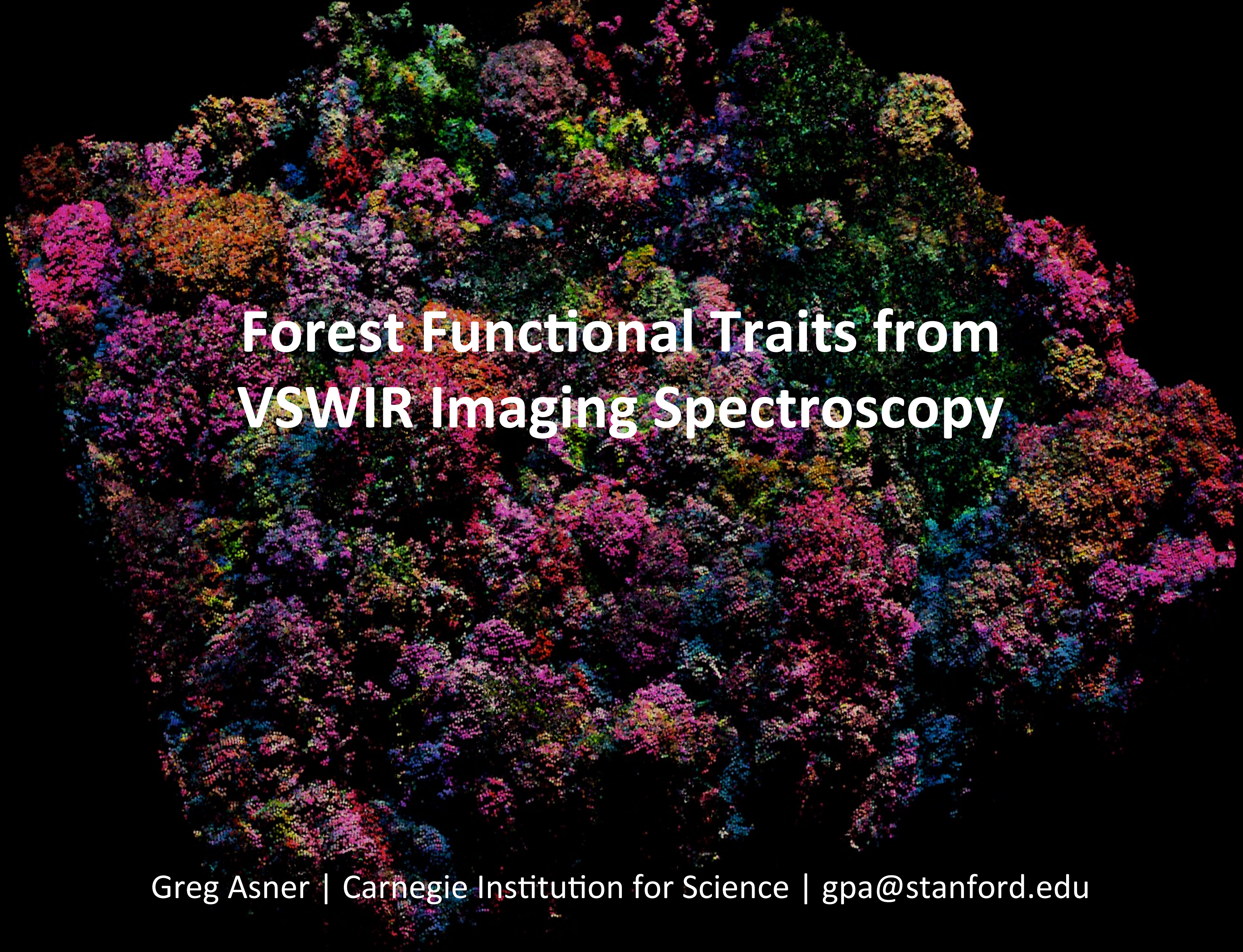
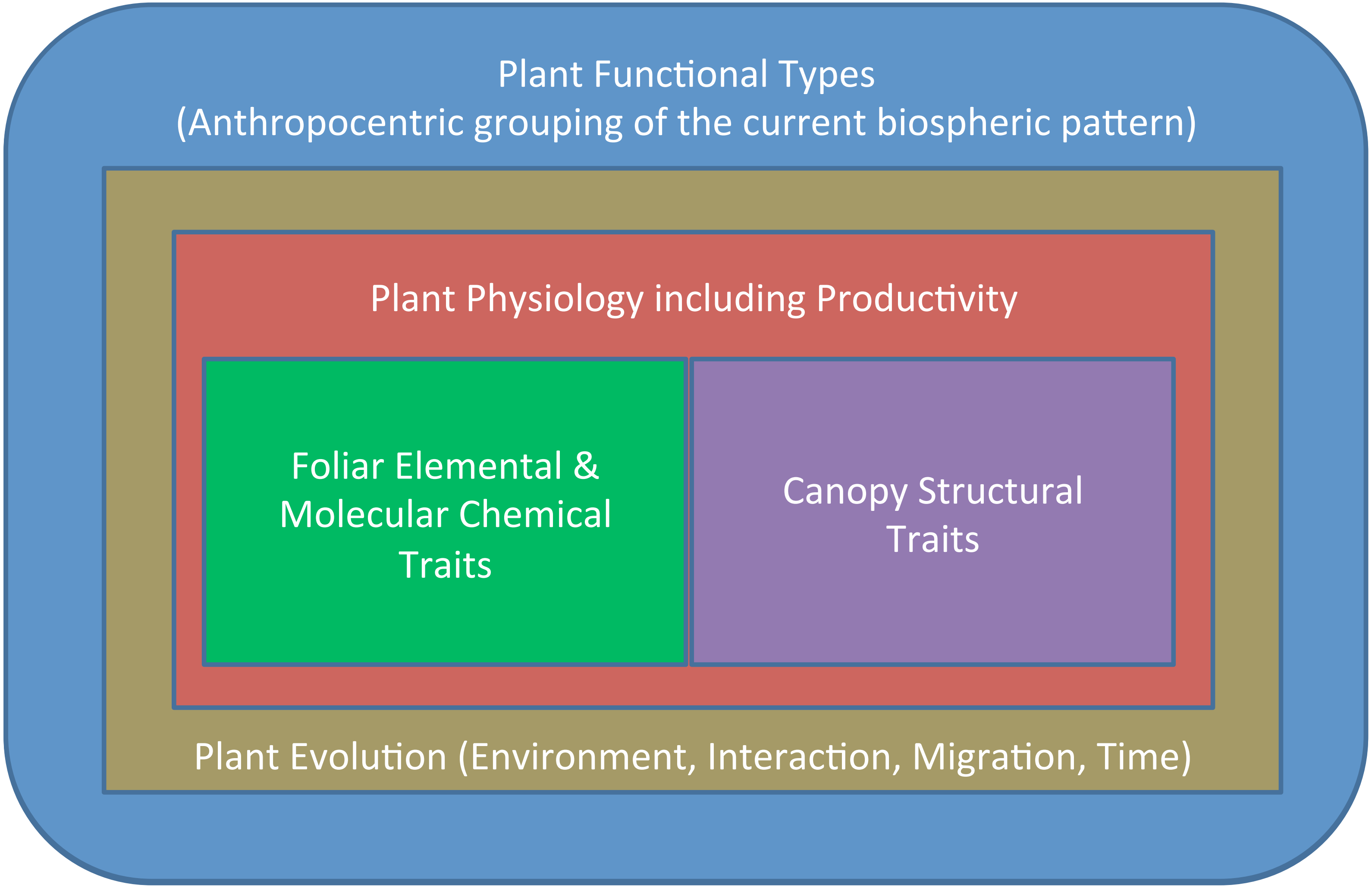


Forest Functional Traits from VSWIR Imaging Spectroscopy

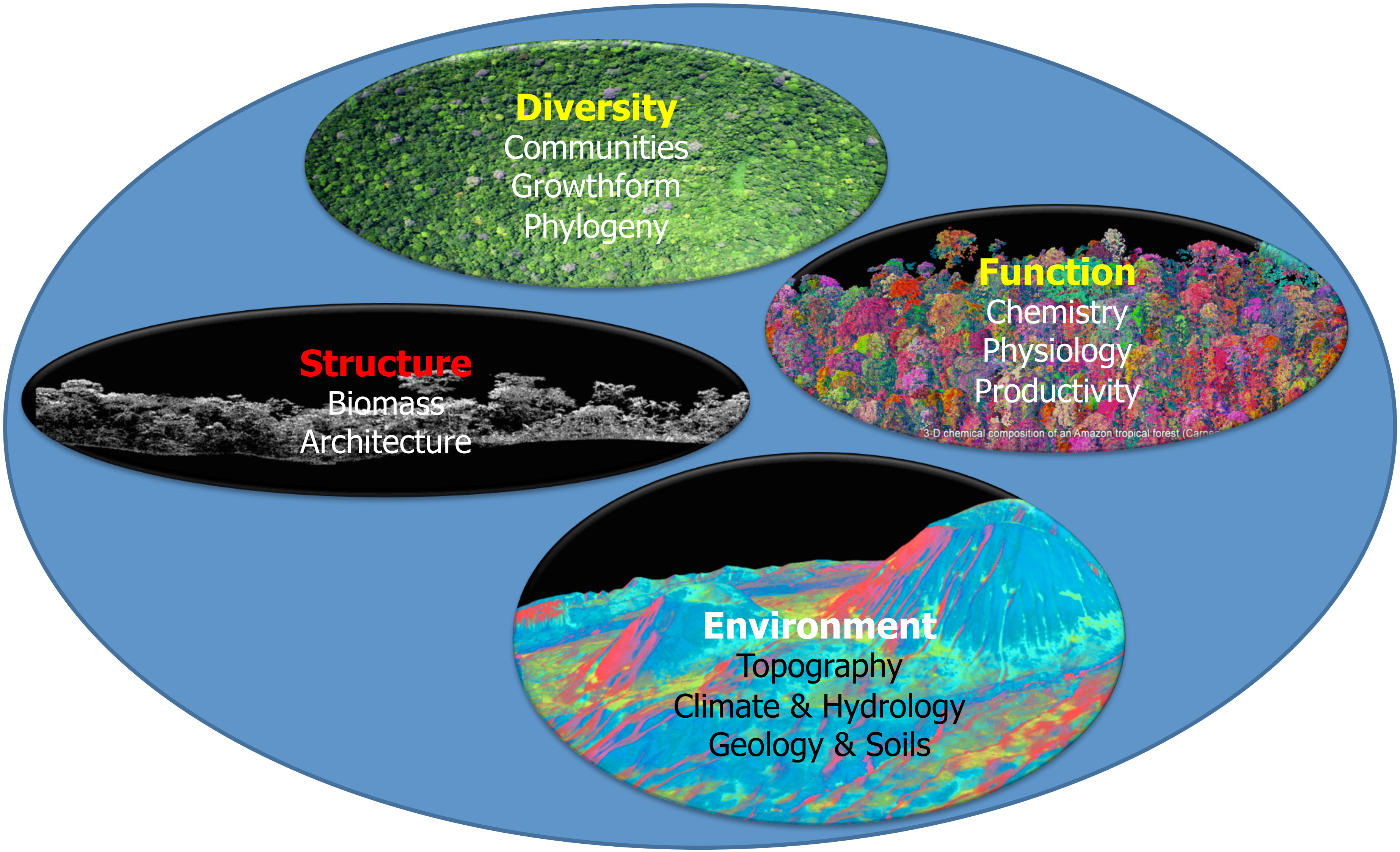
Greg Asner | Carnegie Institution for Science | gpa@stanford.edu

How are plant functional “traits” and “types” related?



