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A Practical Photometer for CIE Performance Based Mesopic Photometry System

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Background: What is Mesopic? Where is Mesopic?

Mesopic vision is a visual condition between photopic and scotopic vision

- Most street lighting scenarios are in the mesopic range

Mesopic luminance range: $0.001 - 10 \text{cd/m}^2$



To apply CIE 191 mesopic photometry system to lighting application, we need an in-situ measurement method

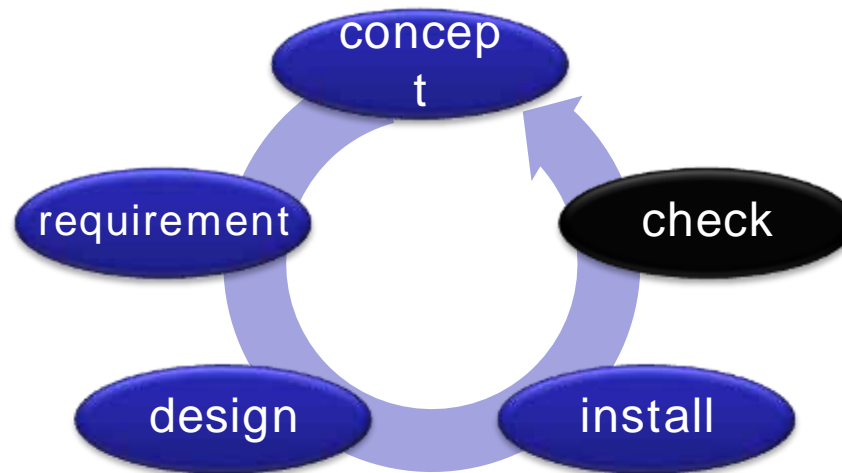
Recent CIE activities regarding mesopic photometry

- CIE 191 “Recommended System for Mesopic Photometry Based on Visual Performance” was published (2010.10)
- CIE TC2-65: Photometric Measurements in the Mesopic Range was started (2009.6)

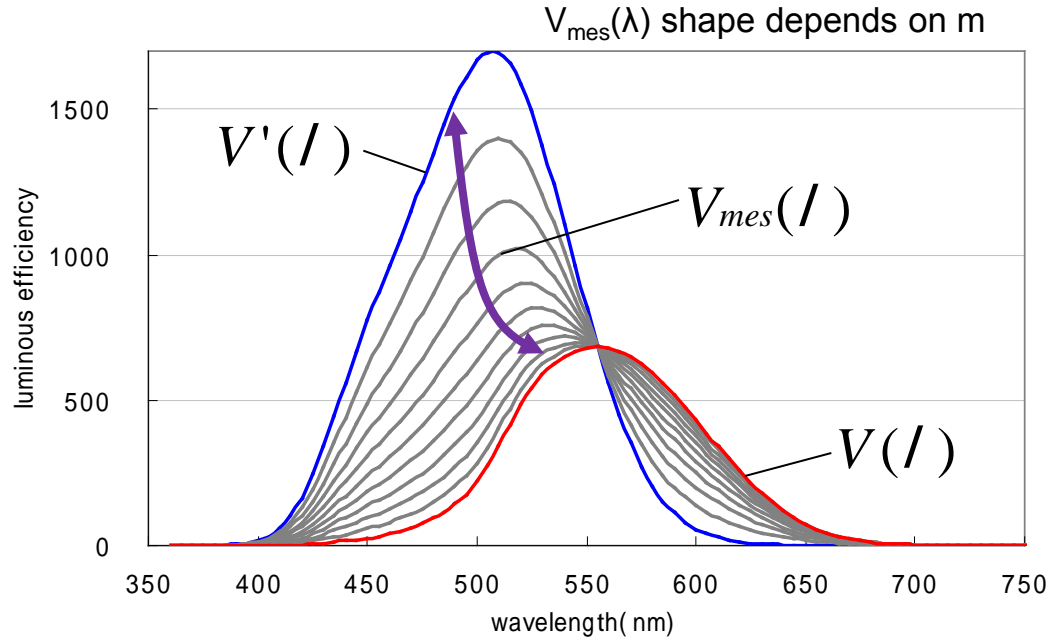
No instruments are available to measure mesopic quantities



We can't confirm whether installed lighting meets its requirements or not!



CIE 191 defined the mesopic spectral lumious efficiency $V_{mes}(\lambda)$ as a simple combination of $V(\lambda)$ and $V'(\lambda)$



$$M(m)V_{mes}(l) = mV(l) + (1 - m)V'(l) \quad \text{for } 0 \leq m \leq 1$$

$$L_{mes} = \frac{683}{V_{mes}(l_0)} \int V_{mes}(l) L_e(l) dl$$

$V_{mes}(l)$: mesopic spectral sensitivity

L_{mes} : mesopic luminance

$V_{mes}(l_0)$: the value of $V_{mes}(\lambda)$ at 555nm

$M(m)$: a normalizing function such that $V_{mes}(\lambda)$ attains a maximum value of 1

$L_e(l)$: spectral radiance in $Wm^{-2}sr^{-1}m^{-1}$

The coefficient m is calculated from the mesopic luminance of an adaptation field, but the adaptation field is NOT defined.

$$m_0 = 0.5$$

$$L_{mes, n} = \frac{m_{(n-1)}L_p + (1 - m_{(n-1)})L_s V'(I_0)}{m_{(n-1)} + (1 - m_{(n-1)})V'(I_0)}$$



Calculated using iterative approach

$$m_n = a + b \log_{10}(L_{mes, n})$$

L_p :the photopic luminance of the adaptation field

L_s :the scotopic luminance of the adaptation field

$V'(I_0)$:683/1699 is the value of scotopic spectral luminous efficiency function at $\lambda_0 = 555\text{nm}$

a :parameter(=0.7670)



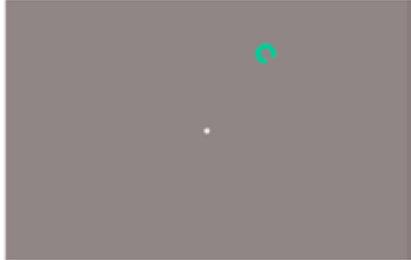

b :parameter(=0.3334)

The value of L_{mes} obtained by the equations above is the mesopic luminance of the visual adaptation field. The mesopic luminance of objects in the visual adaptation field is obtained according to equations (2) and (3) using the value of m determined for the adaptation field.

