

Color Monitors for Medical Workstations

ES → Relevance of color displays

ES → Professional efforts

MF → Color Monitors - current technology

MF → ICC Color Management

HR → Calibration of color monitors

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Why
Color?



- Accelerated adoption of electronic color renditions in medicine:
 - radiology, cardiology, pathology, dermatology, endoscopy, microscopy, ophthalmology
- Lack of a standard methodology for characterization of color display systems
 - How do we set up a color display?
 - How do we measure display color performance?
 - What performance is acceptable for specific applications?
 - How much tolerance is allowable?



Colorization schema

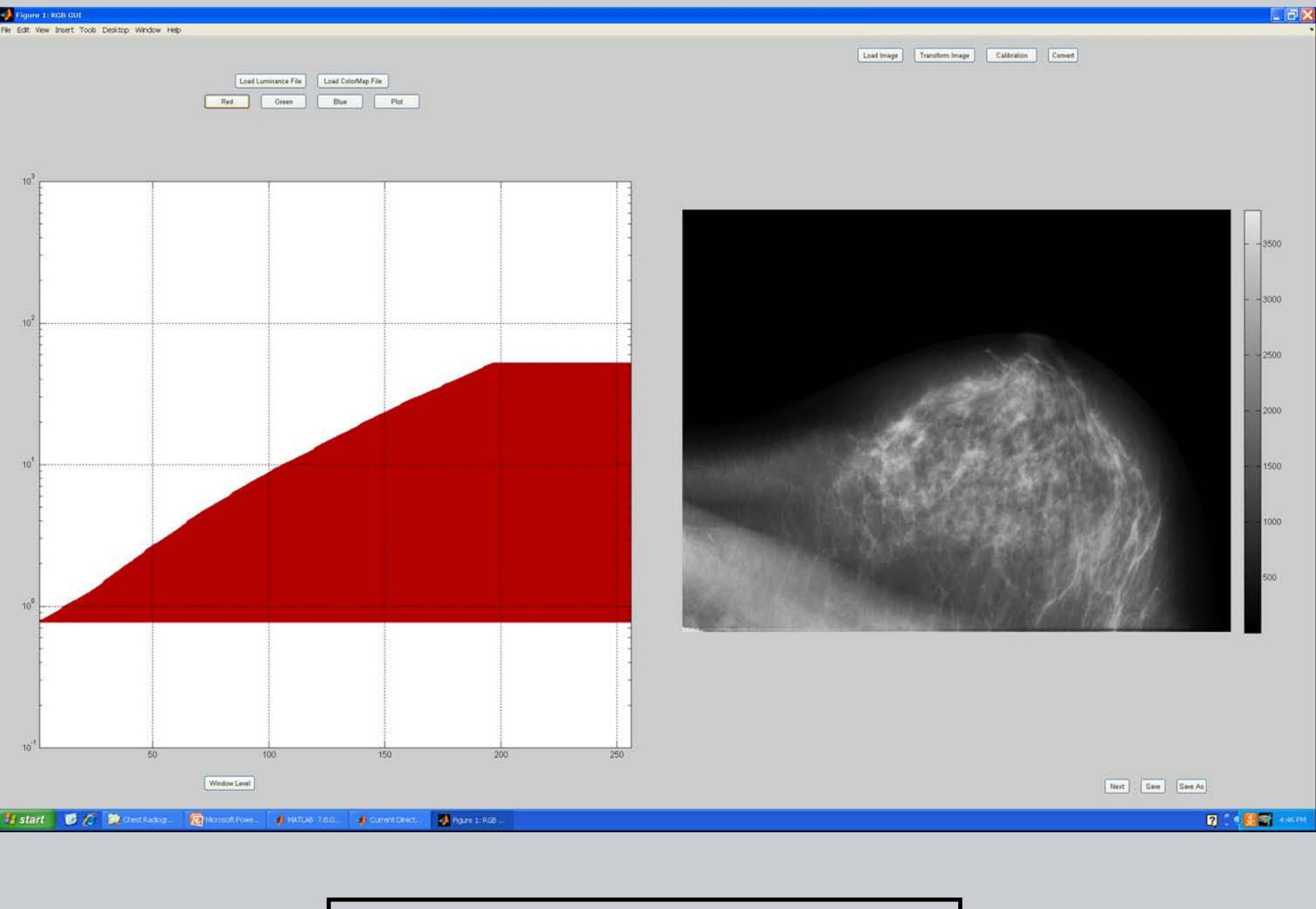




Figure 1: RGB GUI

File Edit View Insert Tools Desktop Window Help



Load Luminance File

Load ColorMap File

Red

Green

Blue

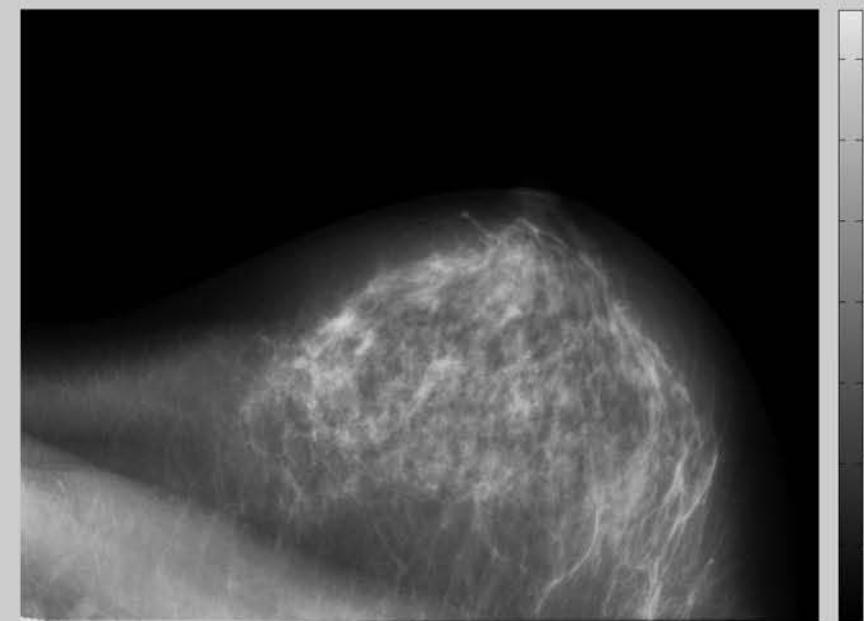
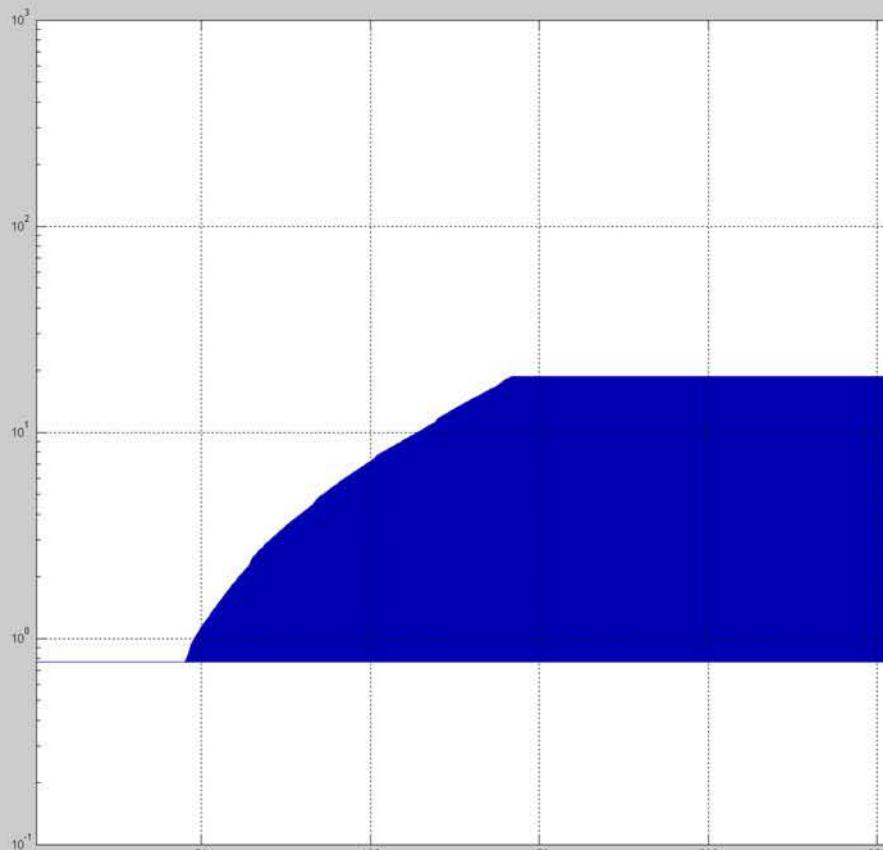
Plot

Load Image

Transform Image

Calibration

Convert



Window Level

Next

Save

Save As

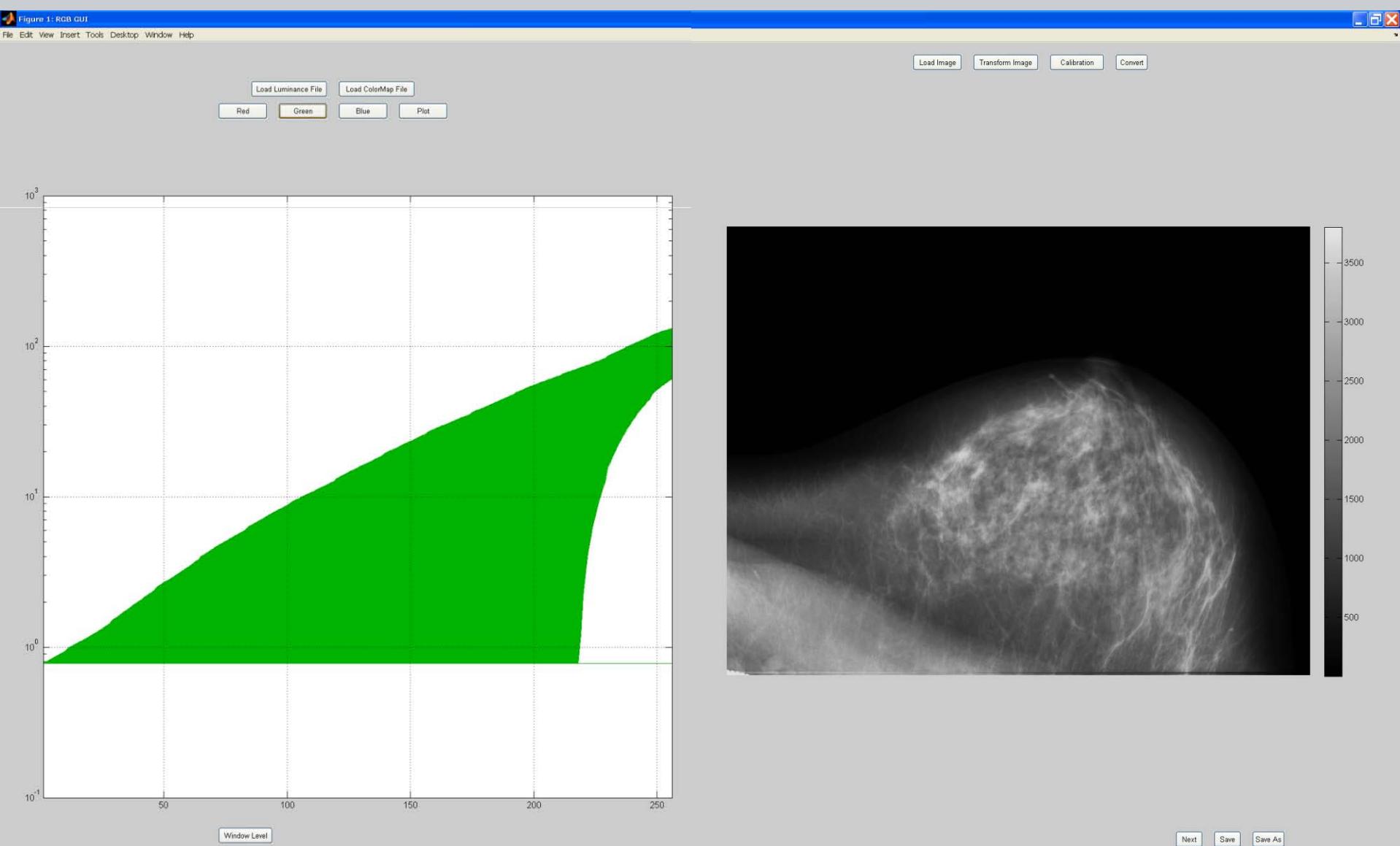
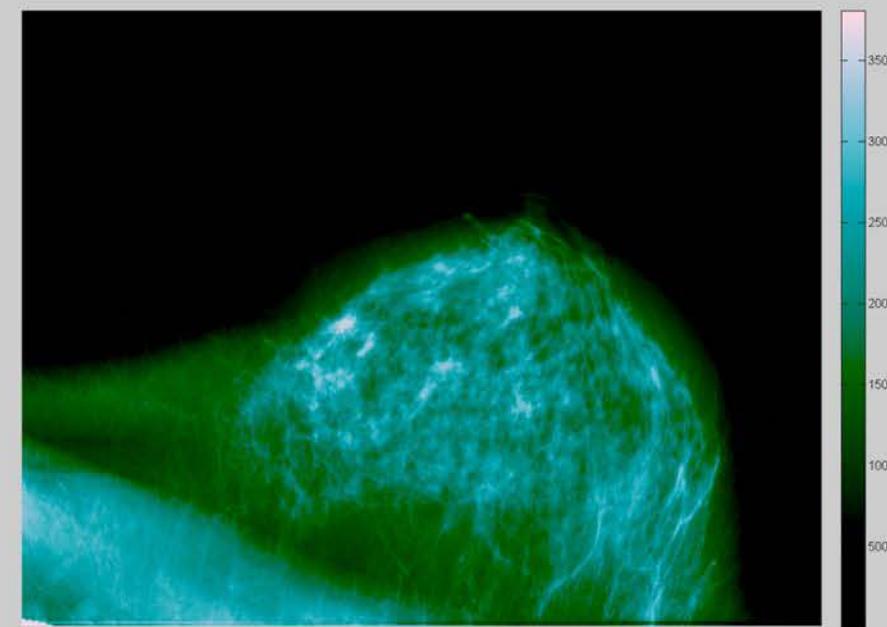
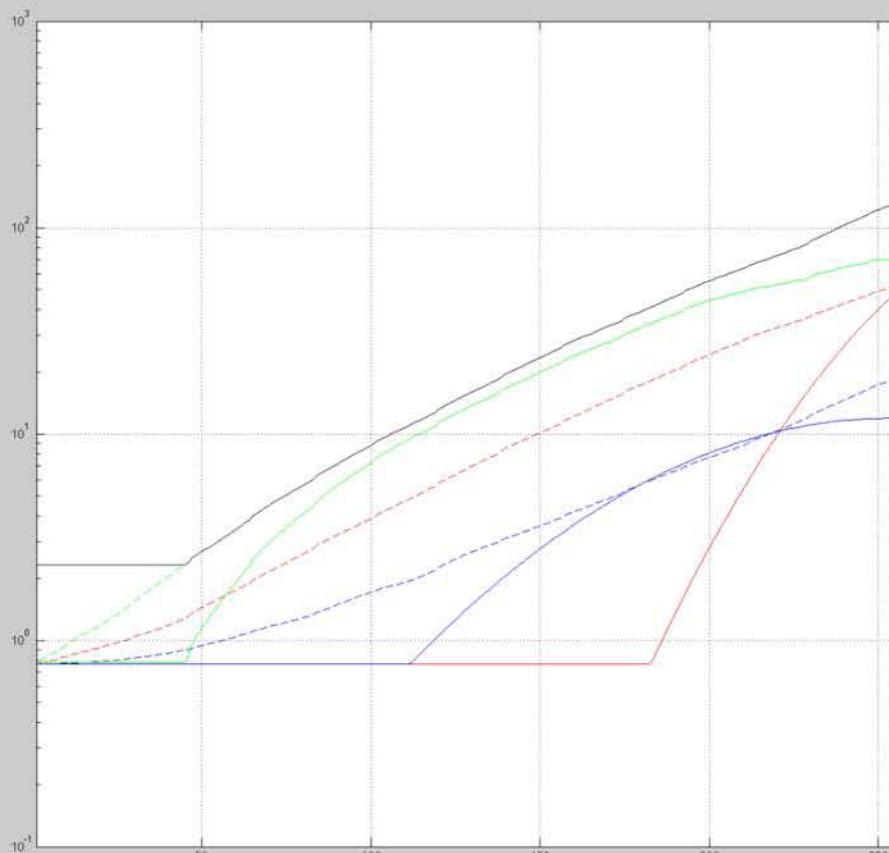




