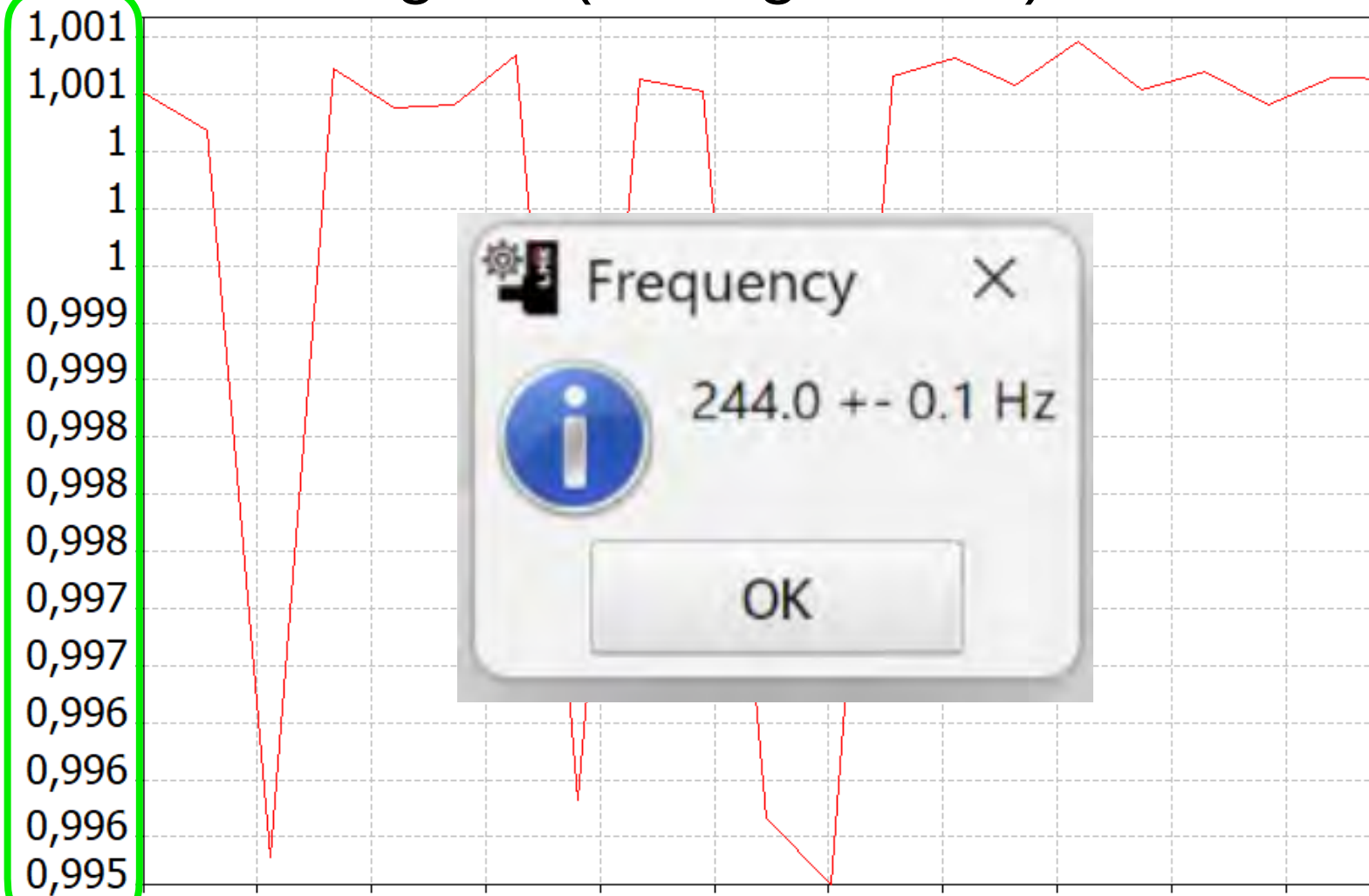
TechnoTeam LMK6-30, LabSoft
GL Optic Spectis 1.0 touch flicker

Time diagram (average Lv = 1)



flickering light frame:
flicker *not* considered
→ *no* reliable measurement values!

Time diagram (average Lv = 1)

