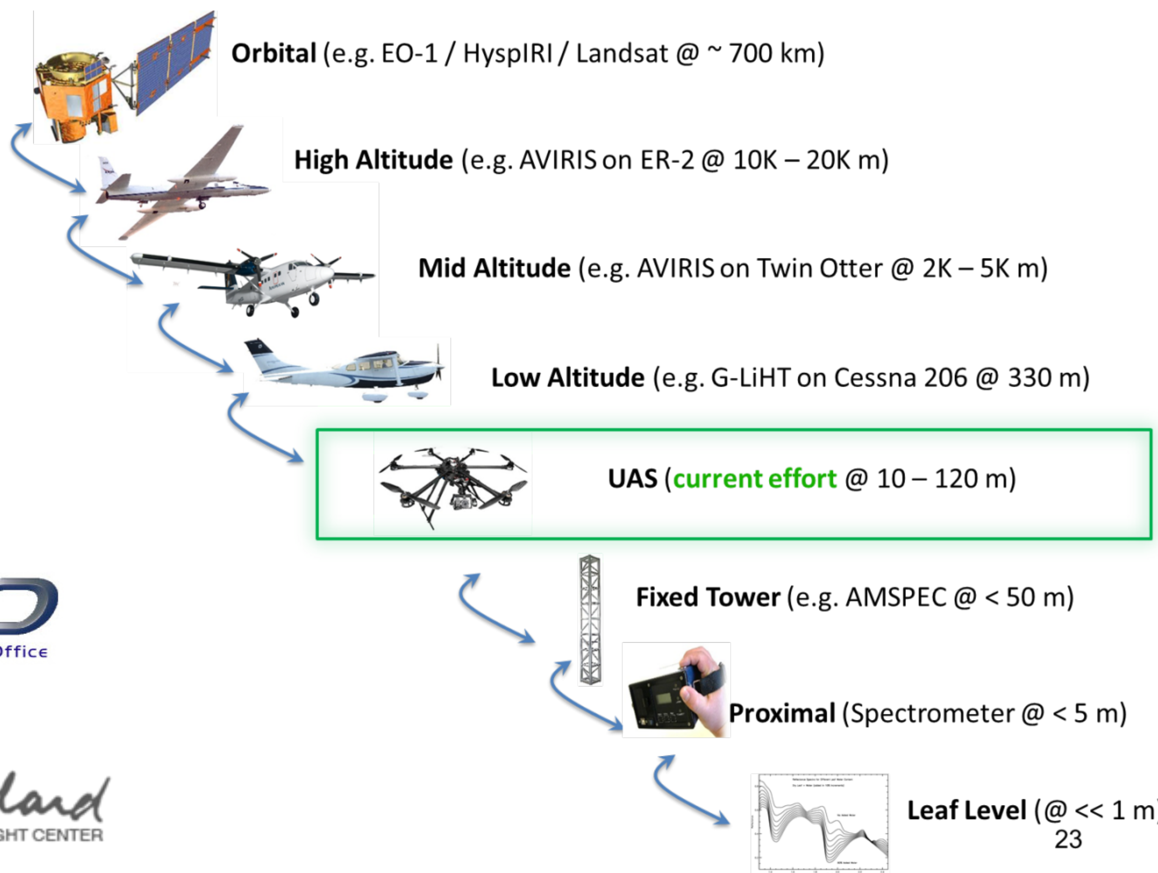
NG UAS-Based SPECTRAL SYSTEMS FOR ENVIRONMENTAL MONITORING

Presenter: Petya Campbell

University of Maryland at Baltimore County, Catonsville, MD and
NASA/Goddard Space Flight Center, Greenbelt, MD



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1. Next Generation Spectral Systems for Environmental Monitoring (NASA/AIST14)

P. Campbell[a,b] - PI, D. Mandl[b] -Technology Lead, P. Townsend [c] - Science Lead, C. Kingdon [c], V. Ly[b], R. Sohlberg[d], L. Corp[b], L. Ong[b], P. Cappelaere[b], S. Frye[b], M. Handy[b], J. Nagol[d] and V. Ambrosia[e]

2. NASA/GSFC EO-1 and HyspIRI Missions Science (NASA/Ecology)

E. Middleton[b] - PI, F. Huemmrich[a,b],P. Campbell[a,b], L. Corp[b], C. Zhang[b]

NASA's Fluorescence Airborne Research Experiment (FLARE, NASA/TE)

B. Cook[b] - PI, L. Corp[b], E. Middleton[b], C. Hansen, Zbyněk Malenovský[j], D. Morton, F. Huemmrich[a,b], P. Campbell[a,b]

3. Collaborators: C. Daughtry[f] , J. Gammon[g], A. McArthur[h], C. van der Tol [i], J. Albrechtova[k], T. Julitta[l]

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Applications

UAV based science quality spectral systems, measuring both reflectance and fluorescence are needed for efficient remote sensing monitoring, including:

- Ecosystem Management - Forestry and Bio-diversity Management, Precision Farming
  - repeated monitoring at the right time
  - monitoring at the right scale and rate of specific trait variation
  - scaling from field to stand and regional scale

- Carbon cycle and ecosystems function
  - reflectance captures the bio-physical traits with seasonal dynamics, such as canopy nitrogen, photosynthetic pigments, LAI, non-photosynthetic material
  - solar induced fluorescence (SIF) provides a direct probe to vegetation photosynthetic function, capturing it's diurnal and seasonal dynamics

- Extreme climatic natural and anthropogenic events
  - disaster response
  - aircraft and satellite measurements may not exist , or be feasible

Next Generation Monitoring – automated, calibrated and flexible (e.g. scale and frequency) reflectance and fluorescence data acquisition.

