Radiometry
Definitions and Sources of Radiation

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Radiometry Lab

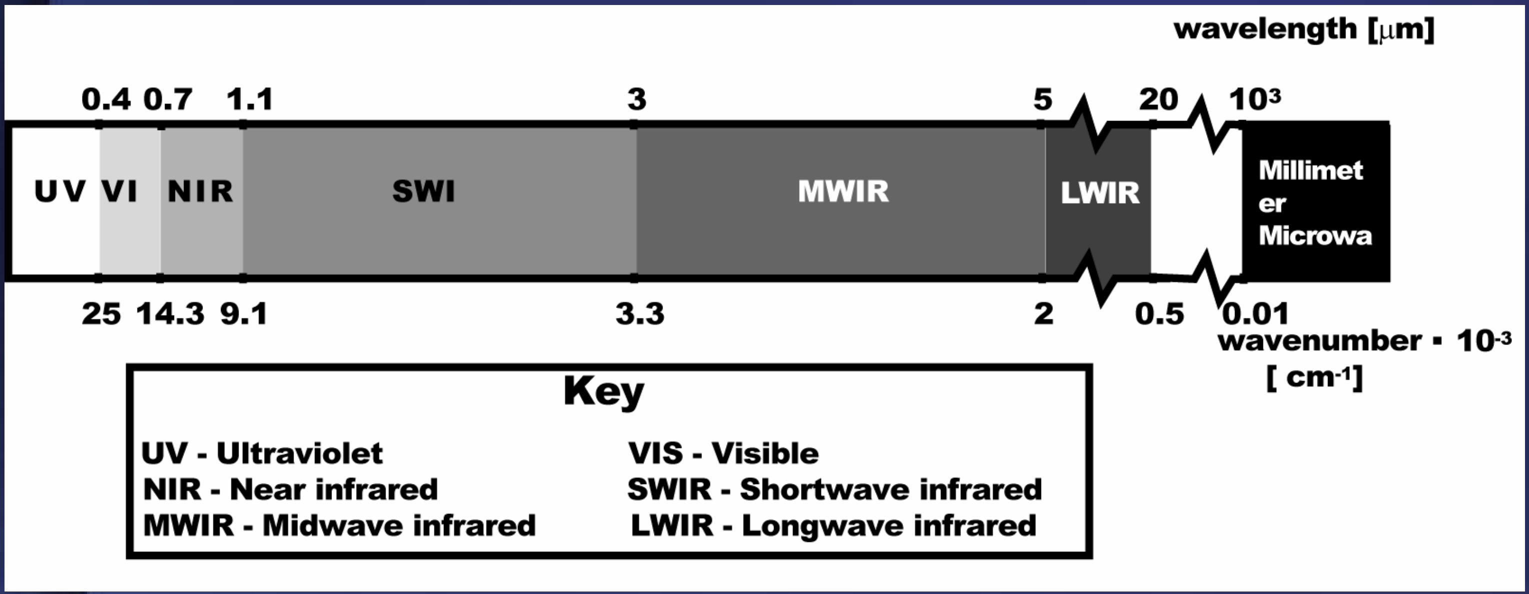
- Wednesdays, 6-9pm, Room 3125
- Lab website
  - **www.cis.rit.edu/class/simg401**
- This Wednesday:
  - Topic: Physics of a Radiometer
  - Handouts are on website

Radiometry Lecture Overview

- What is Radiometry?
- What is Photometry?
- Radiometric / Photometric Definitions
- Sources
  - Blackbody radiation
  - Gas
  - Fluorescent
  - Photodiode
  - LASER
  - Carbon Arc
  - Electron Beam

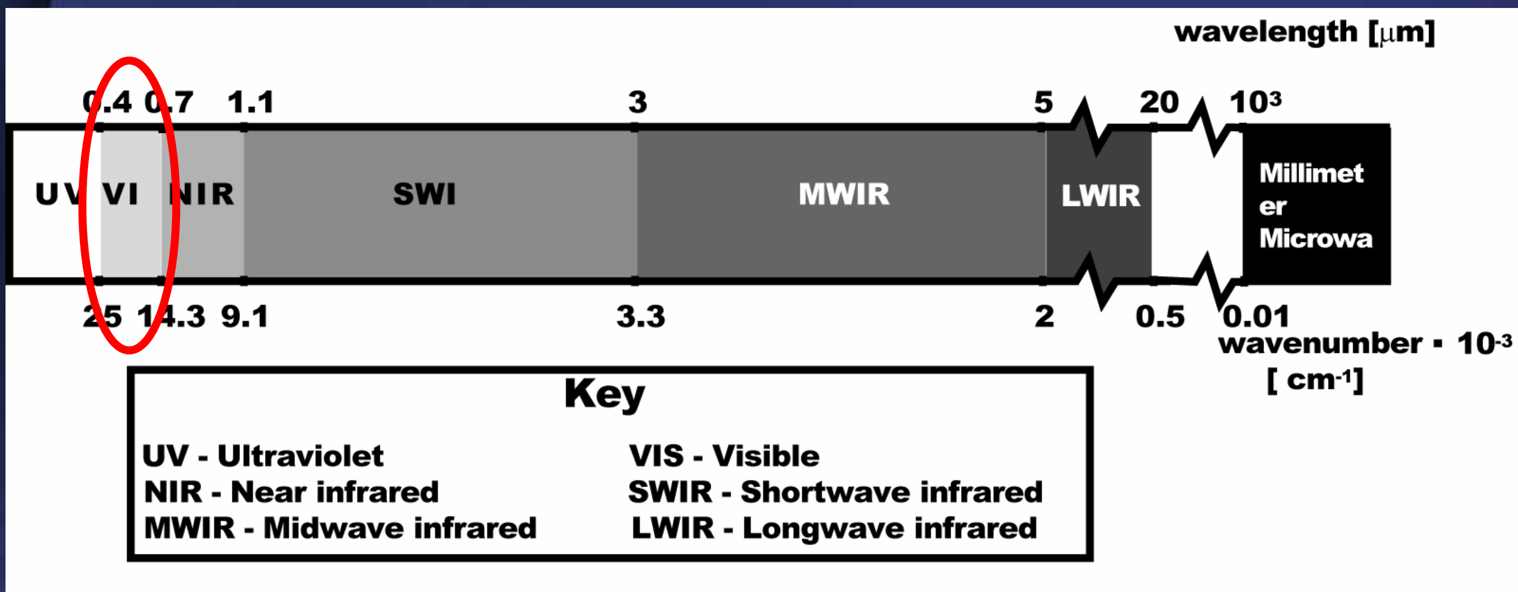
What is Radiometry?

