Brewer Spectrophotometer laboratory wavelength characterization with a tunable-laser

- implications to the Brewer ozone retrieval-

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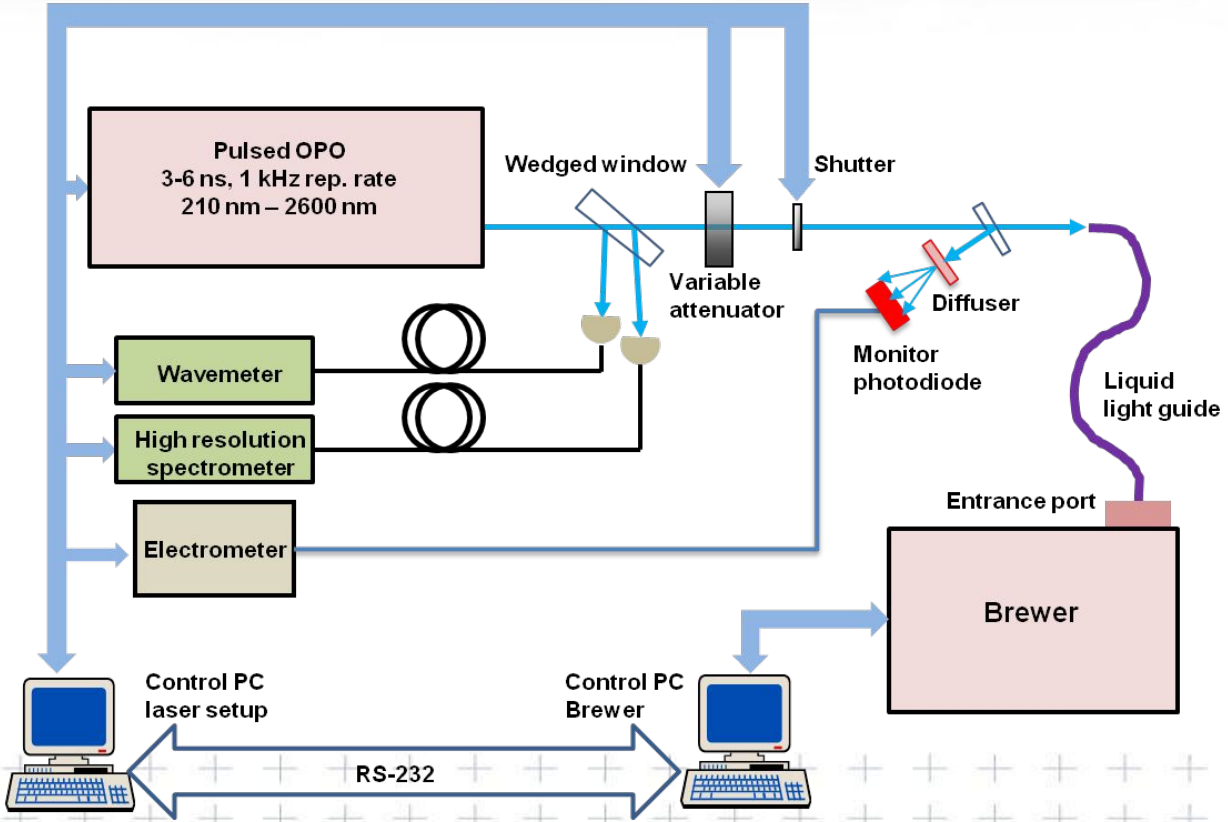
#1 - Dispersion measurements using spectral lamps (zinc, cadmium and mercury).

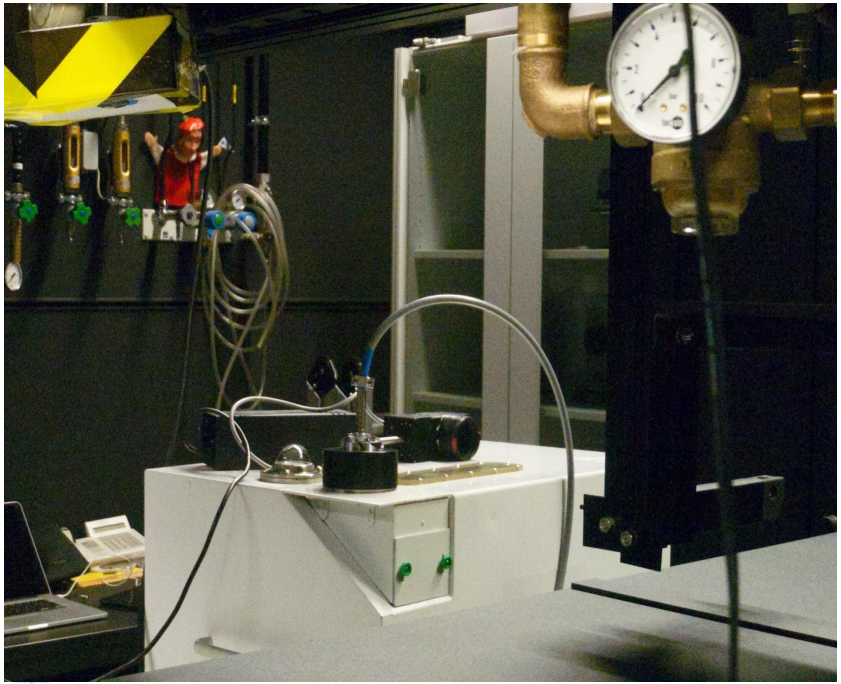
#2- Dispersion measurements using tunable laser (Brewer scanning).
While Laser is emitting in a fixed wavelength, the Brewer will scan around this wavelength (±2nm) moving the grating and using the 6 slits. This process will be repeated 16 times, using wavelengths ranging from 290 nm to 365 nm with an increment of 5 nm.

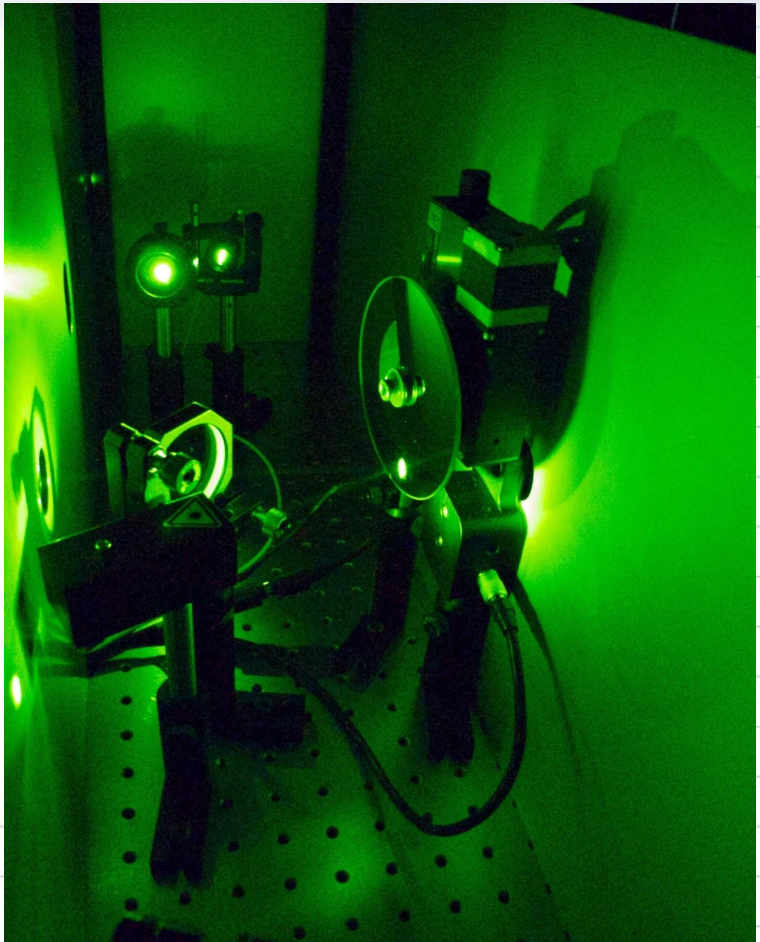
#3 - Dispersion measurements using tunable laser (Laser scanning).
While Brewer is measuring in ozone mode and in aerosol mode, the laser will scan around (±2nm) the six Brewer slits with a step of 0.05nm for different grating positions.

- Brewer in ozone mode. Laser scan ±2nm from the 6 brewer slits in ozone mode, with a step of 0.05 nm.
- Brewer in **aerosol mode**. Laser scan ±2nm from the 6 brewer slits in aerosol mode (4 different grating positions), with a step of 0.05 nm.

