Leaf-level Gas Exchange Instrument theory

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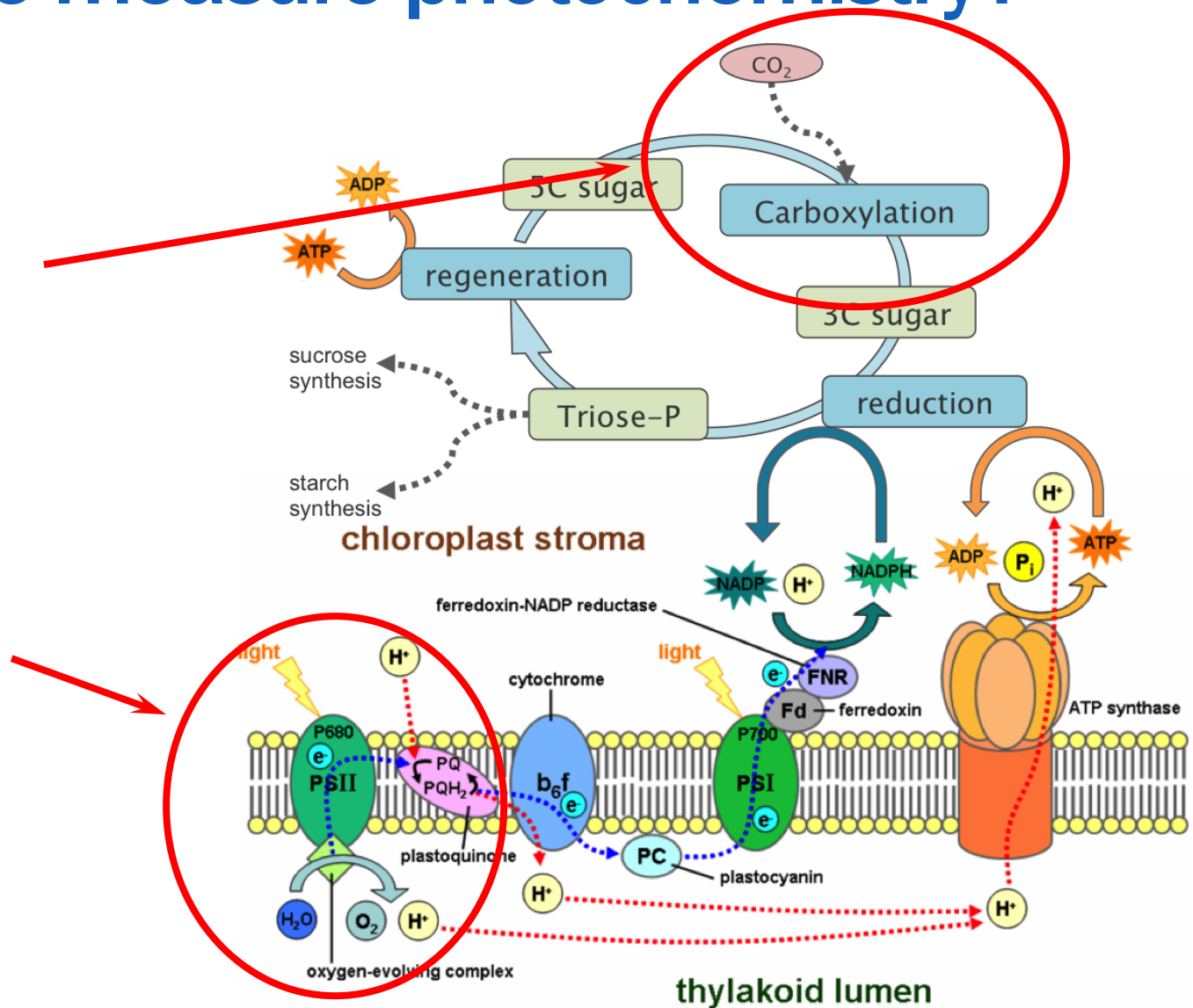# How do we measure photosynthesis?

- Photosynthesis

- Gas exchange

- Assimilation
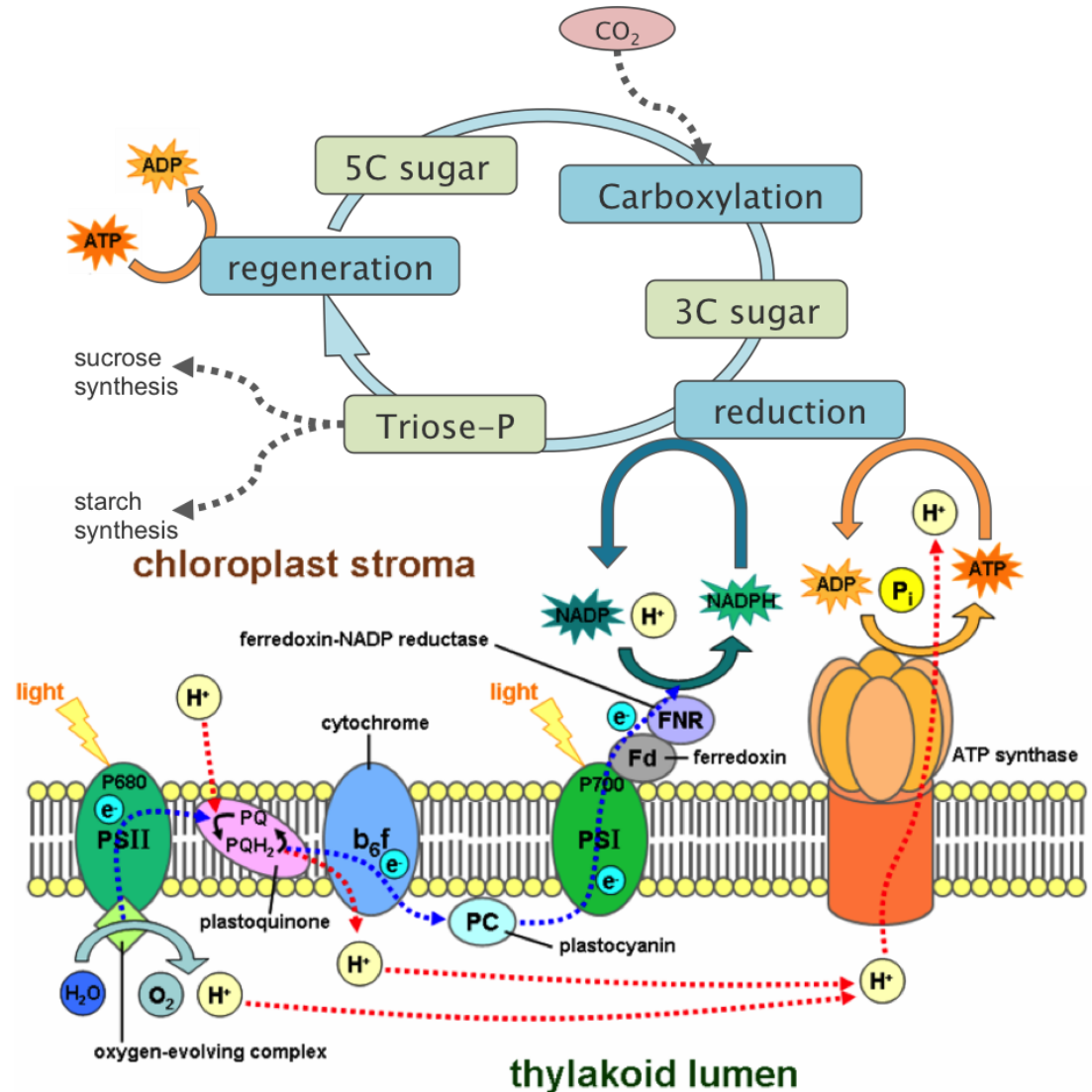
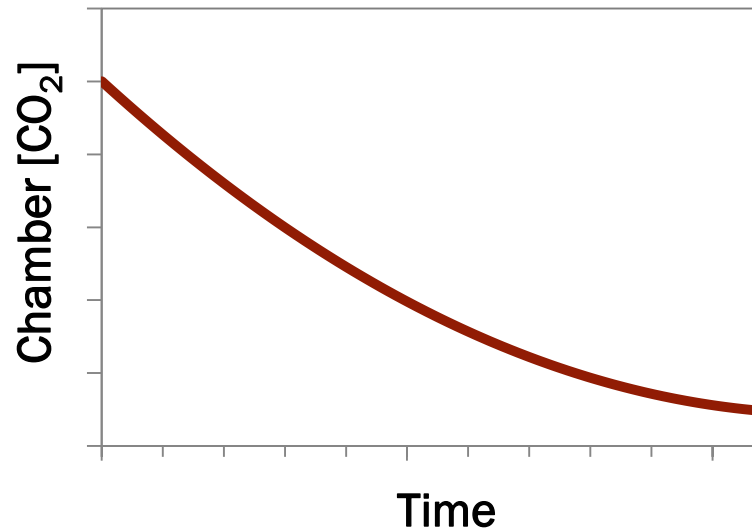# How do we measure photochemistry?