Photograph by Don Deering

Measurements - *WHAT and WHEN*

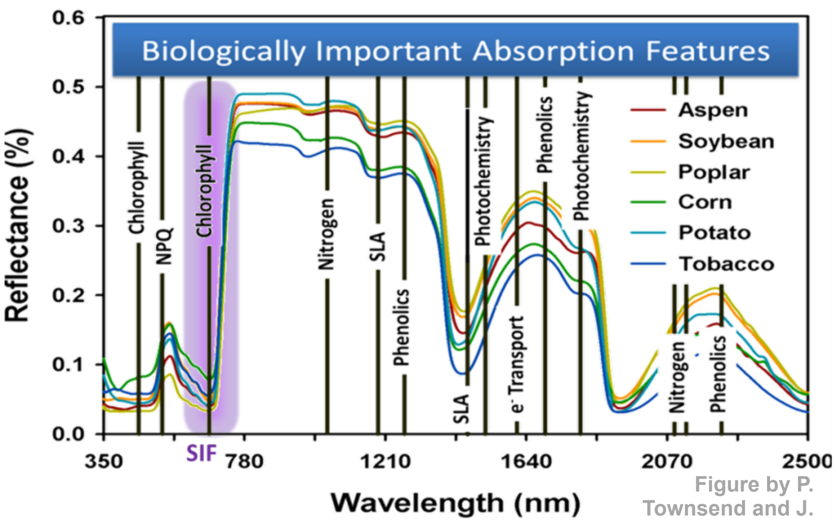
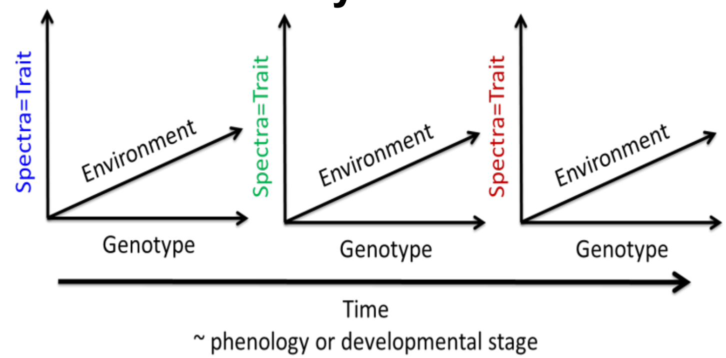
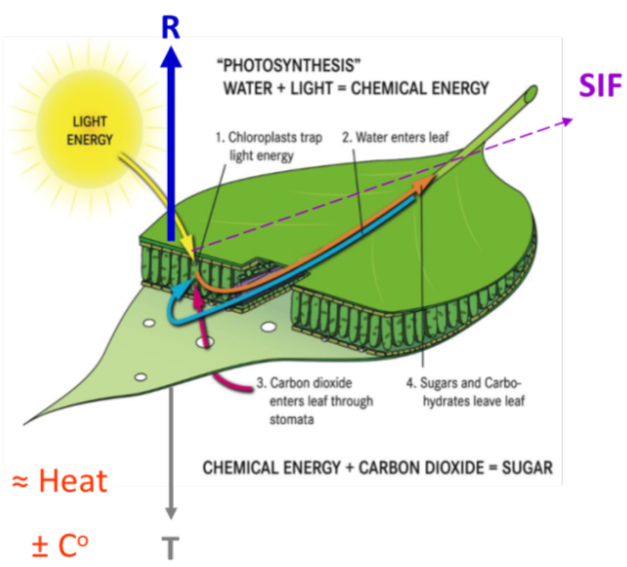


Figure by P. Townsend and J. Couture

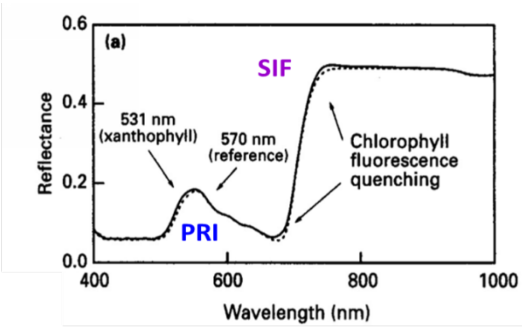
Traits with Different Diurnal & Seasonal Dynamics



- Canopy reflectance and fluorescence vary at different rates
- Photosynthesis varies diurnally and is dynamically regulated



"Photosynthesis" from ESA/FLEX final report, 2015. Modified adding reflectance, transmittance, heat and fluorescence (P. Campbell, 2015).



✓ Vegetation water content, rate of photosynthesis and the associated reflectance spectra

✓ Solar Induced Fluorescence (SIF)

Science Objectives & Approach

The project goal is develop a high spectral resolution Unmanned Aerial System (UAS), with line and imaging spectrometers capable of:

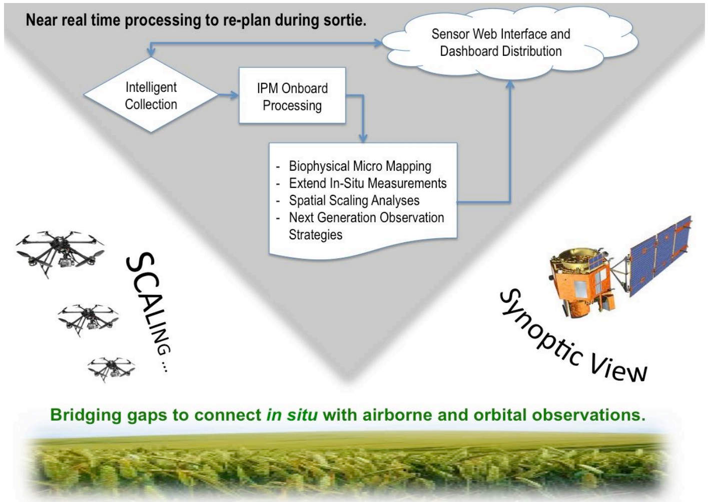
- Producing science-quality spectral data:
  - For retrieval of biochemical and physiological traits
  - Objective: identify key flight and instrument parameters that can be manipulated to maintain the quality of the spectra
    - Integration time
    - UAS location relative to sun and shadow
    - Other parameters TBD
- Employing an intelligent gathering scheme to semi-automate:
  - spectral data acquisition,
  - processing workflows, and
  - tasking and operation strategy
- ULITAME GOAL - Characterizing diurnal and seasonal cycles in vegetation function

Next Generation UAV Spectral Systems for Environmental Monitoring

PI: Petya Campbell, University of Maryland Baltimore County and NASA Goddard Space Flight Center

Objectives

- Develop capability to depict diurnal and seasonal cycles in vegetation function:
  - accurate measurements of vegetation reflectance at high spectral resolution
  - high temporal frequencies and stability
  - Spatial variability with high resolution
  - Optimize data acquisition and workflow
- Demonstrate the capability to produce science-quality spectral data from UASs
  - suitable for scaling ground measurements
  - Comparison to on-orbit data products
- Integrate small hyperspectral UAS with SensorWeb components



Approach:

- Test and validate measurements *in-situ* at well-characterized sites
  - ✓ Step 1 - Integrate line spectrometer and imaging spectrometer on moving field platforms
  - ✓ Step 2 - Integrate spectrometers on UAS
- Develop Rapid Data Assimilation and delivery system
- Develop data gathering campaign strategy to optimize data quality and yield
  - ✓ Leverage EcoSIS online spectral library

Co-Is/Partners:

Daniel Mandl, NASA/GSFC; Philip Townsend, University of Wisconsin-Madison; Robert Sohlberg, University of Maryland; Lawrence Ong, NASA/GSFC-SSAI; Vuong Ly, NASA/GSFC; Lawrence Corp, NASA/GSFC-SSIA; Patrice Cappelaere, Vightel Co.; Jyoteshwar Nagol, UMD; Clayton Kingdon and Felix Navarro, University of Wisconsin-Madison; Vincent Ambrosia, CSUMB.

