### PolSALT – a walkthrough Presented by Danièl Groenewald and Kenneth Nordsieck

SALT workshop - Cape Town - 14 Nov 2022

## polSALT software (beta version)

Available at https://github.com/saltastro/polsalt

- (1) Basic CCD reductions
- (2) Wavelength calibration
- (3) Spectra extraction
- (4) Calculating the raw Stokes parameters
- (5) Calculating the final (calibrated) Stokes parameters

) Plotting



### (1) Basic CCD reductions:

Script: imred.py

- **×** Overscan subtraction.
- **X** Gain correction
- X Crosstalk correction
- × Mosaicing.
- **\*** Produces "mxgbpP..." fits files.
- \* Add variance and BPM information necessary for the polarimetric reduction.

This step is only necessary for data taken <u>before</u> 2022/02/04. From 2202/02/05 these steps are performed by the primary SALT pipeline & now included in the product data.



# (2) Wavelength Calibration:

Script: specpolwavmap.py

- X O (bottom) and E (top) beamsplitter beams are split & calibrated separately.
- **×** The "specidentify" interface appear & lines are identified.
- X Cosmic-ray rejection is done next.
- \* Produces "wmxgbpP..." fits files beams are split (saved in different extensions) & wavelength map plane added.



600

500

400

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-100 -500

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1

arc\_110\_0.fits

Filename:

Y1:

nrows:

Auto-Identify

500

0

1000

1500

Y2:

273

rstep: 20

2000

2500

3000

3500

x=793.177 y=185.433 [97.7]

Update 5 Next

O-beam

#### \_\_\_\_ 🛛





#### 1 0 0 + 1 0 0

Filename:	arc_110_0.fits			
Y1:	272	Y2:	273	
X1:	0.00	wl:	4200	Add
Function:	legendre 💌	Order:	3	6Update
Matchlines 💌	Run			Save





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Filename:	None		-
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Filename: None

3.0

Averag

Sigma:

Change to 1.5





Std( ): 0.39

Nite 5

10 Reject

Filename: None

Averag . Je-1. Sigma:

1.5



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Std(): 0.07

11

Reject



InterIdentify (on astro2015.cape.saao.ac.za)

Order: 3

Function:

Matchlines

•

legendre

Run

2Update

Save

600

500

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-100 -500

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1

arc\_110\_0.fits

Filename:

Y1:

nrows:

Auto-Identify

500

0

1000

1500

Y2:

273

rstep: 20

2000

2500

3000

3500

x=793.177 y=185.433 [97.7]

