Optical Remote Sensing

Basic Physics

- Radiometry
- Reflectance

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1. Radiometry

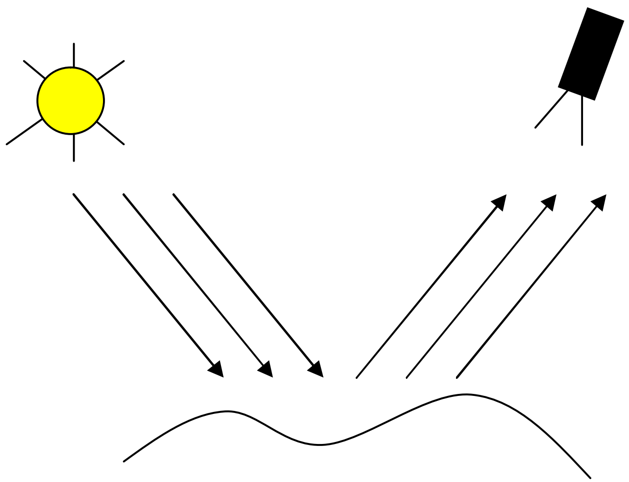
Basic Definitions

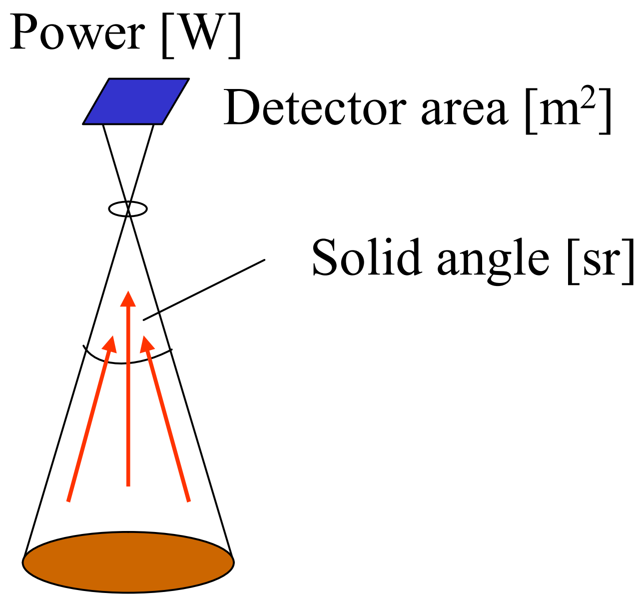
- **Radiant Energy** **Q** [J] = [W s]
- **Radiant Power**, or: photon flux **Φ** [W] = dQ/dt
  i.e. Energy per time interval
- **Radiant Flux F** [W m^{-2}]
  E: irradiance // M: emittance (thermal sources)
  i.e. Power per area
  sun: irradiance is flux perpendicular to propagation (directional flux)
  general term of flux: includes hemispherical radiation
- **Radiant Intensity** **I** [W sr^{-1}]
  i.e. Power per solid angle
- **Radiance** **L** [W m^{-2} sr^{-1}]
  i.e. Power per (detector) area and solid angle
- **Spectral quantities, e.g. spectral radiance: L per bandwidth**:
  L_λ [W m^{-2} sr^{-1} µm]

- The sensor detects:

Radiance, At-Sensor Radiance L [W m^{-2} sr^{-1}] or [W m^{-2} sr^{-1} µm]

