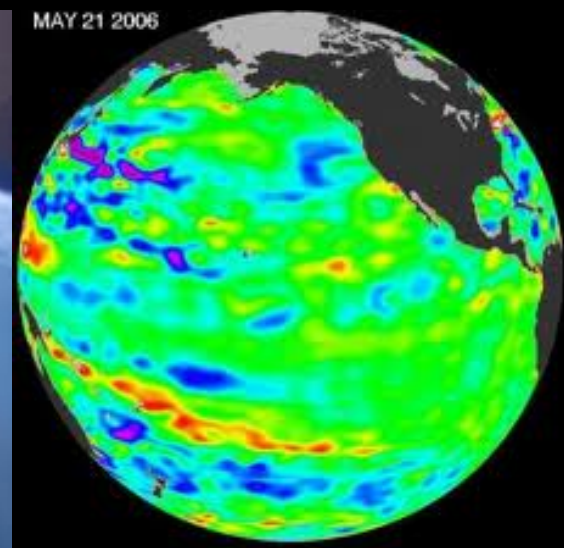

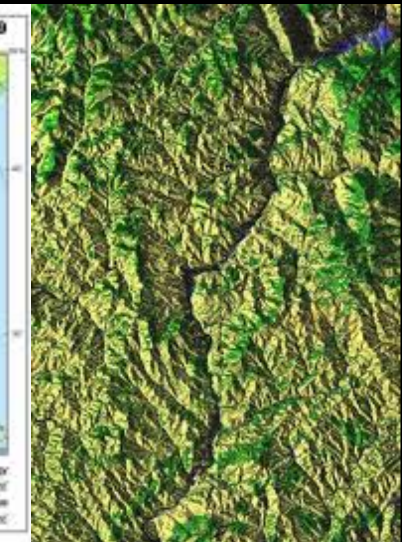

Mid-term review

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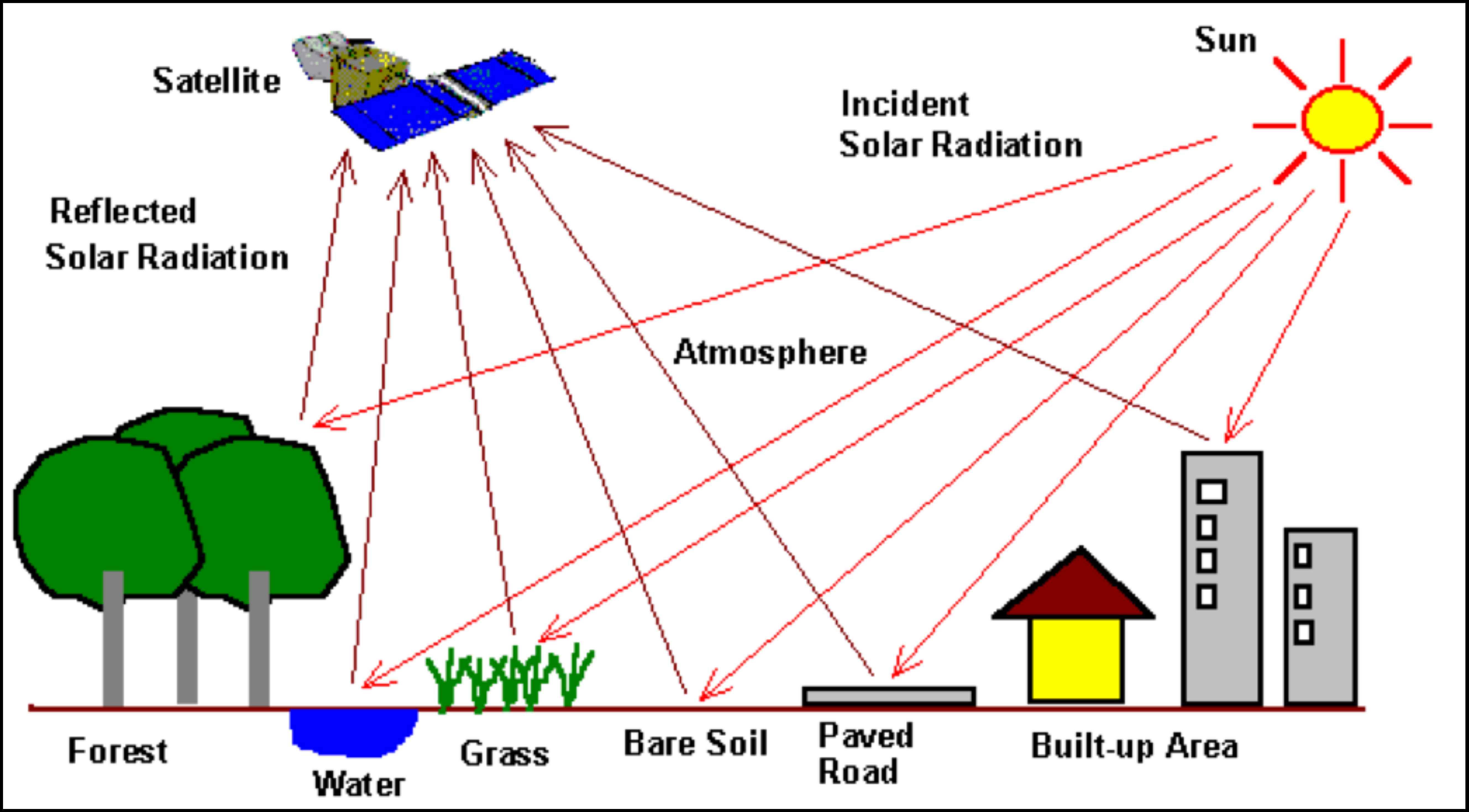
EVSC 4010/7010 Week 8

