Product Categories

- Goniophotometer
- Spectroradiometer
- Integrating Sphere
- LED Test Instruments
- CFL Testing Instruments
- Photometer and Colorimeter
- EMI and EMC Test Systems
- Electronic Ballast Tester
- Electrical Safety Tester
- Environmental Test Chamber
- Plug and Switch Testing
- AC and DC Power Supply
- Object Color and Glossiness Test
- Mask Produce and Test Machine
- Electronic Components Test

High Precision Spectroradiometer Integrating Sphere System

Product No: LPCE-2(LMS-9000)

Description | Video | Download

LPCE-2 Integrating Sphere Spectroradiometer LED Testing System is for single LEDs and LED lighting products light measurement. LED' s quality should be tested by checking its photometric, colorimetric and electrical parameters. According to CIE 177, CIE84, CIE-13.3, IES LM-79-19, Optical-Engineering-49-3-033602, COMMISSION DELEGATED REGULATION (EU) 2019/2015, IESNA LM-63-2, IES-LM-80 and ANSI-C78.377, it recommends to using an array spectroradiometer with an integrating sphere to test SSL products. The LPCE-2 system is applied with LMS-9000C High Precision CCD Spectroradiometer or LMS-9500C Scientific Grade CCD Spectroradiometer, and A molding integrating sphere with holder base. This sphere is more round and the test result is more accruacy than the traditional integrating sphere.

Related Applications

LM-79 and LM-80 Test Solutions

LEDs and Luminaire Test Solutions

HID Lamp Test Solutions

Fluorescent Lamp Test Solutions

Automotive Electronics Test Solutions

Related Standards

IEC International Electrotechnical Commission

CIE International Commission on Illumination

SASO Saudi Arabian Standards Organization

BIS Bureau of Indian Standards

NOM Norma Oficial Mexicana

• Electrical: Voltage, Current, Power, Power Factor, Displacement Factor, Harmonic
• LED Light Decay Test according to LM-80: Flux VS time, CCT VS time, CRI VS time, Power VS time, Power Factor VS time, Current VS time and Flux Efficiency VS time.

Option: The LPCE-2(LMS-9000C) or LPCE-2(LMS-9500C) work with a IS-1.5MT Constant Temperature Integrating Sphere and TMP-8 Multiplex Temperature Tester can fully meet IES LM-82

High Precision LPCE-2(LMS-9000C) System Configuration (It is suitable for the Middle & Small Manufactory or General Test Lab):
High Precision CCD Spectroradiometer (LMS-9000C), Optical Fiber (CFO-1.5M), Digital Power Meter (LS2050B/LS2050C/LS2012), DC Power Source (DC Series), AC Power Source (LSP-500VARC or LSP-500VARC-Pst), Integrating Sphere (IS-1.5MA and IS-0.3M), Standard Light Source (SLS-50W and SLS-10W), 19 Inch Cabinet (CASE-19IN). You can download the detail PDF here: LPCE-2 (LMS-9000C) High Precision CCD Spectroradiometer Integrating Sphere System Brochure

Specification:
• Spectral Wavelength Accuracy: ±0.3nm, Wavelength Reproducibility: ±0.1nm
• Sample Scanning Steps: ±0.1nm
• Accuracy of Chromaticity Coordinate (Δx, Δy): ±0.002 (under Standard A Lamp)
• Correlated Color Temperature CCT: 1,500K~100,000K, CCT Accuracy: ±0.3%
• Color Rendering Index Range: 0~100.0, Accuracy: ±(0.3%rd±0.3)
• Luminous Flux Range: 0.01-200,000lm; Photometric linear Accuracy: ±0.5%
• Stray light: <0.015%(600nm) and <0.03%(435nm)
• Integration Time: 0.1~10,000ms
• It can measure the temperatures inside and outside of integrating sphere
• Flux testing method: spectrum, photometric and spectrum with photometric revision
• The system includes the auxiliary lamp device and the software includes self-absorption function
• It can measure the temperatures inside and outside of integrating sphere
• Connect with PC via USB cable. The English version software can be run in Win7, Win8, Win10 and Win11 (The driver was Certificated by Microsoft)
• The LM-79 Photometric, Colorimetric and Electricity report can be exported PDF and LED Optical Maintenance test report can be exported Excel or PDF

LISUN Model	LMS-9000C	LMS-9000CUV-VIS	LMS-9000CVIS-NIR
Wavelength	350-800nm	200-800nm	350-1050nm

Agriculture lighting PAR, PPF and PPFD introduce and relevant test instruments

Color and spectrum measurement difference between goniospectraodiometer and integrating sphere system

Led test instruments supplier in China

Integrating sphere setup for the LED light measurement

What is the Integrating sphere, and how does it work

Integrating sphere: Sphere with light source

Based on the LM-79 standard, how to use the integrating spheres and spectrophotometers to test the LED luminaire

Agricultural plant growth market development

How you can use light source in an integrating sphere to get product reliability results

Related Successful Case

French-LISUN engineer repair LSG-1700B probe for customers free of charge

Germany-Customers independently installed LPCE-2 (LMS-9000) High Precision Spectroradiometer Integrating Sphere System by watching the video

France-Successfully installed LSG-1700B high-precision goniophotometer by watching the video

Spectroradiometer Integrating Sphere System Brochure

Specification:
• CCD detector: Hamamatsu TE-cooled (Temp: -10°C ±0.05°C) high sensitivity back-thinned detector
• Spectral wavelength accuracy: ±0.2nm, Resolution: ±0.1nm, Sample scanning steps: ±0.1nm
• Accuracy of chromaticity coordinate (Δx, Δy): ±0.0015 (under Standard A Lamp)
• Correlated color temperature CCT: 1, 500K~100, 000K, CCT accuracy: ±0.2%
• Color rendering index range: 0~100.0, Accuracy: ±(0.3%rd±0.3)
• Photometric linear Accuracy: ±0.2%
• Stray light: <0.015%(600nm) and <0.03% (435nm)
• Integration time: 0.1ms-60s
• It can measure the temperatures inside and outside of integrating sphere
• Flux testing method: spectrum, photometric and spectrum with photometric revision
• The system includes the auxiliary lamp device and the software includes self-absorption function
• It can measure the temperatures inside and outside of integrating sphere
• Connect with PC via USB cable. The English version software can be run in Win7, Win8, Win10 and Win11 (The driver was Certificated by Microsoft)
• The LM-79 Photometric, Colorimetric and Electricity report can be exported PDF and LED Optical Maintenance test report can be exported Excel or PDF

LISUN Model	LMS-9500C	LMS-9500CUV-VIS	LMS-9500CVIS-NIR
Wavelength	350-800nm	200-800nm	350-1050nm

Taejin Choi

2020-01-12

It was an essential product for manufacturing and research. I purchased it after confirming that it is a CIE/IEC certified product. The quality of the product is excellent and the satisfaction with the price is high. Employees are also satisfied with their response to repairs and after-sales services.

Tags : Integrating Sphere , LPCE-2 , LPCE-2 (LMS-9000A) , LPCE-2 (LMS-9000B) , LPCE-2 (LMS-9000C) , LPCE-2(LMS-9000) , Spectroradiometer

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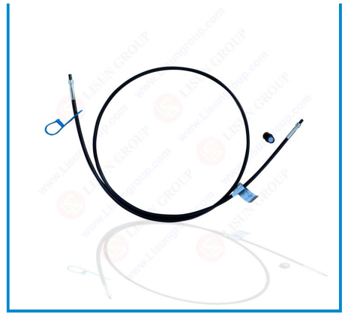
- India-Installation and training for LSG-1700B Goniophotometer and Maintenance of LPCE-2 Integrating Sphere Testing System
- India-LISUN engineer visit India to do installation and training for LPCE-2 High Precision Spectroradiometer Integrating Sphere System
- Egypt – Installation of LSG-1800B Goniophotometer and LPCE-2 (LMS-9000B) Integrating Sphere System

IS-*MA Integrating Sphere With Holder Base



CFO-1.5M Optical Fiber

SLS-50W Standard Light Source

DC3005 Digital CC and CV DC Power Supply

Goniophotometer | Integrating Sphere | Surge Generator

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NEMA Standards Publication

ANSI C78.377-2015

Electric Lamps — Specifications for the Chromaticity of Solid-state Lighting Products

National Electrical Manufacturers Association

ANSI C78.377-2015

American National Standard for Electric Lamps— Specifications for the Chromaticity of Solid-state Lighting Products

Secretariat:

National Electrical Manufacturers Association

Approved June 17, 2015

American National Standards Institute, Inc.

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Foreword (This Foreword is not a part of ANSI C78.377-2015)

This is a revised standard recently updated by the industry.

Suggestions for improvement of this standard are welcome. They should be sent to:

Secretary, ASC C78
National Electrical Manufacturers Association
1300 North 17th Street, Suite 900
Rosslyn, VA 22209

This standard was processed and approved for submittal to ANSI by the Accredited Standards Committee on Electric Lamps, C78, and its Work Group, C78WG09. Approval of the standard is not meant to imply that all Work Group members voted to approve it.

Andrew Jackson, Chair, ASC C78
Jianzhong Jiao, Technical Coordinator, C78.377
Karen B. Willis, Secretary, ASC C78

Contents

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Introduction

The purposes of this standard are, first, to specify the range of chromaticities recommended for general lighting with solid-state lighting products to ensure high-quality white light and, second, to categorize chromaticities with given tolerances so that the white light chromaticity of the products can be communicated to consumers. For this second purpose, the existing chromaticity standard (ANSI C78.376) for fluorescent lamps (FLRs) uses six nominal correlated color temperatures (CCTs), some of which are given names, such as Warm White (3000 K), Cool White (4100 K), and Daylight (6500 K). These names are often printed on product packages to communicate nominal CCT of the products to consumers. 2700 K and 5000 K, however, do not have names. Each of the six FLR lamp nominal CCTs has tolerances given as ellipses in the CIE 1931 (*x, y*) chromaticity diagram. Four-step MacAdam ellipses are used in ANSI C78.376; seven-step MacAdam ellipses and seven-step quadrangles are used in the U.S. Environmental Protection Agency's (EPA) ENERGY STAR specification for Lamps, v1.0.

