Spectral Signatures

Learning Objectives

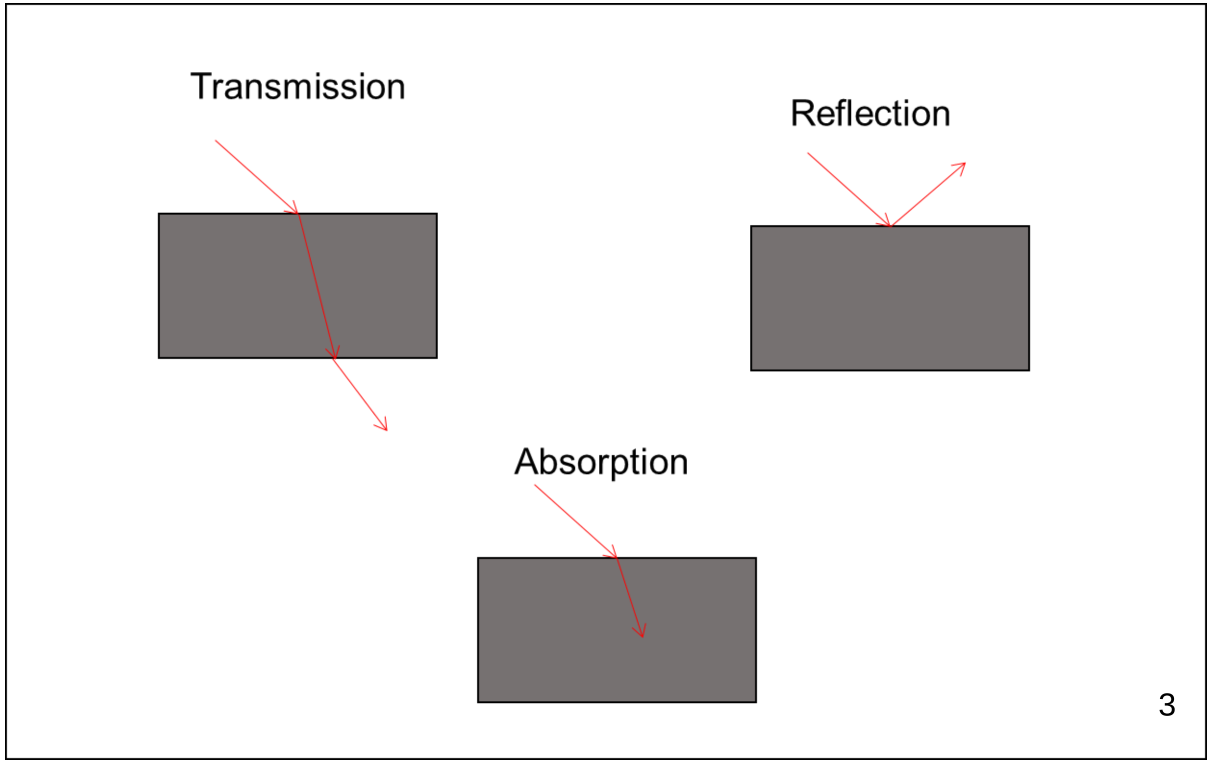
- In this lecture you will learn…
  - Understand a spectral signature and what it looks for a number of basic Earth surfaces
  - Understand the spectral response of vegetation

Surface Interactions

Electromagnetic radiation interacts with feature on the Earth's surface in one of three ways

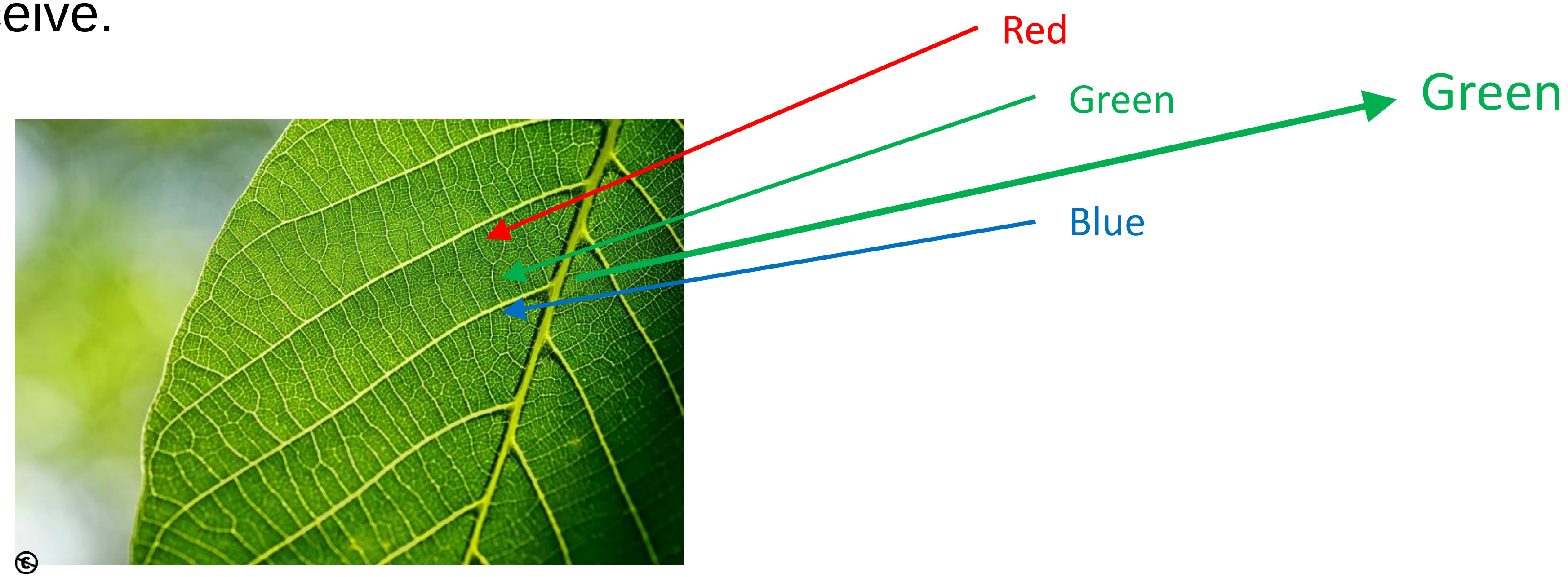
It can be

- absorbed,
- reflected,
- and transmitted.



Surface Interactions

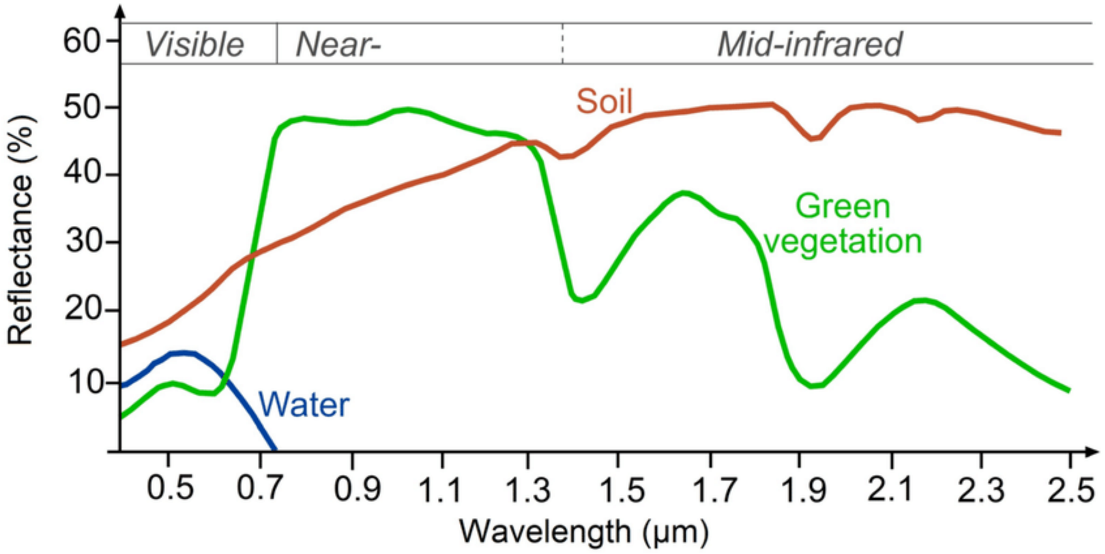
- For visible light striking a leaf is partially reflected, creating the image of the leaf we see.
- The portion not reflected is absorbed or transmitted (which is why some light can be seen through it).
- Absorbed energy raises the temperature of the leaf and is reemitted as heat.
- The leaf's reflectance and absorption characteristics are what give it the color we perceive.

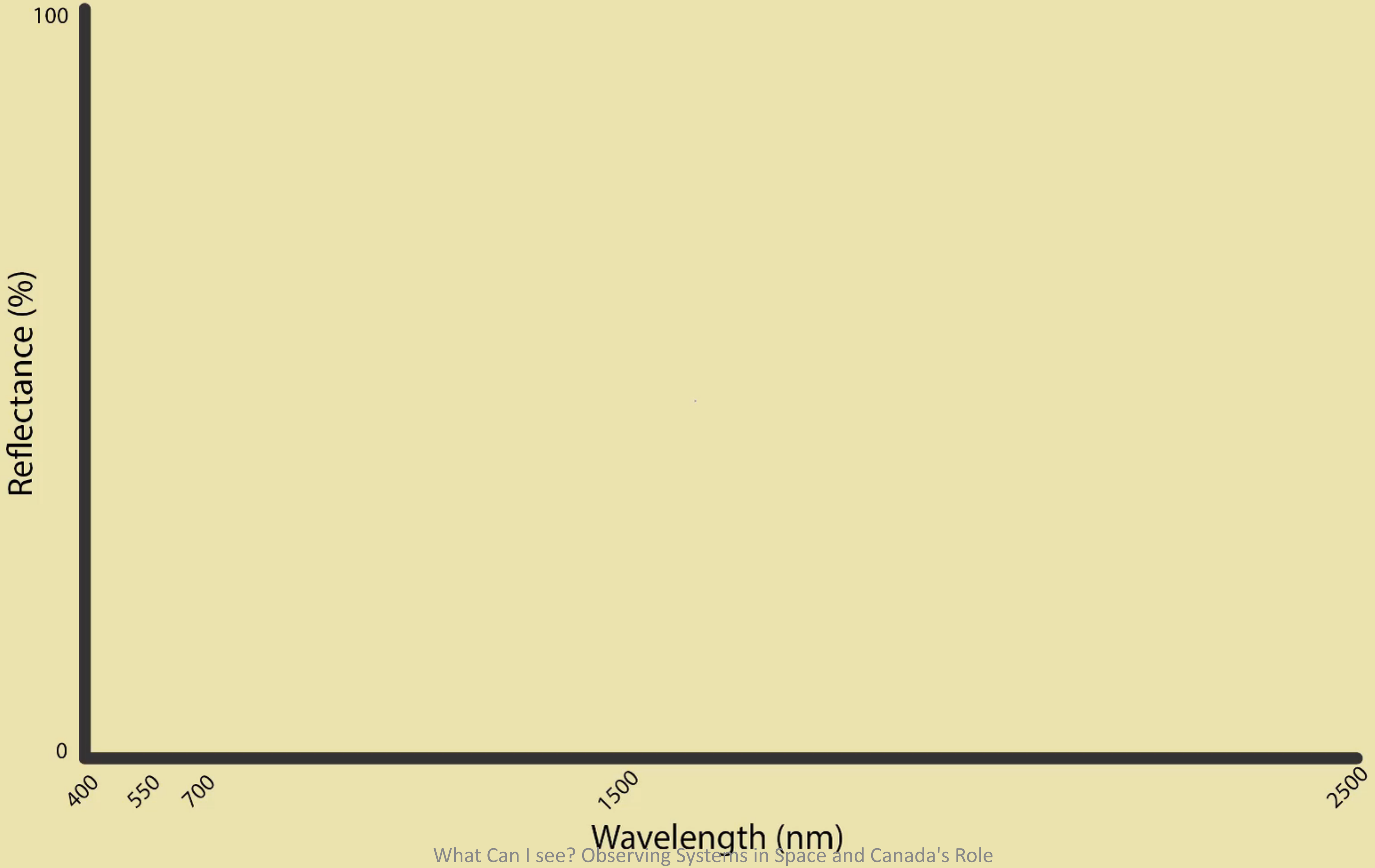


Spectral Signatures

- A *spectral signature* is the pattern of spectral response of a material
  - Typically visualized with a graph
  - Showing the percentage of radiation of different wavelengths reflected from an object

- By plotting spectral signatures of different materials together:
  - The portions of the spectrum where their signatures differ can be readily identified

