Liquid Crystal Polarization Rotator (LCPR) calibration

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Abstract

This technical report describes the preliminary tests on the chromatic polararization response of the Meadowlark (MLO) Liquid Crystal Polarization Rotator (LCPR). The rotation of input linear polarization as function of bias voltage has been measured at 500, 530 and 633 nm. The results show that the MLO LCPR has a more stable and less chromatic response for bias voltage > 2500 mV.

1. Introduction

The Liquid Crystal Polarization Rotator (LCPR) rotates electro-optically the polarization direction of a linearly polarized input beam. The design consists of a Liquid Crystal Variable Retarder (LCVR) whose birifrangence changes as a function of the applied potential bias, combined with a zero order polymer quarter-wave retarder (fig. 1-1). The fast axes of the two retarders are 45° apart. The linear polarize acting as output analyzer must be parallel to the quarter wave retarder slow axis. Polarization rotation is achieved by electrically controlling the retardance of the LCVR. There is no mechanical motion. The quarter-wave retarder converts elliptical polarization formed by the Liquid Crystal Variable Retarder into linear polarization. The rotation angle is equal to half the retardance change in the LCVR. Polarization purity is defined as the ratio of the rotated linear component to the orthogonal component. A selected rotation is very sensitive to applied voltage and operating temperature. On average, polarization purity, or contrast ratio is better than 150:1 [1].

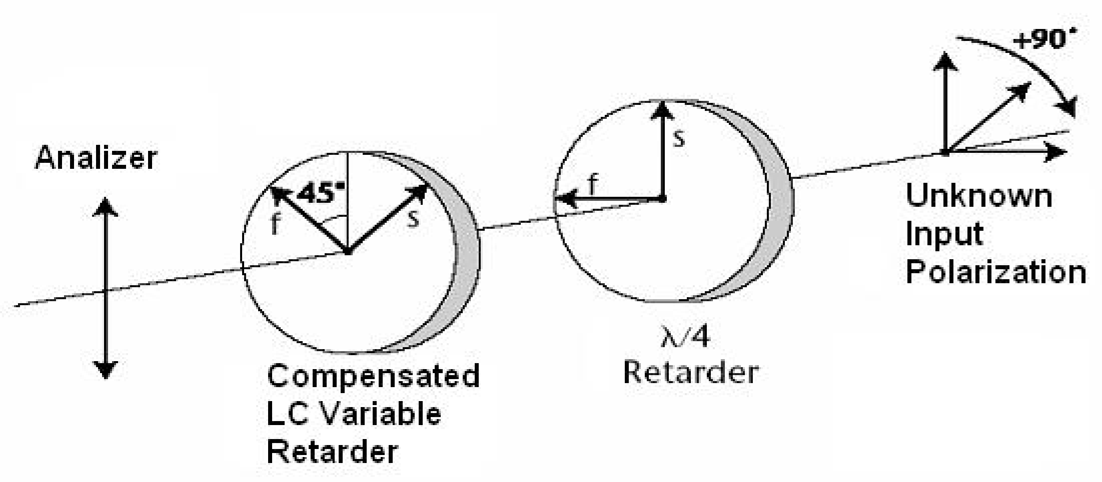

Figure 1-1-1 - *Operation of Liquid Crystal Polarization Rotator showing complete rotation of a linearly polarized input beam [1].*

The goal of our measurements has been the characterization of the LCPR Meadowlark Optics LPR-200-VIS-DP-TSO (C001094, 01-288) as a function of the applied voltage, at different wavelengths. The setup will be described in the next chapter. The control voltage control and temperature setting of the LCPR are done through a digital controller, the Meadowlark D2040, programmable through PC. In the tests, the control software supplied by Meadowlark Optics has been used. Temperatures as not been monitored. Detailed information on the LCPR can be found in the official documentation of the Meadowlark Optics [1].

2. Set-up used for tests

In this section we describe the setup used for the measurements carried out in date 16-12-2004 at the Optical Laboratory of the Turin Astronomical Observatory (OATo).

2.1 Light source

The source is an quartz-tungsten halogen lamp (QTH). In particular, the light source model is the Oriel Photomax 6333, 100 W. This types of light sources are popular visible and near infrared sources because of their smooth spectral curve and stable output. They do not have the sharp spectral peaks that arc lamps exhibit, and they emit little UV radiation. QTH lamps use a doped tungsten filament inside a quartz envelope. They are filled with a rare gas and a small amount of halogen. Current flowing through the filament heats the tungsten to >3000 K. The filaments of this light sources are dense planar structures for highest image brightness. The white light produced radiates through the clear quartz envelope. In Appendix B.1 is reported the spectral irradiance for this light source at 0.5m and the spectral irradiance from 250 to 500 nm for the 6333 100 W lamp at different voltages. (The filament plane was parallel to the slit of the radiometer for maximum irradiance.) As voltage is reduced, total output is reduced and the peak wavelength shifts only slightly to the red. The output at a wavelength in the blue end of the spectrum can change significantly with a slight change in voltage [2]. The lamp's power supply is the Thermo Oriel 68938 with a voltage output from 0 to 14V. For other information see [2].

2.2 Monochromator and spectrograph

A monochromator is used to select a spectral band or one determined frequency of the electromagnetic spectrum. The monochromator's type is a Czerny-Turner, model Lot Oriel MS257™. We report in figure B-2-1 the outline of this instrument. See Appendix B.2 for details.

During our tests, the wavelength selection was made with a LabVIEW[1]-based software piloting the instrument through IEEE-488 interface.

For our measures, we used 12mm x 3.5mm slits and a 1800 l/mm grating (Lot-Oriel 77753). Spectral resolution is ~73Å. The monochromator settings are summarized in Tab. 2-5-1.

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[1] LabVIEW is a development tool produced from National Instruments [3].

2.3 Optical power meter and Detector

Optical power meter is used for data acquisition. The model is a Newport 1830-C. Newport 1830-C is a digital power meter with 0.1 pW resolution, used through IEEE-488 interface and controlled with an acquisition system that realized in LabVIEW. The detector is a silicon diode Newport (Newport 818-SL). The response curve is shown in figure B.3-1 (green curve). Additional information are available in [4] and in Appendix B.3. The detector properties are summarized in Tab. 2-5-1.

2.4 Polarimetric components

Polarimetric components used for this tests are:

- 1 linear polarizer;
- 1 analyzer.

Both are supplied by Meadowlark Optics [1]. Appendix B.4 shows the transmission curve for the linear polarizer.

2.5 Setup and its preparation

The set-up used for the tests it is outlined in figure 2-5-1.

The lamp focused the light on the entrance slit of the monochromator. A particular frequency is selected. A fiber optic bundle from the exit slit feeds a collimator to illuminate the polarimetric components of the set-up: the linear polarizer, then the LCPR and finally the linear analyzer, in front of detector. The measured intensity follows the Malus law:

$$I = I_0 \cos^2[\Phi(V)]$$

from which:

$$\Phi(V) = \arccos\left(\sqrt{\frac{I}{I_0}}\right) \qquad \textbf{(E.1)}$$

where I is the value of read luminous intensity, I_0 its maximum and $\Phi(V)$ the relative rotation.

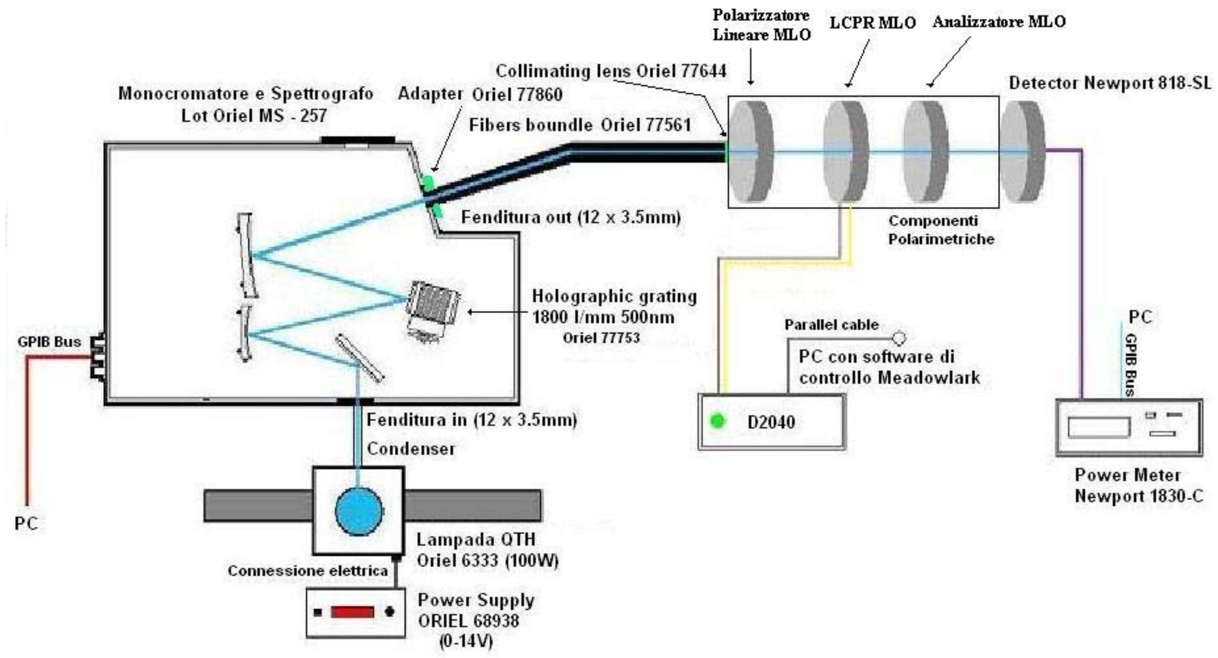

Figure 2-5-1 - *Outline of the set-up for the measure of the rotation of the LCPR in function of the applied voltage and the wavelength.*

Set-up properties are reassumed in tab. 2-5-1:

Beam Collimator	Spot size	1.6 mm (0.2mm)
	Focal length	19 mm
	Beam divergence	~ 5° (~ 0.6°)
	Beam size	10 mm

Monochromator	Type	Czerny-Turner; Oriel MS257 1/4m
	Slit (H x W)	12mm x 3.5 mm
	Grating	1800 l/mm
	Spectral resolution	7.3 nm

Detector	Spectral range	0.4 – 1.1 µm
	Responsivity	≥ 0.1 A/W
	Linearity	± 0.5 %
	Saturation current	4.6 mA/cm^2

Tab. 2-5-1 – *Set-up properties*

3. Data acquisition and data analysis

For three different wavelengths (5000, 5300 and 6330 Å), the intensity as a function of the voltage applied to the LCPR has been measured. The lamps power at 8.5V is 60W. The slit width of the monochromator was set at 3,5 millimetres.

The data acquired are plotted in the figures 3-1, 3-2 and 3-3.

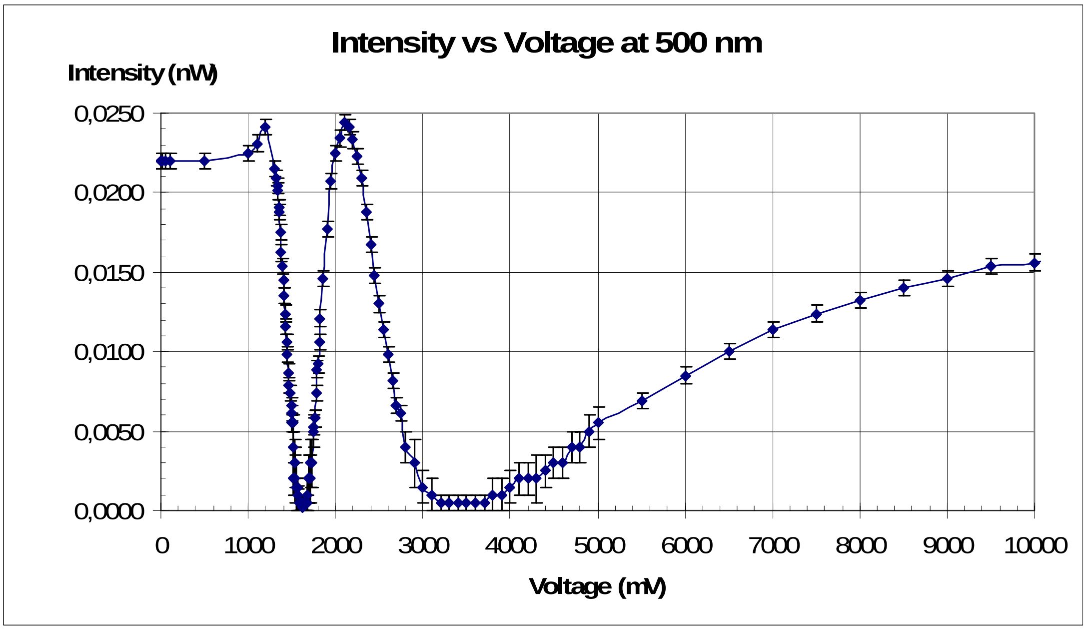

Figure 3-1 - *Luminous intensity in function of the voltage applied to LCPR at 5000 Å.*

