Light and Radiometry

How to quantitatively describe "how much" light there is, where it is going, etc.?

Different ways to quantify light:

- Energy: [W m^{-2}]. Useful when we are interested in heating rates.

- Number of photons: [Einstein= Mol ($6.023 \cdot 10^{23}$) photons m^{-2} s^{-1}].

- At what wavelength?

Depends on the specific application

*Based, in parts, on lectures by Mobley, Roesler & Lewis

Radiometry

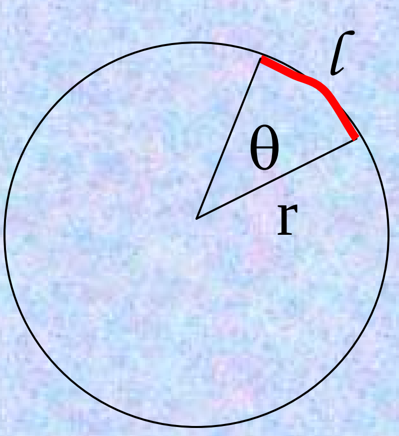
The science of measuring electromagnetic energy.

Detectors:
Thermal-instrument response is proportional to energy (absorbed and converted to heat)

Quatum-response is proportional to number of photons.

Calibration of radiometric instrument is non trivial (~2% accuracy, precision ~0.1%).

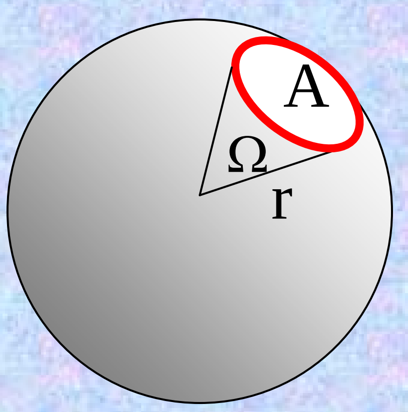
Solid angle review:



θ= arc-length/radius

or

$\ell = \theta r$

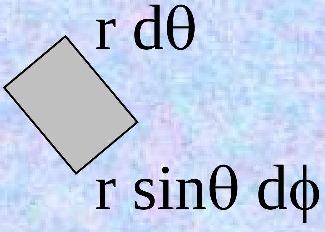


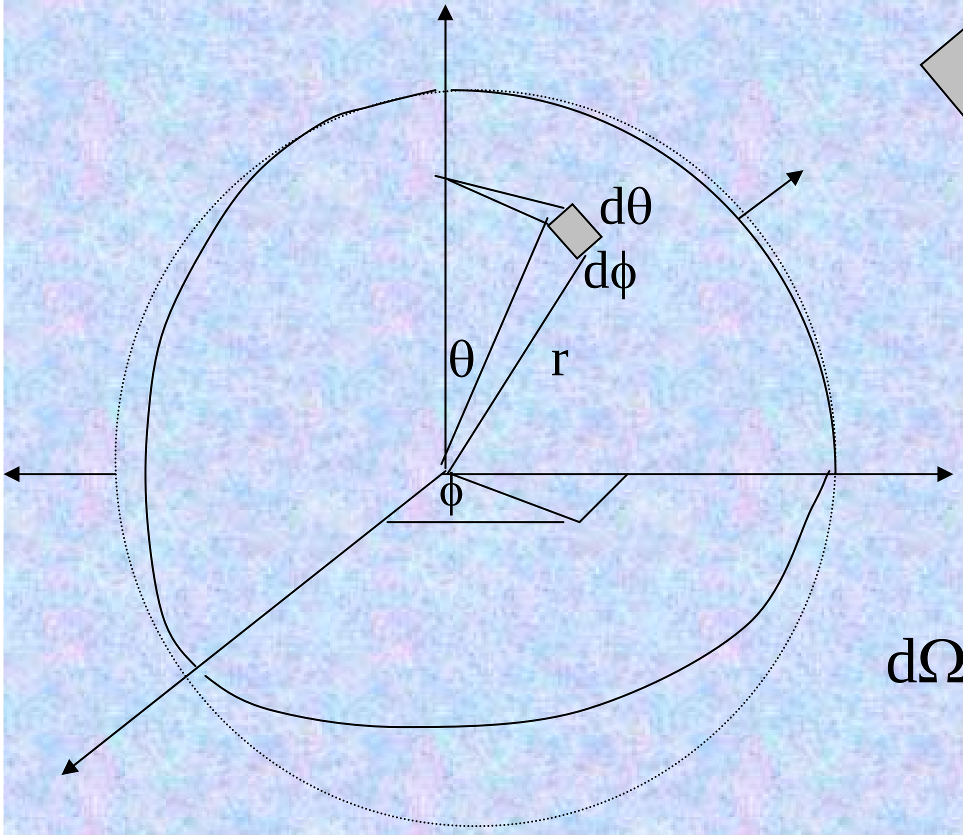
Ω= Area/radius^2

or

$A = \Omega r^2$

Computing solid angles:





$$d\Omega = dA/r^2$$

$$d\Omega = r^2 \sin\theta \, d\theta \, d\phi / r^2$$

θ-zenith angle
ϕ-azimuthal angle

Radiance:

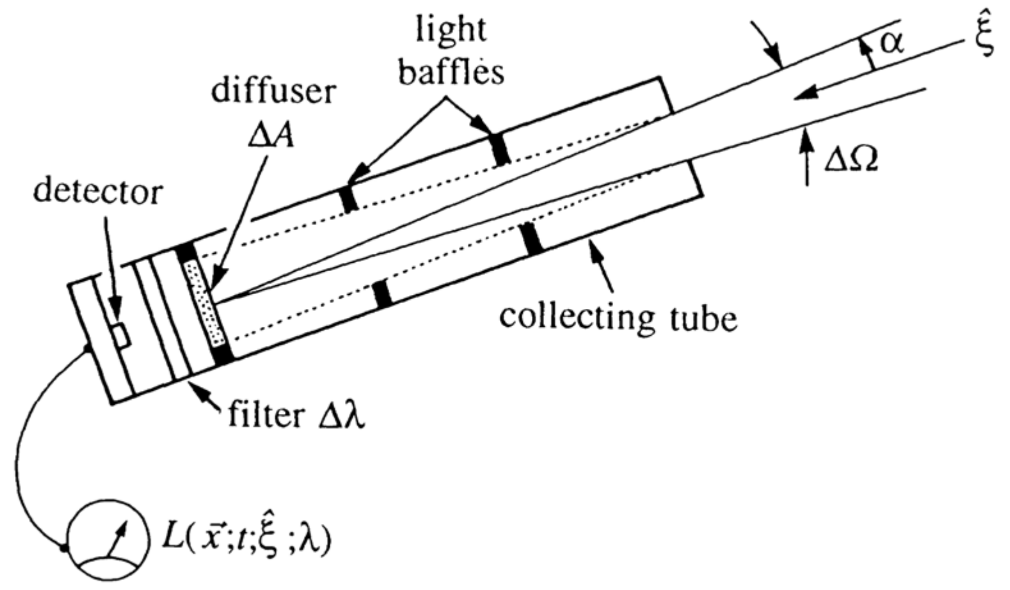


Fig. 1.5. Schematic design of an instrument for measuring unpolarized spectral radiance.

$$L(\vec{x},t,\phi,\theta,\lambda) \equiv \frac{\Delta Q}{\Delta t \Delta A \Delta \Omega \Delta \lambda}\left[\frac{\mathrm{J}}{\mathrm{s\ m^2\ sr\ nm}} = \frac{\mathrm{W}}{\mathrm{m^2\ sr\ nm}}\right]$$

$L(\theta,\phi,\lambda)$ (W $\mathrm{m^{-2}\ sr^{-1}\ nm^{-1}}$)

All other radiometric quantities are derived from *L*.