Figure 1: RGB GUI

File Edit View Insert Tools Desktop Window Help

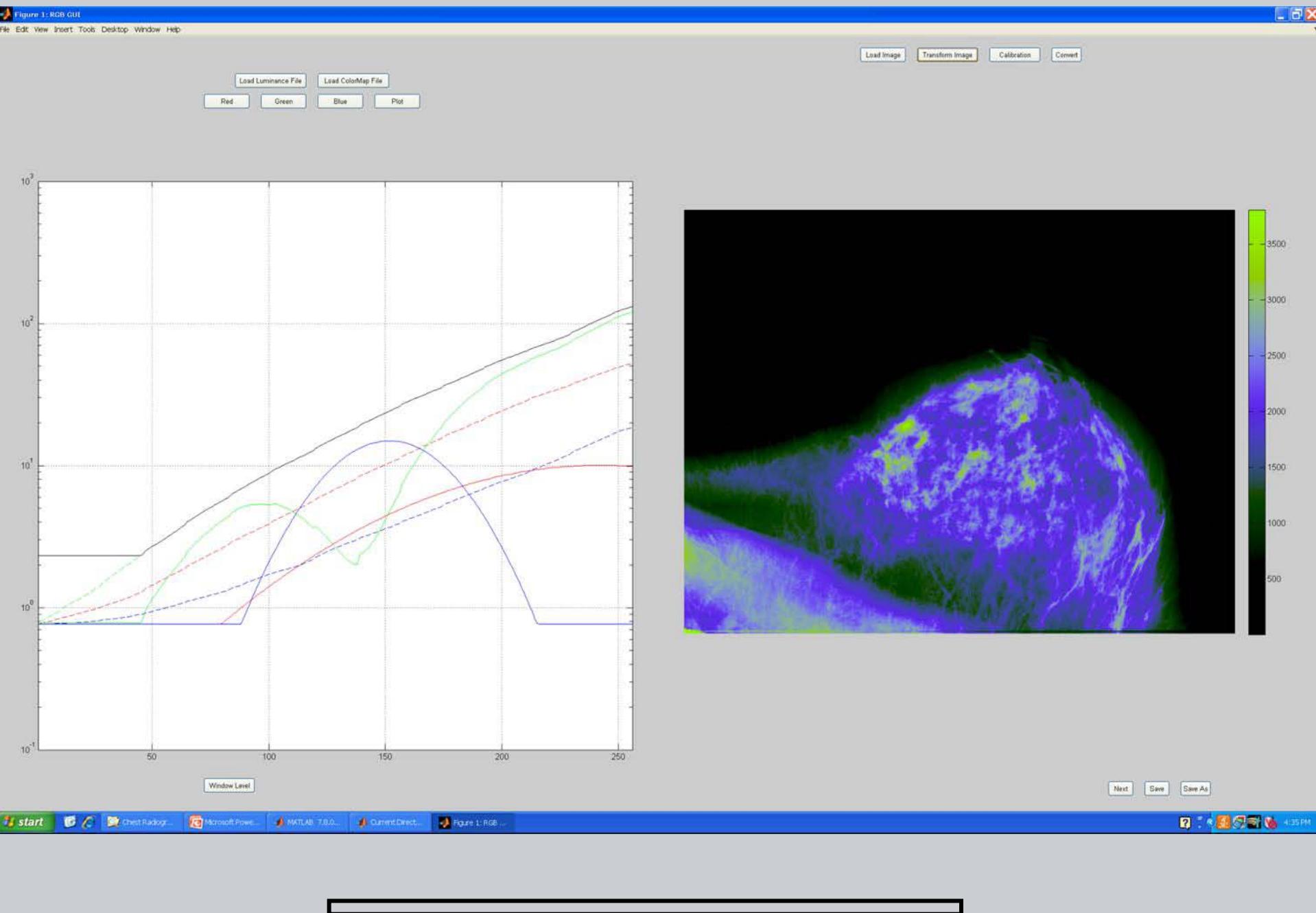




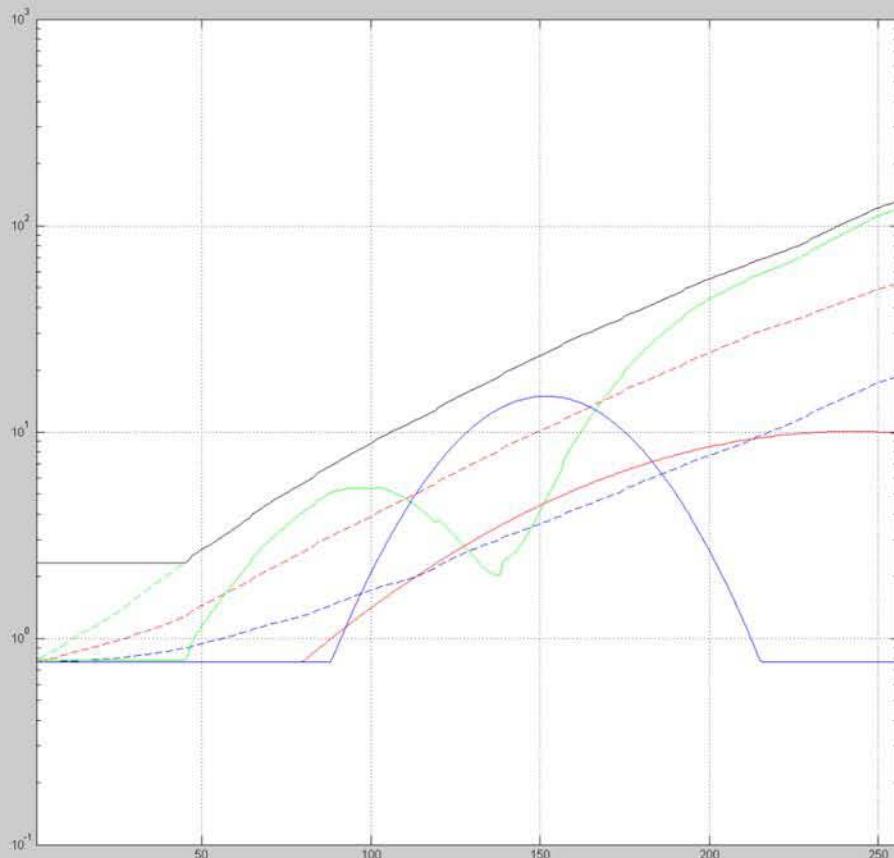
Figure 1: RGB GUI

File Edit View Insert Tools Desktop Window Help



Load Luminance File Load ColorMap File
Red Green Blue Plot

Load Image Transform Image Calibration Convert



Window Level

Next Save Save As

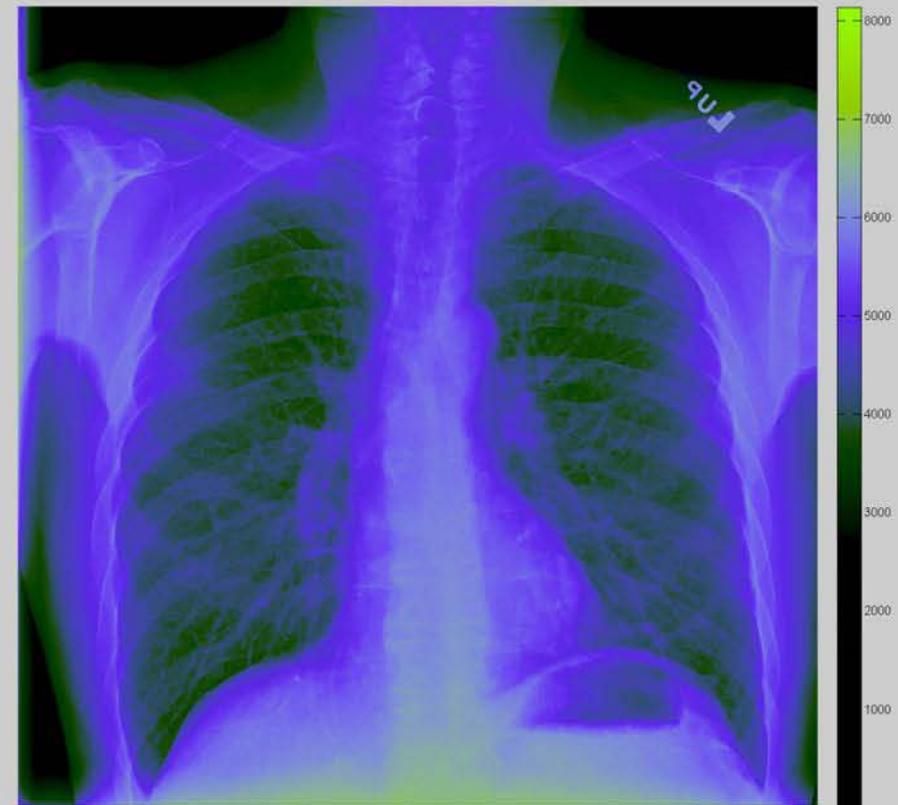


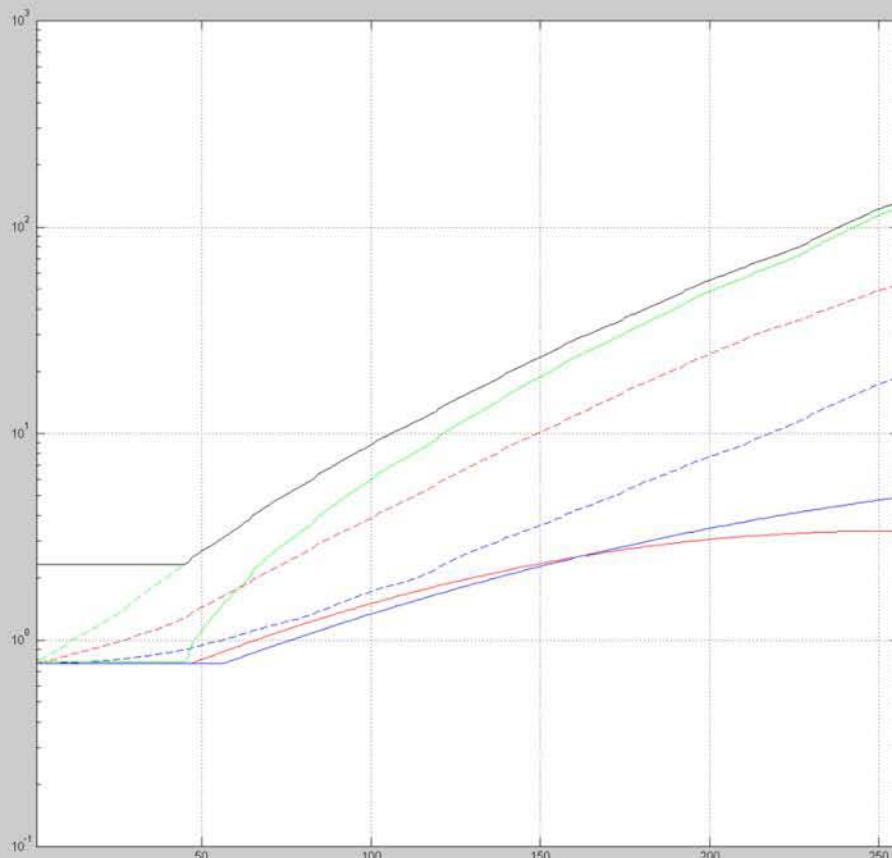


Figure 2: RGB GUI

File Edit View Insert Tools Desktop Window Help



Load Image Transform Image Calibration Convert

Load Luminance File Load ColorMap File
Red Green Blue Plot

Window Level

Next Save Save As

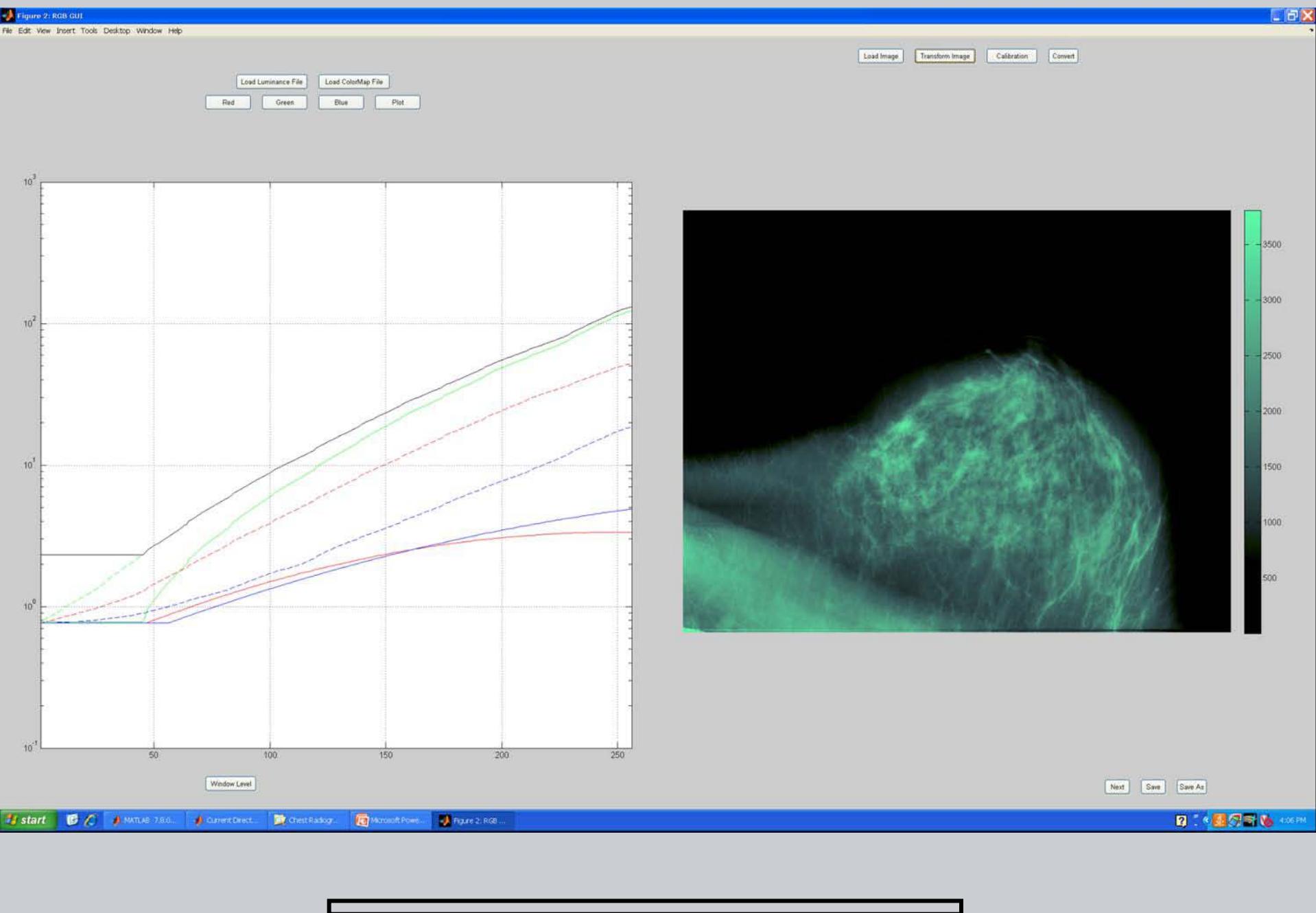


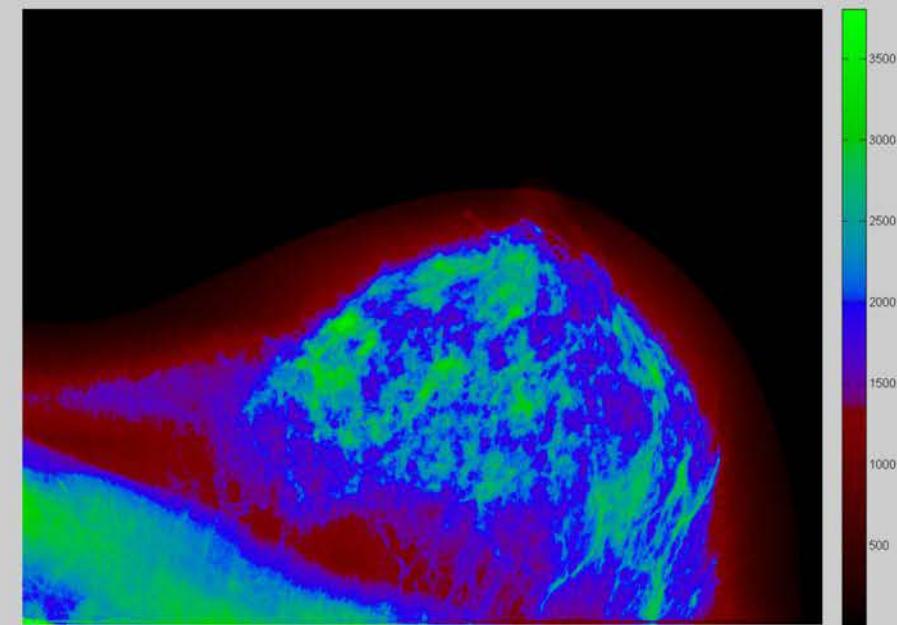
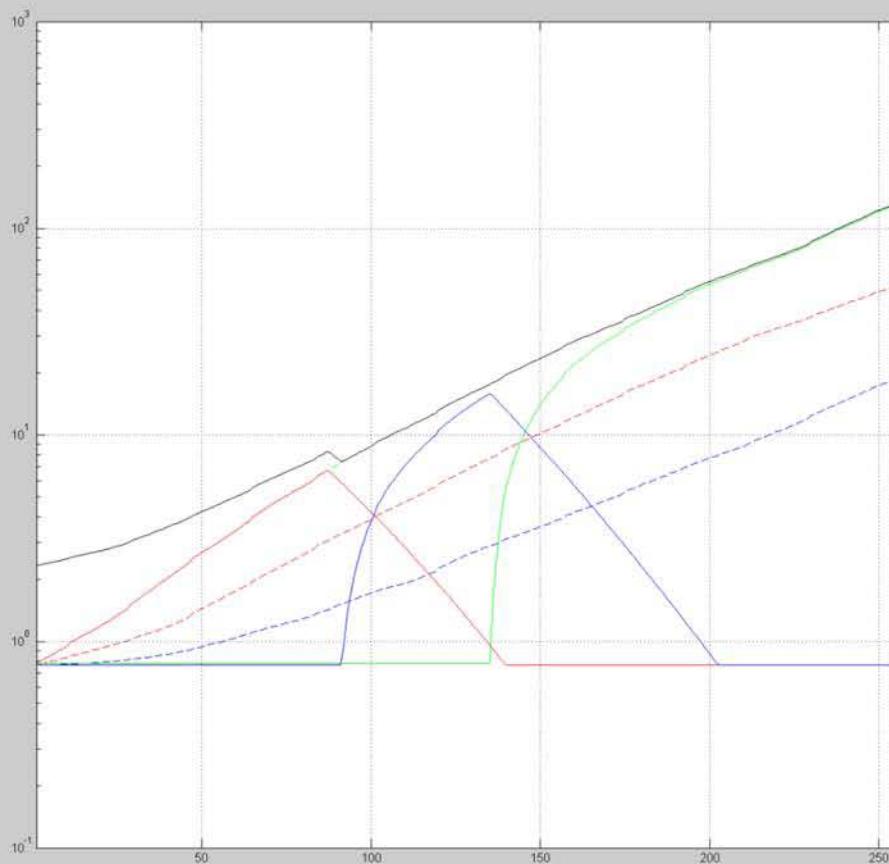


Figure 1: RGB GUI

File Edit View Insert Tools Desktop Window Help



Load Image Transform Image Calibration Convert

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Red Green Blue Plot

Window Level

Next Save Save As



Figure 1: RGB GUI

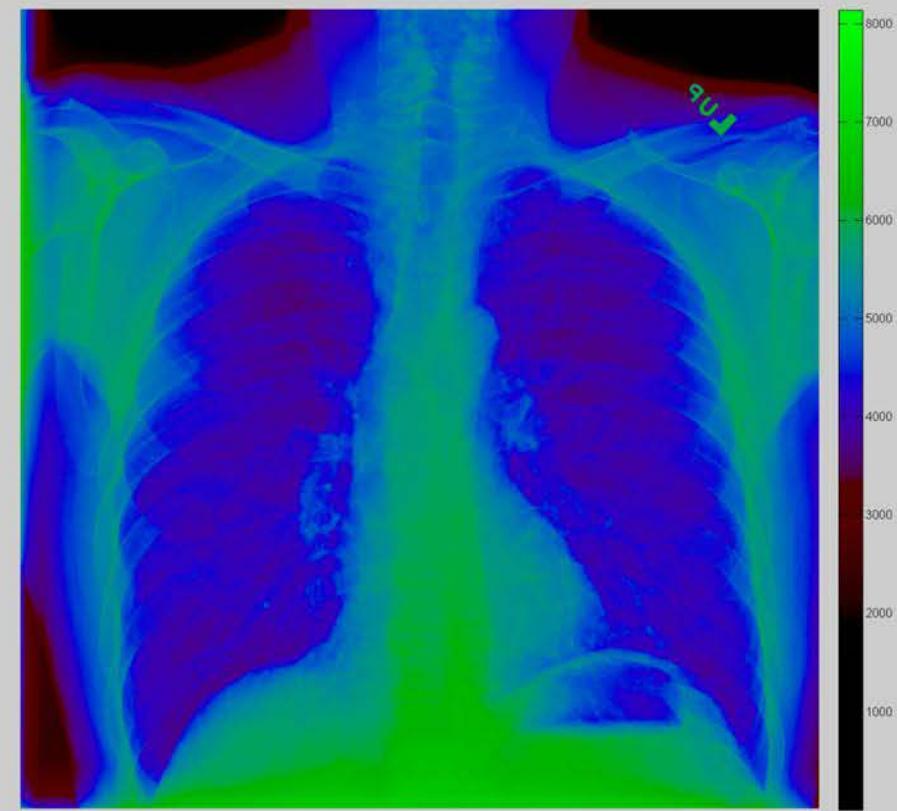
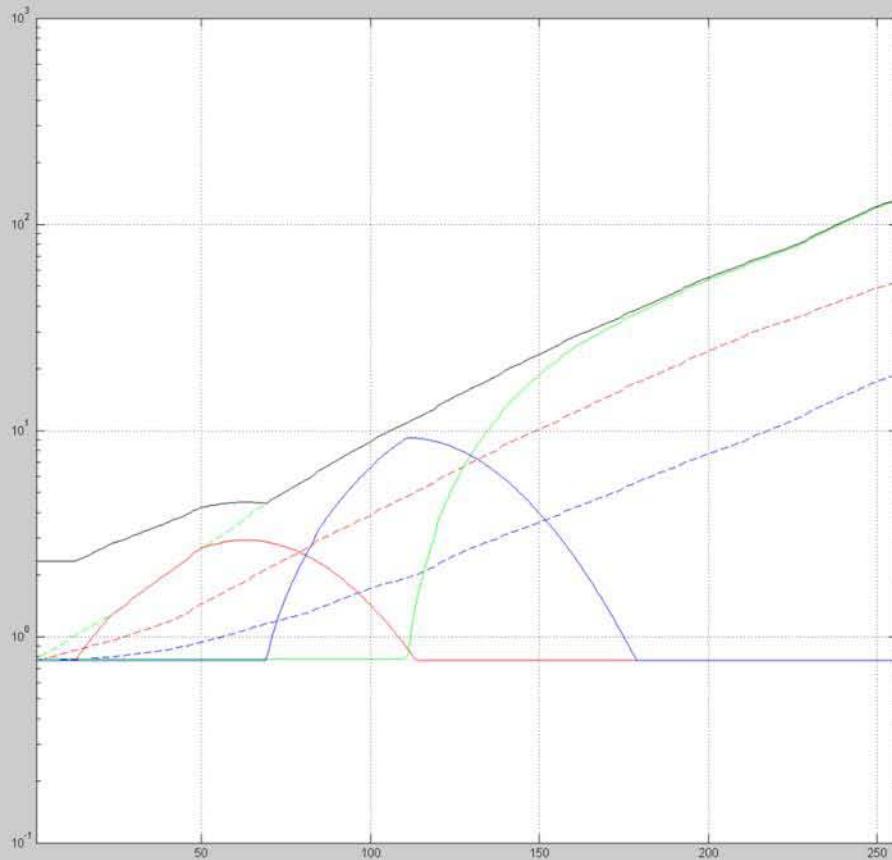
File Edit View Insert Tools Desktop Window Help



Load Image Transform Image Calibration Convert

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Red Green Blue Plot



Window Level

Next Save Save As



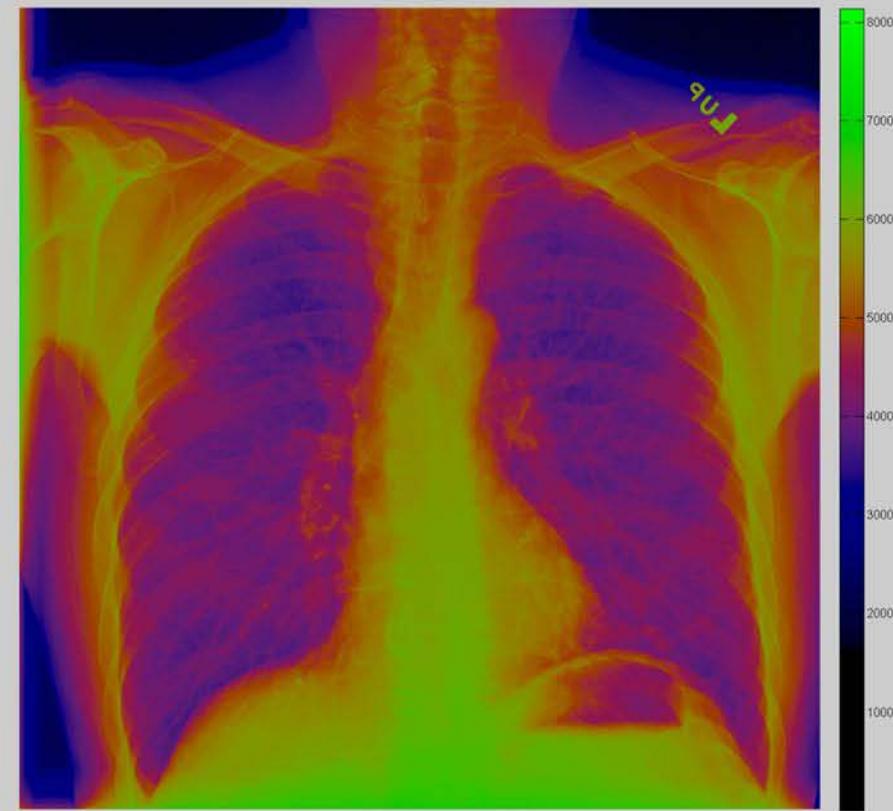
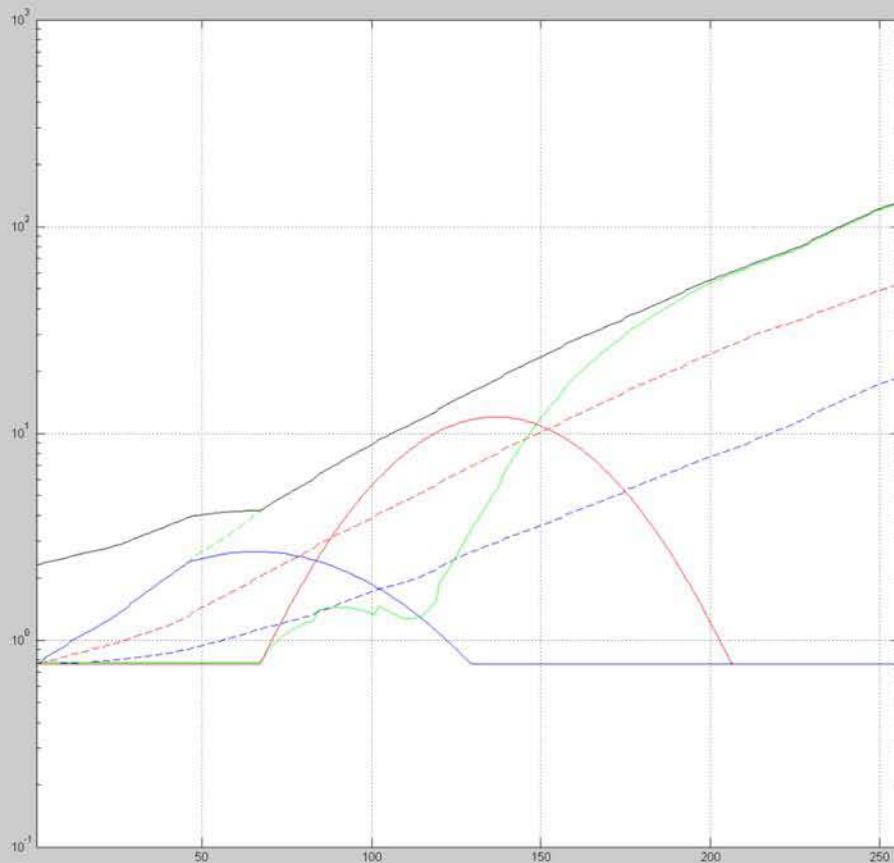
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Red Green Blue Plot

Load Image Transform Image Calibration Convert



Window Level

Next Save Save As

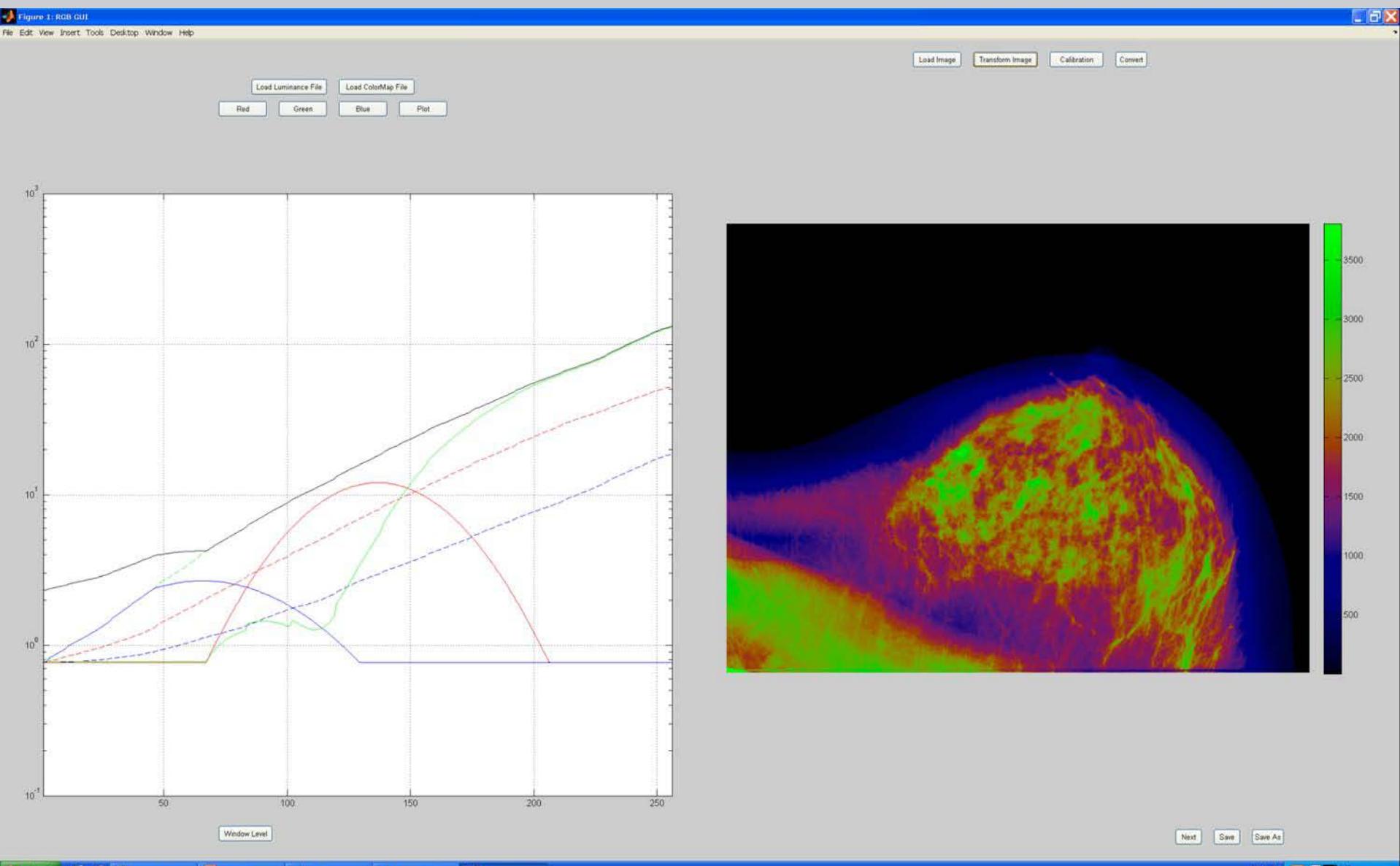




Figure 2: RGB GUI

File Edit View Insert Tools Desktop Window Help

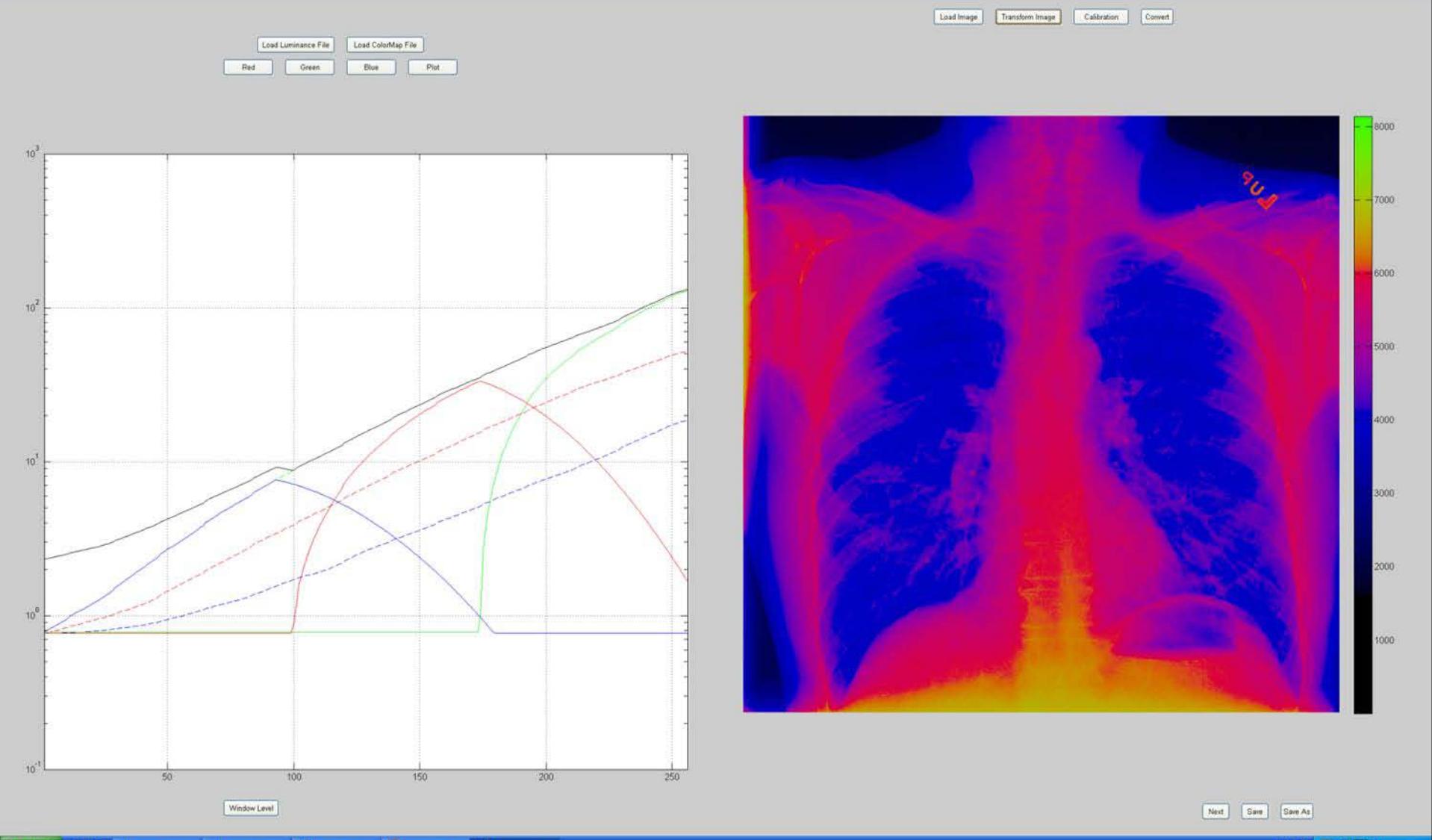




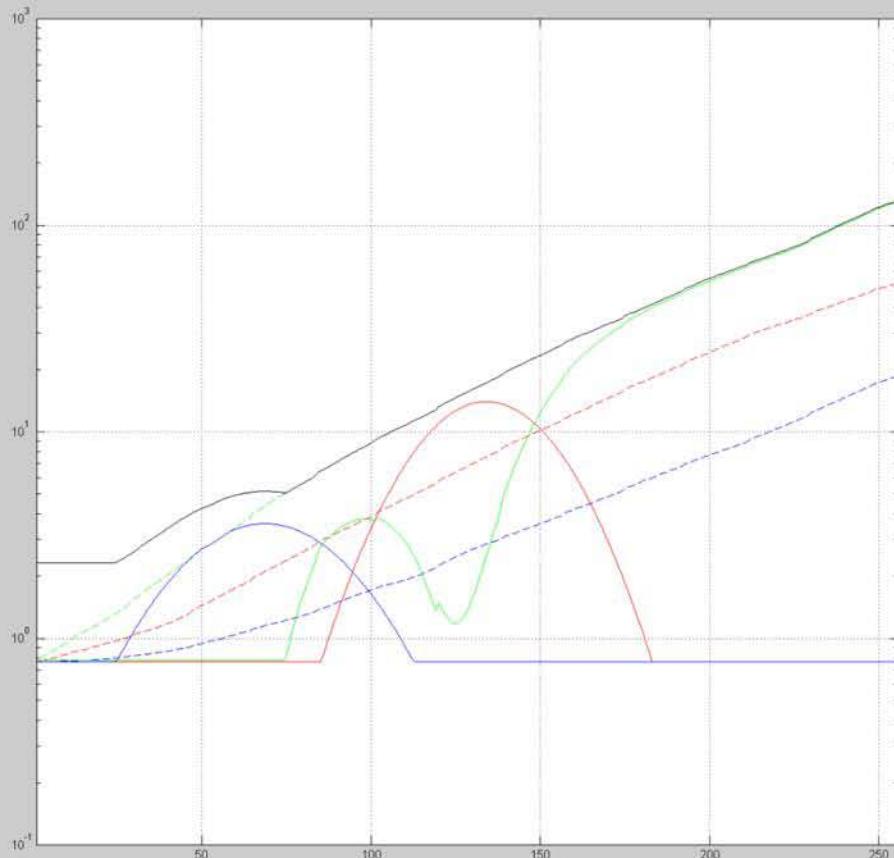
Figure 2: RGB GUI

File Edit View Insert Tools Desktop Window Help

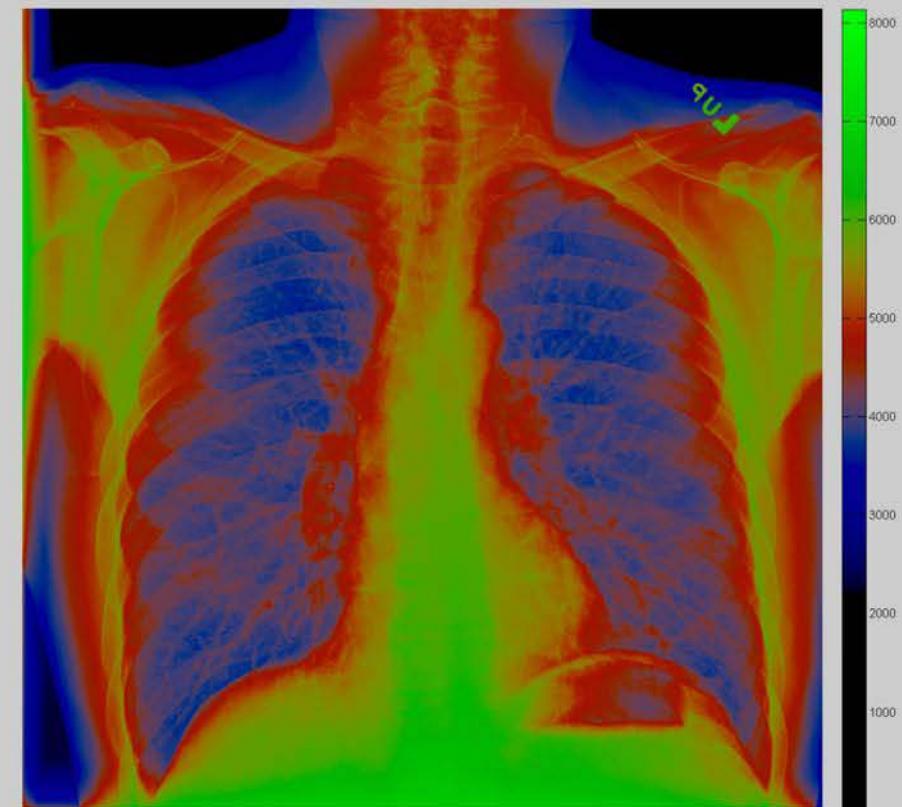


Load Luminance File Load ColorMap File
Red Green Blue Plot

Load Image Transform Image Calibration Convert



Window Level



Next Save Save As



Introduction

In medicine, managed color is of particular significance for clinical images obtained in Ophthalmology, Pathology, and Dermatology.

Retinal fundus image showing intermediate age-related macular degeneration.

