Southern African Large Telescope

Title: **RSS stability and flexure models**

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ABSTRACT

We present in this report a study of different aspects of RSS flexure and repeatability of the RSS spectral setups. We calculated 1D models for RSS flexure and RSS flexure drift depending on two parameters: azimuth angle and rho angle. Our results show that (1) RSS flexure is obviously a function of two parameters: azimuth and rho angle; (2) RSS repeatability after correction for the flexure has a standard deviation of 1.63 pixels (2×2 binning); (3) the RSS flexure drift is obviously a function of two parameters: azimuth and rho angle, but also has a random part with a dispersion of ∼0.17 pixels (2×2 binning).

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1 Introduction

Understanding the stability and flexure of the Robert Stobie Spectrograph (RSS) is vital for the proposal preparation procedure and for the planning of standard calibrations procedure. Some studies were done previously, see e.g. report from Keith S. on *http://wiki.salt.ac.za/index.php/RSS_wavelength_stability* page. With many uniform observations currently available in the SALT database it is possible to measure the stability and flexure and calculate some simple models. In this report we examine a set of spectral data which was obtained with the same setup over a long enough time span and with different azimuthal and rho angles.

2 Data and Analysis

Observational data analysed in this report were taken from commisionning programs with the RSS during 2011–2012. All observations were taken with the same spectral setup: grating GR900 at an articulation angle of 30.25 resulting in a wavelength range of approximately 4200-7200 Å. All data were observed with slit 1.25 arcsec and 2×2 binning. Three exposures were uaually taken.

All data were extracted from the SALT database and the position of the night-sky line 5577.35 Å in the middle of the frame was measured using the IRAF `imexam` task. No any additional reduction after pipeline was done. All data used are shown in Table 1. The measured position is presented in column (4), and columns (5) and (6) show rho angle and azimuth angle for each frame. Column (7) presents information when frames were observed in sequence.

3 Results

Altogether, 82 frames were measured, which cover all the range of azimuth and rho angles. All studied observations were obtained with the same RSS setup, while the RSS was configured each time before the observation of the block. For that reason all these observations were completely independent and the measured position for the 5577 line has two kind of errors:

- A random error which is the result of the RSS hardware accuracy. We can call it "RSS stability" or "RSS repeatability"
- A systematic error which is the result of RSS flexure depending on some parameters.

We would like to check how accurate the RSS hardware is to the setup instrument. For that we need to exclude flexure first. As a starting point, we suggest that flexure is a function of azimuth and/or rho angle.

