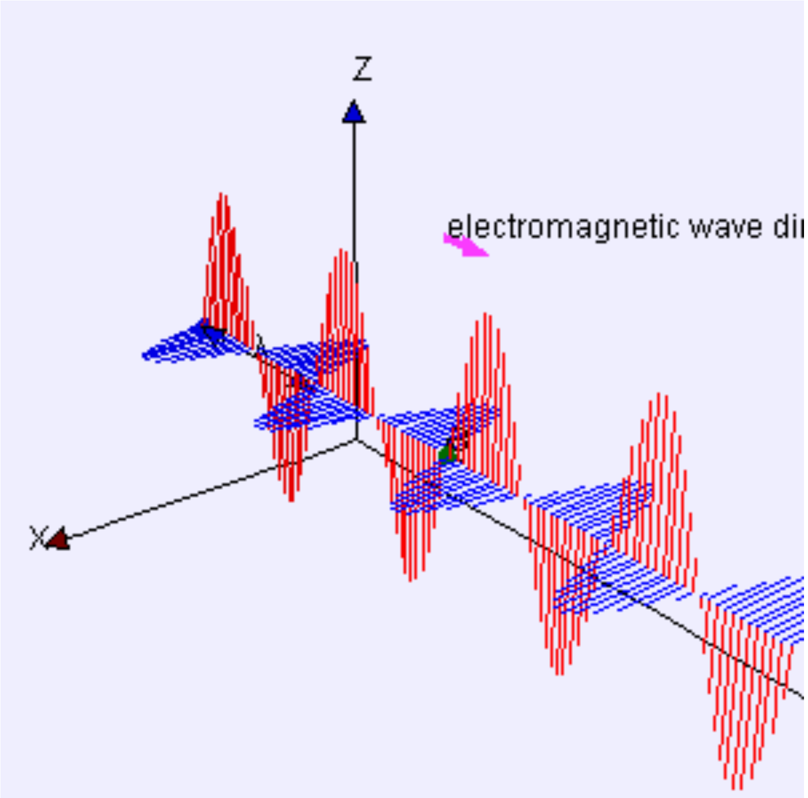
Electromagnetic waves

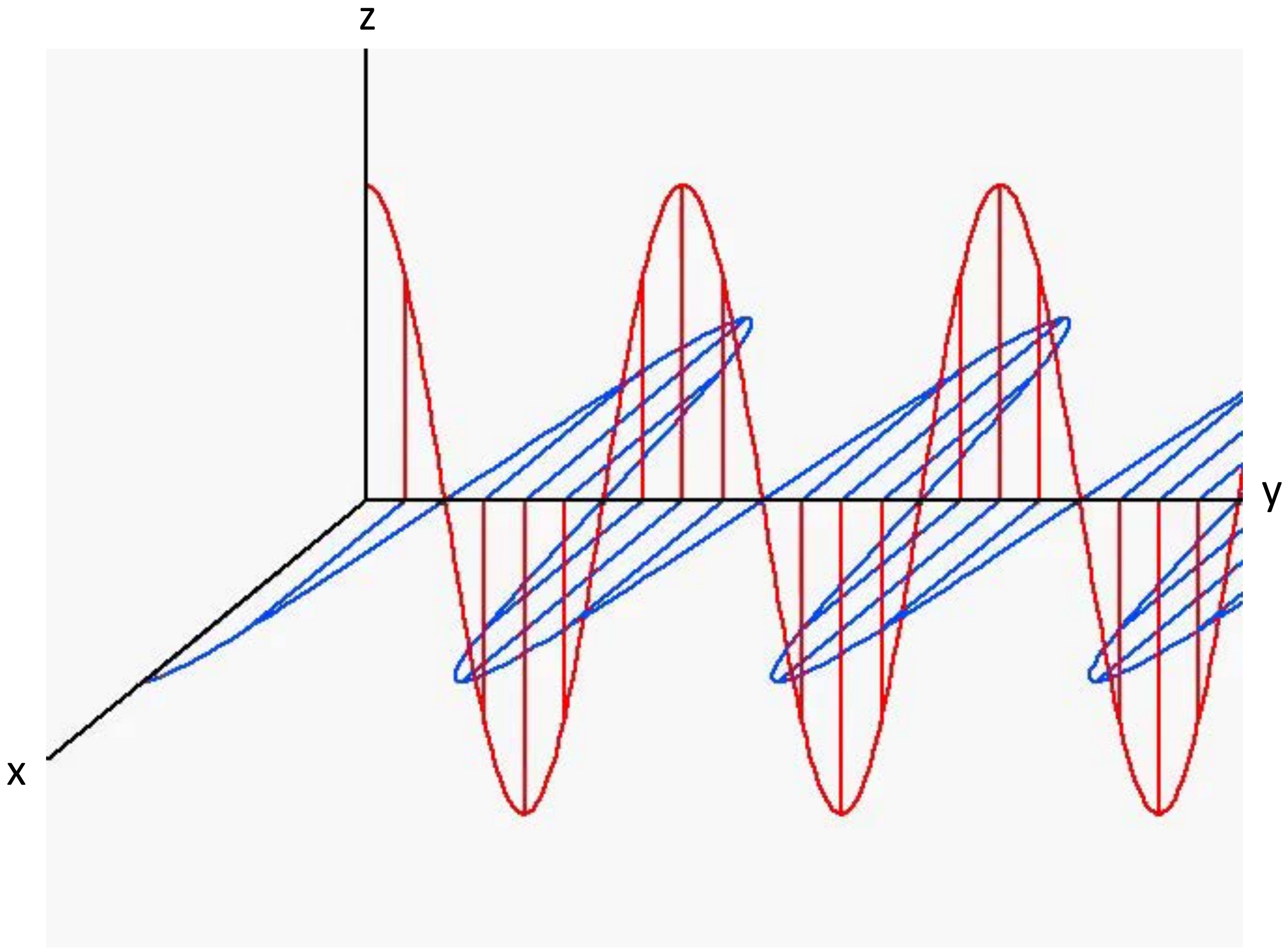


$E_z = E_0\cos(\omega t - ky)$; $E_x = E_y = 0$

$B_x = (E_0/c)\cos(\omega t - ky)$; $B_y = B_z = 0$

$$c = \omega/k = 1/\sqrt{(\varepsilon_0\mu_0)}$$

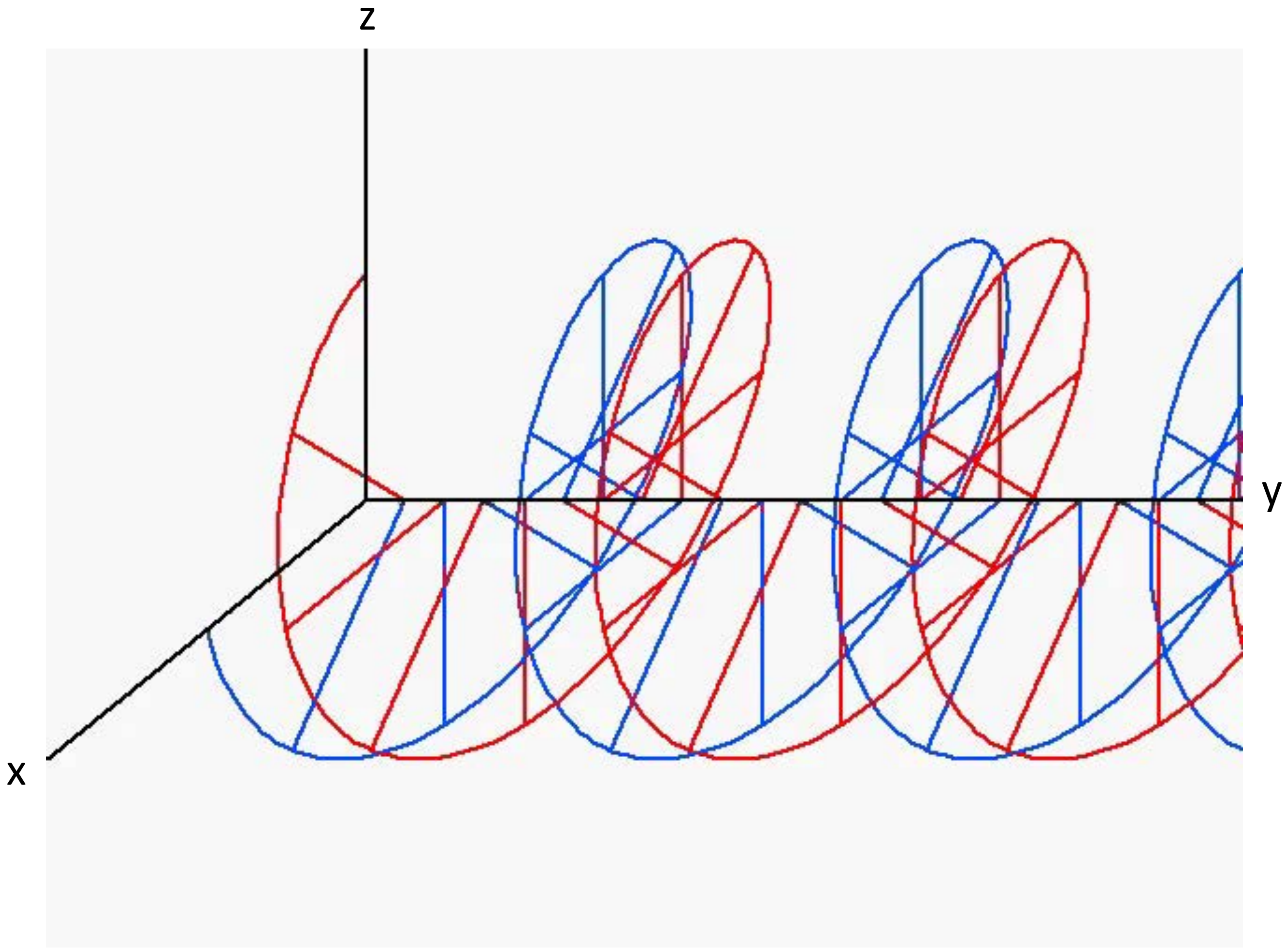
Plane polarized light



$E_z = E_0\cos(\omega t - ky);$ $\qquad E_x = E_y = 0$

$B_x = (E_0/c)\cos(\omega t - ky);$ $\qquad B_y = B_z = 0$

Circularly polarized light



$E_x = E_0\cos(\omega t - ky + \pi/2)$; $E_z = E_0\cos(\omega t - ky)$; $E_y = 0$

$B_x = (E_0/c)\cos(\omega t - ky)$; $B_z = (E_0/c)\cos(\omega t - ky - \pi/2)$; $B_y = 0$

In general (e.g., random polarization)

$E_x = E_{0x}\cos(\omega t - ky + \Delta\phi)$; $E_z = E_{0z}\cos(\omega t - ky)$; $E_y = 0$