Gas exchange

Chlorophyll Fluorescence

Gas exchange systems

- Closed-transient
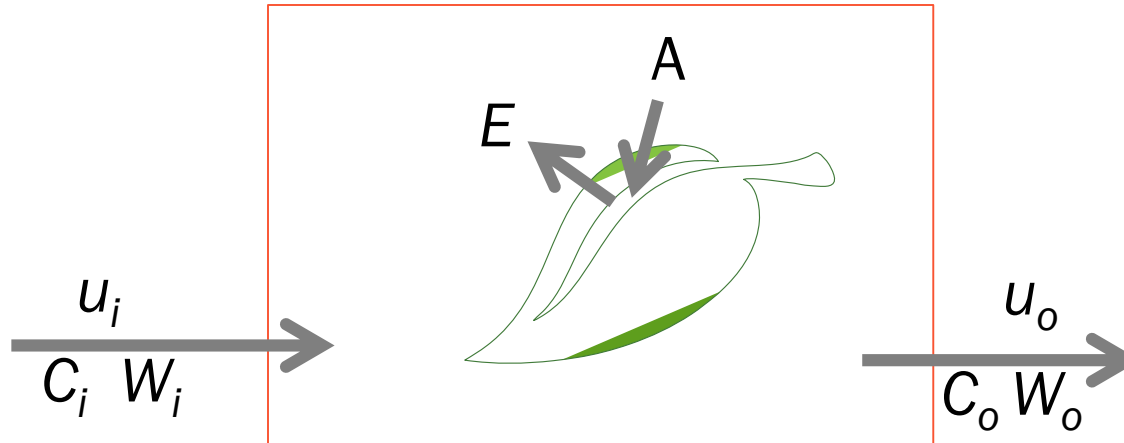- Compensating

Gas exchange systems

- Closed-transient
- Compensating
- Open flow through

Key physiological parameters *computed*

- Fluxes from mass balance
  - A – CO_2 Assimilation rate
  - E – Transpiration rate
- Calculated parameters
  - g_{sw} – Stomatal conductance to H_2O
  - C_i – Intercellular CO_2 concentration

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Mass balance in an open system

$$E = \frac{u_o W_o - u_i W_i}{S}$$

$$A = \frac{u_i C_i - u_o C_o}{S}$$

- S leaf area
- E transpiration
- u flow rate
- W concentration of water vapor
- A carbon assimilation
- C concentration of CO_2

Mass balance in an open system

$$E \gg \frac{u\left(W_o - W_i\right)}{s}$$

$$\approx \text{mol s}^{-1}(\text{mmol mol}^{-1})/\text{m}^2$$

$$\approx \text{mmol m}^{-2}\,\text{s}^{-1}$$

$$A \gg \frac{u\left(C_i - C_o\right)}{s}$$

$$\approx \text{mol s}^{-1}\,(\mu\text{mol mol}^{-1})/\text{m}^2$$

$$\approx \mu\text{mol m}^{-2}\,\text{s}^{-1}$$

Accounting for dilution

$$A = \frac{F\left(C_r - C_s\left(\dfrac{1000 - W_r}{1000 - W_s}\right)\right)}{100 S}$$

r denotes *reference* concentration, same as incoming
s denotes *sample* concentration, same as outgoing

More on water corrections…

- Explains basis of broadening and effective pressure
- Derive dilution corrections
- How IRGAs work