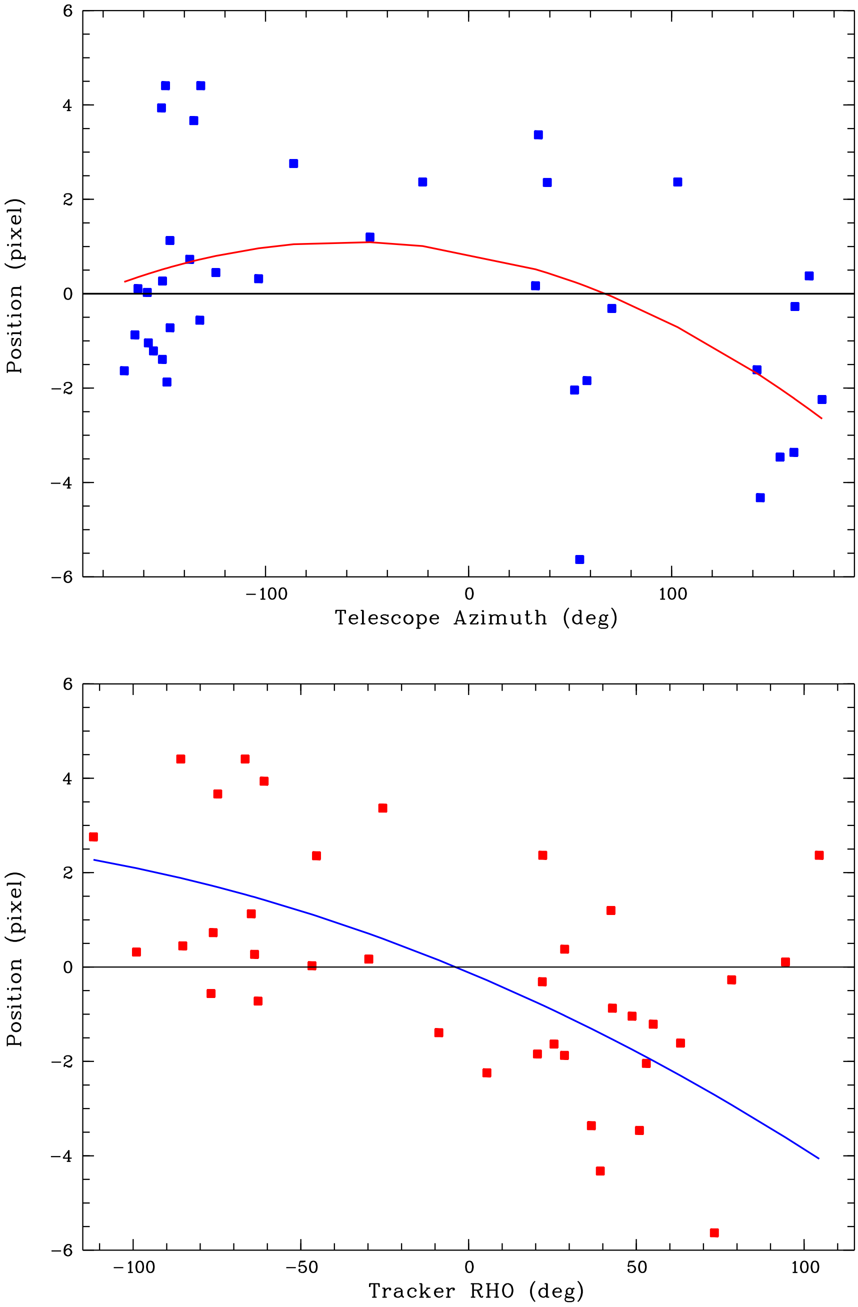

Figure 1: The distributions for measured positions depending on azimuth angle (top panel) and rho angle (bottom panel). Result of the second order polynomial fit is also shown for both panels.