Note two different amplitudes E_{0x}, E_{0z}

B-field always oriented 90° "rightward" of E-field

Characterize time-averaged polarization using Stokes parameters:

$I = \langle E_{0x}{}^2\rangle + \langle E_{0z}{}^2\rangle$ $= 2\sqrt{(\mu_0/\varepsilon_0)}$ * flux density

$Q = \langle E_{0x}{}^2\rangle - \langle E_{0z}{}^2\rangle$ — linear x,z polarization

$U = \langle 2E_{0x}E_{0z}\cos(\Delta\phi)\rangle$ — linear polarization 45° from x,z

$V = \langle 2E_{0x}E_{0z}\sin(\Delta\phi)\rangle$ — circular polarization

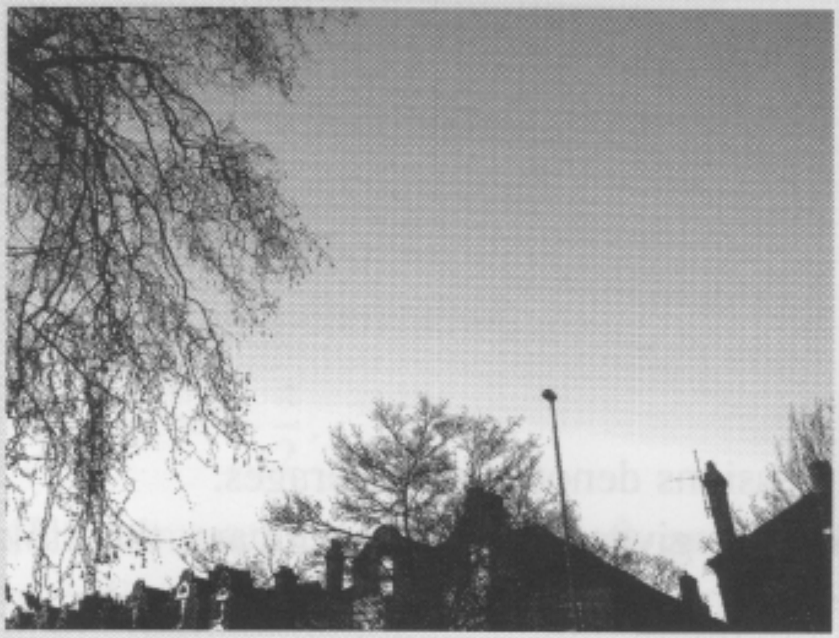
Matters because: *1) detector may be polarization-specific*

2) polarization carries information!

How strongly polarised is natural light?

