Welcome to the Fifth Almost-Annual Better Light Owners' Conference

…it's gonna be HOT!!

COLOR ACCURACY

more than you ever wanted to know

- including -

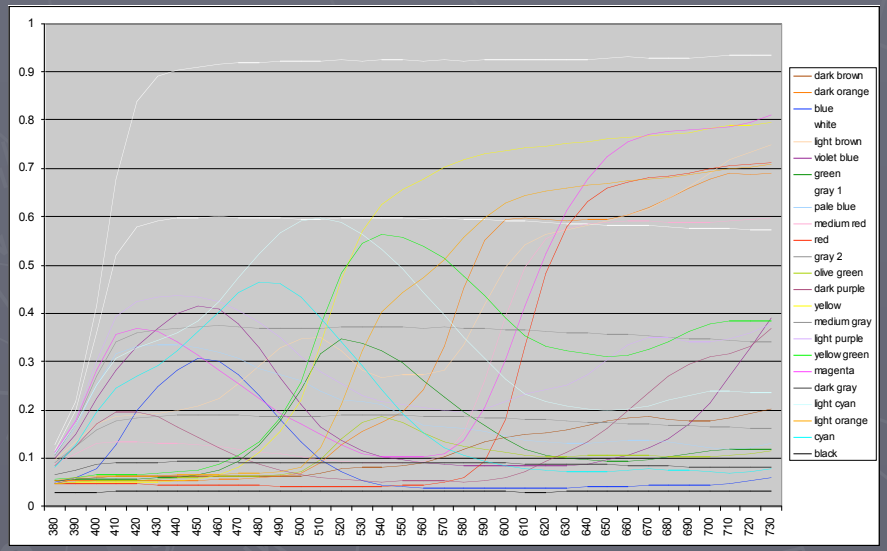
how to improve your camera profile

“Color Accuracy”…

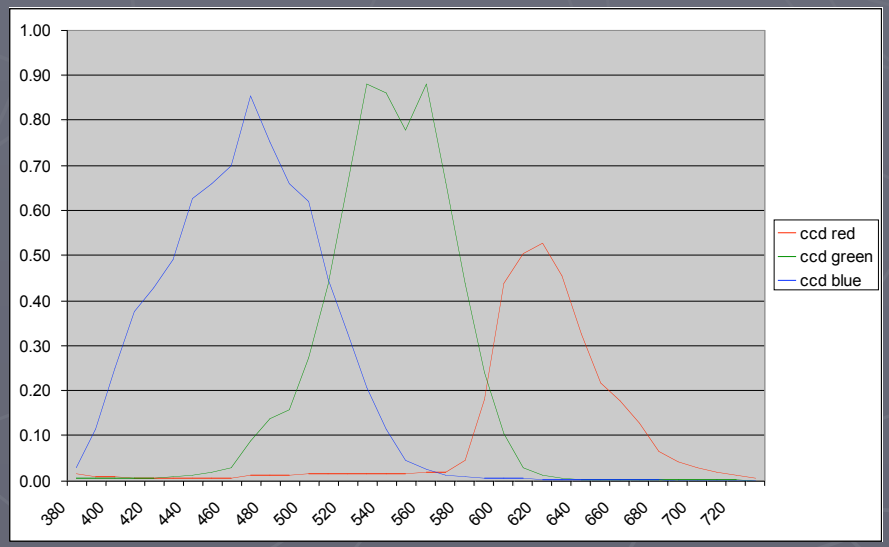
- How accurately does a device render color?
- …compared to what?
- …under what conditions?
- …using what terminology?

Spectral response method

compares the actual response of a device with its theoretical response, based on spectral data for the reference chart being used, and for the device

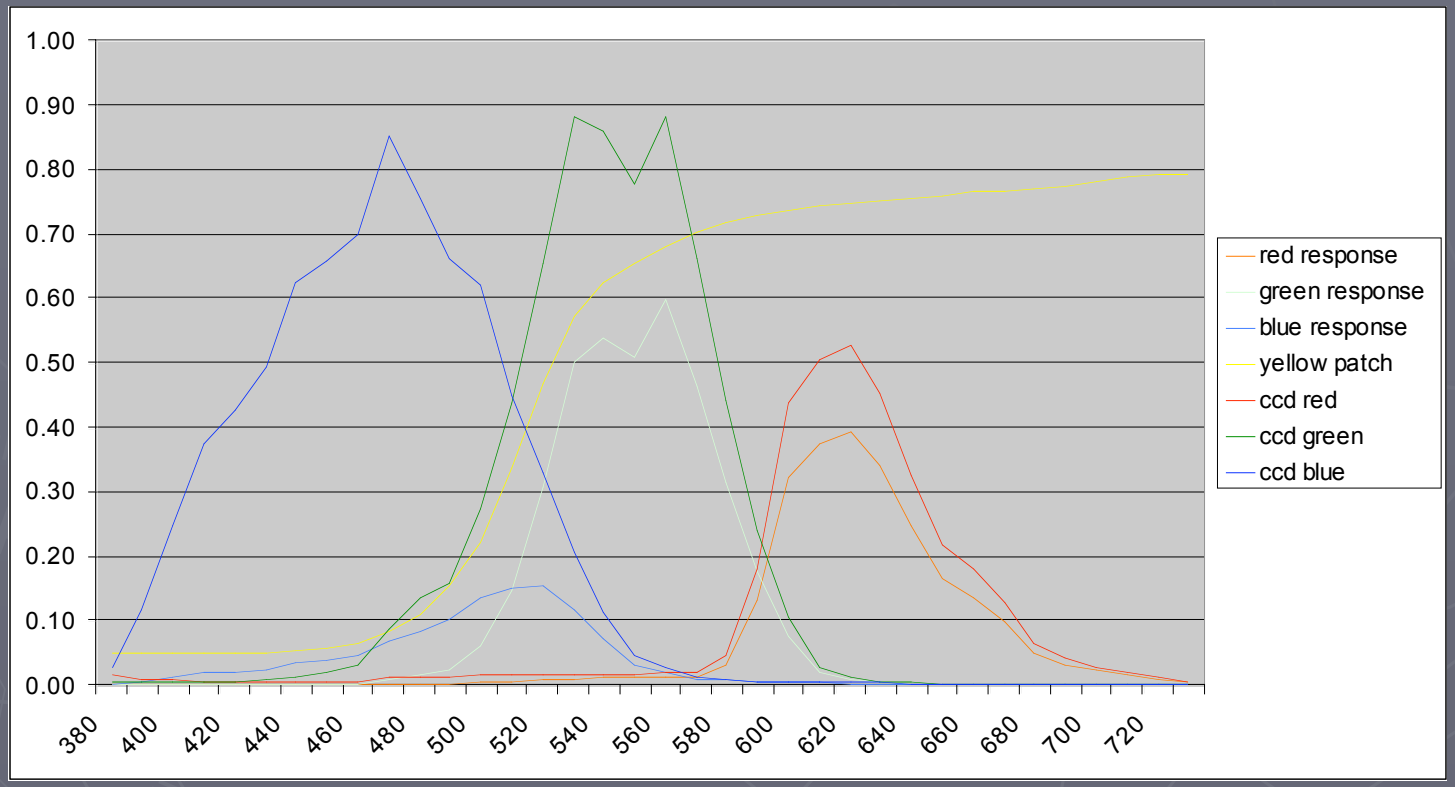


reference chart spectral data



device spectral response data

Calculated device response to each reference chart color patch:



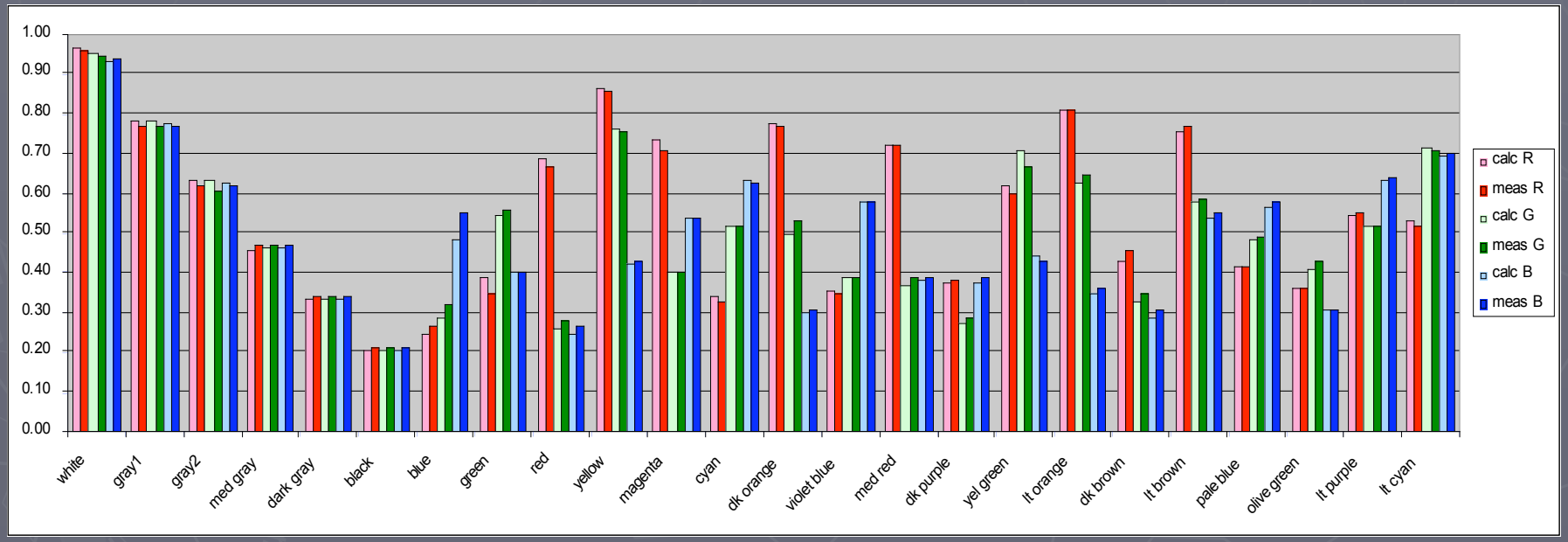
area under each response curve represents the relative signal level for that color channel

This method involves many calculations…

white R	white G	white B	gray1 R	gray1 G	gray1 B	gray2 R	gray2 G	gray2 B	mdgray R	mdgray G	mdgray B	dkgray R	dkgray G	dkgray B	black R	black G	black B	blue R	blue G	blue B	green R	green G	green B	red R	red G	red B
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01
0.00	0.00	0.10	0.00	0.00	0.09	0.00	0.00	0.07	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01
0.00	0.00	0.25	0.00	0.00	0.19	0.00	0.00	0.13	0.00	0.00	0.07	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.02
0.00	0.01	0.36	0.00	0.00	0.25	0.00	0.00	0.15	0.00	0.00	0.08	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.09	0.00	0.00	0.02	0.00	0.00	0.02
0.00	0.01	0.44	0.00	0.01	0.29	0.00	0.00	0.18	0.00	0.00	0.09	0.00	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.12	0.00	0.00	0.03	0.00	0.00	0.02
0.00	0.01	0.56	0.00	0.01	0.37	0.00	0.00	0.23	0.00	0.00	0.12	0.00	0.00	0.06	0.00	0.00	0.02	0.00	0.00	0.18	0.00	0.00	0.04	0.00	0.00	0.03
0.00	0.02	0.60	0.00	0.01	0.39	0.00	0.01	0.25	0.00	0.00	0.13	0.00	0.00	0.06	0.00	0.00	0.02	0.00	0.01	0.20	0.00	0.00	0.04	0.00	0.00	0.03
0.01	0.03	0.64	0.00	0.02	0.42	0.00	0.01	0.26	0.00	0.01	0.13	0.00	0.00	0.06	0.00	0.00	0.02	0.00	0.01	0.21	0.00	0.00	0.05	0.00	0.00	0.03
0.01	0.08	0.78	0.01	0.05	0.51	0.00	0.03	0.32	0.00	0.02	0.16	0.00	0.01	0.08	0.00	0.00	0.03	0.00	0.02	0.23	0.00	0.01	0.08	0.00	0.00	0.04
0.01	0.13	0.69	0.01	0.08	0.45	0.00	0.05	0.28	0.00	0.03	0.14	0.00	0.01	0.07	0.00	0.00	0.02	0.00	0.03	0.17	0.00	0.02	0.10	0.00	0.01	0.03
0.01	0.15	0.61	0.01	0.09	0.39	0.00	0.06	0.24	0.00	0.03	0.12	0.00	0.01	0.06	0.00	0.00	0.02	0.00	0.03	0.12	0.00	0.03	0.12	0.00	0.01	0.03
0.01	0.25	0.57	0.01	0.16	0.37	0.01	0.10	0.23	0.00	0.05	0.12	0.00	0.02	0.06	0.00	0.01	0.02	0.00	0.04	0.08	0.00	0.07	0.15	0.00	0.01	0.03
0.01	0.40	0.41	0.01	0.26	0.27	0.01	0.16	0.17	0.00	0.08	0.08	0.00	0.04	0.04	0.00	0.01	0.01	0.00	0.04	0.04	0.01	0.14	0.14	0.00	0.02	0.02
0.01	0.61	0.30	0.01	0.39	0.20	0.01	0.24	0.12	0.00	0.12	0.06	0.00	0.06	0.03	0.00	0.02	0.01	0.00	0.05	0.02	0.01	0.23	0.11	0.00	0.03	0.01
0.01	0.81	0.19	0.01	0.53	0.12	0.01	0.33	0.08	0.00	0.17	0.04	0.00	0.08	0.02	0.00	0.03	0.01	0.00	0.05	0.01	0.01	0.30	0.07	0.00	0.04	0.01
0.02	0.79	0.10	0.01	0.51	0.07	0.01	0.32	0.04	0.00	0.16	0.02	0.00	0.08	0.01	0.00	0.03	0.00	0.00	0.04	0.00	0.01	0.28	0.04	0.00	0.04	0.00
0.01	0.72	0.04	0.01	0.46	0.03	0.01	0.29	0.02	0.00	0.15	0.01	0.00	0.07	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.23	0.01	0.00	0.03	0.00
0.02	0.81	0.03	0.01	0.52	0.02	0.01	0.33	0.01	0.00	0.16	0.01	0.00	0.08	0.00	0.00	0.03	0.00	0.00	0.03	0.00	0.00	0.23	0.01	0.00	0.04	0.00
0.02	0.61	0.01	0.01	0.40	0.01	0.01	0.25	0.01	0.00	0.12	0.00	0.00	0.06	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.15	0.00	0.00	0.03	0.00
0.04	0.41	0.01	0.03	0.26	0.01	0.02	0.16	0.00	0.01	0.08	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.01	0.09	0.00	0.00	0.03	0.00
0.17	0.22	0.01	0.11	0.14	0.00	0.07	0.09	0.00	0.03	0.04	0.00	0.02	0.02	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.03	0.04	0.00	0.02	0.02	0.00
0.41	0.10	0.01	0.26	0.06	0.00	0.16	0.04	0.00	0.08	0.02	0.00	0.04	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.06	0.01	0.00	0.08	0.02	0.00
0.47	0.03	0.00	0.30	0.02	0.00	0.18	0.01	0.00	0.09	0.01	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.06	0.00	0.00	0.17	0.01	0.00
0.49	0.01	0.00	0.31	0.01	0.00	0.19	0.00	0.00	0.09	0.00	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.02	0.00	0.00	0.06	0.00	0.00	0.25	0.01	0.00
0.42	0.01	0.00	0.27	0.00	0.00	0.16	0.00	0.00	0.08	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.05	0.00	0.00	0.26	0.00	0.00
0.30	0.00	0.00	0.19	0.00	0.00	0.12	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.03	0.00	0.00	0.21	0.00	0.00
0.20	0.00	0.00	0.13	0.00	0.00	0.08	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.14	0.00	0.00
0.17	0.00	0.00	0.10	0.00	0.00	0.06	0.00	0.00	0.03	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.12	0.00	0.00
0.12	0.00	0.00	0.07	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.09	0.00	0.00
0.06	0.00	0.00	0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.04	0.00	0.00
0.04	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00
0.03	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00
0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.13	6.22	6.78	1.99	4.03	4.49	1.22	2.50	2.81	0.61	1.26	1.44	0.30	0.61	0.71	0.10	0.21	0.24	0.15	0.44	1.57	0.41	1.82	1.06	1.47	0.35	0.35
2.17	1.09	1.00	2.26	1.12	1.00	2.29	1.13	1.00	2.38	1.14	1.00	2.37	1.16	1.00	2.35	1.16	1.00									
2.32	1.13	1.00																								
7.27	7.06	6.78	4.63	4.57	4.49	2.85	2.83	2.81	1.41	1.43	1.44	0.69	0.69	0.71	0.24	0.24	0.24	0.35	0.50	1.57	0.95	2.07	1.06	3.42	0.40	0.35

...with little surprise

the measured response of a Better Light scanning back corresponds very closely to its calculated response

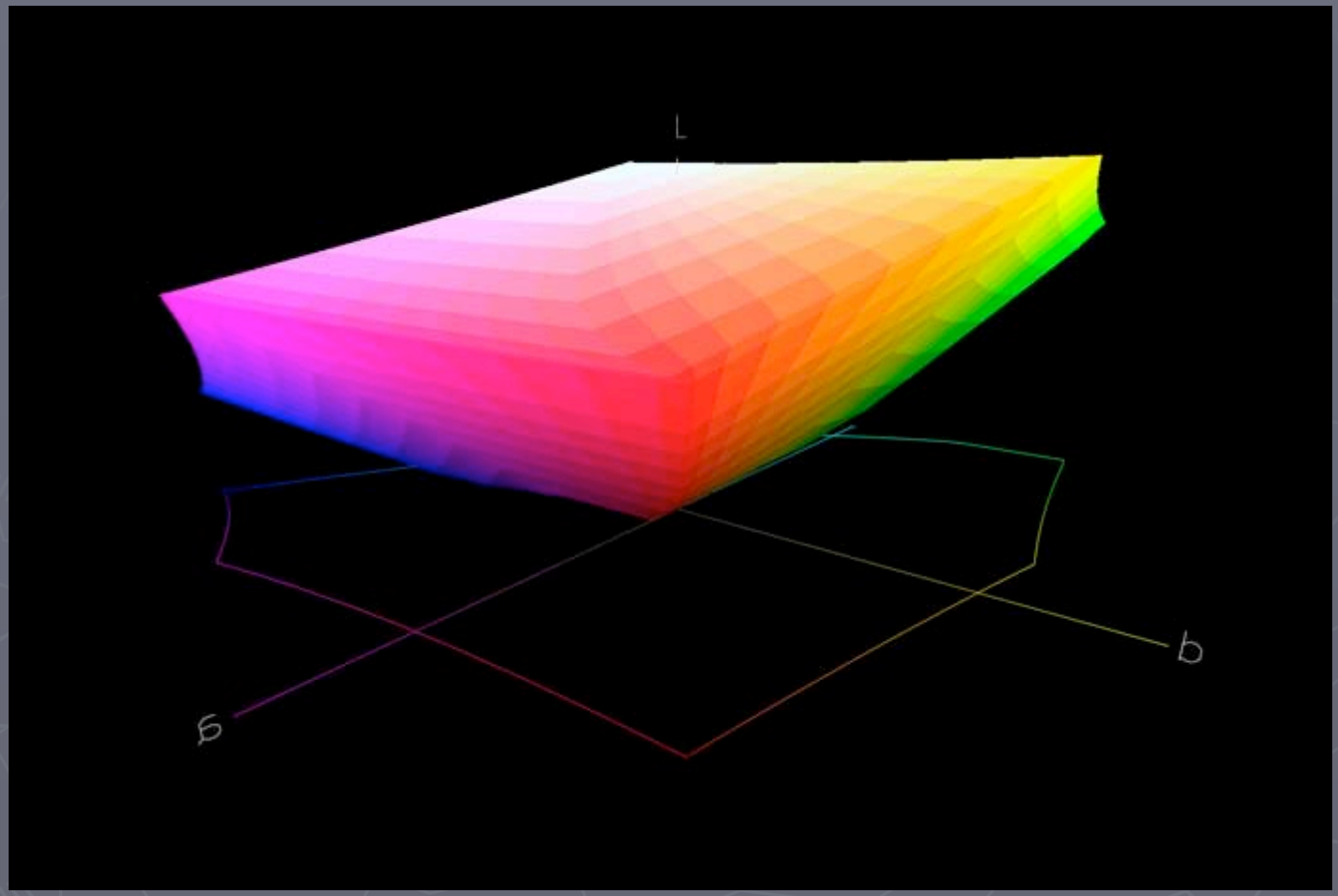


but how well does the device response correspond to a standard response?

What is a standard response?

