Next Generation UAS Based Spectral Systems for Environmental Monitoring

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Co-Is: C. Kingdon , V. Ly, L. Ong , P. Cappelaere, L. Corp, R. Sohlberg, S. Frye, M. Handy, J. Nagol and V. Ambrosia

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Outline

- Background and Motivation
- Objectives
- Technology Evaluation and Development Plan
  - Key instrumentation and technology
  - Next generation intelligent acquisition strategy
  - Processing workflows
- Preliminary Outcomes Assessing Vegetation Traits
  - Constrains and considerations
  - Success criteria and optimization approach
- Summary Take Home Message

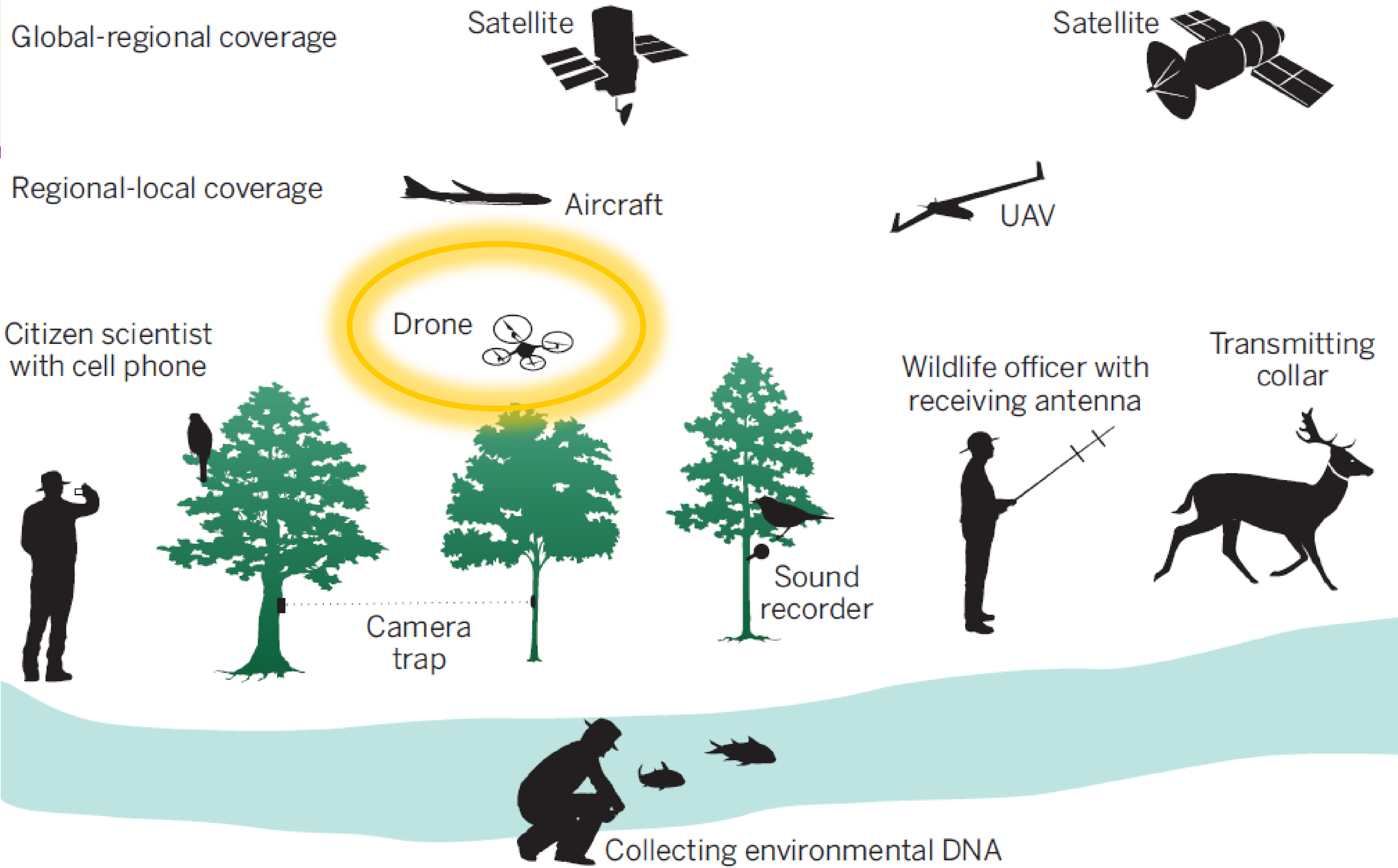
Background

- Foliar and canopy spectra can characterize sets of traits, which we can use to understand vegetation function and diversity.

- Measurement of these traits at only one point in time and observation geometry limits our ability for vegetation monitoring and understanding.

Motivation

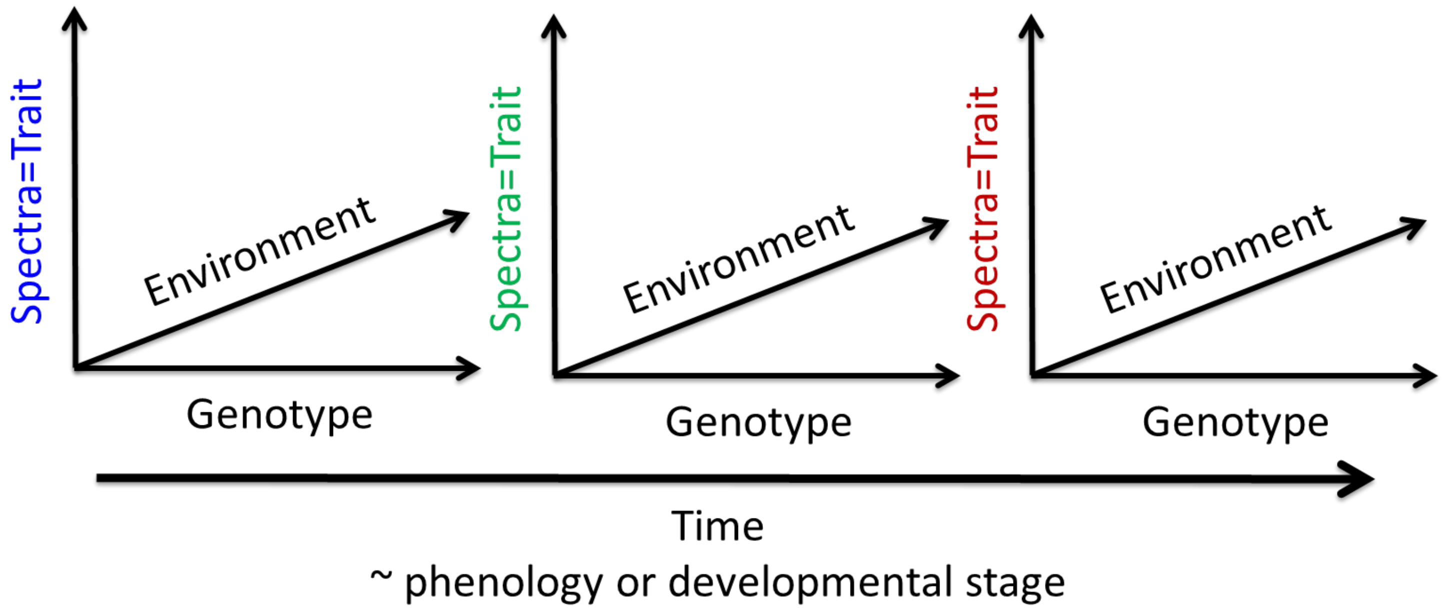
- There is a distinct need to use UAV-based monitoring to enable:
  - '*Just-in-time*' or '*right-time*' measurements
  - Repeated observations
  - Flexible spectral and spatial resolution observations
  - Field and stand scale measurements
- Aircraft and satellite measurements may not exist (and aircraft monitoring may not be feasible or cost effective)



Sensor power. Networking satellite and airborne remote sensing with in situ sensing will allow changes in many elements of biodiversity to be tracked over time.

Sensing biodiversity
Woody Turner (October 16, 2014)
Science **346** (6207), 301-302. [doi: 10.1126/science.1256014]

Spectral Measurements of Traits



- Trait values (hence, spectra) vary with environmental variation.
- Different genotypes of a species may have different trait/spectral responses to environmental variations (e.g. change in photosynthetic efficiency, leaf characteristics, biomass, yield, stress response).
- Traits/spectra vary over the course of a day and/or a growing season

Traits of Interest to Monitor

- Nitrogen
- Chlorophyll
- Leaf Mass per Area (LMA)
- Lignin
- Sugars, carbohydrates
- PRI (~pigments, NPQ)
- Secondary Metabolites
- Other minerals
- Chlorophyll Fluorescence
- Photosynthetic Capacity
- Stress/water status
- Disease
- Genotype
- Phenotype

All are important to vegetation function, CO_2 uptake, productivity, yield and/or physiology.

