

The portable Finnish Geodetic* Institute Field Goniospectrometer

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Finnish Geodetic Institute

- Governmental research institute
 - scientific basis for Finnish maps and geospatial information
 - research on methods for the measurements, data acquisition, processing and exploiting of geospatial information
- Departments:
 - **Geodesy and Geodynamics,**
 - **Remote Sensing and Photogrammetry,**
 - Geoinformatics and Cartography,
 - Navigation and Positioning

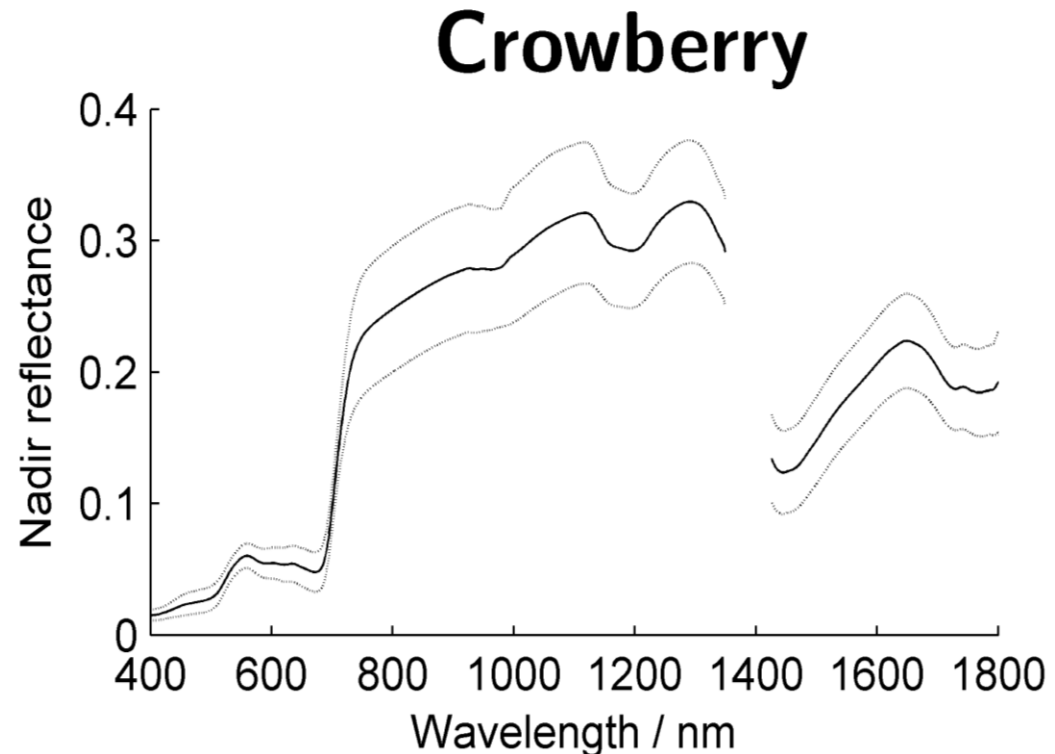


Measurement and Analysis of Bidirectional Reflectances



Reflectance factor

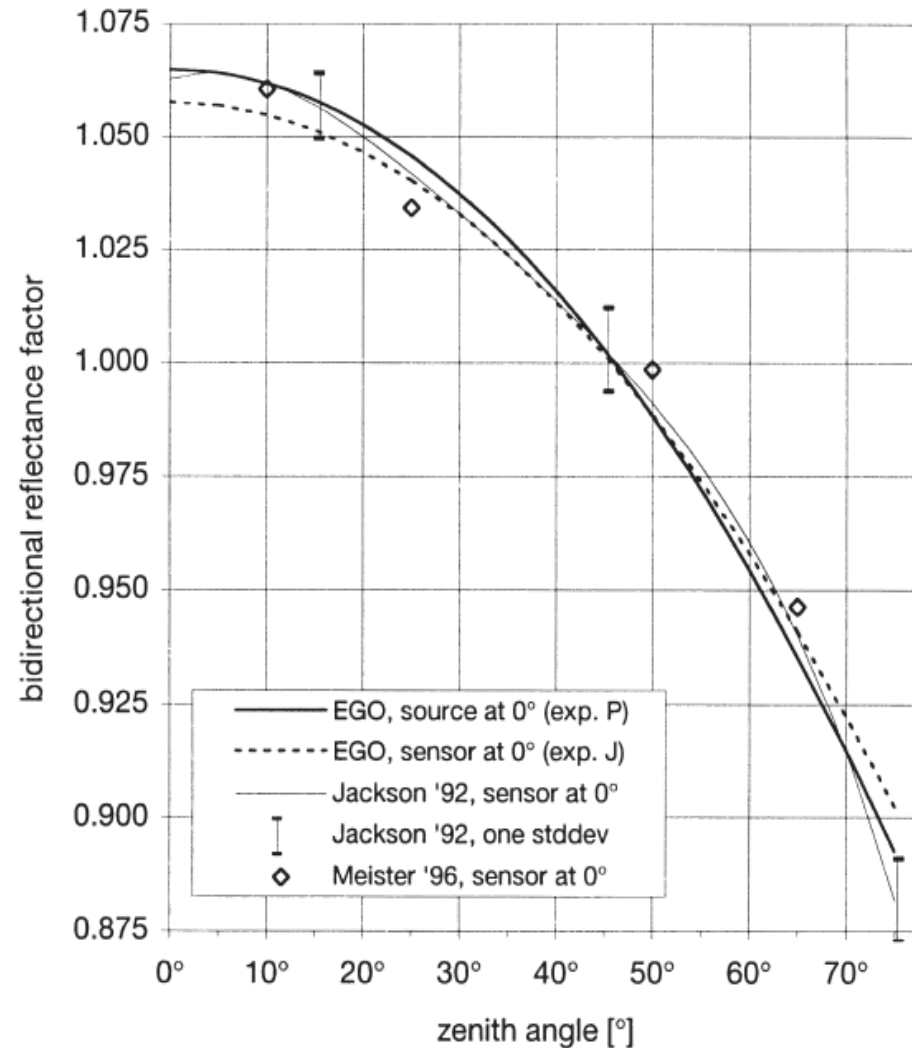
- Radiance from target divided by radiance from white matte (Lambertian) surface
 - 0 for black surface
 - 1 for white diffuse surface (Lambertian)
- The most typical reference material is Spectralon



Lambertian surfaces

- An ideal surface that
 - ...is perfectly matte
 - ...scatters same amount of light to all view directions
 - ...is not affected by illumination direction
- Do not exist in real life
 - All surfaces are more or less anisotropic scatterers
 - Not even Spectralon is Lambertian..

