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Sources, Surfaces and Scatter

An investigation into the interaction of
light sources, surfaces, eyes &
the scattering of light by the atmosphere

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Jefferey F. Knox

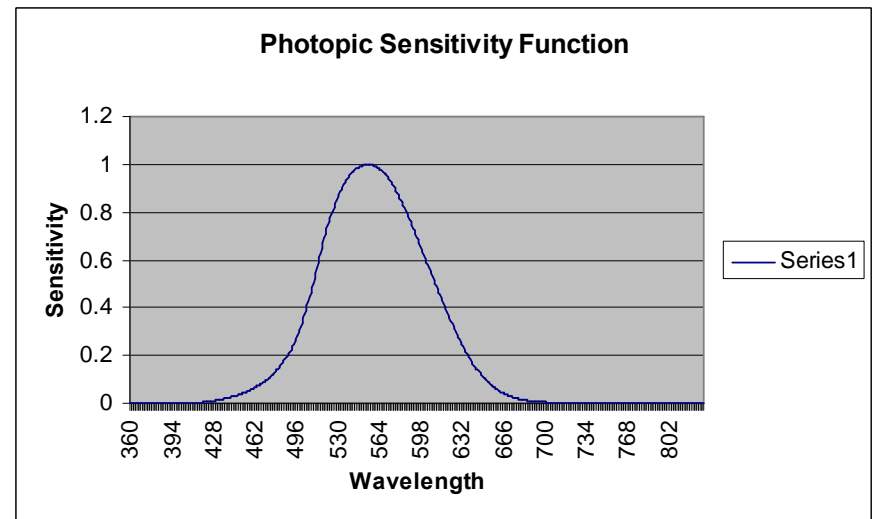
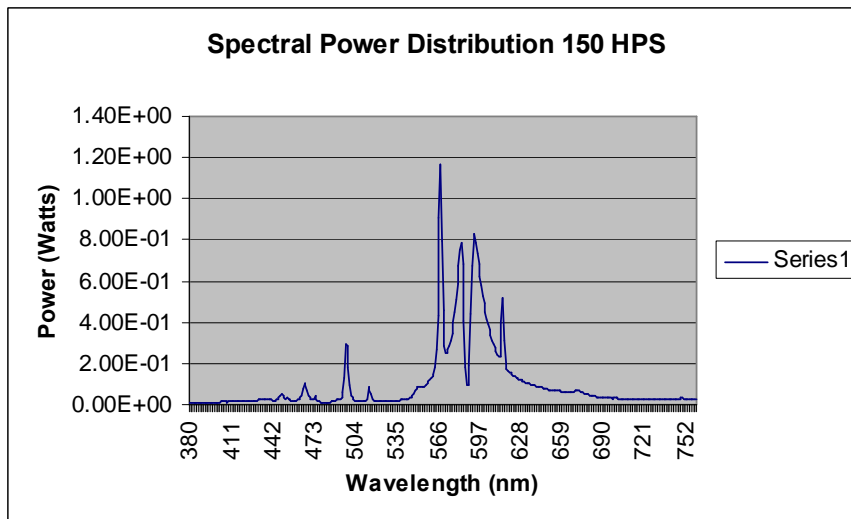
IESNA Roadway Lighting Committee, 2003

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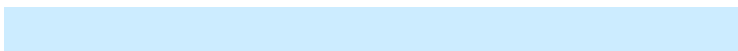
Lighting Basics: The Lumen

$$\text{Lumens} = K * \sum [P(\lambda) * v(\lambda)]$$



$$\text{Lumens}_{\text{source}} = K * \sum [S(\lambda) * v(\lambda)]$$

Sum λ from 360 to 770 nanometers



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Lighting Basics : The Lumen

- * Implications of the definition of the Lumen: the summation over the visible spectrum makes every lumen "spectrally ignorant"
- * A Lumen is a Lumen is a Lumen
 - ó but are they "the same"? How could we tell?
- * for evaluating the magnitude of spectrally sensitive effects, such as atmospheric scatter, use radiation, NOT lumens!

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Lighting Basics: Reflectance

- * Reflectance = $\text{Lumens}_{\text{off}} \div \text{Lumens}_{\text{on}}$
 - ó this calculation is specific to a particular source
- * Average Reflectance
 - ó What is average reflectance?
 - ó Is it related to a specific source?
 - É For CRI we use the CIE's D65 and A (incandescent)
- * Because reflectance is lumen-based, it too is óspectrally ignorantö

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Lighting Basics: Reflectivity

- * reflectance may be spectrally sensitive, so:
 - ó do not convert to lumens until at the retina!
 - ó replace average reflectance with

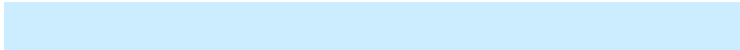
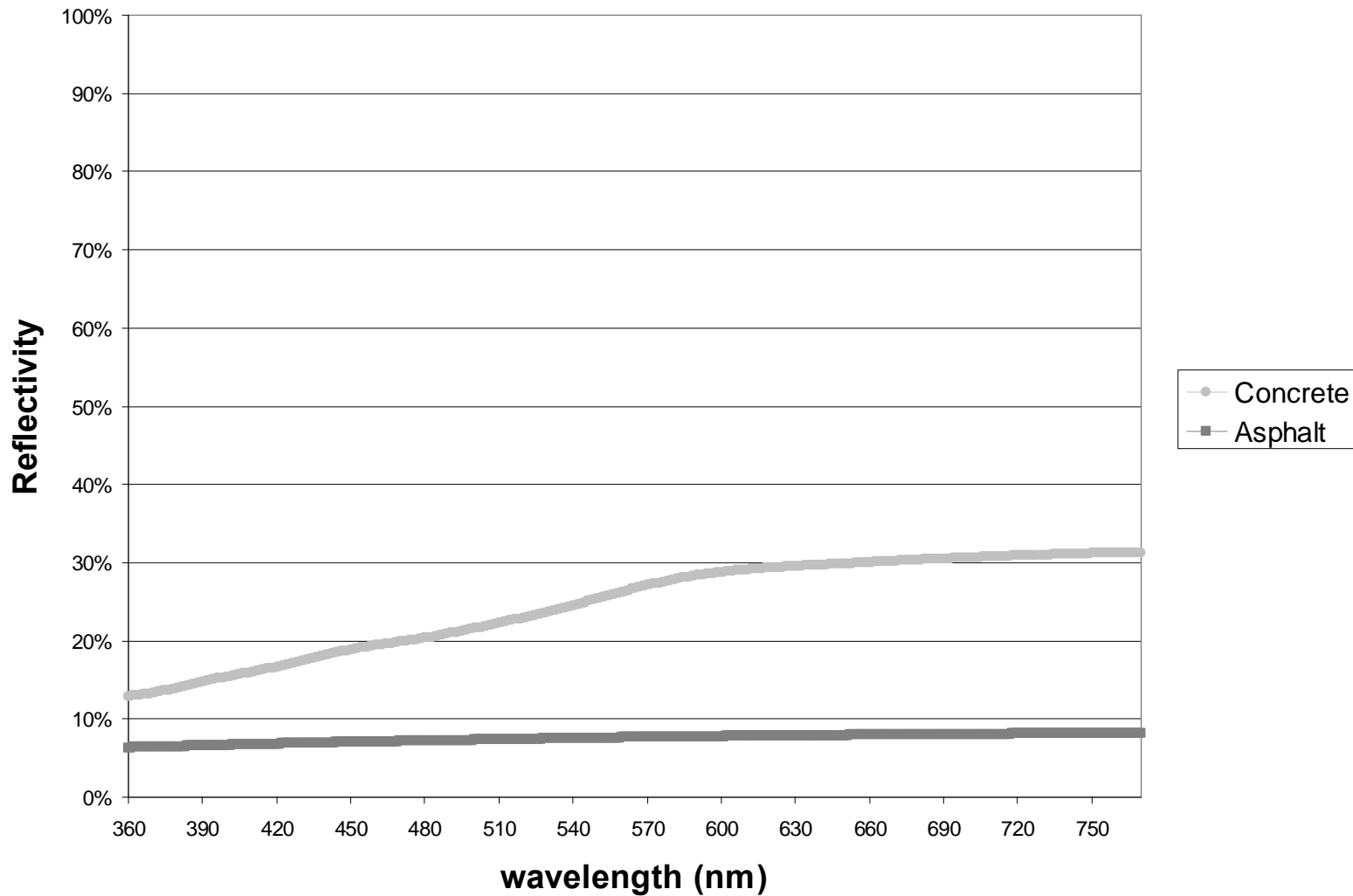
$$\text{Reflectivity} = \frac{\sum [P(\lambda)_{\text{on}} * \rho(\lambda)]}{\sum [P(\lambda)_{\text{on}}]}$$

