FACTS ABOUT EM RADIATION

- ✓ EM radiation travels in Vacuum with speed of light
- ✓ Shorter the wavelength, higher is the energy carried by EM radiation
- ✓ Any object, whose temperature is above absolute zero (0 K) emits EM radiation
- ✓ Distribution of energy at each wavelength is not uniform (depends on temperature of object)
- ✓ A black body absorbs all radiation that reaches to it
- ✓ The integrated radiance (area under exitance curve) increases as T increases
- ✓ Peak radiance shifts towards shorter wavelength as T increases (Weins displacement law)
- ✓ Total spectral emittance by a black body at a temperature is governed by Stefan – Boltzmanns law

FACTS ABOUT EM WAVE BANDS

- ✓ Radio waves are used to transmit radio and TV signals
- ✓ Wavelength range: < 1 cm to hundreds of meters
- ✓ Radio waves are used in remote sensing to exchange information between satellite and ground station
- ✓ Natural objects DO NOT emit radio waves

- Microwaves are emitted from sun, earth surface, cars, planes, …
- Wavelength range: 1 mm to 300 cm
- Emitted microwaves are function of object temperature
- Active Microwaves: Ex: RADAR (high resolution remote sensing)

FACTS ABOUT EM WAVE BANDS

- ✓ RADAR
- ✓ Uses radio waves to determine the range, angle, or velocity of objects
- ✓ Consists of a transmitter producing electromagnetic waves in the radio or microwaves domain, a transmitting antenna, a receiving antenna (often the same antenna is used for transmitting and receiving) and a receiver and processor to determine properties of the object(s).
- ✓ LIDAR
- ✓ A surveying method that measures distance to a target by illuminating the target with pulsed laser light and measuring the reflected pulses with a sensor
- ✓ Used to make high-resolution maps, with applications in geodesy, geomatics, archaeology, geography, geology, geomorphology, seismology, f orestry

FACTS ABOUT EM WAVE BANDS

- ✓ Infrared region wavelength range: 0.7 μm to 1 mm
- ✓ Infrared region is divided into 3 sub regions
- ✓ Near IR (0.7 to 1.5 μm) – behaves like visible light, detected by special photographs and satellites
- ✓ Middle IR (1.5 to 3.0 μm) – Is of solar origin, reflected by earth surface
- ✓ Far IR (3.0 to 15.0 μm) – Emitted by earth surface, sensed as heat (thermal IR region). Much of emitted energy is absorbed by atmosphere
- ✓ Applications:

  Health of Crops

  Forest fires

  Heat leakage from houses

FACTS ABOUT EM WAVE BANDS

- ✓ Visible region wavelength range: 0.4 to 0.7 μm
- ✓ Contains BLUE, GREEN, and RED portions EM spectrum
- ✓ Sensed by human eye, photographic films, satellite sensors

- Ultraviolet region wavelength range: 0.01 to 0.4 μm
- Most of the UV is blocked (absorbed) by ozone
- Not used in satellite remote sensing

- ✓ X-rays wavelength region: 10^{-5} to 0.01 μm
- ✓ Used in medical applications, not in remote sensing

PRINCIPLES OF RADIOMETERY

- ✓ Radiometry deals with the quantitative measurement of electromagnetic radiation *(due to emission or interaction with matter)*
- ✓ Deals with transfer of radiation from source to detector through a medium for quantitative evaluation
- ✓ Radiometry → Deals with electromagnetic radiation *[all wavelengths]*
- ✓ Photometry → Light interaction that is detected by human eye *[visible band]*
- ✓ Radiometry is a set of techniques for measuring electromagnetic radiation, including visible light.
- ✓ Radiometry Involves the following steps:

    1) Measurement of Geometry

    2) Measurement of Spectrum

RADIOMETERS

Crookes Radiometer

Net Radiometer

Pyranometer

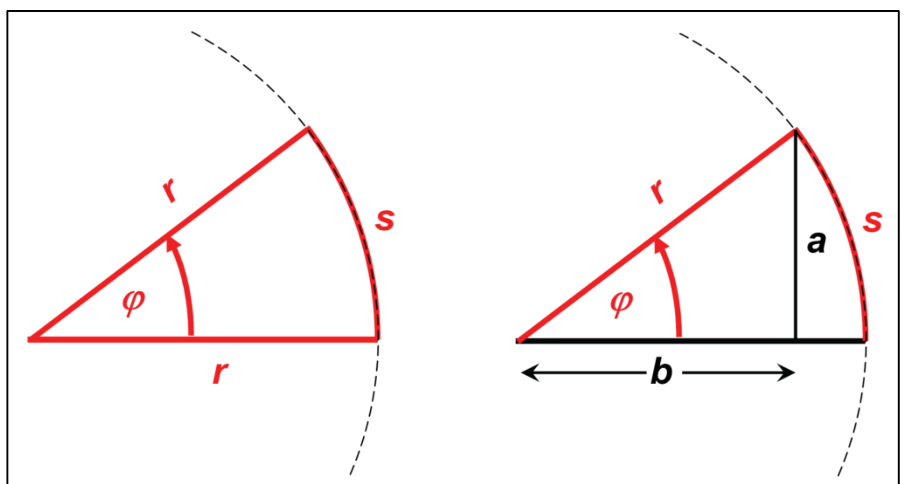
Wavelength and amplitude

Spectroradio meter

GEOMETRY MEASUREMENT

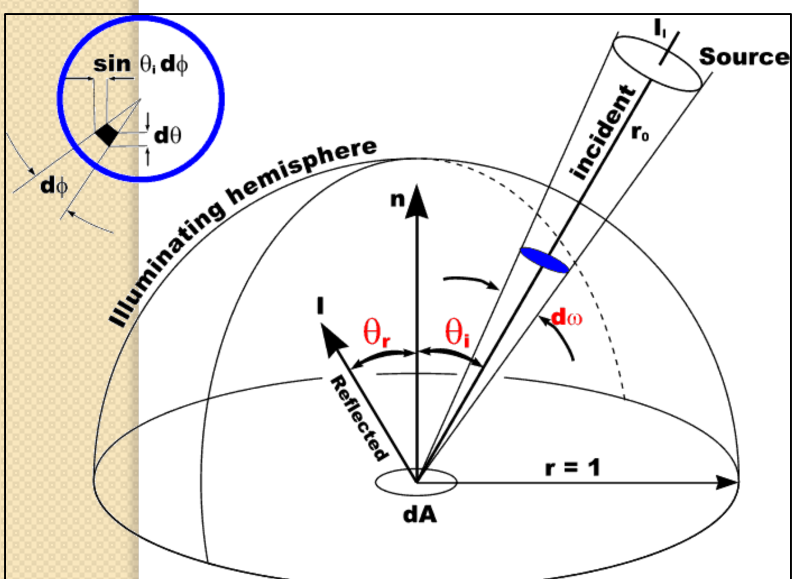
- ✓ Plane Angle *(ϕ)* → Angle contained by two straight lines meeting at a point
- ✓ Used in 2-D analysis
- ✓ In radians, it is the ratio of arc length *(s)* to radius *(r)*
- ✓ For small angles, the curvature of arc length is neglected

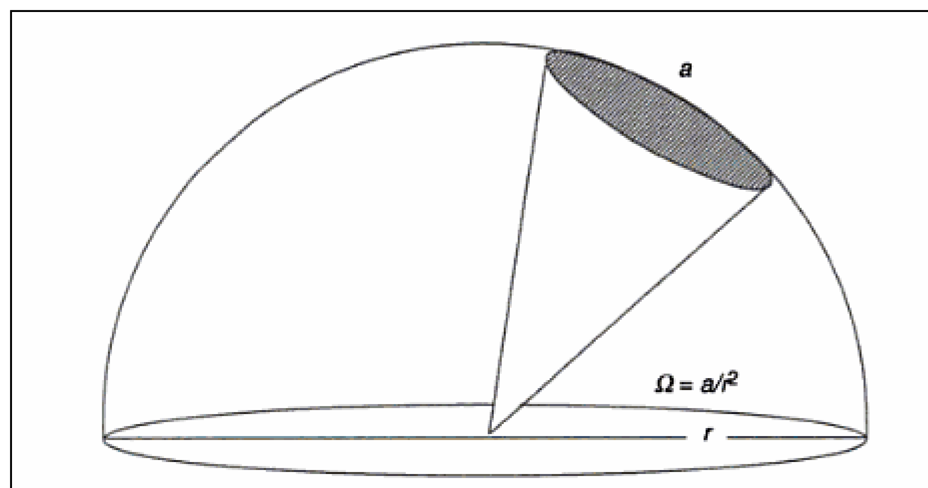
$$\emptyset = \frac{s}{r} \approx \frac{a}{r} = tan\emptyset$$



GEOMETRY MEASUREMENT

- ✓ Solid Angle (Ω) → The two dimensional angle in three-dimensional space that an object subtends at a point (centre)
- ✓ It is a measure of how large the object appears to an observer looking from that point.
- ✓ Measured in Steradians (dimensionless)
- ✓ Equal to the ratio of surface area of object to the square of the radius (A / r^2)
- ✓ Steradian is the solid angle subtended by area at a point
- ✓ For a spherical arrangement, $\Omega = 4\pi$





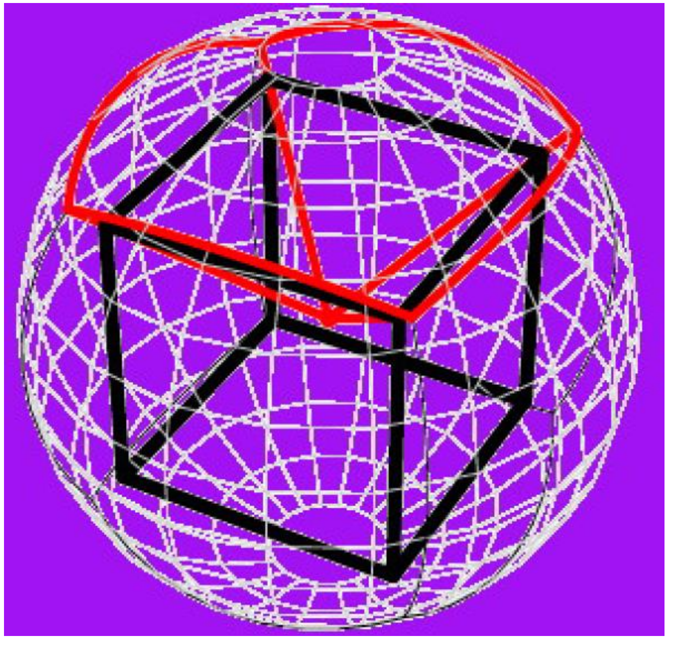
GEOMETRY MEASUREMENT

- ✓ Solid angle is a measure of, how big an object looks to an observer
- ✓ Solid angle is the angle made by the object (surface of interest) when projected on to a unit sphere
- ✓ A small object nearby may subtend the same solid angle as a larger object farther away
- ✓ For a sphere: Ω = 4 ∏
- ✓ For any other surface:

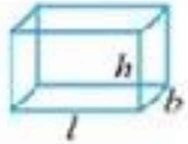
$$\Omega = \int\int_S \sin(\phi)\, d\theta\, d\phi$$

ϕ → Co latitude (0 to ∏) – Complementary latitude (angle from north pole)

θ → Longitude (0 to 2 ∏)

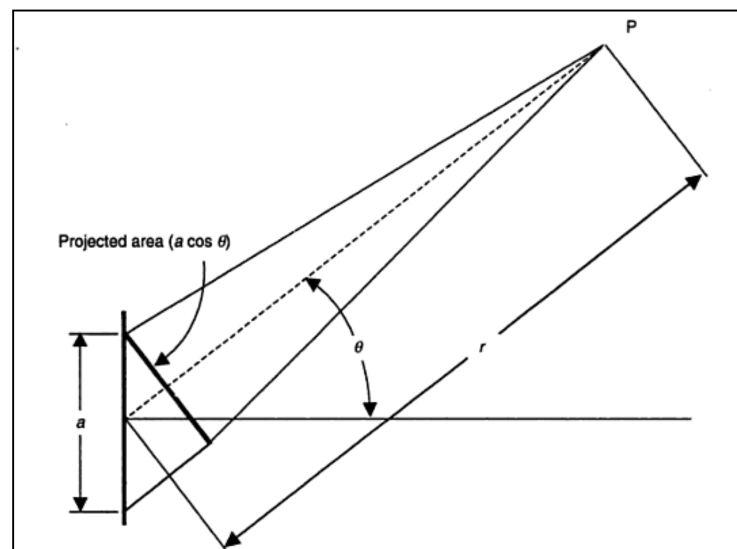


GEOMETRY MEASUREMENT

Name of the Solid	Figure	Lateral/Curved Surface Area	Total Surface Area
Cuboid		$2h(l + b)$	$2(lb+bh+hl)$
Cube		$4a^2$	$6a^2$
Right prism		Perimeter of base × height	Lateral surface area + 2 (area of one end)
Right circular cylinder		$2\pi rh$	$2\pi r(r+h)$
Right pyramid		$\frac{1}{2}$ (perimeter of base) × slant height	Lateral surface area + area of the base
Right circular cone		πrl	$\pi r(l+r)$
Sphere (Solid)		$4\pi r^2$	$4\pi r^2$
Hemisphere (Solid)		$2\pi r^2$	$3\pi r^2$

GEOMETRY IN REMOTE SENSING

- ✓ Solid Angle subtended by a flat surface *(rather than curved surface)* is to be considered for RS applications
- ✓ Ex: Solid angle made by ground pixel *(photograph)* at the lence
- ✓ Flat area estimates can be used in place of spherical areas, when solid angle is less than 0.03 Steradians *(Less than 1 % error)*
- ✓ Solid Angle of a surface *(area: a),* whose normal is making an angle 'θ' in Steradians is given by: $\frac{aCos\theta}{r^2}$
- ✓ *Projected area has to be considered*



RADIOMETRIC MEASUREMENTS

I) RADIANT ENERGY (Q)

- Quantity of energy carried by electromagnetic radiation (stream of photons)
- Calculated by integrating radiant flux (or power) with respect to time
- Measure of capability to perform physical work (heat, change of state, movement, …) when interacting with matter
- Consists of energy at all wavelength bands
- Expressed in Joules (Ws)
- Radiant energy at a specific wavelength is called as spectral radiant energy (Q_A)

$$Q_A = \frac{dQ}{d\lambda}$$

RADIOMETRIC MEASUREMENTS

2) RADIANT FLUX (RADIANT POWER) - ϕ

- Rate at which, the radiant energy is emitted (or, transmitted, or received) in the form of EM radiation from a point (source) to the surface
- Represents energy per unit time *(Power)*
- Measured in Joules per Sec (or, Watts)

$$\emptyset = \frac{dQ}{dt}$$

- Spectral radiance flux is the transfer of radiant flux per unit wavelength at a given wavelength λ

$$\emptyset_\lambda = \frac{d\emptyset}{d\lambda}$$

RADIOMETRIC MEASUREMENTS

3) IRRADIANCE (E)

- Measure of radiant flux per unit area
- Expresses in Watts per square meters

$$E = \frac{d\emptyset}{dA}$$

- If the surface is not perpendicular to the direction of propagation of EM wave, projected area has to be considered
- Projected Area = $dACos\theta$
- Irradiance (E) → Flux density of radiant flux arriving at a surface
- Exitance (M) → Radiant flux emitted (leaving) from a surface
- Exitance from a source is inversely proportional to the square of the radial distance from the source

RADIMETRIC MEASUREMENTS

4) RADIAL INTENSITY (I)

- Radiant flux leaving a source per unit solid angle in a given direction
- Expressed in Watts per Steradians

$$I = \frac{d\emptyset}{d\omega}$$

- If a point source radiates equally in all directions *(isotropic)*, I = ϕ / 4 π

5) RADIANCE (L)

- Radiant flux per unit solid angle leaving an extended source in a given direction per unit projected area in the direction
- Expresses in Watts per Steradians per square meters

$$L = \frac{d^2\Phi}{d\Omega dA \cos\theta}$$

RADIMETRIC MEASUREMENTS

S. No.	Quantity	Symbol	Unit	Definition
1.	Radiant energy	Q	joule	Quantity of energy carried. Is a measure of the radiation to do work.
2.	Radiant flux (radiant power)	Φ	watts	Radiant energy emitted or incident upon a surface per unit time. That is, rate of flow of energy.
3.	Irradiance	E	watts m^{-2}	Radiant flux falling per unit area of the surface.
	Exitance	M	watts m^{-2}	Symbol M is used for radiant flux emitted by unit area.
4.	Radiant intensity	I	watts sr^{-1}	Radiant flux leaving per unit solid angle, in a specified direction.
5.	Radiance	L	watts $m^{-2}sr^{-1}$	Radiant flux per unit projected area and per unit solid angle.

