

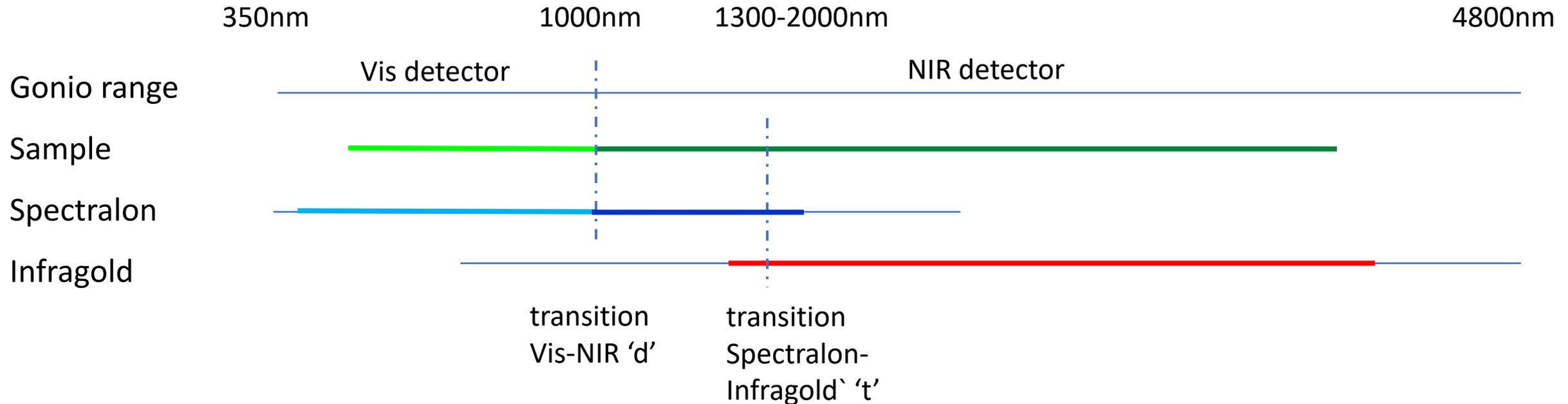
Software for photometric
calibration of reflectance data
from the Spectro-gonio
radiometers
SHINE and SHADOWS

What the soft can do

- **Read** single/multi the 13-column “full” file format created by the goniometer software.
- **Calibrate** one or more spectra, as well as different series of spectra:
 - 1) absolute reflectance calibration with the measurement of the “Spectralon” reference target in the visible and part of near-infrared ranges.
 - 2) relative calibration of the near-infrared range with the “Infragold” reference target

With many improvements and added flexibility and efficiency
- **Visualize** the raw flux and the calibrated reflectance factor
- **Convert** the measurement angles from “remote sensing” angular reference into “physical” values
- **Save** the results as single files or a ‘compiled’ file with the calibration info

The calibration



- Calibration in 3 parts

- Vis detector + Spectralon => absolute calibration
- NIR detector + Spectralon => absolute calibration
- NIR detector + Infragold => scaled relative calibration

- Subtract the "dark" signal from the 2 detectors: visible (Si) and Near-IR (cooled InSb).
- Take the measurement geometry of the Spectralon into account for absolute calibration

The calibration equations

- from spectrum start to `transition Vis-NIR` `d`

$$Rsam_{spe}(\lambda \leq d) = Rspe * (Fsam - Dsam_{vis}) / (Fspe - Dspe_{vis})$$

- from `transition Vis-NIR` to `transition Spectralon-Infragold` `t`

$$Rsam_{spe}(d < \lambda \leq t) = Rspe * (Fsam - Dsam_{nir}) / (Fspe - Dspe_{nir})$$

- from `transition Spectralon-Infragold` to spectrum end

$$Rsam_{inf}(\lambda > t) = Rinf * (Fsam - Dsam_{nir}) / (Finf - Dinf_{nir})$$

- Absolute Reflectance

$$Rsam(\lambda \leq t) = BRDFspe(i,e,az) * [Rsam_{spe}(\lambda \leq d) \cup Rsam_{spe}(d < \lambda \leq t)]$$

$$Rsam(\lambda > t) = BRDFspe(i,e,az) * Rsam_{inf} * Rsam_{spe}(t) / Rsam_{inf}(t)$$

Fsam : Sample measured flux

Dsam_{vis} : Sample dark flux in Visible

Dsam_{nir} : Sample dark flux in NIR

Rsam_{spe/inf} : Sample relative reflectance

Rsam : Sample absolute reflectance

Fspe: Spectralon meas. flux

Dspe_{vis} : Spectralon dark flux in Vis

Dspe_{nir} : Spectralon dark flux in NIR

Rspe: Spectralon dir.-hem. refl.