Spectra and Traits with Seasonal Dynamics

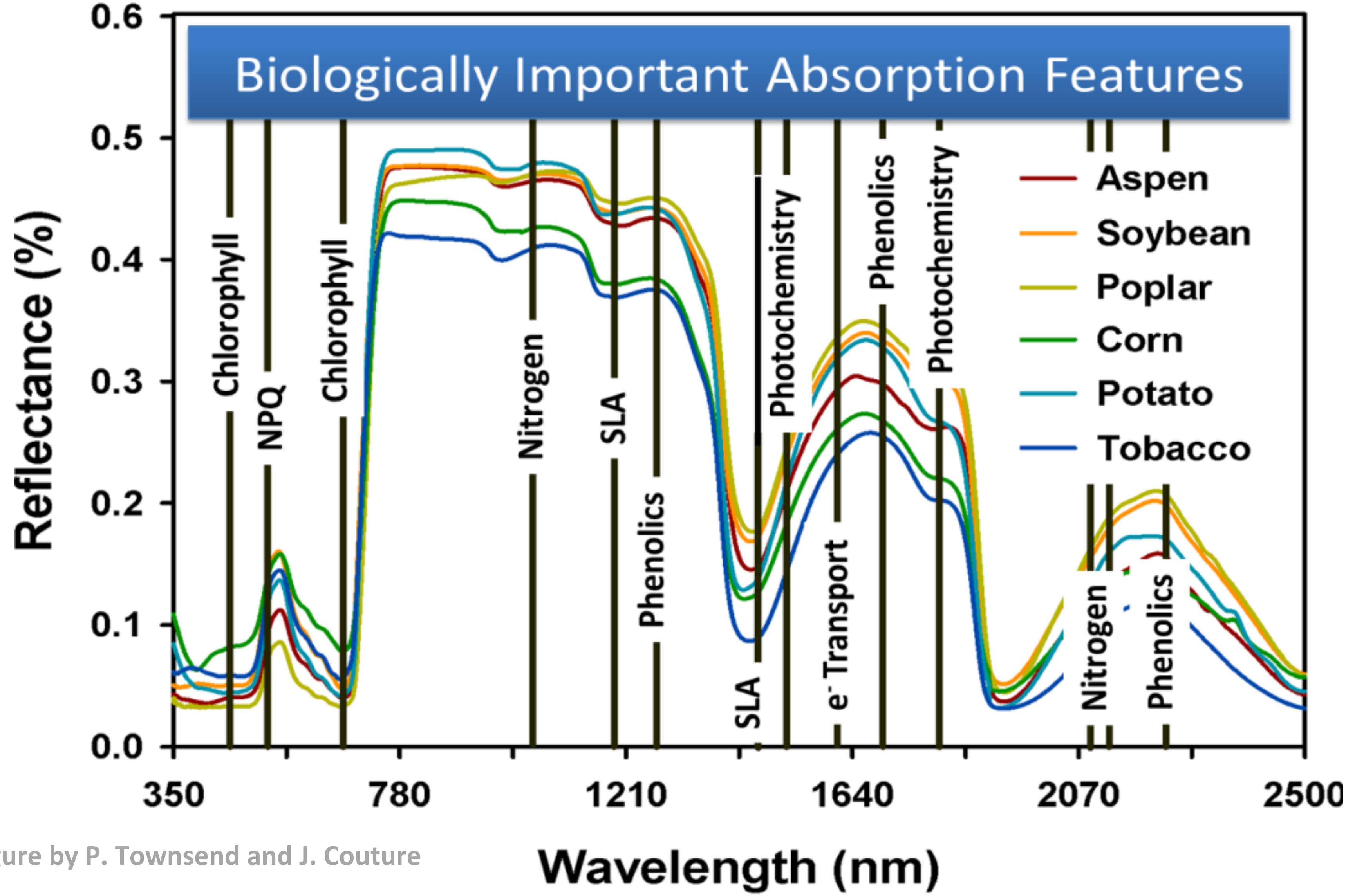
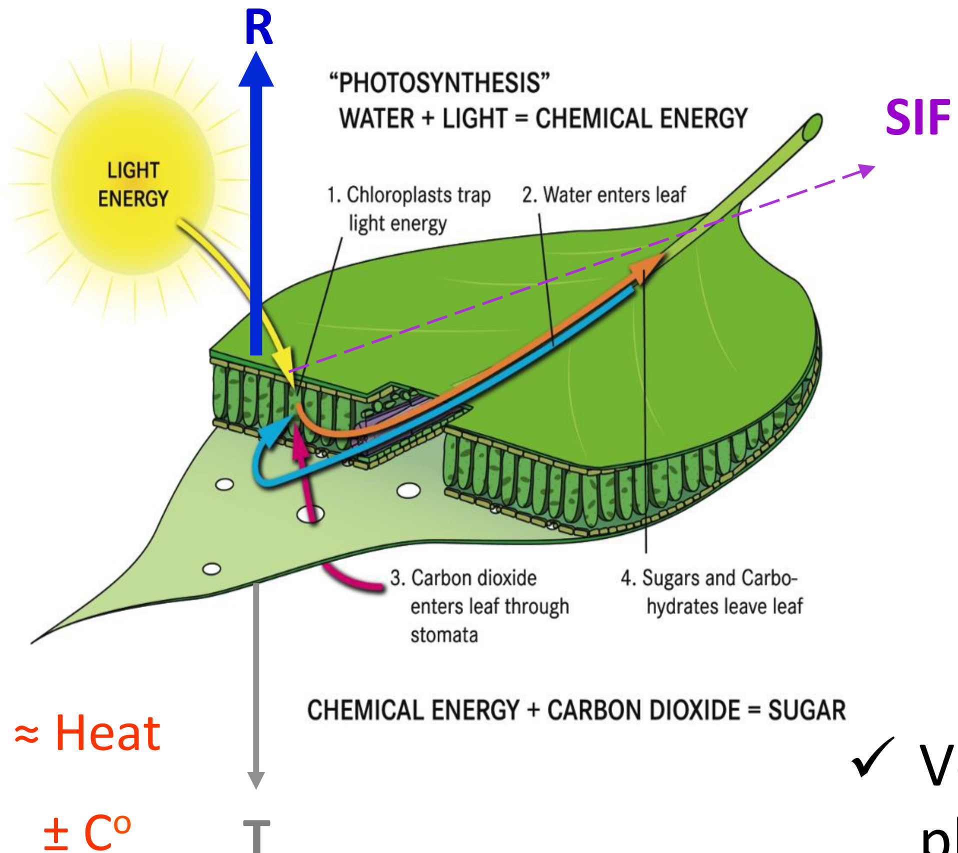
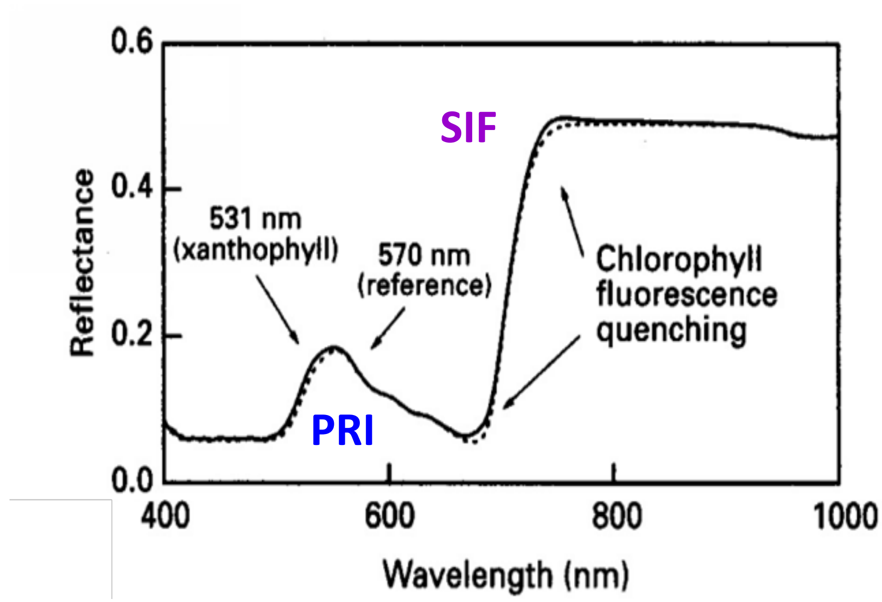


