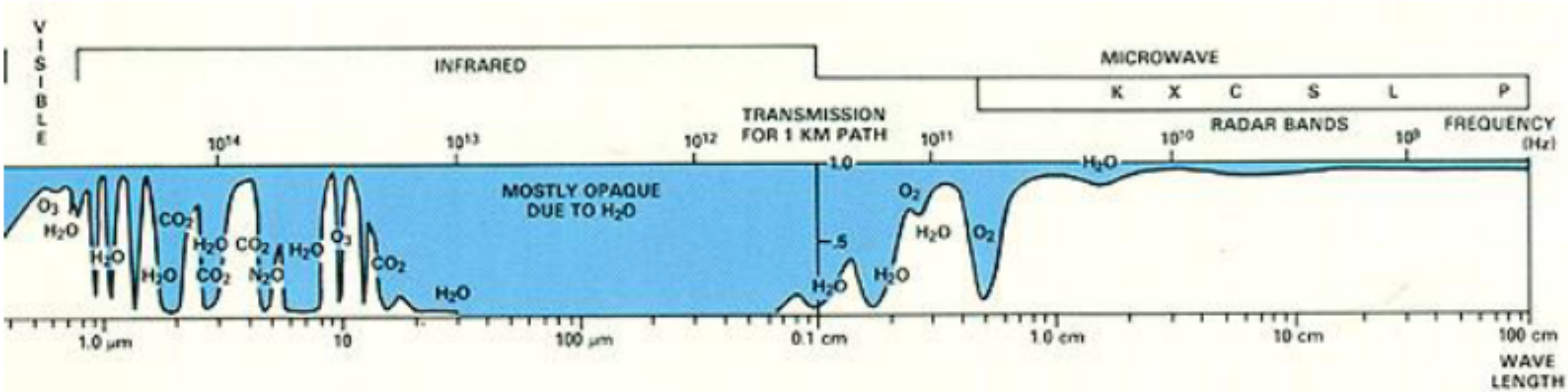
Earth Atmosphere and Remote Sensing Windows



The transparency of the atmosphere varies with wavelength. Terrestrial windows of relative transparency are used for surface remote sensing:

1) Visible-Near IR (0.4 – 3.0 microns)

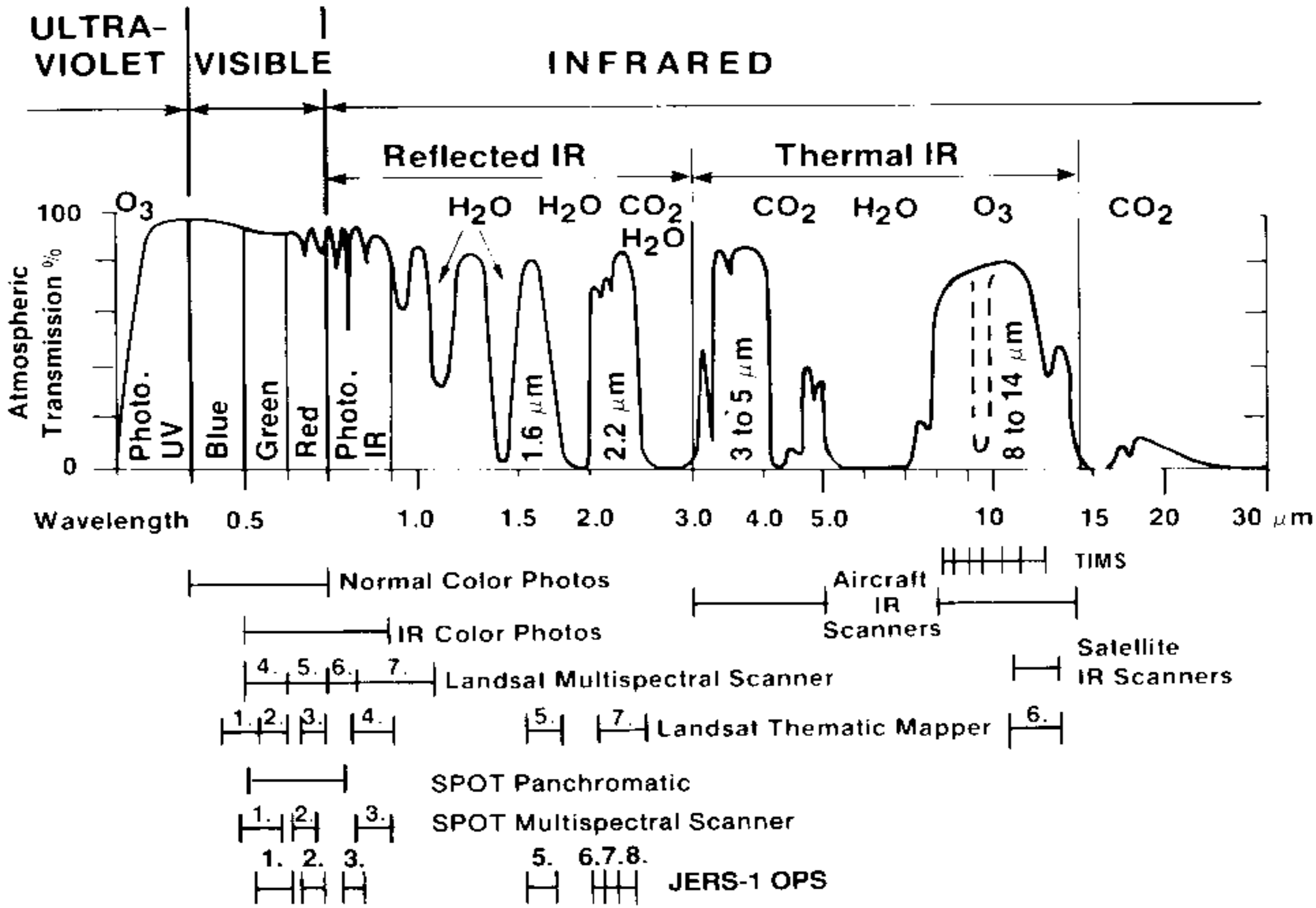
   (VIS, SWIR)

2) Mid/Thermal IR (8 – 15 microns) — Location of this region depends on the surface temperature of the planet

3) Microwave/Radar (1 - 100 centimeters)

