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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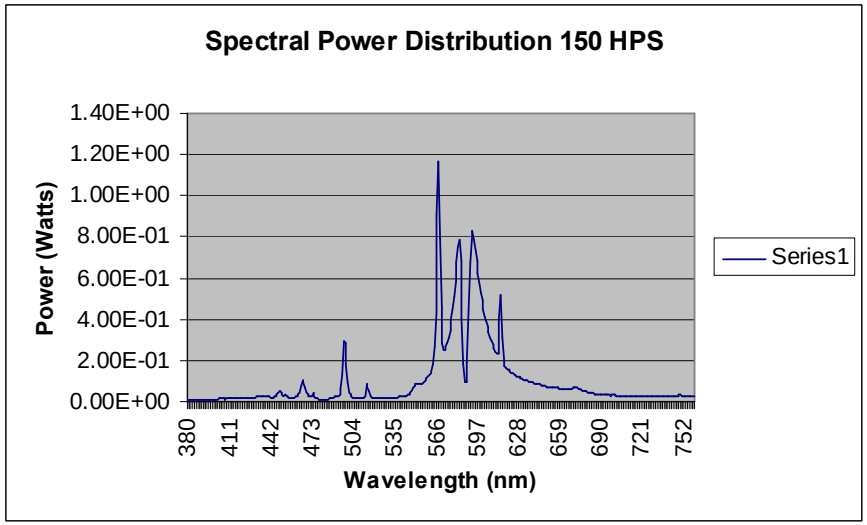
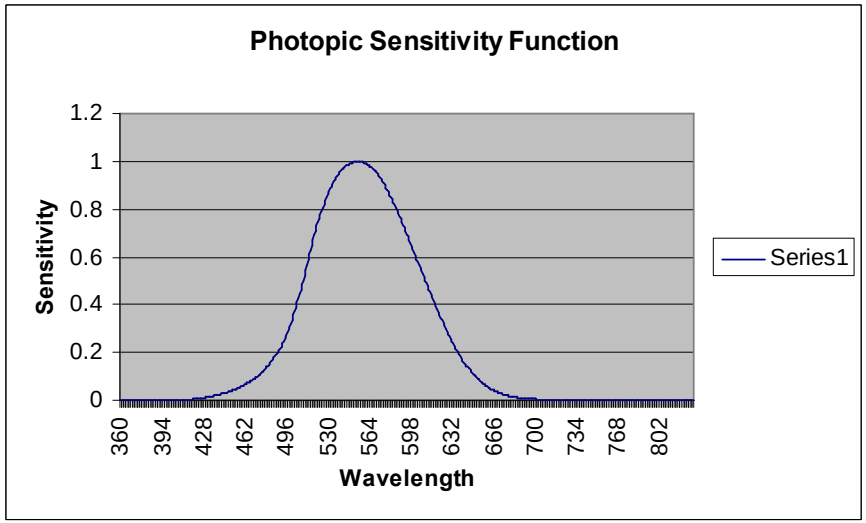
IESNA Roadway Lighting Committee, 2003

Lighting Basics: The Lumen

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





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

Sum λ from 360 to 770 nanometers

Lighting Basics : The Lumen

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

Lighting Basics: Reflectance

* Reflectance = $\text{Lumens}_{\text{off}} \div \text{Lumens}_{\text{on}}$
  - ï this calculation is specific to a particular source
* Average Reflectance
  - ï What is average reflectance?
  - ï Is it related to a specific source?
    - ÅFor CRI we use the CIEôs D65 and A (incandescent)
* Because reflectance is lumen-based, it too is ñspectrally ignorantò

