Color gamut of goniochromatic and fluorescent colors

Francisco Martínez-Verdú (REG2- UA)

6th Progress xD-Reflect meeting
21 – 23 June 2016, Torino (Italy)

Outline

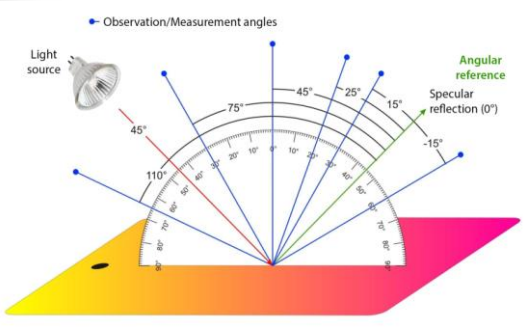
- **Purpose and Strategy for:**
  - **D1.5.2-3: color gamut of gonio-chromatic panels**
  - **D3.5.2-3: color gamut of gonio-fluorescent colors compared with Rösch-MacAdam limits vs. ISO & CIE gamuts**
- **Materials**
  - **Instruments:**
    - **Multi-angle spectrophotometers: X-Rite MA98 & BYK-mac**
    - **Modular multi-angle-spectrofluorimeter PTI QuantaMaster 3-PH**
  - **Panels: xD-Reflect sets**
- **Methods: Rösch-MacAdam limits vs. ISO & CIE gamuts**
- **Results & Discussion**
- **Conclusions**

Purpose

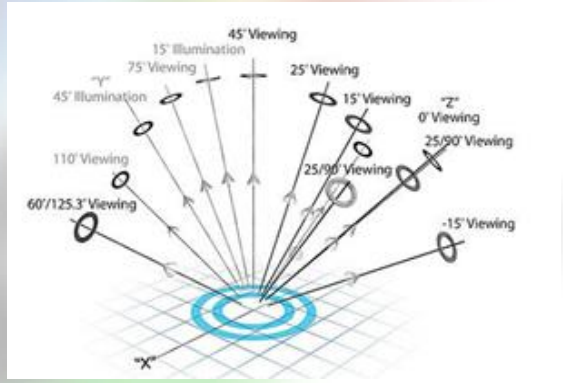
- **D1.5.2-3 (March – May 2016)**
  - **Report on the analysis of the color gamut of special-effect pigments with regard to the classical Rösch-MacAdam color solid**
- **D3.5.1-3 (October – December 2015)**
  - **Color gamut of current fluorescent materials and standards analyzed (real color gamut for non-fluorescent materials)**
  - **Analysis comparing with ISO and CIE gamuts**

Materials: instruments

- **Multi-angle-spectrophotometers:**
  - **BYK-mac, following ASTM E2194 (6 geometries)**

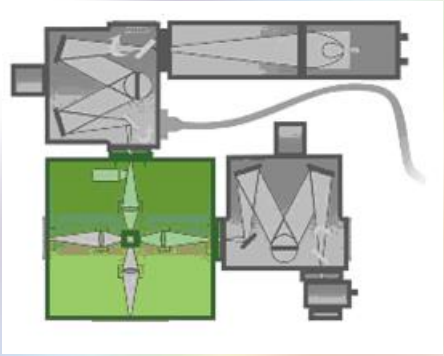


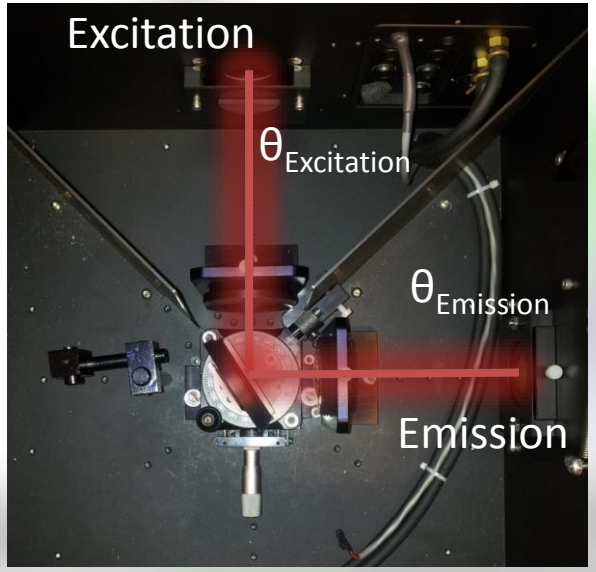
  - **X-Rite MA98, following ASTM E2539 (8 geometries)**
    - **19 geometries (in & out-plane), included 6 of BYK-mac**



Materials: instrument

- **Multi-angle-spectrofluorimeter**
  - **PTI QuantaMaster 3-PH**
  - **Restrictions: measurement geometries are not free:**
    - $\theta_{excitation} + \theta_{emission} = 90°$
    - **45/45**
    - **35/55**
    - **25/65**
    - **15/75**





Materials: fluorescence measurement

- **Donaldson matrix by CIE 182:2007 + paper 2015**

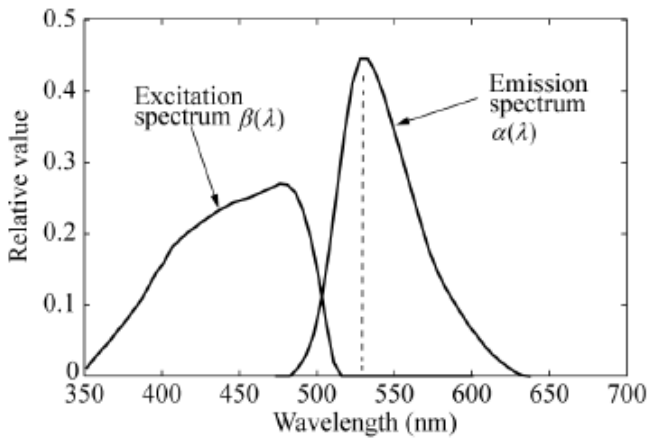
Estimation of bispectral Donaldson matrices of fluorescent objects by using two illuminant projections

SHOJI TOMINAGA,* KEITA HIRAI, AND TAKAHIKO HORIUCHI

$$D_L(\lambda_{out},\lambda_{in}) = \alpha(\lambda_{out})\beta(\lambda_{in})$$

$$\mathbf{D} = \begin{bmatrix} d_{11} & 0 & \cdots & 0 \\ d_{21} & d_{22} & \ddots & \vdots \\ \vdots & \vdots & \ddots & 0 \\ d_{N1} & d_{N2} & \cdots & d_{NN} \end{bmatrix} = \mathbf{D}_R + \mathbf{D}_L$$

$$= \begin{bmatrix} s_1 & 0 & \cdots & 0 \\ 0 & s_2 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & s_N \end{bmatrix} + \begin{bmatrix} 0 & & \cdots & & 0 \\ \alpha_2\beta_1 & 0 & & & \\ \alpha_3\beta_1 & \alpha_3\beta_2 & 0 & & \vdots \\ \vdots & \vdots & \ddots & \ddots & \\ \alpha_N\beta_1 & \alpha_N\beta_2 & \cdots & \alpha_N\beta_{N-1} & 0 \end{bmatrix}$$



$$\beta(\lambda) = e(\lambda)(1 - s(\lambda))$$

Materials: panel sets

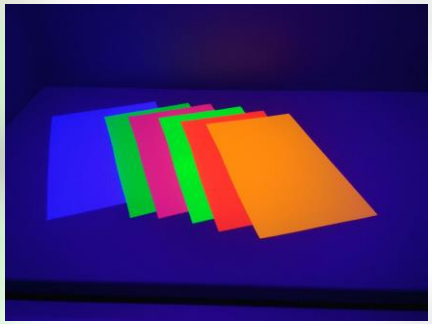
- **xD-Reflect sets: Merck®, JDSU® and Eckart® pigments**