BRDFspe(i,e,az): Spectralon BRDF

Finf: Infragold meas. flux

Dinf_{nir} : Infragold dark flux in NIR

Rinf: Infragold refl.

The dark signal

- Sum of a number of contributions that offset the signal of the measurement of both your sample and the references
 - Non-monochromatic modulated light reaching the detector (depends on λ)
 - Part of the electronic 'white noise' existing at the modulation frequency (amplifiers, synchronous detection, ...)
 - Detector dark noise : D_{det} (depends on T° for Vis detector)
 - Offset of the analogic-digital converter

But considered independent of λ , as it play a significant role only over a short λ range

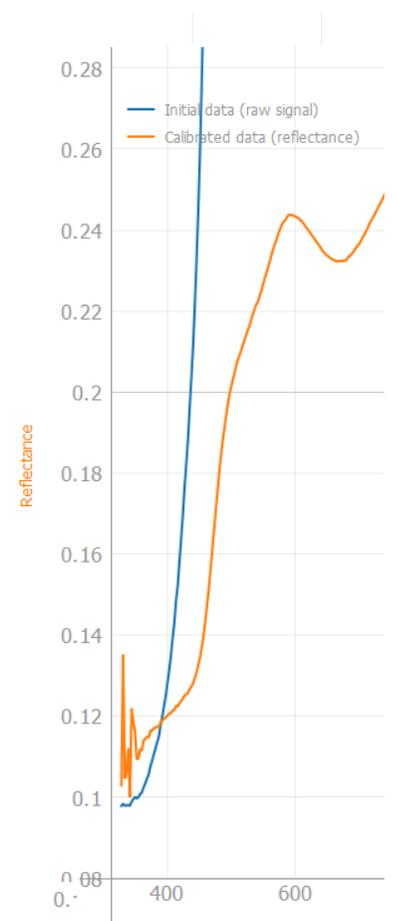
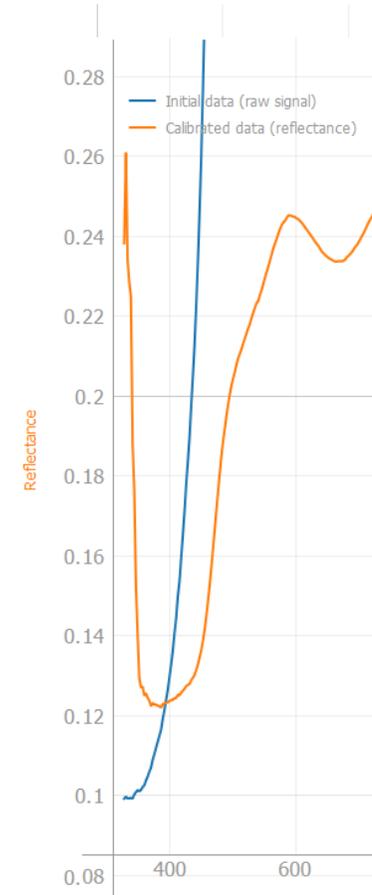
**=> Need to be measured as frequently as possible,
ideally before each measurement !**