- CIE 191:2010

CIE 191 is based on experiments setups of which have wide background scene

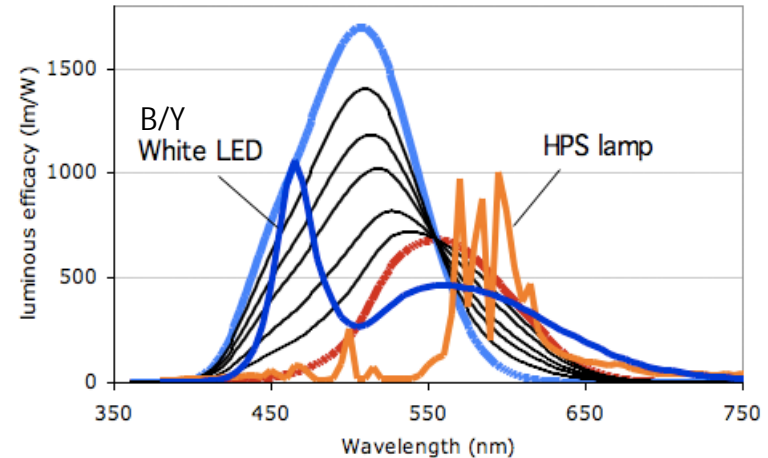
(Freiding et al. 2007, Walkey et al. 2007, Varady et al. 2007, He et al. 1997,1998)

Setup name	Modified Goldman perimeter	Large uniform hemisphere	Computer controlled CRT display	Driving Simulator
	HUT, FINLAND	HUT, FINLAND	CU, UK	TNO, NETHERLANDS
stimuli	Size:1.5 x 2deg. WL: 4-500, 5-600, 6-700nm Position: 0(fovea), 10°	Size: 0.29deg. WL: LED (red, amber, green, cyan) Position: 0(fovea), 10deg.	Size: 2deg. Landolt C WL: no mentioned (broad band) Position: 10deg.	Size: 2deg. WL: same as BG(broad band) Position: 10deg.
back-ground	Size: 180x180deg. Source: 4000K MH luminance: 0.01, 0.1, 1, 10cd/m ²	Size: 180x180deg. Source: 5400K FL luminance: 0.1, 1, 10cd/m ²	Size: 23 x 36deg. CRT:7003K(x,y)=(0.305,0.323) luminance: 0.01, 0.03, 0.1, 1, 10cd/m ²	Size: 30 x 120deg. projector: white, yellow, red, blue luminance: 0.01, 0.1, 1, 10cd/m ²
image				

High S/P ratio light sources (ex. LEDs) will be more efficient for street lighting

$$S / P = \frac{K'_m \int S(\lambda) V'(\lambda) d\lambda}{K_m \int S(\lambda) V(\lambda) d\lambda}$$

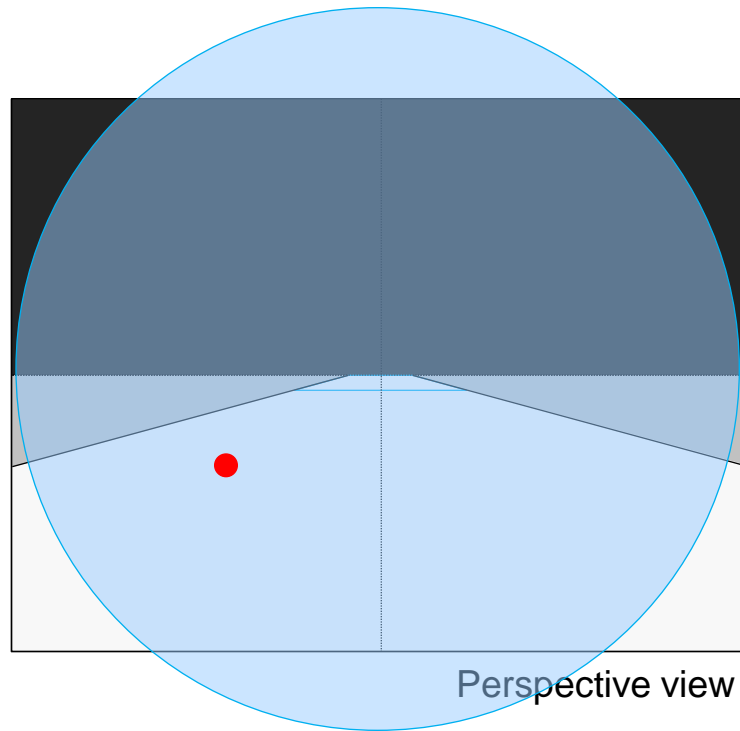
$S(\lambda)$: spectral distribution of the light source



