ChroTel Helium-I Lyot Filter

Introduction

The Helium I Lyot filter is one of three used in ChroTel. The particular design uses liquid crystal variable retarders to rapidly tune each of the four Lyot stages to wavelengths near Helium I, 1083.03nm. In operation, it is expected that the filter will rapidly cycle through seven pass bands and linear combinations of these solar images used to infer chromospheric velocities. This document describes the design of the filter, how it is characterized, and its performance.

Filter Design

The Chromospheric Helium-I Imaging Photometer (CHIP) has been operating at the Mauna Loa Solar Observatory since 1966. The CHIP Lyot filter was designed and built by Meadowlark Optics using calcite from an existing HAO Lyot filter (Halle #9). The ChroTel filter is based upon this design with a couple of refinements based upon experience with the CHIP filter. All four Lyot stages are wide fielded for ChroTel instead of three in the CHIP filter and each stage lies between crossed polarizers (instead of aligned) to increase contrast. The steps in construction were to inventory crystals in the KIS Halle filter #54, purchase new polarizers, wide field retarders, LCVRs, and cover windows, design a filter housing and oil together the crystals in the housing.

Inventory of Halle #54

KIS shipped this filter to HAO to be disassembled with the calcite elements going to ChroTel. The original filter was designed for Hydrogen α at 42.78C. Crystals are octagonal and 30mm from flat side to flat side. The second narrowest Lyot stage is duplicated at one end of the crystal stack with an external switchable polarizer selects this contrast element or not. All of the crystals up to the polarizer at the back of the narrowest stage could rotate, thereby allowing the filter to be tuned over about 0.1nm. Several of the stages include thick and thin pairs of crystals, to isolate two pass bands simultaneously. Figure 1 shows the original stacking of Halle #54. A best guess at the identification of the crystals in Halle #54 is shown in Table 1. Lengths were measured with a traveling microscope. Thickness of the grease between crystals is included in the crystal lengths. With edge chips and beveling, it is difficult to obtain exact thicknesses. The eight pieces of calcite used in the ChroTel filter are from the wide fielded elements with calcite thicknesses of approximately 11.08mm, 5.54mm, 2.77mm, and 1.885mm.

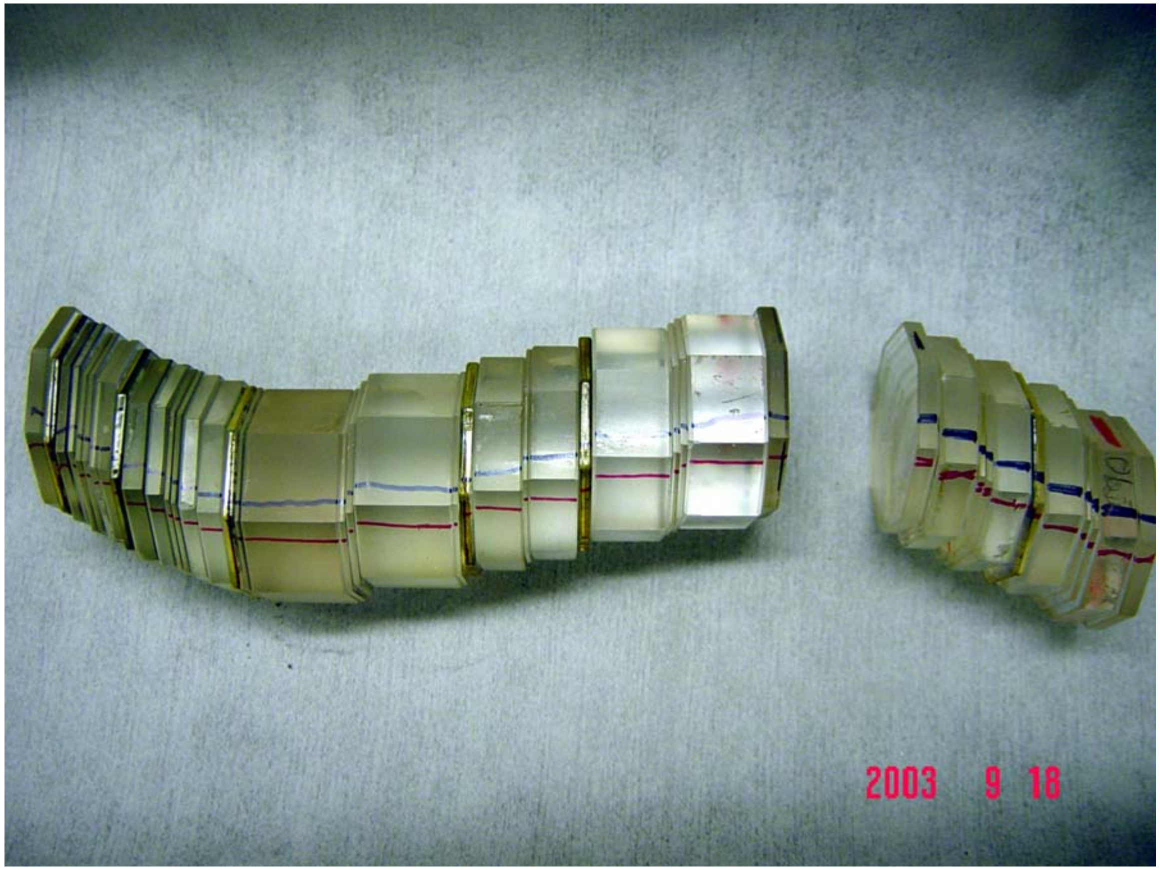


Figure 1. Halle #54 exposed. The thickest calcite is in the wide fielded stage just left of the break between the two sections of the filter. The next narrowest elements are both of the wide fielded elements in the right section. The narrowest calcite elements are on the far left. See Table 1 for identification.

Chrotel Halle filter crystal thicknesses	Running Distance	Running Dist ance	Change In Distance	18-Sep-03		DFE		
	mm	mm	mm	Tentative Identification				
	5.117							
	8.346		3.229					
	10.045		1.699	Polarizer				
	11.755		1.71	Quartz				
	13.215		1.46	**Calcite**				
	14.128		0.913	WFE				
	15.162		1.034	WFE				
	16.556		1.394	**Calcite**				
	18.249		1.693	Quartz				
	20.12		1.871	Polarizer				
	23.5		3.38	Quartz				
	26.45		2.95	**Calcite**				
	27.369		0.919	WFE				
	28.392		1.023	WFE				
	31.115		2.723	**Calcite**				
	34.459		3.344	Quartz				
	36.439		1.98	Polarizer				
	37.29		0.851	Quartz				
	50.718	5	13.428	Quartz	6.725	3.3625	1.68125	0.840625
		5.991	0.991	WFE				
		7.035	1.044	WFE				
		20.495	13.46	Quartz				
		21.314	0.819	Quartz				
		23.3	1.986	Polarizer				

	30.25	6.95	Quartz			
	30.862	0.612	???			
	37.577	6.715	Quartz			
	39.548	1.971	Polarizer			
5	50.623	11.075	**Calcite**	5.54	2.77	1.885
5.984		0.984	WFE			
7.02		1.036	WFE			
18.111		11.091	**Calcite**			
21.143		3.032	???			
24.149		3.006	???			
29.704		5.555	**Calcite**			
29.785		0.081	WFE			
30.753		0.968	WFE			
36.338		5.585	**Calcite**			
38.314		1.976	Polarizer			
43.854		5.54	**Calcite**			
44.864		1.01	WFE			
45.871	30	1.007	WFE			
	35.571	5.571	**Calcite**			
	38.55	2.979	???			

Table 1. Inventory of Halle #54. Calcite and quartz elements are identified by the ratio of thicknesses and the fact that the second narrowest calcite (contrast) element is repeated.

Chrotel Filter 1 Mar. 2004 DFE

Element #	Stage #	Element	Thickness	Octagon	Diameter	Material	Orientation	Vendor	Part #	National Inst
			mm	mm	mm		degrees			Analog
1		Window	10.00		50.8	Fused Silica		JML	0	Output
2		Window	6.450	30		Fused Silica		Meadowlark	0	Channel
3	1	Polarizer	0.487	30		POLARCOR	0	Corning	1	
4	1	Retarder	1.385	30		Calcite	-45	Halle		
5	1	Retarder	2.350	30		Quartz	0	Meadowlark	1245	
6	1	Retarder	1.385	30		Calcite	45	Halle		
7	1	LCVR	9.530	30		Fused Silica	45	Meadowlark	211	0
8	3	Polarizer	0.487	30		POLARCOR	90	Corning	3	
9	3	Retarder	5.540	30		Calcite	-45	Halle		
10	3	Retarder	2.350	30		Quartz	0	Meadowlark	1243	
11	3	Retarder	5.540	30		Calcite	45	Halle		
12	3	LCVR	9.530	30		Fused Silica	45	Meadowlark	213	1
13	4	Polarizer	0.487	30		POLARCOR	0	Corning	4	
14	4	Retarder	11.080	30		Calcite	-45	Halle		
15	4	Retarder	2.350	30		Quartz	0	Meadowlark	1244	
16	4	Retarder	11.080	30		Calcite	45	Halle		
17	4	LCVR	9.530	30		Fused Silica	45	Meadowlark	214	2
18	2	Polarizer	0.487	30		POLARCOR	90	Corning	2	
19	2	Retarder	2.770	30		Calcite	-45	Halle		
20	2	Retarder	2.350	30		Quartz	0	Meadowlark	1242	
21	2	Retarder	2.770	30		Calcite	45	Halle		
22	2	LCVR	9.530	30		Fused Silica	45	Meadowlark	212	3
23	2	Polarizer	0.487	30		POLARCOR	0	Corning	5	
24		Window	6.450	30		Fused Silica		Meadowlark	5	
25		Window	10.00		50.8	Fused Silica		JML	5	
			124.405							

Table 2. Description of each of the 25 elements of the ChroTel Helium I filter.

