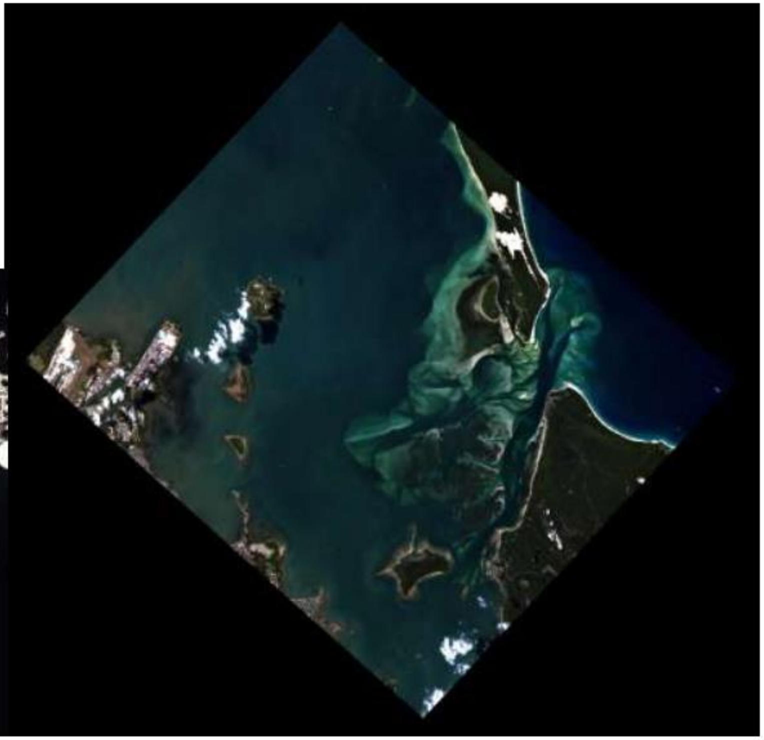

GEO 418 – „Hyperspectral Earth Observation“

Martin.Bachmann@dlr.de

Field Spectroscopy

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DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Contents of Module

- Sampling
  - Geographic sampling strategies
  - Sampling strategies for RS (ground „truthing“)
- Theory of field spectroscopy
  - Physical basics & measurement principle
  - Instrumentation
  - Illumination
  - Post-Processing
  - Lab- Vs. field spectroscopy
- Practical issues of field spectroscopy
  - How to measure?
  - How to protocol?
- References

Sampling Strategies

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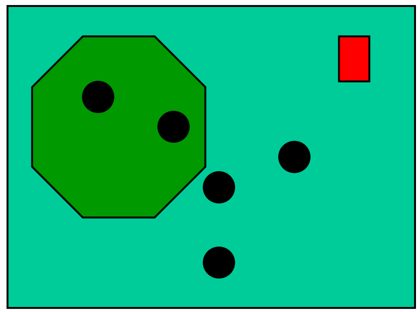
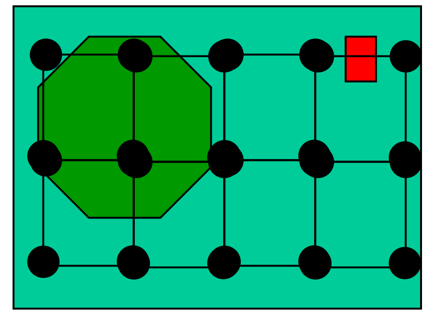
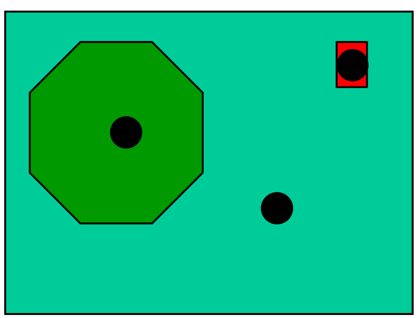
Sampling Strategies



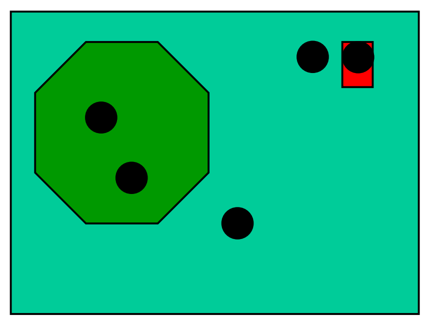
Random



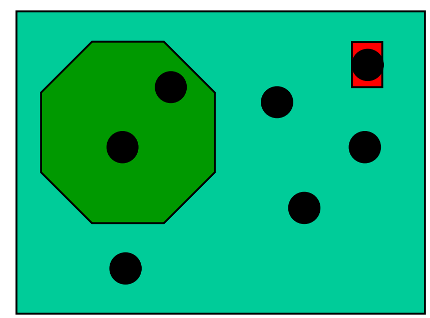
Rectangular
Sampling



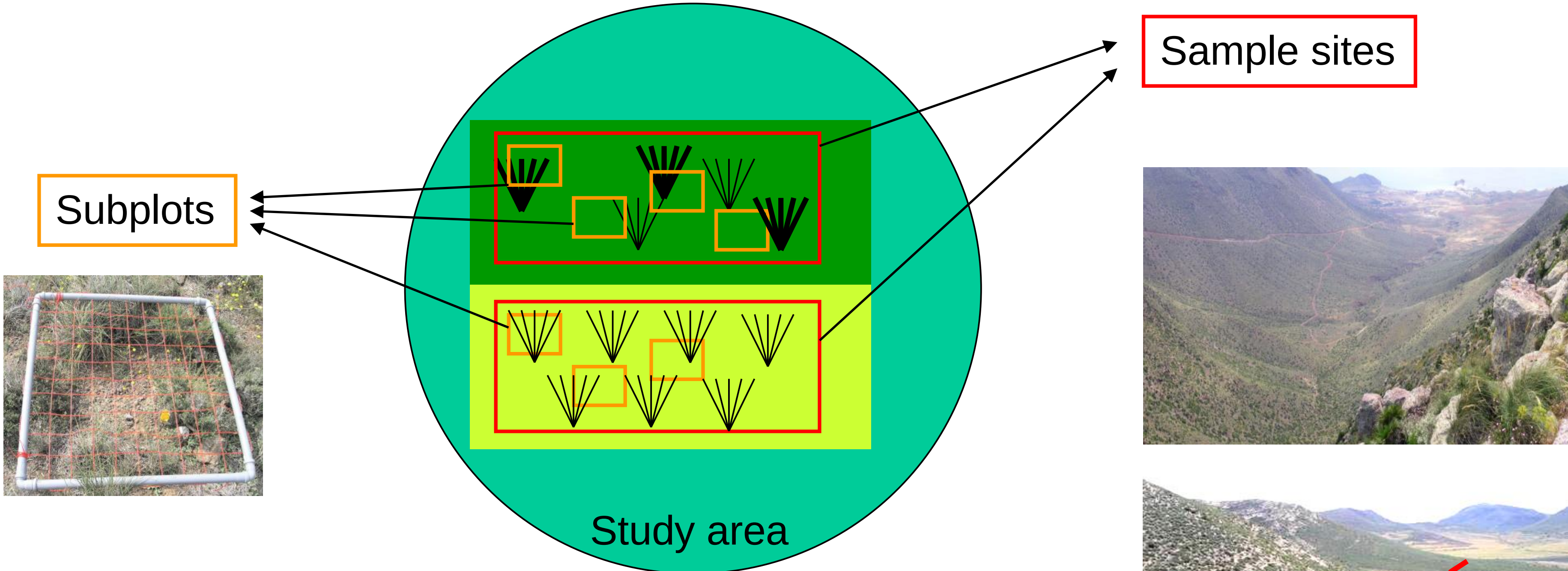
Stratified



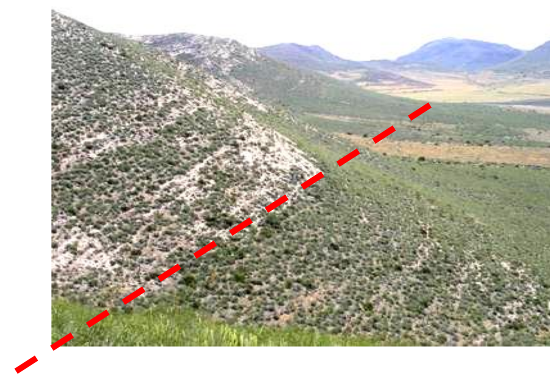
Stratified
Random

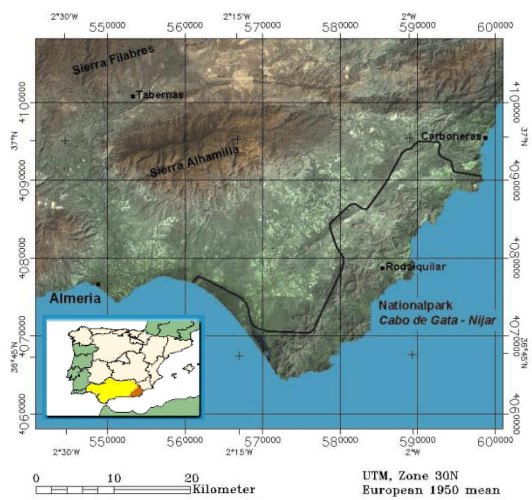


Stratified
Areal weighted



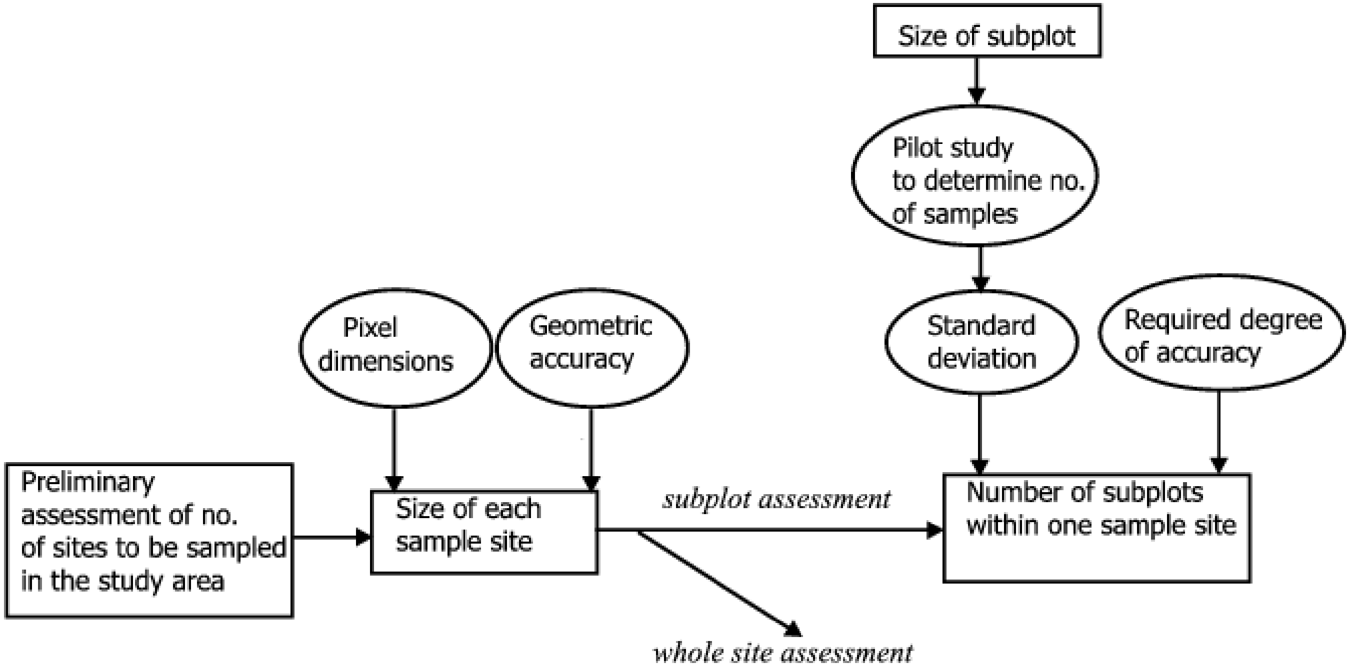
Subplots
Sample sites
Study area





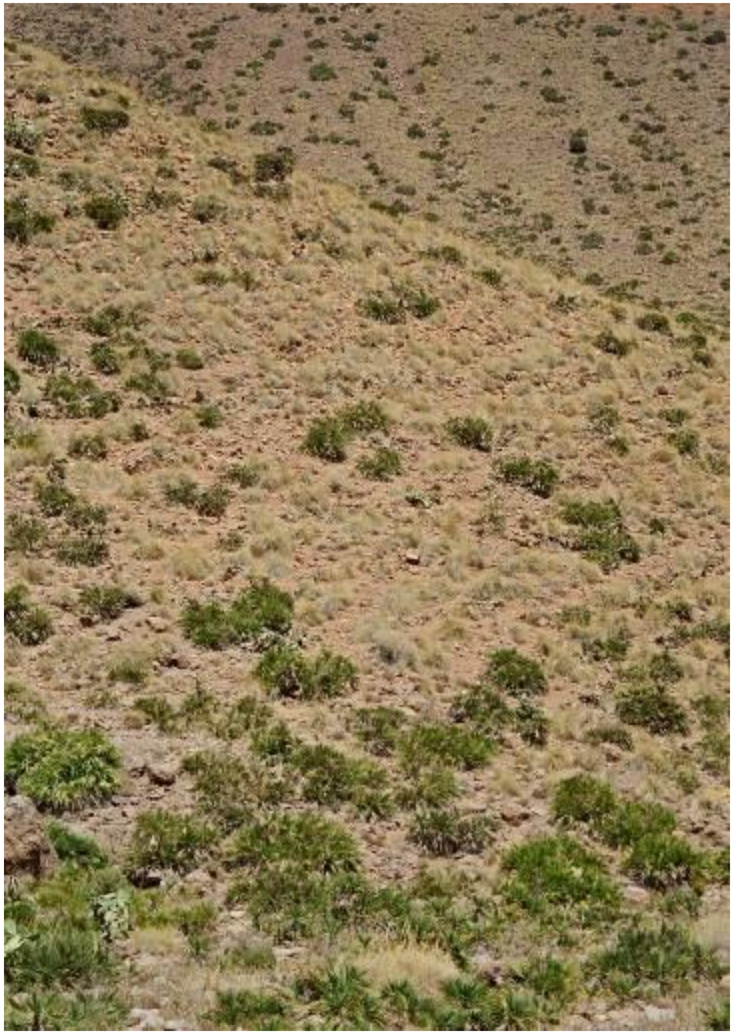
Sierra Filabres
Tabernas
Sierra Alhamilla
Carboneras
Rodalquilar
Almeria
Nationalpark
Cabo de Gata - Nijar
0 10 20 Kilometer
UTM, Zone 30N
European 1950 mean