Irradiance

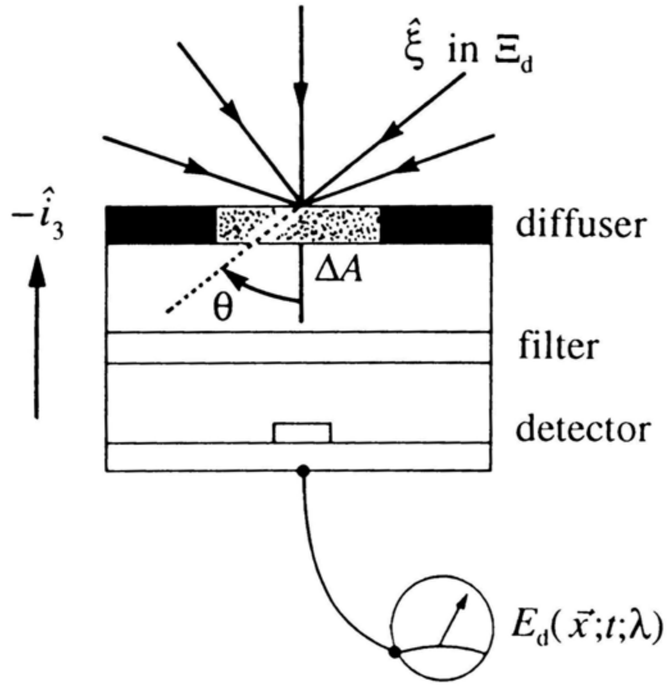


Fig. 1.6. Schematic design of an instrument for measuring spectral plane irradiance.

$$E_d \equiv \frac{\Delta Q}{\Delta t \Delta\Omega \Delta\lambda}\left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr\ nm}}\right]$$

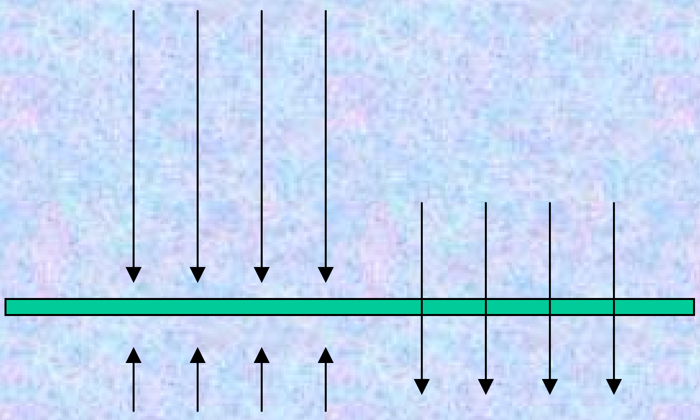
$$E_d(\theta,\phi,\lambda) \equiv \int_{UH} L(\Omega,\lambda)\left|\cos\theta\right| d\Omega = \int_0^{2\pi}\int_0^{\pi/2} L(\theta,\phi,\lambda)\left|\cos\theta\right| \sin\theta \, d\theta \, d\phi$$

Downward irradiance is the downward component of the L vector, weighted by its angle to the detector (effective area over which the light is spread).

Net Downward Irradiance (vector)

$\vec{E} = E_d - E_u$

Describes net flux



$$\vec{E}(\theta,\phi,\lambda) \equiv \int_0^{4\pi} L(\Omega,\lambda)\left|\cos\theta\right| d\Omega = \int_0^{2\pi}\int_0^{\pi} L(\theta,\phi,\lambda)\left|\cos\theta\right| \sin\theta d\theta d\phi$$

