KU LEUVEN

KAHO SINT-LIEVEN

LIGHT&LIGHTING LABORATORY

Chromaticity of White

ISCC Bridge Session at:
Color, Light & Appearance Week at NIST,
June 15-20, 2014, Gaitherburg, USA

Dr. Kevin Smet

FWO VLAANDEREN

"unique white"

"Achromatic"

"White"

"Neutral"

"Grey"

"neither red, green, yellow or blue"

Achromatic chromaticity in literature

- Priest (1921): 5100 K
- Helson and Michels (1948): 15 000 K
- Hurvich and Jameson (1951): 6200 K

  (range: 5500 – 7500 K)
- Honjyo and Nonaka (1970): 6800 K

  (range: 5000 – 14000 K)
- Valberg (1971): 6300 K

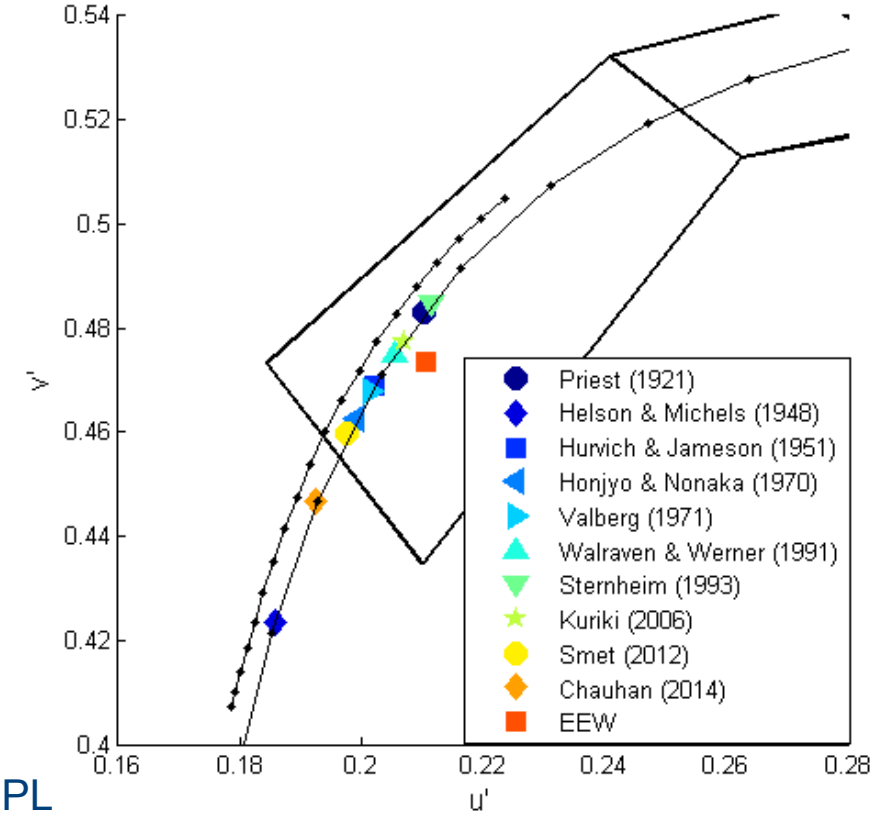
  (range: 5600 K – 11000 K)
- Walraven and Werner (1991): 5700 K

  (4000 K & 7400 K, luminance invariance)
- Sternheim (1993): 5000 K

  (1 observer → 6000 K at lower luminance)
- Kuriki (2006): 5500 K
- Rea (2013): "line of whites":

  (CCT > 4000 K above PL, CCT < 4000 K below PL)
- Ohno (2013): "line of preferred whites" below PL

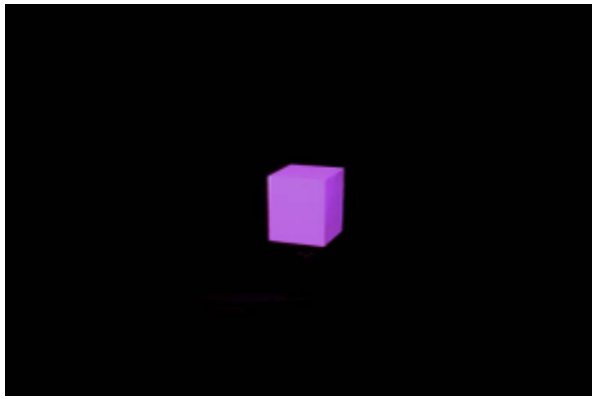
  (Duv ≈ - 0.013)
- Chauhan (2014): 8800 K



