UNIVERSITÄT OSNABRÜCK

Smart fLAIr

A Smartphone Application for Fast LAI Retrieval using Ambient Light Sensors

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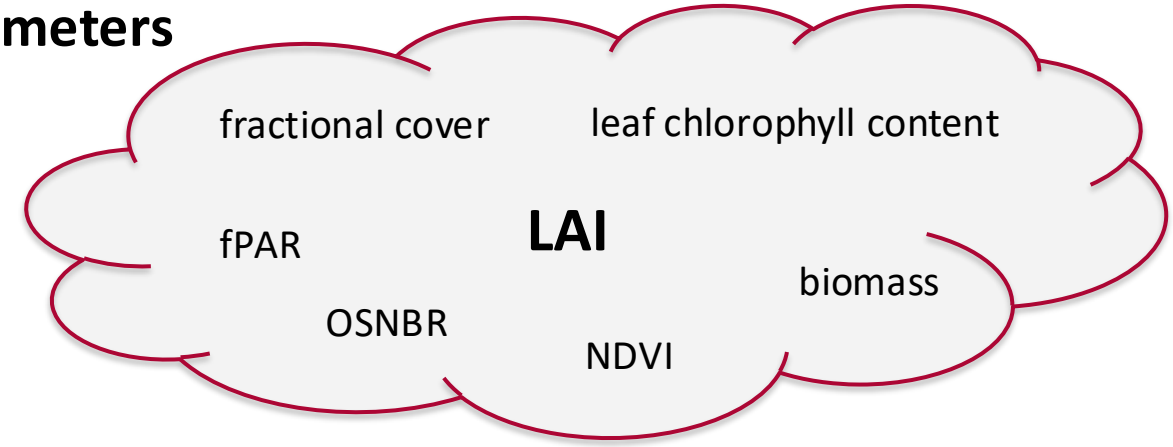
Precision Farming

- crop **yield optimization**
- precise **management**, incl.
  - **fertilization**
  - **irrigation**
  - **identification** of crop diseases

Demand for situational awareness

- **How to determine and monitor crop parameters?**

Crop Parameters



Leaf Area Index (LAI)

- indicator for **photosynthetic performance** and **yield-limiting processes**
- **key variable for models** in agronomy, climatology, ecology, …

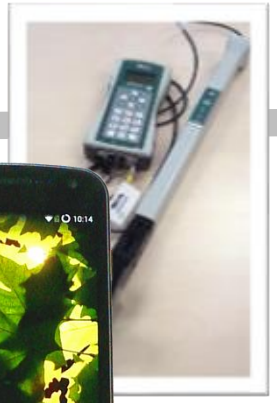
$$LAI = \frac{\text{green leaf area}}{\text{ground surface area}}$$

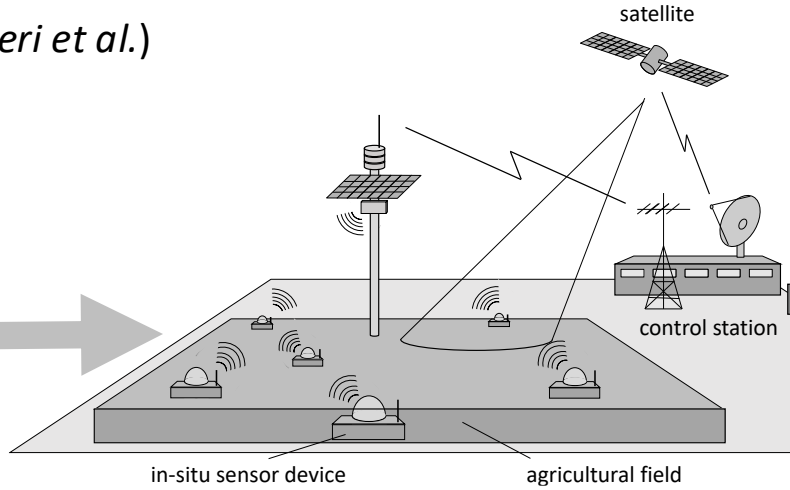
Direct LAI assessment

- leaf area scanner

Indirect LAI assessment

- remote sensing
- wireless sensor networks
- **in-situ** measurements
  - **gap size distribution** (e.g., PocketLAI *Confalonieri et al.*)
  - **gap fraction** (e.g., LAI-2200, AccuPar, SunScan)





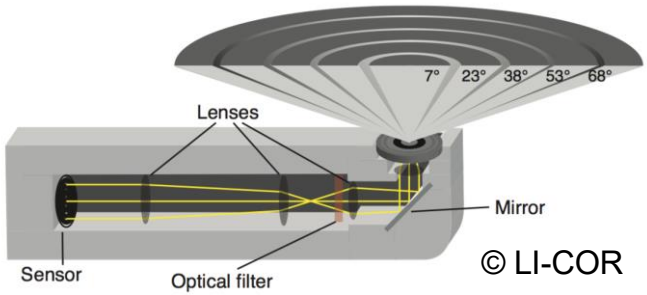
pro: precision
con: time-inefficient

pro: resolution
con: monetary cost

→ **cost-efficient alternative**

LI-COR LAI-2200

- **optical sensor system**
- **properties**
  - 148° field-of-view, 5 rings
  - wavelength range: 320-490 nm



- **LAI estimation based on gap fraction**
  - canopy light interception: **transmittance** measurement
    → above + below canopy
  - LAI derived from transmittance (Miller 1967)

LI-COR, "LAI-2200 Plant Canopy Analyzer - Instruction Manual," http://www.licor.co.za/manuals/LAI- 2200_Manual.pdf, Last checked: April, 2016.
Miller, J.B., 1967. A formula for average foliage density. Australian Journal of Botany 15, 141–144.

Idea

- adoption of **LI-COR's approach**
- **above + below** light measurements via smartphone
- **Ambient Light Sensor (ALS)**

Prototype

- Samsung Galaxy Nexus (GT-i9250)
- Android 4.4.4 Kitkat (not rooted!)