Scalar Irradiance

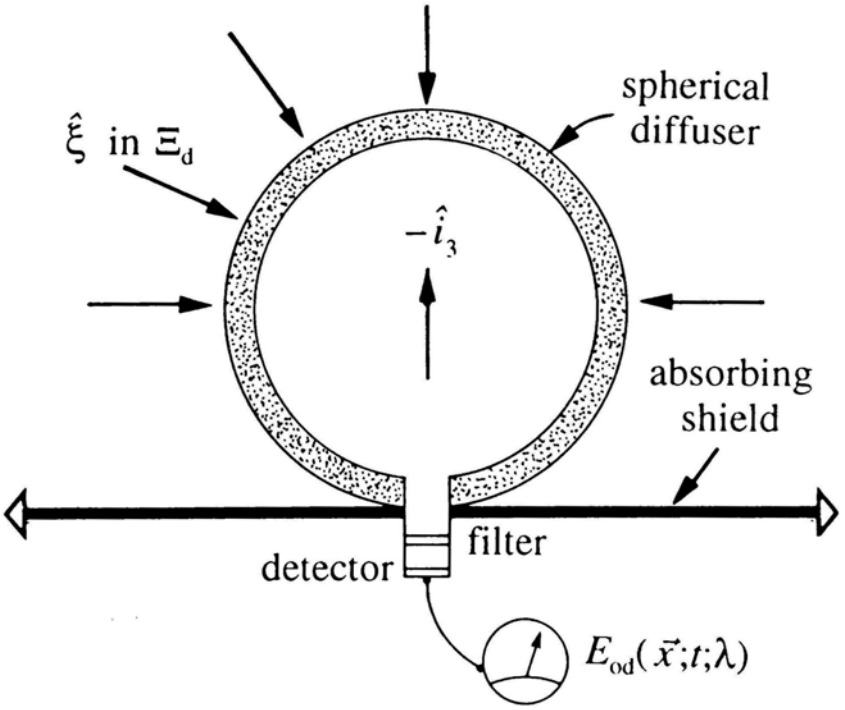


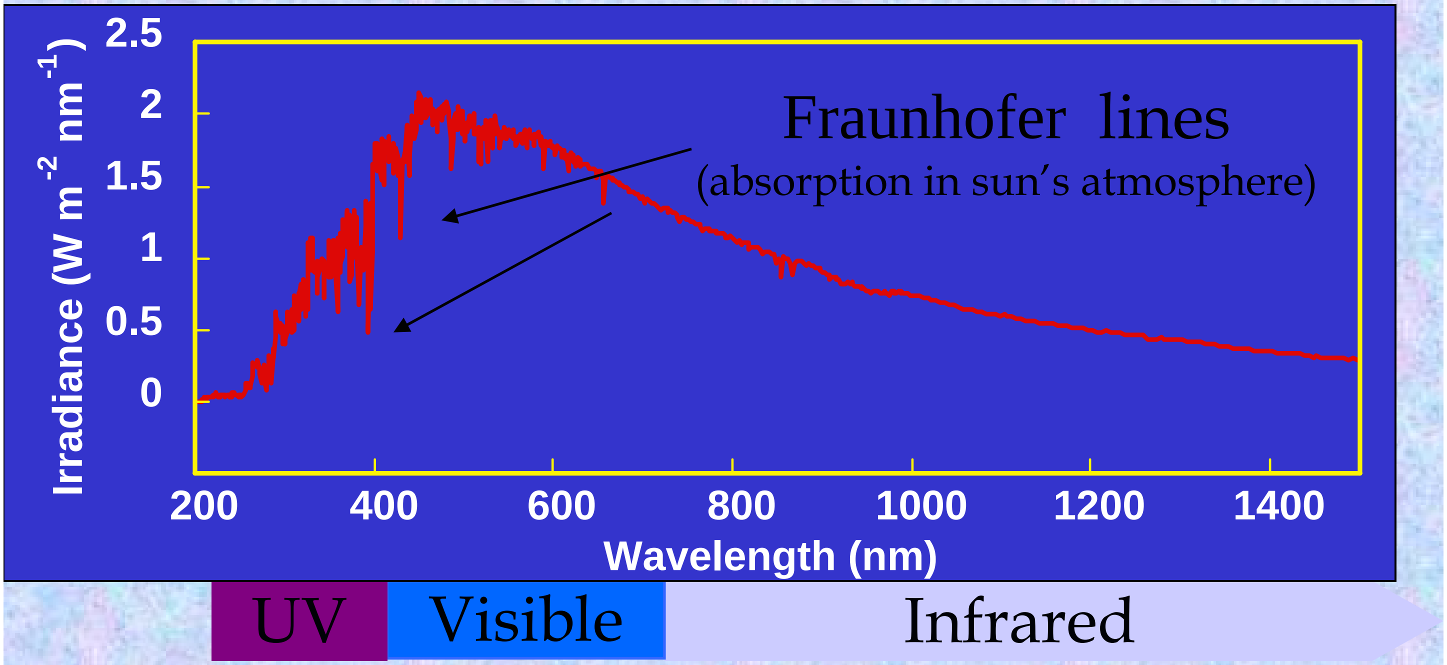
Fig. 1.7. Schematic design of an instrument for measuring spectral scalar irradiance.