National Eye Institute, NIH
Ref#: EDA22

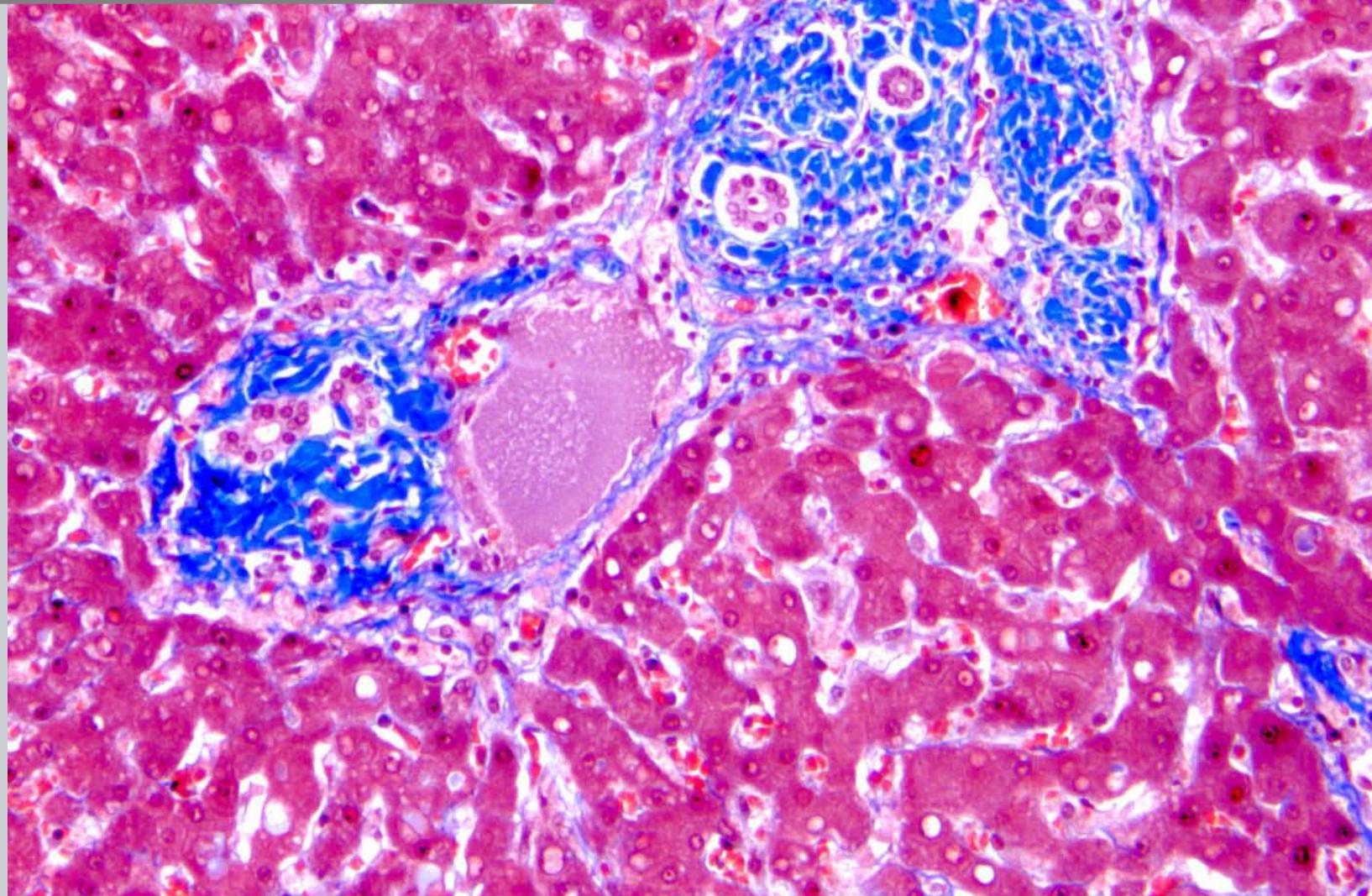




Introduction

Pathology

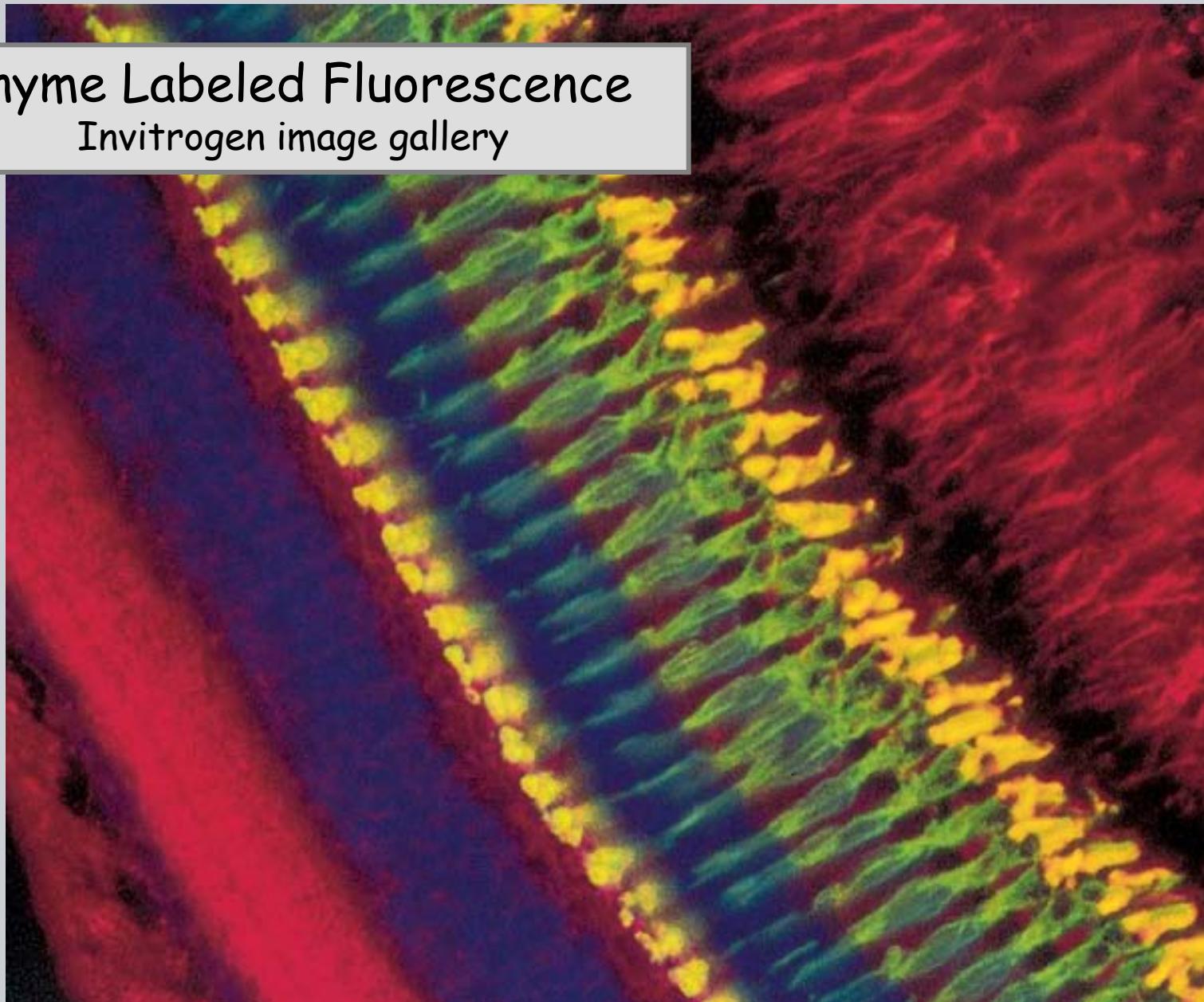
Liver - Masson Stain.
Paxcam image gallery





Enzyme Labeled Fluorescence

Invitrogen image gallery





Introduction

Dermatology

Lyme Disease
Delayed Rash
US CDC





Standardization Efforts



Professional efforts

- IEC 62563-1:2010:
 - Medical image display systems. Evaluation methods
 - Focused on monochrome performance
 - w/o defining values
 - A maintenance team is envisioned to address color
- AAPM TG 18 (2005) :
 - Assessment of Display Performance for Medical Imaging Systems
 - focused on monochrome performance
 - w/ defined values
- AAPM TG 196 (2010-?0):
 - Requirements and Methods for Color Displays in Medicine
 - focused on color performance



TG 196 Purpose

- Provide guidelines for proper implementation, utilization, and performance testing of electronic color display monitors intended for medical use
- Define standard testing methods and performance requirements for color displays
- Facilitate the comparison of color display systems
- Facilitate communication between industry and medical professionals
- Expand the role of medical physics in the growing areas of informatics, molecular imaging, and non-radiology image-based disciplines



- ① 101 of color handling in color displays
- ② 101 of color presentation consistency
- ③ Color display evaluation
 - 1. Four dimensional color evaluation (RGB and luminance)
 - 2. Temporal measurements
 - 3. Angular dependencies
 - 4. GSDF and grayscale properties
 - 5. Input-output evaluations
 - 6. ...



④ Application-based color management

1. Radiology: Nuc Med, Doppler US, MRI, Multi-dimensional imaging
2. Pathology
3. Dermatology
4. Endoscopy
5. Microscopy
6. Ophthalmology



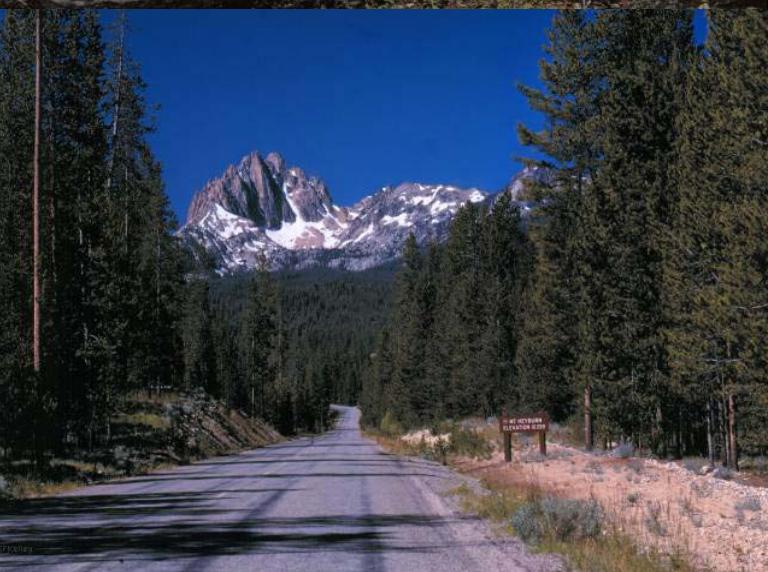
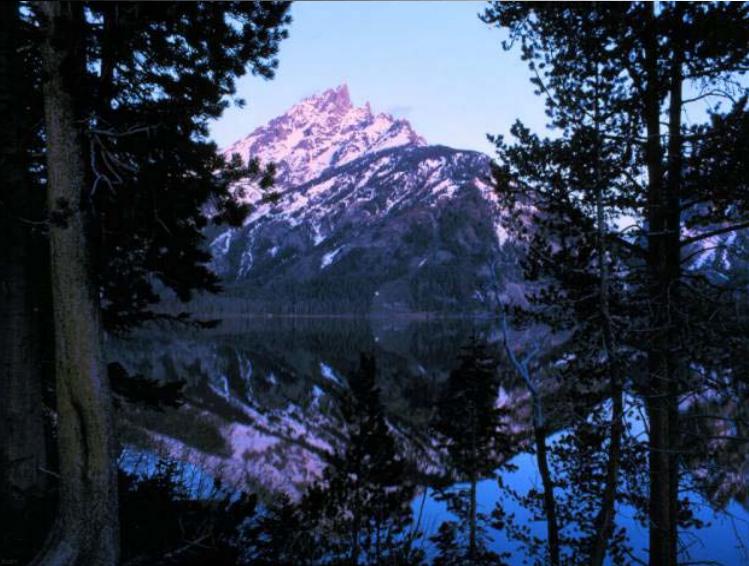
- ⑤ Appendix A: Color display technology
- ⑥ Appendix B: Color management and ICC profiles
- ⑦ Appendix C: Color and Human visual system
- ⑧ Appendix D: Color measurement instrumentation
- ⑨ Appendix E: Test pattern definitions
- ⑩ Appendix F: Glossary
- 11 Appendix G: Classified bibliography

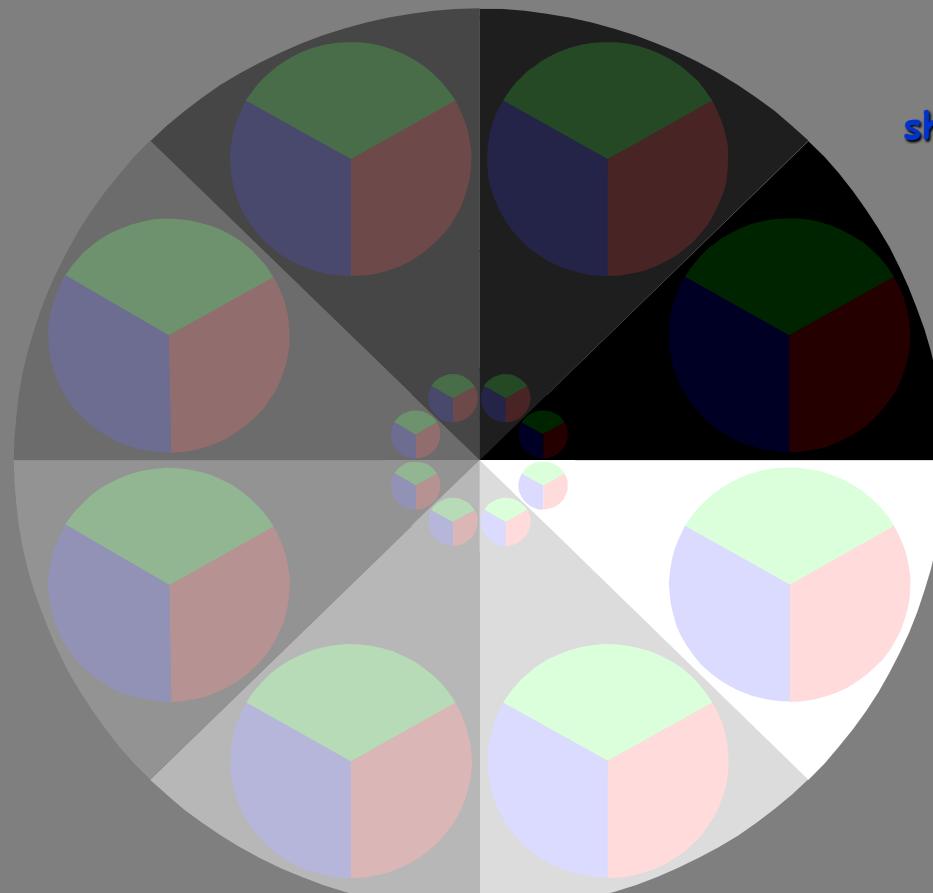


*Face coloration
should look natural.
All gray shades
should be visible.*

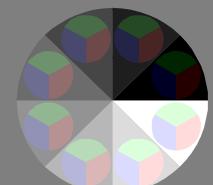
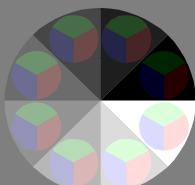
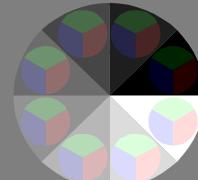
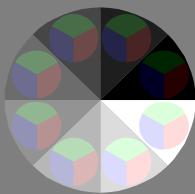
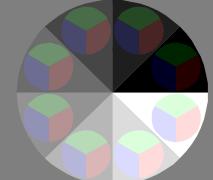
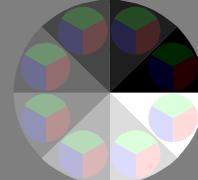
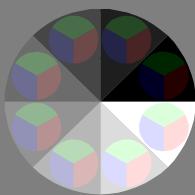
**Scenes should look natural,
detailed.**

All gray shades should be visible.





Three colors
should be visible
in all areas.





- Want to be involved or informed:

Ehsan Samei

samei@duke.edu



HVS and color definitions



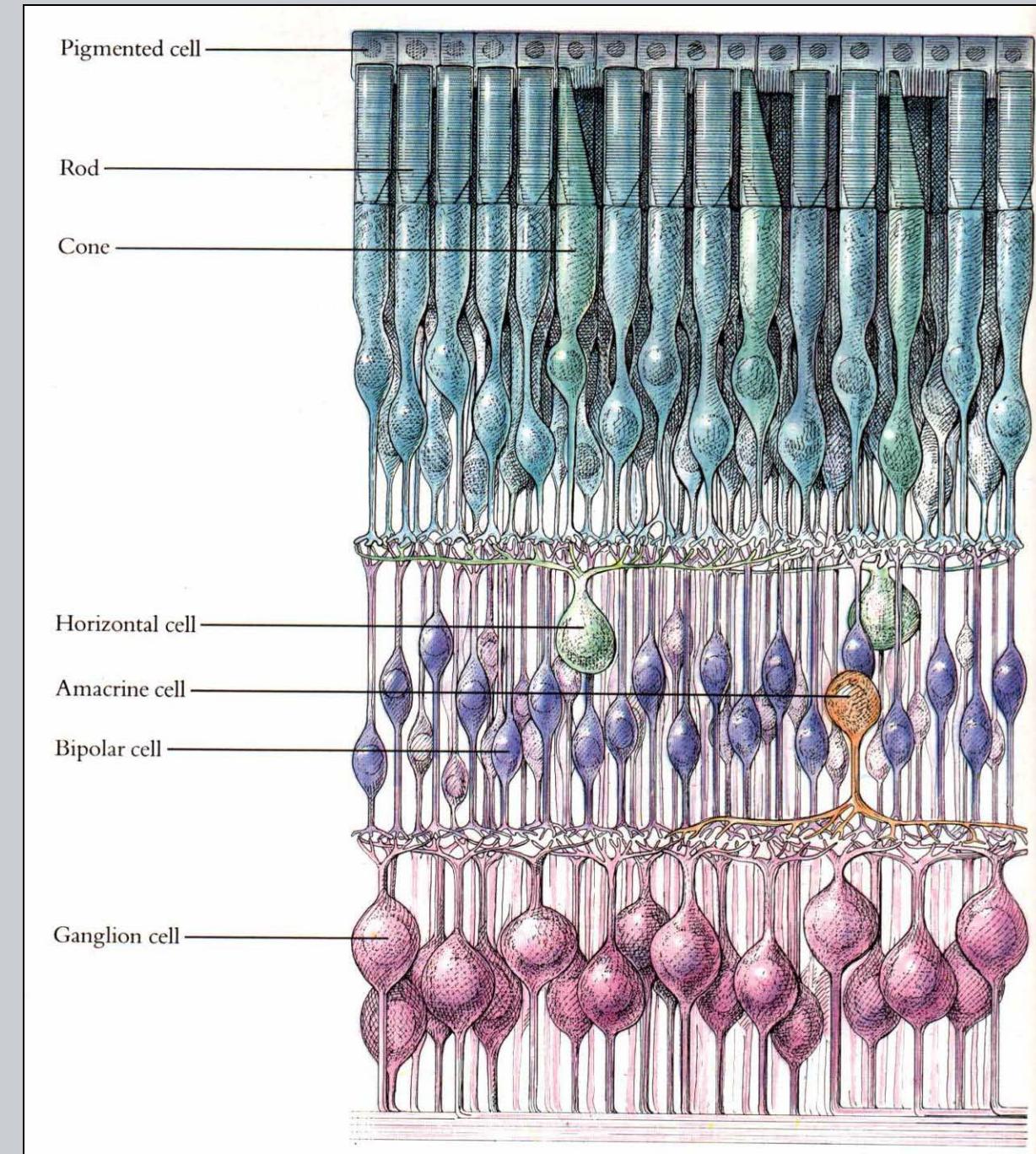
HVS: Rods and Cones

160 million rods

high sensitivity
gray response

6-7 million cones

low sensitivity
color response





HVS: Cone spectral response

- The pigments for three different types of cone receptors have varying spectral response.
- The spectral response was measured in 1965 and are often labeled as beta(blue), gamma (green) and rho(red).

The Retina

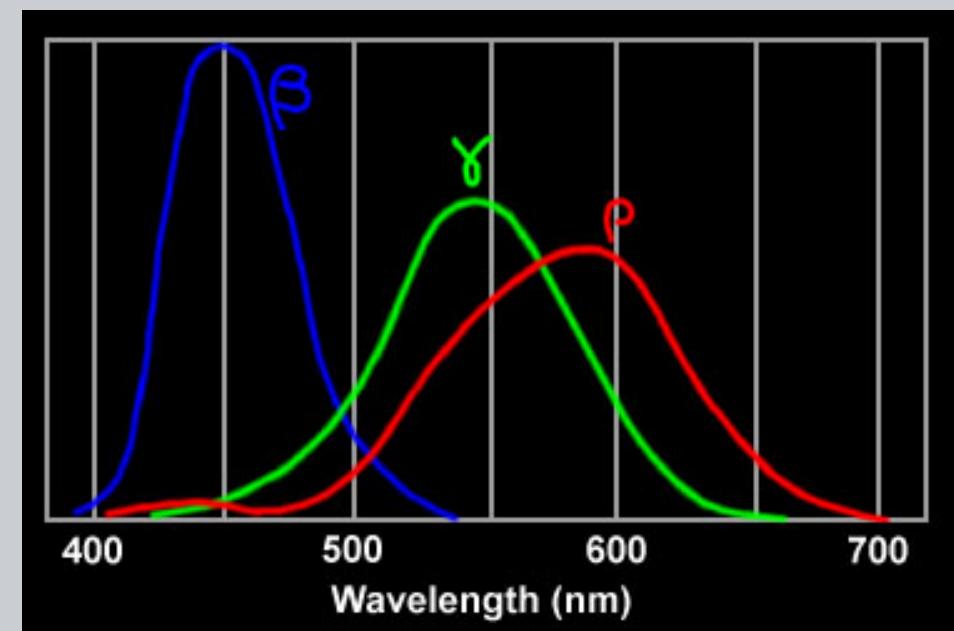
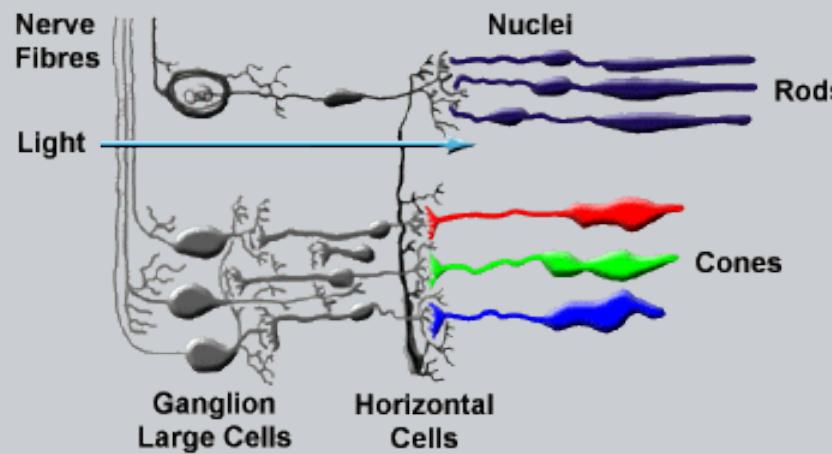
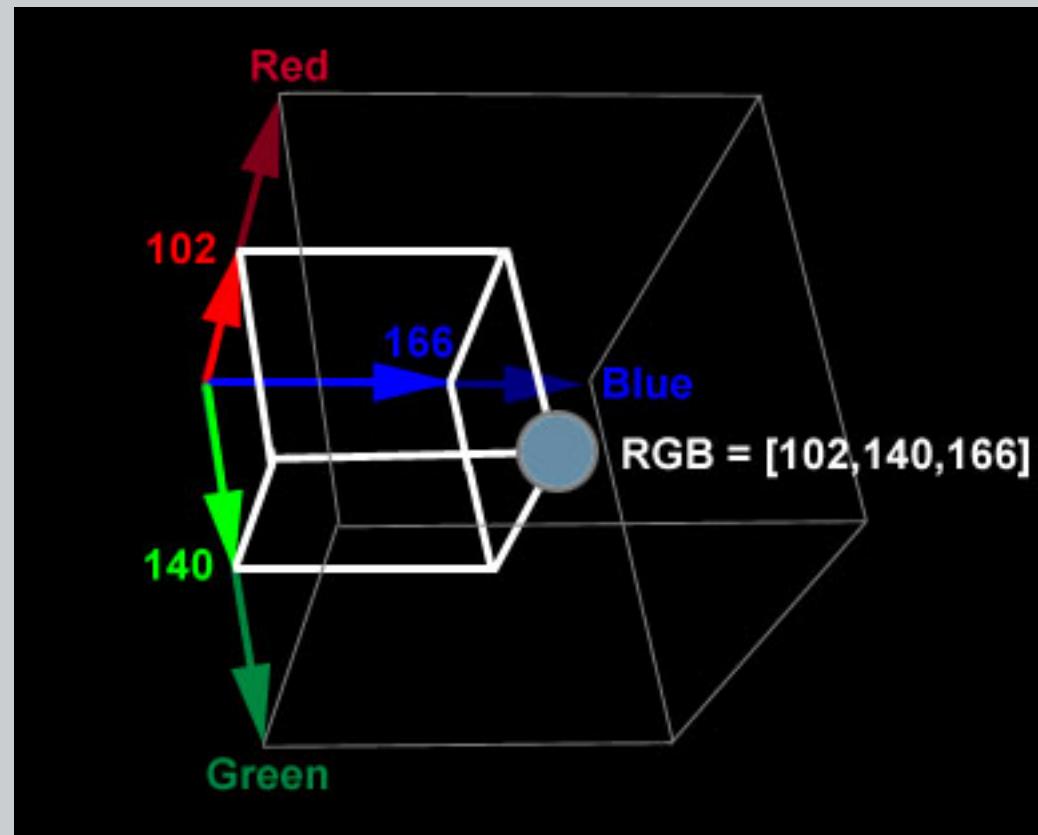


Illustration from Photo.net (Ed Scott)



HVS: The Color Cube

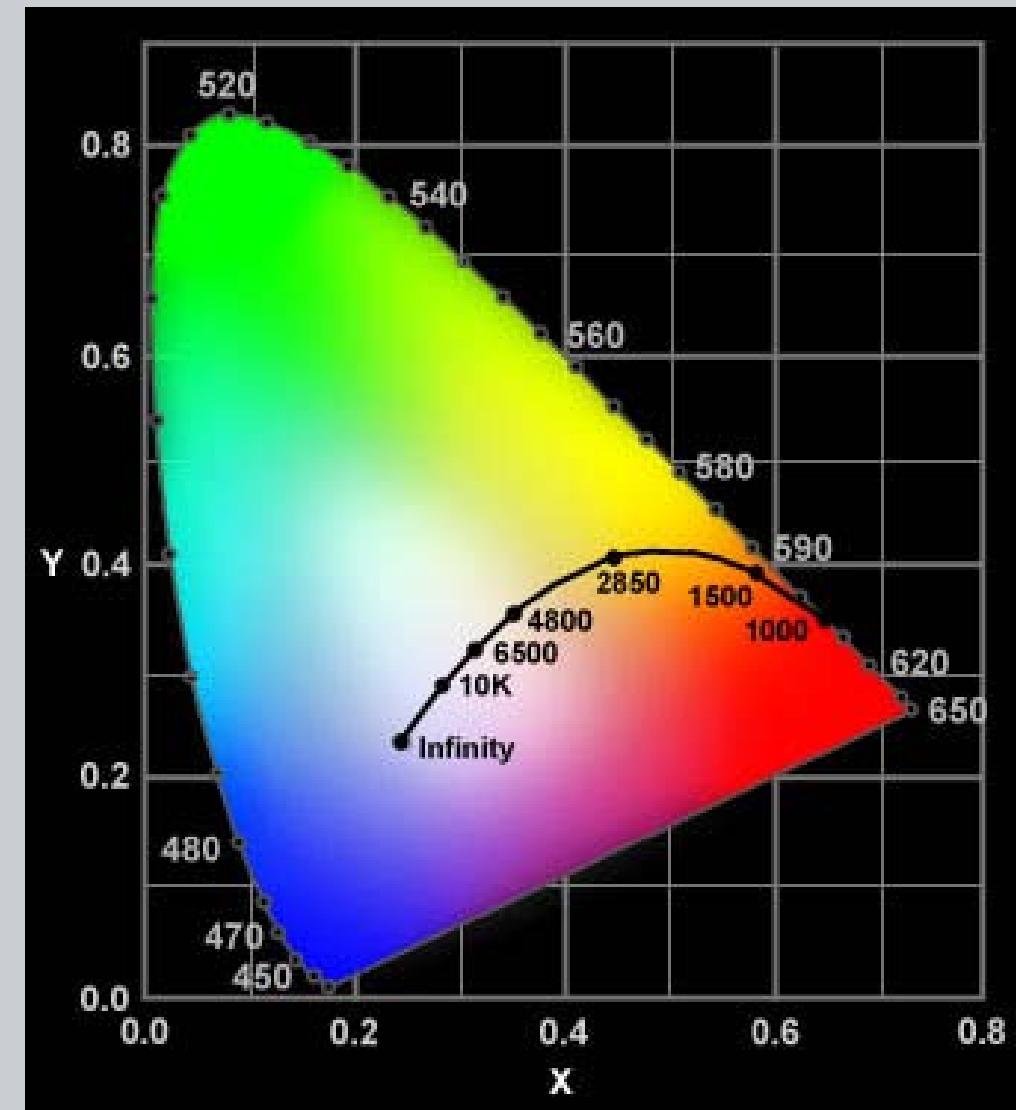
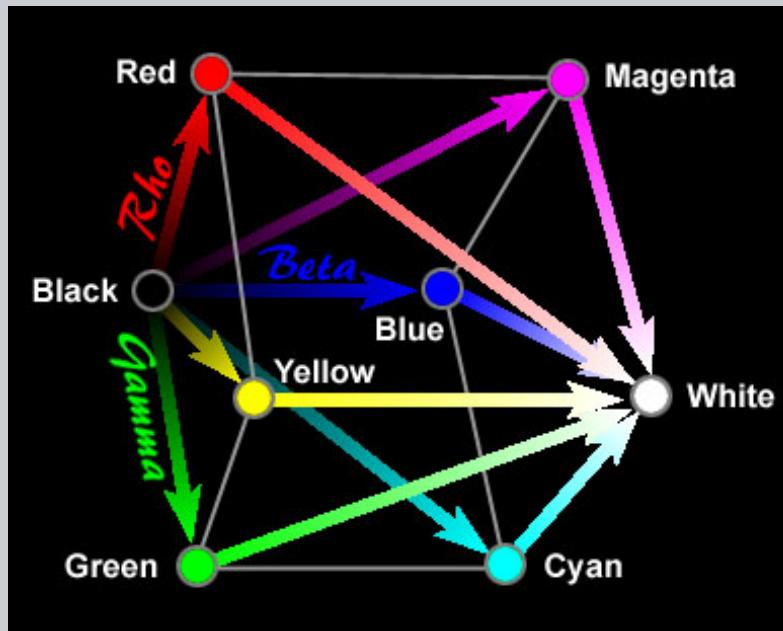
The perception of color can be modeled using a tristimulus 3D space formed by vectors for the rho, gamma, and beta cone response.