The dark signal

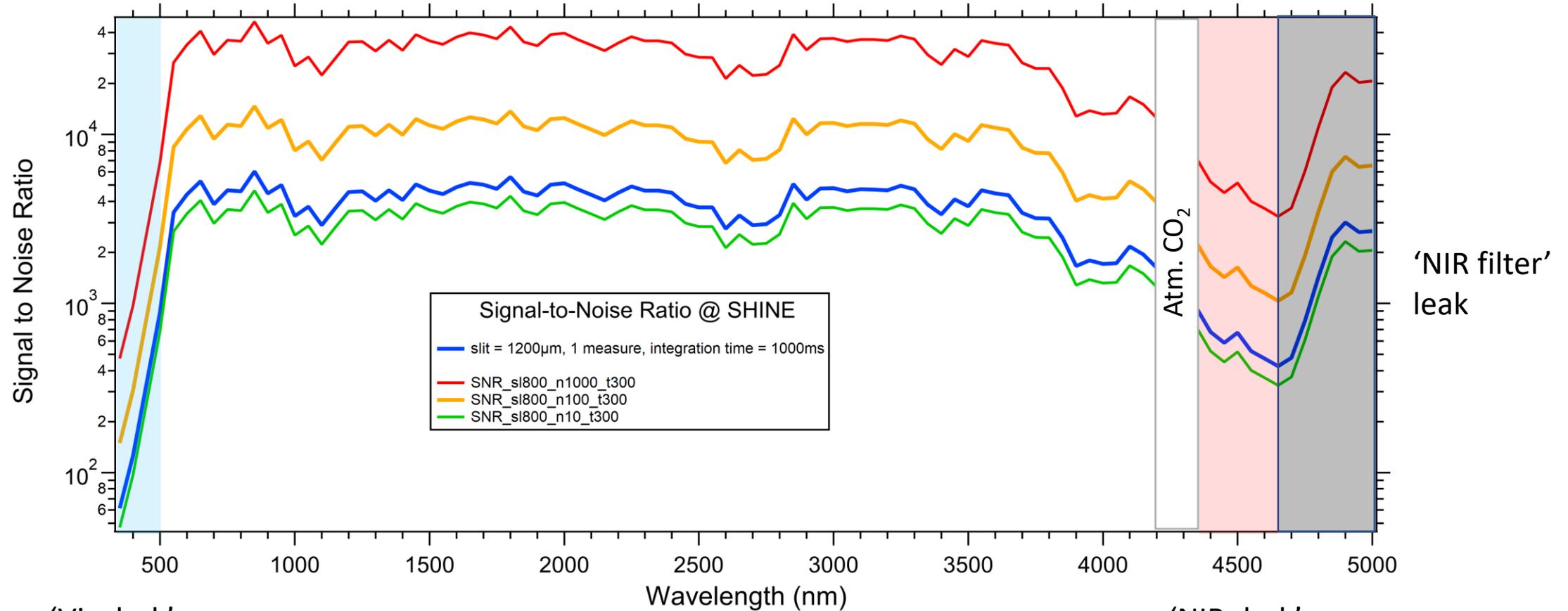
- Correction very important for low signals
< 500-550 nm and > 4200 nm

Exemple 1: Signal = 99 Reference = 100 dark = 1
 with dark corrected: => $R = 98/99 = 98.99\%$
 without dark: => $R = 99/100 = 99\%$
=> **abs. & rel. errors = 0.01%**

Exemple 2: Signal = 2 Reference = 100 dark = 1
 with dark corrected: => $R = 1/99 = 1,01\%$
 without dark: => $R = 2/100 = 2\%$
=> **abs. error = 1% rel. er. = 100%!**



Signal-to-noise ratio



'Vis dark'
correction
range

Blue curve is the 'standard SNR': slit=1200nm, 1 meas., t= 1000ms

'NIR dark'
correction
range

$$\text{SNR} = \text{SNR}_{\text{std}} * (\text{slit} / 1200)^2 * t_{\text{integr.}} / 1000 * \text{Nb}_{\text{measures}}^{1/2}$$

Reflectance errors

- 1- σ error on the reflectance factor
- Now the calculation takes into account:
 - The error on the sample measurement
 - The error on both reference measurements
 - The error on the dark signal
 - The number of measurements of sample and reference at each wavelength
 - The relevant calibration factors in the 3 spectral ranges

The software: Reading the data files

- **1. Load data:** 13 column 'gonios' format
 - A single file or a series (with different angles or temperature, or any other series using the same references)
- **Angles type:** always 'remote sensing' for gonios
- **Angles:** BRDF (included in file name) => read from file name
Other spectra (currently not stored in gonio file): fill the values in deg.

[Temperature]: Temperature series (included in file name) => read from file name

- **Dark:**
 - **from file header :** « ... Detectors noises: Visible = 0+/-0mV, Infrared = 0+/-0mV » (but currently set to '0')
 - **or Manual:** provided from measurements
 - Either with shutter off (but take into account only part of 'dark')
 - recorded at $\lambda < 350-370$ nm (no more flux at these λ !) before effective spectrum
- **Vis-NIR transition (detectors):** read from the header

The software: Reading the reference files

- **2. References:**

- A Spectralon and an Infragold file if you cover both Vis and IR
- A Spectralon file if you cover only the Vis and very near IR (< 2000 nm)
- For BRDF you can also read a full set of Spectralon files with same geometry as the data
 - ➔ Each measurement will be calibrated with its respective geometry (useful at high 'i')

- **3. Calibration: 'set full calibration preset'**

- Includes: a standard calibration spectrum and BRDF of Spectralon reference target
a standard calibration spectrum of Infragold reference target
- or (advanced): import the specific calibration spectra of your references
(ex: 50% Spectralon, ...)