What else can we determine with gas exchange?
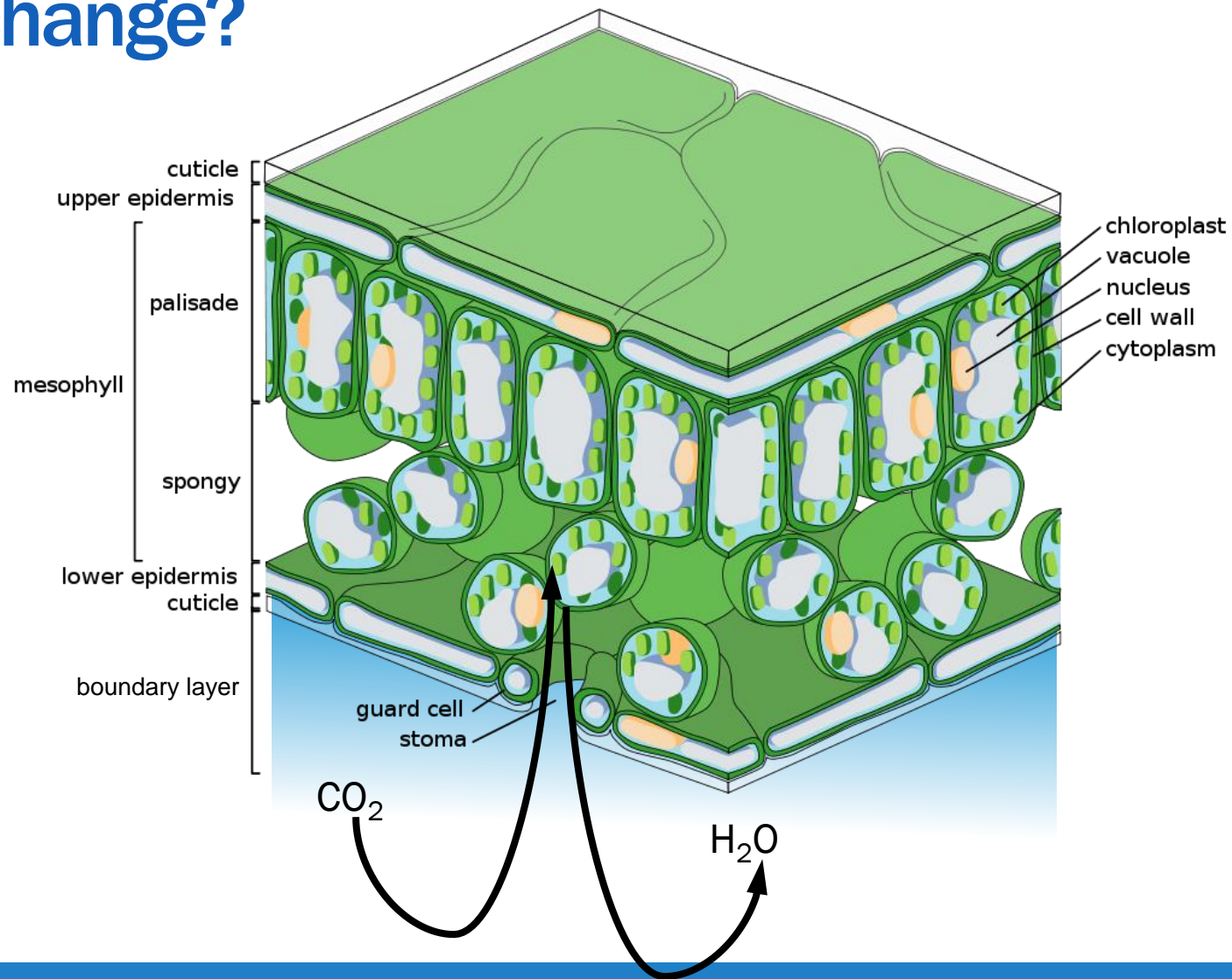
What else can we determine with gas exchange?

- Fick's First Law

$$J_j = -D_j \frac{\partial c_j}{\partial x} = g_j \Delta c_j$$

J_i = flux
D_j = diffusivity coefficient
$\delta c_i/\delta x$ = change in concentration
g_j = conductance
Δc_j = concentration gradient

What else can we determine with gas exchange?

$$E \approx g_{total}^{H_2O}(W_i - W_a)$$

$$A \approx g_{total}^{CO_2}(C_a - C_i)$$

- Measure E & w_a ($w_a = W_s$)
- Measure leaf temperature
- Calculate W_i
- Solve for $g_{total}^{H_2O}$

- Measure A & c_a ($c_a = C_s$)
- $g^{CO2} = g^{H2O}/1.6$
- Solve for c_i

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What else can we determine with gas exchange?

Ohm's Law Analogy

$$r_{total} = r_{bl} + \left(\frac{1}{r_s} + \frac{1}{r_c} \right)^{-1} + r_{mes}$$

Assumptions:
- end point of diffusion path is mesophyll surface
- cuticular resistance is near infinite

$$r_{total} \gg r_{bl} + r_s$$

guard cell

stoma

Boundary layer

v

s^{bl}

l
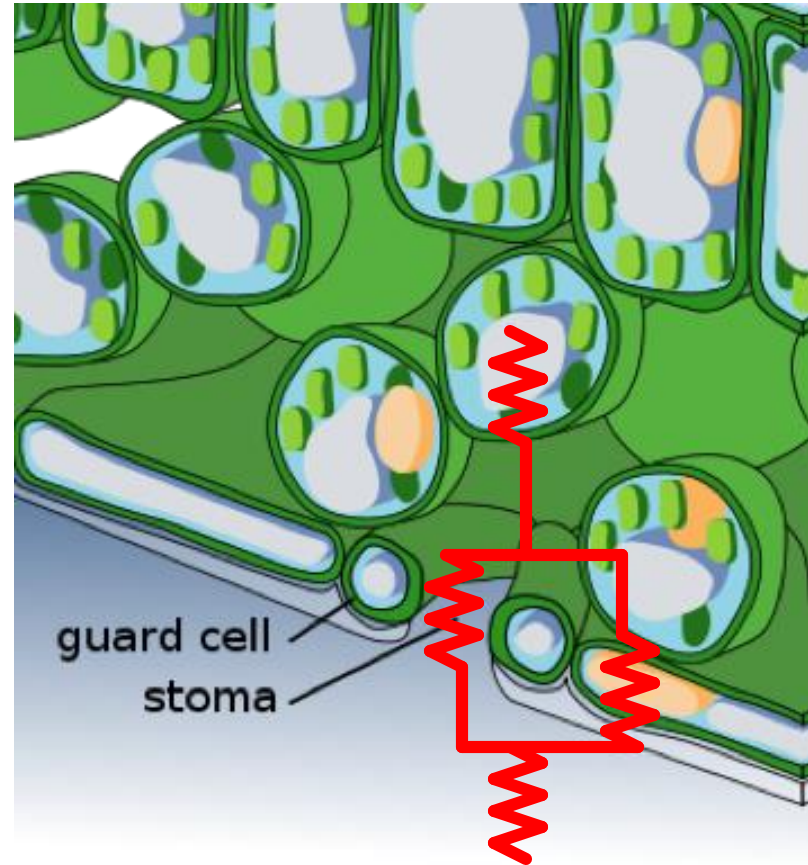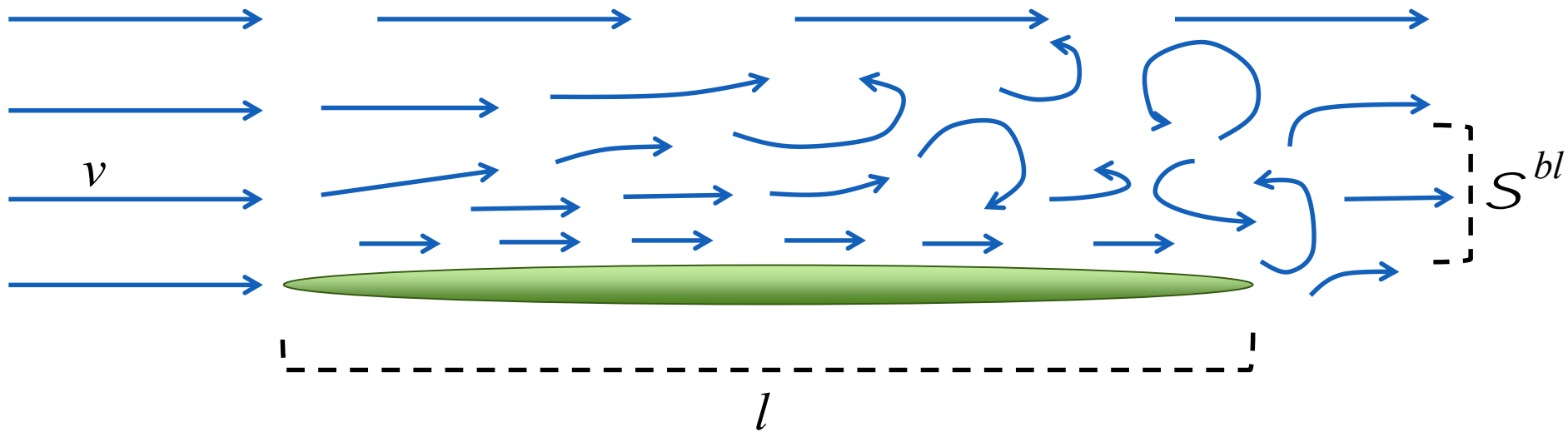
$$s^{bl} = 4\sqrt{\frac{l}{v}}$$

