UMTRI-2004-6

CHROMATIC ABERRATIONS NEAR THE CUTOFF OF LOW-BEAM HEADLAMPS

Michael Sivak
Michael J. Flannagan
Brandon Schoettle
Go Adachi

March 2004

CHROMATIC ABERRATIONS NEAR THE CUTOFF OF LOW-BEAM HEADLAMPS

Michael Sivak
Michael J. Flannagan
Brandon Schoettle
Go Adachi

The University of Michigan
Transportation Research Institute
Ann Arbor, Michigan 48109-2150
U.S.A.

Report No. UMTRI-2004-6
March 2004

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-2004-6		
4. Title and Subtitle Chromatic Aberrations Near the Cutoff of Low-Beam Headlamps		5. Report Date March 2004 6. Performing Organization Code 302753
7. Author(s) Sivak, M., Flannagan, M.J., Schoettle, B, and Adachi, G.		8. Performing Organization Report No. UMTRI-2004-6
9. Performing Organization Name and Address The University of Michigan Transportation Research Institute 2901 Baxter Road Ann Arbor, Michigan 48109-2150 U.S.A.		10. Work Unit no. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency Name and Address The University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

The Affiliation Program currently includes AGC America, Autoliv, Automotive Lighting, Avery Dennison, BMW, DaimlerChrysler, DBM Reflex, Denso, Federal-Mogul, Ford, GE, General Motors, Gentex, Guide Corporation, Hella, Honda, Ichikoh Industries, Koito Manufacturing, Lang-Mekra North America, Magna International, Mitsubishi Motors, Muth, Nichia America, Nissan, North American Lighting, Olsa, OSRAM Sylvania, Philips Lighting, PPG Industries, Reflec USA, Reflexite, Renault, Samlip, Schefenacker International, Sisecam, Solutia Performance Films, Stanley Electric, TG North America, Toyota Technical Center USA, Valeo, Vidrio Plano, Visteon, 3M Personal Safety Products, and 3M Traffic Safety Systems. Information about the Affiliation Program is available at: http://www.umich.edu/~industry

16. Abstract

Projector low beams are subject to color aberrations near the vertical cutoff caused by dispersion of light when passing through the lens. Color aberrations are especially of concern with high-intensity discharge (HID) lamps, because these color changes likely contribute to the discomfort-glare complaints for HIDs.

The purpose of this study was to evaluate the extent and magnitude of color aberrations in HID and tungsten-halogen projector low beams. Specifically, we made colorimetric measurements near the cutoffs of 8 projector HIDs and 4 projector tungsten-halogens. For experimental control, we also evaluated 9 nonprojector HIDs and 5 nonprojector tungsten-halogens.

Major color changes were present for 38% of the HID projector lamps, 50% of the tungsten-halogen projector lamps, and (as expected) for 0% of the HID or tungsten-halogen nonprojector lamps. Transformation of the chromaticity data into a perceptually uniform color space indicated that the color changes caused by aberrations near the cutoff were often considerably greater than the typical color differences between tungsten-halogen and HID sources. This suggests that some of the recent concern about headlamp color and glare on the part of the driving public may be caused by color aberrations—in either tungsten-halogen or HID lamps—rather than by HID lamps themselves. To minimize discomfort glare (especially for HIDs), it is important to avoid color aberrations in the regions of the beam pattern with substantial luminous intensity levels that may be directed toward oncoming drivers.

17. Key Words			18. Distribution Statement
Color, aberrations, cutoff, low beams, HIDs, projector lamps, low beams			Unlimited
19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
None	None	19	

ACKNOWLEDGMENTS

Appreciation is extended to the members of the University of Michigan Industry Affiliation Program for Human Factors in Transportation Safety for support of this research. The current members of the Program are:

AGC America
Autoliv
Automotive Lighting
Avery Dennison
BMW
DaimlerChrysler
DBM Reflex
Denso
Federal-Mogul
Ford
GE
General Motors
Gentex
Guide Corporation
Hella
Honda
Ichikoh Industries
Koito Manufacturing
Lang-Mekra North America
Magna International
Mitsubishi Motors
Muth
Nichia America
Nissan
North American Lighting
Olsa
OSRAM Sylvania
Philips Lighting
PPG Industries
Reflec USA
Reflexite
Renault
Samlip
Schefenacker International
Sisecam
Solutia Performance Films
Stanley Electric
TG North America
Toyota Technical Center, USA
Valeo
Vidrio Plano
Visteon
3M Personal Safety Products
3M Traffic Safety Systems

CONTENTS

INTRODUCTION

Projector type automobile headlamps have gained substantial popularity during the past few years. Some reasons for their popularity are the smaller size and better ability to create sharper vertical cutoffs. On the other hand, projector headlamps are subject to color aberrations near the cutoff. These aberrations are caused by dispersion of white light when passing through the lens (Vozenilek, Purma, and Stefka, 2000). The color changes are especially of concern with high-intensity discharge (HID) headlamps, because their color composition (even without color aberrations) is known to lead to more discomfort-glare complaints (Flannagan, Sivak, Battle, Sato, and Traube, 1993), and the aberrations are likely to exacerbate the problem.

The purpose of this study was to evaluate the extent and magnitude of color aberrations in HID and tungsten-halogen projector low beams. Specifically, we made colorimetric measurements near the cutoffs of 8 projector HIDs and 4 projector tungsten-halogens. As a control, we also evaluated 9 nonprojector HIDs and 5 nonprojector tungsten-halogens.

METHOD

Lamp sample

The sample consisted of 17 HID and 9 tungsten-halogen low beams, for a total of 26 beams. The optical constructions of the lamps are listed in Table 1.

The HID lamps were 17 of the 19 lamps that we used in a previous study on the luminous output of HID lamps (Sivak, Flannagan, Schoettle, and Nakata, 2002). All of them were made for use in the U.S. for model year 2000 vehicles. The 9 tungsten-halogen lamps included 3 lamps for use in Europe and 6 lamps for use in the U.S., with 7 for model year 2000 and 2 for model year 1997. Information about the light sources in the tested lamps is presented in Table 2.

Table 3 lists the numbers of companies that produced the different types of lamps that were included in this study.

Table 1
Optical constructions of the tested lamps.

Lamp type	Optics	Number
HID	Projector	8
	Lens	5
	Reflector	4
Tungsten-halogen	Projector	4
	Reflector	3
	Lens	2

Table 2
Specific light sources of the tested lamps.

