Spectral Properties of Leaves & Plants

January 17Topics:

Spectroscopy of Leaves and Plants

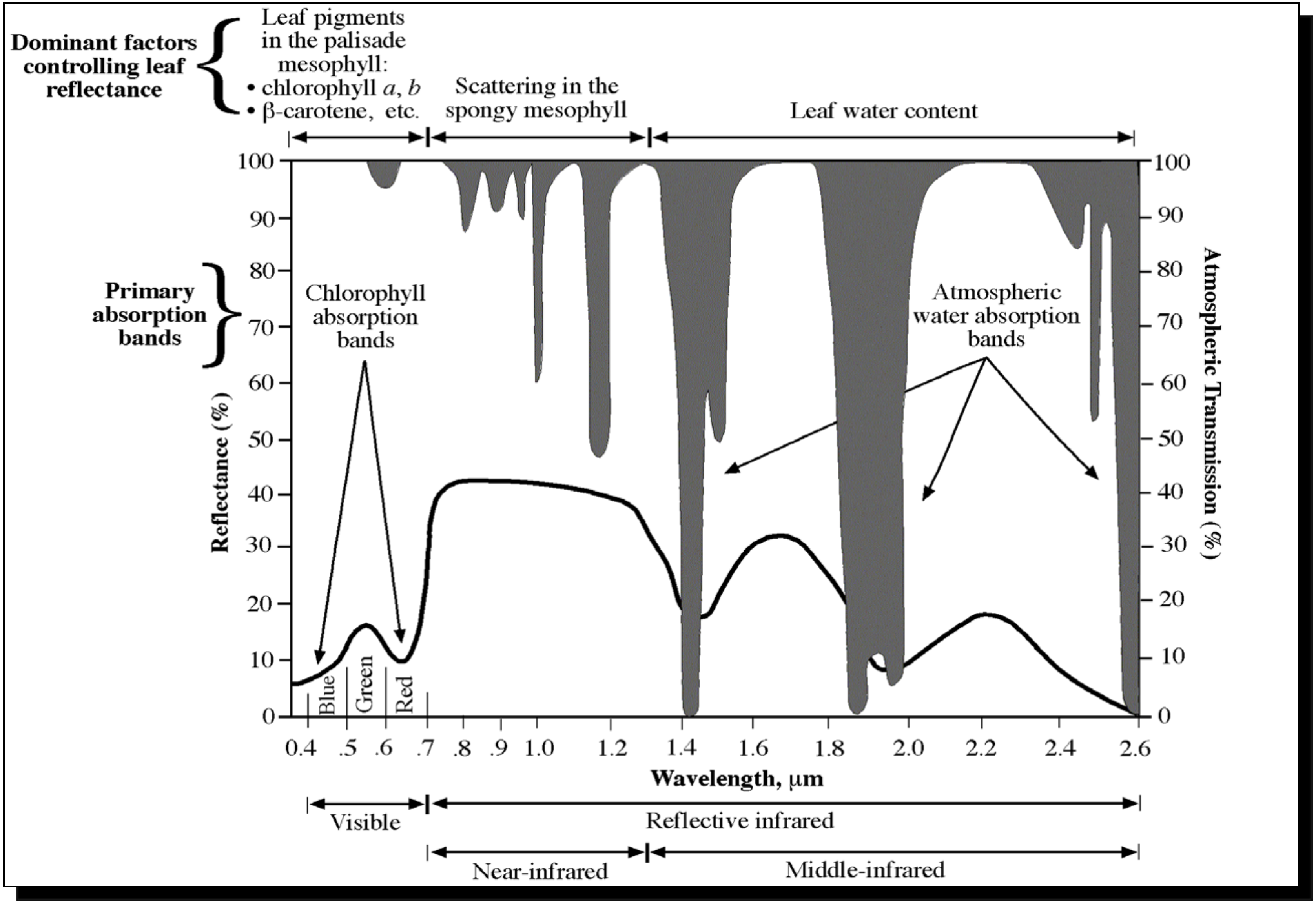
Reading: Chapters 11, 2

Optical Properties of leaves and canopies

Plant functions (photosynthesis, respiration, transpiration)

Bidirectional Reflectance Distribution Function

Leaf Functions

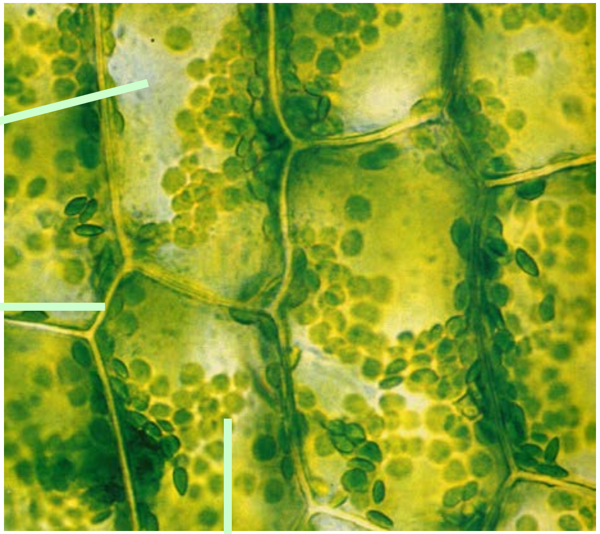


Pigment absorption is the dominant process in **visible**;
Scattering is the dominant process in **near-infrared**;
Water absorption is increasingly important with wavelength in the **mid-infrared.**

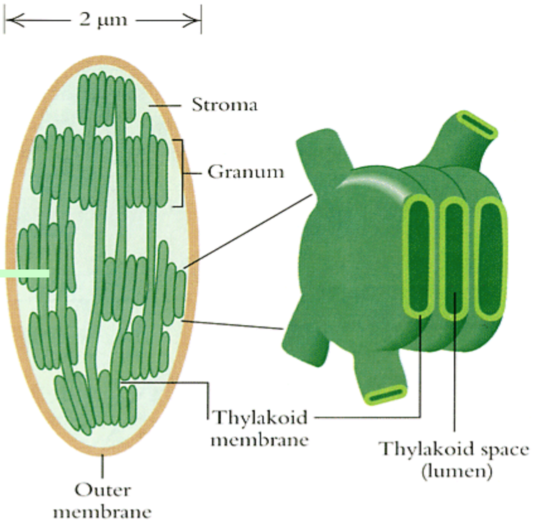
Leaf biochemical composition

A typical fresh-green leaf contains:

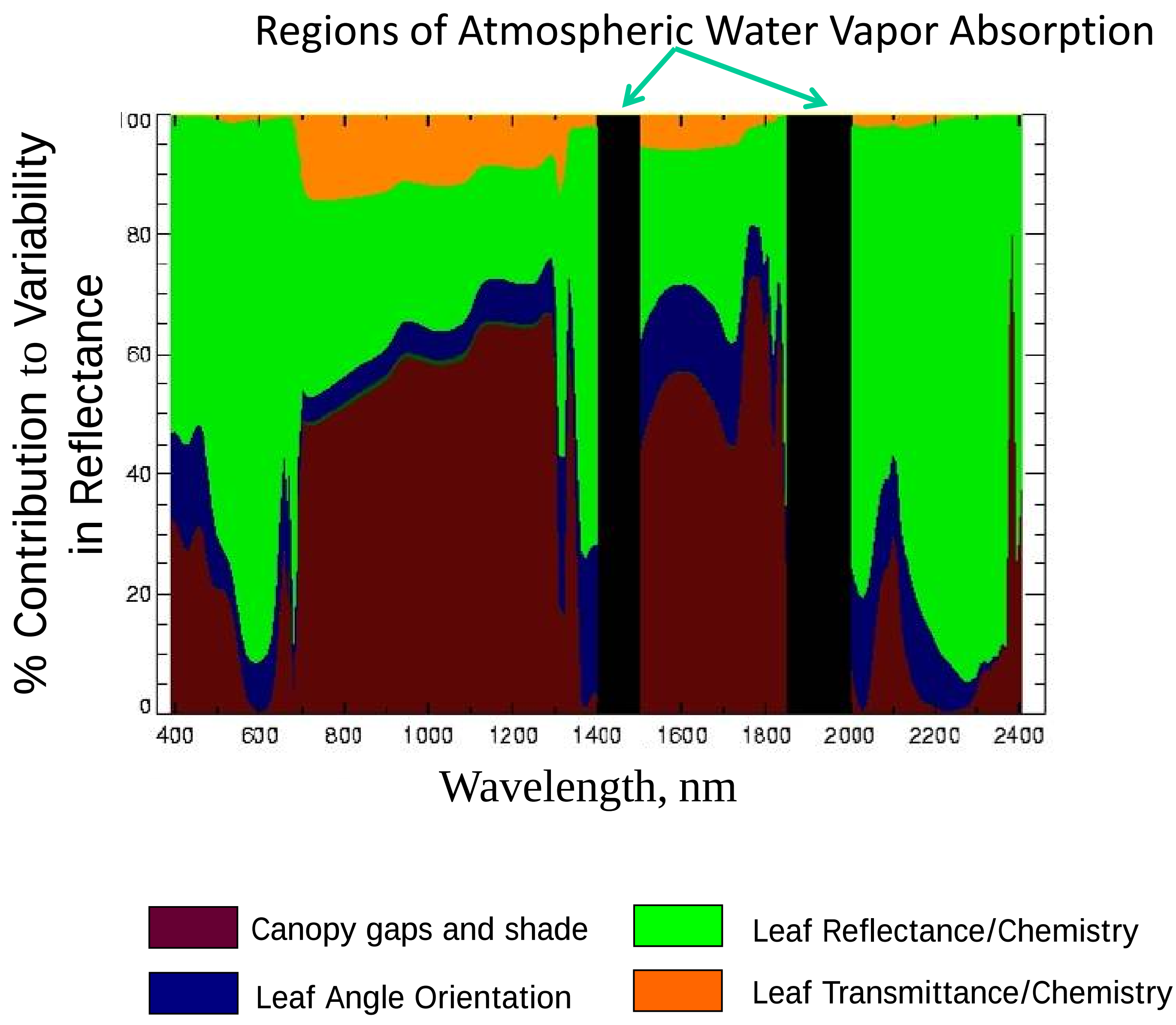
- water (vacuole): 90-95%
- dry matter (cell walls): 5-10%
  - cellulose: 15-30%
  - hemicellulose: 10-30%
  - proteins: 10-20%
  - lignin: 5-15%
  - starch: 0.2-2.7%
  - sugar
  - etc.



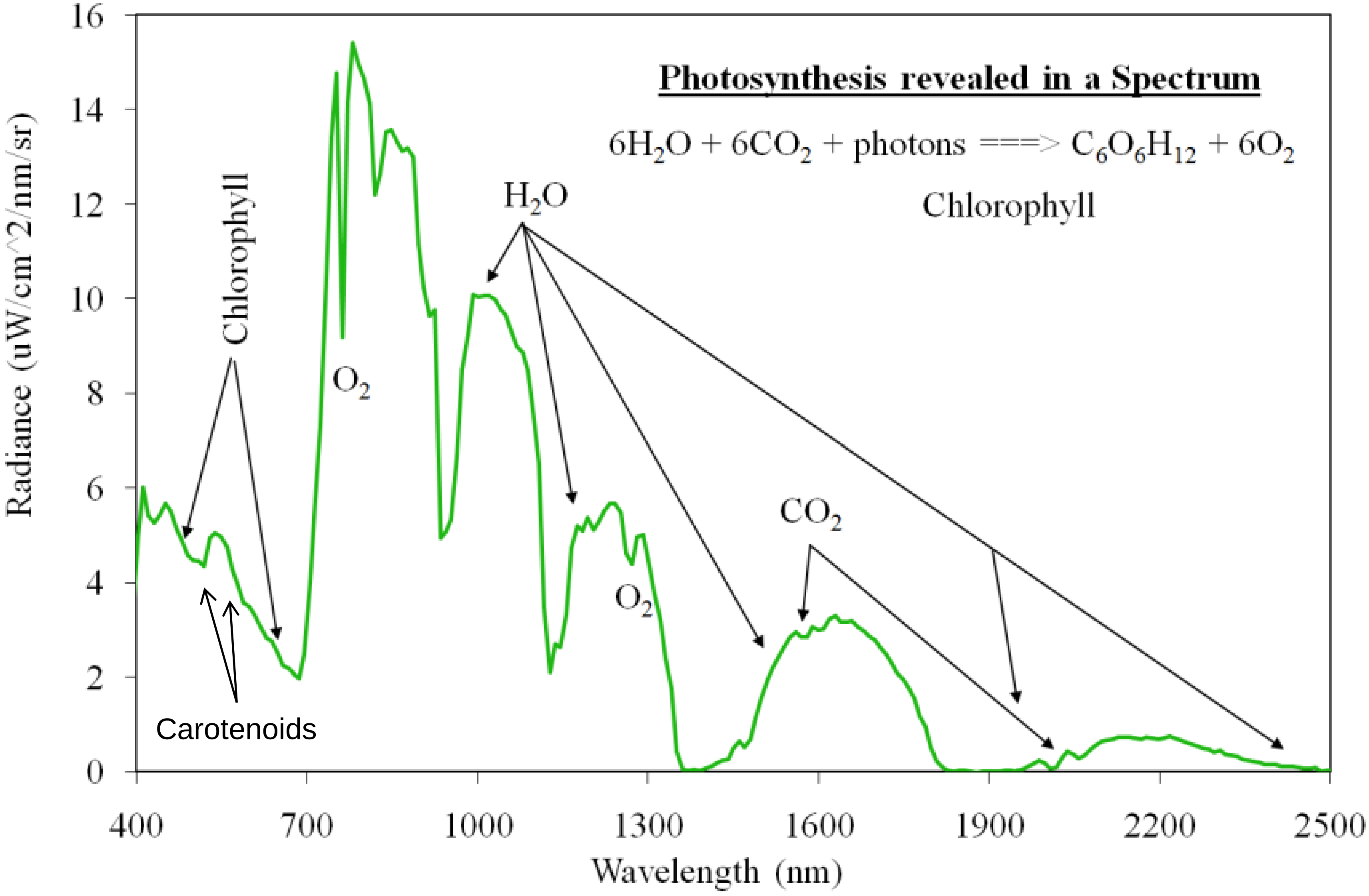
- wax (cuticle)
- chlorophylls *a* and *b* (chloroplasts)
- carotenoids (chloroplasts)
- other pigments (cytoplasm)
  - anthocyanins, flavons
  - ”brown pigments”
  - etc.



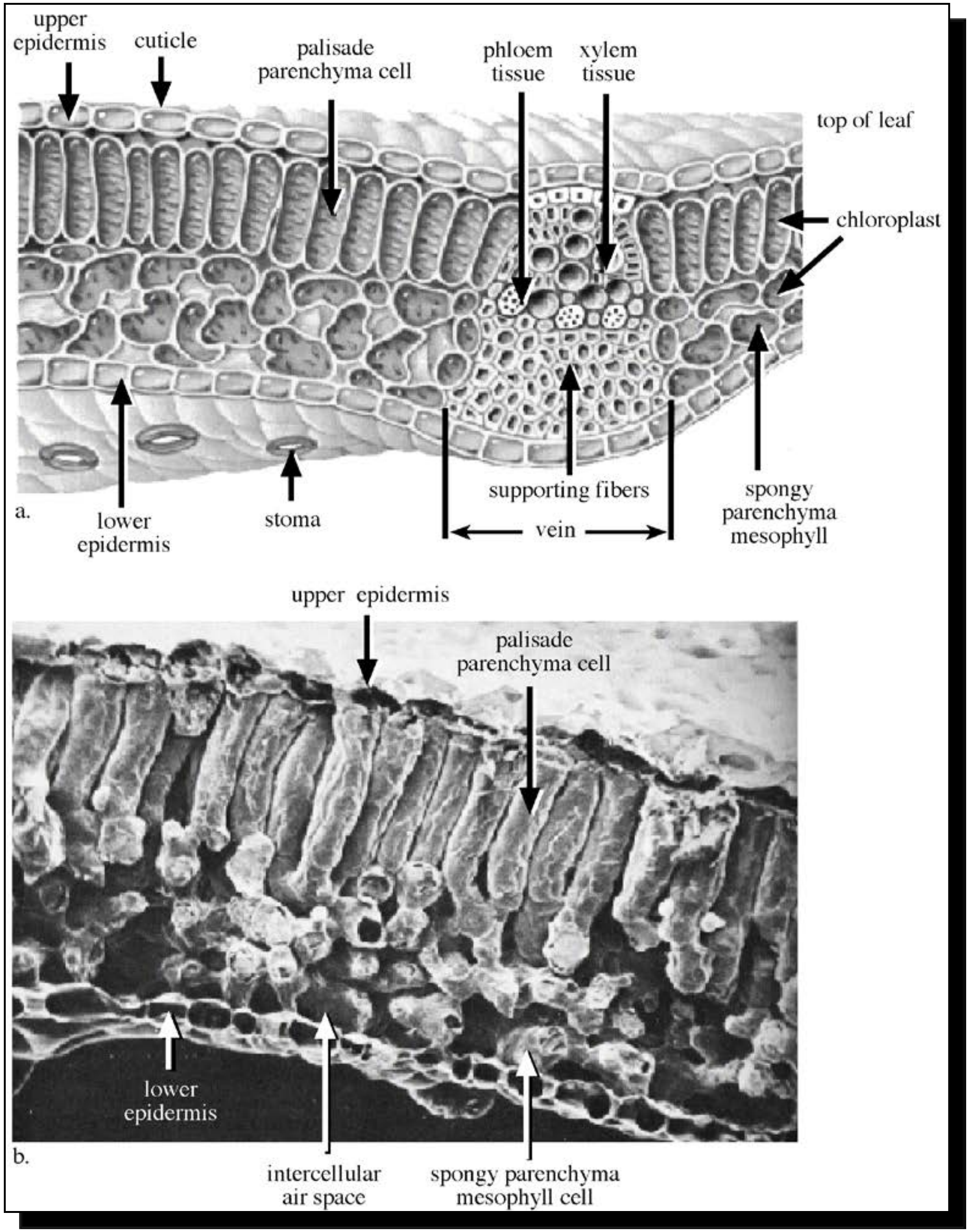
Contribution of Leaf and Canopy Properties to Pixel Reflectance



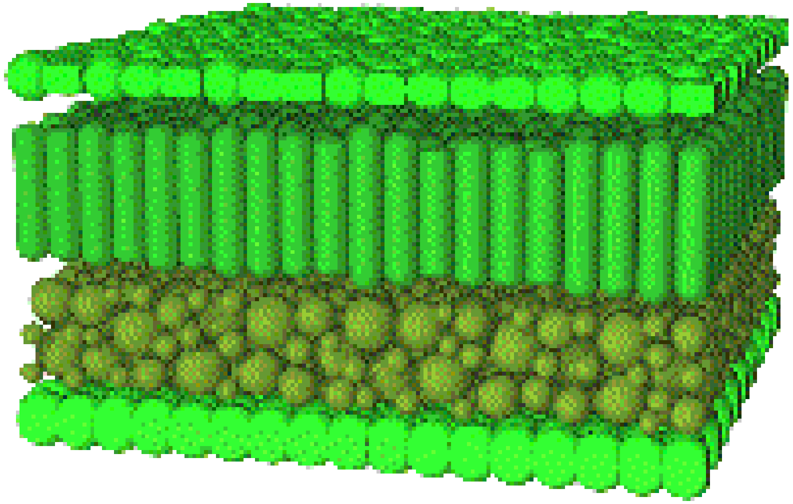
Components of Photosynthesis Revealed via Spectroscopy



