joshua pines

chief trouble maker and luddite
technicolor digital intermediates

“…from scene to screen…”

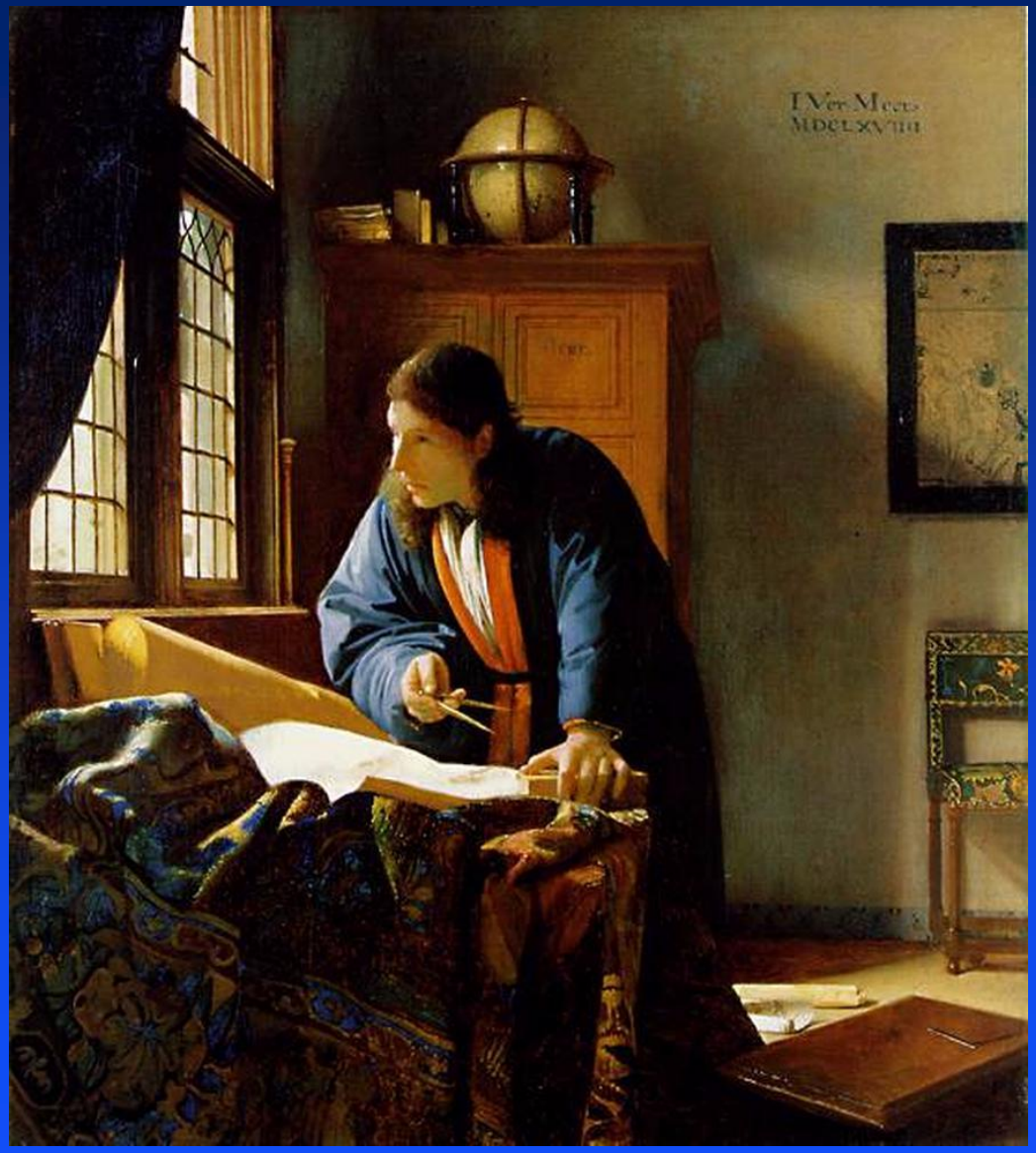
color enhancement and rendering in film and game production

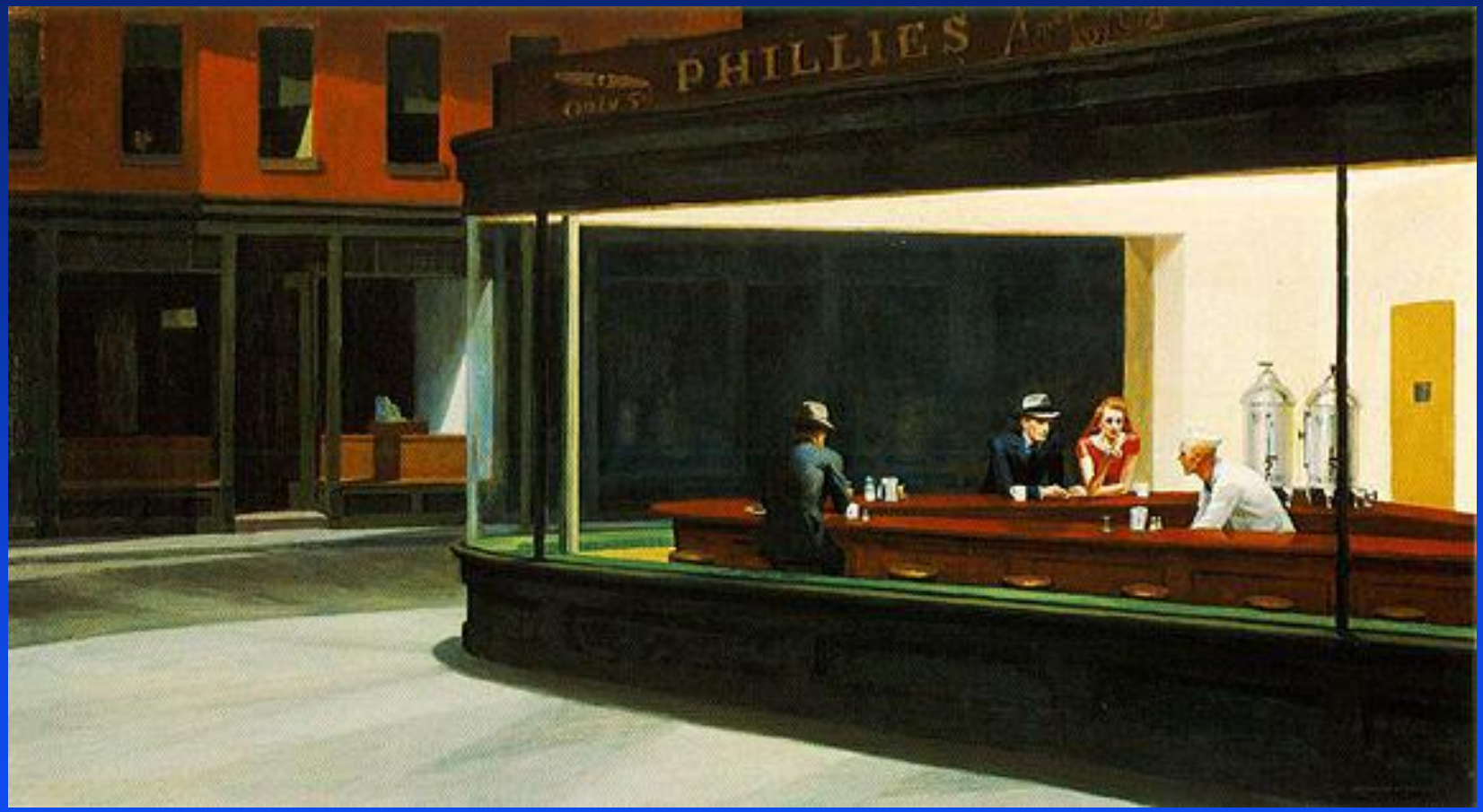
siggraph july27, 2010 los angeles, california


SIGGRAPH2010
You are Here

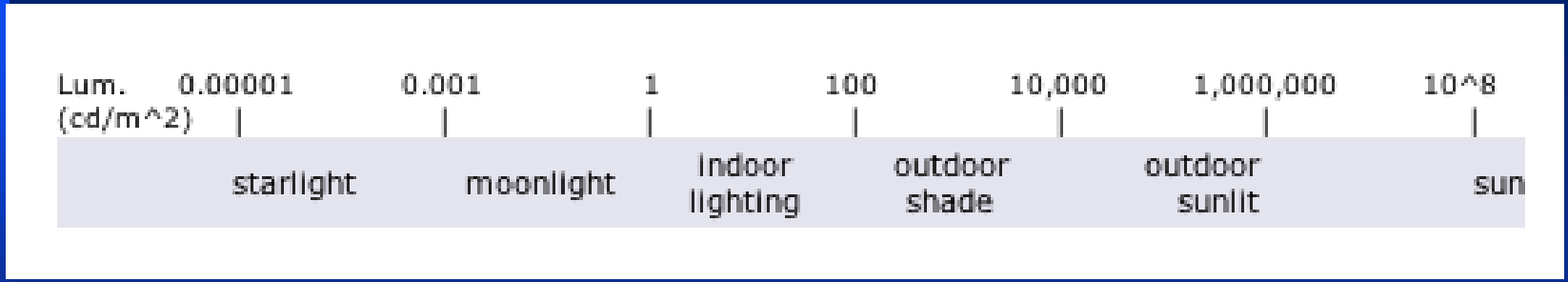
IRE	0	10	20	30	40	50	60	70	80	90	100
10 Bit CV	0	64	151	239	326	414	502	489	677	764	852	940	1023

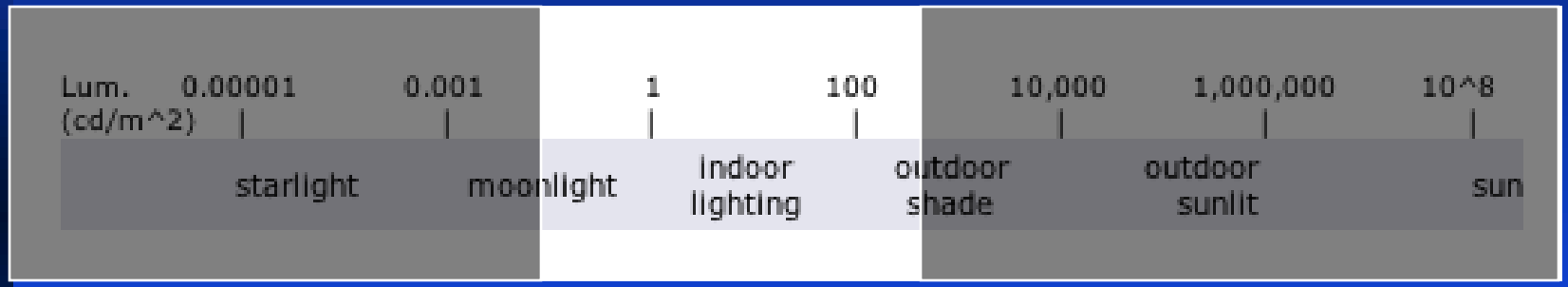
Cave painting, Lascaux, France, 15,000 to 10,000 B.C.


