

Post processing of data from array spectroradiometer

«*Workshop-Tutorial*»

Luca Egli¹ , Julian Gröbner¹ and M. Blumthaler²

¹Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Davos Switzerland

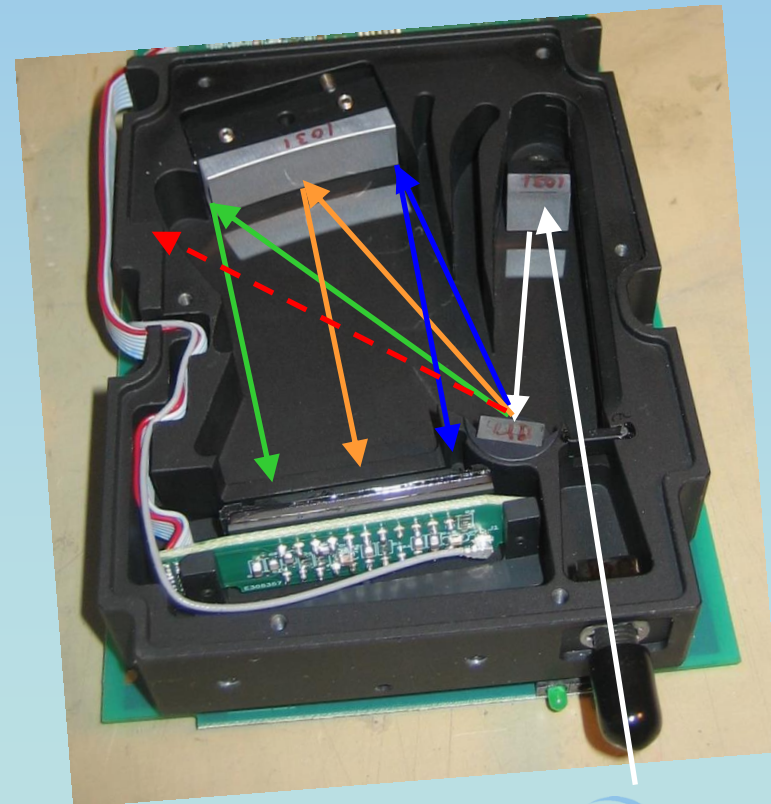
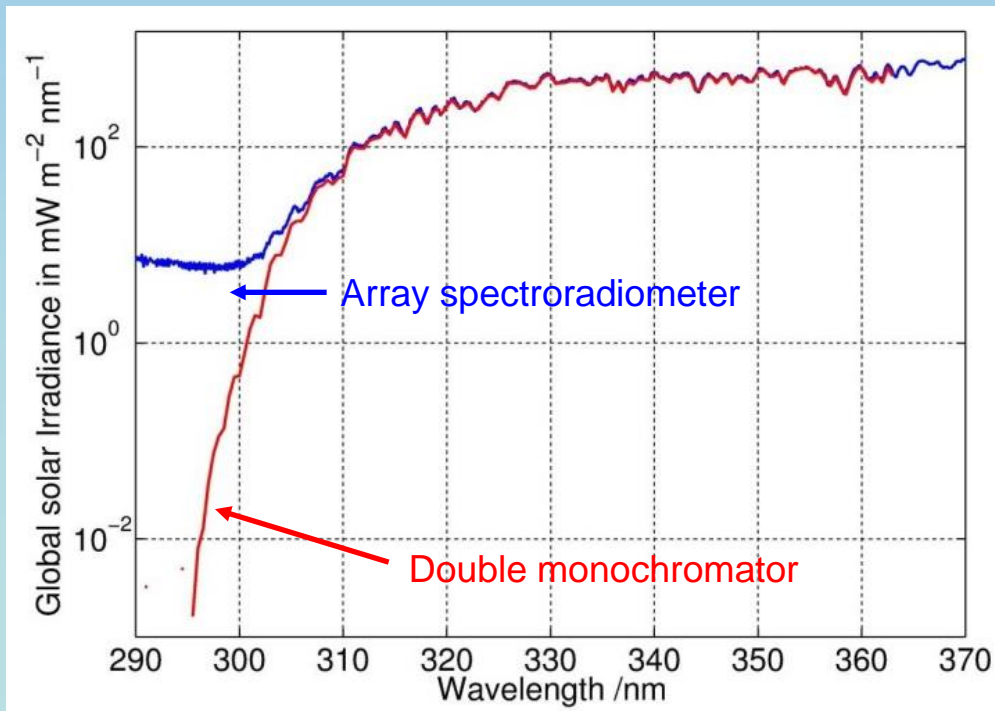
²Innsbruck Medical University, Biomedical Physics, Innsbruck, Austria

***The European Metrology Research Programme (EMRP) is jointly funded by the EMRP participating countries
within EURAMET and the European Union.***

PMOD Instrument «AVOS»

Avantes AvaSpec ULS2048 /CCD Hamamatsu back illuminated

Wavelength: 280 – 390 nm (irregular grid)



Adressing Data Post Processing

1. Data Acquisition
2. Linearity correction
3. Dark Measurements
4. Handling several integration times
5. Stray Light Correction
4. Bandwidth and wavelength correction / homogenization

“Matshic”

5. Discussion of experience of users of other array spectroradiometers

Data Acquisition

- Setting **integration** time and **dark measurement**

messparamfig_avos [File Spectrograph]

Spectrograph: 1010176U1

Viewing Options

- ☒ Plot all scans
- ☐ Plot averages
- ☐ Calibrated

File Saving

- ☒ mat-file
- Filename: Global Irradiance: Direct Irradiance:

Comment

Timing Options

- ☒ Time
 - Start:
 - Next:
 - Repeat rate:
- ☐ SZA (Check/Change Location)
 -
 - ☒ Add Local Noon SZA
- ☒ Schedule Continuous

Dark Options

Beginning of Measurement
End of Measurement

Input Optics

Delay for Start Time (min)

Integration Time

- ☐ Autorange
- ☒ Fixed (ms)
- ☐ Fixed & Autorange

Wavelength (nm) (for 2nd autoIT)
Saturation Limit (max. 65536)

Averaging Options

Number of Scans
Number of Dark Scans
Bins (Global & Direct, Dark)

OK **Cancel**

Data Acquisition

- Setting integration time

messparamfig_avos Spectrograph

Spectrograph: 1010176U1

Viewing Options

- ☒ Plot all scans
- ☐ Plot averages
- ☐ Calibrated

File Saving

- ☒ mat-file
- Filename: Global Irradiance: GLO Direct Irradiance: DIR

Comment

intercomp

Timing Options

- ☒ Time
 - Start: Immediate 145700
 - Next: Immediate 000200
 - Repeat rate: inf
- ☐ SZA (Check/Change Location)
 - [-90:1:90]
 - ☒ Add Local Noon SZA
- ☒ Schedule Continuous

Dark Options

Beginning of Measurement
After each Integration Time
End of Measurement
Skip

Input Optics Global

Delay for Start Time (min)

Integration Time

- ☐ Autorange
- ☒ Fixed (ms)
- ☐ Fixed & Autorange [1000 9000]

Wavelength (nm) 310
(for 2nd auto)

Saturation Limit 55000
(max. 65536)

Averaging Options

Number of Scans 1

Number of Dark Scans 1

Bins (Global & Direct, Dark) 10,4

OK Cancel

Data Acquisition

- Setting integration time

messparamfig_avos
File Spectrograph

Spectrograph: 1010176U1

Viewing Options

- ☒ Plot all scans
- ☐ Plot averages
- ☐ Calibrated

File Saving

- ☒ mat-file
- Filename
- Global Irradiance: GLO
- Direct Irradiance: DIR

Comment

intercomp

Timing Options

- ☒ Time
- Start: Immediate 145700
- Next: Immediate 000200
- Repeat rate: inf
- ☐ SZA (Check/Change Location)
- [-90:1:90]
- ☒ Add Local Noon SZA
- ☒ Schedule Continuous

Dark Options

Beginning of Measurement
After each Integration Time
End of Measurement
Skip

Input Optics

Global

Delay for Start Time (min)

Integration Time

- ☐ Aurange
- ☒ Fixed (ms)
- ☐ Fixed & Aurange
- [1000 9000]
- Wavelength (nm) 310
- (for 2nd auto)
- Saturation Limit 55000
- (max. 65536)

Averaging Options

Number of Scans 1

Number of Dark Scans 1

Bins (Global & Direct, Dark) 10,4

OK Cancel

**Be careful in
changing Integration
times !!**

Data Acquisition

- Setting dark measurement

messparamfig_avos
File Spectrograph

Spectrograph: 1010176U1

Viewing Options

- ☒ Plot all scans
- ☐ Plot averages
- ☐ Calibrated

File Saving

- ☒ mat-file
- Filename: Global Irradiance: GLO Direct Irradiance: DIR

Comment

intercomp

Timing Options

- ☒ Time
 - Start: Immediate 145700
 - Next: Immediate 000200
 - Repeat rate: inf
- ☐ SZA (Check/Change Location)
 - [-90:1:90]
 - ☒ Add Local Noon SZA
- ☒ Schedule Continuous

Dark Options

- ☒ Beginning of Measurement
- ☐ After each Integration Time
- ☐ End of Measurement
- ☐ Skip

Input Optics

Global

Delay for Start Time (min)

Integration Time

- ☐ Autorange
- ☒ Fixed (ms)
- ☐ Fixed & Autorange
- [1000 9000]
- Wavelength (nm) (for 2nd autoIT): 310
- Saturation Limit (max. 65536): 55000

Averaging Options

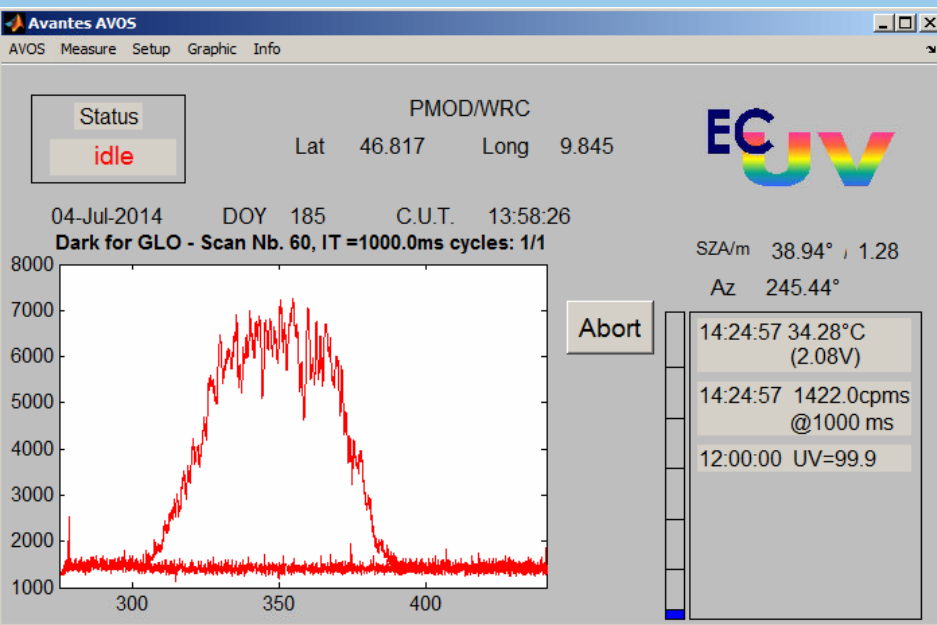
- Number of Scans: 1
- Number of Dark Scans: 1
- Bins (Global & Direct, Dark): 10,4