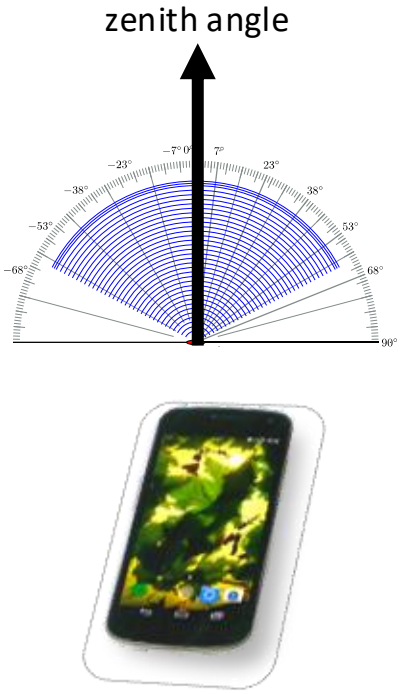
ALS

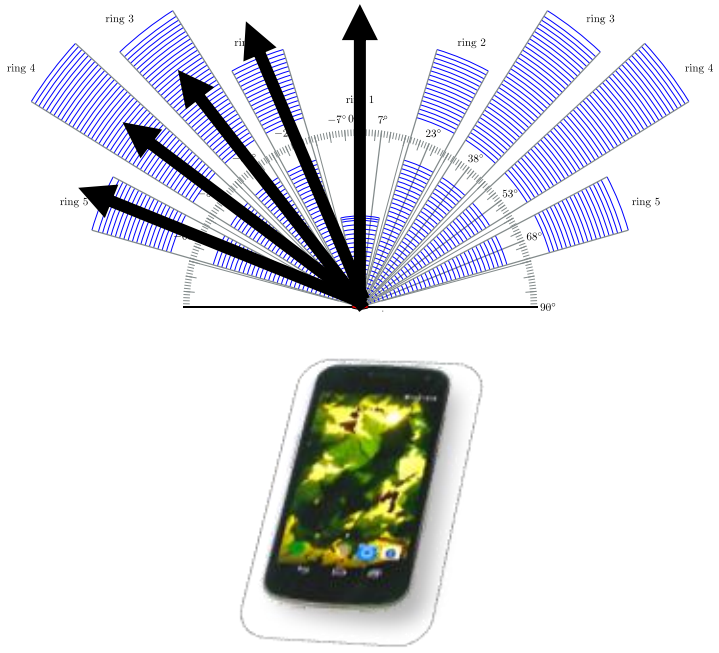
- Sharp GP2A
- resolution: 1.0 lx
- range: 0-55000 lx
- sampling rate: 43 Hz
- default:
  ~50 samples/probe (~1.2s)

optional: **sensor accessory**, i.e., diffuser and band-pass filter

Single- vs. multi-angle mode

- **inertial sensor** for ALS orientation
- user **rotation** along y-axes
- orientation **tolerance**: ± 4°





Study area

- maize field (*Zea mays L.*)
- Osnabrück, Germany

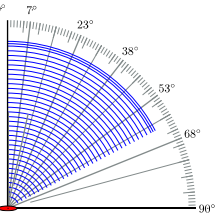
Methodology

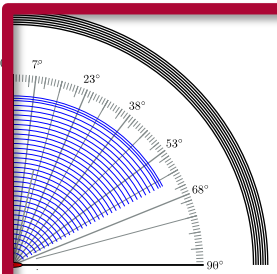
- LI-COR LAI-2200 as reference device

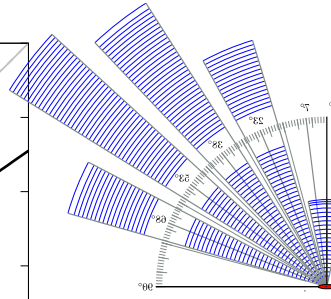
Campaigns

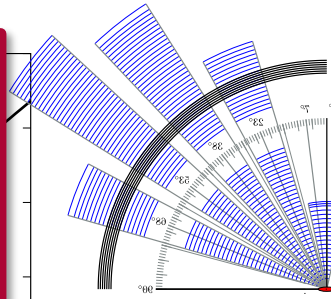
- September 2014 and August 2015
- stable cloud cover → diffuse lighting conditions

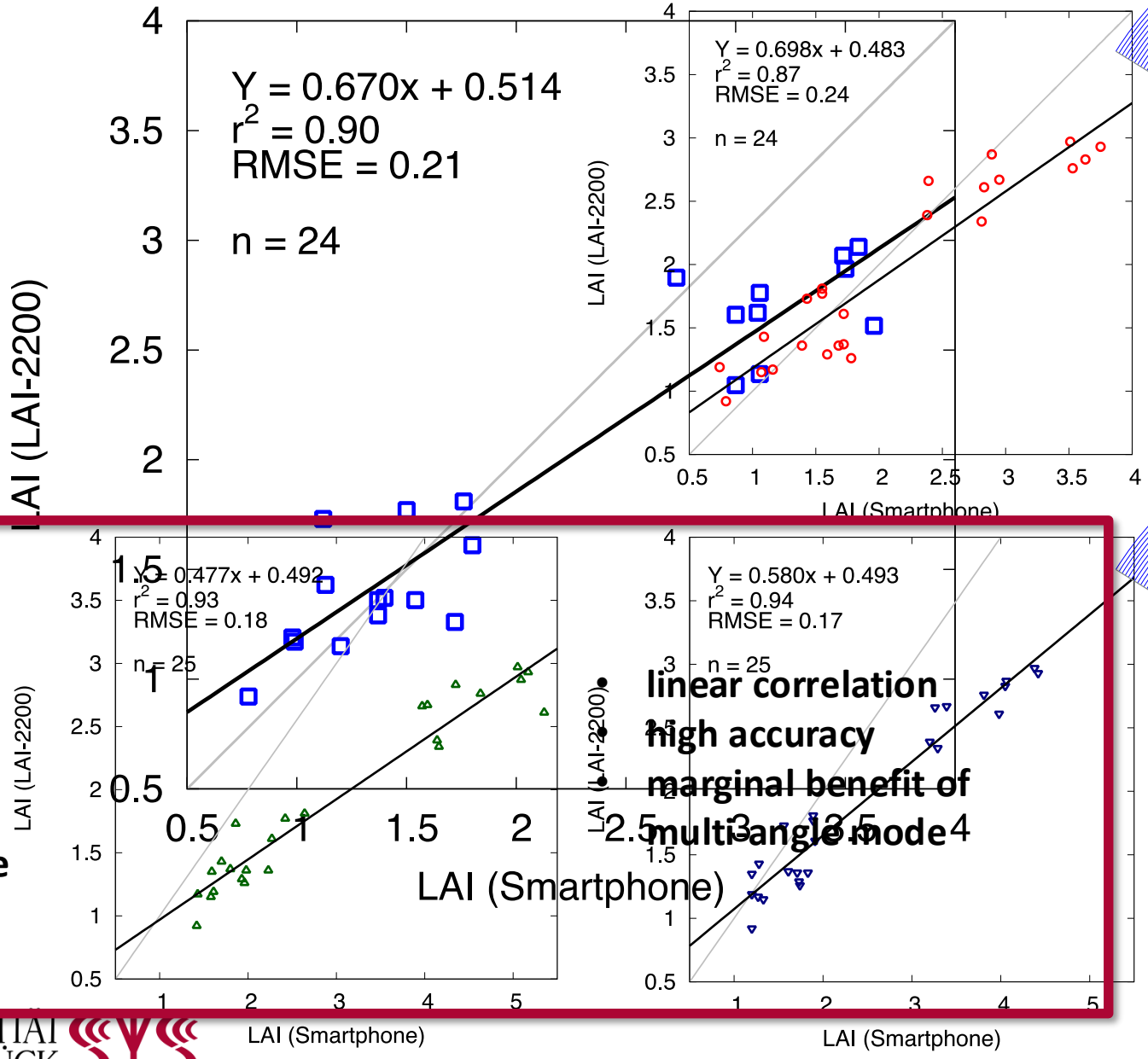
Evaluation: Impact of Multi-Angle Mode & Optical Diffuser