I Ver Meer
MDCLXVIII

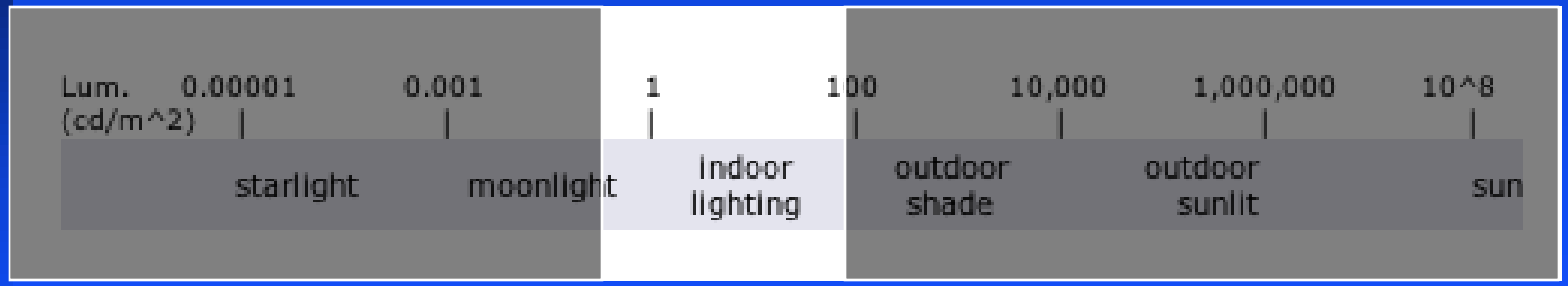

PHILLIES

real world dynamic range



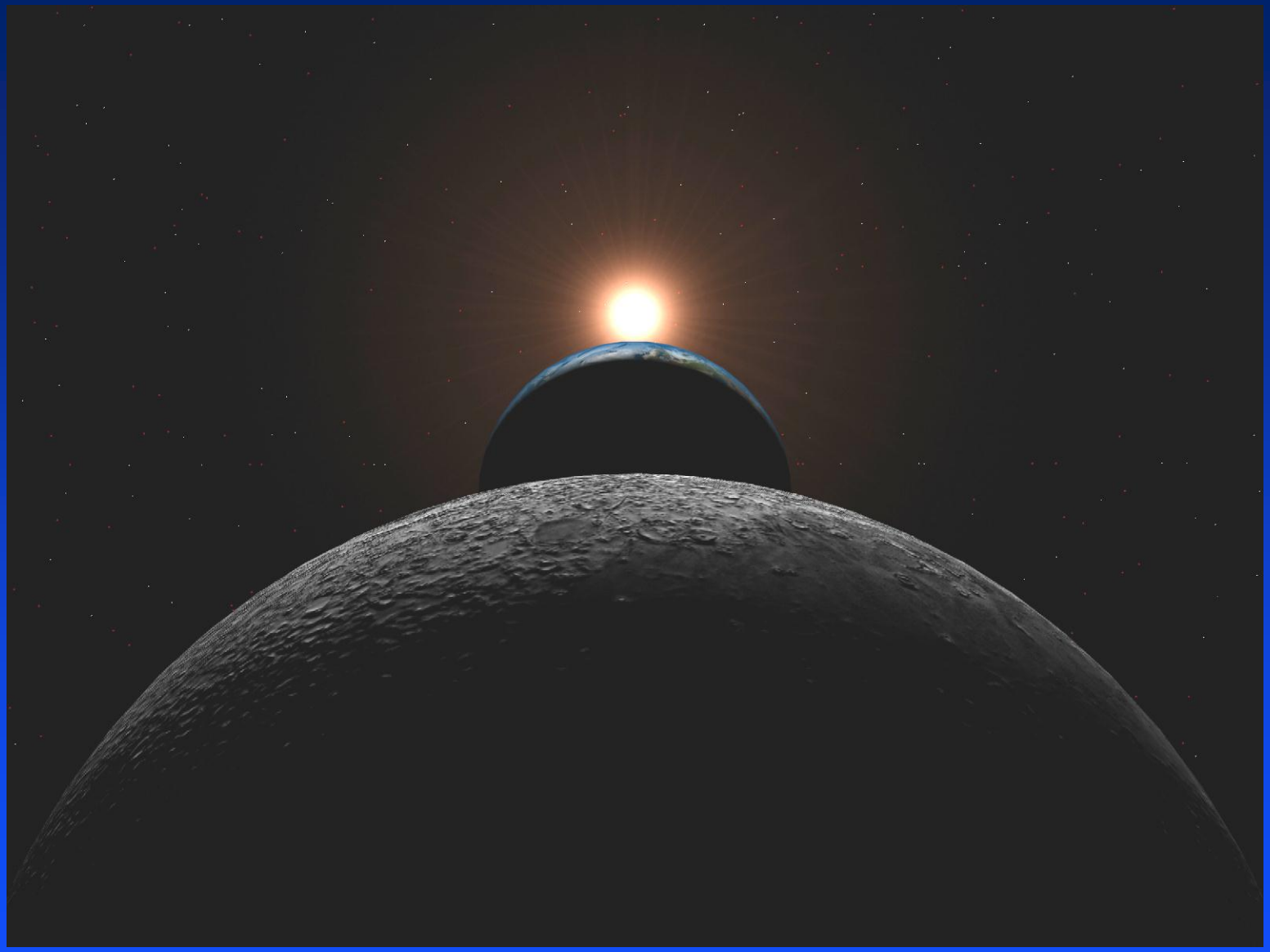


camera acquisition dynamic range

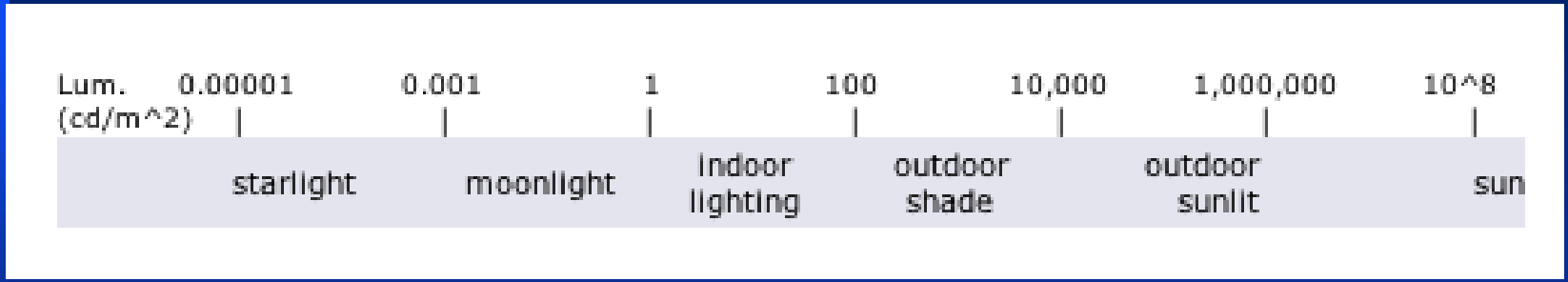


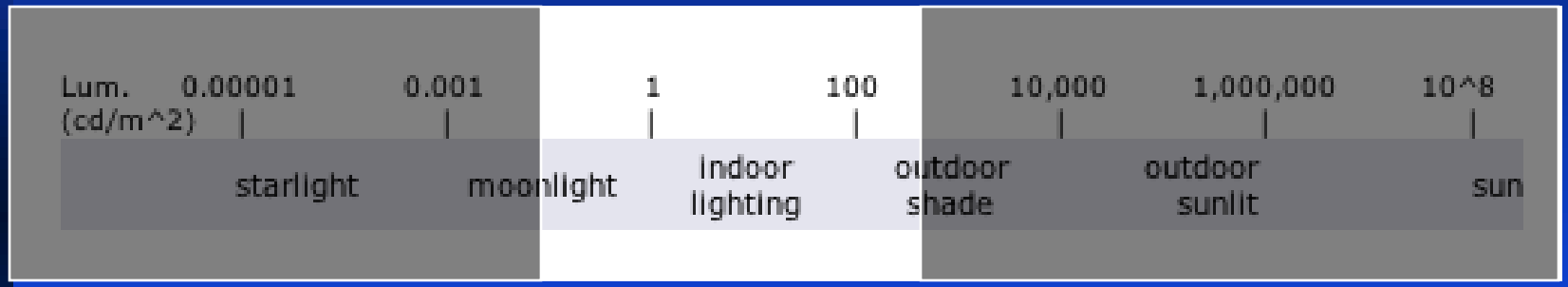
display dynamic range


2001: A SPACE ODYSSEY

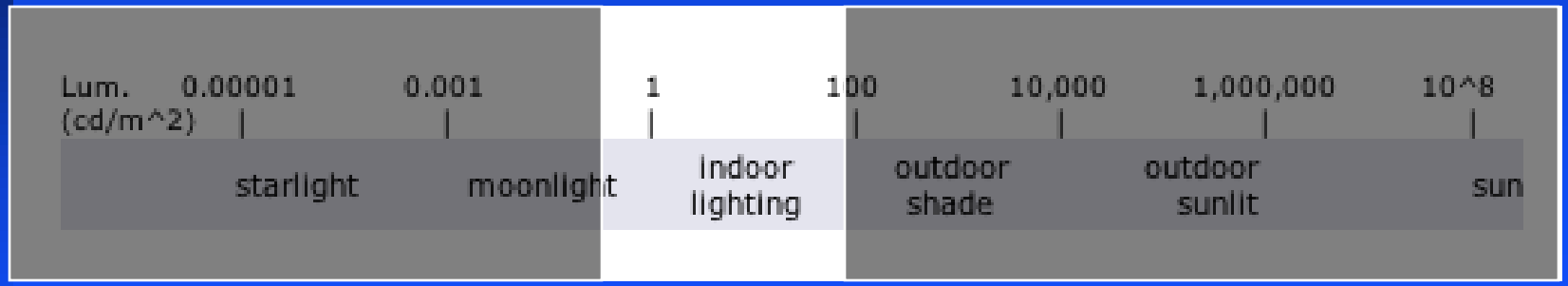


real world dynamic range



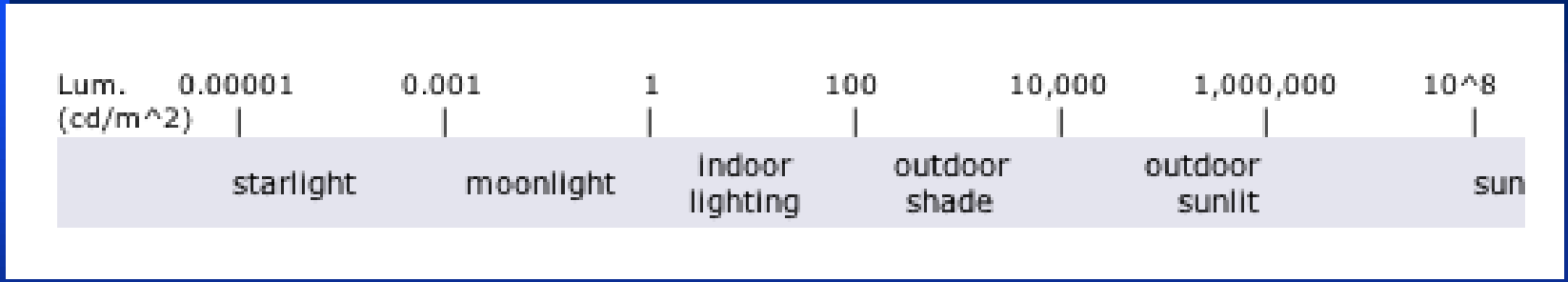


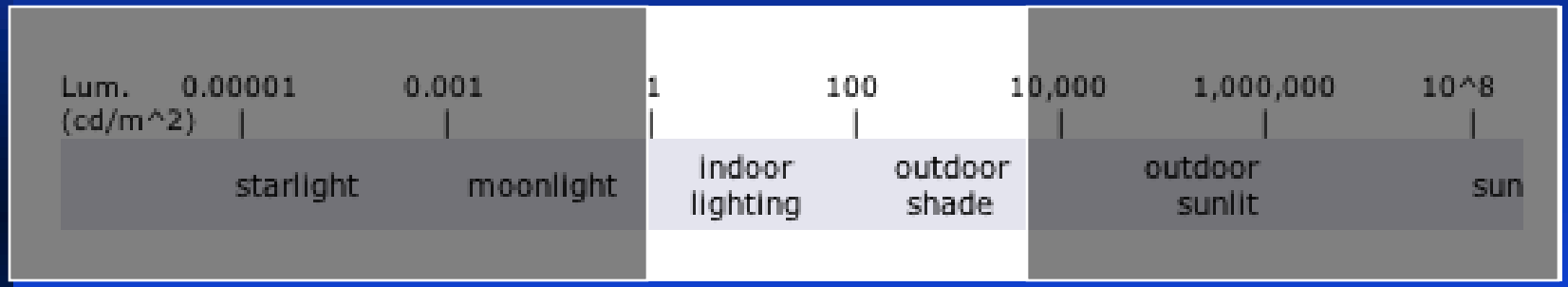
camera acquisition dynamic range



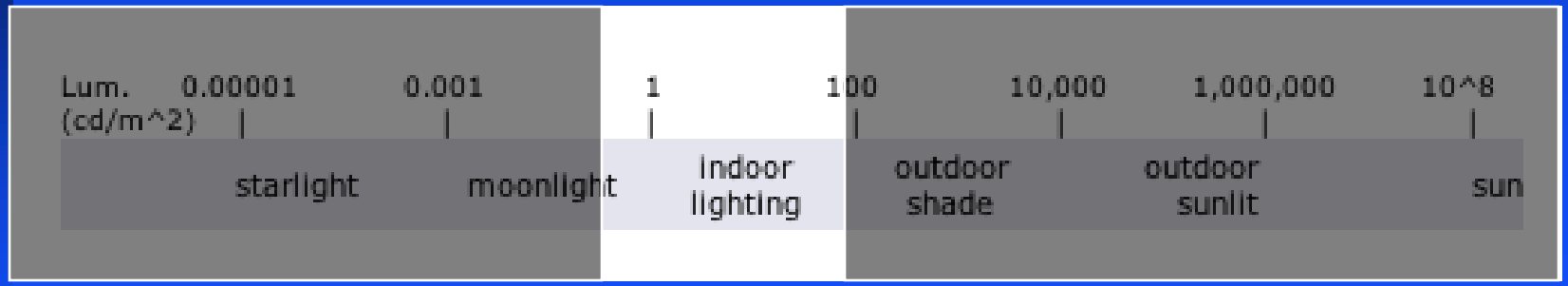
display dynamic range

real world dynamic range



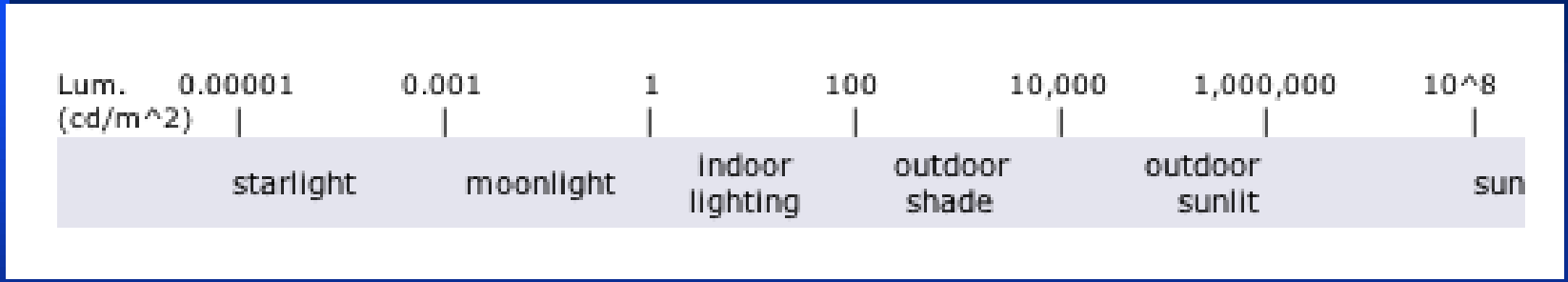


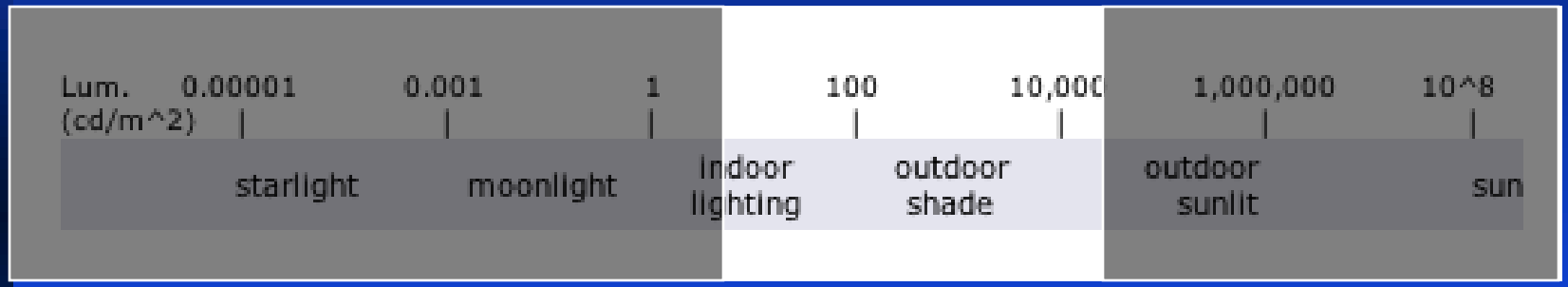
camera acquisition dynamic range



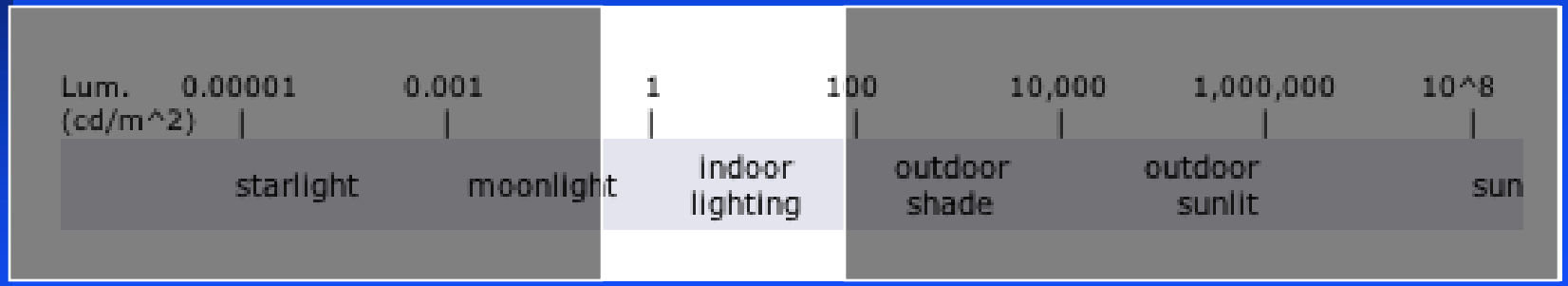
display dynamic range

real world dynamic range





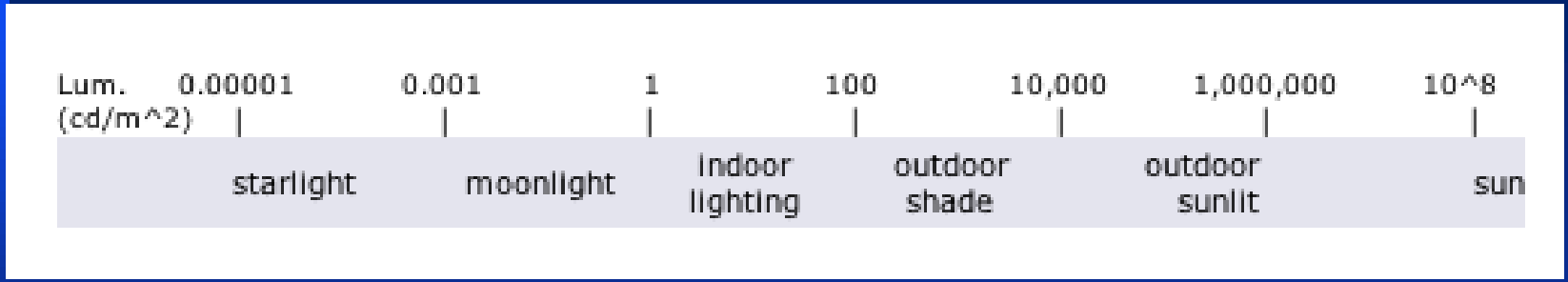
camera acquisition dynamic range

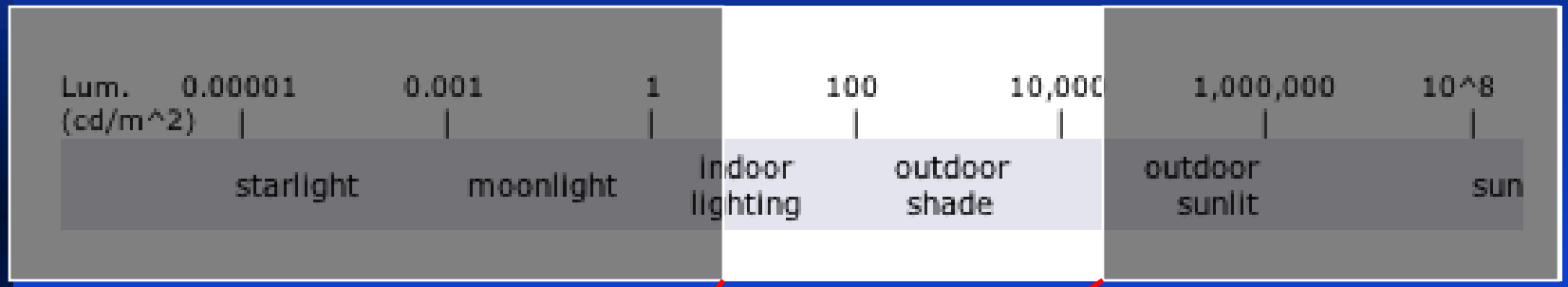


display dynamic range

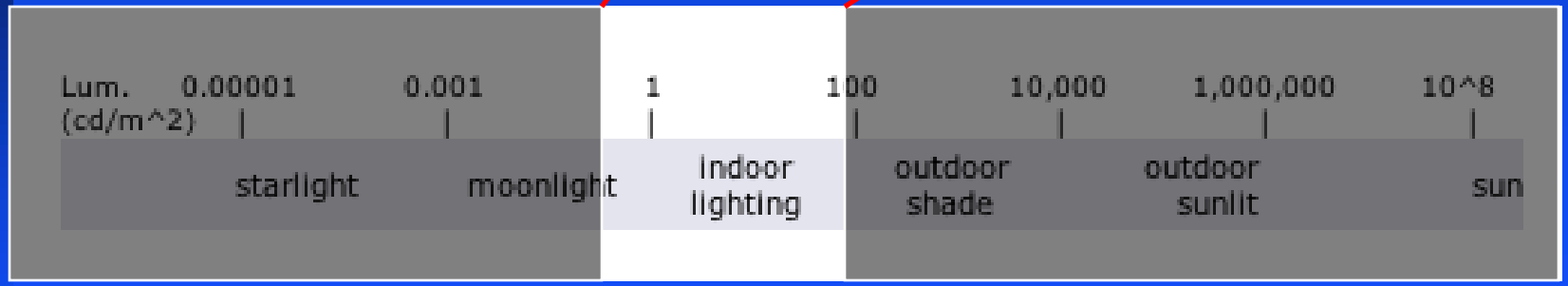
first approach -
scale full acquisition dynamic range into display dynamic range

real world dynamic range





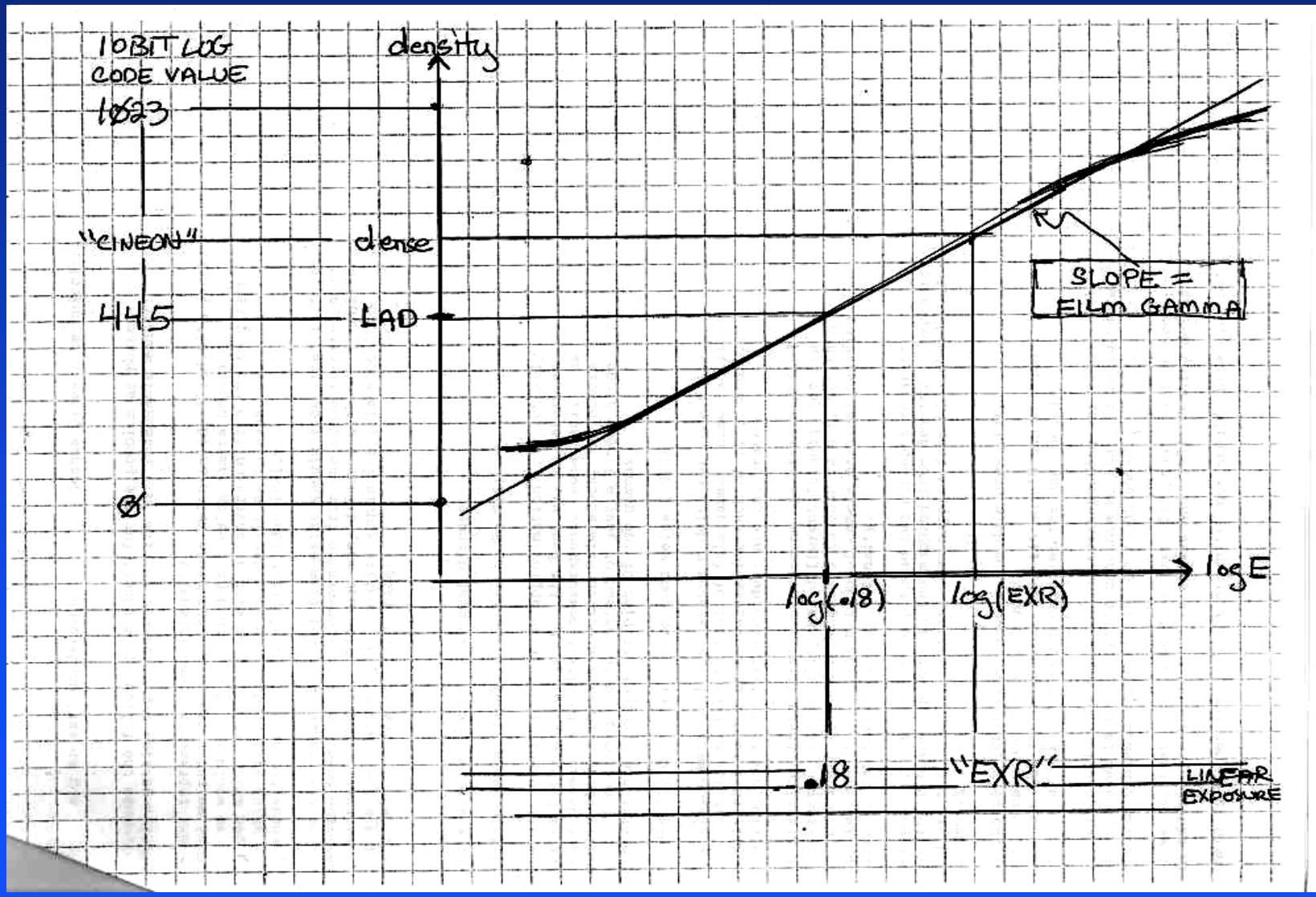
camera acquisition dynamic range



display dynamic range

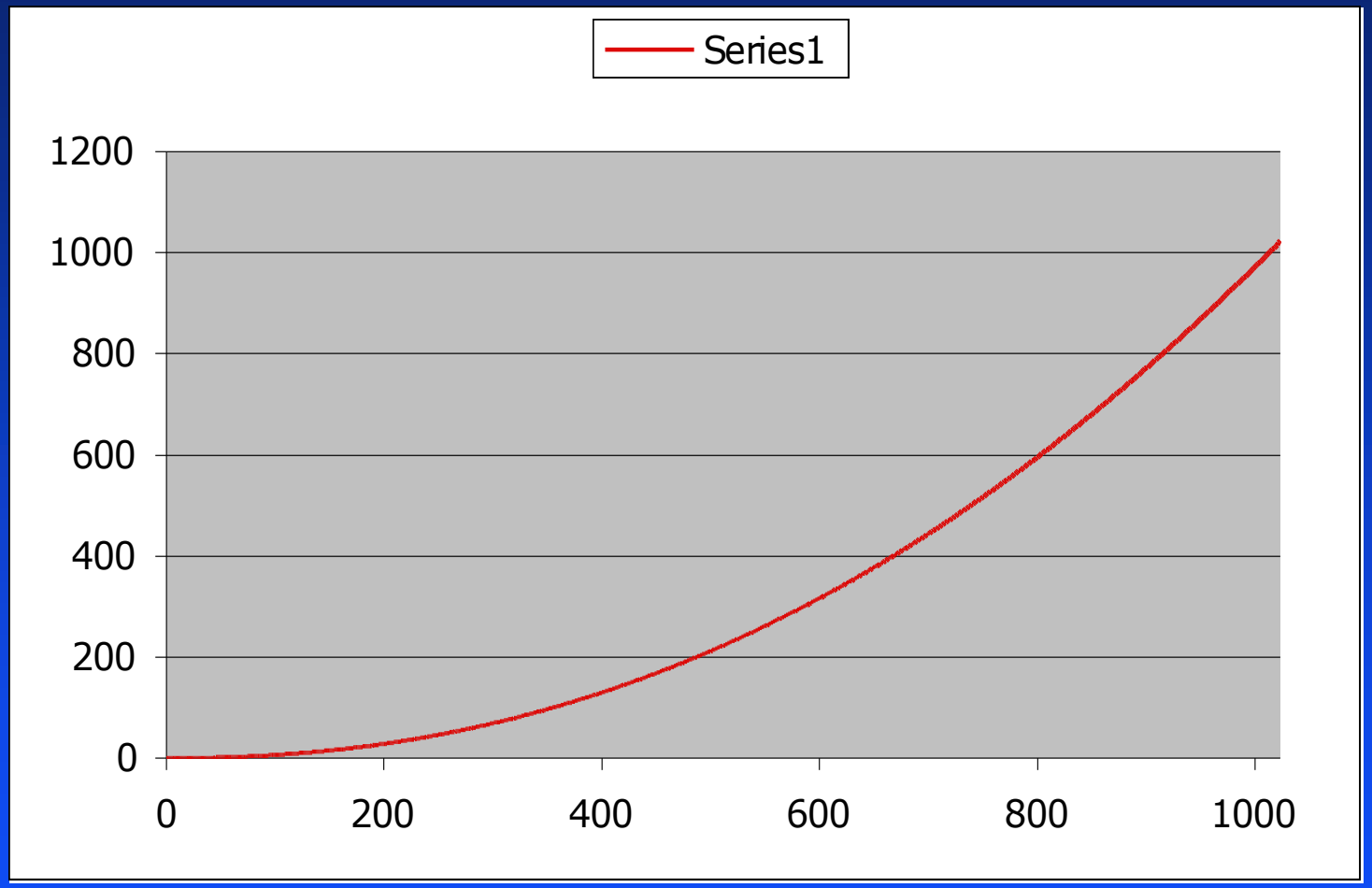
marcie - 10 bit log film scan

exr -> 10bit log conversion

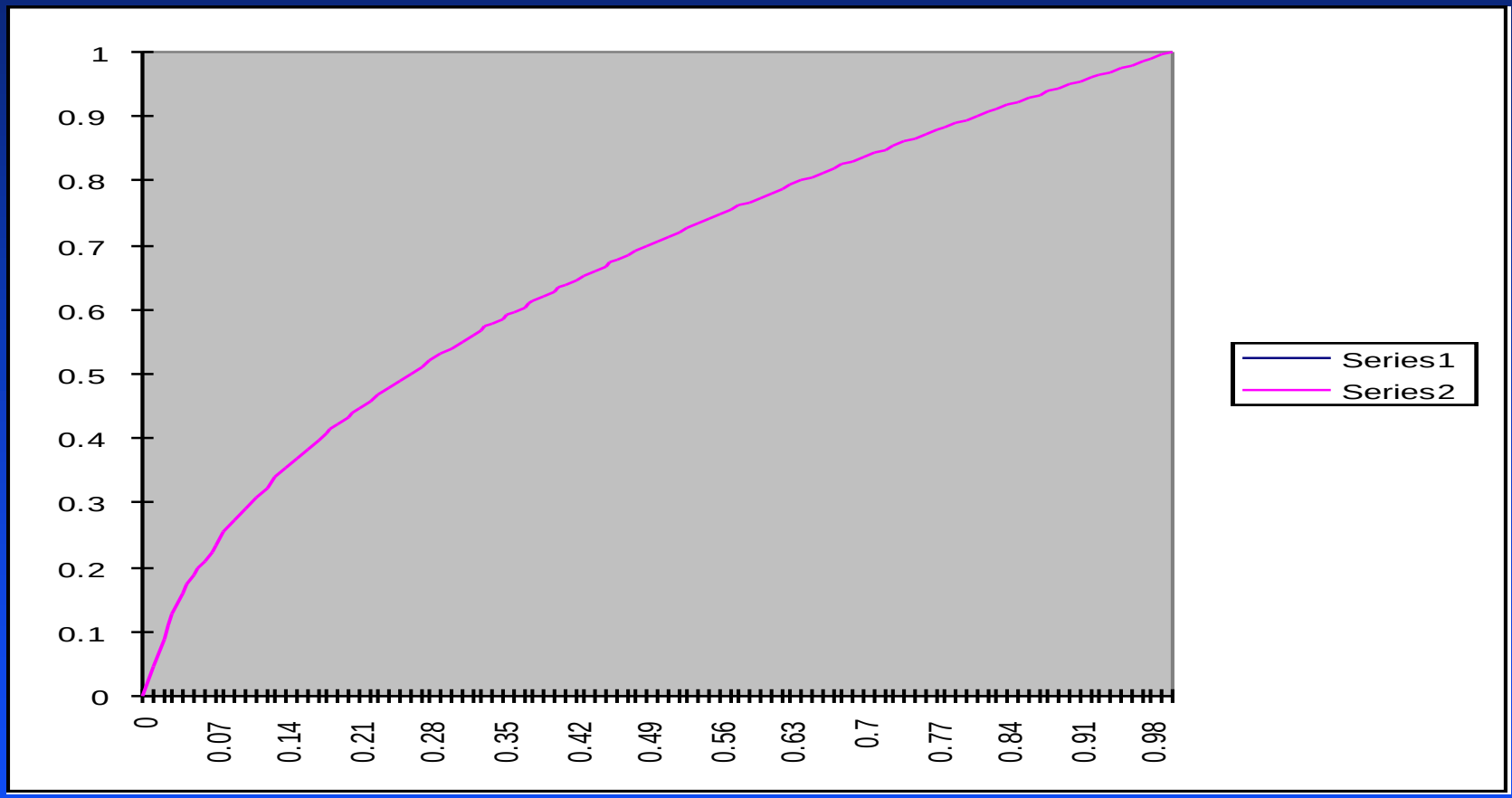


marcie - converted to “radiometric linear”

“typical” display response



compensation for display response

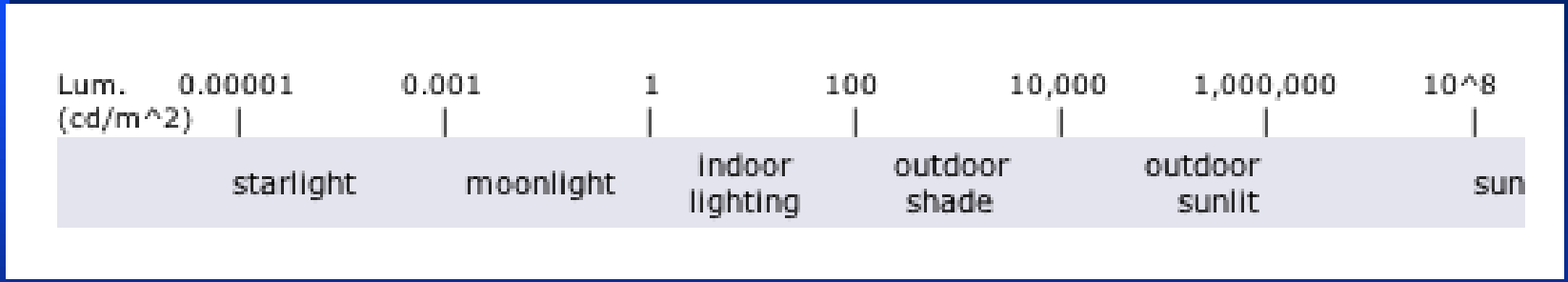


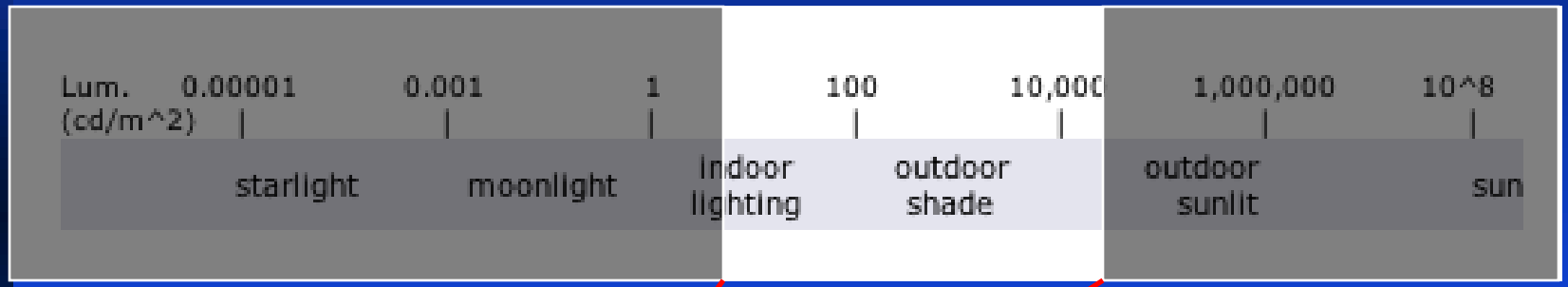
marcie - converted to “radiometric linear”

full range acquisition scaled to display dynamic range (and gamma corrected)

