PHYSICALLY-BASED CALIBRATION

ACCURATE MATERIAL PRODUCTION IN FORZA HORIZON 4

VIDEO - Forza Horizon 4 Intro

PHYSICALLY-BASED CALIBRATION

ACCURATE MATERIAL PRODUCTION IN FORZA HORIZON 4

FORZA HORIZON 4

Playground Games

TURN 10

XBOX GAME STUDIOS

GDC


OLD
(Hand-Tuned)
NEW
(Physically-Calibrated)
Manufacturer Paint: "Viridian Green Metallic" by Aston Martin™

FORZA HORIZON 4

YIBO LIU

SENIOR TECHNICAL ARTIST | PLAYGROUND GAMES

Playground Games

XBOX GAME STUDIOS

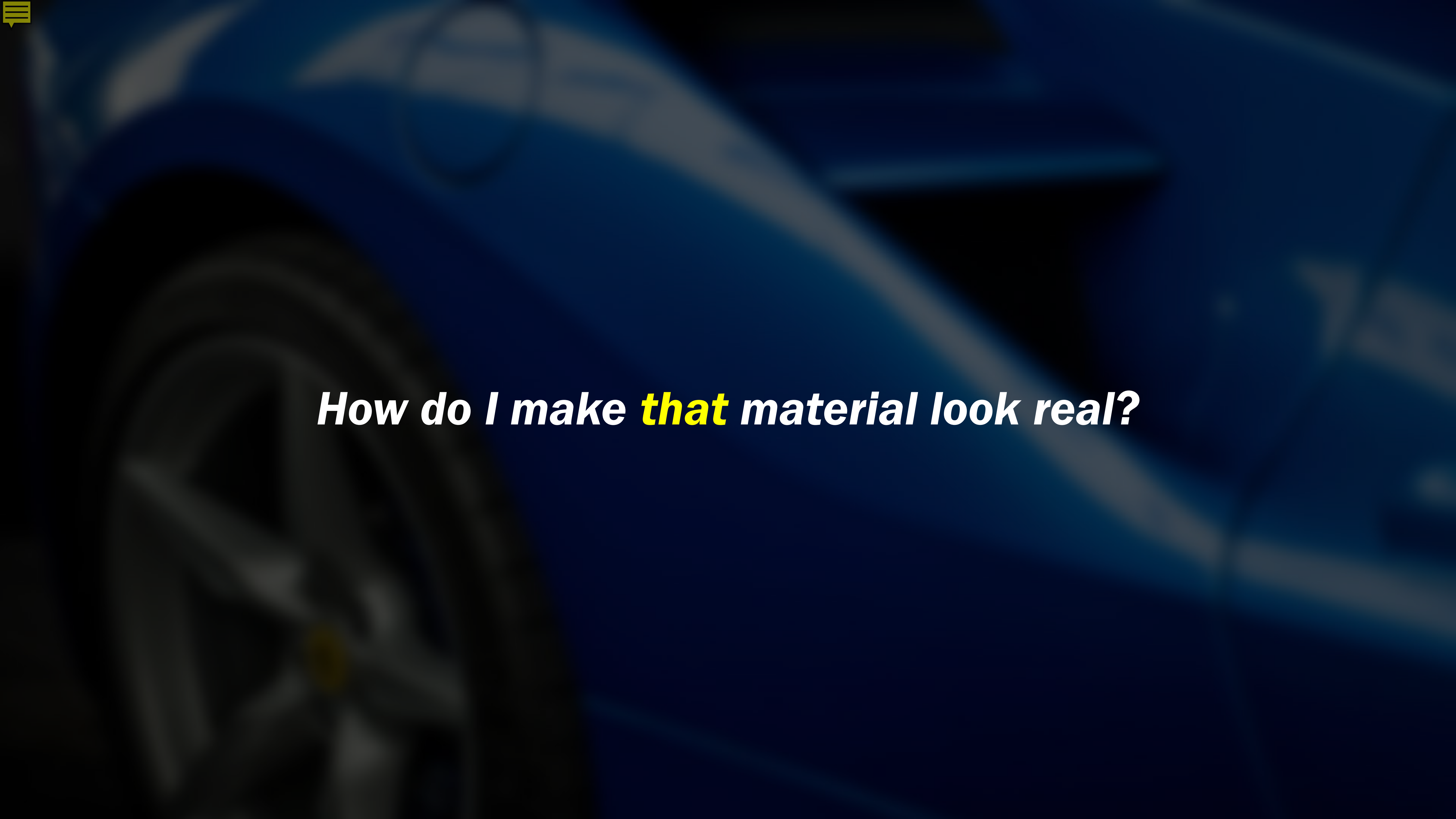
PLAYGROUND GAMES

Playground Games

XBOX
GAME STUDIOS


FORZA
HORIZON 4
HORIZON
FORZA HORIZON 4
Xbox One & Windows 10 PC
Playground Games
TURN 10
XBOX
GAME STUDIOS

How do I make that material look real?


How do I make that material look real?

Dev: *"My system can render a wide variety of horses."*

Gamer: *"But what I want is **that** special horse from LOTR."*

Dev: *"My system can render a wide range of cars."*

Gamer: *"But what I want is **that** special car in BMW's Space Grey Metallic paint."*

'The Dress'

Went viral in 2015

1) Blue and Black (57%*)
2) White and Gold (30%)
3) Blue and Brown (11%)
4) Something else (2%)

What is Real ≠ What is Perceived as Real

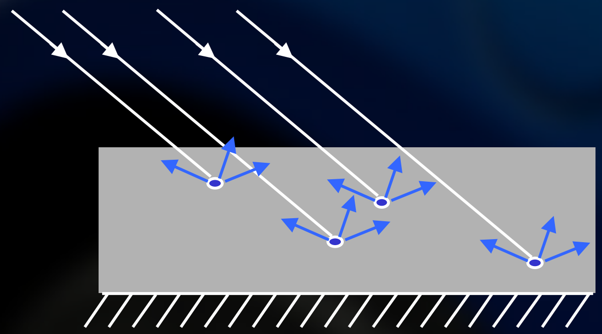
*Source: *Striking individual differences in color perception uncovered by 'the dress' photograph*. Current Biology, volume 25, issue 13, 2015

“The Calibration Problem”

Automotive Paint

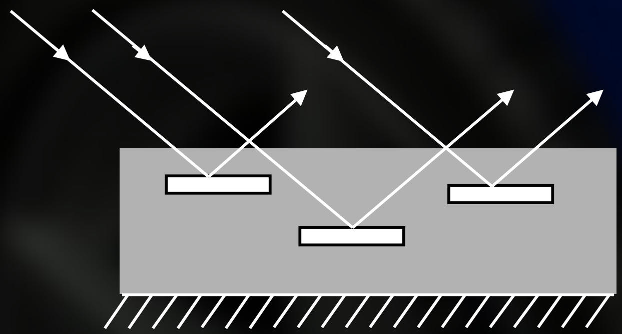
Automotive Paint is 'Gonioapparent'

Automotive Paint is 'Gonioapparent'



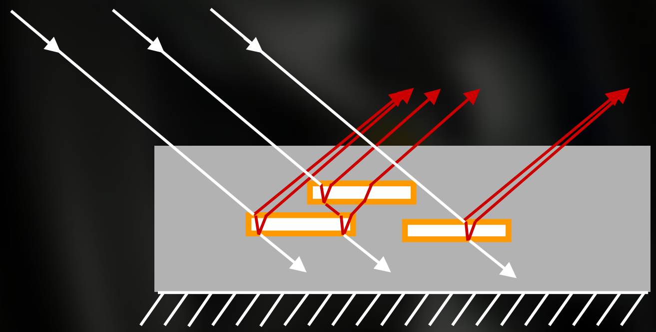
Absorption Pigments

Specific Colour –
Due to selective **absorption** and scattering of light



Metallic Pigments

Metallic Gloss –
Due to mirror-like **reflection** of light



Pearl Luster Pigments

Specific Colour, Luster and Colour Flop -
Due to **interference** of light

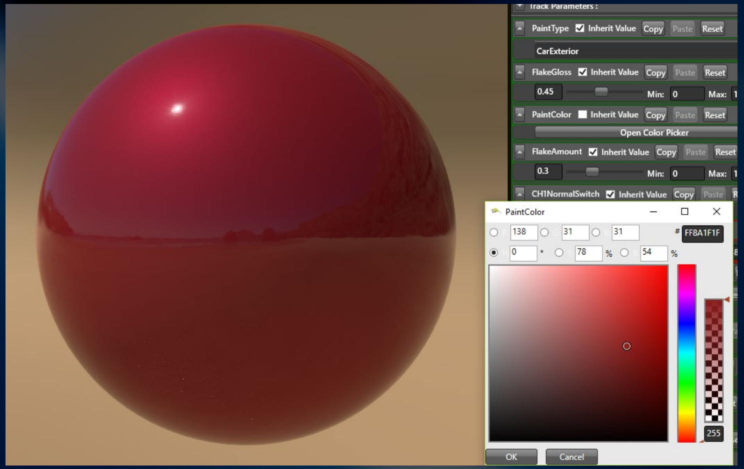
Courtesy of MERCK

Many Biases in Traditional Workflow

REFERENCE

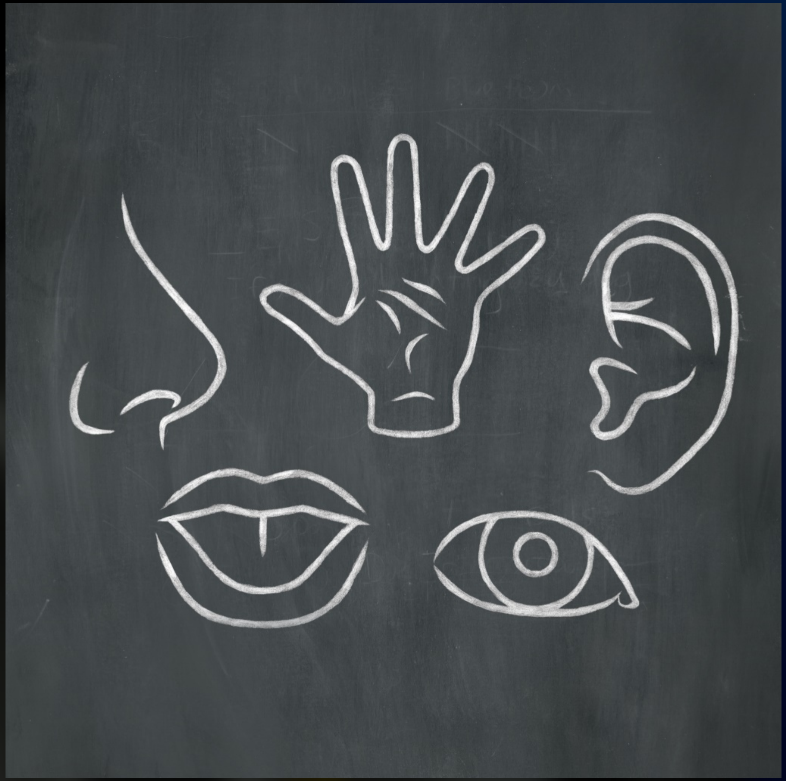
- Photographs Only
- Unknown/Uncontrolled Factors
  - Lighting Conditions
  - Reflected Environment
  - Camera Settings
  - Image Editing

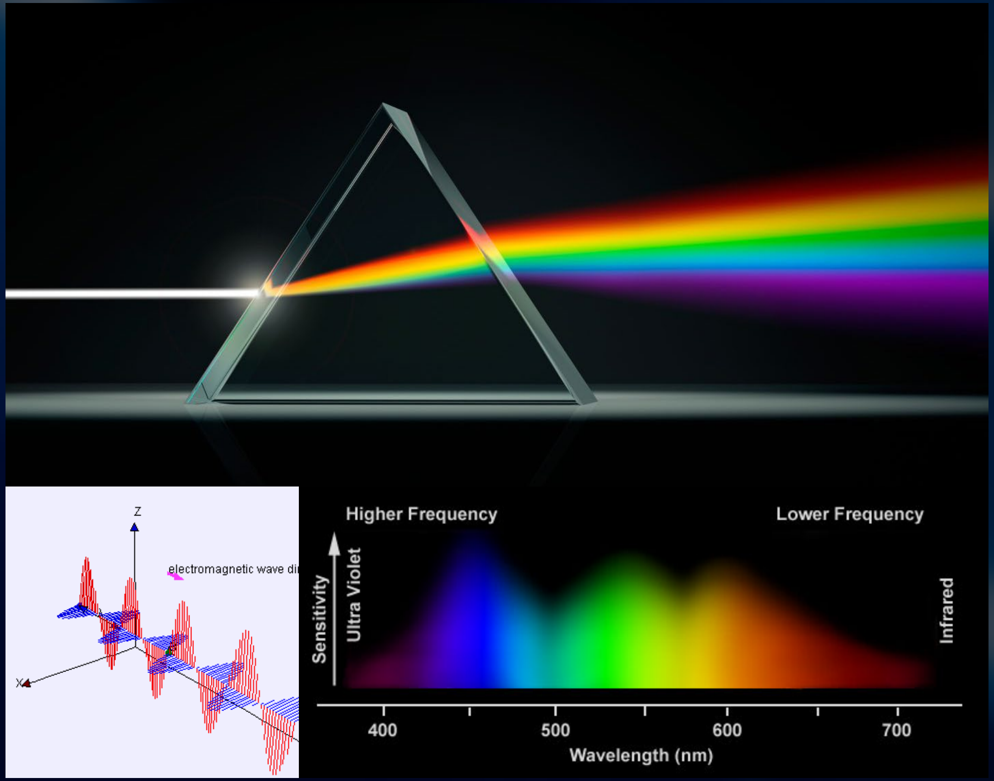
TUNING



- Based on 'Feelings'
- Difficult to Match Scientifically
  - Monitor Conditions
  - Reflected Environment
  - Rendering Configurations
  - Viewing Conditions

Perceptually Based → Physically Based





Colour Management in the Automotive Industry

BYK-mac i

Total color impression of effect finishes

The appearance of effect finishes is influenced by different viewing angles and viewing conditions. Apart from a light-dark flop and color shift special sparkling effects can be created. The BYK-mac i spectrophotometer is unique as it measures both multi-angle color and flake characterization in one portable device.

- Traditional 5-angle color measurement: 15° / 25° / 45° / 75° / 110°
- Additional color measurement behind the gloss for color travel of interference pigments: -15°
- Sparkle and graininess measurement for flake characterization

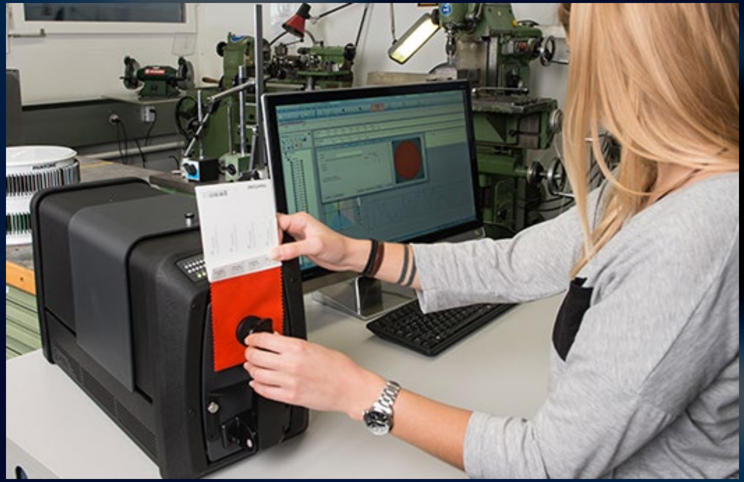
Source: BYK Additives & Instruments GmbH

- **Spectrophotometer**
- **NOT a camera**
- **Built-in D65 Light Source**
- **Multi-Angle Sensors**
- **For Quality Control Purposes**
- **ASTM International Standards**