- Setup for bandpass and wavelength characterisation of Brewer at PTB







PTB

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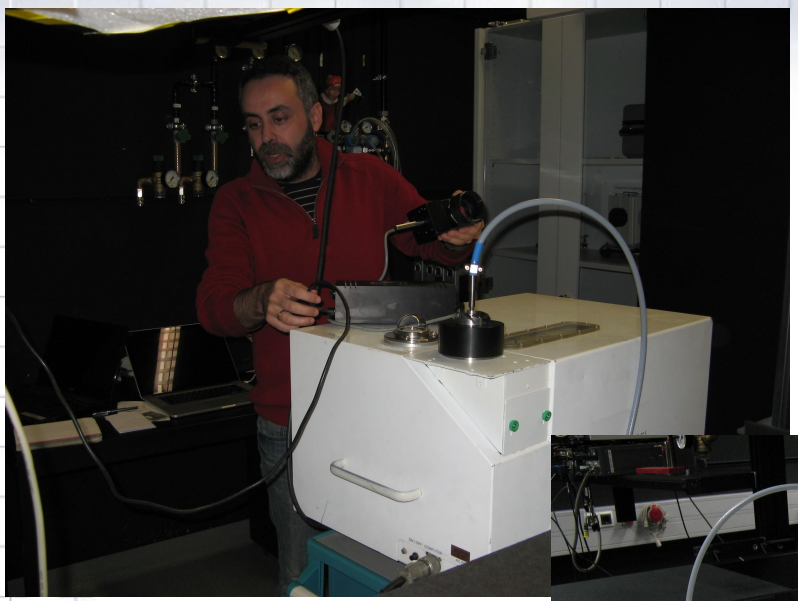
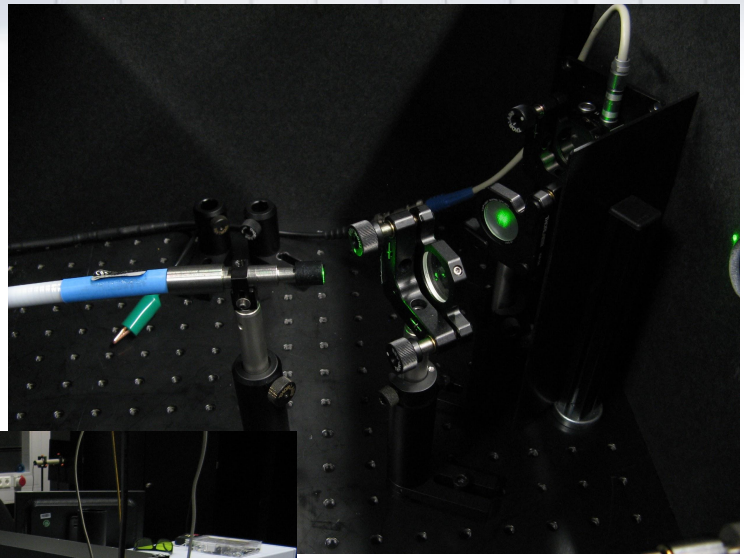
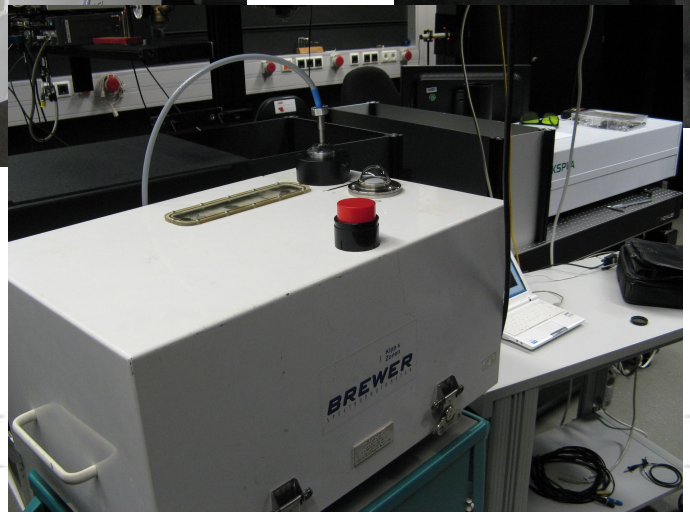
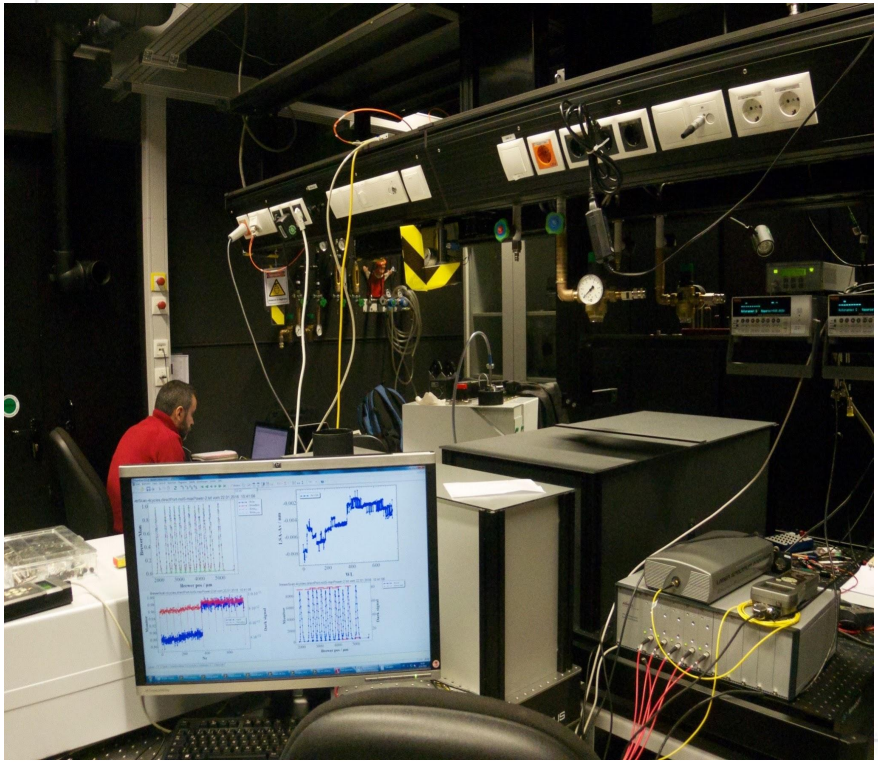
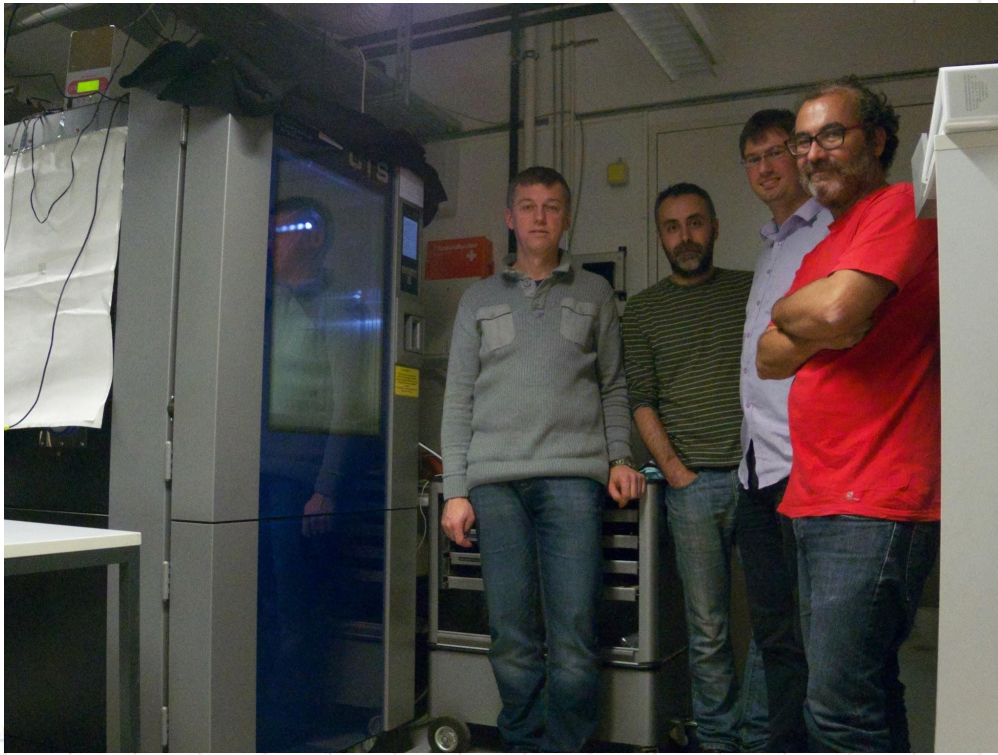
AEMet Agencia Estatal de Meteorología

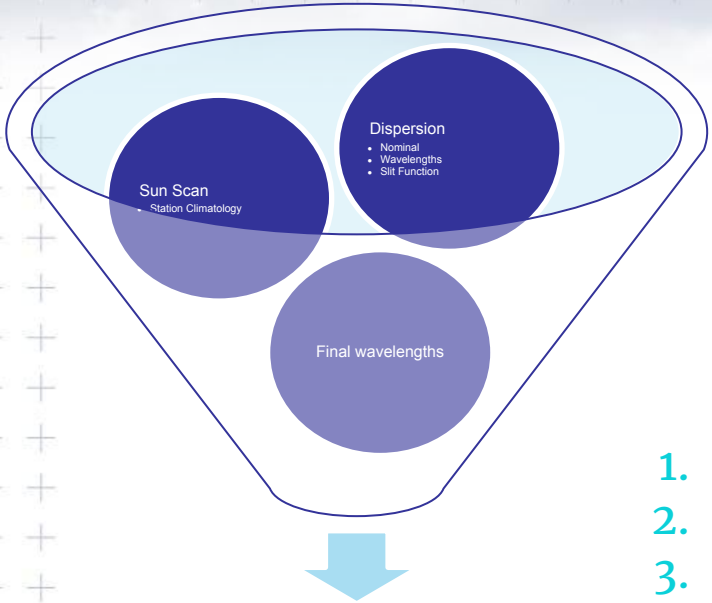












Ozone Absorption Coefficient

$$O_3 = \frac{F - ETC}{\alpha m}$$

Wavelength Calibration

1. Optimized wavelengths (Sun Scan)
2. Dispersion test, (discharge lamps)
3. Ozone Cross Sections (Bass & Paur, T= -45).

$$\widetilde{\alpha}(X,\mu) = \sum w_i \frac{\int \alpha(\lambda) * S(\lambda,\lambda') * F(\lambda,\lambda',X,\mu) d\lambda'}{\int S(\lambda,\lambda') * F(\lambda,\lambda',X,\mu) d\lambda'}$$

Alpha = ozone cross section Wi= ozone weighting coefficients

S = Slit Function, (ILS) F = Sun Spectra , (X, and nu)

- Use “ideal” slits , (no wings, no stray light, '0' outside the triangle)
- The FWHM of the triangle is dependent of the slit.
- This o3 cross section is Bass & Paur absorption coefficient.
- Flat Spectra : Solar Spectra is not considered
- The 03abs (also SO2, Rayleight,) are calculated for an interval of steps around the ozone position, for possible cal-step changes.

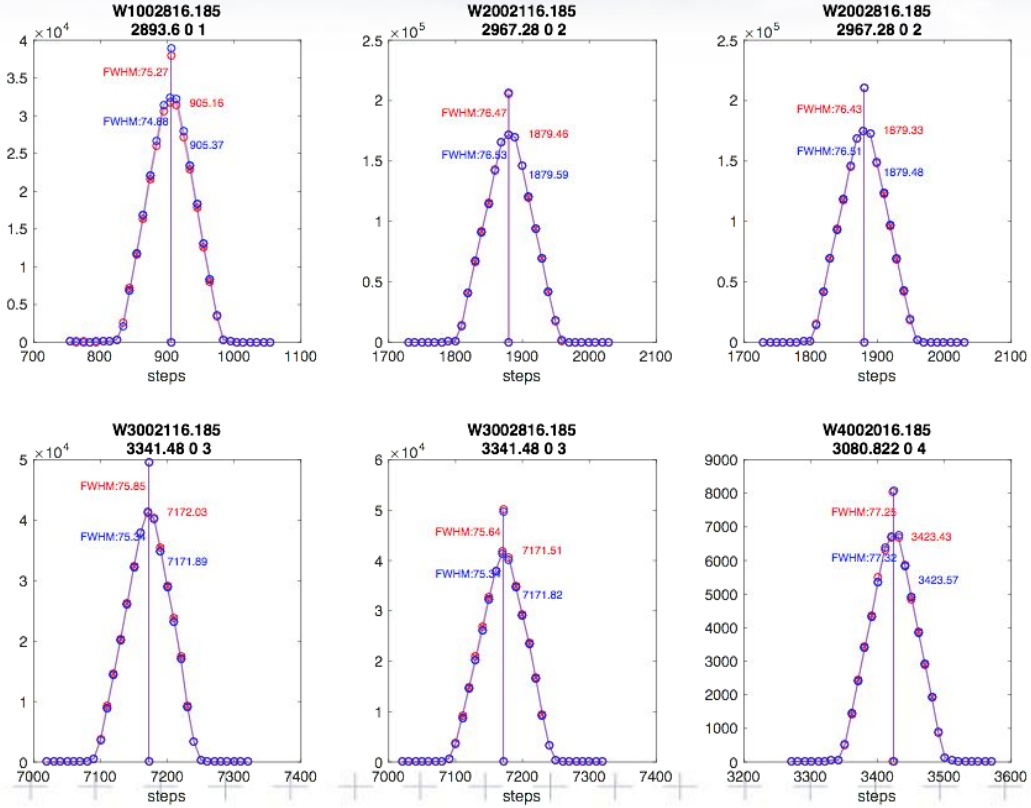
Brewer Dispersion procedure summary:

The brewer scan every 10 steps (~0.6) A the emisión lines of Hg and Cd, using a particular slit

1. Central step and fwhm (step) are calculated for the six slits, assuming a isosceles triangle.
2. The dispersion relation (wavelength vs step) is determined
   a. Standard quadratic polynomial
   b. Cubic (Gröebner & Ker 1998)
3. The central and fwhm steps are converted to wavelength.
4. Parametrized Slit are used for cross section calculation.