		Photopic luminance $\text{cd}\cdot\text{m}^{-2}$										
		S/P	0,01	0,03	0,1	0,3	0,5	1	1,5	2	3	5
LPS ~	0,25		-75 %	-52 %	-29 %	-18 %	-14 %	-9 %	-6 %	-5 %	-2 %	0 %
	0,45		-55 %	-34 %	-21 %	-13 %	-10 %	-6 %	-4 %	-3 %	-2 %	0 %
HPS ~	0,65		-31 %	-20 %	-13 %	-8 %	-6 %	-4 %	-3 %	-2 %	-1 %	0 %
	0,85		-12 %	-8 %	-5 %	-3 %	-3 %	-2 %	-1 %	-1 %	0 %	0 %
	1,05		4 %	3 %	2 %	1 %	1 %	1 %	0 %	0 %	0 %	0 %
MH warm white ~	1,25		18 %	13 %	8 %	5 %	4 %	3 %	2 %	1 %	1 %	0 %
	1,45		32 %	22 %	15 %	9 %	7 %	5 %	3 %	3 %	1 %	0 %
	1,65		45 %	32 %	21 %	13 %	10 %	7 %	5 %	4 %	2 %	0 %
	1,85		57 %	40 %	27 %	17 %	13 %	9 %	6 %	5 %	3 %	0 %
LED cool white ~	2,05		69 %	49 %	32 %	21 %	16 %	11 %	8 %	6 %	3 %	0 %
	2,25		80 %	57 %	38 %	24 %	19 %	12 %	9 %	7 %	4 %	0 %
MH daylight ~	2,45		91 %	65 %	43 %	28 %	22 %	14 %	10 %	8 %	4 %	0 %
	2,65		101 %	73 %	49 %	31 %	24 %	16 %	12 %	9 %	5 %	0 %

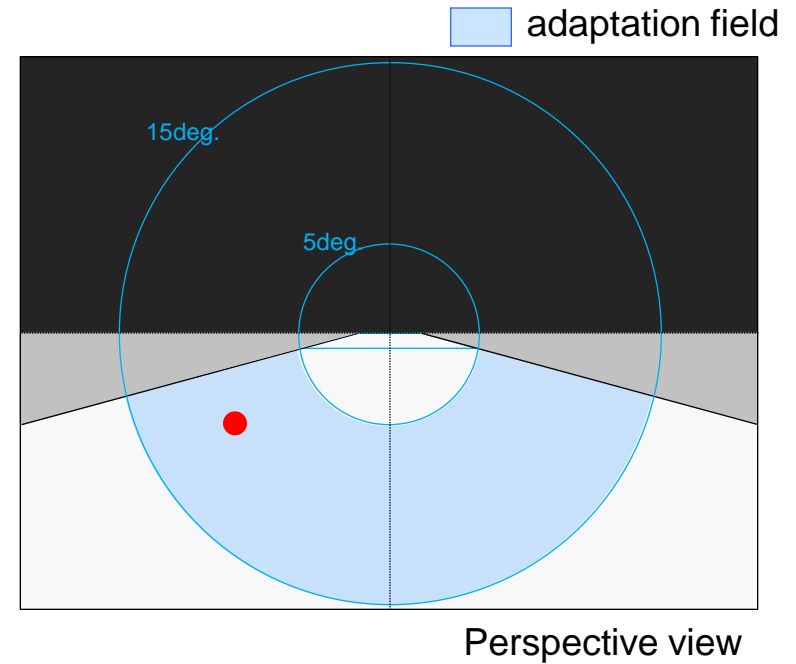
The adaptation field depends on adaptation mechanism - Global or Local?

■ Global adaptation is dominant



Illuminance meter type is better

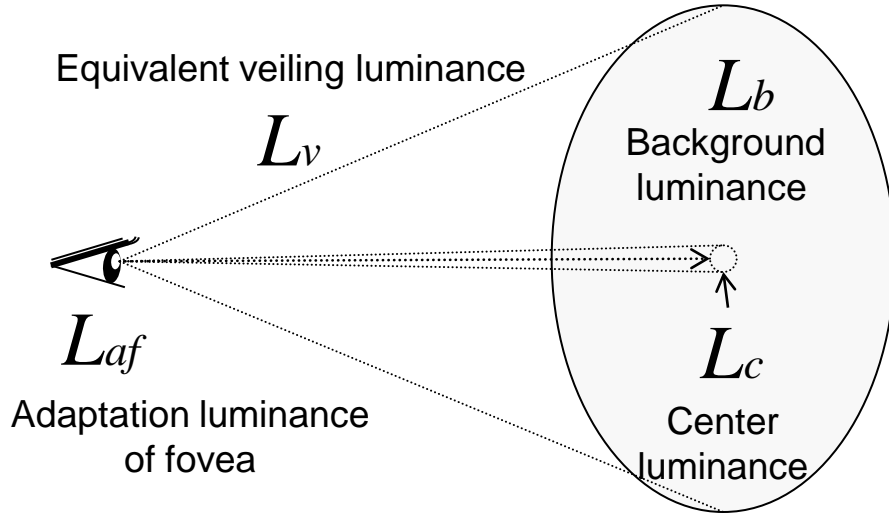
■ Local adaptation is dominant



Luminance meter type is better

Fovea cells adapt to sum of center luminance and equivalent veiling luminance when it adapt to luminance pattern distributed wide field of view

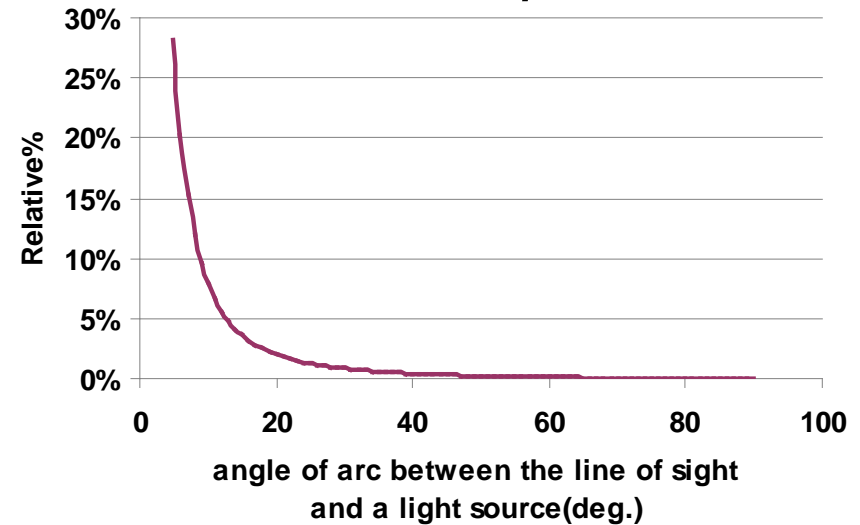
(Holladay 1926, Crawford 1936, Moon & Spencer 1943, Fry et al. 1963)