OK Cancel

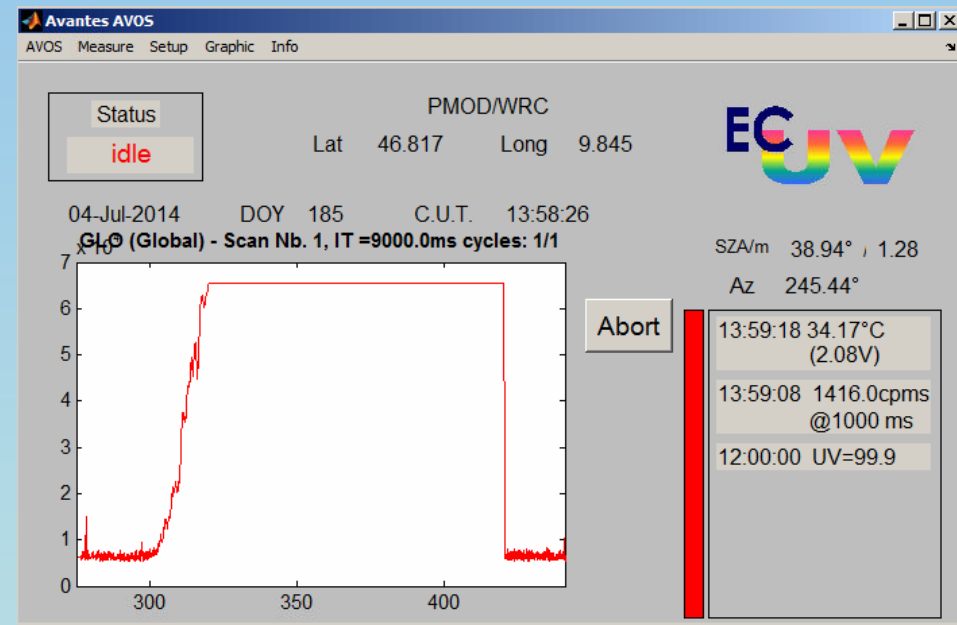
Data Acquisition

- Monitoring schedule

1000 ms

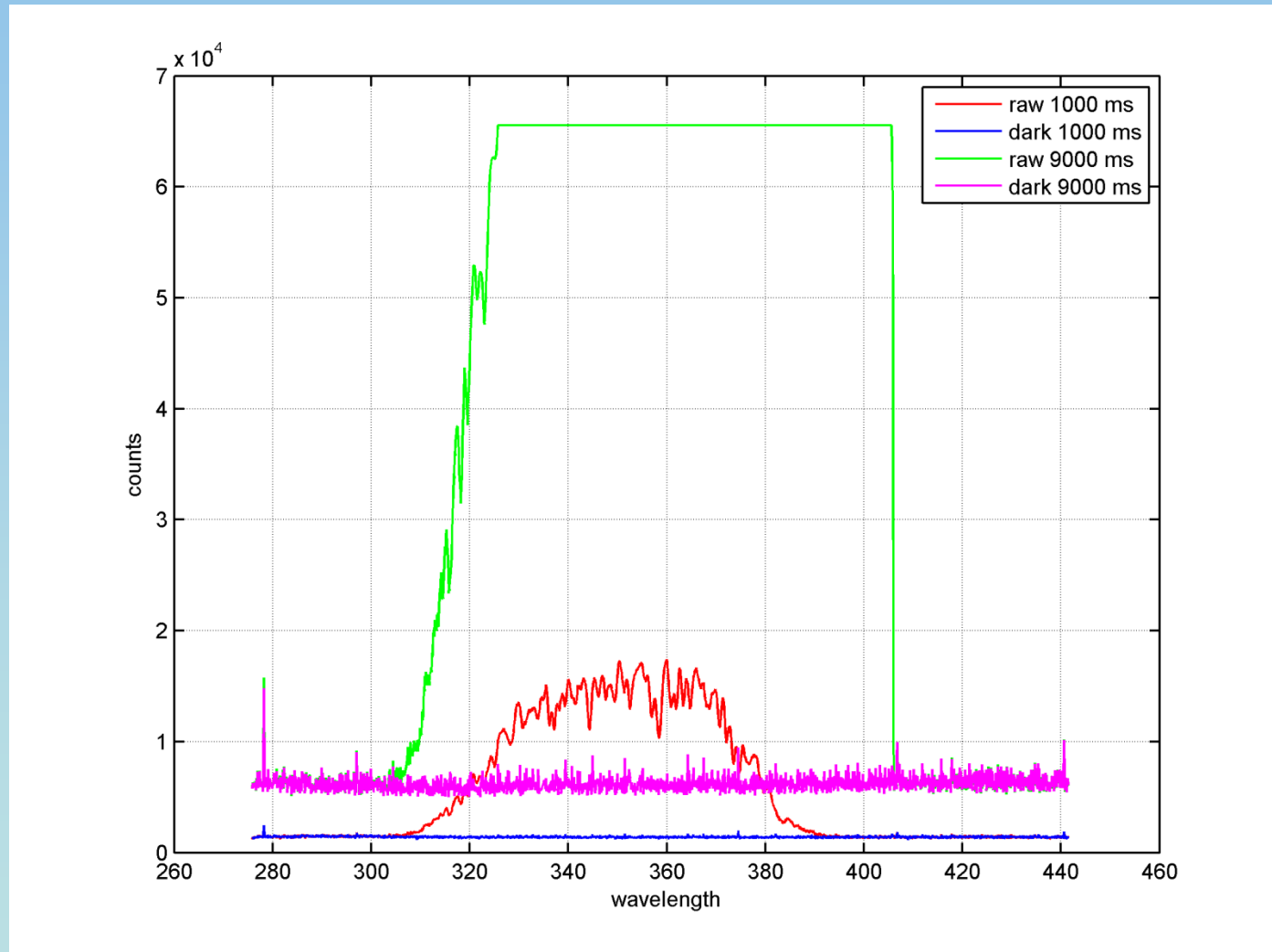


9000 ms



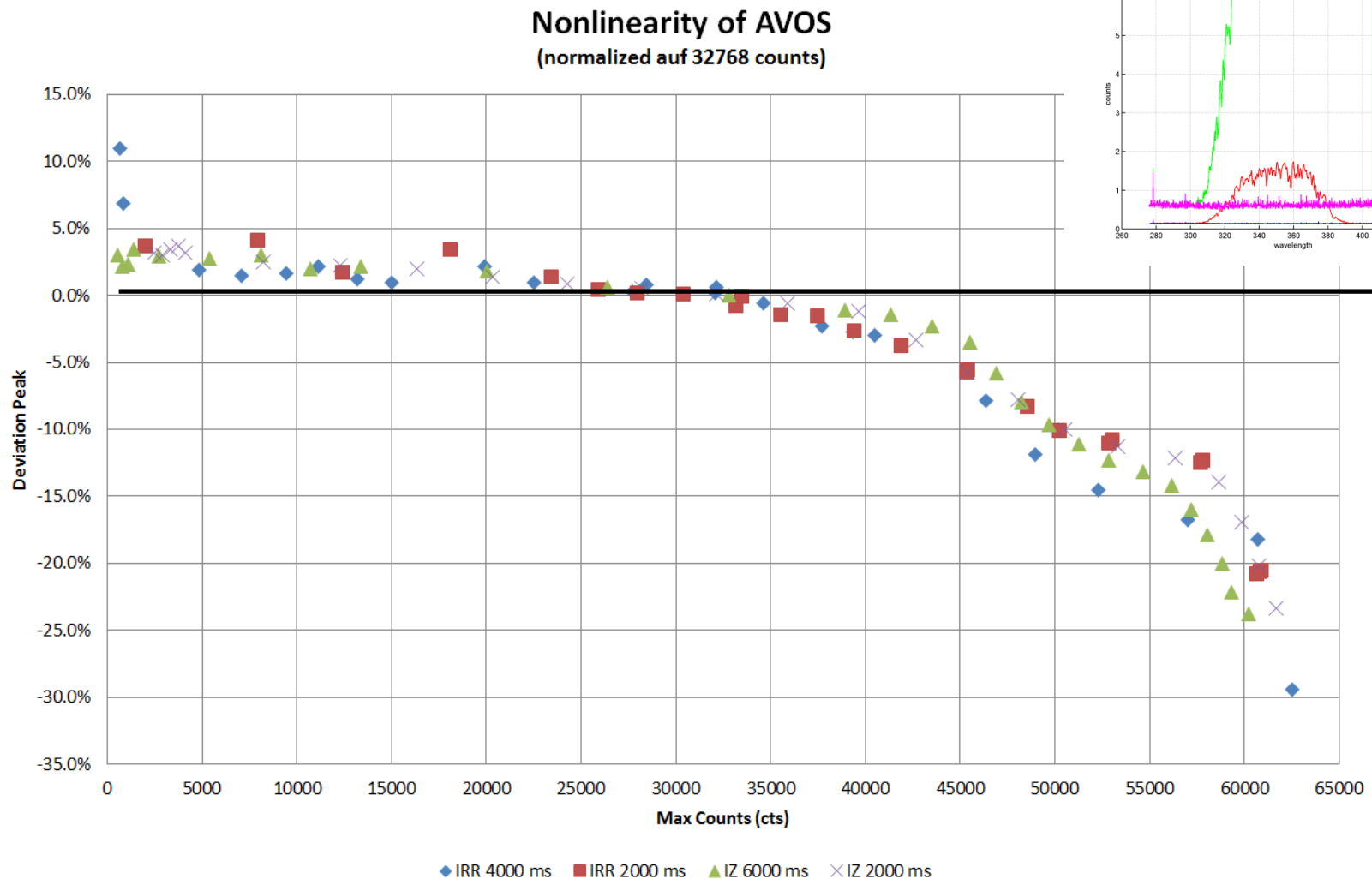
After Linearity correction: **Dark Measurements**

- Subtracting dark measurements for each scan and integration time



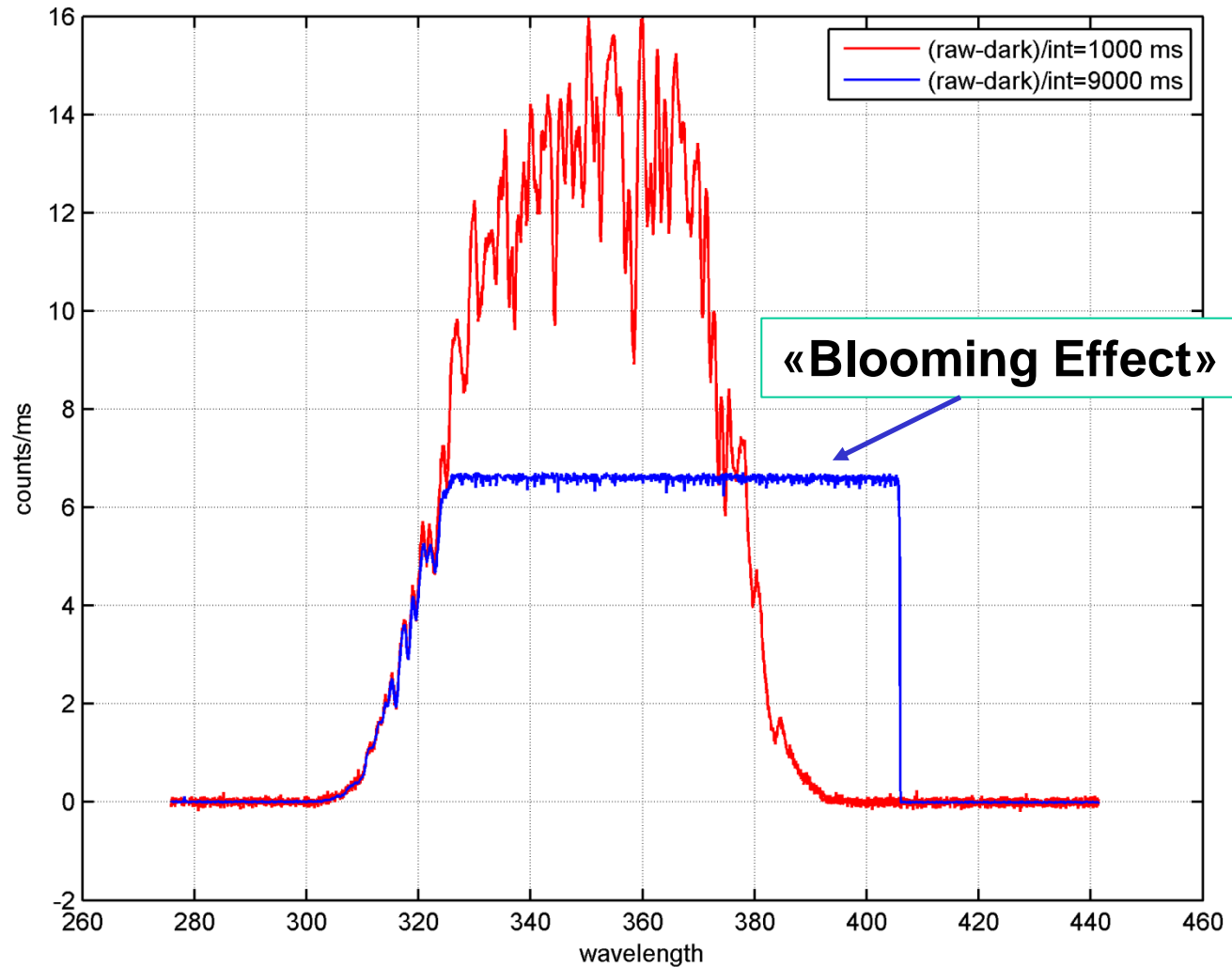
Linearity correction

- Correcting **raw signal (in counts)** for linearity



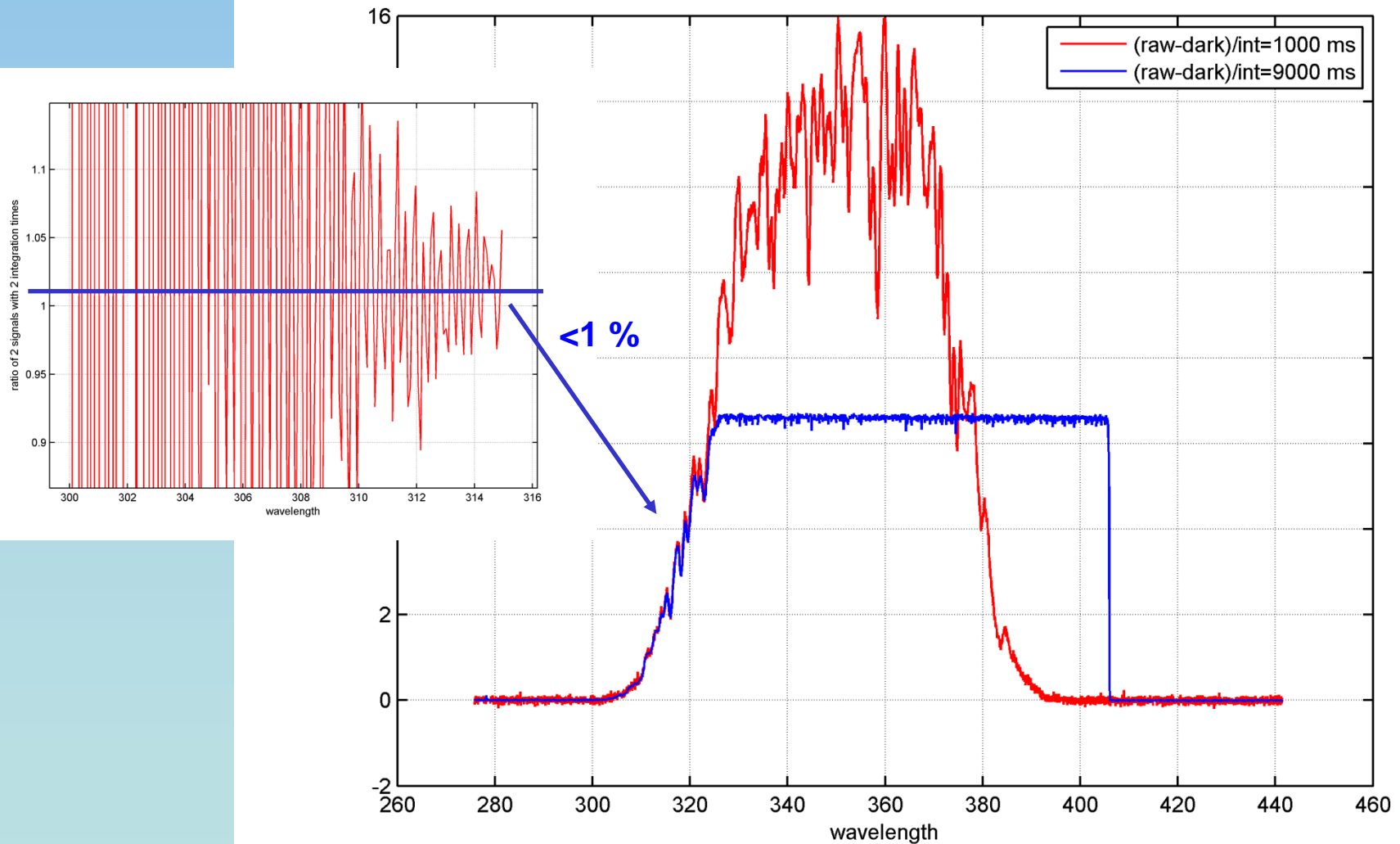
Normalized Signal

- Dividing to integration time [counts/ms]