Gröbner, J., Wardle, D. I., McElroy, C. T. y Kerr, J. B.: Investigation of the wavelength accuracy of Brewer spectrophotometers, APPLIED OPTICS, 37(36), 1998.

Brewer Dispersion (I)



Lamp	Line (nm)	Slits
Mercury (Hg)	**289.36**	**0–1**
Indium (In)	293.263	0–3
Hg	**296.728**	**0–3**
Zinc (Zn)	301.836	0–5
Zn	303.578	0–5
Cd (multiplet)	**308.082**	**0-5**
Cd	**313.3167**	**0–5**
Cd	**326.1055**	**0–5**
Zn	328.233	0–5
Hg	**334.148**	**0–5**
Cd	**340.3652**	**0–5**
Cd	**349.995**	**4–5**
Cd (multiplet)	**361.163**	**5**

Saving ozonecoeffs to ./opos02616_PTB.185

1020 WL(A)	3031.84	3062.95	3100.43	3134.90	3167.98	3199.90	
Res(A)	11.39	11.12	10.93	11.24	10.98	10.83	
O3abs(1/cm)	**2.6018**	**1.7813**	**1.0051**	**0.6765**	**0.3750**	**0.2943**	**O3: 0.3423**
Daumt O3abs(1/cm)	2.6086	1.7761	0.9968	0.6706	0.3681	0.2949	O3: 0.3530
So2abs(1/cm)	3.4603	5.6249	2.4003	1.9180	1.0545	0.6144	
1e4*Rayabs(1/cm)	5051.1	4832.6	4585.2	4371.7	4178.7	4002.6	R: 0.0011
I0(mW m^-2nm^-1)	0.07	0.12	0.19	0.32	0.40	0.48	

Ozone offset due to Rayleigh: -3.1 DU

Ratio Ozone for So2(A3)= 1.1483, So2/O3(A2)= 2.7537

Non linearity of PMT

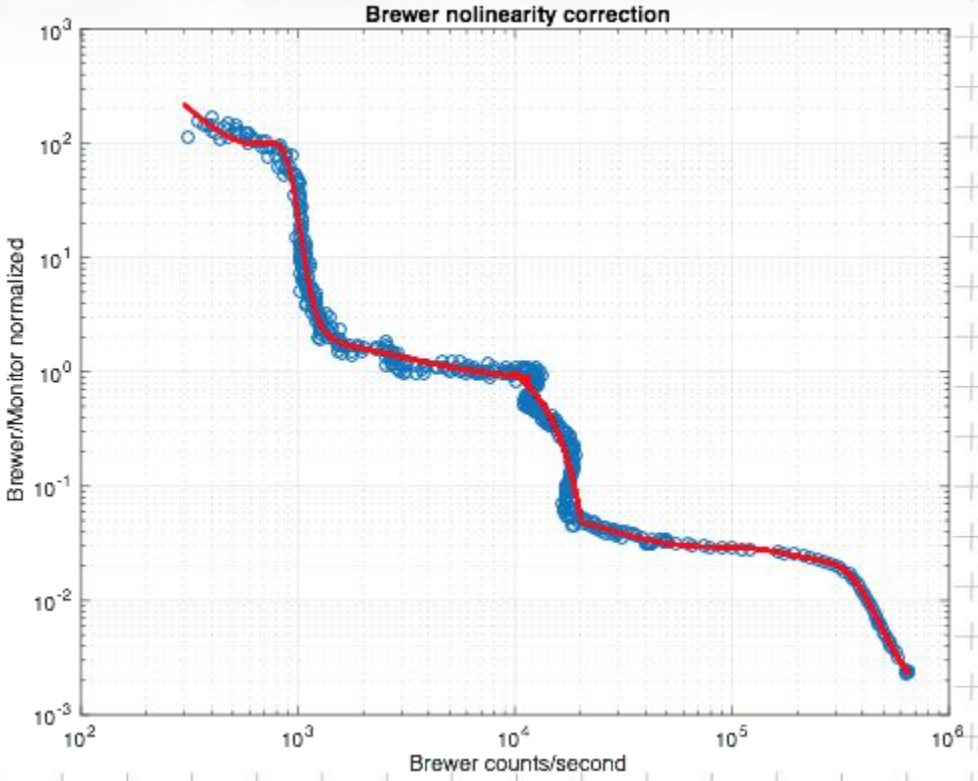
-The PMT requires a different configuration to measure pulsed sources (thanks Volodya !!).

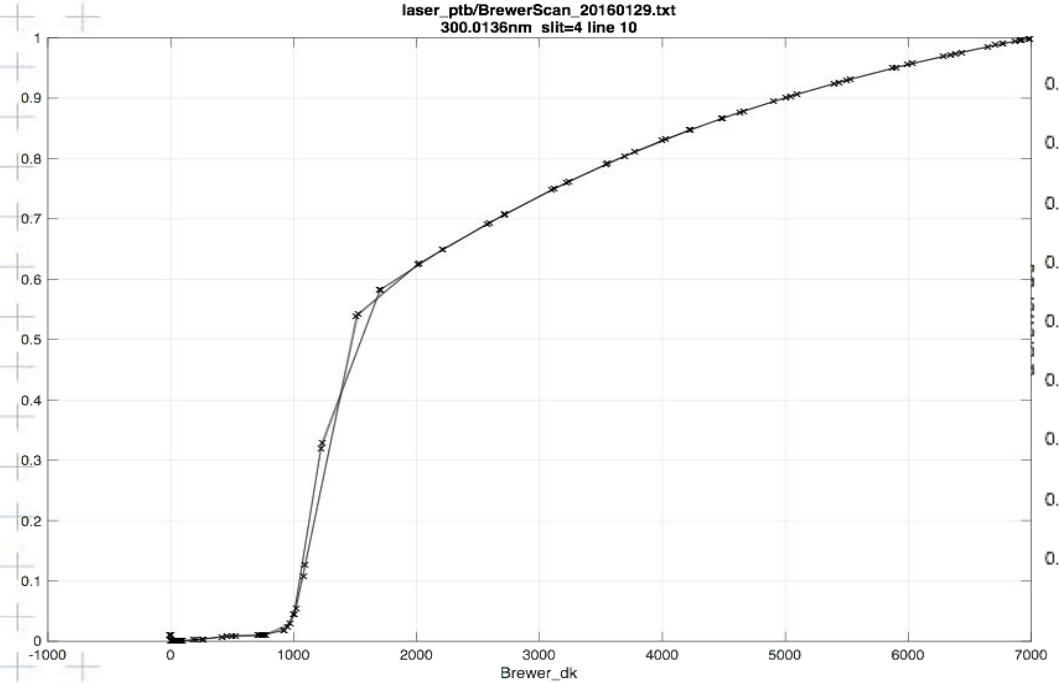
- We can work on “linear regions” using the direct port for maximizing the laser output.

Two critical areas:

- Low counts ~100 c/s

- Hysteresis -~ 10^4 c/s

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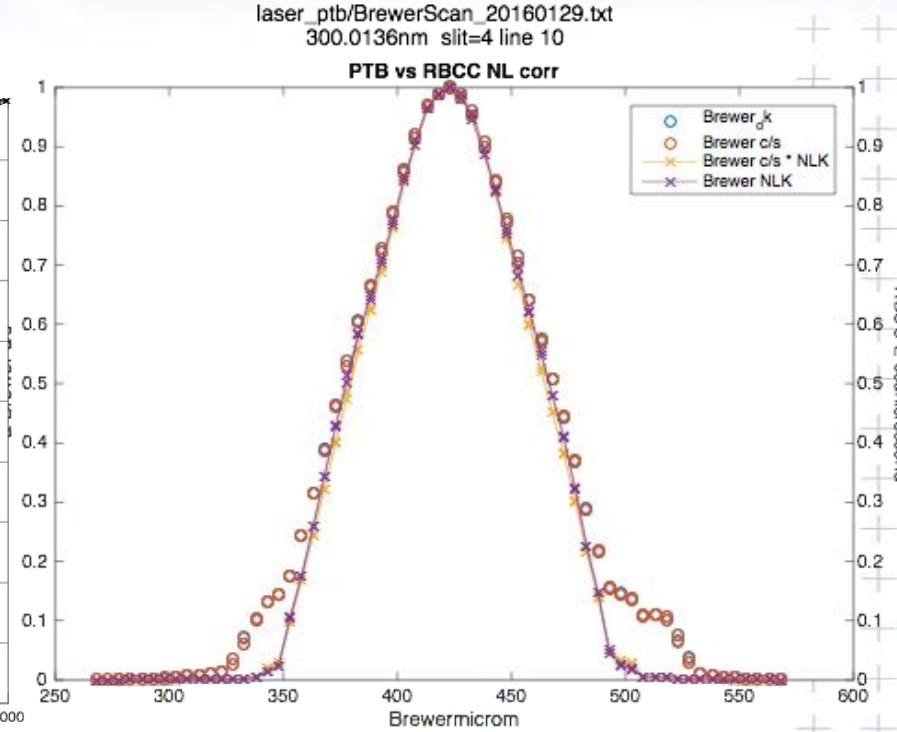
300.0136nm slit=4 line 10
Brewer_dk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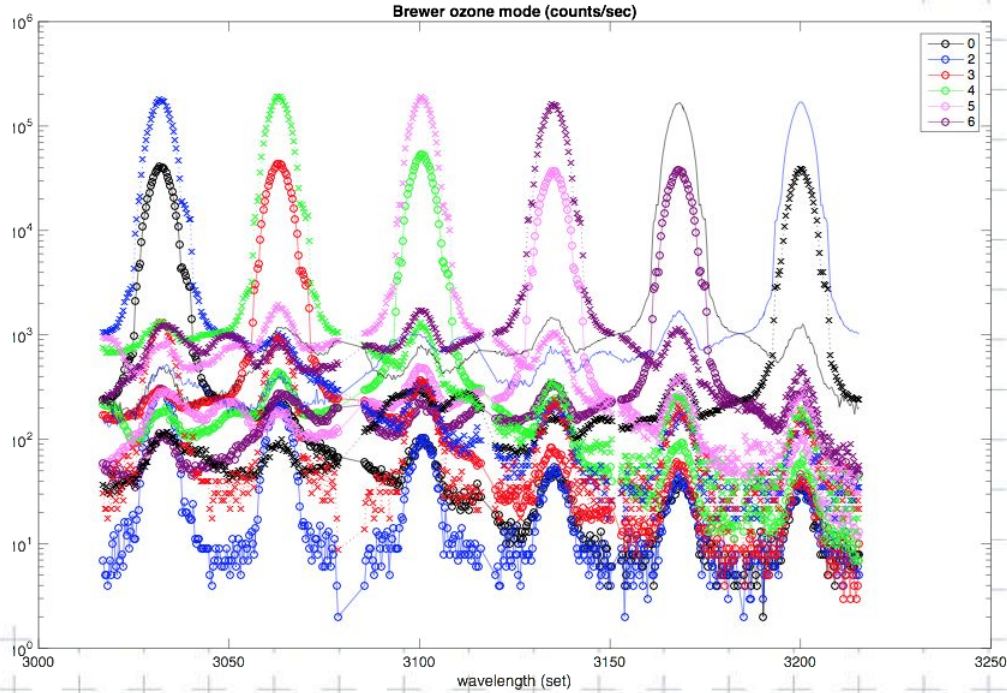
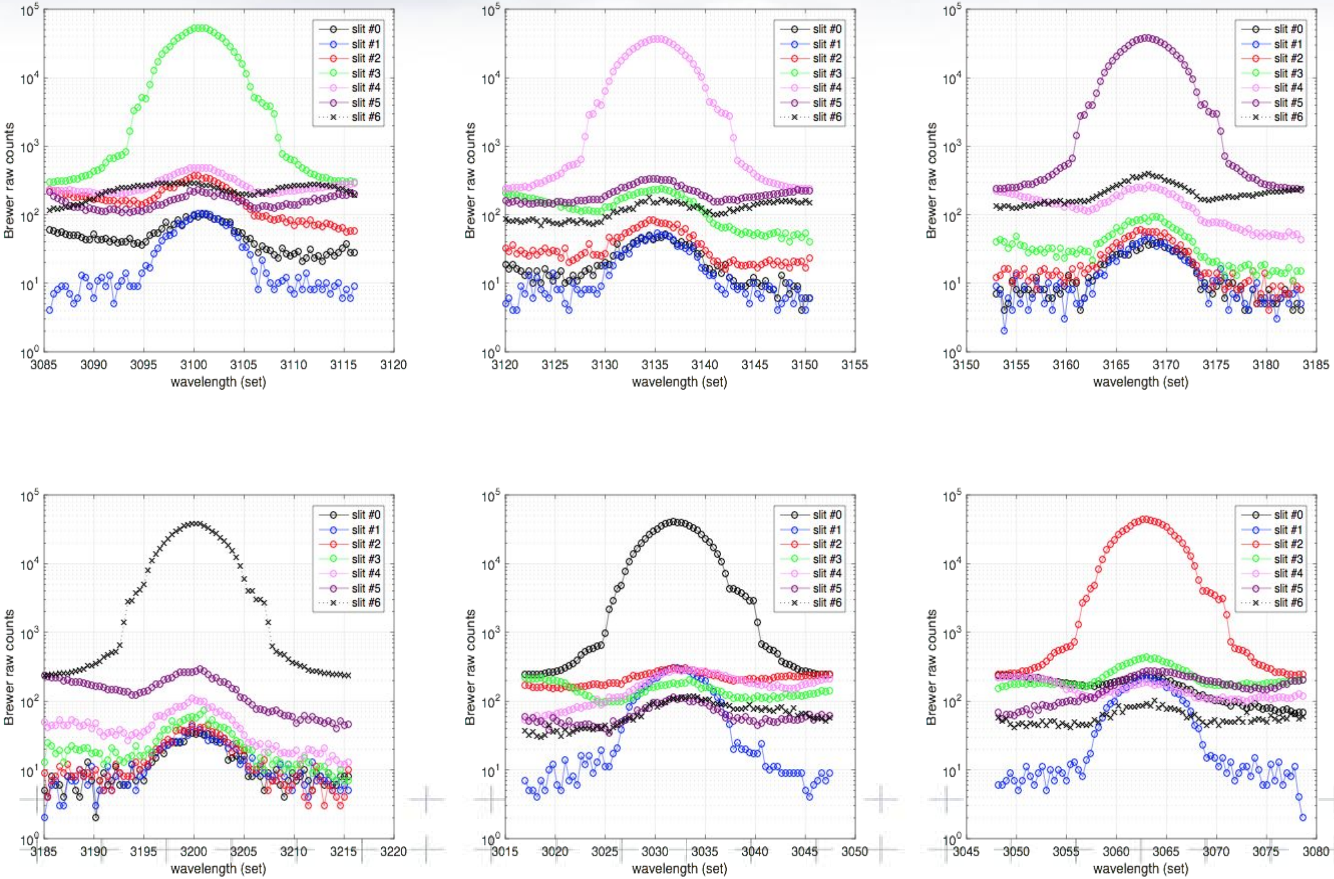
300.0136nm slit=4 line 10
PTB vs RBCC NL corr
Brewer_dk
Brewer c/s
Brewer c/s * NLK
Brewer NLK
Brewermicrom

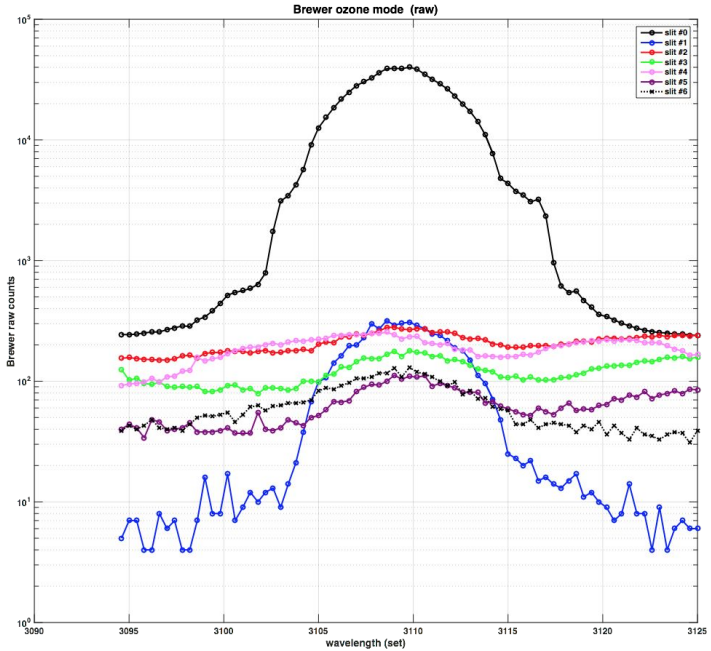
Laser scan : brewer measure in ozone mode (six slits +dark)