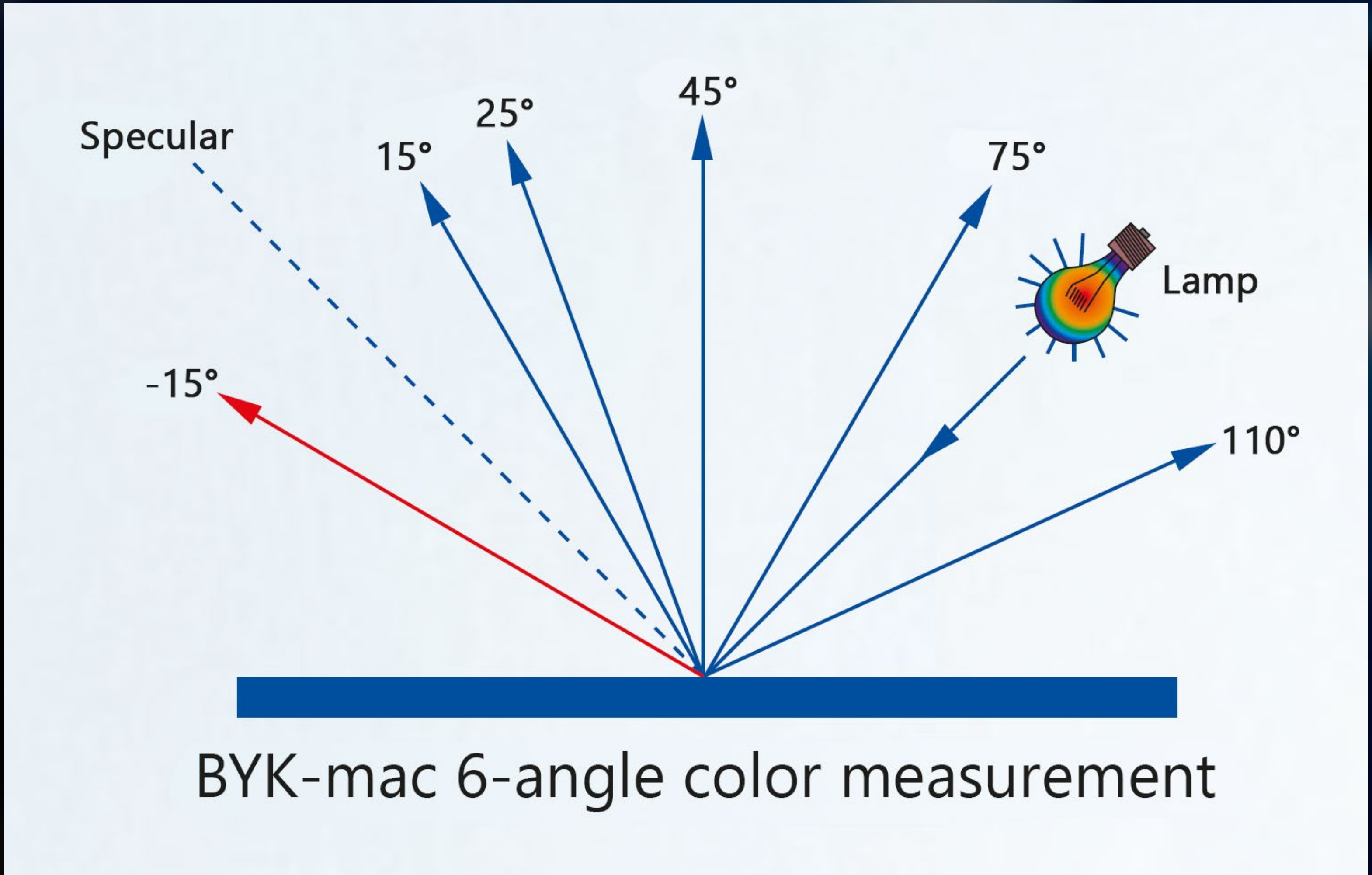
ASTM INTERNATIONAL

Colour Management in the Automotive Industry

Other Applications

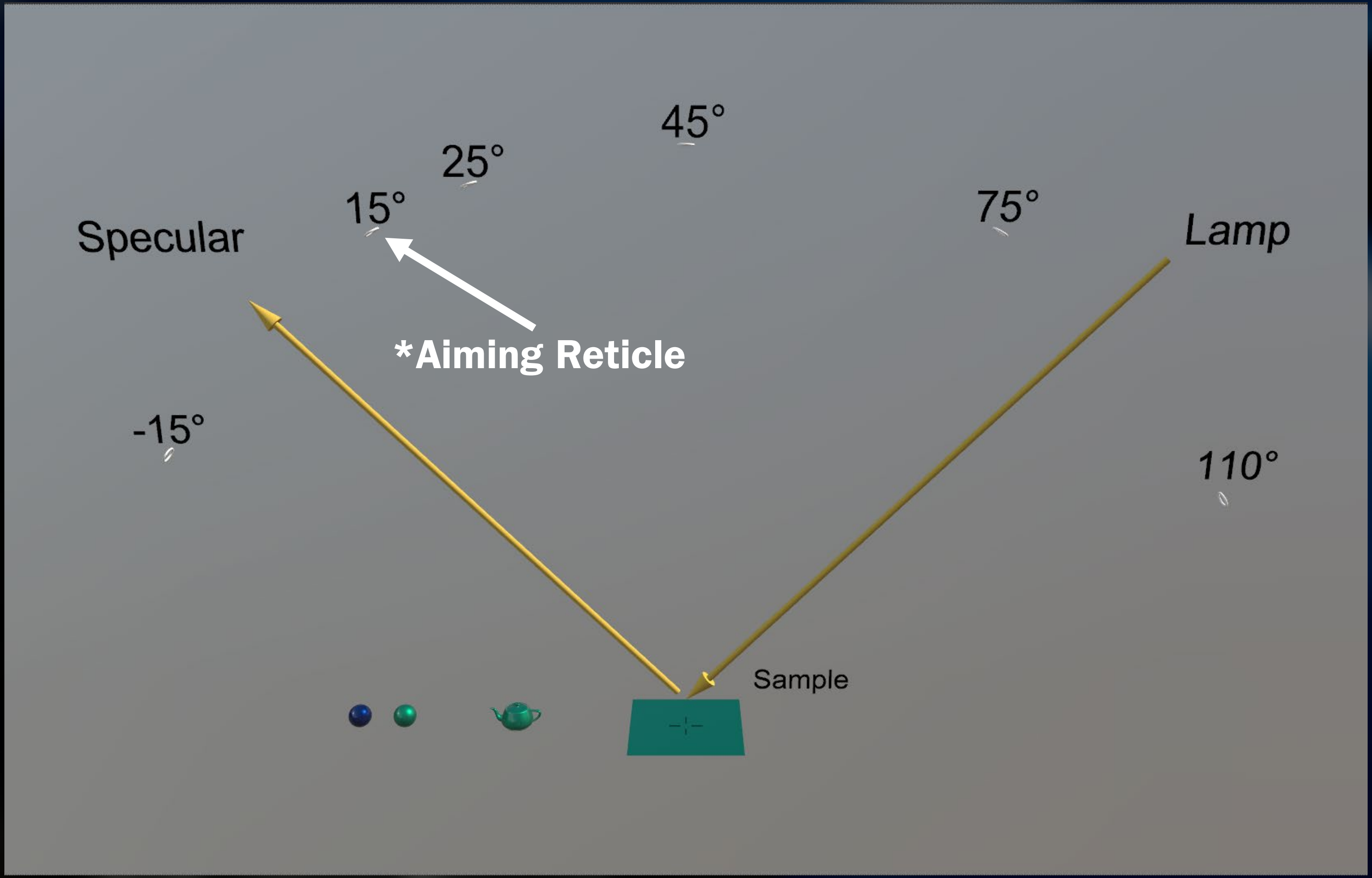


Multi-Angle Measurement – In Reality

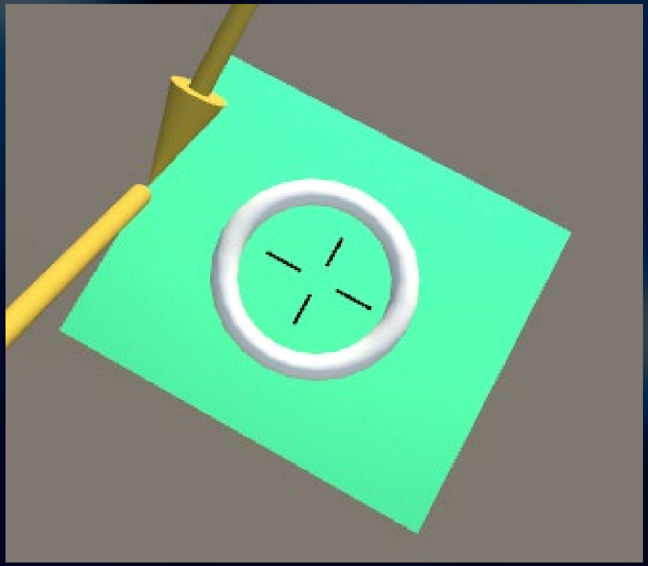


Source: BYK Additives & Instruments GmbH

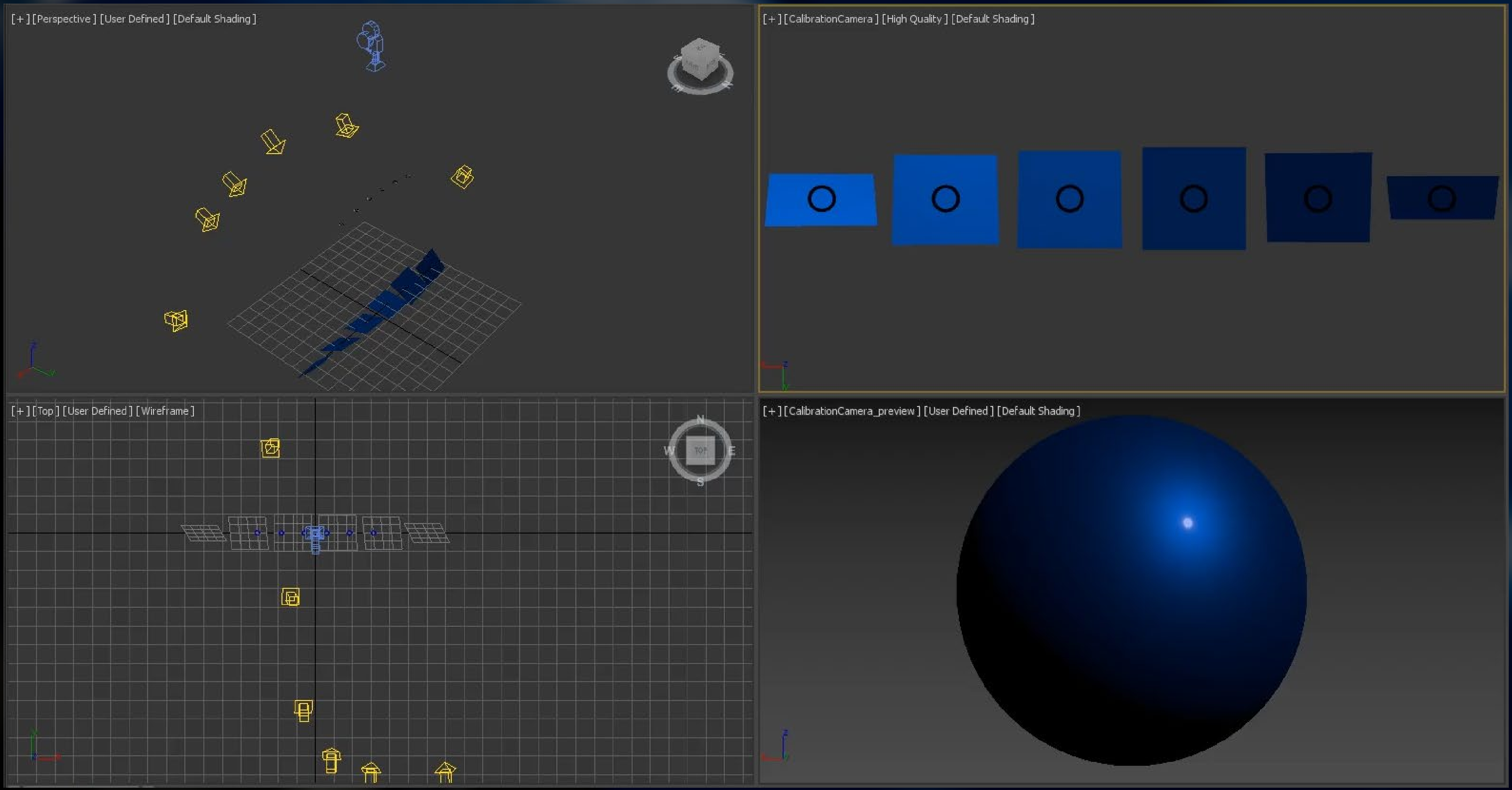
Multi-Angle Measurement – In Game



- **Early Game Material Measurement Test**

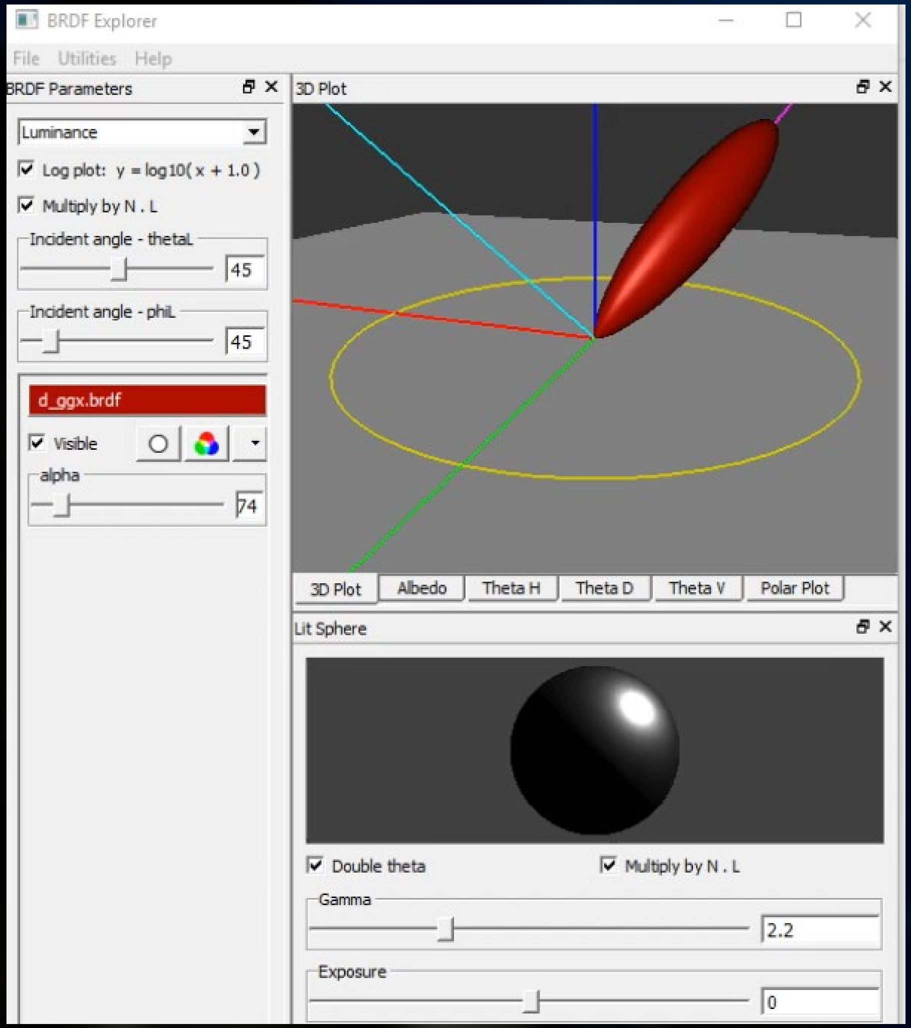


Multi-Angle Measurement – In Game (3Ds Max)



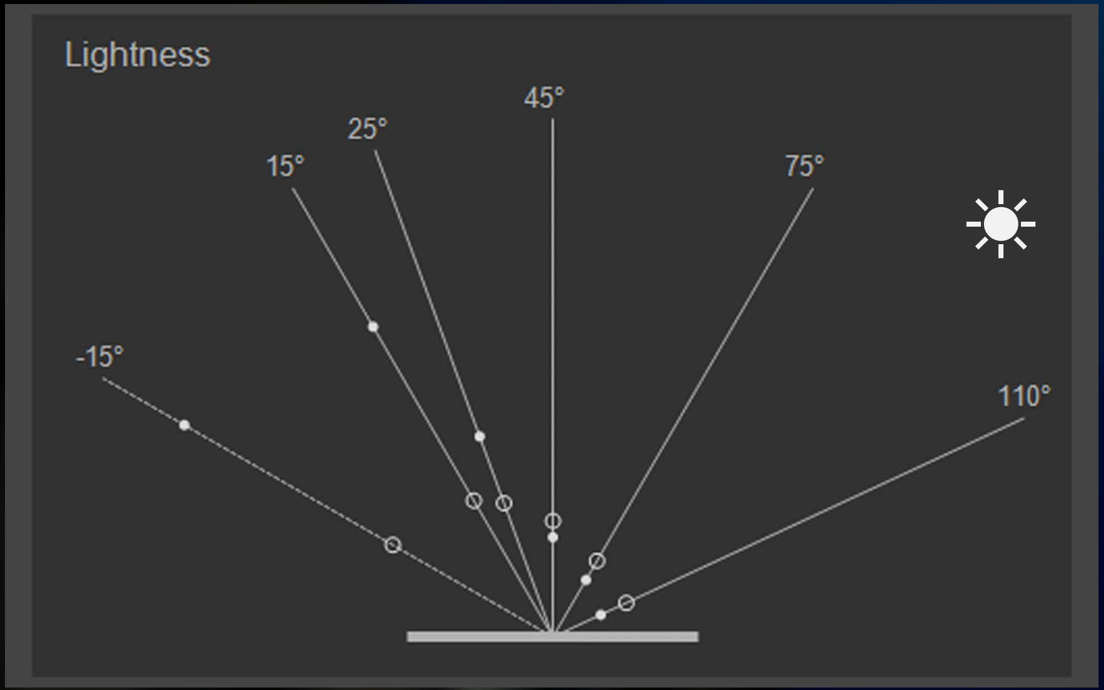
Inspiration - Visualising BRDF

GGX Shading Model Visualisation



Bidirectional Reflectance Distribution Function

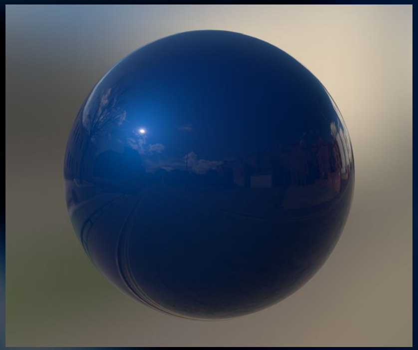
It’s All About the Reflectance Distribution



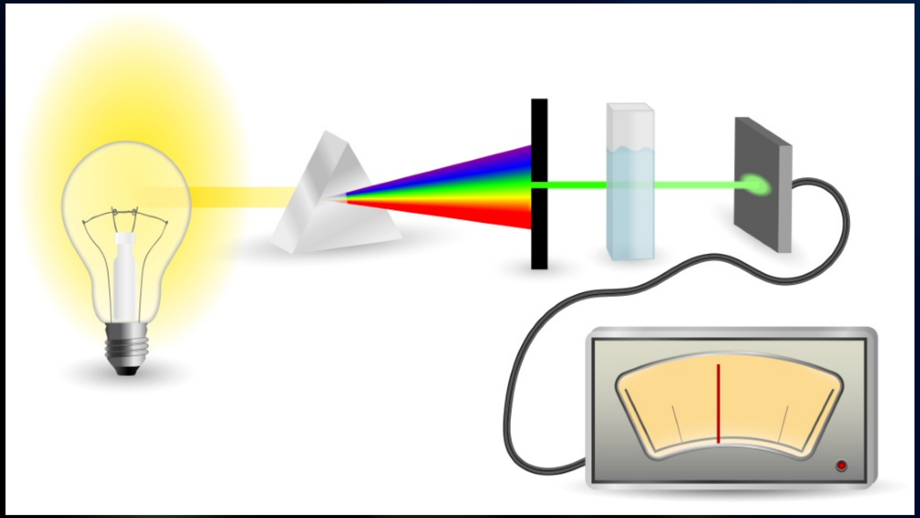
- **Physical** Measurements
- **Game** Measurements

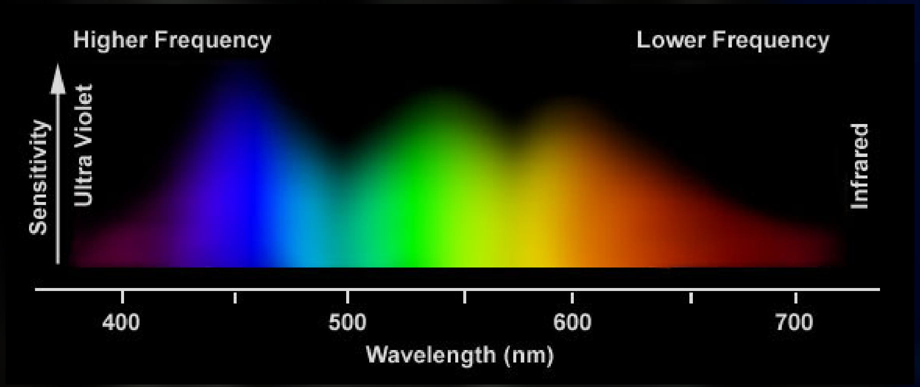
Match the Reflectance Distribution, and you match the material

Apple-to-Apple Comparison – Quantitative Colour Analysis



Spectrophotometry





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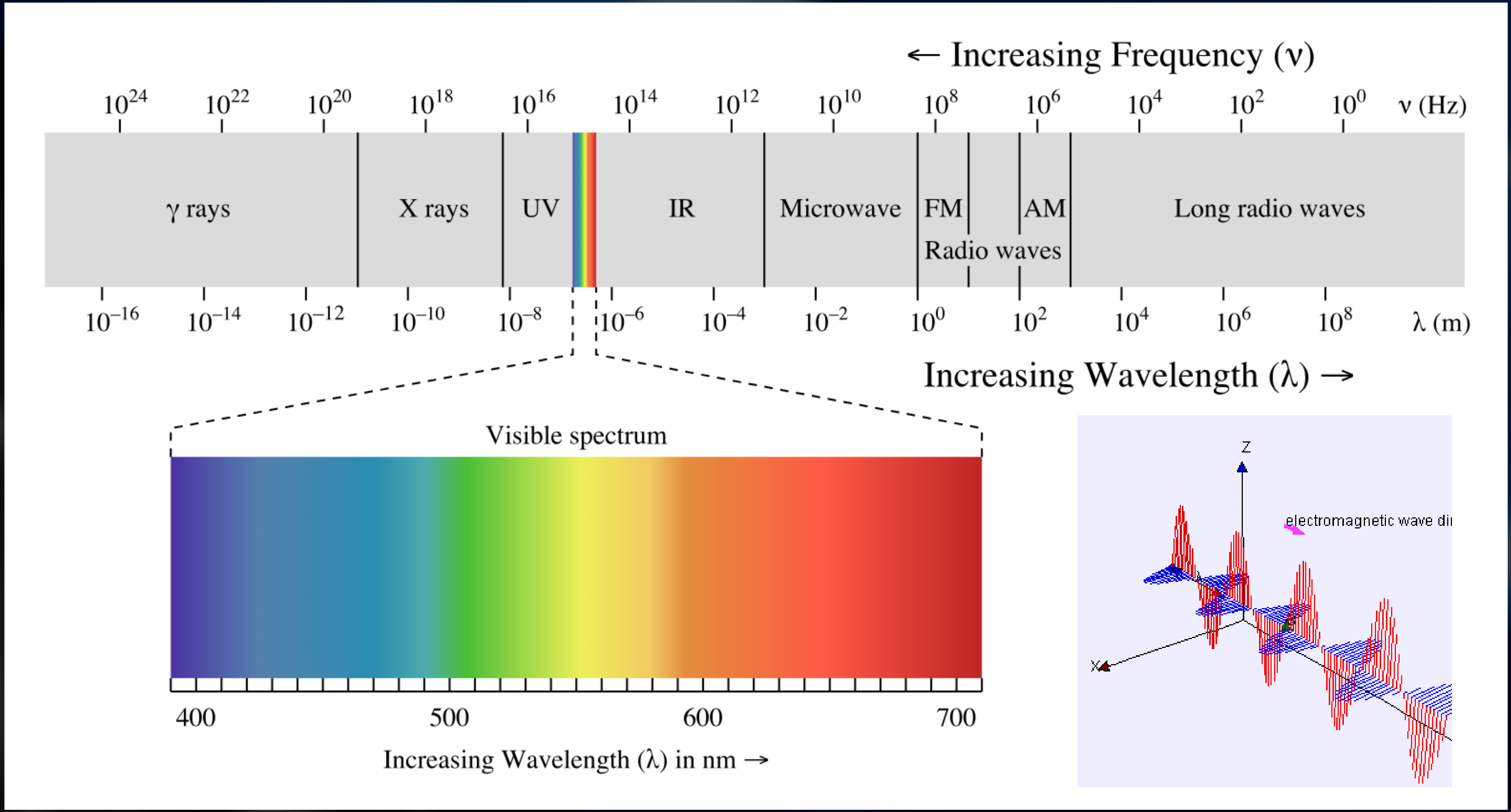
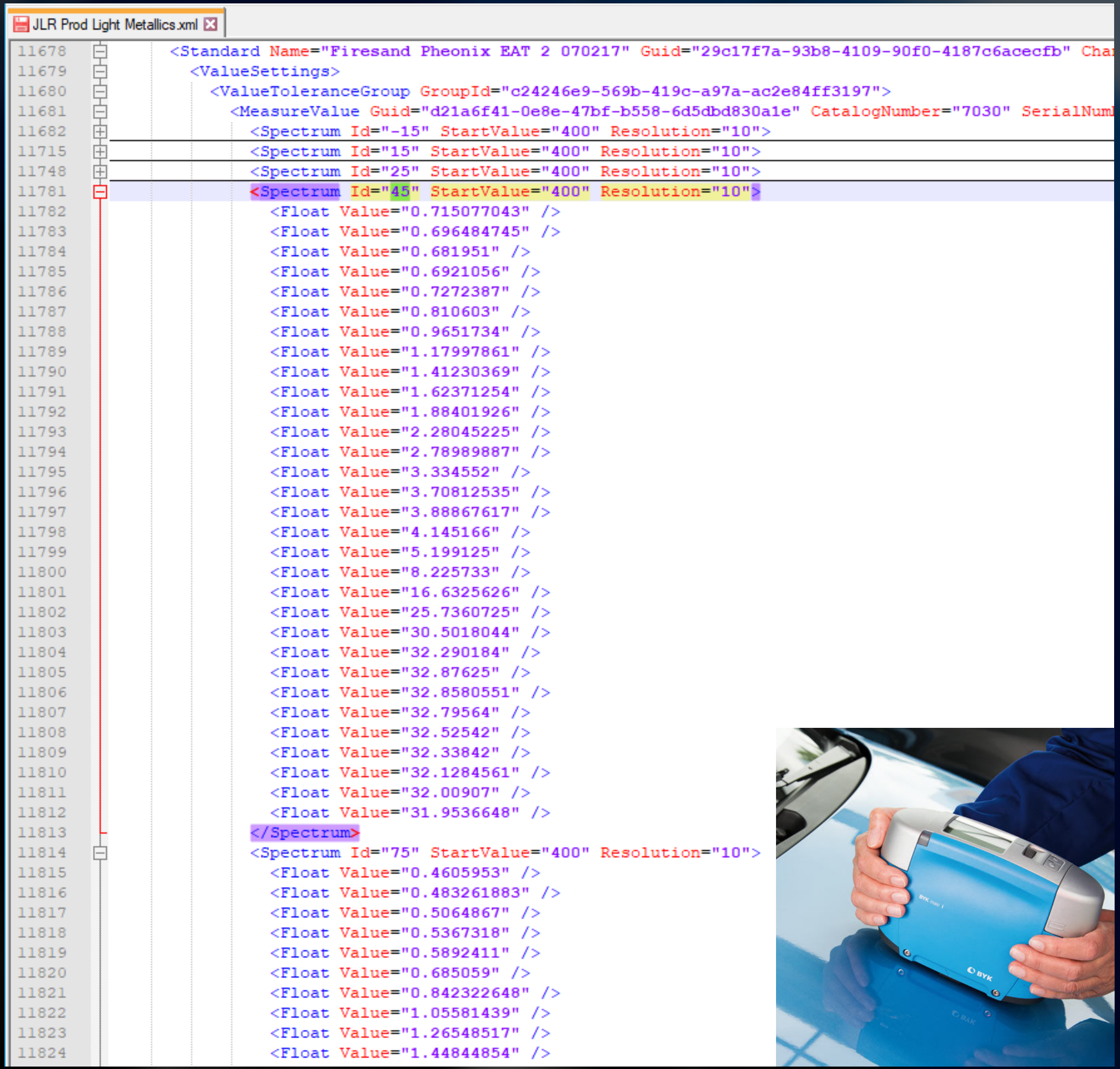