Update 13 Next

O-beam

```
specpol20220626.log
 Open
                                                                                                            Save
                                         dvilioen on astro2015.cape.saao.ac.za /h...vilioen/polarimetry/Eta_Car/20220626/sci
28 Proccessing extension 1 in arc 110 0.fits
29
                GR-ANGLE
30 Grating
                              AR-ANGLE
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31 PG0900
                                            5773.23
                                                           2534.903582
           15.125
                         30.224
                                     0.60
32
33
34 2022-11-08 12:44:05 MESSAGE -----
35 Saving WS value for row 272 with rms=0.112538 for 17 lines
36
37 2022-11-08 12:45:05 MESSAGE
                            38 Saving WS value for row 272 with rms=0.066958 for 15 lines
39
40 2022-11-08 12:45:31 MESSAGE -----
41 Running Auto
  Line
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    272
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                               Printed to the terminal BUT also included in the
46
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        13 0.05
48
    212
        14 0.14
                               specpol20220526.log found in the sci directory.
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    332
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     72 13 0.07
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    472 15 0.12
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     52 15 0.10
    492 14 0.04
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     32
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67
68 2022-11-08 12:46:19 MESSAGE -----
69 specidentify completed
70 arcdb 110 0.txt rms: 0.016%
71 SPECIDENTIFY images=arc 110 1.fits
72 linelist=/home/dviljoen/iraf/pysalt/data/linelists/Xe.salt
73 outfile=arcdb 110 1.txt guesstype=file guessfile=wavguess 110 1.txt
74 automethod=Matchlines function=legendre order=3 rstep=20 rstart=243 mdiff=20
75 thresh=3 niter=5 smooth=3 subback=0 inter=True startext=0 clobber=True
76 textcolor=black preprocess=False logfile=specpol20220626.log verbose=True
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79 2022-11-08 12:46:20 MESSAGE -----
80 Starting specidentify
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specpol20220626.log
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                                           dvilioen on astro2015.cape.saao.ac.za /h...vilioen/polarimetry/Eta_Car/20220626/sci
21 2022-11-00 12:33:33 MESSAUL
28 Proccessing extension 1 in arc 110 0.fits
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           15.125
                           30.224
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32
33
34 2022-11-08 12:44:05 MESSAGE -----
35 Saving WS value for row 272 with rms=0.112538 for 17 lines
36
37 2022-11-08 12:45:05 MESSAGE
38 Saving WS value for row 272 with rms=0.066958 for 15 lines
39
40 2022-11-08 12:45:31 MESSAGE
41 Running Auto
42 Line
          N RMS
                   * For each arc image nn, it will save an arcdb nn 0.txt (O beam) and
43
    272
         15 0.08
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    252
         14 0.06
                      arcdb_nn_1.txt (E beam) in the sci directory.
45
    292
         13 0.04
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    232
         14 0.04
47
    312
         13 0.05
    212
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         14 0.14
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    452
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     72
        13 0.07
    472
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64
     52 15 0.10
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    492 14 0.04
     32
         7 2.91
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68 2022-11-08 12:46:19 MESSAGE ------
   pecidentify completed
69
70
   arcdb 110 0.txt rms: 0.016%
71 SPECIDENTIFY images=arc 110 1.fits
72 linelist=/home/dviljoen/iraf/pysalt/data/linelists/Xe.salt
73 outfile=arcdb 110 1.txt guesstype=file guessfile=wavguess 110 1.txt
74 automethod=Matchlines function=legendre order=3 rstep=20 rstart=243 mdiff=20
75 thresh=3 niter=5 smooth=3 subback=0 inter=True startext=0 clobber=True
76 textcolor=black preprocess=False logfile=specpol20220626.log verbose=True
77
78
79 2022-11-08 12:46:20 MESSAGE -----
80 Starting specidentify
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Open         specpol20220626.log           dviljoen on astro2015.cape.saao.ac.za /hviljoen/polarimetry/Eta_Car/20220626/sci	Save			• 🧉
27 2022-11-08 12:33:33 MESSAGE				
29 30 Grating GR-ANGLE AR-ANGLE Slit WCEN R 31 PG0900 15.125 30.224 0.60 5773.23 2534.903582 32 33				
34 2022-11-08 12:44:05 MESSAGE				
<ul> <li><sup>41 Running Auto</sup></li> <li><sup>42 Line N RMS</sup></li> <li><sup>43 272 15 0.08</sup></li> <li><sup>44 252 14 0.06</sup></li> <li><sup>45 292 13 0.04</sup></li> <li><sup>46 232 14 0.04</sup></li> <li><sup>47 312 13 0.05</sup></li> <li><sup>48 212 14 0.14</sup></li> <li><sup>49 332 15 0.07</sup></li> <li><sup>50 192 15 0.10</sup></li> <li><sup>52 172 15 0.06</sup></li> <li><sup>48 If it is larger than 0.05%, a fallback waymap which has no curv</sup></li> </ul>	d out spec	ctral e is u	ıse	d.
to avoid spoiling the sky line subtraction. $\frac{57}{412}$ $\frac{13}{13}$ $\frac{0.04}{0.04}$ <b>X</b> Tin: these arcdb files may be conject into future sci folders, rep	amin	n to		- 1
The incise areas may be copied into future set folders, refined and $\frac{59}{432}$ $\frac{15}{15}$ $\frac{0.08}{00}$ $\frac{92}{15}$ $\frac{15}{0.10}$ $\frac{15}{61}$ $\frac{452}{14}$ $\frac{13}{0.07}$ $\frac{13}{63}$ $\frac{472}{12}$ $\frac{15}{15}$ $\frac{0.12}{0.12}$ $\frac{13}{65}$ $\frac{0.07}{492}$ $\frac{14}{14}$ $\frac{0.04}{0.04}$ $\frac{110}{65}$ $\frac{110}{4}$ $\frac{110}{2}$ $\frac{110}{15}$ $\frac{110}{100}$ $\frac{110}$	vill be	e use	ed	as
<pre>68 2022-11-08 12:46:19 MESSAGE</pre>				
80 Starting specidentify 81				16



Be aware of the following in PG300 grating observations





### (3) Extraction:

Script: specpolextract\_sc.py

- \* Each beam is corrected for beamsplitter distortion and tilt using the brightest spectrum in the image.
- \* Produces "cwmxgbpP.." fits files.
- X Using wavmap plane, the sky and spectrum is extracted vs wavelength. Extracted 1D spectra of O & E beams stored as separate extensions in "ecwmxgbpP..." fits files.
- **X** Overview:
  - $\rightarrow$  Locate window is the whole slit: (-120,120)" and is the default but can be changed.
  - ➔ Science object is the brightest signal in this window.
  - Object spectrum then extracted from an "extract" window centered on the brightest object.
  - → Default extract window is 10"\*:
    - → \*advise PG0300 grating observation to keep as default to avoid 2<sup>nd</sup> order cont
    - $\rightarrow$  \*can be adjusted for other gratings to avoid nearby objects.



### (4) Raw stokes:

Script: specpolrawstokes.py

- \* "Waveplate position pairs" identified (4 waveplate positions stations, 45 degrees apart).
- \* Taken together result in linear polarization signal swapping between the O and E beams.
- Combined into "raw stokes" fits files basically single stokes parameters (unnormalized I, S & degree of polarization being S/I).
- \* Produces "<object>\_<config>\_h<12>\_<cycle>.fits" files eg. EtaCarina\_c0\_h04\_01.fits for object EtaCarina, 1<sup>st</sup> configuration, waveplate position pair 0 and 4, 1<sup>st</sup> cycle of the observation.



### (5) Final stokes:

Script: specpolfinalstokes.py

- **×** Multiple cycles of observation combined here.
- \* Spikes in data are culled, "sys %err" along with a "chi-square" are evaluated for each waveplate pair.
- × Full pattern used to determine Q & U.
- \* The polarimetric zero-point, the waveplate efficiency & axis calibrations are applied to give the final Stokes parameters.
- × Unnormalized I,Q,U, with degree of polarization being Q/I and U/I.
- Produces "<object>\_<config>\_<cycles>\_stokes.fits" eg. EtaCarina\_c0\_1234\_123\_stokes.fits for object EtaCarina, 1<sup>st</sup> configuration for cycles 1-3 of the observation.



# (5) Final stokes:

Some definitions before we get to the example:

- × **<u>Culling</u>**: eliminate outliers.
  - ➔ for multiple cycles, compare each wavelength in cycle with every other cycle to get probability P.
  - $\rightarrow$  bad comparisons are flagged if P < .02%; chisq > 13.8
  - ➔ for cycles > 2, vote to cull specific pair/wavelength, otherwise cull both wavelengths.

### × <u>Sys err:</u>

- $\rightarrow$  estimate offset systematic error over all wavelengths (bad if > 0.1%).
- for each normalized rawstokes, average of (value-mean), weighted by 1/(photon error).
- X <u>Chi-square:</u> compare error to expected photon error (bad if >~ 2).
  - ➔ for each normalized rawstokes, find stdev over wavelengths of fit of Gaussian to (value-mean)/(photon error) (should be 1).