Compariosn of normalized signal

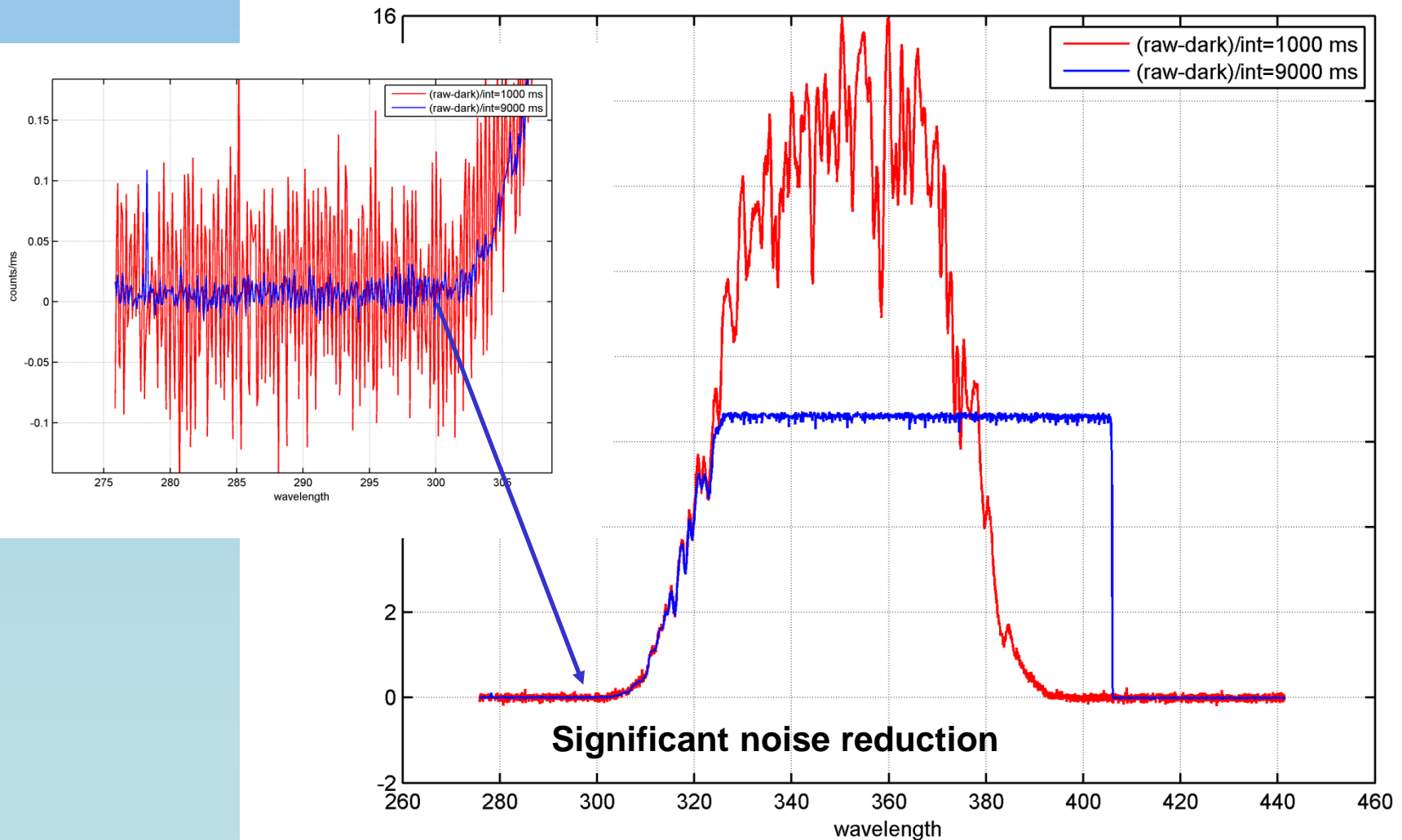
- Dividing to integration time [counts/ms]



Noise reduction

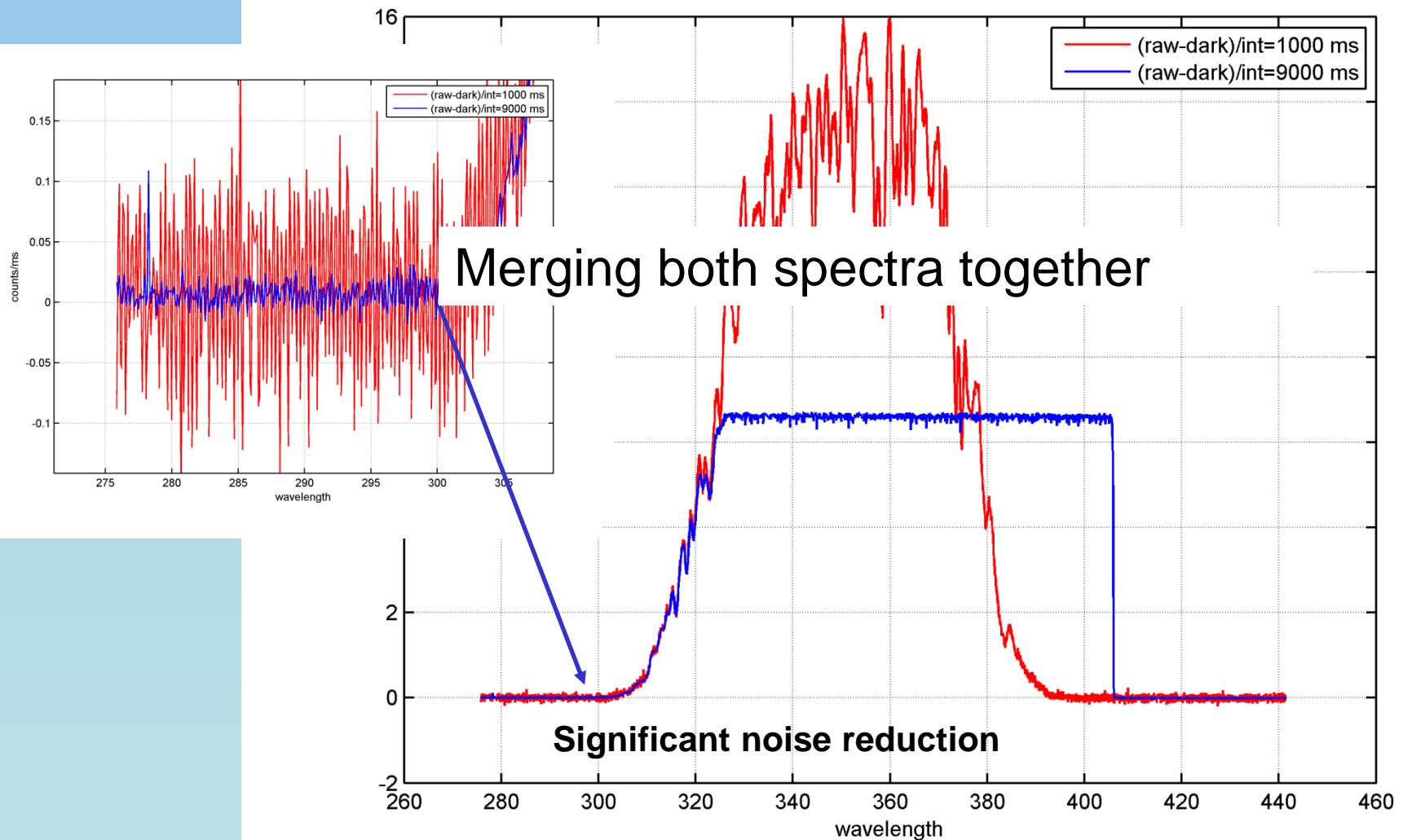
- Effect of longer integration time

Longer integration time reduce noise more than averaging several spectra!

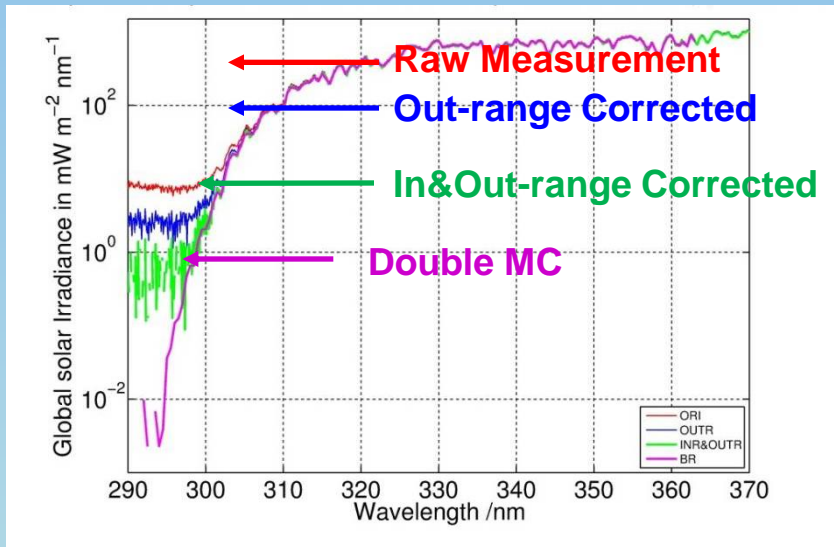


Merging

- Selecting best parts of the normalized signal

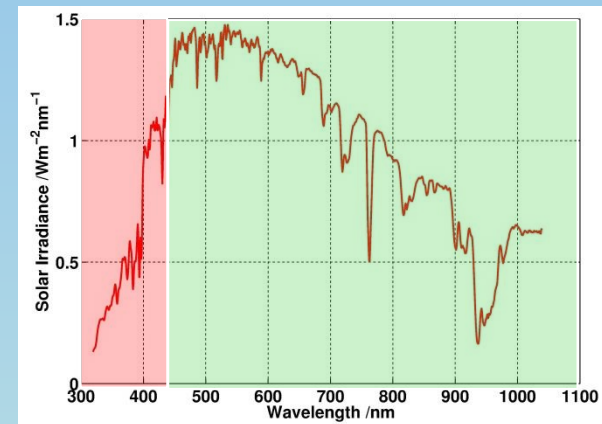


Stray Light Correction



This Array Spectroradiometer

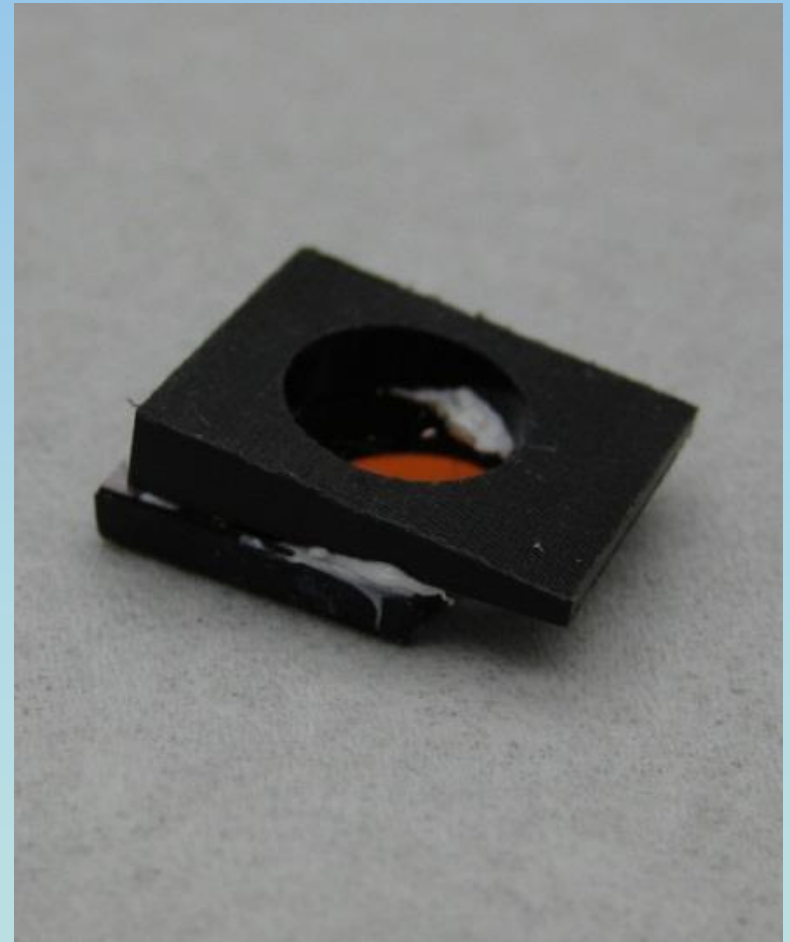
- Nominal Sensitivity: **280 – 440 nm**
- Out-range Radiation from 440 nm to ~1100 (Silicon) nm