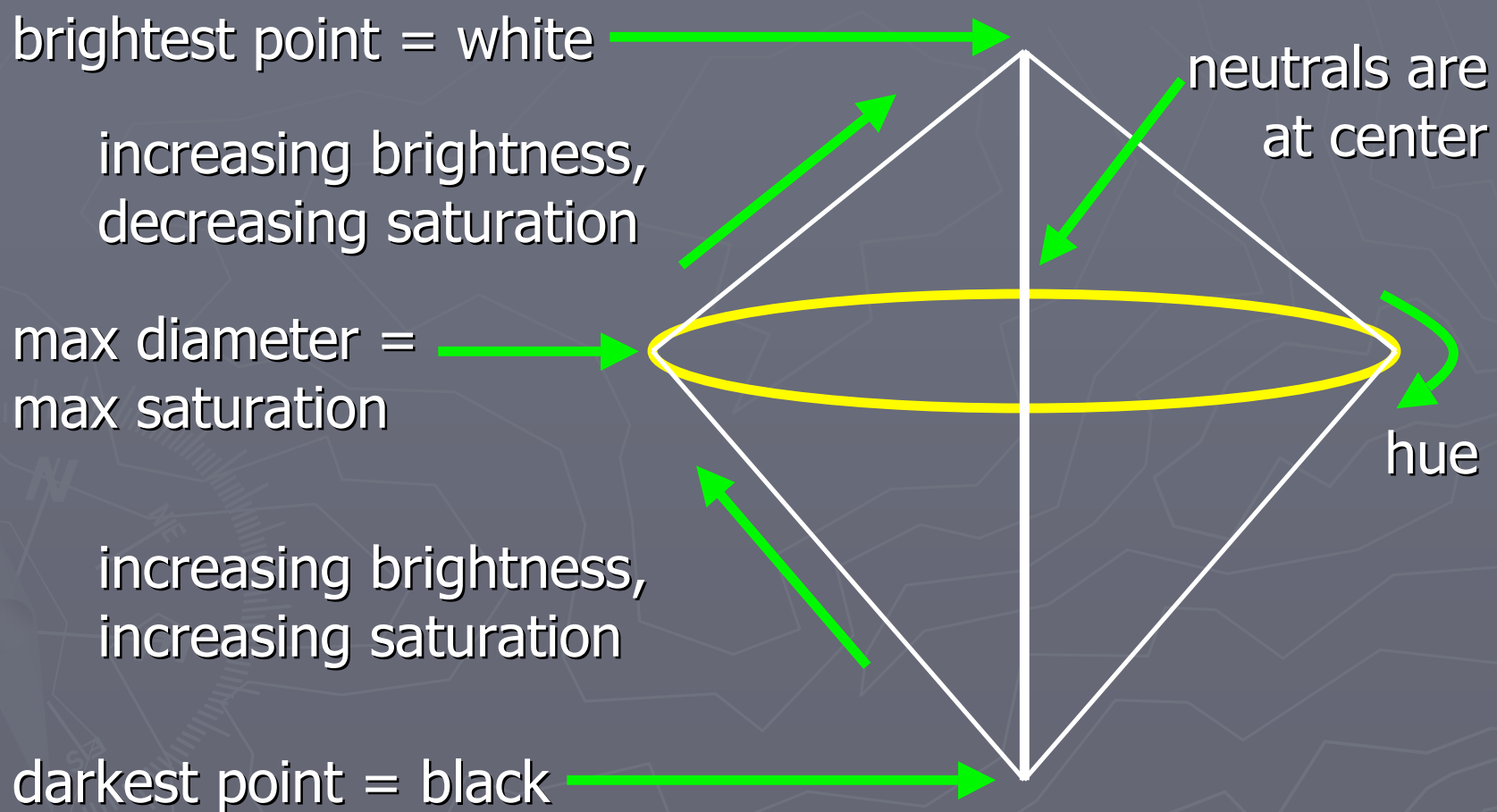
- Characterizing the "native" response of a device is a good first step, but a device should also be capable of rendering colors according to an accepted standard, to provide a "standard response"
- This usually involves three-dimensional calculations to convert the device response to a standard response
- The above is equivalent to converting from the color space of the device to a standard color space

Color space – the final frontier…



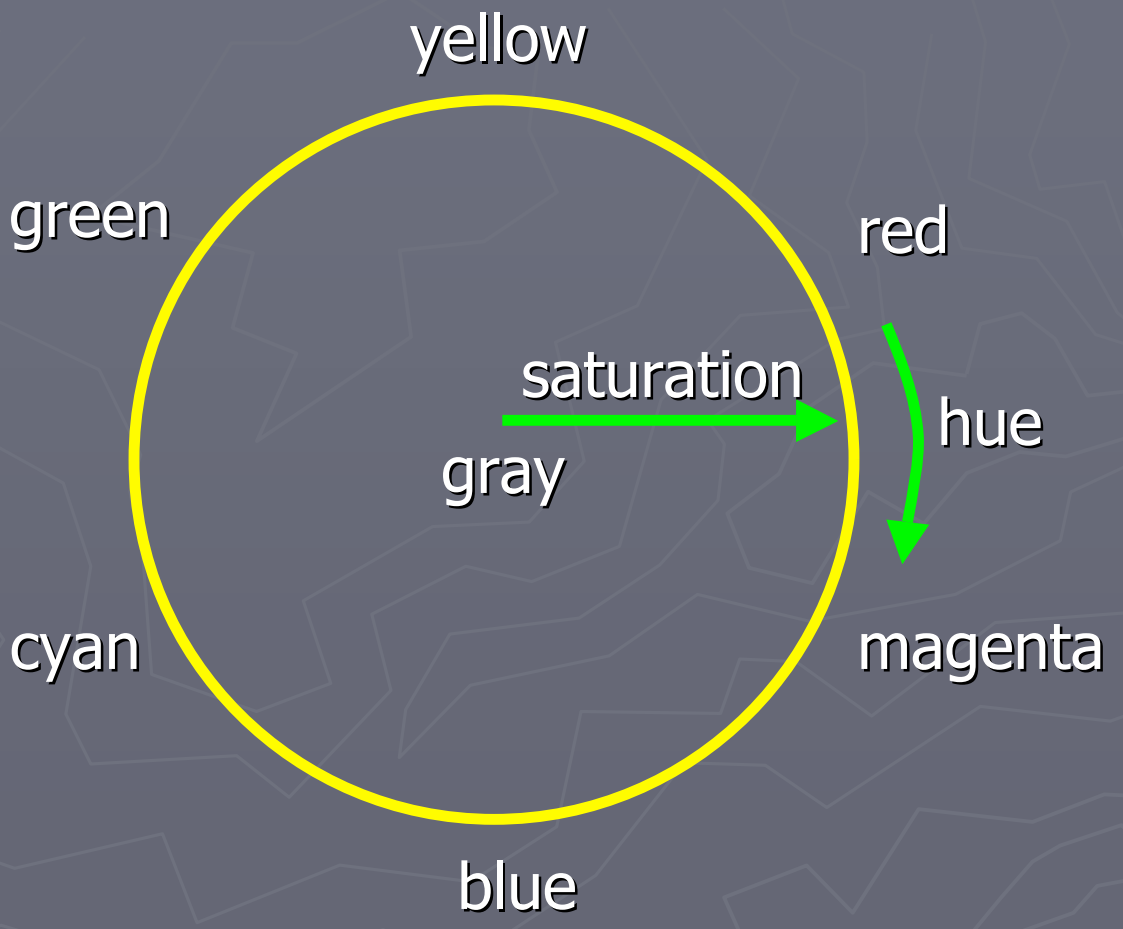
Adobe RGB 1998 color space displayed by ColorThink

Describing color with a 3D space



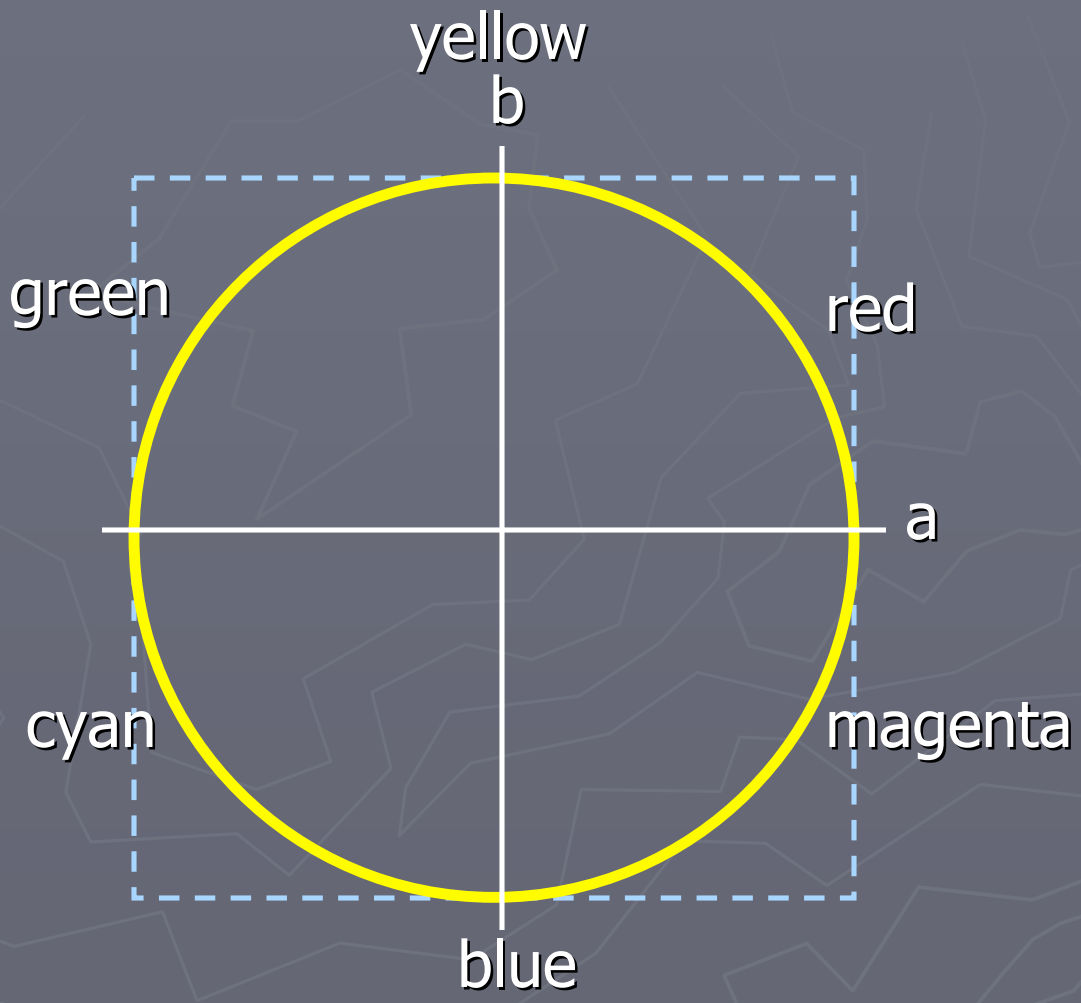
Describing color with a 2D space

Brightness (3rd dimension) is perpendicular to this color plane

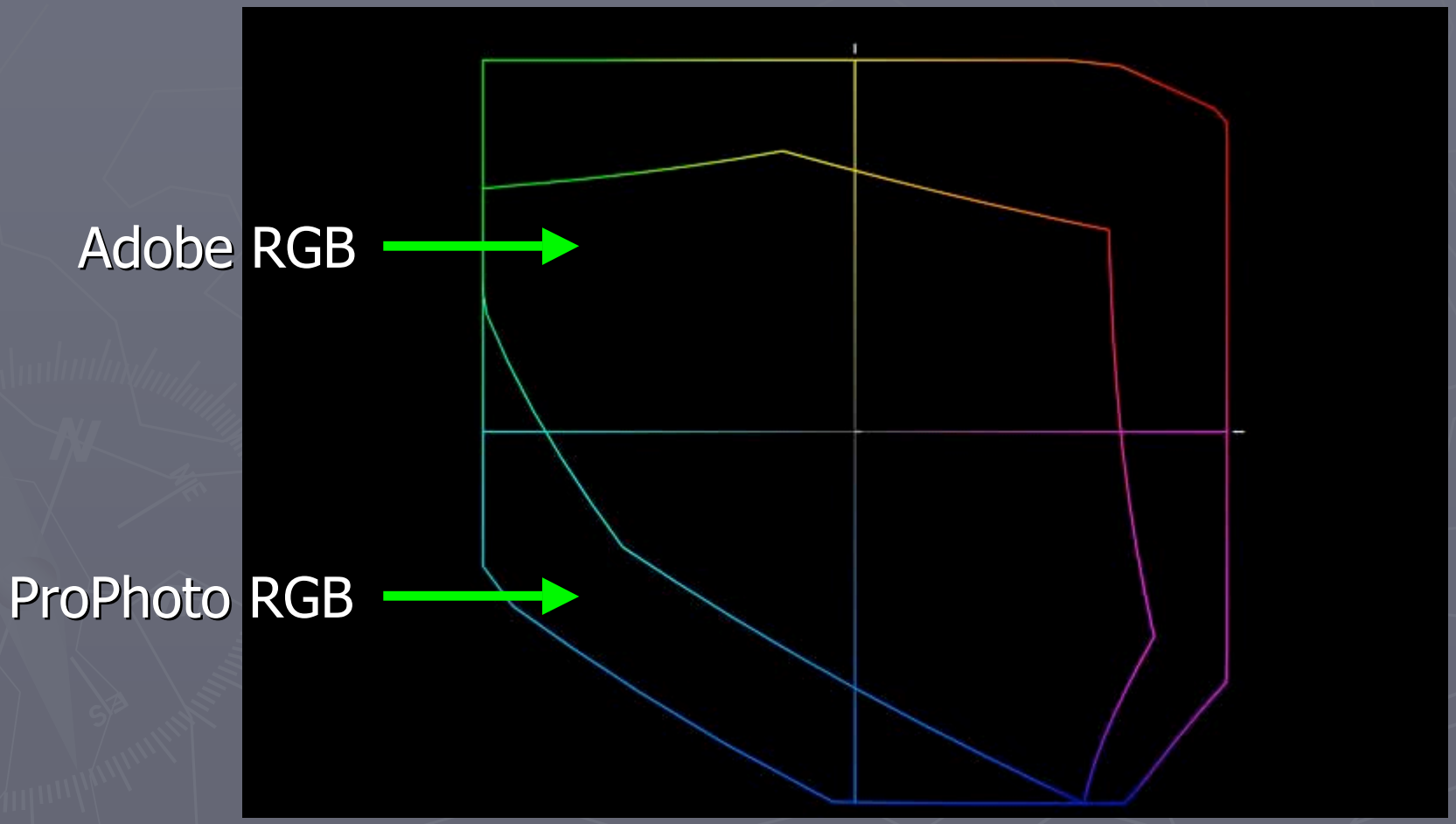


Describing color with a standard space

Lightness (3rd dimension) is perpendicular to this color plane

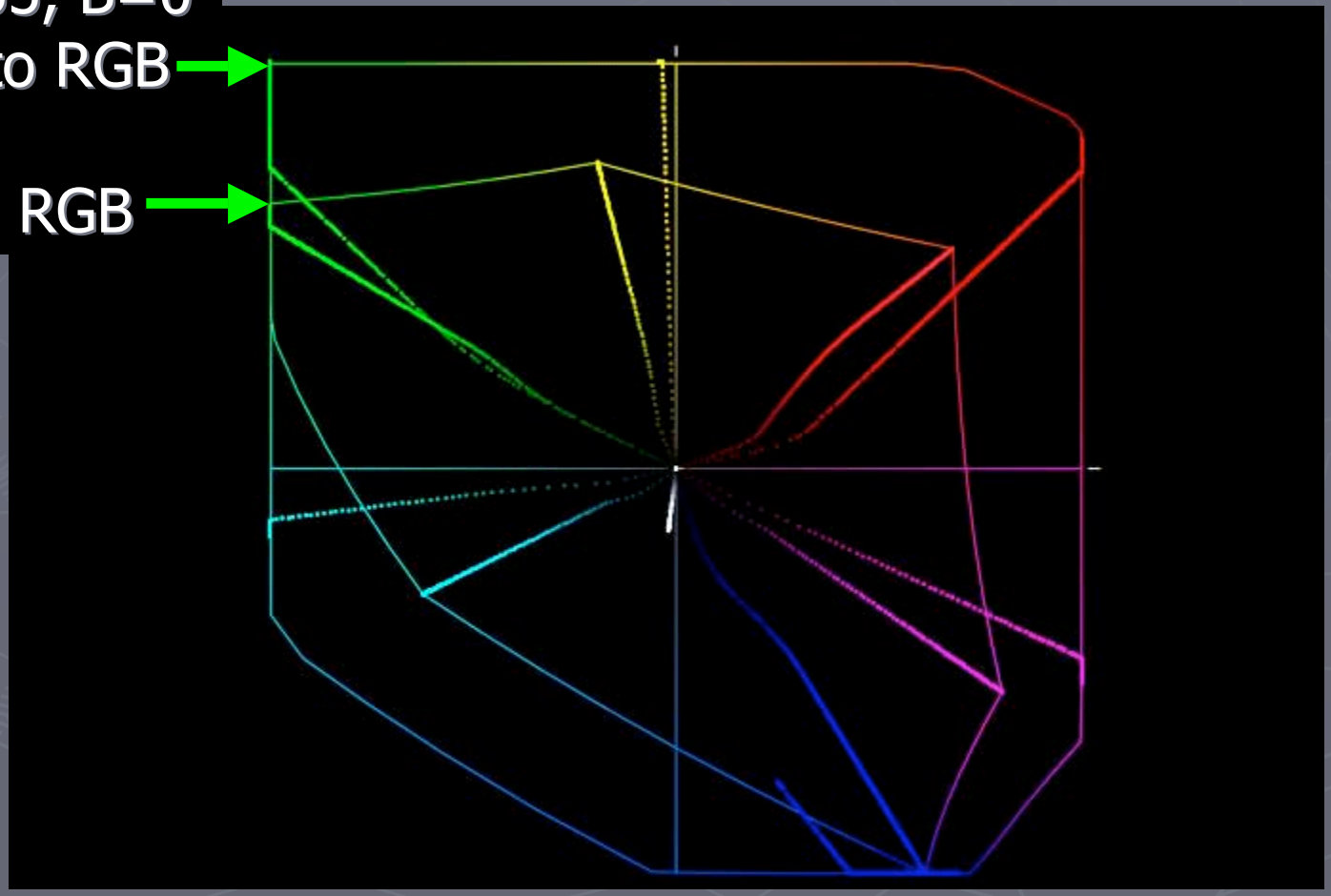


Not all color spaces are equal



Identical RGB data can represent different colors in different color spaces

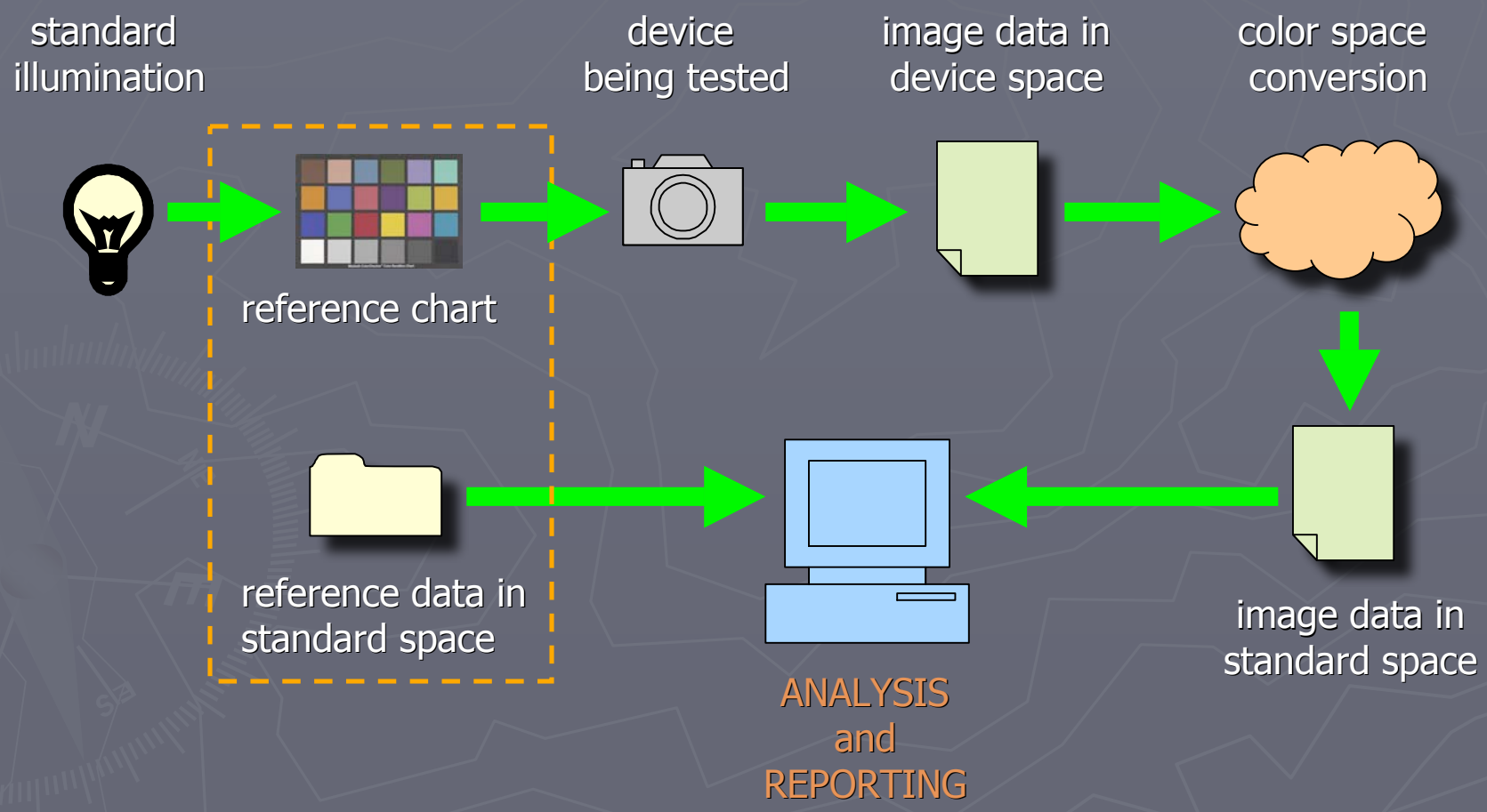
R=0, G=255, B=0
in ProPhoto RGB
and
in Adobe RGB



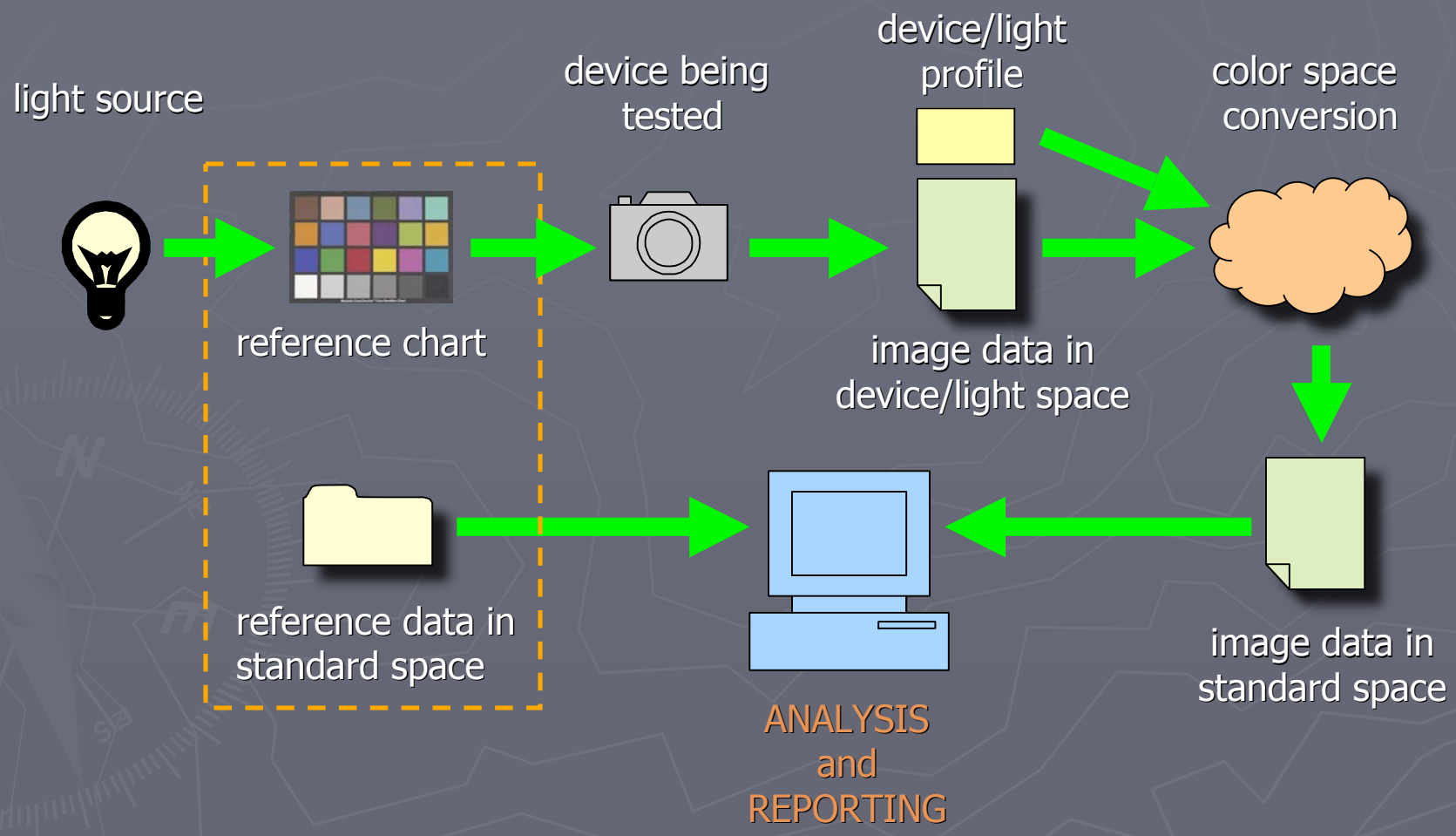
A standardized method for evaluating and expressing color accuracy

