Drivers and variability of Chl fluorescence emission spectra from the leaf to canopy

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[5]Soil and Crop Sciences, Cornell University
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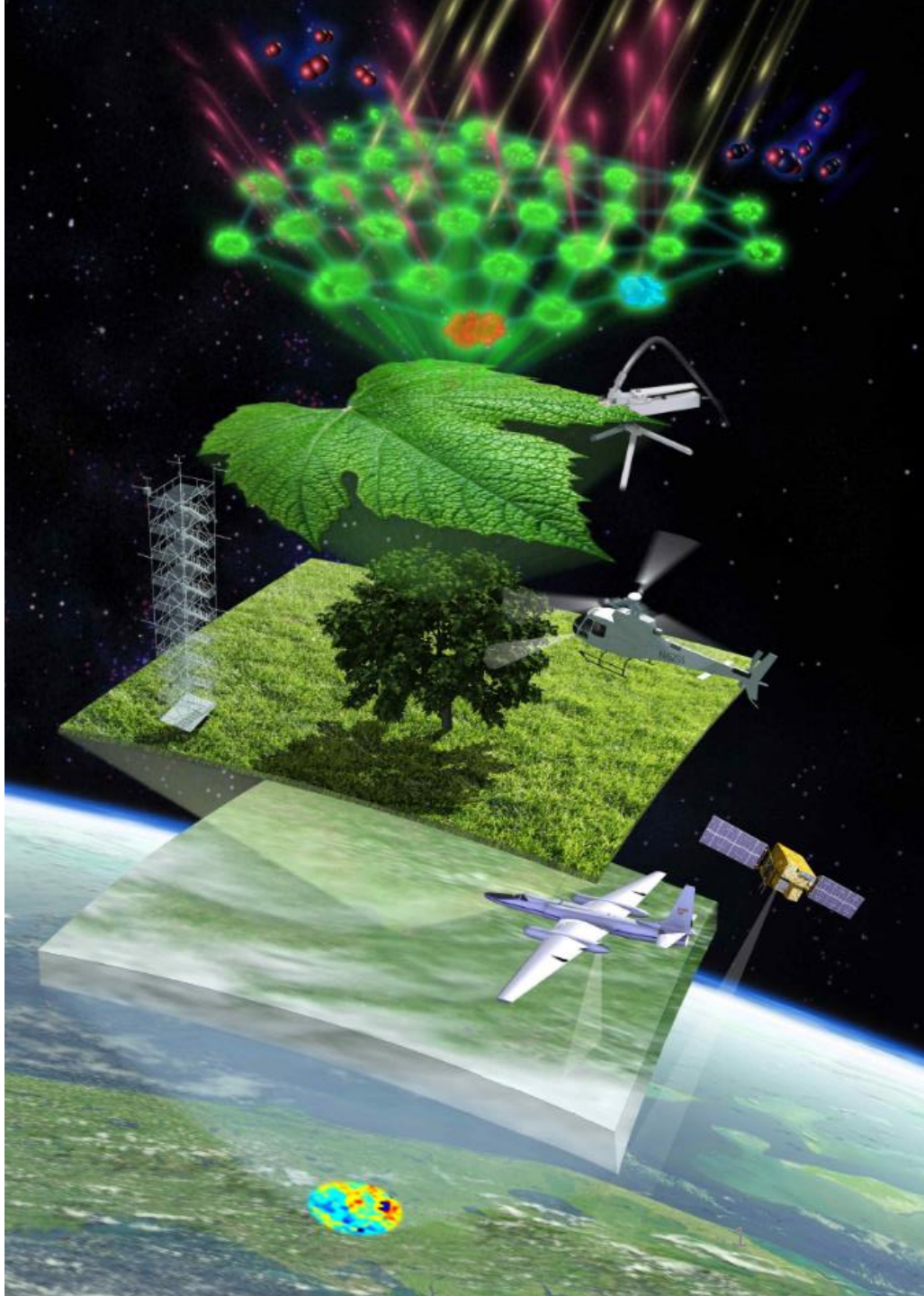

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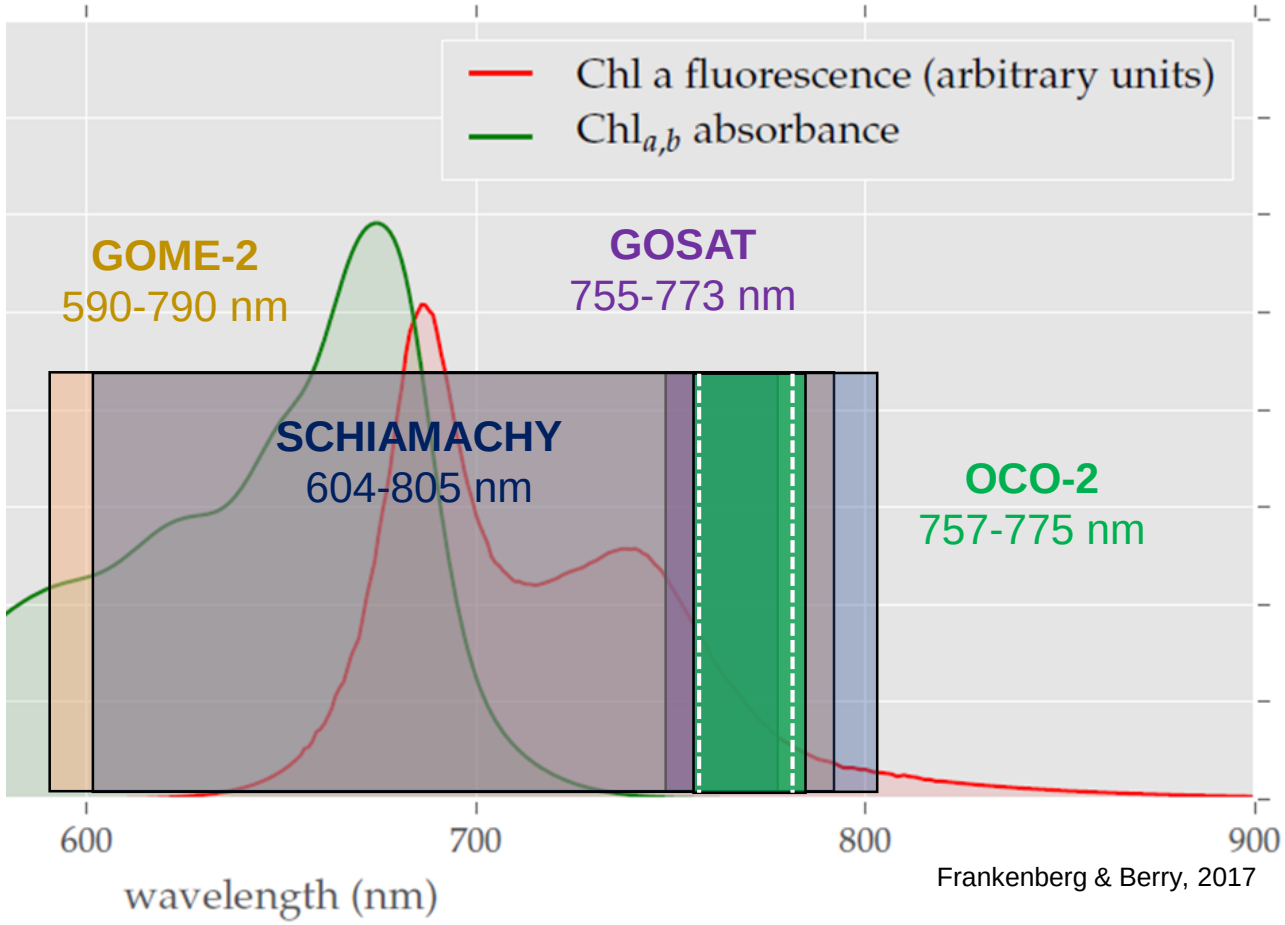


Frankenberg & Berry, 2017

Frankenberg et al., 2011; Joiner et al., 2011; Guanter et al., 2012

Joiner et al., 2013; Guanter et al., 2014; Koehler et al., 2015

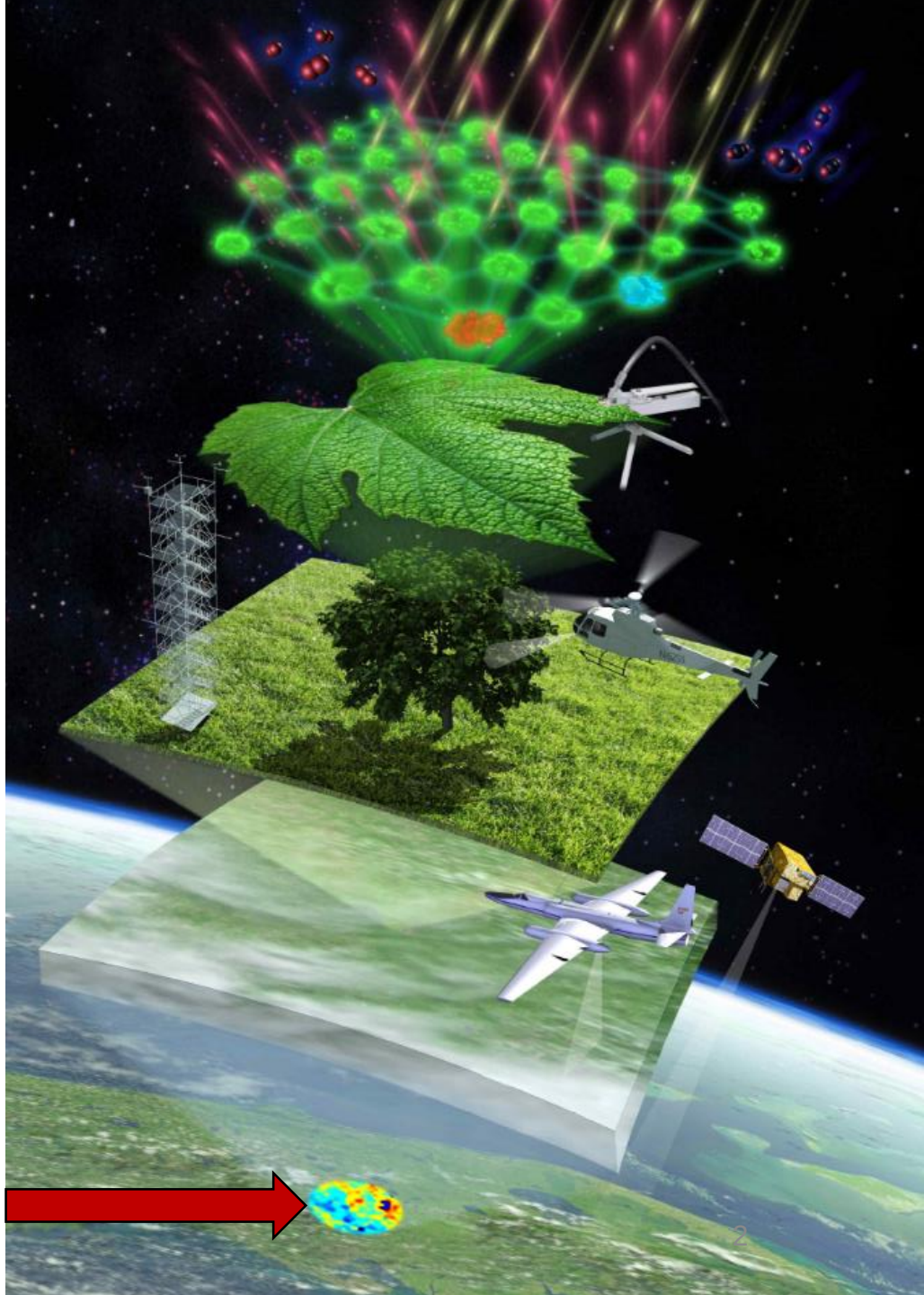
Joiner et al., 2012; Koehler et al., 2015

Frankenberg et al., 2014; Sun et al., 2017

Satellite

-course in space/time

-limited wavelengths



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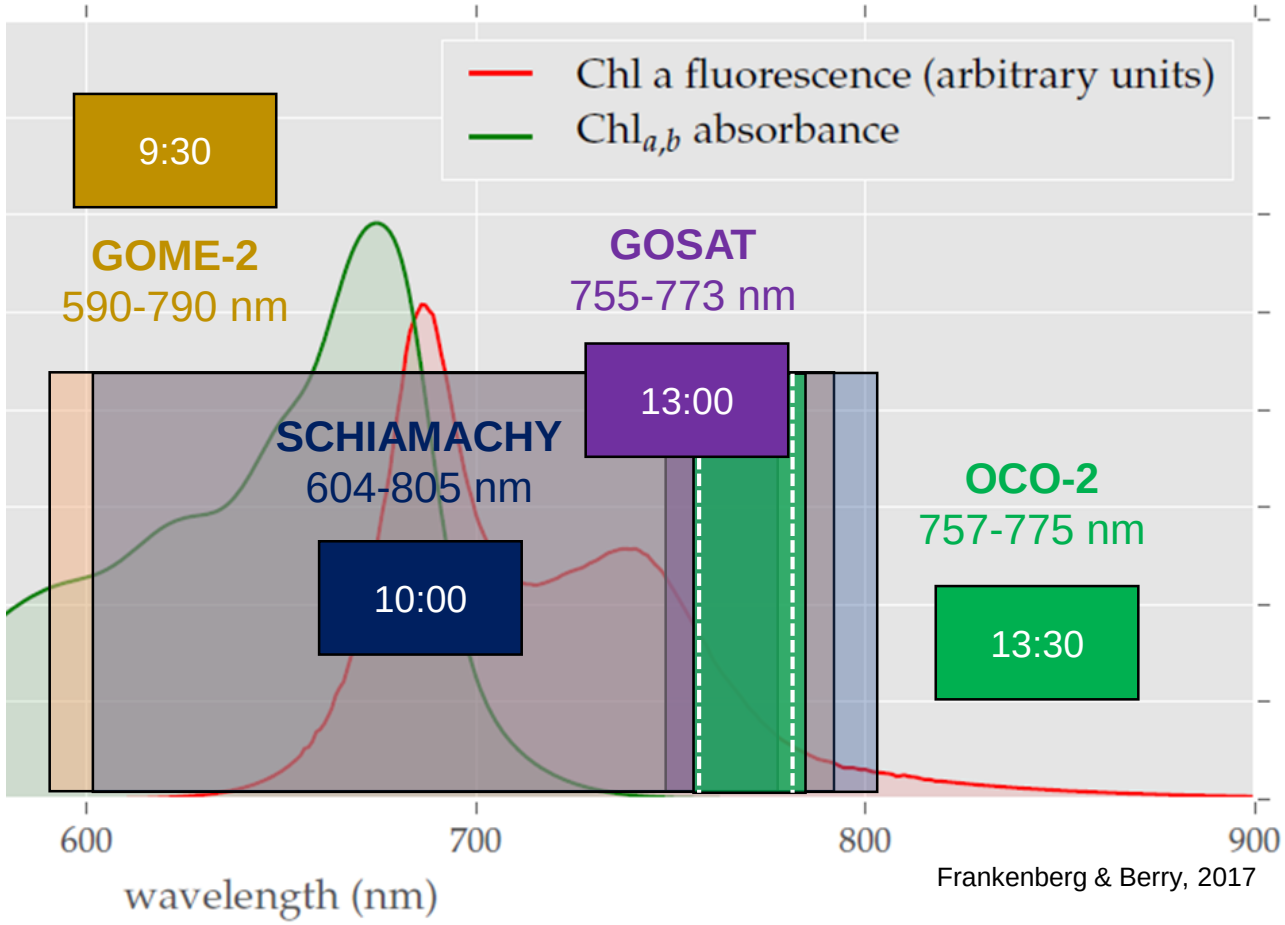
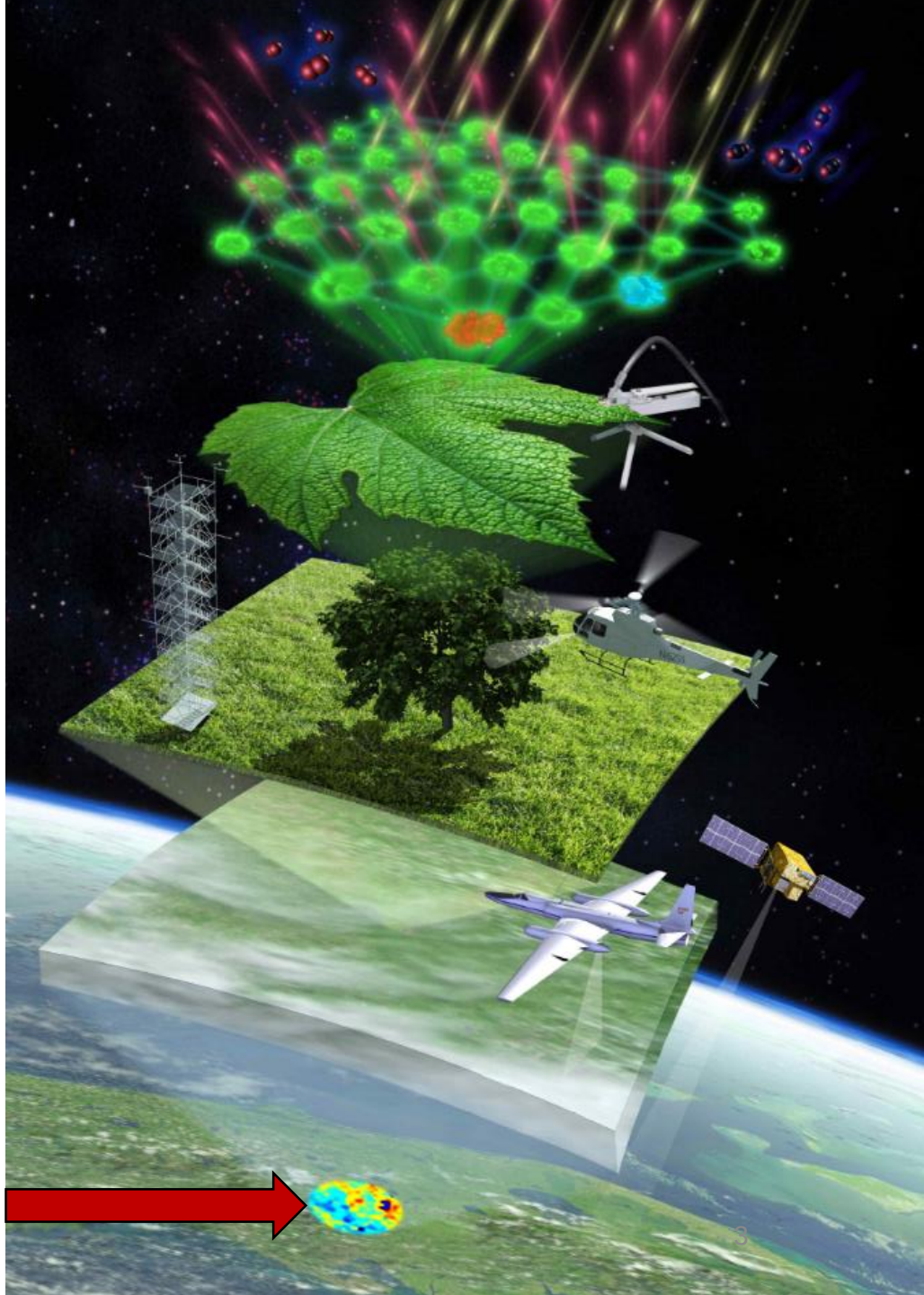


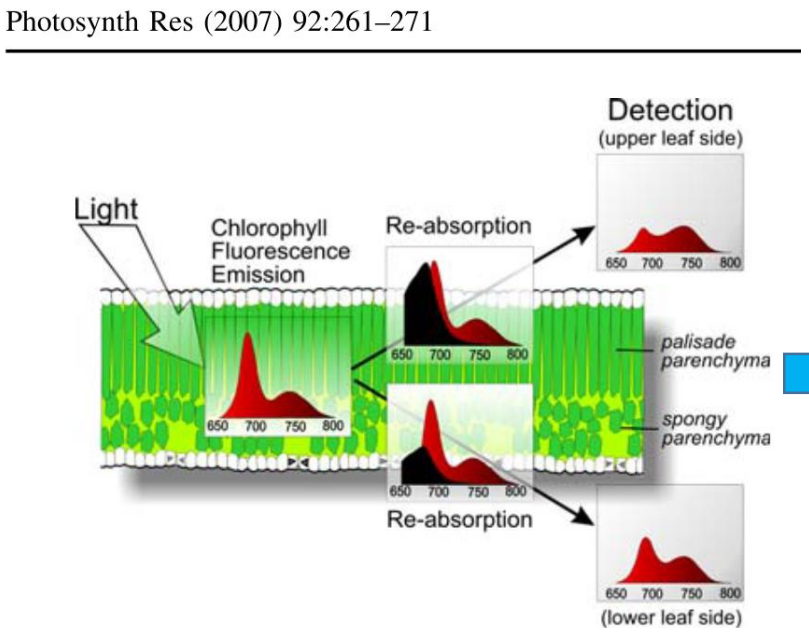
Frankenberg & Berry, 2017

- Spectral resolution (.025-.5 nm)
- Pixel size (1.3x2.25 km – 40x80 km)
- Signal:Noise (300<3000)

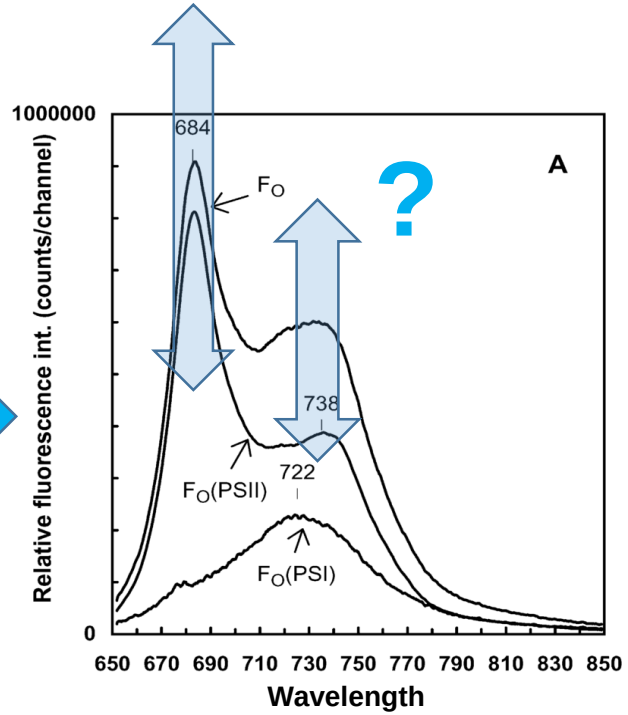
Satellite
-course in space/time
-limited wavelengths



Drivers and variability of Chl fluorescence emission spectra from the leaf to canopy



Buschmann, 2007

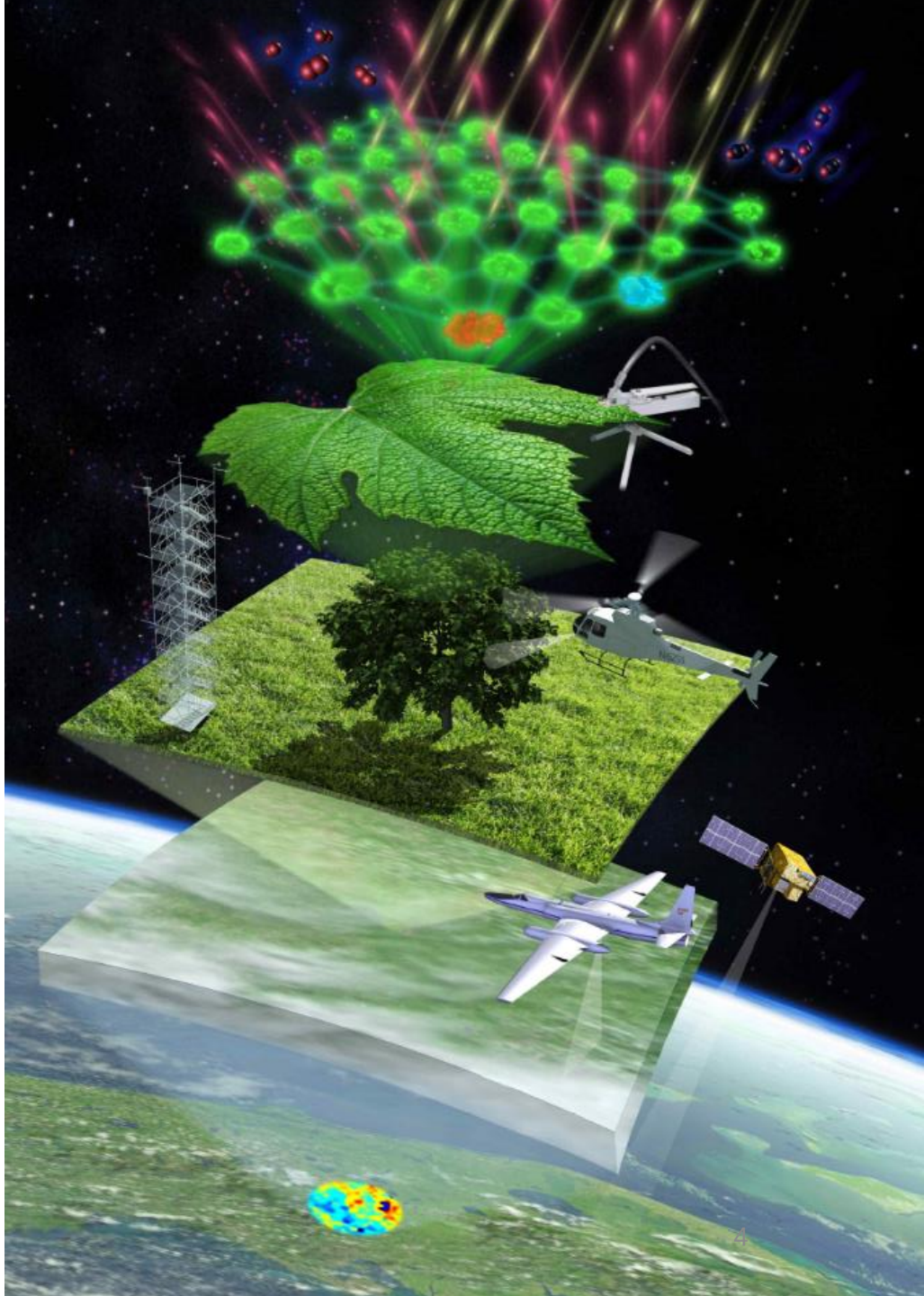


Franck et al., 2002

Chlorophyll re-absorption impacts SIF red/far-red ratio

Disentangling overlapping features?

