



## LRIS: Polarimetry with the ADC

The use of the ADC (Atmospheric Dispersion Compensator) with LRIS may have some effect on polarization measurements with the LRISp polarimetry module. On May 22, 2007 a half night of engineering was used to investigate these effects. Both the polarimetry module and the ADC were installed, and linear polarimetry on two unpolarized, “null” standards and two polarized standards was performed.

### Expectations

We might expect the glass in the ADC prisms to act as weak wave plates. In this sense, we would expect unpolarized light to remain unpolarized, and polarized light to be partially converted (linear to circular and vice versa), changing both the fractional polarization and the position angle (for linear polarimetry).

Such behavior will be constant for any piece of the glass, but might be expected to be a function of:

- Physical rotator angle.  
This determines which part of the ADC prisms the starlight passes through. As the rotator’s physical angle, ROTPPOSN, changes, the instrument looks through different parts of the nonrotating ADC.
- Prism separation.  
At a given physical rotator angle, as the prisms change separation (which they will as the ADC compensates for the changing atmospheric dispersion), the “footprint” of the star on each prism change.
- Elevation.  
The changing gravity loading on the ADC glass might change the effects of the stress birefringence, and hence the effect of the ADC on the polarization.

It seems likely that the elevation term will be a minor effect, since most of the stress-induced birefringence in glass is caused by high internal stresses, not external stress. Similarly, the prism separation represents a change in the area of the prisms that are sampled by the starlight. This is a second-order effect, and is expected to be low if there are only low-spatial frequency changes in the ADC birefringence. However, even lower spatial frequencies of variation could result in the ADC’s polarization effects varying from one part of the glass (i.e. one rotator angle) to another.

### Observational Details

With the ADC and polarimetry module both installed, we took linear polarimetry data on two null standards, HD 94851 and HD 109055, and two polarized standards, HD 142863 and HD 155528. The rotator was used in PA mode, which meant that it was rotating as different exposures within the polarimetry sequence were taken. While this adds a slight



level of uncertainty in comparisons between different rotator angles, it greatly simplifies data reduction and analysis, by allowing the use of standard tools.

Only the red side of LRIS was used, with the 300/5000 grating providing wavelength coverage from 3817 to 8590 Å at a dispersion of 2.45 Å/pixel.

Data reduction used standard tools in the image-processing package *VISTA*, resulting in spectra of the two linear Stokes parameters,  $Q$  and  $U$ , for each of the sets of four standard polarimetry exposures. Subsequent analysis, also using *VISTA*, took the (unweighted) mean value of the Stokes parameters over the wavelength range 5000–6000 Å, approximating the  $V$  band in which polarimetry measurements for the standards are available in the literature.

## Results

### *Prism Separation*

At a fiducial value of the rotator angle,  $\text{ROTPPOSN} = -60^\circ$ , two data sets on HD 142863 were taken at each of three prism separations: “nulled,” or with the prisms at minimum separation; maximum separation; and in the middle. The results are shown below.

**Table 1. Measured polarization vs. prism separation**

ADC	P	$\theta$
null	1.939%	113.0°
midway	1.964%	112.3°
maximum	1.951%	112.6°

The results show that changing the separation of the ADC prisms has little effect on the measured polarization, at a level of 0.013% for a  $P = 2\%$  star. This is good news, in the sense that this dimension of the parameter space can be ignored, and the ADC can be operated in its normal mode when used with the polarimeter.