Large inter-observer variability

Methodology

- Stimulus:
  - Real 3D spectrally “flat” cube
  - 8.5^3 cm^3 → FOV: 5.7°
  - Illuminated with data projector
  - Surround:< 0.1 cd/m², dark adapted conditions
- Observers:
  - 7 male, 6 female
  - avg. Age: 31 y ± 8 y
- Experiments:
  - **<u>3 luminance levels</u>:**
    - **200,1000 & 2000 cd/m²**
  - **<u>2 methods:</u>**
    - Unique white **adjustment**
    - Unique white **rating**

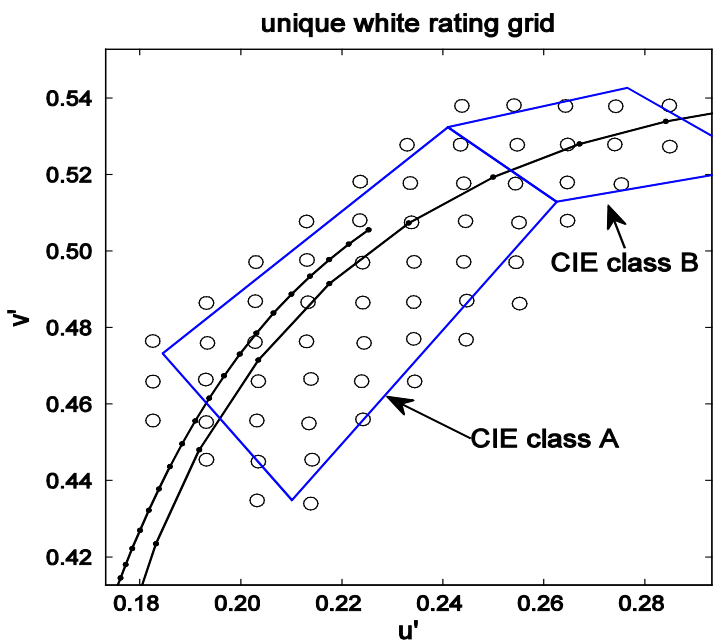


Methodology: experimental methods

- Unique White **adjustment**
  - 9 UW-settings:
    - 1-2: trial
    - + **7** random starting stimuli:
      - ✓ *Excitation purity within projector gamut*
      - ✓ *Dominant wavelengths of 7 stimuli uniformly distributed*
  - *u'v' navigation*
  - After satifactory setting:
    - Spectral measurement
    - Rating on 0-10 scale:
      - <5: observable hue
      - ≥5: warm, cold or neutral

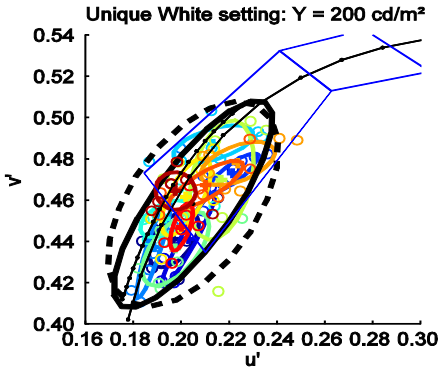
        (with higher values for increasing neutrality)

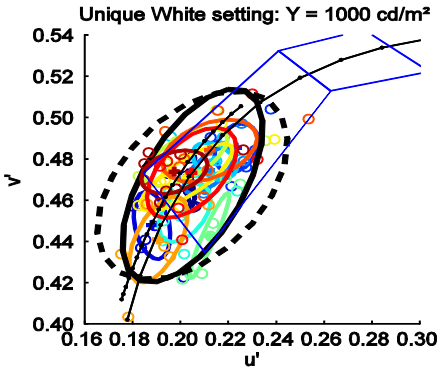
- Unique white **rating**
  - **59** chromaticities randomly selected from uniformy spaced grid in *u'v'* diagram
  - Grid extended slightly beyond CIE class A and B white regions
  - Rating on 0 – 10 scale

