iVac Spectrometer

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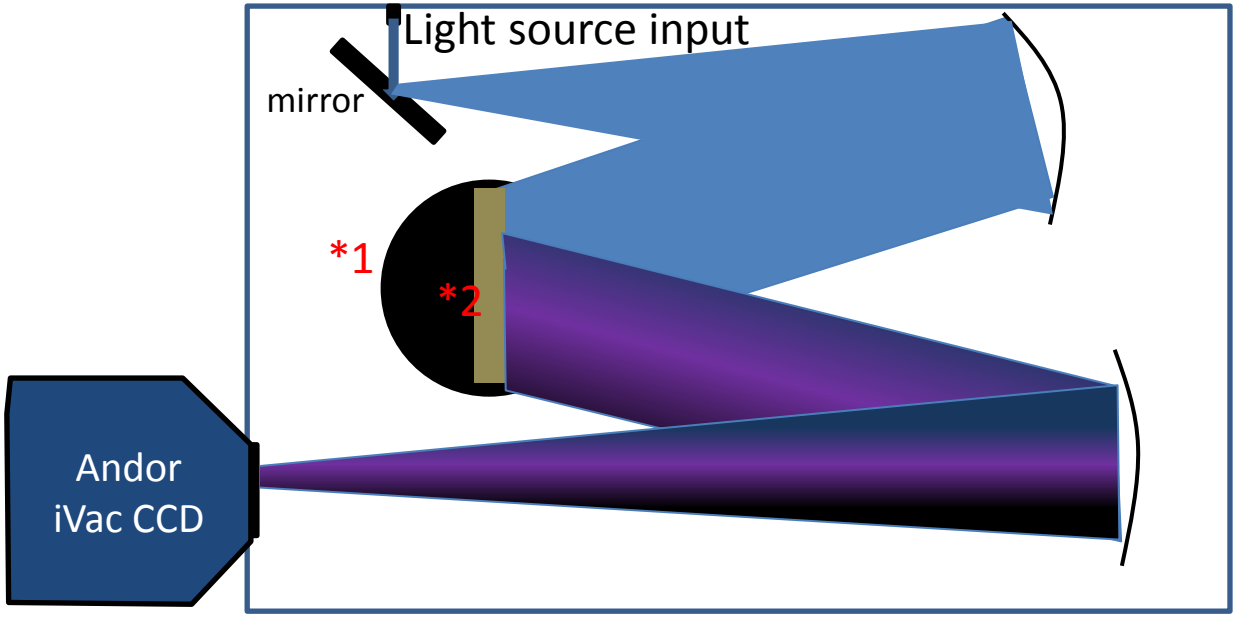
Specification

Basic Components of iVac Spectrometer

- Andor iVac
- Newport plane Holographic reflection grating.*1
- PAT-001 rotational stepper motor. *2

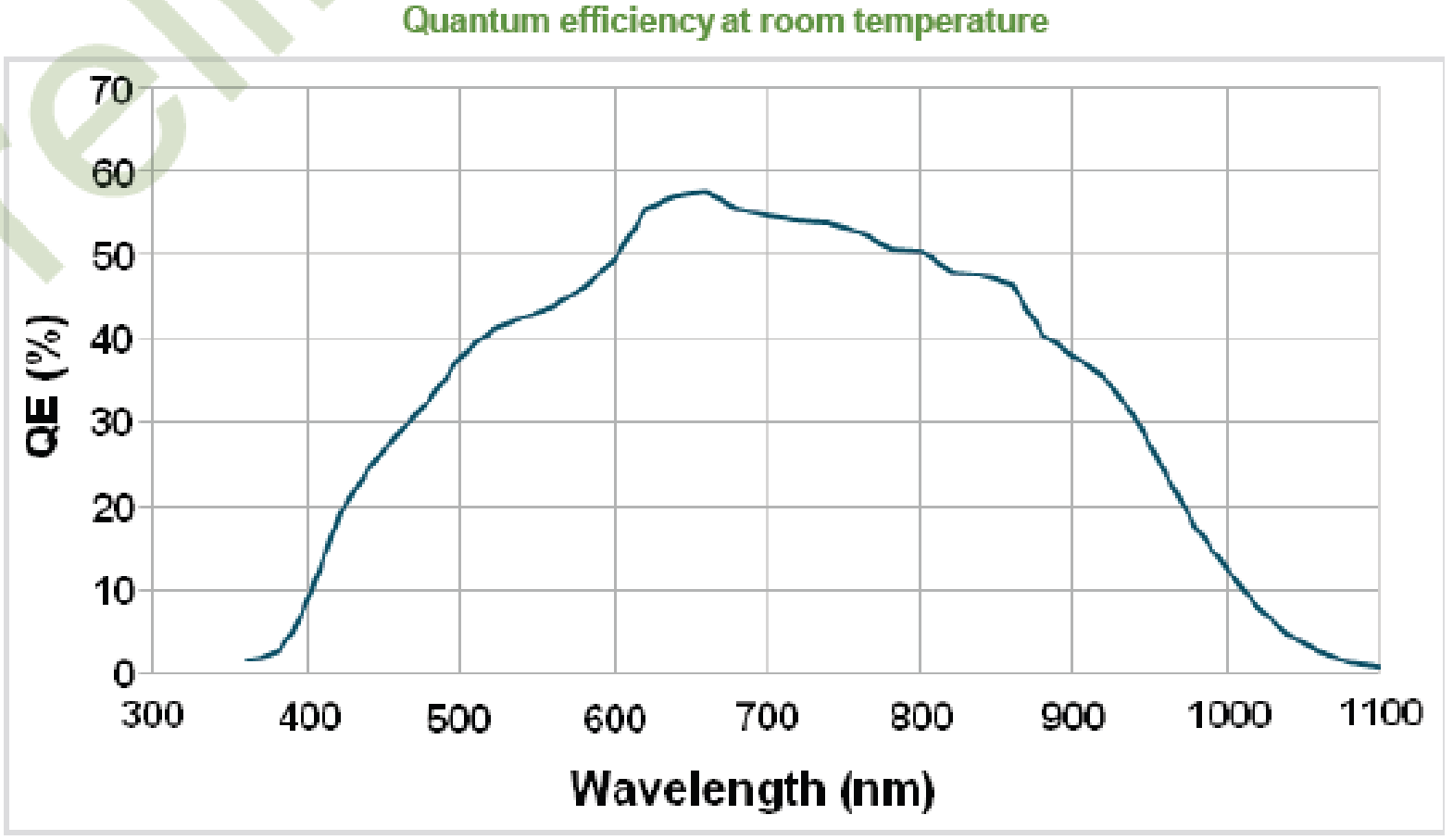


Specification of Andor iVac

Key Specifications

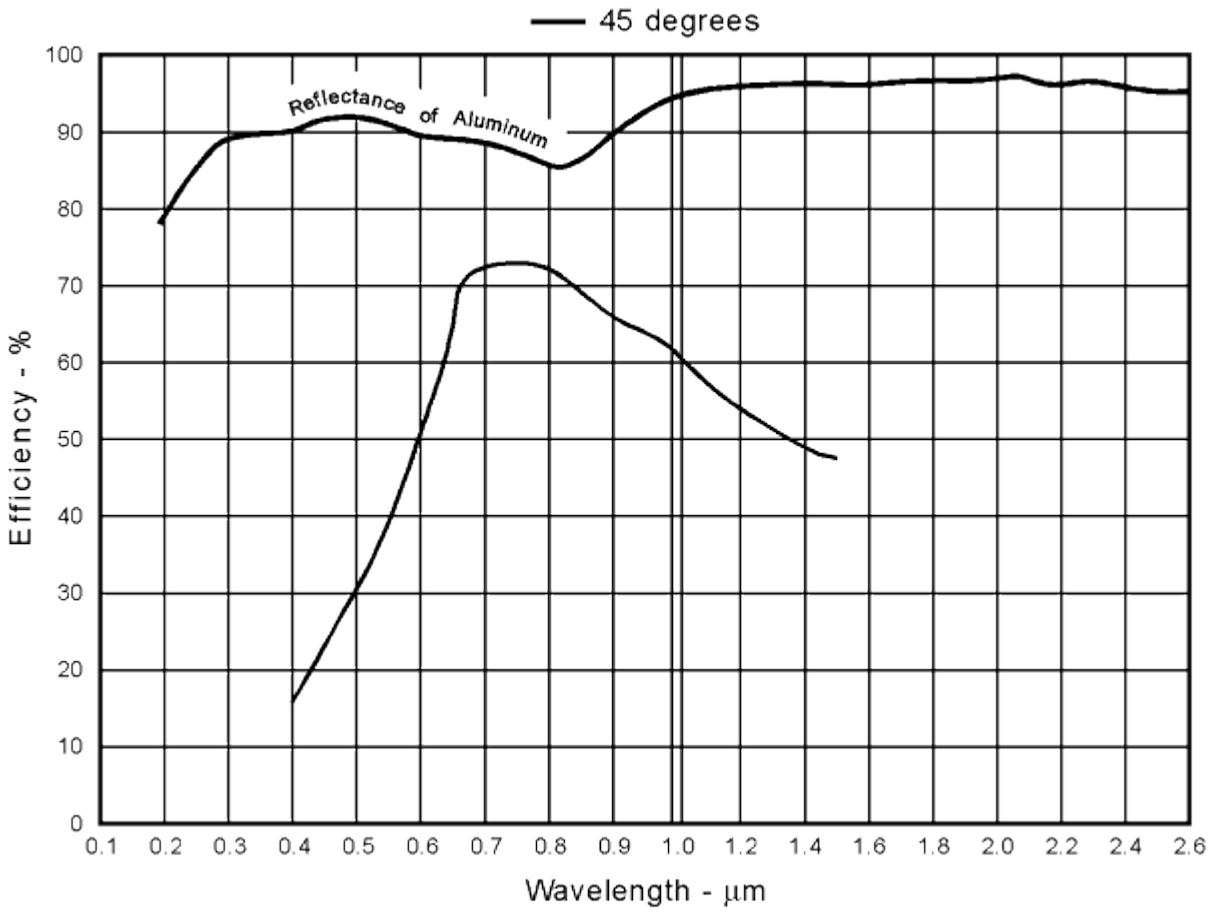
Model Number	iVac
Sensor option	CCD - 2198
Active pixels	1650x200 pixels
Pixel Size	16 um x 16 um
Image area	26.6x3.2 mm
Minimum Readout Speed	35kHz
Dark current (@ 25°C ambient)	0.1 @ -50°C 0.02 @ -60°C (e^-/pixel/sec)
Read Noise	5 e^- @ 35 kHz

