Spectral and Temporal Factors Associated with Headlight Glare: Implications for Measurement

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Lighting Research Center

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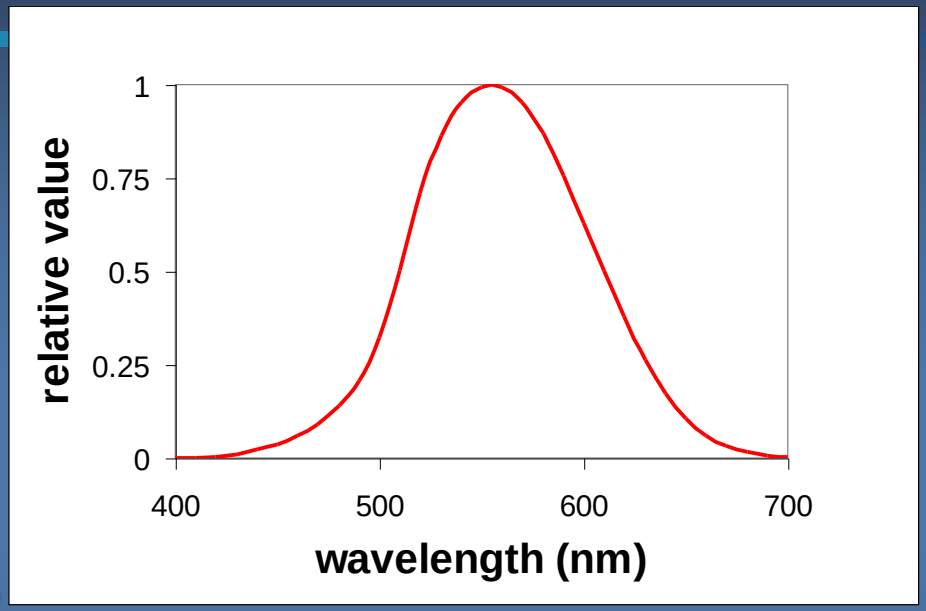
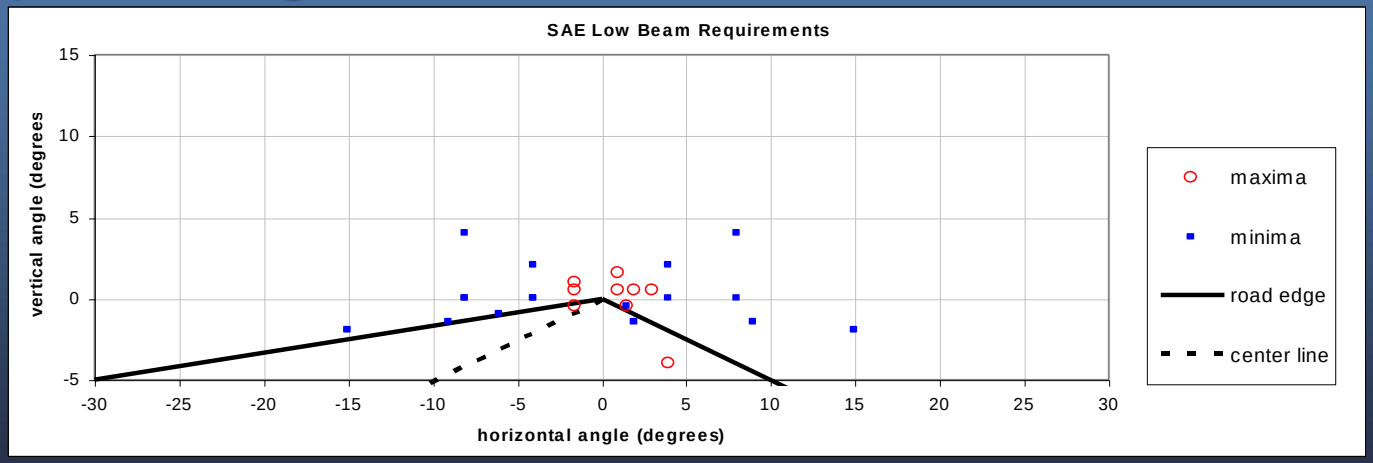
Background

- Present characterization of vehicle headlight photometry is based on:
  - Photopic luminous efficiency function
  - Luminous intensity values at specific angular locations





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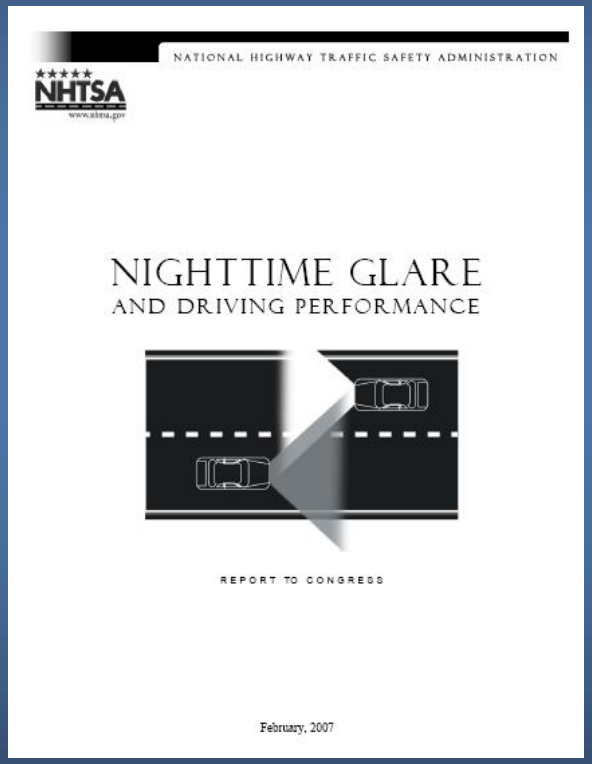
The Perfect Storm?