ó $\rho(\lambda)$ from NASA's ASTER Spectral Library

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Lighting Basics: Reflectivity



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Lighting Basics: Skyglow

- * What is the problem?
 - ó light gets in the way of seeing the night sky
- * How does the light get in the way?
 - ó the light is redirected by the atmosphere
- * Where does the light come from?
 - ó uplight can be direct from sources
 - ó uplight generally occurs from reflectance

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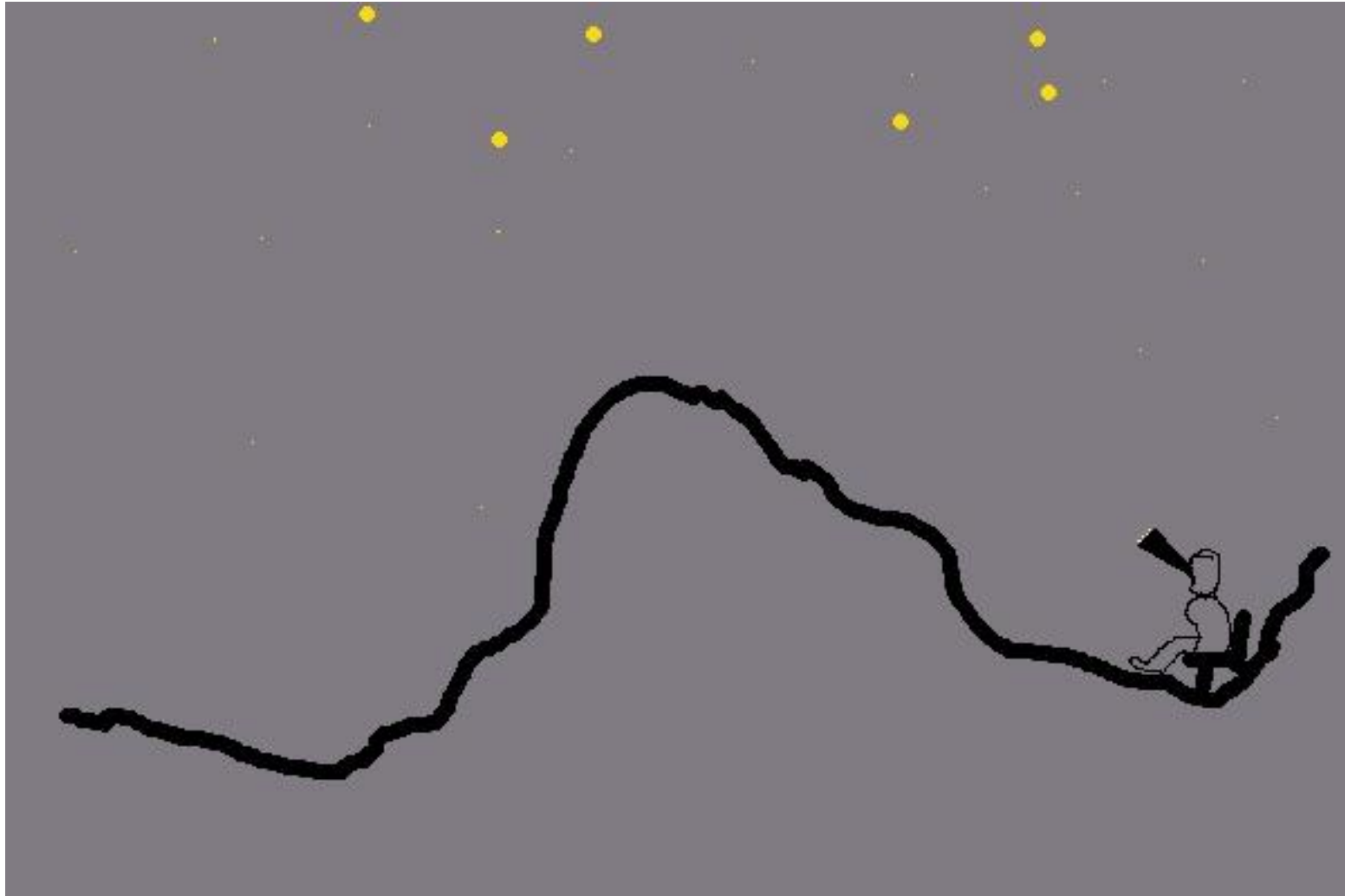
Why uplight matters . .

- * uplight is the unavoidable result of exterior lighting (and windows without curtains!)
- * since we want to see objects, we make them reflective and luminous themselves
- * the same light that we can use to see can also escape up into the sky
- * when there is more uplight ó there is more skyglow too!

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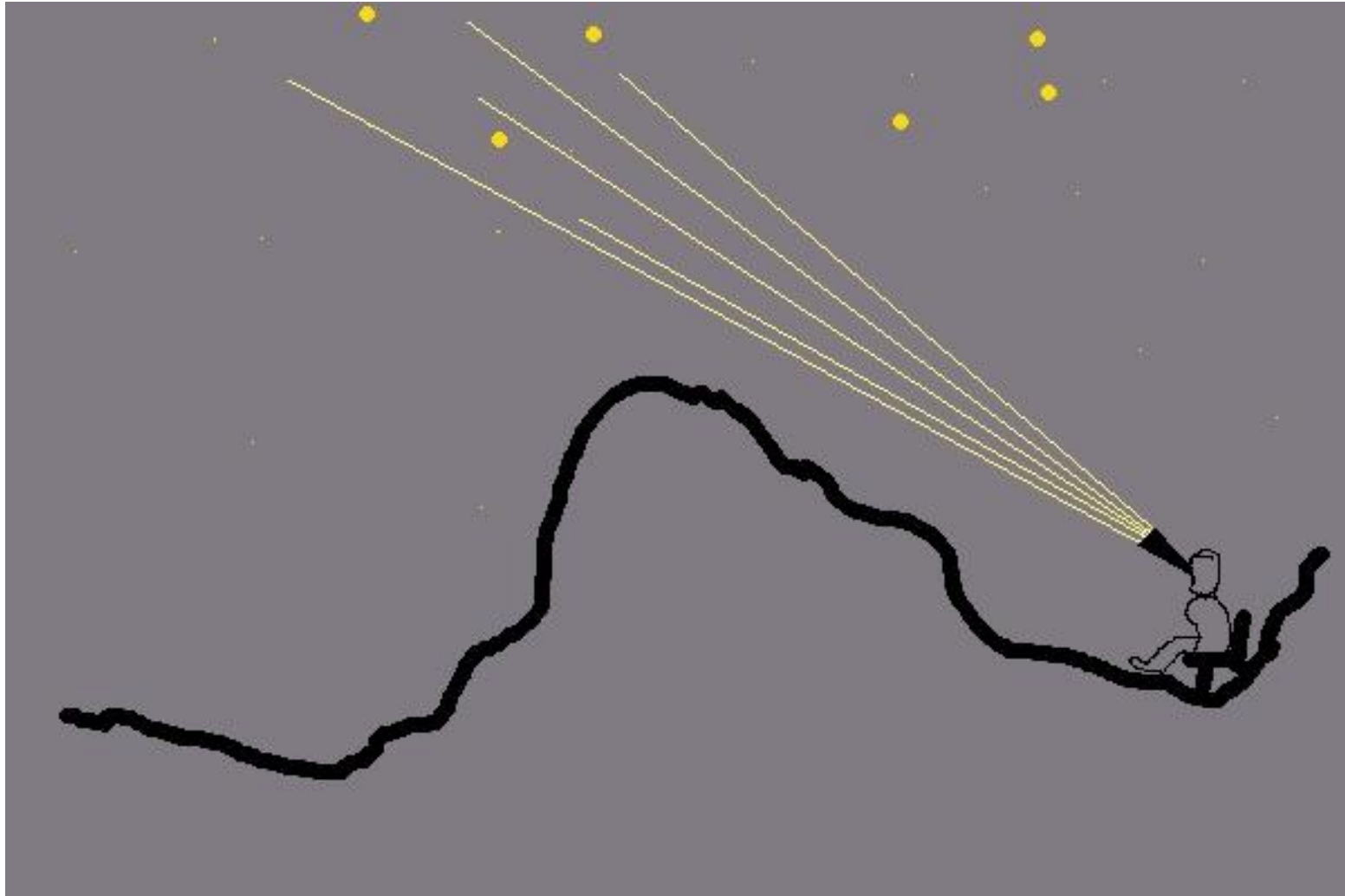
An observer looks at the sky . .