Spectralon @ 600 nm

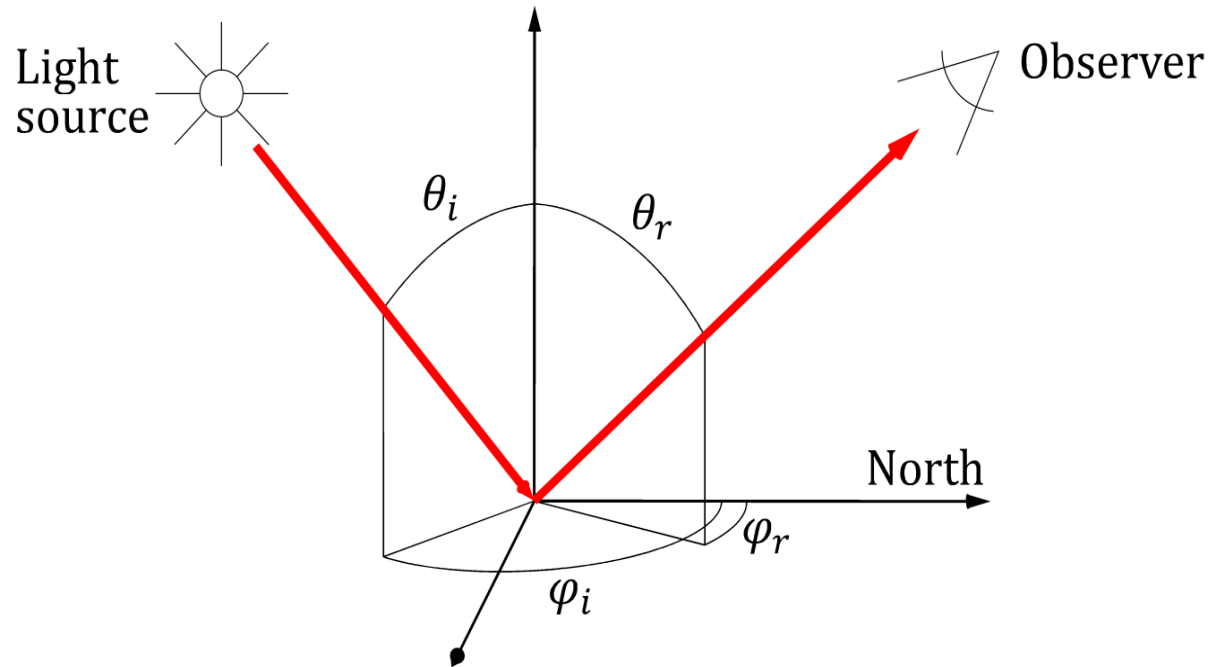


Sandmeier et al., RSE, 64,176-191 (1998)

Bidirectional Reflectance Factor

- Anisotropy of reflectance is described with concept Bidirectional Reflectance Factor (BRF)
- Bidirectional geometry is defined by illumination and view directions

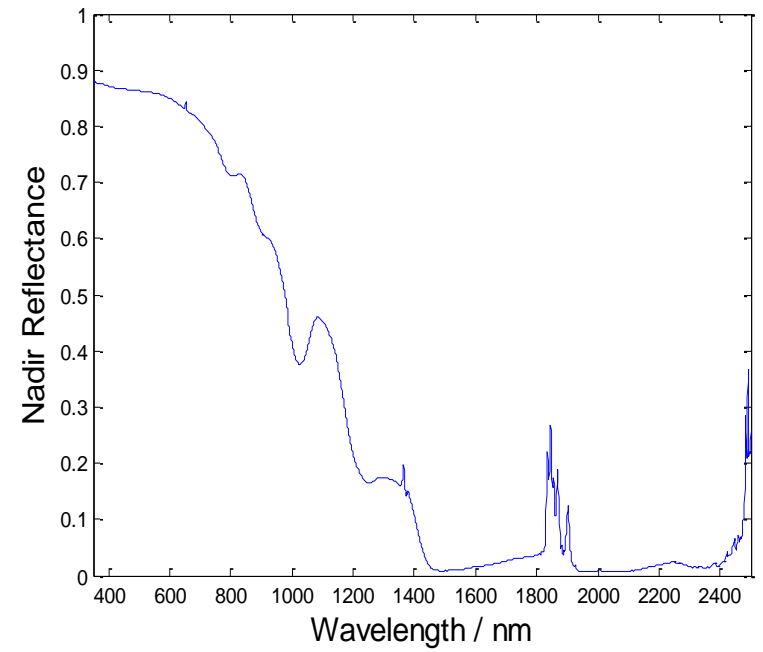
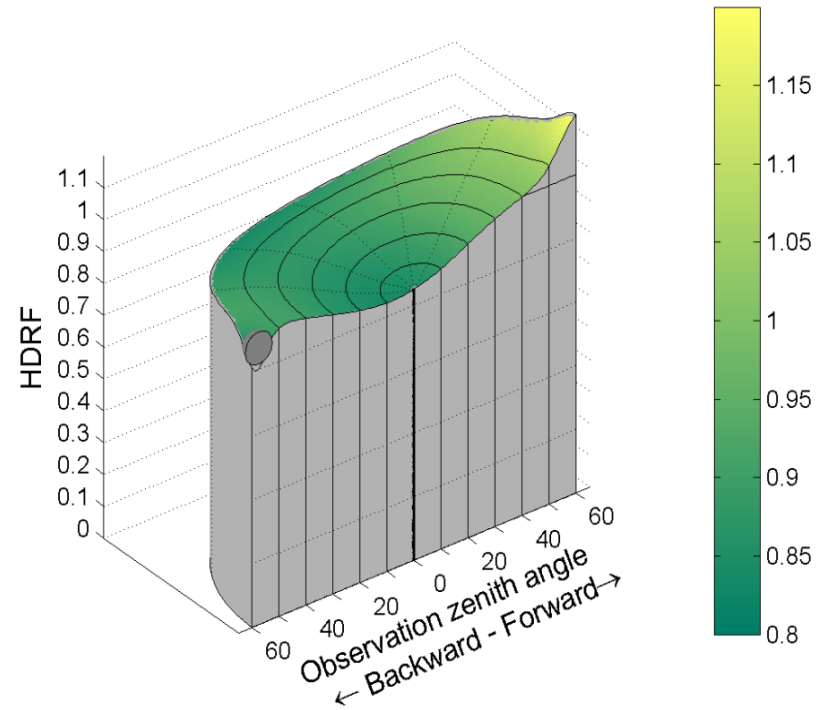
θ zenith angle
 φ azimuth angle



EXAMPLES OF BRF/HDRF

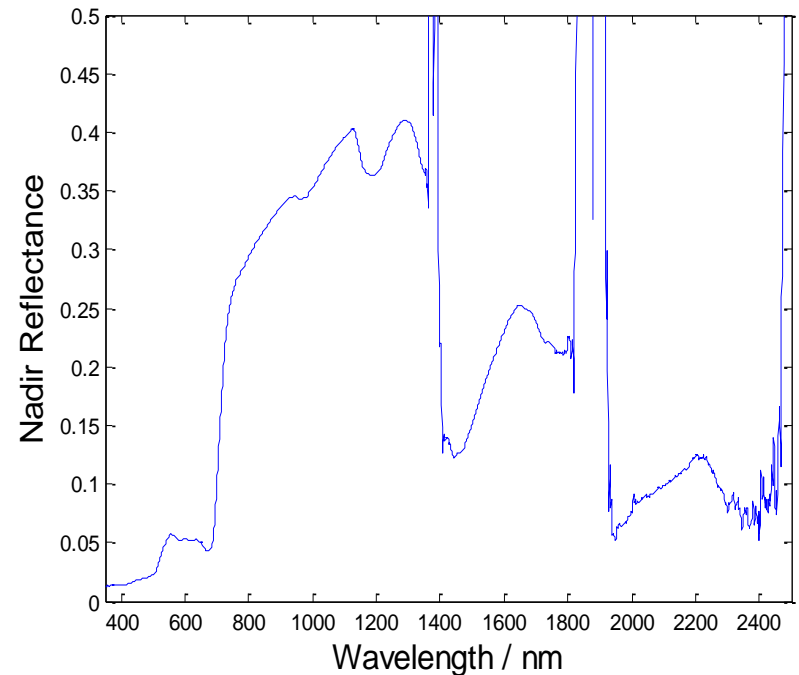
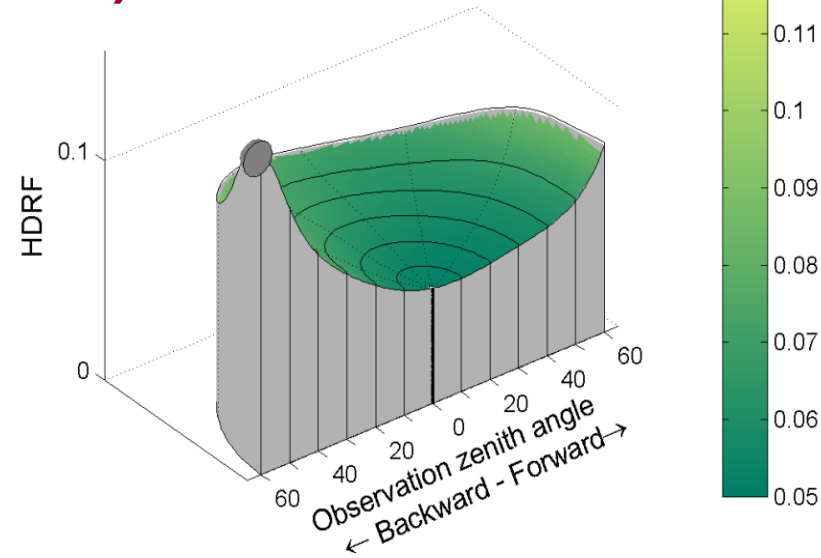
Snow (Sodankylä)