99 samples



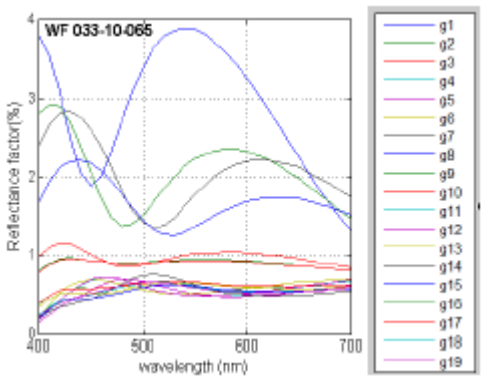
- **Fluorescent sets: 12 samples**
  - **AVIAN & Innventia**

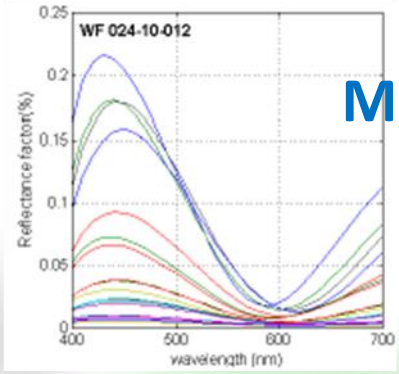
Materials: spectral data

- **Gonio-chromatic pigments & samples**

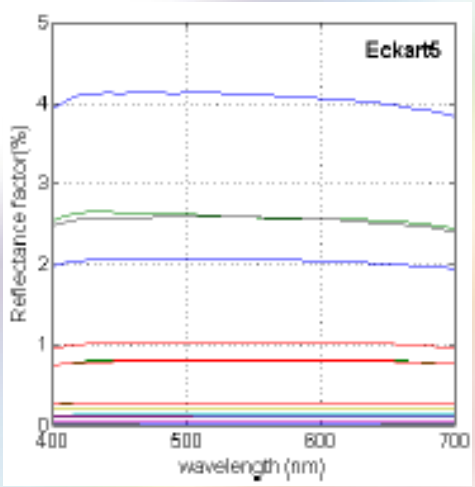
18 % Viola Fantasy



18 % + 3.5 % Black1

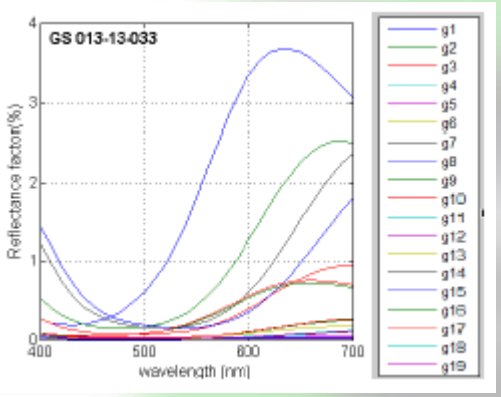


Metallic

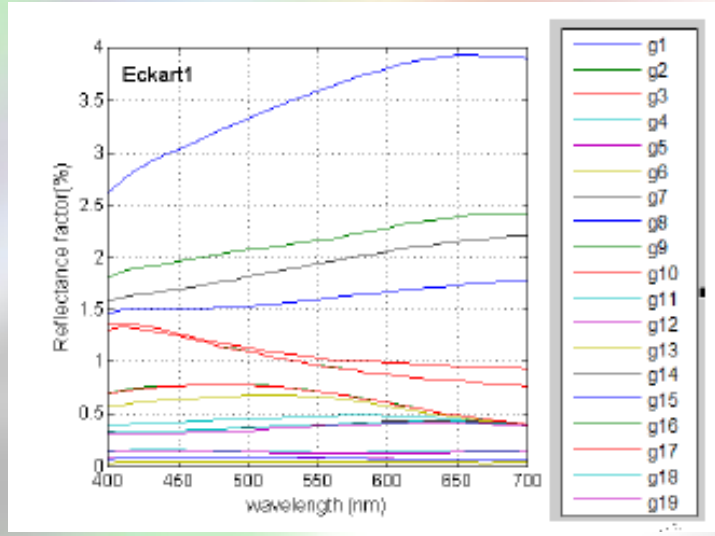


Interference

18 % Chromaflair

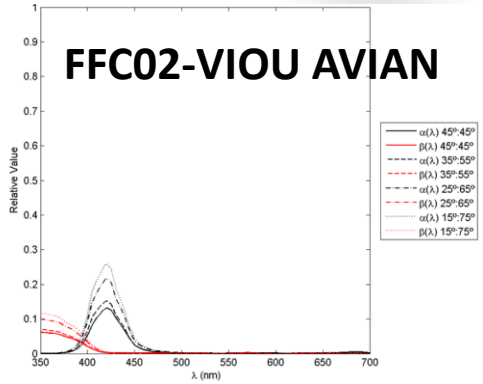


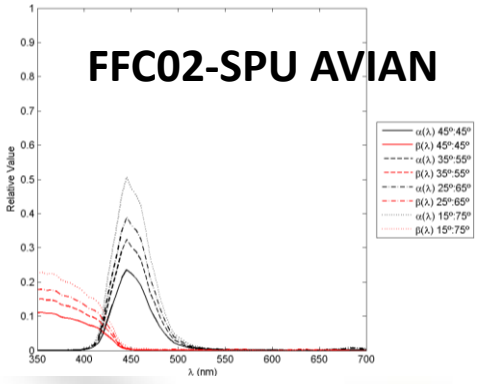
Diffractive

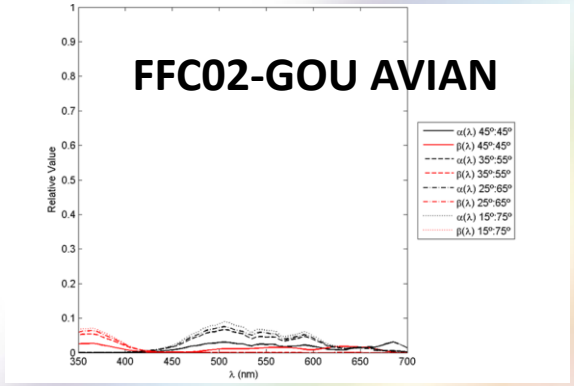


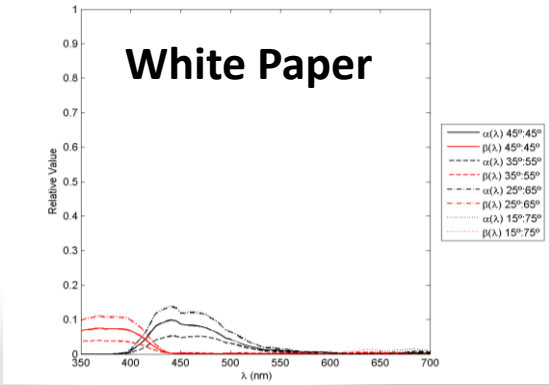
Materials: spectral data

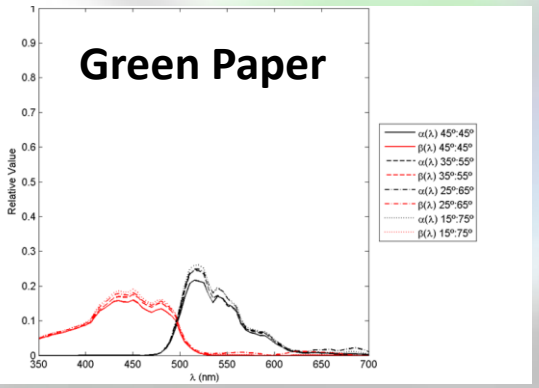
- **Excitation & emission spectra: 45/45 , 35/55 , 25/65 , 15/75**

