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Connecting infrared spectra with plant traits to identify species

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ABSTRACT

Plant traits are used to define species, but also to evaluate the health status of forests, plantations and crops. Conventional methods of measuring plant traits (e.g. wet chemistry), although accurate, are inefficient and costly when applied over large areas or with intensive sampling. Spectroscopic methods, as used in the food industry and mineralogy, are nowadays applied to identify plant traits, however, most studies analysed visible to near infrared, while infrared spectra of longer wavelengths have been little used for identifying the spectral differences between plant species. This study measured the infrared spectra (1.4–16.0 μm) on individual, fresh leaves of 19 species (from herbaceous to woody species), as well as 14 leaf traits for each leaf. The results describe at which wavelengths in the infrared the leaves' spectra can differentiate most effectively between these plant species. A Quadratic Discrimination Analysis (QDA) shows that using five bands in the SWIR or the LWIR is enough to accurately differentiate these species (Kappa: 0.93, 0.94 respectively), while the MWIR has a lower classification accuracy (Kappa: 0.84). This study also shows that in the infrared spectra of fresh leaves, the identified species-specific features are correlated with leaf traits as well as changes in their values. Spectral features in the SWIR (1.66, 1.89 and 2.00 μm) are common to all species and match the main features of pure cellulose and lignin spectra. The depth of these features varies with changes of cellulose and leaf water content and can be used to differentiate species in this region. In the MWIR and LWIR, the absorption spectra of leaves are formed by key species-specific traits including lignin, cellulose, water, nitrogen and leaf thickness. The connection found in this study between leaf traits, features and spectral signatures are novel tools to assist when identifying plant species by spectroscopy and remote sensing.

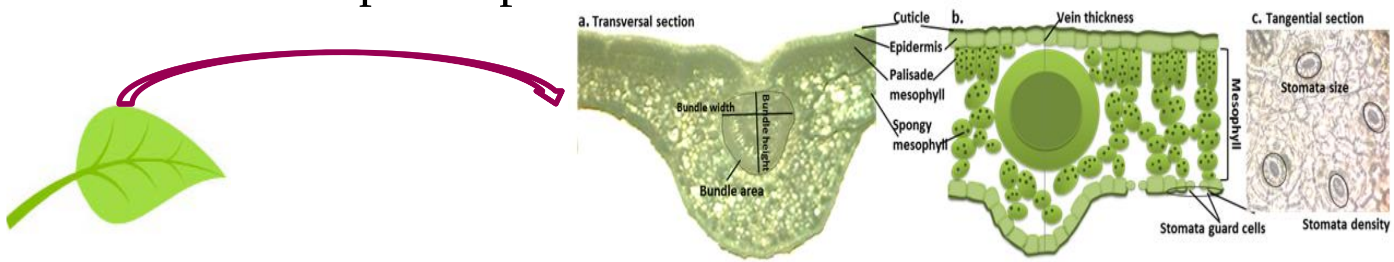
1. Introduction

The global biological diversity of all plants exceeds >350,000 species ranging from grasses to woody plants (Plant List, 2013). Every year, new plant species are discovered, especially in remote

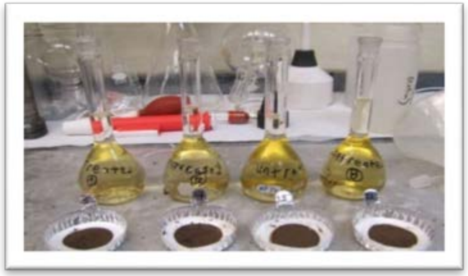
observations of traits can be used to classify plants into species as well as determine a plant's health and its potential to provide ecosystem services (Lavorel and Garnier, 2002). The correct estimation of leaf traits is essential for the conservation of natural ecosystems since efforts towards the conservation of plant biodi-

CONTEXT

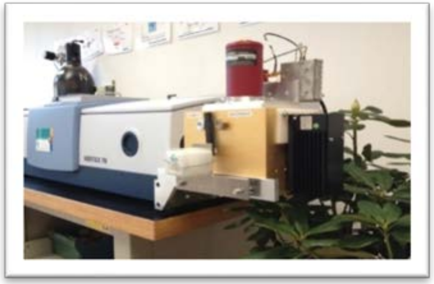
- Leaf traits differentiate plant species and plant health.



- Conventional methods are expensive and time-consuming.