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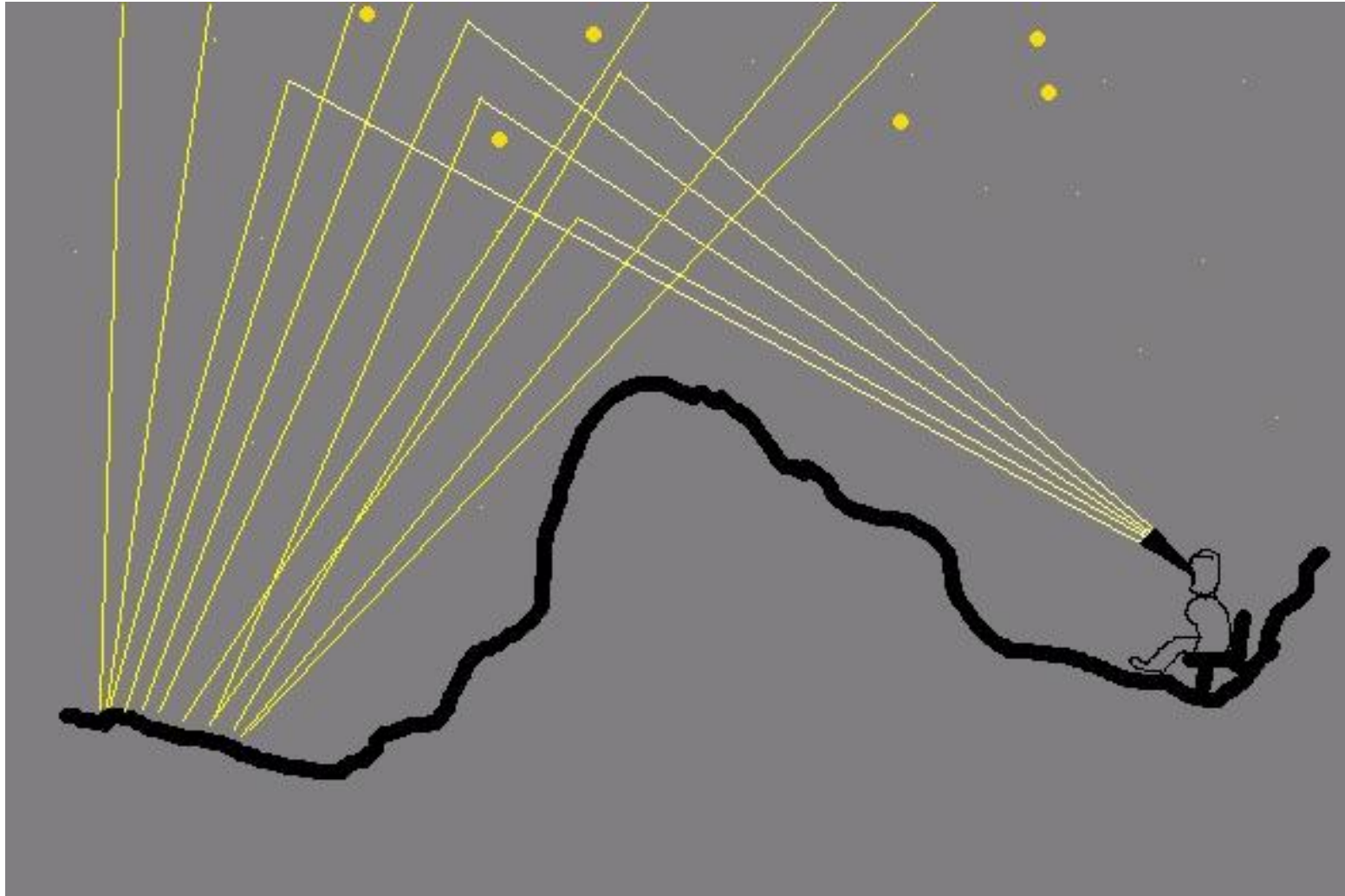
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.. where he sees skyglow ..



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.. which is caused by uplight ..



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.. scattered by the atmosphere.

- * atmospheric scattering redirects light
 - ó like surfaces do - but without ãa surfaceö!
- * Rayleigh scatter is what makes the sky blue
 - ó also causes the colors at sunrise and sunset
 - ó scatter is extremely dependent on wavelength
 - ó redirection can be extreme, normal or minimal
- * Mie scatter causes halo around the sun or moon, small change in direction, small effect
- * Inelastic scatter is minor contribution

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Rayleigh Scatter Index

- * Rayleigh scatter is proportional to the:
 - ó quantity of light, separated into bands ($S(\lambda)$)
 - ó wavelength of the light (λ , in nanometers) to **the inverse 4th power!**
- * so the equation for RSI is:

$$\text{RSI} = k \left(S(\lambda) / \lambda^4 \right)$$

for λ from 360 to 770 nm, with constant
 $k = 5.0E11$ for $S(\lambda)$ at 1 W over spectrum

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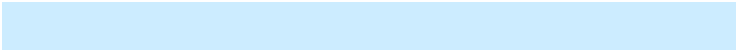
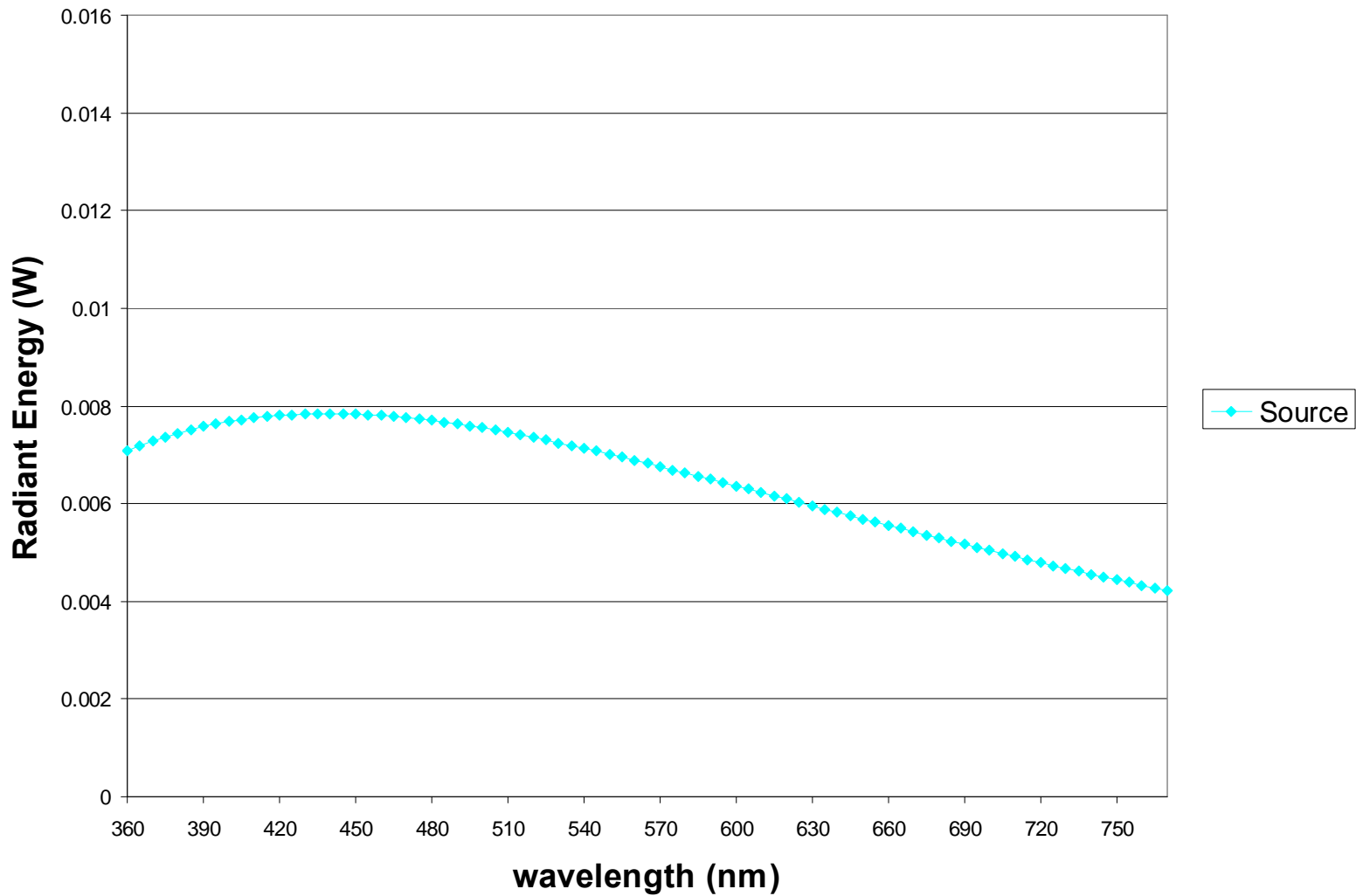
What does RSI indicate?

