UNCERTAINTIES IN THE RELATIONSHIP BETWEEN HYPERSPECTRAL DATA AND LEAF NITROGEN CONTENT IN TEMPERATE AND BOREAL FORESTS

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HYSPIRI DECADAL SURVEY MISSION SCIENCE WORKSHOP
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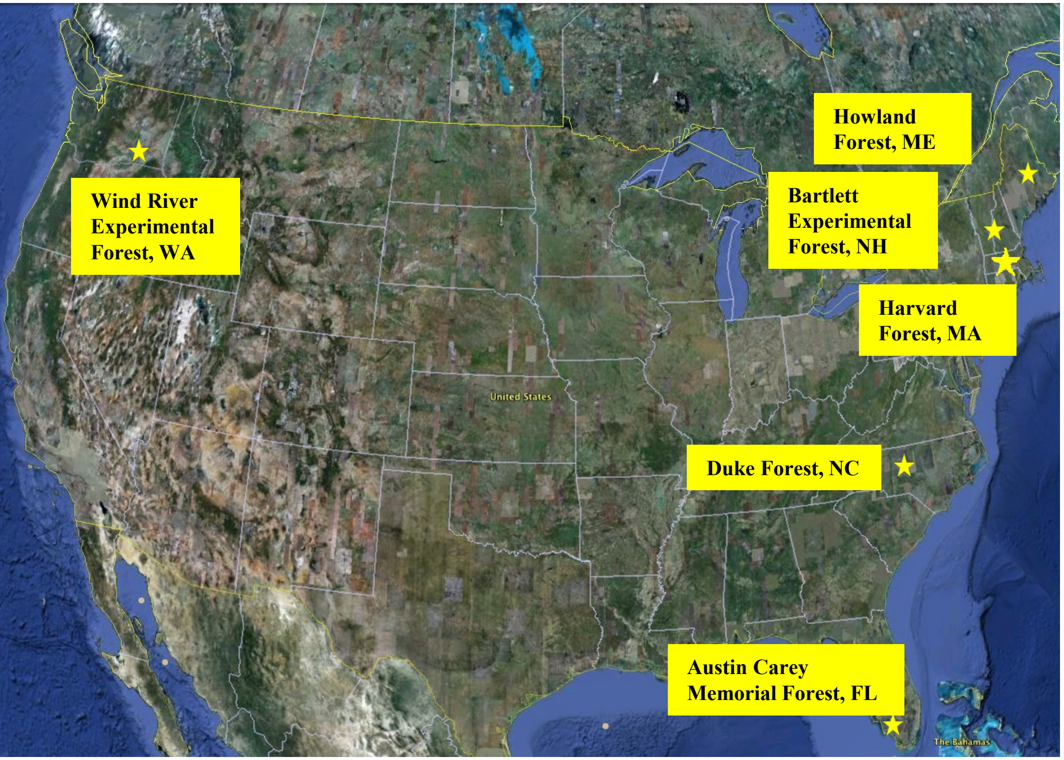
MOTIVATION

- **The importance of nitrogen for terrestrial ecosystem carbon dynamics and its climate feedback has been well recognized**
- **Interaction between carbon and nitrogen at leaf level is among the fundamental mechanisms that directly control the dynamics of terrestrial vegetation carbon**
- **This process influences absorption and scattering of solar radiation by foliage, which in turn impacts radiation reflected by the vegetation and measured by satellite sensors**

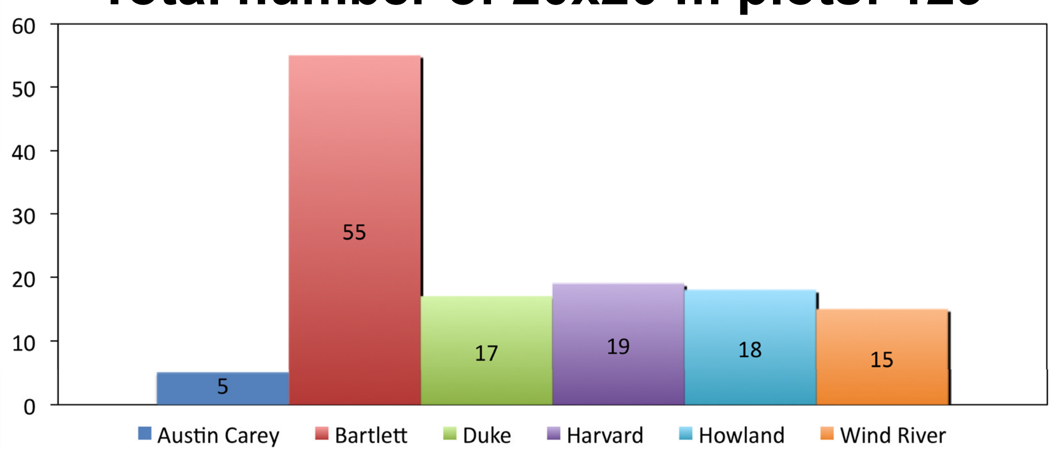
How much information about foliar nitrogen do hyperspectral data convey?

SITE AND DATA DESCRIPTION



Site	Airborne data	Description
Austin Carey Memorial Forest, FL	AVIRIS	Planted and natural pine
Bartlett Experimental Forest, NH	AVIRIS AirMISR LVIS CHRIS/PROBA	Mixed northern hardwood
Duke Forest, NC	AVIRIS	Pine, pine-hardwood
Harvard Forest, MA	AVIRIS AirMISR LVIS CHRIS/PROBA	Mixed temperate deciduous forest
Howland Forest, ME	AVIRIS AirMISR LVIS CHRIS/PROBA	Boreal-northern hardwood forest
Wind River Experimental Forest, WA	AVIRIS	Temperate evergreen

