Education & Training

Methodology: Ground truthing and application of ground truth data for hyperspectral image analysis

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Outline

- AIM?
- Basics!
- Sampling Design!!
- WHAT?
- HOW?
- Lab!

Groundtruthing…in a hyperspectral sense

Why do we need GT information in RS studies?

1. Image Calibration purposes
    1. Geometric correction
    2. Atmospheric correction
2. Target Calibration for quantitative assessment
    1. Vegetation health
    2. Contamination quantities
    3. Water quality criteria
    4. Etc…
3. Target Calibration for qualitative assessment
4. Target Validation for accuracy analysis
5. Endmember collection for classification

FIELD SPECTROSCOPY

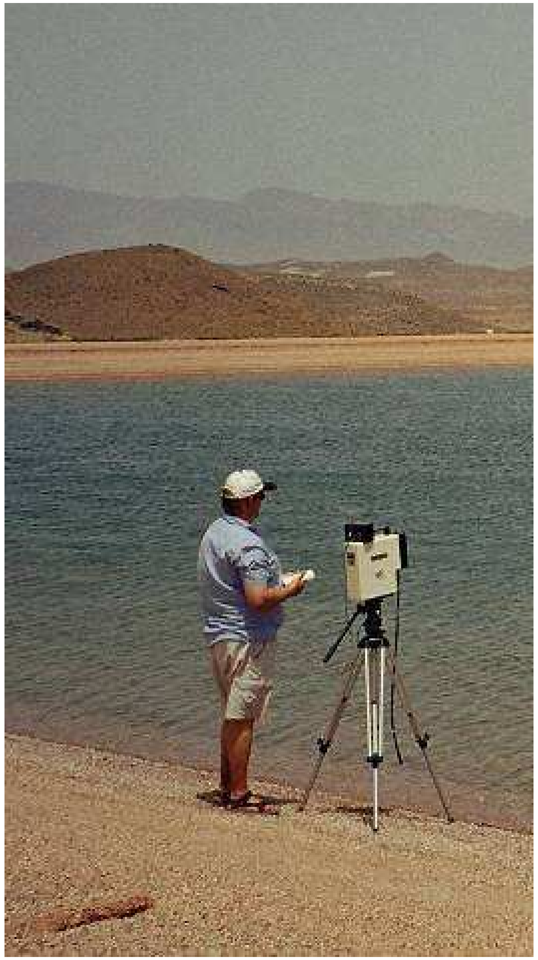
Ground truthing using Field Spectroscopy

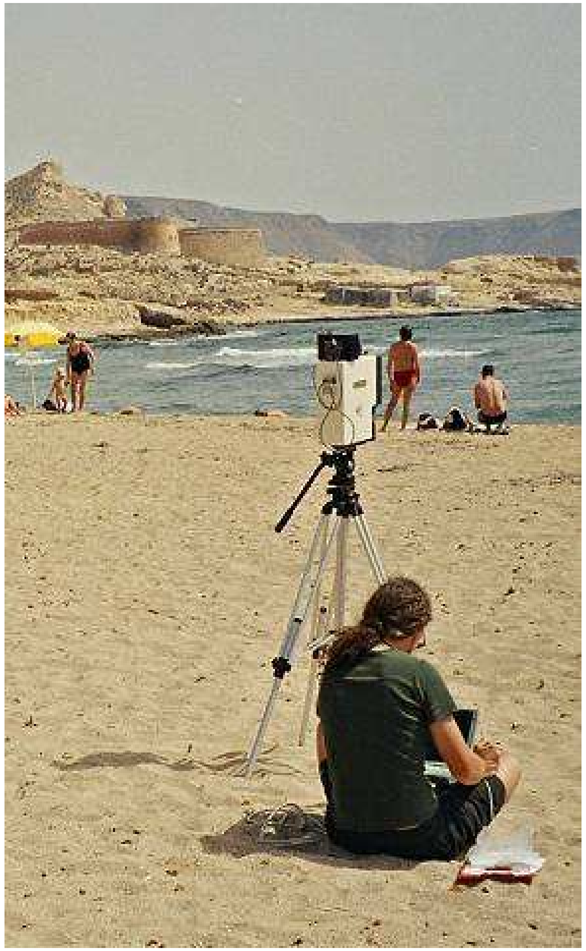
30 years ago !

Milton, E.J., Schaepman, M.E., Anderson, K., Kneubühler, M., & Fox, N. (2009). Progress in field spectroscopy. *Remote Sensing of Environment, 113*, S92-S109

Ground truthing using Field Spectroscopy

10 years ago !





Ground truthing using Field Spectroscopy

3 years ago…

Ground truthing using Field Spectroscopy

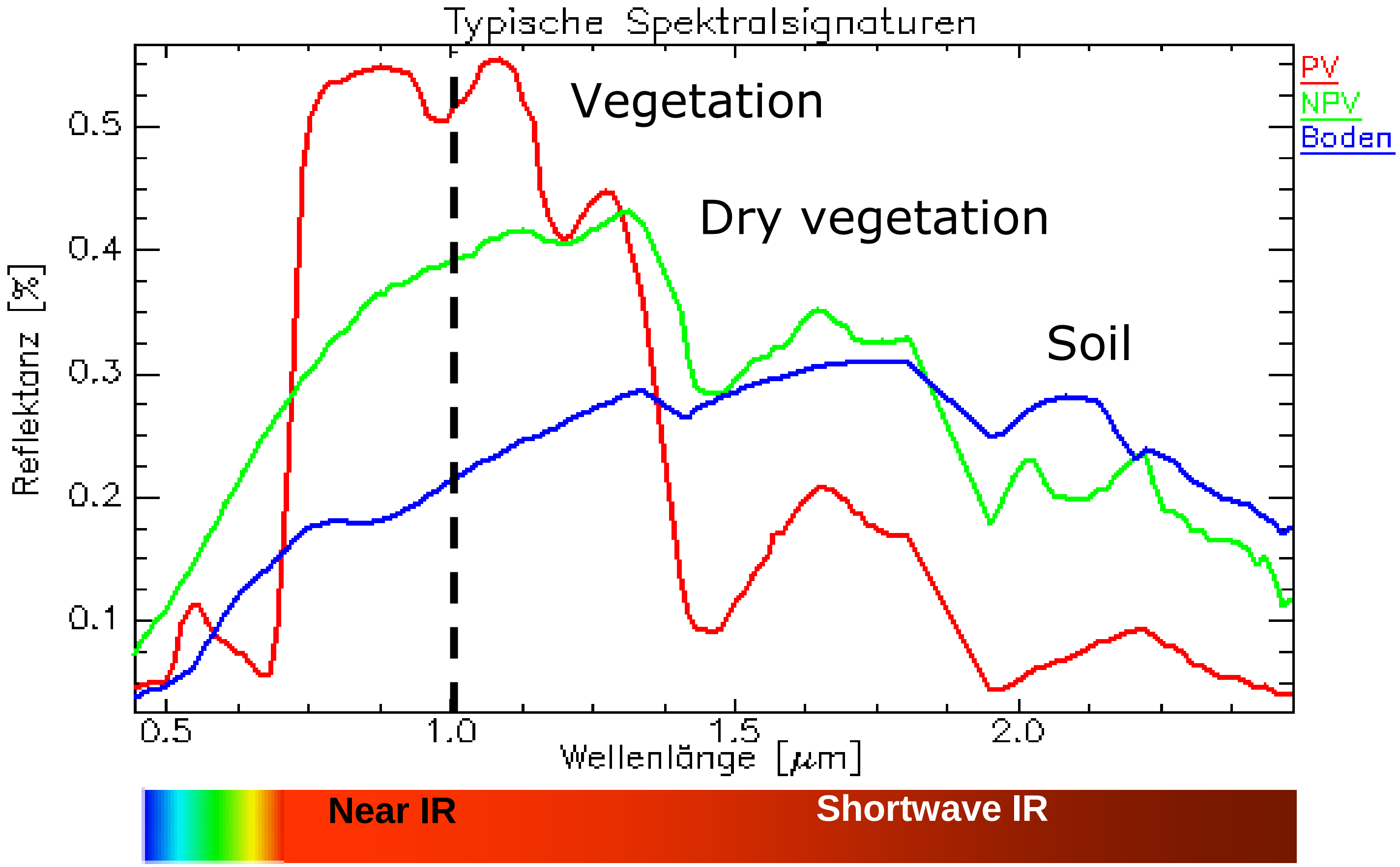
This week !

http://www.oceanoptics.com/products/usb2000+precon.asp

Spectroscopy

... measurements based on the **interactions between electromagnetic radiation and materials** as a function of wavelength

•Ocean Optics



Spectroscopy

- **General Application: material identification & quantification**
  - Transmission spectroscopy widely applied in laboratory equipment
  - Analytical chemistry, biology, astronomy, …

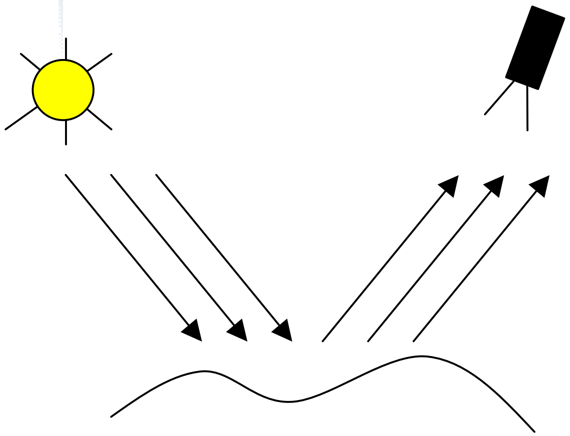
- **Support for Remote Sensing**
  - Calibration / validation of RS images (DN => at-sensor radiance)
  - Atmospheric correction (at-sensor radiance => reflectance)
  - Material identification in the field ("Spectral Geologist")
  - Characterization of surface materials for image interpretation
  - Compilation of Spectral Libraries
  - Model development / quantitative information extraction
  - In-situ measurements of anomalies
  - …

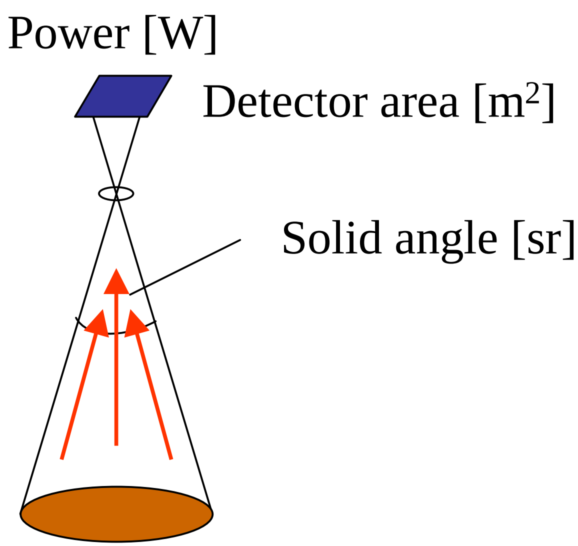
Spectroscopy – Measuring with light

- **The sensor measures:**

Radiance, At-Sensor Radiance L [W m^{-2} sr^{-1}]

=> Unit after system correction, described as L1 product

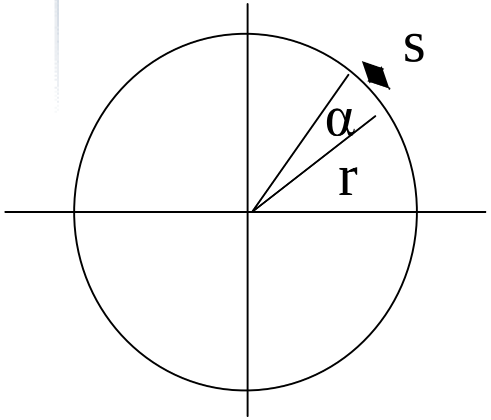




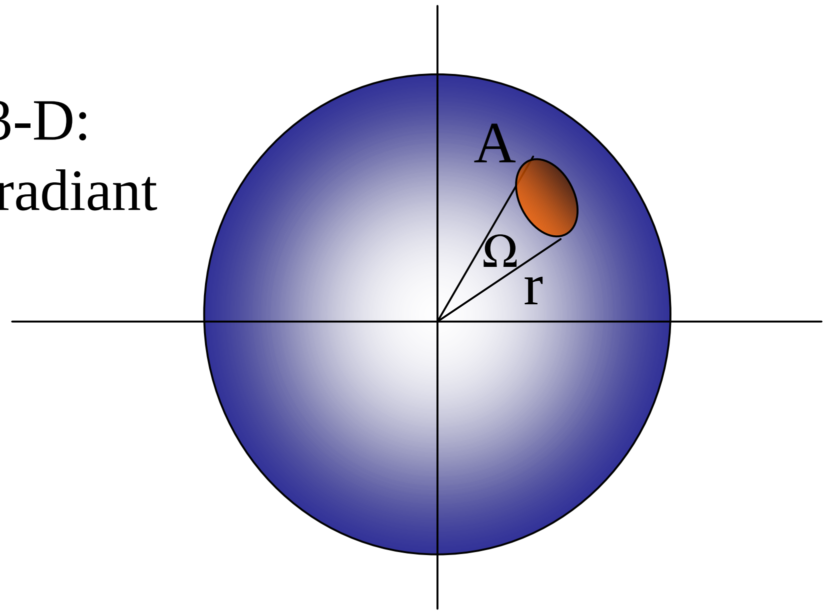
Physical Basics

- **Solid Angle Ω steradiant = area / radius²**
- **Sphere = 4π r² / r² = 4 π [sr]**
- **Sky = 2 π [sr]**

In 2-D:
Radiant



In 3-D:
Steradiant



Physical basics

Measure should be:

I. Independent of incoming radiation (power and geometry)

II. Independent from atmospheric conditions

III. Independent of sensor properties (instrument & detector characteristics)

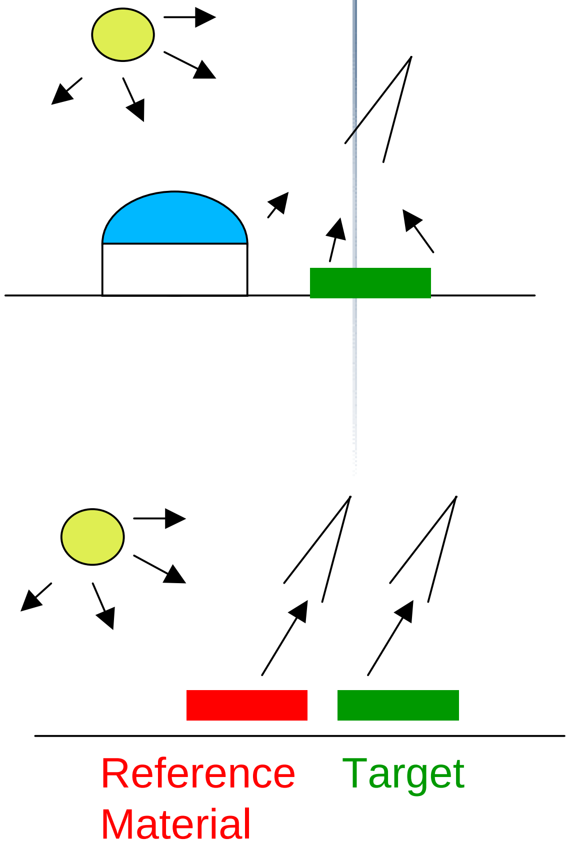
=> Material property only !