This generates a goal:

Develop time-varying maps of multiple plant traits to understand changing functional & biological diversity in the Earth system



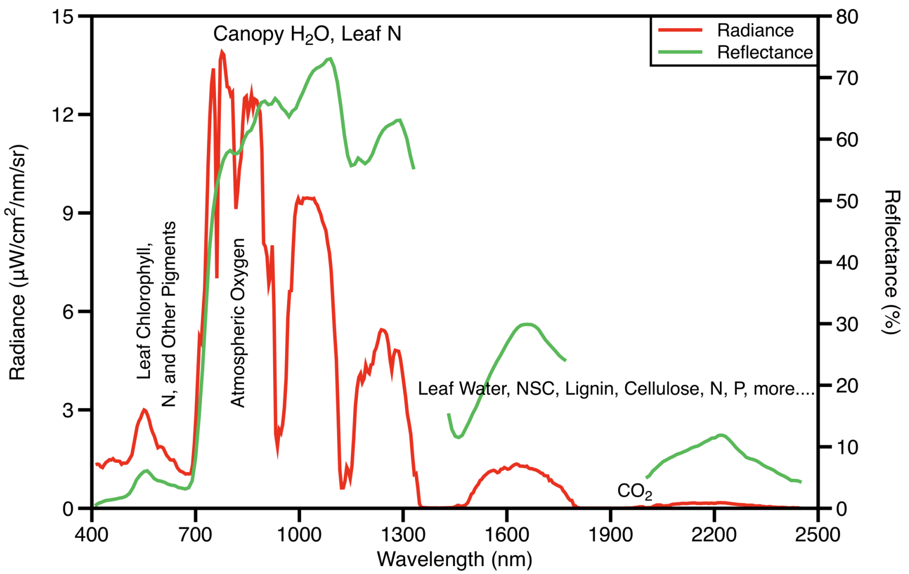
How do we treat our vegetation spectra?

Brief History of Plant Spectroscopy in Biospheric Studies

- **1980s & prior (acclimation phase):** Lab and field spectroscopy; Measurements seeking chemical contributions to spectral reflectance

- **1990s (reductionism phase):** Going quantitative at lab, field and airborne levels; Over-emphasis on lab-like spectrometric techniques for estimation of chemical constituents; Over-emphasis on spectral absorption; Under-emphasis on spectral scattering-absorption (structure-function)

- **2000s (emergentism phase):** Recasting of canopy chemistry and spectroscopy in concept of plant functional types; "Plant spectral types"; Recasting of spectroscopy in plant physiological context; Rise of evolutionary thinking in canopy spectroscopy (Spectranomics)



CarnegieSpectranomics

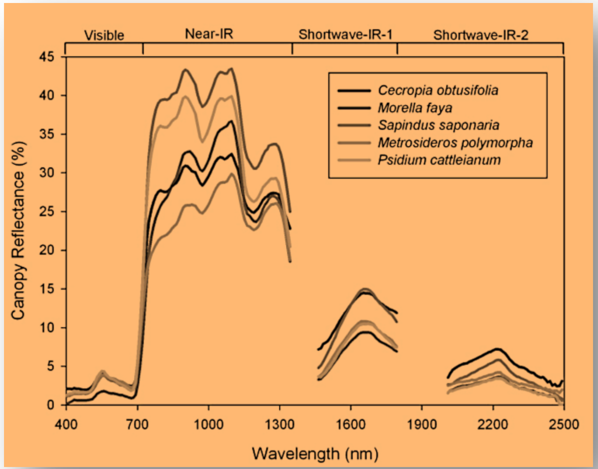
Mapping biodiversity from plant biochemistry

Background and Purpose

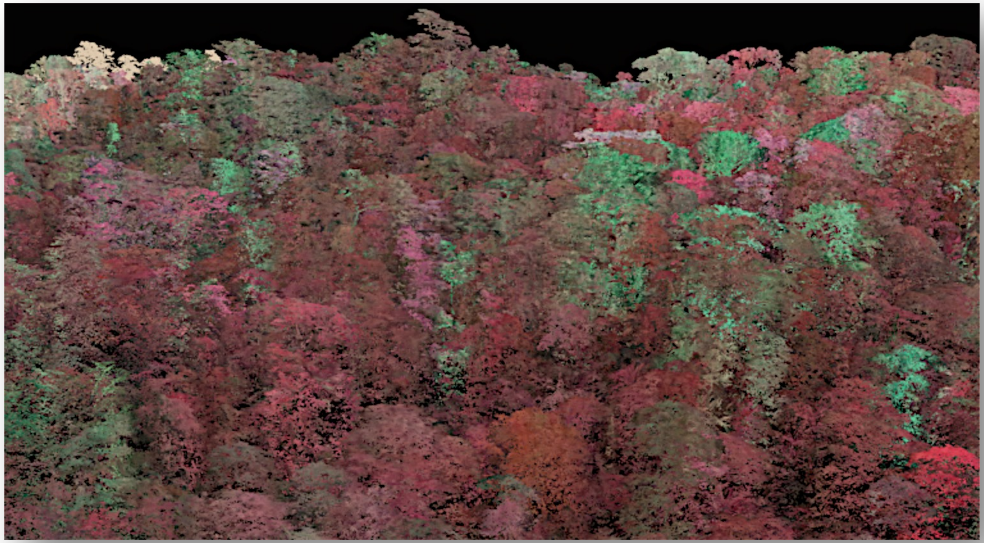
- The **chemical diversity** of plants is an expression of **taxonomic & phylogenetic diversity.**
- **Chemical diversity** is, in turn, expressed in the **spectral signatures** of plant canopies.
- The Carnegie Spectranomics Project links **chemical, spectral and phylogenetic patterns** among plant canopy species.
- The overarching purpose of Spectranomics is to **explore the chemical assembly of forests,** and to develop **maps of forest functional & biological diversity based on chemistry.**

Phylogeny

Spectroscopy



Canopy Chemistry



CarnegieSpectranomics

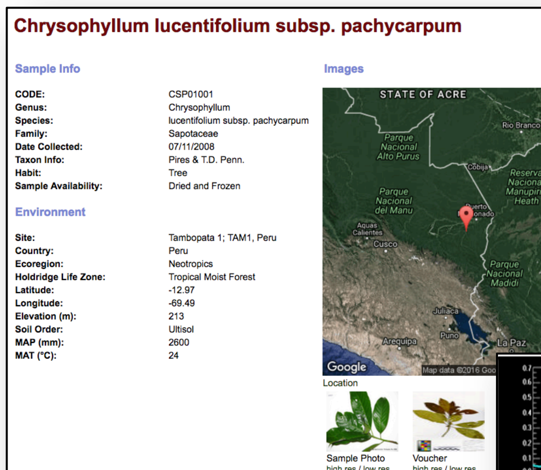
Mapping biodiversity
from plant biochemistry

Project Status

- Collections contain about half of all known canopy tree species on Earth.
- Frozen Forest has more than **3.5 million foliar samples** for chemical, evolutionary, and remote sensing research.
- Standard assay provides **23 chemical traits** for each canopy specimen. Taxonomic vouchers permanently archived.
- CSP **spectroscopic and chemometric** analyses connect forest canopy species and their remotely sensed signatures.

Spectranomics Field Sites

Spectranomics Database



Chrysophyllum lucentifolium subsp. pachycarpum

Sample Info

CODE:	CSP01001
Genus:	Chrysophyllum
Species:	lucentifolium subsp. pachycarpum
Family:	Sapotaceae
Date Collected:	07/11/2008
Taxon Info:	Pires & T.D. Penn.
Habit:	Tree
Sample Availability:	Dried and Frozen

Environment

Site:	Tambopata 1; TAM1, Peru
Country:	Peru
Ecoregion:	Neotropics
Holdridge Life Zone:	Tropical Moist Forest
Latitude:	-12.97
Longitude:	-69.49
Elevation (m):	213
Soil Order:	Ultisol
MAP (mm):	2600
MAT (°C):	24