- Measurement or characterization of *EM radiation* and its interaction with matter



What is Photometry?

- Measurement or characterization of *EM radiation* which is detectable by the human eye



Why develop these concepts?

- Given an optical system, for example
  - Camera, telescope, etc
  - Any optical radiation source, a surface, detector, etc
- Can calculate how much radiation gets to the detector array or film in the image plane
- Can calculate the value of the Signal-to-Noise (SNR) or exposure

Radiometry Definitions: Summary

- Units can be divided into two conceptual areas
  - Those having to do with energy or power
    - Energy, Q (joule or [J])
    - Power or flux, Φ (watt or [W])
  - Those that are geometric in nature
    - Irradiance, E [W/m^2]
    - Exitance, M [W/m^2]
    - Intensity, I [W/sr]
    - Radiance, L [W/m^2 sr]

Photometry Definitions: Summary

- Units can be divided into two conceptual areas
  - Those having to do with energy or power
    - Energy, Q (lumen second or [lm s] or Talbots)
    - Power or flux, Φ, (lumen or [lm] = [cd sr])
  - Those that are geometric in nature
    - Illuminance [lm/m^2 = lux or lx]
    - Emittance [lm/m^2 = lux or lx]
    - Intensity [lm/sr = candela or cd]
    - Luminance [lm/m^2 sr = cd/m^2 = nit]
      - Sometimes called *Luminosity*

Systeme International d'Unites (SI)

- SI developed in 1960
- 7 SI Base Units
  - Kilogram [kg]
  - Second [s]
  - Meter [m]
  - Ampere [A]
  - Kelvin [K]
  - Mole [mol]
  - Candela [cd]
- All others are *SI derived units*
  - *Previous slide radiometric definitions are all SI derived units*

Radiometric Definitions

- Photon Energy, *q*
  - We think of energy as being transferred in terms of energy packets or quanta
  - The energy carrier is a "photon"
  - Each photon carries energy,

$$q = h\nu = \frac{hc}{\lambda} \quad [\text{joules}]$$

  - Shorter wavelength photons carry more energy than longer wavelength photons

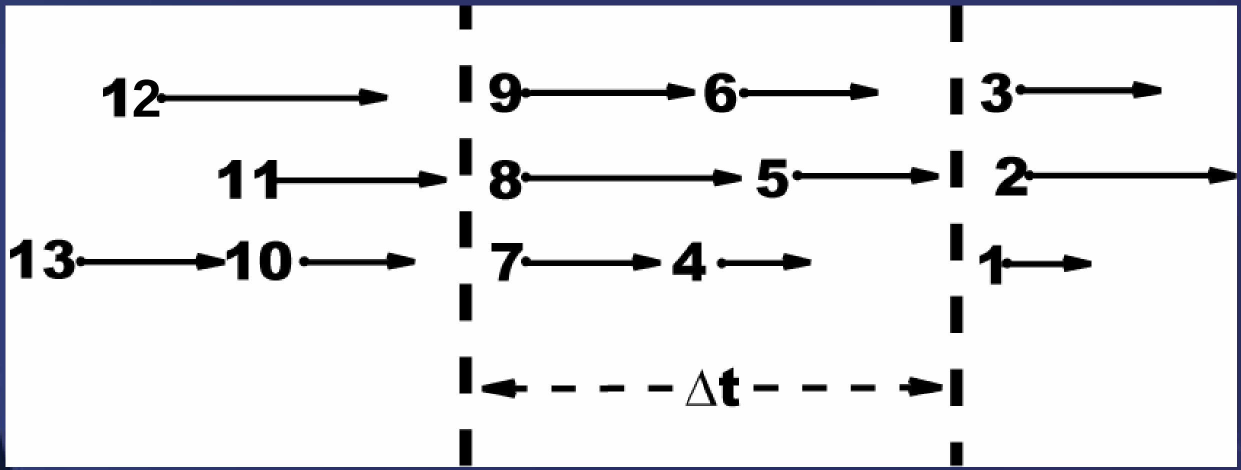
Radiometric Definitions

- Radiant Energy, *Q*
  - The total energy (Q) in a beam is a function of:
    - Frequency or wavelength of the photons, ν or λ
    - Number of photons, *n* of a particular ν or λ

$$Q = \sum q_i = \sum_i n_i h \nu_i \quad [\text{joules}]$$

Radiometric Definitions

- Radiant Flux or Power, Φ
  - Quantity of *energy* propagating onto, through, or emerging from, a specified surface of a given area in a given period of *time*