Lamp type	Light source	Number
HID	D2R	9
	D2S	8
Tungsten-halogen	HB2	5
	H7	2
	H1	1
	HB3	1

Table 3
Number of different manufacturers represented by the lamps included in the samples for each of the four major types of lamps.

Lamp type	Projector	Nonprojector
HID	3	4
Tungsten-halogen	2	4

Colorimetry

Colorimetry was performed using a Photo Research PR-650 SpectraScan SpectraColorimeter. This colorimeter has a spectral measuring range of 380 to 780 nm (± 2 nm). The color measurement accuracy (Illuminant A, CIE 1931 chromaticity system) is $x \pm 0.0015$ and $y \pm 0.001$.

The measurements were made in a darkened laboratory. The data were collected by measuring each lamp's reflectance from the Photo Research RC-3 Reflectance Standard. The reflectance standard is a white, diffuse reflecting surface, with an absolute reflectance of 99% (± 1%) from 370 to 780 nm. The reflectance standard was positioned (and data were recorded) at 12 different measurement points constituting a vertical pass through the left-side cutoff of each lamp.

Each headlamp was positioned 15 m from, and perpendicular to, the aiming screen. Figure 1 presents a schematic diagram of the setup. The aiming of all lamps was done visually. The lamp was aimed to align the left-side cutoff with a predetermined horizontal line (H-H), and the vertical axis of the lamp remained aligned with the vertical axis of the aiming screen (V-V). This assured that all measurements were performed at the same relative locations in the beam pattern.

Figure 2 schematically illustrates the aiming method and the locations of the 12 measurement points. The lateral angular offset of these measurement points was 3.4° left of the vertical axis (V-V). This position was chosen because it corresponds to B50L, a European glare test point (ECE, 1992). Vertically, the test points ranged from +0.6° to –0.5° (relative to the horizontal cutoff line, H-H), at 0.1° increments. The measurements were recorded at 12.8 V, with only the low beam energized.

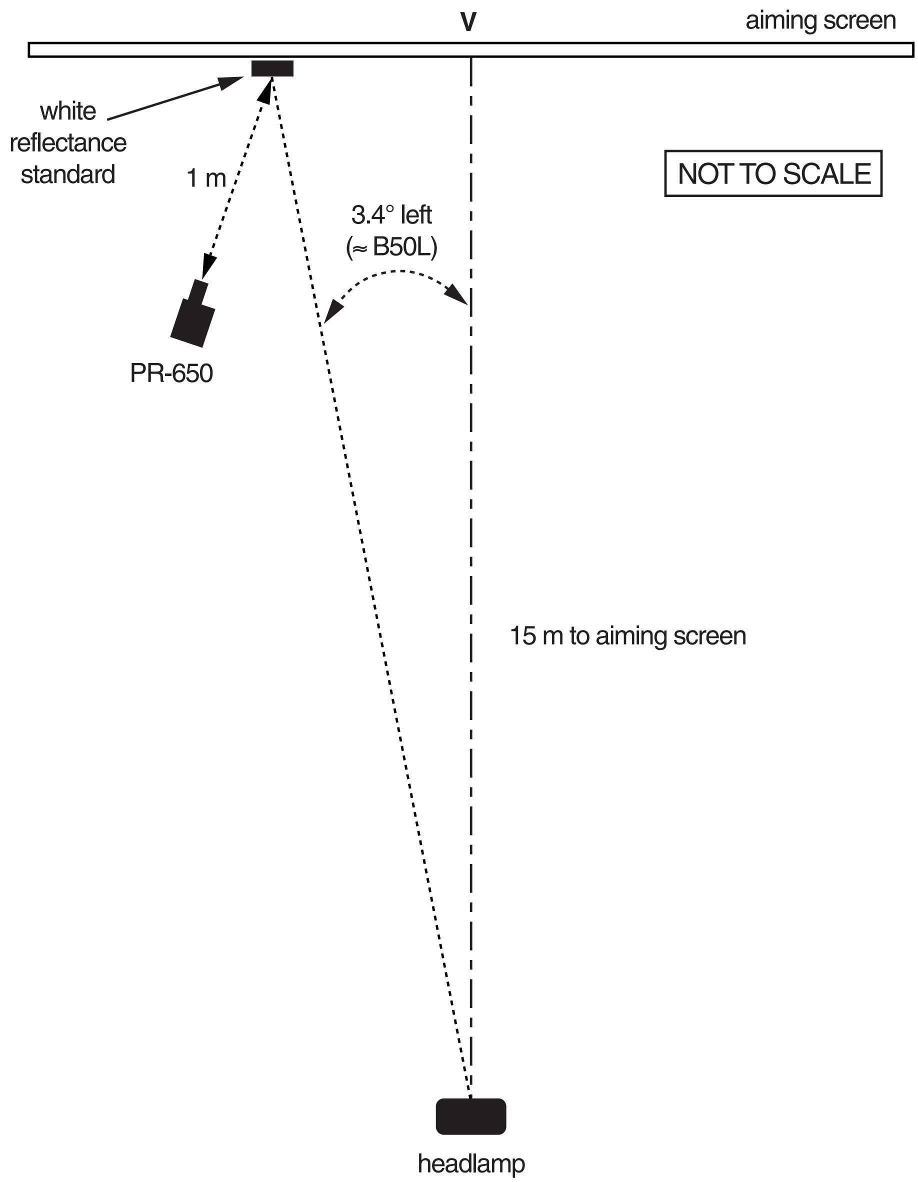

Figure 1. A schematic of the laboratory setup.