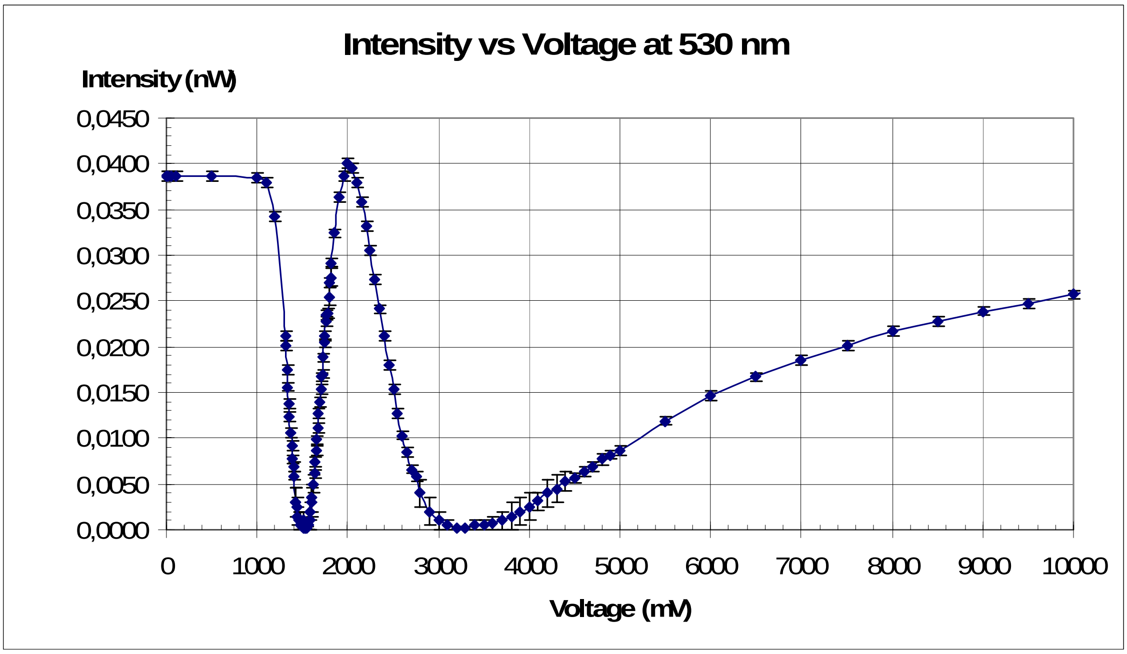

Figure 3-2 - *Luminous intensity in function of the voltage applied to LCPR at 5300 Å.*

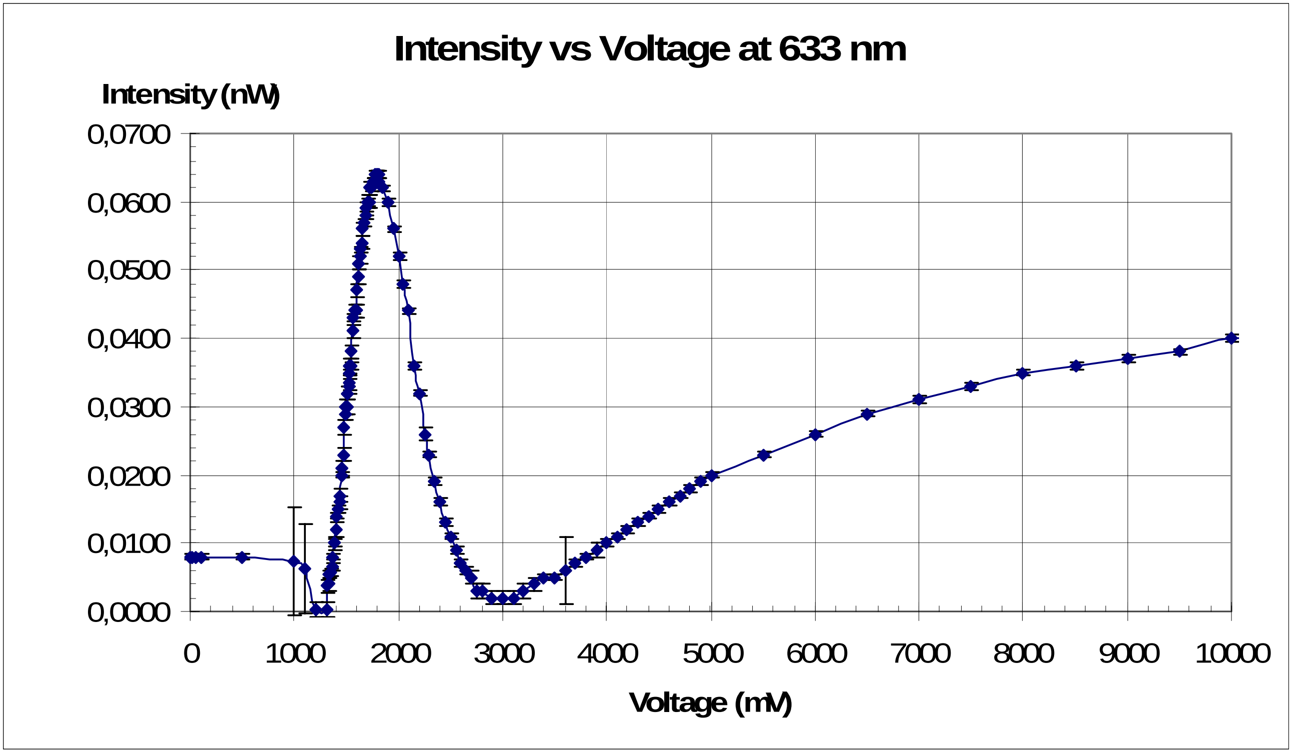

Figure 3-3 - *Luminous intensity in function of the voltage applied to LCPR at 6330 Å.*

From the equation (E.1), the values of rotation in function of the voltage have been derived. The results are plotted in figures 3-4, 3-5, and 3-6.

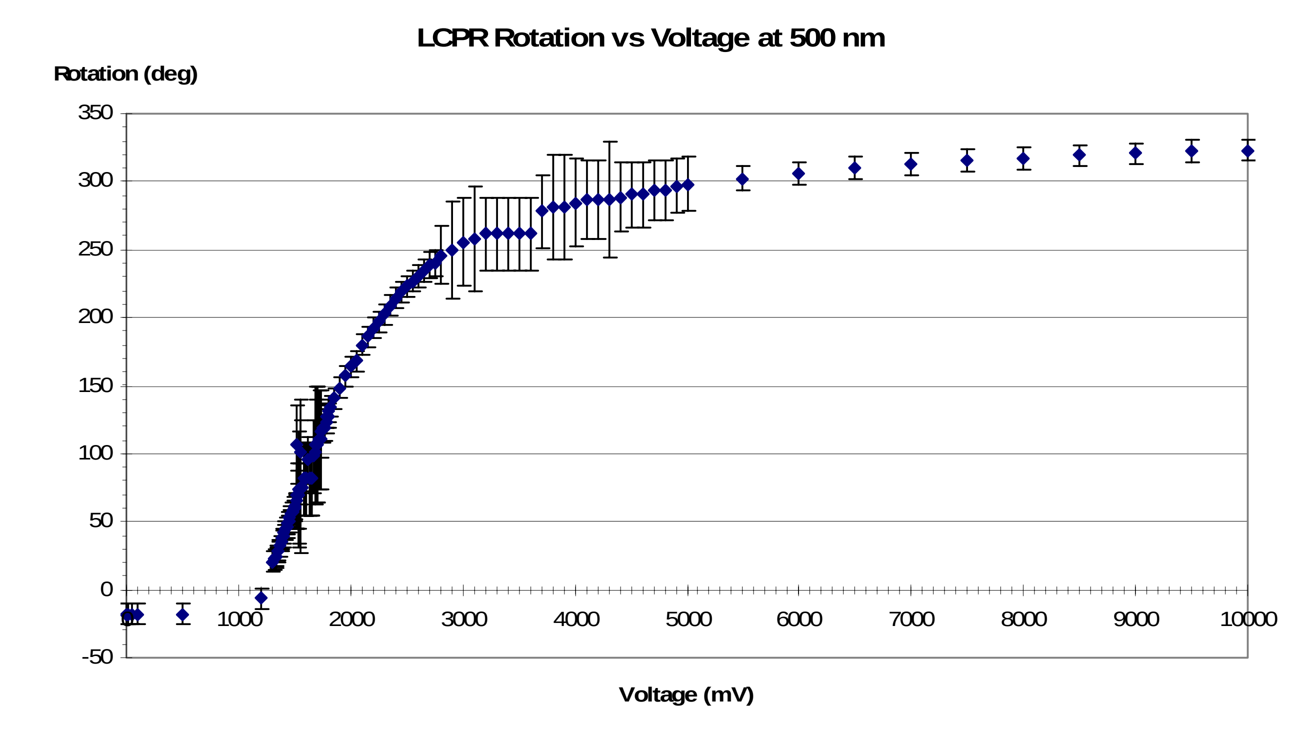

Figure 3-4 – *Rotation in function of the voltage applied to LCPR at 5000 Å.*

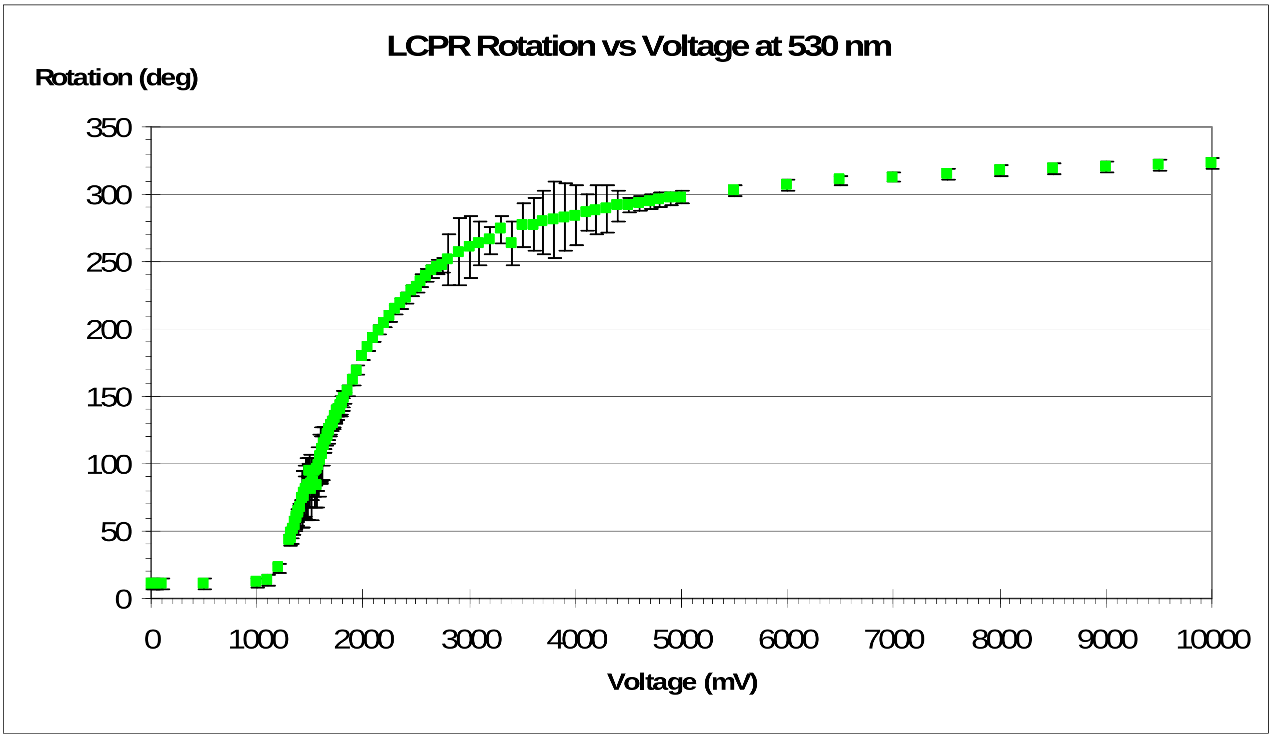

Figure 3-5 - *Rotation in function of the voltage applied to LCPR at 5300 Å.*

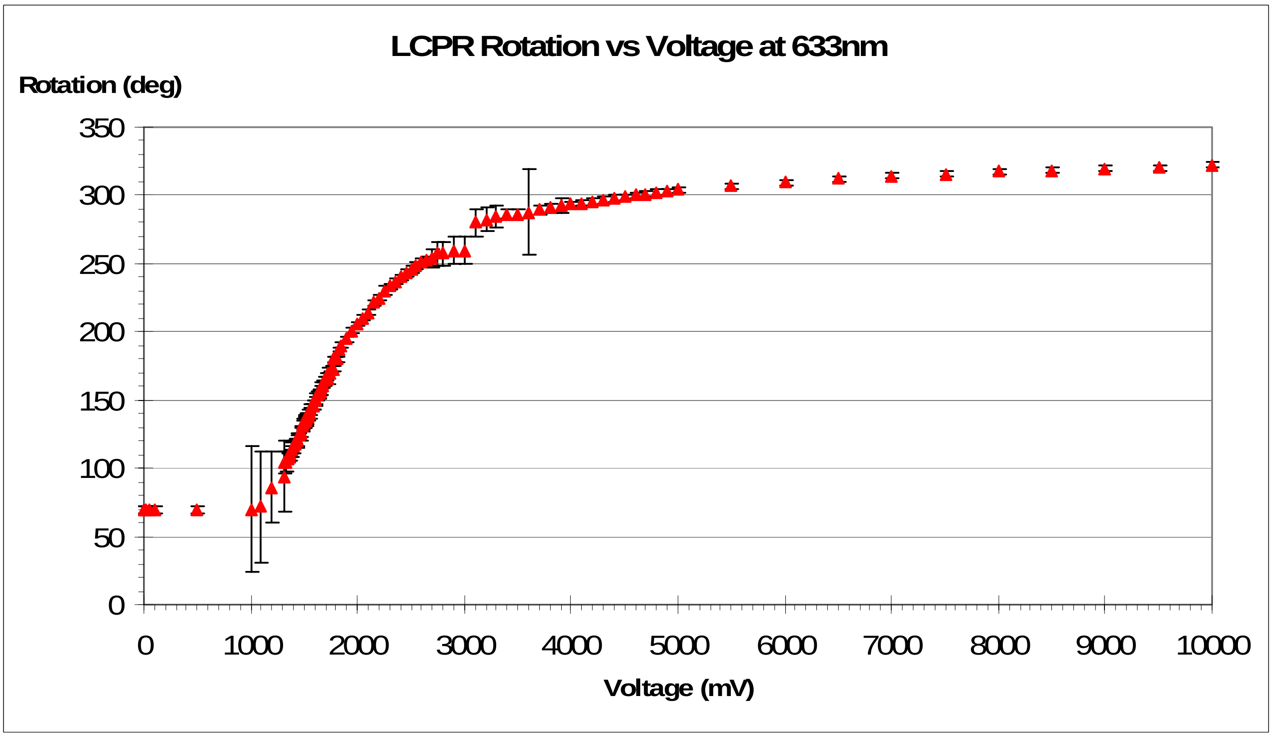

Figure 3-6 - *Rotation in function of the voltage applied to LCPR at 6330 Å.*

The error bars in the rotation diagrams, have been obtained by error propagation, according to the formula:

$$\Delta\Phi(V) = \frac{\sqrt{\frac{I}{I_0}}}{2\left[1+\frac{I}{I_0}\right]}\left(\frac{\Delta I}{I} + \frac{\Delta I_0}{I_0}\right) \qquad \textbf{(E. 2)}$$

Note that the error is inversely proportional to the luminous intensity. Therefore in the points of low intensity, the error will be greater. Figure 3-7 shows the LCPR response curves for all three wavelengths.