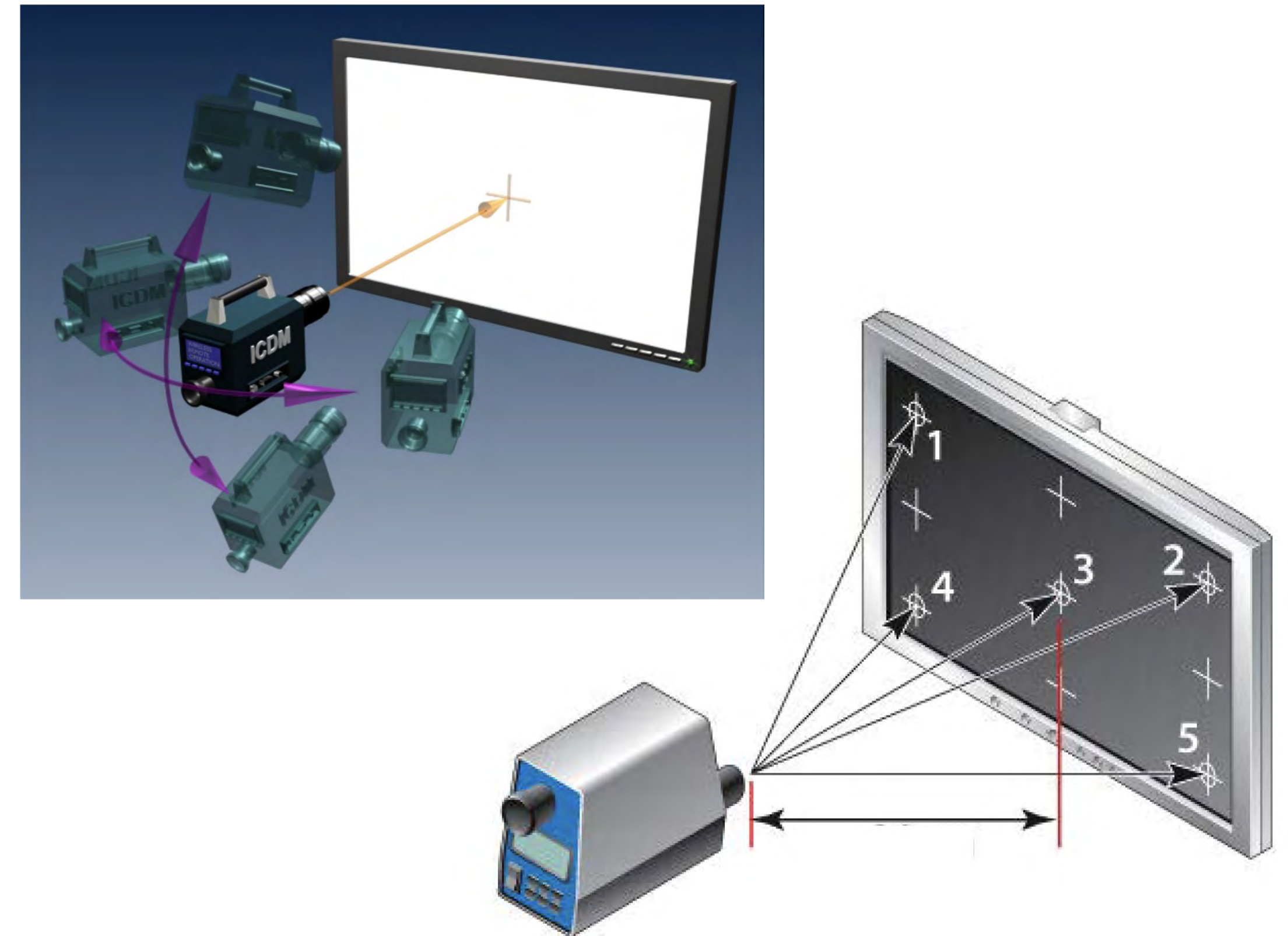


flickering light frame:
flicker considered (here 244 Hz)
→ reliable measurements

Display issue – *viewing angle dependency* of the brightness and color appearance

Brightness and color depending on the viewing angle:

- Brightest and most color-accurate result when viewed perpendicularly (as during calibration)
 - *Darker appearance* when the *vertical* viewing angle (*elevation*) deviates from the surface normal
 - *Color shift* when the *horizontal* viewing angle (*azimuth*) deviates from the surface normal
- “*Measure as you see*”: use the viewer’s viewing angle for the measurement.



Source: ICDM

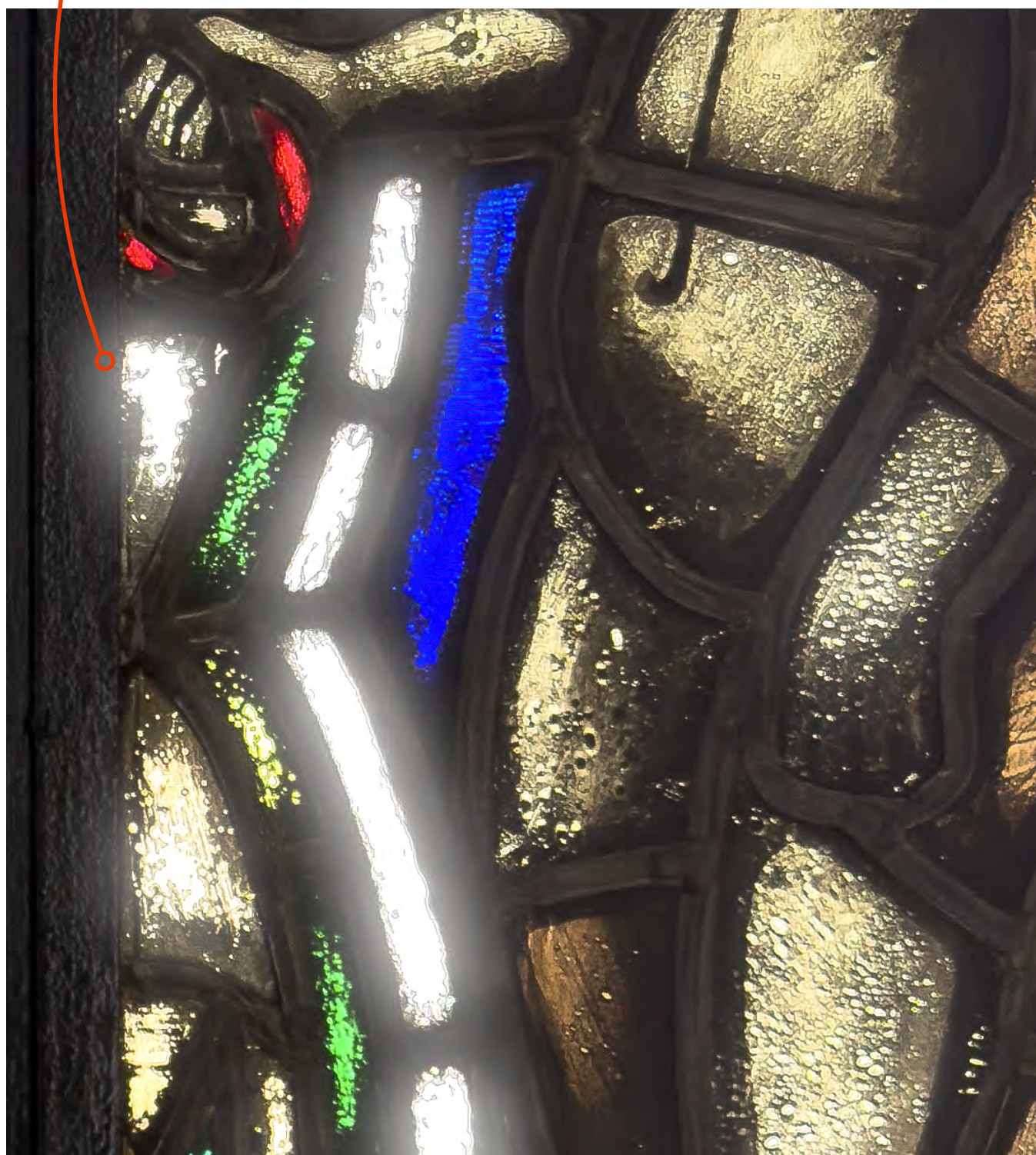
Mini-LED Display – Local dimming causes blooming: *Blooming halo effect* around (small) bright areas