- * RSI is a comparative measure of the likelihood that light going up will be redirected by Rayleigh scatter, the dominant contributor to skyglow when atmospheric conditions are most appropriate for viewing the night sky - clear sky, few clouds, little pollution or particulates, corresponding to blue sky conditions of daytime

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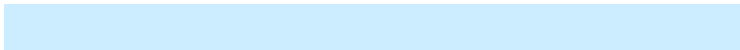
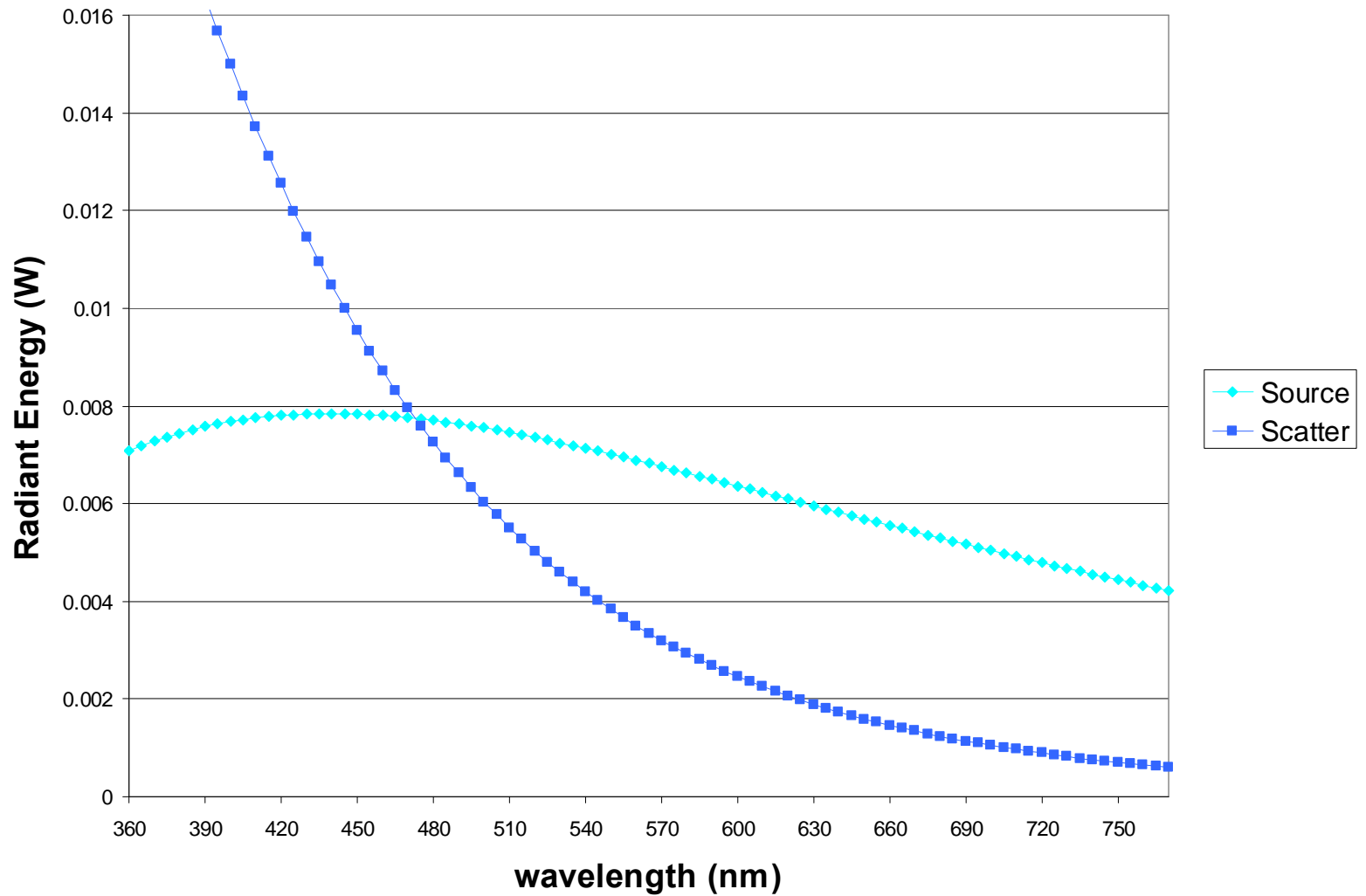
Sunlight: Blackbody at 6600K



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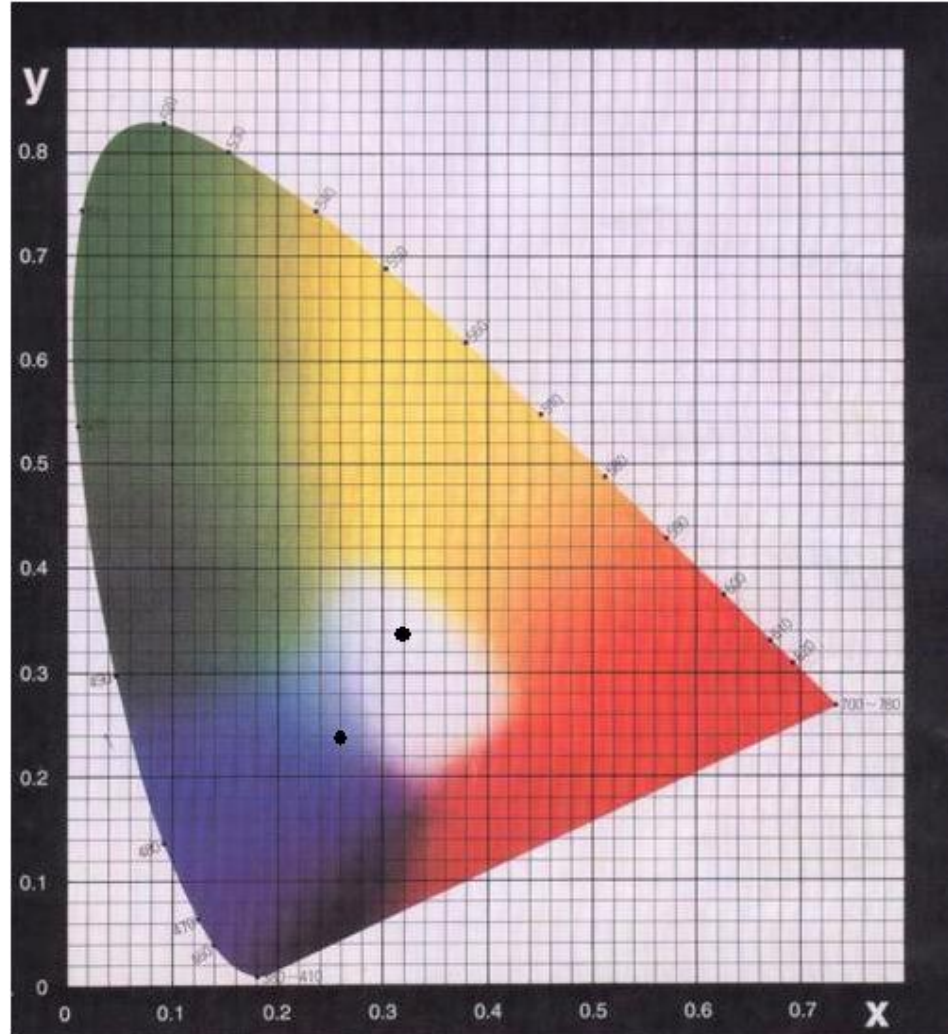
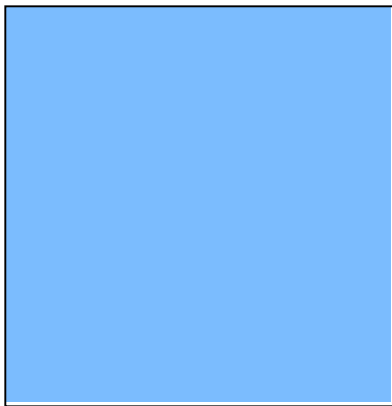
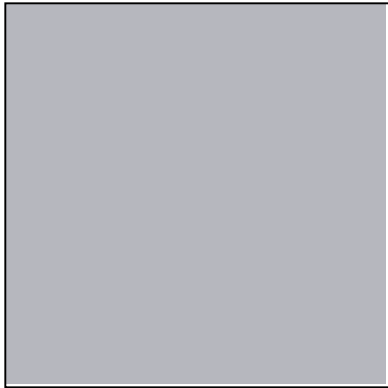
Scattered Sunlight