Equivalent veiling luminance:

Luminance at the fovea caused by light coming from peripheral field of view and scattered in eye

$$L_v = k \int_0^{2\pi} \int_0^{\frac{p}{2}} \frac{L(q, f) \sin q \cos q}{q^2} dq df$$

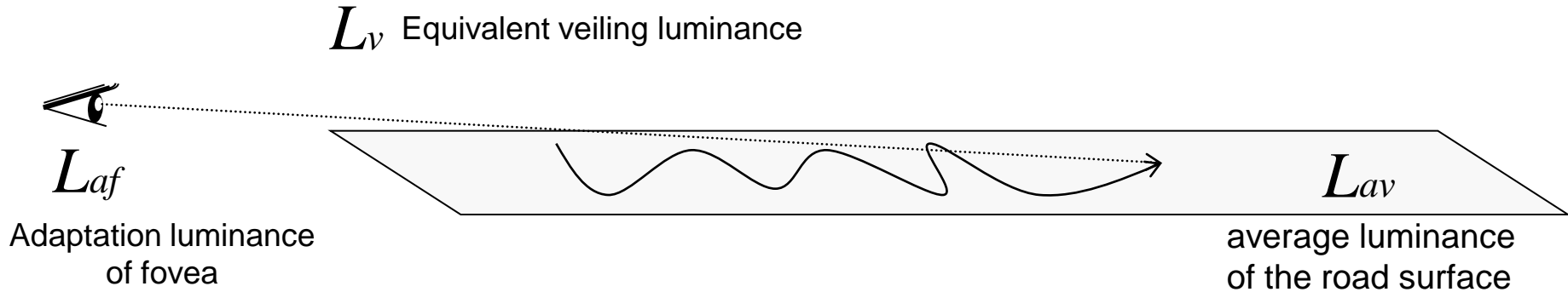


Ex. at uniform 1cd/m² 2π field of view

$$L_{af} \gg 1.048(\text{cd/m}^2)$$

Average luminance of a road surface is defined as an adaptation luminance of fovea

(Definition of Threshold Increment TI in CIE 140-2000)



$$L_{af} = L_c + L_v$$

At the road lighting scene in night time...

Since the line of sight scans everywhere road surface

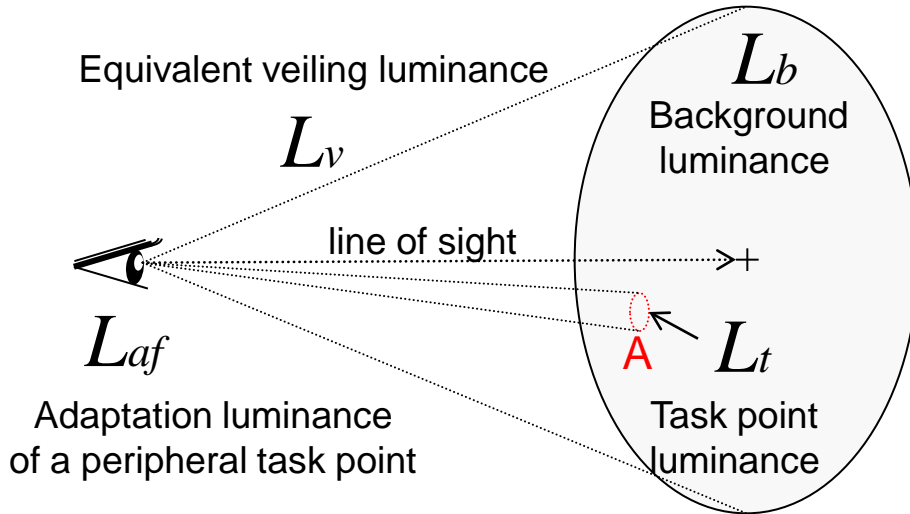
Luminance of peripheral field of view is low enough

$$L_c = L_{av}$$

$$L_v \ll L_c$$

$$\setminus L_{af} \gg L_{av}$$

Peripheral cells also adapt to sum of task point luminance and equivalent veiling luminance?



$$L_{af} = L_t + L_v$$

Equivalent veiling luminance:

Luminance at the fovea caused by light coming from peripheral field of view and scattered in eye

$L_v = ?$ Angle characteristics is unknown



We need evidences how luminance of other field of view affect the task performance at point A.