PSI assumed constant
PSII dynamic:
changes in energy partitioning (NPQ, PQ, F)

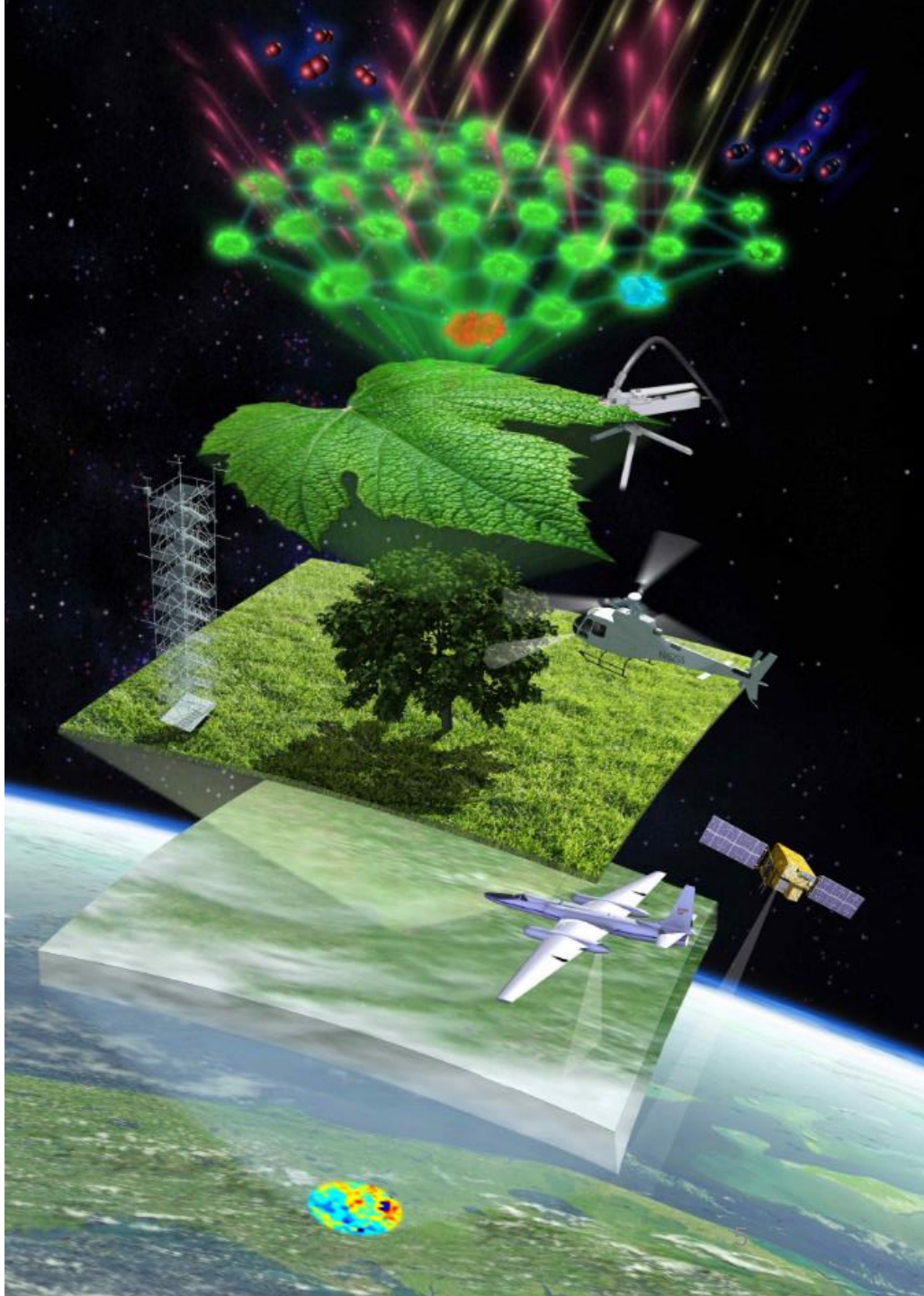


Drivers and variability of Chl fluorescence emission spectra from the leaf to canopy

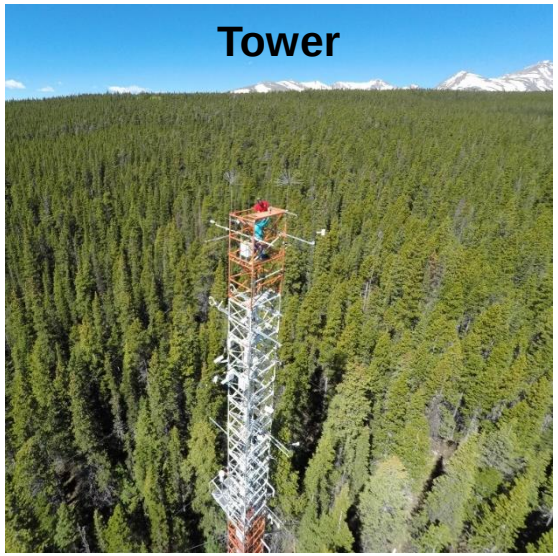
We lack a complete understanding of the drivers and variability of SIF spectra:

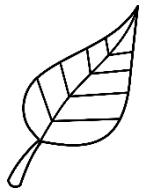
1) At physiological temperatures
2) Under different stress conditions
3) Across species
4) At diurnal and seasonal scales

Can we exploit the additive information content of SIF spectra at scales relevant to remote sensing?

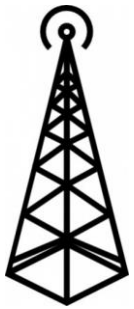


Drivers and variability of Chl fluorescence emission spectra from the leaf to canopy





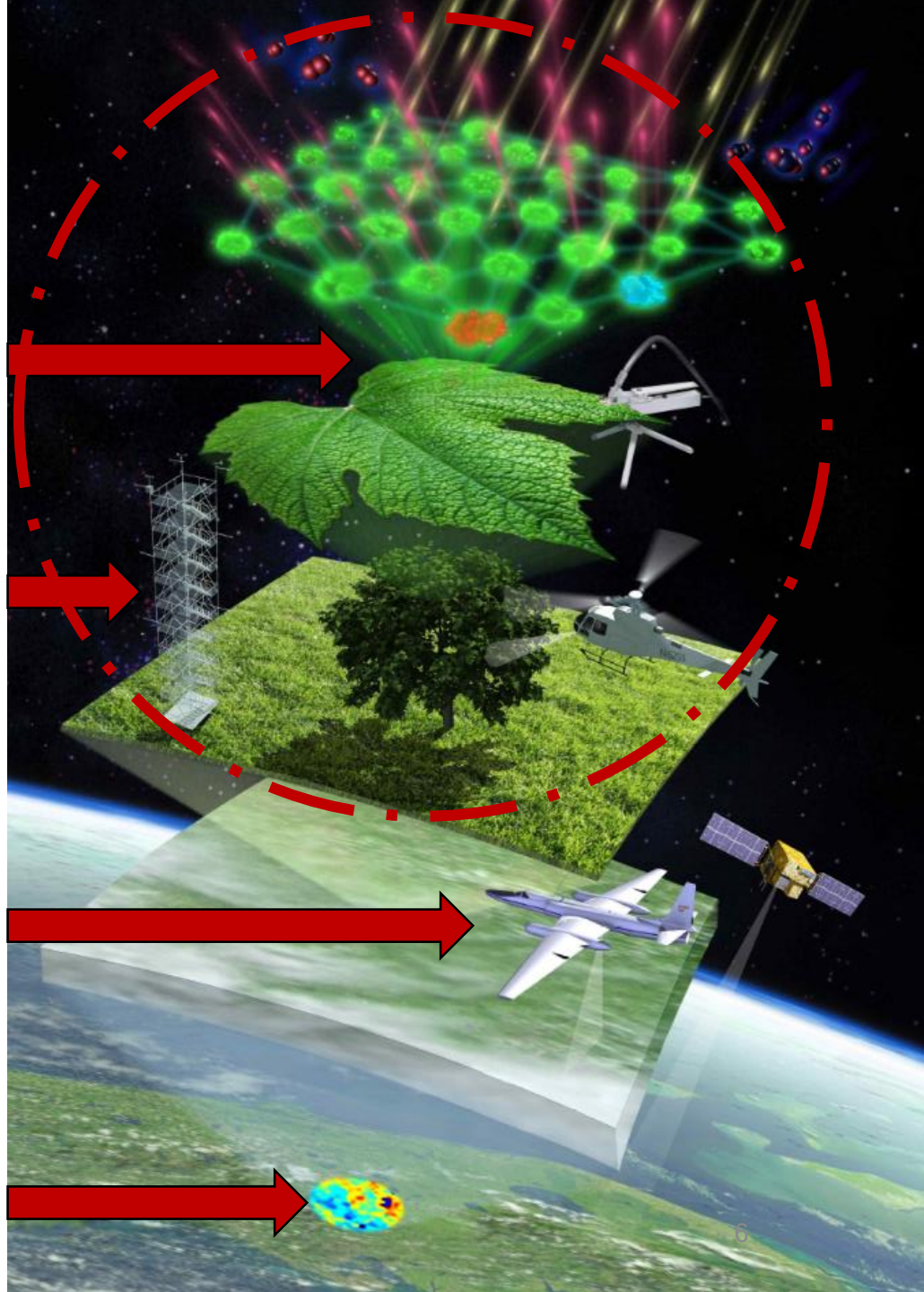
Leaf
-full spectra (no noise)
-mechanistic



Tower
-high temporal resolution
-limited spatial extent
-high spectral sampling

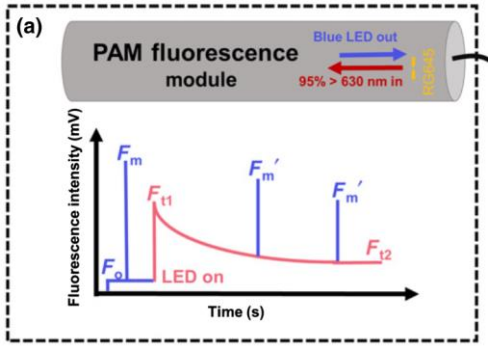
Aircraft
-high spatial resolution
-limited temporal

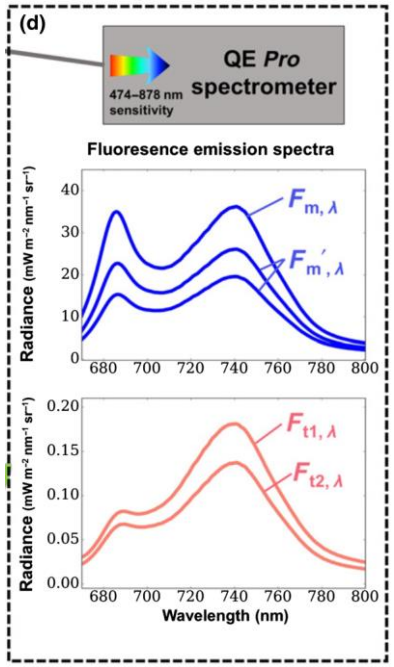
Satellite
-course in space/time
-limited wavelengths

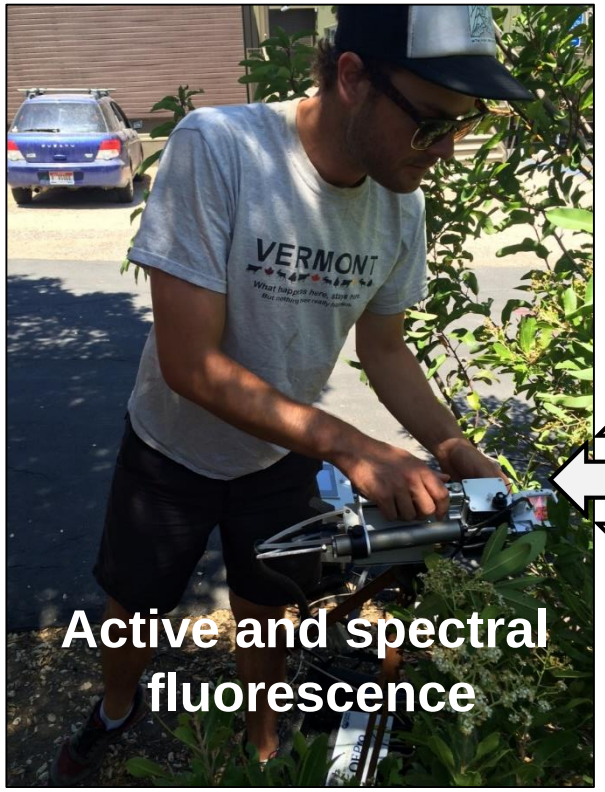


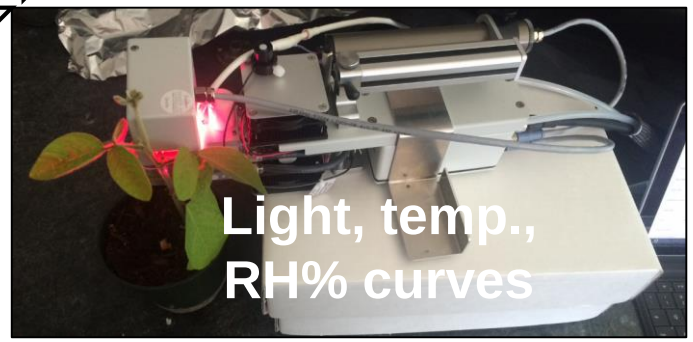
Connecting active and passive fluorescence with photosynthesis

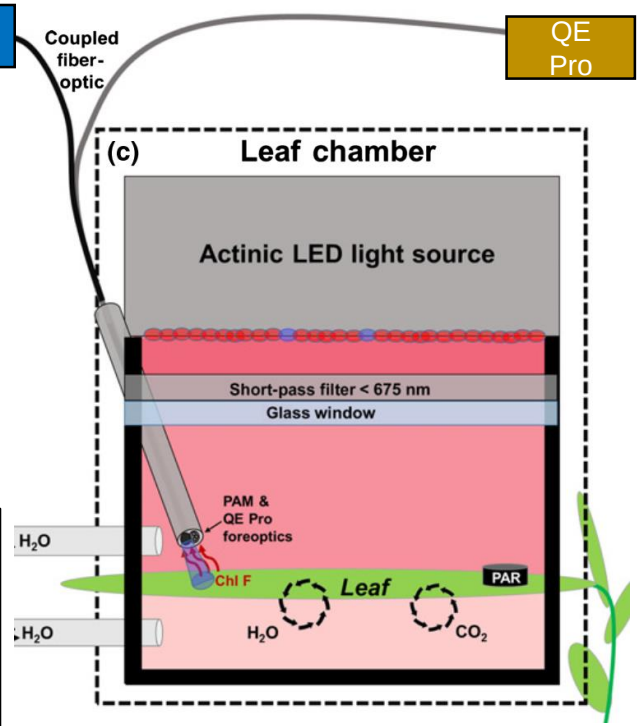
Leaf
-full spectra (no noise)
-mechanistic











Magney et al., 2017, *New Phytologist*

Controls on the shape of the SIF spectrum at the leaf scale

Link passive and active fluorescence

Three experiments

Steady-state

- 25 species
  - Tropics -> Boreal
  - >200 individuals
- 600 PAR; 50% RH; 25ºC

Light intensity

- 6 species (5 replicates)
  - Light response curves
- 25-1200 PAR; 50% RH; 25ºC

Rapid induction

- Kautsky effect (n = 48)
  - Dark -> light transition
- Dark->600 PAR
- 0.2 s sampling rate

Singular Value Decomposition (SVD) on Spectra

$$F_{t,\lambda} = \sum_{i=1}^{n} u_i * s_i * v_i^T$$

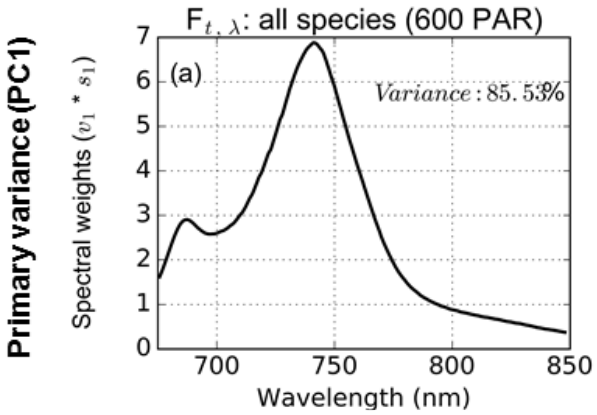
Non- and photochemical quenching (NPQ, PQ)
Pigments, absorbed PAR (aPAR)

SIF spectra = sample weights * singular values * spectral weights

Variance in spectral shape

Controls on the shape of the SIF spectrum at the leaf scale

Steady-state



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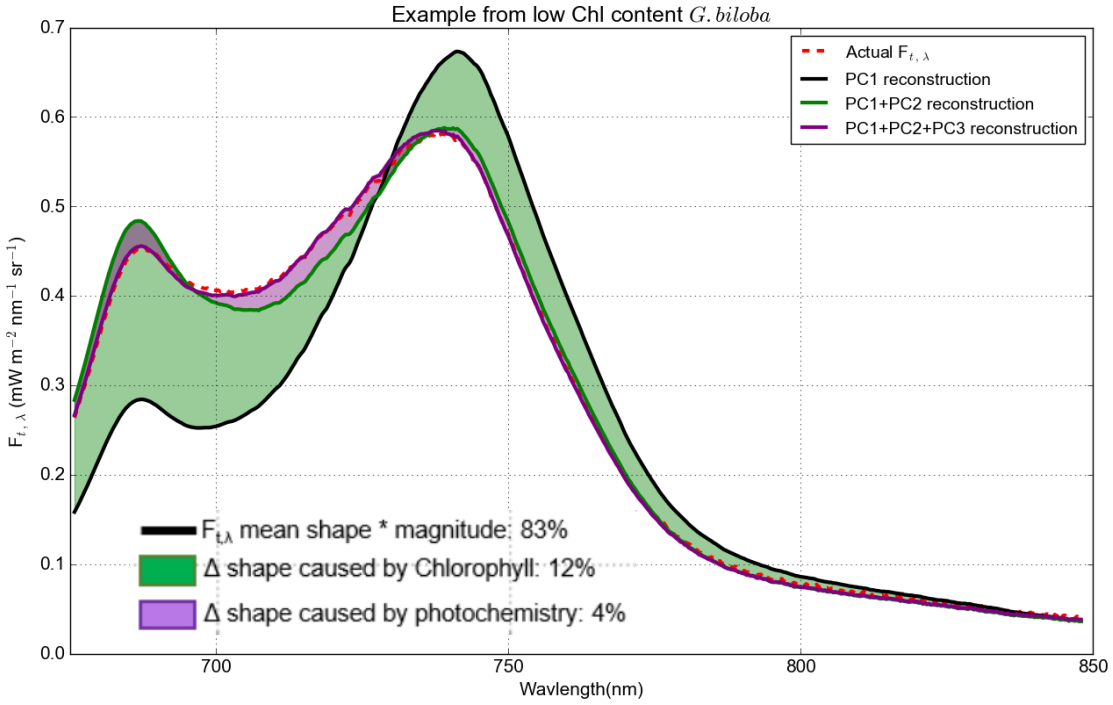
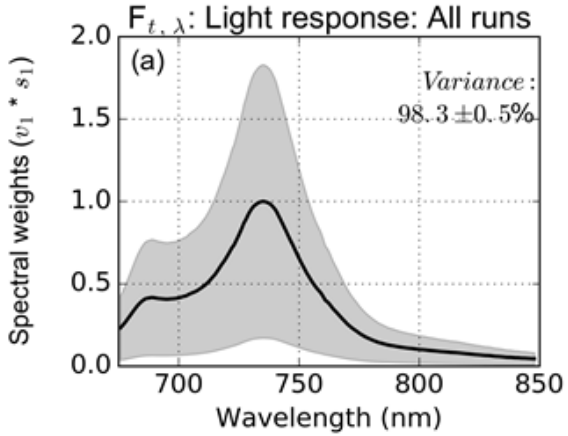


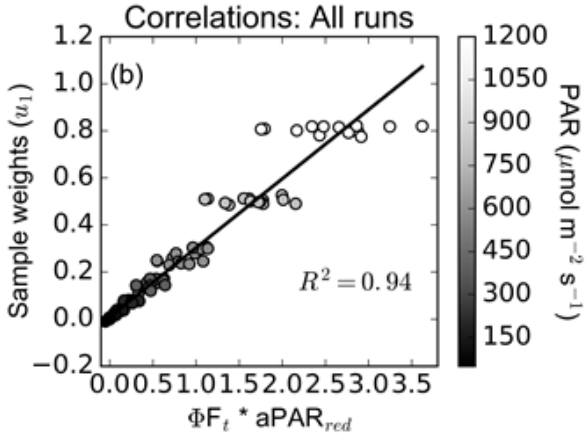
Magney et al., *in review*

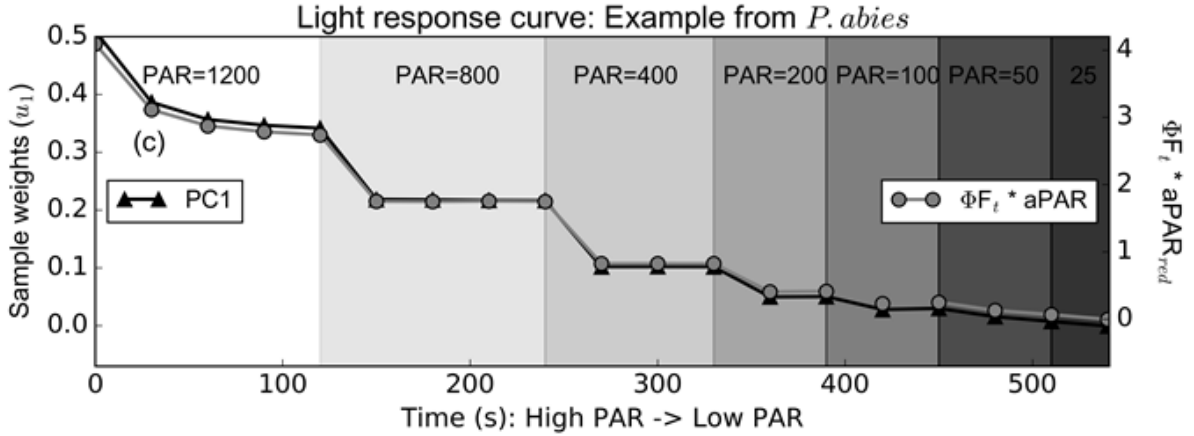
Controls on the shape of the SIF spectrum at the leaf scale