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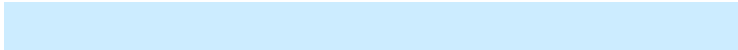
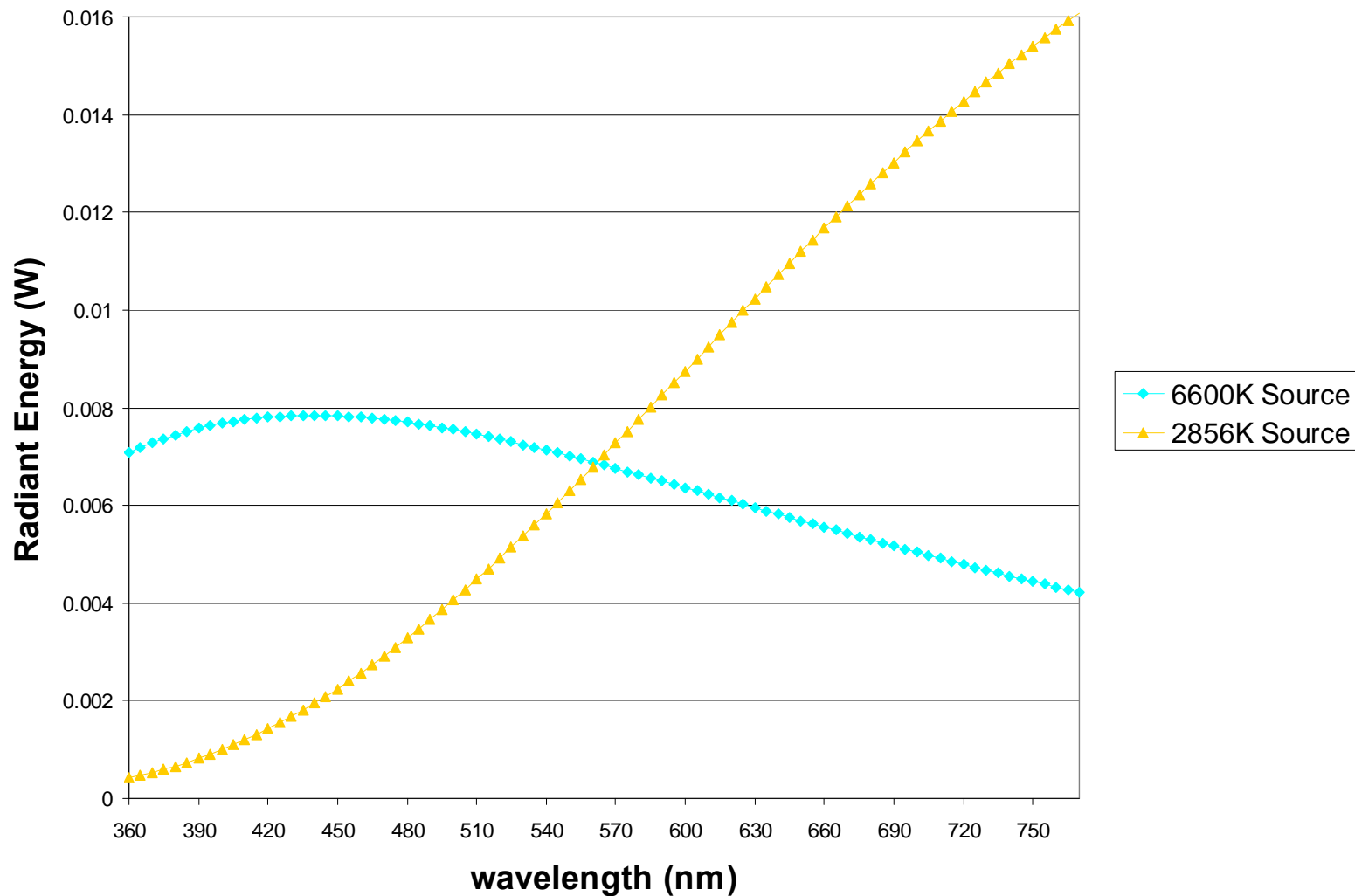
Color Shift for Scattered Sunlight



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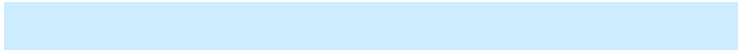
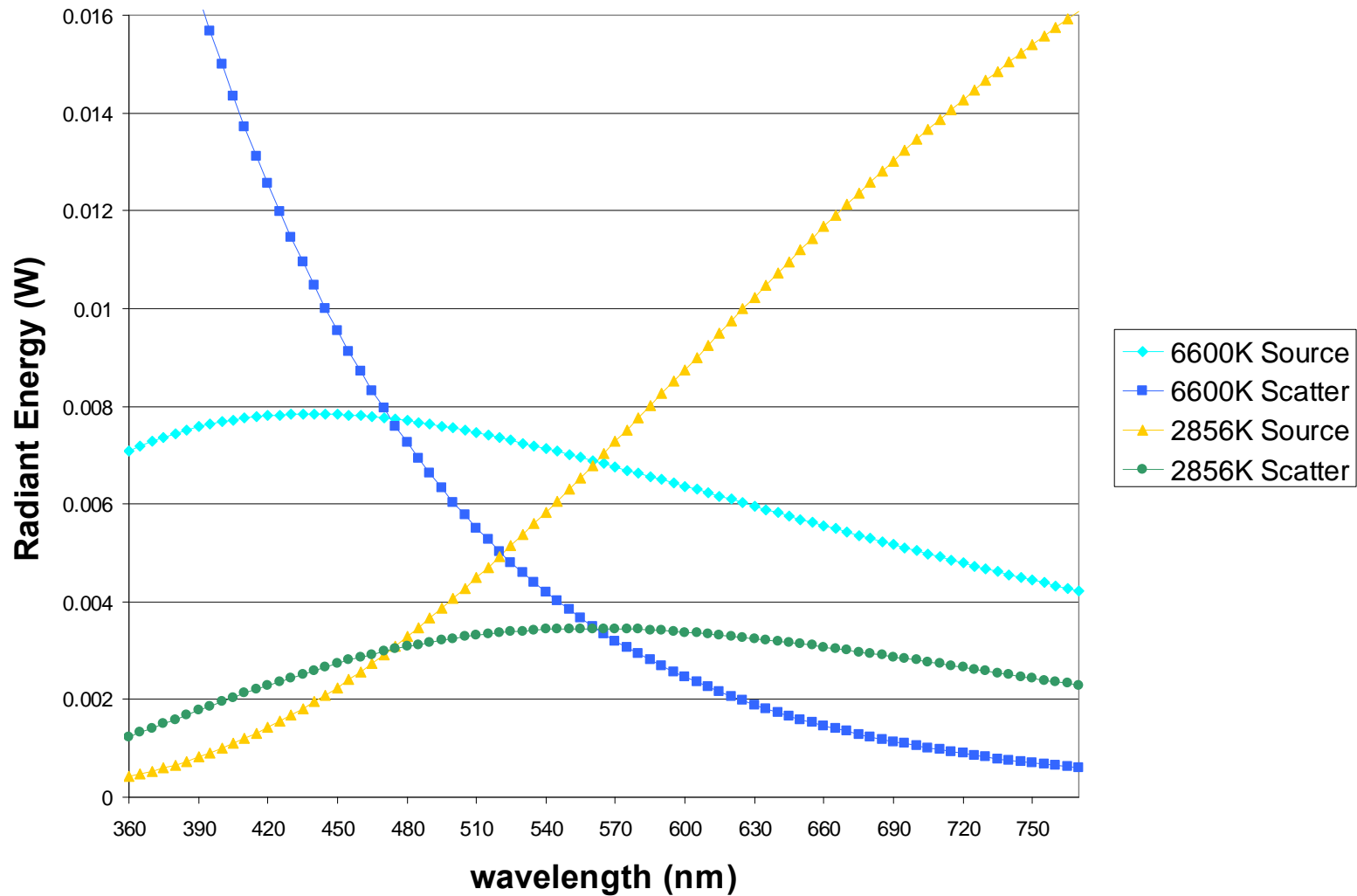
Compare Blackbody Sources