Quantum Efficiency Curves of Andor iVac



Newport Plane Holographic Reflection Grating

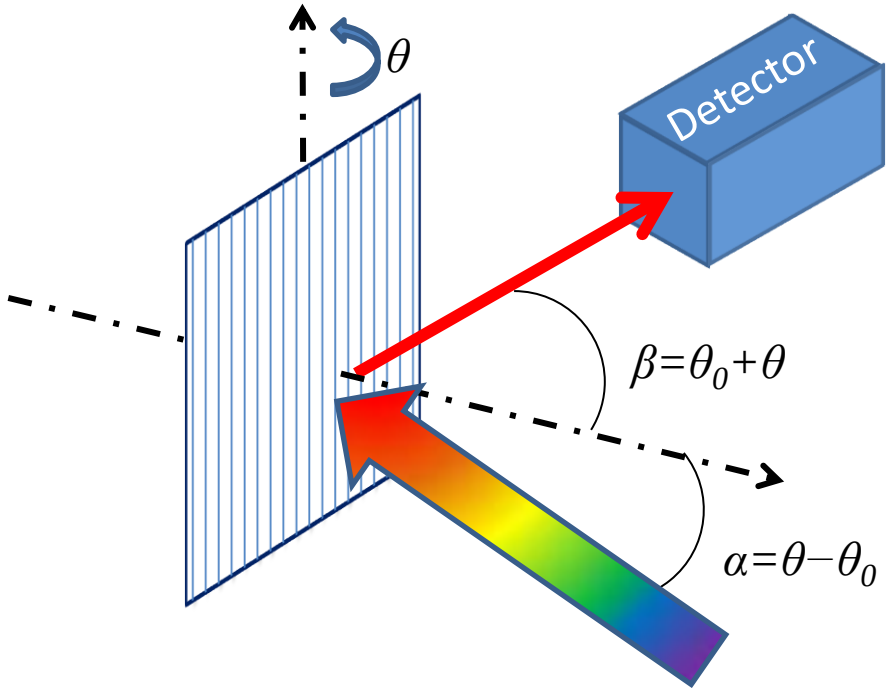
Catalog No.	20HR1200-800-1
Groove Frequency	1200 per mm
Dimensions	50x50x6mm
Blazed or Modulation	High modulation
Nominal Blazed Wavelength Tolarance	±25 µm
Coating	Aluminum
Spectral Region	500-1200 nm
Max efficency	@ 800nm



Calibration Protocal

**現用以前的Data做Center Wavelength校正

Basic Grating Equations – for Center Wavelength



$$Gm\lambda = \sin\alpha + \sin\beta$$

G: Groove Density (Groove/nm) (eq.1)

m: Diffraction Order

$$\lambda = \frac{2}{G}\cos\theta_0 \sin\theta$$ (eq.2)

θ = angle rotated from $\alpha = \beta = \theta_0$

θ_0 = (Deviation Angle)入射光與出射光夾角的一半

= 同時也是Zero Order之角度

Pulses to central wavelength

Peak position (nm)	pulse number	Fitted Difference (nm)
404.66	24371	-0.04518
407.78	24416	-0.03493
435.83	24821	0.01517
546.08	26431	0.04036
576.96	26889	0.06177
579.07	26919	-0.03202
696.54	28694	-0.09431
706.72	28855	0.17889
727.29	29171	0.02383
738.4	29345	0.09619
750.39	29531	0.01265
751.46	29547	-0.03543
763.51	29735	-0.10551
772.42	29879	0.12591
794.82	30232	0.00531
800.62	30326	0.1065
801.48	30340	0.12425
809.32	30464	0.04551
810.37	30480	-0.00476
811.53	30499	0.02191
826.45	30737	-0.08102
840.82	30967	-0.21666
842.46	30993	-0.25286
852.14	31154	-0.02584
866.79	31394	0.01417
871.66	31474	0.0198
912.3	32146	-0.09001
922.45	32319	0.06856
965.78	33053	-0.11618
978.45	33274	0.01242
1013.97	33896	0.02162
1047	34487	0.05853
1092.16	35316	0.10358
1153.92	36492	0.00528
1158.14	36574	-0.02664
Standard Deviation of Fitting Errors		0.090583

Fitting Process

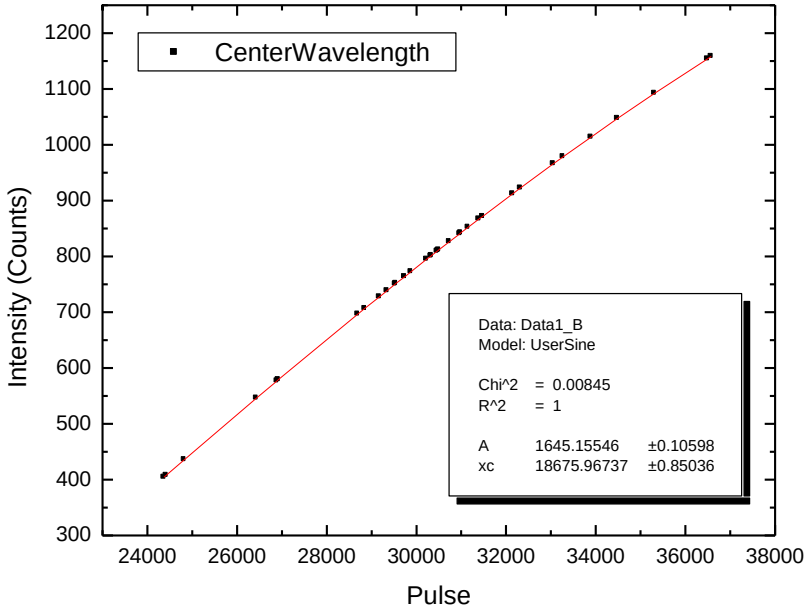
•透過原先的Fitting將較弱的Peak位置補齊，同時確認並建立CAL-2000的Data Base

$$\lambda = A\sin\left(\frac{P - P_0}{72000} \times \pi\right) \quad \text{(eq.3)}$$

•We got –

A = 1645.15546 (nm)

P_0 = 18675.96737 (pulse)