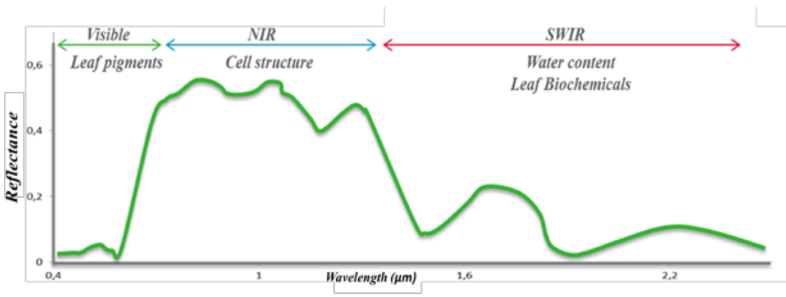


- Spectroscopic methods are accurate and faster?

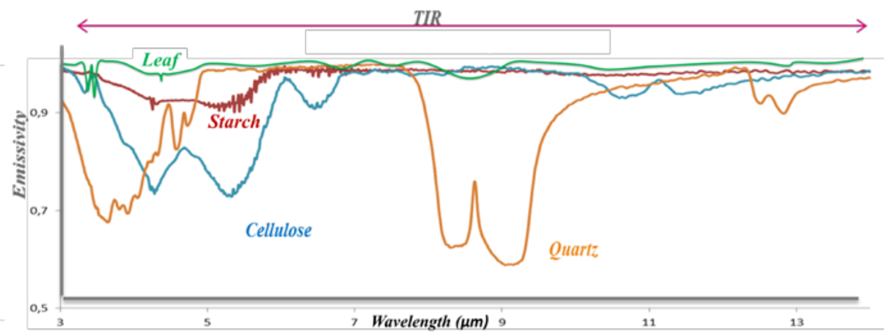


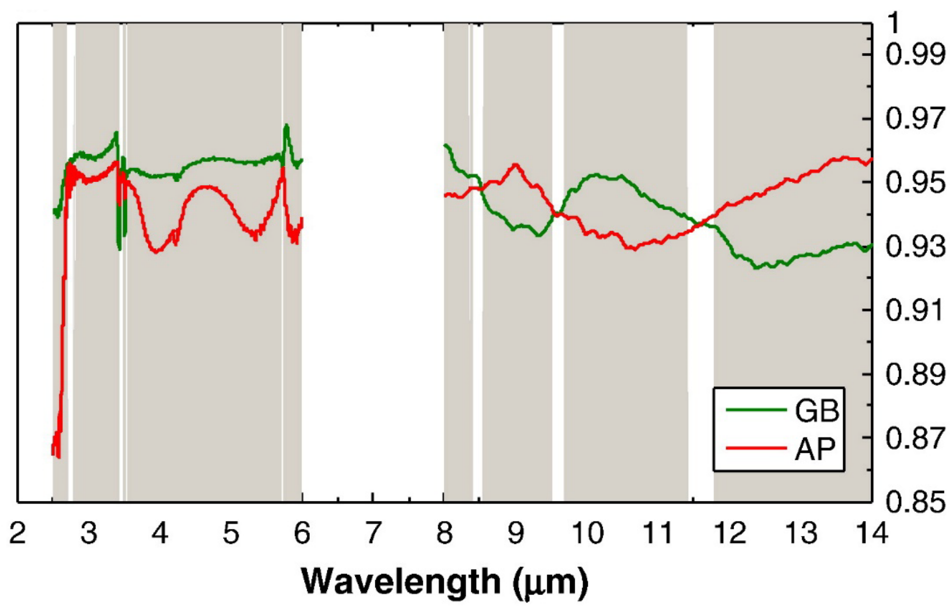
WHY THERMAL INFRARED SPECTROSCOPY?

VNSWIR range: change in pigments and water (commonly done)



Infrared: Changes in water, chemicals and microstructure.





Source: Saleem et al.,2012: RSE

Plants have spectral info in LWIR!

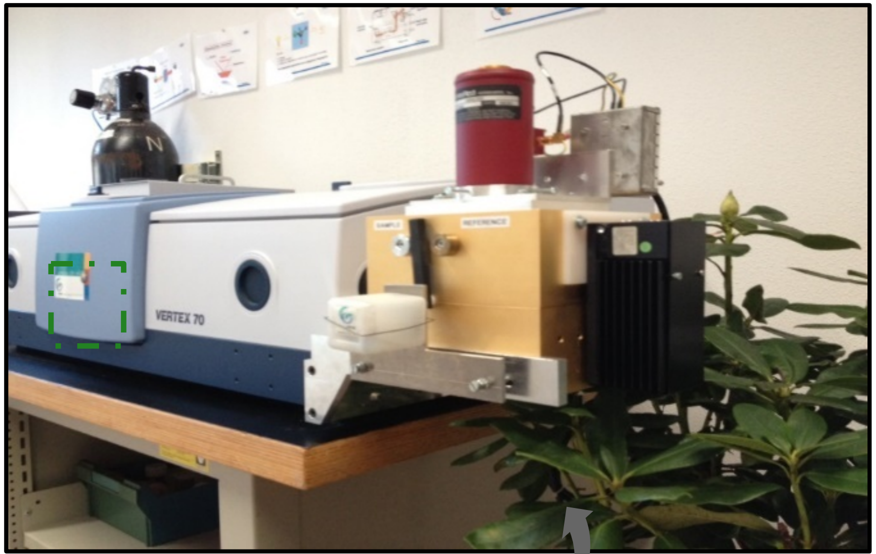
(work of e.g. Ribeiro da Luz; Ullah Saleem et al (2012)