- **Reference transition (Spectralon-infragold):** read from the header

The software: Calibrate the data

4: Calibrate the data

- Absolute calibration made with the Spectralon (its spectrum and BRDF taken into account)
- NIR range with relative calibration with Infragold and adjusted to the Spectralon range at the transition wavelength

BRDF

- with single Spectralon: all measurements are calibrated with it
- with Spectralon spectrum at each geometry: measurement at each geometry will be calibrated with its respective Spectralon
- Spectralon BRDF file (steps 'i': 10°, 'e' & 'az' = 5°) can be interpolated along one of the angles (either i, e or az)

Cells (windows correction)

- Calibrate with spectralon inside the cell (with same windows) and Infragold with or without cells or better:
- Calibrate with spectralon and Infragold without cells and correct for the windows multiple reflections
→ **post processing** (another soft, under development)

The software: Visualize the data

- **Visualize the data**

- Visualize and check the calibrated reflectance spectrum
 - You can flip autoscale between 'raw signal' and 'reflectance'
 - You can change the spectrum in a series: list of spectra on top of graph

- **Adjust the dark subtraction**

- Still a 'poorly corrected dark effect' at < 500 nm ?
 - ➔ Slightly change (decrease) the 'dark VIS' value + Calibrate

- **offsets at grating or detector changes**

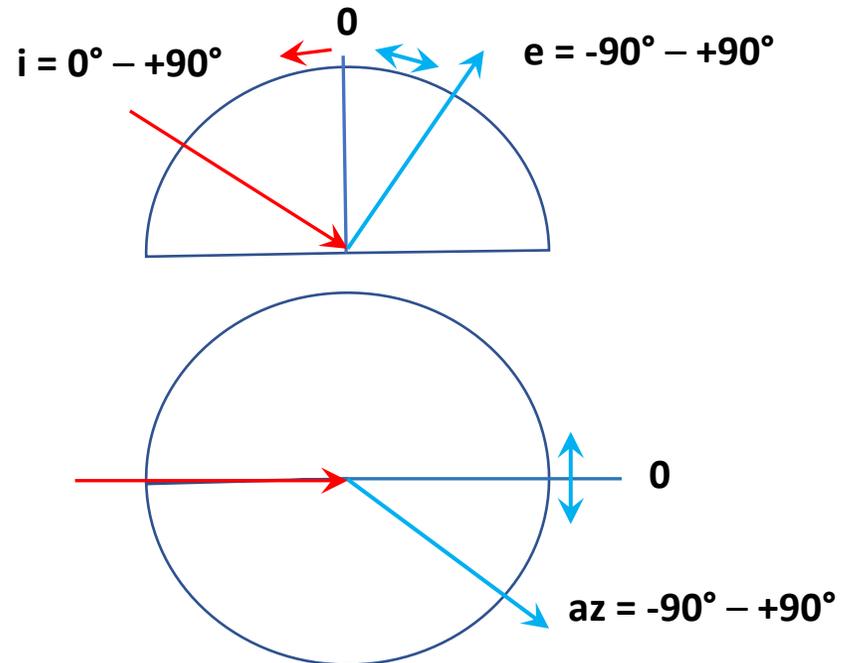
- Check possible offsets at grating or detector changes
 - Yes: ➔ use the « Spectro_decalage_gonio » software after the end of calibration