Light-intensity

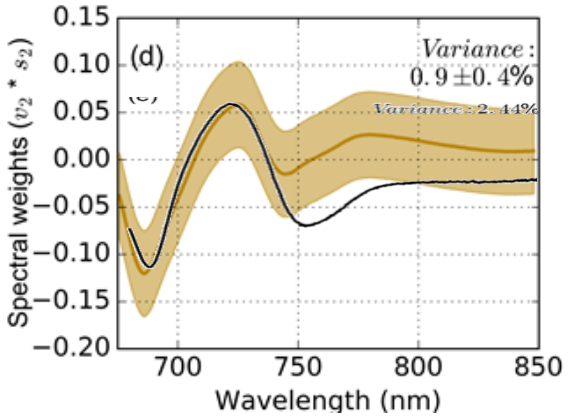
Primary variance (PC1)

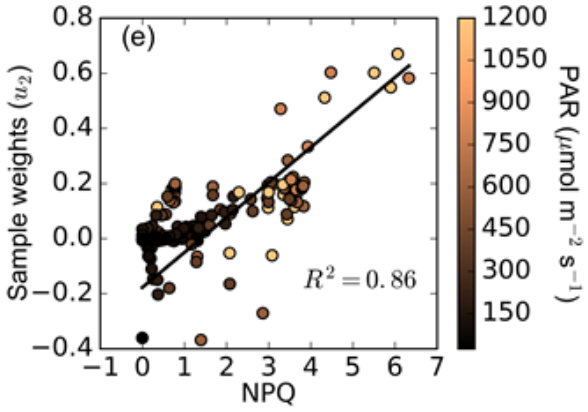


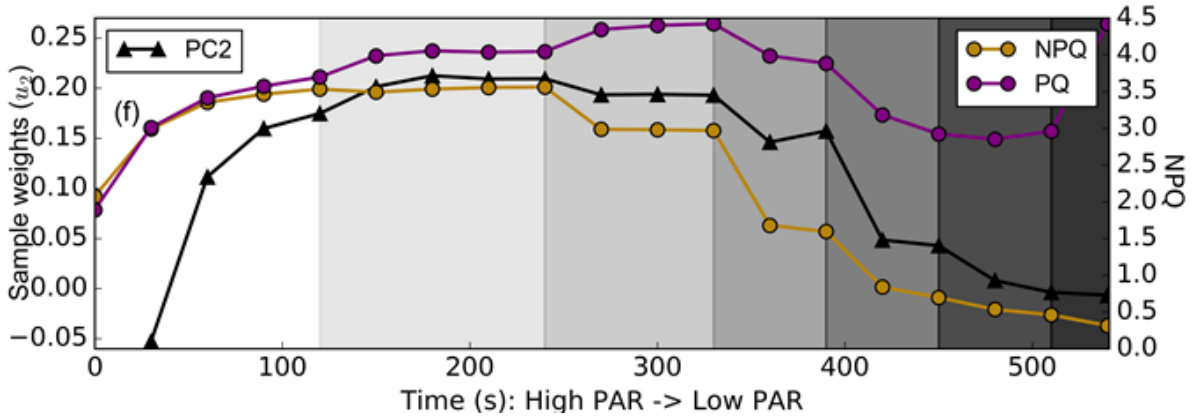




Secondary variance (PC2)





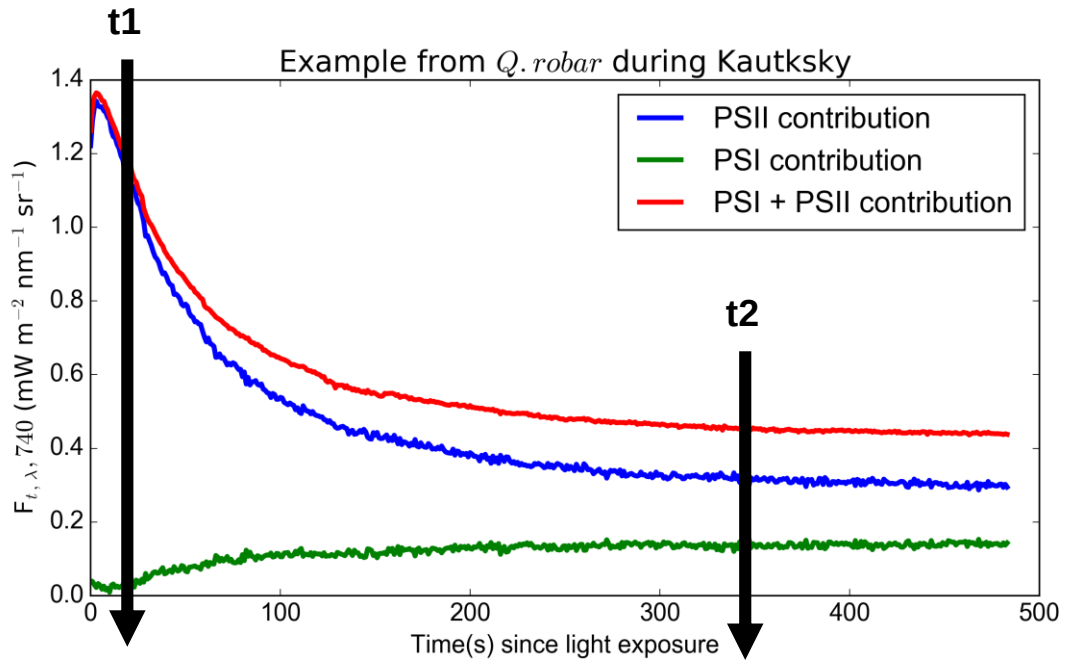


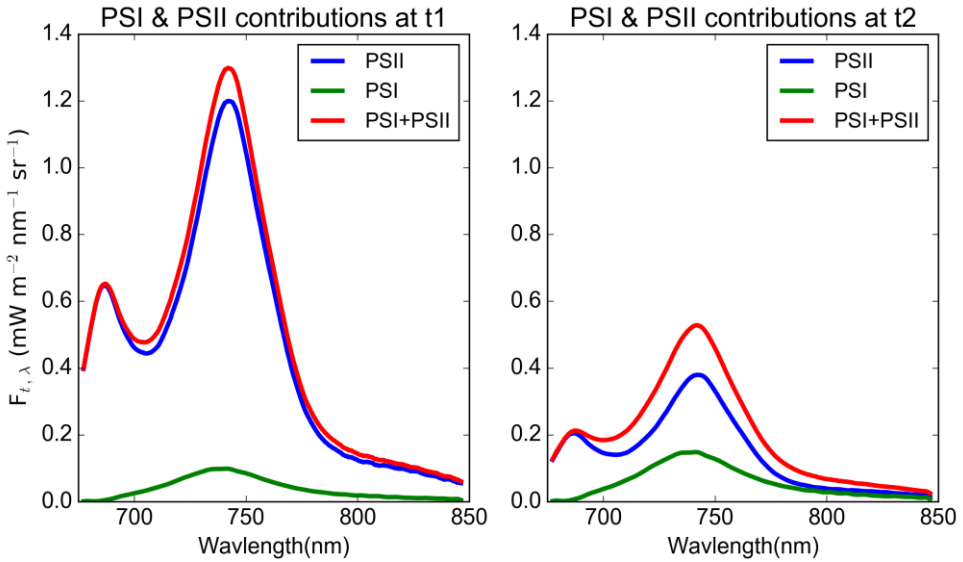
Tertiary variance (PC3) from steady-state exp.

Magney et al., *in review*

Controls on the shape of the SIF spectrum at the leaf scale

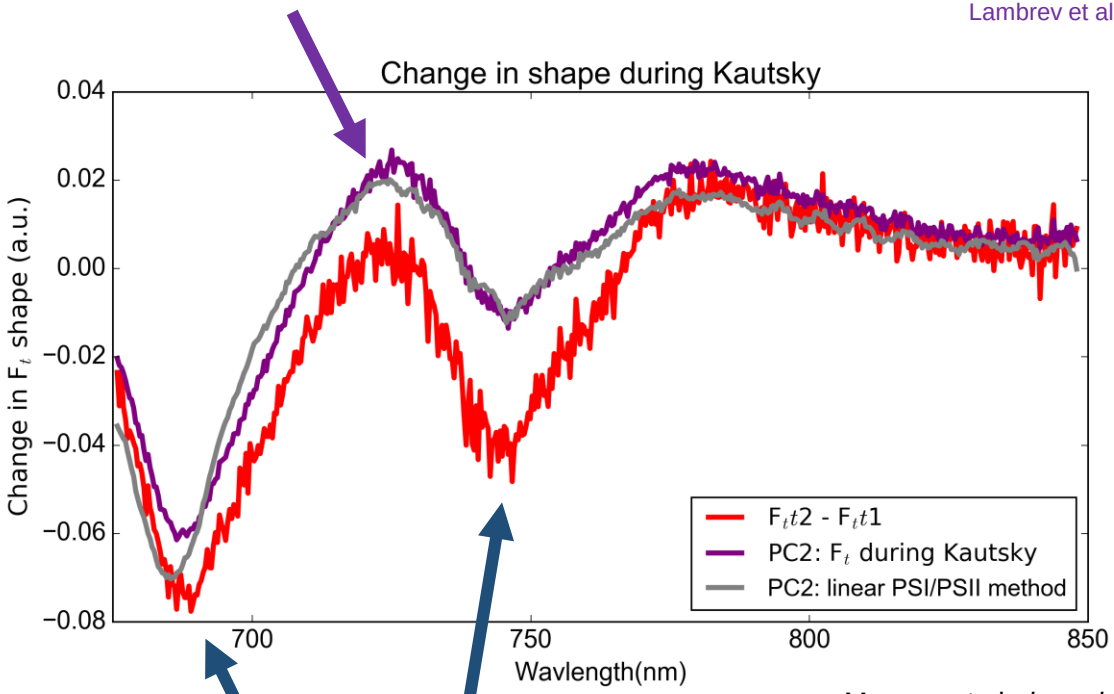
Rapid induction





Increase at 720 nm = rapidly reversible energy dependent quenching

Lambrev et al., 2010



Magney et al., *in review*

Decrease at 686 nm = ΔPSII (>99%) SIF
Decrease at 740 nm = ΔPSI (30%) + ΔPSII (70%) SIF

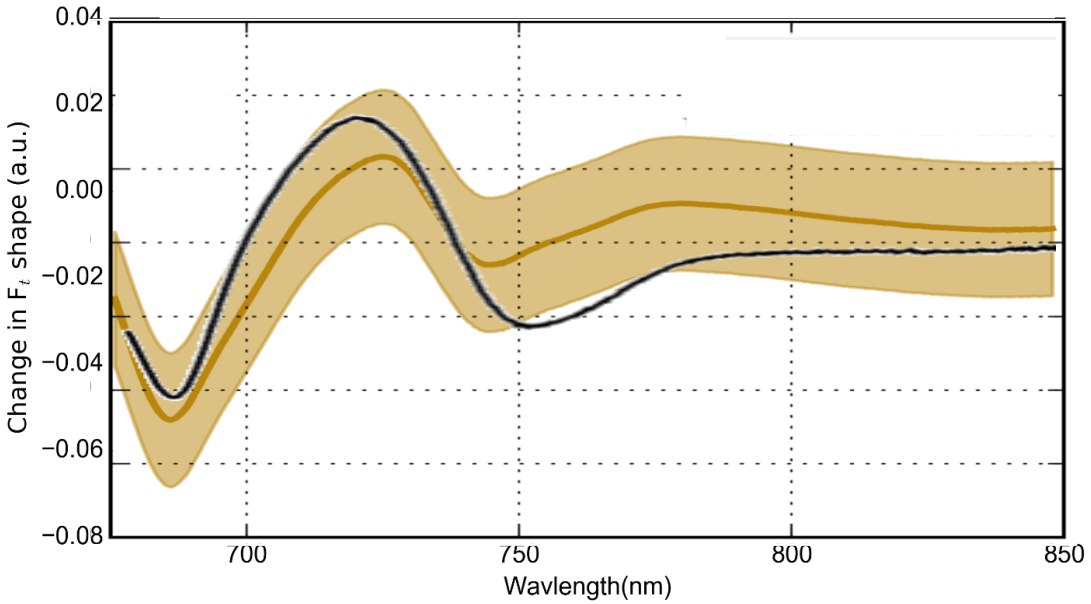
Controls on the shape of the SIF spectrum at the leaf scale

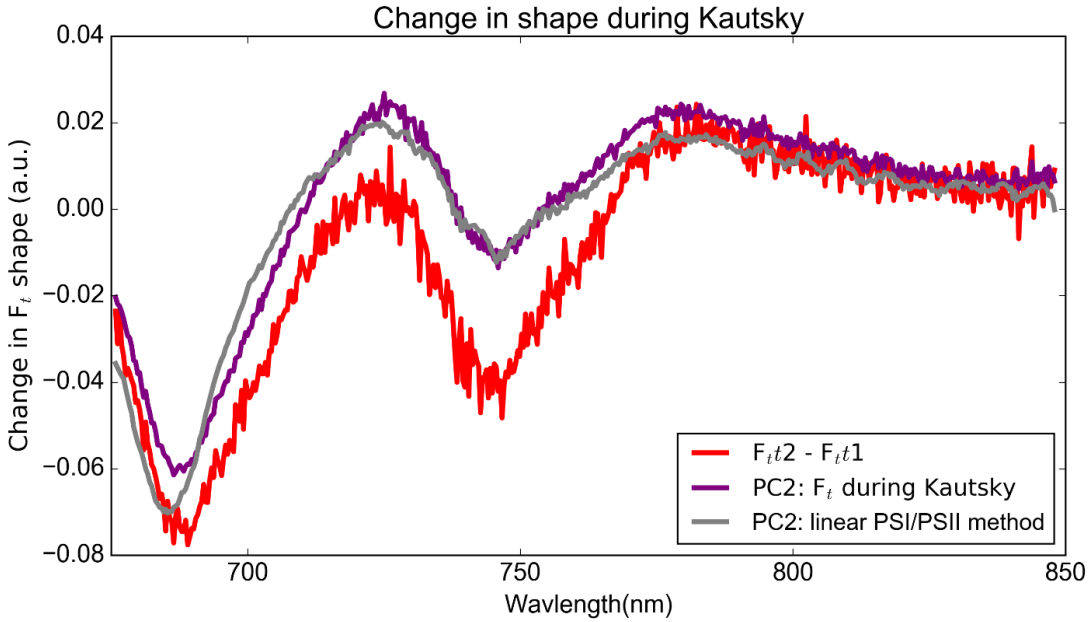
Rapid induction

Light-intensity

Steady-state

Spectral change due to quenching (NPQ/PQ) dynamics, i.e., fractional contribution of PSI/PSII SIF.



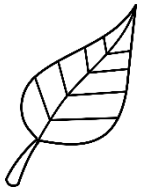


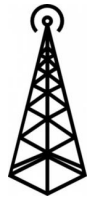
PC2 from light-intensity experiment

PC3 from steady-state experiment

PC2 from rapid induction experiment

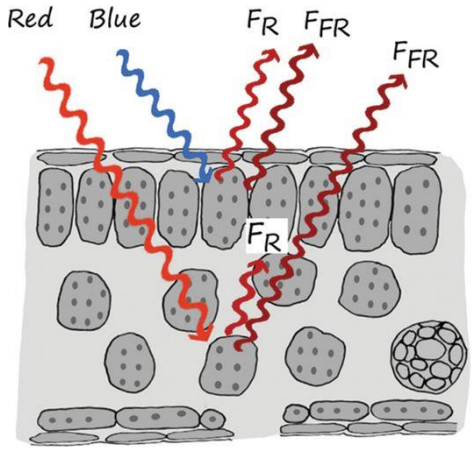
Disentangling changes in SIF spectral shape at canopy scales



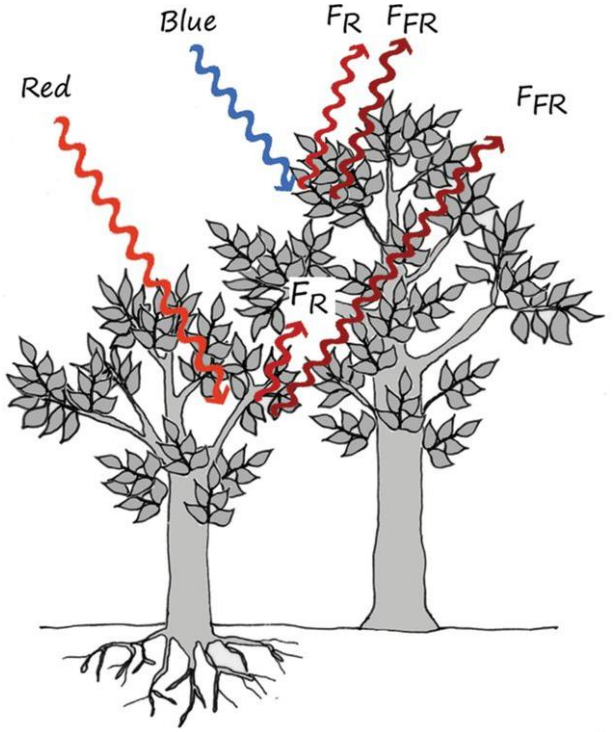


1) Mean shape **2) Chl. content** **3) NPQ/PQ**

Leaf cross section



Porcar Castell et al., 2014, *JExB*



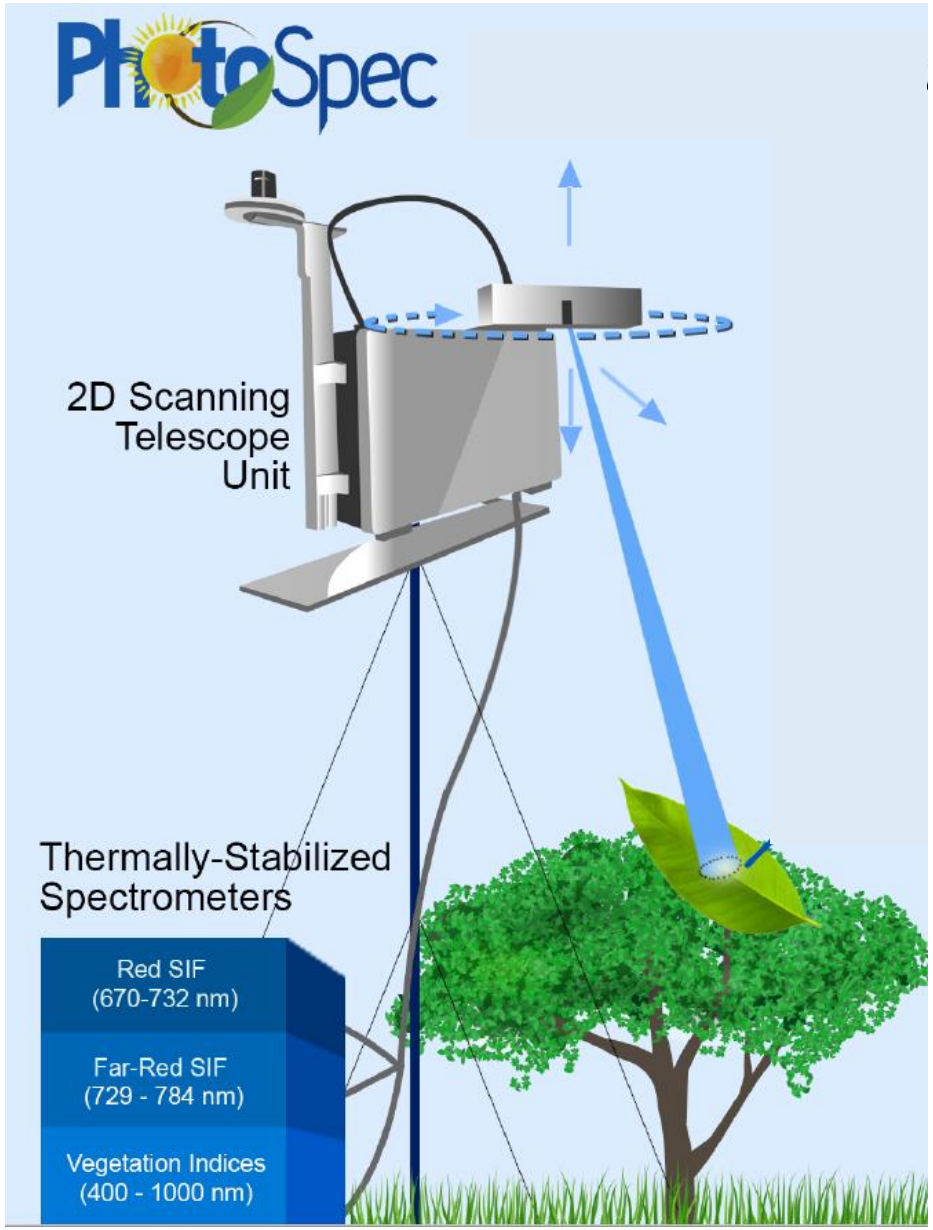
Leaf scale considerations

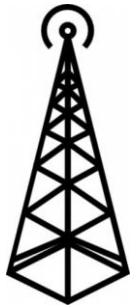
Leaf morphology, species, pigments, biochemistry, eco-physiology, PSI/PSII

Canopy scale considerations

Canopy architecture, Viewing/ Illumination geometries, Photon scattering/ re-absorption, Sun/ shade fraction

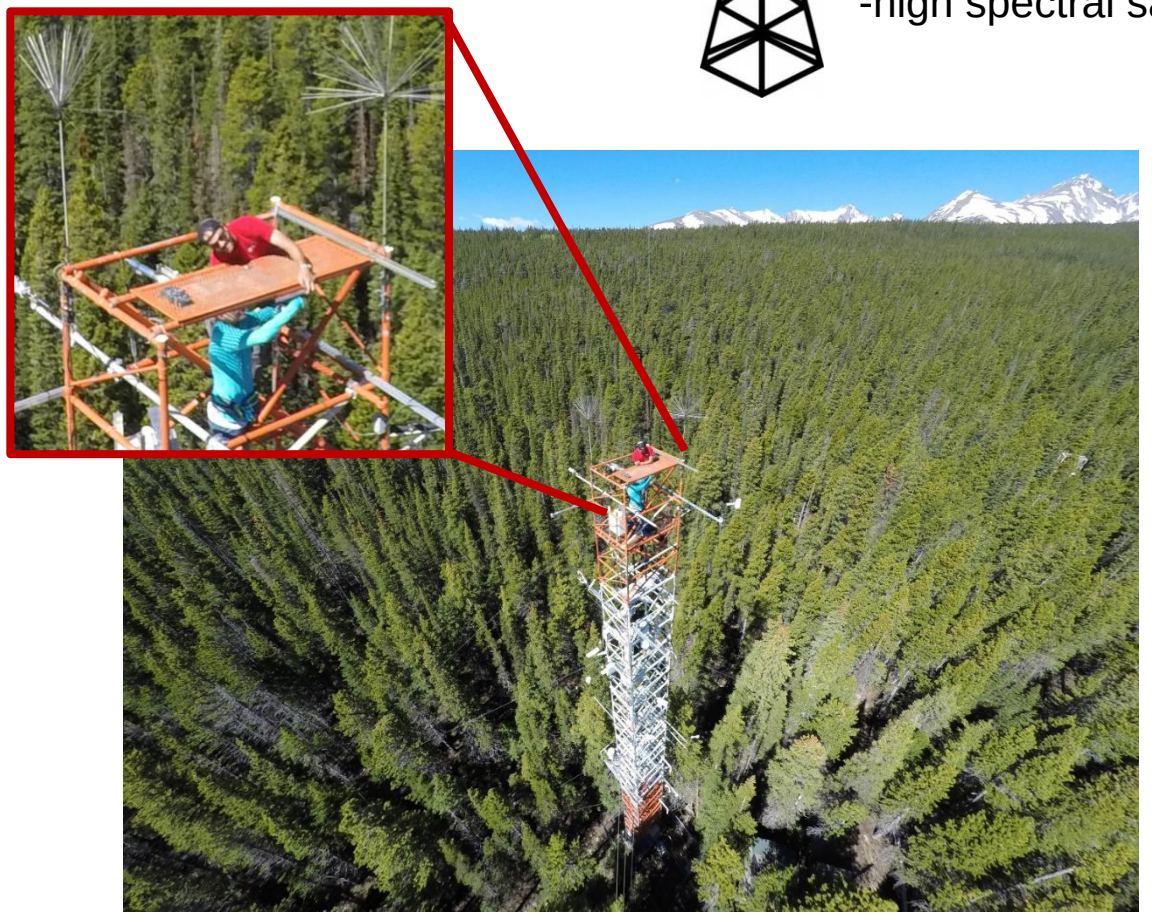
High resolution red and far-red canopy SIF: PhotoSpec