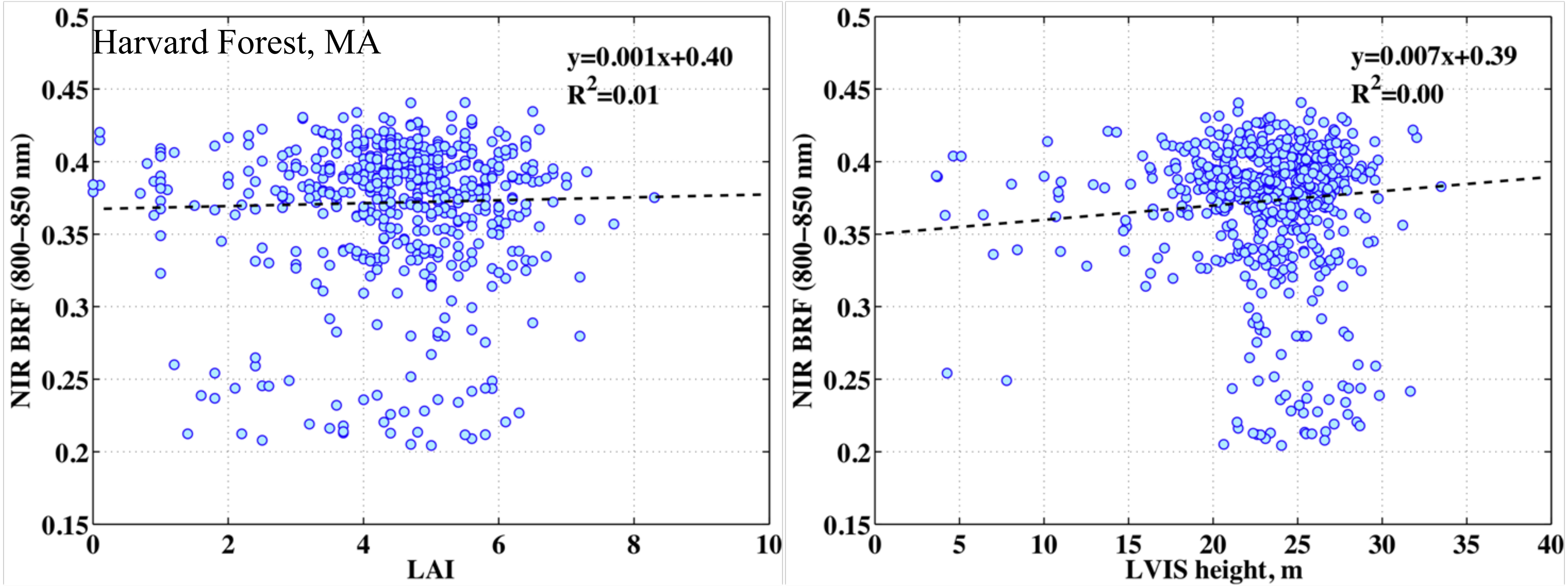
Total number of 20x20 m plots: 129



Ground data was collected at 20x20 m plots

Smith, M.L., & Martin, M.E. (2001). A plot-based method for rapid estimation of forest canopy chemistry. *Can. J. of For. Res., 31, 549-555.*

DENSE VEGETATION CANOPY



- Sites represent closed canopy forests (LAI~5)
- Impact of canopy background is negligible
- No correlation between BRF, LAI and height

Schull, M.A. (2010). Application of spectral invariants for monitoring forest across multiple scales. PhD Thesis. Department of Geography and Environment, Boston University, November 2nd, 2010, 137 pp., http://library.bu.edu/search/X

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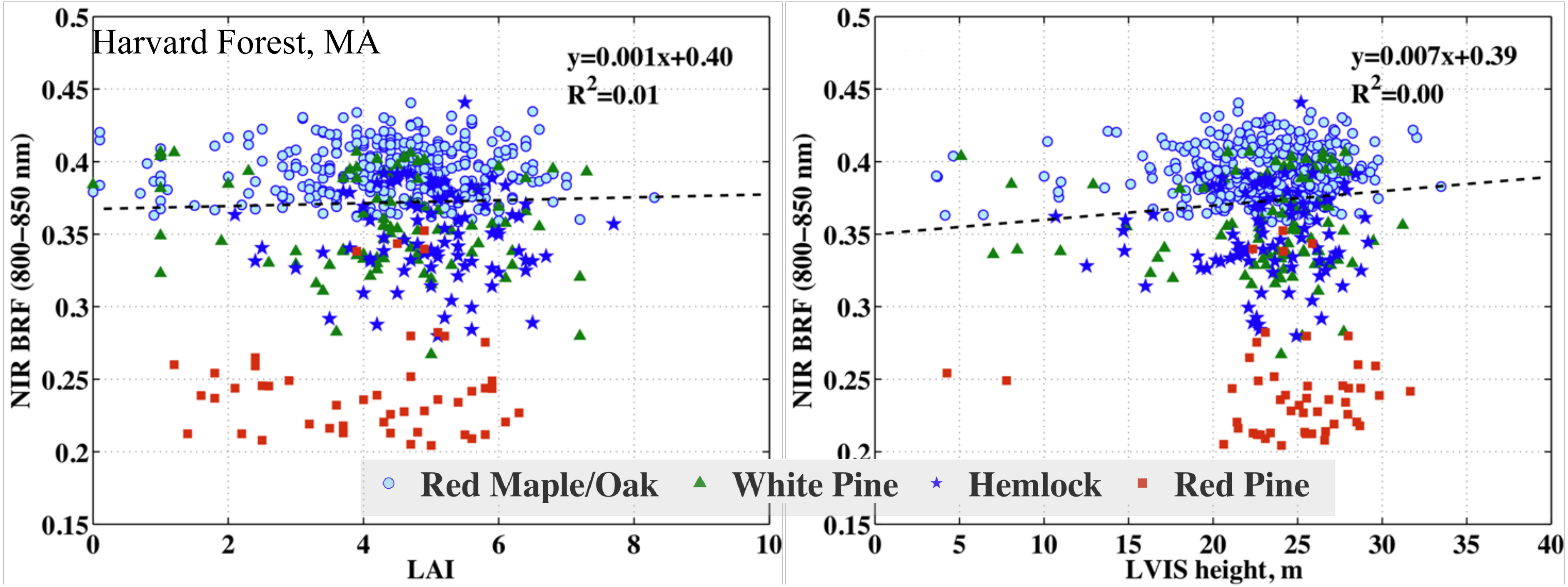

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But there are 3D effects of structure

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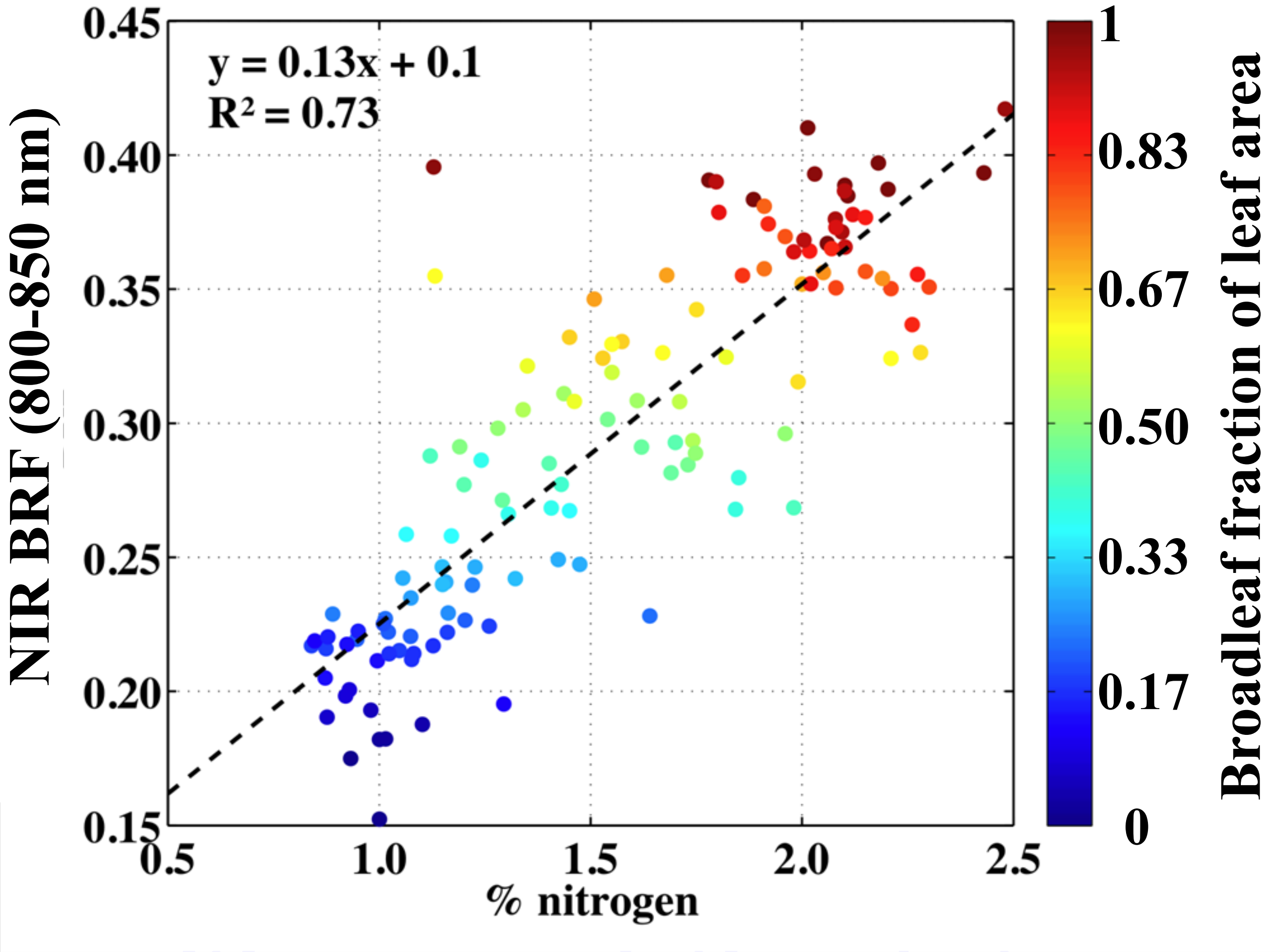
Huang et al., (2008). Stochastic transport theory for investigating the three-dimensional canopy structure from space measurements. Remote Sens. Environ. 112, 35-50.

