Cal/char file formats

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Radiometers for OC

Currently supported by HyperCP (Hyperspectral Community Processor):

Sea-Bird HyperOCR

TriOS RAMSES

In-situ Marine Optics DALEC

Output data

HyperOCR:
Data acquisition: "SatView", records binary datafiles.
Binary-to-ASCII datafile conversion: "SatCon".
Varying subrange of pixels is recorded and converted.
Contains temperature data.

RAMSES:
Data acquisition and file conversion: "MSDA_XE",
records binary (MS ACCESS) or ASCII datafiles.
255 pixel values are recorded, incl. the black pixels.
Temperature data availabe for second generation (G2) devices.

DALEC:
Data acquisition: "DALECview" or terminal program, ASCII datafiles.
Subrange of pixels, averaged black pixel signal.
Temperature available for each of the three spectrometer modules.

MSDA_XE example datafile

serial number

date & time

comments

integration time

256 pixel numbers and raw readings

```
[Spectrum]
Version              = 1
IDData               = DB43_2007-10-10_10-47-55_599_050
IDDevice             = SAM_8166
IDDataType           = SPECTRUM
IDDataTypeSub1       = RAW
IDDataTypeSub2       =
IDDataTypeSub3       =
DateTime             = 2007-10-10 10:47:55
PositionLatitude     = 0
PositionLongitude    = 0
Comment              =
CommentSub1          =
CommentSub2          =
CommentSub3          =
IDMethodType         = SAM Control
MethodName           = SAM_8166
RecordType           = 0

[Attributes]
CalFactor = 1
IDBasisSpec =
IDDataBack = DLAB_2006-05-04_09-11-52_144_774
IDDataCal = DLAB_2006-05-04_09-59-07_917_979
IntegrationTime = 128
PathLength = +INF
Temperature = +NAN
Unit1 = $05 $00 Pixel
Unit2 = $03 $05 Intensity counts
Unit3 = $f0 $05 Error counts
Unit4 = $f1 $00 Status
[END] of [Attributes]
[DATA]
 0 6 0 0
 1 3941 0 0
 2 5479 0 0
...
 255 1353 0 0
[END] of [DATA]
[END] of [Spectrum]
```

HyperOCR cal file

```
# SATLANTIC HYPER-OCR Hyperspectral Radiometer
# Instrument Identification: SATHPL0392 / Spec Number 091633
# Wet Labs Inc / 2015-7005 / with Bioshutters
# Generated by  Jennifer |Instrument Serial 392 |Start Channel 2 |End Channel 256 |Coefficients 298.1,3.3204,4.12558E-4,-1.90216E-6
##################################################################################################################...
# Calibration History
# Date       |Operator |SW Version |Rev |Type |Int Time ... |Output wavelengths(channels) |Display wavelengths(channels)...
#-----------------------------------------------------------------------------------------------------------------...
# 2015-04-21-14-17-11 |Jennifer |1.9.15_194 |B   |LU   |512.0    ...    |304.74 to 901.33 (2-181)    |347.99 to 851.95 (15-166)...


INSTRUMENT SATHPL '' 6 AS 0 NONE
SN 0392 '' 4 AI 0 COUNT
...
# Average SPECTEMP during calibration
CALTEMP 24.08 'C' 0 BU 0 NONE

# Thermal Responsivity derived value
THERMAL_RESP NONE '' 0 BU 1 THERM1
-0.01131601    4.95350e-05    -7.488197e-08  4.33976e-11    20.0

# Spectrum Data
...
LU 347.99 'uW/cm^2/nm/sr' 2 BU 1 OPTIC3
668.397        4.63918883687e-005            1.776          0.512
...
LU 901.33 'uW/cm^2/nm/sr' 2 BU 0 NONE

# Number of Dark Samples
DARK_SAMP LU '' 1 BU 0 COUNT

# Average Dark Value
DARK_AVE LU '' 2 BU 0 COUNT

# Spectrometer temperature sensor
SPECTEMP NONE 'C' 6 AF 0 COUNT

# Frame Counter (Data Integrity)
FRAME COUNTER '' 1 BU 0 COUNT

# Time since commencement of normal operation
TIMER NONE 'sec' 10 AF 0 COUNT

# Check Sum (Data Integrity)
CHECK SUM '' 1 BU 0 COUNT

# Frame Terminator
CRLF TERMINATOR '' 2 BU 0 NONE
```

date & time

serial number

cal temperature

available pixels

integration time

cal coefs

pixels wavelengths

HyperCP cal/char files

For the OC community processor HyperCP, a set of file formats were defined, containing the calibration and characterization results and supporting further processing of the field data with uncertainties by HyperCP.
The files contain necessary metadata (lab name, serial numbers, date, versions) for optimal flexibility and compatibility.

The following formats are defined so far:

CP_*_RADCAL_*.txt	radiometric calibration & radiometric linearity
CP_*_ANGULAR_*.txt	angular response in two azimuth planes
CP_*_THERMAL_*.txt	temperature coefficients of the radiometric responsivity
CP_*_POLAR_*.txt	amplitude & phase angle of the polarisation sensitivity
CP_*_STRAY_*.txt	the spectral stray light matrix

Details can be found in the HyperCP documentation.