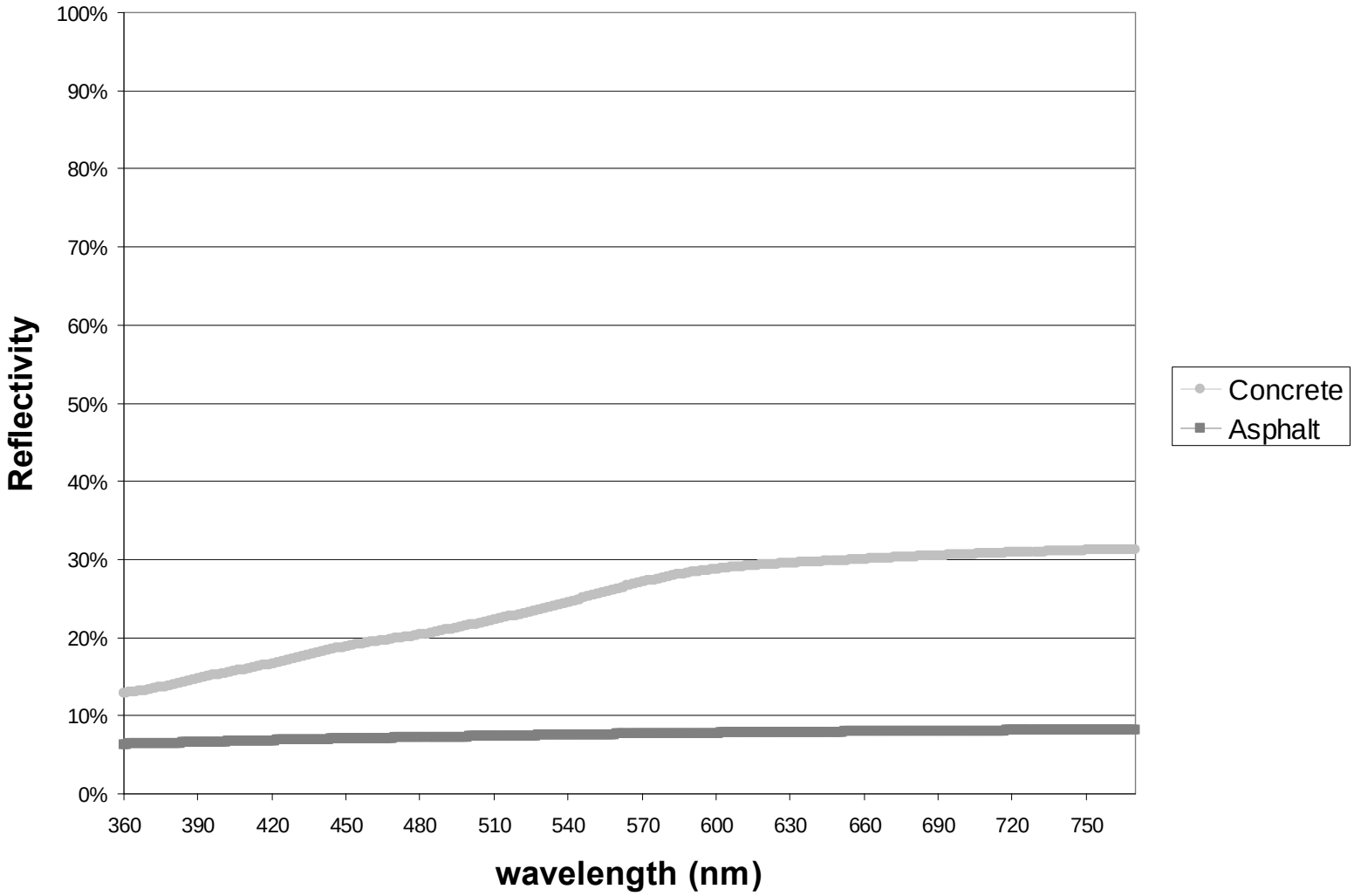
Lighting Basics: Reflectivity

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

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

  - ï $\rho(\lambda)$ from NASAôs ASTER Spectral Library

Lighting Basics: Reflectivity



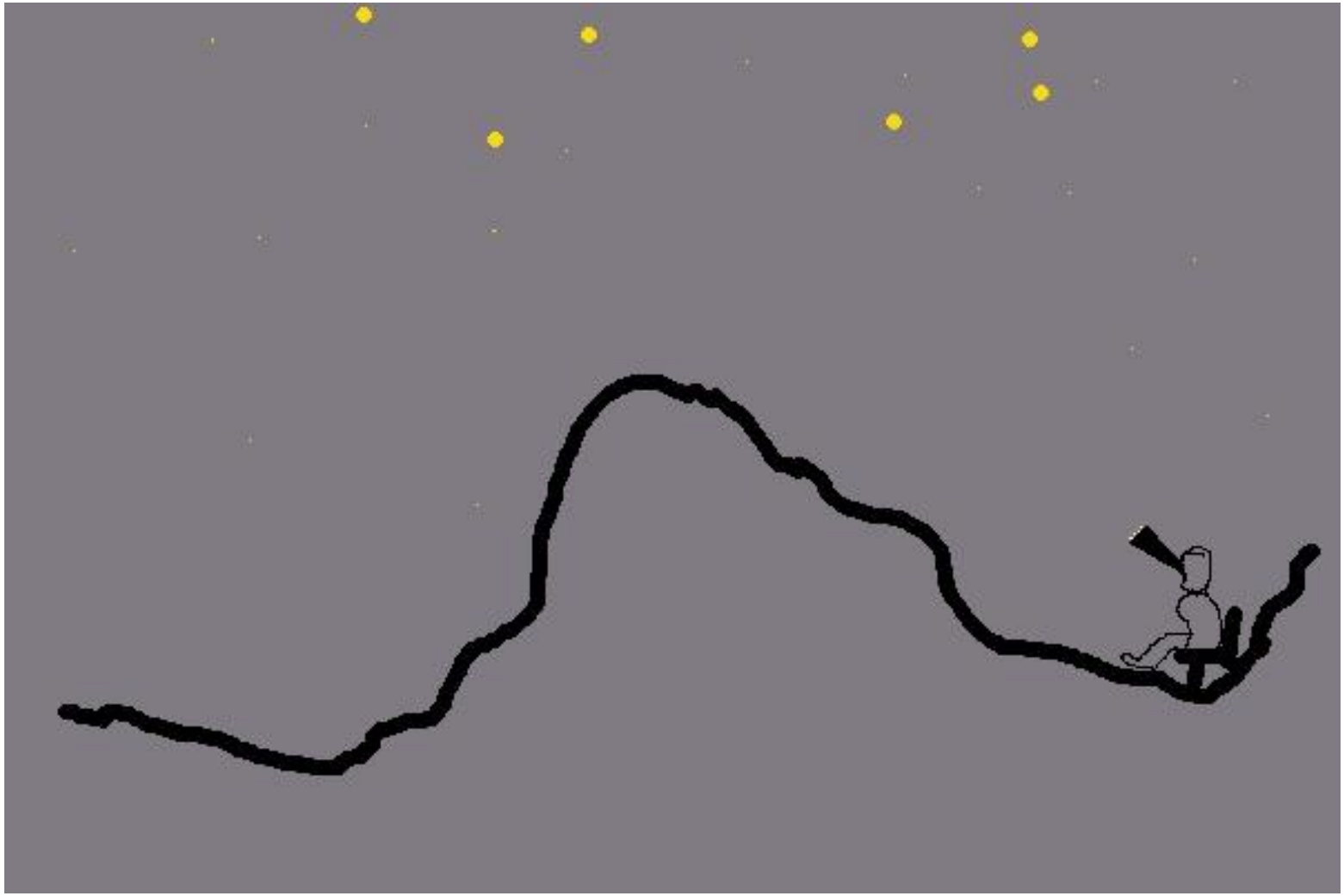
Lighting Basics: Skyglow

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

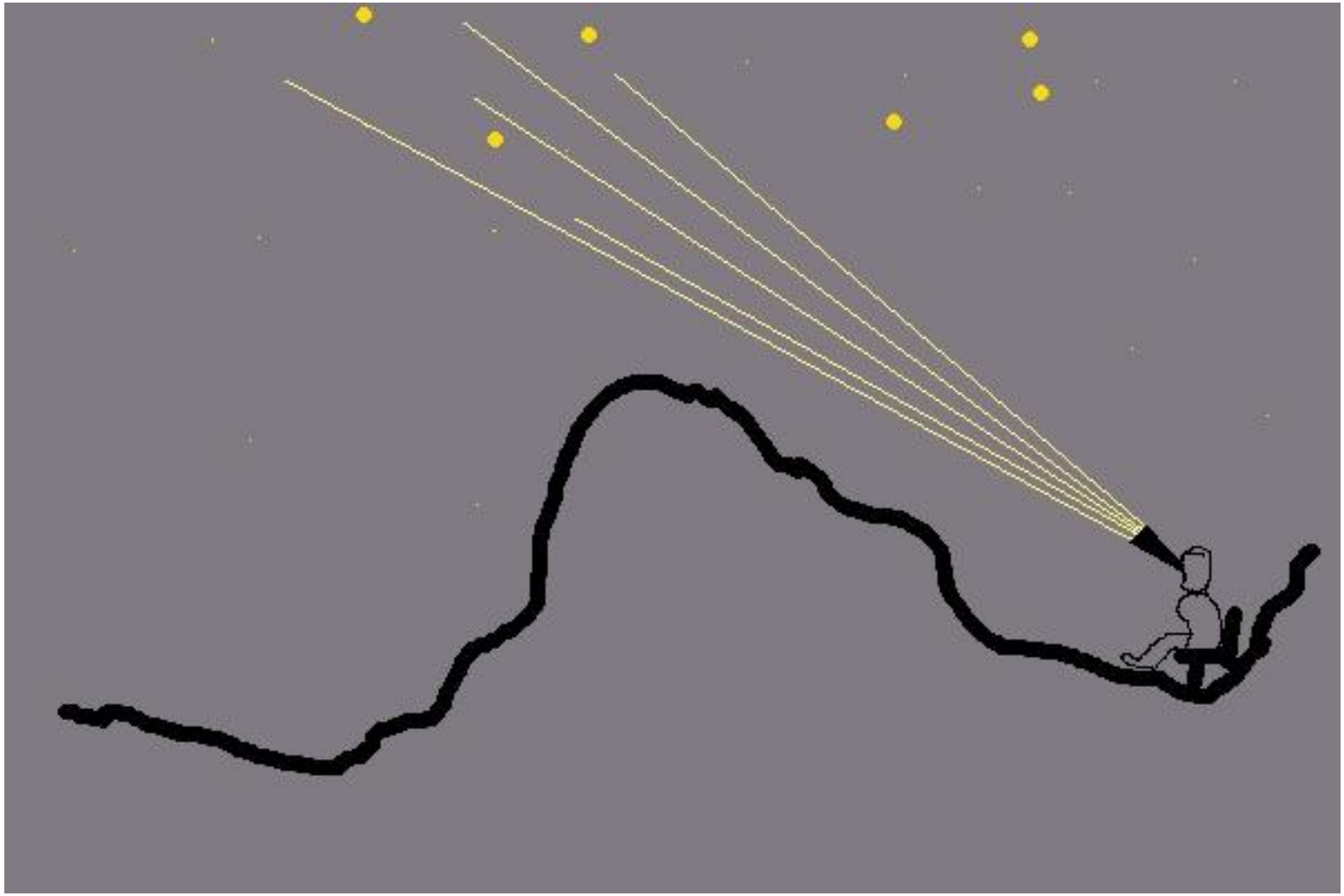
Why uplight matters . .

* 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 ï there is more skyglow too!