- a physical reference chart to photograph with the device being tested under standard conditions
- a reference chart color space with the ideal data values for the chart under standard conditions
- a way to relate or convert the device color space to the reference chart color space
- a way to measure and show errors in the device's rendition of the reference chart

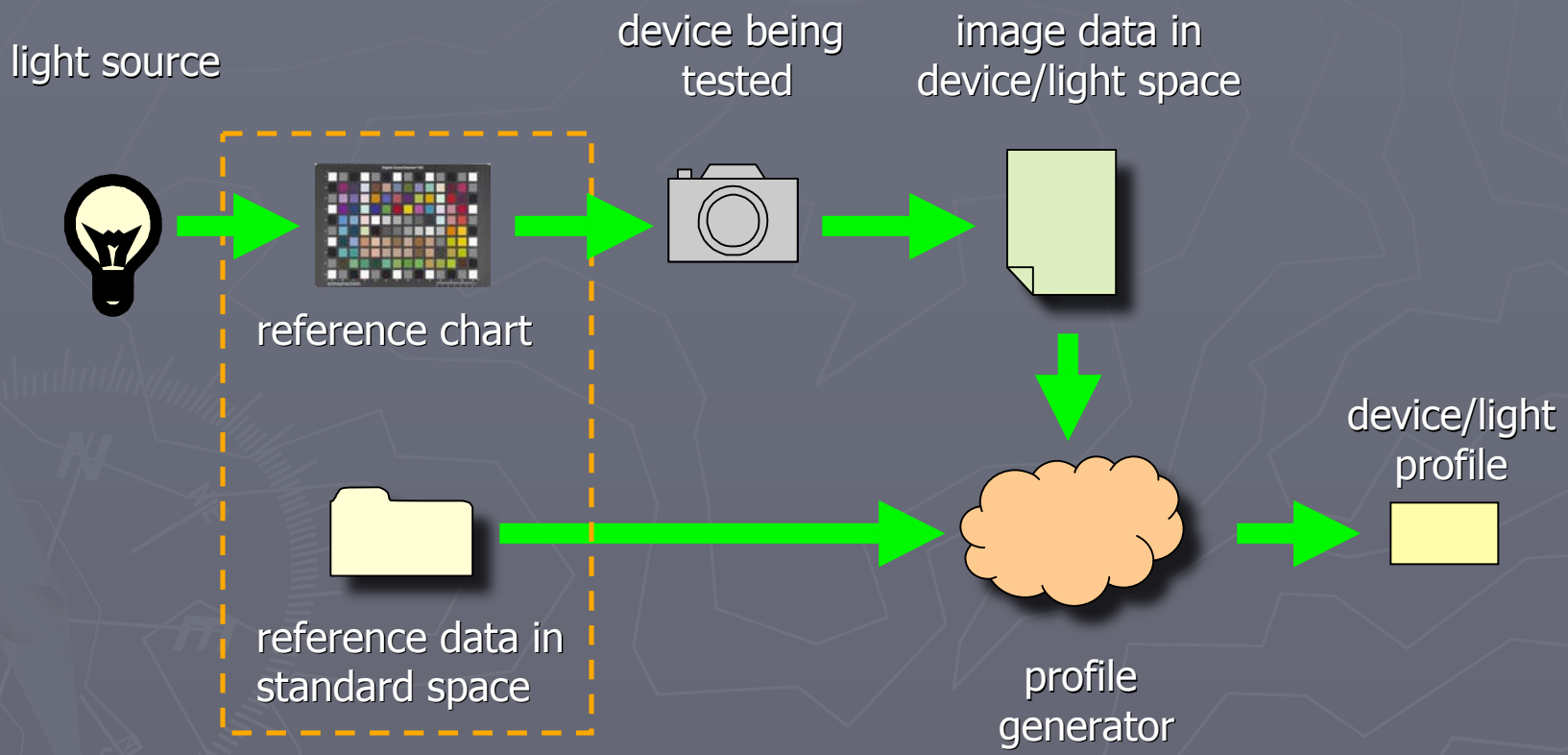
A standardized method for evaluating and expressing color accuracy



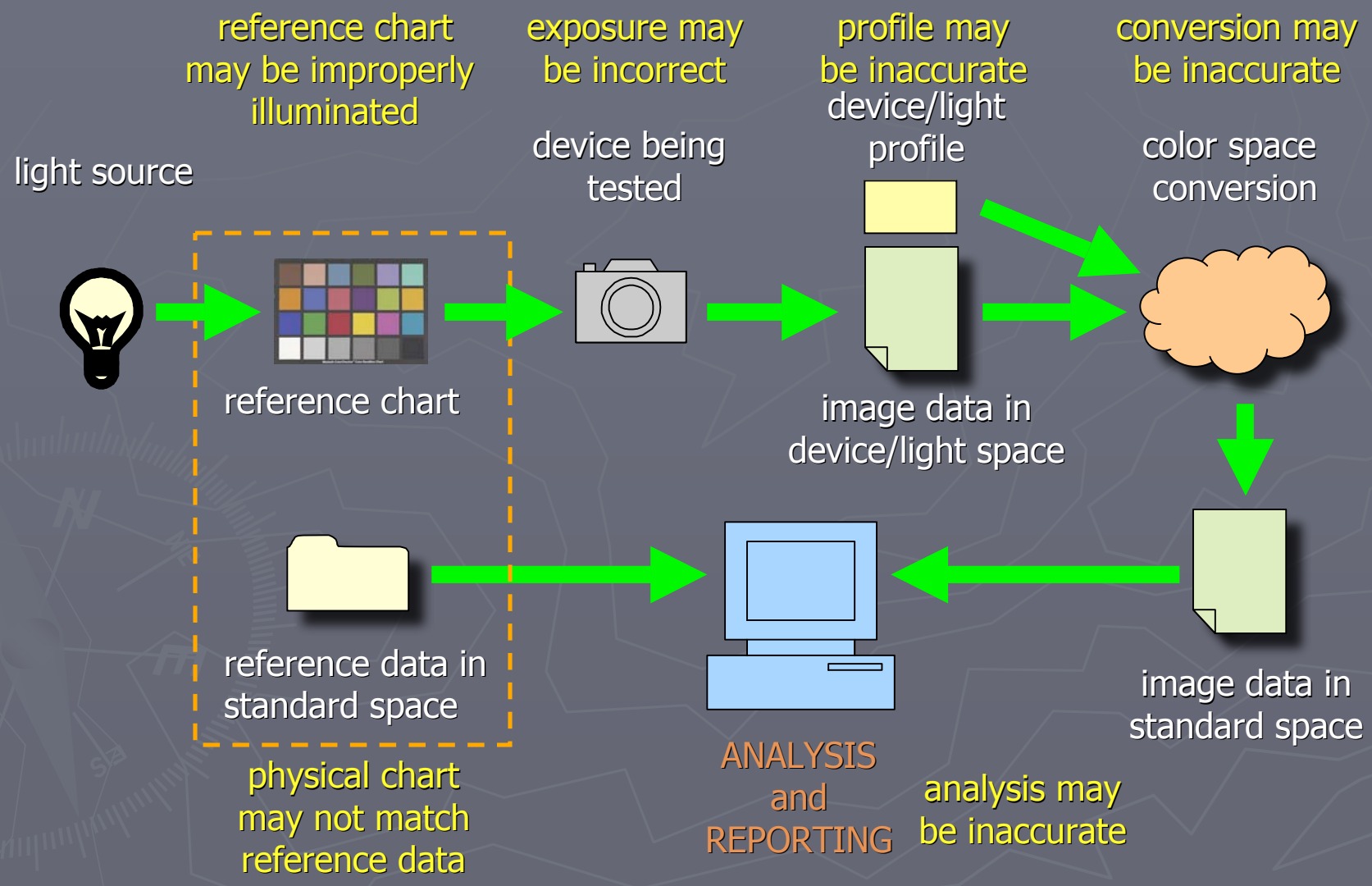
This same method can be used to evaluate the accuracy of a profile



Ideally, the device/light profile is generated by a different reference chart



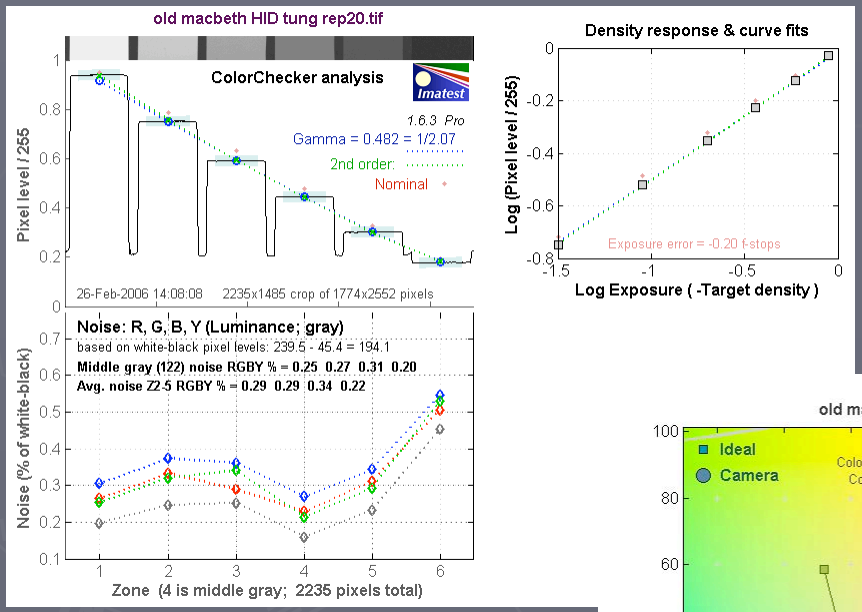
Potential sources of error



Items needed for these tests:

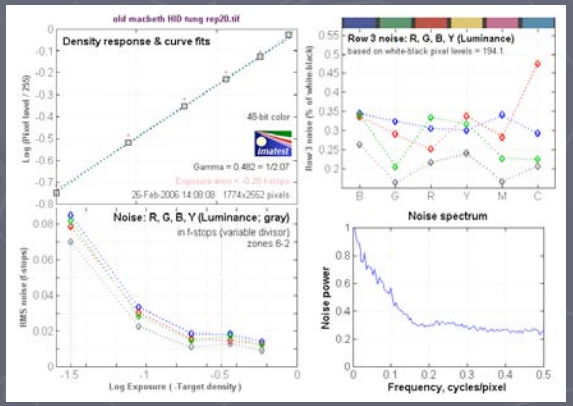
- consistent light source
- reference chart for making profile
- reference chart for evaluating accuracy
- profiling software
- color space conversion software
- analysis and reporting software
- curiosity and persistence

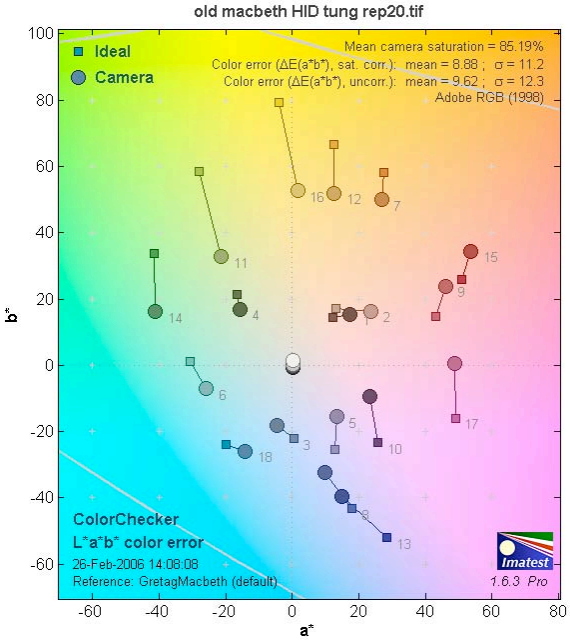
Analysis and Reporting software

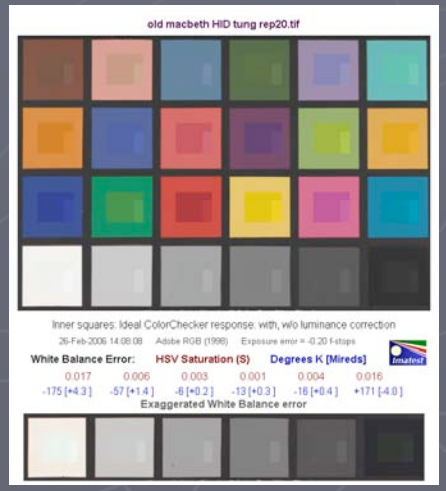


inexpensive color accuracy evaluation software is now available from

www.imatest.com



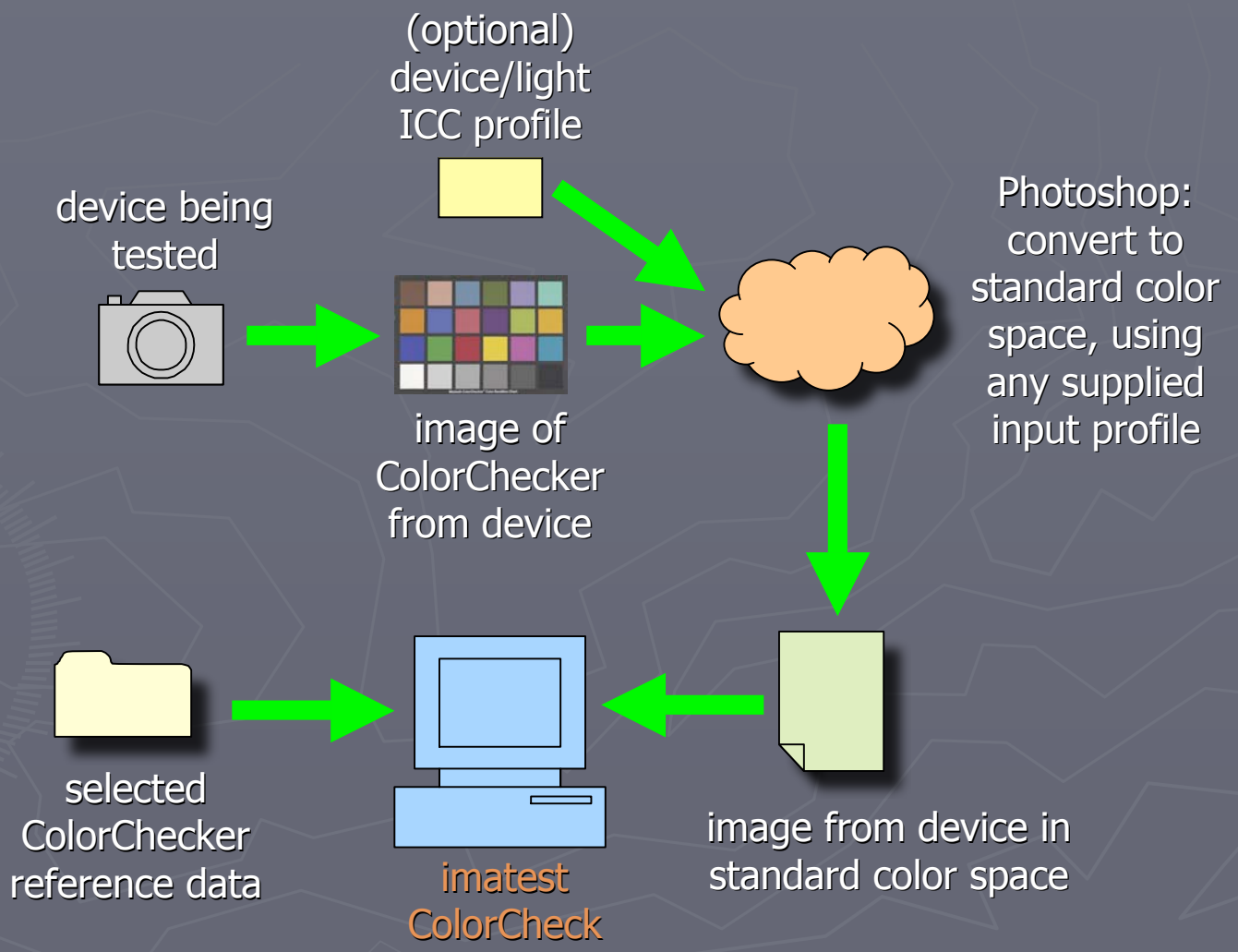




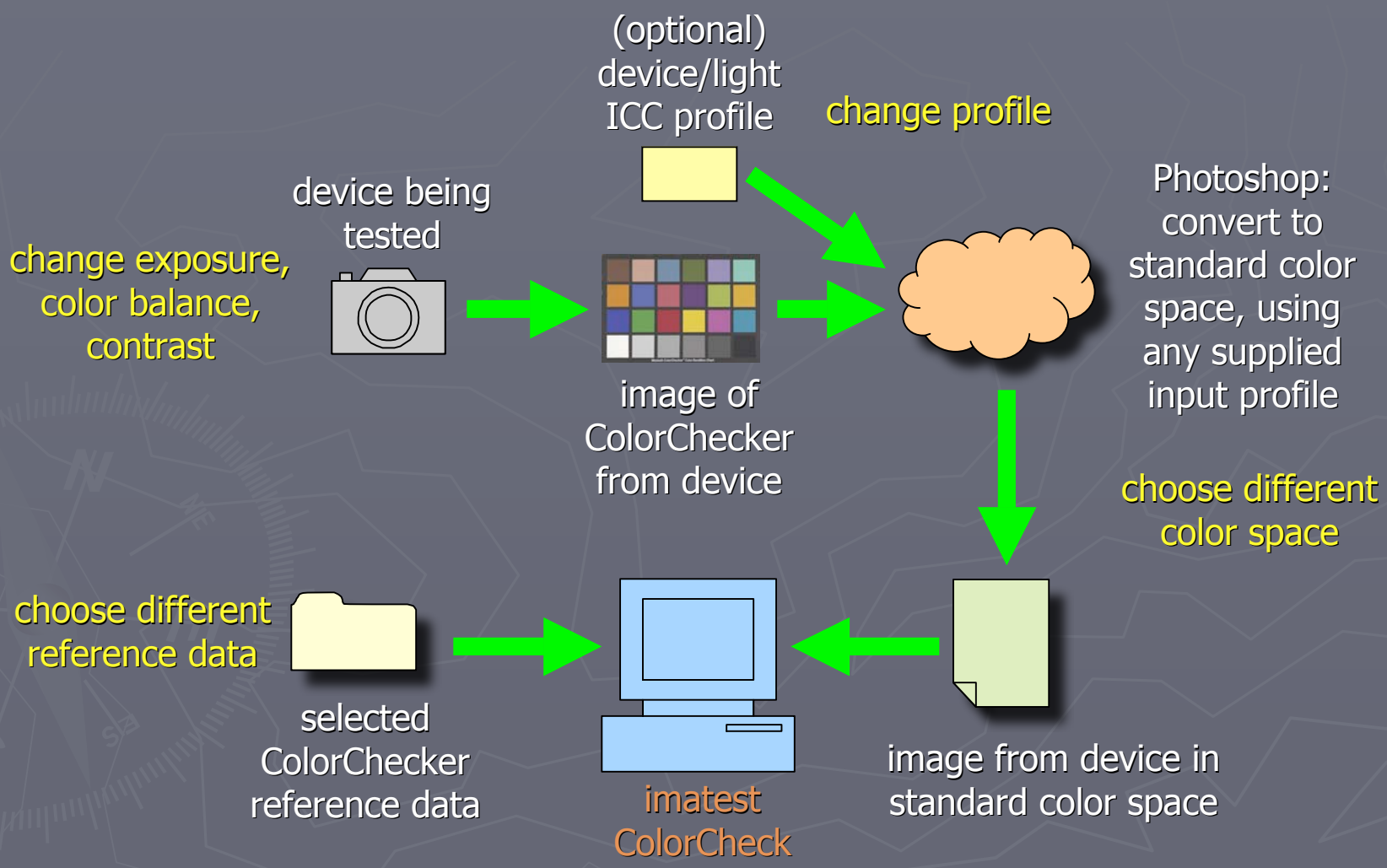
Imatest ColorCheck

- compares the color accuracy of an image of a Macbeth ColorChecker captured by the device being tested, expressed in your choice of standard color spaces, to your choice of reference data
- many different versions of reference data for the ColorChecker exist – for different color spaces and/or illuminants
- ColorCheck requires the device image to be converted to the selected standard color space (does not recognize or use ICC profiles)
- expresses results in several easy-to-understand ways, including graphic plots and visual comparison charts

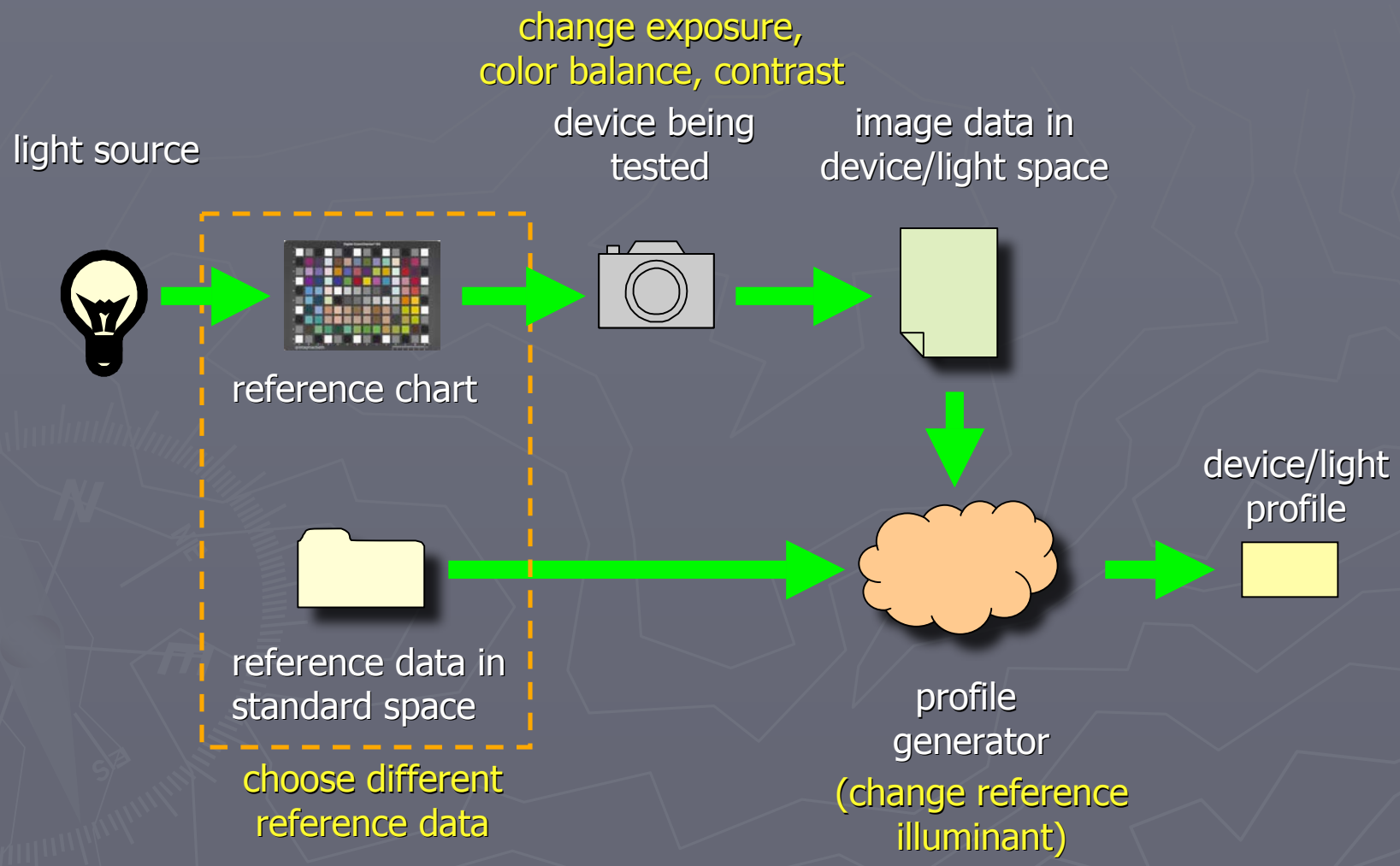
ColorCheck workflow



ColorCheck variables



ICC profile variables



So many variables, so little time…

- reference chart should be uniformly illuminated
- position chart in the center of the image area
- reference chart image should be neutral-balanced and properly exposed for the gamma of the reference data set
- adjust the Tone curve (if used) to fine-tune gray scale for proper gamma, if necessary
- ColorCheck reference data color space and target standard space should be the same

More simplifications

- use your Photoshop working space as the target standard color space (presuming ColorCheck supports this space as a reference data color space)
- choose a reference data set using the reference data color space (= working space)
- only need one perfectly neutral-balanced and exposed ColorChecker image adjusted for the target (working space) gamma

So what ARE we changing?