Images

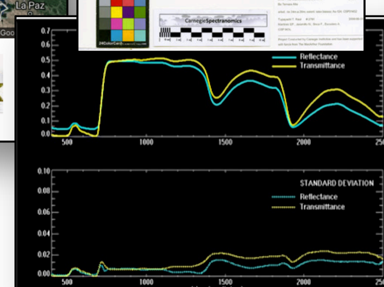
STATE OF ACRE

Google

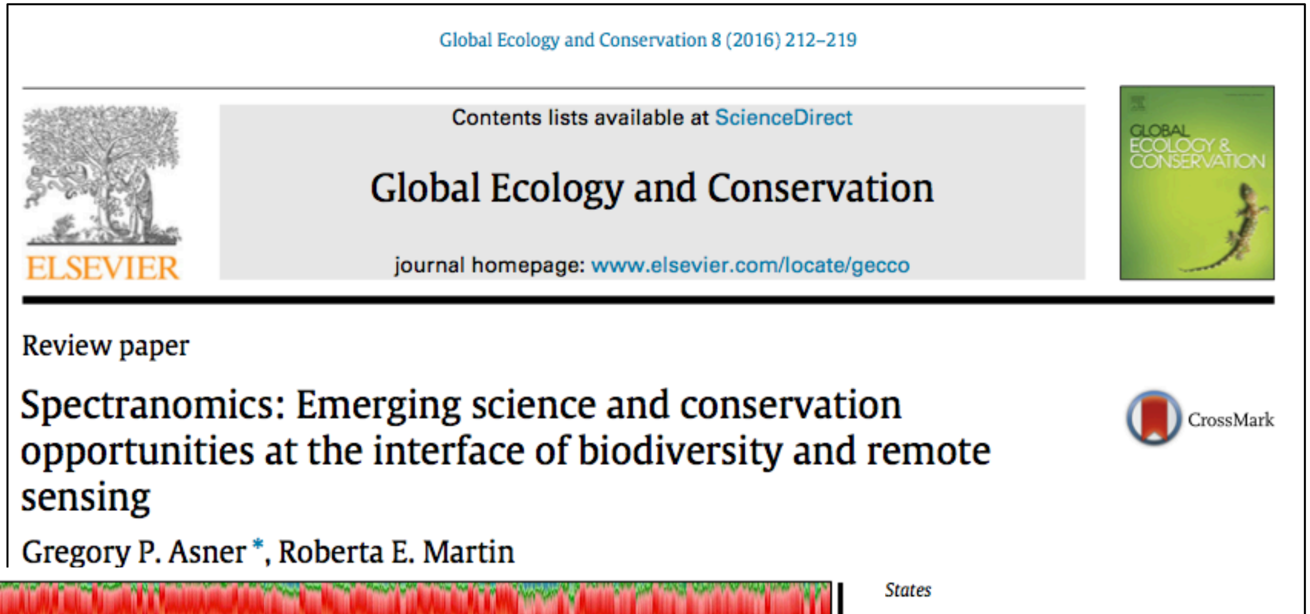
Location

Sample Photo
high res / low res

Voucher
high res / low res



July 2016: 10th anniversary



Global Ecology and Conservation 8 (2016) 212–219

Contents lists available at ScienceDirect

Global Ecology and Conservation

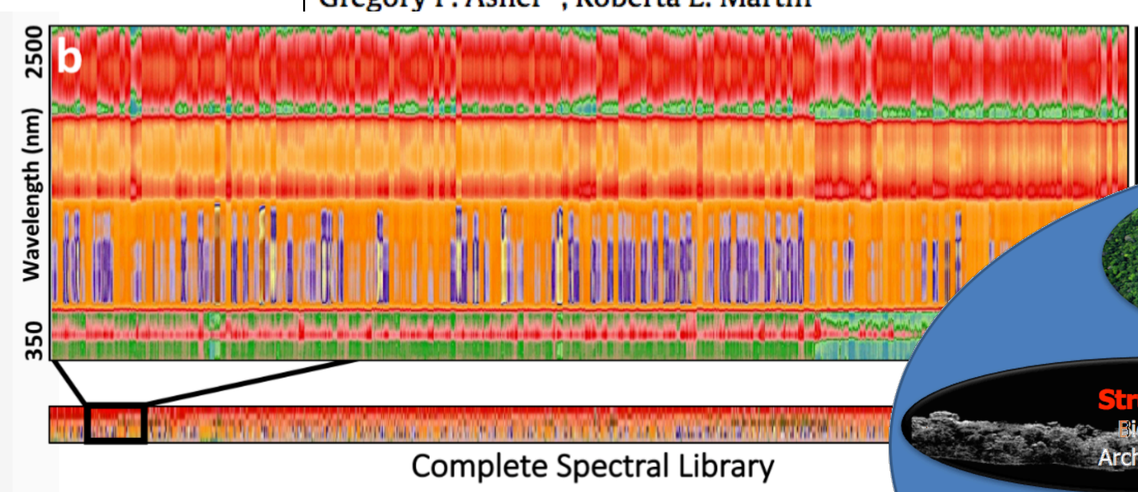
journal homepage: www.elsevier.com/locate/gecco

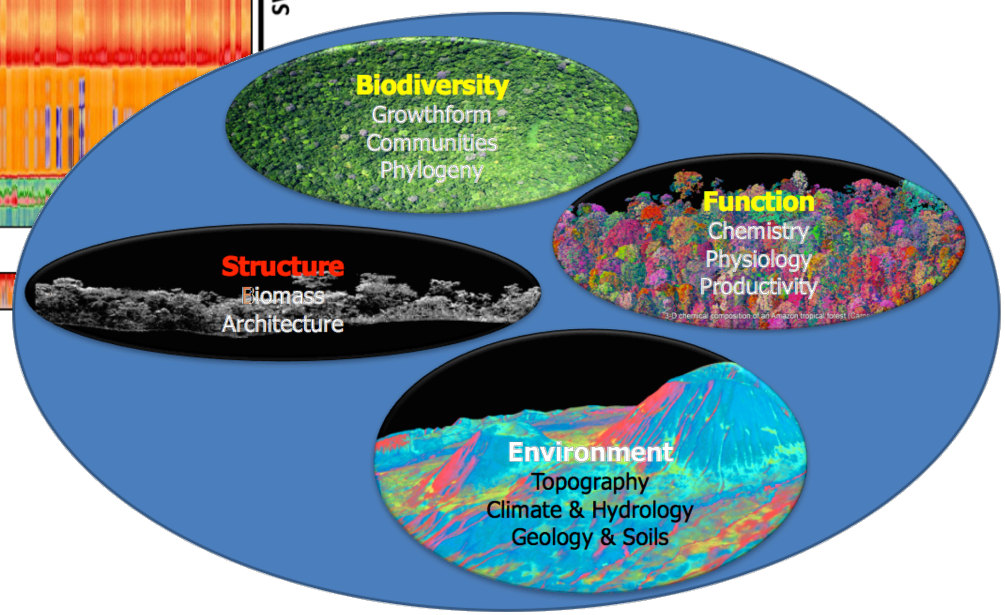
Review paper

Spectranomics: Emerging science and conservation opportunities at the interface of biodiversity and remote sensing

Gregory P. Asner *, Roberta E. Martin

States

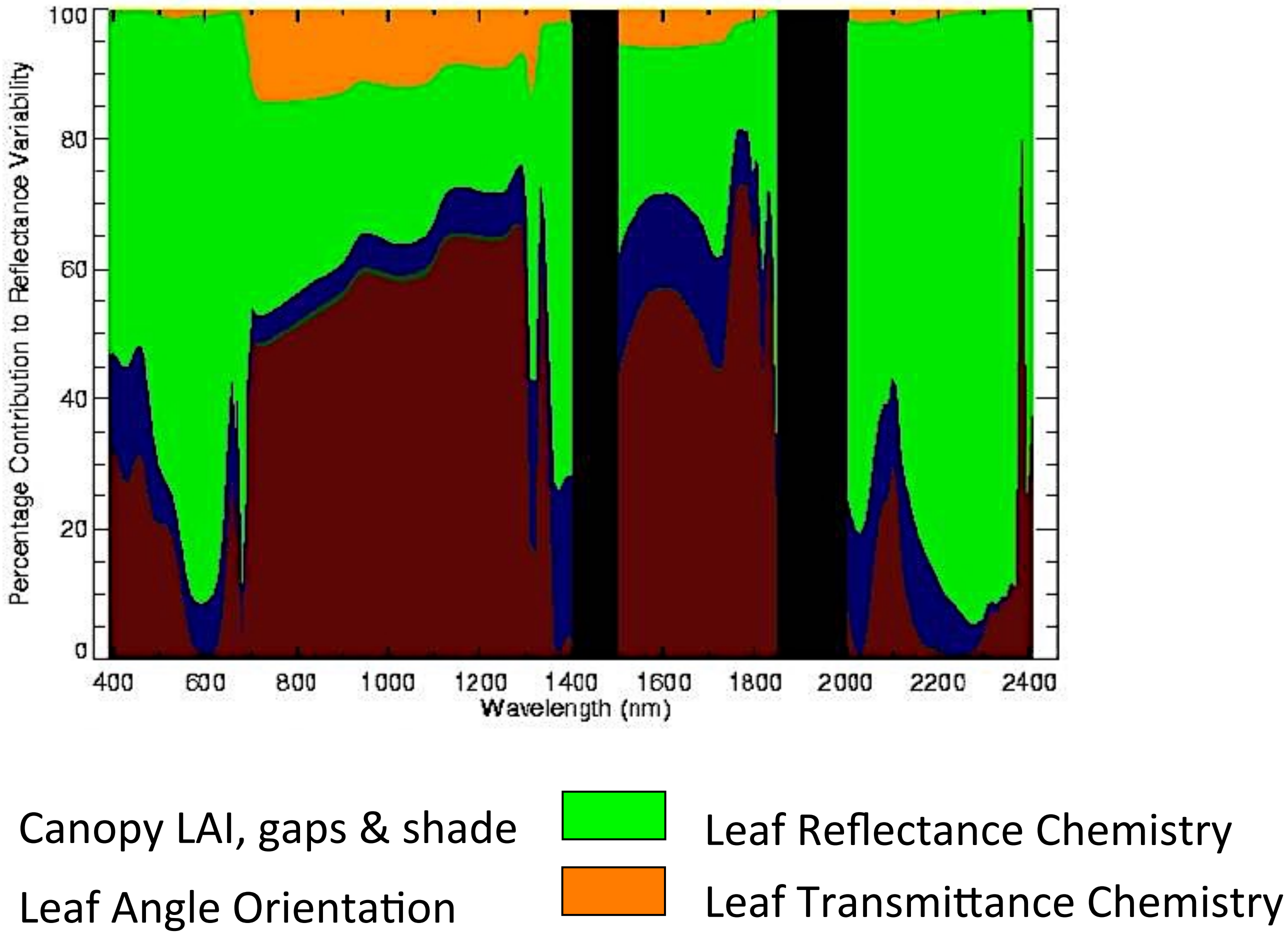




Spectranomics Outcome Type 1:

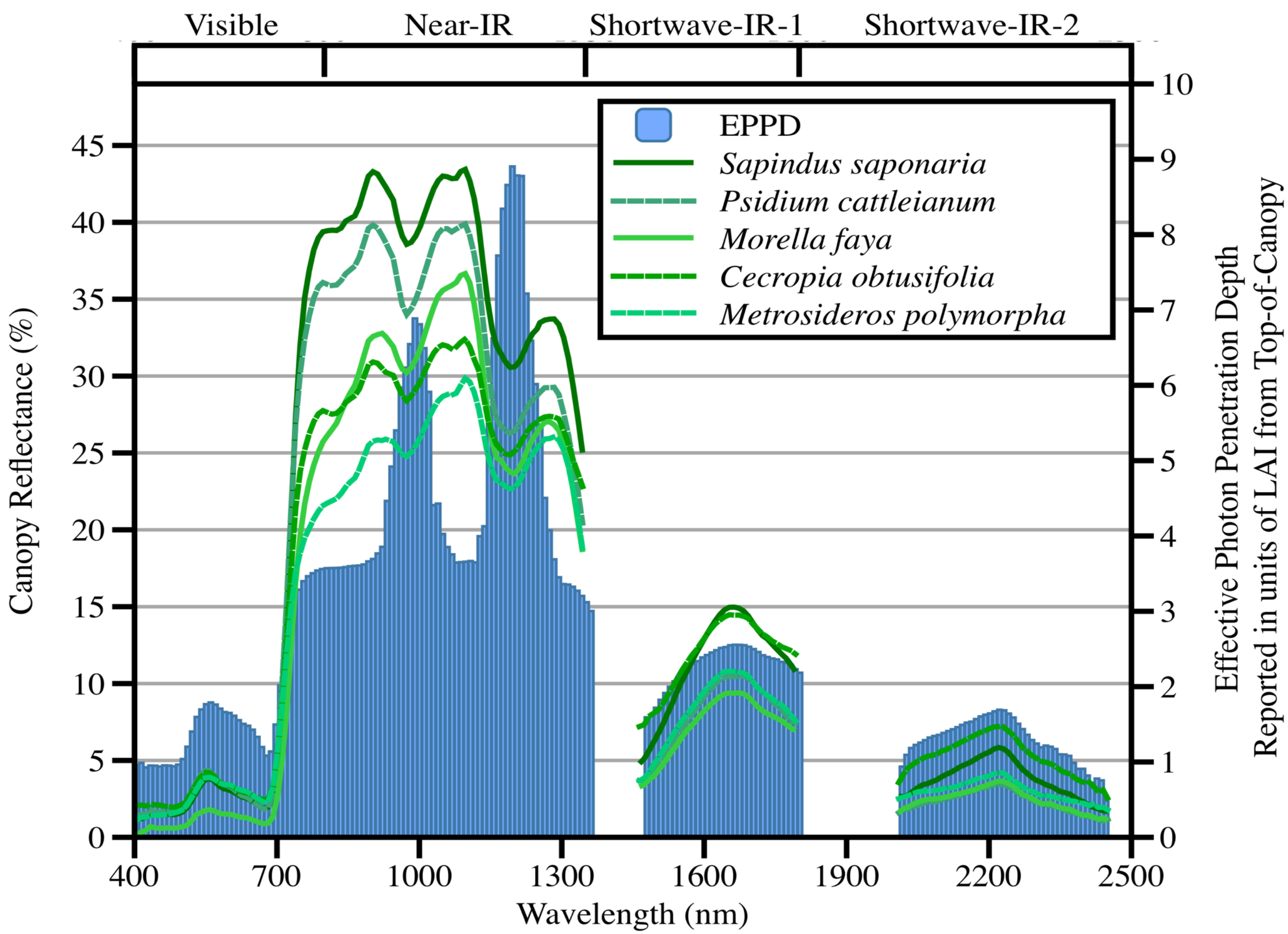
Scalable methods for functional trait mapping from imaging spectroscopy

First, what controls canopy reflectance of forests?