“Digital Masters”

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“Digital Masters” XML

Spectral Power Distribution (SPD)

JLR Prod Light Metallics.xml


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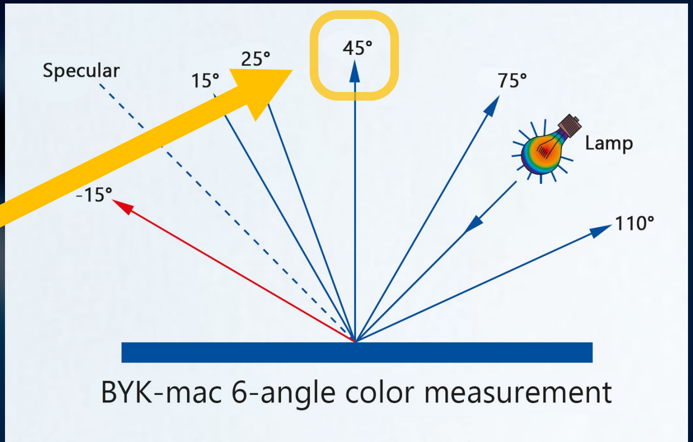
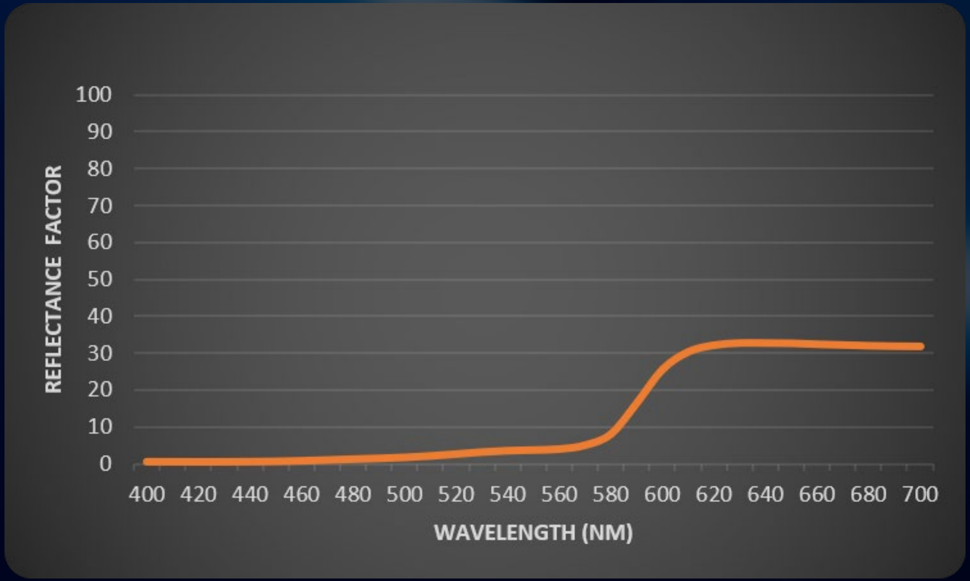
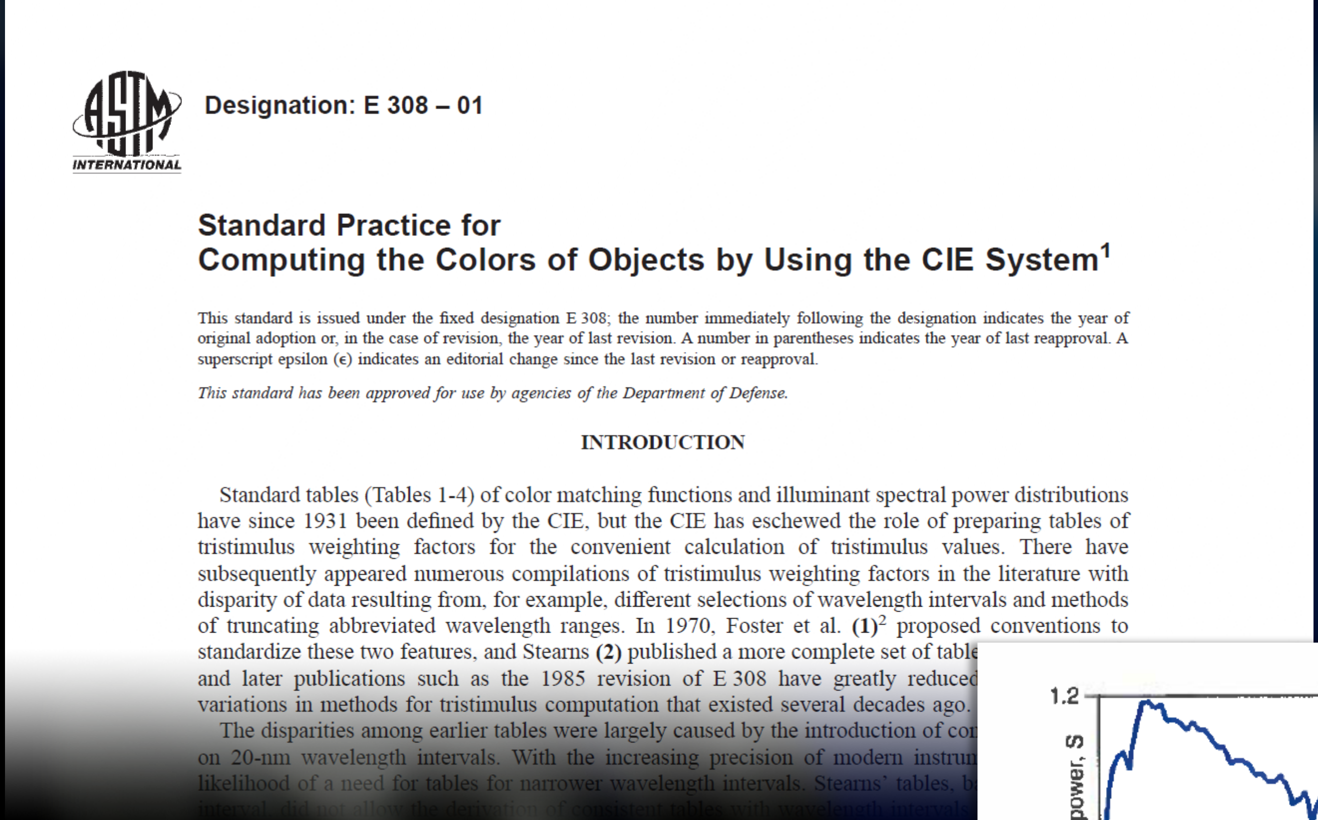
One SPD for One Angle





ASTM E 308 Standard



Designation: E 308 – 01

INTERNATIONAL

Standard Practice for
Computing the Colors of Objects by Using the CIE System[1]

This standard is issued under the fixed designation E 308; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

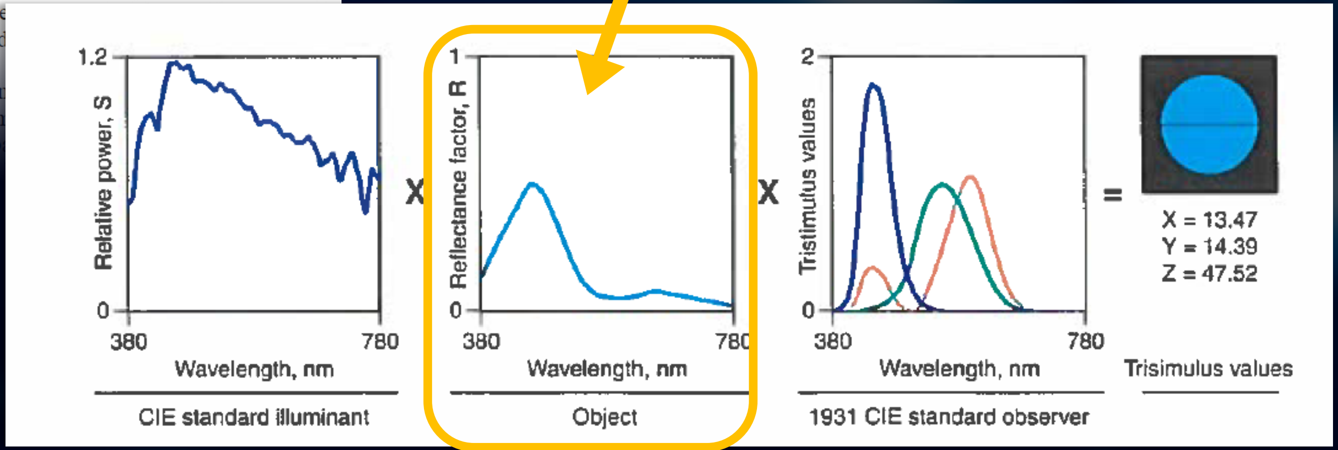
INTRODUCTION

Standard tables (Tables 1-4) of color matching functions and illuminant spectral power distributions have since 1931 been defined by the CIE, but the CIE has eschewed the role of preparing tables of tristimulus weighting factors for the convenient calculation of tristimulus values. There have subsequently appeared numerous compilations of tristimulus weighting factors in the literature with disparity of data resulting from, for example, different selections of wavelength intervals and methods of truncating abbreviated wavelength ranges. In 1970, Foster et al. **(1)**[2] proposed conventions to standardize these two features, and Stearns **(2)** published a more complete set of table and later publications such as the 1985 revision of E 308 have greatly reduced variations in methods for tristimulus computation that existed several decades ago.

The disparities among earlier tables were largely caused by the introduction of co on 20-nm wavelength intervals. With the increasing precision of modern instrum likelihood of a need for tables for narrower wavelength intervals. Stearns' tables, b

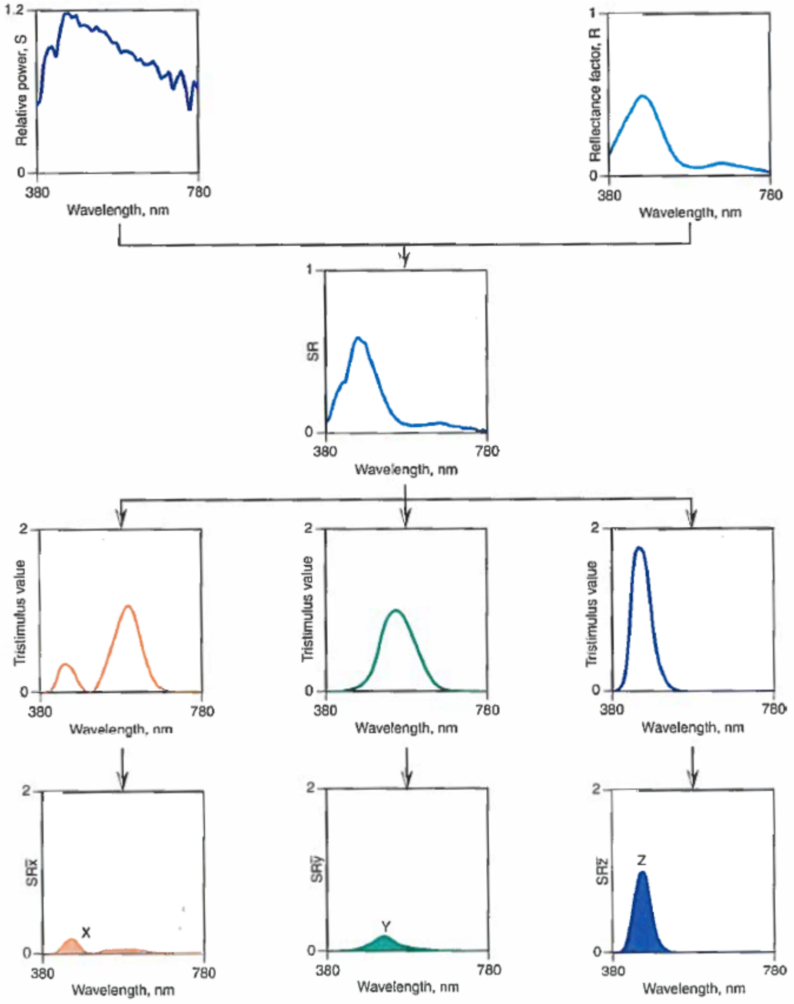
- **From Spectral Power Distribution (SPD) to Colour Information**
- **SPD → XYZ**

SPD Data from “Digital Masters” XML



Source: *Billmeyer and Saltzman's principles of color technology*

From SPD to XYZ Colour



In a little more detail than in the figure on page 56, here are all the spectral curves needed to calculate CIE tristimulus values *X*, *Y*, and *Z*. Wavelength by wavelength, the values of the curves of *S* and *R* are multiplied together to give the curve, *SR*. Then this curve is multiplied, in turn, by $\bar{x}$, by $\bar{y}$, and by $\bar{z}$, to obtain the curves $SR\bar{x}$, $SR\bar{y}$, and $SR\bar{z}$. The areas under these curves, followed by a normalization, are the tristimulus values *X*, *Y*, and *Z*.

Source: ***Billmeyer and Saltzman's principles of color technology***

- **Integrating a continuous spectrum into merely 3 numbers (Tristimulus Integration)**
- **International Commission on Illumination (CIE)**
- **CIE 1931 XYZ Colour Space**

X = $\int$ % reflectance * illuminant factor * x factor of standard observer

Y = $\int$ % reflectance * illuminant factor * y factor of standard observer

Z = $\int$ % reflectance * illuminant factor * z factor of standard observer

Merged as W

From SPD to XYZ Colour

Calculating tristimulus values using the ASTM E308 method:

$$X = \sum_{\lambda} R_{\lambda} W_{x}$$

$$Y = \sum_{\lambda} R_{\lambda} W_{y}$$

$$Z = \sum_{\lambda} R_{\lambda} W_{z}$$

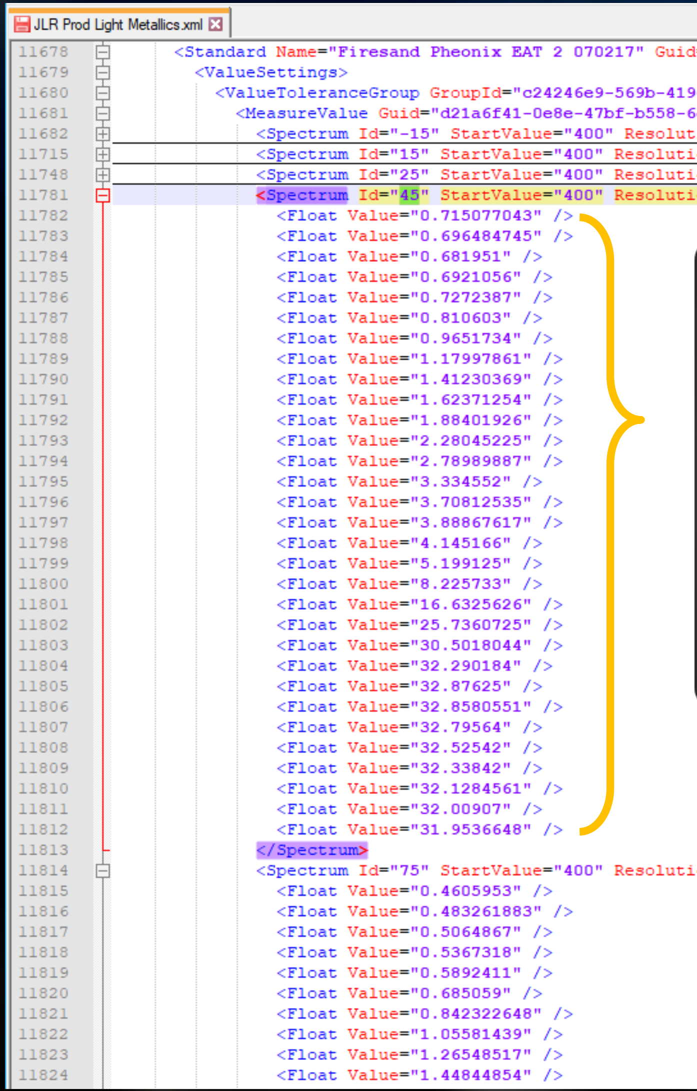
- R_{λ} **is Reflectance as a function of wavelength**
- W_{n} **is the tristimulus weights for the human eye under controlled D65 illuminant defined by ASTM E308 standard (shown on the right)**

E 308

Table 5.17 Illuminant D65, 1931 Observer 10 nm Interval

nm	W_x	W_y	W_z
360	0.000	0.000	0.001
370	0.002	0.000	0.010
380	0.006	0.000	0.026
390	0.022	0.001	0.104
400	0.101	0.003	0.477
410	0.376	0.010	1.788
420	1.200	0.035	5.765
430	2.396	0.098	11.698
440	3.418	0.226	17.150
450	3.699	0.417	19.506
460	3.227	0.664	18.520
470	2.149	0.998	14.137
480	1.042	1.501	8.850
490	0.333	2.164	4.856
500	0.045	3.352	2.802
510	0.098	5.129	1.602
520	0.637	7.076	0.791
530	1.667	8.708	0.420
540	2.884	9.474	0.202
550	4.250	9.752	0.086
560	5.626	9.419	0.037
570	6.988	8.722	0.019
580	8.214	7.802	0.014
590	8.730	6.442	0.010
600	9.015	5.351	0.007
610	8.492	4.263	0.003
620	7.050	3.145	0.001
630	5.124	2.113	0.000
640	3.516	1.373	0.000
650	2.167	0.818	0.000
660	1.252	0.463	0.000
670	0.678	0.248	0.000
680	0.341	0.124	0.000
690	0.153	0.055	0.000
700	0.076	0.027	0.000
710	0.040	0.014	0.000