Radiometric Definitions

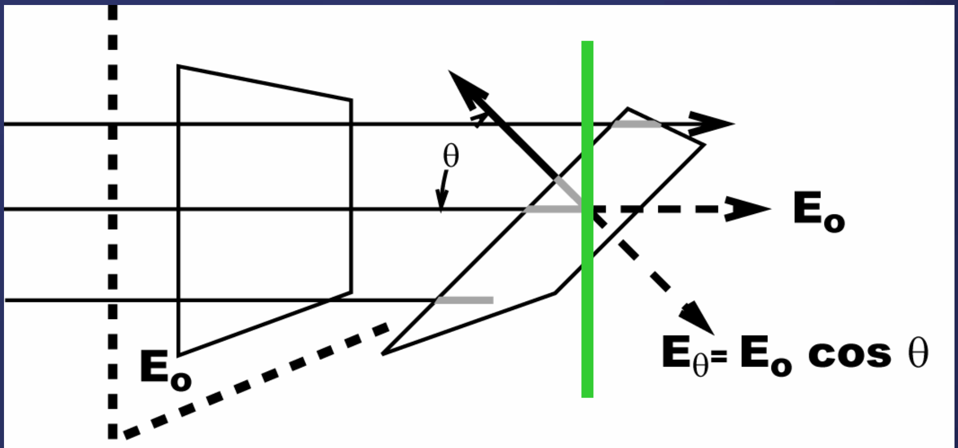
- Radiant Flux or Power, Φ
  - Quantity of *energy* propagating onto, through, or emerging from, a specified surface of a given area in a given period of *time*

$$\Phi = \frac{dQ}{dt} = \frac{1}{\Delta t}\sum_{i=4}^{9} Q_i \quad [\tfrac{J}{s} = \text{watt or W}]$$

Radiometric Definitions

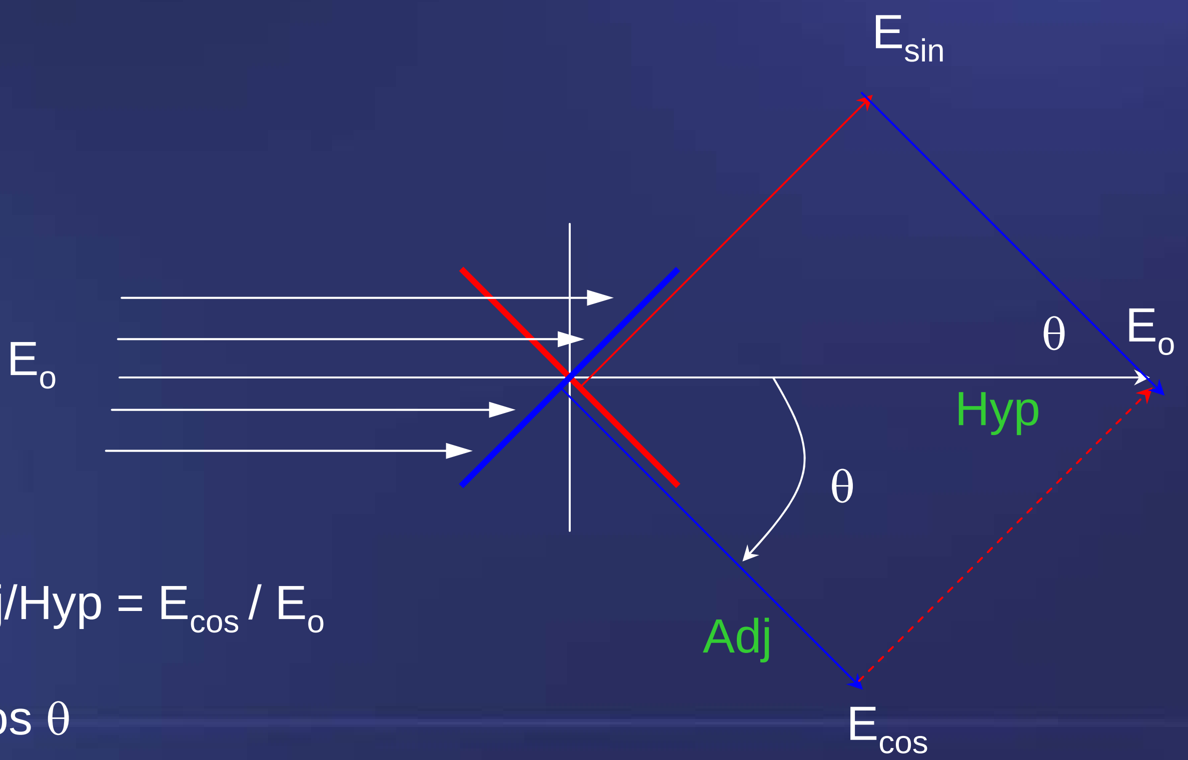
- Irradiance, *E (flux density)*
  - Rate at which radiant flux, Φ is delivered onto a surface (*e.g.*, a detector surface)