ChroTel Helium I Filter Optical Configuration

Table 2 shows the thicknesses of the elements in the ChroTel filter and their orientations. Polarizers are POLARCOR 1060 material. Meadowlark compound quartz retarders are used for the wide fielding half wave plates. An LCVR is added to each stage. These LCVRs are a sandwich of 3 substrates and two oppositely oriented LC layers. This design reduces switching time and increases field of view of the LCVR. Fused silica entrance windows are used. The two outside surfaces are AR coated. Elements are oiled together using Dow corning 200 100,000cS grease. The assembled stack is shown in Figure 2

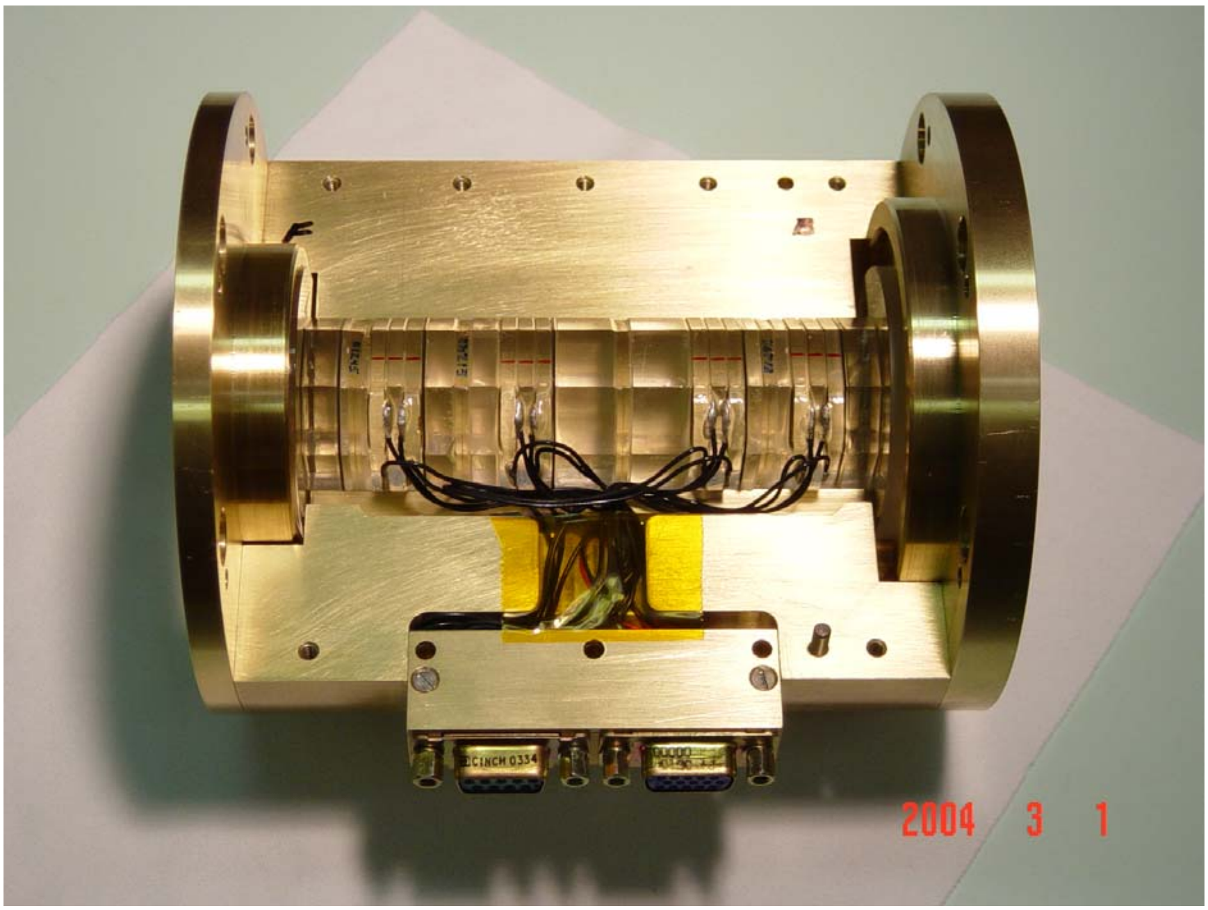


Figure 2. Assembled stack with LCVR wiring.

Housing

The housing is brass. The interior profile was cut using a wire Electrode Discharge Machining (EDM) process. Crystals are registered on two sides 90º apart. Six springs, Associated Spring P/N SC0120-012-0440, press against the retainer for the 50mm diameter window at one end. The total force of all 6 springs is 18.2N. Outside diameter is 133.35 mm and the total length is 160.02 mm. There are two connectors, one for LCVR drive, and one for temperature control. The exterior of the filter is delrin (Figure 3). DO NOT mount the filter by drilling and tapping into this insulator. The plastic will not support the 11kg mass of the filter. A clamp system is preferred for mounting. Drilling into the insulator could also compromise the thermal stability of the filter.

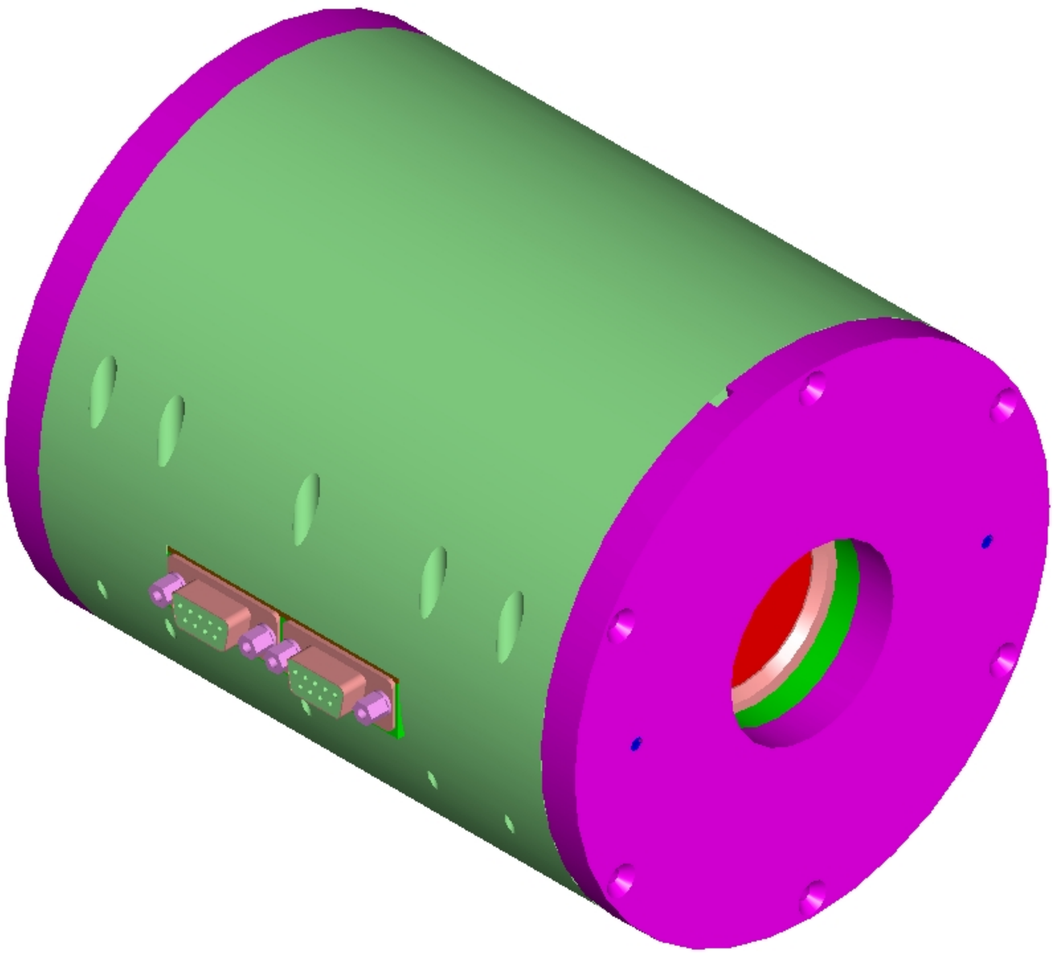


Figure 3. Entire filter. Purple and green exterior is delrin.