The Big Picture



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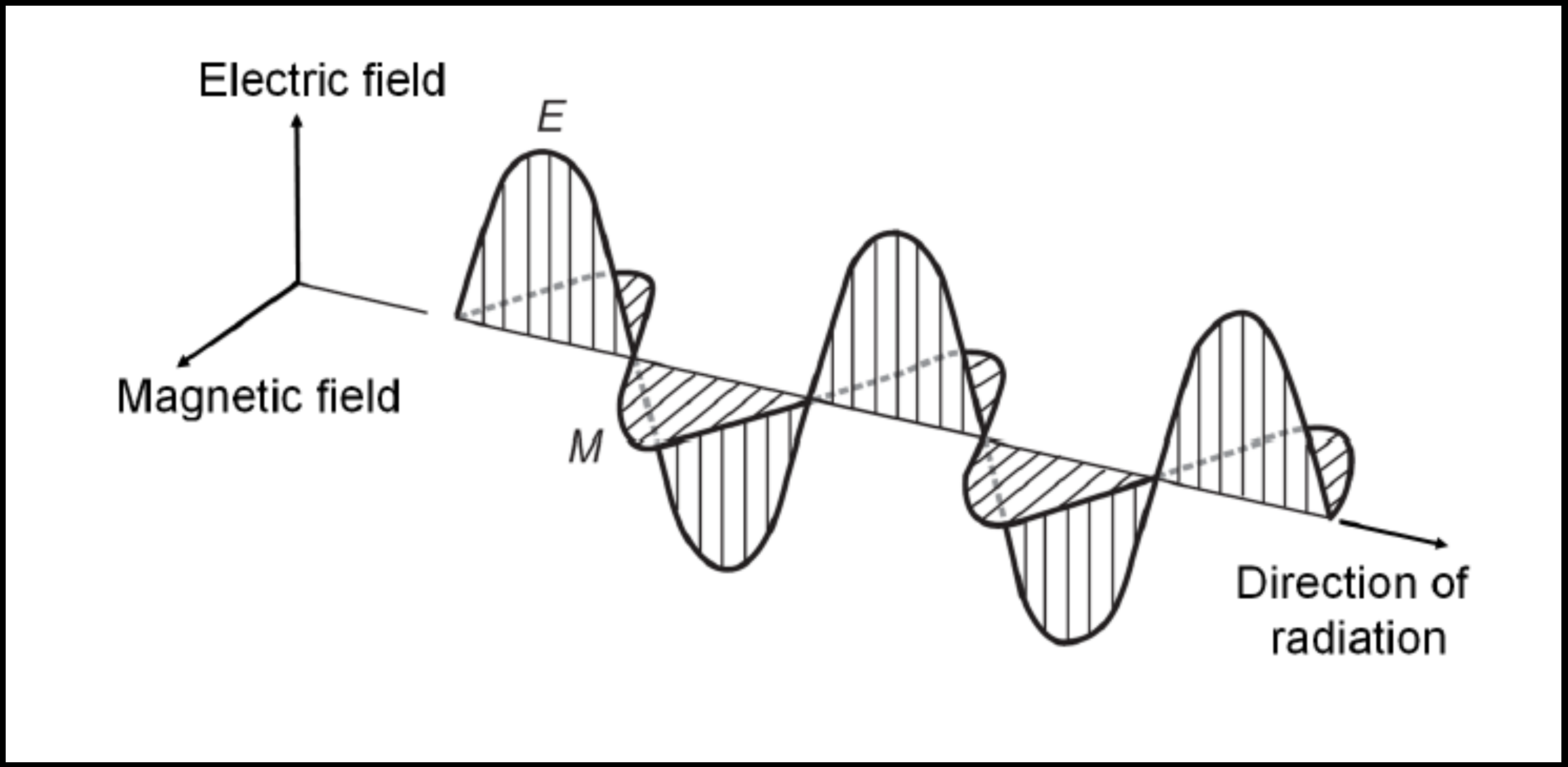
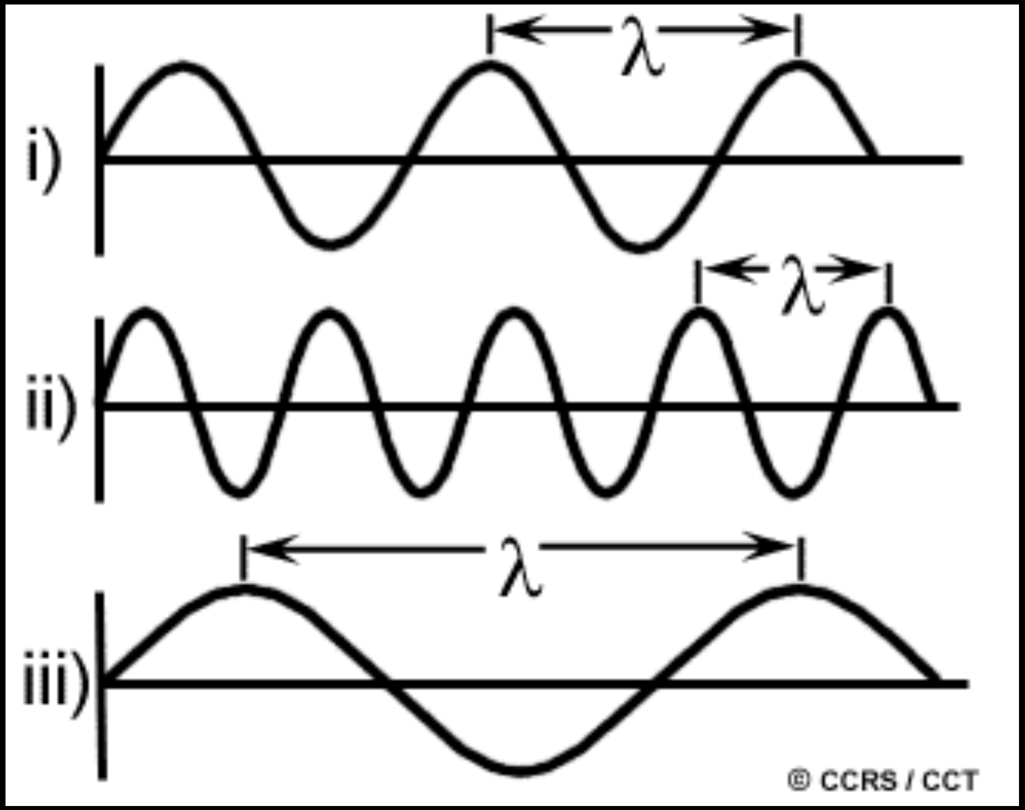
Electromagnetic wave





- Wavelength (λ): the distance between successive crests of a wave
- Frequency (ν) = c/λ.
- Q = hc/λ = hν. Q is in joule, h is Planck's constant.

Basic concepts

- Radiant Energy (Q, unit: joule): the total energy radiated toward a surface.
- Radiant Flux ($\Phi = \delta Q/\delta t$, unit: joule/s=watt): the energy per unit of time
- Irradiance ($E = \delta\Phi/\delta A$, unit: w/m^2): the radiant flux arriving on a surface per unit area
- Exitance or Emittance (M, w/m^2): the radiant flux *leaving* a surface
- Radiance (L, unit: $w\ m^{-2}\ sr^{-1}$): the total energy exiting in a certain direction per unit area per solid angle of measurement.
- Spectral Irradiance ($E = \delta\Phi/\delta A/\delta\lambda$, unit: $w/m^2/nm$): the radiant flux arriving on a surface per unit area per unit wavelength.
- Spectral Radiance (L, unit: $w\ m^{-2}\ sr^{-1}\ nm^{-1}$): the total energy exiting in a certain direction per unit area per solid angle of measurement per unit wavelength.

EMR wavelengths

- ***Visible*** (400 nm-700nm). Red: 620-700 nm; Green: 500-578 nm; Blue: 446-500 nm.

- ***Infrared*** (0.7 um-100um). NIR: 0.7 - 1.4 um; SWIR: 1.4-3 um (and beyond); TIR: 8 -14 um;

- **Microwave** (1 mm - 1 m).

- Solar spectrum: what is its wavelength range?

EM laws

- Planck's law of radiation: the spectral distribution of the emittance of a blackbody is a function of its temperature and wavelength.

$$M(\lambda) = \frac{c_1}{\lambda^5 (e^{(c_2/\lambda T)} - 1)} = f(\lambda, T)$$

c_1=3.741x10^8 W m^{-2} um^{-1};
c_2= 1.438x10^4 um K

- Stefan-Boltzmann law:

$$M = \sigma T^4$$

σ=5.6697x10^{-8} W m^{-2} K^{-4}

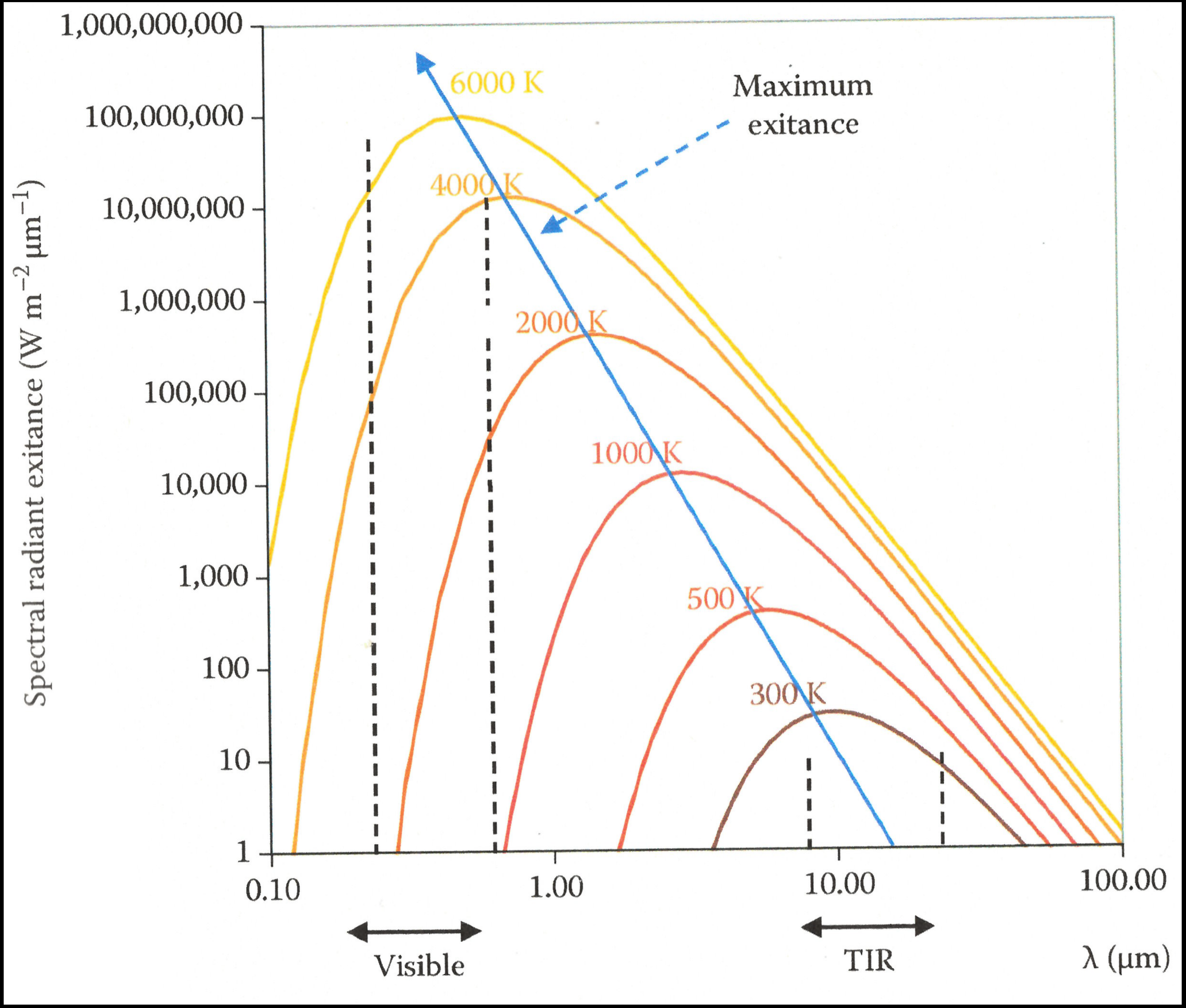
- An application of Kirchhoff's law:

$$M = \varepsilon \sigma T^4$$

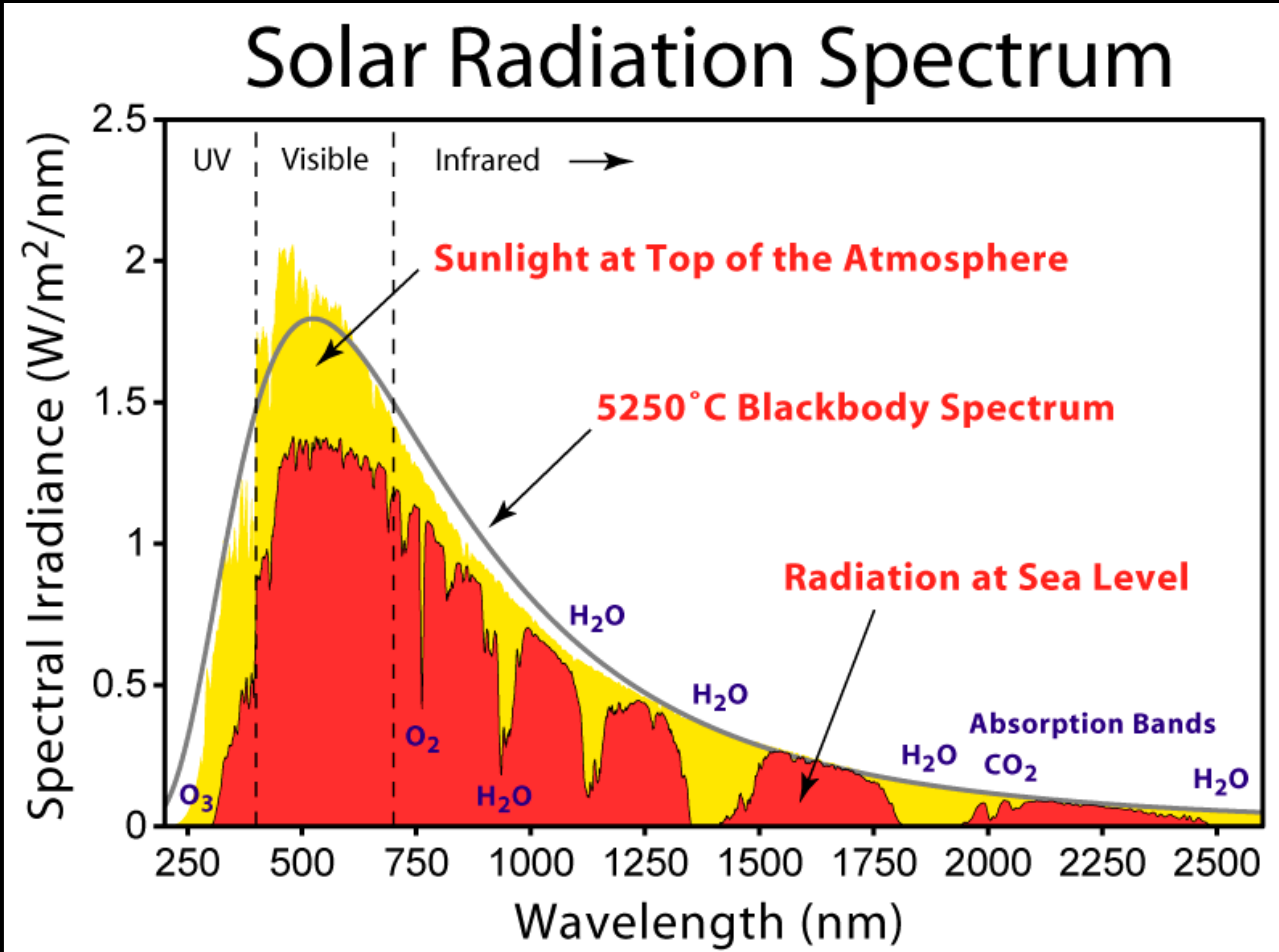
ε=0-1
σ=5.6697x10^{-8} W m^{-2} K^{-4}

- Wien's Displacement Law: $\lambda_{\max} = \frac{2898}{T}$

EM laws

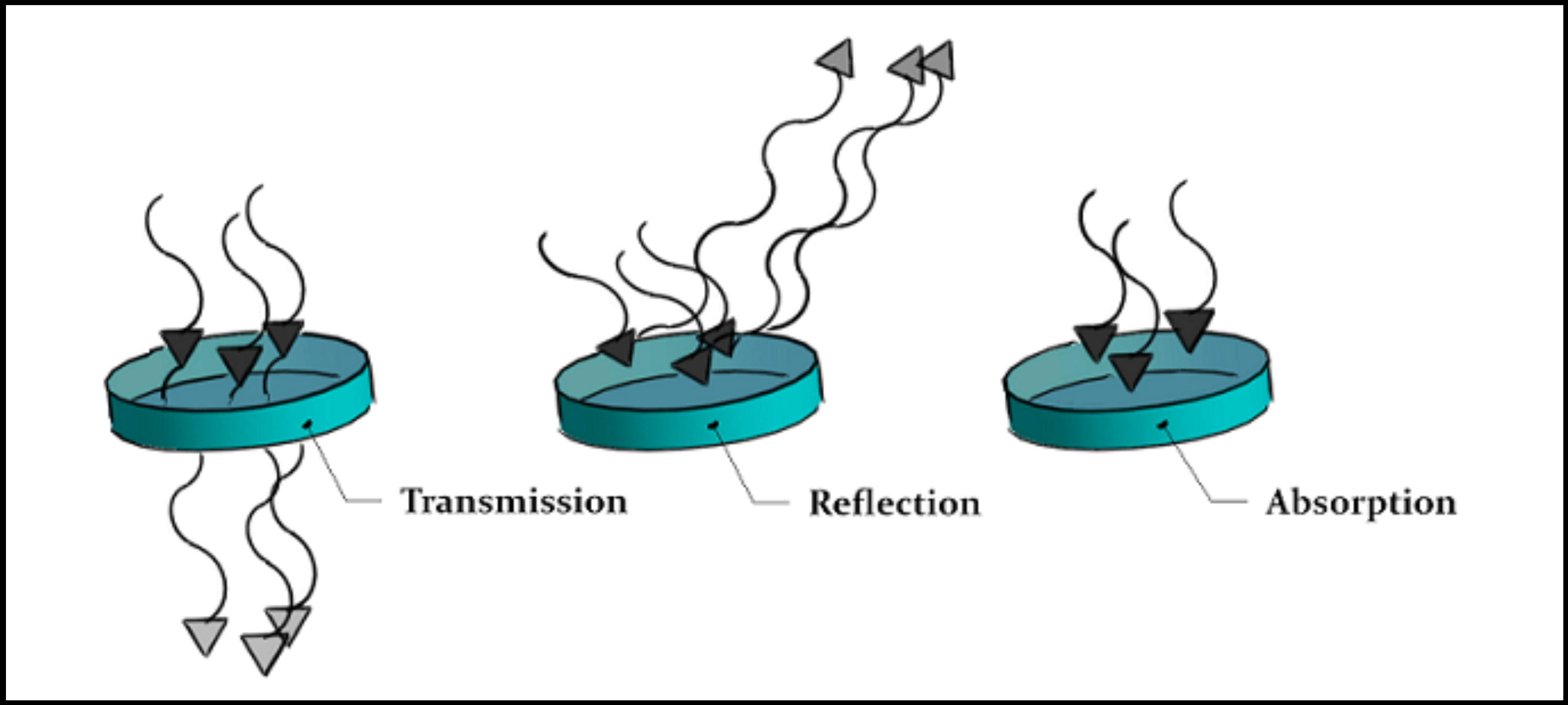


1,000,000,000
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
Spectral radiant exitance (W m^{-2} μm^{-1})
6000 K
4000 K
2000 K
1000 K
500 K
300 K
Maximum
exitance
0.10
1.00
10.00
100.00
Visible
TIR
λ (μm)



Solar Radiation Spectrum
Spectral Irradiance (W/m2/nm)
Wavelength (nm)
UV
Visible
Infrared
Sunlight at Top of the Atmosphere
5250˚C Blackbody Spectrum
Radiation at Sea Level
Absorption Bands
O3
O2
H2O
CO2
0
0.5
1
1.5
2
2.5
250
500
750
1000
1250
1500
1750
2000
2250
2500