$$E = E(x,y) = \frac{d\Phi}{dA} \quad [\mathrm{wm}^{-2}]$$



Radiometric Definitions

- Projected Area



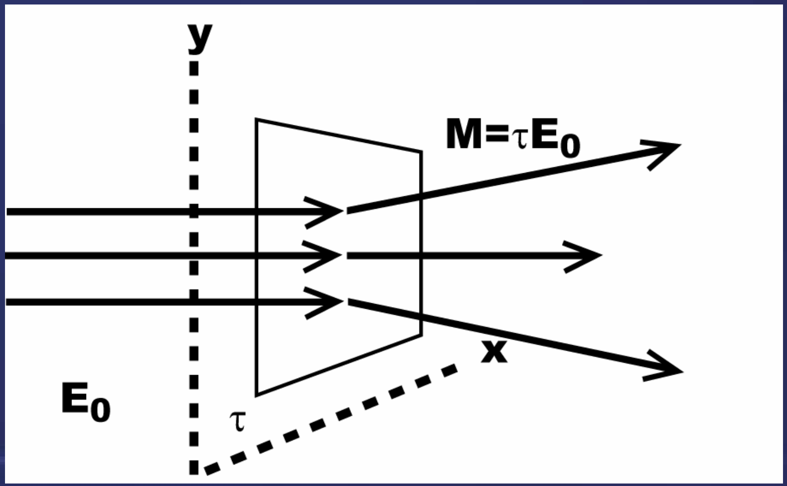
$\cos\theta$ = Adj/Hyp = E_{cos} / E_o

$E_{cos} = E_o \cos\theta$

Radiometric Definitions

- Radiant Exitance, *M*
  - Rate at which radiant flux, Φ is delivered away from a surface (*e.g.*, a diffuser, reflected surface)

$$M = M(x, y) = \frac{d\Phi}{dA} \quad [\mathrm{wm}^{-2}]$$

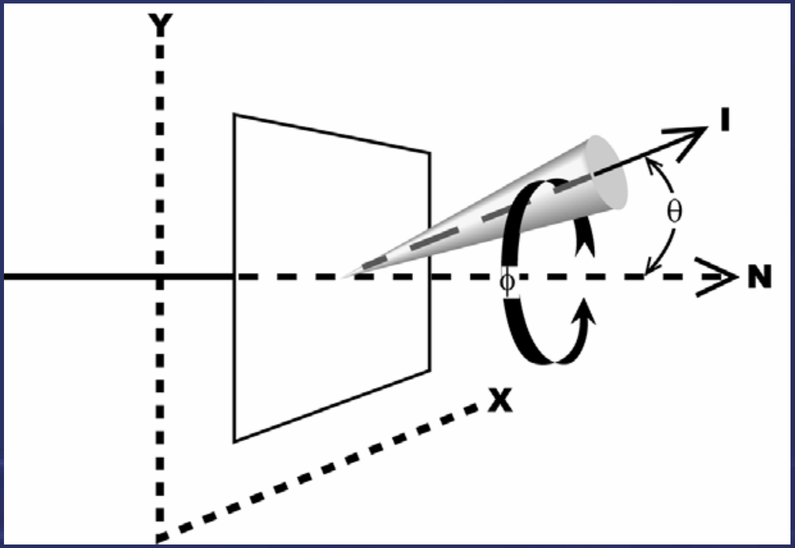


Radiometric Definitions

- Radiant Intensity, I
  - Rate at which radiant flux, Φ is incident on, passing through, or emerging from a point in space in a given direction

$$I = I(\theta,\phi) = \frac{d\Phi}{d\Omega} \quad [\mathrm{w\,sr^{-1}}]$$

"steradian"

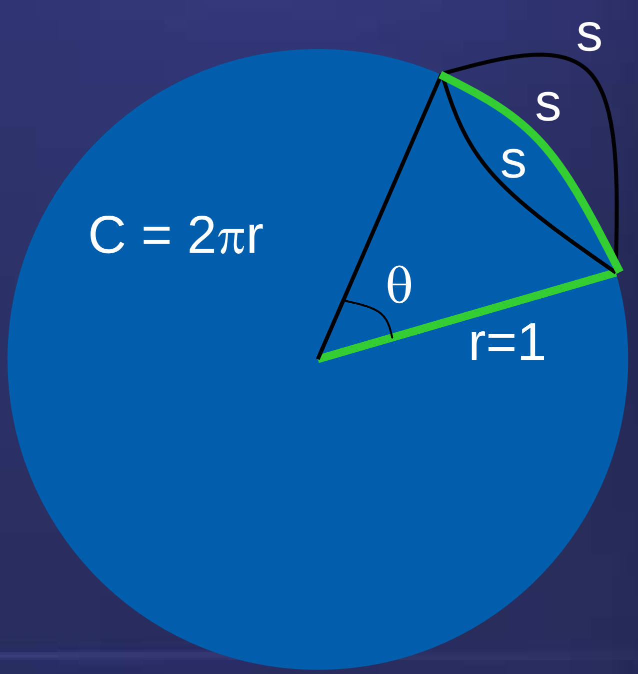


Radiometric Definitions

- Plain angle or linear angle, θ
  - Length of arc, *s* divided by the radius, *r*
  - Plain angle is dimensionless
  - SI assigns unit of measure:
    - radian