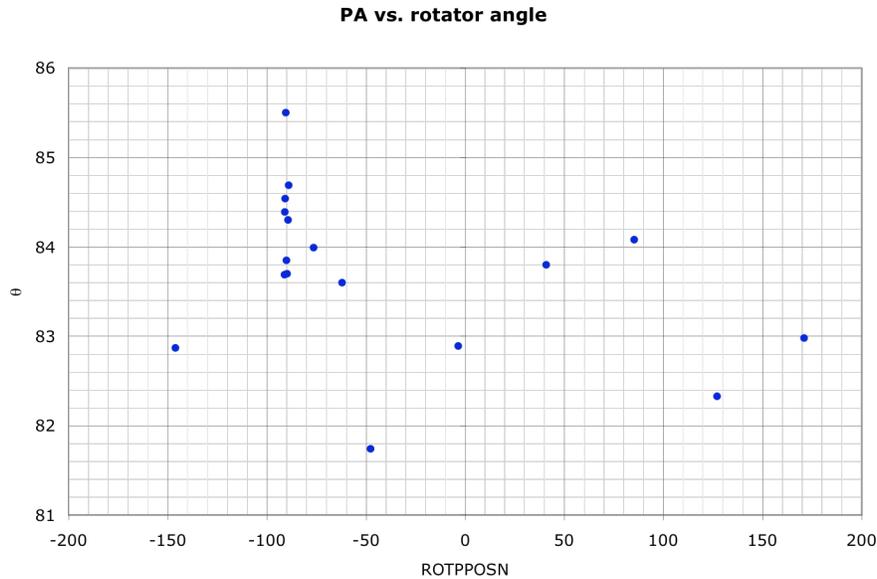
### *Rotator Angle*

With the ADC in its minimum separation position (“nulled”) the same star (HD 142863) was observed at multiple rotator angles. While the rotator was used in PA mode during the exposures, so that the *physical* angle,  $\text{ROTPPOSN}$ , was changing slightly during the polarimetry data sets, we proceed by assuming that this effect is small, and we use the value of  $\text{ROTPPOSN}$  from the image headers below. Values of  $\text{ROTPPOSN}$  separated by  $30^\circ$  provide some sense of the scale of any variations in the ADC’s effects on polarization.

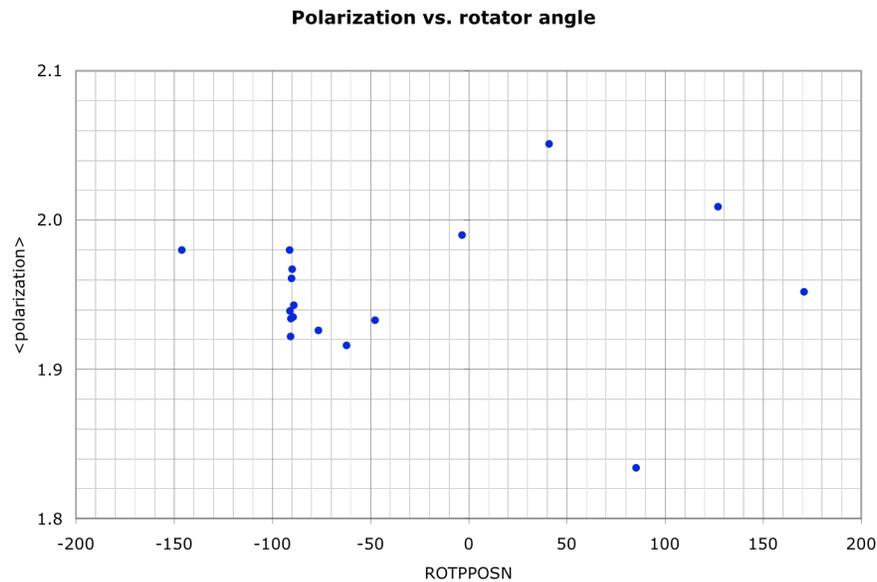
Of the 17 different measurements, eight were taken at close to the same  $\text{ROTPPOSN}$ , although four of these were used at different ADC positions for the ADC separation test described above. Given that the prism separation does not seem to affect the measured polarization significantly, we include all the measurements in the rotator analysis.



Plots of  $P$  and  $\theta$  vs. ROTPPOSN may better show the results:



**Figure 1. Measured polarization position angle of HD 142863 versus rotator physical angle. The uncertainty in the data points is calculated to be  $0.07^\circ$ , much less than the observed scatter.**



**Figure 2. Measured polarization of HD 142863 versus rotator physical angle. The uncertainty in the data points is calculated to be 0.004%.**

The plot shows variation in the measured polarization larger than expected from the standard noise statistic, which is roughly 0.004% in  $P$  and  $0.07^\circ$  in  $\theta$  for each data point.