Gamma rays, UV, and the Mid-IR are much used on other planetary bodies

Seeing through the atmosphere



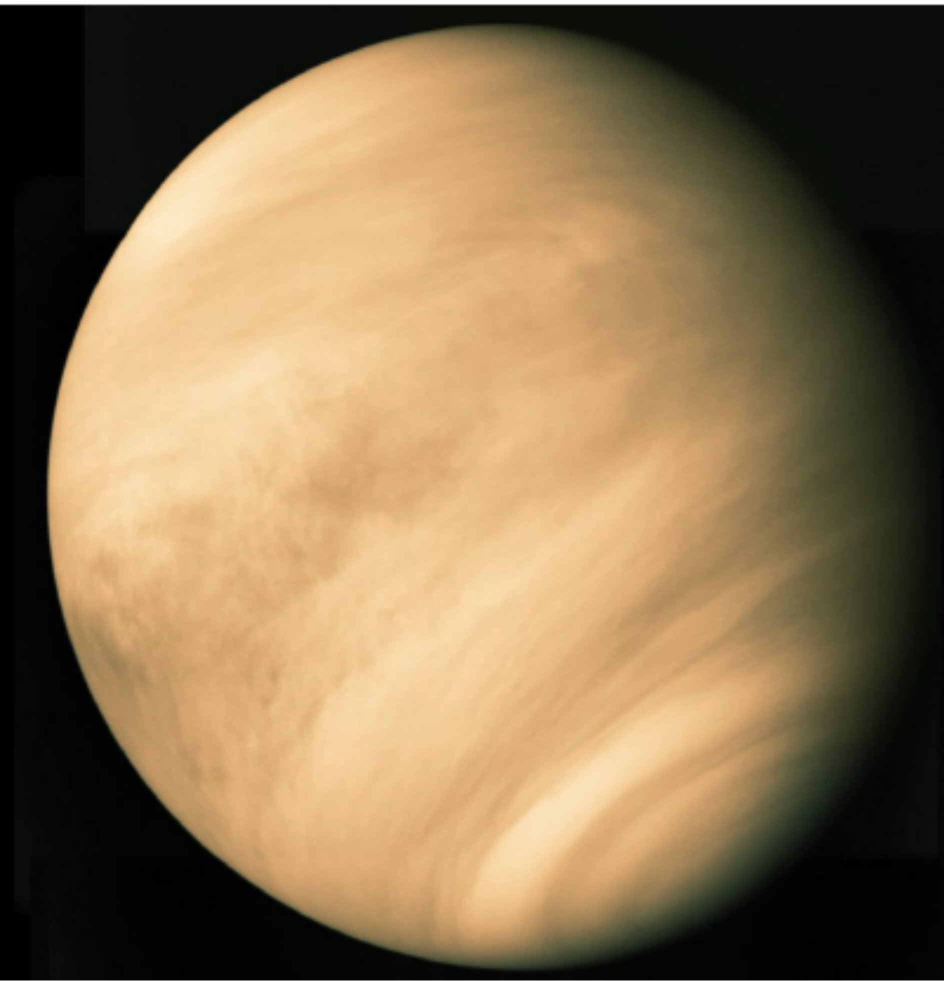
from Sabins, Fig. 1-3

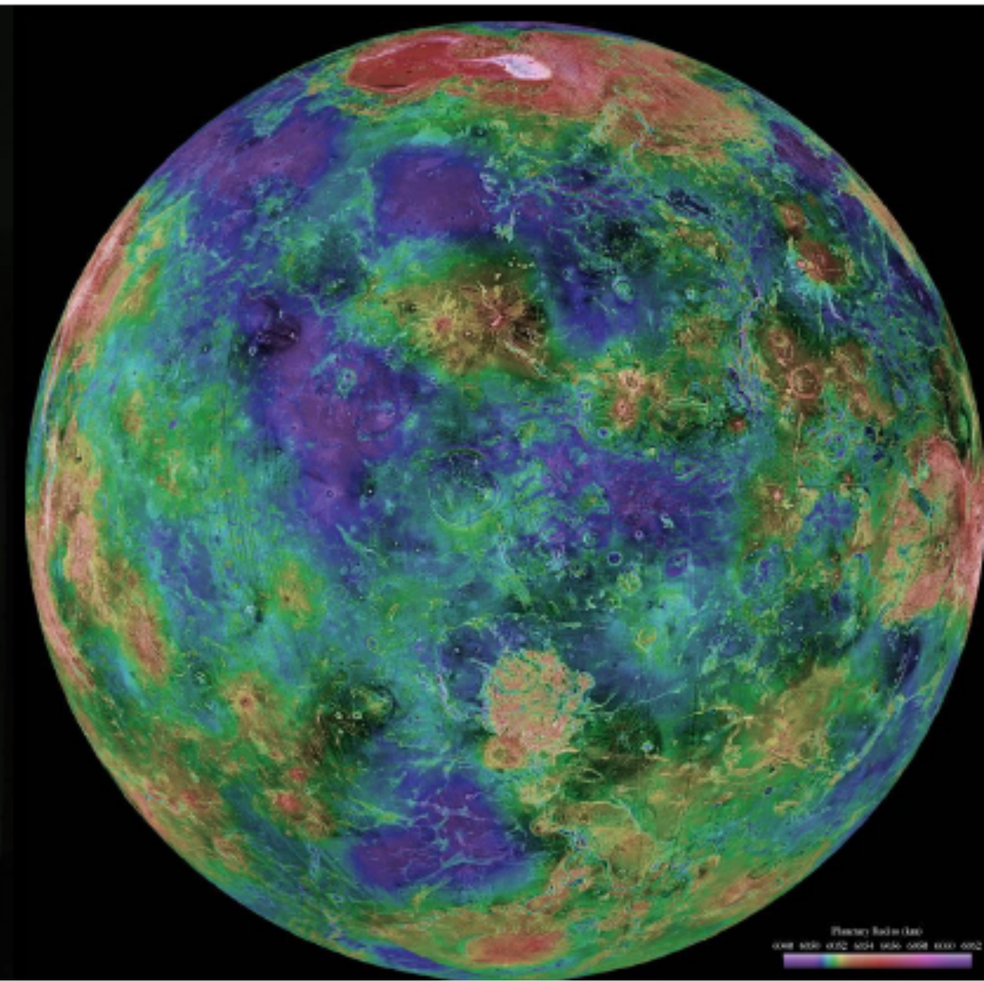
Atm windows are not the same for all planets

Venus

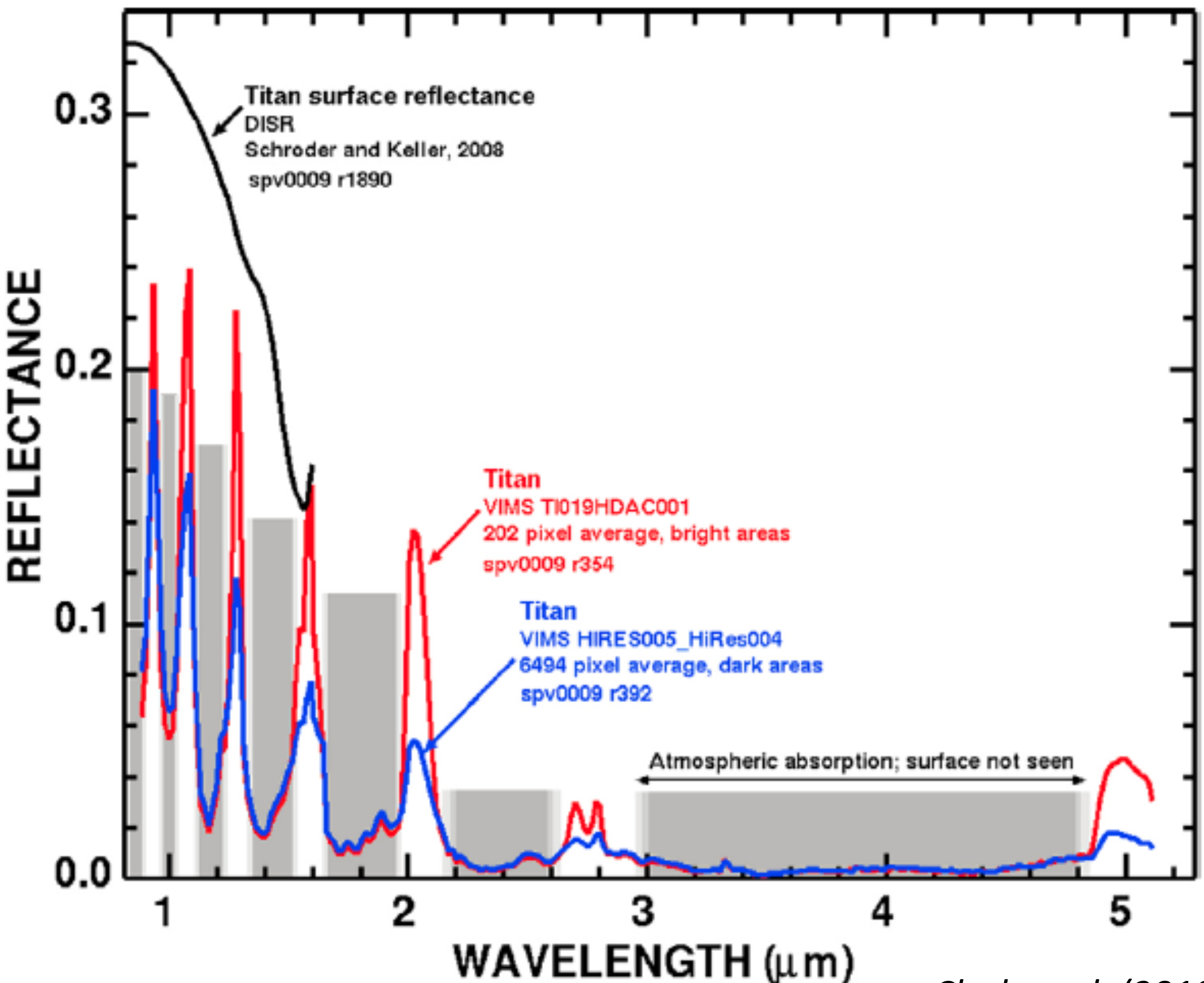
Mariner 10: Visible Near IR cannot penetrate cloud cover