For any *s*

$$\theta = \frac{s}{r}\left[\frac{m}{m} = rad\right]$$



2π radians in a full circle

Radiometric Definitions

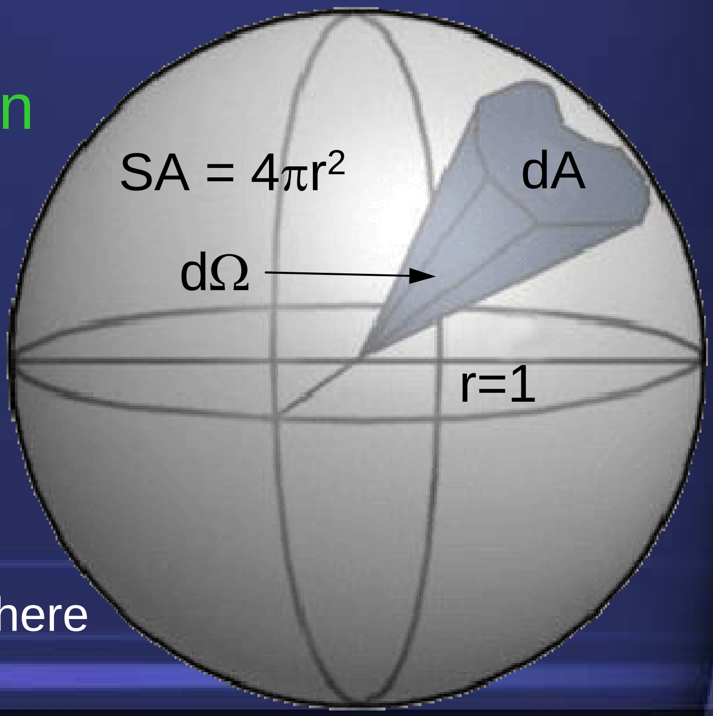
- Plain angle or linear angle, θ
  - A straight line or even a curved line can subtend the same angle as an arc on the circle
  - DEF: Plane angle is the projection of a line on a unit circle, and the line need not be straight

Radiometric Definitions

- Solid angle, Ω
  - 3D equivalent of a plane angle
  - Projection of a area (or a closed curve in space) onto a unit sphere
  - "square radians" or steradian

For any *A*

$$d\Omega = \frac{dA}{r^2}\left[\frac{m^2}{m^2} = sr\right]$$



4π steradians in a sphere

Radiometric Definitions

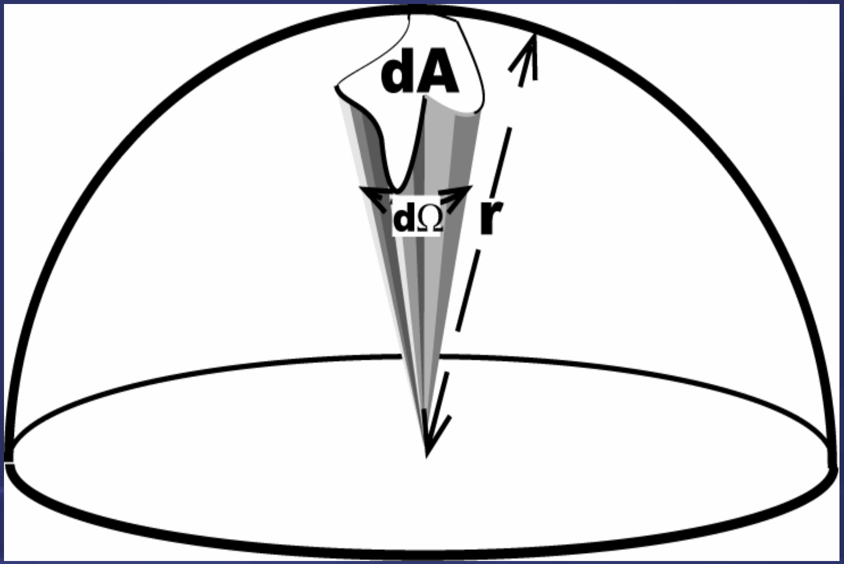
- Solid angle example
  - A point source that radiates equally well in all directions (isotropic), and whose output Intensity is 1 W sr^{-1}, has a total output power of 4π watts.

$$I = \frac{d\Phi}{d\Omega}\left[\mathrm{w\,sr^{-1}}\right]$$

$$d\Phi = I\ d\Omega$$

$$d\Phi = \left(1\tfrac{w}{sr}\right)\left(4\pi\ sr\right)$$

$$\Phi = 4\pi \approx 13\,watts$$



Radiometric Definitions

- Radiance, *L*
  - Combine the concepts of irradiance and intensity
  - Function of both position and direction
  - Flux, Φ incident on, passing through, or emerging in a specified direction from a specified point in a specified surface

$$L = \frac{d^2\Phi}{d\Omega\, dA} = \frac{d^2\Phi}{d\Omega\,(dA_0 \cos\theta)}$$

