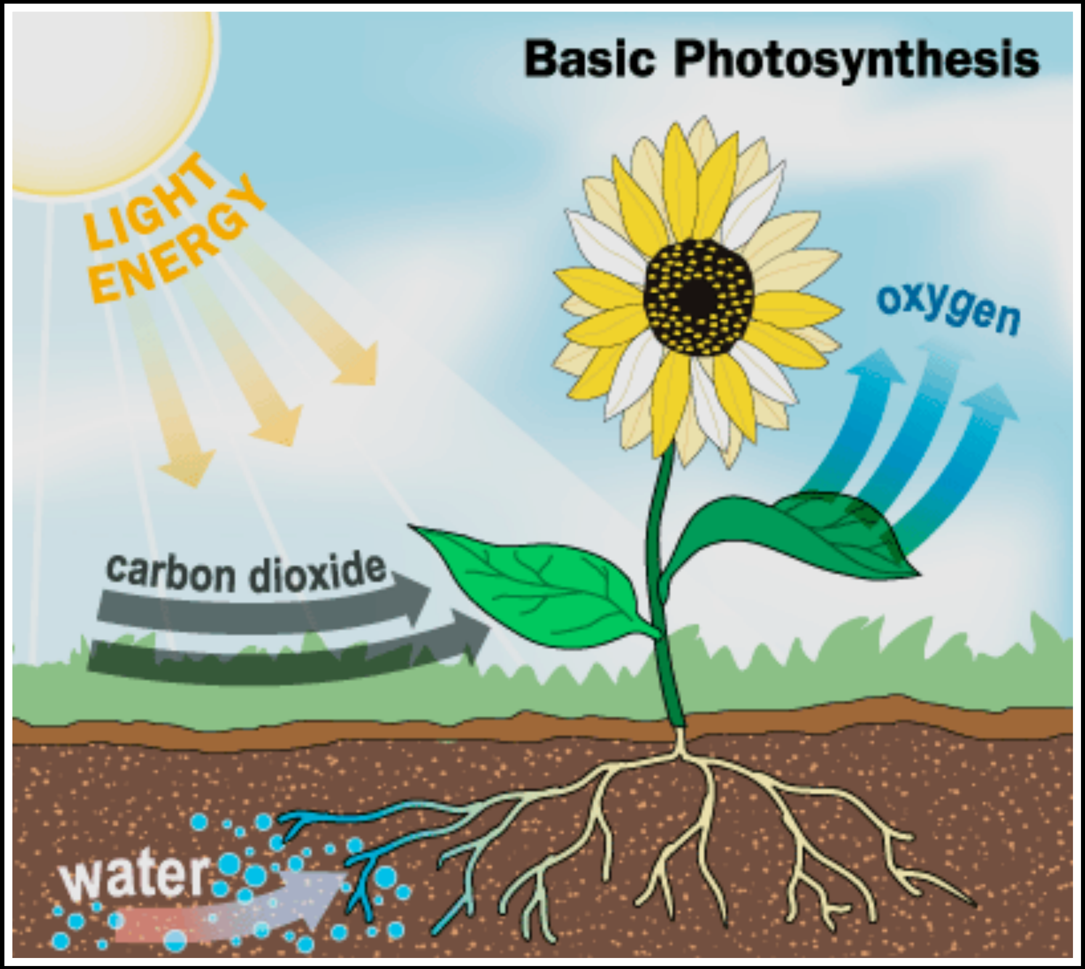
Plant Photosynthetic Mechanism:

The Theoretical and Empirical Basis for Imaging Spectroscopy

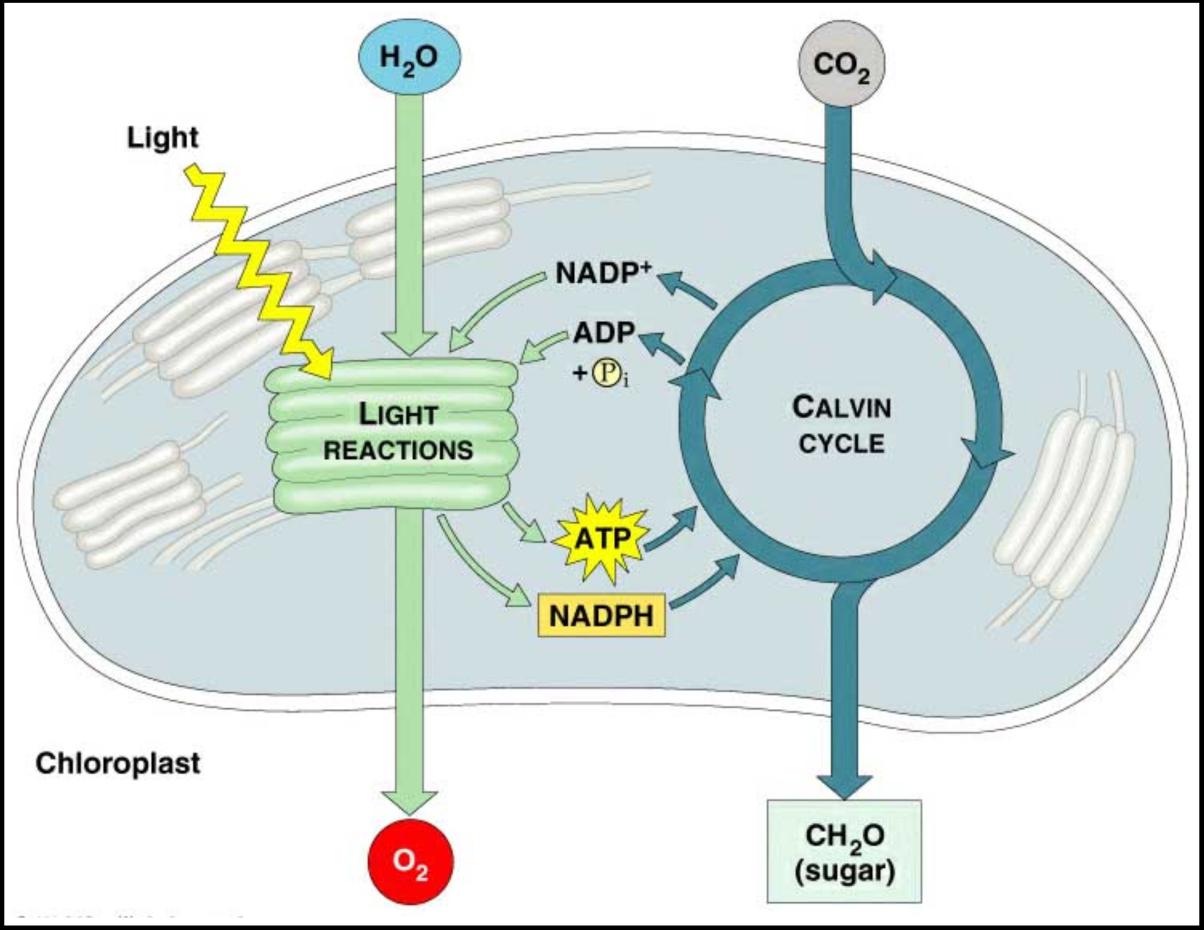
All images not otherwise attributed are from the Townsend lab or wikipedia.org.

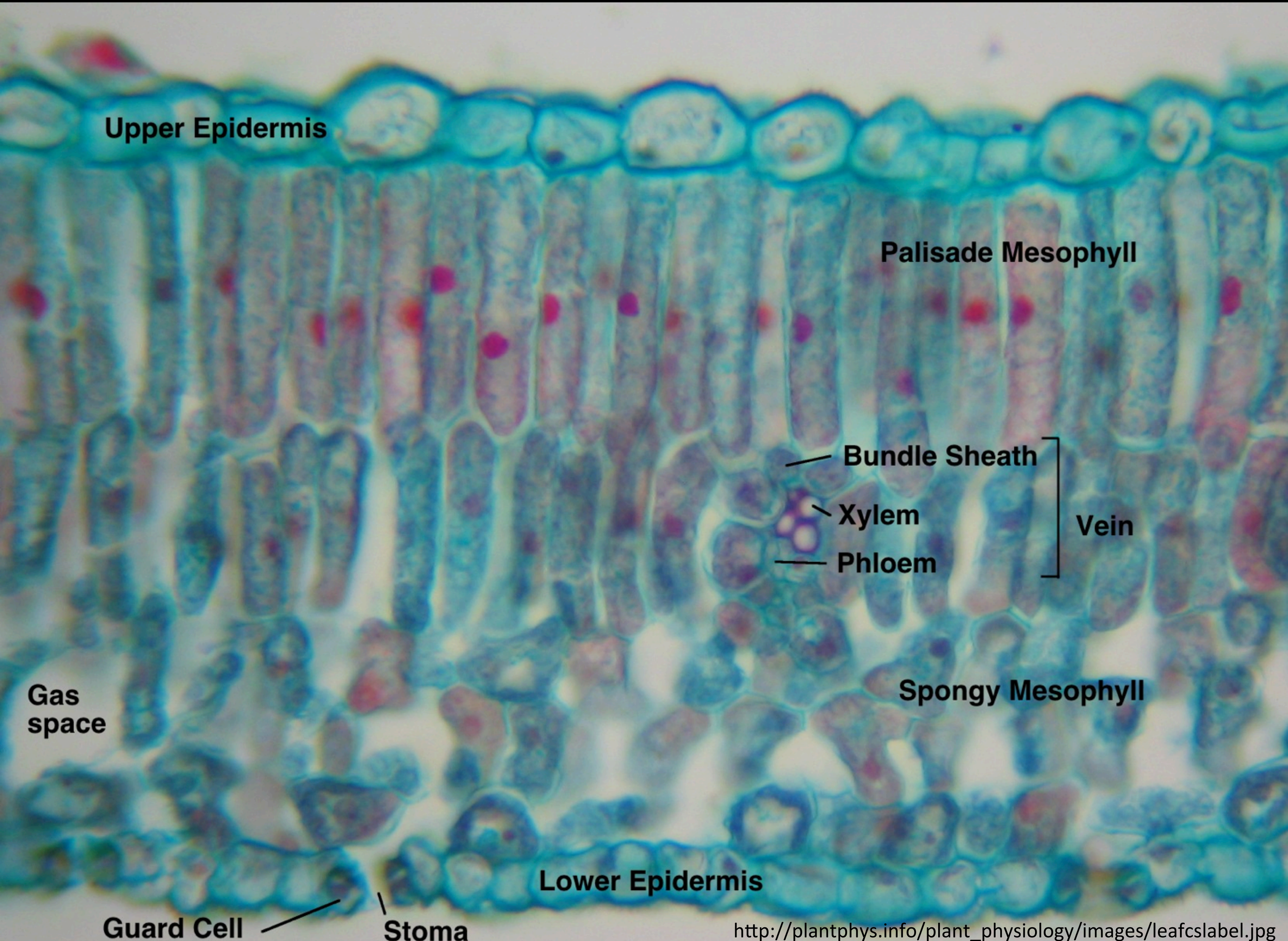
This is photosynthesis:



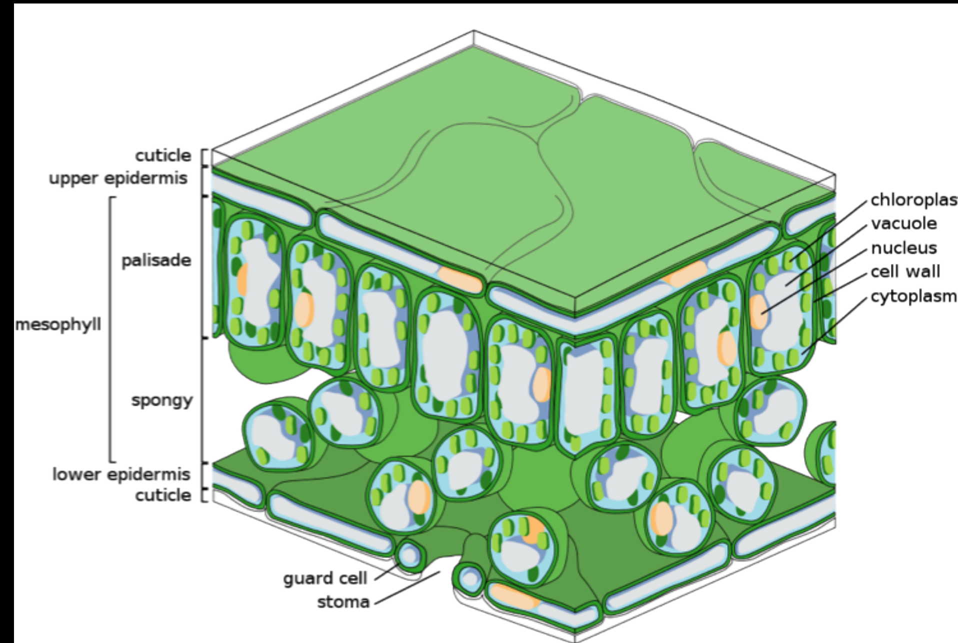
$6H_2O + 6CO_2 + \text{Light} \rightarrow C_6H_{12}O6 + 6O_2$