Sampling Strategies for RS

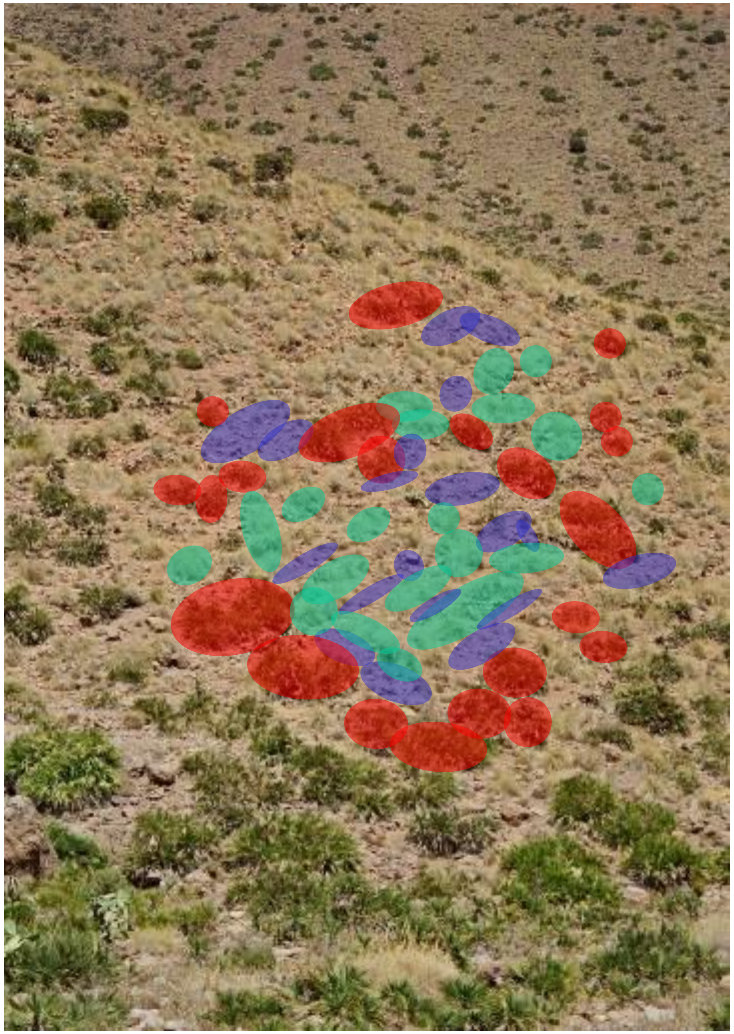


Brogaard & Ólafsdóttir 1997

Ground Cover Percentage – *Cabo de Gata*



Ground Cover Percentage – *Cabo de Gata*



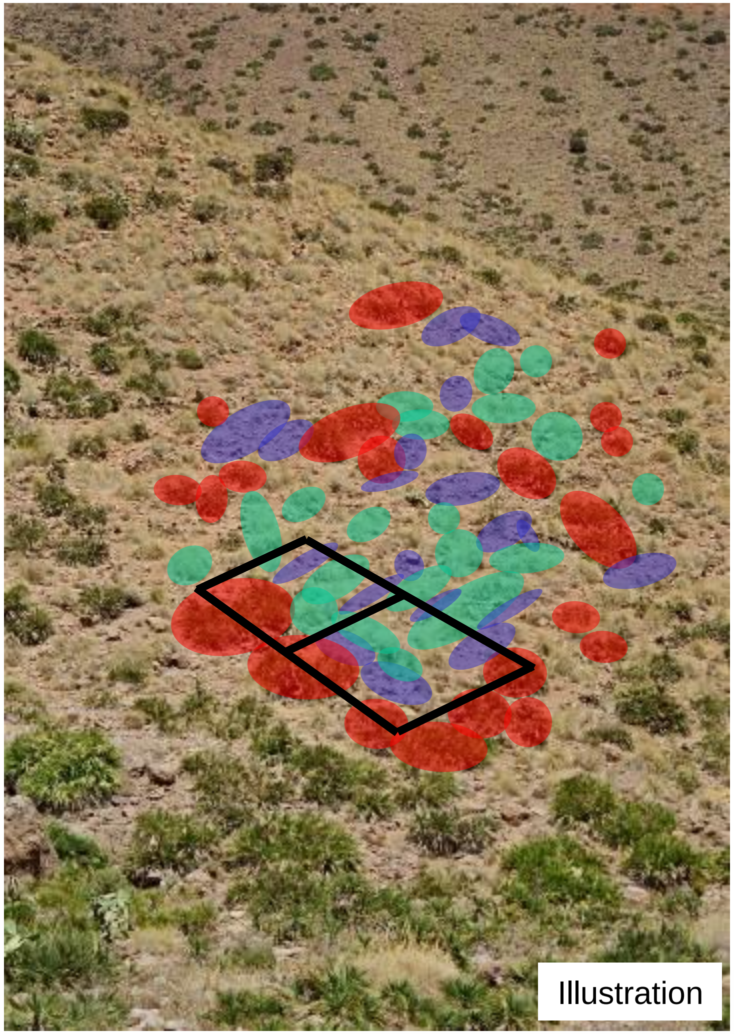
Spatial distribution of:

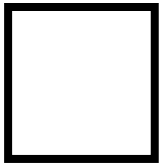
Vital vegetation
e.g. Opuntia ficus-indica,
Chamaerops humilis

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

Bare soil
e.g., Regosol,
Leptosol

Scale of spatial heterogenity



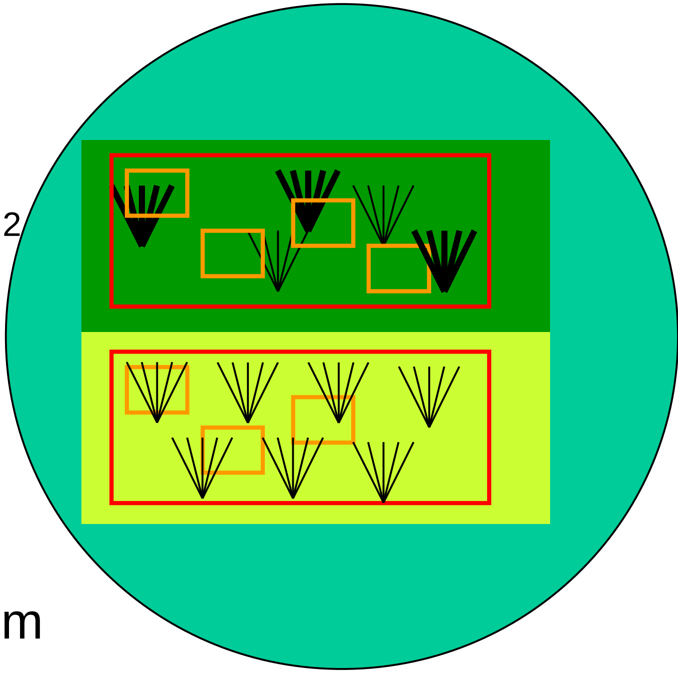


Spatial resolution (pixel size) of HyMap data:
5m x 5m

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

- 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

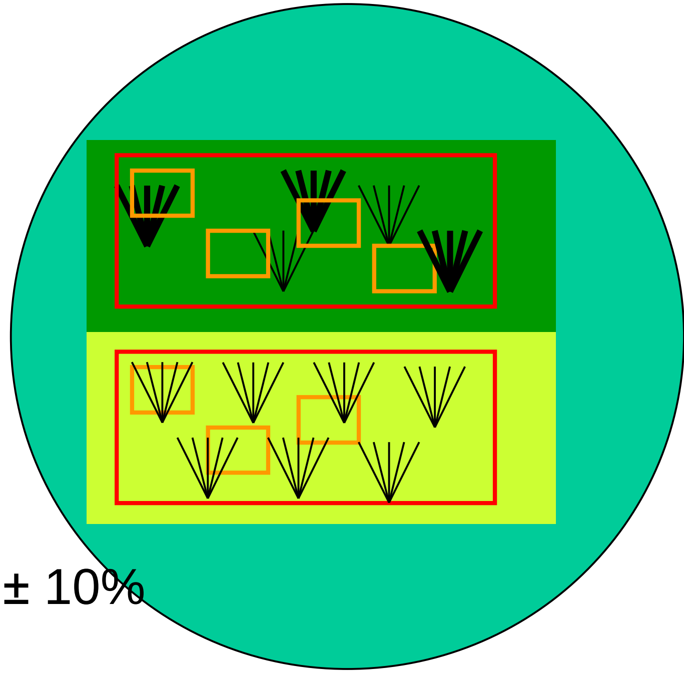


Study area

- 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

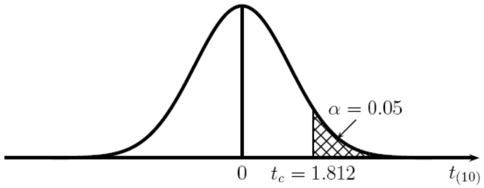
Brogaard & Ólafsdóttir 1997

- Min. number of subplots $N = (\sigma t / a)^2$
  - 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)
  - $\sigma = 0.07$ N = 2
  - $\sigma = 0.09$ N = 5
  - $\sigma = 0.19$ N = 19

Study area

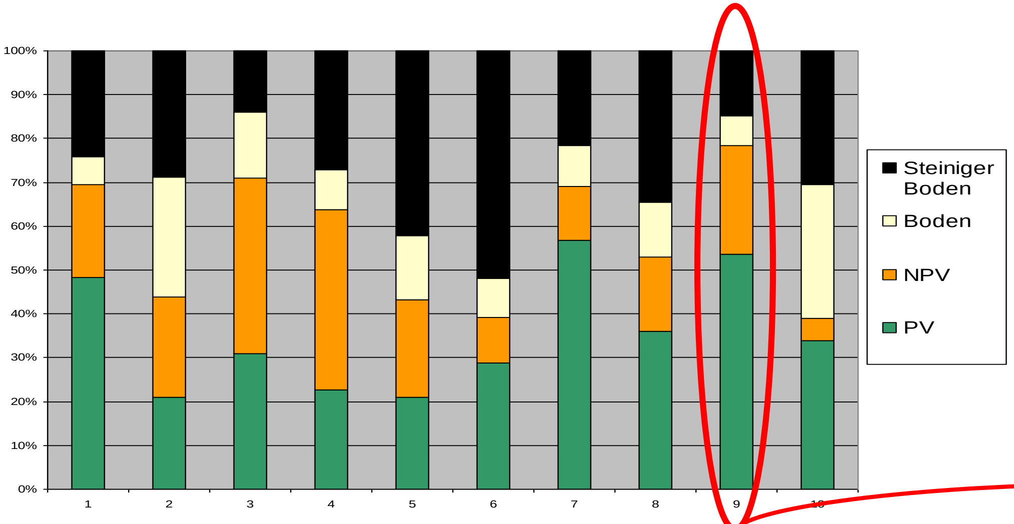


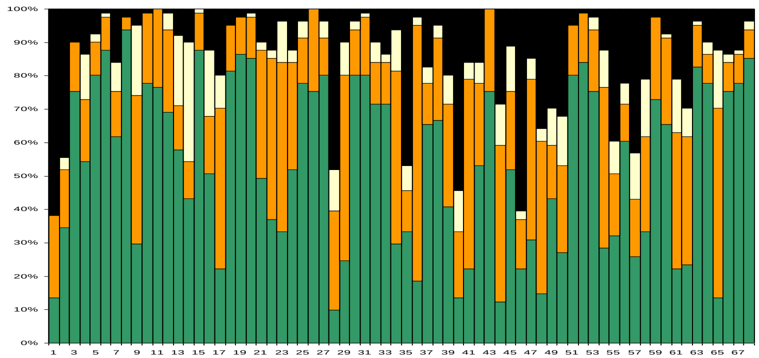
Brogaard & Ólafsdóttir 1997

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

Field spectroscopy - Introduction

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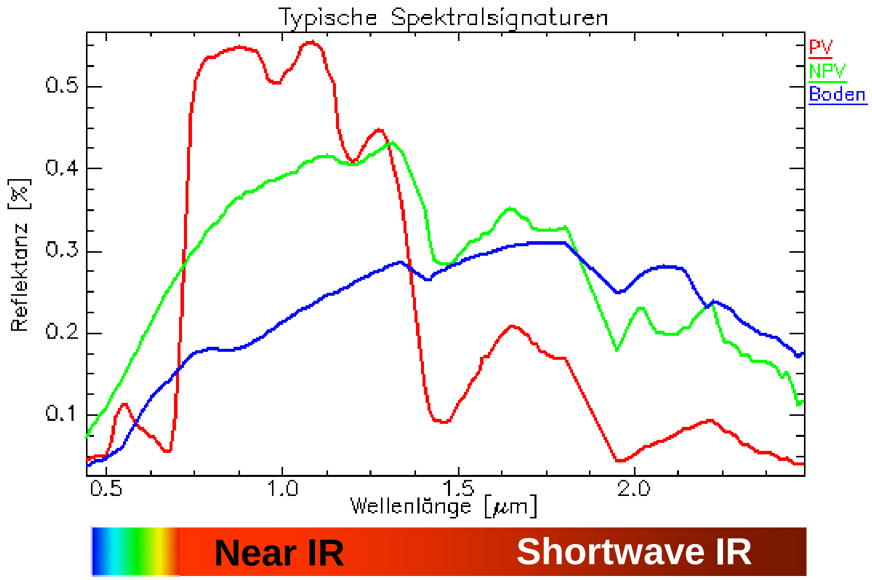
Spectroscopy