- our intention is to produce a device profile and workflow that consistently delivers the most accurate color response compared to a standard response
- we can fine-tune the profile by optimizing the profile reference chart exposure, and by changing profile generation characteristics
- we can fine-tune the workflow itself

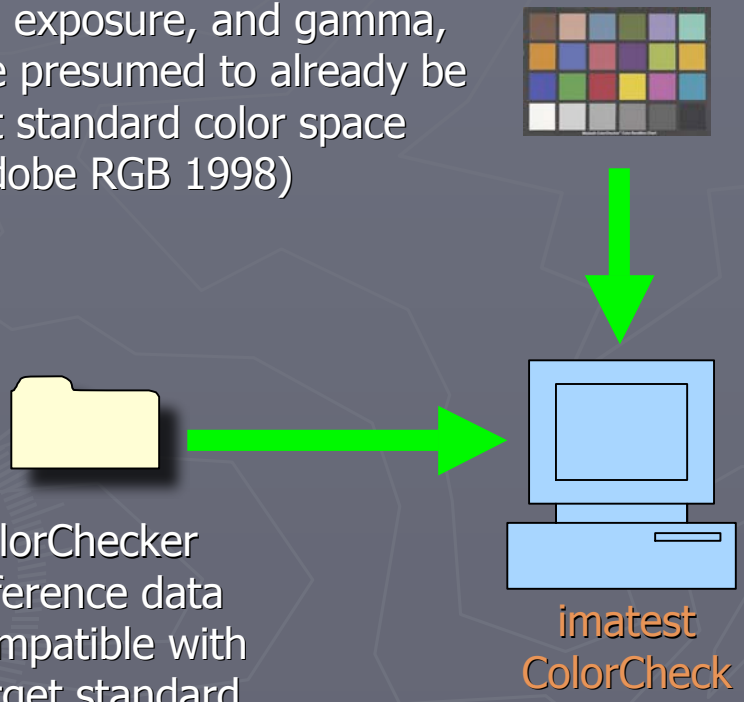
Getting started

- capture a properly-exposed and neutralized image of a ColorChecker adjusted for the gamma of your Photoshop working space (e.g., 2.2 for Adobe RGB 1998)

RGB values from Robin Myers:	RGB values expected by ColorCheck:
white = 243	white = 242
gray1 = 201	gray1 = 201
gray2 = 161	gray2 = 161
gray3 = 122	gray3 = 122
gray4 = 85	gray4 = 84
black = 53	black = 54

Testing an unprofiled image

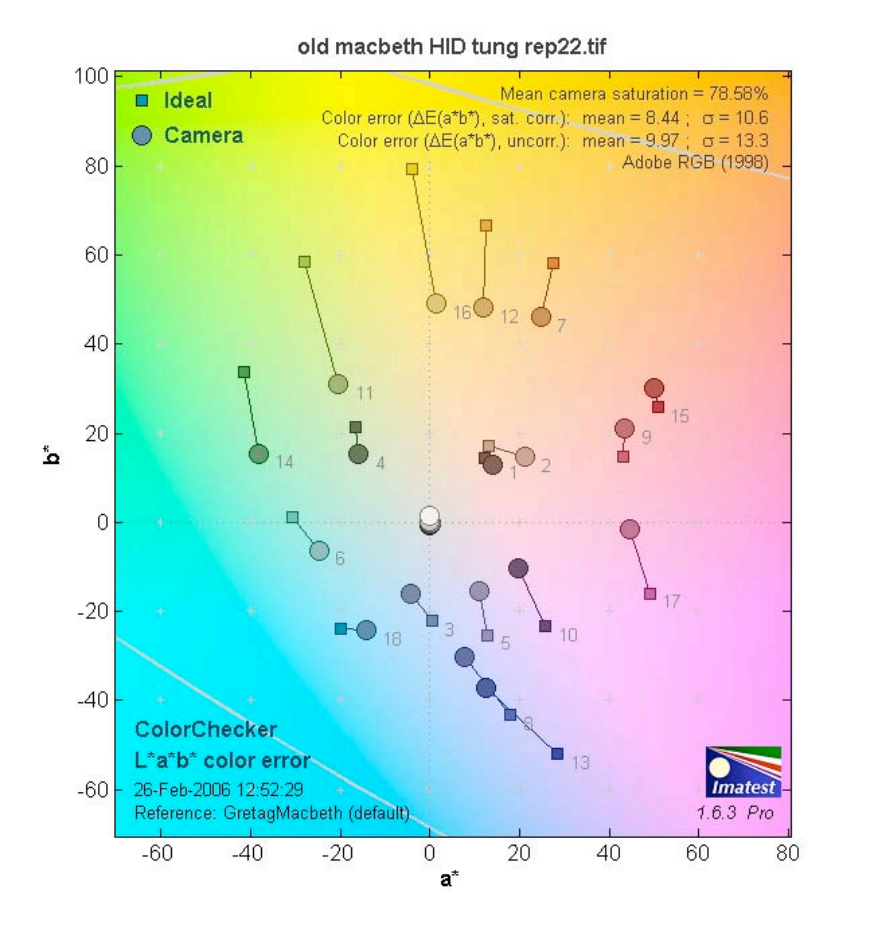
since ColorChecker image has been adjusted for proper neutral balance, exposure, and gamma, it can be presumed to already be in target standard color space (e.g., Adobe RGB 1998)

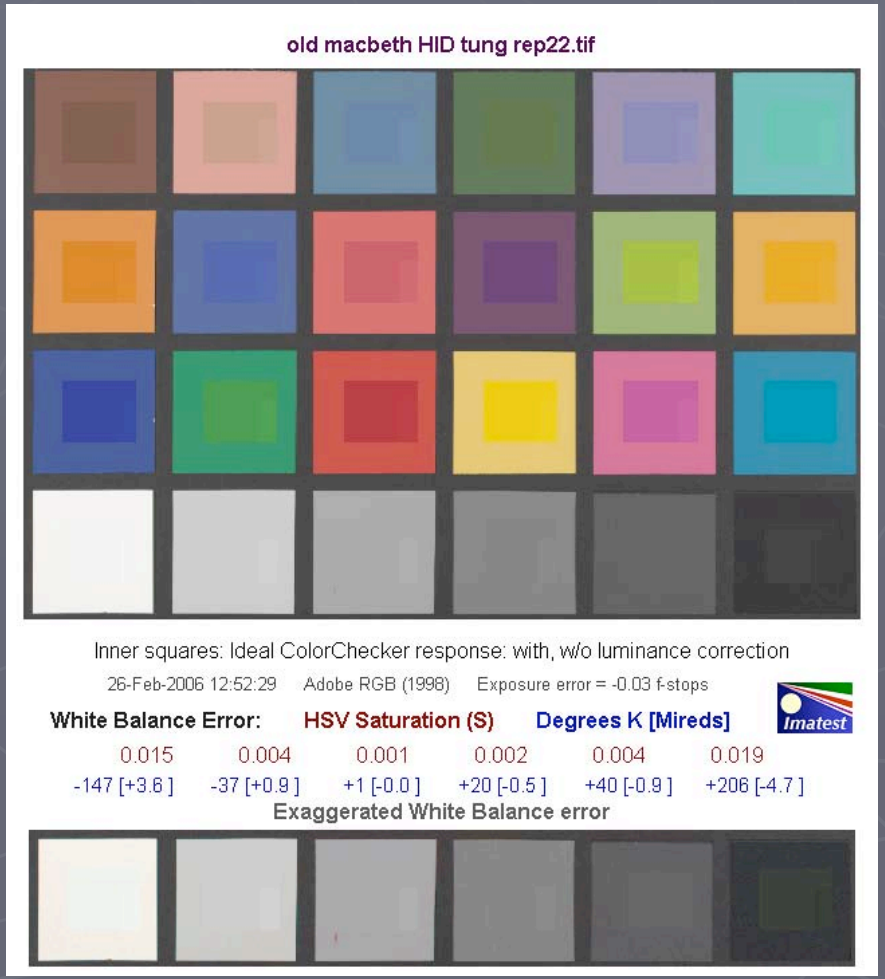


1. open and crop ColorChecker image in imatest ColorCheck
2. select appropriate reference data (e.g., GretagMacbeth default)
3. select proper target standard color space (e.g., Adobe RGB 1998)
4. click OK to run ColorCheck

Testing an unprofiled image

Repro 2.2 curve unprofiled: Sat 79% deltaE 8.44 sigma 10.6 expErr -.03





Testing a profiled image

open ColorChecker image in Photoshop

1. ASSIGN desired device profile
2. CONVERT to target standard color space (e.g., Adobe RGB 1998)
3. SAVE converted image with unique file name

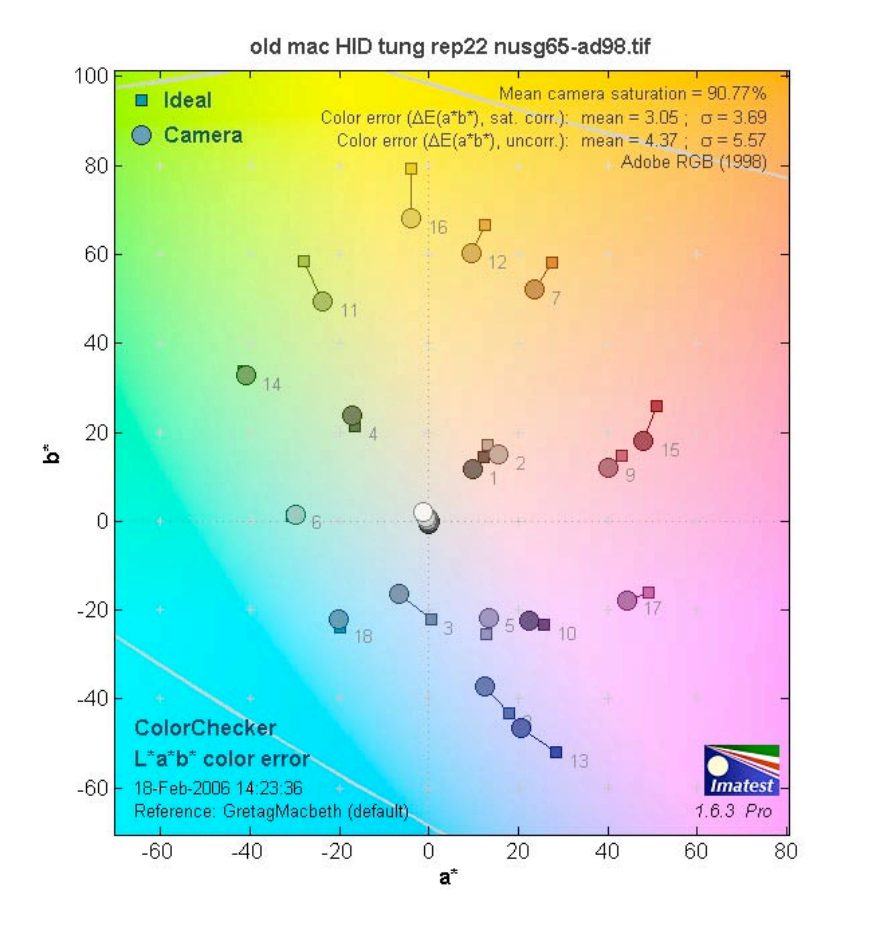
ColorChecker reference data compatible with target standard color space

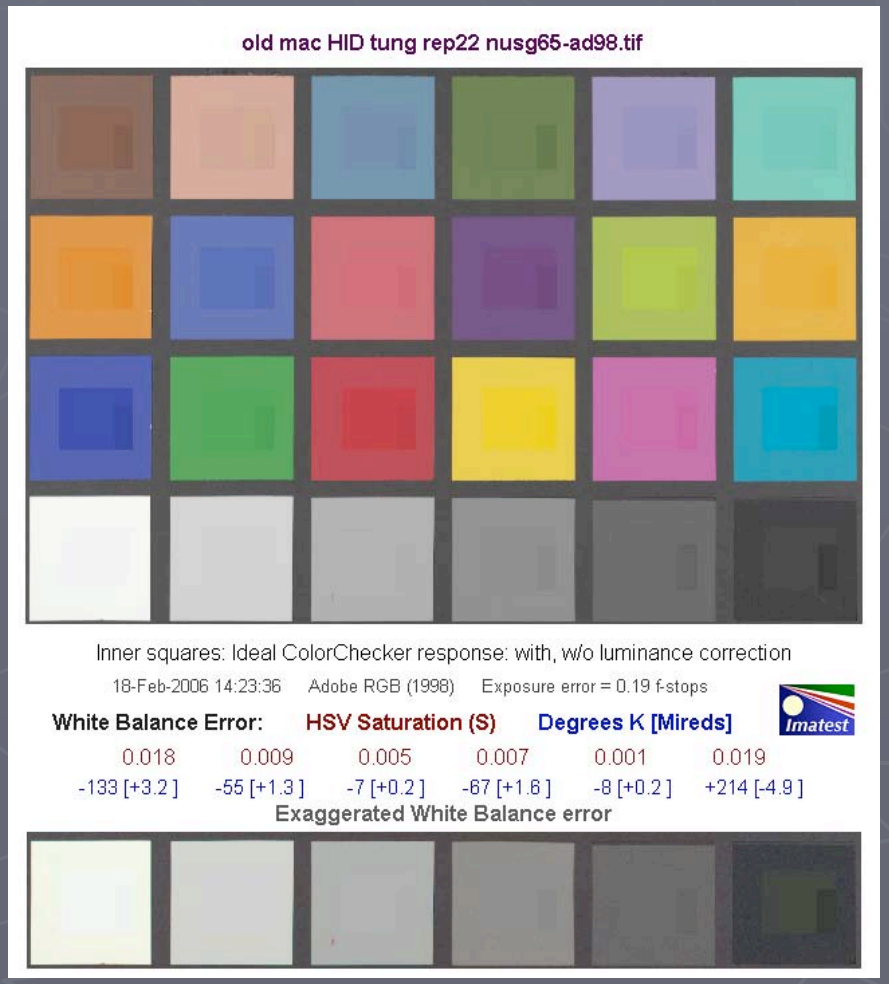
1. open and crop converted image in imatest ColorCheck
2. select appropriate reference data (e.g., GretagMacbeth default)
3. select proper target standard color space (e.g., Adobe RGB 1998)
4. click OK to run ColorCheck

imatest ColorCheck

Testing a profiled image

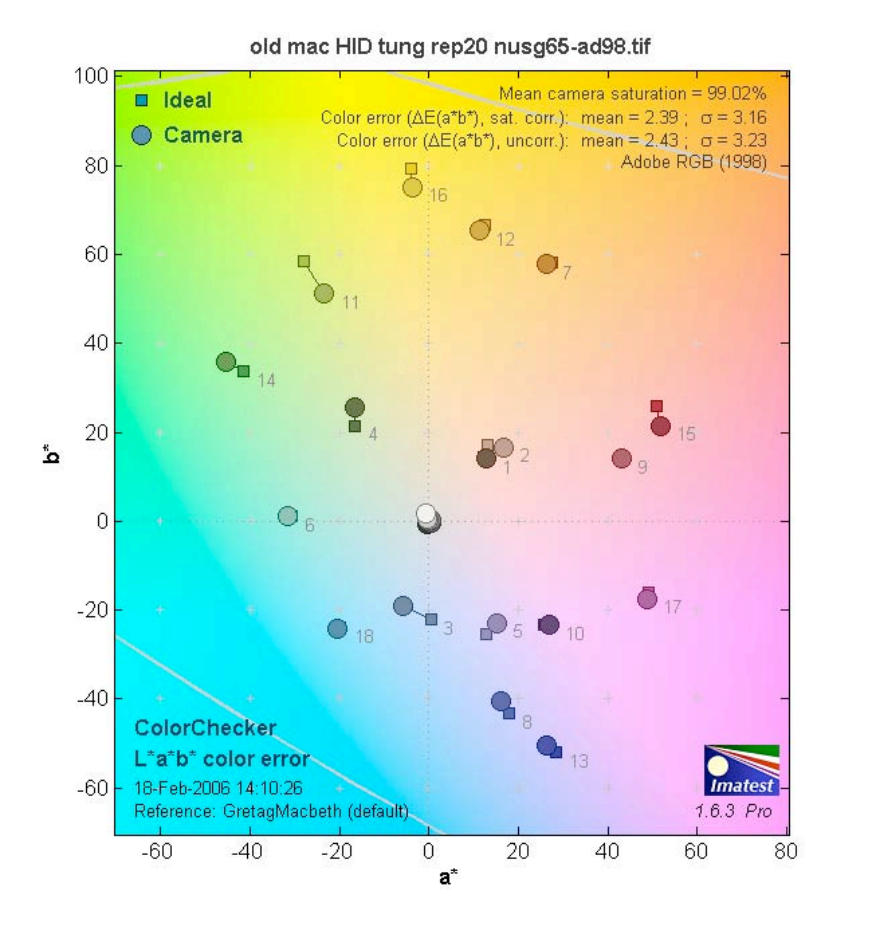
Repro 2.2 profiled(2.0; d65): Sat 91% deltaE 3.05 sigma 3.69 expErr 0.19

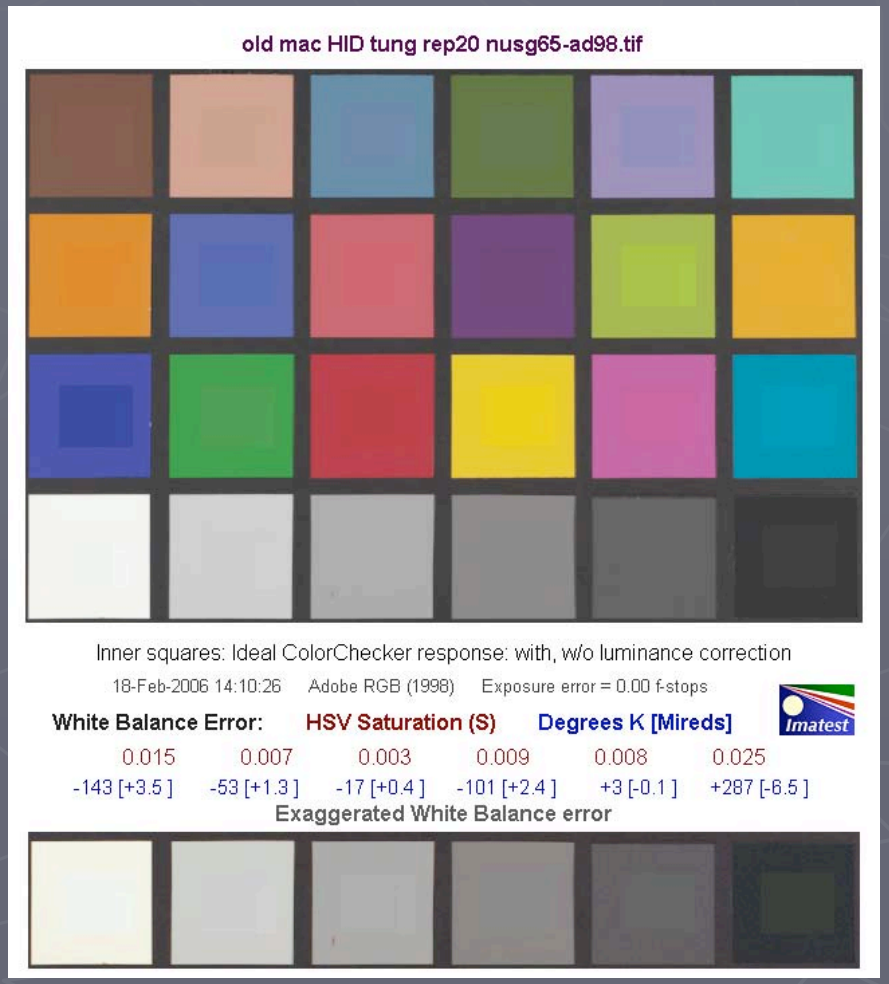




The importance of matching profile and test image gamma

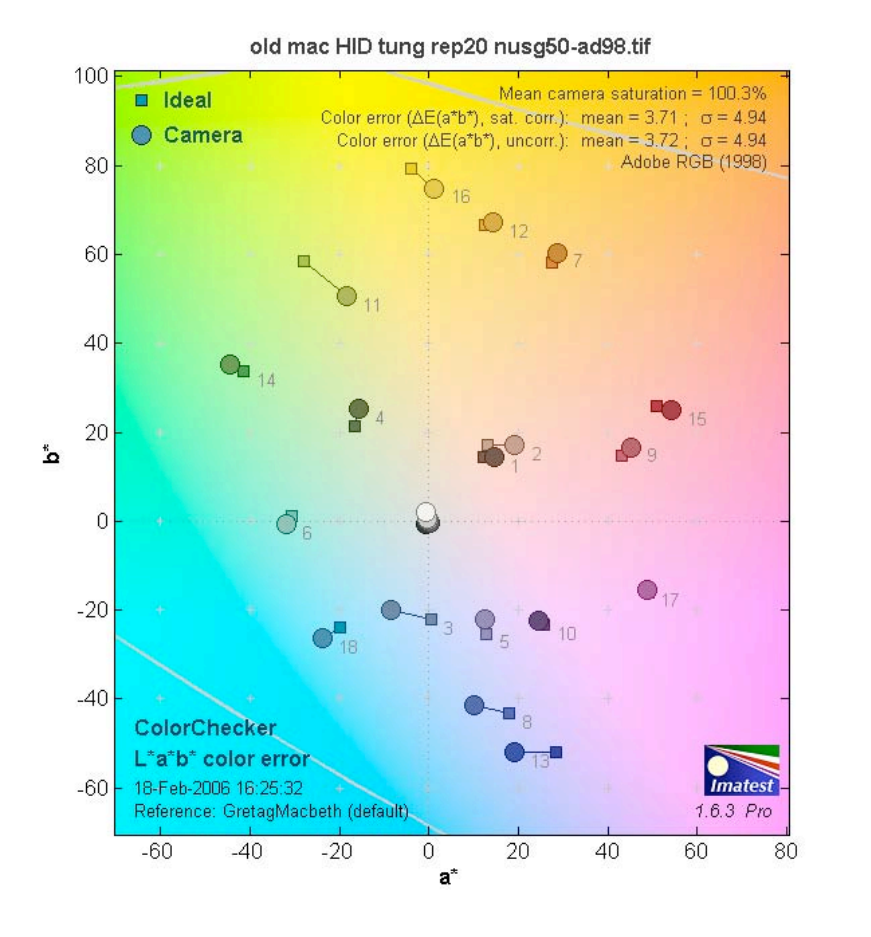
Repro 2.0 profiled(2.0; d65): Sat 99% deltaE 2.39 sigma 3.16 expErr 0.00