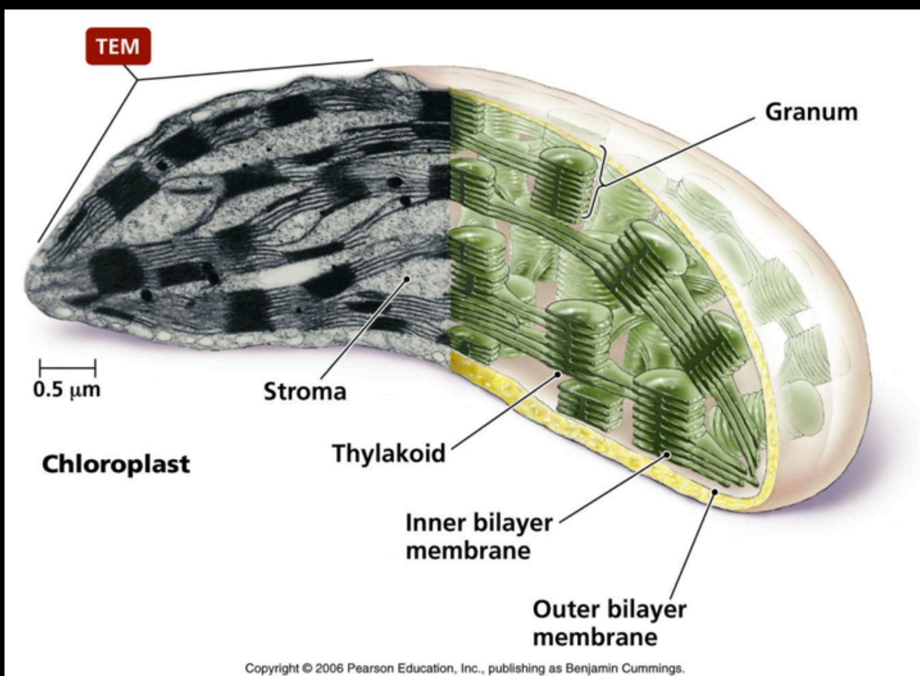
This is photosynthesis:

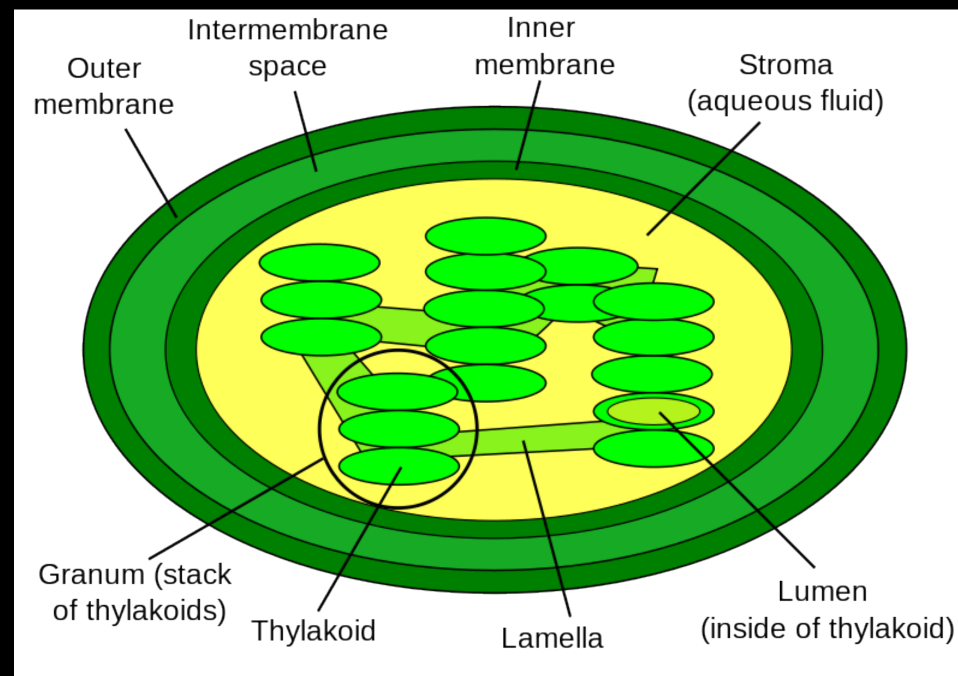




http://plantphys.info/plant_physiology/images/leafcslabel.jpg

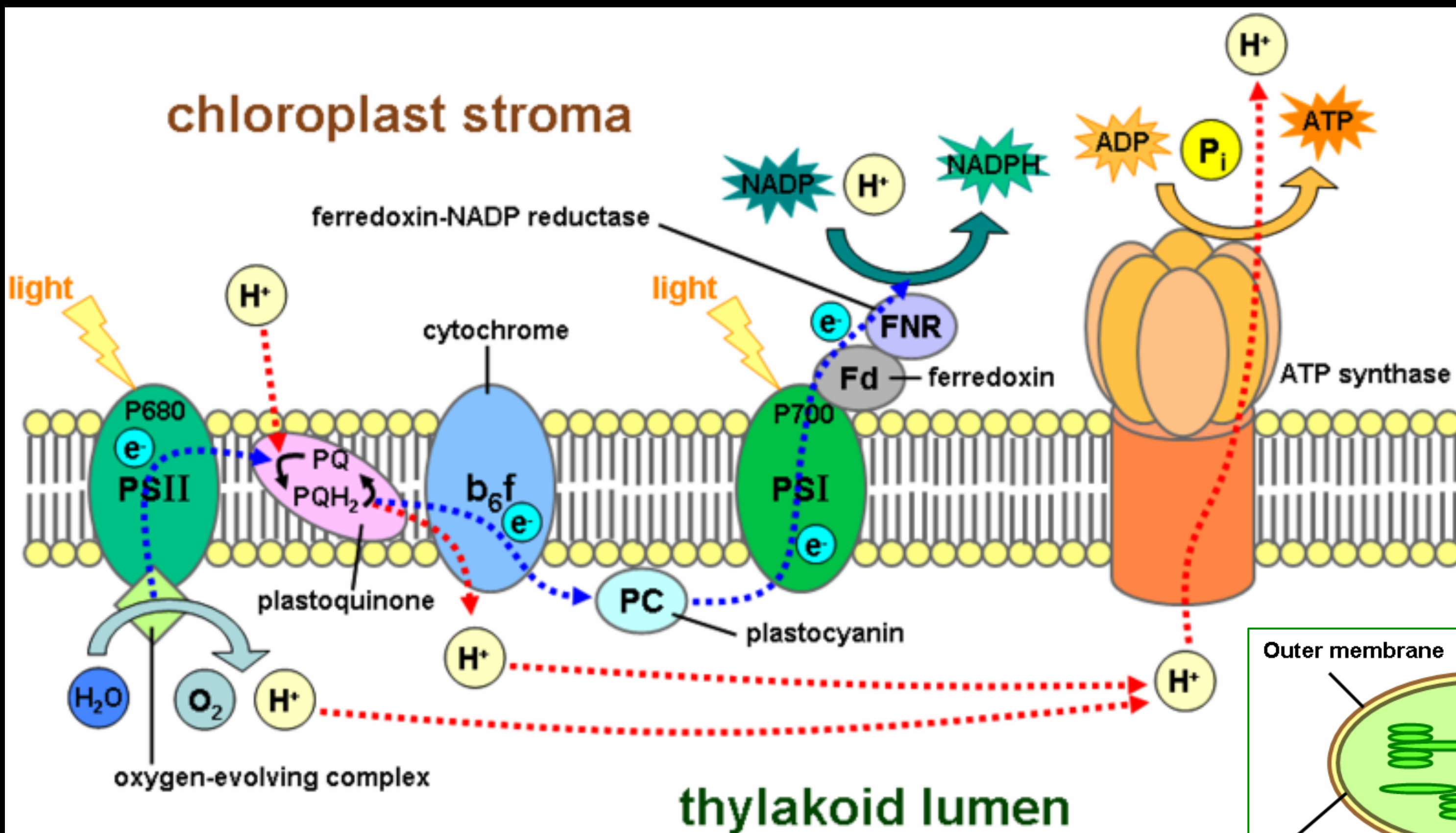

cuticle
upper epidermis
mesophyll
palisade
spongy
lower epidermis
cuticle
guard cell
stoma
chloroplast
vacuole
nucleus
cell wall
cytoplasm

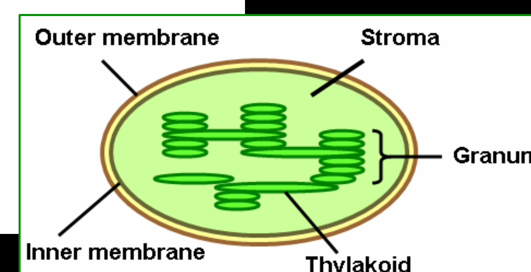

TEM
Granum
0.5 µm
Stroma
Chloroplast
Thylakoid
Inner bilayer membrane
Outer bilayer membrane
Copyright © 2006 Pearson Education, Inc., publishing as Benjamin Cummings.


Outer membrane
Intermembrane space
Inner membrane
Stroma (aqueous fluid)
Granum (stack of thylakoids)
Thylakoid
Lamella
Lumen (inside of thylakoid)

Light reactions:

Chloroplast gains a proton and loses an electron and other stuff happens



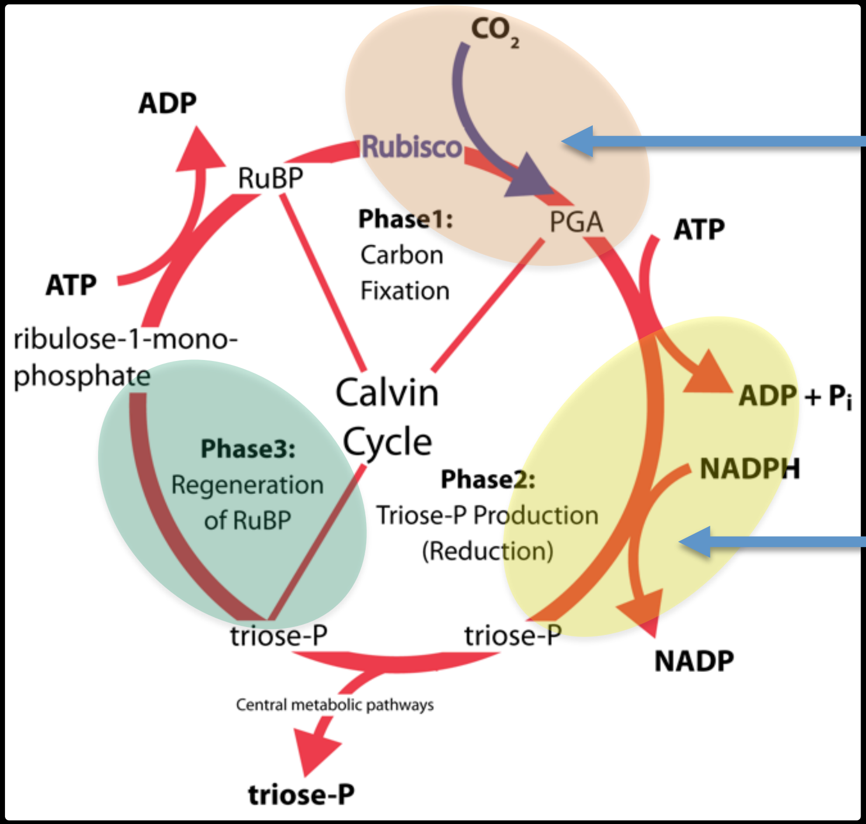


Electron transport chain is set in motion. NADP is reduced to NADPH. ATP is synthesized.

