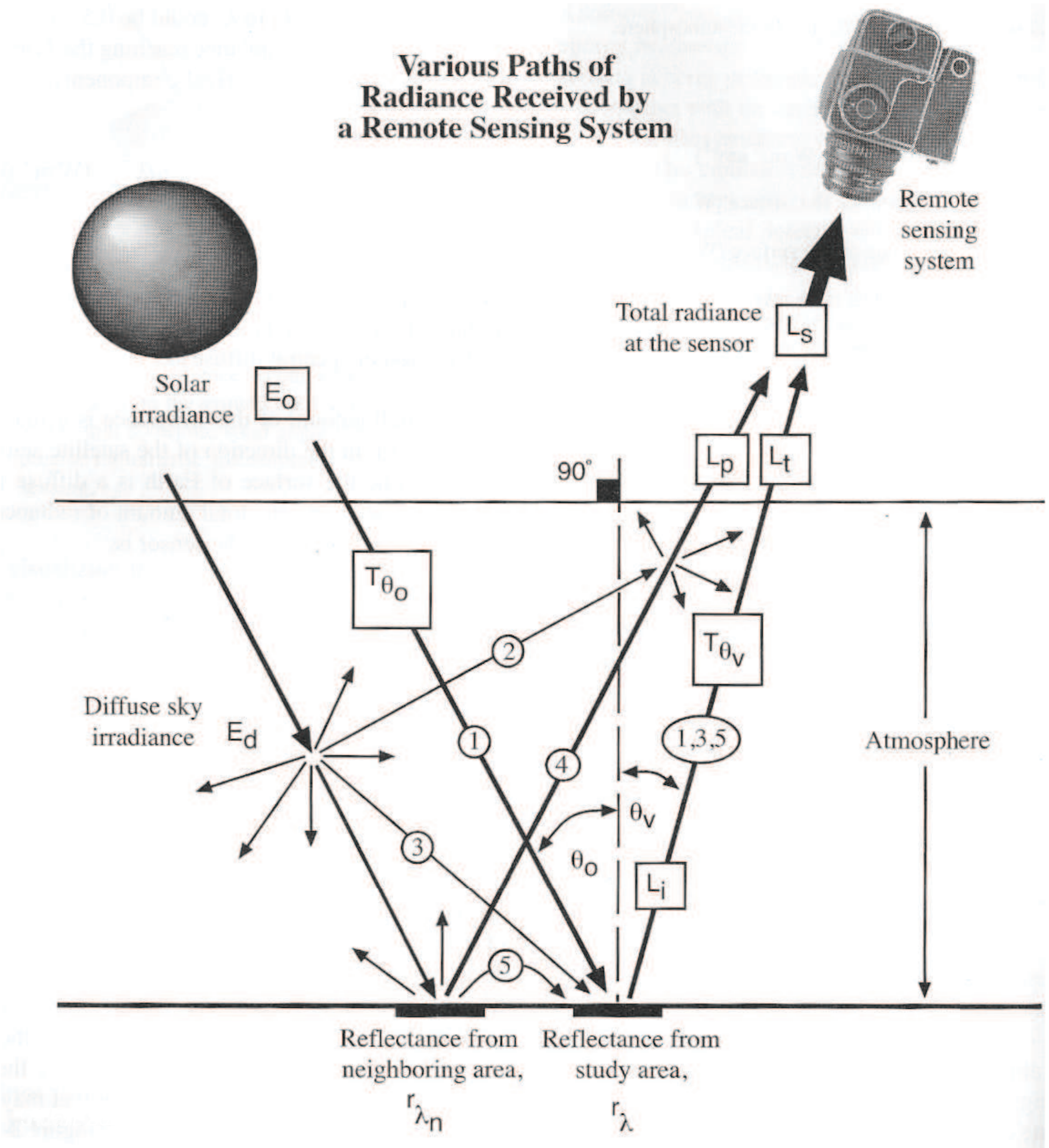

Illumination

# What This Lecture is About

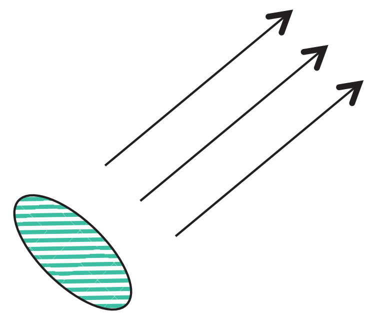



- Characteristics of illumination sources
- Atmospheric attenuation

# In Context with Coming Lectures

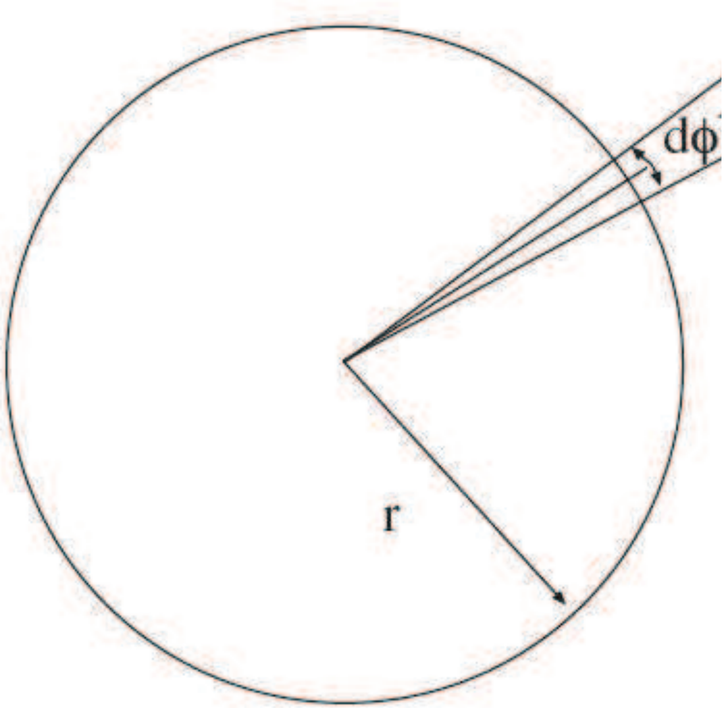
- Today: illumination
- Next week:
  - Reflection and color
  - Cameras: optics, detectors
  - Geometric camera modeling and calibration
- Reading material:
  - Forsyth chapter 1 and sections 2.1, 3.1, 3.2
- Additional references:
  - Szeliski chapter 2 (image formation)
  - Forsyth sections 22.1 and 22.2, or Szeliski appendix A (appendices on linear algebra and optimization techniques)