FOREST REFLECTANCE AND FOLIAR NITROGEN



- Strong positive correlation between forest NIR zenith reflectance and foliar N
- Valid for the global SW radiation (400-2,500nm)

Ollinger, S.V. et al. (2008). Canopy nitrogen, carbon assimilation, and albedo in temperate and boreal forests: Functional relations and potential climate feedbacks. Proc. Natl. Acad. of Sci., 105, 19336-19341.

MONITORING FOLIAR NITROGEN FROM SPACE

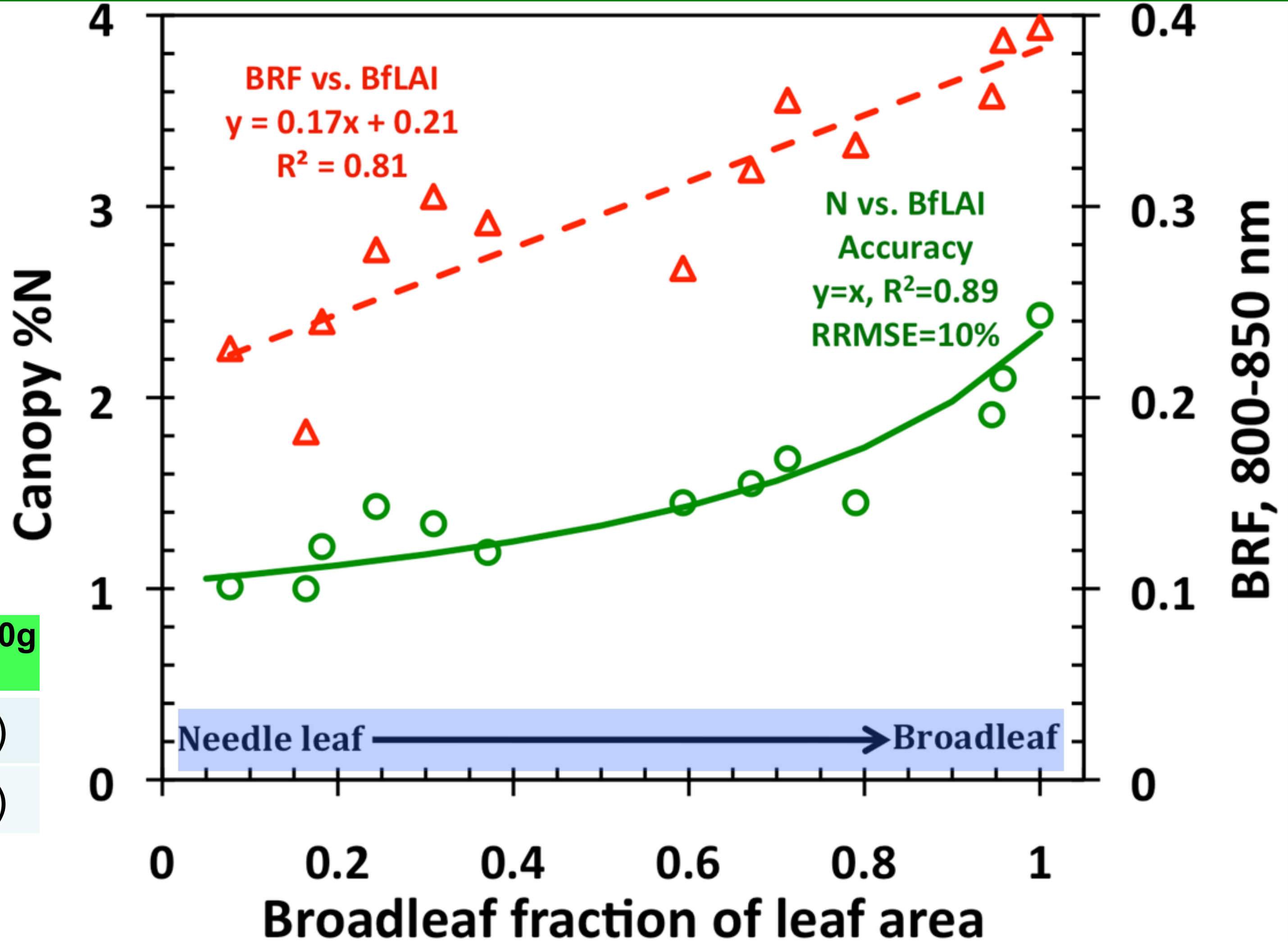
- **Does the positive BRF vs. N relationship provide a basis for monitoring the foliar nitrogen from space using NIR and/or SW surface reflectance data?**
  - Canopy structure is the dominant factor that positively relates NIR BRF and N
  - The observed BRF vs. N correlation conveys no information about foliar N.

- **What about hyperspectral data?**
  - 3D effects of canopy structure can easily be removed
  - provide a link to leaf optics
  - leaf surface properties have an impact on forest reflectivity, lowering its sensitivity to leaf absorbing pigments …

N AND BRF ARE STRONGLY AND POSITIVELY RELATED TO BfLAI

Bartlett Forest

Mean N (std), in g per 100g of dry leaf mass[1]	
needle	1.24 (0.26)
flat leaf	2.17 (0.40)