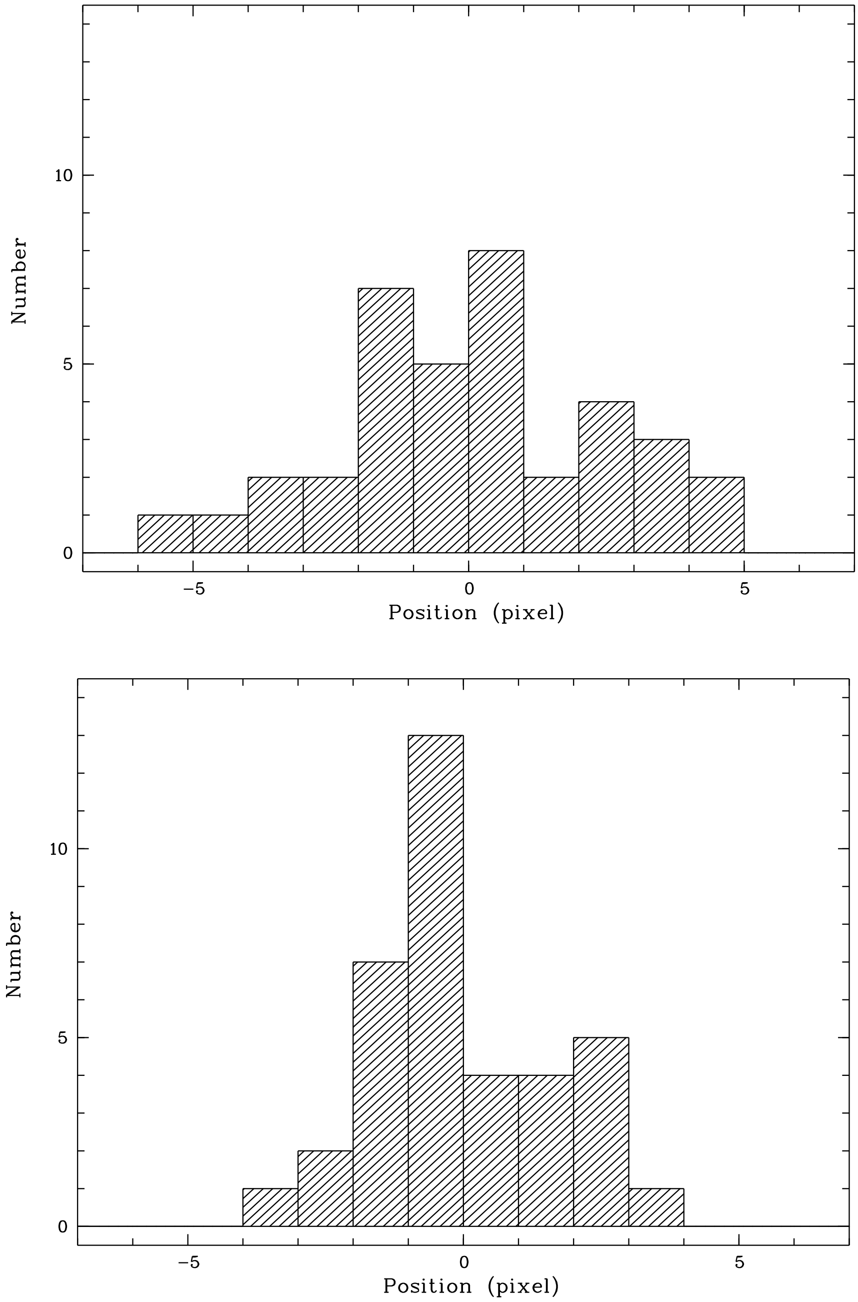

Figure 2: **Top panel:** The histogram of all measured positions for the 5577 night-sky line. The mean value 1389.4421 pixel was subtracted from this distribution. The standard deviation for this distribution is 2.41 pixels. **Bottom panel:** The same histogram after correction for azimuthal and rho angle. The standard deviation for this distribution is 1.63 pixels.