σ^{bl} = boundary layer thickness
v = air velocity
l = leaf width

Boundary layer conditions

At saturation

Boundary layer

near saturation

near ambient

Turbulent air

ambient

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Boundary layer conditions

At saturation

near saturation

near ambient

ambient

Boundary layer

Turbulent air

At saturation

chamber

Turbulent air

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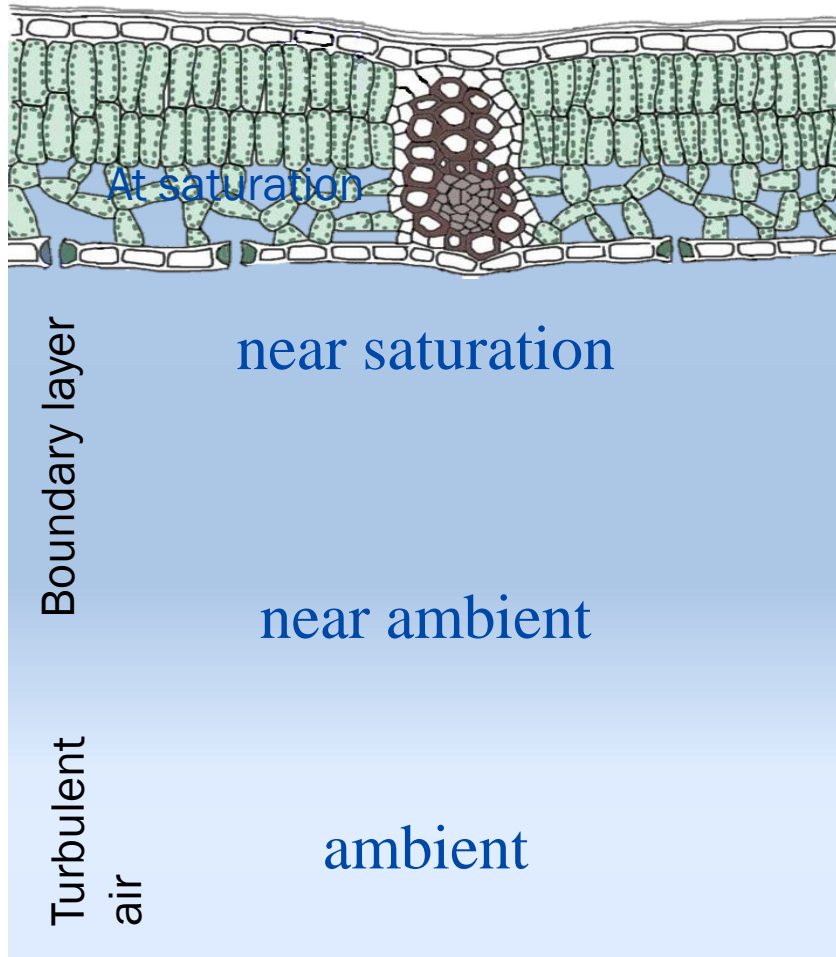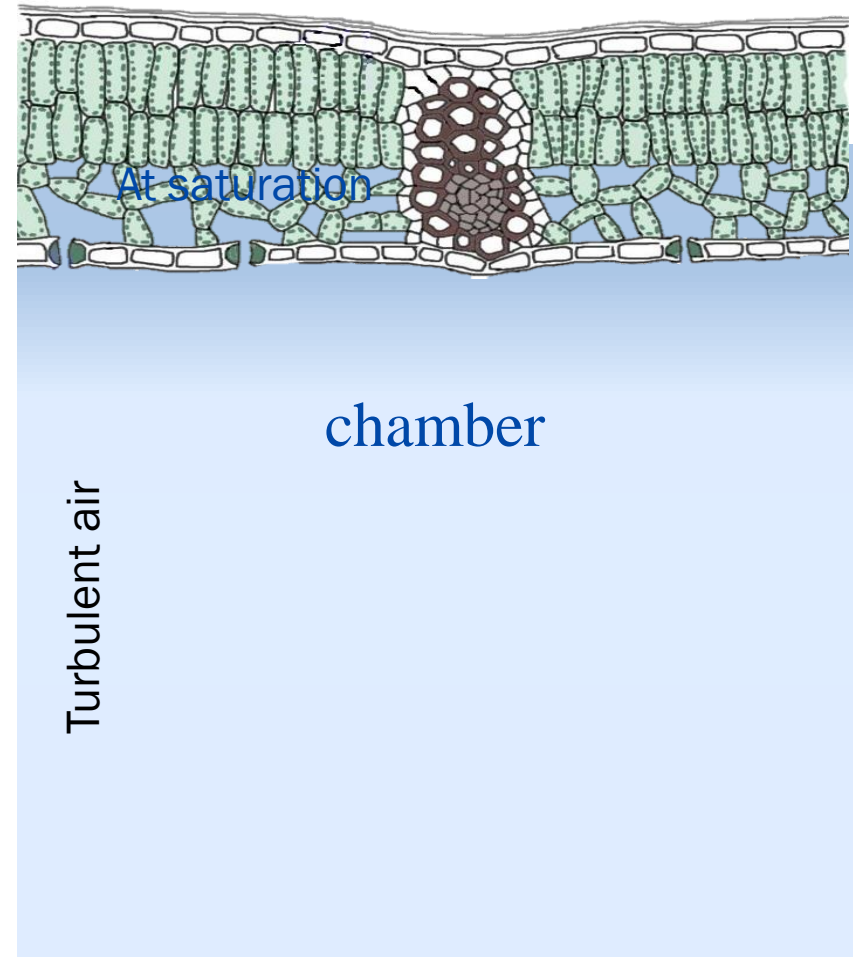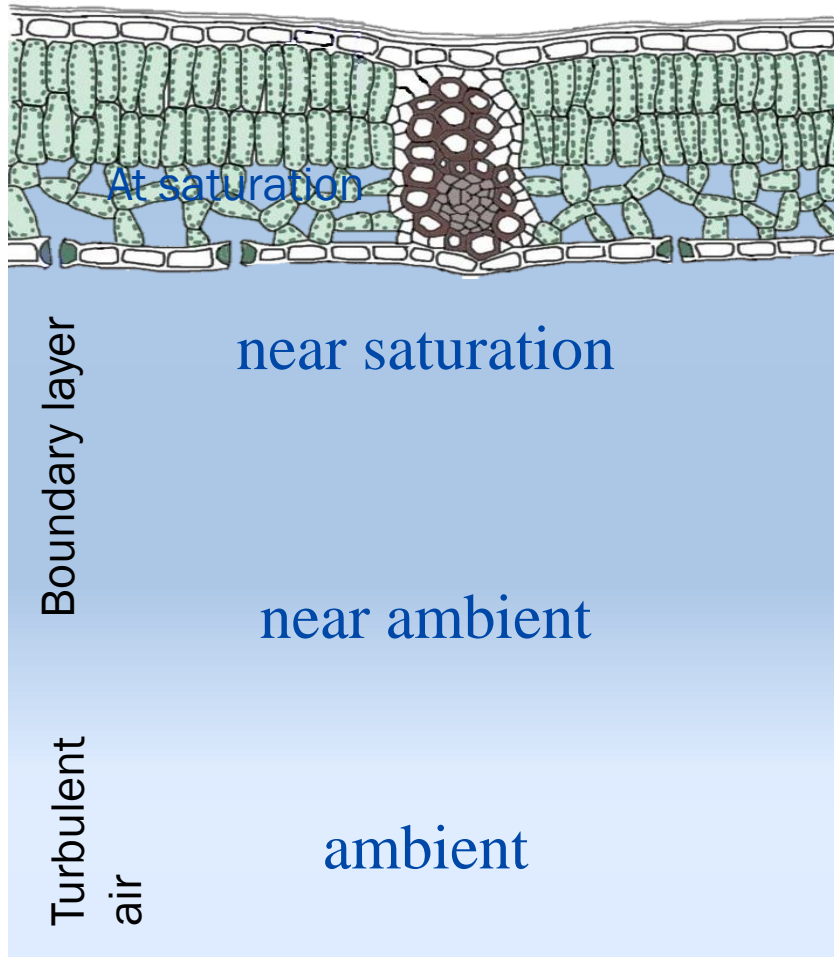
What does this mean for interpreting the data?