- In the past decade, vehicle headlights have evolved in a number of ways (NHTSA, 2007):
  - New (often "bluer") and sometimes higher-output light sources
    - High-intensity discharge (HID, or xenon)
    - Coated-bulb halogen
    - Coming soon: light-emitting diode (LED)
  - Increased mounting heights (e.g., SUVs)
  - Decreased likelihood of proper aim


NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

NHTSA

NIGHTTIME GLARE
AND DRIVING PERFORMANCE

REPORT TO CONGRESS

February, 2007

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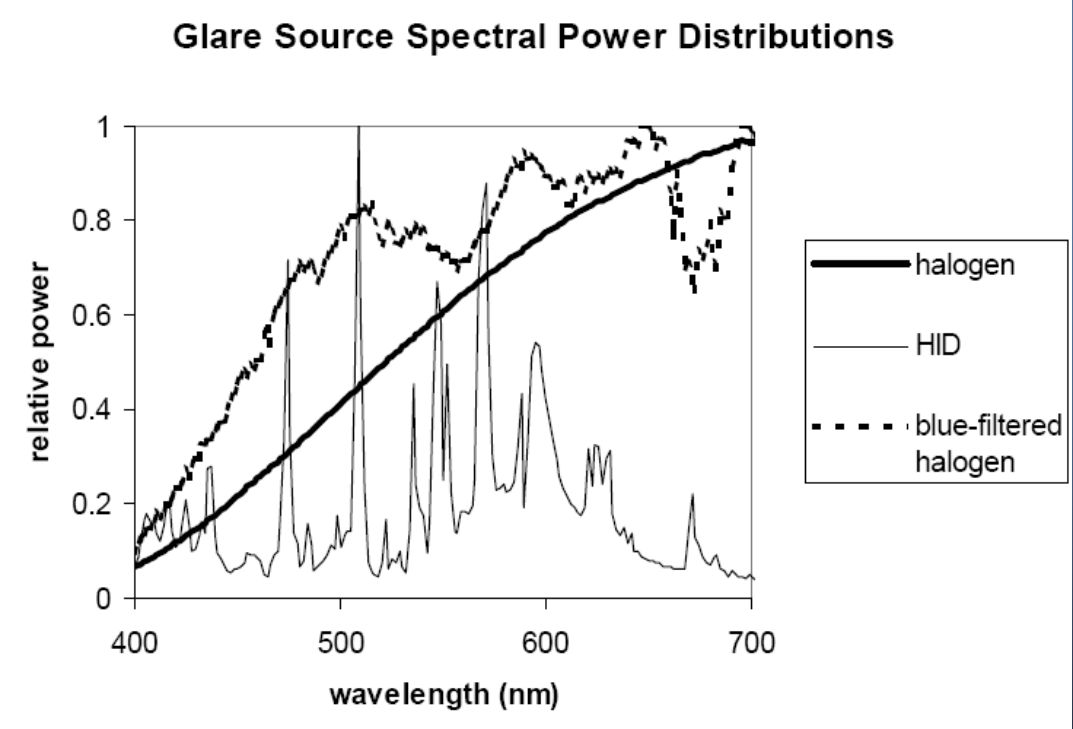
Spectral Power Distribution

- The trend with newer headlight sources is toward increased short-wavelength light output



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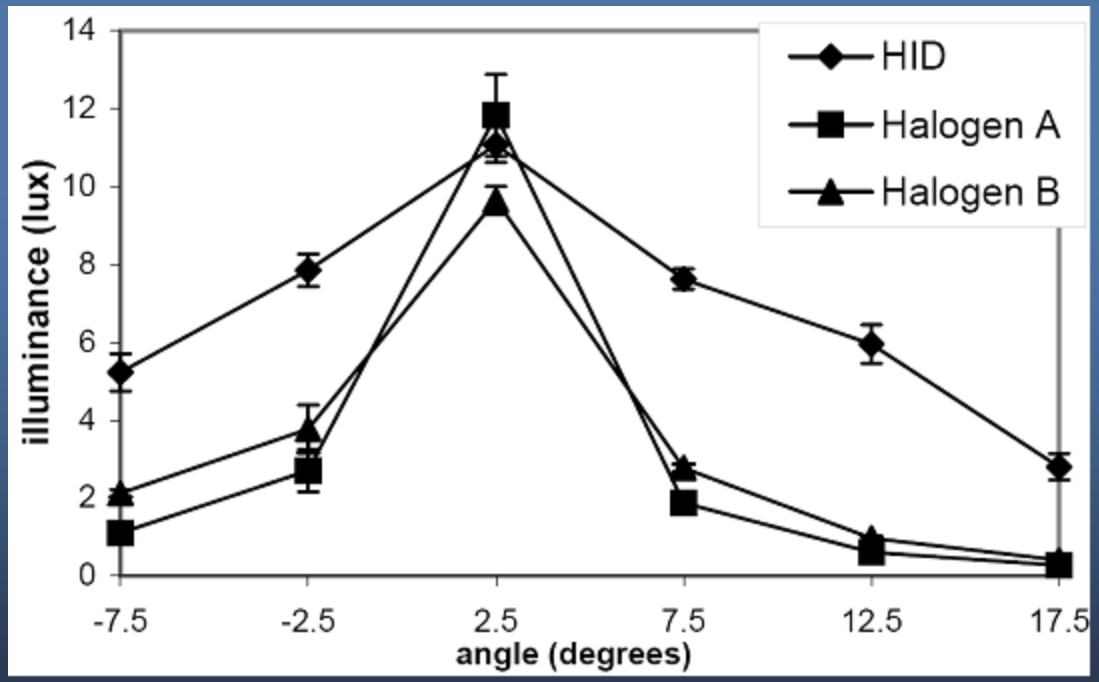
Spatial Distribution

- Because of improved luminous efficacy, HID headlamps have increased peripheral light output



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Characterizing Headlight Glare

- Disability glare
  - Reduction in visibility caused by luminous veil due to scattered light in the eye
  - Well-understood quantitatively for decades (Fry, 1954)
- Discomfort glare
  - Annoying or painful sensation when exposed to a bright light in the field of view
  - Much less understood (Rea, 2000)

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Characterizing Headlight Glare

- Visual recovery
  - Reduction in visibility caused by increased visual adaptation followed by several seconds of reduced visual sensitivity *after* exposure to a bright light