HVS: CIE Color Representation

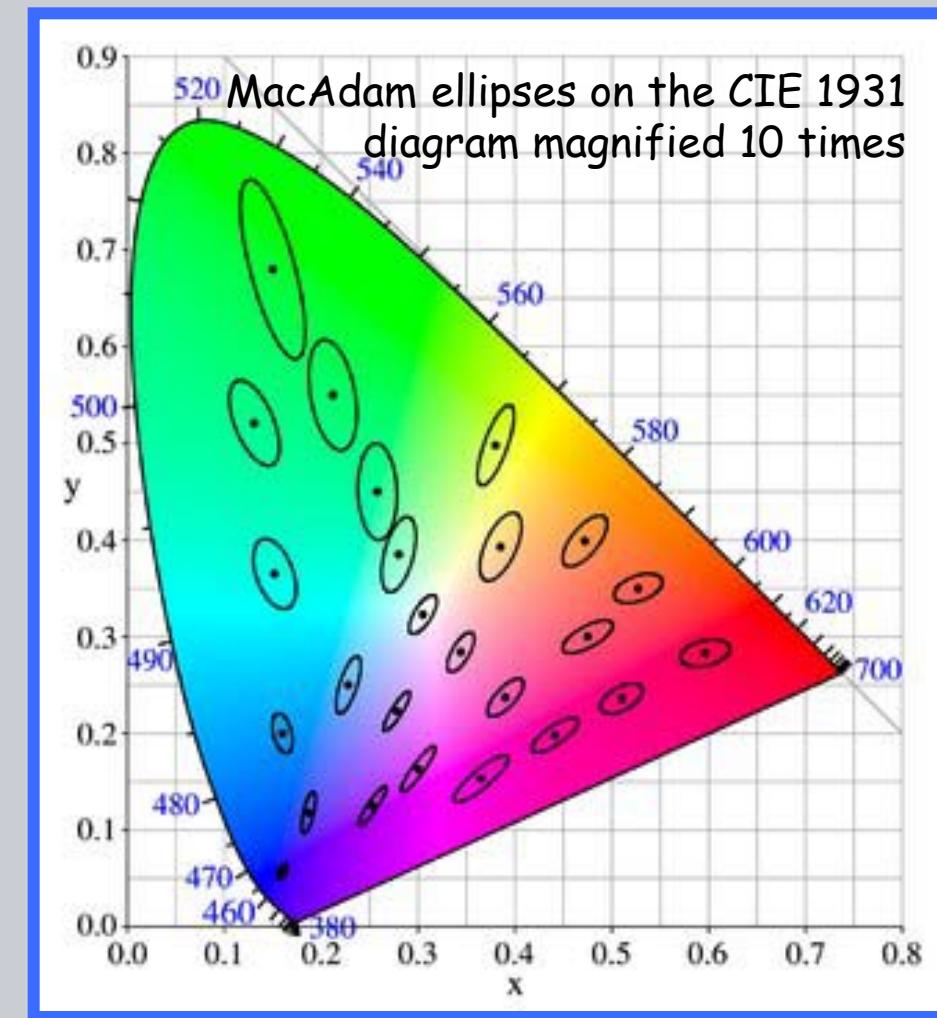
The CIE color system describes chrominance using two coordinates that correspond to surfaces of the color cube.





MacAdam ellipses

For the foveal vision, related to a visual field of 2° , the non uniformity of the chromatic scale has been measured by D. MacAdam in 1942 and is graphically represented by ellipses on the chromaticity diagram



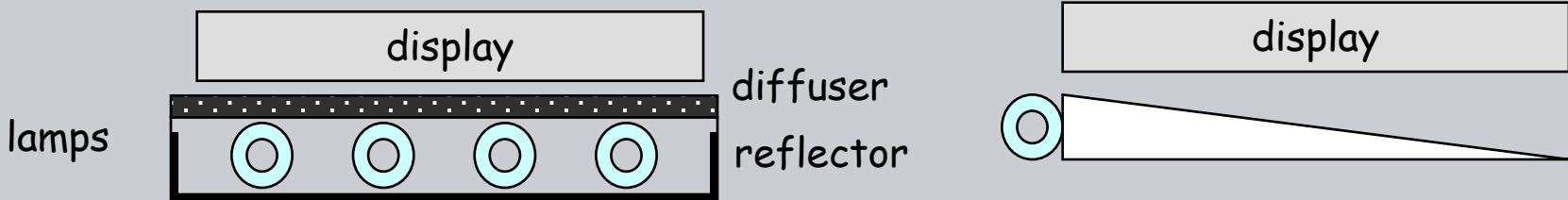
Poor visual detection of color changes makes the u,v perturbation of a color grayscale imperceptable.



Color Monitors



Brightness by Backlight



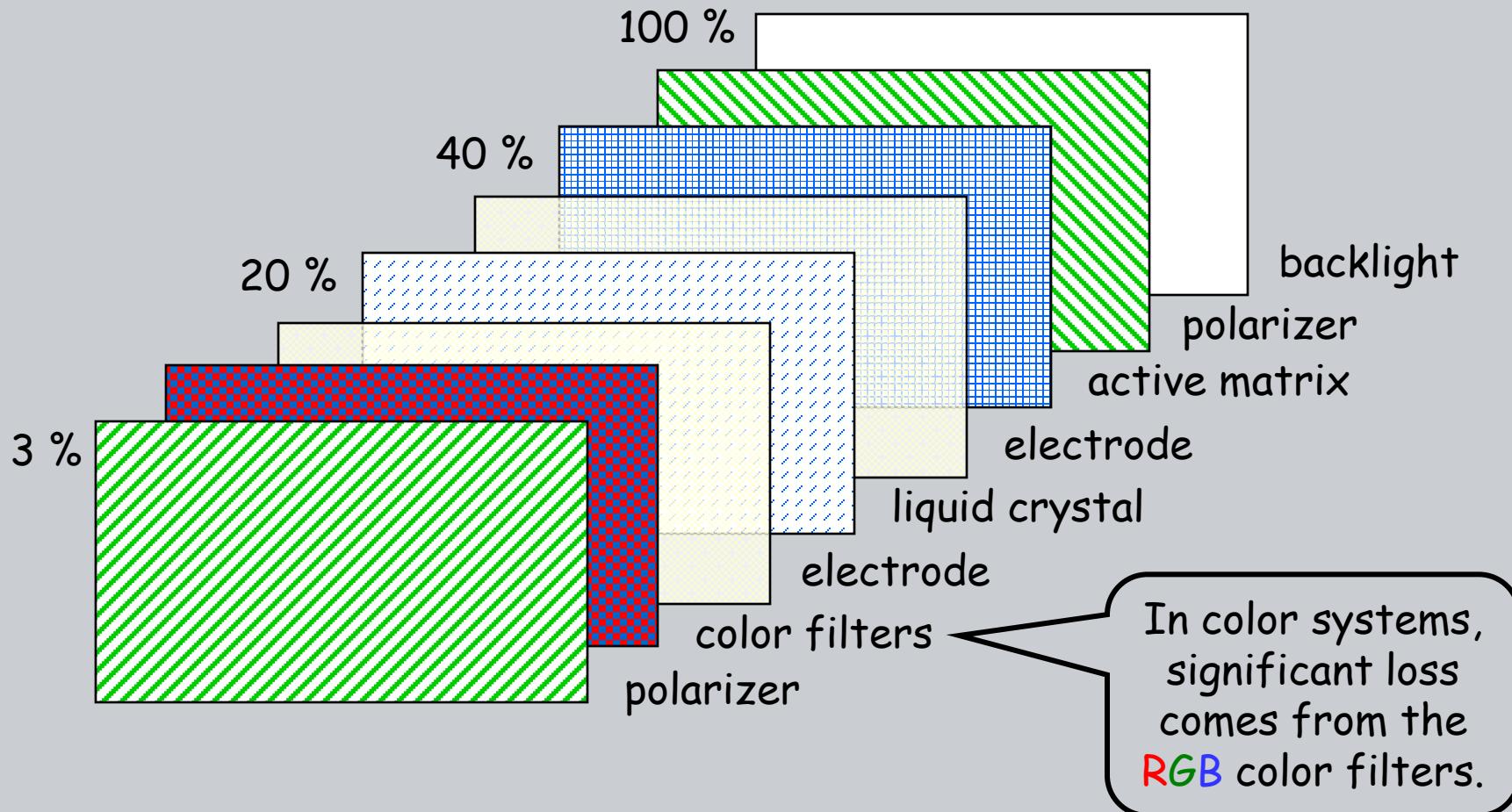
Backlight:

- Multiple-phosphor lamps, reflector, diffuser.
- Behind panel (brighter) or on edge (uniform & thin).
- HCFT (hot cathode fluorescent tube): bright, 10 kh life.
- CCFT (cold cathode fluorescent tube): 20 kh life.
- LED (Light Emitting Diode): wide color gamut



Brightness and Light Transmission

Power efficiency and brightness are related to optical performance of several layers.

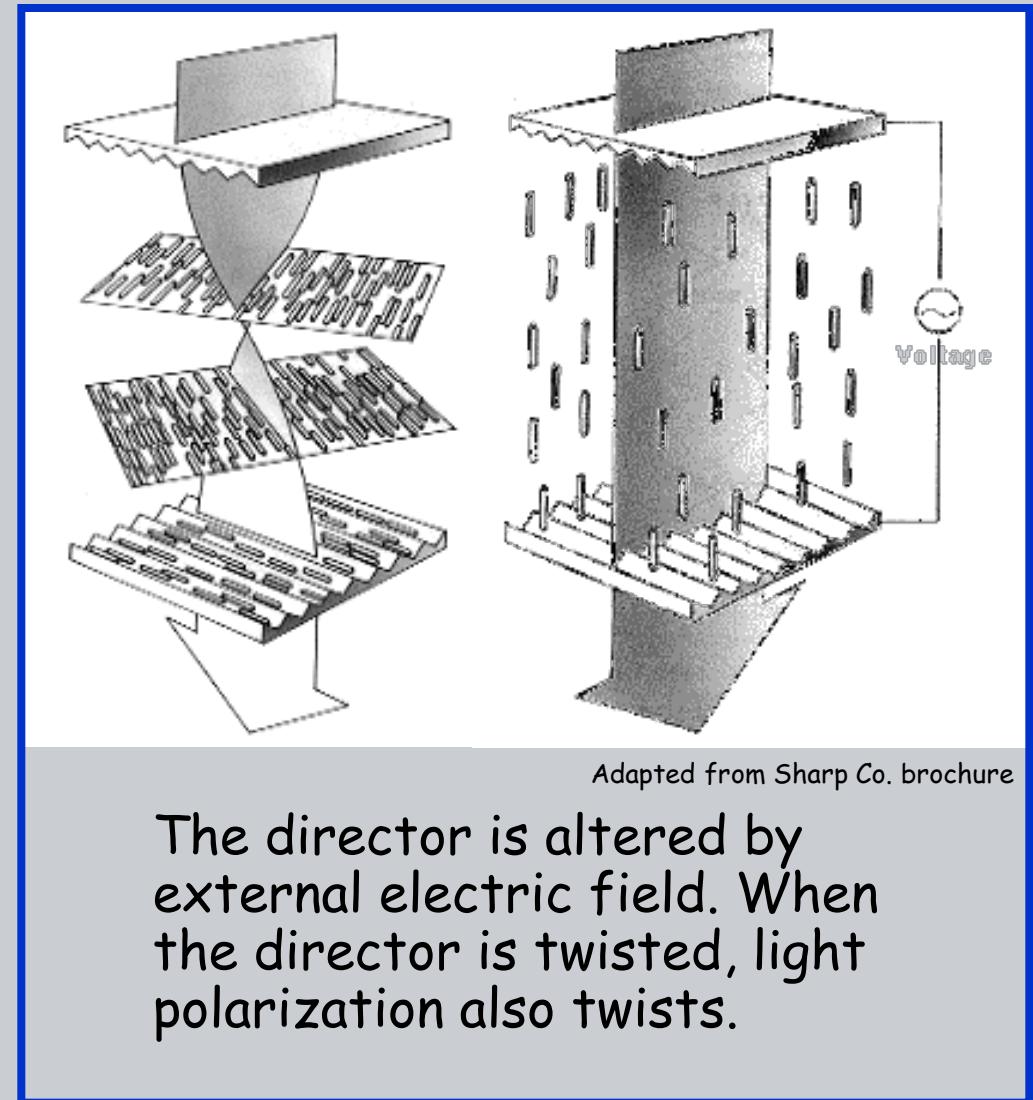
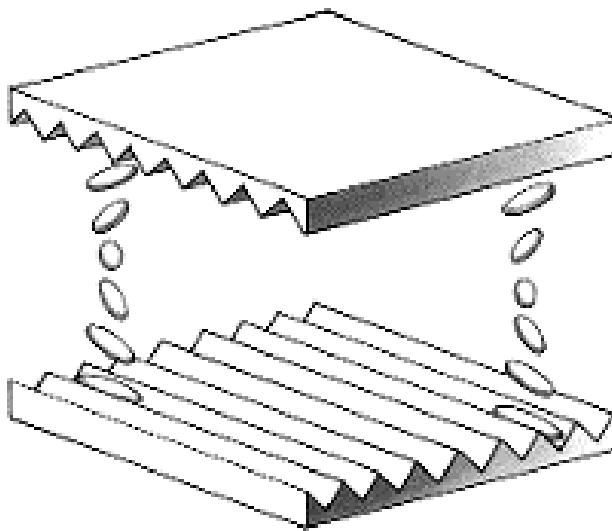




Electro-optical Effect

Twisted Nematic (TN) LC cell

When LC molecules contact a grooved surface, they align parallel to the grooves.



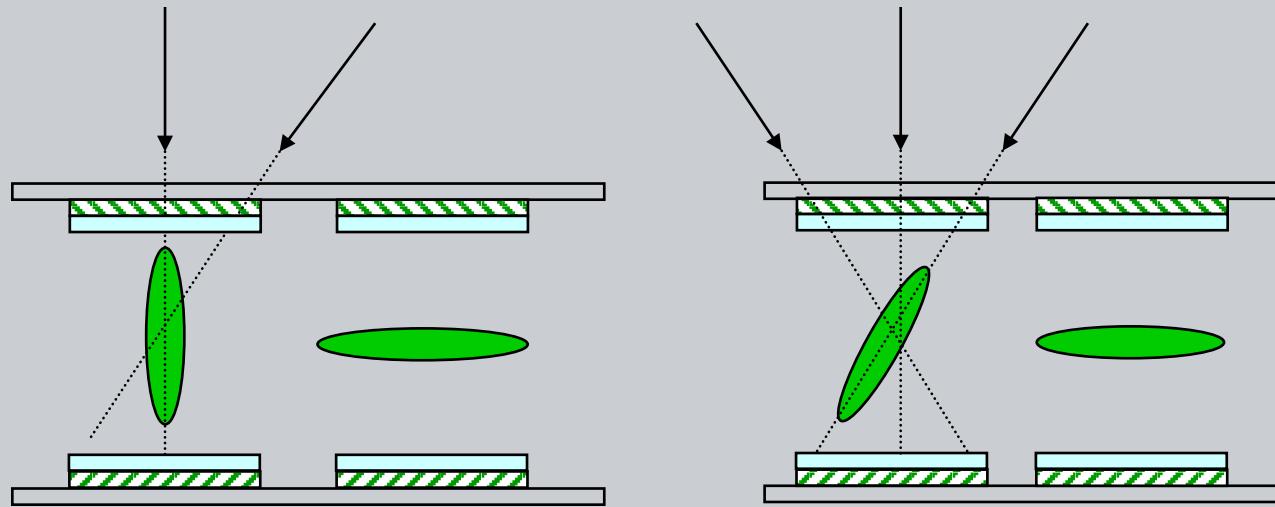
The director is altered by external electric field. When the director is twisted, light polarization also twists.



The TN Viewing Angle Problem

Due to the high anisotropy of light modulation:

- The effective cell gap (ON/OFF state) changes.
- The effective LC orientation differs for intermediate gray-level.



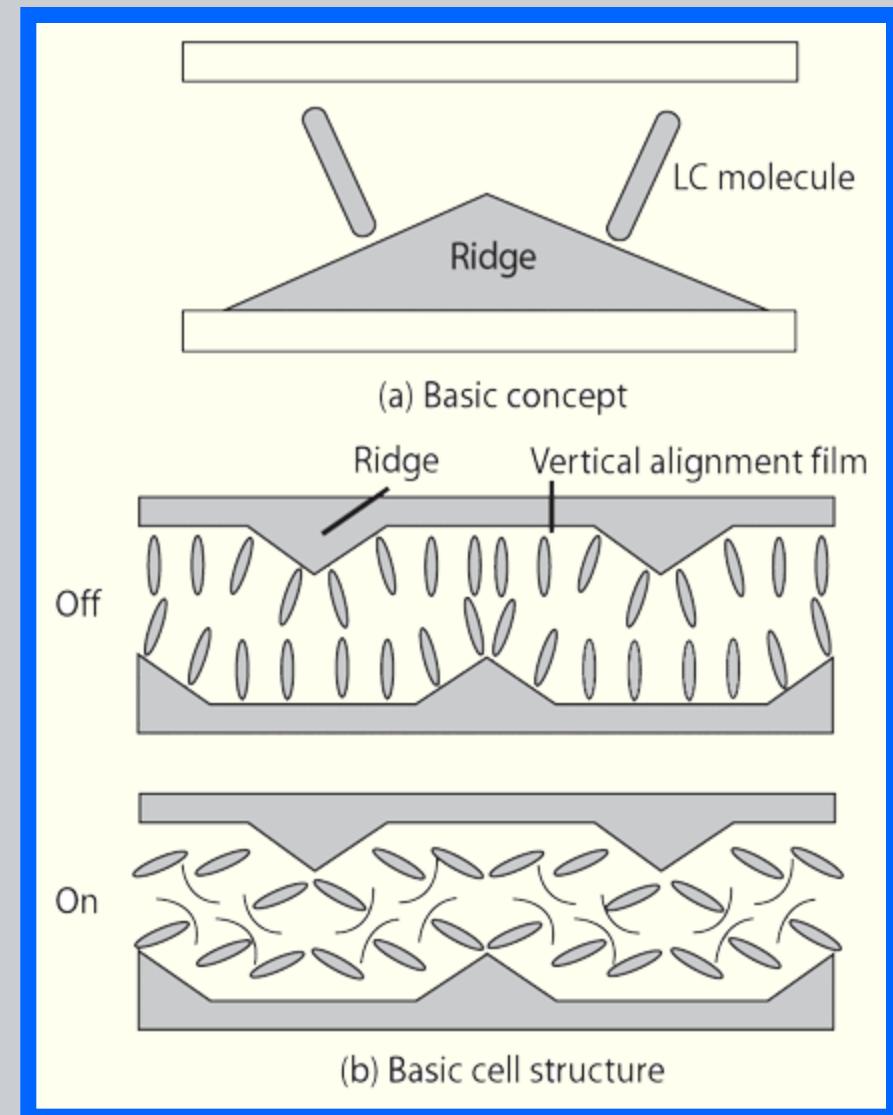
- Solutions:
- Compensation foils
 - Multiple sub-pixel domains (m)
 - In-plane switching (IPS, mIPS)
 - vertical alignment (VA, mVA)



Vertical Alignment (VA)

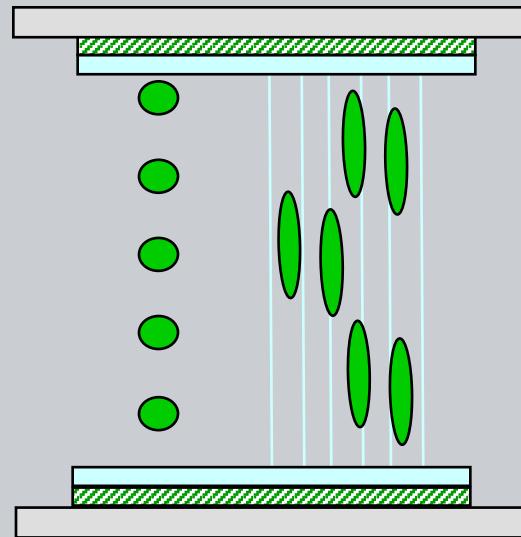
Vertically Aligned LCD

- LC alignment is from a protrusion producing directors that are perpendicular to the display surface. No rubbing processes are employed.
- The sub pixel is divided into several regions in which the crystals are free to move, independently of their neighbors, in opposite directions (mVA).
- Wide horizontal and vertical viewing angle.
- Excellent low luminance response (deep black).
- Switching times are ~1/2 that of IPS designs producing improved cine display.

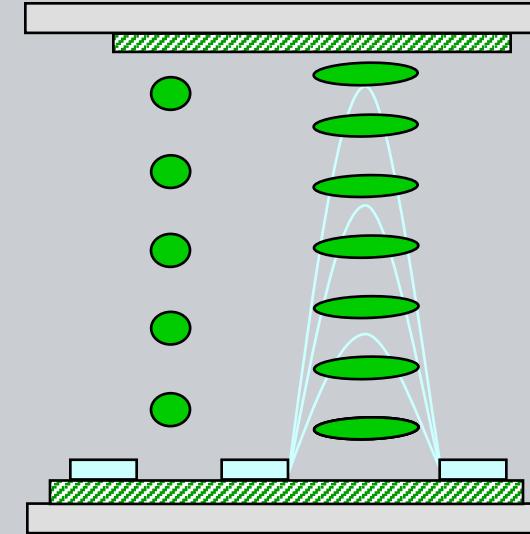




In Plane Switching (IPS)



TN cell
OFF (W) ON (B)



IPS cell
OFF (B) ON (W)

For in-plane switching (IPS) designs, the rubbing directions are the same on the top and bottom of the cell. When an electric field is applied, the directors remain in plane producing improved viewing angle response.

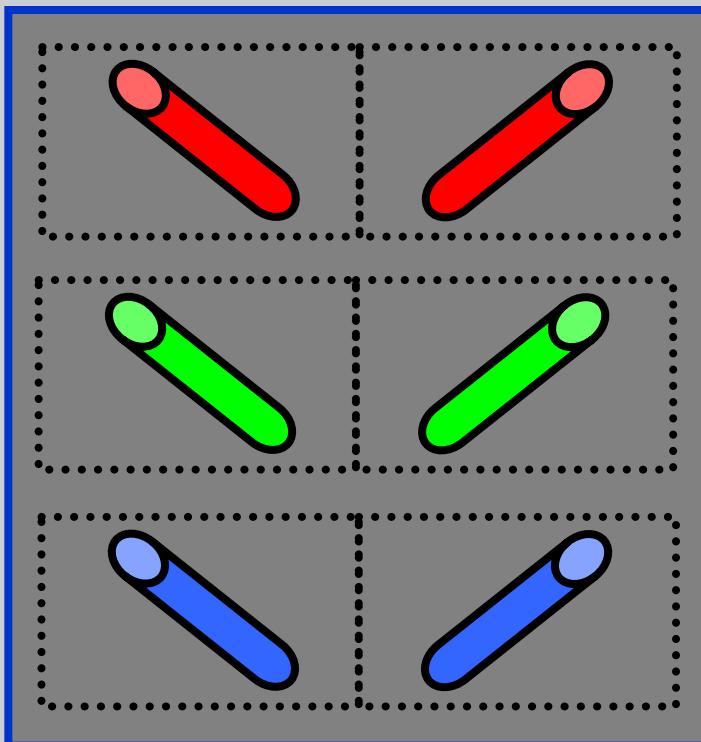
Advantage: High contrast (excellent black).

Disadvantages: low aperture ratio -> reduced brightness.
Relatively high power
slow response time.



Multi-domain Cells

Emission angles can be distributed by using multiple domains with different orientations for each of the sub-pixels structures.



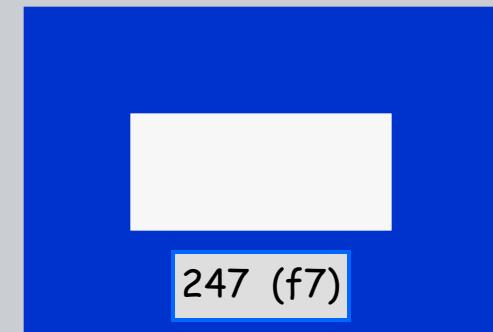
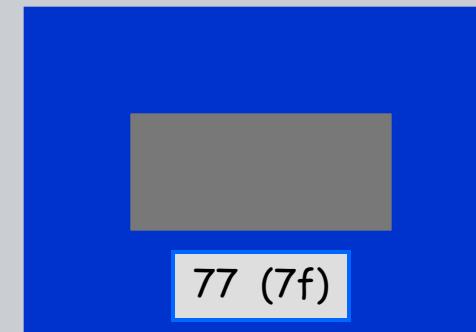
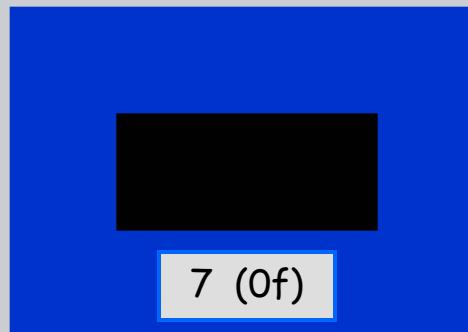
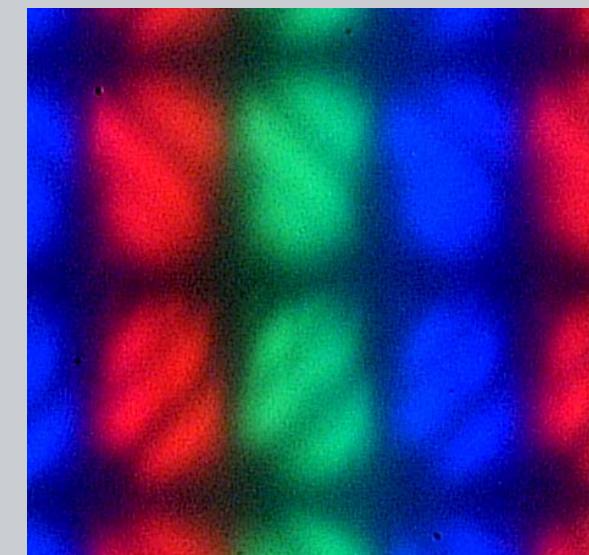
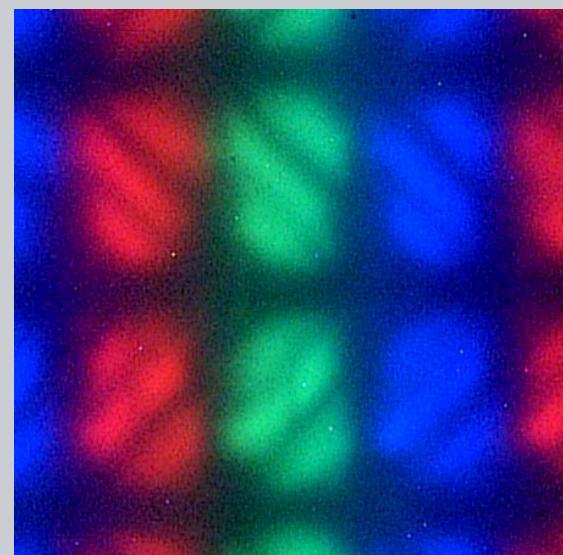
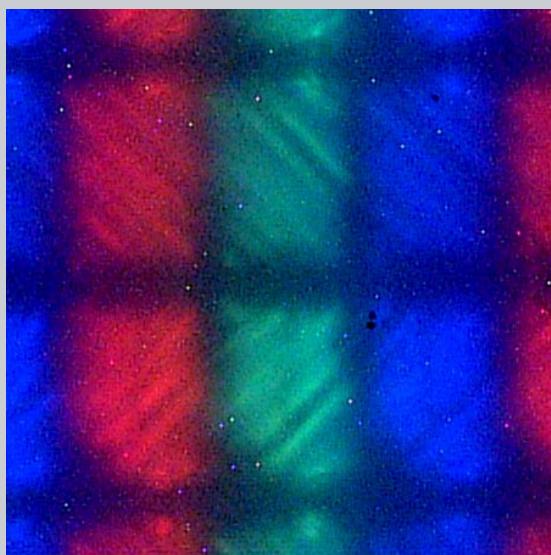
- Domain areas are defined with different alignments using
 - Sequence of differential rubbing treatments and photolithography.
 - Patterned alignments with differential UV light exposure.
- Challenges:
 - domain stability
 - more fabrication steps and cost



SHARP 2MP COLOR

VA - dual domain

Macro photographs recorded with varying luminance.
Contrast/Brightness adjusted for similar appearance.