- E = Real count of H_2O molecules leaving the leaf

$$g_s = \frac{E}{(w_i - w_a)}$$
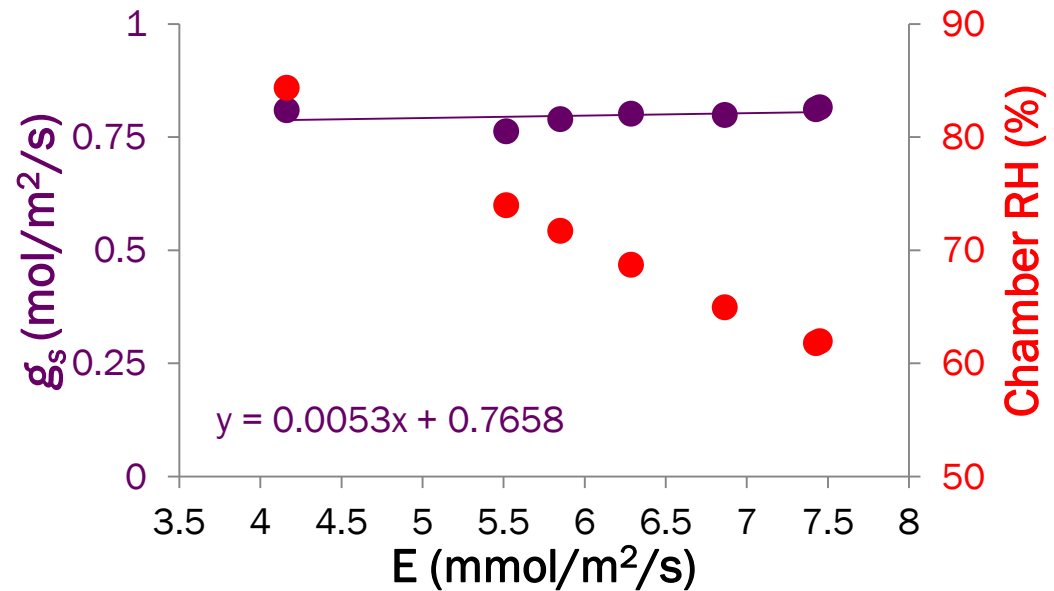
y = 0.0053x + 0.7658

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Key physiological parameters *computed*

- Fluxes from mass balance
  - A – CO_2 Assimilation rate
  - E – Transpiration rate
- Calculated parameters
  - g_{sw} – Stomatal conductance to H_2O
  - C_i – Intercellular CO_2 concentration