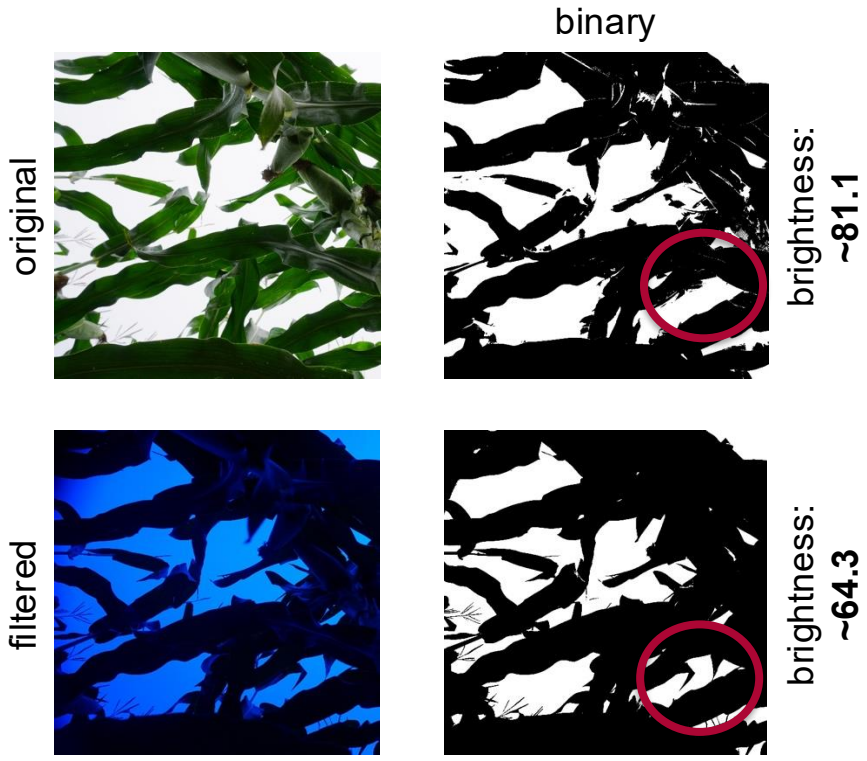


single-angle + diffuser

linear correlation
high accuracy
marginal benefit of multi-angle mode

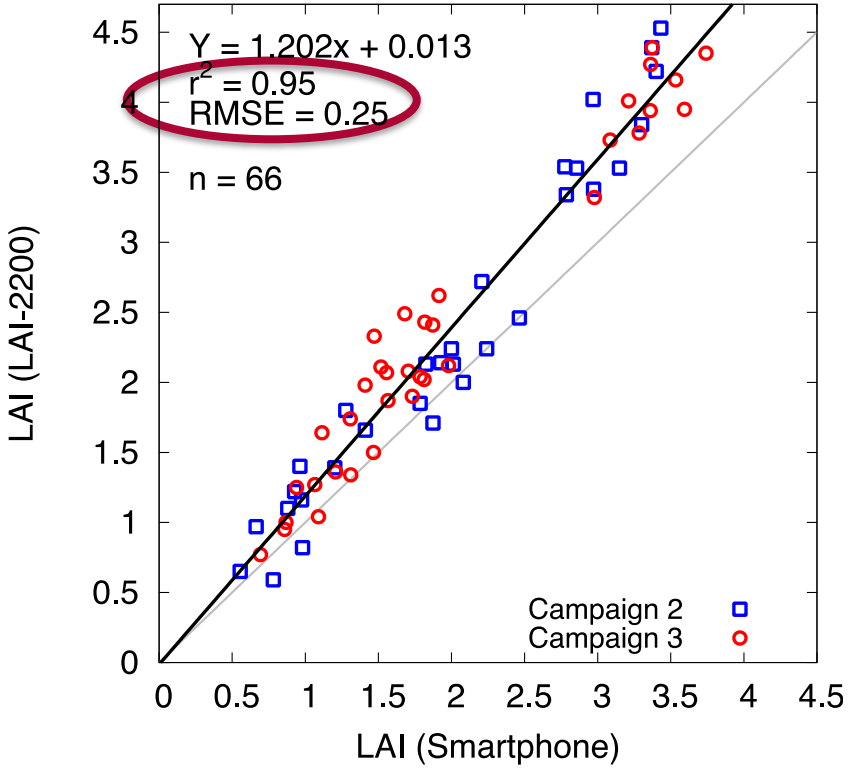
Observation

- low absorption of green vegetation in green spectrum
  - → high transmittance
  - → **low contrast**



Solution

- **band-pass filter** (blue spectrum)
  - → **high contrast**



Conclusion

- **feasibility**
  - **LAI assessment via smartphone**
- **Smart fLAIr**
  - **cost-efficient**
  - **credible results**
- **diffuser and filter** as beneficial sensor accessory

Future work

- field campaigns with
  - different smartphones
  - different crops and cultivars

Thanks for your attention!

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- LI-COR, "LAI-2200 Plant Canopy Analyzer - Instruction Manual," http://www.licor.co.za/manuals/LAI-2200_Manual.pdf, Last checked: Apr, 2016.
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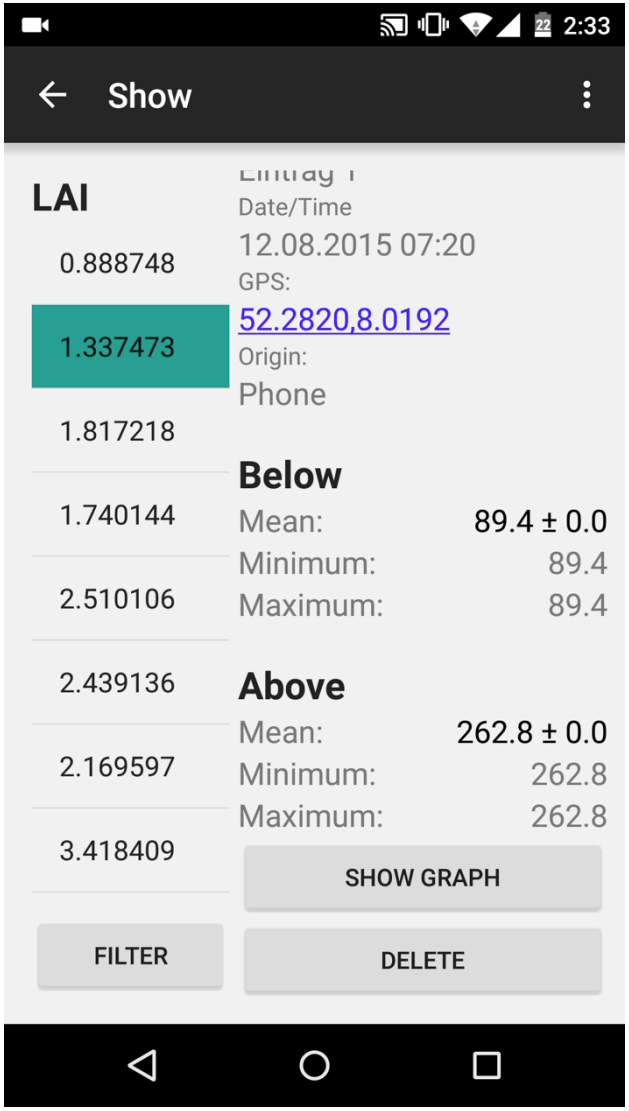
- Miller, J.B., 1967. A formula for average foliage density. Australian Journal of Botany 15, 141–144.