$$E_{0d} \equiv \frac{\Delta Q}{\Delta t \Delta\Omega \Delta\lambda}\left[\frac{\mathrm{W}}{\mathrm{m}^2\ \mathrm{sr}\ \mathrm{nm}}\right]$$

$$E_{0d}(\theta,\phi,\lambda) \equiv \int_{UH} L(\Omega,\lambda)d\Omega = \int_0^{2\pi}\int_0^{\pi/2} L(\theta,\phi,\lambda)\sin\theta d\theta d\phi$$

Downward scalar irradiance has the same effective area for *L* in any direction. No cosθ factor

Extraterrestrial Solar Radiation



Fraunhofer lines

(absorption in sun's atmosphere)

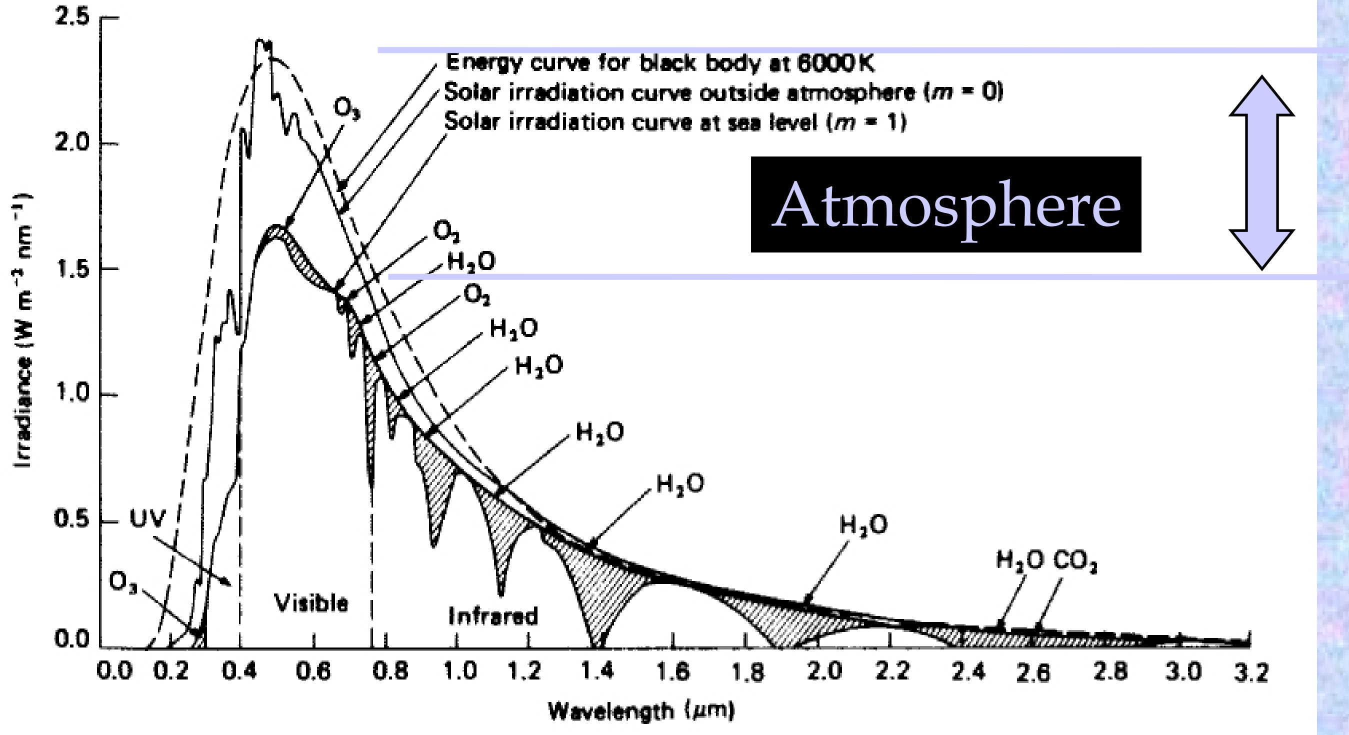
http://rredc.nrel.gov/solar/standards/am0/NewAM0.xls