Table 3.1 Radiometric quantities and units.

ENERGY INTERACTIONS

SCATERING

- Re-direction of EM waves by particles suspended in the atmosphere (or) by gas molecules
- Amount of scattering depends on:
    - a) Size (Diameter) of the particles
    - b) Abundance
    - c) Wavelength of EM wave
    - d) Depth of atmosphere through which EM wave is passing
- Amount of Scattering increases as wavelength becomes shorter (Rayleigh's Scattering – Considering NO atmospheric impurities)
- Scattering $\alpha \frac{1}{\lambda^4}$
- Blue and UV spectra are not useful in remote sensing due to high scattering

ENERGY INTERACTIONS

SCATERING ..

- **Rayleigh scattering** occurs when particles (small specks of dust or nitrogen and oxygen molecules) are very small compared to the wavelength of the radiation.
- Rayleigh scattering causes shorter wavelengths of energy to be scattered much more than longer wavelengths.
- Rayleigh scattering is the dominant scattering mechanism in the upper atmosphere.
- The fact that the sky appears "blue" during the day is because of this phenomenon
- At sunrise and sunset the light has to travel farther through the atmosphere than at midday and the scattering of the shorter wavelengths is more complete; this leaves a greater proportion of the longer wavelengths to penetrate the atmosphere

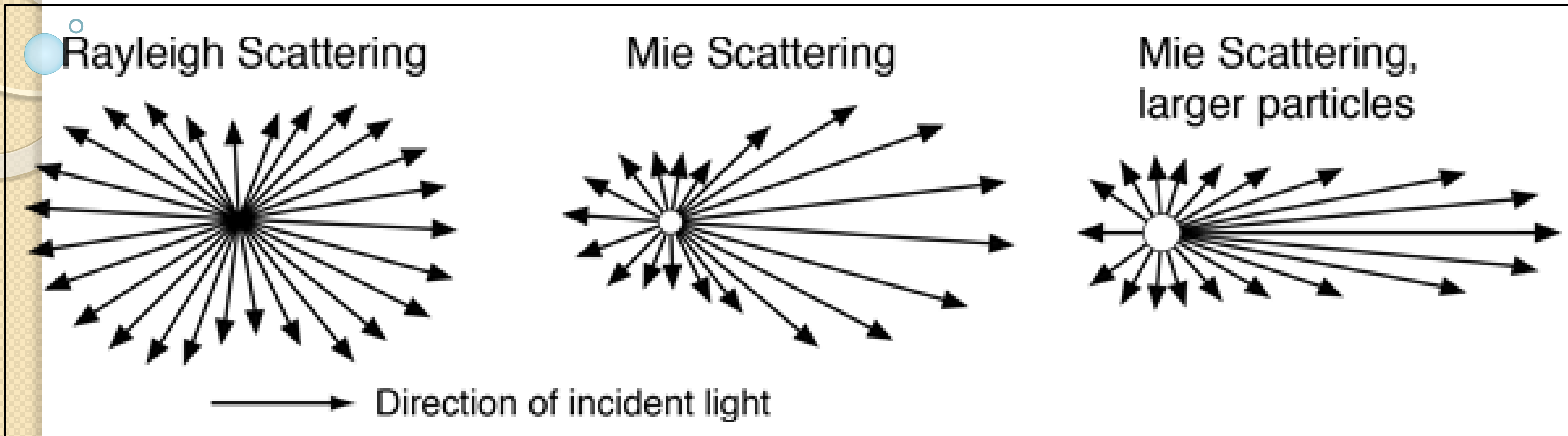
ENERGY INTERACTIONS

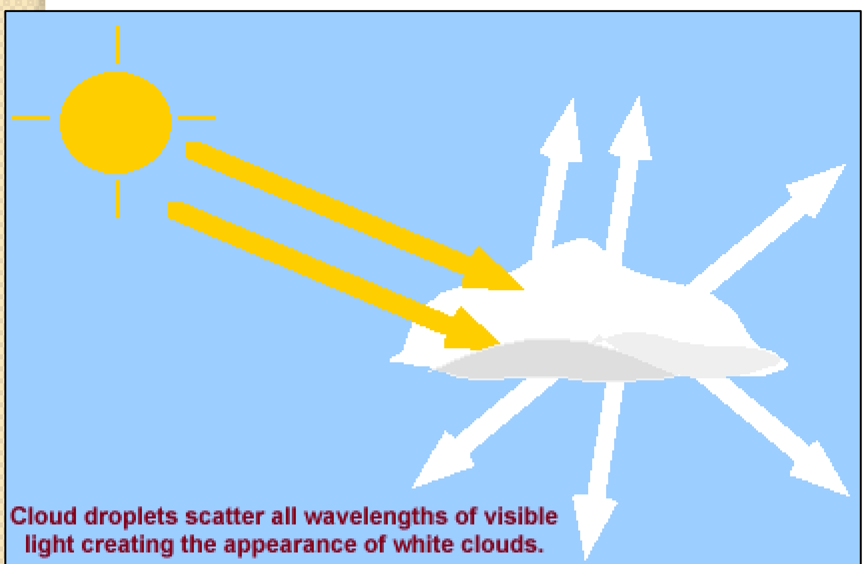
SCATERING ..