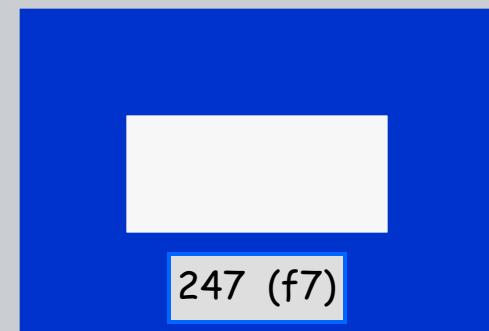
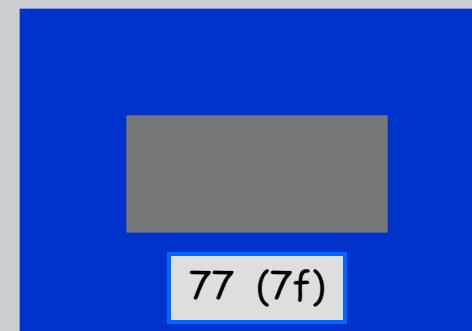
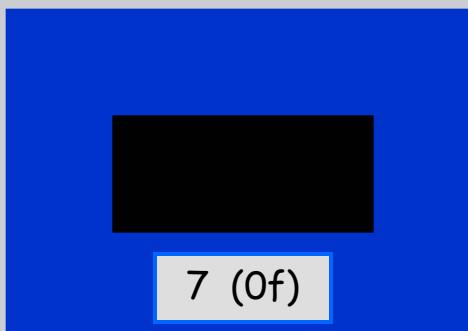
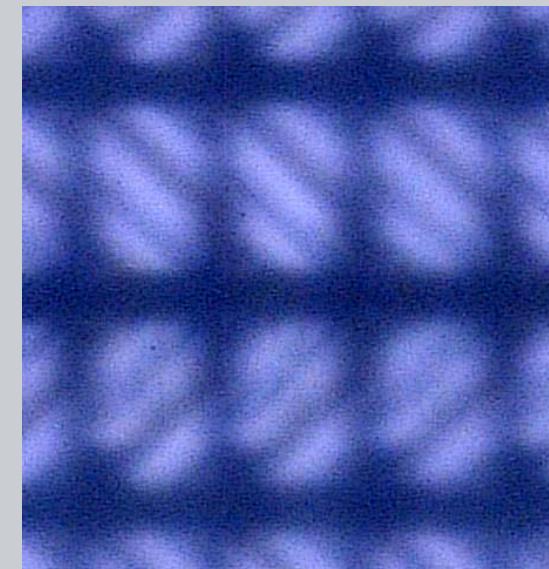
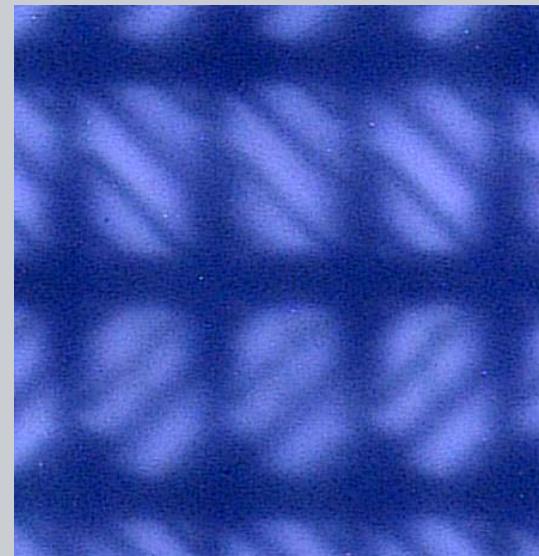
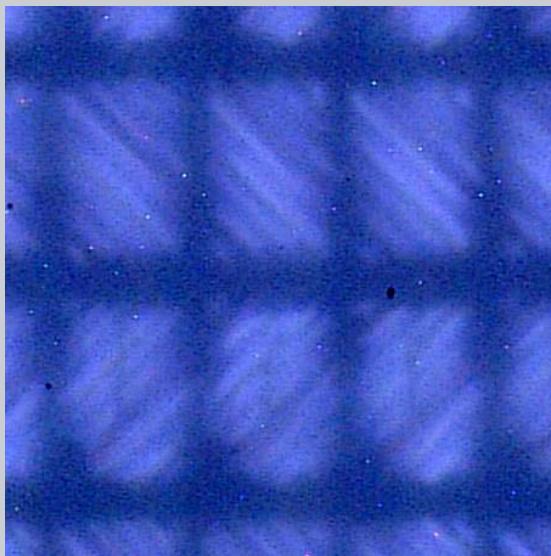


SHARP 2MP MONOCHROME

VA - dual domain

Macro photographs recorded with varying luminance.

Contrast/Brightness adjusted for similar appearance.

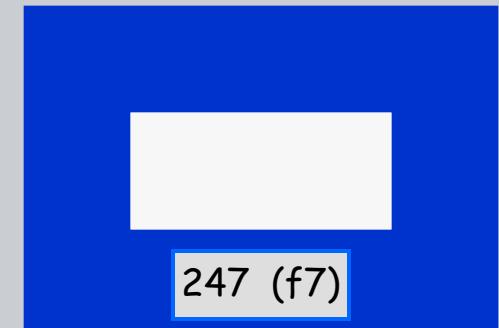
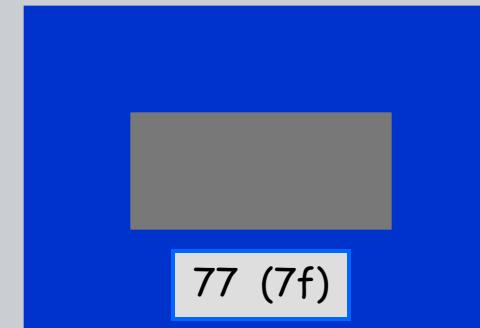
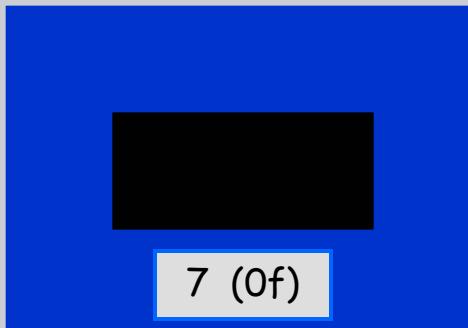
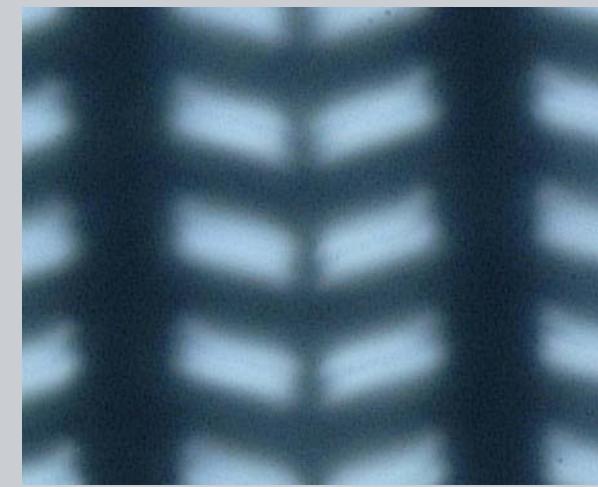
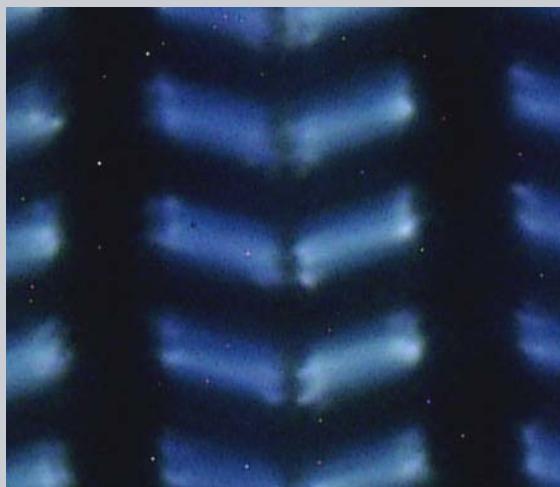




NDS Nova (IBM panel) - 3MP

IPS - dual domain

Macro photographs recorded with varying luminance.
Contrast/Brightness adjusted for similar appearance.





Medical 3MP monitors

- Improved backlight efficiency has led to color 3 MP monitors with brightness that is the same as for traditional 3MP monochrome monitors.
- The present market cost for color 3MP monitors is only slightly more than for monochrome devices.



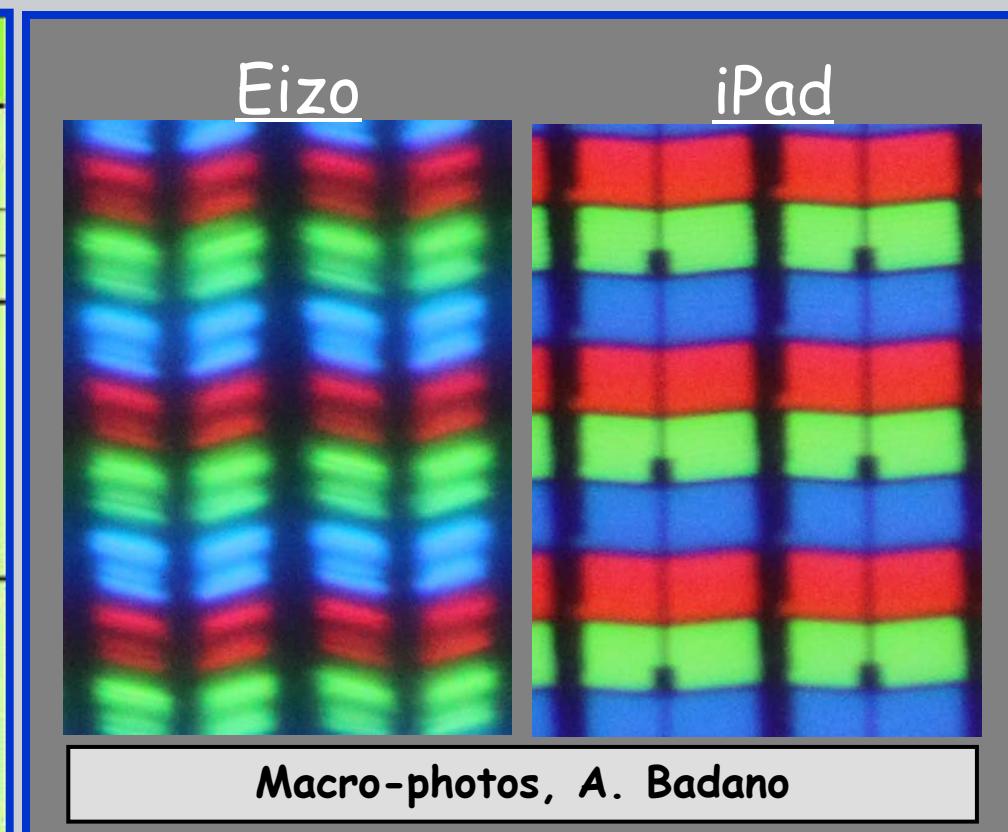
Note:
monochrome monitors with very high brightness are also available, but are not required in Radiology.



Improved IPS pixel structures

- The traditional IPS structure suffers from poor transmission associated with a low fill factor.
- A series of improvements have eliminated this problem.

S-IPS (1998)	AS-IPS (2002)	IPS-Pro (2004 -)
Color Shift Free	High Transmittance	High Contrast Ratio
100	130	156
137	250	313
Electrode	Transparent Electrode	Transparent Electrode
LC Molecule (L/R Rotation) Two Domains	Shield Signal Line by Common electrode	Inter Digital Pixel and Plane Common Electrodes





LG IPS terminology

S-IPS - The term for the traditional IPS technologies with enhancements.

H-IPS - In more panels, LG Display has altered the pixel layout giving rise to horizontal IPS panels. Most modern IPS panels are H-IPS.

e-IPS - In 2009, LG simplified the IPS structure to produce less expensive panels but with a slight sacrifice in viewing angle performance.

P-IPS - A term used by NEC to refer to panels with 30 bit graphic support and wide gamut.



30 bit professional graphic monitors

- A significant development in the market involves the introduction of professional graphic monitors at attractive cost
 - with wide color gamut (aRGB) and 30 bit color.
- 30 bit color support (10 bits for R, G, & B) is now supported by;
 - Windows 7 as a color object
 - Recent graphic cards
 - Display port monitor interface
 - Professional graphic monitors
- Monitor suppliers
 - NEC
 - Apple
 - HP
 - Dell
 -
- 24", 27", 30" wide format
- 2560 x 1440 array (16:9)





ICC color management



- An industry consortium
- Established in 1993 by eight industry vendors
- Now approximately 70 members
- Goal: Create, promote and encourage evolution of an open, vendor-neutral, cross-platform colour management system architecture and components



Founders:

Adobe Systems Incorporated

Agfa-Gevaert N.V.

Apple Computer, Inc.

Eastman Kodak Company

FOGRA-Institute (Honorary)

Microsoft Corporation

Silicon Graphics Inc.

Sun Microsystems, Inc.

Taligent, Inc.



- ICC develops and promotes a standard colour profile specification (ICC Profile).
- Available as PDF at
www.color.org
- The current version of the ICC Profile Specification is 4.2.0.0 (ICC.1:2004-10).
- This version is essentially the same as ISO 15076-1:2005, which is available from ISO.



- Gamut = range of realisable colours.
- A colour gamut for a device depends on the device, media and viewing conditions:
 - e.g. dynamic range and separation quality for input, or ink and substrate for printers.
 - chromaticity and illumination level of the illuminant, and colour and luminance of the surround, for viewing the image.
- A gamut can be visualised as a plane or volume in a standard colour space



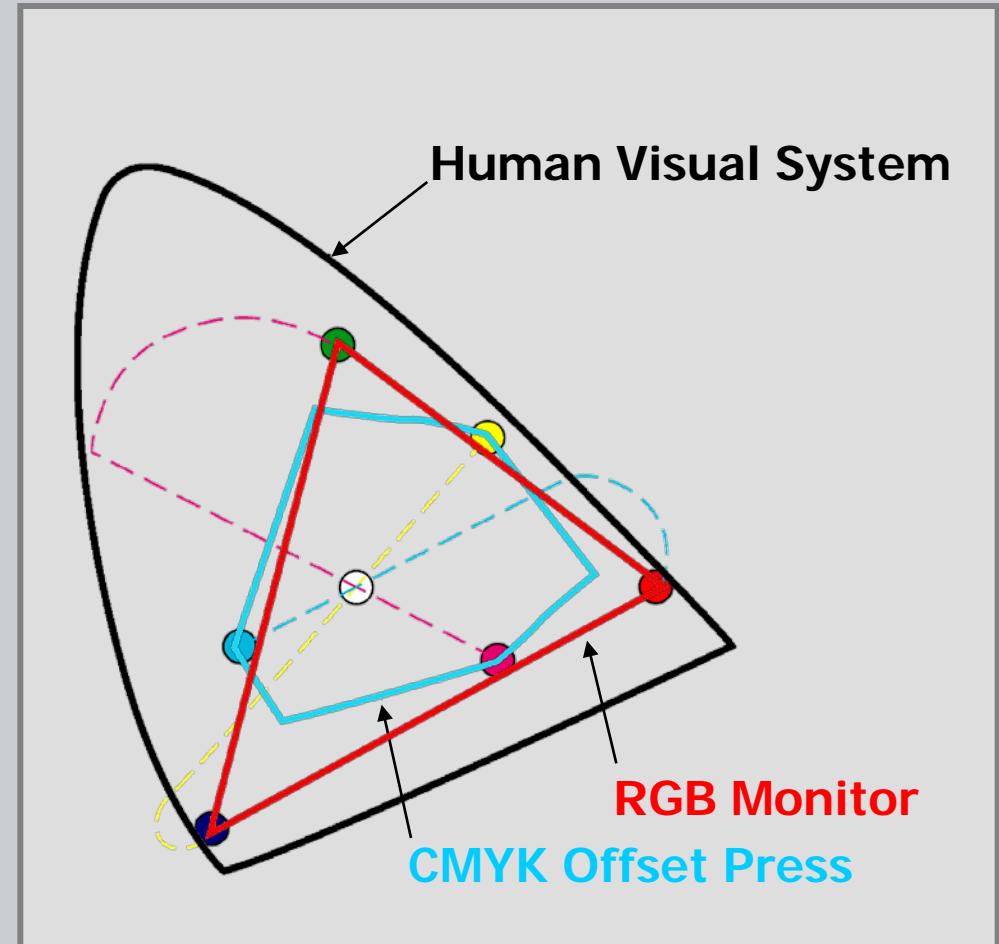
CIE x,y chromaticity diagram of an offset press and monitor gamut.

Note that:

Red is not 1 - Cyan

Green is not 1 - Magenta

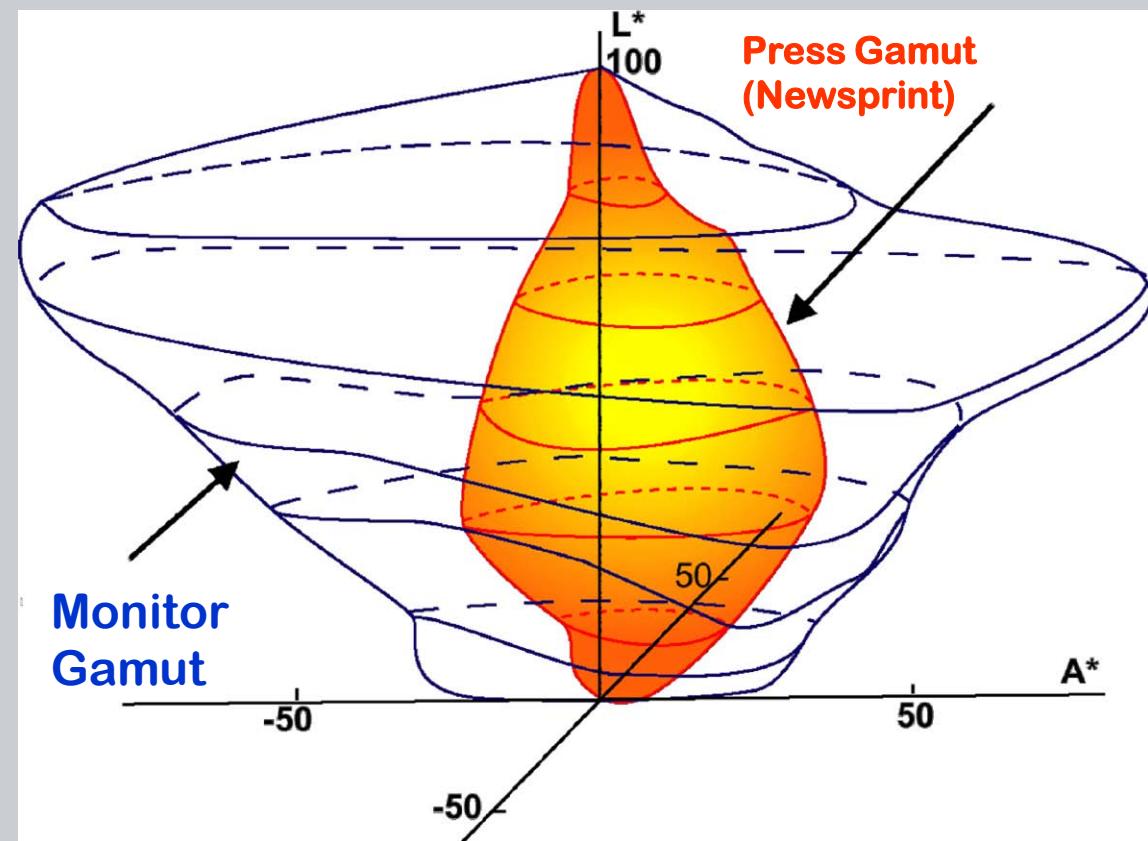
Blue is not 1 - Yellow





Gamuts are more fully represented as volumes.

Monitor and
press gamuts in
CIELAB space.



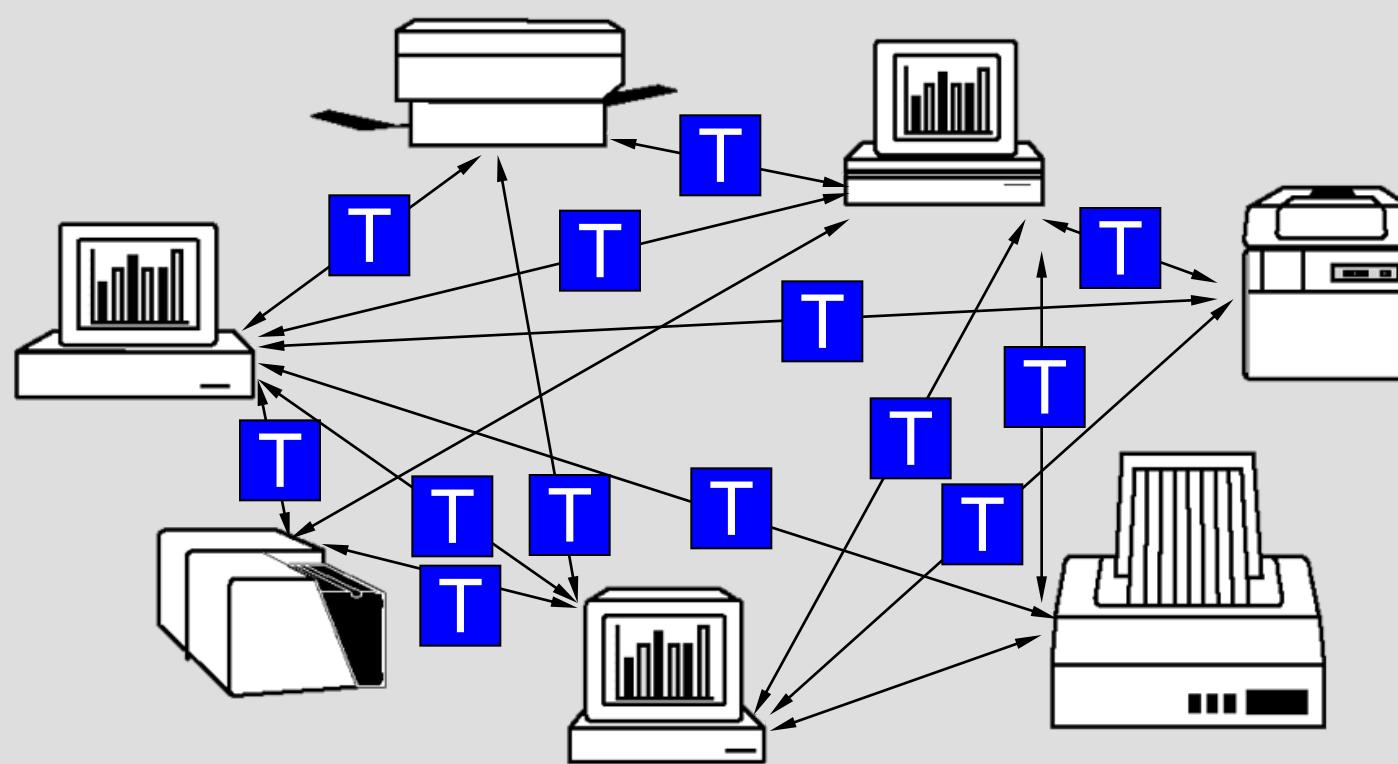


- A transform is needed to map the colours
 - from one (**source**) device colour space
 - to another (**destination**) device colour space.
- The transform must account for the colour characteristics of both source and destination devices as well as the viewing condition.





Device-dependent colour transformations



= each a different device-to-device transform

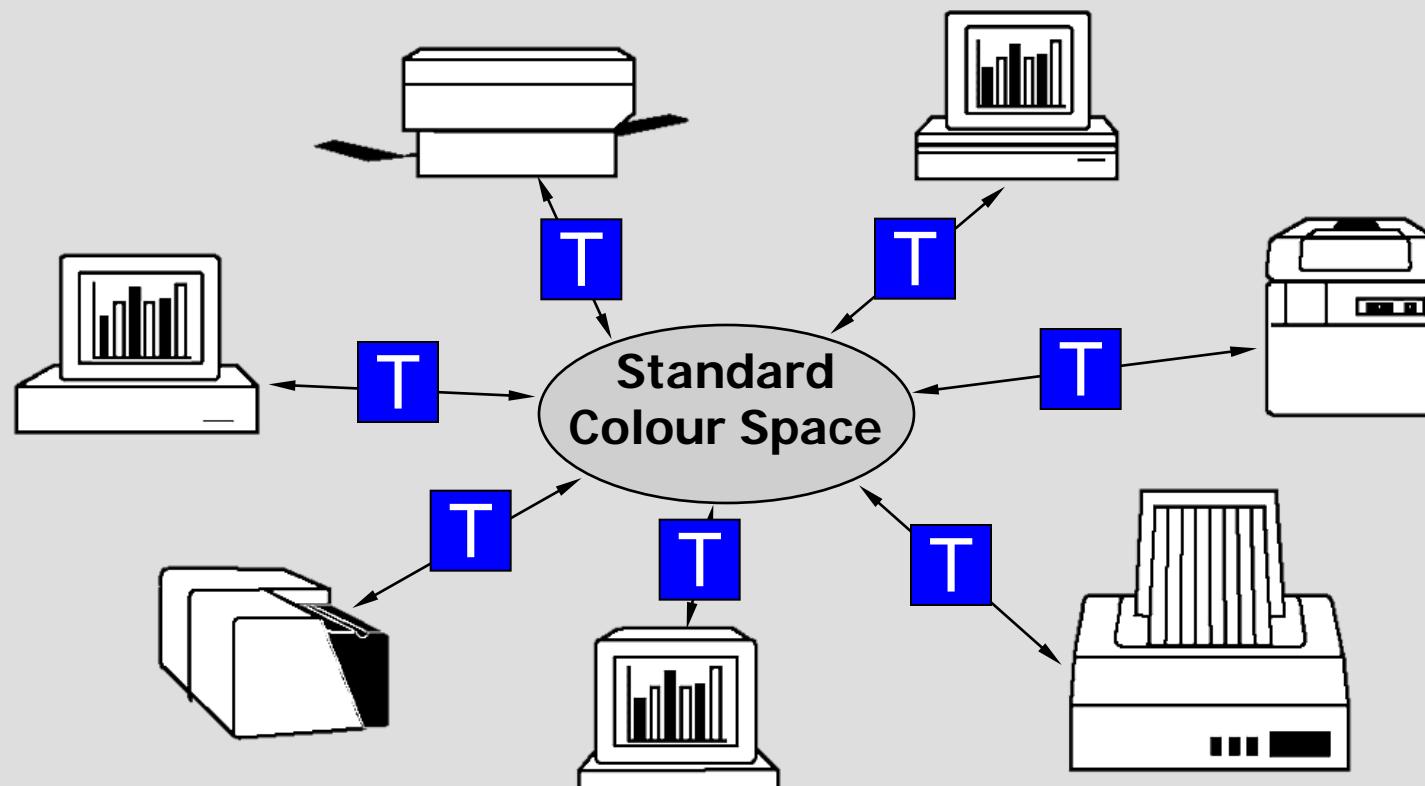


Disadvantages:

- A system of n devices,
requires n^2 transforms.
- Adding a device
requires n new colour transforms.
- Re-calibrating a device
requires n new colour transforms.



Device-independent colour transformation



= each a device-to-standard colour space transform



- For each device, there is a transformation from the device to a standard colour space.
- Transformations have **source-to-standard** colour space or **destination-to-standard** colour space information.

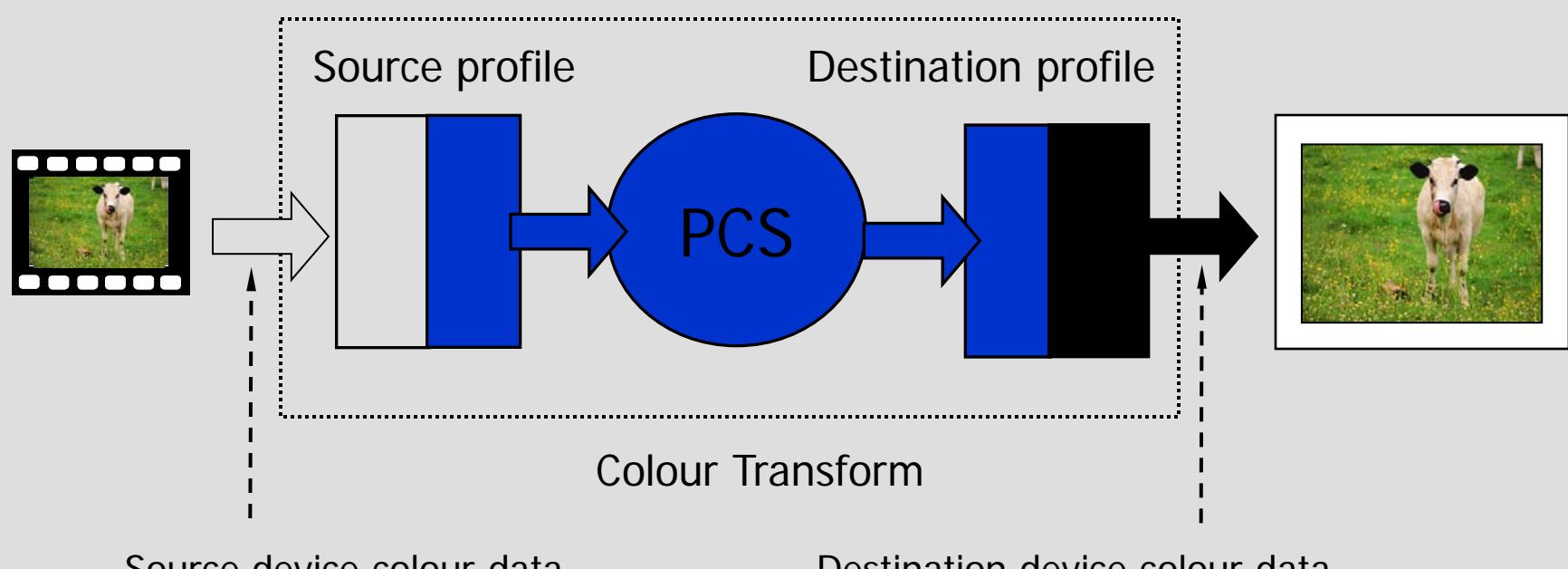


Advantages:

- For a system of n devices,
 n transforms are needed.
- Adding a new device requires
only one new colour transform.
- Re-calibrating a device requires
only one new colour transform.