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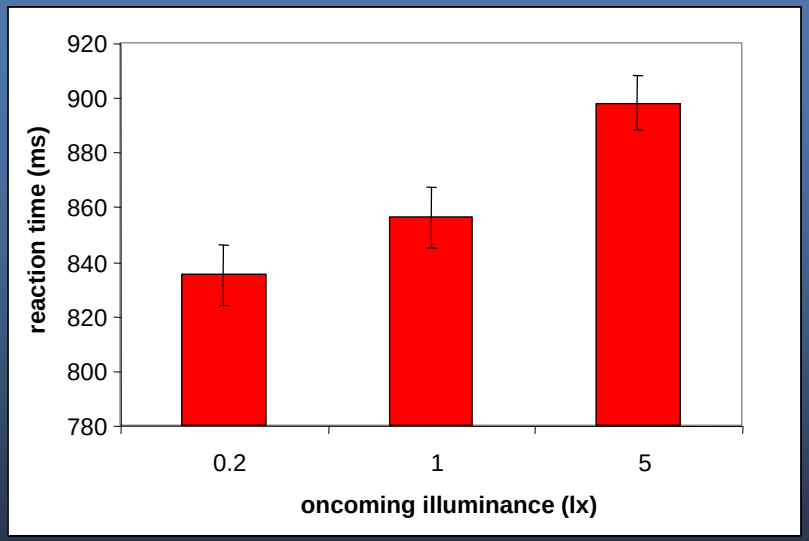
Disability Glare

- Reductions in visibility from oncoming headlights with different spectral power distributions depended only on the photopic illuminance at the eye (Bullough et al., 2003)
  - Conventional photometric characterization has utility in predicting disability glare



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Discomfort Glare

- Mechanisms are not understood
- Methods to characterize discomfort glare physiologically have not been successful
  - Pupil size fluctuation
  - Electrophysiological measures
  - Squinting
- Psychology surely plays a role, too

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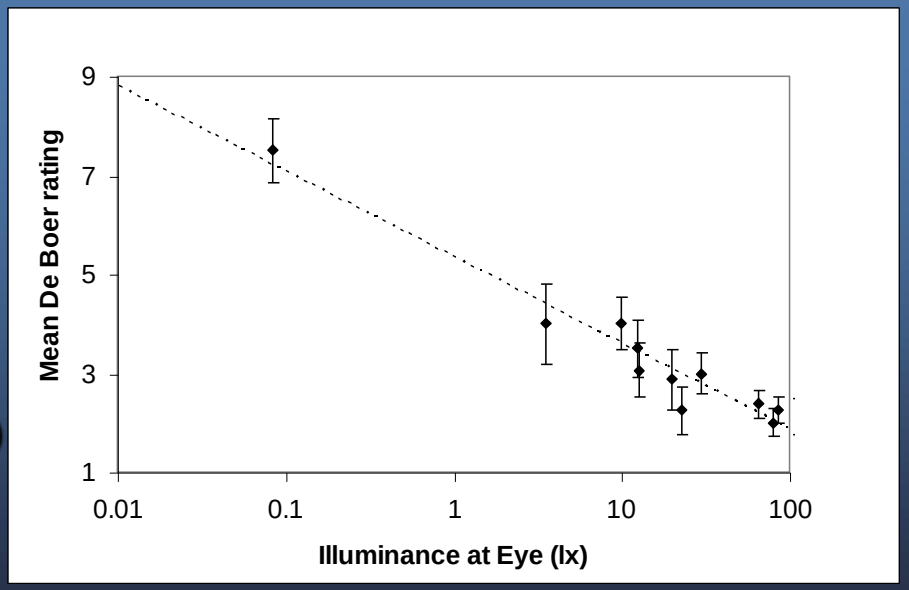
The State of the Art in Discomfort Glare

- Subjective ratings
  - De Boer (1967) scale is common in automotive lighting research
  - Discomfort glare ratings are strongly correlated with illuminance at the eye
    - Background light level, location in field of view, and even what one is doing when rating the glare all influence the absolute level of discomfort (Bullough et al., 2002, 2003, in press; Theeuwes et al., 2002)

9: Just Noticeable
8:
7: Satisfactory
6:
5: Just Acceptable
4:
3: Disturbing
2:
1: Unbearable



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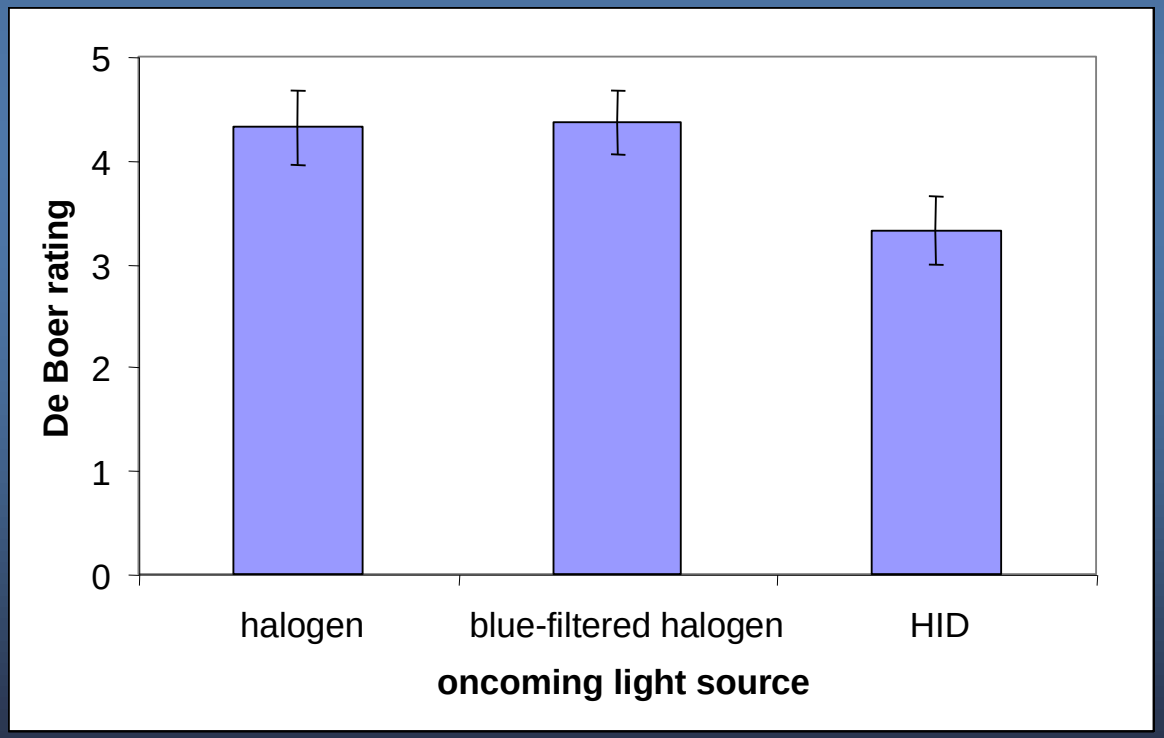
Discomfort Glare