Radiometric responsivity units

RAMSES

irradiance responsivity=output signal/irradiance [$1/(mW \cdot m^{-2} nm^{-1})$]

radiance responsivity=output signal/radiance [$1/(mW \cdot m^{-2} nm^{-1} sr^{-1})$]

HyperOCR

irradiance responsivity=irradiance/output signal [$\mu W \cdot cm^{-2} nm^{-1}$]

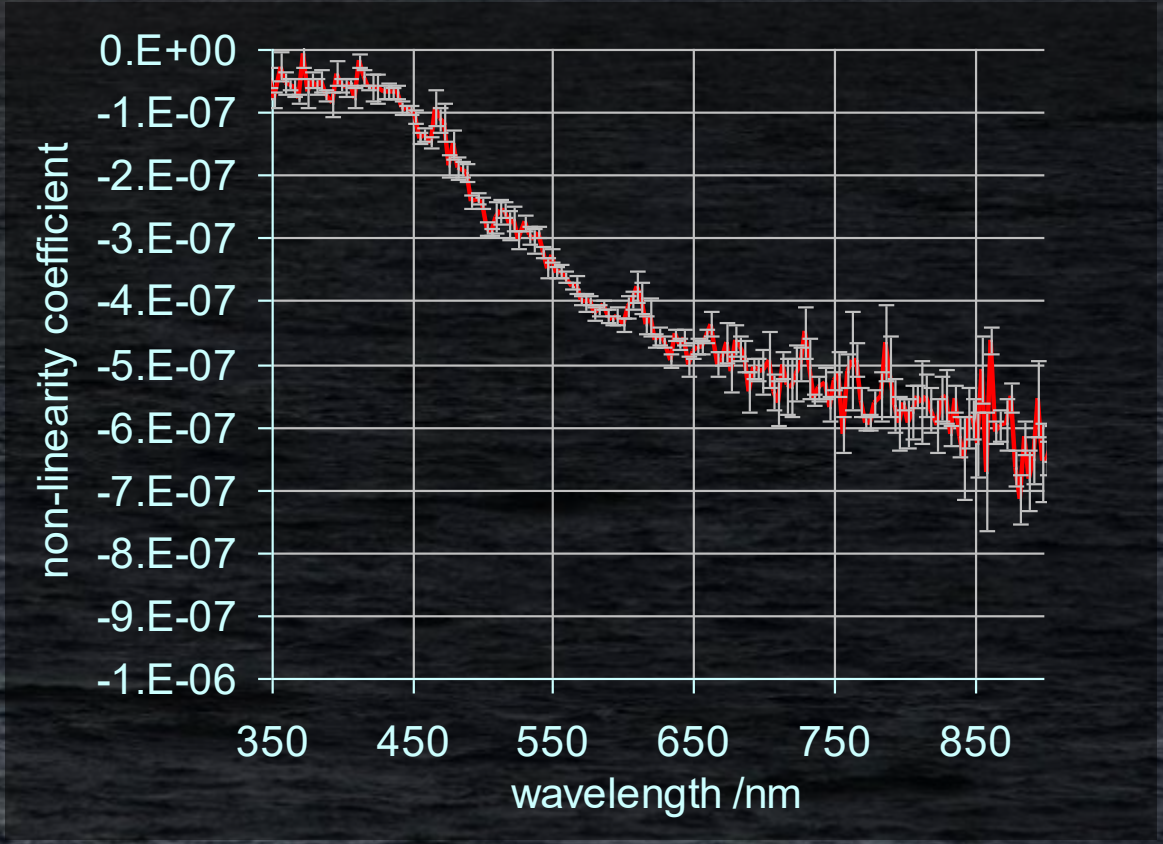
radiance responsivity=irradiance/output signal [$\mu W \cdot cm^{-2} nm^{-1} sr^{-1}$]

Radiometric non-linearity

Calibration source is measured with two integration times *t1* and *t2*:

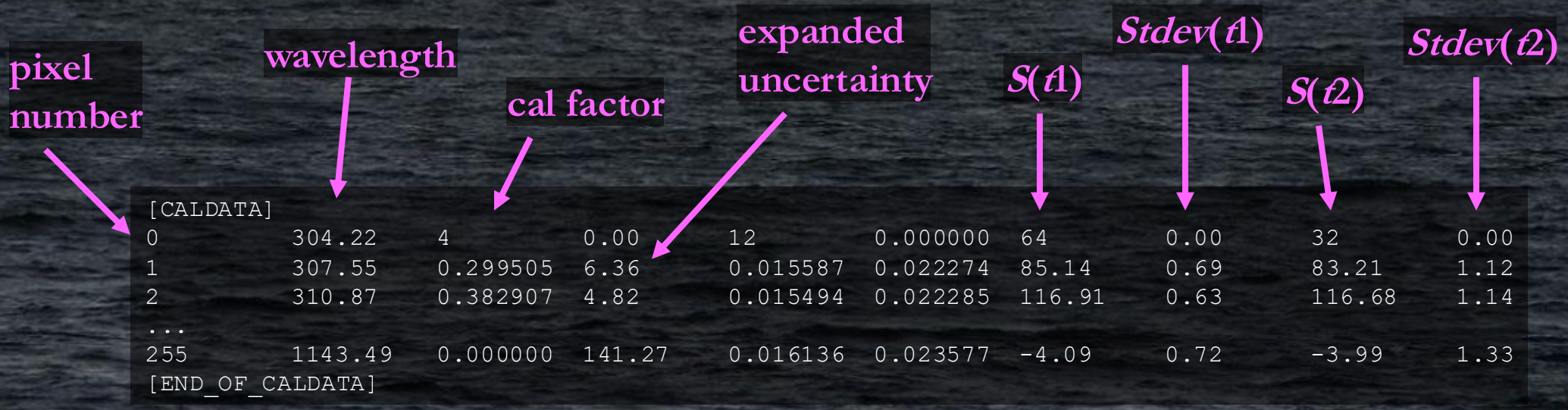
$$\begin{cases} \dfrac{S(t1)-S_{true}}{S_{true}} = \alpha \cdot S_{true} \\ \dfrac{S(t2)-S_{true}}{S_{true}} = \alpha \cdot S_{true} \end{cases}$$