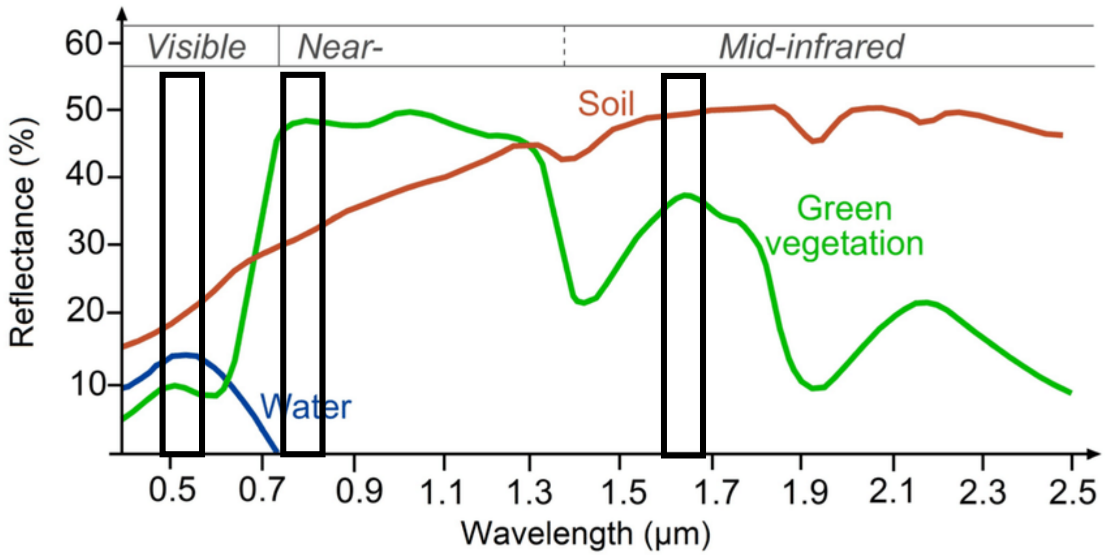


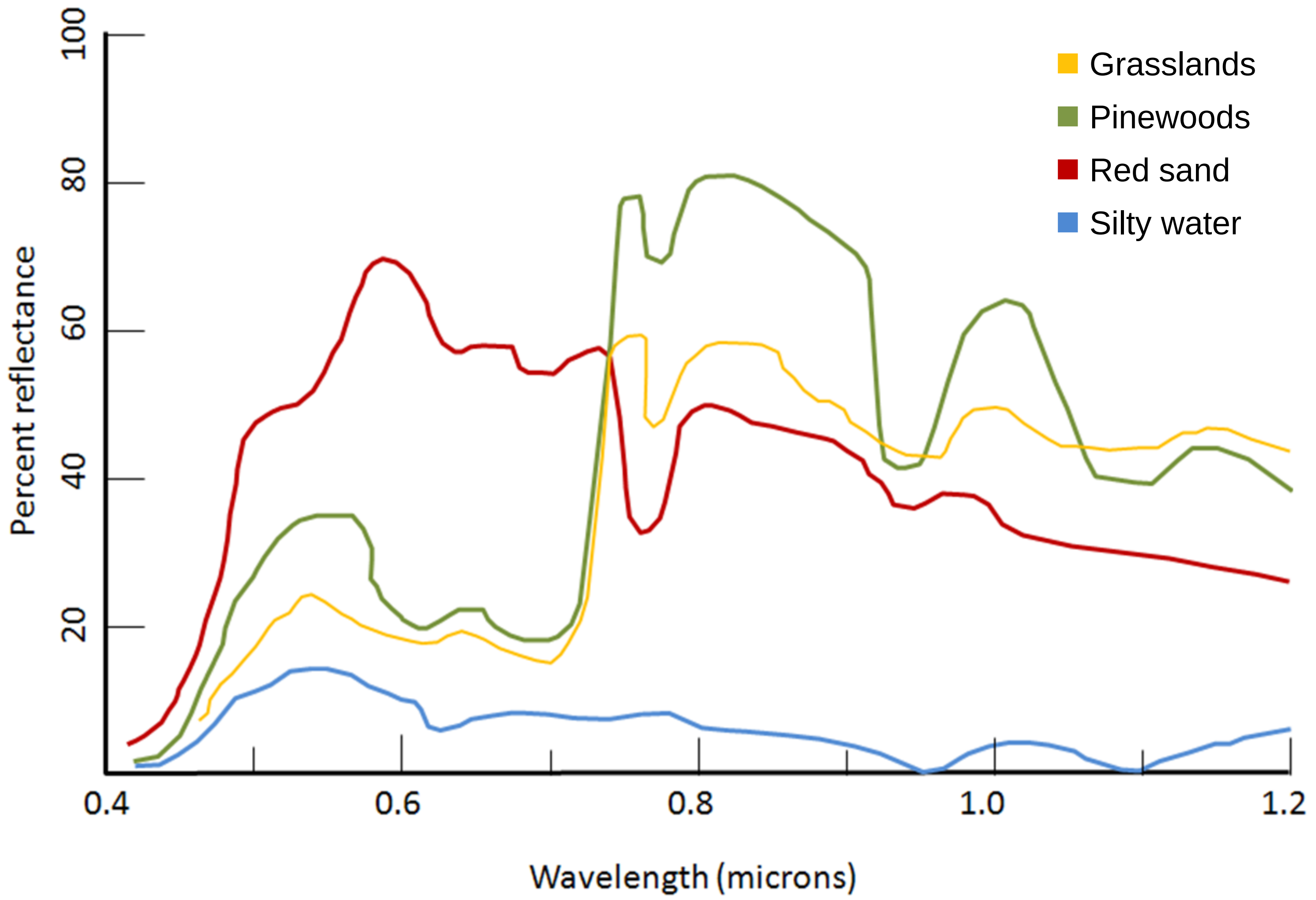

100
Reflectance (%)
0
400
550
700
1500
2500
Wavelength (nm)

Spectral Signatures

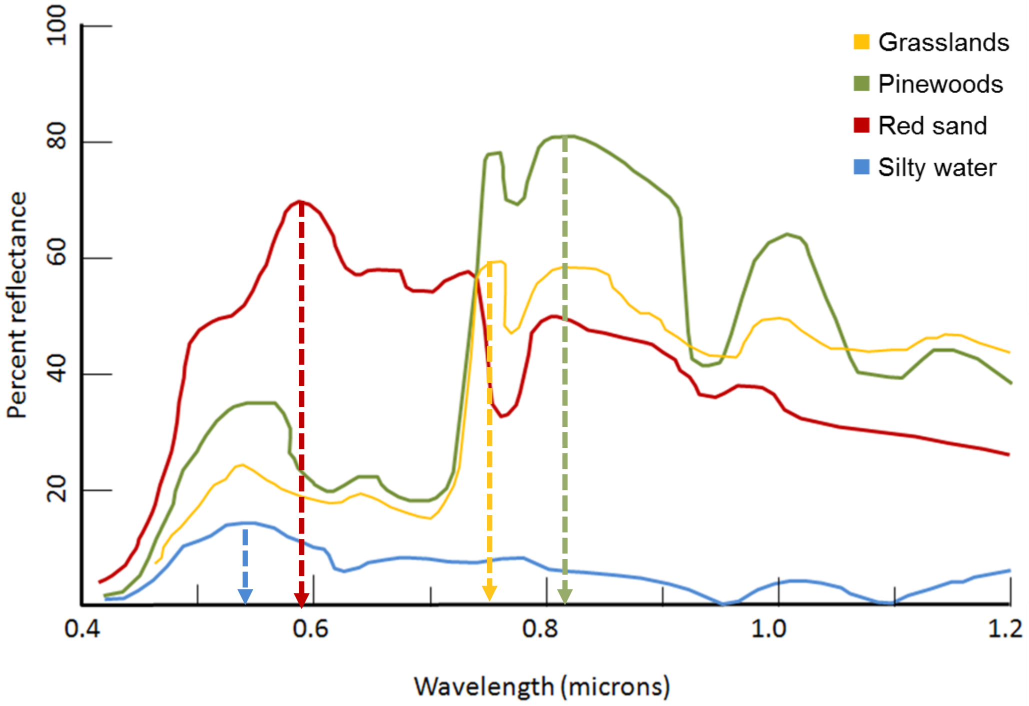
- When we use more than two wavelengths, the plots in multi-dimensional space tend to show more separation among the materials.

- This improved ability to distinguish materials due to extra wavelengths is the basis for multispectral remote sensing





Grasslands
Pinewoods
Red sand
Silty water
Percent reflectance
100
80
60
40
20
0.4
0.6
0.8
1.0
1.2
Wavelength (microns)



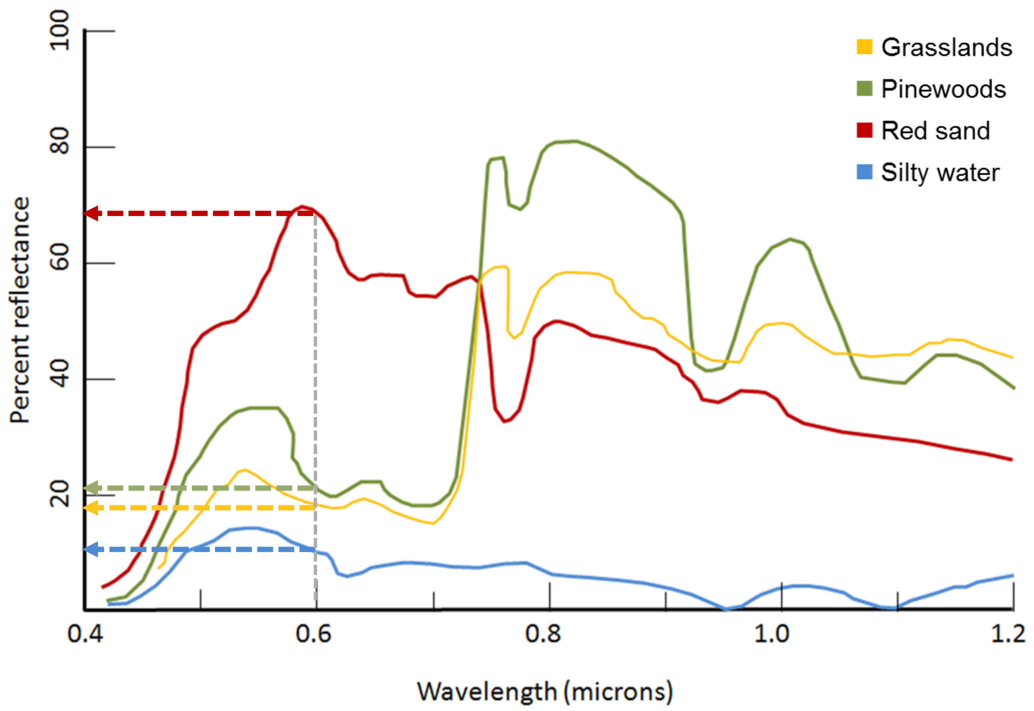
Which region of the spectrum (wavelength) shows the greatest reflectance for:

a) grasslands?

b) pinewoods?

c) red sand?

d) silty water?



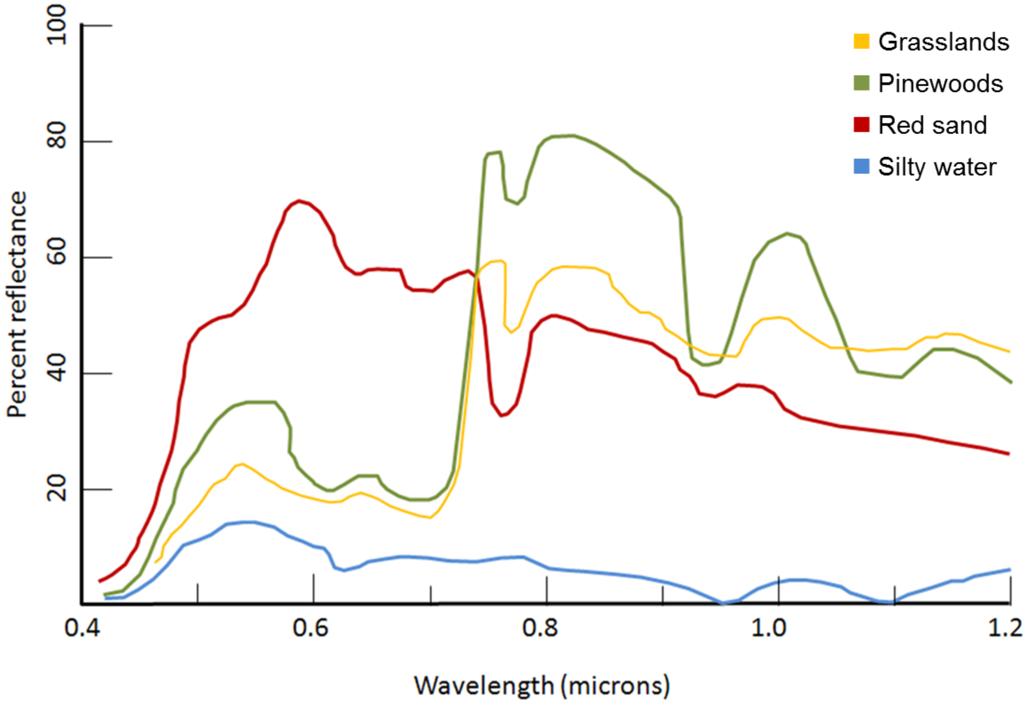
At 0.6 μm, are these four classes distinguishable?:

a) grasslands?

b) pinewoods?

c) red sand?

d) silty water?



Which material is brightest at:

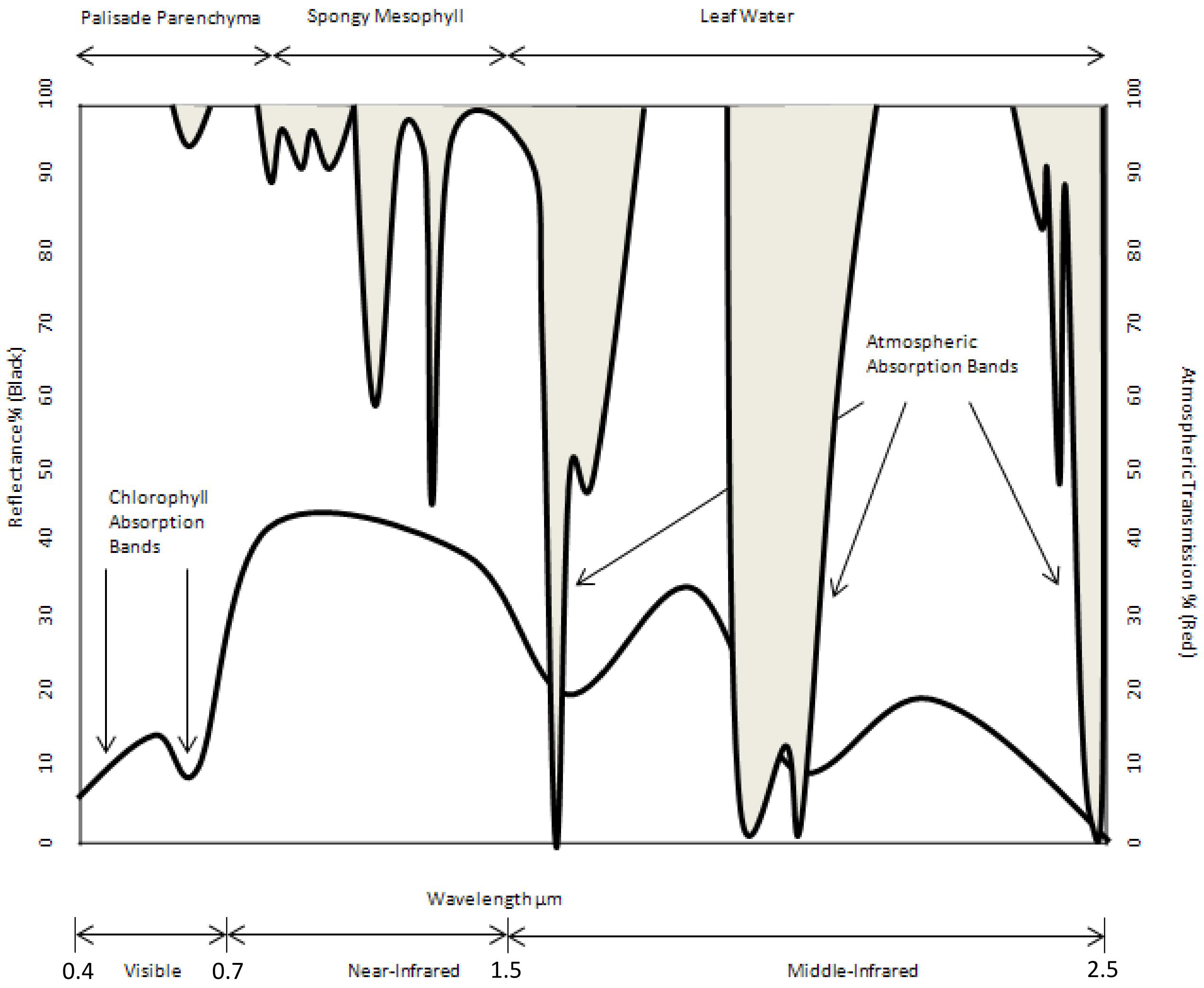
a) 0.6 μm?

b) 1.2 μm?