- Headlights with greater short-wavelength light output produced greater discomfort (Bullough et al., 2002, 2003; Flannagan, 1999)



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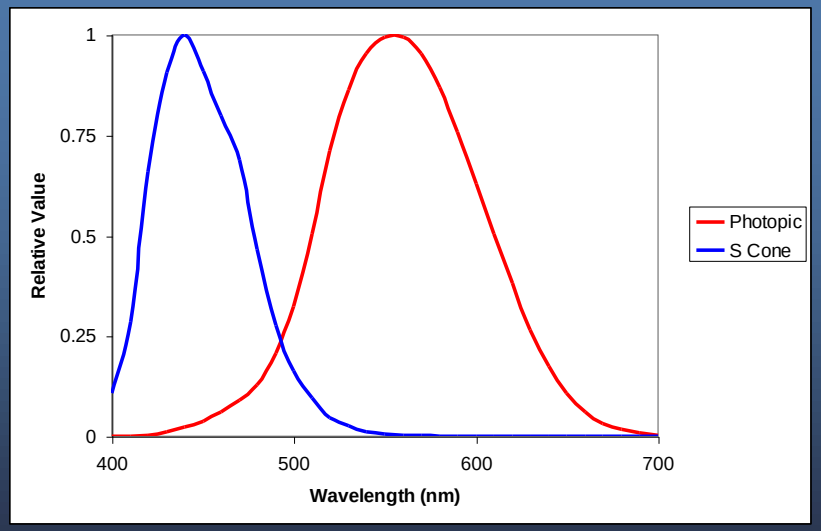
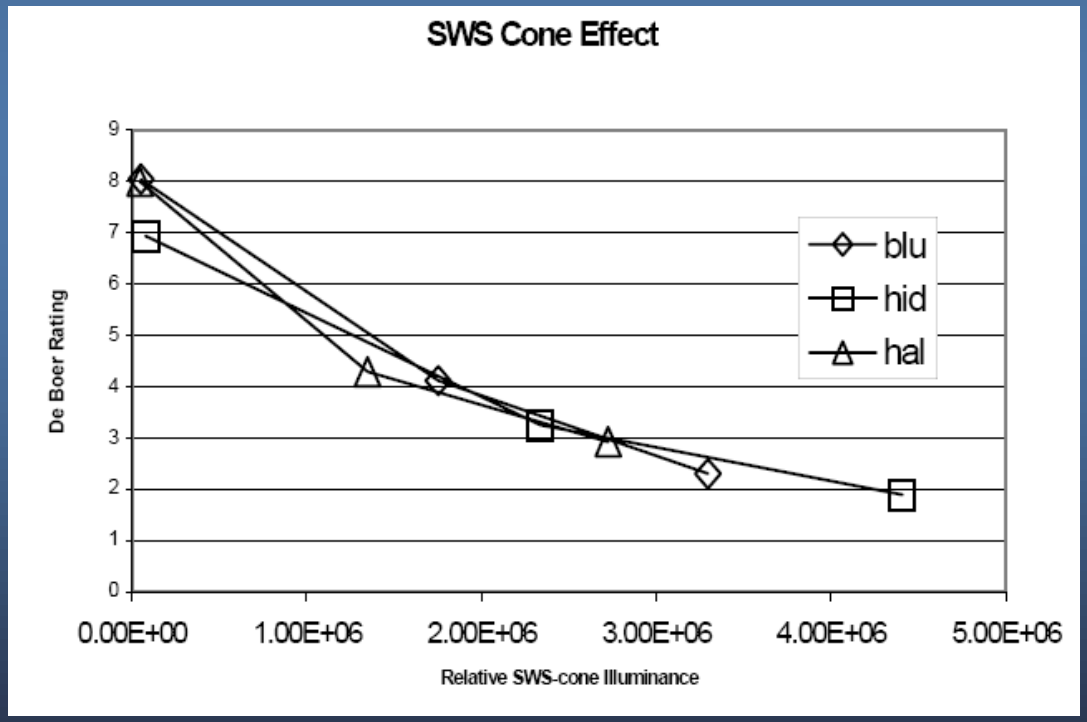
A Possible Mechanism?

- Imagine creating a luminous efficiency function from the short-wavelength (S) cone photoreceptor spectral sensitivity
  - Peak near 450 nm





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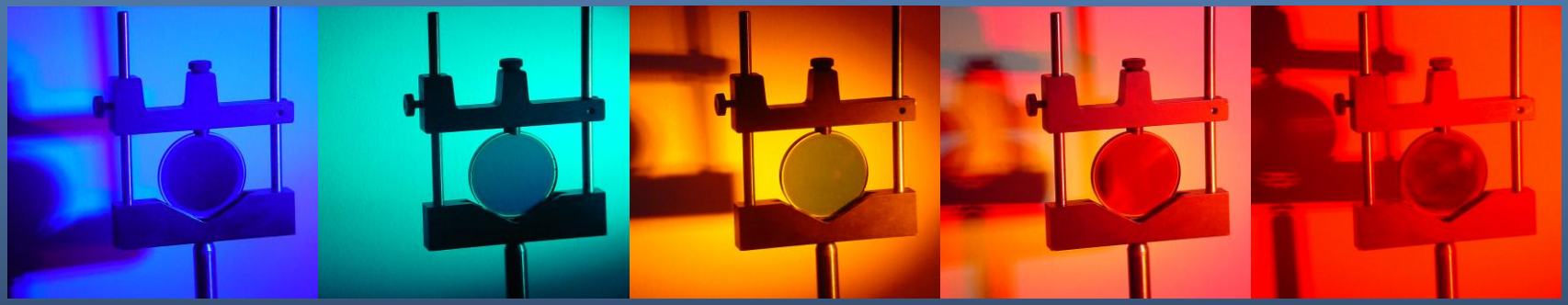
Further Experiments