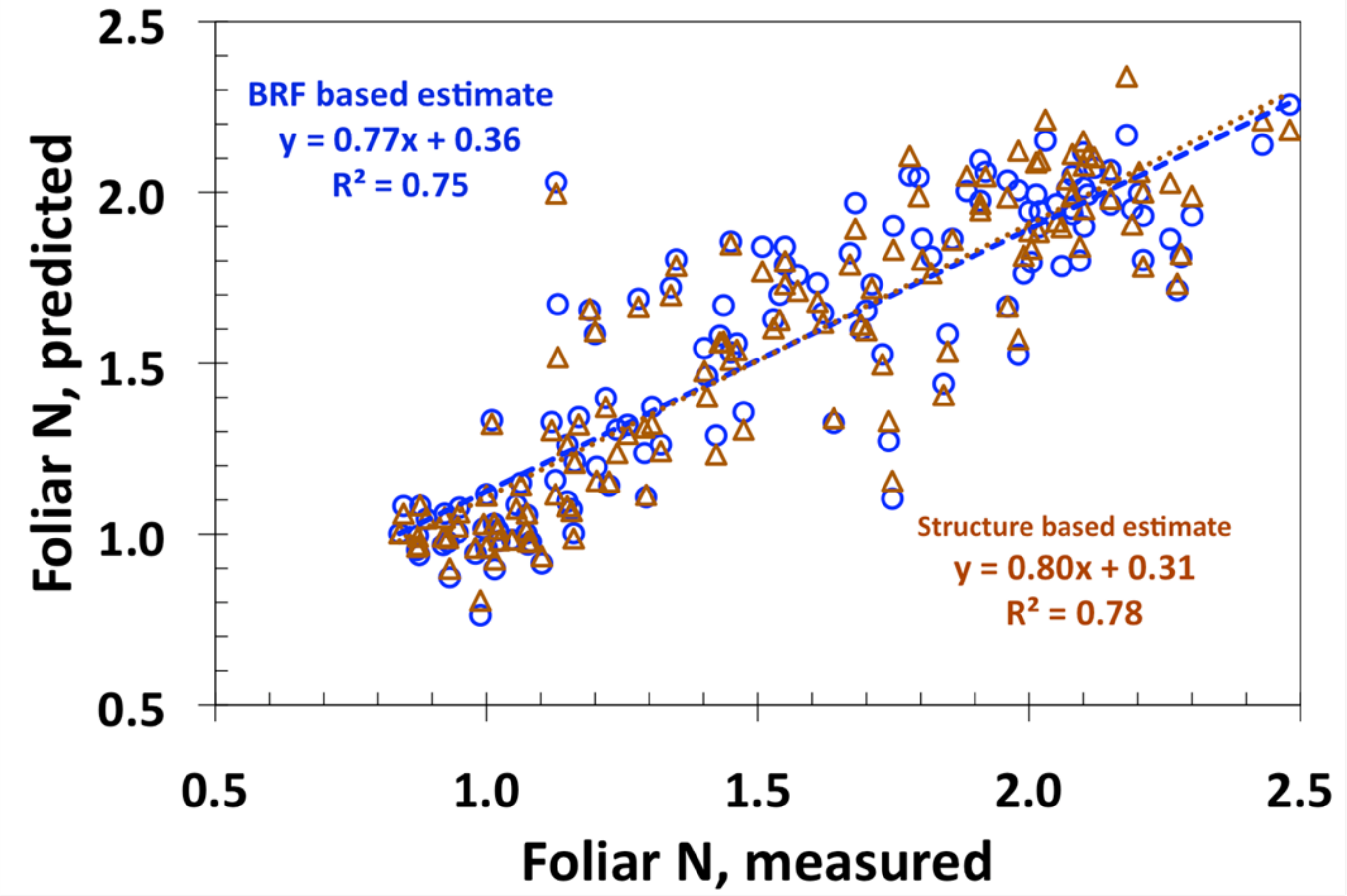


Structure positively relates NIR BRF(zenith) and N

[1]Smith, M.L., & Martin, M.E. (2001). A plot-based method for rapid estimation of forest canopy chemistry. Can. J. of For. Res., 31, 549-555

Rautiainen&Stenberg (2005). Application of photon recollision probability in coniferous canopy reflectance simulations. Remote Sens. Environ. 96, 98-107.

OUT-OF-SAMPLE TEST

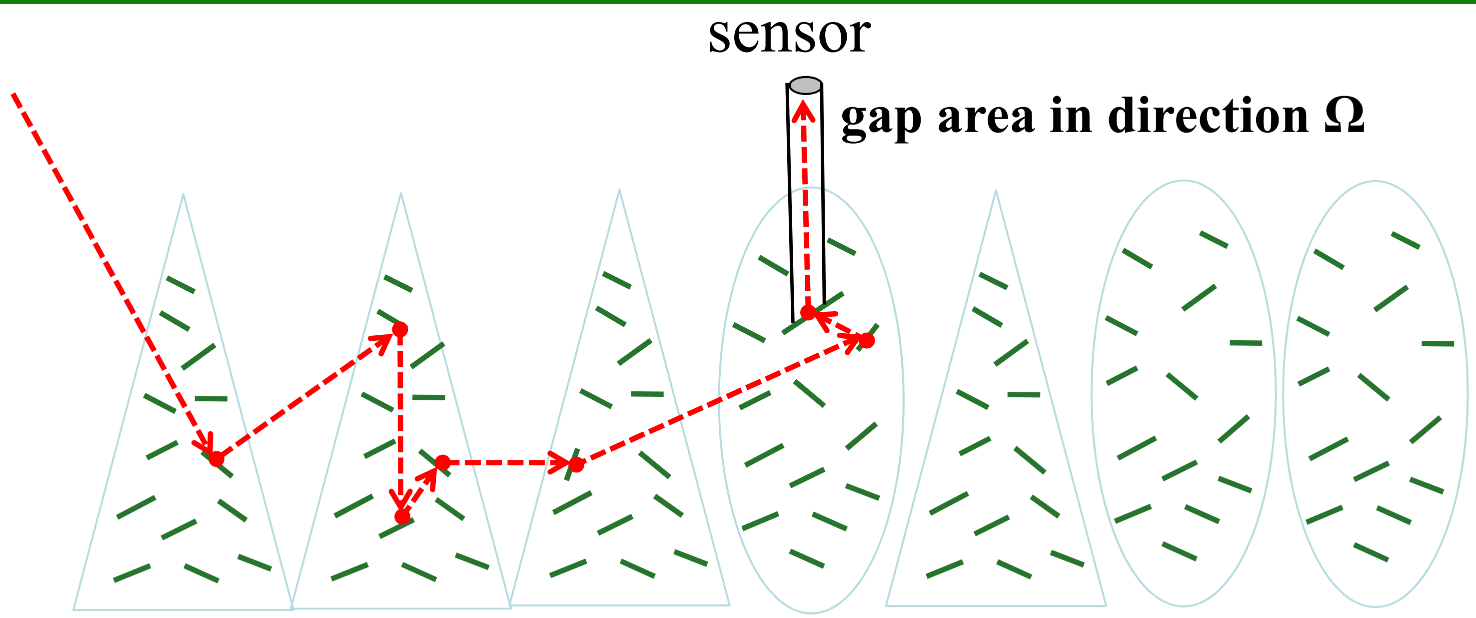


Method 1: Use the empirical NIR BRF vs. N relationship to estimate N

Method 2: Use spectral interval [710,790] to estimate canopy structure first and then N

Schull, M.A. (2010). Application of spectral invariants for monitoring forest across multiple scales. PhD Thesis. Department of Geography and Environment, Boston University, November 2nd, 2010, 137 pp., http://library.bu.edu/search/X