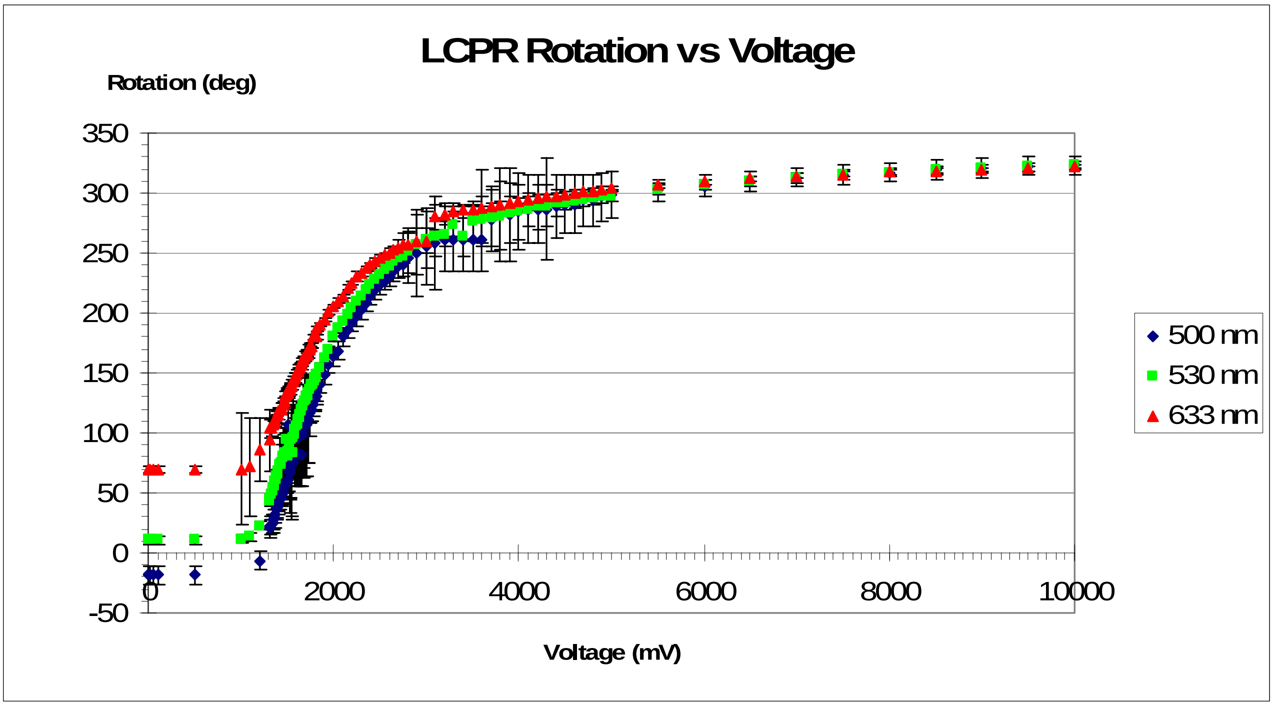

Figure 3-7 - *Rotation in function of the voltage applied to LCPR at different wavelengths.*

We can divide the response curve in 3 regions: the first one (from 0 to approximately 1300 mV) where the rotation is approximately constant for varying voltage (fig. 3-8), the second region (1300 to approximately 3100 mV) where the rotation follows a logarithmic behavior (fig. 3-9) and a third region, beyond the 3000 mV, where the rotation flattens, for large voltages (fig. 3-10). Therefore the sensibility of the LCPR will be greater in the central region where, for small variations of the voltage applied correspond large rotations. The third region shows more achromaticity. In figure 3-8, it can be noticed that for the curve at 633 nm, the error bars for 1000, 1100 and 1200 mV are much larger than those in all other points. This is probably due, to an error in the data transcription.

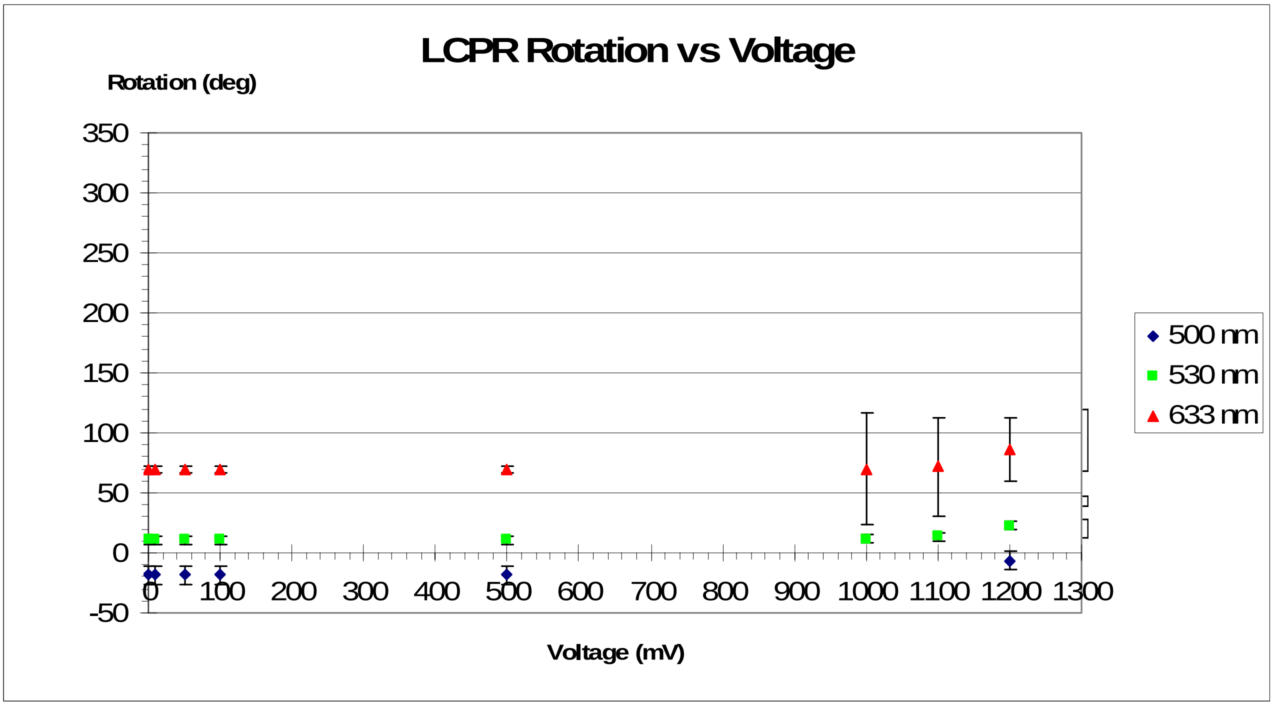

Figure 3-8 - *Rotation in function of the voltage applied (0-1300mV) to LCPR at different wavelengths.*

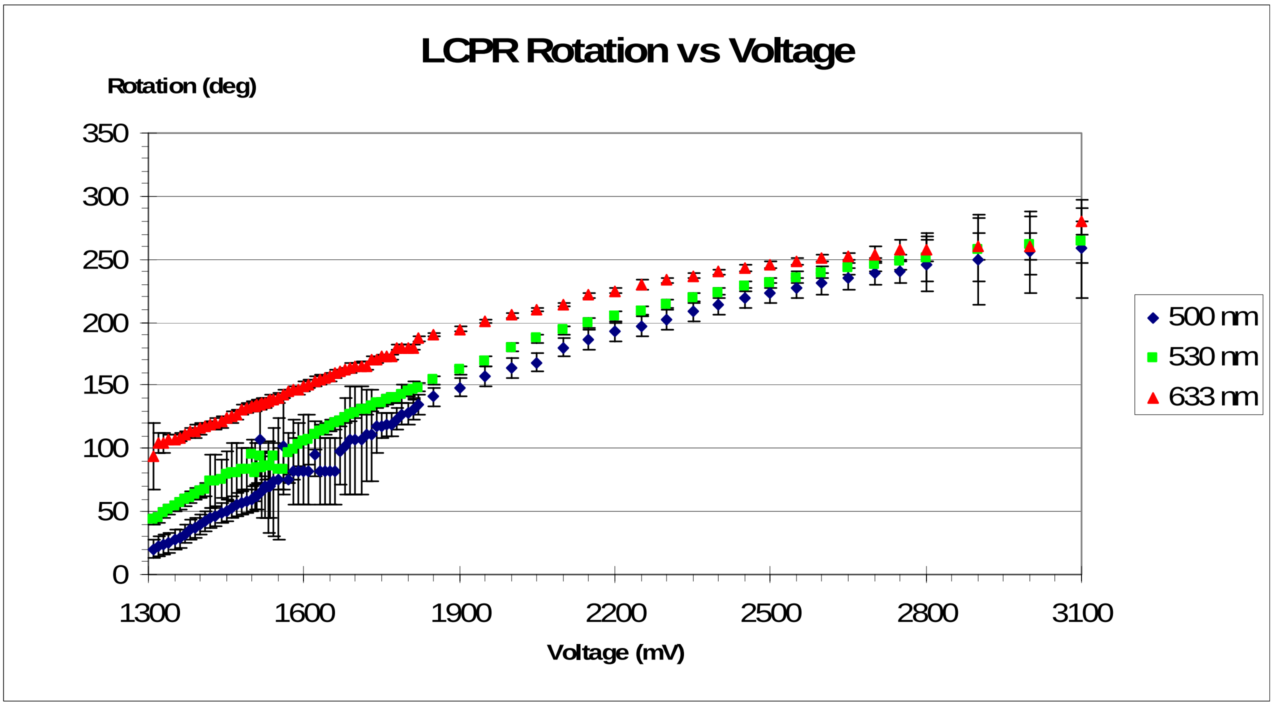

Figure 3-9 - *Rotation in function of the voltage applied (1300-3100mV) to LCPR at different wavelengths.*

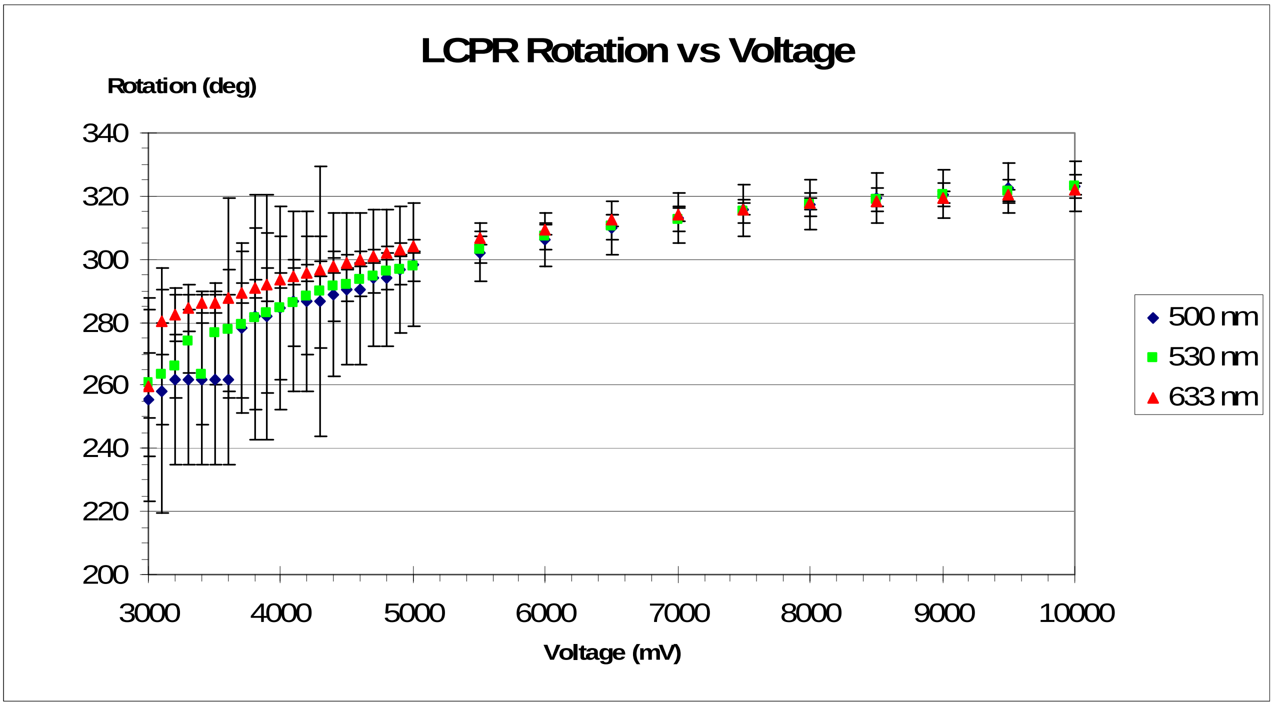

Figure 3-10 - *Rotation in function of the voltage applied (3000-10000mV) to LCPR at different wavelengths.*