Spectral Analysis of Vegetation

Autumn leaves (Source: Flickr)

Dominant Factors Controlling Leaf Reflectance



Water absorption bands:

0.97 µm

1.19 µm

1.45 µm

1.94 µm

2.70 µm

Surface Signatures of Vegetation

Palisade parenchyma cells

Spongy parenchyma Mesophyll cells

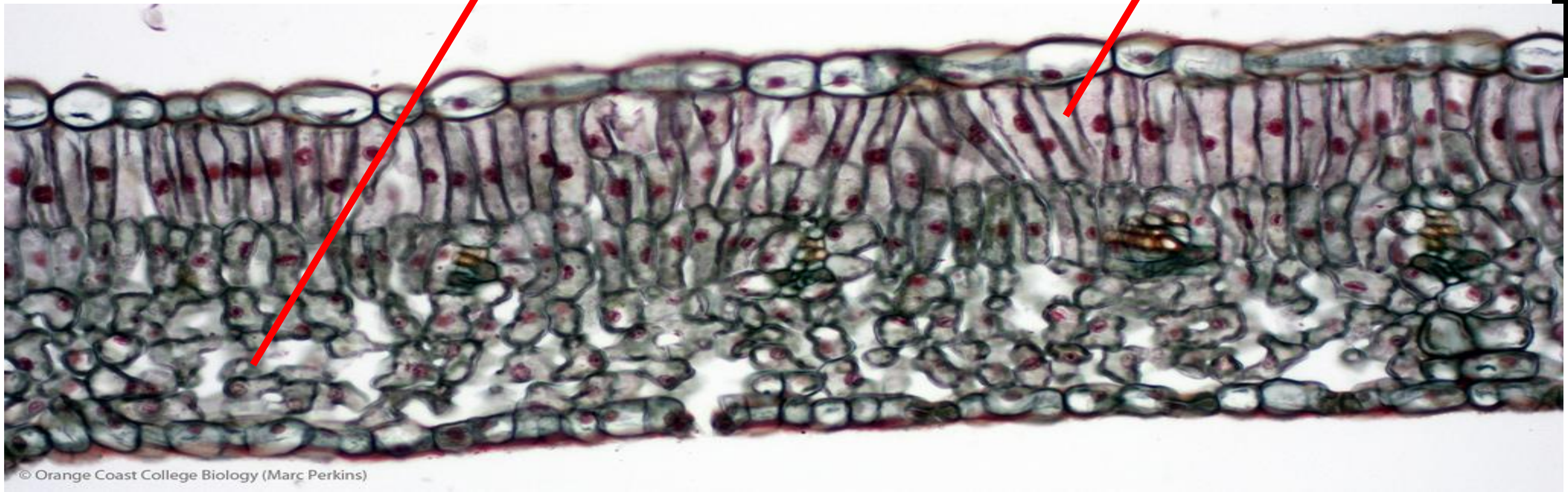
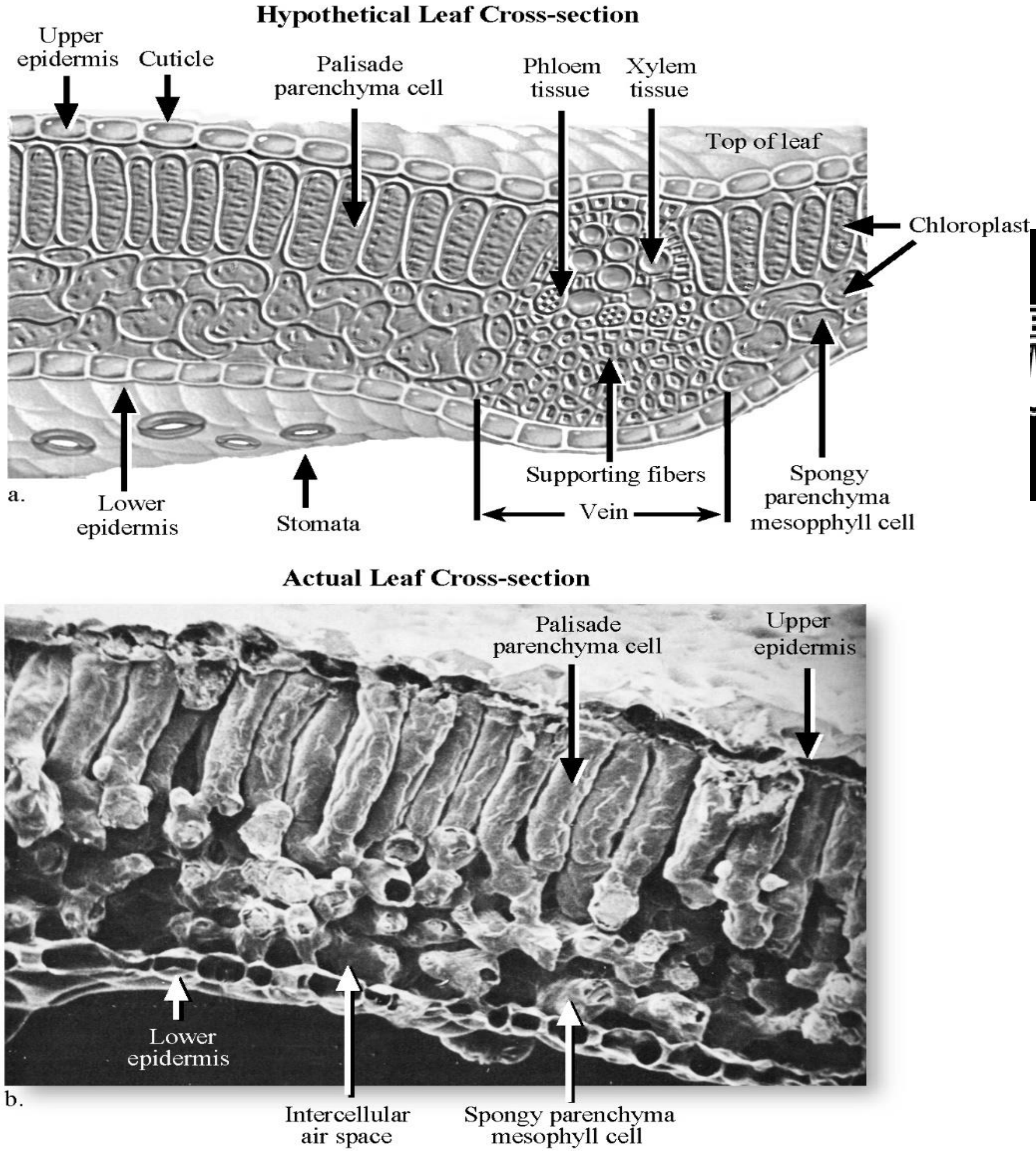


Photo Credit: Approved for OCC Biology Department's photos via Getty Images

Revealing the major structural components that determine the spectral reflectance of vegetation

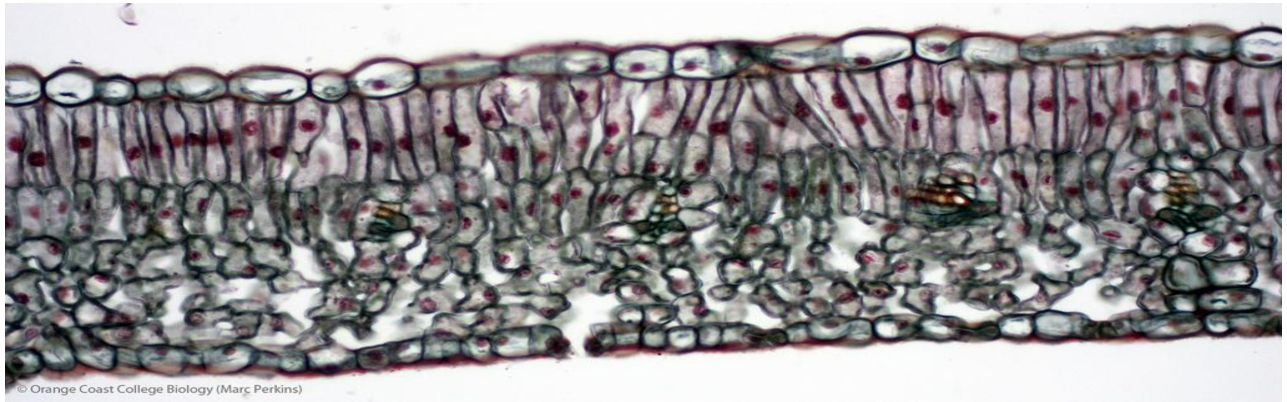
Surface Signatures of Vegetation

Revealing the major structural components that determine the spectral reflectance of vegetation

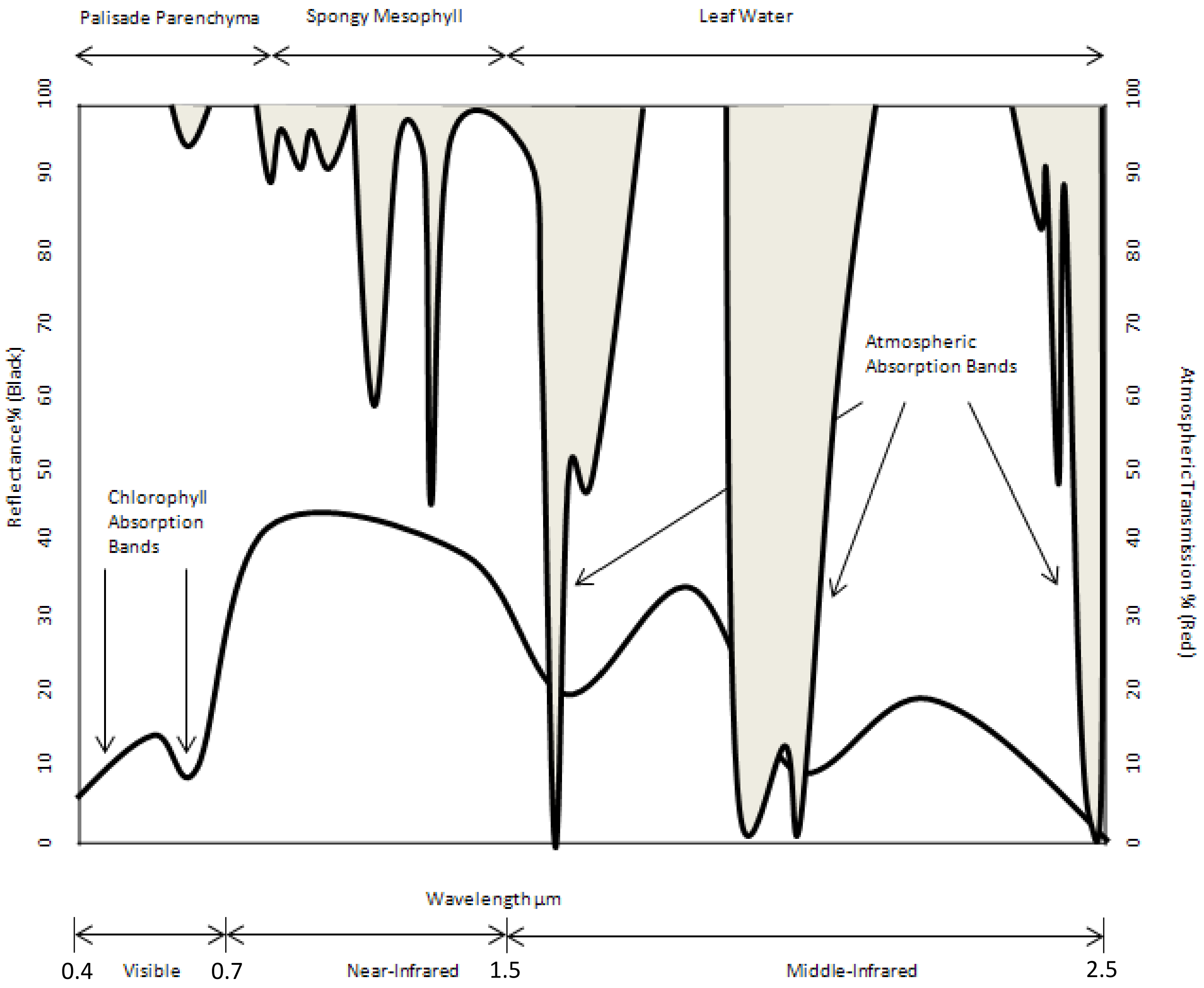


Dominant Factors Controlling Leaf Reflectance

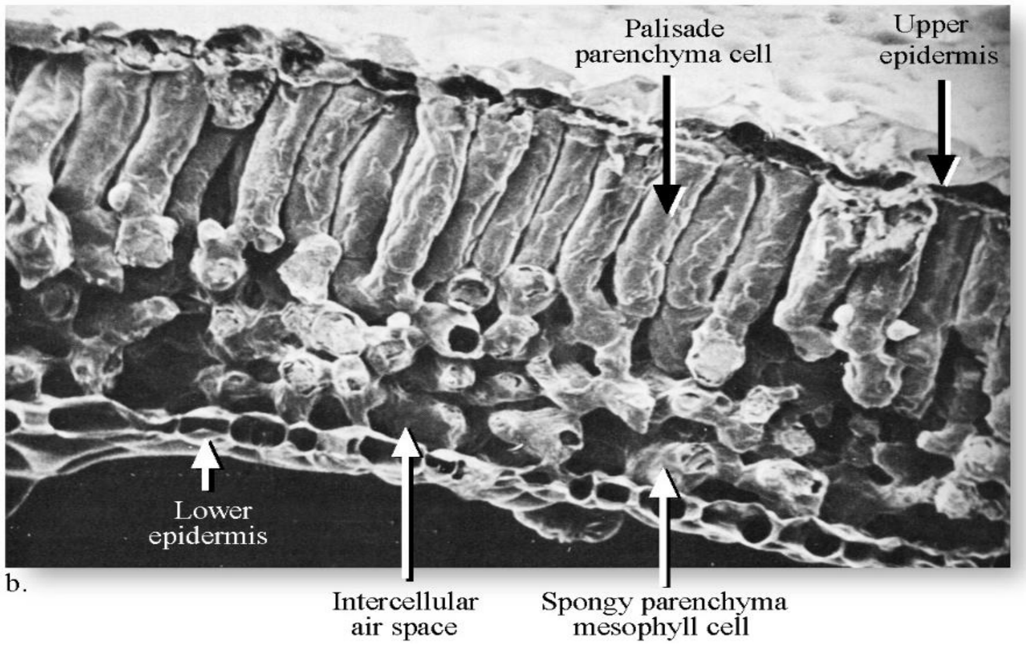
- Chlorophyll pigments in the Palisade parenchyma mesophyll cells have a significant impact on the absorption and reflectance of visible light.
- Spongy parenchyma mesophyll cells have a significant impact on the absorption & reflectance of NIR incident energy.