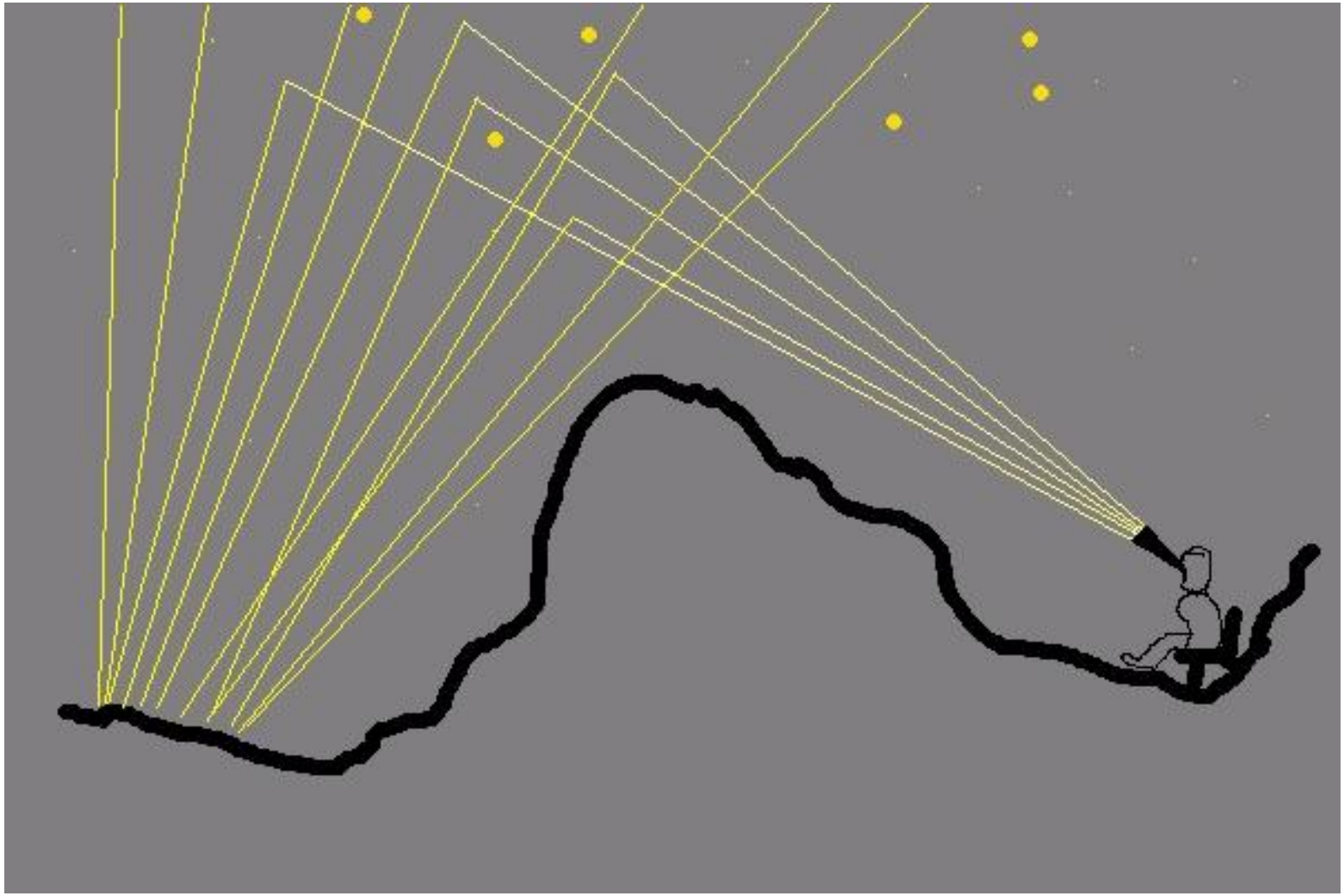
An observer looks at the sky . .



. . . where he sees skyglow . . .



. . which is caused by uplight . .



. . scattered by the atmosphere.

* atmospheric scattering redirects light
  - ï like surfaces do - but without ña surfaceò!
* Rayleigh scatter is what makes the sky blue
  - ï also causes the colors at sunrise and sunset
  - ï scatter is extremely dependent on wavelength
  - ï 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

Rayleigh Scatter Index

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

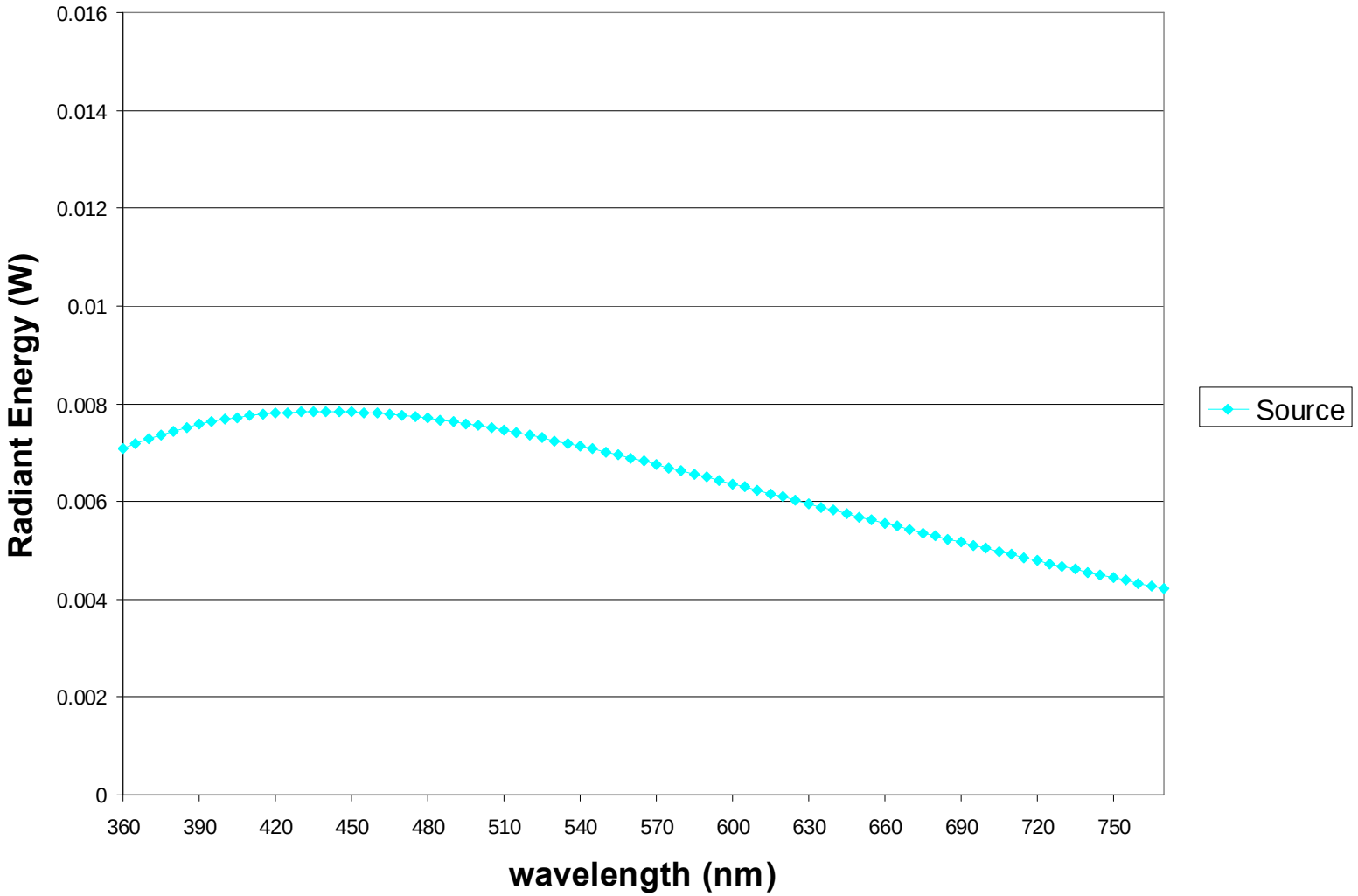
$$RSI = k \int (S(\lambda) / \lambda^4)$$