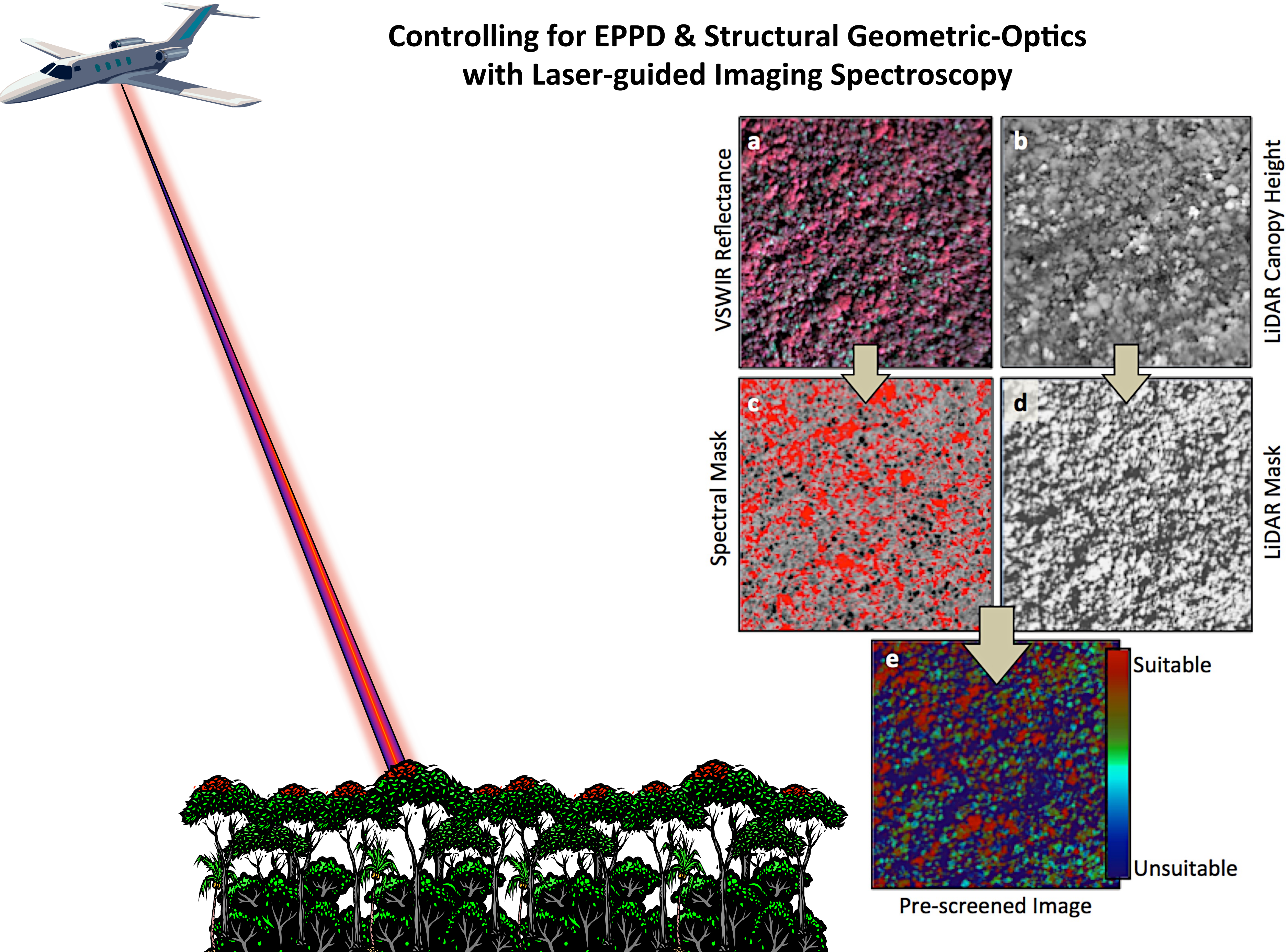
Asner 1998

Concept of Effective Photon Penetration Depth (EPPD)



Asner 2008

Controlling for EPPD & Structural Geometric-Optics with Laser-guided Imaging Spectroscopy



Asner & Martin RSE 2008

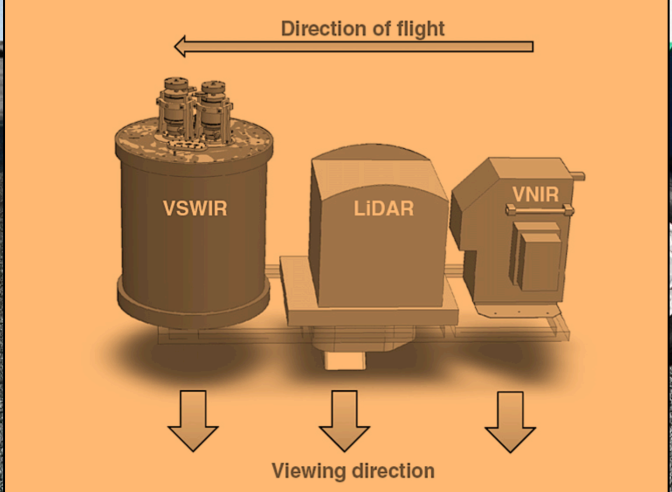
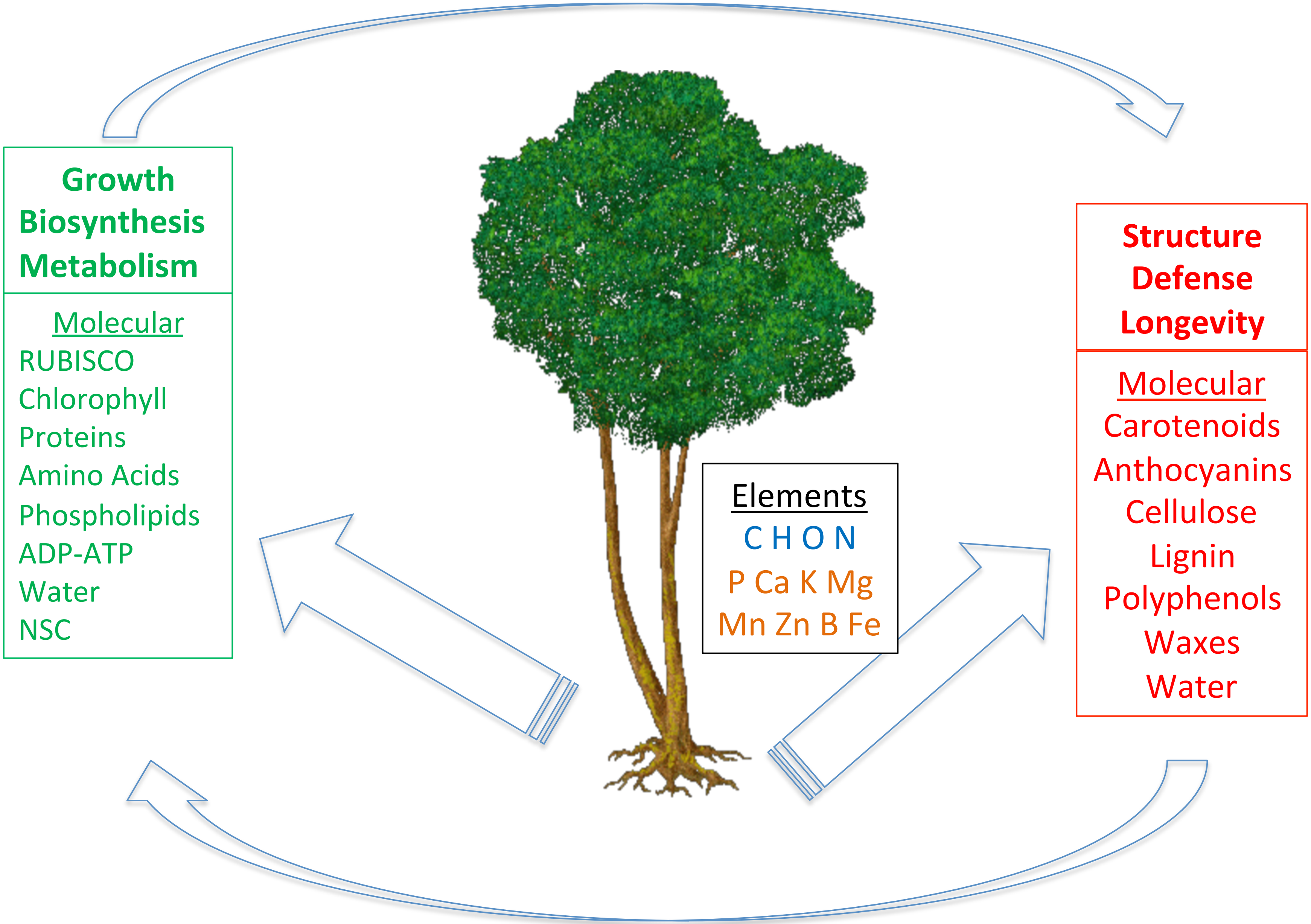
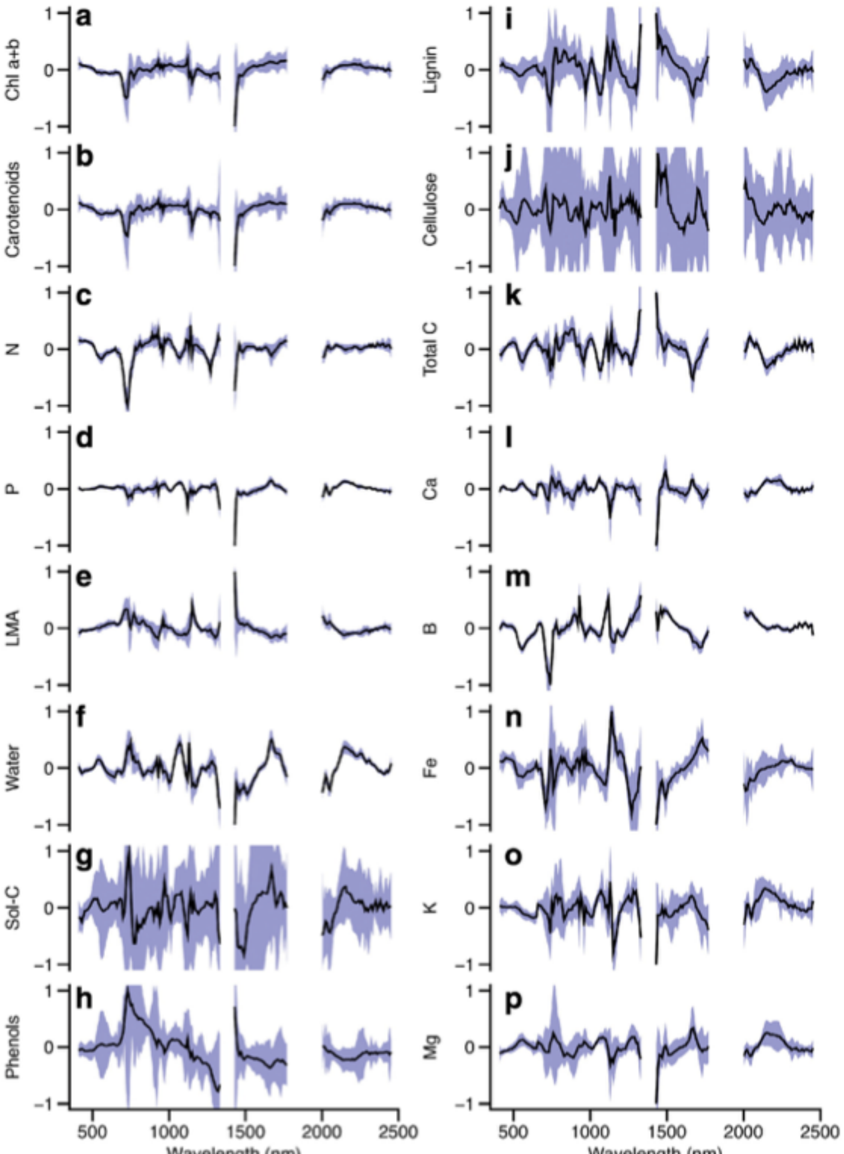