Light from the Sun is randomly polarised, so its degree of polarisation is 0. However, light that has been scattered by molecules in the atmosphere (i.e. what we see as blue sky, as discussed in Chapter 4) is generally polarised. The degree of polarisation depends on the direction relative to the Sun, and is greatest when the line of sight to the sky is perpendicular to the line of sight to the Sun, in which case the skylight is approximately 75% linearly polarised if the air is clean. This can be verified, at least qualitatively, using a polarising filter such as the lens of a pair of polarising sunglasses.

The photographs show the sky viewed perpendicular to the direction of the Sun, close to sunset. The photographs were taken using a polarising filter: the photograph on the left shows the vertically polarised component and the photograph on the right the horizontally polarised component.



Some Physical Units Associated with Remote Sensing

- *Power*:

  Energy per unit time, measured in Watts (=Joules/second)

- *Radiant Flux Density* (also ‘Irradiance’ or ‘Exitance’ depending on use):

  Power per unit area, measured in Watts / meter^2

- *Radiance*:

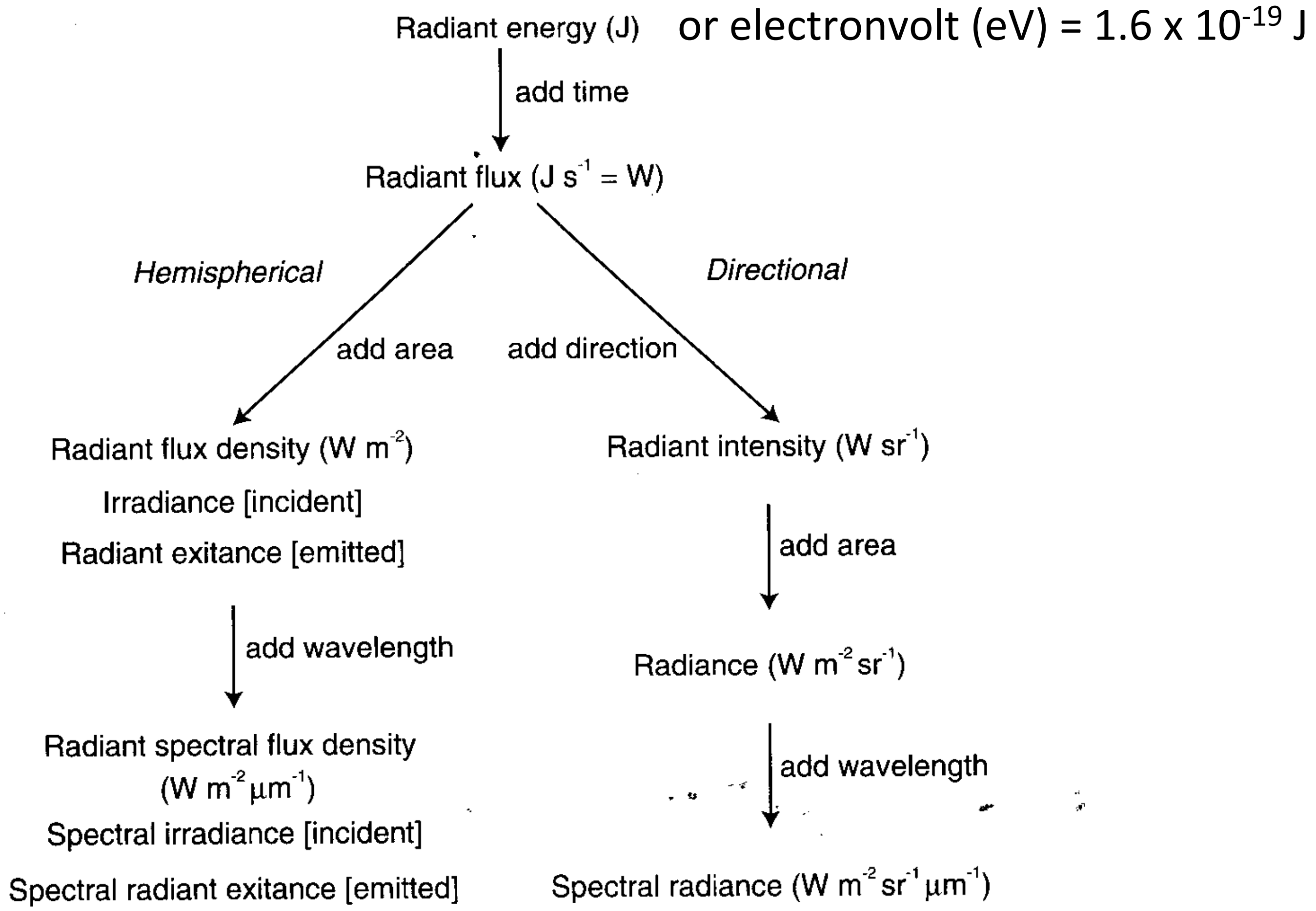
  Amount of radiation intercepted by a detector, measured in Watts / (meter^2 steradian)

- *Spectral Radiance*:

  Amount of radiance in a small wavelength interval, usually measured in Watts / (meter^2 steradian micron)

Flux density, radiance, etc.

730 **APPENDIX A** RADIOMETRIC CONCEPTS, TERMINOLOGY, AND UNITS



Radiant energy (J) or electronvolt (eV) = 1.6 x 10^{-19} J

add time

Radiant flux (J s^{-1} = W)

Hemispherical

add area

Radiant flux density (W m^{-2})

Irradiance [incident]

Radiant exitance [emitted]

add wavelength

Radiant spectral flux density (W m^{-2} μm^{-1})

Spectral irradiance [incident]

Spectral radiant exitance [emitted]

Directional

add direction

Radiant intensity (W sr^{-1})

add area

Radiance (W m^{-2} sr^{-1})

add wavelength

Spectral radiance (W m^{-2} sr^{-1} μm^{-1})

Figure A.4 Relationship among the various terms used in hemispherical and directional radiation measurement. (Adapted from Campbell and Norman, 1997; see Chapter 1 Works Cited herein.)

From Remote Sensing and Image Interpretation, 6th Ed., by Lillesand, Kiefer, & Chipman