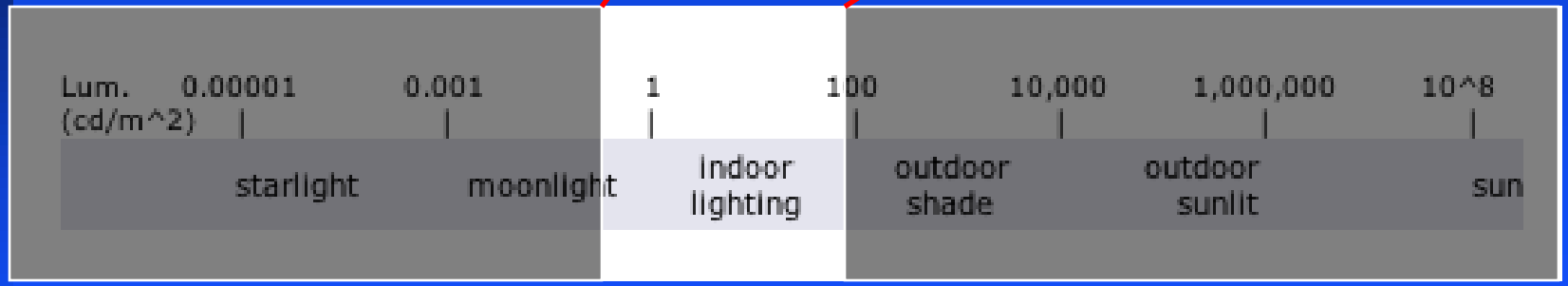
second approach - extract display's dynamic range from full acquisition dynamic range

real world dynamic range



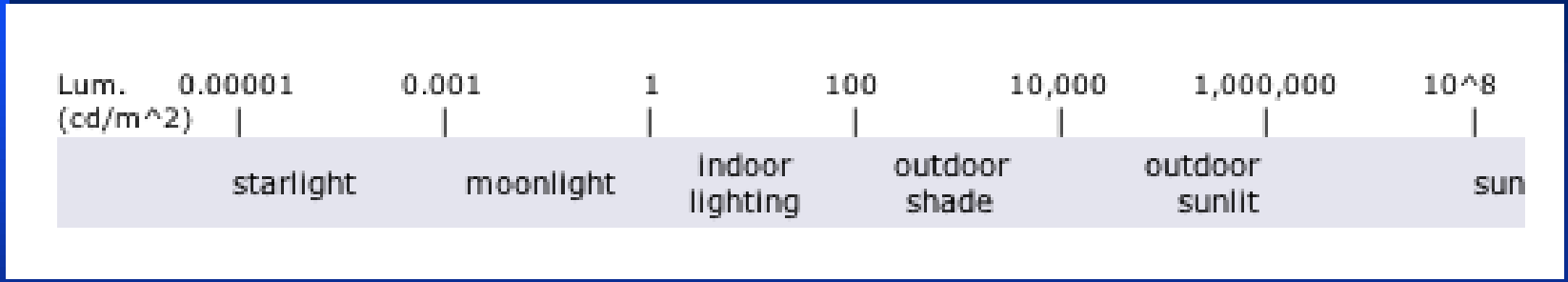


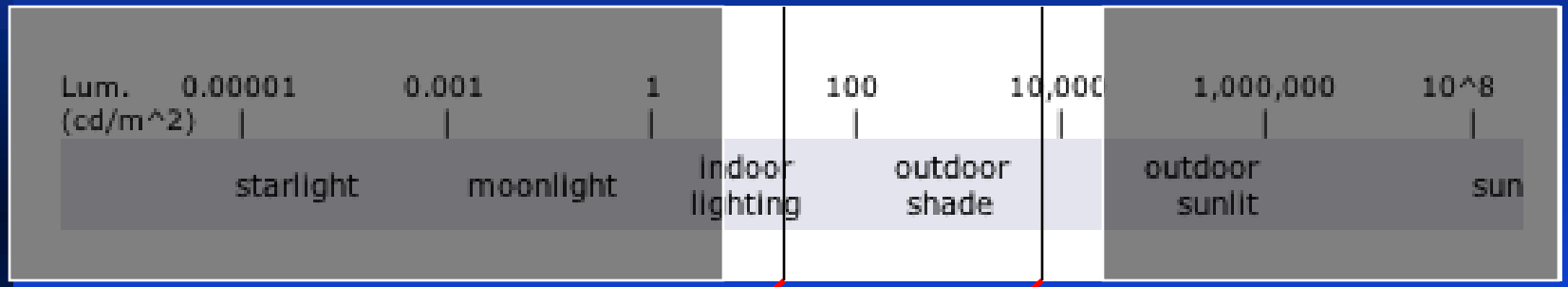
camera acquisition dynamic range



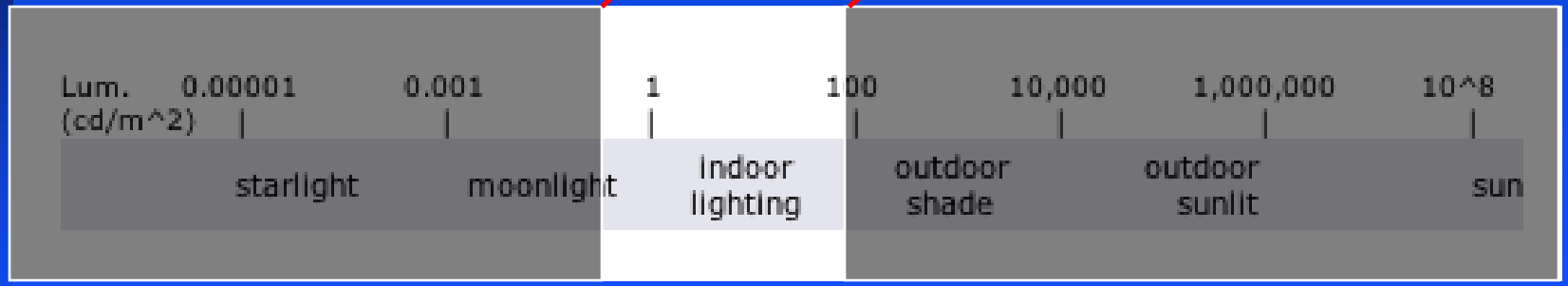
display dynamic range

real world dynamic range



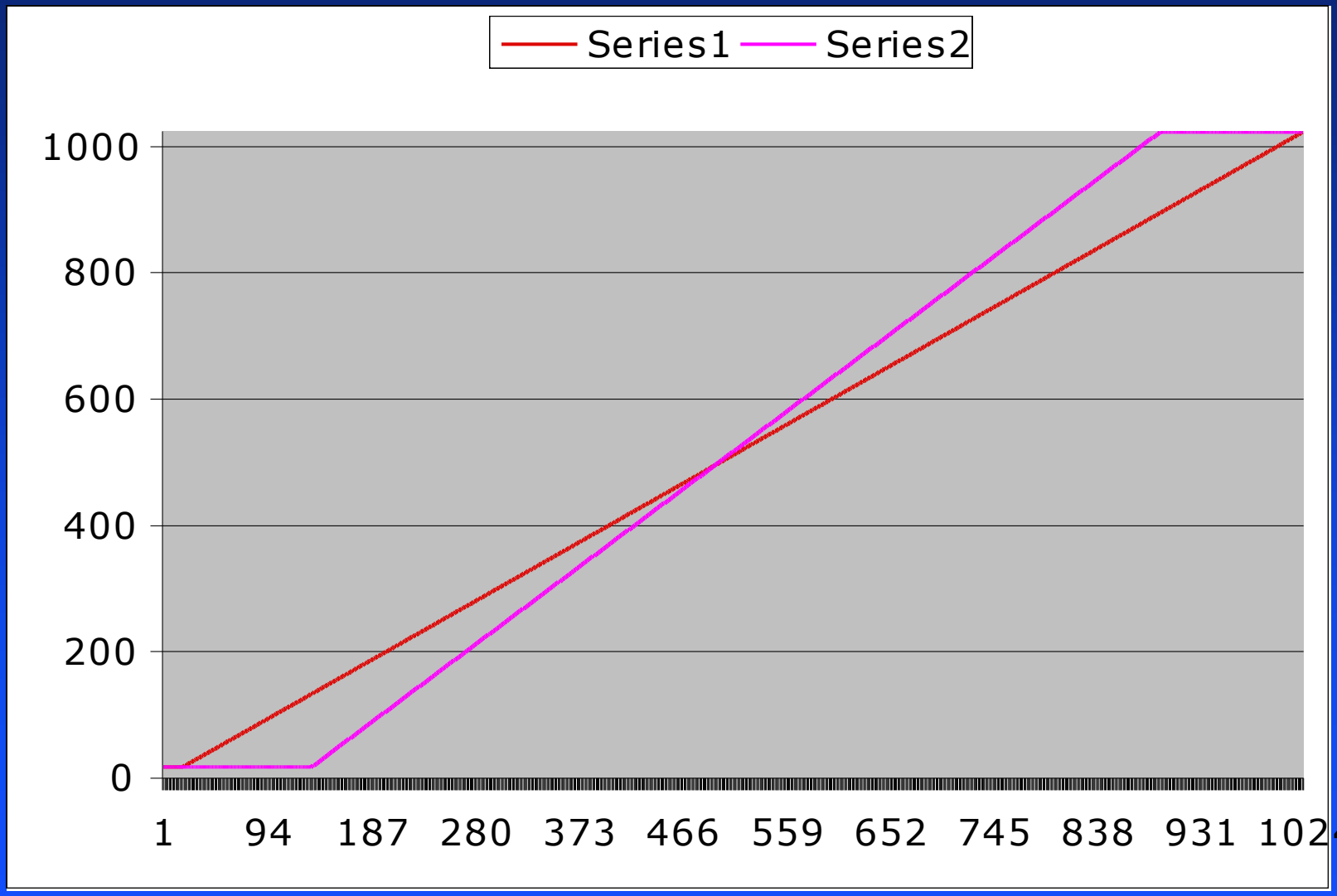


camera acquisition dynamic range



display dynamic range

match display dynamic range instead of full acquisition dynamic range



full range acquisition scaled to display dynamic range (and gamma corrected)

match display dynamic range from acquisition preserving relative intensities

limiting to the display's dynamic range while preserving relative intensities is an improvement - but still looks "low contrast" - why?

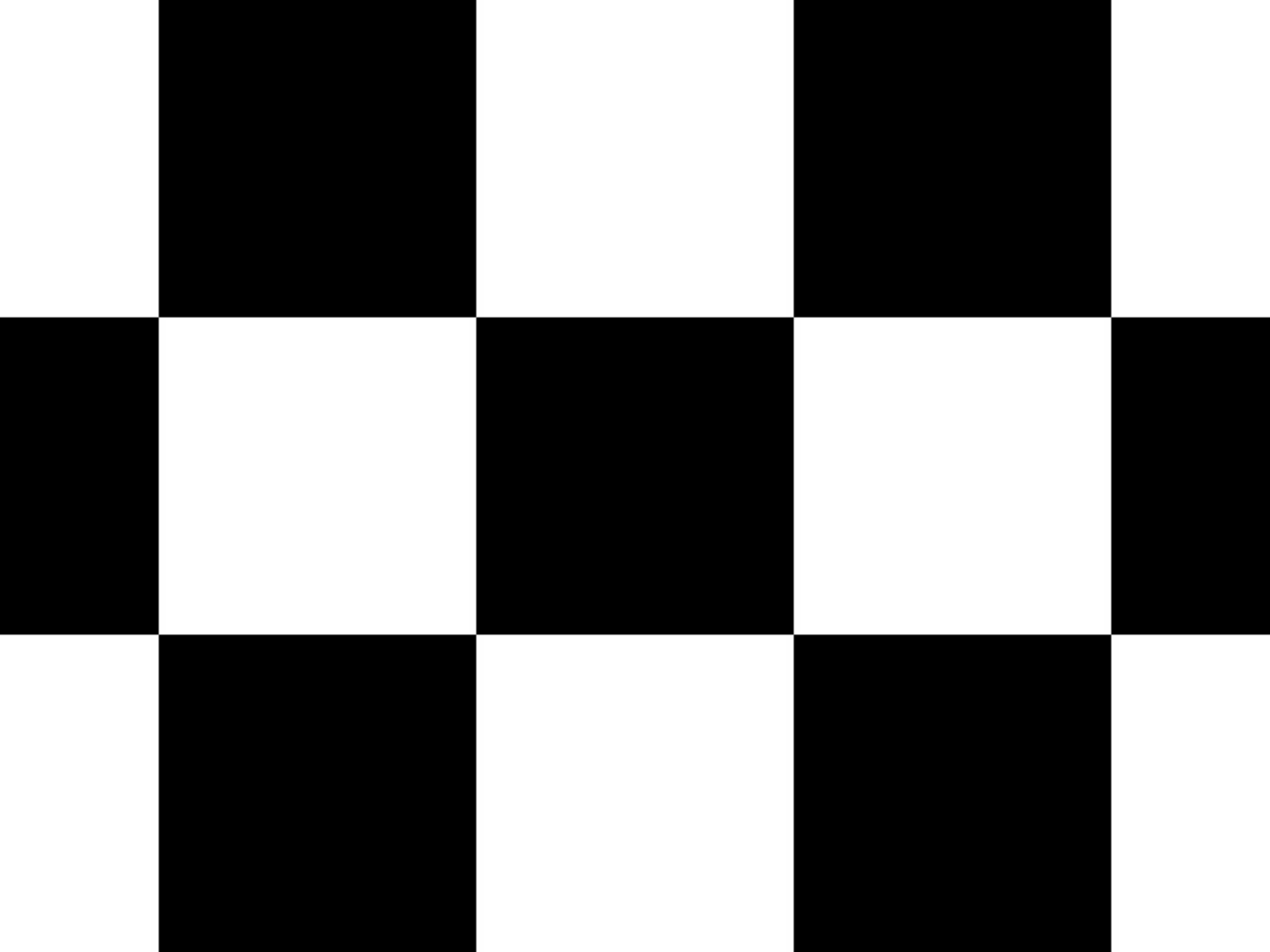
limiting to display's dynamic range while preserving relative intensities is an improvement - but still looks "low contrast" - why?

- stevens effect - perceived contrast decreases at lower luminance
- hunt effect - perceived "colorfulness" also decreases at lower luminance


445, 445, 445
Kodak
KODAK Digital LAD Test Image
445, 445, 445
Kodak
KODAK Digital LAD Test Image
445, 445, 445
Kodak
KODAK Digital LAD Test Image
445, 445, 445
Kodak
KODAK Digital LAD Test Image

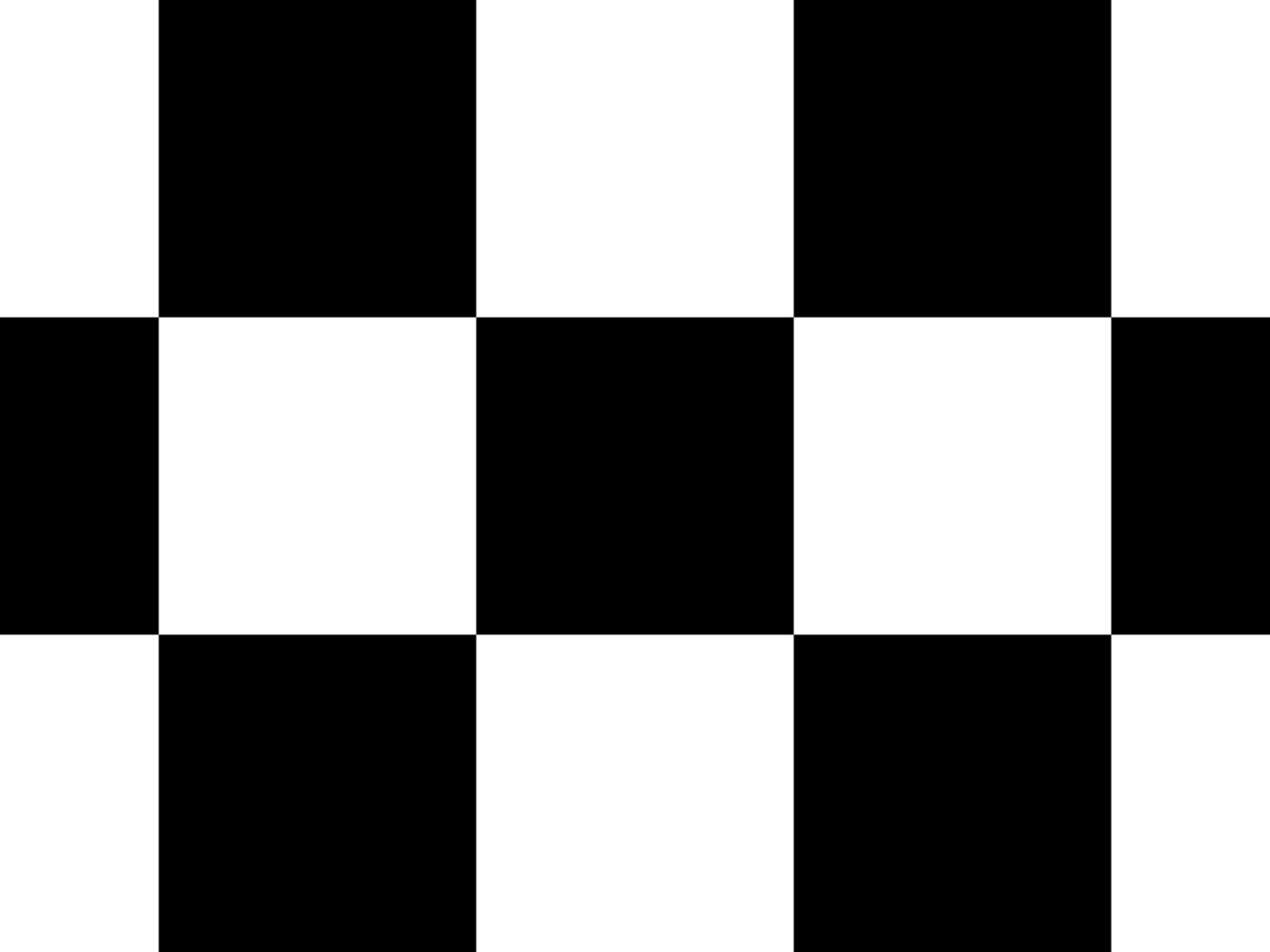
limiting to display's dynamic range while preserving relative intensities is an improvement - but still looks "low contrast" - why?

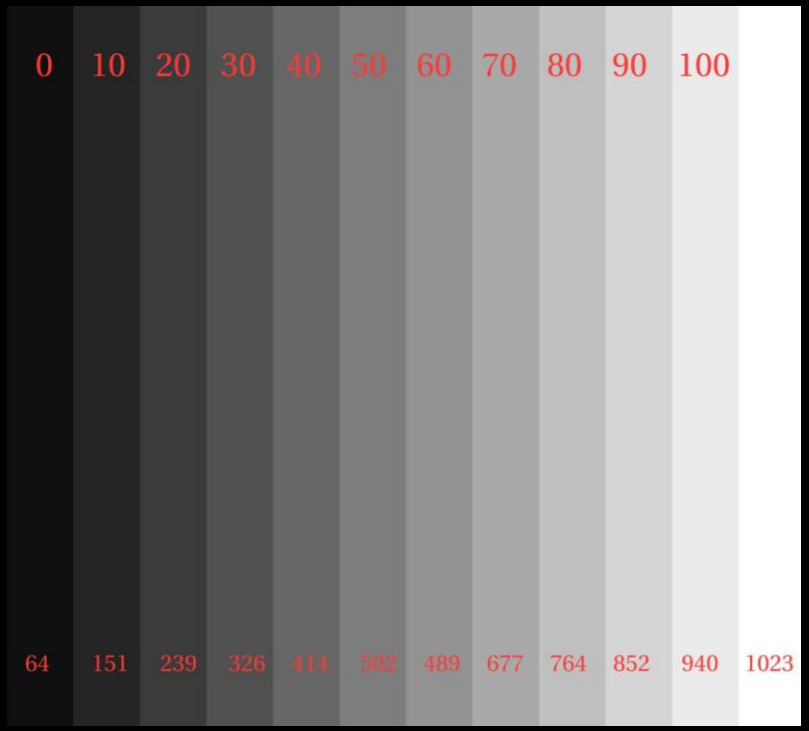
- stevens effect - perceived contrast decreases at lower luminance
- hunt effect - perceived "colorfulness" also decreases at lower luminance
- display flare characteristics reduce contrast - sequential contrast vs. simultaneous contrast



limiting to display's dynamic range while preserving relative intensities is an improvement - but still looks "low contrast" - why?

- stevens effect - perceived contrast decreases at lower luminance
- hunt effect - perceived "colorfulness" also decreases at lower luminance
- display flare characteristics reduce contrast
- bartleson-breneman effect - a "dark" surround decreases perceived contrast




IRE
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70
80
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100
10 Bit CV
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64
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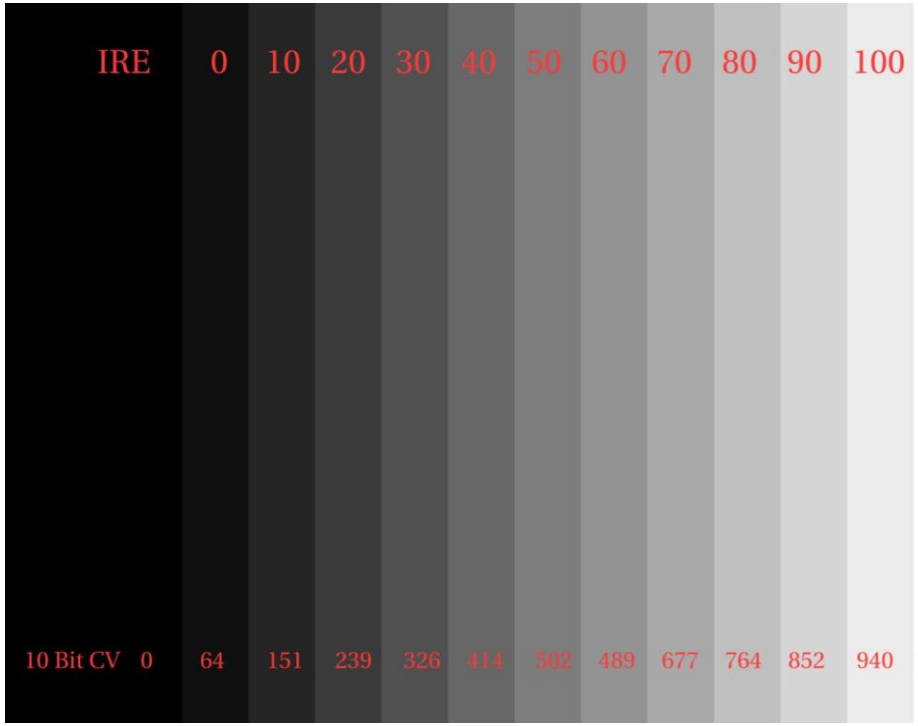
239
326
414
502
489
677
764
852
940
1023


IRE
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60
70
80
90
100
10 Bit CV
0
64
151
239
326
414
502
489
677
764
852
940
1023

“normal surround” - (office)

“dim surround” - (living room)

“dark surround” - (theatrical)

“normal surround” - (office)
display gamma = 2.2

“dim surround” - (living room)
display gamma = 2.4

“dark surround” - (theatrical)
display gamma = 2.6

limiting to display's dynamic range while preserving relative intensities is an improvement - but still looks "low contrast" - why?

- stevens effect - perceived contrast decreases at lower luminance
- hunt effect - perceived "colorfulness" also decreases at lower luminance
- display flare characteristics reduce contrast
- bartleson-breneman effect - a "dark" surround decreases perceived contrast

solution - increase contrast!

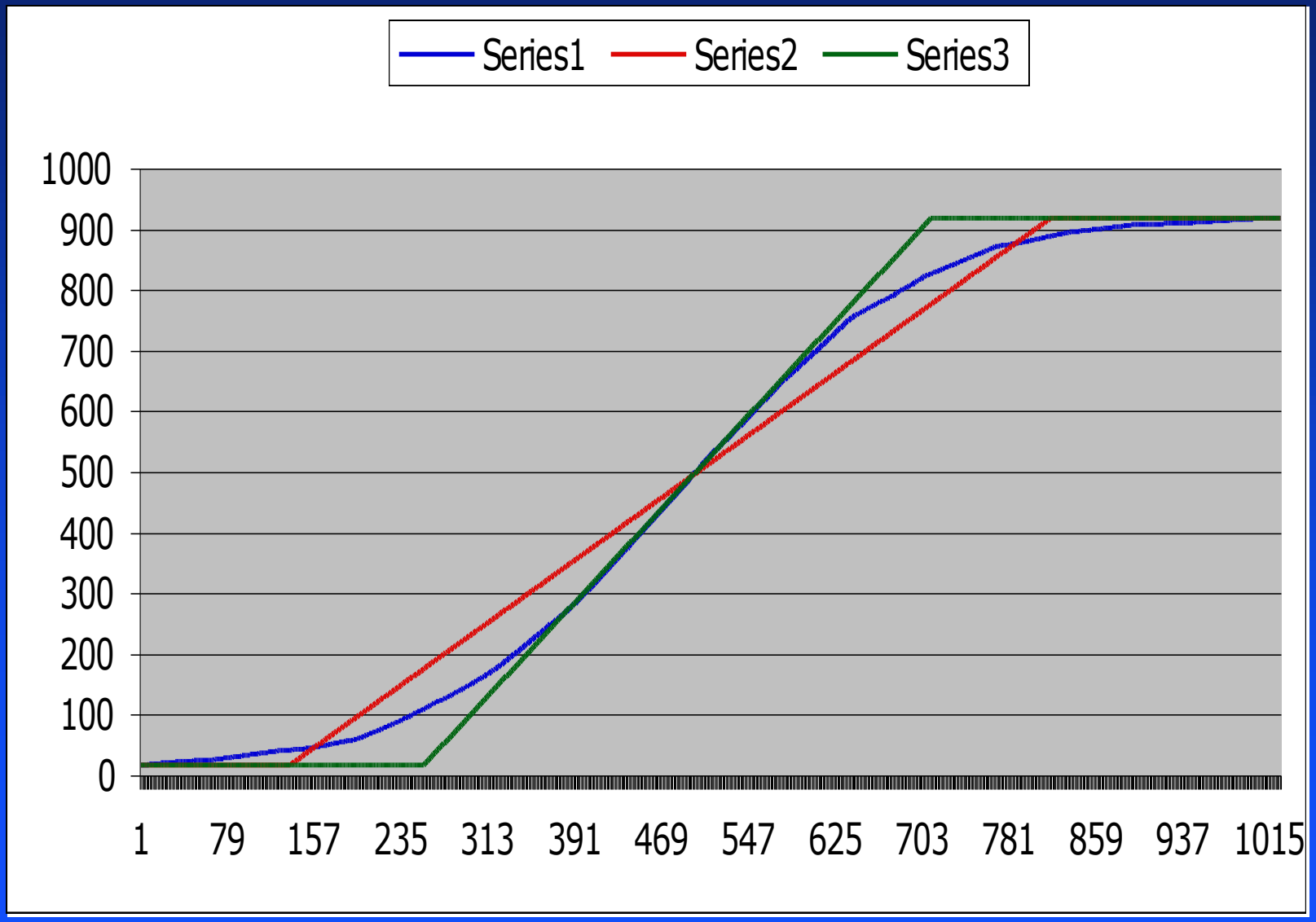
match display dynamic range from acquisition preserving relative intensities

match display dynamic range +
add contrast (1.25 - 1.50)

…but now we've added clipping artifacts

- add "toe" and "shoulder" to reduce clipping artifacts
- …which also brings back some shadow and highlight detail

solution - increase contrast + add toe and shoulder (the infamous “S-curve”)