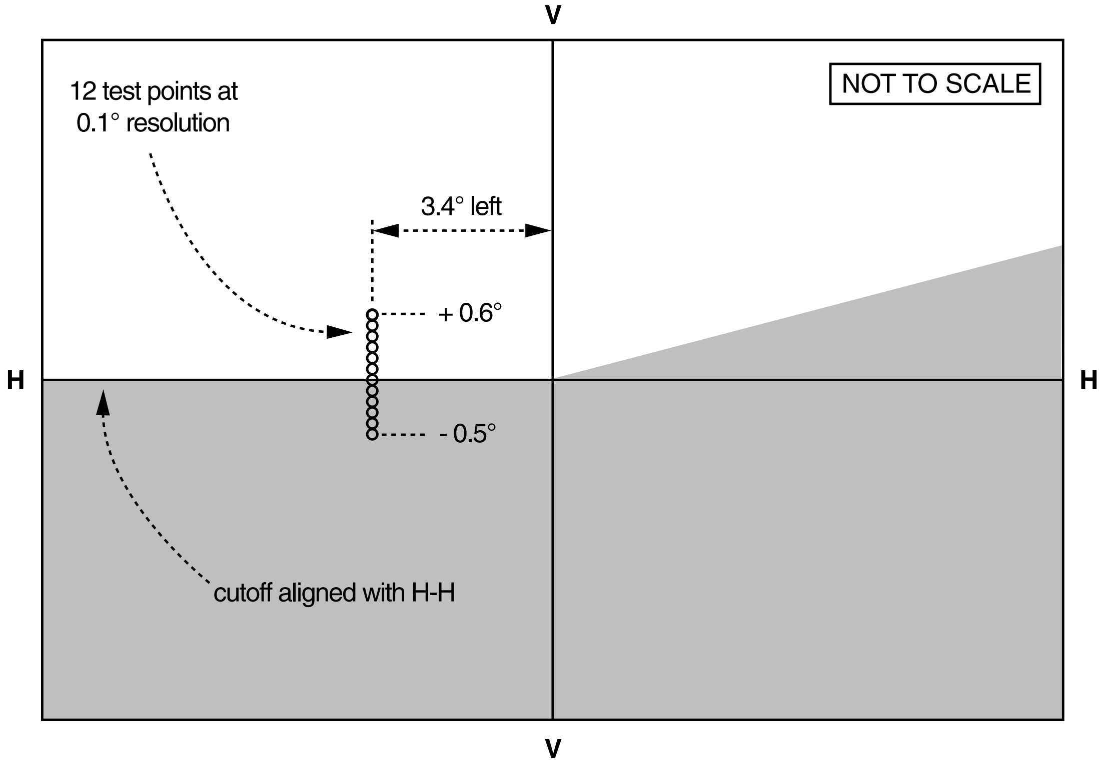

Figure 2. Aiming method and test point locations.

RESULTS

Figures 3 and 4 present the CIE *x, y* chromaticity coordinates (1931 color space) for the HID and tungsten-halogen projector lamps, respectively. Figures 5 and 6 contain the analogous data for nonprojector lamps. For reference, these figures include the blackbody curve with points marked for selected correlated color temperatures (CCTs), and the SAE and ECE white limits (SAE, 1995; ECE, 2001).

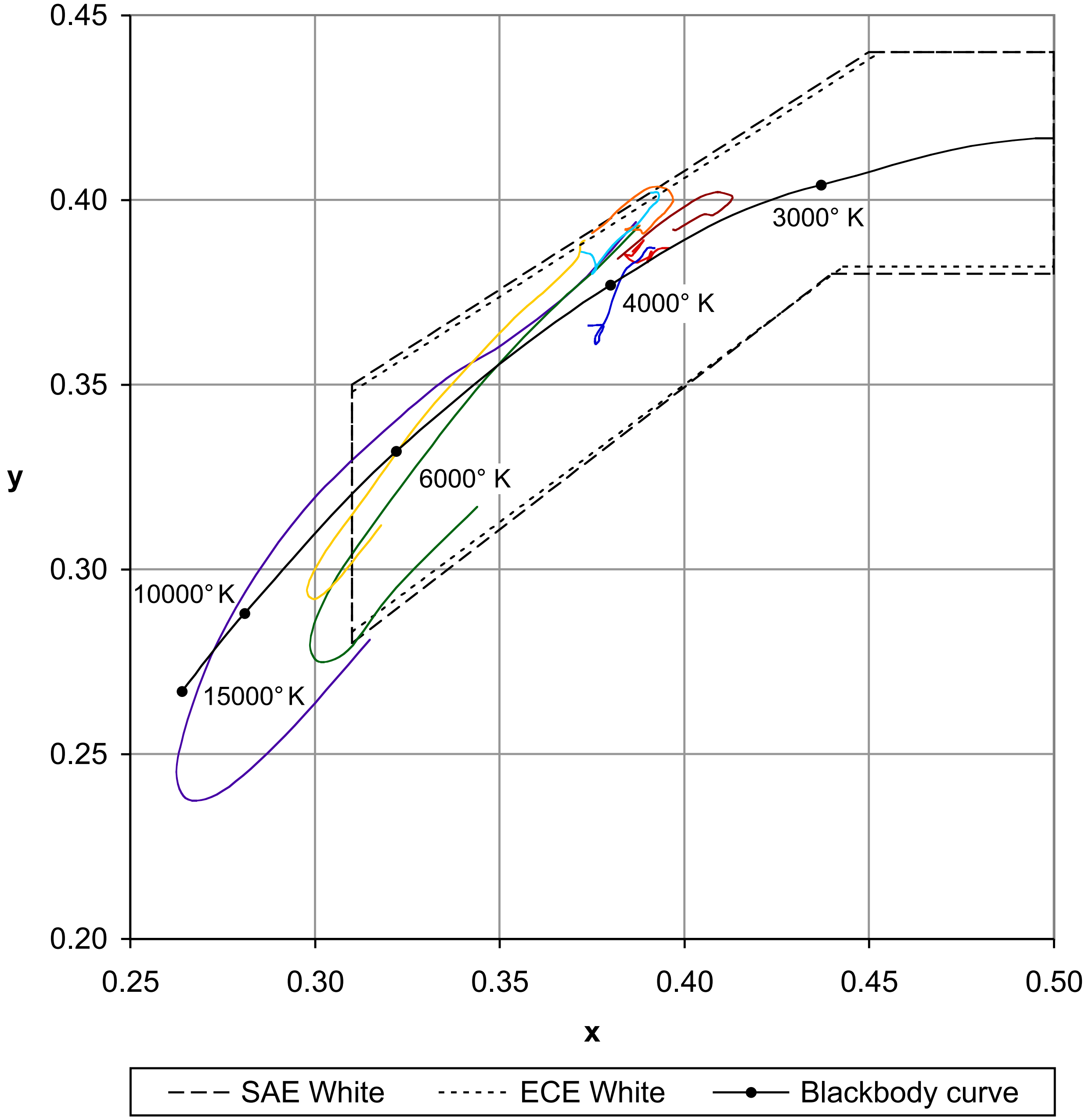

Figure 3. Changes in the CIE 1931 chromaticity coordinates for HID projector low beams when moving through the vertical cutoff. Colors represent different lamps.