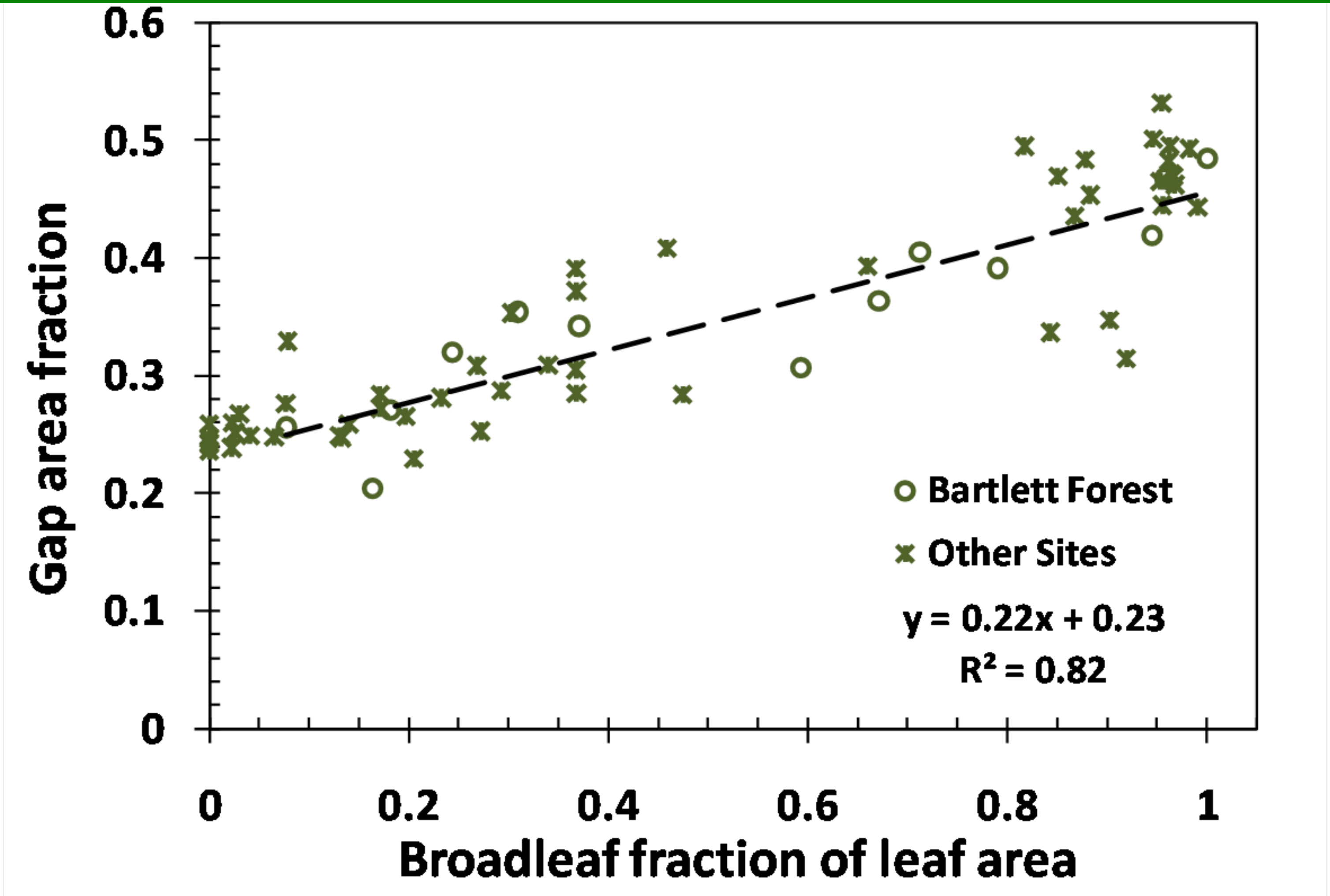
PARAMETERIZATION OF CANOPY STRUCTURE



- Gap area fraction: total gap area in *Ω* normalized by the total leaf area = fraction of leaf area that "sensor sees" in a given direction
- Can directly be estimated from BRF spectrum in [710,790nm] (no models are needed!)
- Physics[1]: (a) multiple scattering dominates; (b) minimal impact of absorbing pigments; (c) sharp jump in leaf albedo

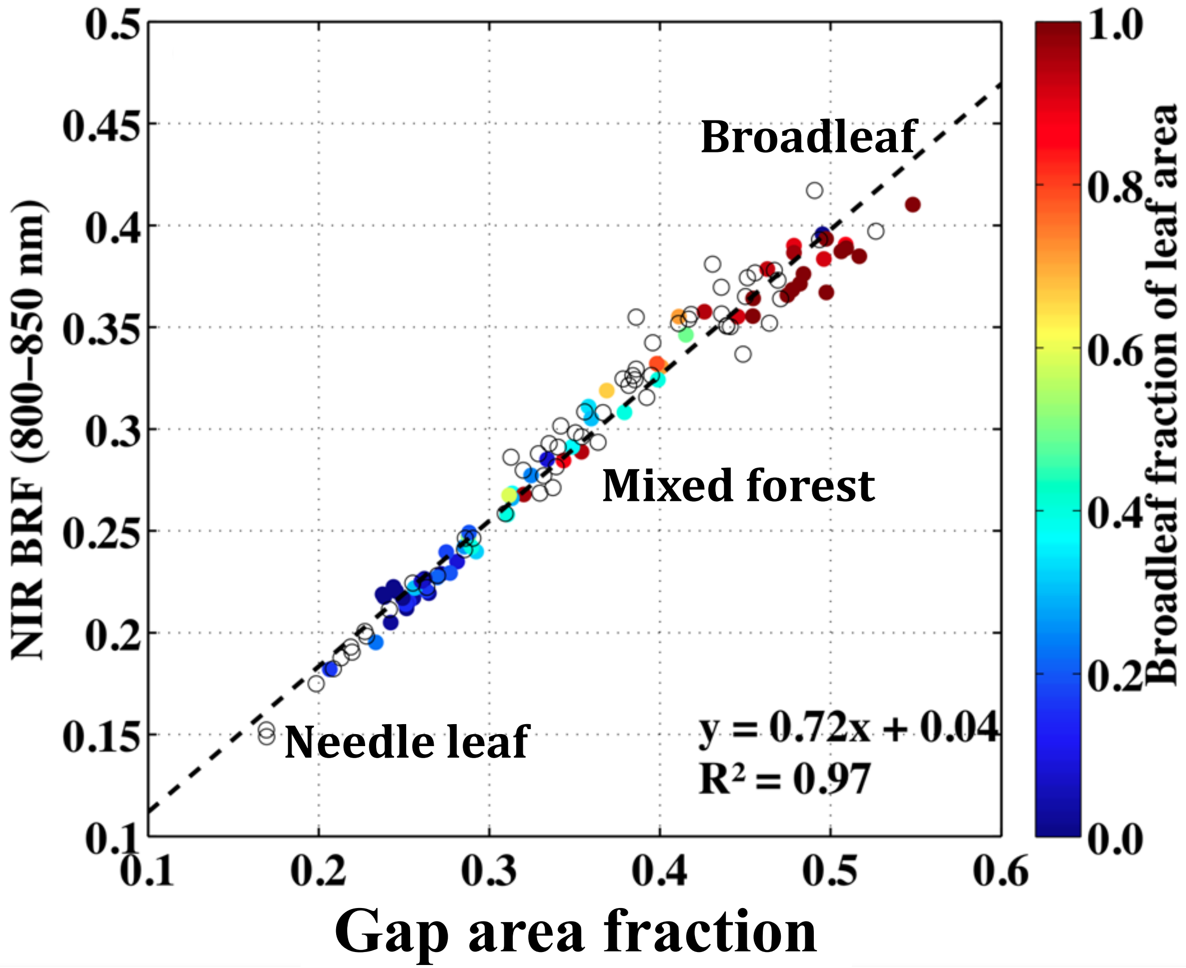
[1]See our poster "Retrieval of distribution of gaps in vegetation canopies using hyperspectral data"