This chromaticity specification for Light Emitting Diode (LED) products was developed to establish an alignment with existing FLR standards, enabling the consistent appearance of various light sources within spaces where multiple technologies are employed. The use of quadrangles to specify the chromaticities comprising the nominal CCTs increases the overall yield, complying with this standard while acknowledging that chromaticities previously excluded (i.e., within the quadrangles but outside the corresponding MacAdam ellipses) are nonetheless very useful in many applications.

This standard provides a basis for specifying chromaticity, explanation of a nominal CCT, target CCT, D_{uv}, and details of SSL chromaticity requirements. In this 2014 revision, the specifications for nominal CCTs of 2200 K and 2500 K have been added.

The annex in this document provides the background information of this standard and tables and graphical representations of the specifications in this standard, as well as those of tighter specifications expected in the future.

1 Scope

The purpose of this standard is to specify the range of chromaticities recommended for general lighting with solid state lighting (SSL) products, as well as to ensure that the white light chromaticities of the products can be communicated to consumers. This standard applies to LED lamps, LED light engines and LED luminaires for general indoor lighting applications.

This document does not apply to lighting fixtures sold without a light source. This standard does not apply to SSL products for outdoor applications. This standard also does not apply to SSL products for some indoor applications that intentionally produce tinted or colored light. This document does not include OLED products.

1.1 PATENT DISCLAIMER

At the time of publication, it was possible that some elements of this document might be the subject of patent rights. When this standard was approved for publication, the Accredited Standards Committee C78 and the National Electrical Manufacturers Association (NEMA) did not know of any patent applications, patents pending, or existing patents. ASC C78 shall not be held responsible for identifying any or all such patent rights.

2 Normative References

All standards are subject to revision, and parties to agreements based on this American National Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below:

CIE 15: 2004, *Commission Internationale de l'Eclairage, Colorimetry*, 3rd edition

ANSI/IES RP-16-10, *Nomenclature and Definitions for Illuminating Engineering*

3 Definitions

Terms used in this document, such as LED lamp and LED luminaire are defined in ANSI/IES RP-16-10, *Nomenclature and Definitions for Illuminating Engineering*.

4 Chromaticity

4.1 BASIS

The chromaticity coordinates and CCT values used in this standard are based on the CIE colorimetry system. While the chromaticity of light is expressed by chromaticity coordinates, such as (*x, y*) and (*u', v'*), the chromaticity of white light can also be expressed by CCT and the distance from the Planckian locus. CCT is a more intuitive measure of the shade of white light than (*x, y*) or (*u', v'*). Since CCT is defined based on the (*u', 2/3v'*) chromaticity diagram, the distance from the Planckian locus should be determined on the same diagram. It should be expressed as a signed value to indicate whether the chromaticity is above or below the Planckian locus. As such a distance parameter with respect to the Planckian locus is not officially defined by the CIE, "Duv" (symbol: D_{uv}) is defined in this document as the closest distance from the Planckian locus on the (*u', 2/3v'*) diagram, with "+" for above and "-" for below the Planckian locus.

4.2 NOMINAL CCT AND TARGET CCT

Nominal CCT is used to specify and communicate white light chromaticity information of a product and, in this document, is a CCT value at 100 K steps that is closest to the target CCT of the product. A target CCT is the CCT value that the product is designed to produce. Individual samples of the product may deviate from the target CCT due to production variation, which is normally controlled to be within a production tolerance. The same applies to target D_{uv}. The target CCT and target D_{uv} are also the center points of the tolerance range of these parameters in this document.

4.3 SPECIFICATIONS

SSL products included in this standard shall have chromaticity values that fall into one of the nominal CCT categories listed in Table 1. SSL products with a given nominal CCT shall have the defined target CCT and D_{uv}, and the values of individual samples shall be within the tolerances of CCT and D_{uv} as listed in Table 1. Measurement of chromaticity shall be made in accordance with methods given in the measurement standard IES LM-79-08.

Table 1
Nominal CCT Categories

<table>
<tr><th>Nominal CCT (K)</th><th>Target CCT and Tolerance (K)</th><th>Target D_{uv}</th><th>D_{uv} Tolerance Range</th></tr>
<tr><td>2200</td><td>2238 ± 102</td><td>0.0000</td><td rowspan="11">T_x: CCT of the source

For $T_x < 2870$ K
0.000 ± 0.0060

For $T_x \geq 2870$ K

$D_{uv}(T_x) \pm 0.0060$

where

$D_{uv}(T_x) = 57700 \times (1/T_x)^2$
$- 44.6 \times (1/T_x)$
$+ 0.00854$</td></tr>
<tr><td>2500</td><td>2460 ± 120</td><td>0.0000</td></tr>
<tr><td>2700</td><td>2725 ± 145</td><td>0.0000</td></tr>
<tr><td>3000</td><td>3045 ± 175</td><td>0.0001</td></tr>
<tr><td>3500</td><td>3465 ± 245</td><td>0.0005</td></tr>
<tr><td>4000</td><td>3985 ± 275</td><td>0.0010</td></tr>
<tr><td>4500</td><td>4503 ± 243</td><td>0.0015</td></tr>
<tr><td>5000</td><td>5029 ± 283</td><td>0.0020</td></tr>
<tr><td>5700</td><td>5667 ± 355</td><td>0.0025</td></tr>
<tr><td>6500</td><td>6532 ± 510</td><td>0.0031</td></tr>
<tr><td>Flexible CCT (2200- 6500)</td><td>T_F [1] ± ΔT [2]</td><td>$D_{uv}(T_F)$ [3]</td></tr>
</table>

[1] T_F is chosen to be at 100 K steps (2300, 2400, …., 6400 K), excluding the ten nominal CCTs listed in Table 1.

[2] $\Delta T = 1.1900 \times 10^{-8} \times T^3 - 1.5434 \times 10^{-4} \times T^2 + 0.7168 \times T - 902.55$

[3] Same as in the D_{uv} Tolerance Range.

Annex A
7-STEP QUADRANGLES

A1 Background Information

This chromaticity specification for SSL products was developed, on one hand, to be consistent with existing fluorescent lamp (FLR) standards, since many applications of SSL products are considered to be for replacement of existing FLRs and luminaires, as well as for incandescent lamps. On the other hand, there are several different requirements to be considered to best reflect the current (and near future) state of the SSL technologies. Since SSL technologies are developing, manufacturing control of chromaticity of light is still not as well established as with linear fluorescent lamps. This was considered to some extent when determining the tolerances of chromaticity in this standard, while acknowledging that smaller tolerances would be preferred. This standard will be updated as SSL technologies evolve and more applications are developed.

In the chromaticity specifications given in this standard, quadrangles rather than ellipses are used for SSL products for the following reasons:

a) quadrangles are commonly used in chromaticity binning of LED products;
b) due to cost-effective binning of LEDs and products, the gaps between chromaticity ranges need to be as small as possible;
c) quadrangles can be specified by the CCT and D_{uv}, and it is easier to judge product acceptance using the quadrangles than using ellipses. Ten fixed quadrangles are defined for the CCT range from 2200 K to 6500 K.

The value of the center points D_{uv} gradually shifts from 0.000 at low CCTs to 0.003 at 6500 K (on both the FLR-based and Flexible CCT systems) based on the fact that the reference daylight (CIE standard illuminant D65) has a D_{uv} of 0.003. This deviates from the center point used in ANSI C78.376 at high CCTs, which was based on available lamp products at the time the original standard was developed and does not represent D_{uv} of real daylight. For this reason, the D_{uv} values and target CCTs in this standard do not follow exactly those of the ANSI C78.376, but are chosen to be reasonably close to the fluorescent specification.

Since nominal CCT names used in ANSI C78.376 (e.g., Warm White, Cool White) have been abandoned in this standard, chromaticity information must be communicated by nominal CCT value. It is known, however, that the four-digit CCT values are not effective for communicating nominal CCTs to general consumers, and a different approach for this communication will be necessary. It is recommended that information on nominal CCT (e.g., a graphic label to indicate CCT) be shown on product package for communicating nominal CCTs. To avoid confusion in the market, it is recommended that a unified method be developed for all SSL products.

A2 Coordinate of Four Corners

Table A1 shows the (*x, y*) and (*u', v'*) chromaticity coordinates of the center points and the four corners of each quadrangle for convenience of plotting these quadrangles (the first corner point starts from the upper right corner noted as A, and follows with counter-clockwise rotation and notations of B, C, and D). Note that the sides of the quadrangles along the Planckian locus are not exactly straight lines, but are slightly curved, so that the D_{UV} value is constant.

