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Whiteness Assessment of Papers – Impact of LED Illumination

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Presentation Outline

- **Whiteness Assessment**
  - What, Why, How ?
  - CIE Method: Limitations
- **Whiter than White**
  - Physics of FWAs
  - NRC Measurement of Fluorescent White
- **Impact of LED sources on Whiteness**
  - SPDs of White LEDs
  - NRC Simulation Results for White LEDs
- **Conclusions**

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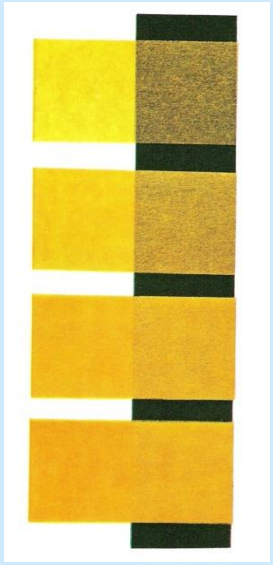
Optical Properties of Paper

- Brightness
- Opacity
- Colour
- Gloss
- **Whiteness**



Product Specifications:

Whiteness 159 CIE (ISO 11475)

Brightness 98% (ISO 2470)

Opacity 95% (ISO 2471)

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Benefits of Increased Paper Whiteness

- **Aesthetic:**
  - enhanced visual appearance
- **Practical:**
  - Improved print quality
    - **Sharper contrast** in B/W printed images
    - **Improved colour brilliance** in colour prints
- **Economic:**
  - Cost of increasing whiteness by 1 unit in fine white paper is *~$3-4 USD/ ton, or ~* ***$100M USD in Canada***

2002 Metrotrade

"It **commands premium value in the marketplace** to have a paper product that is seen as being **very white**".

Robert Wood, Executive Director of the Pulp and Paper Technical Association of Canada

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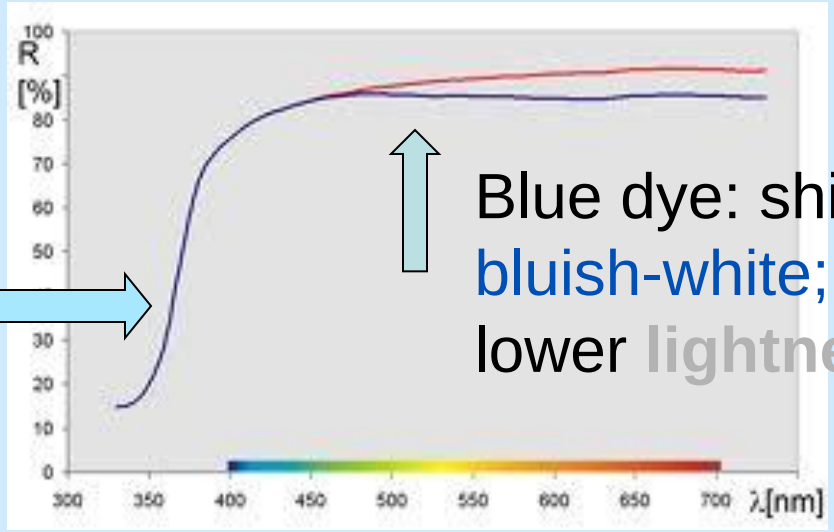
What is Whiteness?

White vs Whiteness

- **Ideal White:** maximum luminous reflectance, no chroma, no saturation (PRD)

- c.f. **White in Nature**

Absorption in UV and blue **=** **yellowish shade**



Blue dye: shift to bluish-white; lower lightness

- People prefer “bluish-white” to grayish, yellowish, etc. whites

- **Whiteness**: high level of luminous reflectance, blue hue, finite saturation (perceptual attribute)

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CIE Whiteness Assessment

CIE Whiteness (10°):

*CIE 15:2004**

$$W_{10} = Y_{10} + 800(x_{n,10} - x_{10}) + 1700(y_{n,10} - y_{10})$$

LIMITATIONS:

-Only for **D65**

-Only for **Near- whites** (CIE limit on W)

$$40 < W_{10} < 5Y - 280$$

*"samples ...**do no differ** much in **colour** and **fluorescence**,..

- Only gives **relative values**: *"..measured on the **same instrument** at nearly the **same time**."

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ISO Standards for Whiteness

- **ISO 11475:** Paper and board – **Determination of whiteness, D65/10° (Outdoor illumination conditions)**

- **ISO 11476**: Paper and board – **Determination of whiteness, C/2° (Indoor illumination conditions)**

Whiteness is based on measurements of:
- **radiance (reflectance) factor data** over the **full visible spectrum**
- **dependent on** the **illumination conditions**

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Key assumptions of Whiteness assessment

- **Colorimetric measurements of Whiteness**
  - Are relevant to end use value only if users **view paper under illumination similar** to that of **reference illuminant**
- **Viewing under Daylight** (outdoor or indoor) conditions
- **CIE whiteness equation is valid** for **CIE illuminant C** (CCT is 6770 K c.f. ~6500 K for D65)

Assume:
Sources with **Similar CCT** give
Similar Whiteness assessment

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Increasing Paper Whiteness, *W*

Increase substrate whiteness:

- Highly bleached pulp
- High bright fillers

Compensate yellowishness:

- Shading colorants (violet, blue)

Adding blue light:

- Fluorescent whitening agents (FWAs)

***W* = 100** *for perfect reflecting diffuser (**PRD**)*

Before FWAs: *W ~ 85*

In Yr 2000 : *W ~ 135*

In Yr 2002 : *W ~ 149*

NOW : ***W ~ > 160 !!***

(at CIE Limit)