Key Milestones

Current

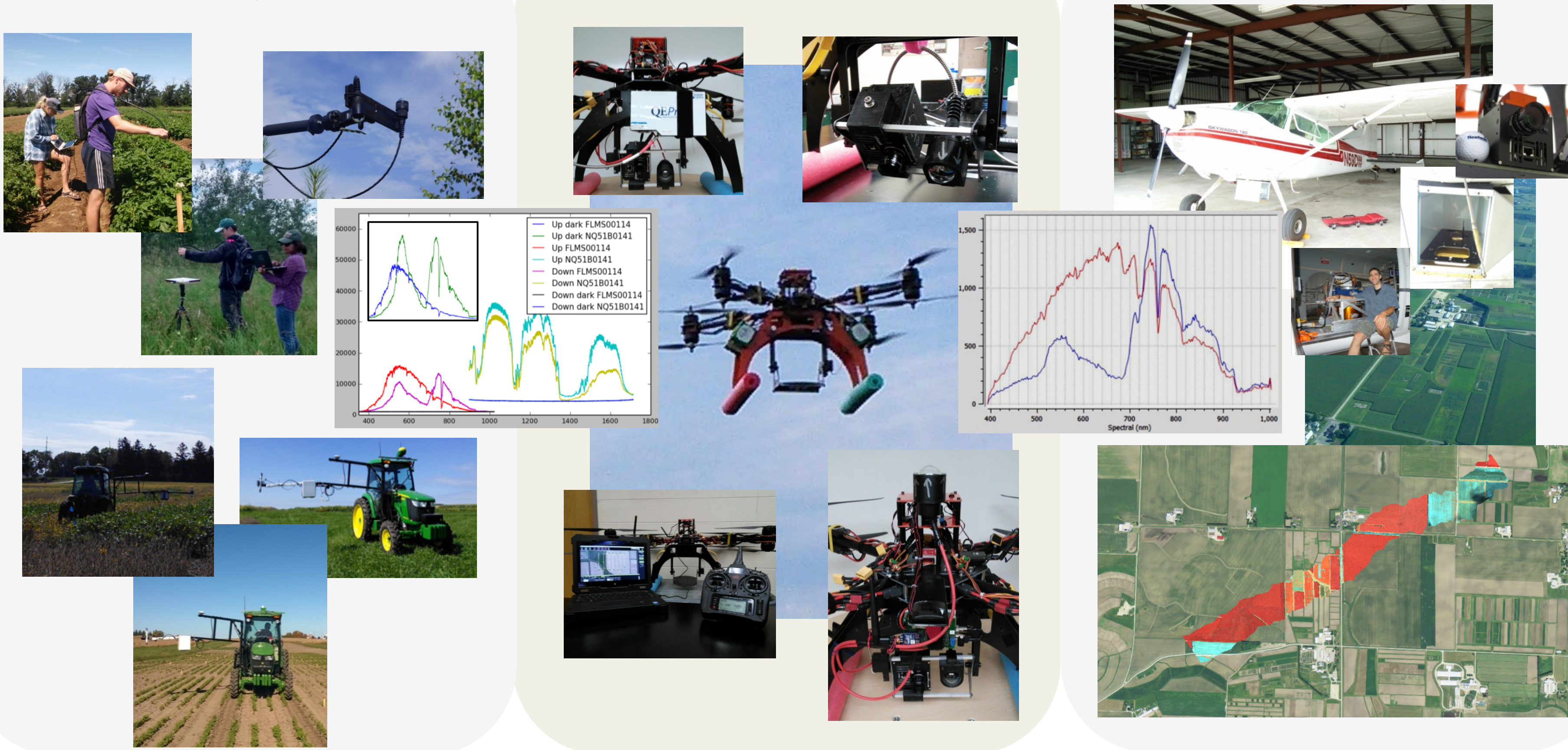
- Start Project 6/2015
- Test spectrometer flight configurations *in-situ* on multiple moving platforms (e.g. tram/tractor) 8/2016
- Flight Readiness Review and Approval 12/2016
- Hexacopter flights with line spectrometers 2/2017
- Hexacopter flights with imaging spectrometer 4/2017
- Semi-autonomous retrieval of vegetation traits 5/2017
- Semi-autonomous retrieval of diurnal and seasonal traits 10/2017

TRL_{In} = 3, TRLcurrent = 4 TRLend = 5/6

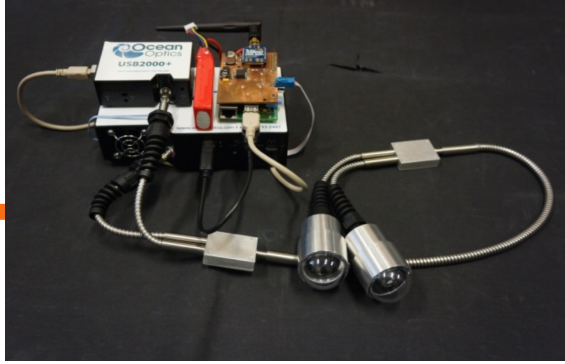
ESTO
Earth Science Technology Office

Field Measurement Tests: Spectroscopic Measurements

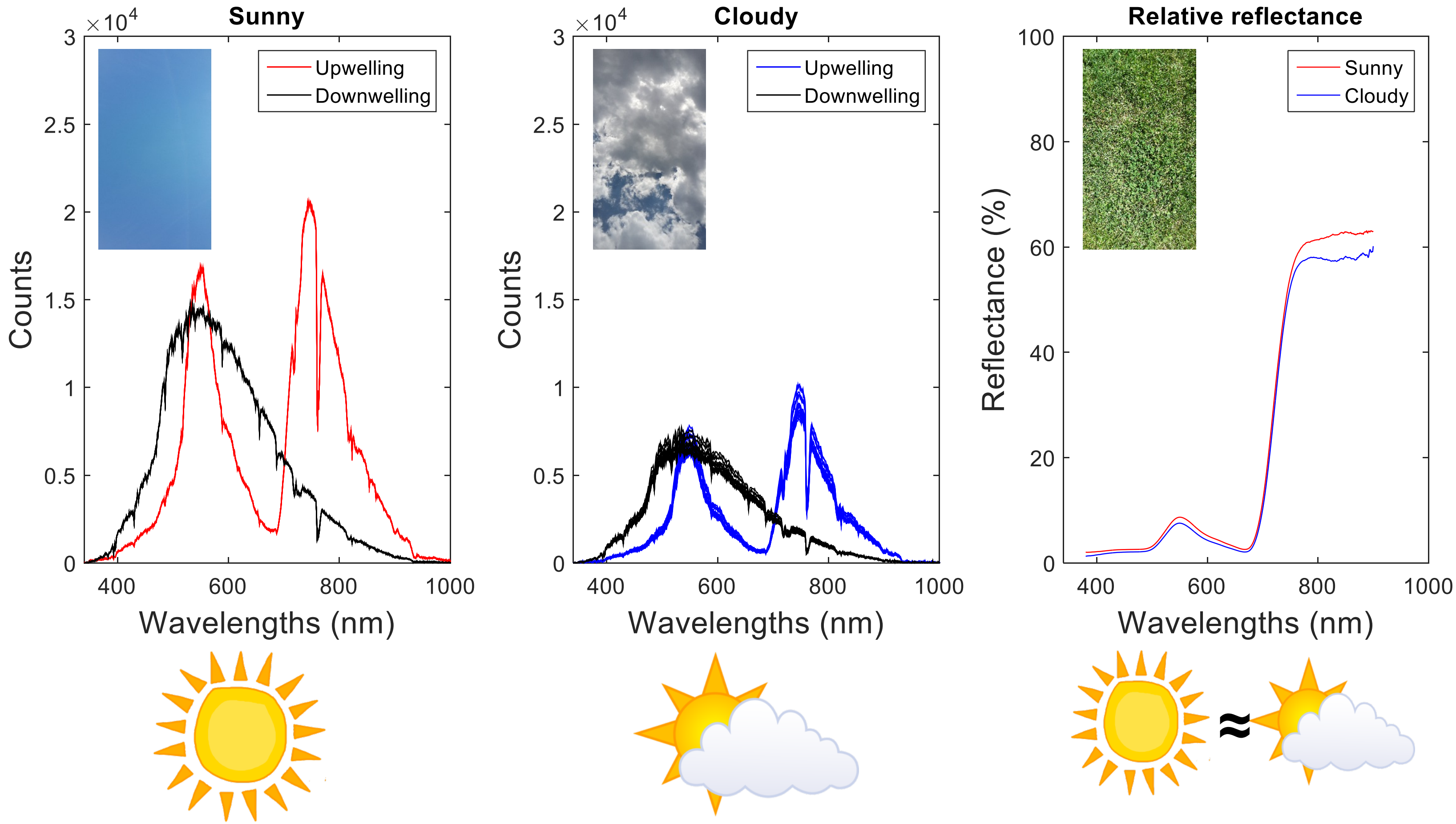
on the ground | in the air | airborne imaging