Fig. 1. Schematic view of the CAO AToMS sensor heads including, from left to right: visible-to-shortwave infrared imaging spectrometer (VSWIR), waveform light detection and ranging (LiDAR) scanner, and visible-to-near infrared imaging spectrometer (VNIR).

Concept of Evolved Chemical Constellations



High-fidelity imaging spectroscopy indicates molecular (thus, elemental) chemistry in plant canopies



	R^2	RMSE	%RMSE
	Light capture and growth		
Chlorophyll a+b*	0.71±0.07	0.84±0.10	15.66
Carotenoids*	0.64±0.08	0.16±0.02	13.15
N*	0.55±0.09	0.30±0.03	14.47
P*	0.72±0.10	0.02±0.00	16.59
LMA*	0.70±0.08	11.87±1.55	9.99
Water	0.49±0.13	2.95±0.38	5.22
Soluble carbon	0.50±0.14	4.40±0.87	9.16
	Structure and defense		
Phenols	0.33±0.10	20.30±1.77	18.37
Lignin	0.54±0.15	3.51±0.62	14.94
Cellulose	0.39±0.12	2.33±0.34	14.34
Total carbon	0.71±0.16	1.35±0.35	2.67
	Maintenance and metabolism		
Ca**	0.79±0.17	0.14±0.06	16.99
B*	0.53±0.07	7.31±0.89	43.33
Fe*	0.56±0.09	12.39±1.94	27.29
K*	0.42±0.22	0.15±0.04	24.57
Mg*	0.34±0.19	0.06±0.01	31.78

Asner et al RSE 2015

The Latest Tech: Ensemble Chemical Estimation Approaches

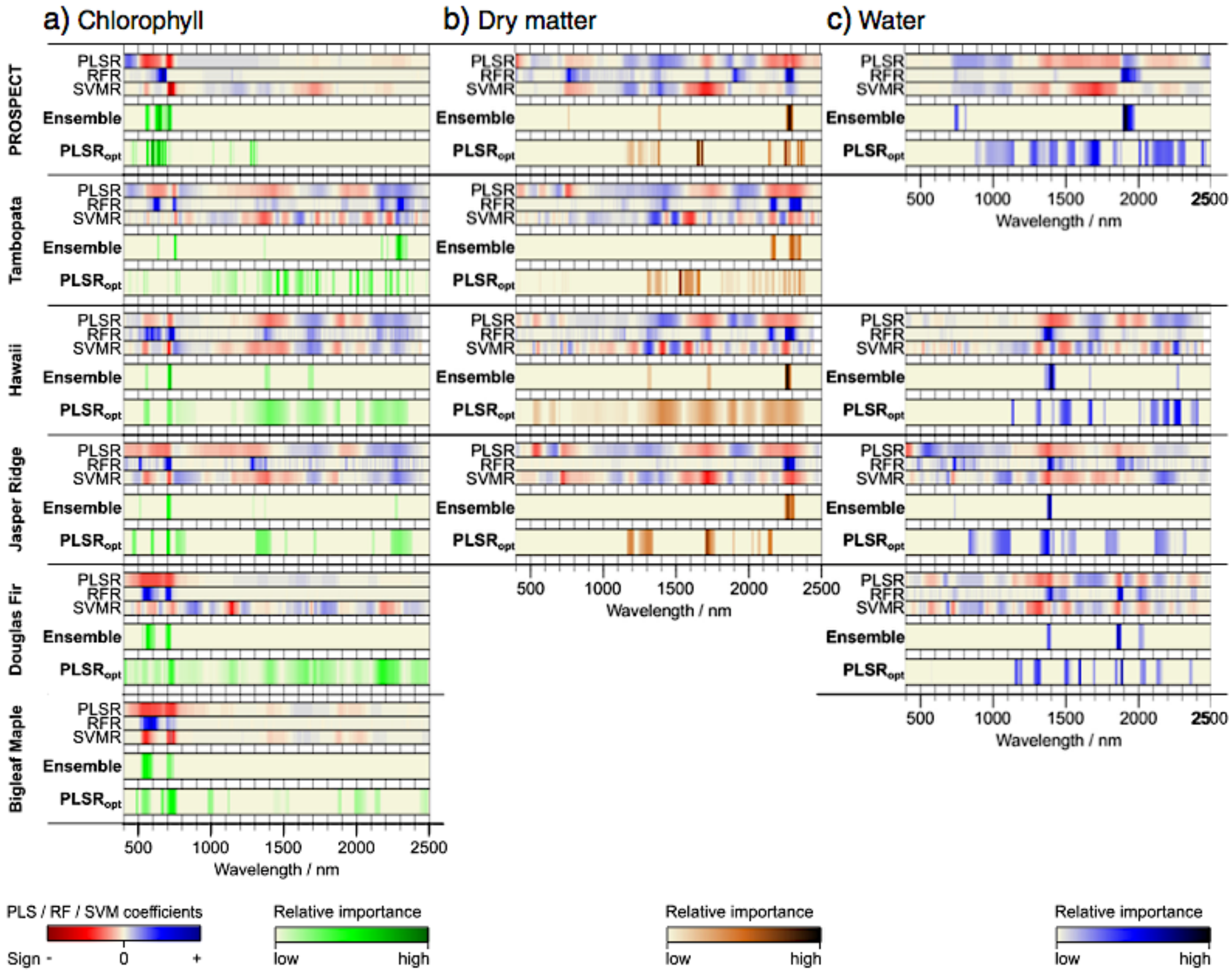


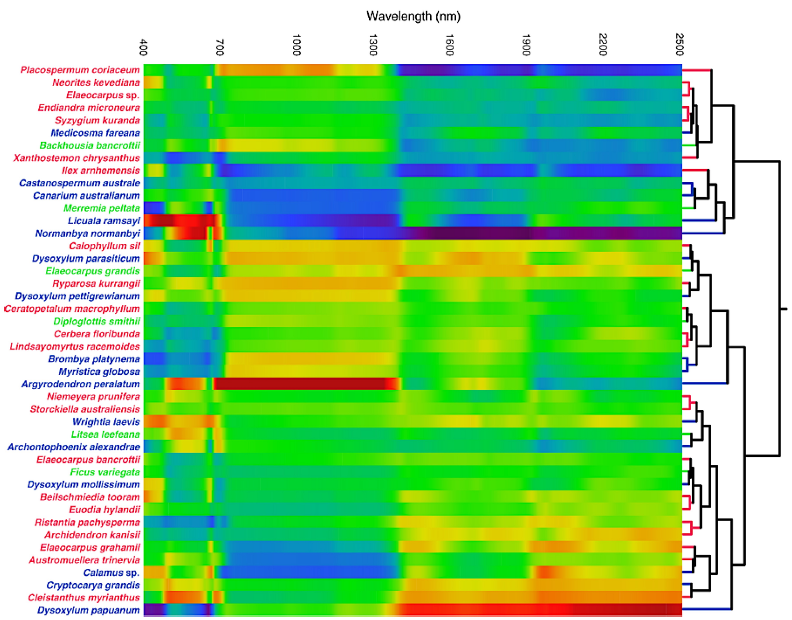
Fig. 4. PLSR, RFR, and SVMR coefficients as measures of band importance within the ensemble, and bands selected by the ensemble and $PLSR_{opt}$ approach for the relation between reflectance and chlorophyll concentration (a), dry matter content (b), and water content (c). The color gradients illustrate the relative importance of the respective spectral band. The combination of PLSR, RFR, and SVMR coefficients determines the ensemble importance. The $PLSR_{opt}$ importances are used for comparison and evaluation purposes.