*尚未確認Zero Order的位置

Equation for Fitting to Deviation Angle

•從eq.3我們利用Fitting得出

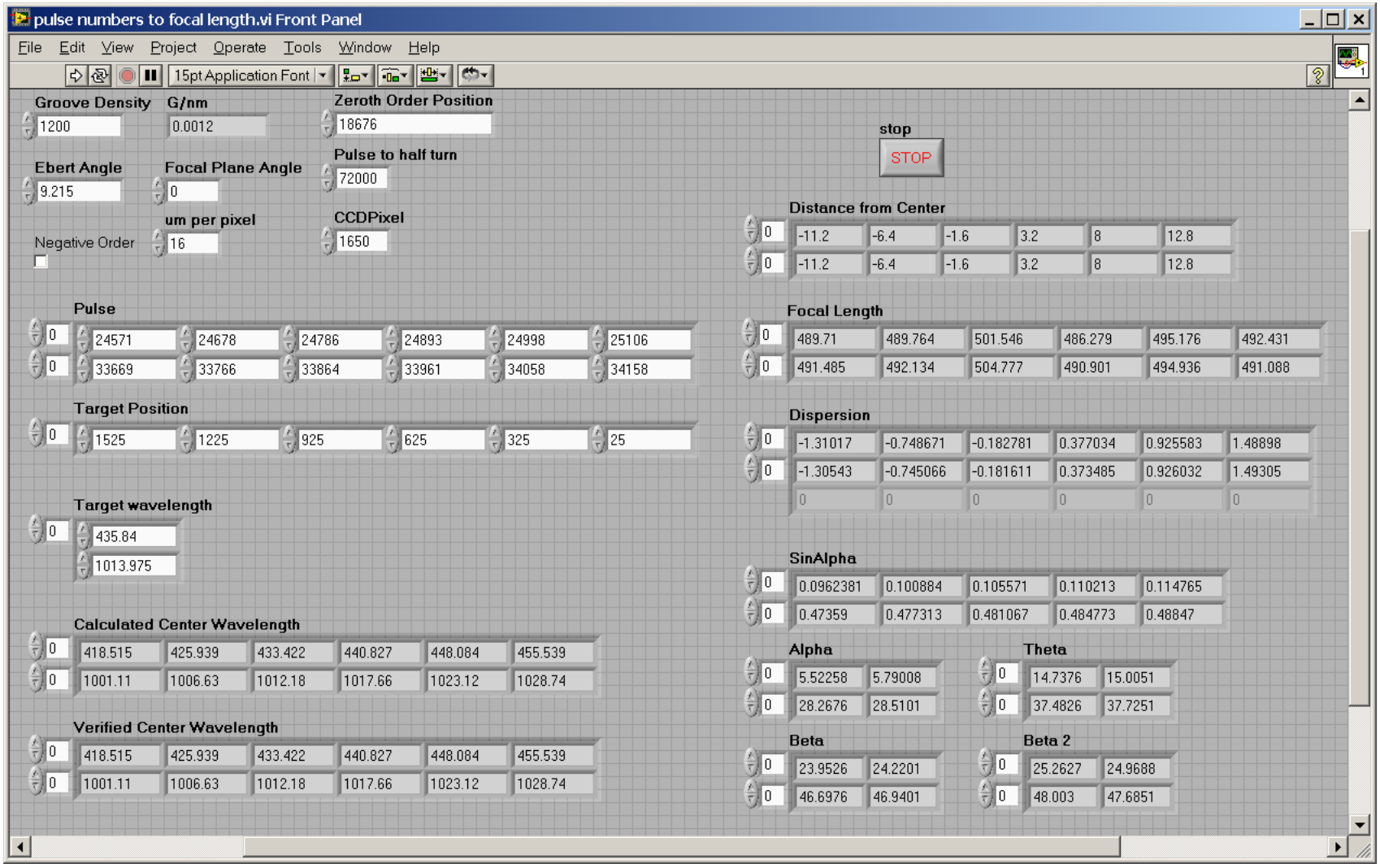
A = 1645.15546 (nm)
P_0 = 18675.96737 (pulse)

$$\lambda = \frac{2}{G}\cos\theta_0 \sin\theta \quad \text{(eq.2)} \Rightarrow \lambda = A\sin\left(\frac{P - P_0}{72000} \times \pi\right) \quad \text{(eq.3)}$$

•由上我們得知，因此可以算出Deviation Angle θ_0。(即JY所述之Ebert Angle)

$$A = \frac{2}{G}\cos\theta_0 \quad \text{(eq.4)} \Rightarrow \theta_0 = 9.215^\circ$$

Front Panel of The Examine Program



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Spectral Dispersion Calculation.llb\pulse numbers to focal length.vi

How to Use – Part I

- Type in “Groove Density”, “Ebert Angle”(θ_0) , “um per pixel”, “Zeroth Order Position”, “CCDPixel”
- “Pulse to half turn” would change while the rotational stage is different
- Focal Plane Angle should better be “0”
- In current setting, “Negative order” can be decided by following method.

  -- If the pulse number goes up while the wavelength of center pixel goes down, than we’re looking at the “Negative order” of this grating, and vise versa.

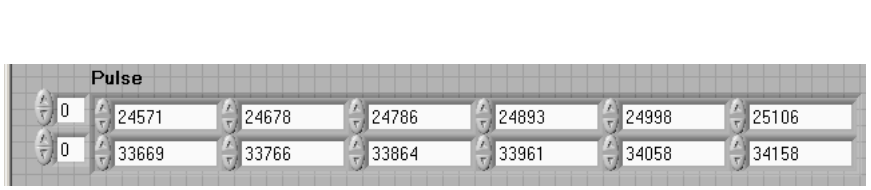
How to Use – Part II

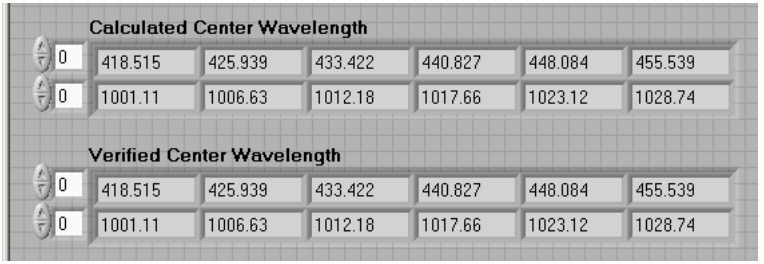
- Fill up “Pulse” array, each element should be decided in respect to element of “Target position”.
- Fill up the “Target Wavelength”

Dispersion Angle – I

•透過改變Center Wavelength，用以將435.84以及1013.98這兩個Peak分別定於CCD上25、325、625、925、1225以及1525 pixel的位置(iVac CCD為1650 Pixels)，並記錄每個位置對應到的Grating轉動的Pulse Number。

•在計算Dispersion以及Focal Length時之中心波長是由真實的Grating pulse position經由eq.2 or eq.3計算出來的結果。同時再以計算出之α、β值驗算中心波長的值、確保α、β以及程式正確。

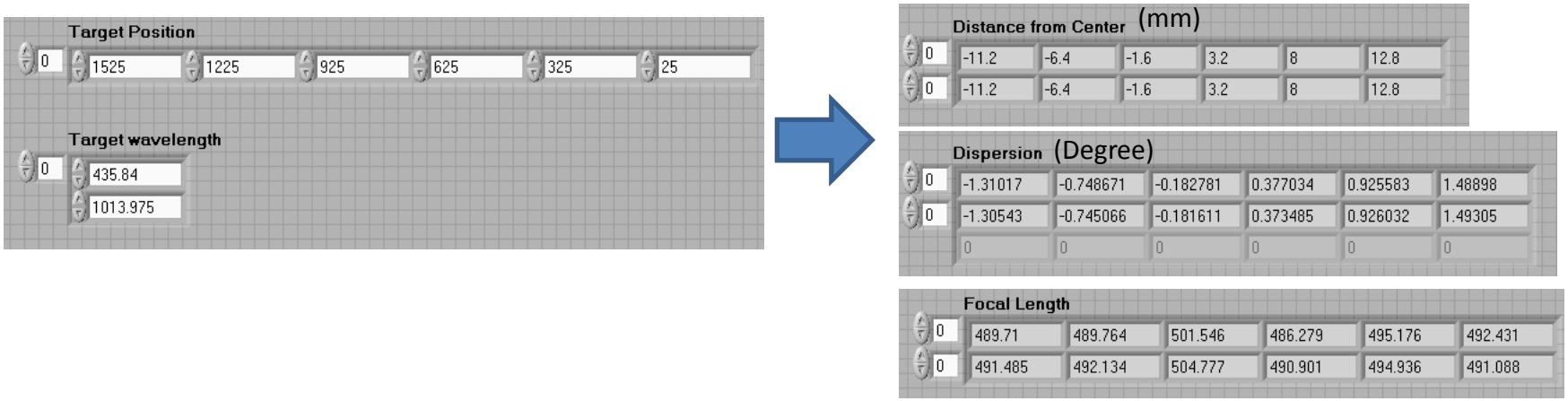




Dispersion Angle – II

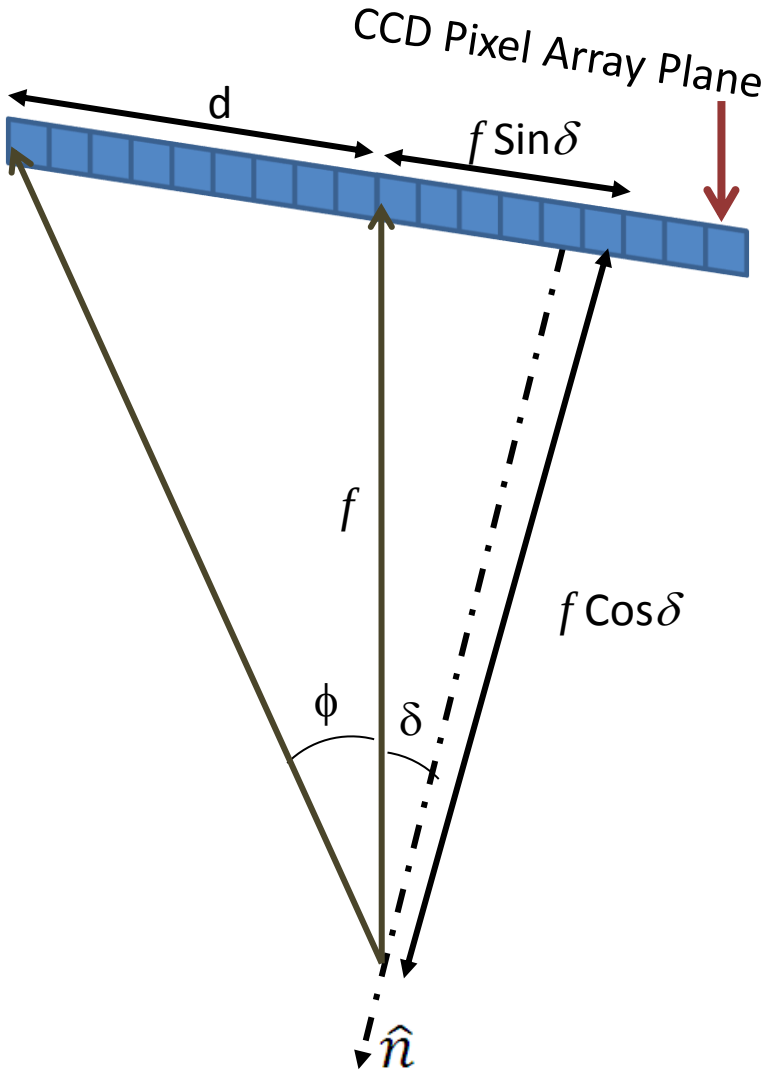
•iVac每個Pixel之大小為16μm,故可計算Distance from Center Pixel
•透過eq.1，我們可以回推估該pixel位置所對應之α、β值，而Dispersion Angle(ϕ_p)實為eq.5，其中β_c為中心波長對應的β值， β_p為某一pixel對應的β值