The Solar Constant is 1366.1 Wm^{-2}.

It is defined as the amount of solar radiation on a surface perpendicular to the solar beam (E_d), at the outer limit of earth's atmosphere, at the mean sun-earth distance.

The atmosphere

The atmosphere attenuates the amount of radiation impinging on earth's surface.

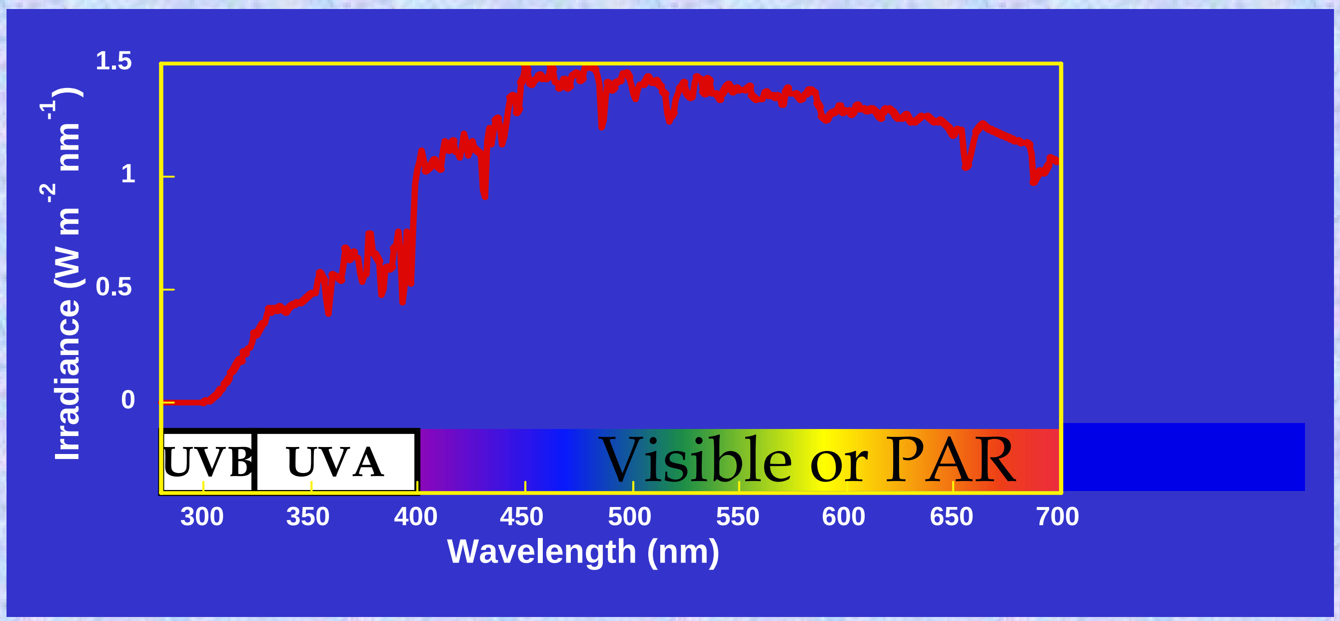


Kirk 1994, Fig. 2.1, p. 27

Solar Radiation Incident on the Ocean

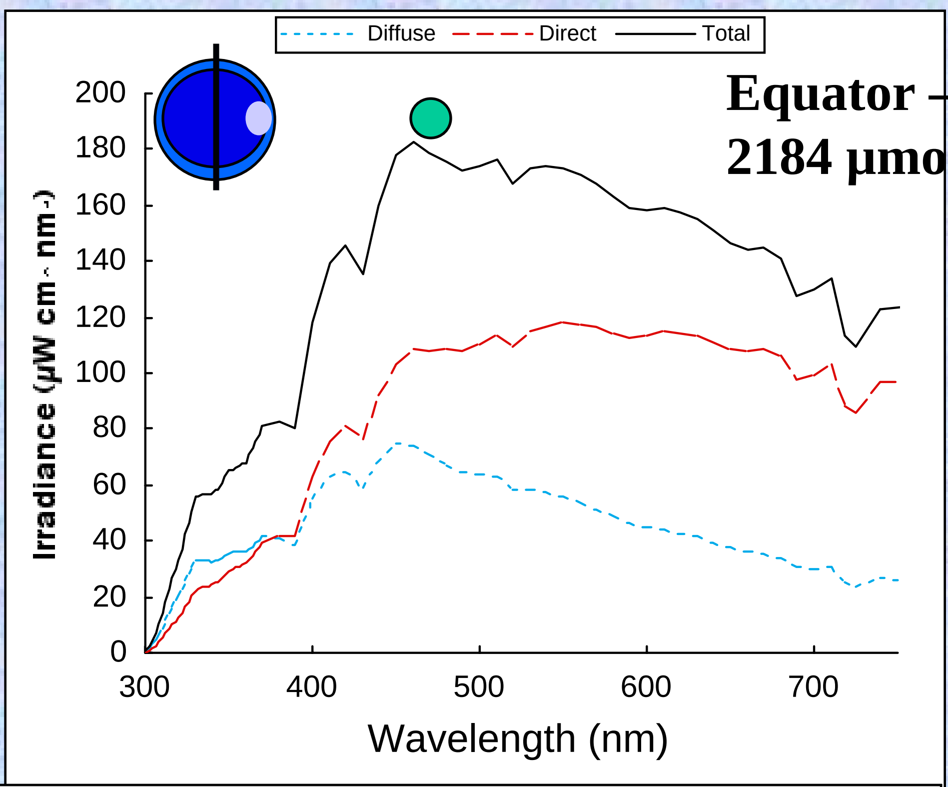
- Transmission through the atmosphere depends on:
  - **Solar zenith angle (latitude, season, time of day)**
  - **Cloud cover**
  - Atmospheric pressure (air mass)
  - Water vapor
  - Atmospheric turbidity
  - **Column ozone (important for UV-B)**
    - Ground albedo (how much light is reflected from the ground) also affects the incident irradiance.
- Midsummer Solar irradiance at 45°N (midday)
  - about 400 W m^{-2} (PAR, energy units)
  - 1900 μmol m^{-2} s^{-1} (PAR, quanta)
- Midwinter Solar Irradiance at 45°N
  - about 130 W m^{-2}; 600 μmol m^{-2} s^{-1}