This might not be surprising, as the measured polarization may vary slightly depending on the trace of the star across the detector, variations in seeing during the experiment, etc. The trace of the star across the detector will vary, for example, because the slit angle is changing with respect to the atmospherically dispersed image, and with the ADC in its “null” position it is not compensating for this. So as the rotator rotates (and the slit changes direction with respect to vertical, the star’s trace will show different curvatures depending on the slit’s angle.

Overall, the measured range of polarizations is  $\pm 0.11\%$ , and the range of angles is  $\pm 1.6^\circ$ . Data taken on the second polarized standard, HD 155528, show similar results. The observed scatter could be due either to variations in the effect of the ADC across the glass, or to unaccounted for measurement uncertainties. Because data sets similar to those described here have not been taken before, it is difficult to compare with the non-ADC mode of polarimetry. We plan on repeating this series of measurements without the ADC in June 2007.

Note that multiple measurements taken at nearly the same rotator angle (ROTPPOSN  $\approx -90^\circ$ ) also show a significant dispersion. The range in  $P$  is relatively small at  $\pm 0.03\%$ , but the range in  $\theta$  is  $\pm 0.9^\circ$ . If this is a real effect it would argue for structure in the birefringence at high spatial frequencies, although this does not seem to be borne out by the prism separation measurements, which were quite stable (and done in this same narrow range of ROTPPOSN).

### ***Elevation***

Relatively sparse data is available on the effects of elevation. Two data sets were taken at the same ROTPPOSN and ADC states ( $-90.7^\circ$  and nulled), but at elevations of  $41.5^\circ$  and  $54.5^\circ$ . The polarization differed by only  $\Delta P = 0.005\%$ , and the position angles by  $\Delta\theta = 1.1^\circ$ . Note that  $\Delta P$  is within the formal uncertainty, while  $\Delta\theta$  is larger by a factor of ten. It is unclear whether or not this is a true difference caused by the change in elevation or uncertainties in the reduction from unknown sources.

### ***Absolute polarization***

The measured polarizations of HD 142863 extend from 1.834% to 2.051% in the range 5000–6000 Å. The reference value of the polarization, from Clemens & Tapia (1990) is  $1.89\% \pm 0.06\%$ . Only one of our measurements, taken at ROTPPOSN  $75^\circ$ , lies at or below this; all other measurements are larger than the reference value. In most spectra, the polarization does not drop to 1.89% until close to 4000 Å, so this cannot be explained away as difference in bandpass.

The same holds true for HD 155528, for which the reference  $V$ -band polarization is given as  $4.85\% \pm 0.05\%$  in Clemens & Tapia (1990). None of our measurements are this low.

Since in general we would expect the ADC glass to decrease the measured linear polarization, this is a bit of a mystery. It could be that these stars are slowly varying in polarization with time. An implication for the discrepancy is that we may not be able to use the reference values of polarization as “ground truth” in our experiment.



## Null Standards

Multiple observations of the two null standards show no evidence for significant instrumental polarization, consistent with previous observations without the ADC.

**Table 2. Measured polarizations of null standards**

Standard	P(ref)	P(obs)	$\theta$ (obs)
HD 94851 <sup>a</sup>	0.015% $\pm$ 0.031%	0.065% $\pm$ 0.006%	64.4°
HD 109055 <sup>b</sup>	0.057% $\pm$ 0.018%	0.157% $\pm$ 0.005%	46.4°

References: <sup>a</sup> Clemens & Tapia (1990, PASP, 101, 179)

<sup>b</sup> Turnshek et al. 1990, AJ, 99, 1243)

Note that the very low polarization of HD 94851 is consistent to within uncertainty to the reference value. The polarization of HD 109055 is nearly  $6\sigma$  higher than the uncertainties. This discrepancy has been reported previously, however; HD 109055 may show signs of low level variations in polarization.

## Note!

There is one caveat that has not been discussed, but is nonetheless significant. If the ADC glass acts as a true wave plate, with some retardance and fast axis, any linear polarization polarized along the fast or slow axes of the “wave plate” will not be altered. So selection of a polarized standard with such a position angle would not show any effect! Since the wave plate’s fast axis presumably remains fixed with respect to the glass, and hence to “elevation,” a single polarized standard observed over a range of parallactic angles could test this possibility. Unfortunately, both polarized standards available for the 2007 May observations were polarized at roughly the same position angle, and observed at similar parallactic angles.