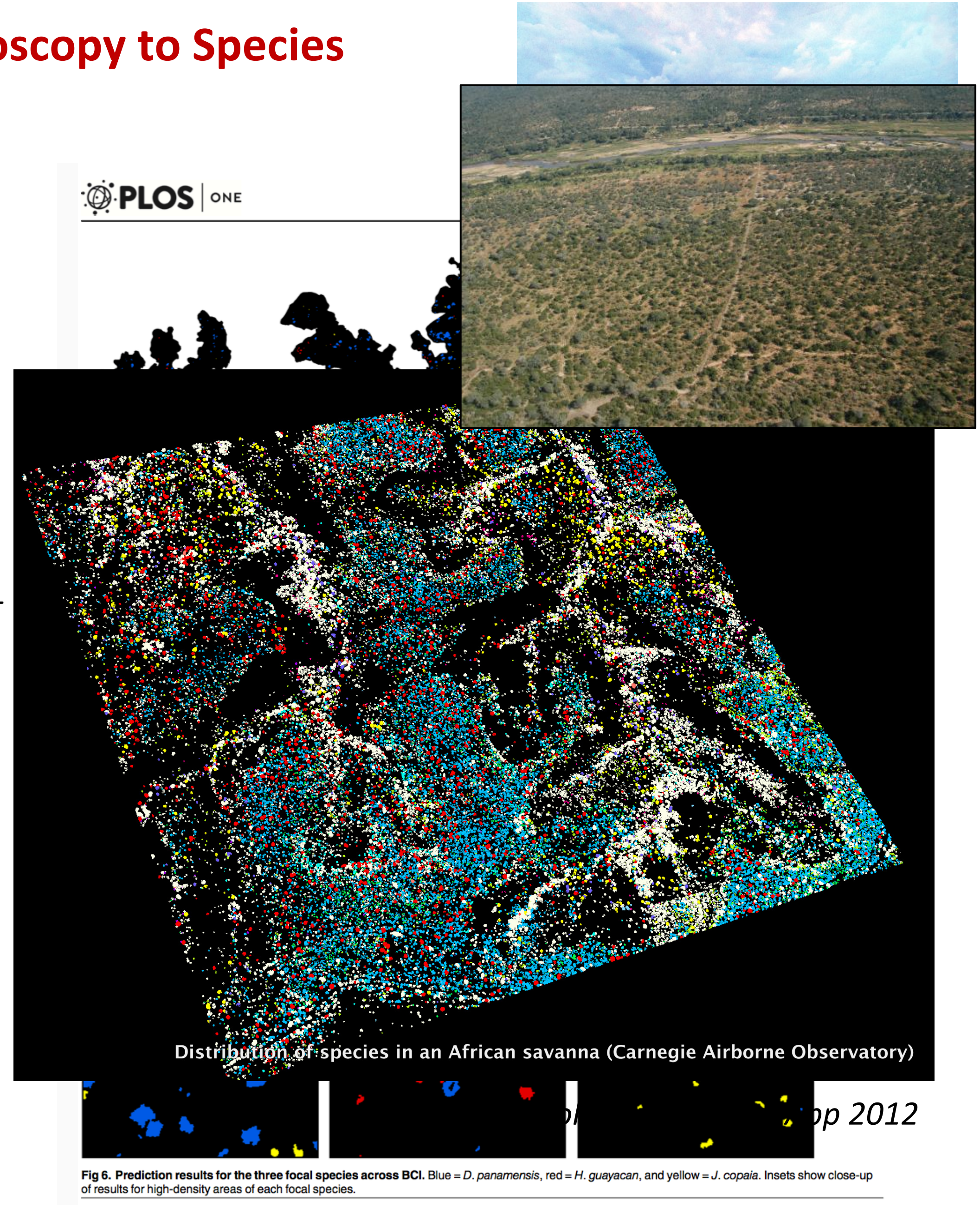
Feilhauer et al RSE 2015

Spectranomics Outcome Type 2:

Different quantitative ways to connect spectroscopy, functional traits, and biological diversity

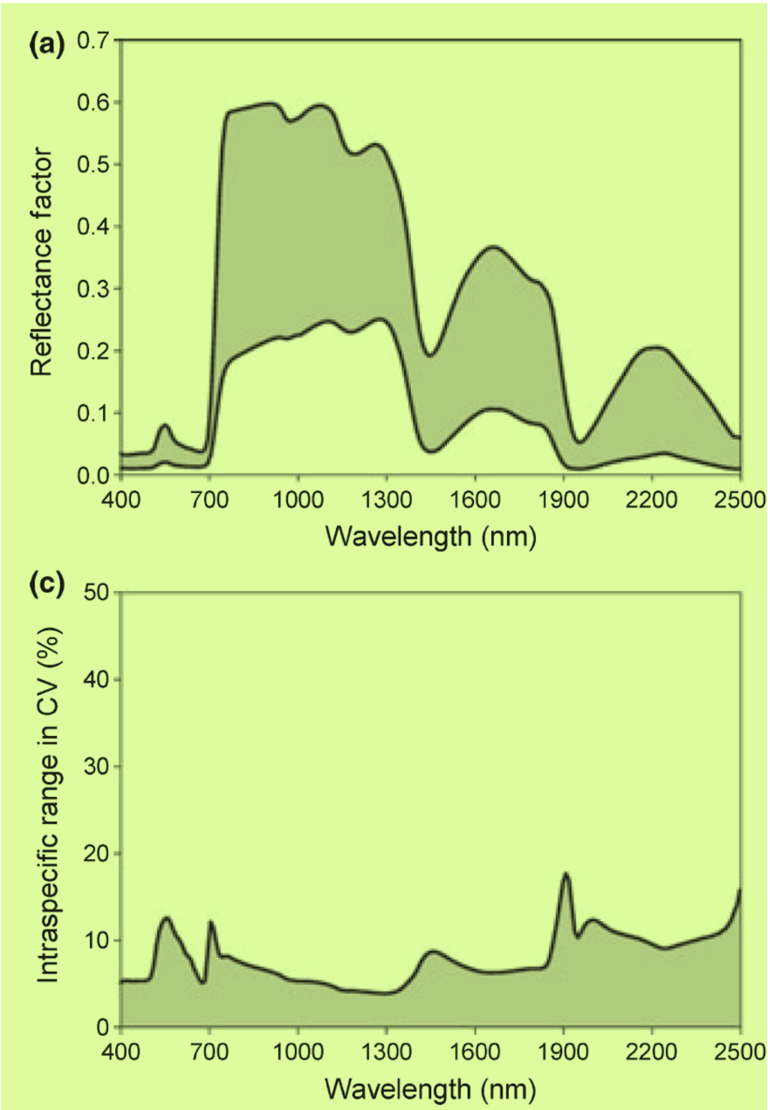
Spectroscopy to Species

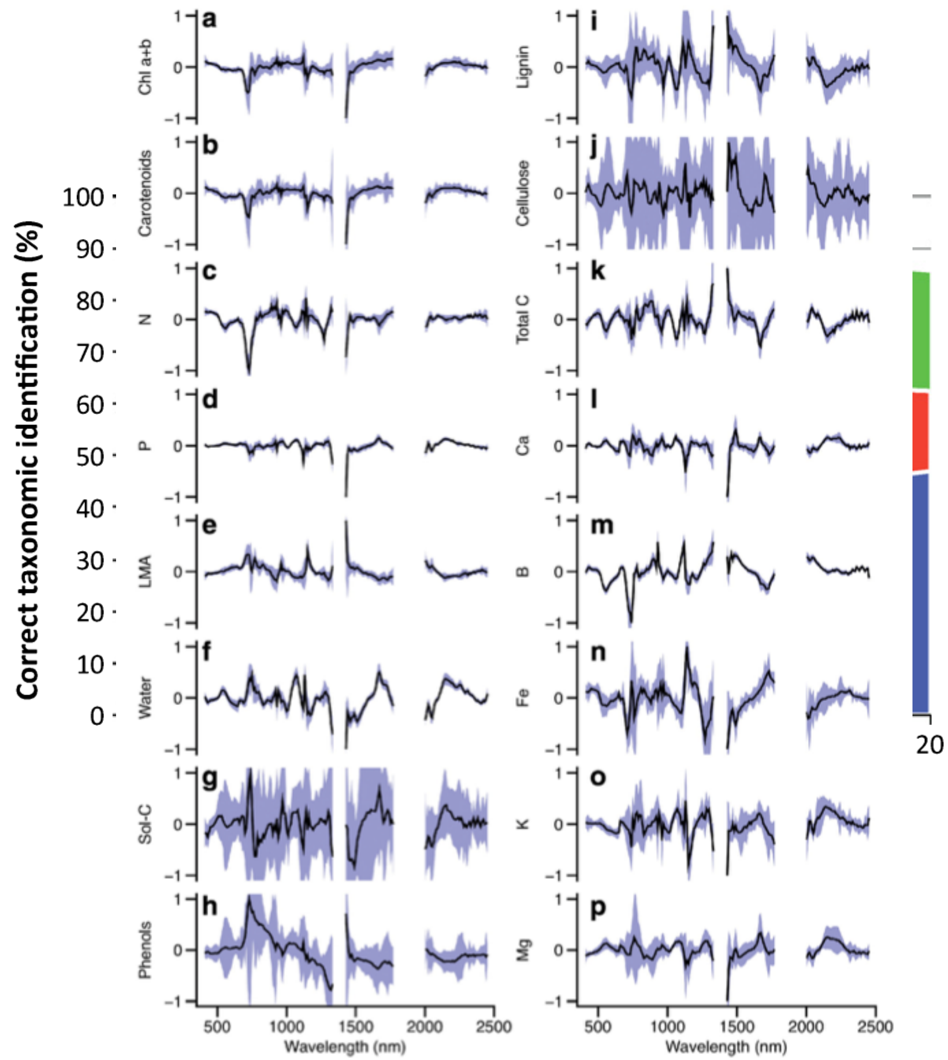




Baldeck et al PLOS 2015

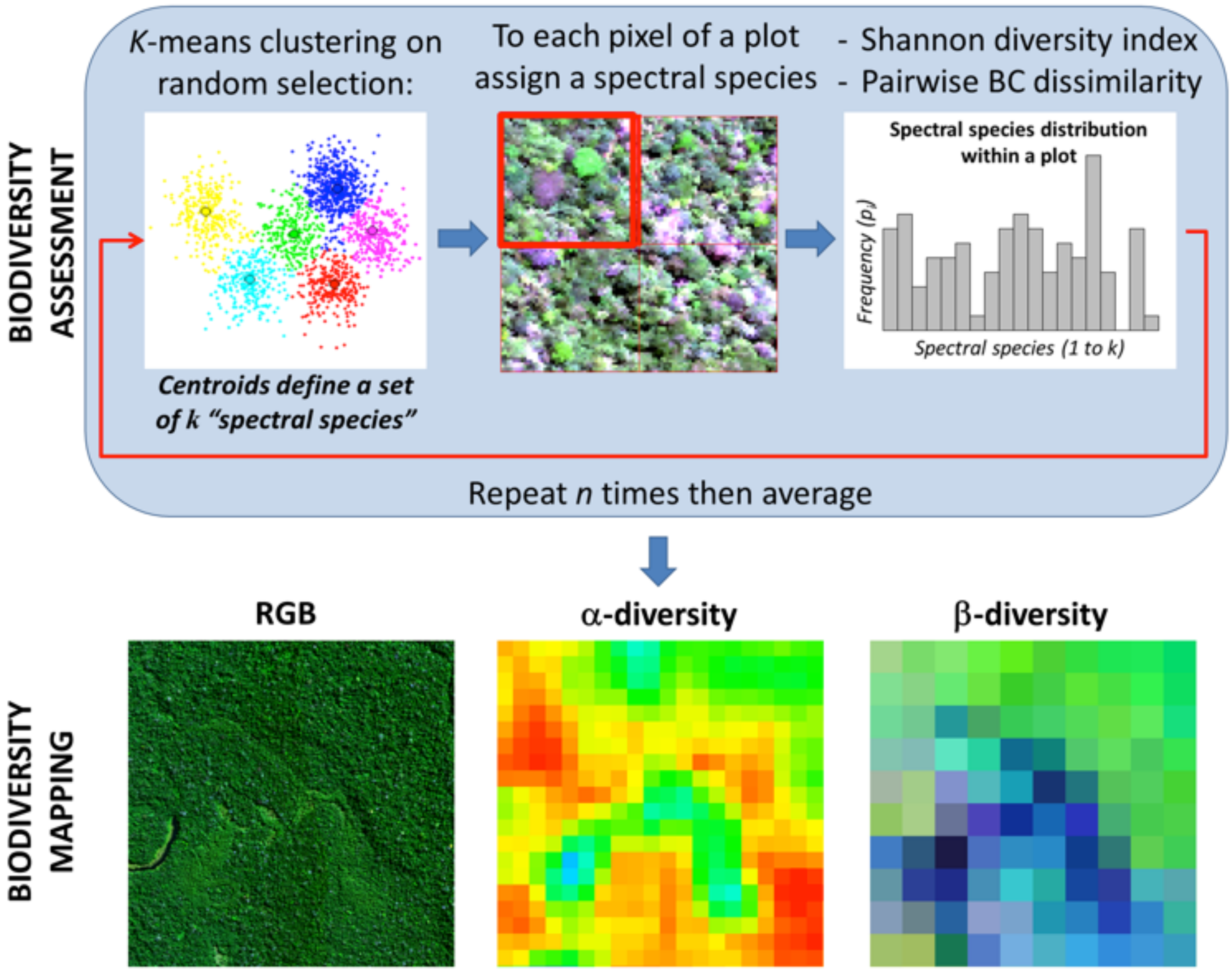
Spectroscopy to Functional Traits to Biodiversity