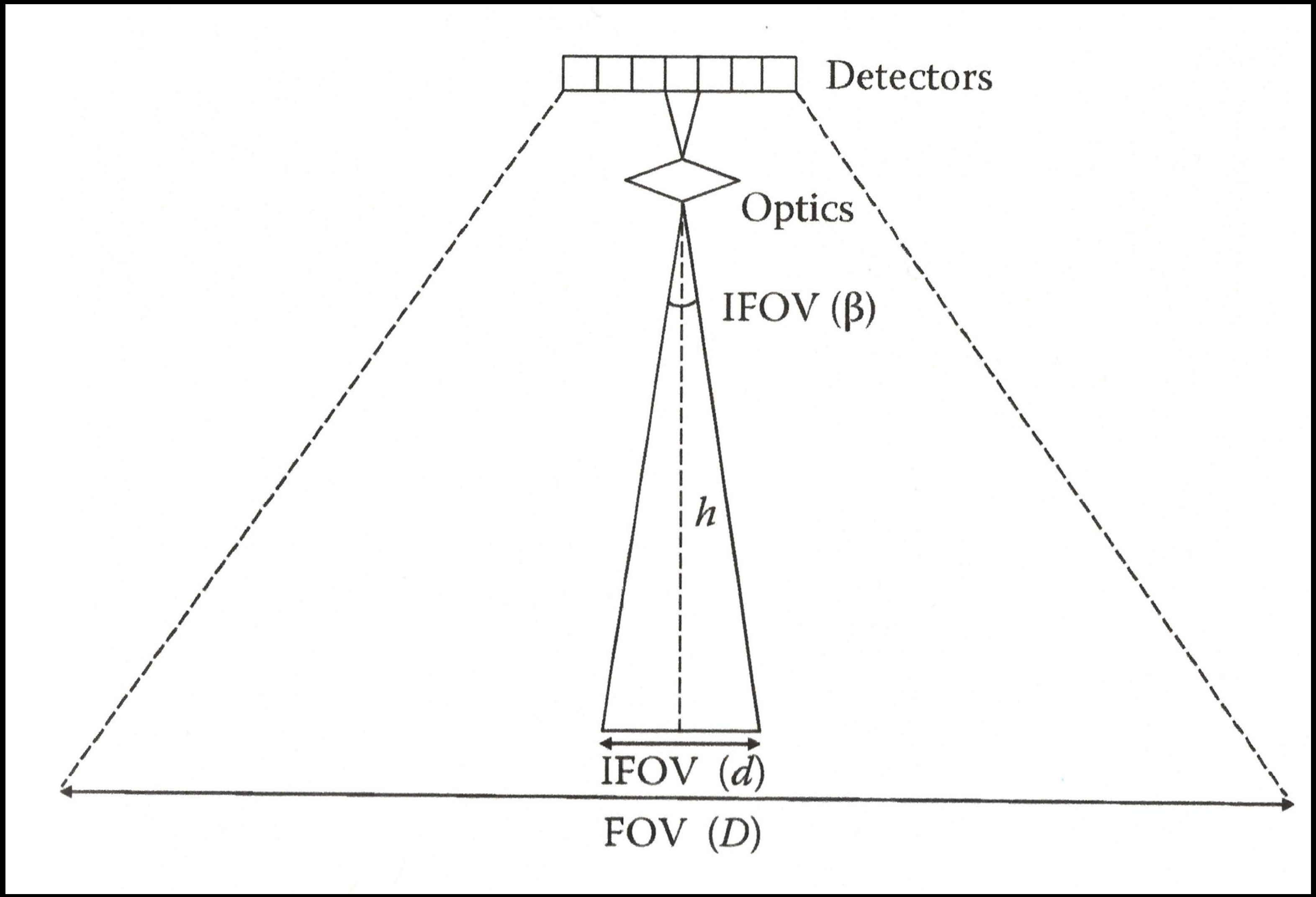
Reflectance

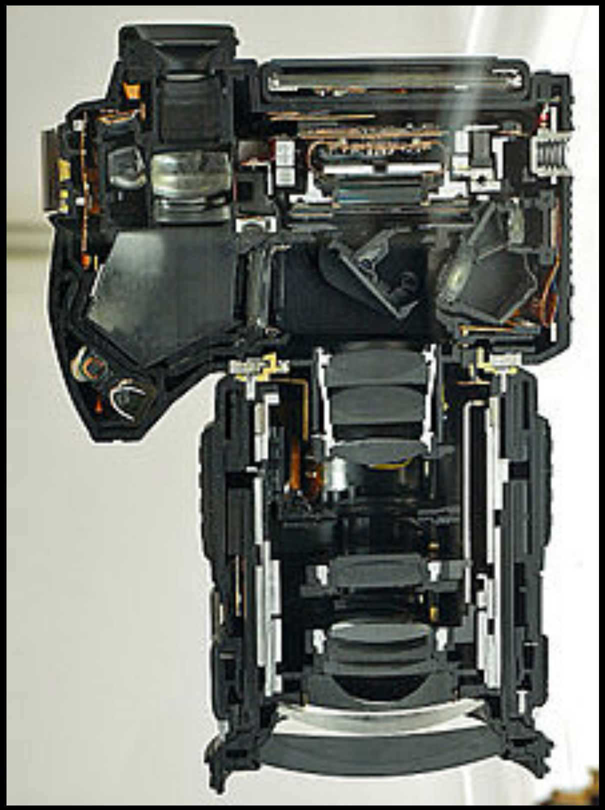


Incoming radiation = Transmission + Reflection + Absorption

1= Transmittance + Reflectance + Absorbance

Spatial resolution





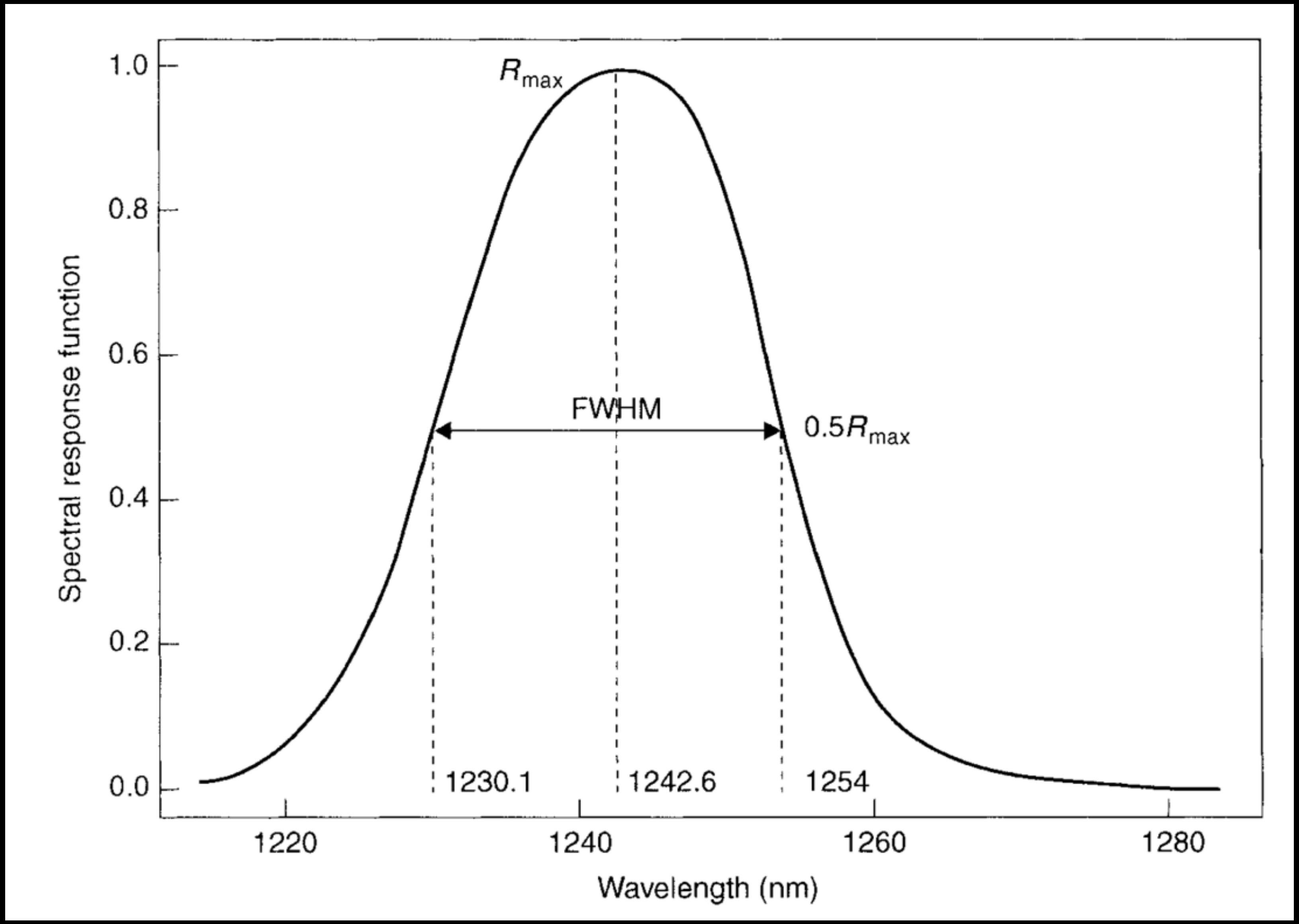
- Field-of-View (FOV)
- Instant Field of View (IFOV) - radian/meter
- Spatial resolution: pixel size small/large (high/low; fine/coarse)