But: at-sensor radiance L [w m^{-2} sr^{-1}] still depends on (I, II, III)

Thus more suitable measure: reflection ρ = % of reflected radiation

- **No unit, but [%]**
- **Independent from illumination & sensor**
- **(Almost) independent from geometry & atmosphere**

Measurement principle



But: **sensors do measure radiance L = f (sensor, illumination, ...)**
We want: **% reflected**

1. **Measuring incoming and reflected radiance, then ratio:**
   $\rho_{target} = L_{target} / L_{reference}$
2. **Commonly for higher precision the hemispherical radiation E is measured:**

   $\rho_{target} = L_{target} * \pi / E$

3. If you use only one instrument:
   measure relative to known reference material

$$\frac{L_{Reference}}{L_{Target}} = \frac{\rho_{Reference}}{\rho_{Target}}$$

Reference material

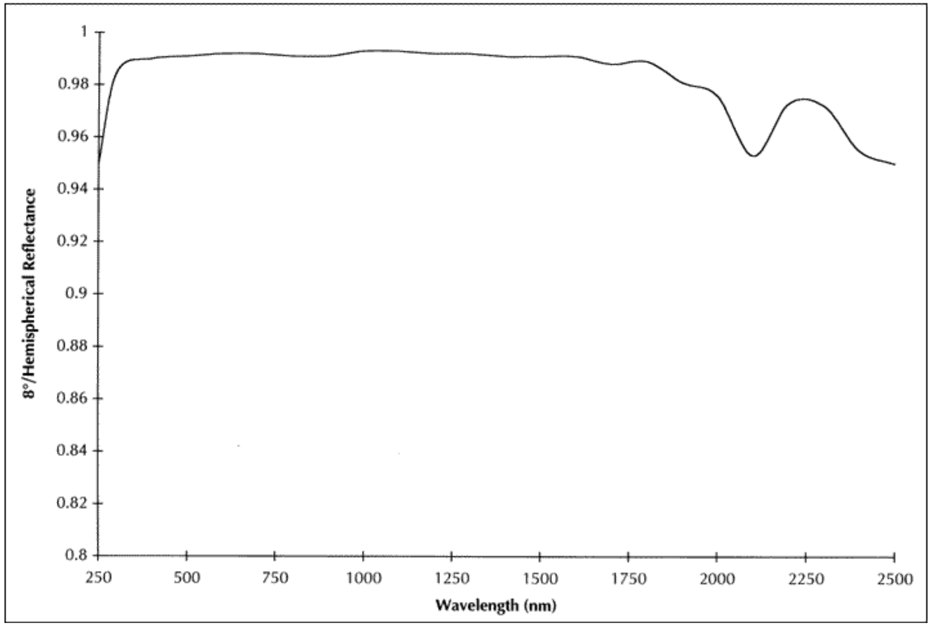
- **White reference $\rho_{referenz}$:**
  - Desired material properties:
    - 100% reflection for all wavelengths
    - Lambert`ian (diffuse) reflection
    - Highly opaque
    - No fluorescent excitation for wavelengths longer than 300 nm
    - Spatially uniform, cleanable, durable, and stable

- **Used: Spectralon™**
  - Barium sulphate $BaSO_4$: cheap, but ρ not constant over longer time intervals (hygroskopic material)
  - Polytetrafluoroethylene PTFE (Spektralon, Halon): best reflection standard, durable but expensive

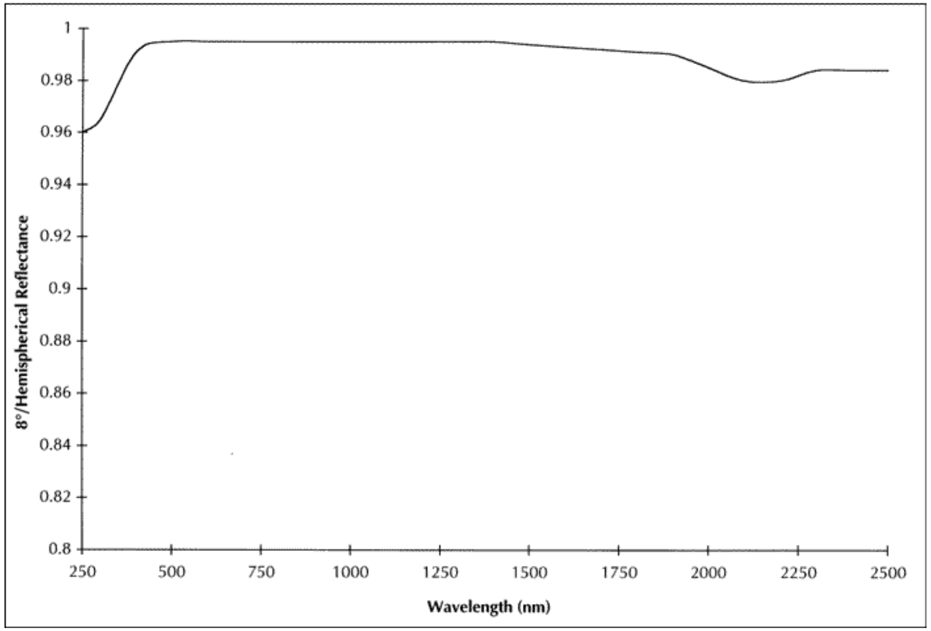
White Reference

- The fraction of solar energy that is reflected back into the atmosphere is called "albedo."
- The albedo of a perfectly white object is 1; the albedo of a perfectly black object is 0.

TYPICAL 8 ° /HEMISPHERICAL REFLECTANCE- OPTICAL GRADE SPECTRALON



TYPICAL 8 ° /HEMISPHERICAL REFLECTANCE- SPACE-GRADE SPECTRALON

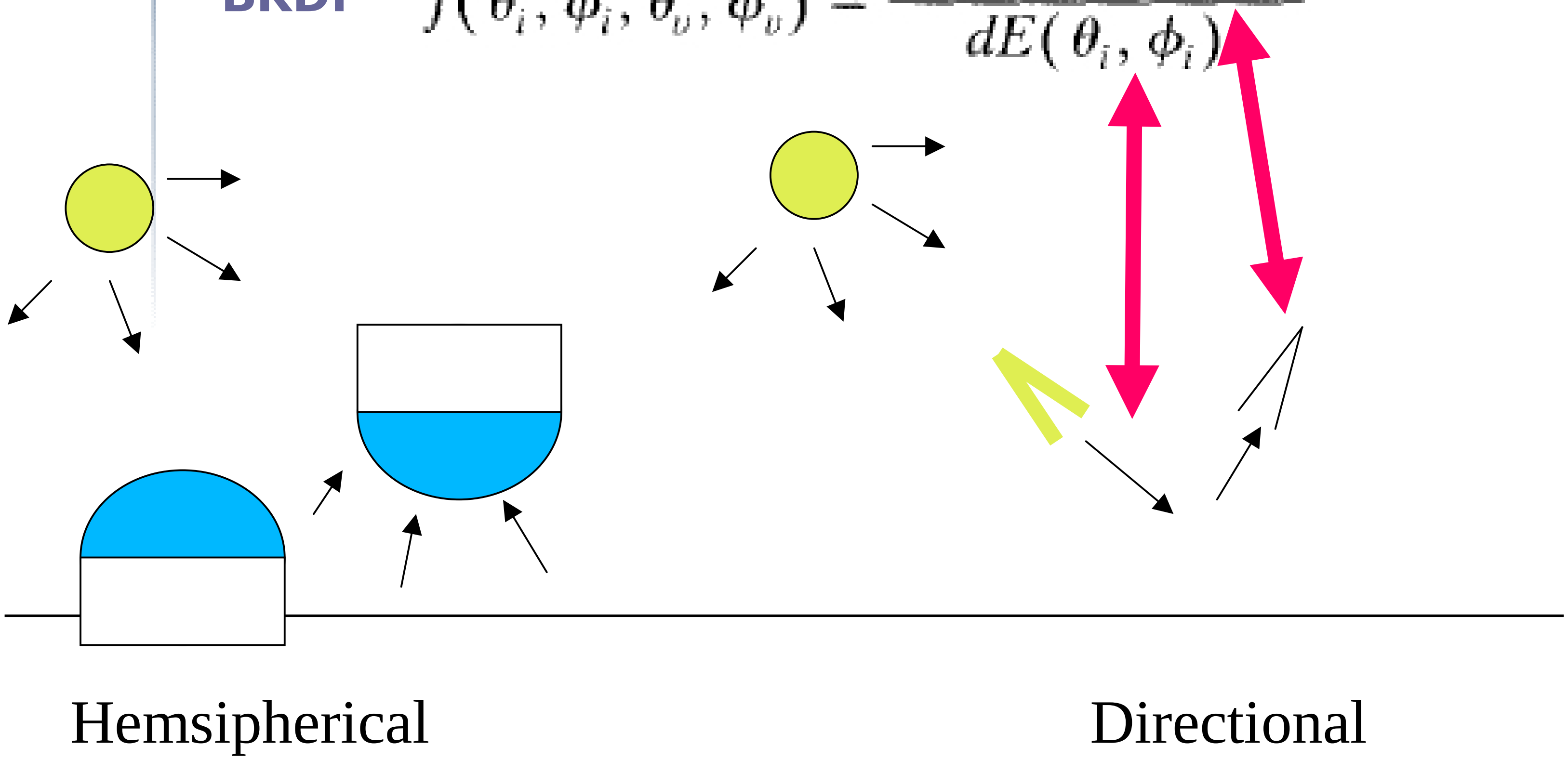


http://www.labsphere.com/

Bidirectional Reflectance Distribution Function (BRDF)

- reflectance depends on both the solar incoming direction and the sensor viewing direction

BRDF $$f(\theta_i, \phi_i, \theta_v, \phi_v) = \frac{dL(\theta_i, \phi_i\, \theta_v, \phi_v)}{dE(\theta_i, \phi_i)}$$



Reflection behaviour of surfaces

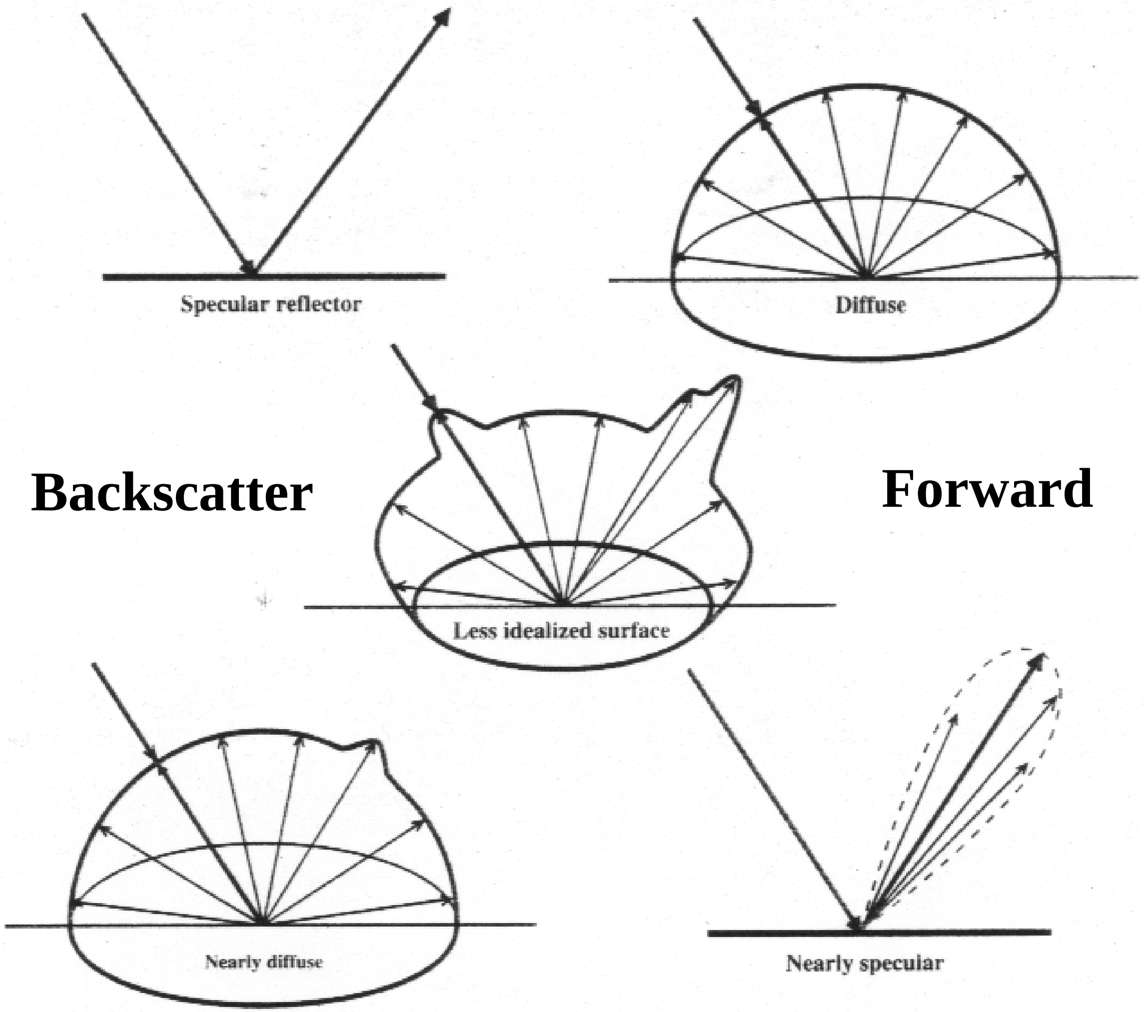
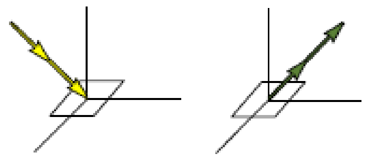
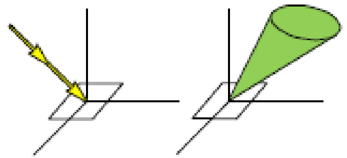
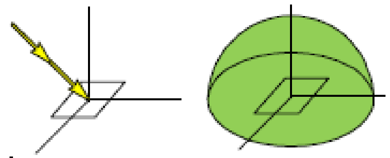
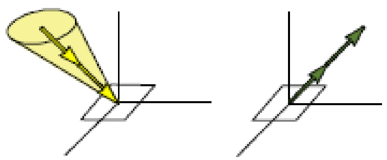
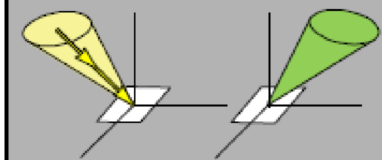
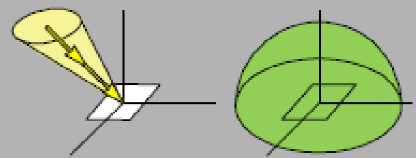
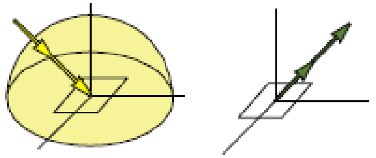
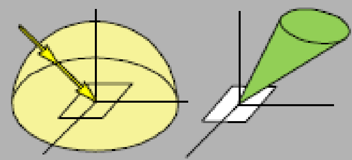
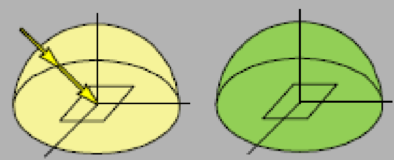


Figure 4.7 Reflectance characteristics of idealized surfaces.