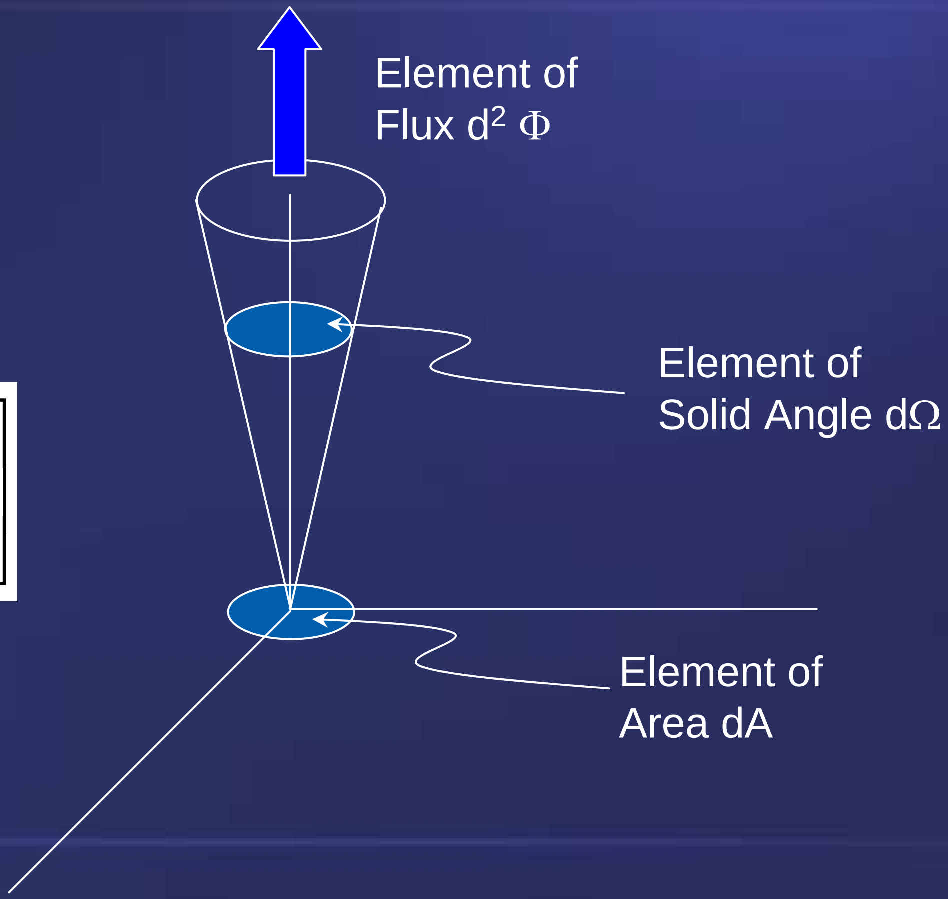
Where $dA = dA_o \cos\theta$ is the projected area