Can be solved for S_{true} and α, both depend on the wavelength.



The CP_*_RADCAL_* file

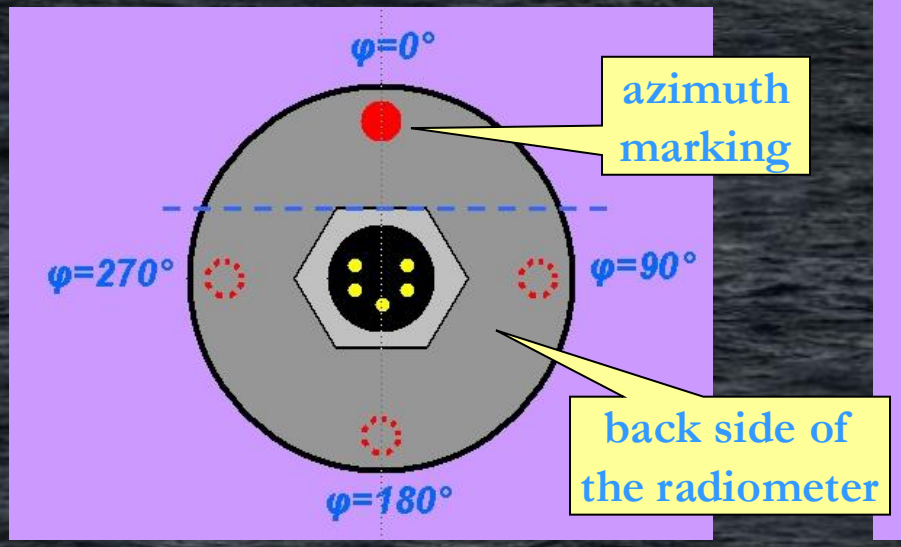
The CP_RADCAL_* file contains $S(t1)$, $S(t2)$, lamp, panel etc. data, necessary for derivation of the cal factors and α with uncertainties. Calculation details can be found in HyperCP documentation.

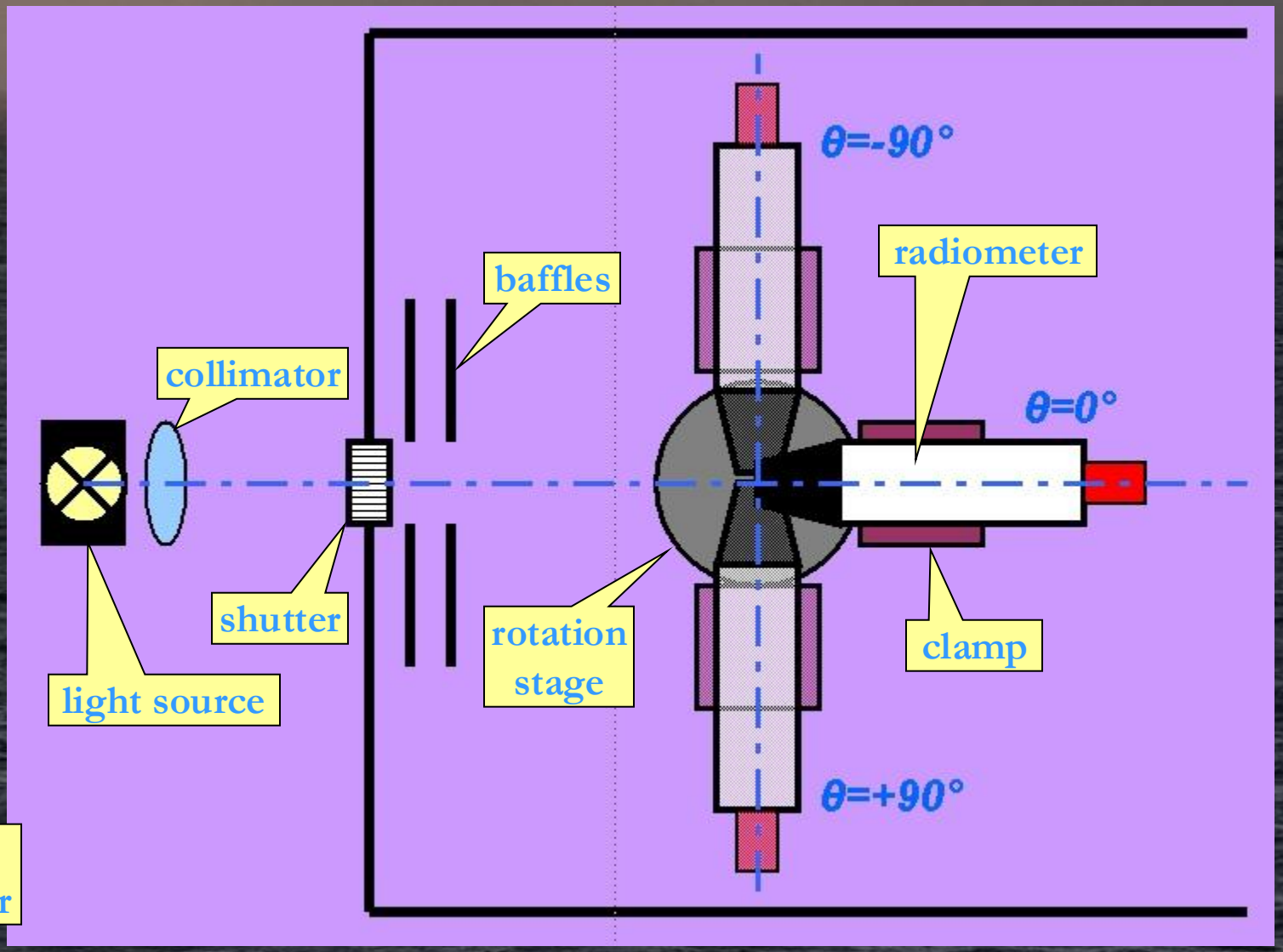



```
[CALDATA]
0         304.22    4         0.00      12        0.000000  64        0.00      32        0.00
1         307.55    0.299505  6.36      0.015587  0.022274  85.14     0.69      83.21     1.12
2         310.87    0.382907  4.82      0.015494  0.022285  116.91    0.63      116.68    1.14
...
255       1143.49   0.000000  141.27    0.016136  0.023577  -4.09     0.72      -3.99     1.33
[END_OF_CALDATA]
```