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Compare Sources & Scatter



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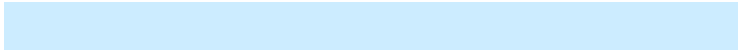
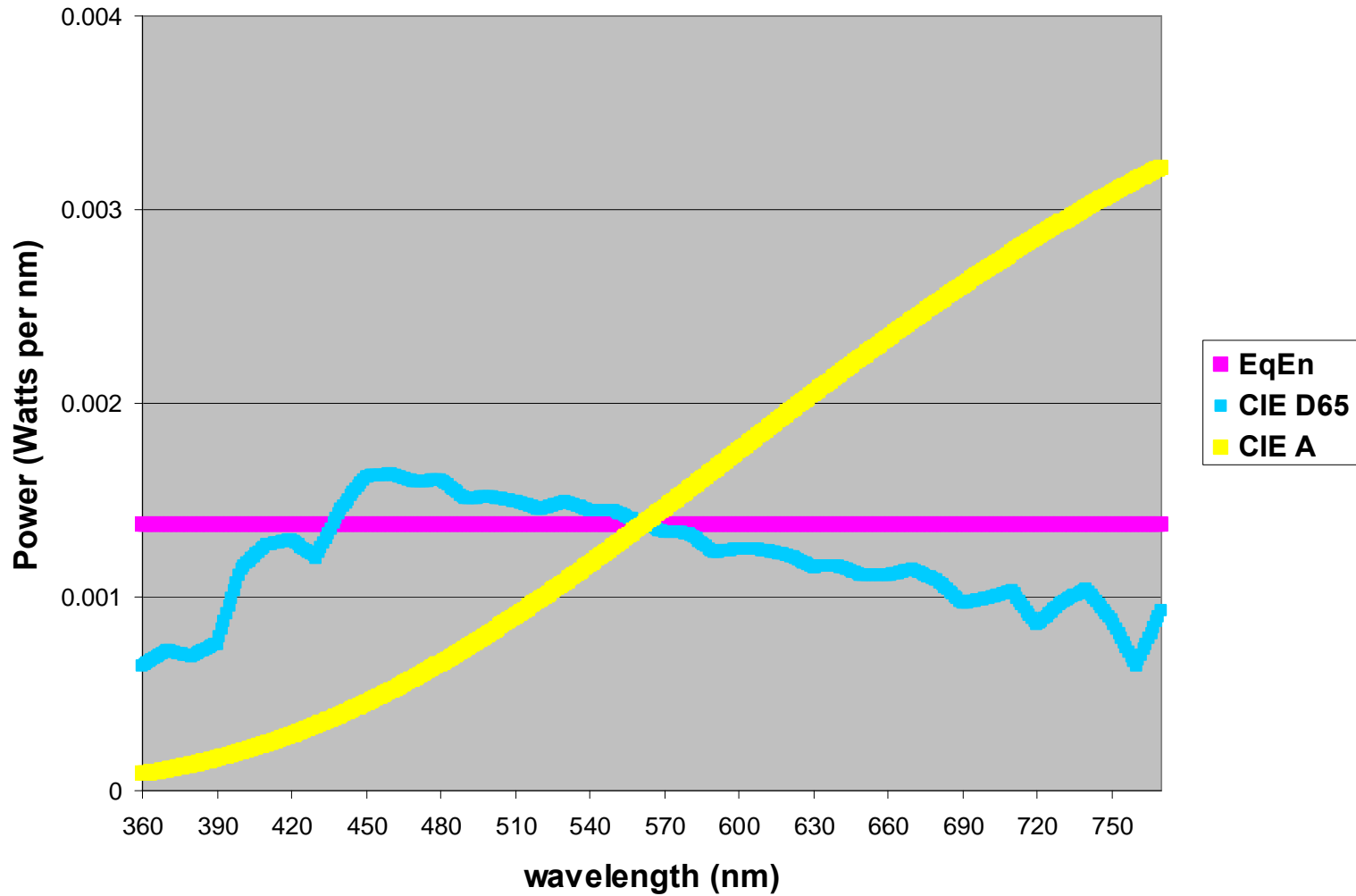
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Scattered Radiation Profiles

- * the RSI calculation creates a spectral radiation profile that represents the **relative distribution** of skyglow for each source
 - ó same procedure applied to different data
 - ó compare magnitudes & distributions between sources
 - É overall radiant energy
 - É photopic lumens
 - É scotopic lumens
 - É specific bands: e.g. between 455 & 465 nm
 - ó identified as significant for melatonin & diurnal cycle

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Equal Energy, CIE D65 & CIE A



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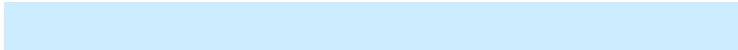
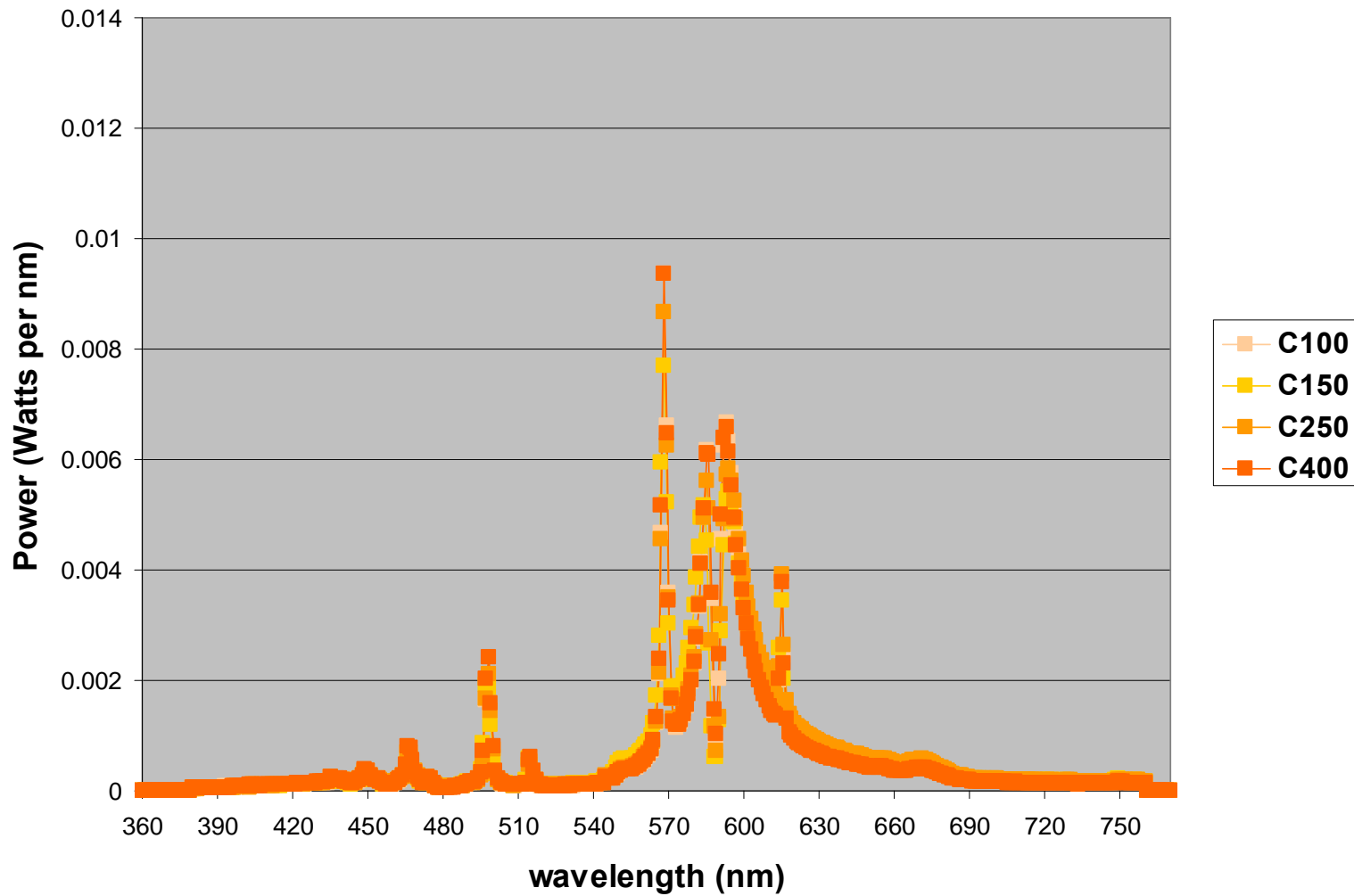
RSI Results: 100 Photopic Lms

	EqEn	D65	CIE A
Radiant Watts	0.56	0.49	0.61
Sources	4.4	3.8	2.3
Asphalt	4.1	3.6	2.3
Concrete	3.5	3.1	2.4

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High Pressure Sodium 100-400W