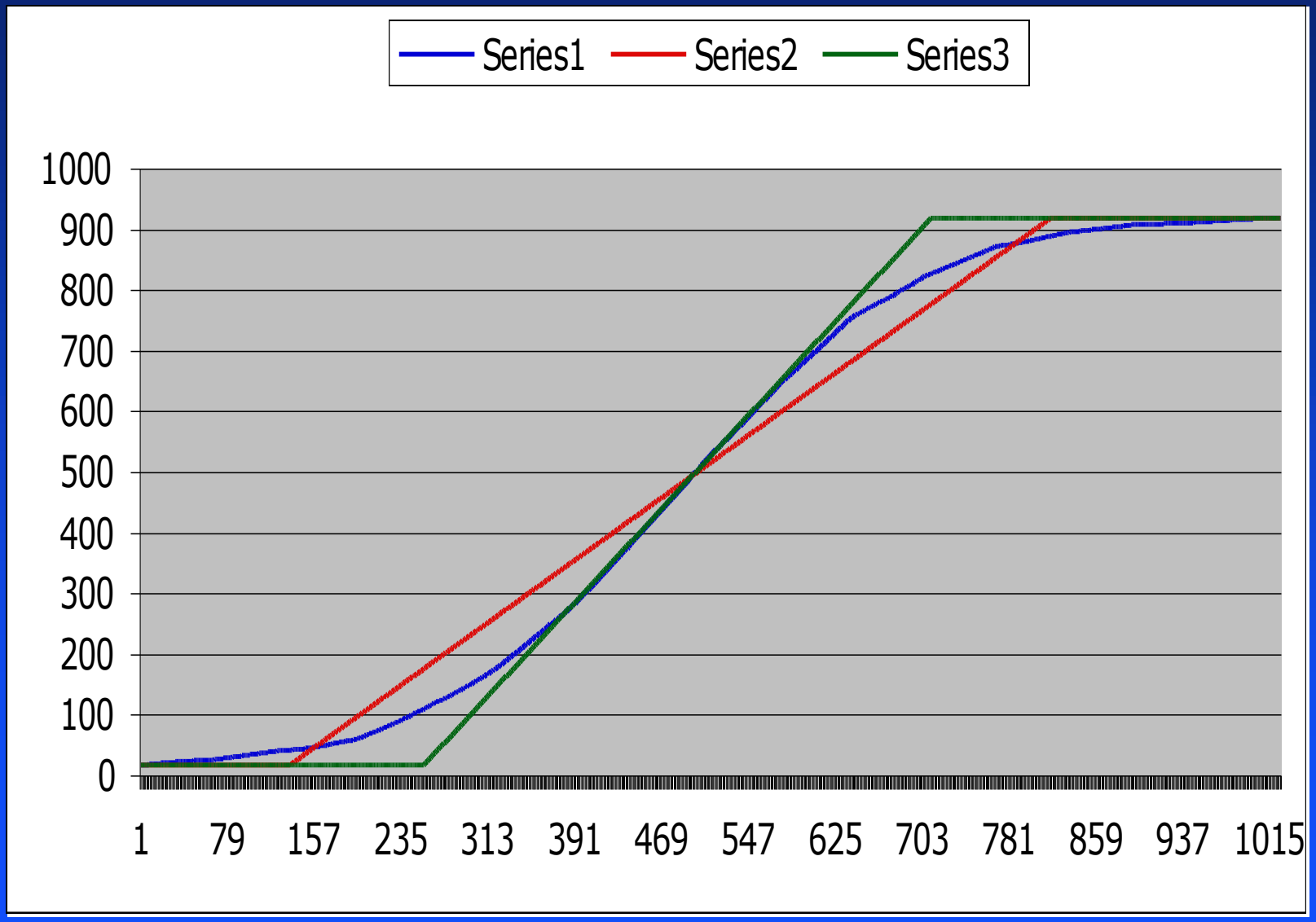
display dynamic range + add contrast (1.25 - 1.50)

display dynamic range + add contrast + add toe and shoulder

display dynamic range + add contrast + add toe and shoulder (b&w)

real film print emulation (b&w)

i cheated - this “simple S-curve” is the real film emulation tone mapping curve



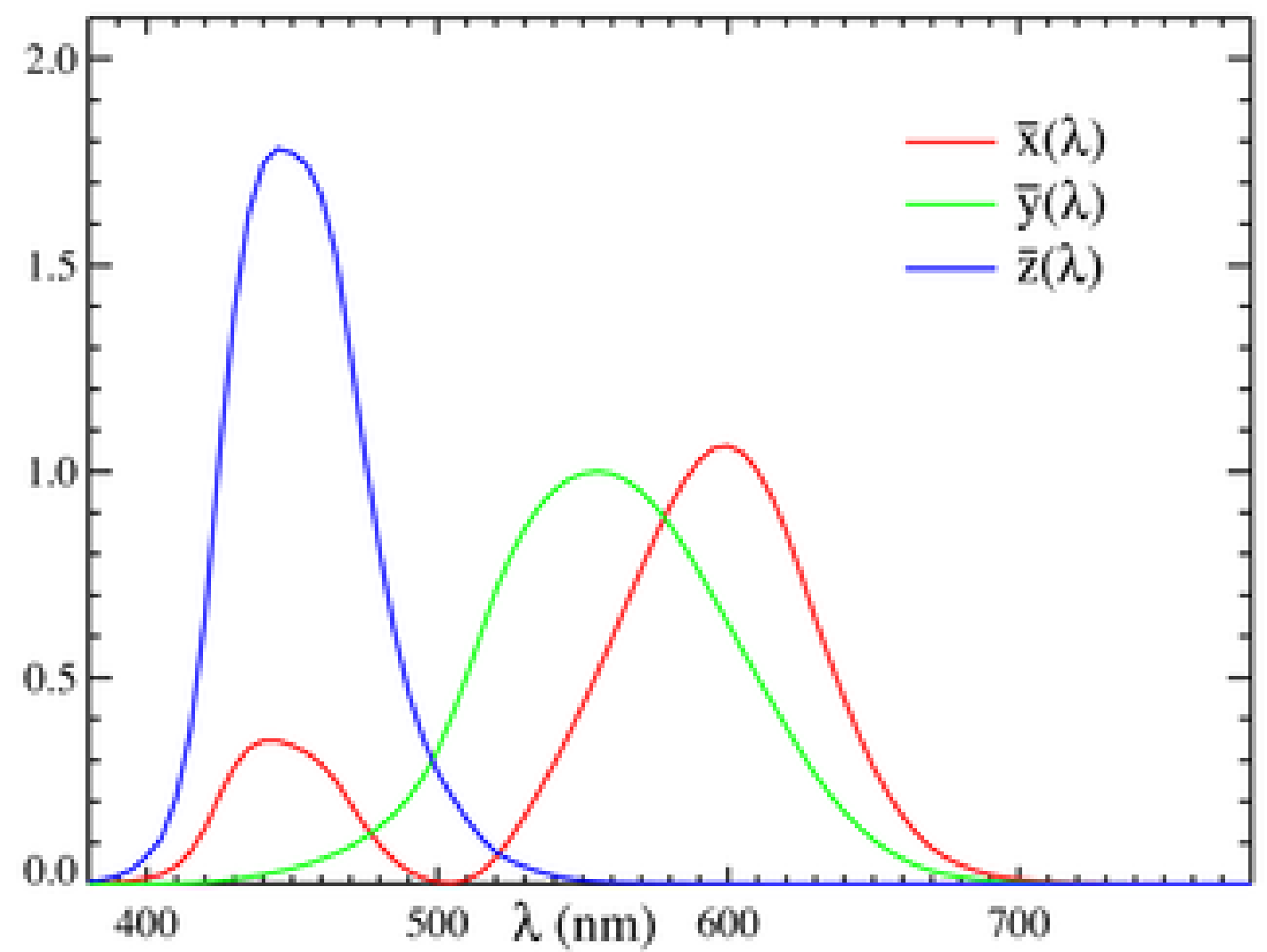
display dynamic range + add contrast + add toe and shoulder (b&w)

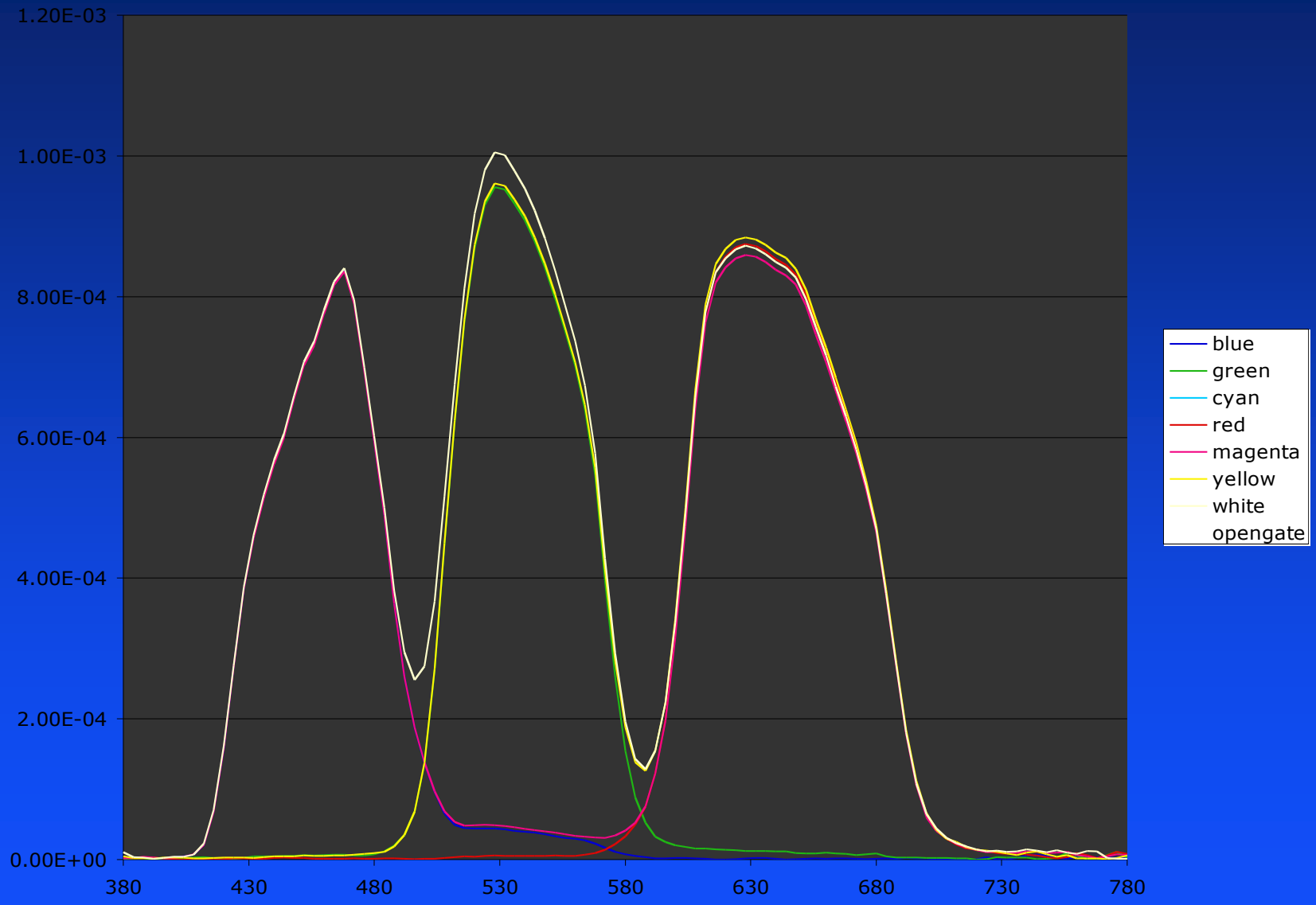
real film print emulation (b&w)

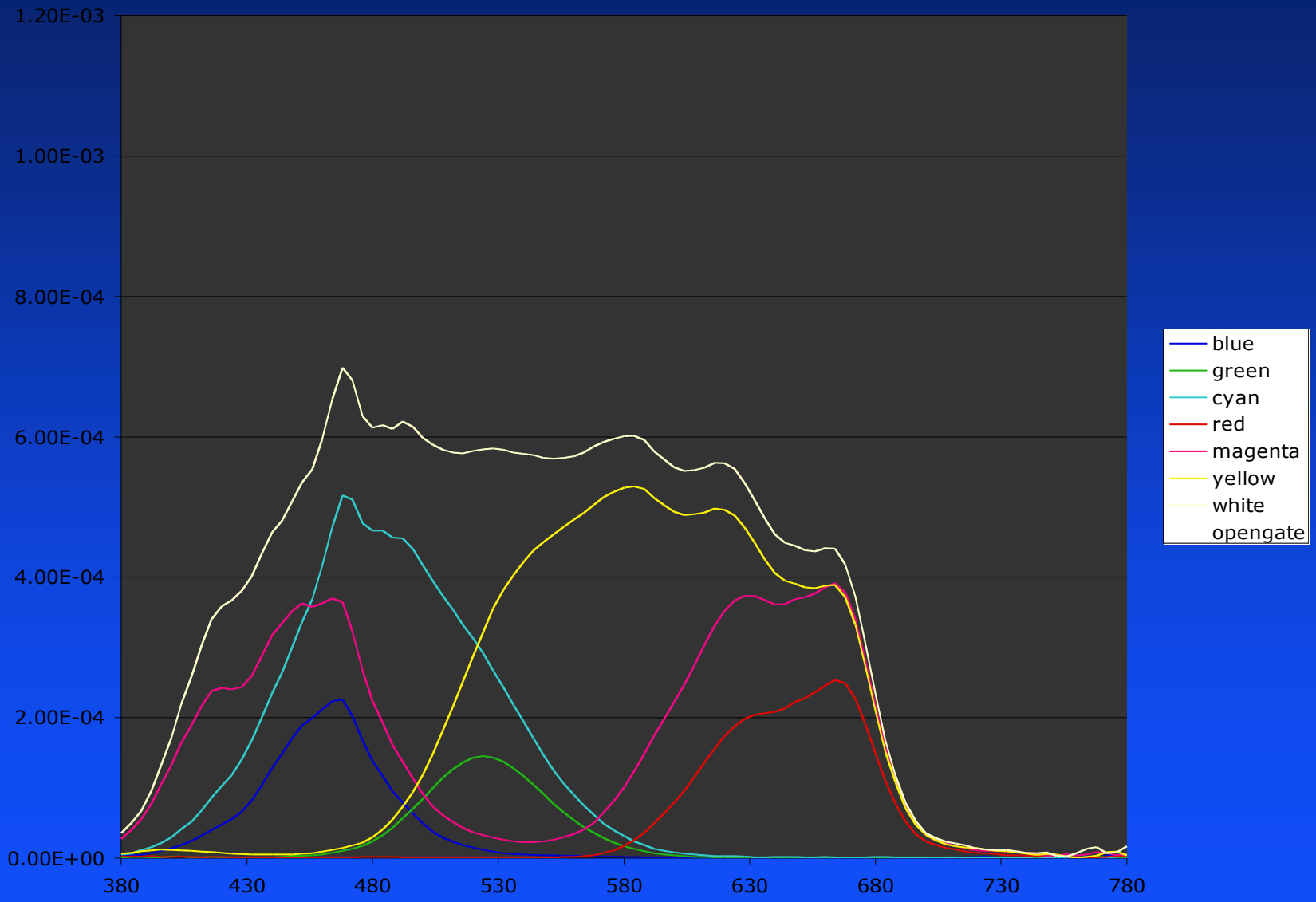
display dynamic range + add contrast + add toe and shoulder

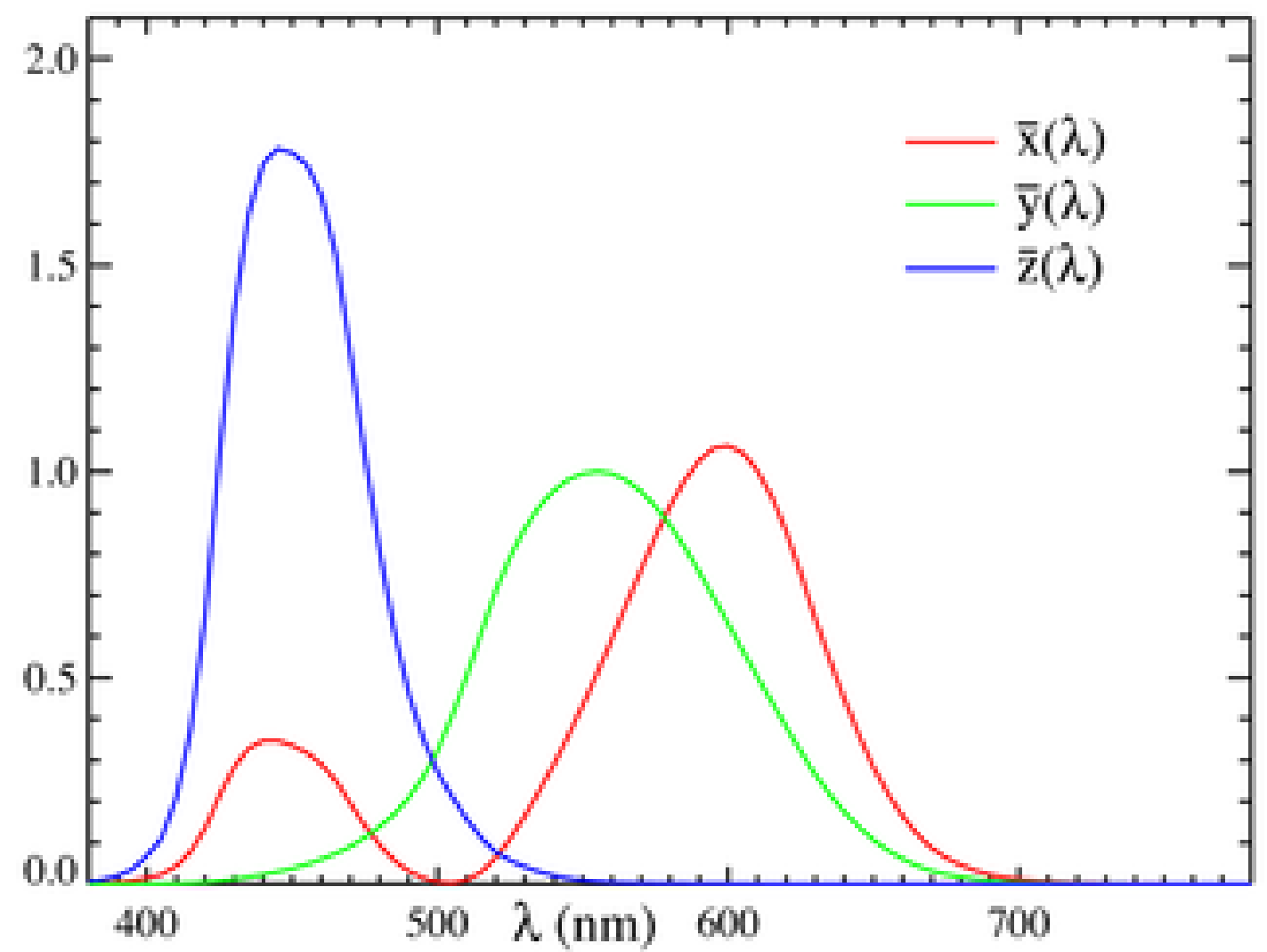
real film print emulation

a little color science
never hurt anybody…


2.0
1.5
1.0
0.5
0.0
400
500
λ (nm)
600
700
x̄(λ)
ȳ(λ)
z̄(λ)


1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
380
430
480
530
580
630
680
730
780
blue
green
cyan
red
magenta
yellow
white
opengate

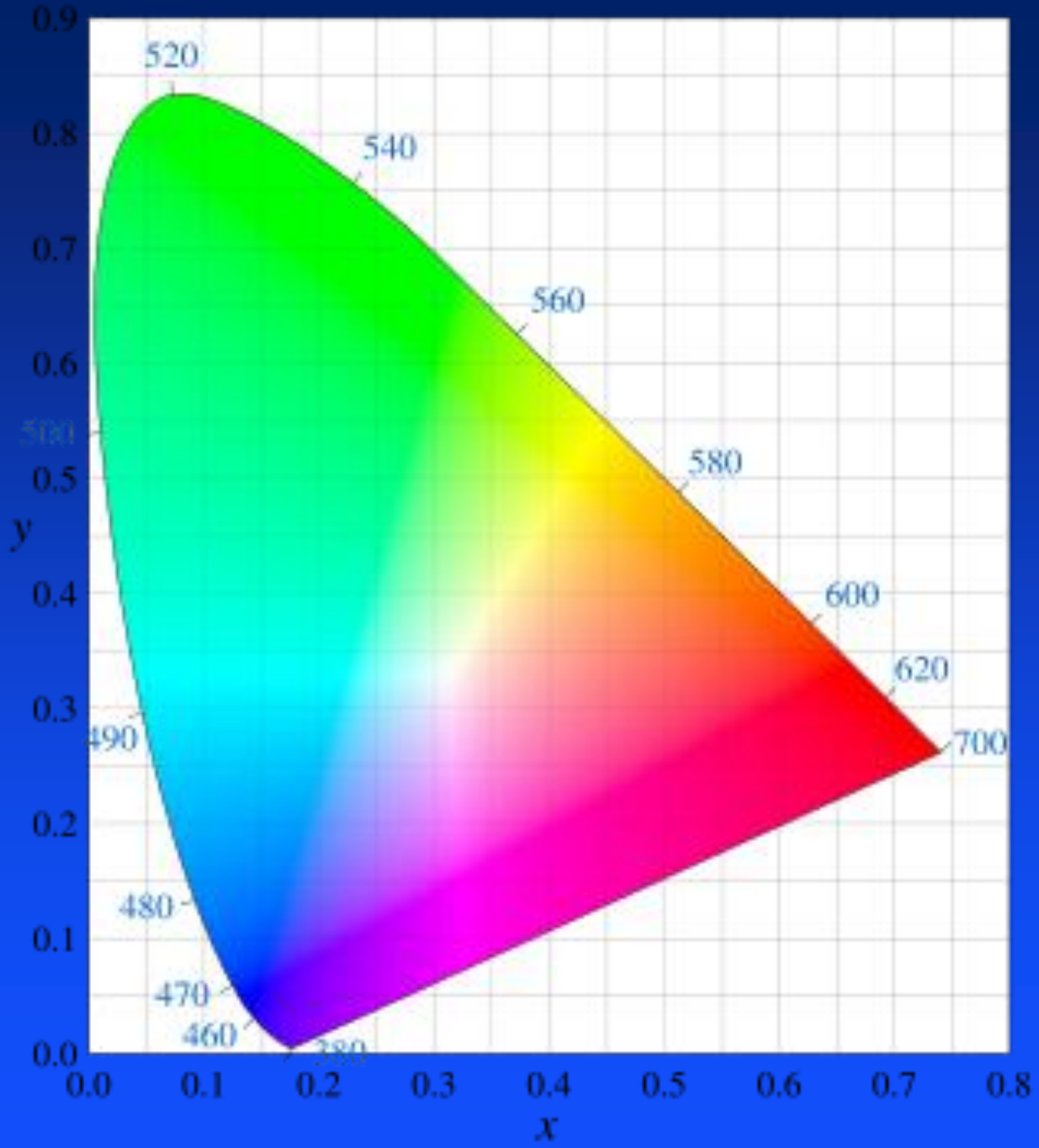

1.20E-03
1.00E-03
8.00E-04
6.00E-04
4.00E-04
2.00E-04
0.00E+00
380
430
480
530
580
630
680
730
780
blue
green
cyan
red
magenta
yellow
white
opengate

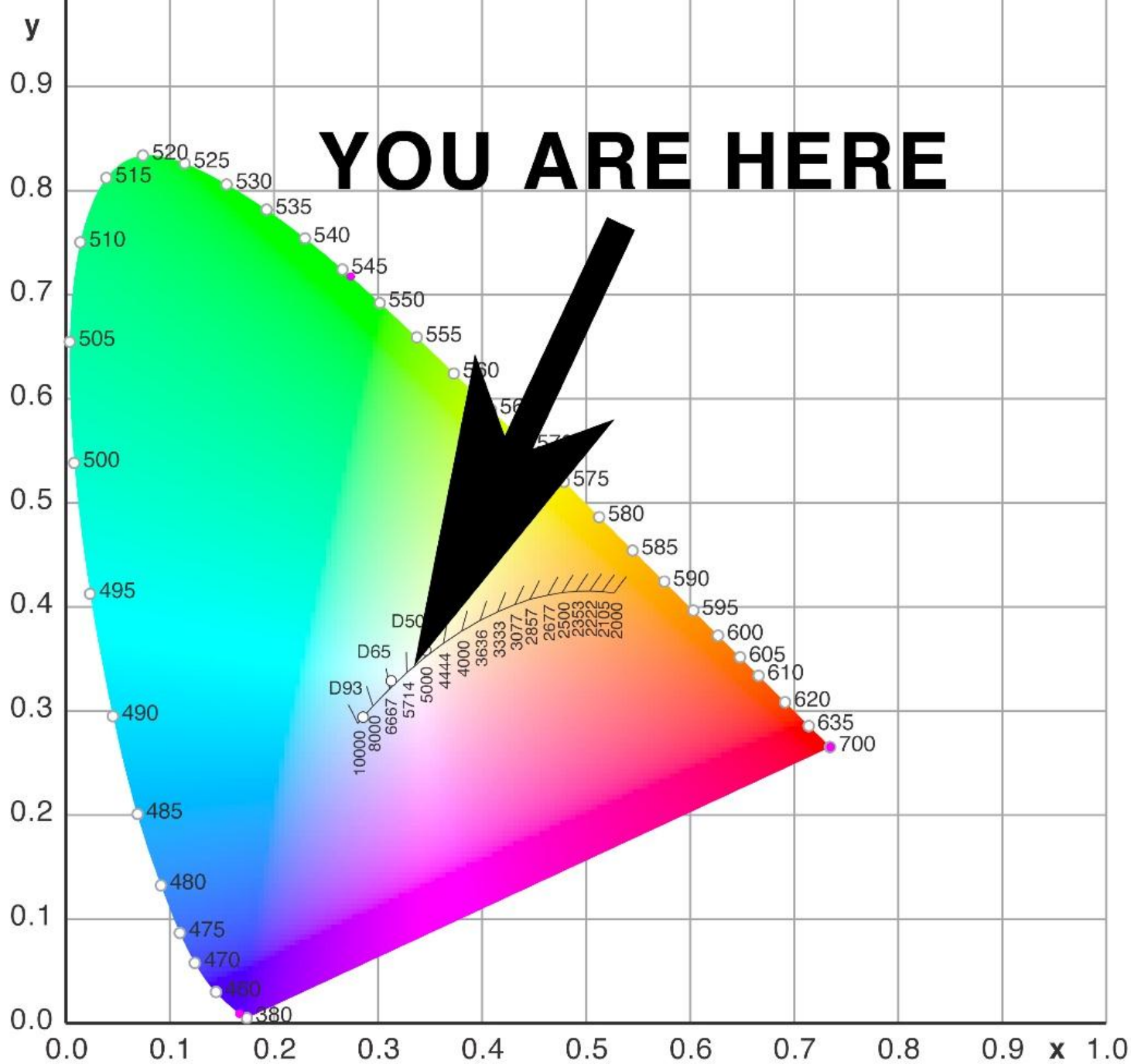

2.0
1.5
1.0
0.5
0.0
400
500
λ (nm)
600
700
x̄(λ)
ȳ(λ)
z̄(λ)