Three resolutions (II) - temporal resolution

- Temporal resolution is observing frequency.
- The temporal resolution of a satellite product depends on the satellite orbit:
    - Geostationary - low inclination, high altitude
    - Polar-orbiting - high inclination, low altitude
        - Sun-synchronous (one type of polar-orbiting)
    - Non-sun-synchronous - medium inclination, low altitude

Three resolutions (III) - spectral resolution

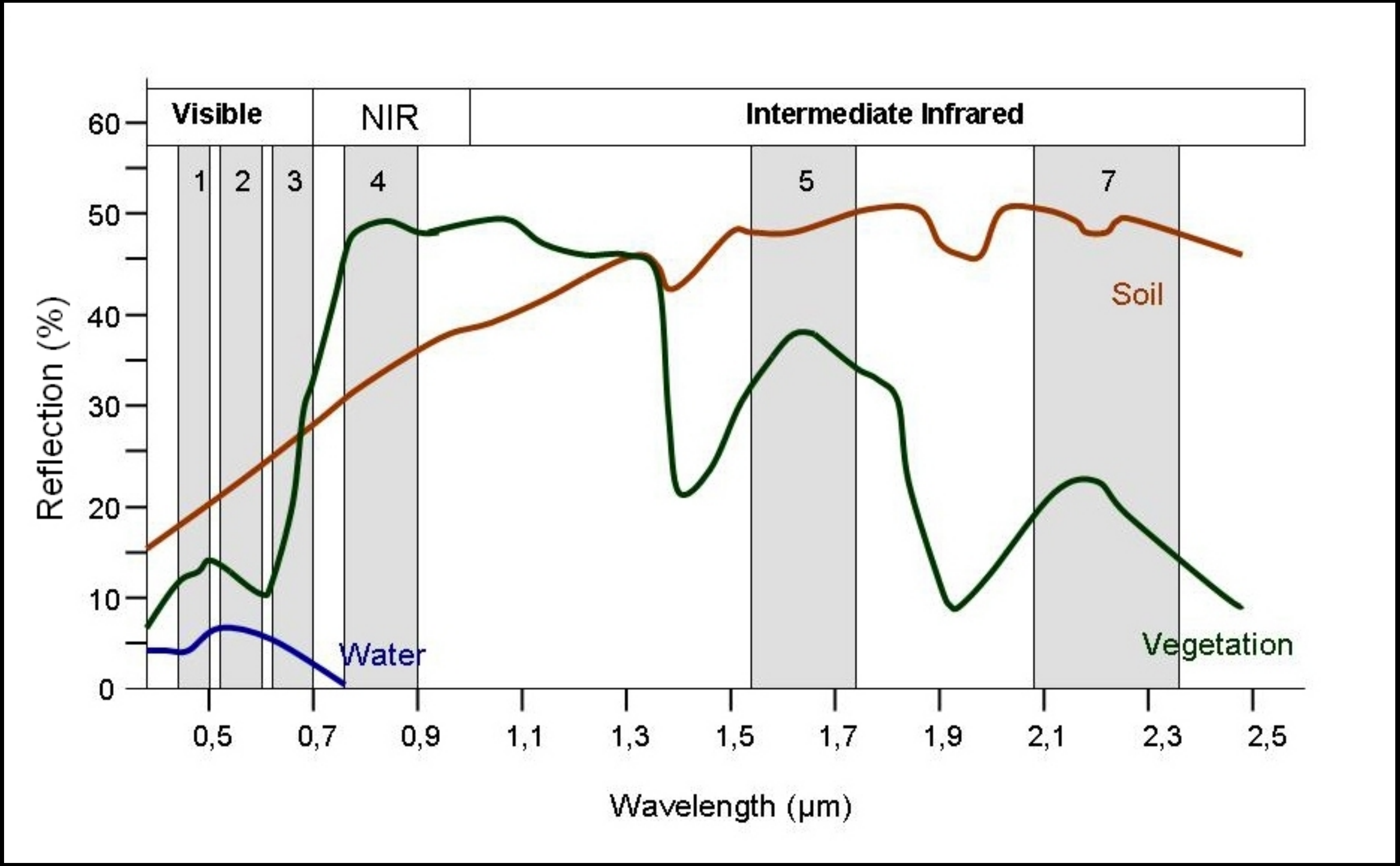
- Spectral resolution refers to the ability to differentiate two lines in the spectrum. It is often described as the Full-Width-at-Half-Maximum (FWHM).



Liang,S. 2002

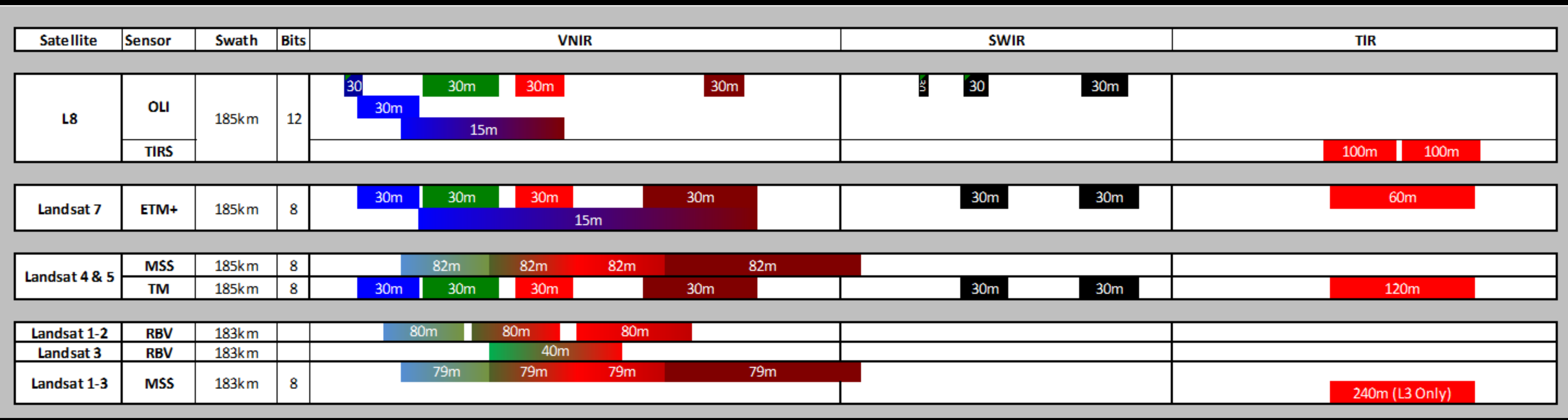
Spectral Bands

- A band refers to a spectral region on the EMR. Satellites are designed to collect spectral radiance of specific wavelengths.