GAP AREA FRACTION AND SPECIES COMPOSITION



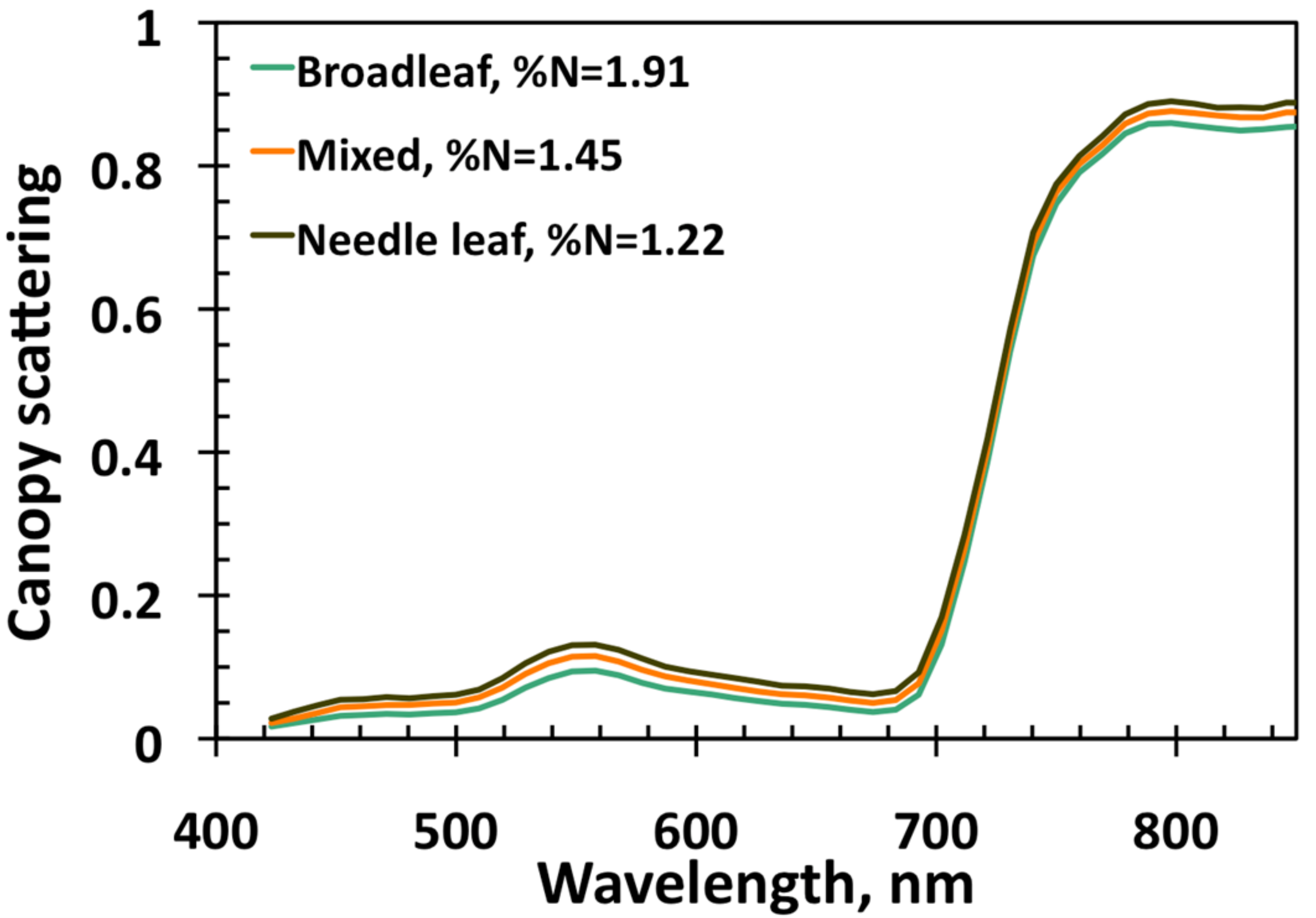
- ➢ GAF depends on species composition
- ➢ Useful in interpretation of LIDAR data
- ➢ BfLAI is labor intensive while GAF not

NIR BRF AND GAP AREA FRACTION

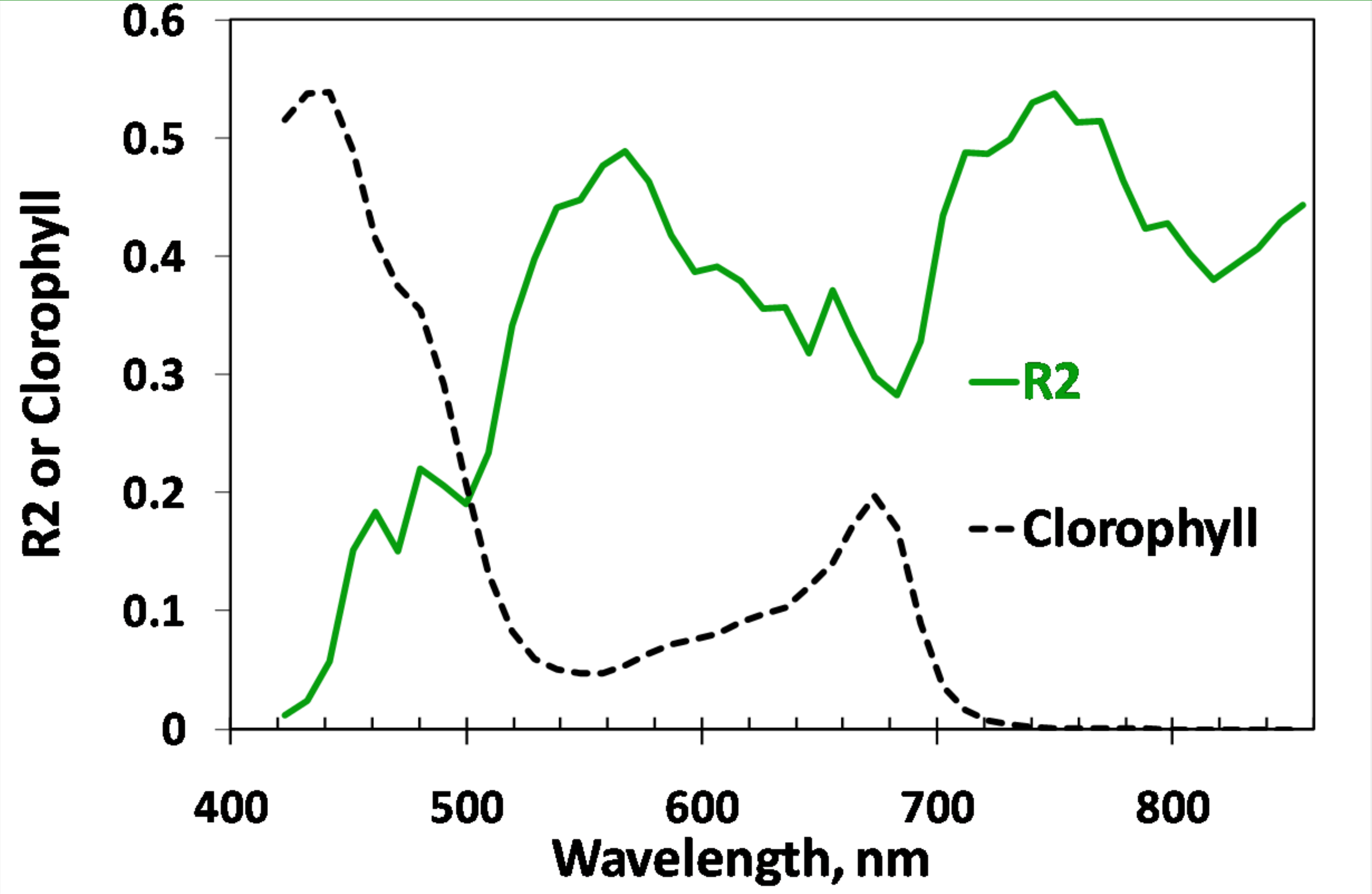


The GAF explains variation in NIR BRF due to variation in canopy structure.