Figure by P. Townsend and J. Couture

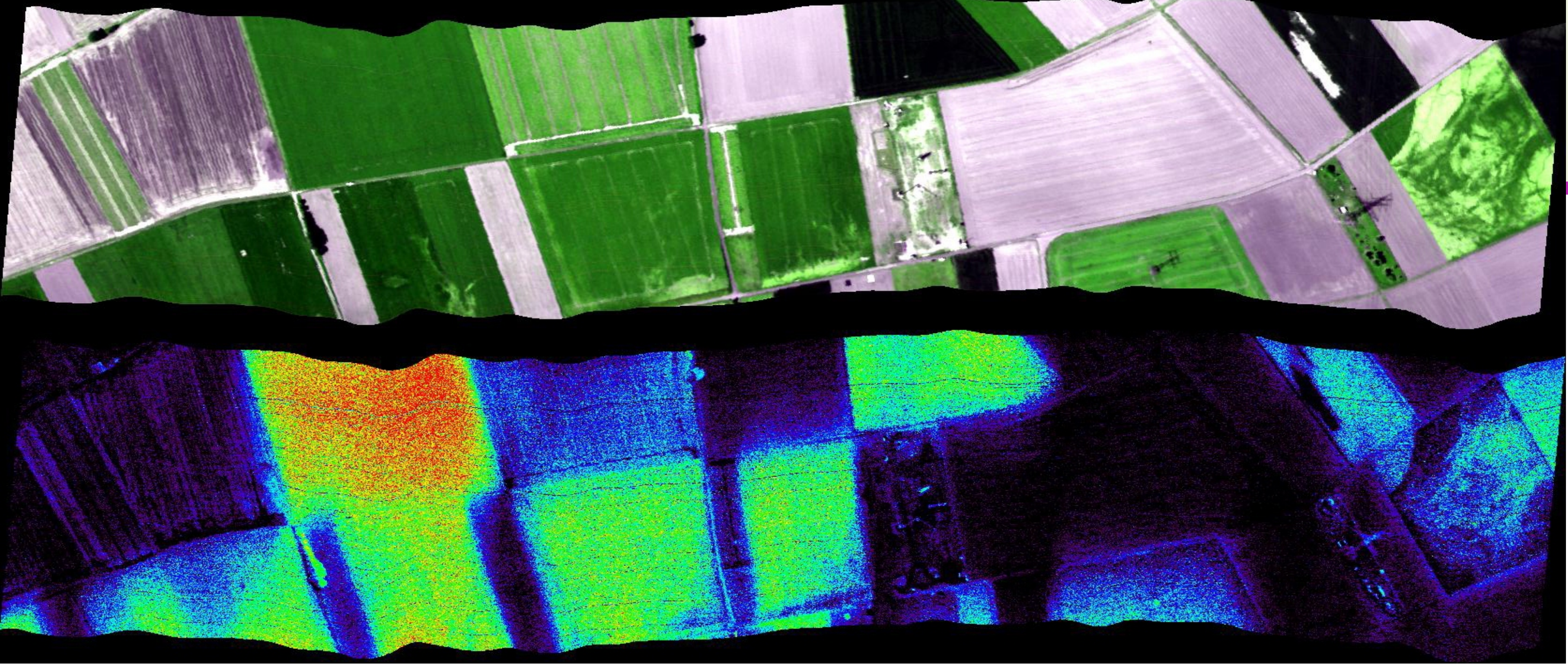
Traits/Spectra with Diurnal & Seasonal Dynamics

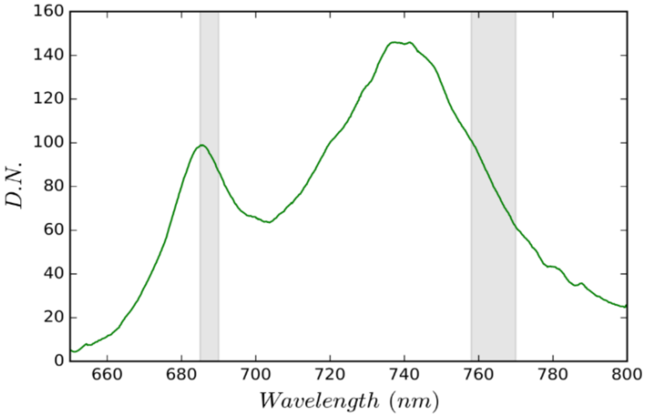


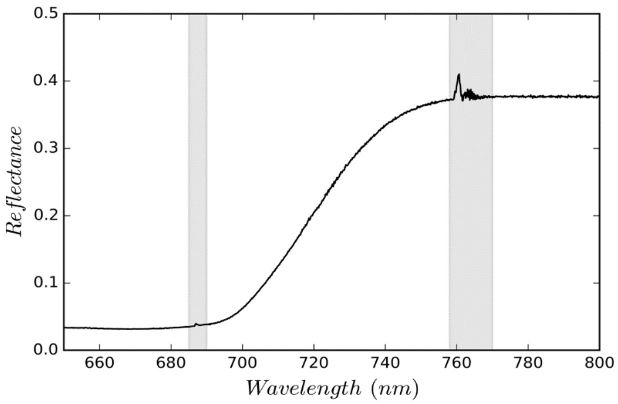


"Photosynthesis" from ESA/FLEX final report, 2015. Modified adding reflectance, transmittance, heat and fluorescence (P. Campbell, 2015).

- ✓ Vegetation water content, rate of photosynthesis and the associated reflectance spectra
- ✓ Solar Induced Fluorescence (SIF)







The project involves reflectance across 400-1000 nm, but also narrow interval spectroscopy for chlorophyll fluorescence.

Top image from Uwe Rascher, downloaded from http://www.esa.int/spaceinimages/Images/2014/02/Fluorescence_from_different_vegetation

PROJECT GOALS

Our goal is to produce in 2 years (June 2015 – June 2017) science-quality spectral data from UASs suitable for scaling ground measurements and comparison against airborne or satellite sensors.

We will develop protocols and a workflow to ensure that VNIR measurements from UAS's are collected and processed in a fashion that allows ready integration or comparison to NASA satellite and airborne data and derived products (e.g. Landsat, AVIRIS EO-1 Hyperion and future HyspIRI).

Objectives

Develop high spectral resolution UAS, capable of:

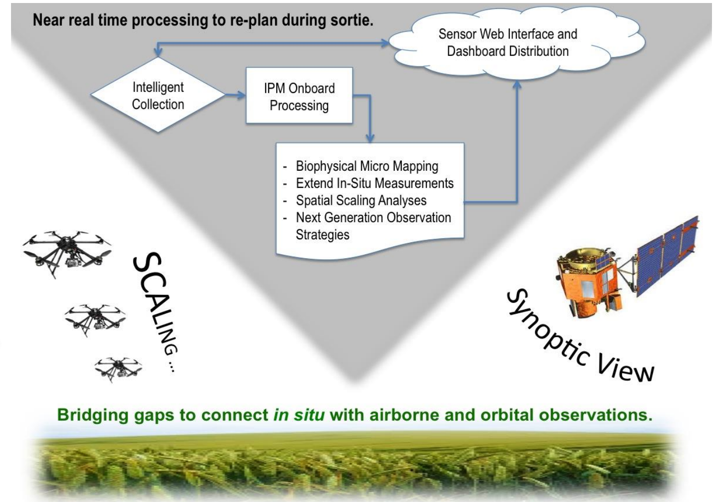
- Producing science-quality spectral data
  - biochemical and physiological traits retrieval
- Employing an intelligent gathering scheme to semi-automate:
  - spectral data acquisition,
  - processing workflows, and
  - tasking and operation strategy
- Characterizing diurnal and seasonal cycles in vegetation function

Next Generation UAV Spectral Systems for Environmental Modeling

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 UAVs
  - suitable for scaling ground measurements
  - comparison to from-orbit data products
- Small UAV hyperspectral sensor-web, filling the gap between ground and satellite measurements



Approach:

- Test and validate measurements *in-situ* at well-characterized sites
  - ✓ Step 1 - Integrate spectrometers 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 06/2015
- Test spectrometer flight configurations *in-situ* on multiple moving platforms (e.g. tram/tractor) 7/2015-8/2016
- Flight Readiness Review and Approval 5/2016
- Hexacopter flights with line spectrometers 5/2016-12/2016
  - ✓ Step 1 manual reflectance retrieval
  - ✓ Step 2 manual trait retrieval
  - ✓ Step 3 diurnal and seasonal variation in vegetation traits, semi-autonomous retrieval
- Hexacopter flights with imaging spectrometer 6/2016-5/2017
  - ✓ Step 1 manual reflectance retrieval
  - ✓ Step 2 manual trait retrieval
  - ✓ Step 3 diurnal and seasonal trait variation, semi-autonomous retrievals

$TRL_{present} = 3$

Earth Science Technology Office

Technology Evaluation Plan

- Testing at well characterized sites from alternate platforms before UAV
- Currently, both imaging spectrometer and Piccolo system are tested concurrently
  - ✓ Stage
  - ✓ Tram
  - ✓ Tractor
  - ✓ Then UAV