Mini-LED Display

high Mini-LED backlight level ...

→ Measured *luminance* L_v of the white light strips *matches* L_v specified by the PQ curve.

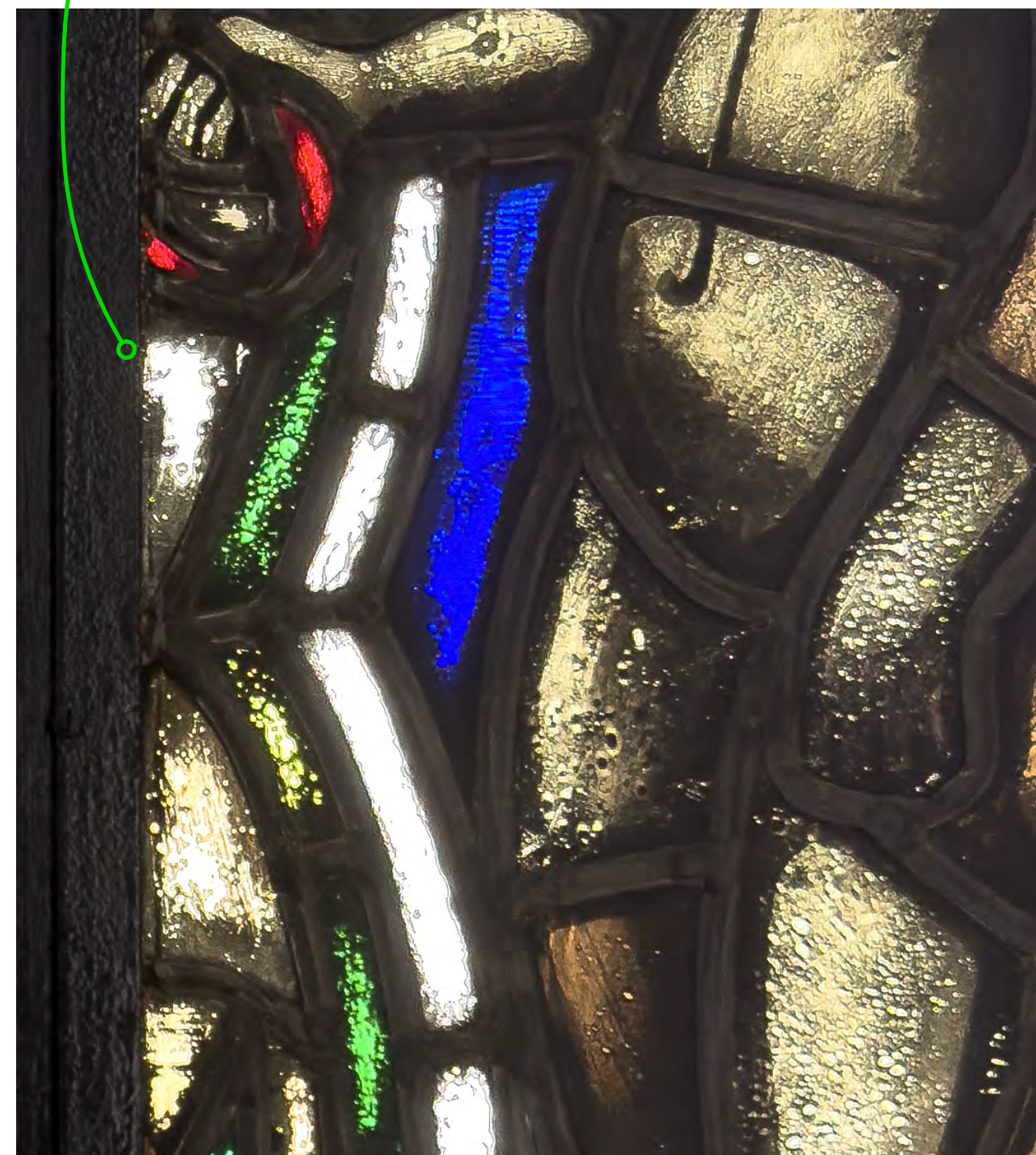
→ *Distracting* blooming halo effect



HDR-Bilddatei, OLED-Display:

Bright image areas, smaller than the dimming-zone size of the Mini-LED display:

→ No distracting blooming halo effect on the dark surroundings

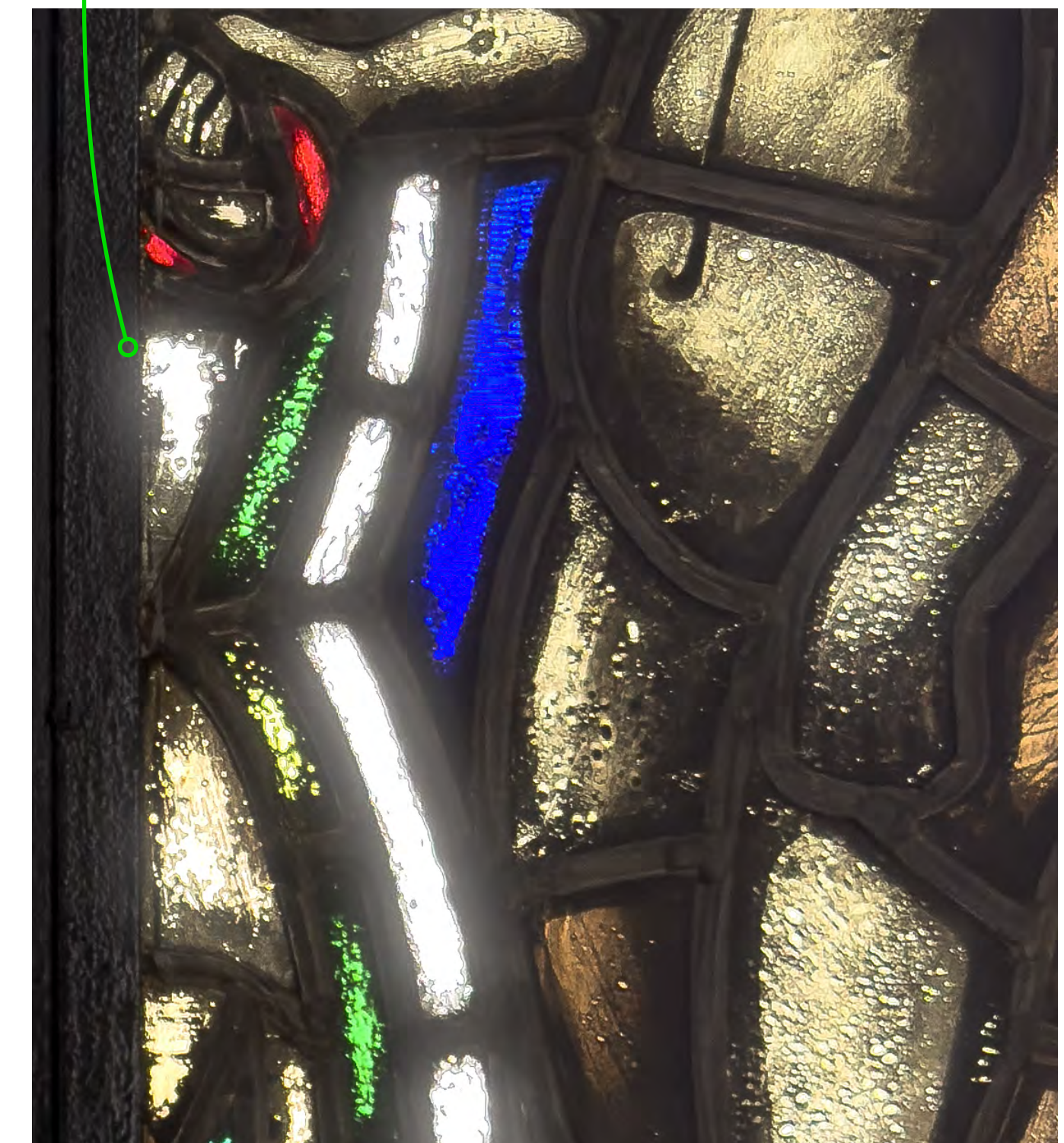


Mini-LED Display

Dimmed Mini-LED backlight

→ Measured *luminance* of the white light strips is *lower* than the L_v specified by the PQ curve