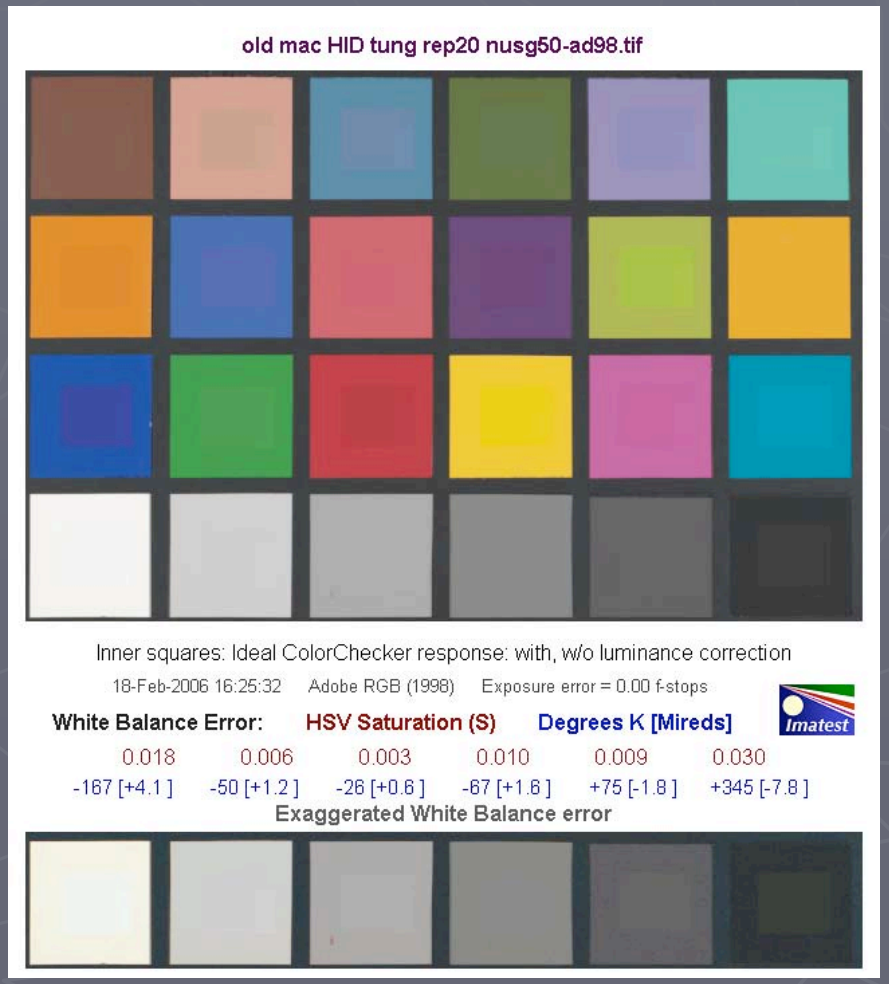




The importance of choosing the right profile illuminant

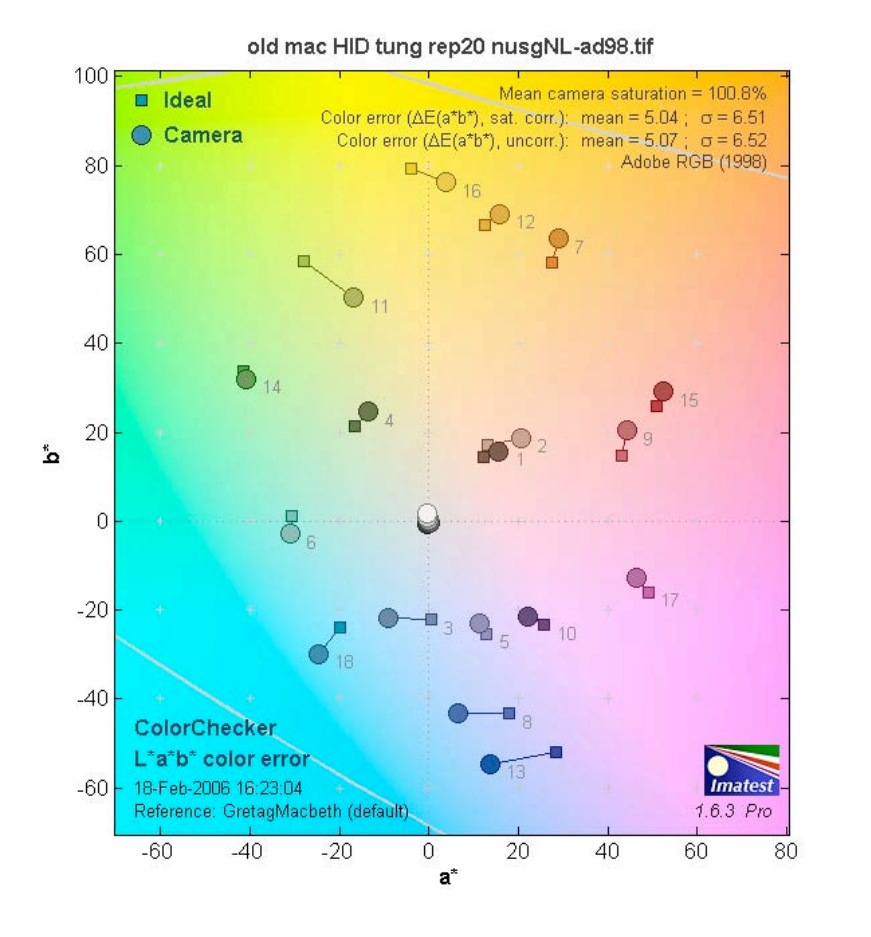
Repro 2.0 profiled(2.0; d50): Sat 100% deltaE 3.71 sigma 4.94 expErr 0.00

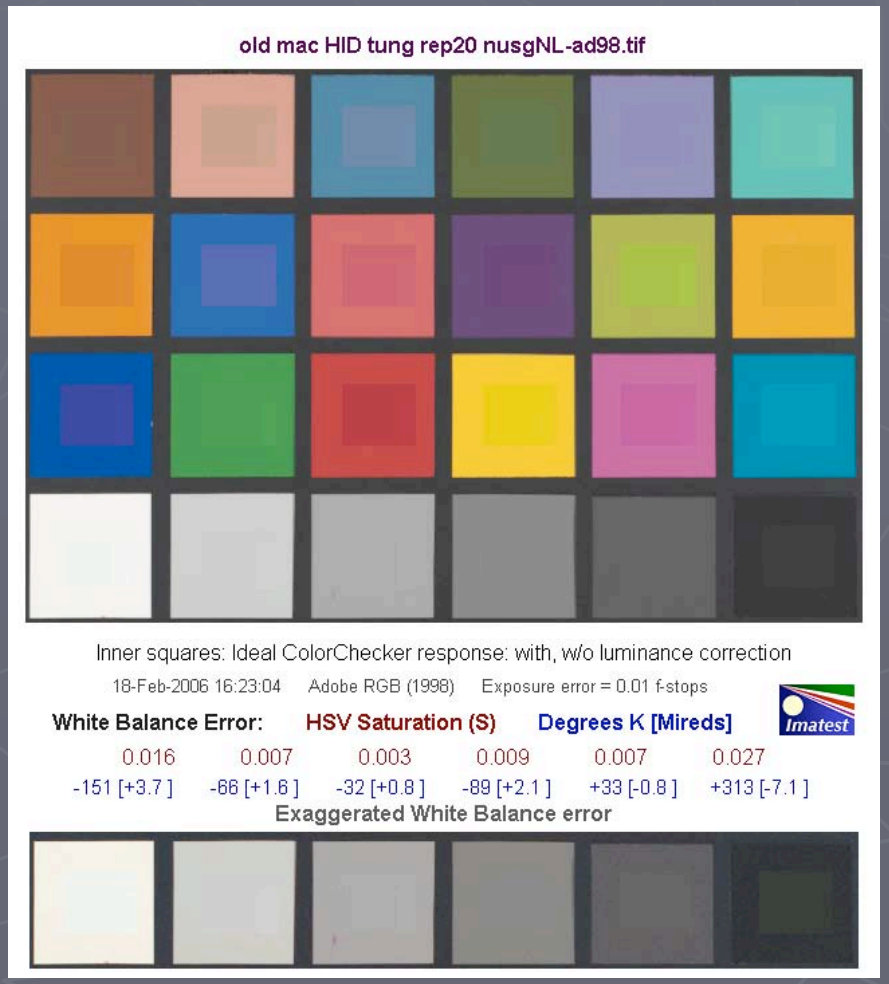




The importance of choosing the right profile illuminant

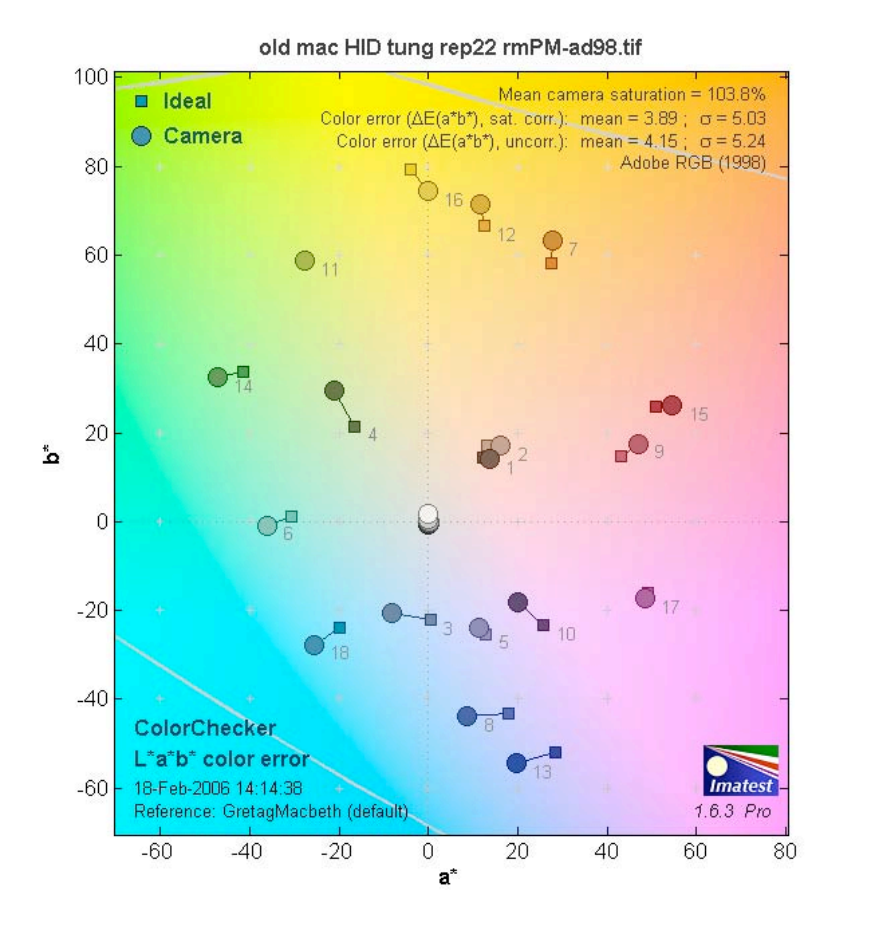
Repro 2.0 profiled(2.0; NL HID): Sat 101% deltaE 5.04 sigma 6.51 expErr 0.01

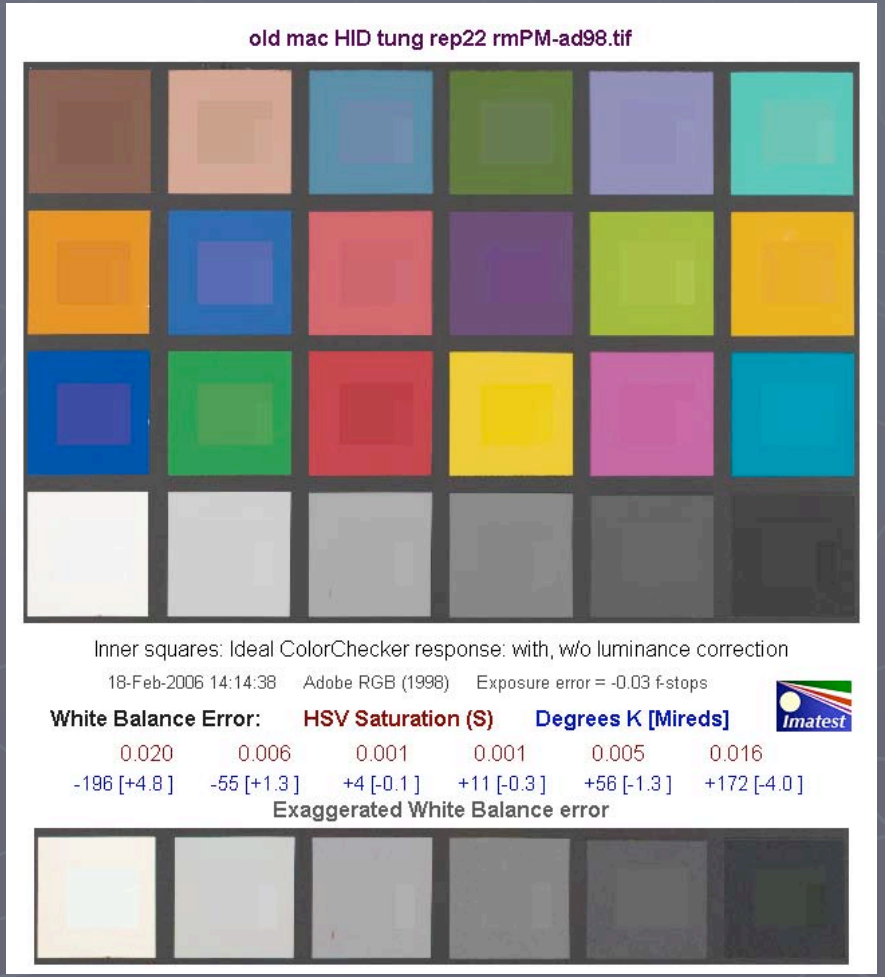




Testing three different profile generation packages

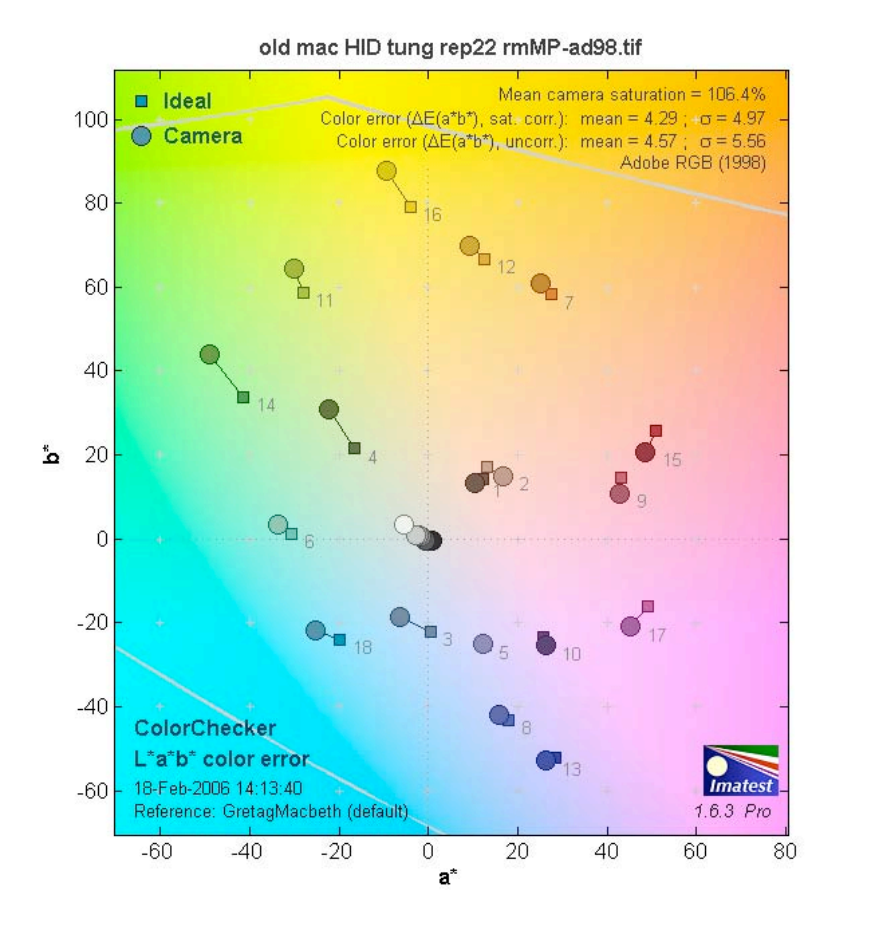
Repro 2.2 profiled(ProfileMaker): Sat 104% deltaE 3.89 sigma 5.03 expErr -.03

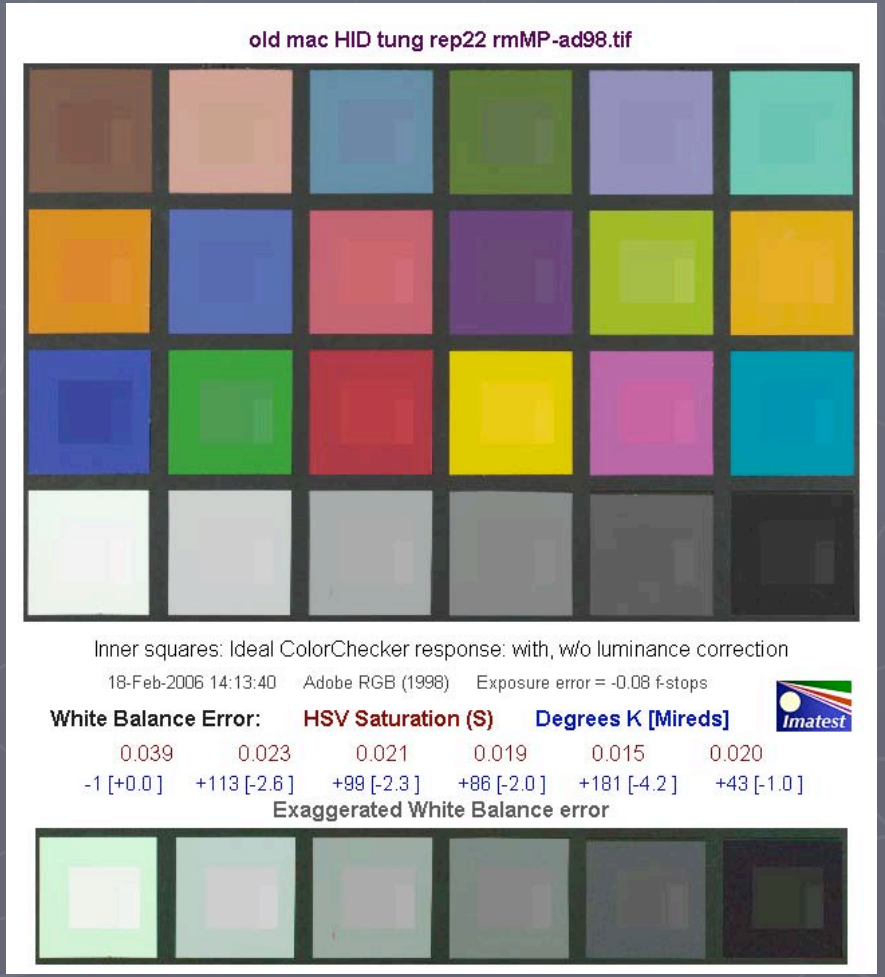




Testing three different profile generation packages

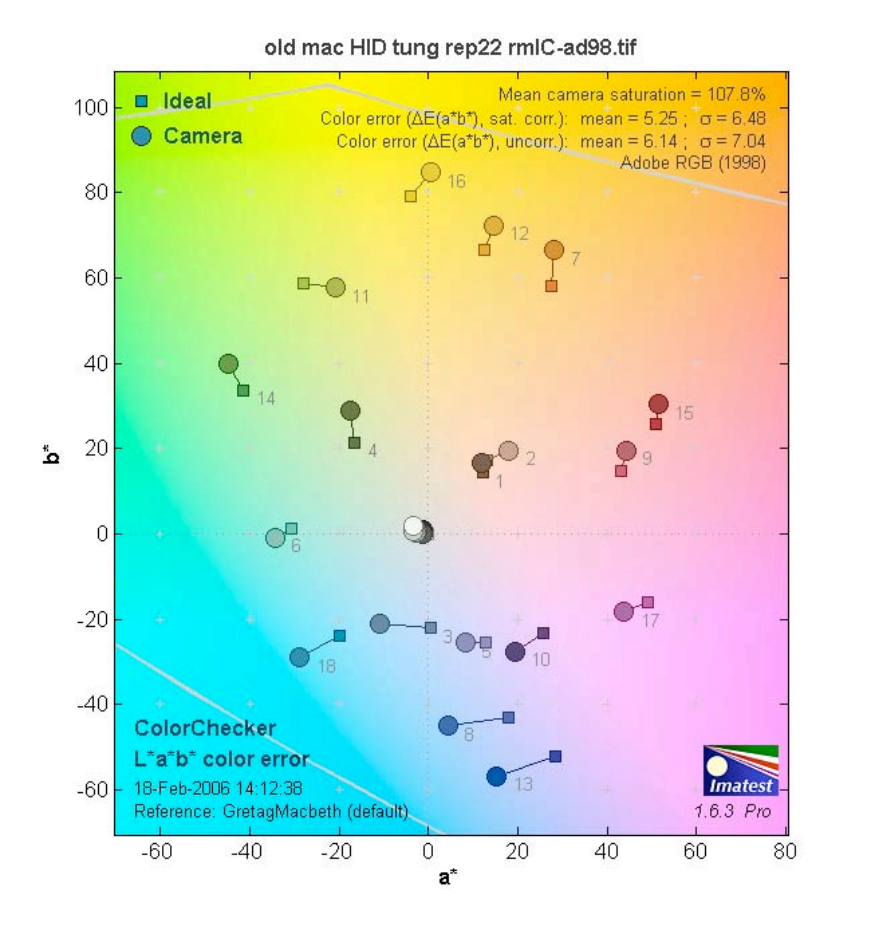
Repro 2.2 profiled(MonacoProfiler): Sat 106% deltaE 4.29 sigma 4.97 expErr -.08