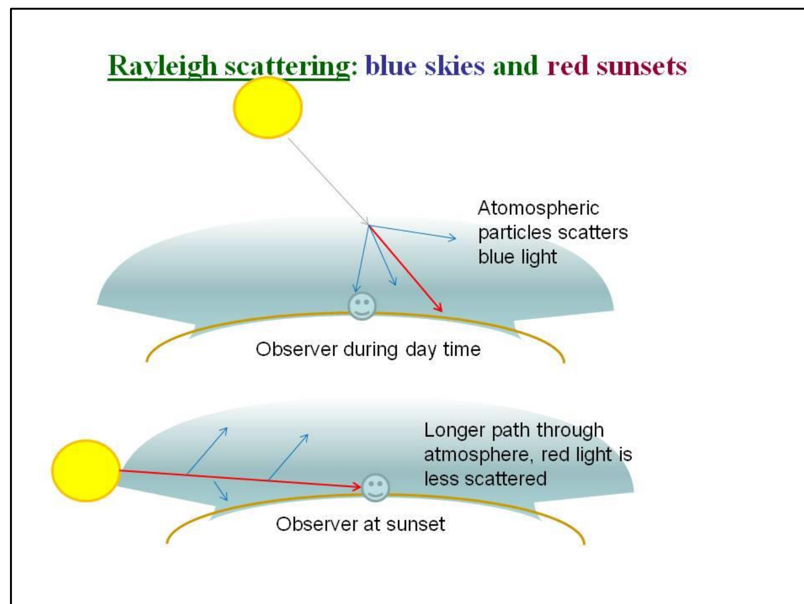
- **Mie scattering** occurs when the particles are just about the same size as the wavelength of the radiation.
- Dust, pollen, smoke and water vapour are common causes of Mie scattering that tends to affect longer wavelengths than those affected by Rayleigh scattering
- Mie scattering occurs mostly in the lower portions of the atmosphere where larger particles are more abundant, and dominates when cloud conditions are overcast
- **Non-selective scattering** occurs when the particles are much larger than the wavelength of the radiation
- Water droplets and large dust particles can cause this type of scattering
- all wavelengths are scattered about equally (hence, non-selective)
- This type of scattering causes fog and clouds to appear white

ENERGY INTERACTIONS

SCATERING ..







ENERGY INTERACTIONS

REFRACTION

- Bending of the EM waves at the intersection of two transmitting media
- Ex: Apparent displacement of objects submerged in clear water
- Refraction index (n) is given by:

$$n = \frac{Velocity\ of\ light\ in\ Vaccum\ (c)}{Velocity\ of\ light\ in\ given\ material\ (cn)}$$

Refraction of light is governed by Snell's law

$$\frac{Sin\theta_1}{Sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

v → Velocity of EM wave in medium

n → Refractive index of the medium

ENERGY INTERACTIONS

ABSORPTION

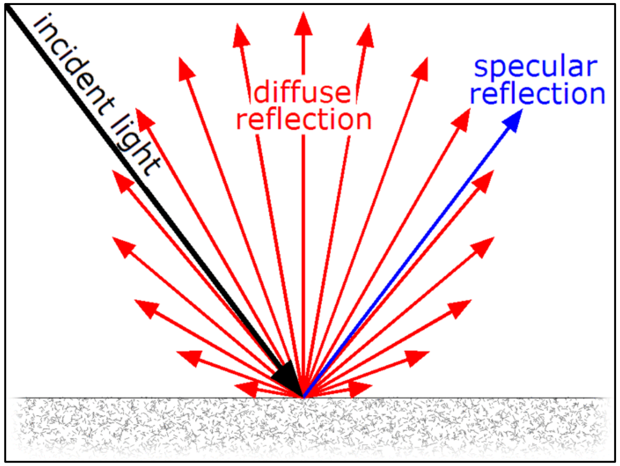
- Absorption occurs when electromagnetic radiation interacts with the atmosphere causes molecules in the atmosphere to absorb energy at various wavelengths
- Ozone, carbon dioxide, and water vapour are the three main atmospheric constituents which absorb radiation
- **Ozone** serves to absorb the harmful ultraviolet radiation from the sun
- Carbon dioxide tends to absorb radiation strongly in the far infrared portion of the spectrum - associated with thermal heating - which serves to trap this heat inside the atmosphere.
- Water vapour in the atmosphere absorbs much of the incoming longwave infrared and shortwave microwave radiation

REFLECTION CHARACTERISTICS

SPECULAR REFLECTION

- ❖ Angle of incident = Angle of Reflection
- ❖ Incident ray, Reflected ray, and Normal to the plane of incident all are in same plane
- ❖ Reflection from a surface that obeys Snell's law is called Specular Reflection
- ❖ Ex: Reflection from a Mirror

DIFFUSE REFLECTION



- ➢ Incident ray will be reflected at many angles rather than at just one angle
- ➢ Ex: Reflection from a non-absorbing powder (plaster)

LAMBERTIAN SURFACE

- If the emergent radiance is constant in all directions in a hemispherical solid angle, the surface is known as Lambertian surface
- Also known as, diffusively reflecting surface
- A sensor with a certain solid angle will give the same output when observing a Lambertian surface irrespective of the angle that the sensor makes with the surface
- The Lambertian surface obeys Lambertian Cosine Law:

$$I(\theta) = I_0 Cos\theta$$

I(ϑ) → Intensity at an angle θ with normal to the surface

I_0→ Intensity at θ = 0

- Apparent brightness of the surface to an observer is the same regardless of observer's angle of view