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



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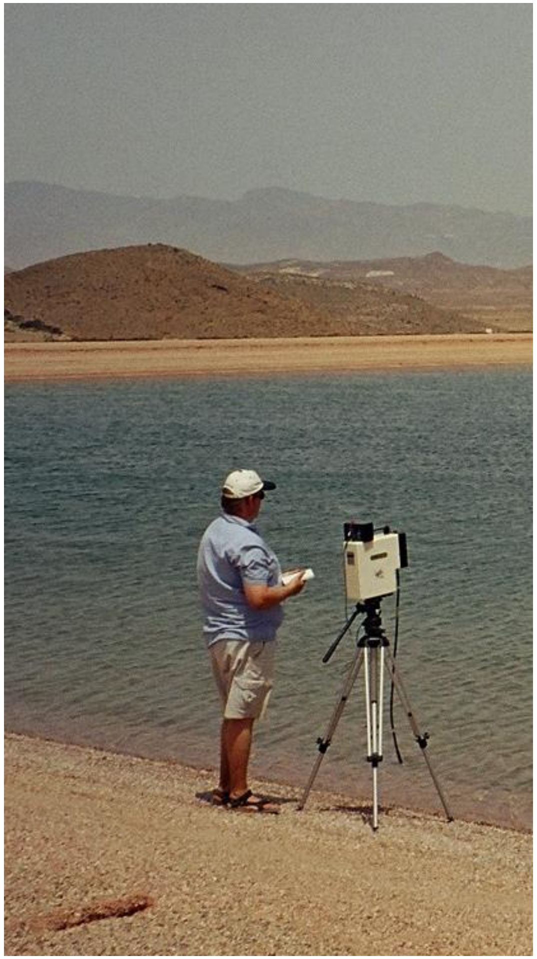
Spectroscopy

- 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
  - …

Milton 2007

Field Spectroscopy

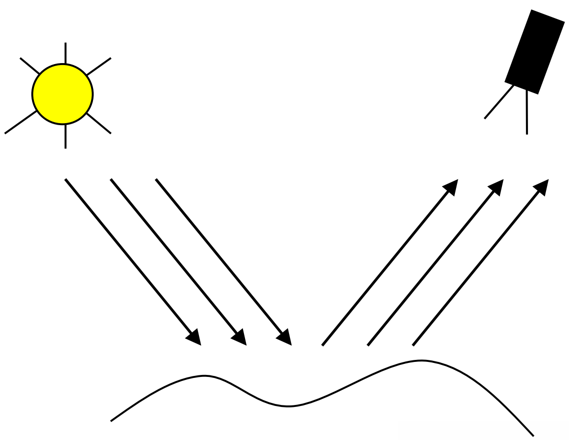


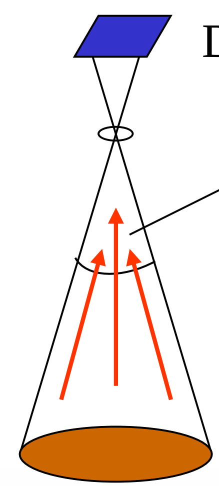
Spectroscopy – Measuring with light

- The sensor measures:

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

=> Unit after system correction, described as L1 product

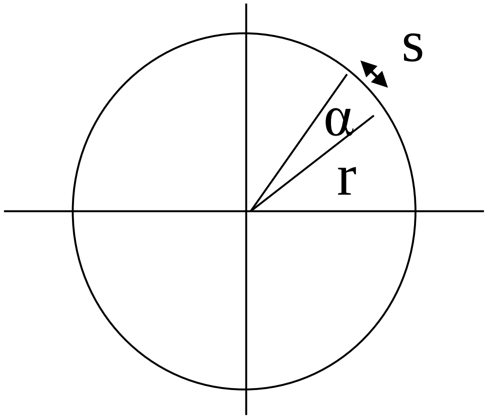




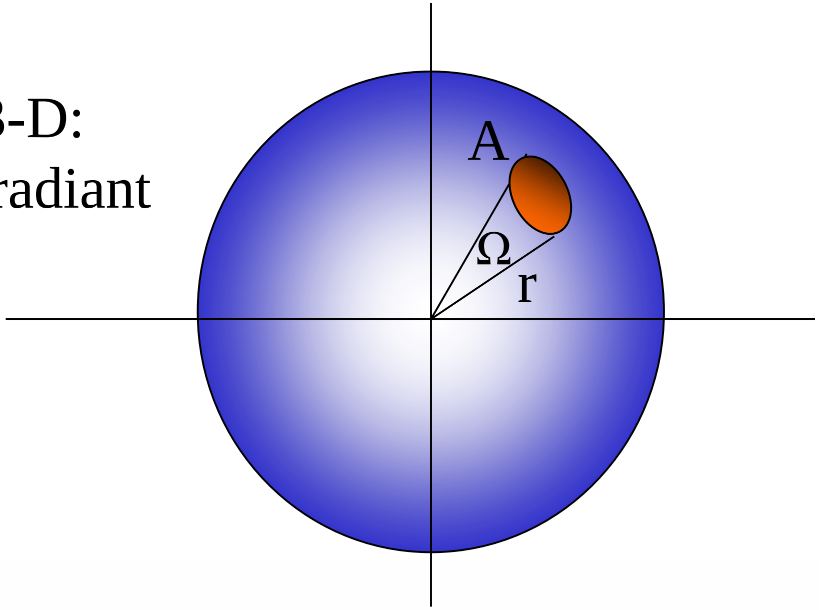
Physical Basics

- Solid Angle Ω (Raumwinkel) steradiant = area / radius^2
- Sphere = $4\pi\, r^2 / r^2 = 4\,\pi$ [sr]
- Sky = $2\,\pi$ [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)

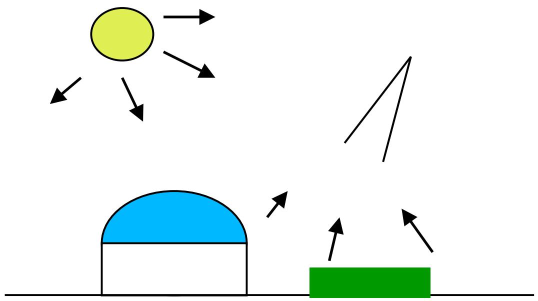
Thus more suitable measure: **reflection ρ = % of reflected radiation**

- 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

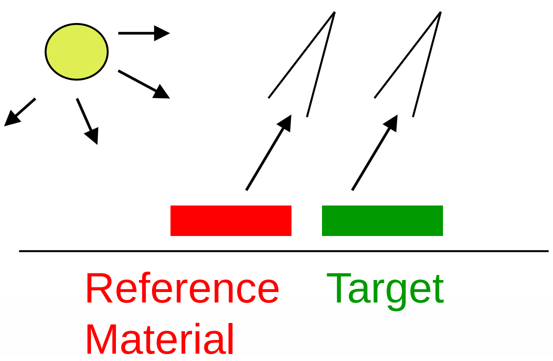


1. Measuring incoming and reflected radiance, then ratio:

$$\rho_{target} = L_{target} / L_{reference}$$

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

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

$$\rho_{target} = (L_{target} / L_{referenz}) * \rho_{referenz}$$

$$\rho_{target,Band\ 1} = (L_{target,\ Band\ 1} / L_{referenz,\ Band\ 1}) * \rho_{referenz,\ Band\ 1}$$

$$\rho_{target,Band\ 2} = (L_{target,\ Band\ 2} / L_{referenz,\ Band\ 2}) * \rho_{referenz,\ Band\ 2}$$

$$\rho_{target,Band\ 3} = (L_{target,\ Band\ 3} / L_{referenz,\ Band\ 3}) * \rho_{referenz,\ Band\ 3}$$

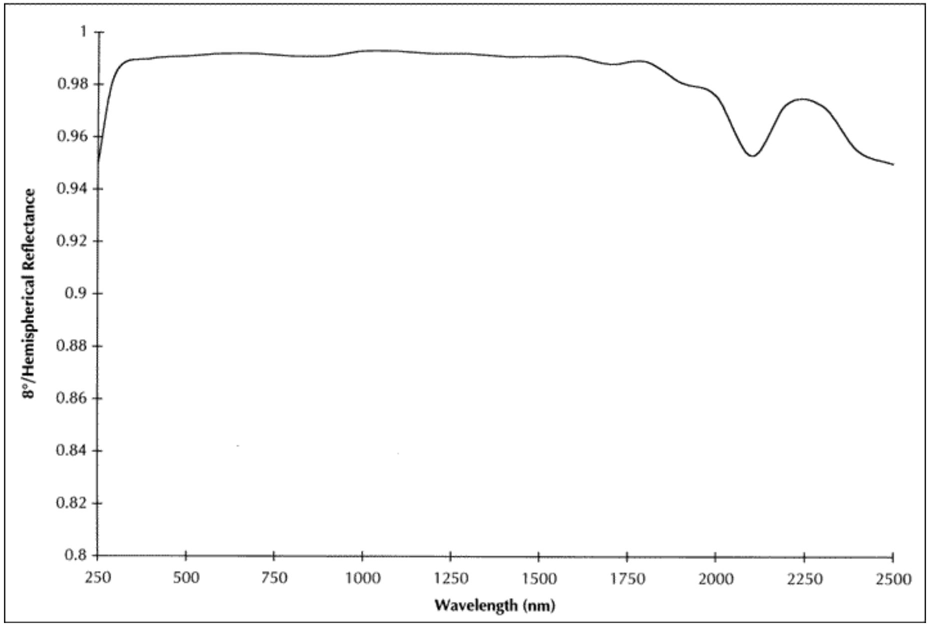
$$\rho_{target,Band\ n} = (L_{target,\ Band\ n} / L_{referenz,\ Band\ n}) * \rho_{referenz,\ Band\ n}$$

White Reference

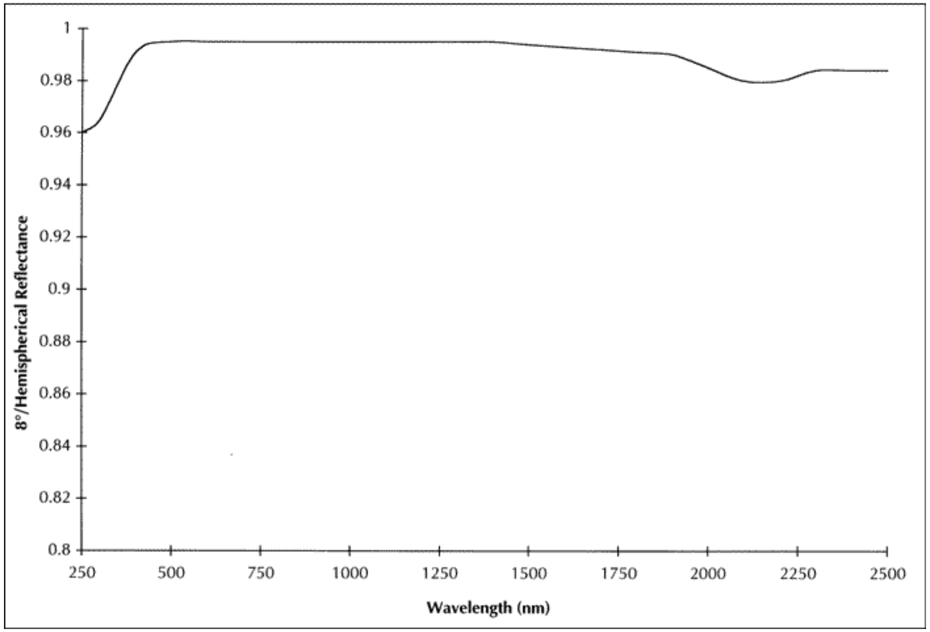
- White reference $\rho_{referenz}$:
  - Desired material properties:
    - 100% reflection for all wavelengths
    - Lambert‘ian (diffuse) reflection
    - Highly opaque
    - No fluorescent excitation for wavelengths longer than 300 nm
    - Spatially uniform, cleanable, durable, and stable
- Used: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