Why Piccolo



Ocean Optics
USB2000+



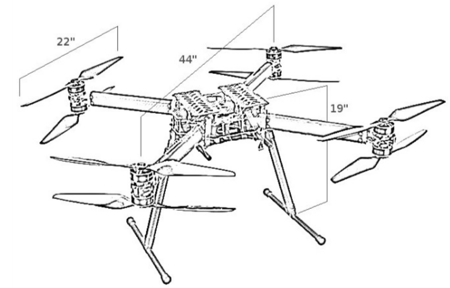
Sunny
Upwelling
Downwelling
Counts
×10^4
Wavelengths (nm)
Cloudy
Upwelling
Downwelling
Counts
×10^4
Wavelengths (nm)
Relative reflectance
Sunny
Cloudy
Reflectance (%)
Wavelengths (nm)
≈

Software Status

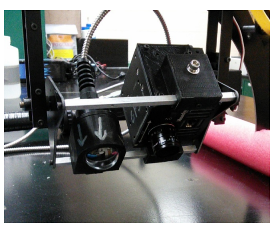
Task	Status
Piccolo V2.0 Integration	
• XBee Software Radios	Field tested
NanoHyperspec Integration	
• Visible/NIR Camera	Lab tested
• Kermit Protocol for Large Image Files	Lab tested
• Auto-Integration	Coded
Data Processing	
• Calibration/Radiance	Coded, lab and field tested
• Reflectance	Coded, implemented, lab and field tested
• Solar Induced Fluorescence (SIF)	Coded, lab and field tested
• Vectors (compressed spectrum for quick look)	Coded

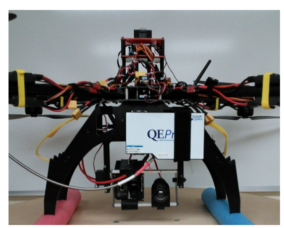
Bergen X8 UAS and Spectrometer Details

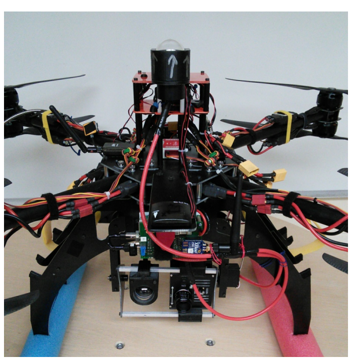
Manufacturer	Model	Wavelength (nm)	Description
Ocean Optics	USB2000+	400 - 1000	visible to near-infrared
Ocean Optics	QEPro	600 - 800	fluorescence
Ocean Optics	NIRQuest	1000 - 1800	short-wave infrared
Headwall	NanoHyperspec	400 - 1000	imaging spectrometer
Piccolo	Doppio	N/A	data processing unit
Turnigy	1,000 mAh	N/A	auxiliary battery

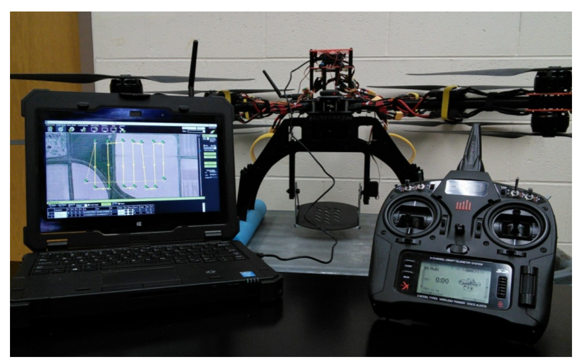


- X8 coaxial configuration
- 3DR Pixhawk flight controller
- 3DR 915 Mhz telemetry radio
- fiberglass & aluminum frame
- 2-axis gimbal w/ Naza M-lite
- 18”/20”/22” props (TBD)
- 4x 16,000 mAh batteries