```
specpol20220626.log
  Open
                                                                                                                     Save
                 patterns
                                                         pol session outline.txt
                                                                                                            specpol20220626.log
387 logfile=specpol20220626.log debug=False HW Cal override=False
388 Linear PolZeropoint override=False PAZeropoint override=False
389
390
391 2022-06-27 14:33:37 MESSAGE
392 Starting specpolfinalstokes
393
394 specpolfinalstokes version: 20171226
395
     PA type: Equatorial
                                                 IFAR's:
396
     PolCal Model: 20170429
397
     HWCal: RSSpol HW Calibration 20061030 v04.txt
398
     PolZeropoint: RSSpol Linear TelZeropoint 20061030 v01.txt
399
     PAZeropoint: RSSpol Linear PAZeropoint.txt 20180410 v01 120.0
400
                                                                  * specpolfinalstokes.py can be used as standalone.
401 Configuration: c0
402
                                                                  X Experiment with culling rawstokes input to improve
403
     Observation: EtaCarina c0 1234 123 Date: 20220626
404
405
                   culled
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                        1
                                                                  X Shown here are "Syserr" & "chi-square" estimates
408
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            2:
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                           -0.036
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409
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                                    0.037
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412
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413
     Estimated sys %error: 0.029%
                                   Mean Chisg:
                                                 2.26
414
       EtaCarina_c0_1234_123_stokes.fits Stokes I,Q,U
415
                                                                     patterns, each raw-stokes in a cycle is compared
416
417
       Existing Fluxdb:
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418 NO OBJECT DATE-OBS GRATING GR-ANGLE CAMANG
419
420
     1 HILT600 2022-03-17 PG0900
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422
       EtaCarina c0 1234 123 stokes.fits Fluxcal:
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427
428
429 2022-06-27 14:33:40 MESSAGE
430 specpolfinalstokes completed
431 SPECPOLFINALSTOKES
432 infilelist=['EtaCarina_c0_h04_01.fits', 'EtaCarina_c0_h04_02.fits', 'EtaCarina_c0_h04_03.fits', 'EtaCarina_c0_h04_04.fits',
   'EtaCarina c0 h26 01.fits', 'EtaCarina c0 h26 02.fits']
433 logfile=specpol20220626.log debug=False HW Cal override=False
434 Linear PolZeropoint override=False PAZeropoint override=False
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436
437 2022-06-27 14:46:23 MESSAGE
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438 Starting specpolfinalstokes
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424           425         Wavelen         % Q         % U         % Q Err         % U Err         % P           426         5736.01         -2.9061         0.6853         0.0010         0.0008         2.9858         8	PA % P Err PA Err 3.365 0.0010 0.007	
<pre>42/ 428 429 2022-06-27 14:33:40 MESSAGE</pre>	fits', 'EtaCarina_c0_h04_03.fits', 'EtaCarina_c0_	_h04_04.fits', 28