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
y
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
x
520
540
560
580
600
620
700
500
490
480
470
460
380


YOU ARE HERE
y
x
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
380
470
475
480
485
490
495
500
505
510
515
520
525
530
535
540
545
550
555
560
575
580
585
590
595
600
605
610
620
635
700
D50
D65
D93
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2857
2677
2500
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2222
2105
2000

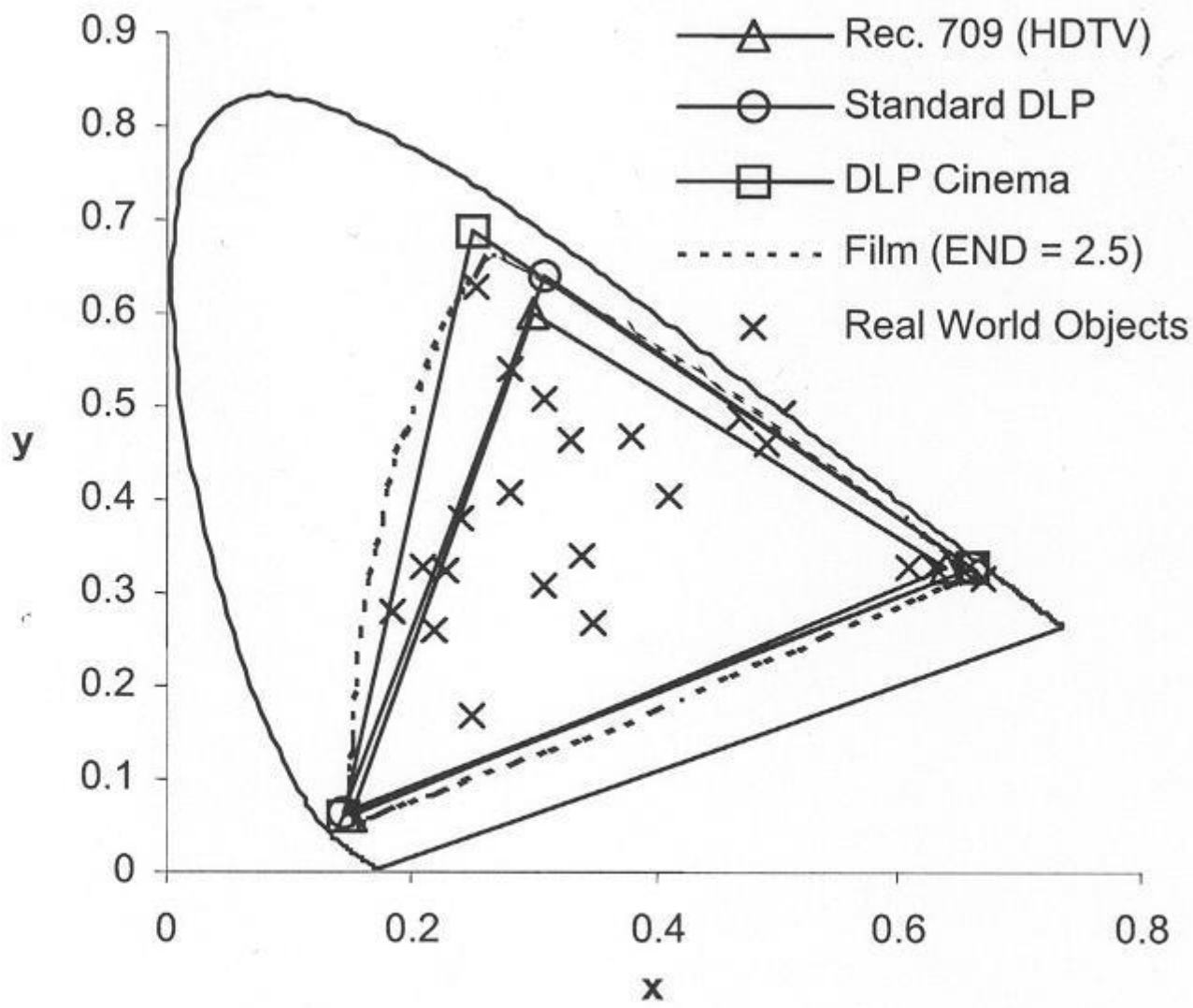
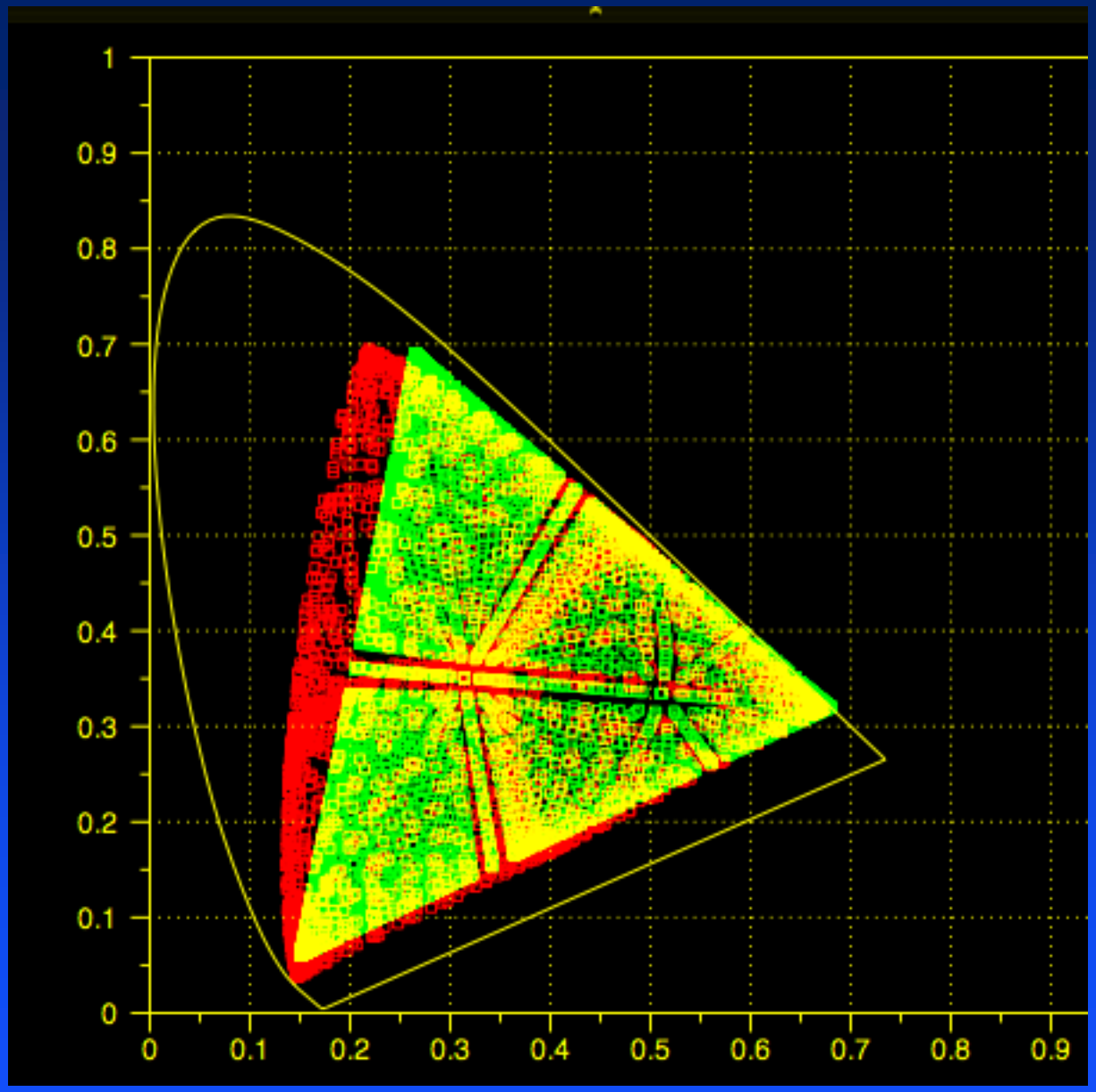
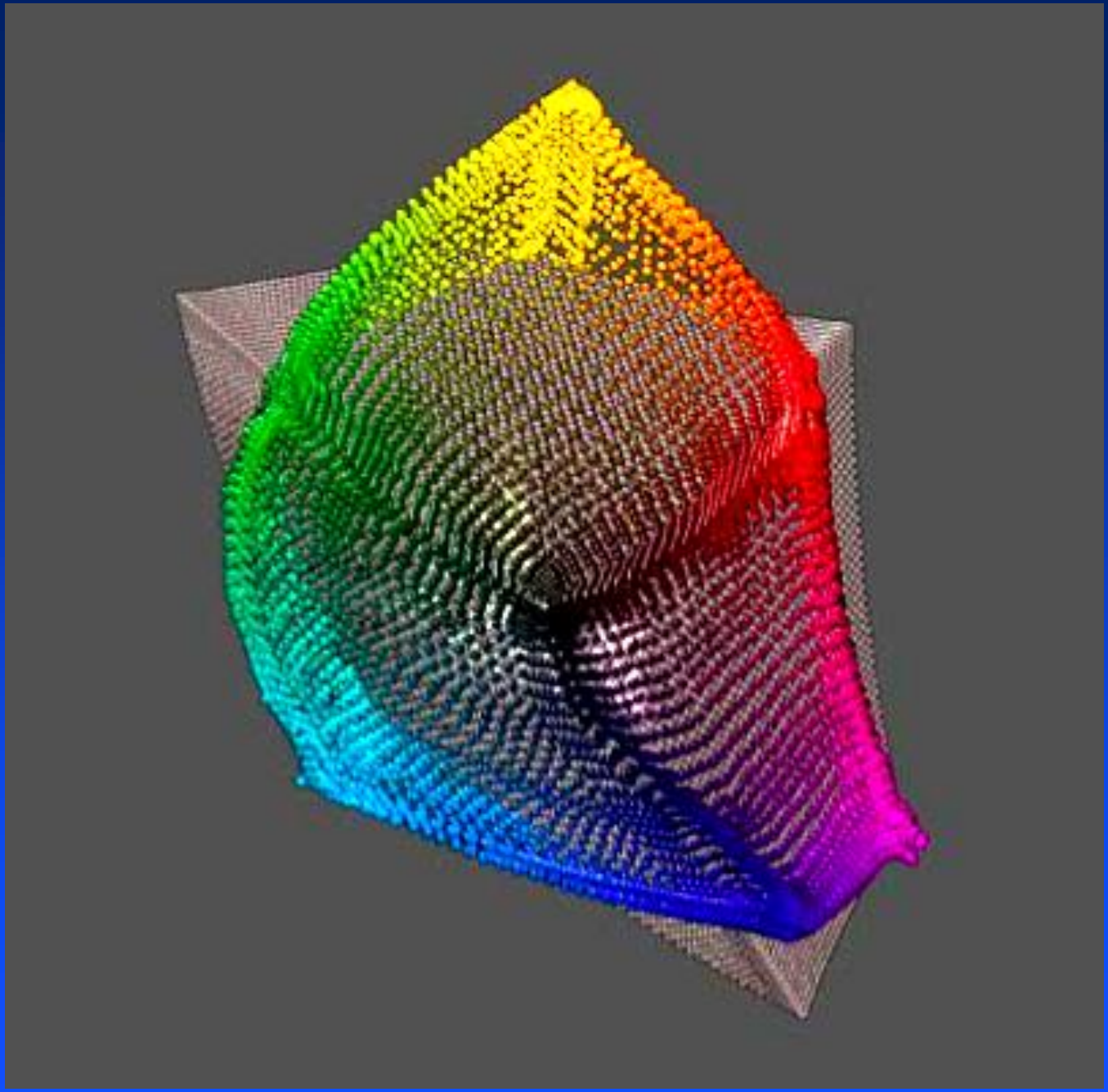


Figure 5. Color gamut comparison of real-world objects with color gamut of various technologies.

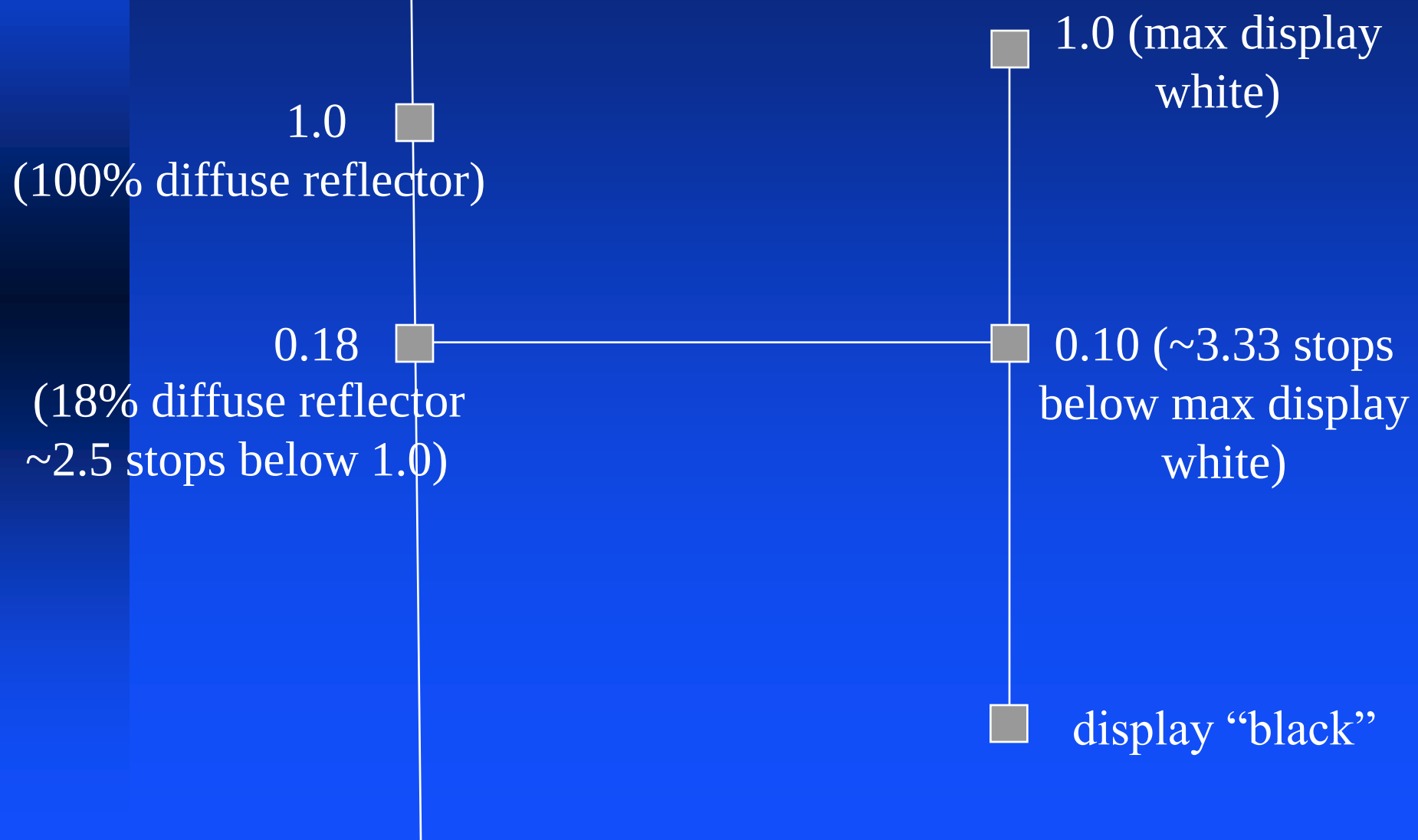

1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9



display dynamic range + add contrast + add toe and shoulder

real film print emulation

mapping “middle grey”
from scene to display
0.18 -> 0.10



ASC “STeM” movie

”standard evaluation material”

ASC “STeM” movie

mean rgb linear intensity = 0.11 0.09 0.11

mapping “middle grey”
from scene to display
0.18 -> 0.10

1.0 (max display white)

1.0
(100% diffuse reflector)

0.18
(18% diffuse reflector
~2.5 stops below 1.0)

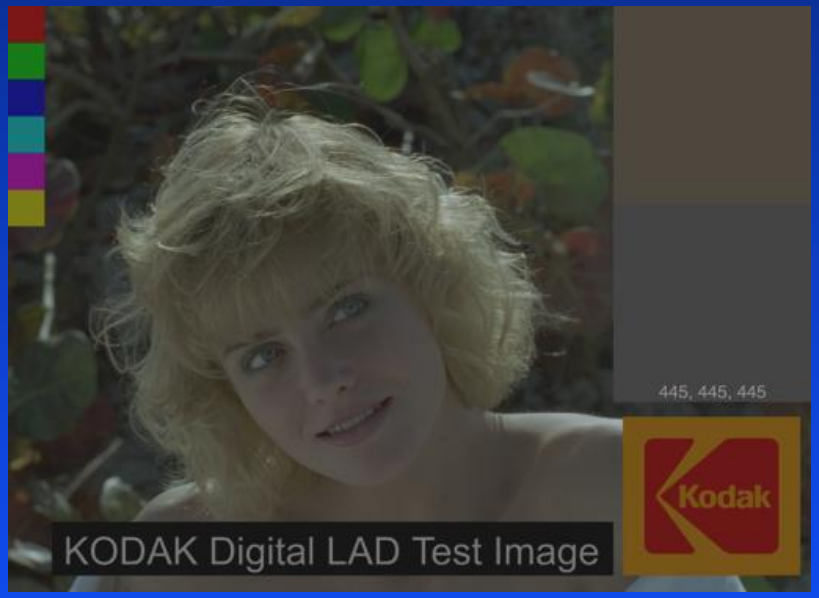
0.10 (~3.33 stops below max display white)

0.004 (8 stops below max display white)

how to build your own rendering transform

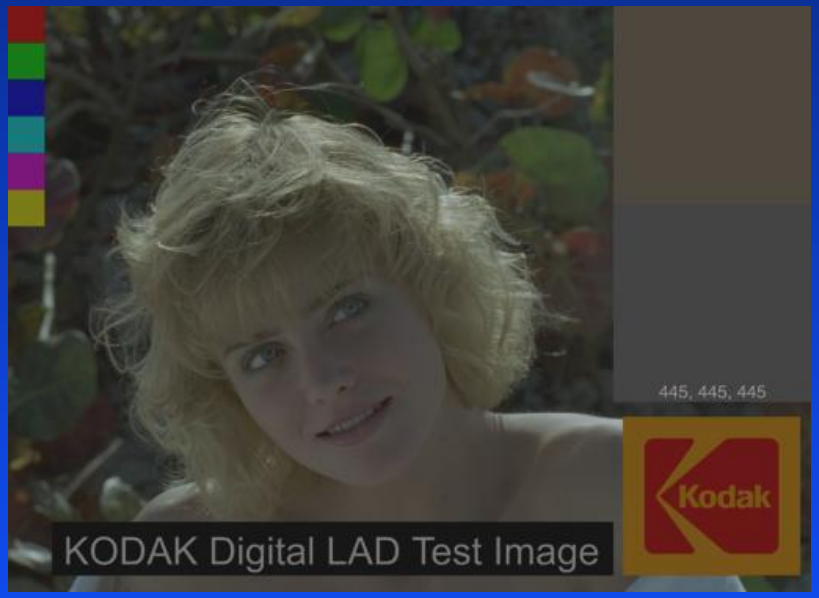
how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)



how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

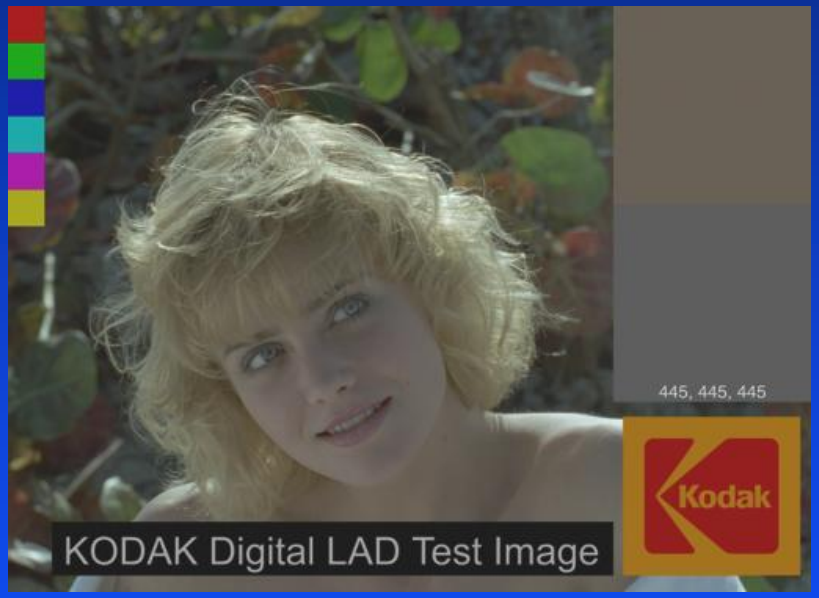


how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")



how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log

how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)

how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

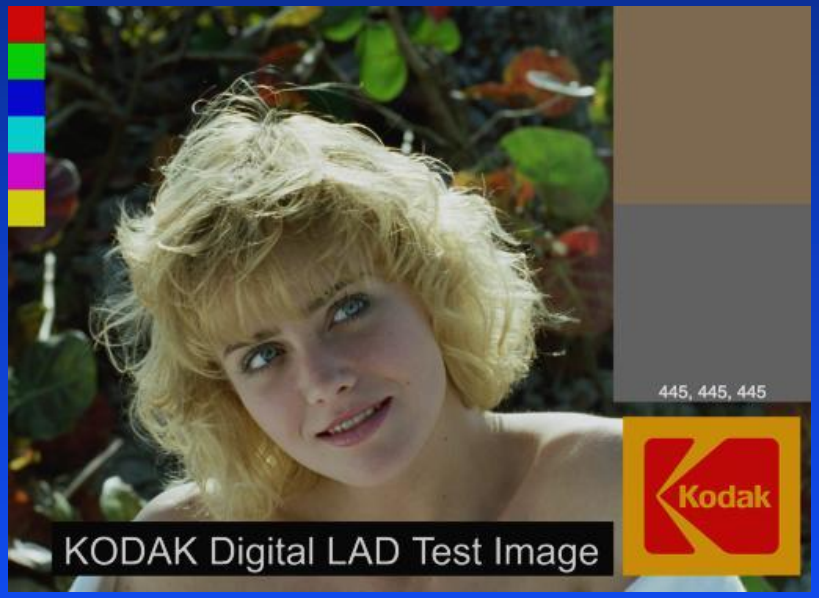
- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)
- increase contrast in log space around middle gray (log(0.18))

how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)
- increase contrast in log space around middle gray (log(0.18))
- add toe and shoulder to taste (requires knowledge of display)

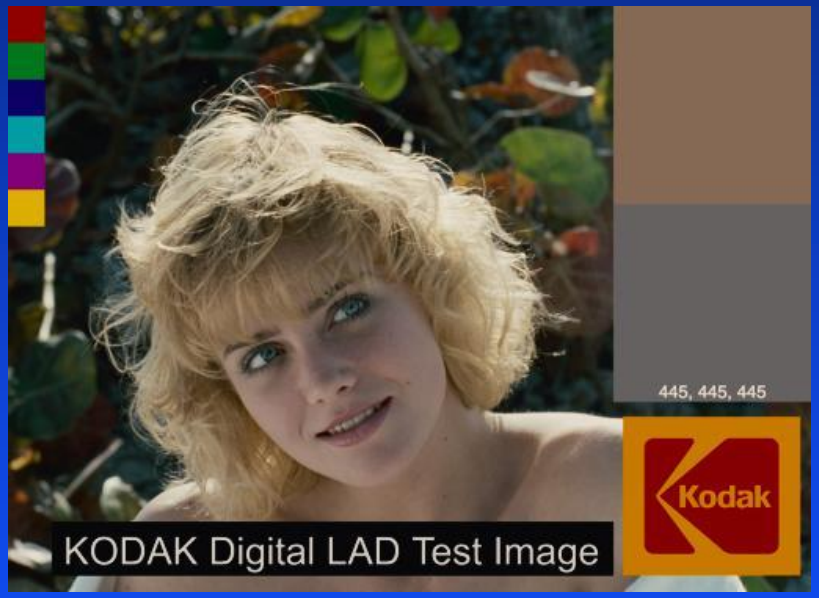


how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)
- increase contrast in log space around middle gray (log(0.18))
- add toe and shoulder to taste (requires knowledge of display)
- darken saturated colors to taste (i.e. to emulate subtractive-color reproduction)