- Melting snow with wet surface layer
- Forward scatterer



Dwarf birch (Abisko)

- A thick layer at the top of a mountain
- Concave shaped HDRF

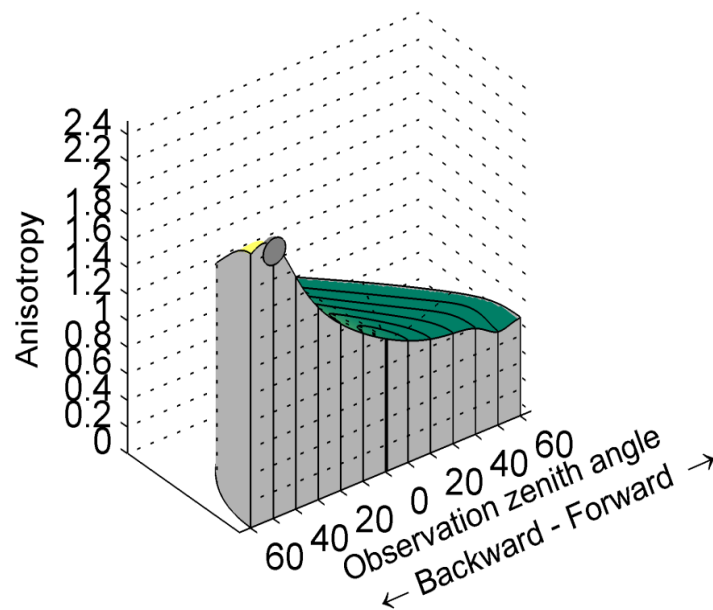


Lichen



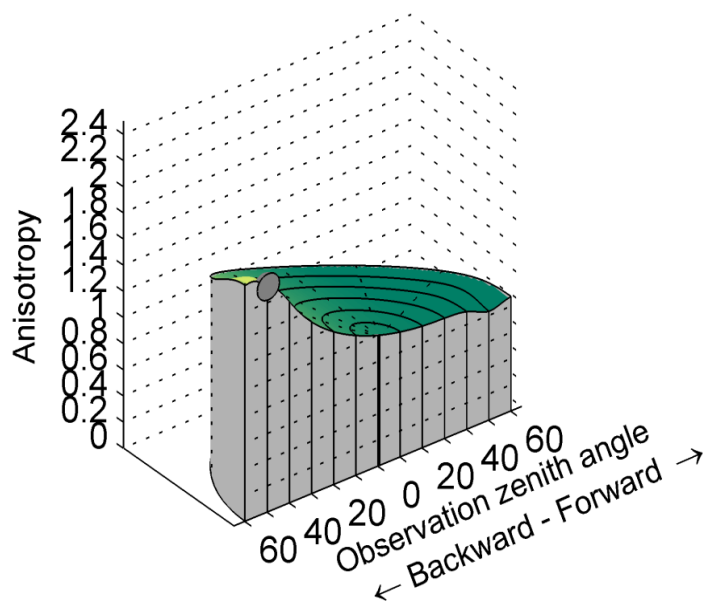
550 nm

Lichen

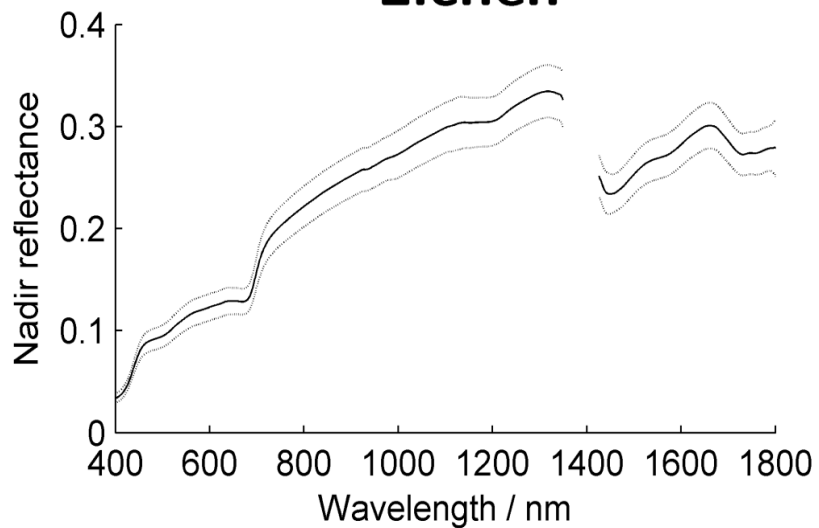


850 nm

Lichen



Lichen

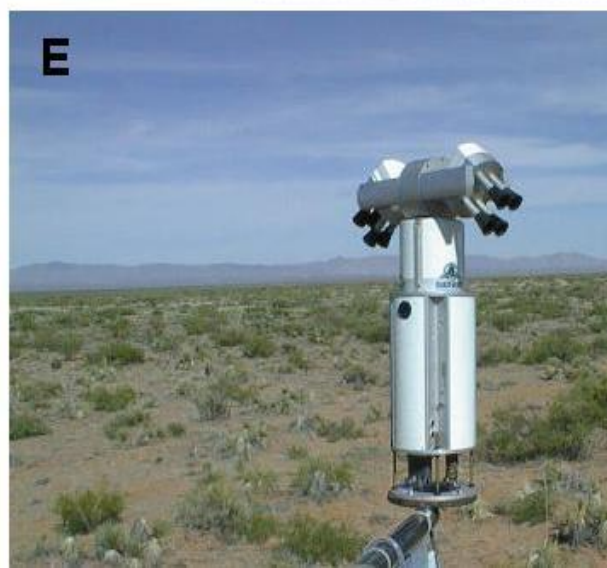
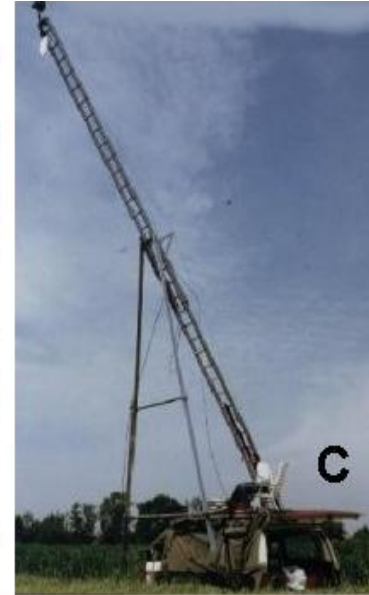
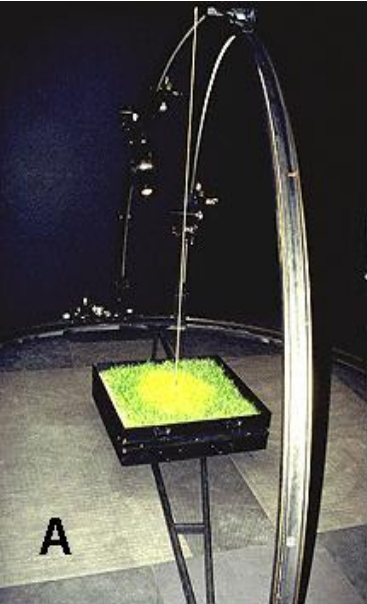


MEASURING BIDIRECTIONAL REFLECTANCE FACTOR

How to measure BRF?