Angular response characterization setup

Measurement method: precise rotation of the radiometer within the collimated beam.
Zero azimuth is marked with a red dot on the radiometer's body.





The CP_*_ANGULAR_* file

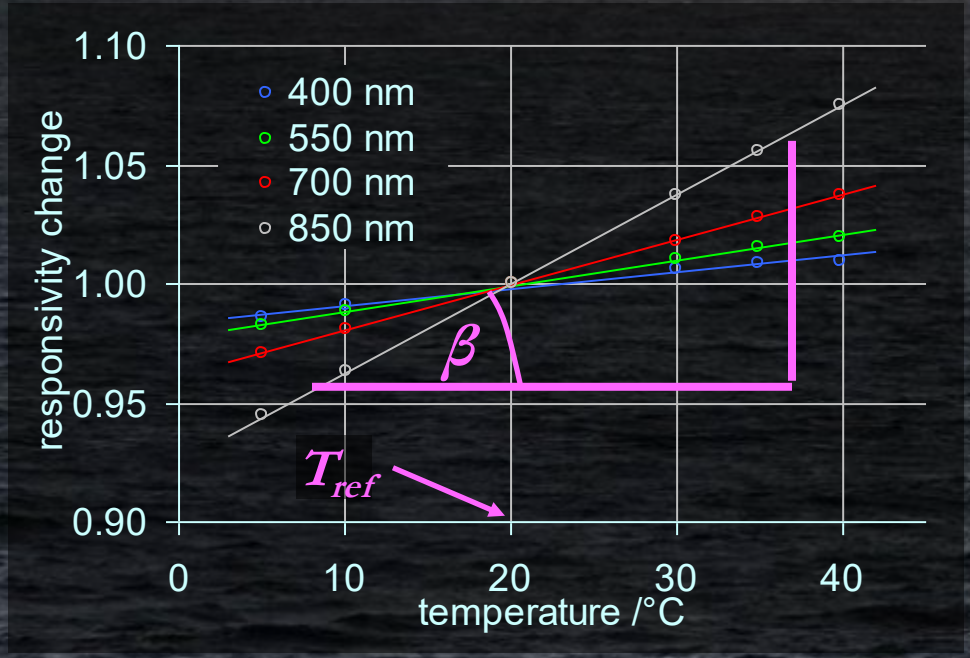
The CP_ANGULAR_* file contains cosine errors in two azimuthal planes with uncertainties.

$$CE(\theta,\lambda) = \frac{S(\theta,\lambda)/S(\theta=0,\lambda) - \cos(\theta)}{\cos(\theta)} \cdot 100\%$$