The software: Export the results

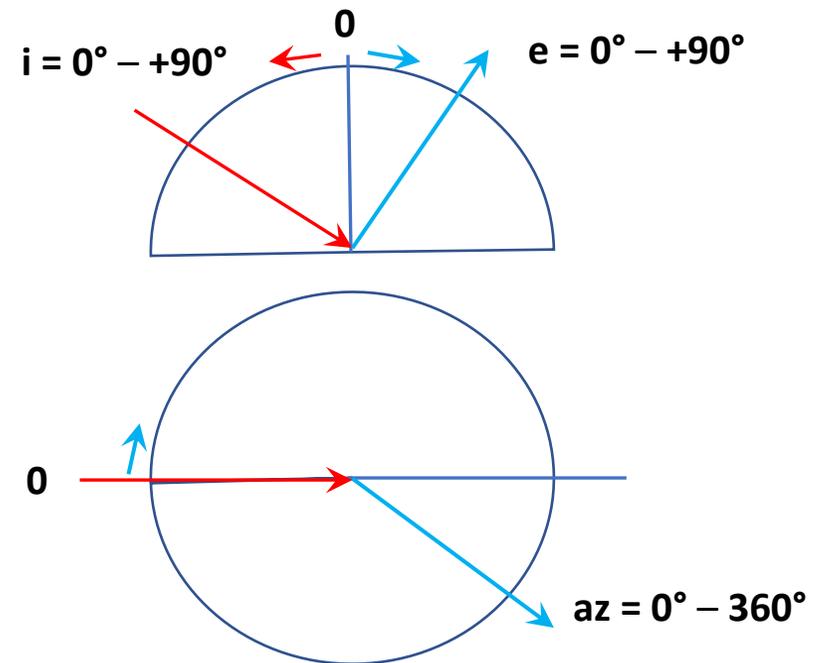
5. Export

- **Angle type:** 'remote sensing' or 'physical'

'remote sensing' (+ variants)



'physical (trigonometric)'



Export the result

File format: Single measurement

- same 13 columns file (extension '_cal')
- but with extended header with:
 - Dark values + errors
 - Angles type
 - Geometry (i, e, az)

```
1 Corrected by D:/Gonio/Mesures/TNA/20240422_Fastelli/20240422_Fastelli_all_spectra/20240422_Spectralon_noWin.txt and
D:/Gonio/Mesures/TNA/20240422_Fastelli/20240422_Fastelli_all_spectra/20240425_Infragold_noWin.txt linked at 1300.0nm Detectors noises: Visible =
0.0055+/-0.0005mV, Infrared = 0.002+/-0.0005mV
2 Angles physical
3 Incidence 0
4 Emergence 30
5 Azimuth 180
6 Wavelength_G11-1_Ta Raw_G11-1_Ta ErrorRaw_G11-1_Ta Reflec_G11-1_Ta ErrorReflec_G11-1_Ta DetecSNR_G11-1_Ta SpecRes_G11-1_Ta Timecst_G11-1_Ta
Averaging_G11-1_Ta Sensi_G11-1_Ta ElTtime_G11-1_Ta TempRes_G11-1_Ta TempSam_G11-1_Ta
7 400.000000 0.018330 0.001258 0.025652 0.001657 14.568265 3.881696 300.000000 20.000000 10000.000000 0.000000 297.343000 297.977000
8 410.000000 0.024315 0.001661 0.026234 0.001325 14.637090 3.880604 300.000000 20.000000 30000.000000 0.530367 297.343000 297.971000
9 420.000000 0.037894 0.001222 0.029912 0.000790 31.017070 3.879355 300.000000 20.000000 100000.000000 0.811000 297.340000 297.999000
10 430.000000 0.054159 0.001054 0.031024 0.000503 51.363802 3.877947 300.000000 20.000000 100000.000000 1.091433 297.338000 298.011000
11 440.000000 0.072979 0.001426 0.032323 0.000416 51.165299 3.876379 300.000000 20.000000 100000.000000 1.371050 297.335000 298.005000
```

Export the result

File format: BRDF

- Series of '13 columns' files (extension '_cal')
but with extended header with: Dark values, Angles type, Geometry (i,e, az)