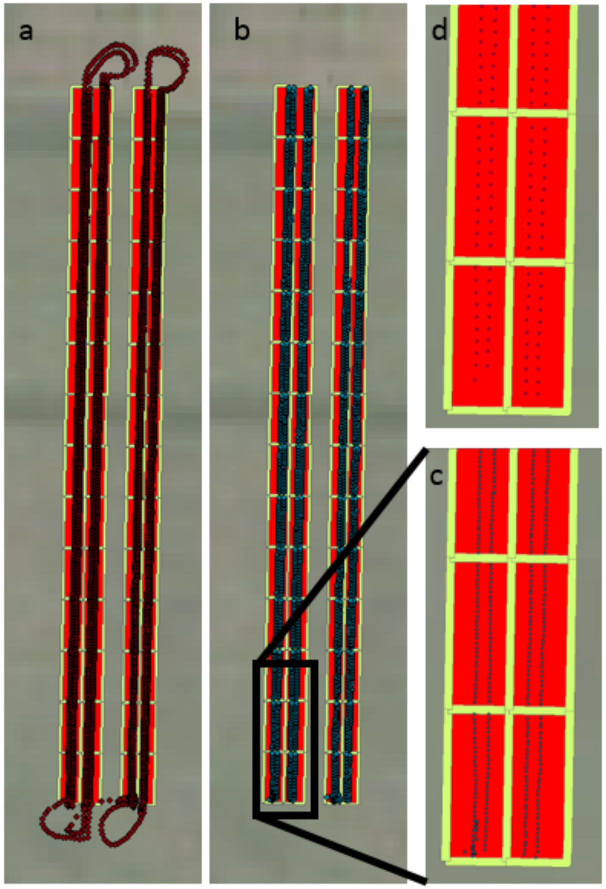


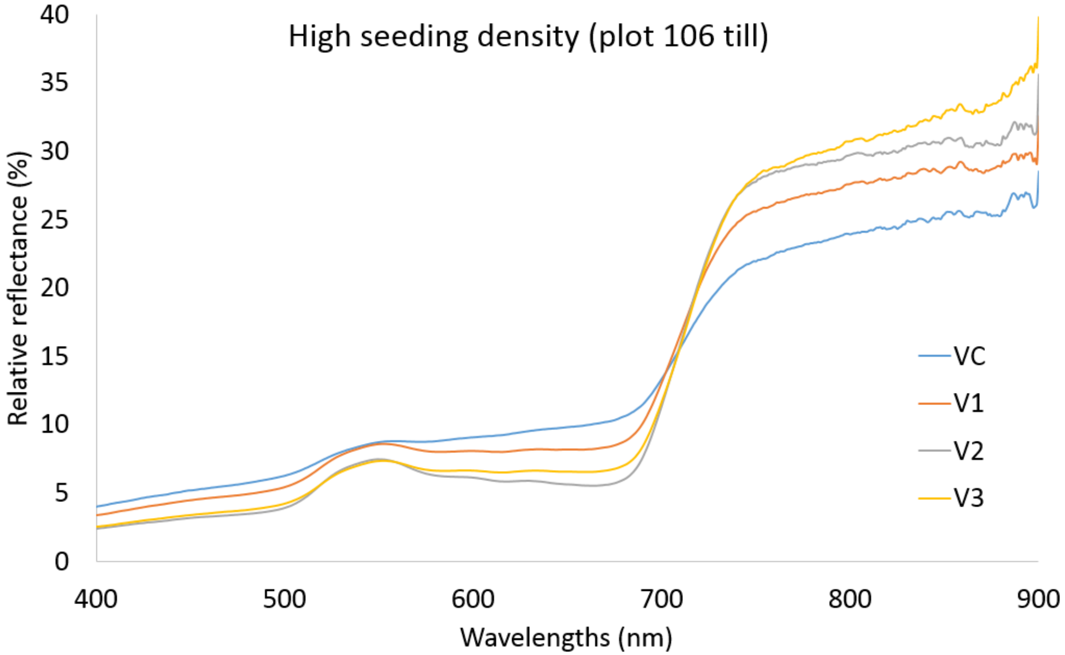






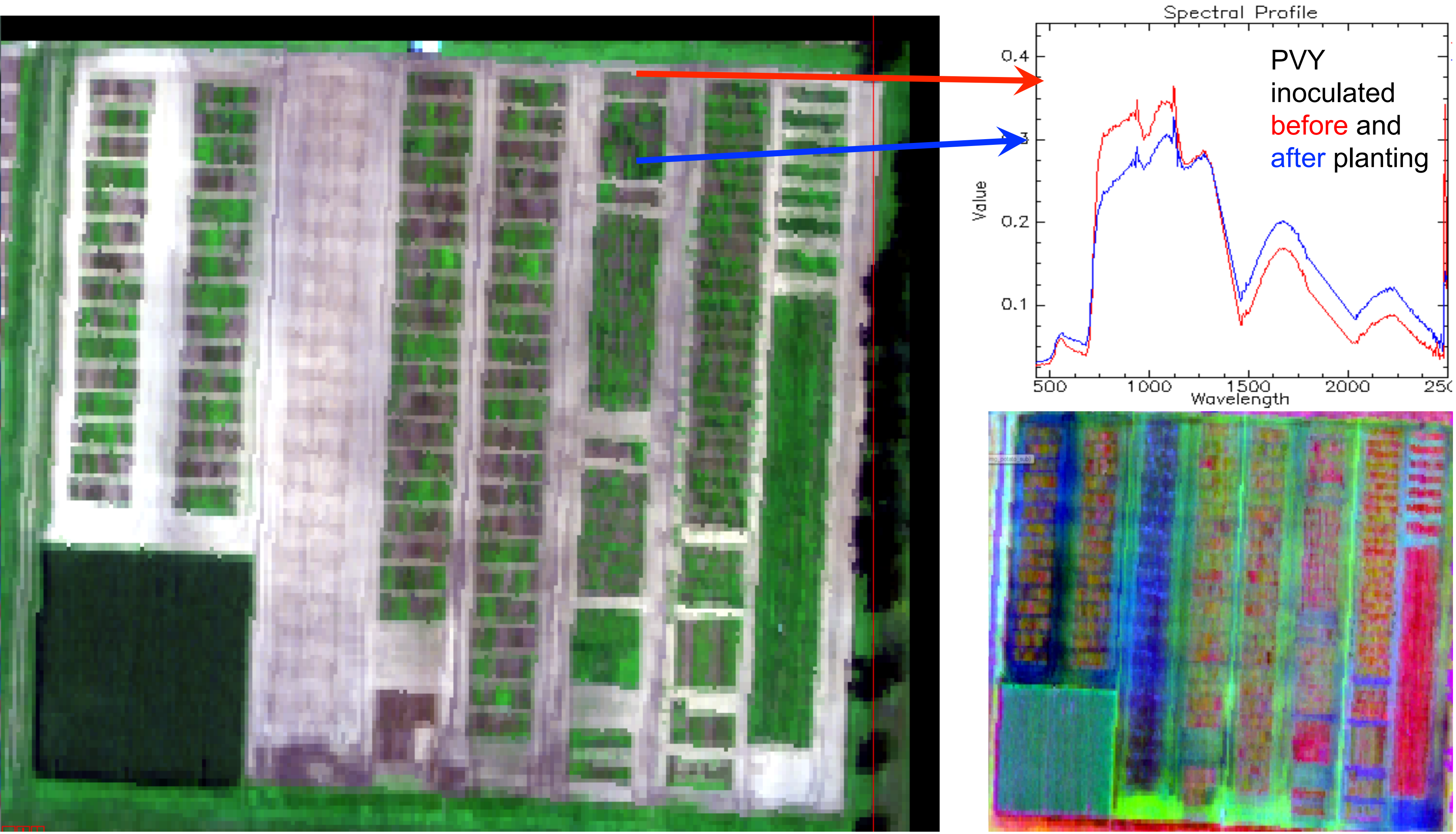
Piccolo: Soybean Seeding Density in Till and No-Till Fields, Madison, WI





The spectral evolution of a high seeding density till plot in the emergence experiment. Spectral data obtained in four development stages from vegetative cotyledon (VC) to vegetative 3rd trifoliate (V3).

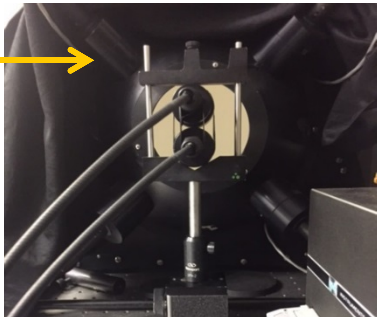
Piccolo: Potato Virus Y (PVY) Vegetation Stress Trials

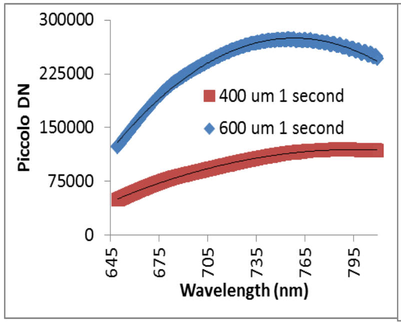


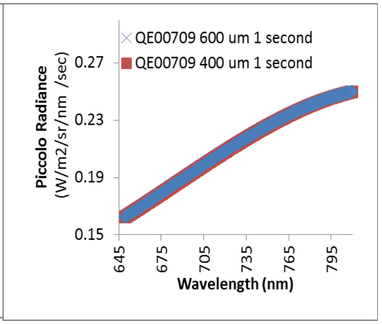
Calibrated Piccolo Digital Numbers to Radiance for Solar Induce Fluorescence (SIF)