Energy of a photon (Planck's Law)

$$\mathbf{E = h\nu = h\omega/2\pi}$$

or

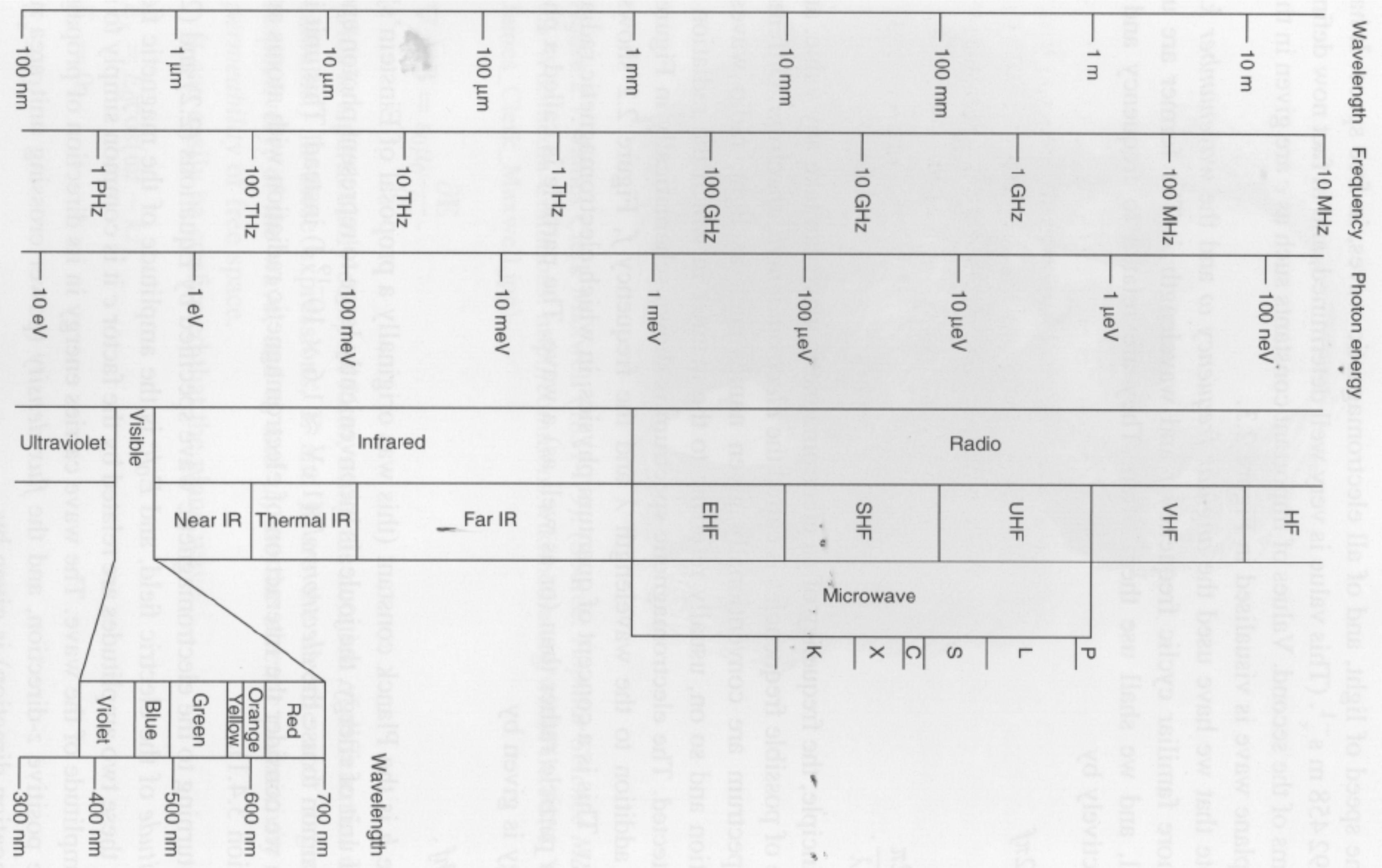
$$\mathbf{E = hc/\lambda = hck/2\pi}$$

where h = 6.626×10^{-34} J s

c = 2.998×10^{8} m s^{-1}

- Long wavelengths have lower energy photons, short wavelengths have higher energy photons.

Electromagnetic spectrum (from Rees)



Wavelength Conversion Factors

- 1 Å = 10^{-10} m
- 1 nm = 10^{-9} m
- 1 μm = 10^{-6} m
- 1 cm = 10^{-2} m

- Also, to convert between microns and wavenumbers:

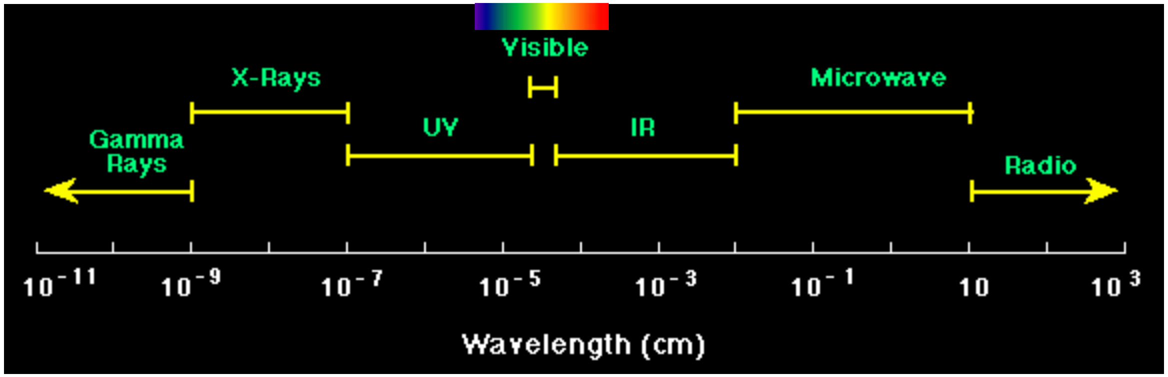
  wavelength(μm) = 10000/wavenumber (cm^{-1})

Spectral Regions

- Gamma Ray: $\lambda < 10$ Å
- X-Ray: 10 Å < λ <100 Å
- Ultraviolet: 100 Å < λ <4000 Å
- Visible: 400 nm< λ <670 nm
- Near-infrared: 0.67 μm < λ < 3.0 μm. Alternatively:
  - NIR: 0.67 μm < λ < 1.0 μm
  - SWIR: 1.0 μm < λ < 3.0 μm
- Thermal Infrared: 3 μm < λ < 50 μm
- Microwaves, radar, radio: 1 mm < λ