Both luminance and illuminance are measured to evaluate street lighting

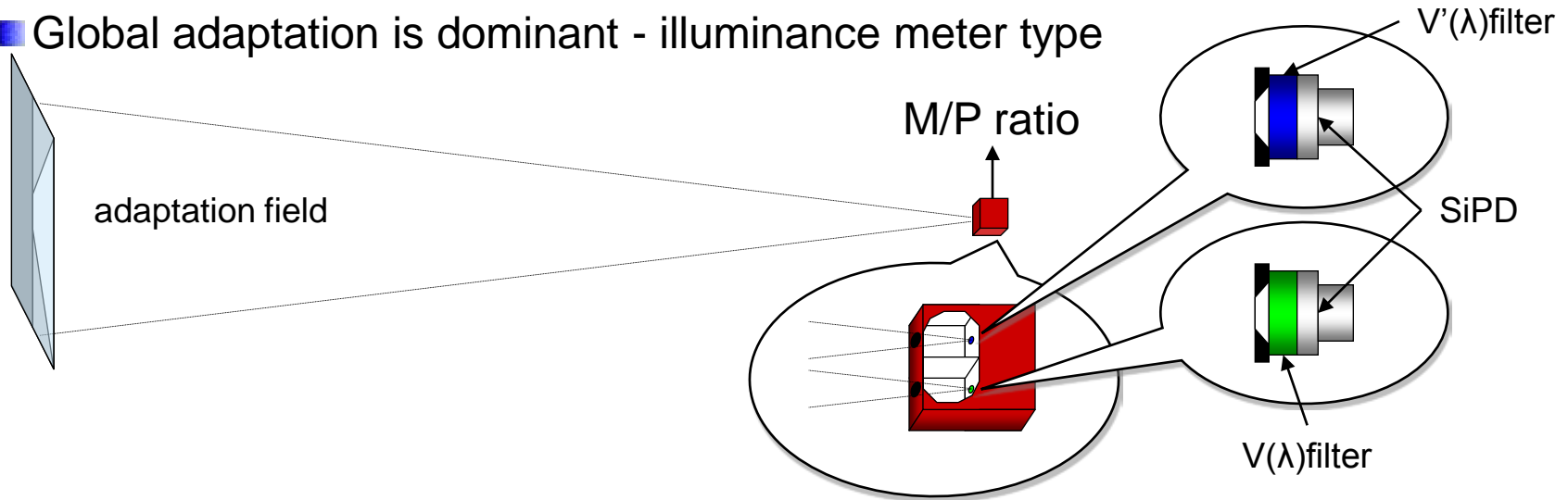
CIE	
CIE 115:2010	luminance

Japan		USA		Europe	
JIS Z 9111	luminance For drivers	IESNA		EN 13201	luminance ME/MEW-Series (medium to high driving speed)
	illuminance For pedestrian				illuminance CE-Series (conflict areas :shopping streets, roundabouts, queuing areas etc.)
MLIT Road Lighting Book		AASHTO	luminance illuminance		
	luminance	State Government Traffic Lighting Manual, etc.	illuminance		

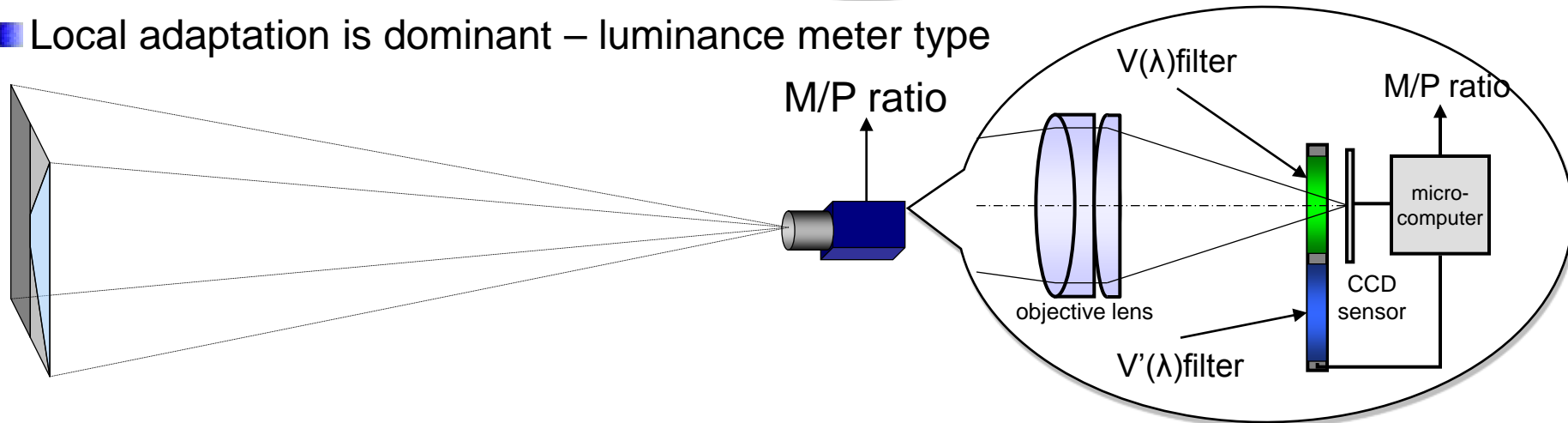
M/P ratio* is useful to adjust the output of existing photometry instruments

* m/p ratio – ratio of the mesopic luminance to the photopic luminance at the adaptation field