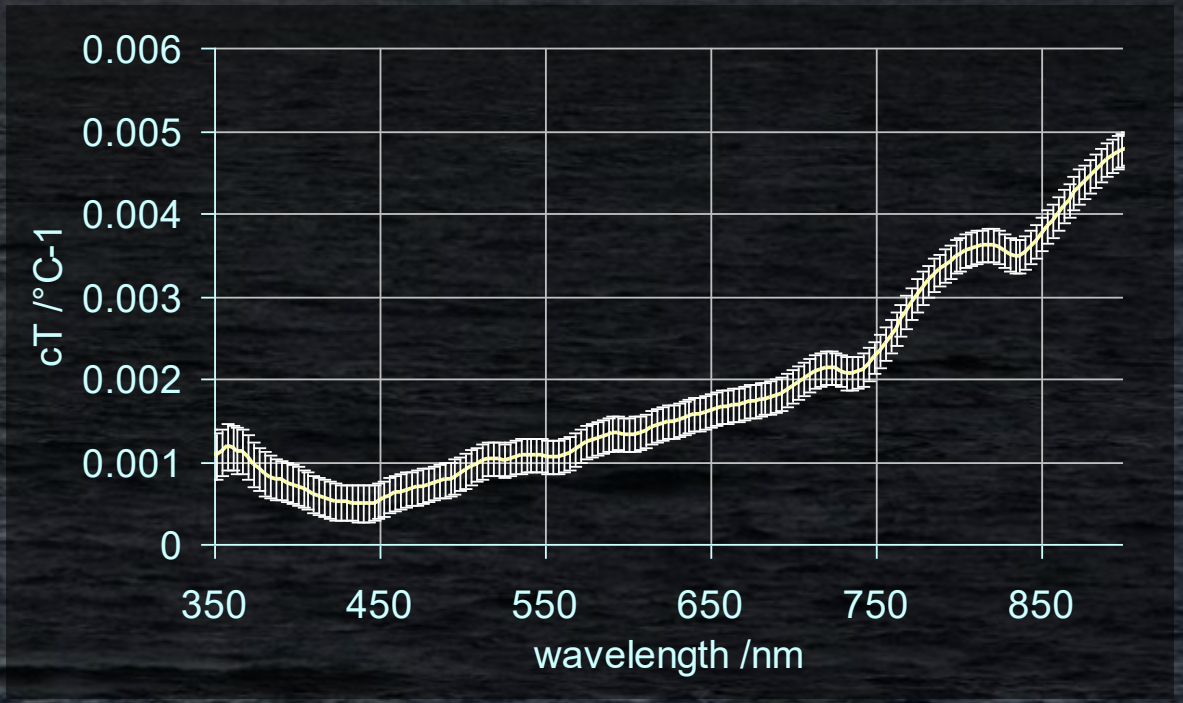
(*S* is the measured signal)

```
...
[AZIMUTH_ANGLE]
0

[COLUMN_NAMES]
px          wl\angle    -90.00      -85.00      -80.00      -75.00      -70.00      -65.00      -60.00      -55.00
[COSERROR]
0           302.08      3.50        3.50        3.50        3.50        3.50        3.50        3.50        3.50
1           305.42      16.42       16.42       1.96        1.68        0.76        1.83        1.52        1.94
...
[UNCERTAINTY]
0           302.08      1.00        1.00        1.00        1.00        1.00        1.00        1.00        1.00
1           305.42      21.19       21.19       11.73       7.29        6.24        4.30        3.18        3.66
...
```