The electromagnetic spectrum

Short λ
High energy
High frequency



Long λ
Low energy
Low frequency

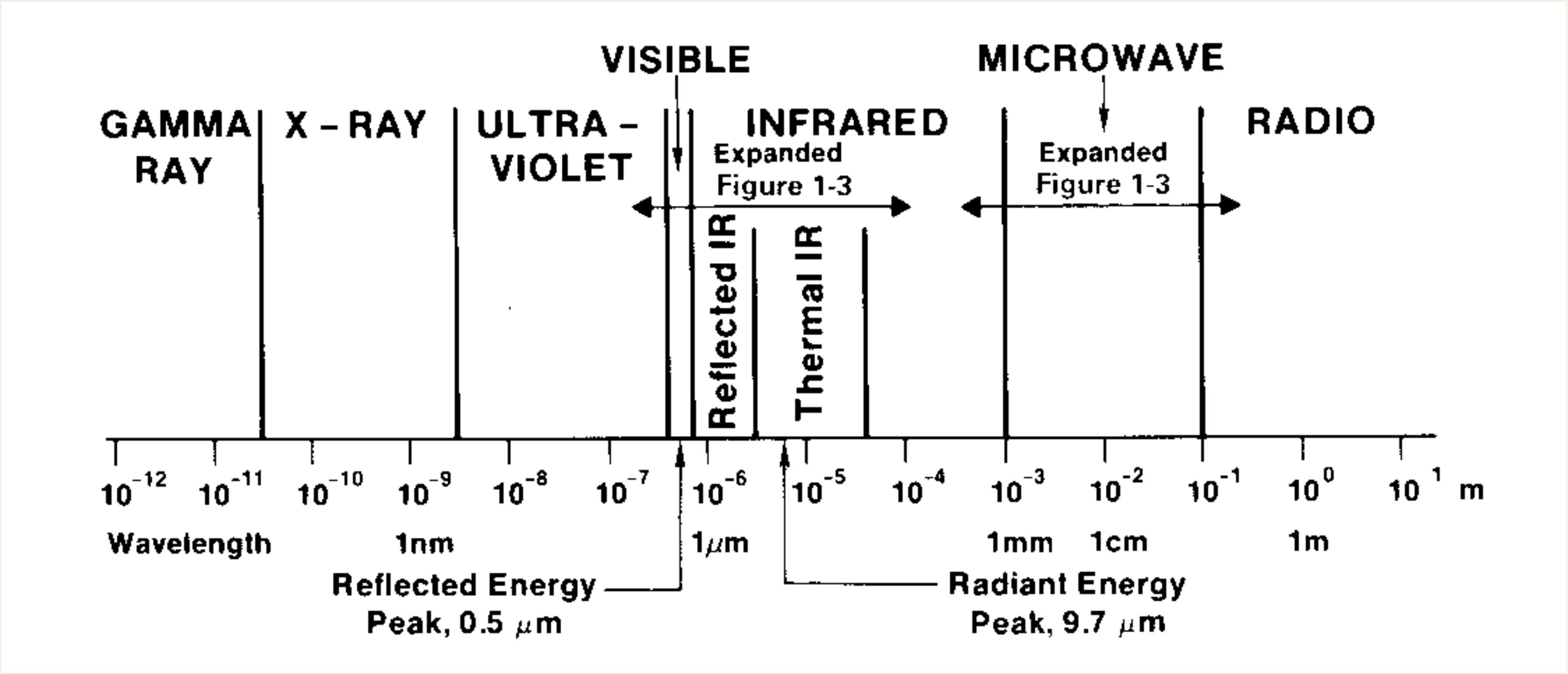
In the spectrum, energy is dispersed by a grating or prism according to frequency or wavelength

Gamma rays		$<10^{-4}$ µm
X rays		10^{-4} - 10^{-2} µm
Ultraviolet		0.01-0.45 µm
Visible blue	B	0.47-0.48 µm
Visible green	G	0.51-0.56 µm
Visible red	R	0.63-0.68 µm
Near infrared	NIR	0.67-1.4 µm
Shortwave infrared	SWIR	1.4-2.5 µm
Mid-wave infrared	MIR	3.5-5.5 µm
Longwave thermal infrared	LWIR	8-14 µm
Microwave	(Radar)	0.1mm-1 m
Radio		1 m - 10 km