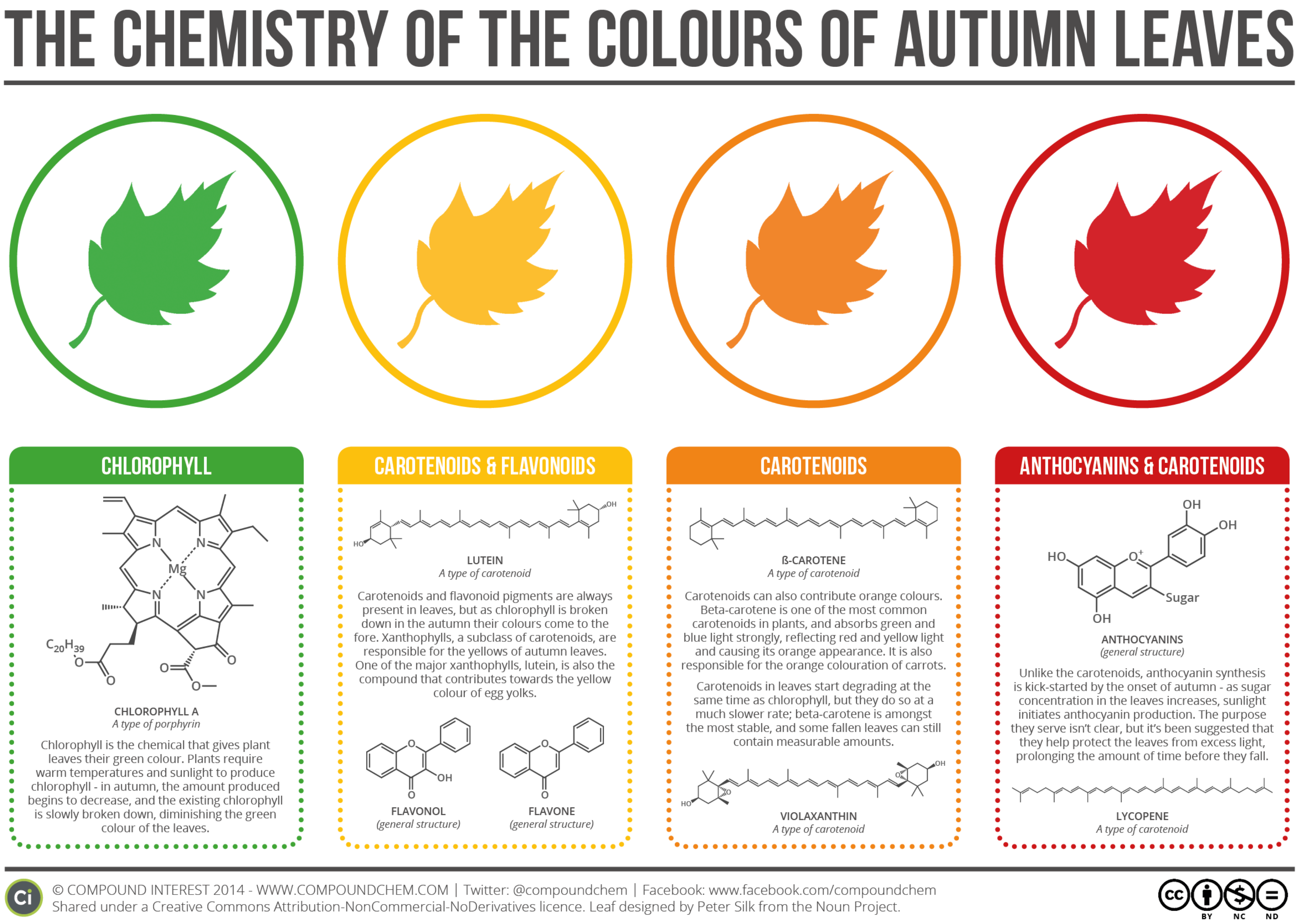


Dominant Factors Controlling Leaf Reflectance



Actual Leaf Cross-section




THE CHEMISTRY OF THE COLOURS OF AUTUMN LEAVES
CHLOROPHYLL
CAROTENOIDS & FLAVONOIDS
CAROTENOIDS
ANTHOCYANINS & CAROTENOIDS
Mg
N
$C_{20}H_{39}$
O
CHLOROPHYLL A
A type of porphyrin
Chlorophyll is the chemical that gives plant leaves their green colour. Plants require warm temperatures and sunlight to produce chlorophyll - in autumn, the amount produced begins to decrease, and the existing chlorophyll is slowly broken down, diminishing the green colour of the leaves.
HO
OH
LUTEIN
A type of carotenoid
Carotenoids and flavonoid pigments are always present in leaves, but as chlorophyll is broken down in the autumn their colours come to the fore. Xanthophylls, a subclass of carotenoids, are responsible for the yellows of autumn leaves. One of the major xanthophylls, lutein, is also the compound that contributes towards the yellow colour of egg yolks.
FLAVONOL
(general structure)
FLAVONE
(general structure)
ß-CAROTENE
A type of carotenoid
Carotenoids can also contribute orange colours. Beta-carotene is one of the most common carotenoids in plants, and absorbs green and blue light strongly, reflecting red and yellow light and causing its orange appearance. It is also responsible for the orange colouration of carrots.
Carotenoids in leaves start degrading at the same time as chlorophyll, but they do so at a much slower rate; beta-carotene is amongst the most stable, and some fallen leaves can still contain measurable amounts.
VIOLAXANTHIN
A type of carotenoid
Sugar
ANTHOCYANINS
(general structure)
Unlike the carotenoids, anthocyanin synthesis is kick-started by the onset of autumn - as sugar concentration in the leaves increases, sunlight initiates anthocyanin production. The purpose they serve isn't clear, but it's been suggested that they help protect the leaves from excess light, prolonging the amount of time before they fall.
LYCOPENE
A type of carotenoid
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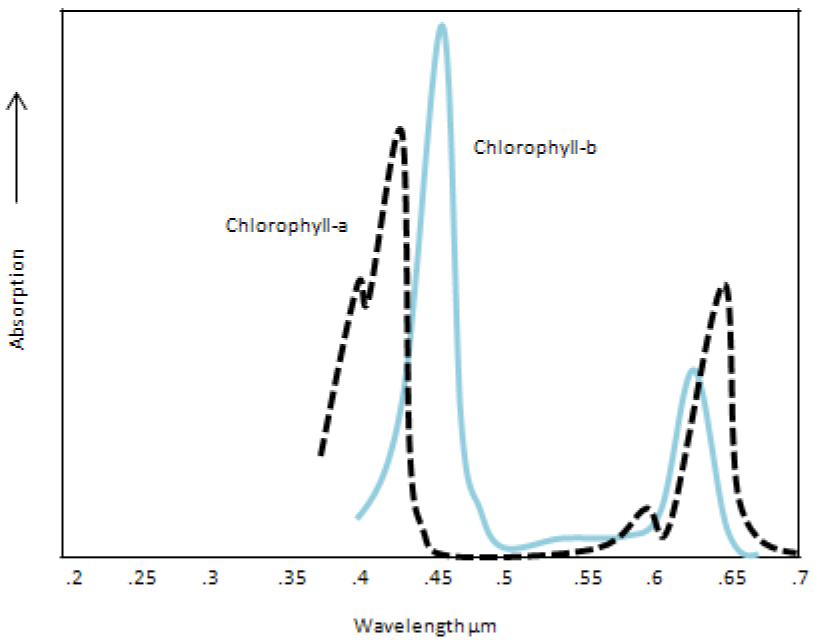
BY NC ND

Dominant Factors Controlling **Visible Reflectance**

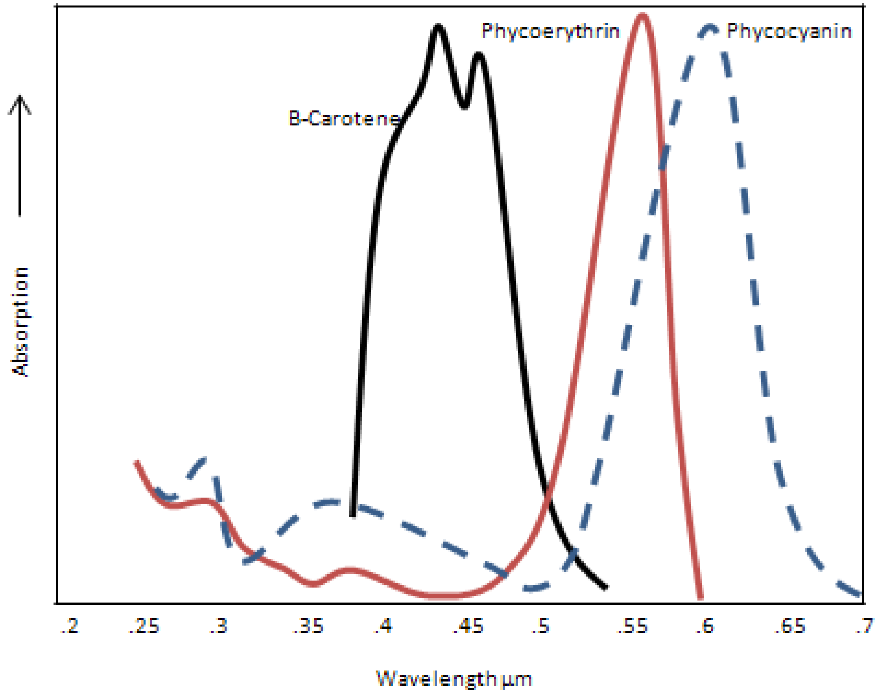


- Chlorophyll *a* peak absorption is at 0.43 and 0.66 µm.
- Chlorophyll *b* peak absorption is at 0.45 and 0.65 µm.
- Optimum chlorophyll absorption windows: 0.45 - 0.52 µm and 0.63 - 0.69 µm

Dominant Factors Controlling **Visible Reflectance**

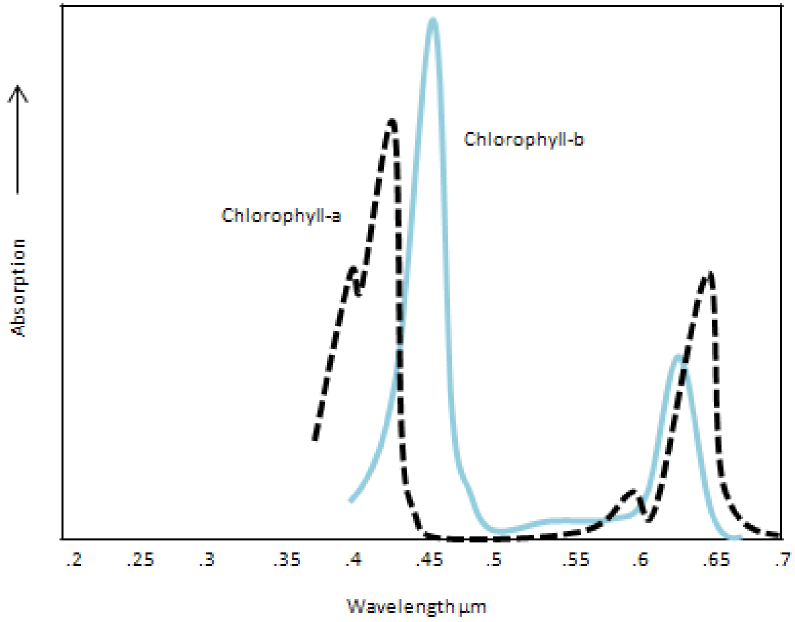
Additional Mesophyll Pigments

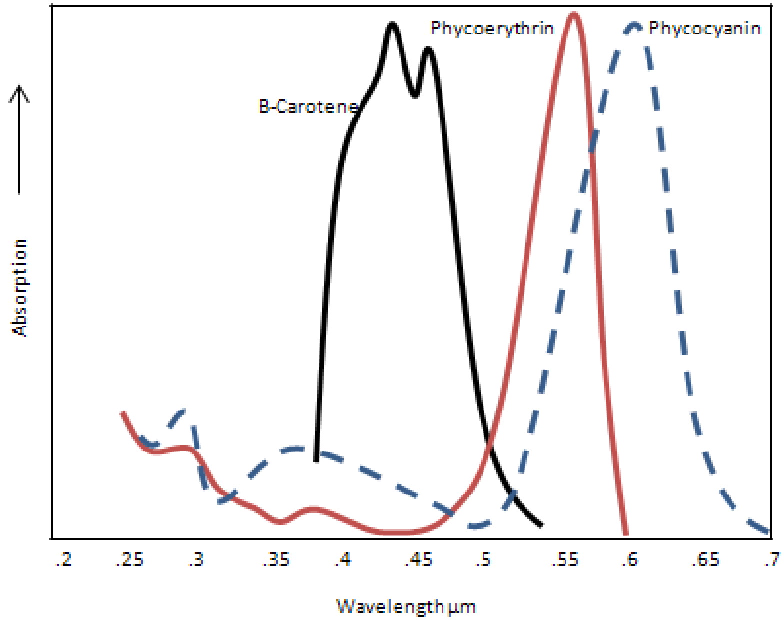
- Yellow carotenes & pale yellow xanthophyll pigments have strong absorptions in the blue λ's.
- β-carotene absorption spectra exhibits strong absorption at ~0.45μm.
- Phycocyanin pigment absorbs primarily in the green and red regions at ~0.62μm.