Table 1: Analysed observations

Date (1)	File (2)	Exp. (sec) (3)	Position (pixel) (4)	RHO (deg) (5)	AZ (deg) (6)	Sequence (7)
20110519	mbxpP201105190002	100.	1385.98	50.91	153.416	1
20110519	mbxpP201105190003	100.	1385.93	50.91	153.416	2
20110519	mbxpP201105190004	100.	1385.96	50.91	153.416	3
20110519	mbxpP201105190006	100.	1386.08	36.587	160.206	1
20110519	mbxpP201105190007	100.	1386.23	36.587	160.206	2
20110519	mbxpP201105190008	100.	1386.19	36.587	160.206	3
20110602	mbxpP201106020015	300.	1388.88	-76.775	-132.383	1
20110602	mbxpP201106020016	300.	1389.07	-76.775	-132.383	2
20110602	mbxpP201106020017	300.	1389.05	-76.775	-132.383	3
20110603	mbxpP201106030033	600.	1388.05	-8.867	-150.816	1
20110603	mbxpP201106030034	600.	1388.15	-8.867	-150.816	2
20110603	mbxpP201106030035	105.	1388.21	-8.867	-150.816	3
20110603	mbxpP201106030036	214.	1388.29	-14.563	-147.974	4
20110603	mbxpP201106030037	600.	1388.37	-16.133	-147.336	5
20110603	mbxpP201106030038	600.	1388.59	-18.381	-146.523	6
20110606	mbxpP201106060037	300.	1388.72	-62.751	-147.018	1
20110606	mbxpP201106060038	300.	1388.82	-62.751	-147.018	2
20110606	mbxpP201106060039	300.	1388.97	-62.751	-147.018	3
20110612	mbxpP201106120003	300.	1387.20	5.44	174.096	1
20110612	mbxpP201106120004	300.	1387.50	5.44	174.096	2
20110612	mbxpP201106120005	300.	1387.53	5.44	174.096	3
20110613	mbxpP201106130002	600.	1389.47	-46.689	-158.271	1
20110613	mbxpP201106130003	600.	1389.38	-46.689	-158.271	2
20110613	mbxpP201106130085	300.	1389.76	-99.012	-103.406	1
20110613	mbxpP201106130086	120.	1390.09	-99.87	-103.823	2
20110613	mbxpP201106130087	120.	1389.74	-99.87	-103.823	3
20110613	mbxpP201106130088	120.	1390.03	-99.87	-103.823	4
20110613	mbxpP201106130089	600.	1389.47	-100.899	-104.329	5
20110613	mbxpP201106130090	600.	1389.47	-100.899	-104.329	6
20110627	mbxpP201106270001	600.	1389.71	-63.798	-150.756	1
20110627	mbxpP201106270002	173.	1389.69	-63.798	-150.756	2
20110627	mbxpP201106270023	500.	1390.17	-76.126	-137.349	1
20110627	mbxpP201106270024	500.	1390.12	-76.126	-137.349	2
20110627	mbxpP201106270025	407.	1390.11	-76.126	-137.349	3
20110627	mbxpP201106270027	300.	1389.61	-29.742	32.964	1
20110627	mbxpP201106270028	300.	1389.30	-29.795	28.833	2
20110709	mbxpP201107090015	600.	1393.11	-74.773	-135.368	1
20110709	mbxpP201107090016	600.	1393.39	-74.773	-135.368	2
20110709	mbxpP201107090017	600.	1393.56	-74.773	-135.368	3
20110720	mbxpP201107200001	600.	1391.81	104.521	102.98	1
20110720	mbxpP201107200002	600.	1392.12	104.521	102.98	2
20110727	mbxpP201107270001	300.	1392.81	-25.586	34.375	1
20110727	mbxpP201107270002	300.	1392.61	-25.586	34.375	2
20110727	mbxpP201107270003	300.	1392.43	-25.586	34.375	3
20110731	mbxpP201107310055	300.	1392.20	-111.829	-86.156	1
20110731	mbxpP201107310056	300.	1392.18	-111.829	-86.156	2
20110731	mbxpP201107310057	300.	1392.25	-111.829	-86.156	3
20110731	mbxpP201107310075	300.	1389.82	28.623	167.774	1
20110731	mbxpP201107310076	300.	1389.84	28.623	167.774	2
20110731	mbxpP201107310077	300.	1389.84	28.623	167.774	3
20110731	mbxpP201107310078	300.	1389.82	23.847	169.756	4
20110801	mbxpP201108010009	600.	1391.81	22.104	-22.617	1
20110801	mbxpP201108010010	600.	1391.57	22.104	-22.617	2
20110801	mbxpP201108010011	550.	1391.39	22.255	-29.803	3
20110802	mbxpP201108020040	300.	1390.64	42.433	-48.563	1
20110802	mbxpP201108020041	300.	1390.50	42.433	-48.563	2
20110802	mbxpP201108020042	300.	1390.56	42.433	-48.563	3
20110825	mbxpP201108250005	900.	1389.17	37.724	-39.912	4
20110825	mbxpP201108250006	900.	1388.83	37.442	-45.351	5
20110803	mbxpP201108030064	300.	1391.80	-45.340	38.734	1
20110803	mbxpP201108030065	227.	1391.67	-45.340	38.734	2
20110806	mbxpP201108060087	300.	1393.38	-60.962	-151.239	1
20110806	mbxpP201108060088	300.	1393.61	-60.962	-151.239	2
20110806	mbxpP201108060089	300.	1393.59	-60.962	-151.239	3
20110806	mbxpP201108060091	300.	1393.85	-66.605	-149.288	1
20110806	mbxpP201108060092	300.	1394.08	-67.767	-148.903	2
20110829	mbxpP201108290001	600.	1390.57	-64.782	-147.078	1
20110829	mbxpP201108290003	600.	1390.58	-68.295	-145.625	2
20110829	mbxpP201108290004	300.	1390.54	-70.545	-144.859	3
20120218	mbxpP201202180064	300.	1389.17	78.412	160.723	1
20120218	mbxpP201202180065	300.	1389.28	77.053	161.817	2
20120218	mbxpP201202180066	300.	1389.42	75.746	162.938	3
20120219	mbxpP201202190087	300.	1388.23	-55.032	-155.229	1
20120219	mbxpP201202190088	60.	1388.24	-55.325	-155.079	2
20120220	mbxpP201202200003	300.	1388.57	-42.875	-164.321	1
20120220	mbxpP201202200004	300.	1388.75	-44.361	-163.678	2
20120221	mbxpP201202210031	300.	1387.40	52.976	52.211	1
20120221	mbxpP201202210032	300.	1387.55	50.684	53.243	2
20120412	mbxpP201204120029	300.	1387.83	63.183	142.041	1
20120412	mbxpP201204120030	300.	1388.06	59.749	143.948	2
20120420	mbxpP201204200097	600.	1389.13	-21.975	70.536	1
20120420	mbxpP201204200098	600.	1388.95	-22.536	68.240	2