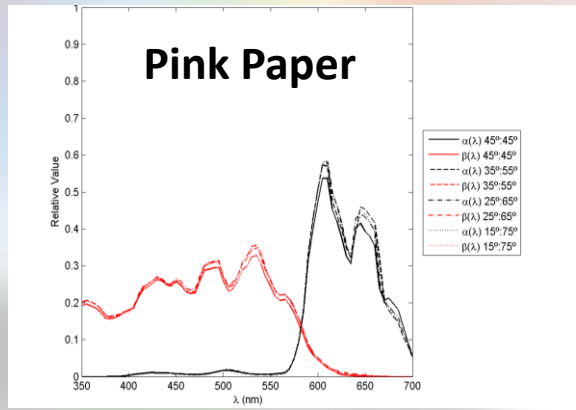






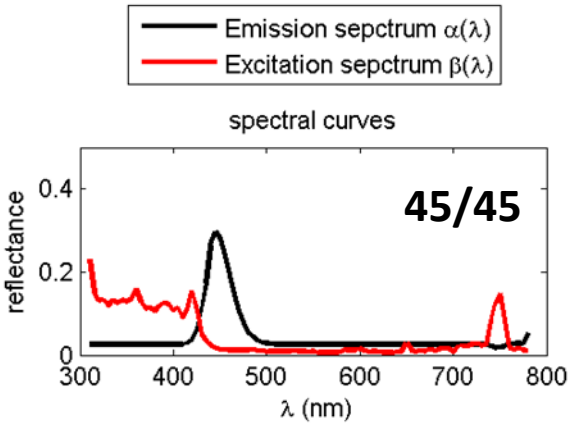


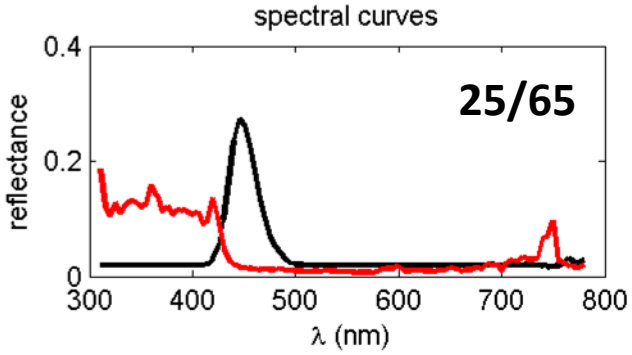


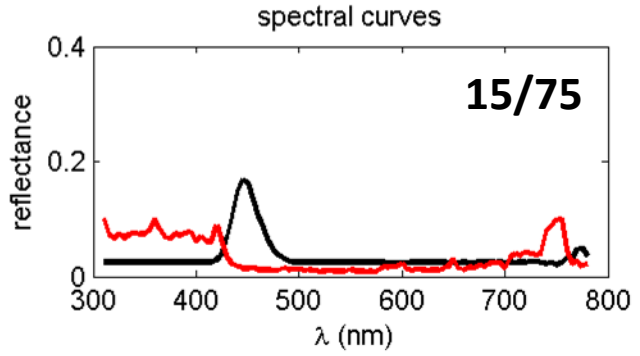


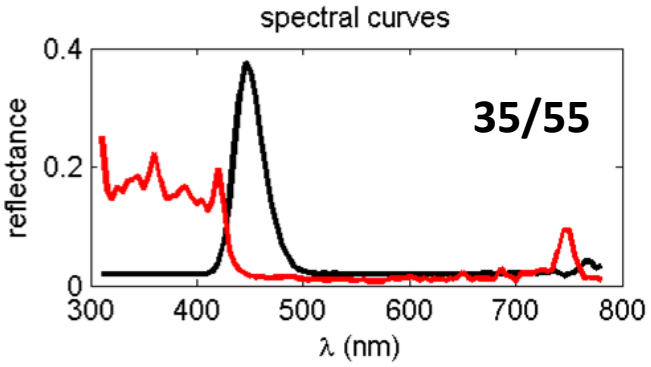
Materials: spectral data

- **FFC02SPU, 4 geom.: 45/45 – 35/55 – 25/65 – 15/75**









Ferrero, A. et al. MEASUREMENT OF GONIOFLUORESCENCE IN PHOTOLUMINISCENT MATERIALS

MEASUREMENT OF GONIOFLUORESCENCE IN PHOTOLUMINISCENT MATERIALS

Ferrero, A.[1], Bernad, B.[1], Velázquez, J.L.[1], Pons, A.[1], Hernanz, M.L.[1], Jaanson, P.[2], Martínez-Verdú, F.M.[3], Chorro, E.[3], Perales, E.[3] and Campos, J.[1]
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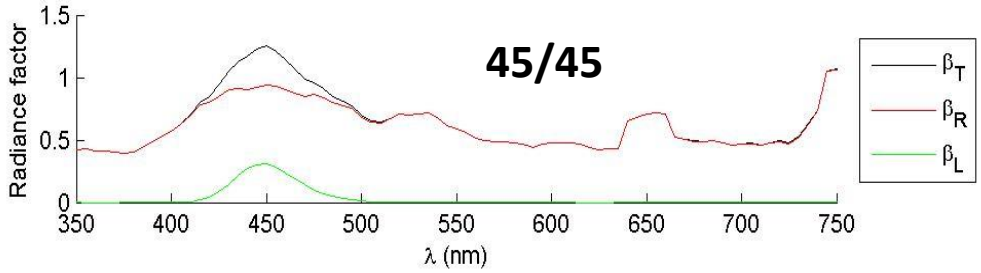
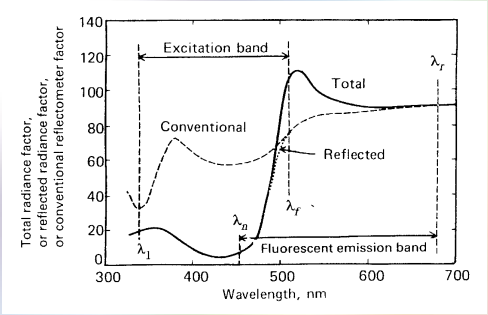
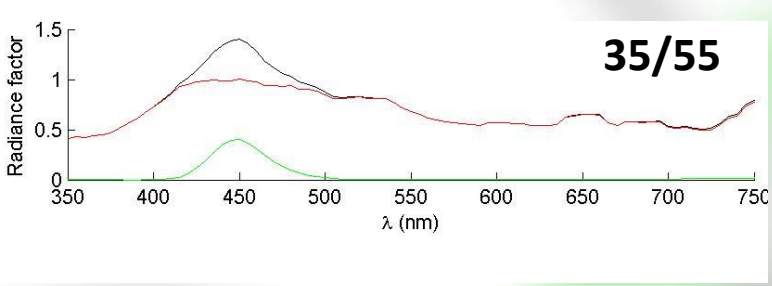
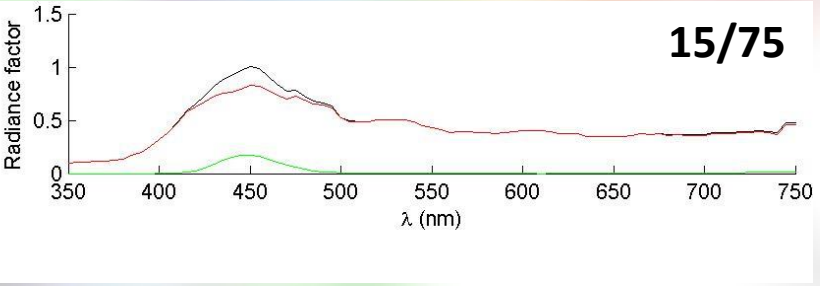
Materials: spectral data