Nomenclature of Nicodemus et al. (1977)

Nicodemus, F. E., et al. (1977). Geometrical considerations and nomenclature for reflectance. Washington, DC: National Bureau of Standards

Incoming/**Reflected**	**Directional**	**Conical**	**Hemispherical**
Directional	Bidirectional Case 1 	Directional-conical Case 2 	Directional-hemispherical Case 3 
Conical	Conical-directional Case 4 	Biconical Case 5 	Conical-hemispherical Case 6 
Hemispherical	Hemispherical-directional Case 7 	Hemispherical-conical Case 8 	Bihemispherical Case 9 

Schaepman-Strub, G., Schaepman, M.E., Painter, T.H., Dangel, S., & Martonchik, J.V. (2006). Reflectance quantities in optical remote sensing—definitions and case studies. *Remote Sensing of Environment, 103*, 27-42

Shade due to surface roughness

HotSpot-effect:

- If view direction = illumination direction => no shade visible
  - => brighter & specular => no Lambertian

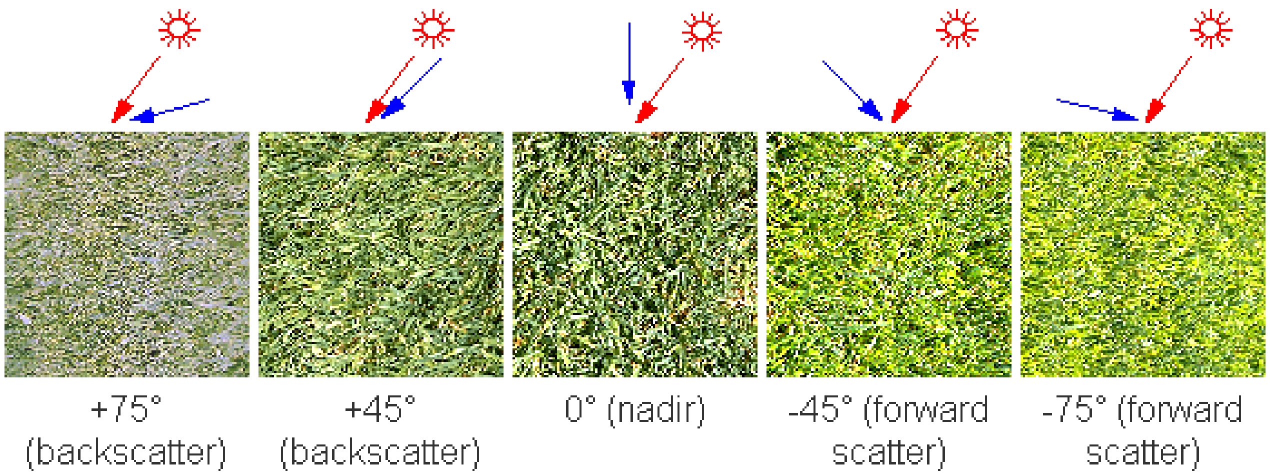
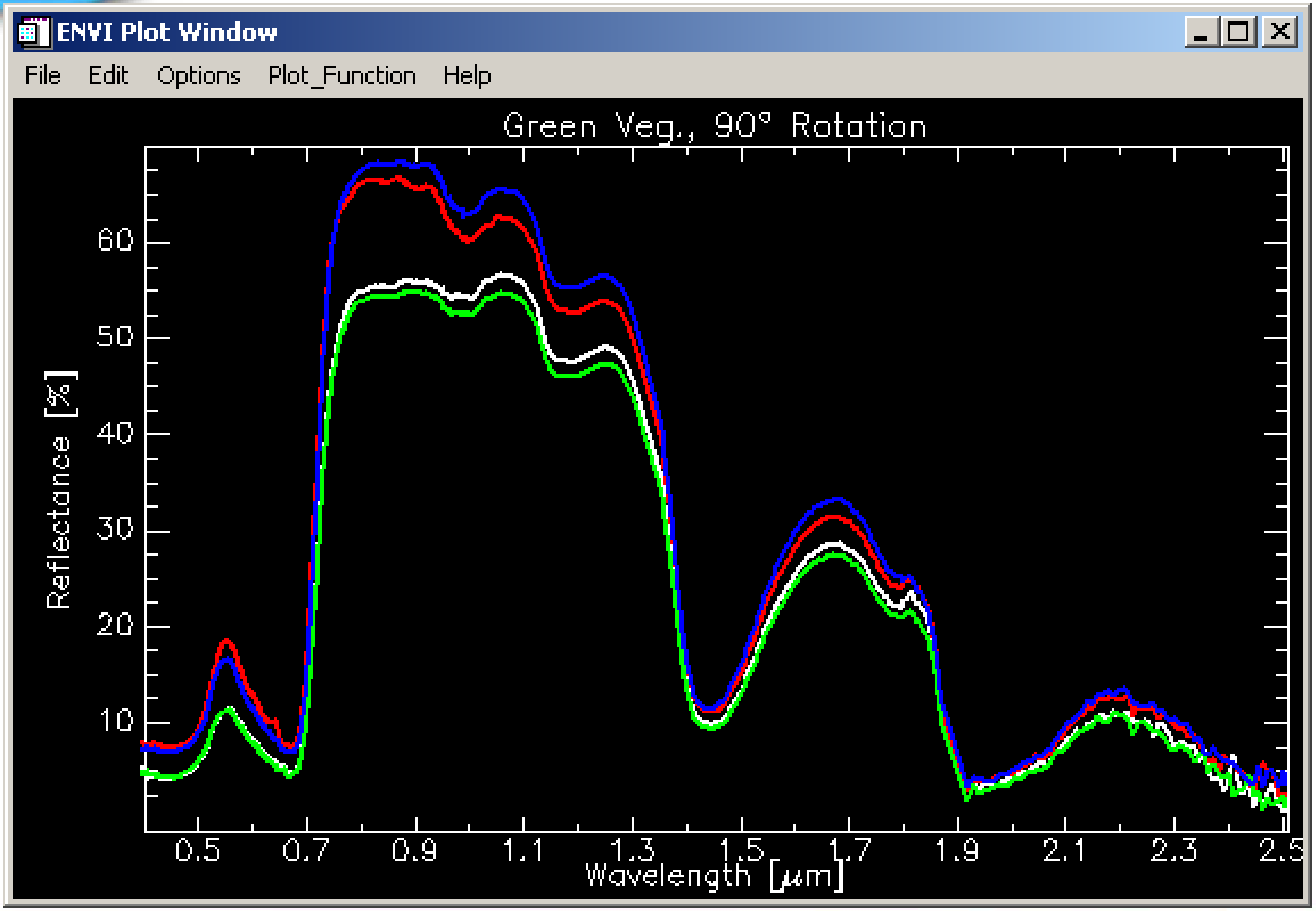


Fig. 2: Bidirectional reflectance effect on a grass lawn, observed under different viewing angles from a FIGOS mounted camera in the solar principal plane. Solar zenith angle is 35°, indicated with red arrows. The view directions are given in blue. The camera is operated in the manual modus keeping aperture, exposure time and focal length constant (k=16, t=1/15, f=135mm).

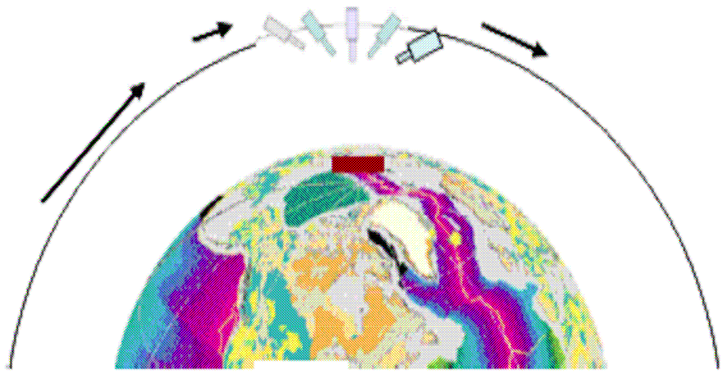
BRDF a ‚concept' in Practice

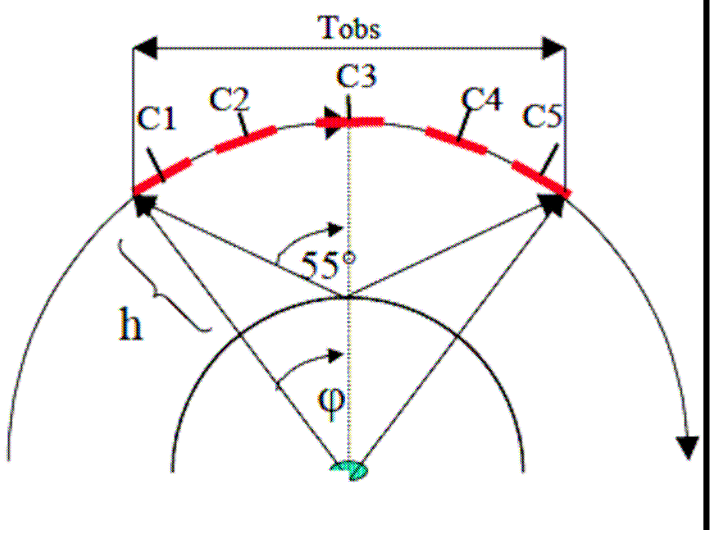


Multi-angular Satellites !

CHRIS PROBA (ESA)

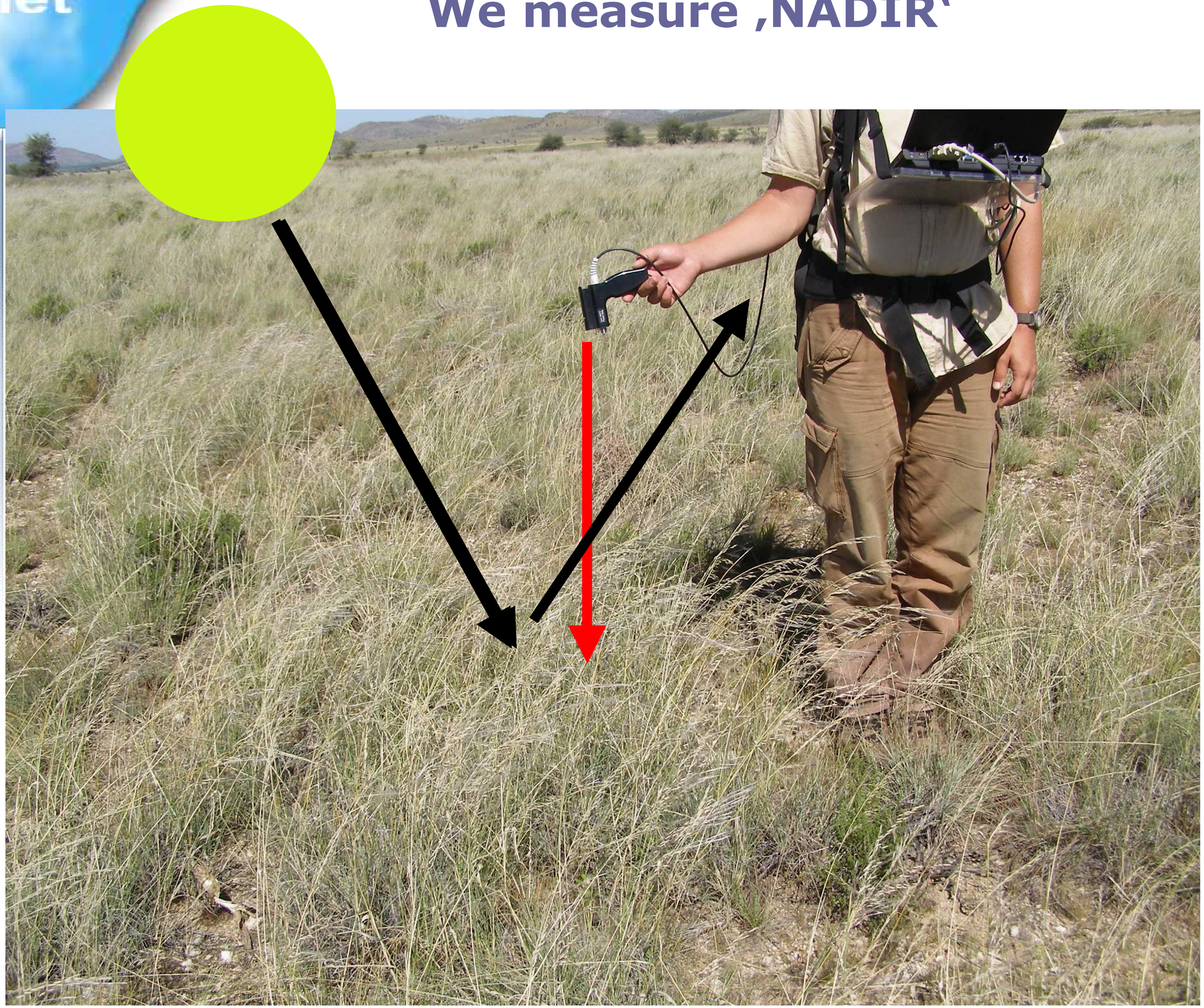
- can estimate BRDF !





Sugianto et al. 2003

We measure ‚NADIR‘



Sampling Design

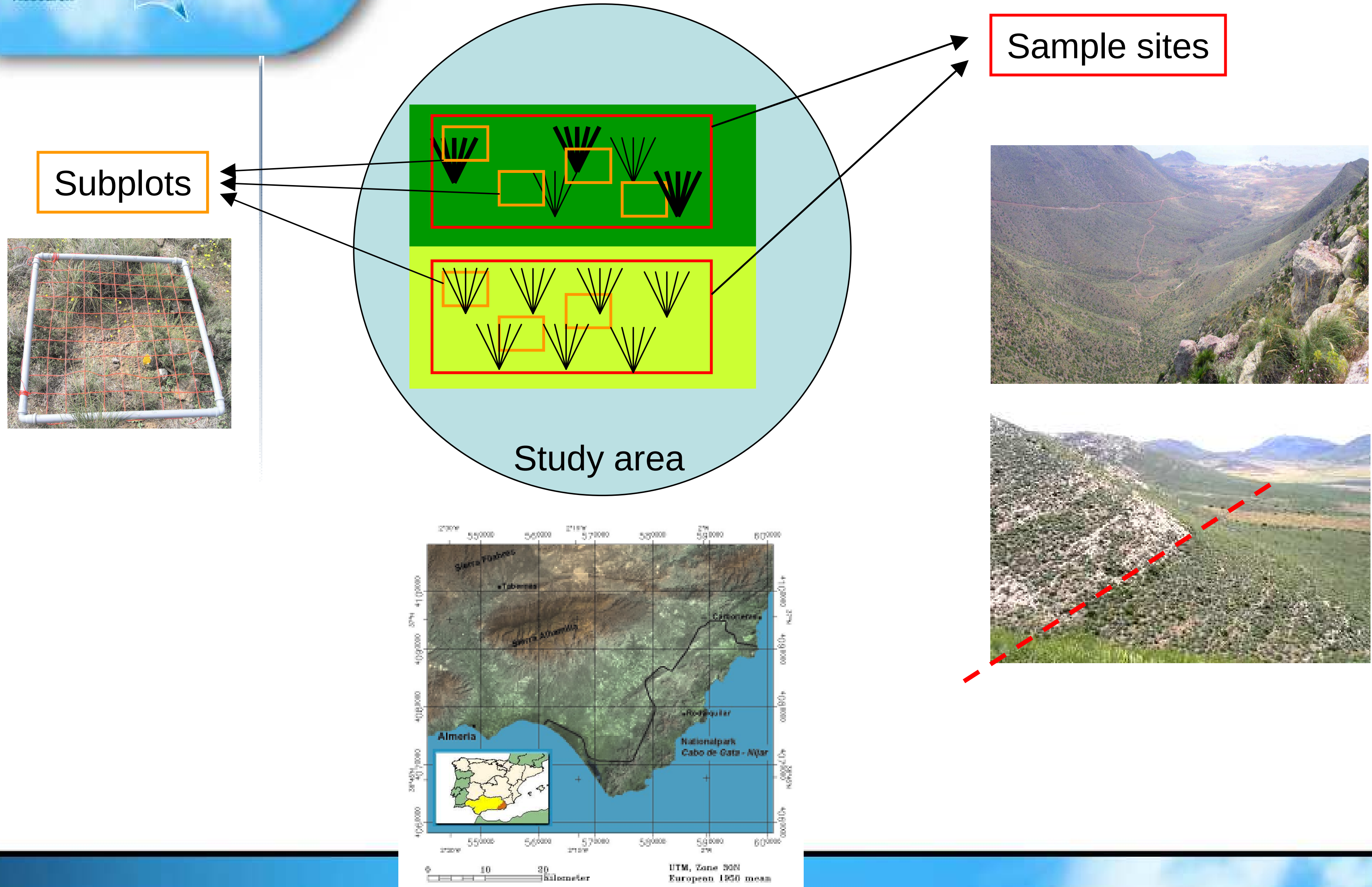
Overall purpose of the fieldwork

- A.) Vegetation/ landuse mapping
  - **Major landuse types / vegetation communities**
- B.) Plant stress detection
  - **Control sites**
- C.) Detection or mapping of specific interest, e.g. contaminants, water quality
  - **Control sites**
- D.) Change detection
  - **Seasonal effects**
- E.) Imagery analysis and groundtruthing
  - **Timeliness of data collection**
- F.) Georeferencing of satellite or airborne imagery
  - **High precision of Reference Points (dGPS!)**

Sampling Design

- the spatial distribution of sample sites within a study area
- the number of sample sites required within a study area
- the required size of the individual sample site
- the number of subplots required within one sample site
- the size of subplots within one sample site