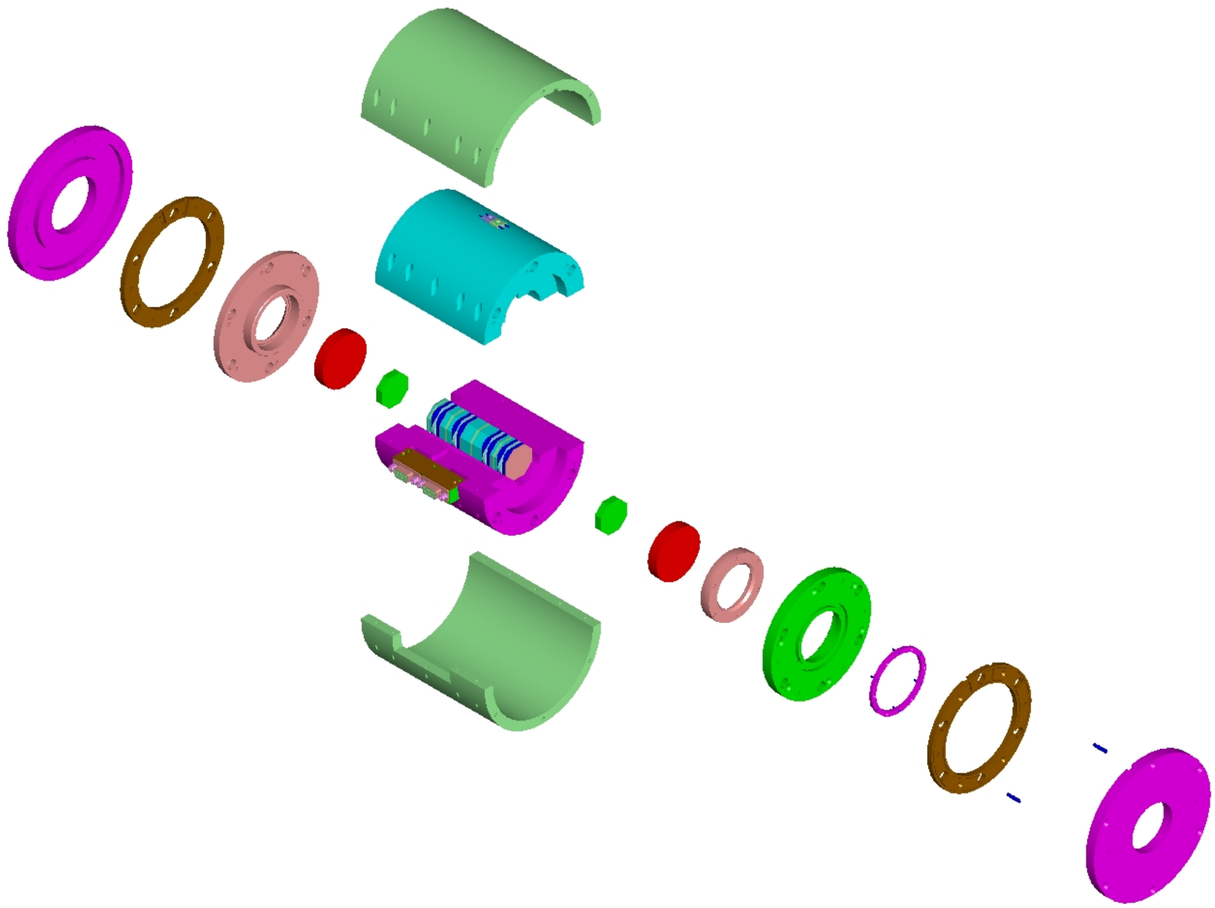


Figure 4. Exploded view of filter housing

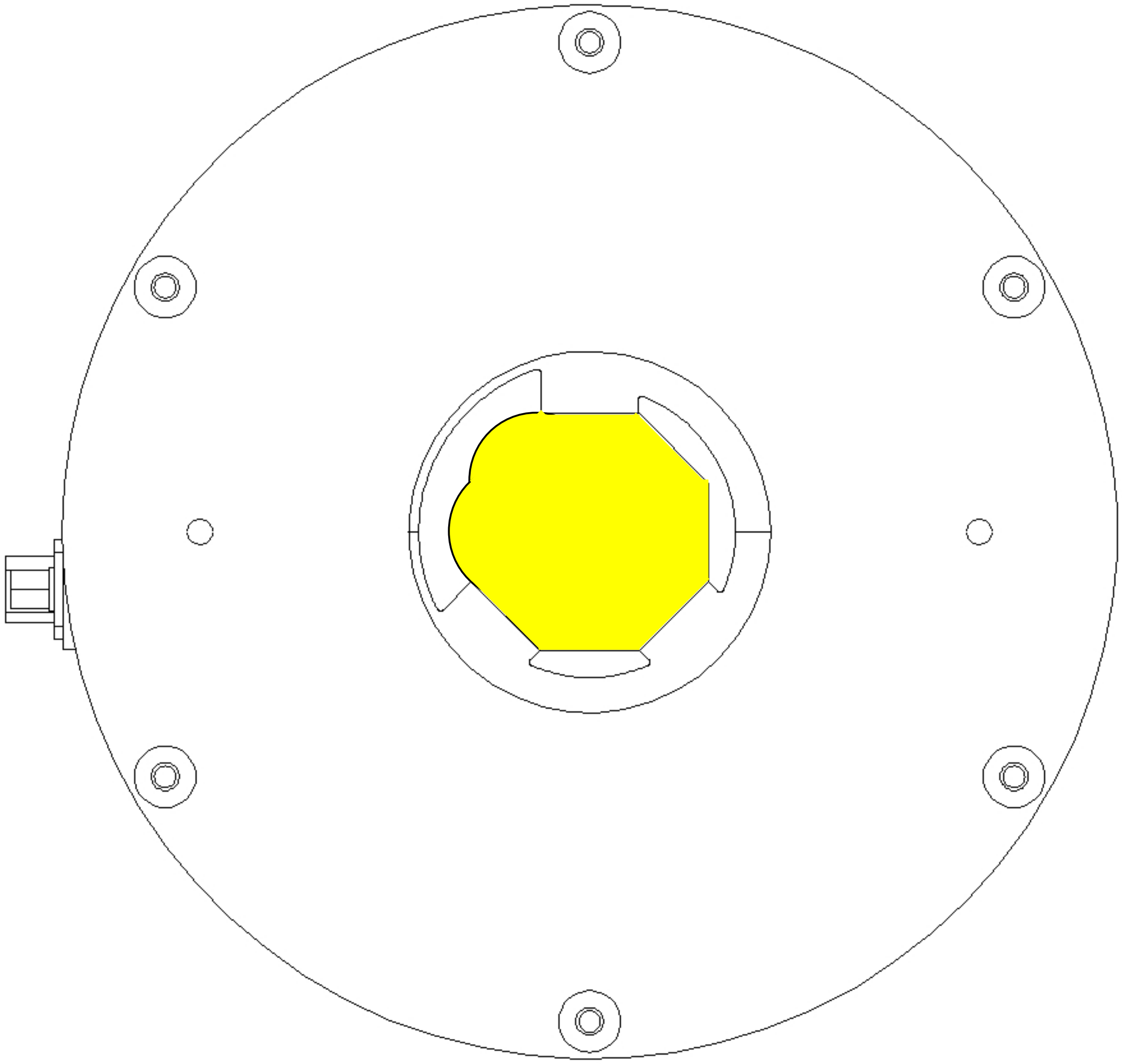
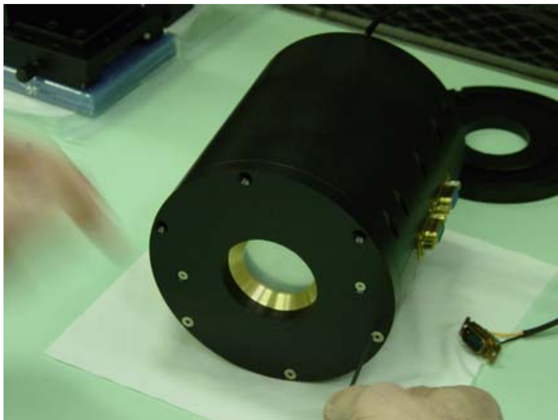
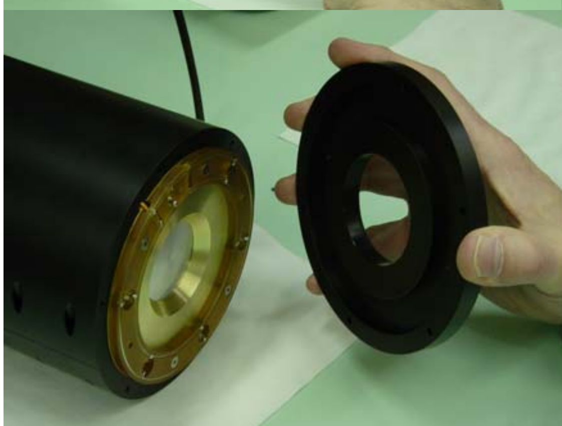


Figure 5. Filter cross section. The bottom left and bottom right mesas are used to register the crystals. The cross section of an LCVR is shown in yellow





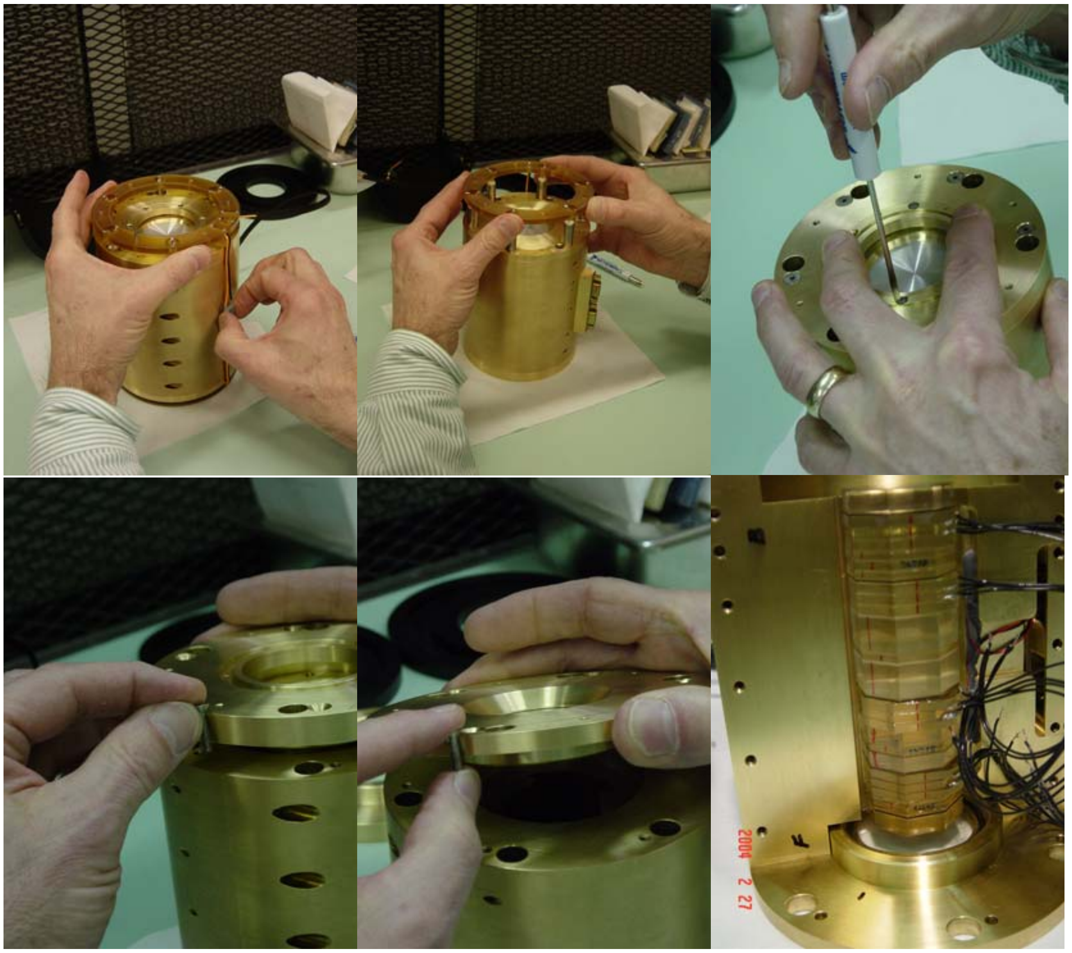



Figure 6. Disassembly of the filter.

ChroTel Lyot Filter Electrical Specification

A Series 800 Alpha Omega Instruments temperature wattage controller drives the 12 Omega/Chromalox Model CIR-2021/120 96Ω/2.3W @ 15VDC heaters. The filter temperature drifts as a function temperature of the controller itself. This drift was measured to be –18.2mC/C. From experience with the CHIP filter we know temperature must be maintained to ±50mC. This means the room or enclosure where the controller is located needs to be controlled to ±2C. Filter temperature control is stable at 35C in less than an hour following turn on of the controller (Figure 7). To make sure the crystals are at the same temperature as the housing, at least an hour should be allowed for the transmission to be stable.

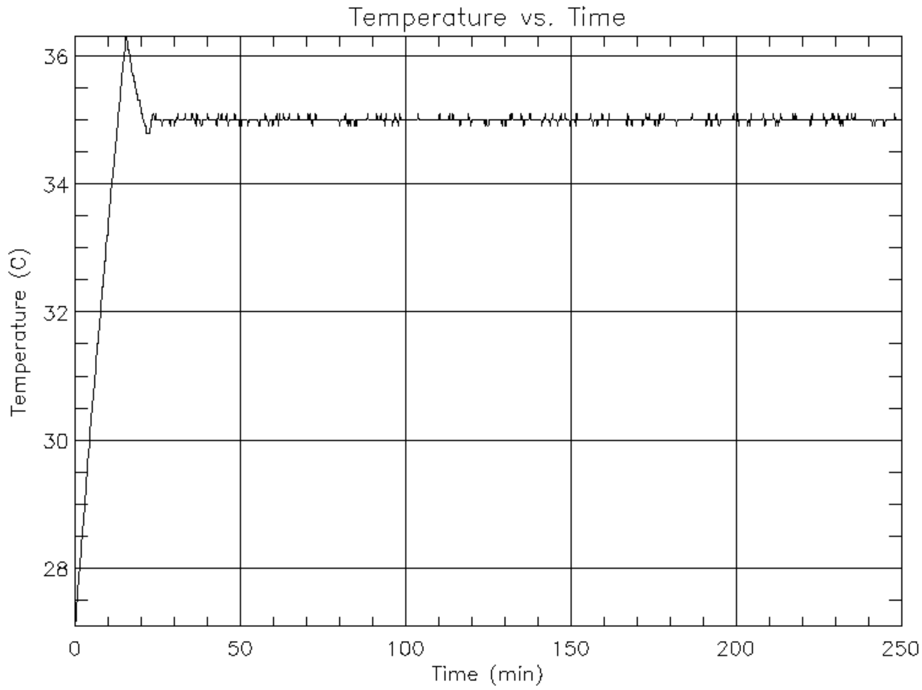


Figure 7. Temperature controller reading vs. time.