Leaf Functioning is closely tied to anatomy

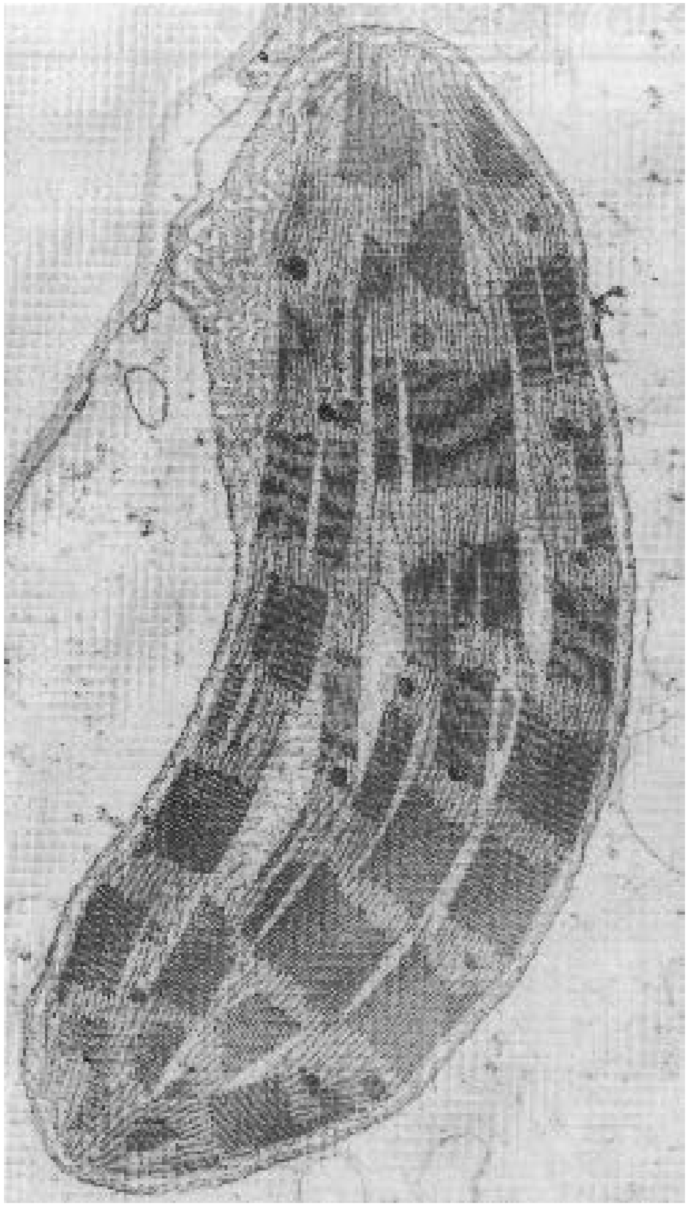


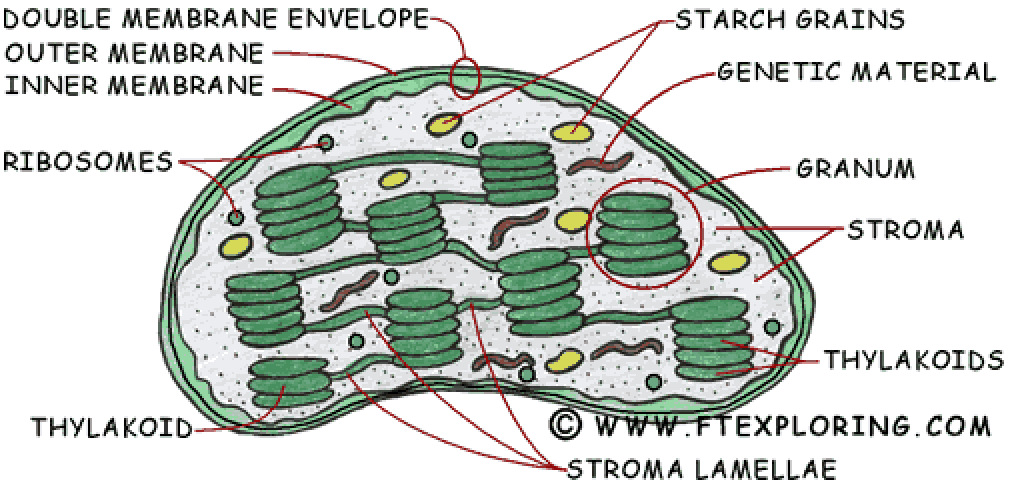
Anatomy of a Leaf



3-D model of a leaf
Goverts et al., 1996

Chloroplasts



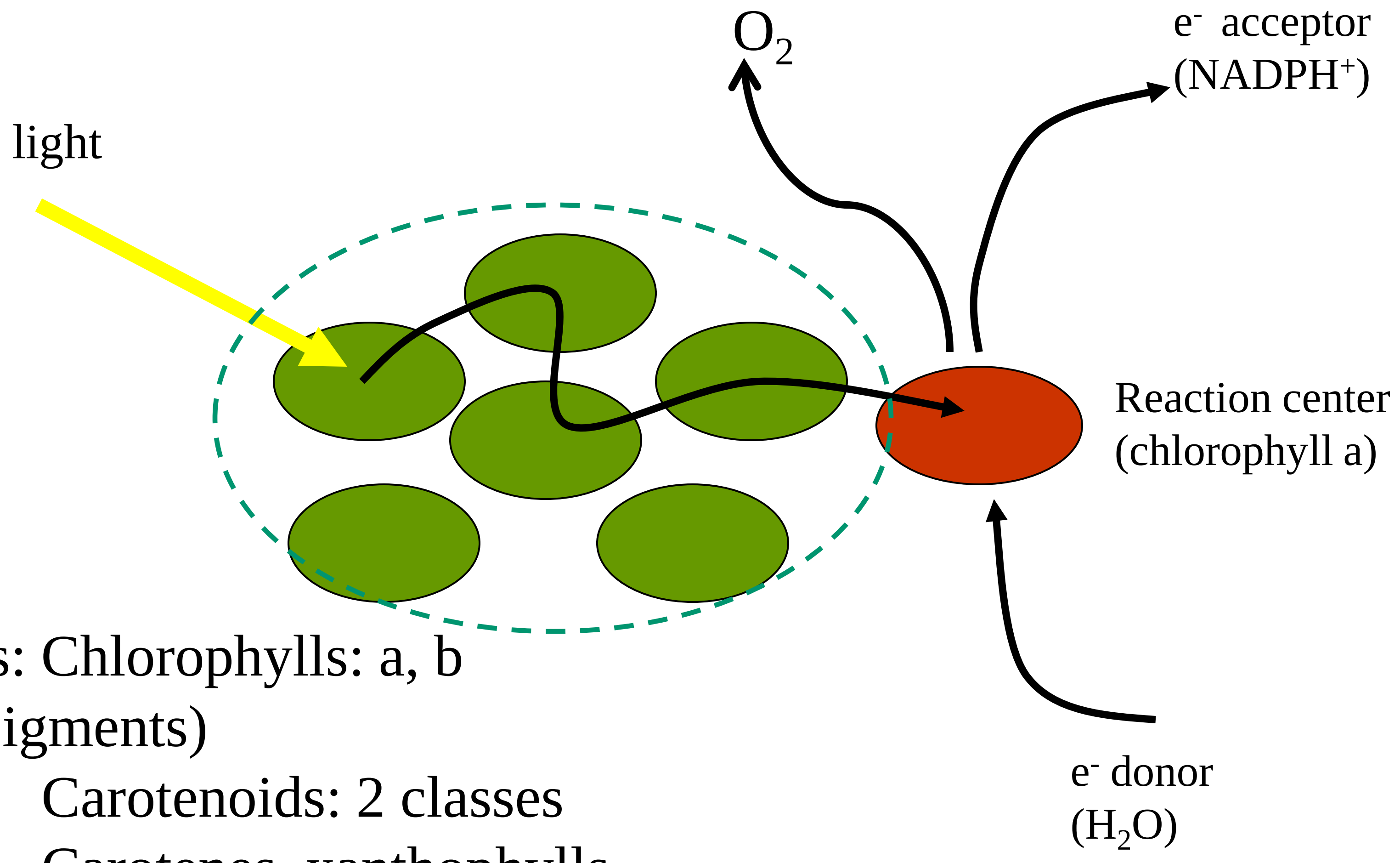


Light harvesting occurs on thylakoid Membranes (stack = granna) in chloroplasts

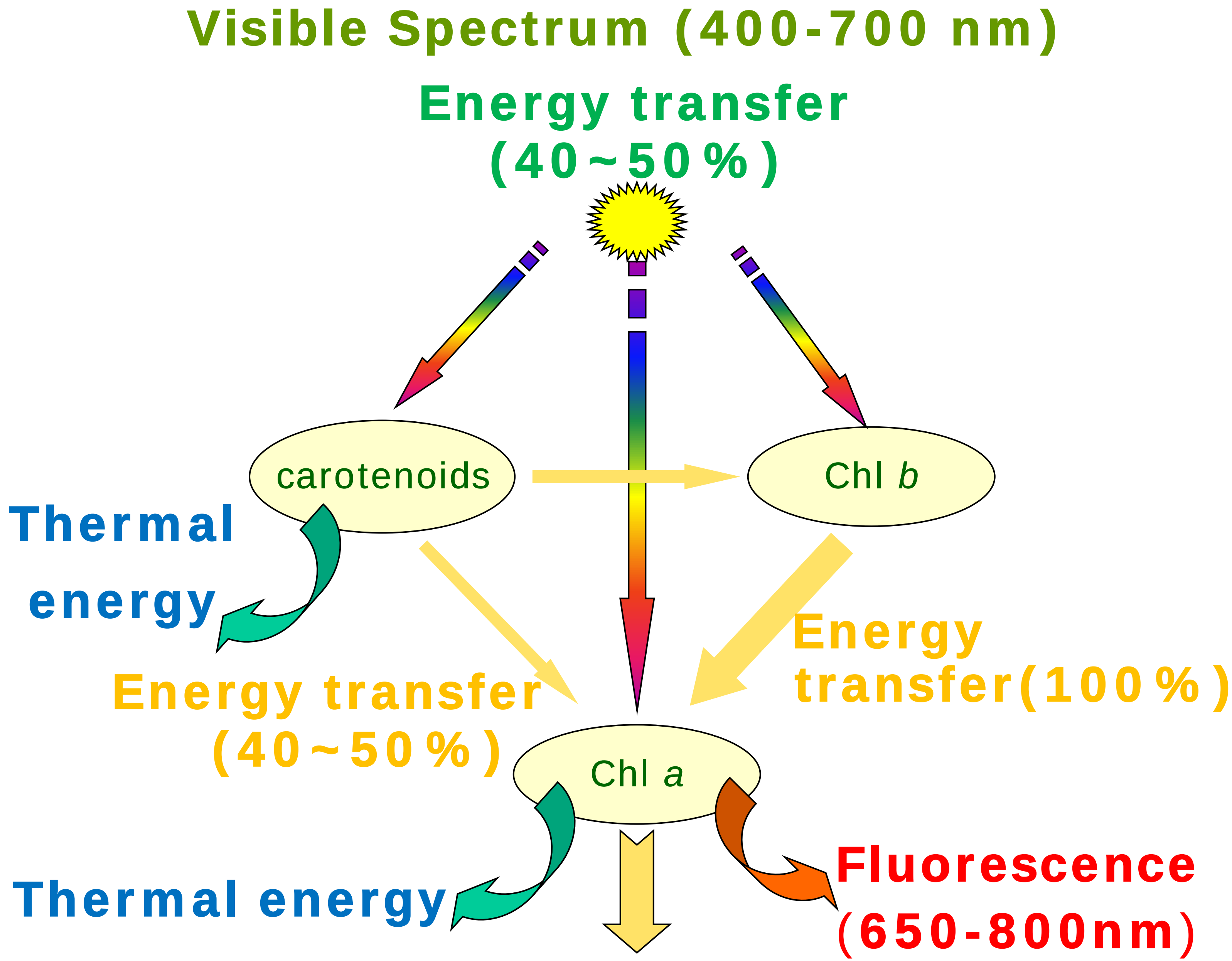
Photosynthesis:

$$6CO_2+6H_2O = C_6H_{12}O_6 + 6O_2$$

Transfer of Photon Energy from Photosystem Antenna to Reaction Center

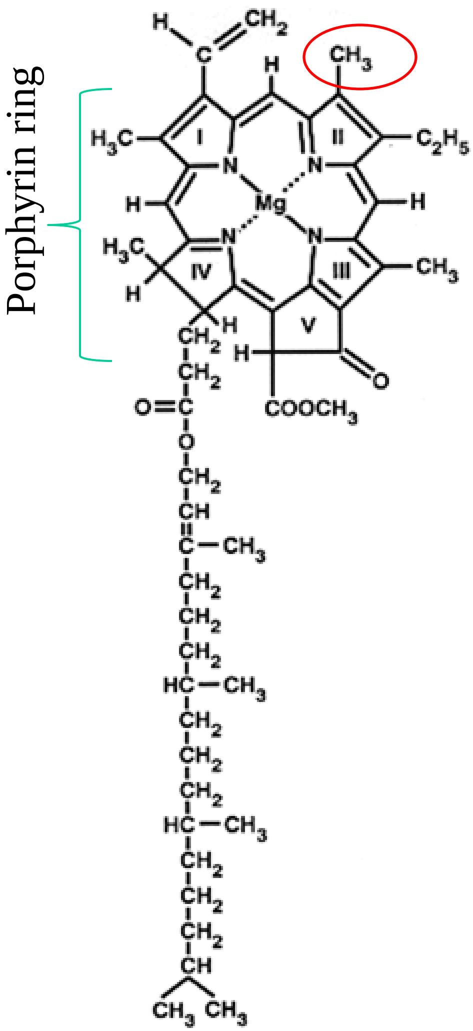


Pigments: Chlorophylls: a, b
(+algal pigments)
Carotenoids: 2 classes
Carotenes, xanthophylls

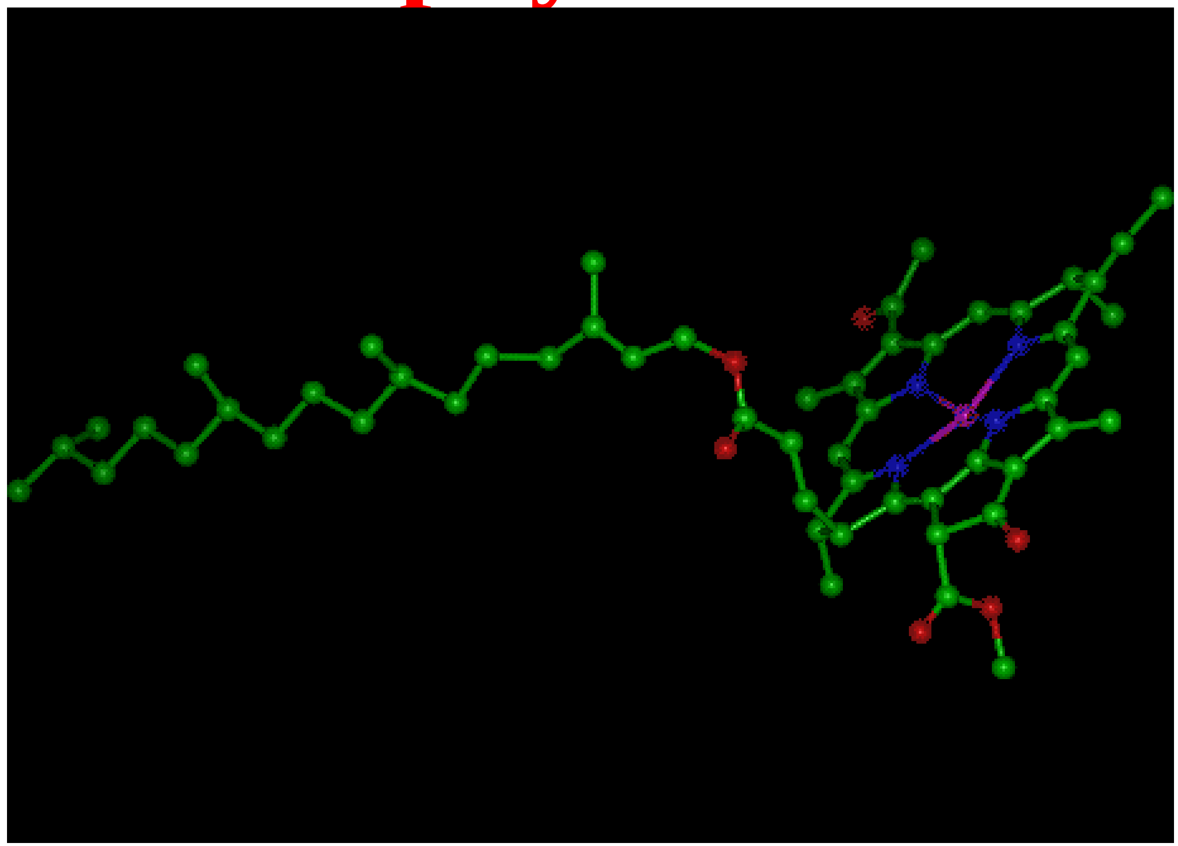


Photosynthetic Pigments: Excitation Energy Transfer

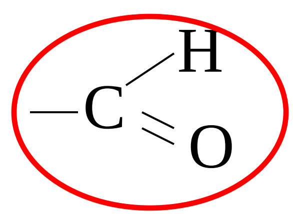
Chlorophyll a and b



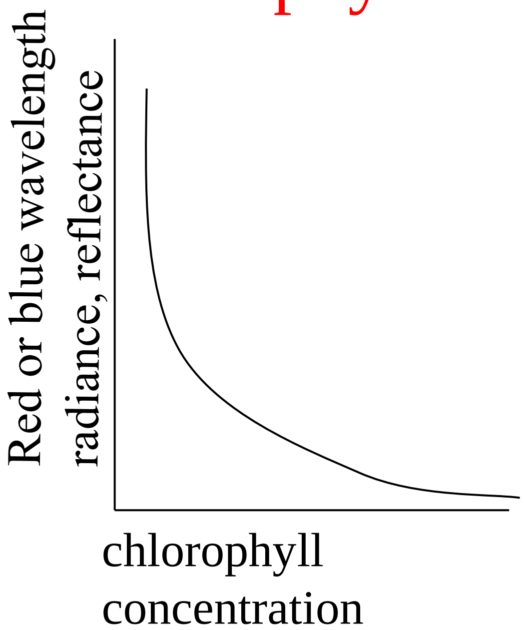
Chlorophyll *a*



Chlorophyll *b*



Chlorophyll Concentration



Vegetation Indexes

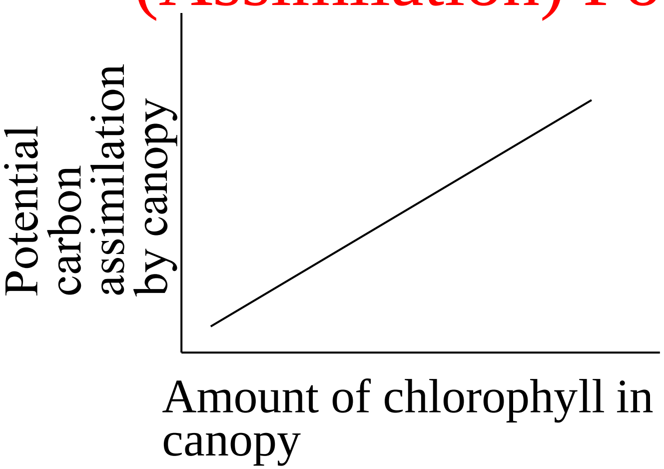
The Simple Ratio Vegetation Index (VI):