$$\emptyset_p = \beta_p - \beta_c \text{ (eq.5)}$$



•程式也會透過下頁的公式去計算Focal Length的長度，其計算值不可波動太大，否則須檢查算式

Focus Length and Focal Plane Angle – Derived from Jobin Yvon Tutorial



•從左圖我們可以得到eq.6之關係

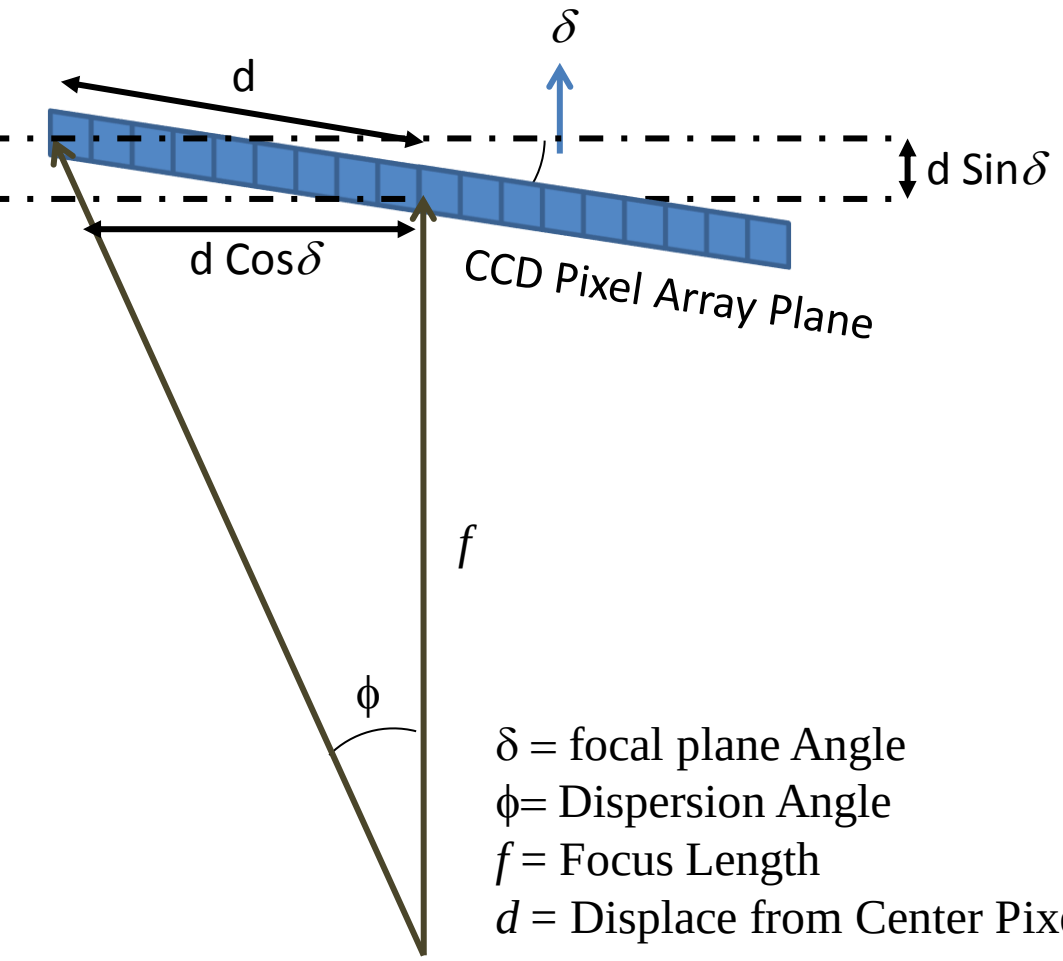
$$\tan(\emptyset + \delta) = \frac{d + f \sin\delta}{f \cos\delta} \quad \text{(eq.6)}$$

•因此，我們得到ϕ對f以及δ之關係，如eq.7，可做為後續fitting之用

$$\emptyset = \tan^{-1}\left(\frac{d + f \sin\delta}{f \cos\delta}\right) - \delta \quad \text{(eq.7)}$$

δ = focal plane Angle
ϕ= Dispersion Angle
f = Focus Length
d = Displace from Center Pixel

Focus Length and Focal Plane Angle – Our Lab



δ = focal plane Angle
ϕ= Dispersion Angle
f = Focus Length
d = Displace from Center Pixel

•從左圖我們可以得到eq.8之關係

$$\tan \emptyset = \frac{d \cos \delta}{f + d \sin \delta} \quad \text{(eq.8)}$$

•由此可計算Focus Length

$$f = \frac{d \cos \delta}{\tan \emptyset} - d \sin \delta \quad \text{(eq.9)}$$

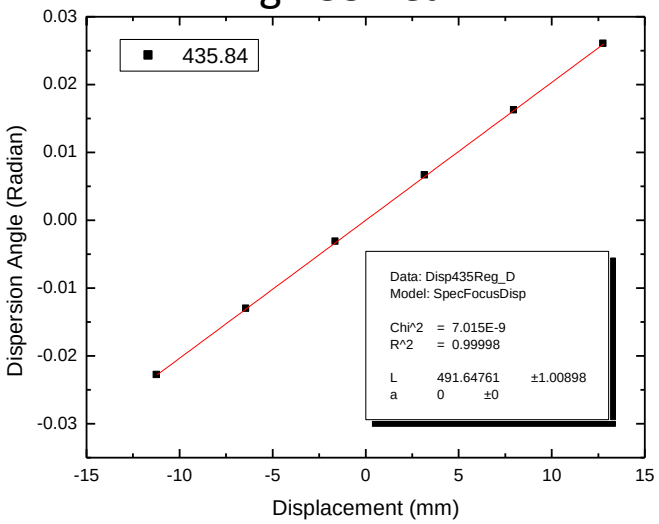
**相較之下，此看法得出之eq.8以及eq.9的形式較為簡單，方便用於直接計算focus length的值，若誤差很小時，則不需要fitting輔助。

Dispersion Angle to Focal Length

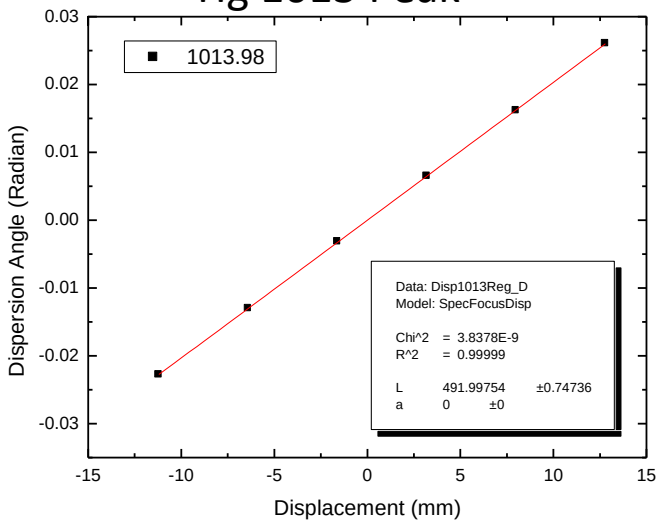
•上述二者所提出之方程式，為等價之方程式，因此用二者其中一項均可採用。先前不經徹底思考，因故採用eq.7。但後來覺得eq.8、eq.9的形式較簡單。