Tower

-high temporal resolution
-limited spatial extent
-high spectral sampling



Abstract

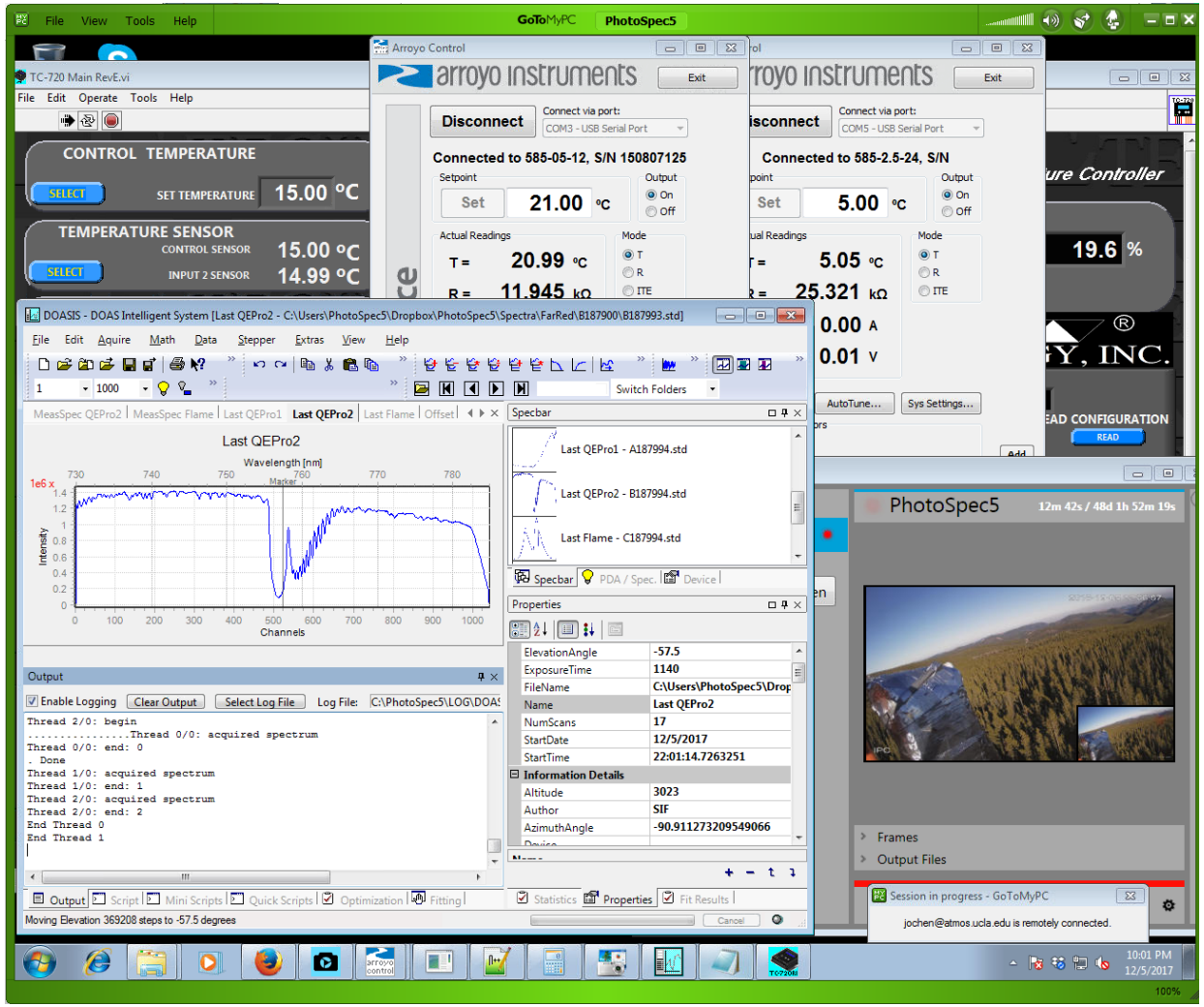
B44C-06 Red and Far-Red Solar-Induced Chlorophyll Fluorescence Observations in the Tropical Rain Forest of Costa Rica

Jochen Stutz

Thursday, 14 December 2017 17:15 - 17:30

New Orleans Ernest N. Morial Convention Center - 383-385

Niwot Ridge, CO: PhotoSpec (1 of 5)



Abstract

B44C-04 Seasonality of photosynthesis of a Rocky Mountain subalpine forest: implications for SIF as a metric for GPP

David R Bowling

Thursday, 14 December 2017 16:45 - 17:00

New Orleans Ernest N. Morial Convention Center - 383-385

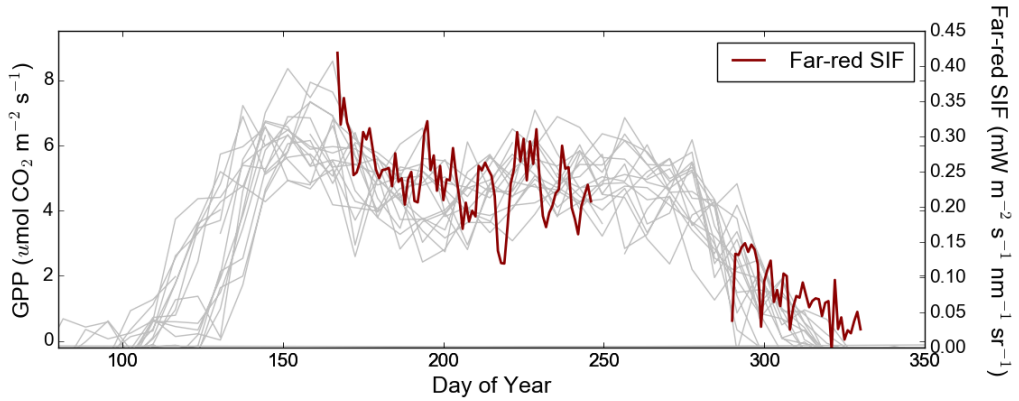
B44C-05 Simulating Canopy-Level Solar Induced Fluorescence with CLM-SIF 4.5 at a Sub-Alpine Conifer Forest in the Colorado Rockies

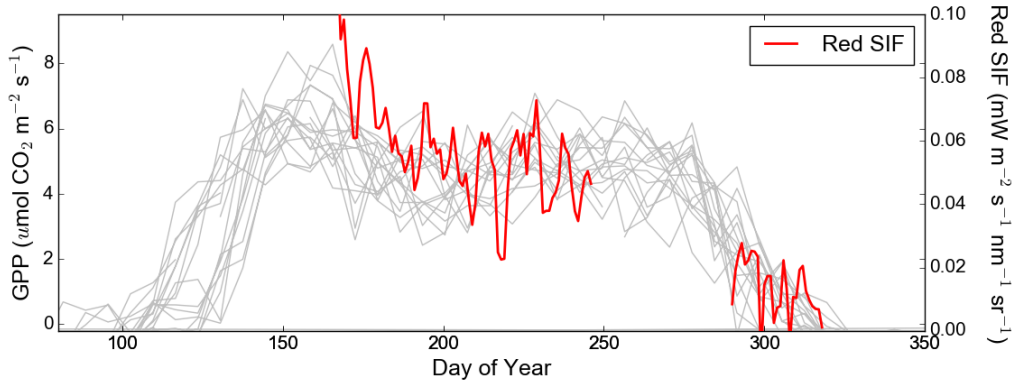
Brett M Raczka[1], *David R Bowling*[2], *John C Lin*[3], *Jung-Eun Lee*[4], *Xi Yang*[5], *Henrique Duarte*[6] *and Lauren Zuromski*[6], *(1)University of Utah, Department of Utah, Biology, Salt Lake City, UT, United States, (3)University of Utah, Salt Lake City, UT, United States, (4)Brown University, Earth, Environmental and P of Virginia, Charlottesville, United States, (6)University of Utah, Salt Lake City, United States*

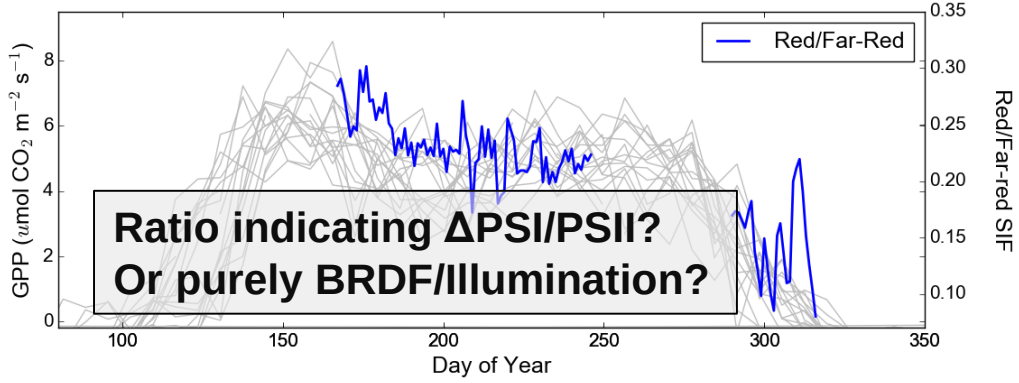
Thursday, 14 December 2017 17:00 - 17:15

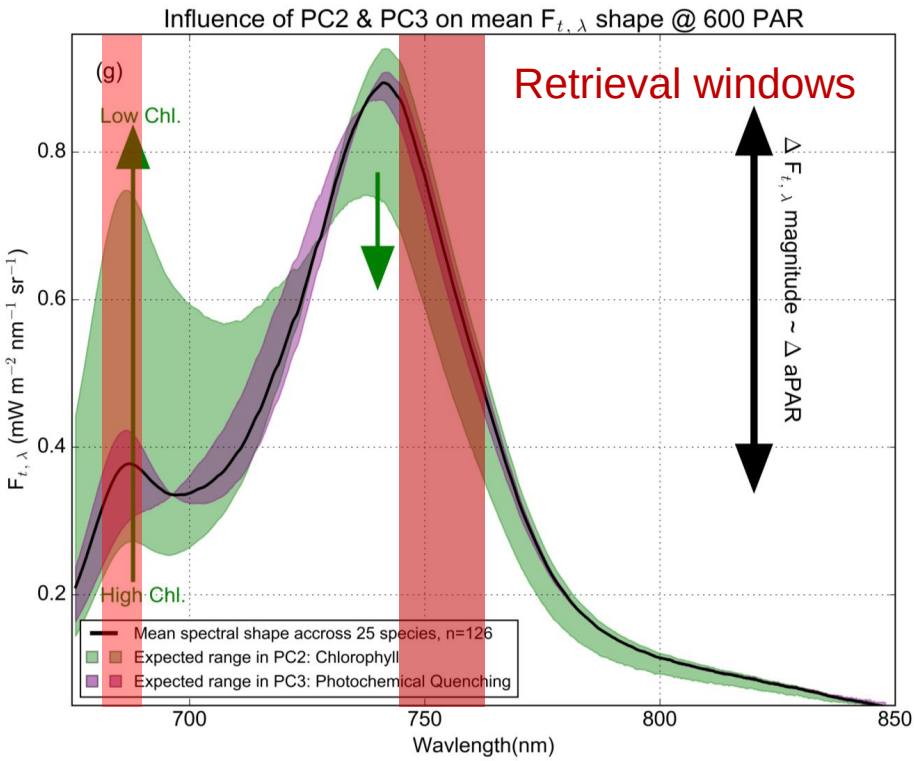
New Orleans Ernest N. Morial Convention Center - 383-385

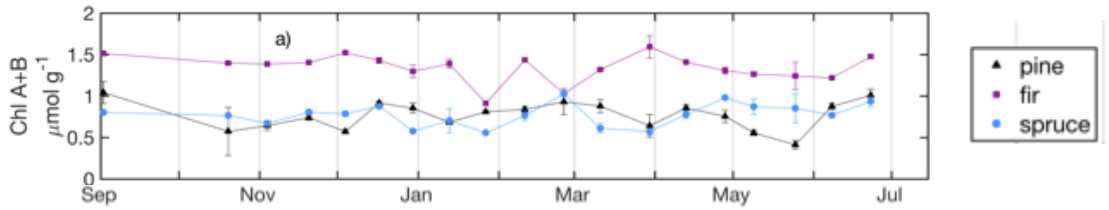
Niwot Ridge, CO: Seasonal canopy average





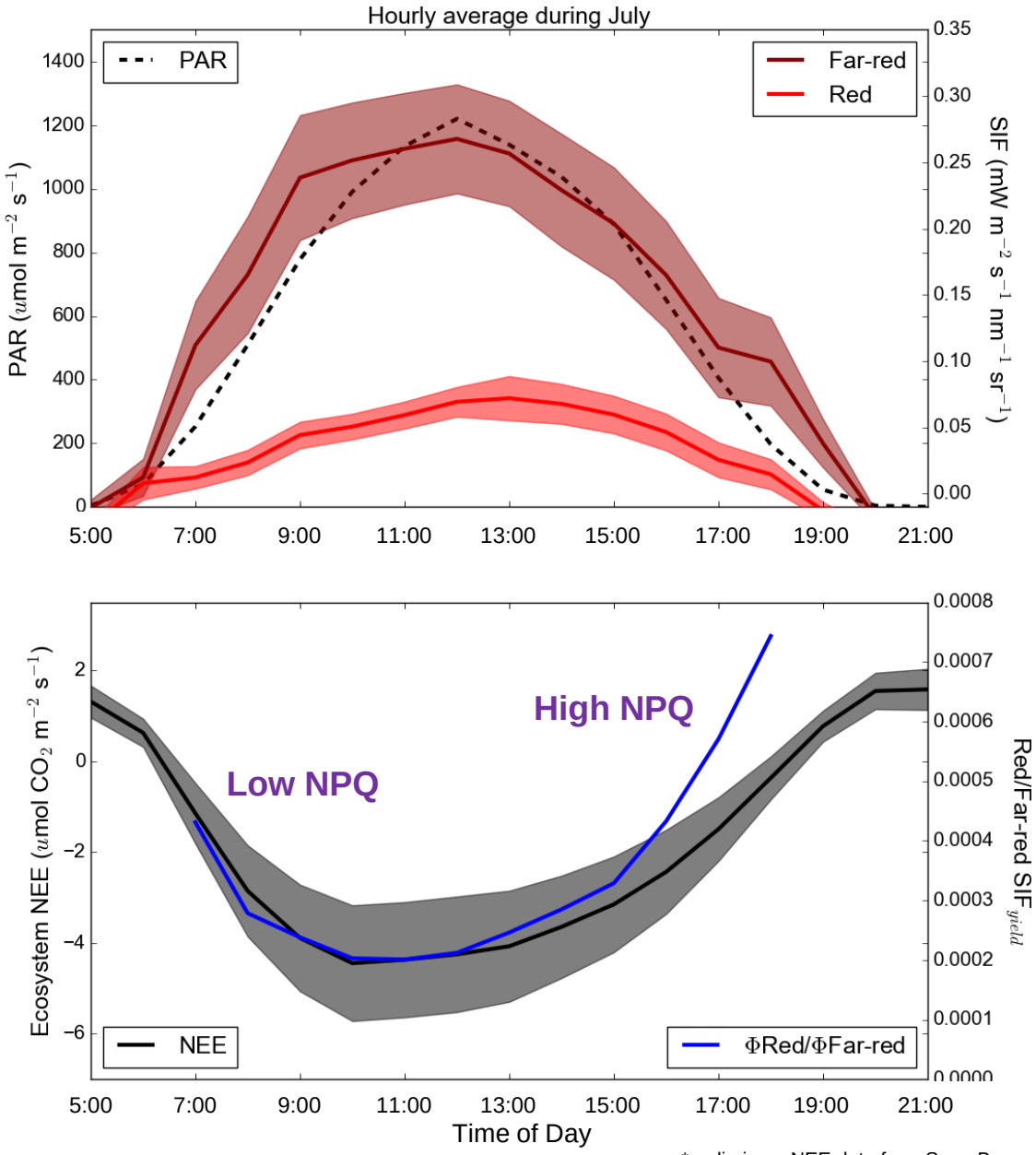




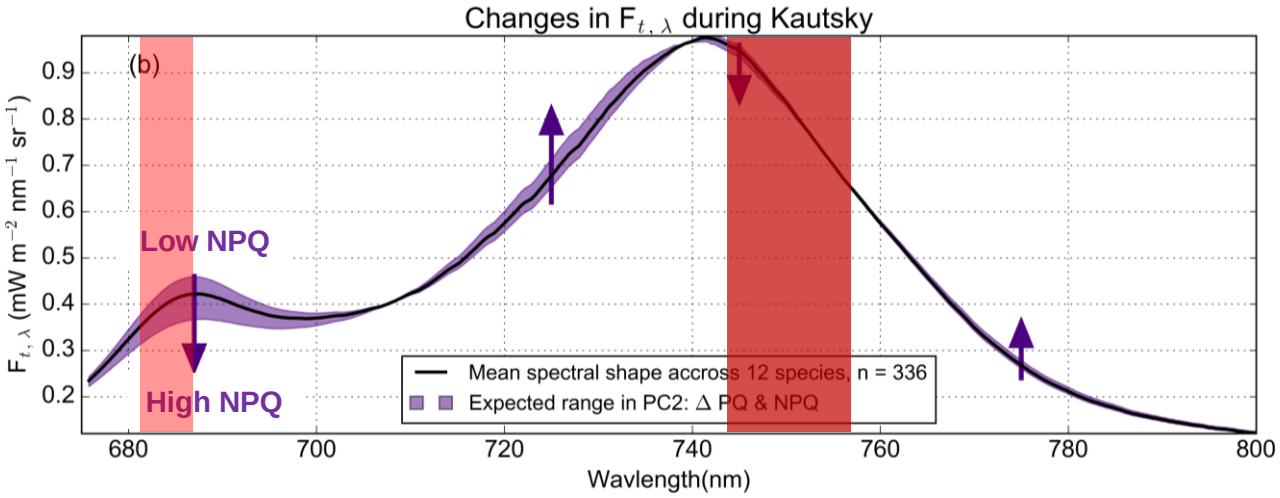


*Not much variation in Chlorophyll Bowling et al., *in review*

Niwot Ridge, CO: Diurnal canopy average



*preliminary NEE data from Sean Burns

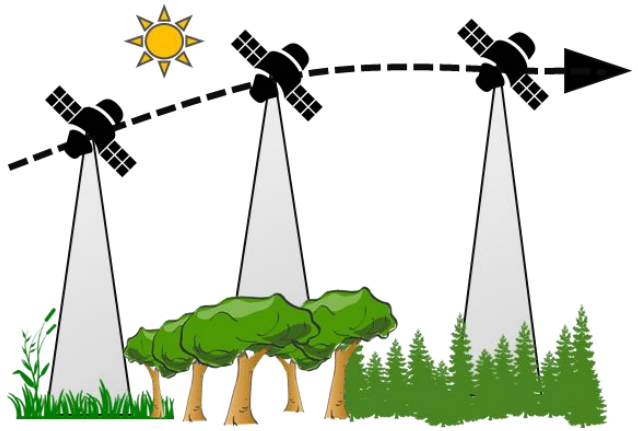


Magney et al., *in review*

Disentangling changes in SIF spectral shape

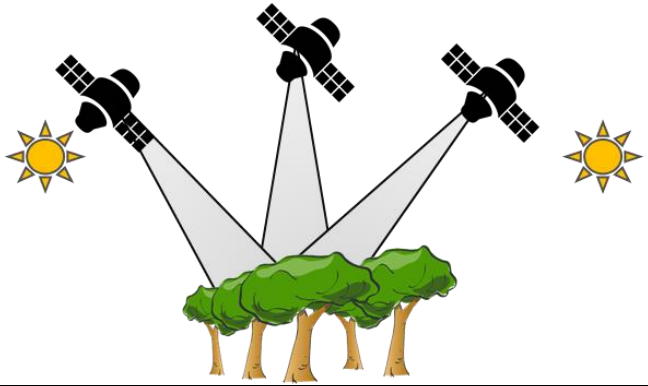
All experiments

Single overpass, multiple canopies (OCO-2)

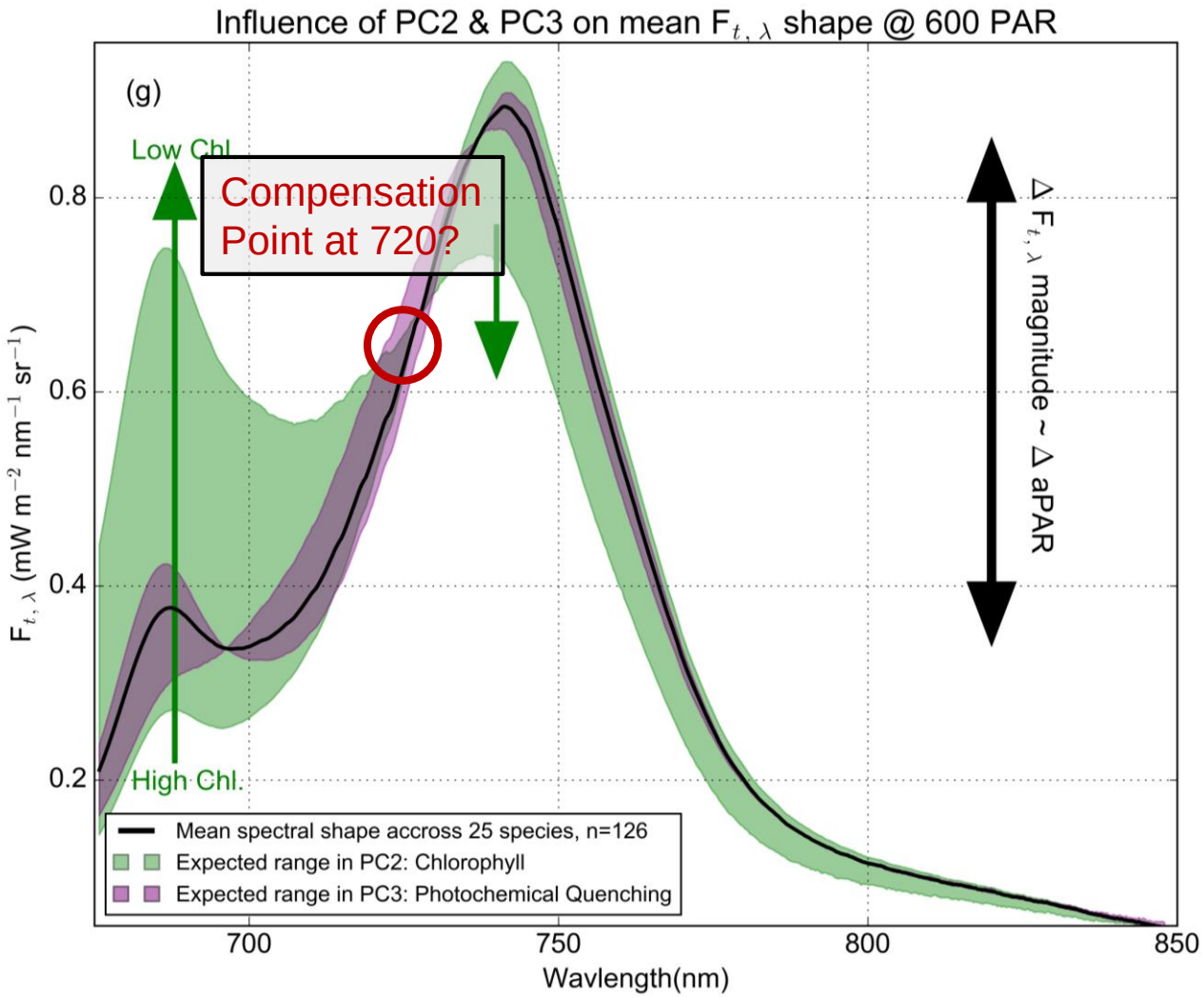


Driven by pigments,
maybe longer term PSI/PSII?