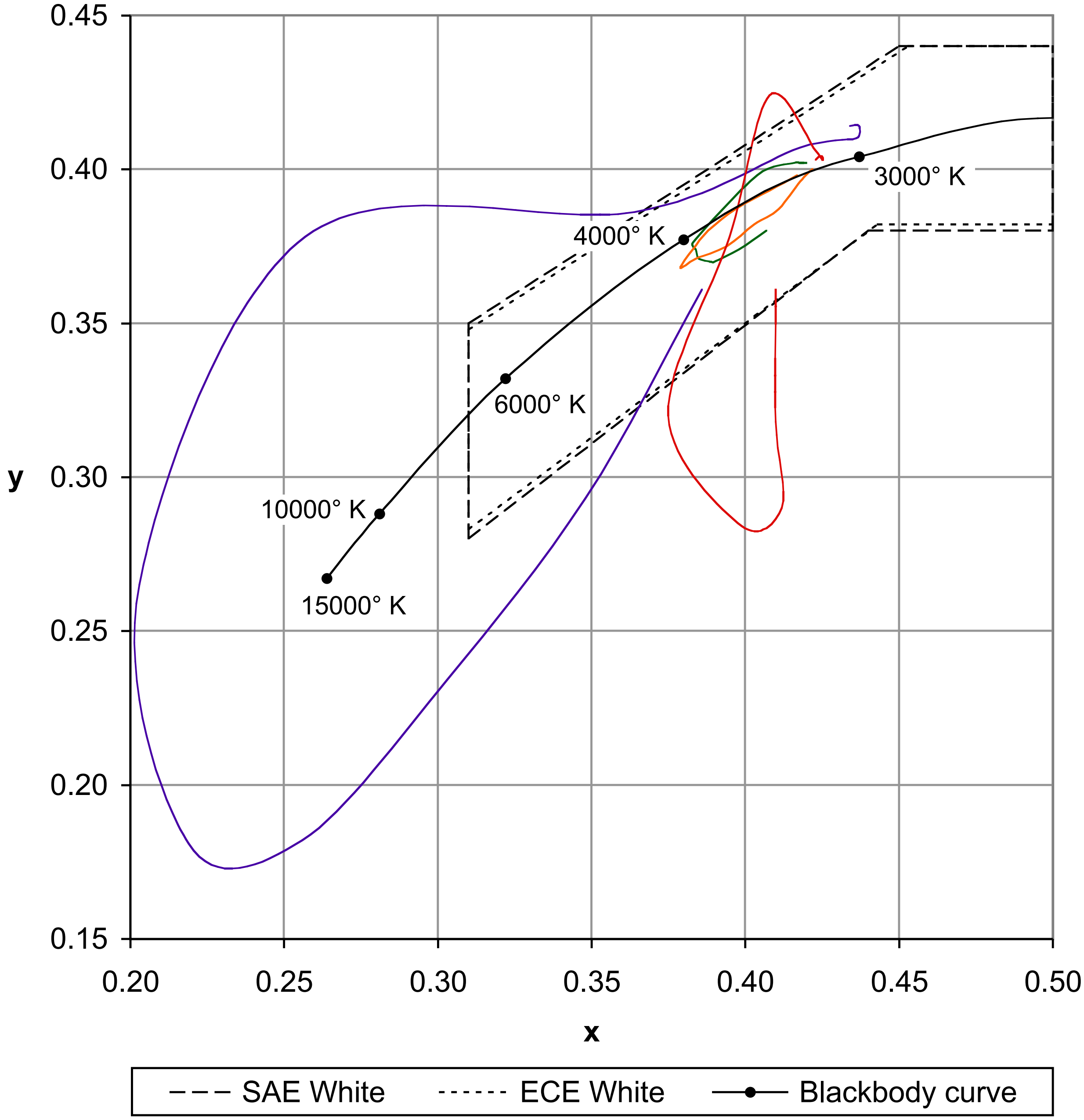

Figure 4. Changes in the CIE 1931 chromaticity coordinates for tungsten-halogen projector low beams when moving through the vertical cutoff. Colors represent different lamps.