From SPD to XYZ Colour



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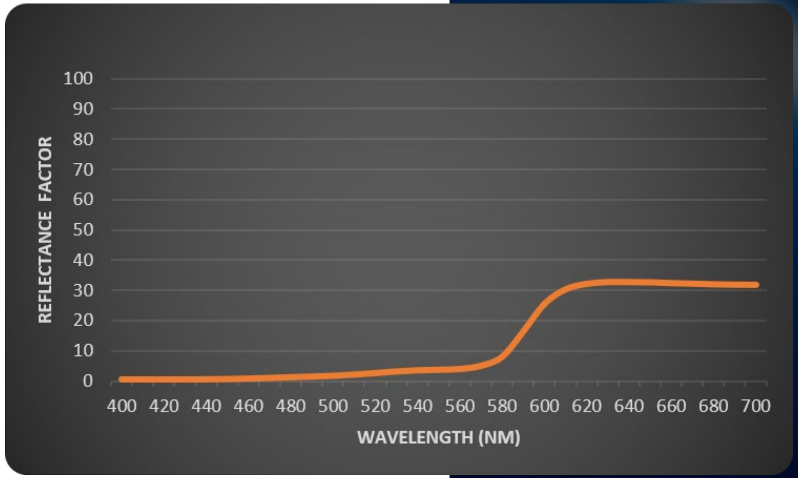
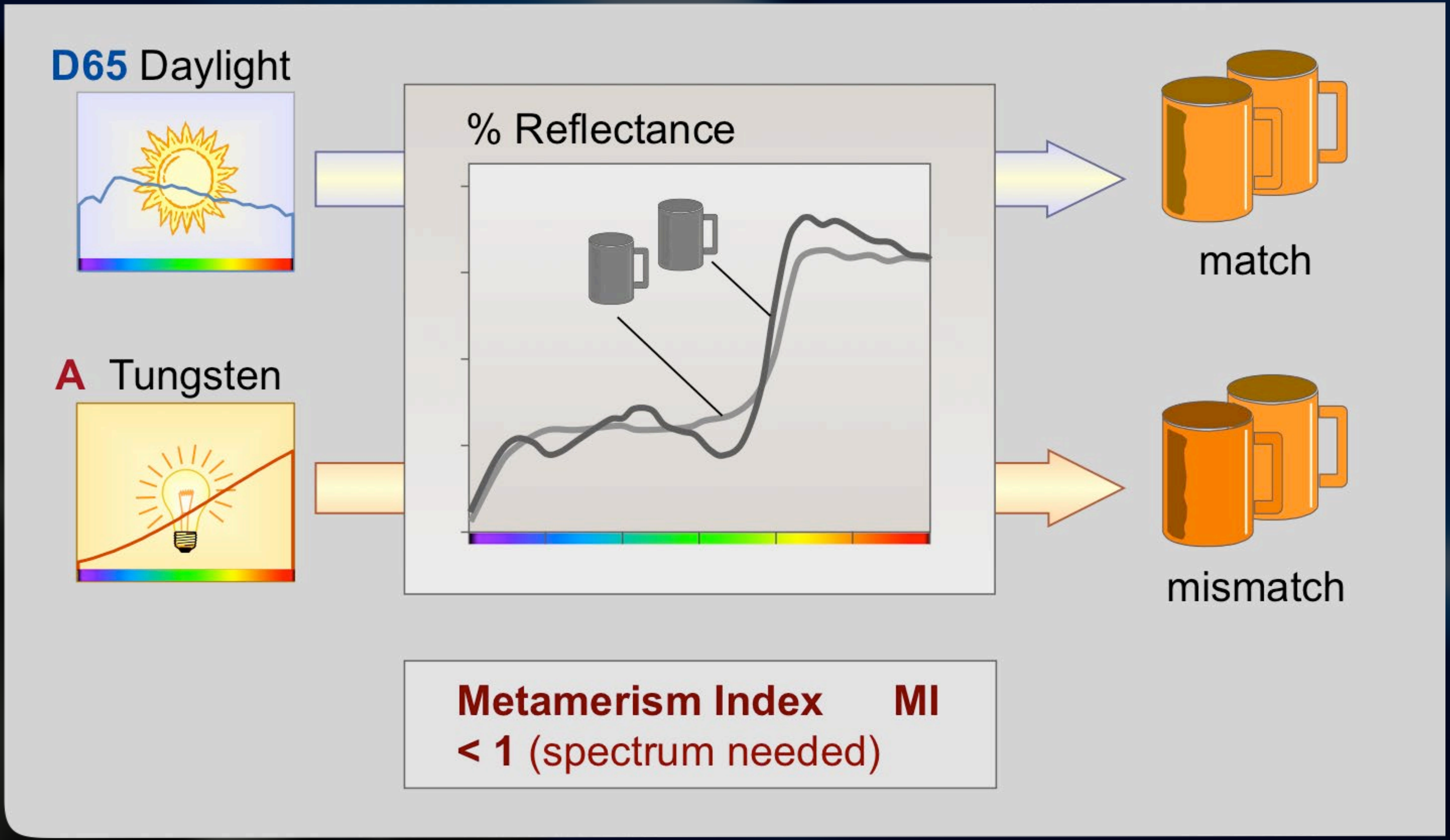


XYZ Colour
[14.80, 9.45, 1.11]

- **Side note – this is a lossy conversion (lookup *Metamerism* for details)**

Metamerism



Source: BYK Additives & Instruments GmbH

From XYZ to Lab

Reference white point for CIE 1931 observer (D65 2°):

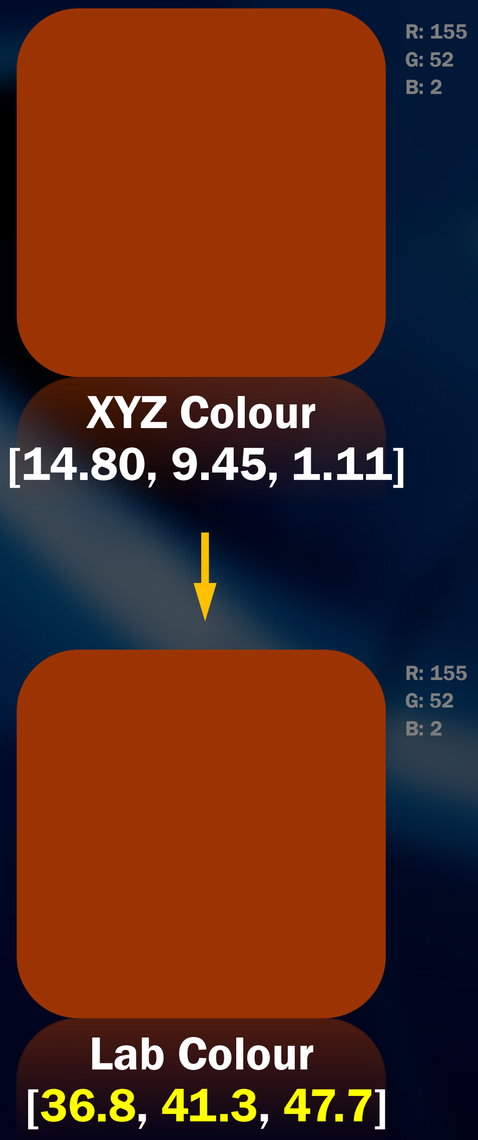
$$X_n = 95.047$$
$$Y_n = 100.0$$
$$Z_n = 108.883$$

$$L^* = 166\left[f\left(\frac{Y}{Y_n}\right) - \frac{16}{116}\right]$$

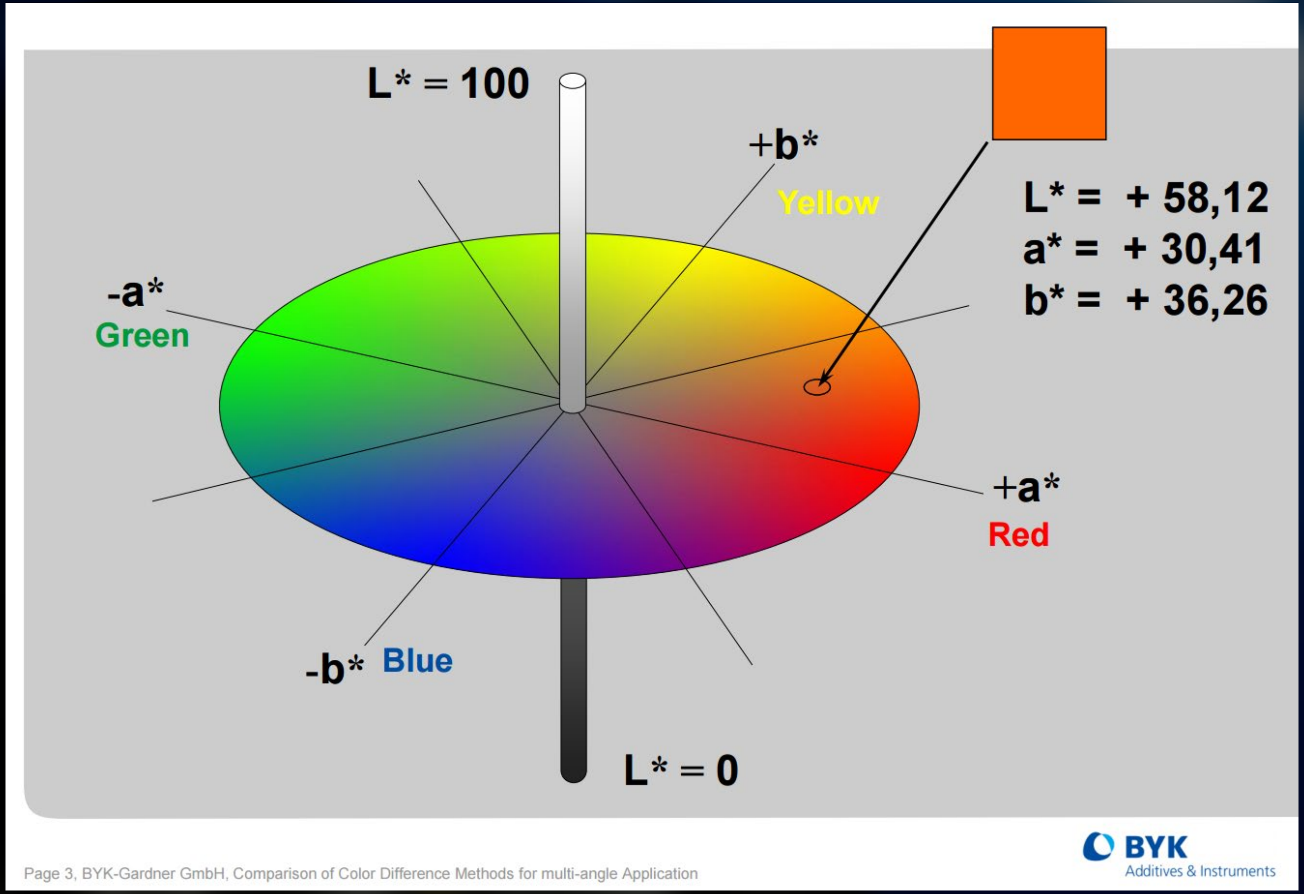
$$a^* = 500\left[f\left(\frac{X}{X_n}\right) - f\left(\frac{Y}{Y_n}\right)\right]$$

$$b^* = 200\left[f\left(\frac{Y}{Y_n}\right) - f\left(\frac{Z}{Z_n}\right)\right]$$

$$f(\mathrm{t}) = \begin{cases} \sqrt[3]{t} & \text{if t} < 0.008856 \\ 7.787t + \frac{16}{116} & \text{otherwise} \end{cases}$$



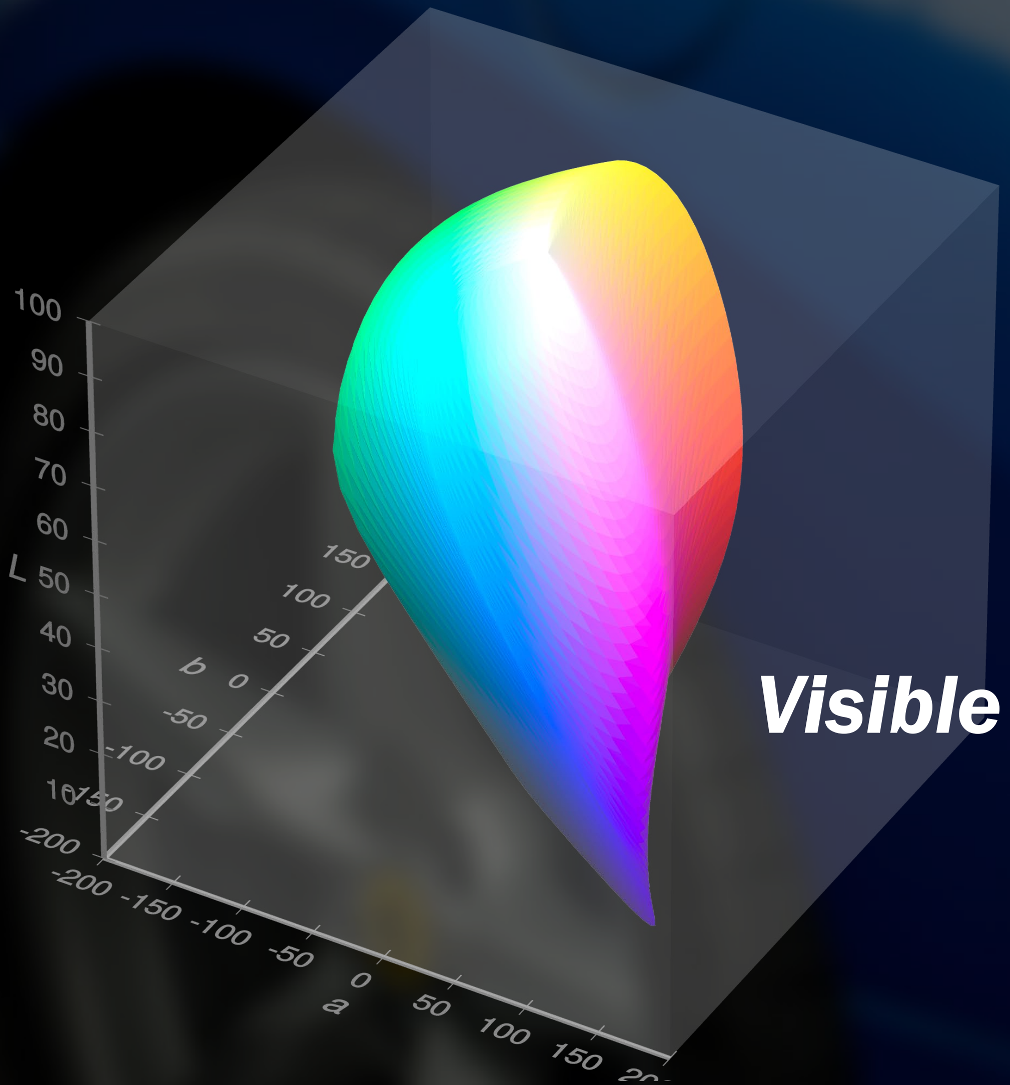
Lab (CIELAB) Colour Space

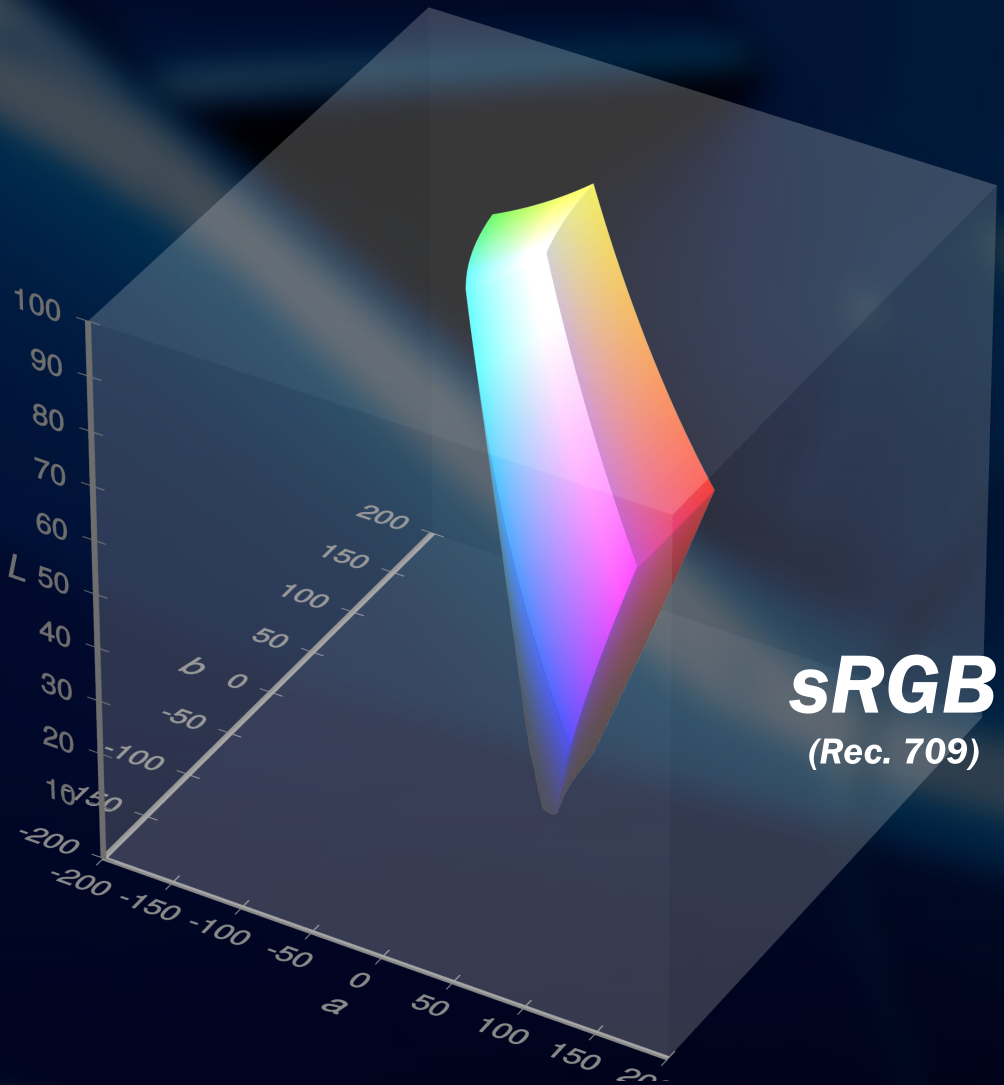


Source: BYK Additives & Instruments GmbH

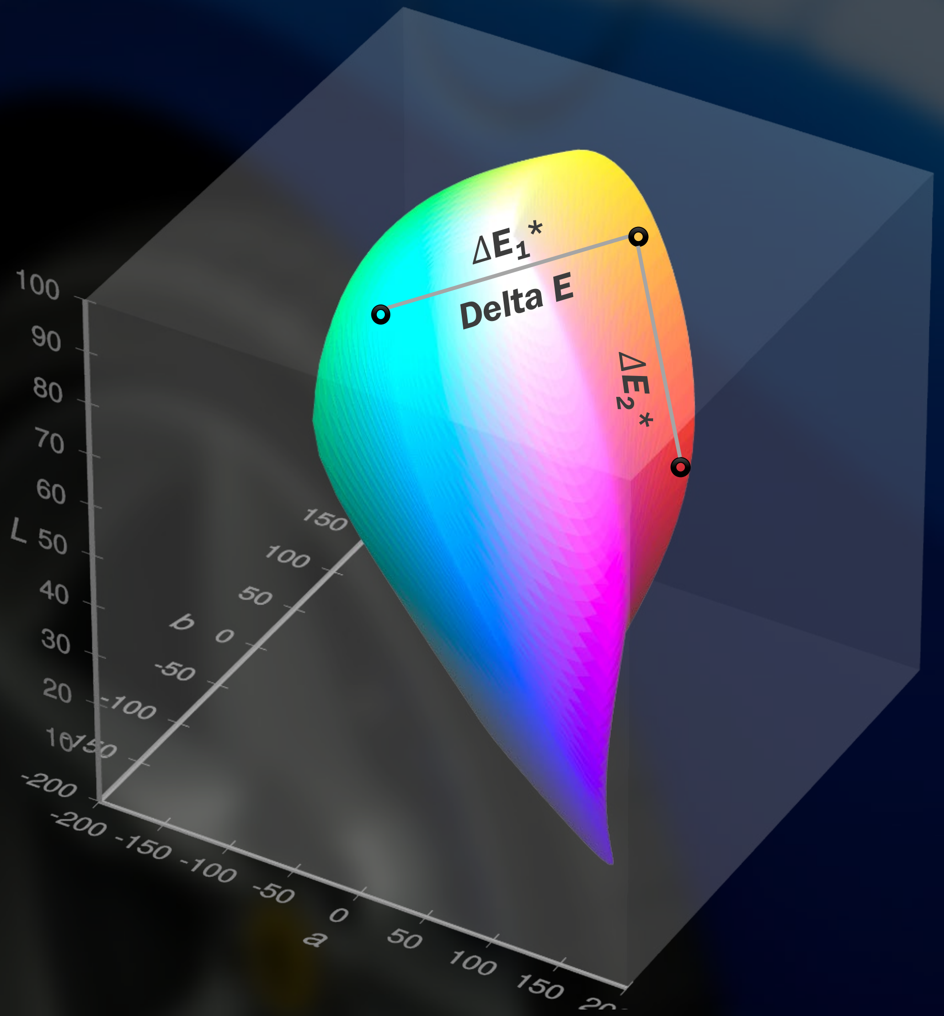
- **Most common colour space for colour comparisons**
- **3 Components:**
  - **L***
  - **a***
  - **b***
- **Advantages:**
  - **Covers All Visible Colours**
  - **Perceptually Uniform (almost*)**
  - **"Delta E" (ΔE)**

Lab (CIELAB) Colour Space





Delta E



- Key feature of Lab colour space
- Just a distance between 2 points
- Colour difference, quantified

$\Delta E_1{}^* =$ [L* = 83.49, a* = 7.57, b* = 66.69] - [L* = 91.09, a* = -48.37, b* = -13.65] = 98

$\Delta E_2{}^* =$ [L* = 83.49, a* = 7.57, b* = 66.69] - [L* = 43.80, a* = 69.20, b* = 58.06] = 73

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

Delta E – Another Example

R: 142
G: 149
B: 105

Reference Colour

Q: Which one is closer to the reference, A or B?