Piccolo and Nano-Hyperspec:

→ Test on tram/ tractor, etc. → Calibrate reflectance → Onboard processing → Ground-based decisions → Inflight decisions

Test Sites

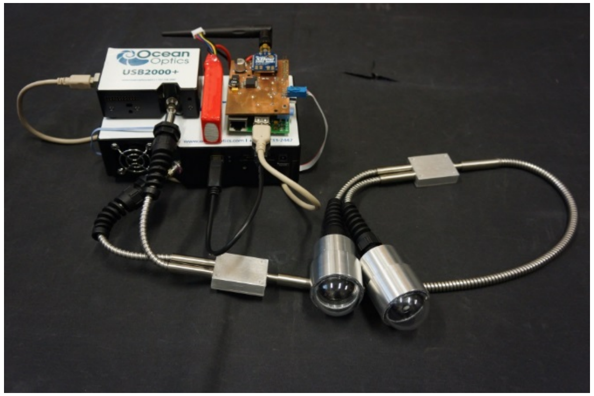
Use instrumented test sites with known composition that are well-studied

Cedar Creek LTER, MN

Credit: *Phil Townsend,, University of Wisconsin*

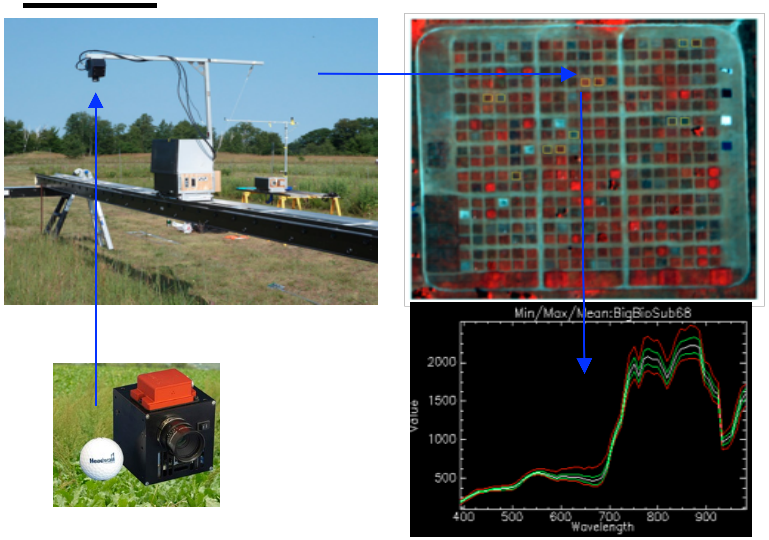
Spectral Instruments and Project Plan

First: Measurements with a spectrometer (one spectra at a time):



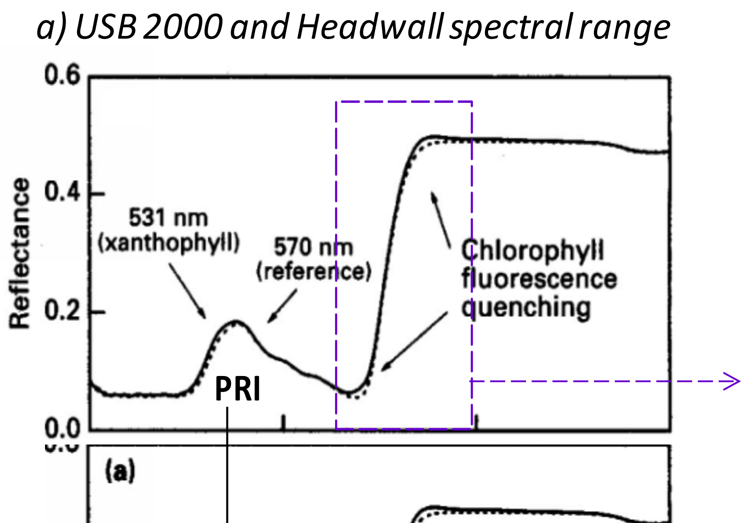
Piccolo system
Dual Up- and Down- welling
Ocean Optics spectrometers
- FLAME (400-900 nm @1 nm)
- QEPro (600-800 nm @ 0.2 nm)

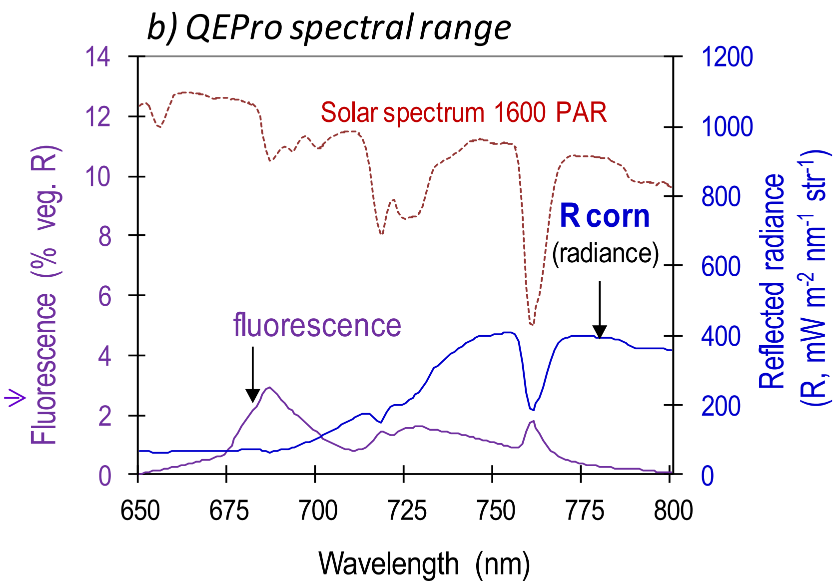
Then: Measurements with an imaging spectrometer:

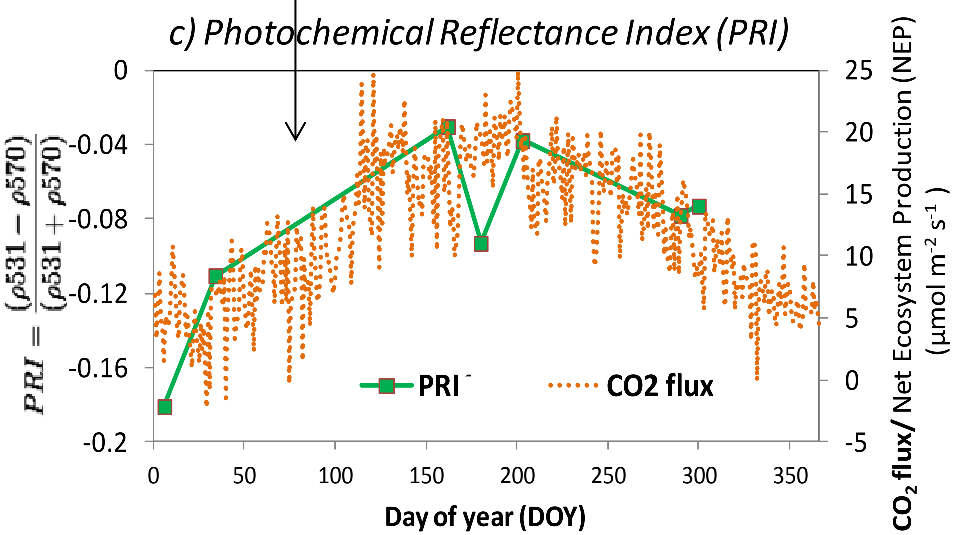


Headwall Nano Hyperspec
- 640 x 640 pixels
- 400-1000 nm, 5nm spectral resolution (FWHM with 20-micron slit)
- 480GB storage capacity
- Size (exclusive of GPS): 3" x 3" x 4.72" (76.2mm x 76.2mm x 119.92mm)
- Weight: less than 1.5 lb. (0.68kg)

Technology/Measurements







To characterize ecosystem biochemical and physiological parameters we will use: reflectance (a) and solar-induced fluorescence (b).