2 H_2O + 2 NADP+ + 3 ADP + 3 P_i + light → 2 NADPH + 2 H^+ + 3 ATP + O2

Light-Independent Reactions:

The Calvin Cycle



Carboxylation

Needed: Rubisco

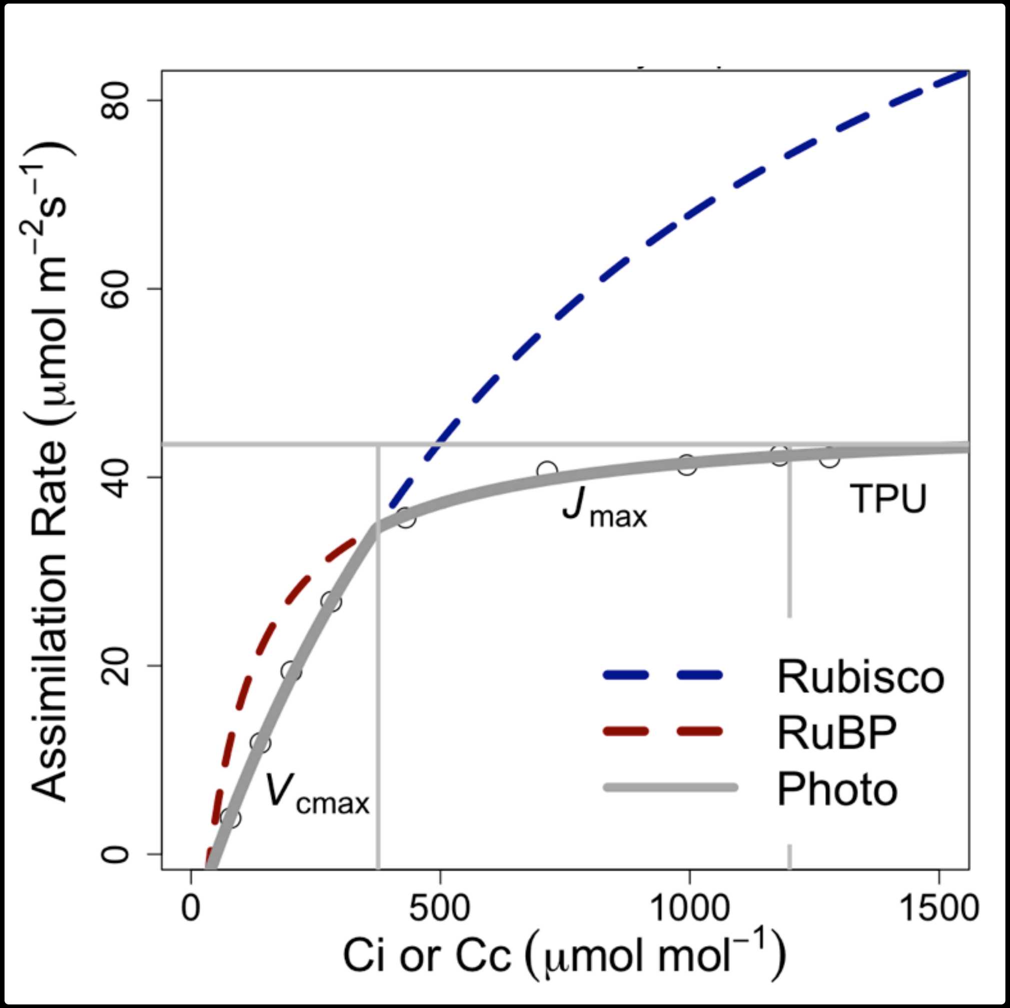
Needed:

NADPH and ATP

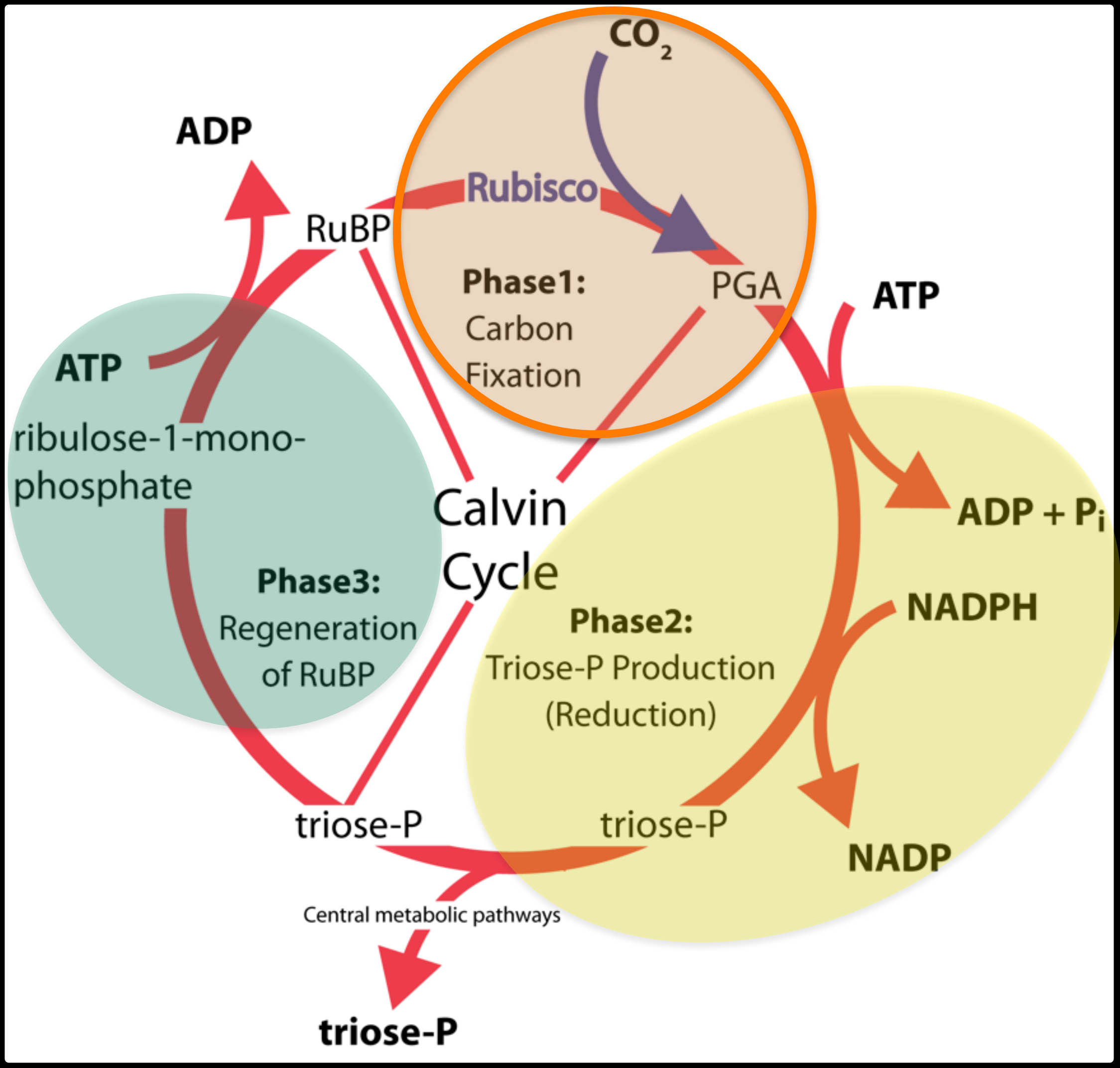
(products of light reactions)

$$3\ CO_2 + 9\ ATP + 6\ NADPH + 6\ H^+ \rightarrow C_3H_6O_3\text{-phosphate} + 9\ ADP + 8\ P_i + 6\ NADP^+ + 3\ H_2O$$

How photosynthesis is modeled:
(temperature dependent)

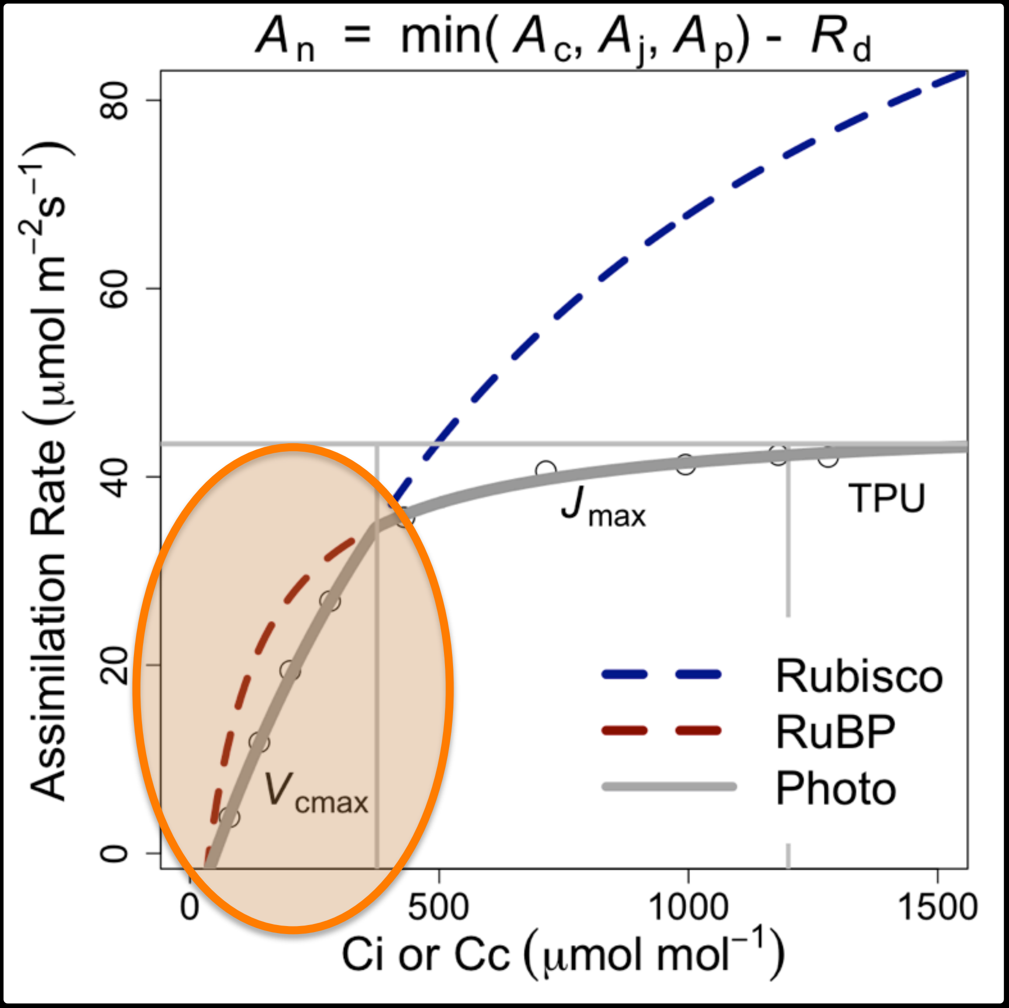


CO_2 Uptake

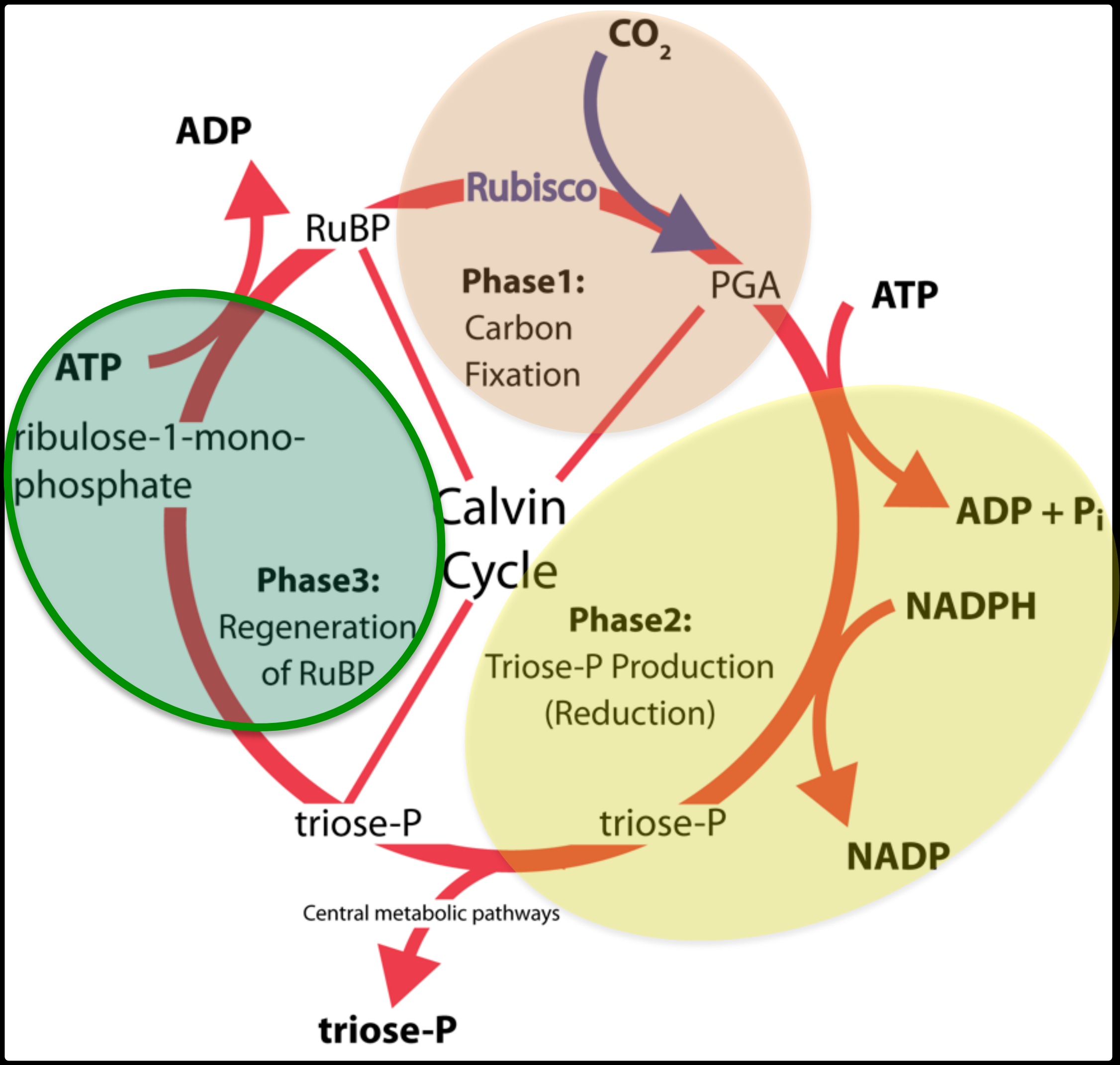


CO2
ADP
Rubisco
RuBP
Phase1:
Carbon
Fixation
PGA
ATP
ATP
ribulose-1-mono-
phosphate
Calvin
Cycle
ADP + Pi
NADPH
Phase3:
Regeneration
of RuBP
Phase2:
Triose-P Production
(Reduction)
triose-P
triose-P
NADP
Central metabolic pathways
triose-P