- Using narrowband filters and a xenon light source, discomfort glare from 5° off-axis was measured for several wavelengths and several illuminances at the eye (Dee, 2003)



450 nm 510 nm 590 nm 650 nm 700 nm

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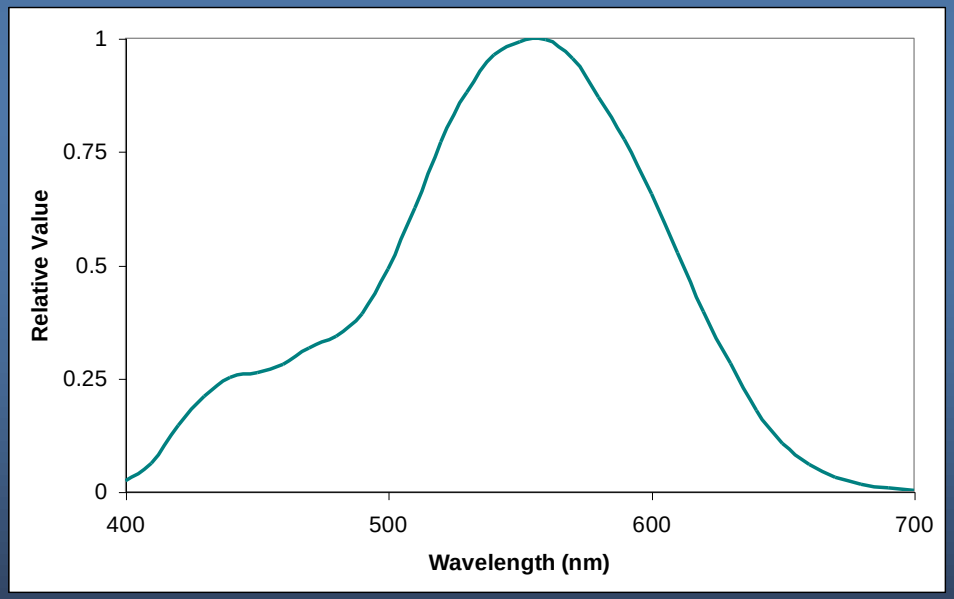
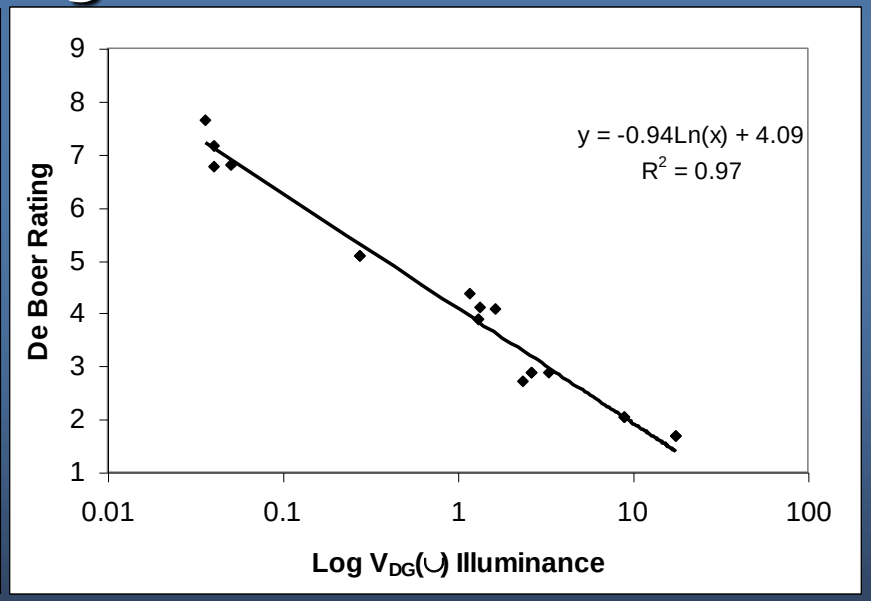
Modeling Spectral Sensitivity for Discomfort Glare

- A combination of $V_{10}(\lambda)$ (CIE, 2005) and short-wavelength cone sensitivity was the best rectifying variable for discomfort ratings