=> Unit after system correction, described as L1 product

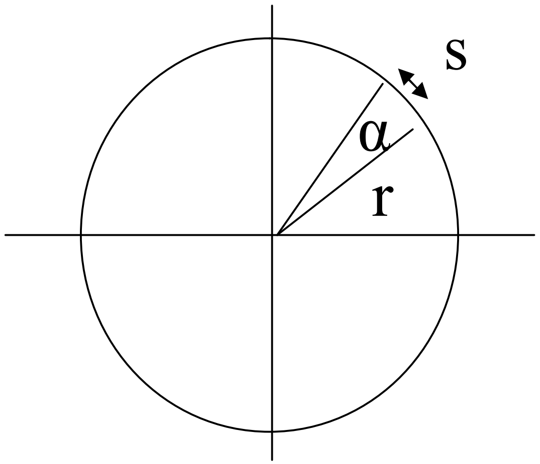




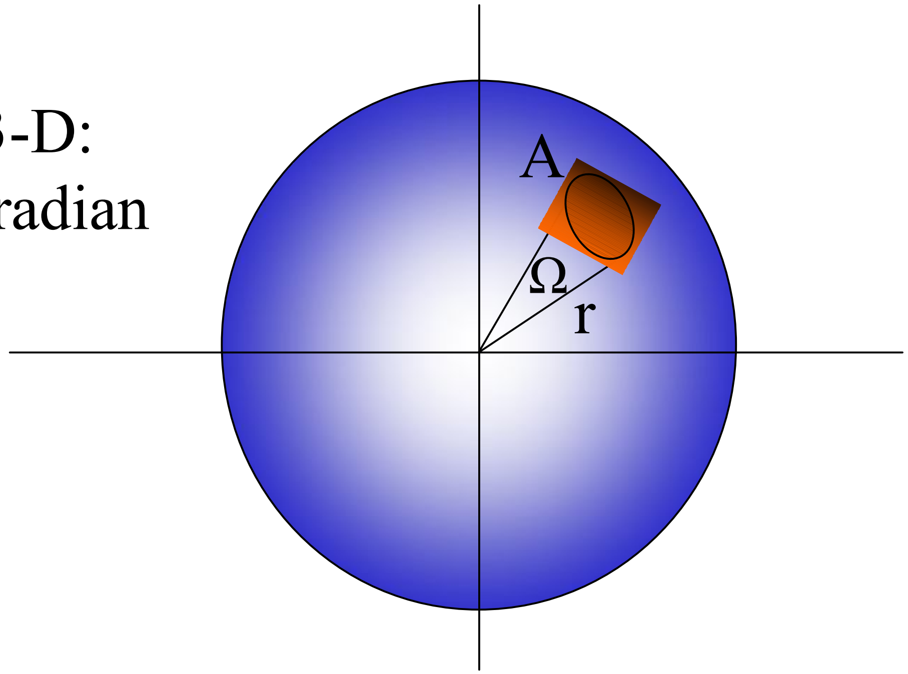
Physical Basics

- Solid Angle Ω steradian = area / radius²
- Sphere = $4\pi r^2 / r^2 = 4\pi$ [sr]
- Sky = 2π [sr]

In 2-D:
Radian



In 3-D:
Steradian



German Remote Sensing Data Center

Physical Basics

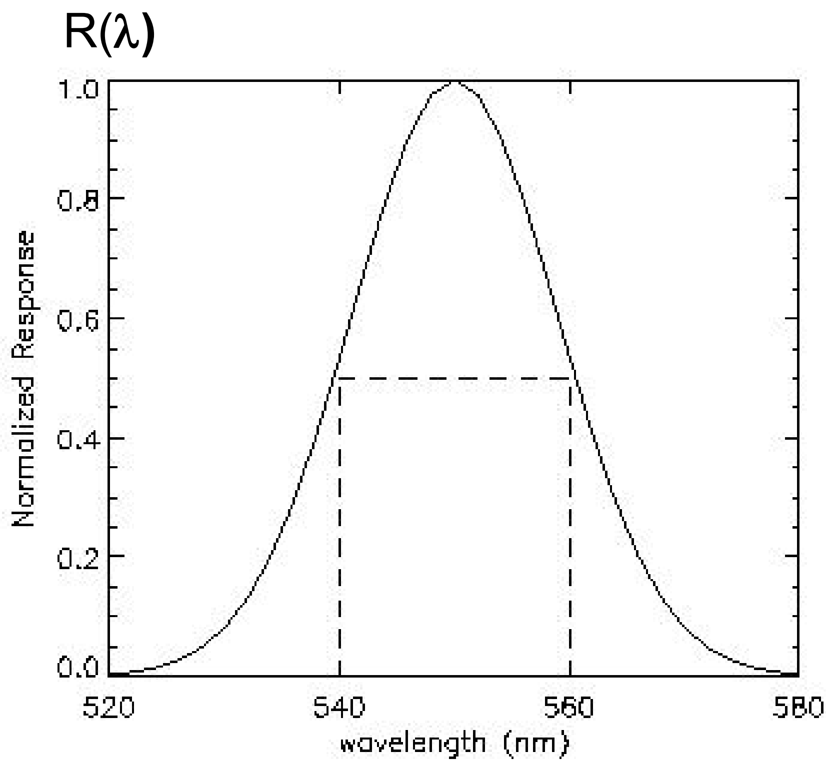
Spectral Response R(λ) : relative or
normalized: 0 - 1

absolute: $R_{abs} = c\, R_{norm}$

meas.: $L = \int R_{abs}(\lambda)\, L(\lambda)\, d\lambda \quad (W\, m^{-2}\, sr^{-1})$

normalized:

$$L_{\Delta\lambda} = \frac{\int R(\lambda)\, L(\lambda)\, d\lambda}{\int R(\lambda)\, d\lambda} \quad (W\, m^{-2}\, sr^{-1}\, nm^{-1})$$



Spectral Resolution (bandwidth):

(full width at half max FWHM, Δλ)

Advantage of normalized radiance :
nearly independent of R(λ)

<u>Normalized</u> is sufficient in most cases:

$$\rho = \frac{\pi\, L_{abs}}{E_{abs}} = \frac{\pi\, c\, L_{norm}}{c\, E_{norm}} = \frac{\pi\, L_{\Delta\lambda}}{E_{\Delta\lambda}}$$

Nomenclature: $L, L(\lambda), L_{\lambda}, L_{\Delta\lambda}$ Pay attention to unit!