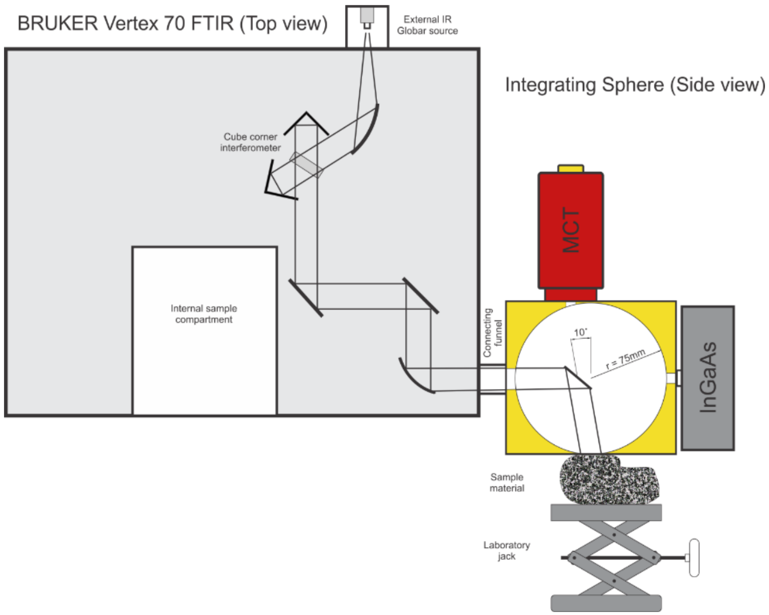
SETUP

- GOAL:
  - establish link between leaf traits and spectral response in IR

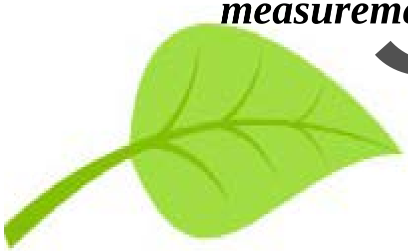
- Experiment
  - 19 plant species
    - Herbaceous - woody; deciduous – evergreen; tropical-temperate
  - Spectroscopic measurements: DHR reflectance (1.4-16.0 µm).
  - Leaf traits (14)
    - Structural: Leaf thickness, cuticle thickness, leaf area, bundle area.. etc..
    - Chemical: lignin, cellulose, nitrogen, leaf water content, … etc..

MEASUREMENTS:

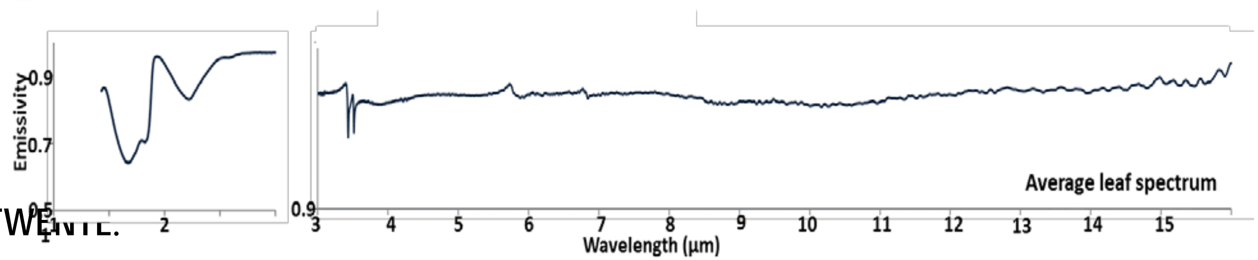




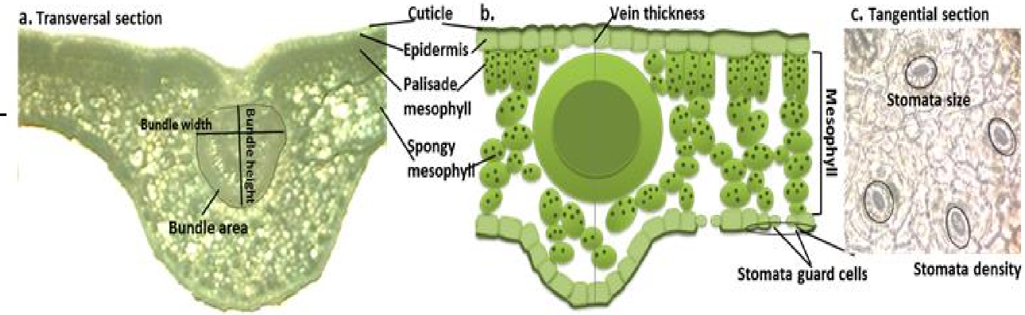
Spectral measurements



Directional – hemispherical reflectance measurements (converted to emissivity)