How photosynthesis is modeled:
(temperature dependent)



CO_2 Uptake



CO2
ADP
Rubisco
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Phase1:
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Fixation
PGA
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ATP
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Triose-P Production
(Reduction)
triose-P
triose-P
NADP
Central metabolic pathways
triose-P

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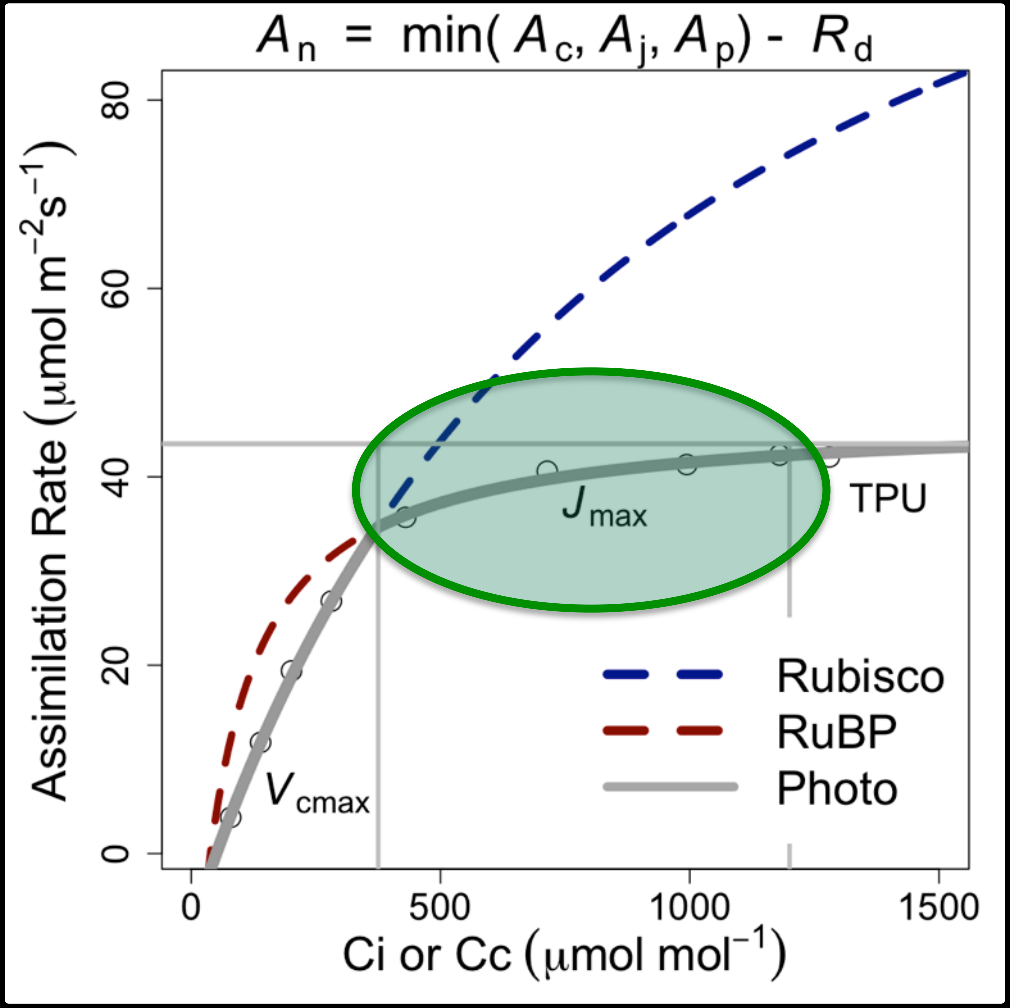
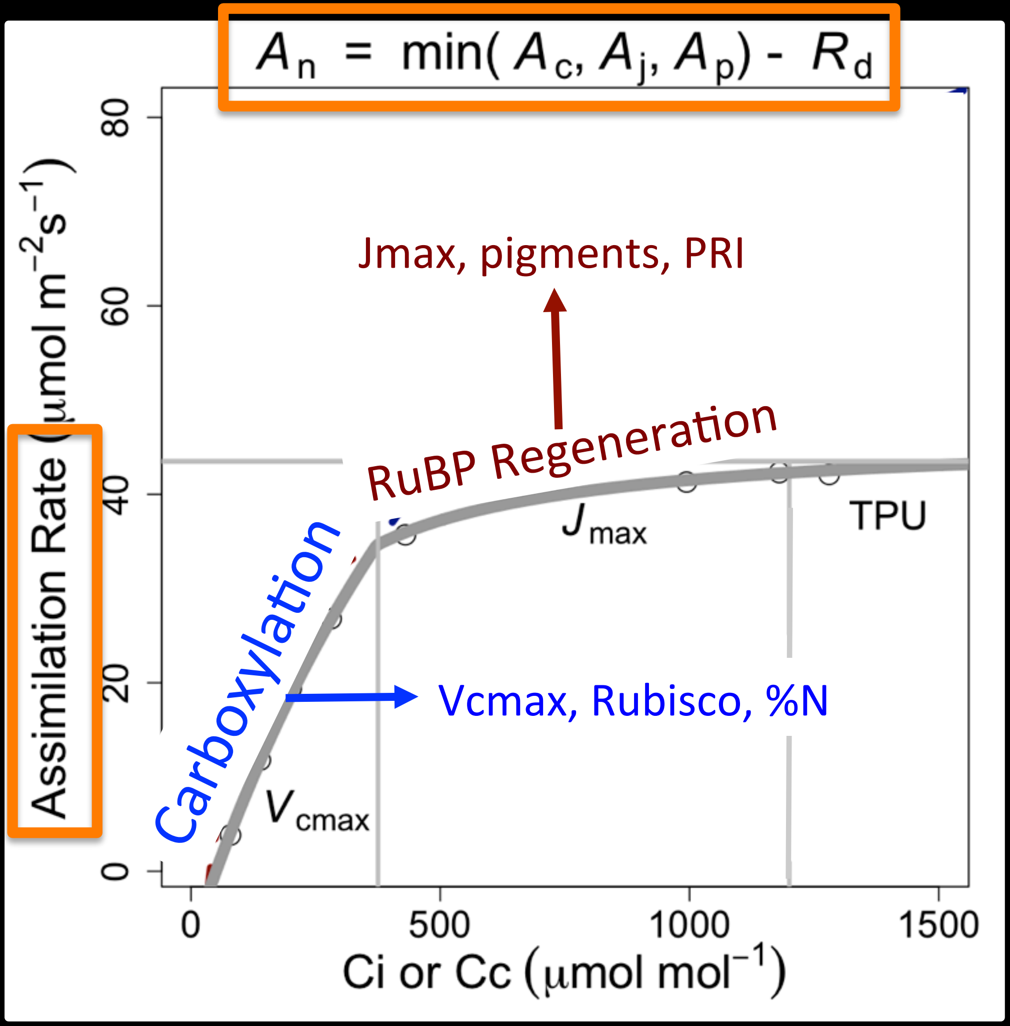
(temperature dependent)

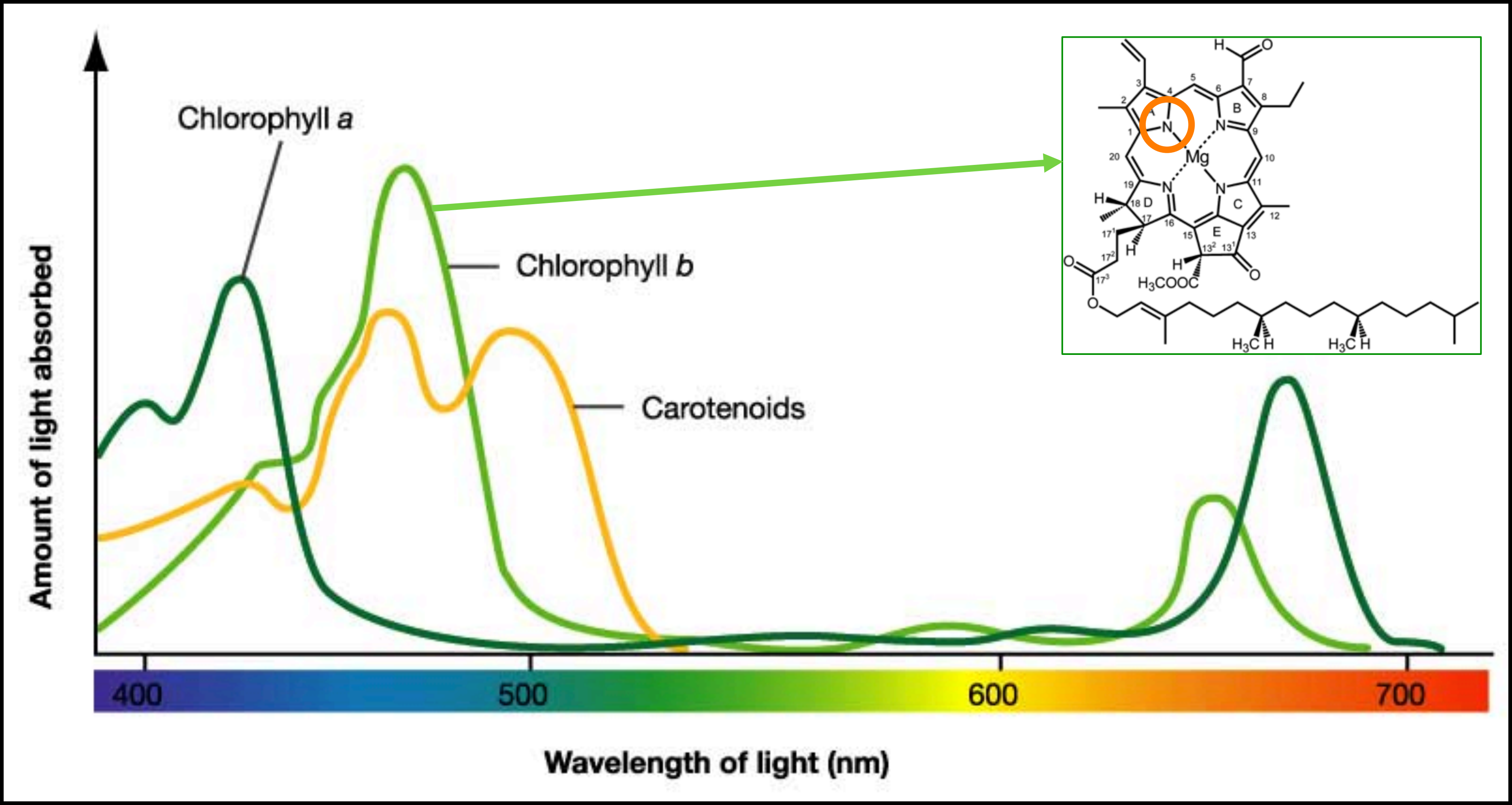


What ecosystem models need?