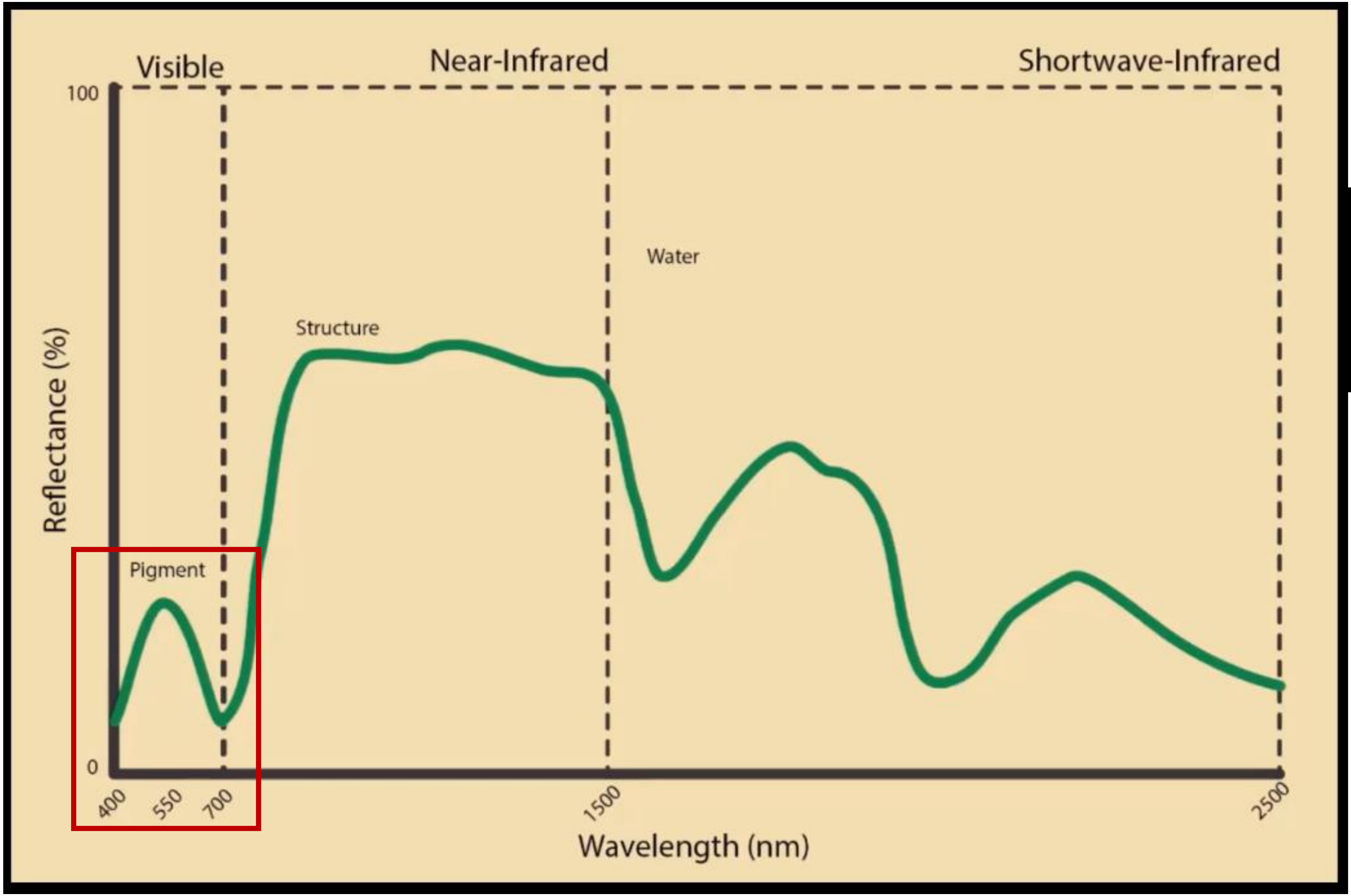


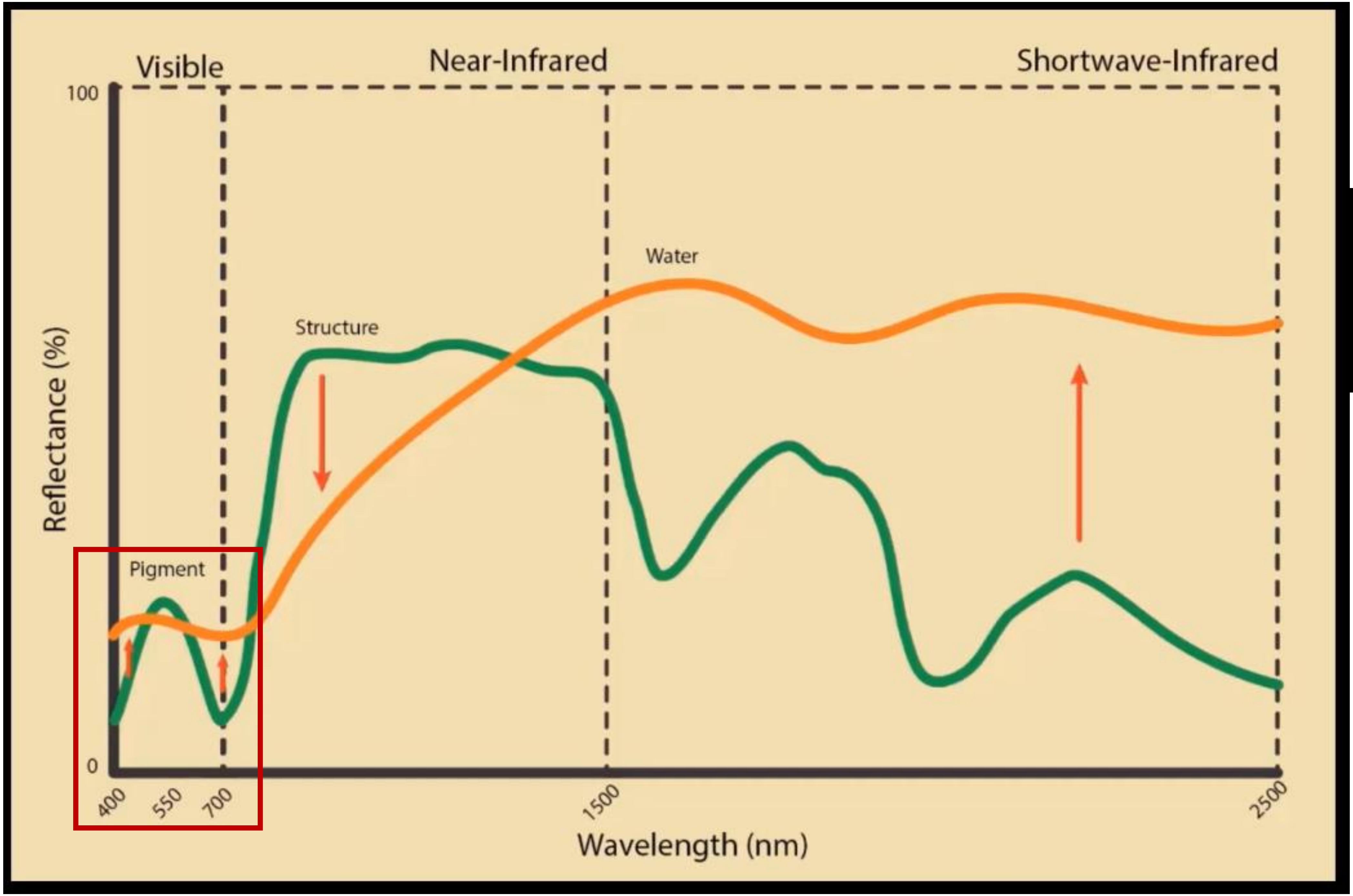
Dominant Factors Controlling **Visible Reflectance**

- When vegetation is healthy, chlorophyll pigments are dominant and can mask carotenes, phycocyanin and other pigments
  - During senescence or severe stress, the chlorophyll dominance may be lost …causing the other pigments to become dominant (*e.g.* at leaf fall).
  - Anthocyanin may also be produced in autumn causing the leaves to appear bright red.






Visible
Near-Infrared
Shortwave-Infrared
100
0
Reflectance (%)
Structure
Water
Pigment
400
550
700
1500
2500
Wavelength (nm)

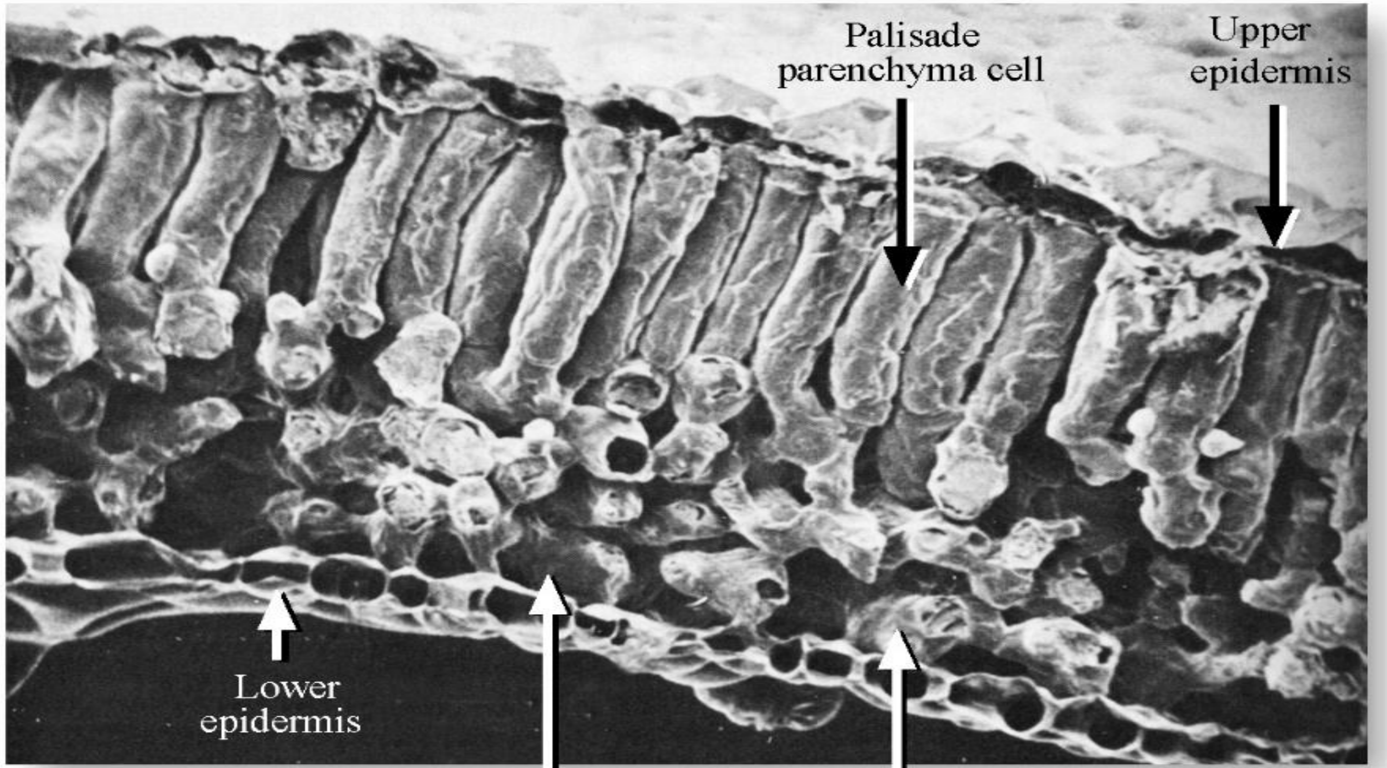

Visible
Near-Infrared
Shortwave-Infrared
100
0
Reflectance (%)
Water
Structure
Pigment
400
550
700
1500
2500
Wavelength (nm)

Dominant Factors Controlling **NIR Reflectance**

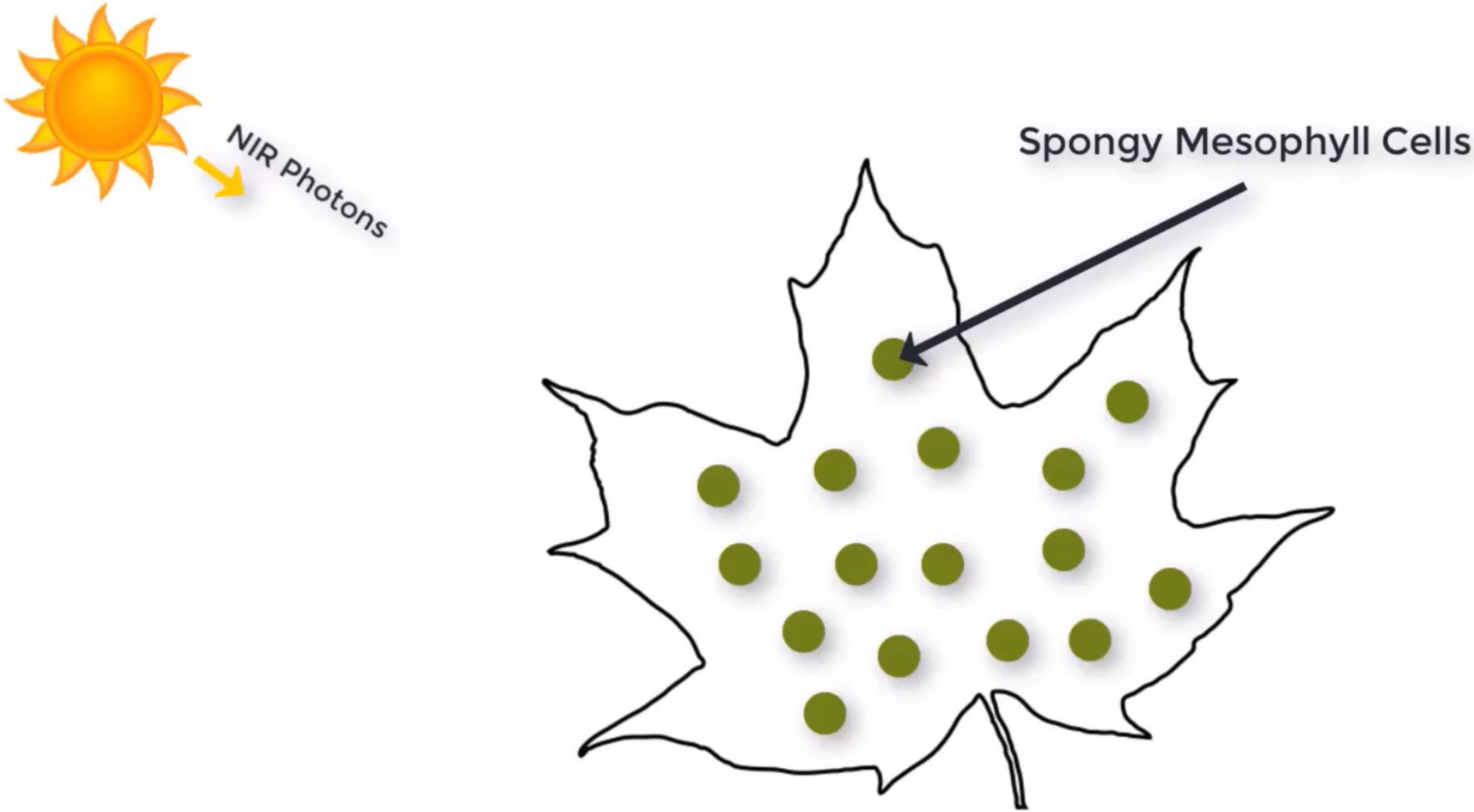
NIR energy interaction within the Spongy Mesophyll cells:

- In a typical healthy green leaf, the near-infrared reflectance increases dramatically between 700 – 1200nm (…Similarly, NIR absorption decreases).
- In the NIR, healthy vegetation is normally characterized by
  - High reflectance (40 – 60%),
  - High transmittance to underlying leaves (40 – 60%),
  - Relatively low absorption (5 – 10%).
- High diffuse reflectance of the NIR (700 – 1200nm) energy from plant leaves is due to internal scattering at the cell wall-air interface.