CANOPY SCATTERING



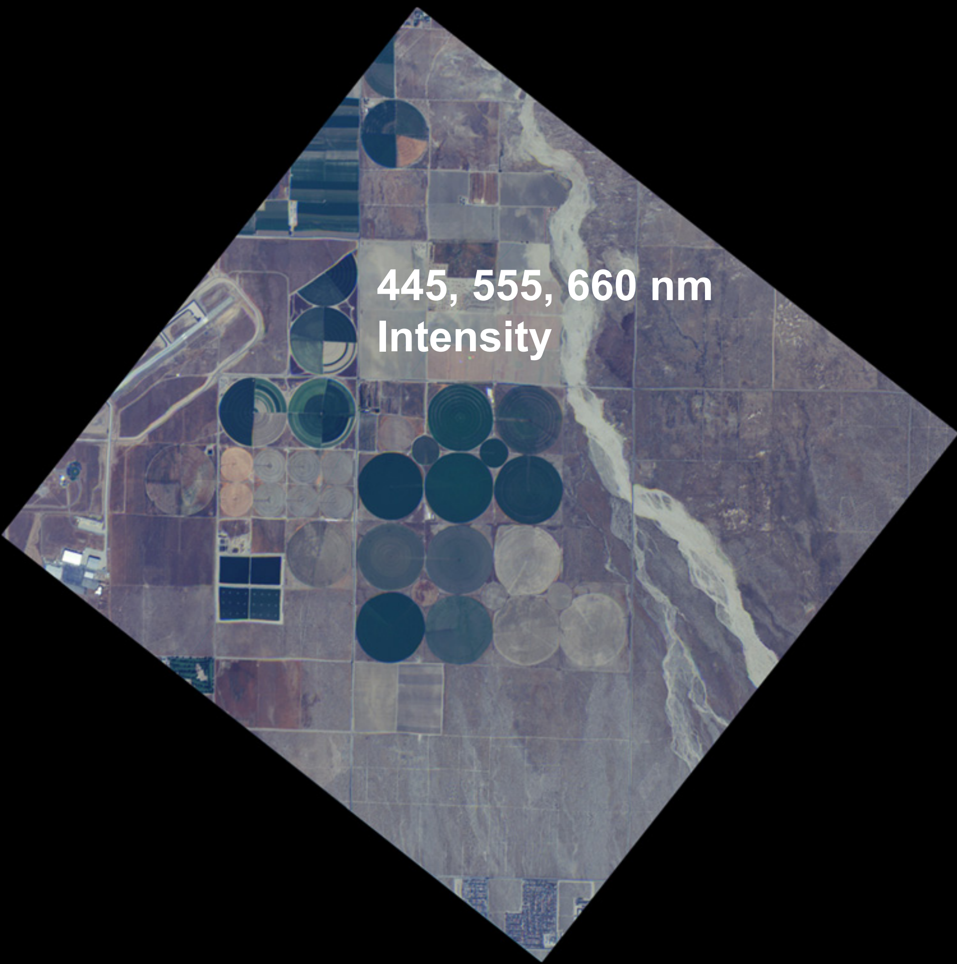
- mimics shape and magnitude of leaf albedo spectrum
- negatively related to N for all wavelength in the interval [420,900 nm]

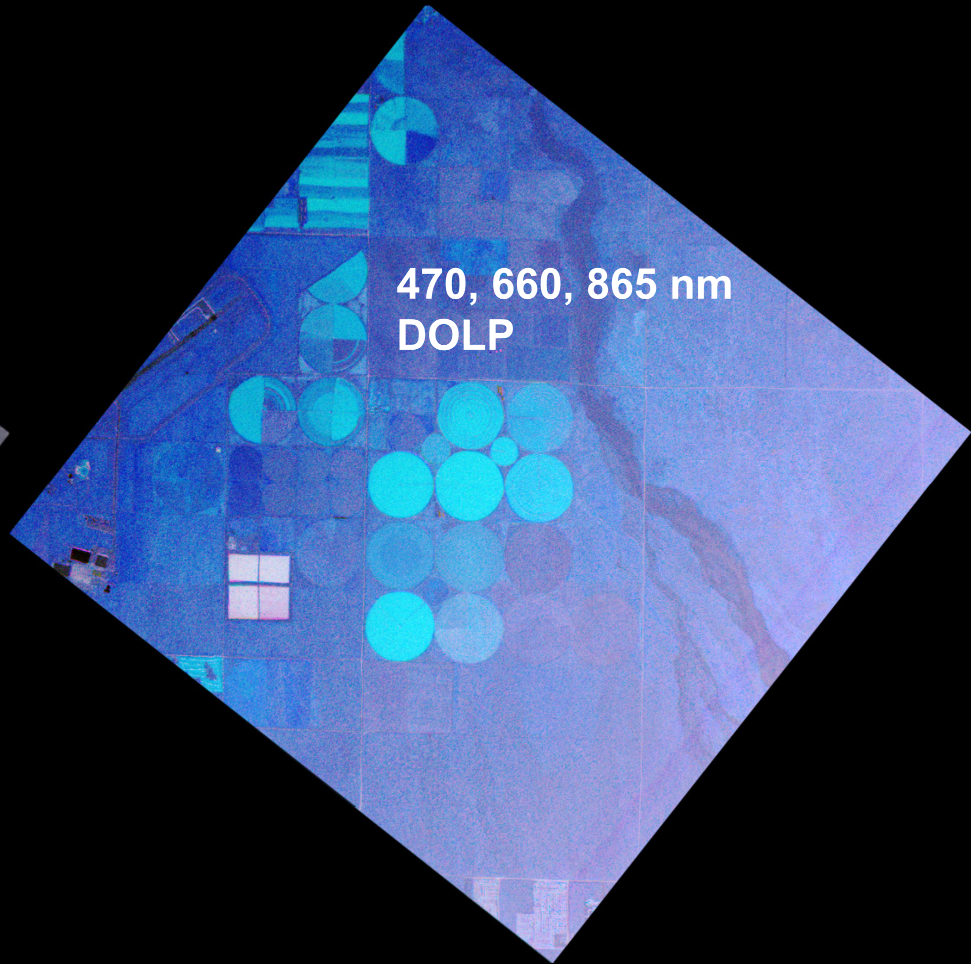


Foliar N can explain up to 55% of variation in AVIRIS spectra in the interval between 400nm and 900nm