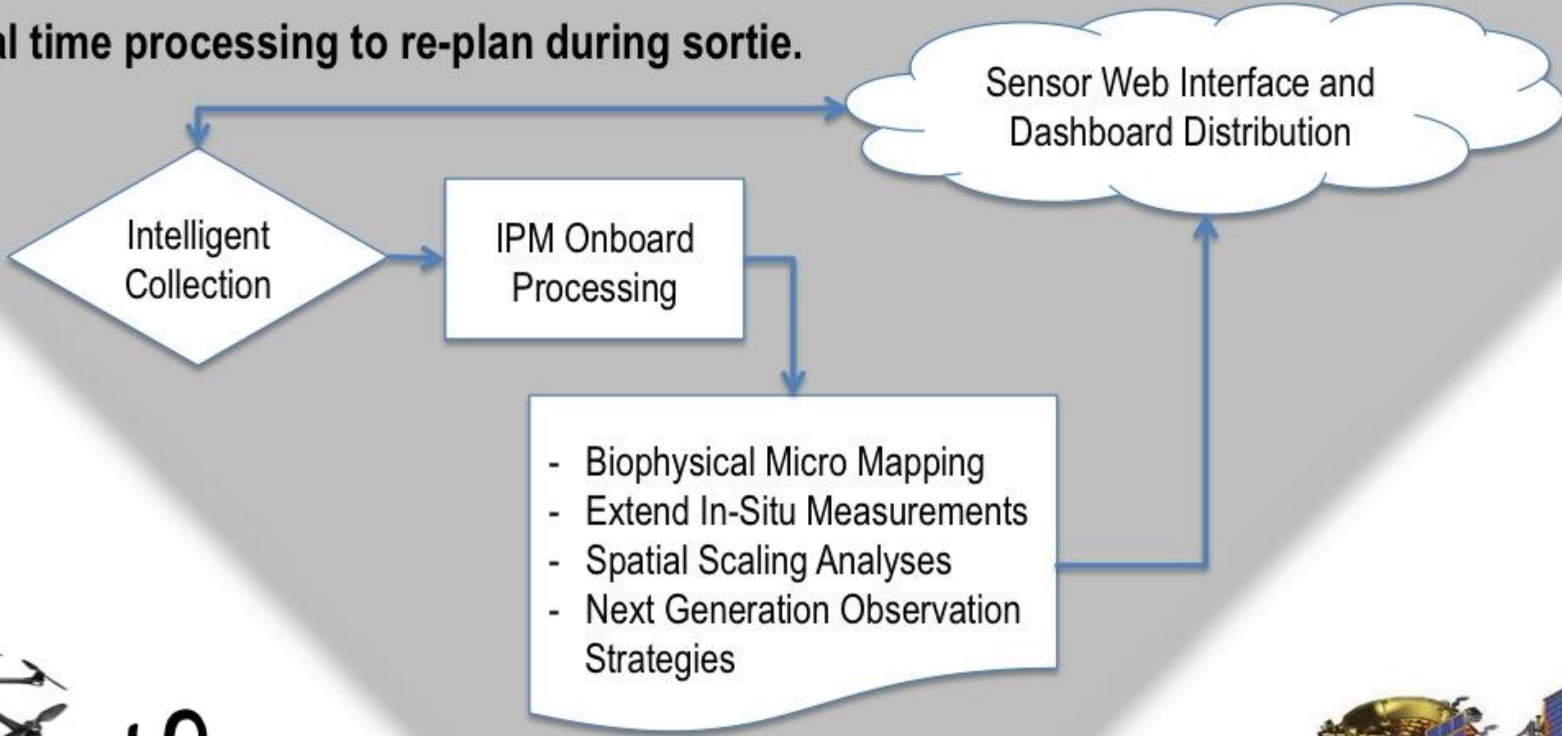
We will use high spectral resolution discrete measurements (Yr1) and imaging spectroscopy (Yr2).

IPM Goals for This Effort

- Real time acquisition strategy
  - ✓ Onboard data processing chain of hyperspectral data from *Piccolo Doppio* spectrometers and Headwall Nano-hyperspec imaging spectrometer
  - ✓ Data subsetting, optimization of acquisition parameters
  - ✓ Real time campaign/way point adjustments based on measurements and objectives (autonomous scheduling, real-time detection for goal oriented abstraction)

- Data product distribution

Near real time processing to re-plan during sortie.

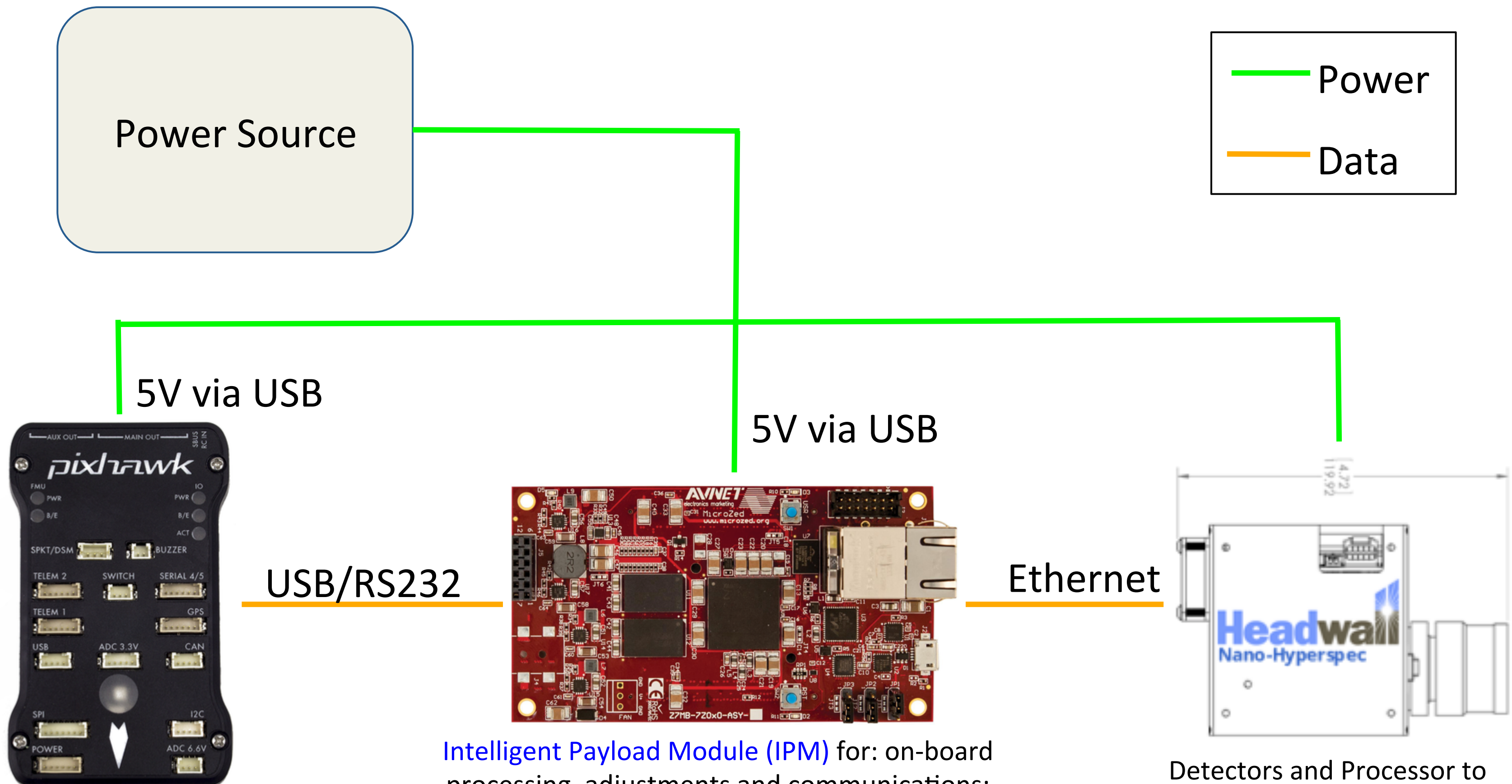


SCALING …

Synoptic View

Bridging gaps to connect *in situ* with airborne and orbital observations.