Brewer in ozone mode, while the laser scan 0.1A

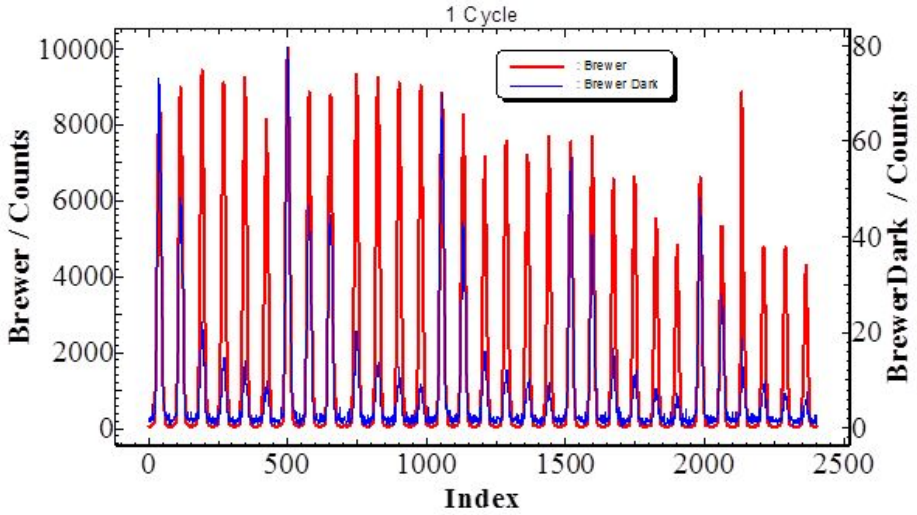


Dark correction



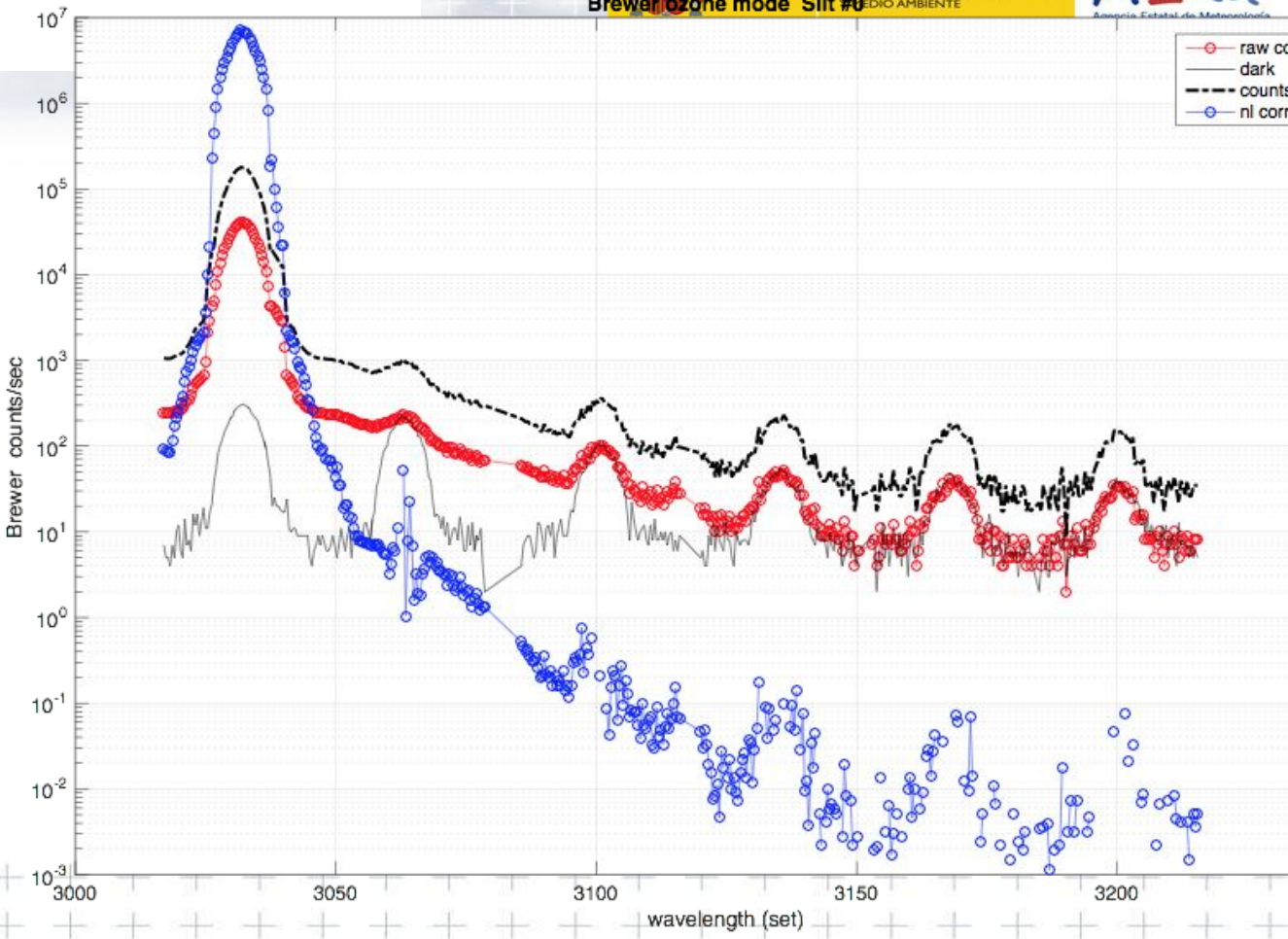
- No linearity and dark correction is not applied
- Slit # 1 measurements correspond to the DARK (blocked) position
- In some experiments the **dark count** is higher than the measurements the brewer correction assign two counts for negative values
- The hysteresis of the no linearity is clear for the asymmetry of the peak.

Dark correction

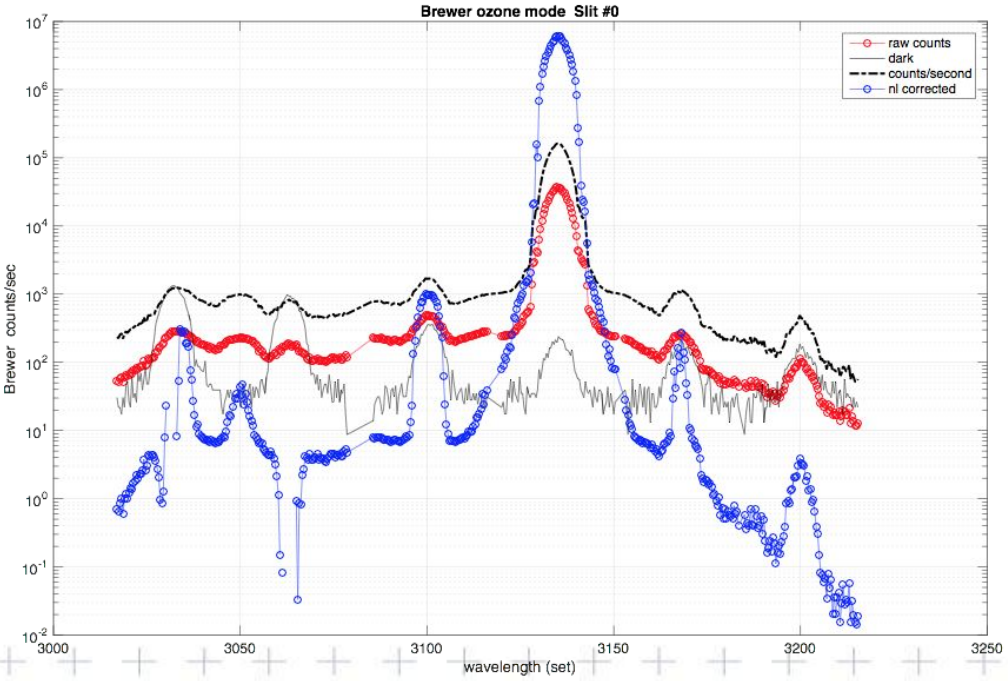


- Dark values were highest immediately after exposing the PMT to the laser light. The dark signal was then gradually decreasing with time.
- The dark values of the PMT may show a fast decay after the excitation, which may cause the values for slit #1 (measured immediately after slit #0) be higher than for some other slits, measured later.

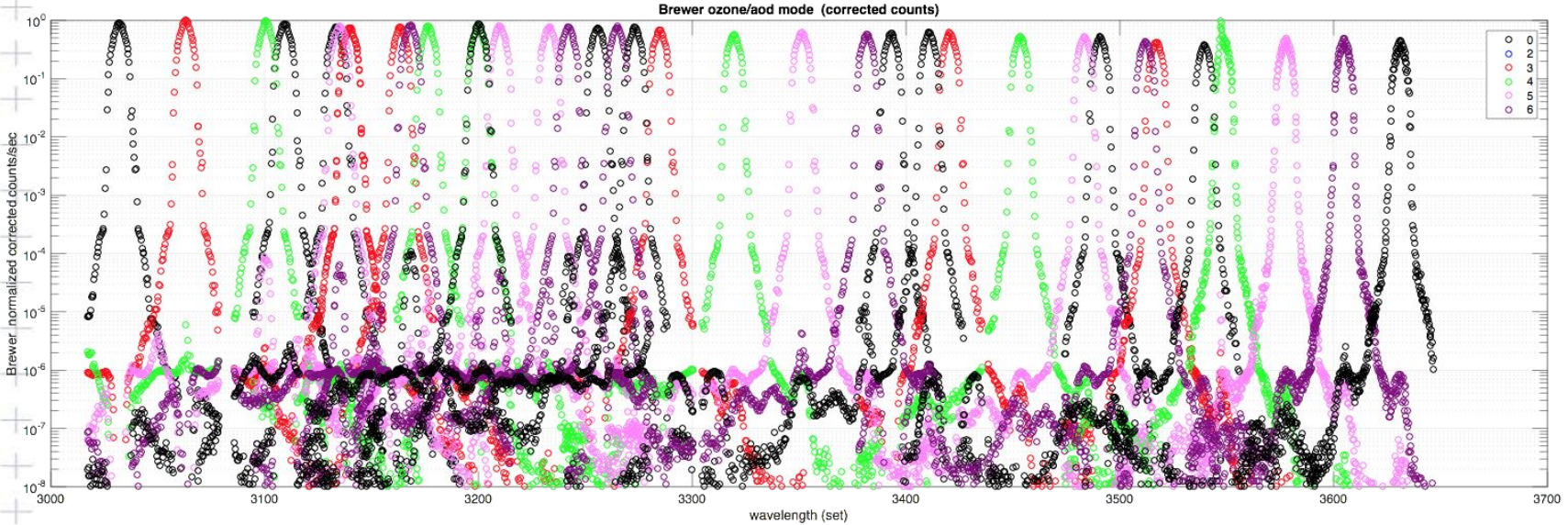
The best results are obtained if the dark count is also corrected by nonlinearity and then subtracted



But,.. only works with slit#0



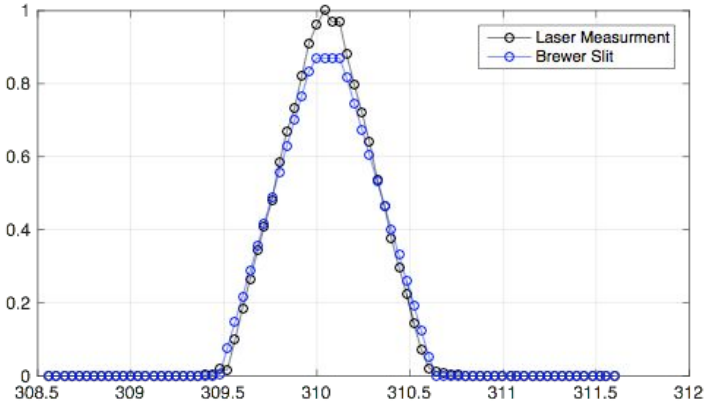
Laser Scaning : Ozone and AOD mode



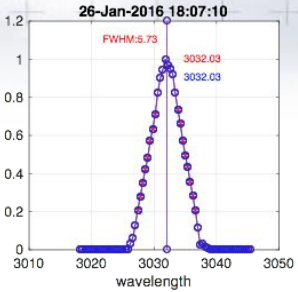
Brewer Slit Parametrization

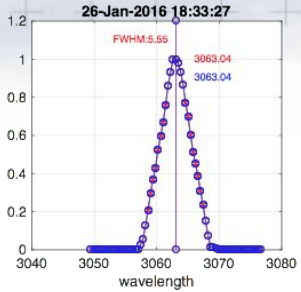
The brewer algorithms assume a trapezoidal slit, cut a 0.87, center and fwhm at the calculated for every slit.

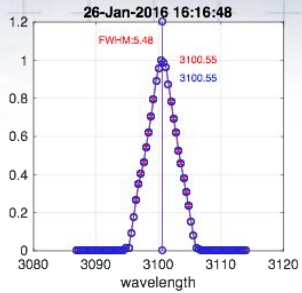
Using the measured slit, the effective ozone cross section calculated is ~**0.9% higher** respect the parametrized brewer slit used on the standard procedure.