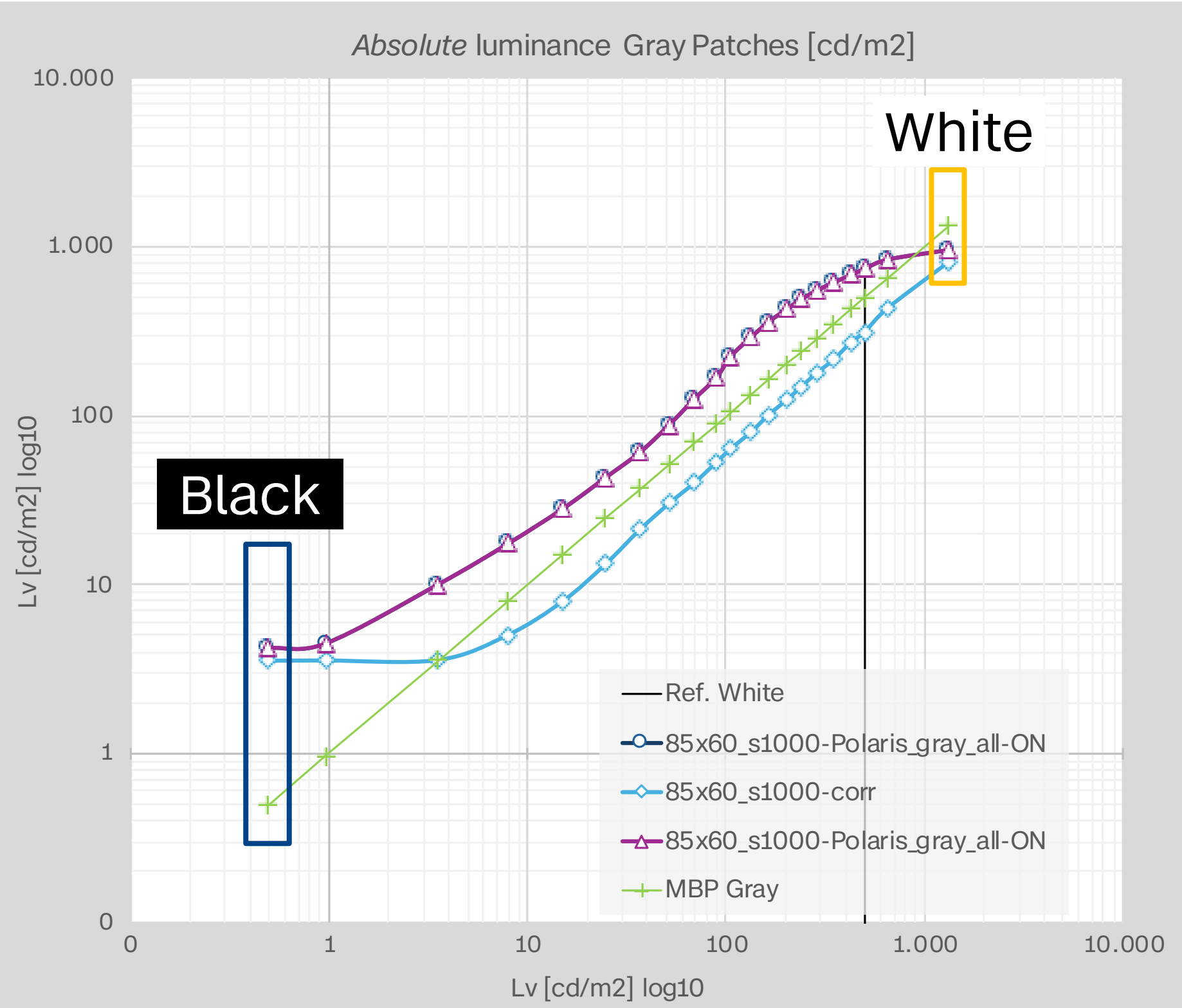
→ *Reduced* blooming halo effect



HDR and backlit print - results



Single layer backlit print vs. HDR display (ref.): lower contrast, different transfer function



Patch	HDR 32float ¹	RGB 8bit	MBP Gray	85x60 s1000-Polaris gray all-ON	85x60 s1000-corr	85x60 s1000-Polaris c
Black	0	0	0,49	4,22	3,55	4,22
	0,004	13	0,96	4,49	3,56	4,49
	0,010	26	3,54	10,03	3,58	10,03
	0,019	38	7,99	17,53	5,05	17,53
	0,033	51	15,12	28,26	8,02	28,26
	0,051	64	24,83	43,2	13,32	43,2
	0,074	77	36,92	60,93	21,26	60,93
	0,100	89	51,72	88,39	30,29	88,39
	0,133	102	69,52	126,29	40,26	126,29
	0,171	115	89,38	168,18	52,99	168,18
	0,216	128	105,72	224,83	63,83	224,83
	0,262	140	133,45	291,09	79,98	291,09
	0,319	153	163,63	358,64	101	358,64
	0,381	166	201,19	425,28	123,6	425,28
	0,453	179	239,86	489,52		489,52
	0,534	191	284,68	548,38		548,38
	0,647	204	347,42	612,86		612,86
	0,798	217	425,18	680,74		680,74
Ref. White	1,012	230	499,84	741,32		741,32
	1,361	242	650,3	839,77		839,77
Peak White	2,642	255	1325,83	957,6	814,5	957,6
Dynamic range:			2706 : 1	227 : 1	229 : 1	227 : 1
D vis:			3,4	2,4	2,4	2,4
Illuminance:			186,95 lx («VS all on»)	186,95 lx («VS all on»)	186,95 lx («VS all on»)	186,95 lx («VS all on»)

¹ HDR 32float : Linear Rec. 2020

HDR patches (headroom)

Backlit print (sample):
dynamic range: **227 : 1**
density range (Dvis): **2.4**

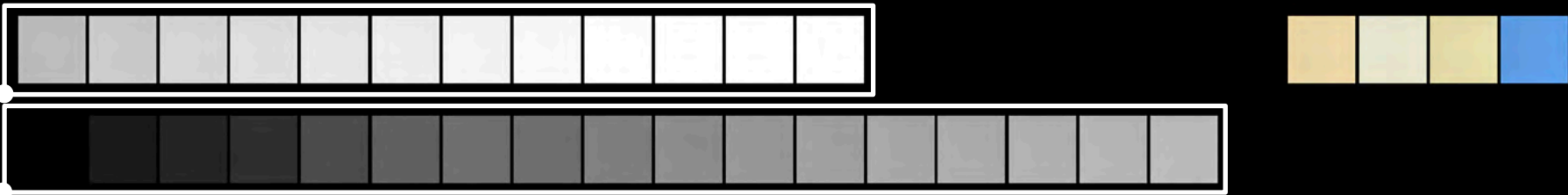
HDR display (reference):
dynamic range: **2.700 : 1**
density range (Dvis): **3.4**