Multiple overpasses, same canopy (GeoCarb)

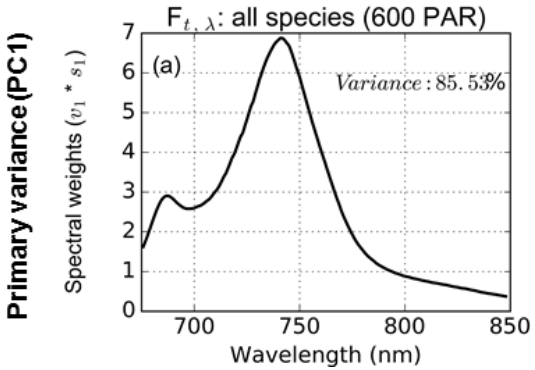


Driven by photochemistry (NPQ/PQ)

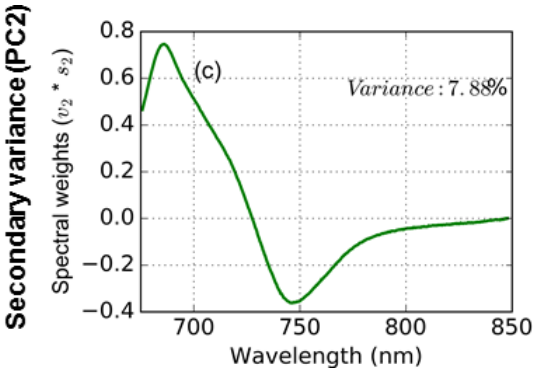


Conclusions

1) The mean spectral shape of SIF explains a lot.

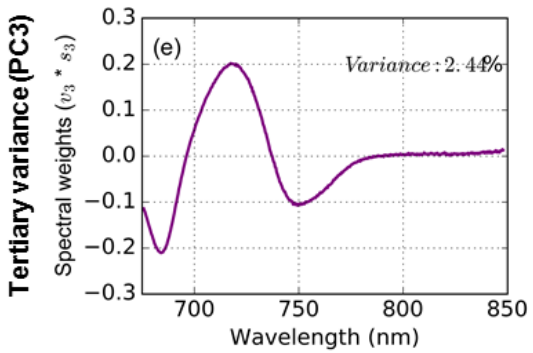


2) Across species and seasons, pigments dominate the shape

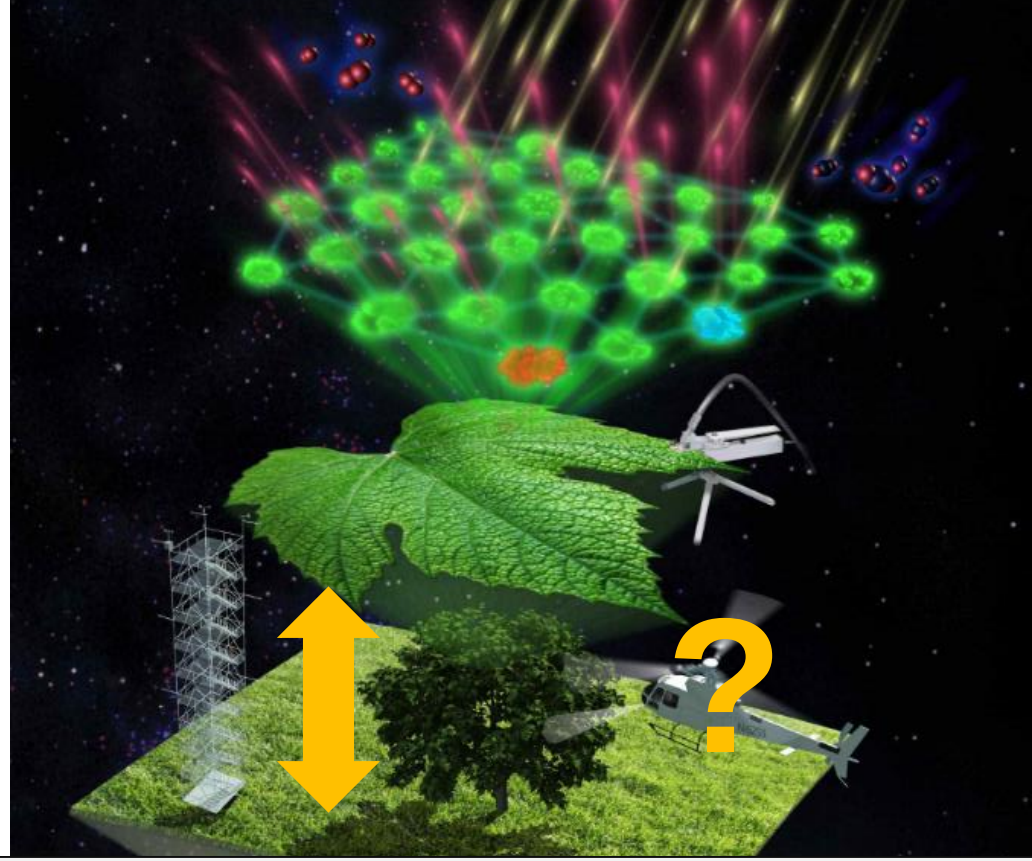


3) At diurnal timescales, the shape is mostly modified by PQ/NPQ dynamics

-difficult to interpret at seasonal time-step

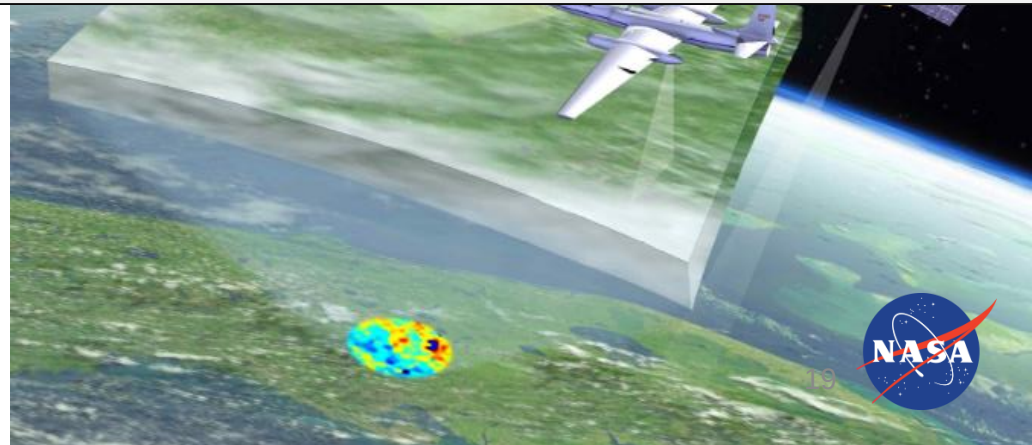


4) Knowing the magnitude, drivers, and location of these spectral shifts will aid in canopy scale SIF interpretation.



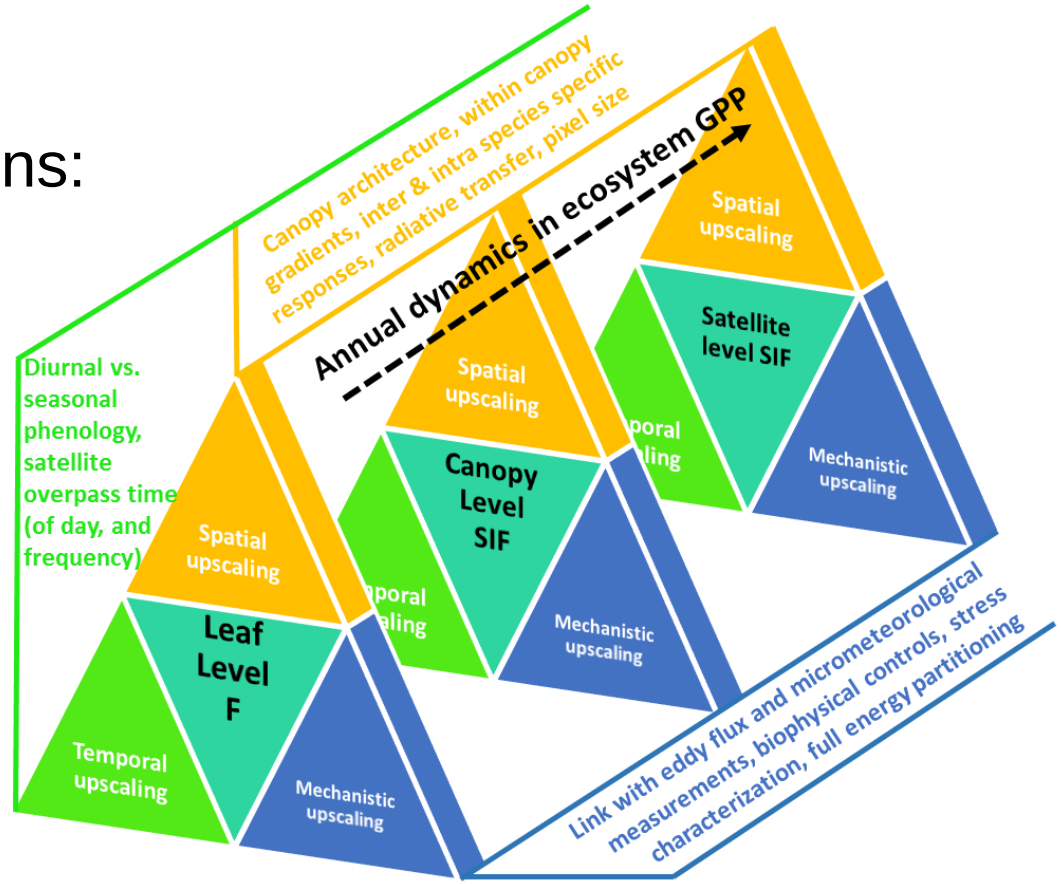
Canopy scale considerations

Canopy architecture, Viewing/ Illumination geometries, Photon scattering/ re-absorption, Sun/ shade fraction



Thank you.

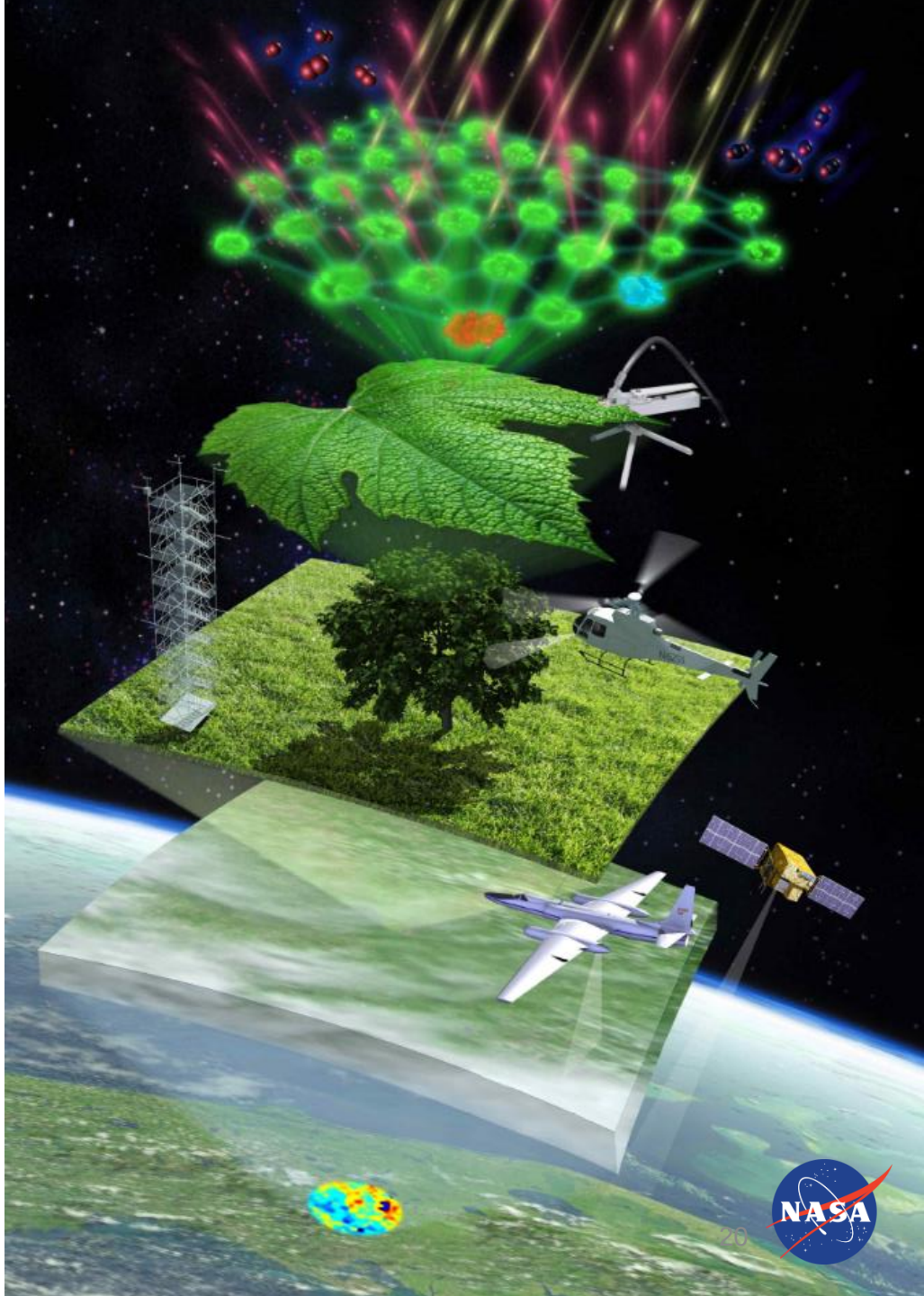
Open questions:



Contact: Troy.S.Magney@jpl.nasa.gov

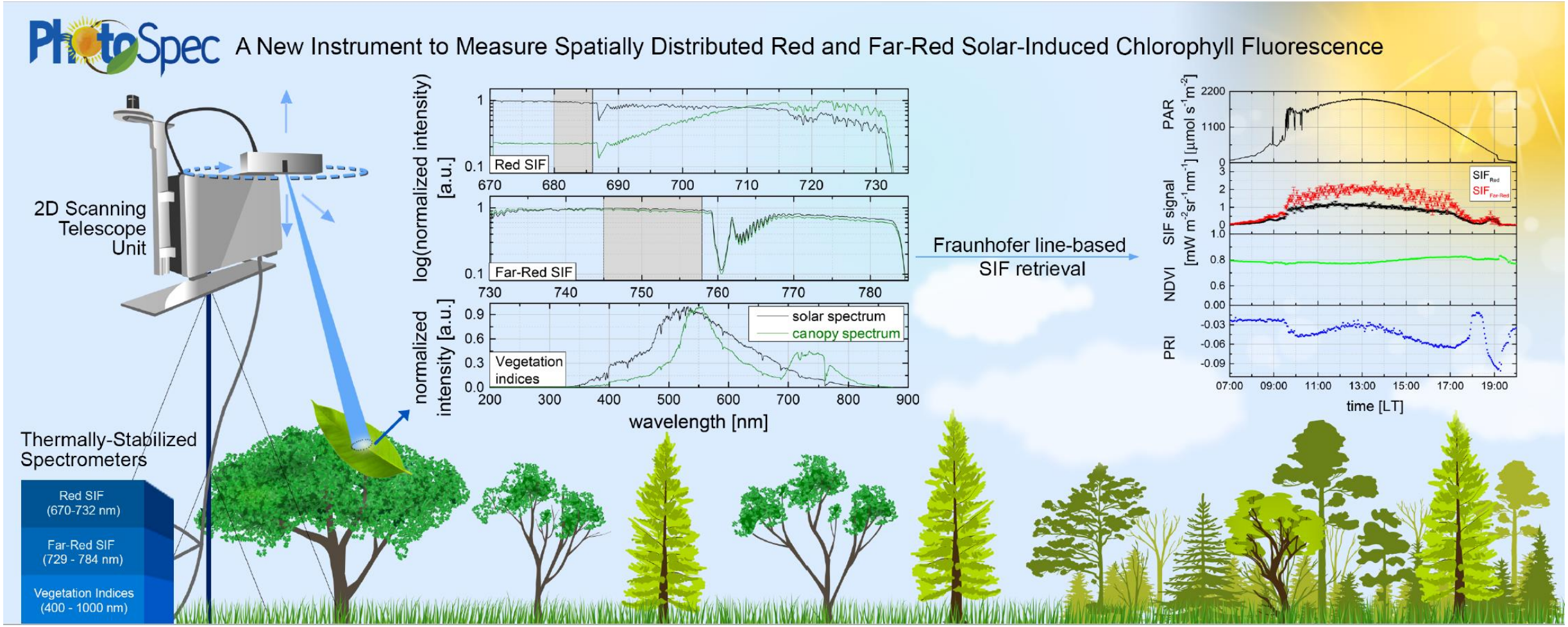
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

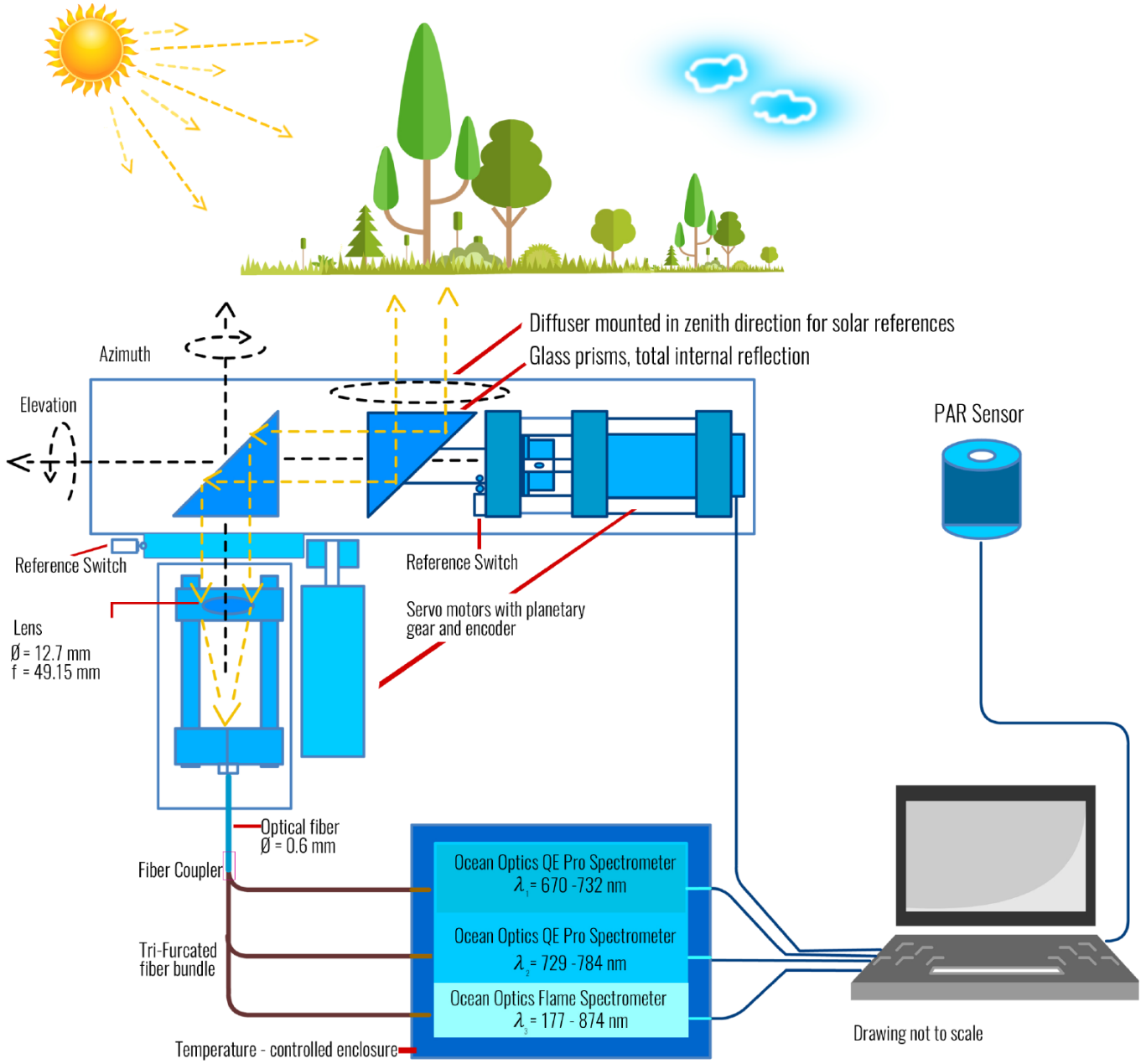


Extra slides below

PhotoSpec characteristics



PhotoSpec characteristics



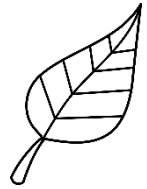
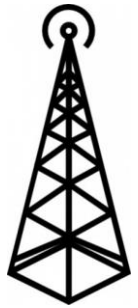
PhotoSpec characteristics

Table 1. Spectral characteristics of the Ocean Optics spectrometer in the PhotoSpec instrument.