and/or

- Compilation file ('root'_geo_cal)
 - but with extended header with: 'Angles type, Geometry (i, e, az)'
with 2 choices for the order:
 - Incidence, Azimuth, Emergence
 - Azimuth, Incidence, Emergence

```
1 Angles physical
2 Incidence 0 0 0 0 0 0 0 0 0 0 0 0 0 30 30 30 30 30 30 30 30 30 30 30 60 60 60 60 60 60 60 60 60 60 60 60 60
3 Emergence 20 30 40 50 60 70 10 20 30 40 50 60 70 0 20 40 50 60 70 10 20 30 40 50 60 70 0 20 30 40 50 70 10 20 30 40 50 60 70
4 Azimuth 0 0 0 0 0 0 180 180 180 180 180 180 180 0 0 0 0 0 0 180 180 180 180 180 180 0 0 0 0 0 0 180 180 180 180 180 180
5 wavelength_nm Refl_Nakhalite_N12S_i0e-20a0 Err_Nakhalite_N12S_i0e-20a0 Refl_Nakhalite_N12S_i0e-30a0 Err_Nakhalite_N12S_i0e-30a0 Refl_Nakhalite_N12S_i0e-40a0
Err_Nakhalite_N12S_i0e-40a0 Refl_Nakhalite_N12S_i0e-50a0 Err_Nakhalite_N12S_i0e-50a0 Refl_Nakhalite_N12S_i0e-60a0 Err_Nakhalite_N12S_i0e-60a0 Refl_Nakhalite_N12S_i0e-70a0
Err_Nakhalite_N12S_i0e-70a0 Refl_Nakhalite_N12S_i0e10a0 Err_Nakhalite_N12S_i0e10a0 Refl_Nakhalite_N12S_i0e20a0 Err_Nakhalite_N12S_i0e20a0 Refl_Nakhalite_N12S_i0e30a0
Err_Nakhalite_N12S_i0e30a0 Refl_Nakhalite_N12S_i0e40a0 Err_Nakhalite_N12S_i0e40a0 Refl_Nakhalite_N12S_i0e50a0 Err_Nakhalite_N12S_i0e50a0 Refl_Nakhalite_N12S_i0e60a0
Err_Nakhalite_N12S_i0e60a0 Refl_Nakhalite_N12S_i0e70a0 Err_Nakhalite_N12S_i0e70a0 Refl_Nakhalite_N12S_i30e0a0 Err_Nakhalite_N12S_i30e0a0 Refl_Nakhalite_N12S_i30e-20a0
Err_Nakhalite_N12S_i30e-20a0 Refl_Nakhalite_N12S_i30e-40a0 Err_Nakhalite_N12S_i30e-40a0 Refl_Nakhalite_N12S_i30e-50a0 Err_Nakhalite_N12S_i30e-50a0
Refl_Nakhalite_N12S_i30e-60a0 Err_Nakhalite_N12S_i30e-60a0 Refl_Nakhalite_N12S_i30e-70a0 Err_Nakhalite_N12S_i30e-70a0 Refl_Nakhalite_N12S_i30e10a0
Err_Nakhalite_N12S_i30e10a0 Refl_Nakhalite_N12S_i30e20a0 Err_Nakhalite_N12S_i30e20a0 Refl_Nakhalite_N12S_i30e30a0 Err_Nakhalite_N12S_i30e30a0 Refl_Nakhalite_N12S_i30e40a0
Err_Nakhalite_N12S_i30e40a0 Refl_Nakhalite_N12S_i30e50a0 Err_Nakhalite_N12S_i30e50a0 Refl_Nakhalite_N12S_i30e60a0 Err_Nakhalite_N12S_i30e60a0 Refl_Nakhalite_N12S_i30e70a0
Err_Nakhalite_N12S_i30e70a0 Refl_Nakhalite_N12S_i60e0a0 Err_Nakhalite_N12S_i60e0a0 Refl_Nakhalite_N12S_i60e-20a0 Err_Nakhalite_N12S_i60e-20a0 Refl_Nakhalite_N12S_i60e-30a0
Err_Nakhalite_N12S_i60e-30a0 Refl_Nakhalite_N12S_i60e-40a0 Err_Nakhalite_N12S_i60e-40a0 Refl_Nakhalite_N12S_i60e-50a0 Err_Nakhalite_N12S_i60e-50a0
Refl_Nakhalite_N12S_i60e-70a0 Err_Nakhalite_N12S_i60e-70a0 Refl_Nakhalite_N12S_i60e10a0 Err_Nakhalite_N12S_i60e10a0 Refl_Nakhalite_N12S_i60e20a0
Err_Nakhalite_N12S_i60e20a0 Refl_Nakhalite_N12S_i60e30a0 Err_Nakhalite_N12S_i60e30a0 Refl_Nakhalite_N12S_i60e40a0 Err_Nakhalite_N12S_i60e40a0 Refl_Nakhalite_N12S_i60e50a0
```