Visible and UV Irradiance Typical Spectrum for summer in Halifax

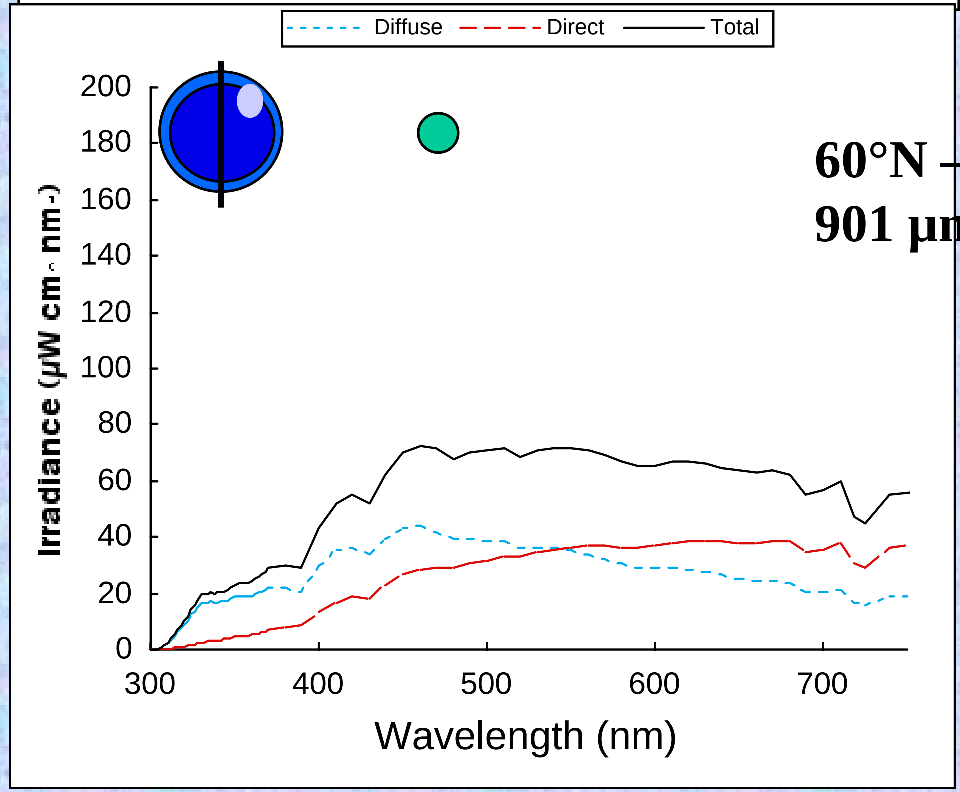


- -Visible: 400 to 700 nm
  - Also called Photosynthetically Available Radiation (PAR)
    - ABOUT 45% OF INCIDENT SOLAR RADIATION IS PAR
- -Ultraviolet
  - UVA 315 (or 320) to 400 nm, UVB 280 to 320 nm, UVC 200 to 280 nm

Examples: Vernal Equinox



Equator — March 21 – noon
2184 µmol m^{-2} s^{-1} PAR



60°N — March 21 — noon
901 µmol m^{-2} s^{-1} PAR

Sun angle accounts for a 50% reduction. Atmospheric pathlength is longer. Diffuse irradiance is enriched in the shorter, scattered wavelengths.

Some relations to phytoplankton:

- What type of irradiance do phytoplankton experience?
- How should the euphotic depth be defined?
- What is PAR?

Irradiance is often measured in units of energy [w/m^2]. Phytoplankton care about number of photons in wavelength they absorb:

$$PAR \equiv \int_{350}^{700} E_0(\lambda)\frac{\lambda}{hc}\,d\lambda \left[\frac{\text{photons}}{\text{m}^2\ \text{s}}\right]$$

But not all photons are equal. Phytoplankton absorb certain wavelength preferably (PUR).

$$PUR \equiv \int_{350}^{700} E_0(\lambda)\frac{\lambda}{hc}\frac{a(\lambda)}{a(440)}\,d\lambda \left[\frac{\text{photons}}{\text{m}^2\ \text{s}}\right]$$

Summary:

- Light is measured in different ways depending on application (e.g. heating rate vs photosynthesis).
- Definitions insure we compare similar quantities.
- Measuring ambient light is not trivial.