Key Architecture Components



Processor to Navigate Drone

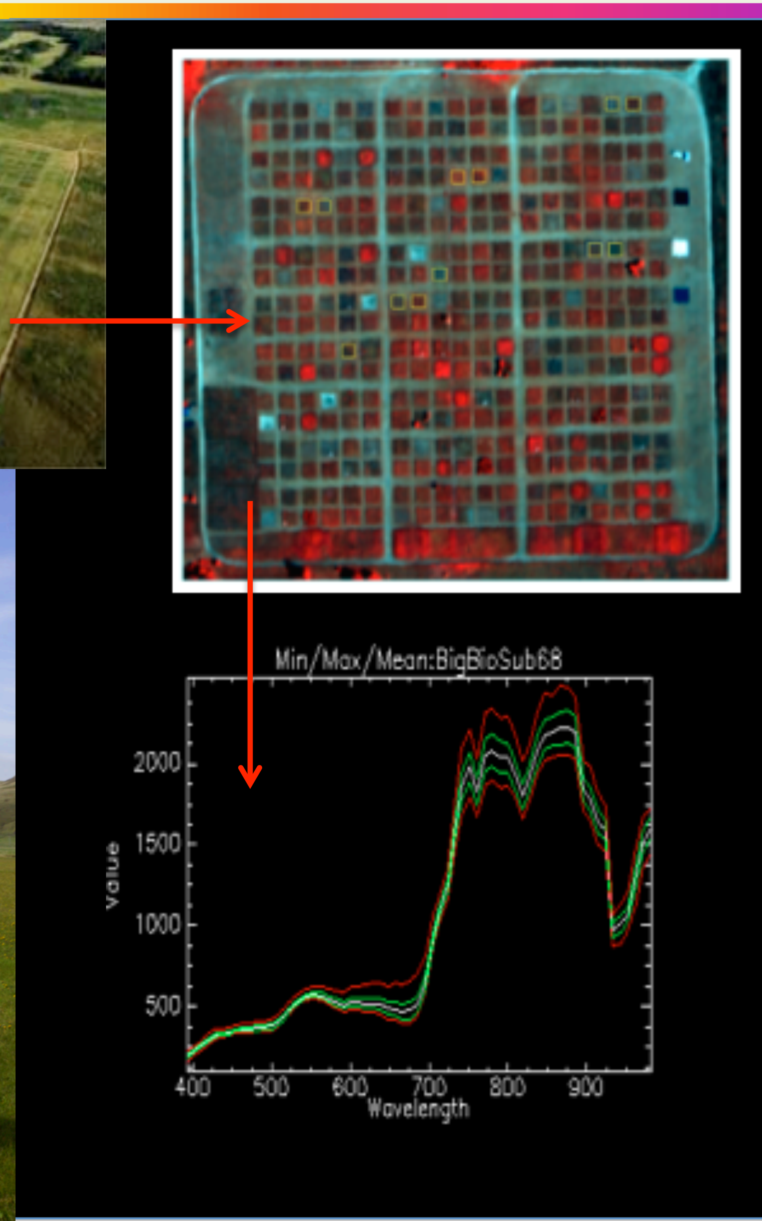
Intelligent Payload Module (IPM) for: on-board processing, adjustments and communications; includes Two Arm Processors and Field Programmable Gate Array (FPGA)