For every wavelength and for voltage values > 1500 mV, the data can be fit with a 'logistic curve'. The expression of this curve is given by:

$$\Phi = a_0 \cdot \frac{1 + a_1 \cdot \exp\left(\frac{-V}{a_3}\right)}{1 + a_2 \cdot \exp\left(\frac{-V}{a_3}\right)} \qquad \textbf{(E.3)}$$

The fits are shown in figs: 3-11, 3-12 and 3-13:

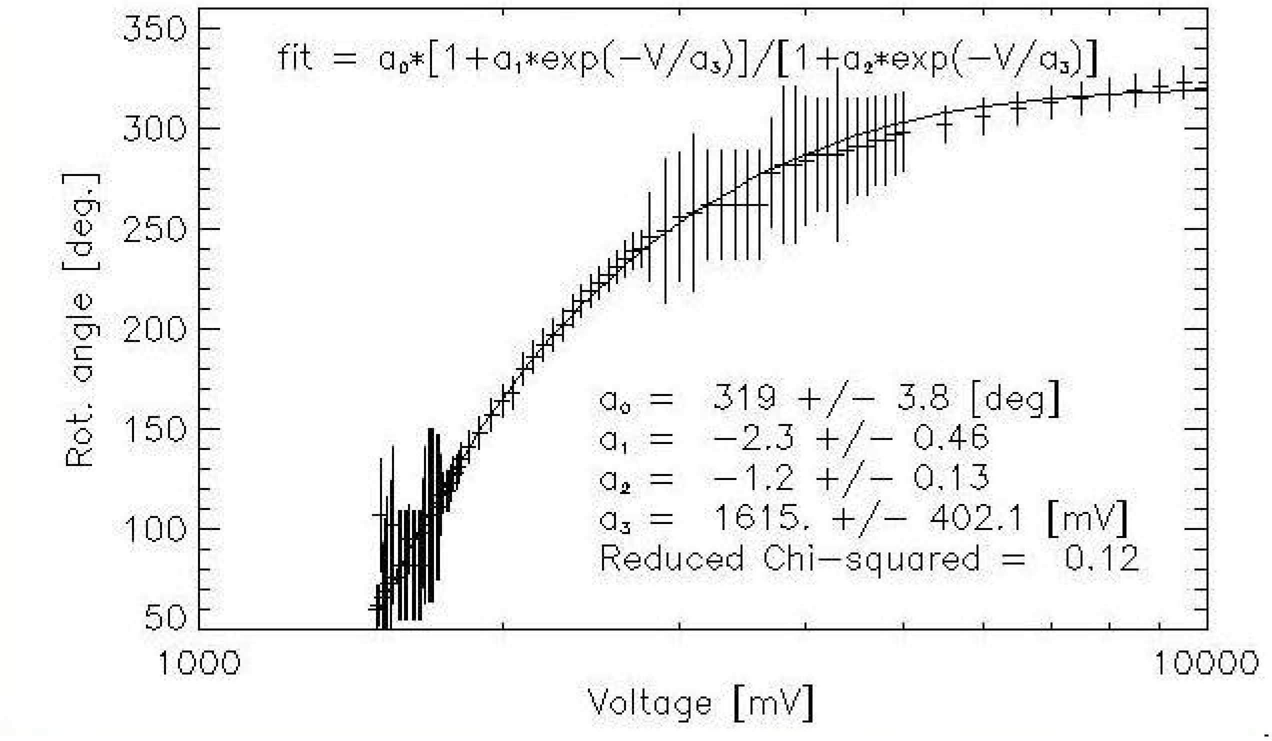

Figure 3-11 - *Rotation in function of the voltage applied to LCPR at 500 nm.*

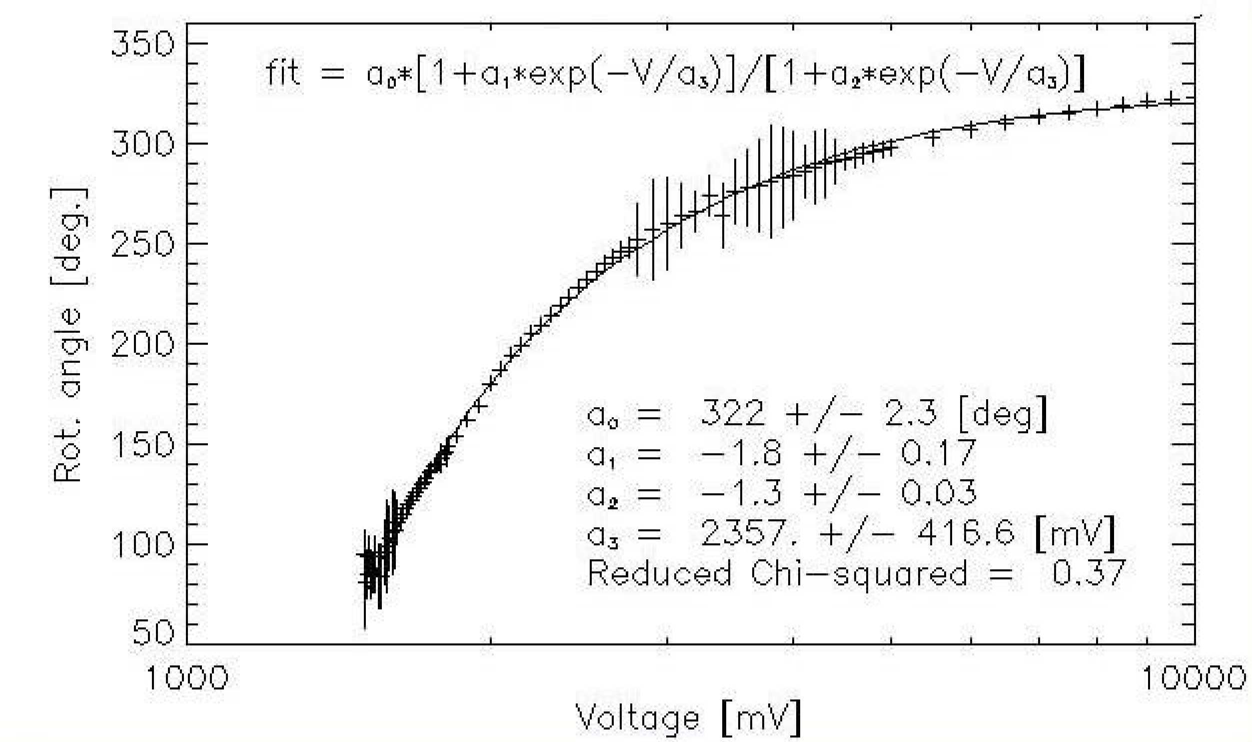

Figure 3-12 - *Rotation in function of the voltage applied to LCPR at 530 nm.*

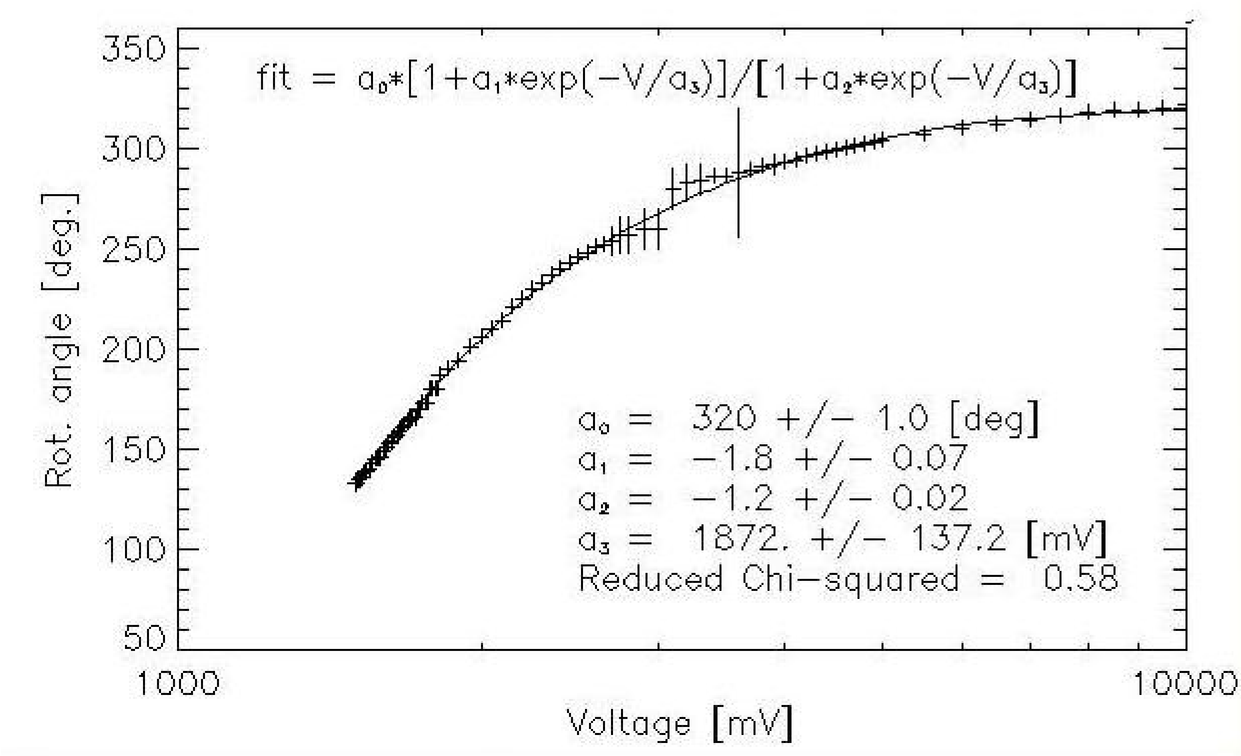

Figure 3-13 - *Rotation in function of the voltage applied to LCPR at 633 nm.*

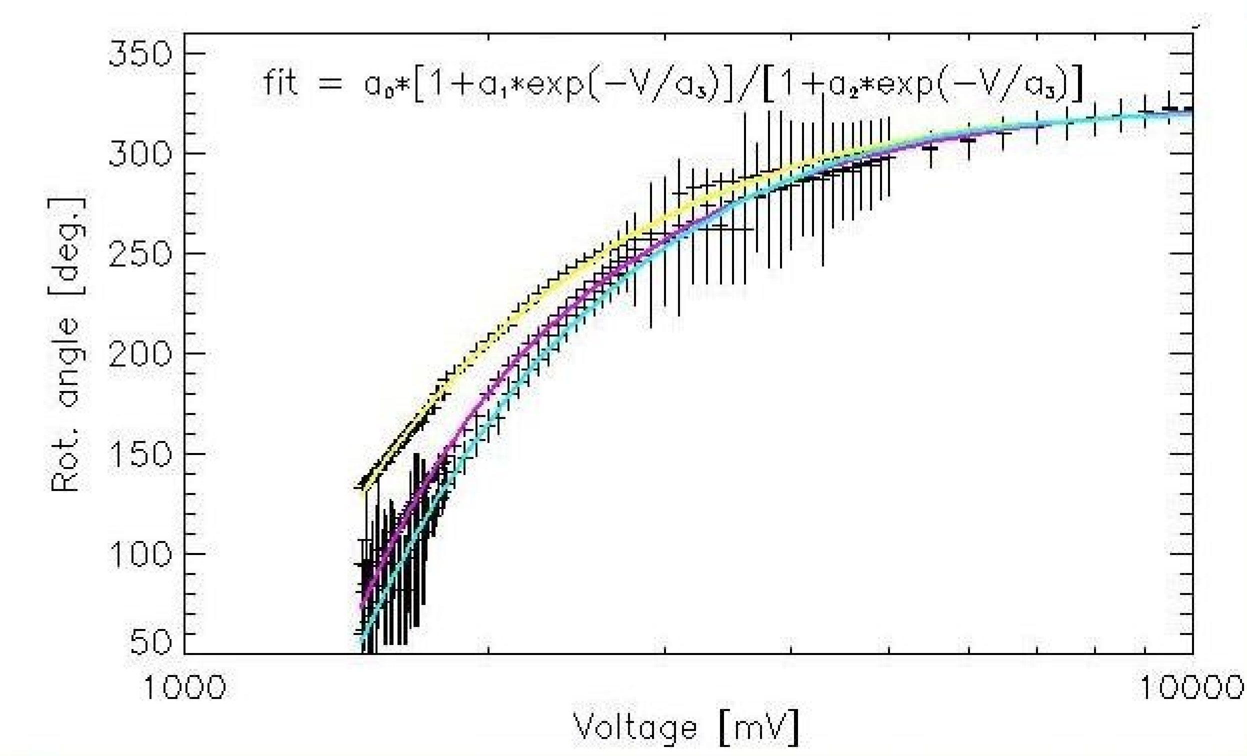

Figure 3-14 - *Rotation in function of the voltage applied for different wavelengths.*

In figure 3-14, we plot the fits for different wavelengths. In this figure, blue line is referred to 500 nm wavelength, violet line to 530 nm and yellow line to 633 nm.