Temperature Sensors:

Manufacturer:	Minco
Model Number:	S200PD(G)
Quantity:	2 (bonded to the brass core of the filter)
Type:	RTD, 100Ω Pt ± 0.1% @ 0°C, IEC 751 Class B
Curve Characteristics:	$\alpha = 0.0038505$
	Callendar – van Dusen coeffiecients
	$A = 3.9083 \times 10^{-3}$
	$B = -5.775 \times 10^{-7}$
	$C = -4.183 \times 10^{-12}$

Signal Name	DE-15S High Density "D" Pin #	Wire Color	Notes	Alpha-Omega Temperature Controller "SENSOR" Connector Pin
RTD 1 V+, I+	1	Red	Primary RTD	POS (2)
RTD 1 V-	2	Black		GND (3)
RTD 1 I-	3	Black		NEG (1)
RTD 2 V+, I+	11	Red	Spare RTD	No Connection
RTD 2 V-	12	Black		No Connection
RTD 2 I-	13	Black		No Connection

Table 3. Wiring from RTDs to Lyot filter connector to Temperature Controller.

The cable that is used to between the Lyot filter and the Alpha-Omega Temperature Controller or any secondary monitoring equipment (using the spare RTD) is Omega part # EXTT-3CU-26S. 3-conductor, 26AWG Nickel plated copper RTD extension wire.

Heaters:

Manufacturer:	Omega / Chromalox
Model Number:	CIR-1034/120V
Quantity:	12 (wired in parallel)
Dimensions:	2” (50.8mm) long X 3/8” (9.53mm) diameter

Power Watts	Voltage Volts AC	Current Amperes AC	Resistance Ohms	Voltage Volts DC	Current (each) Amperes DC	Power (each) Watts	Number of Heaters	Total Power Watts*	Total Current Amperes DC*	Total Resistance Ohms*	
150	120	1.250	96.0	15	0.156	2.3	12	28.1	1.875	8.0	Alpha-Omega Temperature Controller @ Nominal Output
150	120	1.250	96.0	**16.33**	**0.170**	**2.8**	12	**33.3**	**2.041**	8.0	**Alpha-Omega Temperature Controller @ Maximum Output**

* 12 heaters wired in parallel

Table 4. Heater specification and maximum power output calculations.

Signal Name	DE-9P "D" Connector Pin #	Wire Color 20 AWG Teflon	Alpha-Omega Temperature Controller Connector Pin
HTR +	1	Orange	TEC +
HTR -	5	Black	TEC -

Table 5. Heater connection to the temperature controller.

Note: Do not connect the black (-) wire of the heater control circuit to chassis or earth ground. Doing so will damage the Alpha-Omega Temperature Controller.

This controller is designed to operate Peltier or Thermo-Electric Device coolers. For this application, it is strapped in a heat only mode, which means that a negative voltage is applied to the Peltier (heaters in the case of the Lyot filter) in order to heat. The output of the Alpha-Omega Temperature Controller is set for a maximum output of –16.3VDC on the TEC + terminal relative to the TEC - terminal.

Temperature Controller:

Manufacturer:	Alpha Omega Instruments
Model Number:	Series 800, 8-150
Sensor Input:	RTD, 100Ω Pt
Output:	15VDC, 150W max.

LCVR Drive Signals:

Filter Stage #	Signal Name	DE-9P "D" Connector Pin #	Belden 8164 Cable Conductor Color	National SCB-68 Connector Block Pin #	National 6713 Analog Output Signal Name
1	Drive 1	1	Red	22	DAC0 OUT
1	Drive 1 RTN	6	Black	55	AOGND
3	Drive 3	2	Blue	21	DAC1 OUT
3	Drive 3 RTN	7	Black	54	AOGND
4	Drive 4	3	White	57	DAC2 OUT
4	Drive 4 RTN	8	Black	23	AOGND
2	Drive 2	4	Green	25	DAC3 OUT
2	Drive 2 RTN	9	Black	59	AOGND

Table 6. LCVR Interconnect

The Belden 8164 interconnect cable is a 4-twisted pair, individually shielded pair with overall shield. 24AWG conductors.

Characterization

Filter characterization is the determination of voltages necessary to drive each LCVR for each wavelength. One needs to record spectrograph images of the filter transmission for various voltages to evaluate how well the filter is tuned. The CHIP filter was characterized one Lyot stage at a time, then fully assembled and the tuning table adjusted. For ChroTel the bold step of characterizing the fully assembled filter was chosen since the LCVRs retardance vs. voltage curves were supplied by Meadowlark, approximate calcite dimensions were known, and from the CHIP experience, measurement of each stage was only an approximation, presumably due to thermal differences between individually mounted stages and the fully assembled filter.

Measurement Setup

The filter is characterized using artificial light sources and the HAO 2-meter focal length spectrograph with a 300 line/mm grating (Figure 7). A Redlake Megaplus 1.6i CCD camera is mounted at the exit port of the spectrograph. The sensor is 1534 x 1030 with 9µm pixels. Three light sources can be used used, a quartz halogen lamp for continuum, a Helium discharge lamp, and an Argon discharge lamp. A Wratten 87A filter is used to block any higher order light. The light source is collimated using a 357mm achromat, passed through an iris taped to the front of the filter to prevent light from passing around the crystal stack, and then imaged on the 20µm spectrograph slit by a 330mm achromat. Control is from a LabView virtual instrument coded by Steve Tomczyk for the CoMP project and kindly modified for use on Chrotel. Software allows the user to adjust LCVR voltage amplitude (2kHz square waves), select CCD rows to be summed, set CCD exposure time, record dark images, record images and save spectra averaged over the selected rows.

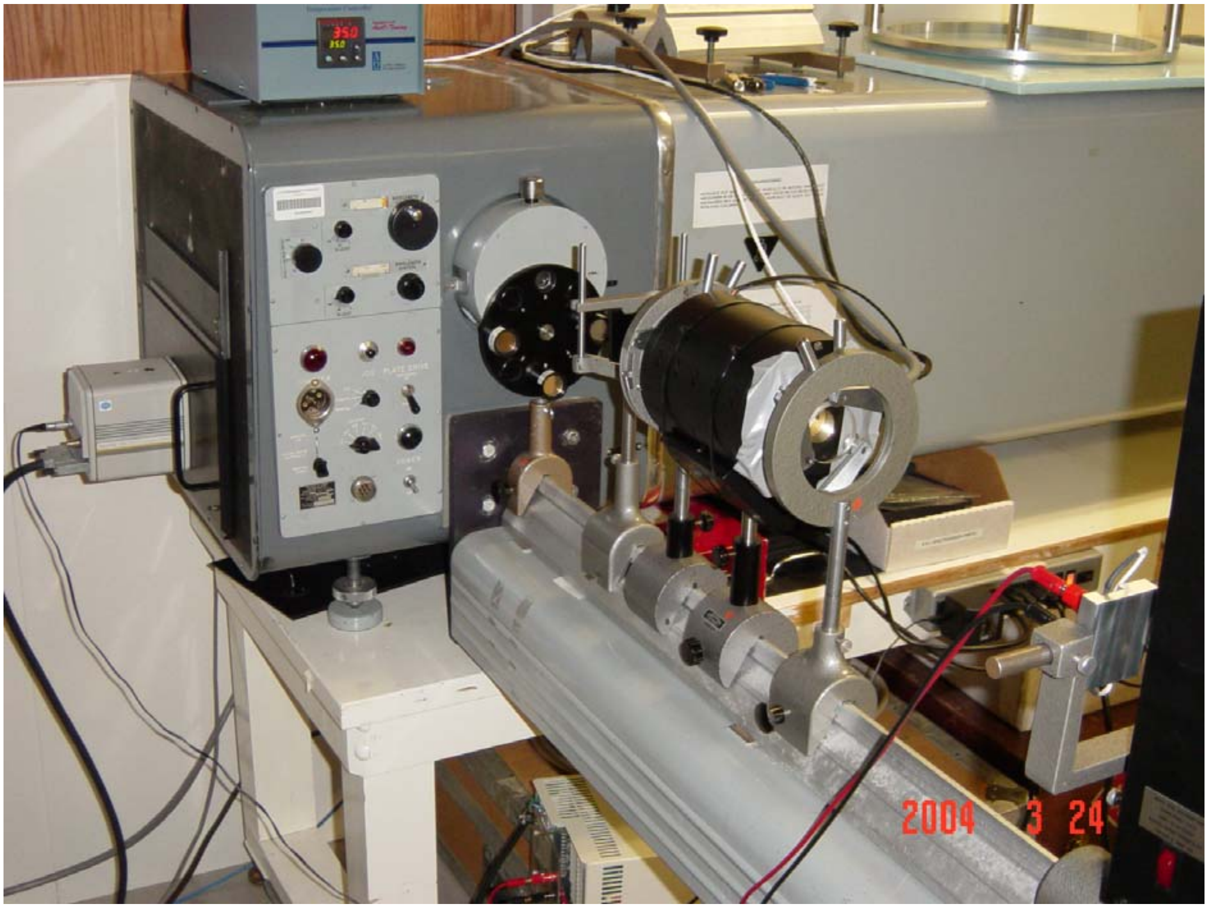


Figure 8. Filter optical test setup.

Image Scale

For all measurements a 20μm slit width is used. The grating is set to 1st order and images recorded with the Helium lamp and with the Argon lamp (Figure 9). A Gaussian fit is used to determine the pixel of each emission line. Helium I is the sum of three components resolved into a major and minor component by the spectrograph. The weighted average wavelength for the two main helium components is computed using values in the CRC handbook and found to be1083.031nm. From the handbook, the Argon wavelength is 1067.3566nm. Measured scale factor is 0.014808 nm/pixel. The calculated value using the grating equation is 0.014800 nm/pixel.