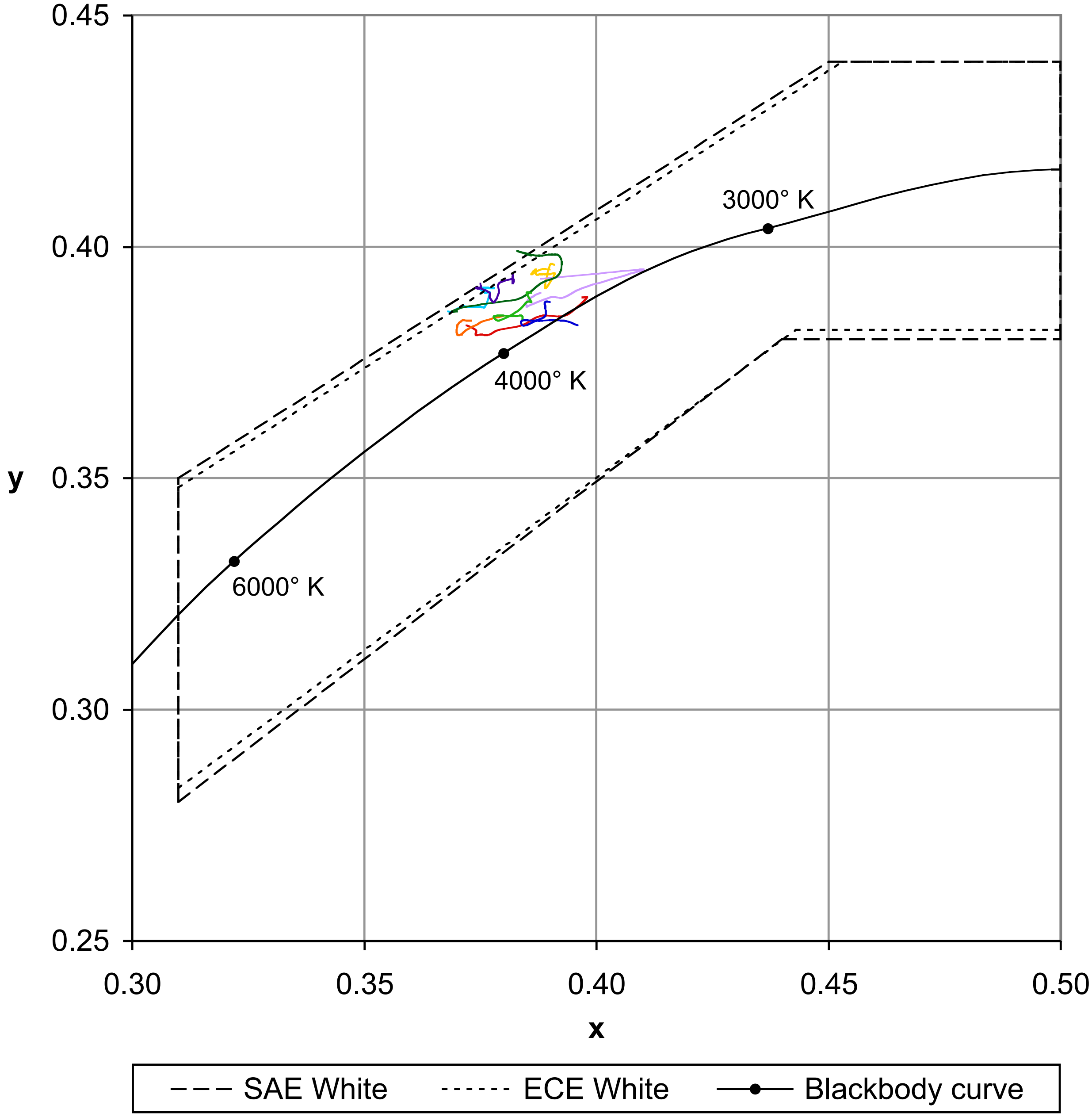

Figure 5. Changes in the CIE 1931 chromaticity coordinates for HID nonprojector low beams when moving through the vertical cutoff. Colors represent different lamps.

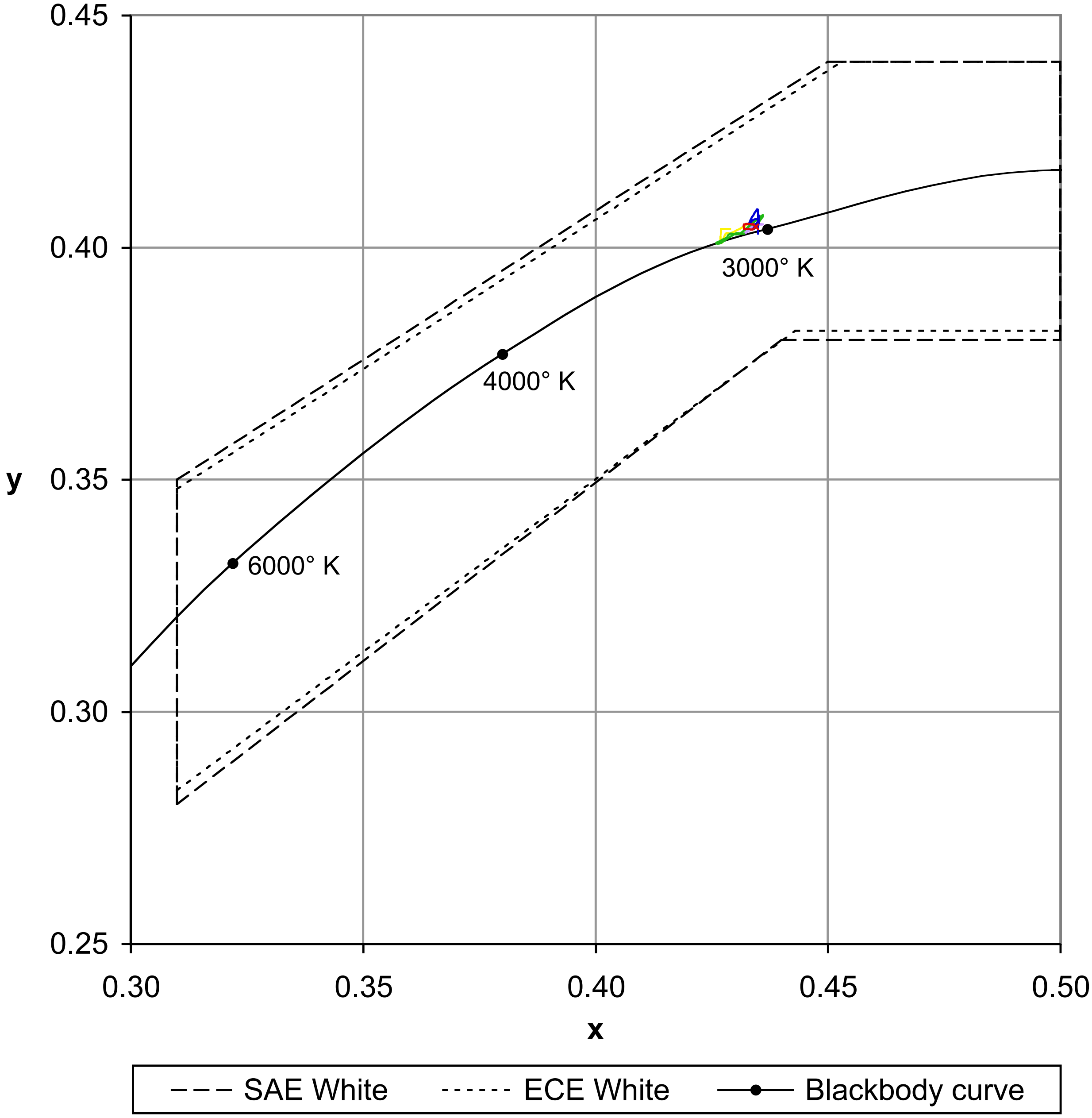

Figure 6. Changes in the CIE 1931 chromaticity coordinates for tungsten-halogen nonprojector low beams when moving through the vertical cutoff. Colors represent different lamps.

The CIE 1931 color space (used to display the data in Figures 3 through 6) is not perceptually uniform (Wyszecki and Stiles, 1982). In other words, in different regions of the space a given two-dimensional distance will not necessarily, or even usually, correspond to a fixed difference in perceived color. To better portray the perceptual magnitude of the range of colors measured near the cutoffs, Figures 7 and 8 show the data for the projector lamps (from Figures 3 and 4) in the more perceptually uniform CIE 1976 color space (u', v'). For reference, Figures 7 and 8 also include the traditional Kelly color boundaries (Keller, 1983). Comparison of Figures 7 and 8 shows that the range of colors caused by color aberrations is considerably larger than the typical color difference between tungsten-halogen and HID sources.