Multi layer print

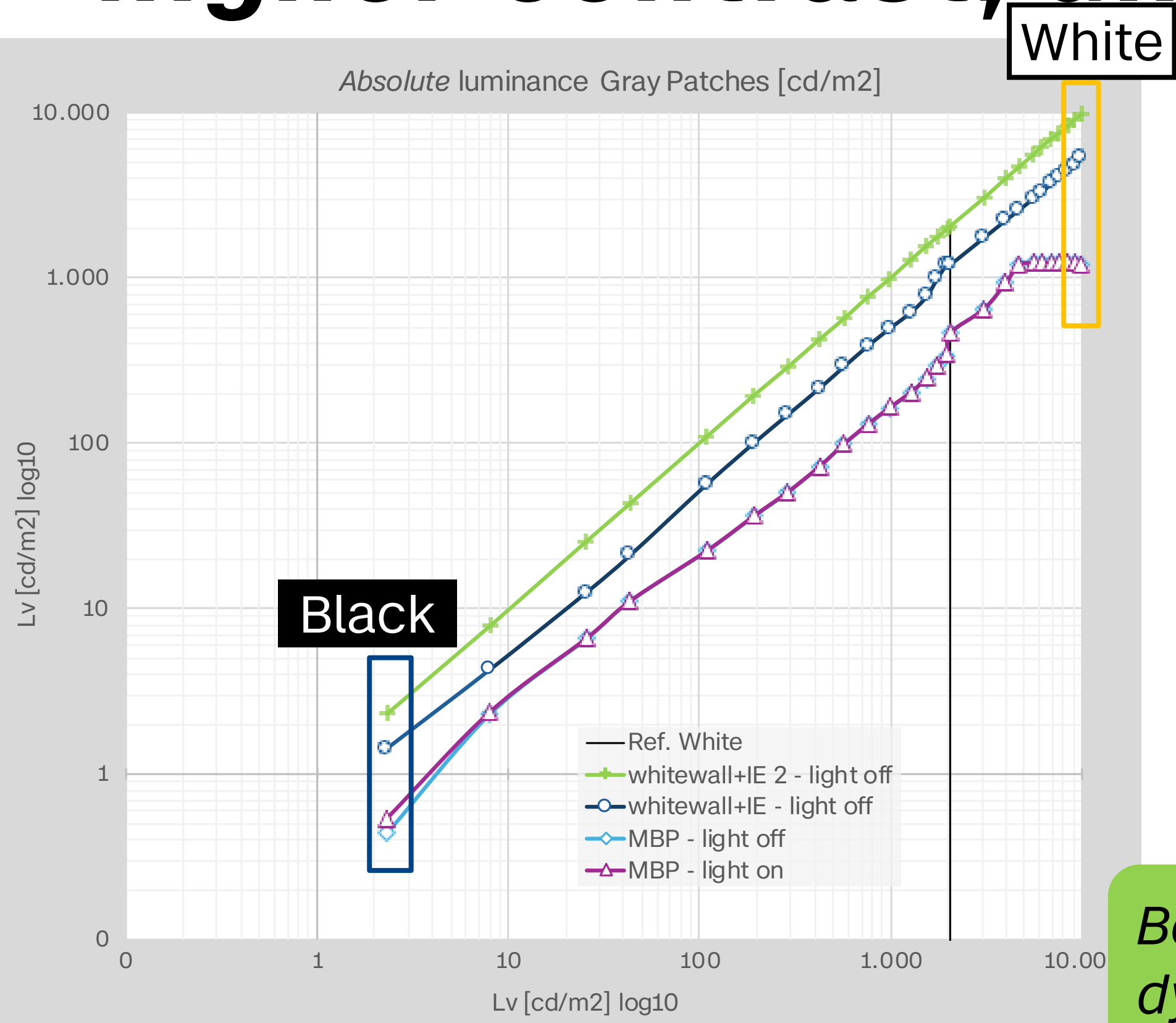


- Gray patches *HDR* headroom:
- 5.6 f-stops in .5 steps (full PQ range)
 - equals Lv Ref. White 203 nits x 48.9

Gray patches *SDR*



Multi layer backlit print (ref.) vs. HDR display: higher contrast, different gradation



Patch	HDR 32float ¹	whitewall+IE 2 - light off	whitewall+IE - light off	MBP - light off	MBP - light on	whitewall+IE 2 - light on
Black	0,000	2,32	1,43	0,44	0,54	2,65
	0,007	8,03	4,30	2,31	2,38	8,36
	0,017	25,60	12,55	6,57	6,63	26,06
	0,026	43,31	21,06	11,11	11,15	43,70
	0,050	109,02	56,59	22,30	22,44	109,64
	0,079	192,60	100,58	36,19	36,46	193,38
	0,110	289,25	148,98	50,55	50,85	290,25
	0,155	423,49	215,09	72,41	72,52	424,98
	0,212	572,75	292,74	99,71	99,90	574,85
	0,279	763,61	390,40	130,37	131,33	766,45
	0,355	986,28	494,36	163,09	164,76	989,64
	0,454	1.276,10	620,16	202,82	204,35	1.281,10
	0,558	1.539,50	772,85	246,90	248,09	1.545,70
	0,679	1.764,70	1.004,10	295,06	297,21	1.772,60
	0,826	1.966,70	1.207,00	341,10	343,10	1.966,70
Ref. White	0,998	2.049,40	1.206,40	465,10	467,10	2.049,40
	1,408	3.064,60	1.745,30	647,10	649,10	3.064,60
	1,998	4.005,90	2.237,80	939,10	941,10	4.005,90
	2,820	4.691,00	2.574,80	1.213,10	1.215,10	4.691,00
	3,004	5.578,90	3.019,10	1.228,10	1.230,10	5.578,90
			3.269,60	1.235,10	1.237,10	
			3.718,20	1.235,10	1.237,10	
			4.053,90	1.245,70	1.247,70	
			4.436,20	1.241,10	1.243,10	
			4.824,50	1.223,90	1.225,90	
			5.308,60	1.204,70	1.206,70	
				1.245,40	1.247,40	
				7.624,30	7.646,30	
Peak White	48,900	10.383,00	5.585,20	1.142,40	1.144,40	10.383,00
Dynamic range/ contrast:		4470 : 1	3901 : 1	2827 : 1	2827 : 1	4470 : 1
D vis:		3,7	3,6	3,4	3,4	3,7
Illuminance:		21,39 lx («lights off»)	249,86 lx («lights on»)	7,72 lx («lights off»)	127,43 lx («lights on»)	34,55 lx («lights off»)

Local dimming:
Rising signal levels
(color values) but
decreasing luminance

Backlit print (reference):
dynamic range: **4.470 : 1**
density range (D_{vis}): **3.7**

HDR display (sample):
dynamic range: **2.827 : 1**
density range (D_{vis}): **3.4**

¹ HDR 32float : Linear P3

HDR backlit print – Work in progress – Status Quo *multi* layer print ...

✅ *White point*

✅ *Black point*

⚠ *tone mapping, gradation, tonal reproduction*

⚠ *local contrast / gradation* deviates from HDR display

⚠ *test patch layout*: improve test patch layout for measurements
considering local dimming, straylight, viewing angle

→ Goal:

- improve tone mapping without reinventing the wheel ...
- adapt display tone-mapping methods (*Gain map, Adaptive gain curve, ICC cicpTag*)

BHT

Berliner Hochschule
für Technik

Studiere Zukunft

More about HDR print by Dorin ...