Actual Leaf Cross-section

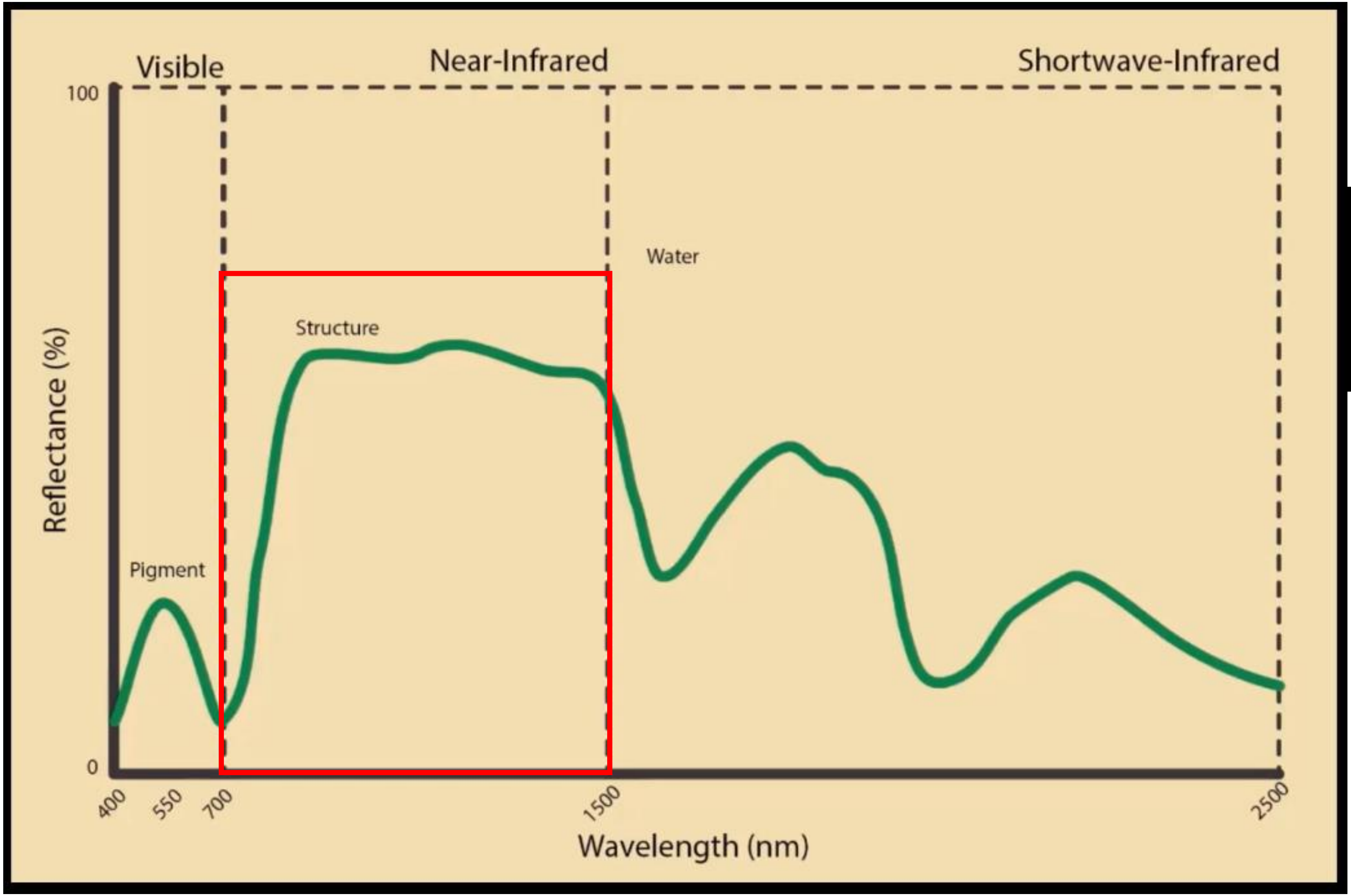


b.


NIR Photons
Spongy Mesophyll Cells

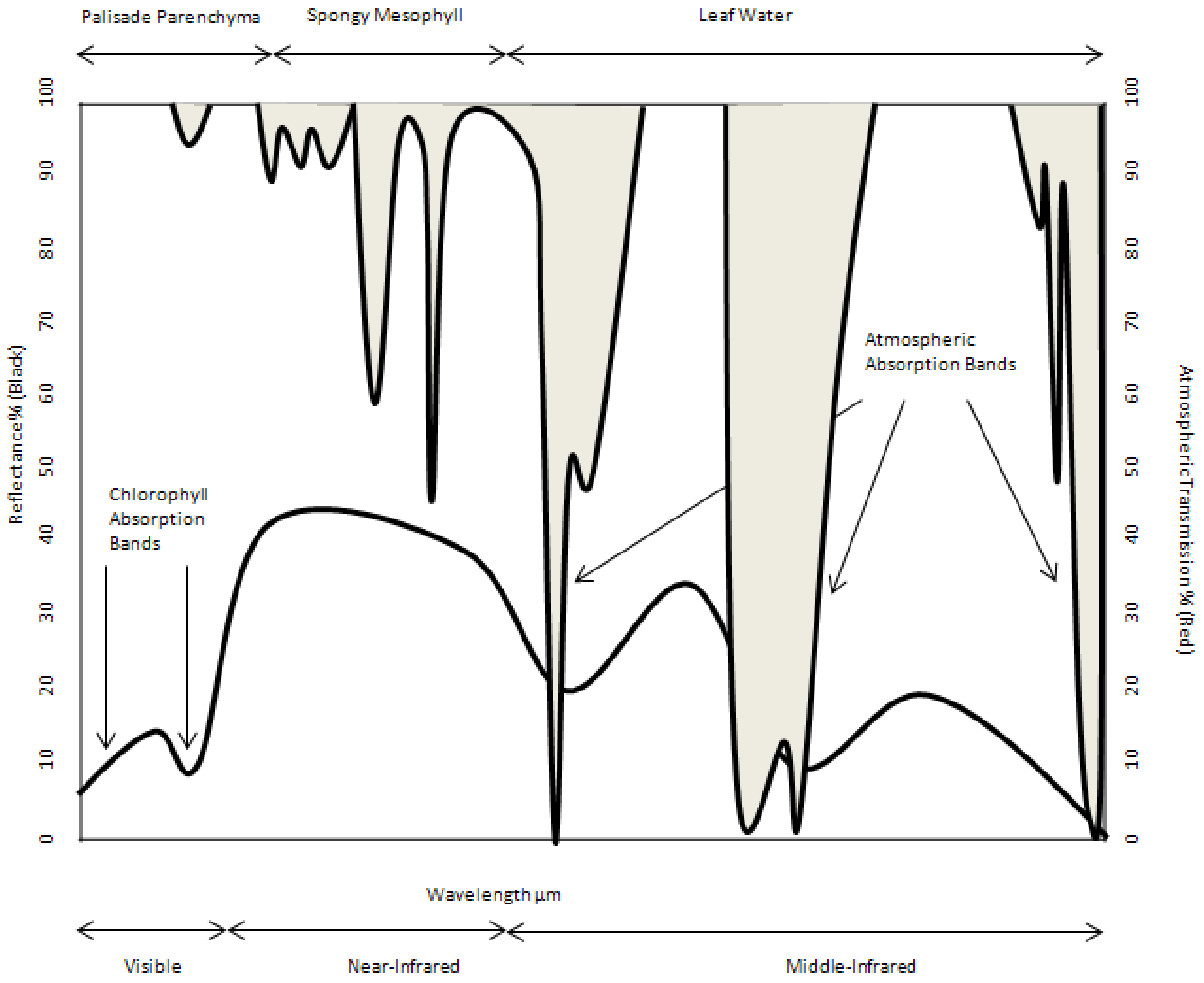
Dominant Factors Controlling **NIR Reflectance**

- The main reasons that leaves reflect so much NIR energy are:
  - The leaf already reflects 40 – 60% of the incident NIR energy from the spongy mesophyll, and …
  - The remaining 45 – 50% of the energy penetrates (i.e. transmitted) through the leaf and can be reflected once again by leaves below it.


Visible
Near-Infrared
Shortwave-Infrared
100
0
Water
Structure
Pigment
Reflectance (%)
400
550
700
1500
2500
Wavelength (nm)

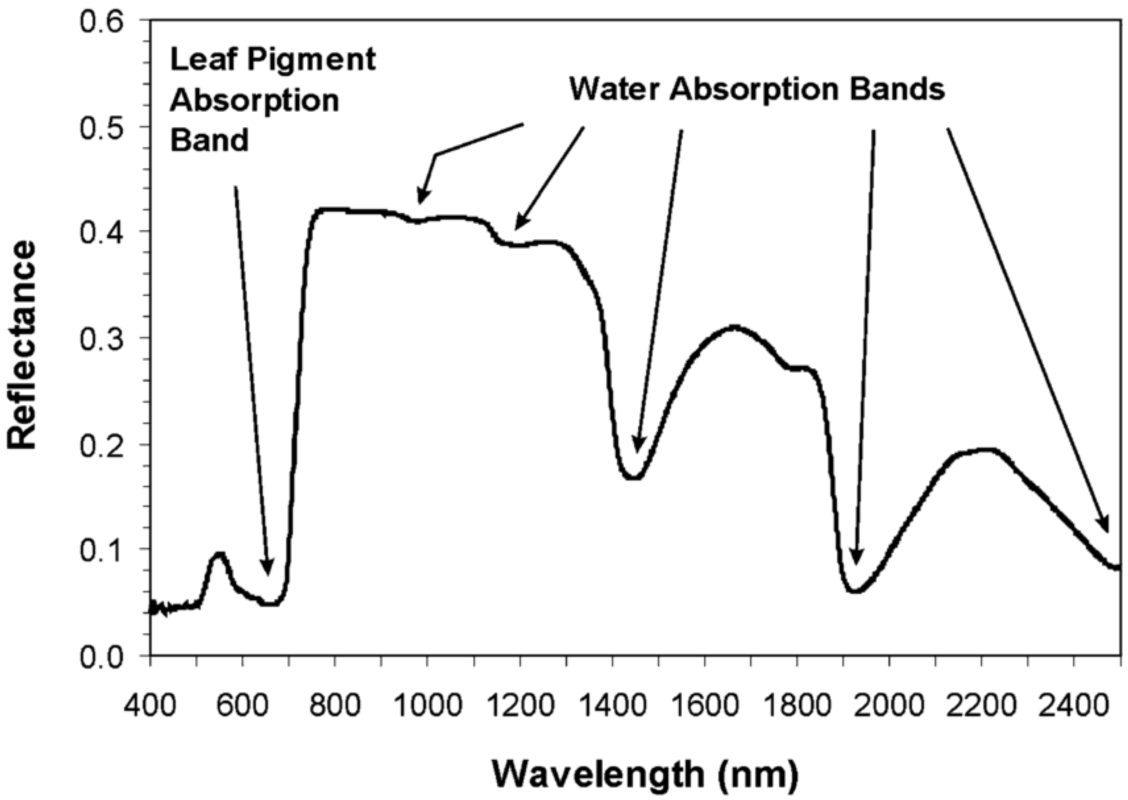
Dominant Factors Controlling **MIR / SWIR Reflectance**

- Water vapour in the atmosphere creates five major absorption bands across the NIR to middle-infrared (MIR) wavelengths.
  - 0.97, 1.19, 1.45, 1.94, and 2.7μm.



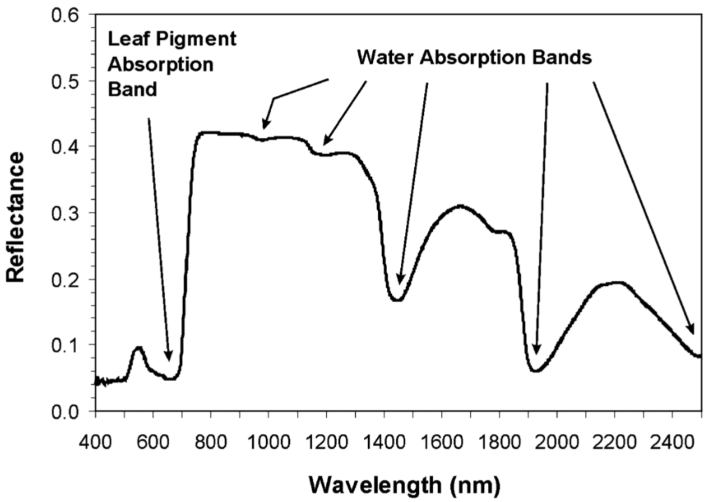
Dominant Factors Controlling **MIR / SWIR Reflectance**

- Likewise, water content in leaves creates water absorption bands at similar wavelengths



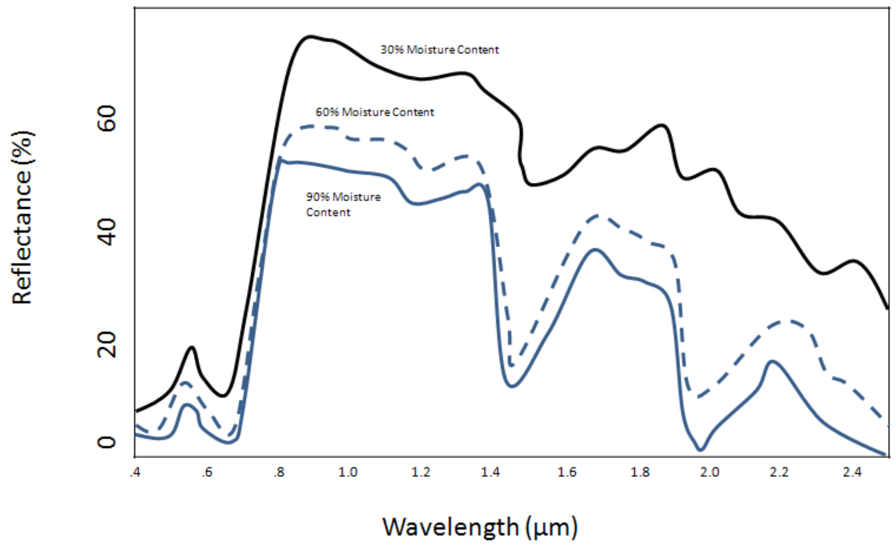
Dominant Factors Controlling **MIR / SWIR Reflectance**

- There is also a strong relationship between the reflectance in the MIR region from 1.3 – 2.5μm …and the amount of water present in leaves.
- Water in leaves absorb incident energy between the absorption bands with increasing strength at longer wavelengths.