Thermal characterization



Thermal coefficient $c_T(\lambda) = \tan\beta$



individual $c_T(\lambda)$ and expanded uncertainty

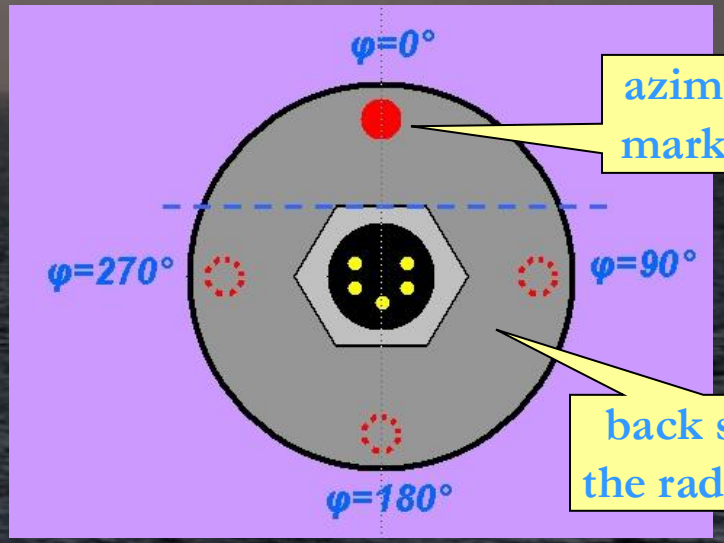
The CP_*_THERMAL_* file

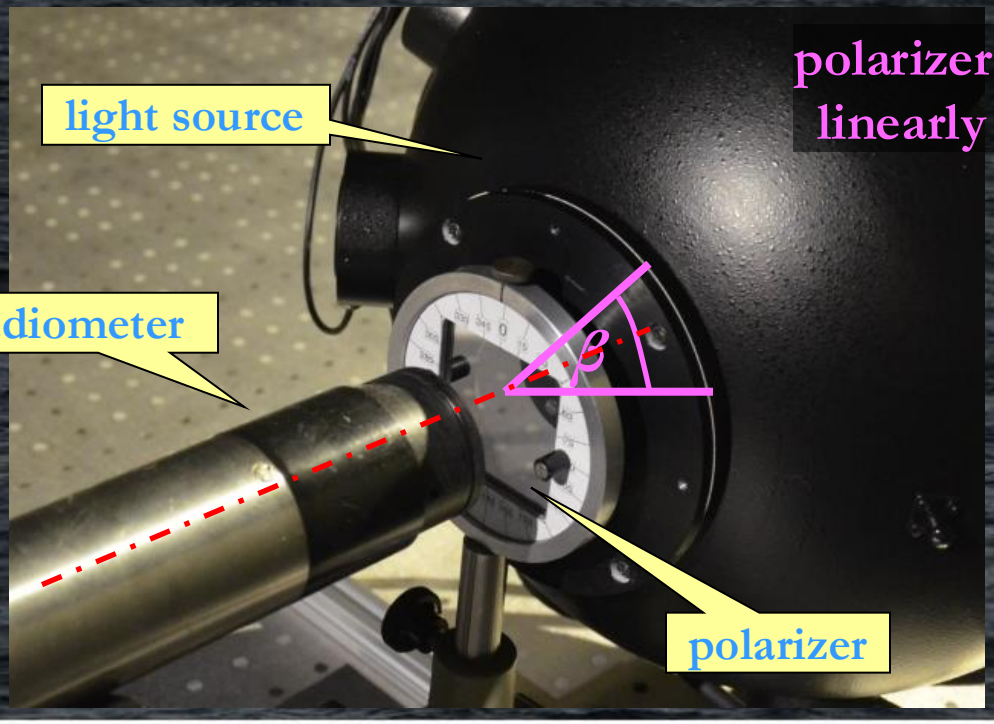
The CP_THERMAL_* file contains $c_T(\lambda)$ with uncertainty.

```
!FRM4SOC_CP
!TEMPDATA
# thermal characterization results

# comments start with # (ignored by the processor)
# no empty lines between the parameter signatures in [] and the parameter values
# parameters are case insensitive
# parameters can be inserted in any order, except the first two signatures
# columns are tab- or space-delimited

[VERSION]
0.1

[CALDATE]
2022-06-22 02:56:43

[CALLAB]
Tartu Observatory

[USER]
Ilmar Ansko

[DEVICE]
SAM_81C9

[AMBIENT_TEMP]
21.0

[REFERENCE_TEMP]
20.0

#px          wl (nm)      cT (1/deg)  ucT (1/deg, k=2)
[CALDATA]
0            302.56       0.000E+000  0.000E+000
1            305.88       1.519E-003  4.078E-004
2            309.19       6.554E-004  3.771E-004
...
253          1136.59      -1.428E-002 1.043E-002
254          1139.75      -5.308E-003 1.743E-002
255          1142.91      -5.549E-002 2.762E-002
[END_OF_CALDATA]
```

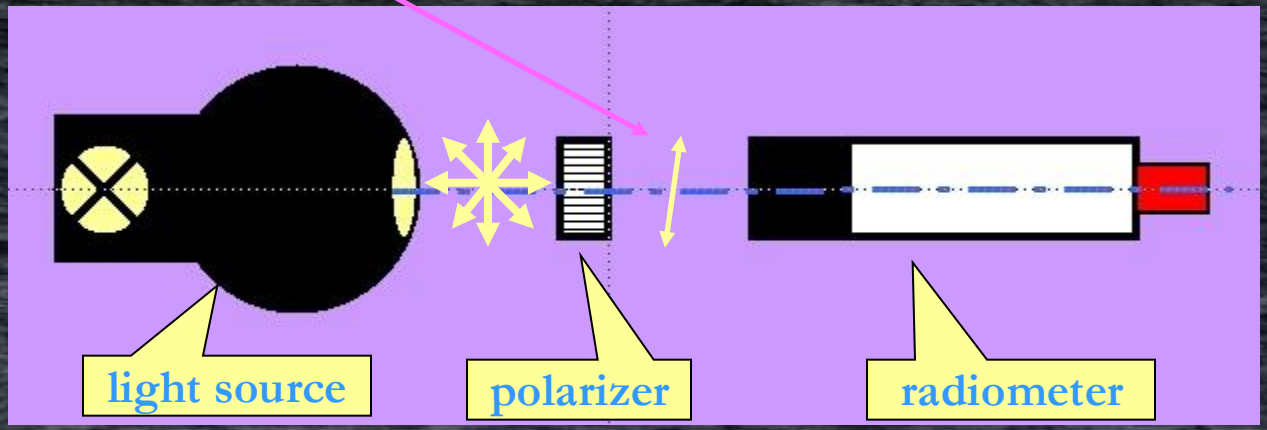
The polarization sensitivity

Output radiation of the sphere is unpolarized.
Polaroid creates linearly polarized beam.
Polaroid is rotated around the optical axis
and the radiometer's output signal recorded.
Angle of the maximum responsivity is
referenced to the "red dot".