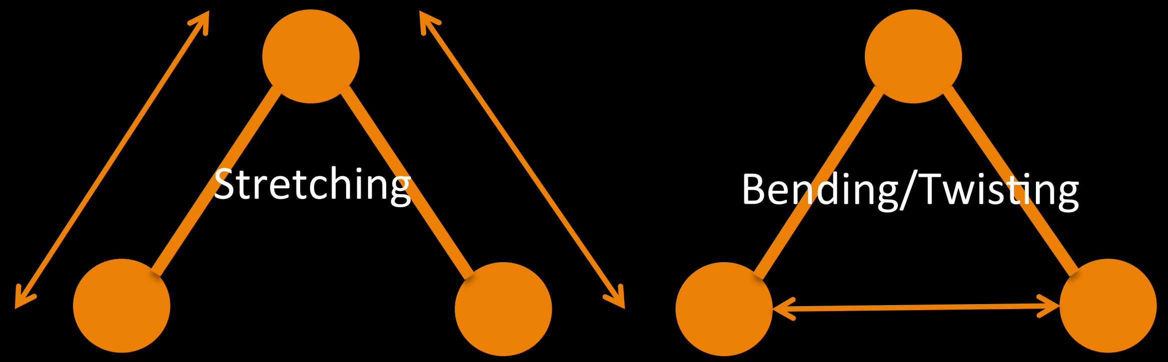


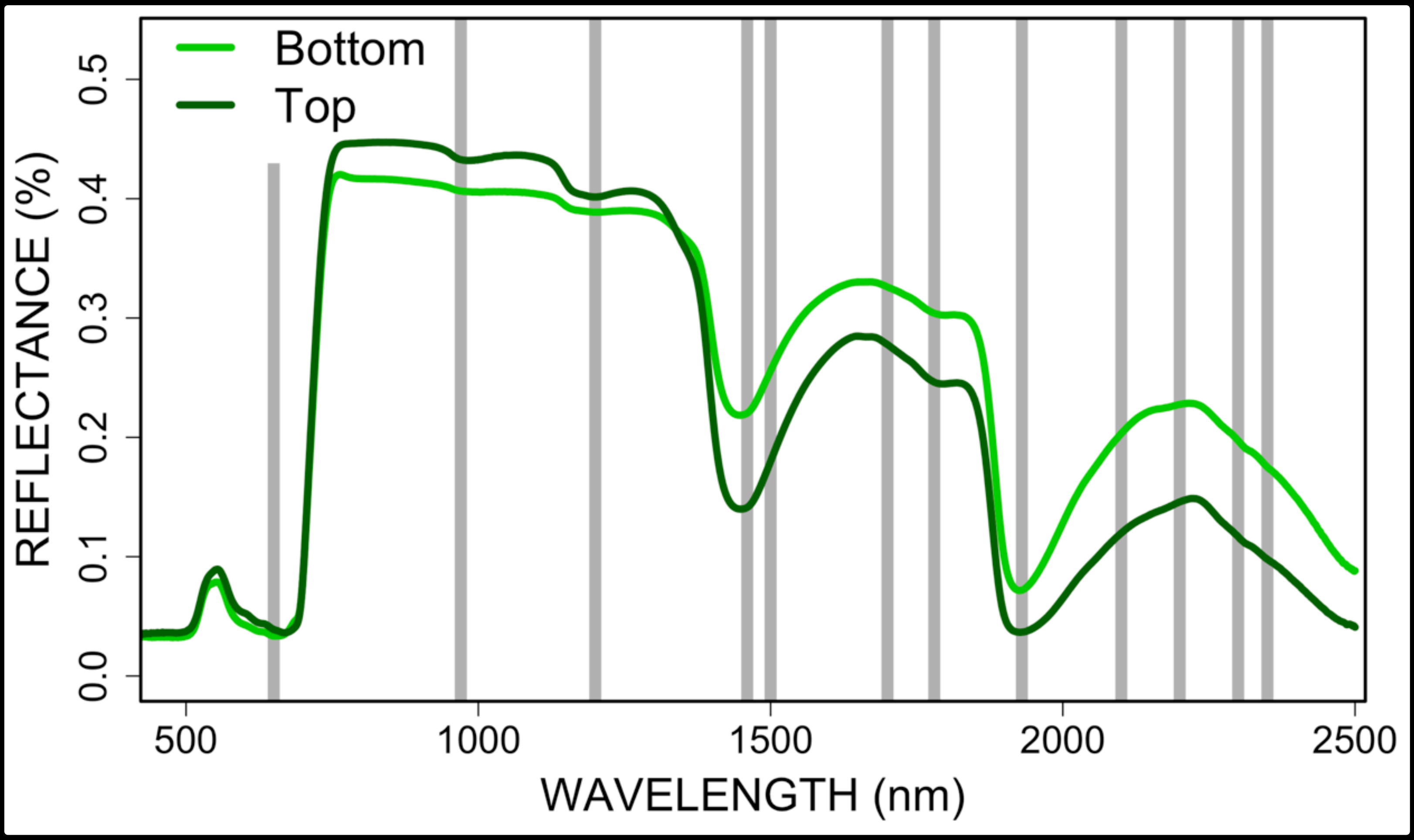
Why imaging spectroscopy?

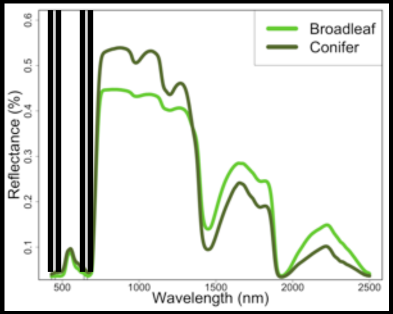
Chlorophyll and other pigments perform light harvesting activities.



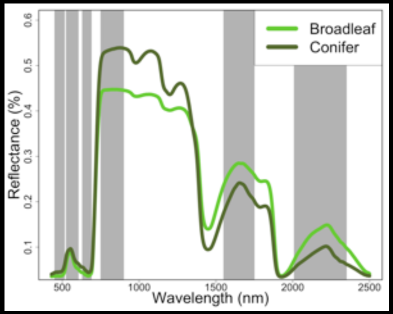
Chemical bonds in the leaf

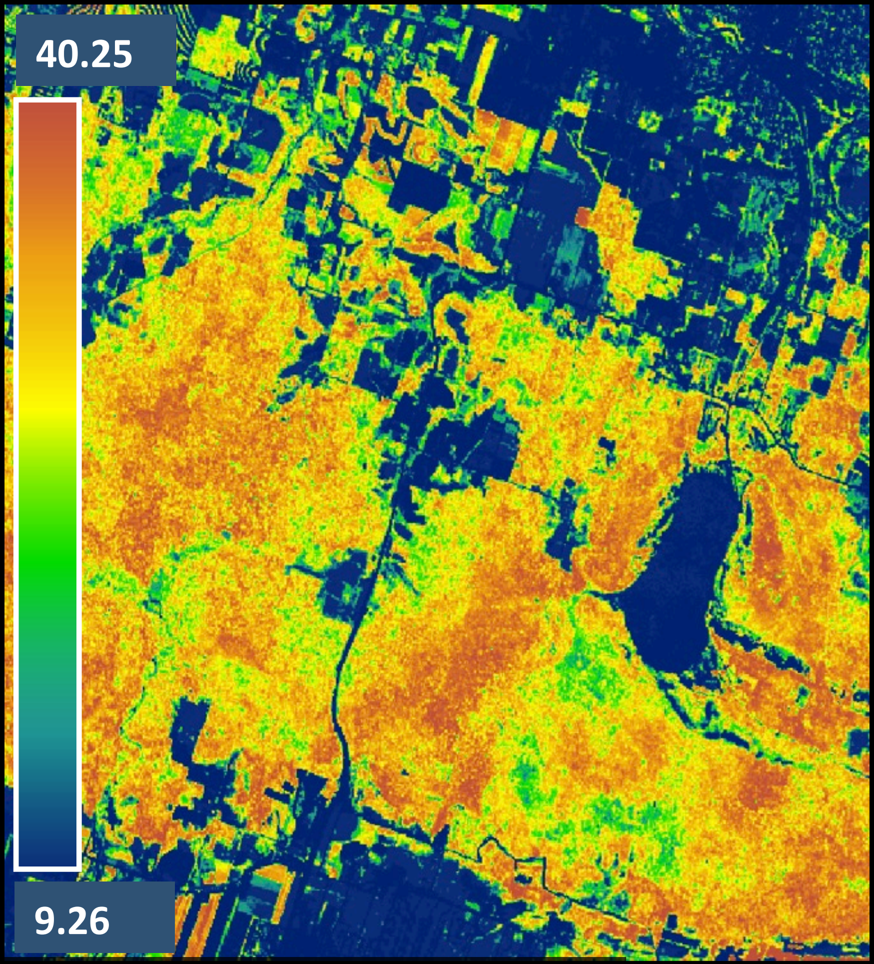


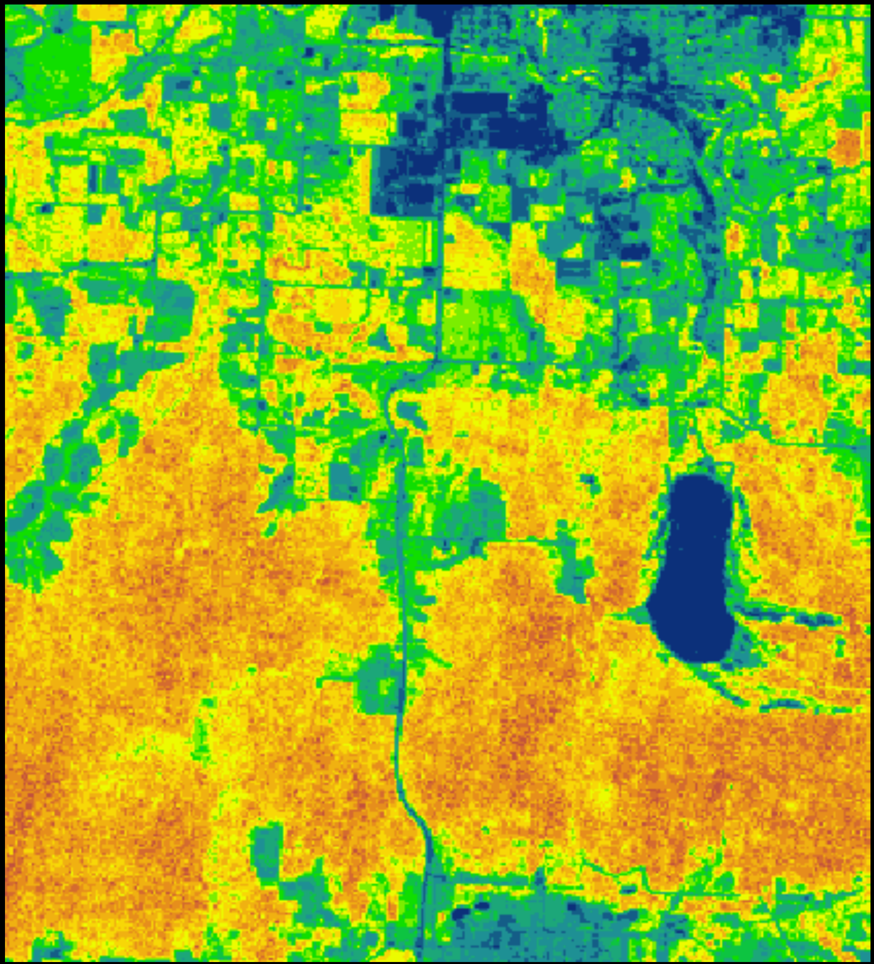




We can measure pigment concentration.