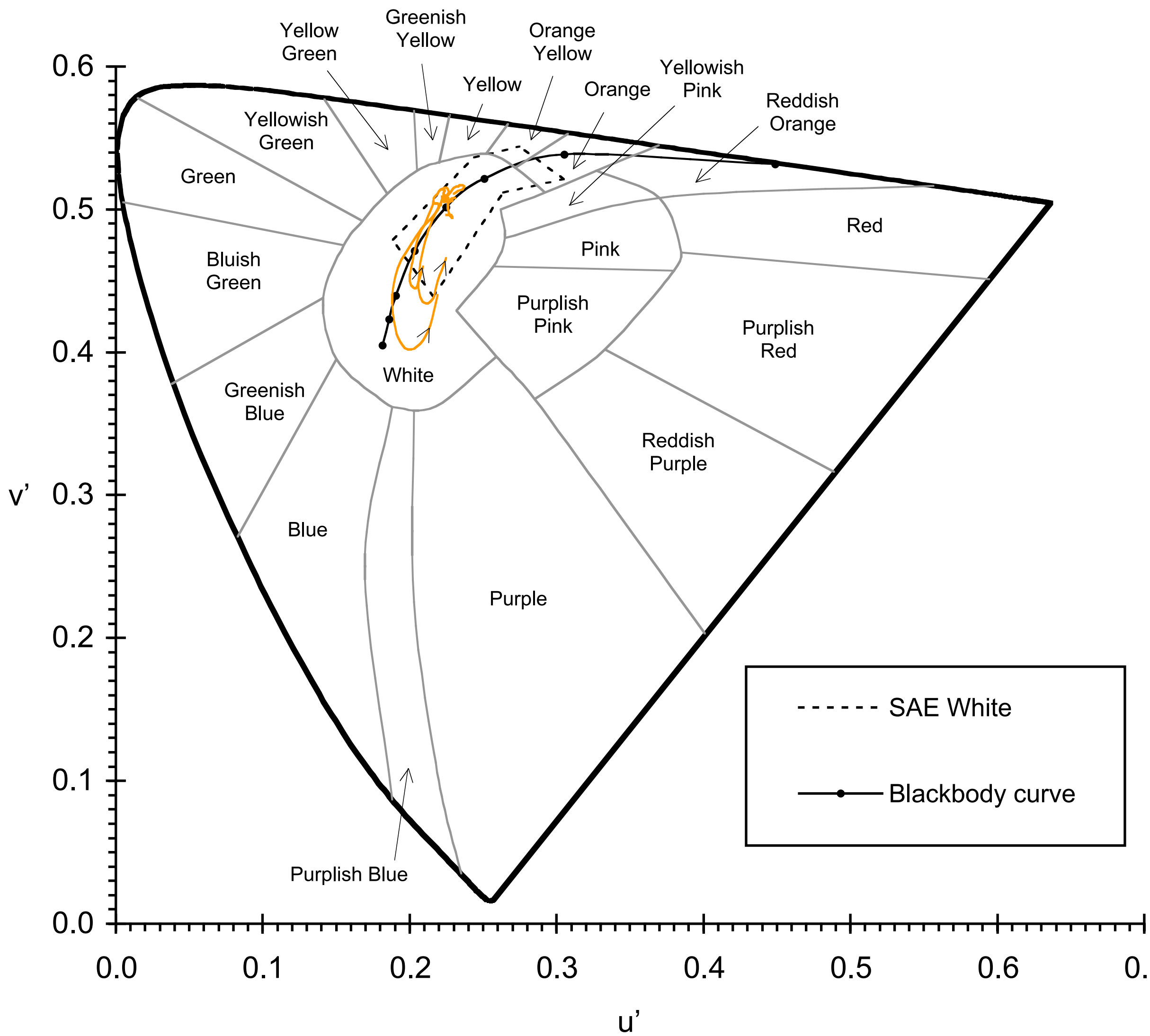

Figure 7. Changes in the chromatic coordinates for the HID projector low beams, plotted in the CIE 1976 uniform color space. The arrows indicate the directions of the changes when moving upwards through the vertical cutoff.