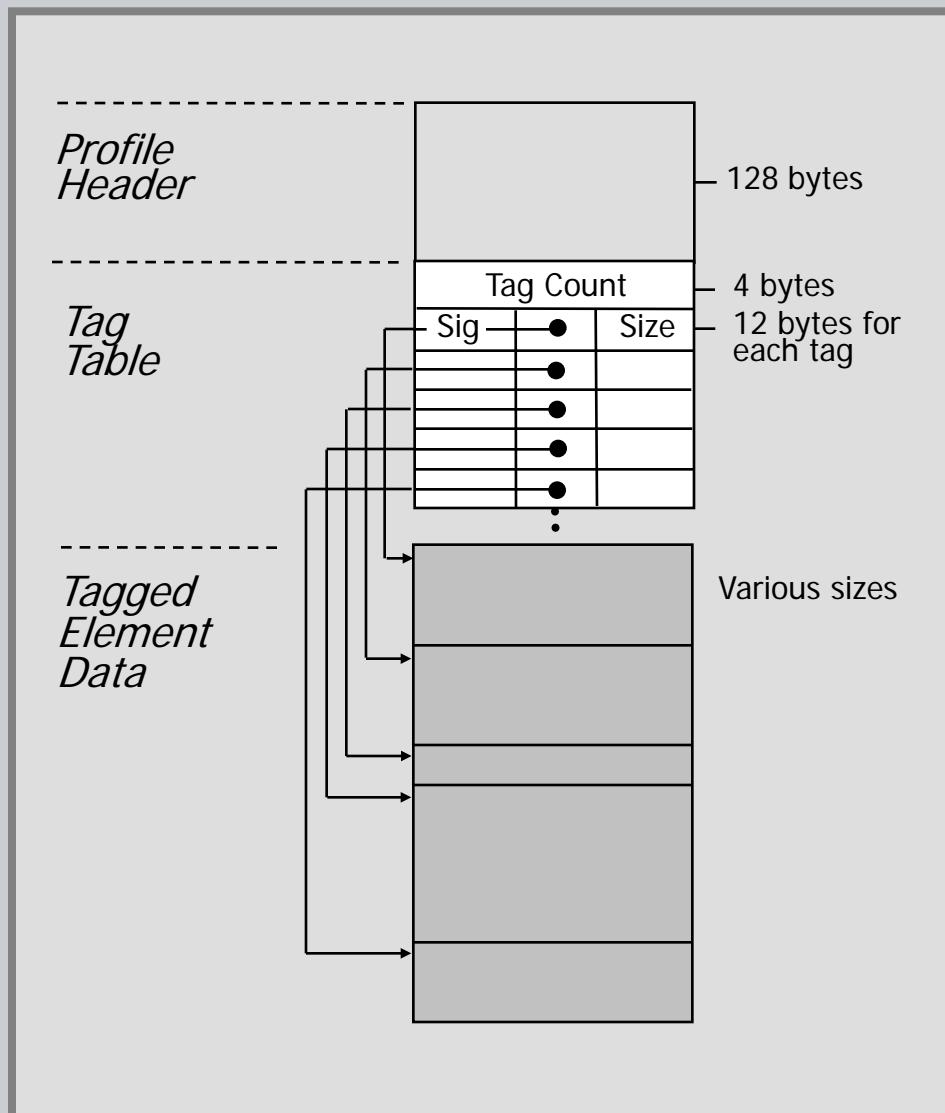


- The transforms from device to standard colour space are embedded in the **ICC profile**.
- The standard colour space is called **PCS** (profile connection space).





- The ICC profile contains the transforms from "**device**" to **PCS**.
- There are several kinds of profiles:
 - *Input device* (scanner, digital camera, etc.)
 - *Output device* (printers, film recorders, etc.)
 - *Display* (CRTs, LCDs, projectors, etc.)
 - *Device Link* (dedicated device-to-device)
 - *Colour space* (sRGB, CIE XYZ, L*a*b*, etc.)
 - *Abstract* (effects, PCS-to-PCS, etc.)
 - *Named Colour* (Pantone®, Truematch®, etc.)



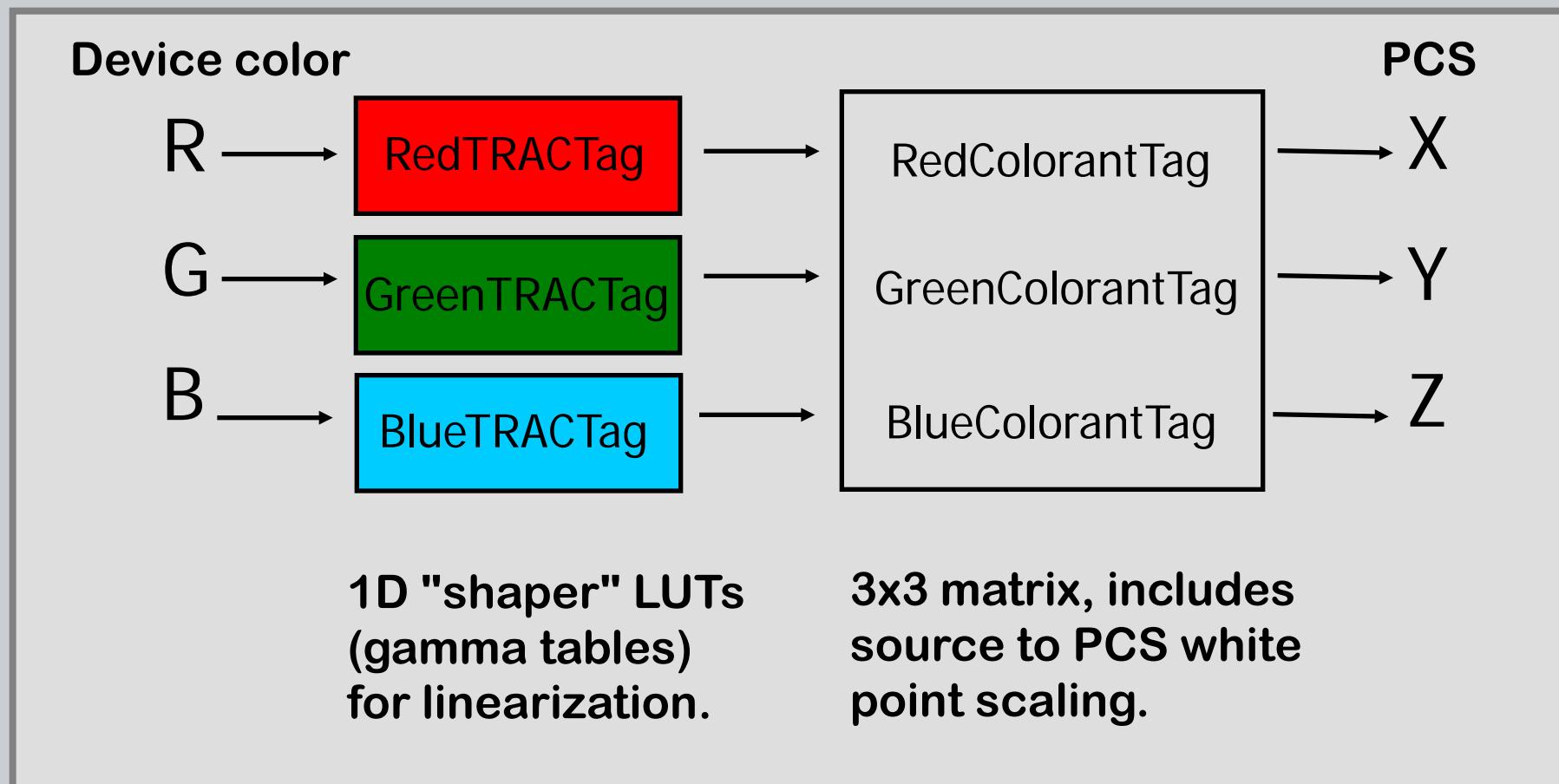
- 128 byte header
- Tag-based (like TIFF)
- Public required tags
- Public optional tags
- Private tags



- Shaper/matrix profiles are used for RGB and single channel (grayscale) input and display profiles.
- Shaper/multi-functional-table (MFT) profiles are used for complex RGB and CMYK input, for RGB, CMYK and n-colorant output, colour space conversion, and abstract profiles.
- The construction and content of the matrices and LUTs in a profile are vendor specific, and not defined in the ICC specifications.



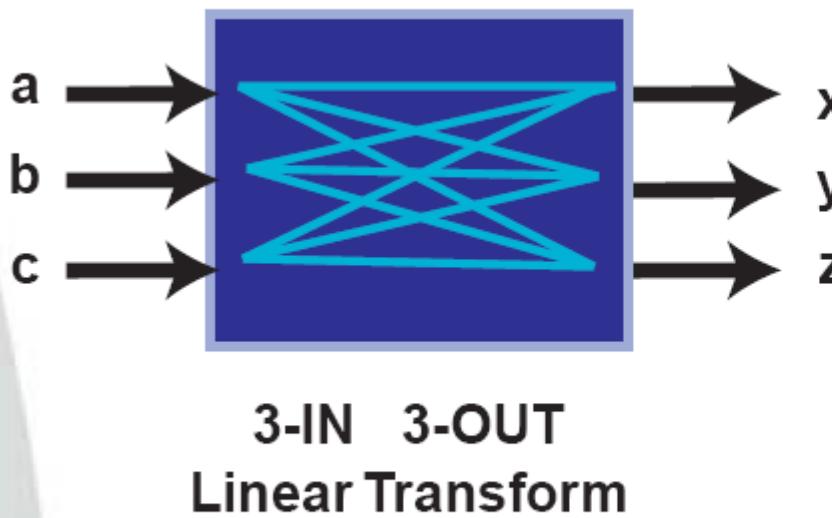
Invertible profile for simple RGB and grayscale devices





ICC Profiles and the PCS

- White point scaling is done by computing the colorants as a linear combination of the input values.
- This is conveniently expressed as a matrix, often called a matrix/shaper.
- The input values must be in linear additive units.



$$x = 1.0 \cdot a + 1.4 \cdot b + 0.8 \cdot c$$

$$y = 0.0 \cdot a + 2.5 \cdot b + 0.6 \cdot c$$

$$z = 1.3 \cdot a + 1.4 \cdot b + 1.3 \cdot c$$

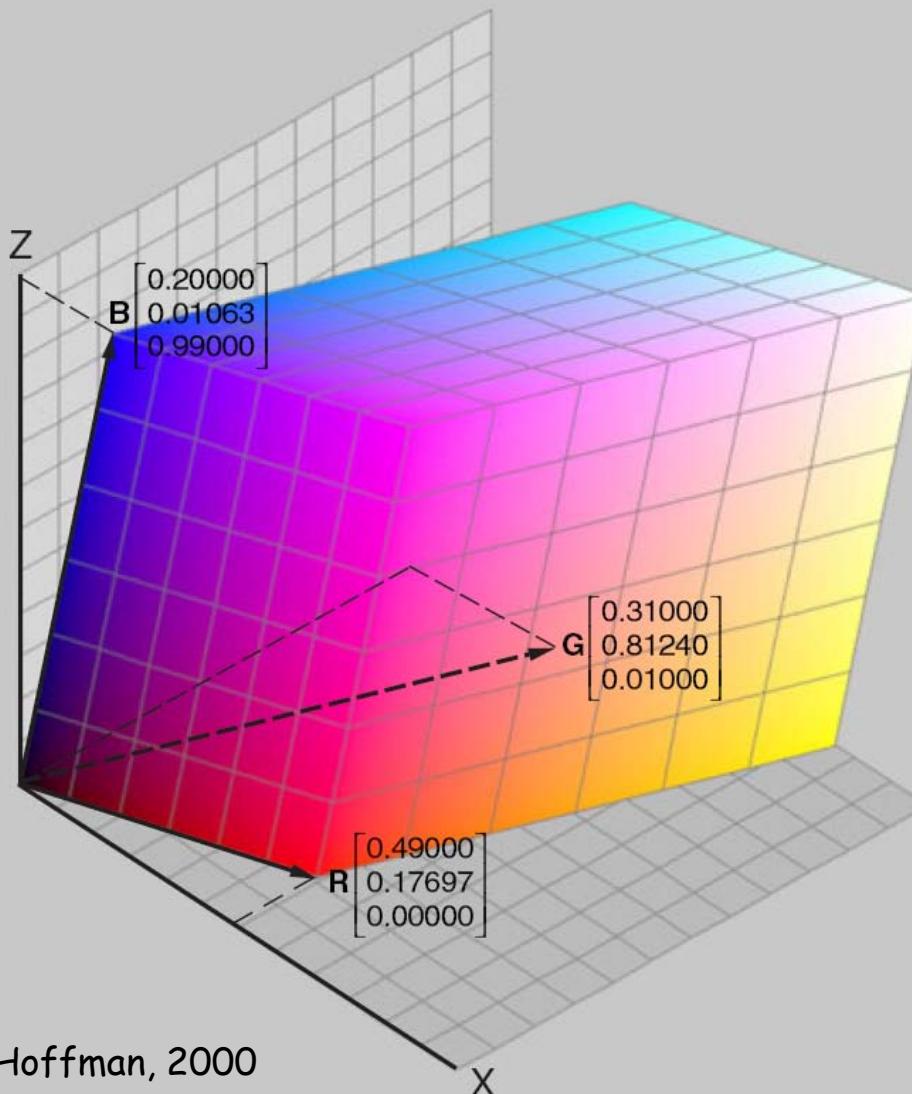
$$\begin{pmatrix} 1.0 & 1.4 & 0.8 \\ 0.0 & 2.5 & 0.6 \\ 1.3 & 1.4 & 1.3 \end{pmatrix}$$

3 x 3 Matrix

From King, Adobe



ICC Profiles and the PCS



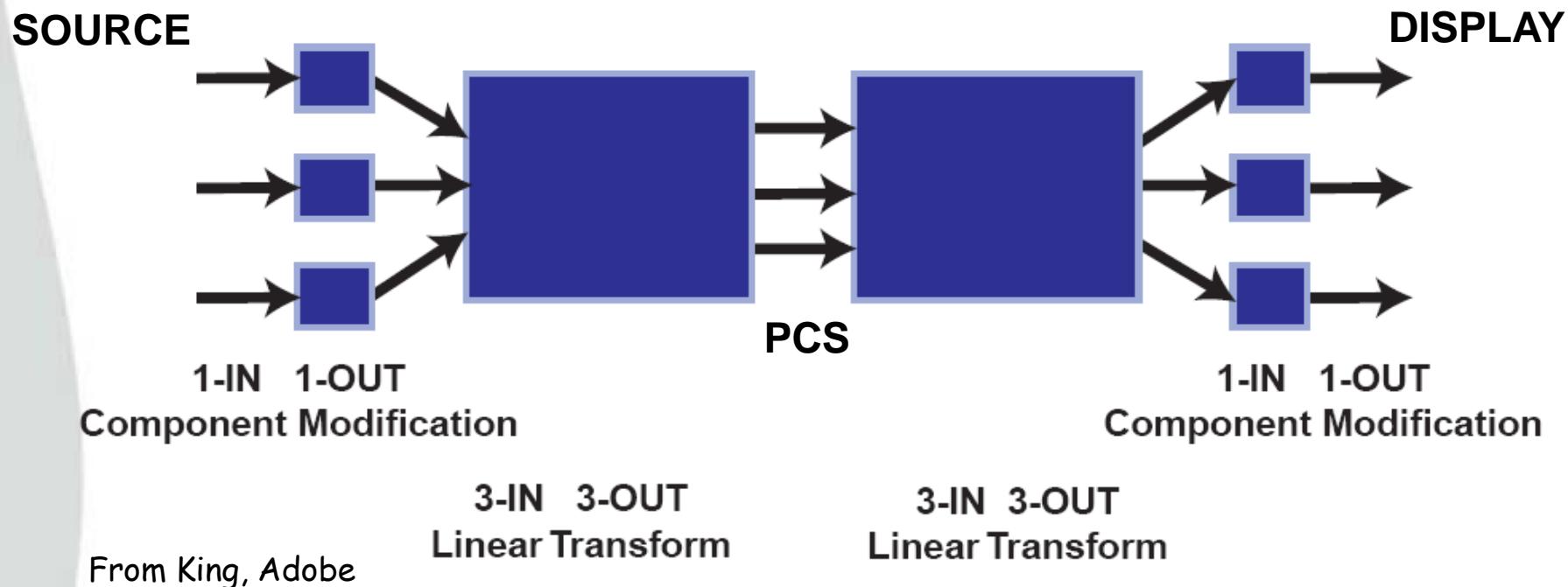
- The profile connection space is defined in the CIE XYZ colour space.
- The 3 orthogonal coordinates define the gamut of visible colors with all positive units.
- XYZ coordinates are associated with RGB colors.
- Colors within the XYZ space are considered to be linearly additive.
- The XYZ coordinates are commonly mapped to CIE XY coordinates to illustrate the colour gamut without luminance information.



ICC Profiles and the PCS

Color managed presentation of an image from an RGB camera

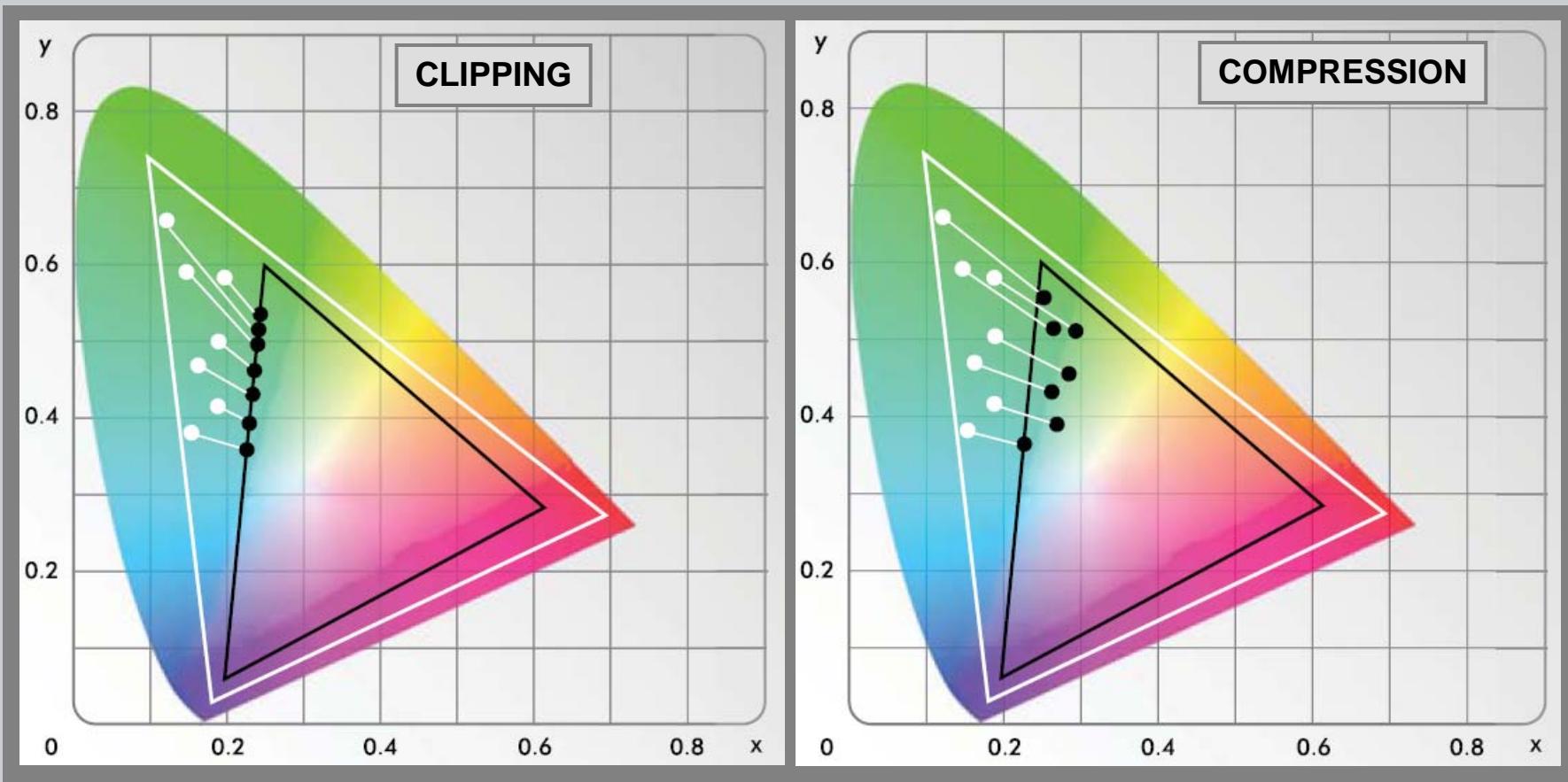
- Linearization and matrix transformation of the source camera data to PCS coordinates.
- Matrix transformation of the PCS values and non-linear colorant modification..





ICC Four Rendering Intents

When the camera color gamut is larger than the display color gamut, some compromise must be made in the presentation.





Relative colorimetric

the white point of the **actual medium** is mapped to the white point of the reference illuminant (i.e. $L^*a^*b^* = 100, 0, 0$ for the medium). The colours map accordingly.

Absolute colorimetric

the white-point of the **illuminant** maps to the white point of the reference illuminant (i.e. $L^*a^*b^* = 100, 0, 0$ for D50). The colours map accordingly.

Note: Both may allow for chromatic adaptation.



Perceptual

the full gamut of the image is compressed or expanded to fill the gamut of the destination device. Grey balance is usually preserved, but colorimetric accuracy might not be.

Saturation

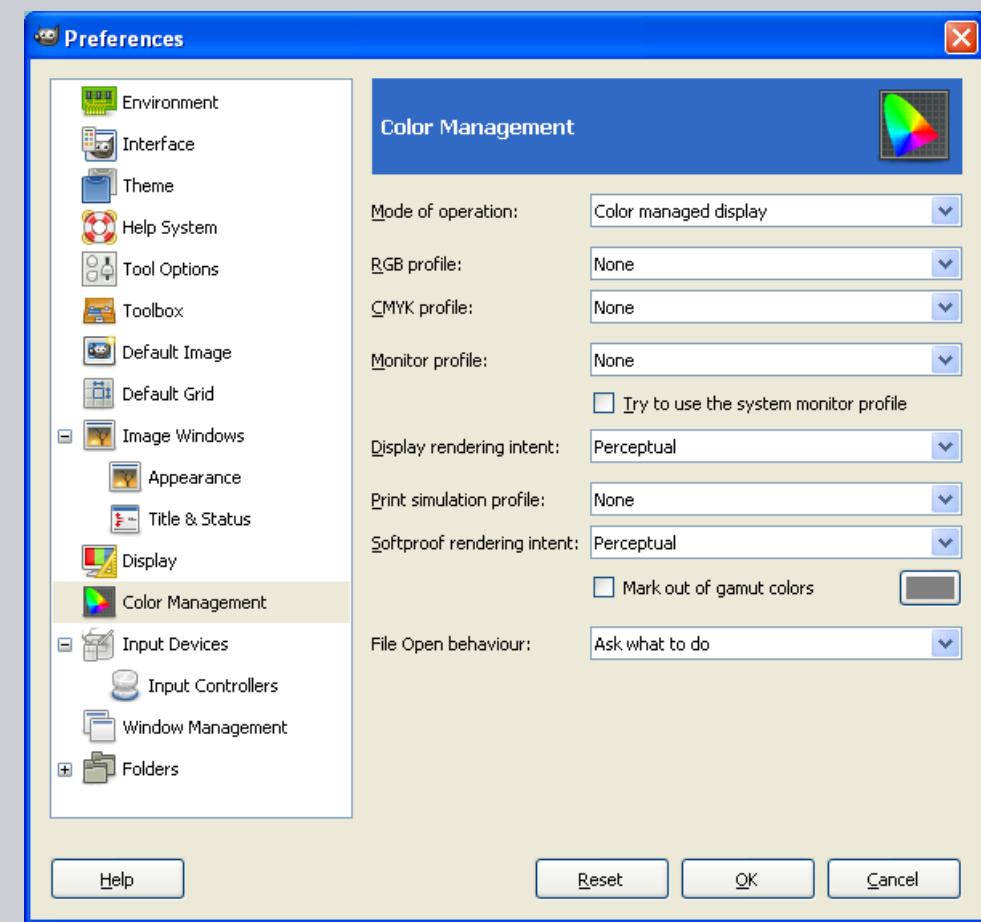
the saturation of the pixels in the image is preserved, perhaps at the expense of accuracy in hue and lightness.





Color Managed Applications

- An application implementing full color management will use both the source device (camera) profile and the display device (monitor) profile.
- Additionally, the user will specify the rendering intent.
- Some applications will also specify a working space allowing the appearance of an image on an output device to be simulated.
- Examples include:
 - Adobe Photoshop
 - Gimp
 - Firefox 3
 - Fast Image Viewer
 - MS Vista Image Viewer



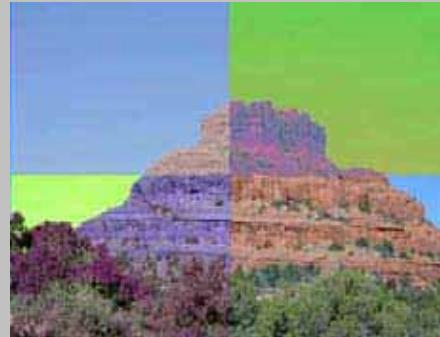
Color Management Window from GIMP



Color Managed Applications

- Source profiles are typically embedded in an image header using digital camera acquisition application.
- The ICC standard defines how to embed an ICC profile into JPEG, GIF and TIFF headers.
- DICOM defines how to embed an ICC profile into a color image object.

ICC Color Management Browser Test, www.color.org



Internet Explorer
No profile support



Firefox v3
Full profile support



Calibration

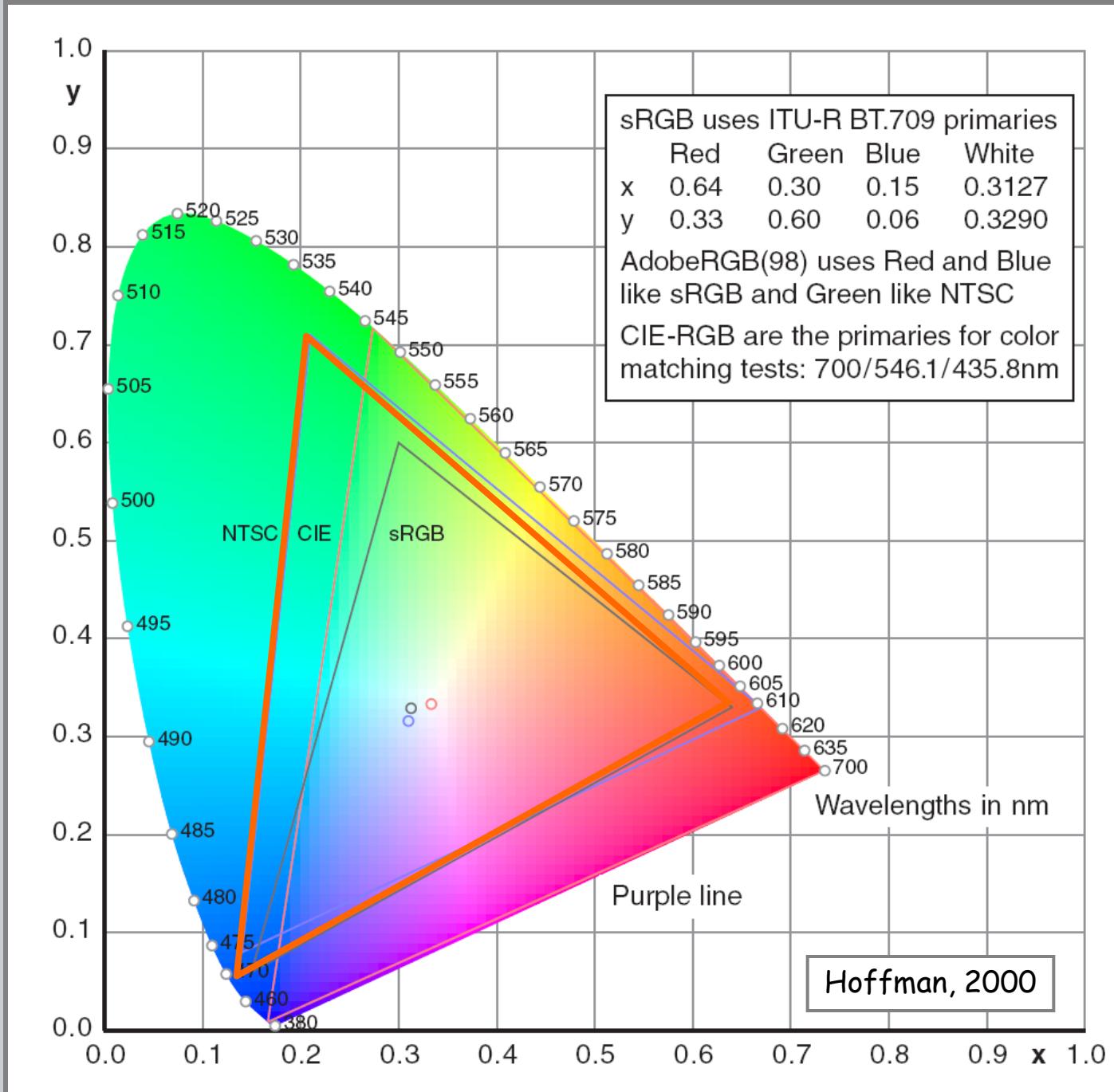
Calibration of a camera or a display monitors is done to establish a device color gamut that matches a defined standard color gamut.



Calibration

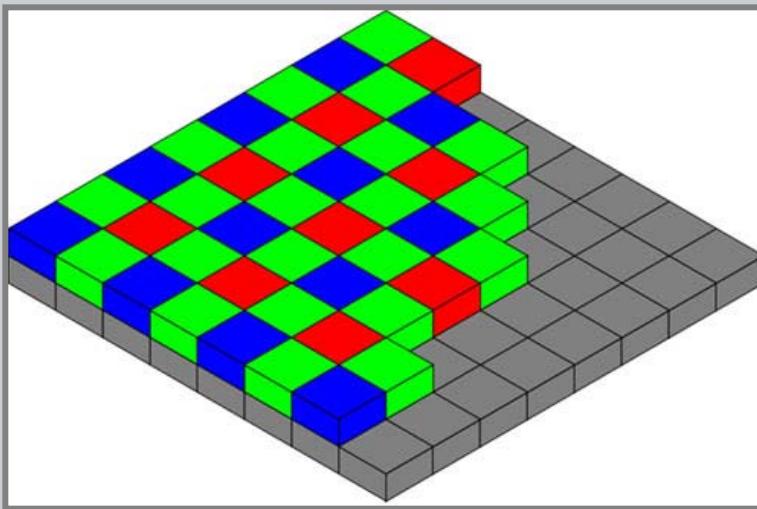
sRGB is modest in saturation and common for consumer monitors.

aRGB has improved saturation and is used in many professional graphics applications.