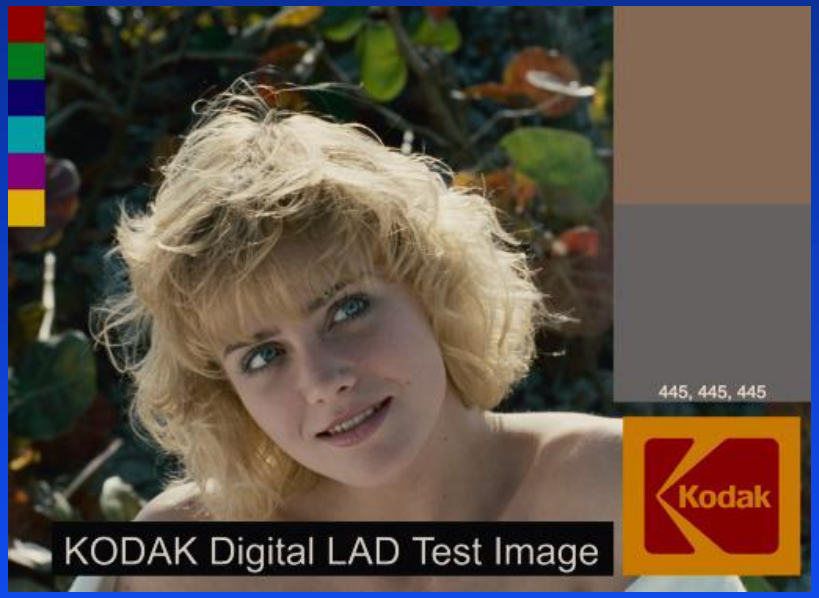
how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)
- increase contrast in log space around middle gray (log(0.18))
- add toe and shoulder to taste (requires knowledge of display)
- darken saturated colors to taste (i.e. to emulate subtractive-color reproduction)

- transform back to lin



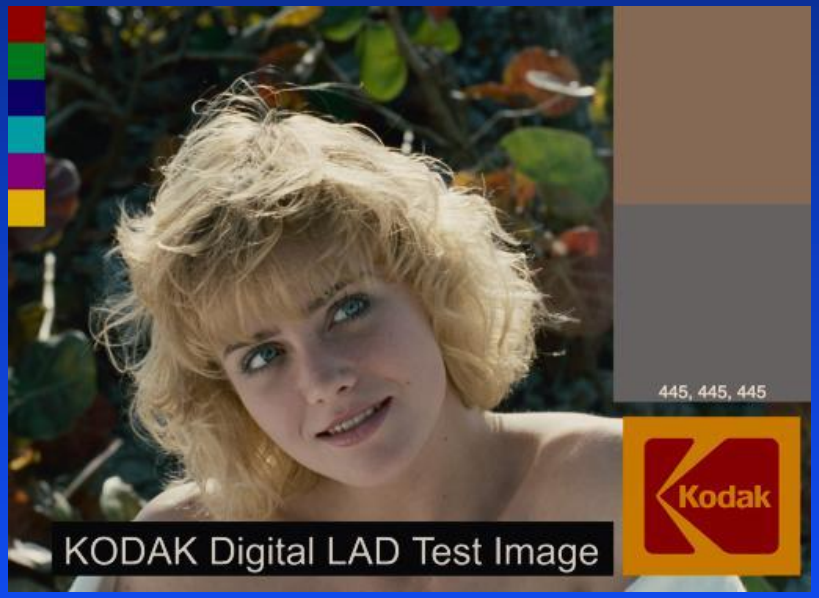
how to build your own rendering transform

- light scene with cgi linear-light (or obtain linear-light image)
- place a "middle gray" 0.18 diffuse reflector "gray card" in scene

---

- scale image accordingly (i.e. "properly set the scene exposure")
- transform to log
- choose dynamic range of "interest" (requires knowledge of display)
- increase contrast in log space around middle gray (log(0.18))
- add toe and shoulder to taste (requires knowledge of display)
- darken saturated colors to taste (i.e. to emulate subtractive-color reproduction)

- transform back to lin
- xform to display space - mapping 0.18 to 0.10 of display maximum



traditional film workflow

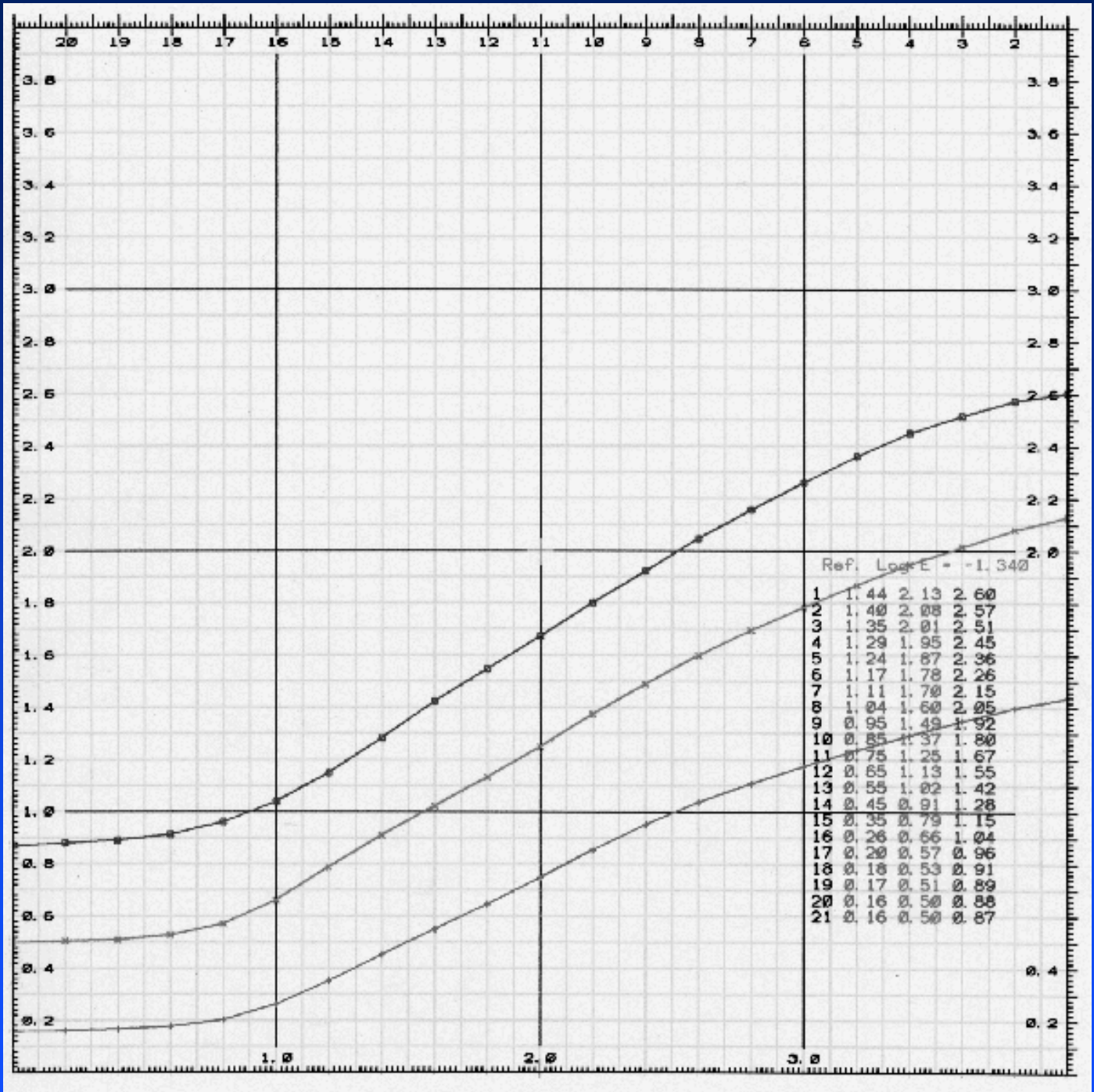
“real world” on-set scene

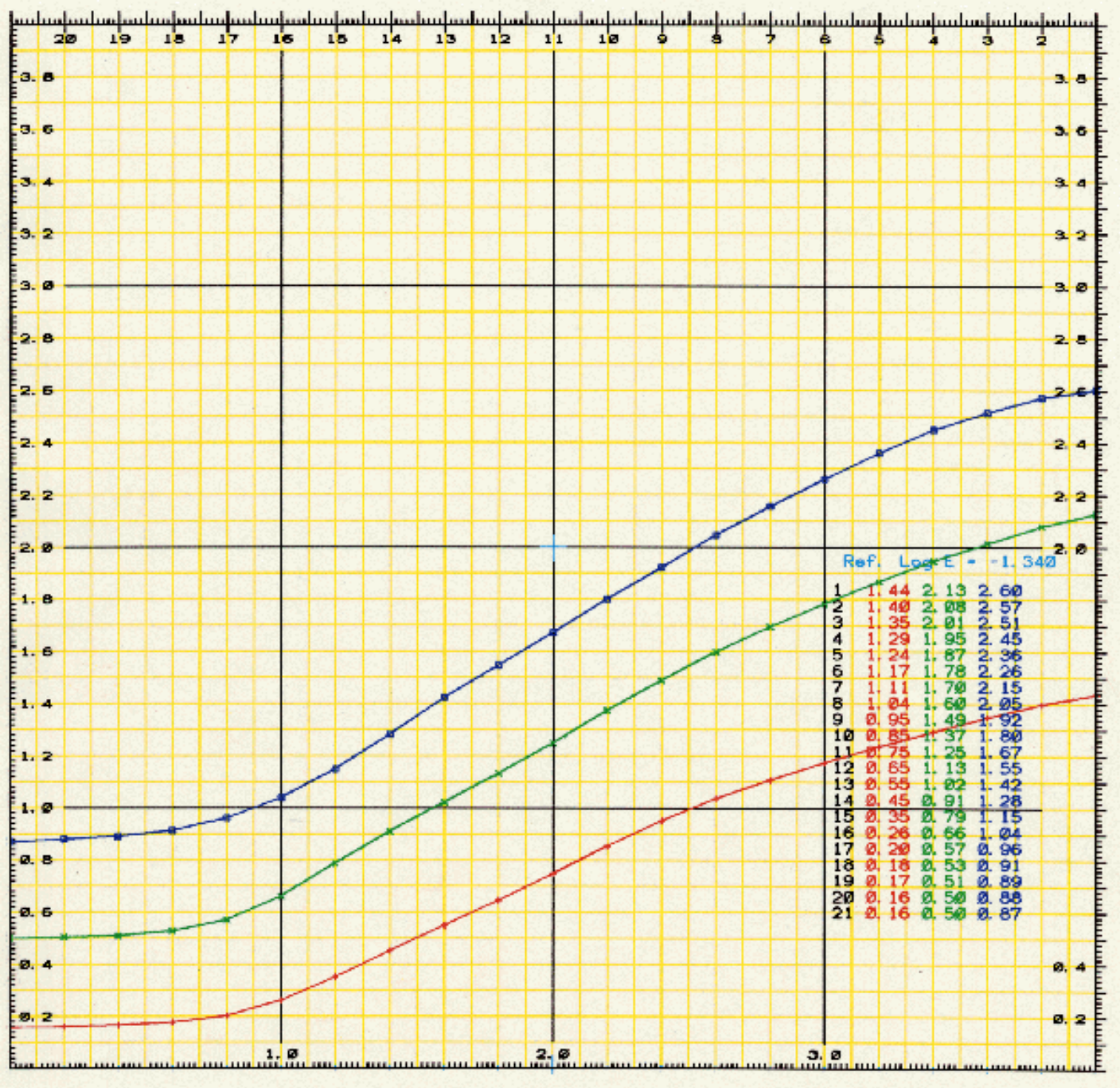
original film negative elements

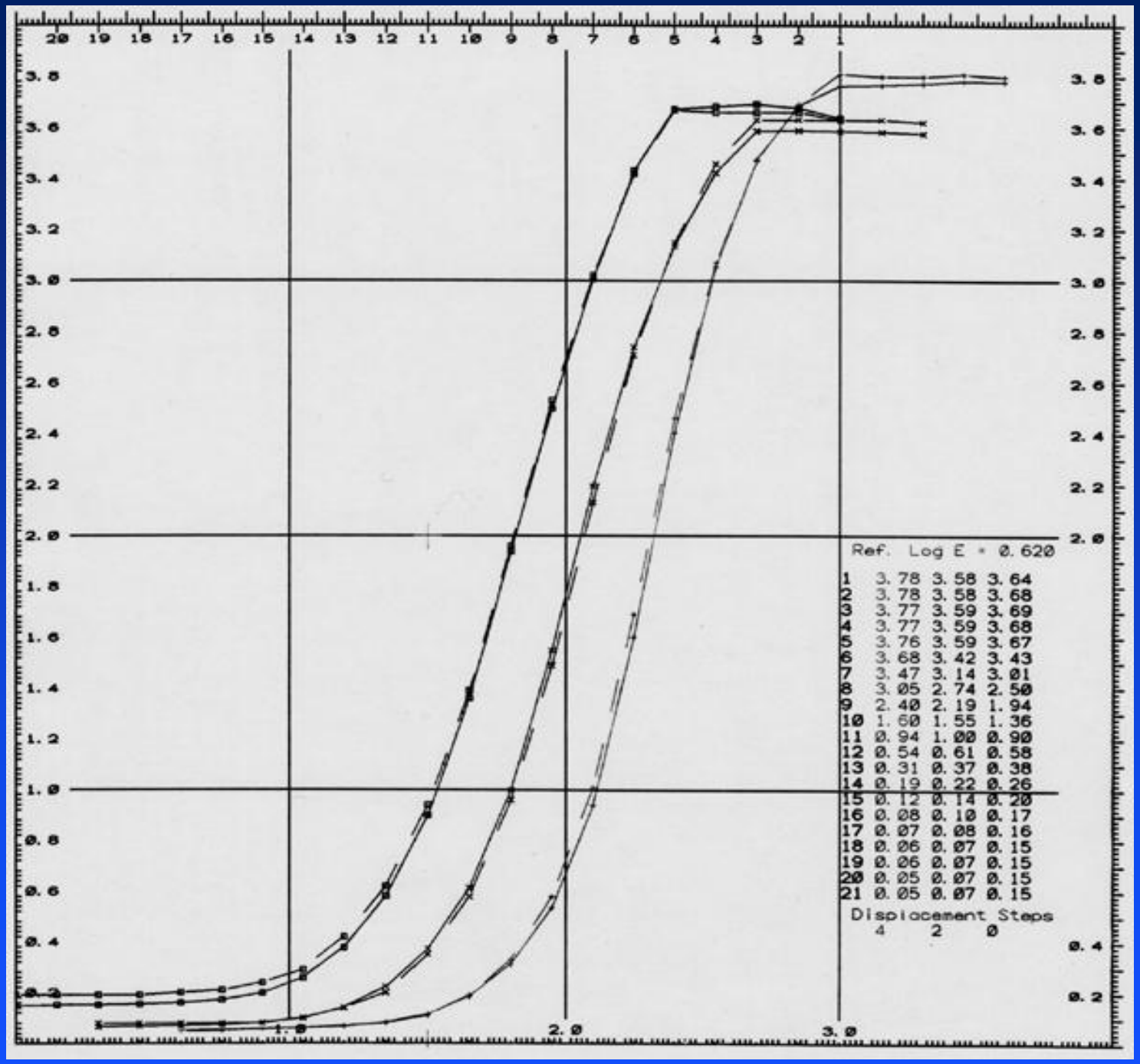
traditional film colour correction

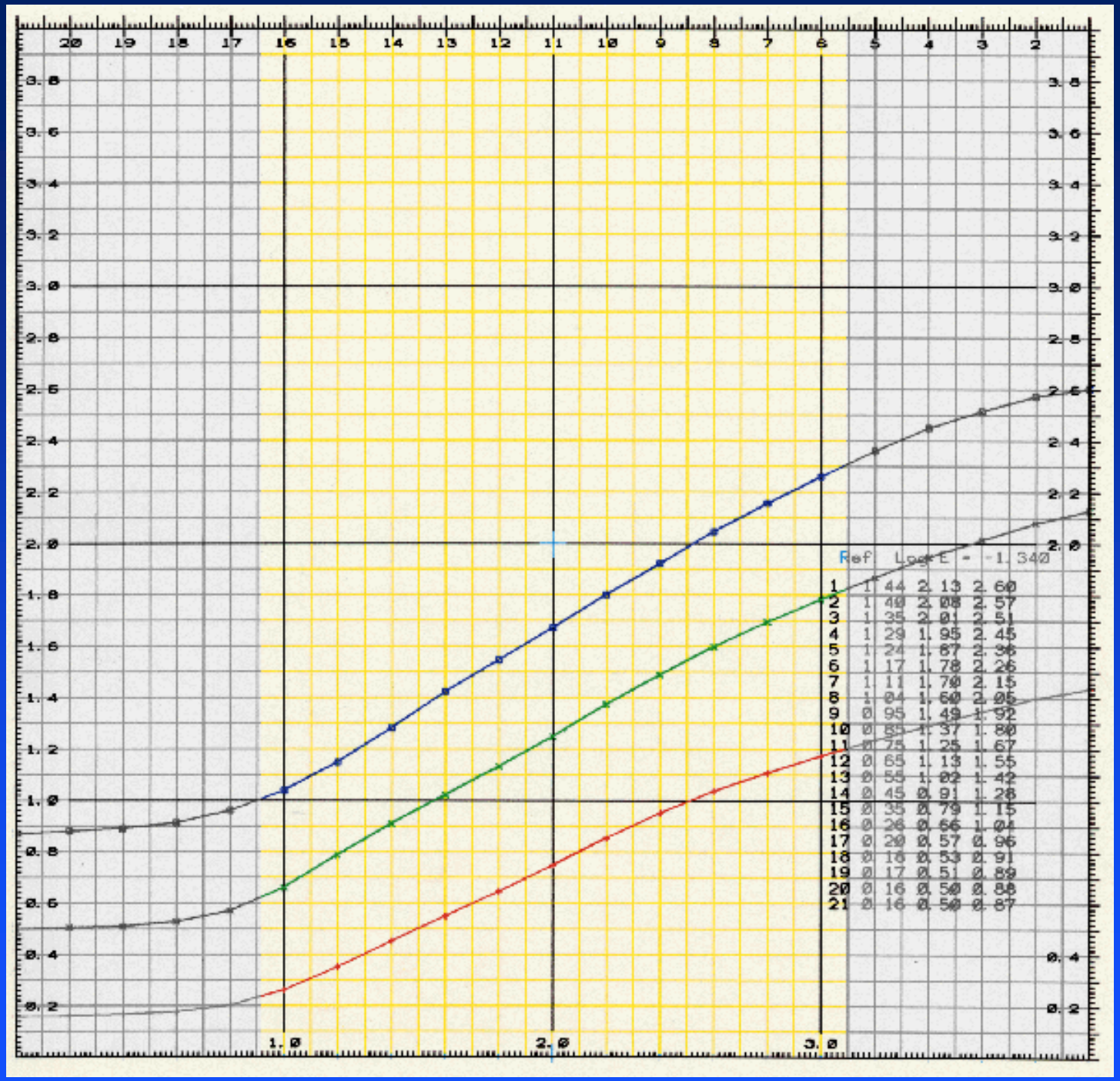
film positive release prints

film projection


20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.0
2.0
3.0
Ref. LogKE = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87


Ref. Log E = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87


20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
1.0
2.0
3.0
Ref. Log E = 0.620
1 3.78 3.58 3.64
2 3.78 3.58 3.68
3 3.77 3.59 3.69
4 3.77 3.59 3.68
5 3.76 3.59 3.67
6 3.68 3.42 3.43
7 3.47 3.14 3.01
8 3.05 2.74 2.50
9 2.40 2.19 1.94
10 1.60 1.55 1.36
11 0.94 1.00 0.90
12 0.54 0.61 0.58
13 0.31 0.37 0.38
14 0.19 0.22 0.26
15 0.12 0.14 0.20
16 0.08 0.10 0.17
17 0.07 0.08 0.16
18 0.06 0.07 0.15
19 0.06 0.07 0.15
20 0.05 0.07 0.15
21 0.05 0.07 0.15
Displacement Steps
4 2 0


Ref Log E = -1.340
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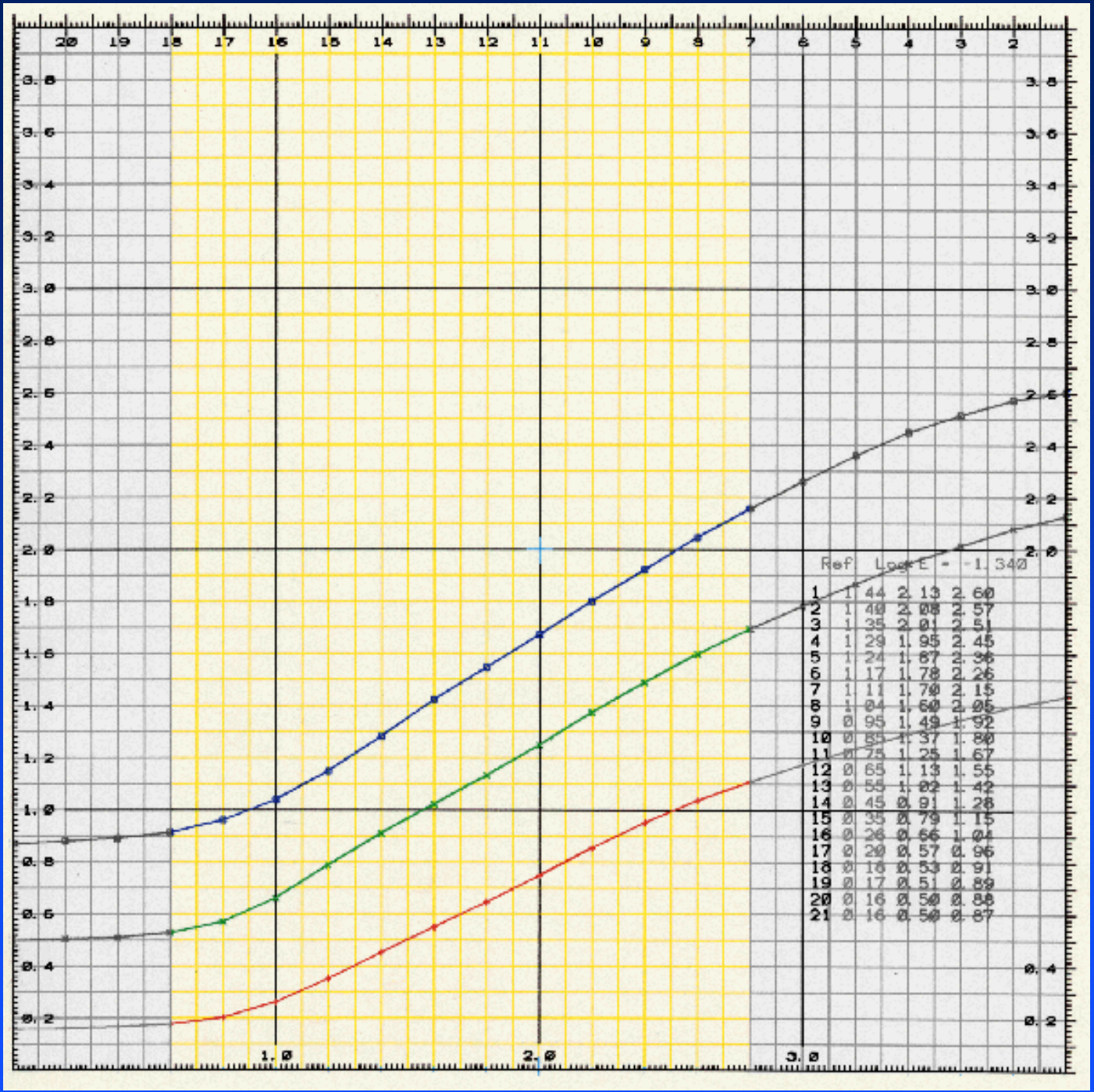
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87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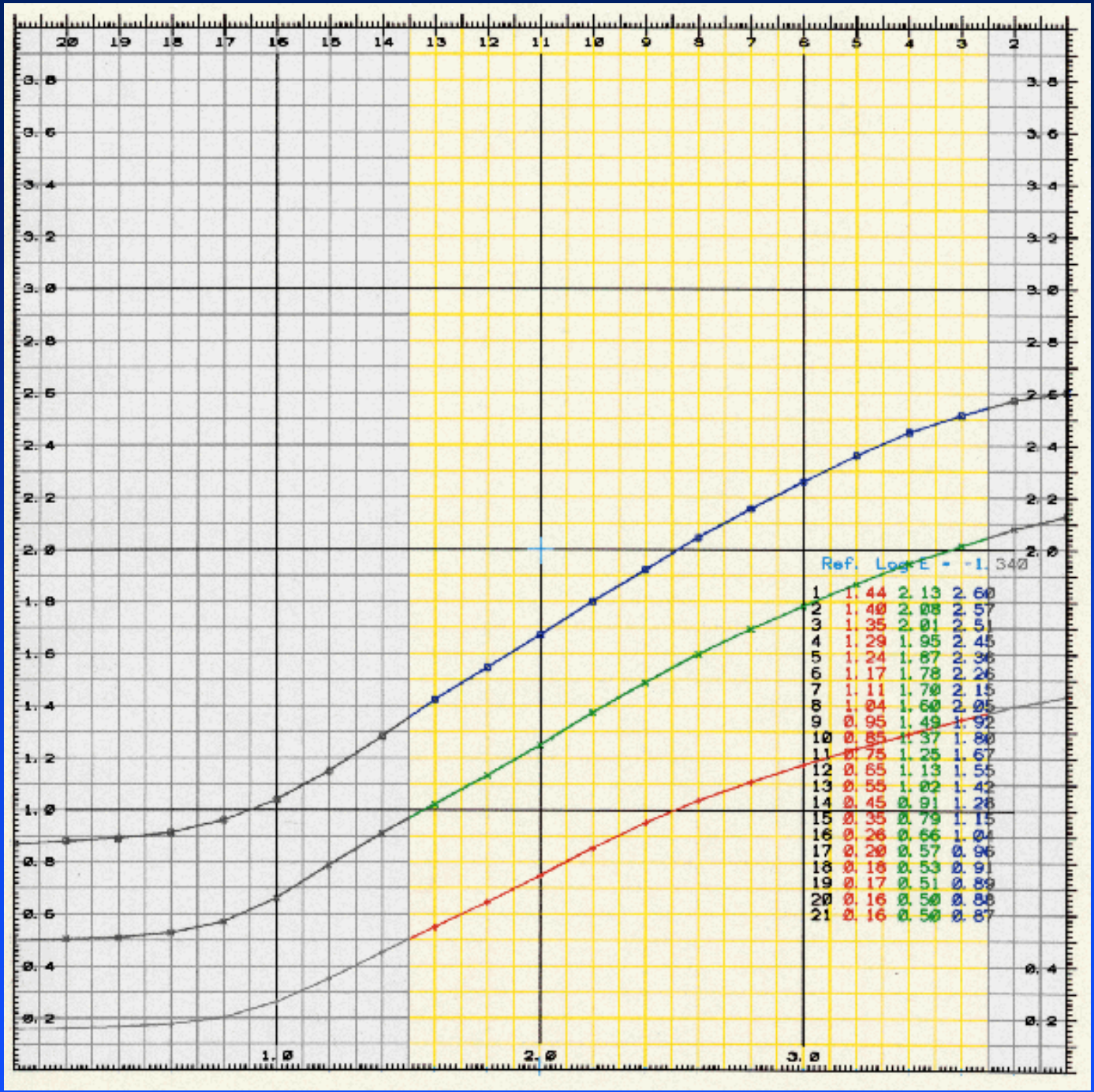
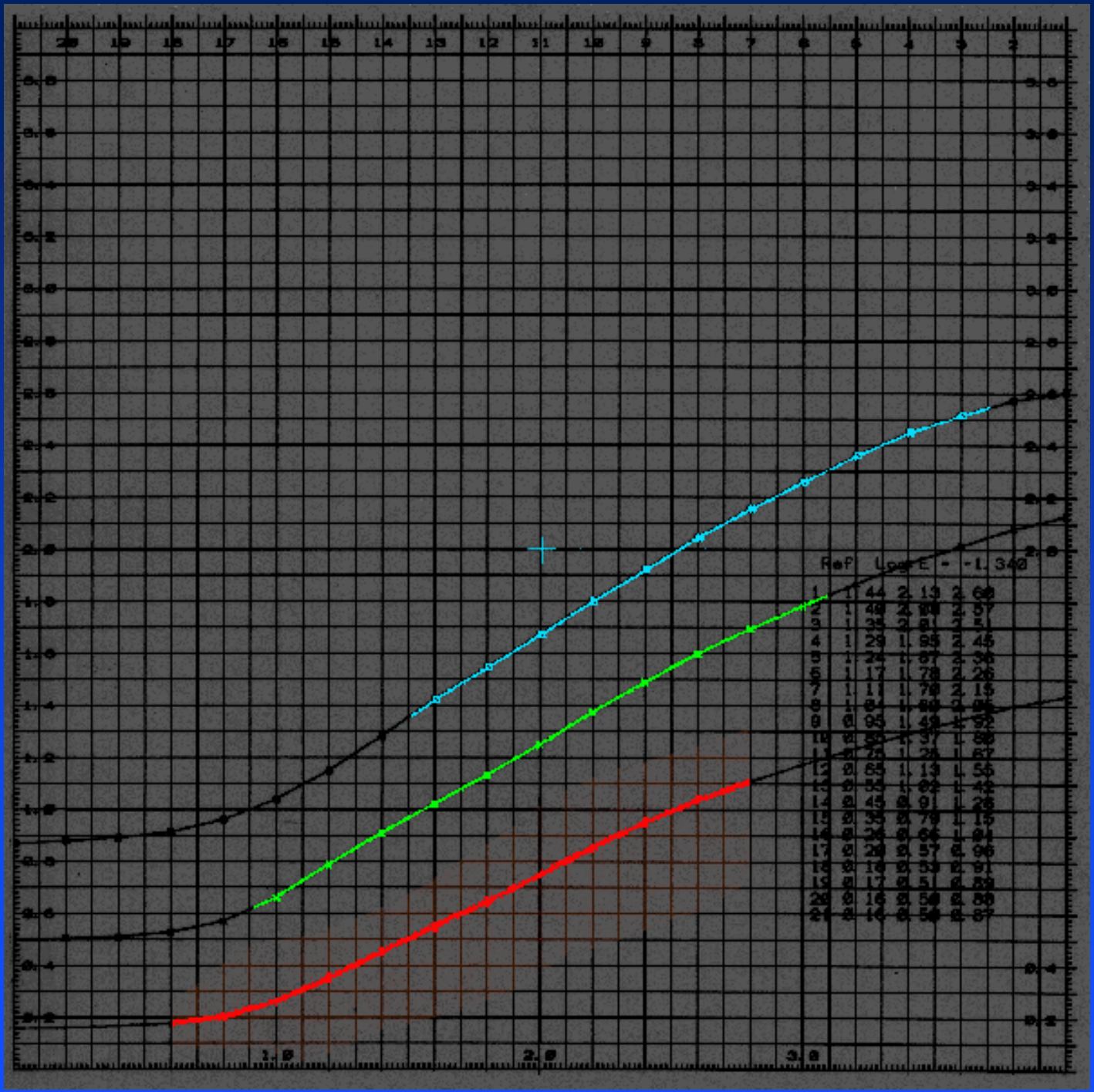
3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2
1.0 2.0 3.0
Ref LogE = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87