- All reflectance factors have some illumination and view geometry
- Thus we need to measure reflectance from multiple directions while registering of illumination and view geometry
- Goniometer devices have been built to solve this task

Some large scale goniometers



- A. EGO
- B. FIGOS
- C. MUFSPeM
- D. Sandmeier
Field
Goniometer
- E. PARABOLA
III

FGI goniometer model III



Model III goniometer

- A fine instrument, but...
 - Heavy
 - limited only to road access sites
 - Large
 - needed a trailer,
 - not suitable for rough ground
 - Manual use
 - slow
 - prone for human errors
 - Laboursome
 - 3 busy operators

FIGIFIGO

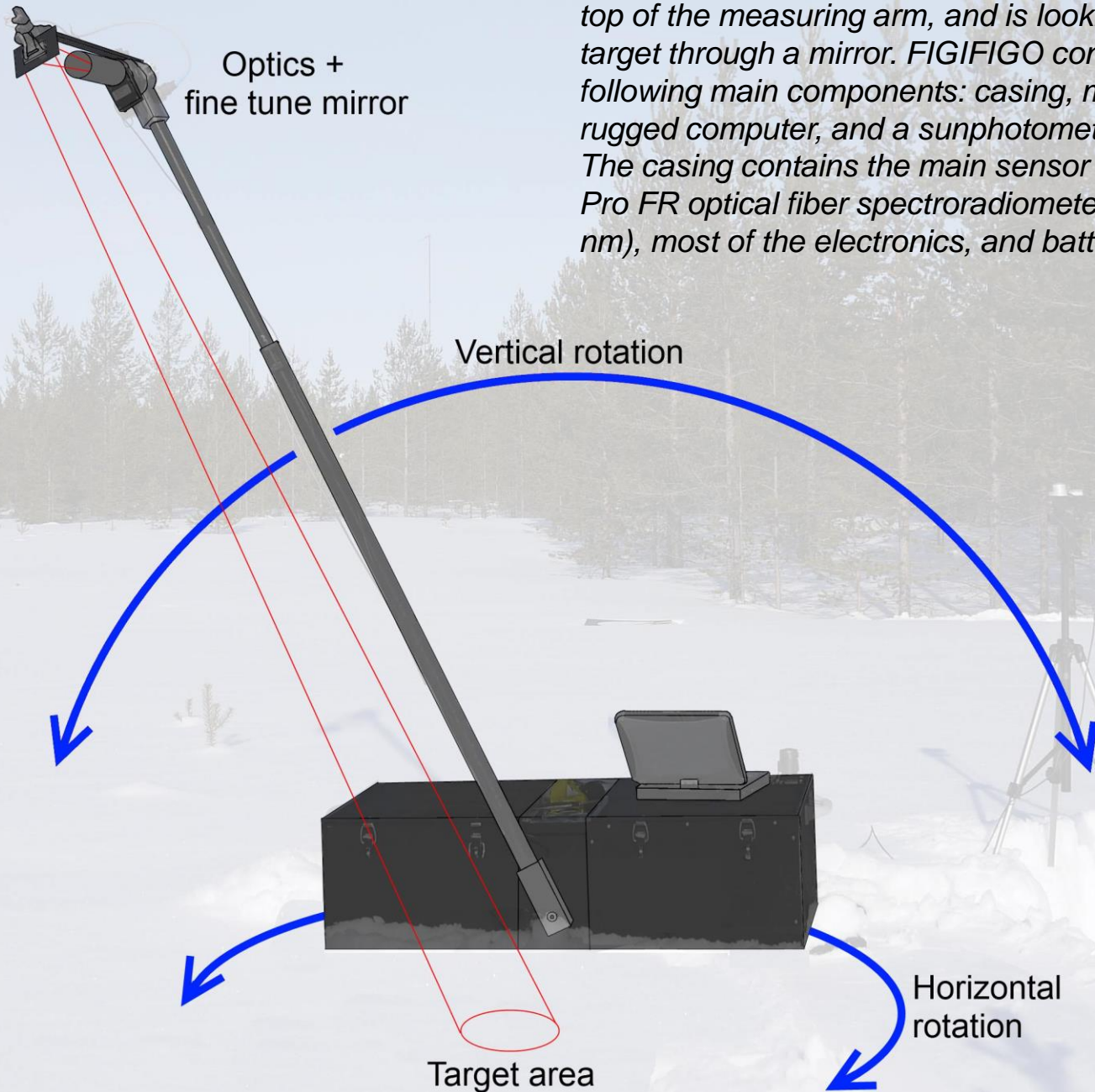
FGI's Field
Goniospectrometer

Primary targets:
Vegetation and snow

Extra Applications:
Planetary science
(e.g. meteorite
measurements and
their matches with
asteroids)

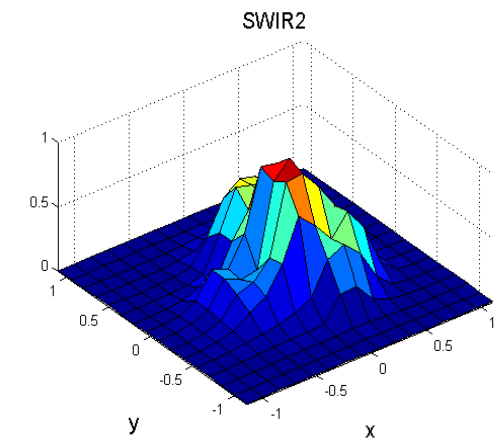
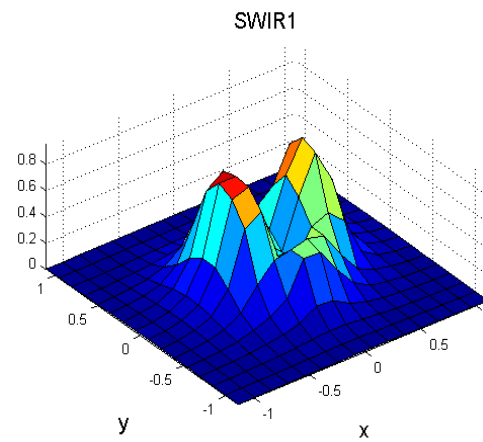
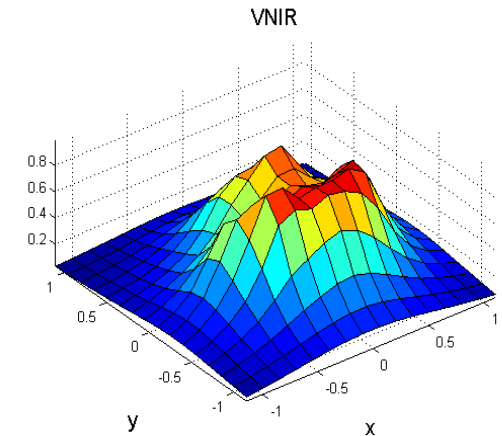
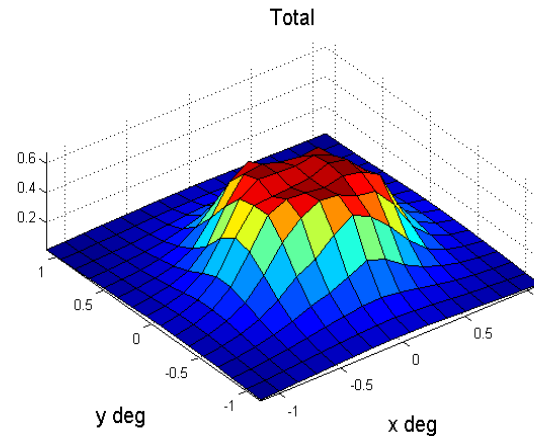


The active optics system is located horizontally at the top of the measuring arm, and is looking down to the target through a mirror. FIGIFIGO consists of the following main components: casing, measurement arm, rugged computer, and a sunphotometer on a tripod. The casing contains the main sensor ASD FieldSpec Pro FR optical fiber spectroradiometer (350 – 2500 nm), most of the electronics, and batteries.