# Parallel Rays in Space



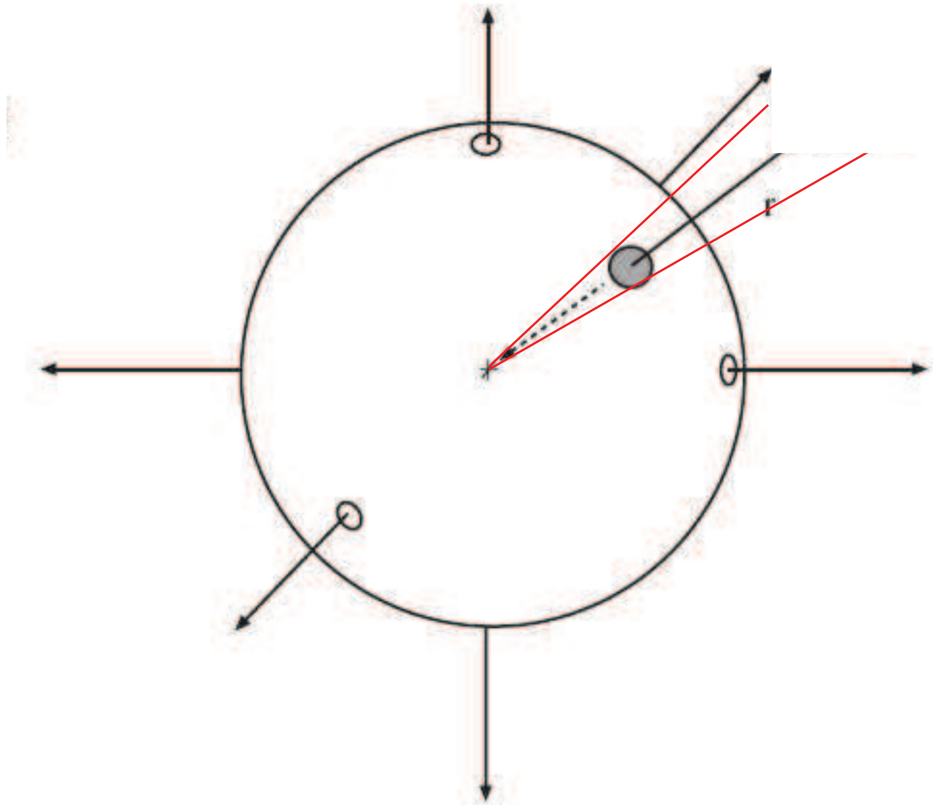
# Solid Angles

Angle




$$d\phi = \frac{dl}{r}$$

Solid angle

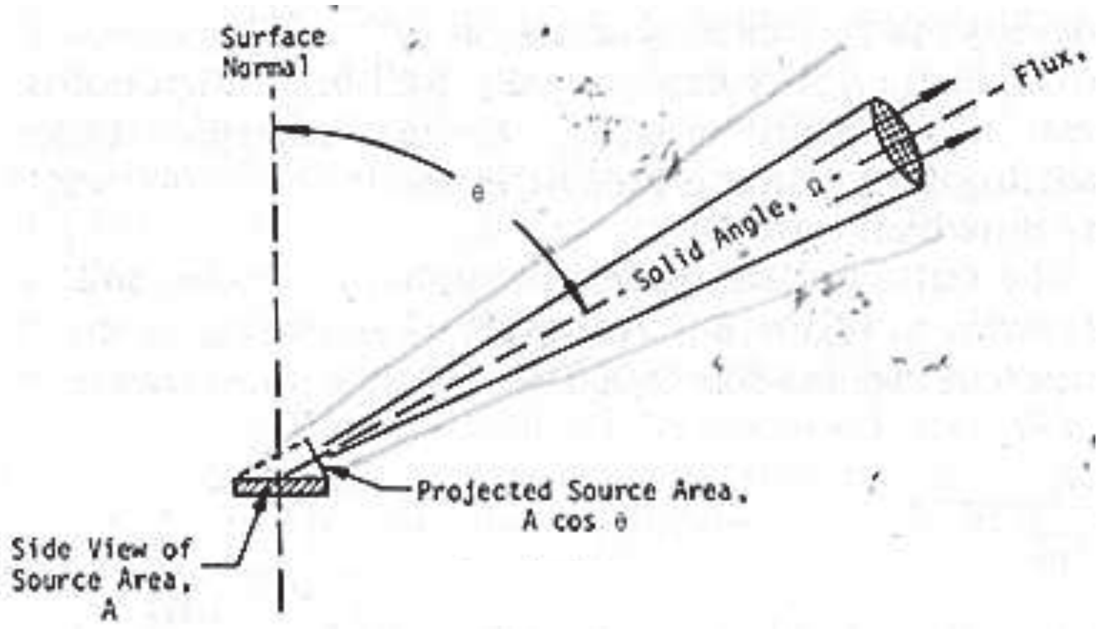


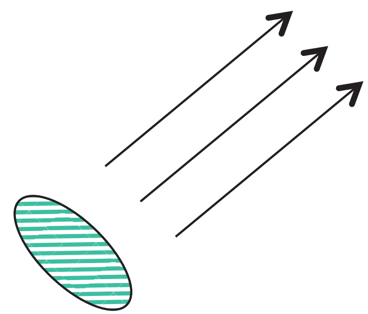

$$d\omega = \frac{dA}{r^2}$$

# Radiance and Irradiance

Radiance:

- The amount of energy travelling at some point in a specified direction, per unit time, per unit area perpendicular to the direction of travel, per unit solid angle ($W\,m^{-2}\,sr^{-1}$). Usually denoted $L(x,\theta,\phi)$.



Irradiance:

- Power per unit area of a collimated beam ($W\,m^{-2}$). Usually denoted $E$.
- Power per unit area impinging on a surface.