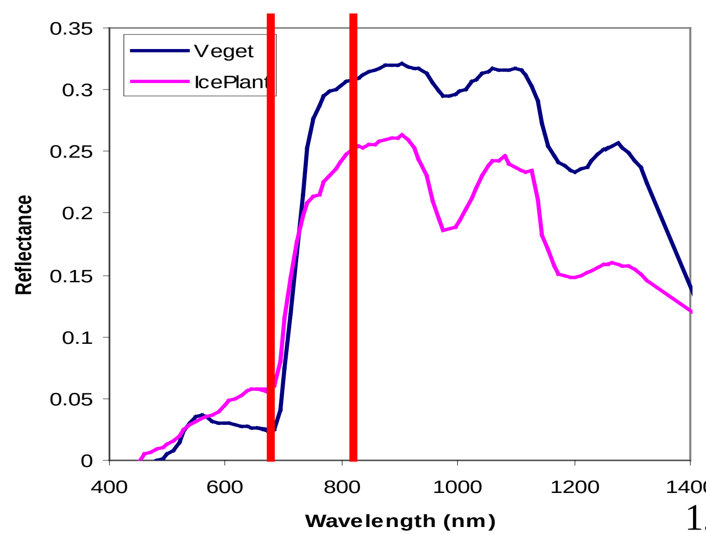
$$\frac{\rho NIR}{\rho Red} = R_{NIR}/R_{Red}$$

The Normalized Difference Vegetation Index (NDVI):

$$\frac{\rho NIR - \rho Red}{\rho NIR + \rho Red} = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}}$$

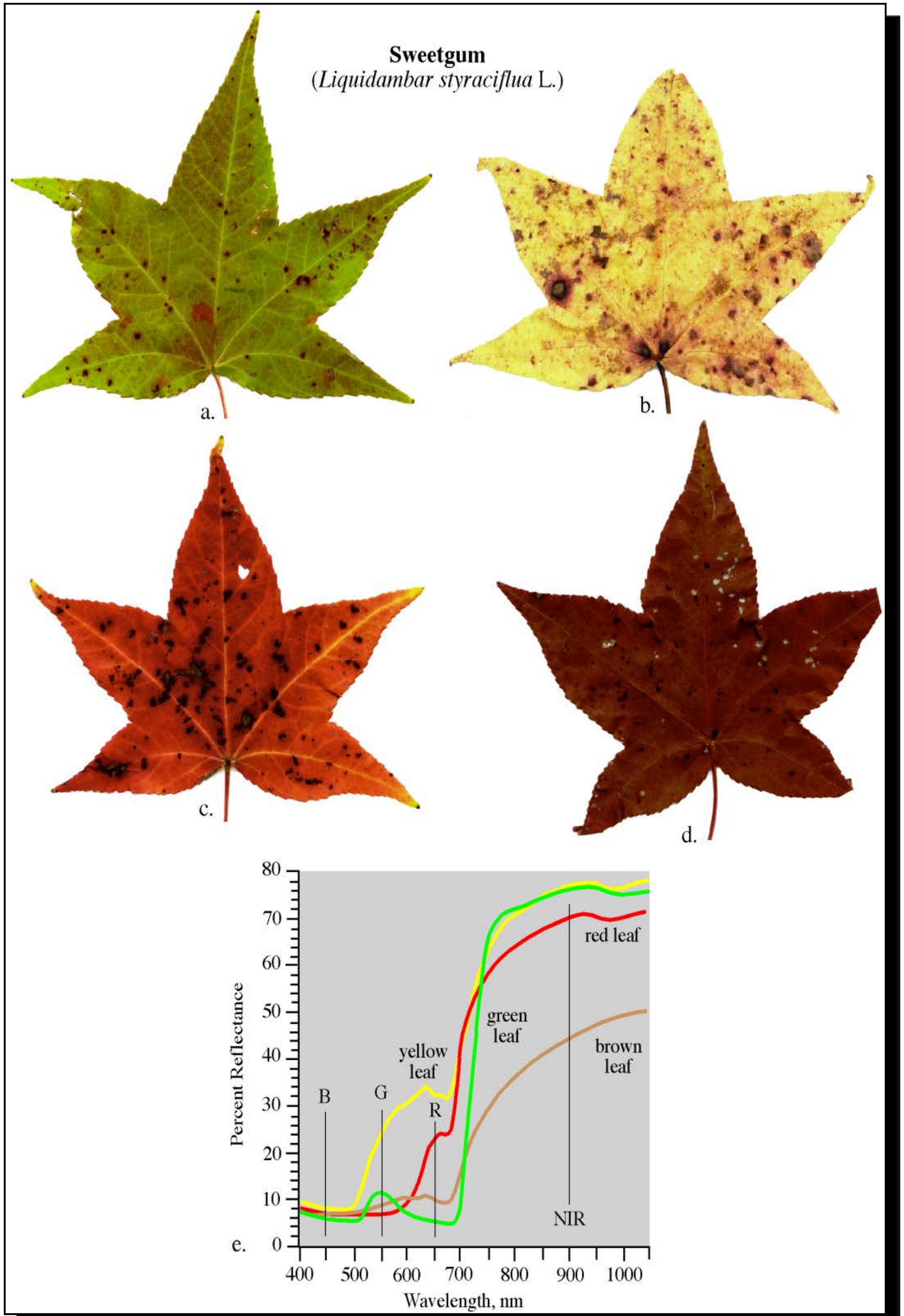
Photosynthesis (Assimilation) Potential





Leaf Functions

Pigment Composition Varies with Condition and Age of Leaves

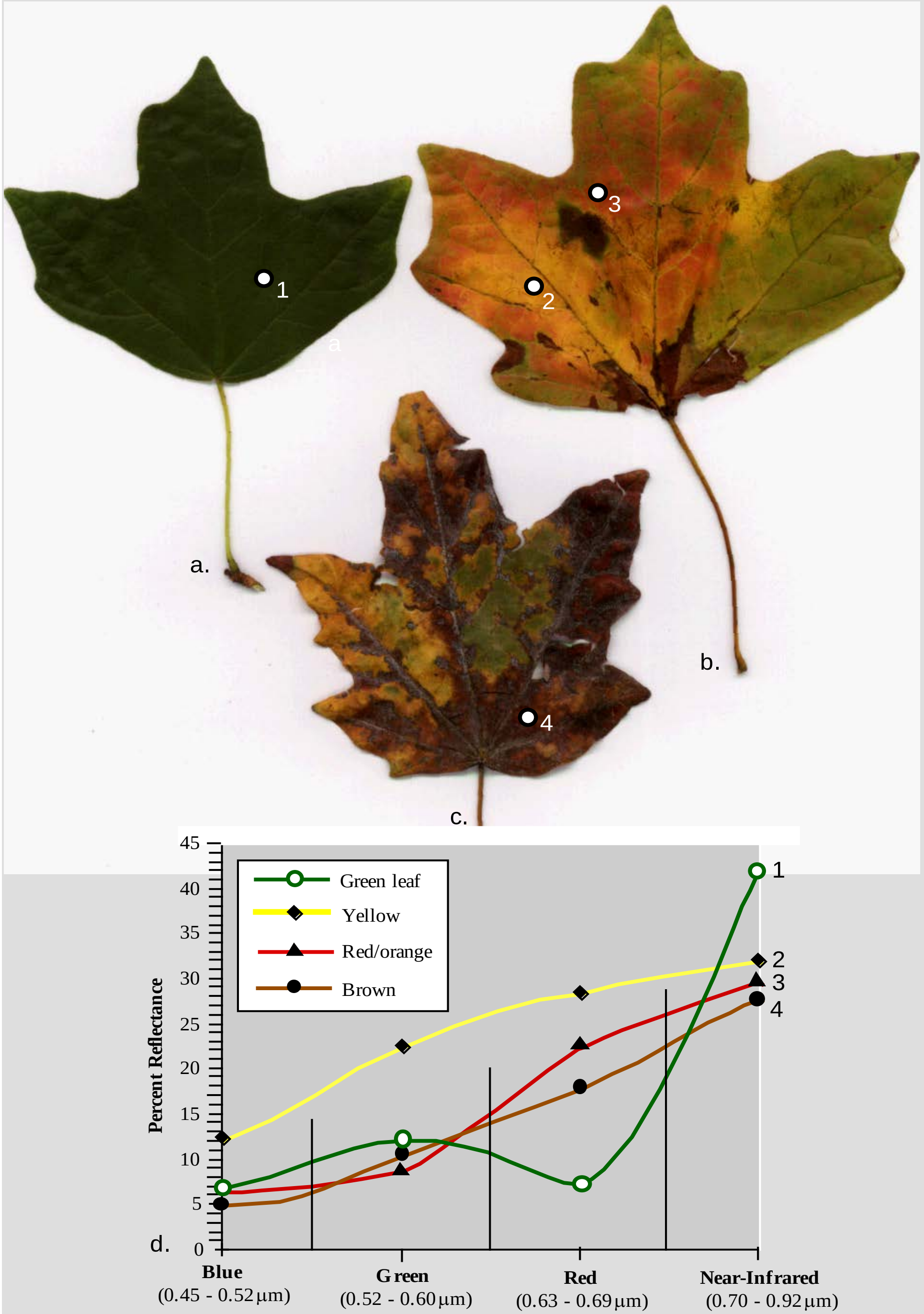


Spectral Reflectance Characteristics of Sweetgum Leaves (*Liquidambar styraciflua* L.)

Jensen, 2007

Leaf Functions

Pigment Composition Varies with: Species, Condition, and Age of Leaves

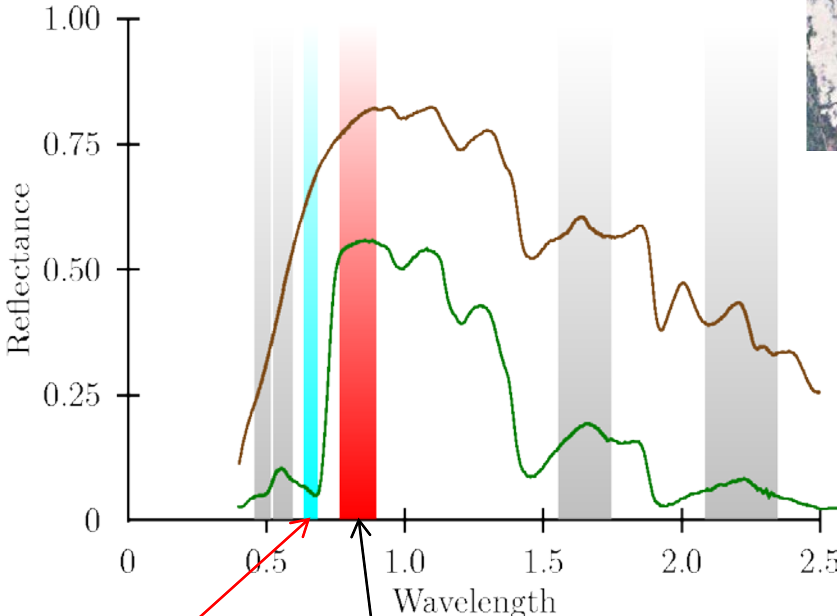


Spectral Reflectance Characteristics of Selected Areas of Blackjack Oak Leaves

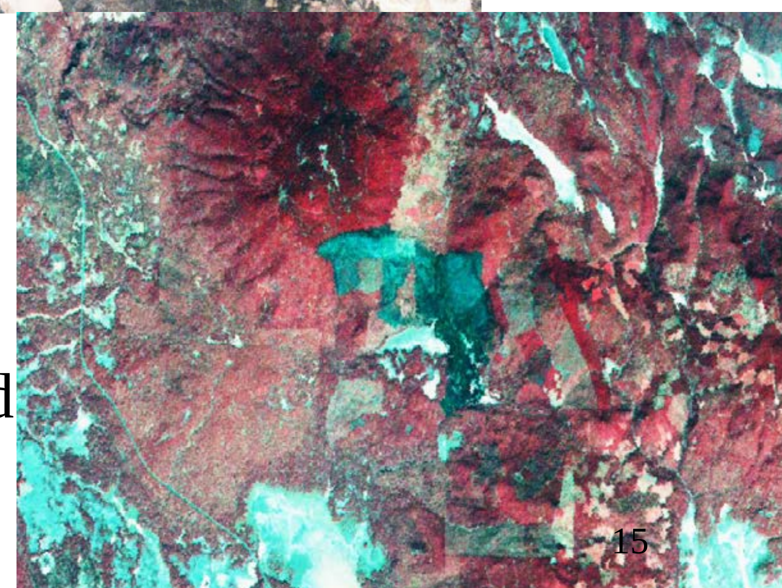
Jensen, 2007

Vegetation Index: a ratio of a band sensitive to a biogeochemical of interest to a band insensitive to that biogeochemical.

Natural Color



Color Infrared

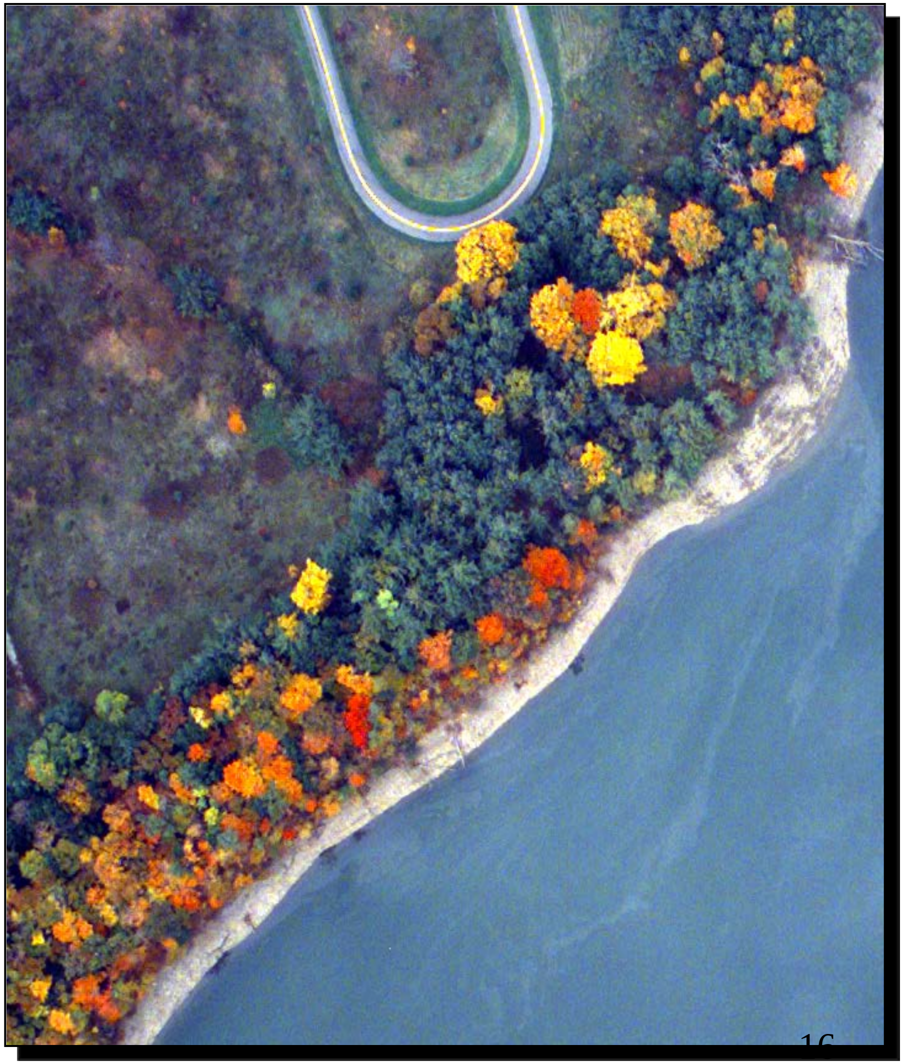


Ex: red and NIR bands for leaf pigments

Plant Functions

CIR image (RGB = NIR,R,G) of Dunkirk, NY, at 1 x 1 m obtained on December 12, 1998, Litton Emerge Spatial, Inc.

Natural color image (RGB = R,G,B) of a N.Y. Power Authority lake at 1 x 1 ft obtained on October 13, 1997.



Simple Ratio (SR) Vegetation Index

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

$$SR = R_{NIR} / R_{R}$$

Takes advantage of the relationship between high absorption by chlorophyll of red radiant energy and high reflectance of near-infrared energy for healthy leaves and plant canopies.