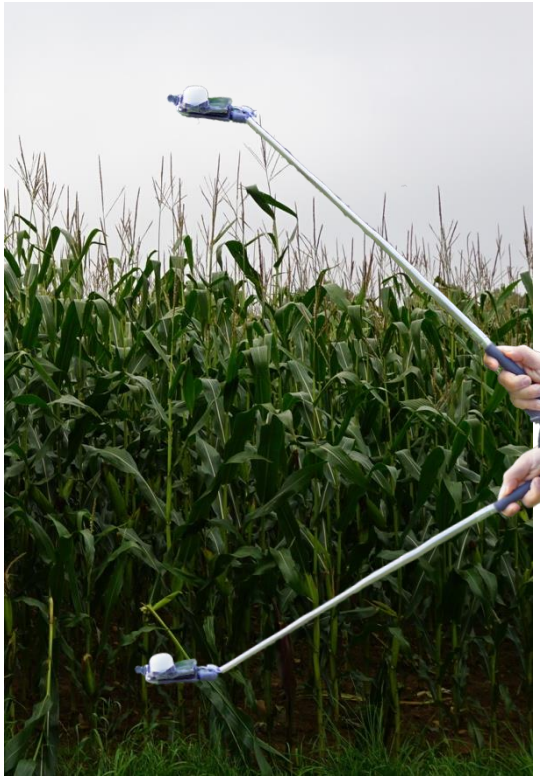
This work was supported by the "Stifterverband für die Deutsche Wissenschaft" (H170 5701 5020 20951)

Evaluation: Comparison to related approaches

Category		Approach	Year	Species	Result (r^2)	Reference
DHP		Ryu et al.	2012	trees	0.94	LAI-2200
Smartphone	PocketLAI™	Confalonieri et al.	2013	rice	0.97	destructive
Smartphone		Francone et al.	2014	grass	0.86	AccuPAR
				maize	**0.92**	AccuPAR
				giant reed	0.88	AccuPAR
Smartphone		Orlando et al.	2015	shrubs	0.78	DHP
				conifers	0.16	DHP
WSN		Qu et al.	2014	**maize**	**0.27-0.97**	LAI-2200
WSN		Bauer et al.	2014	shrubs	0.95-0.90	LAI-2200
Smartphone		**Smart fLAIr**	**2016**	**maize**	**0.95**	**LAI-2200**

Demo: Smart fLAIr in the wild





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- Y. Ryu, J. Verfaillie, C. Macfarlane, H. Kobayashi, O. Sonnentag, R. Vargas, S. Ma, and D. Baldocchi, "Continuous observation of tree leaf area index at ecosystem scale using upward-pointing digital cameras," *Remote Sensing of Environment*, vol. 126, pp. 116–125, 2012.
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- F. Orlando, E. Movedi, L. Paleari, C. Gilardelli, M. Foi, M. Dell'Oro, and R. Confalonieri, "Estimating leaf area index in tree species using the PocketLAI smart app," *Appl. Vegetation Science*, vol. 18, pp. 717–723, 2015.
- Y. Qu, Y. Zhu, W. Han, J. Wang, and M. Ma, "Crop Leaf Area Index Observations With a Wireless Sensor Network and Its Potential for Validating Remote Sensing Products," *IEEE Journal of Selected Topics in Applied Earth Observations & Remote Sensing*, vol. 7, no. 2, pp. 431–444, Feb 2014.
- J. Bauer, B. Siegmann, T. Jarmer, and N. Aschenbruck,"On the Potential of Wireless Sensor Networks for the In-Field Assessment of Bio-Physical Crop Parameters," in *Proc. of Int. Workshop on Practical Issues In Building Sensor Network Applications (SenseApp)*, Edmonton, Canada, pp. 523–530, 2014.

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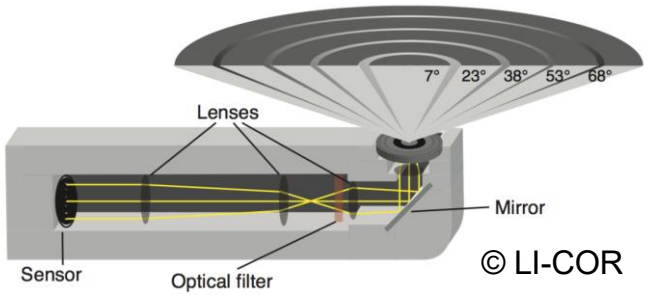
LI-COR LAI-2200

- **optical sensor system**
- **properties**
  - 148° field-of-view, 5 rings
  - wavelength range: 320-490 nm



- **LAI estimation based on light interception**
  - transmittance measurement
  - LAI derived from transmittance
  - formula (Miller 1967)

Transmittance

$$L = 2\int_0^{\pi/2} -\frac{\overline{lnP(\theta)}}{S(\theta)} sin\theta d\theta = 2\sum_{i=1}^{5} \overline{K_i} W_i$$

$$\overline{K_i} = \frac{1}{N_{obs}} \sum_{j=1}^{N_{obs}} \frac{-ln\left(\frac{B_{ij}}{A_{ij}}\right)}{S_i}$$

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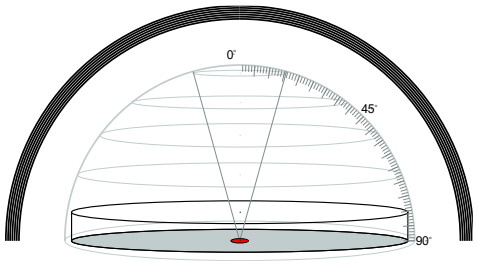
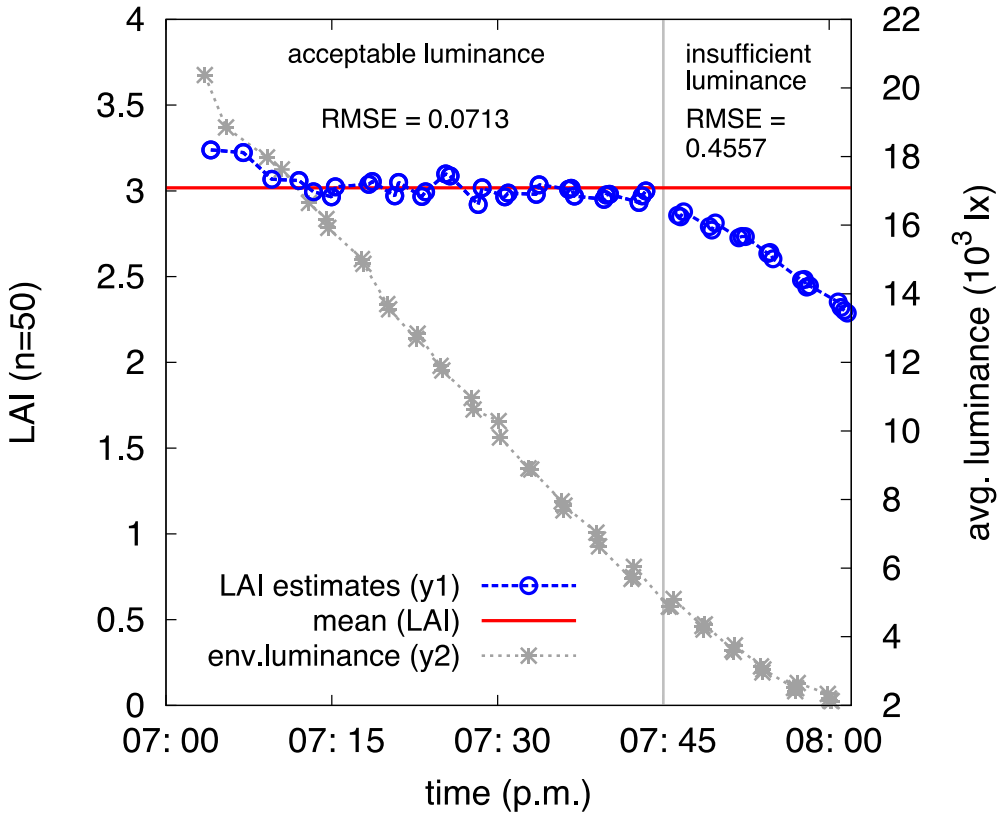
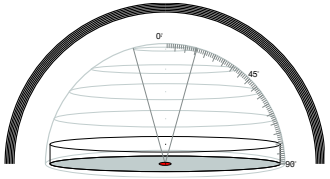