We plot rotation as a function of wavelength, we obtain the graph shown in figure 3-15.

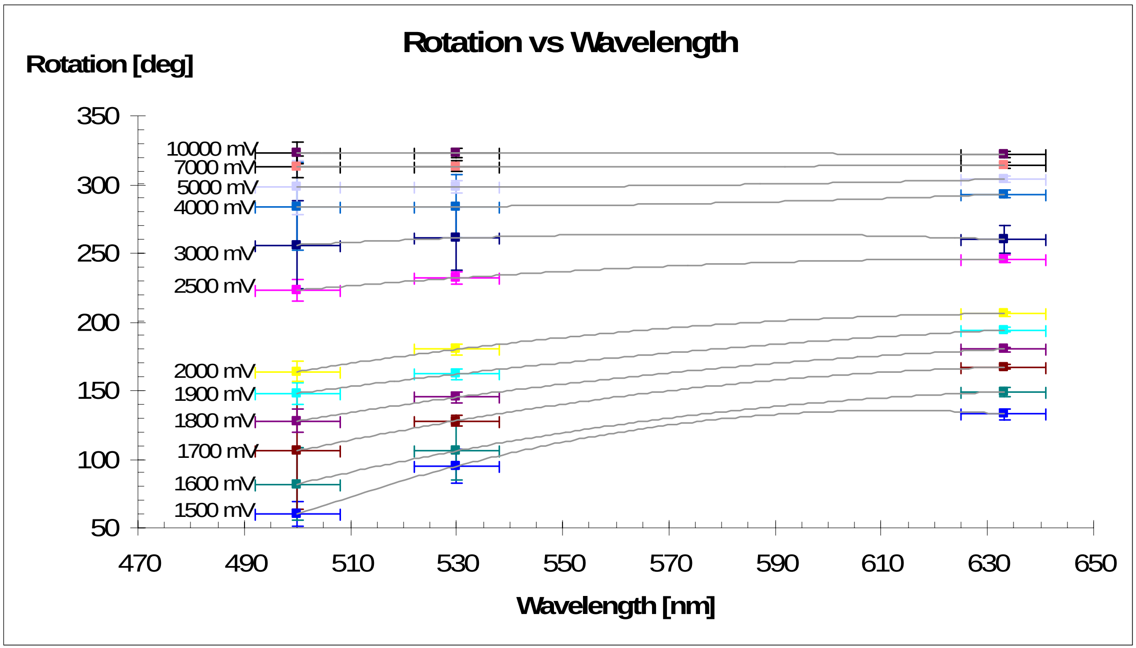

Figure 3-15 - *Rotation in function of wavelength for different voltages.*

The achromaticity is best at voltage larger than 3000 mV.

4. Comparison with data supplied from the manufacturer

In figure the 4-1 shows the comparison between the curves obtained at 530 nm and that supplied by MLO. As shown in figure, the data are in good agreement. The Meadowlark data refers to the family LPR-200-530 (C001094).

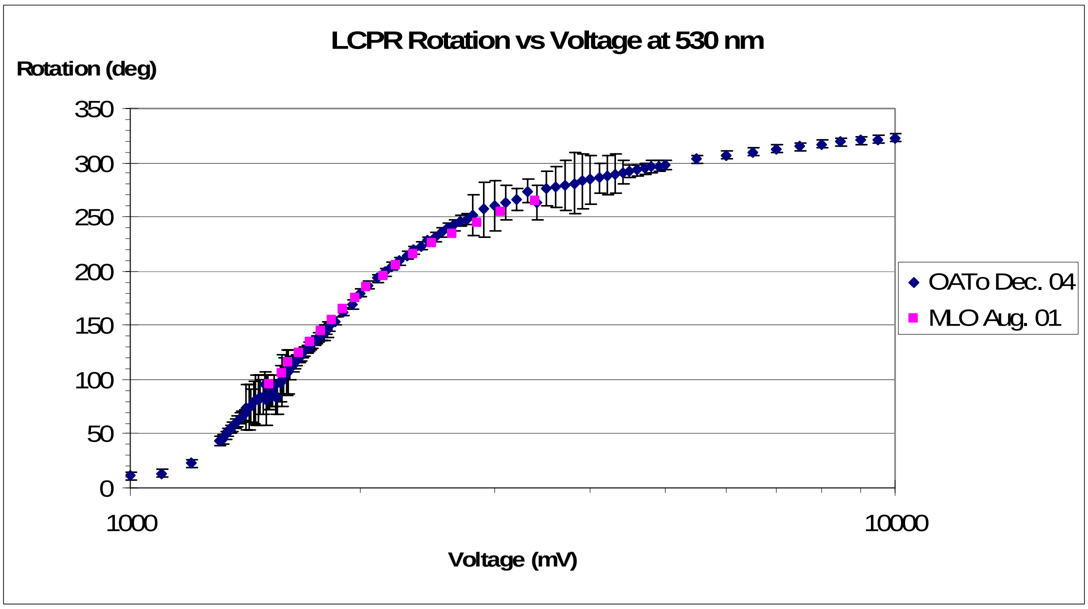

Figure 4-1 – *MLO Voltage-Rotation curve comparated with curve that we obtained.*

5. Results

From this preliminary analysis, we have characterized the LCPR response. In particular, at different wavelengths, for voltages > 5000 mV, the rotation is weakly wavelength dependent [5]. The response curve is fit by logistic curve. This curves are defined by four parameters. The parameters for the curves at three wavelengths measured are given in table 5-1. This curve is the best fit for data distribution for voltages larger than 1500 mV. The 530 nm data are in good agreement with MLO data.

	a_0 [deg]	**a_1**	**a_2**	**a_3 [mV]**
500 nm	319 ± 4	-2.3 ± 0.5	-1.2 ± 0.1	1615 ± 402
530 nm	322 ± 2	-1.8 ± 0.2	-1.3 ± 0.03	2357 ± 417
633 nm	320 ± 1	-1.8 ± 0.1	-1.2 ± 0.02	1872 ± 137

Tab. 5-1 – *Best fit parameters at different wavelength.*

Appendix A – Meadowlark D2040 voltage calibration test

A.1 Introduction

In this appendix we describe the Meadowlark (MLO) D2040 voltage calibration tests. D2040 is a liquid crystal digital controller product from Meadowlark Optics [1] for LC-based optics driving. It is programmable by parallel port and it has 2 outputs. The *voltage output* that is a BNC output and the *temperature output* that is a 5 pin output. The voltage output set the LCVR voltage and the temperature output read and set his temperature.
The voltage output is a square wave width 2kHz frequency and ± Vset voltage. If there is no signal input, the voltage output has value 40Vp-p (Fig. A-1-1).
The voltage output has been measured with a digital oscilloscope for every voltage setting.

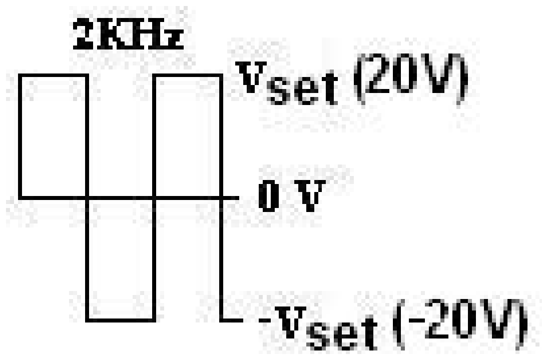

Figure A-1-1 –*Meadowlark D2040 voltage output.*

A.2 Set-up for voltage calibration tests

The set-up used for voltage calibration tests is illustrated in Fig. A-2-1 and is comprised of:

- PC with operative system Windows 95 running in MS-DOS modality.
- Digital oscilloscope Tektronix TDS 3014.
- Meadowlark D2040 digital controller and MLO control software.

The D2040 voltage output is injected and sampled from digital oscilloscope. The temperature control and monitoring is not connected.

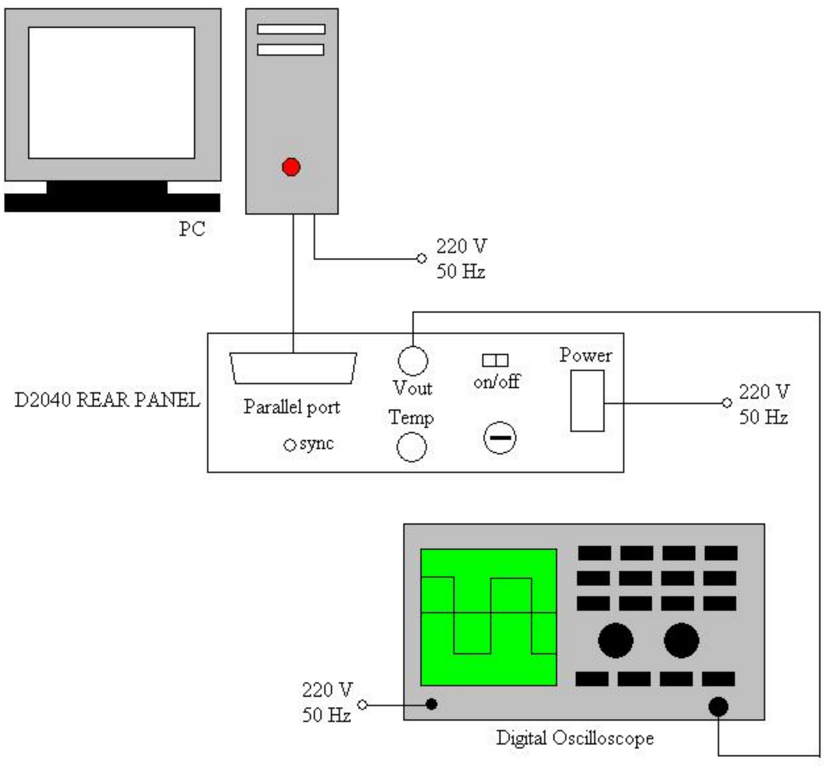

Figure A-2-1 – *Set-up used for D2040 voltage calibration tests.*

A.3 Data acquisition and data analysis

We're execute this tests connecting D2040 voltage output to the oscilloscope. With Meadowlark software we set 6 different voltages, each for 15 seconds. We repeat this tests 5 and 3 times. The data acquired are in tab.A-3-1 and tab.A-3-2:

	0 mV	1000 mV	1500 mV	3000 mV	5000 mV	10000 mV
1 V_{out}^{+}	0	1010	1520	2960	5000	10100
V_{out}^{-}	0	-1010	-1520	-3100	-5120	-10200
2	0	940	1460	2960	5000	10100
	0	-1080	-1600	-3100	-5120	-10200
3	0	1010	1510	3000	5000	10100
	0	-1010	-1520	-3100	-5120	-10200
4	0	1010	1460	2980	5000	10100
	0	-1010	-1600	-3100	-5120	-10200
5	0	1010	1460	3000	5000	10100
	0	-1010	-1580	-3120	-5100	-10200

Tab. A-3-1 - $V_{out}^{+/-}$ *for* V_{set} *= 0V, 1V, 1.5V, 3V, 5V and 10V.*

		500 mV	1100 mV	1200 mV	1300 mV	3500 mV	4000 mV
1	V_{out}^{+}	480	1040	1200	1280	3440	3960
	V_{out}^{-}	-520	-1080	-1280	-1360	-3560	-4080
2		480	1040	1120	1240	3480	3960
		-520	-1160	-1200	-1360	-3600	-4080
3		480	1040	1160	1240	3480	3960
		-520	-1120	-1200	-1320	-3600	-4080

Tab. A-3-2 - $V_{out}^{+/-}$ *for* V_{set} *= 0.5V, 1.1V, 1.2V, 1.3V, 3.5V and 4V.*

We calculate V_{out} average and relative standard deviation for every V_{set}. This data are reassumed in Tab.A-3-3.

Vset [mV]	V_{out}^{+} (mean) [mV]	V_{out}^{+} (st. dev.) [mV]	V_{out}^{-} (mean) [mV]	V_{out}^{-} (st. dev.) [mV]
0	0	10*	0	10*
500	480	10*	520	10*
1 000	1000	31	-1020	31
1 100	1040	10*	-1120	40
1 200	1160	46	-1230	46
1 300	1250	23	-1350	23
1 500	1480	30	-1560	41
3 000	2980	20	-3100	10*
3 500	3470	23	-3590	23
4 000	3960	10*	-4080	10*
5 000	5000	10*	-5120	10*
10 000	10100	10*	-10200	10*

Tab. A-3-3 - $V_{out}^{+/-}$ *and relative error for every* V_{set}*. *We estimate strumental error equal to 10 mV. When standard deviation is less than this value, we assuming the error equal to10 mV.*

The maximum percentage error is in the order of 4%. This is the error in the esteem of the output reproducibility. In the other words, *the output is reproducible with the maximum error of 4%*.