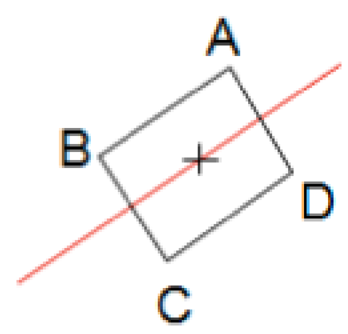

Table A1
Coordinates of Four Corners for 7-step Quadrangles

			A	B	C	D			A	B	C	D
CCT		**Center**	**(*x*, *y*) Tolerance Quadrangle**					**Center**	**(*u*′, *v*′) Tolerance Quadrangle**			
2200 K	*x*	0.5018	0.5259	0.5045	0.4799	0.4993	*u*′	0.2876	0.2939	0.2801	0.2822	0.2953
	y	0.4153	0.4342	0.4344	0.3967	0.3967	*v*′	0.5355	0.5459	0.5427	0.5250	0.5280
2500 K	*x*	0.4806	0.5045	0.4813	0.4593	0.4799	*u*′	0.2743	0.2801	0.2666	0.2696	0.2822
	y	0.4141	0.4344	0.4319	0.3944	0.3967	*v*′	0.5318	0.5427	0.5384	0.5209	0.5250
2700 K	*x*	0.4578	0.4813	0.4562	0.4373	0.4593	*u*′	0.2614	0.2666	0.2535	0.2573	0.2696
	y	0.4101	0.4319	0.4260	0.3893	0.3944	*v*′	0.5269	0.5384	0.5325	0.5155	0.5209
3000 K	*x*	0.4339	0.4562	0.4303	0.4150	0.4373	*u*′	0.2490	0.2535	0.2408	0.2457	0.2573
	y	0.4033	0.4260	0.4173	0.3821	0.3893	*v*′	0.5206	0.5325	0.5255	0.5091	0.5155
3500 K	*x*	0.4078	0.4303	0.4003	0.3895	0.4150	*u*′	0.2364	0.2408	0.2274	0.2336	0.2457
	y	0.3930	0.4173	0.4035	0.3709	0.3821	*v*′	0.5126	0.5255	0.5157	0.5003	0.5091
4000 K	*x*	0.3818	0.4003	0.3737	0.3671	0.3895	*u*′	0.2248	0.2274	0.2164	0.2237	0.2336
	y	0.3797	0.4035	0.3880	0.3583	0.3709	*v*′	0.5031	0.5157	0.5055	0.4912	0.5003
4500 K	*x*	0.3613	0.3737	0.3550	0.3514	0.3672	*u*′	0.2163	0.2163	0.2090	0.2171	0.2236
	y	0.3670	0.3882	0.3754	0.3482	0.3585	*v*′	0.4943	0.5055	0.4972	0.4839	0.4913
5000 K	*x*	0.3446	0.3550	0.3375	0.3366	0.3514	*u*′	0.2098	0.2090	0.2025	0.2112	0.2171
	y	0.3551	0.3753	0.3619	0.3373	0.3481	*v*′	0.4863	0.4972	0.4885	0.4762	0.4839
5700 K	*x*	0.3287	0.3375	0.3205	0.3221	0.3366	*u*′	0.2037	0.2025	0.1963	0.2057	0.2112
	y	0.3425	0.3619	0.3476	0.3256	0.3374	*v*′	0.4777	0.4885	0.4791	0.4679	0.4763
6500 K	*x*	0.3123	0.3205	0.3026	0.3067	0.3221	*u*′	0.1978	0.1963	0.1901	0.2001	0.2057
	y	0.3283	0.3477	0.3311	0.3119	0.3255	*v*′	0.4679	0.4791	0.4680	0.4580	0.4679
Flexible CCT	*x*	0.4237	0.4461	0.4184	0.4049	0.4286	*u*′	0.2439	0.2484	0.2354	0.2408	0.2527
	y	0.3998	0.4229	0.4123	0.3780	0.3868	*v*′	0.5177	0.5299	0.5218	0.5058	0.5131

Figures A1 and A2 show the graphical representation of the specification of the SSL products as listed in Table 1 on the (*x, y*) and (*u', v'*) diagrams. The (*u', v'*) diagram is more uniform than the (*x, y*) diagram and is better suited for evaluating color differences of light sources.

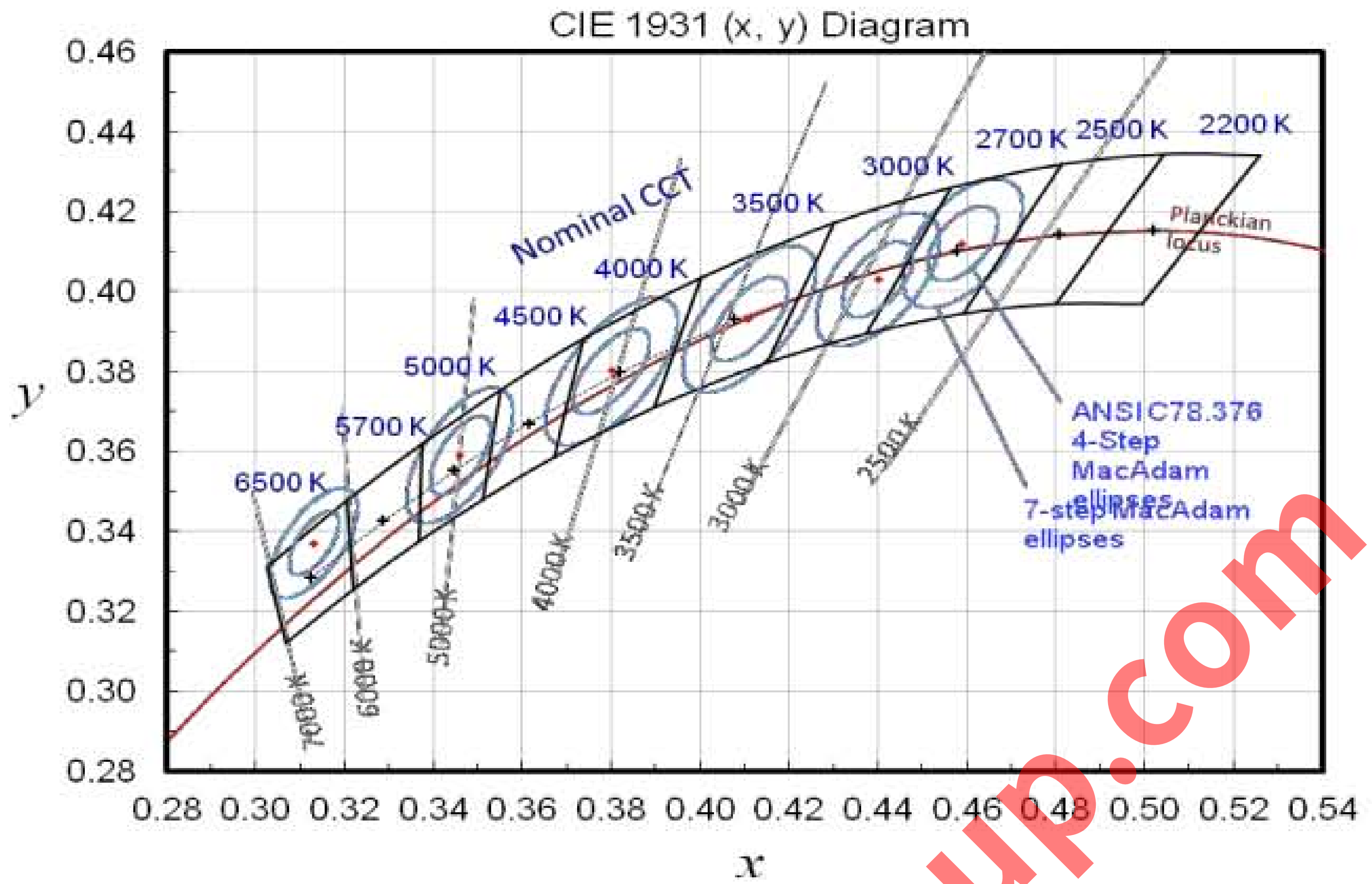

Figure A1
Graphical Representation of the Chromaticity Specification of Table 1 on the CIE (*x, y*) Chromaticity Diagram

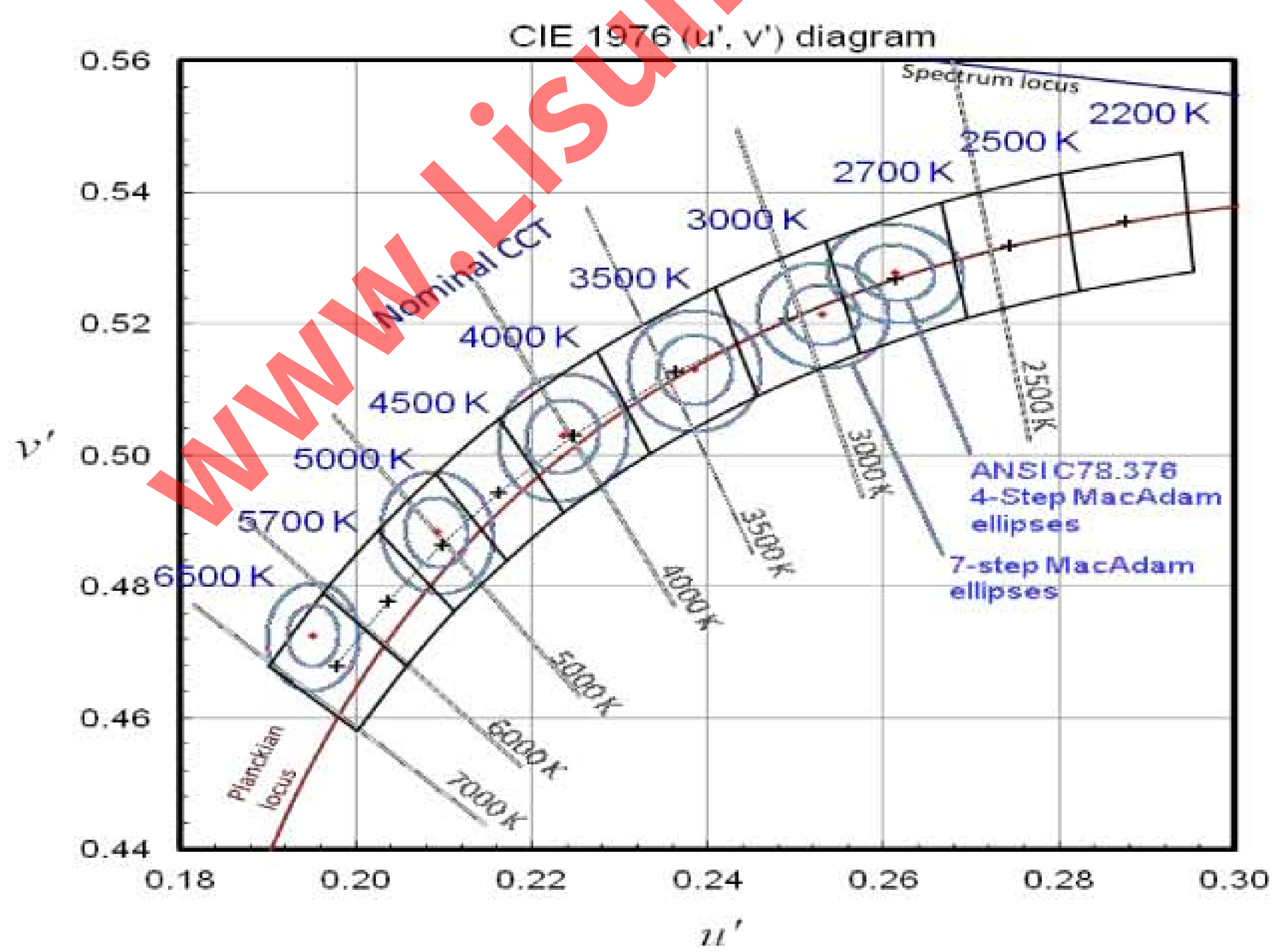

Figure A2
Graphical Representation of the Chromaticity Specification of Table 1 on the CIE (*u', v'*) Chromaticity Diagram

A3 Flexible CCT

In some applications, CCTs other than the ten nominal CCTs specified in Table 1 might be desired. Flexible CCT is used to specify nominal CCT between 2200 K and 6500 K at 100 K step intervals. The tolerances of CCT and D_{uv} are calculated using the defined equations and a corresponding quadrangle is given, which has approximately the same size as the 7-step MacAdam ellipses. See an example in figures A3 and A4. To avoid confusion and to maintain consistent tolerance ranges, Flexible CCT is only to be used to specify products that have nominal CCTs other than the defined ten nominal CCTs in Table 1.