CHASING DYNAMIC RANGE: A JOURNEY TOWARD HDR- LIKE BACKLIT PRINTING

Mission:
Using Multiple Layers Sandwich Printing



ICC HDR and
Spectral Imaging
Experts' Day



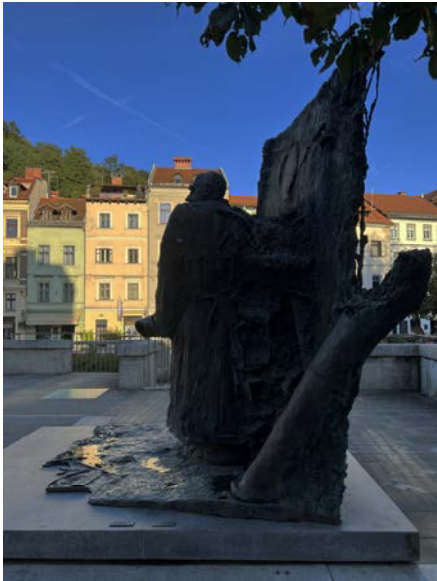
Highlights

For later reading, **with key facts**

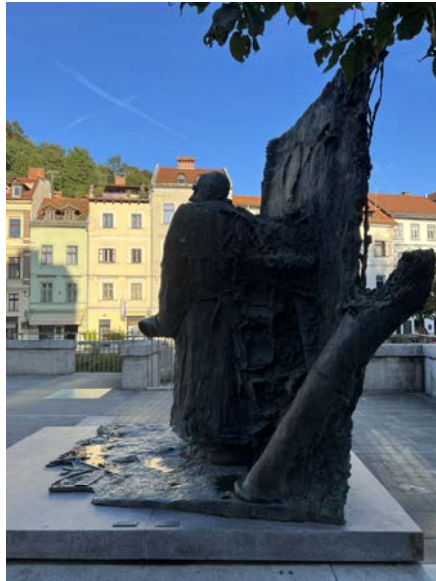
ONE PRINT, TWO VIEWING CONDITIONS

Earlier challenge: one separation, different appearance

BACKLIGHT OFF



BACKLIGHT ON



Illustrative images reused from the earlier talk

A fixed reflective reproduction

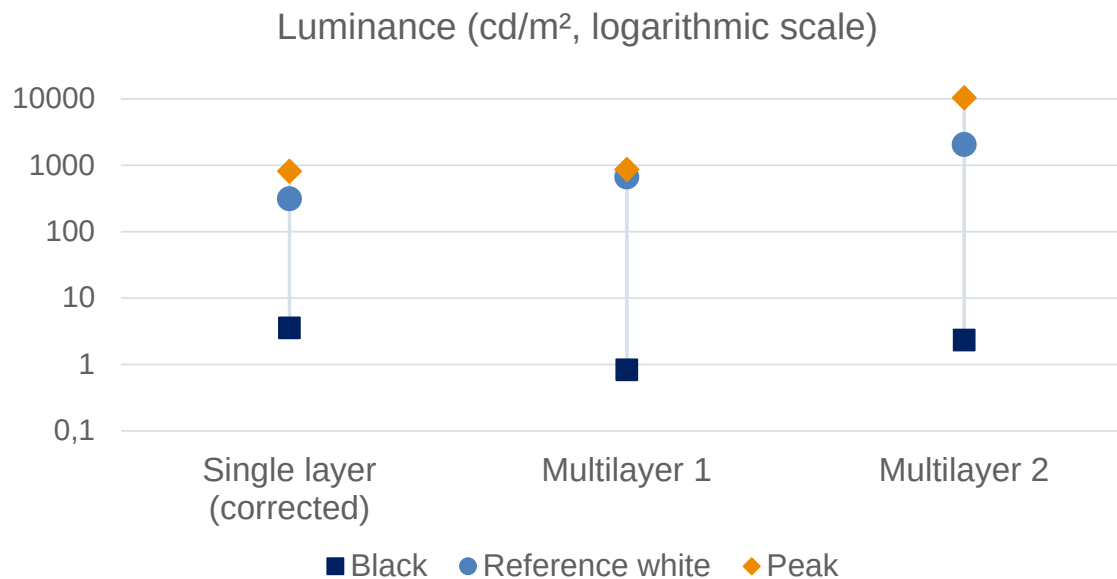
Calculate the additional side against a transmitted target.

Today: a deliberate HDR-like target

Choose reference white and reserve room for highlights.

CONTRAST AND HEADROOM IN BACKLIT PRINT

Florian's measurements of completed reproductions



Reproduction	Contrast	Headroom
Single layer ¹	229:1	1.38 stops
Multilayer 1	1,040:1	0.37 stop
Multilayer 2	4,470:1	2.34 stops

Dynamic range / contrast = peak ÷ black

Reference white: the designated white of the base SDR image.

Headroom = $\log_2(\text{peak} \div \text{reference white})$

Multilayer examples offer a wider range; tonal reproduction still needs control.

² ¹ Tone correction: contrast 227 → 229:1; headroom 0.37 → 1.38 stops.

Different samples and viewing conditions. Florian Süß: CMS 2026, pp. 15, 17; Gjøvik 2026, pp. 8, 10.

FROM DAY/NIGHT MATCHING TO SDR/HDR PRINT

Keep the reflective image



Calculate the extra layers



Meet the transmitted aim



Then: match an expected day/night appearance.

3 Now: retain SDR reflection and choose HDR reference white and highlights.

Concept from Colour Management for Backlit Applications, pp. 11–16. Illustration, not a measured appearance comparison.

THE CONTROLLABLE LAYER MODEL

Linked five-layer construction used in this study



B: CMYK for reflective SDR

Also contributes to the transmitted HDR response

L: linked W1 / K / W2

Imagewise coverage, driven by the supplied WHITE channel

A: additional CMYK

Correction for the backlit target

Textile substrate

Supports the ink; transmits, scatters and absorbs light

4 The lightbox supplies the light. The substrate and ink shape its output.

Screening and lighter A are illustrative, not calculated RIP separations. Grey carriers reveal white dots; they are not extra layers.