Terminology



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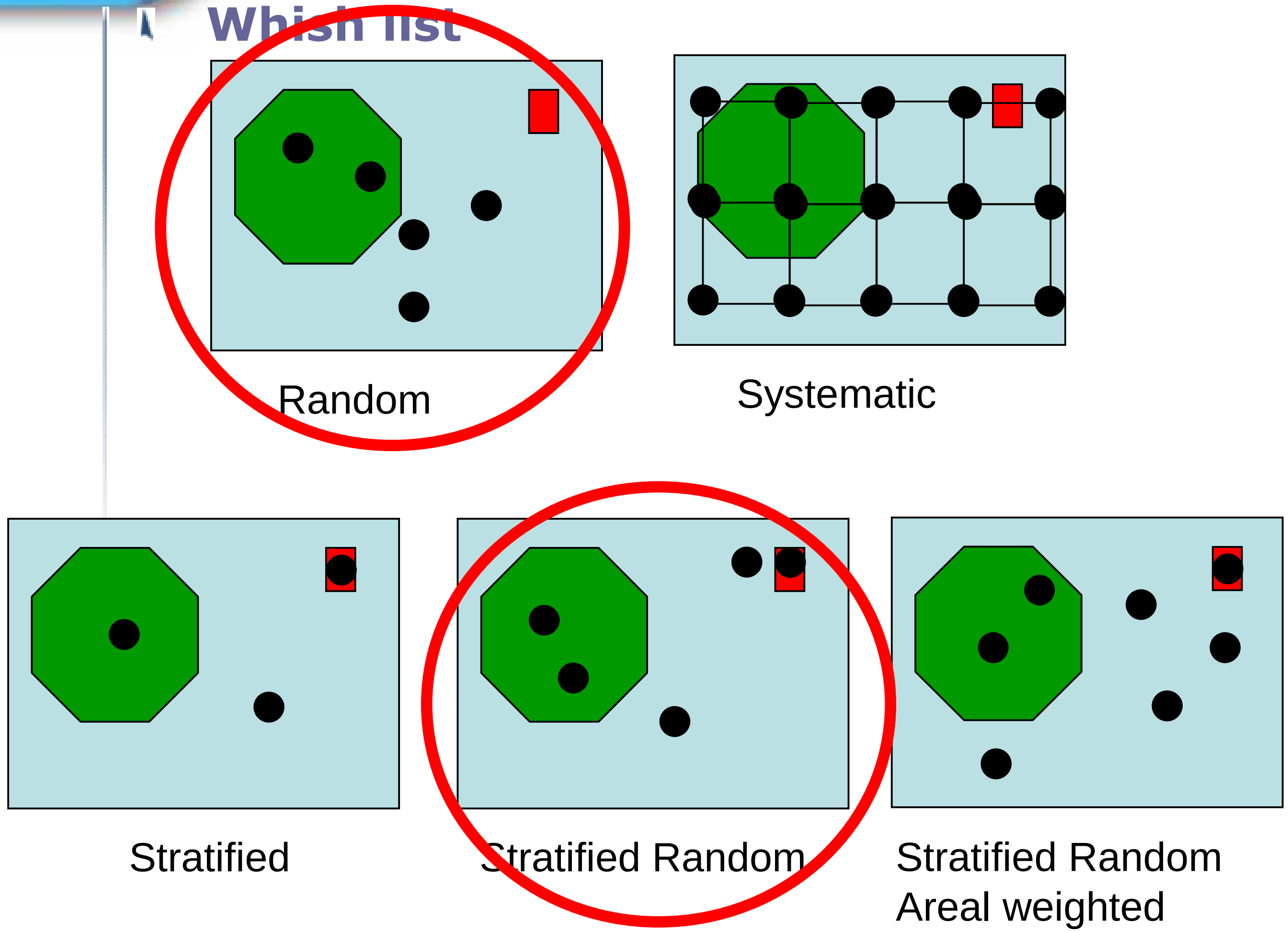
Sampling strategies

Whish list



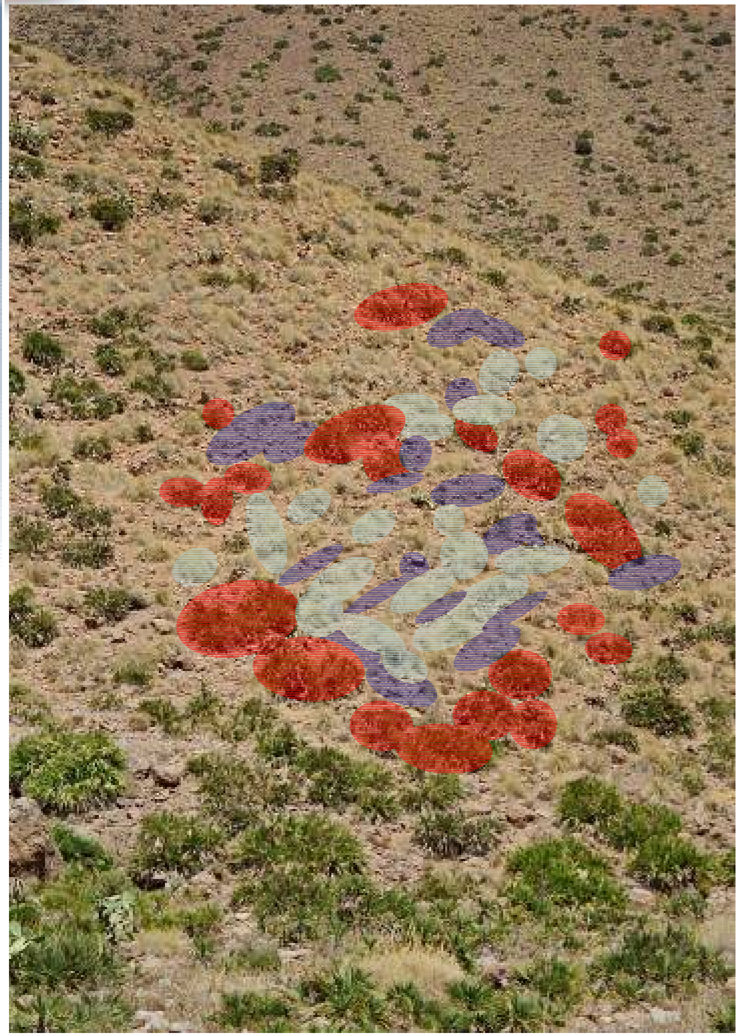
WITH FIXED NUMBER OF SITES PER CATEGORY

Philosophy

- **narrow-deep sampling**
  - collect many readings in a single location
- **broad-shallow sampling**
  - collect few samples at many locations

Zomer, R., & Susan, L.U. (2010). Ground-Truth Data Collection Protocol for Hyperspectral Remote Sensing. In (p. 28). Davis: University of California

Ground Cover Percentage – *Cabo de Gata*



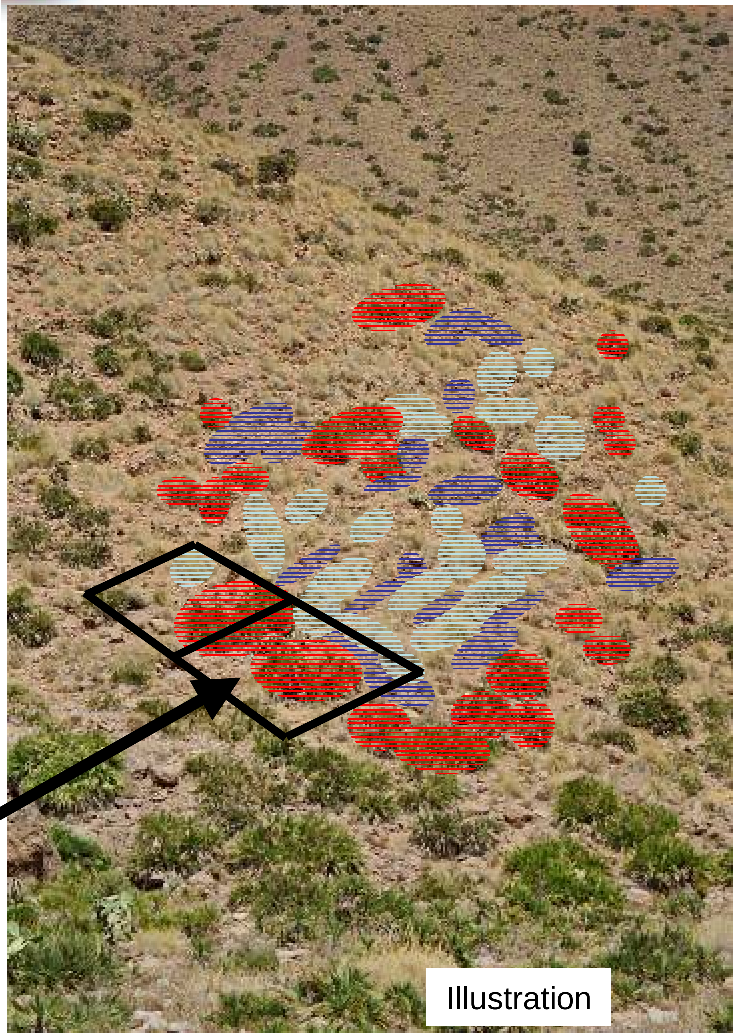
Spatial distribution of:

Vital vegetation
e.g. Opuntia ficus-indica,
Chamaerops humilis

Dry / dead vegetation
e.g. Stipa tenacissima,
S. capensis

Bare soil
e.g., Regosol,
Leptosol

Scale of spatial heterogenity



Mixture!

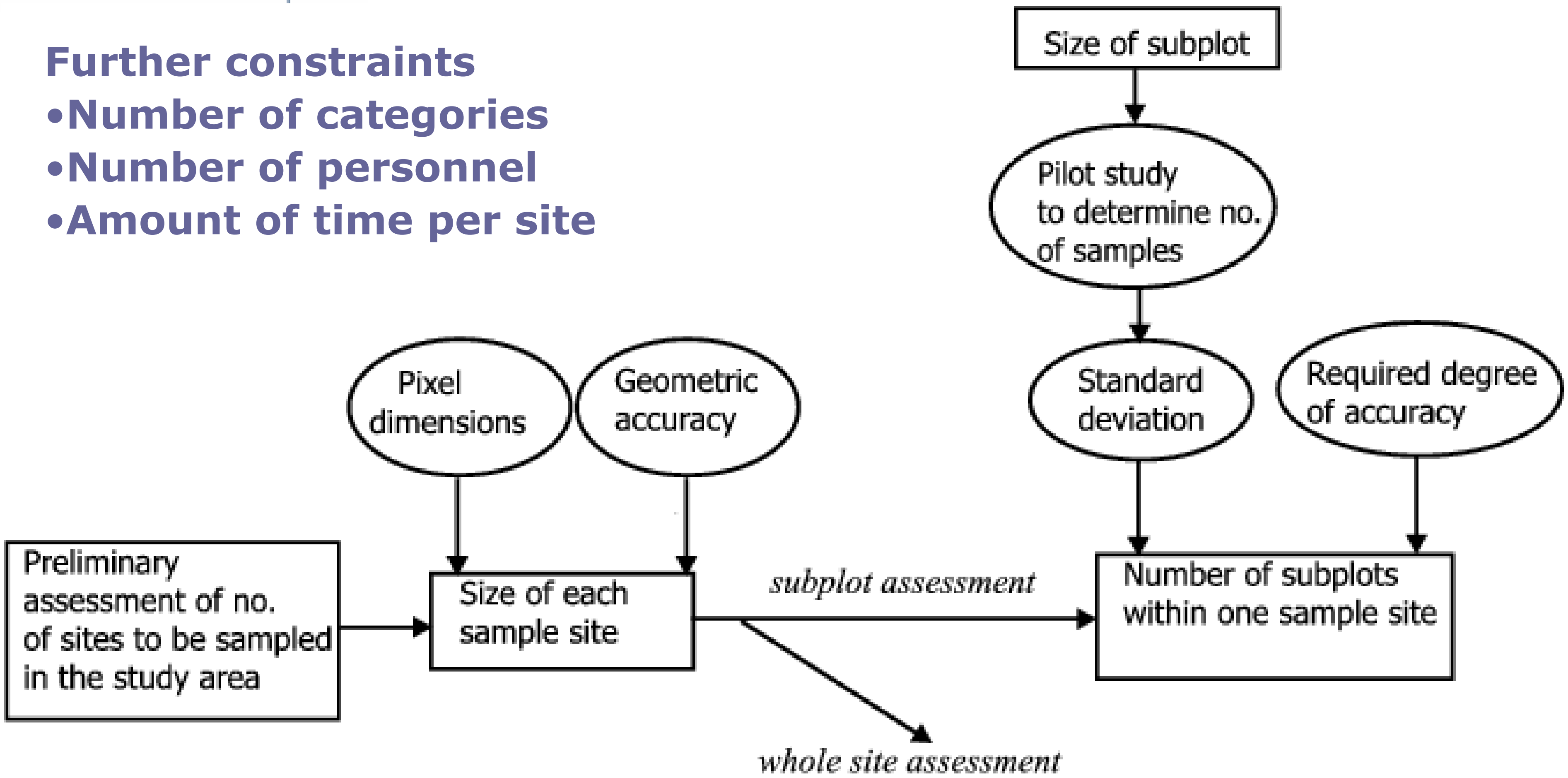
Spatial resolution (pixel size) of HyMap data:
5m x 5m

Natural size of vegetation & soil patches
<< 2 m^2

How many sites and subplots?

Further constraints

- **Number of categories**
- **Number of personnel**
- **Amount of time per site**



Brogaard & Ólafsdóttir 1997

Determining Size of Sampling Site

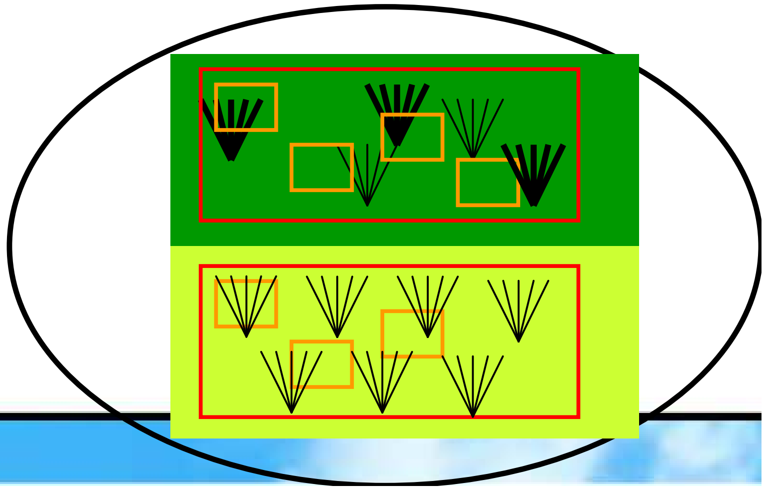
- **Sampling of heterogeneous parameters**

- **Min. sampling area A = (GSD (1+ 2*$\Delta_{x,y}$))^2**
  - $\Delta_{x,y}$:accuracy of georeferenzation
  - GSD: Ground Sampling Distance

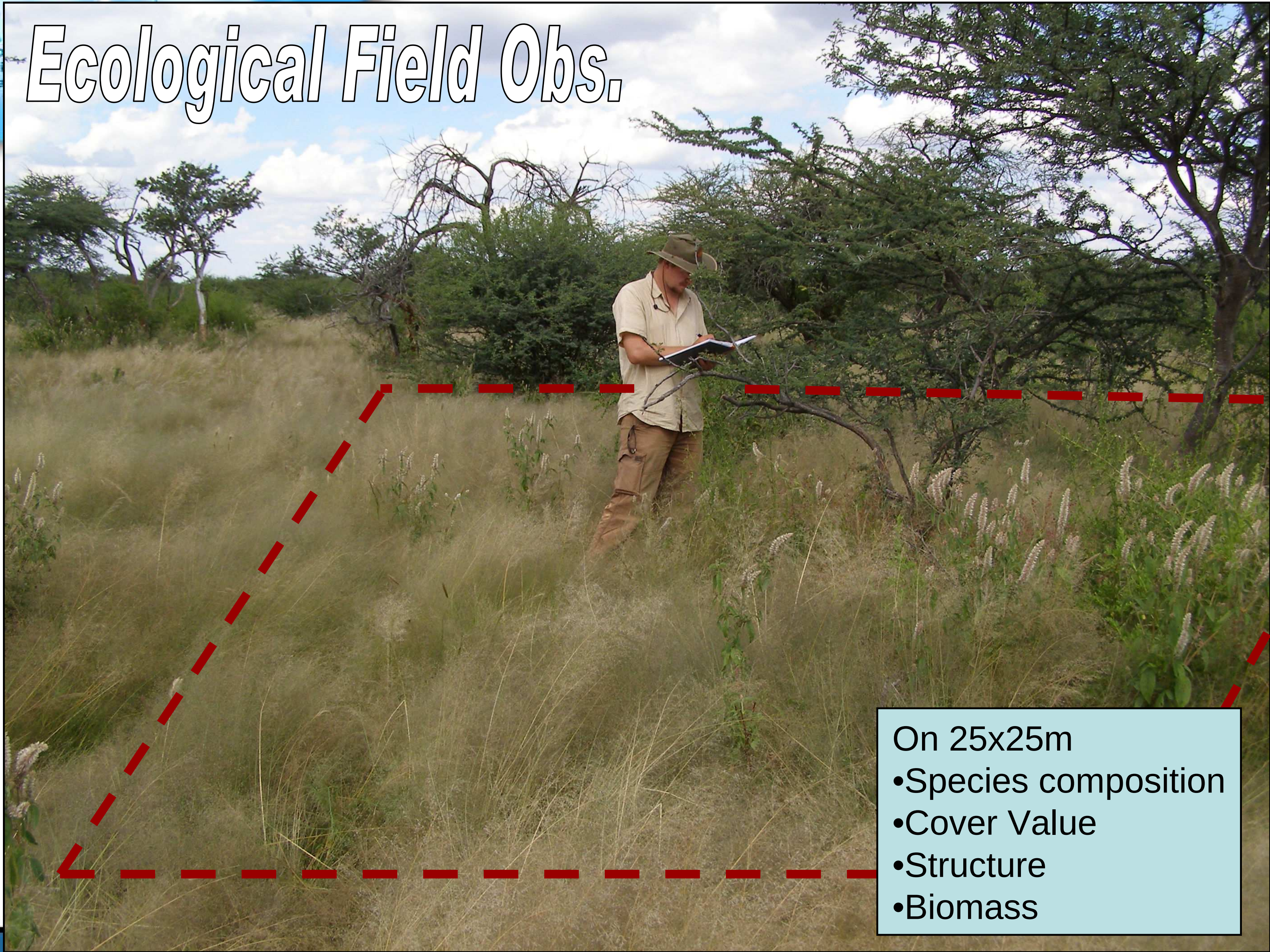
- **GSD = 30m, $\Delta_{x,y}$ = 2 pix.** **A= 150*150m**
- **GSD = 30m, $\Delta_{x,y}$ = 0.5 pix.** **A = 60 * 60 m**
- **GSD = 10m, $\Delta_{x,y}$ = 2 pix.** **A = 50 * 50 m**
- **GSD = 10m, $\Delta_{x,y}$ = 0.5 pix.** **A = 20 * 20 m**

Brogaard & Ólafsdóttir 1997

Study area



Ecological Field Obs.