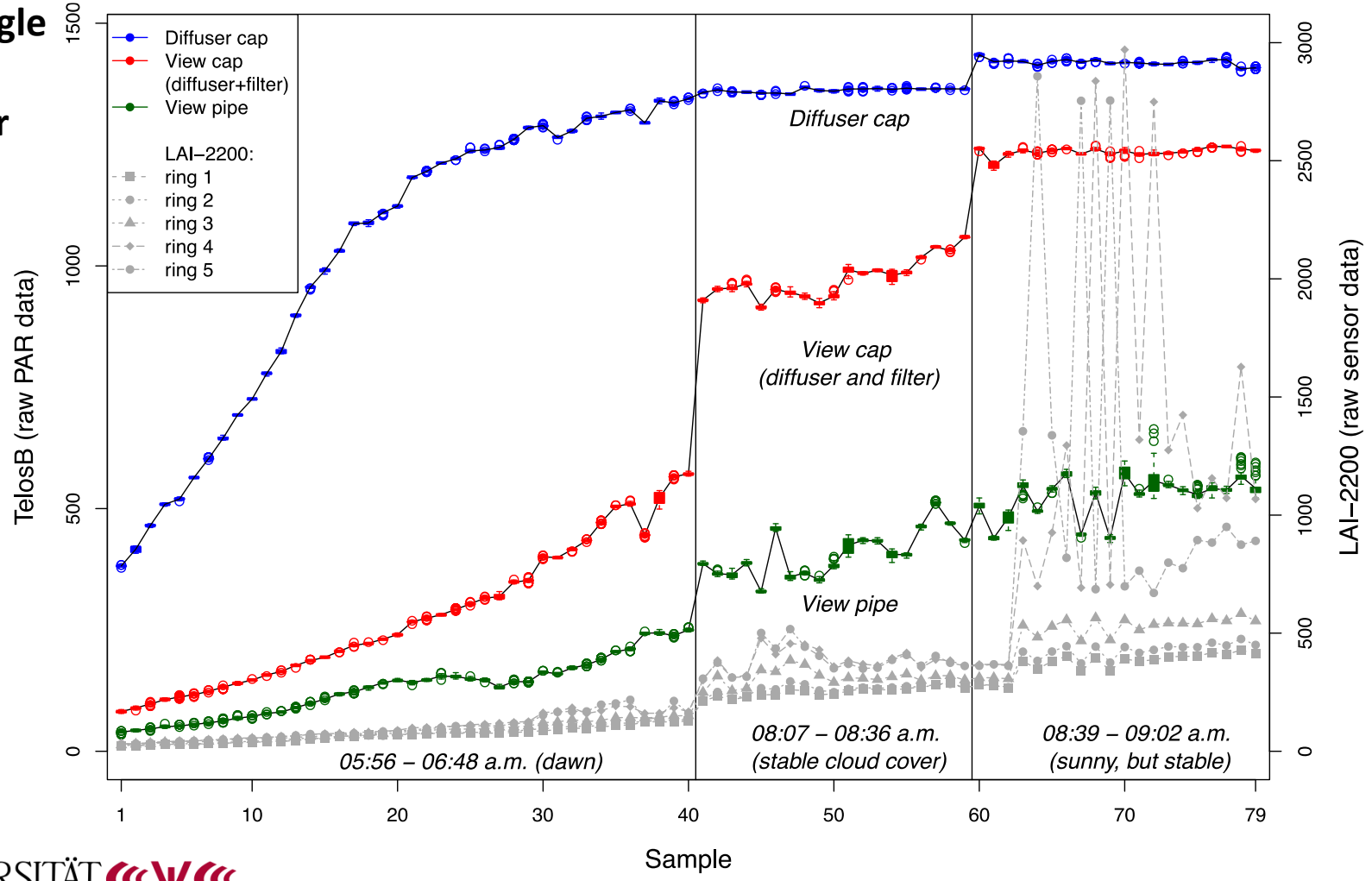
single-angle
+
diffuser



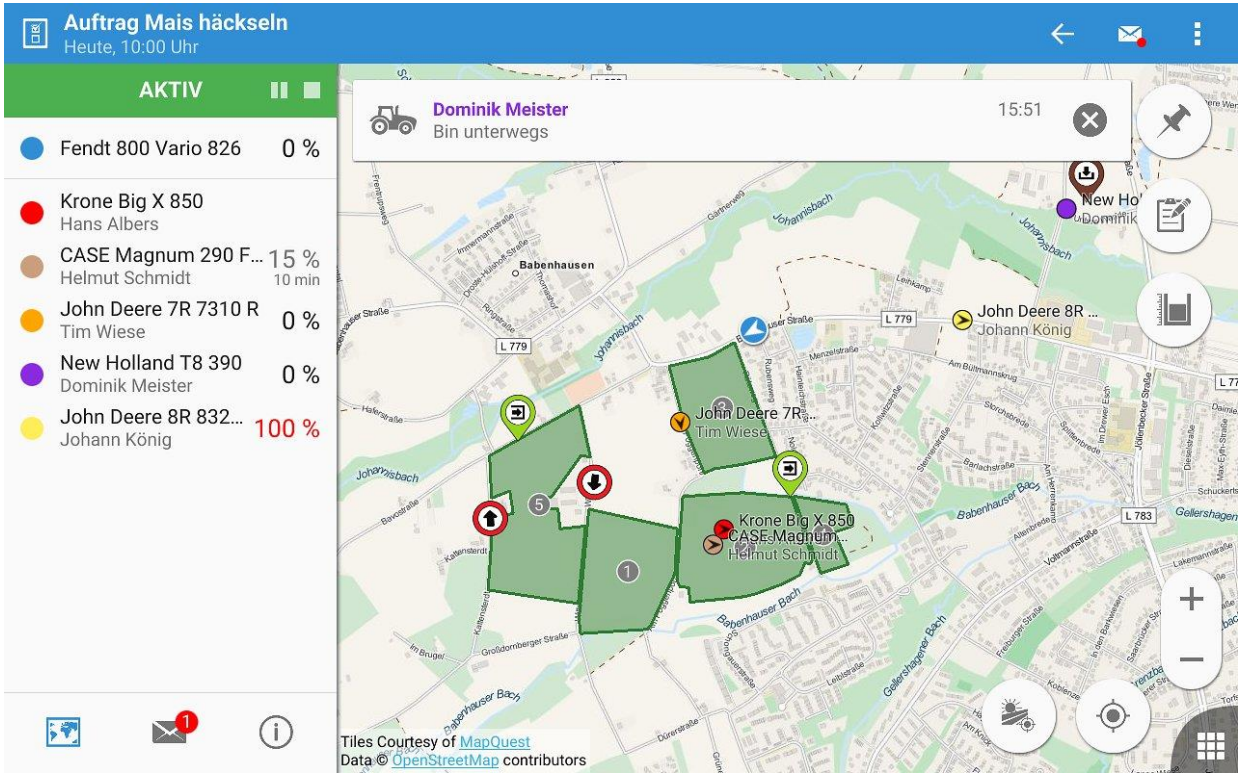
Evaluation: Robustness



single-angle + diffuser

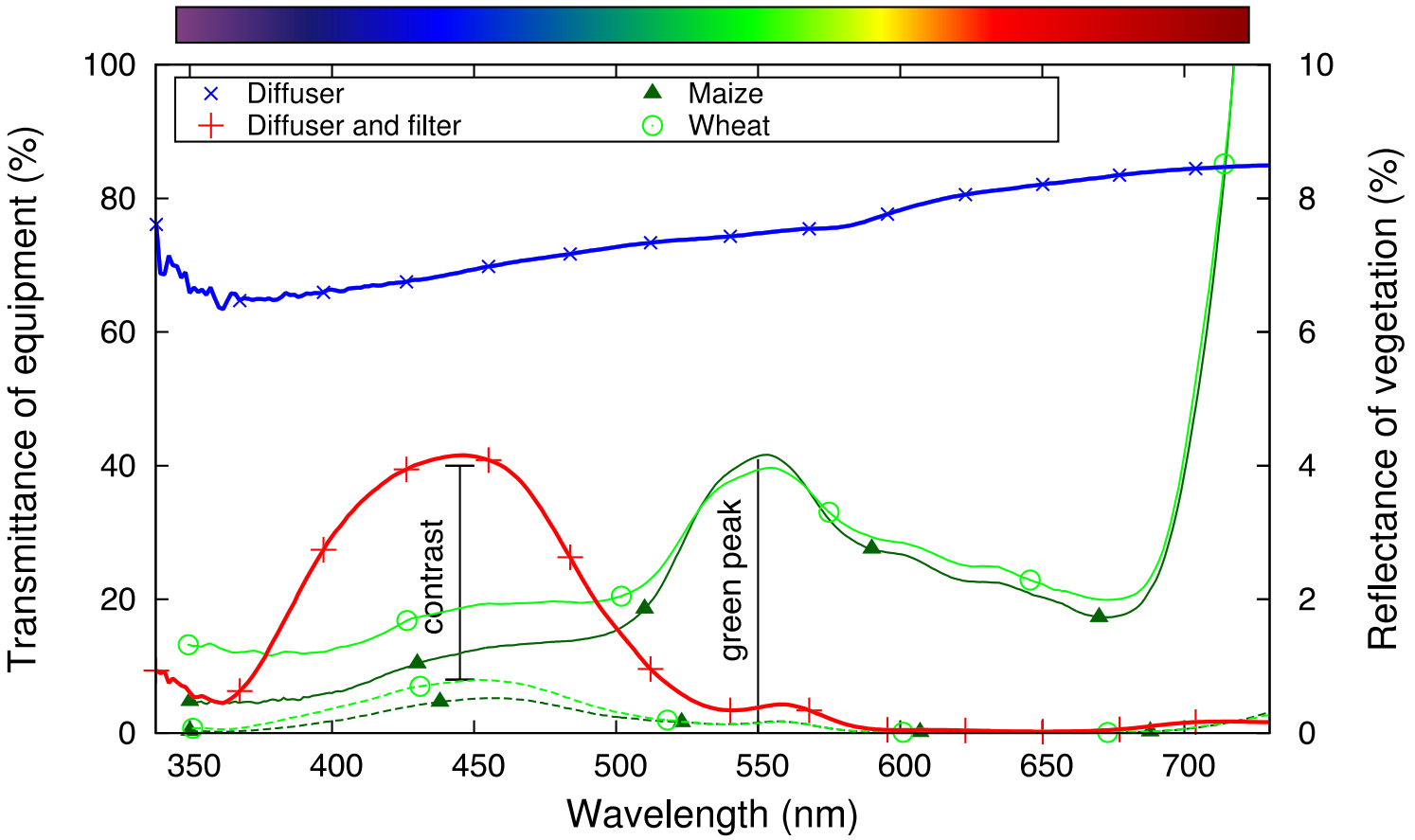


Farmtune
Work smart. Enjoy farming