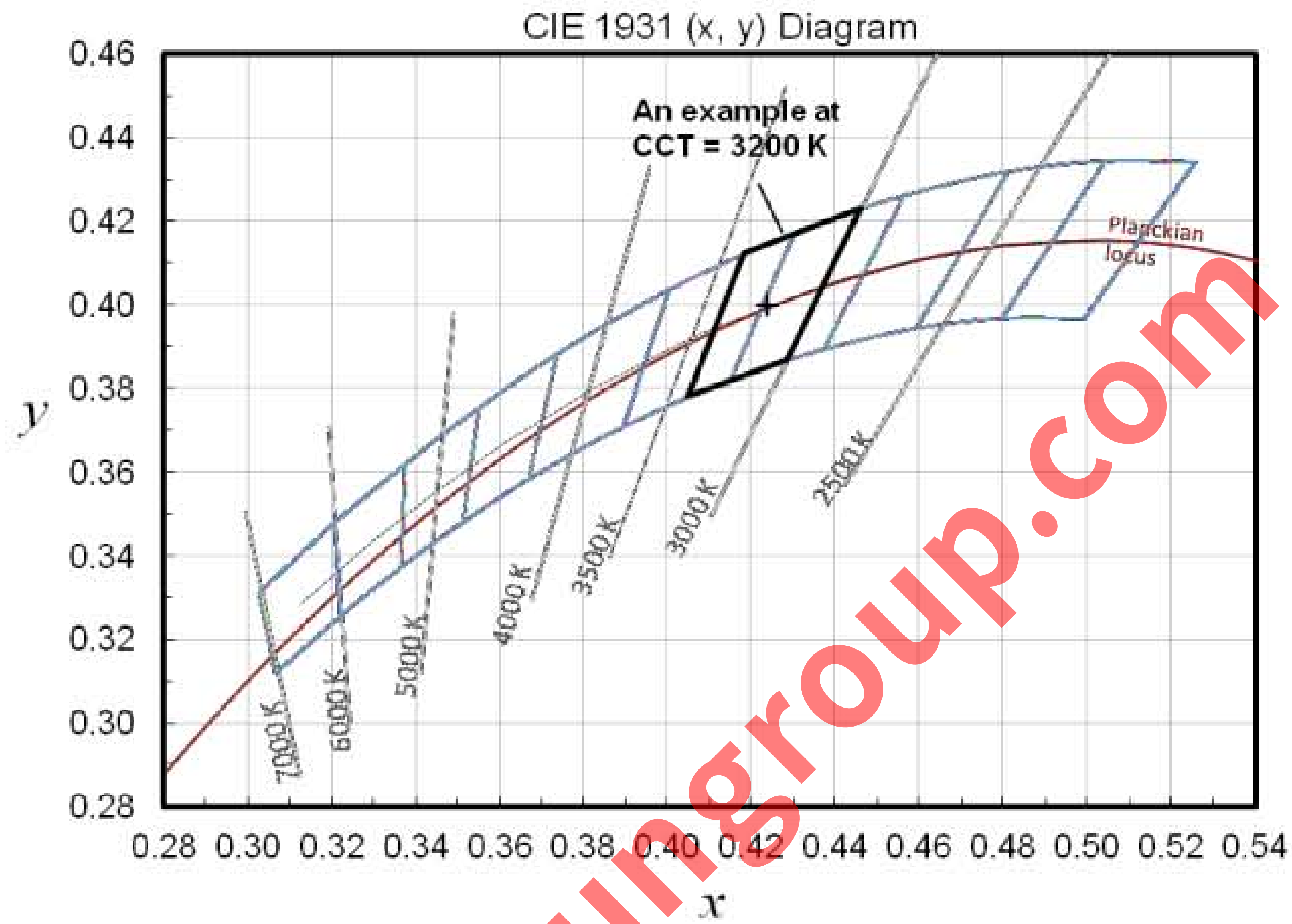

Figure A3
Example of Chromaticity Specification for Flexible CCT at Nominal CCT of 3200 K on the CIE (*x*, *y*) Chromaticity Diagram

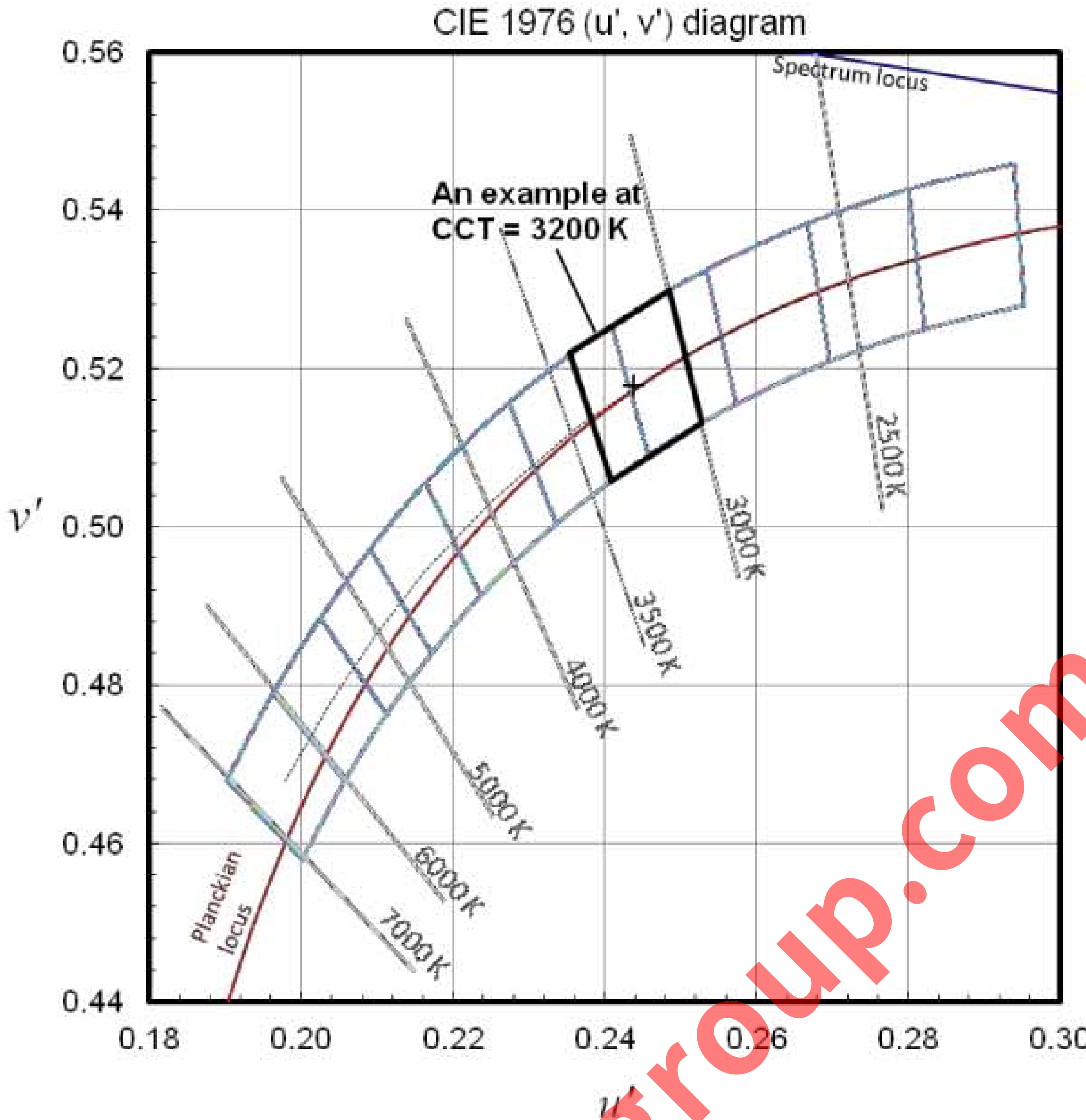

Figure A4
Example of Chromaticity Specification for Flexible CCT at Nominal CCT of 3200 K on the CIE (*u'*, *v'*) Chromaticity Diagram

Annex B
4-STEP QUADRANGLES

For the purpose of SSL products with tighter tolerances in some applications, 4-step quadrangles or circles (see Annex C) may be considered.

B1 Specifications for 4-step Quadrangles

Table B1 shows the specifications for 4-step quadrangles using the same center points specified in Table 1. The size of quadrangles corresponds to the size of 4-step MacAdam ellipses used in ANSI C78.376.