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

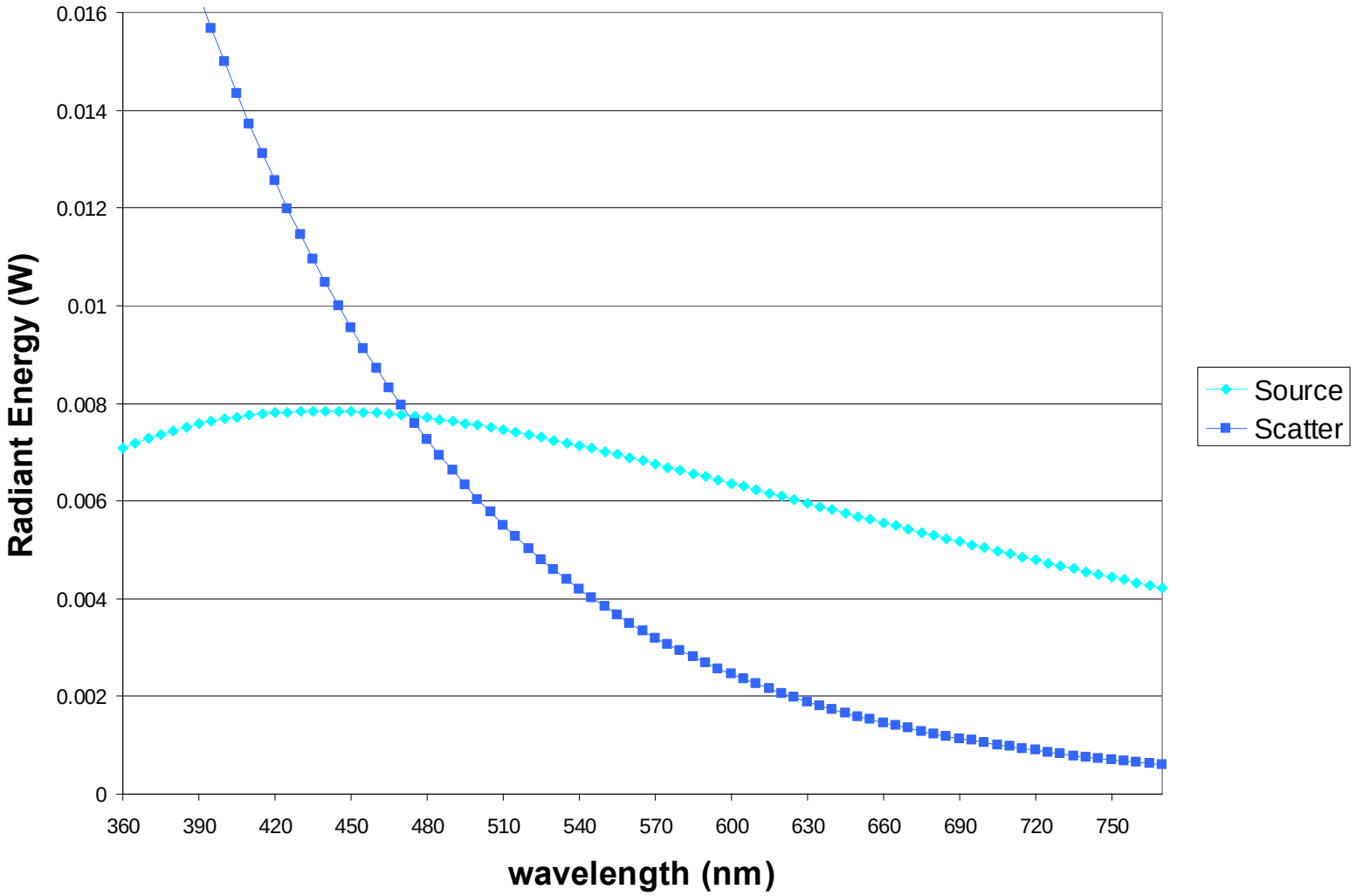
What does RSI indicate?

* RSI is a comparative measure of the likelihood that ñlightò 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 ñblue skyò conditions of daytime