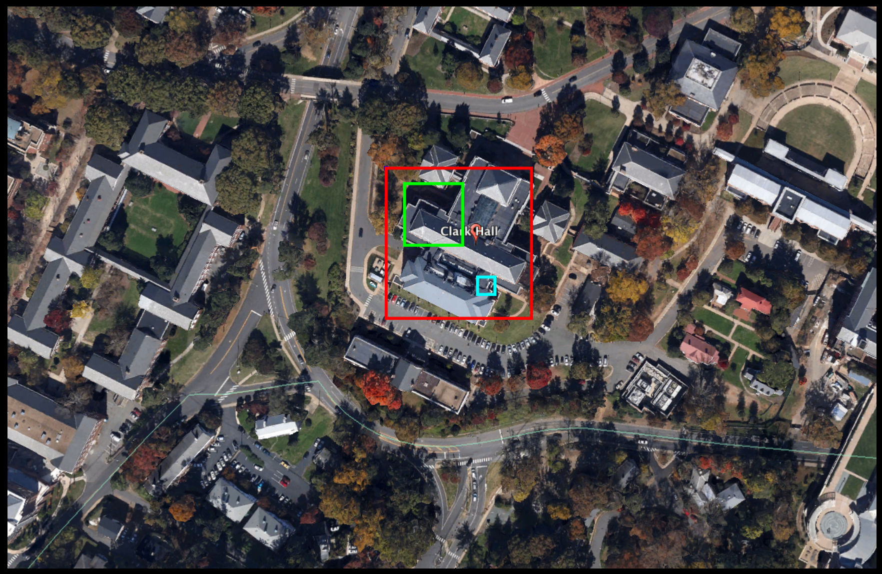


Liang,S. 2002

Spatial resolution of TM, ETM+, and OLI

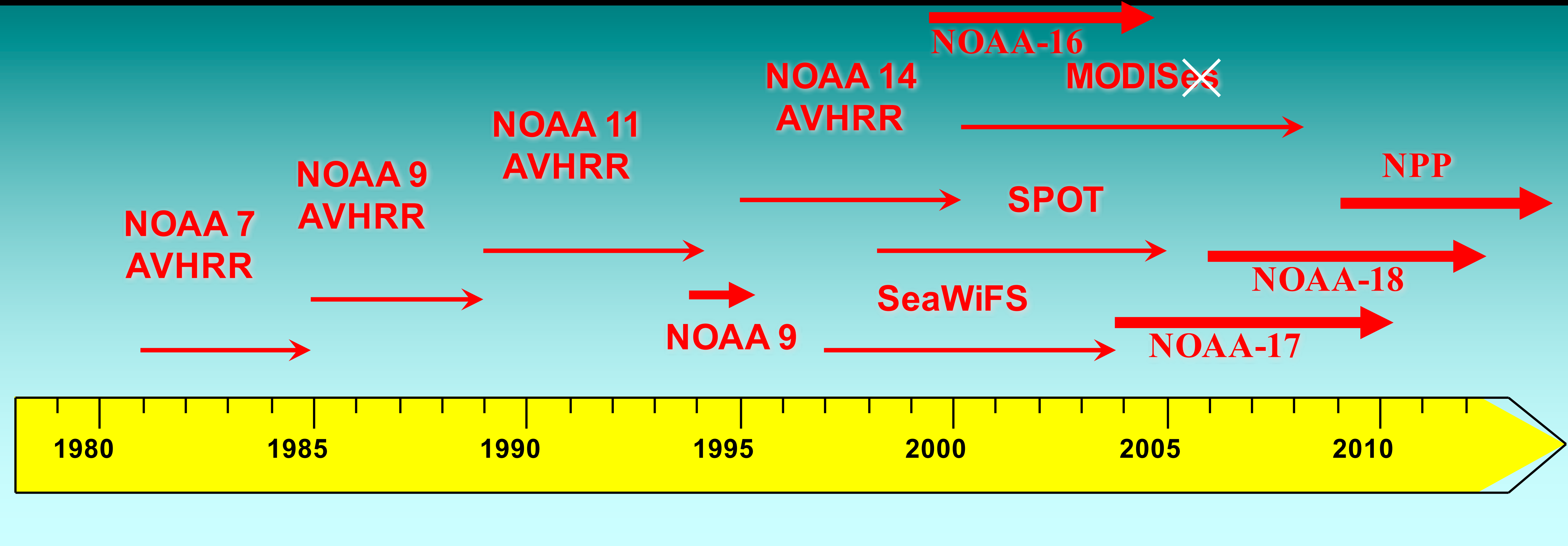


- VNIR + SWIR: 80m -> 30m;
- TIR: 240m -> 120m -> 60m -> 100m;
- Panchromatic: 15m



NOAA/AVHRR & MODIS

New Era for Global Monitoring



- AVHRR: Adanced Very High Resolution Radiometer
- MODIS: MODerate resolution Imaging Spectrometer

Radiometric calibration (II) - Radiance

$$L_\lambda = \left(\frac{\mathrm{LMAX}_\lambda - \mathrm{LMIN}_\lambda}{Q_{\mathrm{cal\,max}}} \right) Q_{\mathrm{cal}} + \mathrm{LMIN}_\lambda$$

Spectral Radiances, $LMIN_\lambda$ and $LMAX_\lambda$ in $W/(m^2.sr.\ \mu m)$								
Processing Date	From March 1, 1984 To May 4, 2003				After May 5, 2003			
Band	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$	$LMIN_\lambda$	$LMAX_\lambda$	$G_{rescale}$	$B_{rescale}$
1	-1.52	152.10	0.602431	-1.52	-1.52	193.0	0.762824	-1.52
2	-2.84	296.81	1.175100	-2.84	-2.84	365.0	1.442510	-2.84
3	-1.17	204.30	0.805765	-1.17	-1.17	264.0	1.039880	-1.17
4	-1.51	206.20	0.814549	-1.51	-1.51	221.0	0.872588	-1.51
5	-0.37	27.19	0.108078	-0.37	-0.37	30.2	0.119882	-0.37
6	1.2378	15.303	0.055158	1.2378	1.2378	15.303	0.055158	1.2378
7	-0.15	14.38	0.056980	-0.15	-0.15	16.5	0.065294	-0.15

Chander,G. 2003

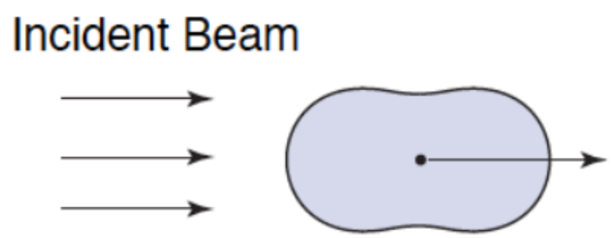
Three types of scattering in the atmosphere

- Rayleigh Scattering
- Mie Scattering
- Non-selective Scattering

Rayleigh and Mie scattering

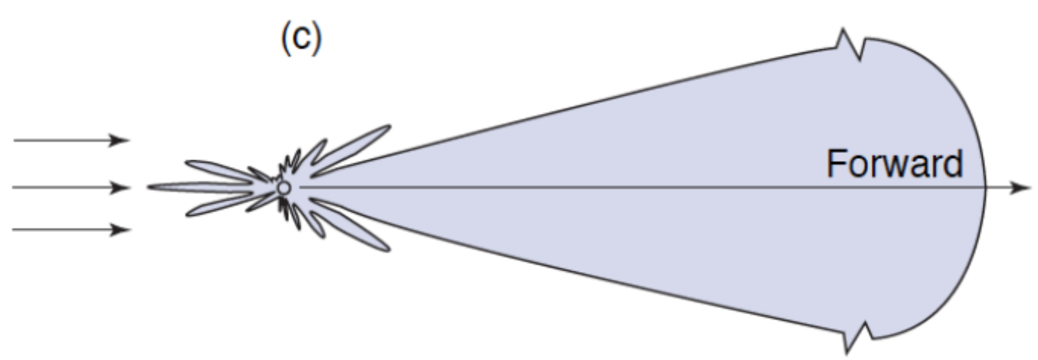
$$x = \frac{2\pi r}{\lambda}$$

Rayleigh scattering



$$K_\lambda \propto \lambda^{-4}$$

Mie scattering



Beer-lambert law

$$I_{\lambda z_0} = I_{\lambda\infty} e^{-\sec\theta \int_{z_0}^{\infty} k_\lambda \rho r\, dz} = I_{\lambda\infty} e^{-\tau_A \sec\theta}$$