- Follow-up study (Watkinson, 2005) confirmed these results

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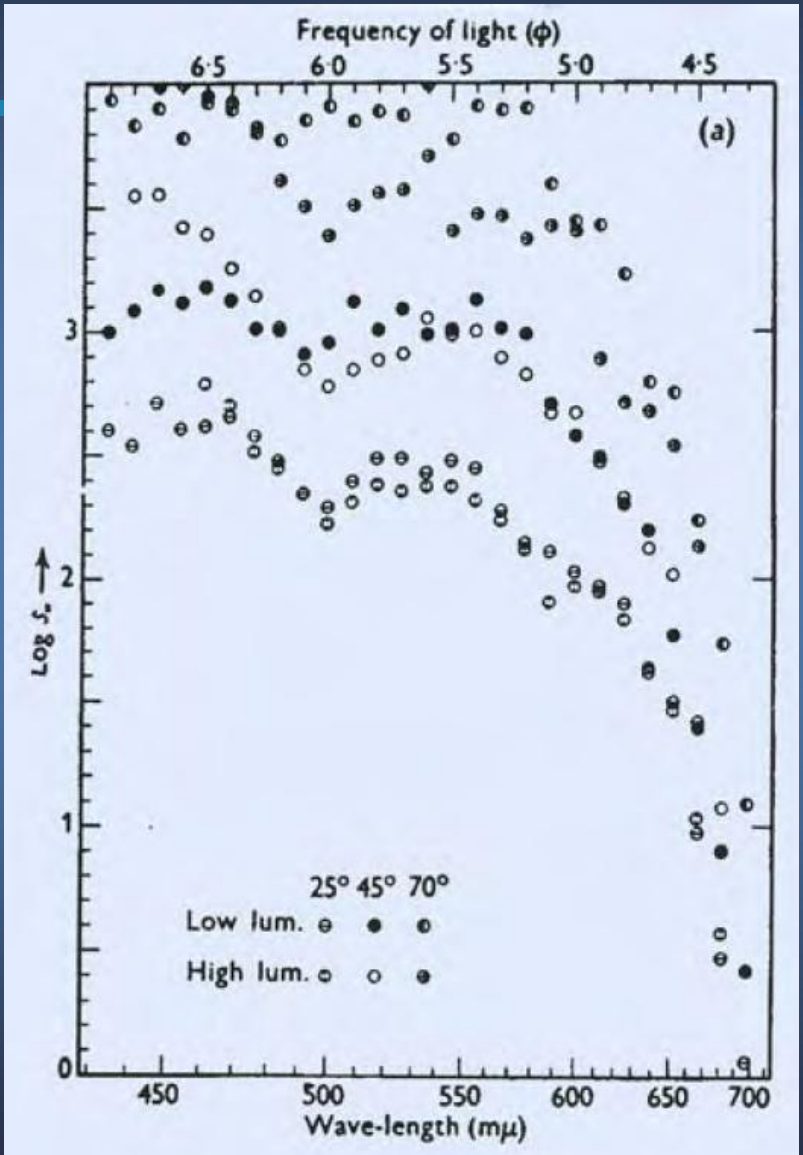
Is Discomfort Glare Excess Brightness?

- If so, peripheral brightness data from Weale (1953) offer an interesting hypothesis for peripheral angles other than 5°



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Role of Spatial Distribution

- Disability and discomfort glare are acute phenomena
- Different headlights provide different illuminance "profiles" to oncoming drivers

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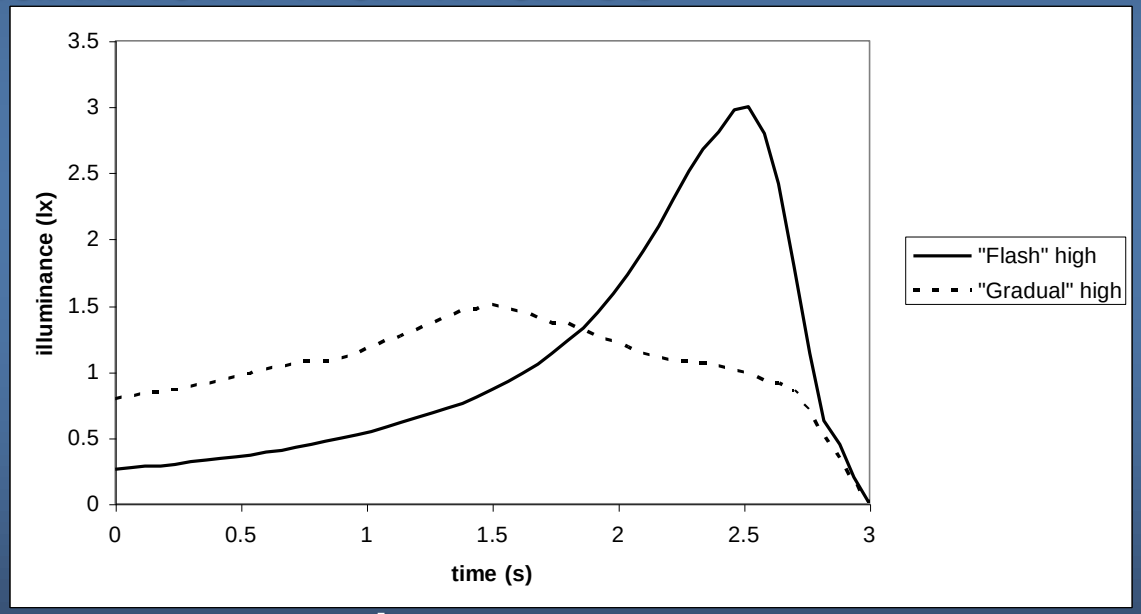
Characterizing Headlights for Visual Recovery

- Dosage: illuminance × duration
- Peak: maximum illuminance



- To what extent to these parameters impact visual recovery?

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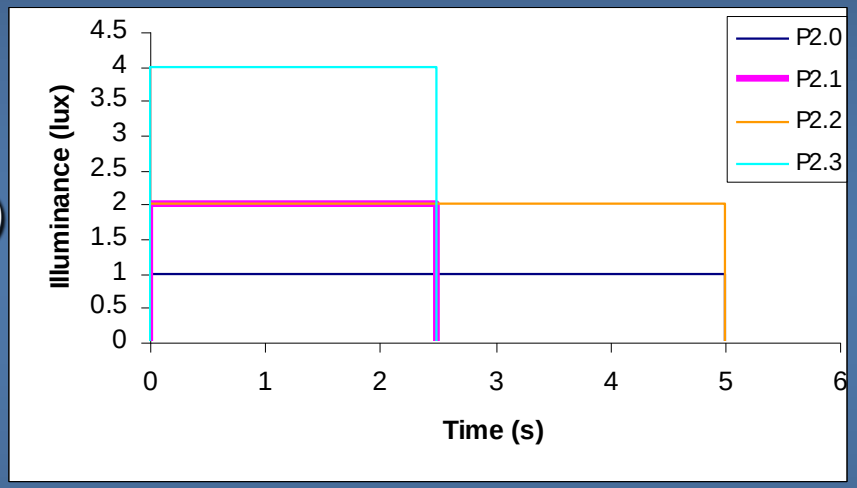
Recovery Laboratory Study