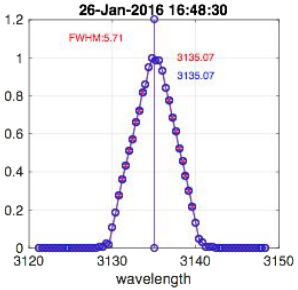


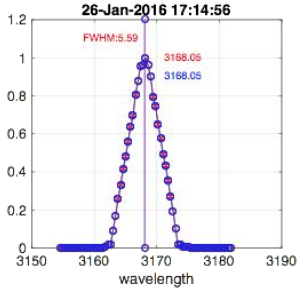
	Parametrized (B&P)	Measured (B&P)
Brw	0.3381	0.3407
B&P	0.333	0.336
DMB	0.3483	0.3514
SDK	0.3392	0.3422

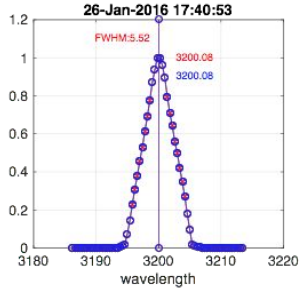












Mic	Slit #	wv	fwhm	Measured	Parametrize
1020	0	3032.0271	5.7258	6.0007	5.9989
1020	2	3063.0381	5.5522	4.0936	4.0935
1020	3	3100.5519	5.4846	2.3063	2.3065
1020	4	3135.0695	5.7049	1.5652	1.565
1020	5	3168.0487	5.5874	0.8598	0.8602
1020	6	3200.0841	5.5148	0.68	0.6784

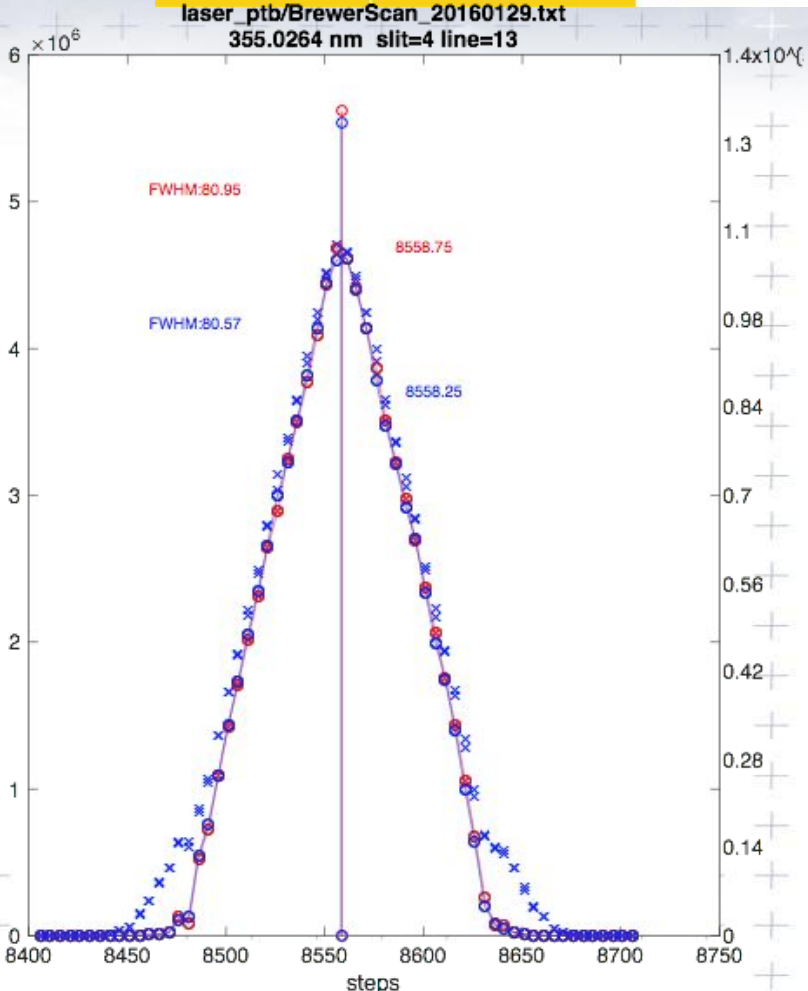
Ozone Absorption Coefficient

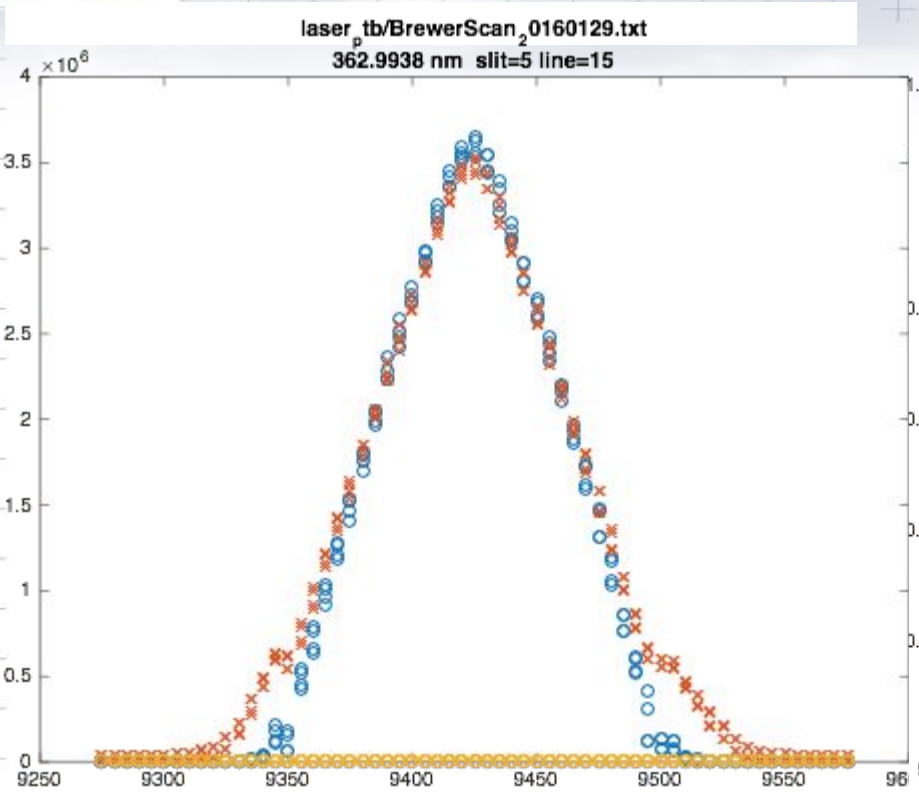
Matlab date	mic	slit	brw_wv	brw_fwhm	brw_sdk_me	brw_sdk_par
736355.7552	1020	0	3032.02711	5.72579	6.00073	5.9989
736355.7734	1020	2	3063.03809	5.55223	4.09356	4.0935
736355.6786	1020	3	3100.55194	5.48458	2.30626	2.30654
736355.7006	1020	4	3135.06955	5.7049	1.5652	1.56504
736355.7187	1020	5	3168.04868	5.58735	0.85981	0.86016
736355.7369	1020	6	3200.08413	5.51482	0.68	0.67842
		Ozone Ratio		0.34226	0.34091	

ozone wv	brw_meas	brw_param
	0.34226	0.34091
ratio	1.00398	1

~0.4 A in FWHM produces 1.2% in the retrieved ozone

-
- Laser emits 295 to 363 every 5 nm
- Brewer scan every 5 steps resolution (~0.3 A) (doubled)
- The readings are corrected by nonlinearity

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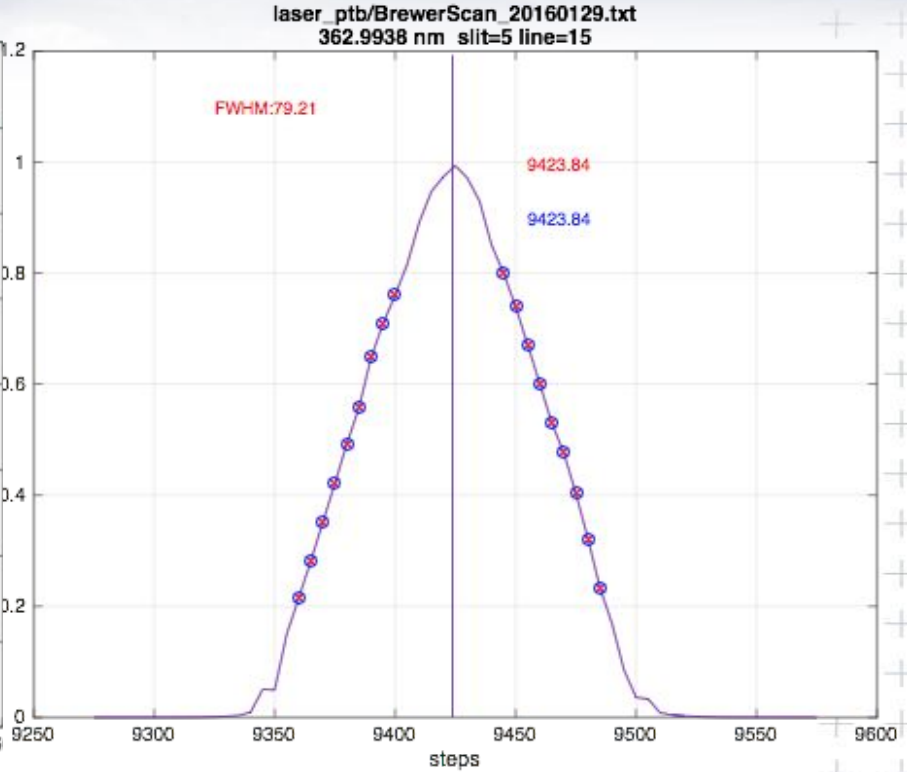
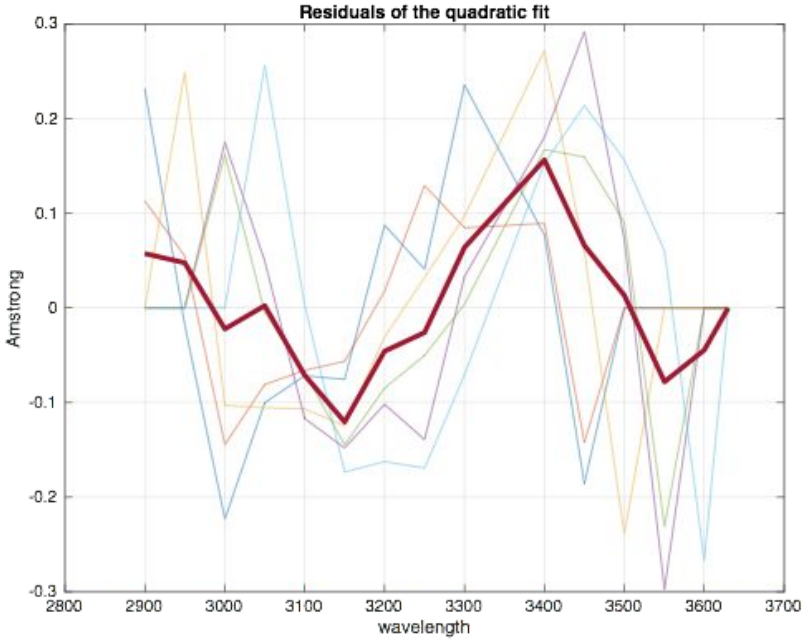
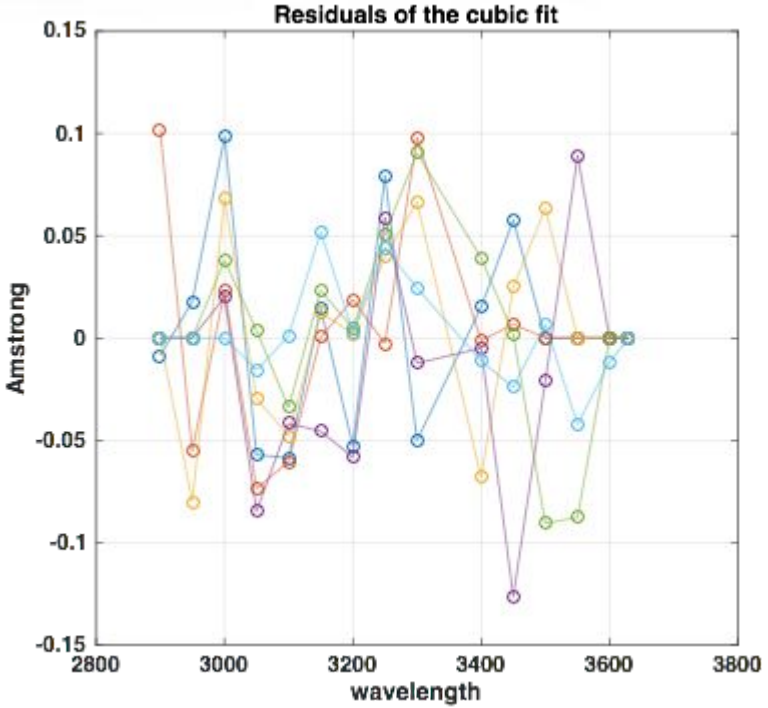
362.9938 nm slit=5 line=15
×10^6
4
3.5
3
2.5
2
1.5
1
0.5
0
9250
9300
9350
9400
9450
9500
9550


laser_ptb/BrewerScan_20160129.txt
362.9938 nm slit=5 line=15
FWHM:79.21
9423.84
9423.84
1.2
1
0.8
0.6
0.4
0.2
0
9250
9300
9350
9400
9450
9500
9550
9600
steps