Detectors and Processor to Capture Data


c/o John Gamon

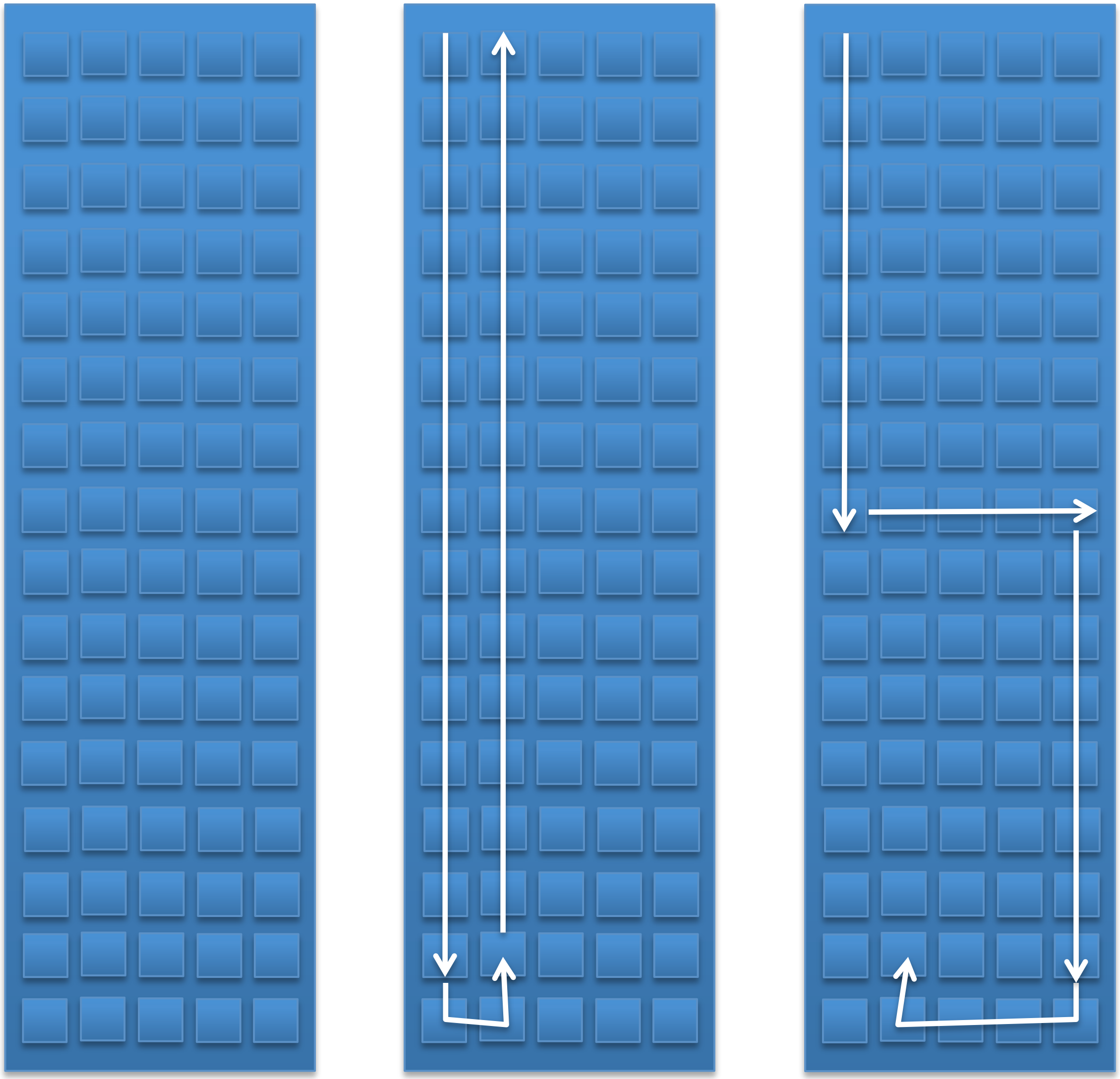
Imaging Spectroscopy

c/o John Gamon



c/o A. MacArthur

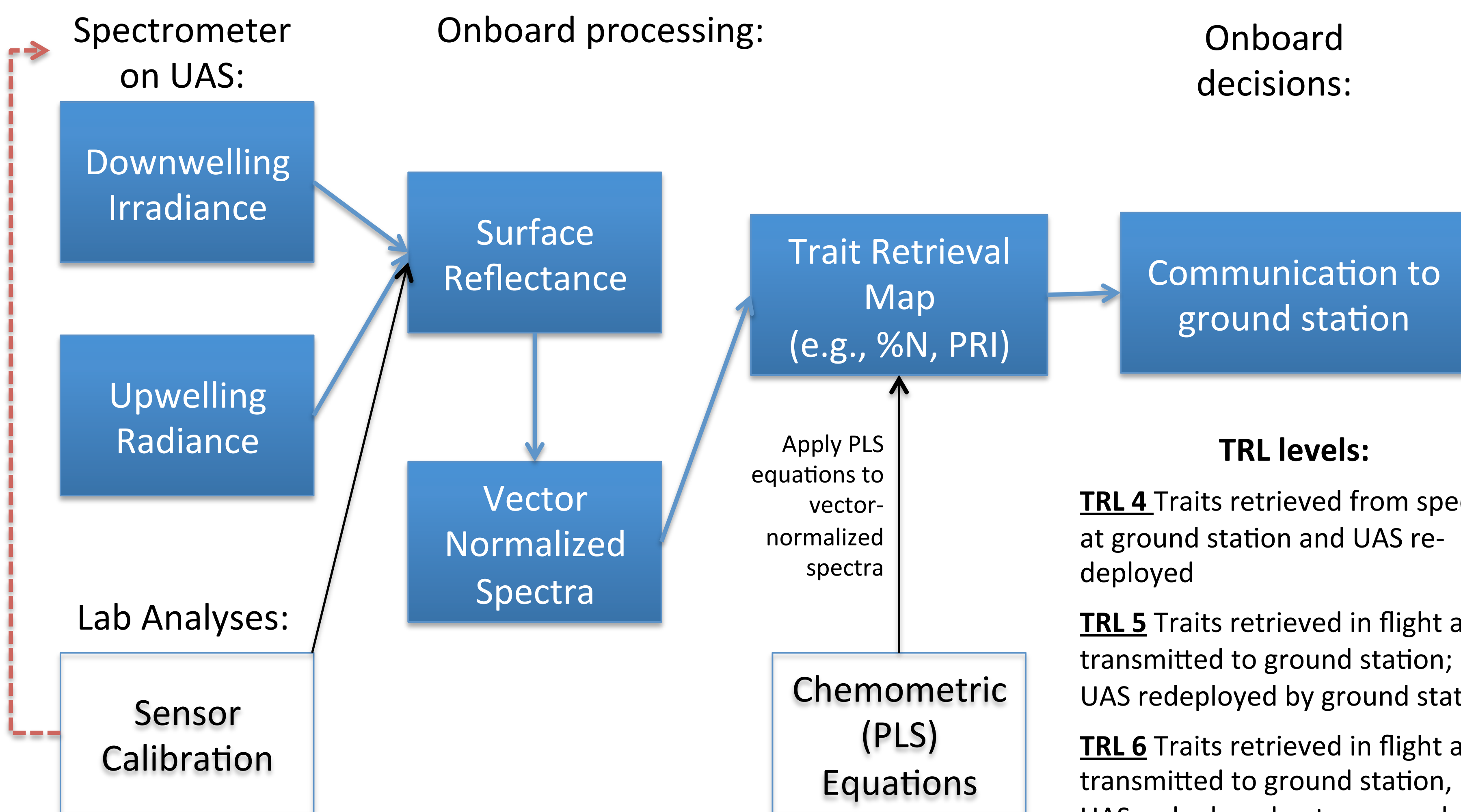
Flexible Acquisition Strategy



<u>Start with</u>:
Pre-programmed flight paths and acquisitions

<u>Advance to</u>:
On-flight optimization and path variation

Trait Retrieval Workflow



TRL levels:

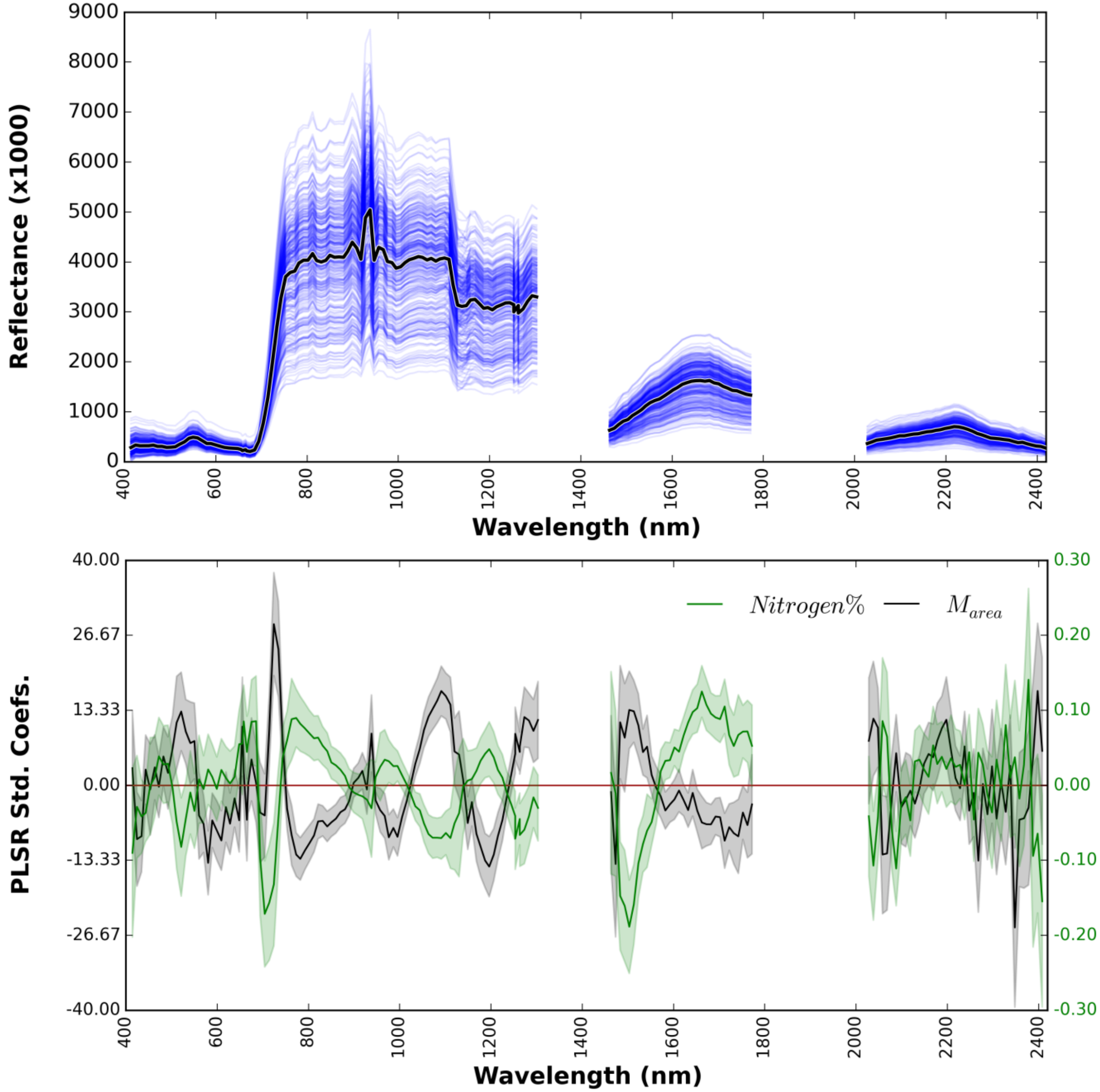
TRL 4 Traits retrieved from spectra at ground station and UAS re-deployed

TRL 5 Traits retrieved in flight and transmitted to ground station; UAS redeployed by ground station

TRL 6 Traits retrieved in flight and transmitted to ground station, UAS redeployed autonomously

TRL - technology readiness level

Assessing Vegetation Traits



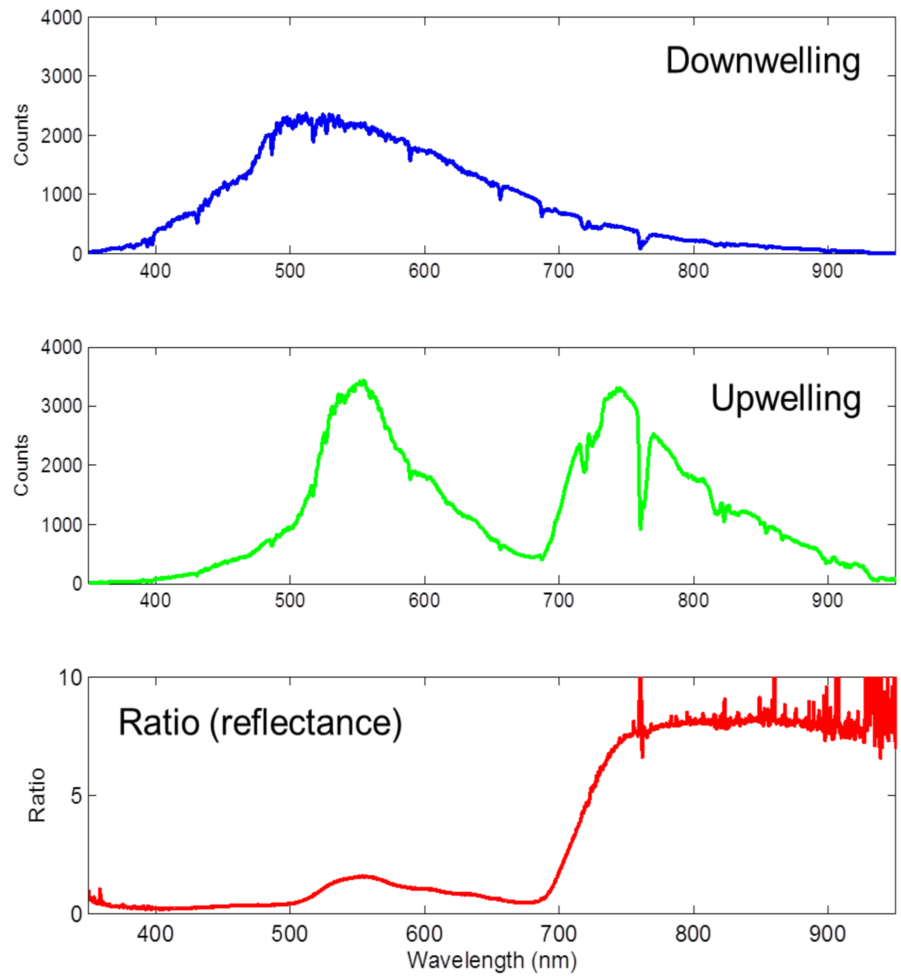
Vegetation spectra is related to a set of traits.

We can build equations to predict those traits as a function of the spectra.

- However, the **signal need to be sufficiently strong and clear** (SNR) to capture the trait variation.