Normalized Difference Vegetation Index (NDVI)

The normalized difference vegetation index (NDVI):

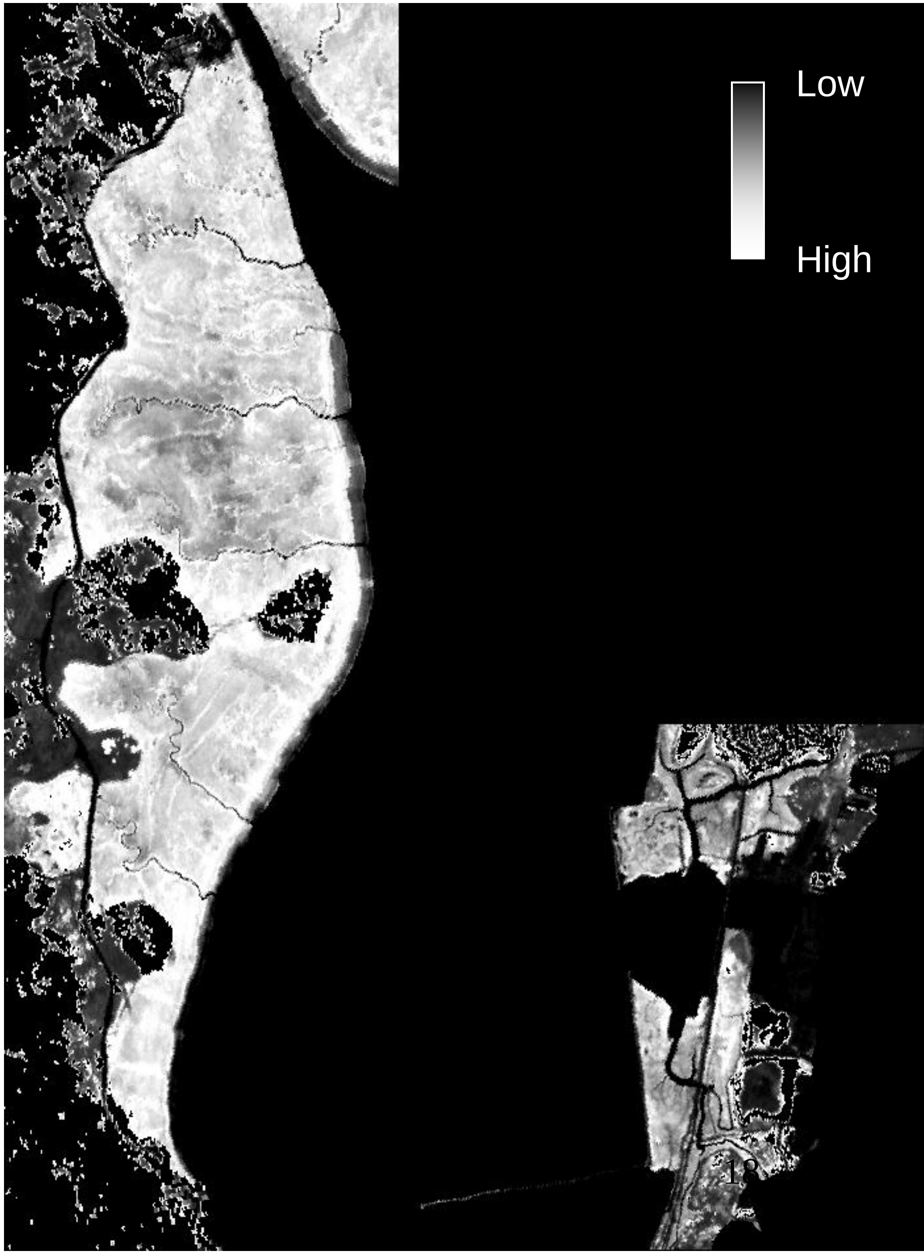
$$\mathbf{NDVI = (R_{NIR} - R_R) / (R_{NIR} + R_R)}$$

Developed to reduce albedo differences due to topography and to normalize reflectance to adjust for calibration differences

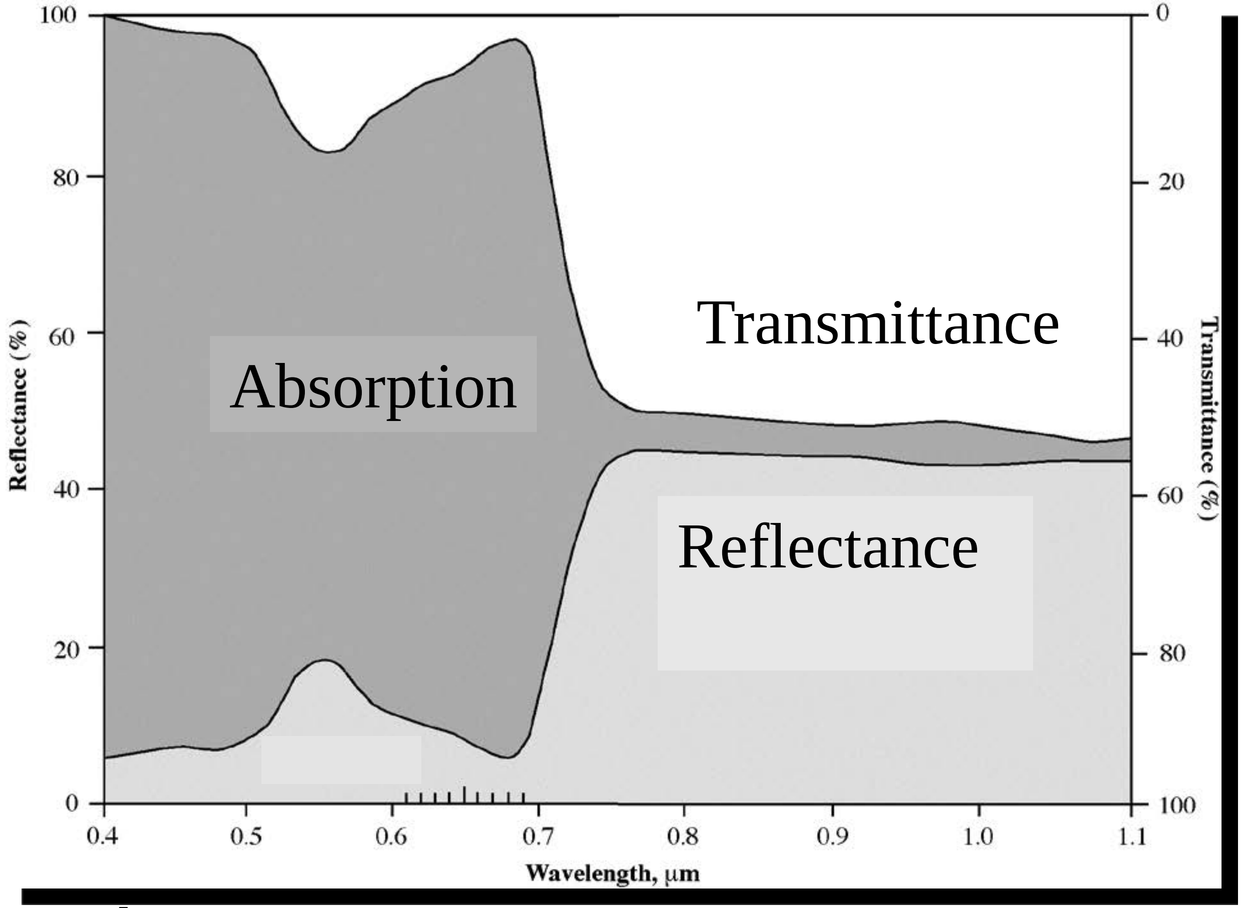
Web of Science (2008) identifies more than 6000 publications citing "vegetation indexes"

Landsat Thematic Mapper TM bands:

$$(TM4 - TM3) / (TM4 + TM3)$$



Leaf Spectrum: Determined by Absorbing Molecules and Scattering Properties



In this figure

Reflectance
+
absorption
+
transmittance

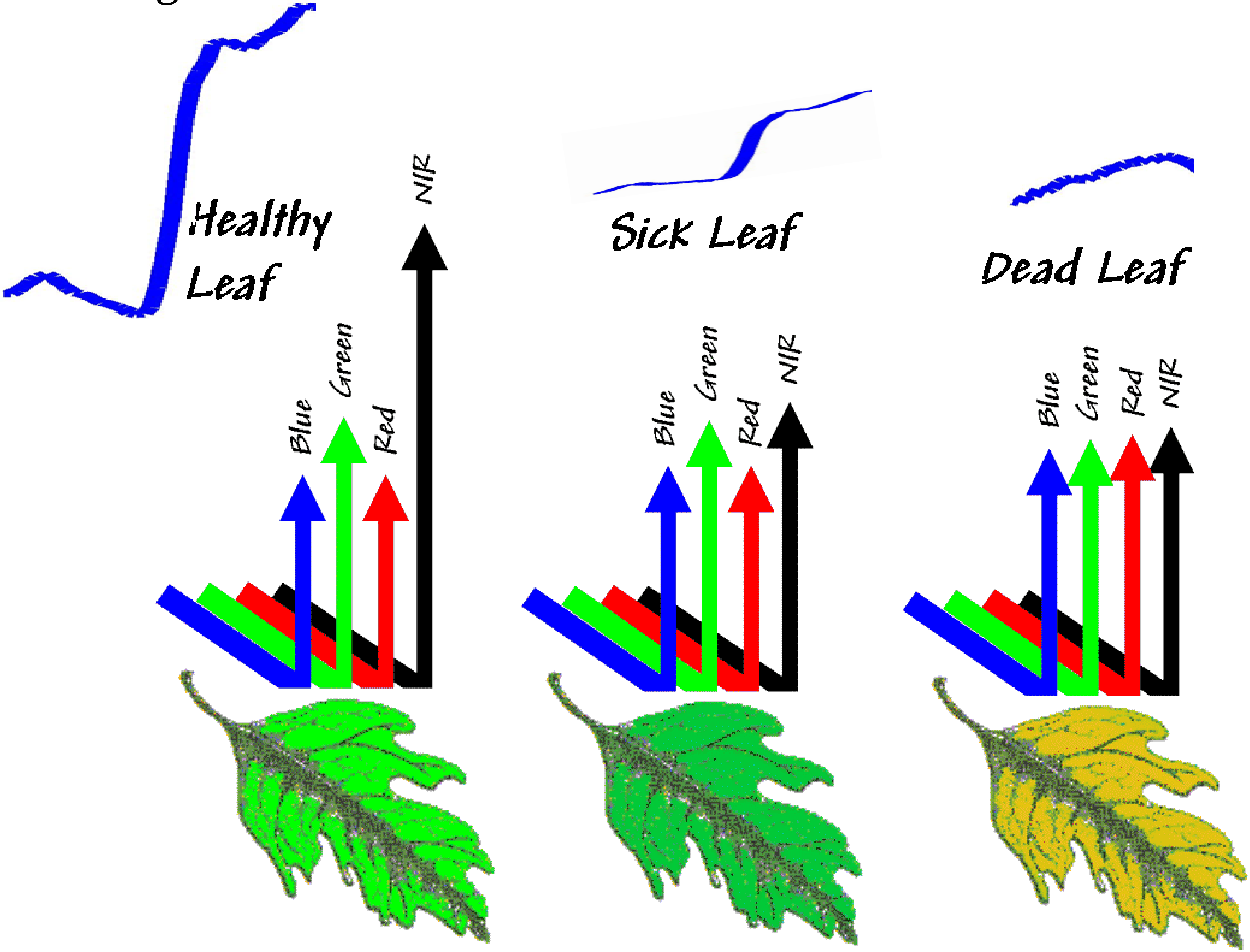
= 1.0

Big Bluestem Grass: reflectance is displayed upwards from 0.0; transmittance is displayed downward from 1.0;

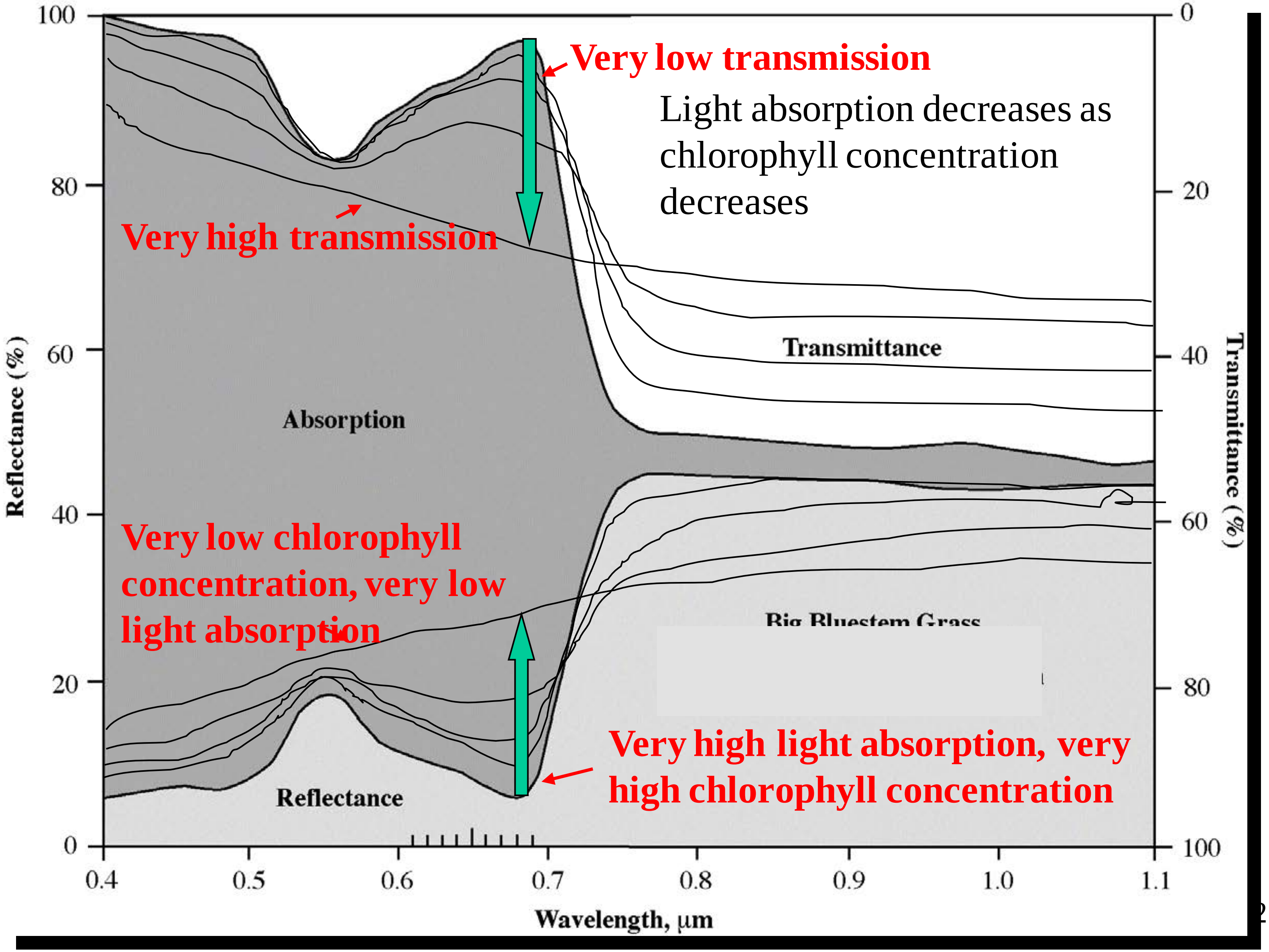
Rearranging the equation shows that [absorption] is the dark grey area between the two curves.

➔ Conclusion: **absorption** dominates in **visible**; **scattering** dominates in the **NIR**.

Changes in Visible and Near-Infrared Reflectance with Leaf Health

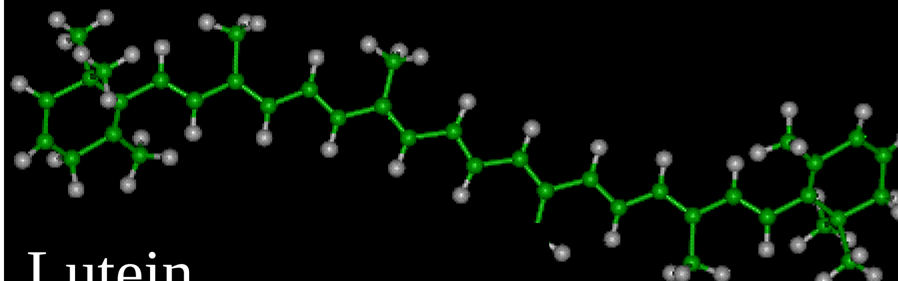


Light absorption varies with leaf pigment concentrations

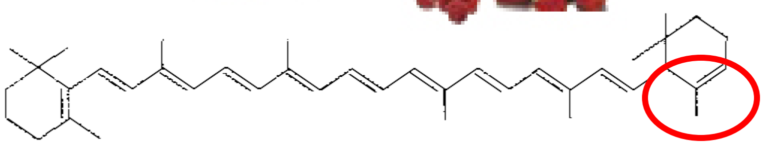


Carotenes

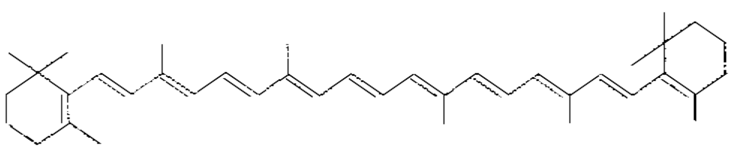
A family of red, orange, or yellow pigments that increase photosynthetic efficiency or regulation of light absorption and serve other plant functions