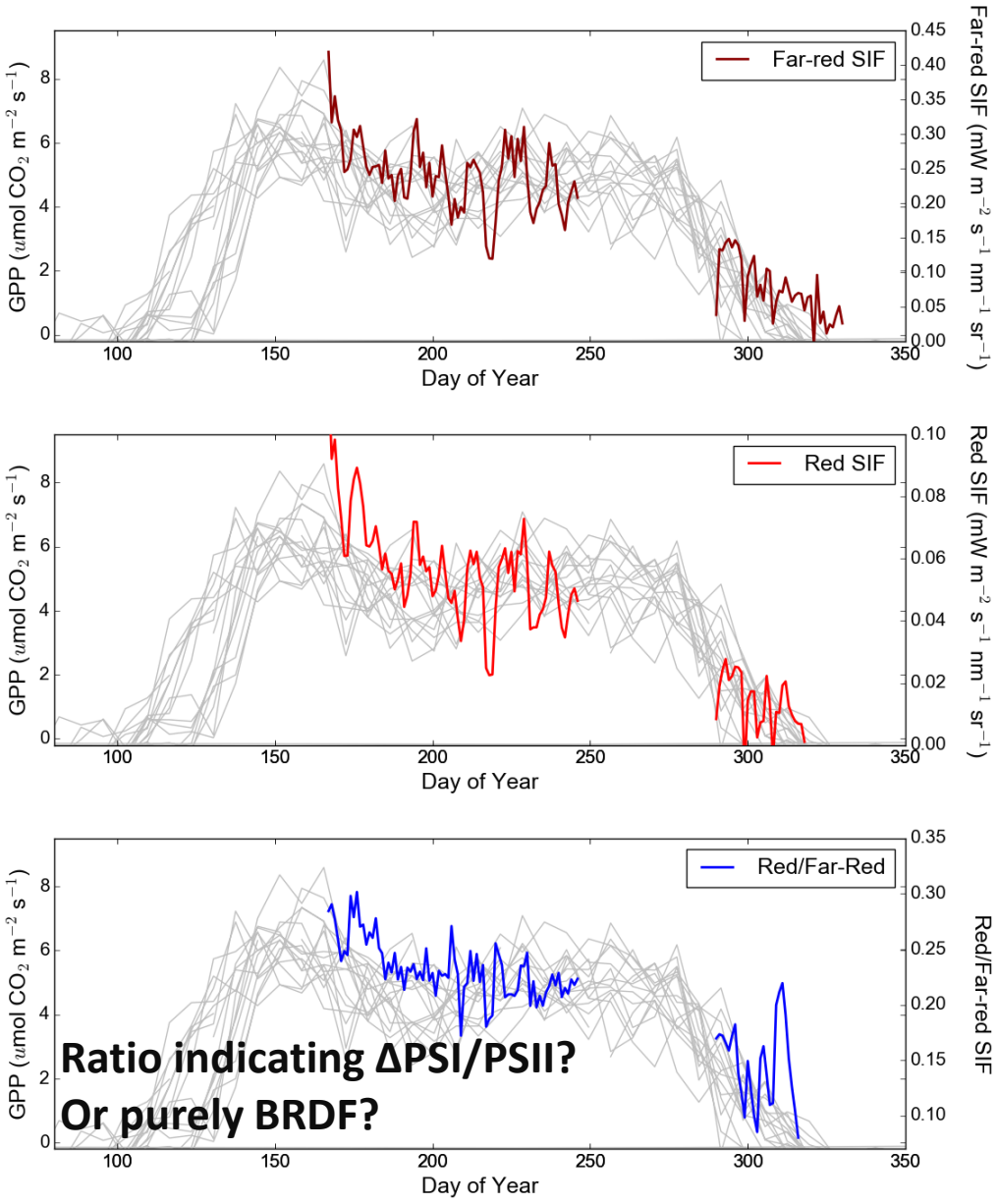
	red	far-red	UV/vis
Spectrometer	QEPro 1	QEPro 2	Flame
Wavelength [nm]	670 - 732	729 - 784	177 - 874
number of pixels	1044	1044	2048
Dispersion [nm/pixel]	0.074	0.067	0.382
FWHM [nm]	0.3	0.3	1.2
Grating [grooves/mm]	2400	2400	600
f/#	f/4	f/4	f/2
Filter	OG590	RG695	2. order
Entrance Slit [µm]	none	none	25
Detector	Hamamatsu S7031-1006	Hamamatsu S7031-1006	Sony ILX511B linear silicon CCD array
quantum efficiency (peak) [%]	90	90	90

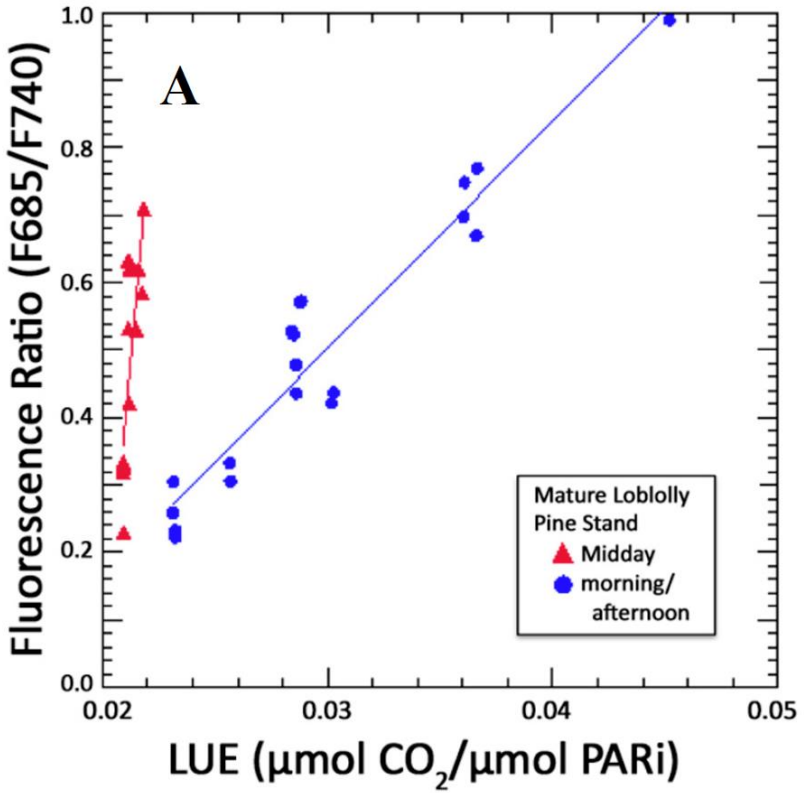
Table 2. Errors of the retrieved SIF data.

Error type	Error source	red	far-red
Statistical	Retrieval Error	0.05 mW m^{-2} sr^{-1} nm^{-1}	0.1 mW m^{-2} sr^{-1} nm^{-1}
	Retrieval Error for a typical SIF signal	4%	5%
Systematic	offset	10^{-3}%	10^{-5}%
	Dark current	$6 \cdot 10^{-4}$%	$6 \cdot 10^{-4}$%
	Detector Nonlinearity	10^{-5}%	10^{-5}%
	Stray light	2.5%	1%
	Calibration	7%	7%

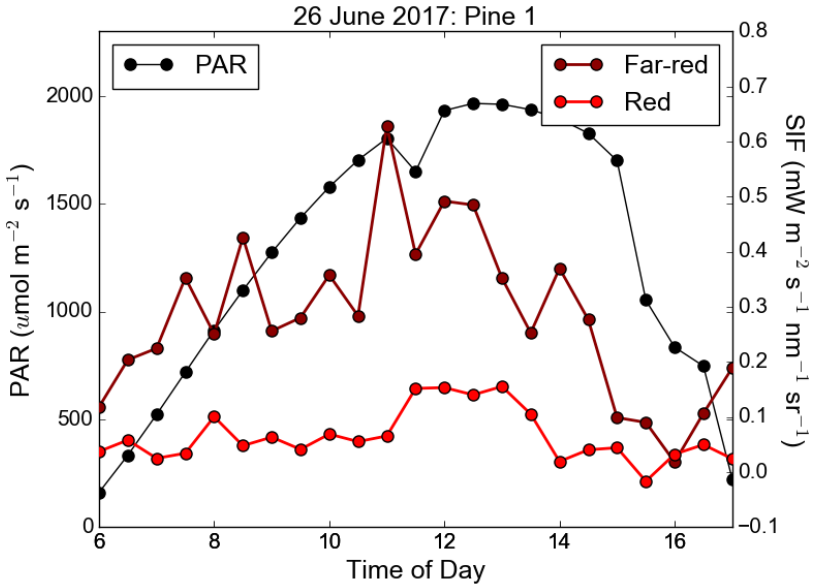
Niwot Ridge, CO PhotoSpec: Seasonal canopy average

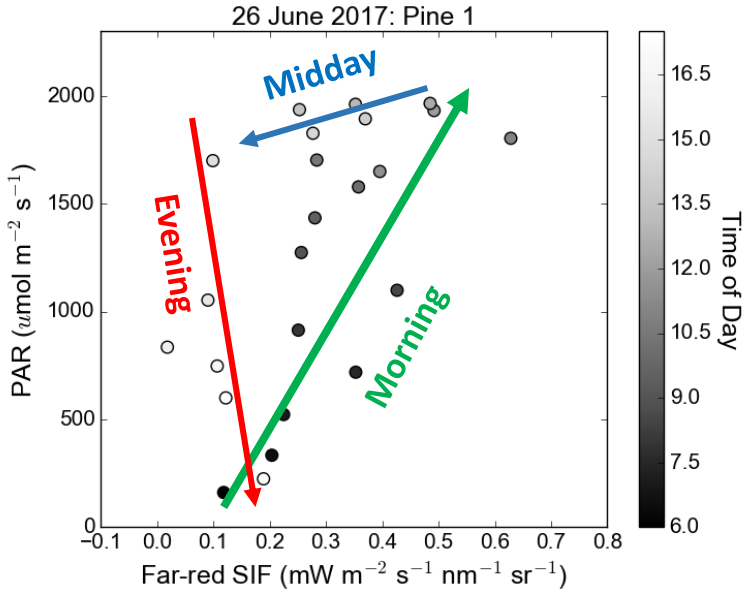


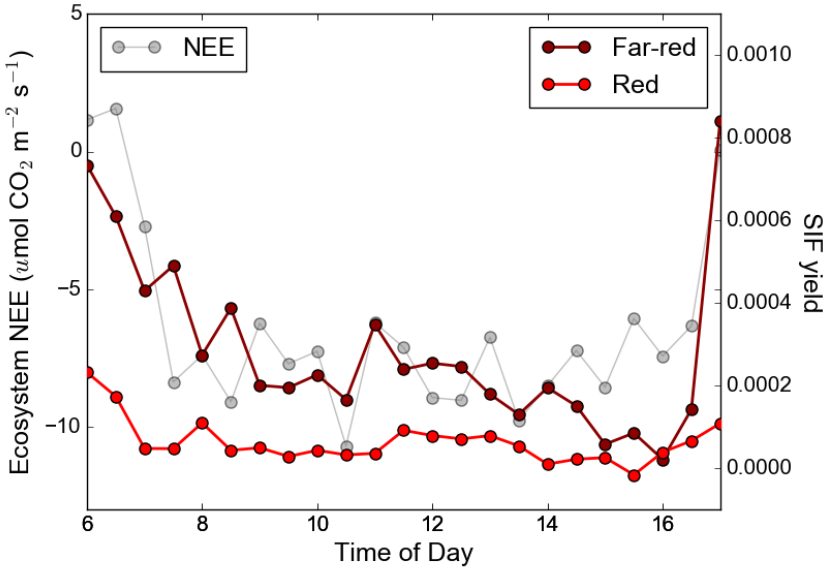


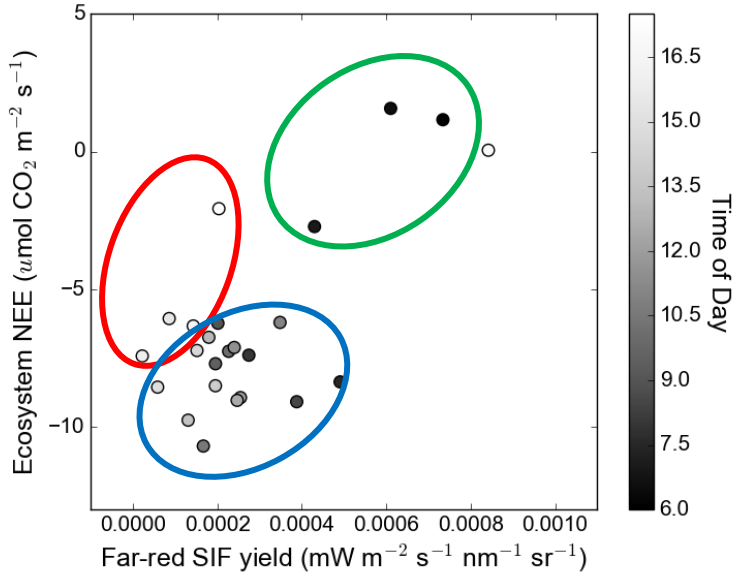
Middleton et al., 2017

Niwot Ridge, CO PhotoSpec: Diurnal cycle







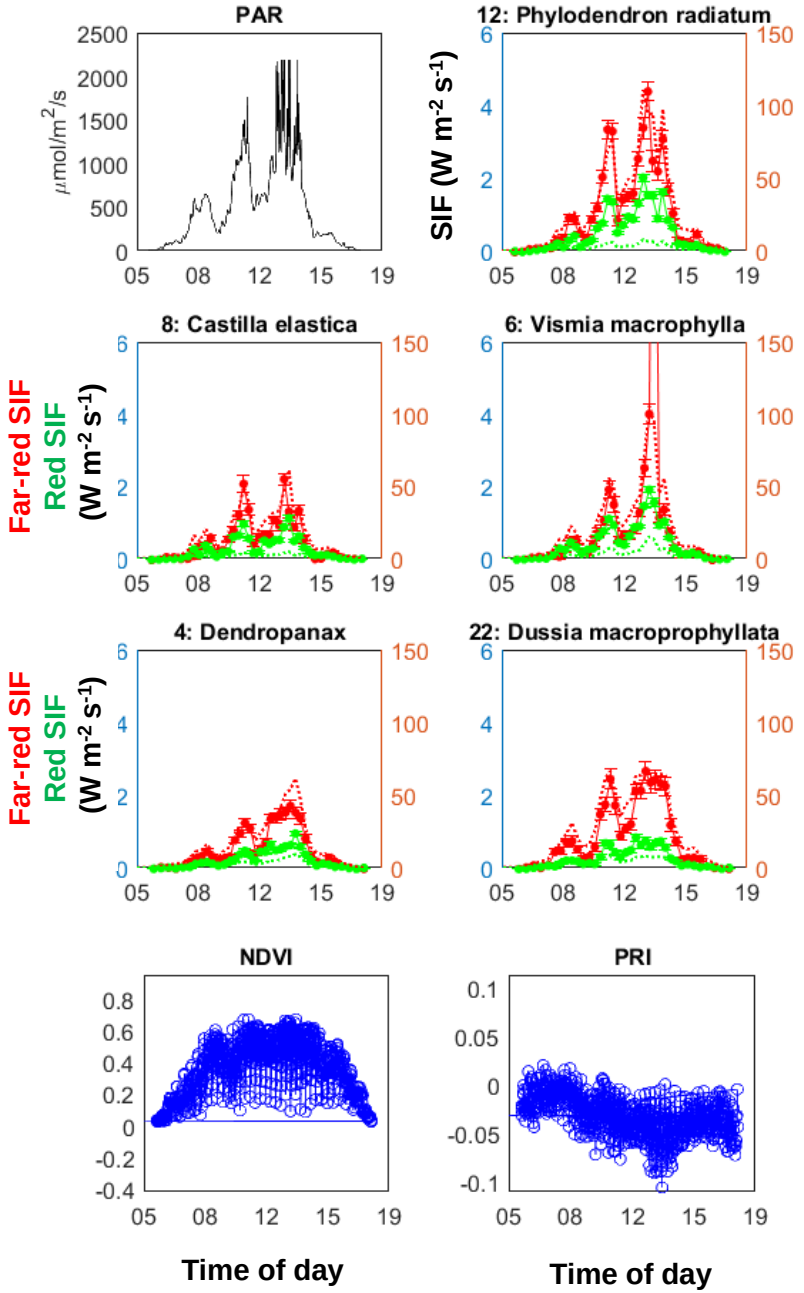


PhotoSpec – tower based SIF retrievals

1) Alpine/Evergreen (Colorado)
2) Tropical Rainforest (Costa Rica)
3) Corn (Iowa)
4) Soy (Iowa)

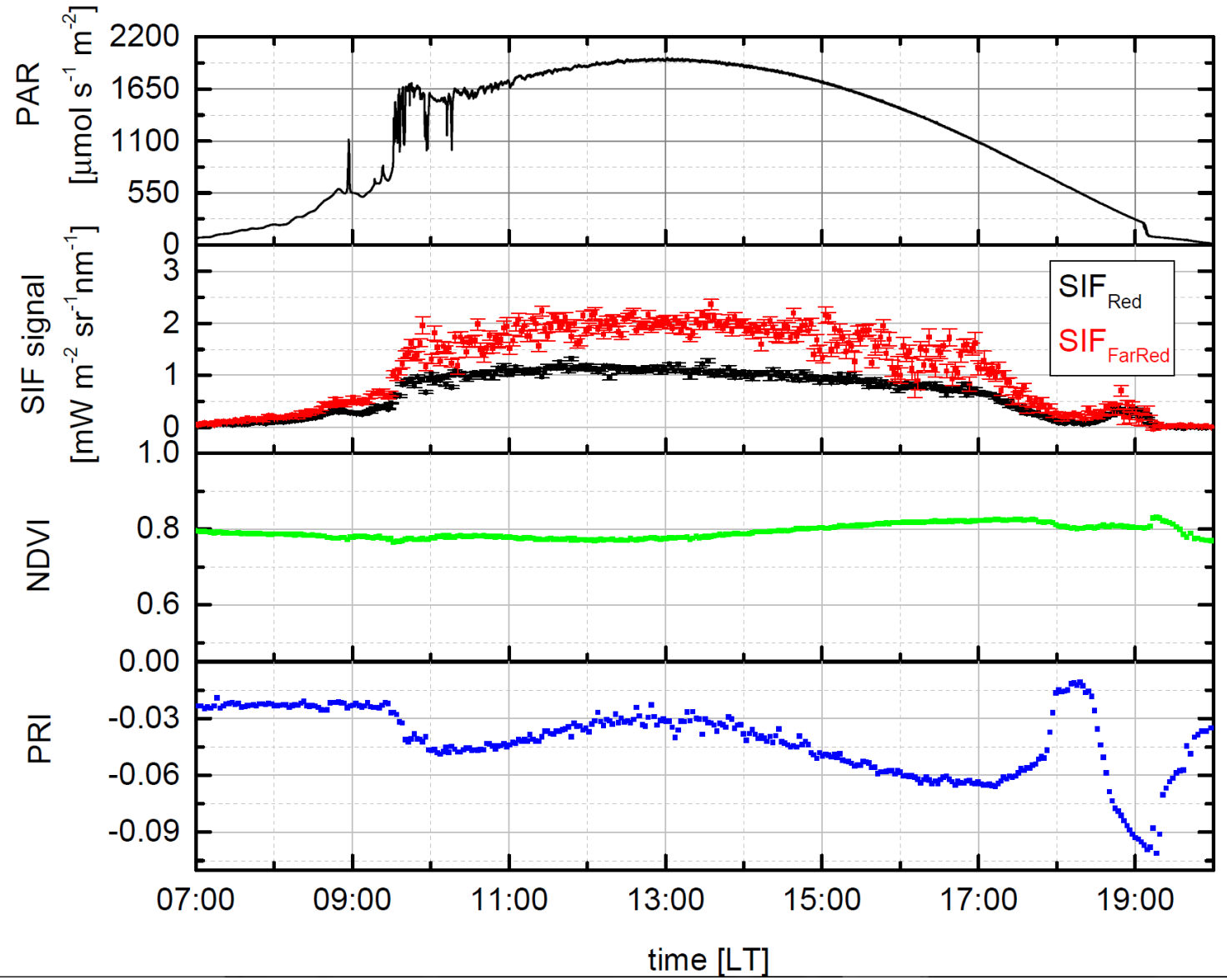
PhotoSpec – tower based SIF retrievals

1) Alpine/Evergreen (Colorado)
2) Tropical Rainforest (Costa Rica)
3) Corn (Iowa)
4) Soy (Iowa)



Grossman, Magney, Frankenberg, Stutz et al., *in review, AMT*

PhotoSpec characteristics



PhotoSpec characteristics

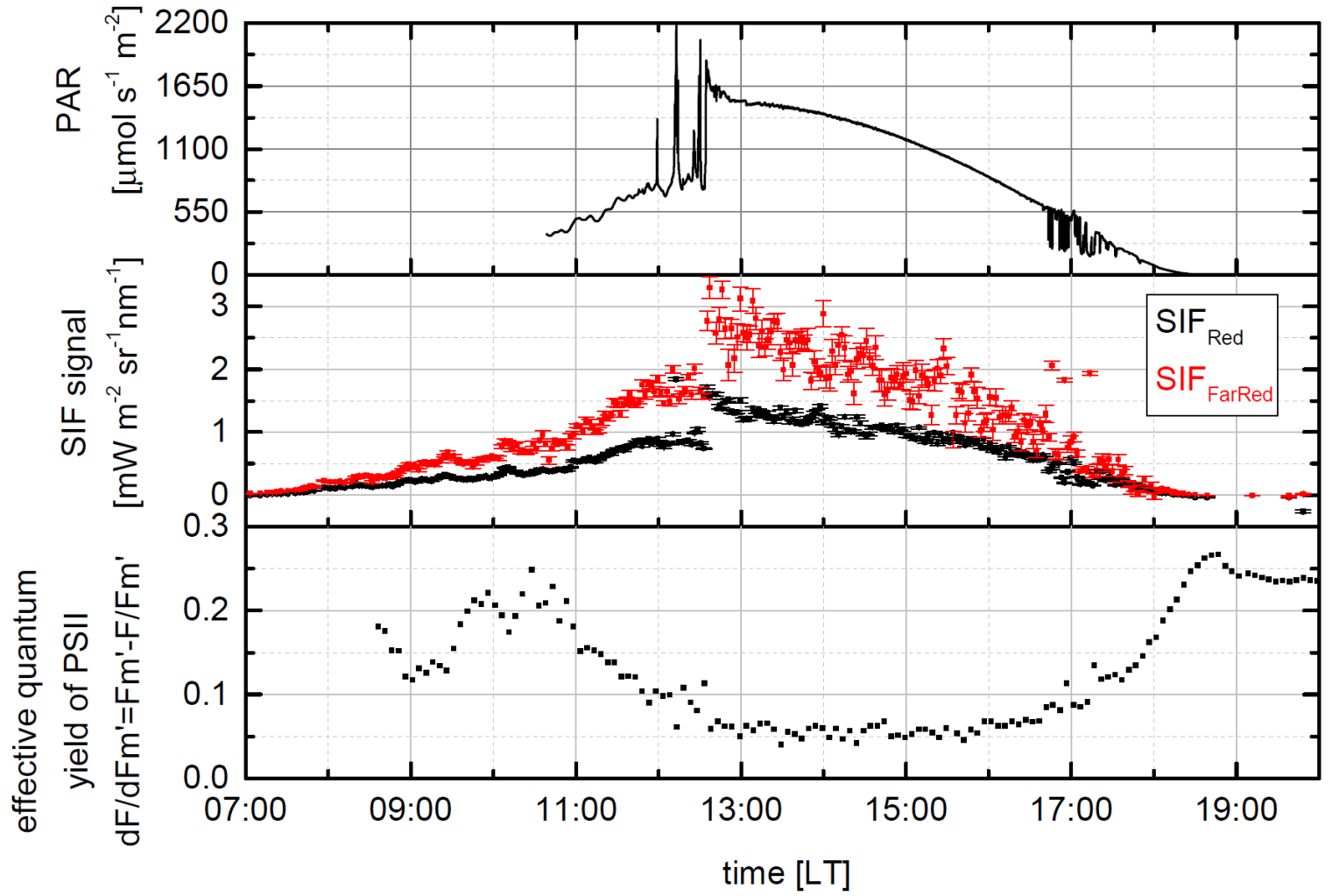


Figure 8. Diurnal cycle of PAR, SIF, NDVI, and effective quantum yield of PSII of a peace lily leaf (10/11/2016). The distance between the peace lily leaf and the PhotoSpec telescope is approximately 1 m.

PhotoSpec characteristics

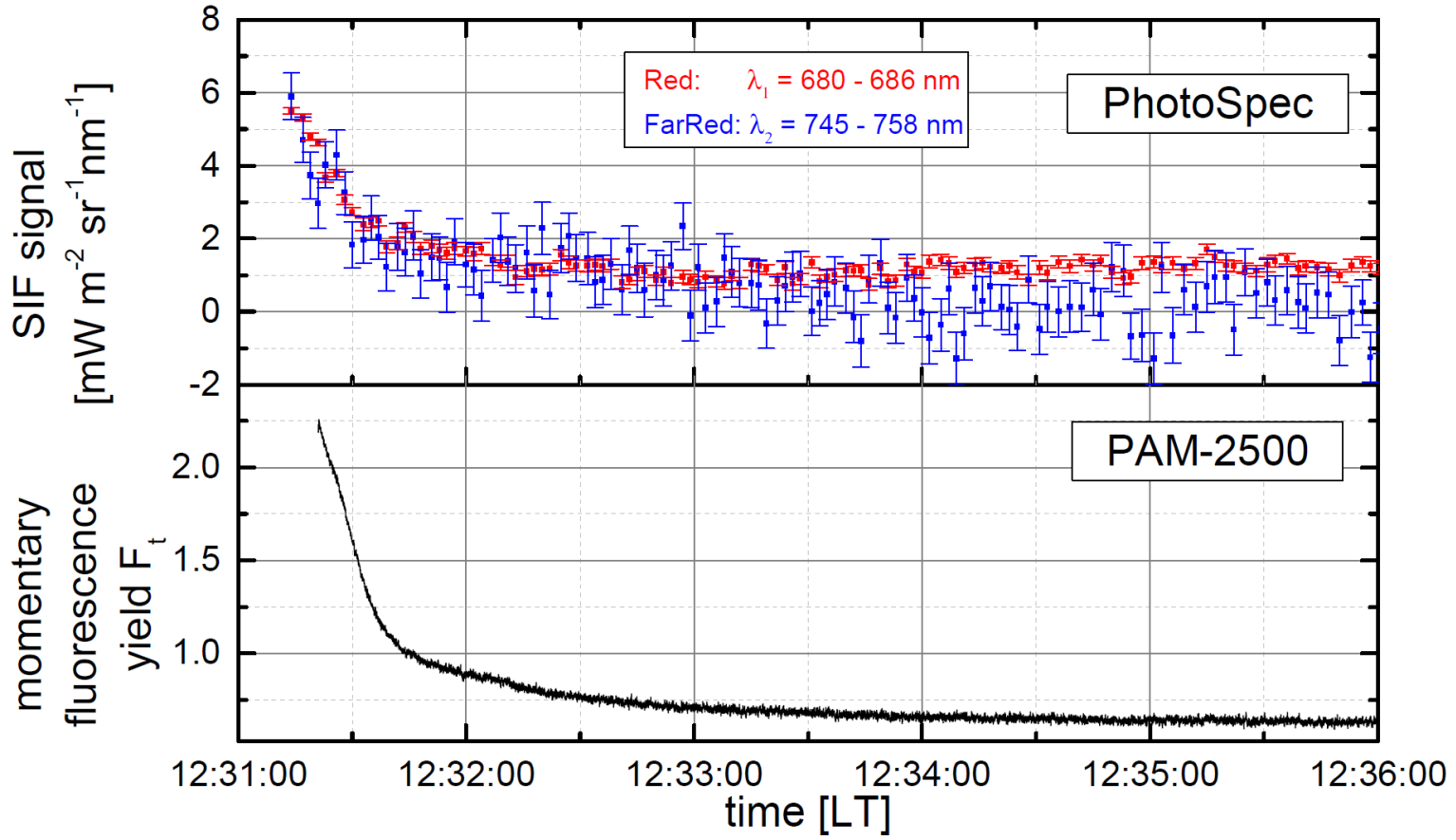


Figure 7. Four dark-light tests (Kautsky curve) of a single banana leaf on 10/18/2016.