Table 2: The final coefficients for the flexure function

a0	a1	a2
4.6324E-01	9.9628E-04	-5.6693E-05
a3	a4	a5
-3.6517E-02	-3.2858E-04	-1.4707E-06
a6	a7	a8
-1.9955E-05	4.3172E-06	4.3492E-08

3.1 RSS flexure and RSS stability without flexure

Figure 1 shows the distributions for measured positions depending on azimuth angle (top panel) and rho angle (bottom panel). The mean value was subtracted from these distributions. If some frames were observed in sequence (see Table 1), we show only the measured position for the first frame in these figures. In total, 37 measurements are shown.

There is an obvious dependence of the measured position on both azimuthal and rho angles, which could be fitted with a second order polynomial each:

$$\delta(\mathrm{AZ}) = -6.9125 \cdot 10^{-5} \times \mathrm{AZ}^2 - 8.1289 \cdot 10^{-3} \times \mathrm{AZ} + 0.86012 \quad (1)$$

$$\delta(\mathrm{RHO}) = -7.6123 \cdot 10^{-5} \times \mathrm{RHO}^2 - 2.9840 \cdot 10^{-2} \times \mathrm{RHO} - 0.11321 \quad (2)$$

The top panel of Figure 2 shows the histogram of all measured positions for the 5577 night-sky line. The mean value was also subtracted from this distribution. The distribution has a standard deviation of 2.41 pixels. After correction for azimuth only, the standard deviation is 2.14 pixels, and after correction for rho angle only, the standard deviation is 2.16 pixels.

After that we used a polynomial fit with two independent variables of the form:

$$\begin{aligned}\delta(\mathrm{AZ}, \mathrm{RHO}) &= \mathrm{a0} + \mathrm{a1} * \mathrm{AZ} + \mathrm{a2} * \mathrm{AZ}^2 + \mathrm{a3} * \mathrm{RHO} + \mathrm{a4} * \mathrm{AZ} * \mathrm{RHO} + \mathrm{a5} * \mathrm{AZ}^2 * \mathrm{RHO} \\ &\quad + \mathrm{a6} * \mathrm{RHO}^2 + \mathrm{a7} * \mathrm{AZ} * \mathrm{RHO}^2 + \mathrm{a8} * \mathrm{AZ}^2 * \mathrm{RHO}^2,\end{aligned}$$

where final values for the coefficients are shown in Table 2. Using this polinomial fit, after correction for both azimuth and rho angle the final distribution has a standard deviation of 1.63 pixels, and the final histogram is shown in the bottom panel of Figure 2.