Reflected sunlight

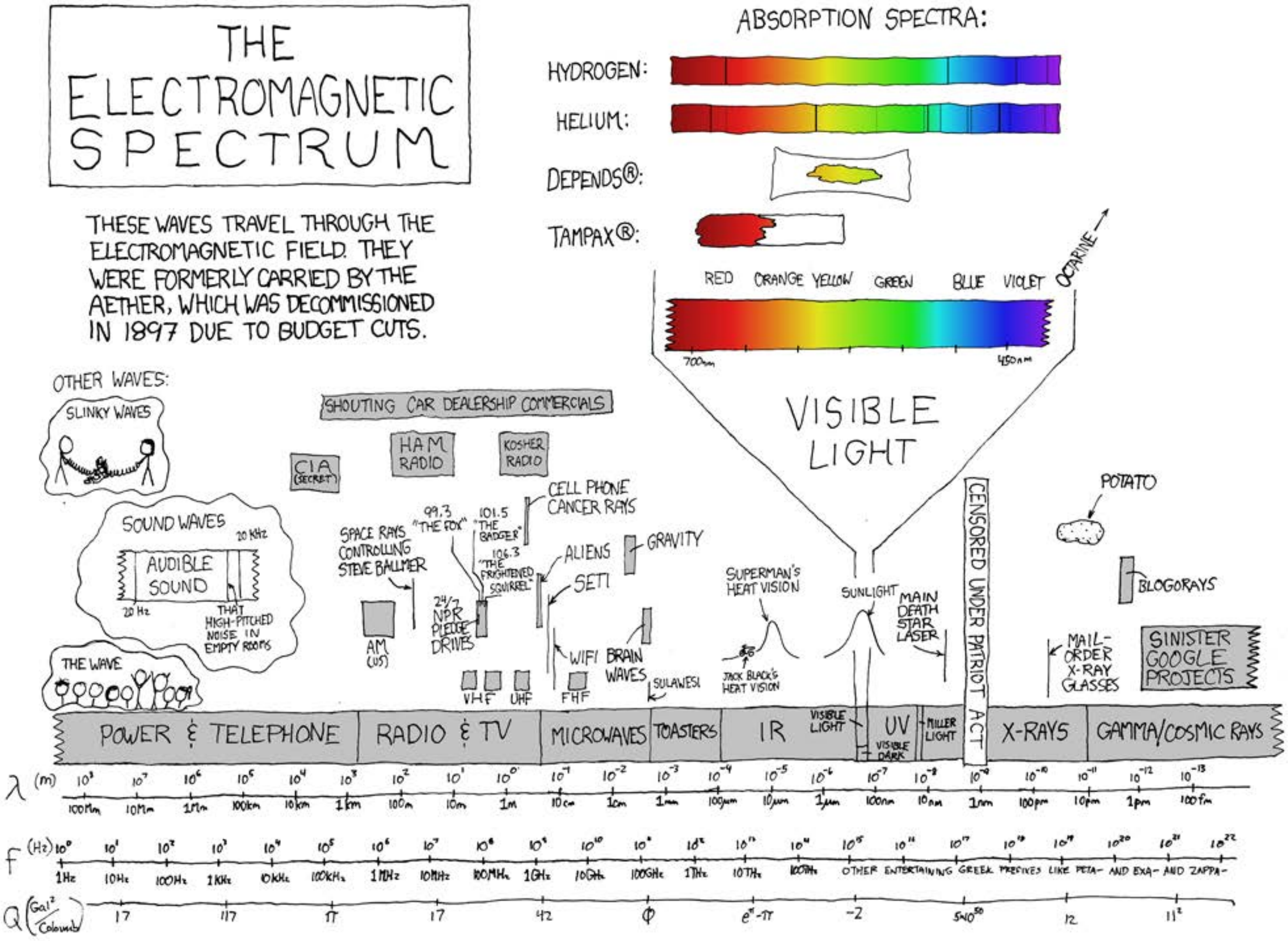
Thermal
radiation

The Electromagnetic Spectrum



from Sabins, Fig. 1-2

Solar Heating & Energy Transport

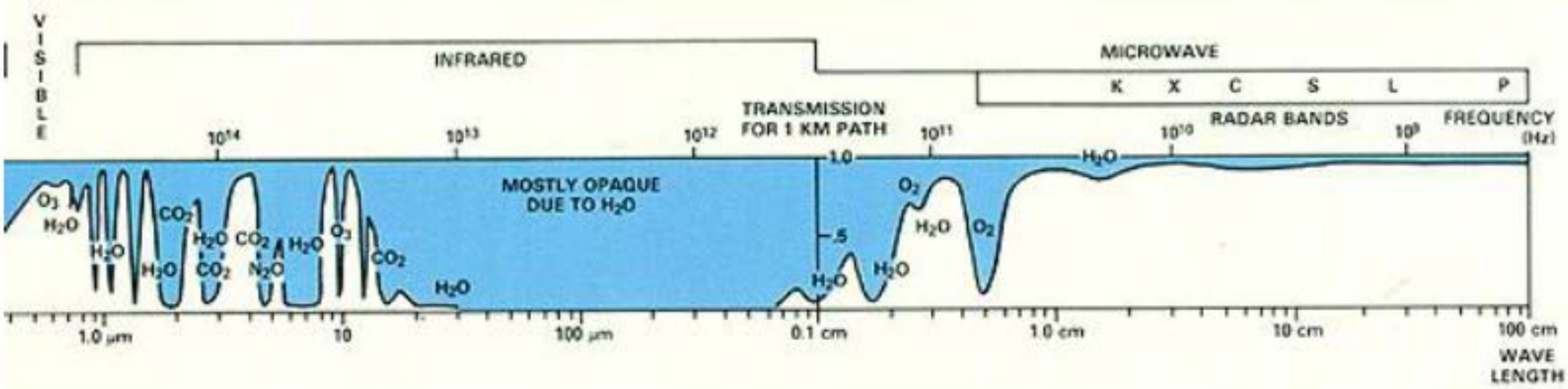


http://xkcd.com

Types of Compositional Information

- Gamma Rays: Nuclear transitions – elemental compositions
- X Rays, UV: Electron transitions – atomic compositions
- Vis, NIR: Electron transitions and lattice molecular vibrational transitions – chemical and mineralogic compositions
- TIR: Lattice vibrational, bending, rotational transitions – mineralogic compositions
- Microwaves, radar, radio: scattering and conduction effects – surface roughness and dielectric constants

Earth Atmosphere and Remote Sensing Windows



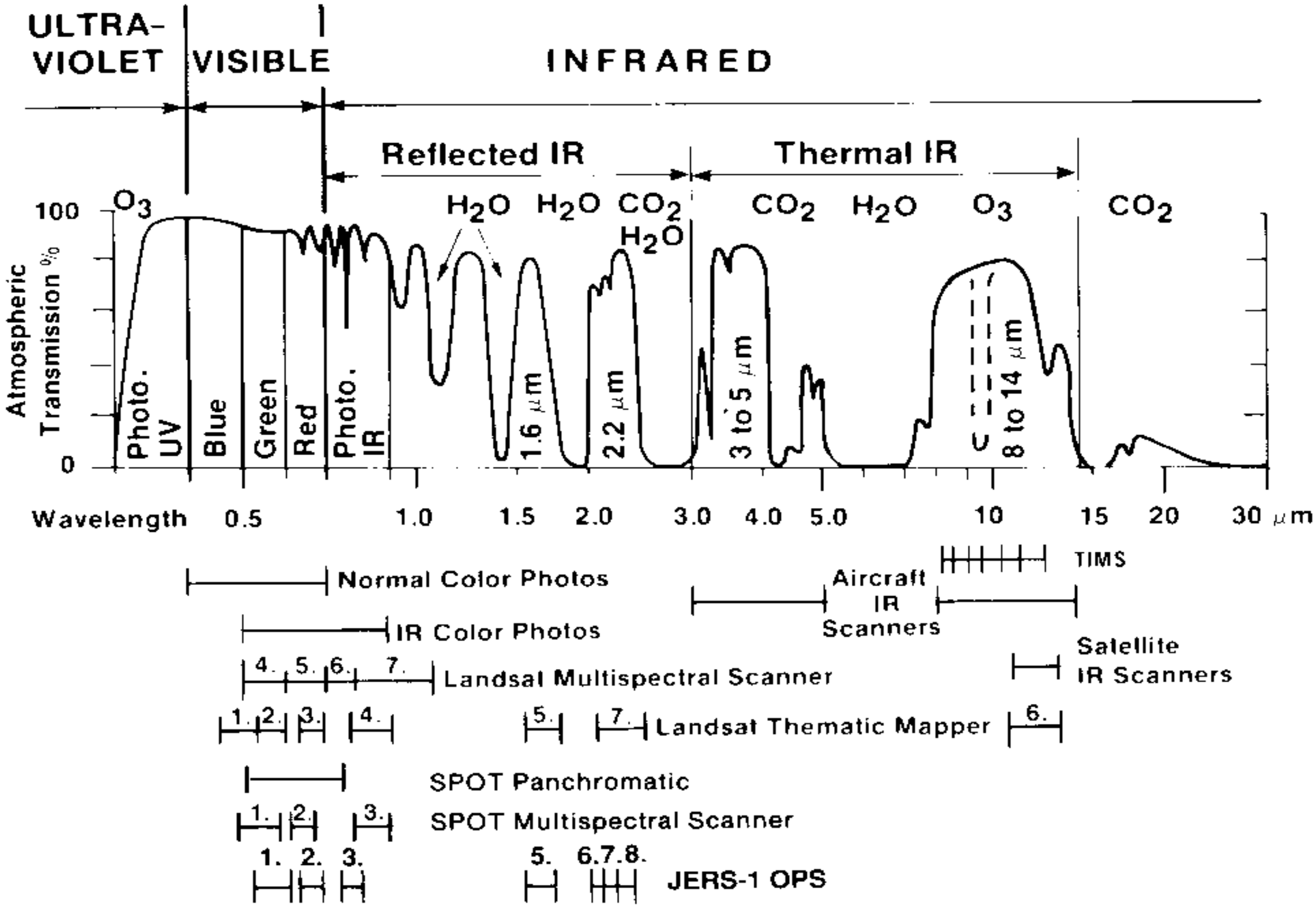
The transparency of the atmosphere varies with wavelength. Terrestrial windows of relative transparency are used for surface remote sensing:

1) Visible-Near IR (0.4 – 3.0 microns)
   (VIS, SWIR)
2) Mid/Thermal IR (8 – 15 microns)
3) Microwave/Radar (1 - 100 centimeters)