R: 143
G: 150
B: 102

ΔE = 2.2

A ✓

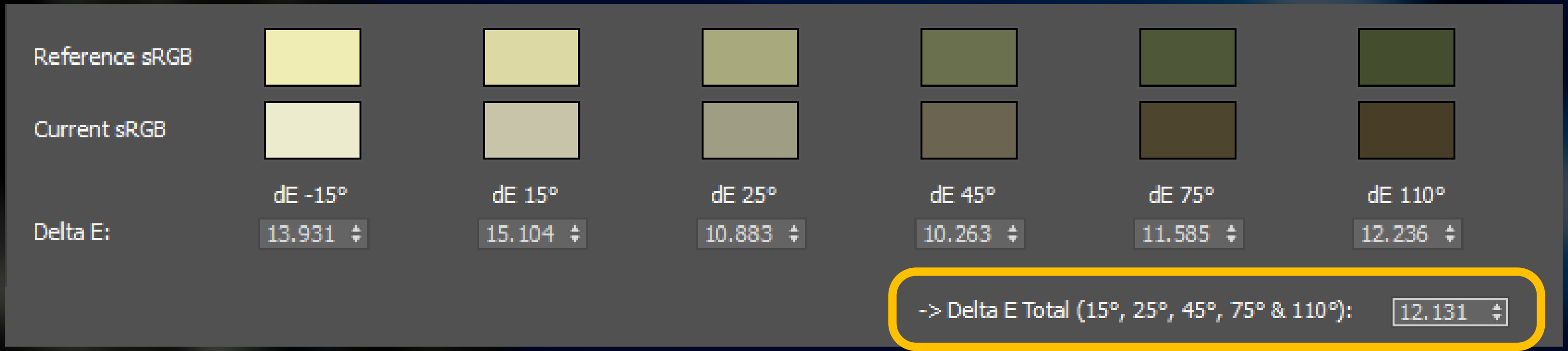
ΔE = 6.4

R: 137
G: 138
B: 103

B

Delta E – Total Colour Difference Analysis

$$\Delta E_{Total} = \sqrt{\frac{\Delta E_{p\,15^\circ}{}^2 + \Delta E_{p\,25^\circ}{}^2 + \Delta E_{p\,45^\circ}{}^2 + \Delta E_{p\,75^\circ}{}^2 + \Delta E_{p\,110^\circ}{}^2}{5}}$$



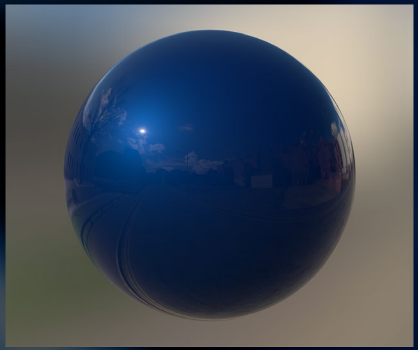
Multiple ΔE values combined into a single $\boldsymbol{\Delta E_{Total}}$

Apple-to-Apple Comparison – Part II

Physical Measurements

SPD

XYZ → Lab



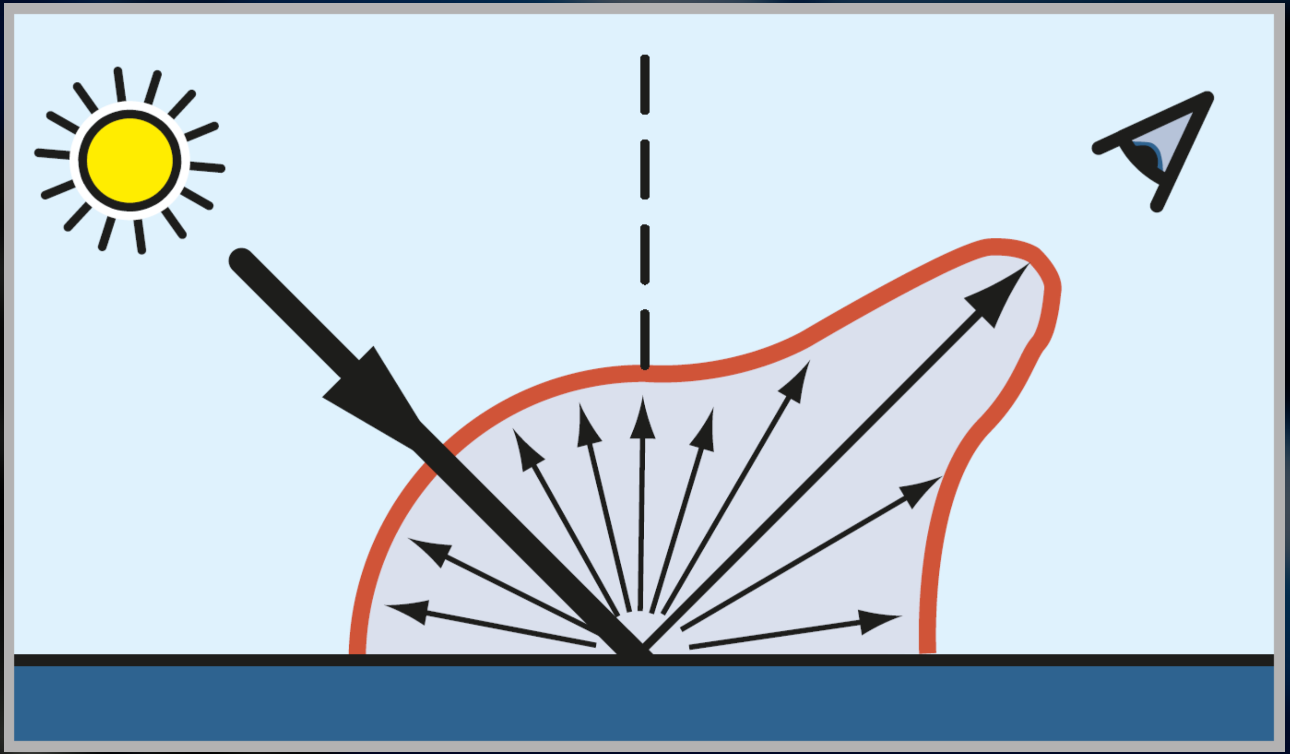
Game Measurements

sRGB (or HDR Linear)

XYZ → Lab

ΔE Compare!

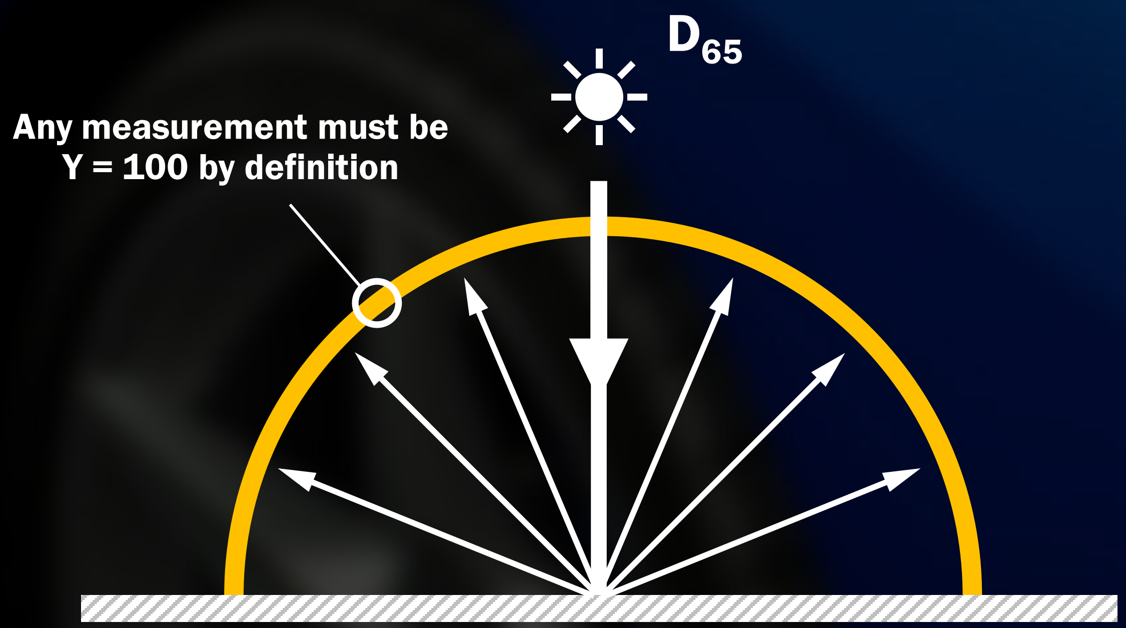
Illumination Information is Essential



Incident Light × Material Properties = Reflected Light

(This is an irreversible operation – it is *impossible* to work out material information without incident lighting information)

Incident Light Control

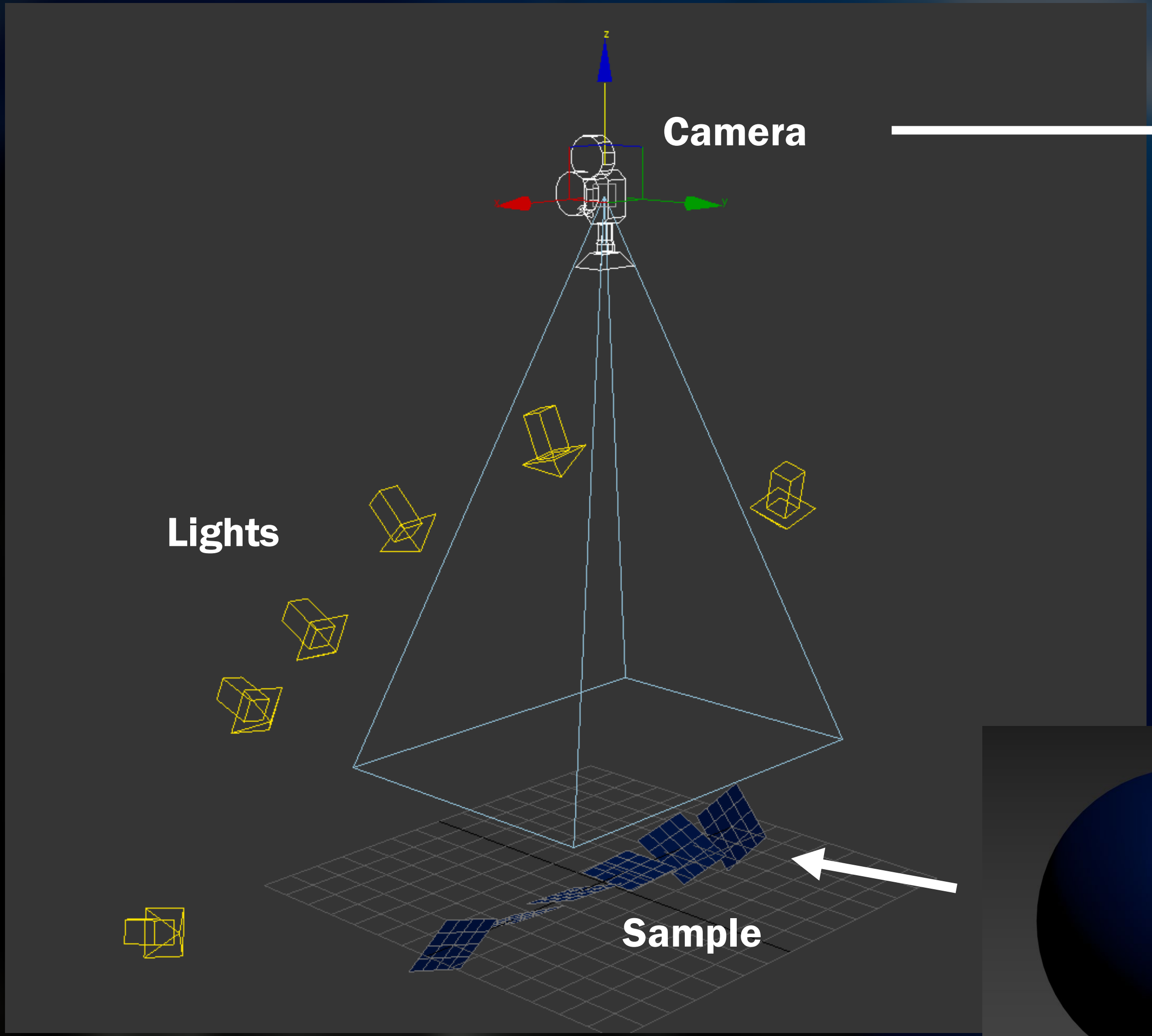


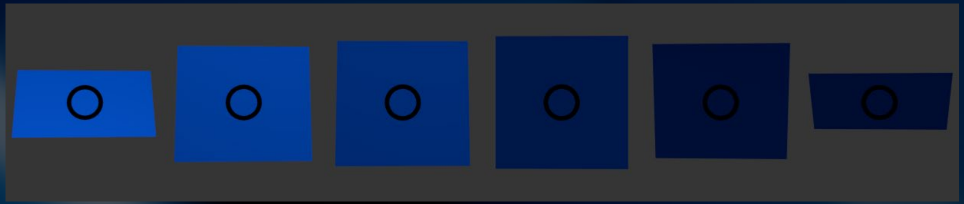
The 'Perfect Reflecting Diffuser'

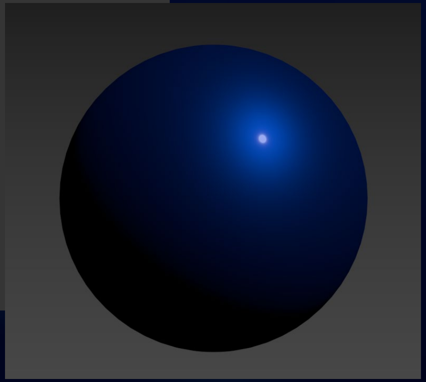
To mimic a D65:

- Light Type: Directional
- Light Colour (sRGB): [255, 255, 255]
- Light Intensity?
- Relative luminance Y = 100 is assigned to the *Perfect Reflecting Diffuser* that reflects 100% at all wavelengths
- Conclusion – intensity should be exactly 1.0

Virtual Measurement Apparatus





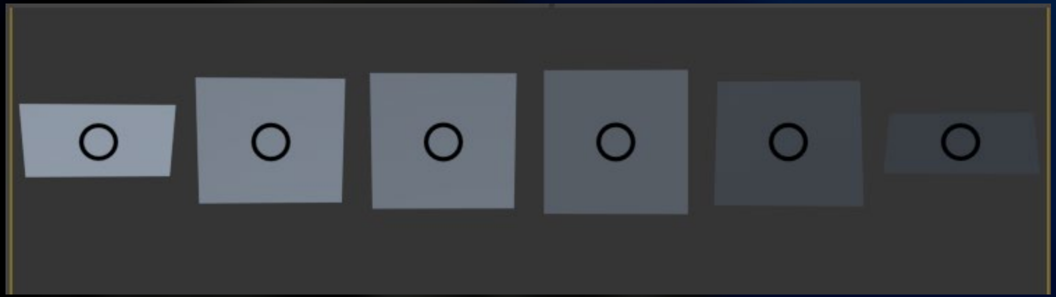


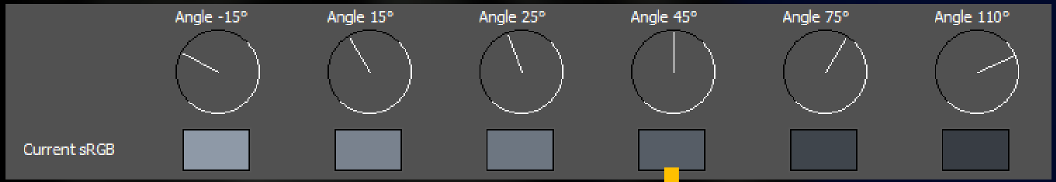
Rendering Environment?

- Maya/Max
- Game Editor
- Game (recommended)

From Game Measurements to Lab

- **Reading Pixels on Game Material Samples**
- **sRGB Colours**



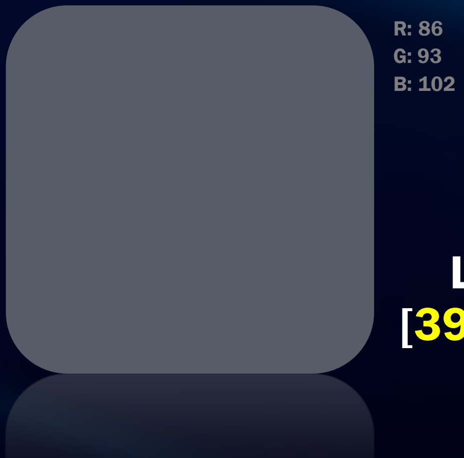


sRGB to Linear RGB then to XYZ:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4124 & 0.3576 & 0.1804 \\ 0.2127 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9503 \end{bmatrix} \begin{bmatrix} R_{linear} \\ G_{linear} \\ B_{linear} \end{bmatrix}$$

XYZ to Lab:

(same procedure as previous)



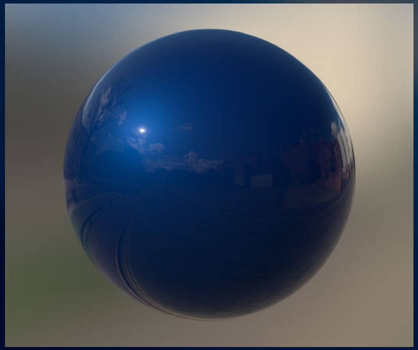
Lab Colour
[39.2, -0.6, -6.1]

Calibration Pipeline

Physical Measurements

SPD

XYZ → **Lab**



Game Measurements

sRGB (or HDR Linear)

XYZ → **Lab**

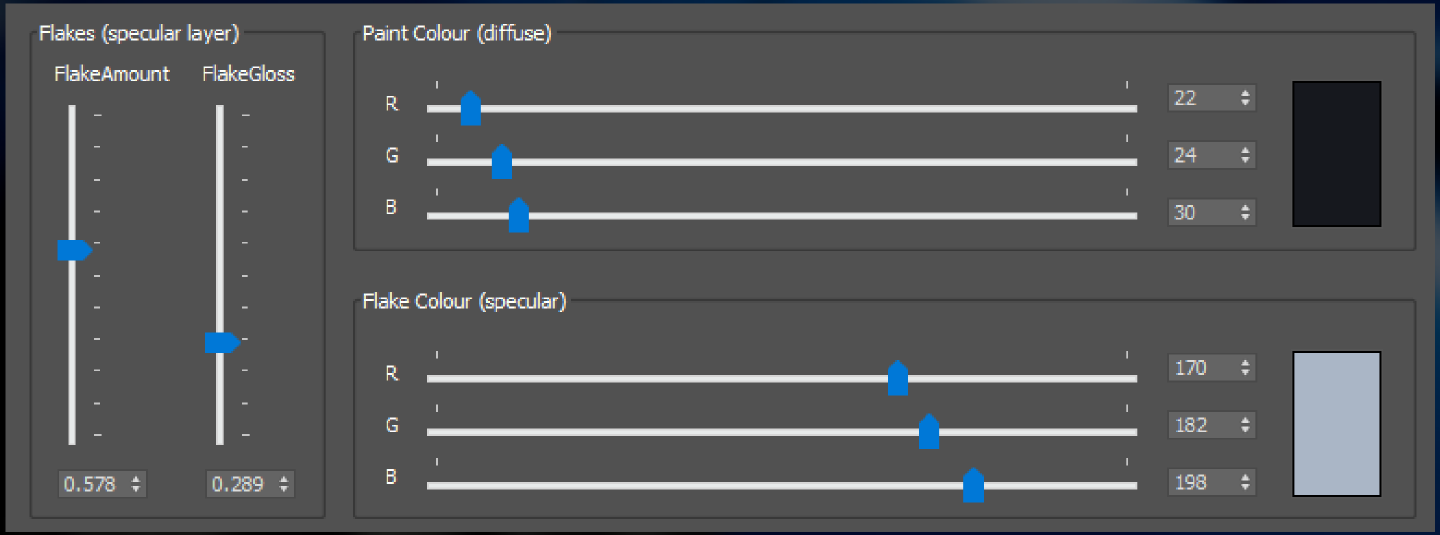
ΔE Compare!