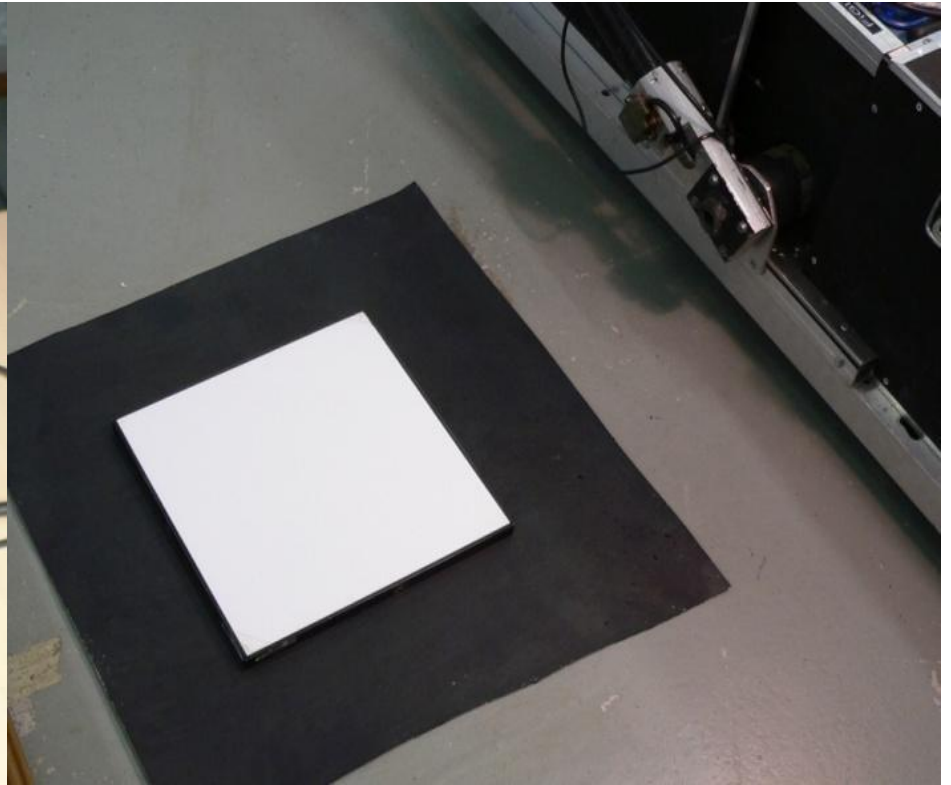
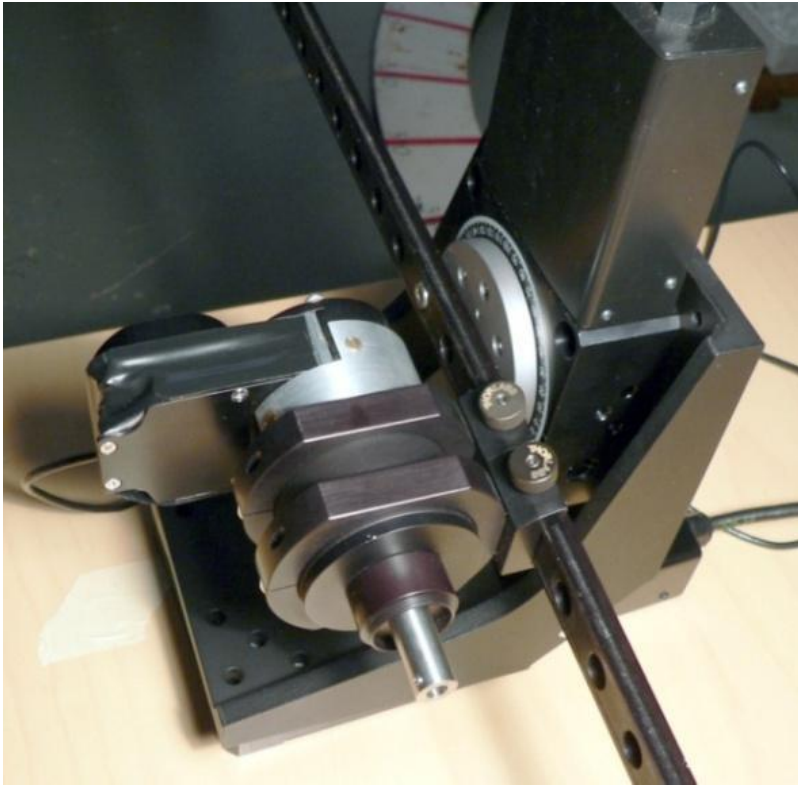


The field of view test results for nonpolarizing optics

The x and y axes display the displacement of each axes in degrees from the center. Z axis represents the normalized intensity values in that direction. The plot is for each individual sensor and total is the combination of all of the sensors.



**Left: Newport Rotation stage with the polarizing optics.
Right: Spectralon reference panel**



FIGIFIGO Key features

- Automated zenith turn
- Manual azimuth turn
- ASD FieldSpec Pro FR
 - 350-2500 nm
 - Changeable optics
 - Field of view 5-25 cm
- Option: Computer turned linearly polarizing optics

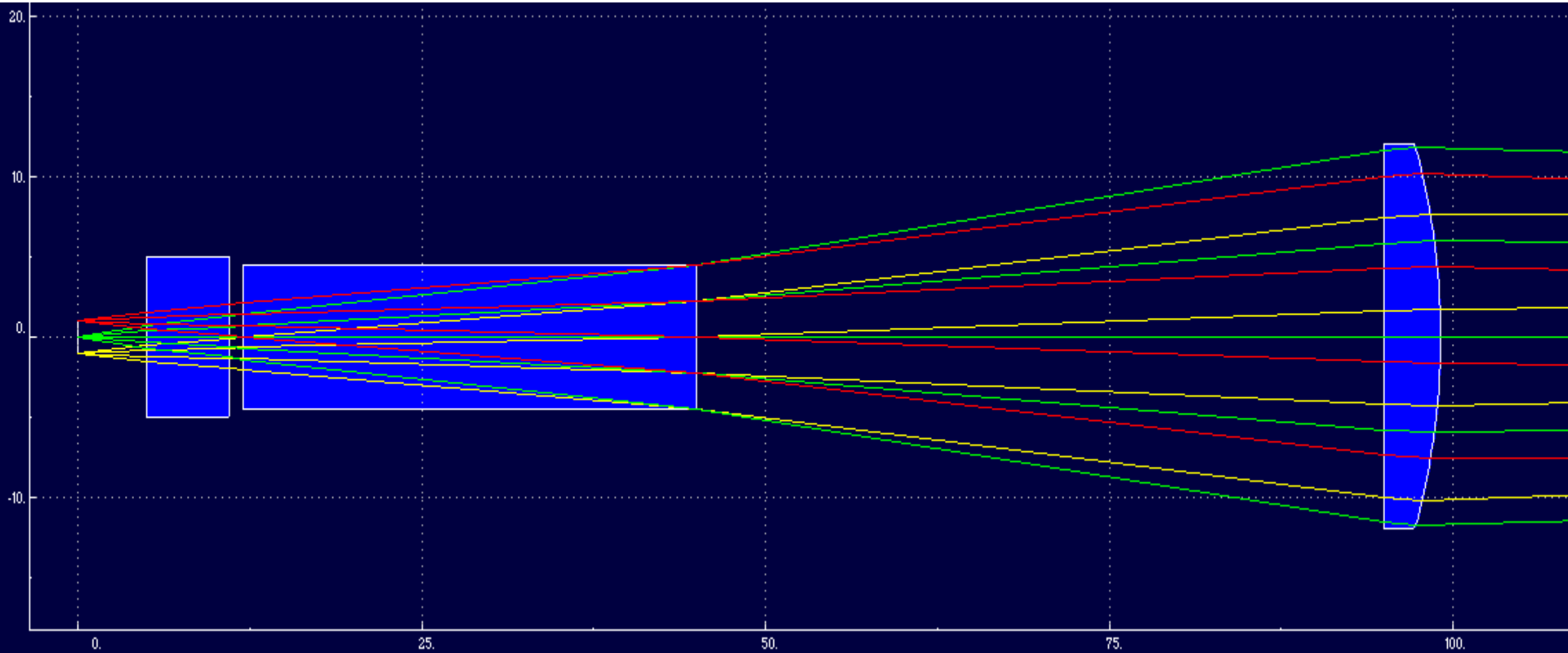


Portability

- Battery powered
- Quick to assemble
- 30 kg
- Fits inside an estate car
- A rugged control computer