Lutein
Zeaxanthin
β-Cryptoxanthin
Lycopene
α-Carotene
β-Carotene

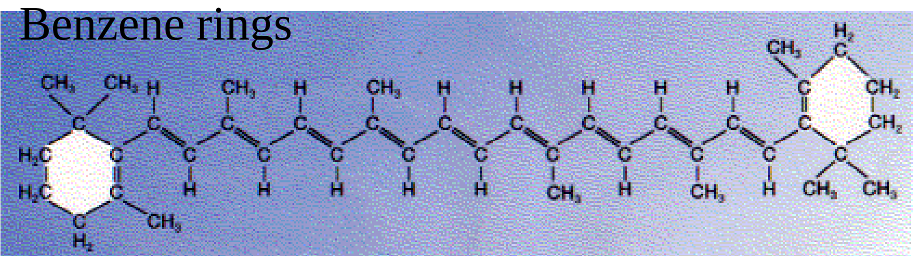


α - carotene

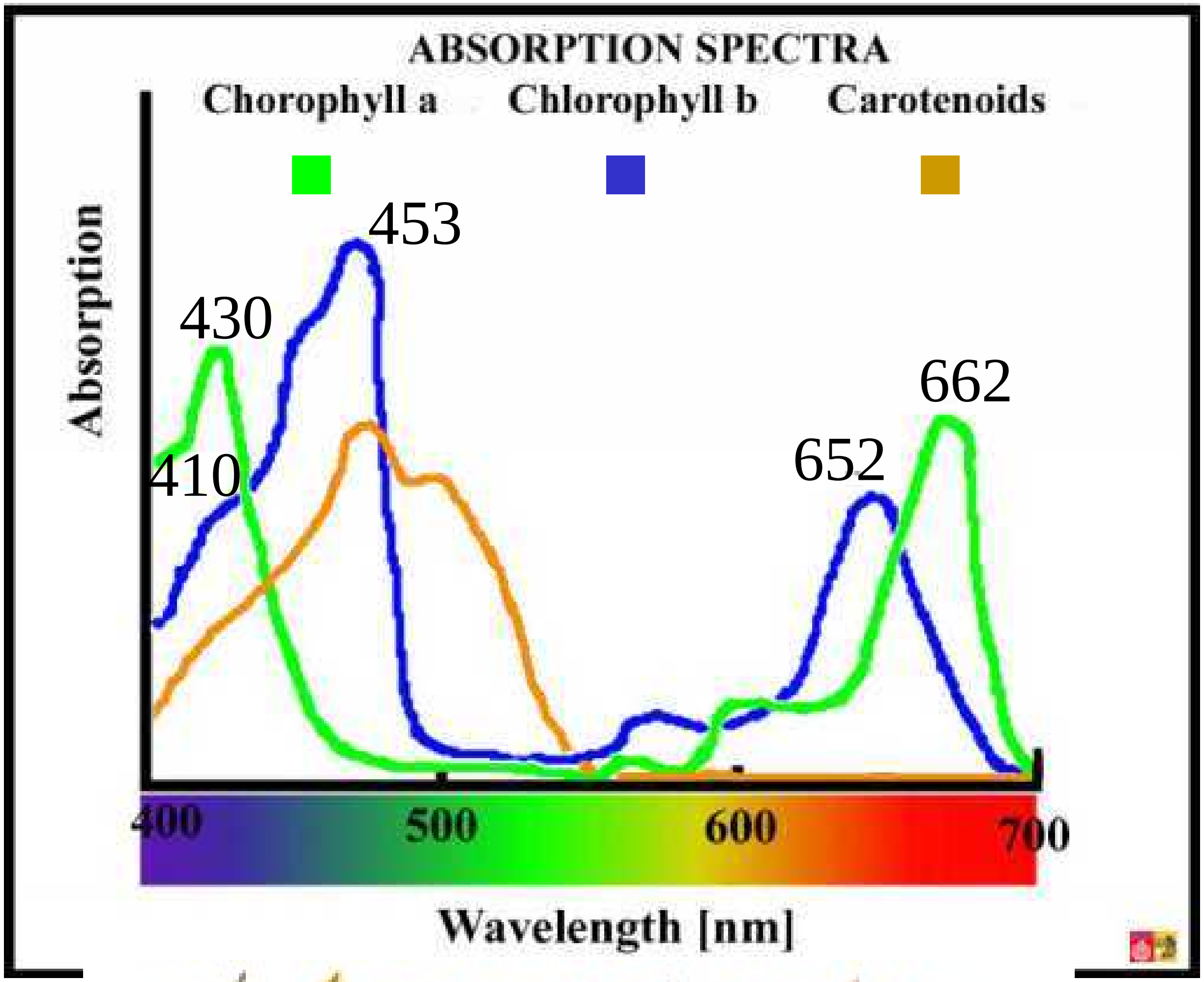


β - carotene

Benzene rings



Leaf Functions



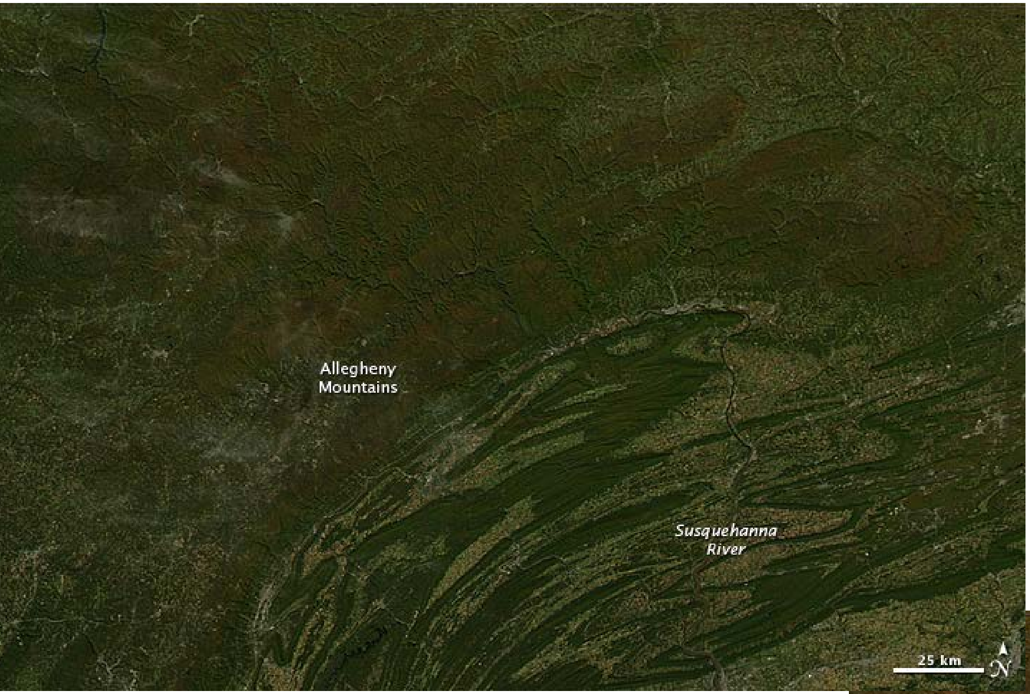
Senescence sequence of a leaf

Fall Colors in the Northeast Deciduous Forest

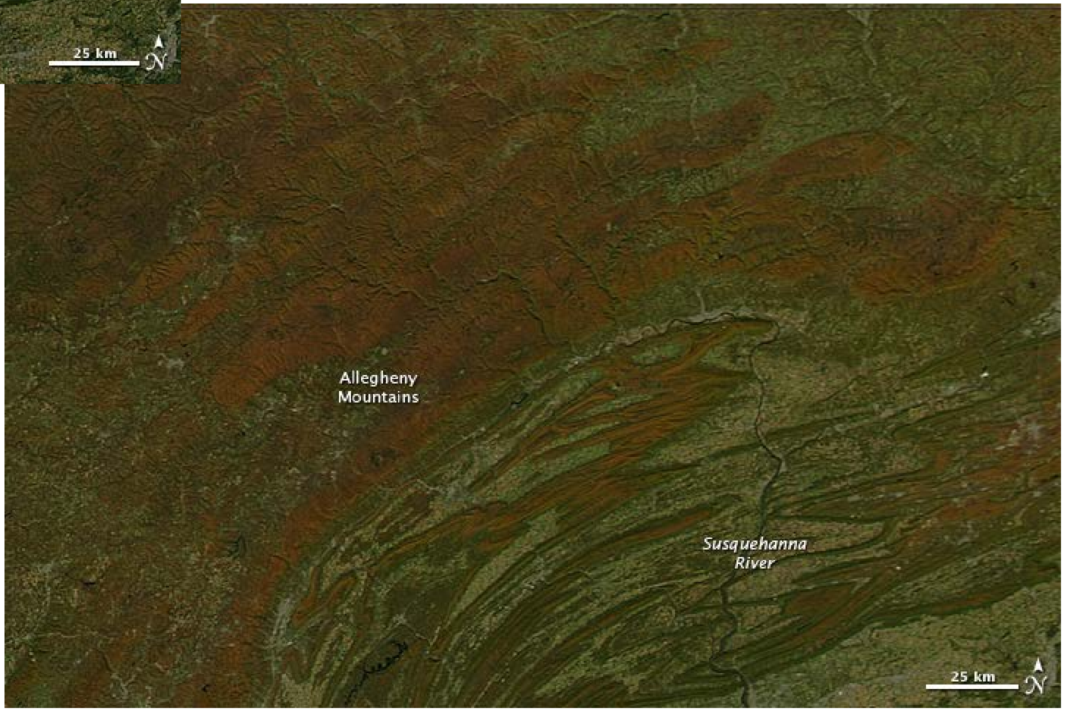
Fall Color Across New England

MODIS, October 12, 2008

Fall Colors in the Allegheny Mountains

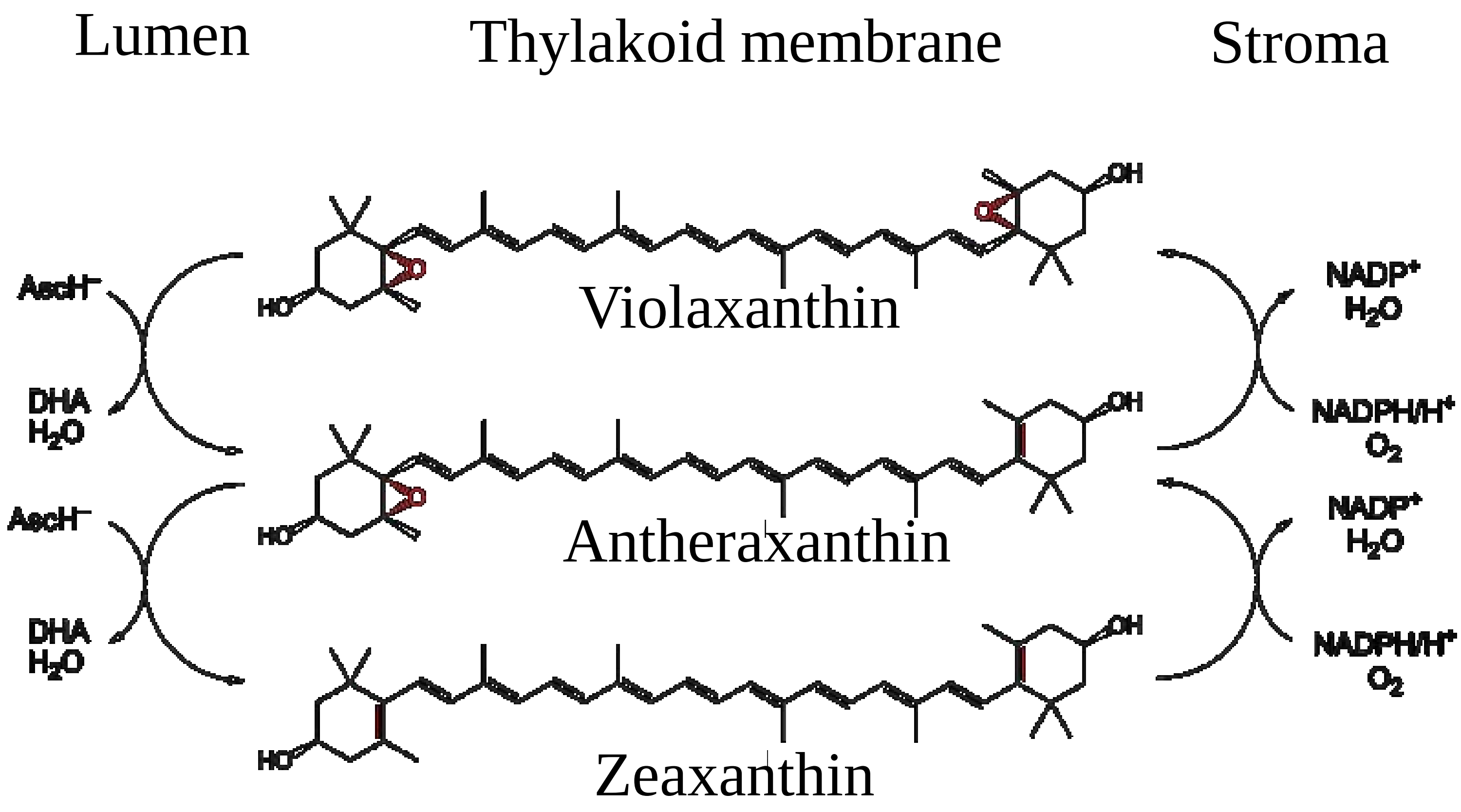


October 8, 2010

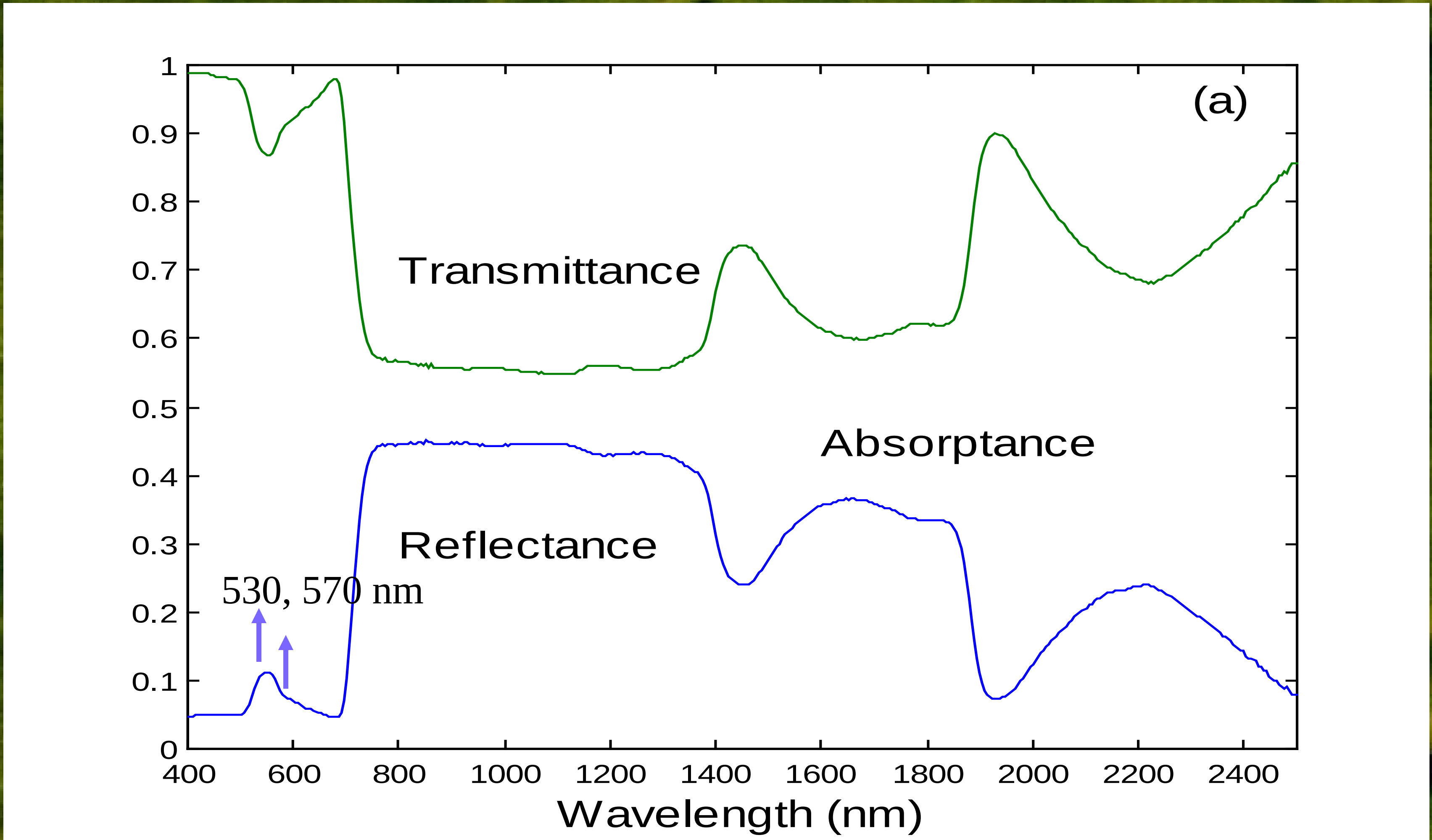


October 13, 2010

Reversable Changes in Xanthophyll Cycle Pigments



Photochemical Reflectance Index (PRI)



Changes in PRI ratio indicates change in Xanthophyll Pigments

Red Pigments in Young (immature) Leaves

Anthocyanins are found in all plant parts: Many functions from reproduction to herbivore defense

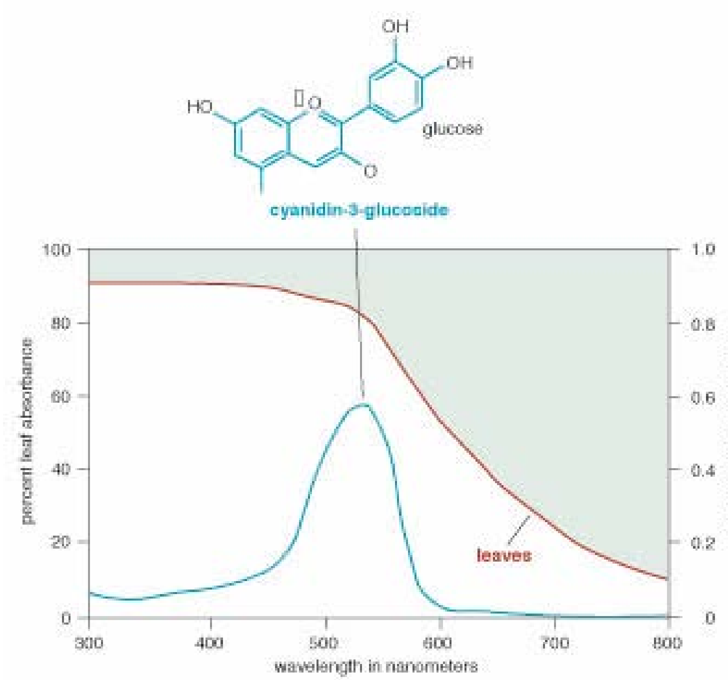
pollinators

Seed dispursal

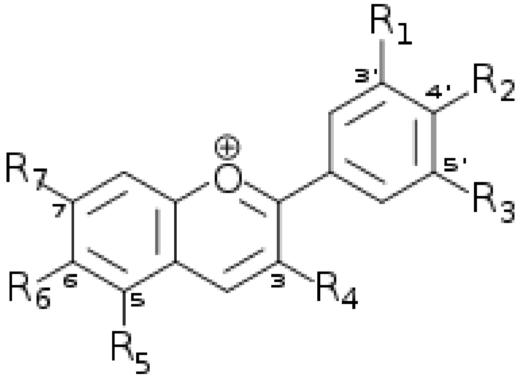
Fruit dispursal

Pseudowintera colorata (horopito)

Pigments always present (herbivore defense or nutrient deficiency)



Anthocyanin-type Pigments



Selected anthocyanidins and their substitutions

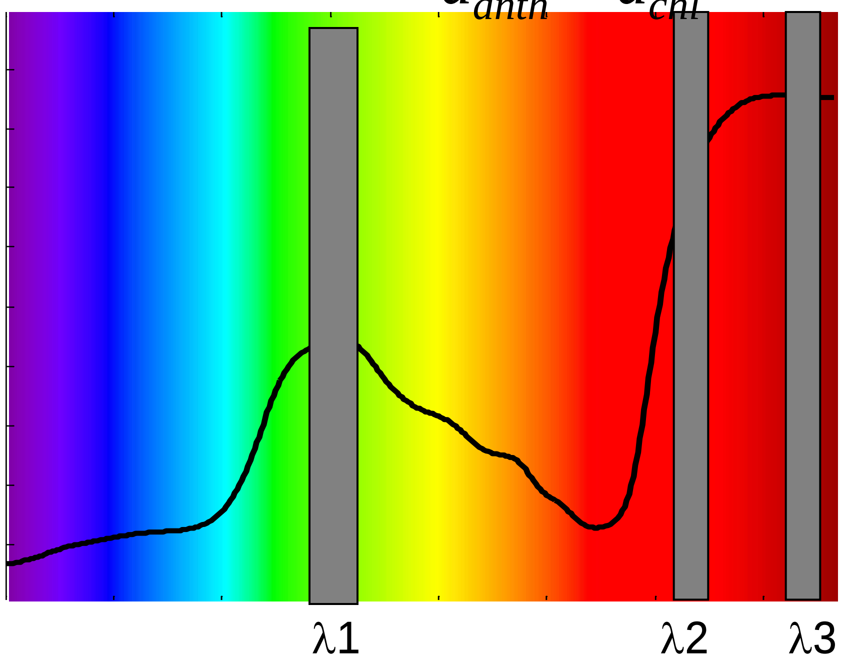
Anthocyanidin	Basic structure	R_1	R_2	R_3	R_4	R_5	R_6	R_7
Auranthinidin		−H	−OH	−H	−OH	−OH	−OH	−OH
Cyanidin		−OH	−OH	−H	−OH	−OH	−H	−OH
Delphinidin		−OH	−OH	−OH	−OH	−OH	−H	−OH
Europinidin		$-OCH_3$	−OH	−OH	−OH	$-OCH_3$	−H	−OH
Luteolinidin		−OH	−OH	−H	−H	−OH	−H	−OH
Pelargonidin		−H	−OH	−H	−OH	−OH	−H	−OH
Malvidin		$-OCH_3$	−OH	$-OCH_3$	−OH	−OH	−H	−OH
Peonidin		$-OCH_3$	−OH	−H	−OH	−OH	−H	−OH
Petunidin		−OH	−OH	$-OCH_3$	−OH	−OH	−H	−OH
Rosinidin		$-OCH_3$	−OH	−H	−OH	−OH	−H	$-OCH_3$