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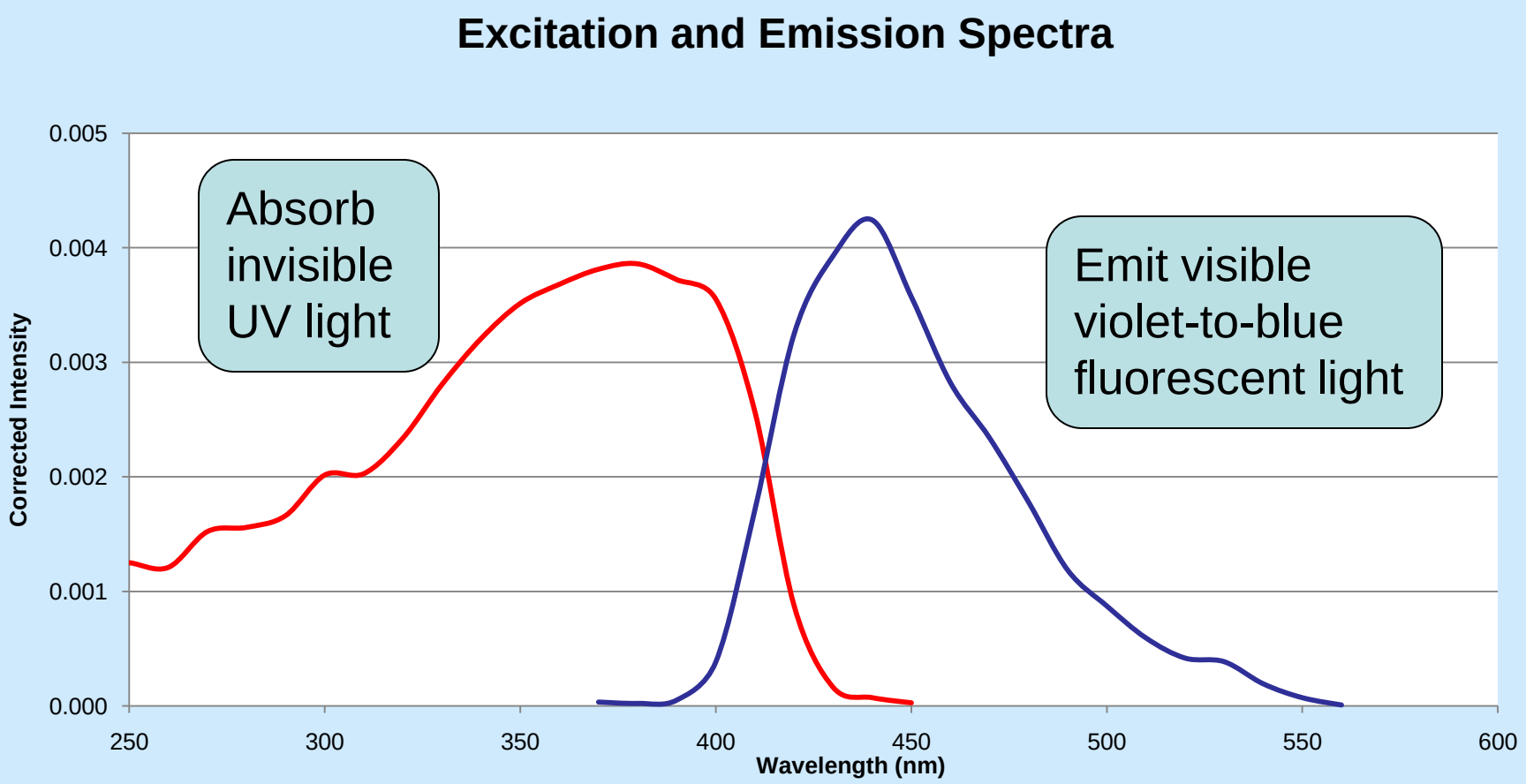
FWA – Excitation/Emission



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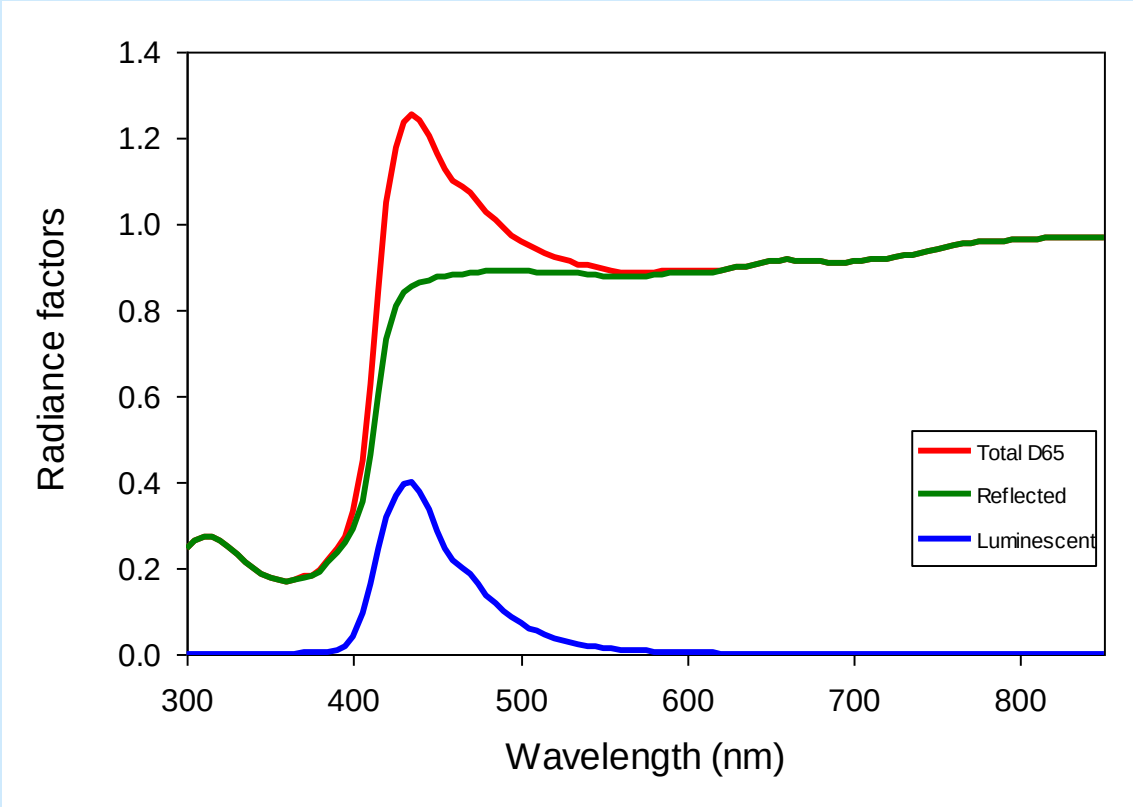
Whiter than White



Fluorescent light (FWA)
+
Reflected light (substrate)
=
Total (whiter than white)

Measure Total Radiance (Reflectance) Factor

$\beta_T = \beta_R + \beta_F$

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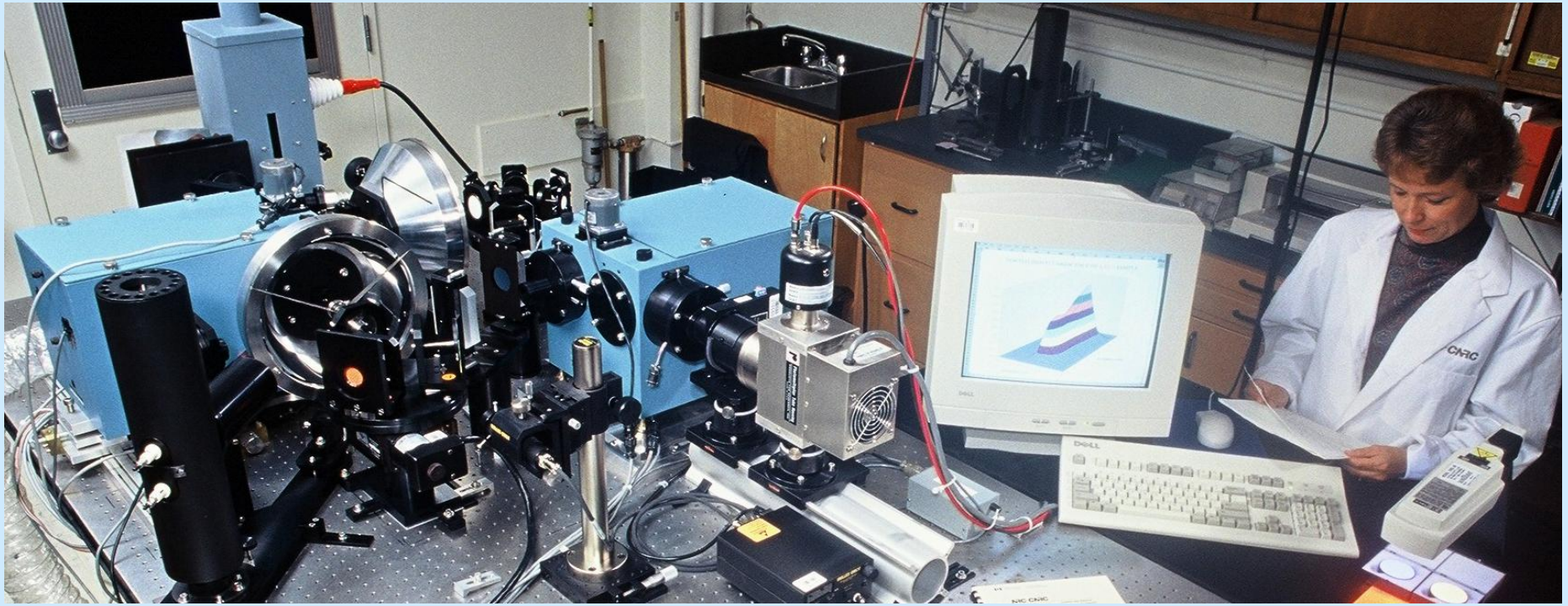
NRC Reference Spectrofluorimeter