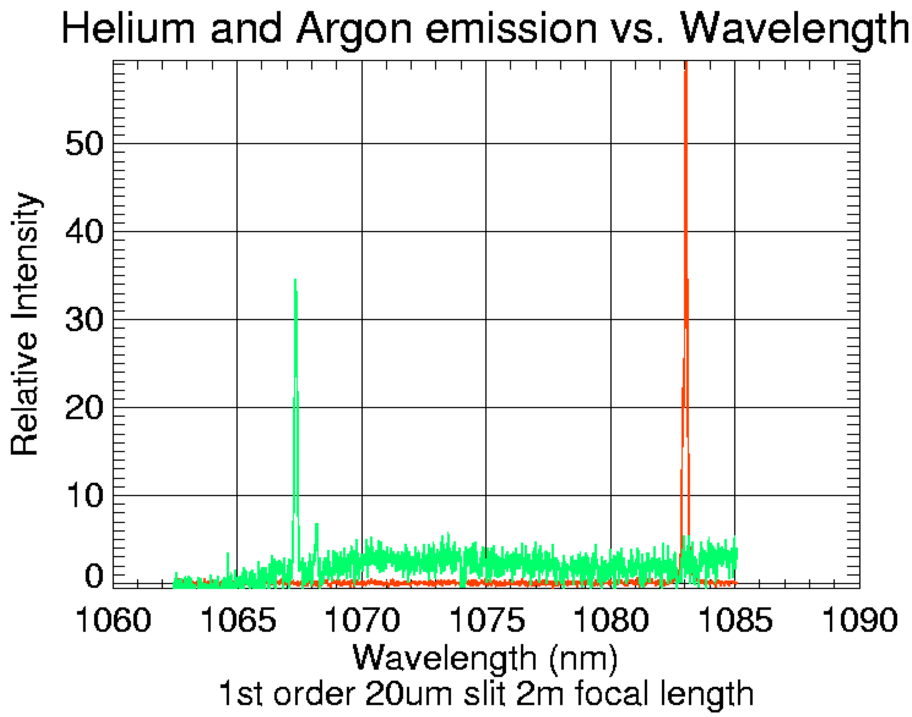


Figure 9. Spectrograph scale for 1st order.

The grating equation is used to calculate the scale factor in 3rd order. The ratio of the calculated 3rd order scale to the calculated 1st order scale is multiplied by the measured first order scale. For 3 rd order, the ratio of dispersion is 3.392 therefore the 3 rd order scale factor is 0.00502nm/pixel. The absolute wavelength scale for 3rd order is measured just before or after continuum source pass band measurements since the spectrograph would drift several pixels over a day. Figure 10 shows a typical fit to the two major components of the Helium emission line. The minor component at 1082.9 is to the left.

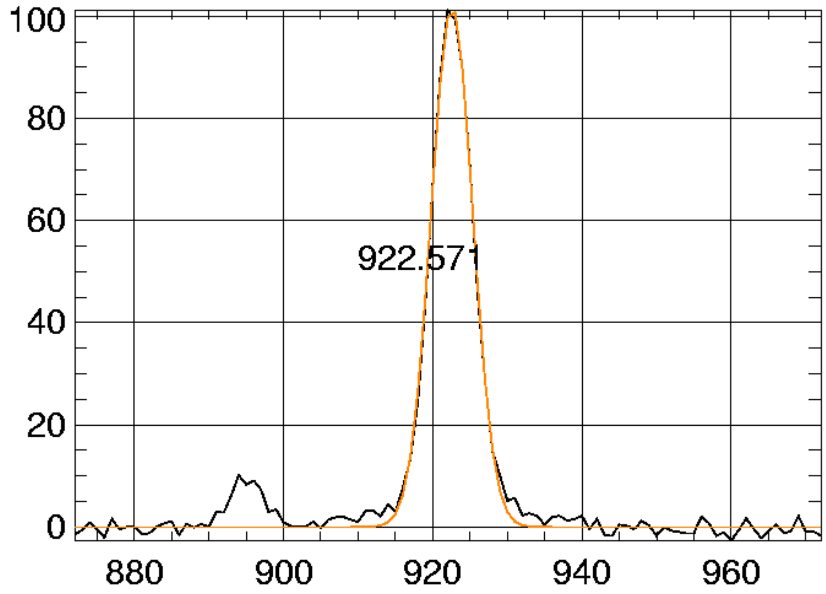
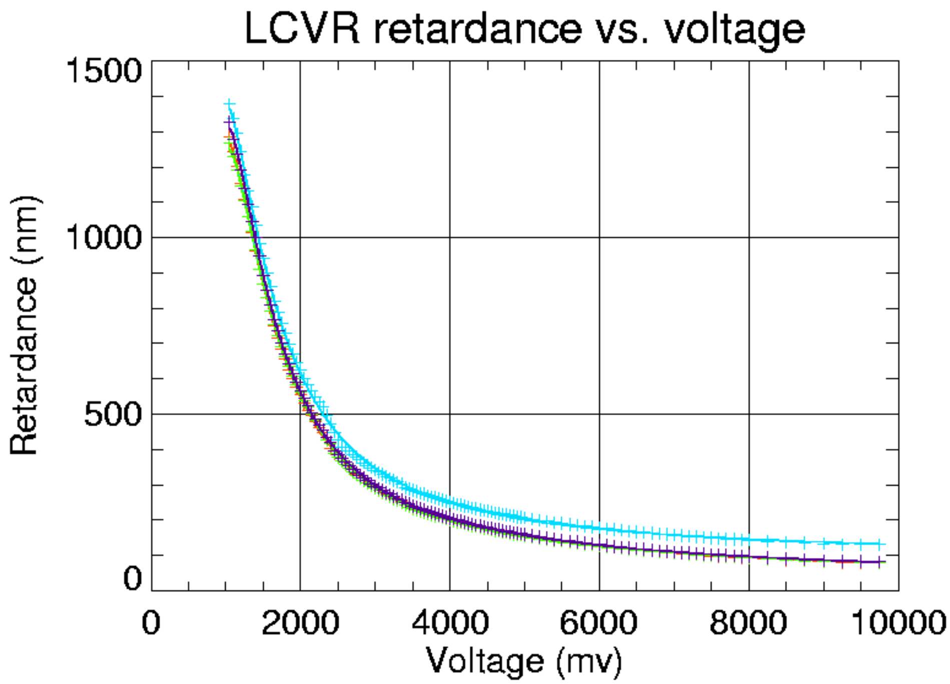
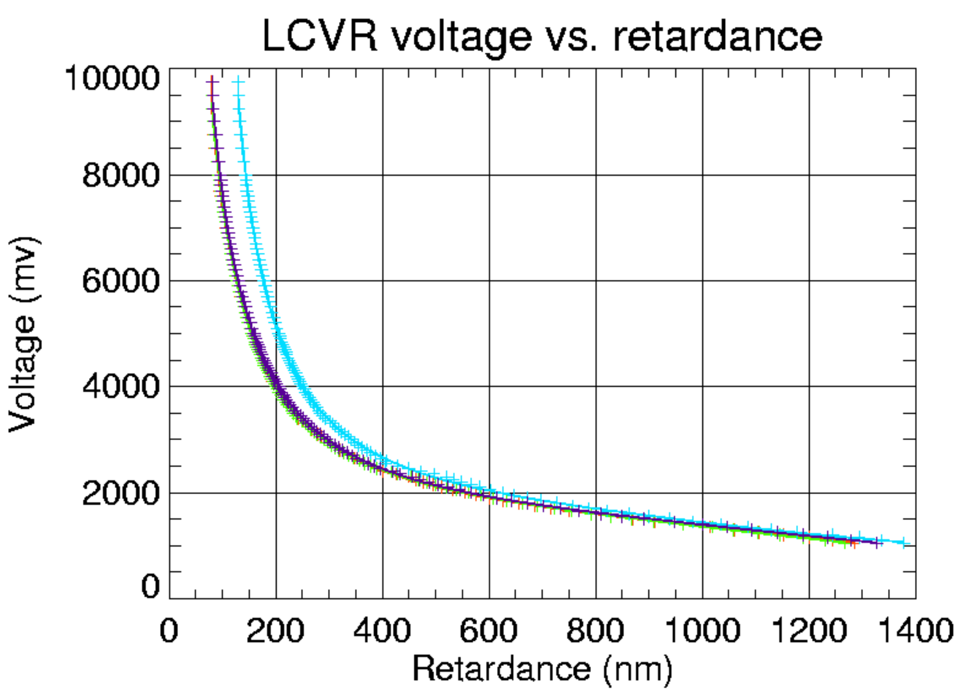


Figure 10. Typical fit to the main component of the Helium I emission line (1083.031nm).

First Approximation Tuning Table

An IDL program, volts.pro, is used to calculate the LCVR voltages for a specific wavelength. LCVR voltage vs. retardance curves were supplied by Meadowlark (Figures 11a,b). A fifth order polynomal fit of inverse voltage vs retardance is used and coded into the LCVR fitting functions, named by serial number, fit_211.pro, fit_212.pro, fit_213.pro, and fit_214.pro. Calcite thickness used by volts.pro can be adjusted by the user, starting with the measured values. Birefringence is calculated using the formula of Beckers and Dunn and coded by Steve Tomczyk. A single wavelength is chosen initially. For this first approximation, the initial voltages maximize the signal for the helium emission lamp major component as seen on the spectrograph. Then using the quartz lamp, voltages to the LCVRs are manually adjusted until a clean profile is obtained, one with balanced and small side lobes. The wavelength of that clean profile is close to 1083.031nm. This wavelength is entered into volts.pro and the thickness values of the calcite crystals adjusted until the program produces the same LCVR voltages as determined at the spectrograph. This technique is sensitive to thickness of a nanometer.





Figures 11a,b. Meadowlark measurements of retardance vs. voltage and voltage vs. retardance for the four LCVRs.

Second Approximation Tuning Table

Several wavelengths between 1083.2nm and 1083.4nm were sampled and found to have excessively large side lobes and wavelength error when using voltages predicted by volts.pro.

This was determined to be due to an error in the voltage vs. retardance data from Meadowlark. I expect the temperature of the Meadowlark measurement was different from the operating temperature of the Helium filter, 35C. The fix is to determine a voltage *offset* for each of the Meadowlark curves. Voltages for a clean transmission profile are loaded and profiles observed on the spectrograph. A convenient wavelength is 1083.031nm. One stage is offset to the maximum, 10V, and the profile shape noted. Typically there are large side lobes to the profile. The stage is then tuned to a low voltage, near 1V, and the voltage adjusted until the filter profile using the low voltage is exactly the same as the profile at 10V. This process is repeated for all four LCVRs. The fit_21X.pro functions were modified so that each adds an offset voltage after the polynomial fit to the Meadowlark measurements. The value of this offset, mV_o is determined from the two voltages giving the same profile shape. These two voltages correspond to an LCVR retardance, R and R + 1083.031nm. For some value of R and some mV_o, the function fit_21X.pro will produce the voltages seen for retardance R and R + 1083.031nm. These values are determined iteratively. Voltage vs. retardance fitting uses the 5th order polynomial fit for inverse millivolts derived from the Meadowlark measurements minus the constant determined in this step. These are the fitting coefficients.