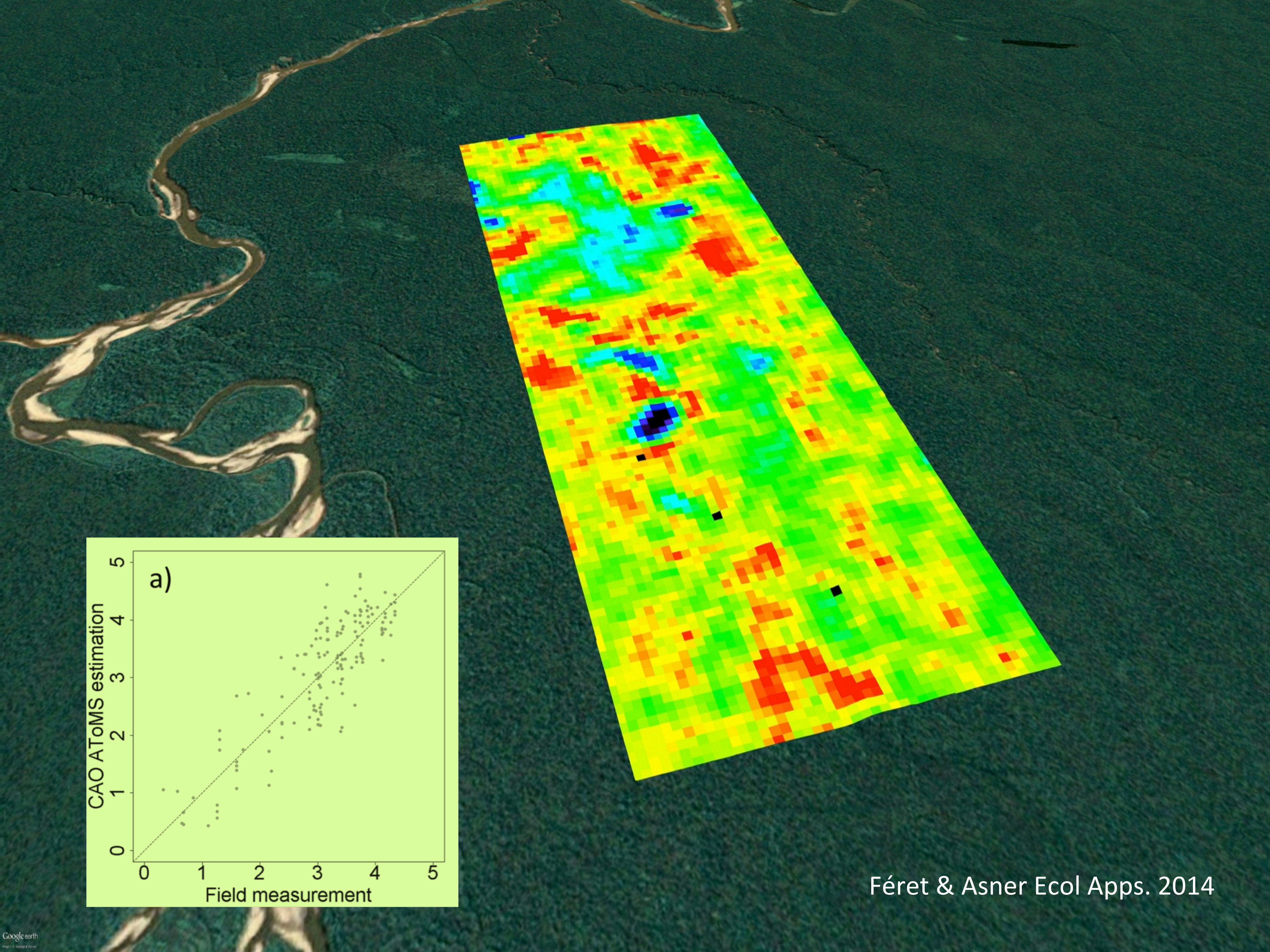


Asner & Martin New Phyt 2011

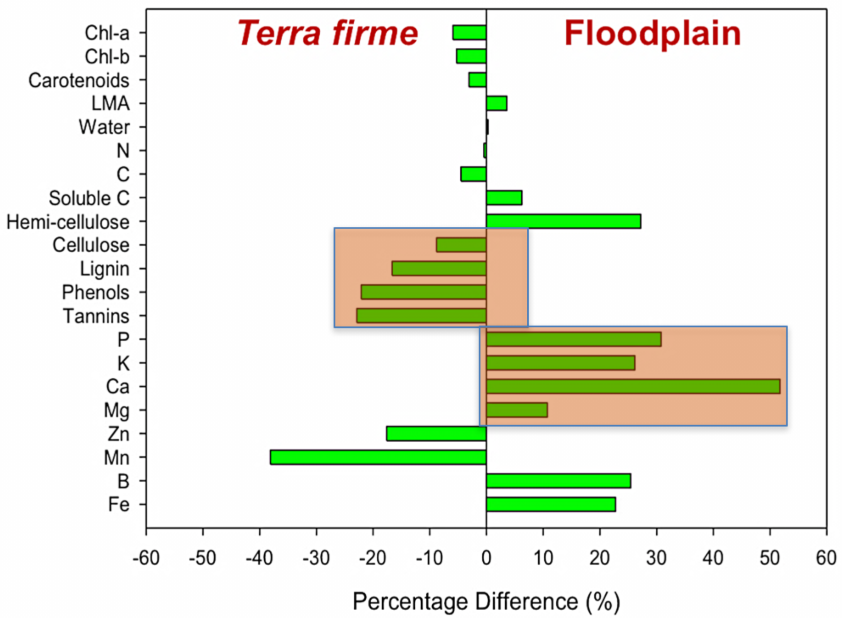
From Traits to Biological Diversity

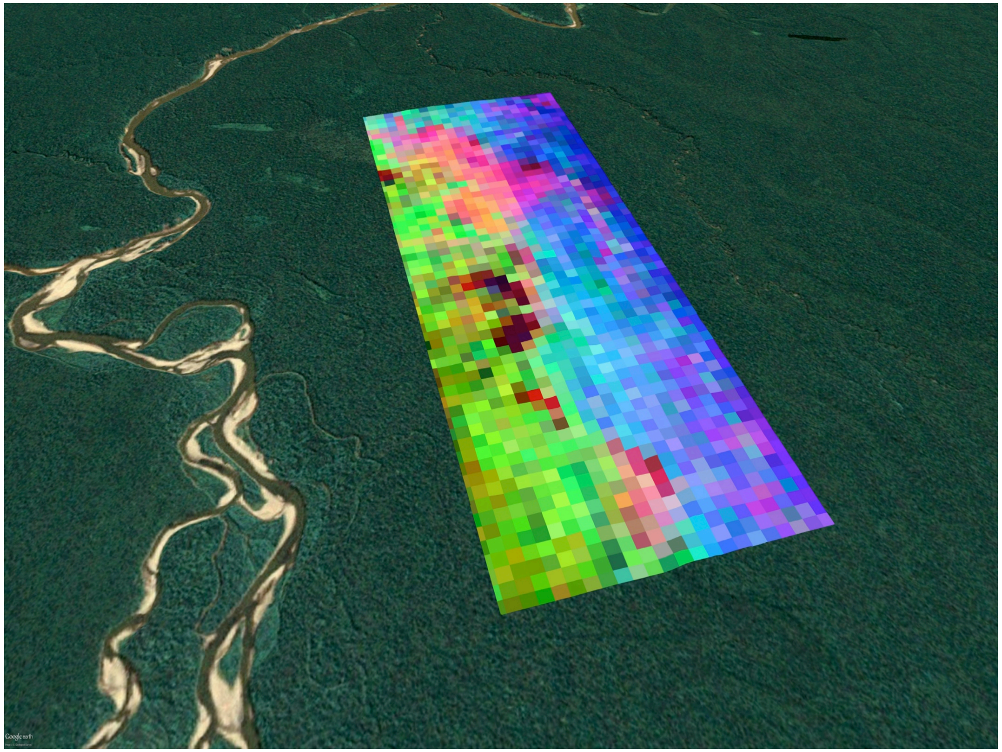


Féret & Asner Ecol Apps. 2014


a)
CAO AToMS estimation
0
1
2
3
4
5
Field measurement
Féret & Asner Ecol Apps. 2014
Google earth