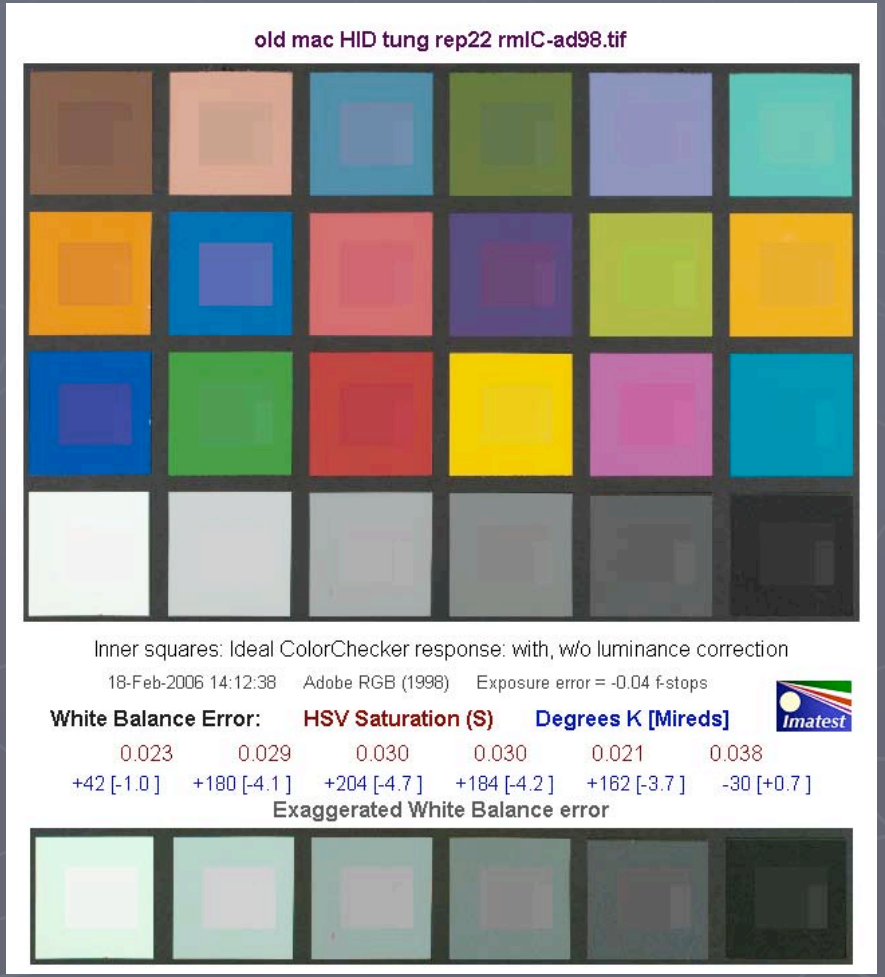




Testing three different profile generation packages

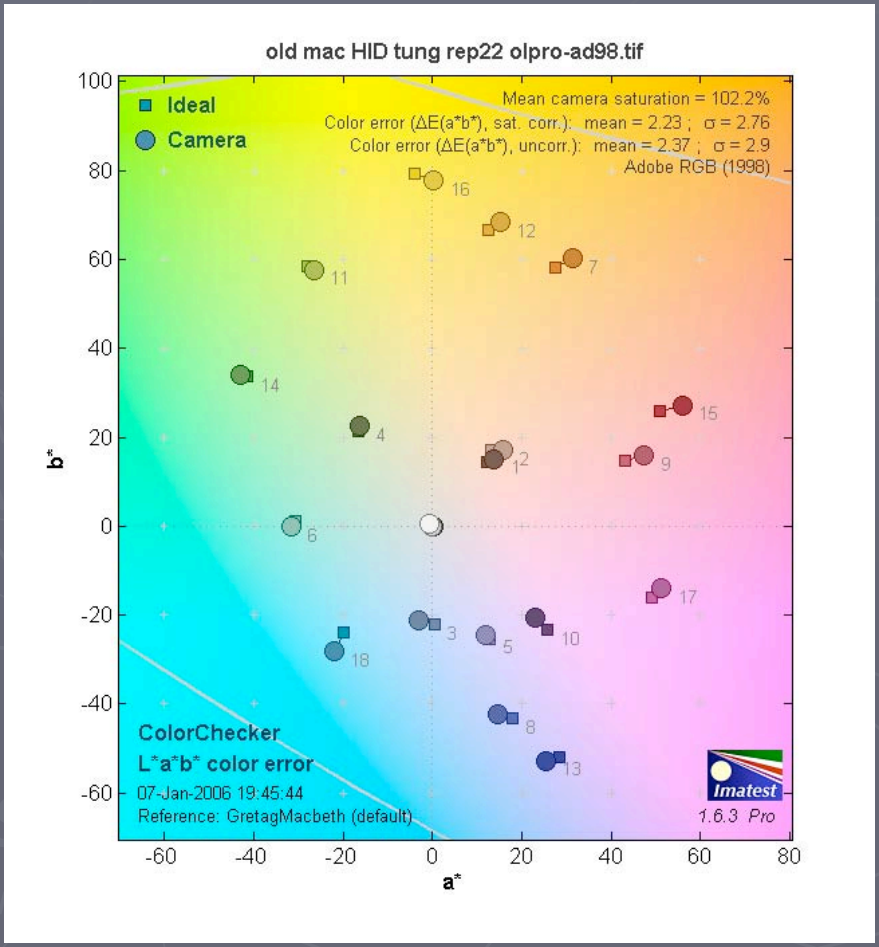
Repro 2.2 profiled(InCamera): Sat 108% deltaE 5.25 sigma 6.48 expErr -.04

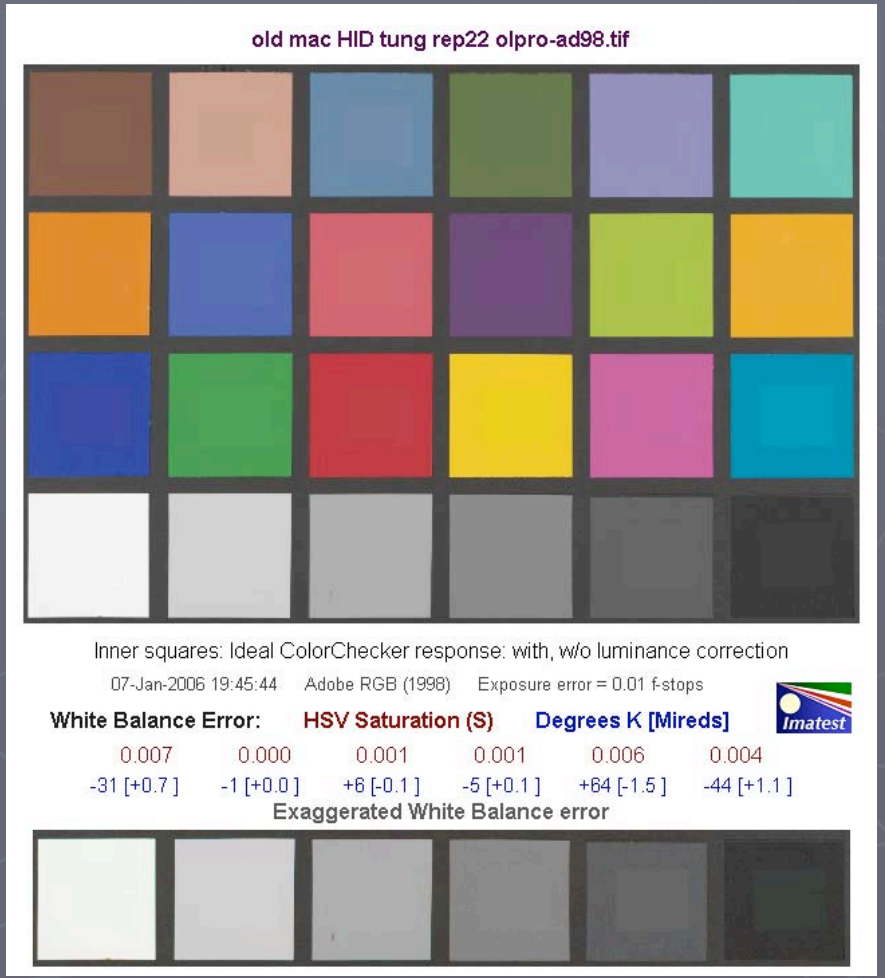




Using the same reference image to make a profile and test accuracy

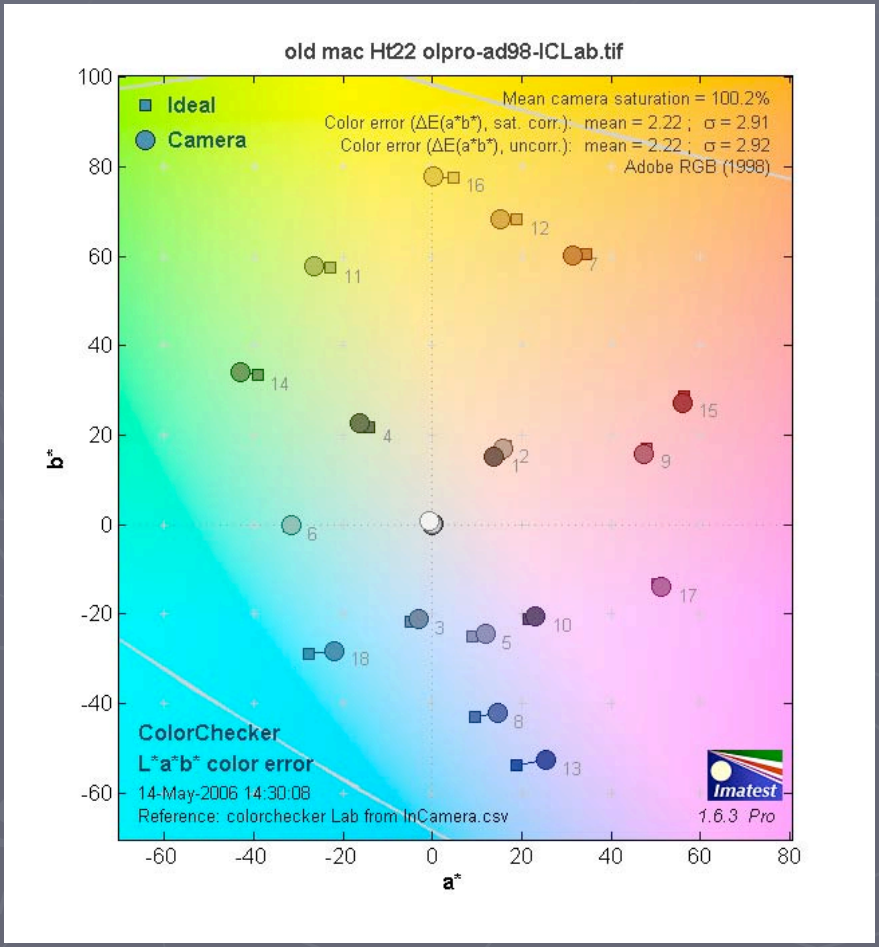
Repro 2.2 profiled(same): Sat 102% deltaE 2.23 sigma 2.76 expErr 0.01

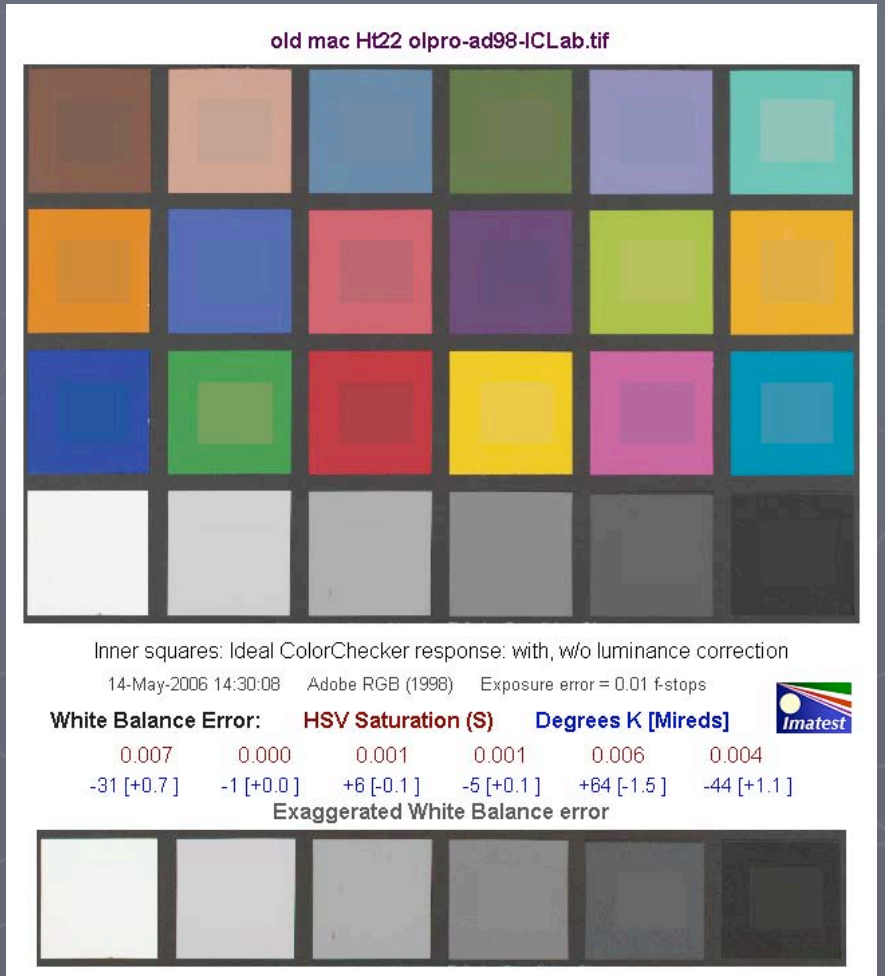




Using the same reference image, but different reference data, to make a profile and test accuracy

Repro 2.2 profiled(same): Sat 100% deltaE 2.22 sigma 2.91 expErr 0.01



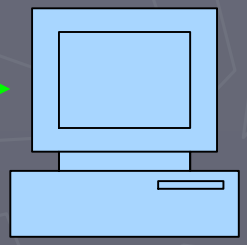


Testing a DNG image

open ColorChecker DNG image in Photoshop

1. adjust Camera Raw curve for proper gray patch RGB values
2. OPEN into target standard color space (e.g., Adobe RGB 1998)
3. SAVE converted image with unique file name

ColorChecker reference data compatible with target standard color space

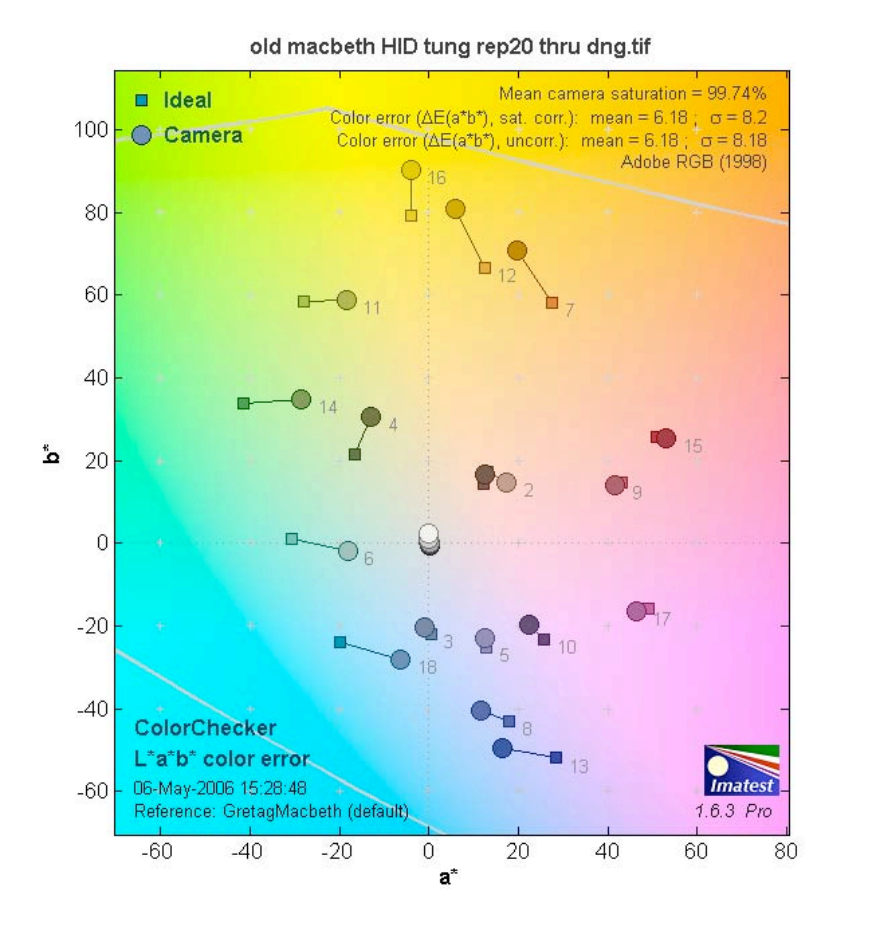


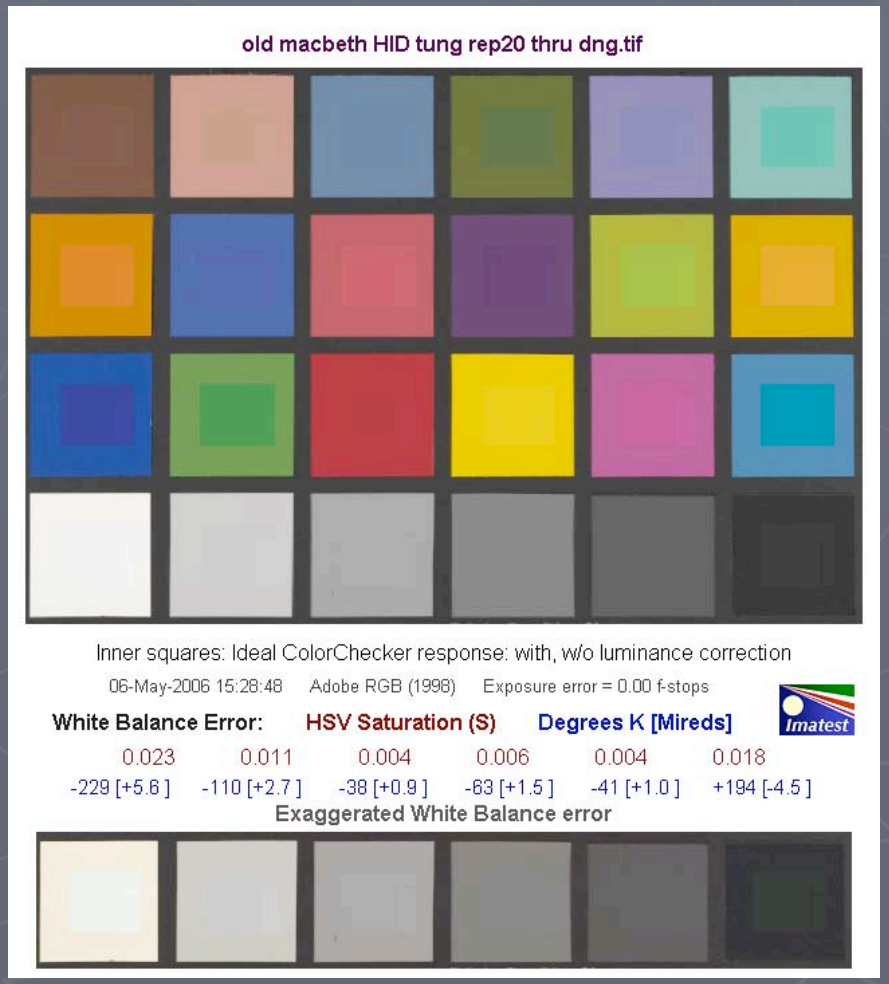
imatest ColorCheck

1. open and crop converted image in imatest ColorCheck
2. select appropriate reference data (e.g., GretagMacbeth default)
3. select proper target standard color space (e.g., Adobe RGB 1998)
4. click OK to run ColorCheck

Testing a DNG image

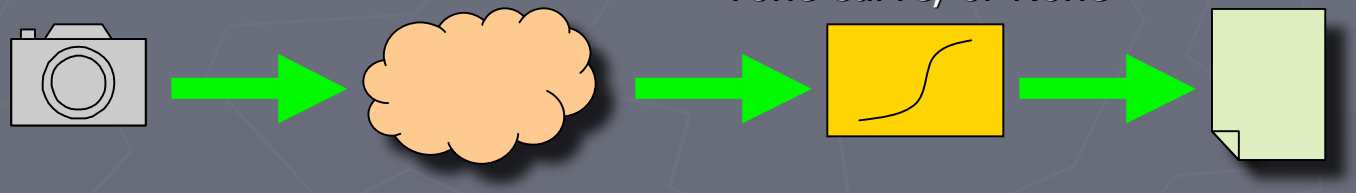
DNG image through Camera Raw: Sat 100% deltaE 6.18 sigma 8.2 expErr 0.00





Another method for improving color accuracy

raw RGB image data being retrieved from Better Light USB2 control box



8 or 16 bit per color Tone curve, or None

(optional attached device profile)

saved RGB file from File Manager

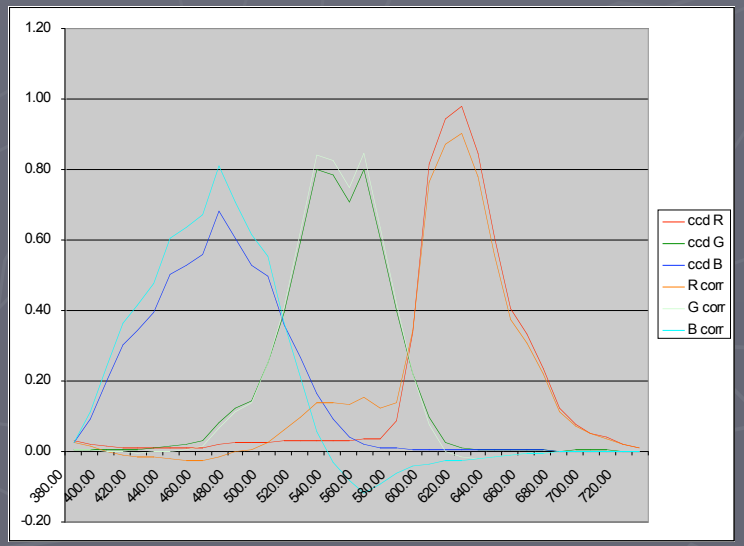
optional raw data color correction module in ViewFinder software

For linear-with-intensity data:

Rcorr = R + (a * (R-G)) + (b * (R-B))

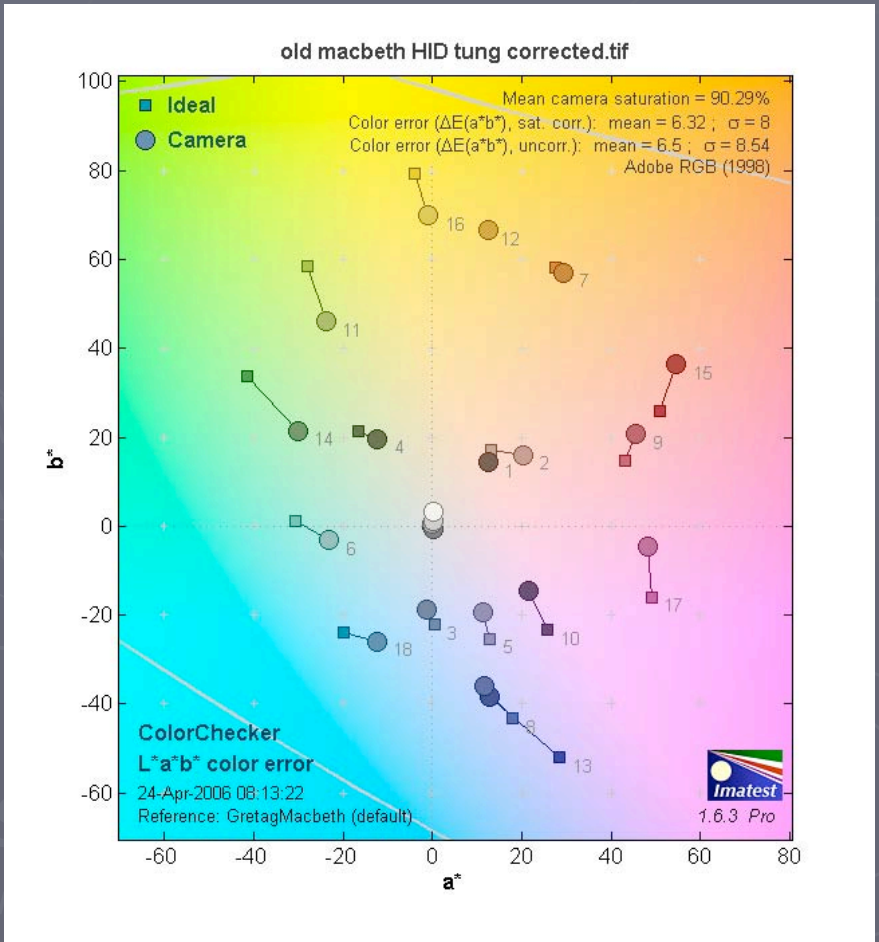
Gcorr = G + (c * (R-G)) + (d * (G-B))