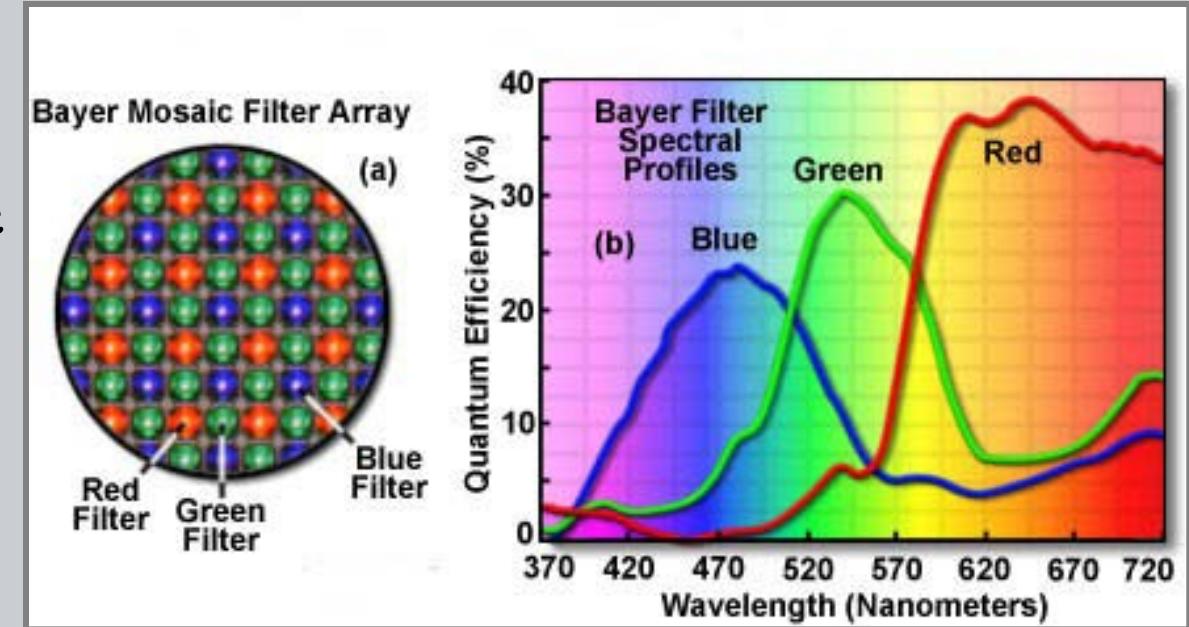


Calibration



In a digital camera, each pixel records through a color filter. The filters are arranged in a Bayer pattern with more green pixels than red or blue. RGB values are obtained by interpolating from the positions of the sensors with the same color.

The spectral sensitivity of the Red, Green, and Blue sensors is NOT like that of the human visual system. The raw data recorded is thus transformed to a suitable color space.



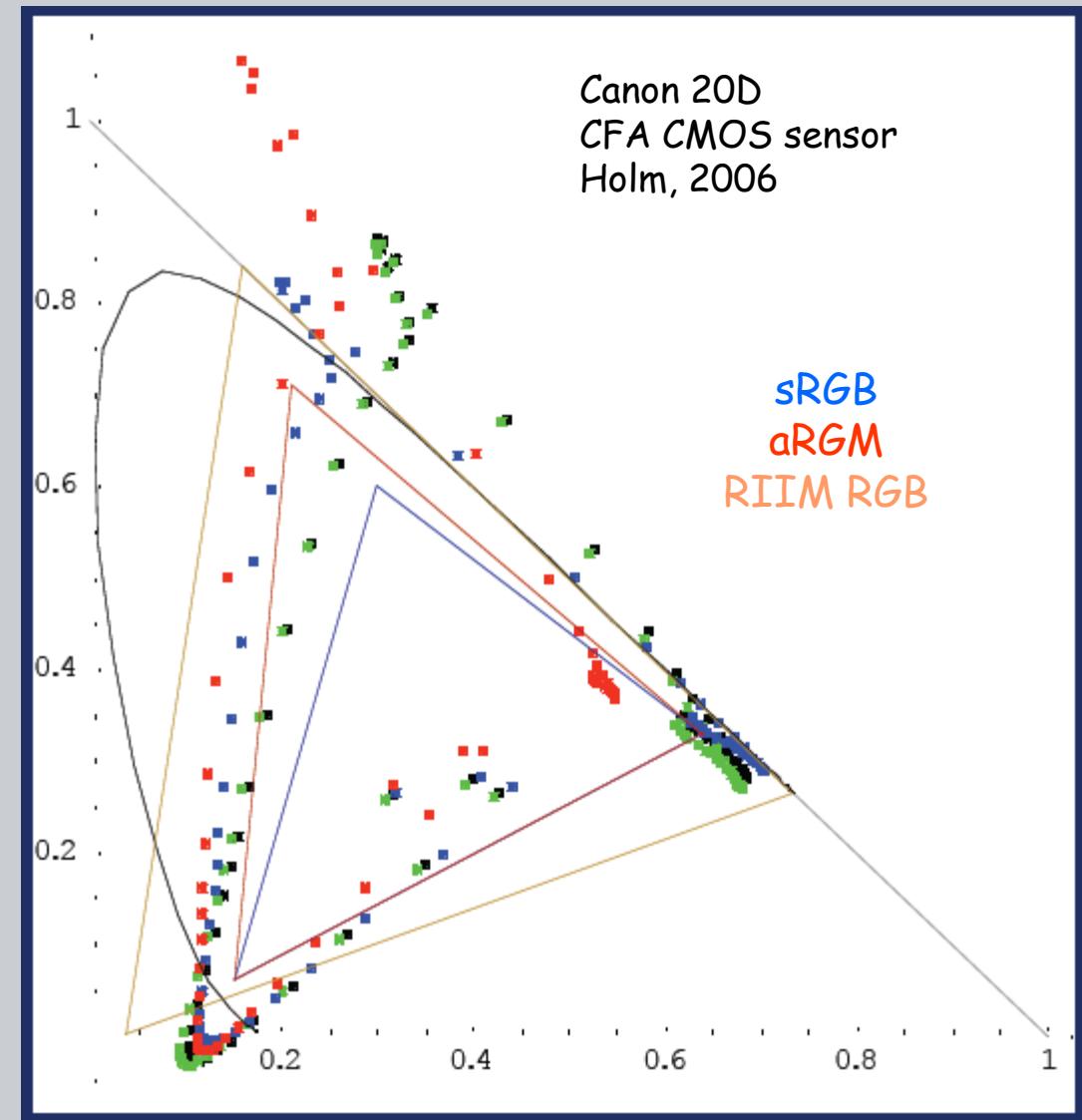


Calibration

Digital camera raw data has a large, irregular color gamut. Illustrated here with 3 different interpolation methods.

RIMM RGB

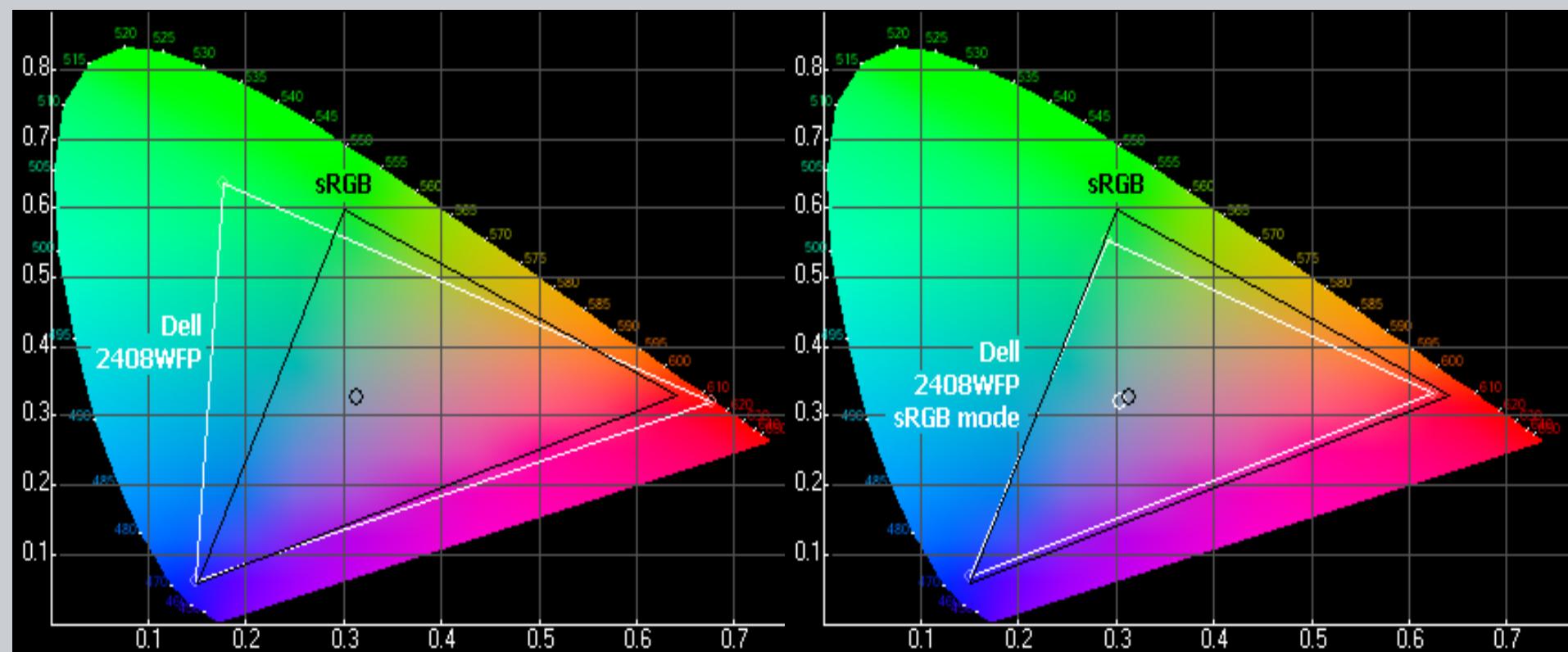
ISO/TS 22028-3,
Photography and graphic
technology - Extended
colour encodings for
digital image storage,
manipulation and
interchange





Calibration

Consumer monitors can have gamuts that are poorly aligned to standard color spaces.
Calibration can result in under saturated colours.

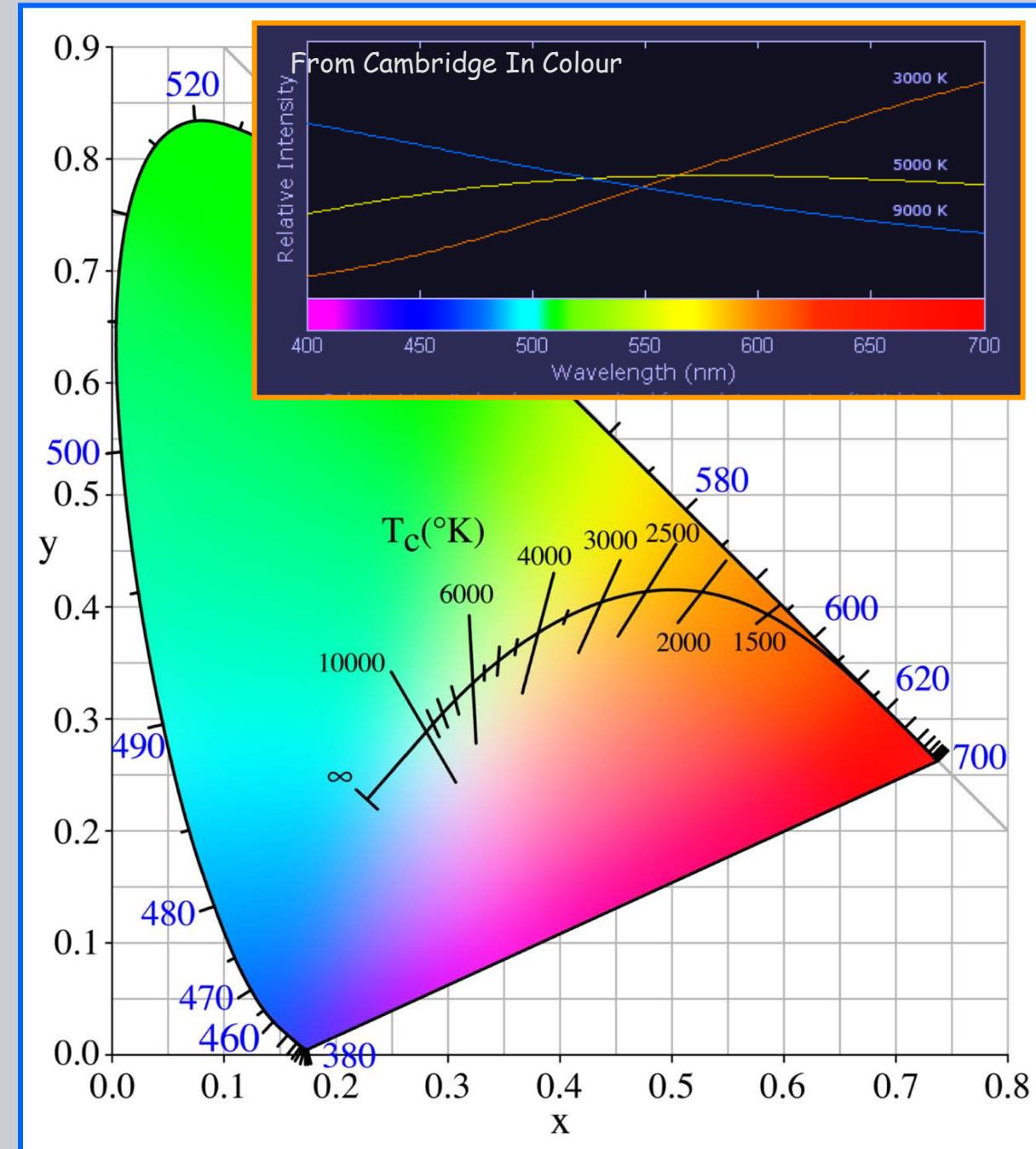




Calibration

The white point for color calibration is often specified as the color associated with the spectrum from a blackbody radiator of specific temperature.

6500 degrees is a common specification for LCD monitors.

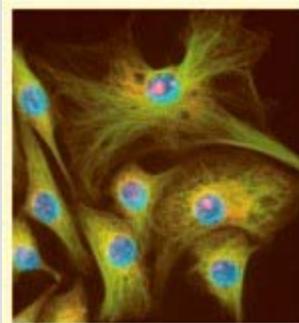




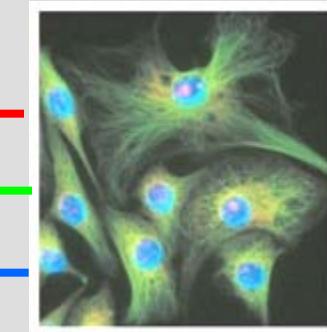
Calibration

Calibration using monitor look-up tables (CLUTs).

GRAPHIC CARD

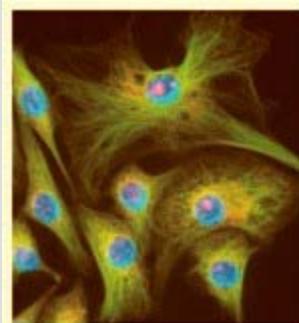


MONITOR

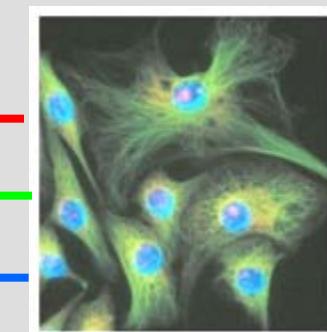


Calibration using graphic card tables (CLUTs).

GRAPHIC CARD



MONITOR





Calibration

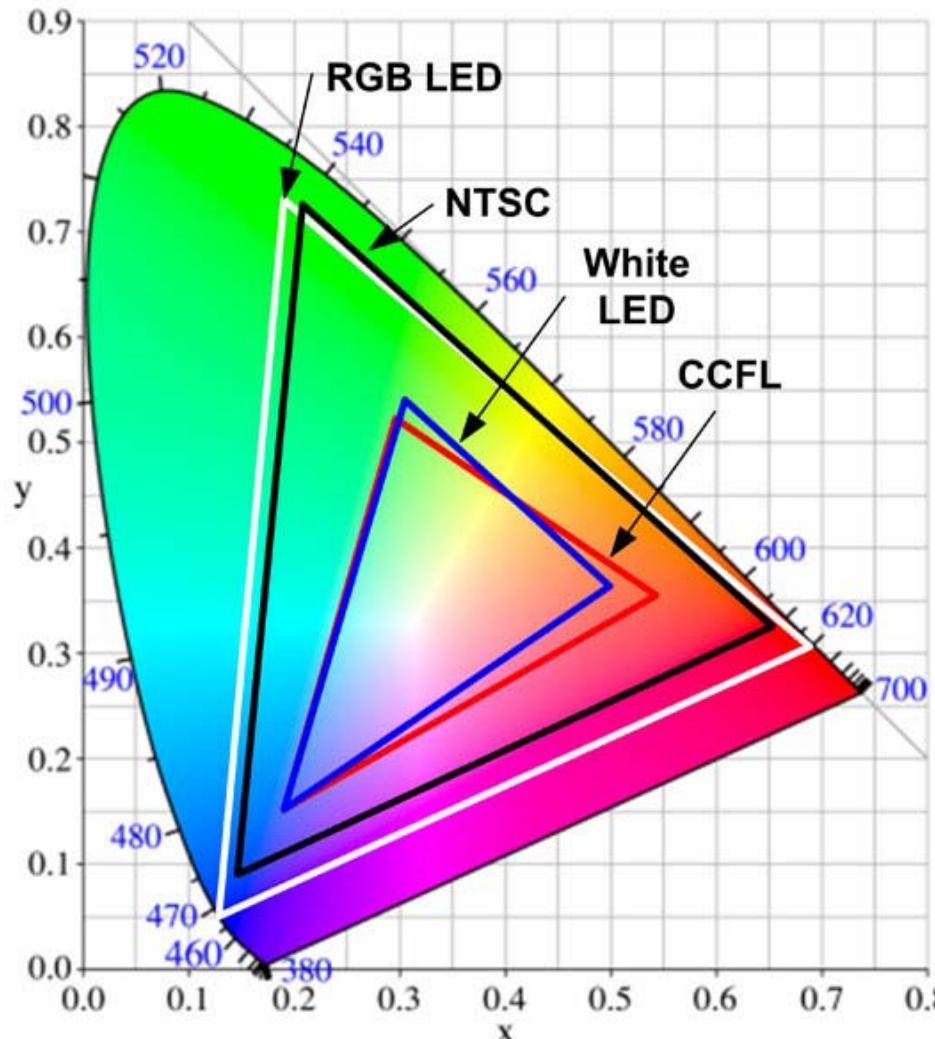


Fig. 3. The color gamut of LCDs with backlights employing CCFL, white LEDs and RGB LEDs are shown here along with the NTSC (television) color gamut.

New technology offers significant improvement in display color gamut.

- Individual R, G, and B LED illuminators for each sub-pixel
- Organic Light Emitting Devices (OLED)



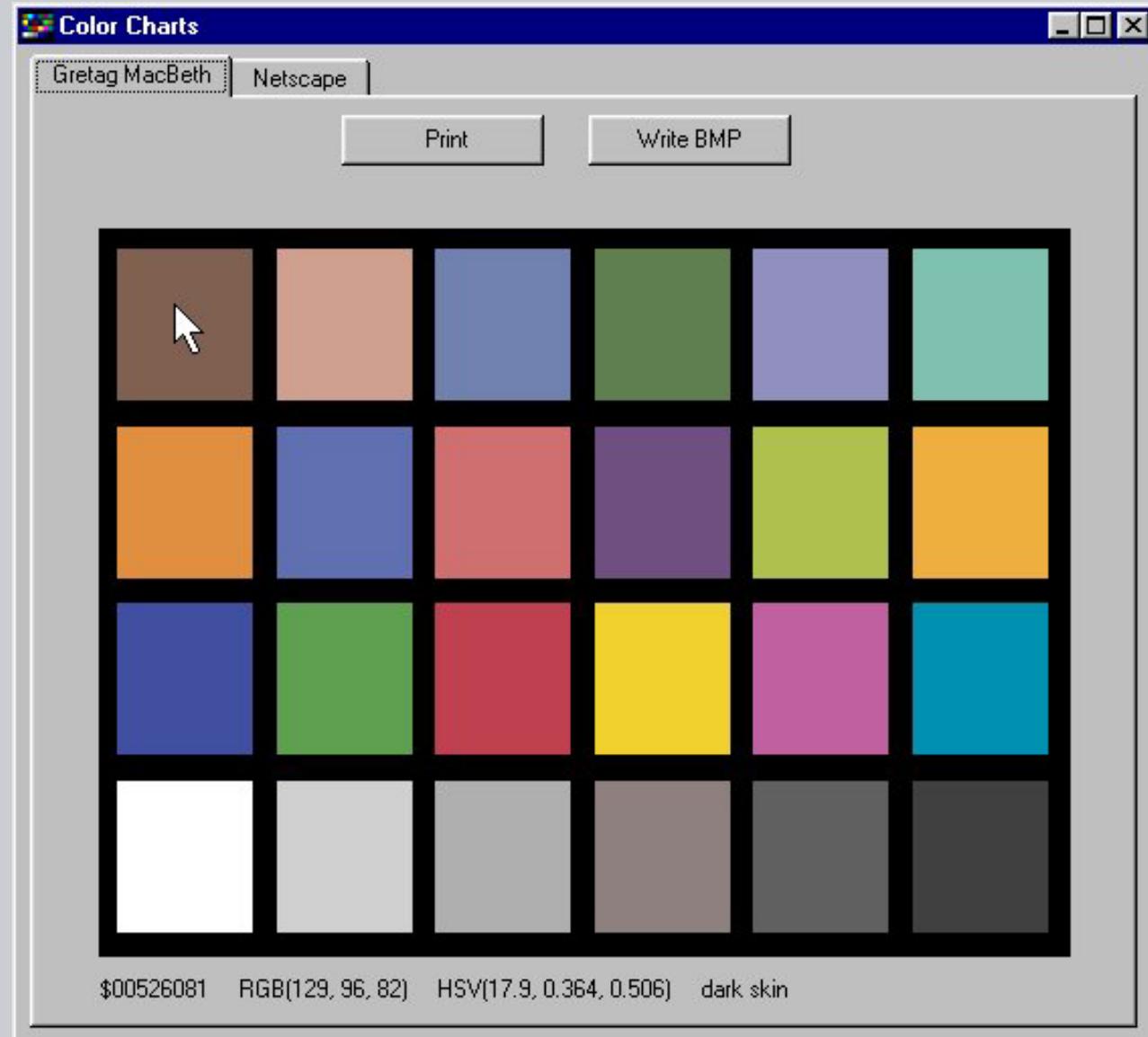
Profiling

Profiling of a camera or a display monitors is done to describe a calibrated device color gamut to support color managed software applications.



Profiling

Profiling
of a
camera is
normally
done by
recording
a printed
color
chart.

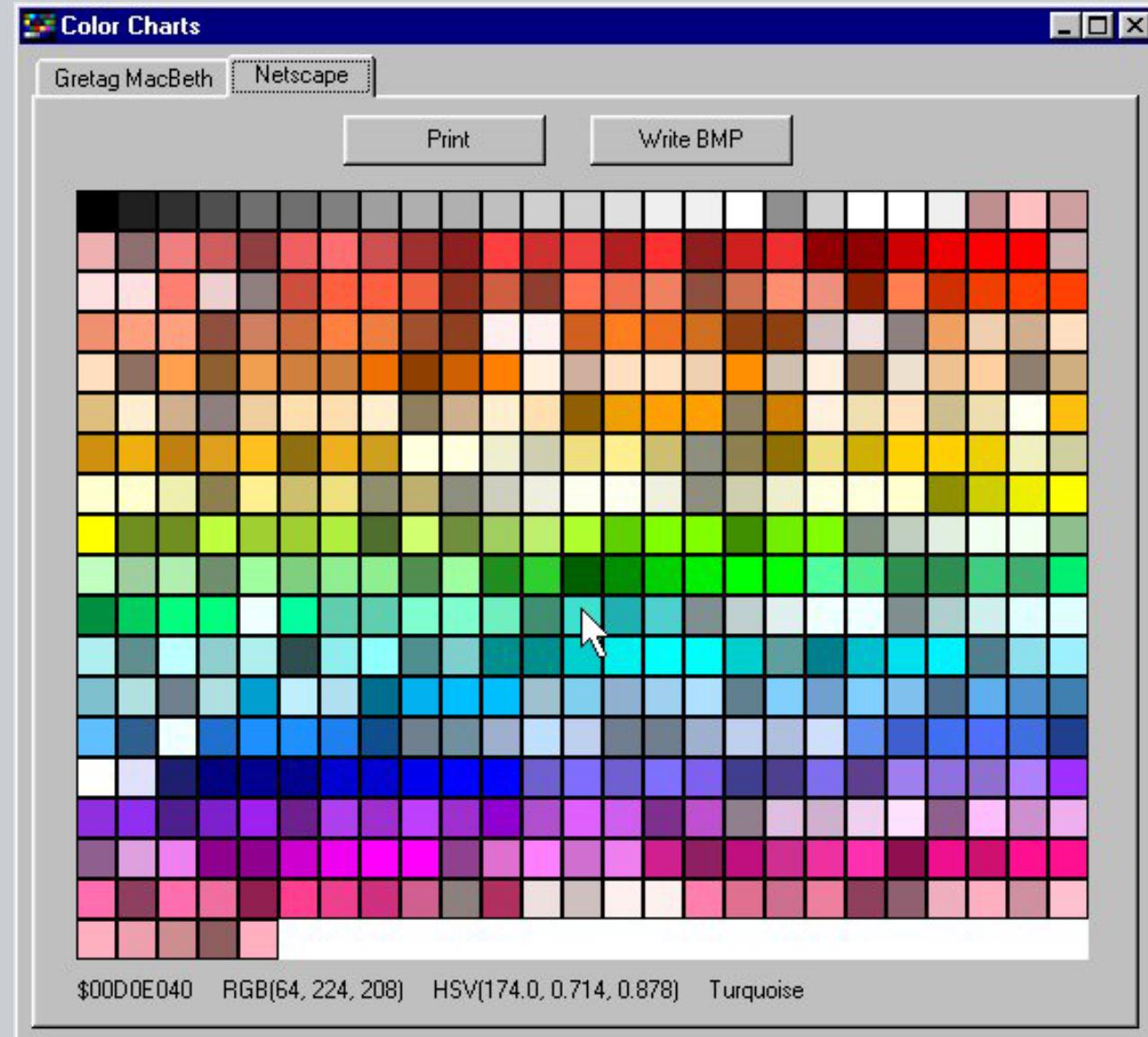


From EFGs computer lab, www.efg2.com



Profiling

Accurate profiles require a large number of color test patterns.



From EFGs computer lab, www.efg2.com



Profiling

- Profiling of a display monitor is done using a software application that puts up a series of color patches with varying color and brightness.
- The color point of each is measured with a colorimeter.
- Generation of an accurate profile requires ~800 patches.
- For matrix/shaper profiles, a best fit 3×3 matrix and 3 LUTs are deduced and coded into a profile (.icc or .icm)



Color Monitors in Medicine

Color management functions

required for various medical applications

Use	DICOM Grayscale		Tone scale CIE, g2.2	White tone Calibr.	Color Gamut Calibration	
	Generic	S/N			sRGB	aRGB
General desktop, document editing, clerical applications, ...						
Referring physician review of Radiology studies with reports	✓					
Specialist review of Radiology studies with multi-monitor stations	✓			✓		
Interpretation of Radiology studies to generate a medical record.		✓		✓		
Clinical physician review of patient photographs with clinic notes			✓	✓	✓	
Specialist interpreting/documenting new patient photos/slides.			✓	✓		✓
Clinical physician reviewing both photographs & Radiology studies	✓		✓	✓	✓	
.....						