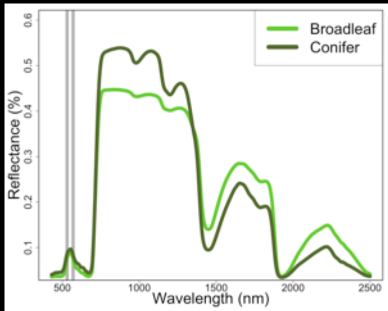




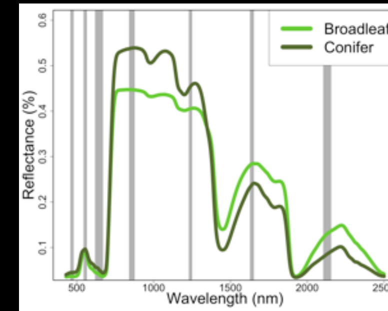


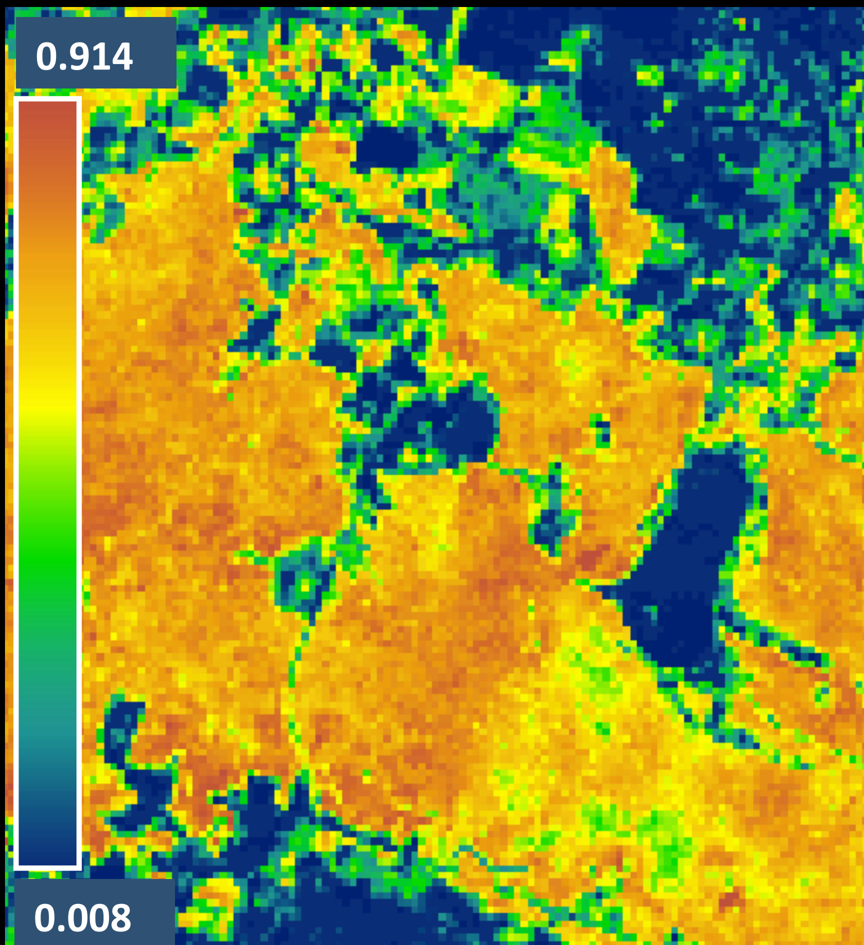
Imaging Spectroscopy

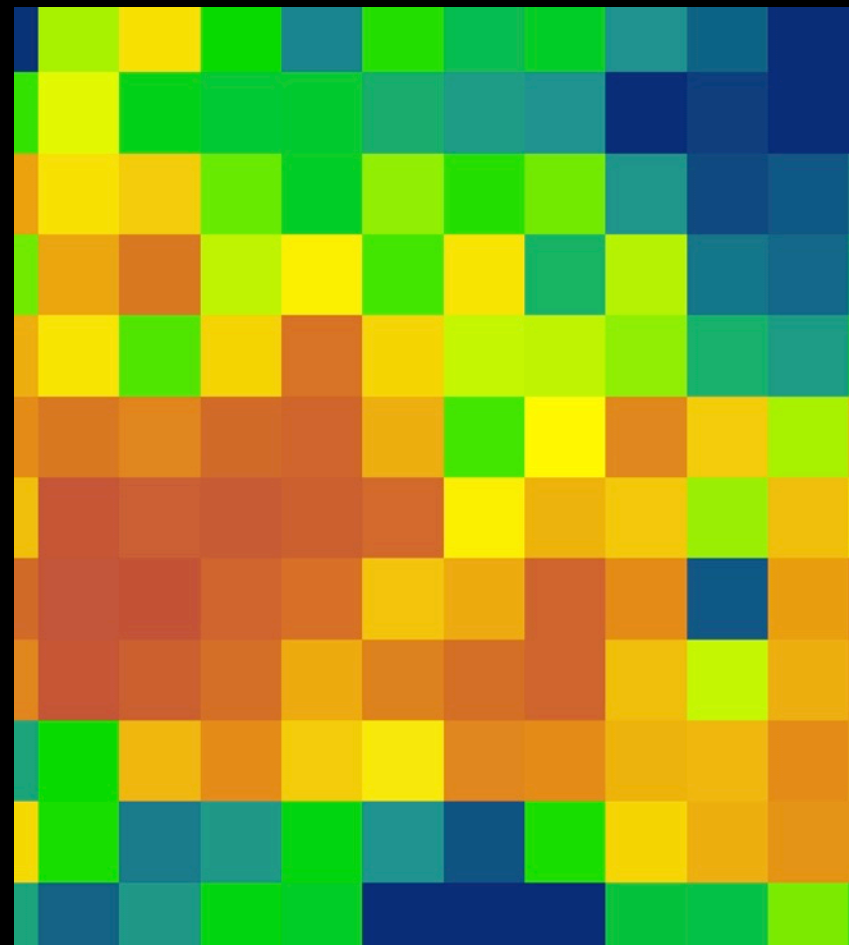
Landsat



Carotenoids, photosynthetic down-regulation and PRI

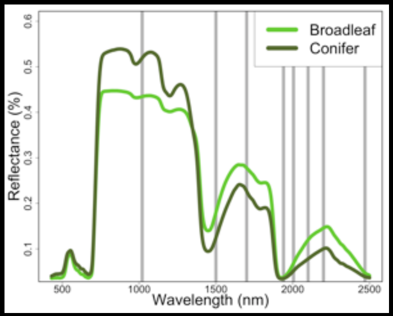






Imaging Spectroscopy

MODIS (simulated)

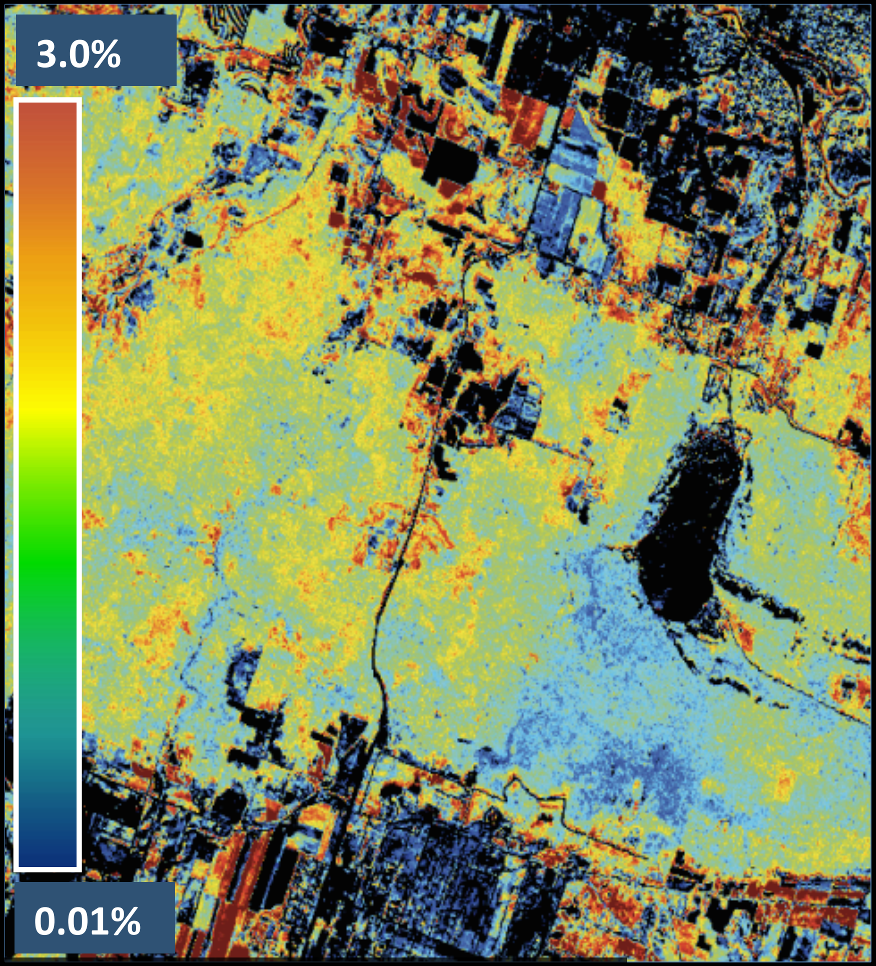


Nitrogen:

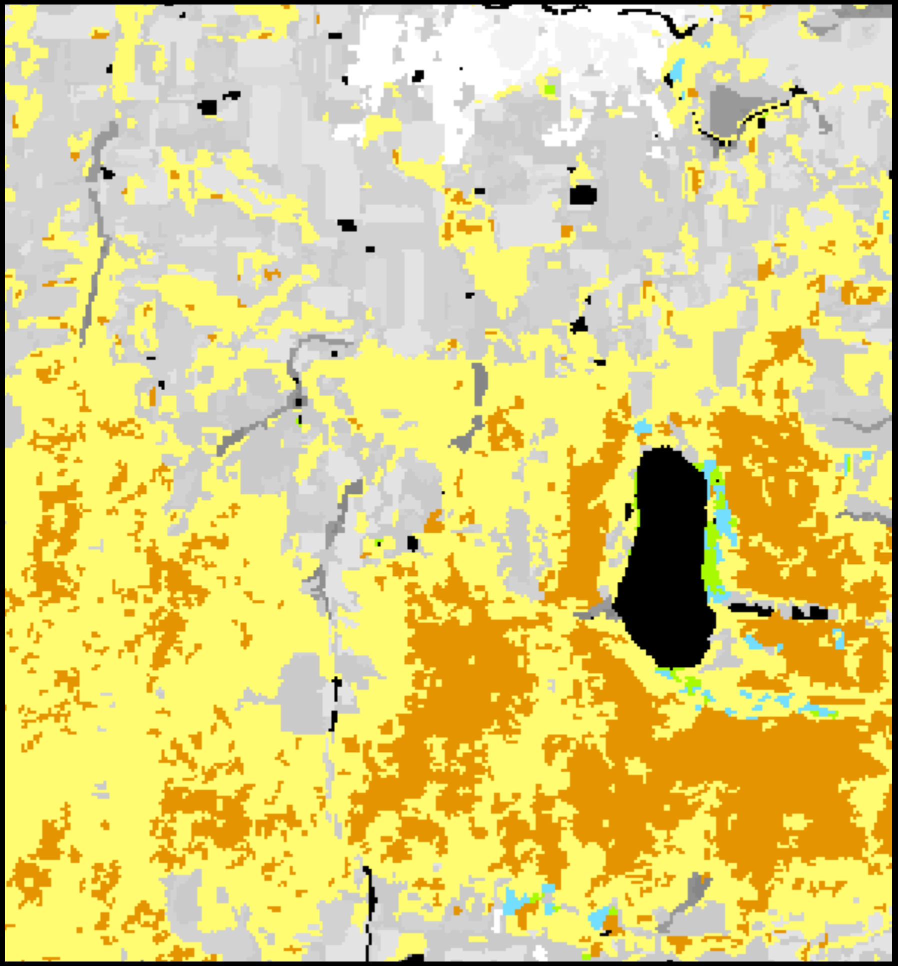
in part, think “Rubisco”

Lookup Table

Cover Type	Value
Maple	2.75
Aspen	2.50
Oak	2.10
Pine	1.50
Spruce	1.00



Imaging Spectroscopy

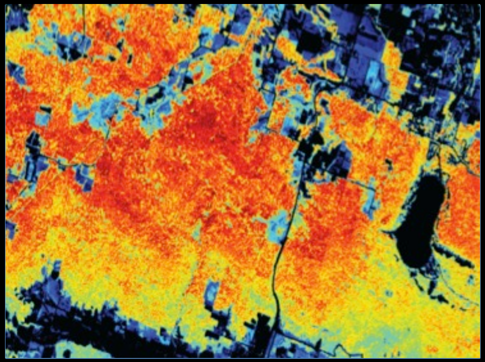


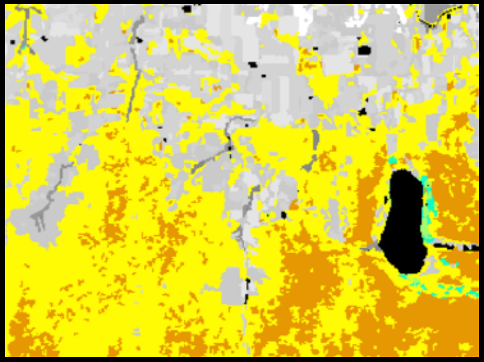
LUT

Traits governing ecosystem processes

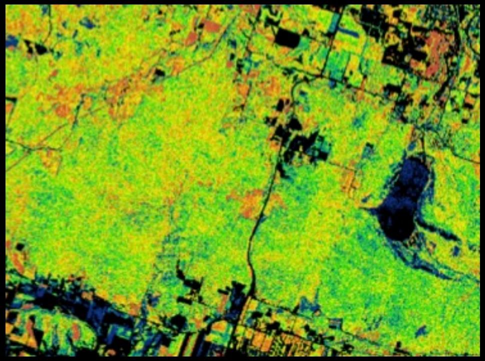
Imaging Spectroscopy

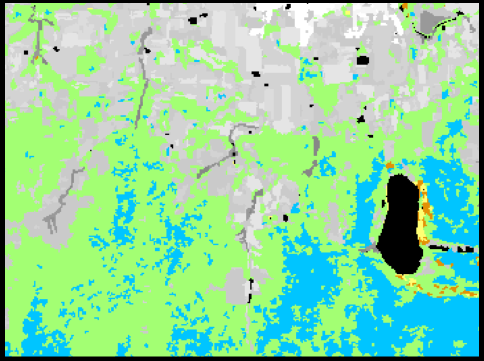
Other



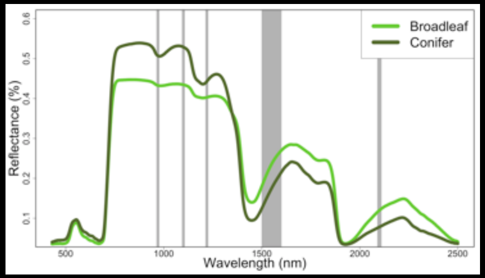


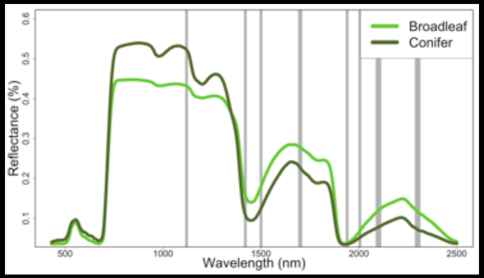
Leaf mass per unit area (LMA):
Describes leaf thickness and is used in models to characterize the metabolic tradeoff between longevity vs. production.