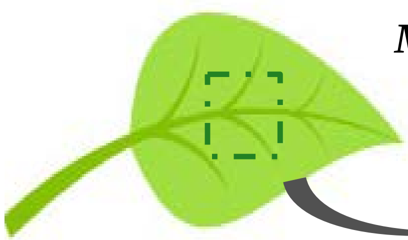


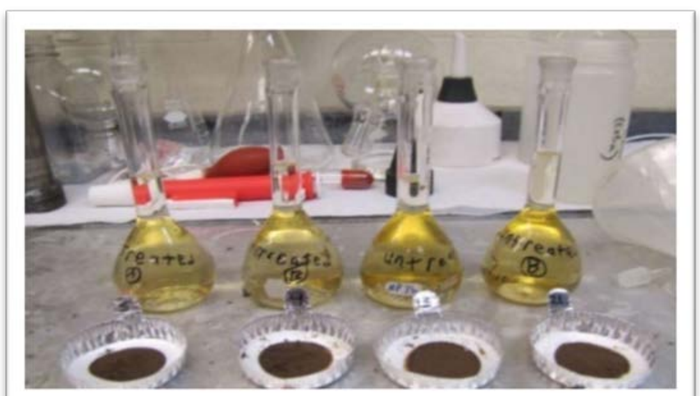
MEASUREMENTS:



Tangential and transversal cut of the leaf

Microscopic and chemical measurements



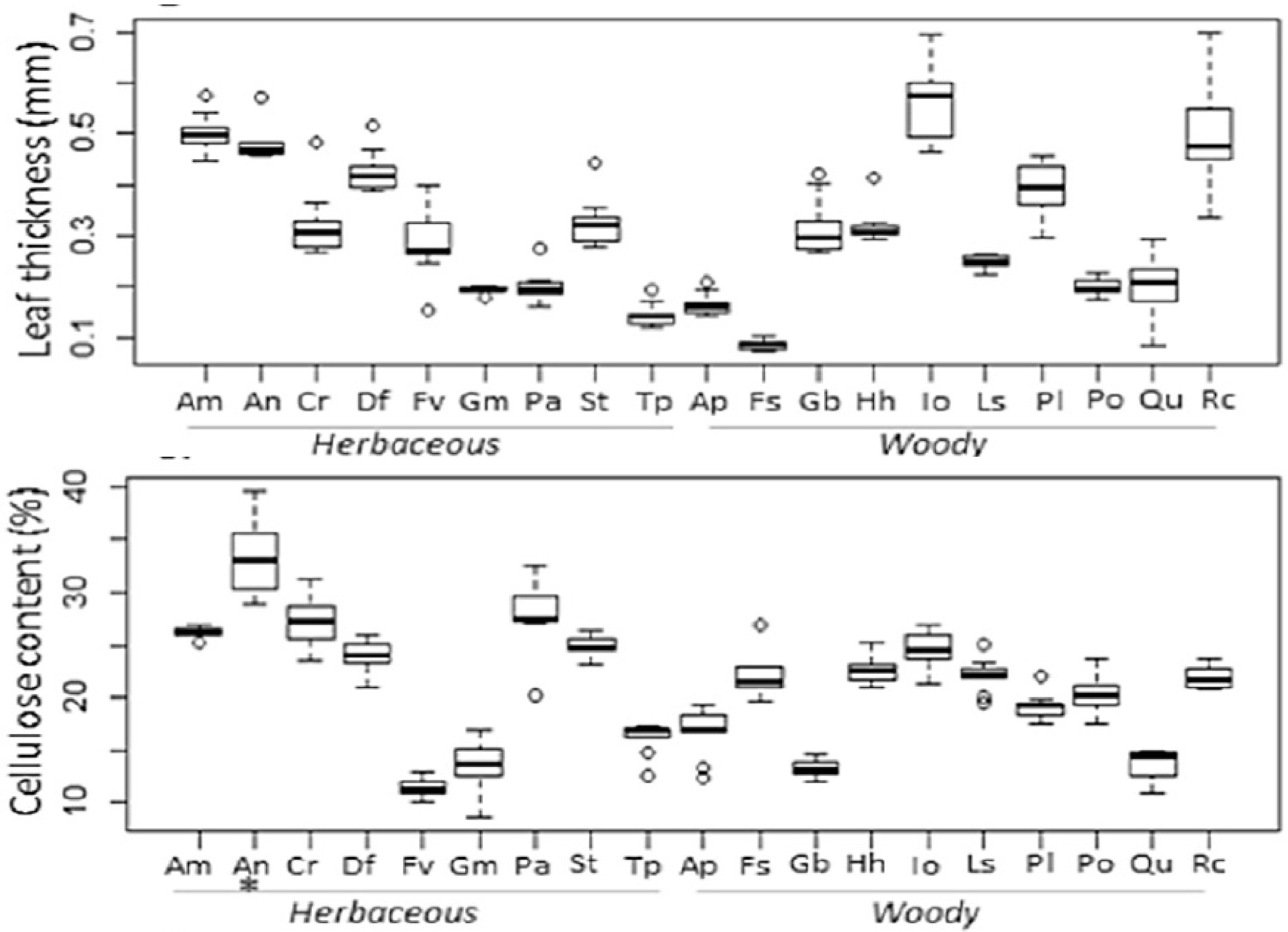


Leaf trait measured

Code	Leaf trait
LWC	Leaf water content
lig	Lignin content
cel	Cellulose content
lig/cel	Lignin/cellulose ratio
N	Nitrogen content
C/N	Carbon/nitrogen ratio
lt	Leaf thickness
ct	Cuticle thickness
et	Epidermis thickness
vt	Vein thickness
ba	Bundle area
ss	Stomata size
sd	Stomata density
la	Leaf area

RESULTS (TRAITS):

Examples: leaf thickness (structural); cellulose (chemical)