Table B1
Nominal CCT Categories with 4-step Quadrangles

Nominal CCT (K)	Target CCT and Tolerance (K)	Target D_{uv}	D_{uv} Tolerance Range
2200	2238 ± 58	0.0000	T_x: CCT of the source For T_x < 2870 K 0.000 ± 0.0033 For $T_x \geq$ 2870 K $D_{uv}(T_x) \pm 0.0033$ where $D_{uv}(T_x) = 57700 \times (1/T_x)^2 - 44.6 \times (1/T_x) + 0.00854$
2500	2460 ± 69	0.0000	
2700	2725 ± 83	0.0000	
3000	3045 ± 100	0.0001	
3500	3465 ± 124	0.0005	
4000	3985 ± 154	0.0010	
4500	4503 ± 185	0.0015	
5000	5029 ± 220	0.0020	
5700	5667 ± 269	0.0025	
6500	6532 ± 340	0.0031	
Flexible CCT (2200- 6500)	T_F[1] ± ΔT[2]	$D_{uv}(T_F)$[3]	

1) T_F is chosen to be at 100 K steps (2800, 2900, …., 6400 K), excluding the ten nominal CCTs listed in Table 1.
2) $\Delta T = 5.45 \times 10^{-10} \times T^3 - 2.63 \times 10^{-6} \times T^2 + 5.49 \times 10^{-2} \times T - 58.0$
3) Same as in the D_{uv} Tolerance Range.

Figures B1 and B2 show graphical representations of 4-step quadrangle specification.

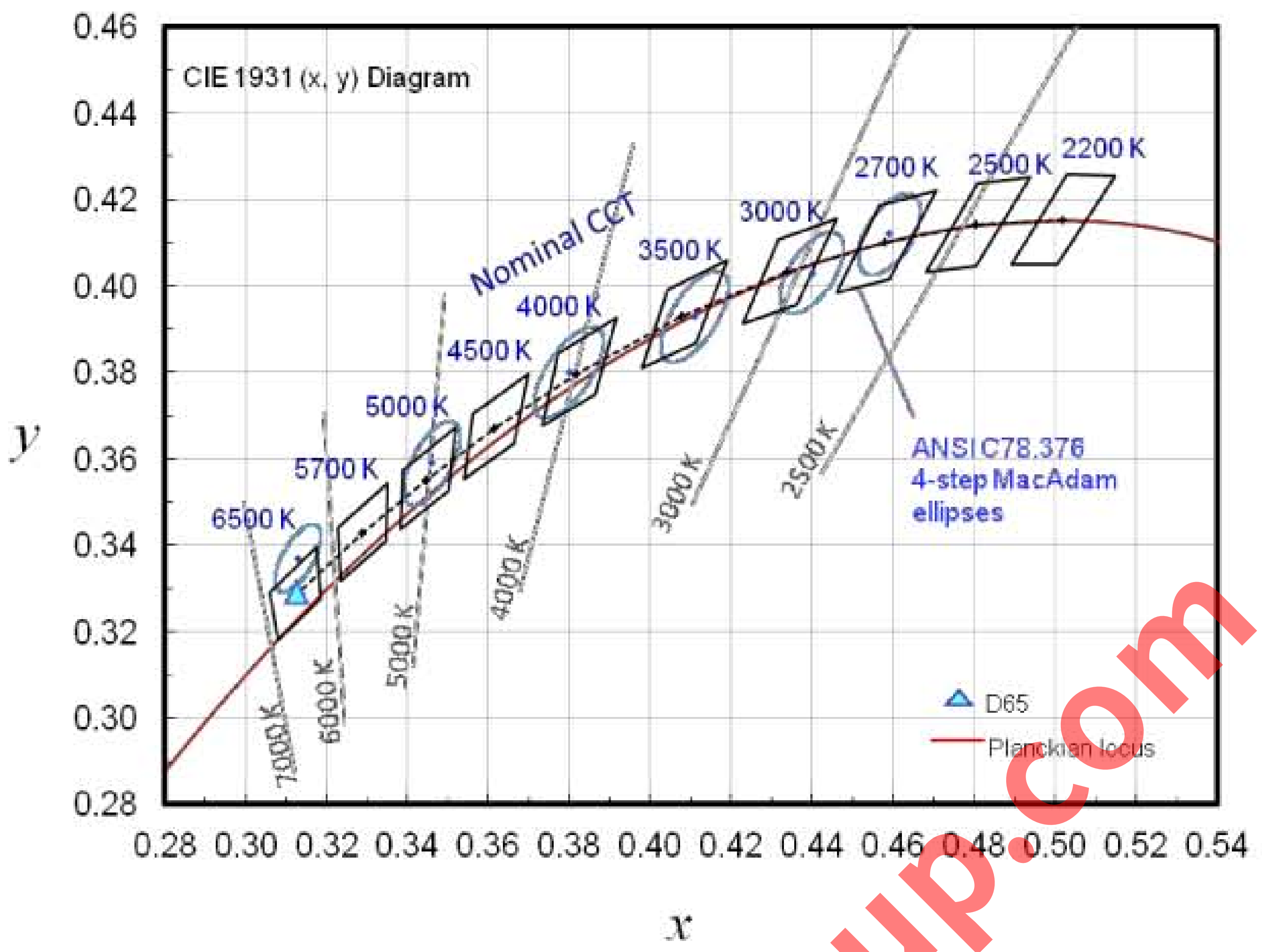

Figure B1
Graphical Representation of the Chromaticity Specification of 4-step Quadrangle Tolerance on the CIE (*x, y*) Chromaticity Diagram

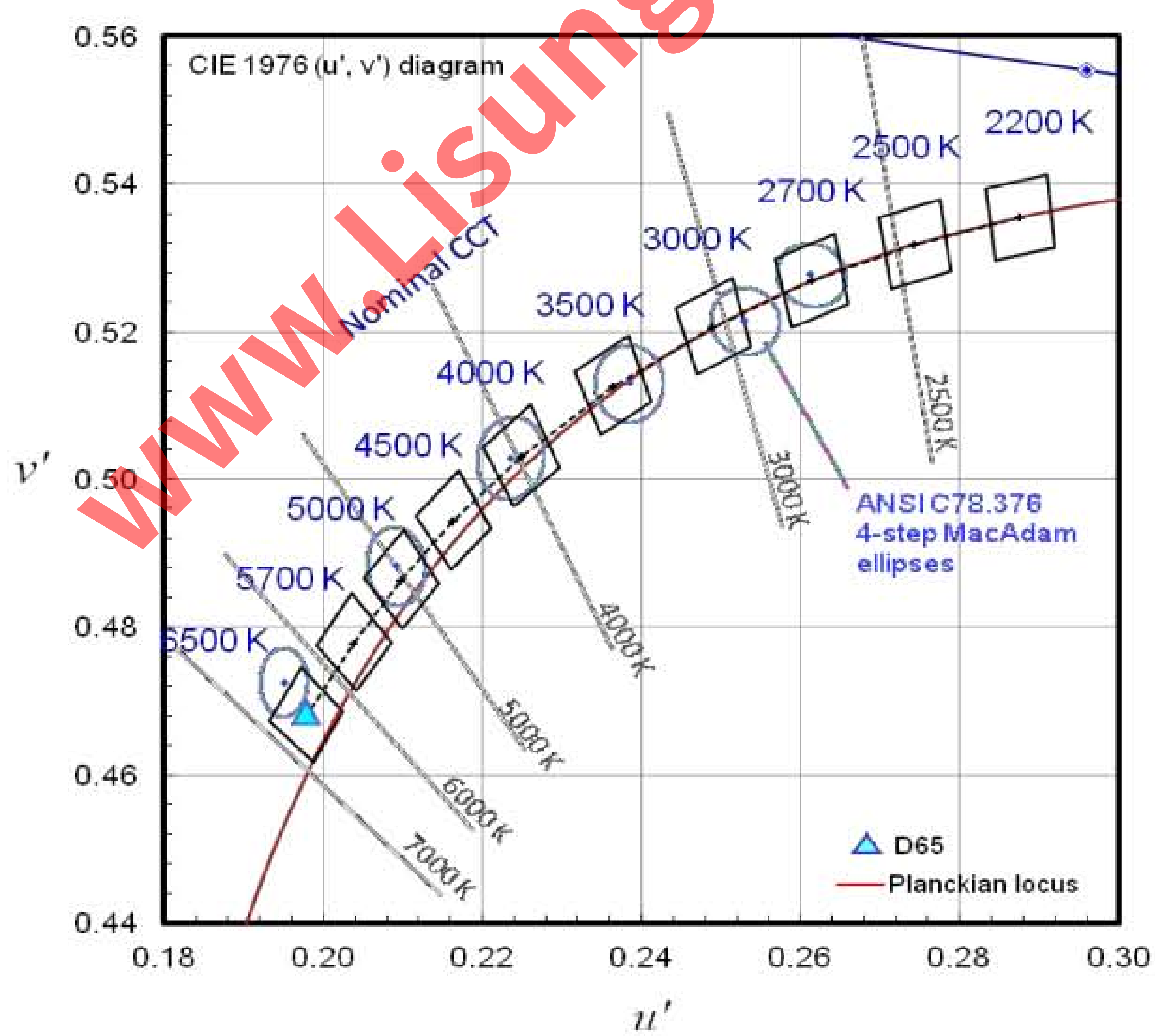

Figure B2
Graphical Representation of the Chromaticity Specification of 4-step Quadrangle Tolerance on the CIE (*u', v'*) Chromaticity Diagram

B2 Flexible CCT

The example of 4-step quadrangle tolerance flexible CCT is demonstrated in figures B3 and B4.