•透過程式搭配eq.1、eq.2得到的Dispersion Angle，加上離中心Pixel的距離，以eq.7做為fitting公式，我們得到：

Hg 435 Peak



Hg 1013 Peak



•We got –

f_{435} = 491.65

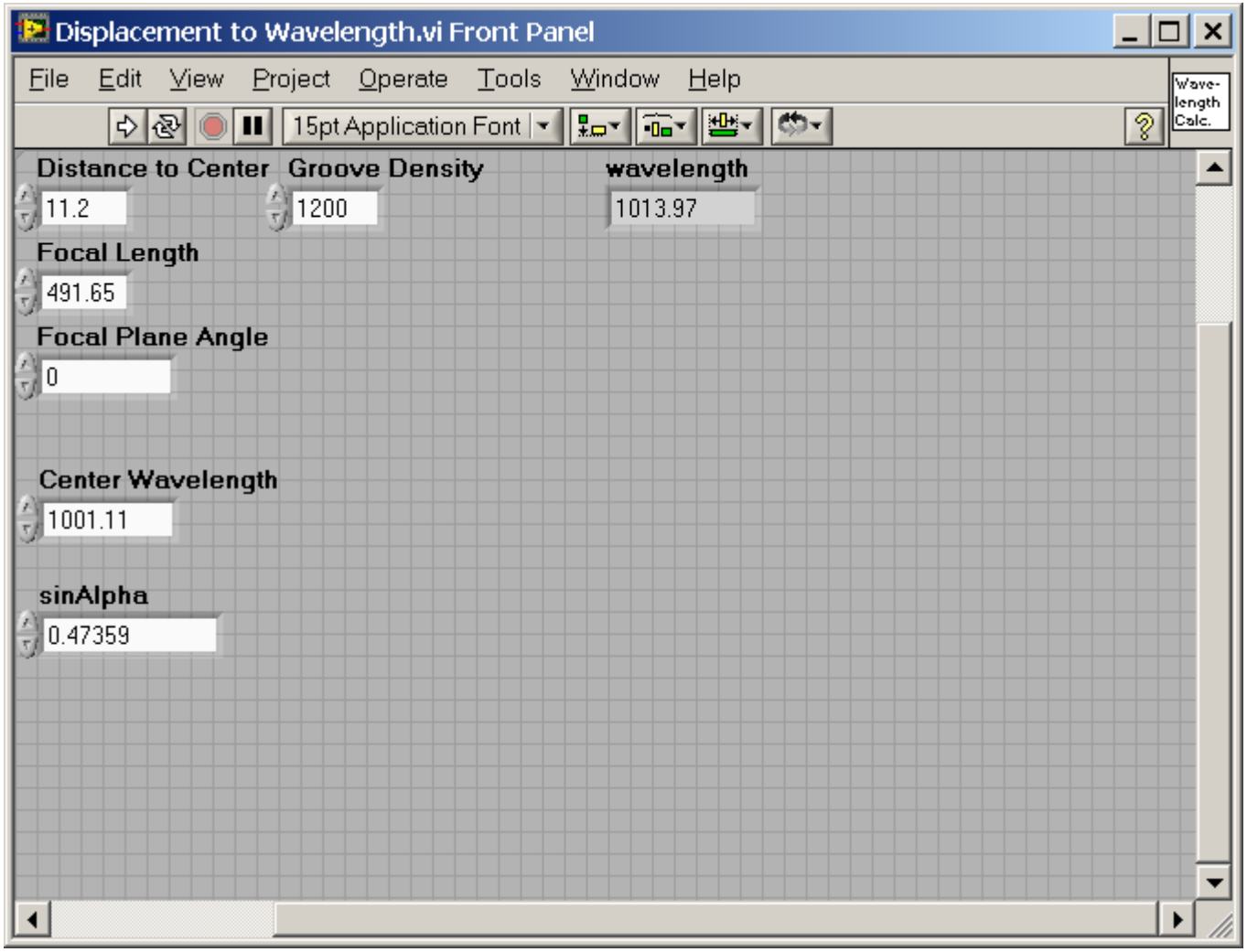
f_{1013} = 492

$\delta_{435} = \delta_{1013} = 0$

•透過下述Examine Program測試，491.65的誤差較小。

f = 491.65

Examine the Fitting



C:\Program Files\ULSLab Programss\General Lib for LabVIEW 8.6\ULSLab SubVIs (86)\Spectral Dispersion Calculation.llb\Displacement to Wavelength.vi

How to Use

- 將所有必要的參數輸入，其中sinAlpha 請使用pulse numbers to focal length.vi，給出來之參數。

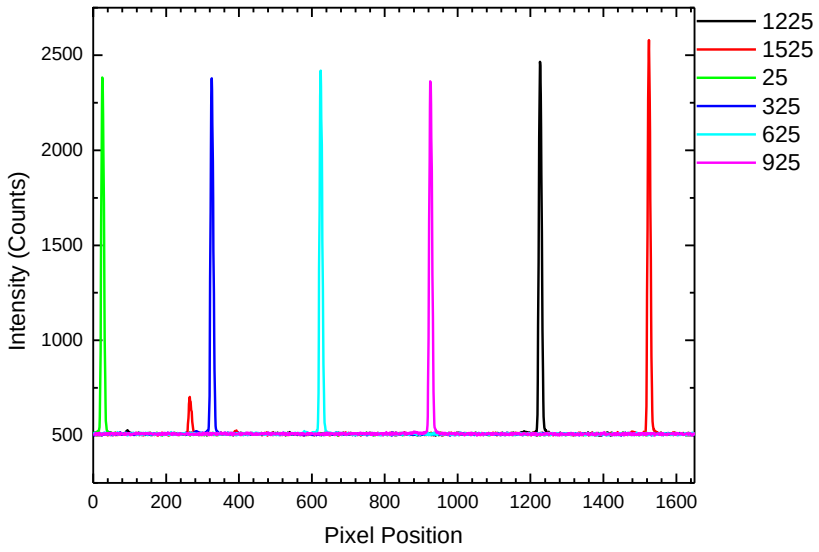
Test Report

Sample

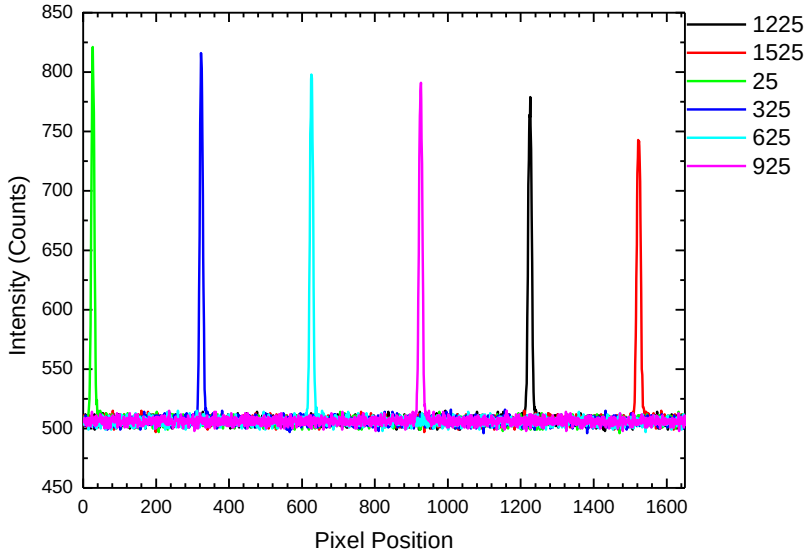
- CAL-2000 Calibration Light Source.
- Exposure : 10ms
- Average : 1 times
- Optical Fiber : 100 µm