TYPICAL 8 ° /HEMISPHERICAL REFLECTANCE- OPTICAL GRADE SPECTRALON



TYPICAL 8 ° /HEMISPHERICAL REFLECTANCE- SPACE-GRADE SPECTRALON



http://www.labsphere.com/

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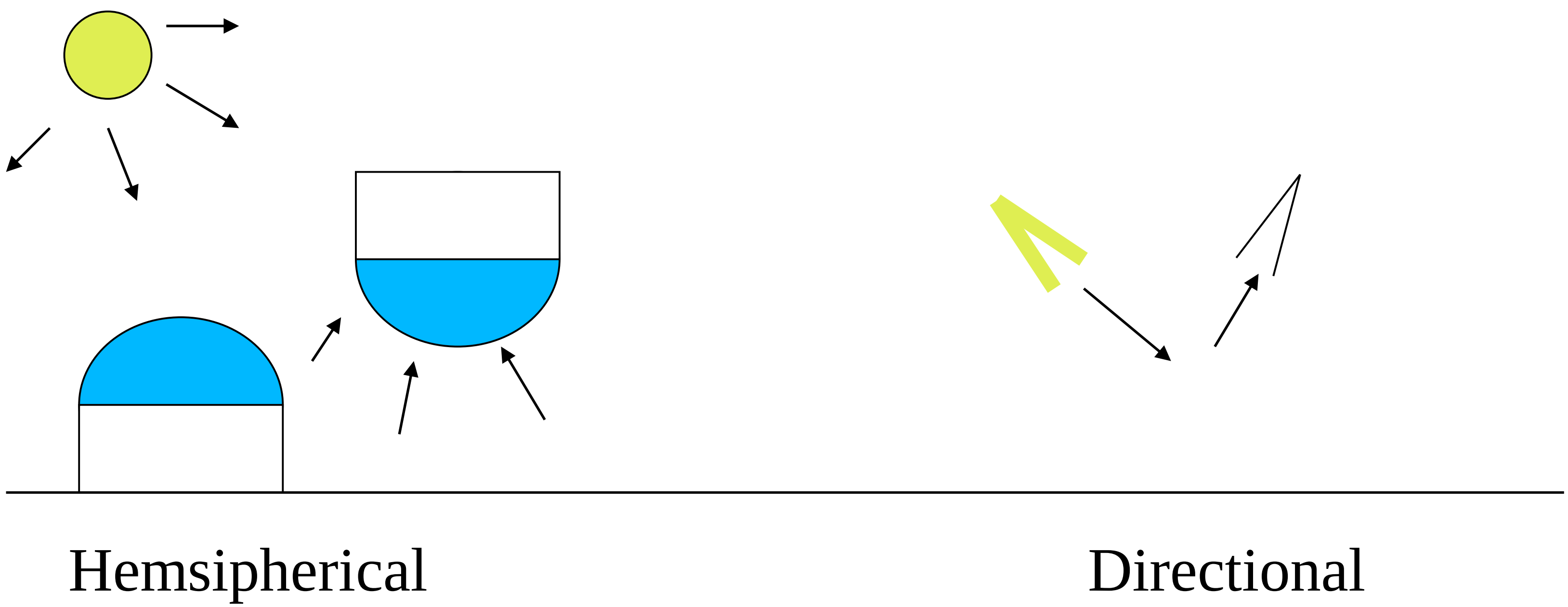
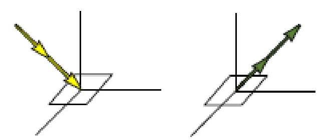
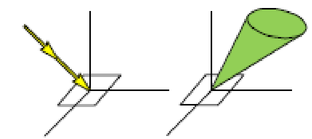
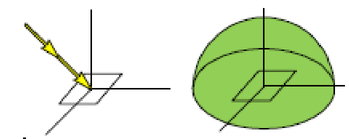
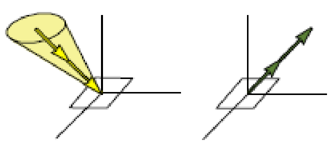
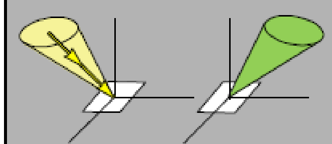
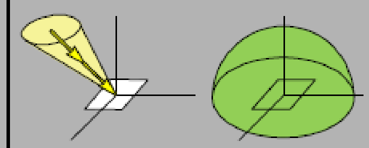
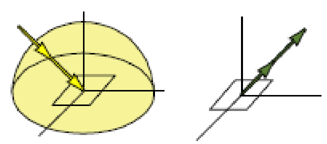
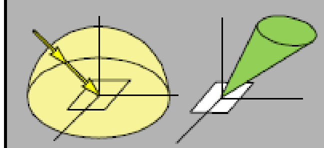
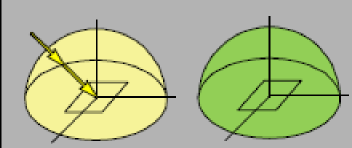

Hemsipherical
Directional

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 2006

Instrumentation

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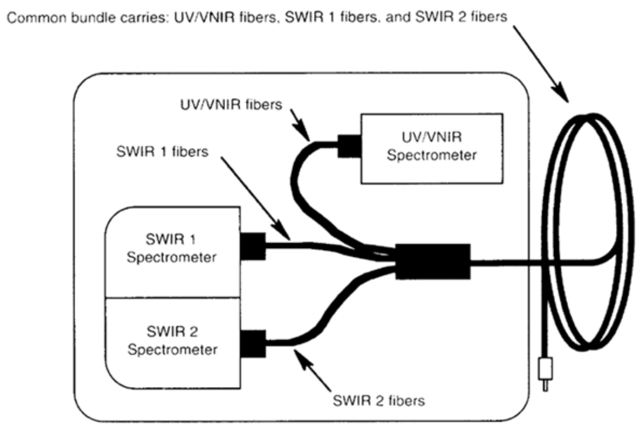
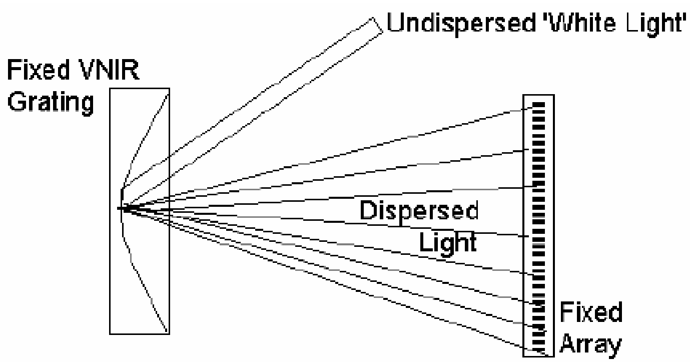
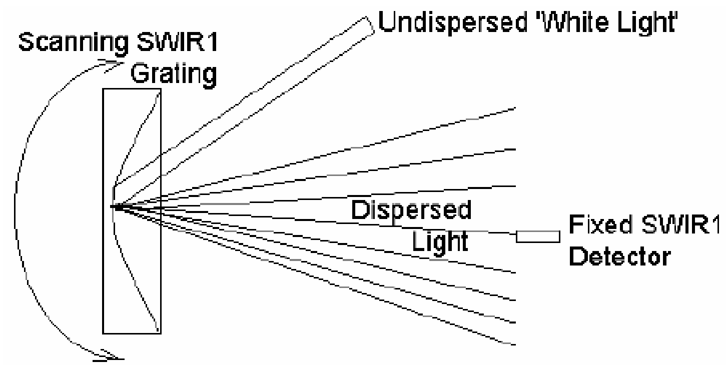


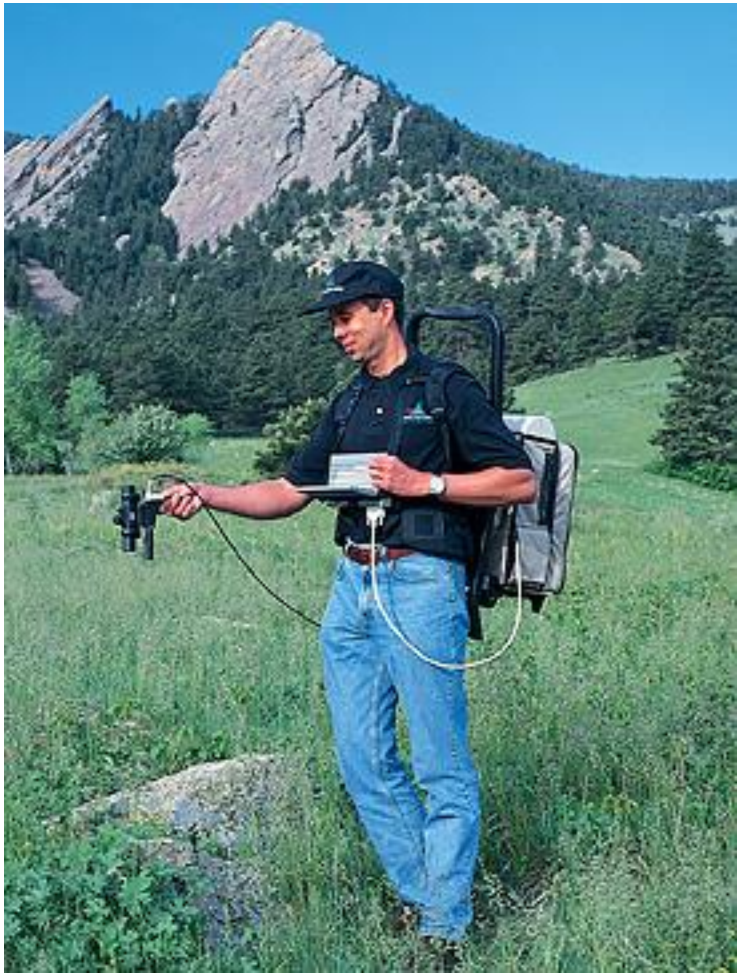




VNIR: Silicone photodiode detector array

SWIR 1+2: InGaAs detector

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

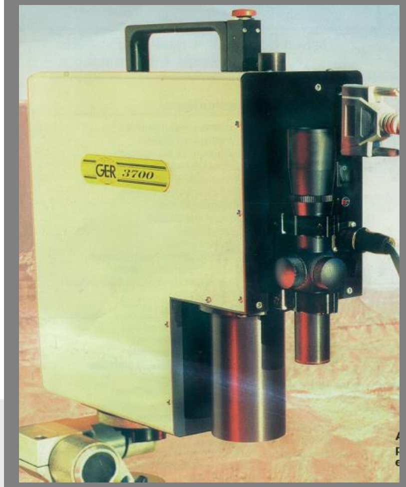


http://www.asdi.com

Instrument Spectral Evolution PSR/PSM-2500

Spectral Range		**350nm to 2500nm**
Channels		**768**
Linear Arrays		(1) 512 Si
		(2) 256 InGaAs
Bandwidth	**1.5nm:**	350nm to ~1000nm
	6.0nm:	~1000nm to 2500nm
Scan Time		100ms and up (selectable)
FOV		**4º standard**
		to 25º option with fiber optic
Weight		~4 kg
Battery Life		~4 hours
Digitization		16 Bit
Wavelength Repeatability		±0.1nm
Noise Equivalent Radiance		0.5 s integ. Time
	400nm:	0.8×10^{-9} $Wcm^{-2}nm^{-1}sr^{-1}$
	1500nm:	1.5×10^{-9} $Wcm^{-2}nm^{-1}sr^{-1}$
	2100nm:	1.8×10^{-9} $Wcm^{-2}nm^{-1}sr^{-1}$
Maximum Radiance Levels	700nm:	1.5×10^{-4} $Wcm^{-2}nm^{-1}sr^{-1}$
Radiometric Calibration Accuracy		
(Traceable to NIST)	400nm:	±5%
	700nm:	±4%
	2200nm:	±7%

"Heritage": GER Instruments split in 2 companies, SpectraVista & S. Evolution



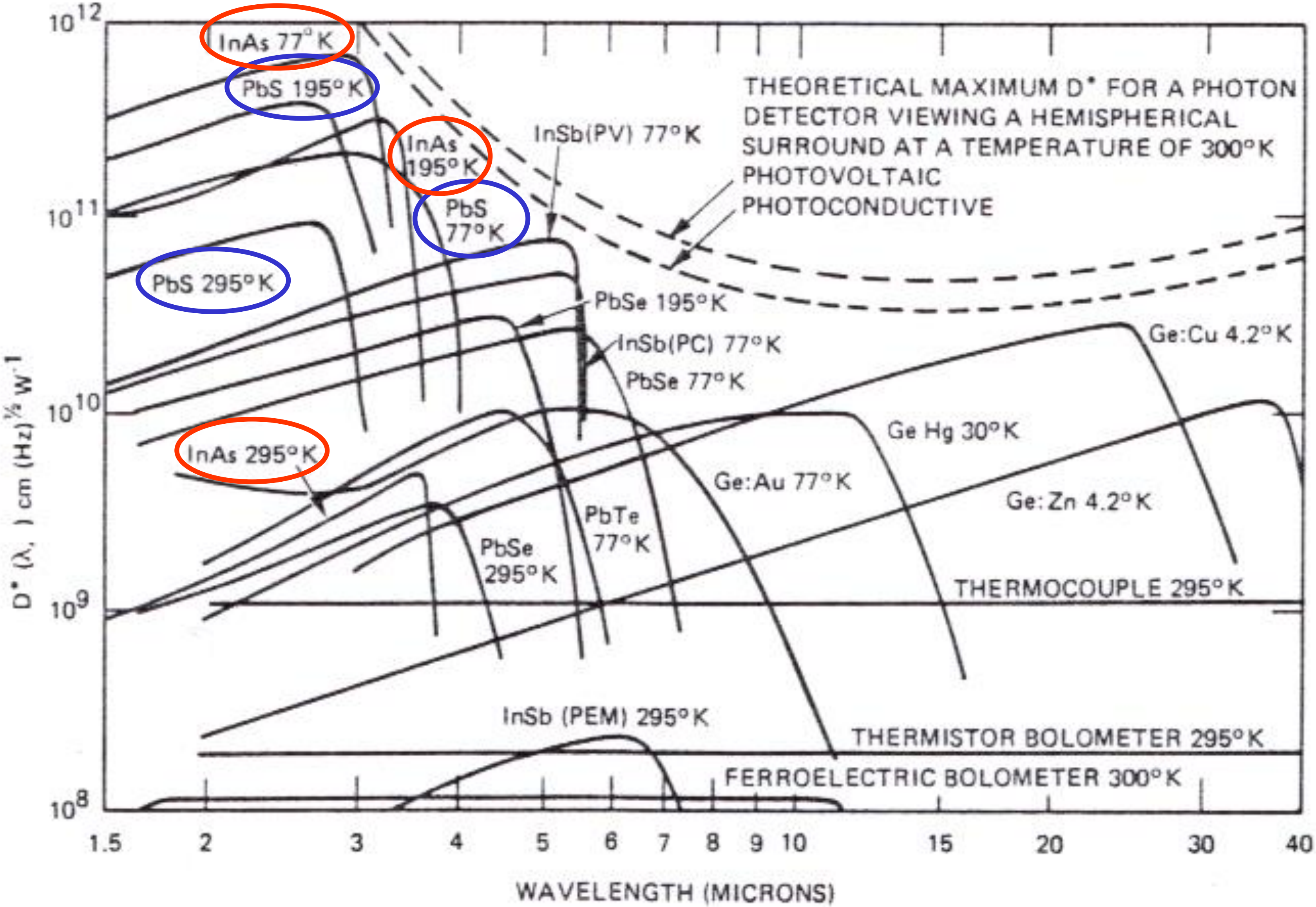


Figure 3-48. Comparison of the D^* of various infrared detectors when operated at the indicated temperature (Hudson, 1969).