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428 429 2022-00 430 specpo 431 SPECPO 432 infile 'EtaCa 433 logfil 434 Linear 435 436 437 2022-00 438 Startin	6-27 14:33:40 MESSAGE lfinalstokes completed LFINALSTOKES list=['EtaCarina_c0_h04_01.fits', 'EtaC rina_c0_h26_01.fits', 'EtaCarina_c0_h26 e=specpol20220626.log debug=False HW_Ca _PolZeropoint_override=False PAZeropoin 6-27 14:46:23 MESSAGE	arina_c0_h04_02.fits', 'EtaCarina_c0_h04_03.fits', 'E _02.fits'] l_override=False t_override=False	29

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424         425         Wavelen         % Q         % U         % Q Err         % U Err         % P         PA           426         5736.01         -2.9061         0.6853         0.0010         0.0008         2.9858         83.	% P Err PA Err 365 0.0010 0.007	
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425         Wavelen         % Q         % U         % Q Err         % U Err         % P           426         5736.01         -2.9061         0.6853         0.0010         0.0008         2.9858	PA % P EFF PA EFF 83.365 0.0010 0.007 May be	re-reduced leaving out this
<pre>428 429 2022-06-27 14:33:40 MESSAGE 430 specpolfinalstokes completed 431 SPECPOLFINALSTOKES 432 infilelist=['EtaCarina_c0_h04_01.fits', 'EtaCarina_c0_h04_0 'EtaCarina_c0_h26_01.fits', 'EtaCarina_c0_h26_02.fits'] 433 logfile=specpol2020626.log debug=False HW_Cal_override=Fa 434 Linear_PolZeropoint_override=False PAZeropoint_override=Fa 435 436 437 2022-06-27 14:46:23 MESSAGE 438 Starting specpolfinalstokes</pre>	0bServa 02.fits', 'EtaCarina_c0_h04_03.fits', ' lse lse	Ation. EtaCarina_c0_h04_04.fits', 31

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440 s 441 442 443 444 445	Specp PA Pol HWC Pol PAZ	olfina type: Cal Mc al: RS Zeropoi	alstoke Equato odel: 2 SSpol_H oint: RS	es vers orial 2017042 HW_Cali 25Spol_L	sion: 201 29 bration_ Linear_T inear_PA	71226 20061030_ elZeropoi Zeropoint	v04.txt nt_200610 .txt 2018	30_v01.tx 0410_v01	t 120.0	× Not	ice that	h26 raw	vstoke	s of cycle	e 3 has I	been	culle	d.	
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470 471 472 473	Wa	avele 5734.	n 05	% Q -2.9243	% U 0.6287	% Q Err 0.0010	% U Err 0.0008	% P 2.9911	PA 83.933	% P Err 0.0010	PA Err 0.008						
474 475 476	2022 spec	06-2 polfi	7 14 nals	1:46:29 ME tokes cor	SSAGE							Dlain Text -	Tab Width	· 0 • 10.207	Col 48	39	INF

## (6) Plotting:

Script: specpolview.py

- Command: python script.py specpolview.py <\*stokes.fits files> <options>

- If more than 1 Stokes file present, results will be overplotted, but individual output files will be saved for each.

Next I will explain some general and plotting options that can be used with this command.