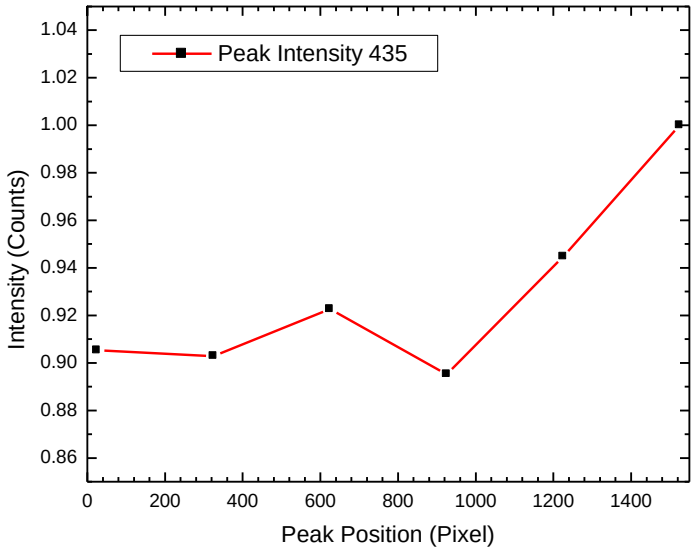
Peak Intensity Variance

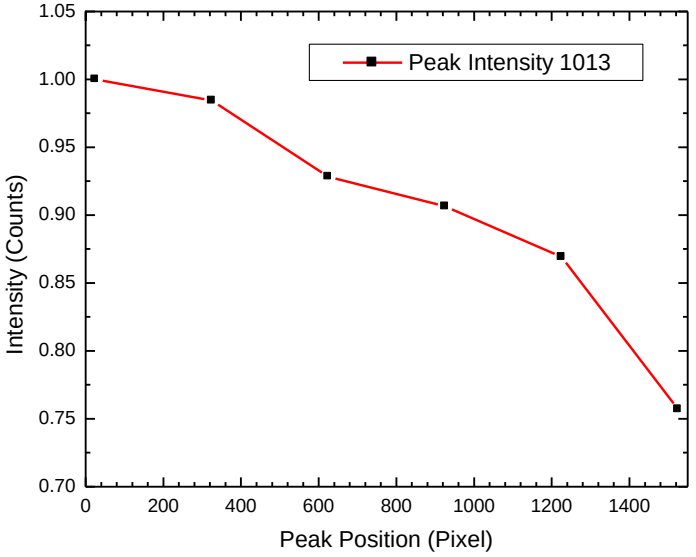
Hg 435 peak



Hg 1013 peak



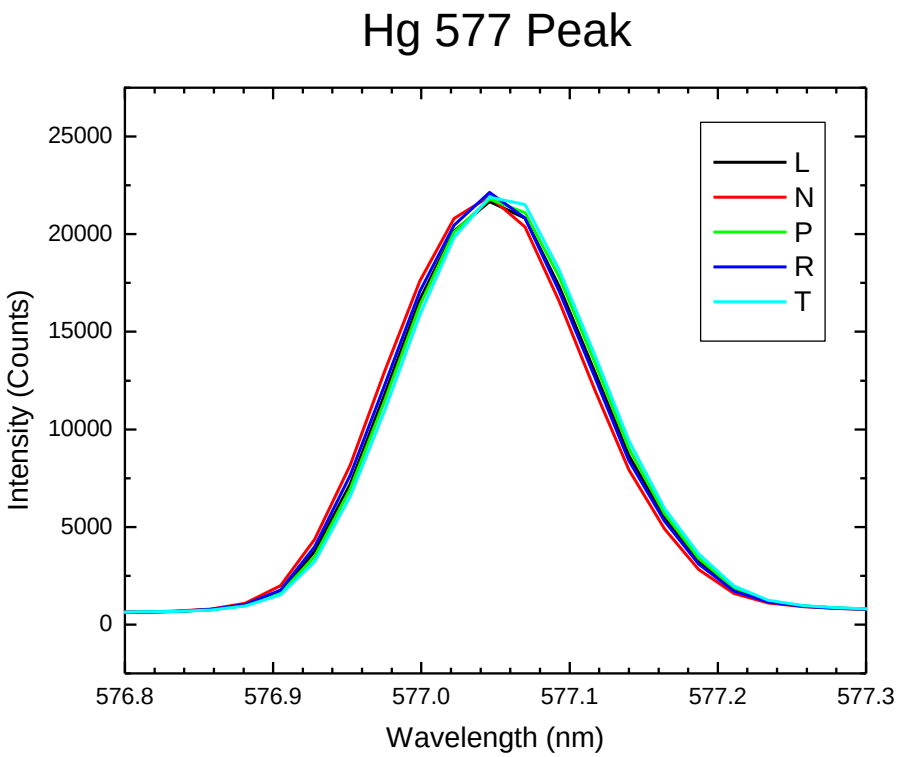


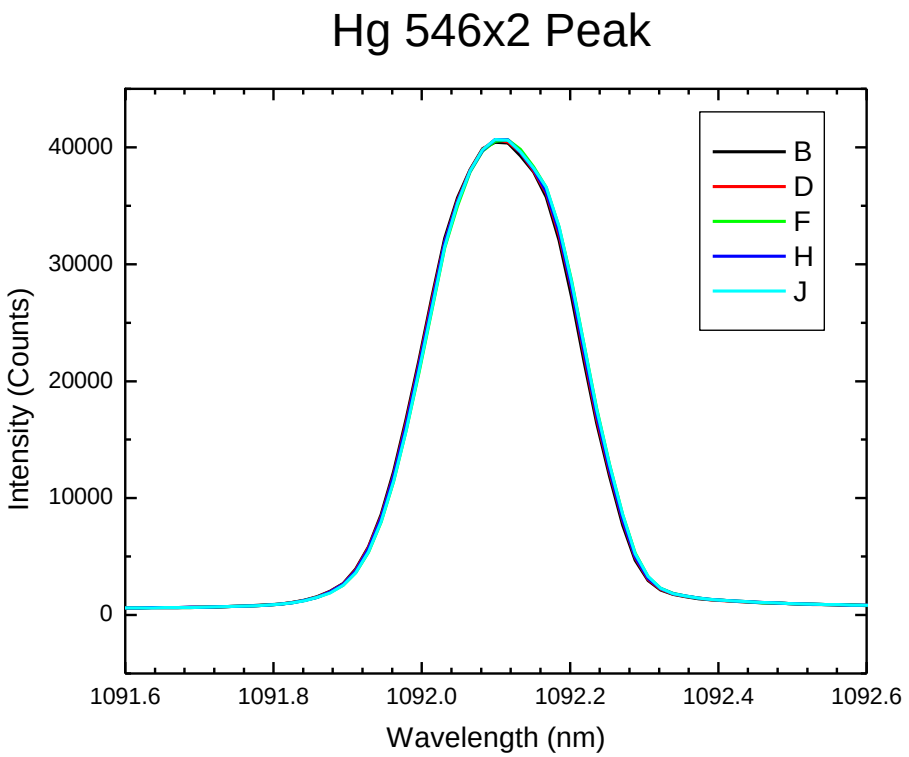


Sample

- CAL-2000 Calibration Light Source with 8um fiber.
- Exposure : 100ms
- Average : 1 times
- Optical Fiber : 50 µm

Repeatability



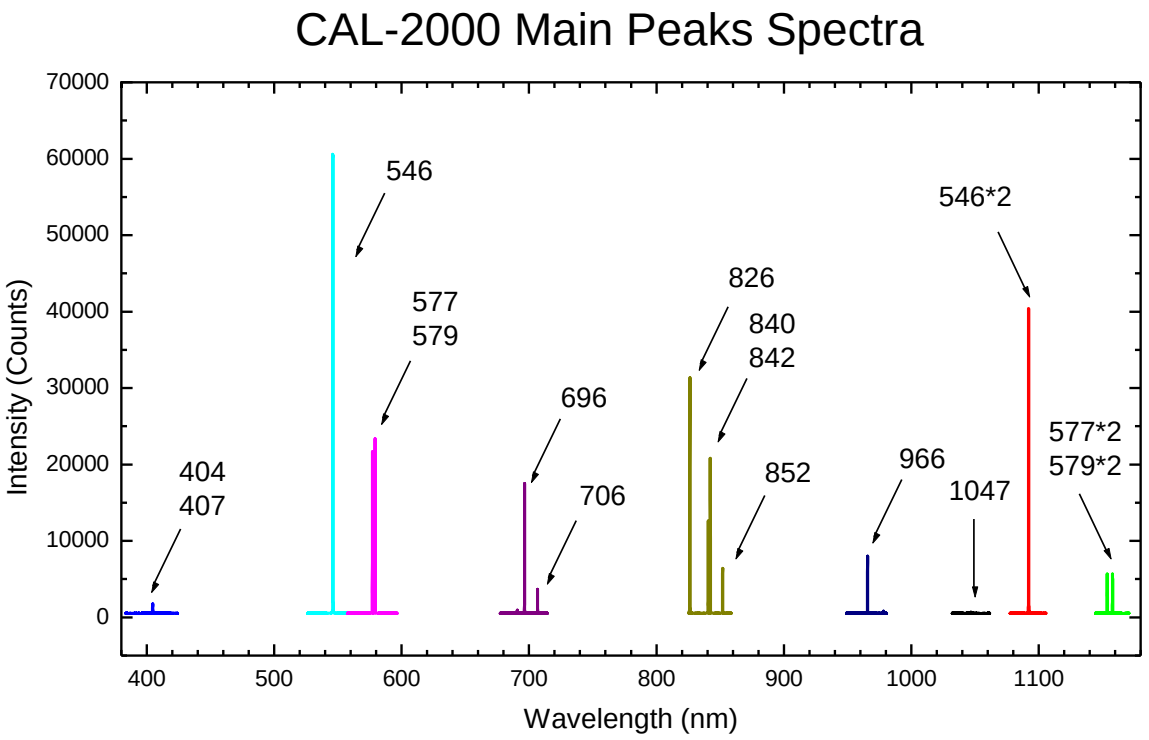


*中心波長為以下：

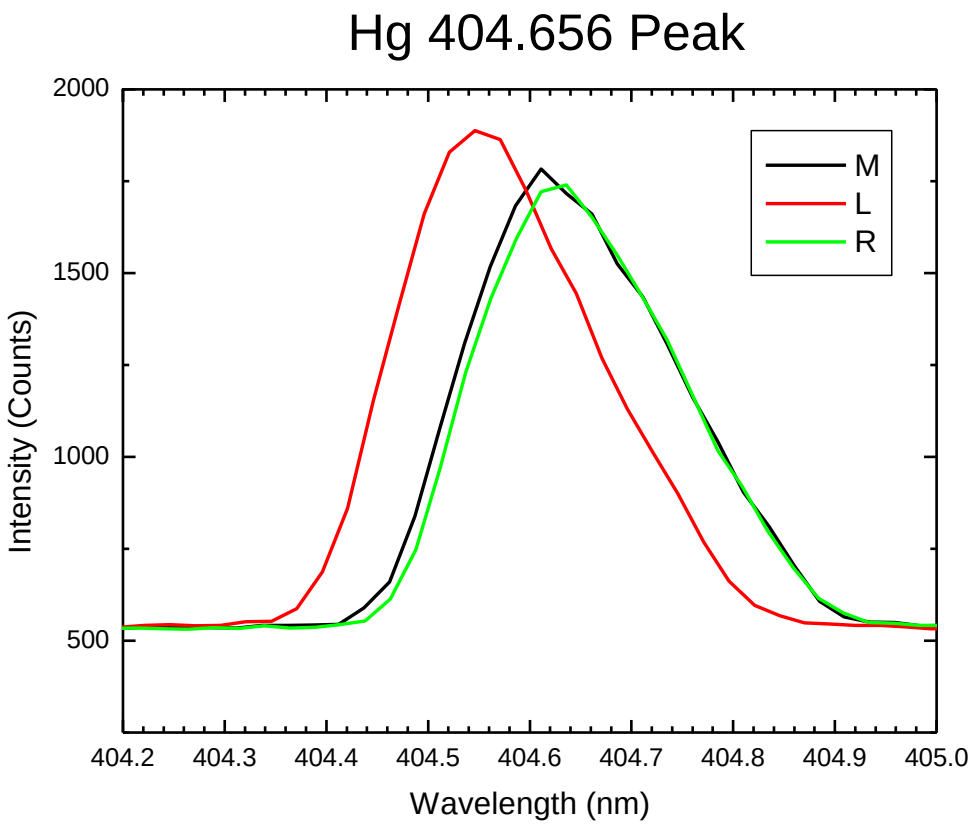
0 -> 577 -> 1092 -> 1200 -> 1092 -> 577 -> 0 ->…