- **Based on two-monochromator method**
- **Measurement geometry: 45° annular illumination/ 0° viewing (45°a::0°)**

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NRC Whiteness Assessment

Total Spectral Radiance Factors

β_T (45°a/0°); $\beta_T = \beta_R + \beta_F$

- *200 nm to 1040 nm*
- *Selected illuminants (D65, C,A, D50,custom)*
- *in accordance with ASTM E991*

$$W_T = W_R + W_F$$

Total Whiteness = Whiteness *(**reflected**)* + Whiteness *(**fluorescent**)*

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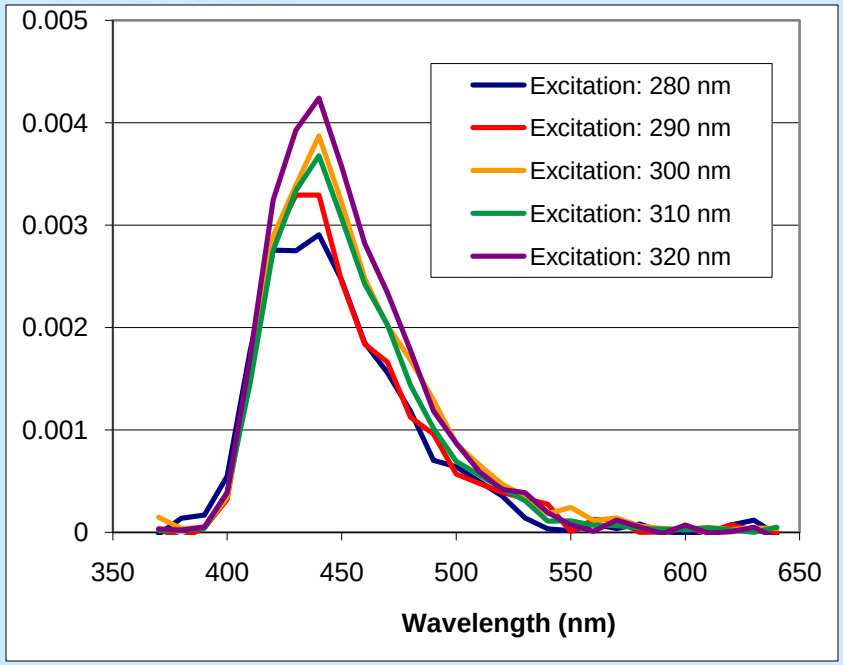
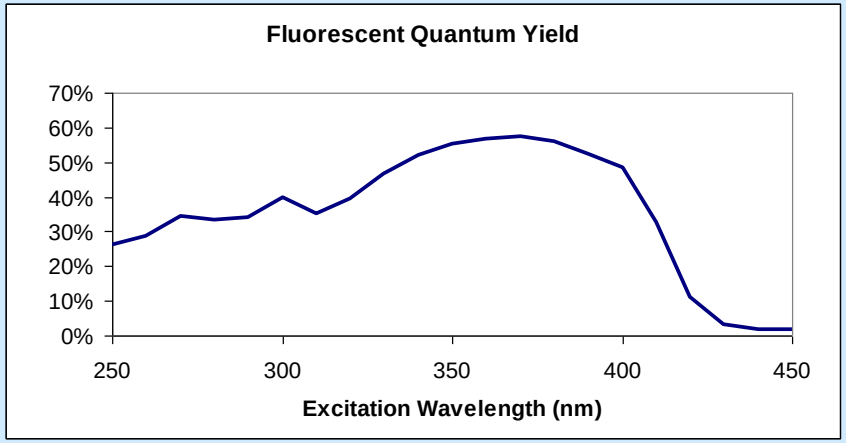
Fluorescent Paper Results





Considerations:

- **Shape of fluorescent peak depends** on **Excitation λ**
- **Fluorescence intensity** (quantum yield) **depends** on **Excitation λ**

Conclusion:

- **SPD** of source is important to both **shape** and **intensity** **of fluorescent light** NOT just relative UV/visible output

Need to measure **bispectral fluorescence**

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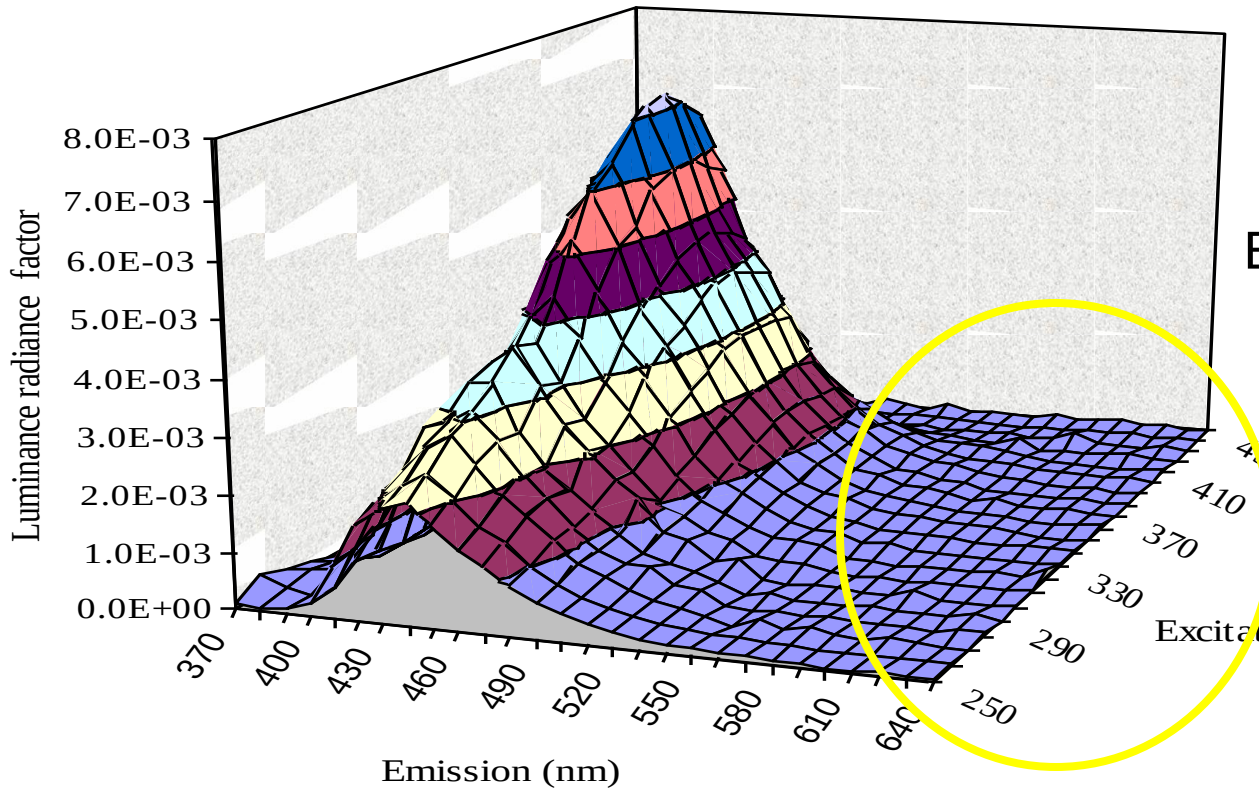
Fluorescent Paper Bispectral Results