P0–P7: COMPONENT INTERACTIONS IN TRANSMISSION

Can we predict the full stack from its components?

Evaluate the transmitted-light response of every configuration, including B.

Condition	A	L	B
P0	—	—	—
P1	●	●	●
P2	●	●	—
P3	●	—	—
P4	—	—	●
P5	—	●	—
P6	●	—	●
P7	—	●	●

A: additional CMYK · L: linked W/K/W

5 B: reflective SDR image

- present in patch field. P0 is reference-derived. This initial set uses linked A/B/WHITE recipes.

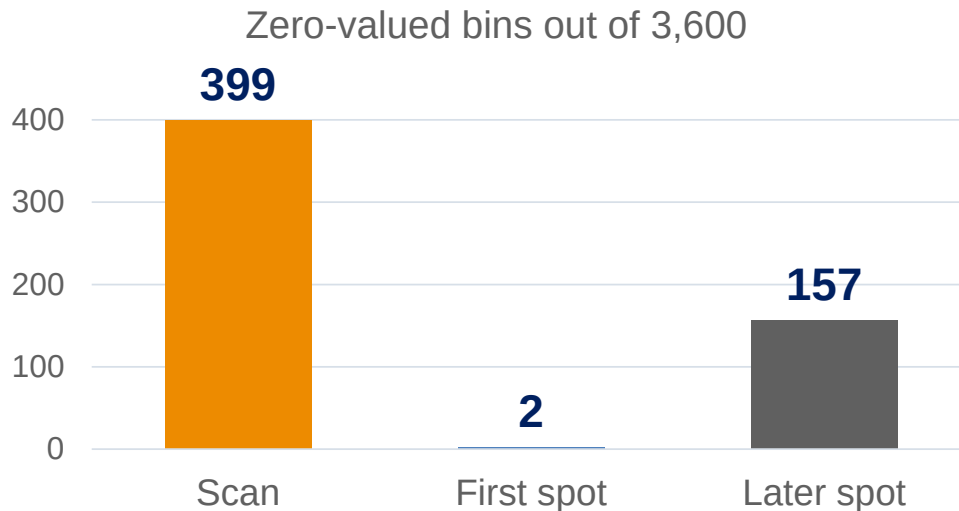
P1: the complete printing condition



Combine isolated spectral responses;
compare the prediction with P1.
Use pair charts to examine interactions.

MEASUREMENT LIMITS AND USABLE DATA

Low signal and acquisition geometry both matter



Emission example: same P1 chart, separate sessions.
These counts do not isolate the cause.

Both measurement routes

Zeros and tiny positive spectral bins can reflect unresolved low signal. A calculated density does not establish measurement accuracy.

Control the acquisition

Keep contact, position and references consistent. Check dark patches with repeat and spot/scan comparisons.

6 Applied: fixed-spot emission and automated transmission

Keep raw spectra. Flag uncertain bins. Limit model claims to tested conditions.

FROM COMPONENT TESTS TO INDEPENDENT CONTROLS

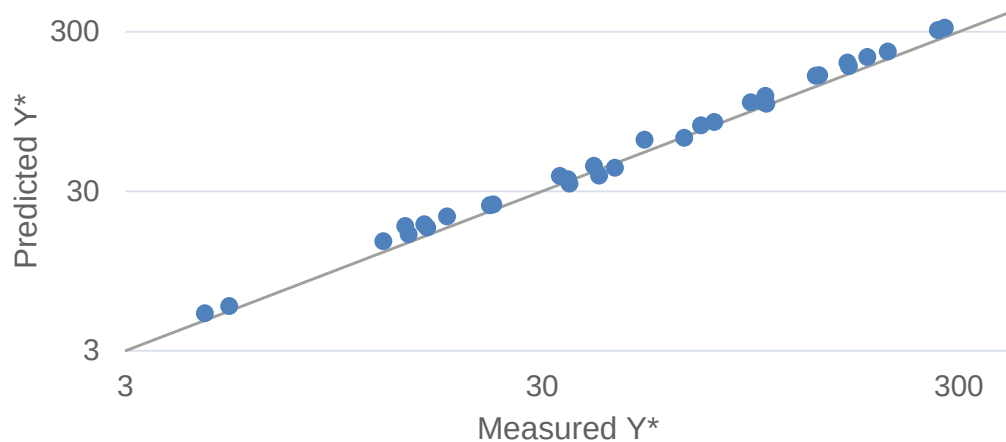
QB140: 140 patches

A proportional to B + WHITE ramps
3 fixed side-B recipes

AX280: 280 patches

Independent A-CMYK + WHITE
8 fixed side-B recipes

32 AX280 recipes reserved before fitting



11.6%

median absolute luminance error

18.3% at the 90th percentile

Median colour error: $\Delta u'v' = 0.00233$

Transmission-derived model:
10.9% median luminance error

7 Local prediction only: deep blacks and arbitrary side-B colours remain unvalidated.

Plot: emissive branch, logarithmic axes. Y* is the project photopic scale. Transmission uses a source-weighted proxy.

CURRENT CAPABILITY AND THE FIRST REPRODUCTION TEST

From an HDR target to testable print separations

SDR base for side B



Gain map + metadata



Implemented: bounded inverse

**Given B and target XYZ,
solve A-CMYK and WHITE
within the sampled controls.**

Next: controlled image test

Define light-on white and headroom.
Extend or restrict side-B coverage.
Print and assess both viewing states.

The same image, with its actual extracted gain map

8 Wider side-B coverage and physical reproduction validation are still needed.

Images show inputs, not a validated reproduction. Reflective characterization informs the side-B SDR conversion.

THANK YOU FOR YOUR ATTENTION

Q & A