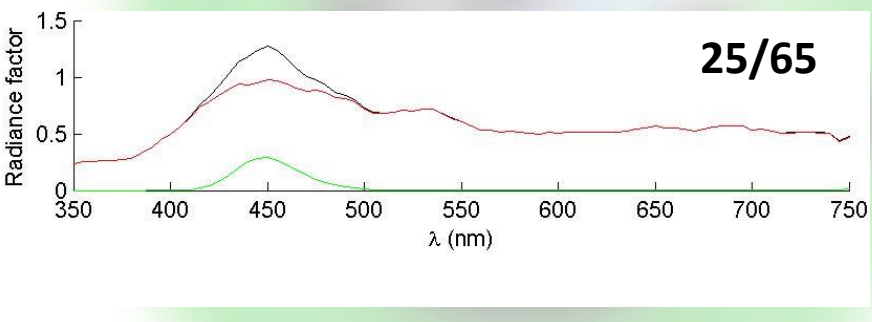
- **Total radiance factor → CIE: all geometries**
  - **Conventional reflectance factor = d/8**





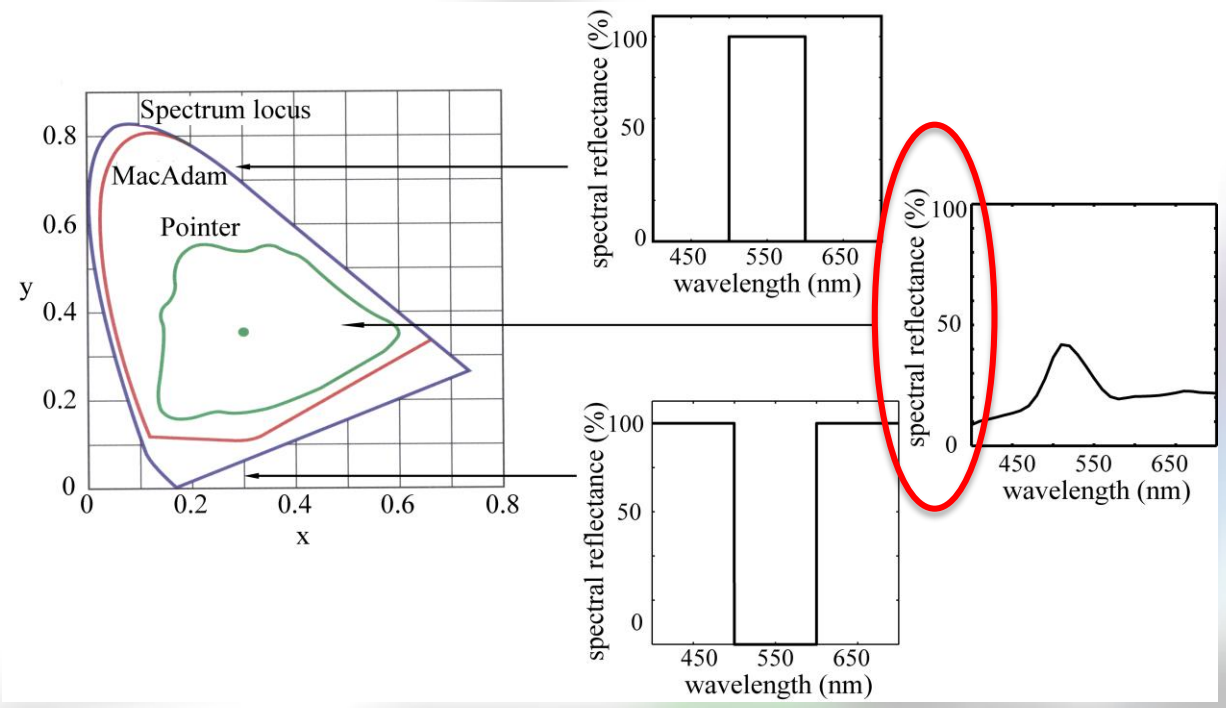


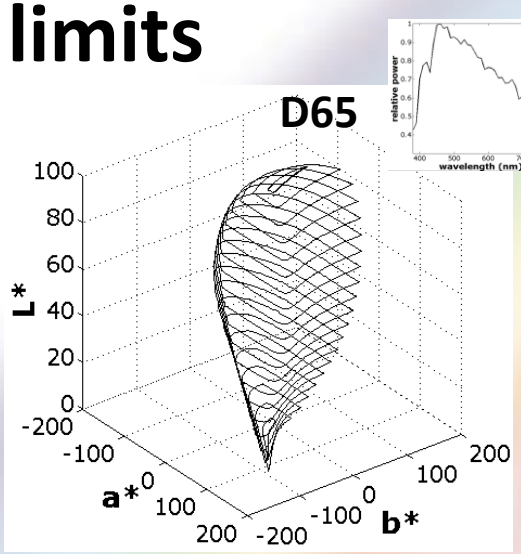


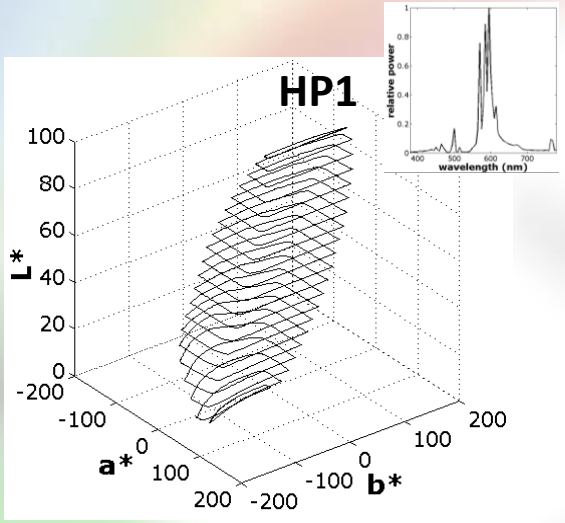


Methods: standard color gamuts

- **Rösch-MacAdam color solid and limits**

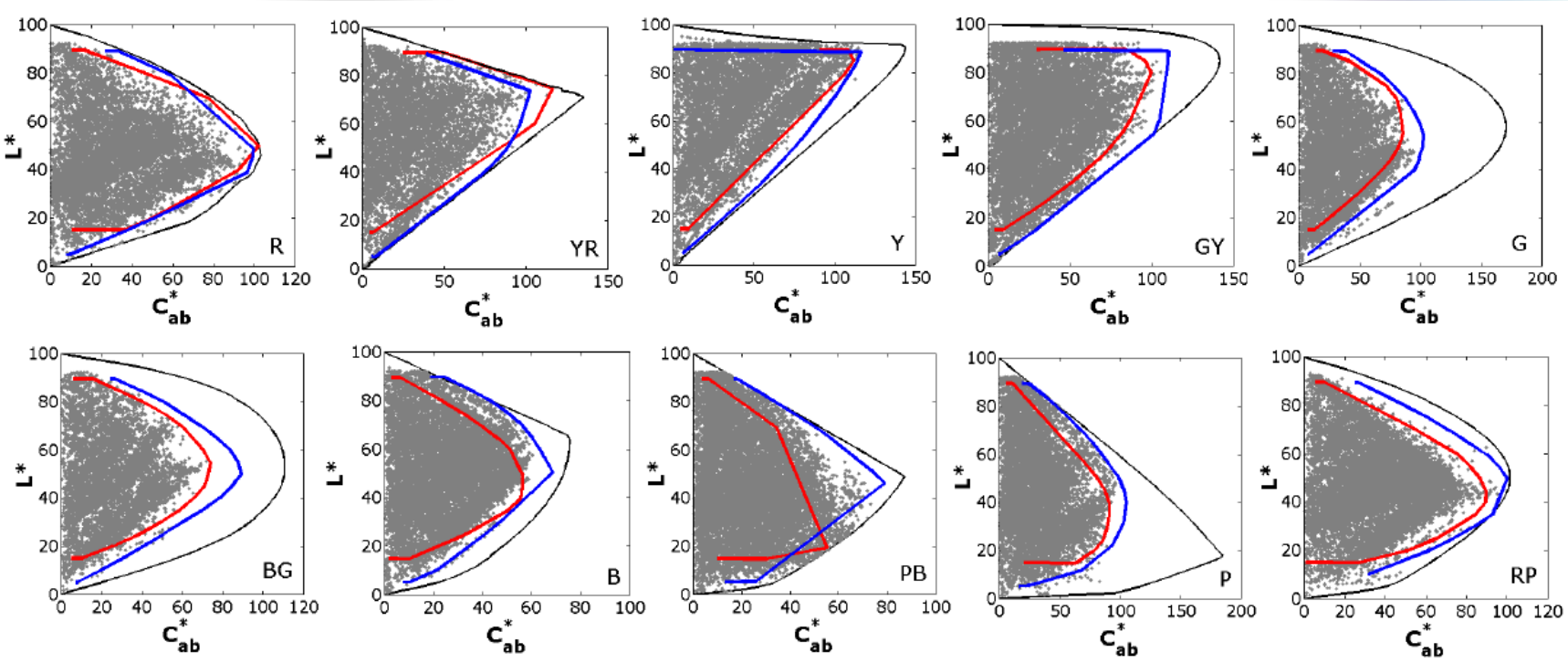






Methods: standard color gamuts