Artist

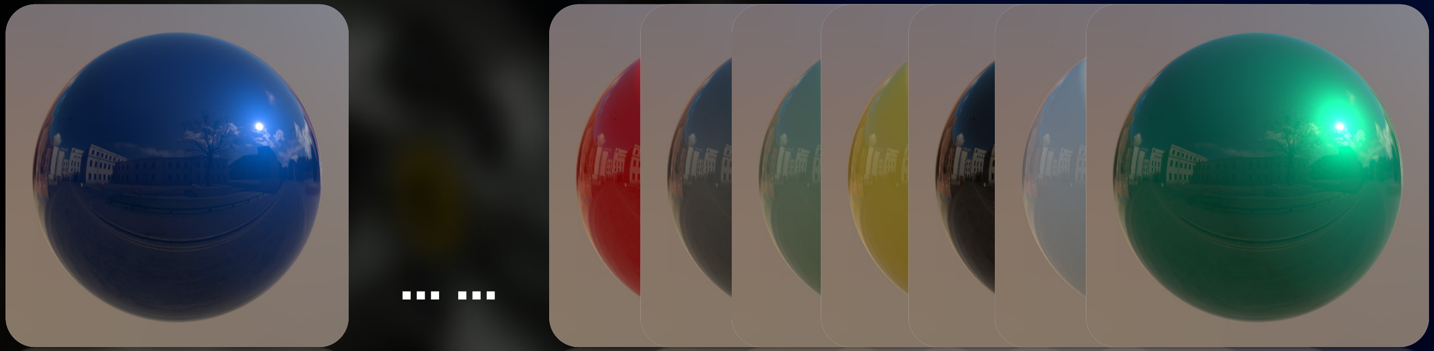
Game Material Inputs

Shading Model Calculations → **Game Measurements**

Shading Inputs, Not Shading Models



Forza car paint material has 8 inputs

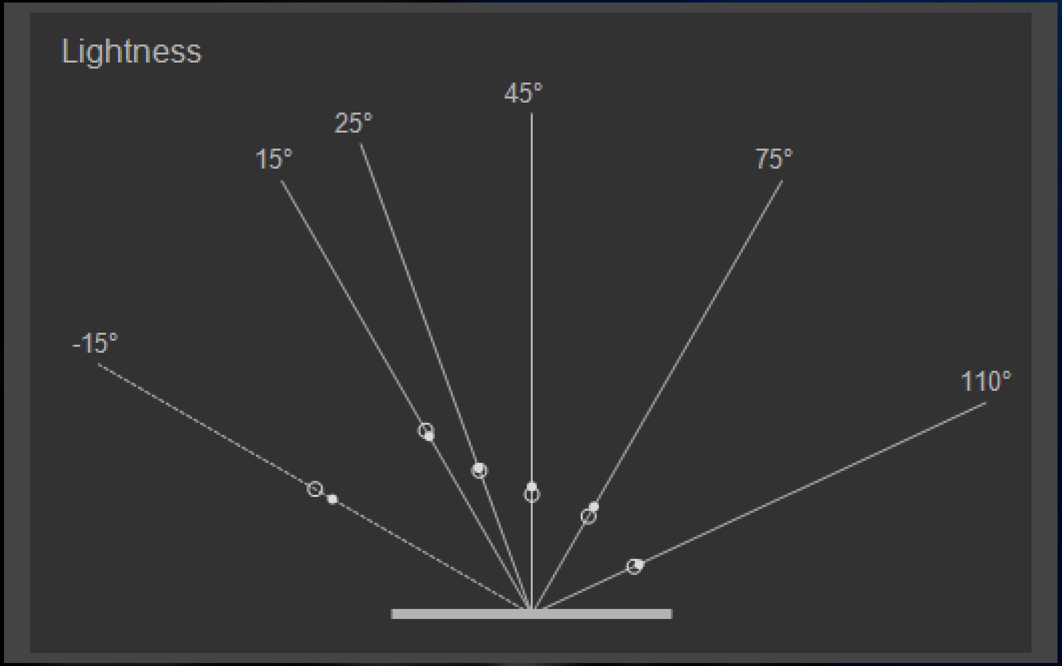


...but 8 inputs can produce a gazillion of combinations (8 degrees of freedom)

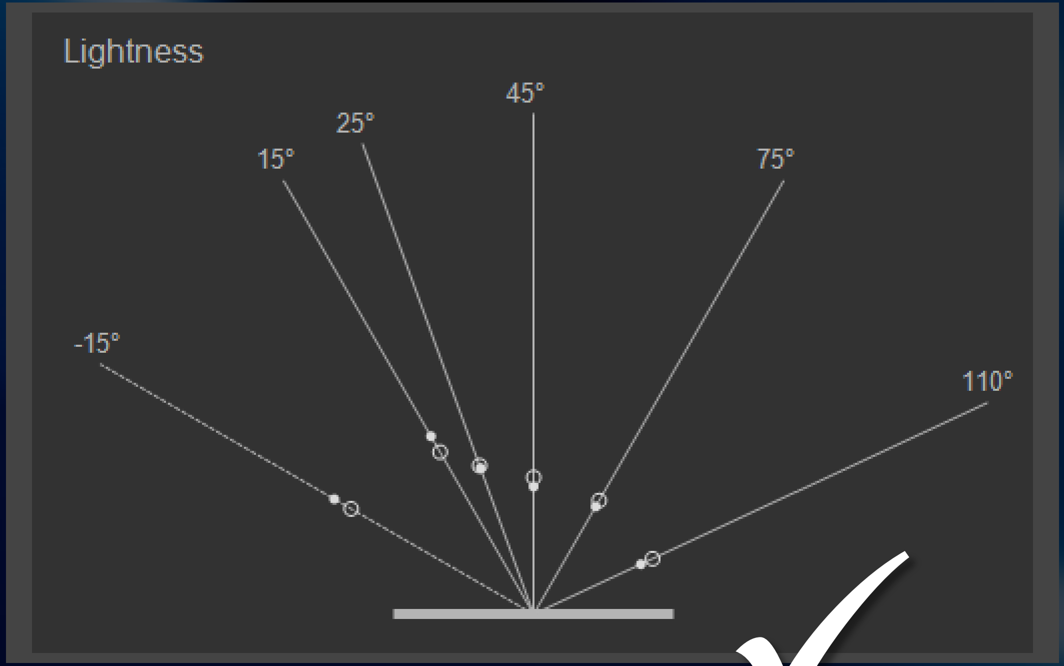
- **It's about finding optimal inputs NOT models**
- **Using the shading model of your choice**
- **It's okay to have different input parameters**

Macro vs Micro Adjustments

Which material configuration is better?



ΔE**$_{Total}$* = ***14.3



ΔE**$_{Total}$* = ***7.8

The most optimal configuration can always be determined with *ΔE*$_{Total}$

Delta E (Advanced)

- **Better and better formula:**

Delta E 76:

$$\Delta E_{76}{}^{*} = \sqrt{(\Delta L^{*})^2 + (\Delta a^{*})^2 + (\Delta b^{*})^2}$$

Delta E 94:

$$\Delta E_{94}^{*} = \sqrt{\left(\frac{\Delta L^*}{k_L S_L}\right)^2 + \left(\frac{\Delta C_{ab}^*}{k_C S_C}\right)^2 + \left(\frac{\Delta H_{ab}^*}{k_H S_H}\right)^2}$$

$$\Delta L^* = L_1^* - L_2^*$$
$$C_1^* = \sqrt{a_1^{*2} + b_1^{*2}}$$
$$C_2^* = \sqrt{a_2^{*2} + b_2^{*2}}$$
$$\Delta C_{ab}^* = C_1^* - C_2^*$$
$$\Delta H_{ab}^* = \sqrt{\Delta E_{ab}^{*\,2} - \Delta L^{*2} - \Delta C_{ab}^{*\,2}} = \sqrt{\Delta a^{*2} + \Delta b^{*2} - \Delta C_{ab}^{*\,2}}$$
$$\Delta a^* = a_1^* - a_2^*$$
$$\Delta b^* = b_1^* - b_2^*$$
$$S_L = 1$$
$$S_C = 1 + K_1 C_1^*$$
$$S_H = 1 + K_2 C_1^*$$

Delta E 2000:

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

$$\Delta L' = L_2^* - L_1^*$$
$$\bar{L} = \frac{L_1^* + L_2^*}{2} \quad \bar{C} = \frac{C_1^* + C_2^*}{2}$$
$$a_1' = a_1^* + \frac{a_1^*}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right) \quad a_2' = a_2^* + \frac{a_2^*}{2}\left(1 - \sqrt{\frac{\bar{C}^7}{\bar{C}^7 + 25^7}}\right)$$
$$\bar{C}' = \frac{C_1' + C_2'}{2} \text{ and } \Delta C' = C_2' - C_1' \quad \text{where } C_1' = \sqrt{a_1'^2 + b_1^{*2}} \quad C_2' = \sqrt{a_2'^2 + b_2^{*2}}$$
$$h_1' = \text{atan2}(b_1^*, a_1') \mod 360°, \quad h_2' = \text{atan2}(b_2^*, a_2') \mod 360°$$

$$\Delta h' = \begin{cases} h_2' - h_1' & |h_1' - h_2'| \le 180° \\ h_2' - h_1' + 360° & |h_1' - h_2'| > 180°, h_2' \le h_1' \\ h_2' - h_1' - 360° & |h_1' - h_2'| > 180°, h_2' > h_1' \end{cases}$$

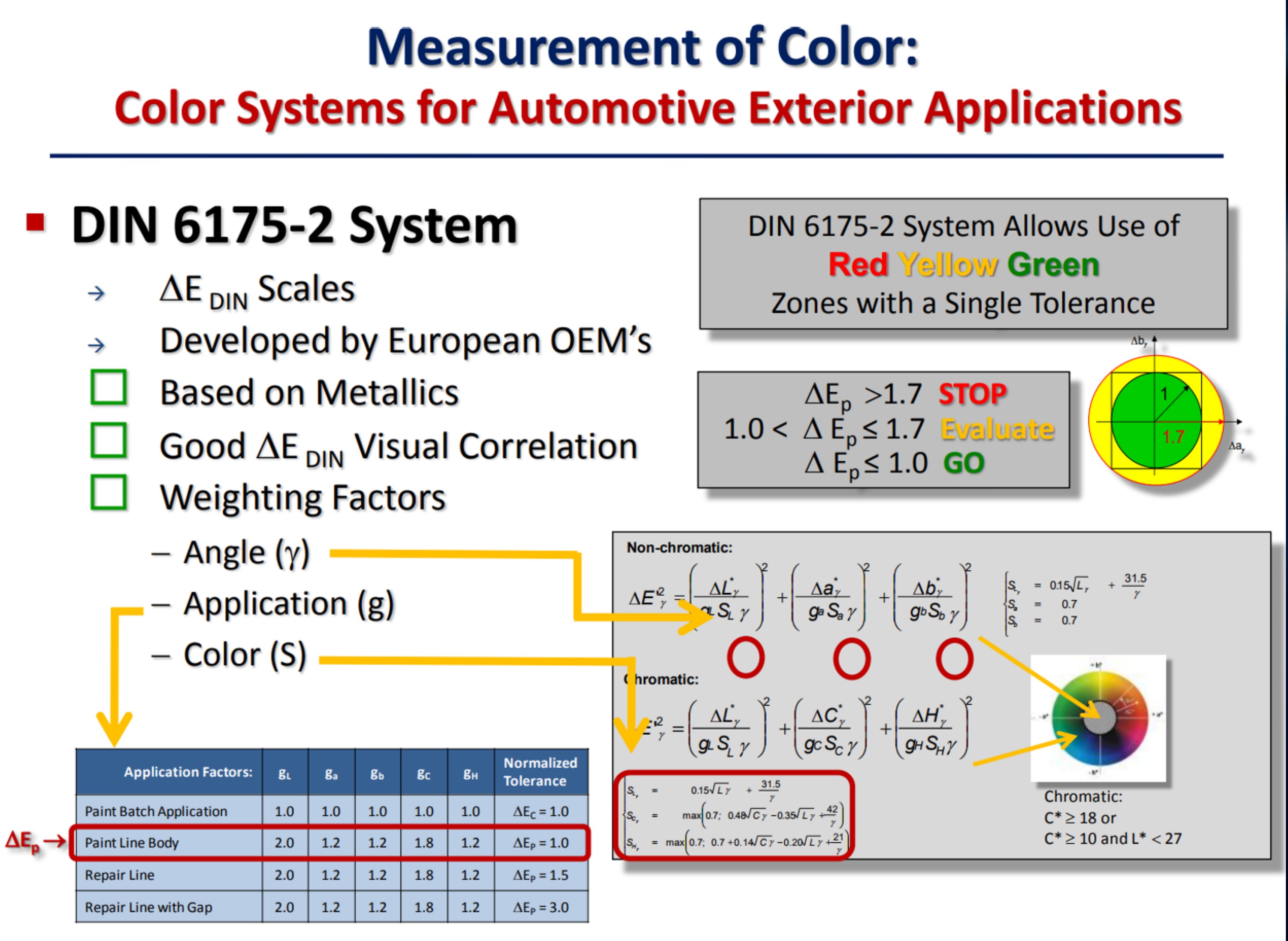
$$\Delta H' = 2\sqrt{C_1' C_2'}\sin(\Delta h'/2), \quad \bar{H}' = \begin{cases} (h_1' + h_2' + 360°)/2 & |h_1' - h_2'| > 180° \\ (h_1' + h_2')/2 & |h_1' - h_2'| \le 180° \end{cases}$$

$$T = 1 - 0.17\cos(\bar{H}' - 30°) + 0.24\cos(2\bar{H}') + 0.32\cos(3\bar{H}' + 6°) - 0.20\cos(4\bar{H}' - 63°)$$

$$S_L = 1 + \frac{0.015\left(\bar{L} - 50\right)^2}{\sqrt{20 + \left(\bar{L} - 50\right)^2}} \quad S_C = 1 + 0.045\bar{C}' \quad S_H = 1 + 0.015\bar{C}'T$$

$$R_T = -2\sqrt{\frac{\bar{C}'^7}{\bar{C}'^7 + 25^7}}\sin\left[60° \cdot \exp\left(-\left[\frac{\bar{H}' - 275°}{25°}\right]^2\right)\right]$$

Delta E (Advanced)



Measurement of Color:
Color Systems for Automotive Exterior Applications

- **DIN 6175-2 System**
  - → ΔE_{DIN} Scales
  - → Developed by European OEM's
  - ☐ Based on Metallics
  - ☐ Good ΔE_{DIN} Visual Correlation
  - ☐ Weighting Factors
    - – Angle (γ)
    - – Application (g)
    - – Color (S)

DIN 6175-2 System Allows Use of
Red Yellow Green
Zones with a Single Tolerance

$\Delta E_p > 1.7$ STOP
$1.0 < \Delta E_p \leq 1.7$ Evaluate
$\Delta E_p \leq 1.0$ GO

Non-chromatic:

$$\Delta E'^2_\gamma = \left(\frac{\Delta L^*_\gamma}{g_L S_L \gamma}\right)^2 + \left(\frac{\Delta a^*_\gamma}{g_a S_a \gamma}\right)^2 + \left(\frac{\Delta b^*_\gamma}{g_b S_b \gamma}\right)^2$$

$$S_{L_\gamma} = 0.15\sqrt{L_\gamma} + \frac{31.5}{\gamma}, \quad S_a = 0.7, \quad S_b = 0.7$$

Chromatic:

$$\Delta E'^2_\gamma = \left(\frac{\Delta L^*_\gamma}{g_L S_L \gamma}\right)^2 + \left(\frac{\Delta C^*_\gamma}{g_C S_C \gamma}\right)^2 + \left(\frac{\Delta H^*_\gamma}{g_H S_H \gamma}\right)^2$$

$$S_{L_\gamma} = 0.15\sqrt{L_\gamma} + \frac{31.5}{\gamma}$$
$$S_{C_\gamma} = \max\left(0.7;\ 0.48\sqrt{C_\gamma} - 0.35\sqrt{L_\gamma} + \frac{42}{\gamma}\right)$$
$$S_{H_\gamma} = \max\left(0.7;\ 0.7 + 0.14\sqrt{C_\gamma} - 0.20\sqrt{L_\gamma} + \frac{21}{\gamma}\right)$$

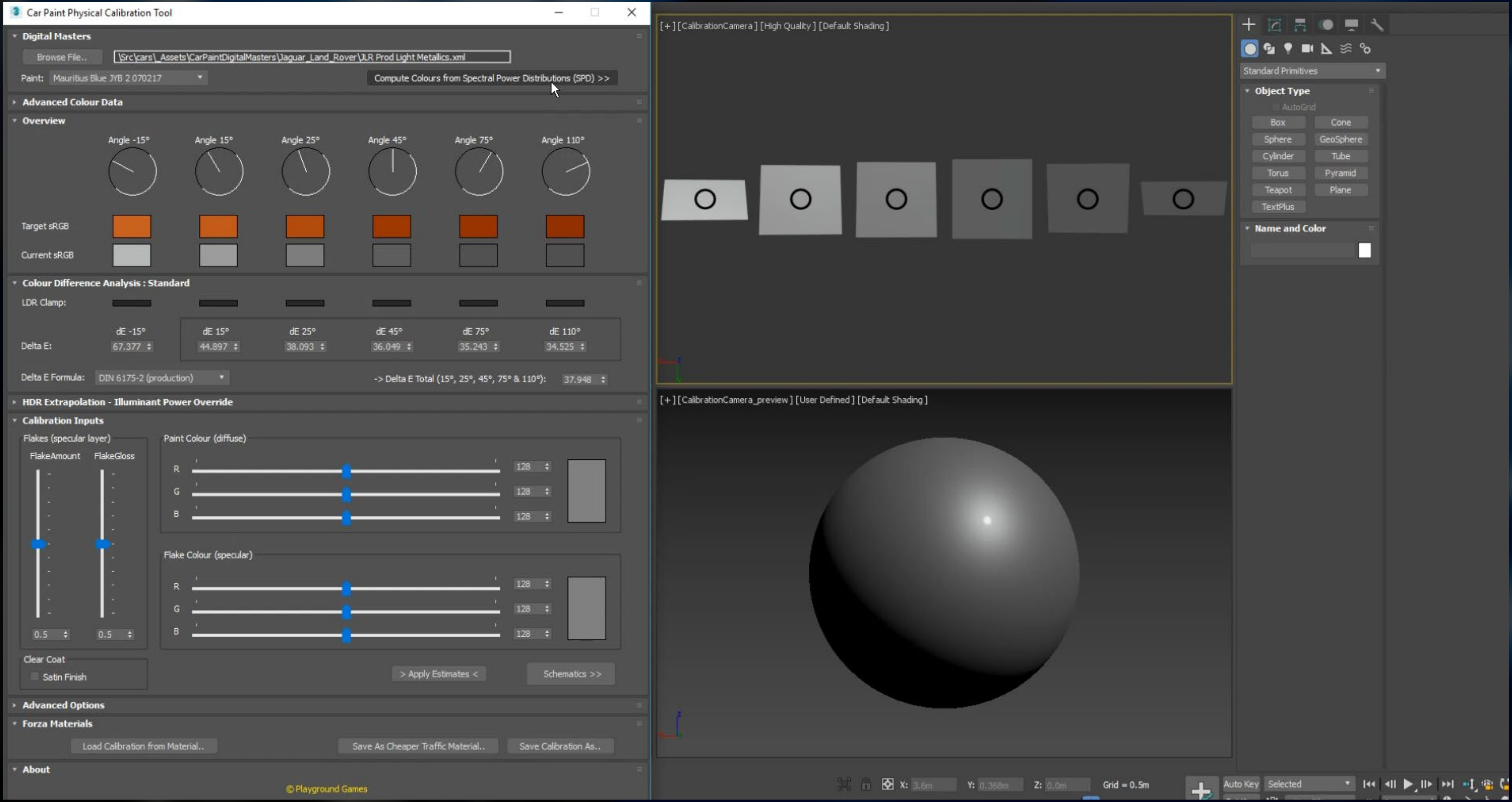
Chromatic:
$C^* \geq 18$ or
$C^* \geq 10$ and $L^* < 27$