*1./mv = a(0) + ret * (a(1) + ret * (a(2) + ret * (a(3) + ret *a(4))))*

211 1./mv vs retardance in nm. LCVR Voltage is 1/mv – 98.1
-1.1581289e-005
1.6293477e-006
-1.8712082e-009
1.2311231e-012
-2.4249332e-016
212 1./mv vs retardance in nm LCVR Voltage is 1/mv – 124.5
-1.4965584e-005
1.6708822e-006
-2.0123540e-009
1.3745303e-012
-2.8200298e-016
213 1./mv vs retardance in nm LCVR Voltage is 1/mv – 128.4
-0.00010968257
1.9550302e-006
-2.4993188e-009
1.7760318e-012
-4.2924830e-016
214 1./mv vs retardance in nm LCVR Voltage is 1/mv – 154.9
-1.2823916e-005
1.5963964e-006
-1.7724579e-009
1.1081501e-012
-2.0240377e-016

From examination of the Meadowlark curves, one might expect a retardance offset, especially considering the one LCVR with a significantly different curve. With this tuning technique any offset, if present, is absorbed into the thickness values used for the calcite.

Third Approximation Tuning Table

The revised functions are linked into volts.pro. A wavelength for which the voltages are known that produces a clean filter profile is entered into volts.pro. The calcite thicknesses are adjusted again so that volts.pro produces the same voltages as needed for this clean profile. The table of CHIP wavelengths plus one shorter and one longer wavelength are entered into volts.pro and the predicted voltages recorded. On the spectrograph, filter profiles are recorded at each of the wavelengths. A helium lamp profile is recorded for an accurate spectrograph scale factor offset. So that the optical and mechanical setup on the spectrograph is not changed between wavelength calibration and pass band measurements, a scan from 1082.95nm to 1083.10nm in 0.01nm increments is used to sample the helium emission profile. The routine helium_scan.pro sums all the profiles and uses a Gaussian fit to determine the pixel number corresponding to the weighted mean of the main components, 1083.031nm. This constant is then coded into IDL routine lcvr_holzer.pro for viewing of the pass band profiles. In lcvr_holzer.pro, continuum filter profiles are fit with Gaussian functions and the measured wavelength compared to the desired wavelengths. Chances are that these two wavelengths do not agree. The wavelength error is computed in this step.

Fourth Approximation Tuning Table

For the voltages giving a clean filter profile, the actual wavelength correcting for wavelength error from step three is entered into volts.pro. Calcite thickness values are adjusted yet again so that the correct voltages are computed by volts.pro for this wavelength. With the new calcite thicknesses a set of voltages for the CHIP wavelengths is produced and checked on the spectrograph. Filter profiles are then plotted vs. scaled wavelength to evaluate the accuracy of the tuning table. Calcite thickness that work with this model are 2.767306mm, 11.081139mm, 22.159250mm, 5.539020mm for electrical channels 0 through 3.

Performance

Table 7 gives the CHIP wavelengths plus 1082.0nm and 1084.0nm. Voltages are listed by electrical connector number. Figures 12, 13, and 14 show the filter profiles as a function of wavelength, the error in wavelength and the full width at half maximum.

Wavelength (nm)	Voltage 0	Voltage 1	Voltage 2	Voltage 3
1082.000	1.199	9.355	1.537	2.710
1082.745	2.773	2.591	4.164	1.249
1082.847	2.513	1.964	1.855	1.141
1082.960	2.295	1.604	1.282	7.499
1083.030	2.186	1.434	5.774	4.686
1083.100	2.091	1.281	2.367	3.533
1083.213	1.962	7.428	1.485	2.650
1083.315	1.863	2.954	1.072	2.236
1084.000	1.408	2.209	2.418	1.193

Table 7. LCVR voltages for the 7 CHIP wavelengths plus 1082nm and 1084nm.

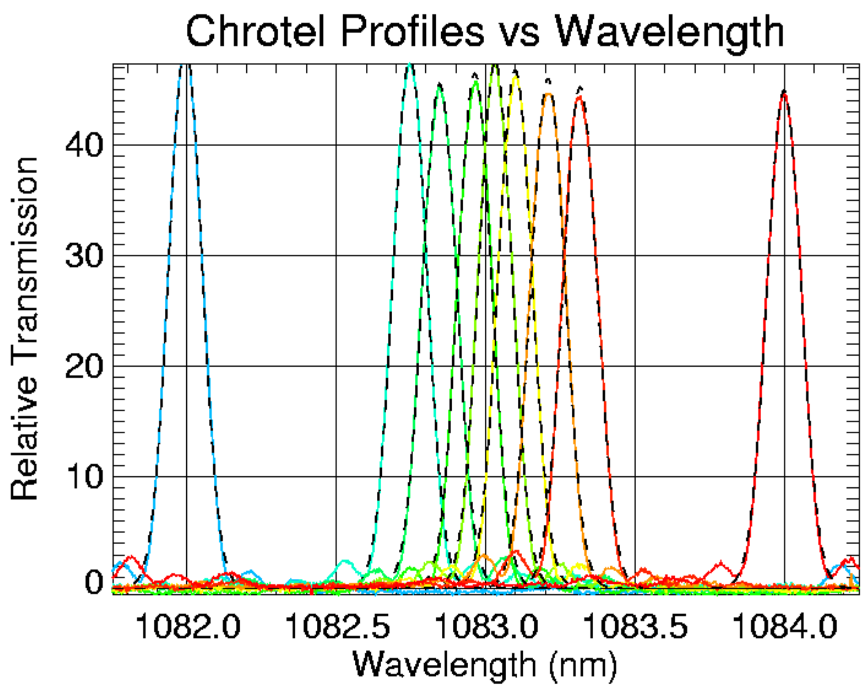


Figure 12. Filter profiles for CHIP wavelengths plus 1082nm and 1084nm. Dotted lines are Gaussian fits to the filter profiles.

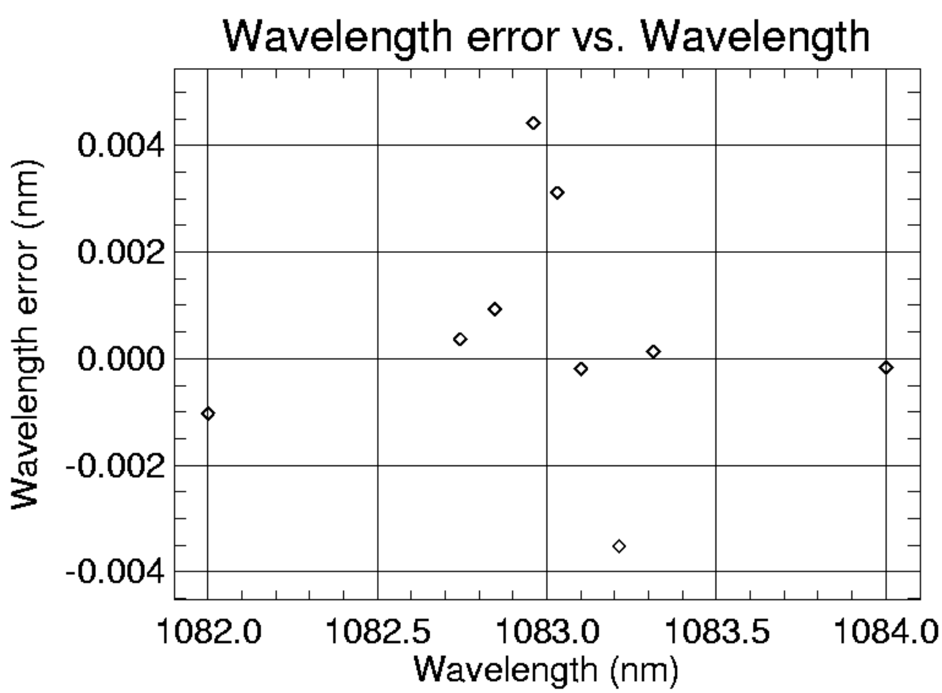


Figure 13. Error in central wavelength of Gaussian fits vs. wavelength for the CHIP wavelengths plus 1082nm and 1084nm.

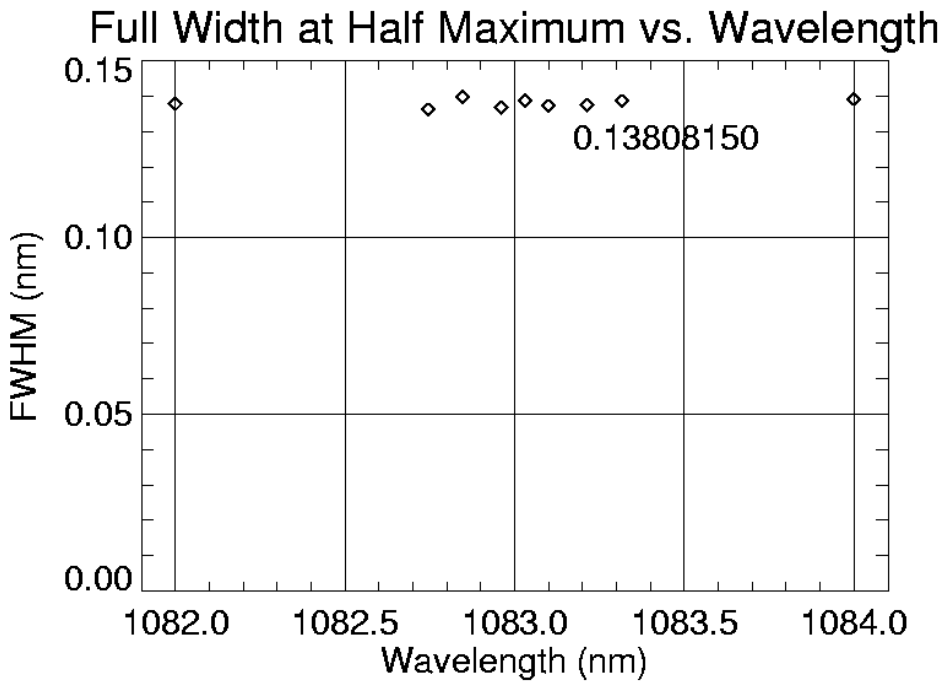


Figure 14. Full width at half maximum vs. wavelength. FWHM is that returned from IDL gaussfit.pro X 1.666 X 1.414.