This instrument only **In-Range** stray light correction

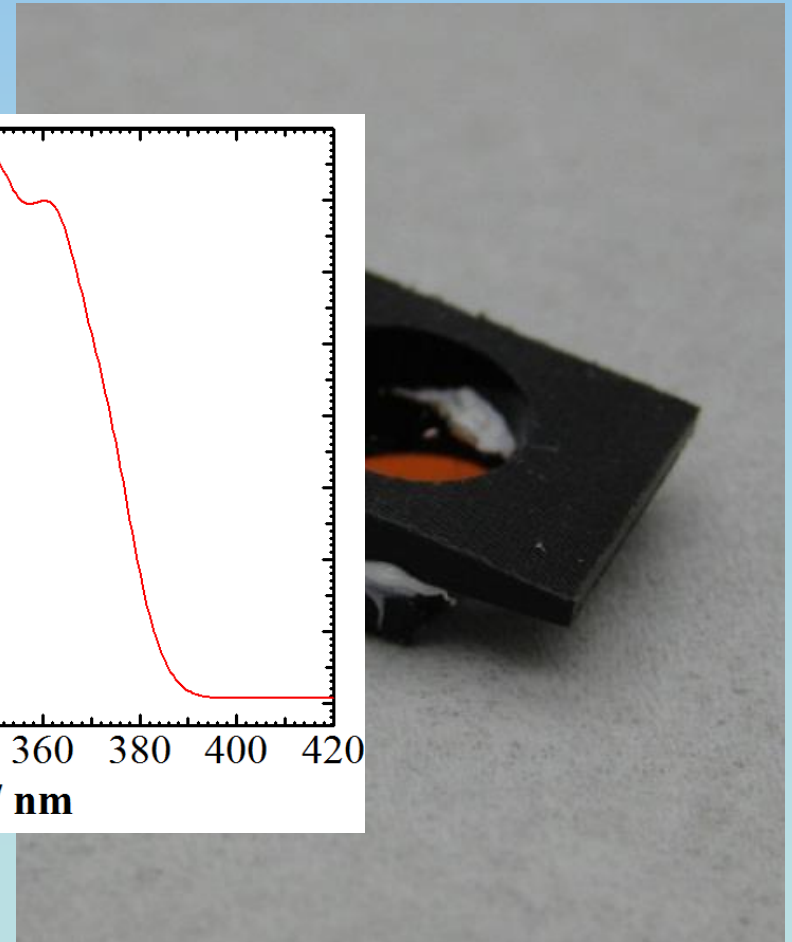
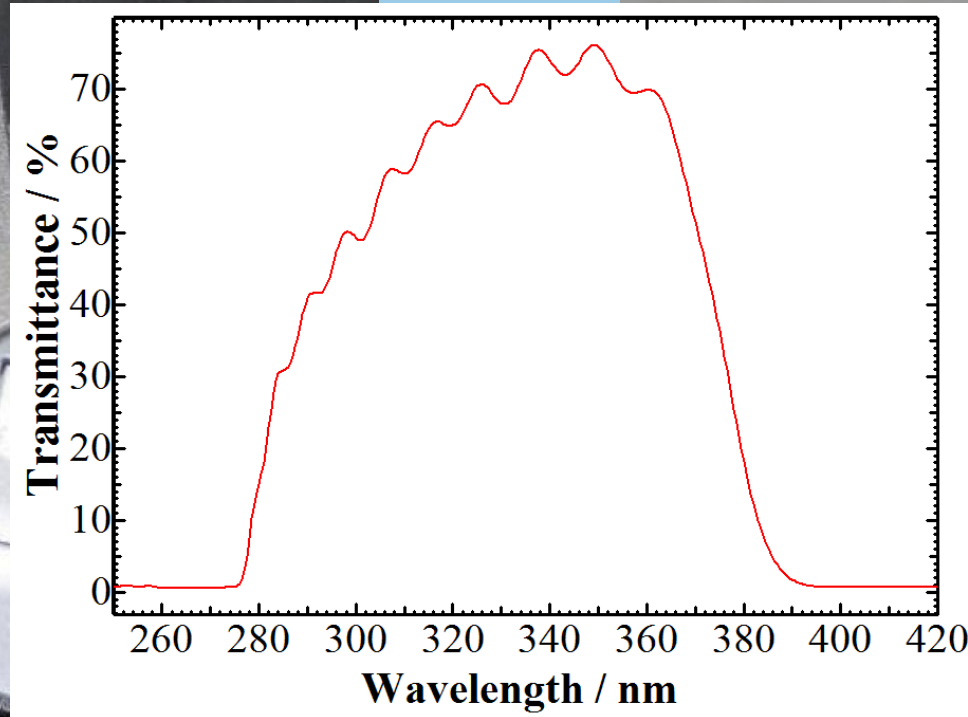
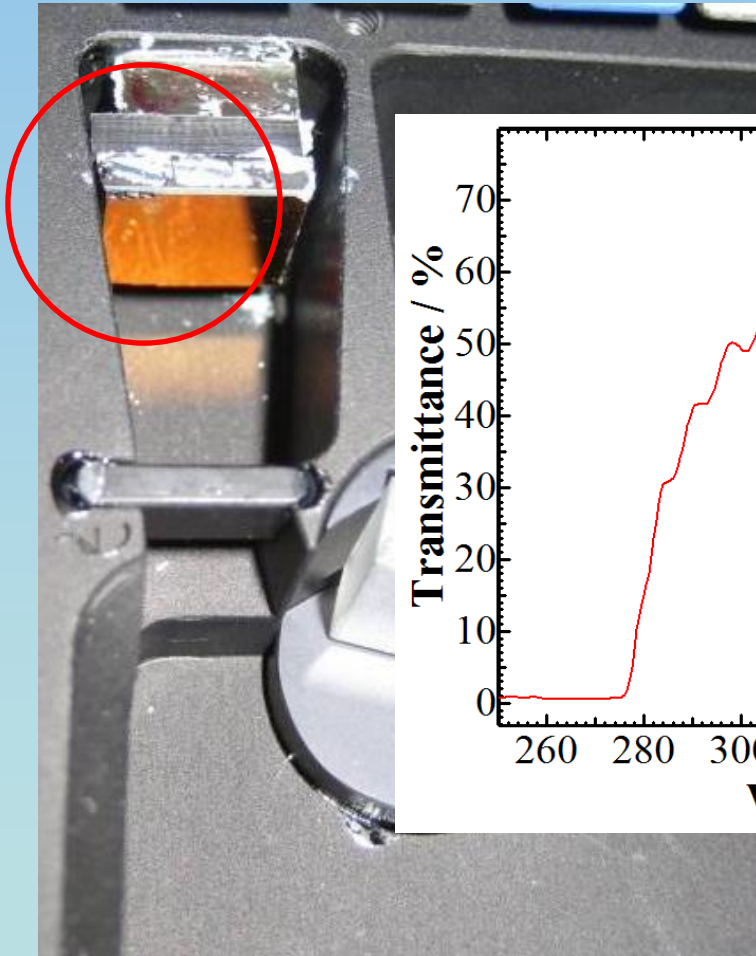
Modification of array spectroradiometer to suppress out-range radiation

We placed a **DUG11X solarblind filter** in the beam path to suppress out-range radiation in the sensitivity range of the silicon CCD detector (390-1100 nm).

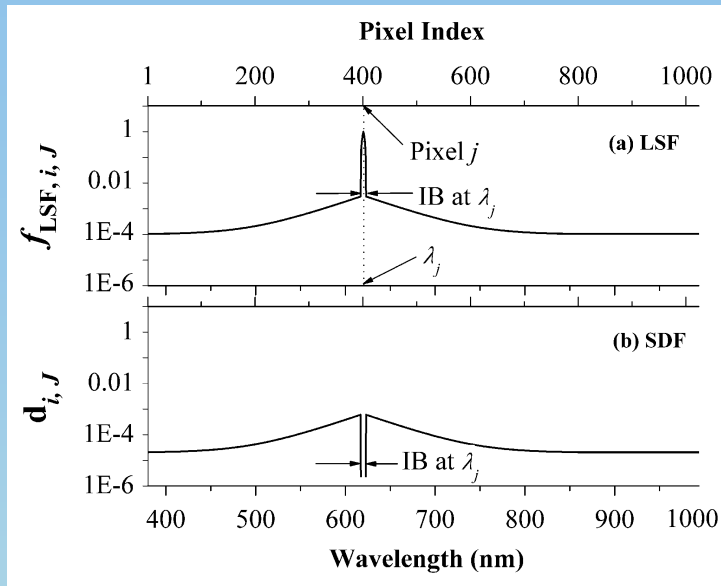


Modification of array spectroradiometer to suppress out-range radiation

We placed a **DUG11X solarblind filter** in the beam path to suppress out-range radiation in the sensitivity range of the silicon CCD detector (390-1100 nm).



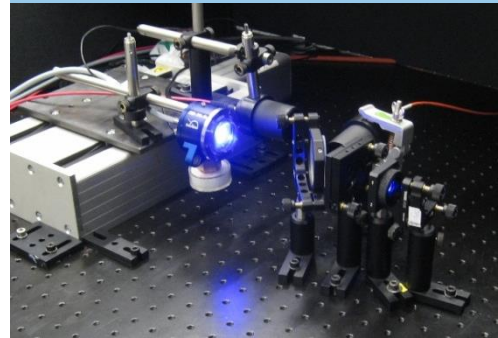
Stray light correction procedure for array spectroradiometer



$$\mathbf{Y}_{IB} = \mathbf{A}^{-1} \cdot \mathbf{Y}_{meas} = \mathbf{C} \cdot \mathbf{Y}_{meas}$$

from Zong et al, 2006

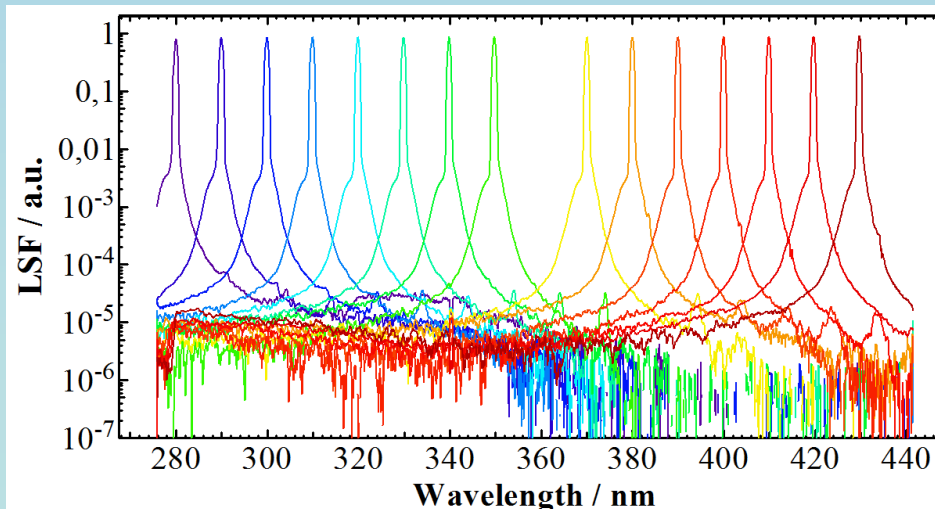
In-range straylight matrix



$$\Delta = \mathbf{s}_{OoR} \cdot \mathbf{E}_{OoR} \cdot \delta\lambda,$$

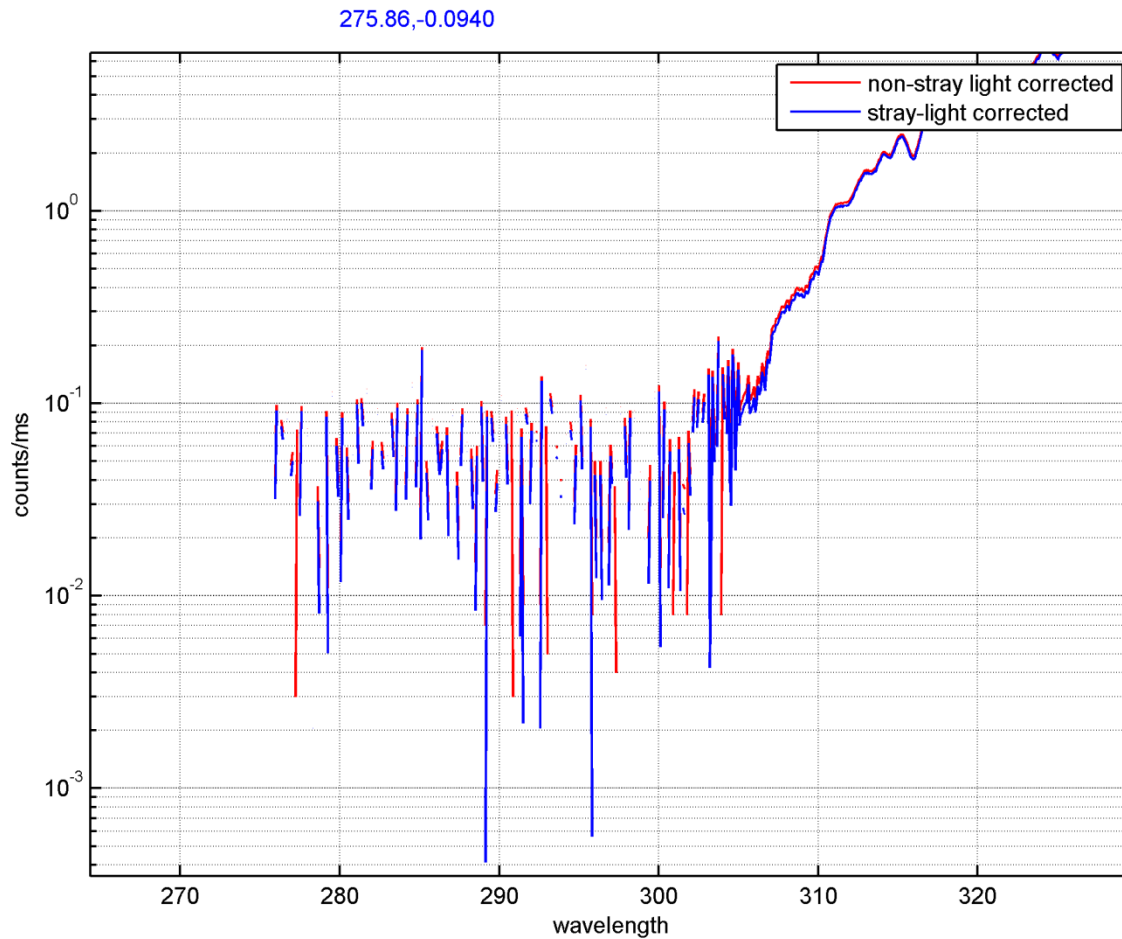
OoR straylight (Nevas et al. 2012)

Slit Functions obtained from tunable laser setup (PLACOS-PTB) - > **creating matrix**



Applying Stray Light Correction

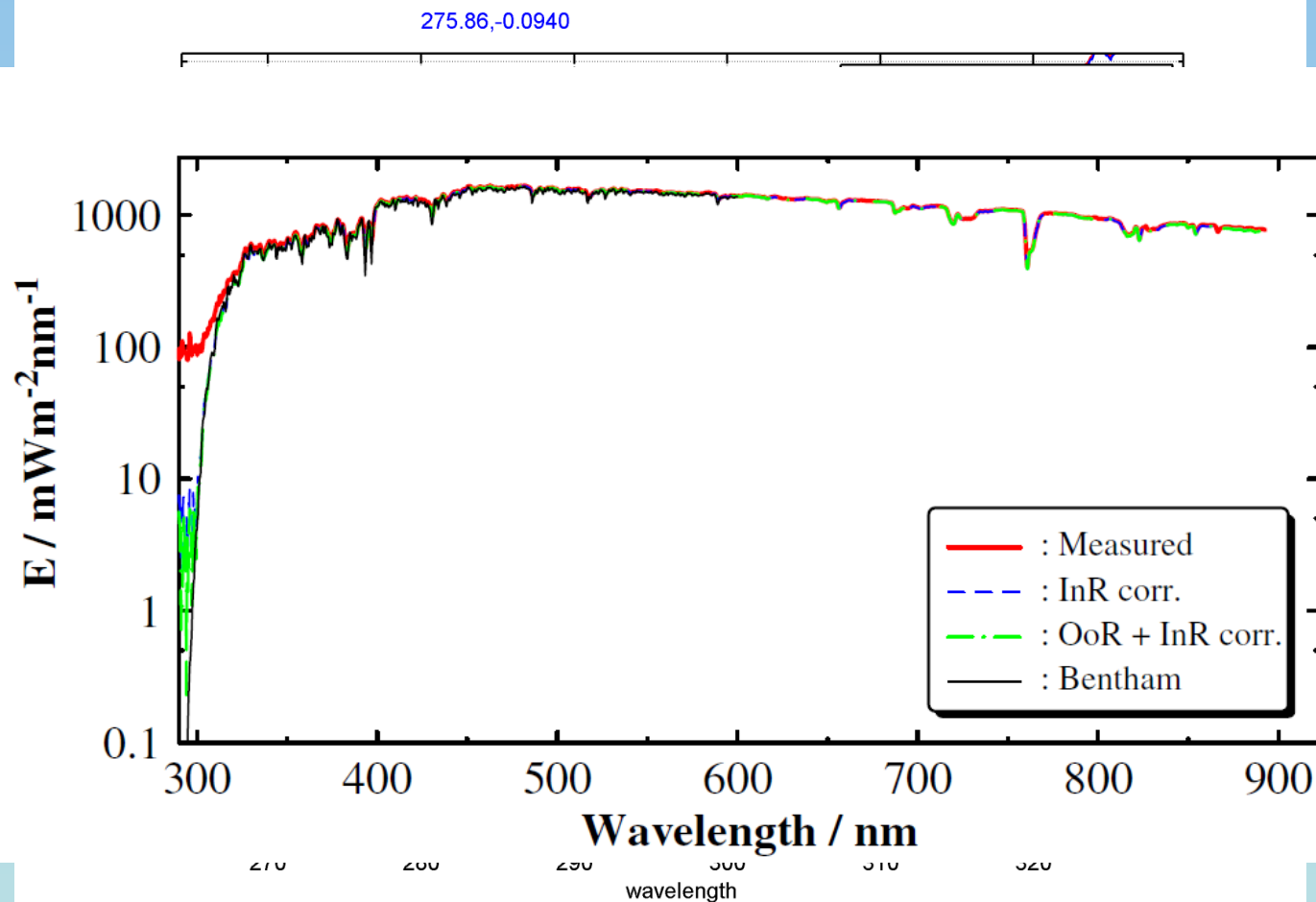
- Linear corrected and normalized signal [counts/ms]