Application Factors:	g_L	g_a	g_b	g_C	g_H	Normalized Tolerance
Paint Batch Application	1.0	1.0	1.0	1.0	1.0	$\Delta E_C = 1.0$
ΔE_p → Paint Line Body	2.0	1.2	1.2	1.8	1.2	$\Delta E_p = 1.0$
Repair Line	2.0	1.2	1.2	1.8	1.2	$\Delta E_p = 1.5$
Repair Line with Gap	2.0	1.2	1.2	1.8	1.2	$\Delta E_p = 3.0$

Source: *Instrumental Color Measurement for Process Control*

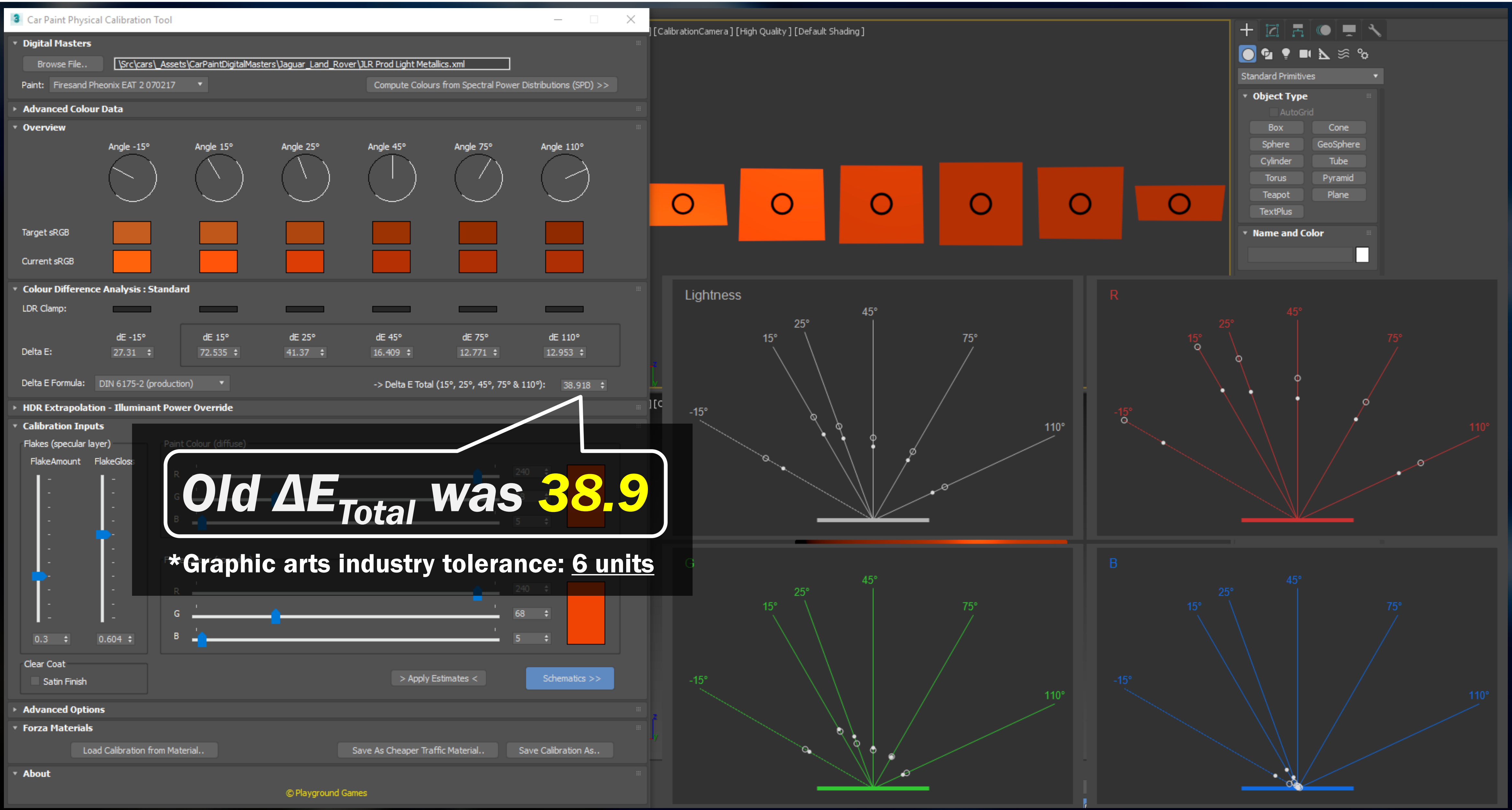
- **Final choice: DIN 6175-2**
- **Best for metallic paints**
- **Used by VW, Audi, GM etc.**
- **Not necessary, but nice-to-have**
- **Prioritises specular angles**

VIDEO – Calibration in Action



Car Paint Physical Calibration Tool
Digital Masters
Browse File..
\Src\cars_Assets\CarPaintDigitalMasters\Jaguar_Land_Rover\JLR Prod Light Metallics.xml
Paint: Mauritius Blue JYB 2 070217
Compute Colours from Spectral Power Distributions (SPD) >>
Advanced Colour Data
Overview
Angle -15° Angle 15° Angle 25° Angle 45° Angle 75° Angle 110°
Target sRGB
Current sRGB
Colour Difference Analysis : Standard
LDR Clamp:
dE -15° dE 15° dE 25° dE 45° dE 75° dE 110°
Delta E: 67.377 44.897 38.093 36.049 35.243 34.525
Delta E Formula: DIN 6175-2 (production)
-> Delta E Total (15°, 25°, 45°, 75° & 110°): 37.948
HDR Extrapolation - Illuminant Power Override
Calibration Inputs
Flakes (specular layer)
FlakeAmount FlakeGloss
0.5 0.5
Paint Colour (diffuse)
R 128
G 128
B 128
Flake Colour (specular)
R 128
G 128
B 128
Clear Coat
Satin Finish
> Apply Estimates <
Schematics >>
Advanced Options
Forza Materials
Load Calibration from Material..
Save As Cheaper Traffic Material..
Save Calibration As..
About
© Playground Games
[+] [CalibrationCamera] [High Quality] [Default Shading]
[+] [CalibrationCamera_preview] [User Defined] [Default Shading]
Standard Primitives
Object Type
AutoGrid
Box Cone
Sphere GeoSphere
Cylinder Tube
Torus Pyramid
Teapot Plane
TextPlus
Name and Color
X: 3.6m Y: 0.368m Z: 0.0m
Grid = 0.5m
Auto Key
Selected

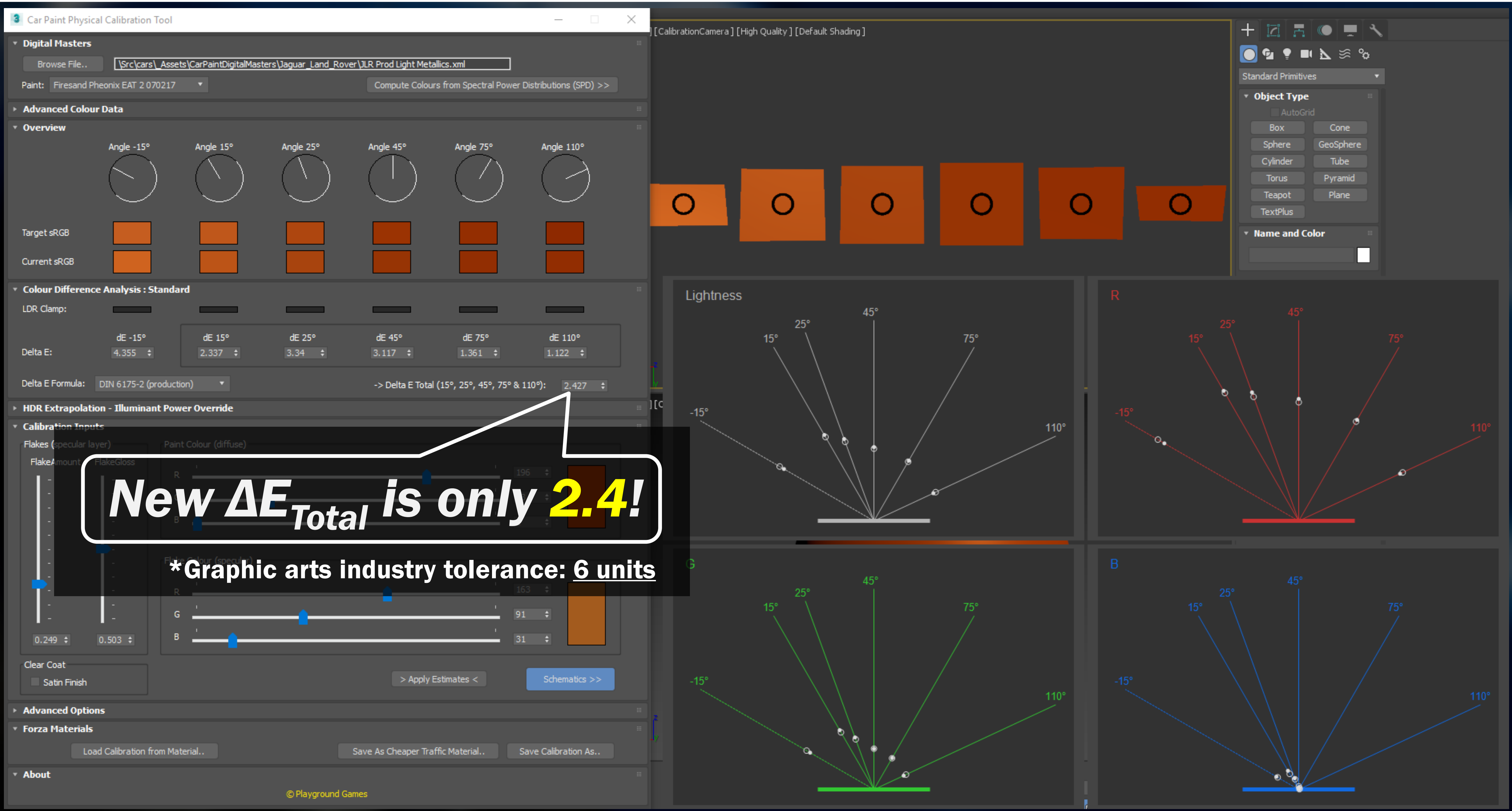
Manufacturer Paint - “Firesand Metallic”



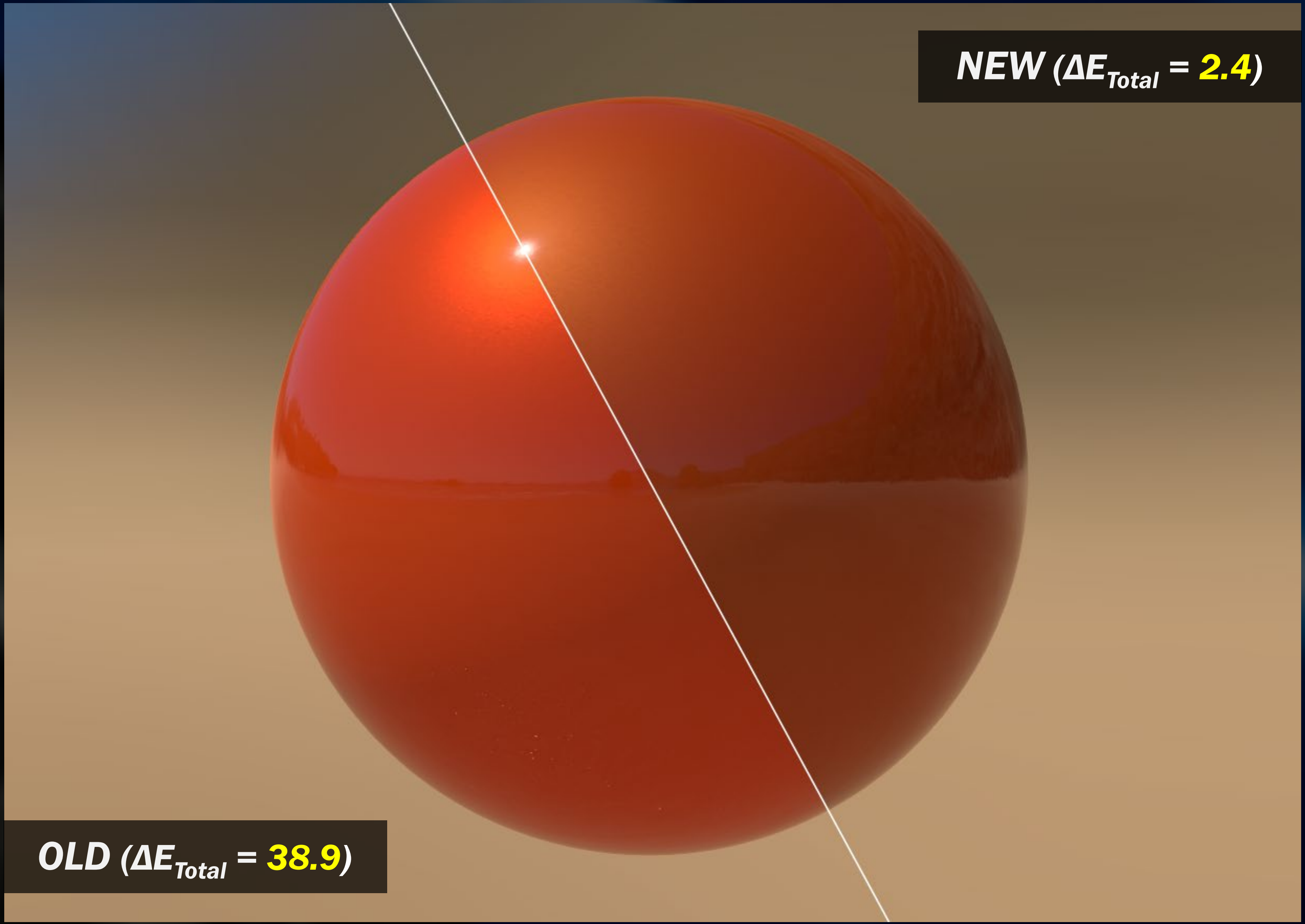
Old ΔE$_{Total}$ was 38.9

*Graphic arts industry tolerance: <u>6 units</u>

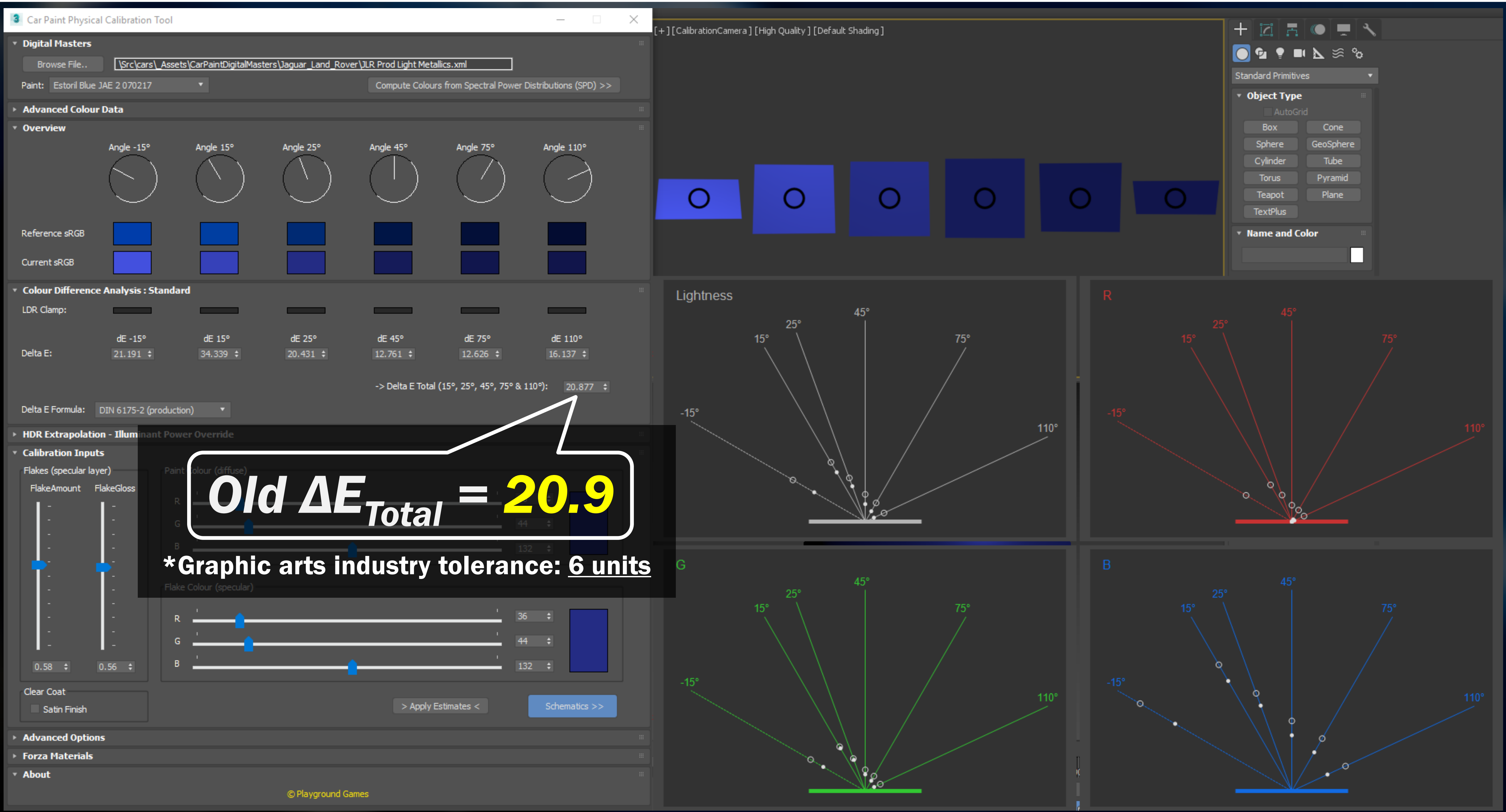
Manufacturer Paint - “Firesand Metallic”



Manufacturer Paint - "Firesand Metallic"