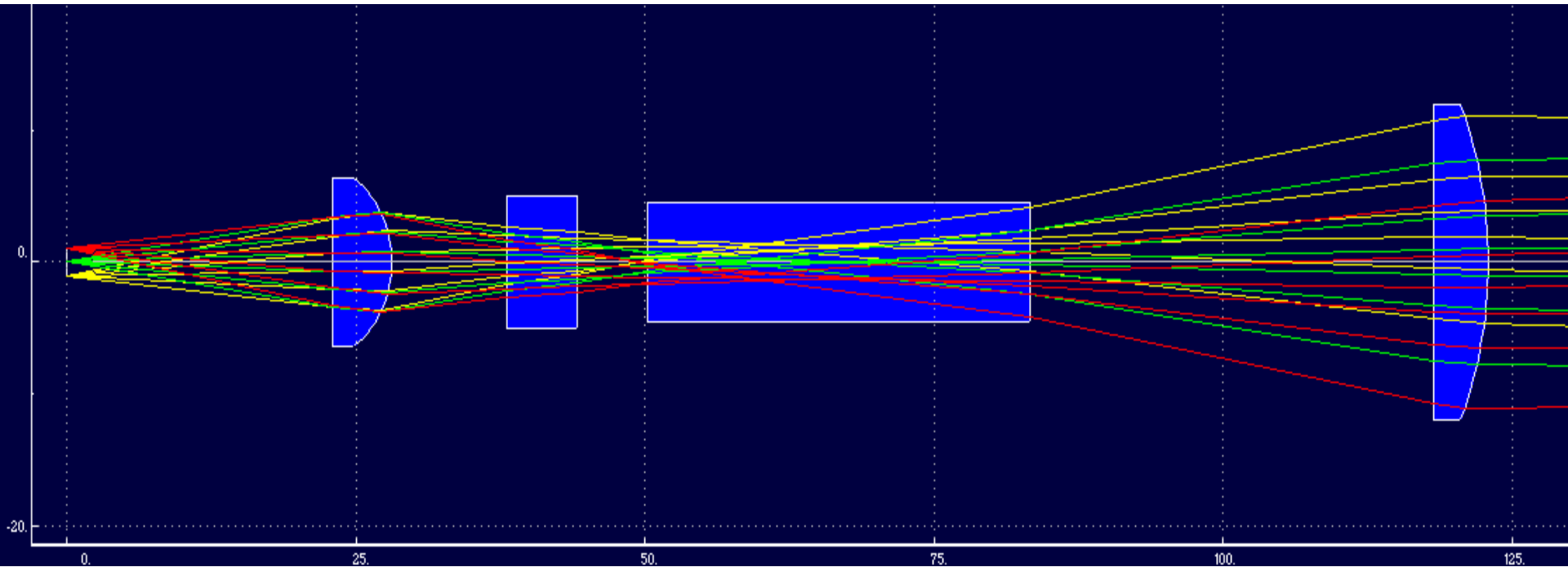


The optical construct of the old polarizing optics



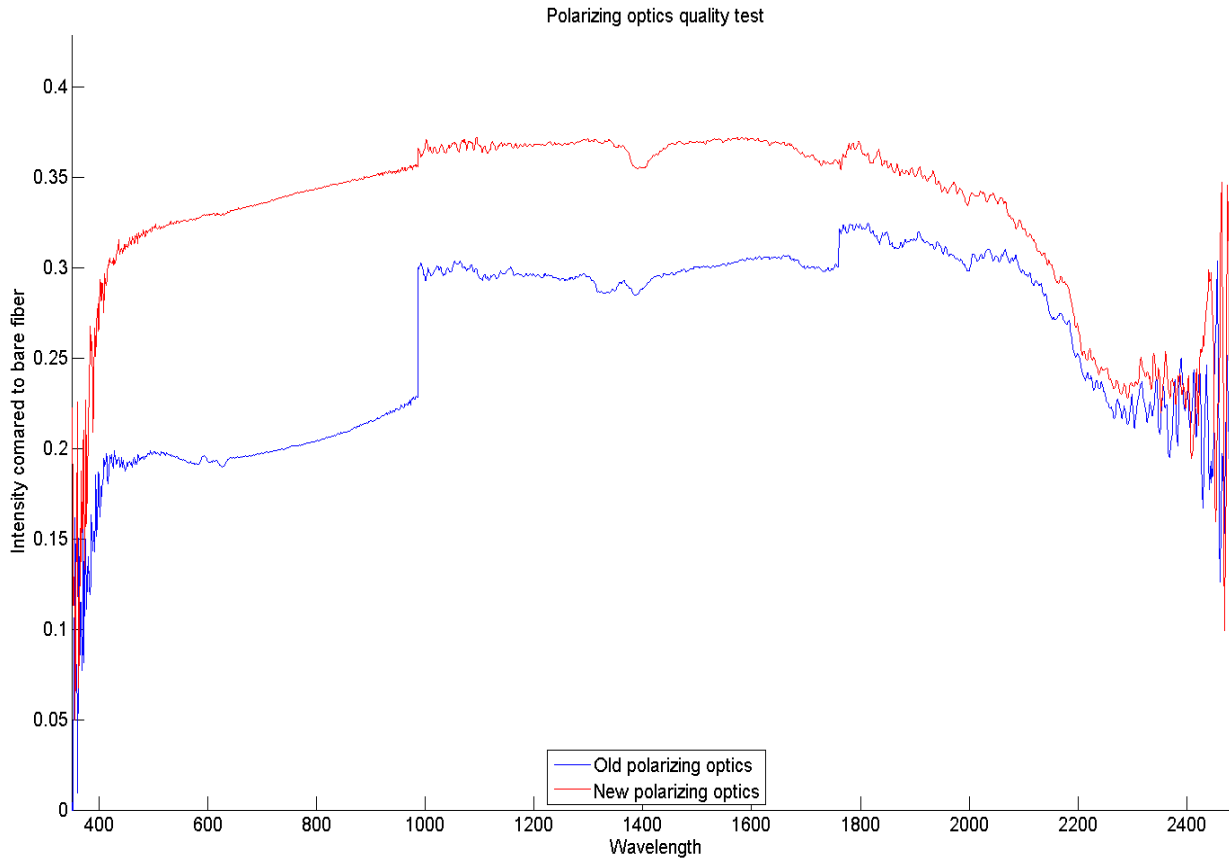
The leftmost is the surface of the optical fiber, next is depolarizer, polarizer and f 75 mm D 25.4 mm lens. The units of the axis are in millimetres. Different colored lines represent beams hitting different areas of the fiber optic bundle

The optical construct of the new polarizing optics



The leftmost is the optical fiber, next is f 15 mm D 12.7 mm lens, depolarizer, polarizer and f 60 mm D 25.4 mm lens. The units of the axis are in millimeters. Different colored lines represent beams hitting different areas of the fiber optic bundle.