一直重複做出5組Data

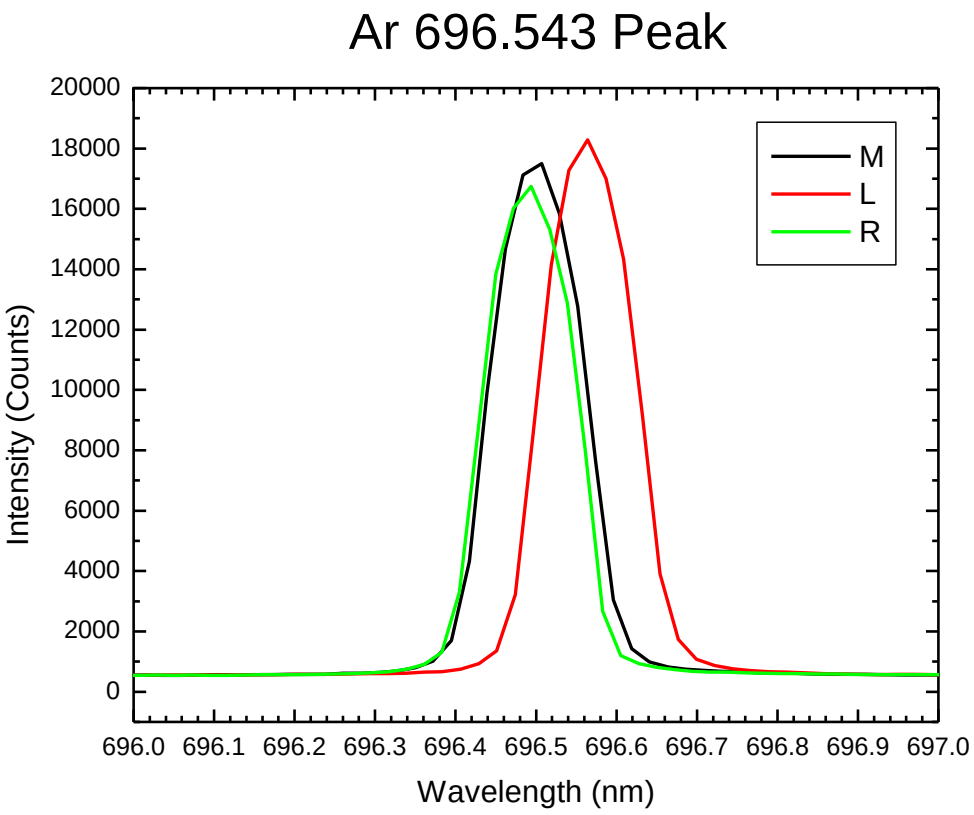
Linearity



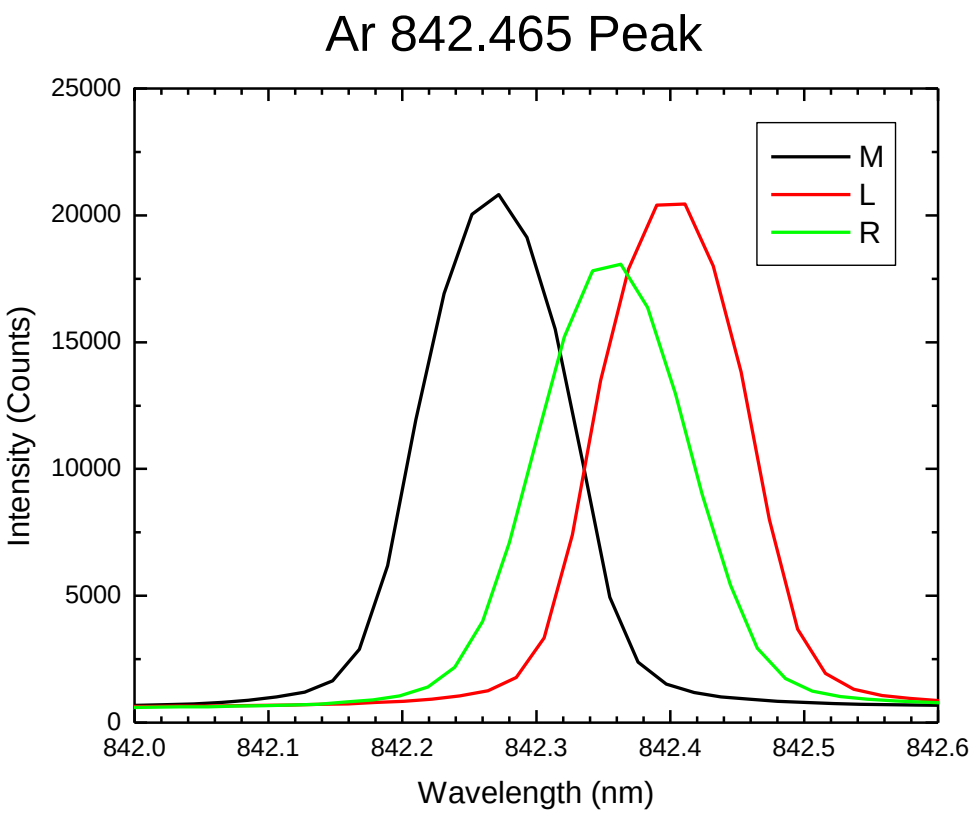
Reading	Theory	Difference
404.611	404.656	-0.045
407.742	407.783	-0.041
577.046	576.96	0.086
579.163	579.066	0.097
696.507	696.543	-0.036
706.671	706.722	-0.051
826.266	826.452	-0.186
840.63	840.821	-0.191
842.272	842.465	-0.193
851.949	852.144	-0.195
965.695	965.789	-0.094
1046.883	1047	-0.117
1092.099	1092.17	-0.071
1153.759	1153.92	-0.161
1157.965	1158.14	-0.175
Root Mean Square Error		0.130



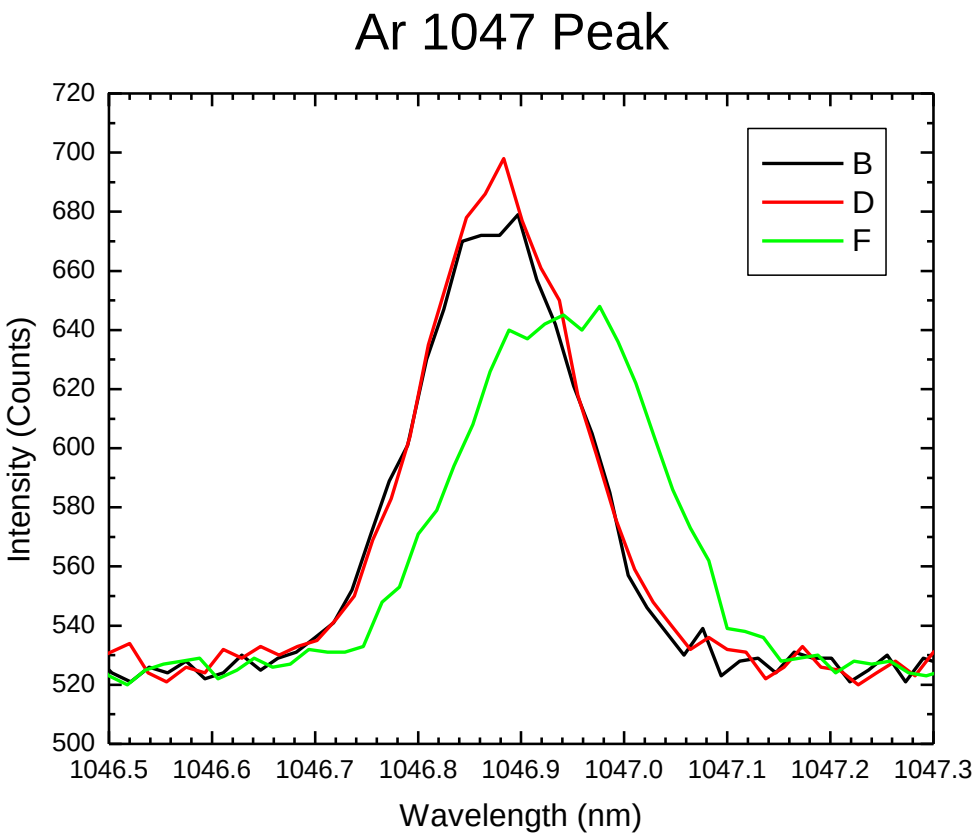
	Reading	Theory	Difference
L	404.611	404.656	0.045
M	404.546	404.656	0.110
R	404.636	404.656	0.020
	Root Mean Square Error		0.070
	In Wavenumber		4.249