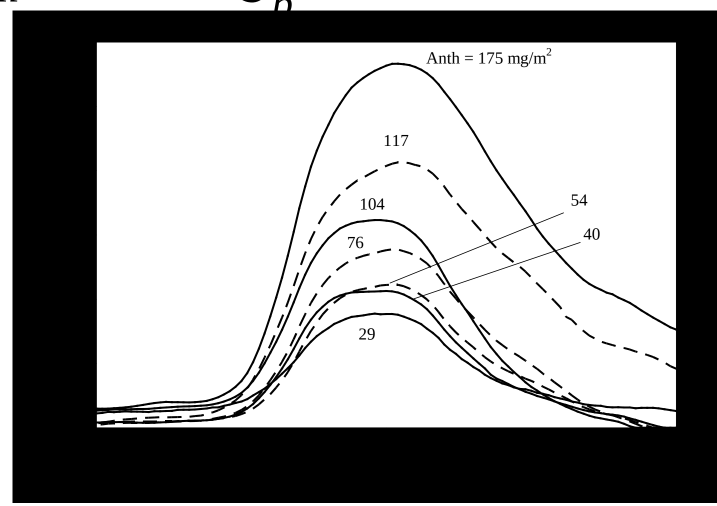
Only HyspIRI is able to uniquely provide it

$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Anthocyanin Reflectance Index

$$ARI_{red\ edge} \propto \underbrace{[\rho^{-1}(\lambda_1)}_{a_{anth}+a_{chl}} - \underbrace{\rho^{-1}(\lambda_2)]}_{a_{chl}} \times \underbrace{\rho(\lambda_3)}_{b_b}$$





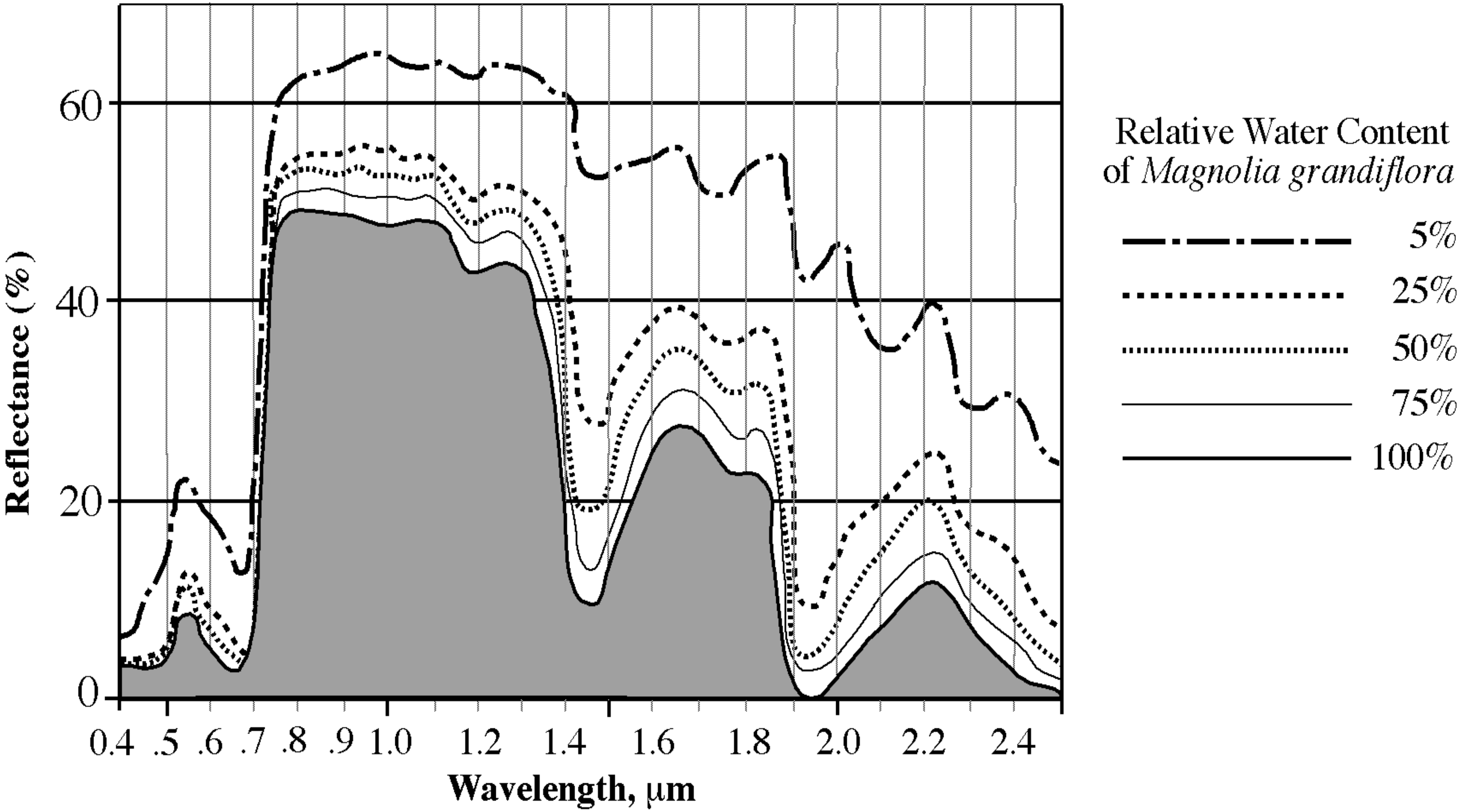
Gitelson et al., 2009

$$\text{Anth} \propto \text{ARI} = (\rho^{-1}_{550} - \rho^{-1}_{red\ edge}) \times \rho_{NIR}$$

Gitelson et al., 2001

Optical Properties: Changes in Leaf Reflectance as it Dries

Reflectance Changes in a Magnolia Leaf (*Magnolia grandiflora*) as Water Content Declines



Hydration of canopy varies with soil water availability

Jensen, 2007

Infrared Water Index

Information about vegetation water content has widespread application in agriculture, forestry, and hydrology.

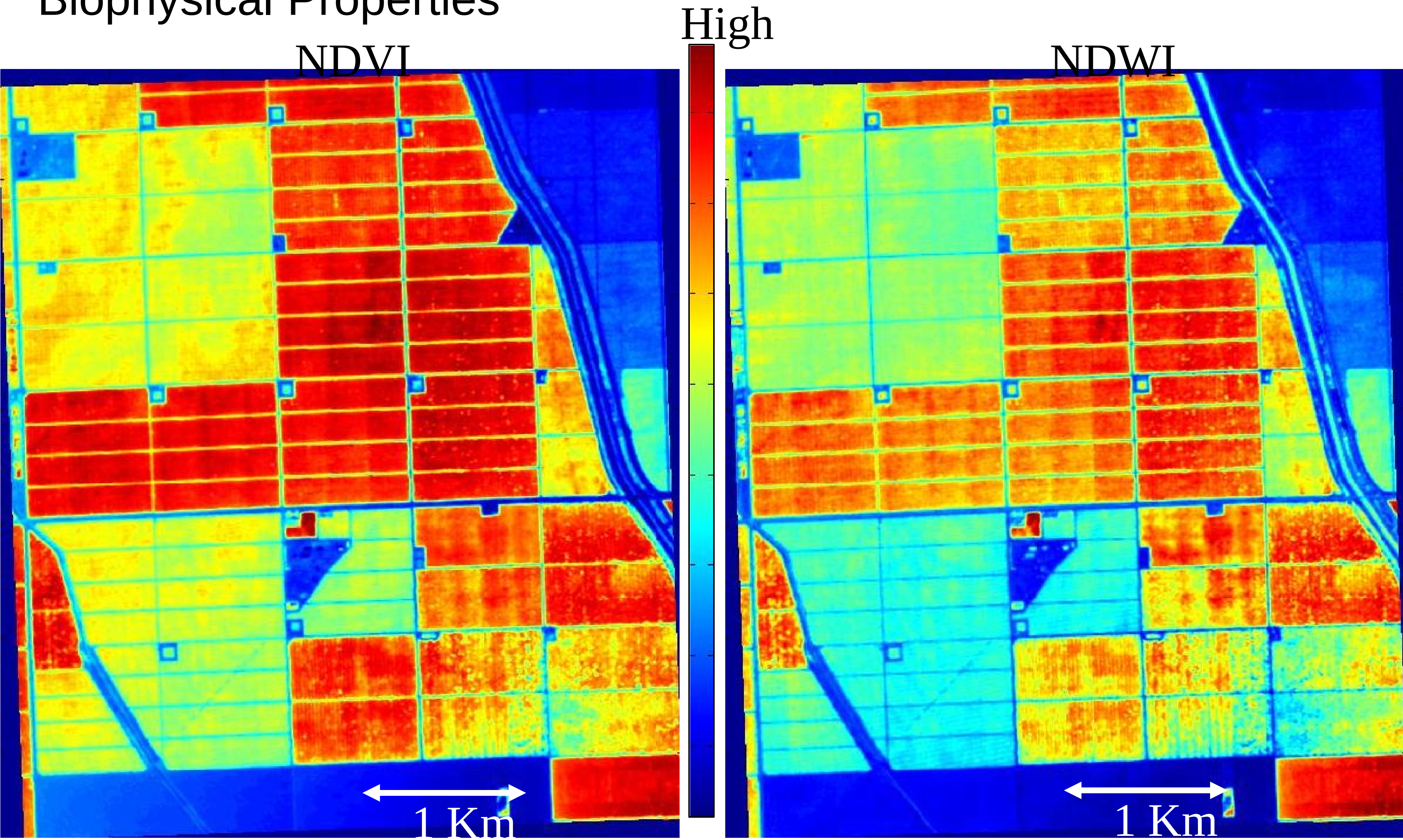
Hardisty et al. (1983) and Gao (1996) found that the *Normalized Difference Moisture or Water Index* (NDMI or MDWI) based on Landsat TM near-and middle-infrared bands was highly correlated with canopy water content and more closely tracked changes in plant biomass than did the NDVI.

$$NDMI = (NIR_{TM4} - MIR_{TM5}) / (NIR_{TM4} + MIR_{TM5})$$

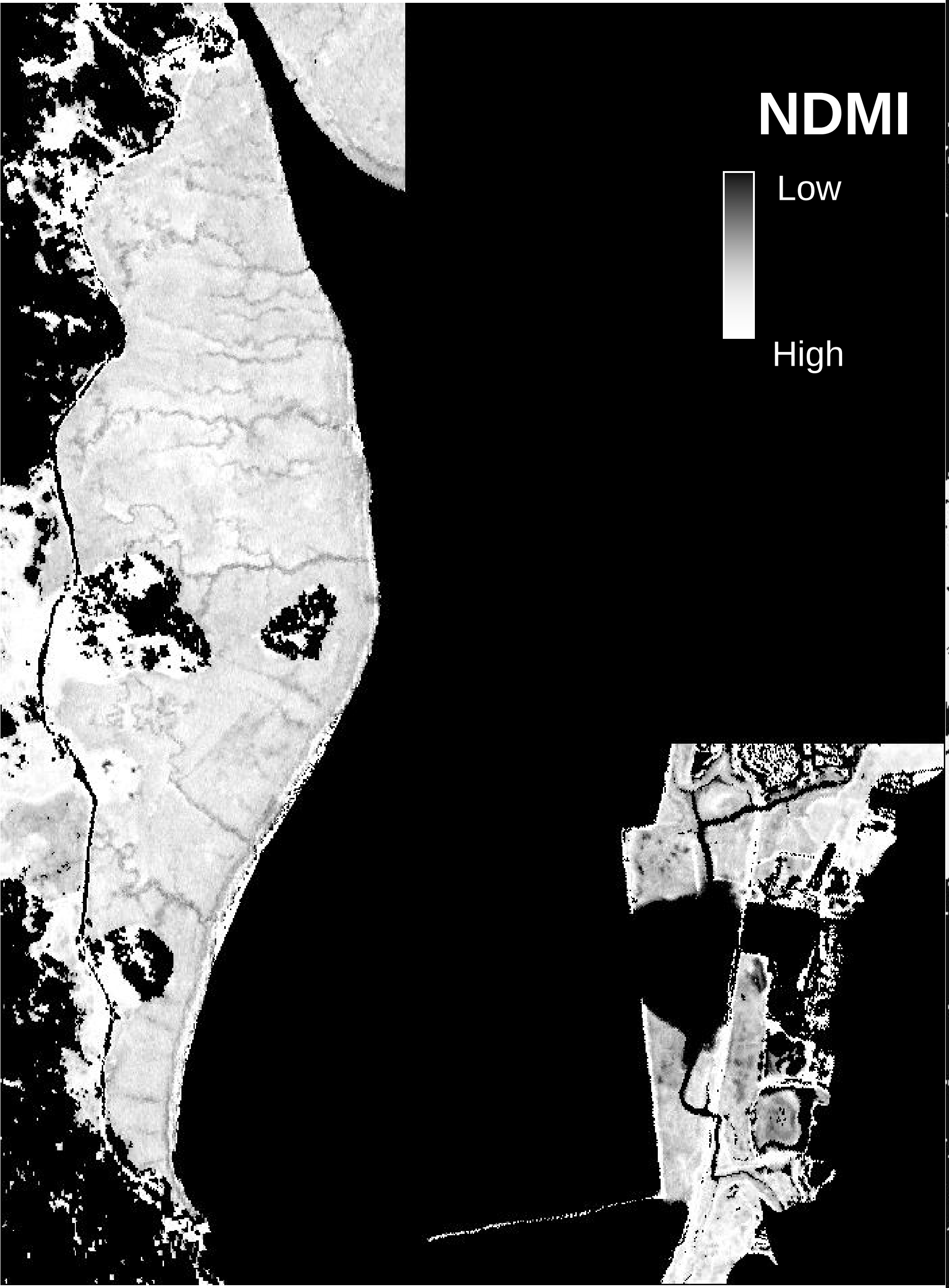
$$NDWI = (NIR_{TM4} - MIR_{TM7}) / (NIR_{TM4} + MIR_{TM7})$$

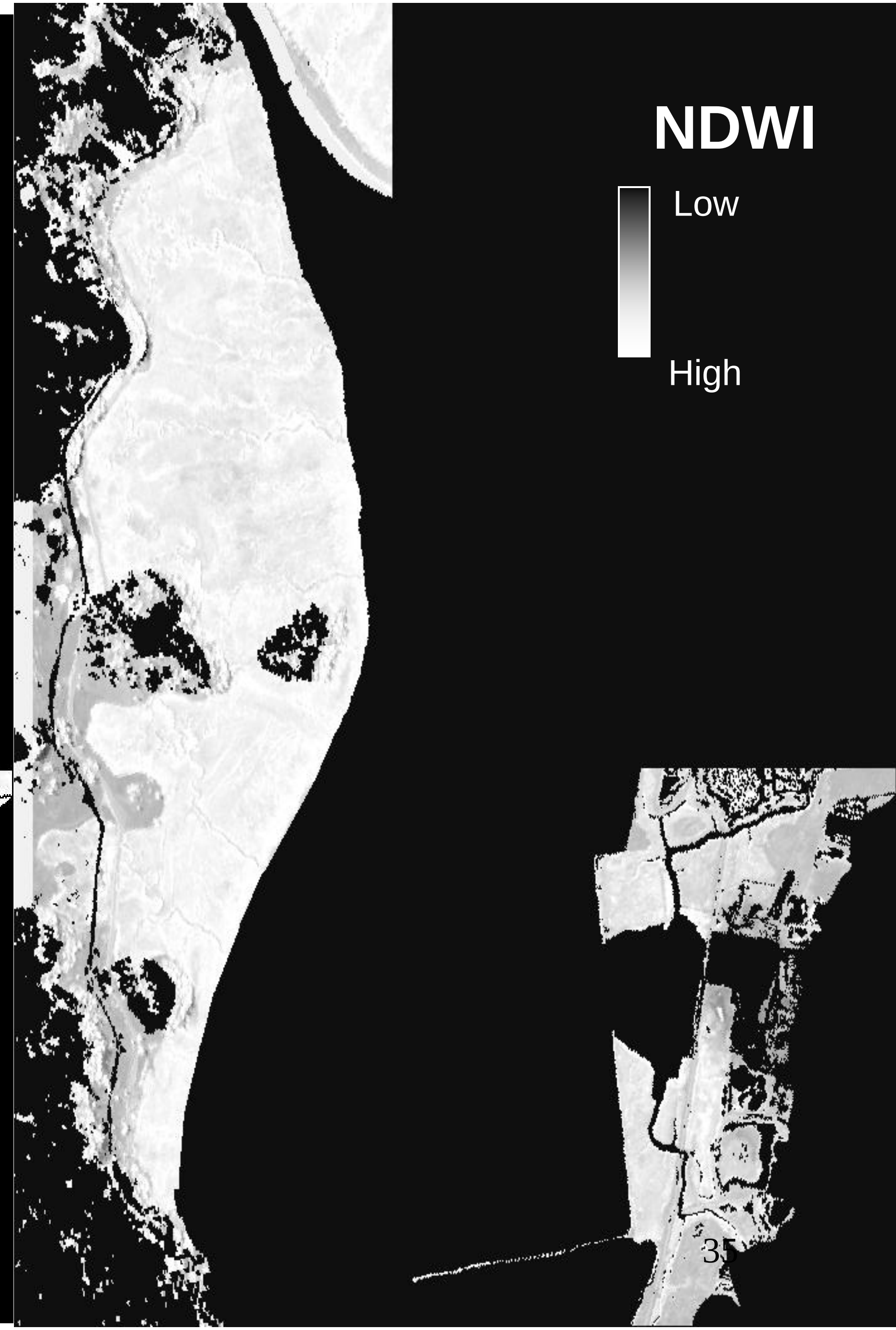
Jensen, 2007

NDVI Patterns Are Only Partially Correlated with Other Leaf Biophysical Properties