■ Global adaptation is dominant - illuminance meter type

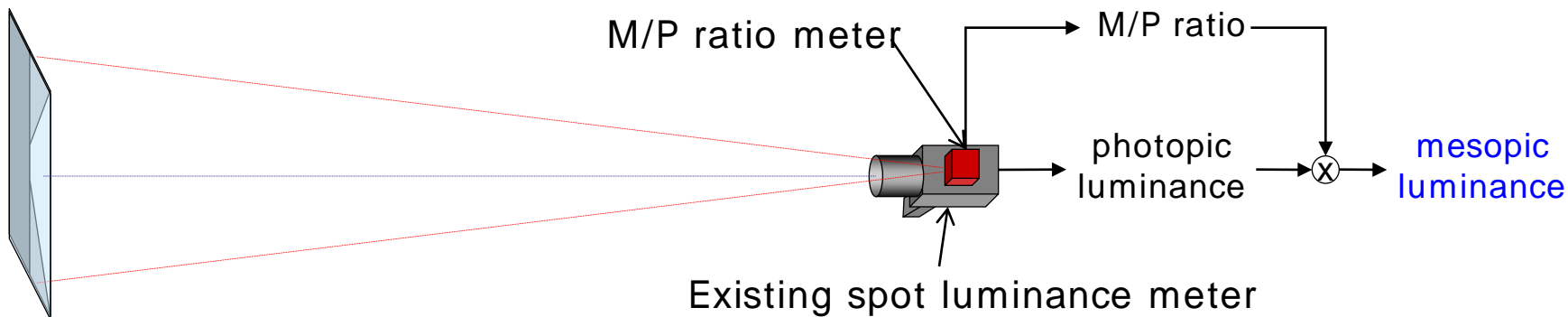


■ Local adaptation is dominant – luminance meter type

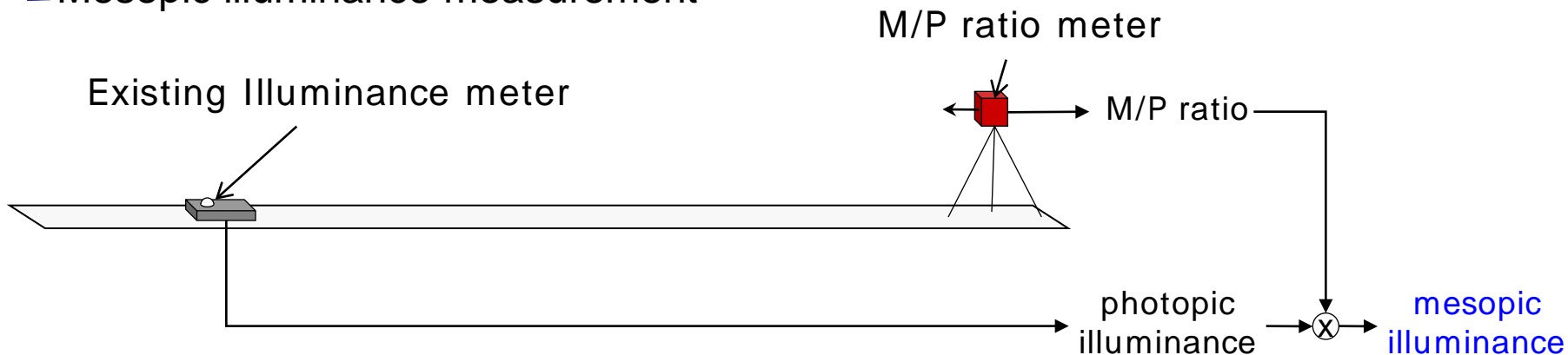


The mesopic luminance/illuminance can be measured by a photopic luminance/illuminance meter combined with a m/p ratio meter

■ Mesopic luminance measurement

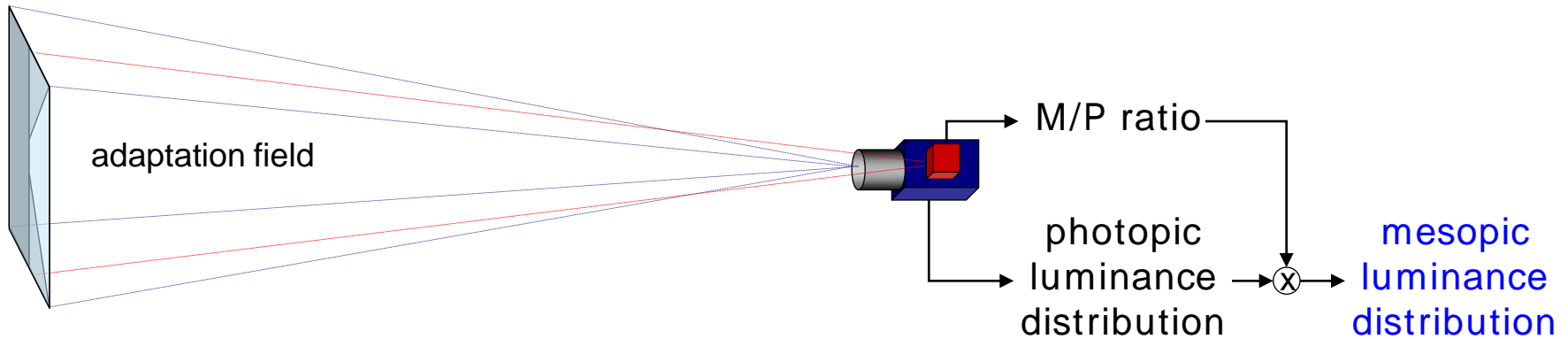


■ Mesopic illuminance measurement



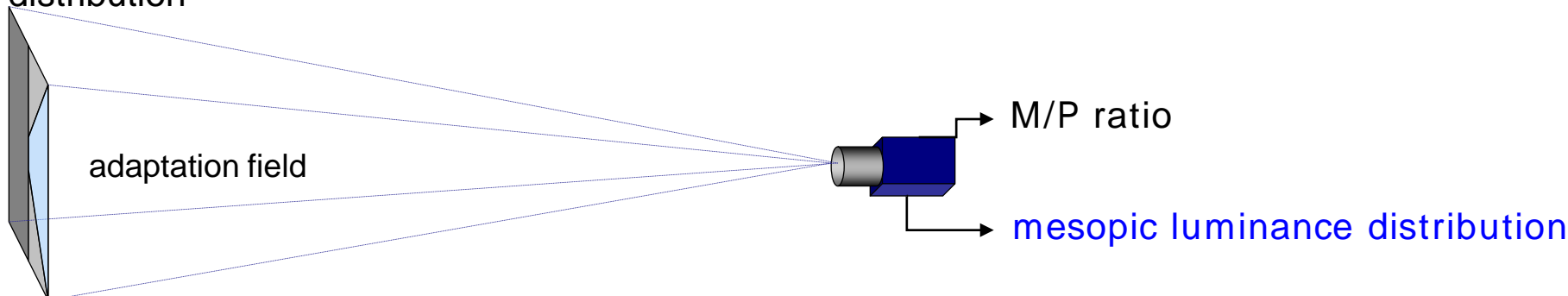
The mesopic luminance distribution can be measured by
a photopic imaging luminance meter combined with a m/p ratio meter
or
a mesopic imaging luminance meter