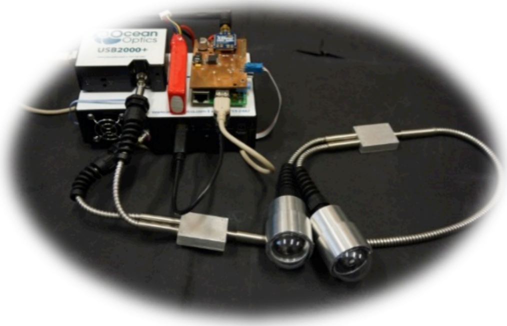
Piccolo fore optics

1. Calibration of the piccolo fore optics - without the glass domes and without the diffuser

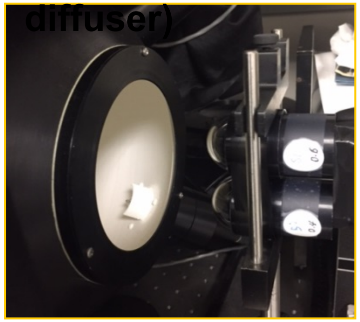


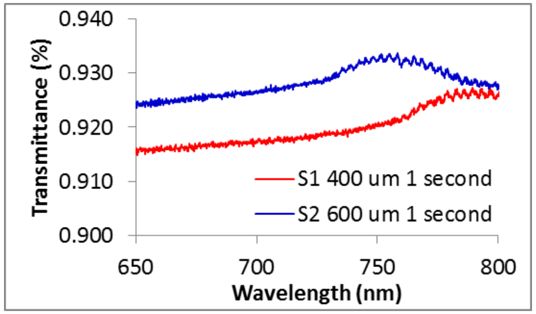




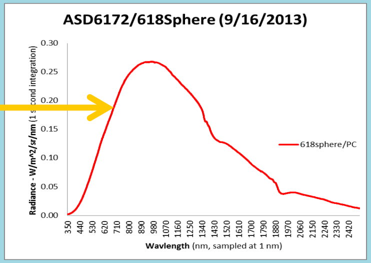


2. Glass domes transmittance (no diffuser)

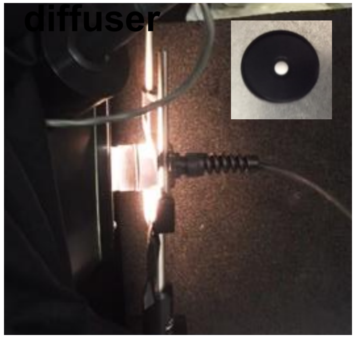


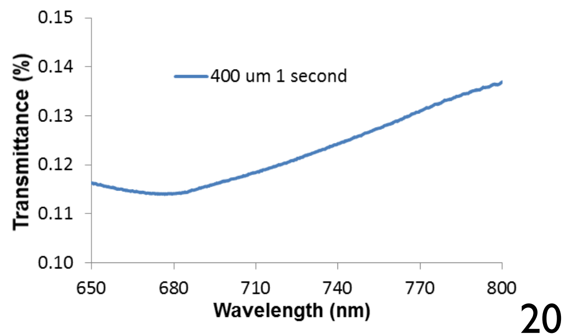


Calibrated sphere providing radiance



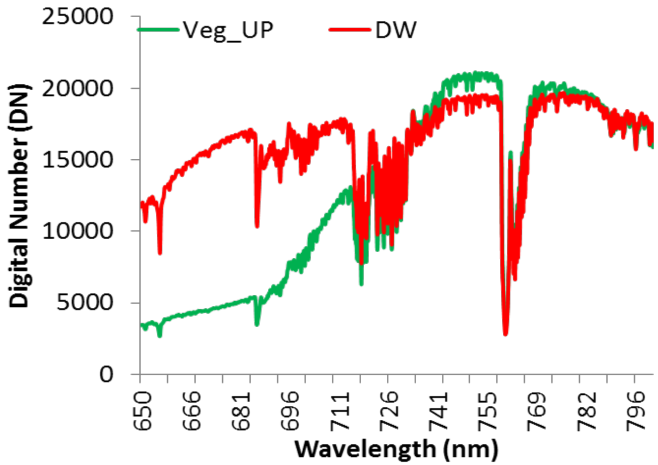
3. Transmittance of the QEPro 400 um fiber diffuser

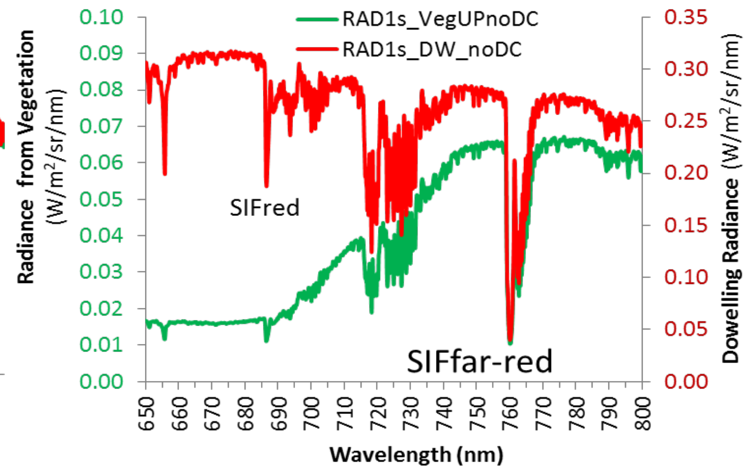


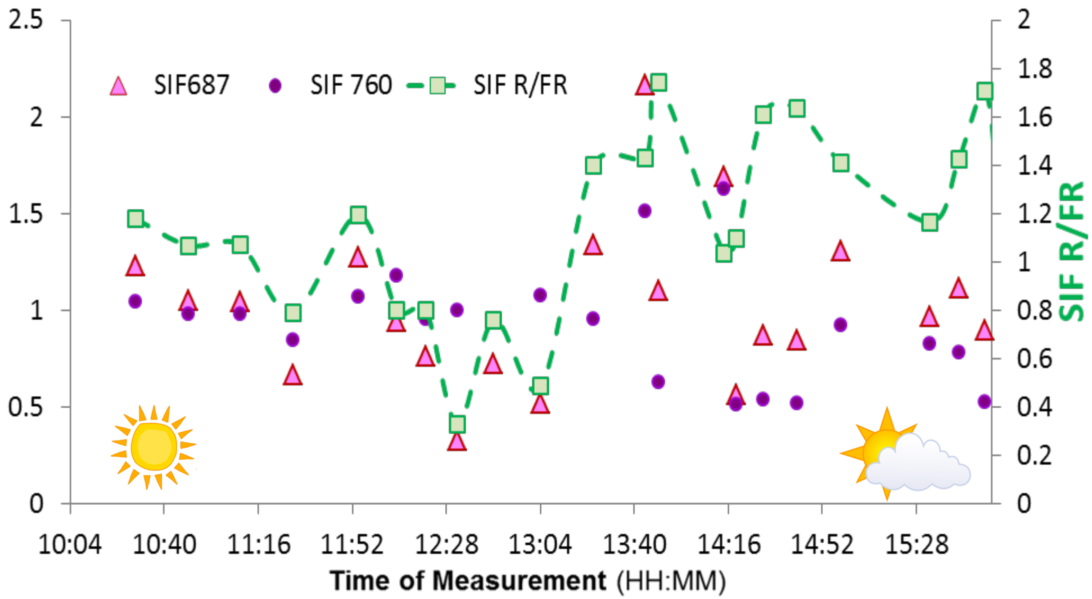


Piccolo: Solar Induced Fluorescence

Diurnals (2016) and Phenology (planned in 2017)







Considerations:

- Scaling/Altitude
- Field of View
- View angle vs. nadir

2017 Field Measurements: June-September

<u>1) Arlington and Hancock Agricultural Research Stations (Madison, WI)</u>

- Biofuels Diversity Experiment (testing approaches to maximizing productivity and ecosystem services).
- Aspen Competition Garden (differing density), Aspen Genotypes Garden (hundreds of genotypes).
- Cranberry plots (N) and Soybean Trials (varying varieties).
- FREQUENCY: <u>Weekly</u> for all and <u>diurnal</u> for crops.