Derive Expression In Class

Radiometric Definitions

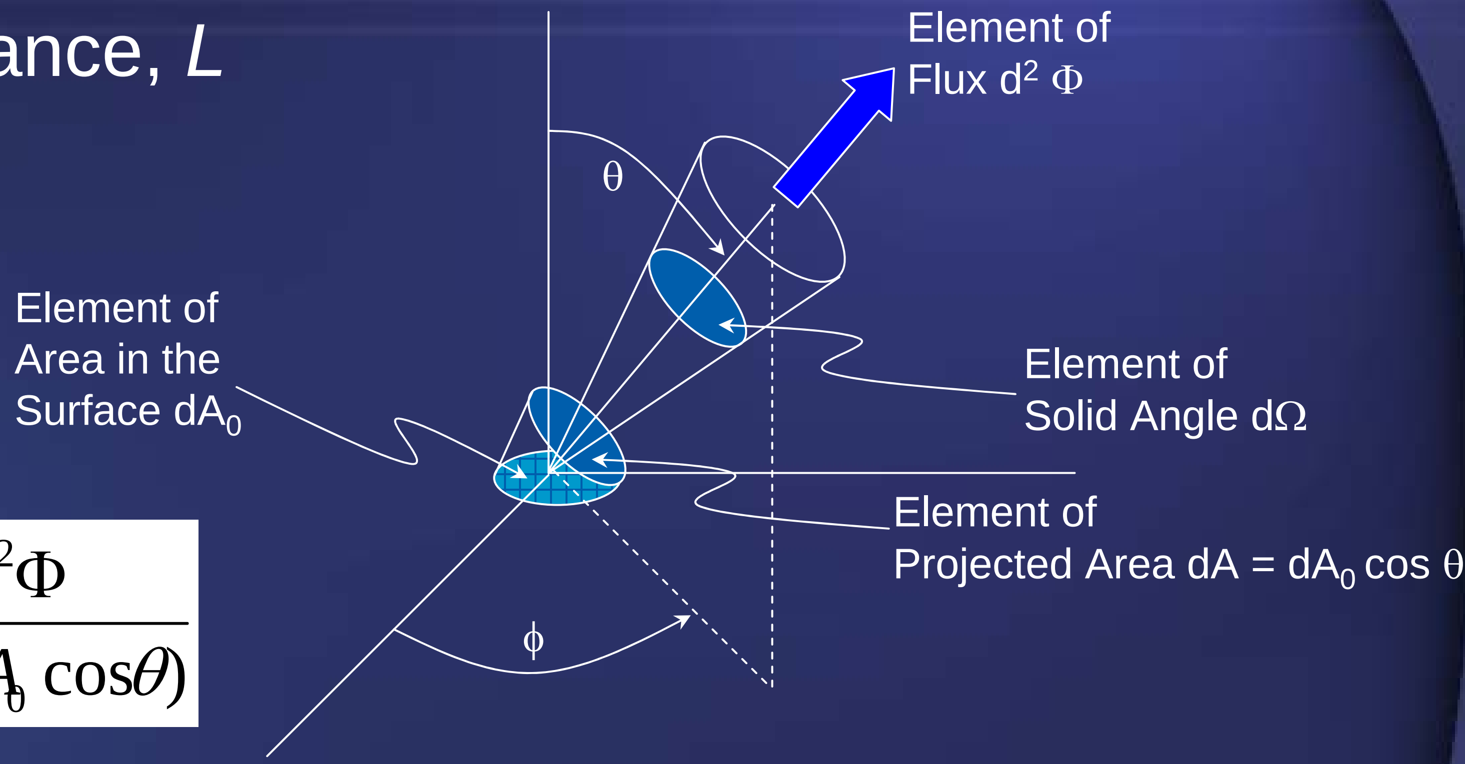
- Radiance, *L*

$$L = \frac{d^2\Phi}{d\Omega\, dA} \quad \left[\frac{w}{sr\, m^2}\right]$$



Radiometric Definitions

- Radiance, *L*

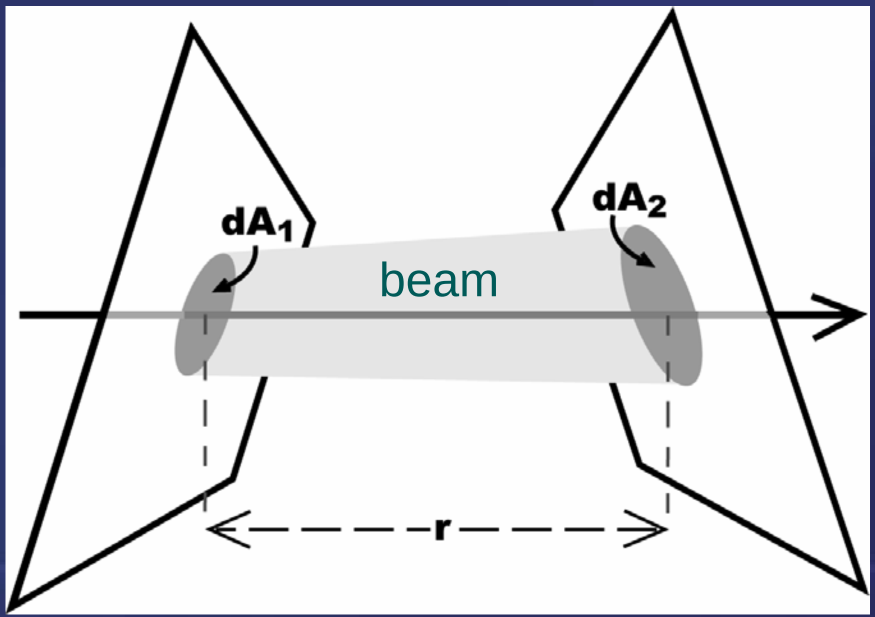


$$L = \frac{d^2\Phi}{d\Omega\,(dA_0 \cos\theta)}$$

The "area" in the units (m^2) is now with respect to the projected area dA.

Constancy of Radiance

- A basic principle in optics
- Assume a beam of energy with constant radiance across the profile
- Assume lossless media

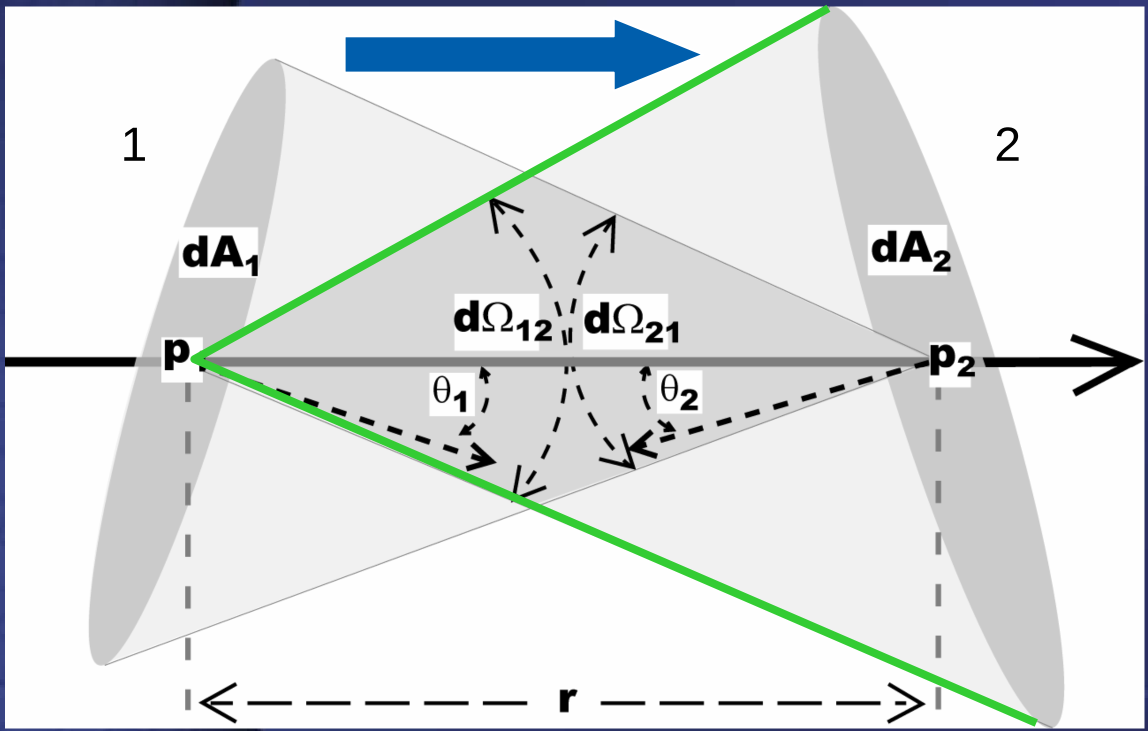


Earth Sensor

$$d\Phi_1 = d\Phi_2 = d\Phi$$

Constancy of Radiance

- How is the radiance at surface 1 (L_1) related to the radiance at surface 2 (L_2)?