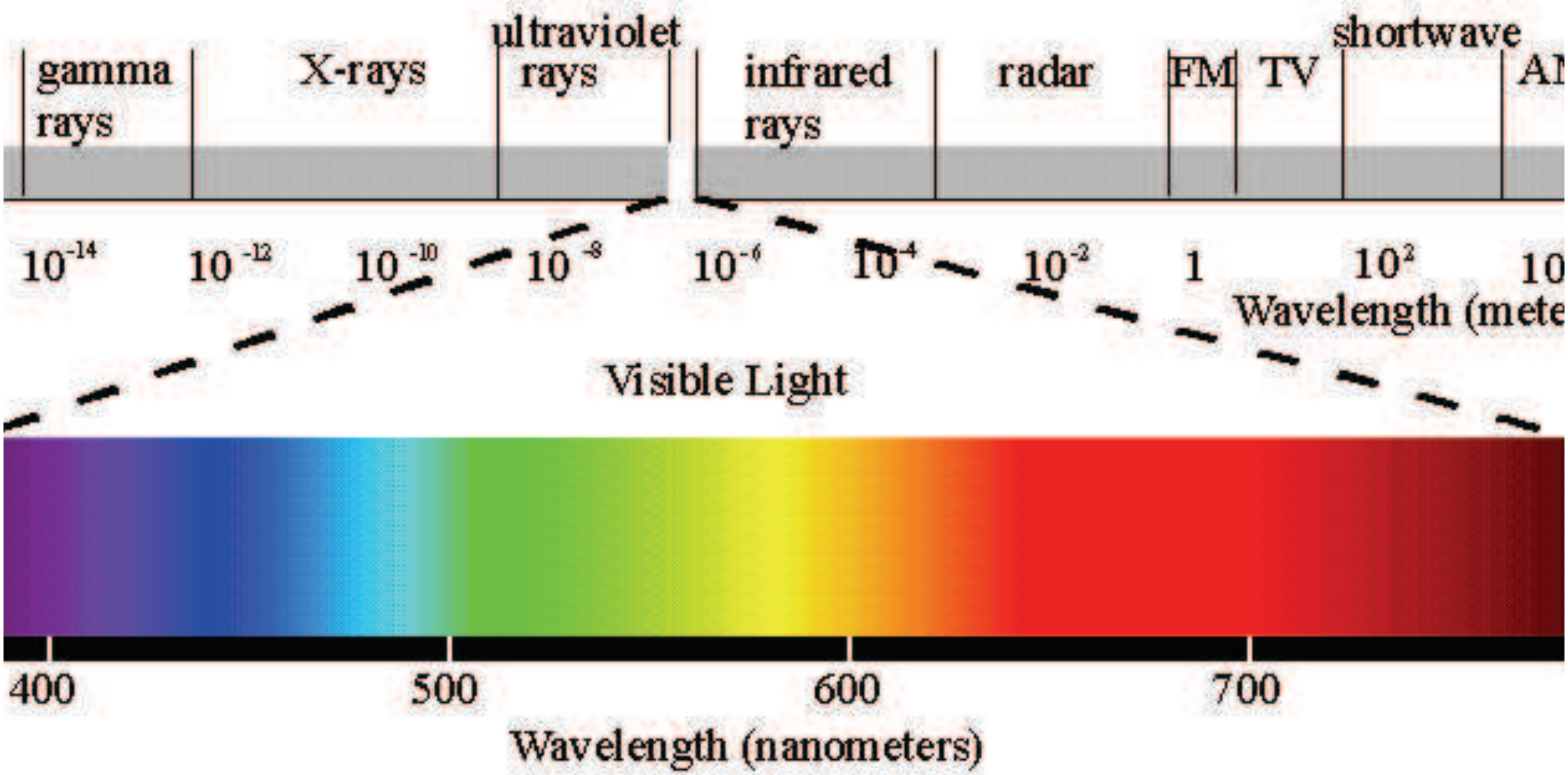
# Photo Arrivals are Poisson Distributed

$$f(x|\lambda) = \frac{e^{-\lambda}\lambda^{x}}{x!}$$

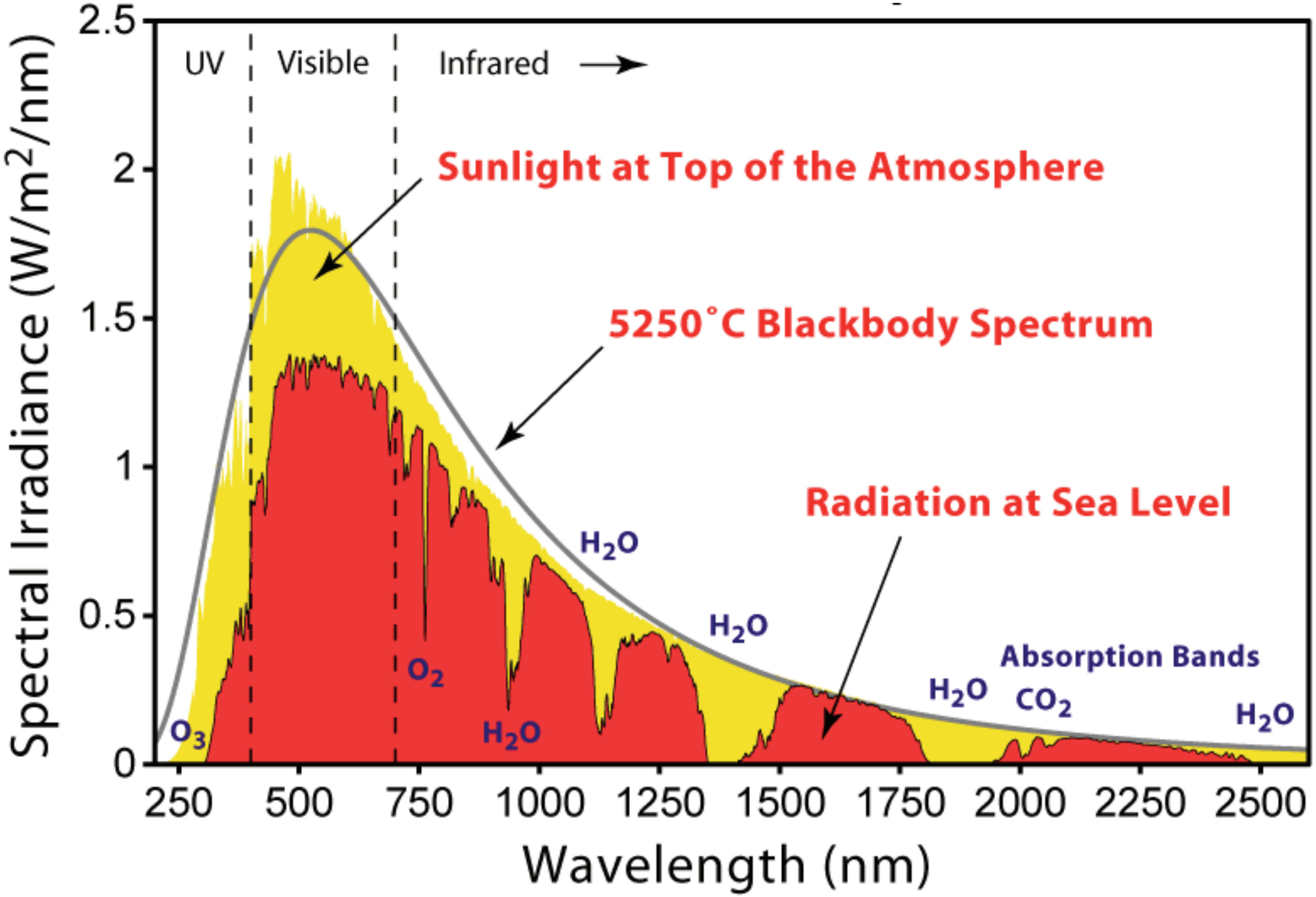
$$\mu = \lambda$$

$$\mathrm{var} = \lambda$$

# Electromagnetic Spectrum



# Solar Spectrum




Total irradiance ~ 1370 W/m$^2$ above atmosphere (*solar constant*)