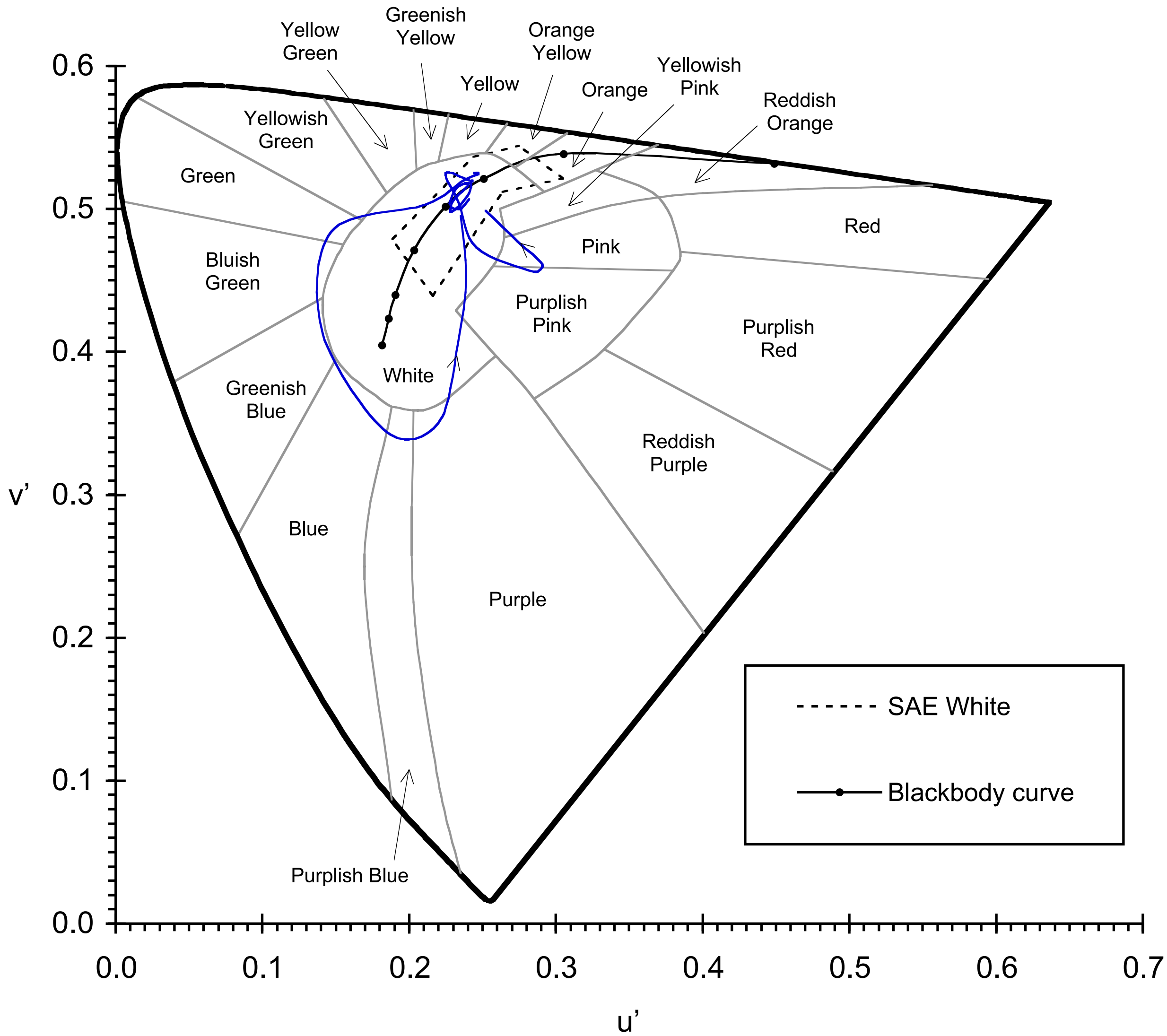

Figure 8. Changes in the chromatic coordinates for the tungsten-halogen projector low beams, plotted in the CIE 1976 uniform color space. The arrows indicate the directions of the changes when moving upwards through the vertical cutoff.

DISCUSSION

Table 4 provides a classification of the obtained magnitudes of color separations (as major or minor) by lamp optics and lamp light source. Separations were classified as minor if the resultant colors were either entirely within the white boxes or only slightly outside them. As expected, major color separations were confined to projector lamps, be they HIDs or tungsten-halogens. All nonprojector lamps exhibited only minor color separations, with tungsten-halogens showing smaller separations than HIDs.

Table 4
The magnitudes of the obtained color separations by lamp optics and light source.

Optics	Light source	Major color separation	Minor color separation
Projector	HID	3	5
	Tungsten-Halogen	2	2
Nonprojector	HID	0	9
	Tungsten-halogen	0	5

For all lamps that showed major color separations, the general pattern is the same: Below the cutoff, the color is within the white boxes and near the blackbody curve; as one moves upwards through the cutoff, color deviations increase toward the middle of the cutoff and then decrease when moving above the cutoff. At the same time, as one moves upwards through the cutoff, the luminous intensity decreases. Figure 9 provides a sample relationship between correlated color temperature and photopic luminous intensity for one of the lamps (the lamp that exhibited the largest color separation in Figure 3).

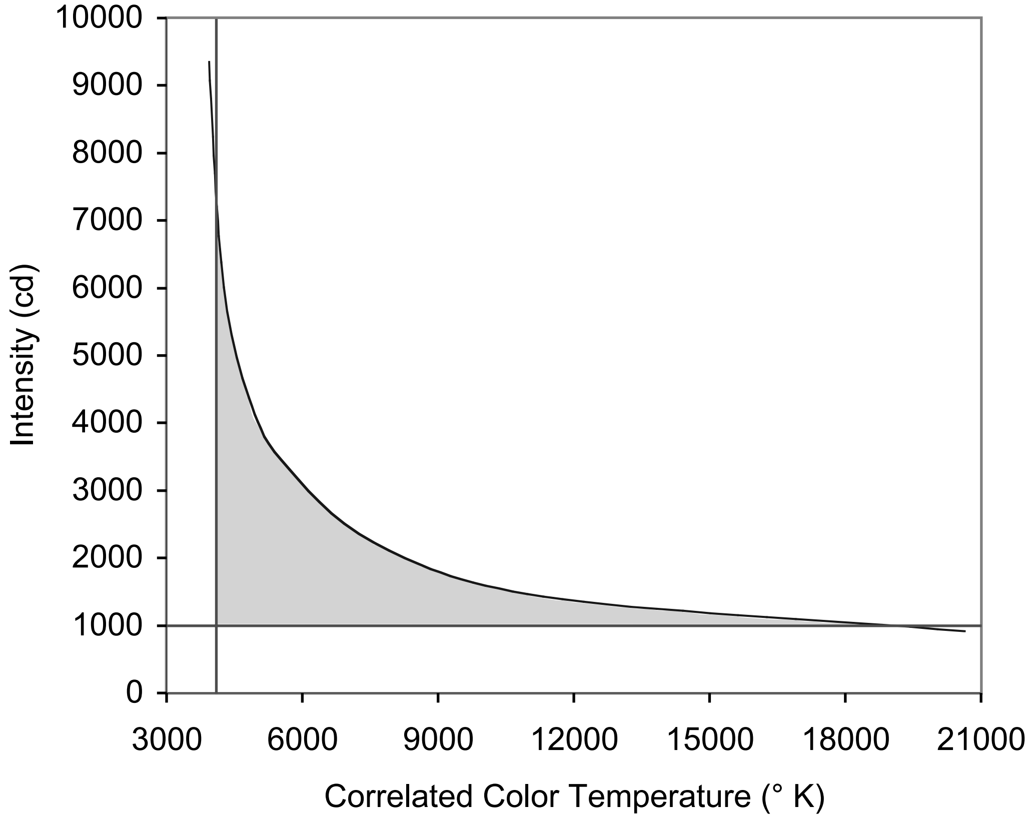

Figure 9. The relationship between correlated color temperature and photopic luminous intensity near the cutoff for a sample low beam showing a major color separation.