Forecasting Spectroscopic Communities to Map

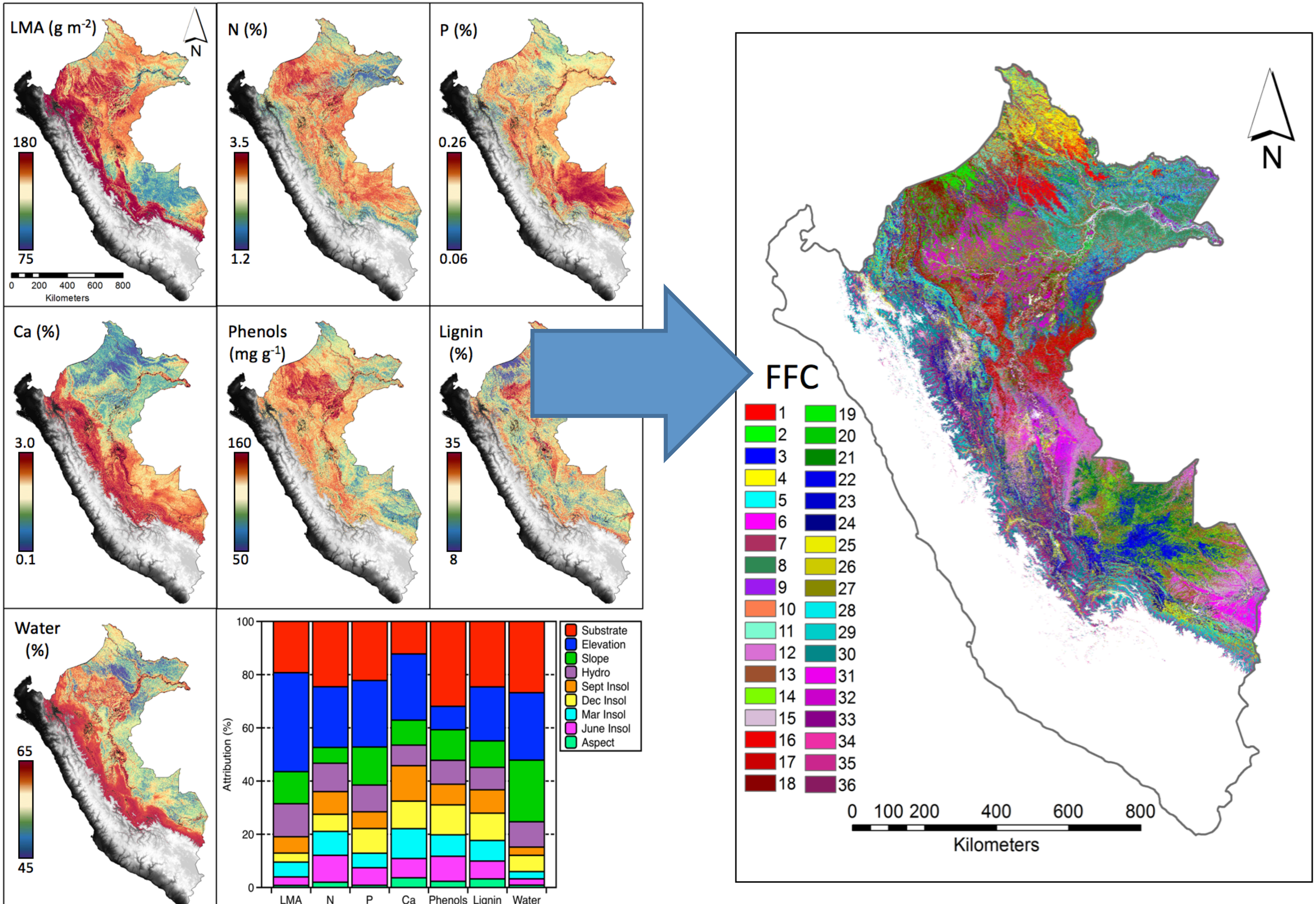




Asner & Martin New Phyt 2011

Feret & Asner Ecol Apps 2014

Big Outcome: Spectroscopic Mapping at the Biospheric Level

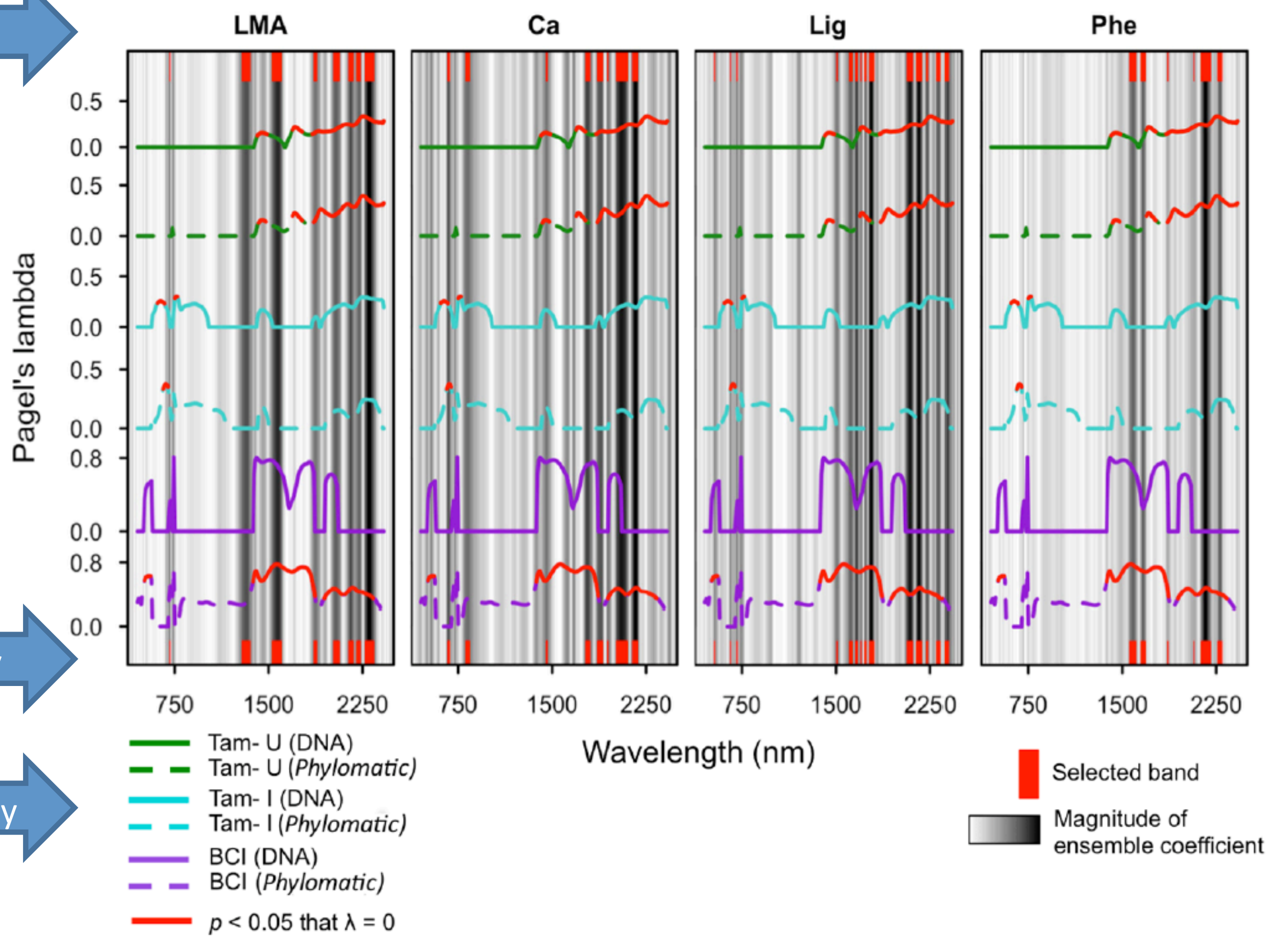


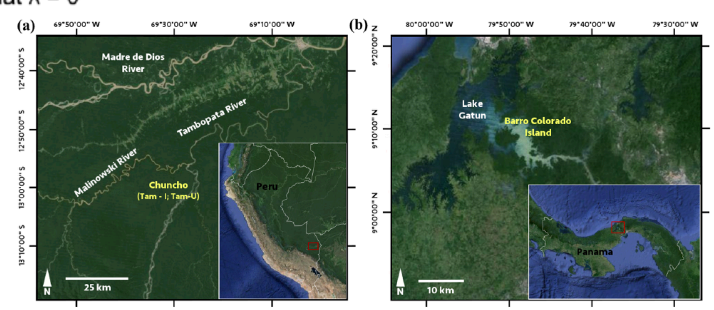
Latest Science: Genetics, Spectroscopy and Functional Traits

Chemistry

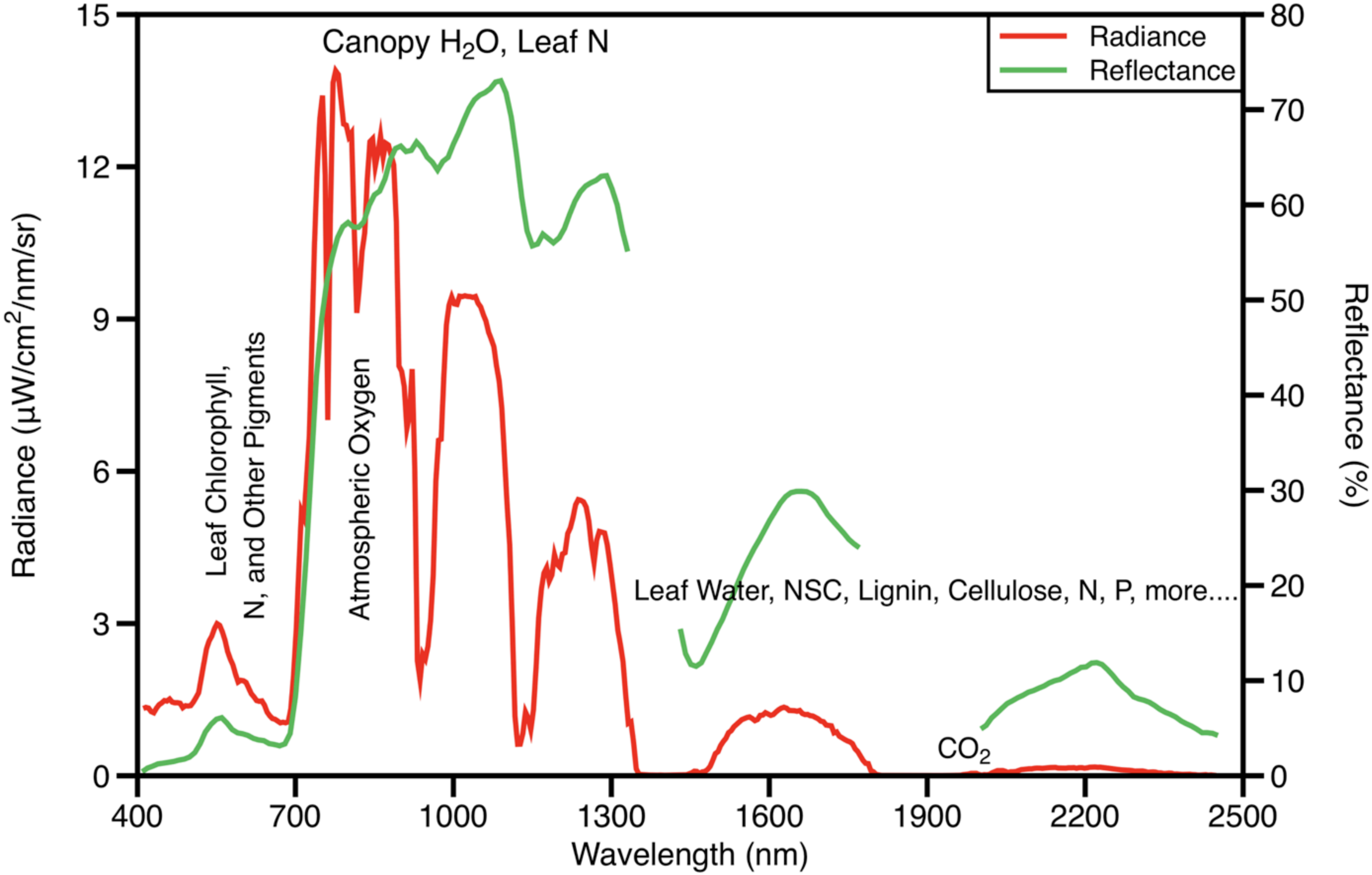
Spectroscopy

DNA Phylogeny





McManus et al RS 2016



Radiance
Reflectance
Canopy H_2O, Leaf N
Leaf Chlorophyll, N, and Other Pigments
Atmospheric Oxygen
Leaf Water, NSC, Lignin, Cellulose, N, P, more....
CO_2
Radiance (μW/cm²/nm/sr)
Reflectance (%)
Wavelength (nm)
0
3
6
9
12
15
0
10
20
30
40
50
60
70
80
400
700
1000
1300
1600
1900
2200
2500

Are we ready for orbit?

- We know how to map the most essential elements of canopy functional and biological diversity. We know how to go global:
  - ✓ Stable high-fidelity imaging spectrometer with appropriate orbit/GSD/revisit
  - ✓ LiDAR/radar filtering techniques ready & available
  - ✓ Scalable algorithm pathways are known
  - ✓ Eco-Evo approach essential for max success

- I would like to get more people using the Spectranomics approach. Detailed protocols are freely available (https://cao.carnegiescience.edu/spectranomics)