Color calibration



Beginnings of Color Management Needs and Techniques at the University of Arizona

Hans Roehrig, Hashmi Fahad, Elizabeth Krupinski

University of Arizona

Lou Silverstein

VCD Sciences, Inc

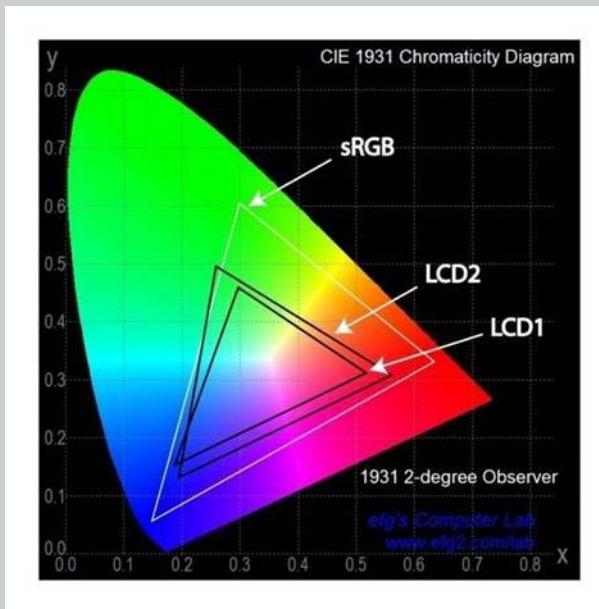
**This work has been funded under the American
Recovery and Reinvestment Act (ARRA) of 2009
with Grant Number 1-R01 EB007311-01A2**



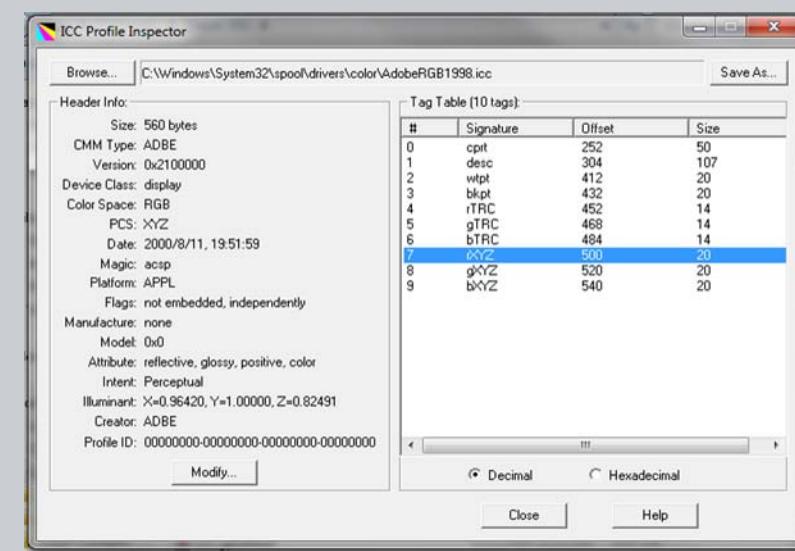
Display Color Calibration and ICC Profiling

Calibration of a display monitor is done to *establish* a device color gamut that matches a defined standard color gamut.

Profiling of a display monitor is done to *describe* a calibrated device color gamut to support color managed software applications (because calibration might not be able to exactly match a standard color gamut.)



Calibrated LCDs with different gamuts



ICC Profile generated after calibration



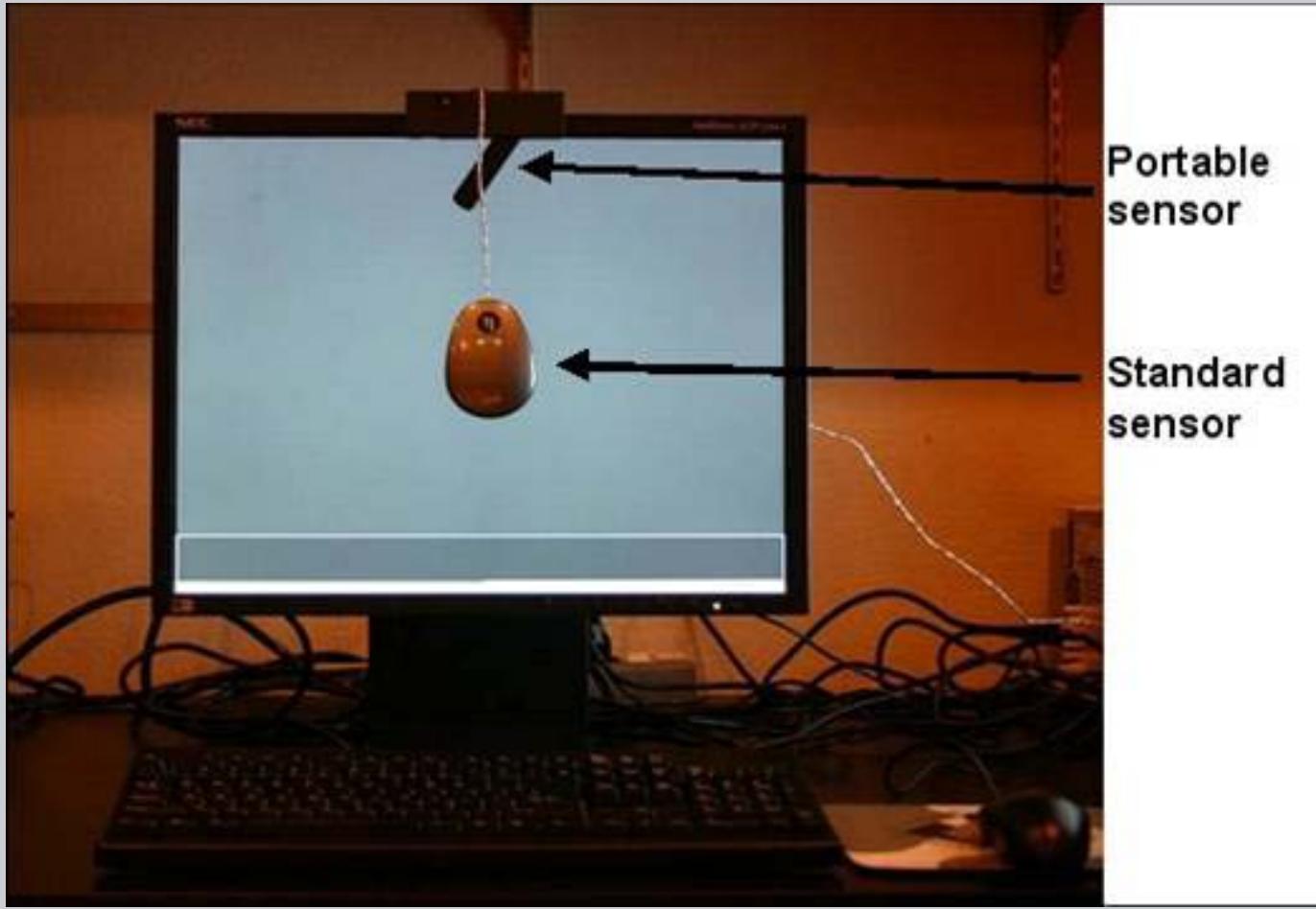
Display Color Calibration and ICC Profiling

A full monitor calibration procedure can be formalized into six stages:

- 1) color temperature adjustment (6500°K),
- 2) selection of minimum and maximum luminance, (White-Point)
- 3) generation of the L^* target Tone-Reproduction-Curve
- 4) computation of RGB luminance correction curves,
- 5) measurement of tristimulus values X, Y, Z for color patches,
- 6) computation of the monitor's RGB to XYZ transformation matrix.

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} M_{XR} & M_{XG} & M_{XB} \\ M_{YR} & M_{YG} & M_{YB} \\ M_{ZR} & M_{ZG} & M_{ZB} \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

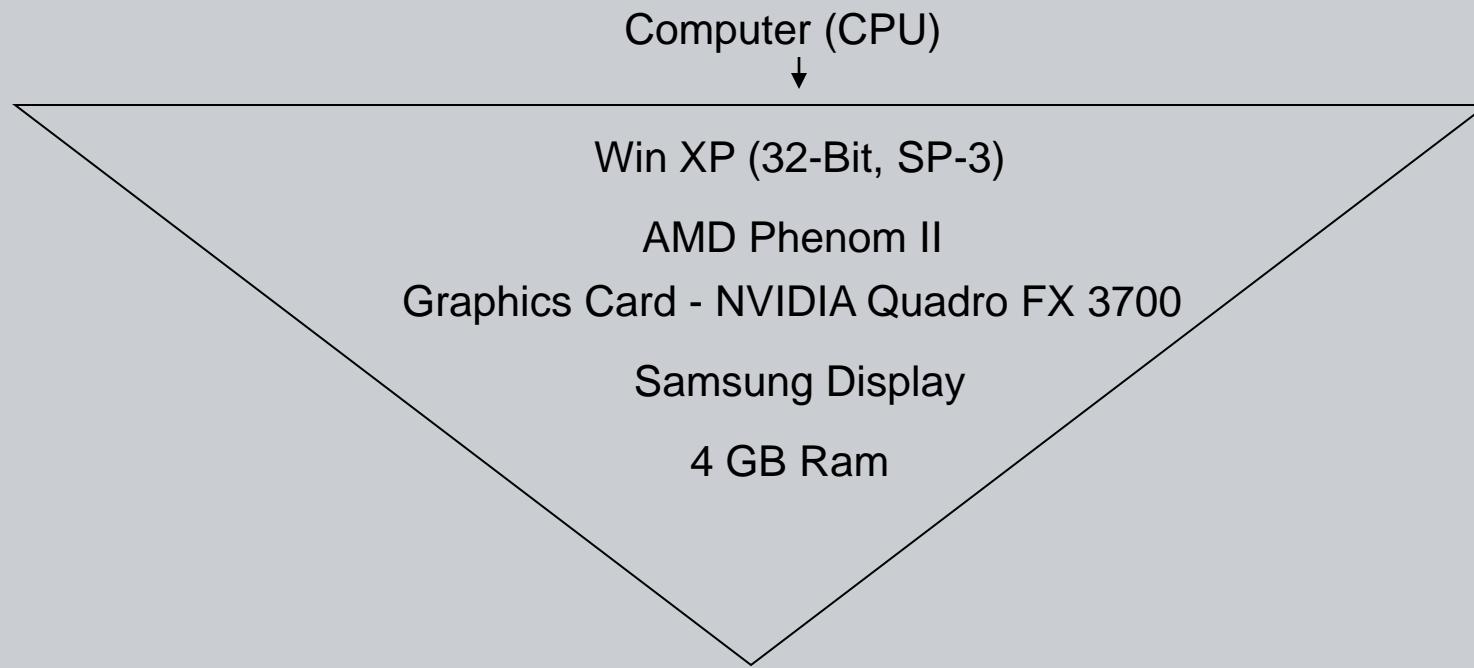
Step 4 is frequently termed *gamma correction*, and the look-up-tables (LUTS) generated are used by either the graphics card driving the monitor or hardware within the monitor. We intend to deal only with the internal LUT. The matrix computed in step 6 can be stored in an ICC profile for use by display software.



This picture shows an example of a standard DICOM calibration detector which recently has been modified to also serve as a color detector. These type of detectors is called "Puck". They do have problems as they are not very accurate.



We built a facility to permit generation of ICC Profiles
and do Color Management



NEC – 2690 WUXi2

NDS –DOME E3cHB

EIZO RX320



Experimental Setup

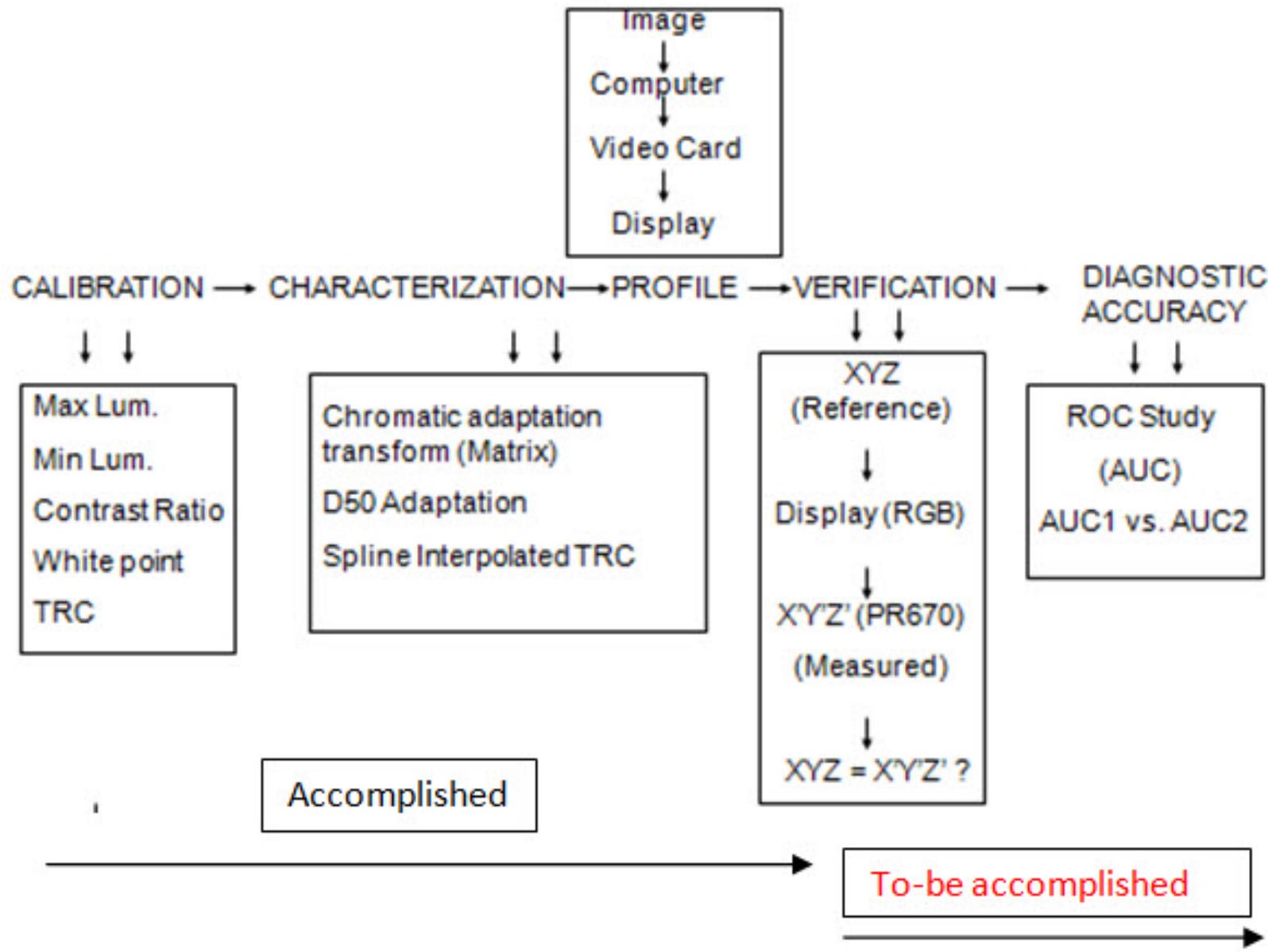


Primary Monitor

PR 670 Spectro-Photometer

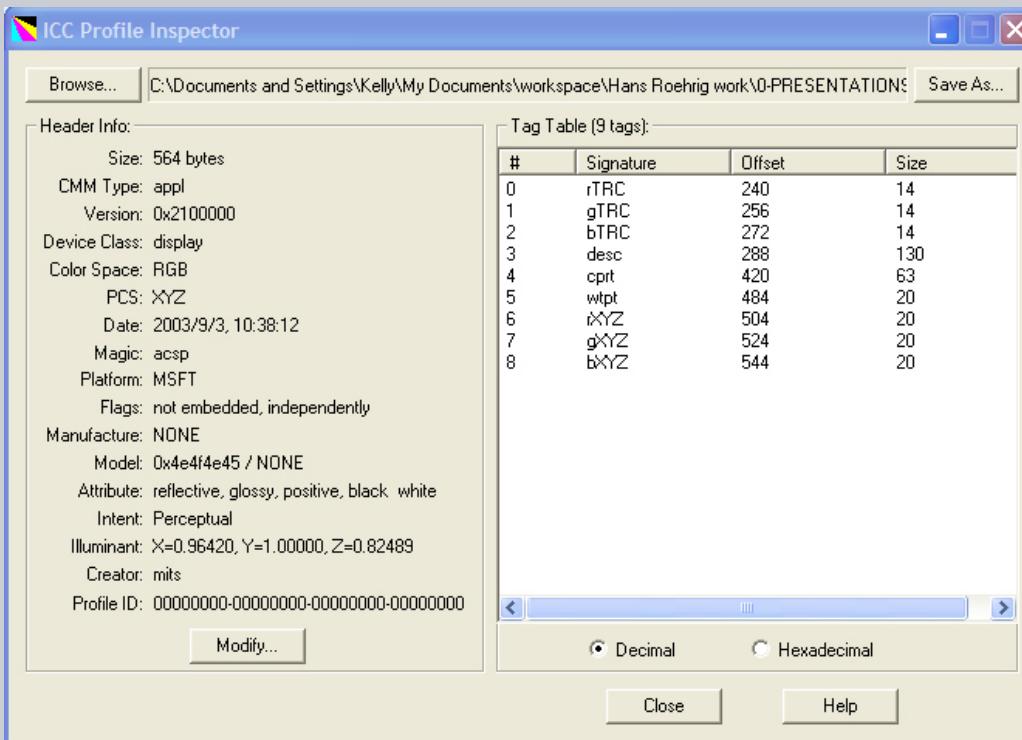
Display Under Test

Project Flow Chart

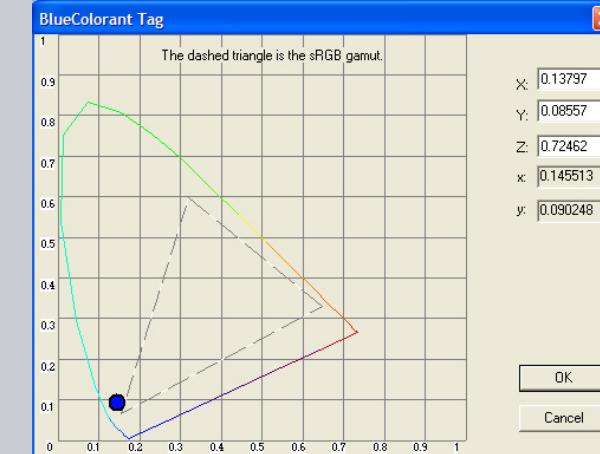
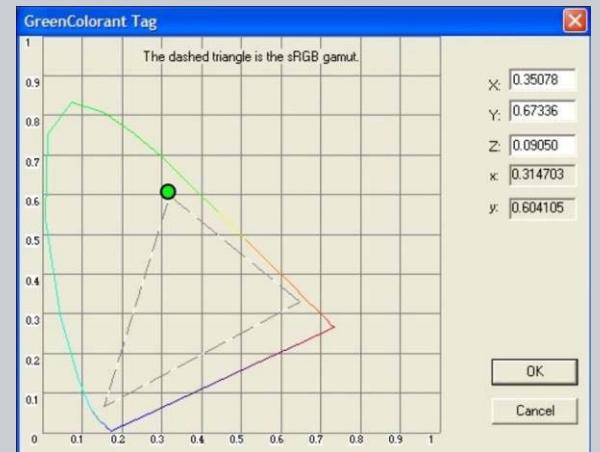
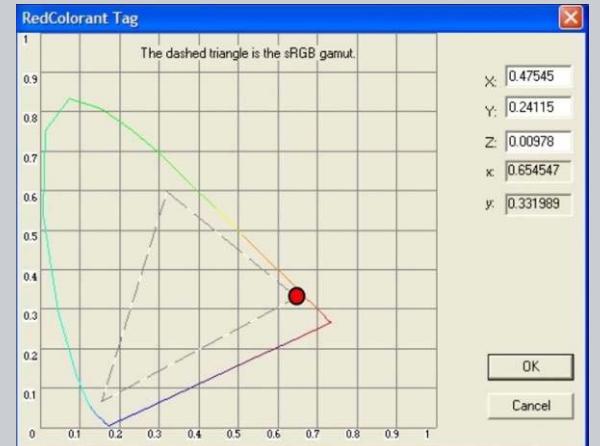




Partial sample of an ICC Profile

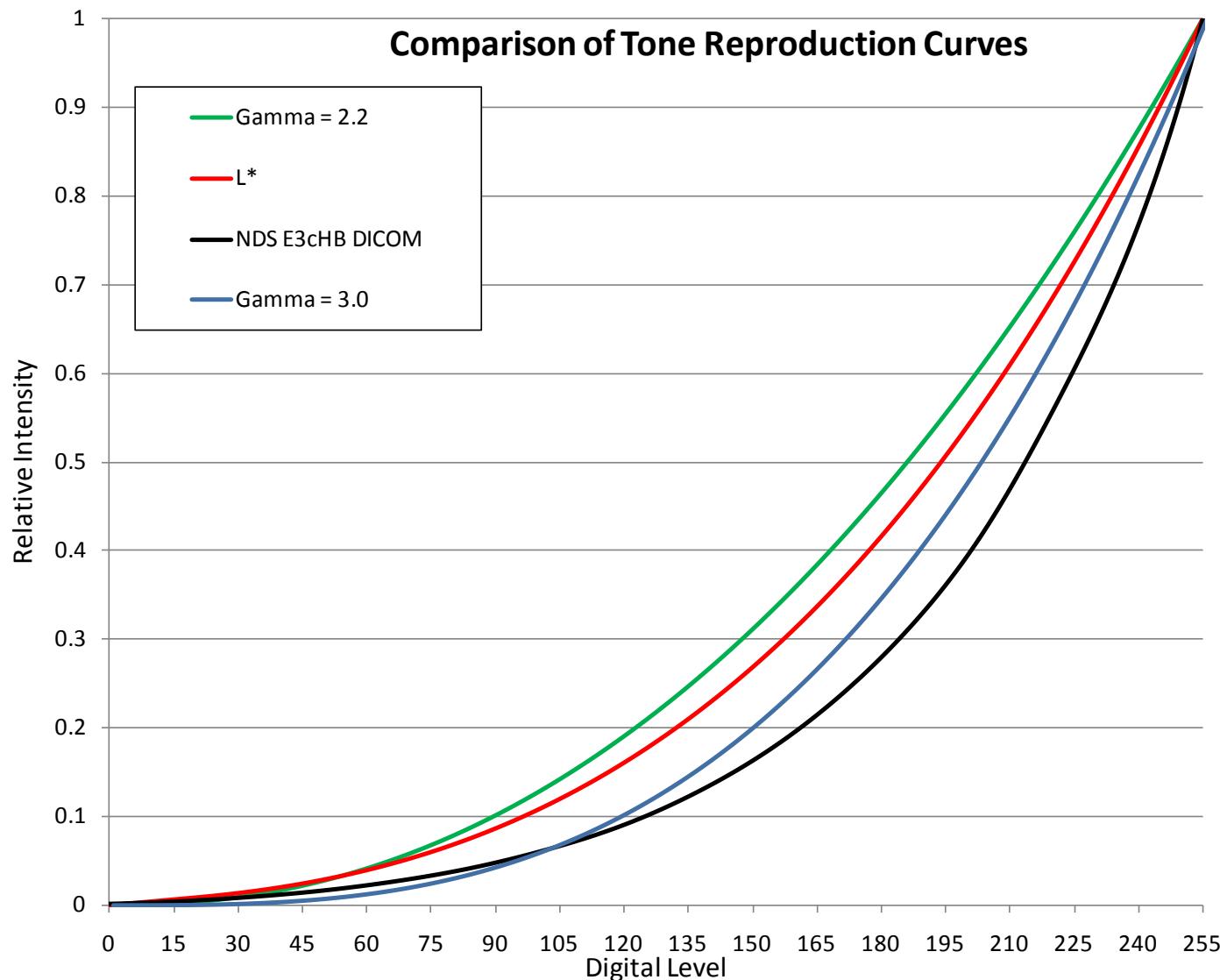


ICC profiles are a bit like DICOM in concept – there are tags and content for each tag. Shown here are the XYZ tristimulus values measured when the monitor was driven to its maximum red, green & blue levels. The plot shows their relationship to sRGB colorspace.





Sample TRC from one of the test displays





Prior Work

A paper was presented at SPIE Medical Imaging Conference (San Diego) -2010. Some of the salient features of this work are discussed in the next three slides.

Color calibration and color-managed medical displays: Does the calibration method matter?

Hans Roehrig¹, Kelly Rehm¹, Louis D. Silverstein³, William J. Dallas¹ Jiahua Fan² Elizabeth A. Krupinski¹

¹Department of Radiology, University of Arizona, Tucson AZ (USA) hans@radiology.arizona.edu

²GE Healthcare, Waukesha, WI (USA), ³VCD Sciences, Inc., Scottsdale, AZ (USA)



- The efficacy of a suite of color calibration and monitor profiling packages has been evaluated.
- A variety of color measurement sensors has been tested.



Spyder3 from
Datacolor

Standard puck (*Eye-
One display 2*) from
X-Rite

Wide gamut puck
adjusted by NEC
(originally from X-Rite)



COLOR JNDs

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L \cdot S_L}\right)^2 + \left(\frac{\Delta C'}{k_C \cdot S_C}\right)^2 + \left(\frac{\Delta H'}{k_H \cdot S_H}\right)^2 + \left(R_T \left(\frac{\Delta C'}{k_C \cdot S_C}\right) \left(\frac{\Delta H'}{k_H \cdot S_H}\right)\right)^2}$$

where

$$L' = L^*$$

$$b' = b^*$$

$$a' = a^*(1+G)$$

$$C^* = \sqrt{(a')^2 + (b')^2}$$

$$h = \tan^{-1} \left(\frac{b^*}{a^*} \right)$$

$$G = 0.5 \sqrt{1 - \left(\frac{C_{ab}^*}{C_{ab}^* + 25^7} \right)^7}$$

$$S_L = 1 + \frac{0.015 (\bar{L}' - 50)^2}{\sqrt{20 + (\bar{L}' - 50)^2}}$$

$$S_C = 1 + 0.045 \bar{C}$$

$$S_H = 1 + 0.015 \bar{C} T$$

$$T = 1 - 0.17 \cos(h' - 30) + 0.24 \cos(2h') + 0.32 \cos(3h' + 6) - 0.20 \cos(4h' - 63)$$

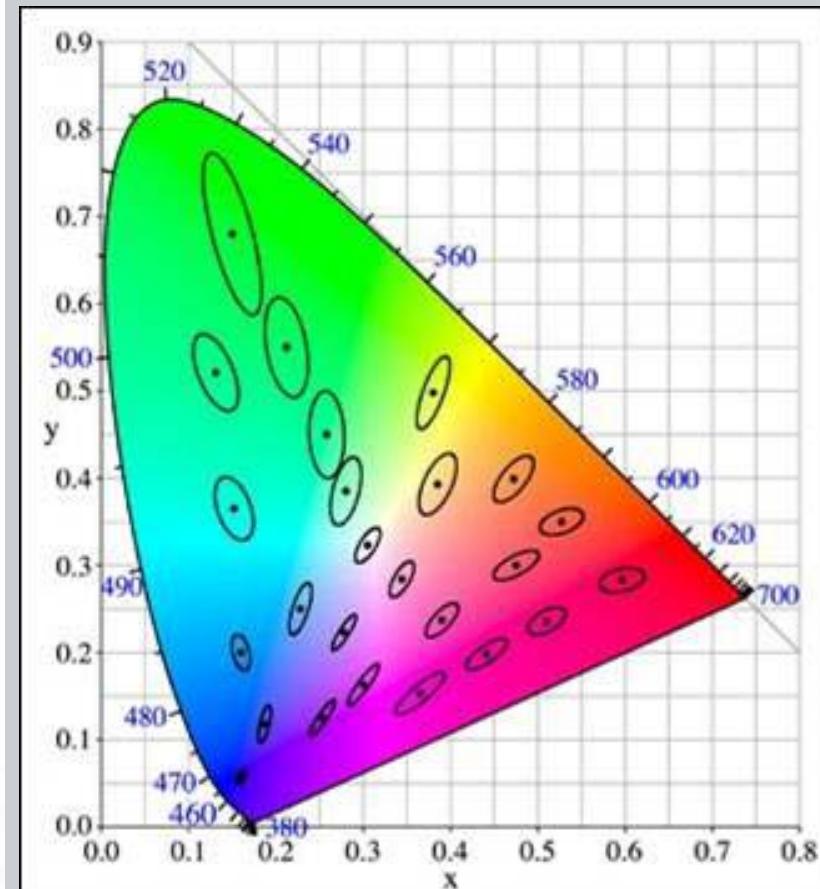
$$R_T = -\sin(2\Delta\theta) R_C$$

$$\Delta\theta = 30 \exp \left(-\left(\frac{h' - 275}{25} \right)^2 \right)$$

$$R_C = 2 \sqrt{\frac{C^7}{C^7 + 25^7}}$$

CIE DE2000 ΔE Formula

MacAdam Ellipses,
equivalent in color to
DICOM JNDs





SOME RESULTS

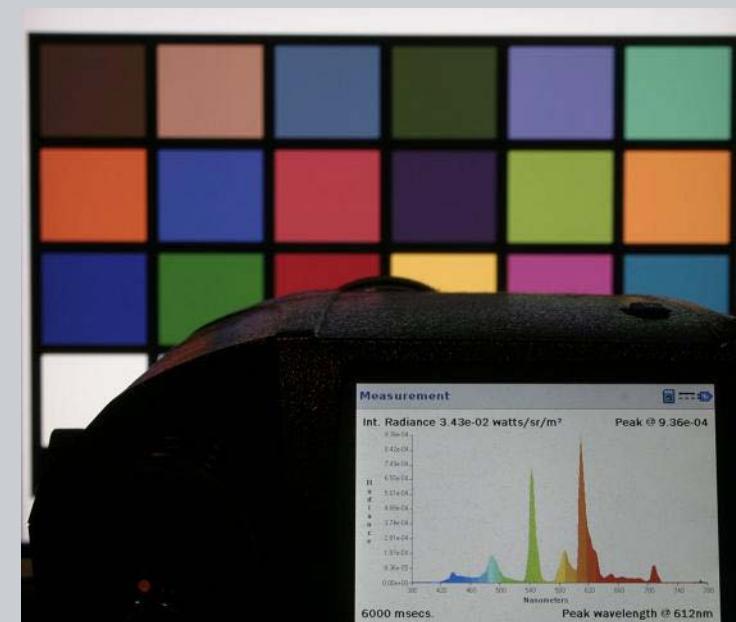
CIE DE2000 ΔE values; comparison of intended sRGB color values with results from SpectraView II software using three different measurement colorimeters (“Pucks”) calibrated to the L*D65 target.

Comparison	Greys	Primaries	ColorChecker	All
Wide gamut X-rite Puck	5.27	4.49	3.33	3.86
Standard X-rite Puck	3.86	4.21	2.77	3.16
Spyder3 Puck	3.44	3.67	2.13	2.58

Pucks do make a noticeable difference..



The issue of calibration and profiling that can simultaneously achieve both a DICOM tone reproduction curve and good color rendition must be addressed. Our concern is also with the accuracy of calibration with the “Pucks”. The result of this study is an indication that calibration with Pucks has to be treated carefully and which is why we are using a Spectro-Photometer as shown below for our calibration.





Questions?