Excitation in both

UVA & UVB

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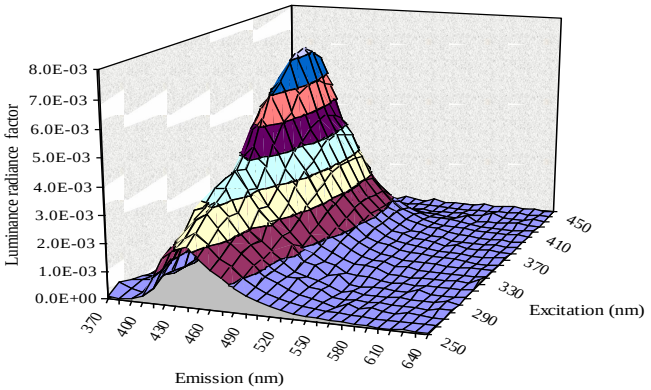
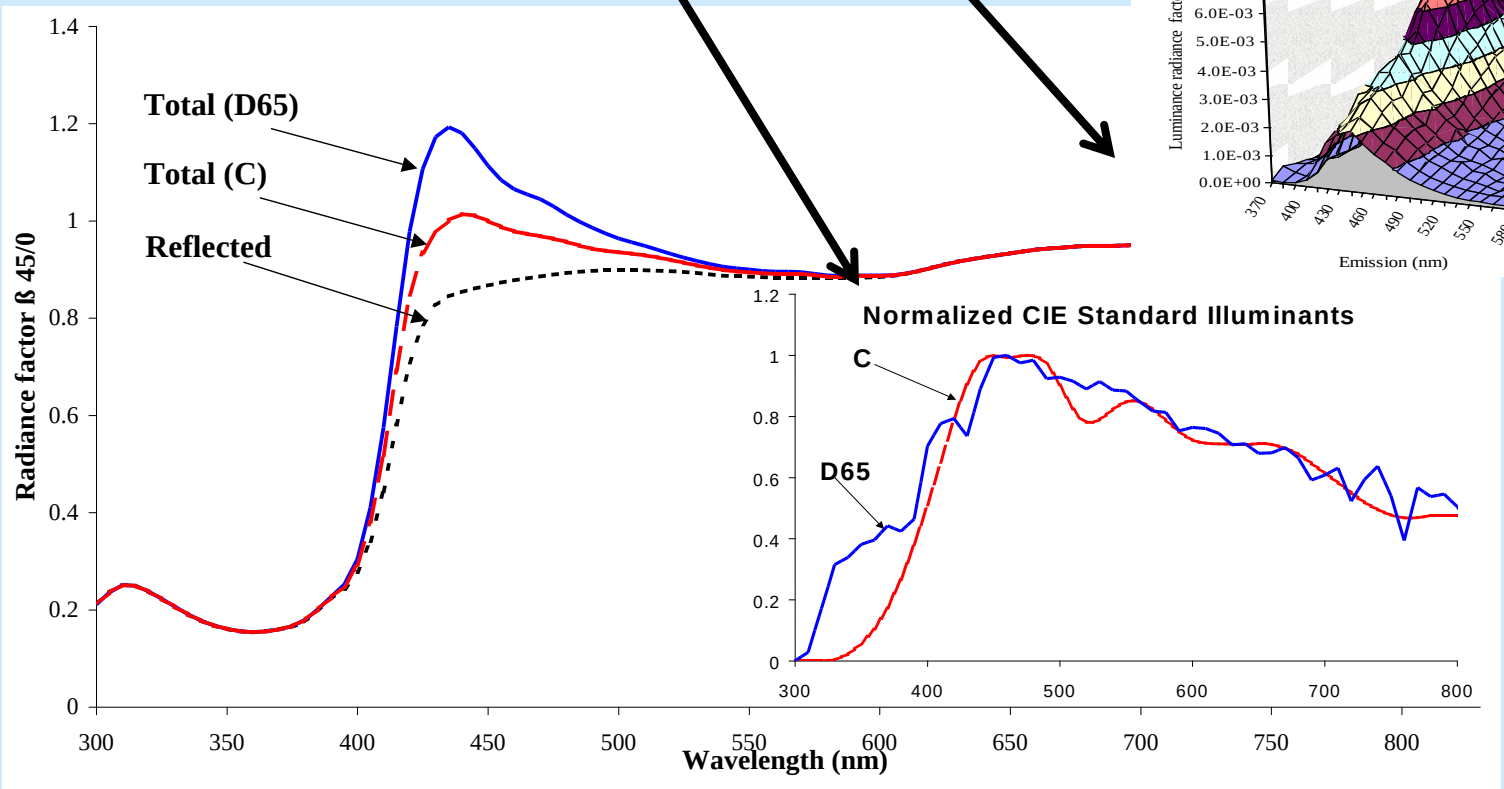
Effect of Illuminant SPD

$$\beta_L(\lambda) = \int_{\mu} E_{st}(\mu) \cdot \beta_{L\lambda}(\mu) d\mu \,/\, E_{st}(\lambda)$$





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Assessing Impact of Source on Whiteness

- Whiteness is ADDITIVE

$$W = Y + 800(x_n - x) + 1700(y_{n,} - y)$$

Y } Lightness (mainly due to non-fluor. substrate)

$800(x_n - x) + 1700(y_{n,} - y)$ } Colour Shift (mainly due to FWA)

Impact of Source: ***W*** **-** ***Y***

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Assessing Impact of Source on Whiteness

- Whiteness is ADDITIVE

$$W_T = W_R + W_F$$

W_R — Whiteness due to reflected light (source-independent)

W_F — Whiteness due to fluorescent light (**source-dependent**)