Abb aus ELACHI

„Extras“:

- Fiberoptics
(FOV: SE: 25° / ASD: 25°)

- Forepotics for smaller FOV:
(SE: 8°, 14° / ASD: 1°, 5°)

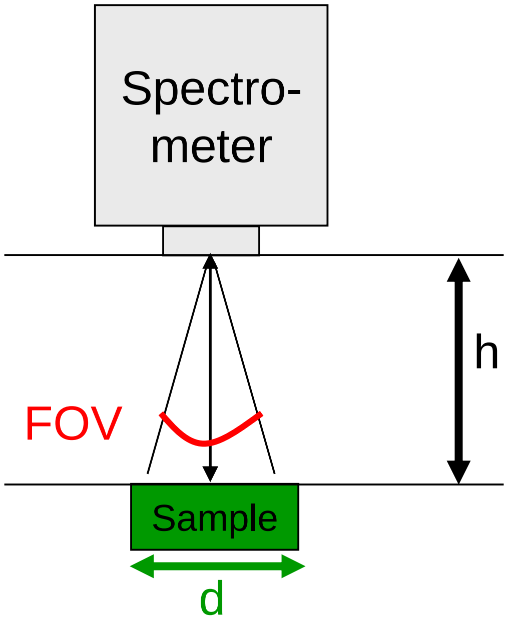
- Contact probes incl. illumination source (=> geol. applic.)

- „Cherry Picker“
for canopy measurements

- Gomiometer for BRDF-measurements

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

Foreoptics & FOV

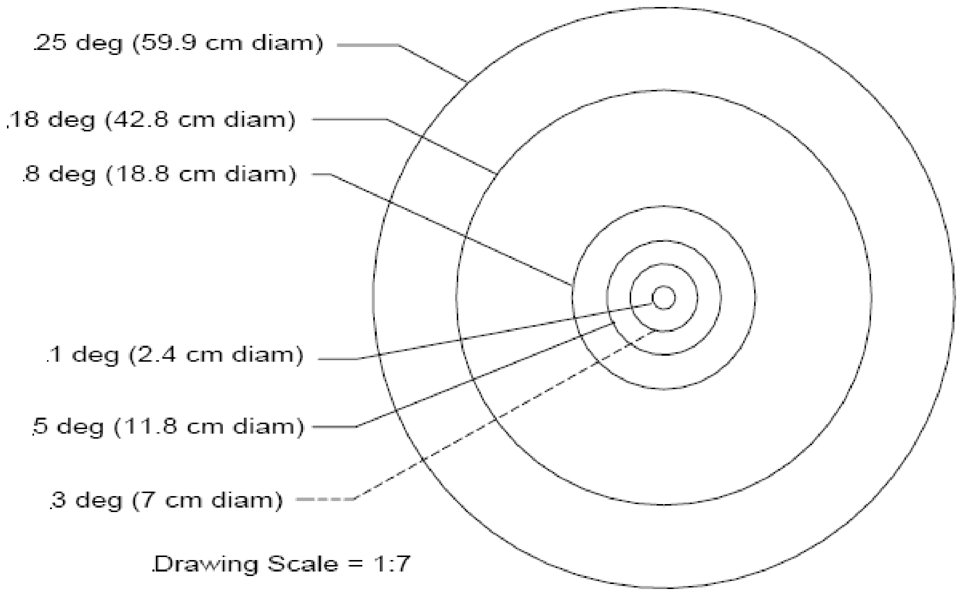


ASD, Bare Fiber, FOV = 25°

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.

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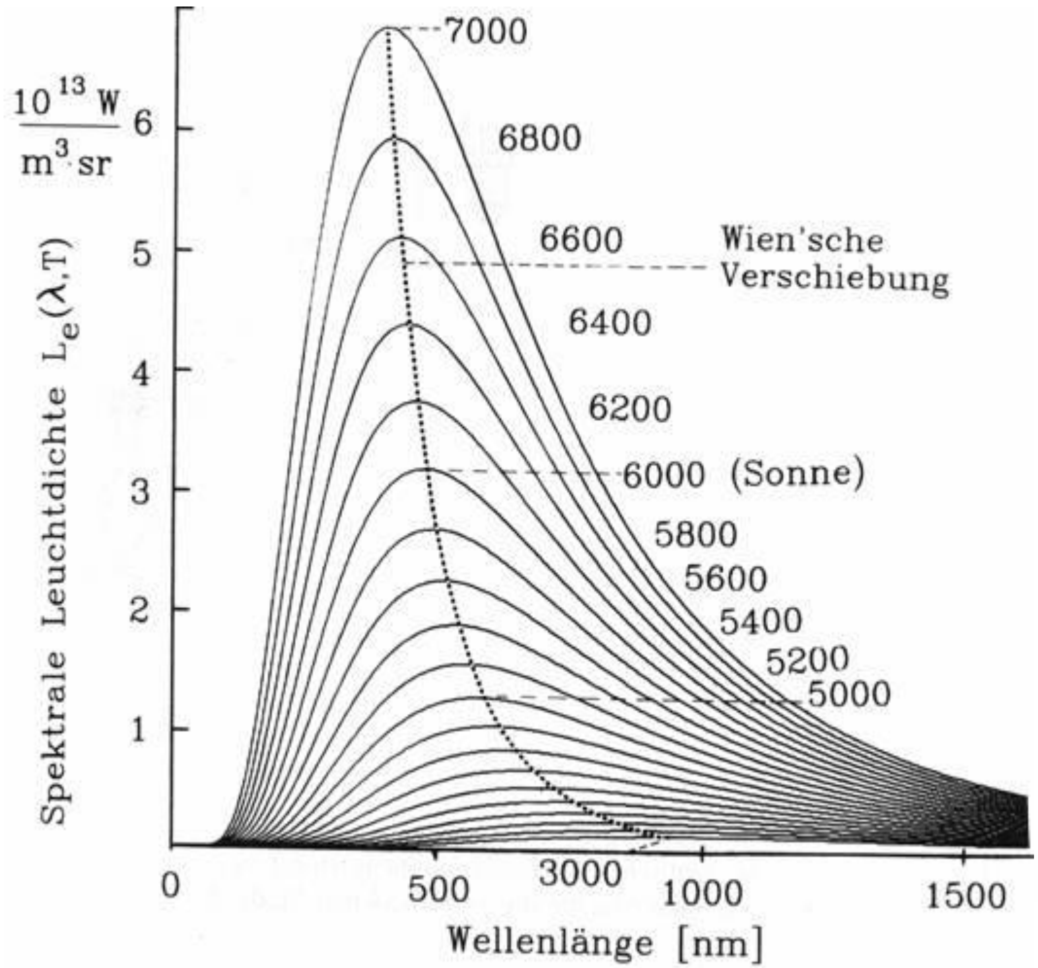
Spectroscopy - Equipment Pools

- **Where to get spectrometers?**
  - DLR – OpAIRS (DFD + IMF)
    - 2* ASD FieldSpec Pro, 1* SVC HR-1024, 1* GER 3700, D&P FTIR, Microtops, ...
    - http://www.caf.dlr.de
  - NERC / U. Edinburgh
    - ASDs, SVCs, GERs, Microtops, ...
    - http://fsf.nerc.ac.uk/
  - University of Zürich
    - ASDs, GERs, FIGOS, ...
    - http://www.geo.unizh.ch/rsl
  - University of Würzburg, Jena, Trier, Munich, ...

Illumination

Every object is emitting **electro-magnetic radiation**

according to its temperature.

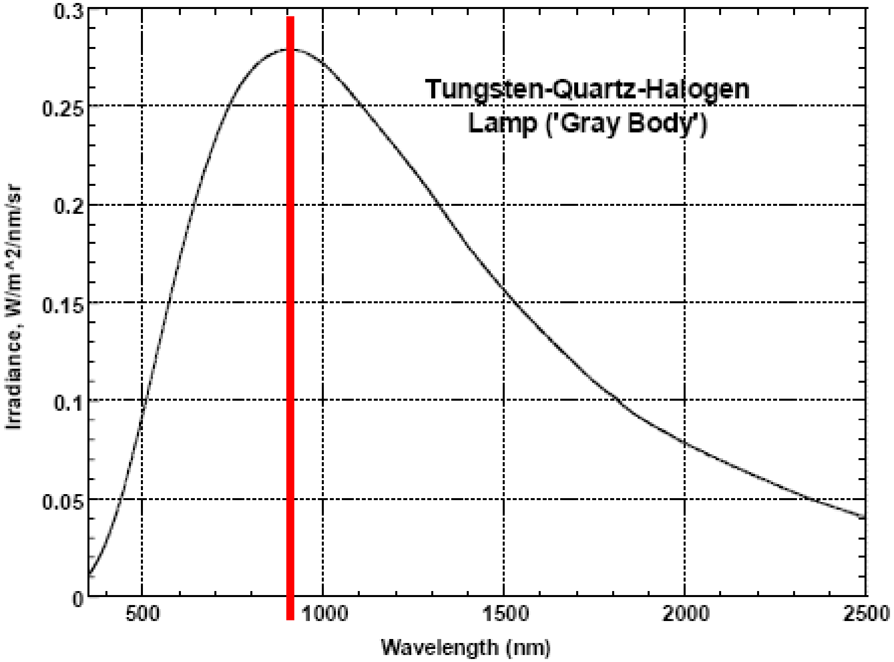


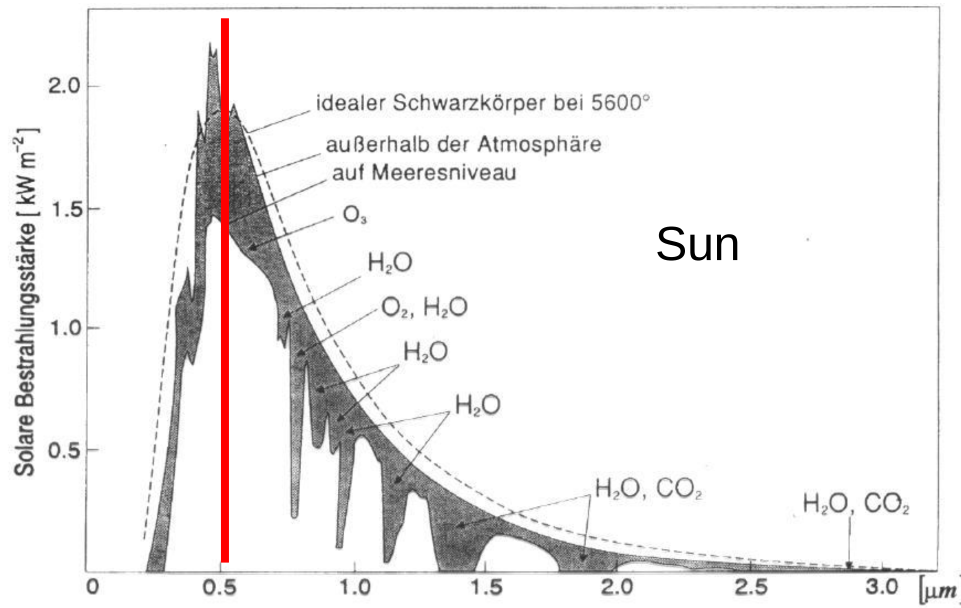
Earth:

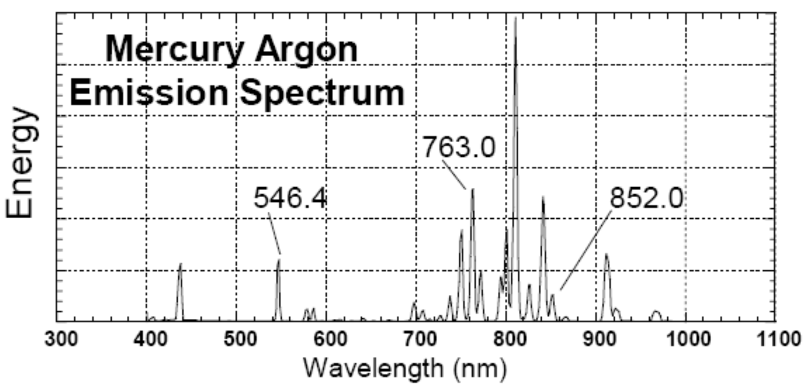
~300k average surface temp.
L_{max} at 10 µm (=10.000nm)

Werner Schmidt: Optische Spektroskopie – Eine Einführung. Wiley-VCH Weinheim, 2. Auflage 2000

Illumination sources







Illumination sources – Influences in the field

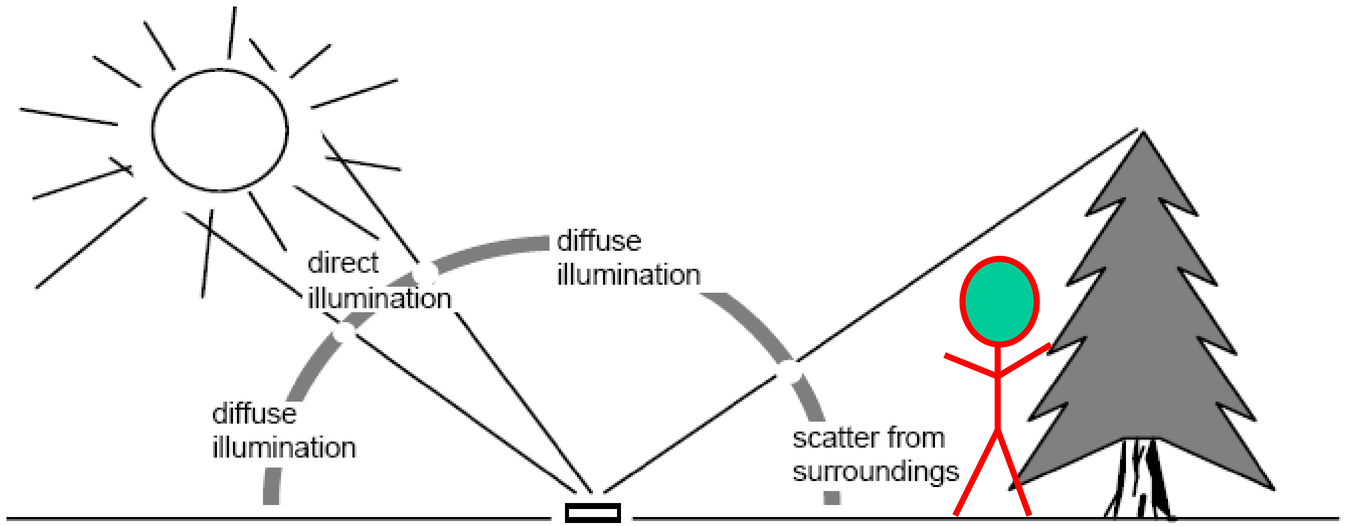
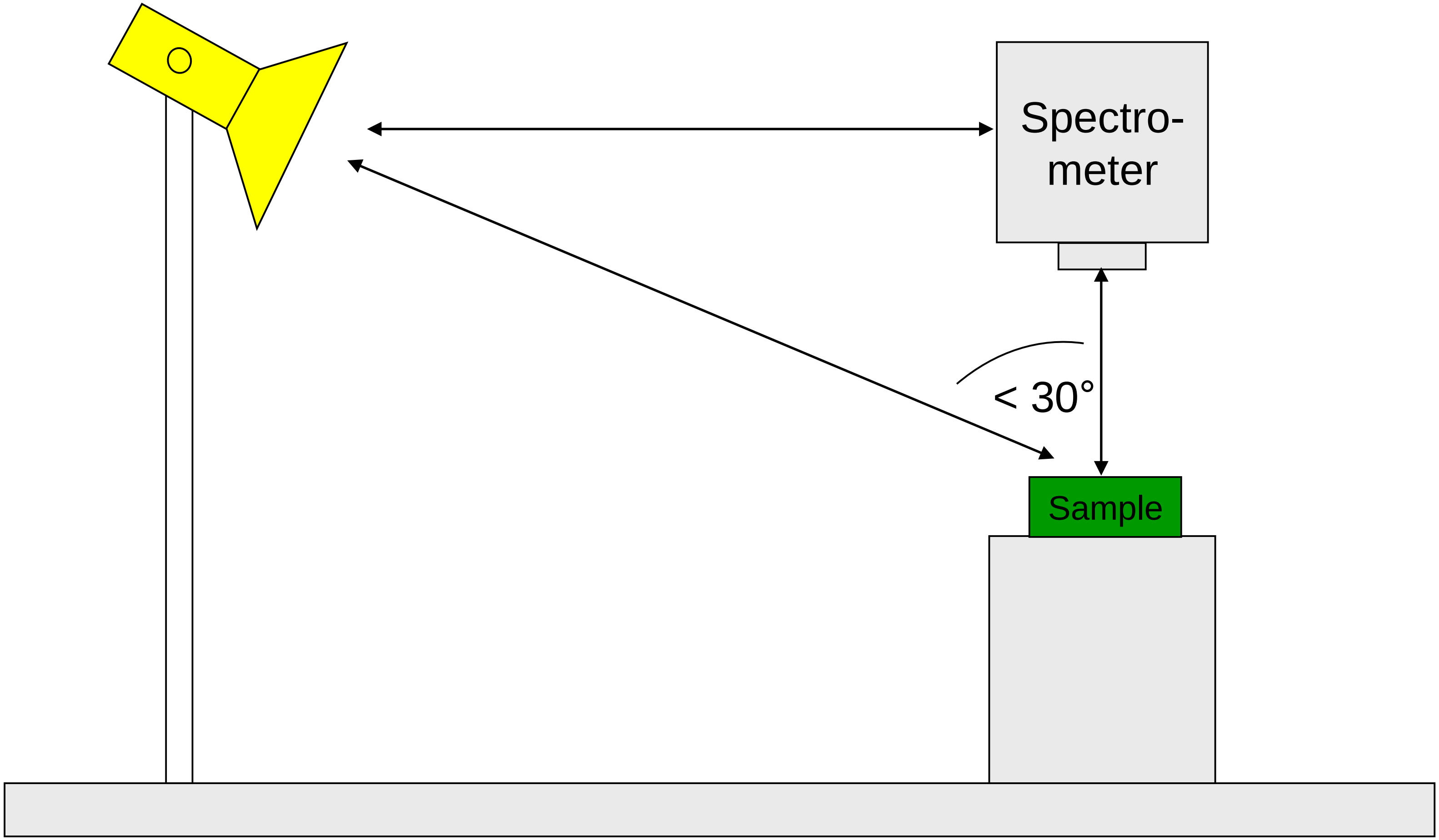
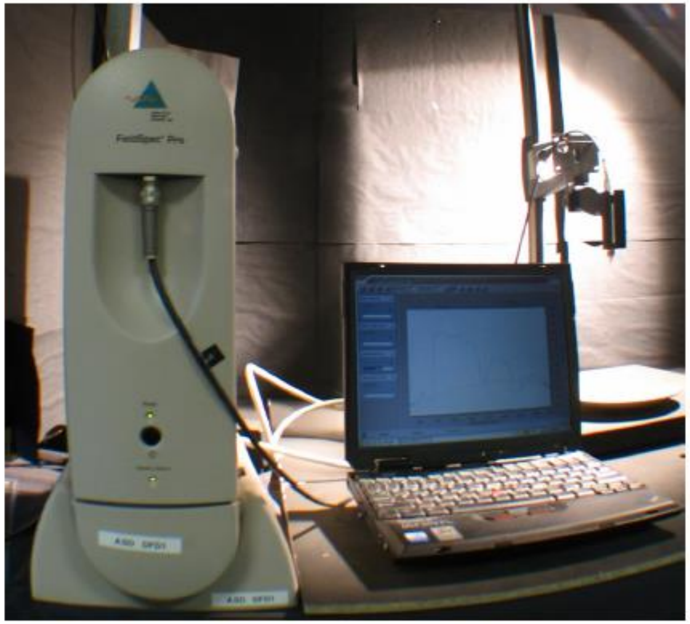


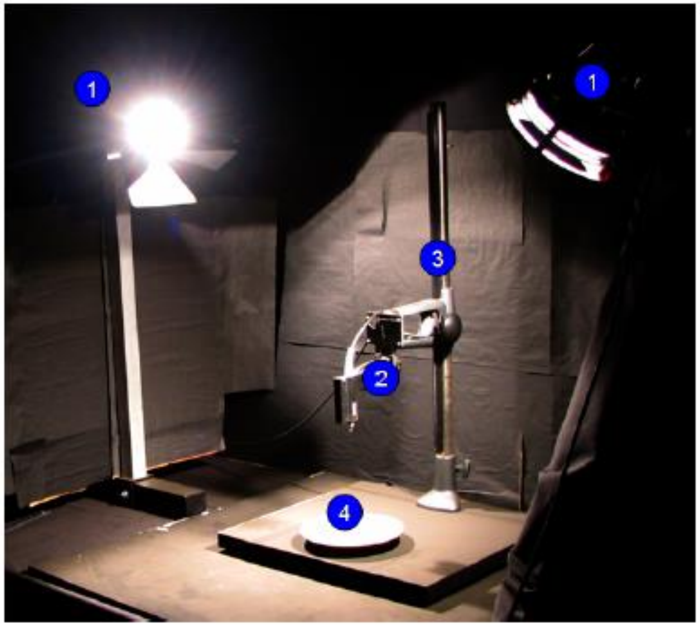
Figure 1. The major sources of illumination. Note that it is possible to have several sources of light scattered off of surrounding objects, each with its own unique spectral distribution.

Typical laboratory setup

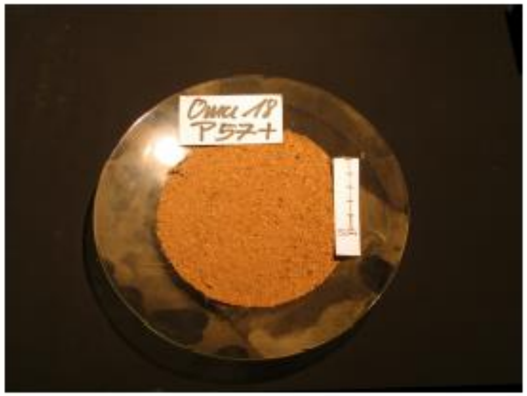


Typical laboratory setup

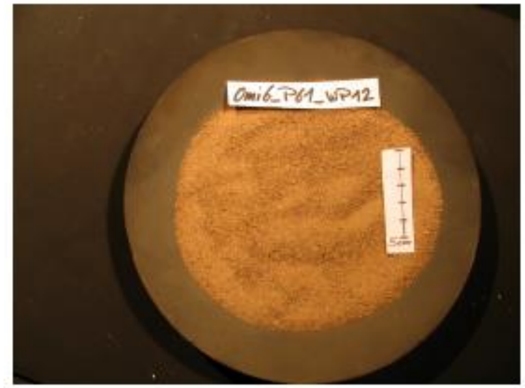




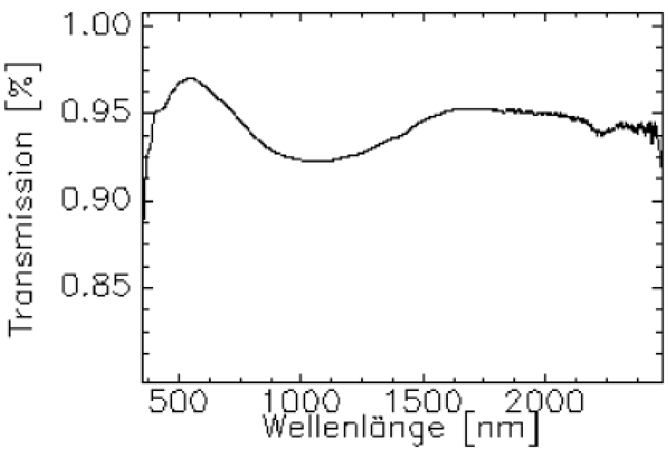
Reflections on sampling dish

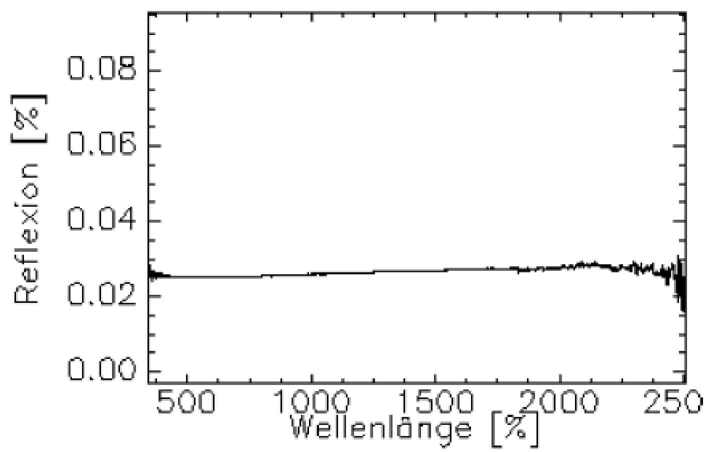


Glass petri dish



Coated with “3M Black”