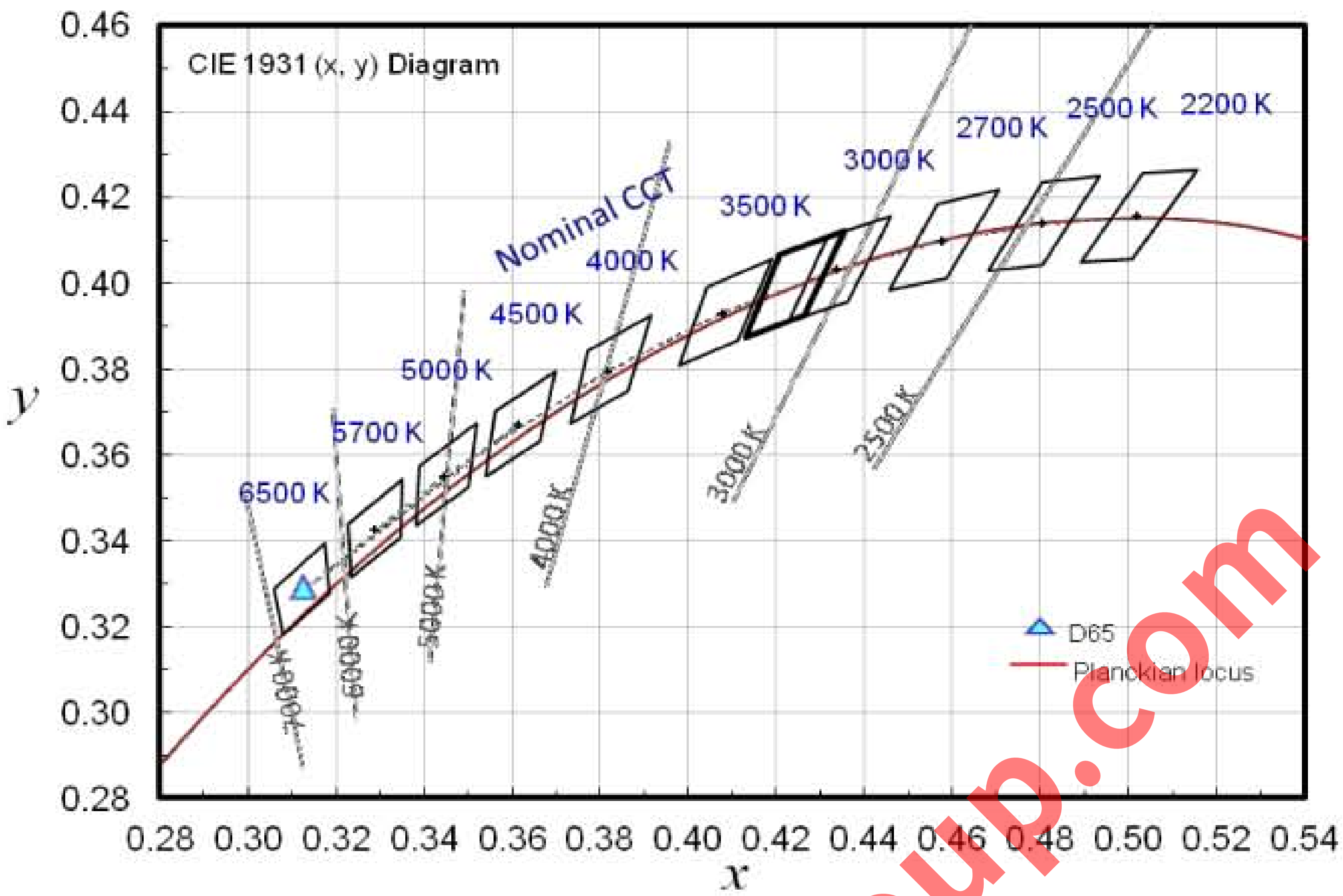

Figure B3
Example of the Chromaticity Specification for 4-step Quadrangle Tolerance of Flexible CCT at Nominal CCT of 3200 K on the CIE (*x, y*) Chromaticity Diagram

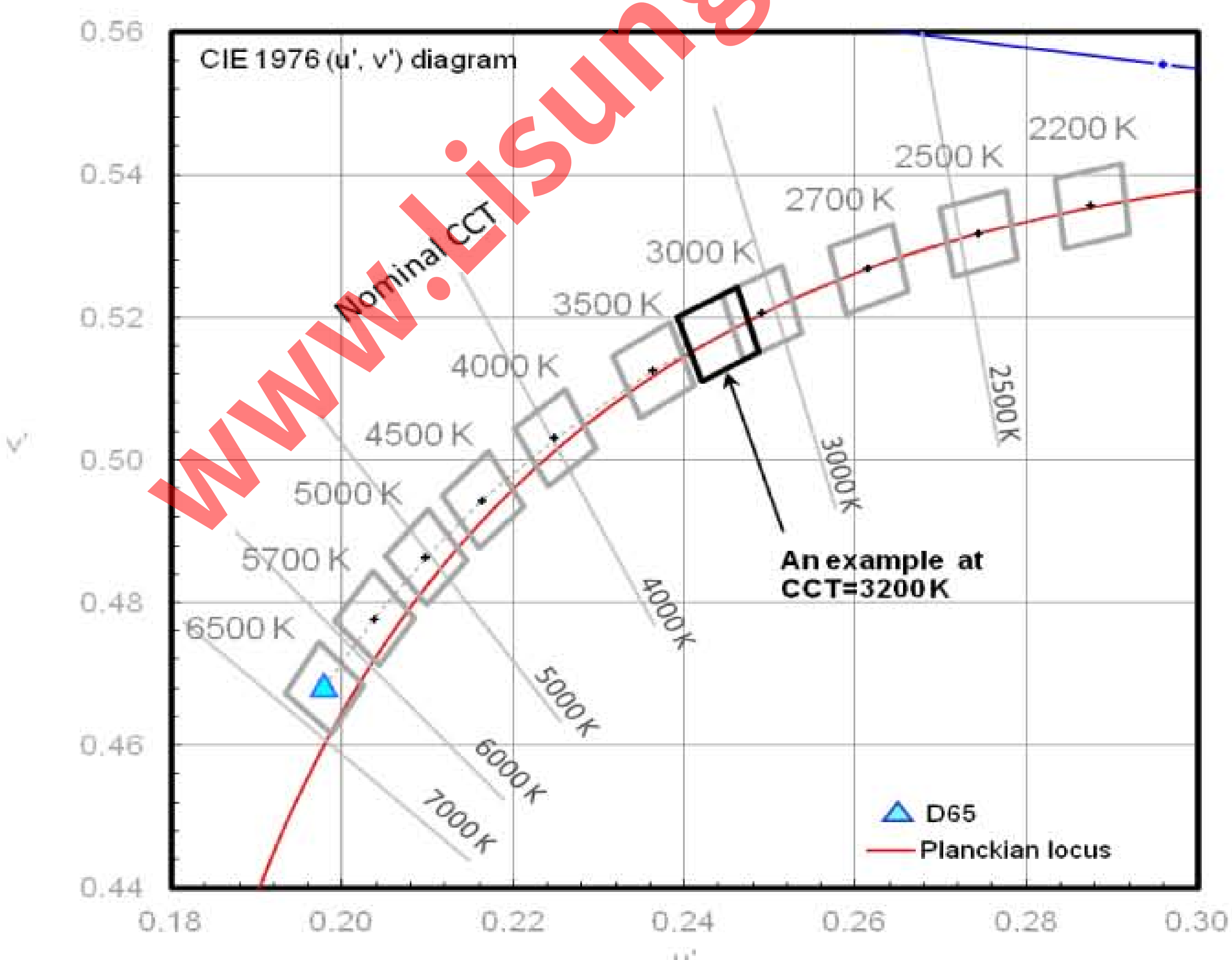

Figure B4
Example of the Chromaticity Specification for 4-step Quadrangle Tolerance of Flexible CCT at Nominal CCT of 3200 K on the CIE (*u'*, *v'*) Chromaticity Diagram

Annex C
4-STEP *u'v'* CIRCLES

C1 Specifications for 4-step u'v' Circles

The *u'v'* circle is an alternate way of specifying chromaticity tolerances in simpler definition, replacing the old MacAdam Ellipses, as recommended by the CIE (see Informative Reference 5). Specifications by the *u'v'* circles are suitable when products can be manufactured to a target chromaticity with small variations; quadrangles are suitable when products have large variation in chromaticity and have to be sorted by bins. Table C1 shows the *u'v'* circles that correspond to the size of 4-step quadrangles.

Table C1
Nominal CCT Categories with 4-step *u'v'* Circle Tolerance

Nominal CCT (K)	Center Point of Circle				Radius of Circle
	CCT (K)	D_{uv}	*u'*	*v'*	
2200	2238	0.0000	0.2876	0.5355	
2500	2460	0.0000	0.2743	0.5318	
2700	2725	0.0000	0.2614	0.5269	
3000	3045	0.0001	0.2490	0.5206	
3500	3465	0.0005	0.2364	0.5126	
4000	3985	0.0010	0.2248	0.5031	0.0044 in (*u'*, *v'*) diagram
4500	4503	0.0015	0.2163	0.4943	
5000	5029	0.0020	0.2098	0.4863	
5700	5667	0.0025	0.2037	0.4777	
6500	6532	0.0031	0.1978	0.4679	
Flexible CCT (2200 – 6500)	T_F [1] ± ΔT [2]	$D_{uv}(T_F)$ [3]	Flexible	Flexible	

1) T_F is chosen to be at 100 K steps (2300, 2400, …., 6400 K), excluding the eight nominal CCTs listed in Table 1.

2) $\Delta T = 5.45 \times 10^{-10} \times T^3 - 2.63 \times 10^{-6} \times T^2 + 5.49 \times 10^{-2} \times T - 58$

3) Same as in the D_{uv} Tolerance Range.

Figures C1 and C2 show graphical representations of 4-step circle specification.