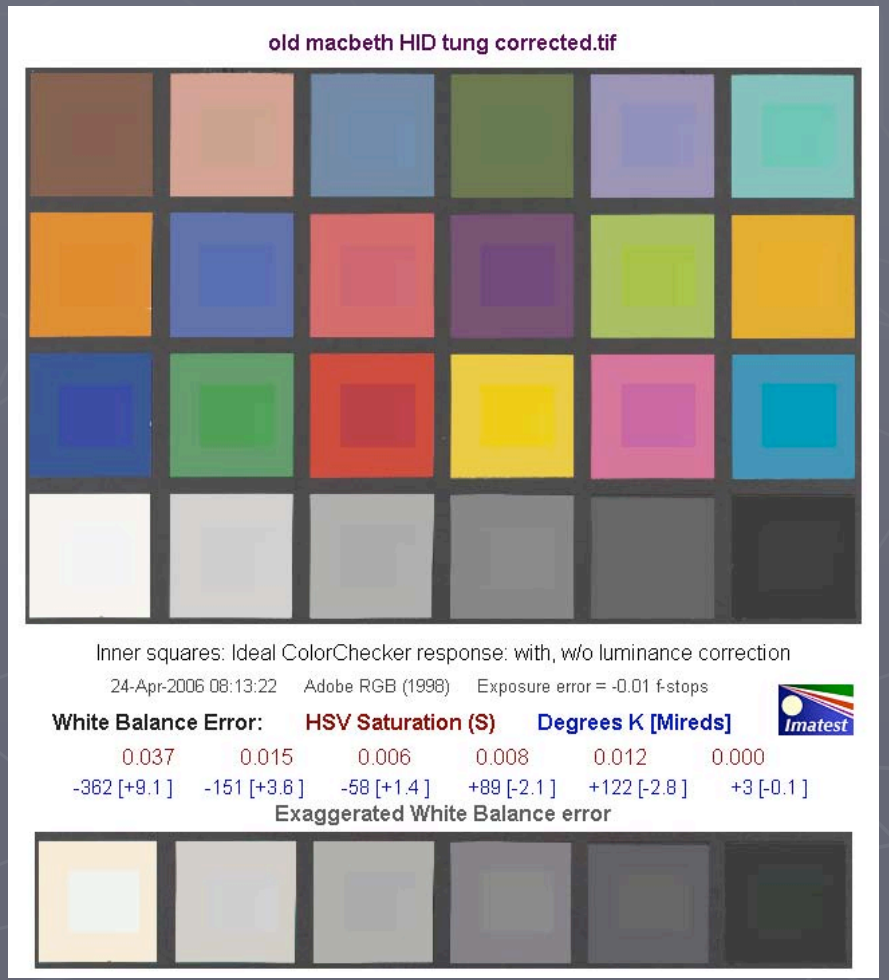
Bcorr = B + (e * (R-B)) + (f * (G-B))



Testing a custom color correction

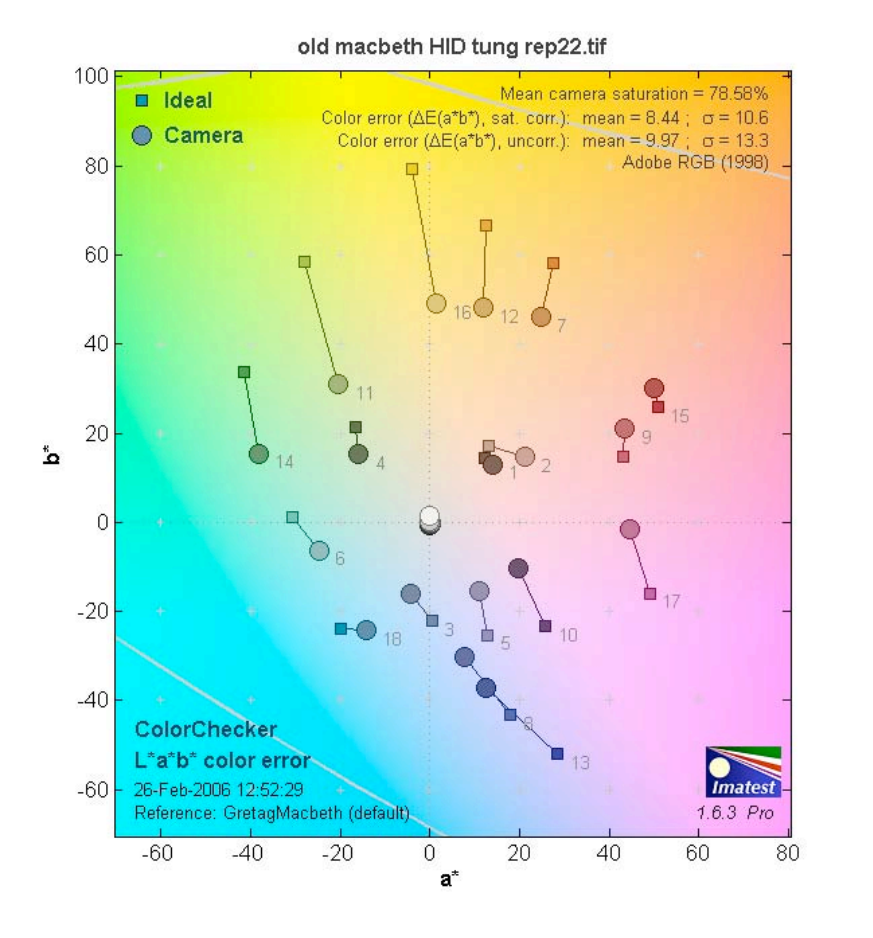
Repro 2.2 corrected: Sat 90% deltaE 6.32 sigma 8 expErr -.01

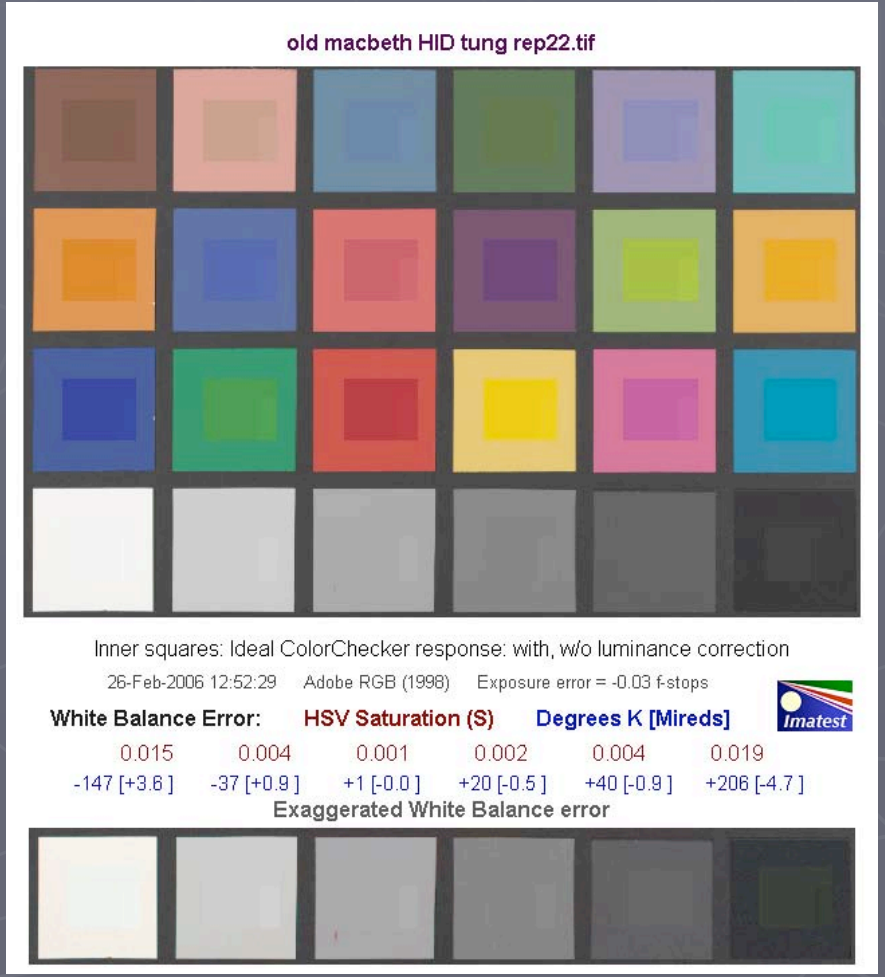




Comparing the custom correction to the unprofiled image

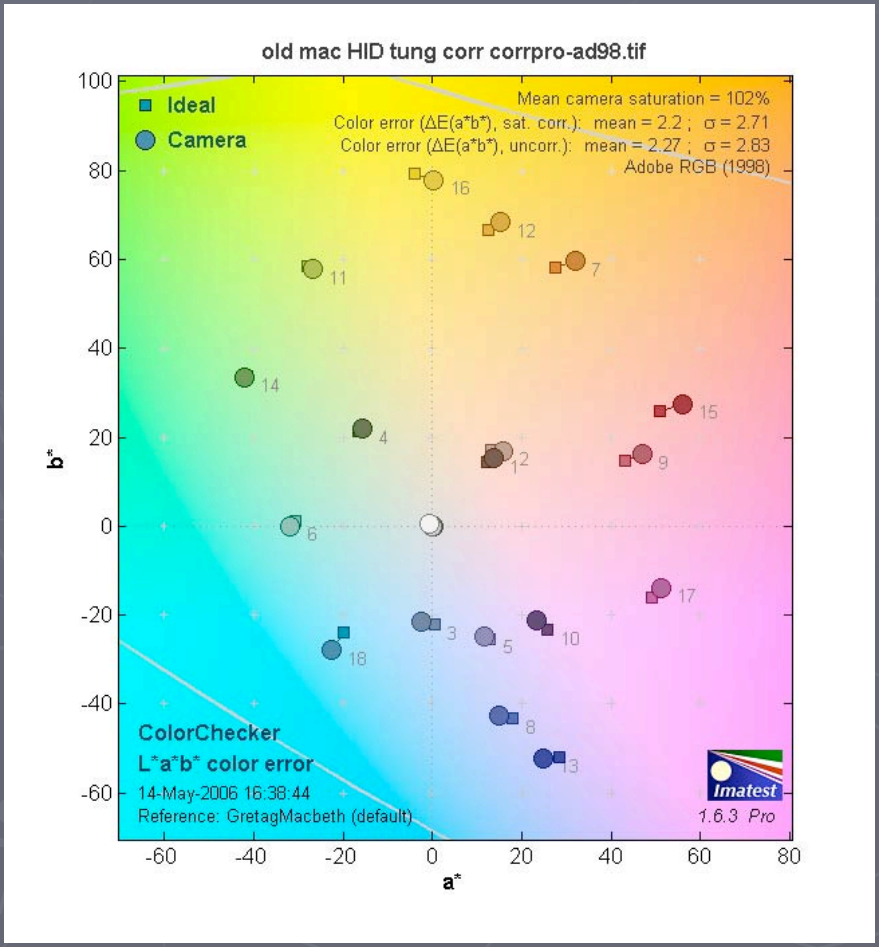
Repro 2.2 curve unprofiled: Sat 79% deltaE 8.44 sigma 10.6 expErr -.03

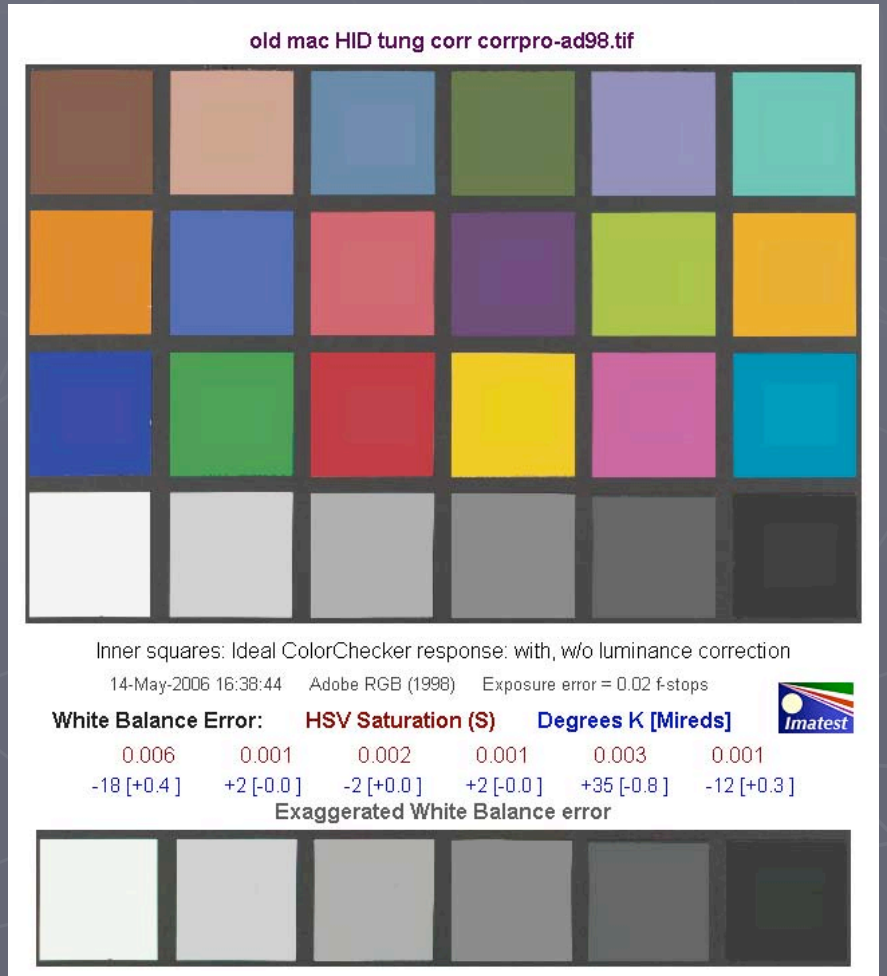




Profiling a custom color correction

Repro 2.2 corrected profiled(same): Sat 102% deltaE 2.2 sigma 2.71 expErr 0.02





But wait – there's more…

- Using a profile to achieve accurate color patch response is fine, but the profile should also be well-behaved throughout the tonal scale
- The Macbeth ColorChecker only has six gray scale patches and eighteen colors for evaluation
- Applying the profile to a special test image provides additional ways of examining the profile's tonal behavior

The *nuSHADES.tif* digitally-generated test image

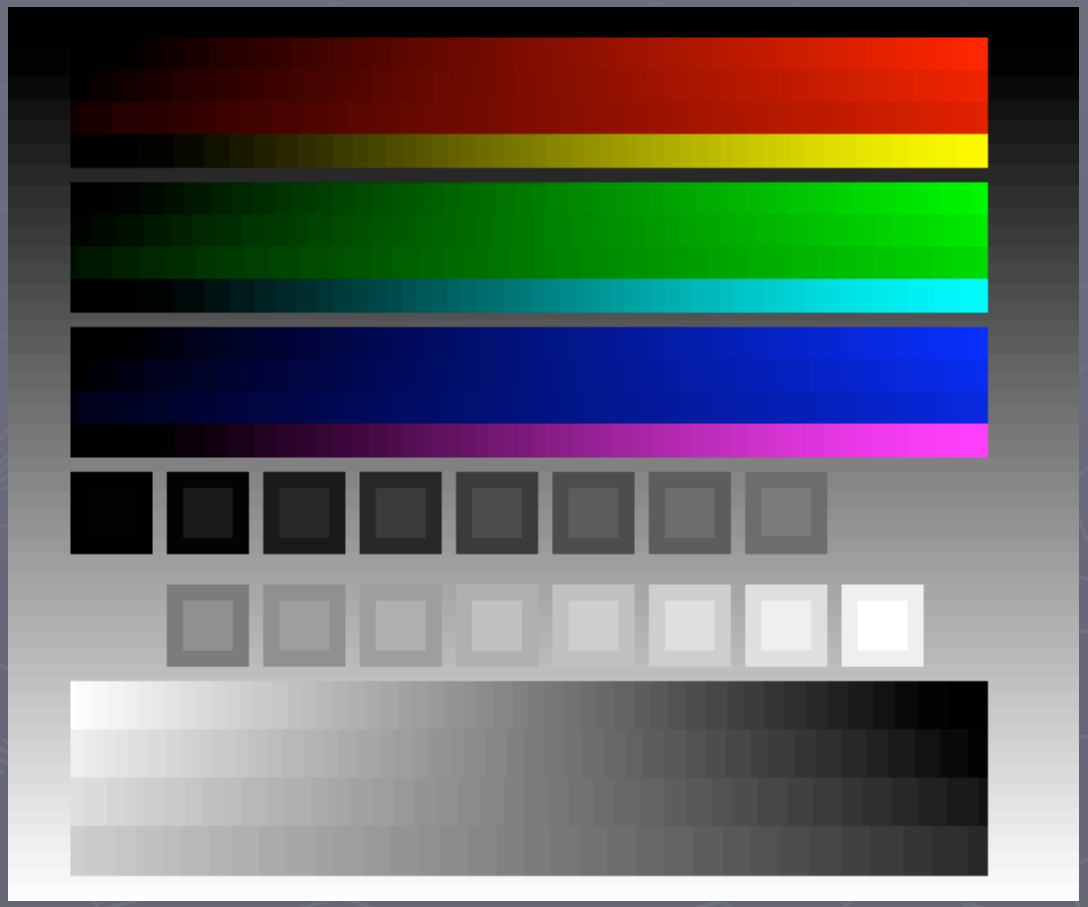
R 0 – 255
R 15 – 240
R 30 – 225
R+G 0 – 255

G 0 – 255
G 15 – 240
G 30 – 225
G+B 0 – 255

B 0 – 255
B 15 – 240
B 30 – 225
B+R 0 – 255

Neutral blocks

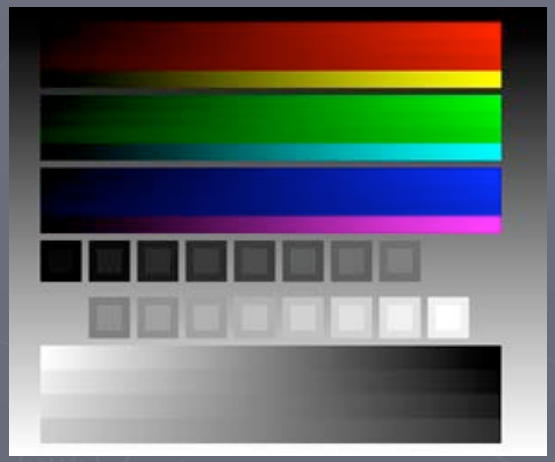
RGB 0 – 255
RGB 15 – 240
RGB 30 – 225
RGB 45 – 210

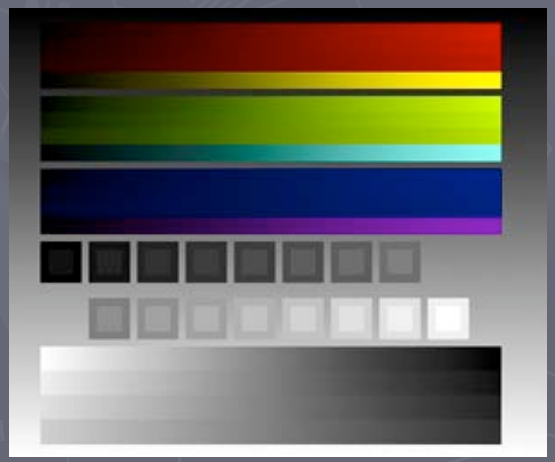


nuSHADES.tif contains pure RED, GREEN, BLUE, CYAN, MAGENTA, YELLOW, and NEUTRAL gradients with all data values from 0 to 255

the Neutral blocks each have a smaller block inside of +16 data values – the smaller block should be visible within each block throughout the tone scale

Applying a profile to nuSHADES



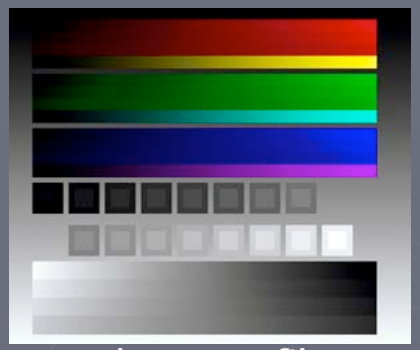


When the image nuSHADES.tif is opened in Photoshop, its "pure", unprofiled RGB data values are displayed in Photoshop's working space (e.g., Adobe RGB 1998).

ASSIGNING a profile to this image will cause Photoshop to display the "pure" image data through the selected profile, thereby showing the effects of the profile on this data. The image with assigned profile can be saved with a unique name for further inspection in ColorThink.

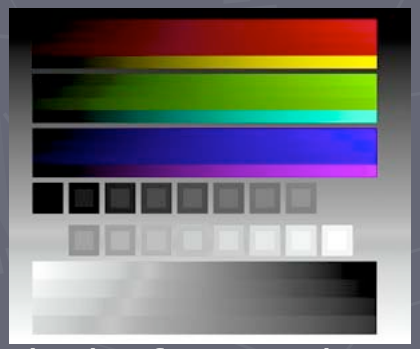
After saving the profiled image, CONVERT the profiled image to Photoshop's working space and save the converted file with a unique name, for use in profile-unaware applications, and to be able to see (read out) the profile-altered RGB data values.