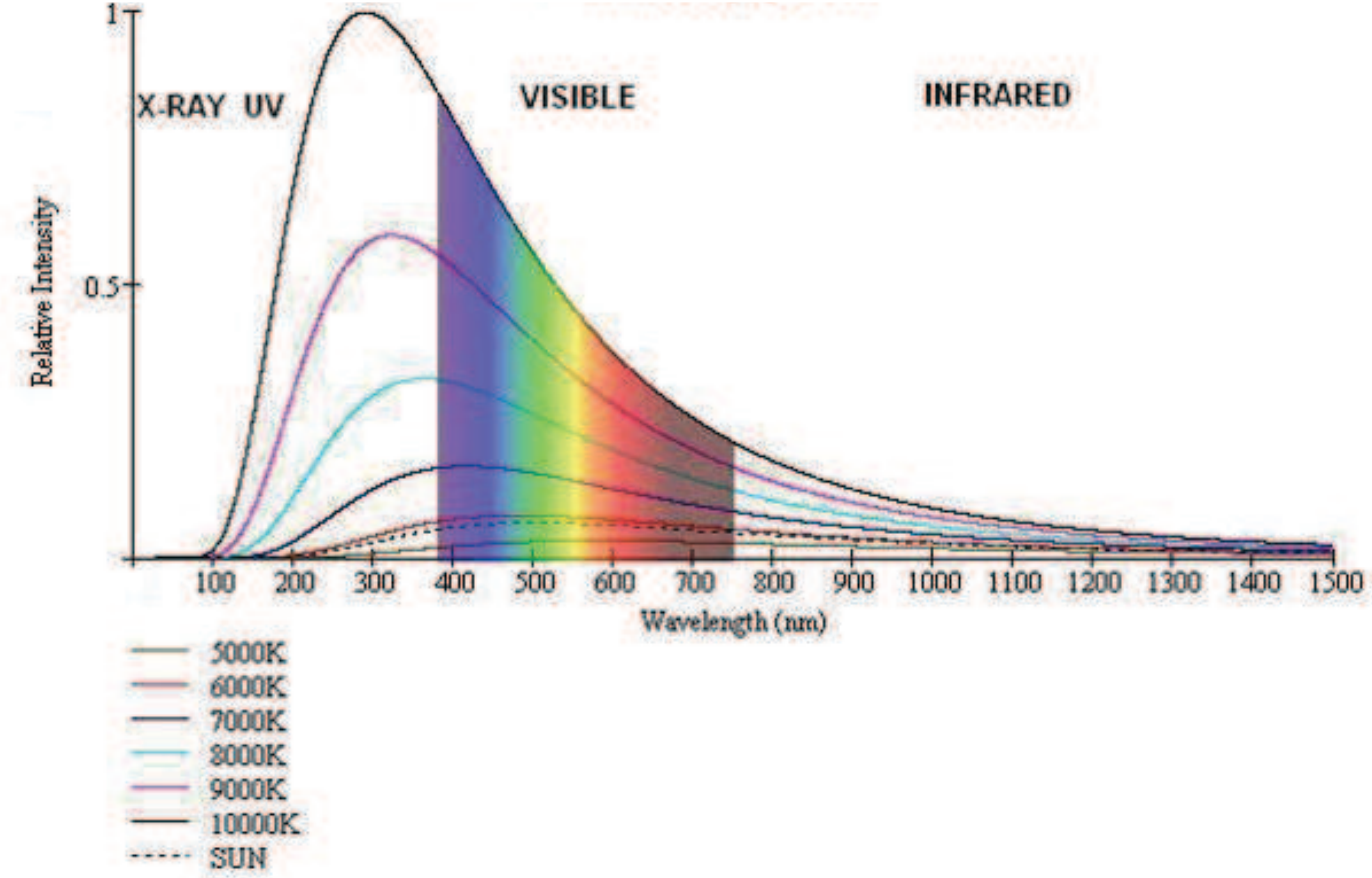
# Blackbody Emission: Planck's Law

$$S(\lambda) = \frac{2\pi hc^2}{\lambda^5} \frac{1}{e^{ch/\lambda kT} - 1}$$

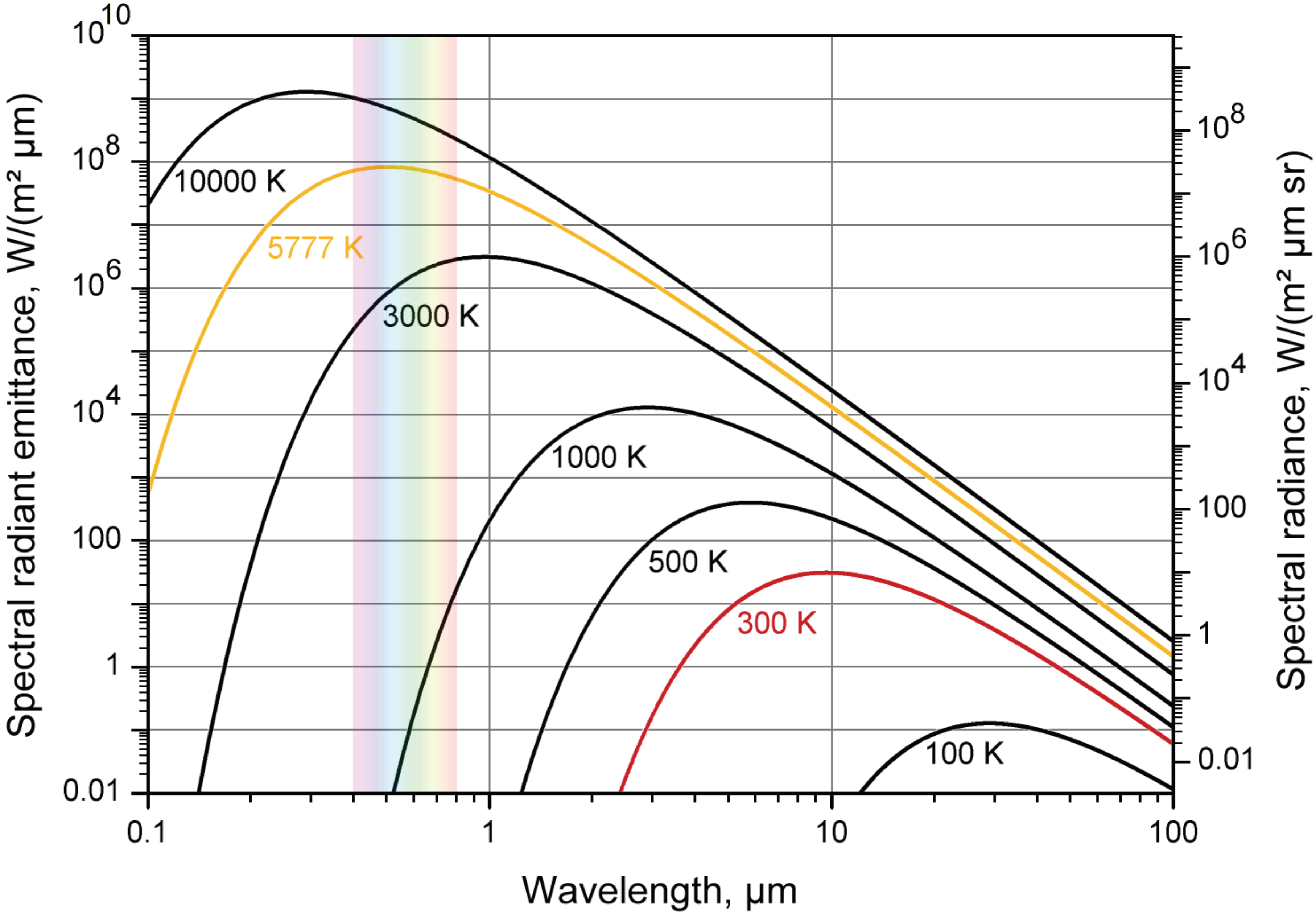
Where

- $S(\lambda)$ = spectral radiant emittance in $W/m^3$ (watts per unit wavelength per unit area)
- $\lambda$ = radiation wavelength
- $h$ = Planck's constant = $6.626 \times 10^{-34}$ $Wsec^2$
- $T$ = absolute temperature in °K
- $C$ = velocity of light = $2.9979 \times 10^8$ m/sec
- $K$ = Boltzmann constant = $1.38 \times 10^{-23}$ Wsec/K