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Two LI-COR Systems

LI-600

LI-6800

H_2O CO_2 - LI-6800
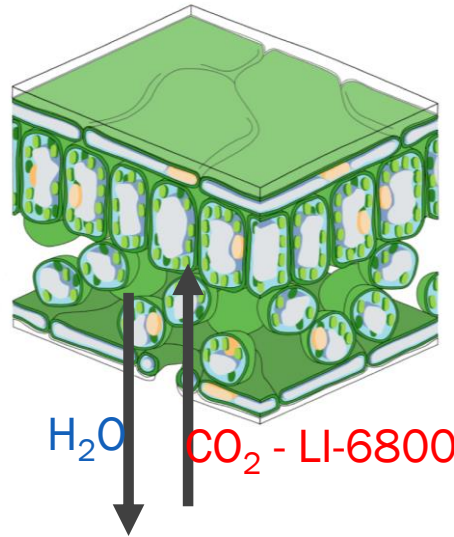
- ## H_2O only
  - ### Porometer (g_{sw})
- ## Ambient Conditions
- ## Rapid Survey
  - ### (5-10 seconds)

- ## H_2O and CO_2
  - ### A, E, C_i, g_{sw}
- ## Environmental Control
  - ### Light, Temp, CO_2, H_2O
- ## Response Curve or Survey

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LI-6800 Environmental Control

- LI-6800:
  - H_2O control
  - CO_2 control
  - Temperature control
  - Light control
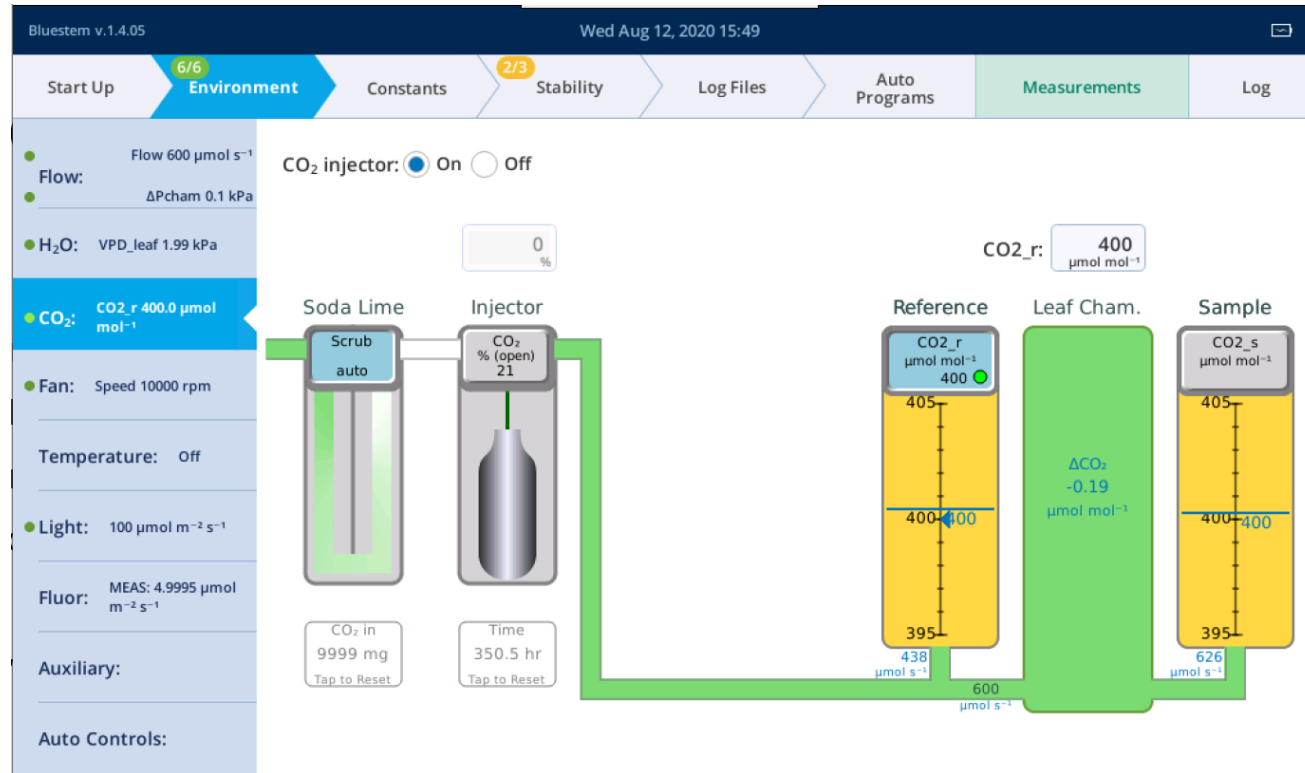
Measurements fall in two categories

- Response Curve – user-set conditions
  - CO_2
  - Light
  - Temperature
  - VPD (Vapor Pressure Difference)
- Survey
  - *In situ* picture under ambient conditions

CO$_2$ Response Curve

V_{Cmax} = 141.42 ± 0.846 r^2 = 0.9999 J_{max} = 203.27 ± 0.819 r^2 = 0.9788

C_i @ inflection = 216 l @ growth [CO$_2$] = 0.05

modeled A$_{Vcmax lim}$ vs. C$_i$

modeled A$_{Jmax lim}$ vs. C$_i$

measured A vs. C$_i$

Photosynthetic Assimilation (μmol$_{CO_2}$ m$^{-2}_{leaf area}$ s^{-1})