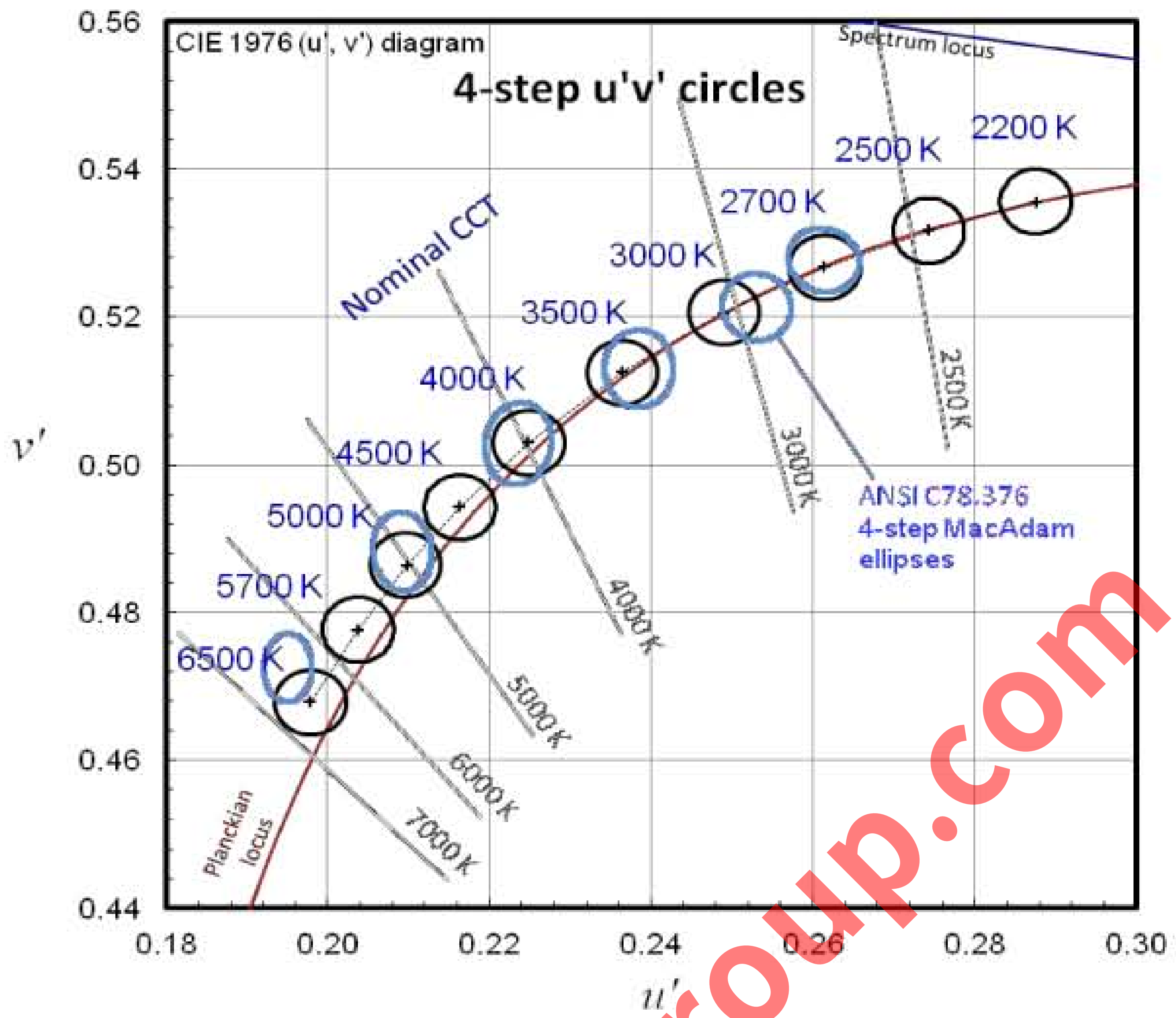

Figure C1
Graphical Representation of the Chromaticity Specification of 4-step Circle Tolerance on the CIE (*u', v'*) Chromaticity Diagram

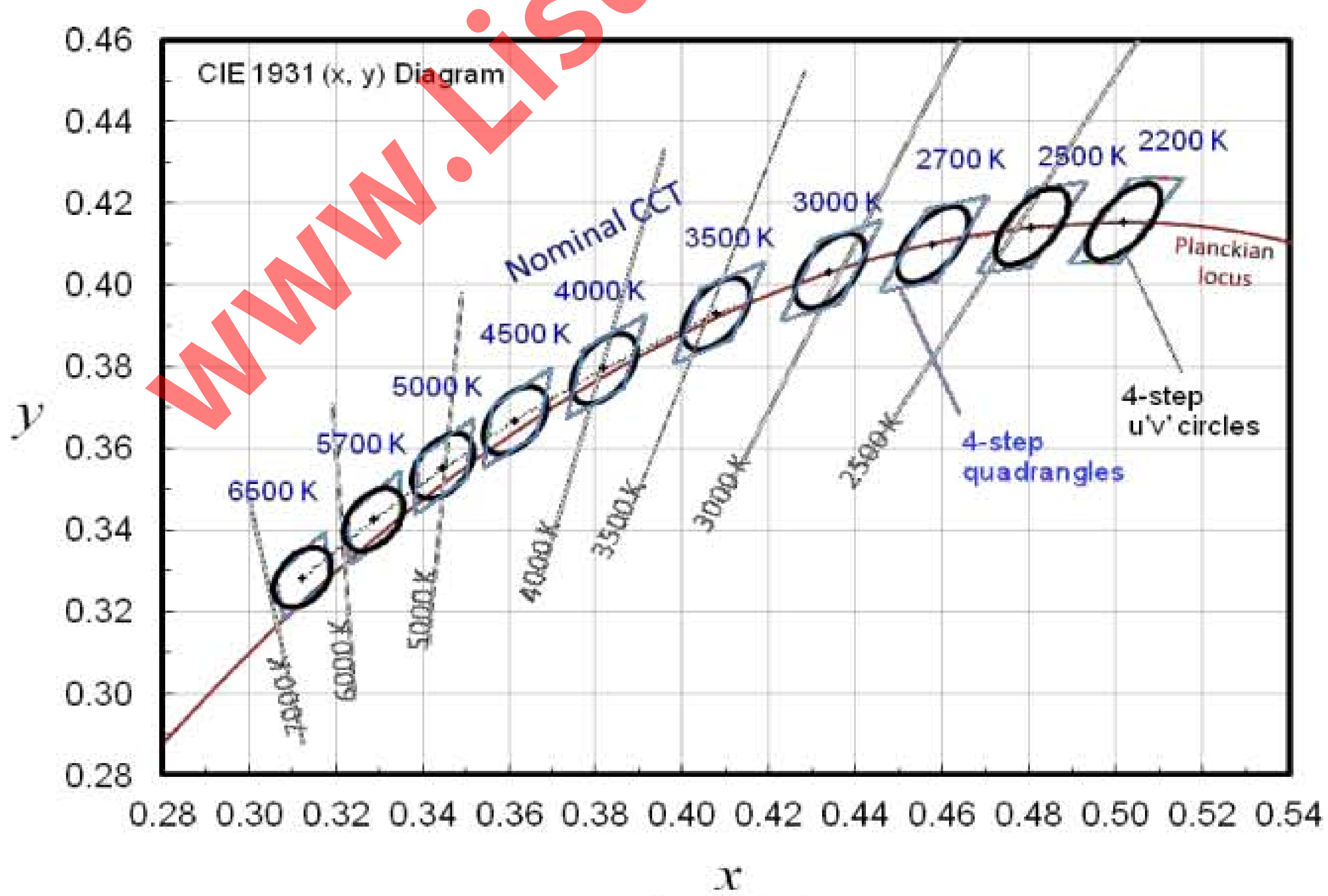

Figure C2
Graphical Representation of the Chromaticity Specification of 4-step Circle Tolerance on the CIE (*x, y*) Chromaticity Diagram

C2 Flexible CCT

An example of 4-step *u'v'* circle tolerance flexible CCT is shown in figures C3 and C4.

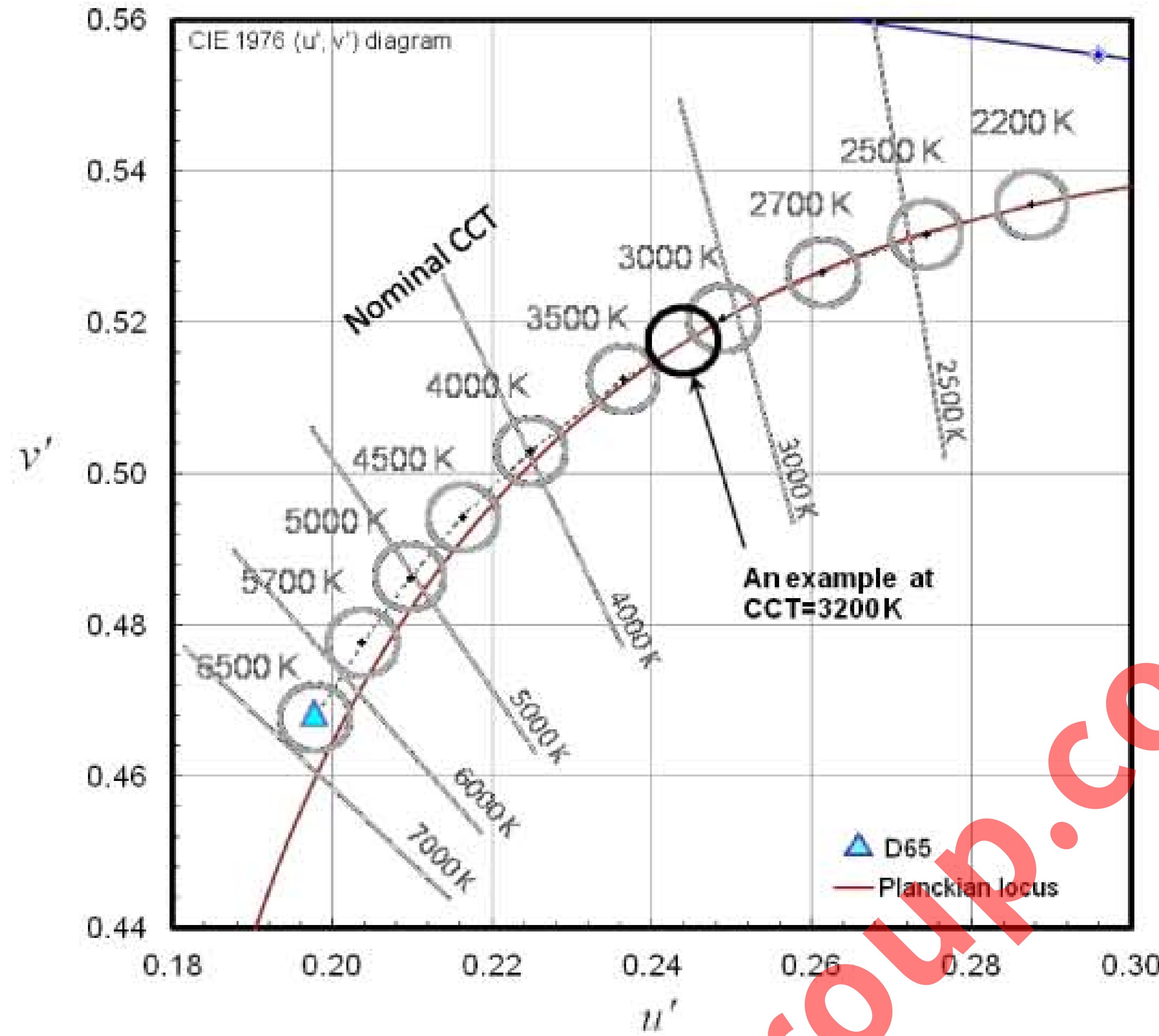

Figure C3
Example of the Chromaticity Specification for 4-step Circle Tolerance of Flexible CCT at Nominal CCT of 3200 K on the CIE (*u'*, *v'*) Chromaticity Diagram