Location of this region depends on the surface temperature of the planet

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

Seeing through the atmosphere



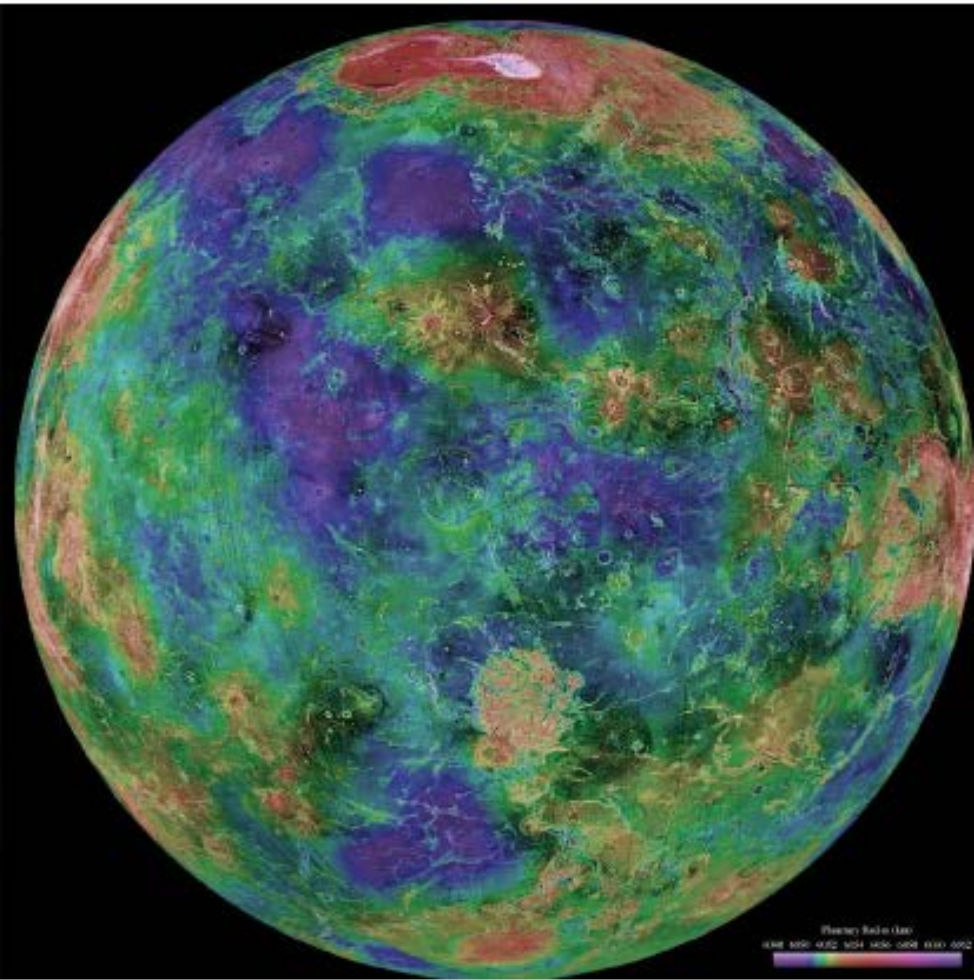
from Sabins, Fig. 1-3

Atm windows are not the same for all planets

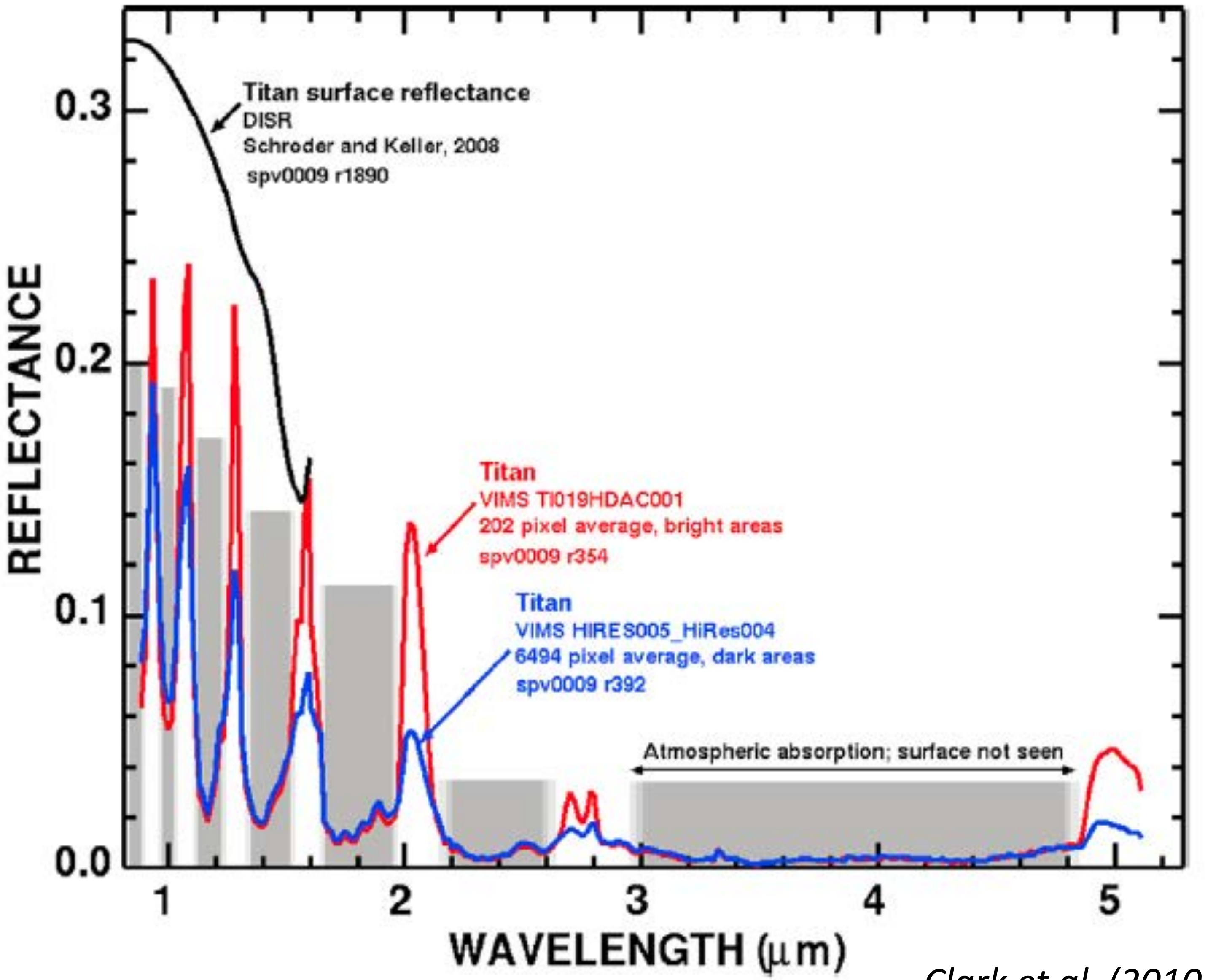
Venus

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

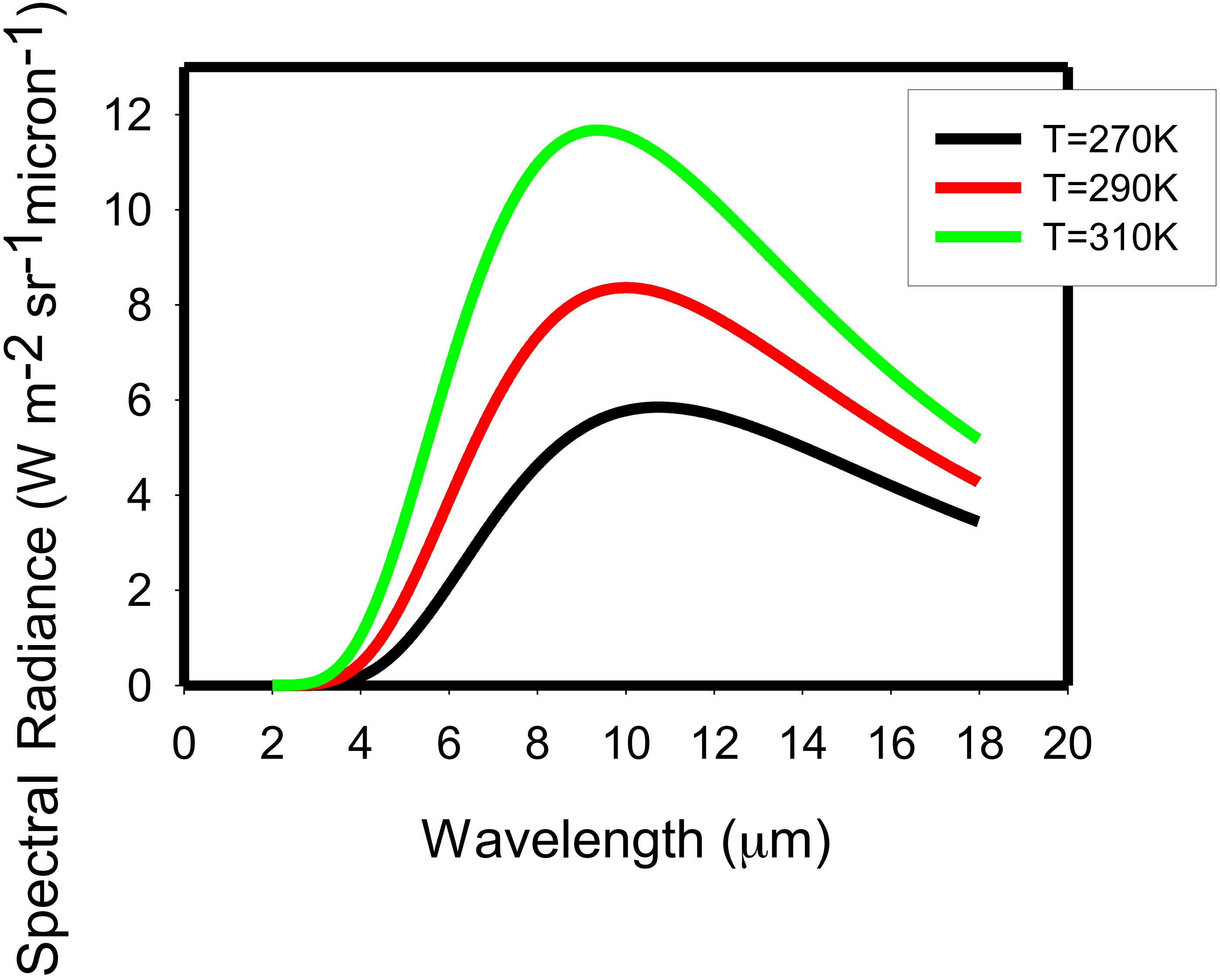