Intercellular [CO$_2$] (μmol$_{CO_2}$ mol$^{-1}_{air}$)
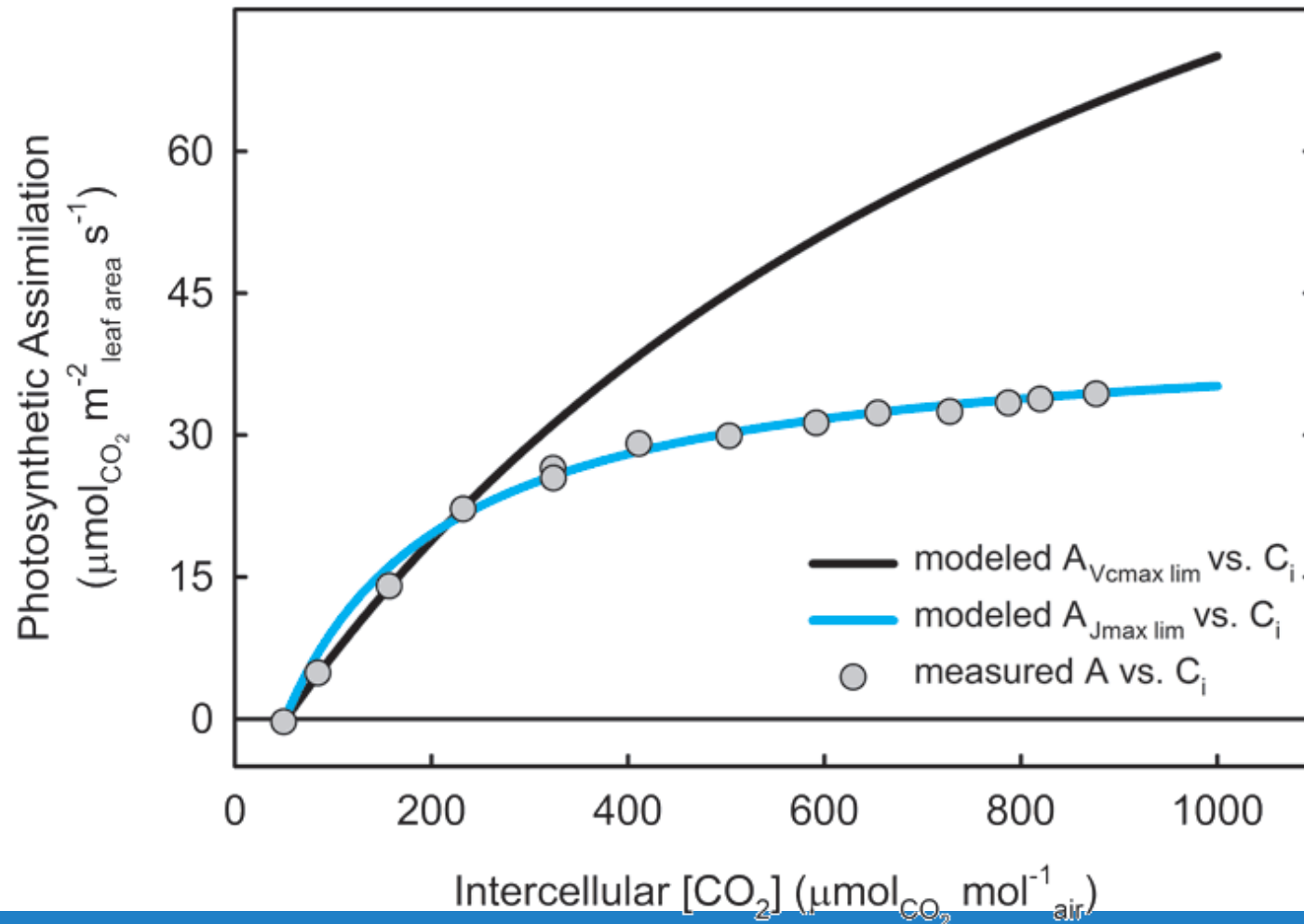
Light Response Curve

A_{sat} = 34.28 ± 0.778 r^2 = 0.9995
R_d = -1.492 ± 0.117
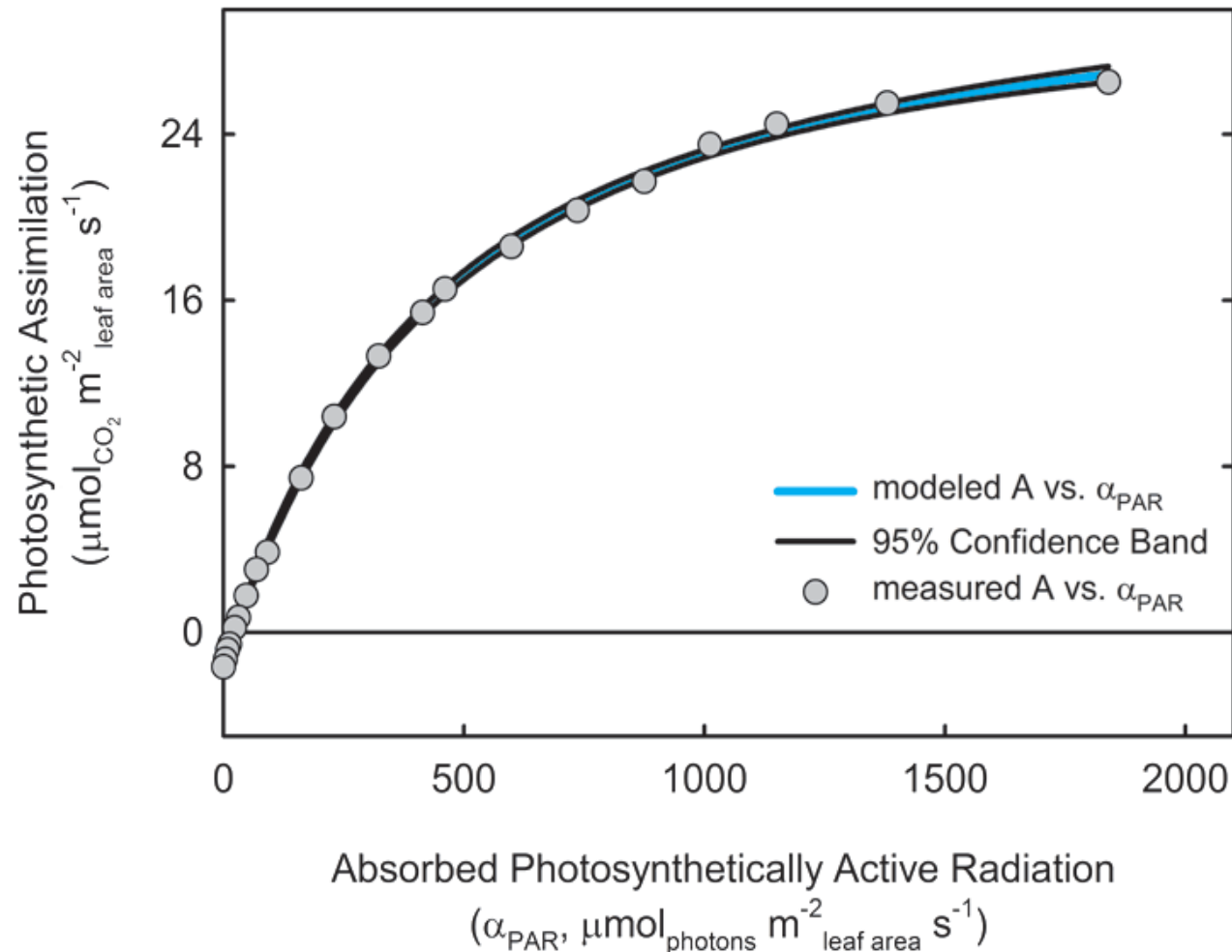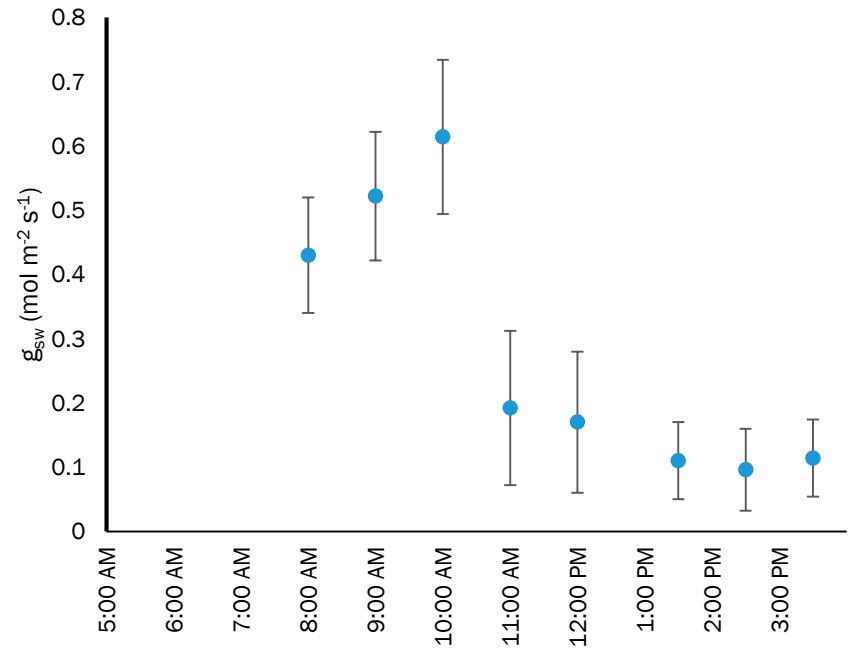