- **Non-fluorescent & gonio-chromatic SOCS**

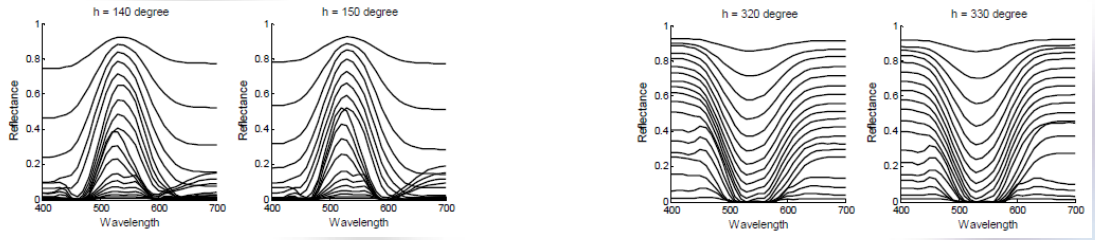


REG2-UA analysis (2009)

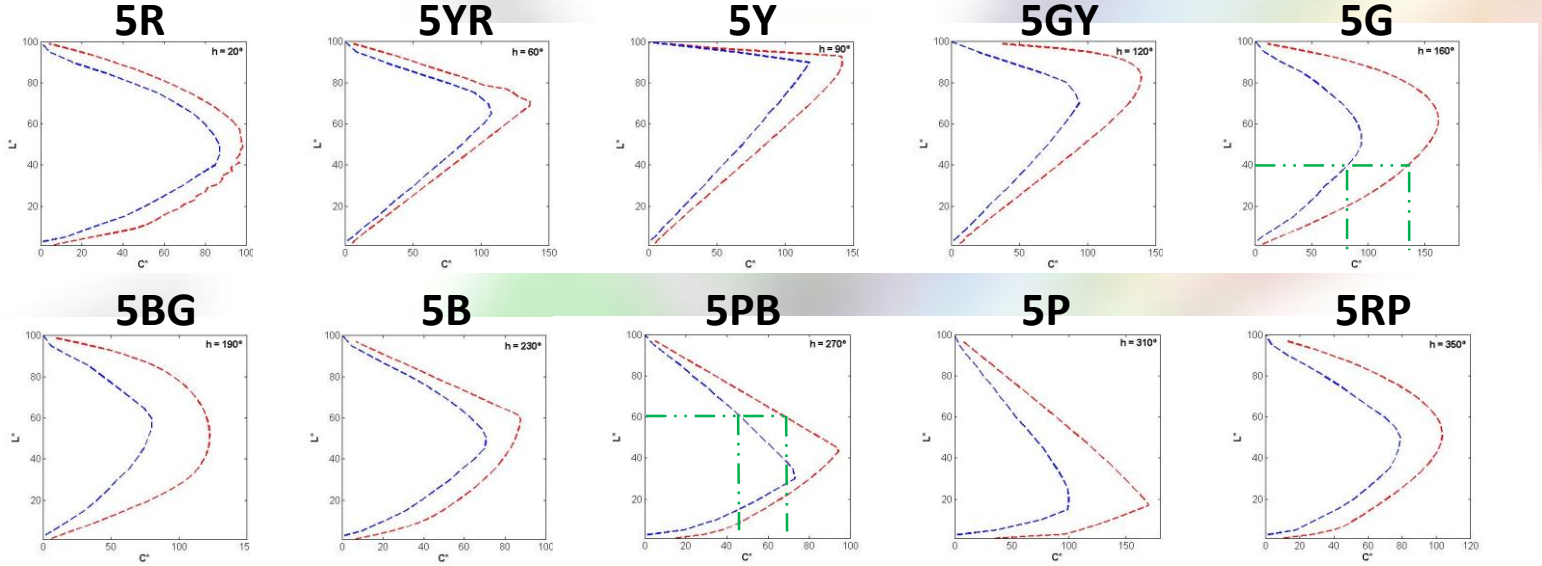
- MacAdam limits
- ISO reference colour gamut (2007)
- Pointer limits (1980)

Methods: standard color gamuts

- **CIE TC1-73 (non-gonio-fluorescent) real colors**
  - **"Spectral Based Gamut for Object Colours" (CR&A 2016), $\rho(\lambda) < 1$**