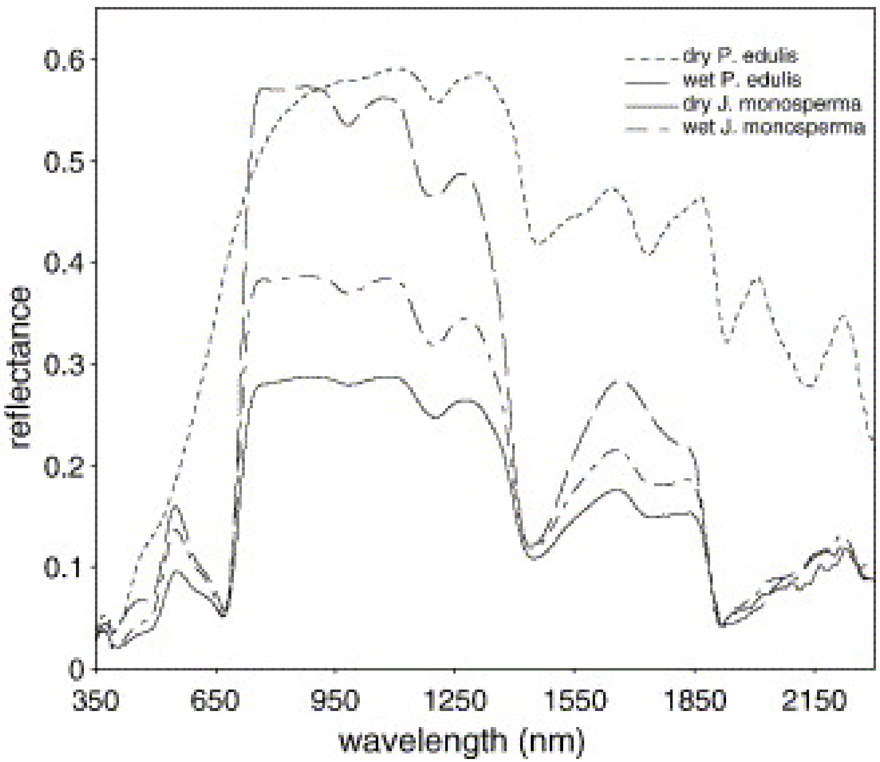


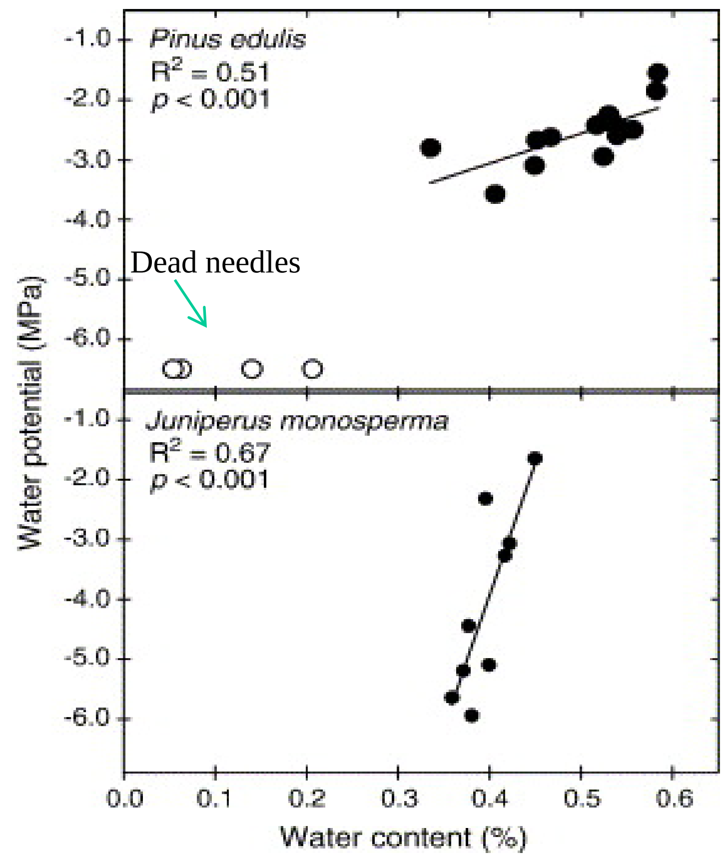
Irrigated Almond and Pistachio Orchards, San Joaquin Valley, CA July, 2009, Airborne MASTER


NDMI
Low
High


NDWI
Low
High

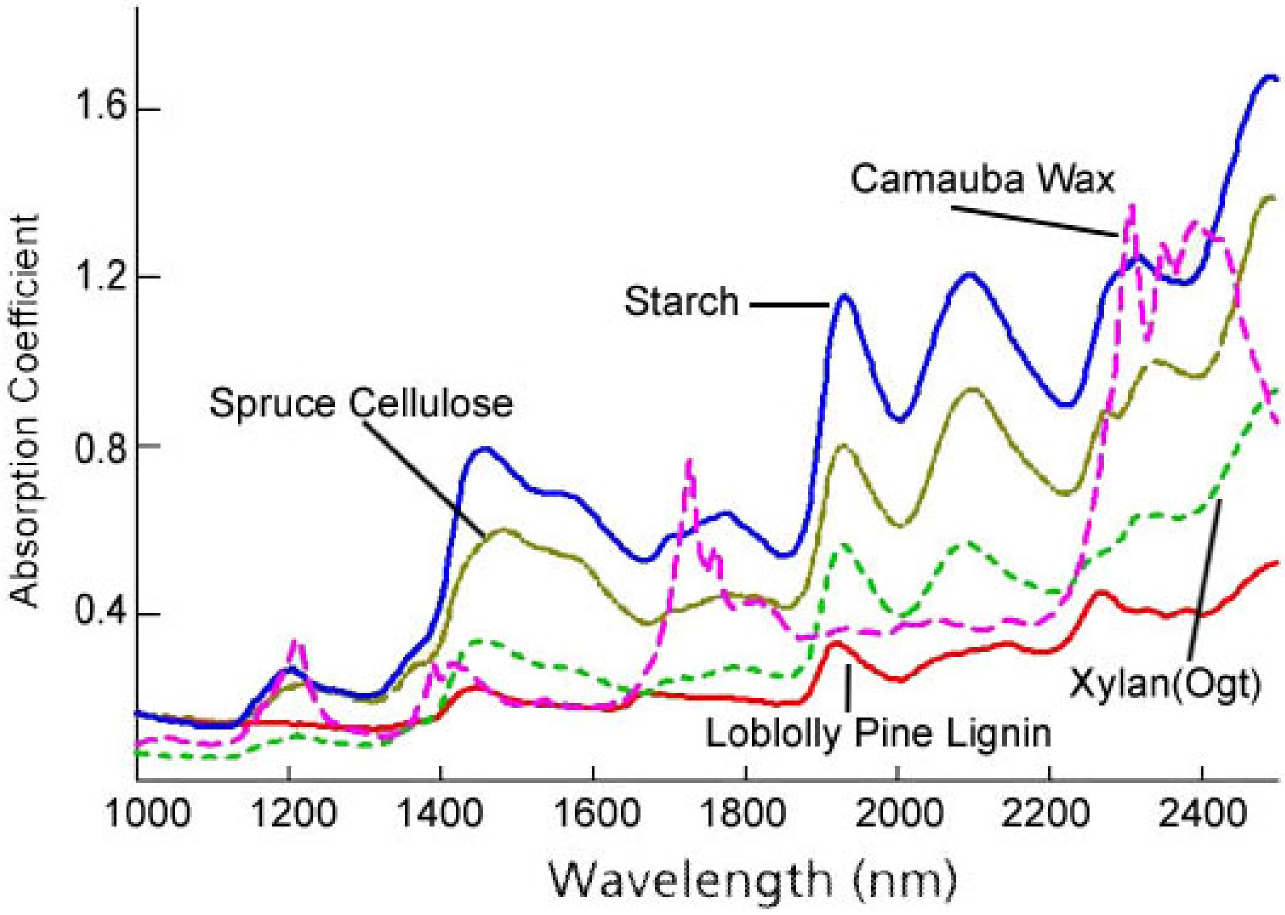
Severe Drought in New Mexico in 2003-2005. Detection of Drought Stress



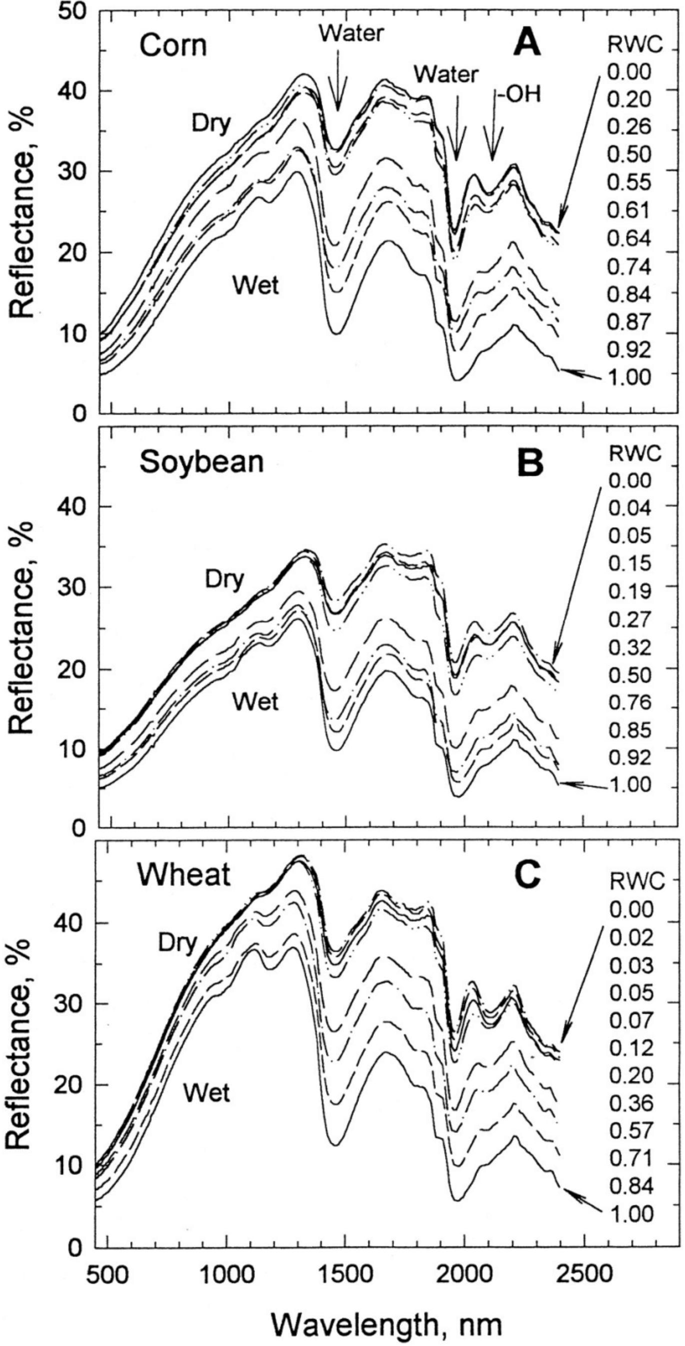


Hugh C. Stimson, David D. Breshears, Susan L. Ustin, Shawn C. Kefauver. 2005. Spectral sensing of foliar water conditions in two co-occurring conifer species: *Pinus edulis and Juniperus monosperma. Remote Sensing of Environment 96:108-118*

Absorptions by Dry Plant Materials

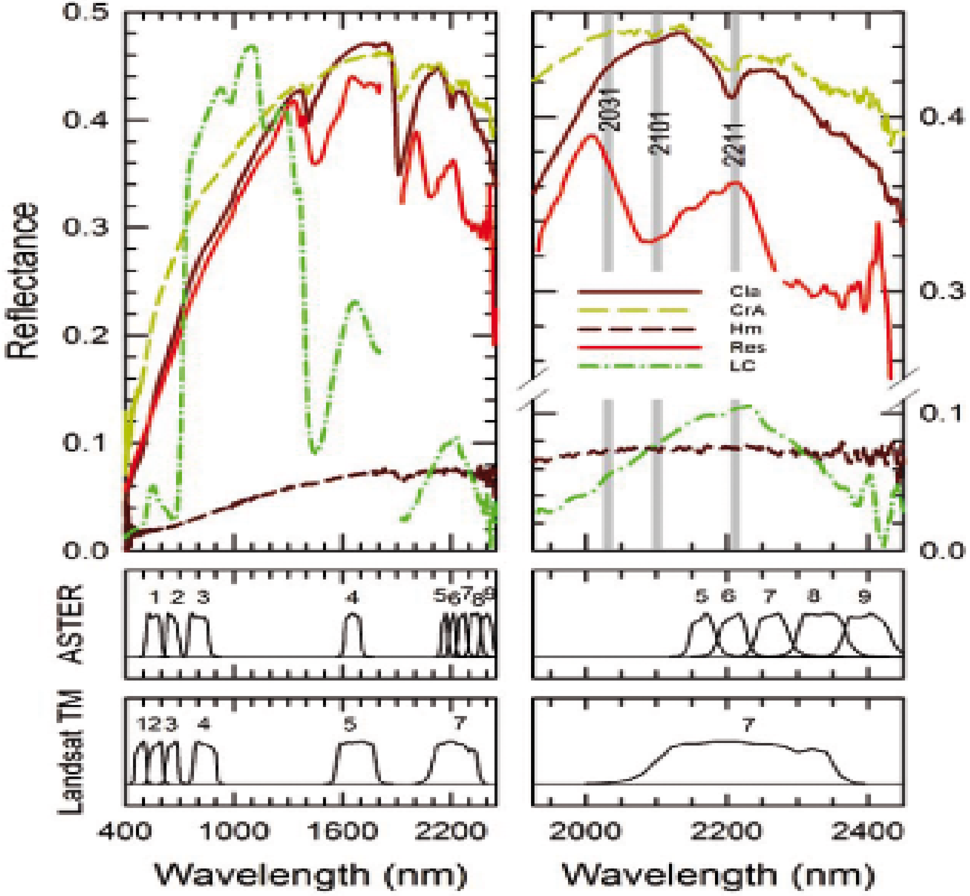


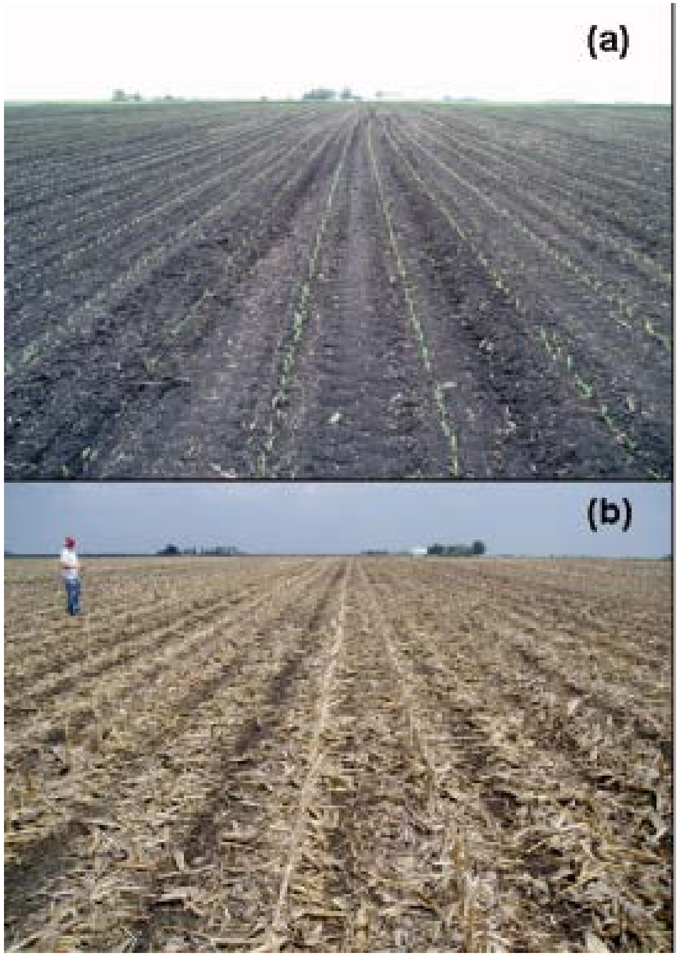
Dry and Wet
Plant Canopy Material:
(stems, leaves)



Craig S.T. Daughtry. 2001. Discriminating Crop Residues from Soil by Shortwave Infrared Reflectance. Agronomy Journal 93: 125-131

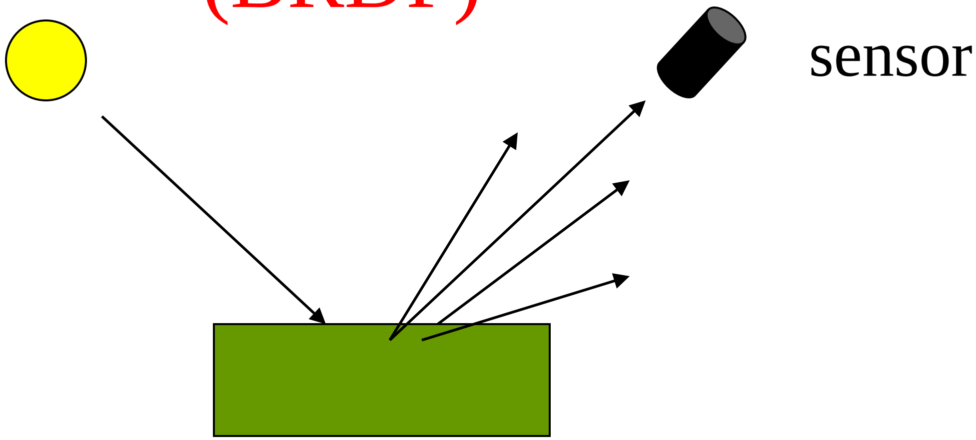
Absorption Spectra of Non-Pigment Plant Materials



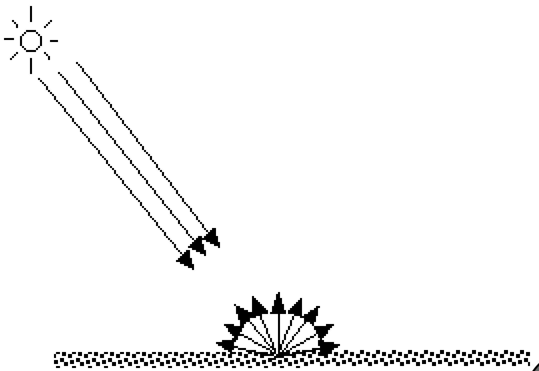


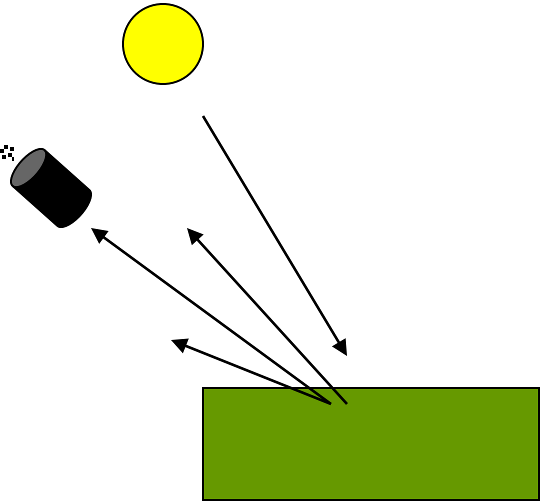
CAI = 0.5 $(R_{2000}-R_{2200})/R_{2100}$

Bidirectional Reflectance Distribution Function (BRDF)



Forward scatter direction (specular direction)