# Blackbody Spectrum



# Blackbody Spectrum



# Stefan-Boltzmann and Wien Laws

- Total flux emitted by a blackbody of unit area (Stefan-Boltzmann law):

$$\int S(\lambda)\,d\lambda = \sigma T^4$$

  - where $\sigma = 5.669 \times 10^{-8}$ W/m$^2$K$^4$

- Wavelength of maximum emission (Wien's law):

$$\lambda_m = \frac{a}{T}$$

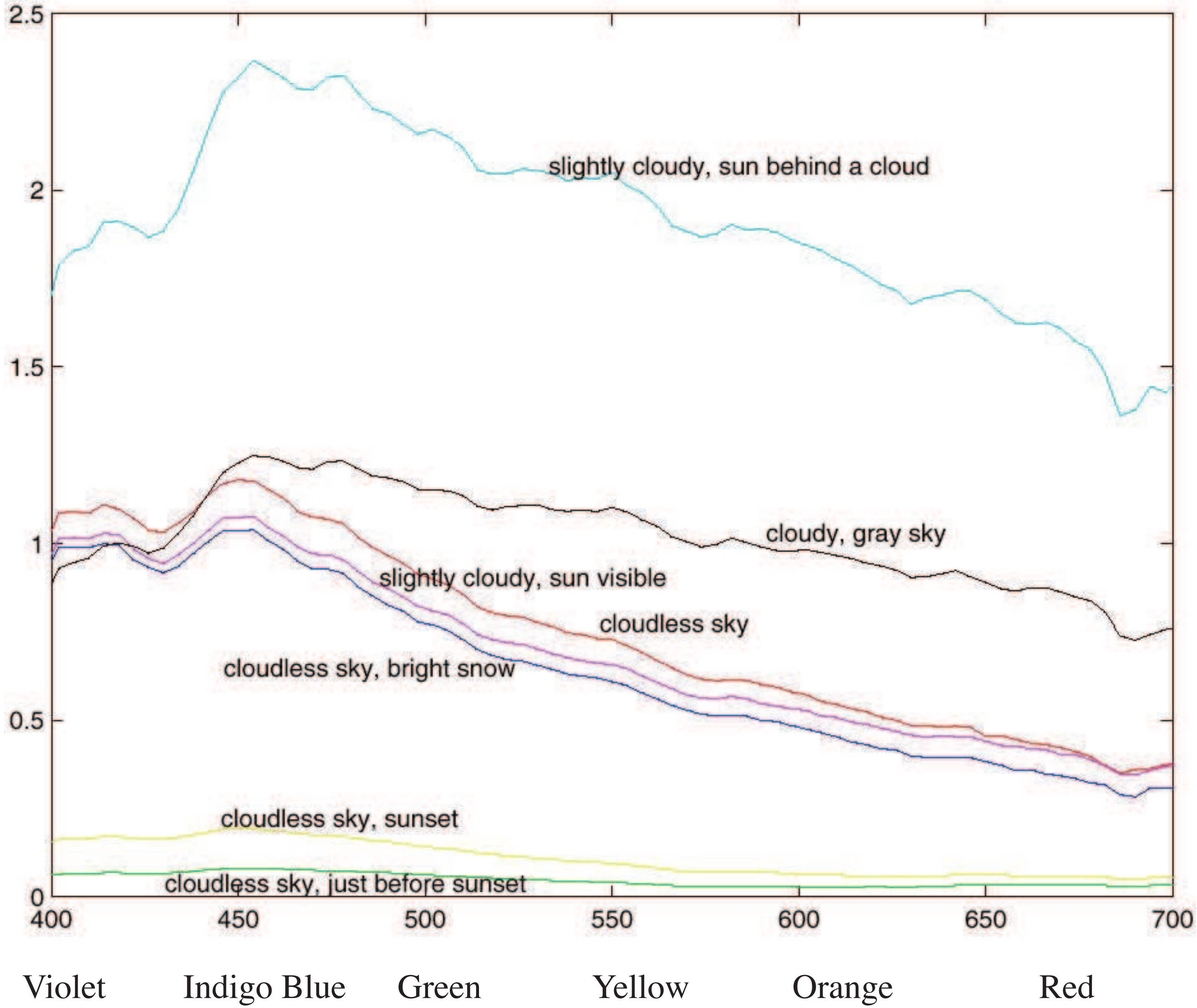
  - where a = 2898 μmK
  - for sun (T ~ 6000 °K), $\lambda_m$ = 480 nm; for Earth surface (T ~ 300 °K), $\lambda_m$ = 9.66 μm

- Photon energy = *hc/λ* (J/photon), so # photons/sec/m$^3$ = *S(λ)λ/hc*

# Some Sources of Illumination

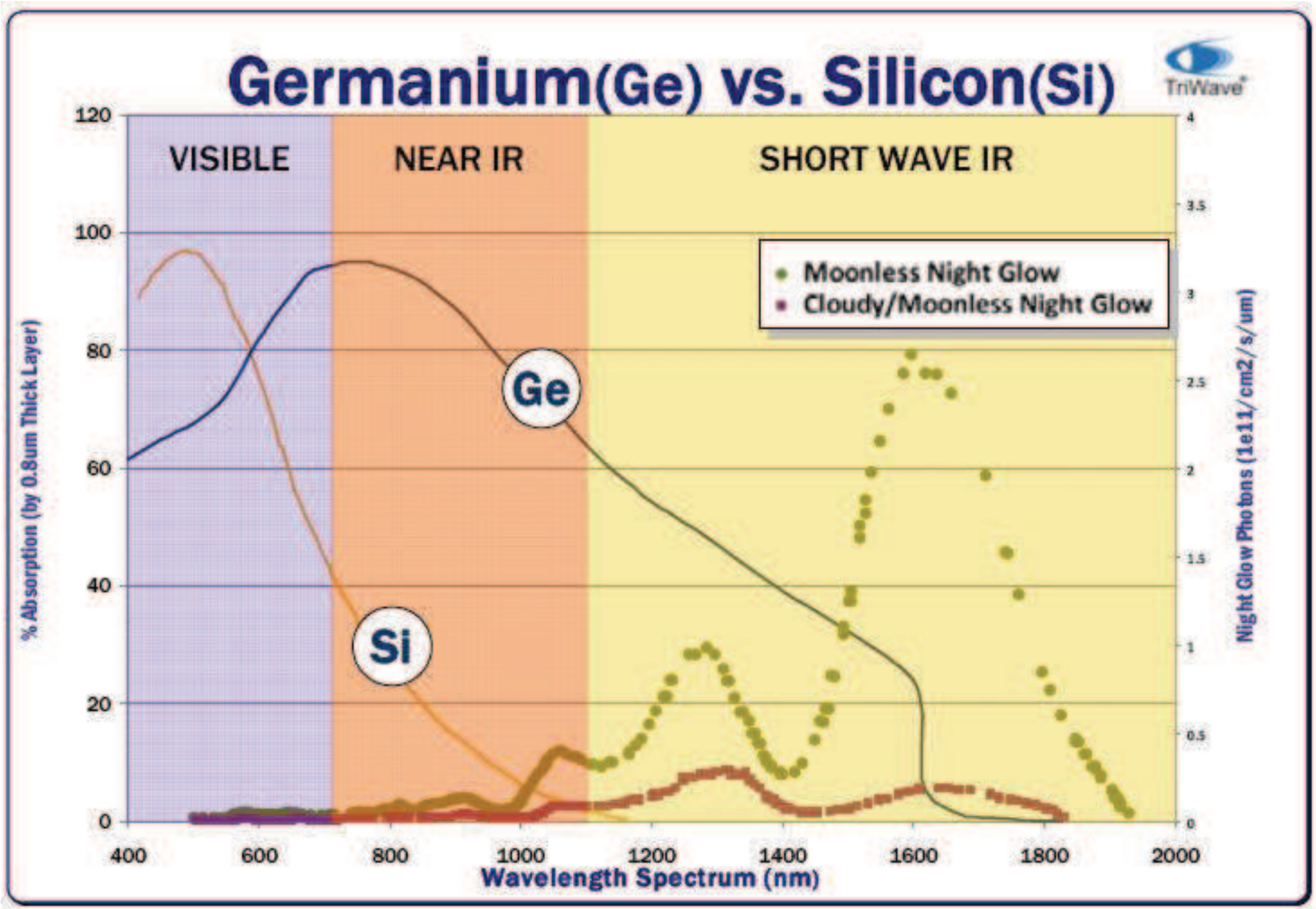
- Sunlight
- Thermal emission
- Skylight
- Night sky glow (*nightglow*)
- Man-made lights: e.g. incandescent bulbs, fluorescent bulbs, arc lamps