  - **Gaps among D50 CIE gamuts (blue line) and Mac-Adam limits (out red)**



Methods: standard color gamuts

- **Gaps** among CIE gamuts and Mac-Adam limits
  - Can be they **covered by** gonio and/or fluorescent colors?
  - Chroma ranges according to hue angle – lightness pairs

h* \ L*	10	20	40	50	60	70	90
20°	25 - 55	48 - 67	85 - 93	86 - 98	80 - 96	68 - 83	18 – 38
60°	10 - 15	37 - 45	65 - 85	84 - 98	102 - 120	105 - 135	30 - 55
90°	12 - 20	25 - 35	55 - 70	68 - 85	80 - 102	95 - 120	120 - 145
120°	13 - 22	30 - 42	57 - 80	71 - 97	83 - 115	95 - 130	43 – 135
160°	20- 48	47 - 80	83 - 137	95 - 105	90 - 164	75 - 157	23 - 90
190°	20 - 46	40 - 82	68 - 118	80 - 122	85 - 118	65 - 113	21 - 69
230°	20 - 40	39 - 58	65 - 79	72 - 84	62 - 88	50 - 68	14 - 22
270°	37 - 50	55 - 62	68 - 92	58 - 85	47 - 69	37 - 52	10 - 18
310°	80 - 145	100 - 165	80 - 135	70 - 112	55 - 85	40 - 60	10 - 20
350°	32 - 52	51 - 70	78 - 99	79 - 102	71 - 101	53 - 87	13 - 39

Results

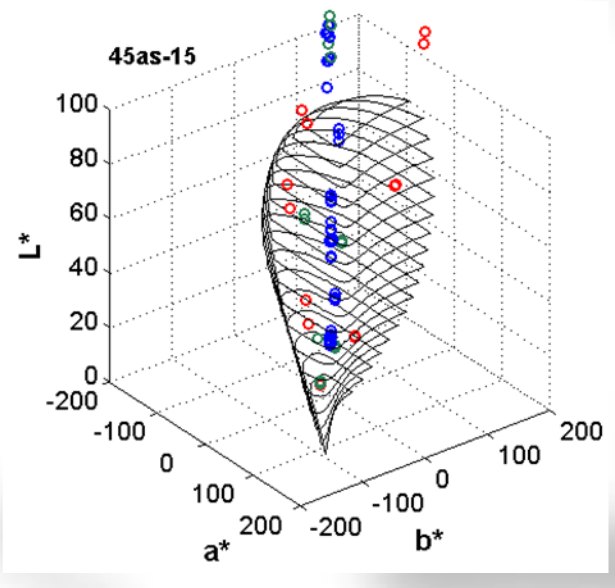
- **xD-Reflect sets vs. MacAdam limits**
  - **$L^* < 100$, but $C^*_{ab} > C^*_{MacAdam}$**
  - **$L^* > 100$**

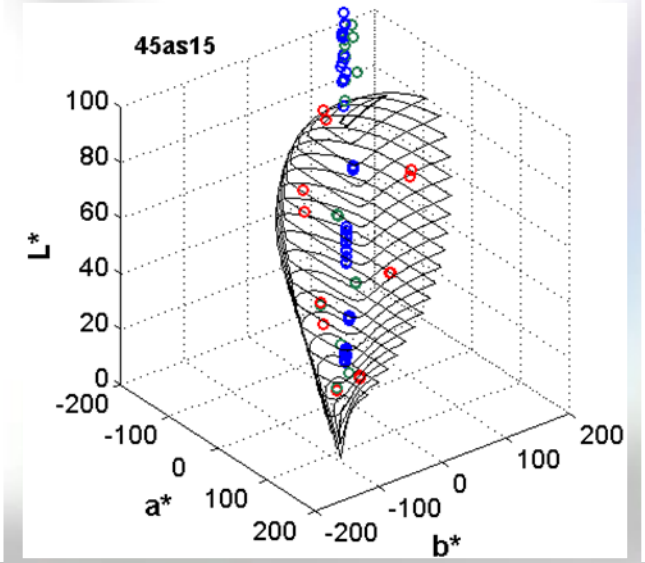
Analysis of the colorimetric properties of goniochromatic colors using the MacAdam limits under different light sources

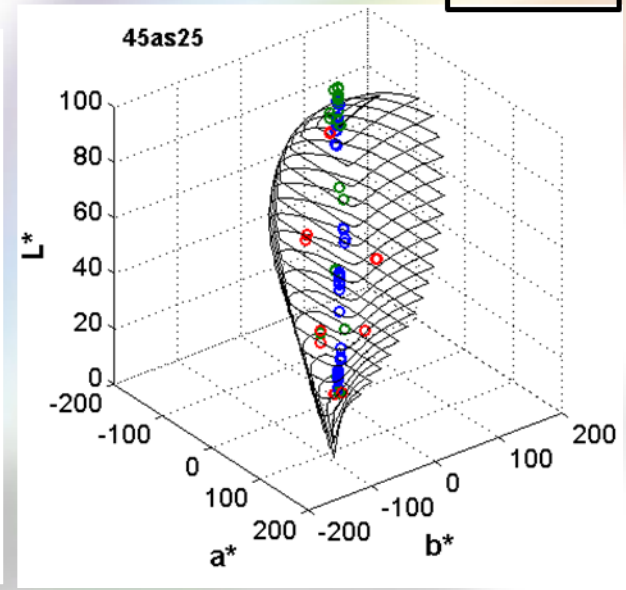
Esther Perales,[1,*] Elísabet Chorro,[1] Werner R. Cramer,[2] and Francisco M. Martínez-Verdú[1]