As illustrated in Figure 9, high correlated color temperatures and high intensities can occur together. Two reference lines are included in Figure 9. One is at 1,000 cd—the intensity limit for glare light at 0.5U, 1.5L for U.S. low beams (FMVSS, 2003), and a reasonable criterion for when intensity is high enough for glare to be a concern. The other line is at 4,200 K—a typical value for the correlated color temperature of an HID headlamp. Together, the two reference lines indicate that some of the combinations of color and intensity produced by chromatic aberrations in projector lamps are likely to be quite noticeable to oncoming drivers if they are exposed to light near the cutoff, as they may be because of headlamp misaim, changes in vehicle pitch, or roadway vertical curvature.

The possible effects of color on glare have been the subject of a considerable amount of research in recent years, primarily because of the introduction of HID headlamps (for a review, see Sivak, Flannagan, Schoettle, and Adachi, 2003). The consensus of that work appears to be that color does influence subjective aspects of glare (discomfort), but not objective aspects (reductions in a driver's ability to see). The relatively blue/white color of HID headlamps appears to make them more prone to causing discomfort than the relatively yellow color of tungsten-halogen lamps. Although correlated color temperature is not a perfect predictor of the effects of color on glare, it appears to be a reasonably good rough predictor within the range of colors that have been used for headlamps. Lamps with higher values of correlated color temperature (relatively blue) are usually experienced as more discomforting than lamps with lower values (relatively yellow). Research on unconventional headlamps that are deeply colored—well beyond the range that would typically be considered "white"—indicates that this pattern can be extrapolated reasonably well, and that deeply blue headlamps are experienced as even more discomforting than HIDs (Flannagan et al., 1993).

As one might expect from the formal research on color and glare, the complaints about headlamp glare that the U.S. National Highway Traffic Safety Administration (NHTSA) has received from the driving public have included mention of lamp color, including descriptions of "blue" and "whiter/bluer" headlamps (Van Iderstine, 2002). Many people have assumed that complaints from the public about the color of headlamps were attributable to HID lamps, and that may be true in many cases. However, given the relative frequency and magnitude of color shifts due to chromatic aberrations in projector lamps–both HID and tungsten-halogen—it may be that a significant part of the public perception of headlamp color is attributable to chromatic aberrations rather than HID sources themselves. It is often difficult to determine the exact reason for complaints from the general public, given that many drivers may not know how to precisely identify the lamps that they are encountering on the road. The possibility that people are misattributing colors from chromatic aberrations to HID lamps is increased by the fact that, at least among the first generation of HID lamps introduced in the U.S., about half of the HID lamps use projector optics (Sivak et al., 2002).

Because glare light with high correlated color temperature (and/or "bluish" color) produces more complaints about subjective discomfort, it would be desirable to control chromatic aberrations from projector lamps in order to reduce the exposure of oncoming drivers to strongly colored glare light, especially bluish light. However, considering the overall perception of headlamp glare by the driving public, the most important benefit of controlling chromatic aberrations may be in reducing the extent to which the public may misattribute the resulting colors to HID headlamps, thereby reducing public acceptance of HID lamps. Although HID headlamps have the potential to improve roadway illumination (Sivak et al., 2003), and although in photometric terms they normally produce about half of the glare levels of tungsten-halogen lamps (Sivak et al., 2002), they have provoked a substantial number of complaints about glare (Van Iderstine, 2002). Given the potential benefits of HID lamps, it would be unfortunate if chromatic aberrations from projector lamps contributed to a public perception that HID lamps produce higher glare levels.

Our data suggest that color aberrations near the cutoff of low beams are not rare with projector lamps. We obtained major color changes in 38% of the HIDs and 50% of the tungsten-halogens. However, color aberrations are a manageable problem with projector lamps. For example, Vozenilek et al. (2000) discuss the importance of the shape and positioning of the shield in eliminating this problem. The manageability of color aberrations is attested to by classifying our data by different lamp manufacturers. The 12 projector lamps in our sample were produced by 3 different lamp manufacturers. Major color separations were present for 3 out of 3 lamps for the first manufacturer, 2 out of 5 lamps for the second manufacturer, and 0 out of 4 lamps for the third manufacturer.

REFERENCES

ECE [Economic Commission for Europe] (1992). *Uniform provisions concerning the approval of motor vehicle headlamps emitting an asymmetrical passing beam or a driving beam or both and equipped with halogen filament lamps (H4 lamps)* (Regulation No. 20). Geneva: United Nations.

ECE [Economic Commission for Europe] (2001). *Uniform provisions concerning the approval of gas-discharge light sources for use in approved gas-discharge lamp units of power-driven vehicles* (Regulation No. 99). Geneva: United Nations

Flannagan, M.J., Sivak, M., Battle, D.S., Sato, T., and Traube, E.C. (1993). *Discomfort glare from high-intensity discharge headlamps: Effects of context and experience* (Report No. UMTRI-93-10). Ann Arbor: The University of Michigan Transportation Research Institute.

FMVSS [Federal Motor Vehicle Safety Standard] (2003). Standard No. 108: Lamps, reflective devices, and associated equipment. In, *Code of Federal Regulations*. Washington, D.C.: Office of the Federal Register.

Keller, P. (1983). 1976 CIE-UCS chromaticity diagram with color boundaries. In, *Proceedings of the Society for Information Display, Vol. 24* (4), 317-321.

SAE [Society of Automotive Engineers] (1995). *Color specification* (SAE Standard J578). Warrendale, PA: Society of Automotive Engineers.

Sivak, M., Flannagan, M. J., Schoettle, B., and Adachi, G. (2003). *Driving with HID headlamps: A review of research findings* (No. SAE Technical Paper Series No. 2003-01-0295). Warrendale, Pennsylvania: Society of Automotive Engineers.

Sivak, M., Flannagan, M.J., Schoettle, B., and Nakata, Y. (2002). *Performance of the first generation of HID headlamps in the U.S.* (Report No. UMTRI-2002-14). Ann Arbor: The University of Michigan Transportation Research Institute.

Van Iderstine, R. L. (2002). *Review of comments from NHTSA's notice of request for comment on nighttime headlighting glare*. Paper presented at the 2002 SAE Government/Industry Meeting, Washington, D.C.

Vozenilek, D., Purma, J., and Stefka, J. (2000). *Color aberrations of the projector systems and their corrections by the shape and position of the shields* (SAE Technical Paper Series No. 2000-01-0430). Warrendale, PA: Society of Automotive Engineers.

Wyszecki, G. and Stiles, W.S. (1982). *Color Science: Concepts and Methods, Quantitative Data and Formulae, Second Edition*. New York, NY: John Wiley & Sons, Inc.