REFLECTION CHARACTERISTICS

REFLECTANCE (ρ)

- Ratio of reflected flux to incident flux
- Ranges from 0 to 1

REFLECTANCE FACTOR (R)

- Ratio of radiant flux reflected within a solid angle in a direction to that reflected in the same direction by Lambertian surface

ALBEDO

- Ratio of total solar radiant energy returned by a body to the solar radiant energy incident on the body

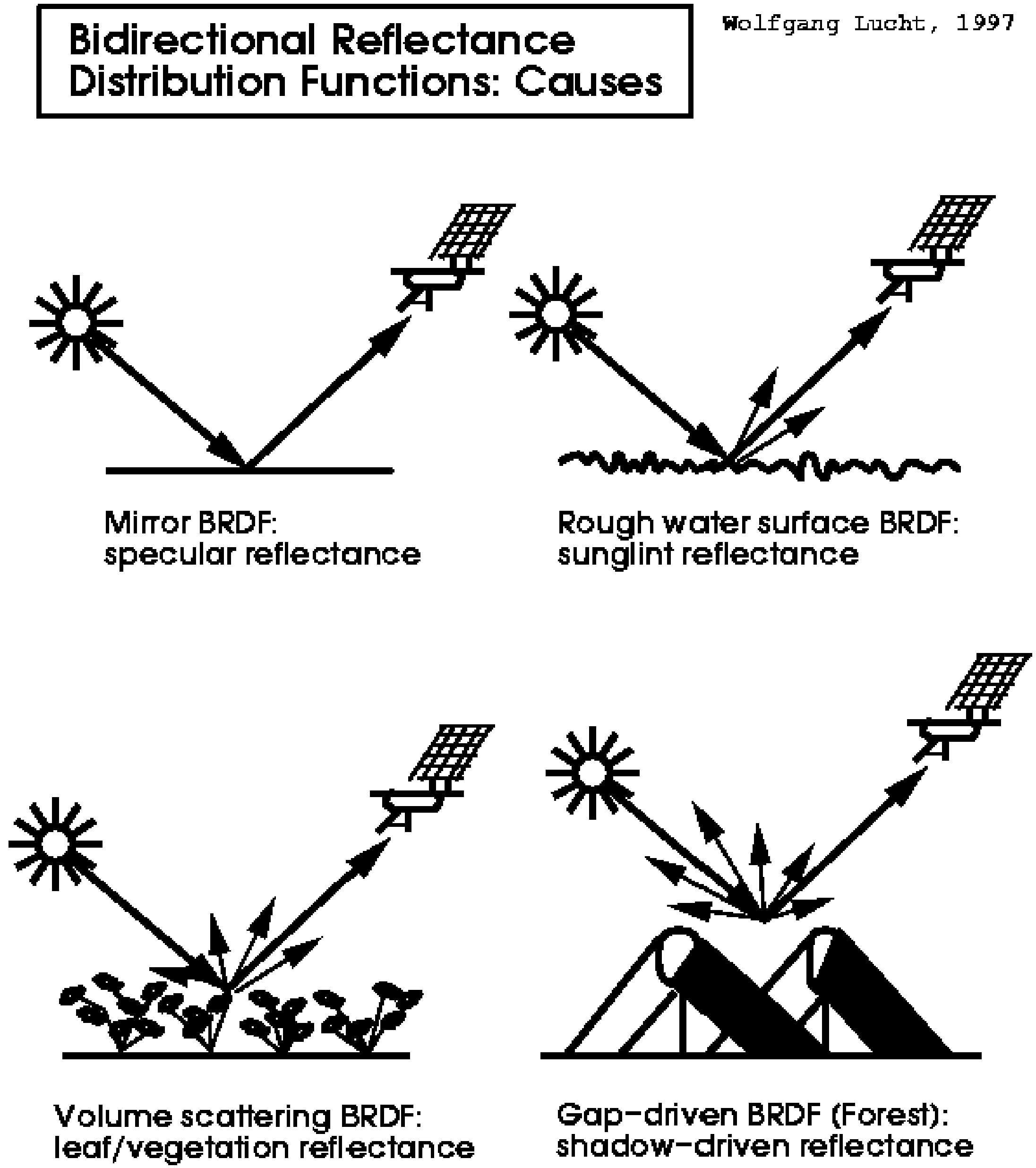
BRDF

- BRDF defines how light is reflected at an opaque surface
- It is a function of four real variables that defines how light is reflected at an opaque surface
- If surface is rough (relative to wavelength), it acts as a diffuse reflector
- If surface is smooth (relative to wavelength), it acts as a specular surface
- Concept of diffuse reflection obeys Lambertian law
- However, Lambertian model doesnot hold precisely for natural surfaces
- Reflection characteristics of a surface are characterized by