# Skylight

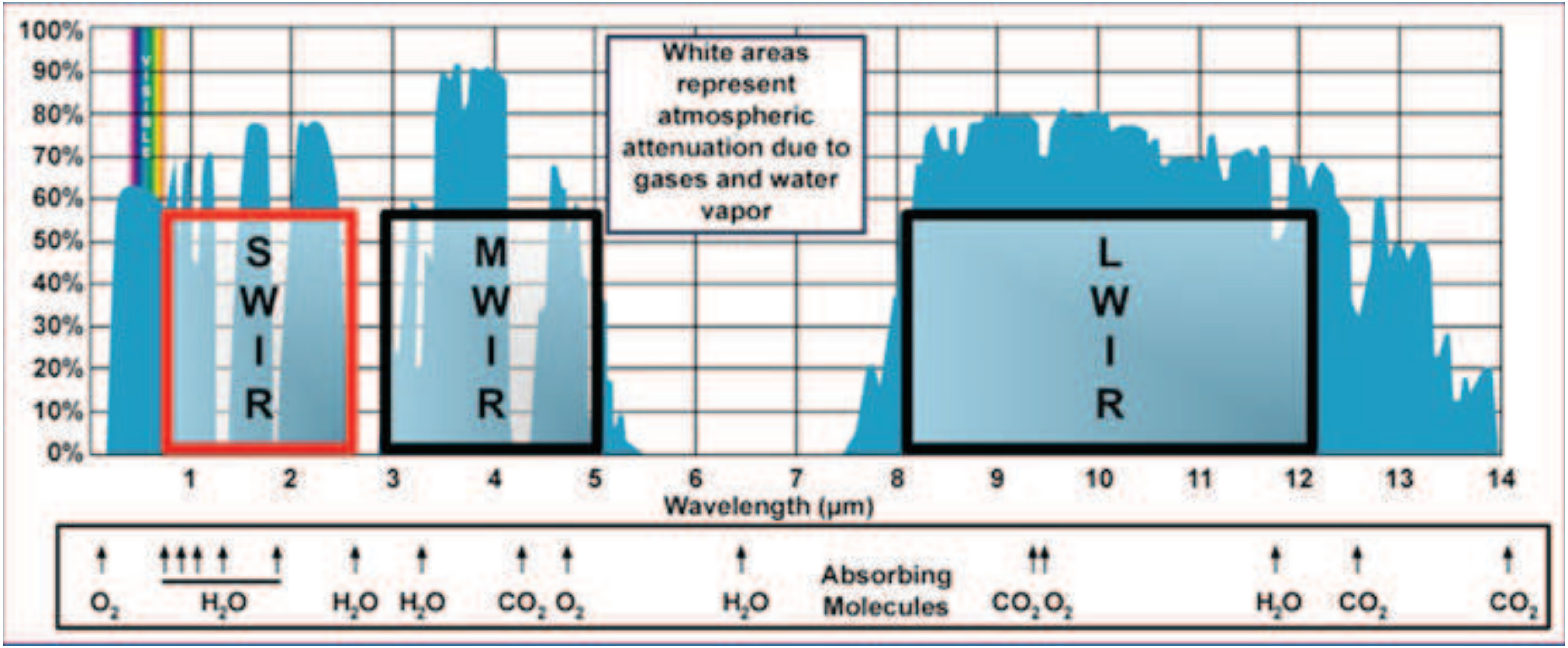


2.5
2
1.5
1
0.5
0
400
450
500
550
600
650
700
slightly cloudy, sun behind a cloud
cloudy, gray sky
slightly cloudy, sun visible
cloudless sky
cloudless sky, bright snow
cloudless sky, sunset
cloudless sky, just before sunset
Violet
Indigo Blue
Green
Yellow
Orange
Red