This instrument only **In-Range** stray light correction between 280 and 390 nm

Applying Stray Light Correction

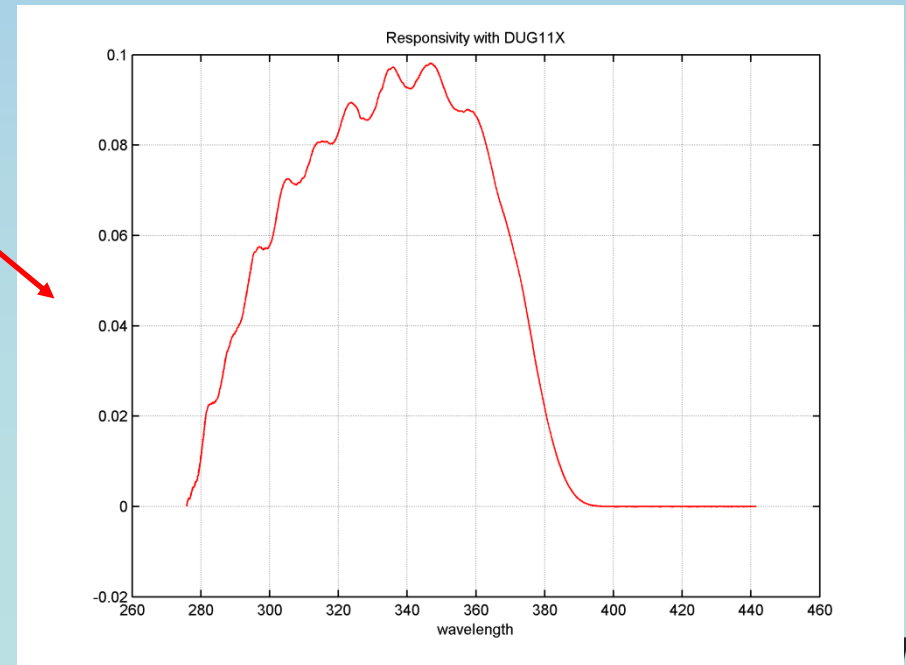
- Linear corrected and normalized signal [counts/ms]



This instrument only **In-Range** stray light correction between 280 and 390 nm

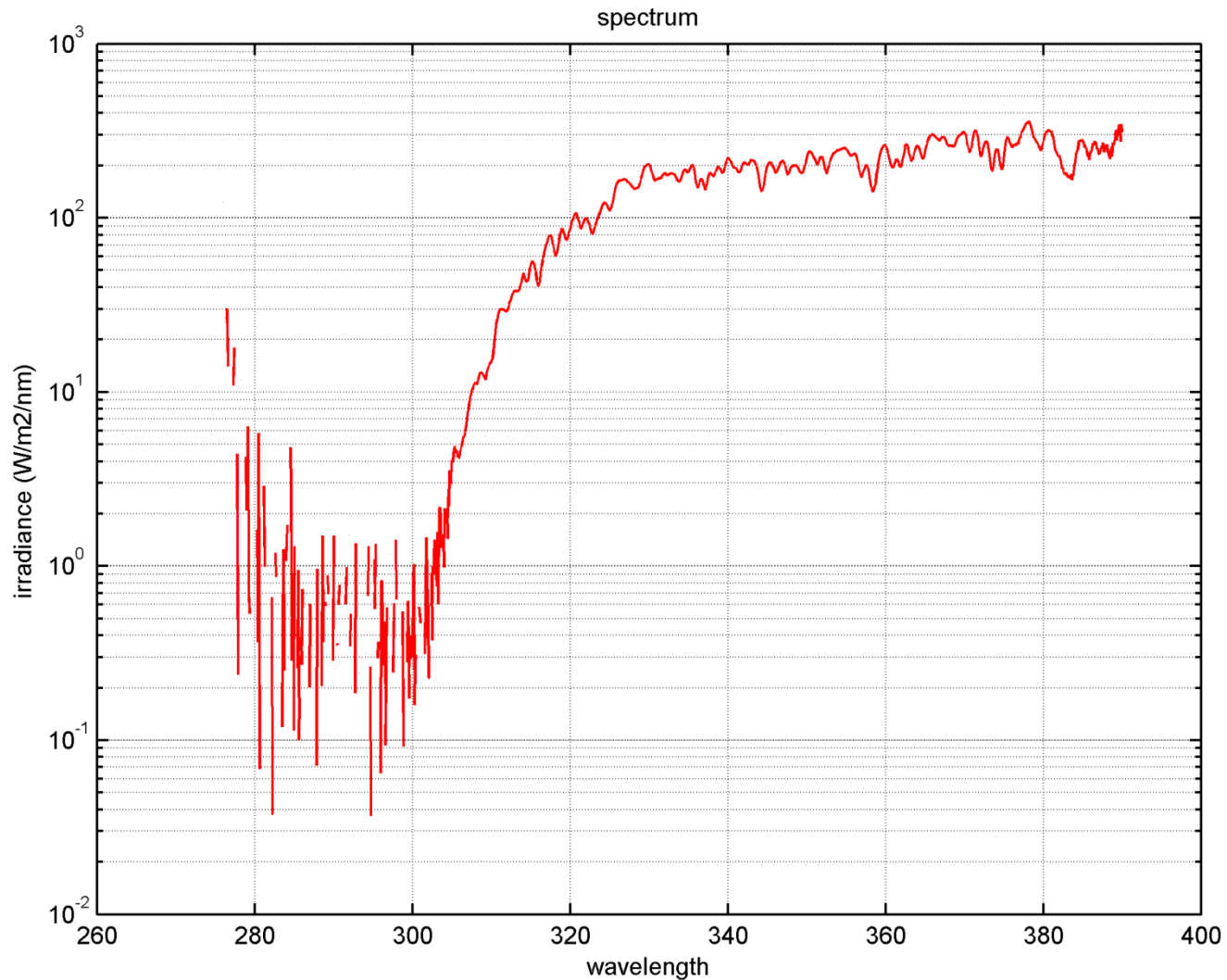
Responsivity

- Measuring standard lamp
- Using same procedure as above:
 - Linear correction of raw signal and dark measurements
 - Stray light correction
- Calculate **responsivity** in [counts/ms \rightarrow measured / (W/m² /nm) \rightarrow known lamp]



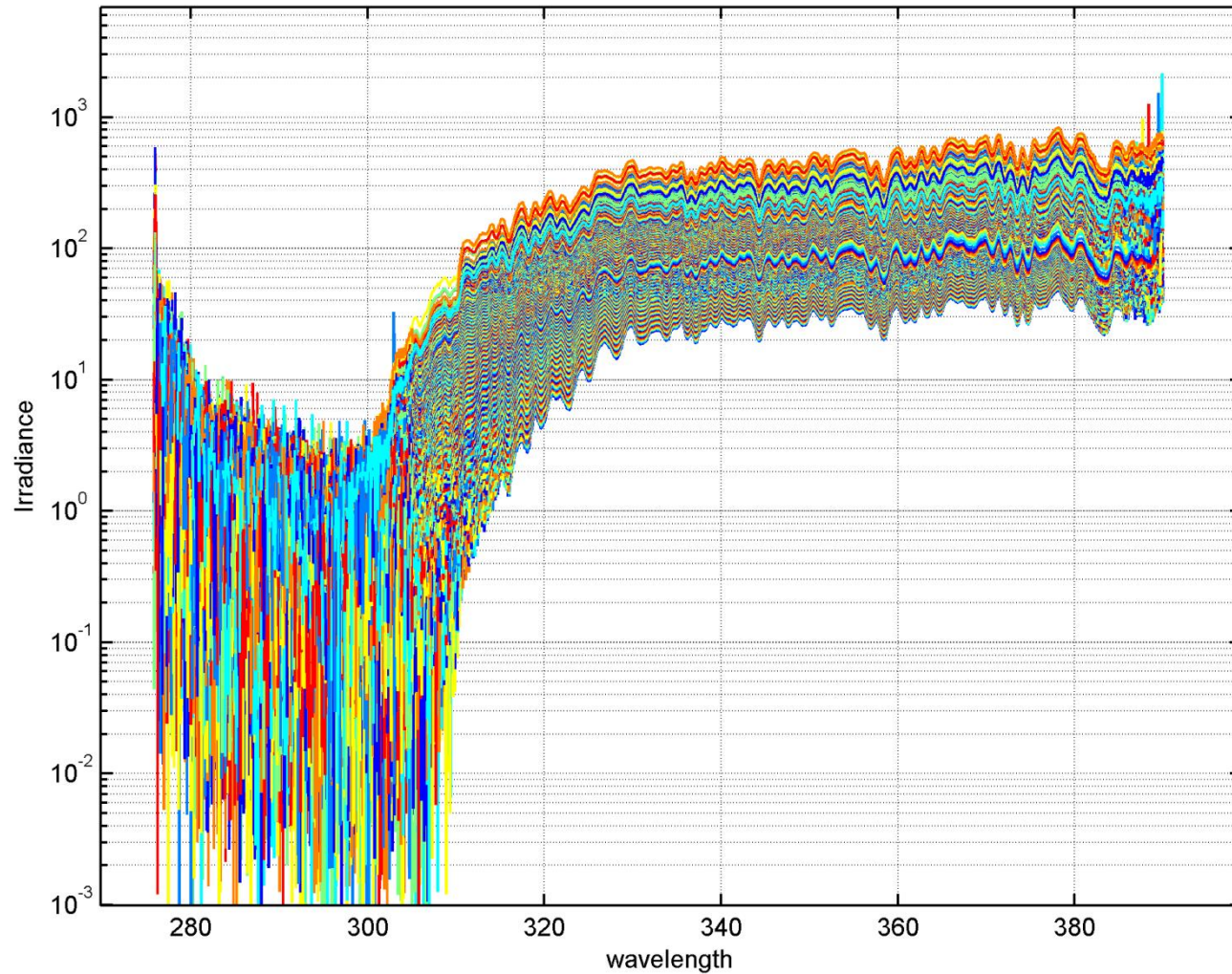
Final spectrum

- Measurements (**counts/ms**) divided by responsivity



Final spectrum

- Measurements (**counts/ms**) divided by responsivity



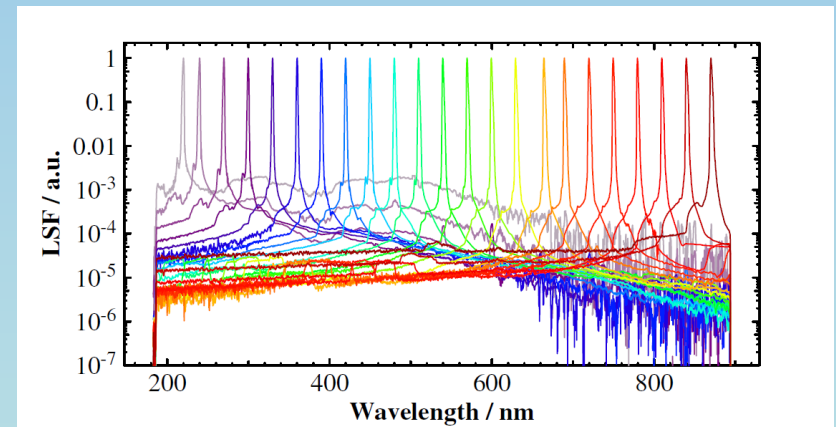
Bandwidth and Wavelength Homegenization

■ Problem:

- **Irregular grid** of wavelength from array spectroradiometer
- **Shift of wavelength** (non ideal characterization pixel – wavelength)
- **Variable slit functions** on array spectroradiometer depending on wavelength

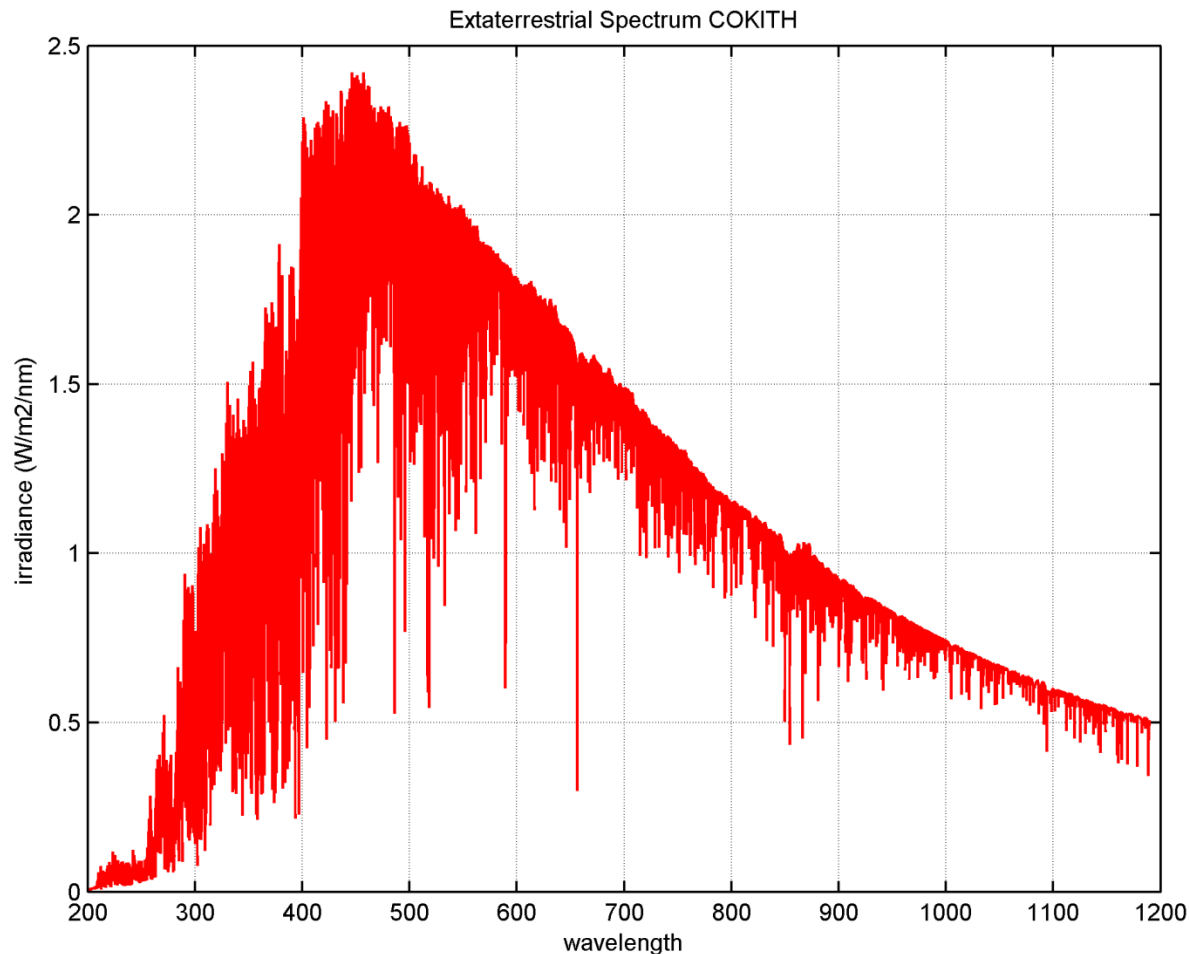
■ Objective:

- **Regular grid** of wavelengths (no splining!)
- Correction for **Wavelength-Shift**
- Nominal slit function for all wavelengths instead of **variable slit functions** from array spectroradiometer



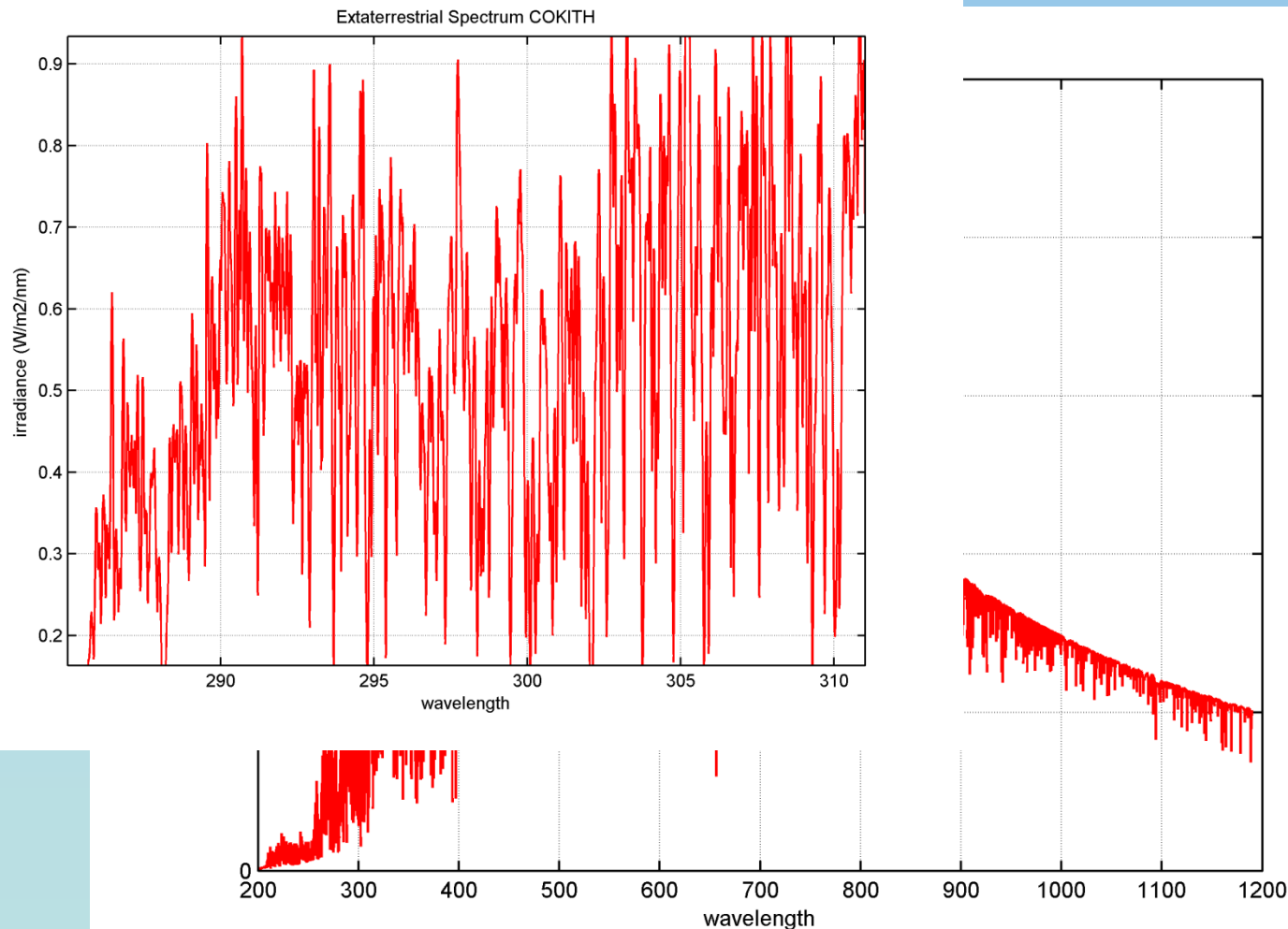
Matshic

- 1. Extra-Terrestrial Spectrum ET (MHP-COKITH)
 - wavelength step 0.01 nm, bandwidth 0.05 nm (Validated from 290 – 500 nm)



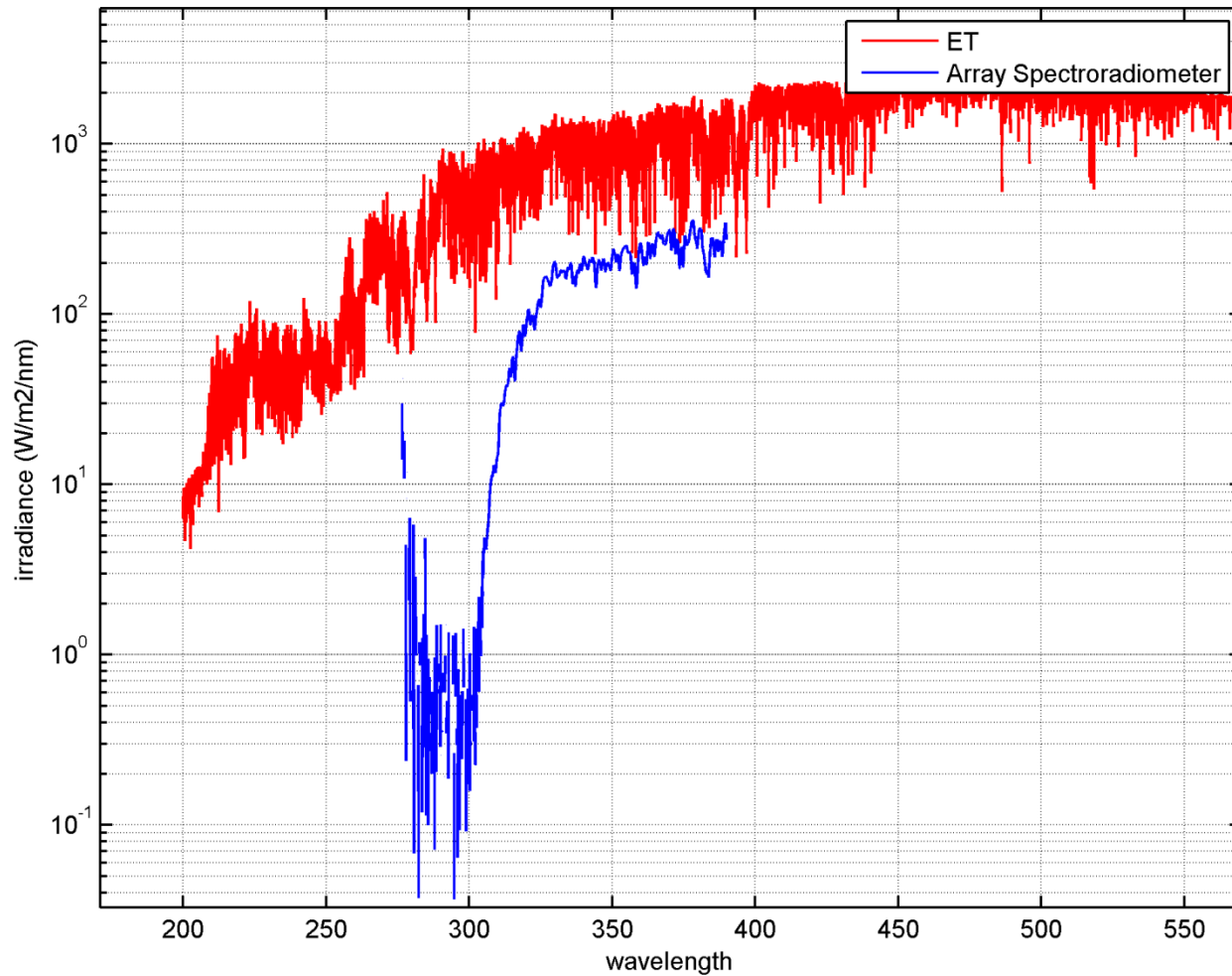
Matshic

- 1. Extra-Terrestrial Spectrum ET (MHP-COKITH)
 - wavelength step 0.01 nm, bandwidth 0.05 nm (Validated from 290 – 500 nm)