- Four illuminance/dosage conditions:
  - 1 lux for 5 seconds (dosage = 5 lx·sec)
  - 2 lux for 2.5 seconds (dosage = 5 lx·sec)
  - 2 lux for 5 seconds (dosage = 10 lx·sec)
  - 4 lux for 2.5 seconds (dosage = 10 lx·sec)



- Time to detect a target presented immediately after exposure profile was measured (Chen, 2004)

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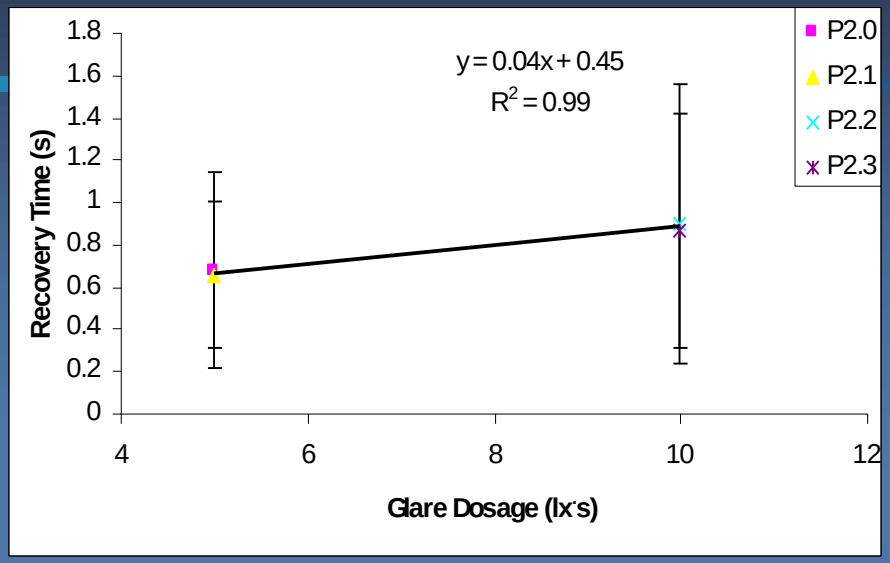
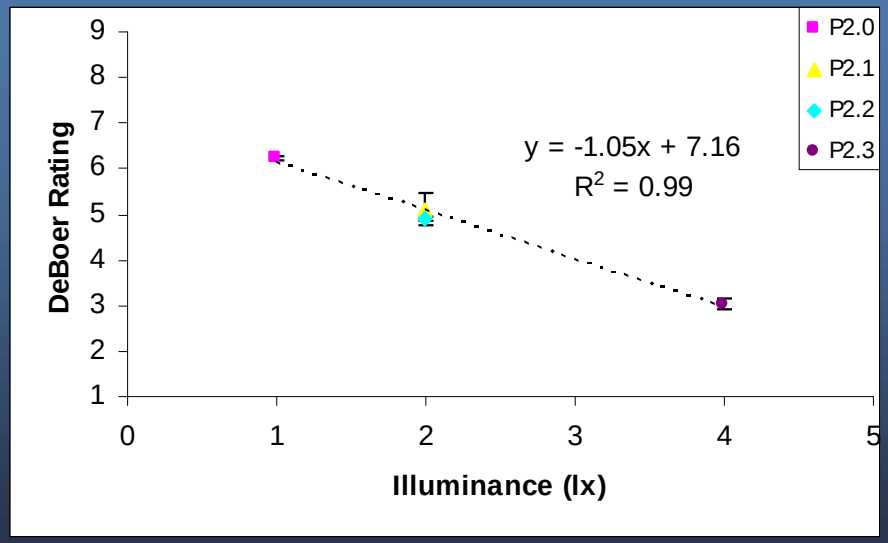
Recovery Laboratory Study Results

- Recovery times were correlated with dosage
- Discomfort ratings were correlated with peak illuminance (Chen, 2004)





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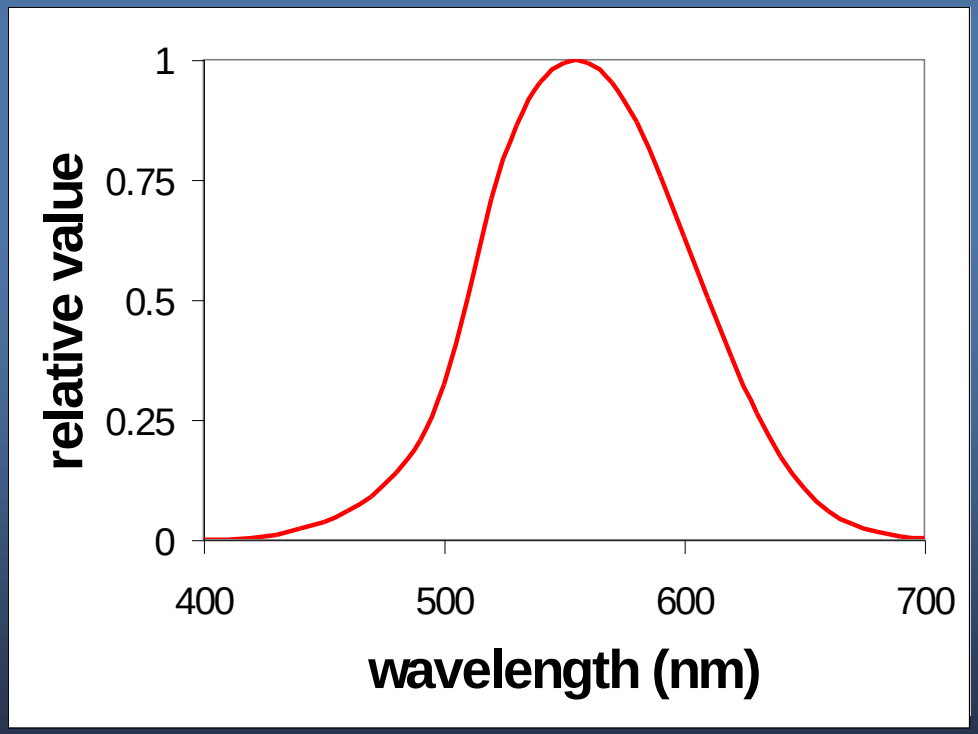
Implications for Headlight Measurement