Physical Basics

- Planck:

  Emittance $M = f(\lambda, T)$

- Boltzmann:

  $M_{blackbody} = \sigma\ T^4$ [W m^{-2}]

  $\sigma = 5.67 * 10^{-8}$ W m^{-2} K^{-1}

  In general: $M = \varepsilon(\lambda)\ T^n$

  n…property of material, ~4

- Wien:
  The higher the temperature (T) the shorter the wavelength (λ_{max}) of maximal energy emittance

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

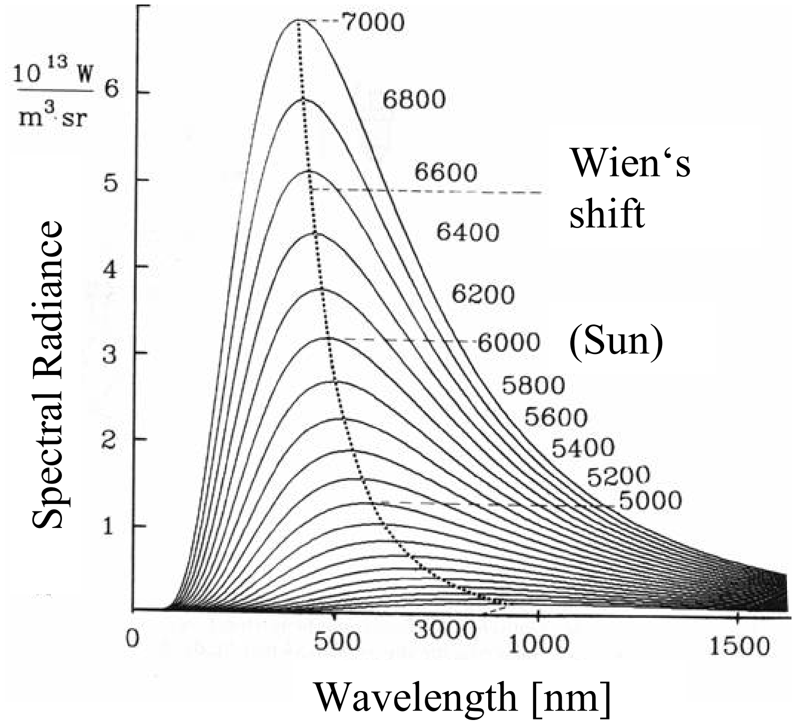
Physical Basics

- Electromagnetic wave (Maxwells Equation)
- Electric vector perpendicular to magnetic
- $c = \lambda * v$ c…Lightspeed in vacuum $3*10^{8}$ m s^{-1}
  v…Frequency

- Energy $q = h * v$
  h: Planck's Constant: $6.63 * 10^{-34}$ [J s]
  ➔ Higher energy per photon with shorter wavelength

- Energy per Photon: green 0.55 µm ➔ $3.61 * 10^{-19}$ J
  TIR 12 µm ➔ $1.66 * 10^{-20}$ J

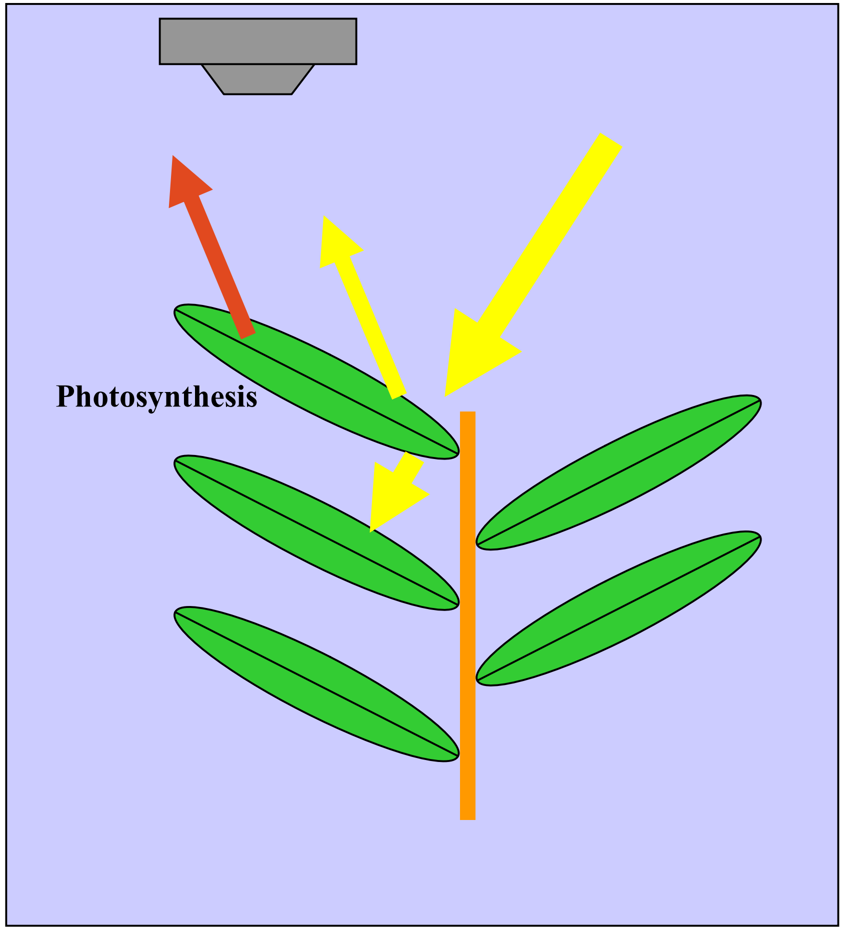
  ➔ 22times higher energy!