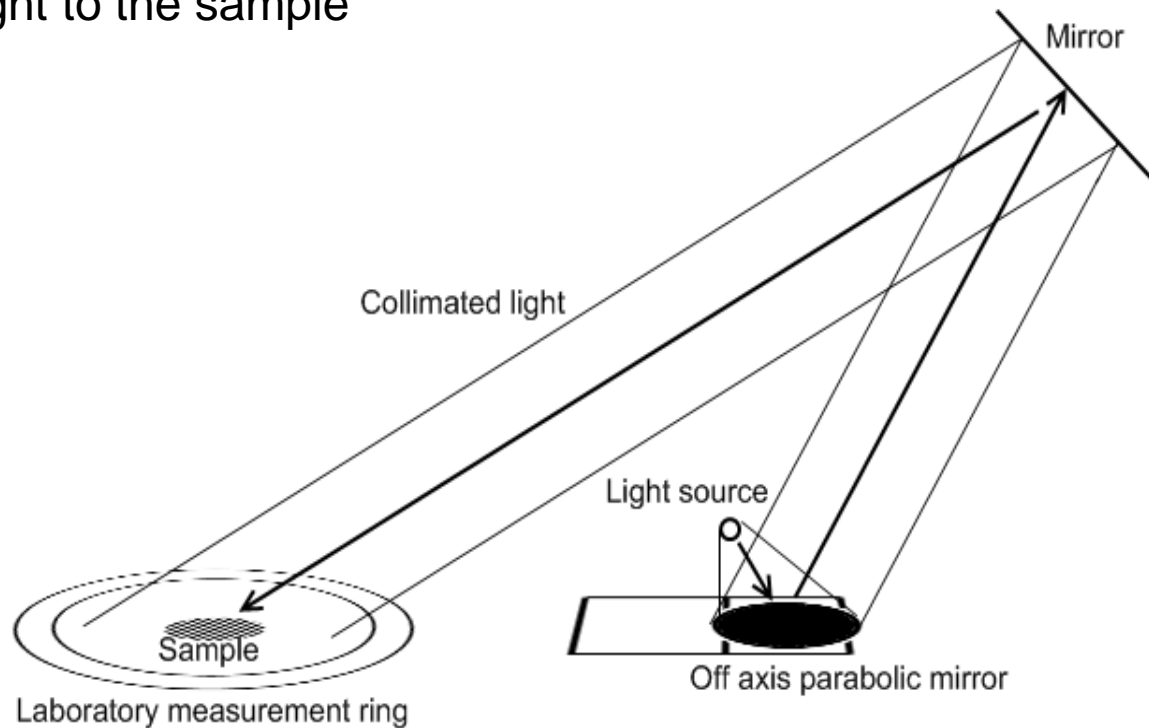
Attenuation of light intensity for old and new polarizing optics



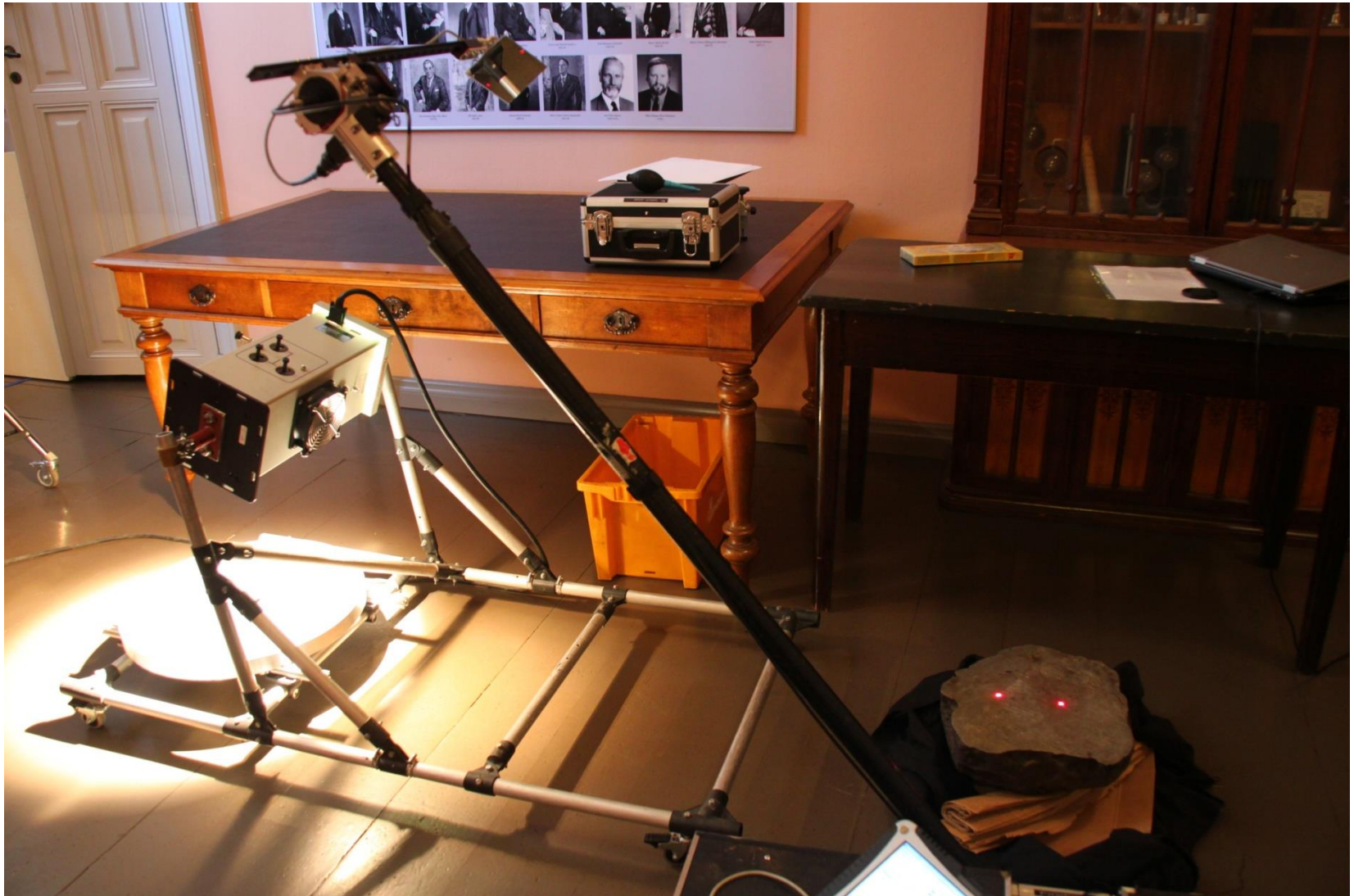
The graph is the signal measured through each optics set divided by the signal from bare fiber. The signal is dropping around 2200 nm because the Glan Thompson polarizer has transmission range of only 350 - 2300 nm. The signal to noise ratio of the detector is poor at the very ends of the measurement range, and thus the data there is mostly noise. The clearly visible steps at sensor borders might be because of the different locations of the fibers in the fiber bundle leading to different sensors

The laboratory lighting setup

The light source and the off axis parabolic mirror are mounted in same frame to keep the geometry constant. A large flat mirror is placed on a heavy tripod, and is used to reflect the light to the sample



The laboratory lighting setup



Problem: Non-constant illumination

- The intensity and the spectrum of the incident irradiance varies over time
- A hemisphere of BRDF measurements may take up to 20 minutes
- In that time sun has moved ~5 degrees
- Even thin, practically invisible, clouds affect the irradiance

Answer: Record the changes in your data

- Work only on clear sky days
- Measure white reference often
- Measure white reference before and after the target and interpolate
- Use a sun photometer to record illumination and scale each spectrum with that
 - Use a second spectrometer if possible



Problem: How to determine view direction?

- In sunlight measurements it is necessary to determine goniometer orientation
- An electronic compass is a plausible solution, but accuracy is at best 2° and it is vulnerable to magnetic disturbances
- Dual-antenna GPS would be an ideal solution, but currently they are large and expensive

Answer: A hemi-spherical sky camera

- All the measurements are taken in direct sunlight
- Sun position can be calculated using GPS data
- A hemispherical sky camera is mounted on the goniometer body
- Sun is detected from the image and with assistance from an inclinometer the orientation is calculated