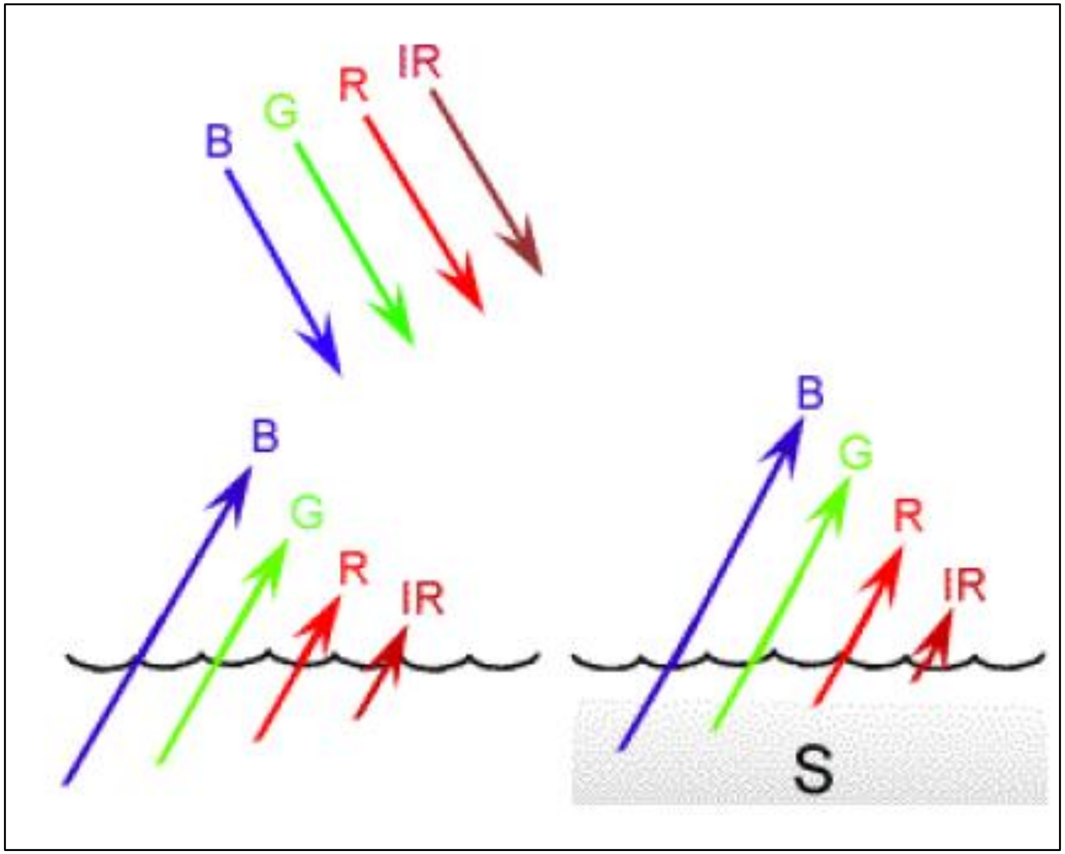
  Bidirectional Reflection Distribution Function (BRDF)

- BRDF is a mathematical description of optical behaviour of the surface with respect to angle of illumination and observance
- Gives the reflectance of an object as a function of illumination geometry and viewing geometry (azimuth and zenith).

BRDF

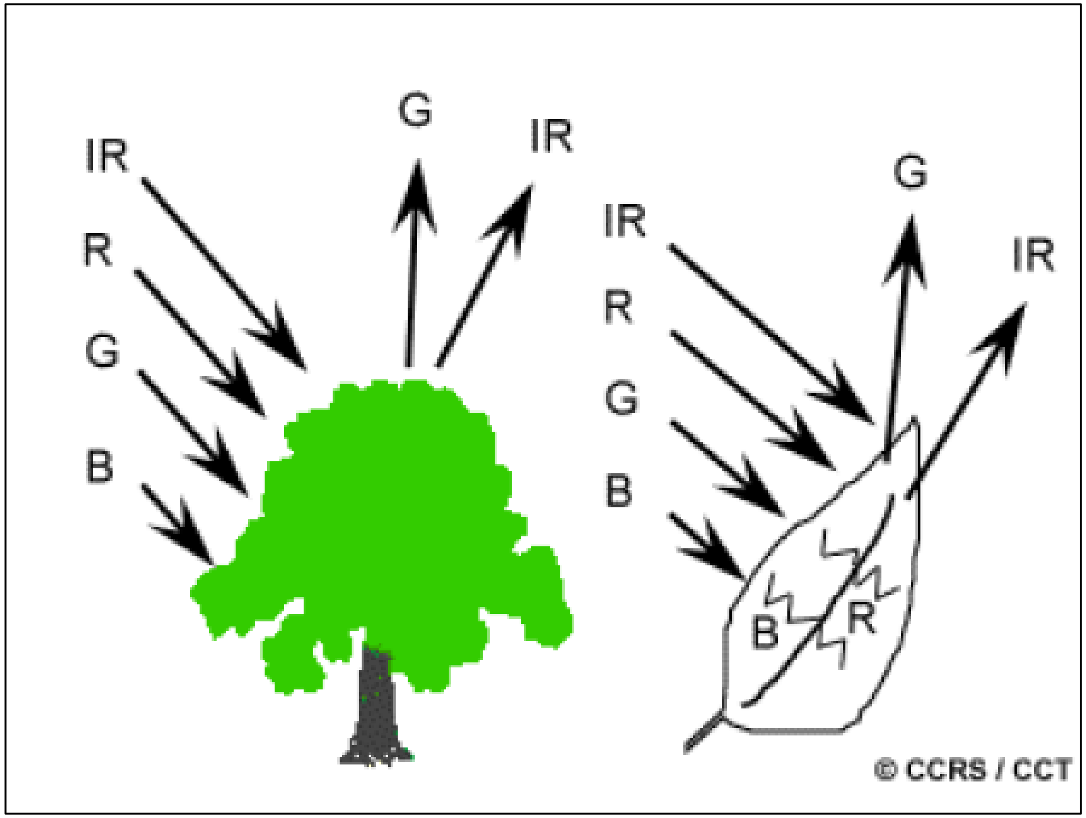

Bidirectional Reflectance
Distribution Functions: Causes
Wolfgang Lucht, 1997
Mirror BRDF:
specular reflectance
Rough water surface BRDF:
sunglint reflectance
Volume scattering BRDF:
leaf/vegetation reflectance
Gap-driven BRDF (Forest):
shadow-driven reflectance