## Conclusions and Recommendations

This study indicates that the ADC glass could have some modest effect on the polarization. Separation of the prisms does not seem to be a major factor. While elevation tests were limited, this parameter also does not seem to have a major effect. The largest effect may be due to different parts of the ADC behaving differently.

Our recommendations are:

1. If you require very accurate measurements, below the level of  $\pm 0.11\%$  in  $P$  or  $1.6^\circ$  in  $\theta$ , you should either not use the ADC, or perform careful measurements of its effects in exactly the mode it was used. Keep in mind that it is not the rotator’s PA relative to North on the sky (keyword ROTPOSN) that is important, but the physical drive angle (keyword ROTPPOSN).
2. If used, operate the ADC in its normal mode, to compensate for atmospheric dispersion. A changing prism separation does not seem to have a large effect.



3. Be sure to take polarized standards, to tie down the zero-point of the position-angle scale. At least two such standards with different position angles are recommended.
4. Do not rely on the “polarizance” curve to tell you anything about the behavior of the ADC. Remember that the polarizers used are *below* the slit, past any effects that the ADC might have on the star’s polarization.



## Appendix A. Data

The following tables present the reduced data from each data set. A data set consists of four observations at wave plate angles of  $0^\circ$ ,  $45^\circ$ ,  $22.5^\circ$ , and  $67.5^\circ$ . Reduction is by conventional techniques, e.g. Goodrich (1991, PASP, 103, 1314). Analysis was done by calculating a straight (unweighted) mean across the wavelength region  $\lambda\lambda 5000\text{--}6000$ , to simulate the  $V$  band. The variation in calculated uncertainty from pixel to pixel within this restricted wavelength range is small, so a weighted mean would not produce substantially different results.

**Table 3. HD 142863 (polarized standard)**

Start file	ROTPPOSN	ROTPOSN	%P ( $\pm 0.004\%$ )	$\theta$ ( $\pm 0.006^\circ$ )
100	-88.98	-151.5	1.943	84.69
104	-89.34	-151.5	1.935	84.30
108	-89.80	-151.5	1.967	83.70
112	-90.19	-151.5	1.961	83.85
116	-90.73	-151.5	1.922	84.54
120	-91.15	-151.5	1.980	83.69
125	-90.96	-150.0	1.939	84.39
129	-76.48	-135.0	1.926	83.99
133	-62.10	-120.0	1.916	83.60
137	-47.68	-105.0	1.933	81.74
141	-3.41	-60.0	1.990	82.89
145	40.96	-15.0	2.051	83.80
149	85.25	30.0	1.834	84.08
153	127.02	75.0	2.009	82.33
157	170.90	120.0	1.952	82.98
161	-146.06	-195.0	1.980	82.87
165	-90.47	-138.0	1.934	85.50

**Table 4. HD 155528 (polarized standard)**

Start file	ROTPPOSN	ROTPOSN	%P ( $\pm 0.004\%$ )	$\theta$ ( $\pm 0.006^\circ$ )
169	-89.95	-149	5.005	91.99
173	-90.42	-149	4.979	91.27
177	-76.94	-135	4.954	91.14
181	-62.57	-120	4.984	91.87
185	-48.18	-105	5.051	90.52
189	-3.91	-60	5.134	90.63
193	40.45	-15	5.121	91.21
197	84.77	30	4.964	91.63
201	129.00	75	4.951	90.73
205	173.11	120	4.923	90.69
209	-143.38	-195	5.106	91.61
213	-90.49	-141	4.969	90.81

**Table 5. HD 94851 (null standard)**

Start file	%Q ( $\pm 0.005\%$ )	%U ( $\pm 0.006\%$ )
62	0.149	-0.078
66	0.047	-0.134
70	0.128	-0.128

**Table 6. HD 109055 (null standard)**

Start file	%Q ( $\pm 0.006\%$ )	%U ( $\pm 0.006\%$ )
84	-0.004	-0.019
88	0.030	-0.093
92	0.001	-0.071
96	-0.139	-0.051



Author	Date	Comment
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