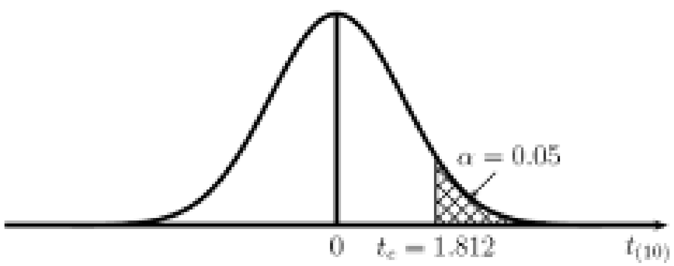


On 25x25m
- Species composition
- Cover Value
- Structure
- Biomass

Number of subplots

- **Min. number of subplots N = (σ t / a)2**
  - σ: standard deviation of sampled parameter
  - t: Student's t-value
  - a: required accuracy of sampled parameter

- **Ground cover sampling with accuracy a: ± 10%**
- **t-value = 2.3 (90% confidence)**
  - σ = 0.07 N = 2
  - σ = 0.09 N = 5
  - σ = 0.19 N = 19



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Example of spatial heterogenity

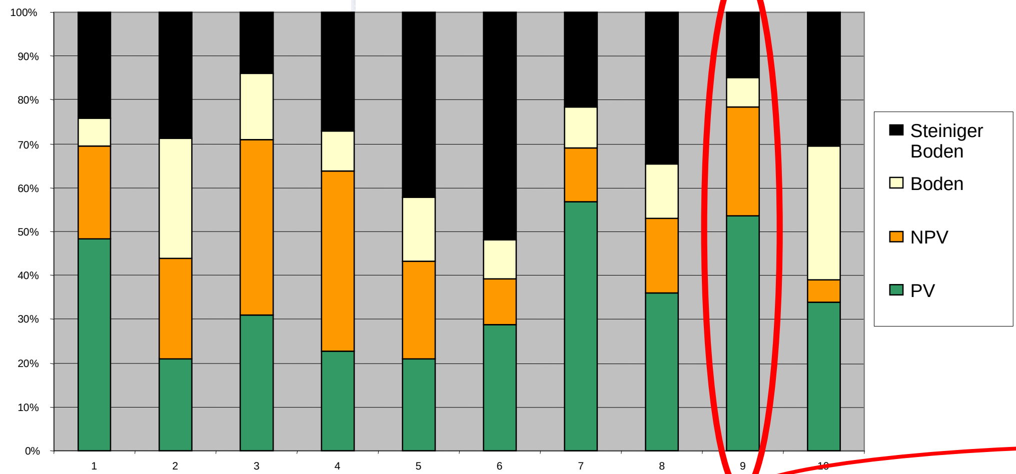
Field measurements for 10 representative sample sites at Cabo de Gata (long-term meaurement installations by Uni Almeria)

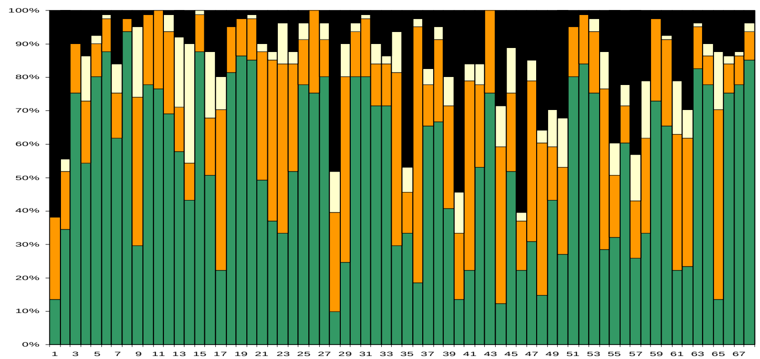
- Various vegetation communities, soils, degradation status

Field measurements 2004

Average ground cover, measured with 1m² frame.

Accuracy: ±10% abundance absolut (literature)





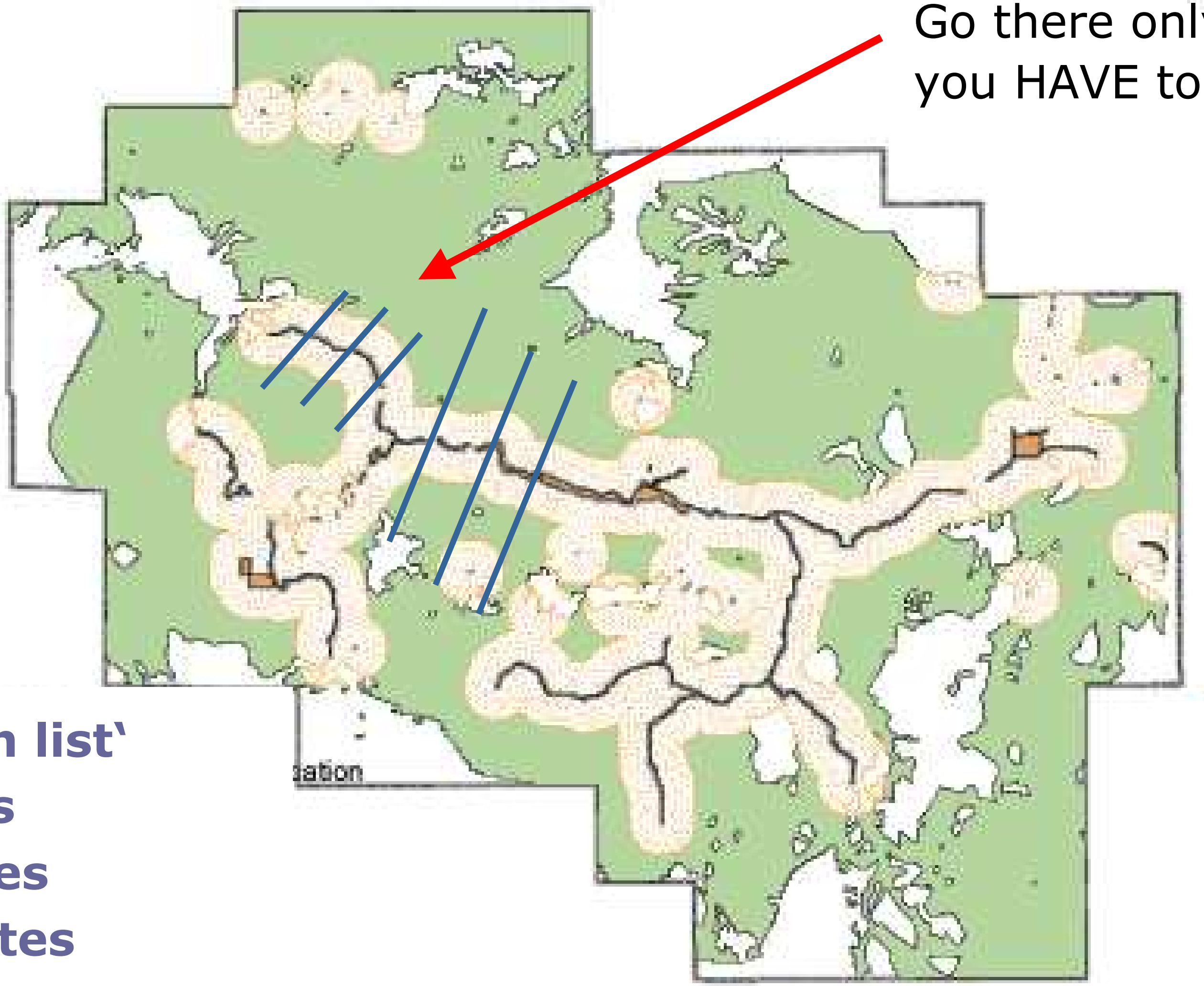
10 sites

each with 20 - 70 subplots

Think of: Accessibility of sites?

Think about:
- Personnell?
- Travelling?
- Time ?

Environmental Gradients?



Go there only if you HAVE to!

http://gis.co.crook.or.us/Portals/3/buffer.gif

Prepare a ‚Whish list'
- Essential sites
- Important sites
- Interesting sites

WHAT to Ground-Truth ?

Recommended Targets

1. Atmospheric Conditions
2. Dark and Light Calibration Targets
3. Surface Water (Where Present)
4. Vegetation
5. Soil, Bare Ground, Rock Outcrop

Atmospheric Conditions

- Temperature
- Humidity
- Haze or aerosols
- Wind Direction & Speed
- Incident Solar Radiation

- → **Atmospheric Correction!**

  - Weather station?
  - Field spectra!!

Atmospheric Correction

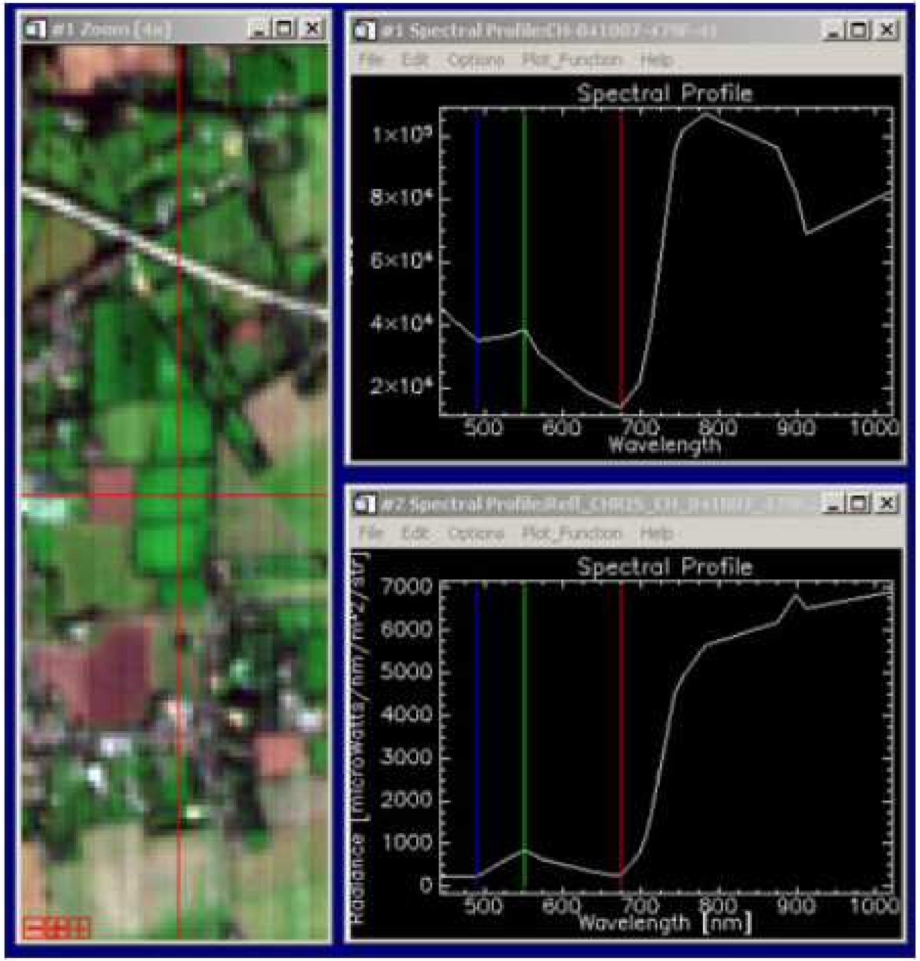
CHRIS PROBA
Image NADIR
Chichester harbor
2004