- A_{sat} – photosynthesis at saturating light
- R_d – Dark respiration rate
- LCP - Light compensation point
- φ – Quantum yield

Survey measurements

- Rapid Screening

- Ambient Conditions   Pac Choi, n = 26 leaves

Two LI-COR Systems

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- Ambient conditions
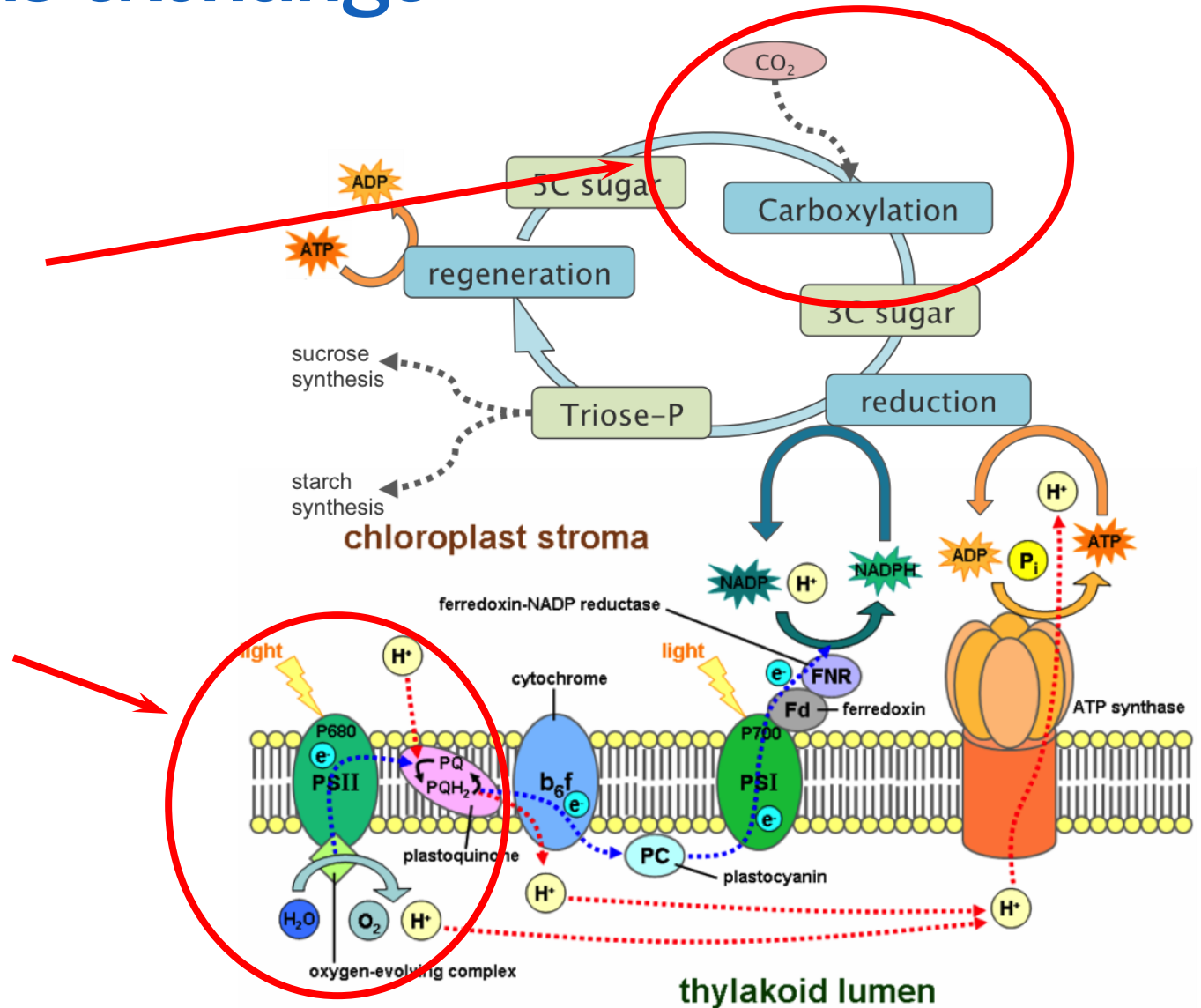 - H_2O flux – Steady state
- Survey Measurements

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- Controlled Environment
  - CO_2 and H_2O flux
- Survey and Response Curves

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Beyond gas exchange

Gas exchange

Chlorophyll
Fluorescence

Chlorophyll Fluorescence

- Ambient Actinic Light
- Fv/Fm/ΦPSII
- ETR

- LED Actinic Light
- Fv/Fm/ΦPSII
- ETR
- Far-red (Fo')
- OJIP kinetics

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Two LI-COR Systems – Parameter Set

- g_{sw}, apparent E
- Φ_{PSII}, F_v/F_m, ETR

- A, C_i, J_{max}, $V_{c,max}$
- g_{sw}, apparent E
- Φ_{PSII}, F_v/F_m, ETR, F_o', induction kinetics etc...

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Questions?

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