■ Global adaptation is dominant



■ Local adaptation is dominant

- A M/P ratio meter with imaging detector can measure both M/P ratio and mesopic luminance distribution



The combination of a M/P ratio meter and a photopic luminance meter cause particular error when it measure chromatic scene

M/P ratio meter

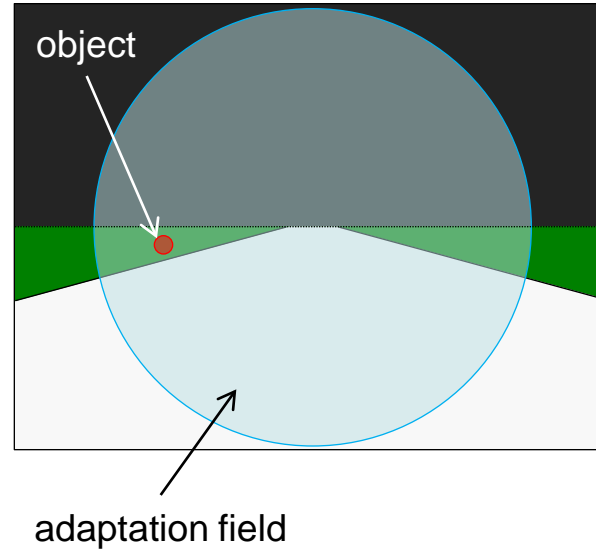
1. Calculate mesopic luminance of adaptation field $L_{mes,a}$

2. Calculate m/p ratio

$$m / p = \frac{L_{mes,a}}{L_{p,a}}$$

3. Calculate mesopic luminance of object $L_{mes,o}$ from $L_{p,o}$ and m/p ratio

$$L_{mes,o} = L_{p,o} \times (m / p)$$



Definition

1. Calculate adaptation field's L_{mes} and m as definition

2. Measure $L_{p,o}$ and $L_{s,o}$ at object

3. Calculate mesopic luminance of object $L_{mes,o}$ from $L_{p,o}$ and $L_{s,o}$

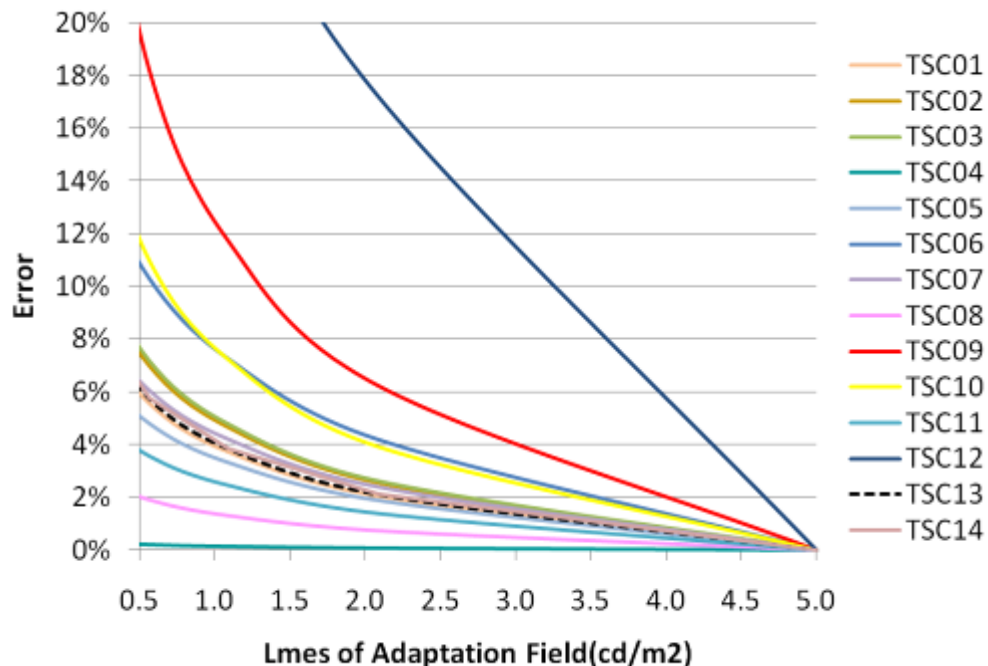
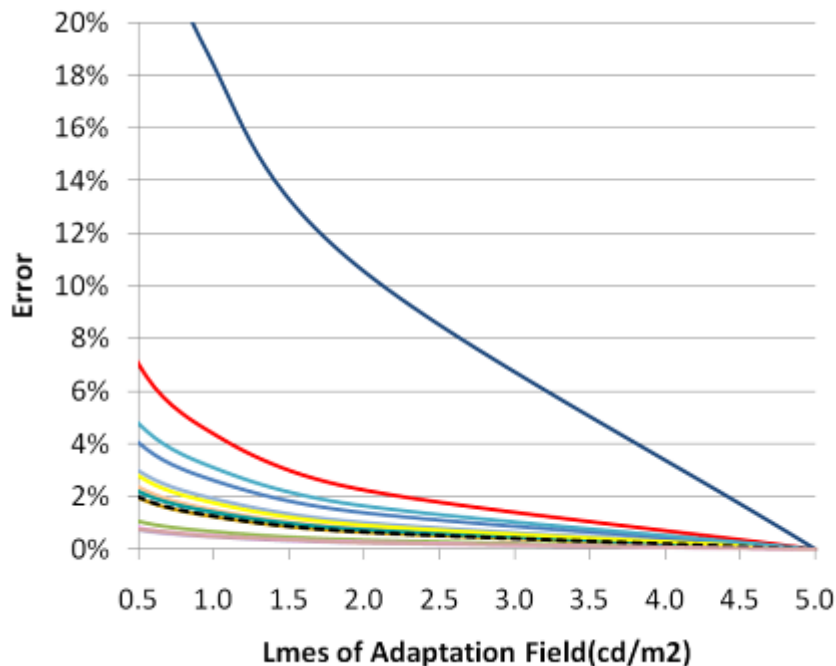
Not equal!