D65
CIE-1931

Set 1
Set 2
Set 3



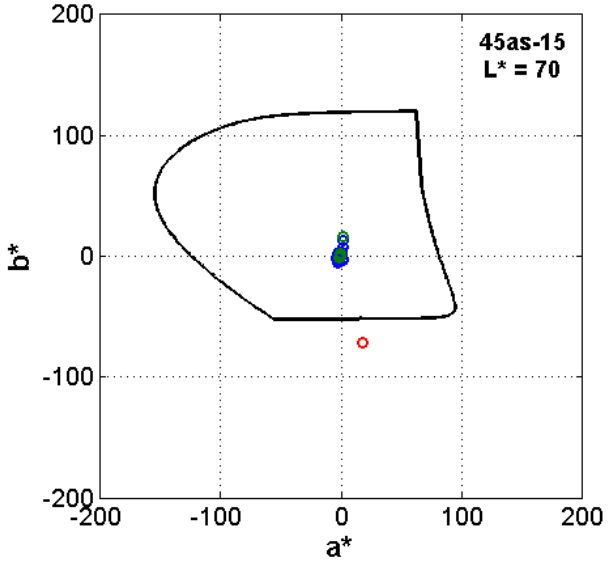


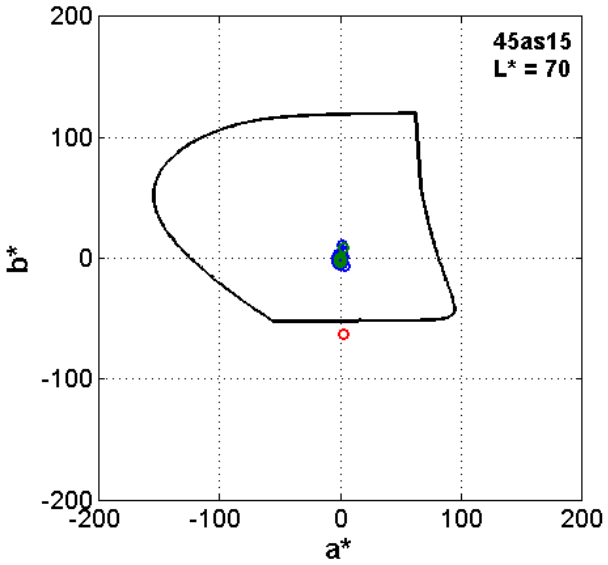


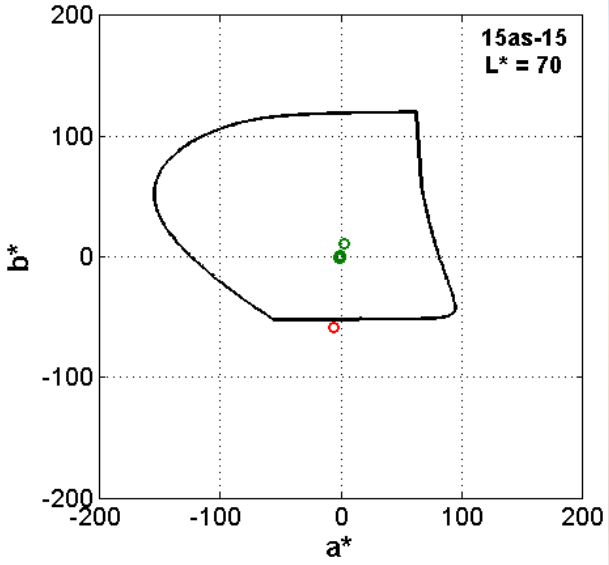
D65
CIE-1931

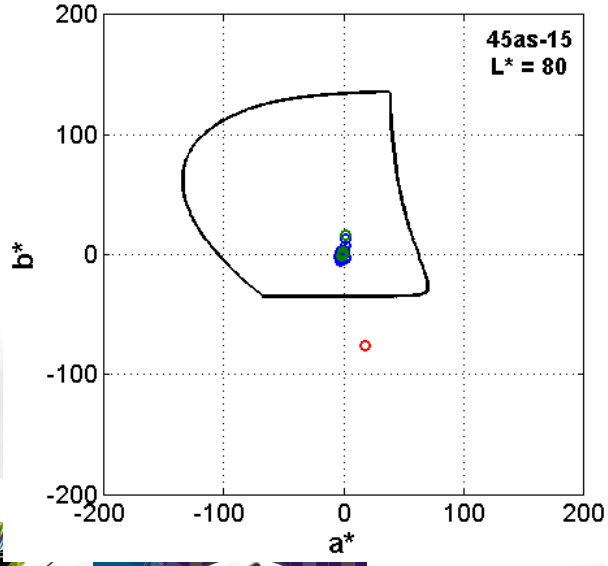
Results

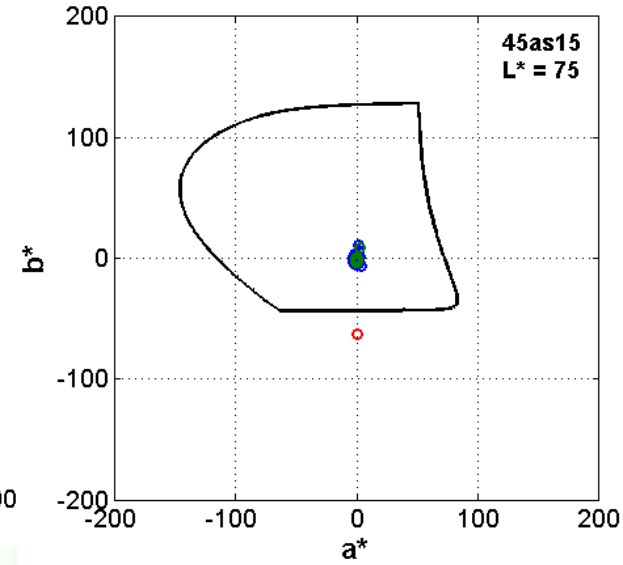
Set 1
Set 2
Set 3

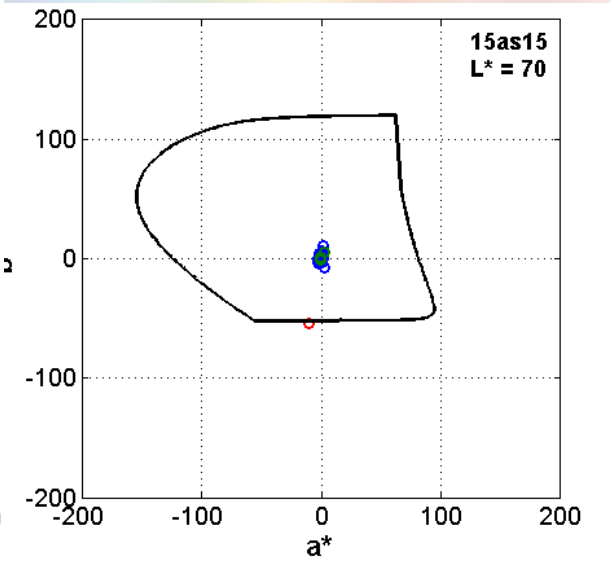






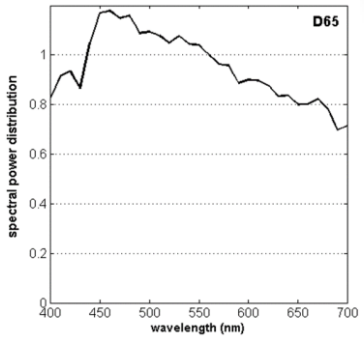


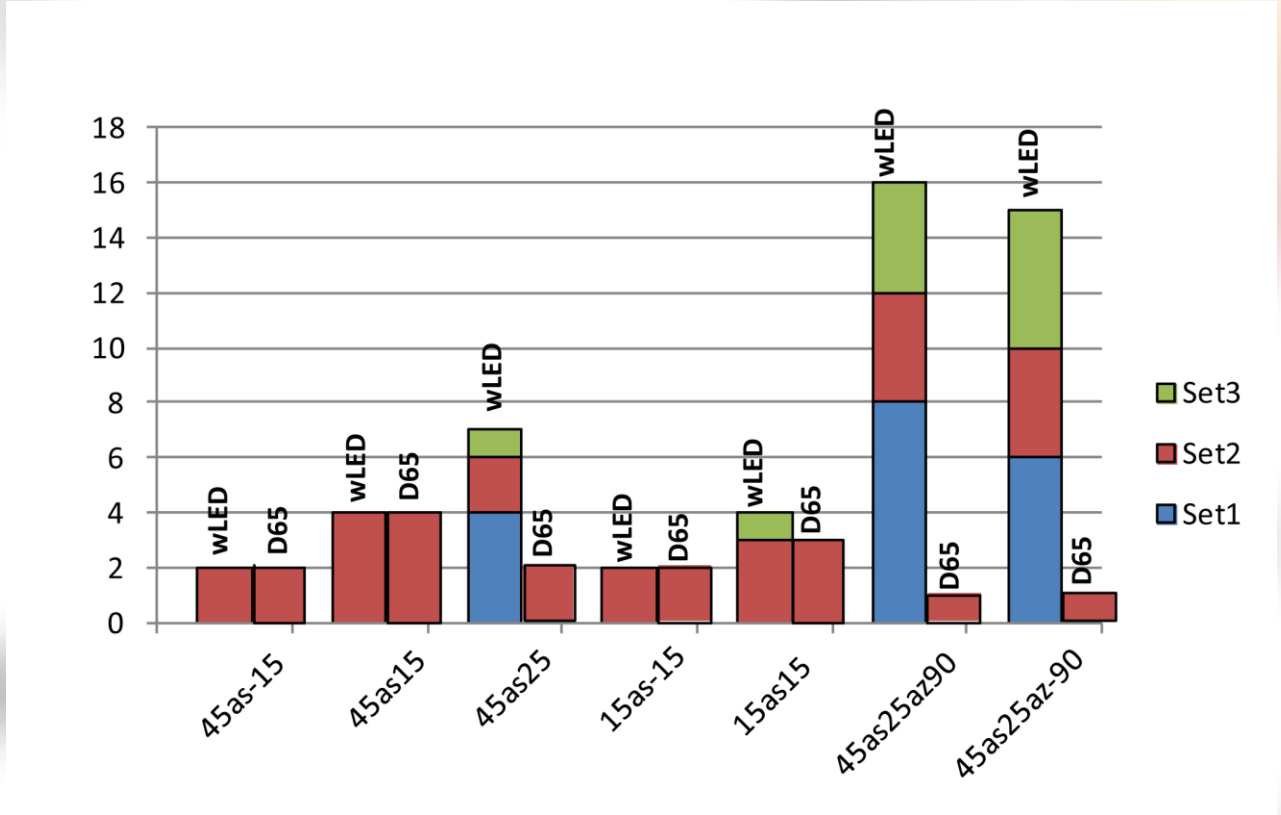




Results

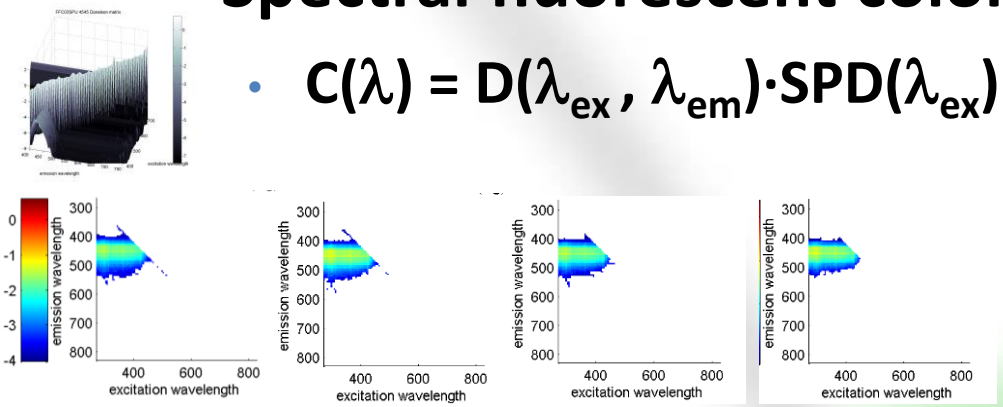
- **$L^* < 100$, but $C^*_{ab} > C^*_{MacAdam}$**
  - **Number of samples does not mean the same specific sample**
  - **Comparing D65 vs. wLED , <u>in vs. out-of-plane</u>**



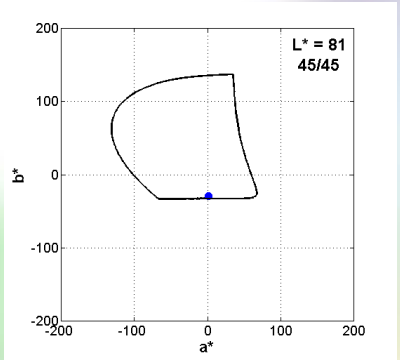


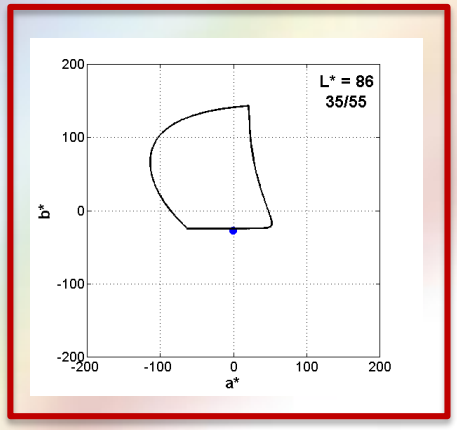
Results

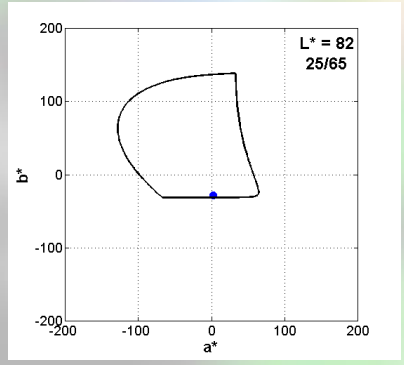
- **CIELAB colorimetry under some CIE illuminants:**
  - **Spectral fluorescent color stimulus:**
    - $C(\lambda) = D(\lambda_{ex}, \lambda_{em}) \cdot SPD(\lambda_{ex}) \Rightarrow$ CIE-XYZ , CIE-L*a*b*

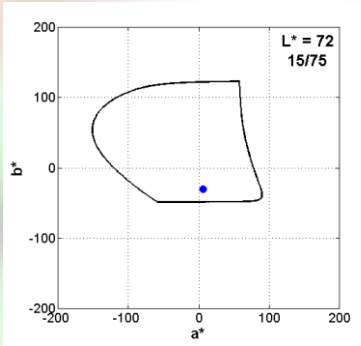


FC02SPU CIE-1931 D65	L*	a*	b*
45/45	81,26	1,72	-29,08
35/55	86,62	-0,87	-27,46
25/65	82,56	2,14	-28,10
15/75	72,87	5,82	-30,53









Preliminary conclusions

- **There are gonio and/or fluorescent colors <u>outside</u> MacAdam limits:**
  - **Goniochromatic samples (examples): $C^* > C^*_{MacAdam}$**
    - **D65, wLED:**