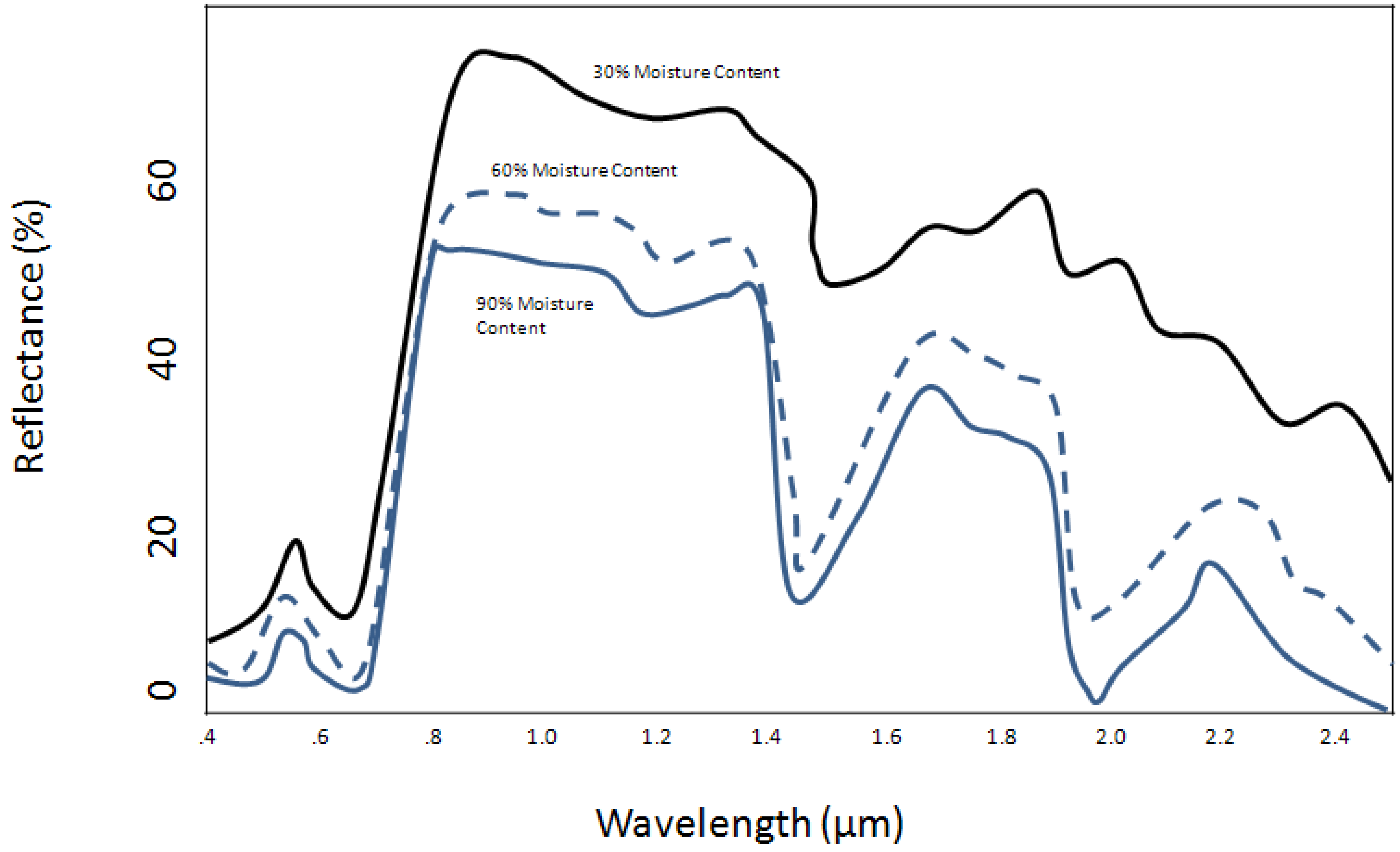


Dominant Factors Controlling **MIR / SWIR Reflectance**

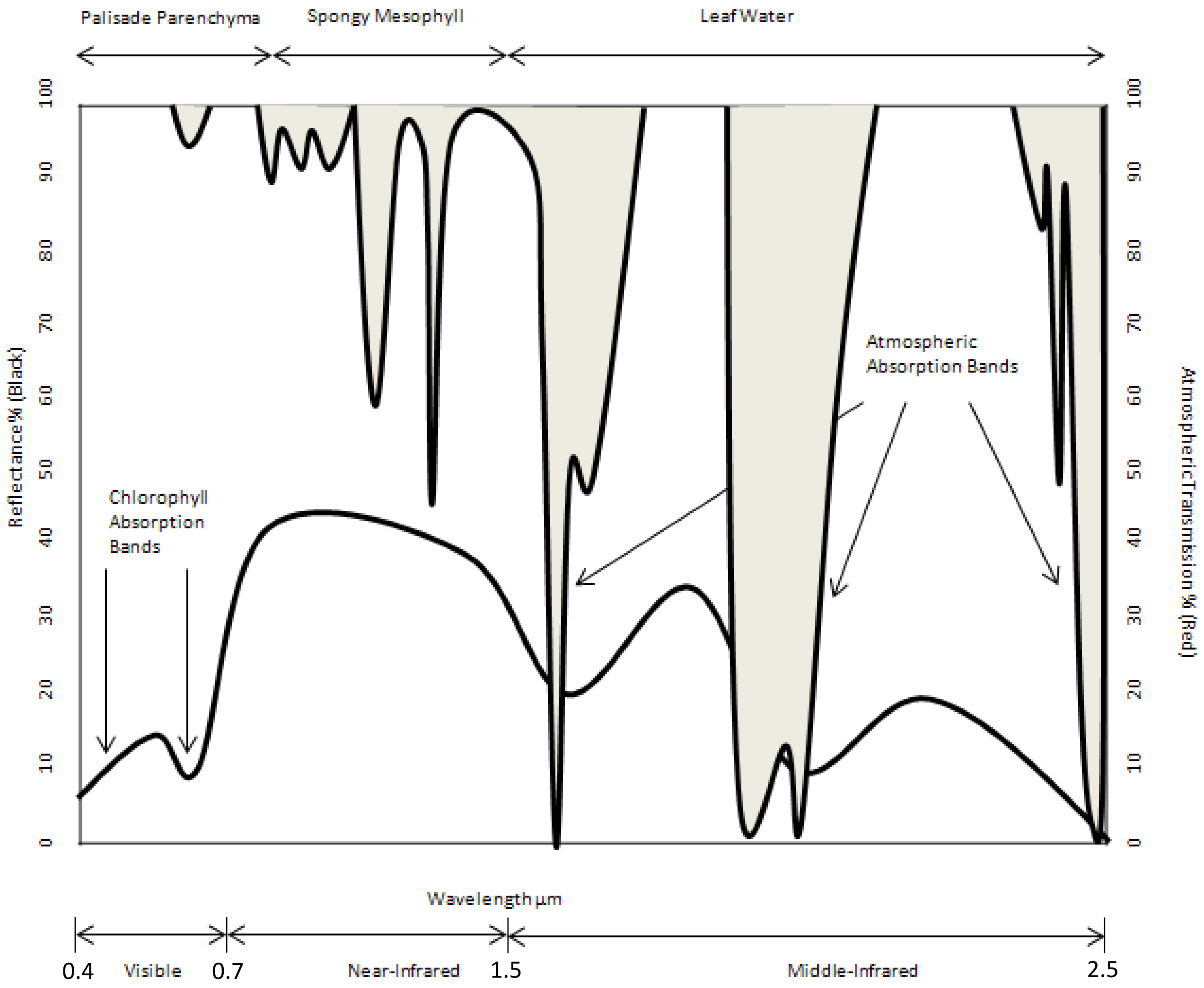
- Water is a good absorber of MIR energy, so the greater the water content of the leaves, the lower the MIR reflectance.
  - o Conversely, …as the amount of plant water in intercellular spaces decreases, this causes greater MIR leaf reflectance.



Dominant Factors Controlling **MIR / SWIR Reflectance**



Dominant Factors Controlling Leaf Reflectance



Water absorption bands:

0.97 µm

1.19 µm

1.45 µm

1.94 µm

2.70 µm

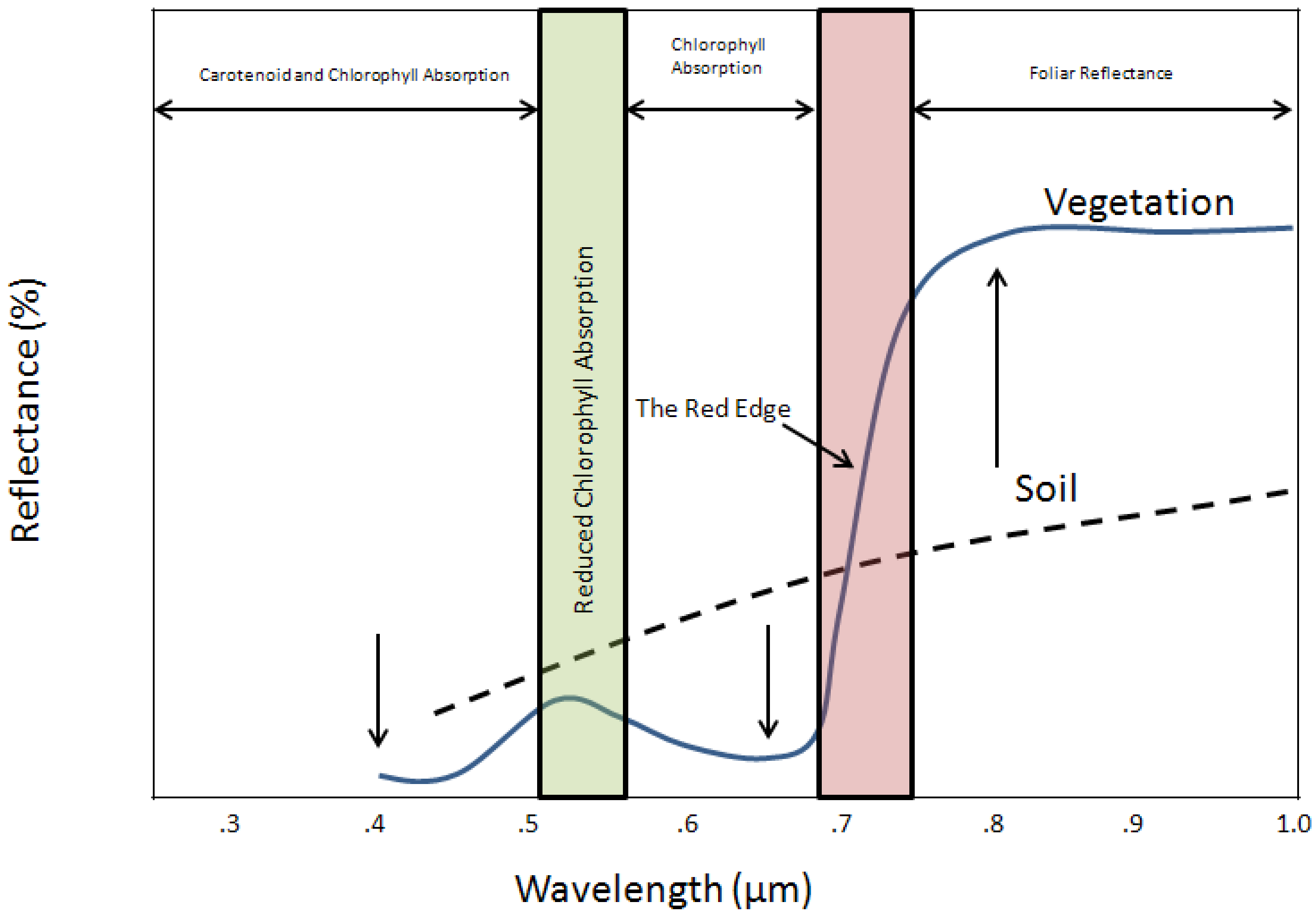
Dominant Factors Controlling Leaf Reflectance

SUMMARY:

The dominant factors controlling leaf reflectance are…

- 0.4 – 0.75μm: the various leaf pigments in the palisade parenchyma (*e.g.* chlorophyll *a* & *b*, and β-carotene).
- 0.75 – 1.35μm: the scattering (i.e. repeated reflectance and transmission) of near infrared (NIR) energy in the spongy mesophyll, and
- 1.35 – 2.8μm: the amount of water in the plant.

Basis of Vegetation Indices



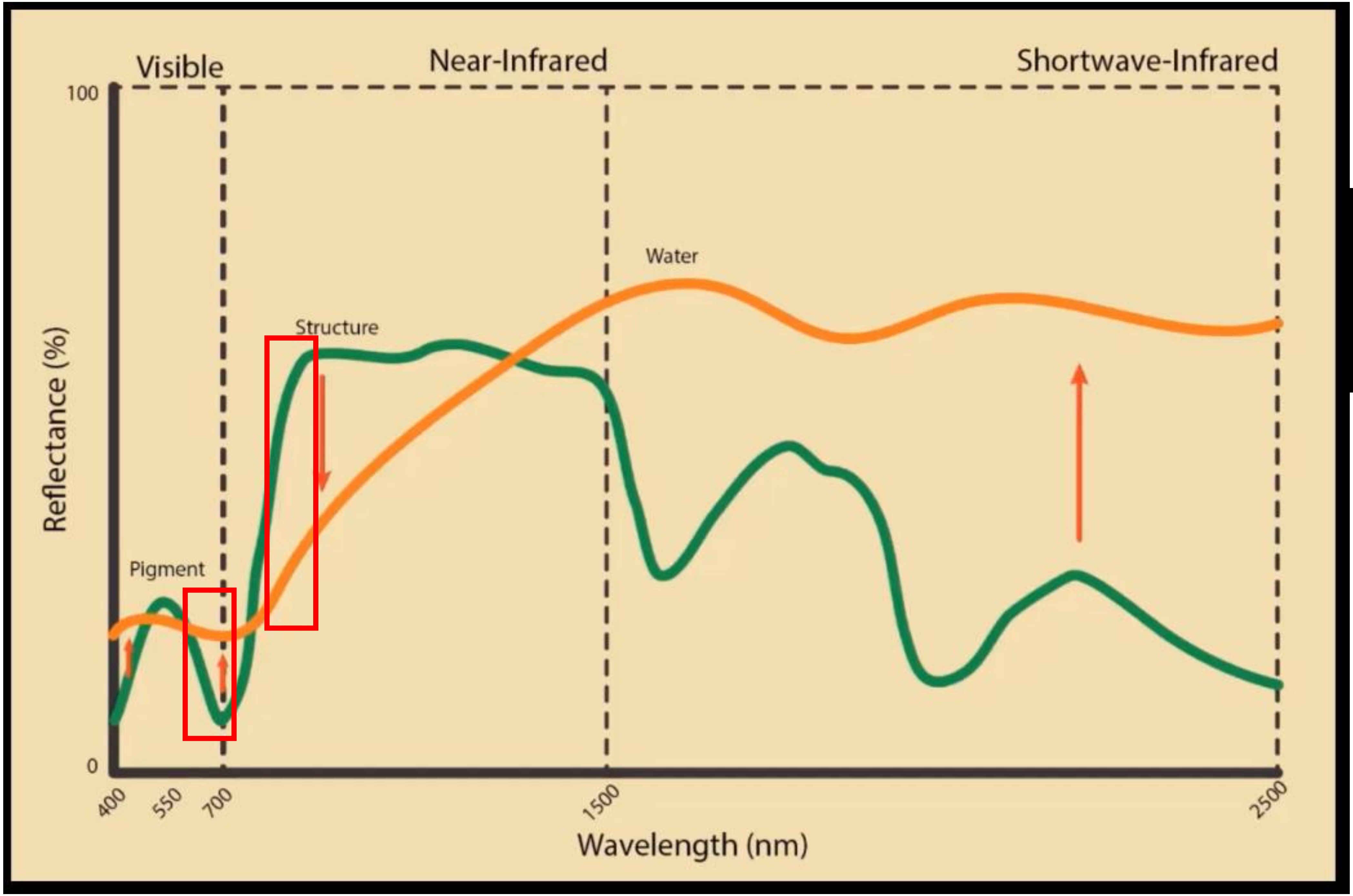
Infrared/Red Ratio Vegetation Index

- The near-infrared (NIR) to red simple ratio (SR) is the first true vegetation index:

$$SR = \frac{NIR}{red}$$

-

  It takes advantage of the inverse relationship between chlorophyll absorption of red radiant energy and increased reflectance of near-infrared energy for healthy plant canopies.