2: Interaction with Matter

Physical basics

- Absorption (uptake of energy)
  - Electron transfer, rotation, vibration
    - Heating, change in matter, emission
- Emission („release“ of energy)
  - Electron transfer, rotation, vibration
- Reflection
  - Change of direction without energy uptake
- Transmission
  - Transfer without absorption or reflection



Physical basics

Energy balance relationship:

- $E_{\text{emitted by sun}} = E_{\text{reflected}} + E_{\text{transmitted}} + E_{\text{absorbed}}$

  E… Incident Energy [W]

- $1 = E_r / E_i + E_t / E_i + E_a / E_i$
- $1 = R + T + A$

  …Reflection-coefficient + Transmission-coefficient + Absorption-coefficient

- opaque material: $T = 0$ ➔ $1 = R + A$

=> Material property, independent of incomig radiant energy!

Absorption

- Sounds pretty simple, **but**:
  - Some features are related to many materials: e.g. OH bond is related to water, cellulose, starch, clays etc.
  - Overlapping features
  - Multiple scattering broadens features
  - No simple relationship between feature depth and component content (saturation effects)
  - In Vivo ≠ In Vitro
  - Noise, spectral bandwidth and position, …

3: Reflectance Behavior

Physical basics

Reflection behaviour of surfaces

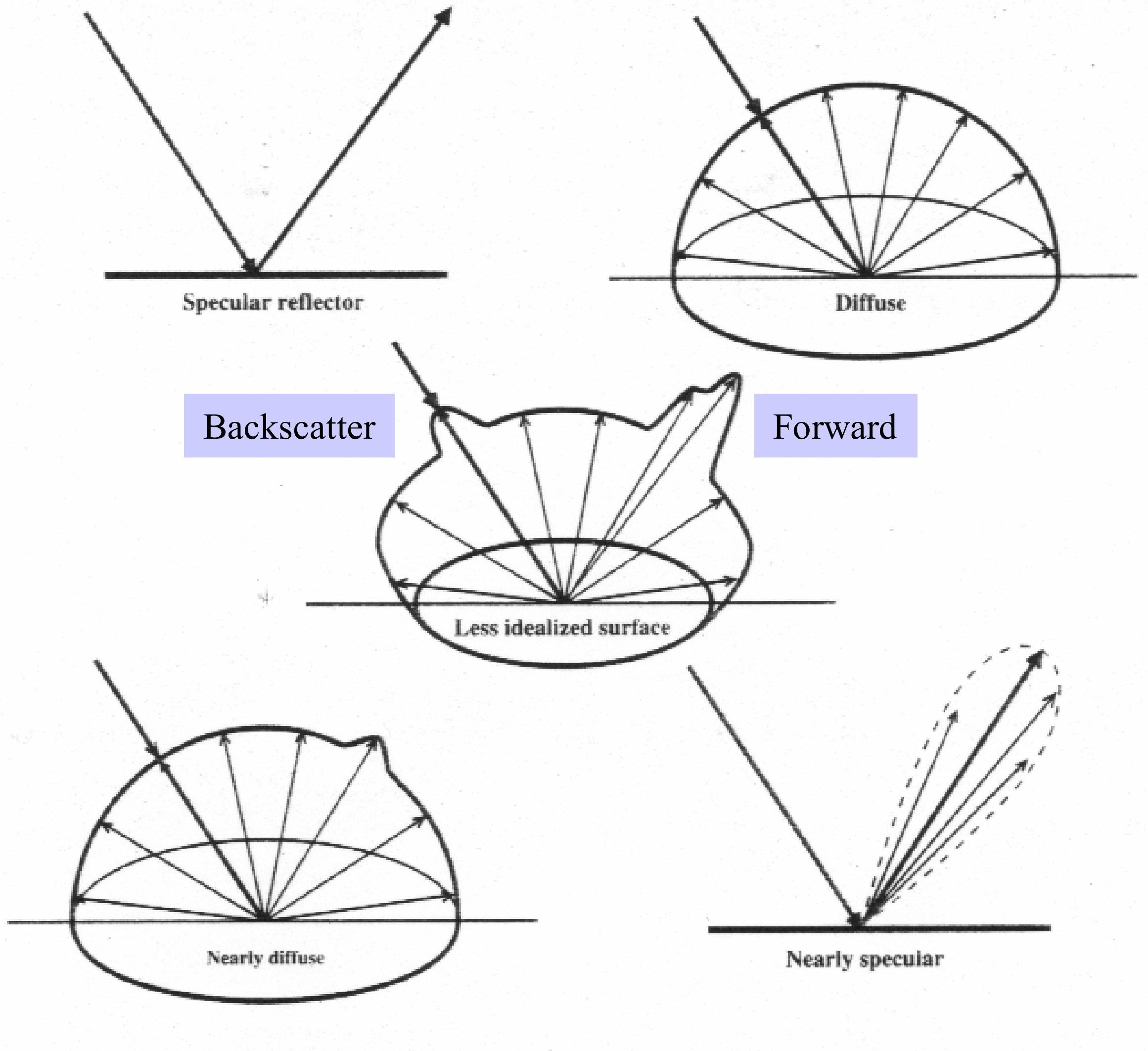
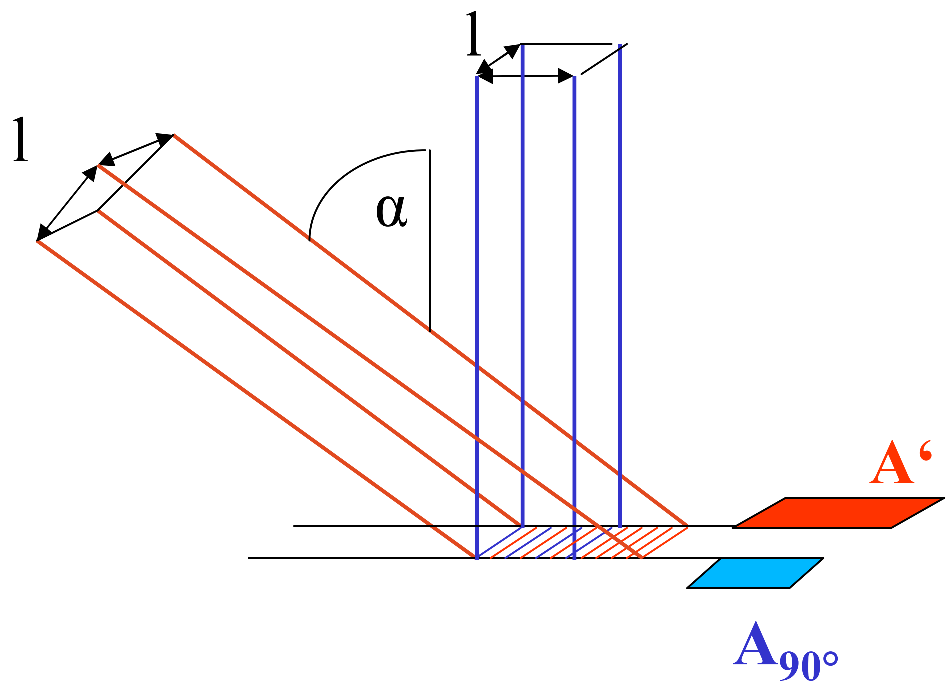