Original

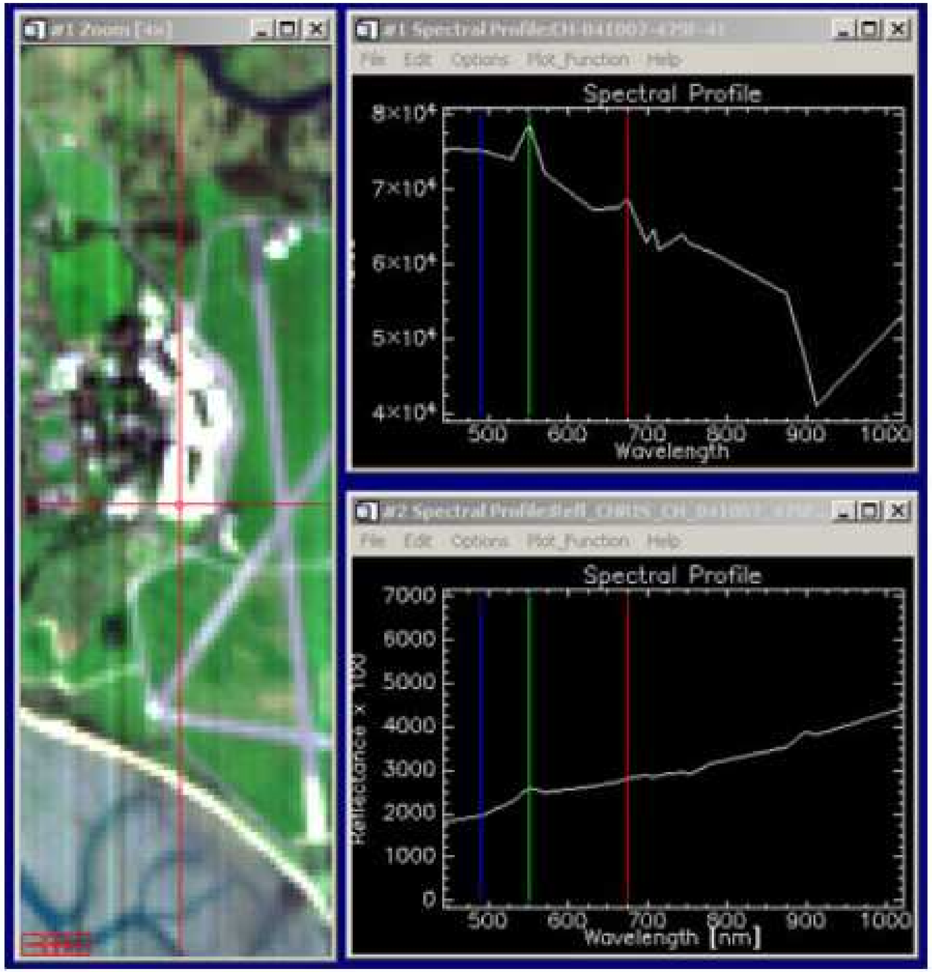
Corrected

•http://www.ncaveo.ac.uk/special_topics/atmospheric_correction/example2/

Effects of Atmospheric Correction



Vegetation



Concrete

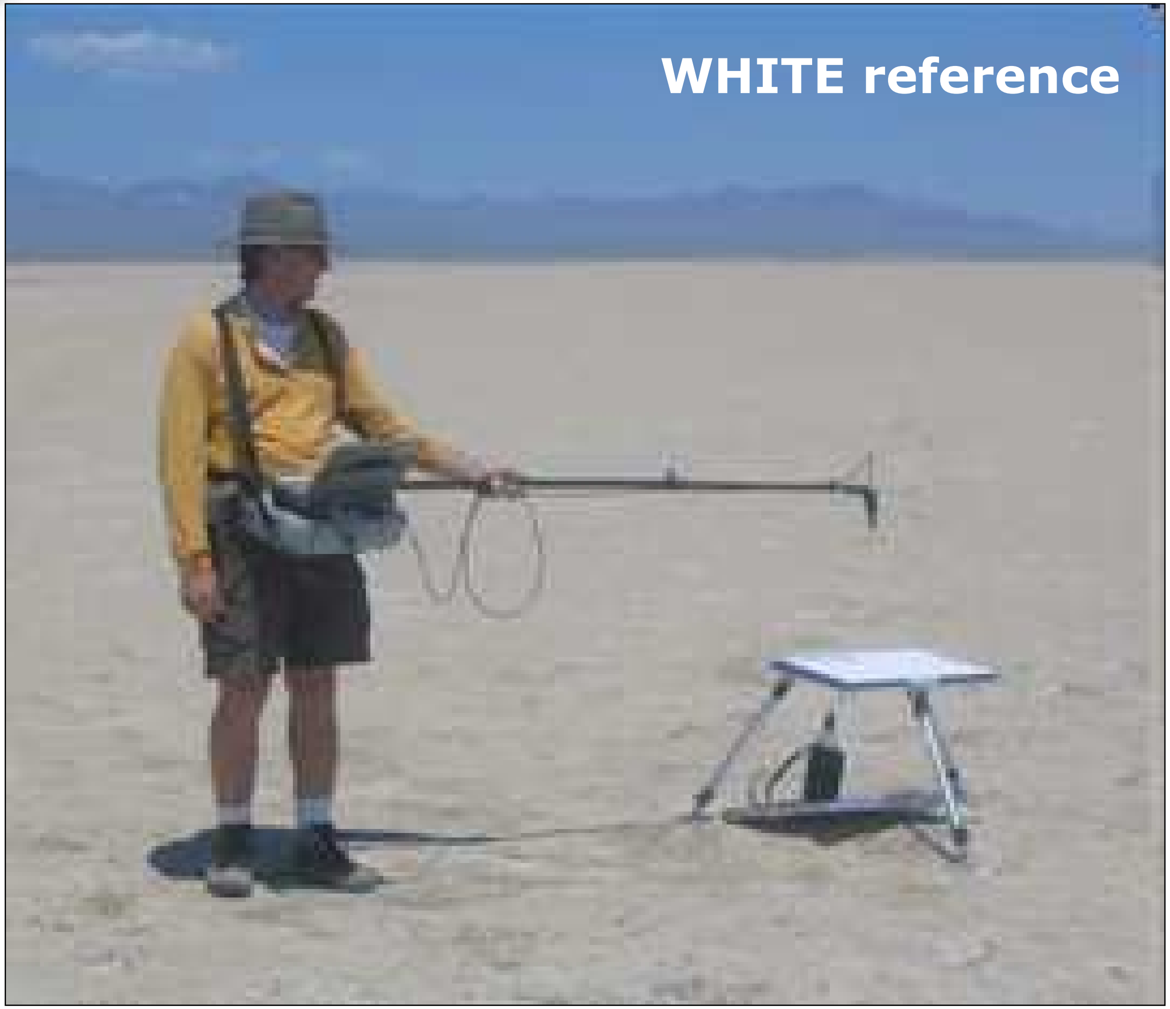
Calibration Targets

- Homogenous NOT heterogenous
- Flat NOT rough
- Target should exceed the size of sensor resolution (optimal target size 9x9 - 25x25)
- Serve as reference objects

•DARK calibration targets

•WHITE calibration targets

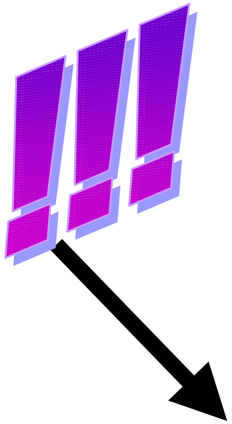
Not to Forget...



Surface Water

- Georeference Point (GPS)
- Incident Solar Radiation
- Water Turbidity,
- Secchi Depth
- Spectroradiometer Readings (Spectral Signature of Calibration Target and Water Surface at ~2 m)
- Chlorophyll Content
- Spectral Signatures Within Water Column at Various Depths
- Spectral Signature of Sample Water Compared to Distilled Water Reference (Bench Test)
- VOC, SVOC, Metal, Other Dissolved Chemical Analyses (Based on Project DQOs)
- General Notes About the Location and Light Conditions

THIS LIST ONLY IF WATER IS A CRUCIAL FACTOR!



Zomer, R., & Susan, L.U. (2010). Ground-Truth Data Collection Protocol for Hyperspectral Remote Sensing. In (p. 28). Davis: University of California

Vegetation

- as many of the classes of vegetation as possible
- above the canopy
- representative of reflectances detected by the airborne or satellite remote sensor

Record

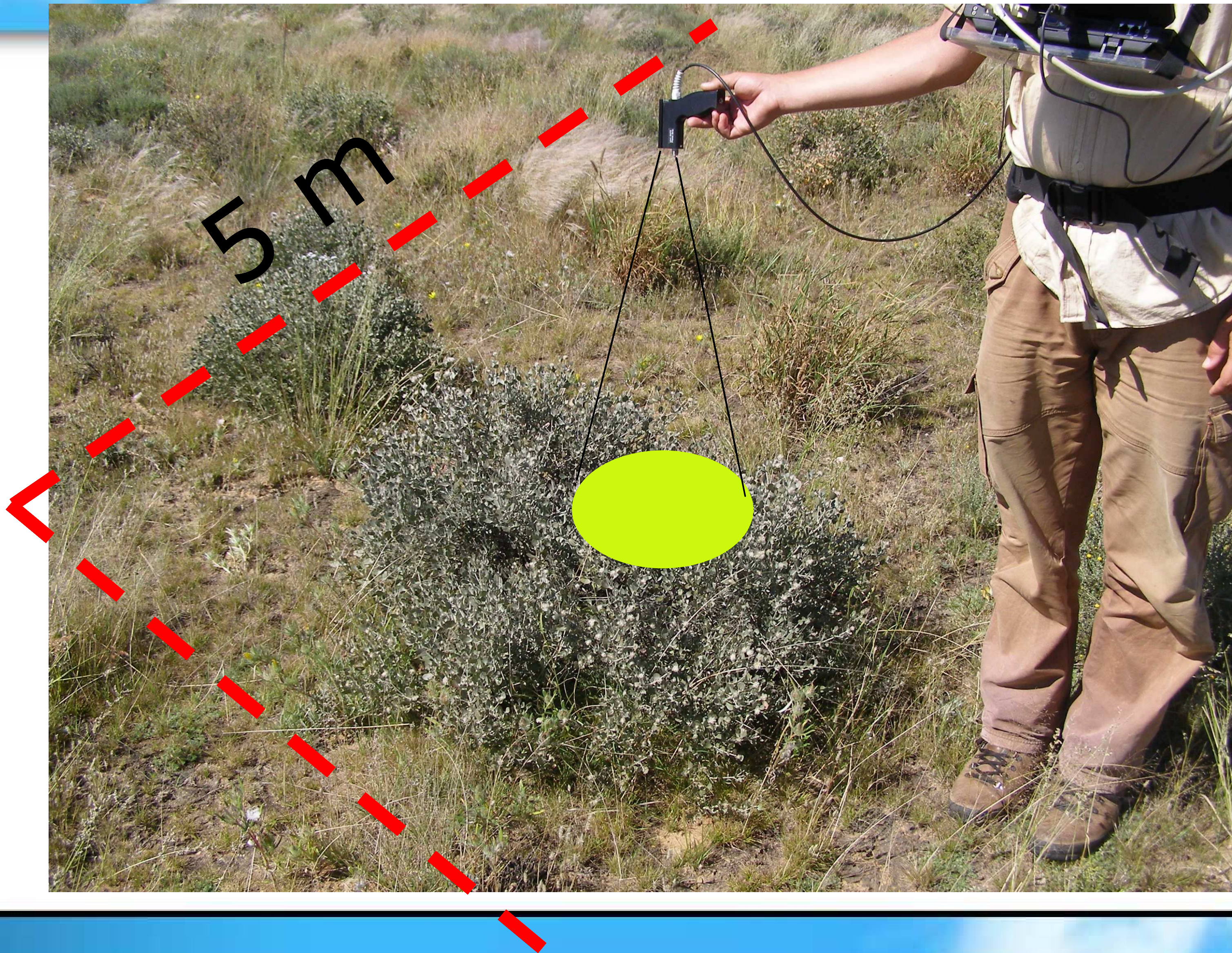
- GPS
- Spectroradiometer of Calibration Target and Vegetation
- Vegetation Sample (Leaf or Leaf Cluster) *
- General Field Notes Regarding Site and Light Conditions

***especially if quantitative measurements in lab have to follow !**

Complexity in Vegetation

•http://biology.unm.edu/Litvak/Juniper%20Savanna/Juniper%20Savanna.htm

Height & FOV



Soil, Bare Ground, Rock Outcrop

- **Similar requirements as for vegetation…**

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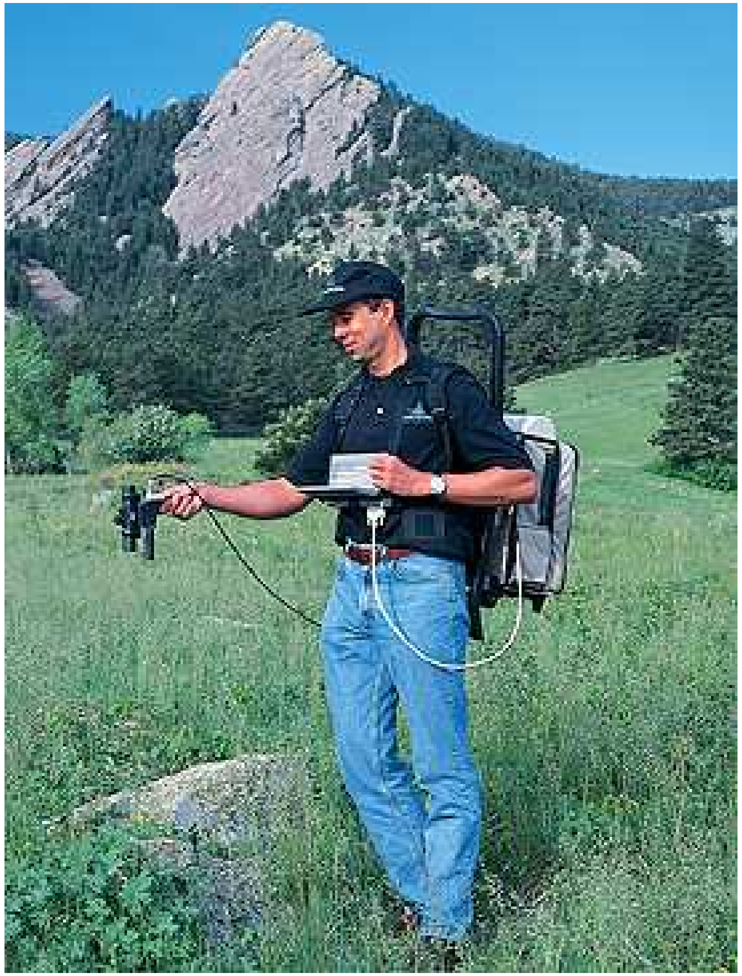
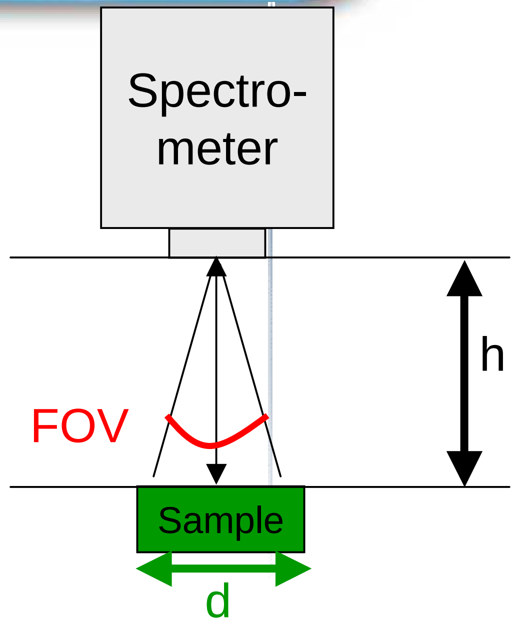
HOW to measure

Name	FieldSpec® Pro VNIR	FieldSpec® Pro JR	FieldSpec® Pro FR
Spectral Range	350-1050 nm	350-2500 nm	350-2500 nm
Spectral Resolution	350-1050 nm	3 nm @ 700 nm 30 nm @ 1400 & 2100nm	3 nm @ 700 nm 10 nm @ 1400 & 2100nm
Sampling Interval	1.4 nm @ 350-1050 nm	1.4 nm @ 350-1050 nm 2 nm @ 1000-2500 nm	1.4 nm @ 350-1050 nm 2 nm @ 1000-2500 nm
Scanning time	Integration times = 2^n x 17 ms for n = 0,1,..., 15	100 milliseconds	100 milliseconds
Detectors	One 512 element Si photodiode array 350-1000 nm	One 512 element Si photodiode array 350-1000 nm Two separate, TE cooled, graded index InGaAs photodiodes 1000-2500 nm	One 512 element Si photodiode array 350-1000 nm Two separate, TE cooled, graded index InGaAs photodiodes 1000-2500 nm
Input	1.4 m fiber optic (25° field of view) Optional foreoptics available	1.4 m fiber optic (25° field of view) Optional foreoptics available	1.4 m fiber optic (25° field of view) Optional foreoptics available
Calibration	Wavelength, reflectance, radiance*, irradiance*. All calibrations are NIST traceable (*radiometric calibrations are optional)		
Noise Equivalent Radiance (NeDL)	UV/VNIR 3.7×10^{-10} W/cm^2/nm/sr @ 700nm	UV/VNIR 2.8×10^{-9} W/cm^2/nm/sr @ 700nm NIR 2.4×10^{-9} W/cm^2/nm/sr @ 1400nm NIR 8.8×10^{-9} W/cm^2/nm/sr @ 2100nm	UV/VNIR 1.4×10^{-9} W/cm^2/nm/sr @ 700nm NIR 2.4×10^{-9} W/cm^2/nm/sr @ 1400nm NIR 8.8×10^{-9} W/cm^2/nm/sr @ 2100nm
Notebook Computer	Pentium processor, 800 MB hard disk, 16 MB Ram, 3.5" floppy disk drive, battery, AC power supply		
Weight	5.7 kg or 12.55 lbs	7.2 kg or 15.8 lbs	7.2 kg or 15.8 lbs



http://www.asdi.com

Foreoptics & FOV

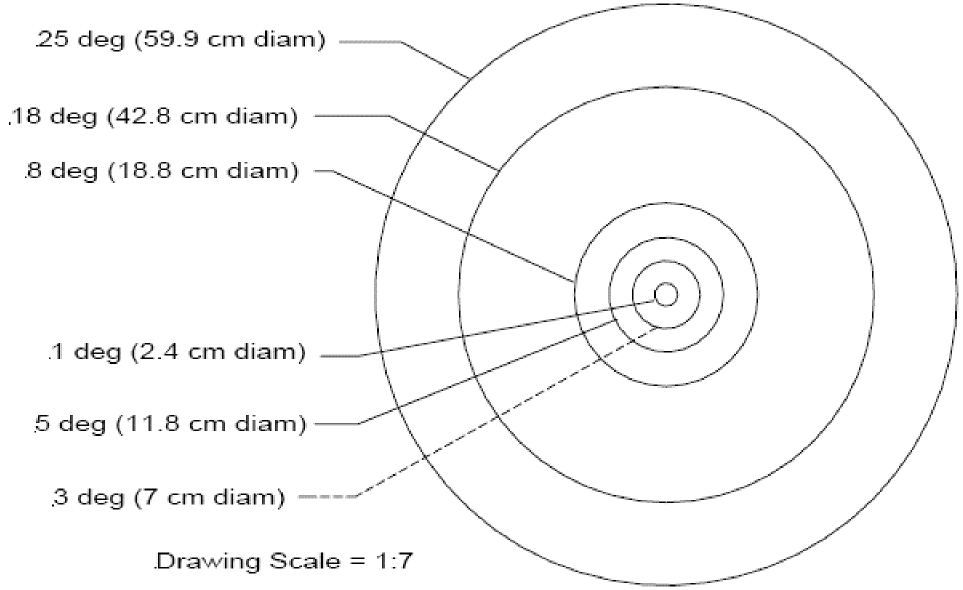


ASD, Bare Fiber, FOV = 25°

tan (FOV/2) = d/2 / h

d ~ 0.44 * h

h = 0.5m d = 0.22m
h = 1.0m d = 0.44m
h = 1.5m d = 0.67m



The figure above shows the available fields-of-view (FOV) for the FieldSpec® FR with an instrument fore optic height of 135 cm. The dashed circle represents the FOV of a non-ASD instrument with a fixed 3° FOV. The solid circles are for ASD's FieldSpec® FR. The largest circle is the FOV of the FieldSpec®'s standard built-in fiberoptic cable, with optional foreoptics providing 1°, 5°, 8°, or 18°. Fore optics covering approximately the same range of angular FOVs are available for the other FieldSpec® instruments.