2) Cedar Creek LTER (East Bethel, MN, 30 mi north of St. Paul)

- BigBio diversity project, 1 - 16 species (324 manipulated plots);
- below and above ground processes, including traits

3) USDA/Greenbelt and UMD Farm

Just outside the DC no-fly zone (red at left) making it one of the few areas near GSFC where we can work. Corn, multiple row crops.

To be used for diurnal and seasonal observations and engineering tests.

FREQUENCY: Eight sortie days beginning June 2017.

➢ New technology experiments will be sequentially folded in as the as the growing season progresses

Orbital (e.g. EO-1 / HyspIRI / Landsat @ ~ 700 km)

High Altitude (e.g. AVIRIS on ER-2 @ 10K – 20K m)

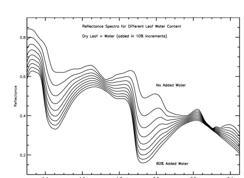
Mid Altitude (e.g. AVIRIS on Twin Otter @ 2K – 5K m)

Low Altitude (e.g. G-LiHT on Cessna 206 @ 330 m)

UAS (current effort @ 10 – 120 m)

Fixed Tower (e.g. AMSPEC @ < 50 m)

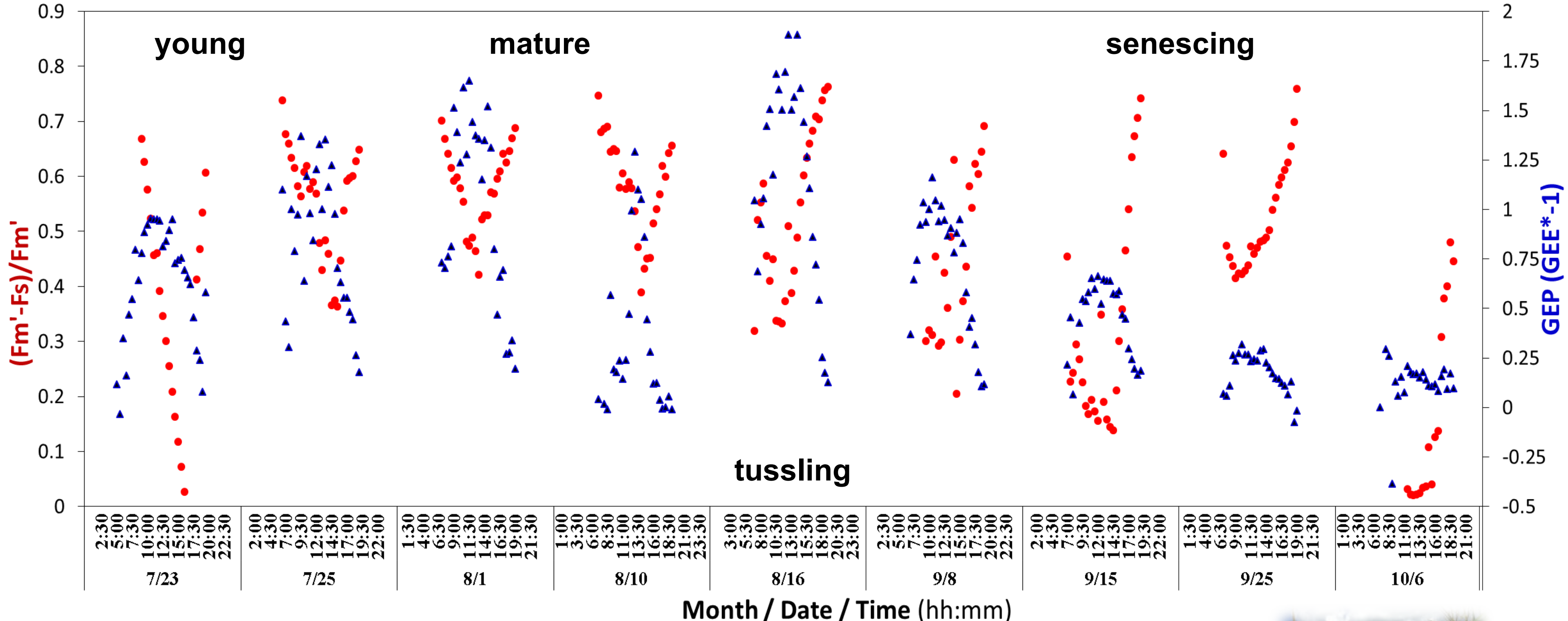
Proximal (Spectrometer @ < 5 m)



Leaf Level (@ << 1 m)

Calibrated imaging spectroscopy data across all spatial scales: Bridge gaps from leaf to field to airborne to space.

Diurnal and Seasonal changes fluorescence and Gross Ecosystem Production (DF=(Fm'-Fs)/Fm‘ and GEP)

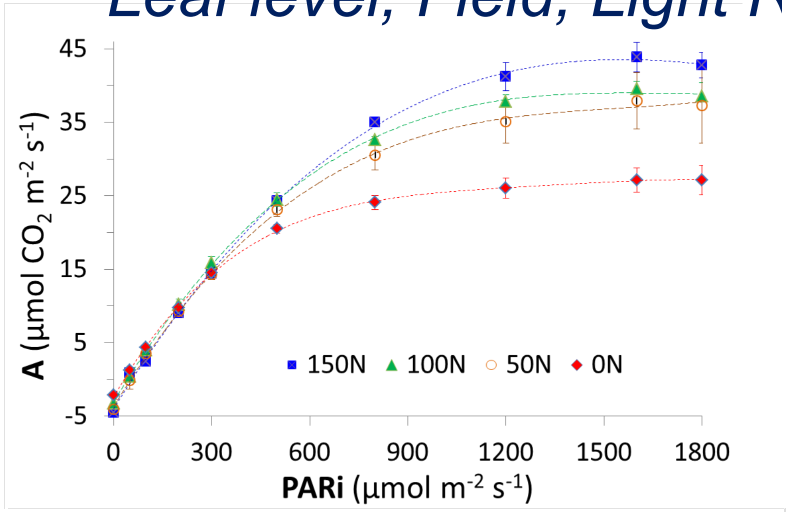


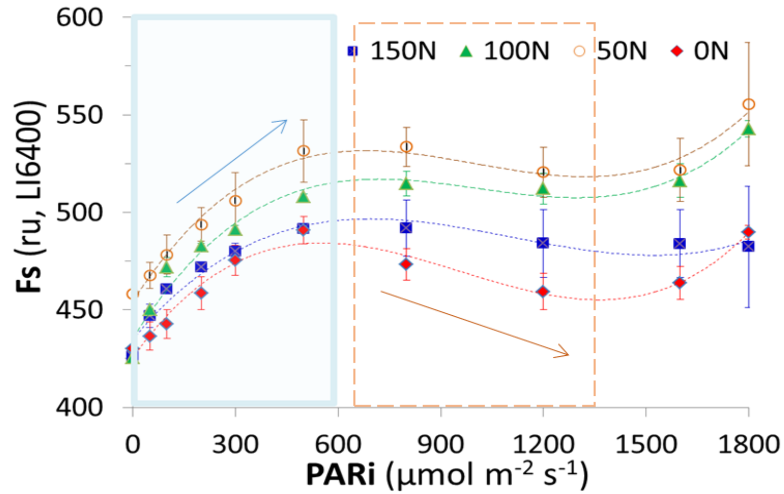
DF **RED**, MONI-PAM (µmol m^{-2} s^{-1})
GEP **BLUE**, FLUX tower (mg m^{-2} s^{-1})
measured on corn under optimal nitrogen deposition (N=100%, OPE3 2015)