REFLECTION CHARACTERISTICS



Water → Longer wavelengths are absorbed
More the sediments (S), more is reflection

REFLECTION CHARACTERISTICS

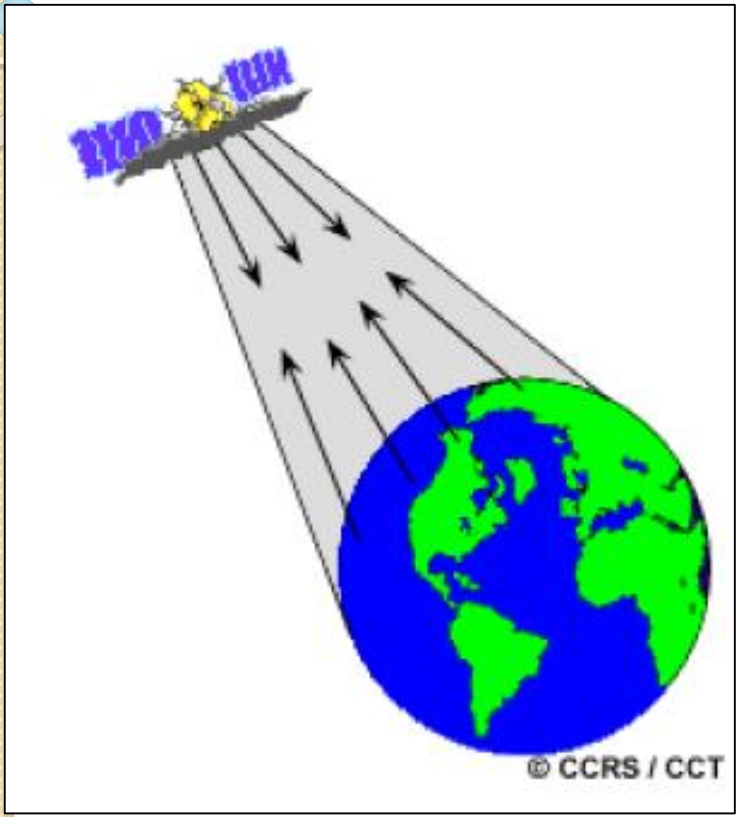


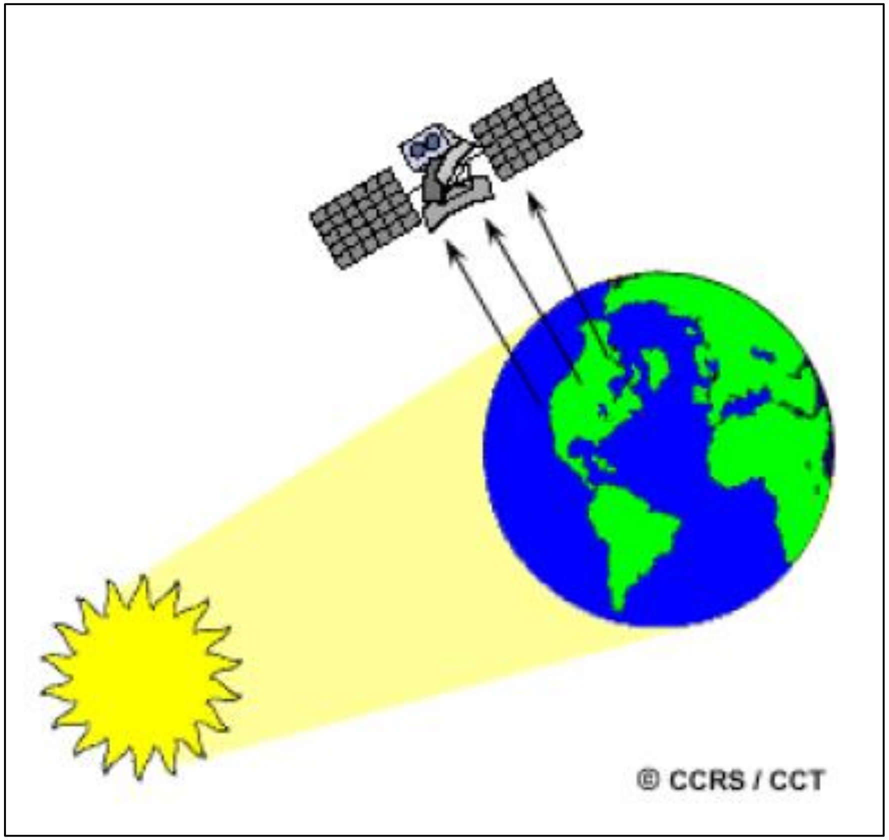
Leaves → Appear Green in Summer ; Red in Autumn

ACTIVE vs PASSIVE REMOTE SENSING

- Remote sensing systems which measure energy that is naturally available are called passive sensors
- Passive sensors can only be used to detect energy when the naturally occurring energy is available
- Active sensors provide their own energy source for illumination
- The sensor emits radiation which is directed toward the target to be investigated
- Able to obtain measurements anytime regardless of the time of day or season
- used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated

ACTIVE vs PASSIVE REMOTE SENSING





QUESTIONS ????