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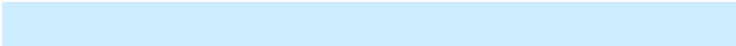
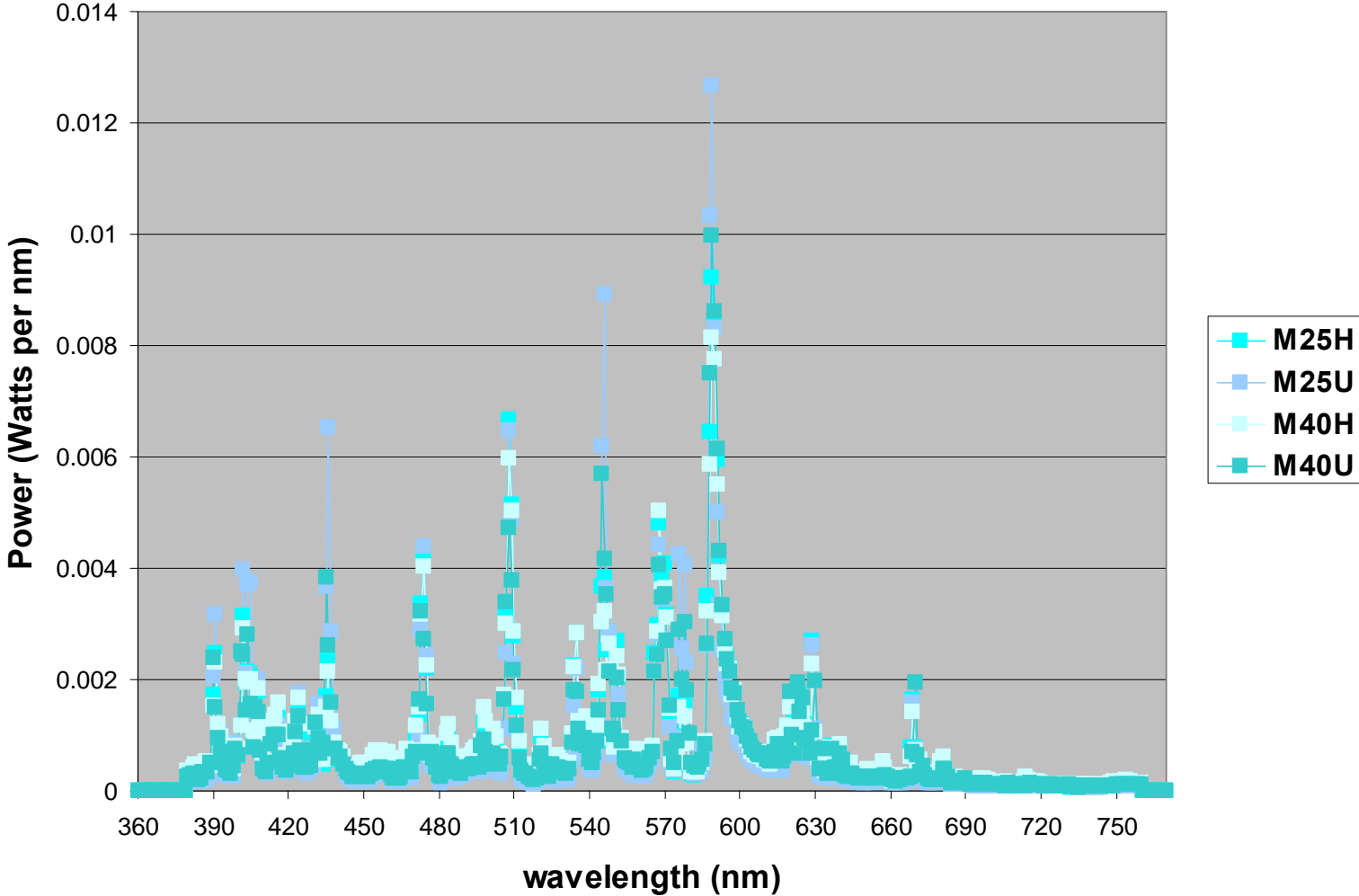
RSI for HPS: 100 Photopic Lms

	C100	C150	C250	C400
Radiant W	0.25	0.25	0.26	0.25
Sources	1.2	1.2	1.2	1.2
Asphalt	1.2	1.2	1.2	1.2
Concrete	1.2	1.2	1.3	1.2

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Metal Halide 250W & 400W



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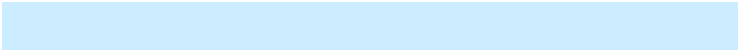
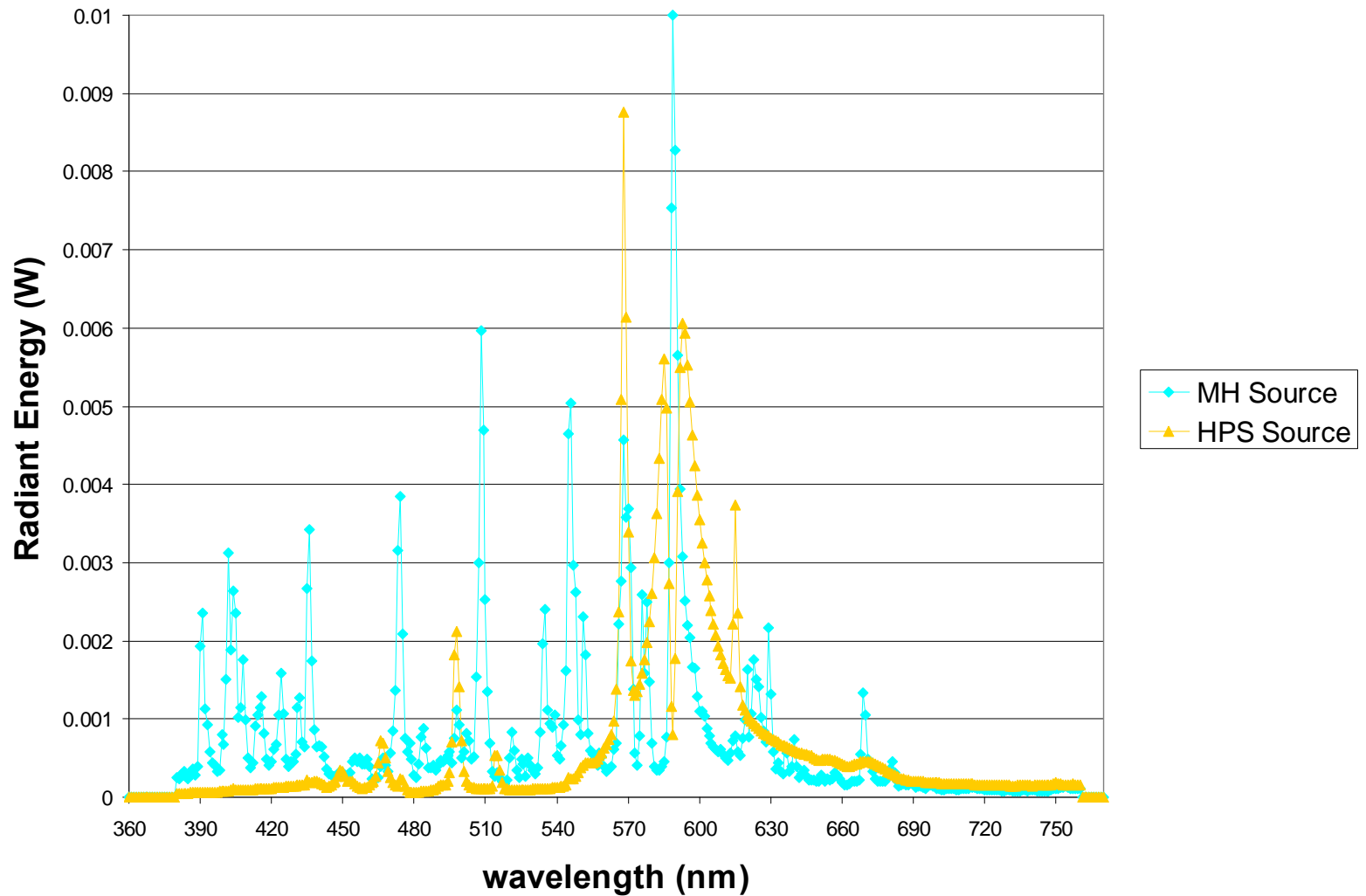
RSI for MH: 100 Photopic Lms

	M25H	M25U	M40H	M40U
Radiant W	0.31	0.30	0.32	0.30
Sources	2.3	2.4	2.5	2.3
Asphalt	2.2	2.3	2.4	2.2
Concrete	2.0	2.0	2.1	1.9