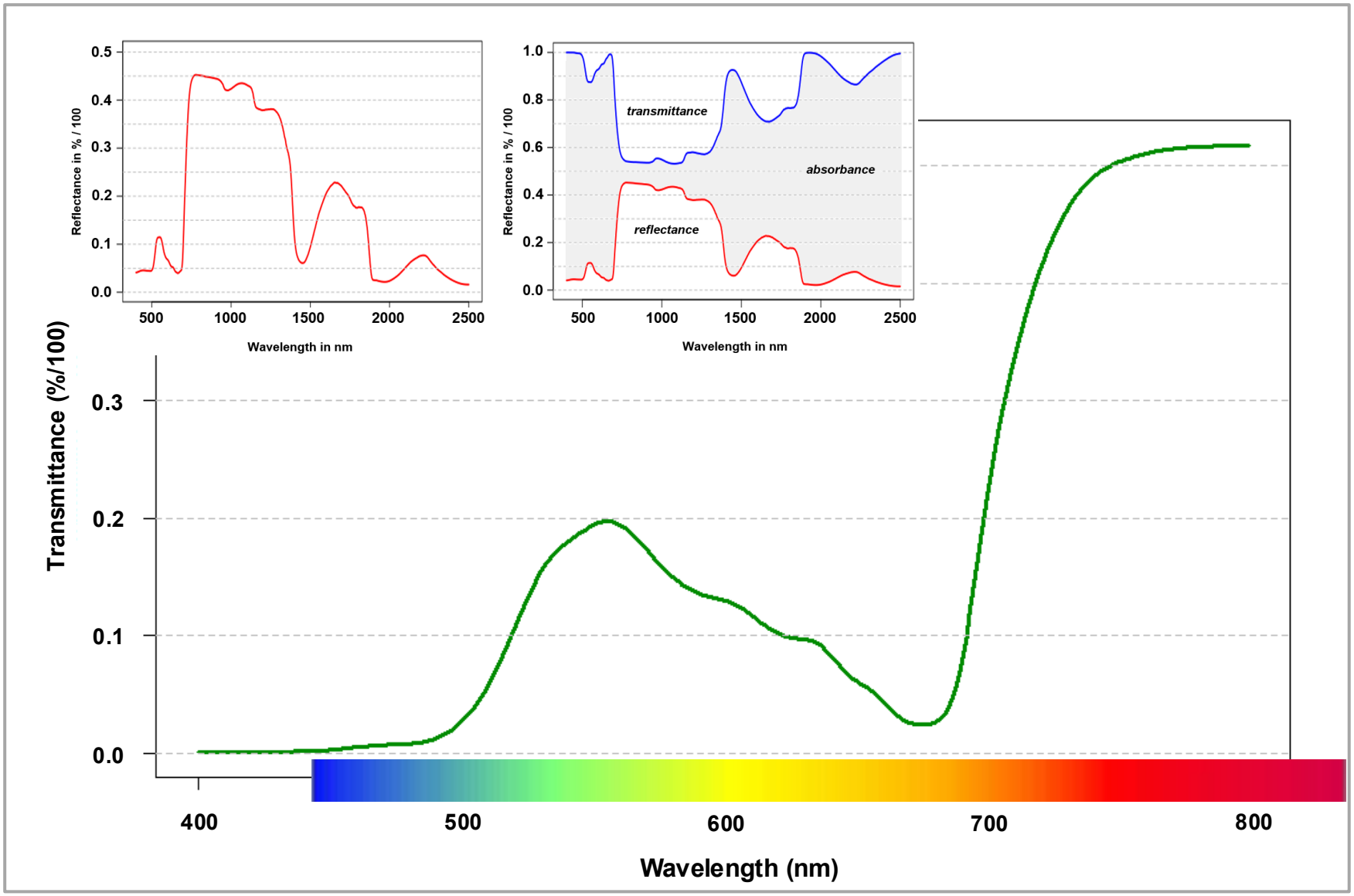


© m2Xpert

Concept: Impact of Blue Band-Pass Filter in the Visible Light Spectrum



Backup: Vegetation Spectrum



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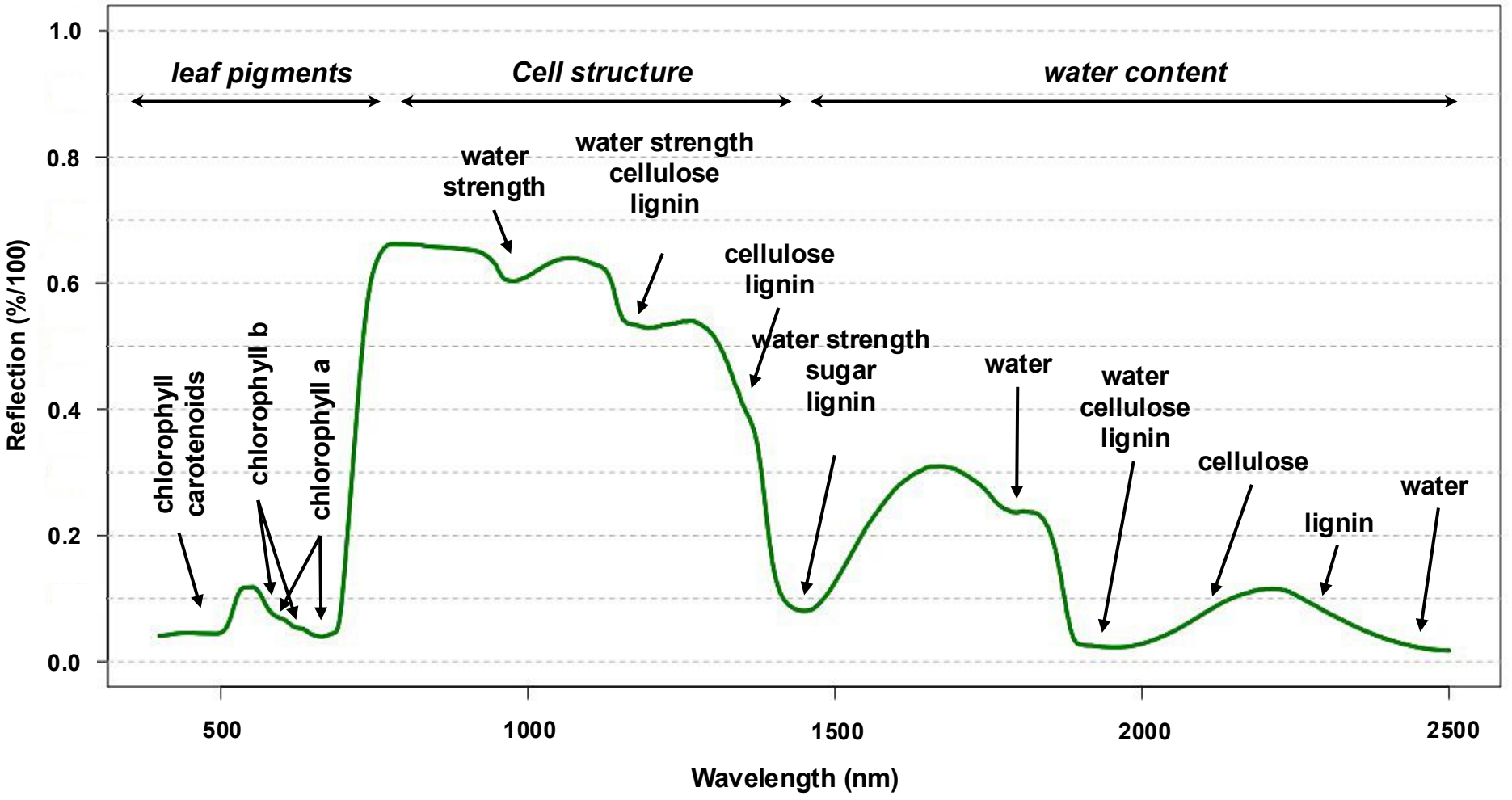
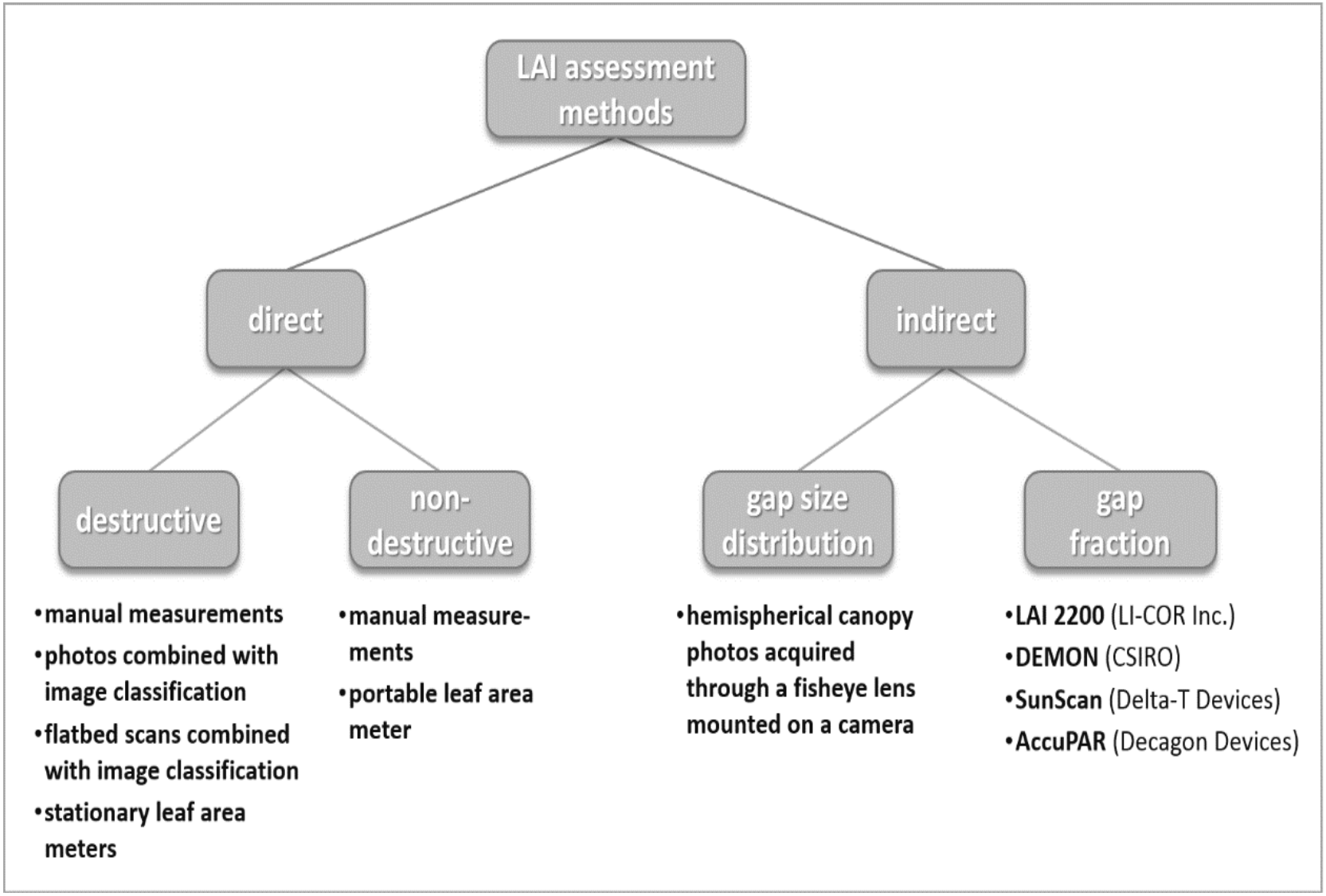