    - **18% Irodin 9221 SW Rutile Fine Blue (Set 2)**
    - **wLED:**
    - **18% Iriodin 9103 SW Rutile Sterling Silver (Set 1)**
    - **Stapa 1515 Cornflake (Set 3)**
  - **Fluorescent samples (examples):**
    - **FFC02SPU: 35/55 ($C^* > C^*_{MacAdam}$)**
    - **FFC02GOU: 45/45 ($C^* > C^*_{MacAdam}$)**
    - **FFC02HGU: 45/45 ($L^* > 100$)**

Preliminary conclusions

- **Special-effect and fluorescent pigments can generate perceptible colors outside the classical color solid**
  - **$L^* > 100$**
  - **$L^* < 100$ but $C^*_{ab} > C^*_{MacAdam}$**

- **These new perceptible colors depend on the measurement geometry and SPD of the light source**
  - **even for in vs. out-of-plane geometries**

Prospective

- Can gonio & fluorescent samples, inside MacAdam limits, cover “gaps” in the ISO/CIE gamuts?
- SPD influence: CIE illuminants vs. SSL lamps
- Theoretical approach: optimal fluorescent colors
  - Excitation (β), emission (α), optical / math modeling
- Also extensible for goniochromatic colors? How?
- Practical approach:
  - Can we apply current or new coloration technologies for producing gonio & fluorescent colors outside MacAdam limits and perceive new discernible colors?

Color gamut of goniochromatic and fluorescent colors

Francisco Martínez-Verdú (REG2- UA)

6th Progress xD-Reflect meeting
21 – 23 June 2016, Torino (Italy)