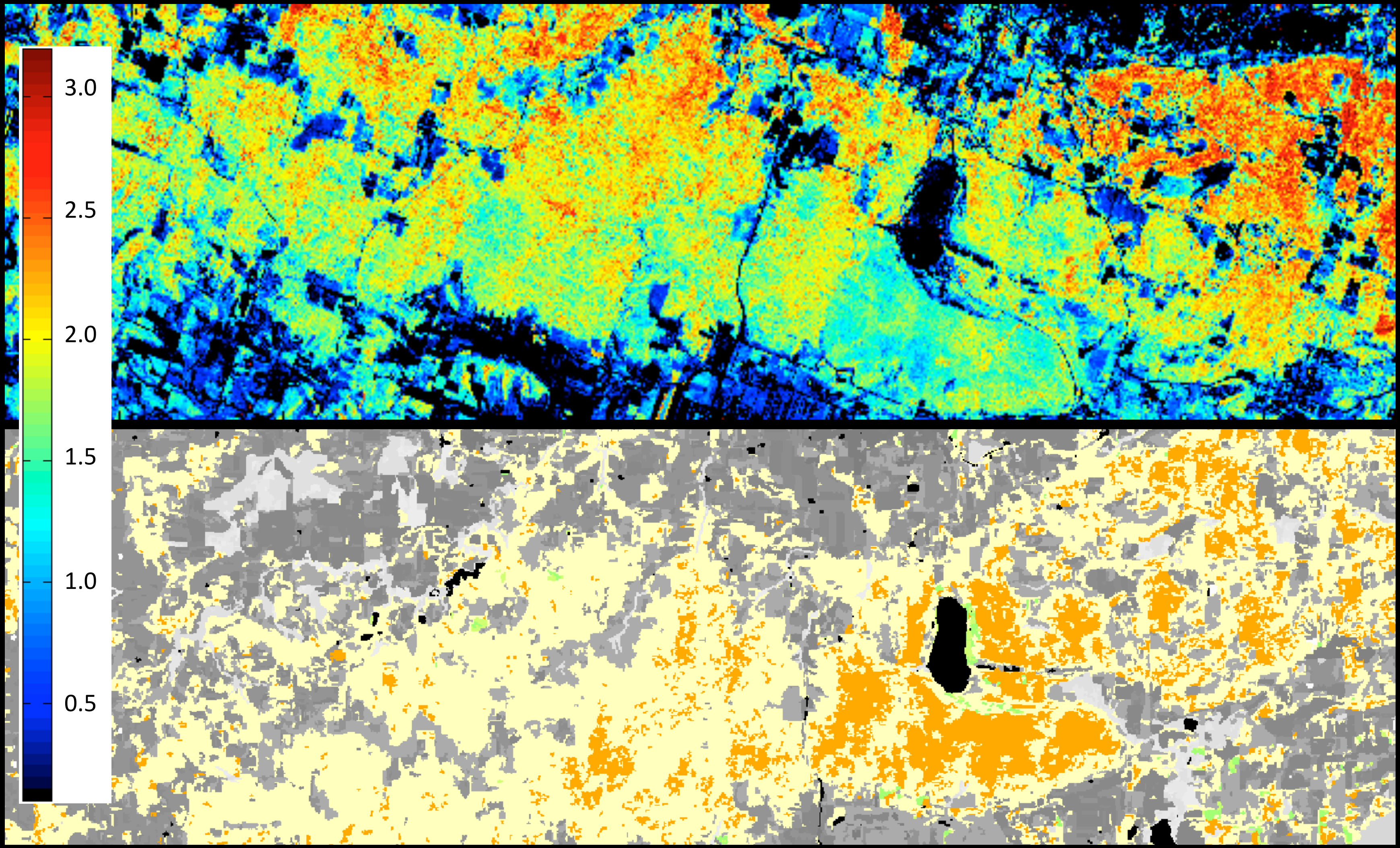
Lignin (also, cellulose):
Between cells and in cell walls. Critical to regulating transport of liquid. Highly recalcitrant and concentration is related to decomposition rates.





Tannins:
Foliar protective compounds.

Light Use Efficiency (gC MJ^{-1})



Leaf Economics

82%

allocation of resources

Leaf Mass per Area

Photosynthetic Assimilation Rate
% Nitrogen (by mass)

Leaf Longevity

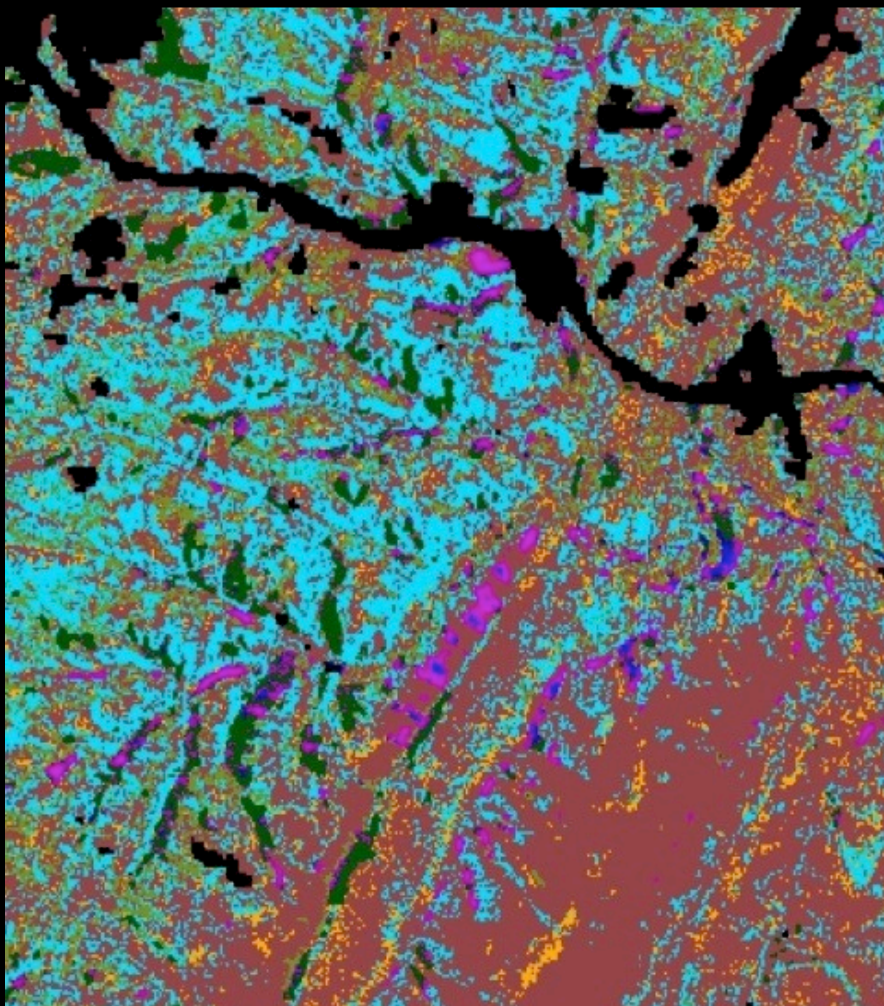
% Phosphorus (by mass)
Dark Respiration

‘Expensive compounds’
(e.g., lignin, lipids)
Stress tolerant

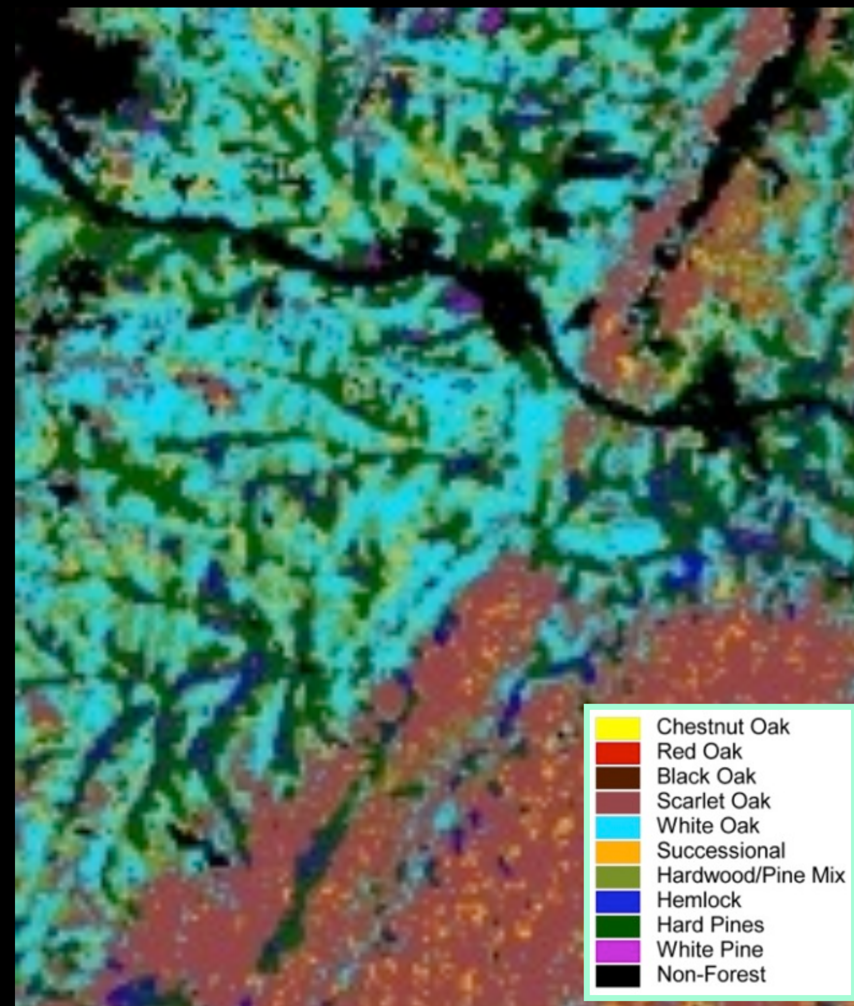
‘Cheap minerals’
(e.g., nutrients)
Fast(er) growing

Plants invest in the construction of leaves, which return a ‘revenue stream’ of photosynthate over their lifetimes (Wright et al 2004).