Figure 4.7 Reflectance characteristics of idealized surfaces.

Physical Basics

Lambertian Cos.-Law



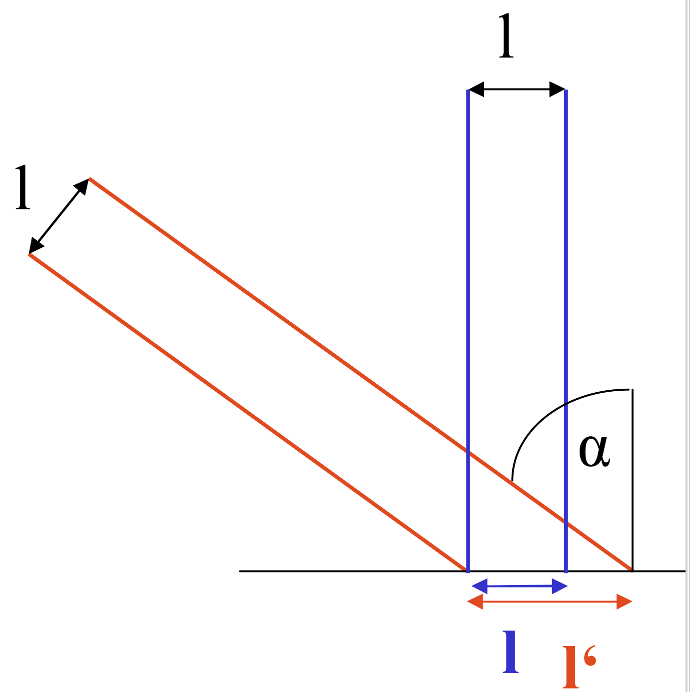
Area $A' = A_{90^\circ} / \cos \alpha$

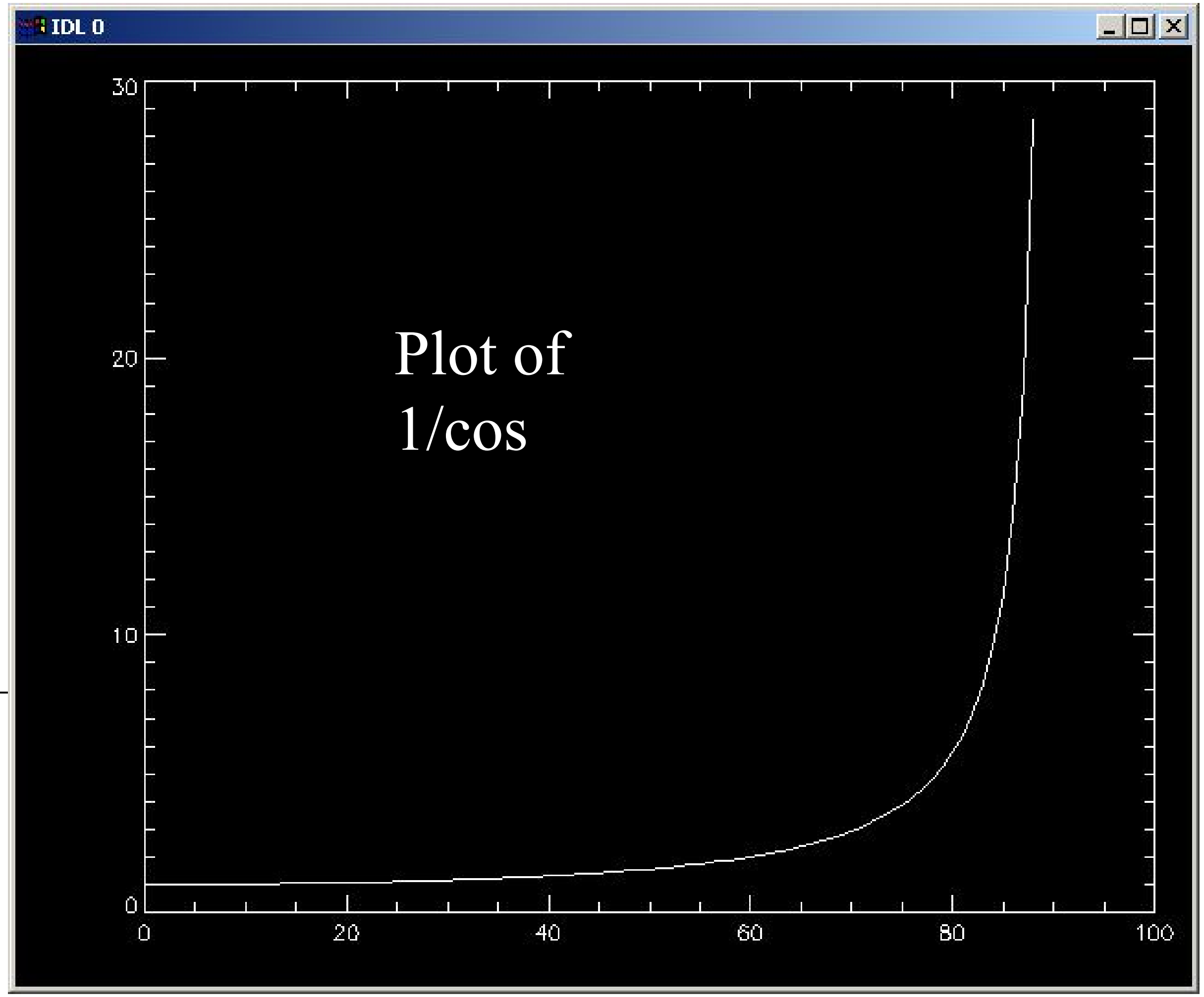
Radiant Flux [W m^{-2}]