Impact of Source: $W_T - W_R$

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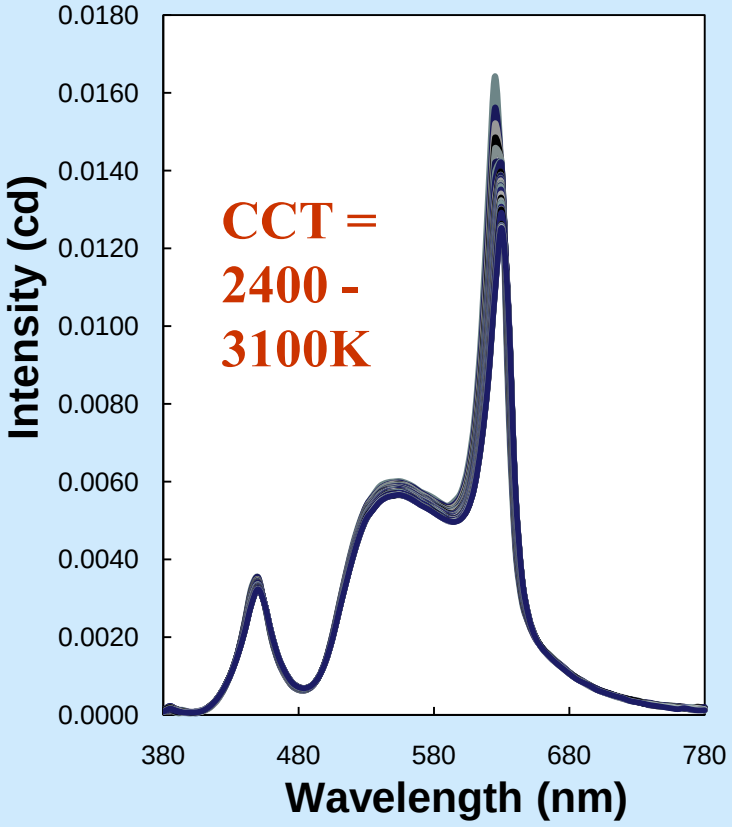
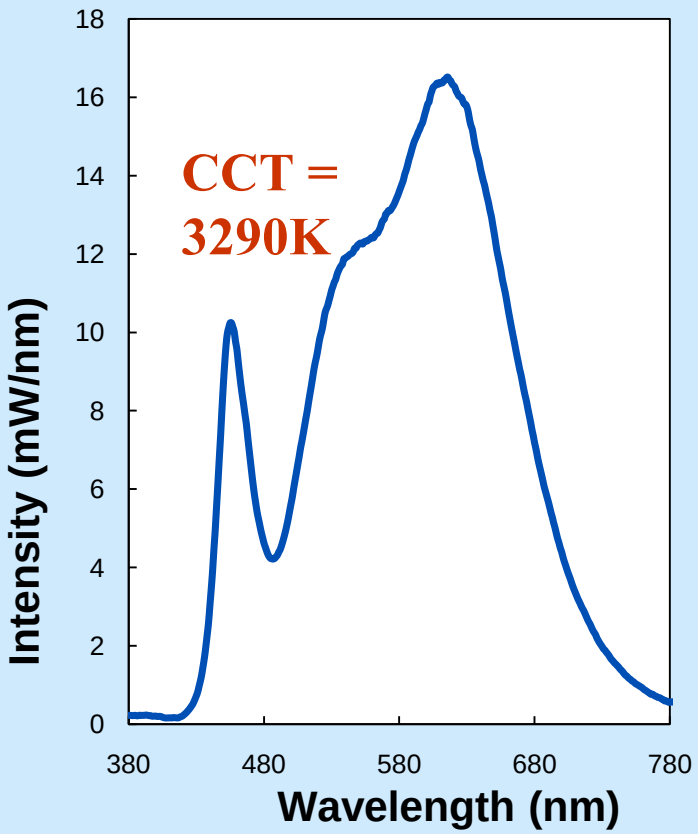
White LED SPDs

Incandescent replacement



Pot light replacement



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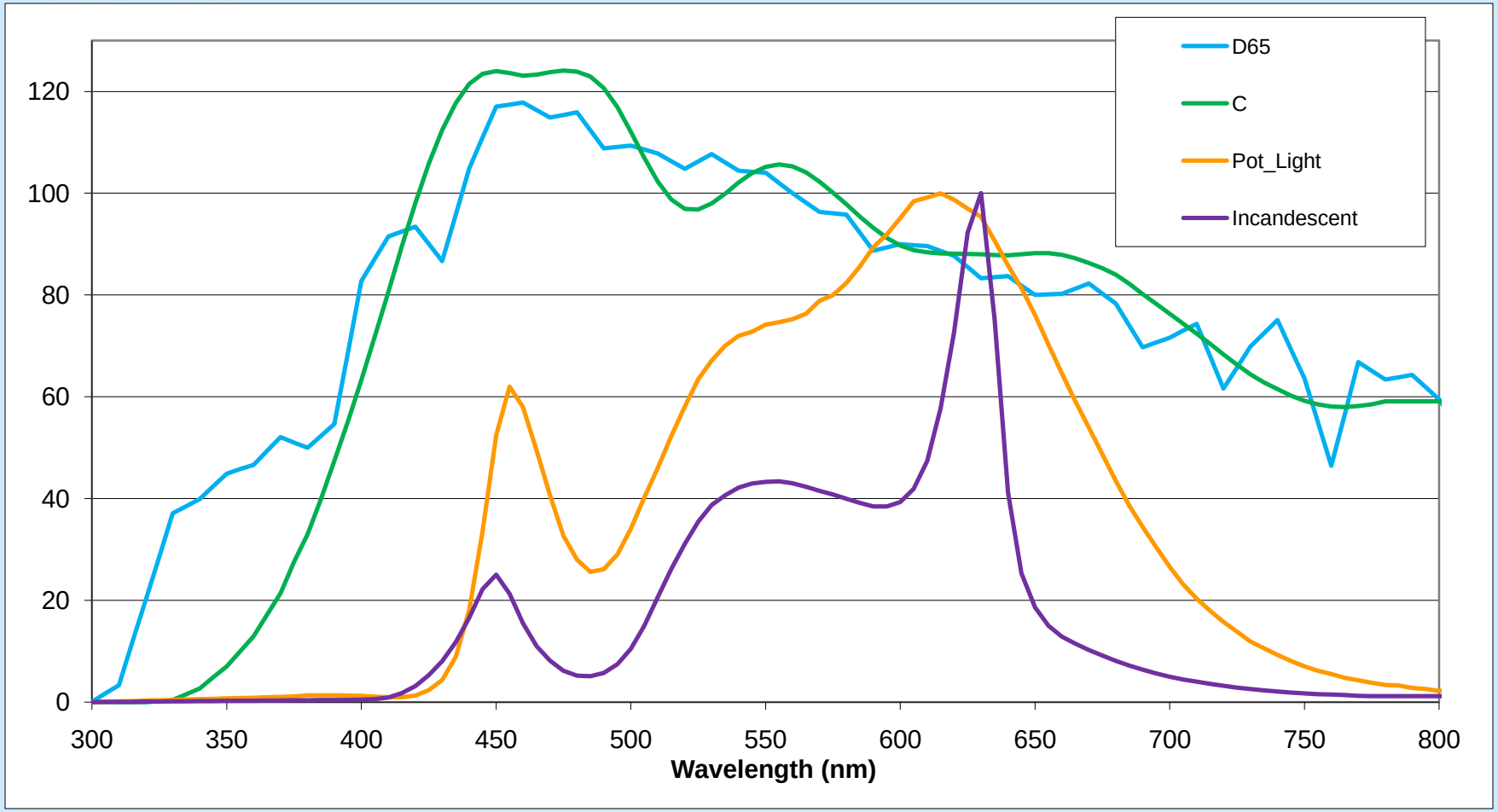
Differences in SPDs