Visible
Near-Infrared
Shortwave-Infrared
100
0
Reflectance (%)
Water
Structure
Pigment
400
550
700
1500
2500
Wavelength (nm)

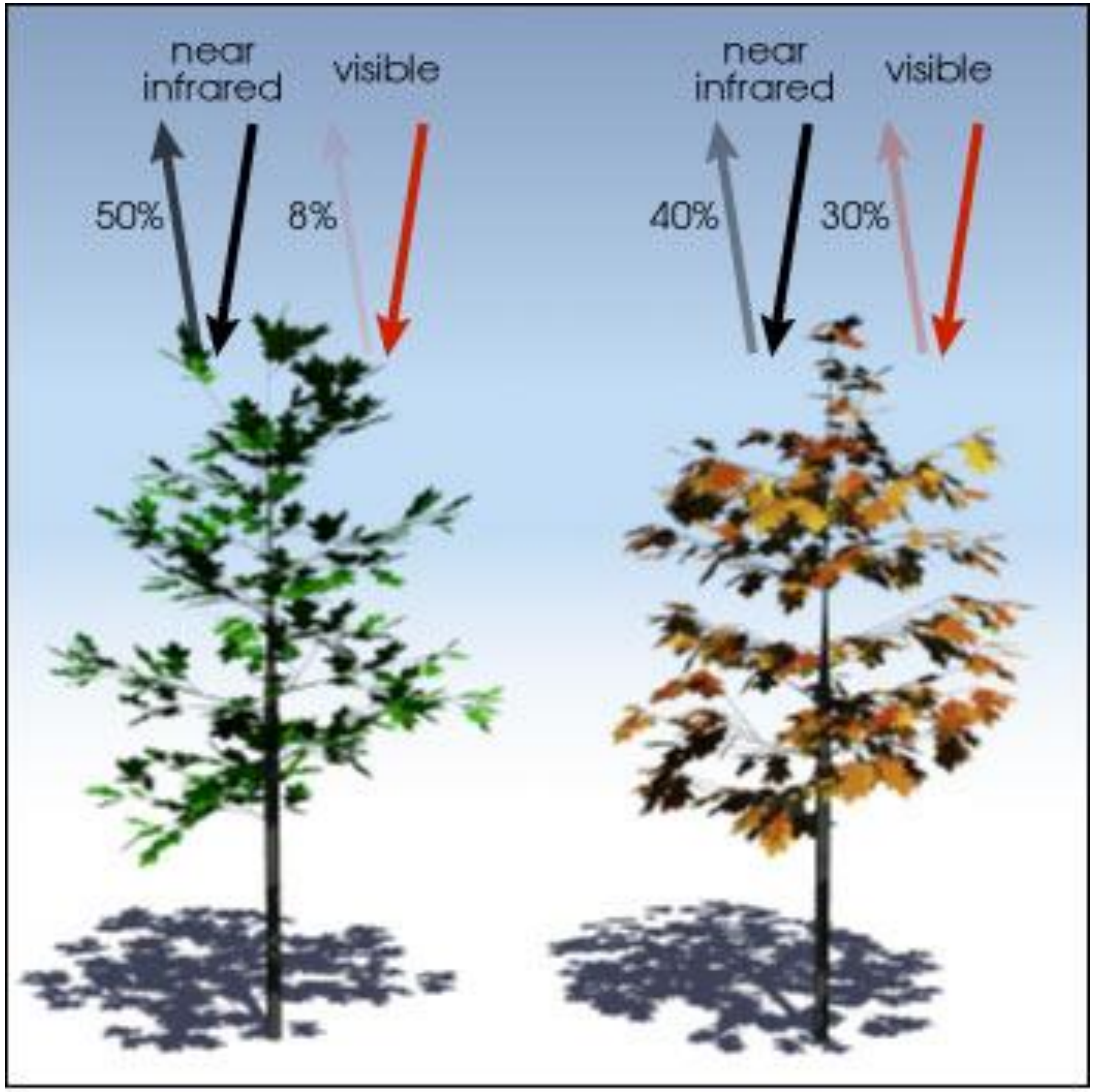
Normalized Difference Vegetation Index

- The generic normalized difference vegetation index (NDVI):

$$NDVI = \frac{NIR - red}{NIR + red}$$

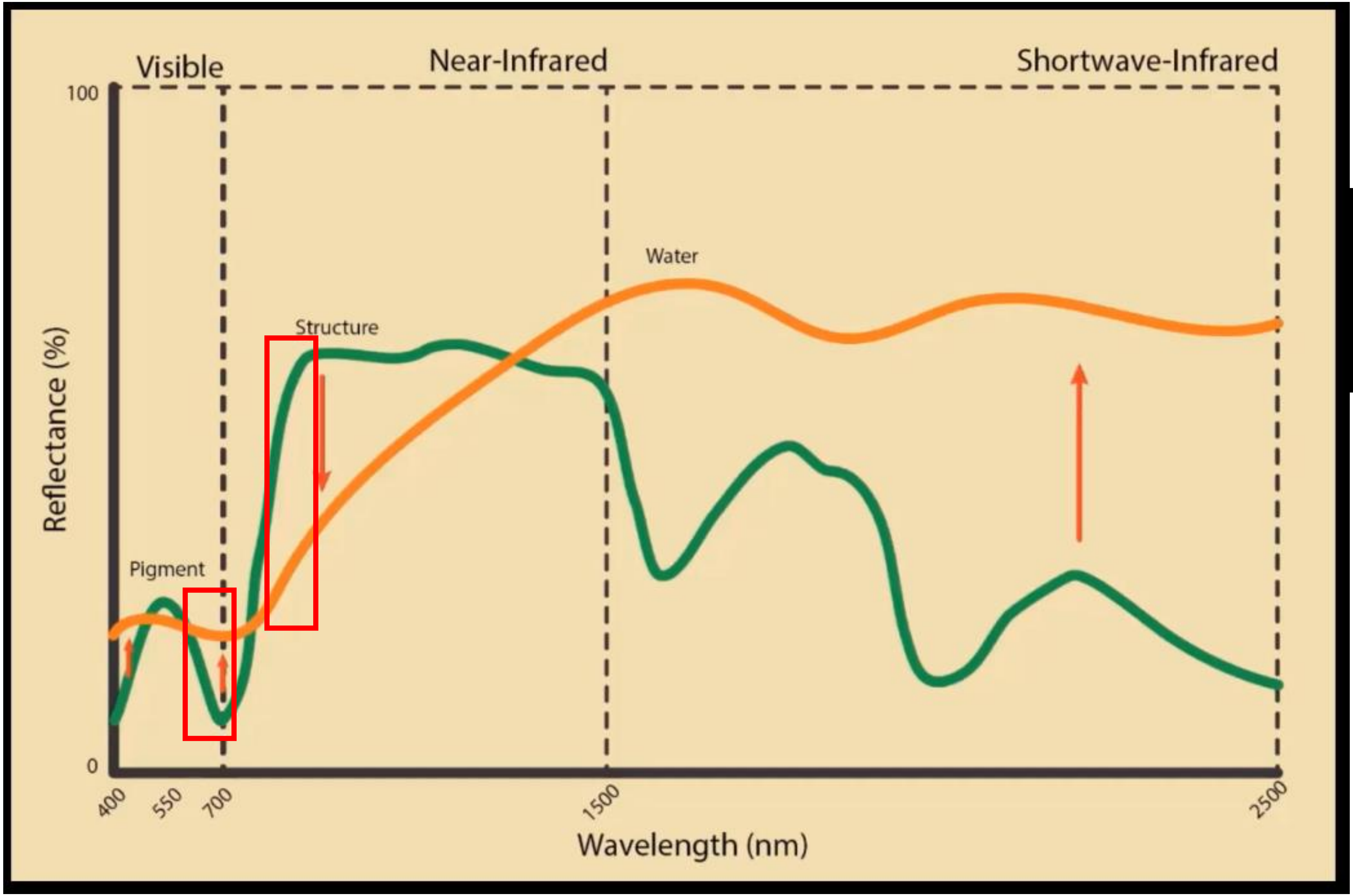
- has provided a method of estimating net primary production over varying biome types, identifying ecoregions, monitoring phenological patterns of the earth's vegetative surface, and of assessing the length of the growing season and dry-down periods.

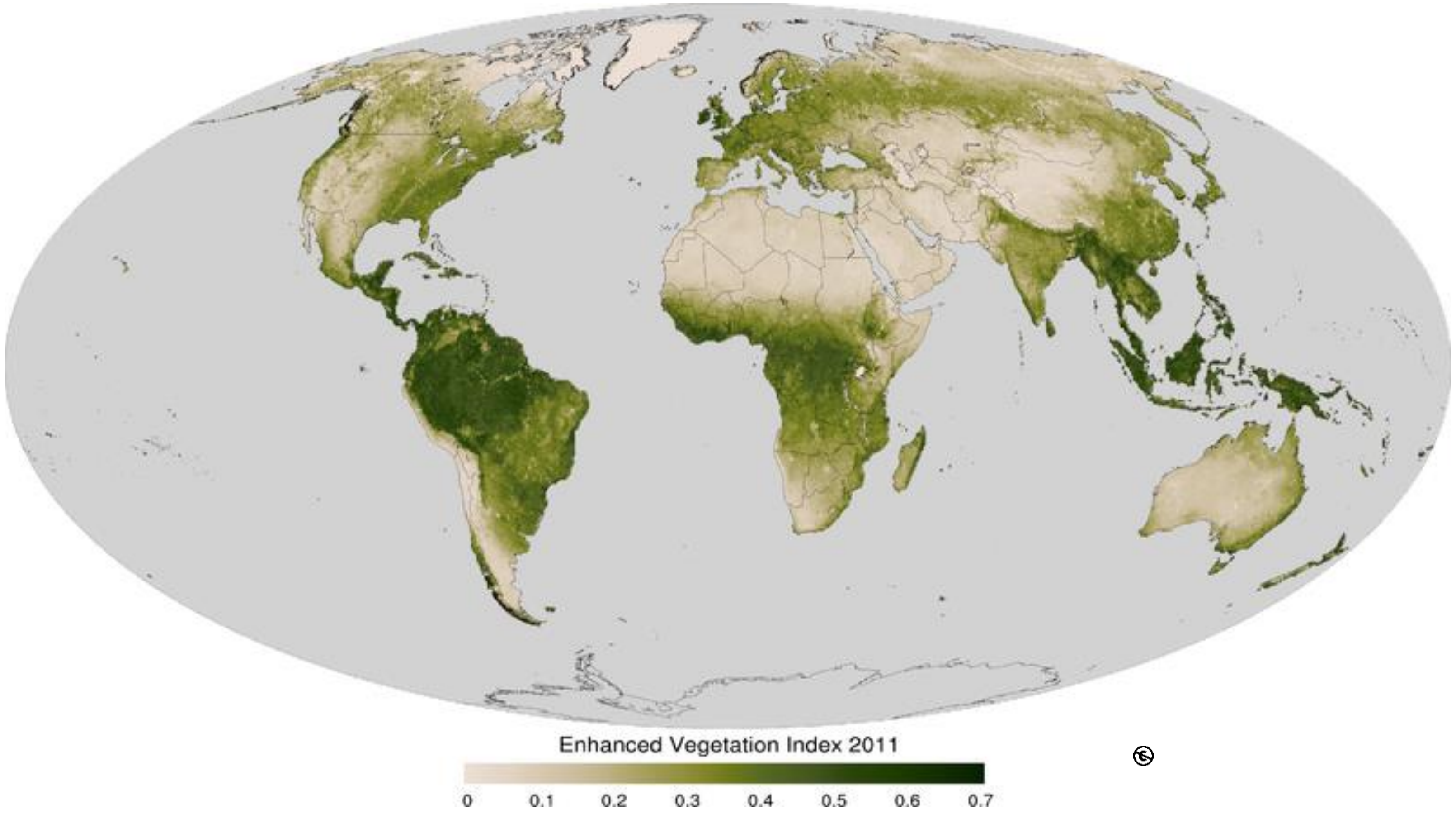
NDVI



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

Calculating NDVI (Source: NASA)


Visible
Near-Infrared
Shortwave-Infrared
100
0
Reflectance (%)
Water
Structure
Pigment
400
550
700
1500
2500
Wavelength (nm)


Enhanced Vegetation Index 2011
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7

Important Topics

- Which surface interaction is used by earth observing satellites to take images of the surface of the earth?
- What are remote sensing scientists able to accomplish by comparing the spectral signatures of different materials?
- What does NDVI stand for and what parts of the EMS does it take advantage of when measuring vegetation?
- What are the dominant factors controlling the spectral response of leaves in the visible, NIR and MIR part of the spectrum?

Images Cited

Autumn leaves (Source: Flickr, **Eva the Weaver**). Image licensed for use under Some rights reserved. Image retrieved from https://www.flickr.com/photos/evaekeblad/1169803024/in/photostream/

Winter jasmine leaf cross section (Source: Wikimedia Commons). This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license. Image retrieved from https://commons.wikimedia.org/wiki/File:Winter_jasmine_leaf_cross_section.png

Calculating NDVI (Source: NASA). Image retrieved from https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php