Finally, we have to conclude that science spectra, which were taken without a reference spectrum and were corrected for the systematic flexure shown above could still have a random shift of ∼1.6 pixels or ∼1.5 Å for GR900 grating. We believe that found fit has to be the same for different gratings since it was found in pixel space.

We have to note here that, from the general point of view, RSS flexure is a 2D function (along columns and rows) and not 1D only (along rows) as we can see in this study. Unfortunately, the shift along columns can not be studied in the same way.

3.2 RSS flexure drift

To study flexure drift, we calculated the difference in the 5577 night-sky line position between the first and the last frames in each sequence and the total exposure time between these frames. The final numbers were normalised to an exposure time of 900s for uniform result. Figure 3 shows the distributions for measured drift values depending on azimuth angle (top panel) and rho angle (bottom panel). In total, 28 measurements are shown.

We make the same analysis as was shown in the previous section and found a second order polynomial fit for each the azimuth and the rwho angle dependence. This fit is also shown in Figure 3:

$$\delta(\mathrm{AZ}) = -1.7182 \cdot 10^{-5} \times \mathrm{AZ}^2 - 1.2886 \cdot 10^{-4} \times \mathrm{AZ} + 0.2395 \tag{3}$$

$$\delta(\mathrm{RHO}) = -2.228 \cdot 10^{-5} \times \mathrm{RHO}^2 - 8.8635 \cdot 10^{-4} \times \mathrm{RHO} + 0.030537 \tag{4}$$

The top panel of Figure 4 shows the histogram of all measured drifts for the 5577 night-sky line, which was normalised to 900s exposure time. This distribution has a standard deviation of 0.25 pixels. After correction for azimuth only, the distribution has a standard deviation of 0.19 pixel. After correction for rho angle only, the distribution has a standard deviation of 0.24 pixel. Correction for both the azimuth and rho angle produces the best result, where the final standard deviation is 0.17 pixels, and the final histogram is shown in the bottom panel of Figure 4. The final coefficients for the best second order polynomial fit with two independent variables are presented in Table 3.

Table 3: The final coefficients for the flexure drift function

a0	a1	a2
3.4082E-01	3.4054E-06	-1.9551E-05
a3	a4	a5
-1.8326E-03	-4.4359E-06	7.4197E-08
a6	a7	a8
-3.6000E-05	-2.7353E-08	1.3593E-09

4 Summary and recomendations

We studied different aspects of RSS flexure and the repeatability of RSS spectral setups.

1. We would like to recommend that all PIs during Phase 2 request a reference spectrum immediately **AFTER** or **BEFORE** the spectral observations for **EACH** spectral block. Otherwise, even after correction for the systematic flexure, your data will have random shift with a dispersion of ∼1.6 pixels (2×2 binning). Please, take into account that since the wavelength calibration function for the RSS is a third order polynomial, this shift will be

NON-LINEAR over the covered spectral region and you will **NOT BE ABLE** to correct for that by just shifting your total spectrum.

2. PIs have to know that RSS flexure drift exist and it is an obvious function of azimuth. The found drift amplitude could be as much as $\sim$0.4 pixels (2×2 binning) per 900s of exposure time and has to be **INDEPENDENT** on the used RSS grating even though it was measured only for GR900 in this report. But even after correction for the systematic part, it still has a random part with a dispersion of $\sim$0.17 pixels (2×2 binning).

For many science projects, shifts of less than one unbinned pixel are acceptable. However, it could be unacceptable for some projects. In this case, we recommend to correct for this random shift using night sky lines **BEFORE** to sum/average different exposures.