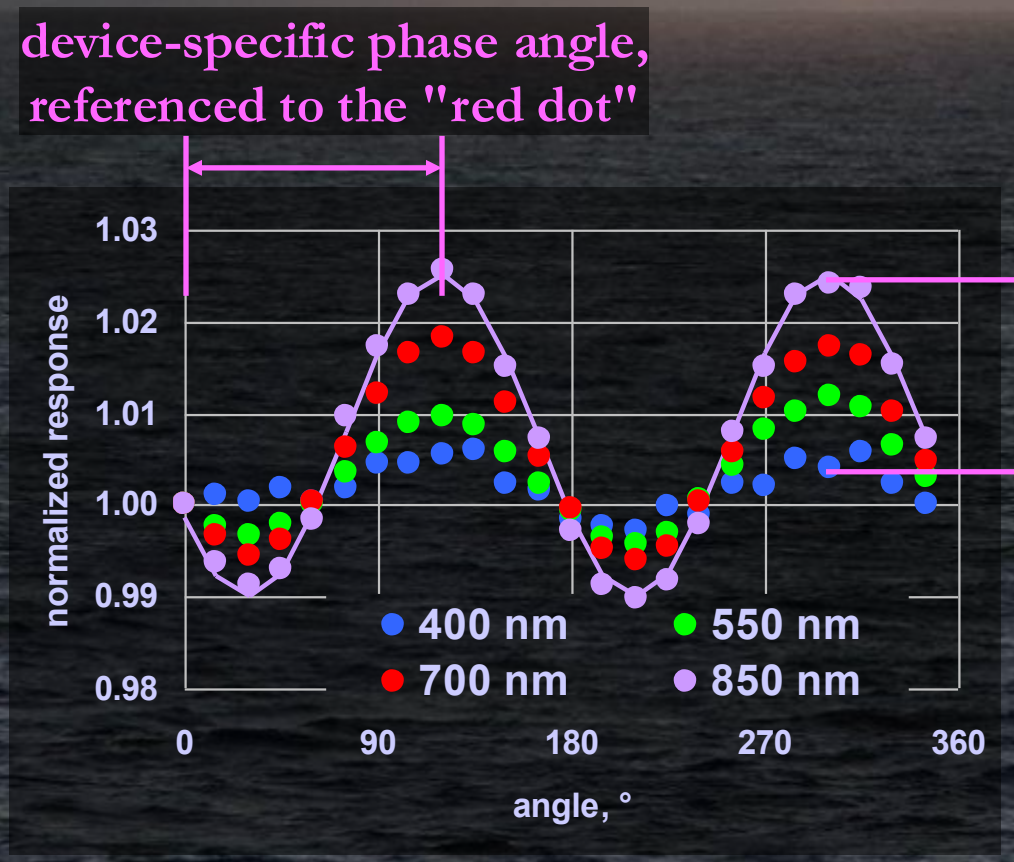


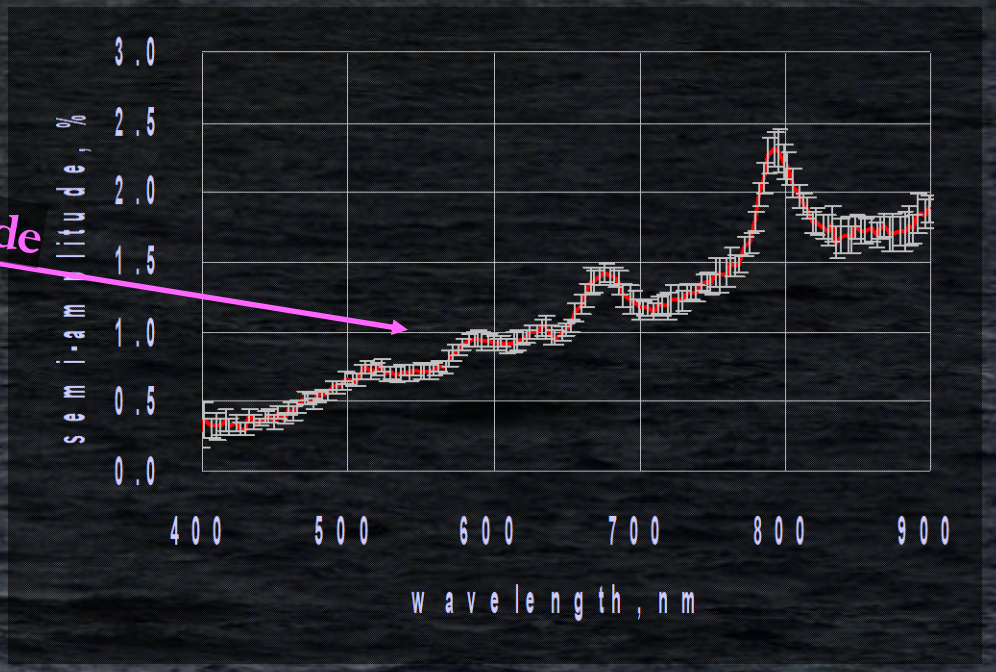


polarizer provides nearly linearly polarized light



Polarization sensitivity





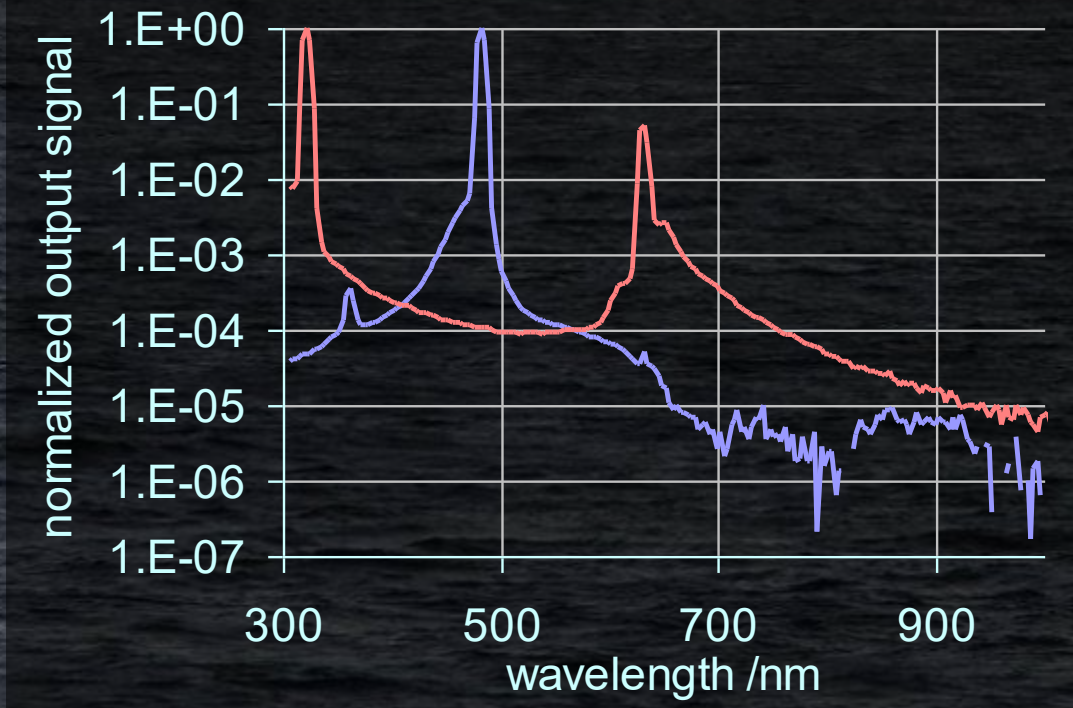
The CP_*_POLAR_* file

The CP_POLAR_* file contains the amplitude and the phase angle of the polarization sensitivity with uncertainties.

```
...
# serial number of the instrument
# type(s): string(255)
[DEVICE]
SAM_8166

# lab temperature (deg Celsius) during cal/char measurements
# type(s): single
[AMBIENT_TEMP]
21.0

# pixel no, wavelength (nm), semi-amplitude, uncertainty (k=2), angle of the max sensitivity plane (rad), uncertainty (rad, k=2)
# type(s): uint8, single, single, single, single, single
[CALDATA]
0           305.10      0.000E+00   0.000E+00   0.000E+00   0.000E+00
1           308.37      1.830E-03   3.920E-03   1.783E+02   5.778E+03
...
253         1130.18     4.933E-01   3.727E-01   9.617E+01   4.383E+01
254         1133.34     2.023E-02   5.631E-02   1.416E+02   3.265E+02
255         1136.49     1.953E-02   2.066E-02   5.063E+01   9.283E+01
[END_OF_CALDATA]
```

Spectral stray light

line spread functions (LSF)



LSFs in columns

$$\begin{bmatrix} z_{n0} & z_{n1} & \cdots & 1 \\ \cdots & \cdots & \cdots & \cdots \\ z_{10} & 1 & \cdots & z_{1n} \\ 1 & z_{01} & \cdots & z_{0n} \end{bmatrix}$$

Line spread functions (LSF) are combined into stray light matrix (SLM).

The CP_*_STRAY_* file

The CP_STRAY_* stores the line spread functions with the standard deviation.

```
...
[LSF]
1.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