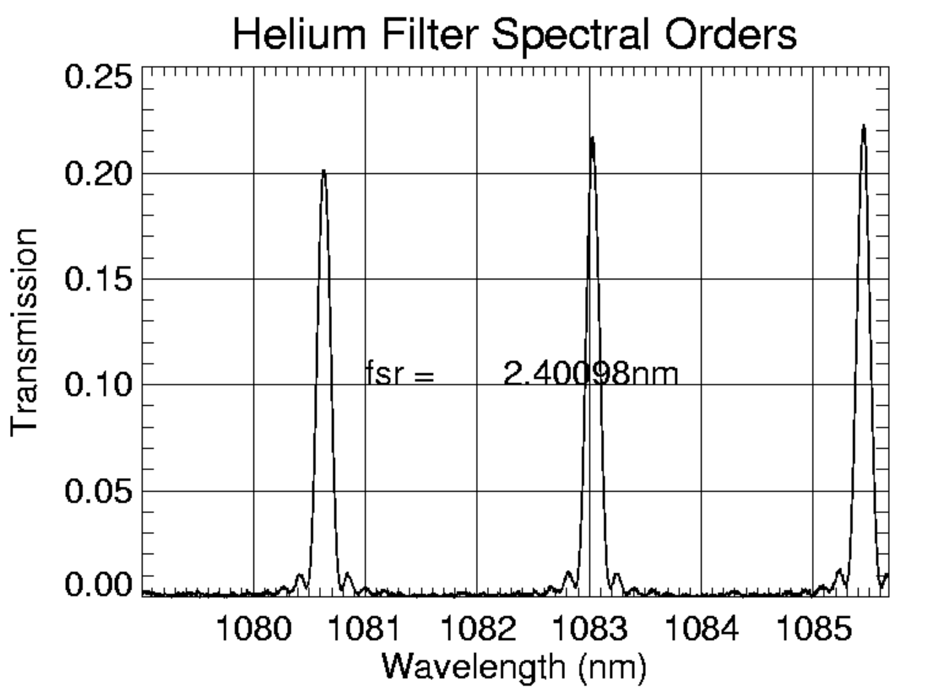


Figure 15. Chrotel Helium filter transmission vs. wavelength showing free spectral range.

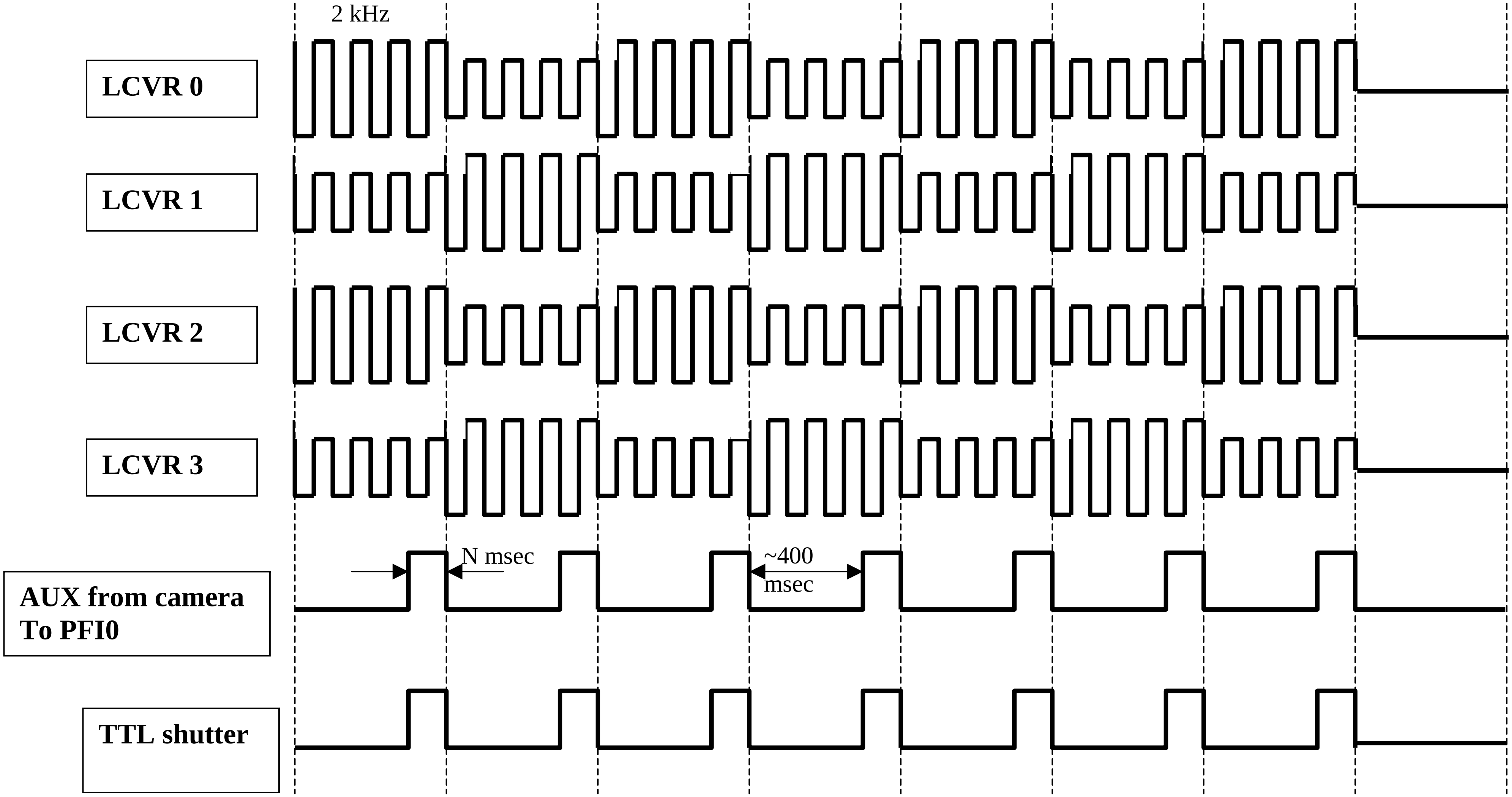
Free spectral range for this 4-stage filter is 2.401nm (Figure 15). A pre-filter with pass band blocking transmission peaks outside the desired order is required. This plot of free spectral range is normalized by quartz lamp intensity without the filter, therefore also shows transmission of the filter.

Chrotel Application

For ChroTel, use the voltages given in table 7 for wavelengths 1082.745nm to 1083.315nm. A timing diagram that sets the voltages for the LCVRs, sends a state number to the computer corresponding to those voltages, and sends a strobe to the camera is shown in table 8. The camera read out time is 200msec. To this, the exposure time of N milliseconds is added. By changing the LCVR voltage amplitude at the beginning of readout, there is plenty of time for the crystals to settle before the next exposure. With expected exposure times of 30msec, all seven wavelengths should be completed in less than 2 seconds.

Table 8. Timing diagram for 7 pass band observations of Helium I.

ChroTel LCVR Timing



Chrotel D/A timing: This 7-state pattern is to be executed upon receipt of a strobe signal from the aux connector on the camera conditioned in the NI SCB68 and sent to the NI6733 board via PFI0. LCVRs operate at 2kHz. Camera exposure times are not fixed but are of the order of 10s of msec. Analog output from the NI6733 is on channels A0 through A3 and are routed through the NI SCB68 interface box. The first LCVR voltages are loaded before the camera is started. After the last frame, LCVRs are set to zero. Circuitry in the NI SCB68 sends out a TTL shutter signal.

Appendix

IDL codes mentioned in the text are contained in the Appendix.

```
;Program:
; volts
; Given thickness of calcite and wavelength
; compute voltages for the four stages of the
; chrotel filter
; The four stages are in electronic order, front
; to back of the filter
;
;Inputs: Prompts from command line
;     wavelength
;     crystal thicknesses
;
;Functions:
;     fit_lcvr    wavelength thick
;           wavelength in nm
;           thick is an array of four calcite thicknesses in mm
;           returns four voltages
;
;The current date is: Mon 03/01/2004
;

;
; Constants
str = 'hello world'
run = 1
volts = dblarr(4)
; for lcvr order 211 212 213 214
thick = [2.767269d,11.081465d,22.158960d,5.539007d]
; for lcvr order 211 213 214 212
thick = [2.767269d,11.081230d,22.159524d,5.539015d]
; model 213 with 212
thick = [2.767306d,11.081561d,22.159250d,5.539020d]
; tweeked for low and high all lcvrs use meadowlark curve
thick = [2.767306d,11.081139d,22.159250d,5.539020d]
ans = 'n'
wavelength = 1083.031

;
; Main loop:  Prompt for wavelength and ask if
; user wants to change calcite thicknesses.
; If so, accetp new thicknesses and recompute
; LCVR volatges for that wavelength
;
while ( run eq 1 ) do begin ;{
      str = 'Wavelength['+string(wavelength)+']'
      read,prompt=str,wavelength
      volts = fit_lcvr(wavelength,thick)
      print,'Voltages are: ',volts/1000.d
      read,prompt='change_thicknesses?',ans
      if ( ans eq 'y' ) then begin ;{
            print,"Enter 0 to leave thickness unchanged"
```

```
            print,thick(0)
            read,prompt='LCVR 1 thickness (mm)
['+string(thick(0))+']',temp
            if ( temp ne '0' ) then thick(0)=double(temp)
            print,thick(1)
            read,prompt='LCVR 2 thickness (mm)
['+string(thick(1))+']',temp
            if ( temp ne '0' ) then thick(1)=double(temp)
            print,thick(2)
            read,prompt='LCVR 3 thickness (mm)
['+string(thick(1))+']',temp
            if ( temp ne '0' ) then thick(2)=double(temp)
            print,thick(3)
            read,prompt='LCVR 4 thickness (mm)
['+string(thick(1))+']',temp
            if ( temp ne '0' ) then thick(3)=double(temp)
      volts = fit_lcvr(wavelength,thick)
      print,'Voltages are: ',volts/1000.d
      endif ;}
endwhile ;}

stop
end
```