$E_\alpha = E_0 \cos \alpha$

Physical Basics

Lambertian Cos.-Law

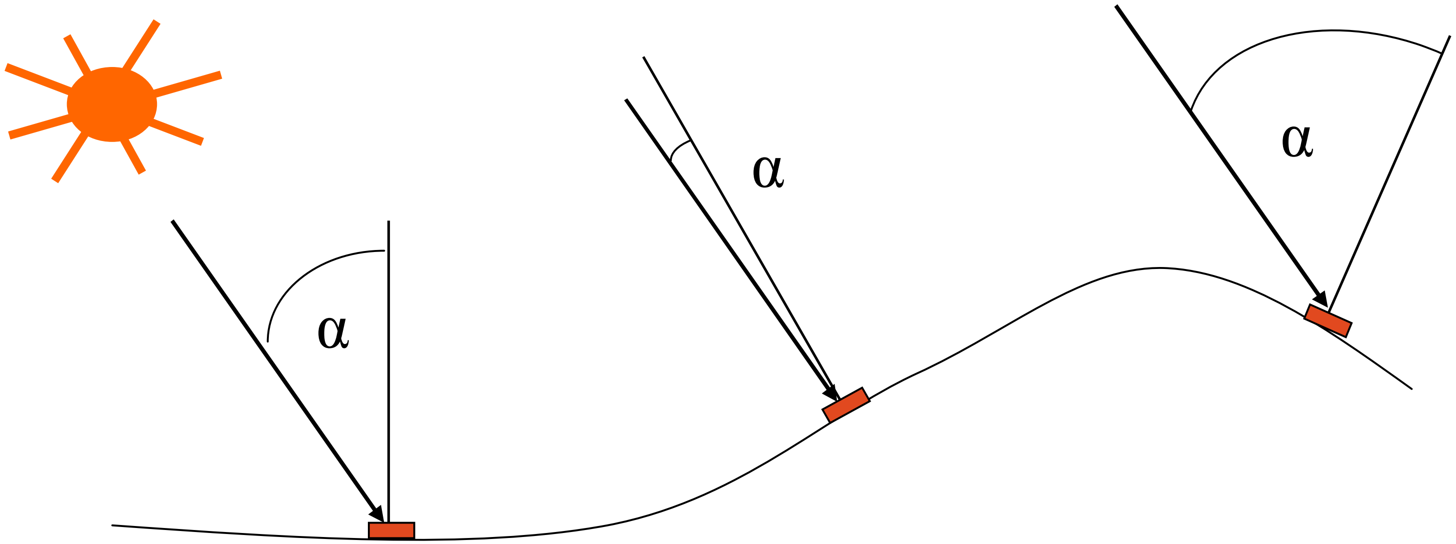




Physical basics

Radiant Flux [W m^{-2}] $E_\alpha = E_0 \cos \alpha$

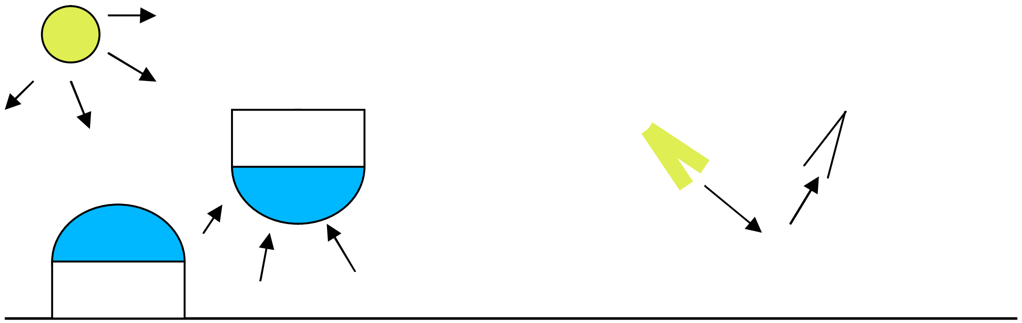
=> Illumination condition depends on relief & sun angle



… Reflectance Nomenclature:

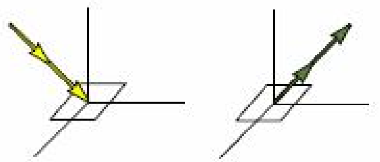
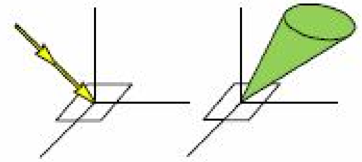
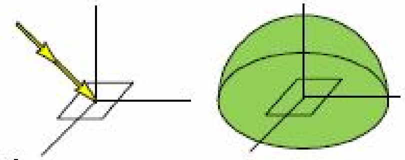
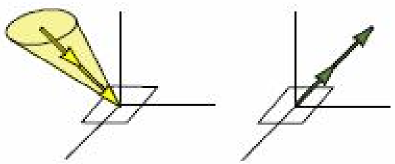
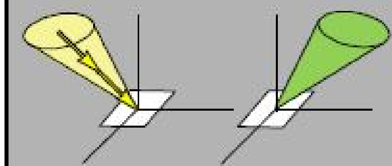
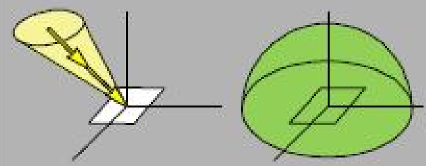
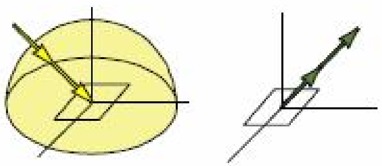
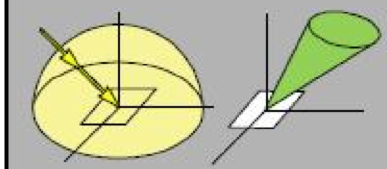
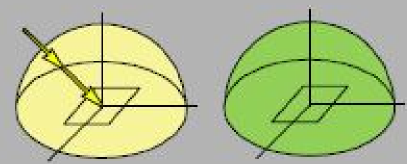
Physical Basics

- Bidirectional
  directional illumination, observation in one direction
- Directional - hemispheric
  directional illumination, observation of hemisphere
- Hemispheric - directional
  hemispherical illumination, observation in one direction
- Hemispheric - hemispheric
  hemispherical illumination, observation of hemisphere



