Plant Photosynthetic Mechanism:
The Theoretical and Empirical Basis for Imaging Spectroscopy
This is photosynthesis:

\[ 6H_2O + 6CO_2 + \text{Light} \rightarrow C_6H_{12}O_6 + 6O_2 \]
This is photosynthesis:

\[
6\text{H}_2\text{O} + 6\text{CO}_2 \text{– Light} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2
\]
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.

\[
2 \text{H}_2\text{O} + 2 \text{NADP}^+ + 3 \text{ADP} + 3 \text{P}_i + \text{light} \rightarrow 2 \text{NADPH} + 2 \text{H}^+ + 3 \text{ATP} + \text{O}_2
\]
Light-Independent Reactions:
The Calvin Cycle

Carboxylation
Needed: Rubisco

Needed:
NADPH and ATP
(products of light reactions)

\[3 \text{CO}_2 + 9 \text{ATP} + 6 \text{NADPH} + 6 \text{H}^+ \rightarrow \text{C}_3\text{H}_6\text{O}_3\text{-phosphate} + 9 \text{ADP} + 8 \text{P}_i + 6 \text{NADP}^+ + 3 \text{H}_2\text{O}\]
How photosynthesis is modeled: (temperature dependent)
CO$_2$ Uptake

**Calvin Cycle**

1. **Phase 1:** Carbon Fixation
   - CO$_2$ + RuBP $\rightarrow$ PGA

2. **Phase 2:** Triose-P Production (Reduction)
   - PGA + NADPH + ATP $\rightarrow$ 3 triose-P + NADP + ADP + Pi

3. **Phase 3:** Regeneration of RuBP
   - 3 triose-P $\rightarrow$ RuBP + ADP + Pi

**Central metabolic pathways**

**ATP**
- ATP is used in Phase 1 for carbon fixation.
- ATP is produced in Phase 2 during triose-P production.

**ADP**
- ADP is produced during the regeneration of RuBP in Phase 3.

**NADPH**
- NADPH is used in Phase 2 for the reduction of triose-P.

**NADP**
- NADP is produced in Phase 2 during the reduction of triose-P.
How photosynthesis is modeled:
(temperature dependent)

\[ A_n = \min(A_c, A_j, A_p) - R_d \]
CO₂ Uptake

Phase 1: Carbon Fixation
- CO₂ + RuBP → PGA
- ATP regeneration

Phase 2: Triose-P Production (Reduction)
- PGA + NADPH + H⁺ → triose-P
- ATP consumption

Phase 3: Regeneration of RuBP
- triose-P + ATP → RuBP
- NADP reduction

Central metabolic pathways
- ADP + P_i → ATP
- NADPH → NADP

ATP, ADP, RuBP, PGA, triose-P, NADPH, NADP
How photosynthesis is modeled:
(temperature dependent)

\[ A_n = \min(A_c, A_j, A_p) - R_d \]
What ecosystem models need?

\[ A_n = \min(A_c, A_j, A_p) - R_d \]
Why imaging spectroscopy?
Chlorophyll and other pigments perform light harvesting activities.

[Diagram showing the absorption spectrum of chlorophyll a, chlorophyll b, and carotenoids across different wavelengths.]
Chemical bonds in the leaf

- Stretching
- Bending/Twisting
We can measure pigment concentration.
Carotenoids, photosynthetic down-regulation and PRI
Nitrogen: in part, think “Rubisco”
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\(^{-1}\))
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: $V_{cmax}$ and $J_{max}$

$V_{cmax} = \text{carboxylation rate}$

$J_{max} = \text{electron transport (RuBP regeneration) rate}$
Why concurrent thermal infrared imagery?

Because photosynthesis is a temperature-mediated chemical reaction.
Thermal context to retrievals:
Imaging spectroscopy provides to ecosystem models:

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

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<tr>
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</thead>
<tbody>
<tr>
<td>Light-use Efficiency</td>
<td>%N*LMA</td>
<td>Modeled</td>
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<tr>
<td><strong>Measure of carbon dioxide uptake</strong></td>
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<tr>
<td>Vcmax</td>
<td>Direct estimate</td>
<td>Modeled</td>
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<tr>
<td><strong>Direct measure of CO₂ uptake at a given temperature</strong></td>
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<tr>
<td>Jmax</td>
<td>Direct estimate</td>
<td>Modeled</td>
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<tr>
<td><strong>Direct measure or RuBP regeneration at a given temperature</strong></td>
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<tr>
<td>Skin temperature</td>
<td>Direct retrieval</td>
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<td><strong>Temperature drives photosynthetic rates</strong></td>
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<tr>
<td>Tannin concentration</td>
<td>Direct estimate</td>
<td>N/A</td>
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<tr>
<td><strong>Leaf defensive chemistry</strong></td>
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Questions?
Plant Biology and Radiation

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