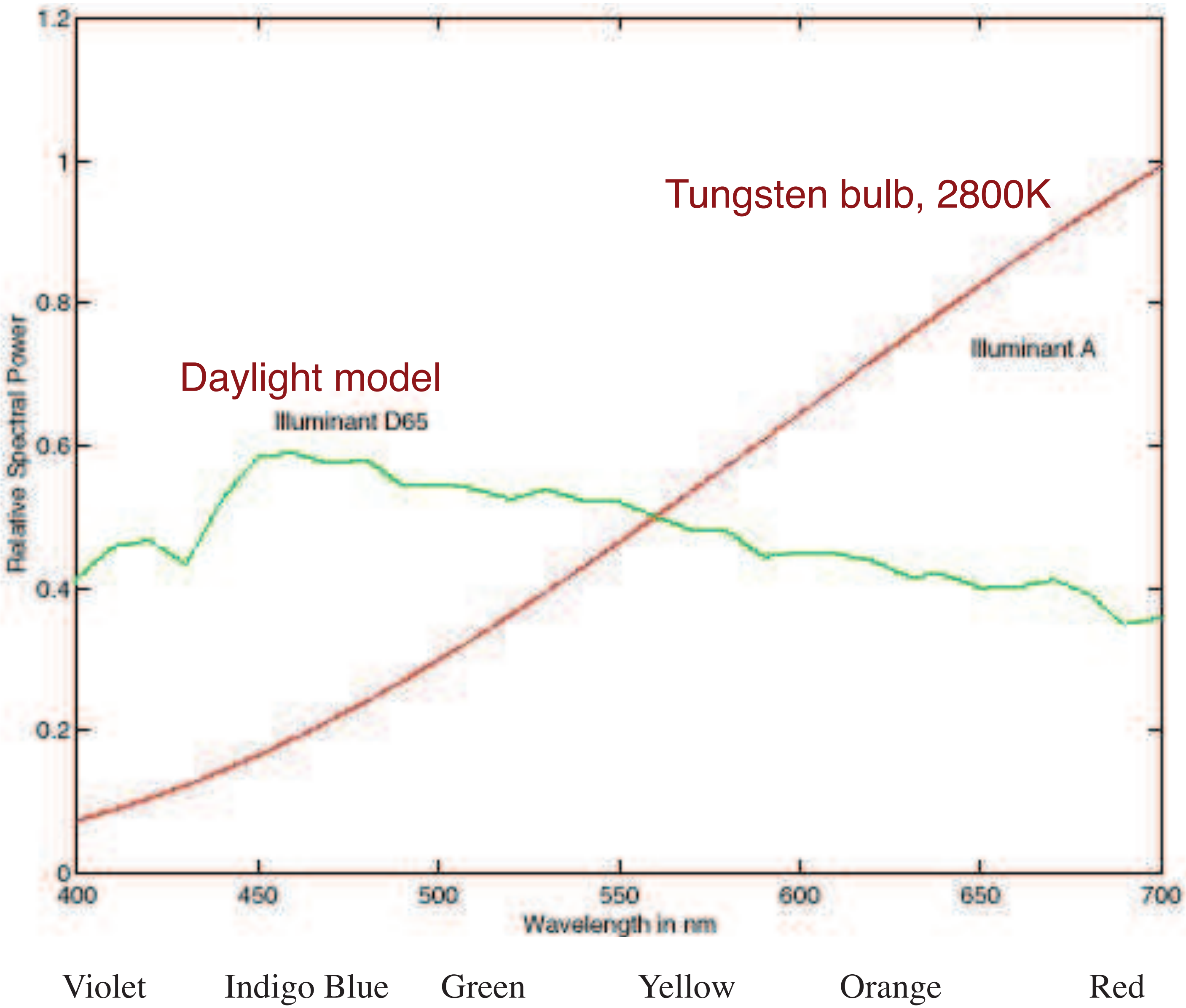
# Night Sky Glow



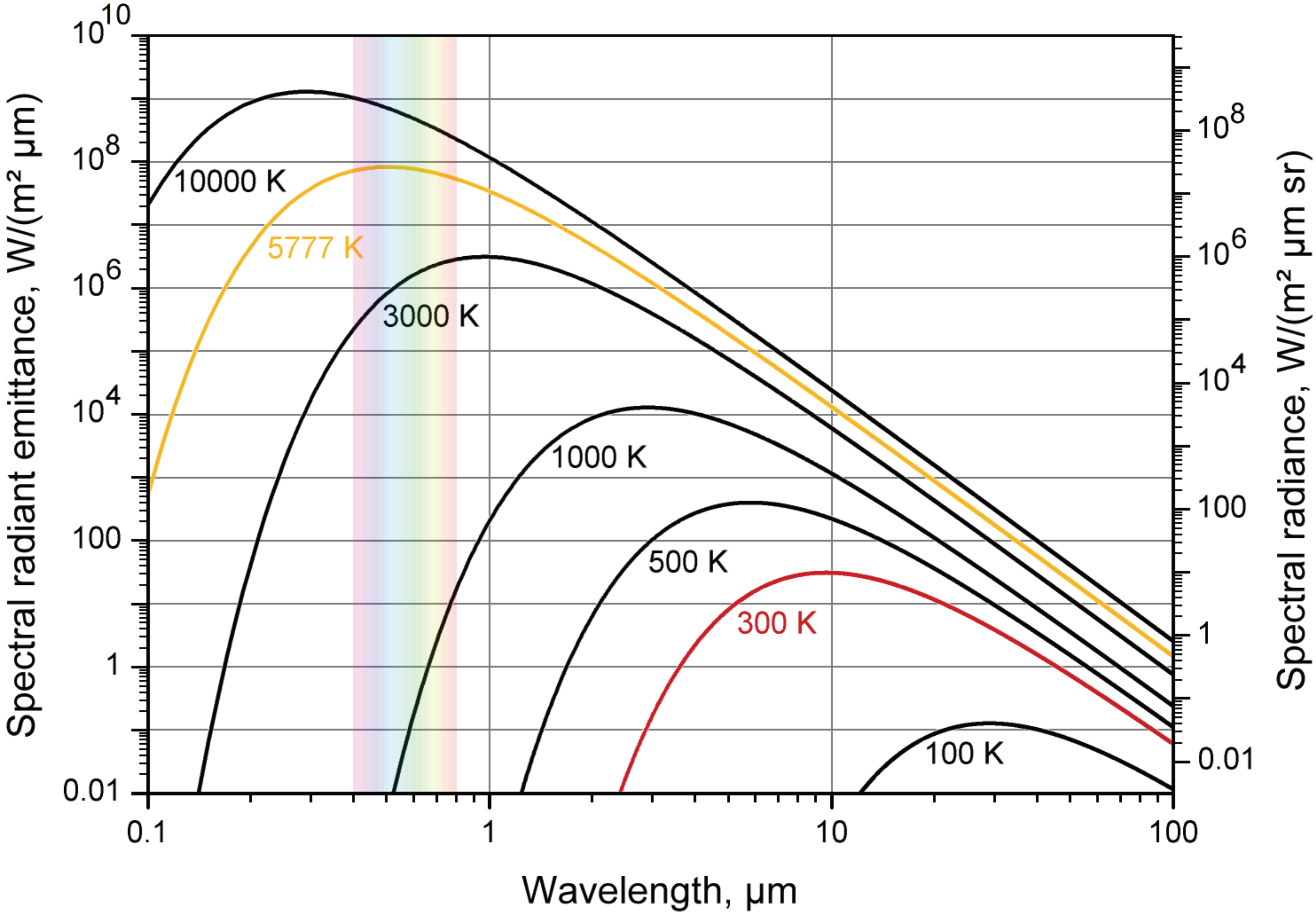
# Atmospheric Windows in the Infrared



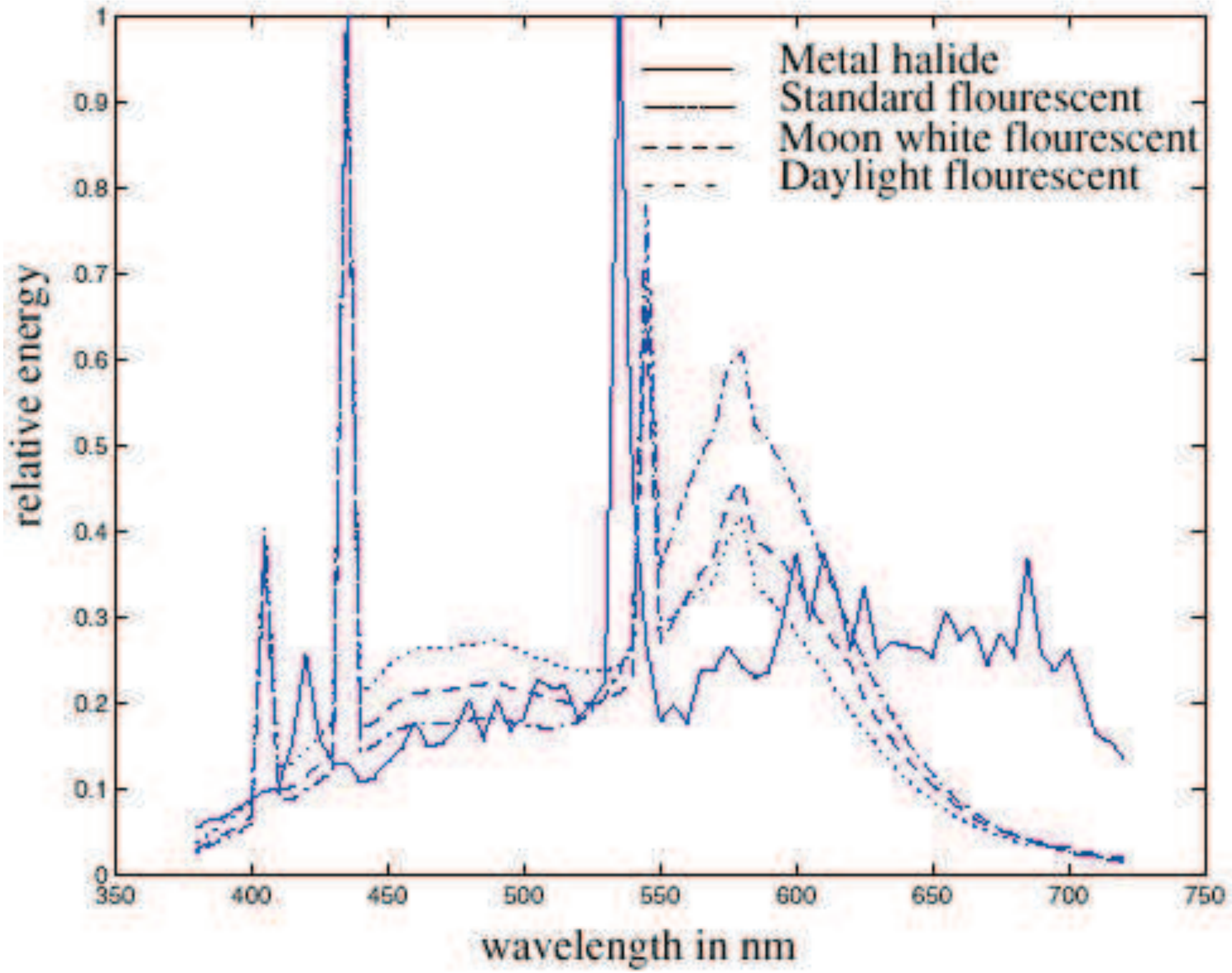
# Incandescent Bulb



# Blackbody Spectrum



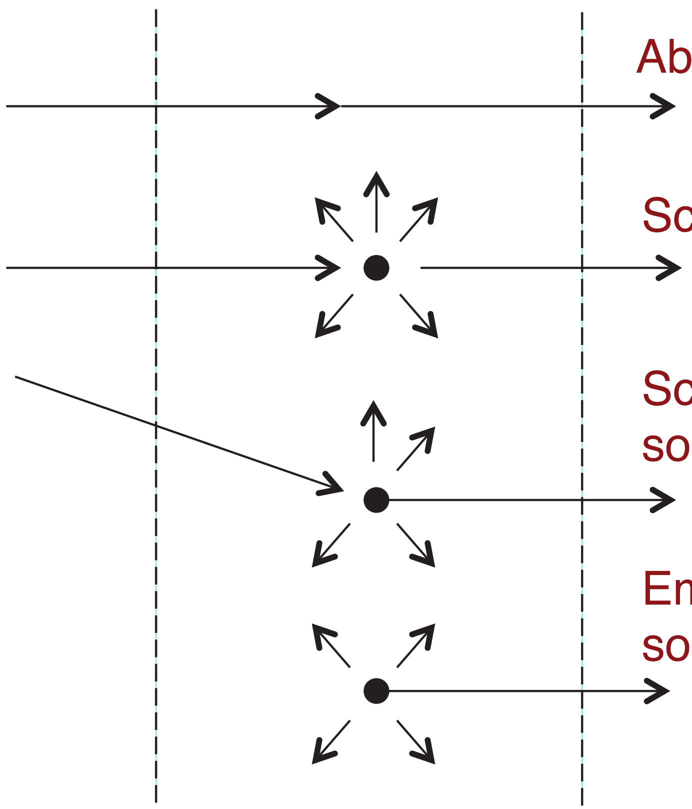
# Metal Halide and Fluorescent Lights




Violet Blue Green Yellow Orange Red

# Atmospheric Propagation

- In general, radiative transfer in the atmosphere has these elements:




Together are "extinction":

$$I(D) = I_0 e^{-\alpha D}, \quad T = e^{-\alpha D}$$

*α* is the *extinction coefficient* (km$^{-1}$)