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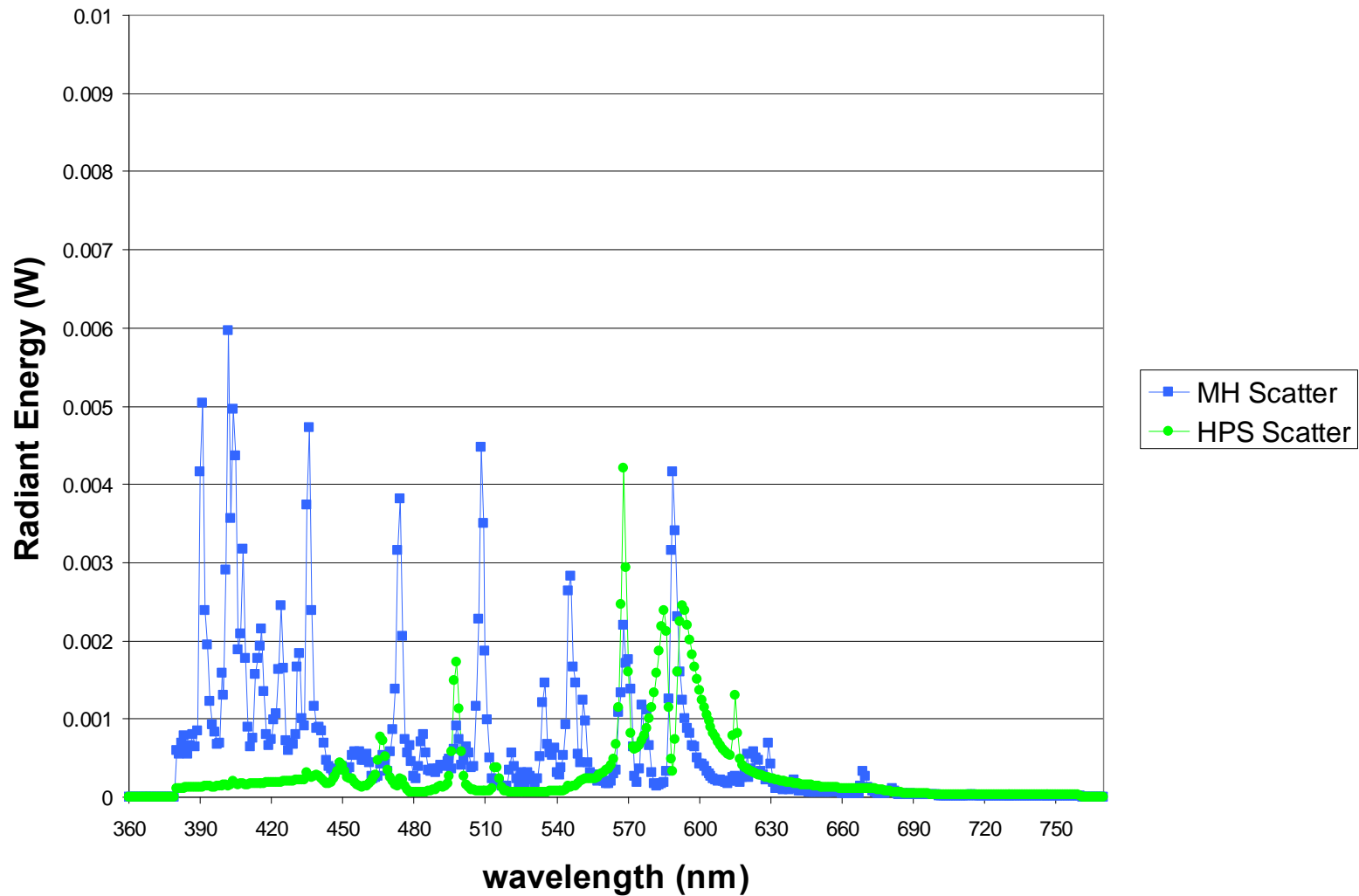
Average MH & HPS Sources



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Average MH & HPS Scatter



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Radiation from the sky per 100 lms

	AvgMH	AvgHPS	MH-to-HPS
Initial W	0.31	0.26	121%
Sources	2.4	1.2	200%
Asphalt	2.3	1.2	189%
Concrete	2.0	1.2	162%

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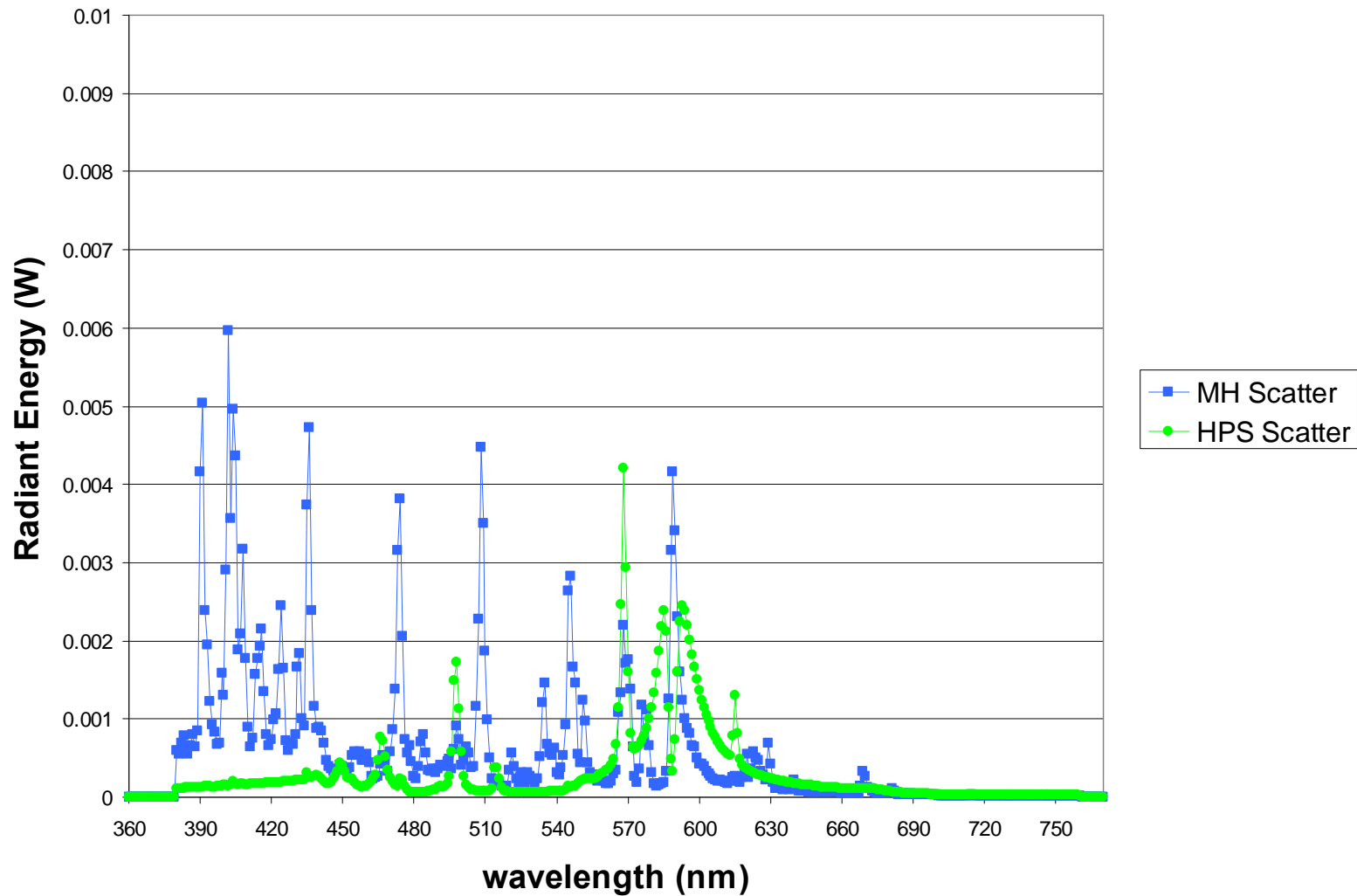
Relative Skyglow from 100 Lumens

	AvgMH	AvgHPS	MH-to-HPS
RSI (radiant W)	2.4	1.2	200%
Photopic Lumens	5.1	4.4	115%
Scotopic Lumens	12.3	4.5	278%
455-465 nm (W)	0.42	0.21	205%
360-460 nm (W)	1.10	0.15	728%

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Average MH & HPS Scatter



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Skyglow & Spectral Sources

- * the phenomenon of skyglow is caused by atmospheric scattering (when the sky is clear!)
- * the dominant form of atmospheric scattering is Rayleigh scattering (inverse 4th power of λ)
- * Rayleigh Scattering Index (RSI) provides relative information about different SPDs
- * HPS produces less skyglow compared to MH λ from the same amount of lumens or radiation

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Sources, Surfaces and Scatter

Get a copy of this presentation at:
<http://resodance.com/mdi/scatter.html>

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