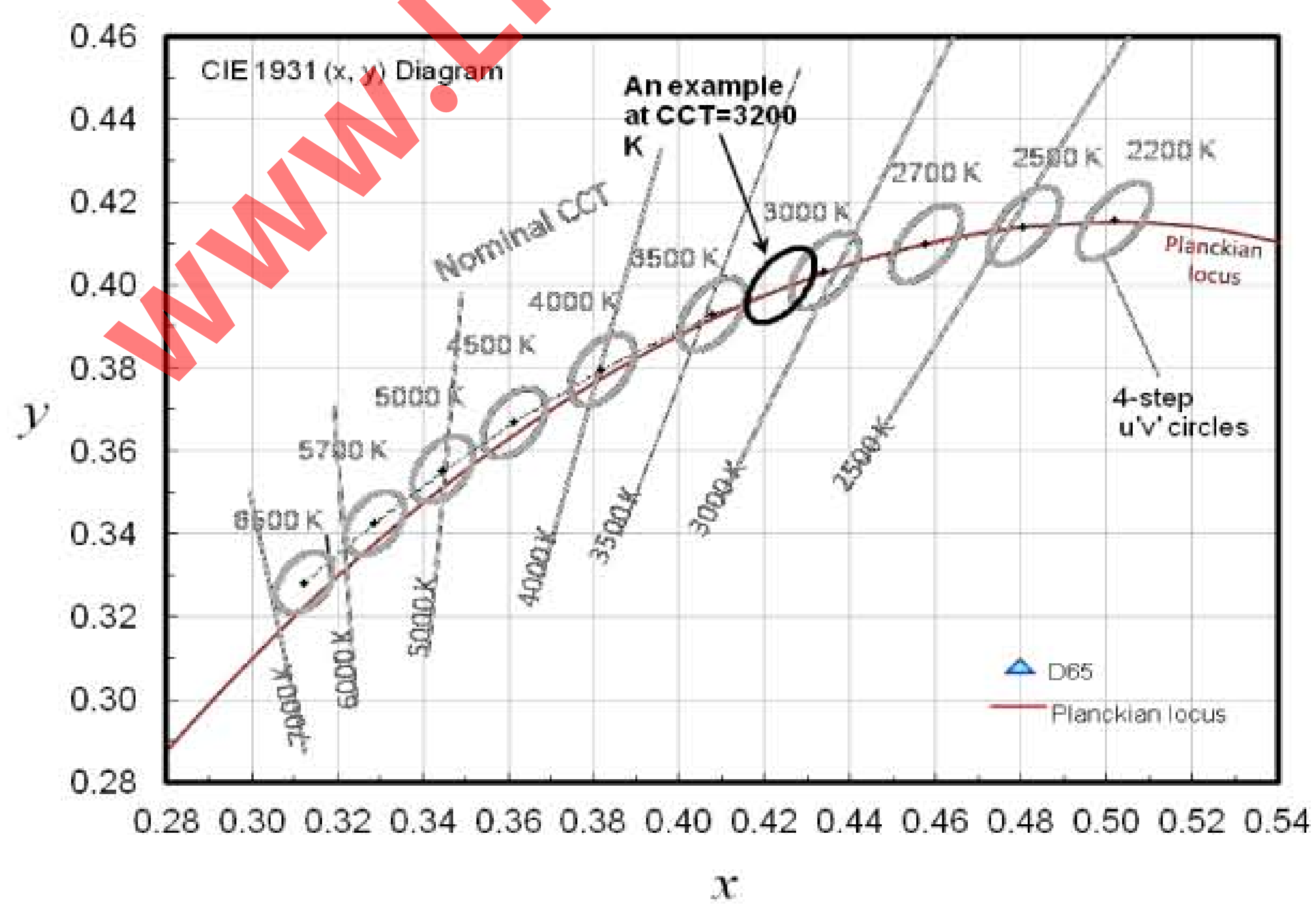

Figure C4
Example of the Chromaticity Specification for 4-step Circle Tolerance of Flexible CCT at Nominal CCT of 3200 K on the CIE (*x*, *y*) Chromaticity Diagram

Annex D
CONVERSIONS BETWEEN CCT, D_{uv} AND (*x, y*) OR (*u', v'*)

In this standard, it is intended that the chromaticities are measured as CCT and D_{uv}, then there is no need to convert these to (*x, y*) or (*u', v'*). However, in case these specifications need to be plotted on the (*x, y*) or (*u', v'*) diagram, the formulae for the conversion from CCT, D_{uv} to (*x, y*) or (*u', v'*) are provided in section D1. Also, in case D_{uv} is not available from the measurement instrument, the calculation formulae are provided in section D2 to calculate D_{uv} from (*x, y*) or (*u', v'*).

D1 Conversion from CCT, D_{uv} to (*x, y*) or (*u', v'*)

Relative spectral distribution of Planckian radiation at the temperature, CCT, T_{cp} (K), is obtained by:

$$S_B(\lambda) = \lambda^{-5}\left[\exp\left(\frac{c_2}{\lambda T_{cp}}\right) - 1\right]^{-1}$$

Where:

c_2 = 0.014388. The tristimulus values X_B, Y_B, Z_B of the Planckian radiation are given by:

$$X_B = k\int_\lambda S_B(\lambda)\bar{x}(\lambda)d\lambda$$
$$Y_B = k\int_\lambda S_B(\lambda)\bar{y}(\lambda)d\lambda$$
$$Z_B = k\int_\lambda S_B(\lambda)\bar{z}(\lambda)d\lambda$$

Where:

$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ are the CIE 1931 color matching functions and *k* is a normalizing constant. The summation at wavelength interval of 5 nm will suffice for most practical applications. For rigorous calculation, 1 nm interval should be used.

The chromaticity coordinate (u_B, v_B)[1] of this Planckian radiation is given by:

$$u_B = 4X_B/(X_B + 15Y_B + 3Z_B)$$
$$v_B = 6Y_B/(X_B + 15Y_B + 3Z_B).$$

Similarly, (u_{B1}, v_{B1}) for CCT, T_{cp}+1 (K), is calculated using the equations above, to obtain the angle of the tangential line of Planckian locus at the CCT point.

The (*u, v*) coordinate corresponding to the given CCT and D_{uv}, (T_{cp}, D_{uv}) is given by:

$$u = u_B + D_{uv} \cdot \frac{v_{B1} - v_B}{\sqrt{(u_{B1} - u_B)^2 + (v_{B1} - v_B)^2}}$$

[1] The (*u, v*) chromaticity coordinate (CIE 1960) is obsolete and is used here only as an intermediate process of the calculation.

$$v = v_B - D_{uv} \cdot \frac{u_{B1} - u_B}{\sqrt{(u_{B1} - u_B)^2 + (v_{B1} - v_B)^2}}$$

The (*x, y*) and (*u', v'*) coordinates are given by:

$$u' = u$$
$$v' = 1.5v$$
$$x = \frac{9u'}{(6u' - 16v' + 12)}$$
$$y = \frac{2v'}{(3u' - 8v' + 6)}$$

D2 Calculation of D_{uv} from (*x, y*) or (*u', v'*)

The value of D_{uv} is normally obtained in the process of calculation of CCT (e.g., see Informative Reference 6). Below is a simple approximation formula to calculate D_{uv} directly from (*x, y*) or (*u'v'*), without calculating CCT.

First, (*x, y*) or (*u', v'*) values are converted to CIE 1960 (*u, v*) by:

$$u = u'$$
$$v = \frac{2v'}{3}$$

or

$$u = \frac{4x}{(-2x + 12y + 3)}$$
$$v = \frac{6y}{(-2x + 12y + 3)}$$

D_{uv} is obtained as follows:

$$L_{FP} = \sqrt{(u - 0.292)^2 + (v - 0.24)^2}$$
$$a = \arccos\left(\frac{u - 0.292}{L_{FP}}\right)$$
$$L_{BB} = k_6 a^6 + k_5 a^5 + k_4 a^4 + k_3 a^3 + k_2 a^2 + k_1 a + k_0$$
$$D_{uv} = L_{FP} - L_{BB}$$

The coefficients in the expression are shown in Table D1. The full digits of each coefficient in the table must be entered in the equation above to ensure accuracy.

Table D1
Coefficients for D_{UV} Calculation

k_6	-0.00616793
k_5	0.0893944
k_4	-0.5179722
k_3	1.5317403
k_2	-2.4243787
k_1	1.925865
k_0	-0.471106

The D_{uv} values obtained by this formula are accurate to within 0.0001 in the range from 2130 K to 20000 K and D_{uv} = 0.000 ± 0.010, which includes the range covered by this standard. The errors increase sharply outside this range, especially at lower CCT.

Annex E
INFORMATIVE REFERENCES

1) IES LM-79-08, *Illuminating Engineering Society of North America, Approved Method for the Electrical and Photometric Measurements of Solid-State Lighting Products*

2) D.L. MacAdam, *Specification of Small Chromaticity Differences*, Journal of Optical Society of America, 33-1, 1943, pp 18-26.

3) U.S. Environmental Protection Agency (EPA), *ENERGY STAR Program Requirements for Lamps,* V1.0, 2013.

4) ANSI C78.376-2001, *Specifications for the Chromaticity of Fluorescent Lamps*

5) CIE TN 001, *2014 Chromaticity Difference Specification for Light Sources*

6) Y. Ohno, "Practical Use and Calculation of CCT and D_{uv}," *LEUKOS*, 10:1, 47-55, DOI: 10.1080/15502724.2014.839020 (2013).

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