Measuring Procedure

TRAVEL to SAMPLING SITES

1. **BEFORE → Get your gear ready:**
   - Batteries reloaded?
   - Spectralon clean?
   - Spare batteries for laptop & ASD?
   - All safely packed?
2. **Power on / warm up of ASD**
   - Min. 15 min before 1st measurement
3. First **connect running** ASD **to laptop,** then **power on** laptop
4. **Check software settings**
   - White Reference mode?
   - Correct directory & base name?
   - Set DC, WR & spectra averaging to (25-) **50**
   - Correct foreoptics selected?

Measuring Procedure cont`

5. Optimization
   - Whenever changes in illumination / instrument temperature
6. **Dark Current (DC)**
   - Automatically retrieved during WR & Optimization
7. White Reference (WR)
   - Wait for stable signal (2x screen refresh) before WR
   - At least every 10 minutes / 25 measurements
8. Measurement
   - Wait for stable signal (1x screen refresh)
   - (Approx.) same geometric setup as WR measurement
   - Number in display "plant.**008**" => the **next** measurement to be saved!
9. Quality Control
   - When pointing at spectralon, are there steps, or deviations from 100% line ?

10."Lifetime": ~2-4 h for one ASD-battery

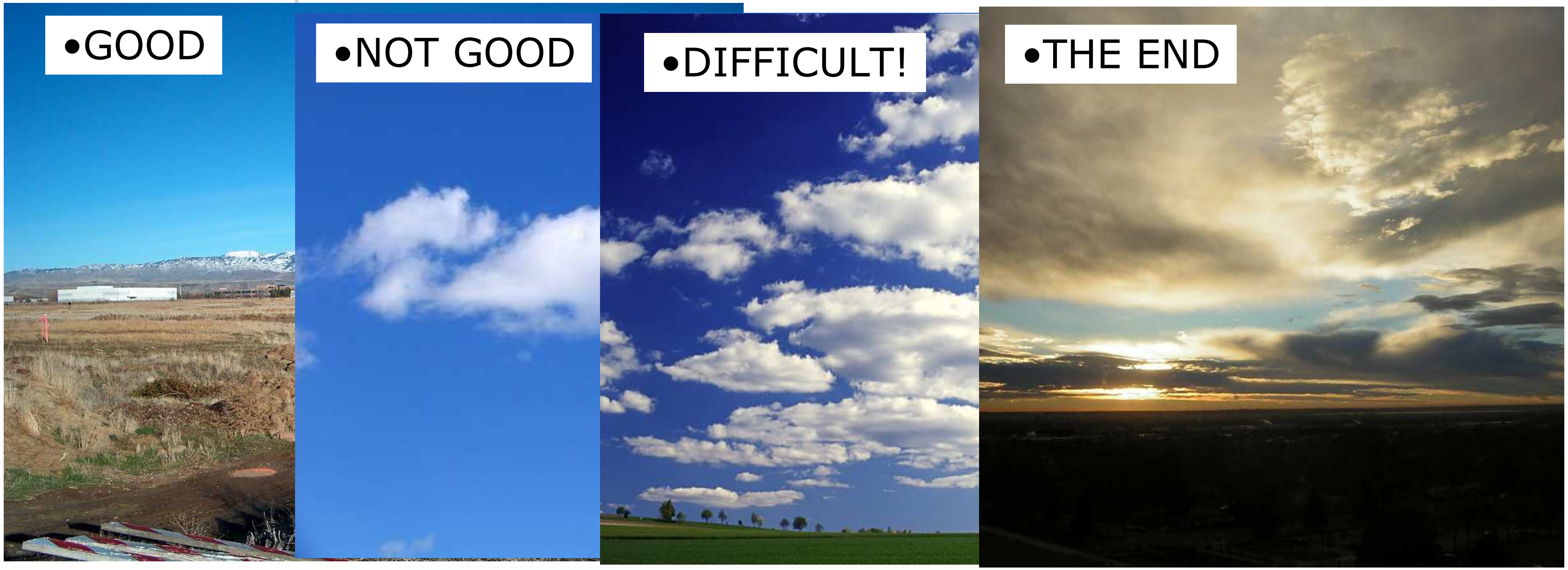
When to measure ?

Solar Noon +- 2 hours ! = 4 hours

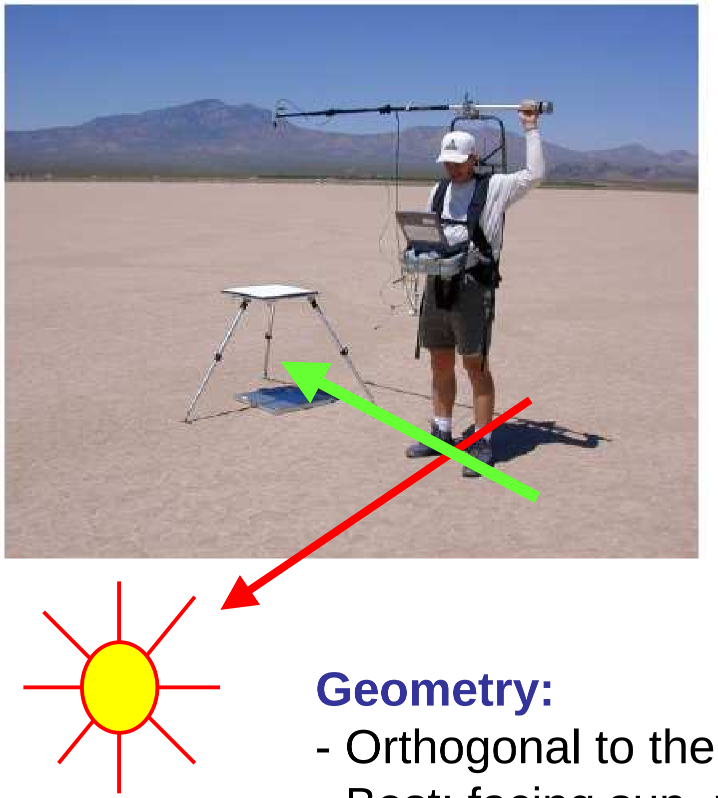
http://www.esrl.noaa.gov/gmd/grad/solcalc/

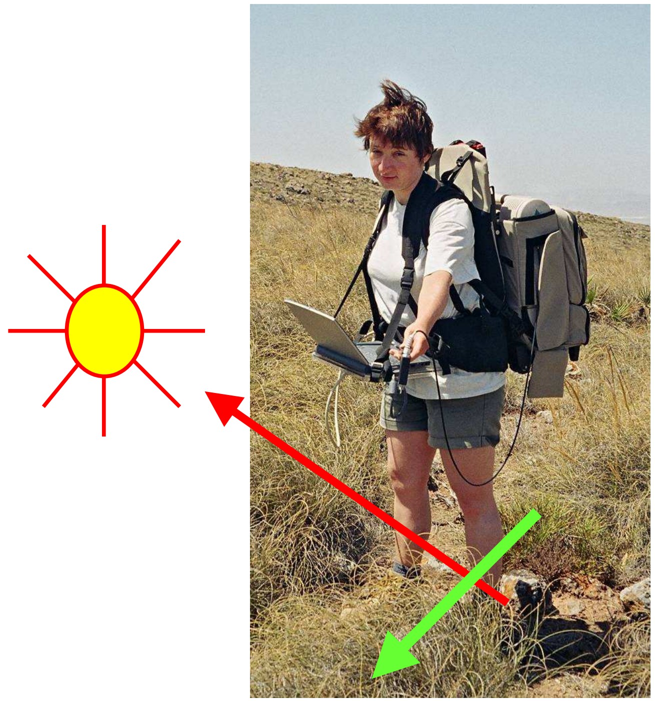
Solar noon in Tihany currently @ 12:53 local time

Cloud conditions



Measuring position Human





Geometry:
- Orthogonal to the sun (no shade)
- Best: facing sun, measure in 90° sideward
- Distance to target ~ as to Spectralon during WhiteReference

Measuring position Instrument

„Extras“:

- Fiberoptics
(FOV: GER: 23°/ ASD: 25°)

- Forepotics for smaller FOV:
(GER: 3°, 6°/ ASD: 1°, 5°)

- Contact probes incl. illumination source
(=> geol. applic.)

- „Cherry Picker“
for canopy measurements

- Gomiometer for BRDF-measurements

SPARC Campaign www.esa.int
RSL Zürich www.geo.unizh.ch/rsl/

Metadata

Common Metadata include:

- Location & description of site (lat, lon, alt, land cover)
- Time of measurement
- Sky conditions, meteorological data (air temp., humidity, areosol optical thickness, water vapor, ...)
- Instrument parameters (instrument, serial-nr., last calibration)
- Measurement method (radiance / reflectance, averaging, ...)
- Sample description (e.g., degraded Stipa tenacissima, Soil Sample B-12)
- Measurement geometry at sample (off-nadir, height above sample, ...)
- But: may need adjustment to each application

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Spectral Measurements Form – Field version

Section A – GENERAL INFORMATION

Project name:		Country:		Region:		
Calibration use:	Yes ☐ No ☐	Observer(s):		Date:		Additional information:
Latitude:	° ´ ´´	Longitude:	° ´ ´´	Altitude	m	
Environment description:	(Middle-european, mediterranean, artic, desert, coastal,...)					
Weather description:						

Section B – EQUIPMENT USED

Spectrometer:	ASD-DFD ☐	ASD-IMF ☐	Other ☐	Specify:	White stand.:	Spectralon A ☐ Spectralon B ☐
Fore optic:	1° ☐ 3° ☐ 5° ☐ 8° ☐ 18° ☐	Other: °	Bare fiber - FOV: °			Additional information:
Light source:	Sun ☐	Reflectance probe ☐	Tripod ☐			

Section C – TARGET INFORMATION

Rock ☐		Soil ☐		Vegetation ☐		
Igneous ☐		Soil type:		Specie:		
Sedimentary ☐		Soil colour:		Dry ☐	Growing ☐	Flowering ☐
Metamorphic ☐		Humus content:				
		Moisture:				
Mineral ☐		Water ☐		Other ☐	Specify:	

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Section D – MEASUREMENTS

Type:	Radiance ☐	Reflectance ☐	DN ☐	Emissivity ☐	Additional information:
Averaging:	Optimisation ☐	White reference ☐	Spectra ☐		
Optimisation ☐	White reference ☐	Measurement height:			

ID	Name	Photo (tick or name)	Time	Additional	Check 100 %	WR
					☐	☐
					☐	☐
					☐	☐
					☐	☐
					☐	☐

Sort out...in the base

- Order large equipment BEFORE starting campaign
- Make an equipment list
- Prepare Maps with Sampling Layout
- Communication in case of accident?
- Safety Training ?
- Charge batteries!!
- File name convention

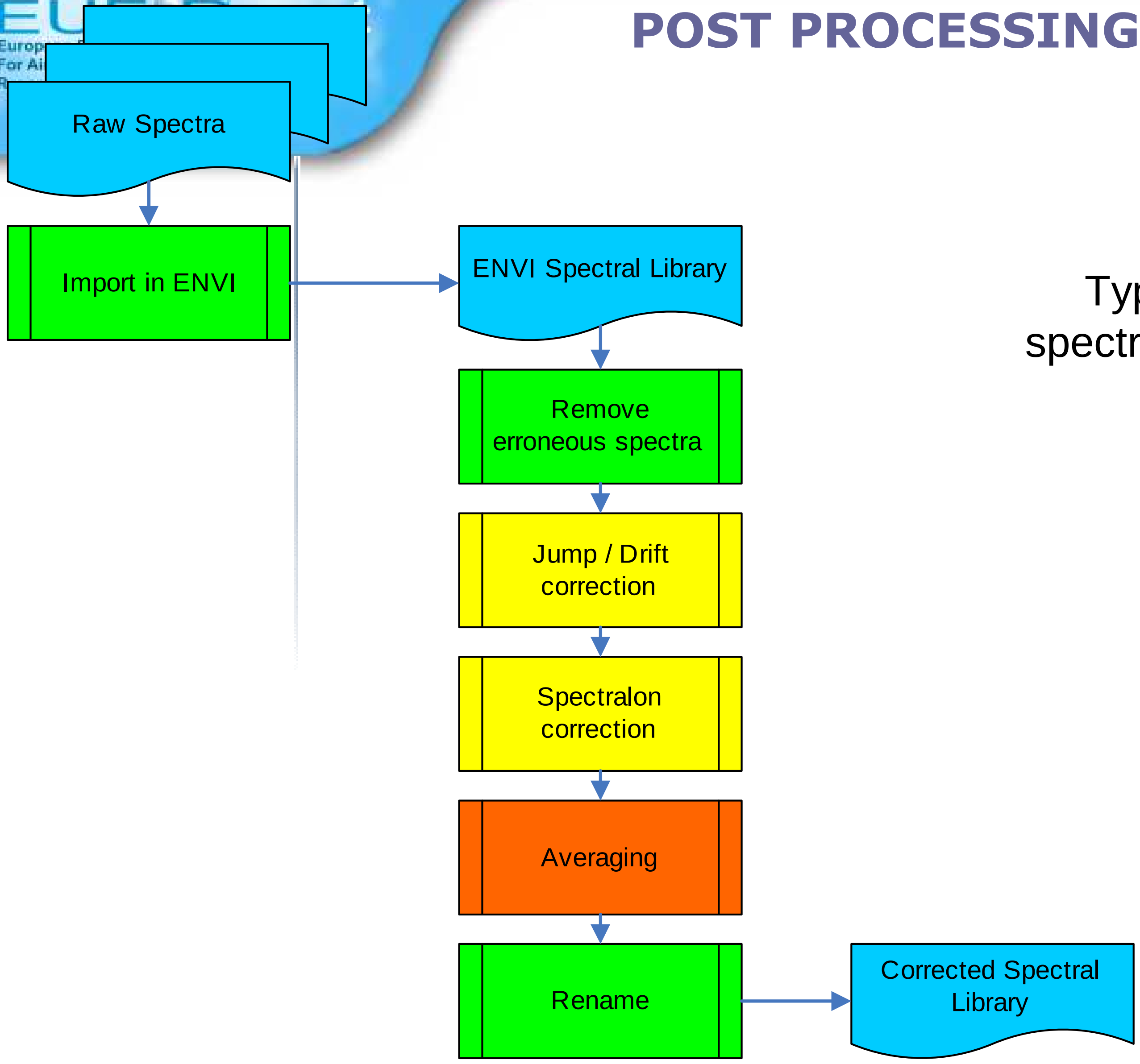
Be aware…in the field

- **Be sure to have at least two persons !**
  - Spectrometer
  - Metadata (Notes + Photo + Assistance (Carrying))
- **Dress in low reflective clothing (DARK)**
- **Drinking water and Food**
- **Synchronize Time (Laptop, watch, GPS)**
- **Check GPS if correct**
- **Carry Plant ID guides (or hire an ecologist)**

Processing of Spectra

- **Pre-Processing:**
  - Radiance to reflectance transformation
  - Sensor drift correction
  - Binning
  - Smoothing & filtering
  - Calculate convex hull & continuum removal
  - Bad-band list
  - Spectral resampling
- **Analysis:**
  - Classify spectra (e.g., compare to spectral library)
  - Identify characteristic features
  - Parameterization of features

POST PROCESSING of Spectra



Typical workflow for spectral library compilation

Laboratory Spectroscopy

Field Spectroscopy

Advantages:

- Natural surface conditions (roughness, moisture)
- Can be linked to a location in HSR imagery

Disadvantages:

- Motion of the sun
  - reduecd measurement time (solar noon ± 2 h)
  - changing illumination geometry
- Light scattered by surrounding
- Costly (time and money)