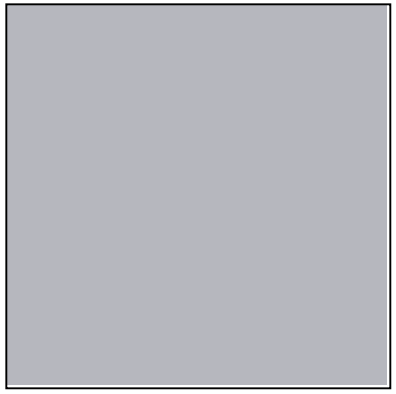
Sunlight: Blackbody at 6600K

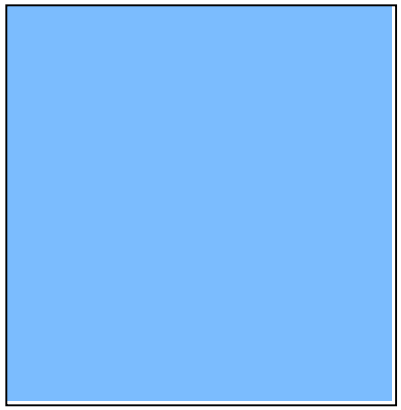


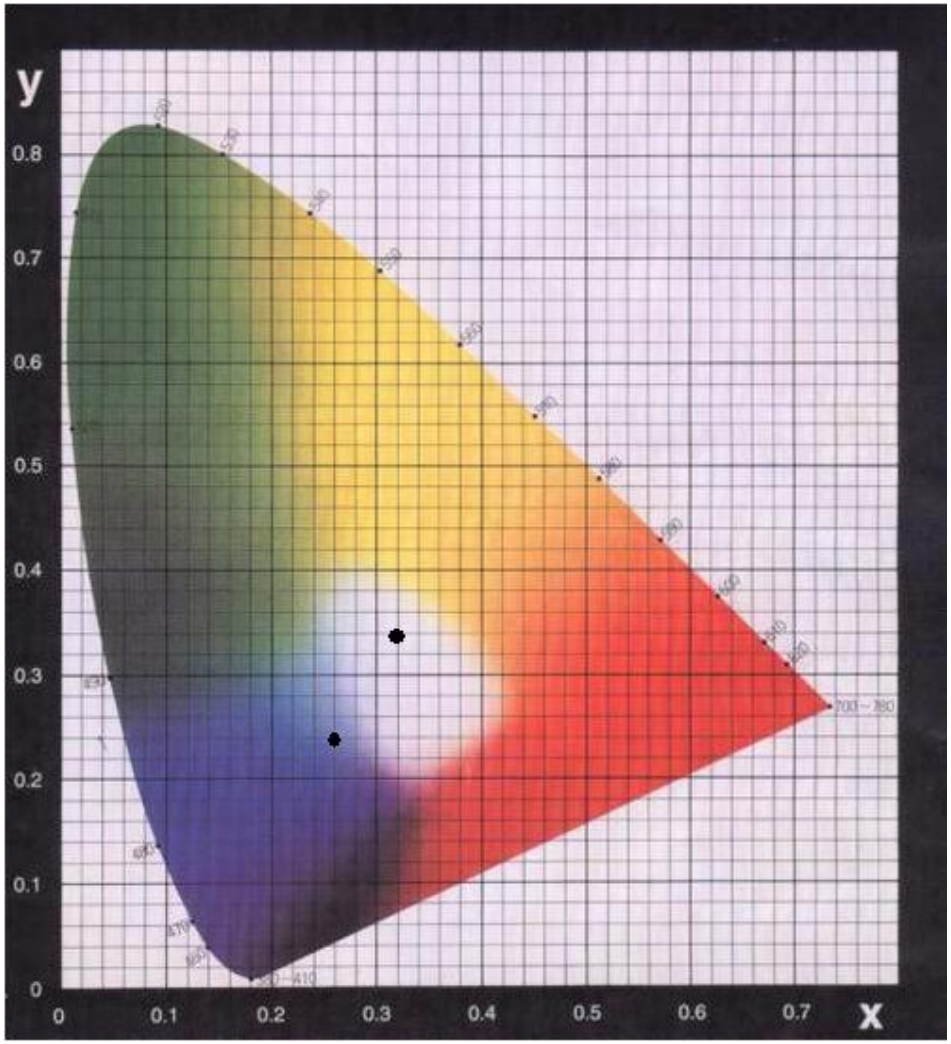
Scattered Sunlight



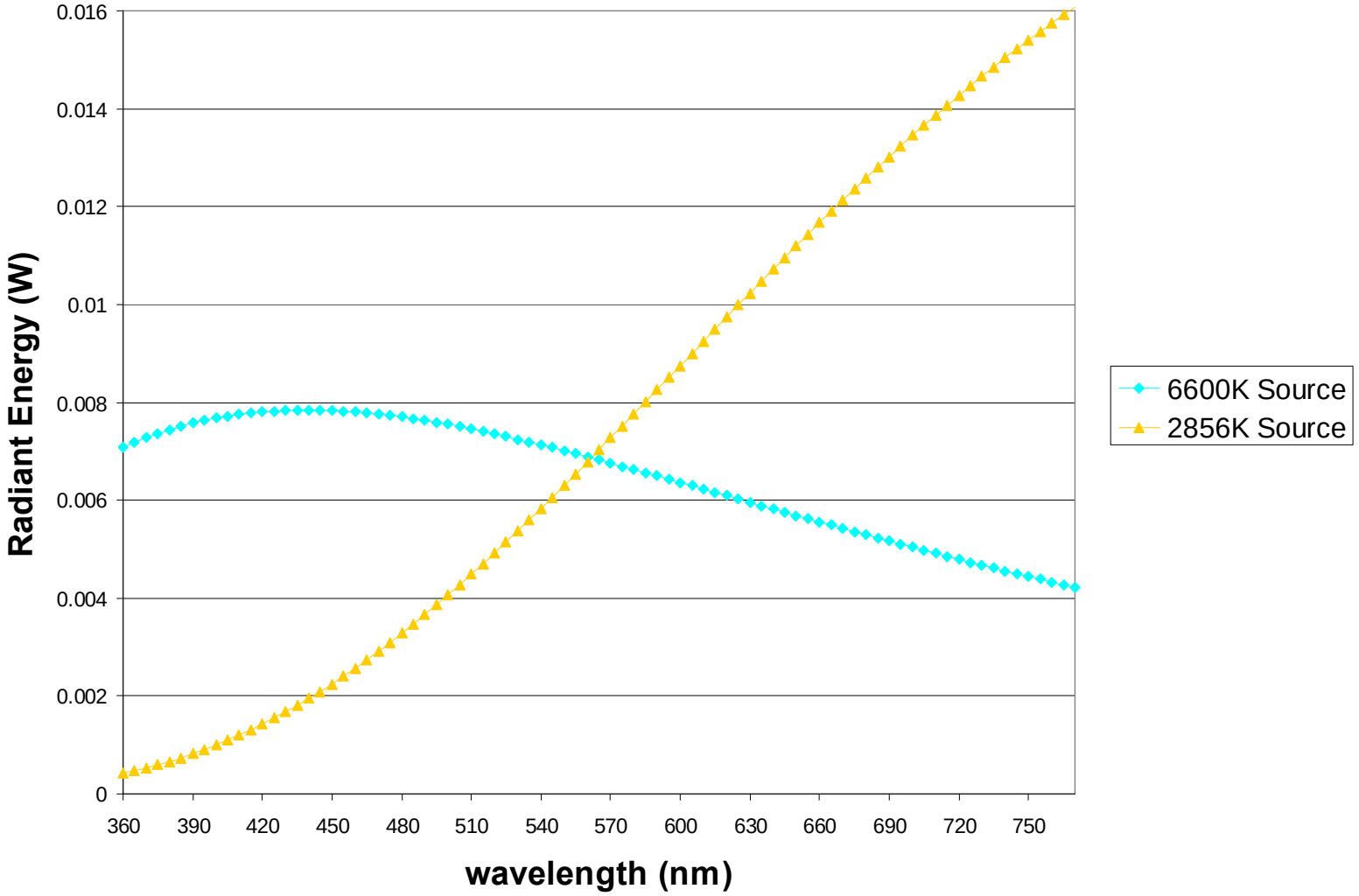
Color Shift for Scattered Sunlight



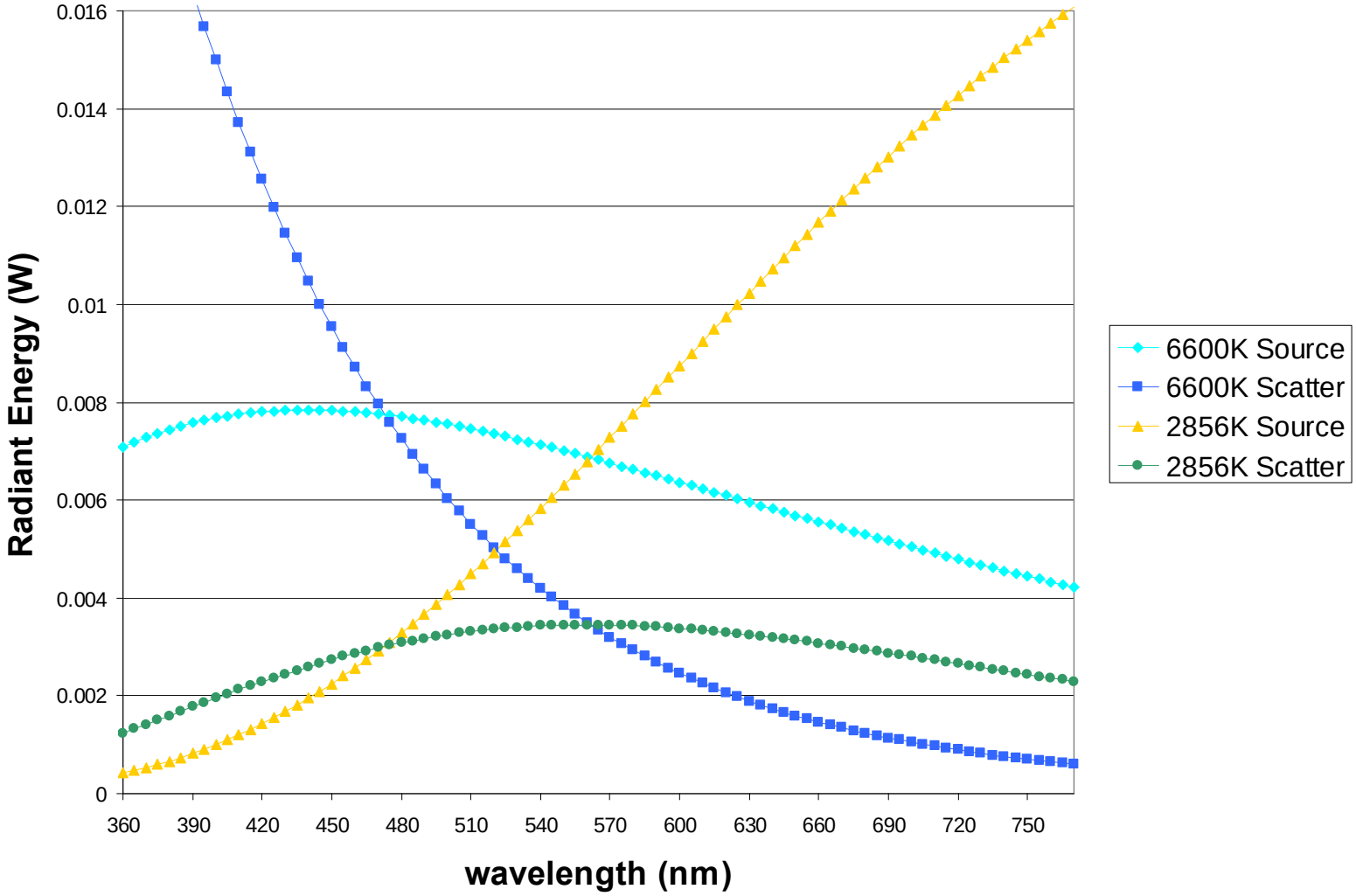




Compare Blackbody Sources



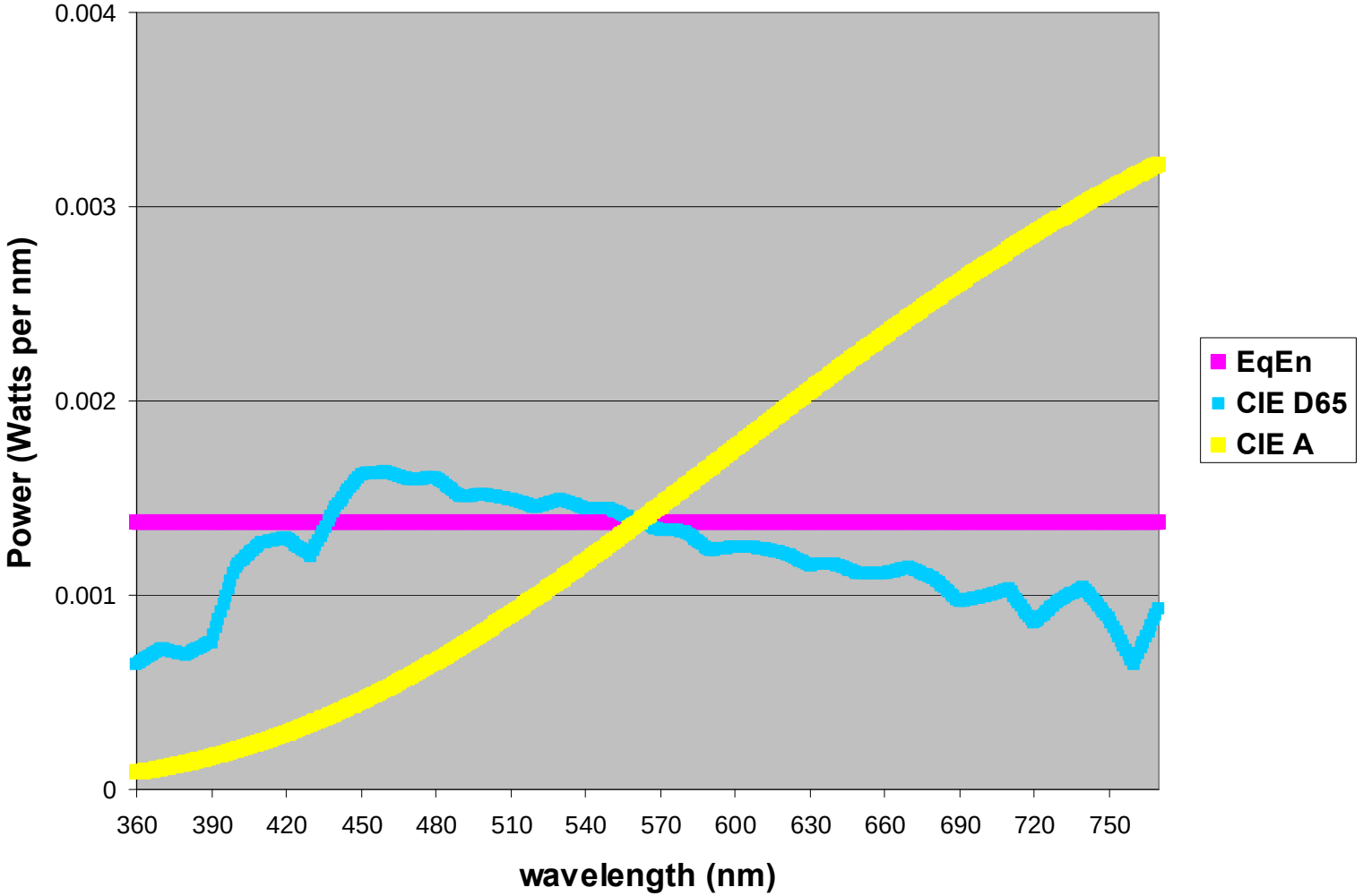
Compare Sources & Scatter