Walz GFS-3000 Modification

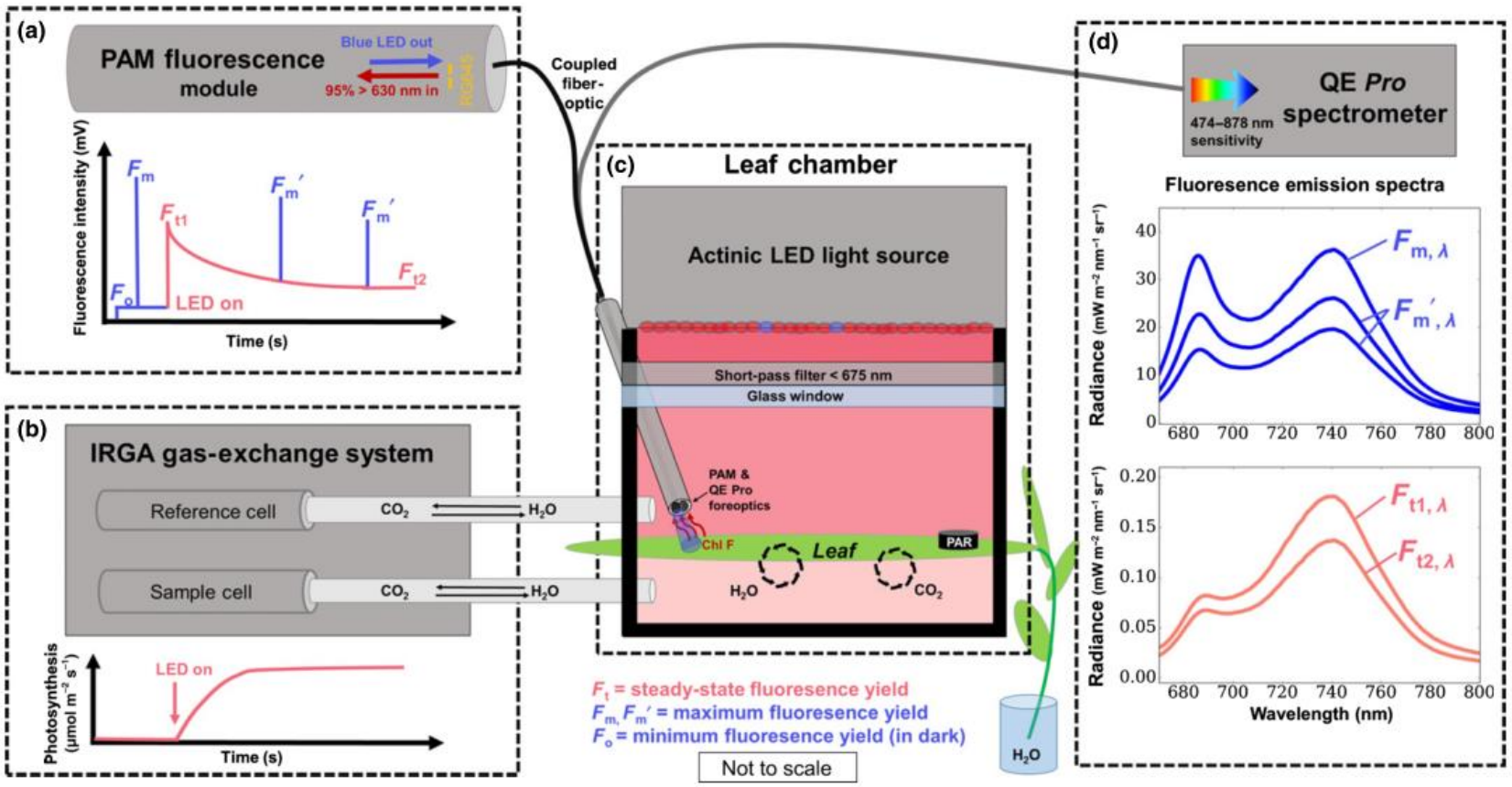
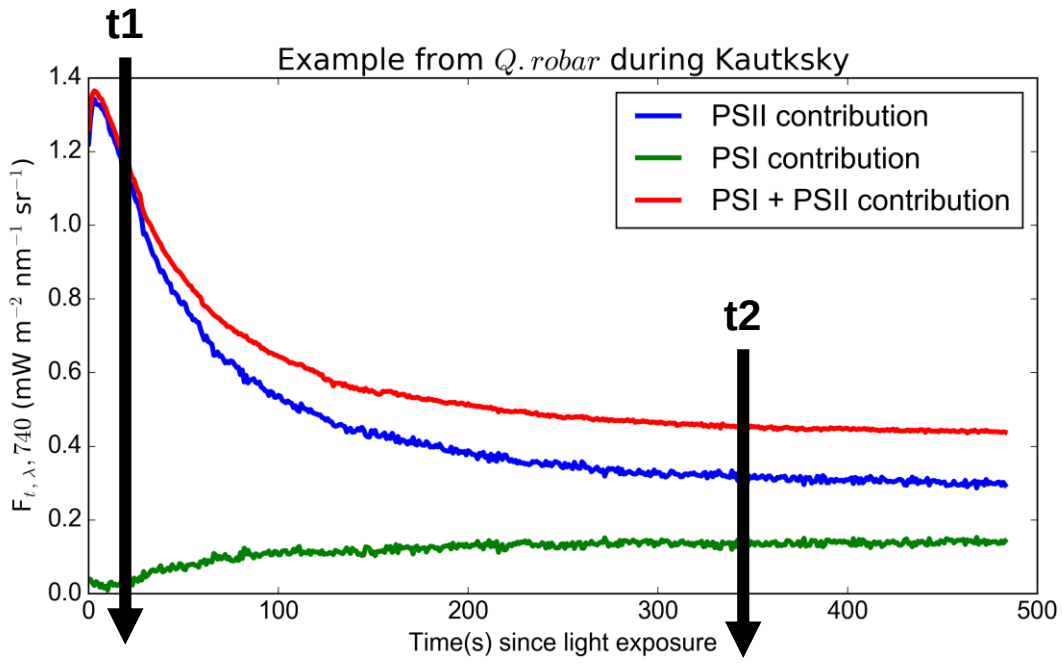
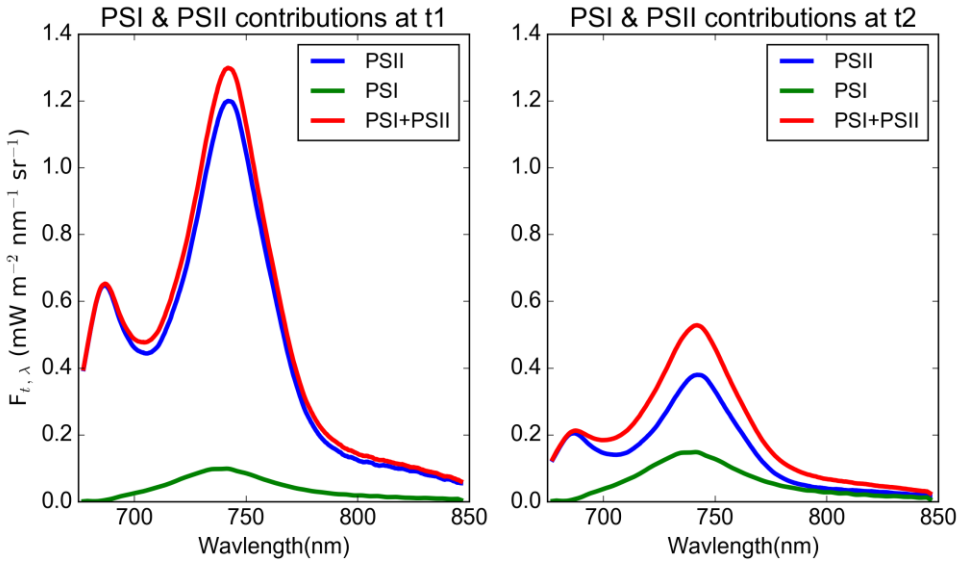


Fig. 1 Schematic of leaf-level measurement system. (a) Typical pulse-amplitude modulation (PAM) fluorescence trace during initial exposure to light. Note that the colors (blue and pink) represent the color of the light that is driving the signal even though all PAM parameters are computed from a blue light-emitting diode (LED). (b) Basic schematic of the infrared gas analyzer (IRGA) with a trace of a light response curve (showing net photosynthesis) under exposure to actinic light (similar in time to (a)). (c) Diagram of the leaf chamber, insertion of the fiberoptics from PAM and spectrometer (QE *Pro*), and the representative colors of light being emitted by the PAM and actinic LEDs. Note that the actinic LED light source is 90% red LEDs and 10% blue LEDs, and is somewhat attenuated by the short-pass filter (showing a slightly lighter 'pink' color beneath filter). A photosynthetically active radiation (PAR) sensor is placed at the leaf surface, and the coupled PAM and QE *Pro* foreoptic is *c*. 2 mm from the leaf surface. (d) Spectral fluorescence curves associated with $F_{m,\lambda}$ and $F_{m',\lambda}$ (driven by blue light) and $F_{t,\lambda}$ (driven by actinic LEDs) and corresponding times shown in the fluorescence trace in (a).

Controls on the shape of the SIF spectrum at the leaf scale

Rapid Induction

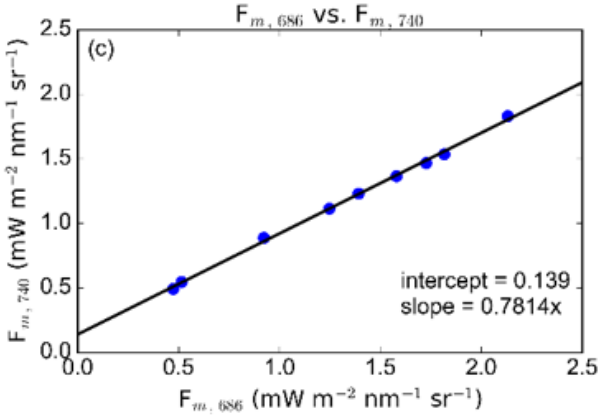




Separation of PSI and PSII spectra

Three assumptions:

1) the contribution of PSI SIF at 685 nm is negligible
2) PSI fluorescence is not dynamic
3) Chl content is constant.



Step 1:

-Offset of F_{686} vs. F_{740} represents PSI

-Palombi et al. 2011

Step 2:

SVD analysis assuming:

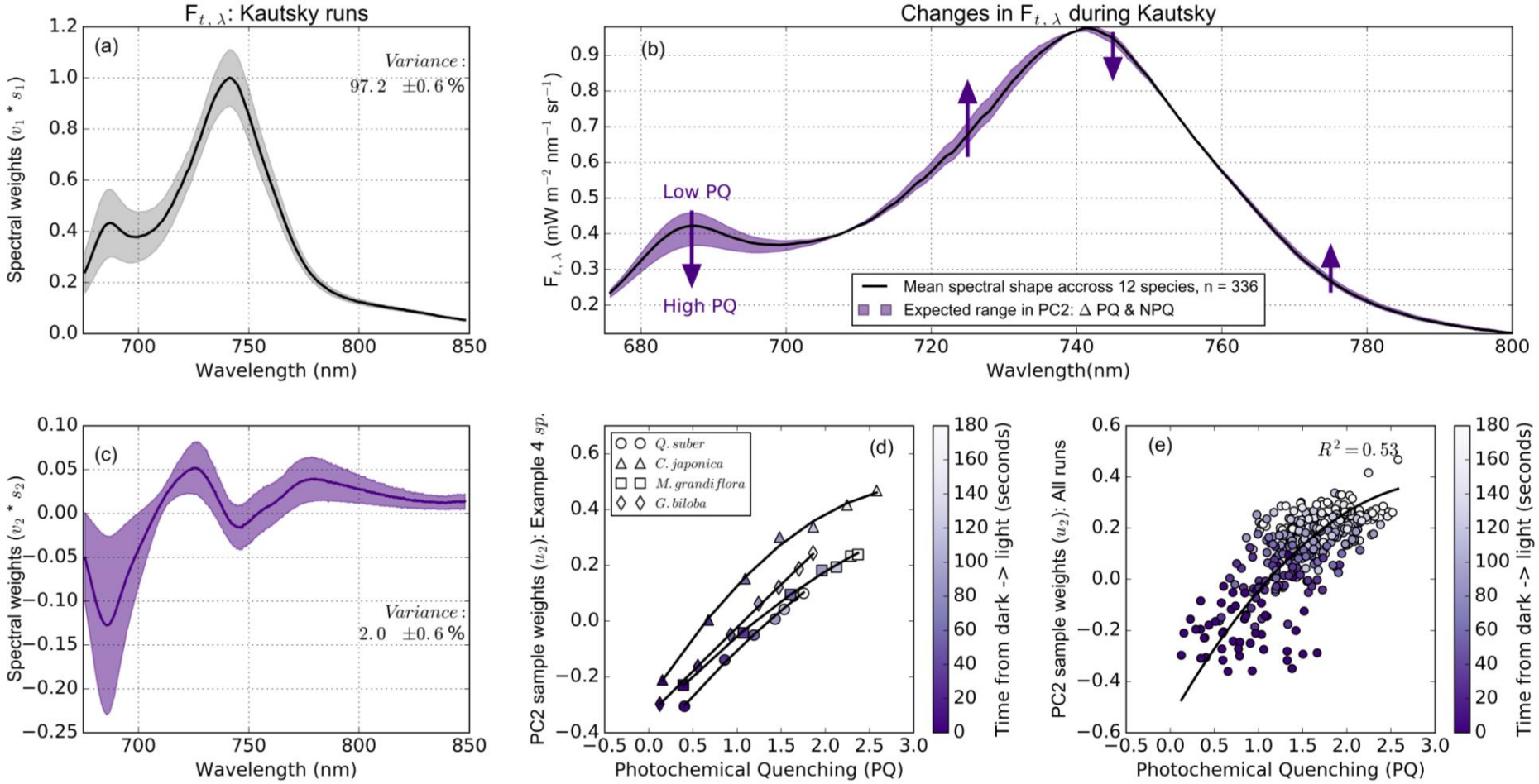
-PSI and PSII are a linear combination of the first two sample weight vectors

PSI = $x_1 * u_1 + x_1 * u_2$

PSII = $x_2 * u_2 + x_2 * u_2$

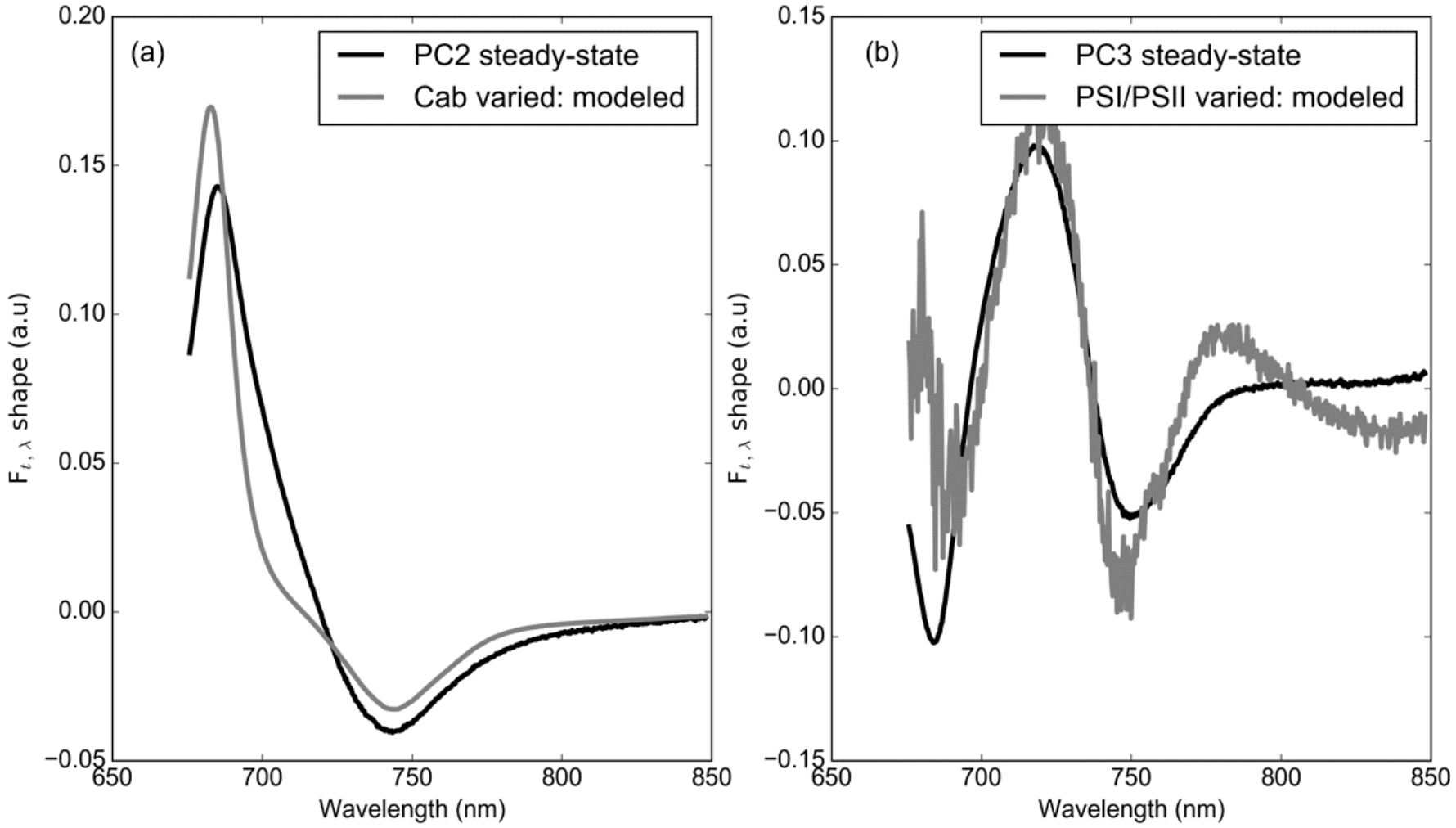
Controls on the shape of the SIF spectrum at the leaf scale