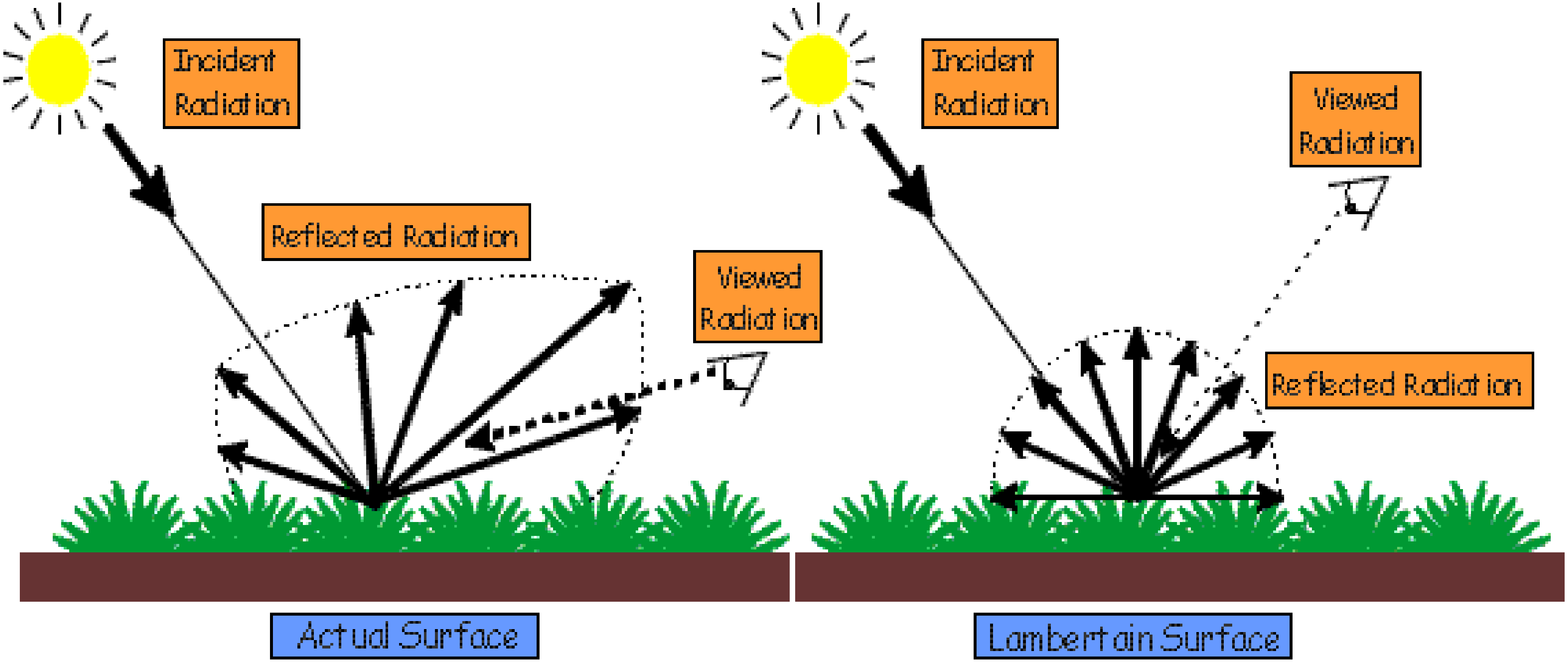




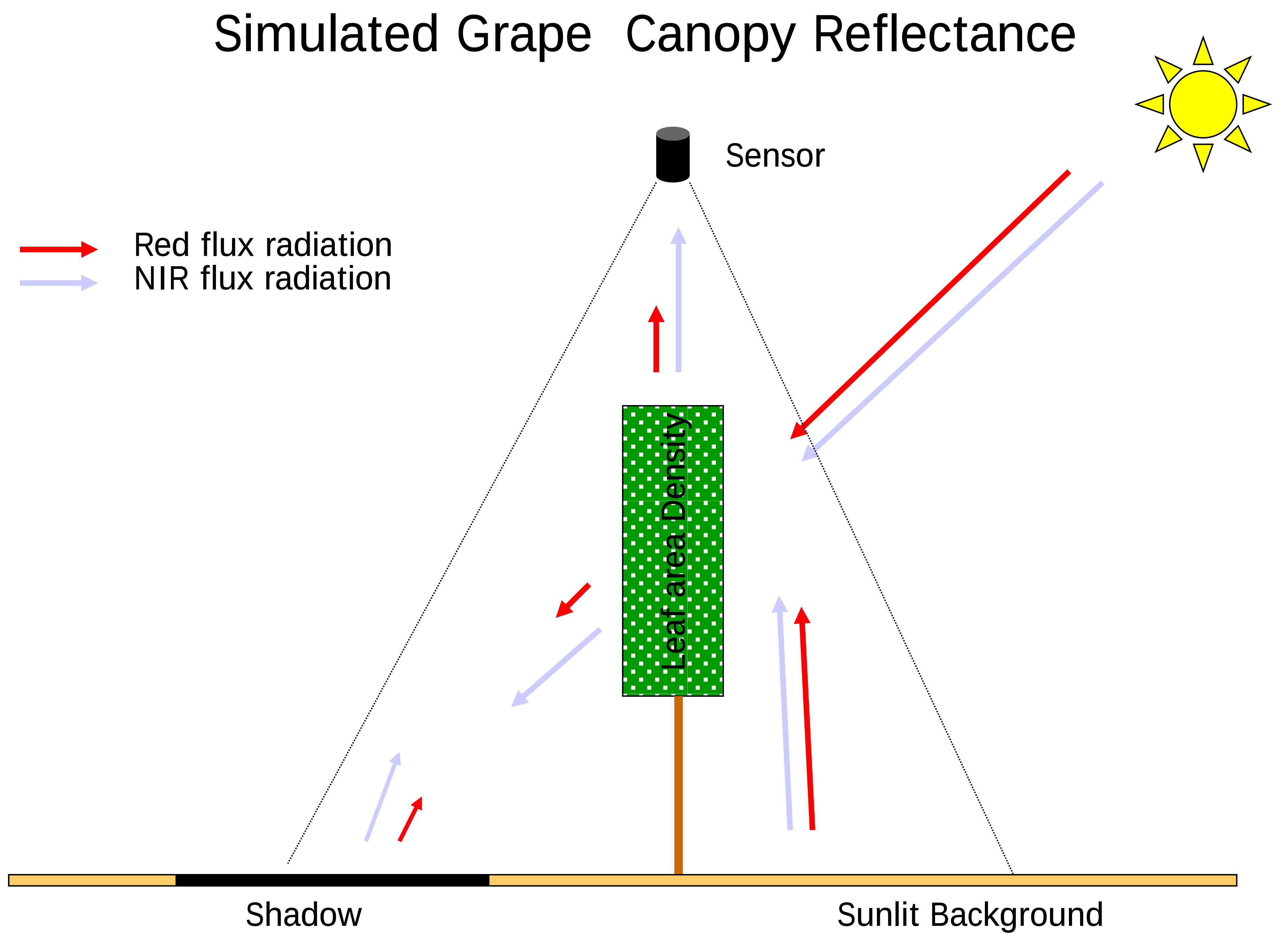
Back scatter direction (hot spot direction)

How to describe Directional Radiation at a Surface: Bidirectional Reflectance Distribution Function (BRDF)

Reflectance is rarely **isotropic**. Most surfaces exhibit **anisotropic** reflectance (reflectance varies with direction).



Canopy BRDF is not constant - Direction of illumination changes during day


Simulated Grape Canopy Reflectance
Sensor
Red flux radiation
NIR flux radiation
Leaf area Density
Shadow
Sunlit Background

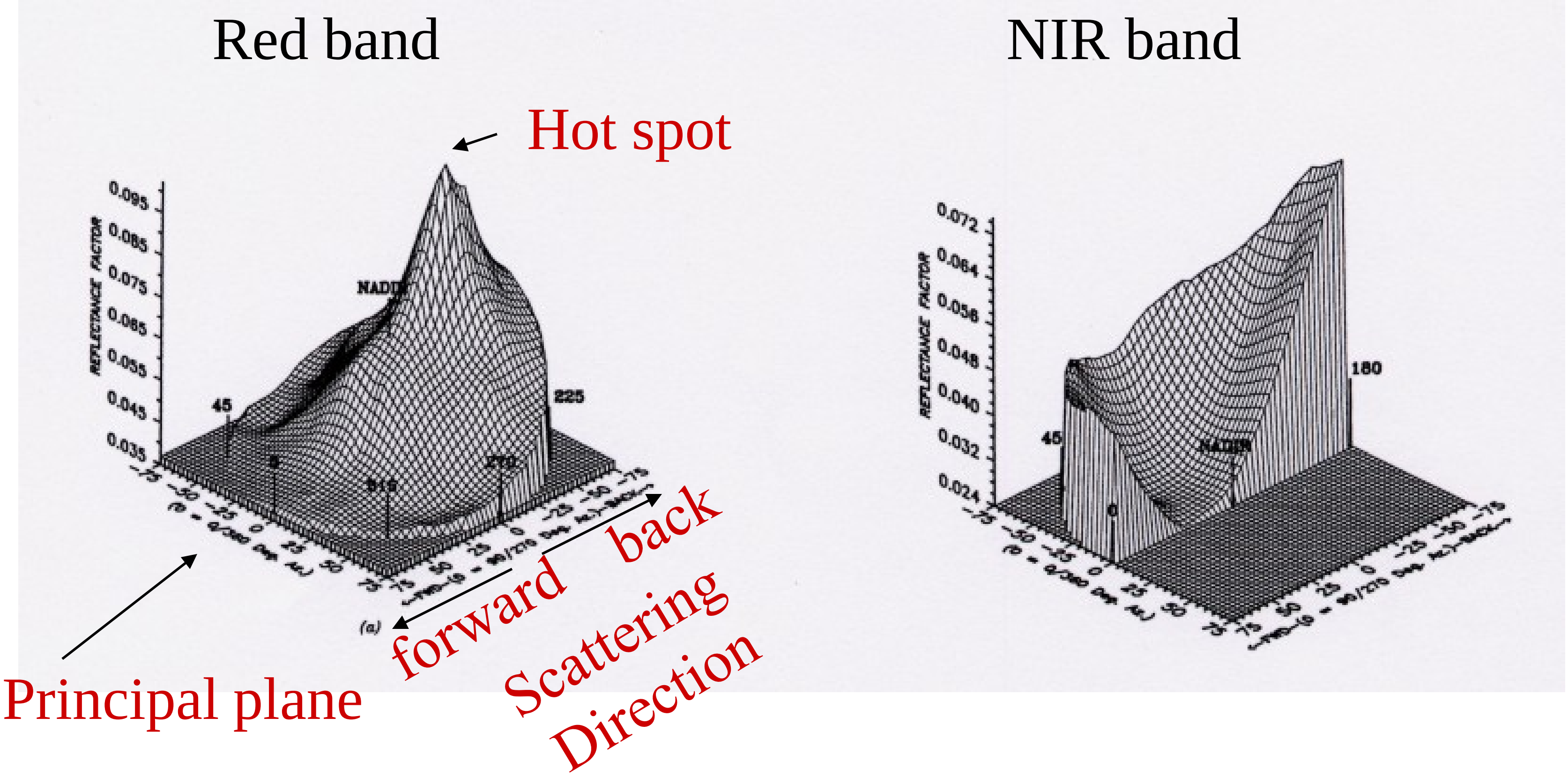
BRDF

Hot
Spot

Backscatter direction

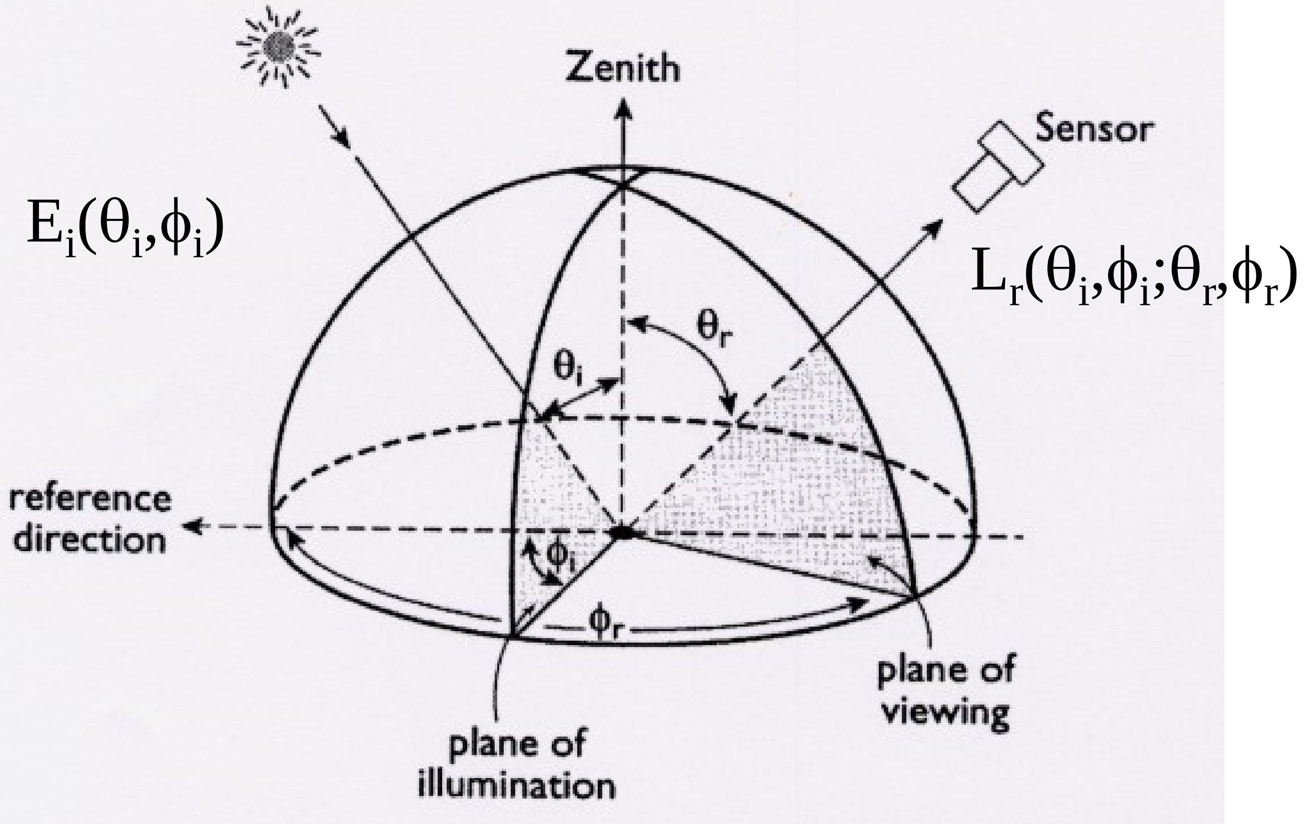
Forward scatter direction

BRDF


Red band
NIR band
Hot spot
Principal plane
forward
back
Scattering
Direction
REFLECTANCE FACTOR
NADIR
(a)

BRDF

$$BRDF = L_r(\theta_i,\phi_i;\theta_r,\phi_r)/\ E_i(\theta_i,\phi_i)$$



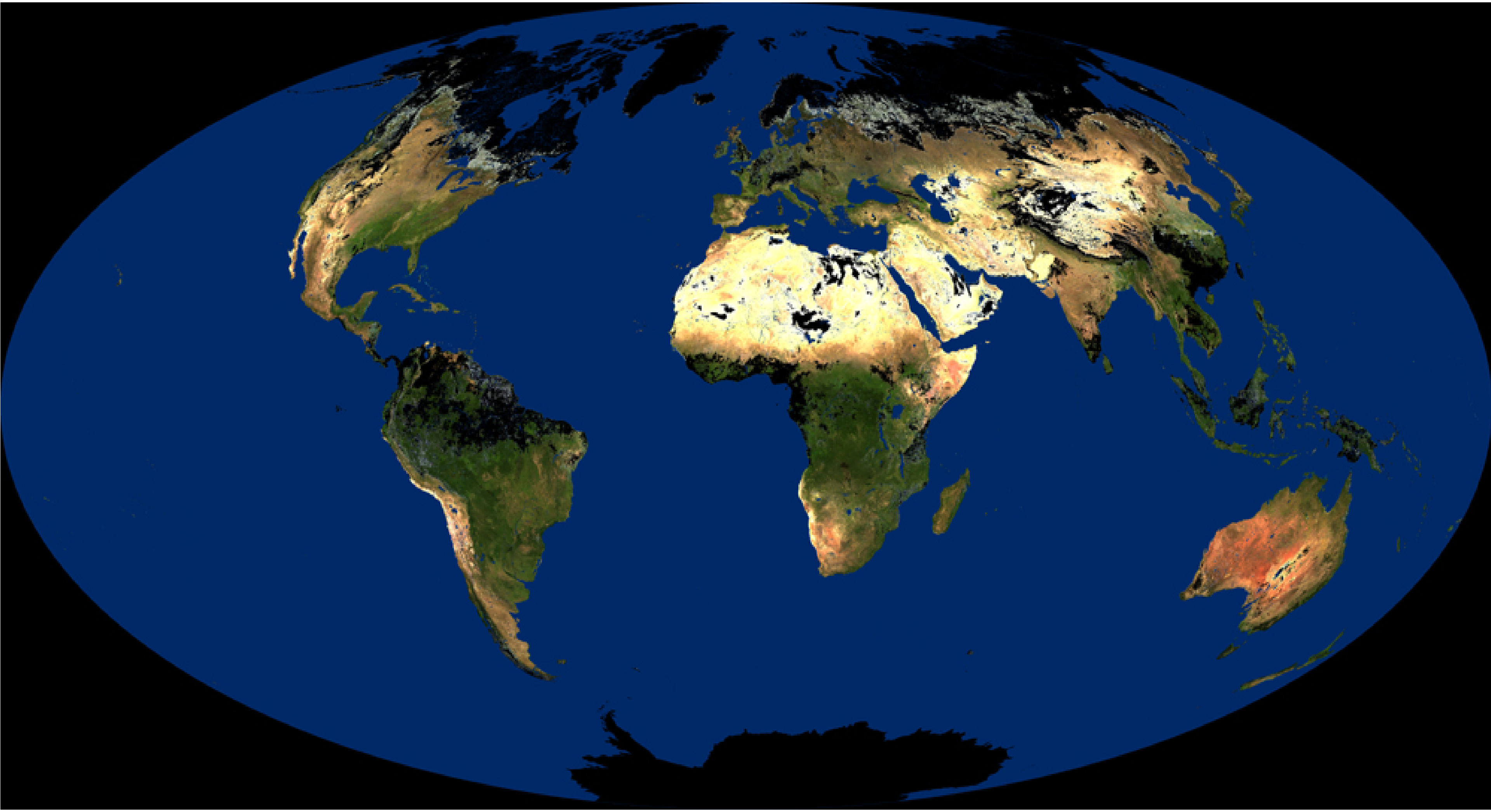
$$BRF(\theta_i,\varphi_i;\theta_v,\varphi_v) = \frac{L_t(\theta_v,\varphi_v;\theta_i,\varphi_i)}{L_p(\theta_v,\varphi_v;\theta_i,\varphi_i)}$$

BRDF: a Goniometer

BRF-data can be acquired in the in the field under natural illumination conditions or in a controlled laboratory environment.

Left: EGO, JRC, Ispra, Italy; Center: FIGOS, RSL, Zurich, Switzerland; Right: PARABOLA, Biospheric Sciences, NASA/GSFC, Greenbelt, MD, USA.

Global Composite Map of Nadir BRDF-Adjusted Reflectance (NBAR) April 7–22 2001



No data

True Color, MODIS Bands 2, 4, 3

10 km resolution, Hammer-Aitoff projection, produced by MODIS BRDF/Albedo Team

MODLAND/Strahler et al

Lecture 2. What you should know:

1. Biochemical absorptions by leaves and canopies
2. Scattering processes of leaves and canopies
3. Physiological processes: photosynthesis. Leaf structure and processes, chloroplast structure, pigments
4. Influence of pigments on leaf reflectance
5. Leaf absorptions by water and other biochemicals
6. Spectral indexes: bands sensitive to biochemical of interest
7. Bidirectional Reflectance Distribution Function