#### **General options**

save=

default: the mean polarization result as seen in the specpolfinalstokes output is printed.

text: A text file, labeled <stokesfile name>\_<bin>.txt is saved, containing columns with binned data: Wavelen Intensity/Flambda % Q % U % Q Err % U Err % P PA % P Err PA Err

*plot*: A pdf plot file (also displayed) is saved, with three plots, intensity or Flambda (unbinned), and two polarization plots (binned), depending on the "type" option below (default %P and PA). An input is requested for optional yscaling of the polarization plots, followed by optional wavelength scaling of all:

Optional scale (bottom-top, comma sep):

for instance, "80,180,2,3,4500,5000" plots PA between 80 and 100 degrees, and polarization 2-3%, for wavelengths between 4500 and 5000 Angstroms. Any values not given (though still comma separated) will be autoscaled.

textplot: both text and plot

 bin= unbin: (default)

nnA: nn Angstrom bins

f.f%: binned to given % error

Plot options These do not effect the text output:

type=

Note: the case is significant: upper case is unnormalized, and lower case is normalized to I (in % or deg). Coming soon: polarized flux IPt and IQU.

Ipt (default): plots intensity or flux, % P, and PA (deg)

Iqu: plots intensity or flux, % Q, and % U. Asks for an optional non zero PA zeropoint, so that Q corresponds to that PA.

• errors= False (default) or True

if True, error bars are plotted.

connect=

default polarization points are plotted, connected by lines.

hist: if binned, the bins are shown histogram-style.

**Command:** python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist



Command: python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist

- Specify that both a text output file and a pdf of the plot are saved.



Command: python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist

- Specify that both a text output file and a pdf of the plot are saved.
- Data are binned using 5 Angstroms.



Command: python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist

- Specify that both a text output file and a pdf of the plot are saved.
- Data are binned using 5 Angstroms.
- Bins are showed in histogram style.



Command: python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist

- Specify that both a text output file and a pdf of the plot are saved.
- Data are binned using 5 Angstroms.
- Bins are showed in histogram style.

#### Terminal output looks like this:

(polsalt-beta	) dviljoer	n@astro20	15:~/pola	rimetry/Et	ta_Car/20	0220626/sc	i_usenewr	awsto	tokes\$ python script.py specpolview.py EtaCarina_c0_1234_12_stokes.fits save=textplot bin=5A connect=hist	
EtaCarina_c0_	1234_12_st	tokes	2022-0	6-26 Wtd	mean	Syserr:	0.017			
Wavelen 5733.91	% Q -2.9163	% U 0.7113	% Q Err 0.0010	% U Err 0.0009	% P 3.0017	PA 83.147	% P Err 0.0010	PA 0.0	A Err 0.008	
Optional scal	e (bottom-	-top, com	ma sep):							l



Command: python script.py specpolview.py EtaCarina\_c0\_1234\_12\_stokes.fits save=textplot bin=5A connect=hist

- Specify that both a text output file and a pdf of the plot are saved.
- Data are binned using 5 Angstroms.
- Bins are showed in histogram style.

#### Terminal output looks like this: -Option to adjust the scale of the plots

3.0017

(polsalt-beta) dviljoen@astro2015:~/polarimetry/Eta Car/20220626/sci usenewrawstokes\$ python script.py specpolview.py EtaCarina c0 1234 12 stokes.fits save=textplot bin=5A

EtaCarina c0 1234 12 stokes 2022-06-26 Wtd mean Svserr: 0.017 % O Err % U Err PA PA Err 83,147

#### Optional scale (bottom-top, comma sep): 70,100,2,4, 4250, 7250

0.7113



-2.9163

5733.91

Plots PA between 70 and 100 degrees, and polarization 2-4%, for wavelengths between 4250 and 7250 Angstroms. Any values not given (though still comma separated) will be autoscaled.









### Further tips:

- Some observations may have comparison object observed alongside the main science target. In this case we advise users to rerun the software a 2<sup>nd</sup> time, however adjusting the extraction values accordingly.
- \* Flux calibration can also be done with polSALT (done via specpolflux.py).
  - $\rightarrow$  IF existing fluxdb files are found in the sci directory.
  - → Users can look at the polSALT wiki page for more info on how to implement this.
  - Users are referred to page 4 of the Observer's guide for more info on the procedure to obtain SALT observations of flux standards.
- **\*** The polarisation, weighted by filter throughput, can also be determined.
  - → We refer users to the polSALT wiki page for more info.



### Future attractions:

- \* Before end of 2022, we will release revised calibrations to take into account illumination variations over track & FOV (refer to Ken's talk)
  - → will be released in github as new specpolfinalstokes.py (300 & 900 gratings).
- Currently working on the 1<sup>st</sup> paper (in the series) where the above mentioned calibrations are explained in greater detail.
- \* A future release of the software will contain calibration revision for other gratings & a new imaging spectropolarimetry mode.
  - → Most exciting is that it will also incorporating MOS capability
  - New wavelength calibration (great news for the 300 grating) and extraction techniques.
- Circular polarimetry calibrations
- **×** Extending into the UV.