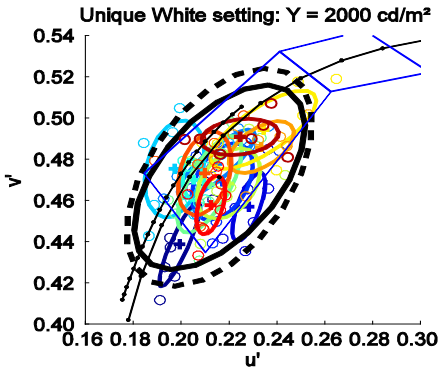


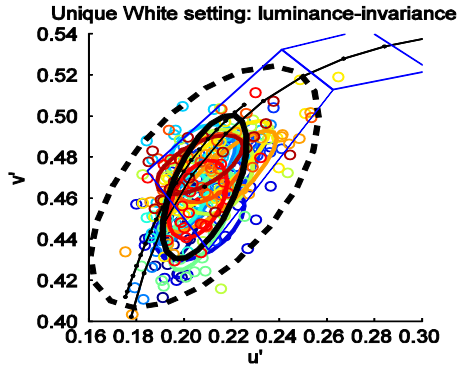
Results: UW-adjustment

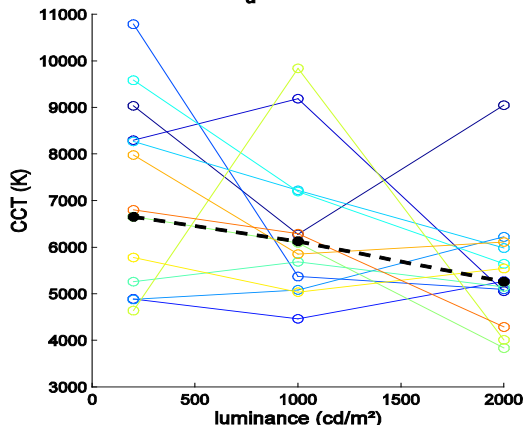
- Large UW-regions:
  - ❑ Intra- > inter-observer variability
  - ❑ 4000 K – 11000 K
  - ❑ Major axis orientated approx. along PL.
  - ❑ Located mostly below PL
  - ❑ Apparent shift towards lower *v'* (higher CCT) as luminance decreases:
    - ➢ 5256 K at 2000 cd/m², 6126 K at 1000 cd/m² and 6652 K at 200 cd/m².
    - ➢ No such trend observable at the individual observer level!
      - → **Luminance-invariant**
        CCT = 5963 ± 267K
        Duv = -0.0065

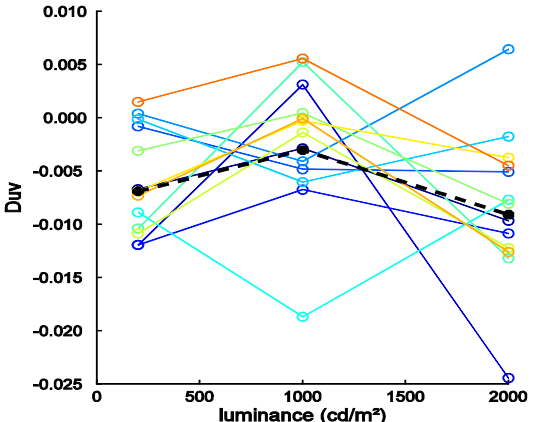












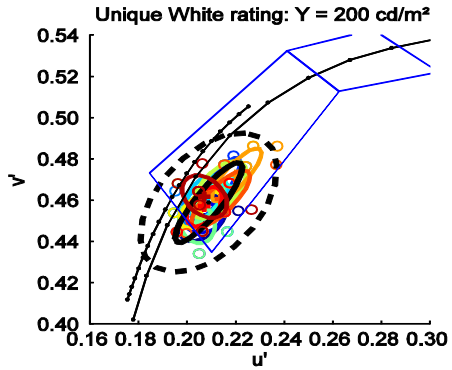
Results: UW-rating (1: 7 highest ratings)

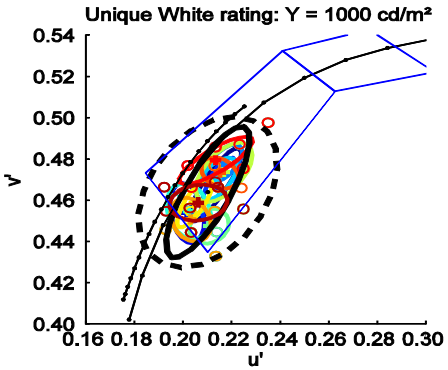
- Similar results using chromaticities with 7 highest ratings:
  - Large UW-regions
  - Major axis orientated approx. along PL.
  - Located mostly below PL
  - Apparent shift towards lower *v'* (higher CCT) as luminance decreases:
    - Not observed at the individual test subject level!