Detection of SIF

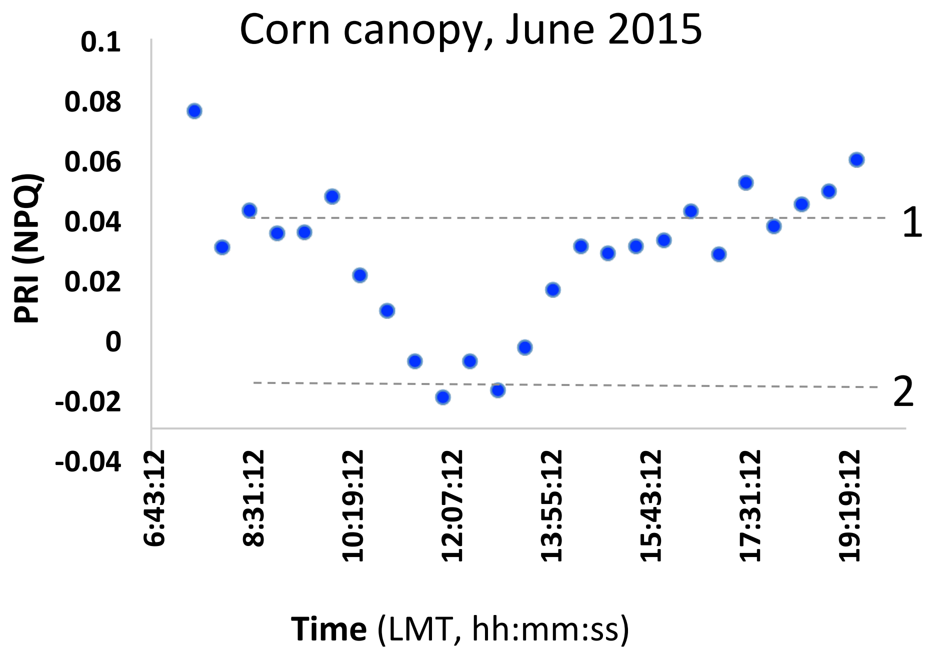
- The solar induced chlorophyll (SIF) fluorescence is 2-3% of the total radiance detected
- High resolution spectrometers needed (FWHM about 0.1-0.3 nm), complex calibration techniques, high SNR and a high spectral and radiometric stability
- The impact of the platform vibrations on spectrometer stability?
- Impact of the atmospheric effect should be considered



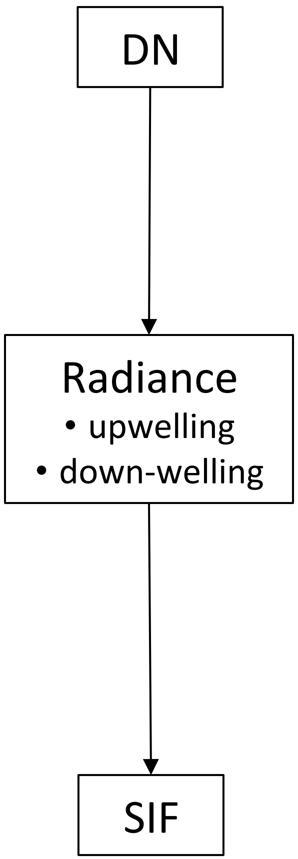
Seasonal and Diurnal Measurements at USDA OPE3, Greenbelt, MD

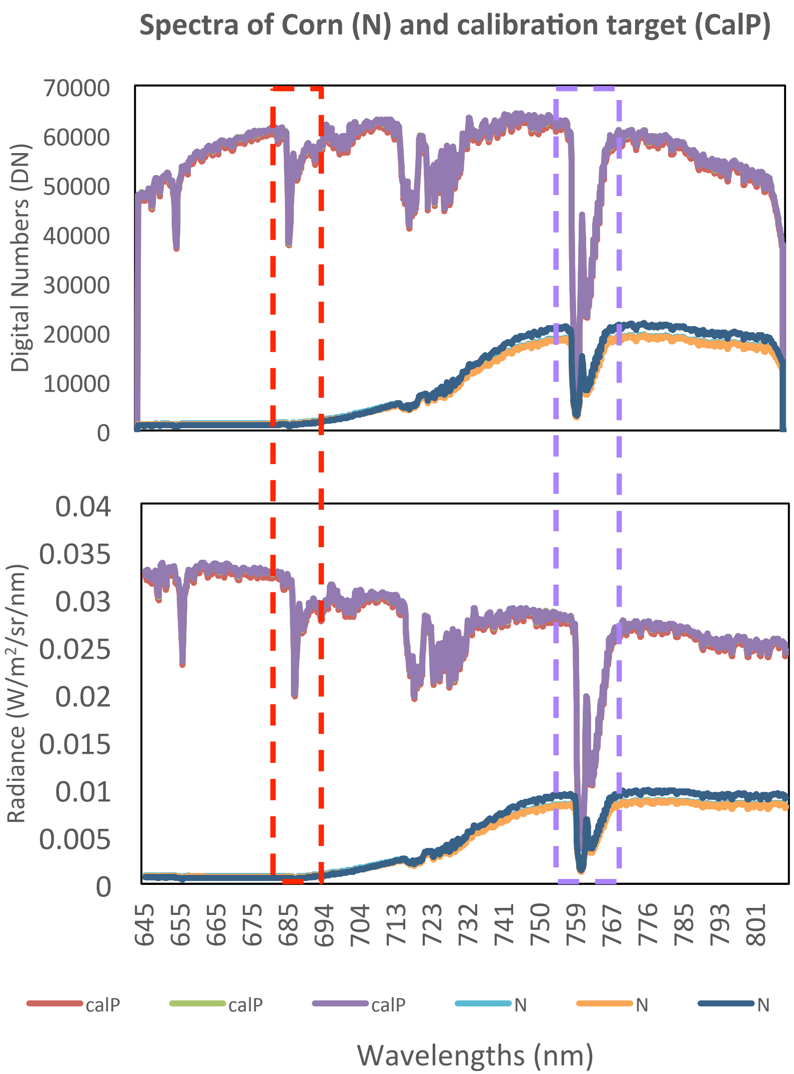
Considerations for SNR

- Light level and quality (e.g. PAR_i)
- Field of view
- View angle



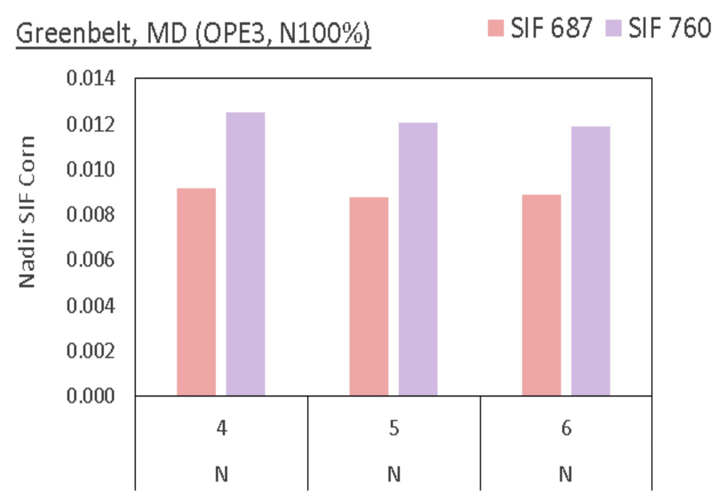
Measuring Solar Induced Fluorescence (SIF)





Radianceλ=(DNλ−DarkCurre

SIF Range (W/ m²/sr/nm)



Summary of Accomplishments

- IPM concepts, components and architecture are identified
- Flight authorization process – in progress, behind original schedule due to changing FAA rules
- Integration of both Piccolo and Nano-Hyperspec on moving platforms
- We are using collaborative efforts and additional moving platforms, such as tram and tractor as a workaround - in 2015 measurements from telescopic pole, tower, tractor and tram
- Data acquisition tests – retrieval of radiance, reflectance, retrieval of traits; -- *work in progress on optimization !*
- University of Wisconsin visit at GSFC in January and June, 2016
- UAS flights and retrieval of spectra and traits during 2016 and 2017
- Data sharing - within the team pilot data set for corn canopy, including raw measurements, calibrated radiance, reflectance and derived traits – ready products will be available via EcoSYS

Take Home Message

- New Generation (NG) spectral systems with flexible, automated acquisition strategy are needed to capture the **diurnal and seasonal dynamics in vegetation traits**.
- Calibrated imaging spectroscopy data is required at all spatial scales, to bridge the gap and connect ***in situ*** **with airborne and space observations**.
- This effort offers a first step toward the development of a small **science quality spectral UAS** for flexible monitoring of vegetation traits at the appropriate scale and rate.
- The NG Spectral UAS is needed for **basic science and practical applications**, such as precision agriculture, forestry, ecology, bio-diversity monitoring, and disaster relief during extreme climatic natural and anthropogenic events.