Export the result

File format: Temperature series

- Series of separate '13 columns' files (extension '_cal') with extended header with:
 - Dark values,
 - Angles type, Geometry (i,e, az)
 - Temperature, Date, Time

and/or

- Compilation file ('root'_temp_cal)
 - but with extended header with List of 'Temperature, Date, Time' with 2 choices for the order:
 - Temperature, Date, Time
 - Date, Time, Temperature

1	Temperature	105	120	135	150	170	190	210	210	230	250	270											
2	Date	24-12-17	24-12-17	24-12-17	24-12-17	24-12-17	24-12-17	24-12-17	24-12-17	24-12-16	24-12-16	24-12-16											
3	Time	11:05	09:21	07:37	05:54	04:06	02:19	00:33	13:51	22:46	21:00	19:13											
4	wavelength_nm	Refl_24-12-17_1105_105_GG-1_Tcryo	Err_24-12-17_1105_105_GG-1_Tcryo	Refl_24-12-17_0921_120_GG-1_Tcryo	Err_24-12-17_0921_120_GG-1_Tcryo	Refl_24-12-17_0737_135_GG-1_Tcryo	Err_24-12-17_0737_135_GG-1_Tcryo	Refl_24-12-17_0554_150_GG-1_Tcryo	Err_24-12-17_0554_150_GG-1_Tcryo	Refl_24-12-17_0406_170_GG-1_Tcryo	Err_24-12-17_0406_170_GG-1_Tcryo	Refl_24-12-17_0219_190_GG-1_Tcryo	Err_24-12-17_0219_190_GG-1_Tcryo	Refl_24-12-17_0033_210_GG-1_Tcryo	Err_24-12-17_0033_210_GG-1_Tcryo	Refl_24-12-17_1351_210_GG-1_Tcryo	Err_24-12-17_1351_210_GG-1_Tcryo	Refl_24-12-16_2246_230_GG-1_Tcryo	Err_24-12-16_2246_230_GG-1_Tcryo	Refl_24-12-16_2100_250_GG-1_Tcryo	Err_24-12-16_2100_250_GG-1_Tcryo	Refl_24-12-16_1913_270_GG-1_Tcryo	Err_24-12-16_1913_270_GG-1_Tcryo
5	400.000000	0.018204	0.004474	0.017119	0.005039	0.024142	0.004645	0.015564	0.004043	0.008568	0.004130	0.018620	0.004578	0.014015									
	0.004511	0.019494	0.005516	0.017162	0.004481	0.016887	0.004221	0.070673	0.012406														
6	410.000000	0.014383	0.003145	0.017646	0.003351	0.020335	0.003679	0.019541	0.003771	0.021766	0.002622	0.016709	0.003236	0.020346									
	0.002814	0.019825	0.003729	0.021792	0.003134	0.022481	0.003586	0.017956	0.004351														
7	420.000000	0.025350	0.002694	0.023335	0.001897	0.022701	0.002068	0.023081	0.002608	0.021446	0.002399	0.023436	0.002694	0.024043									

Warnings and some known bugs

Warnings

- The soft checks several criteria of compatibility between the list of wavelengths of your sample measurement, of the reference measurements and with the values provided for the Vis-NIR and the Spectralon –Infragold transitions
 - ➔ issue 'Warning' if some are not fullfiled

Known bugs

- Sometimes the wavelength and reflectance scales (X, Y axes) of the plot became wrong when zooming but the calibration is OK
- If you have calibrated a file needing both Spectralon and Infragold, and then you want to calibrate a file needing only Spectralon, it will issue an error (not possible to remove the old Infragold), but calibration should work.

Future improvements

Dark

- Individual darks for sample, Spectralon and Infragold
- Individual darks for series of samples (inside the files)

Data format

- New input/export format (HDF5) that will be developed for the new goniometer software

Infragold range calibration

- Adjustment ratio on the average of several points in the common range of Spectralon and Infragold (define number ?)

Bug corrections

How to install

- **on PC:**
 - Simply unzip
 - But keep the 'calibration_references' directory in same directory as the executable
- **on MAC:**
 - First install a PC compatibility layer, such as 'Wine' <https://www.winehq.org/>
 - Or any other soft derived from Wine: cf <https://www.clubic.com/pro/entreprises/apple/dossier-386901-4-solutions-gratuites-pour-utiliser-ses-logiciels-windows-sur-un-mac-m1.html>
- **'calibration_references' directory:**
 - contains the standard calibration and BRDF files of the Spectralon and Infragold references

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