REFLECTION AND POLARIZATION

Airborne MultiangleSpectroPolarimetric Imager: georectified Image of Palmdale

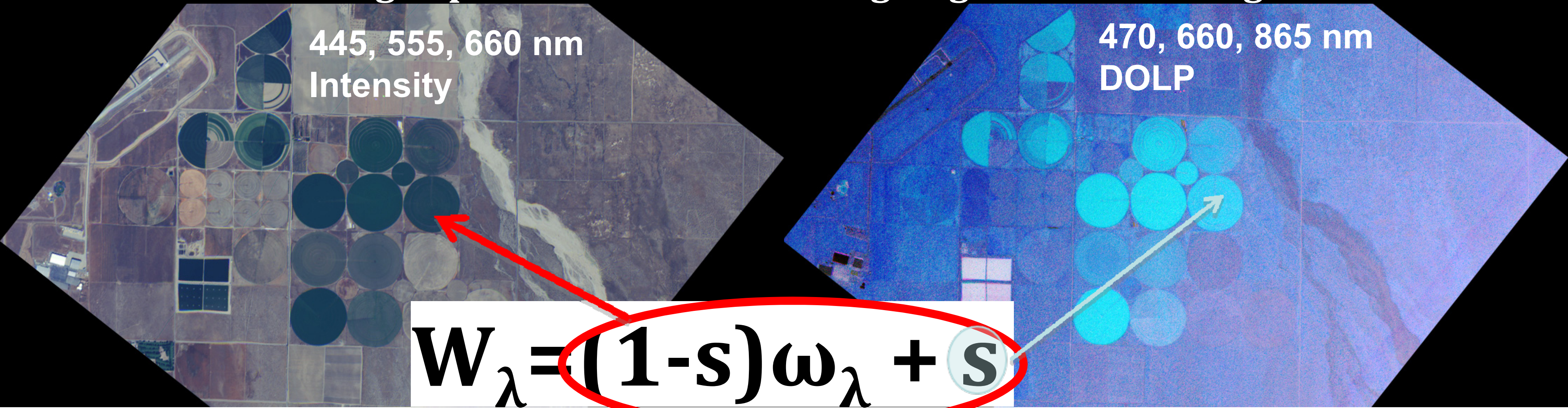




Images from D.Diner et al., Early results from Ground MSPI and AirMSPI, MISR Data Users Science Symposium, Dec. 2010.

SURFACE AND DIFFUSE LEAF SCATTERING

Airborne MultiangleSpectroPolarimetric Imager: georectified Image of Palmdale



$$W_\lambda = (1-s)\omega_\lambda + s$$

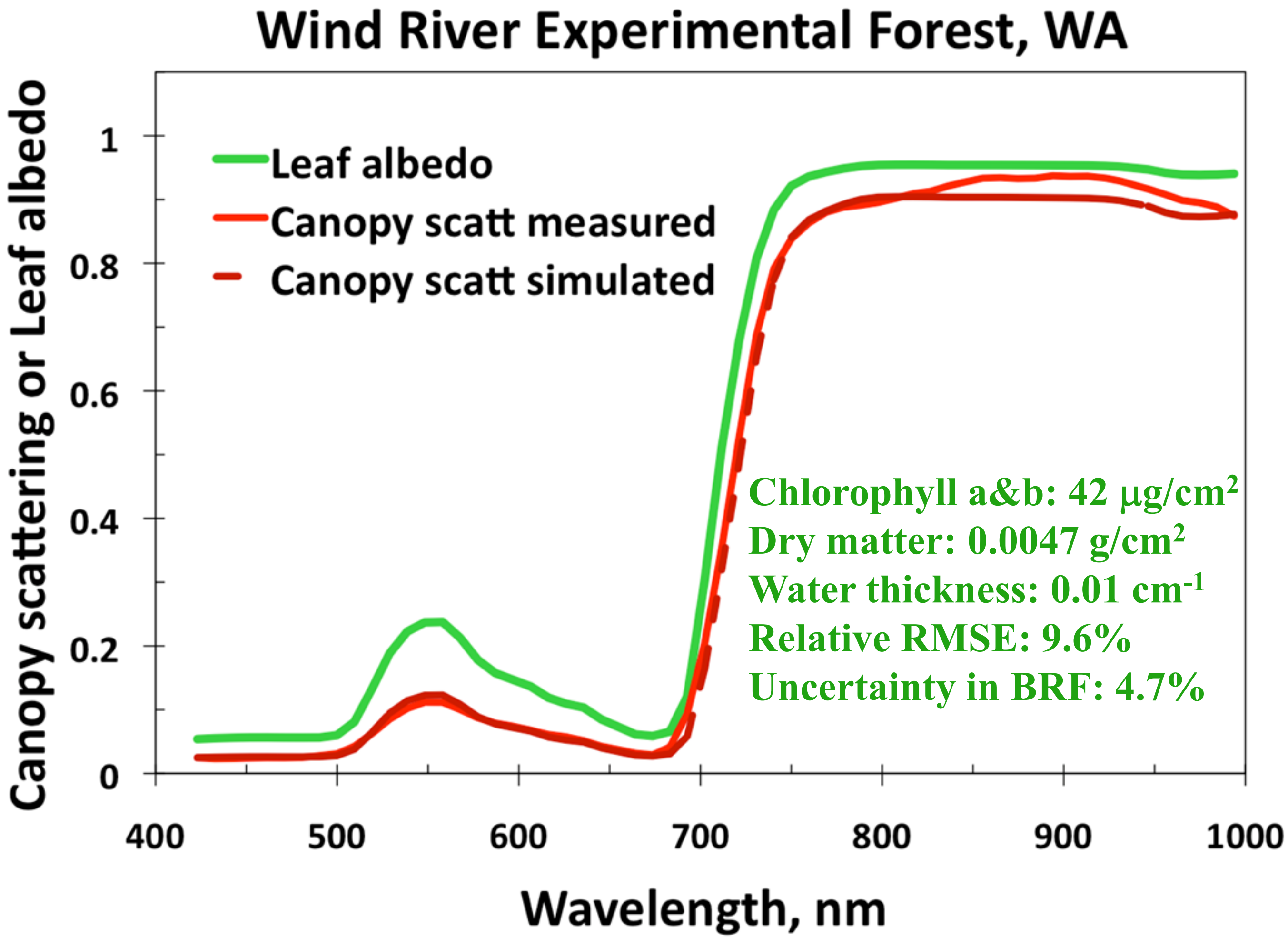
Radiation scattered by a leaf includes two components

1) Radiation reflected at the air-cuticle interface
   - polarized; weak spectral variation; depends on the leaf surface properties; <u>no info about leaf interior</u>
2) Diffuse radiation due to "within leaf photon interactions"
   - non-polarized, depends on absorption spectra of leaf pigments; <u>conveys info about leaf interior</u>

Polarized reflectance of 9% can account for 68% of the total leaf reflection[1]

[1]Grant et al.,(1993) Polarized and Specular Reflectance Variation with Leaf Surface-Features. Physiol Plantarum 88(1):1-9.
Images from D.Diner et al., Early results from Ground MSPI and AirMSPI, MISR Data Users Science Symposium, Dec. 2010.

LEAF BIOCHEMISTRY FROM SPACE



Information about leaf surface properties may require to fully remove impact of canopy structure

SUMMARY

- Canopy structure can significantly suppress the sensitivity of hyperspectral data to leaf optics
- Reflectance spectra in the interval [710, 790 nm] are required to obtain the Gap Area Fraction
- The Gap Area Fraction explains variation in measured reflectance spectra due to variation in canopy structure
- Leaf surface properties may have an impact on forest reflectivity, lowering its sensitivity to leaf absorbing pigments
- Foliar nitrogen concentration can explain up to 55% of variation in AVIRIS spectra. The remaining factors could be due to
  a) impact of leaf surface properties and/or
  b) under-sampling of leaf optical properties due to the single view of the AVIRIS sensor