From data acquired and write in Tab.A-3-1 and Tab.A-3-2 we notice that the output is not symmetric with zero, some in ideal conditions, but there is an offset and an amplification (fig. A-3-1).

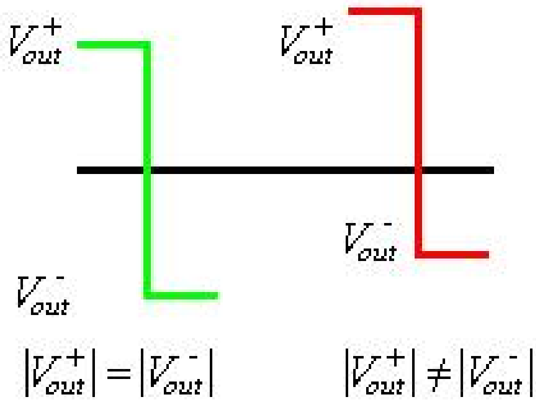

Figure A-3-1 – *V_{out} in ideal case (green curve) and in real case (red curve).*

The equations that describes $V_{out}^{+/-}$ are the follows:

$$V_{out}^{+} = A \cdot |\ V_{set}\ | + V_{offset} \quad \textbf{(E. 4)}$$

$$V_{out}^{-} = -A \cdot |\ V_{set}\ | - V_{offset} \quad \textbf{(E. 5)}$$

where:

$A = \dfrac{V^{+} - V^{-}}{2 \cdot V_{set}}$ is the amplification coefficient, and

$V_{offset} = \dfrac{V^{+} + V^{-}}{2}$ is the offset.

In table A-3-4 we calculate V_{offset} and A for every V_{set}.

V_{set} [mV]	A	σ_A	V_{offset} [mV]	$\sigma_{Voffset}$ [mV]
0	1,00	1,00	0	10
500	1,00	0,02	-20	10
1 000	1,01	0,03	-10	31
1 100	0,98	0,02	-40	25
1 200	1,00	0,04	-35	46
1 300	1,00	0,02	-50	23
1 500	1,01	0,02	-40	35
3 000	1,013	0,005	-60	15
3 500	1,009	0,007	-60	23
4 000	1,005	0,002	-60	10
5 000	1,012	0,002	-60	10
10 000	1,015	0,001	-50	10

Tab. A-3-4 – *Amplification, V_{offset} and relative errors for every V_{set}.*

Plotting A in function of V_{set} we obtain the fig. A-3-2 graph.

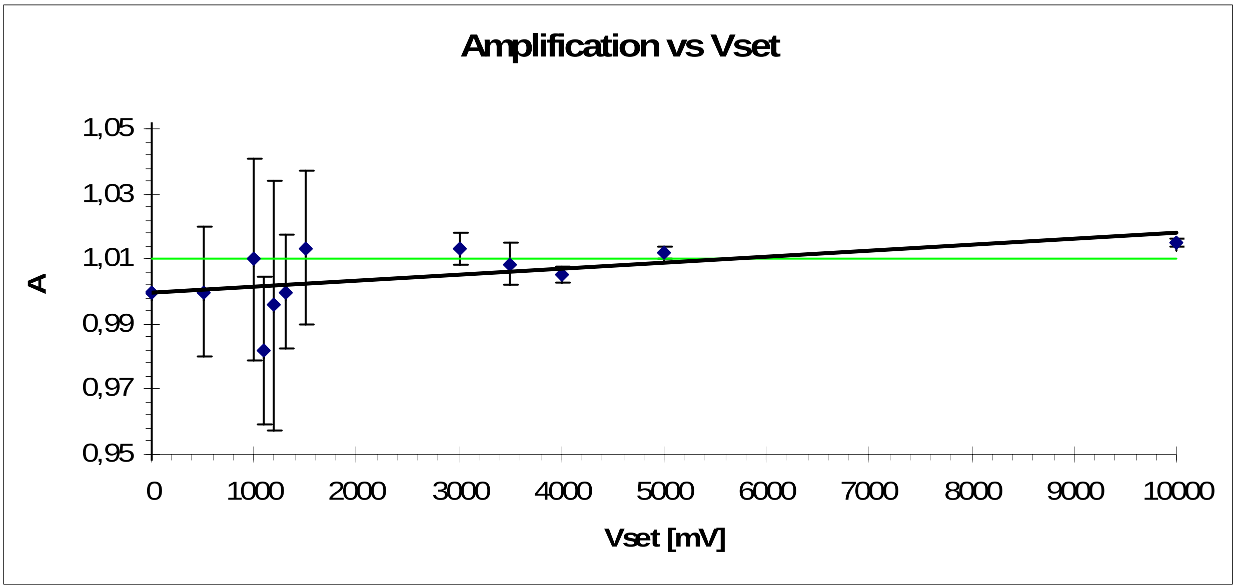

Figure A-3-2 – *Amplification coefficient in function of Vset.*

We fit this data distribution with a constant (green line).

$A = 1.01$ **(E. 6)**

This is the law for amplification (A) in function of V_{set}.

Plotting V_{offset} in function of V_{set} we obtain the fig. A-3-3 graph.

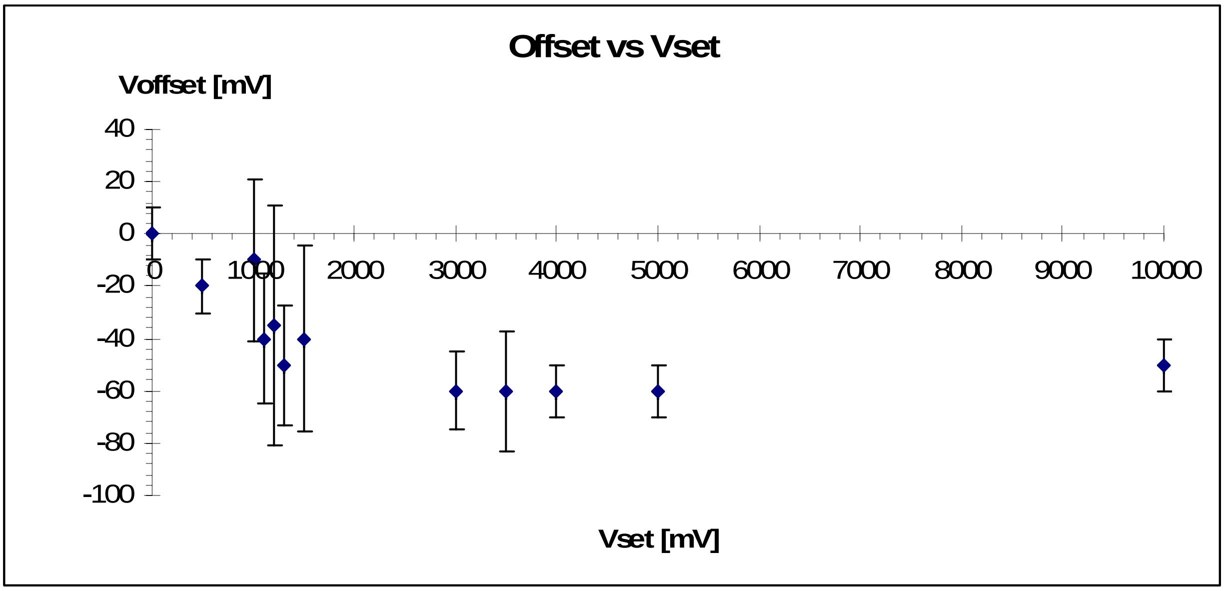

Figure A-3-3 – V_{offset} *in function of Vset.*

We execute the fit with 'logistic curve', that is the best fit for this data distribution. The expression of this curve is the follow:

$$V_{offset} = a_0 \cdot \frac{1 + a_1 \cdot \exp\left(-V_{set}/a_3\right)}{1 + a_2 \cdot \exp\left(-V_{set}/a_3\right)}$$

Fit is reported in fig.A-3-4 and the parameter of this fit with errors is the follows:

$$\begin{cases} a_0 = -57 \pm 5.6 mV \\ a_1 = 1 \pm 0.5 \\ a_2 = 2 \pm 8.6 \\ a_3 = 597 \pm 977 mV \\ \chi^2_{rid} = 0.200 \end{cases}$$

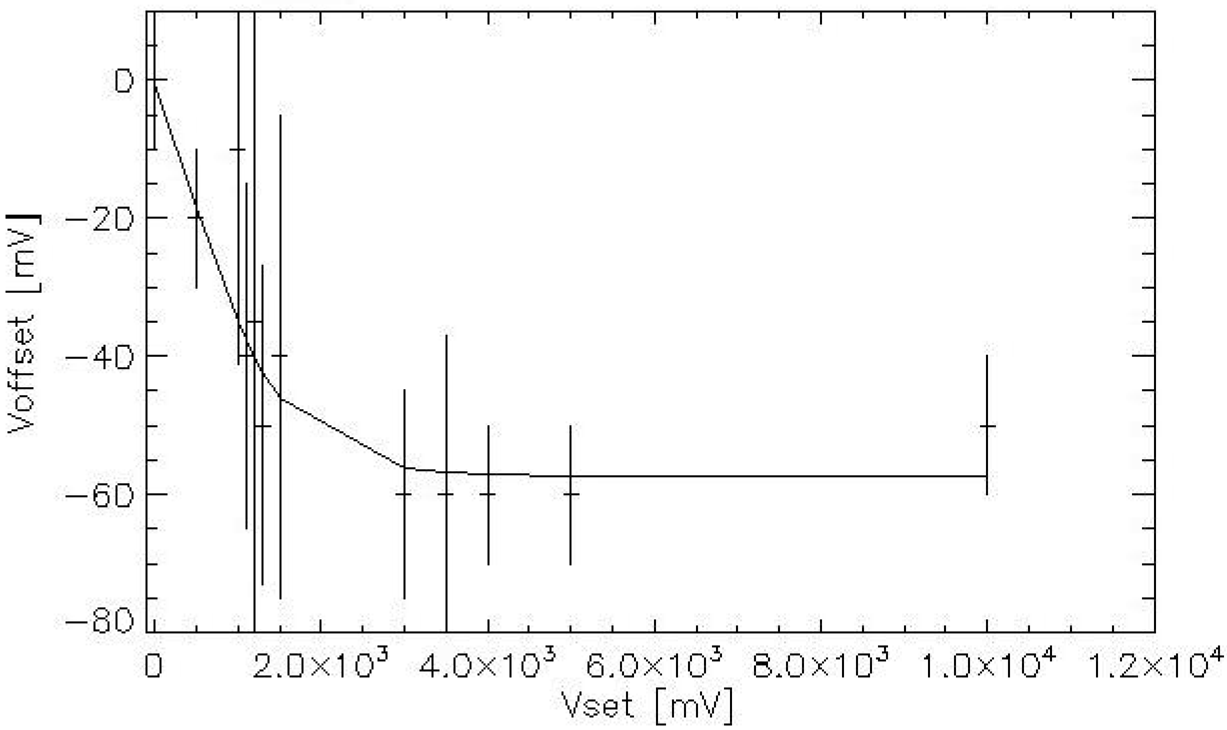

Figure A-3-4 – *V_{offset} in function of V_{set} and relative fit.*

The low for V_{offset} in function of V_{set} is the follow:

$$V_{offset} = -57 \cdot \frac{1 + \cdot \exp^{-Vset/(597)}}{1 + 2 \cdot \exp^{-Vset/(597)}} \qquad \textbf{(E.7)}$$

From E.4, E.5, E.6 and E.7, we obtain:

$$V_{out}^{+/-} = \pm(1.01) \cdot \left| V_{set} \right| \mp 57 \cdot \frac{1 + \cdot \exp^{-Vset/(597)}}{1 + 2 \cdot \exp^{-Vset/(597)}} \qquad \textbf{(E.8)}$$

A.4 Results

In conclusions, after MLO D2040 calibration tests, we rewrite the $V_{out}^{+/-}$ with E.8 equations. From this equations is possible to estimate the real D2040 voltage output in function of V_{set}.

For $V_{set} > 2500$ mV, the exponential terms of E.7 is approximately zero, and E.8 become:

$$V_{out}^{+/-} = \pm(1.01) \cdot \left| V_{set} \right| \mp 57mV$$

The voltage output is reproducible with a good approximation (less or equal to 4% of V_{set}).