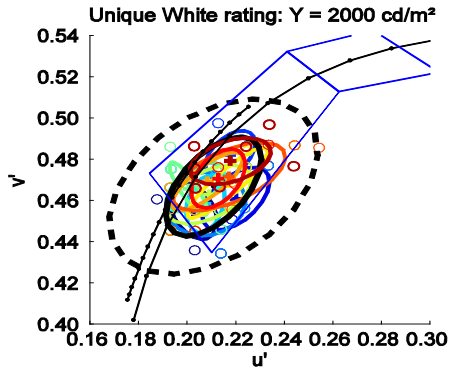
      → **luminance invariant**

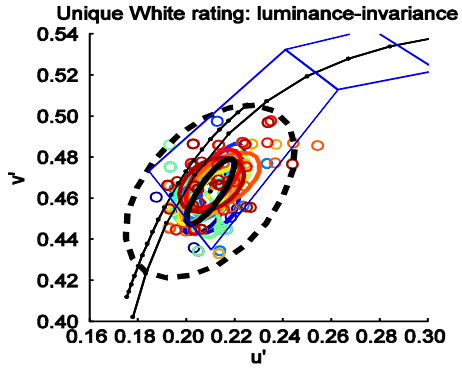
      CCT = 5989 ± 136 K

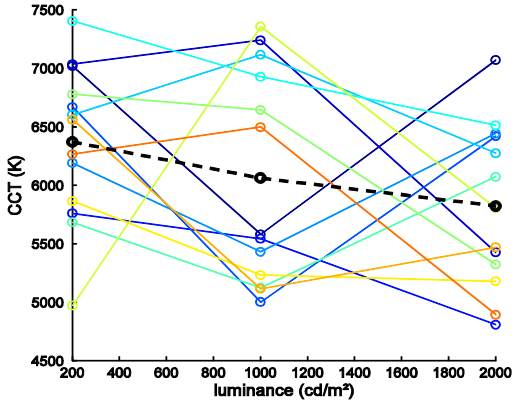
      Duv = -0.0085

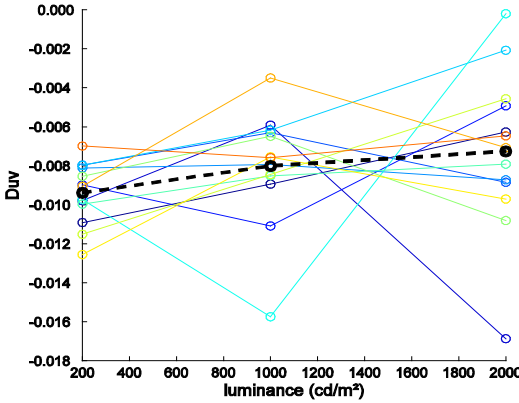






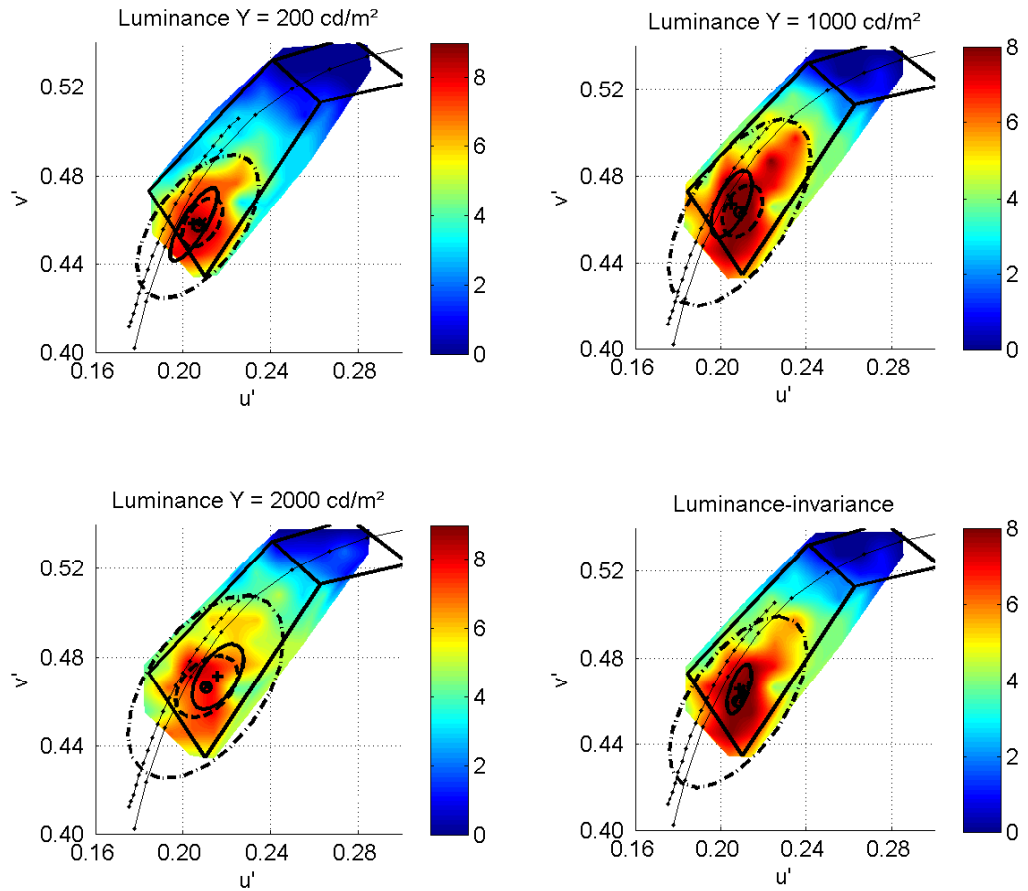






Results: UW-rating (2: full data set)

- Using full data set of 59 chromaticities:
  - ***Median observer:***
    - *CIE class A & B respectively over- and slightly under- estimate CCT range*
    - *Duv range approx. ok*
    - *Neutral **region** below PL*

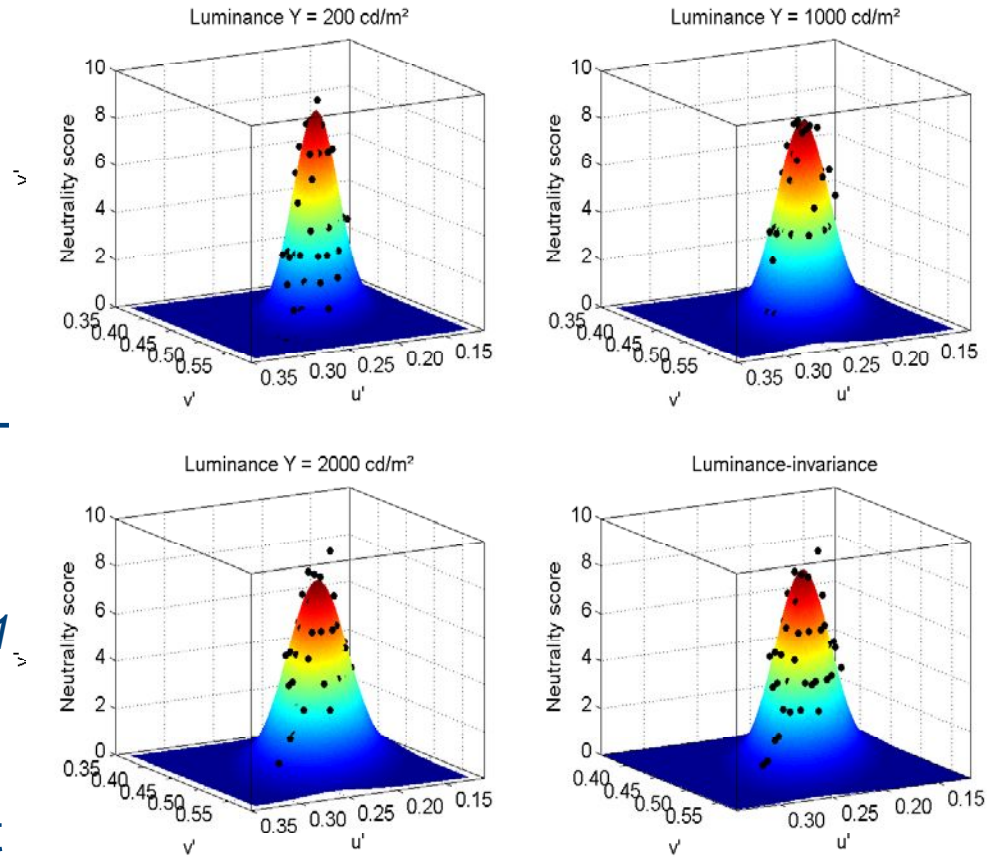


Results: UW-rating (2: full data set)

- Using full data set of 59 chromaticities:
  - ***Median observer bivariate Gaussian model:***
    - *Good agreement with "7-rating" results*
    - *Good fit:*
      - *STRESS of fit: 0.19 - 0.21*
      - *Interobserver STRESS: 0.27-0.29*
    - Here also, apparent shift towards higher CCT as luminance decreases:

      → luminance invariant

      CCT = 6324 K; Duv = -0.0087



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Conclusions

- Unique white or neutrality (for a dark adapted observer):
  - rather **large region**
  - Predominantly **below the Planckian locus**
  - Respectively **over- and under-estimated** by the CIE **Class A white region**
  - Average showed a shift towards higher CCT as the luminance increased, although no such trend was observable at the individual observer level.
  - ***Degree of neutrality*** could be satifactorily modeled by a **bivariate Gaussian function**