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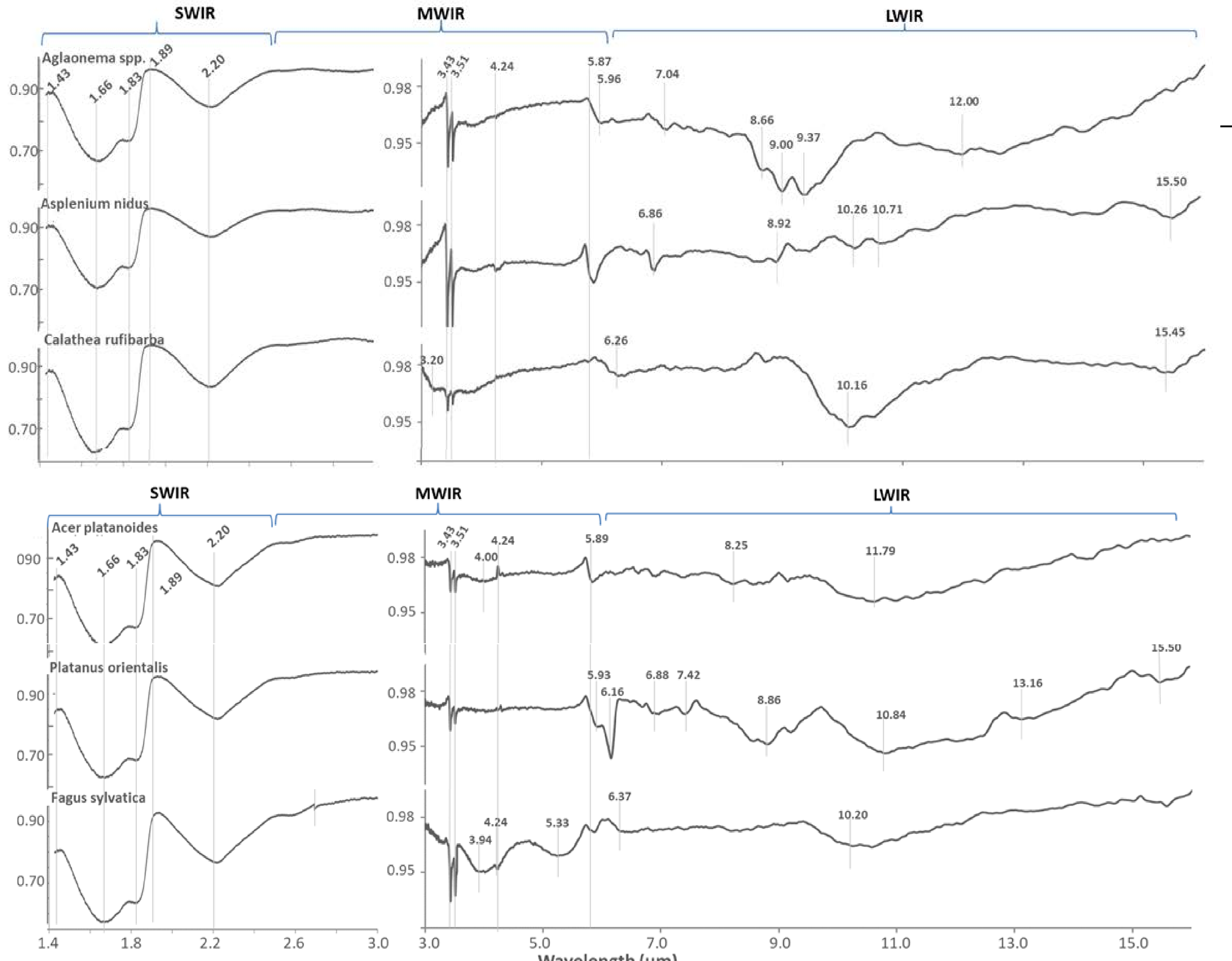
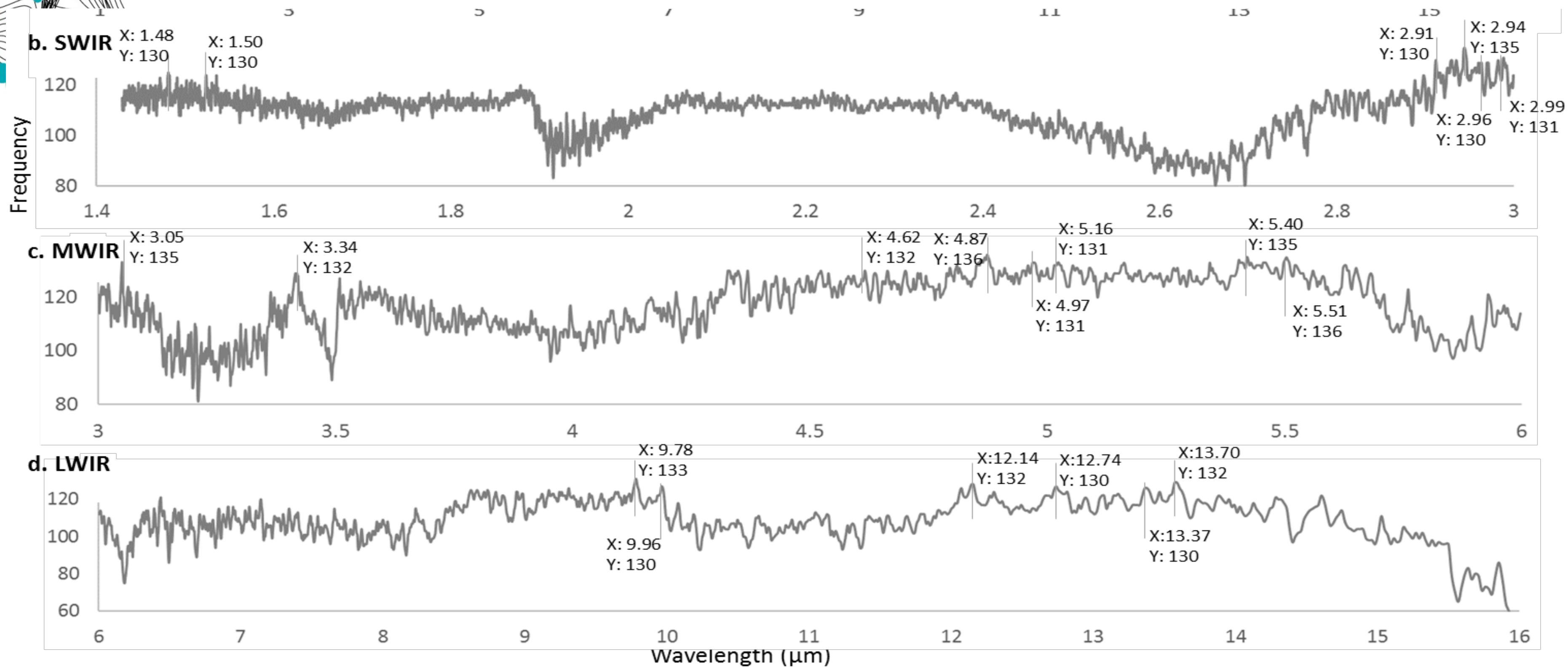
Intra vs inter species variability!