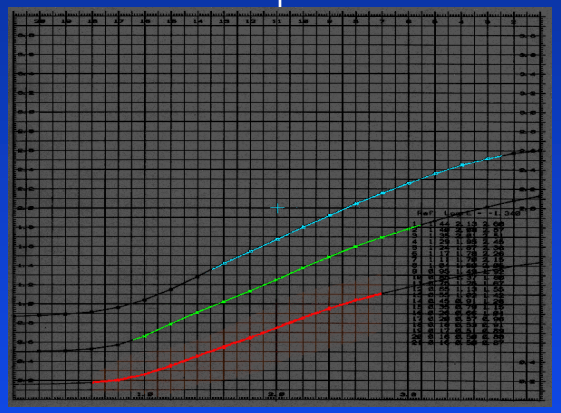

Ref. Log E = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87


20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2
1.0
2.0
3.0
RaP LogE - -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.93 2.45
5 1.24 1.87 2.38
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.86 1.37 1.80
11 0.76 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.36 0.79 1.15
16 0.26 0.66 1.01
17 0.20 0.57 0.96
18 0.16 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.14 0.50 0.87

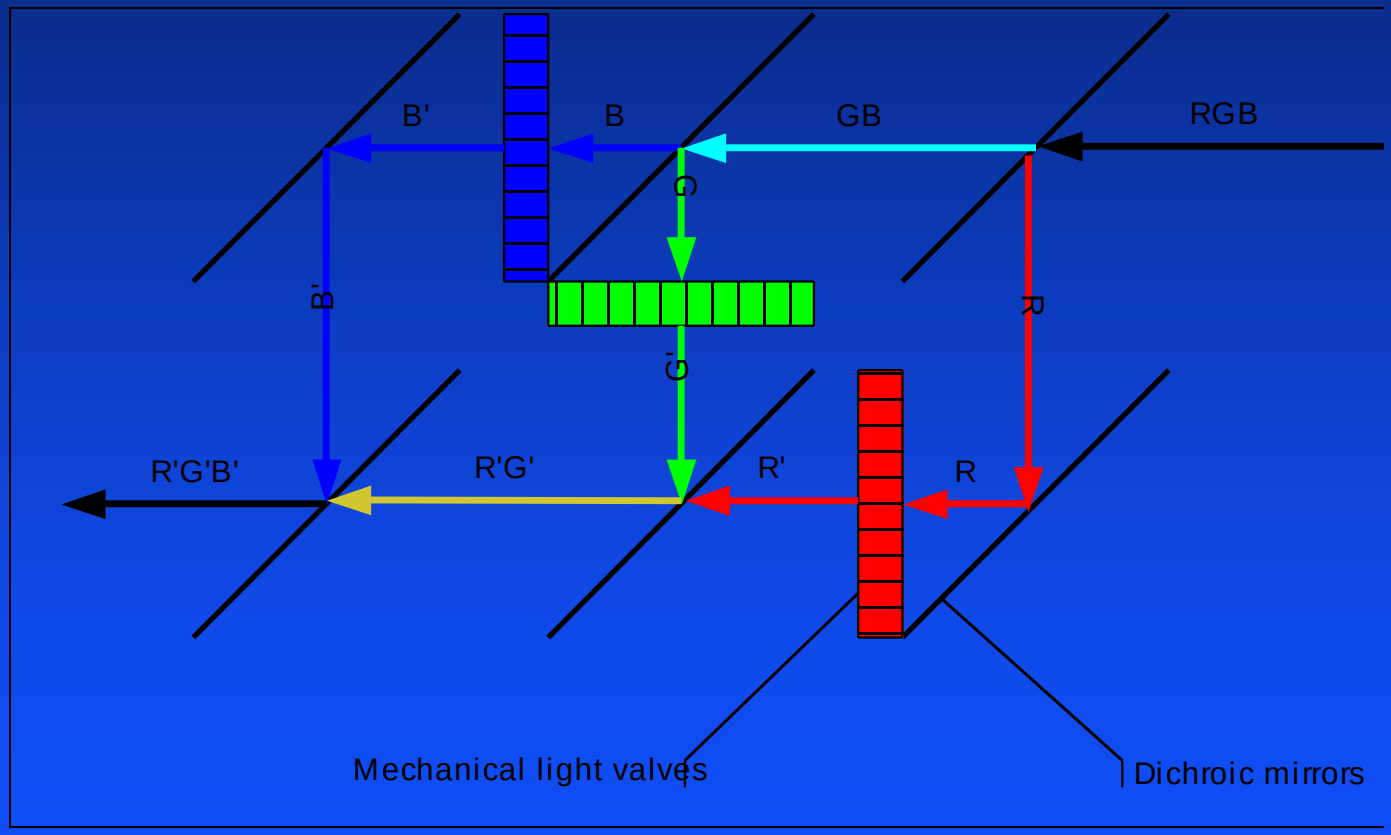
original film elements

traditional film colour correction

film answer prints

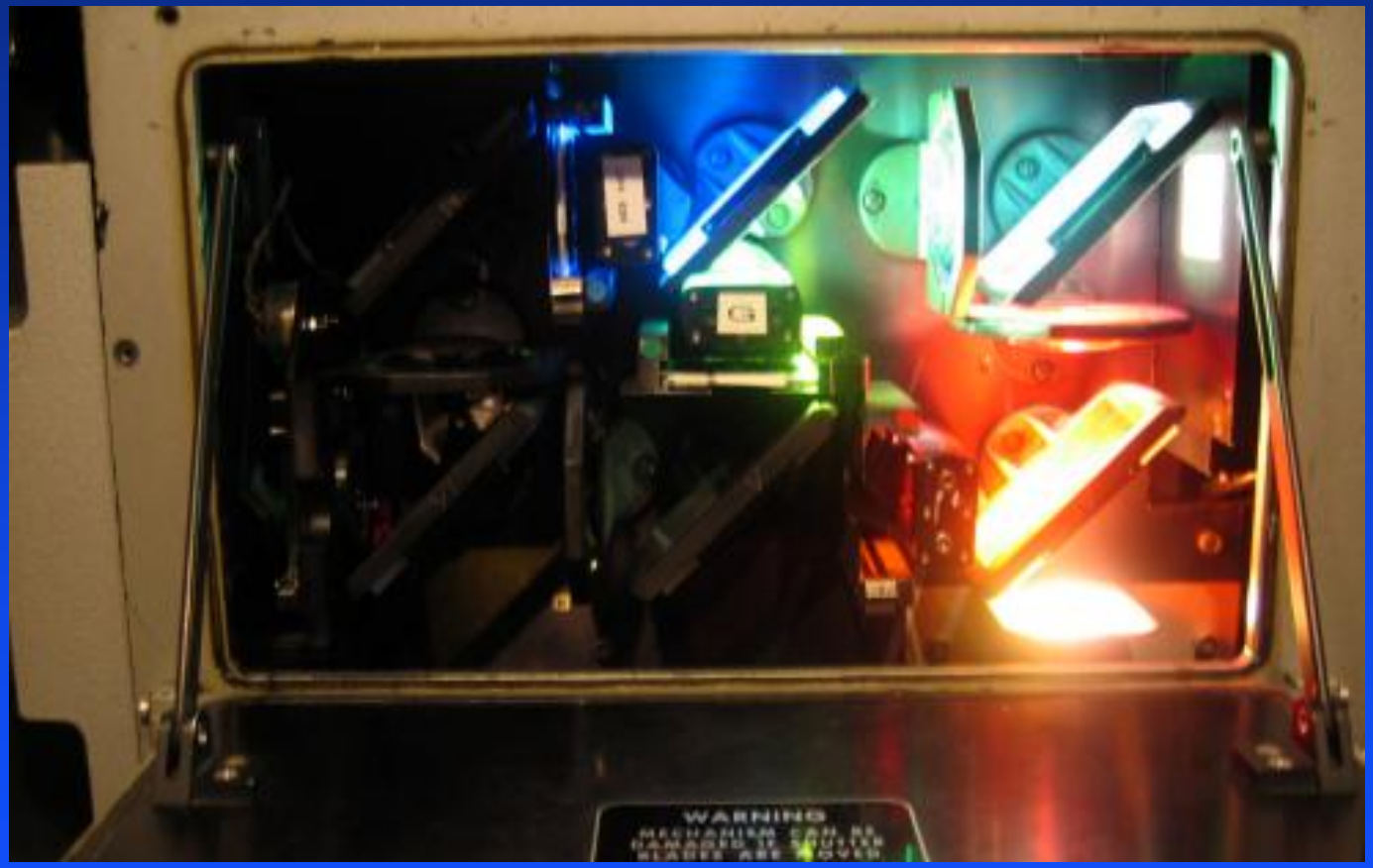


colour grading optical system



Color grading optical system. Schematic view.

colour grading optical system



“ppt” secret decoder ring

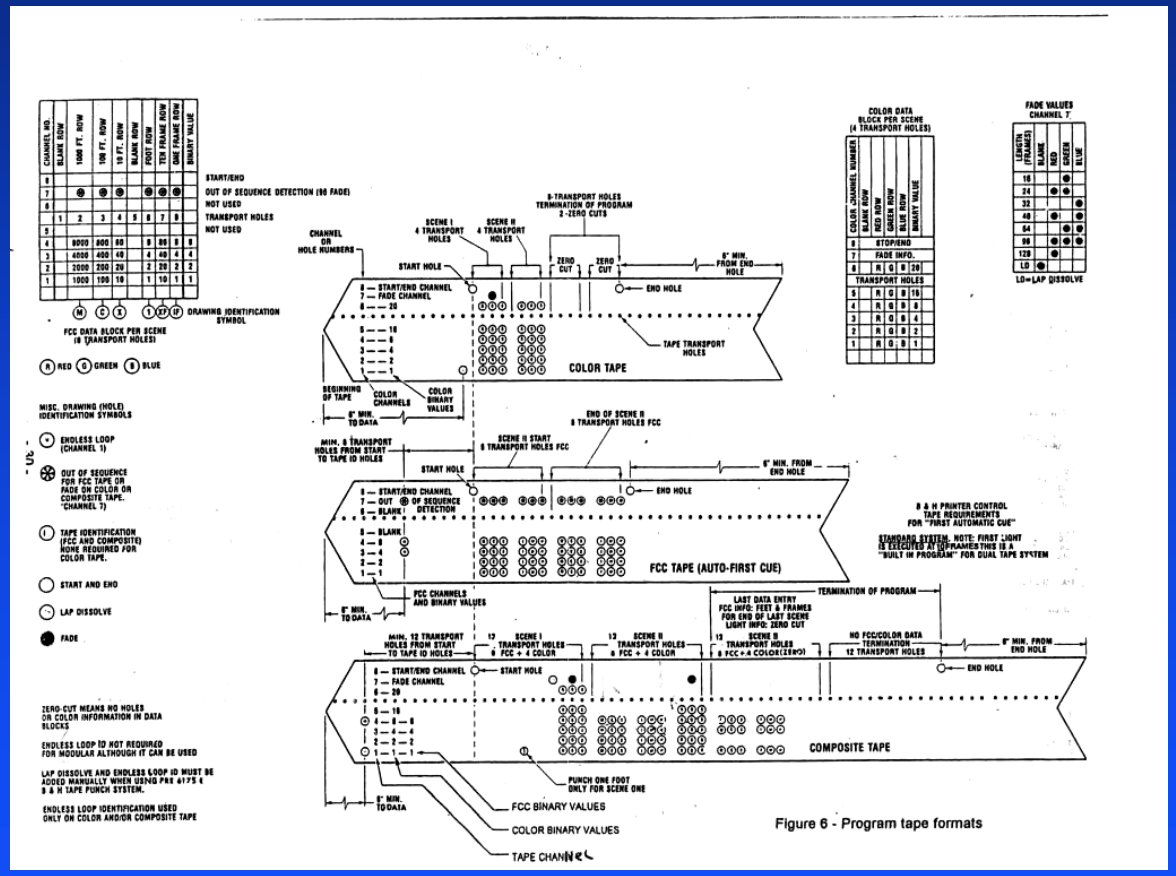


Figure 6 - Program tape formats

“ppt” secret decoder ring

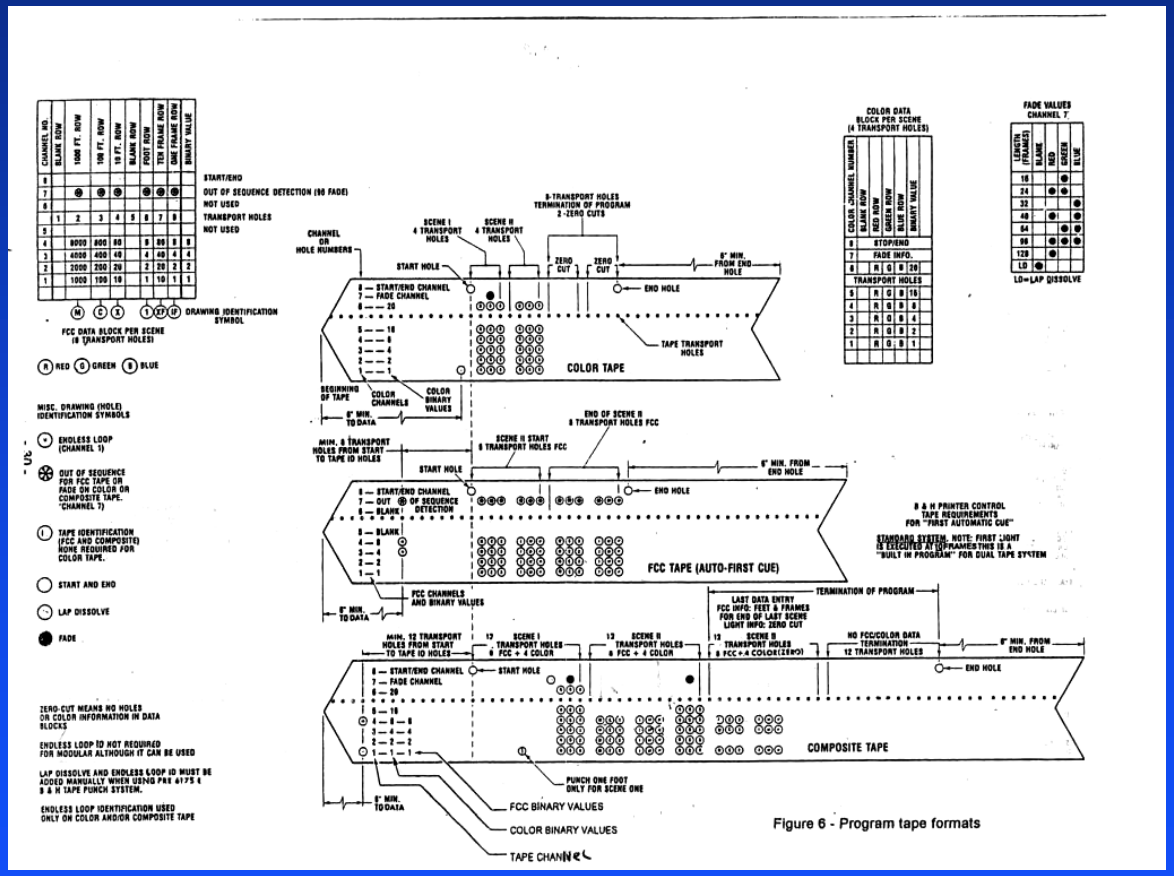
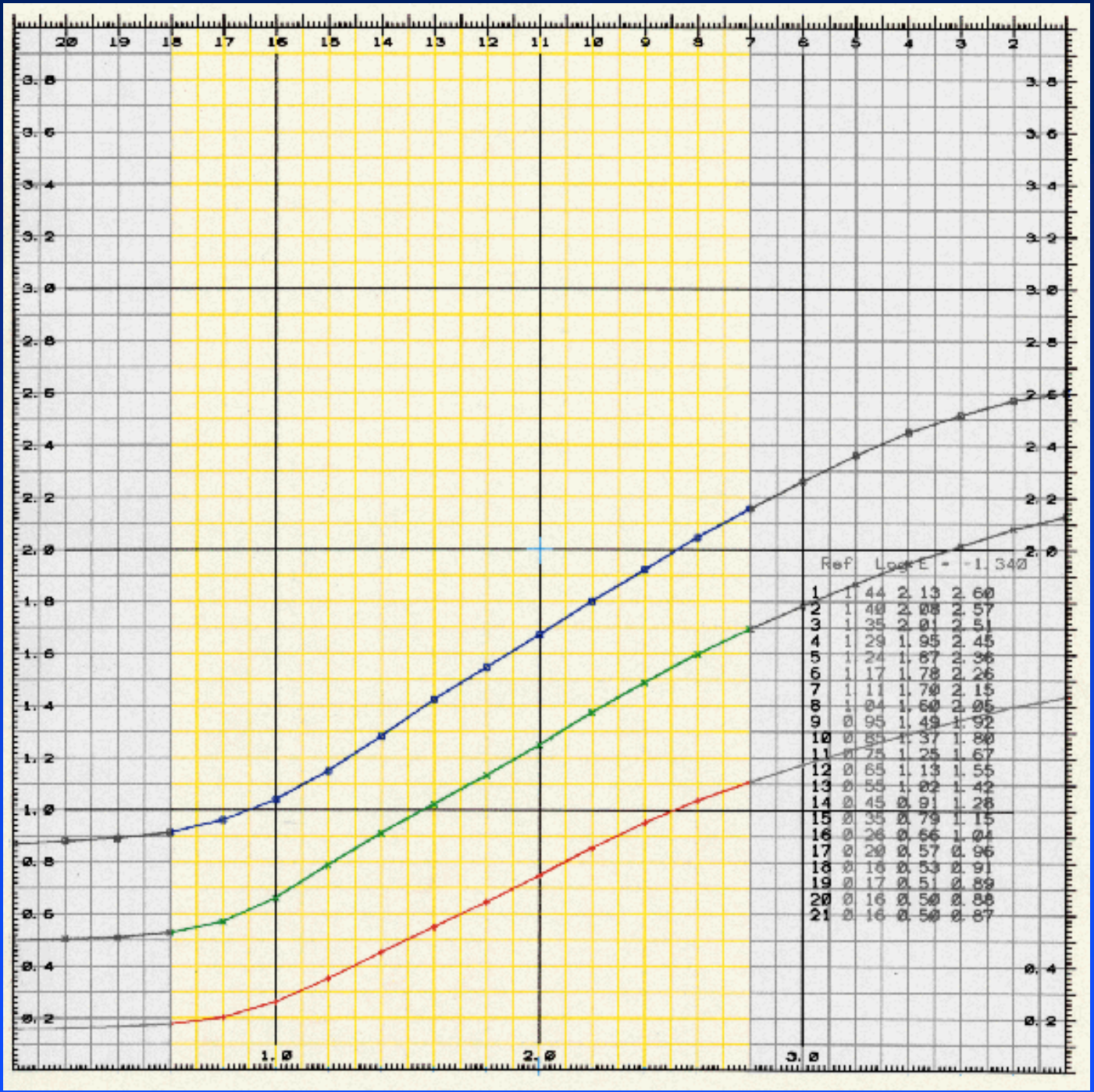
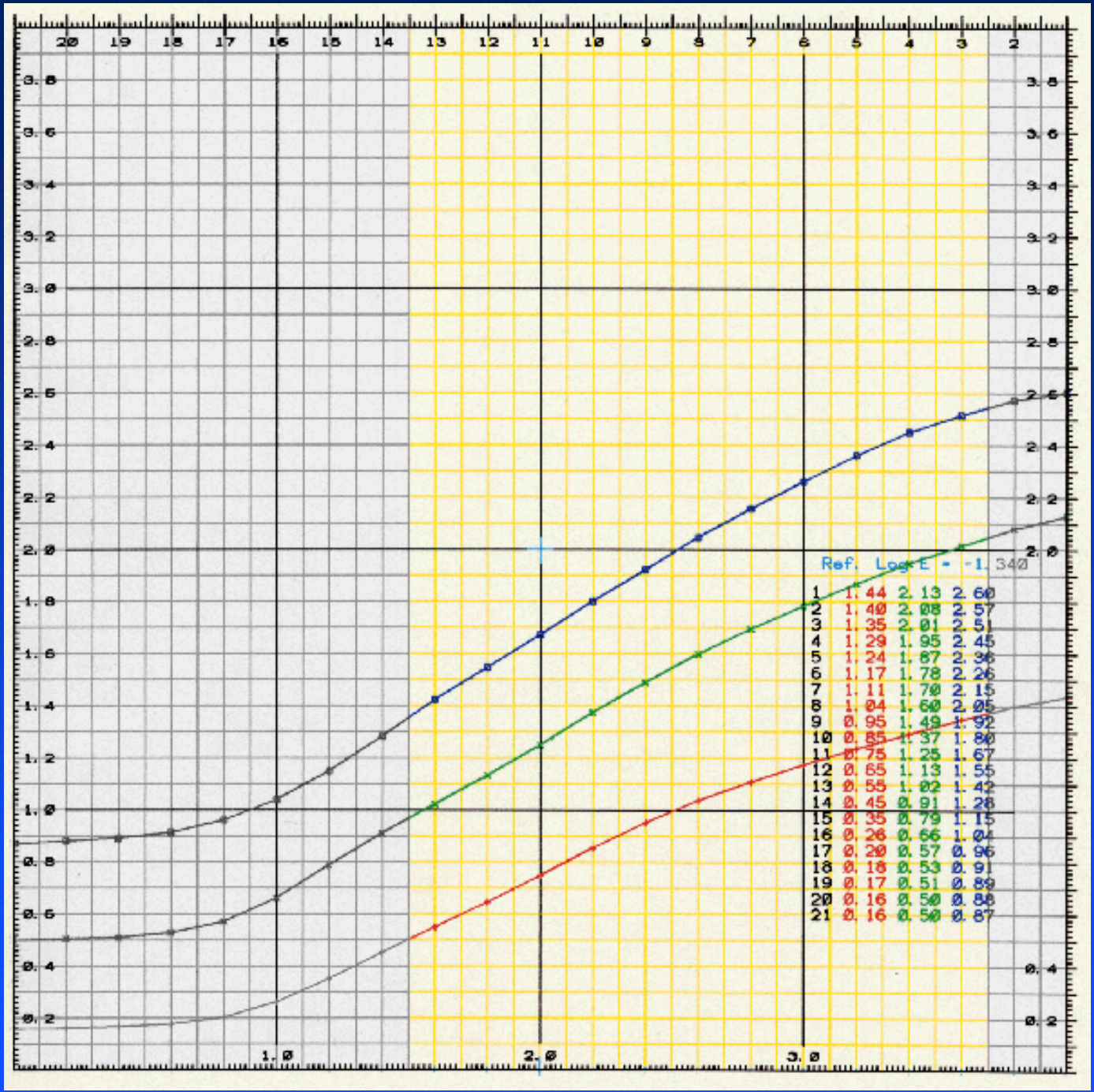