Assume: constant interpolation of SPD from 380 to 300 nm

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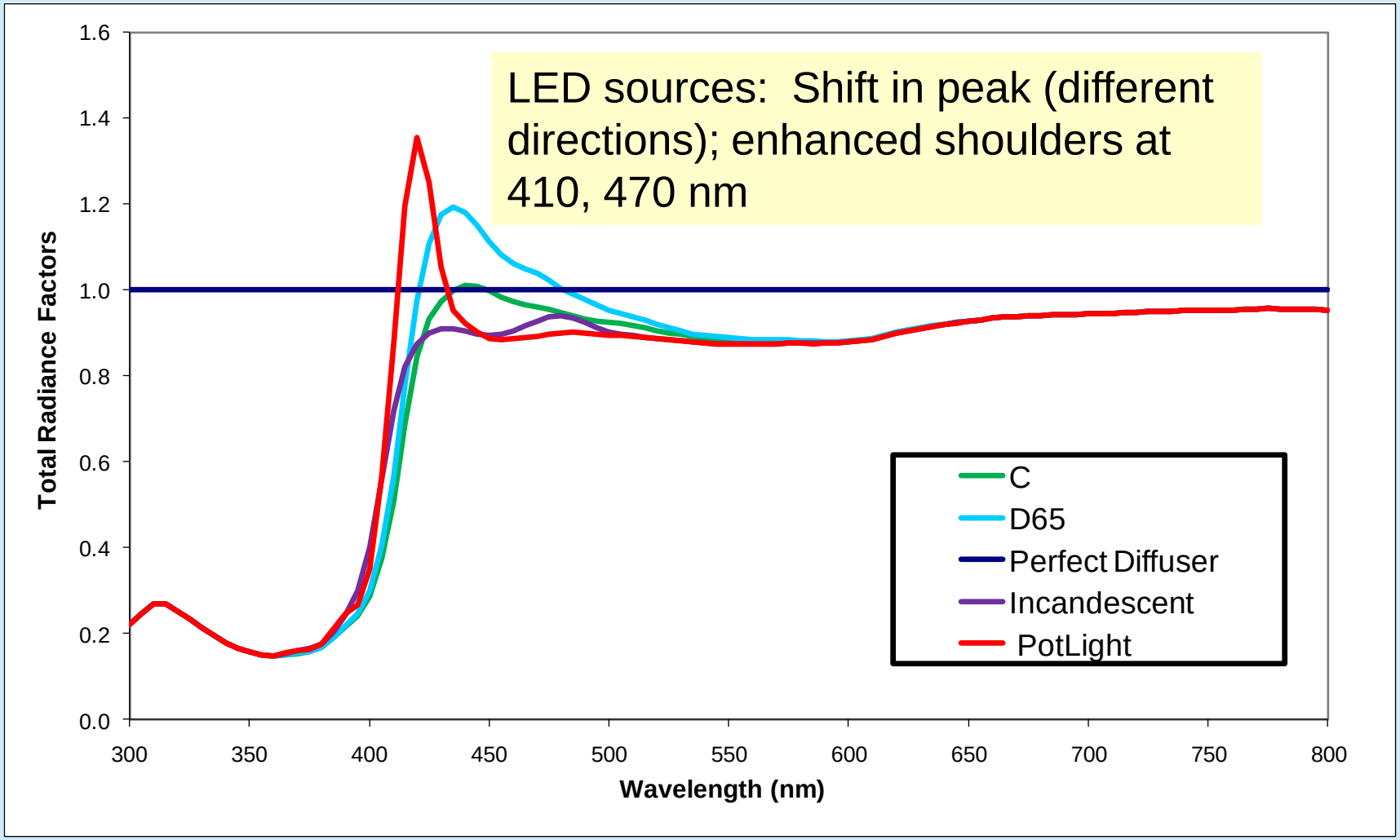
Total Radiance Factor Results



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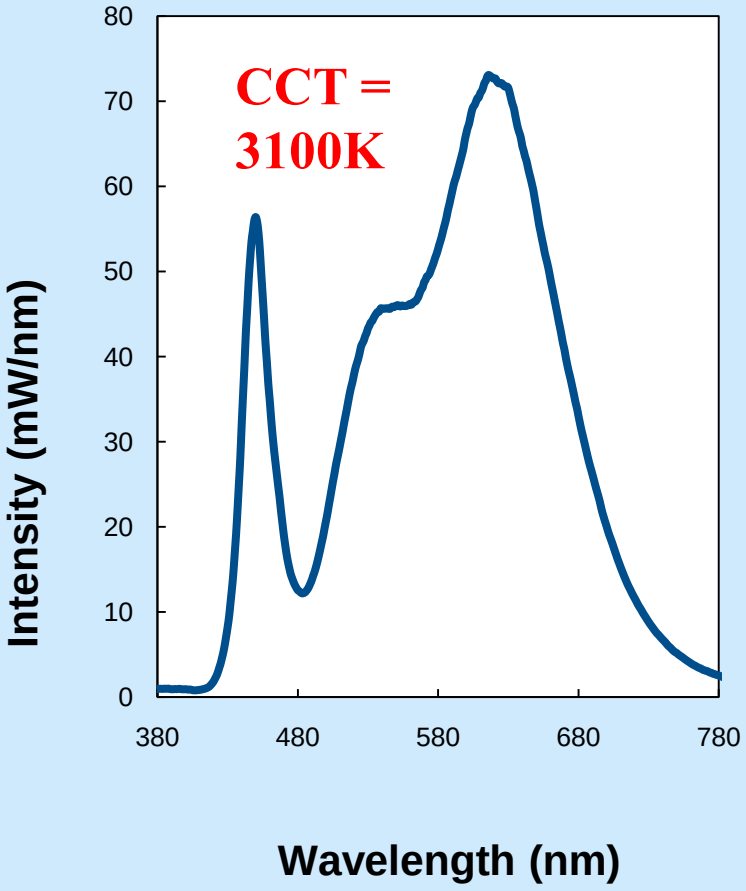
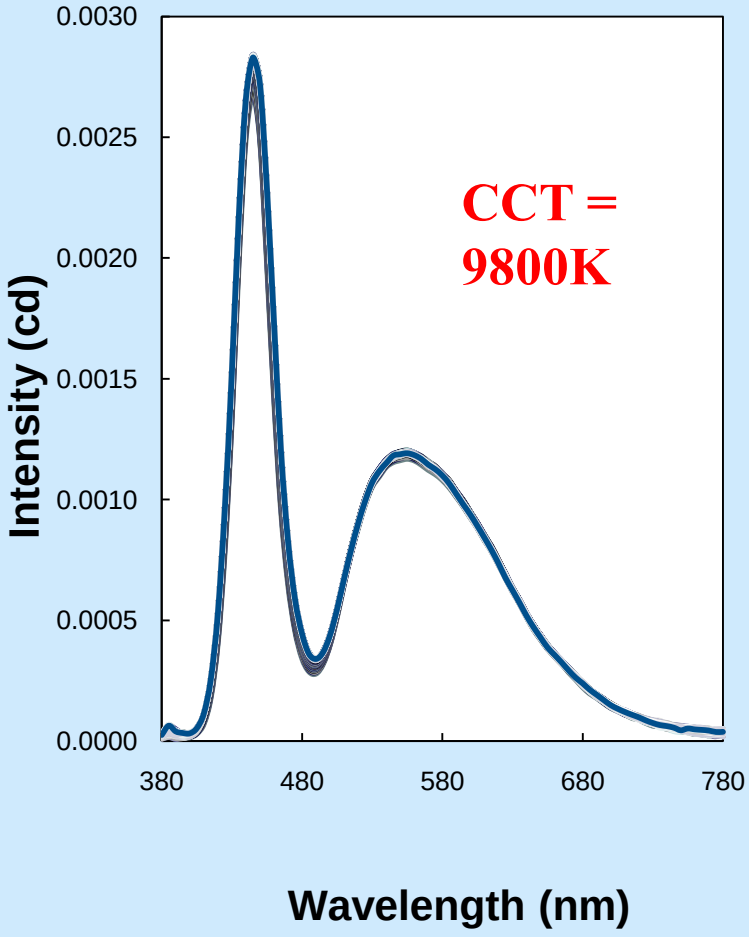
White LED SPDs