Rapid Induction

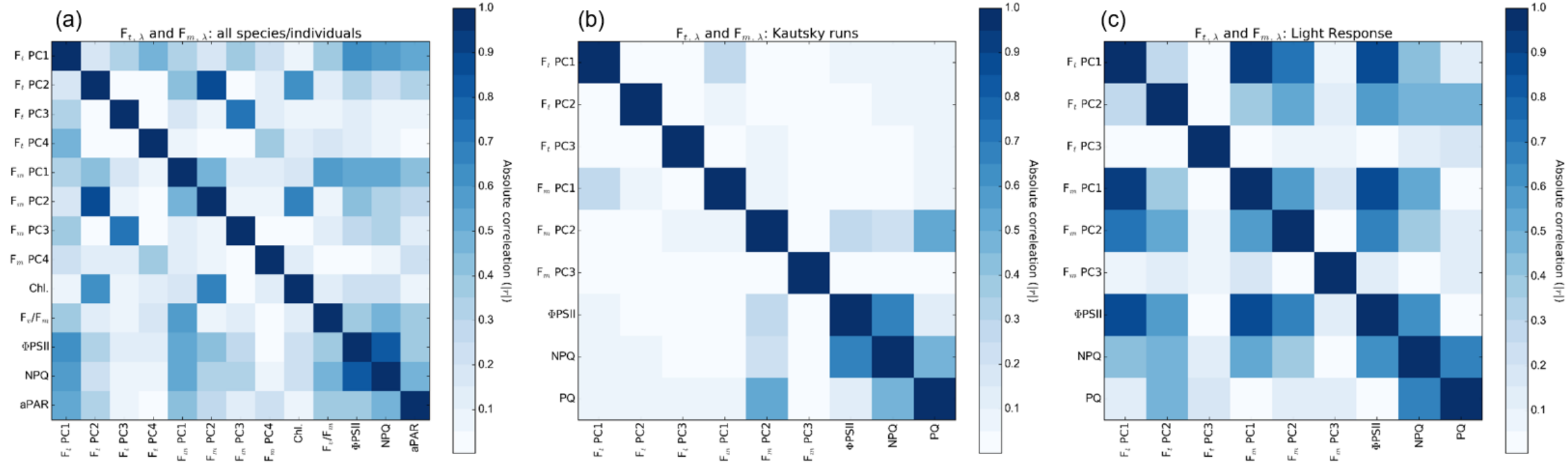


Controls on the shape of the SIF spectrum at the leaf scale

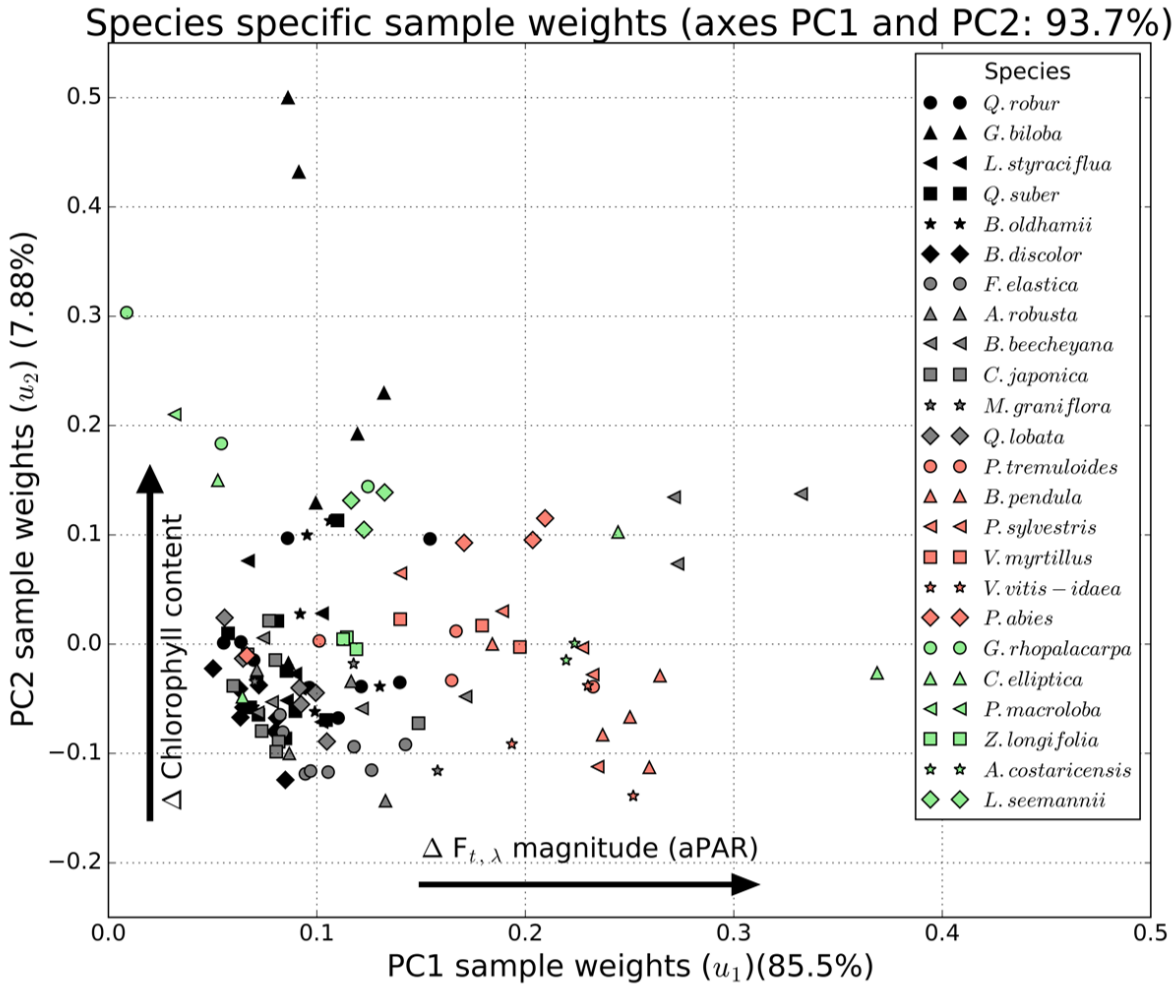
Steady-state



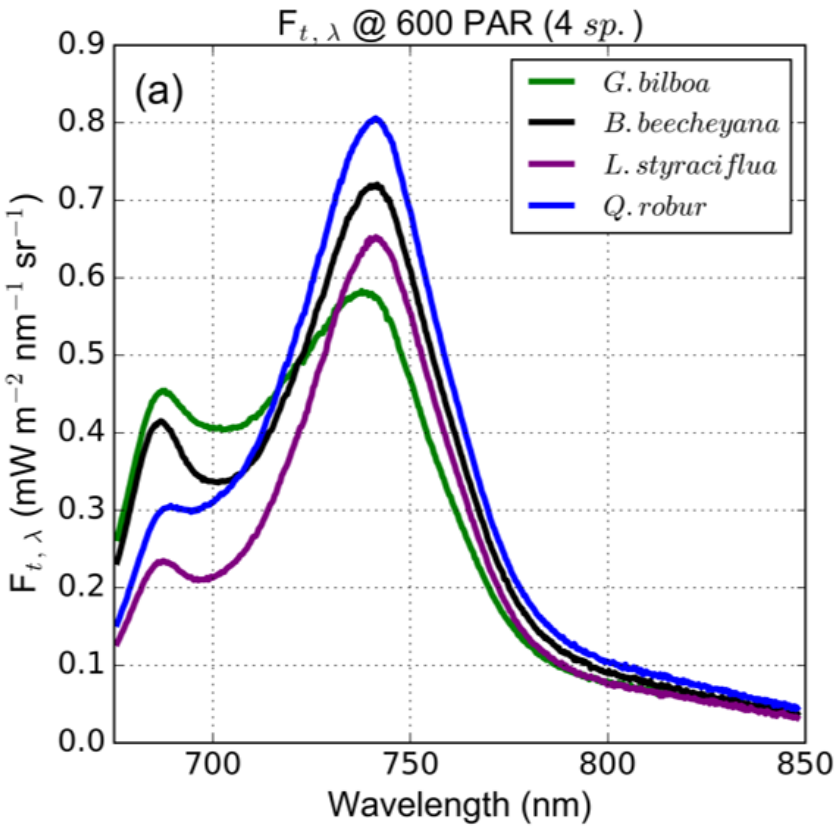
Sample weights vs. ancillary data

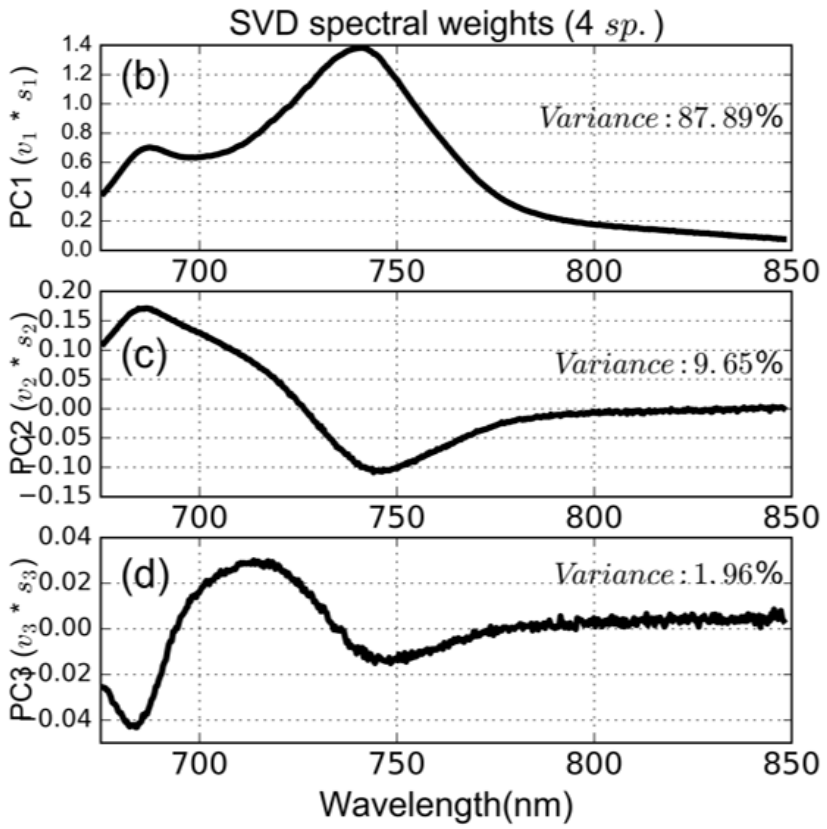


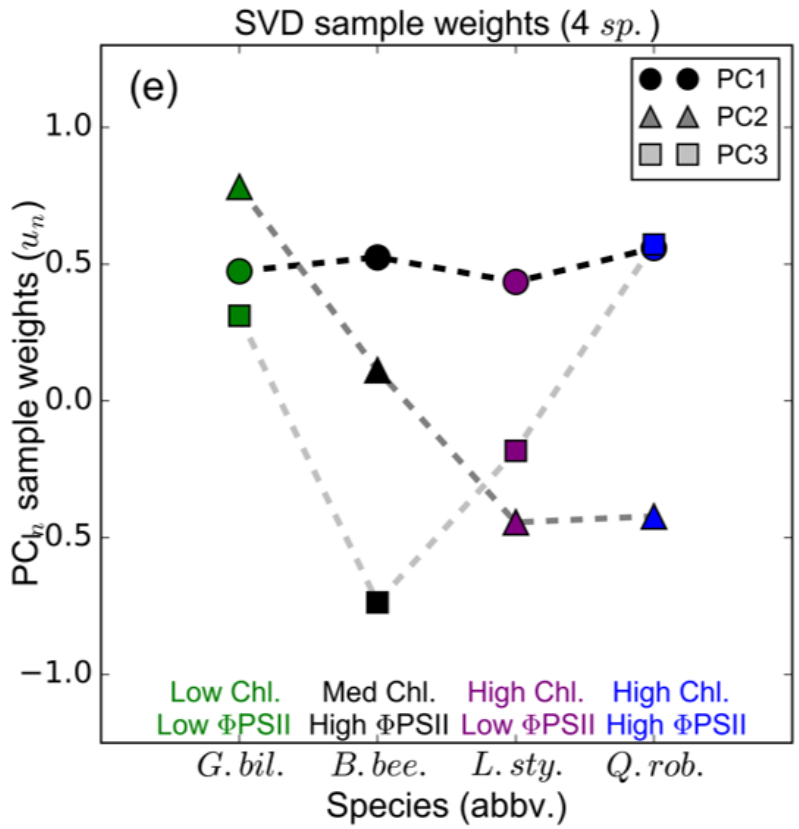
No species specific clustering = no species specific signal?



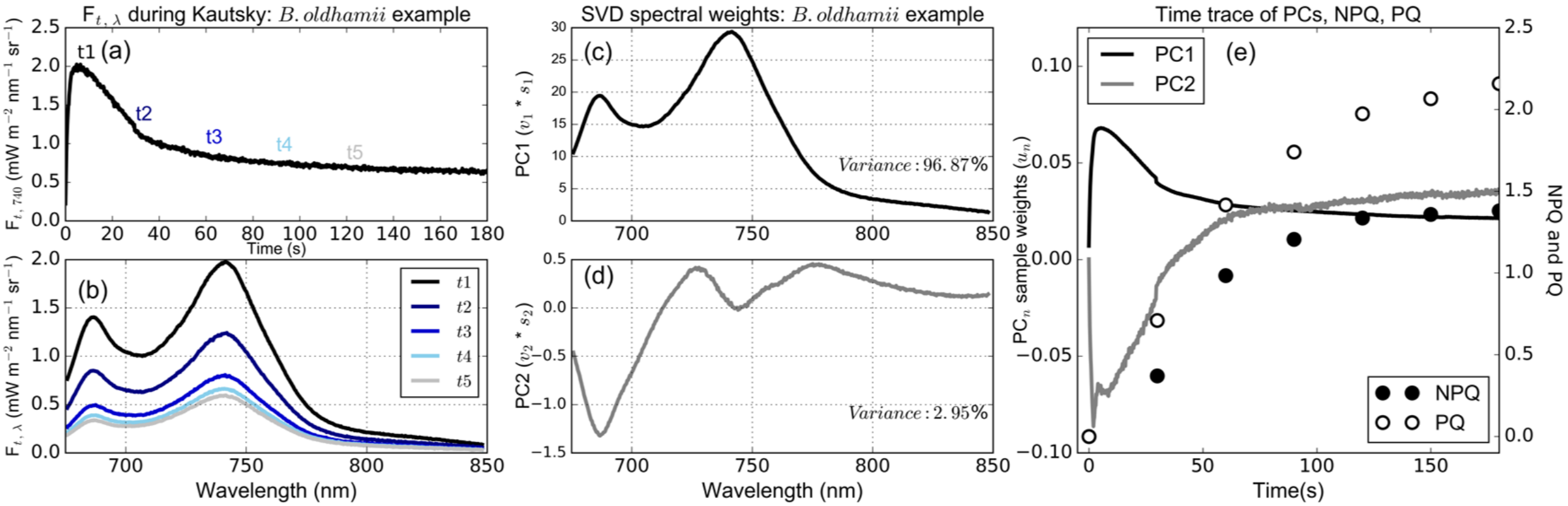
Steady-state experiment design



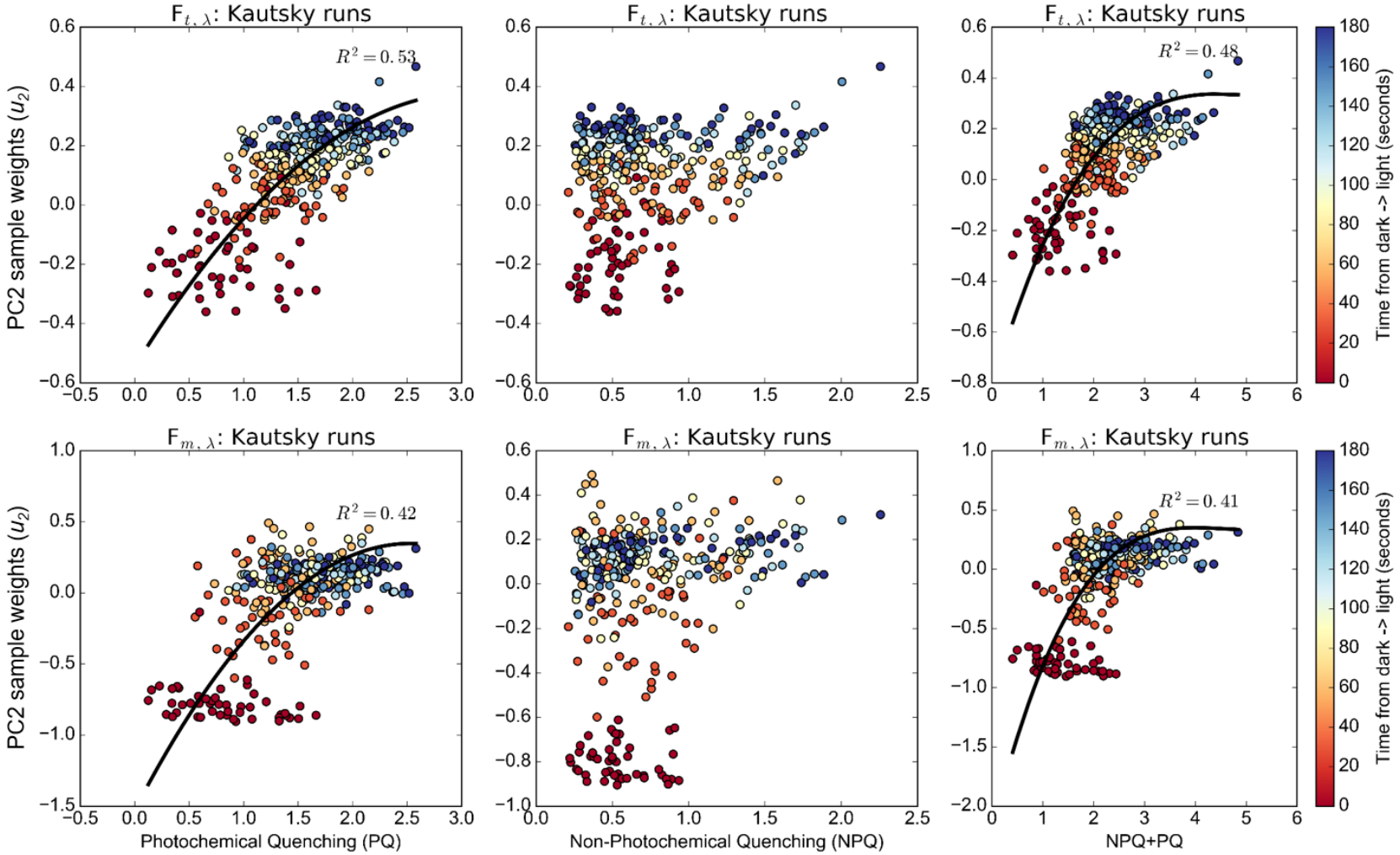




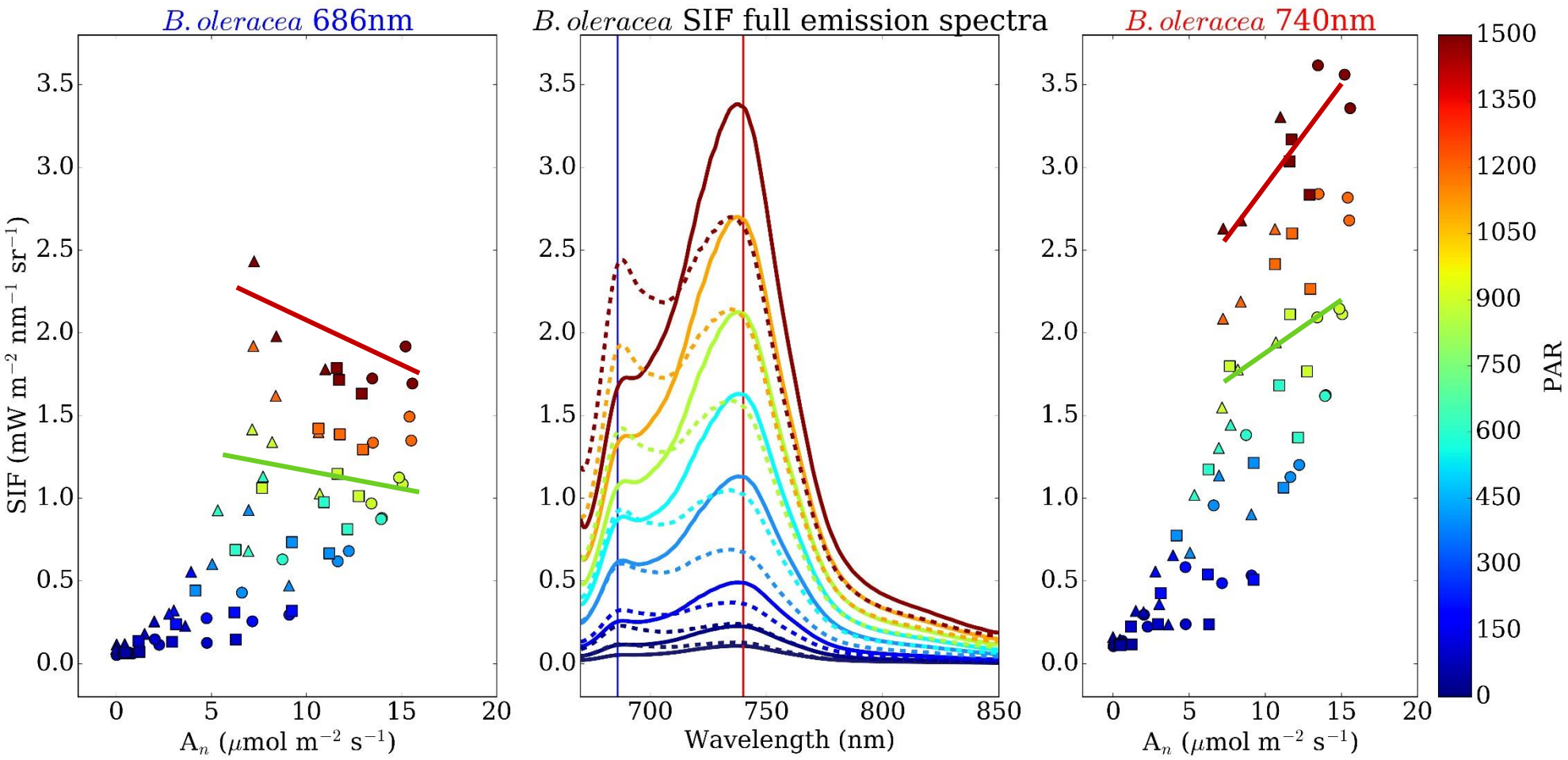
Rapid induction (Kautksy) experiment design



PC2 from Kautsky corresponds with both NPQ and PQ
…but NPQ saturates



Red and Far-red SIF vs. photosynthesis



Magney et al., *in prep.*

Low Water
Medium Water
High Water

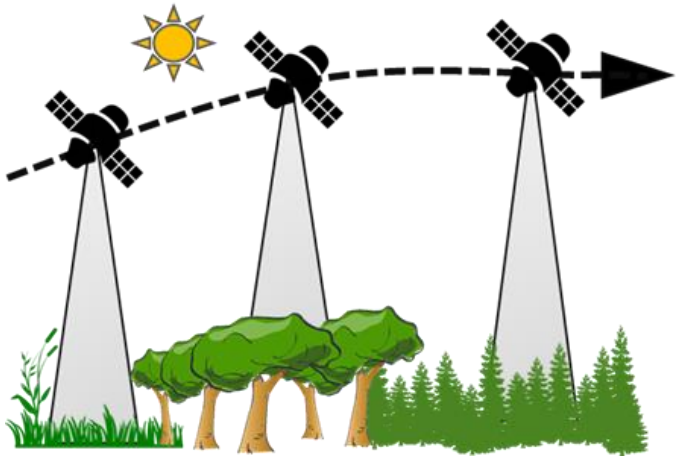
Low Water
Medium Water
High Water

Low Water
Medium Water
High Water

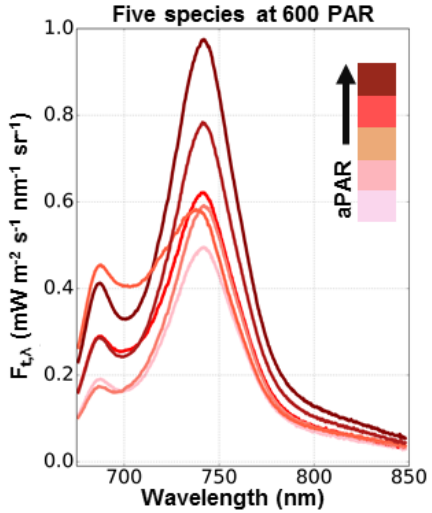
Controls on the shape of the SIF spectrum at the leaf scale

All experiments

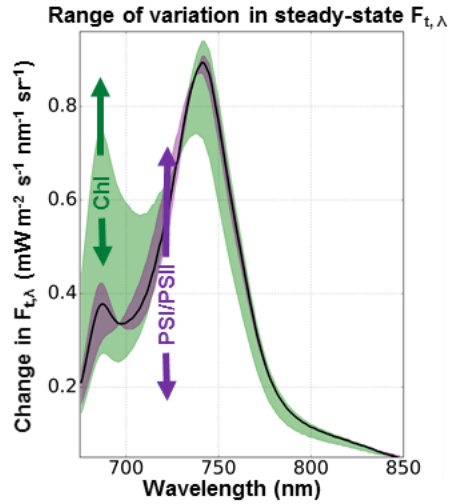
Single overpass, multiple canopies



Analogous to…



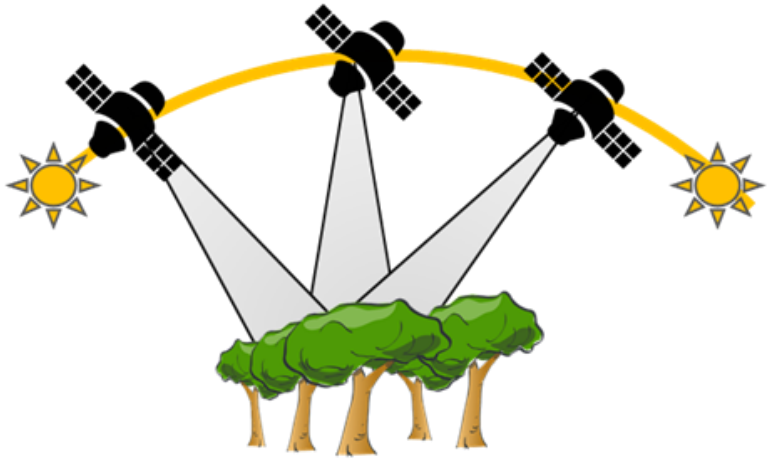
Primary control (magnitude)
-aPAR * $\Phi F_{t,\lambda}$



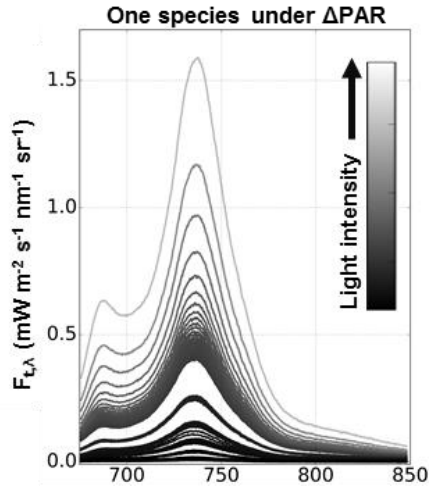
Secondary control (shape)
-Pigments, Chlorophyll

Tertiary control (shape)
-Photochemistry, Δ NPQ, PQ

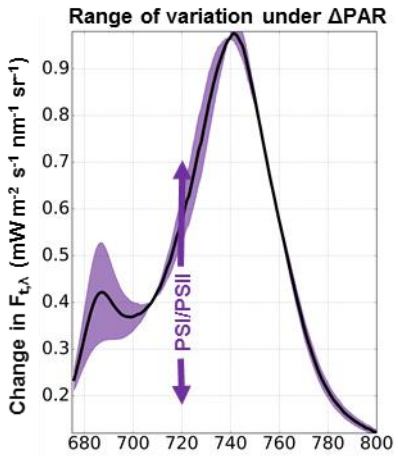
Multiple overpasses, same canopy



Analogous to…



Primary control (magnitude)
-aPAR * $\Phi F_{t,\lambda}$



Secondary control (shape)
-Photochemistry, Δ NPQ, PQ yields