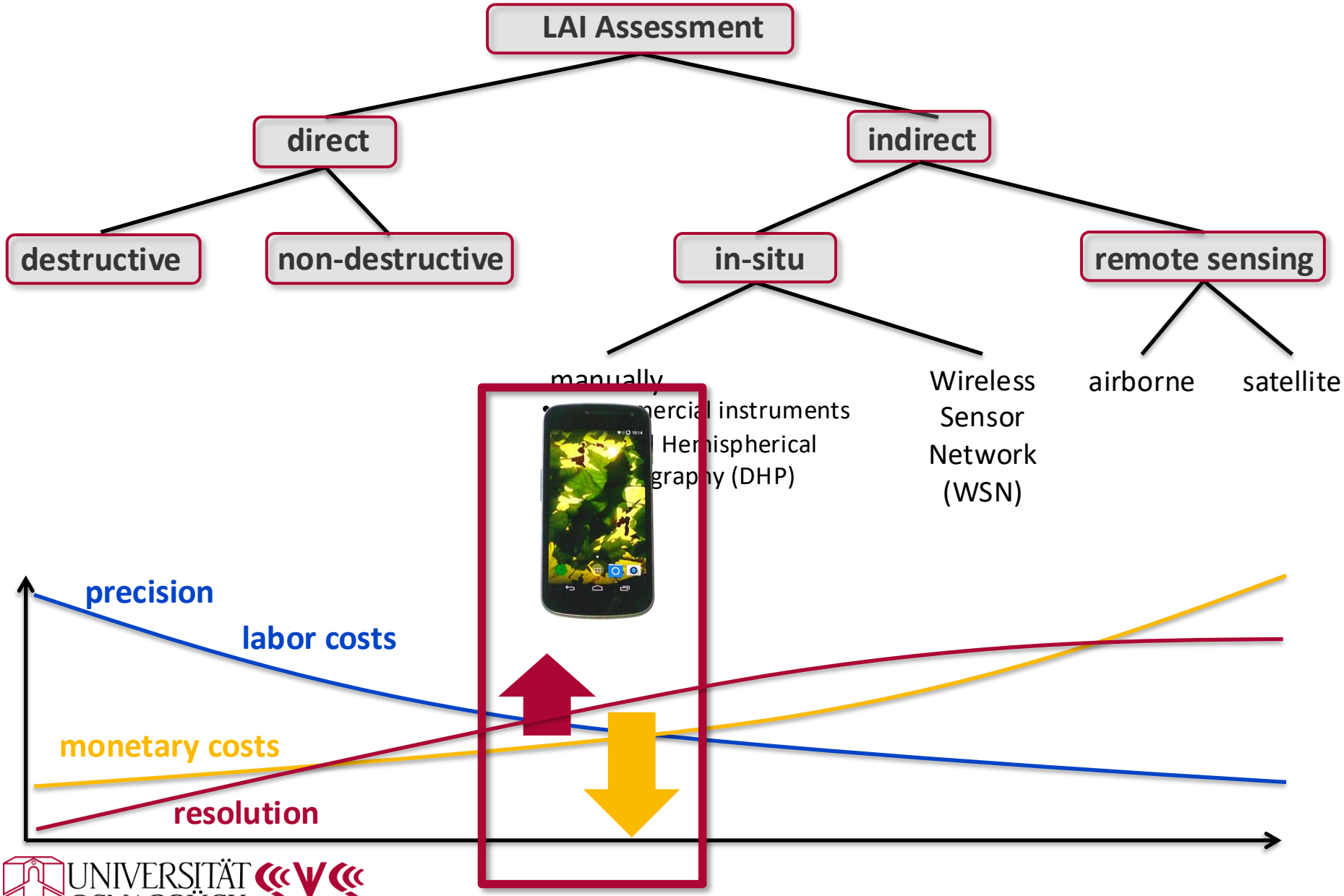




Background: Classification of LAI Assessment Methods



WSN Application:

- Sensors:
  - **Hamamatsu S1087 PAR Sensor**
  - Senserion SHT11 (MTS400 sensor board)
  - PerkinElmer VT900
- Platform: TelosB
- Software: TinyOS

- **Data Collection:**
  - PAR + temperature + humidity
  - sampling rate: 3 Hz
  - 17 samples per packet
  - broadcast every 6 s
  - centralized LAI processing

Distributed setup

Memory Footprint:

ROM	16.932 kB	< 35 %
RAM	780 byte	< 8 %