Fluorescent replacement



Light engine



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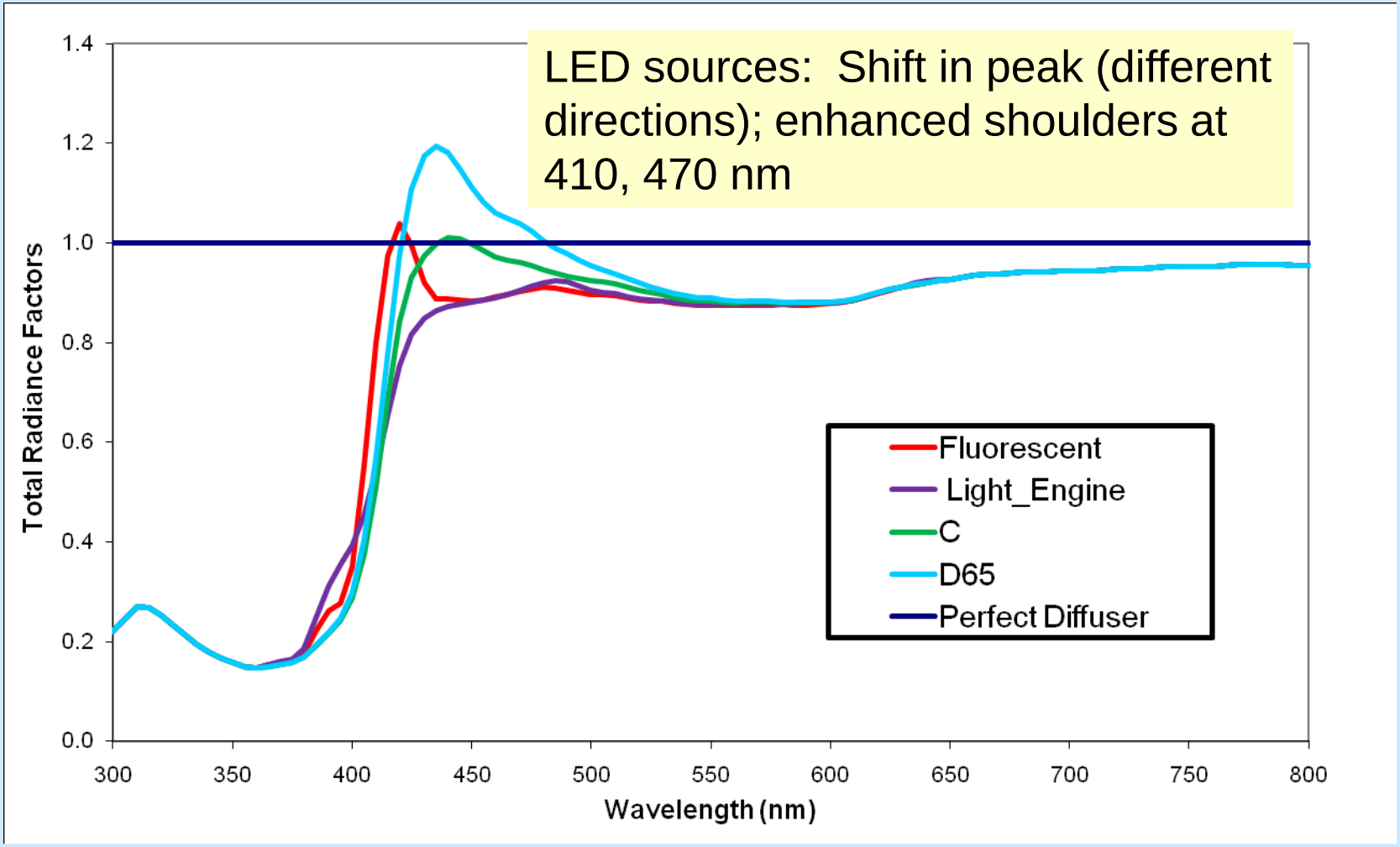
Total Radiance Factor Results