Campbell et al. 2017, in

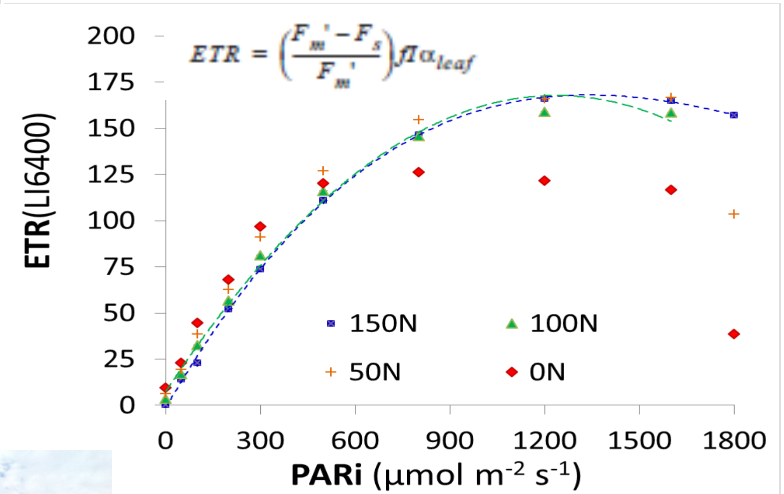
Corresponding changes in photosynthesis and fluorescence

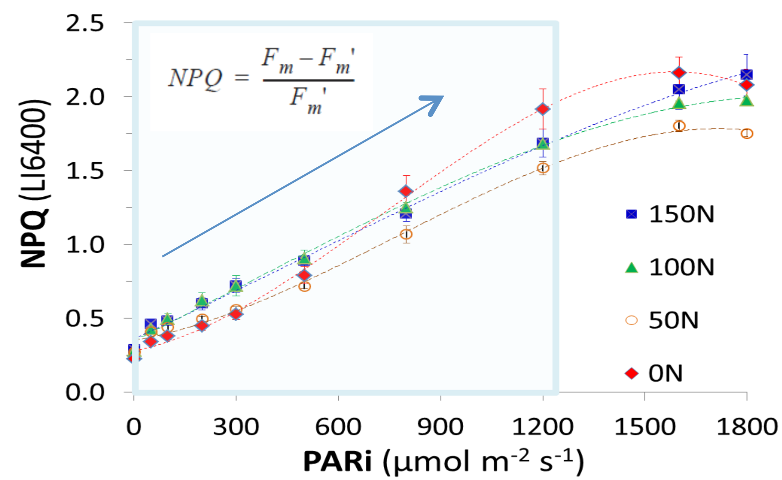
Leaf level, Field, Light Response by Nitrogen Treatment





Nitrogen deficiency (N 50%)

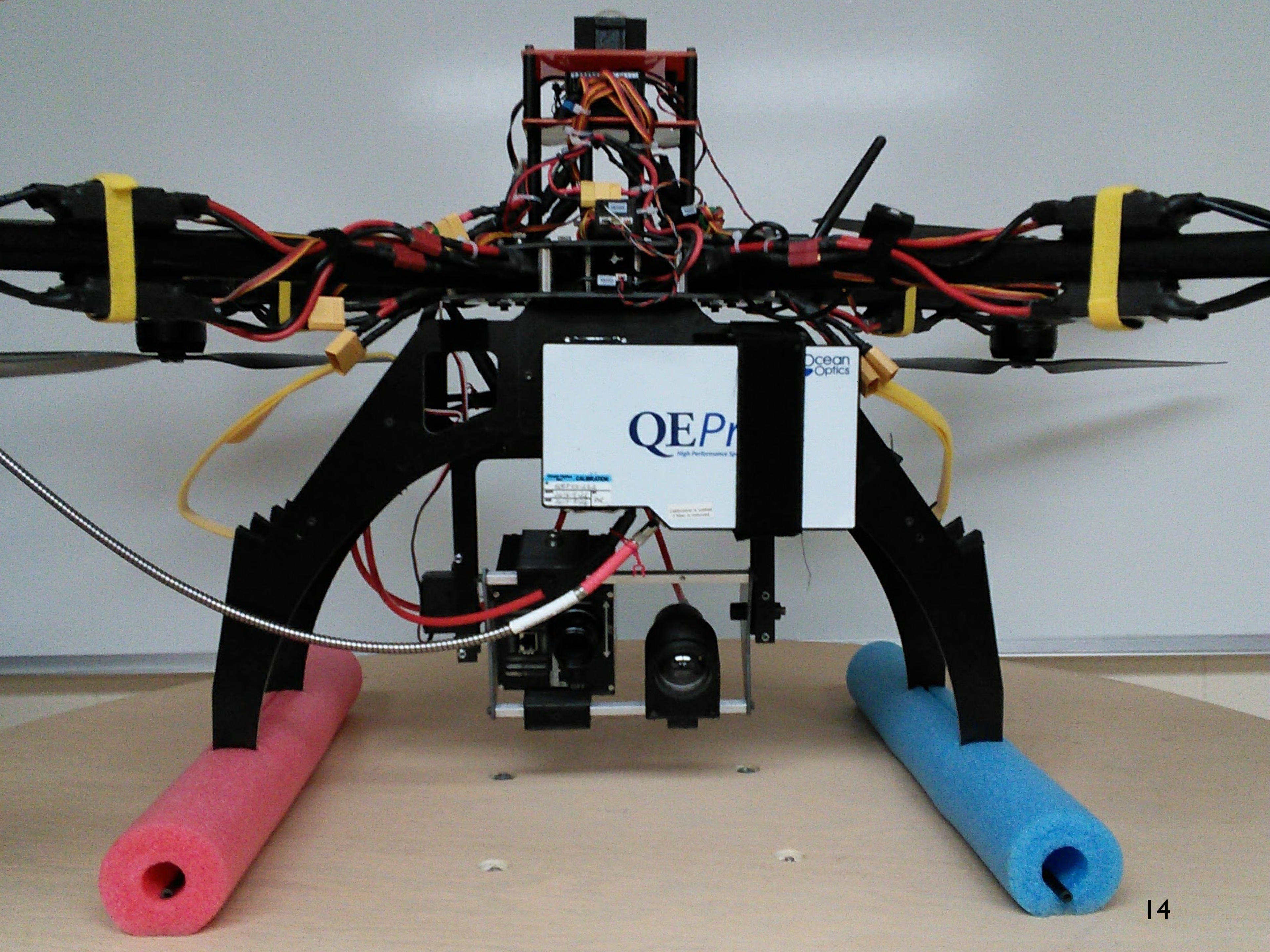




Optimal nitrogen (N 100%)

Photosynthesis and active ChlF parameters

Campbell et al. 2017, in


Ocean Optics
QEPr


Ocean Optics
USB2000+