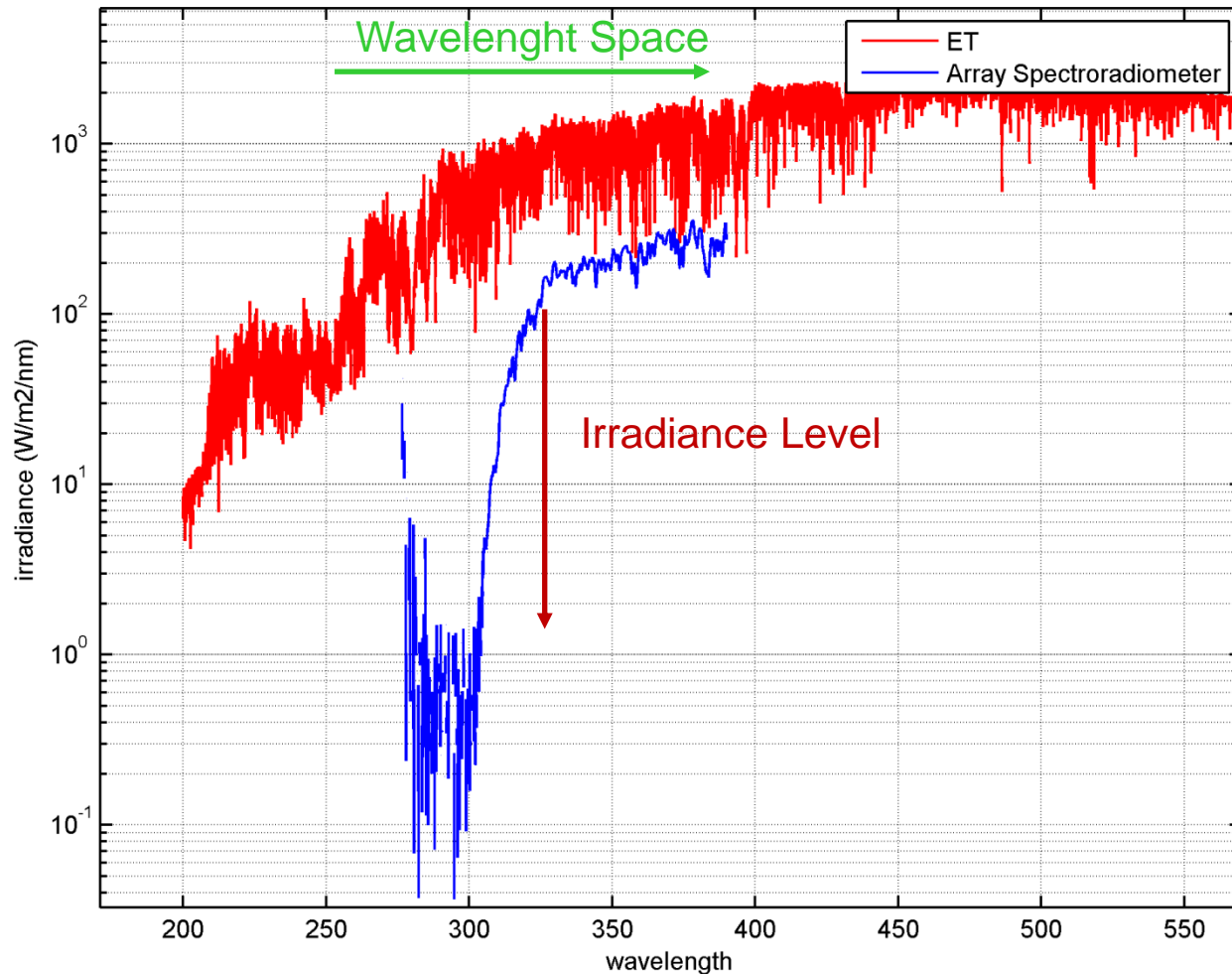
Matshic

■ 2. Relation between ET and measured Spectrum



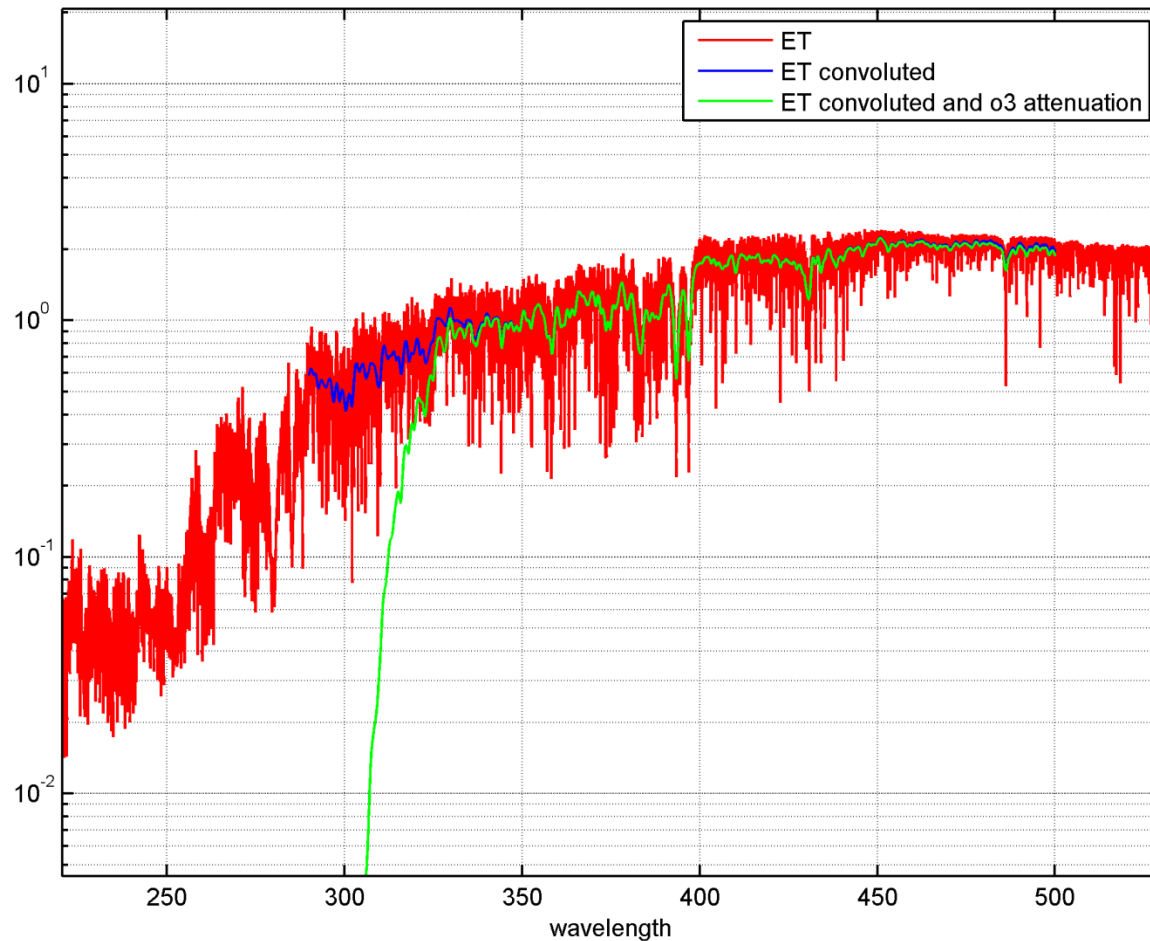
Matshic

■ 2. Relation between ET and measured Spectrum



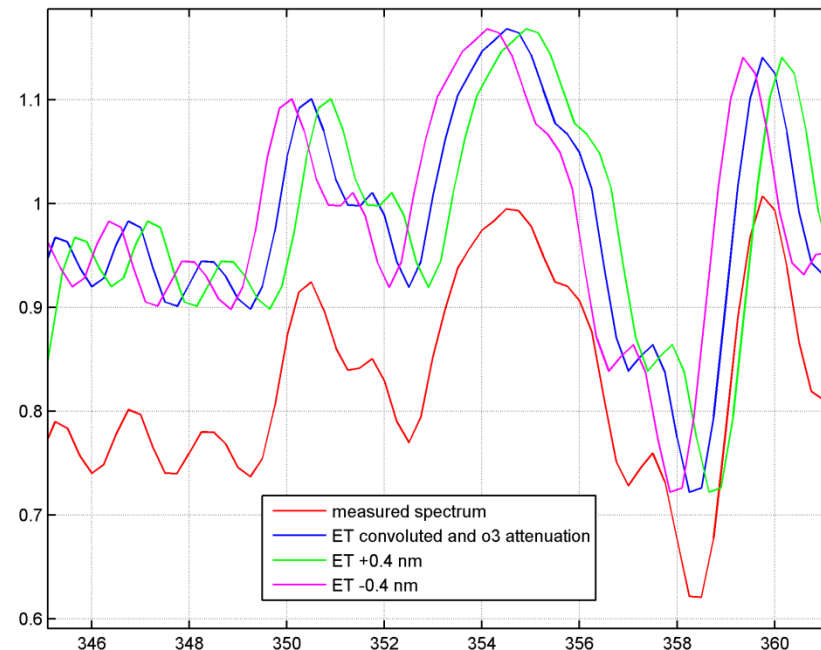
Matshic - Procedure

- a) convoluting ET - using the instruments (variable) slit function
- b) determine O3 attenuation

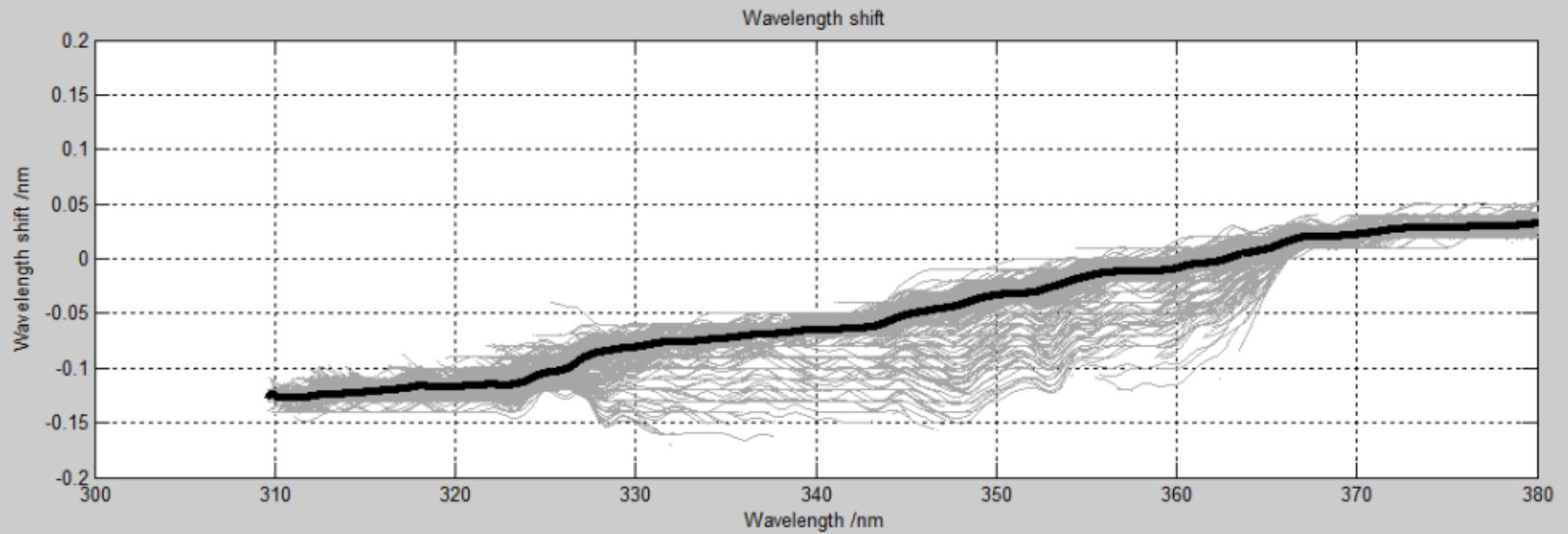


Matshic - Procedure

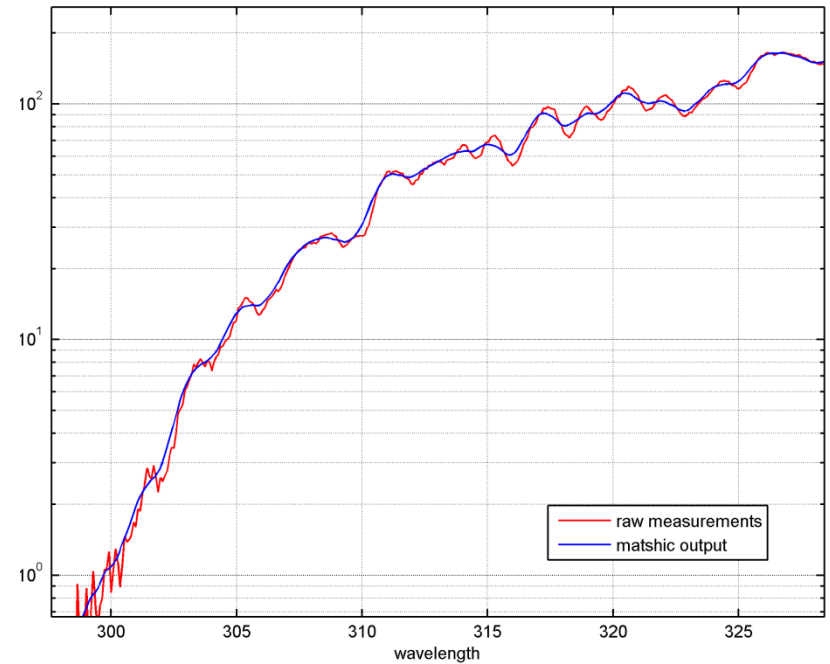
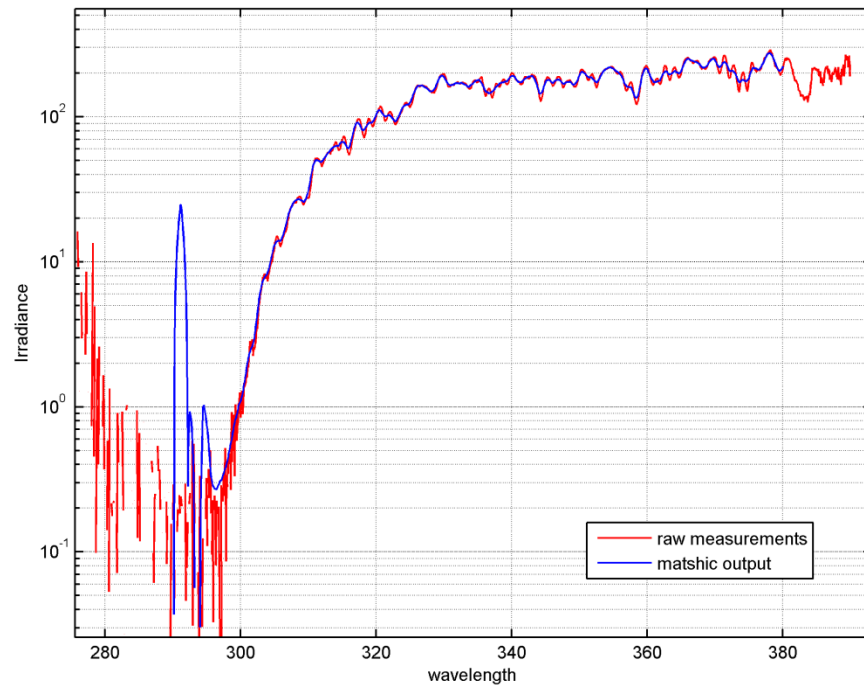
- a) **comparison** of measured spectrum with processed ET
- b) **shift the ET** for wavelength in 0.005 nm step.
- c) determine the **best congruence** of measurements with ET for all **wavelengths-steps** and **all wavelength** of the array spectroradiometer
- d) **applying the best wavelength shift** to the ET
- e) applying **measured** irradiance scale to the ET with selectable: **bandwidth & wavelength grid**



Matshic Results



Matshic Result



Matshic in Matlab

- Data-In: Matlab Matrix or ASCII (in uvdata)
- Slit- function (variable or single slit)

\\CORONA\calib\uv\matshic

Organize Open Burn New folder

OS (C:)
HP_RECOVERY (D:)

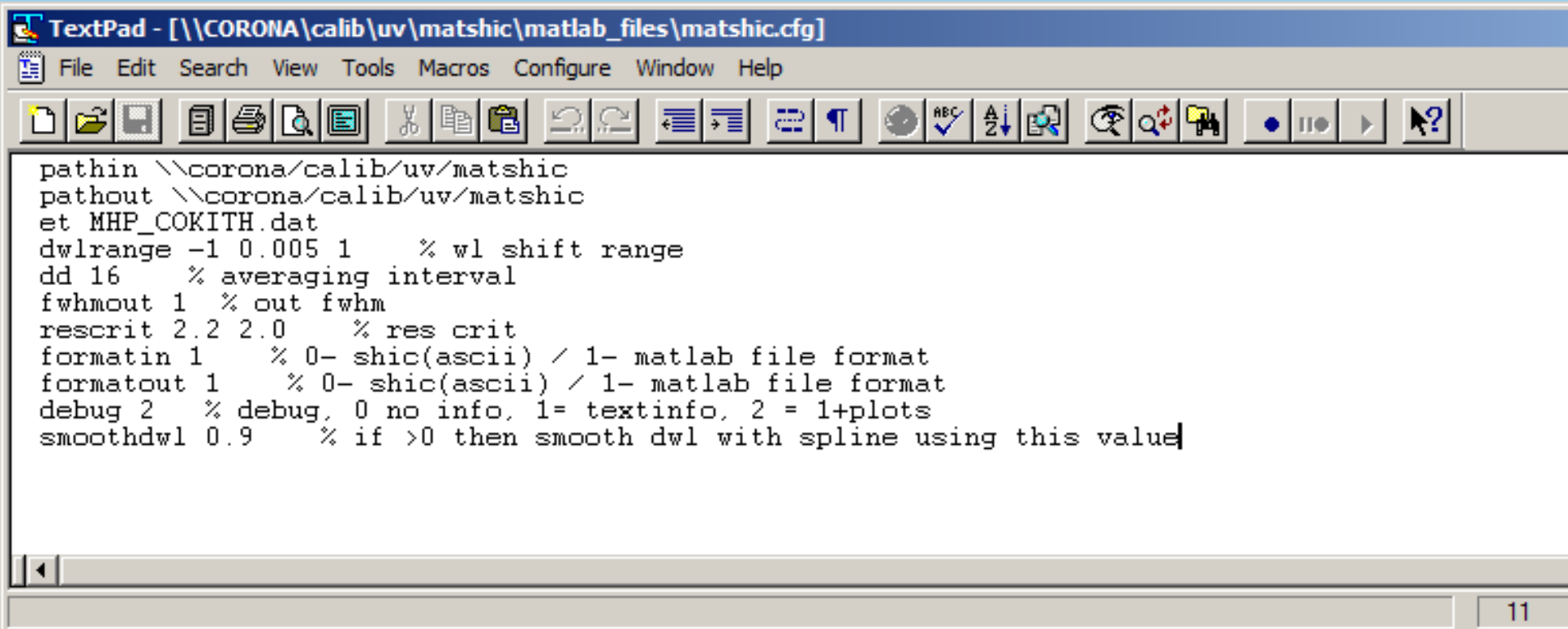
Network
ALETSCHORN
ALTELS
AMSEFLUH
ANGSTROEM1
APP-ABACUS
APP-ADMIN
APP-GLASSFISH
APP-LICENSE
APP-RDS
APP-RETROSPECT
APP-SHAREPOINT
APP-SIPASS
APP-SOLIDWORKS
APP-VEEAM
ARLANDA
AUBRIG
BACHTEL
BALMHORN
BELLINZONA
BLACKCOMB