Appendix B – Set-up Equipment Data Sheets

B.1 Light source

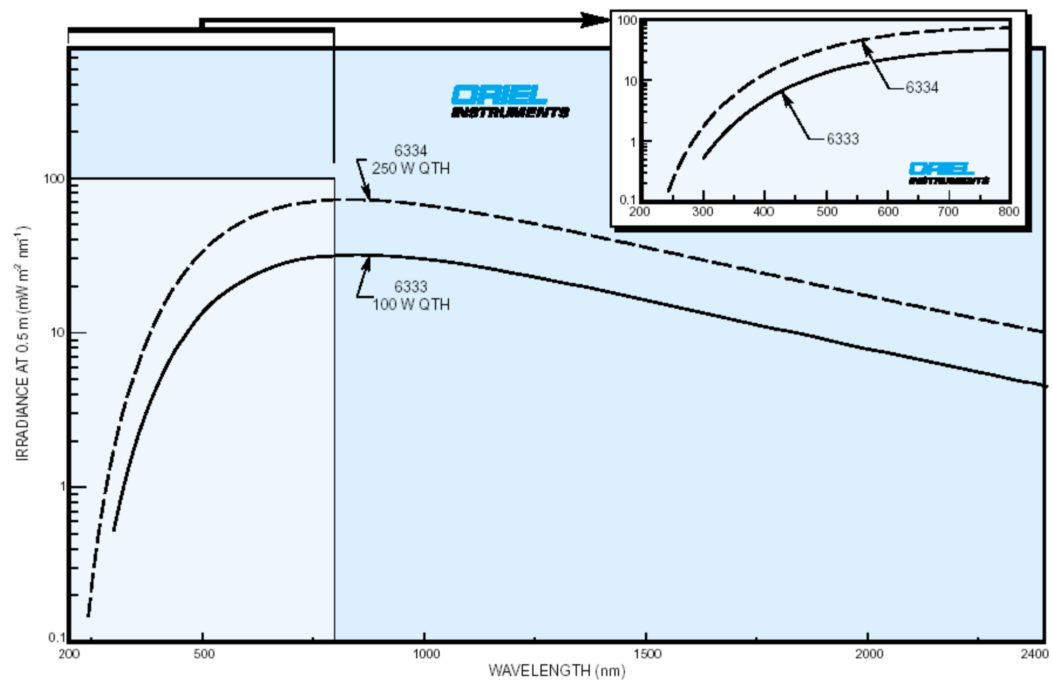

Figure B-1-1 – *Spectral irradiance at 0.5m for light source ORIEL 6333 [2].*

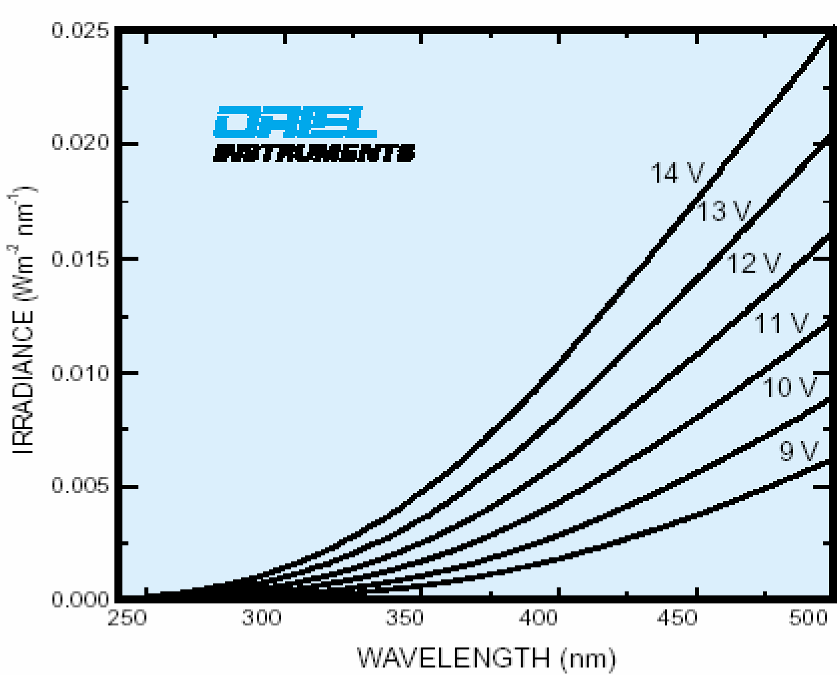

Figure B-1-2 - *Spectral irradiance at 0.5 m from the 6333 100 W QTH Lamp at different voltages. The lamp is rated for 100 W at 12 V [2] .*

B.2 Monochromator and Spectrograph

Spectra-Physics

MS257™ 1/4 m MONOCHROMATOR AND SPECTROGRAPH

SPECIFICATIONS

All specifications are with a 77700, 1200 l/mm grating and 10 µm x 2 mm slit, at 546 nm.

System

Design:	Asymmetrical Czerny-Turner
Configuration:	In line using turning mirrors, plus axial port
Ports:	1 input, 2 output (2 input with Auxiliary Input Port accessory)
Usable wavelength range:	170 nm to 24 µm (grating dependent)
F/Number (input):	3.9
Input focal length:	220.0 mm
Exit focal length:	257.4 mm
Included angle at grating:	23.66°
Main mirrors:	
77700	Spherical
77702	Toroidal
Optical height:	5 inch (127 mm)
Stray light:	3×10^{-4} at 250 nm (Deut. + Glass filter) 1.5×10^{-5} 20 nm from 633 nm laser line
Dimensions:	See page 4-48
Weight:	40 to 45 lbs. (18 to 20.5 kg)

Optical Field

Full field:	28 mm x 28 mm
Flat field (77702):	28 mm x 10 mm
Field tilt relative to mounting face:	
77700	3.1°
77702	6.7°
Focal plane clearance (All Ports):	30.0 mm

Imaging

Horizontal magnification (Both models):	1.1
Vertical magnification (77702):	1.6
Imaging spatial resolution (77702)* (Aberration limited):	~40 µm
Image vertical stability:	±125 µm
Image horizontal stability:	±5 µm

*** We suggest that 200 µm input channels should be separated by >150 µm edge to edge for practical systems.**

Ports

Port selection repeatability (Motorized mirror):	±0.05 nm
Port changeover time:	5 s

Gratings

(Kinematically interchangable single and multiple grating turrets)

Grating rotation:	Optical center @ grating face
Grating size:	50 x 50 mm
Kinematic repeatability:	±0.1 nm
Grating change time:	~1 s per grating
Grating selection repeatability:	
Wavelength:	±0.06 nm
Image vertical position:	±125 µm

Wavelengths

Reciprocal dispersion:	3.22 nm/mm
Wavelength resolution:	0.1 nm typical, <0.15 nm max.
Wavelength accuracy:	±0.1 nm typical,<0.15 nm max.
Wavelength repeatability:	±0.028 nm typical, <0.06 nm max.
Wavelength step size:	0.028 nm
Wavelength drive speed:	up to 280 nm/s @ full slew
Temperature stability:	c. 0.01 nm/°C
Wavelength drift:	c. 0.001 nm/hr

Slits

Fixed slits:	10 µm wide x 2 mm tall to 5 mm wide x 20 mm tall
Micrometer driven slit assembly:	Variable from 4 µm to 3.0 mm x 15 mm high
Precision:	±10 µm
Accuracy:	±10 µm, ≤250 µm ±5%, >250 µm
Motor driven slit assembly:	Variable from 4 µm to 2.0 mm x 15 mm high
Precision:	±5 µm
Step size:	2 µm
Accuracy:	±10 µm

Calibration

Interferometrically mapped drive
Factory default referenced to internal optomechanical home
Individual grating calibration factors

System Control

Central control by on board CPU
External control by hand controller
Programmed control by external computer

External Interface

RS-232 (Included)
IEEE-488 (Optional)

Software

Configuration Software (Included)
TRACQ32™ Data Acquisition Package (Optional)
Device Drivers For Windows™ 3.x (Optional)
LabView™ VIs (Optional at no charge)

Handheld Controller

40 key hand held keypad
4 line, 20 character, backlit supertwist LCD
5 status lights
Remote/local switching
14 ft (4.26 m) long cable

Background Shutter (Model 77755)

Light leakage:	<0.001 %
Transition rise time:	~2 ms
Response delay:	~20 ms
Max. rep. rate:	0.5 Hz
Blade coating:	Black anodize
External trigger:	TTL

Fast Shutter (Model 77717)

Configuration:	Normally closed
Light leakage:	<0.01 %
Transition rise time:	1.5 ms
Response delay:	2.5 ms
Cycle time:	25 ms (burst)
Minimum window:	5.0 ms
Blade coating:	$AlMgF_2$
Output synch timing signal:	TTL, > 90% open
External trigger:	TTL

Filter Wheel

Filter wheels supported:	2
Optical length per wheel:	38 mm
Number of filters per wheel:	5
Filter size:	1 inch (25 mm)
Maximum thickness:	0.4 inch (10 mm)
Clear aperture:	22 mm
Transition time:	~1 s per filter

Auxiliary Input Port

F/#:	4.9
Changeover time:	5 s
Dimensions:	7.5 x 6.5 x 6 inch (190 x 165 x 150 mm)
Input:	110/230, 50/60 Hz, 1A

Tab. B-2-1 – *Monochromator Specifications*

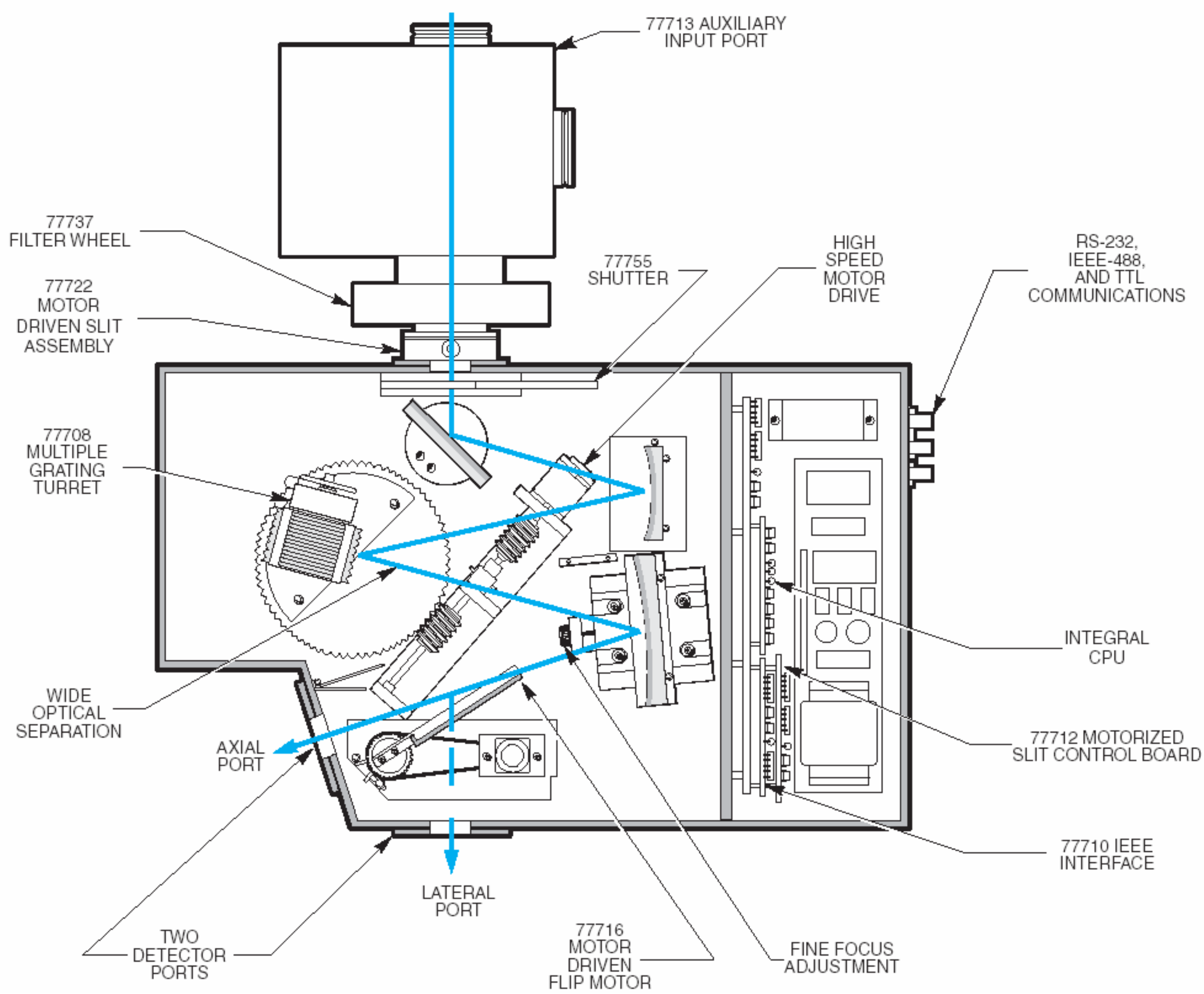

Figure B-2-1 – *Outline of the monochromator and spectrograph Lot Oriel MS257™ with our accessories [2].*

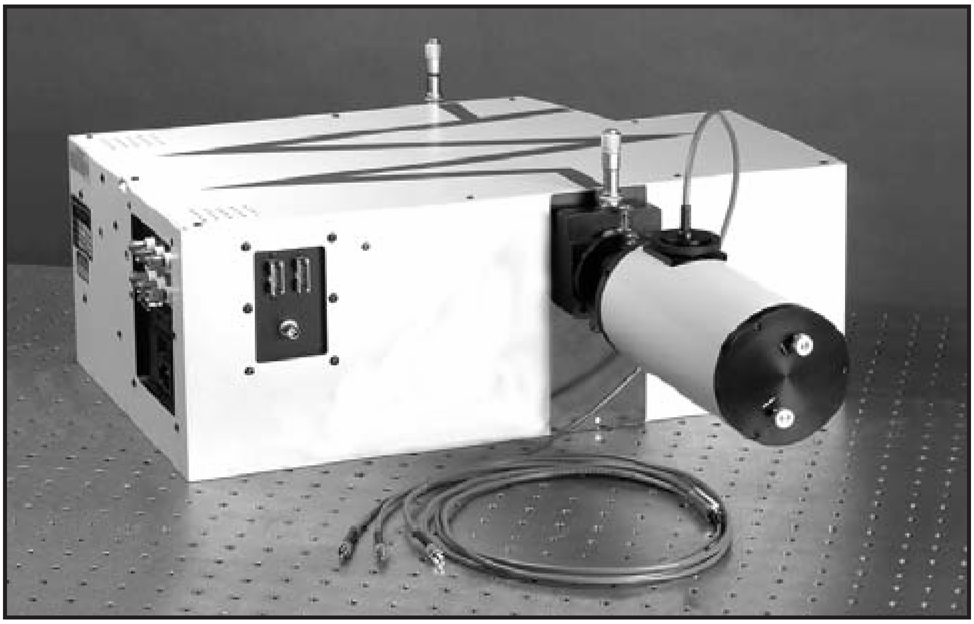

Figure B-2-2 – *Monochromator and spectrograph Lot Oriel MS257™ with our accessories [2].*