Magellan: Radar allows surface features to be seen





Titan: windows between the CH_4 bands



Clark et al. (2010)

Perfect Emission: The Blackbody

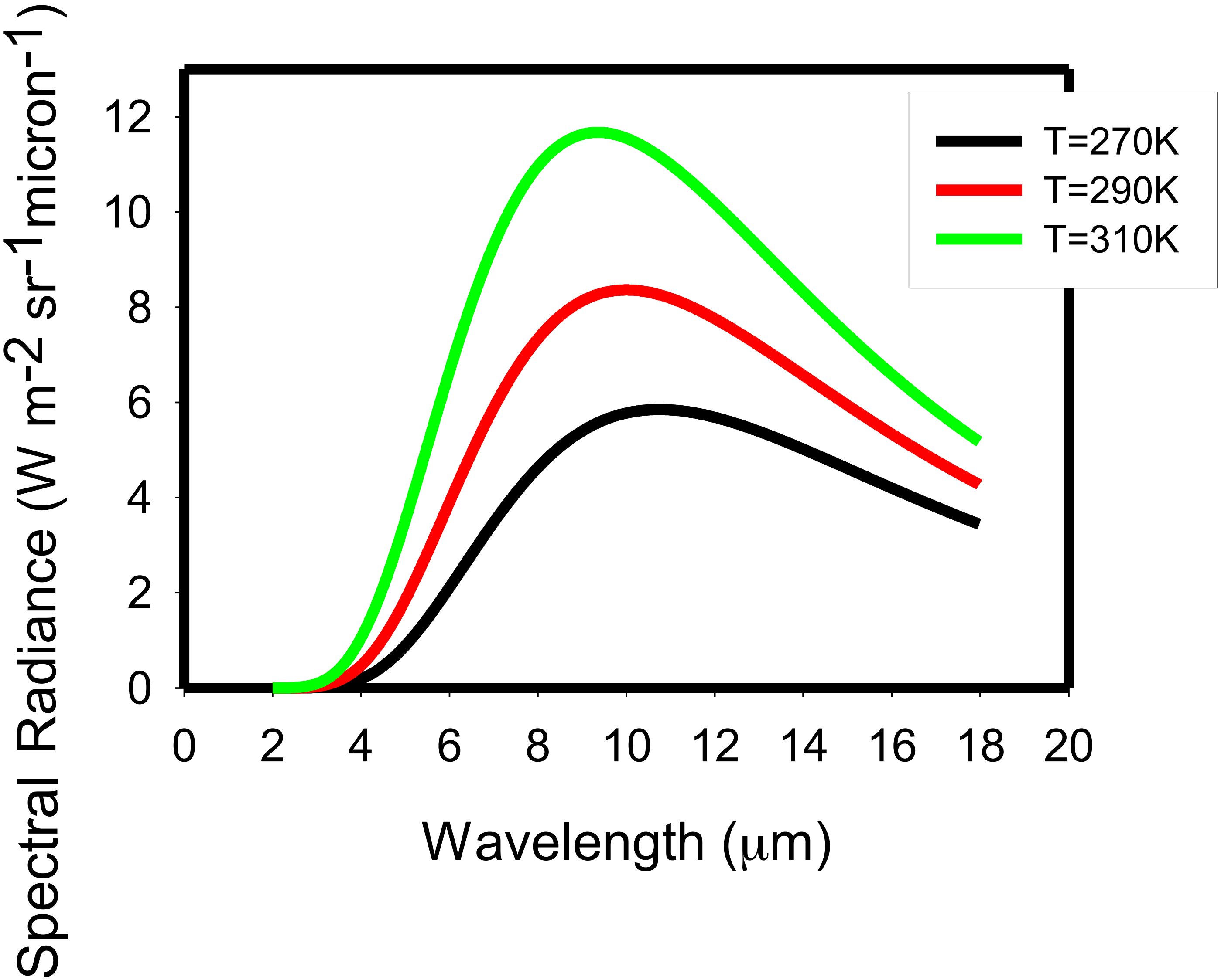
Blackbody: An ideal substance that absorbs all the radiant energy on it and emits radiant energy at the maximum possible rate per unit area for any given temperature.

The power per unit area emitted by a blackbody is given by the Stefan-Boltzmann Law:

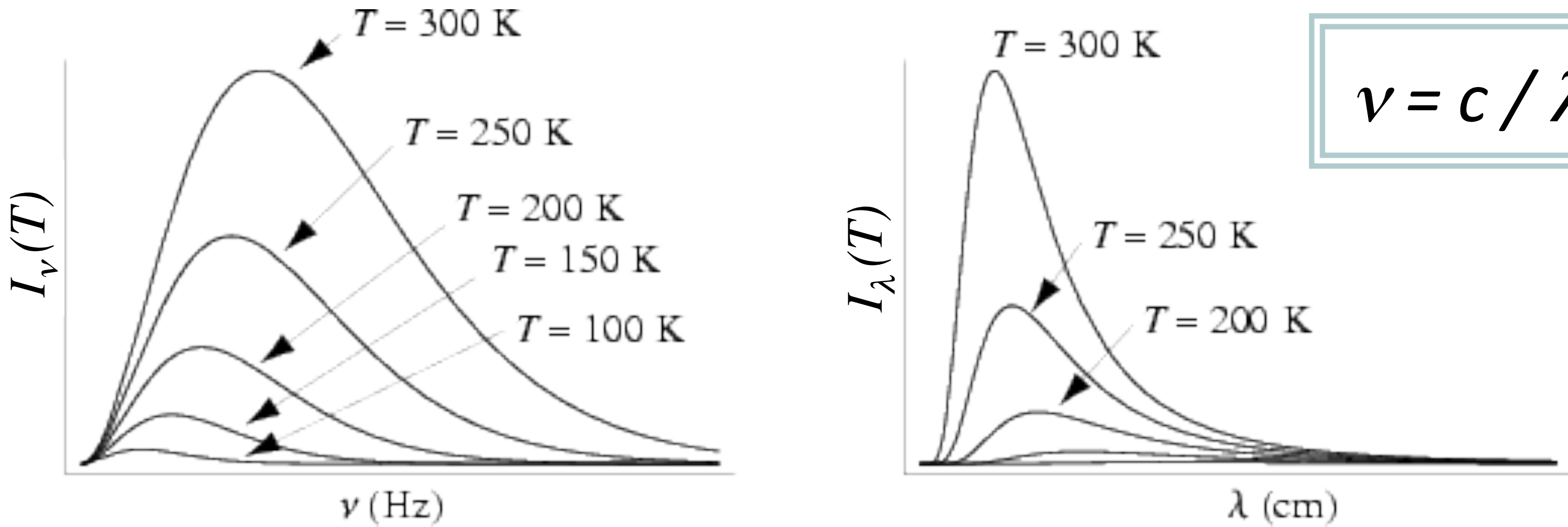
$$F = \sigma T^4$$

where $\sigma = 5.67 \times 10^{-8}\ W/m^2\, K^{-4}$

Blackbody curves



Planck's Law for Black Body Radiation



$$\nu = c / \lambda$$

$$I(\nu, T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

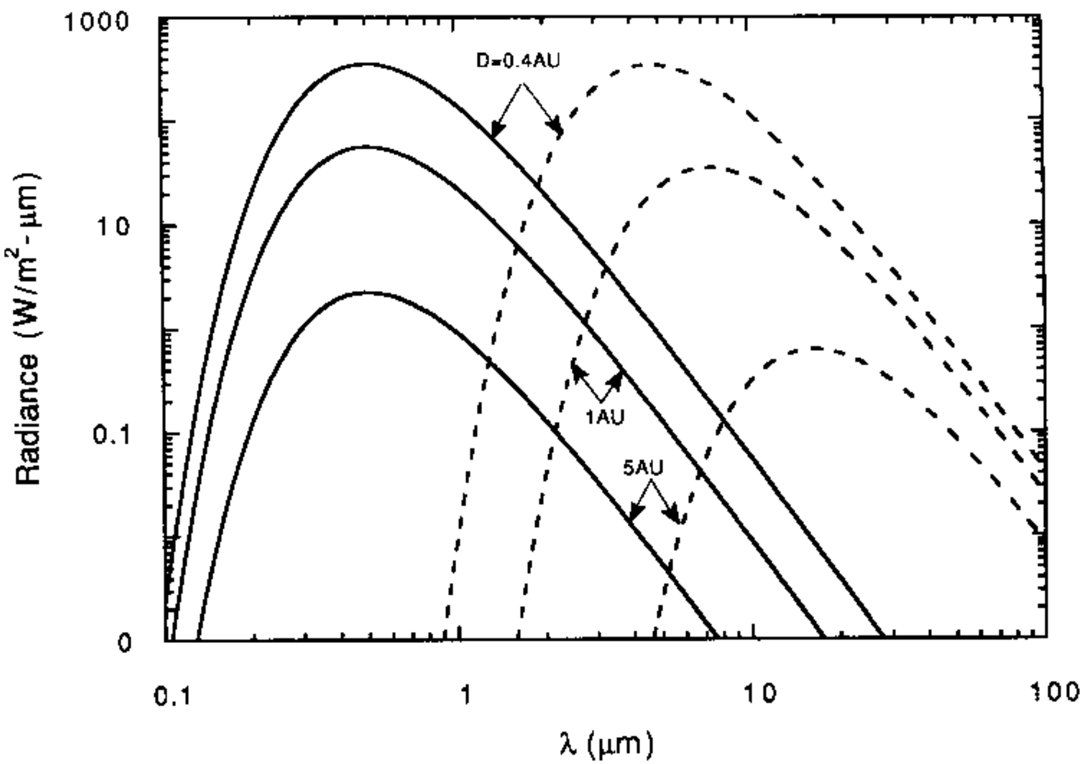
Figure modified from Eric W. Weisstein

Specific Brightness:

$$B_\nu(T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{\frac{h\nu}{kT}} - 1}$$

Solar radiance vs. Emission

Figure 13.1. Comparison of sunlight reflected (solid lines) from a surface with a visual albedo of 0.1 with the radiation thermally emitted (dashed lines) from the surface with an IR emissivity of 1.00, for three different distances from the sun.



from Hapke, 1993

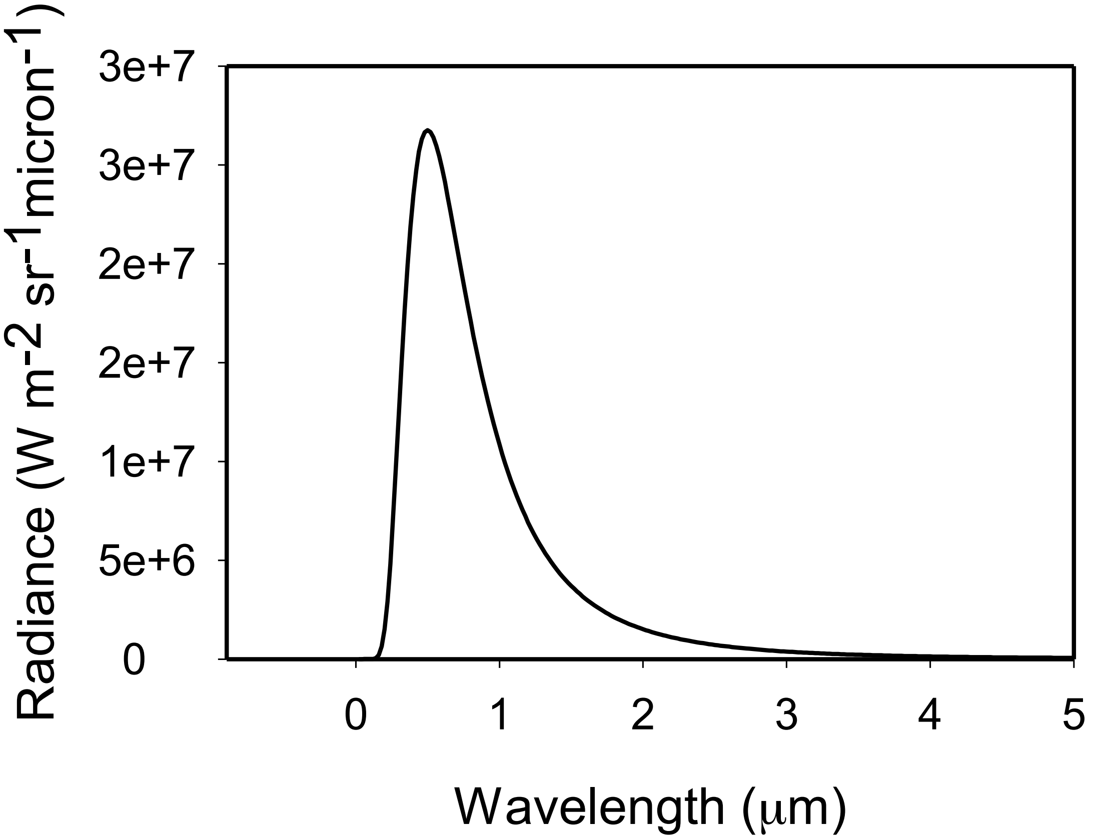
Properties of Blackbody Curves

- They don't cross each other
- The wavelength of the maximum spectral radiance is inversely proportional to temperature – Wien's Law:

For λ measured in microns and T in K:

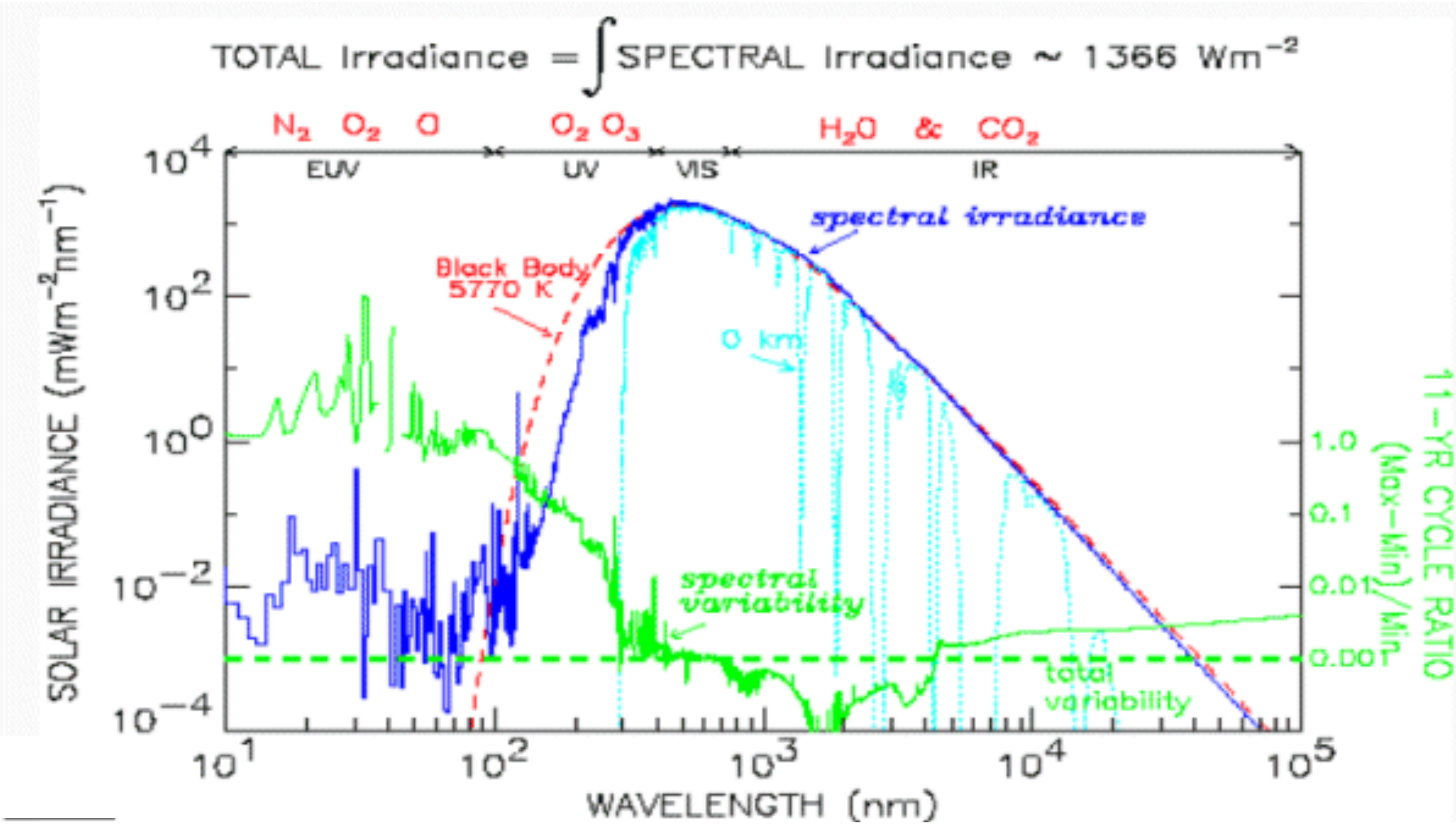
$$\lambda_{max} = 2898/T$$

The Sun's spectrum is approximated as a Blackbody at 5800K

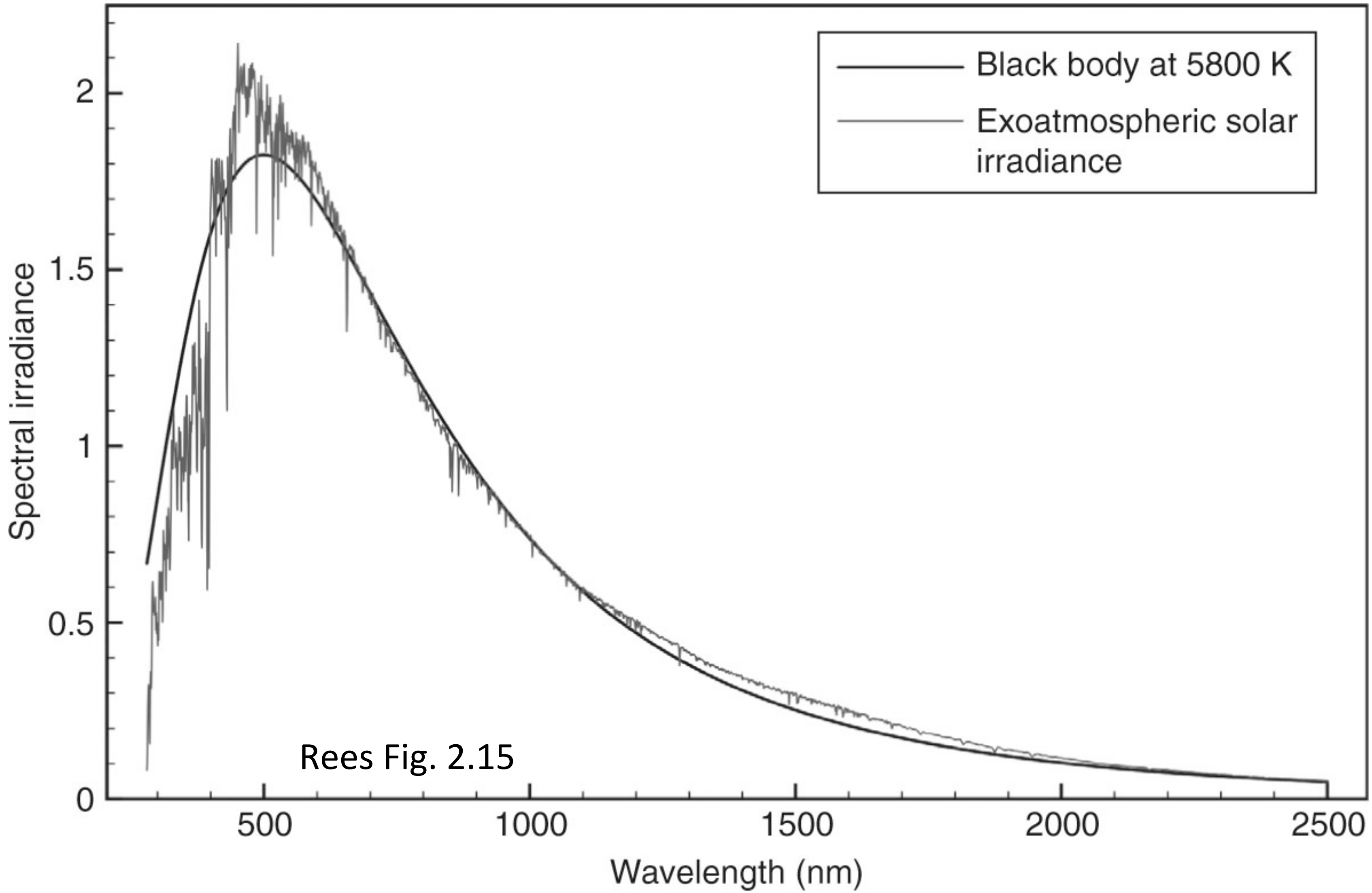


See Java tool at:
http://webphysics.davidson.edu/Applets/Blackbody/BlackBody.html