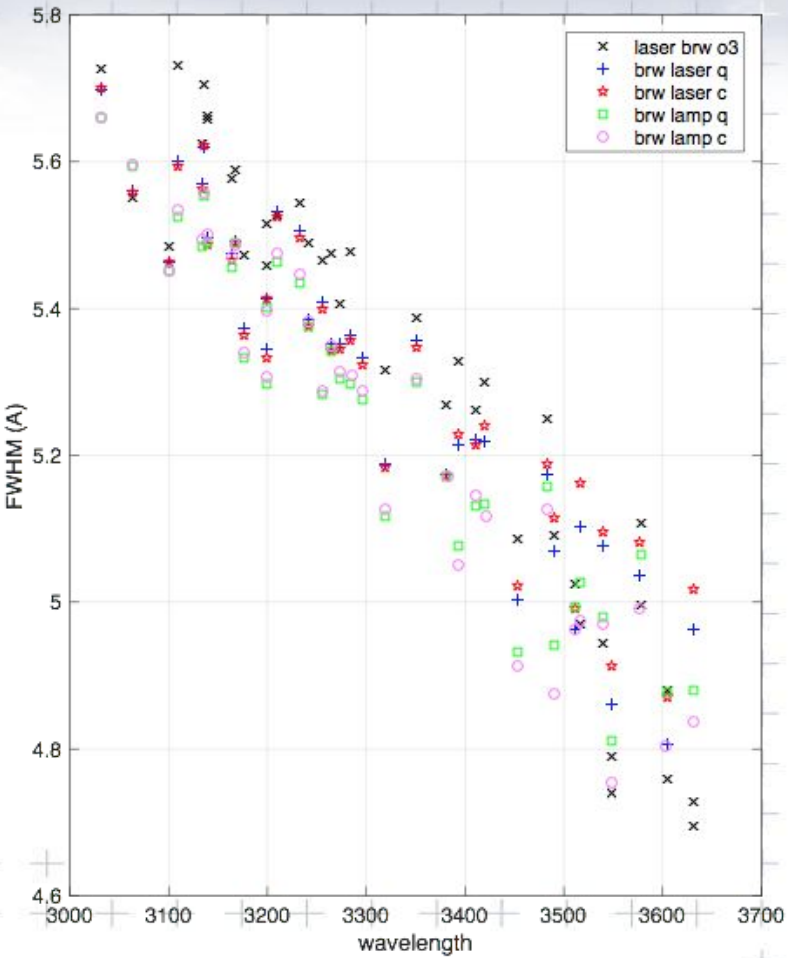
Residuals of the fit



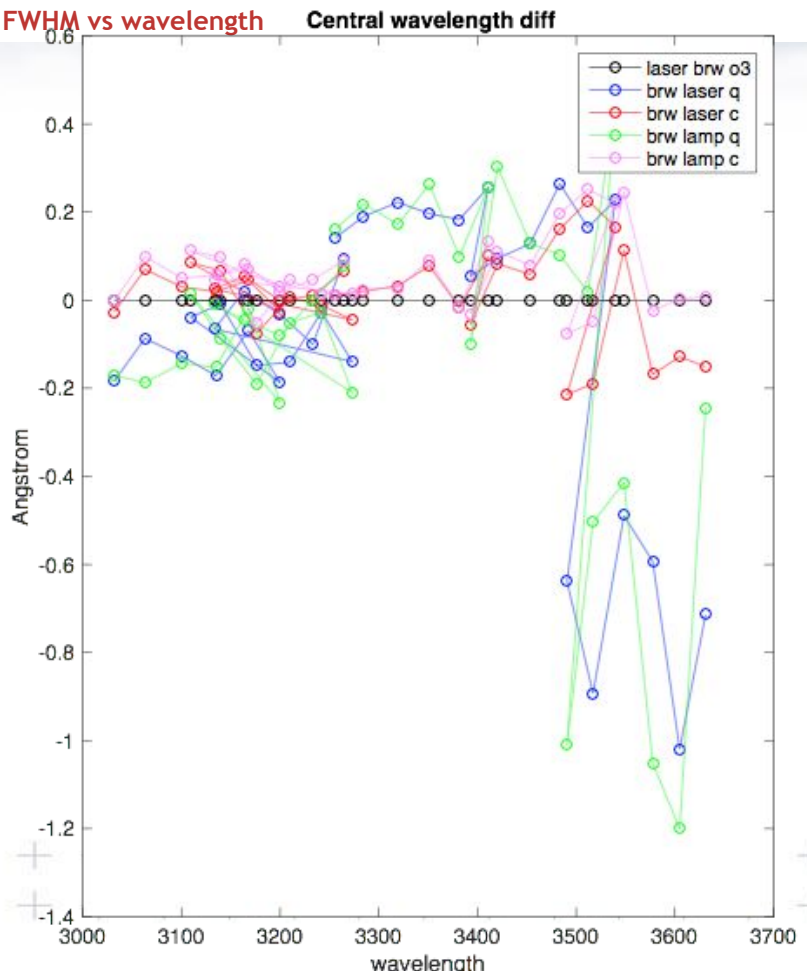


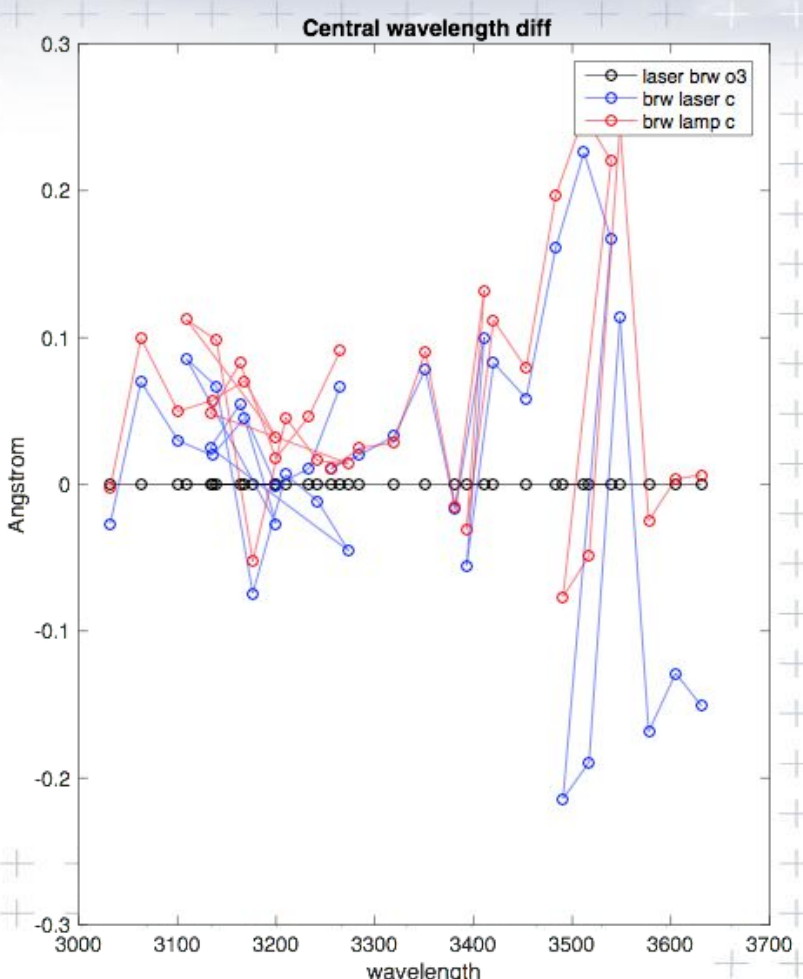
Wavelength calibration experiments :

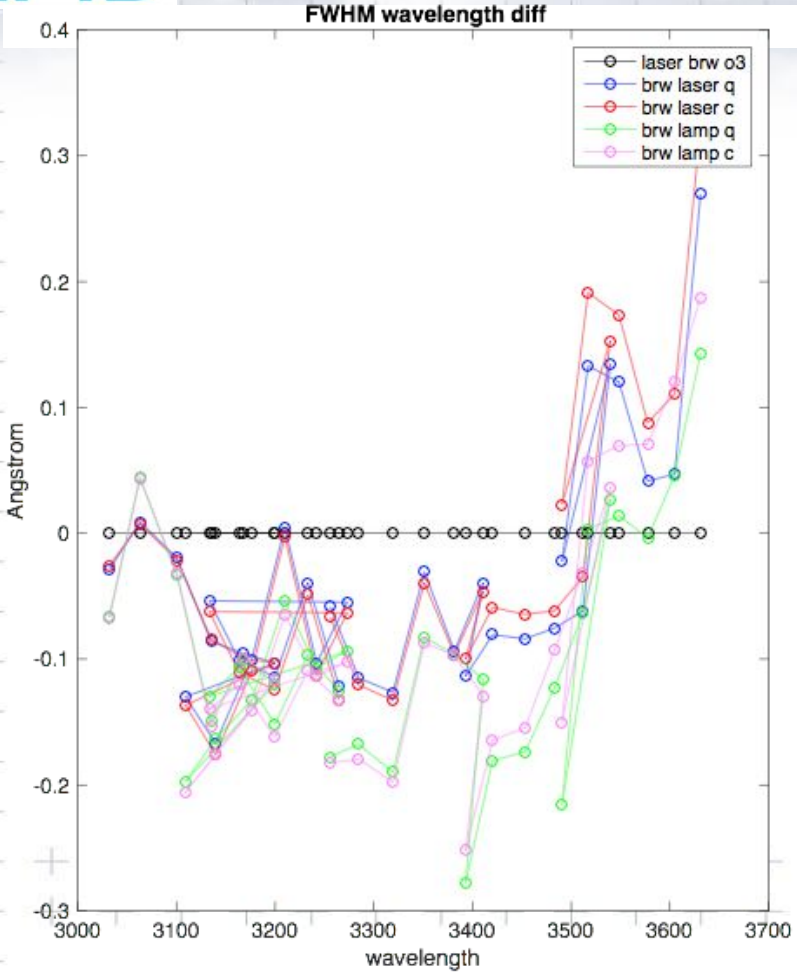
1. **Laser** wavelength scanned @ fixed Brewer position : **Laser_brw_o3**
2. Brewer grating pos. changed @ fixed **laser** wavelength, dispersion approx. by a **quadratic** function : **Brewer_laser_q**
3. Brewer grating pos. changed @ fixed **laser** wavelength, dispersion approx. by a **cubic** function : **Brewer_laser_c**
4. Brewer grating pos. changed @ fixed **lamp** emission wavelength, dispersion approx. by a **quadratic** function: **Brewer_lamp_q**
5. Brewer grating pos. changed @ fixed **lamp** emission wavelength, dispersion approx. by a **cubic** function : **Brewer_lamp_c**