Species composition

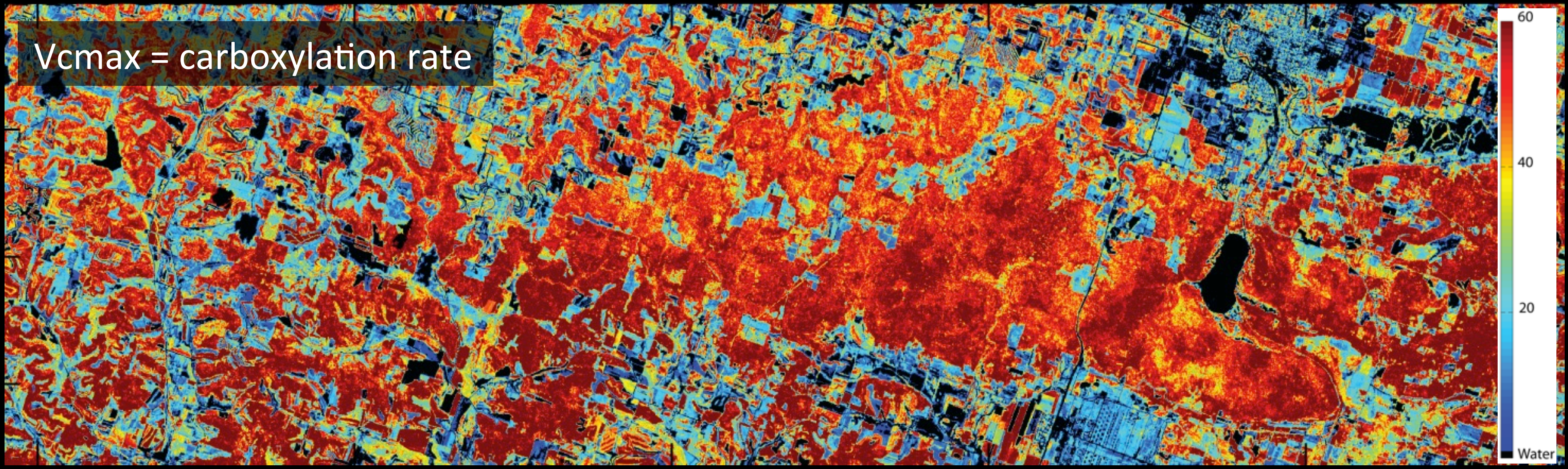


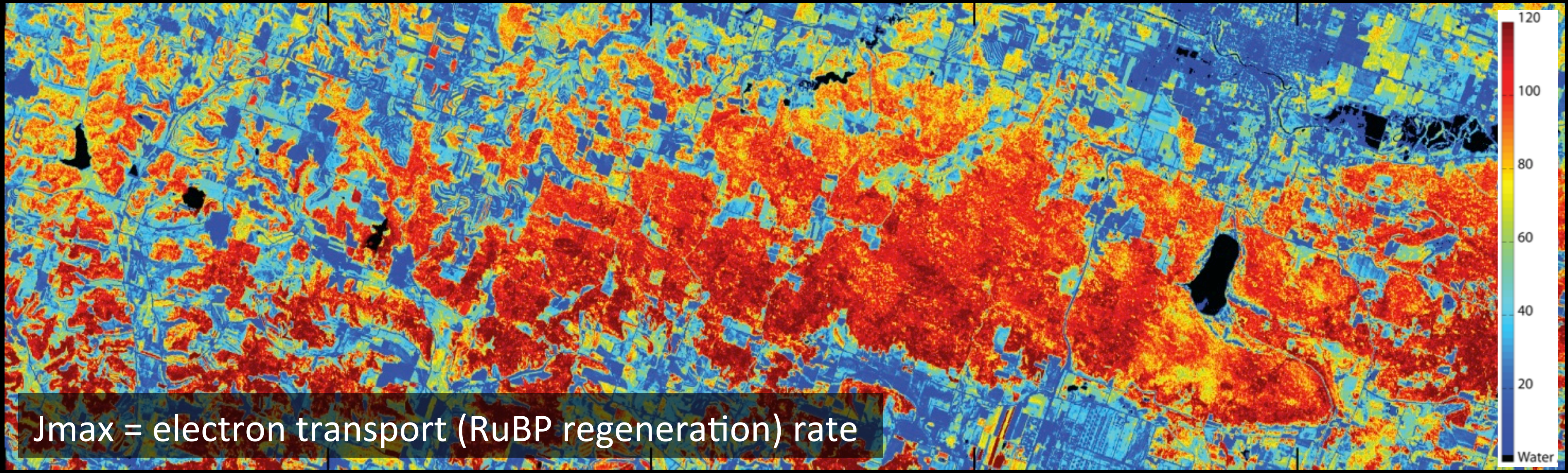
AVIRIS 82% accuracy



LANDSAT 65% accuracy

CO_2 Assimilation: Vcmax and Jmax

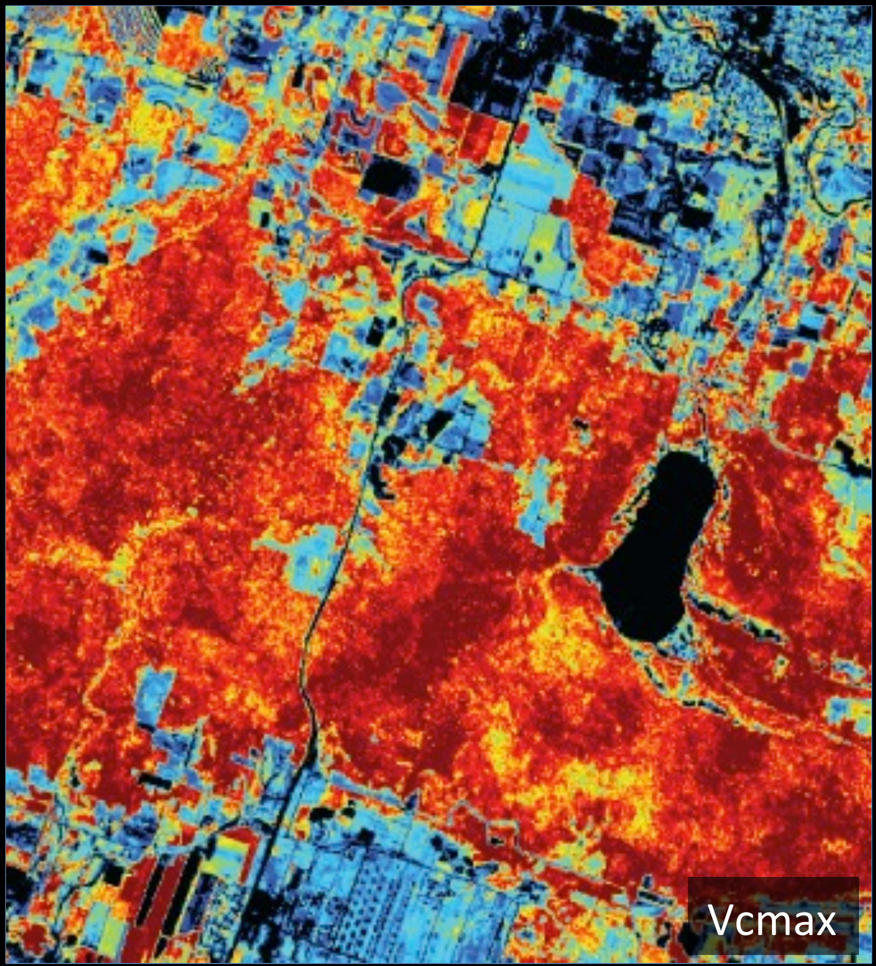




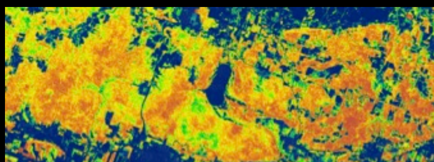
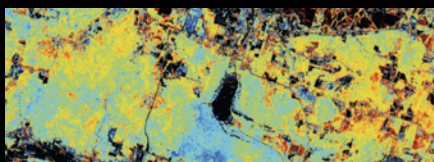
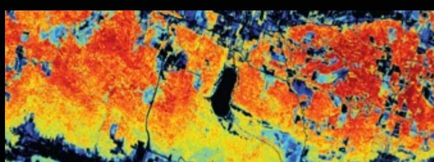
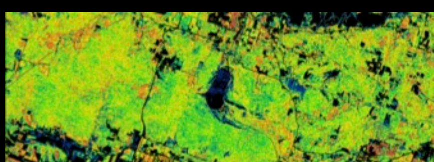
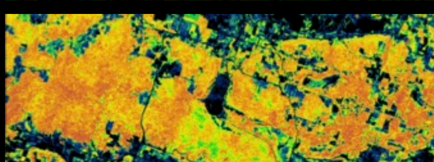
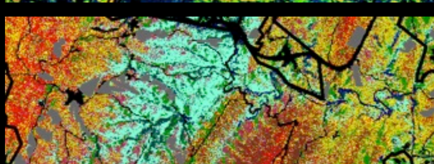
Why concurrent thermal infrared imagery?

Because photosynthesis is a temperature-mediated chemical reaction.

Thermal context to retrievals:

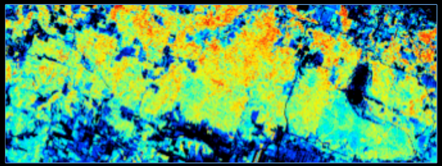


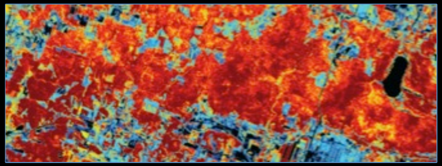
Imaging spectroscopy provides to ecosystem models:

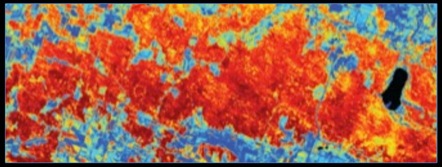
	Measurement	HyspIRI	Current Approach
	Chlorophyll Concentration *Measures photosynthetic capacity (light reactions)*	Direct estimate	Less precision
	Nitrogen Concentration *Measures photosynthetic capacity (light-independent reactions)*	Direct estimate	Lookup table
	LMA *Leaf allocation of resources*	Direct estimate	Lookup table
	Lignin/cellulose *Decomposition*	Direct estimate	Lookup table
	PRI *Measure of photosynthetic down-regulation and plant stress*	Direct calculation	N/A
	Species Composition *Plant functional type distribution*	SMA, CART, LDA	Inferred

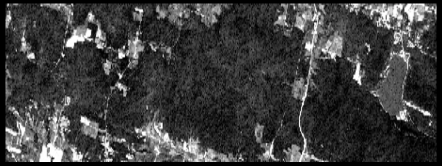
HyspIRI may also provide:

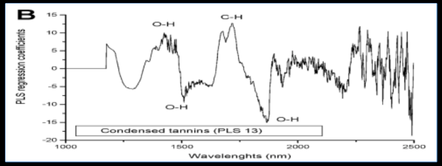
Measurement	HyspIRI	Current Approach
Light-use Efficiency *Measure of carbon dioxide uptake*	%N*LMA	Modeled
Vcmax *Direct measure of CO_2 uptake at a given temperature*	Direct estimate	Modeled
Jmax *Direct measure or RuBP regeneration at a given tempertature*	Direct estimate	Modeled
Skin temperature *Temperature drives photosynthetic rates*	Direct retrieval	N/A
Tannin concentration *Leaf defensive chemistry*	Direct estimate	N/A







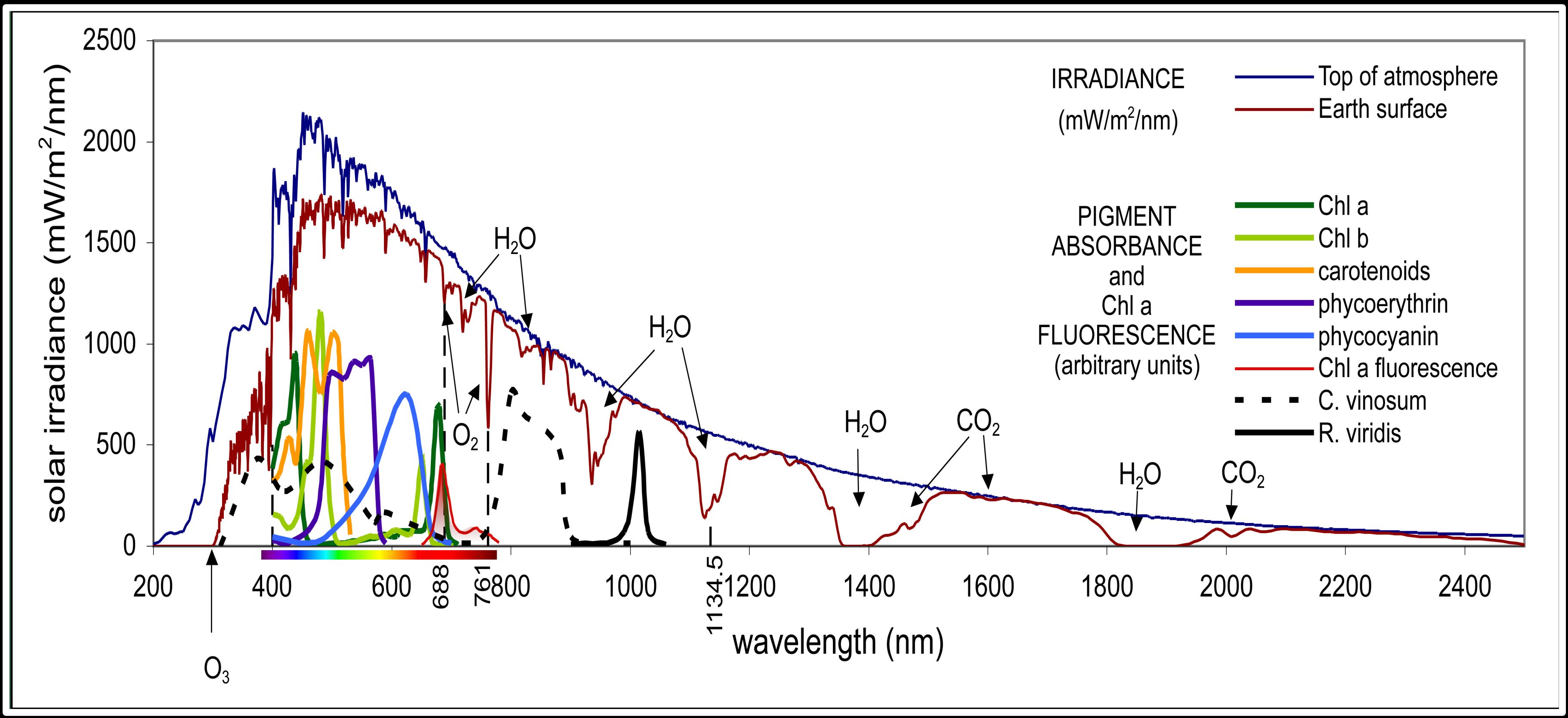




Co-authors: Shawn Serbin, Aditya Singh, Clayton Kingdon

Questions?

Plant Biology and Radiation



By: Nancy Kiang (NASA GISS) and Govindjee (UIUC)