RESULTS (SPECTRA): *Herbaceous vs. Woody species*

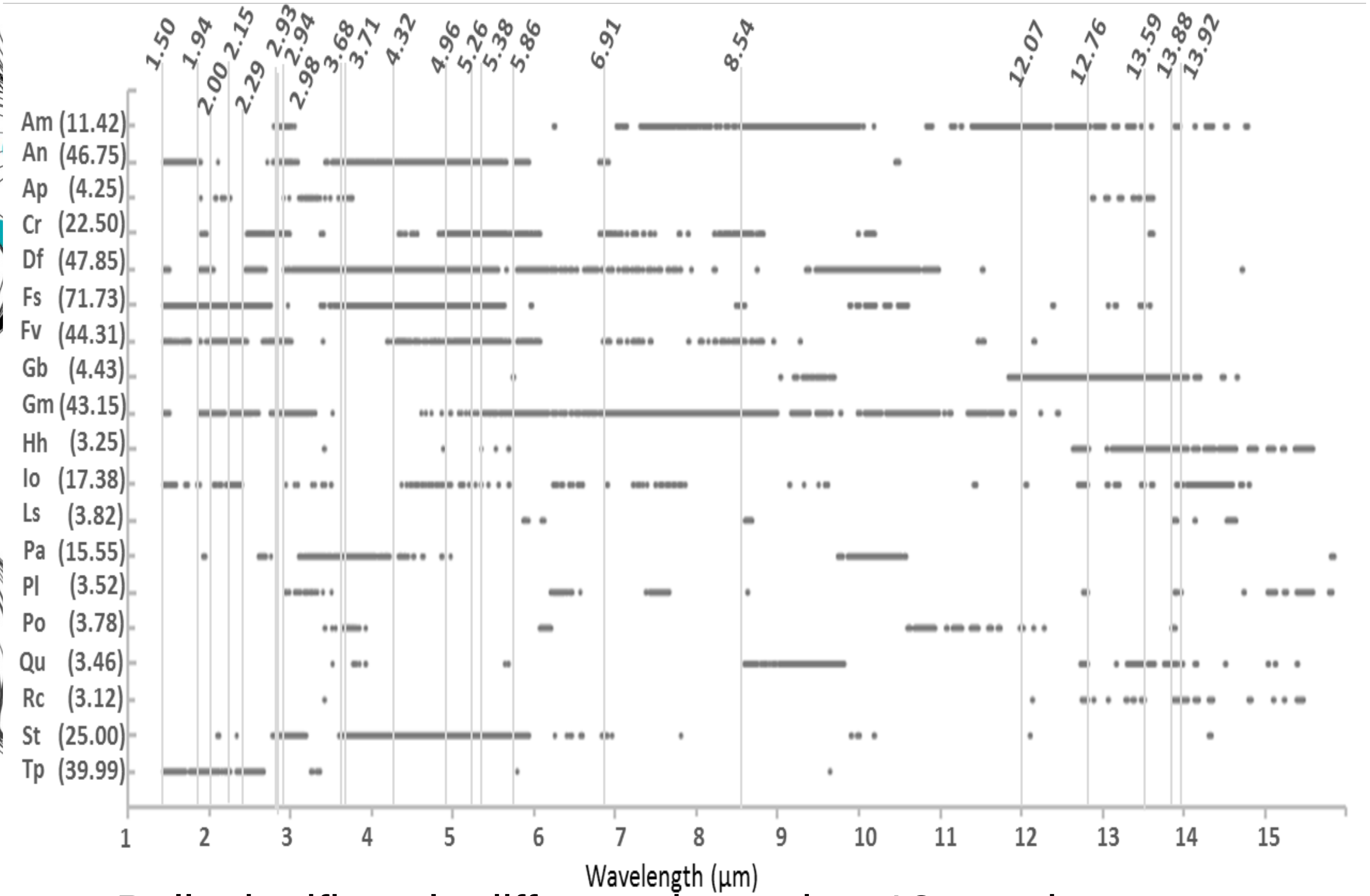


RESULTS: ***Selecting bands that separate plant species***



Tukey Sign. Diff. test between 2 species (171 combinations)
If more than 75% of combinations different => wavelength flagged

RESULTS: ***Selecting bands that separate plant species***



Ball: significantly different than other 18 species
Flag: more than 50% species have a ball

RESULTS: NARROW DOWN AND CLASSIFY

- Take all flagged bands
- Use a stepwise Quadratic Differentiation Analysis (QDA) => reduce number of bands (to ca. 5)
- QDA => Classify into species

- IR Full: 1.50, 2.15, 5.40, 8.54, 9.78 um : Kappa = 0.96
- SWIR: 1.50, 1.52, 2.00, 2.15, 2.29 um : Kappa = 0.93
- MWIR: 3.05, 3.68, 4.87, 5.26, 5.40 um : Kappa = 0.84
- LWIR: 6.91, 8.54, 9.78, 12.14, 12.76 um: Kappa = 0.94