Solar Spectrum, Variability, and Atmospheric Absorption



A linear plot of the solar spectrum



Rees Fig. 2.15

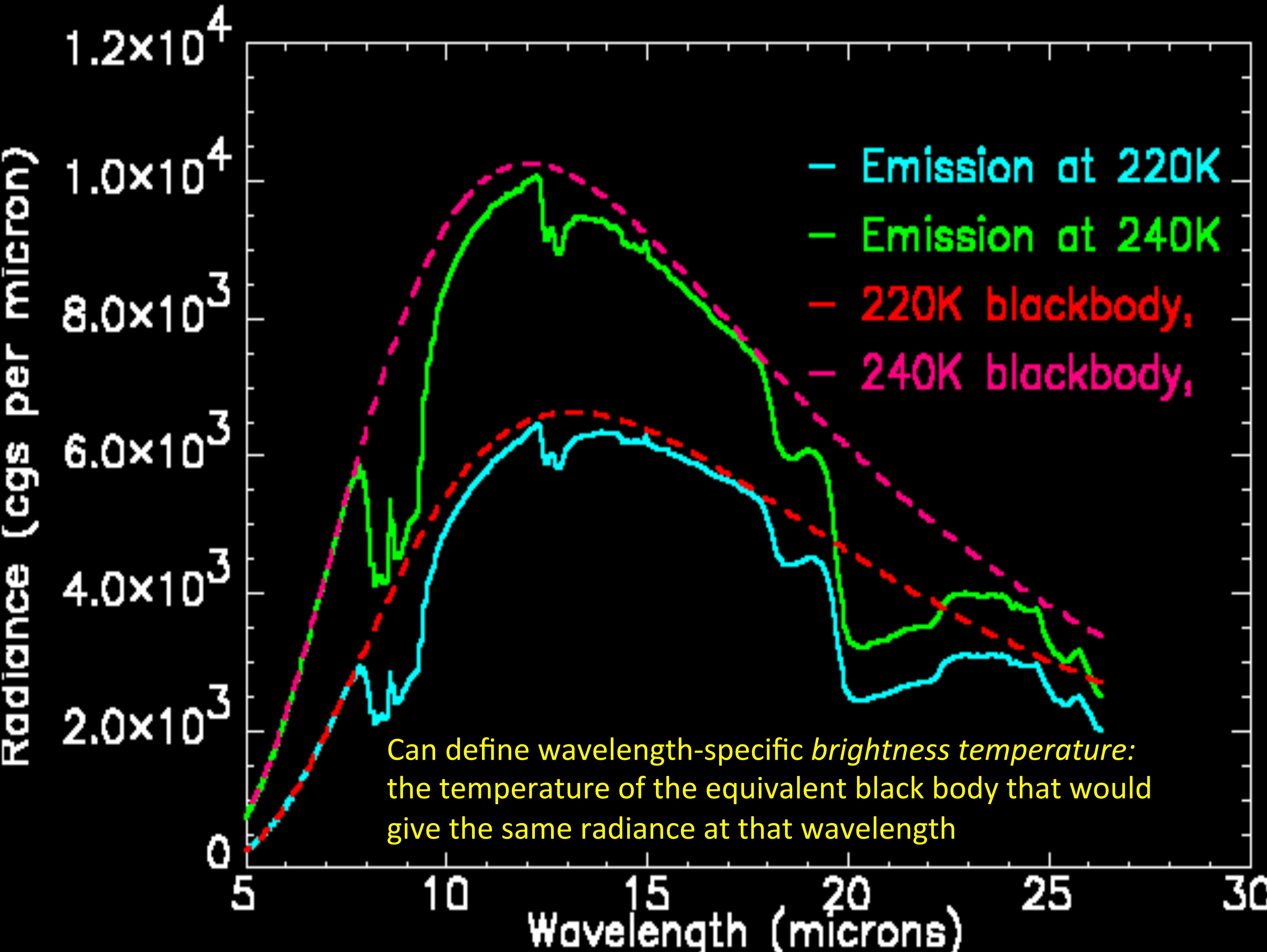
Emission and Reflection

- Most "real" materials do not emit as perfect blackbodies.

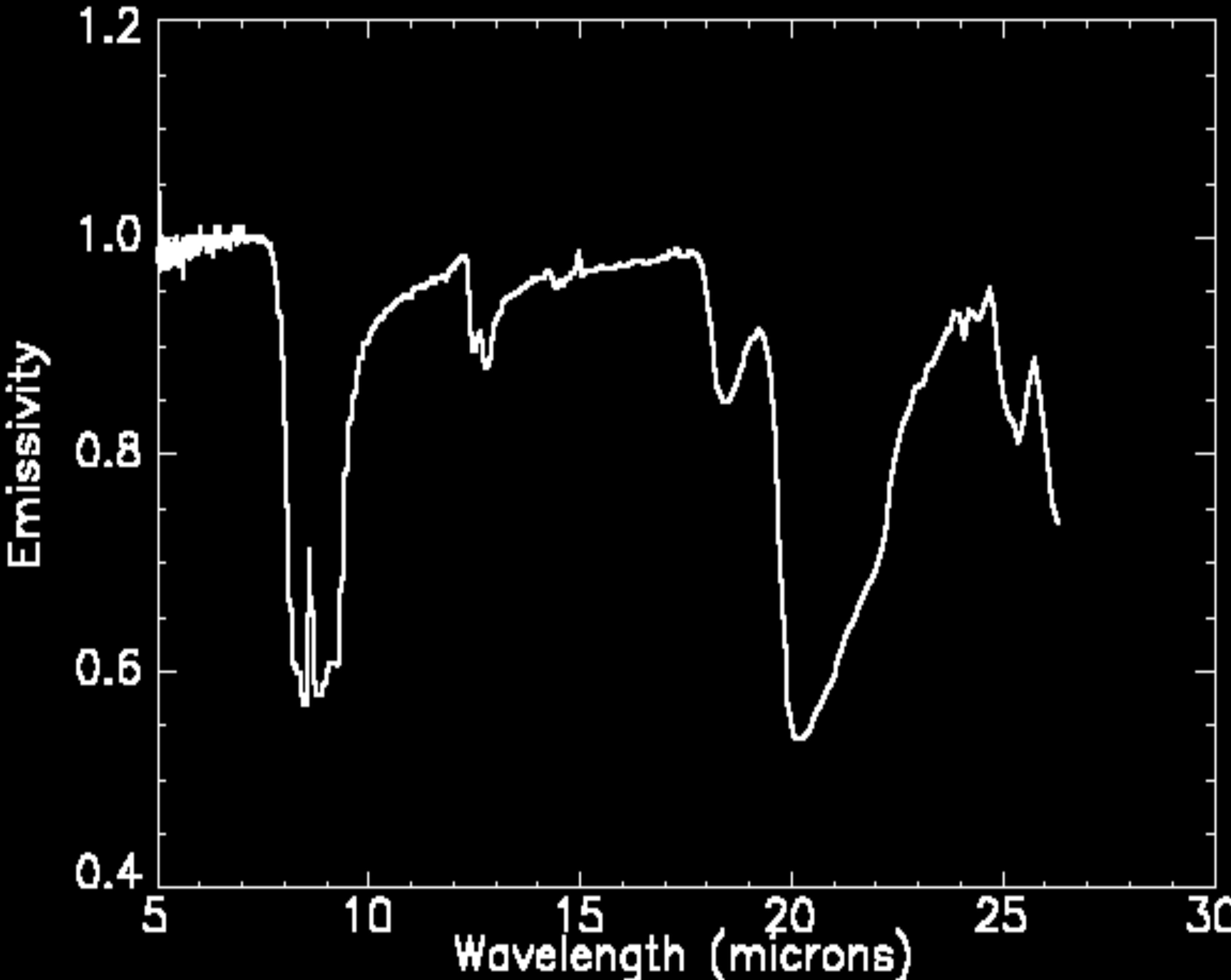
  Emissivity (ε) is the ratio of (radiation actually emitted) to (the radiation of a blackbody at the same temperature). Emissivity varies with wavelength.