Additional influencing factors

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Physical basics

Reflection behaviour of surfaces

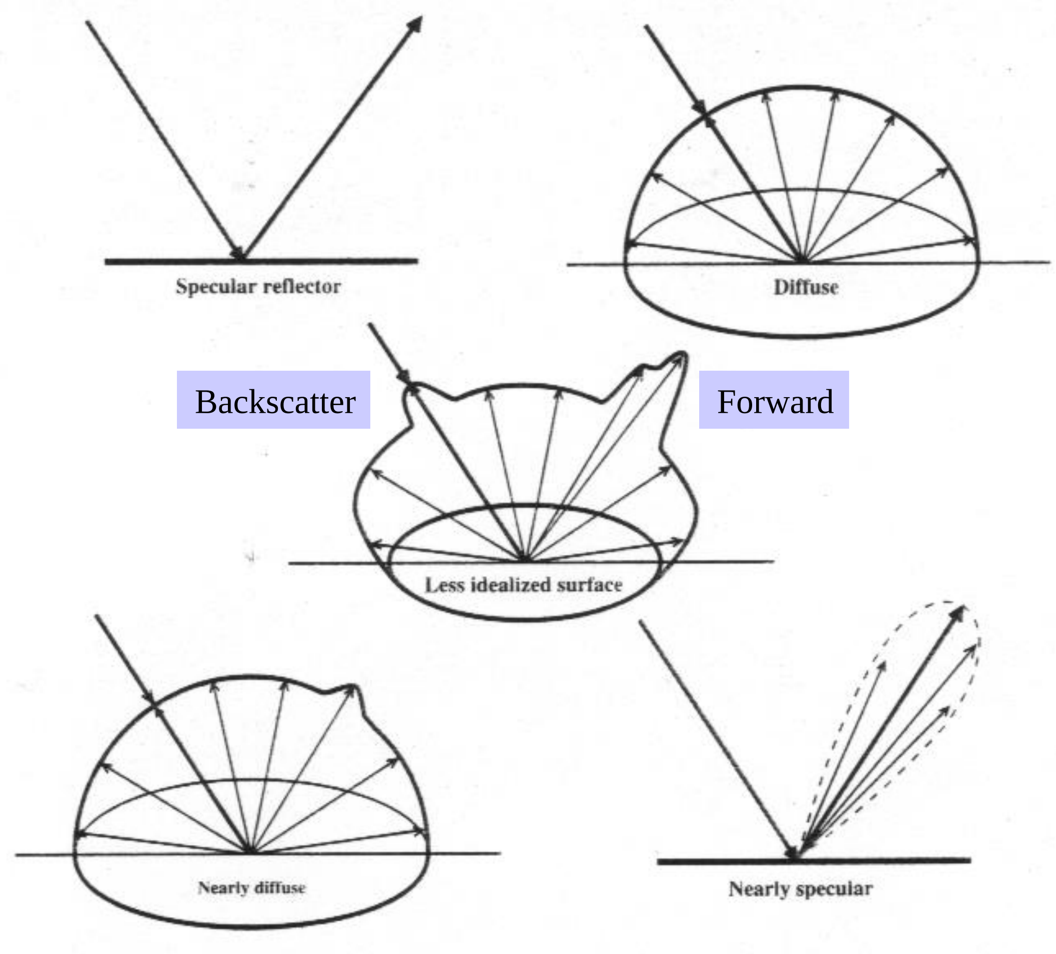


Figure 4.7 Reflectance characteristics of idealized surfaces.

Physical Basics

- BRDF

$L_\lambda = \rho_\lambda E_\lambda (\cos \Theta) f_r$ f_r = bidirectional distribution function

for Lambertian surfaces.: $\rho_\lambda = (L \lambda \pi) / (E \lambda \cos \Theta)$

- Shade due to surface roughness

- HotSpot-effect:

If view direction = illumination direction => no shade visible

=> brighter & specular => no Lambertian

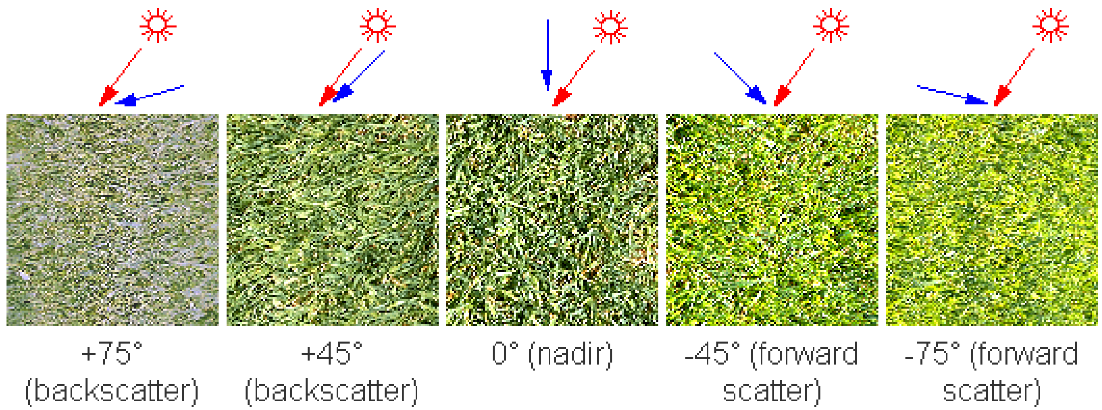


Fig. 2: Bidirectional reflectance effect on a grass lawn, observed under different viewing angles from a FIGOS mounted camera in the solar principal plane. Solar zenith angle is 35°, indicated with red arrows. The view directions are given in blue. The camera is operated in the manual modus keeping aperture,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

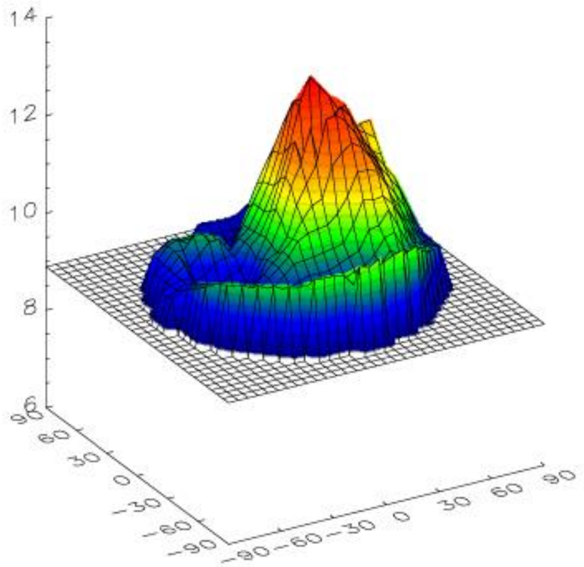
http://www.geo.unizh.ch/rsl/

DAISEX-1999

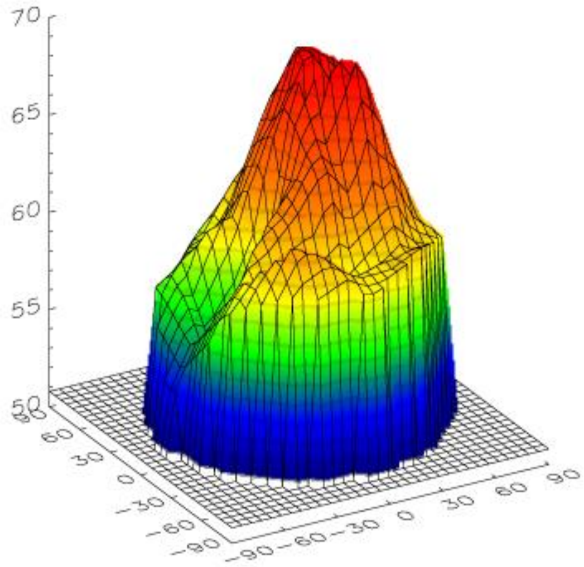
FIGOS data

Barrax, Spain

ALFALFA



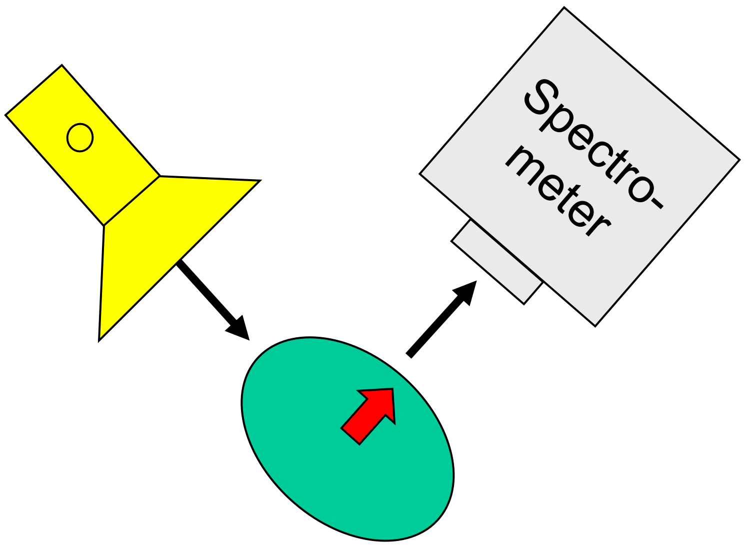
FIGOS (550 nm)

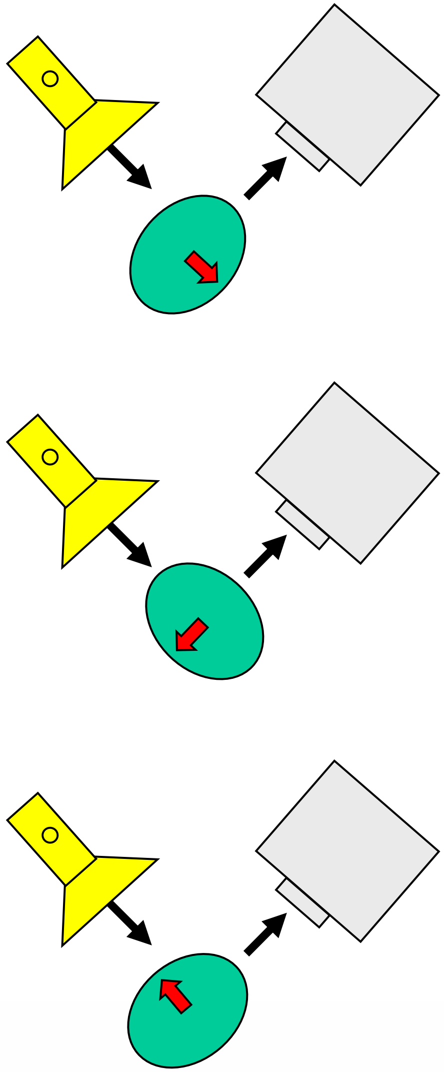


FIGOS (800 nm)

BRDF - signatures

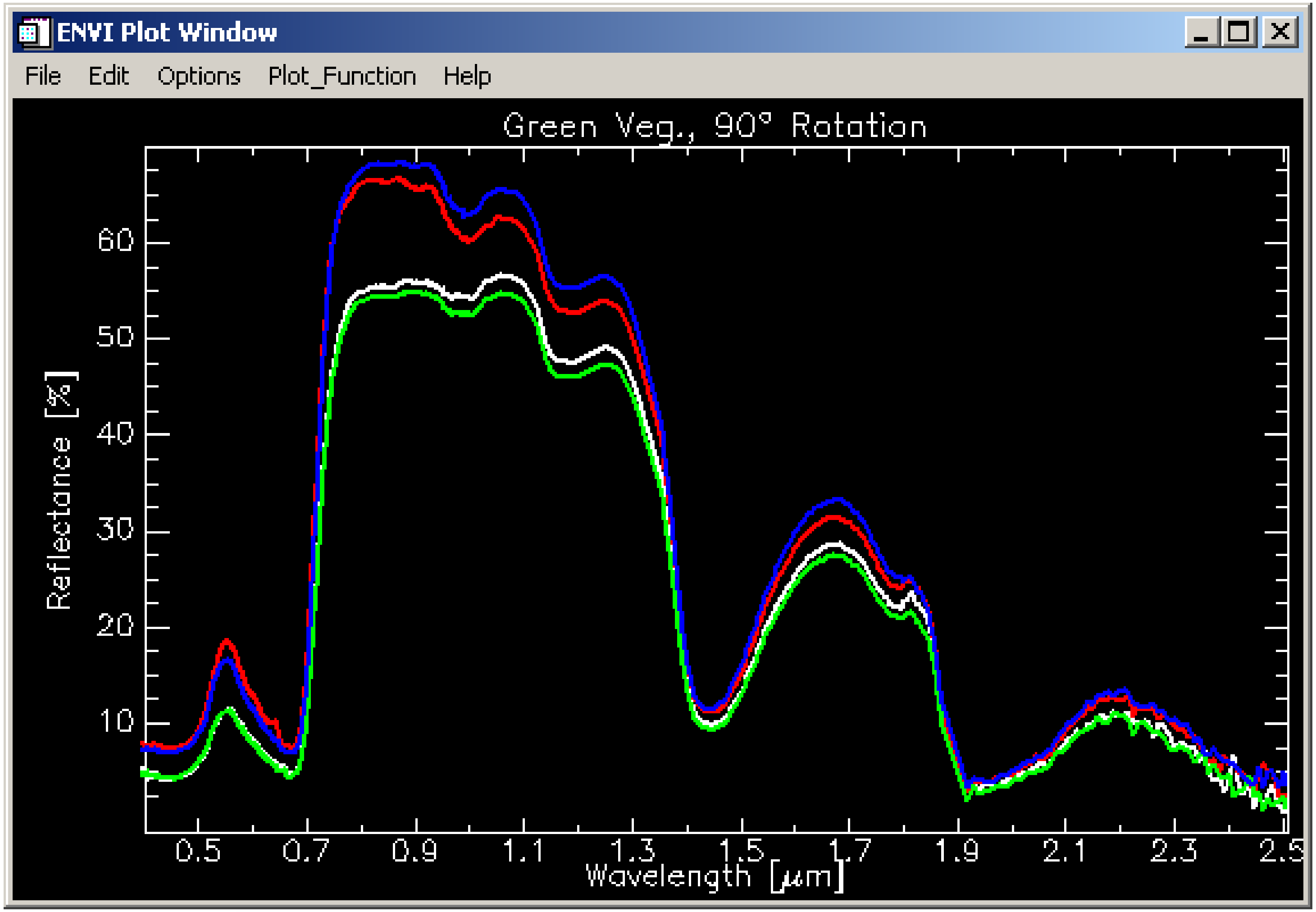
Sample orientation & BRDF effects





- Take 2-5 measurements
- Rotate the sample by steps of 90°
- Measure again
- Rotate again
- …