$$\tau_\lambda = \int_{z_0}^{\infty} k_\lambda \rho r\, dz$$

Radiative Transfer in the Atmosphere

Case 1: No atmosphere

$$L_{sat} = \frac{\rho E_o \cos\theta_s}{\pi}$$

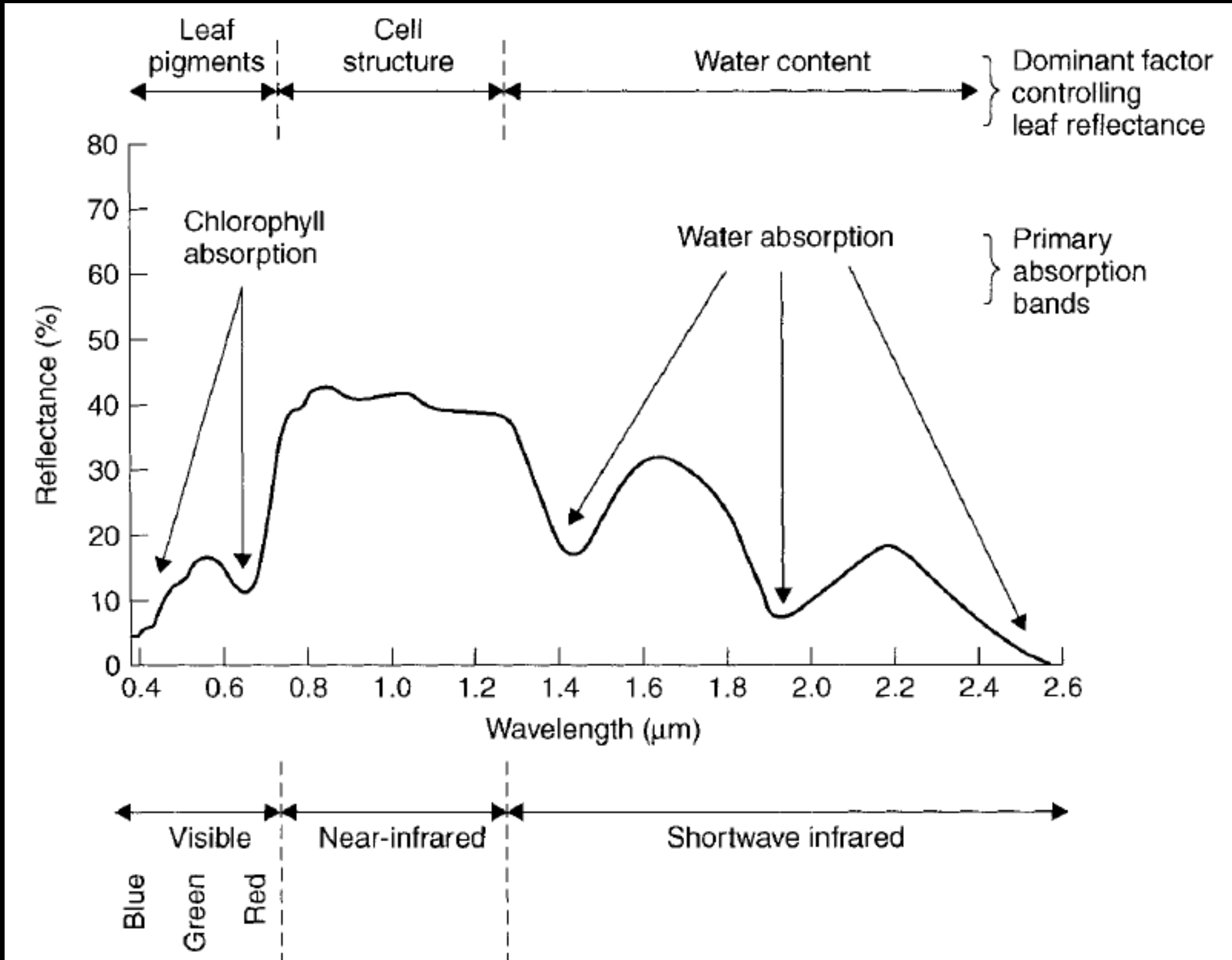
L_{sat}: radiance at sensor
E_o: TOA solar irradiance
ρ: surface reflectance
θ: solar zenith angle

Case 2: Atmosphere attenuation

$$L_{sat} = \frac{\rho T_\phi [T_\theta E_o \cos\theta_s + E_D]}{\pi} + L_{path}$$

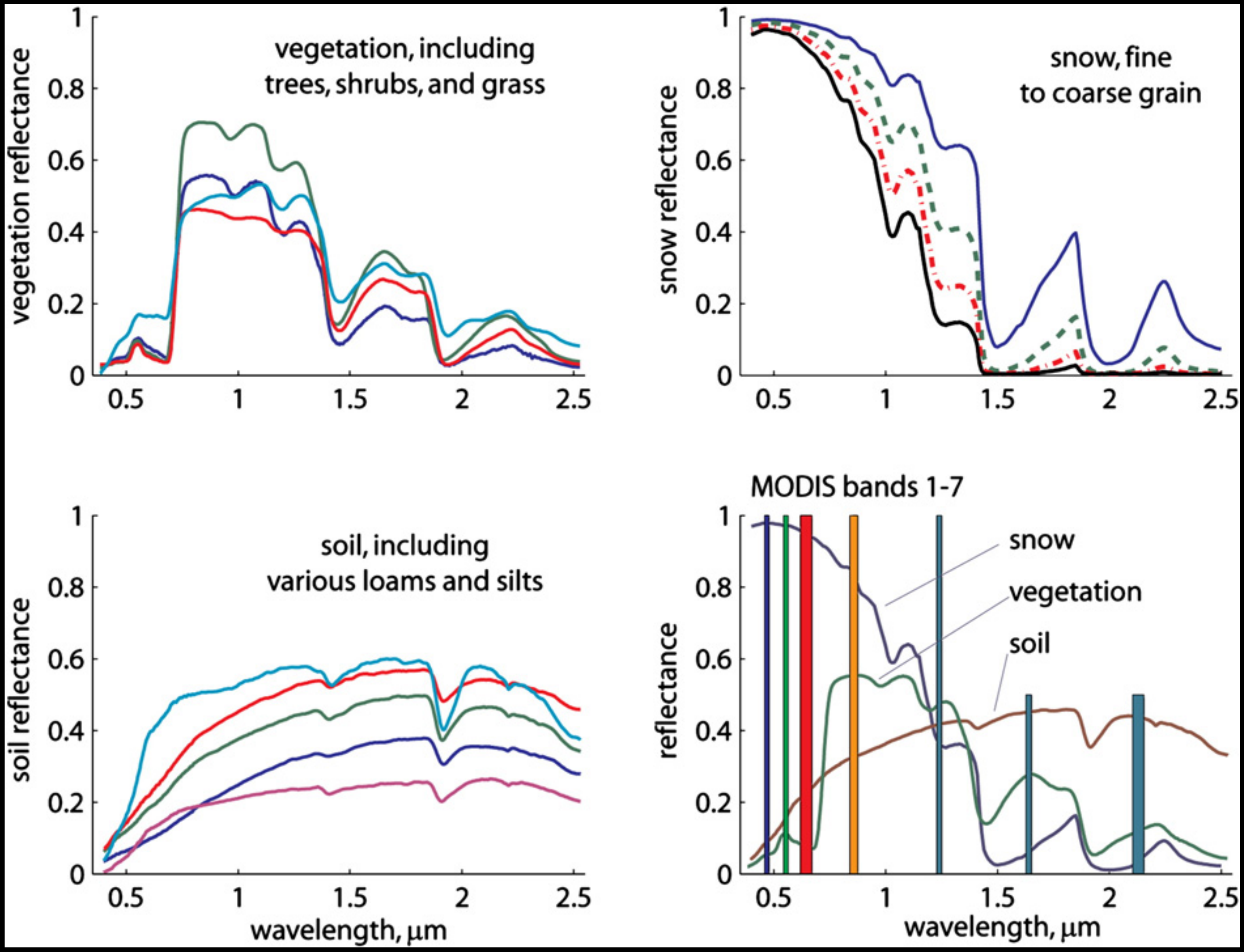
T_θ: Transmission of the atmosphere from TOA to the surface
T_φ: Transmission of the atmosphere from the surface to TOA
E_D: Downwelling scattered irradiance
L_{path}: Path irradiance