$$\varepsilon(\lambda) = L(\lambda, T) \,/\, L_{bb\_emit}(\lambda, T)$$

$$L(\lambda, T) = \varepsilon(\lambda)\, L_{bb\_emit}(\lambda, T)$$



Radiance (cgs per micron)
1.2x10^4
1.0x10^4
8.0x10^3
6.0x10^3
4.0x10^3
2.0x10^3
0
5
10
15
20
25
30
Wavelength (microns)
Emission at 220K
Emission at 240K
220K blackbody,
240K blackbody,
Can define wavelength-specific *brightness temperature:* the temperature of the equivalent black body that would give the same radiance at that wavelength



1.2
1.0
0.8
0.6
0.4
Emissivity
5
10
15
20
25
30
Wavelength (microns)

Emission and Reflection

- Likewise, most materials do not reflect perfectly.

  Reflectance (R) is the ratio of (radiation reflected) to (the incident radiance).

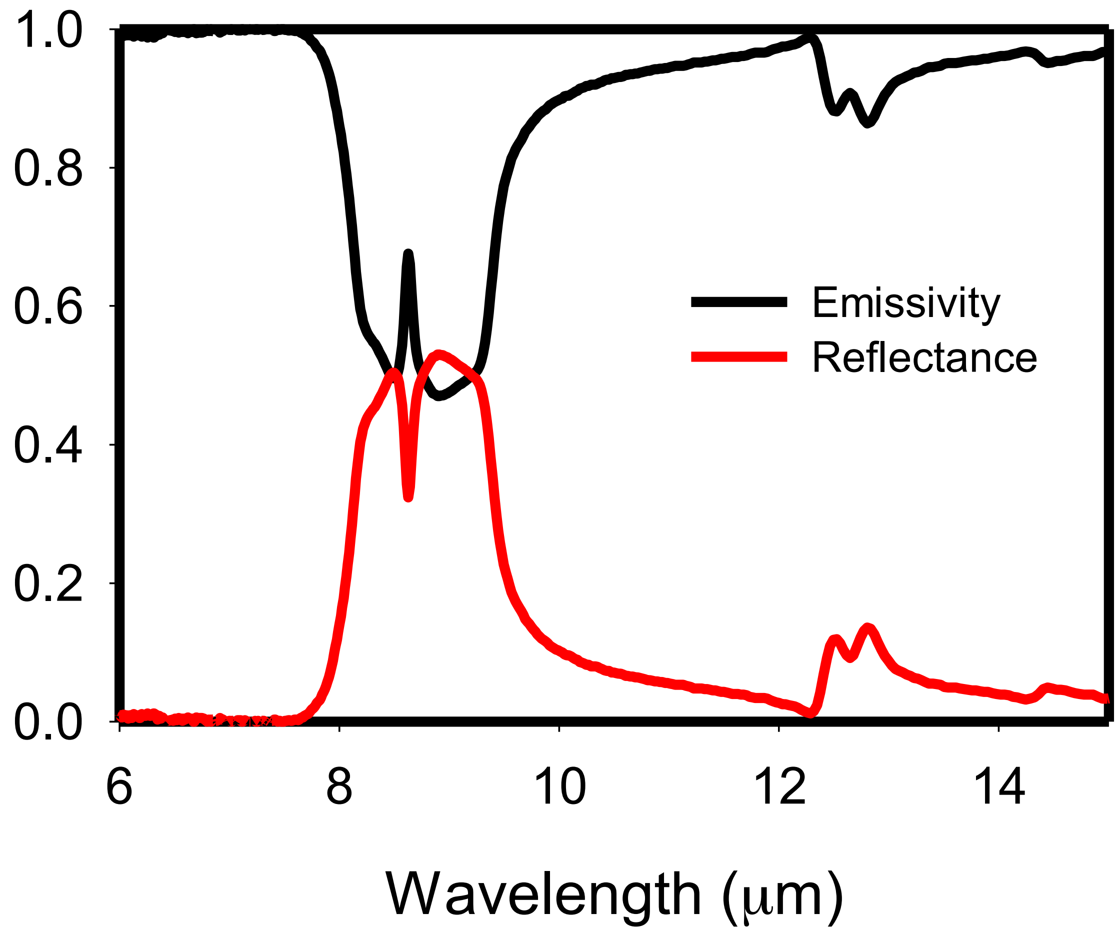
  $$R(\lambda) = L(\lambda, T) \,/\, L_{bb\_incid}(\lambda, T)$$