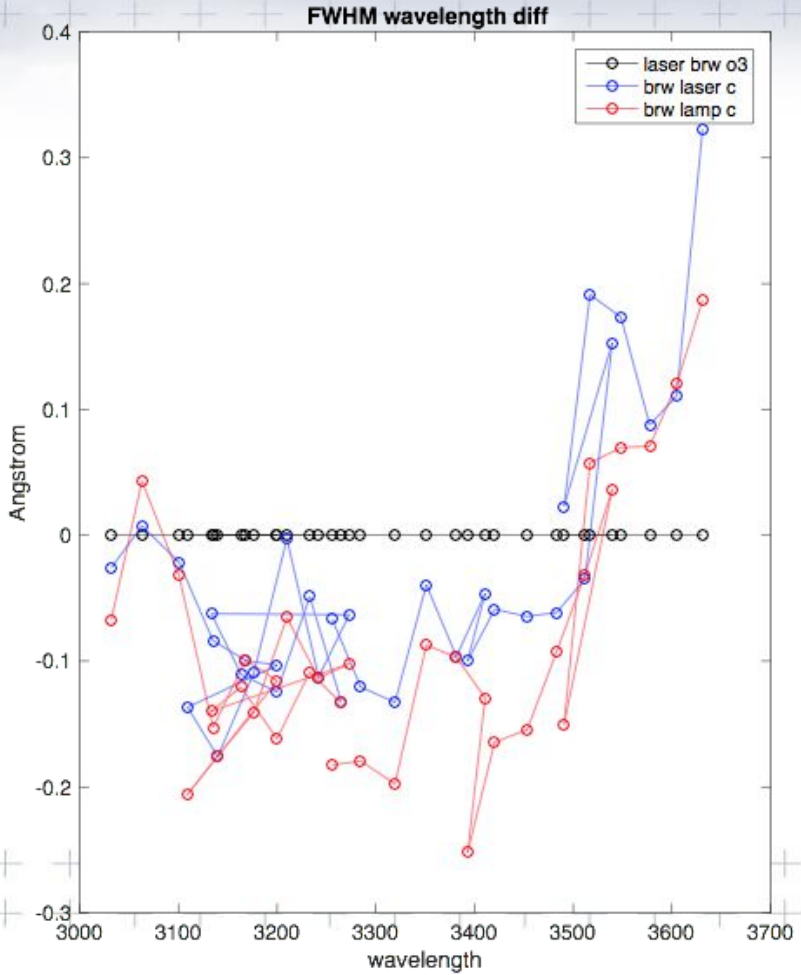


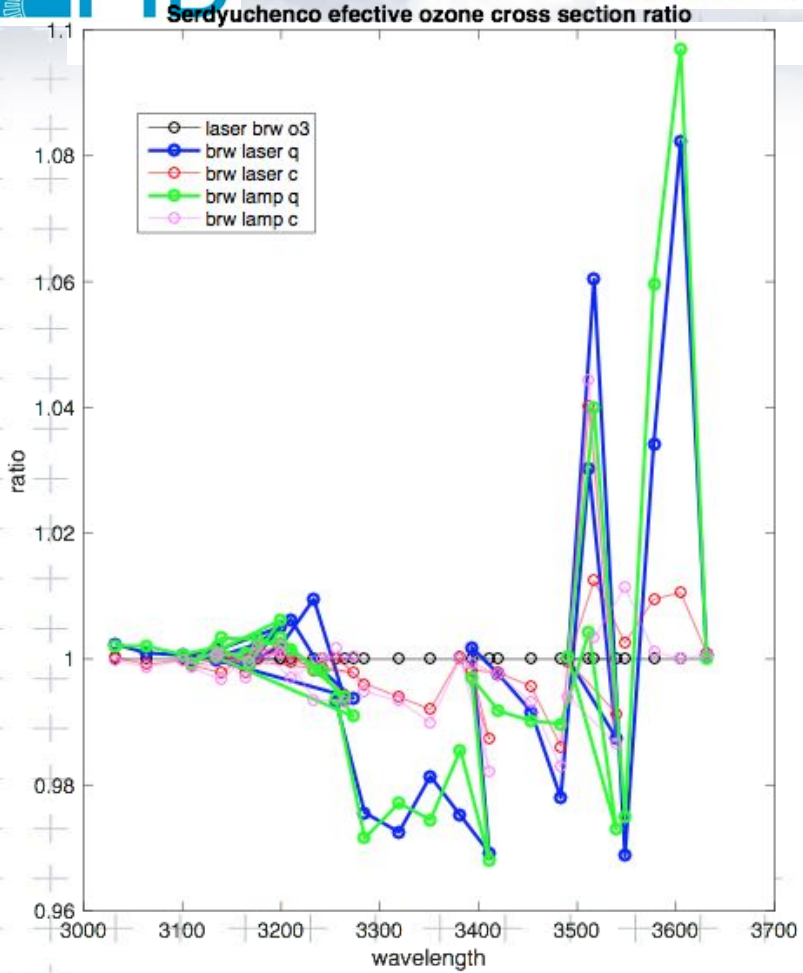
FWHM vs wavelength

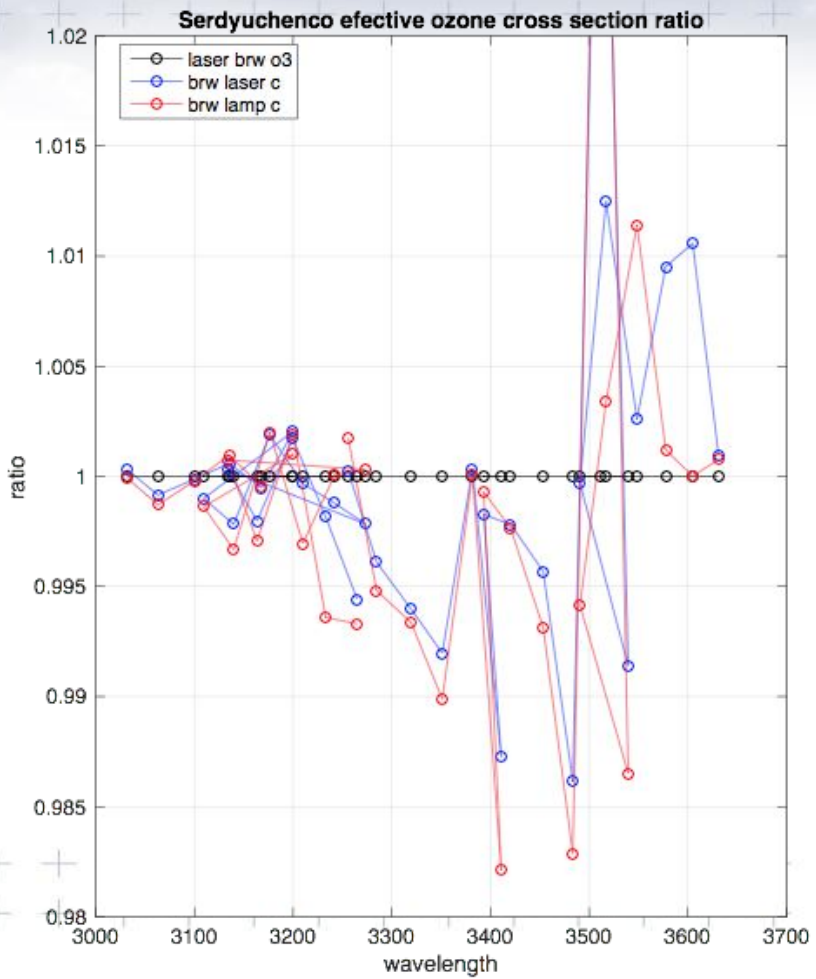





FWHM wavelength diff
laser brw o3
brw laser q
brw laser c
brw lamp q
brw lamp c
Angstrom
wavelength
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
3000
3100
3200
3300
3400
3500
3600
3700


FWHM wavelength diff
laser brw o3
brw laser c
brw lamp c
Angstrom
wavelength
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
3000
3100
3200
3300
3400
3500
3600
3700


Serdyuchenco efective ozone cross section ratio
laser brw o3
brw laser q
brw laser c
brw lamp q
brw lamp c
ratio
wavelength
1.1
1.08
1.06
1.04
1.02
1
0.98
0.96
3000
3100
3200
3300
3400
3500
3600
3700


Serdyuchenco efective ozone cross section ratio
laser brw o3
brw laser c
brw lamp c
ratio
wavelength
1.02
1.015
1.01
1.005
1
0.995
0.99
0.985
0.98
3000
3100
3200
3300
3400
3500
3600
3700

Wavelength calibration methods:

1. **Laser** wavelength scanned @ fixed Brewer position
2. Brewer grating pos. changed @ fixed **laser** wavelength, dispersion approx. by a **quadratic** function
3. Brewer grating pos. changed @ fixed **laser** wavelength, dispersion approx. by a **cubic** function
4. Brewer grating pos. changed @ fixed **lamp** emission wavelength, dispersion approx. by a **quadratic** function
5. Brewer grating pos. changed @ fixed **lamp** emission wavelength, dispersion approx. by a **cubic** function

Method	1.	2.	3.	4.	5.
SGW	0.3409	0.3442	0.342	0.3446	0.3412
ratio	1	1.0096	1.0033	1.0108	1.001

Many thanks :

Volodya Savastiouk
Pavel Babal
Keith Wilson

Still data for analyze

- Laser replication of Cd lines.
- Repeated laser measurements.
- Comparison for HeCd laser.
- ….

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