Lab Spectroscopy

Advantages

- Independent of weather & daylight
- Stable, constant illumination source
- Fixed measurement setup
- Repeatable

Disadvantages

- Changed surface roughness & moisture
- Large objects (trees) ???
- Leaf spectra eventually not representative for canopy spectra

Illumination sources – Influences in the field

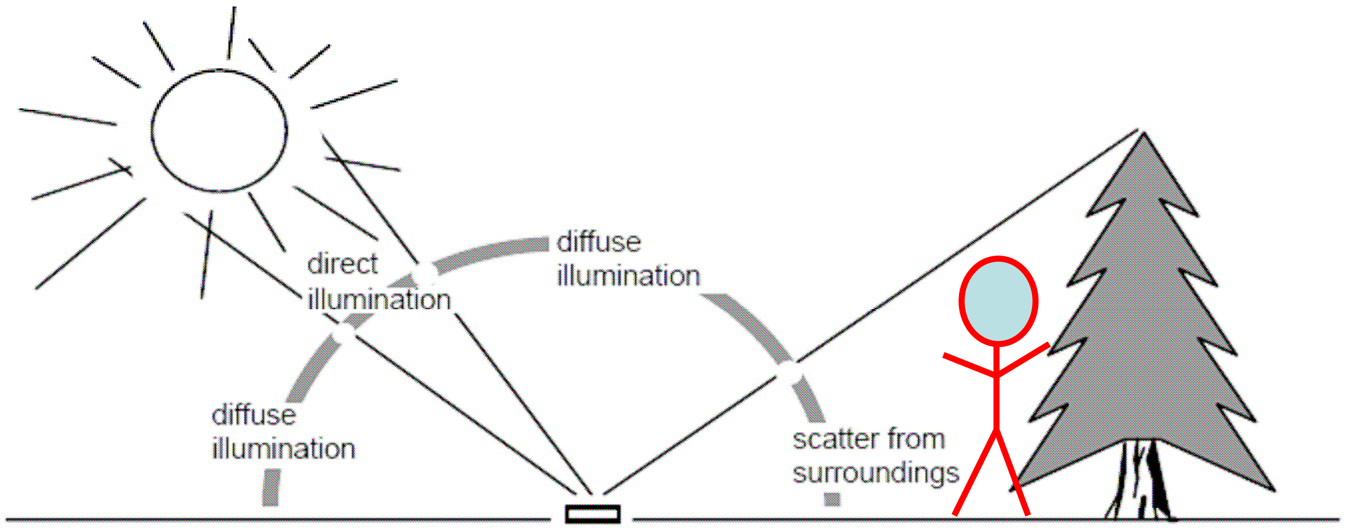
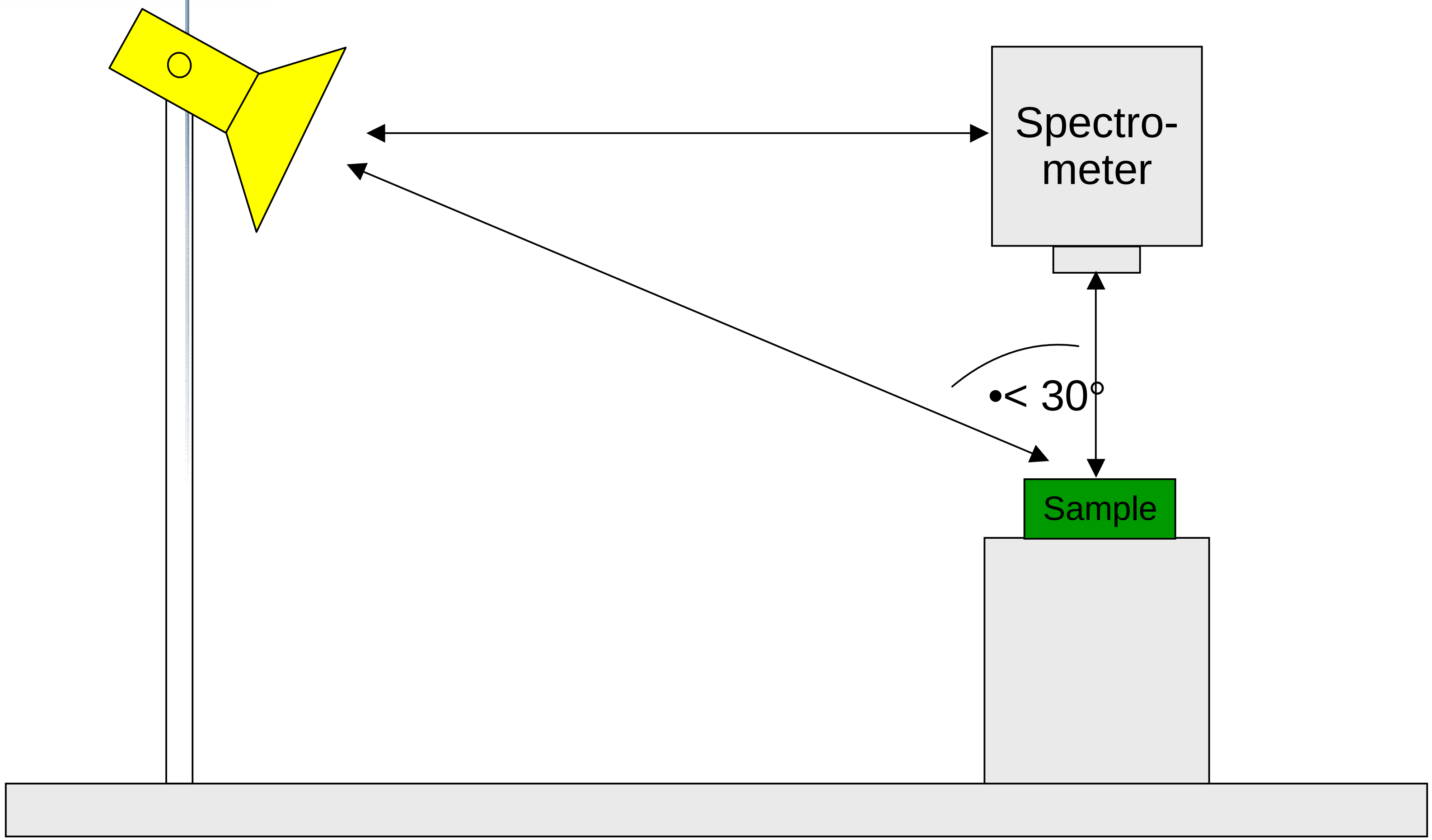
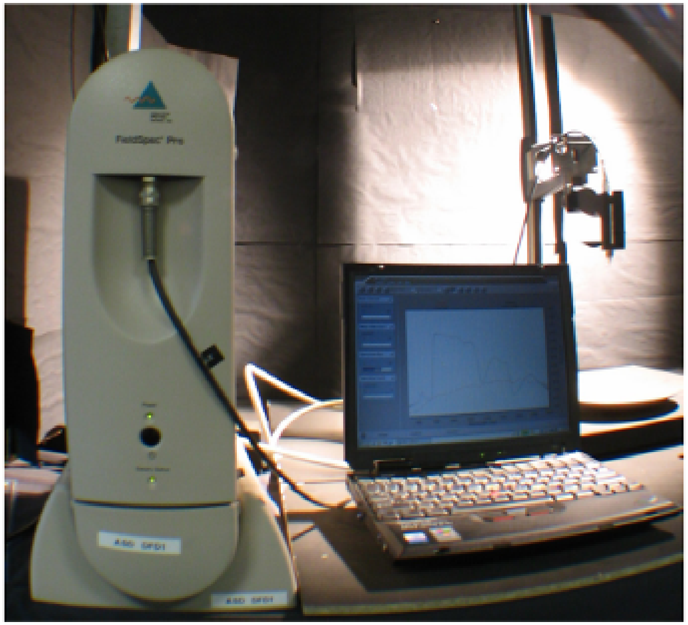
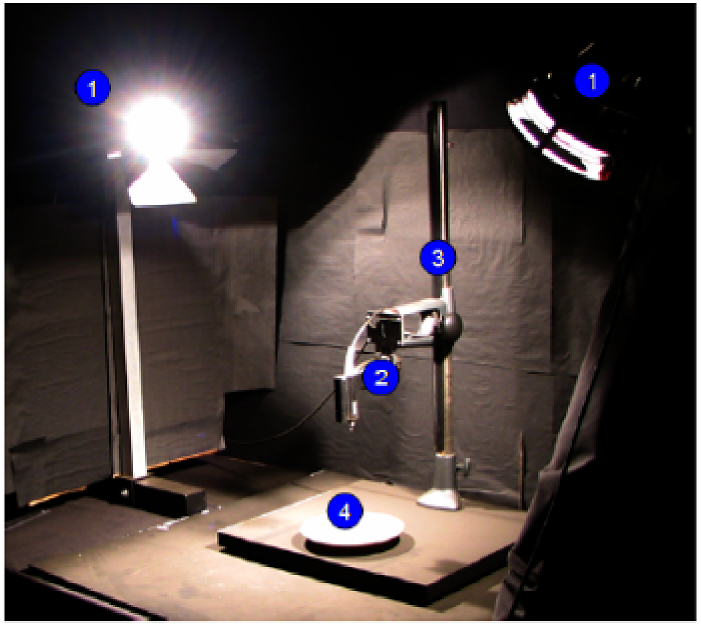


Figure 1. The major sources of illumination. Note that it is possible to have several sources of light scattered off of surrounding objects, each with its own unique spectral distribution.


Spectro-
meter
•< 30°
Sample

Typical laboratory setup





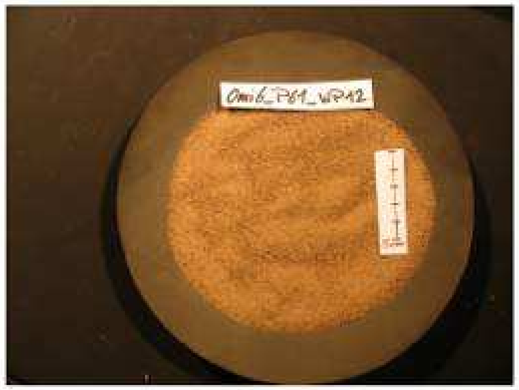
Laboratory spectroscopy

How to measure in the lab:

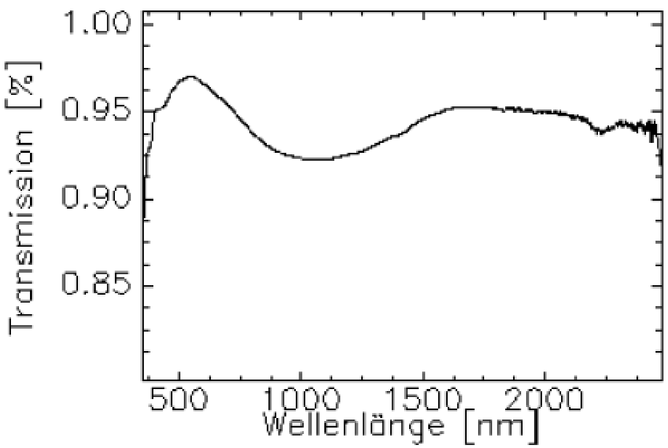
- **Illumination using zenith angle ~30°**
- **Pre-heat lamp (remember Planck‘s law)**
- **„Black“ surrounding!**
- **Distance lamp – material should be large, otherwise lamp heat would dry the sample**
- **Reduce surface roughness & BRDF effects: use 2 lamps, rotate samples by 90°**
- **White Reference at least every 25 measurements**

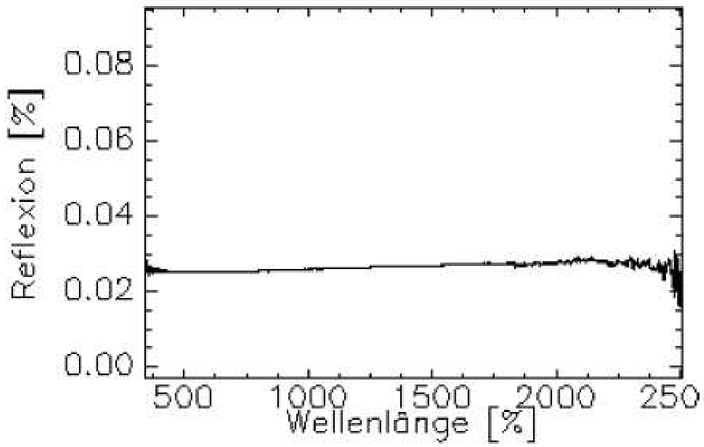
Reflections on sampling dish

•Glass petri dish

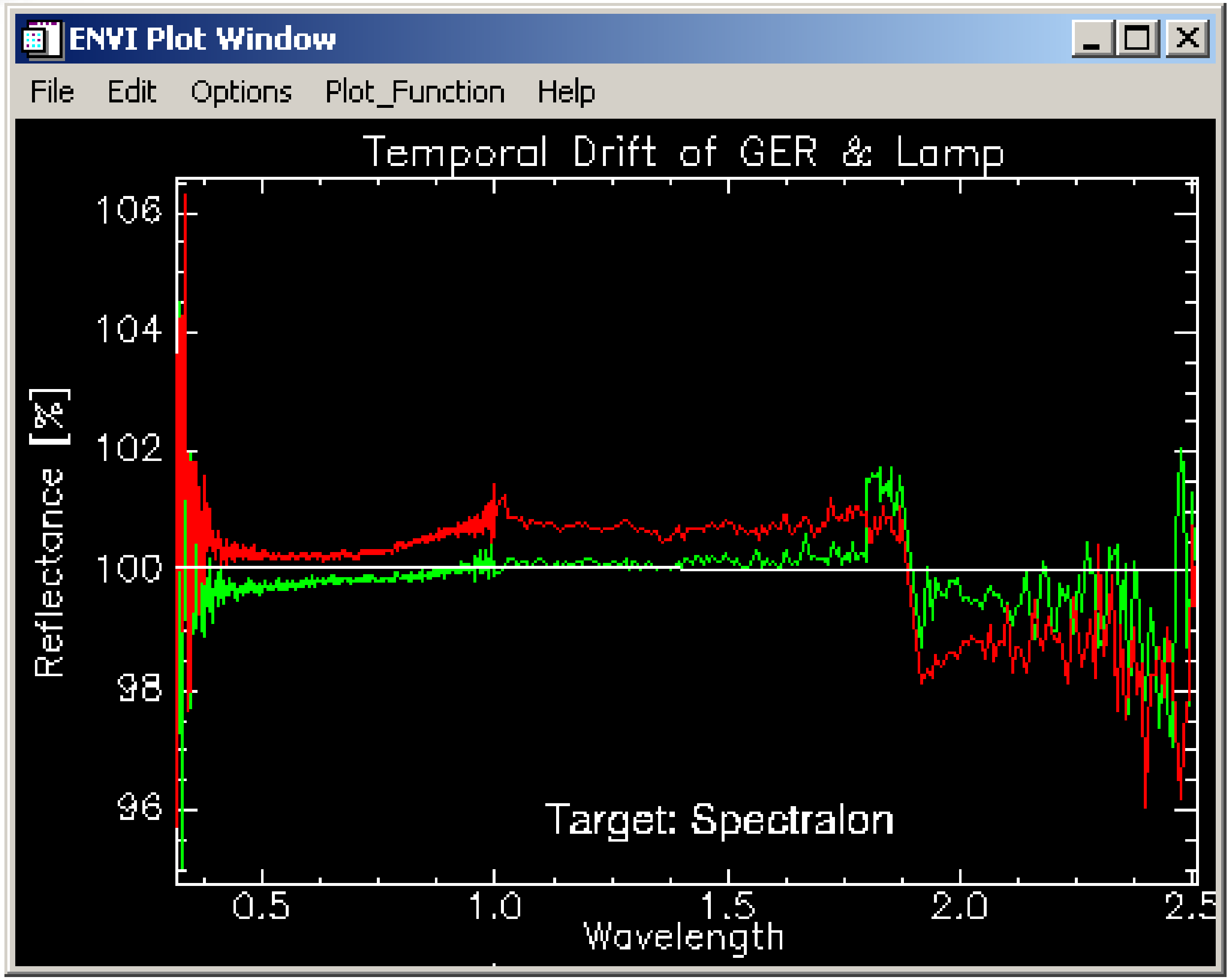


•Coated with “3M Black”





Lamp- and Instrument-Drift



Thank you

- Imelda and András for inviting me
- Martin Bachmann, Andreas Müller, Rolf Richter and colleagues from DLR for providing me a great part of the slides
- You for your attention (and patience)
- And EUFAR for funding