Scattered Radiation Profiles

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

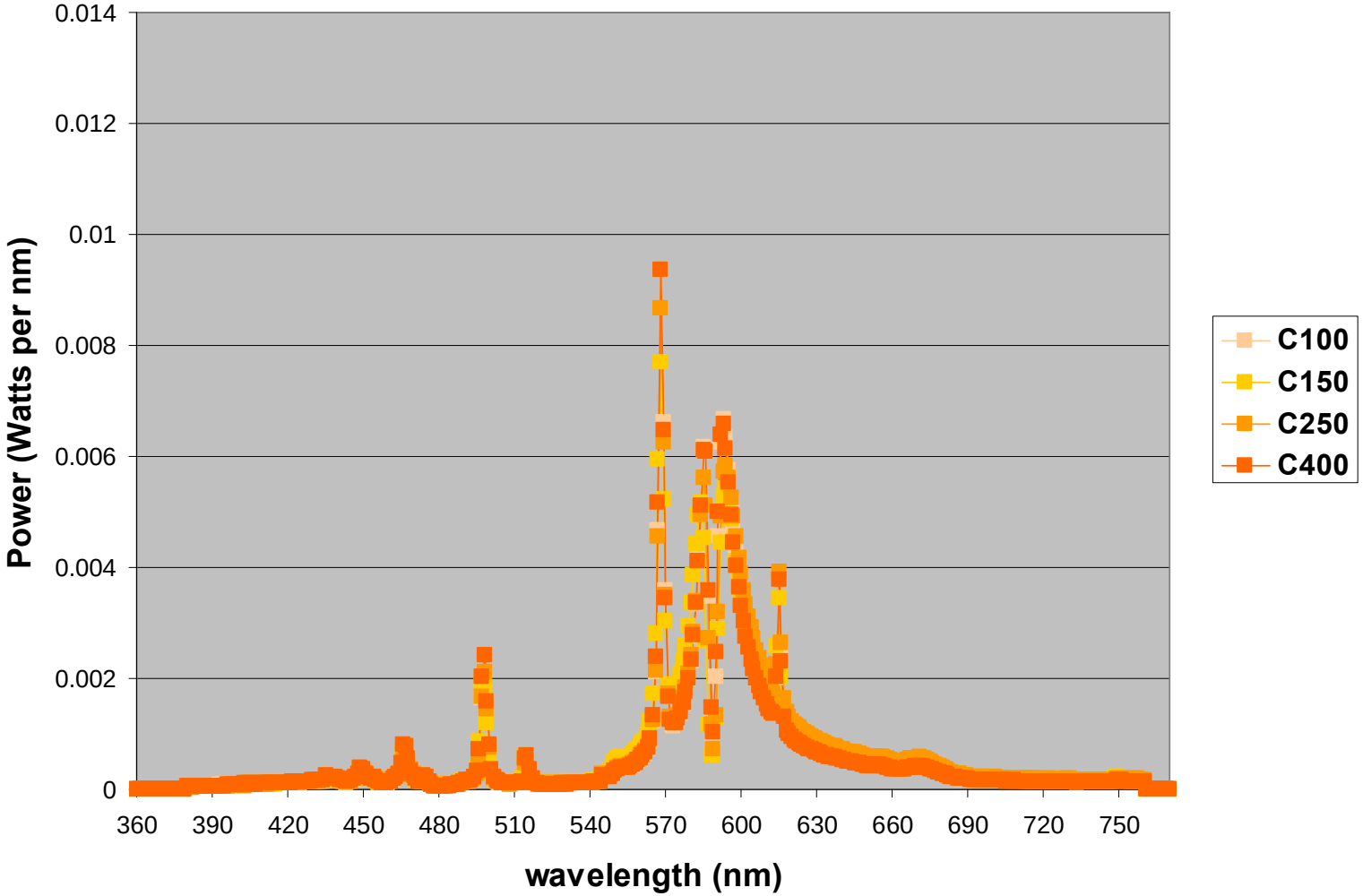
Equal Energy, CIE D65 & CIE A



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**

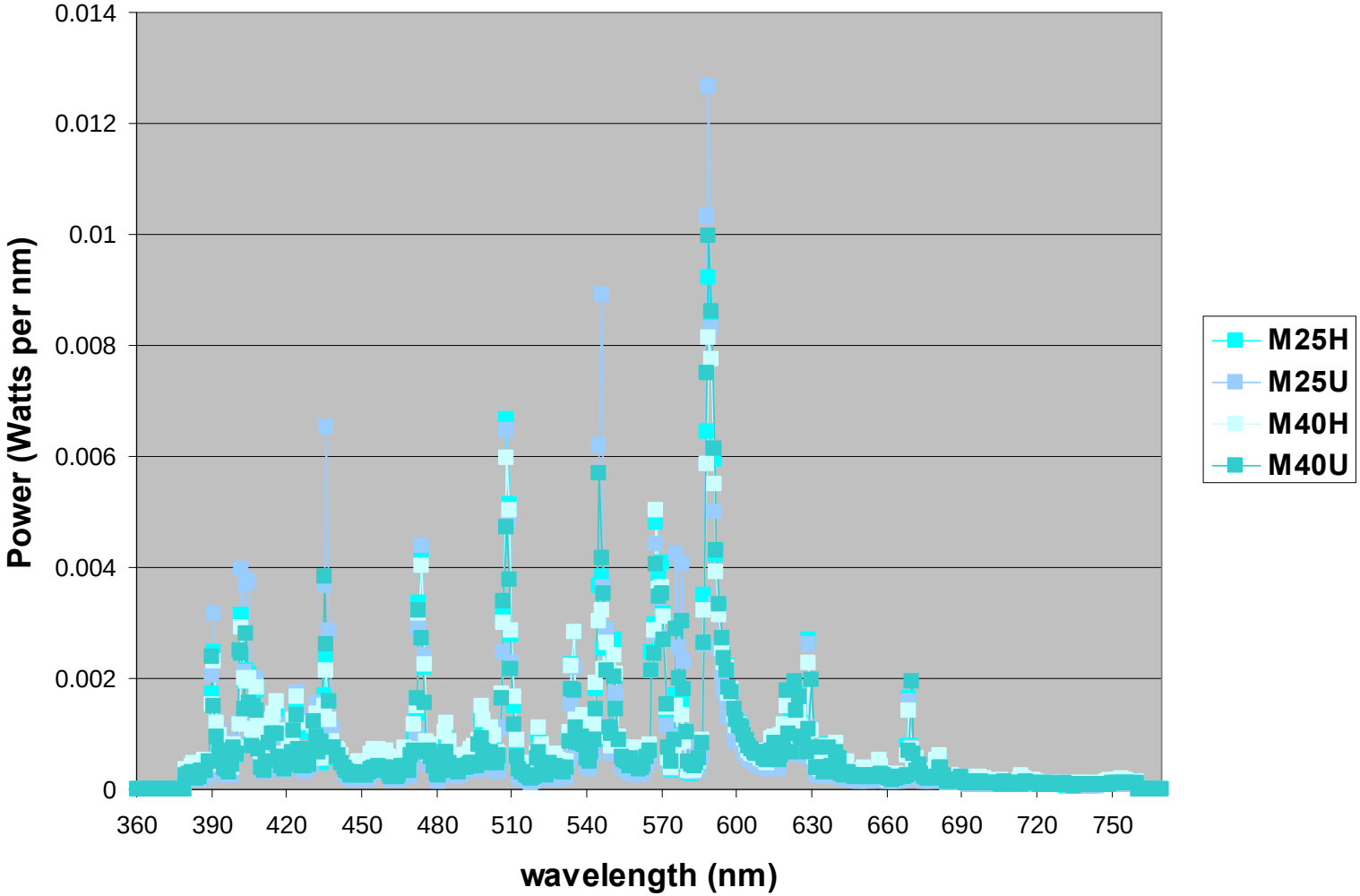
High Pressure Sodium 100-400W



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**

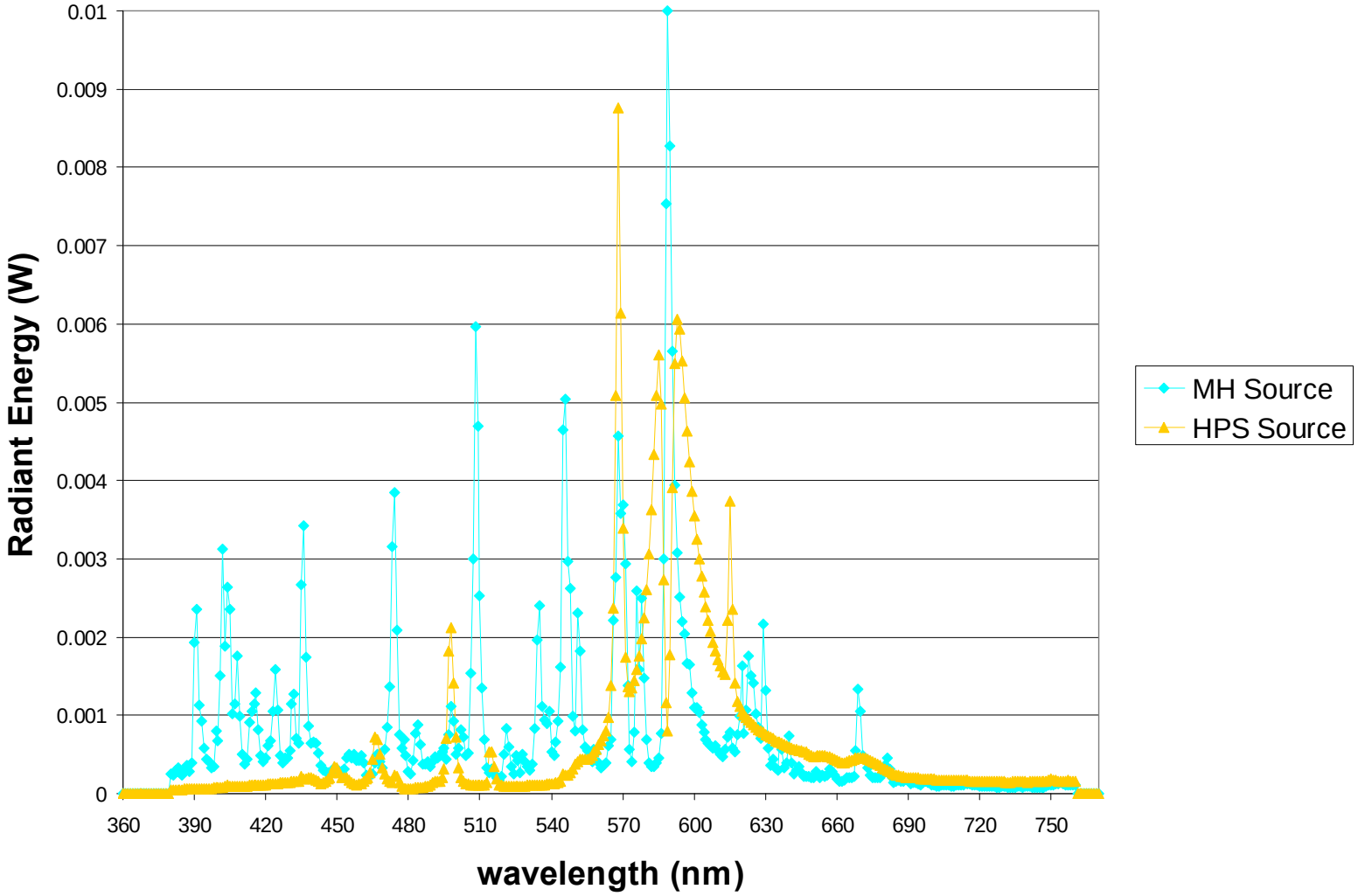