Name	Date modified	Type	Size
2011	11.11.2013 13:48	File folder	
2012	02.05.2013 08:25	File folder	
2013	07.11.2013 13:11	File folder	
2014	11.06.2014 07:40	File folder	
matlab_files	02.07.2014 14:49	File folder	
testcases	12.02.2014 15:33	File folder	
uvanalys	12.04.2014 12:48	File folder	
uvdata	28.02.2014 08:43	File folder	
avo.dat	05.03.2014 14:21	DAT File	1 KB
avo.sli	07.02.2014 11:32	SLI File	1'625 KB
avos.dat	07.02.2014 14:13	DAT File	1 KB
avos.sli	07.02.2014 11:32	SLI File	1'625 KB
avv.dat	05.03.2014 14:10	DAT File	1 KB
avv.sli	03.03.2014 16:49	SLI File	5 KB
berlin.dat	01.04.2014 11:39	DAT File	1 KB
davos.dat	28.01.2014 11:13	DAT File	1 KB
inta.dat	12.04.2014 12:43	DAT File	1 KB
isq.dat	02.07.2014 08:45	DAT File	1 KB
isq.sli	10.06.2014 10:54	SLI File	4 KB

avo.dat Date modified: 05.03.2014 14:21 Date created: 05.03.2014 14:21 Offline status: Online
DAT File Size: 95 bytes Offline availability: Not available

Matshic in Matlab

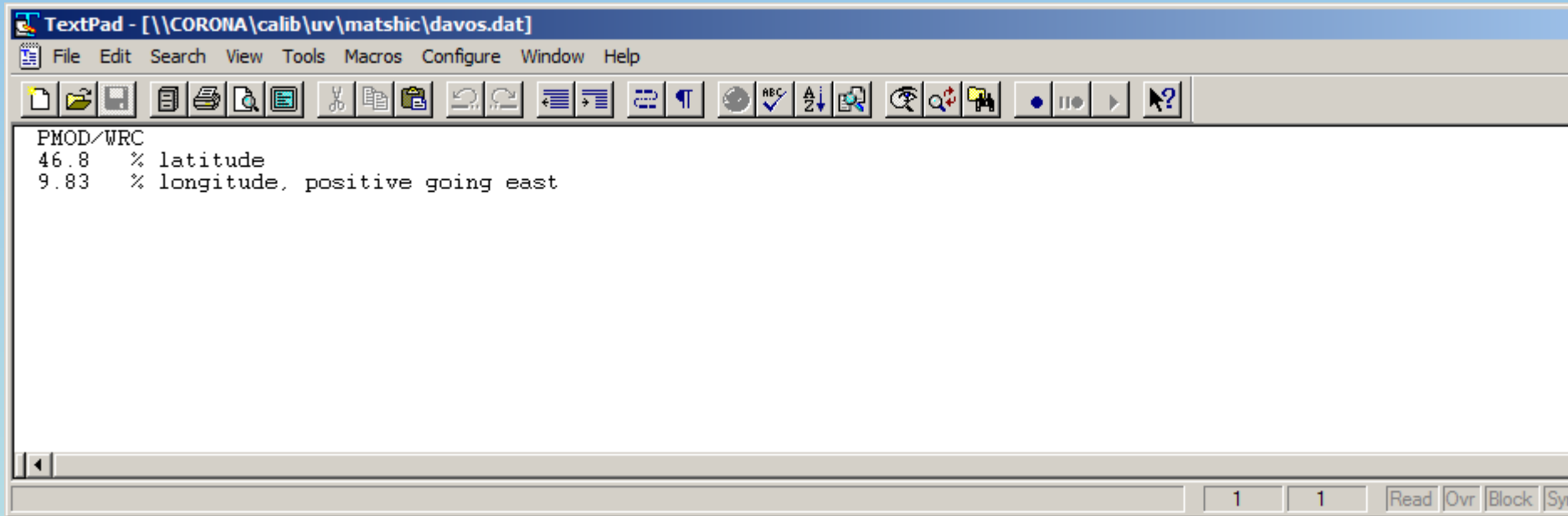
- Main -Configuration:
 - ET
 - WL-shift-range
 - Analysing window for WL-Shift
 - Bandwidth of output spectrum
 - Format in and out (ASCII or Matlab)



```
pathin \\corona/calib/uv/matshic
pathout \\corona/calib/uv/matshic
et MHP_COKITH.dat
dwlrange -1 0.005 1 % wl shift range
dd 16 % averaging interval
fwhmout 1 % out fwhm
rescrit 2.2 2.0 % res crit
formatin 1 % 0- shic(ascii) / 1- matlab file format
formatout 1 % 0- shic(ascii) / 1- matlab file format
debug 2 % debug, 0 no info, 1= textinfo, 2 = 1+plots
smoothdwl 0.9 % if >0 then smooth dwl with spline using this value
```

Matshic in Matlab

- Location -Configuration:
 - Latitude and Longitude

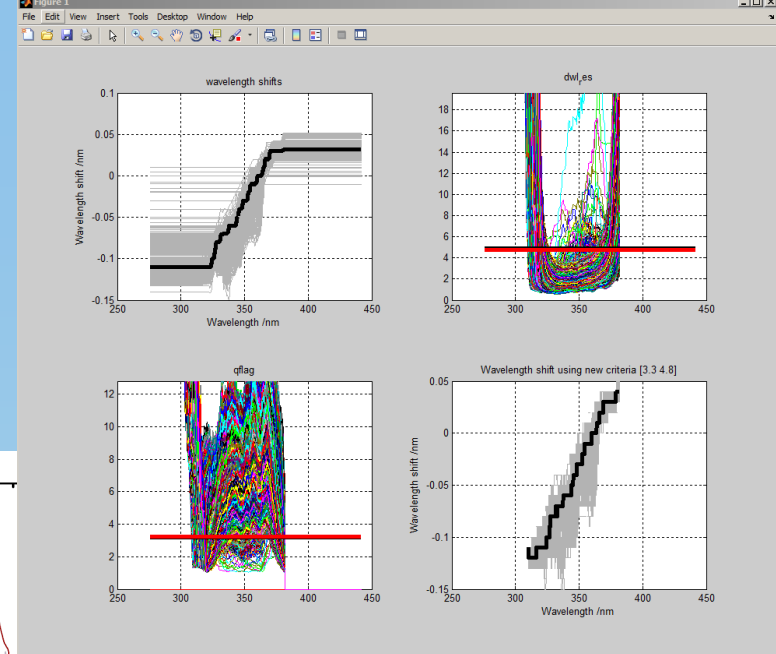
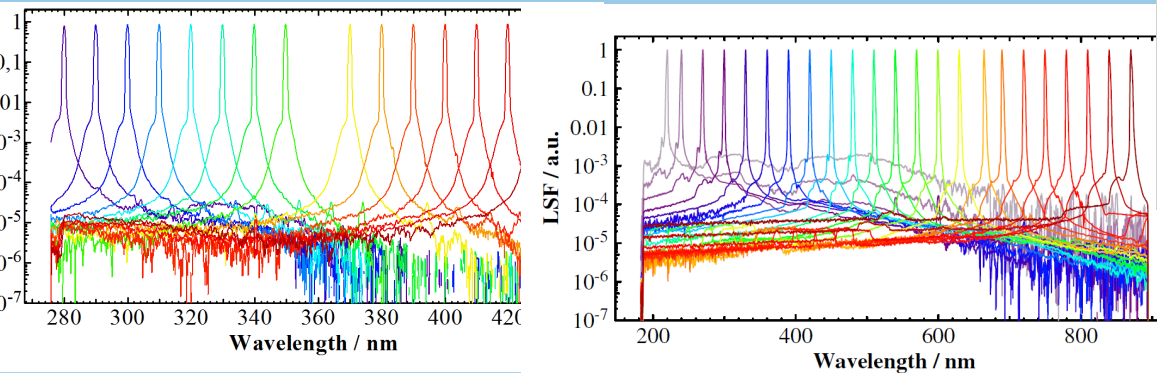


```
TextPad - [\\CORONA\\calib\\uv\\matshic\\davos.dat]
File Edit Search View Tools Macros Configure Window Help

PMOD/WRC
46.8 % latitude
9.83 % longitude, positive going east
```

Matshic in Matlab

- Instrument-Configuration:
 - criteria individually for each inst. (-debug 2)
 - wl-range of output spectrum
 - using single slit (if variable is available)



TextPad - [\\CORONA\\calib\\uv\\matshic\\avo.dat]

File Edit Search View Tools Macros Configure Window Help



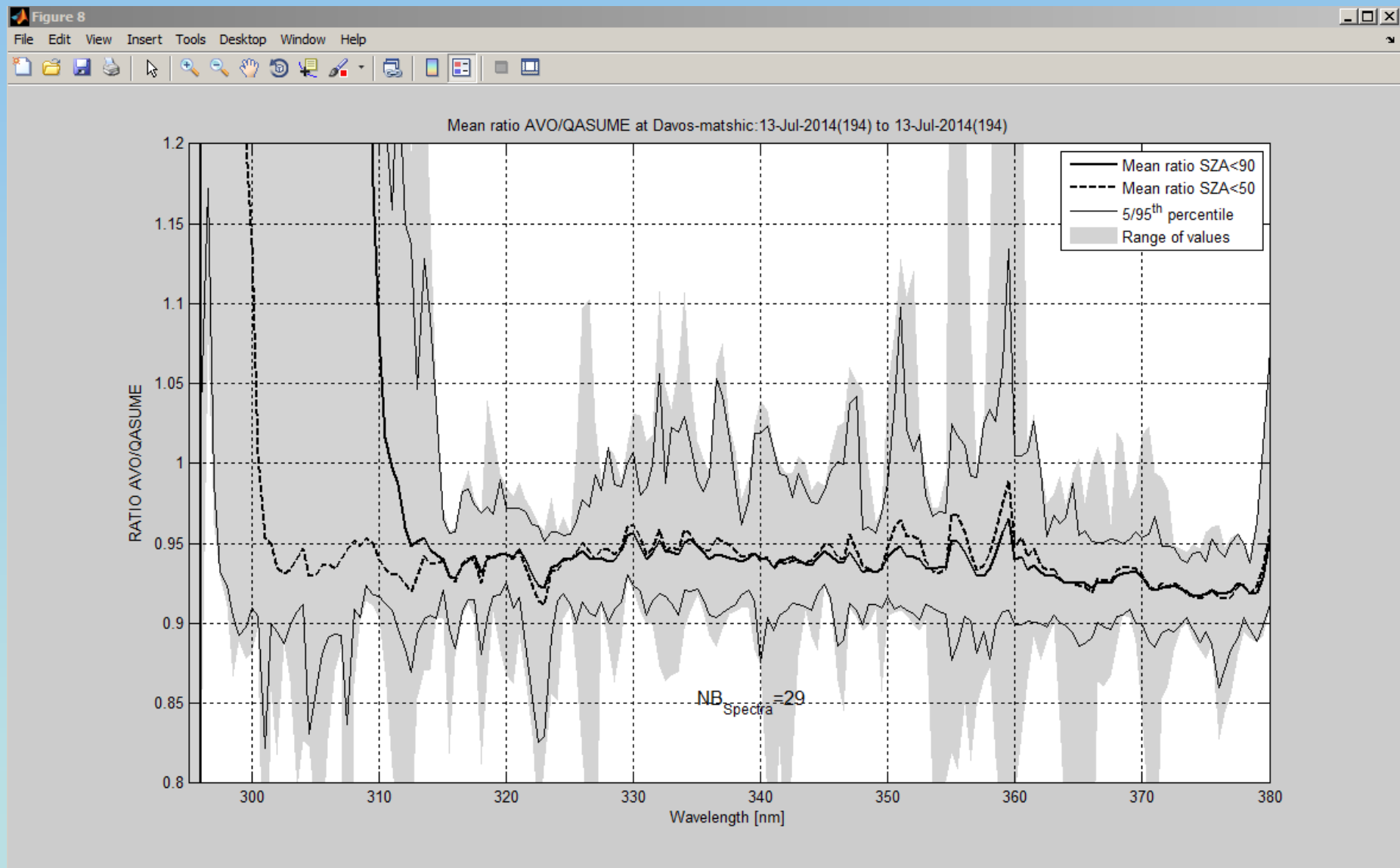
```
rescrit 3.2 3.8  
dwrange -1 0.01 1  
wlout 290 0.5 360  
fileformat 1  
debug 2  
singleslit 320
```

Matshic in Matlab

- Running Matshic:

```
>>
>>
>> matshic('12-jul-2014','12-jul-2014','davos','jrc');
jrc : Center WL=-0.000 nm FWHM=0.824 nm
Processing 12-Jul-2014 : 32 spectra
-----
\\corona/calib/uv/matshic/uvdata/2014/jrc/mat_uv1932014.jrc : scan Nb:1/32
12-Jul-2014 03:00:01 o3= 0 DU  sza=96.0  m=7.5
12-Jul-2014 03:00:01 o3= 254 DU  sza=96.0  m=7.5
Elapsed time for wlshift: 1.237772 sec
Elapsed time for shifted spec: 0.176548 sec
-----
\\corona/calib/uv/matshic/uvdata/2014/jrc/mat_uv1932014.jrc : scan Nb:2/32
12-Jul-2014 03:30:01 o3= 95 DU  sza=92.0  m=11.1
Elapsed time for wlshift: 0.635063 sec
Elapsed time for shifted spec: 0.175998 sec
-----
\\corona/calib/uv/matshic/uvdata/2014/jrc/mat_uv1932014.jrc : scan Nb:3/32
12-Jul-2014 04:00:01 o3= 129 DU  sza=87.5  m=10.9
Elapsed time for wlshift: 0.638603 sec
Elapsed time for shifted spec: 0.174926 sec
-----
\\corona/calib/uv/matshic/uvdata/2014/jrc/mat_uv1932014.jrc : scan Nb:4/32
12-Jul-2014 04:30:01 o3= 232 DU  sza=83.1  m=6.9
Elapsed time for wlshift: 0.636201 sec
Elapsed time for shifted spec: 0.175035 sec
-----
\\corona/calib/uv/matshic/uvdata/2014/jrc/mat_uv1932014.jrc : scan Nb:5/32
12-Jul-2014 05:00:01 o3= 306 DU  sza=78.4  m=4.6
Elapsed time for wlshift: 0.639906 sec
Elapsed time for shifted spec: 0.174948 sec
```

Result



Conclusion

- For array spectroradiometer data post-processing is important and should **be tailored individually** to the specific instrument.
 - *integration times*
 - *linear correction*
 - *stray light correction*
 - *wavelength shift detection*
- Matshic provides **bandwidth and wavelength homogenized spectra** – to be compared with other instruments

Discussion – Experience of other Users