Blackbody: An ideal substance that absorbs all the radiant energy on it and emits radiant energy at the maximum possible rate per unit area for any given temperature.

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

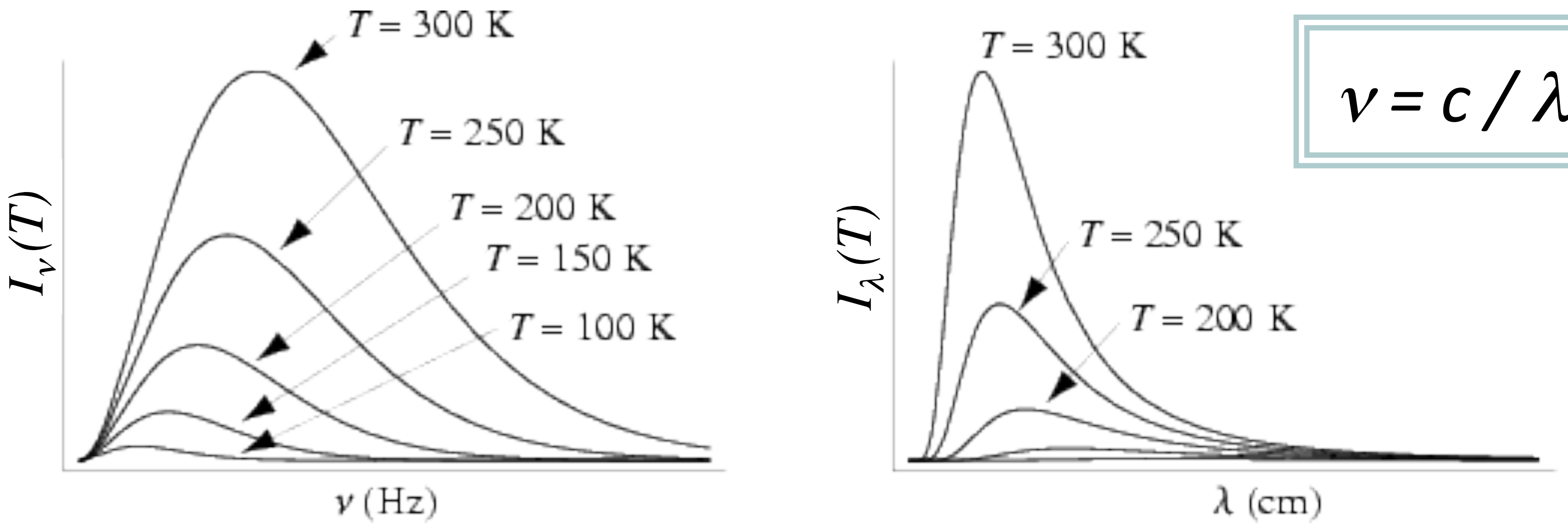
$$F = \sigma T^4$$

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:

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