Figure 6 - Program tape formats

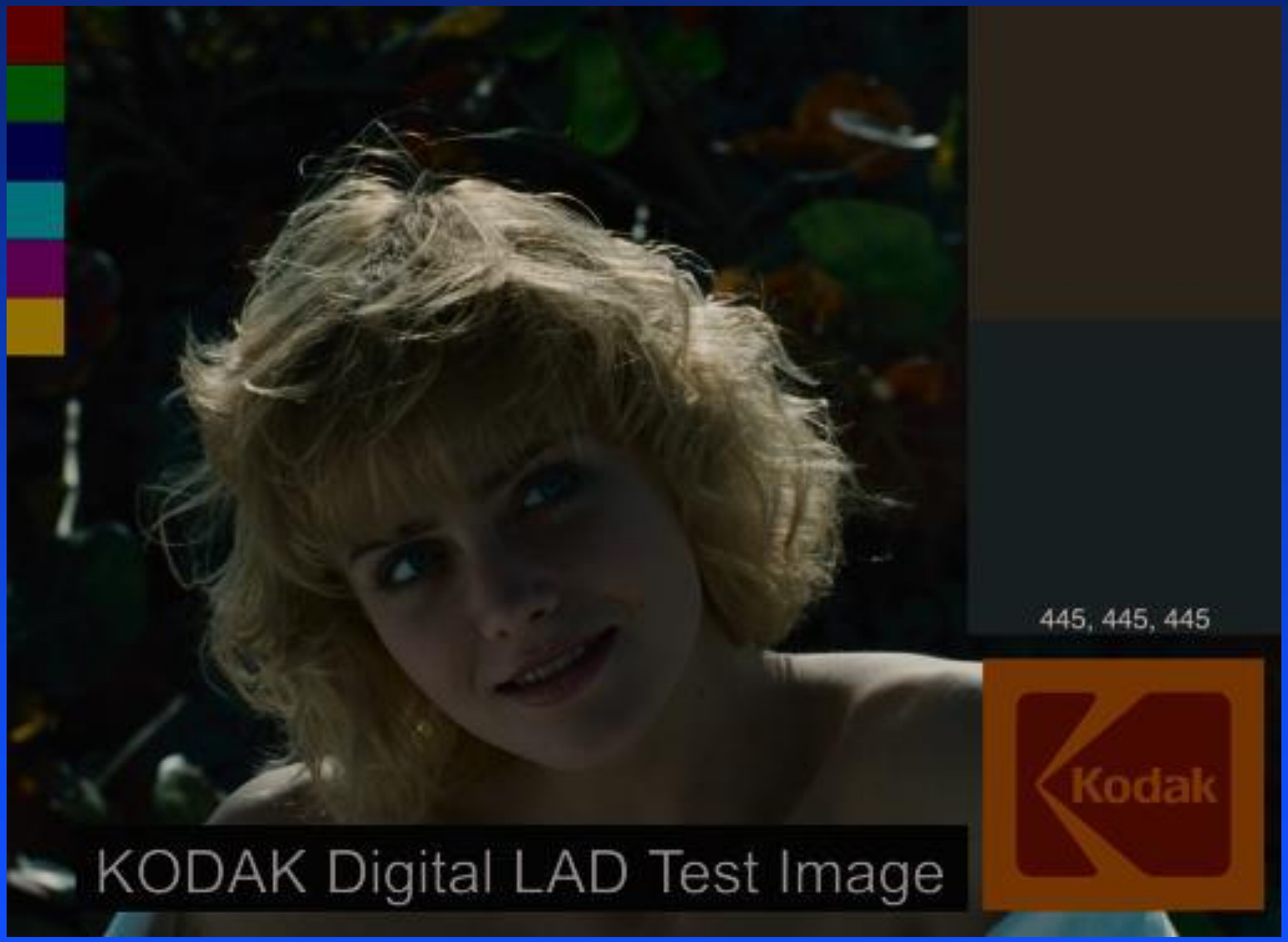
“…i never met a data i didn’t like…”


20 19 18 17 16 15 14 13 12 11 10 9 8 7 6 5 4 3 2
3.8 3.6 3.4 3.2 3.0 2.8 2.6 2.4 2.2 2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2
1.0 2.0 3.0
Ref LogE = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87

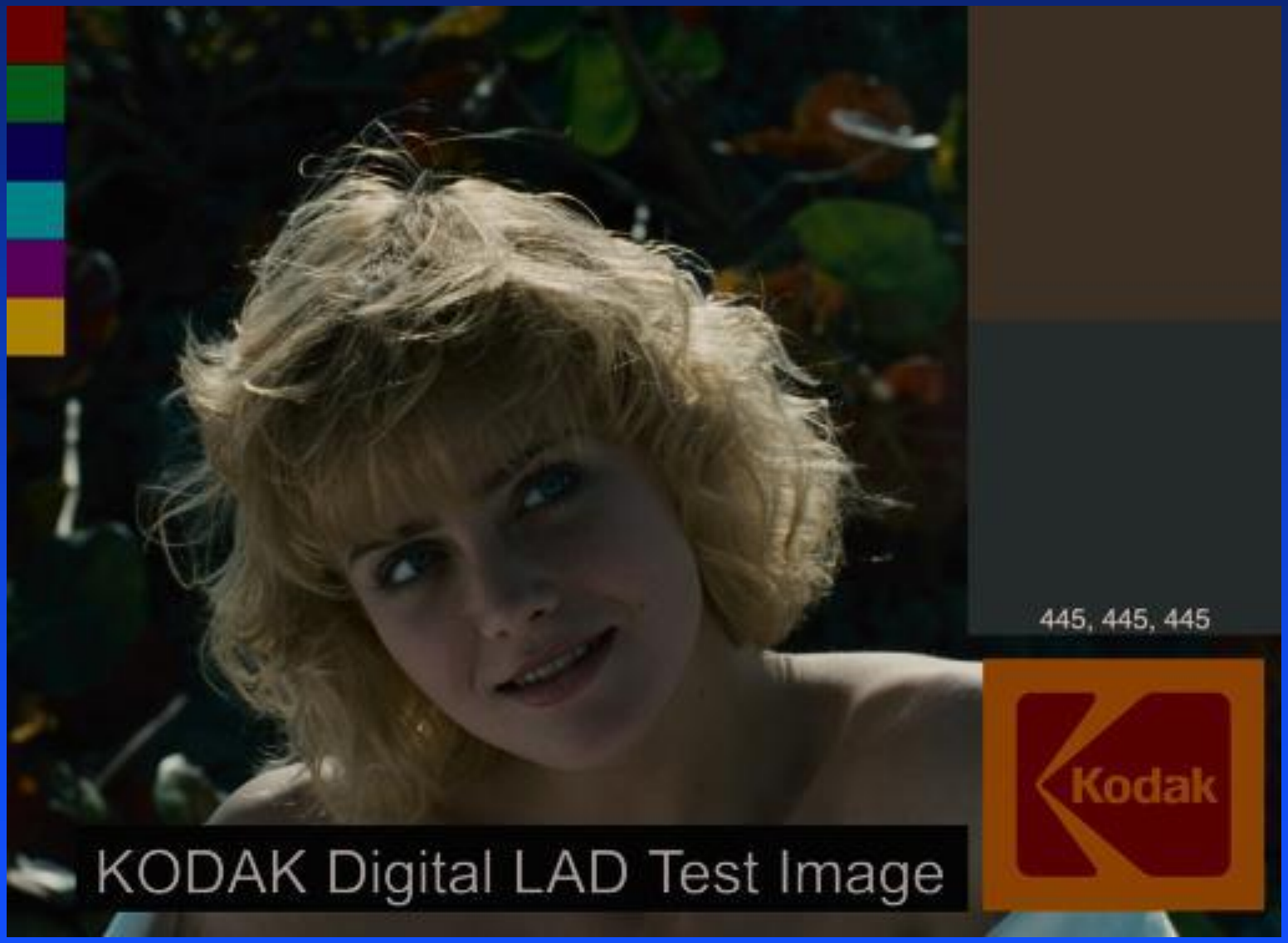

Ref. Log E = -1.340
1 1.44 2.13 2.60
2 1.40 2.08 2.57
3 1.35 2.01 2.51
4 1.29 1.95 2.45
5 1.24 1.87 2.36
6 1.17 1.78 2.26
7 1.11 1.70 2.15
8 1.04 1.60 2.05
9 0.95 1.49 1.92
10 0.85 1.37 1.80
11 0.75 1.25 1.67
12 0.65 1.13 1.55
13 0.55 1.02 1.42
14 0.45 0.91 1.28
15 0.35 0.79 1.15
16 0.26 0.66 1.04
17 0.20 0.57 0.96
18 0.18 0.53 0.91
19 0.17 0.51 0.89
20 0.16 0.50 0.88
21 0.16 0.50 0.87

print +0.0 stops

print -2.0 stops



print -1.5 stops



print -1.0 stop

print -0.5 stop

print +0.0 stops

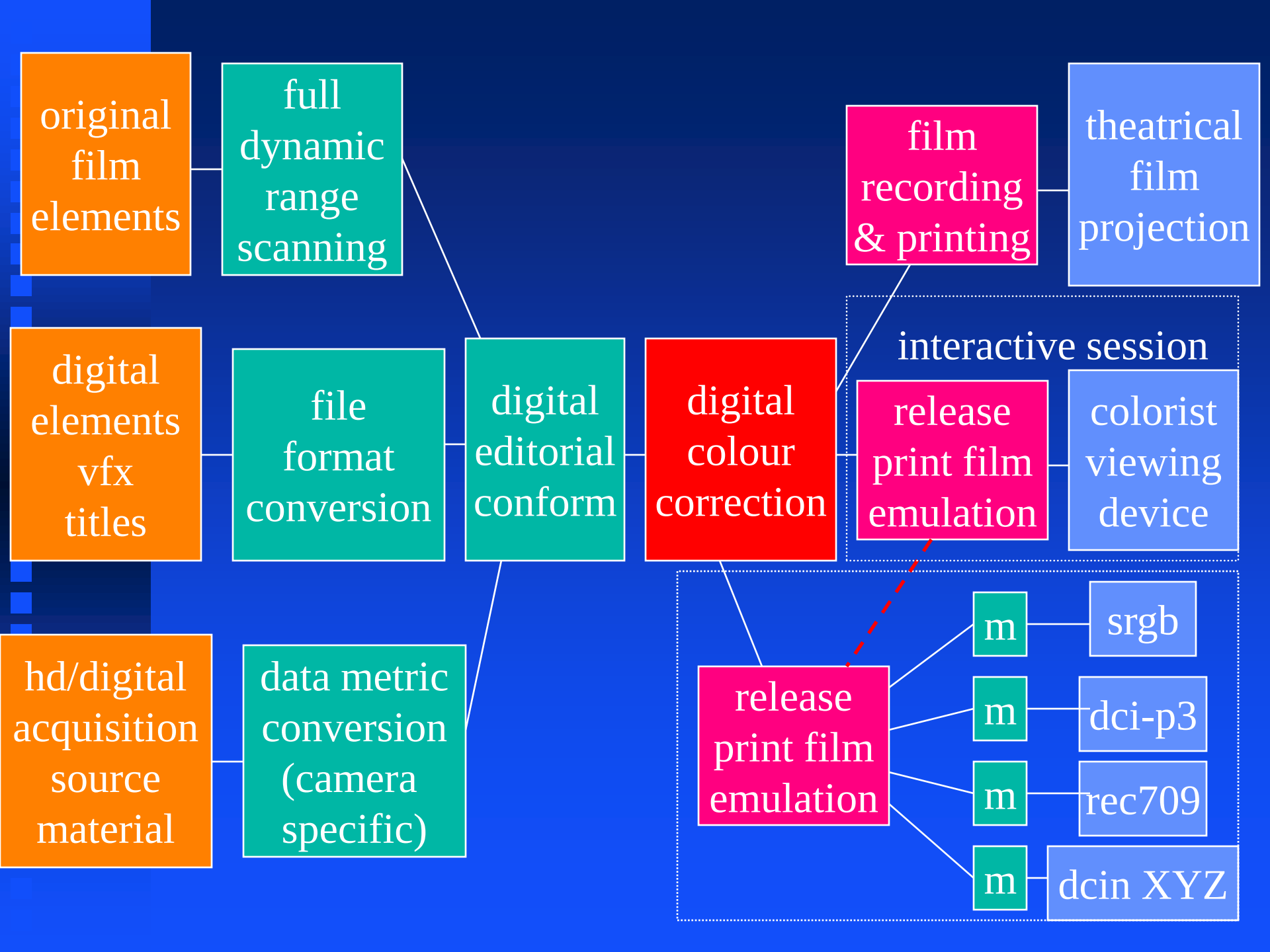
print +0.5 stop

print +1.0 stop

print +1.5 stops

print +2.0 stops

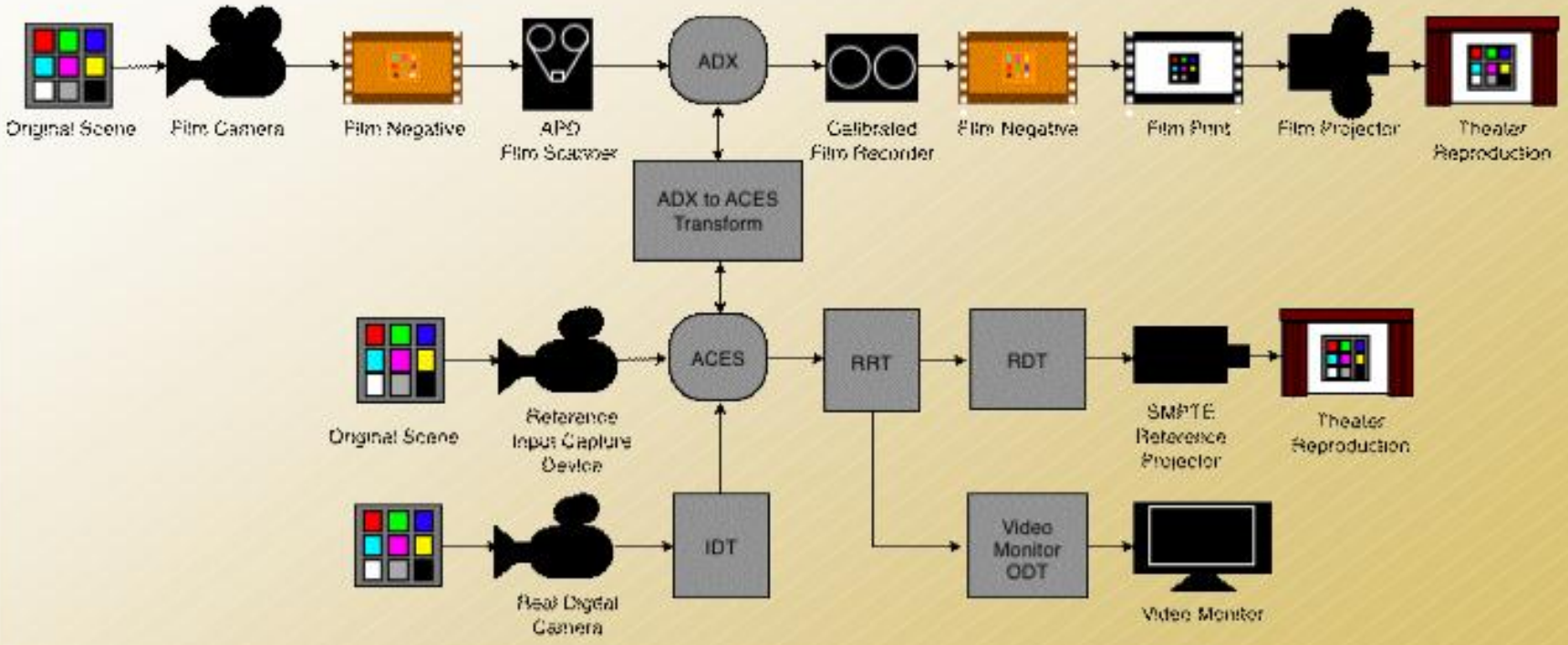
digital intermediate workflow


original film elements
full dynamic range scanning
digital elements vfx titles
file format conversion
hd/digital acquisition source material
data metric conversion (camera specific)
digital editorial conform
digital colour correction
film recording & printing
theatrical film projection
interactive session
release print film emulation
colorist viewing device
release print film emulation
m
srgb
m
dci-p3
m
rec709
m
dcin XYZ

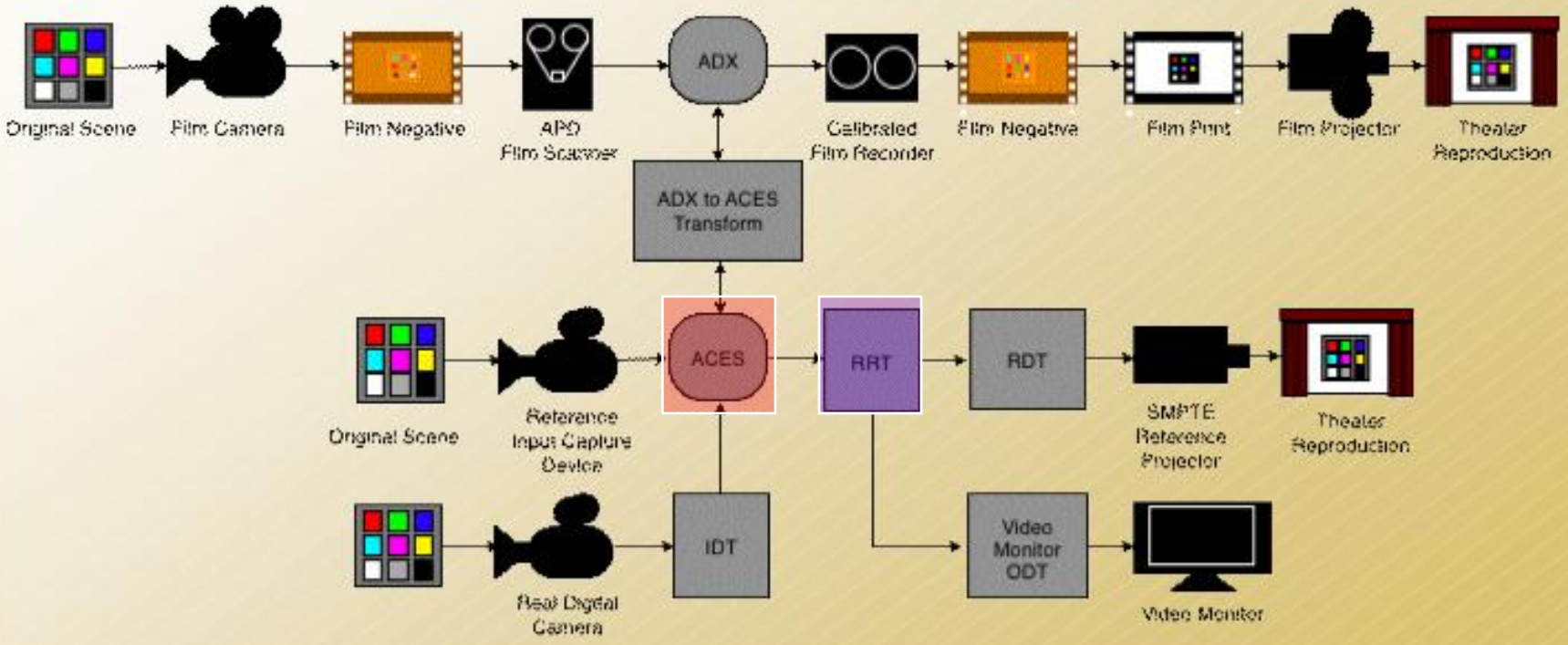
“null” colour correction

“bleach bypass” colour correction (extreme hicon + desat)

Idealized System



Idealized System



scene space vs. display space

scene space vs. display space

- “input referred”
- “output referred”

scene space vs. display space

- “input referred”
- cgi "rendering"

- “output referred”
- photoshop

scene space vs. display space

- “input referred”
- cgi "rendering"
- the laws of physics

- “output referred”
- photoshop
- the talents of artists

scene space vs. display space

- “input referred”
- cgi "rendering"
- the laws of physics
- high dynamic range

- “output referred”
- photoshop
- the talents of artists
- limited dynamic range

scene space vs. display space

- “input referred”
- cgi "rendering"
- the laws of physics
- high dynamic range
- 18% diffuse reflector

- “output referred”
- photoshop
- the talents of artists
- limited dynamic range
- 10% of max intensity

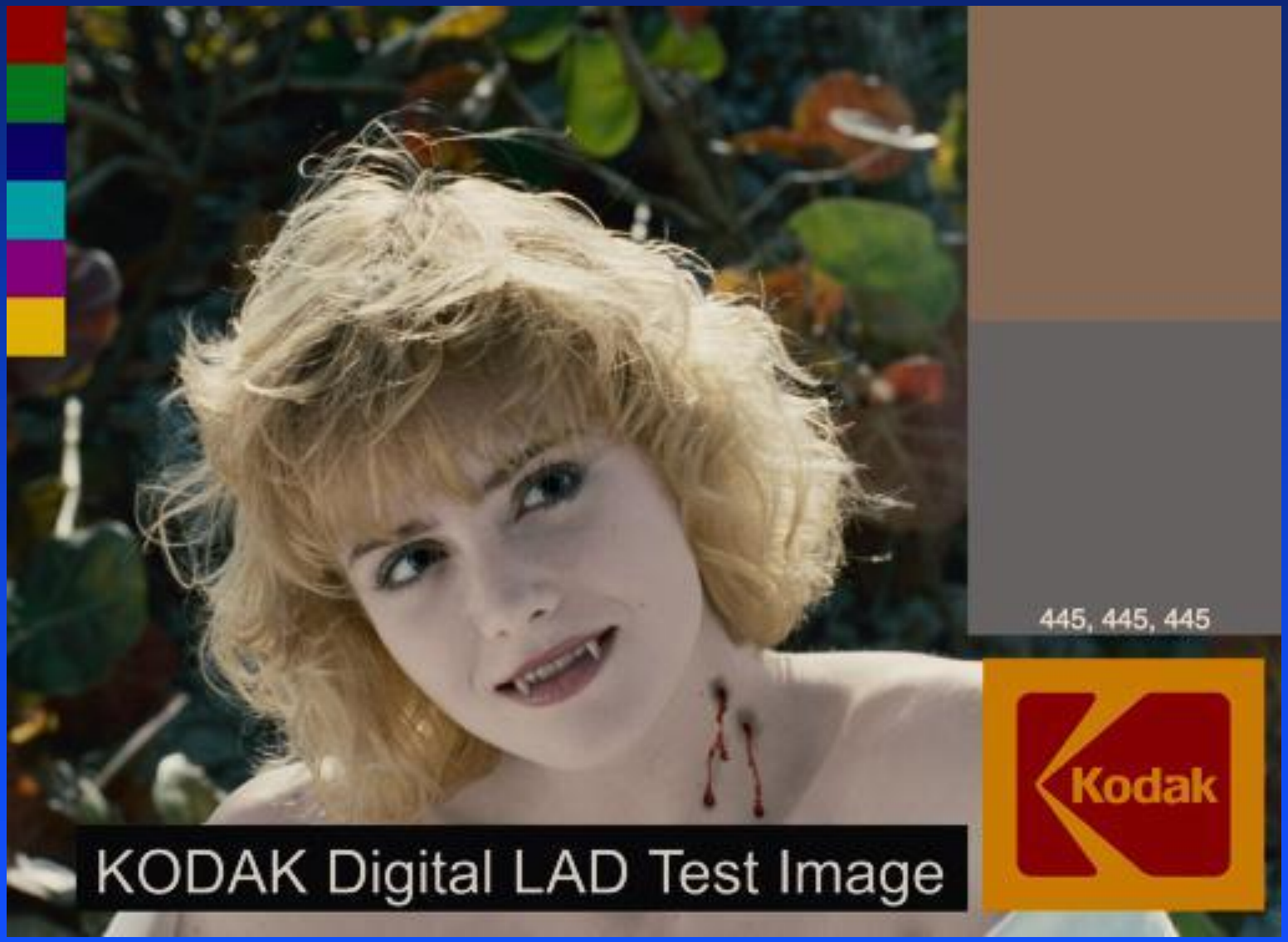
scene space vs. display space

- “input referred”
- cgi "rendering"
- the laws of physics
- high dynamic range
- 18% diffuse reflector
- werewolves(powerful)

- “output referred”
- photoshop
- the talents of artists
- limited dynamic range
- 10% of max intensity
- vampires(sexy)

real film print emulation

vampire film print emulation




The End