Leaf spectra

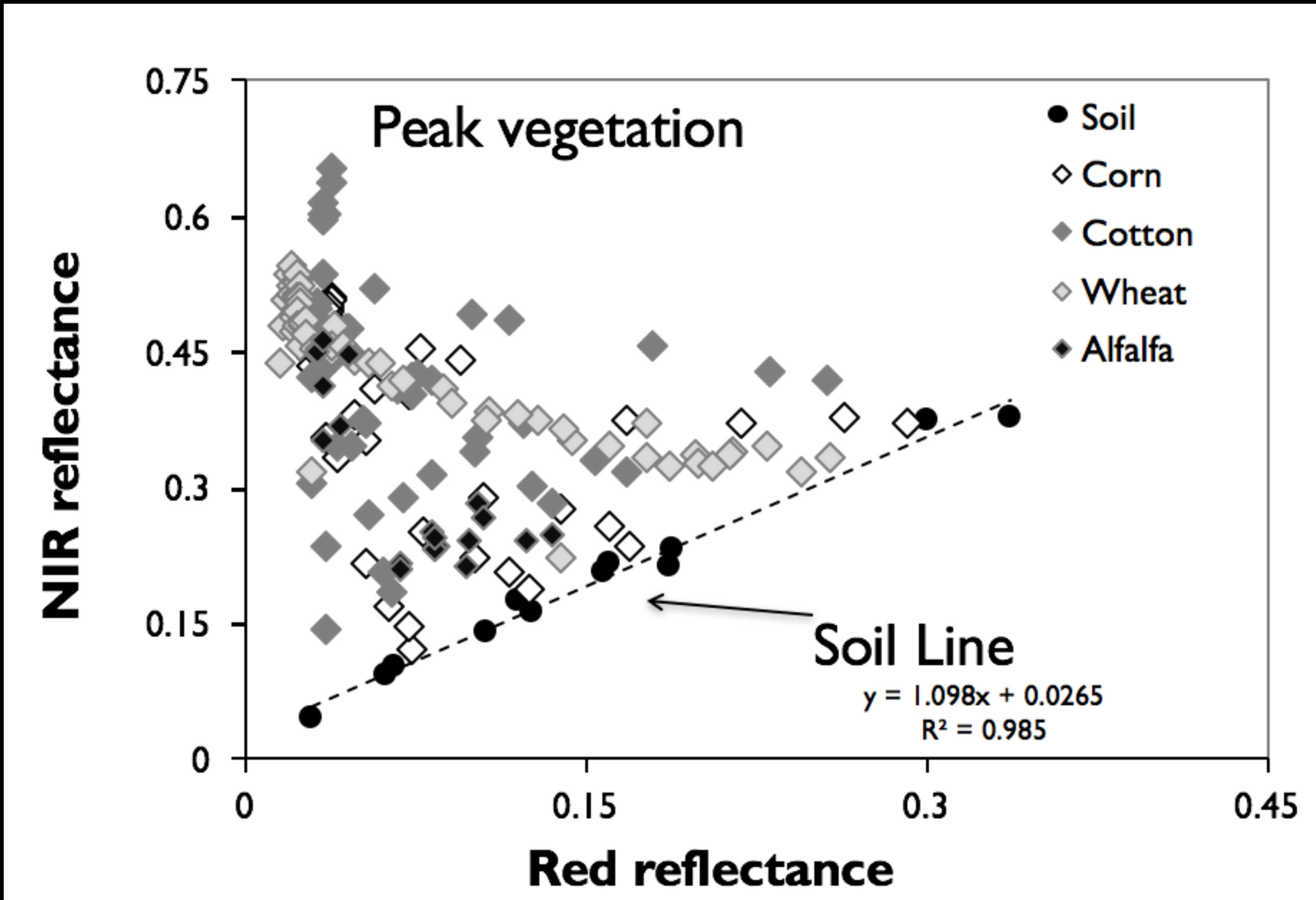


Liang, S. 2002

Identify spectra



Soil line



Peak vegetation
Soil
Corn
Cotton
Wheat
Alfalfa
Soil Line
y = 1.098x + 0.0265
R² = 0.985
NIR reflectance
Red reflectance
0
0.15
0.3
0.45
0.6
0.75
0
0.15
0.3
0.45

Vegetation indices

- Simple Ratio (SR): SR = NIR/R;
- Normalized Difference Vegetation Index (NDVI): NDVI = (NIR-R)/(NIR+R);
- Enhanced Vegetation Index:

$$EVI = 2.5 \frac{NIR - R}{NIR + 6R - 7.5B + 1}$$

Spectral Mixture Analysis

- Basic assumption: the reflectance of a pixel is a linear combination of the endmember spectra times their relative **cover** fraction.
- Two parts to the algorithm:

$$\sum_{i=1}^{N} F_i = F_1 + F_2 + \ldots + F_N = 1$$

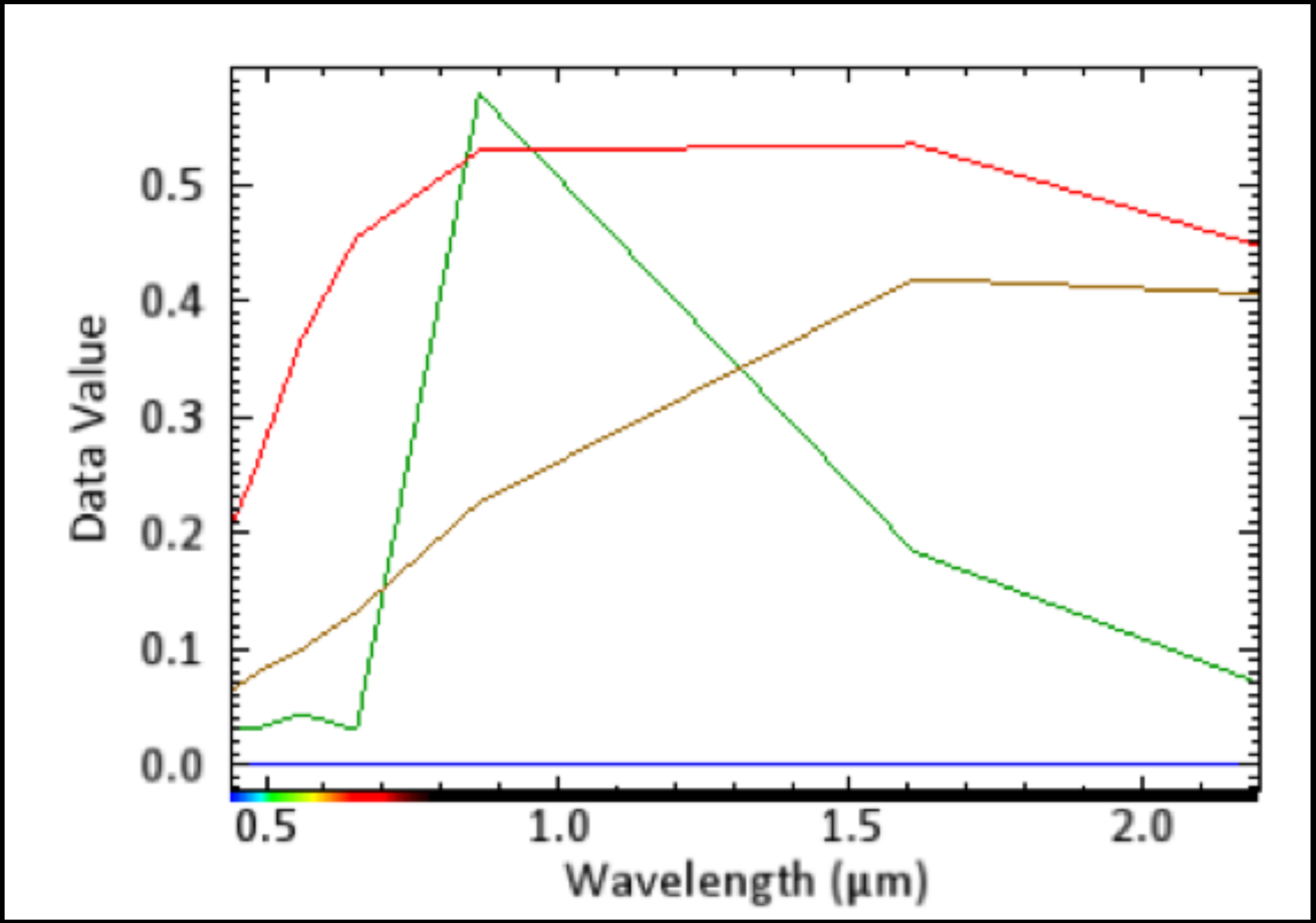
Sum to 100%: endmembers must collectively "explain" the pixel

$$\rho_\lambda = F_1\rho_{\lambda,1} + F_2\rho_{\lambda,2} + \ldots + F_N\rho_{\lambda,N} + E_\lambda$$

Best-fit fractions (and error) are calculated for each DN value for each band of each pixel

F_i=fraction of endmember *i* in pixel (usually $0 \le F_i \le 1$)
ρ_λ=the pixel reflectance for band λ
$\rho_{\lambda,1}$=the reflectance for band λ of endmember 1
E_λ=error term for band λ

Choosing Endmembers



- Represents a major land cover in the image
- Spectrally distinct

Land cover classification

Supervised classification assumes knowledge of some parts of the study area ("training fields") is acquired by external sources or fieldwork.
The accuracy of supervised classification depends on the quality of these "training fields".

Unsupervised classification identifies spectral classes in the image by finding clusters of pixels with similar pixel values.

Classification accuracy

- Ground truth: from geolocated field observations; aerial survey; other data sources.

- Two types of errors:
  - Omission Error (“false negative”, OE): the number of unassigned pixels / total number of pixels in that category.

  - Commission Errors (“false positive”, CE): pixels that are included in a given category when they are not in fact part of that category.

- Two types of accuracies:
  - Producer Accuracy (PA): 1-OE
  - User Accuracy (UA): 1-CE.

Confusion Matrix

	Reference											
Classification	**1**	**2**	**4**	**5**	**6**	**7**	**9**	**A**	**B**	**Total**	**User's Accuracy**	**Commission Error**
1	927	49	63		42		5	87		1173	79	21
2	35											
4	6											
5												
6	11											
7												
9	99											
A	70											
B												
Total	1148											
Producer's Accuracy	80.7											
Omission Error	19.3											

$$OE_i = \frac{X_{+i} - X_{ii}}{X_{+i}}$$

$$PA_i = \frac{X_{ii}}{X_{+i}}$$

$$CE_i = \frac{X_{i+} - X_{ii}}{X_{i+}}$$

$$UA_{u,i} = \frac{X_{ii}}{X_{i+}}$$

Overall Accuracy (OA):

$$\widehat{OA} = \frac{\sum_{i=1,n} x_{ii}}{\sum_{i=1,n} \sum_{j=1,n} x_{ij}}$$