*T* is the *transmission coefficient*

| | Visible | LWIR | 35 GHz MMW |
|---|---|---|---|
| Haze | 0.02-2 | 0.02-0.4 | 0.001 |
| Dust | 0.2-4 | 0.2-4 | < 0.005 |
| At 0.5 km: | | | |
| $T_H$ | 0.37 | 0.82 | 0.9995 |
| $T_D$ | 0.14 | 0.14 | 0.998 |

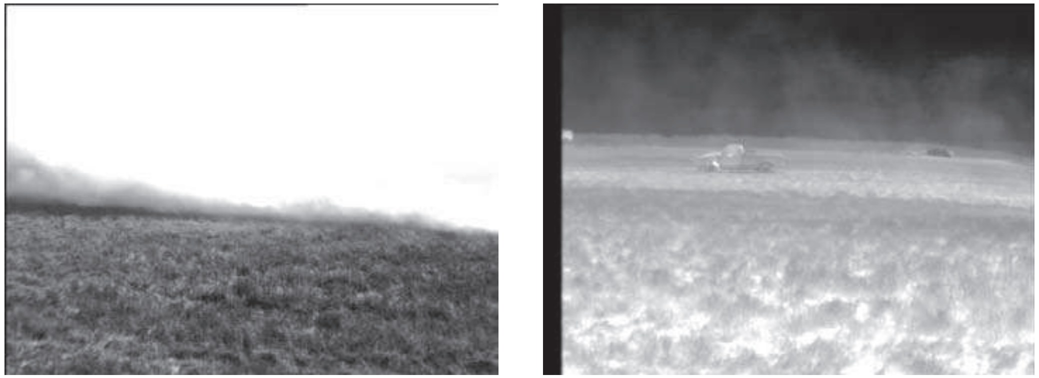
- We won't study details of each

# Some Illustrations


SWIR nightglow image (no moon)

Visible vs. thermal image at night

Visible vs. SWIR in haze



Visible vs. thermal in smoke

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Questions?