$$L_{mes,o} = \frac{m}{V_{mes}(I_0)M(m)} L_{p,o} + \frac{(1-m)K_m}{V_{mes}(I_0)M(m)K'_m} L_{s,o}$$

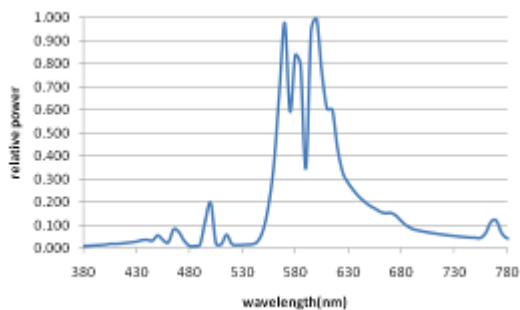
This process assume that the spectral distribution of the object is equal to the adaptation field

High saturation colors cause relatively large error

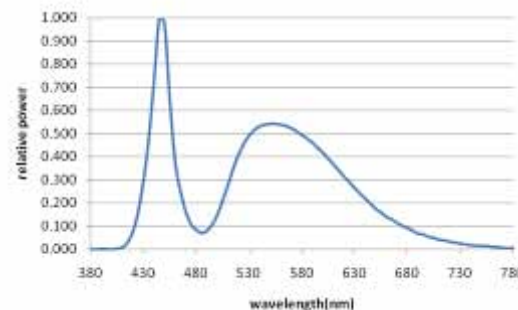
Midium saturation colors have 6-8% error in practical luminance range



HPS(NH360.L) 2050K

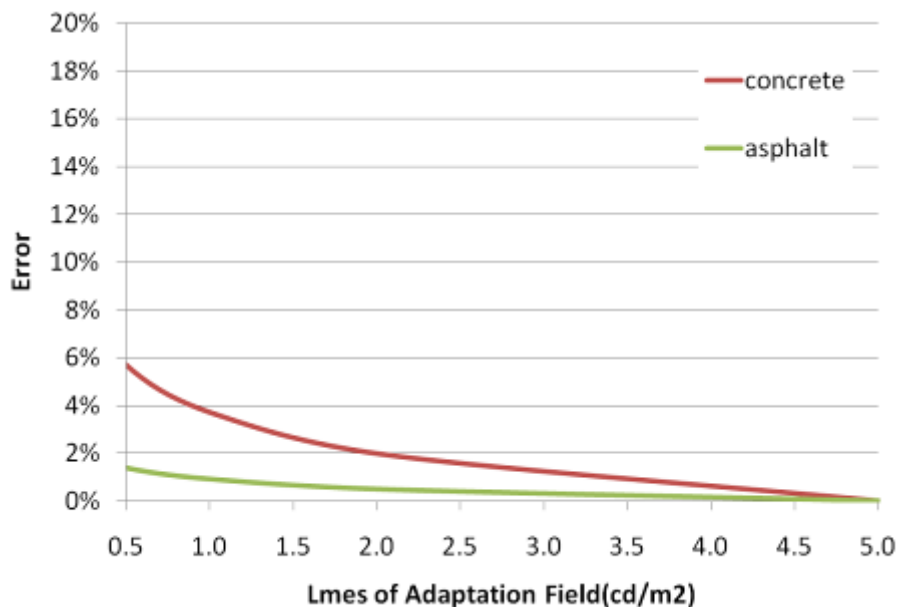


LED(NNN21935)

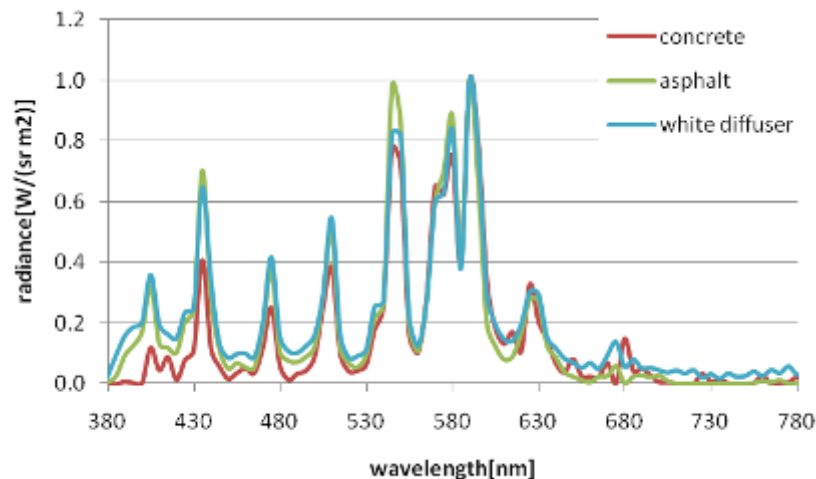


Asphalt surface has less than 2% error
 Concrete surface has less than 6% error

- Calculate errors from spectral radiance of road surface lit by MH



Use spectral radiance of a white diffuser put at "concrete" as spectral radiance of the adaptation field



- determine allowance of uncertainty for mesopic luminance meter to evaluate street lighting
- Make $V(\lambda) / V'(\lambda)$ detector / detector array
- Correct evidences whether global or local adaptation is dominant for the peripheral visual task performances
 - If it's not exist, psychophysical experiments are required.
- Develop a calibration method for a M/P ratio meter and mesopic luminance meter including imaging system

This study is partially funded by NEDO.

Thank you for your attention!