Hemispheric Directional

Physical Basics

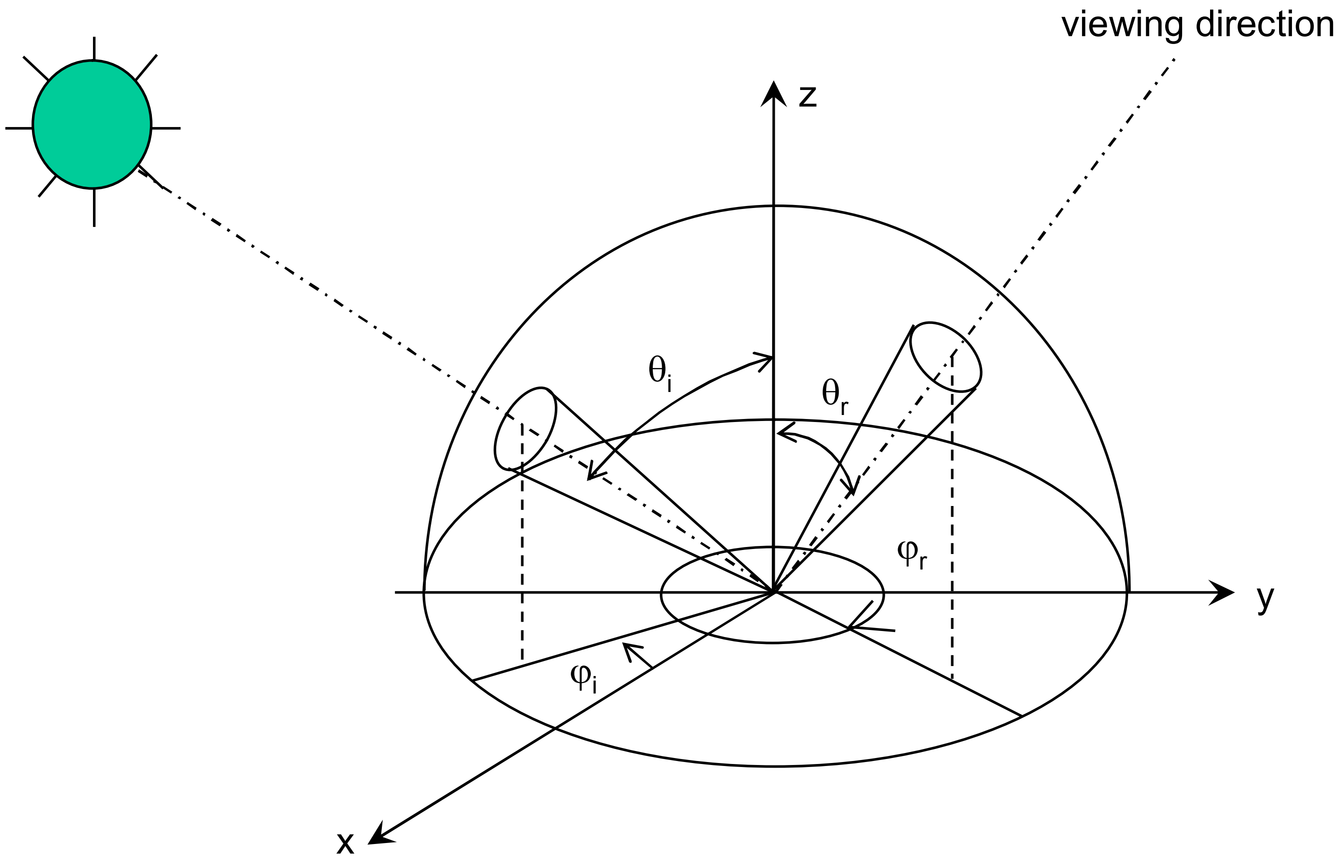
Incoming/**Reflected**	**Directional**	**Conical**	**Hemispherical**
Directional	Bidirectional Case 1 	Directional-conical Case 2 	Directional-hemispherical Case 3 
Conical	Conical-directional Case 4 	Biconical Case 5 	Conical-hemispherical Case 6 
Hemispherical	Hemispherical-directional Case 7 	Hemispherical-conical Case 8 	Bihemispherical Case 9 

Schaepman-Strub, RSE 2006

Physical Basics

BRDF

Bidirectional Reflectance Distribution Function



Physical Basics

- BRDF
  $L_\lambda = \rho_\lambda E_\lambda (\cos \Theta) f_r$ f_r = bidirectional reflectance distribution function
  for Lambertian surfaces.: $\rho_\lambda = (L \lambda \pi) / (E \lambda \cos \Theta)$
- Shade due to surface roughness
- HotSpot-effect:

If view direction = illumination direction => no shade visible
=> brighter & specular => no Lambertian

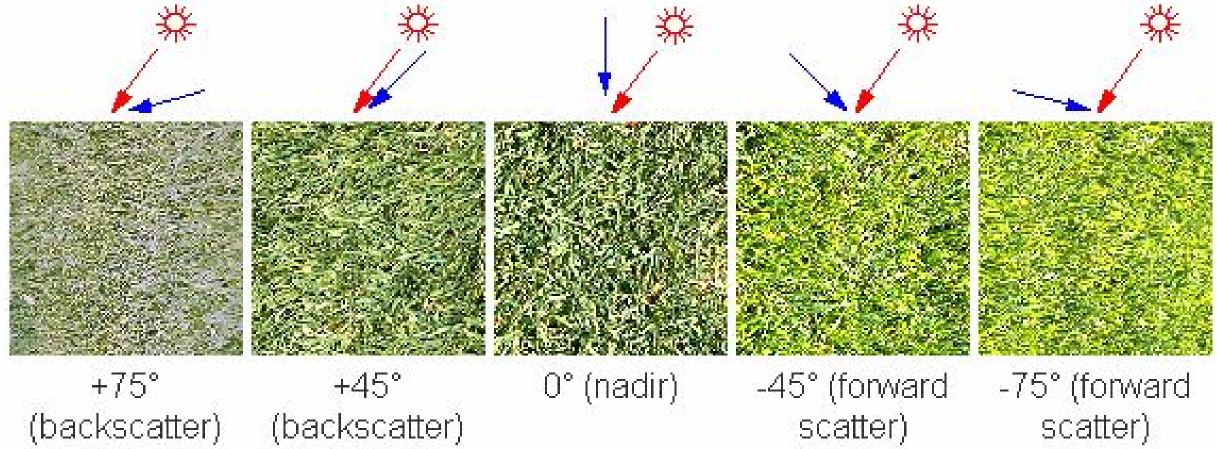


Fig. 2: Bidirectional reflectance effect on a grass lawn, observed under different viewing angles from a FIGOS mounted camera in the solar principal plane. Solar zenith angle is 35°, indicated with red arrows. The view directions are given in blue. The camera is operated in the manual modus keeping aperture, exposure time and focal length constant (k=16, t=1/15, f=135mm).

http://www.geo.unizh.ch/rsl/