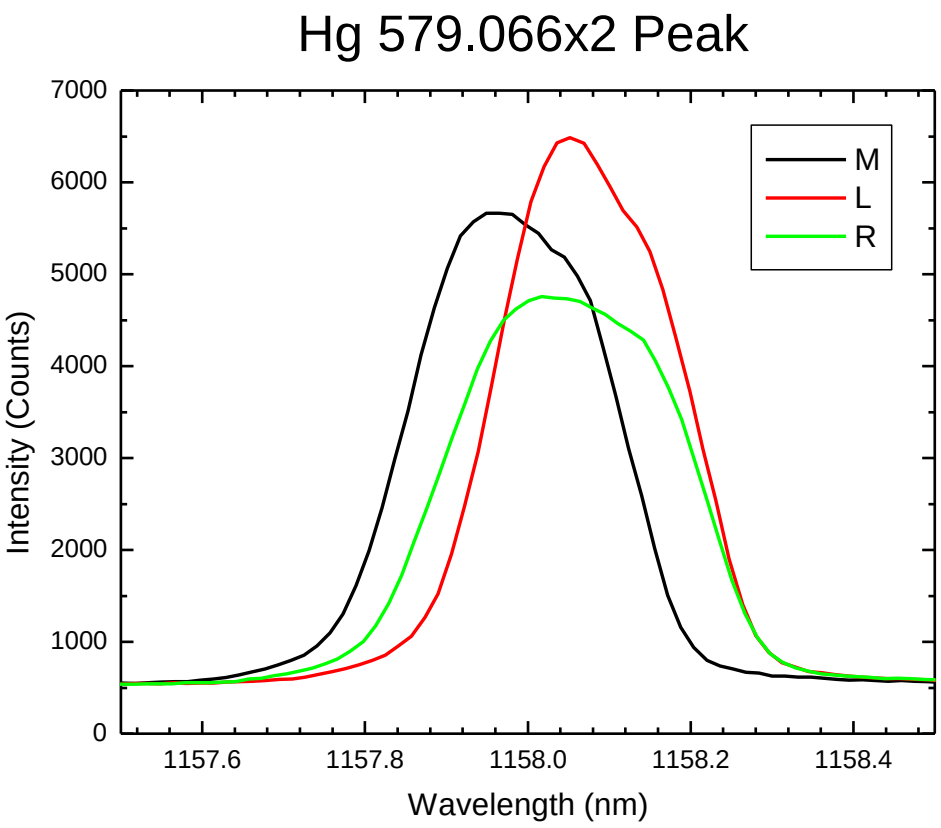
	Reading	Theory	Difference
L	696.564	696.543	-0.021
M	696.507	696.543	0.036
R	696.494	696.543	0.049
	Root Mean Square Error		0.037
	In Wavenumber		0.765



	Reading	Theory	Difference
L	842.39	842.465	0.075
M	842.272	842.465	0.193
R	842.363	842.465	0.102
	Root Mean Square Error		0.133
	In Wavenumber		1.877

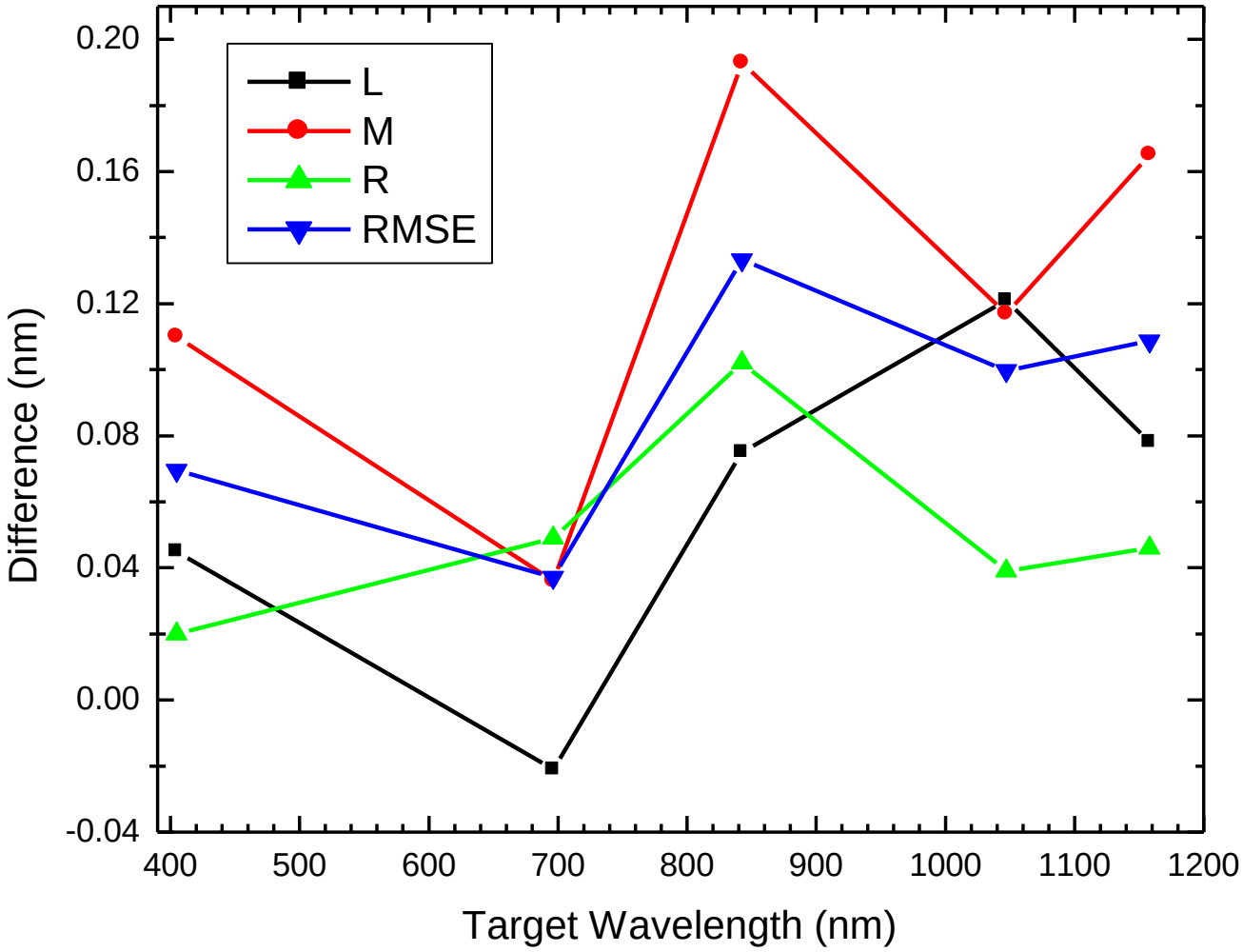


	Reading	Theory	Difference
L	1046.879	1047	0.121
M	1046.883	1047	0.117
R	1046.961	1047	0.039
	Root Mean Square Error		0.100
	In Wavenumber		0.910



	Reading	Theory	Difference
L	1158.052	1158.13	0.078
M	1157.965	1158.13	0.165
R	1158.084	1158.13	0.046
	Root Mean Square Error		0.109
	In Wavenumber		0.810

Calibration Error v.s. Wavelength



Band Pass (FWHM of line spectrum) – From Jobin-Yvon Tutorial

- 假設入射光源為真實的單色光，而在CCD端的line peak半高寬則視為，” 狹縫的成像(Slit Width x Magnification)” x” 單位距離的波長變化(Dispersion)” 。

$$\text{Dispersion (nm/mm)} = \frac{d\lambda}{dx} = \frac{10^6 \cos\beta}{GmL_B} = 1.67\cos\beta \quad \text{Eq .10}$$

$$\text{Slit Width} \times \text{Magnification} = w \times \left(\frac{\cos\alpha}{\cos\beta} \times \frac{L_B}{L_A}\right) \quad \text{Eq .11}$$

- JY 定義量到的光譜半高寬為” Band Pass”

$$\text{Band Pass(FWHM)} = w \times \frac{10^6 \cos\alpha}{GmL_A} = 100 \times 10^{-3} \times \frac{10^6 \times \cos\alpha}{1200 \times 500} = 0.167\cos\alpha$$

Eq .12

w = enterance slit
α = input angle
G = groove density
m = diffraction order
L_A = focal length of entrance mirror

Resolution – Spectra FWHM

Peak Position (nm)	FWHM (nm)	Alpha (degree)	Theoretical FWHM (nm)
404.656	0.261	23.45	0.153
696.543	0.135	34.26	0.138
842.465	0.131	40.02	0.128
1047	0.201	48.74	0.132
1158.13	0.284**	53.96	0.196**

** 1158.13 is second order peak of Hg line 579.066

G = 1200 groove/mm
m = 1 (first order)
L = 500 mm
w = 100 x 10^{-3} mm

- Use eq.12 to get "Theoretical FWHM"

$$\text{Band Pass} = 0.167 \cos\alpha$$