0.000E+000  1.000E+000  6.483E-001  1.430E-001  1.027E-002  6.913E-003  7.105E-003  6.577E-003  6.565E-003  6.203E-003  5.798E-003
0.000E+000  0.000E+000  1.000E+000  6.764E-001  1.260E-001  7.369E-003  5.680E-003  5.857E-003  5.900E-003  5.871E-003  5.648E-003
...
0.000E+000  0.000E+000  -4.594E-003 -4.924E-003 -1.811E-003 -7.017E-004 -4.584E-004 -2.597E-004 -1.920E-004 -1.113E-004 -8.450E-005
0.000E+000  0.000E+000  1.207E-003  -2.148E-003 -2.304E-004 -3.542E-004 -2.892E-004 -1.085E-004 -4.636E-005 -9.178E-005 -5.629E-005
0.000E+000  0.000E+000  -3.311E-003 -2.886E-003 -1.534E-003 -8.405E-004 -5.907E-004 -1.208E-004 -4.335E-005 -2.051E-005 -7.909E-006
[END_OF_LSF]

[UNCERTAINTY]
0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
0.000E+000  0.000E+000  7.329E-004  9.854E-004  2.444E-004  1.534E-004  1.203E-004  1.187E-004  1.033E-004  1.339E-004  1.093E-004
0.000E+000  0.000E+000  0.000E+000  1.123E-003  2.415E-004  1.439E-004  1.153E-004  1.063E-004  9.246E-005  1.237E-004  1.231E-004
...
0.000E+000  0.000E+000  8.323E-004  8.216E-004  2.078E-004  1.288E-004  1.049E-004  5.722E-005  5.134E-005  1.952E-005  1.863E-005
0.000E+000  0.000E+000  6.871E-004  7.152E-004  2.659E-004  1.387E-004  1.079E-004  6.155E-005  5.342E-005  3.287E-005  1.852E-005
0.000E+000  0.000E+000  6.450E-004  7.952E-004  2.224E-004  1.200E-004  1.168E-004  6.888E-005  4.516E-005  3.081E-005  2.563E-005
[END_OF_UNCERTAINTY]
```

Summary

The instrument calibration and characterization results are expected in the HyperCP format or at least having all the necessary data available in the machine-readable form.

New HyperCP file formats and versions are possible (cooperation highly appreciated).