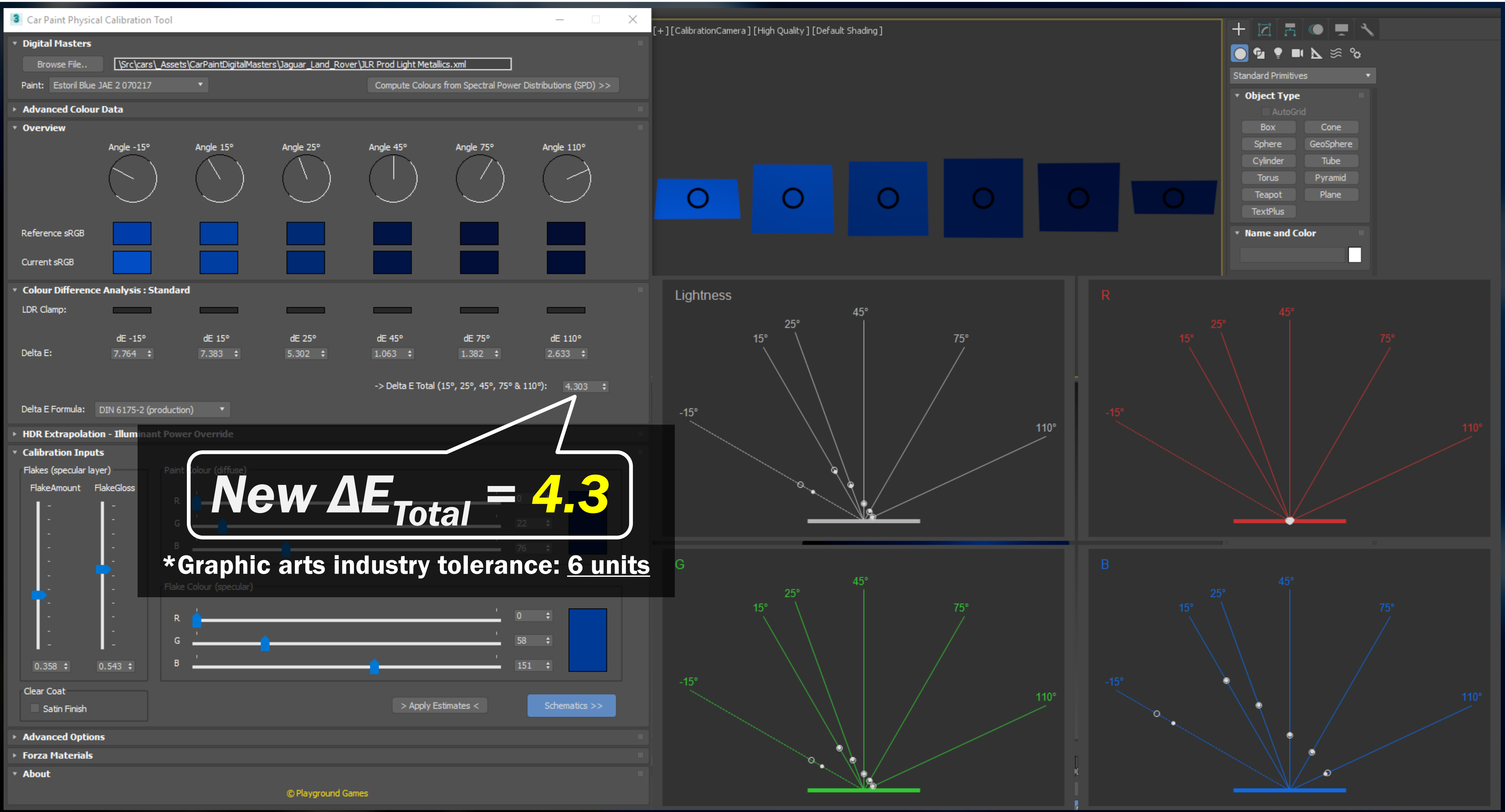
Manufacturer Paint - “Estoril Blue Metallic”



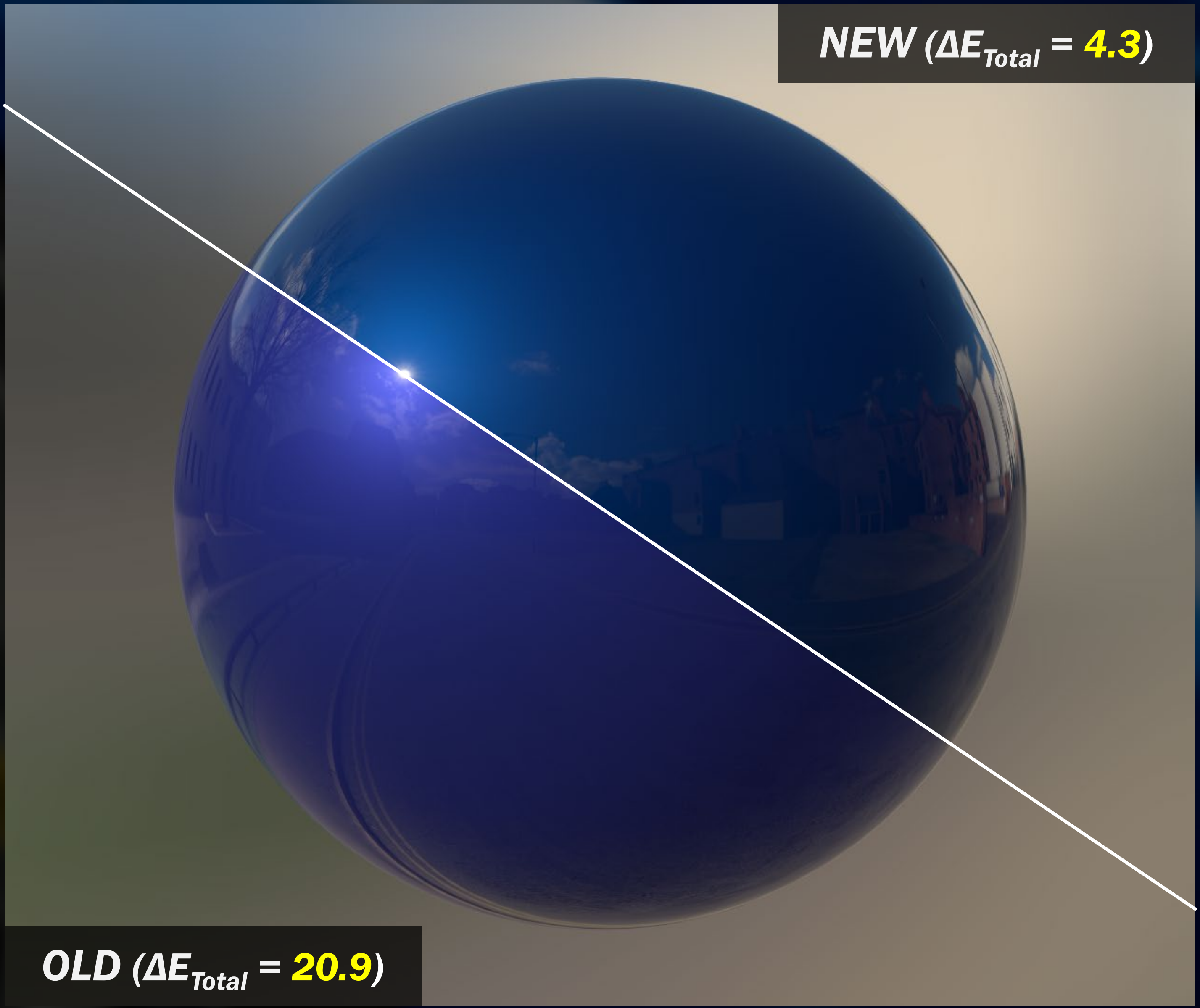
Old ΔE_{Total} = **20.9**

*Graphic arts industry tolerance: 6 units

Manufacturer Paint - "Estoril Blue Metallic"



Manufacturer Paint - “Estoril Blue Metallic”




OLD
NEW
"Estoril Blue Metallic" – Jaguar Land Rover™


OLD
NEW
HORIZON
RANGE ROVER
“Estoril Blue Metallic” – Jaguar Land Rover™


‘Shading’ Was Also Improved
OLD
NEW
RANGE ROVER
HORIZON
“Estoril Blue Metallic” – Jaguar Land Rover™


OLD
NEW
“Viridian Green Metallic” – Aston Martin™


HORIZON
OLD
NEW
"Moonstone Metallic" – BMW™


OLD
NEW
"Grey Bull" – Aston Martin™

Sourcing for Production

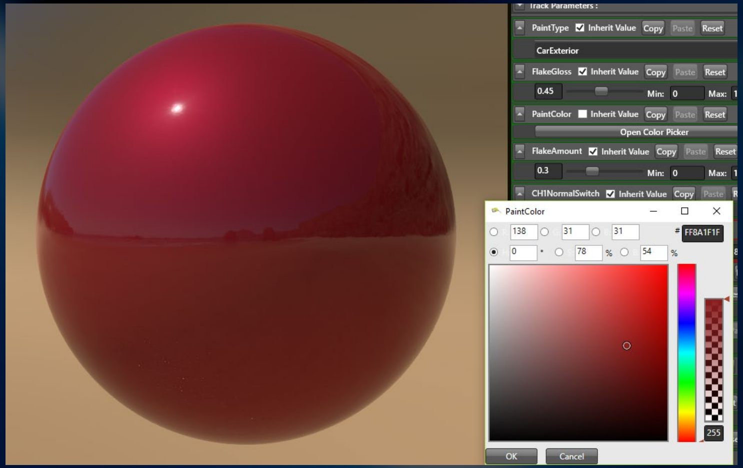
Ferrari Dealership Visit
Swindon, UK

Production Summary

REFERENCE

- Photographs Only
- Unknown/Uncontrolled Factors
  - Lighting Conditions
  - Reflected Environment
  - Camera Settings
  - Image Editing

TUNING



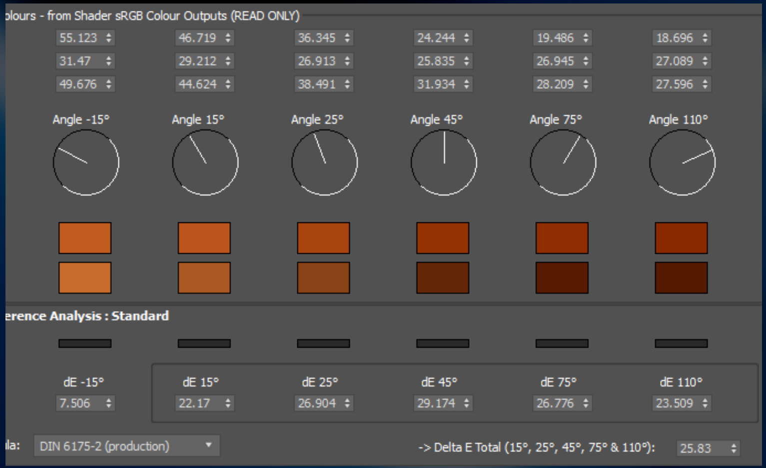
- Based on 'Feelings'
- Difficult to Match Scientifically
  - Monitor Conditions
  - Reflected Environment
  - Rendering Configurations
  - Viewing Conditions

Production Summary

REFERENCE

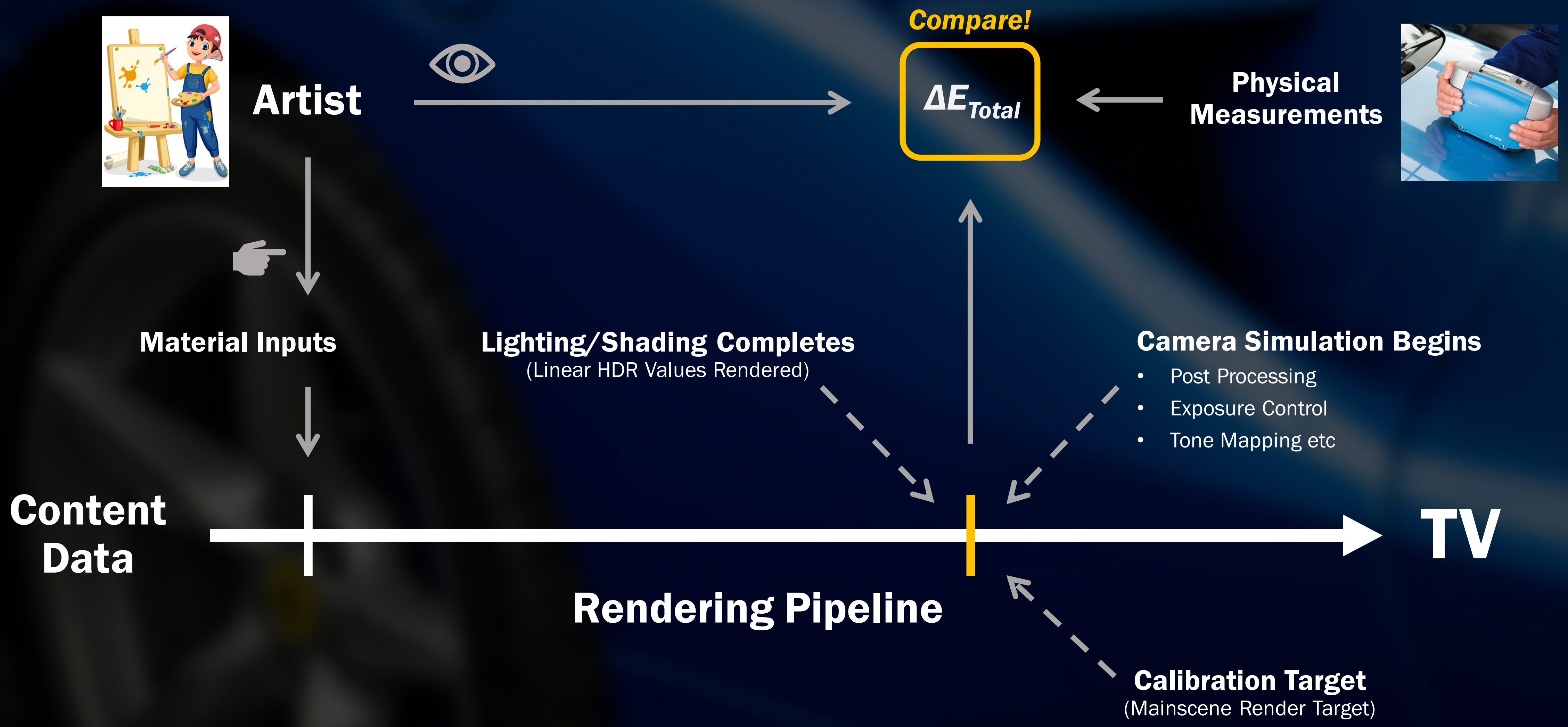
Spectrophotometric Data

TUNING

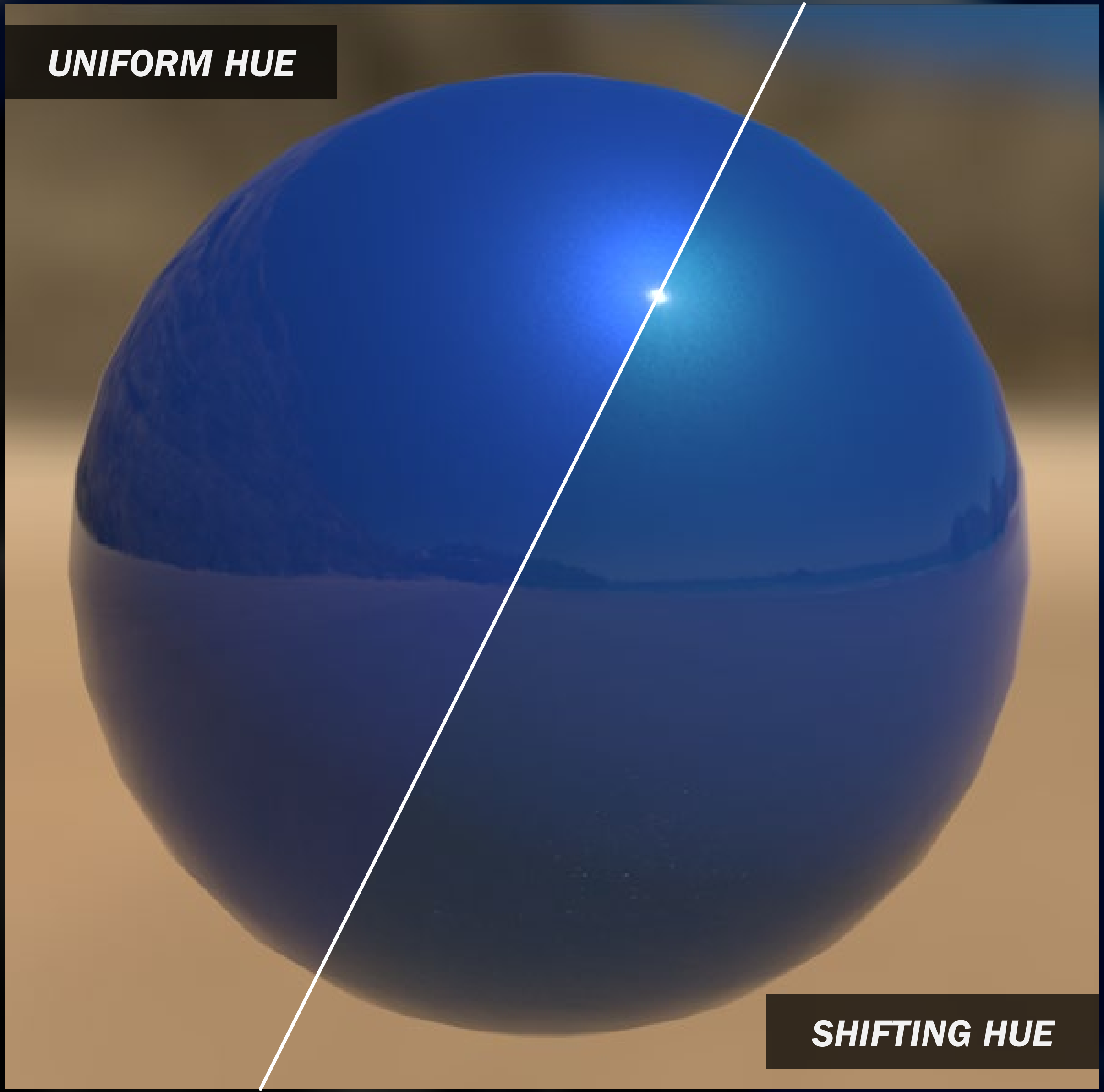


Quantitative Calibration

Calibration Summary

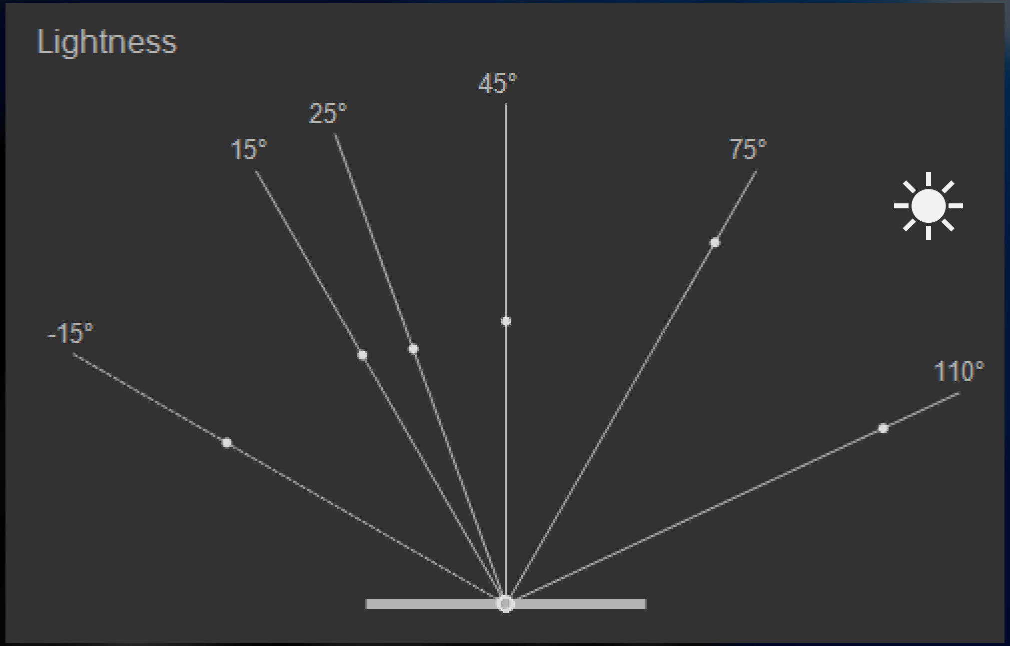


Happy Accidents



- Hue Shift Phenomenon
- ‘PBR Guide’ does not always apply
- Facing visual issues, there’s extra confidence to blame lighting ☺

Happy Accidents



Performance and Limitations

Performance:

- Zero performance cost at runtime ☺
- Sample acquisition: 6 sec per scan
- Artist calibration time: ~5 mins per material (close to 900 materials calibrated in FH4)
- Most PBC materials: $\Delta E_{Total} < 5.0$

Limitations:

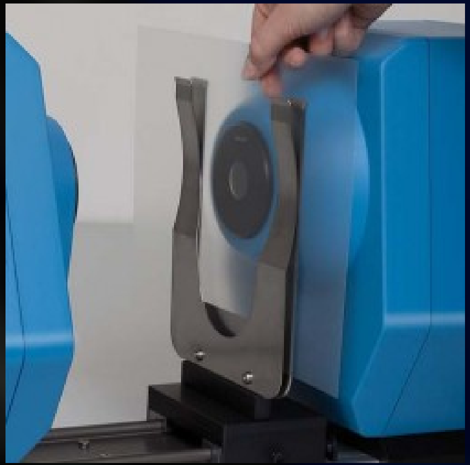
- Data availability
- Instrument cost
- Lack of texture information
- Calibrated with directional light only (loophole)

Future Work

Gloss Meter

Haze Meter

Orange Peel Meter



Transparency Meter

- Feasibility on non-paint materials
- Wide gamut pipeline
- Solutions for capturing textures
- Spectrophotometer is just the tip of an ice berg
- Much to learn from the appearance industry

Special Thanks

Alex Killpack

Alex Logan

Gareth Harwood

Kelvin Janson

Neil Massam

Sally Upex

Simon Gibson

Michael Bishop

Reference List

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There are no real colours, only real Optical Properties

There's more to the world than meets the eye


QUESTIONS?