Effects of applying different profiles to nuSHADES

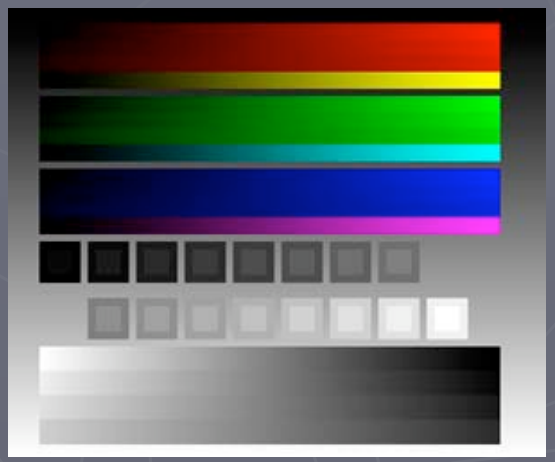


olcorr profile

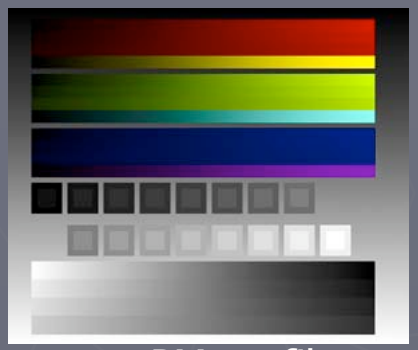
nusg65 profile



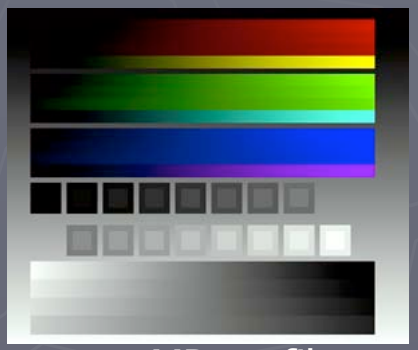
bad reference chart



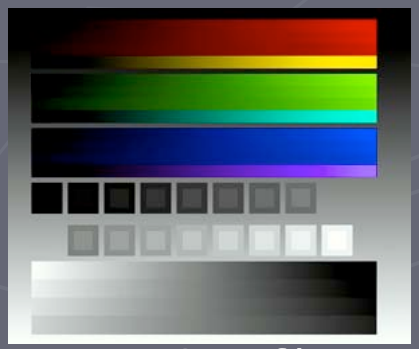
no profile



rmPM profile

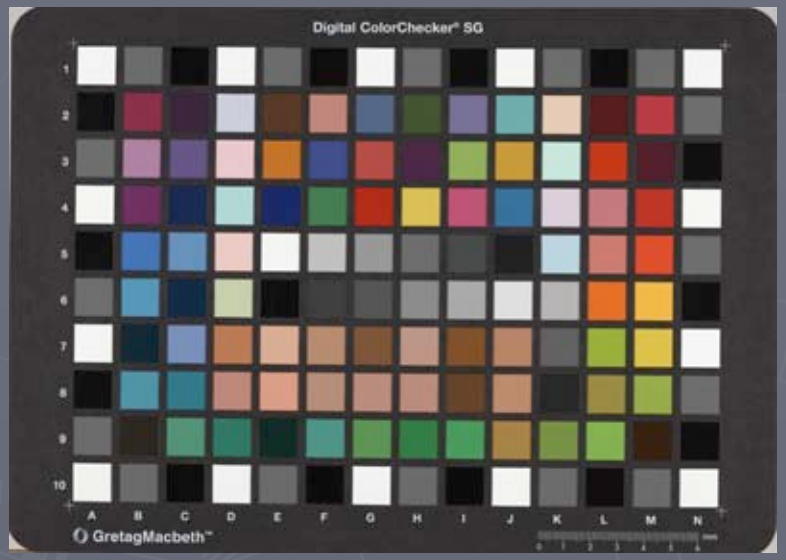


rmMP profile

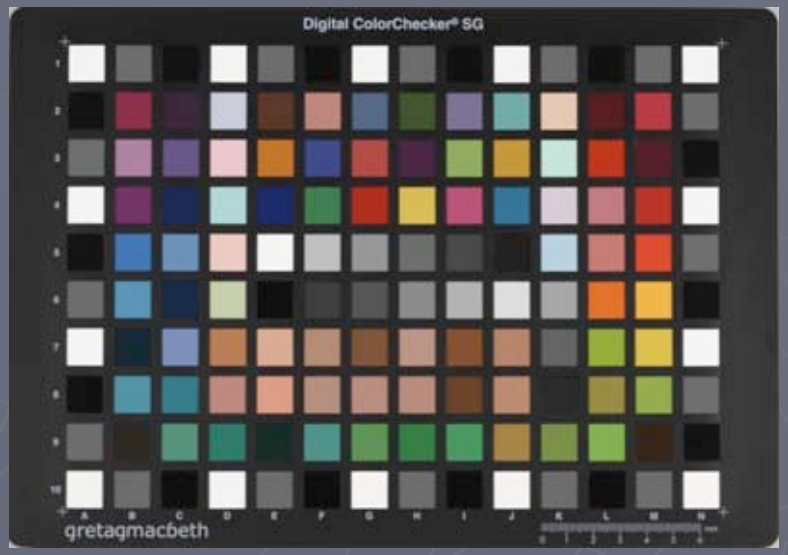


rmIC profile

Example of a bad reference chart



bad SG chart (top)

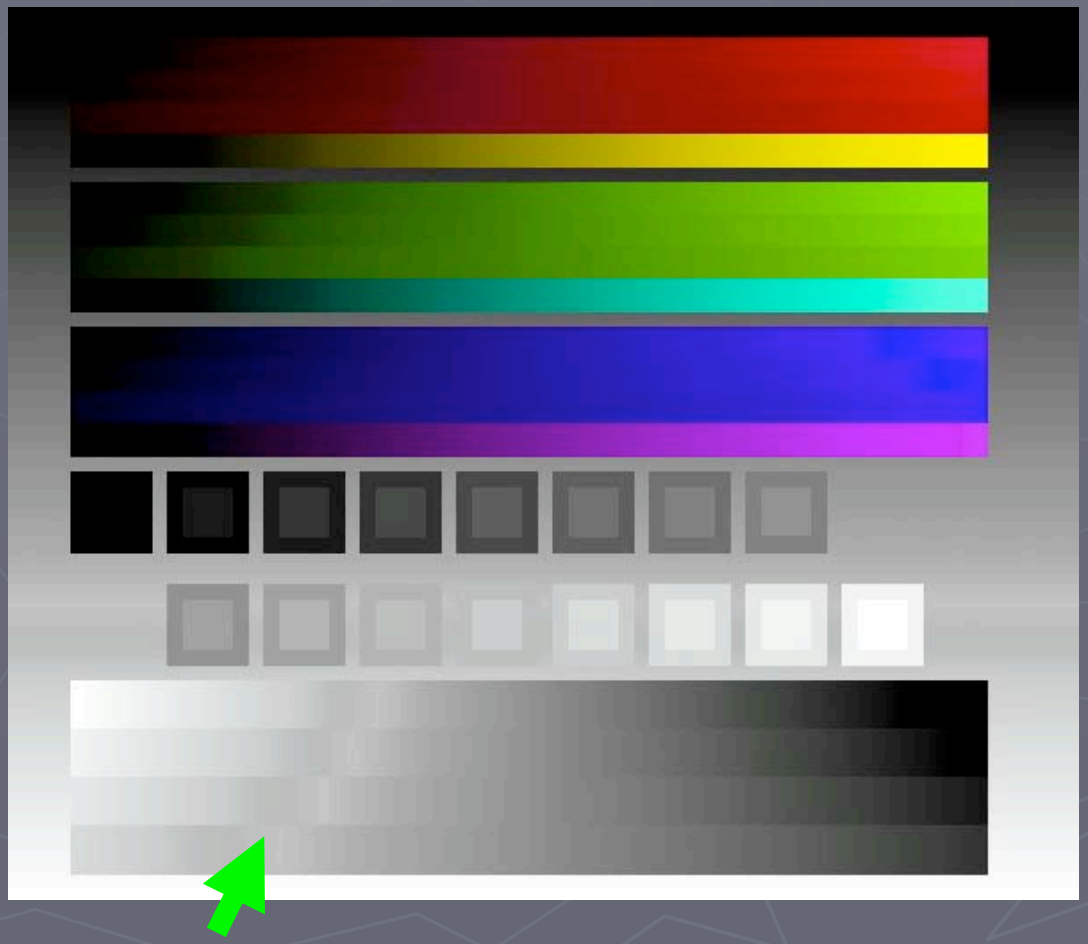


new SG chart (bottom)

Effect of bad reference chart profile applied to nuSHADES

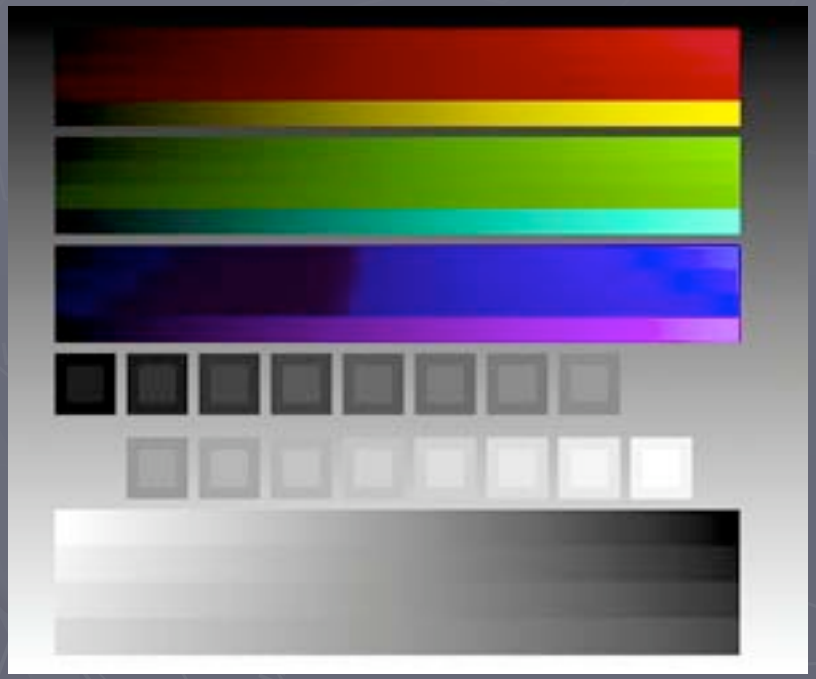
Neutral gradients have an unwanted inflection (arrow) because of improper gray patch reflectance, but color gradients appear unaffected

(a profile made from this chart still provides very accurate color matching)



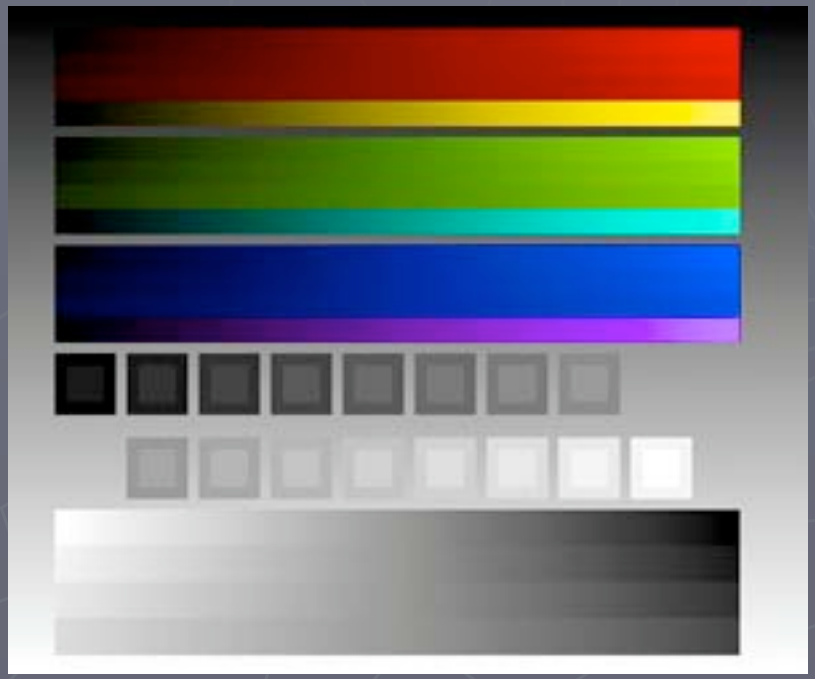
two more examples...

Repro 2.0 profiled(2.0; d65):
Sat 99% deltaE 2.39 sigma 3.16 expErr 0.00



nusg65 profile
repro 2.0 gamma
d65 illuminant

Repro 2.0 profiled(2.0; NL HID):
Sat 101% deltaE 5.04 sigma 6.51 expErr 0.01

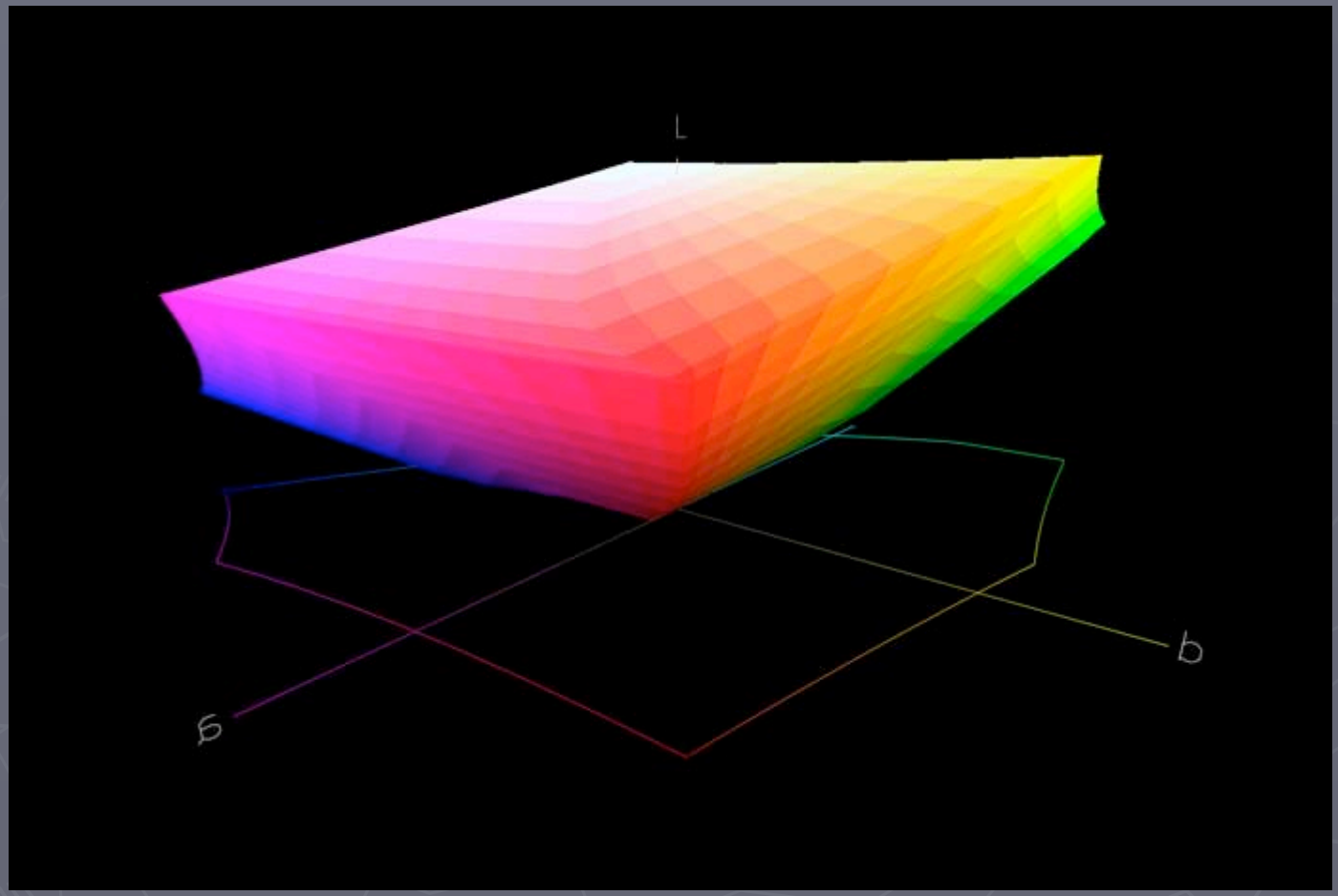


nusgNL profile
repro 2.0 gamma
NL HID illuminant

Using ColorThink to examine profiles

- ColorThink (available from www.chromix.com) includes a color space viewing/graphing utility that provides another way to examine profiles
- In addition to displaying the calculated gamut enclosed by a profile, this utility can display the location of specific RGB data values that have been characterized by a profile
- This capability lets us examine the overall volume (gamut) of a profile, and also the individual characteristic curves for neutrals and pure RGBCMY colors (using nuSHADES)

Example of a well-behaved profile



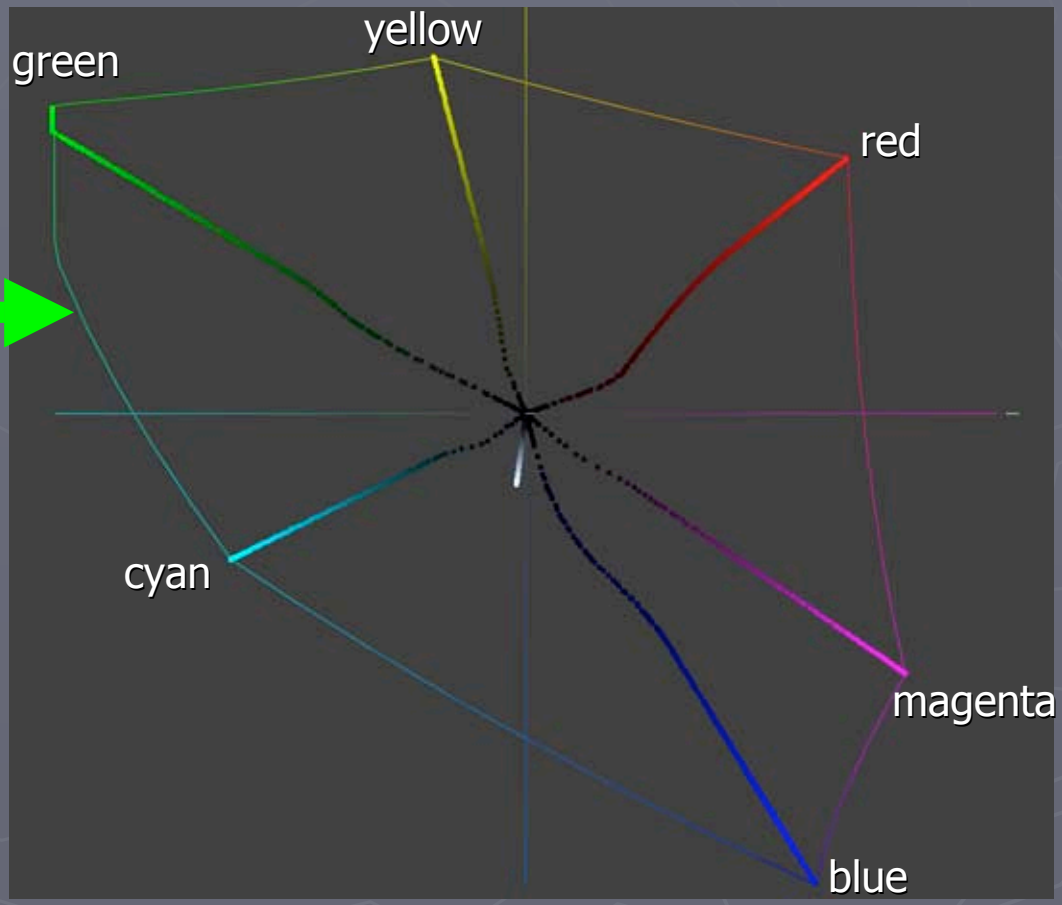
Adobe RGB 1998 color space displayed by ColorThink

Viewing nuSHADES in ColorThink (2D)

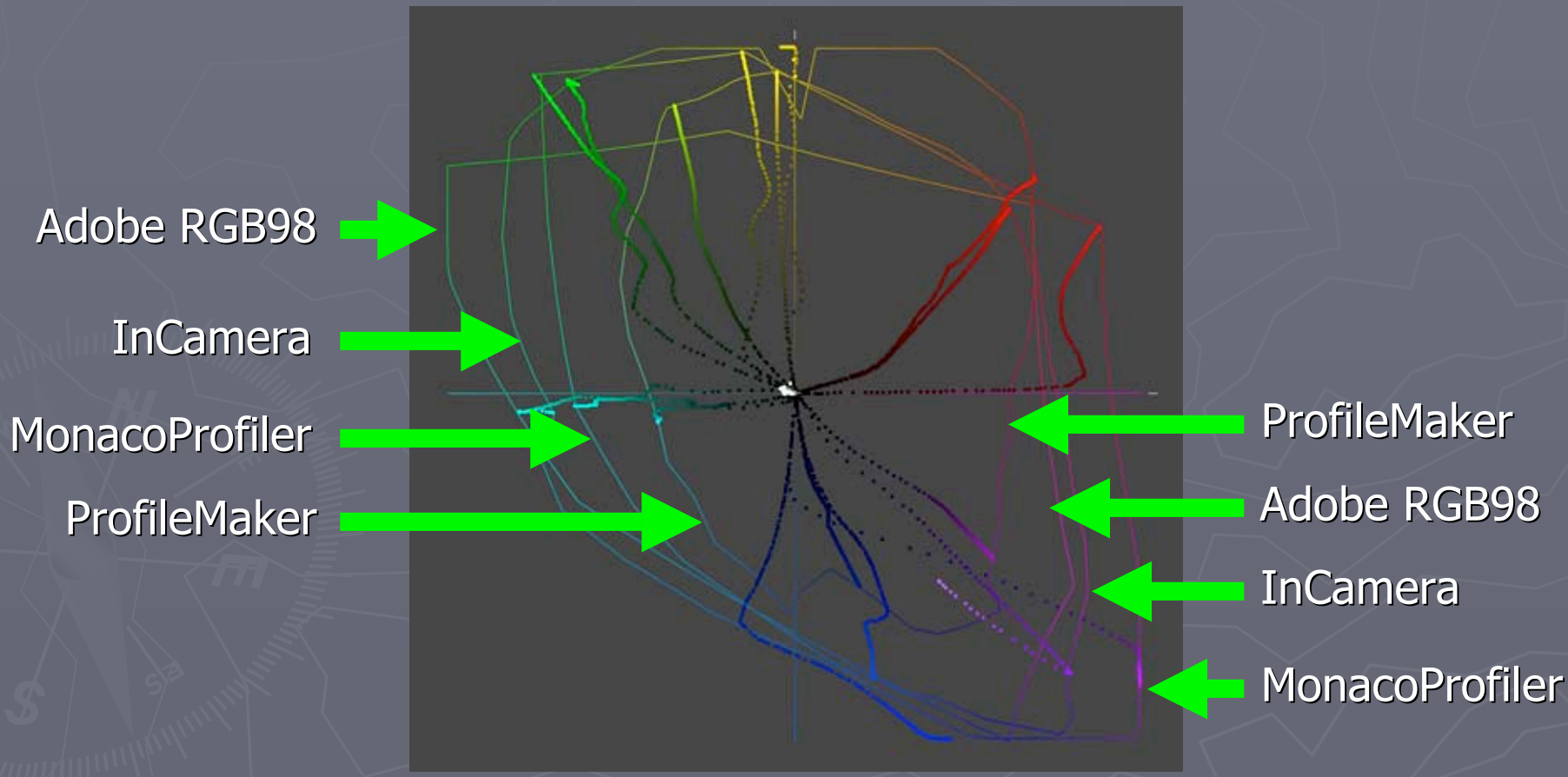
Adobe RGB 1998
profile gamut

plus

nuSHADES with
Adobe RGB 1998
profile assigned



Three different vendors' input profiles for the same reference chart image



Conclusions

- A well-made profile can improve the standard color response of a Better Light scanning back
- There are many opportunities for errors when making a profile
- Color accuracy is only one aspect of a well-made profile – smoothness and linearity are others
- Only ONE well-made profile should be required for a given device & light source

Resources

- Imatest is available from www.imatest.com
  - for Windows only (or Virtual PC on Macs)
  - Imatest Light costs US$99
  - Imatest Pro costs US$299
  - NEW GamutVision utility now in beta
- ColorThink is available from www.chromix.com
  - for Windows or Macs
  - ColorThink 2 costs US$149
  - NEW ColorThink Pro now available
- nuSHADES test image is free from www.betterlight.com