Metal Halide 250W & 400W



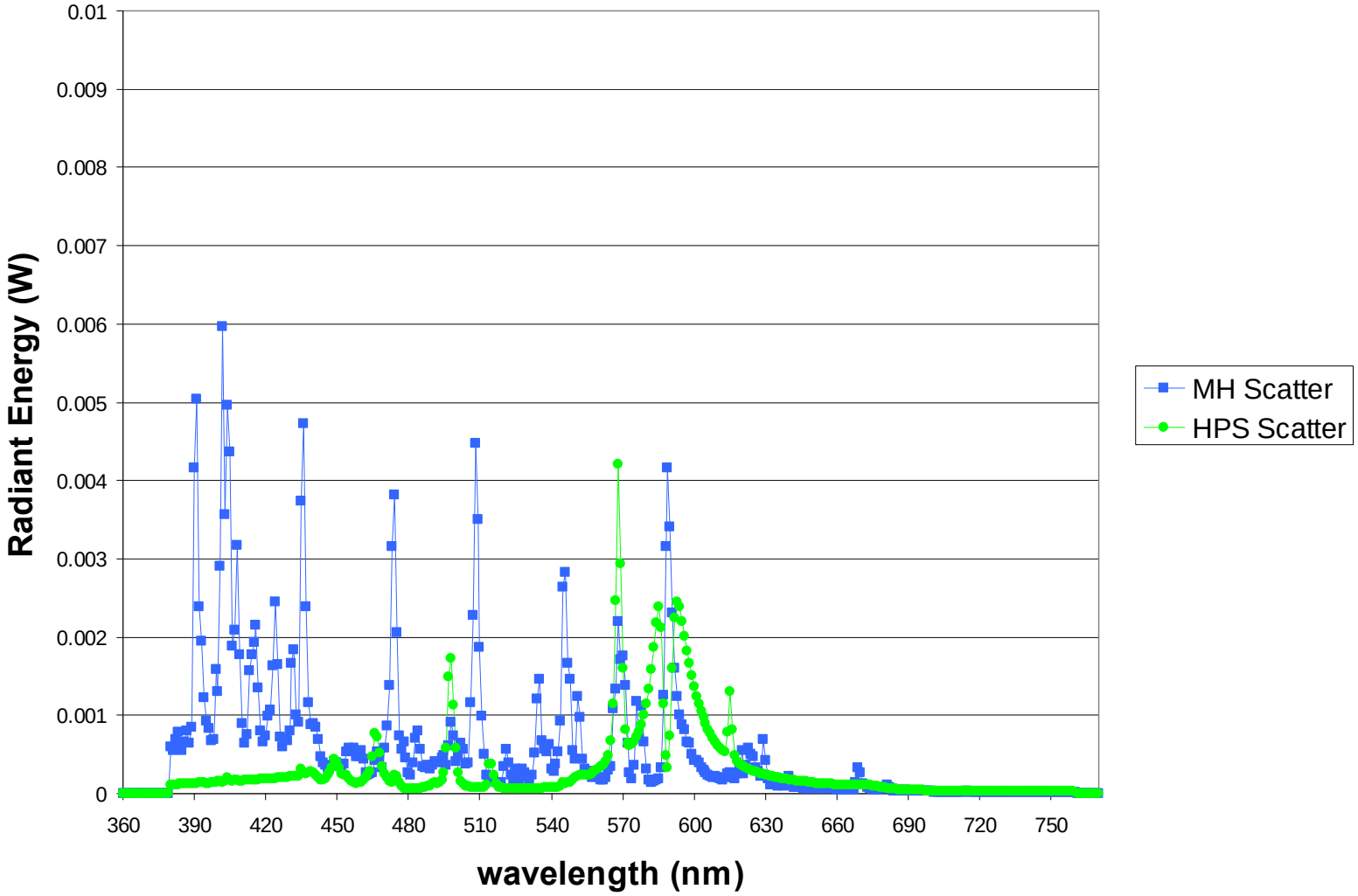
RSI for MH: 100 Photopic Lms

	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**

Average MH & HPS Sources



Average MH & HPS Scatter



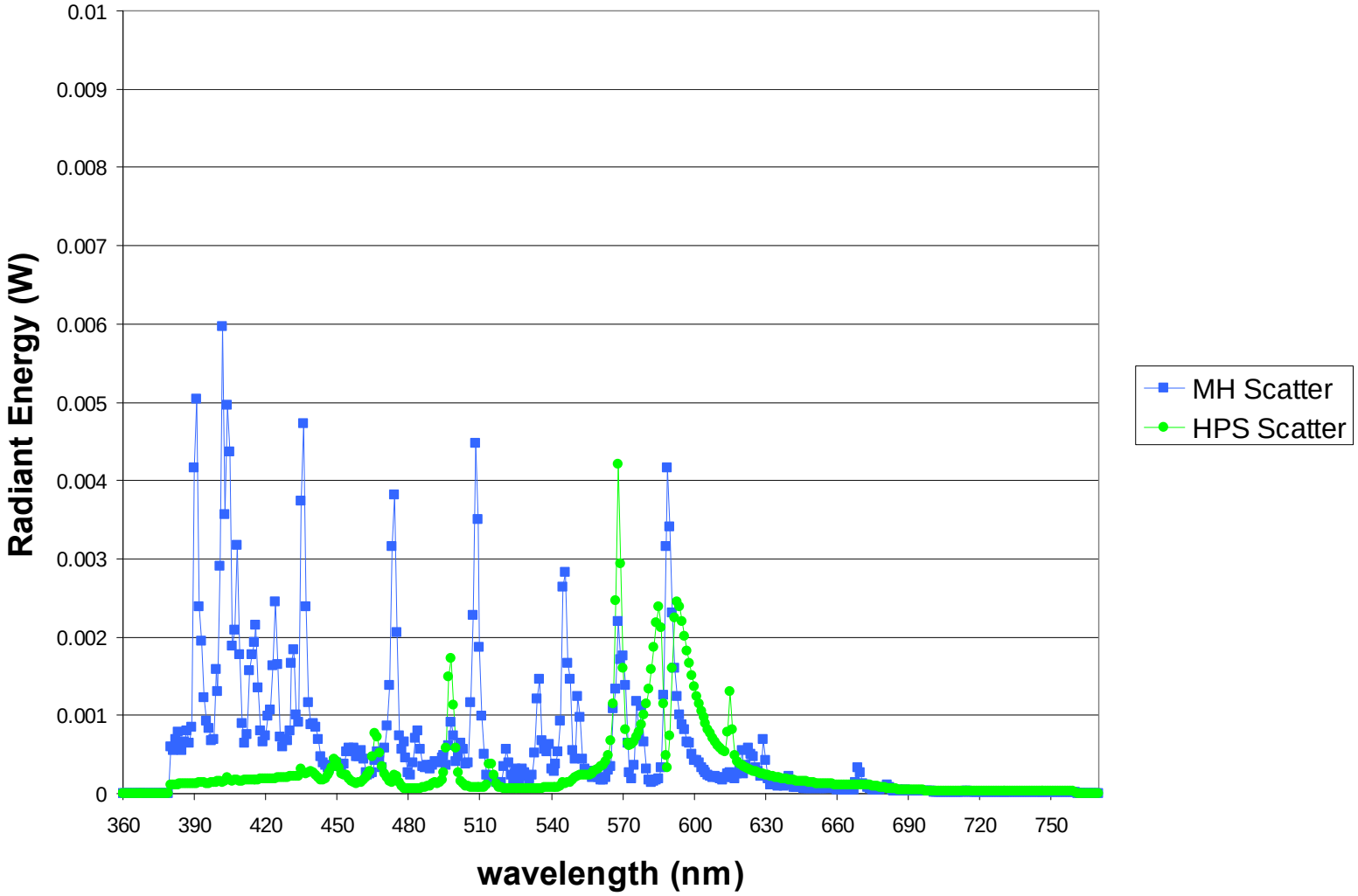
Radiation from the sky per 100 lms

	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%**

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%**

Average MH & HPS Scatter



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 ə)
* Rayleigh Scattering Index (RSI) provides relative information about different SPDôs
* HPS produces less skyglow compared to MH
  - ï from the same amount of lumens or radiation

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

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