RESULTS: CORRELATE WITH TRAITS

a) Correlation matrix between stepwise QDA bands and traits

b) Known chemical vibrational bonds and associated molecules reported

Wavelength (µm)	a. Cel	Lig	Lig/Cel	N	C/N	LWC	LA	LT	VT	ET	SD	b. Chemical bond reported at this wavelength	Elements and molecules involved at this wavelength*
1.50	**0.65**	-0.16	-0.41	-0.31	0.33	0.06	-0.01	**0.74**	0.48	0.45	-0.17	O-H stretch, C-H stretch	Cellulose, N, Protein [a, b, c]
1.52	**0.61**	-0.12	-0.35	-0.34	0.38	-0.15	-0.04	**0.76**	0.45	0.35	-0.11	N-H stretch	N, protein [c]
2.00	**0.62**	-0.21	-0.44	-0.20	0.22	0.04	-0.08	**0.60**	0.41	0.55	-0.11	O-H deformation	Cellulose, lignin, starch [b, d, e]
2.15	**0.49**	0.05	-0.18	-0.32	0.44	-0.38	0.05	**0.62**	0.37	0.28	0.12		Lignin [e]
2.29	**0.49**	0.00	-0.22	-0.33	0.44	-0.36	0.01	**0.65**	0.35	0.29	0.12	C-O, C-H and O-H stretch	Cellulose, lignin, starch, N [e, f, g]
3.05	-0.39	-0.17	-0.02	**0.53**	-0.42	0.29	-0.06	**-0.43**	-0.20	0.03	0.03	O-H stretch	Cellulose, polysaccharides, water [h, i, j, k]
3.68	-0.39	-0.17	-0.02	**0.53**	-0.42	0.29	-0.06	**-0.43**	-0.20	0.03	0.03		
4.87	-0.27	-0.23	-0.09	**0.45**	**-0.47**	0.44	-0.23	-0.34	-0.15	0.25	0.00		Lignin [h]
5.27	-0.30	-0.22	-0.07	**0.41**	**-0.41**	0.37	-0.27	-0.26	-0.20	0.30	0.01		Lignin [g]
5.40	-0.29	-0.25	-0.11	**0.42**	**-0.42**	0.39	-0.30	-0.24	-0.20	0.32	0.00		
6.91	**-0.47**	-0.27	-0.06	**0.45**	**-0.45**	0.38	-0.22	**-0.48**	-0.34	0.12	0.01		Cellulose [h]
8.54	-0.27	**-0.36**	-0.19	0.11	-0.16	**0.33**	-0.26	0.13	**-0.33**	0.25	-0.16	Ester-linked hydroxy	Lignin, cutin, wax [l, m]
9.79	0.13	0.01	-0.03	0.06	-0.06	**0.27**	0.21	**-0.28**	0.22	-0.03	-0.16		(9.68-9.92) Cellulose, wax [h, i, m]
12.10	0.10	**-0.38**	**-0.34**	-0.07	-0.07	**0.34**	-0.12	-0.06	-0.20	0.25	-0.17	C-H out of plane vibration	(12.16) Lignin [m, n]
12.80	0.19	-0.12	-0.15	0.03	-0.09	**0.23**	**0.23**	-0.22	**0.27**	0.20	-0.19		

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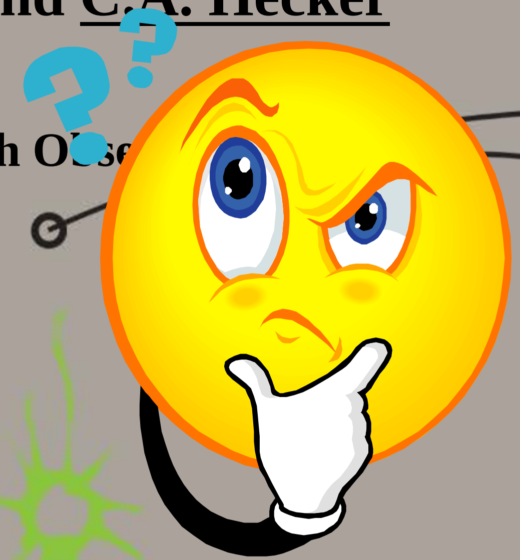
CONCLUSIONS:

- This study shows that:
  - infrared spectra of fresh leaves of 19 investigated plant species
    - differentiate and classify species.
    - More different in SWIR and LWIR than in MWIR
  - Bands can be linked to leaf traits
    - Strongest correlations:
      - Cellulose and Leaf thickness (SWIR)
      - Nitrogen (MWIR)
      - LWC (LWIR)
  - Remote Sensing:
    - SWIR works and is easier (sensor complexity and availability)
    - The LWIR: species demonstrated particular features that can further improve classification accuracy. Effect of Canopy?

QUESTIONS?



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