  $$L(\lambda, T) = R(\lambda)\, L_{bb\_incid}(\lambda, T)$$

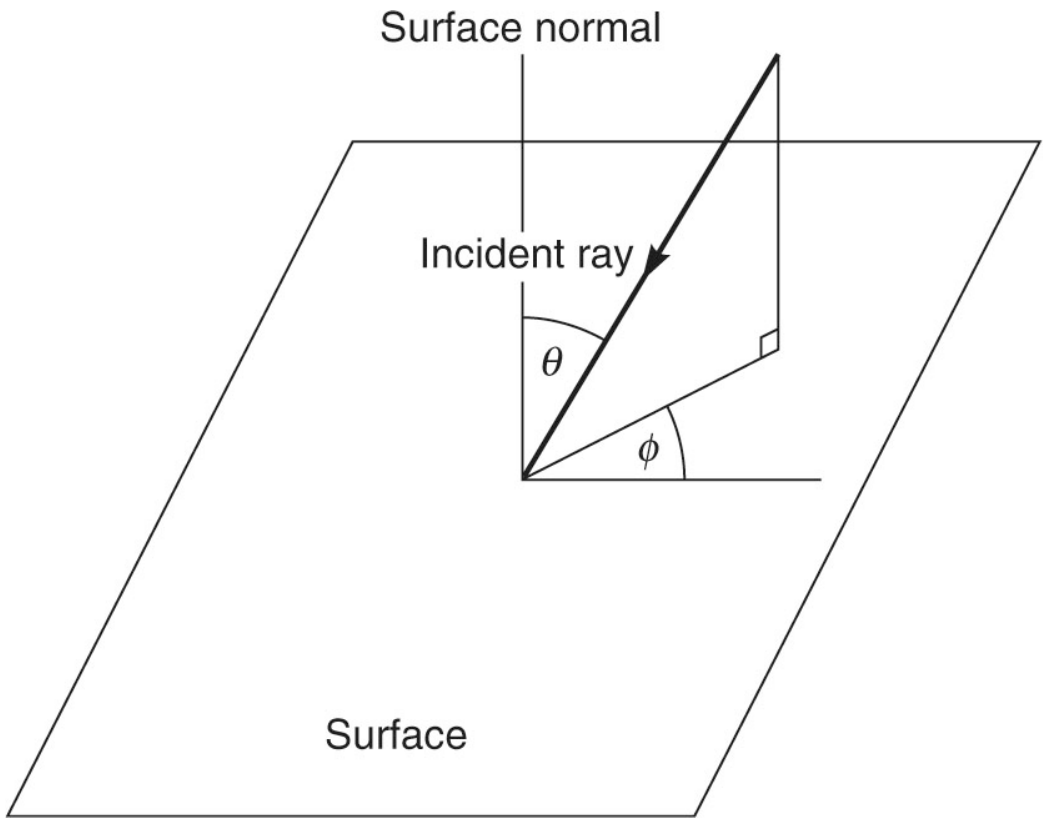
Kirchhoff's Law

$$\varepsilon = 1 - R$$

Empirically verified to high precision



Angular distributions of radiation



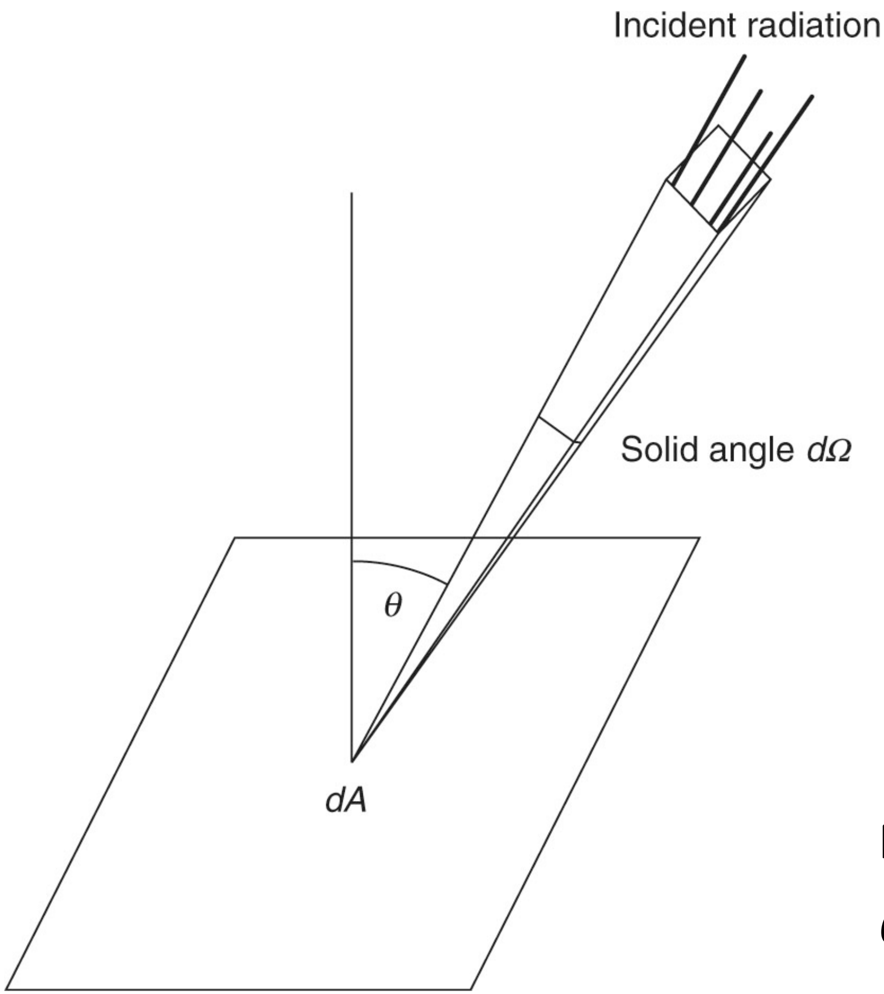
Rees Fig. 2.9

Incidence angle θ, azimuthal angle ϕ

*can also define **emergence angle**,*

*and **phase angle** between incidence and emergence*

Angular distributions of radiation



Rees Fig. 2.10

$d\Omega = \sin\theta d\theta d\phi$

Measured in steradians, of which there are 4π in 360°

Power incident on *dA* from *dΩ*:

$dP = L\cos\theta dA d\Omega$

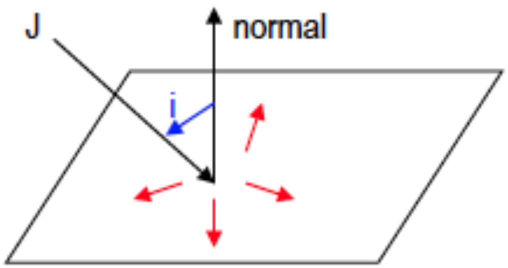
Lambert Albedo

$$J\cos(i)A_L = \pi I$$

Incident irradiance, colliminated beam

Lambert Albedo

I integrated over outgoing hemisphere



A_L is a directional, hemispherical albedo

$$A_L = \pi I/J\cos(i)$$

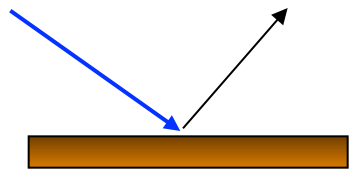
Note that I does not vary with emergence or phase angles only the incidence angle.

Makes it relatively easy to model the surface reflectance and retrieve Lambert Albedos

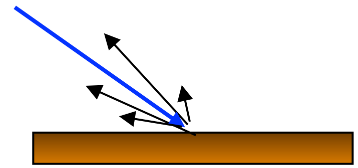
Not a bad assumption for modest values of incidence, emergence, and phase angles

Surfaces may be

- specular

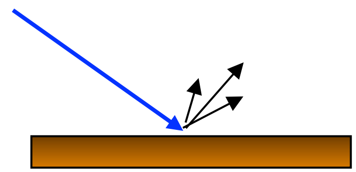


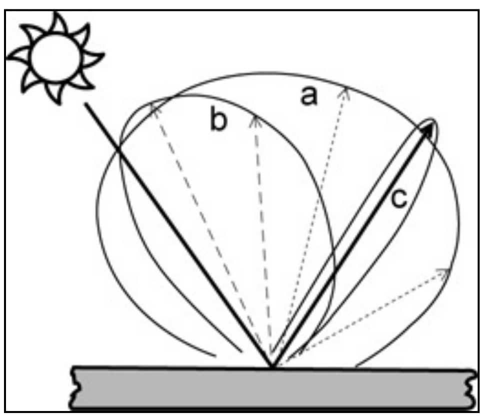
- back-reflecting



- forward-reflecting

- diffuse or Lambertian





Reflection envelopes

Smooth surfaces (rms<<λ) generally are specular or forward-reflecting

examples: water, ice

Rough surfaces (rms>>λ) generally are diffuse

example: sand

Complex surfaces with smooth facets at a variety of orientations are forward- or back-reflecting

example: leaves