BRDF effects



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Post-Processing

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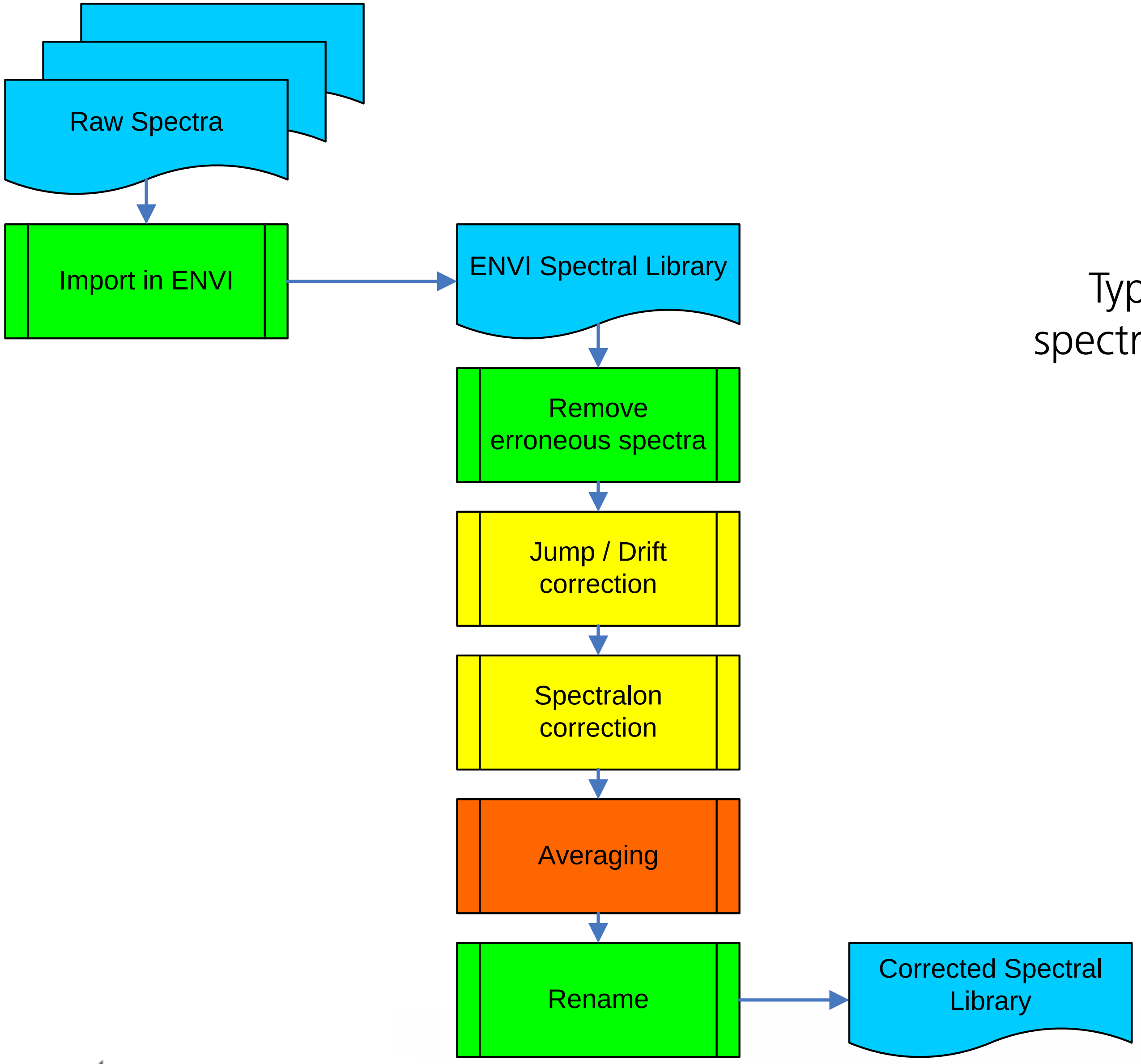

Typical workflow for spectral library compilation

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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)
  - Indentify characteristic features
  - Parameterization of features

Field / Laboratory Spectroscopy

Laboratory spectroscopy

Advantages

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

Disadvantages

- Changed surface roughness & moisture
- Large objects (trees) ???

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

Field spectroscopy

Advantages:

- Natural surface conditions (roughness, moisture)

Disadvantages:

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

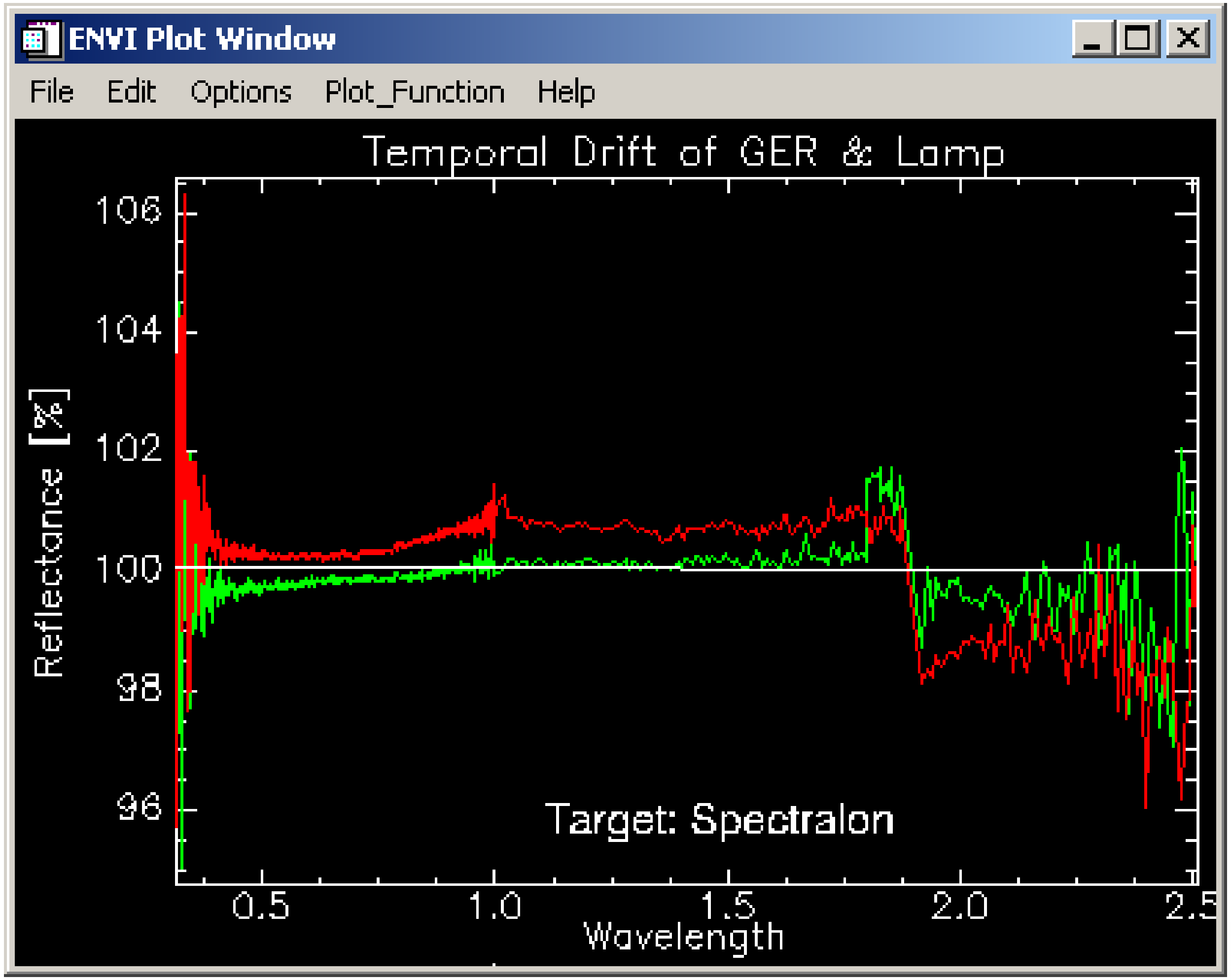
Field spectroscopy

- Measurements in the field

  - Measure with high solar zenith angle (at solar noon ± 2 h)
  - Azimuth angle to illumination ~ 90°
  - Vegetation: keep distance to canopy
    or: close to single leaf
  - GER (< FOV)
    ~5 measurements with slightly changing view angle
    (geometrical oversampling)
  - ASD (> FOV)
    ~5 measurements with identical view angle (temporal oversampling)
    or: measure continuous transect

Sources of error in the lab

Lamp- and Instrument-Drift



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Now: How to measure?

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How to measure

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

How to measure

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

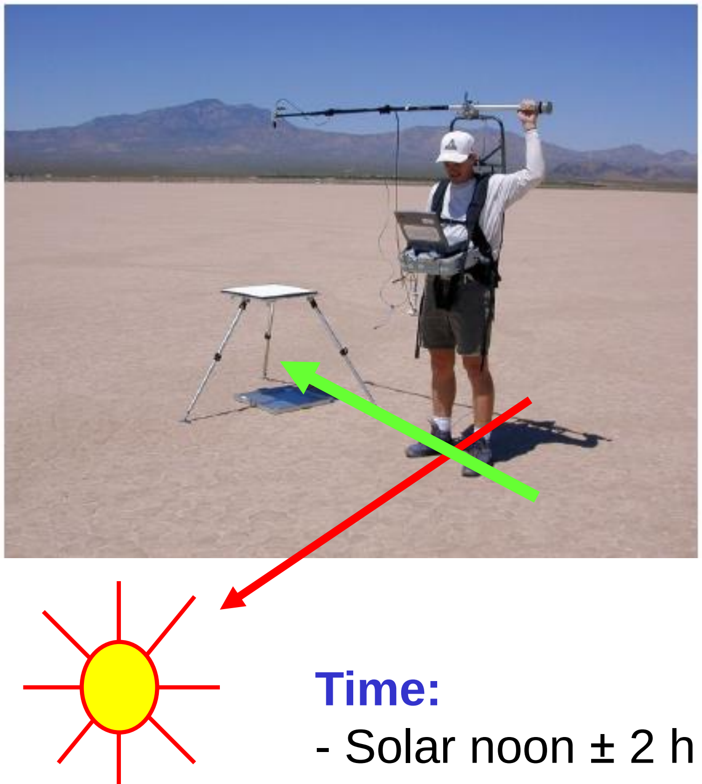
- Wait for stable signal (1x screen refresh)
- (Approx.) same geometric setup as WR measurement
- Number in display “plant.**008**” => the **next** measurement to be saved!

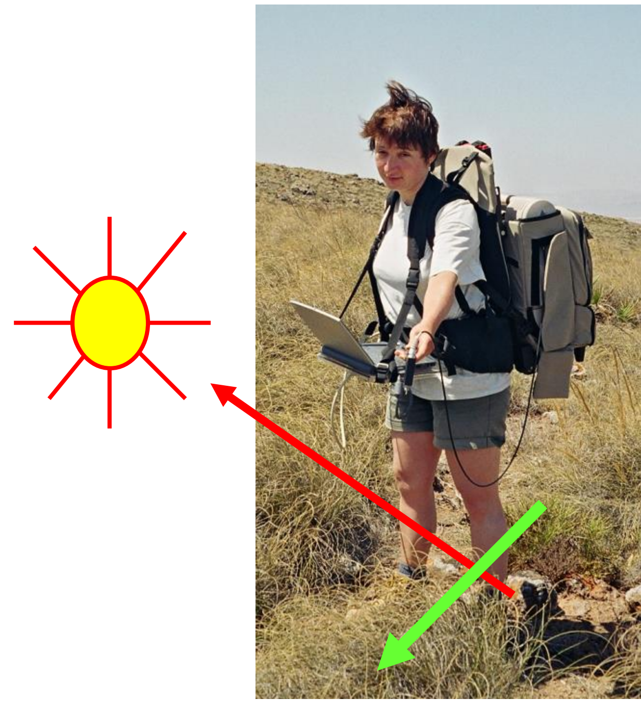
9. Quality Control

- When pointing at spectralon, are there steps, or deviations from 100% line ?

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

How to measure





Time:

- Solar noon ± 2 h (depends on season & latitude)

Geometry:

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

How to protocol your measurements

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

Spectral Measurements Form – Field version

DLR

Section A – GENERAL INFORMATION

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

Additional information:

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: °
Light source:	Sun ☐	Reflectance probe ☐	Tripod ☐				

Additional information:

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:	

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
					☐	☐
					☐	☐
					☐	☐
					☐	☐
					☐	☐

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