B.3 Detector and Optical Power Meter

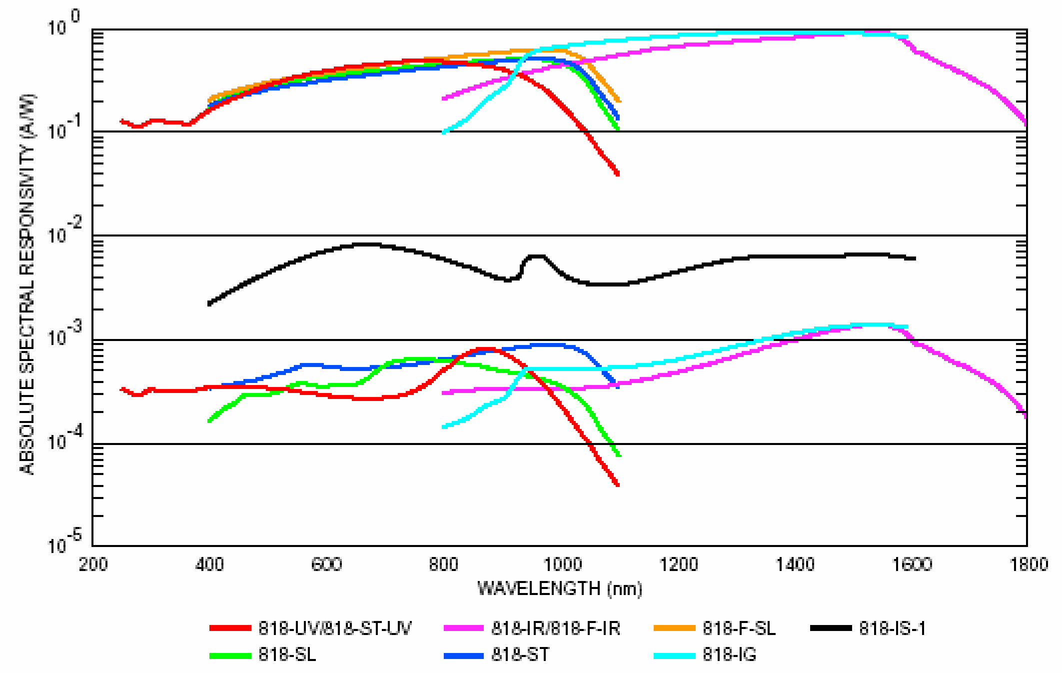

Figure B-3-1 – *Newport 818-SL response curve [4].*

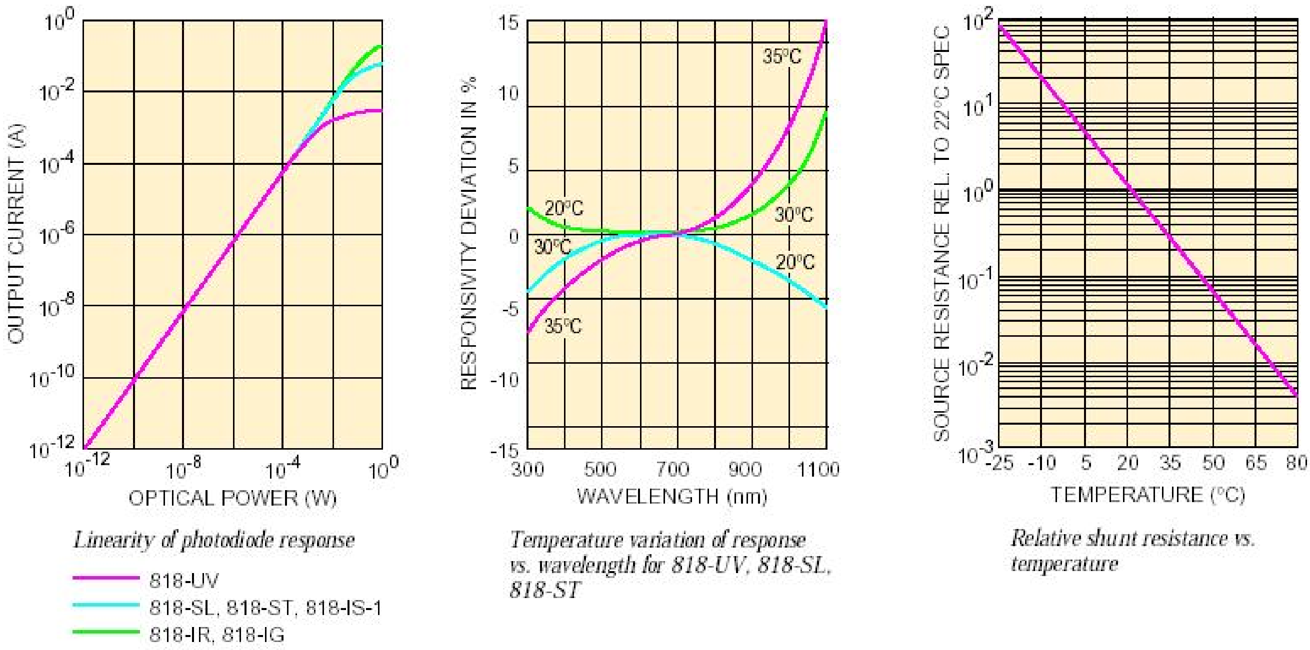

Figure B-3-2 – *Newport 818-SL linearity of photodiode response curve, Temperature Variation of response vs. wavelength curve and relative shunt resistance vs. temperature curve [4].*

818 Series Detector Specifications

Model **w/ Calib. Module** **w/ DB15 Connector**	**818-ST** **818-UV/CM** **818-ST/841**	**818-SL** **818-SL/CM** **818-SL/841**	**818-F-SL**	**818-ST** **818-ST/CM** **818-ST/841**	**818-IR** **818-F-IR / 818-IR/CM** **818-IR/841**	**818-IG** **818-IG/CM** **818-IG/841**
Spectral Range (µm)	0.4–1.1	0.4–1.1	0.4–1.1	0.4–1.1	0.78–1.8	0.8–1.65
Power, Average Max w/ Attenuator (W/cm^2)[1]	2	2		2	2[6]	2
Power, Average Maximum w/o Attenuator (mW/cm^2)[1]	2	2	2	2	3	3
Pulse Energy, Maximum - w/ Attenuator ($\mu J/cm^2$)[2]	0.03	1		0.03	0.35 Not Avail.[3]	0.35
Pulse Energy, Maximum - w/o Attenuator (nJ/cm^2)[2]	0.03	1	0.03	0.03	0.35	0.35
Accuracy at constant temperature	±2% @ 0.4-1.1	±2% @ 0.4-1.1	±2% @ 0.4 - 1.1	±2% @ 0.4-1.1	±3% @ 0.78-1.7; ±5% @ 1.71-1.8; ±7% w/ Attenuator[5]	±2% @ 0.8-1.65
Uniformity[4]	±2%	±2%	±2%	±2%	±2%	±2%
Linearity	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%	±0.5%
Saturation Current (mA/cm^2)	8	4.6	2	8	400	250
Responsivity	>0.1 A/W 400–1000 nm	>0.1 A/W 400–1000 nm	>0.1 A/W 400–1000 nm	>0.1 A/W 400–1000 nm	≥0.2 A/W 850–1700 nm	≥0.1 A/W 800–1600 nm
Responsivity (Peak)	>0.5 A/W @ 400–1000nm	>0.5 A/W @ 400–1000 nm	>0.4 A/W @ 400–1000 nm	>0.5 A/W @ 400–1000 nm	>0.8 A/W @ 850–1700 nm	>0.9 A/W @ 800–1600 nm
Rise Time (µs)	≤3	≤2	≤1	≤3	≤2	≤2
Shunt Resistance (MΩ) (typ)	≥50	≥2	≥200	≥50	≥35	≥20
Die Capacitance (pF)	1,100	12,000	160	1,100	14 nF	1500
Reverse Bias, Maximum (V)	5	10	5	5	0.25	2
NEP (W/√Hz)	1.5×10^{-14}	5.5×10^{-13}	1.1×10^{-14}	1.5×10^{-14}	0.7×10^{-12}	3.0×10^{-14}
Material	Silicon	Silicon	Silicon	Silicon	Germanium	Indium Gallium Arsenide
Active Area (cm^2)	1	1	0.071	1	0.071	0.071
Active Diameter (cm)	1x1	1.13	0.3	1x1	0.3	0.3
Shape	Wand	Cylinder	Fiber Module	Wand	Cylinder[5] Fiber Module[3]	Cylinder
Attenuator, OD3	Built-In	Detachable		Built-In	Detachable[5] Not Avail.[3]	Detachable

1) Applies to entire spectral response
2) 15 ns pulse width
3) Applies to 818-F-IR
4) When measured with 1.0 mm diameter beam centered within 80% of active area
5) Applies to 818-IR and 818-IR/CM
6) Not applicable to 818-F-IR

Figure B-3-3 –*Detector Specifications [4].*

Figure B-3-4 – *Optical power meter Newport 1830-C with detector [4].*

Instrument Specifications

Signal Ranges	Up to 8 decades (dependent on detector type)
Display Type	4.5 digit, annunciated, backlit, wide-angle view LCD
Display Update Rate (ms)	75
Auto-Ranging Time	200 ms (typical)
GPIB Bus Transfer Time	10 ms (typical)
Analog Output	0–2V into 1 MΩ
DC Accuracy	<±0.2% (typical)
Connectors	
Calibration Module	8 pin Sub-mini DIN
Analog Output	0–2V into 1 MΩ
RS-232C	9 pin D-Sub
GPIB	24 Conductor D
Power Requirements	100–120/220–240 VAC, 50/60 Hz
Absolute Maximum Line Current Rating (W x H x D) (mA)	200
Dimension (W x H x D) [in. (mm)]	3.7 (94) x 7.5 (191) x 9.0 (229)
Weight [lb (kg)]	5 (2.3)
Enclosure (W x H x D)	Metal case, painted 7.5 (191) x 9.0 (229) in. (94 x 191 x 229 mm)
Operating Temperature	0°C to +40°C; <70% RH noncondensing
Storage Temperature	-20°C to +60°C; <90% RH noncondensing

Figure B-3-5 – *Optical Power Meter Specifications [4].*

B.4 Linear Polarizer

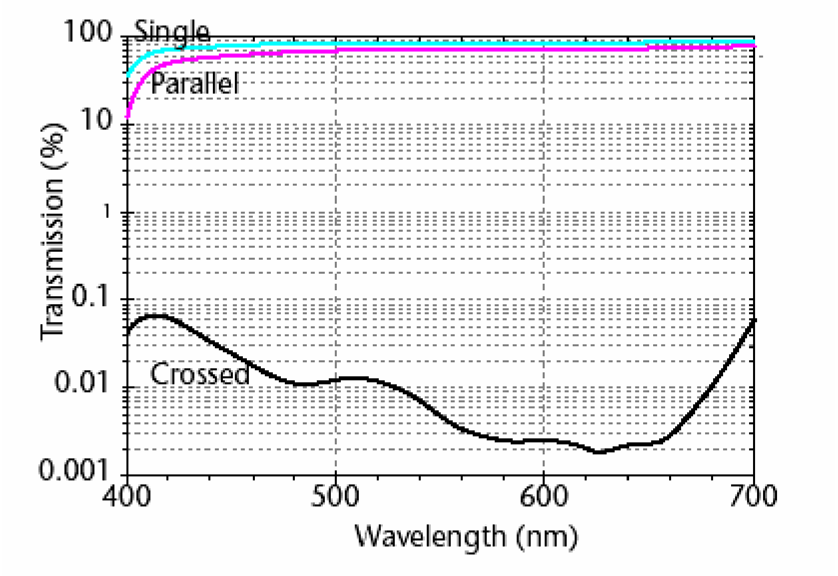

Figure B-4-1 – *MLO Linear Polarizer Transmission curve [1].*

B.5 LCPR

SPECIFICATIONS

Retarder Material:	Nematic liquid crystal with Birefringent polymer
Substrate Material:	Optical quality synthetic fused silica
Wavelength:	450-1800 nm (specify)
Polarization Rotation:	0-180°
Polarization Purity:	150:1 average
Transmittance:	92% with polarized input
Transmitted Wavefront Distortion (at 632.8 nm):	$\lambda/4$
Surface Quality:	40-20 scratch and dig
Beam Deviation:	2 arc min
Reflectance (per surface):	0.5% at normal incidence
Diameter Tolerance:	±0.005 in.
Temperature Range:	10 °C to 50 °C
Recommended Safe Operating Limit:	500 W/cm^2 CW 300 mJ/cm^2 10 ns, visible

Figure B-5-1 – *MLO LCPR Specifications [1].*

Bibliography

[1] Meadowlark Optics

Official web page:

http://www.meadowlark.com

[2] Lot Oriel Italia

Official web page:

http://www.lot-oriel.com

[3] National Instruments

Official web page:

http://www.ni.com

[4] Newport Corporation

Official web page:

http://www.newport.com

[5] S. Fineschi et al.

KPol: liquid crystal polarimeter for K-corona observations from the SCORE coronagraph

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