$$L_1 = \frac{d^2\Phi_1}{dA_1 \cos\theta_1 d\Omega_{12}}$$

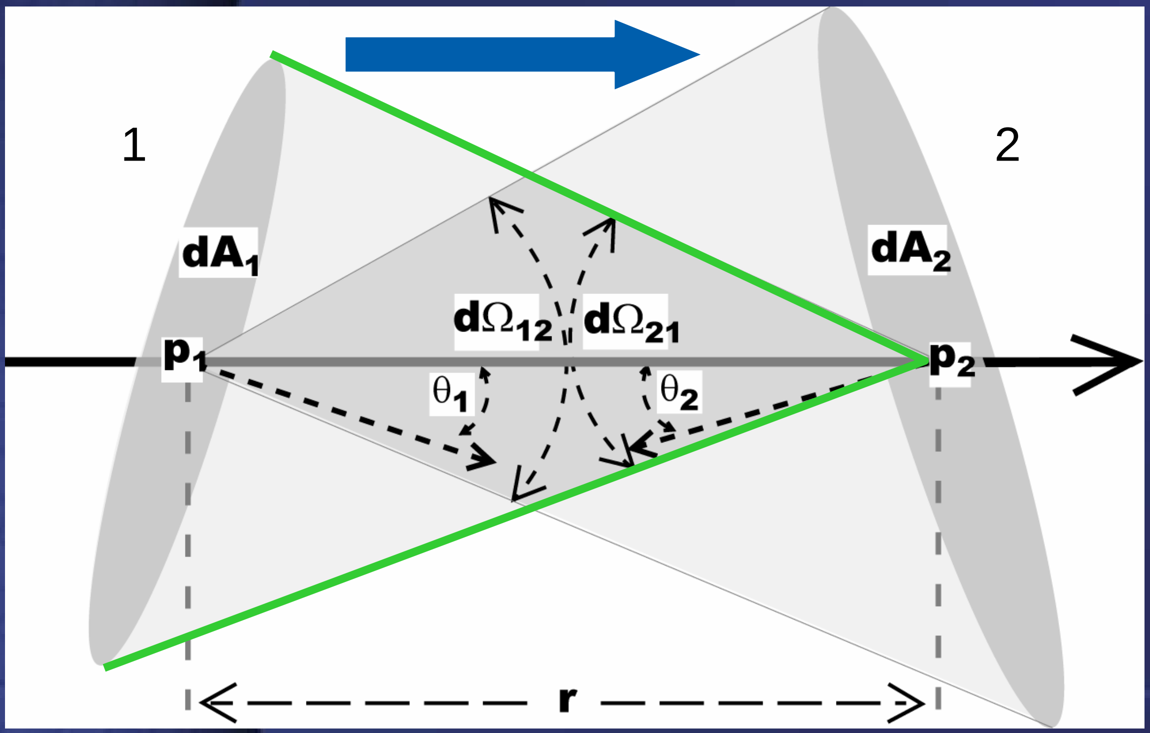
Earth

Sensor

- Radiance <u>from the Earth</u>, p_1

Constancy of Radiance

- How is the radiance at surface 1 (L_1) related to the radiance at surface 2 (L_2)?



Earth

Sensor

- Radiance at the sensor, p_2

$$L_2 = \frac{d^2\Phi_2}{dA_2 \cos\theta_2 d\Omega_{21}}$$

Constancy of Radiance

$$L_1 = \frac{d^2\Phi_1}{dA_1 \cos\theta_1 d\Omega_{12}}$$

$$L_2 = \frac{d^2\Phi_2}{dA_2 \cos\theta_2 d\Omega_{21}}$$

- Let "r" be an arbitrary distance between p_1 and p_2

$$\tau_1 = dA_1 \cos\theta_1 d\Omega_{12} = dA_1 \cos\theta_1 \frac{dA_2 \cos\theta_2}{r^2}$$

$$\tau_2 = dA_2 \cos\theta_2 d\Omega_{21} = dA_2 \cos\theta_2 \frac{dA_1 \cos\theta_1}{r^2}$$

- We see that,

$$\tau_1 = \tau_2 = \tau$$

Constancy of Radiance

- Re-write radiance using this information

$$L_1 = \frac{d^2\Phi_1}{\tau_1}$$

$$L_2 = \frac{d^2\Phi_2}{\tau_2}$$

$$\tau_1 = \tau_2 = \tau$$

$$d\Phi_1 = d\Phi_2 = d\Phi$$

$$L_1 = L_2 = \frac{d^2\Phi}{\tau}$$

- This tells us that radiance along a ray is <u>constant</u> over distance in a lossless media