- Conventional headlight photometry only partially characterizes their glare-related properties
  - Disability glare



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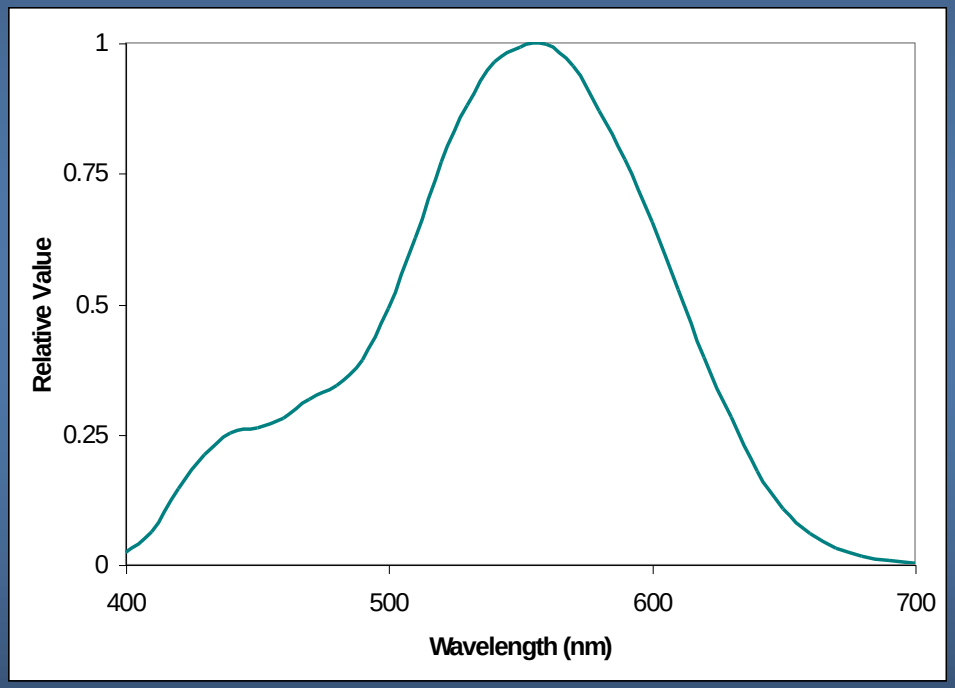
Characterizing Discomfort Glare

- A function combining photopic (large-field) sensitivity and short-wavelength (S cone) sensitivity appears to rectify discomfort glare from different spectra (at 5°)



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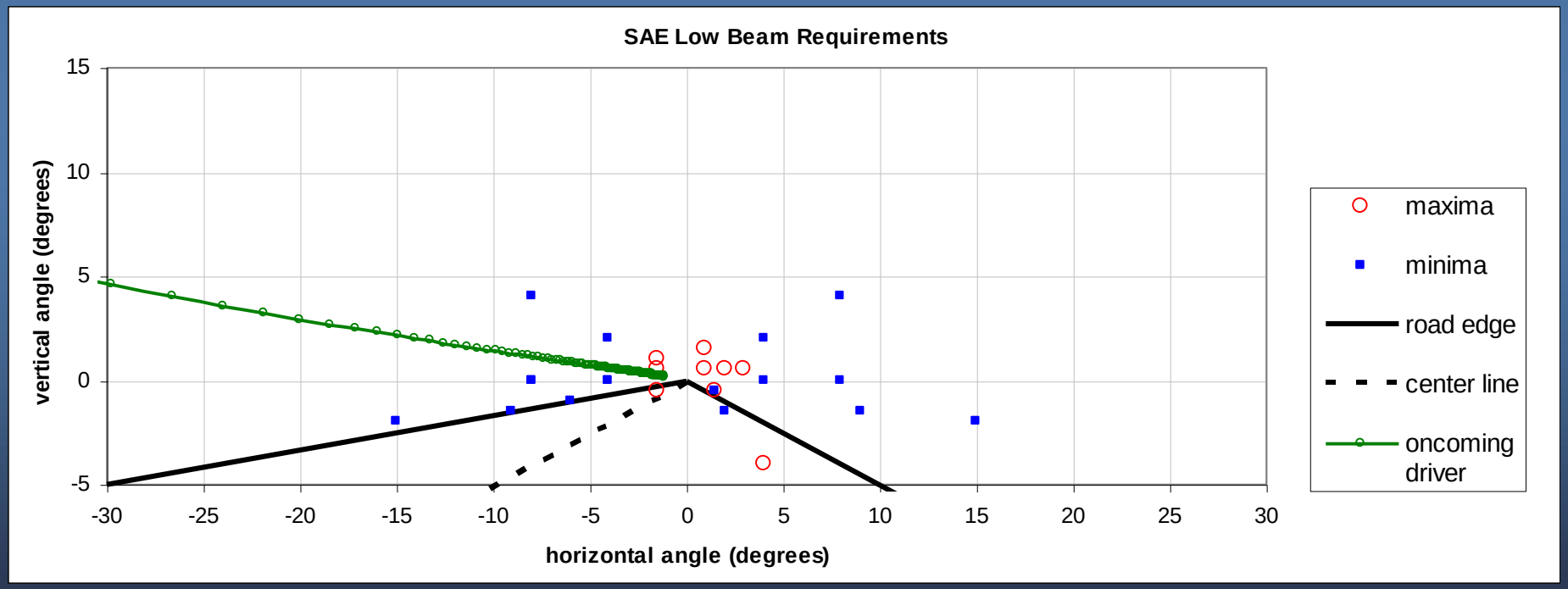
Characterizing Visual Recovery

- Integrated value of intensity over angles of interest might be a more suitable measure of potential for long recovery times following headlamp exposure



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Acknowledgments

- Spectral sensitivity studies
  - Transportation Lighting Alliance
    - Automotive Lighting, DaimlerChrysler, GE Lighting, General Motors, Guide Corporation, Hella, Philips Lighting, OSRAM Sylvania
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