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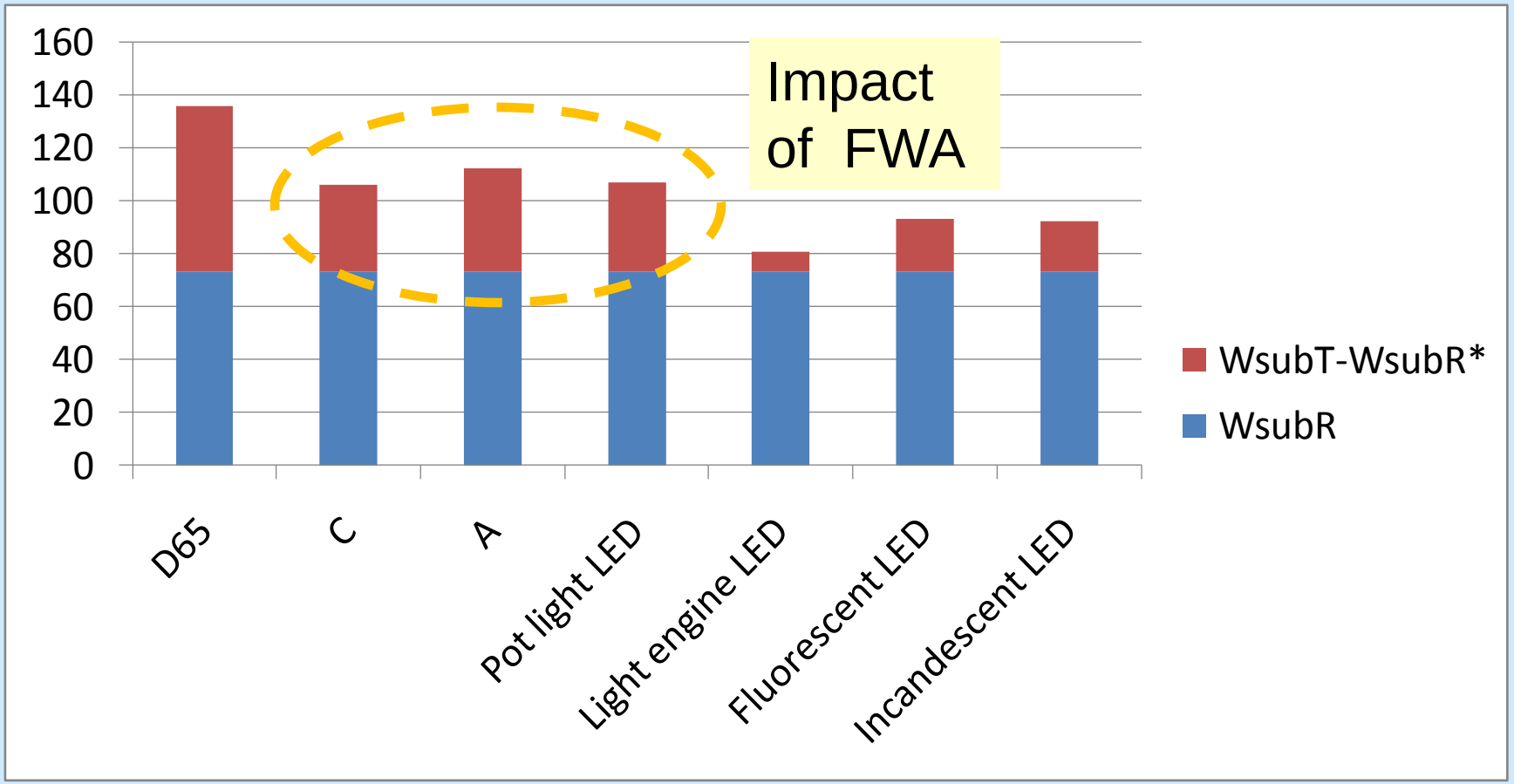
Whiteness Results

Impact of Source: $W_T - W_R$

ISO 11475 CIE Whiteness (D65/10)



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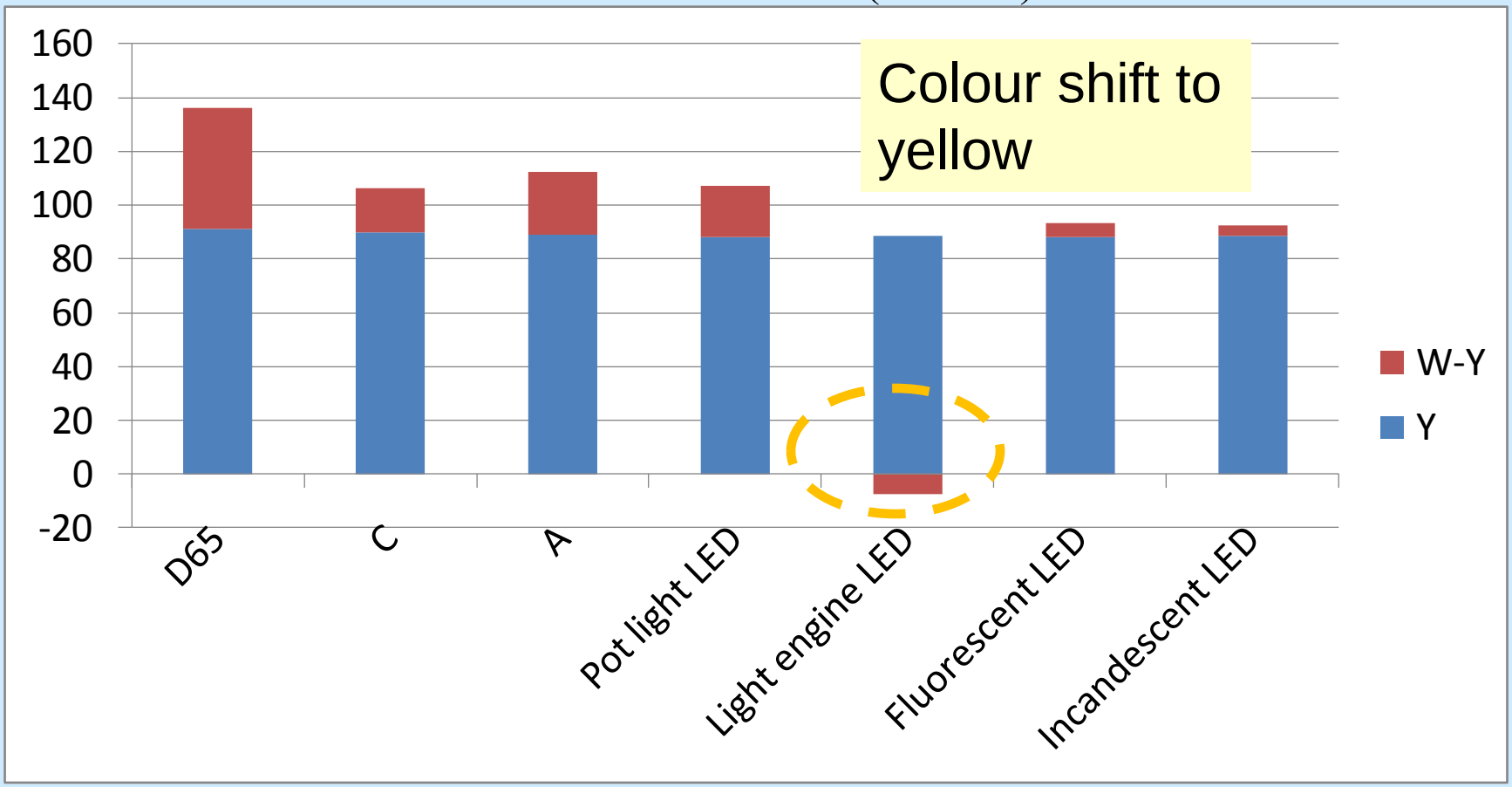
Whiteness Results

Impact of Source: *W* - *Y*

ISO 11475 CIE Whiteness (D65/10)



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Conclusions

- **Limitations to current methods of whiteness assessment:**
  - Need Source SPD data to 300 nm
  - Validity needs to be tested for white LEDs
    - differ considerably from CIE illuminant conditions
- **CCT** – not sufficient metric for characterizing whiteness of paper
- **Pot-light replacement white LED - best performance**:
  - predicting CIE whiteness (w.r.t CIE A, CIE C)
- **Full advantages of FWAs cannot be realized:**
  - **Papermakers** - reconsider current technologies// strategies for increasing paper whiteness OR
  - **Consumers** – satisfied with lower levels of whiteness

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Provision of White LED

SPD

and CRI data

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Discussion / Questions

Thank you for your attention

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