function fit_lcvr,wave,thick

```
;
; Function:
; fit_lcvr, wave, thick
;     wave is wavelength of observation in nm
;     thick is an array of four calcite thicknesses in mm
; Returns:
;     array of four LCVR voltages in electronic order
;
; Functions:
;     calcite_biref(wavelength,temperature)
;           wavelength in microns
;           Temperature in C, hardwired to 35 for ChroTel
;     fit_211, fit_212, fit_213, fit_214
;           Accept retardance in nm
;           Return voltage for that LCVR
;           These use Meadowlark curves with a mv offset
;           determined by matching 10v and low voltage retardances
;
; The current date is: Tue 03/23/2004
;

vol = dblarr(4)

; Calcite birefringence for wavelength (microns) and temp
; From Beckers and Dunn, coded by Tomczyk
; Hard wired temperature for ChroTel filter of 35C
; Determine the excess retardance the LCVR needs
; to make up to reach wavelength.  If out
; of range high or low, add a wave or two and
; try again.
;
```

```
; order is electrical
; correct lcvr tables assigned as built into filter
;
; Since polarizers are crosses, for actual thickness
; half incremental wavelengths should be added.
; Therefore thicknesses are in error by a half wave
; For establishing a tuning table, this is of negligible
; importance.
; This formulation is correct for a filter with
; aligned polarizers such as CoMP
;
;
;
cbiref = calcite_biref( wave/1.d3,35.)
cbiref = abs(cbiref)

cret = thick(0)*cbiref/(wave*1.e-6)
ret = fix(cret)-cret
ret = wave*ret
;211 mv vs retardance in nm
vol(0) = fit_211(ret)
if ( (vol(0) gt 10000.) or (vol(0) lt 0.) ) then begin
      ret = fix(cret+1d)-cret
      ret = wave*ret
      vol(0) = fit_211(ret)
endif
if ( (vol(0) gt 10000.) or (vol(0) lt 0.) ) then begin
      ret = fix(cret+2d)-cret
      ret = wave*ret
      vol(0)=fit_211(ret)
endif
;print,cret,ret

cret = thick(1)*cbiref/(wave*1.d-6)
ret = fix(cret)-cret
ret = wave*ret
;213 mv vs retardance in nm
vol(1) = fit_213(ret)
if ( (vol(1) gt 10000.) or (vol(1) lt 0.) ) then begin
      ret = fix(cret+1d)-cret
      ret = wave*ret
      vol(1) = fit_213(ret)
endif
if ( (vol(1) gt 10000.) or (vol(1) lt 0.) ) then begin
      ret = fix(cret+2d)-cret
      ret = wave*ret
      vol(1)=fit_213(ret)
endif
;print,cret,ret

cret = thick(2)*cbiref/(wave*1.d-6)
ret = fix(cret)-cret
ret = wave*ret
;214 mv vs retardance in nm
vol(2)=fit_214(ret)
if ( (vol(2) gt 10000.) or (vol(2) lt 0.) ) then begin
      ret = fix(cret+1d)-cret
```

```
      ret = wave*ret
      vol(2)=fit_214(ret)
endif
if ( (vol(2) gt 10000.) or (vol(2) lt 0.) ) then begin
      ret = fix(cret+2d)-cret
      ret = wave*ret
      vol(2)=fit_214(ret)
endif
print,cret,ret

cret = thick(3)*cbiref/(wave*1.d-6)
ret = fix(cret)-cret
ret = wave*ret
;212 mv vs retardance in nm
vol(3)=fit_212(ret)
if ( (vol(3) gt 10000.) or (vol(3) lt 0.) ) then begin
      ret = fix(cret+1d)-cret
      ret = wave*ret
      vol(3)=fit_212(ret)
endif
if ( (vol(3) gt 10000.) or (vol(3) lt 0.) ) then begin
      ret = fix(cret+2d)-cret
      ret = wave*ret
      vol(3)=fit_212(ret)
endif
return,vol
end
```

function calcite_biref,w,t

```
;  routine to return birefringence of calcite from  Beckers and Dunn paper
;  w is wavelength in microns, t is temperature in degrees C
;     Steve Tomczyk

mu=-0.163724d0 -3.15d-3/w^2 -3.896d-5/w^4 -2.911d-6/w^6 +3.037d-3*w^2 $
 +2.54d-4*w^4 -2.52d-5*w^6 +1.d-5*(t*(1.044-0.16*w)+0.00043*t^2)

return,mu
end
```

function fit_211,ret

```
;
; Function fit_211(retardance)
;     retardance in nm
;     return voltage for this serial number LCVR
;

invmv = -1.1581289d-005 + ret * ( $
  1.6293477d-006 + ret * ( $
 -1.8712082d-009 + ret * ( $
  1.2311231d-012 + ret * ( $
 -2.4249332d-016 ))))

;;; Magic offset to make the curve match at
; 10 and low volts
```

```
;
;return,1.d/invmv - 79.1
return,1.d/invmv - 98.1
end
```

function fit_212,ret

```
;
; Function fit_212(retardance)
;     retardance in nm
;     return voltage for this serial number LCVR
;

invmv =  -1.4965584d-005 + ret * ( $
  1.6708822d-006 + ret * ( $
 -2.0123540d-009 + ret * ( $
  1.3745303d-012 + ret * ( $
 -2.8200298d-016 ))))

;;; Magic offset to make the curve match at
; 10 and low volts
;
;return,1.d/invmv - 108.7
return,1.d/invmv - 124.5
end
```

function fit_213,ret

```
;
; Function fit_213(retardance)
;     retardance in nm
;     return voltage for this serial number LCVR
;

invmv = -0.00010968257 + ret * ( $
  1.9550302e-006 + ret * ( $
 -2.4993188e-009 + ret * ( $
  1.7760318e-012 + ret * ( $
 -4.2924830e-016 ))))

;
; This value is real for 213.
;10v = 1.09v

return,1.d/invmv - 128.4

end
```

function fit_214,ret

```
;
; Function fit_214(retardance)
;     retardance in nm
;     return voltage for this serial number LCVR
;

invmv =  -1.2823916d-005 + ret * ( $
  1.5963964d-006 + ret * ( $
 -1.7724579d-009 + ret * ( $
```

```
  1.1081501d-012 + ret * ( $
 -2.0240377d-016 ))))

;;; Magic offset to make the curve match at
; 10 and low volts
;
;return,1.d/invmv - 185.1
return,1.d/invmv - 154.9
end
;


; Program:
```

; helium_scan

```
;     Find pixel # corresponding to main eomponents
;     of Helium I 1083.031nm line
;
; Record filter scans at 1082.95 through
; 1083.10 in 0.01nm incrementsusing the chrotel test
; LabView vi
; Use 2 m spectrograph with 300l/mm grating in
; third order
; 20 micron slit width
; Megaplus camera with 9 micron square pixels
;
;     Take pixel # the fit to the helium line
;     and copy it to lcvr_holzer to plot filter
;     profiles with a calibrated scale factor
;
;
; approximate pixel for a start
hepix = 922.
; data must be in this file
filename = 'helium_scan.dat'
; Expected are the 16 wavelengths from 1082.95 through
; 1083.10nm

numscan = 16

setupwin
!x.range=0
!p.color=0
!p.background=255
fred = 'hello'

;
; Read in and convert ascii data file
;
close,1 & openr,1,filename
for jj = 0,numscan-1 do begin

; first line has date/time and lcvr volts
      readf,1,fred
; second line has string of ascii spectral values
      readf,1,fred
      spec = strsplit(fred,/extract)
      if ( jj eq 0 ) then begin
```

```
            n = n_elements(spec)
            hspec = fltarr(numscan,n)
      endif
      for ii=0,n-1 do begin
            hspec(jj,ii) = string(spec(ii))
      endfor
endfor

; plot max one first guess at the 11th waveelngth
!x.range=[hepix-50,hepix+50]
plot,hspec(10,*)
for jj=0,numscan-1 do begin
      oplot,hspec(jj,*)
endfor
stop

; Add all spectra together to see helium profile
; do a gaussian fit to get exact line pixel
; Copy this value to lcvr_holzer.pro for absolute
; pixel for 1083.031nm
;
allspec = total(hspec,1)
plot,allspec
afit = gaussfit(findgen(41)+hepix-20, $
      allspec(hepix-20:hepix+20),ares,nterms=3)
aspec = fltarr(n)
aspec(hepix-20:hepix+20) = afit
oplot,aspec,color=192
xyouts,hepix-20,max(aspec)/2.,strtrim(string(ares(1)))

stop
end

;
; Program:
; lcvr_holzer
;     Plot performance of ChroTel filter
; Input:
;     holzer_volts.dat
;
;     This file is generated with Steve's chrotel test
;     LabView virtual instrument.
; Holzer's set of CHIP wavelengths plus one short and one long
; are expected 1082.00,1082.745,1082.847,1082.960,1083.030,
                  1083.100,1083.213,1083.315,1084.00
; Data collected on 2 meter spectrograph
; with kodak 9 micron x 9 micron pixel camera
; Third order 300l/mm grating.
;
; Use helium_scan to get absolute pixel for
; 1083.031nm
;
; Modify constants for any other spectrograph setup
;
;
filename = 'holzer_volts.dat'
```

```
setupwin
!x.range=0
!y.range=0
loadct,39

;
; Modify the following lines as appropriate
;
angperpix = 0.148097 ; from measurements or grating equation 1st order
dispfac = 3.392d  ; 3rd dispersion/1st dispersion from grating equation

hepix = 920.462   ; just measured it with he_scan
he = 10830.31

wavelengths=[1082.00,1082.745,1082.847,1082.960,1083.030, $
                  1083.100,1083.213,1083.315,1084.00]

; Where in the field of view do we expect to find the profiles
; relative to 1083.031
profpix=[-238,-66,-44,-15,0,15,38,64,222]
profpix = profpix+hepix

;
; Number of pass bands
n = 9
fred = 'hi'

;
; Read in ascii files created by Steve's virtual instrument
;
offset = 0.
close,1 & openr,1,filename
for ii = 0,n-1 do begin
      readf,1,fred
      print,fred
      readf,1,fred
      spec = strsplit(fred,/extract)
      m = n_elements(spec)
      if ( ii eq 0 ) then profiles = dblarr(n,m)
      for jj=0,m-1 do begin
            profiles(ii,jj) = string(spec(jj))
      endfor
      profiles(ii,*) = profiles(ii,*) - min(profiles(ii,*)) - offset
end

;
; Plot and gausian fit all the profiles
;
!p.color=0
!p.background=255
firstpix = he - hepix*angperpix/dispfac
wave = firstpix+findgen(m)*angperpix/dispfac
wave = wave
wave = wave/10.
!p.title = 'Chrotel Profiles vs Wavelength'
!x.title = 'Wavelength (nm)'
!y.title = 'Relative Transmission'
```

```
hres=dblarr(n,3)
hspec=dblarr(n,m)
hspec(*,*)=0.
!x.range=[1081.75,1084.25]
plot,wave,profiles(1,*),/nodata
for ii=0,n-1 do begin
      oplot,wave,profiles(ii,*),color=90+ii*20
      hfit=gaussfit(wave(profpix(ii)-70:profpix(ii)+70),profiles(ii, $
      profpix(ii)-70:profpix(ii)+70),res,NTERMS=3)
      hres(ii,*)=res
      print,hres(ii,*)
      hspec(ii, profpix(ii)-70:profpix(ii)+70) = hfit
      oplot,wave,hspec(ii,*),line=2,color=90+ii*20
      oplot,wave,hspec(ii,*),line=2,color=0
end
stop

;
; Plot the error in wavelenght  vs wavelength
;
!p.title = 'Wavelength error vs. Wavelength'
!y.title = 'Wavelength error (nm)'
!x.range=[min(wavelengths)-.1,max(wavelengths)+.1]
!y.range=[min(hres(*,1)-wavelengths)-.001,max(hres(*,1)-wavelengths)+.001]
plot,wavelengths,hres(*,1)-wavelengths,psym=4
stop

;
; Plot FWHM vs wavelength
;
!y.range=0
!p.title = 'Full Width at Half Maximum vs. Wavelength'
!y.title = 'FWHM (nm)'
!y.style=0
plot,wavelengths,hres(*,2)*1.666*1.414,psym=4
m = moment(hres(*,2))
xyouts,1083,.125,strtrim(string(m(0)*1.414*1.666))
stop

end
```

pro setupwin

```
; Set Elmore's default plot settings
; for windows OS.

!x.title = ''
!y.title = ''
!p.title = ''
!p.multi=0
!y.style=1
!x.style=1
!y.ticklen=1
!x.ticklen=1
!x.range=0
```

```
!y.range=0
!p.charsize=1.5
!p.font=0
!p.thick=3
!p.charthick=2.
!p.multi=0
!p.background=0
!p.color=255

radfac = !pi/180.
end
```