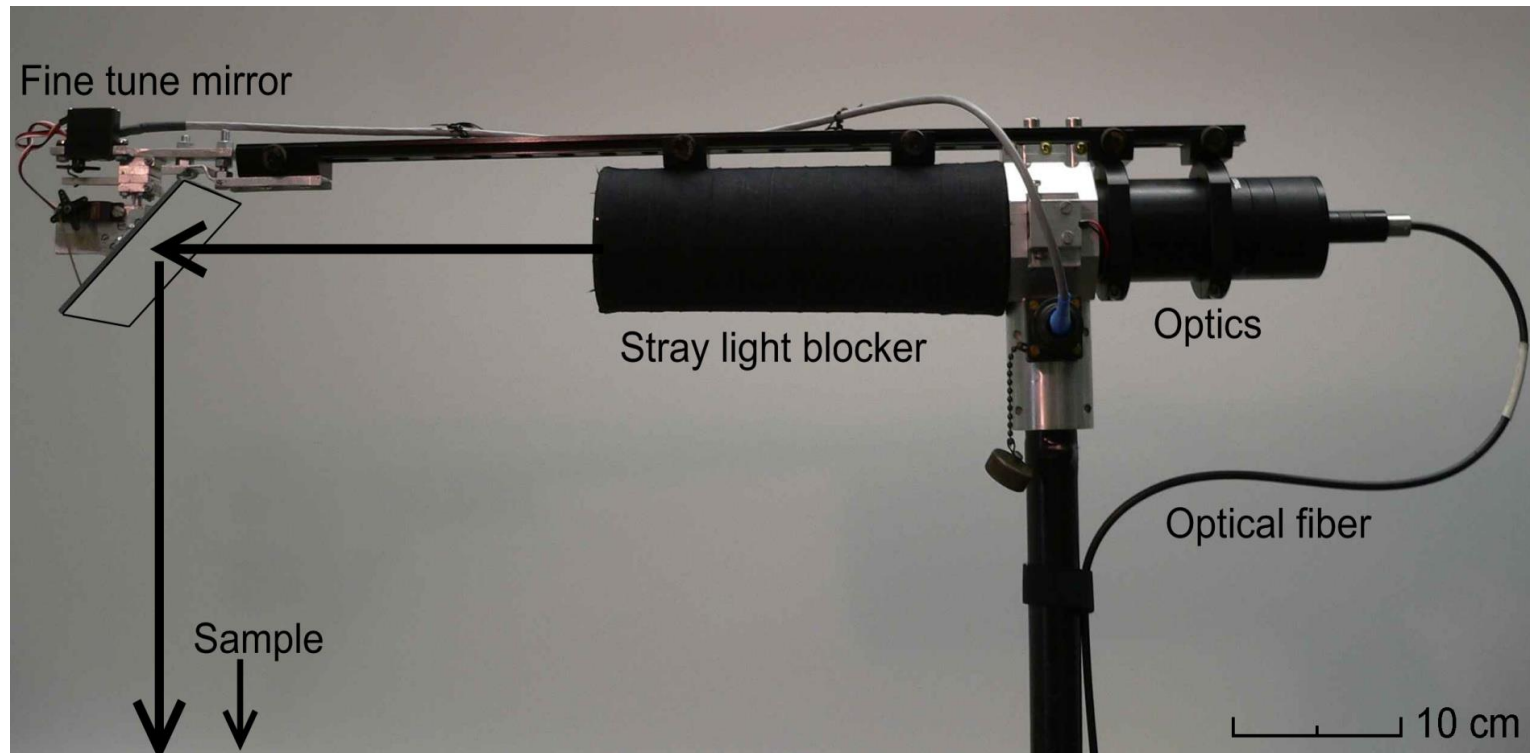
+ we get automated cloud/sky images



Problem: spectrometer footprint position

- On heterogenous surfaces, the spectrometer footprint should be held constant in order to produce consistent BRF
- Two major error sources
 - Rotation of a goniometer
 - Elevation of the sample

Answer: laser pointer & active optics



- Spectrometer optics have laser pointers to show the footprint position
- Sample elevation is entered and a servo controlled mirror adjusts the footprint according to tilt

Problem: Representativeness of the sampling

- The BRF measurement is usually taken from a small area, ~15cm in diameter
- It is too slow to repeat measurements in tens of spots



Answer: Use traditional field spectroscopy for support

- Take a spectrometer and measure tens of reflectances around the area
 - Scale the BRF with mean reflectance spectrum
- Repeat principal plane BRF measurement in a few places
 - Most distinct BRF effect are seen on principal plane

Tips for successful measurements

- Always take tea/coffee/candy/sandwiches with you 😊
 - Hungry/cold/bored operators produce low quality results ;)
- Wear sunglasses, hat and use protective sunscreen
 - You need to watch for clouds and stare at the Sun
- Take your time to observe the target
 - Natural samples always have more details and properties than you might imagine

BRF retrieval accuracy

- The general accuracy of FIGIFIGO BRF measurement is between 1-5% for a well defined sample
- Accuracy depends especially on wavelength, sample reflectance factor, and solar zenith angle
 - Spectrometer noise causes error that is proportional to reflected radiance
 - Levelling of Spectralon panel

Level your Spectralon!

- If a Spectralon panel is tilted even slightly towards the Sun, the panel will receive and reflect significantly more light and spoil the reference

$$\frac{E_{\Delta\theta}}{E_{ideal}} = \frac{\cos(\theta_i - \Delta\theta)}{\cos(\theta_i)} \approx 1 - \Delta\theta \tan(\theta_i)$$

- E.g. at 60° solar zenith angle the panel is tilted only 1°, the reflectance factor will have an error of 3%
- A panel held on hand can easily be tilted 5 degrees, one must use a bubble level

FGI reflectance library

- Currently the library contains BRF/HDRF measurements of over 150 samples
- A pdf datasheet is produced from each library file
 - Shows contents of the file
 - Describes the reflectance properties of the sample
- The library files can be opened using e.g. Matlab or IDL tools
 - A toolbox is available: *FGI Reflectance toolbox for Matlab*

Conclusions / Take home messages

- Polarised Multiangular Reflectance Measurements Using FGI's Goniospectrometer are possible
- Reflectance factor is a function of both view and illumination angle
- BRF/HDRF effects are source of errors if ignored, but also a valuable source of information
- If you want to have accurate measurement results
 - Take Spectralon reflectance into account
 - Always level your Spectralon panel with a bubble level

THANK YOU

FIGIFIGO checklist for the use in laboratory

1. Starting preparations:

1. Connect the battery to the battery charger
2. Connect the battery charger to the power socket
3. Raise the arm to an upward position
4. Connect the goniometer power cables to the battery
5. Flip the two switches below the system power button
6. Turn on the spectrometer (switch is behind the spectrometer). Spectrometer should be on for about 15 minutes before starting the measurements
7. Flip the system power switch
8. Turn on the computer
9. Connect the USB-cable to the computers left side and topmost USB-connector
10. Start the software

2. Measurement preparations:

11. In the campaign folder, create a new folder with a descriptive name for each measurement. Copy the name for later use
12. In the folder you created for the measurement, create a “RawData” folder
13. In the “RawData” folder, paste the name in the field below and click “OK”
14. As target name, paste the name again and fill in other data as needed (In the lab the light source is “Oriol QTH Parabolic” and Azimuth sensor is “Encoder”)
15. Measure the arm length and fill it in
16. Click “Write”
17. Remove the lamp cover and flip the main switch of the lamp power unit
18. Press “lamp start” to turn on the lamp (after turning on the lamp you should wait about 15 min before doing measurements)
19. Close the curtains and switch off the lights in the lab
20. Orient the light so it hits the target area

3. Measurement procedure:

21. From “turn arm” select the angle of lighting
22. Make sure the optical fiber can move freely and won’t get stuck or bend
23. Adjust the shadow of the arm so it is between the dots of the lasers
24. Fill in “light zenith”, it is the reading from “sensor zenith”
25. Click reset (relative azimuth)
26. Click “Turn arm” and then click “Drive 0”
27. Choose the sensor zenith limits (e.g. +70 and -70)
28. Place the Spectralon on the target area and make sure it is clean and leveled
29. Click “optimize”
30. Click “white reference”
31. Remove Spectralon and place sample on the target area
32. Click “measure”
33. Rotate the device 10, 10, 20, 20 and 30 degrees in between each measurement
34. Remove the sample and place the Spectralon on the target area
35. Click “white reference”
36. Click “exit”
37. Press CTRL-R to restart the software

4. At the end of the measurements:

38. Turn off light from “lamp off” button
39. Remove the USB-cable from the computer
40. Flip the system power switch and then the two buttons below it
41. Unplug the battery charger
42. Remove the cables of the goniometer (remove also the battery cables if you are not doing more measurements anytime soon)

HOLD THE ARM BEFORE REMOVING THE CABLES!

43. Turn off the spectrometer
44. Turn off the computer
45. Turn off the lamp power unit