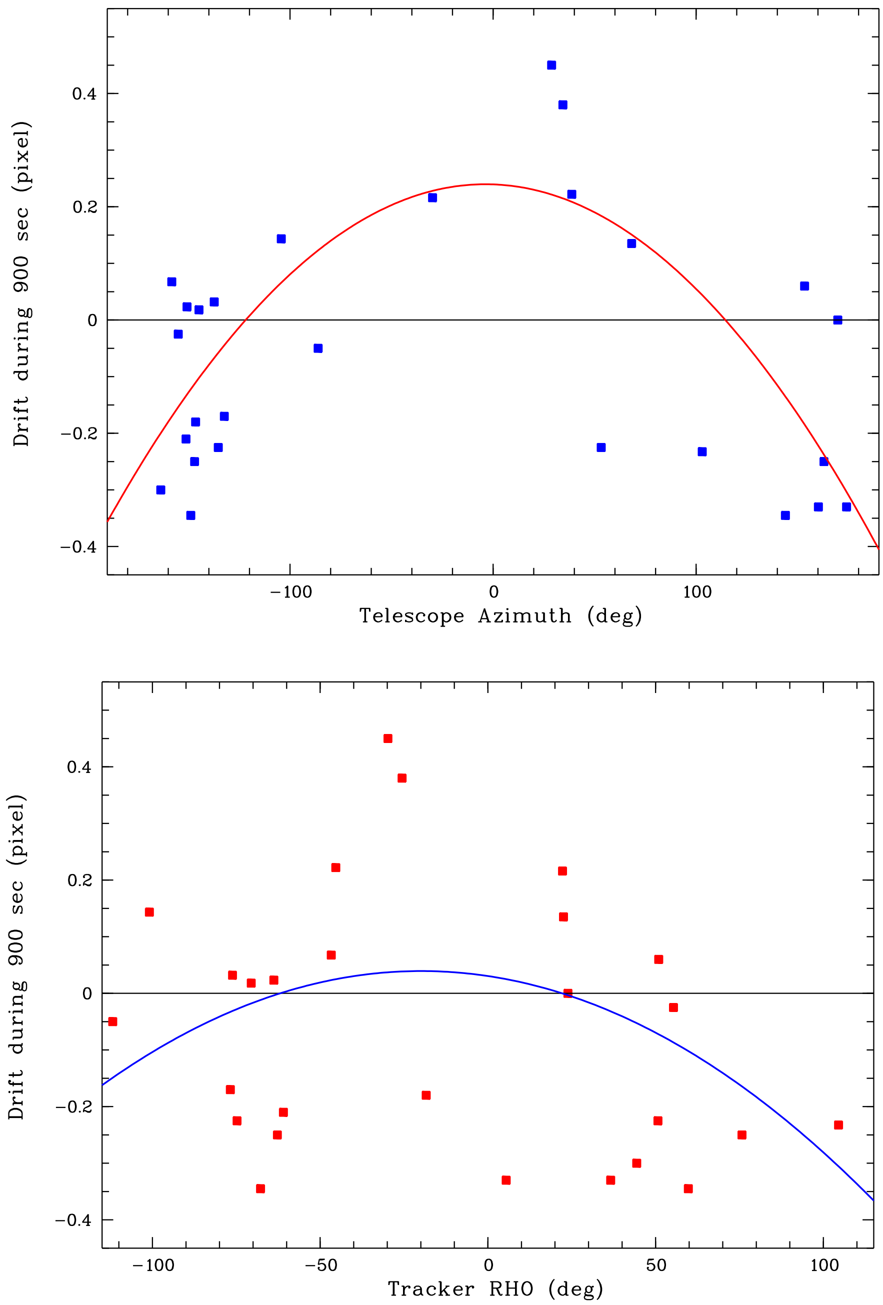

Figure 3: The distributions for measured drift values depending on azimuth angle (top panel) and rho angle (bottom panel). The result of the second order polynomial fit is also shown for both panels.

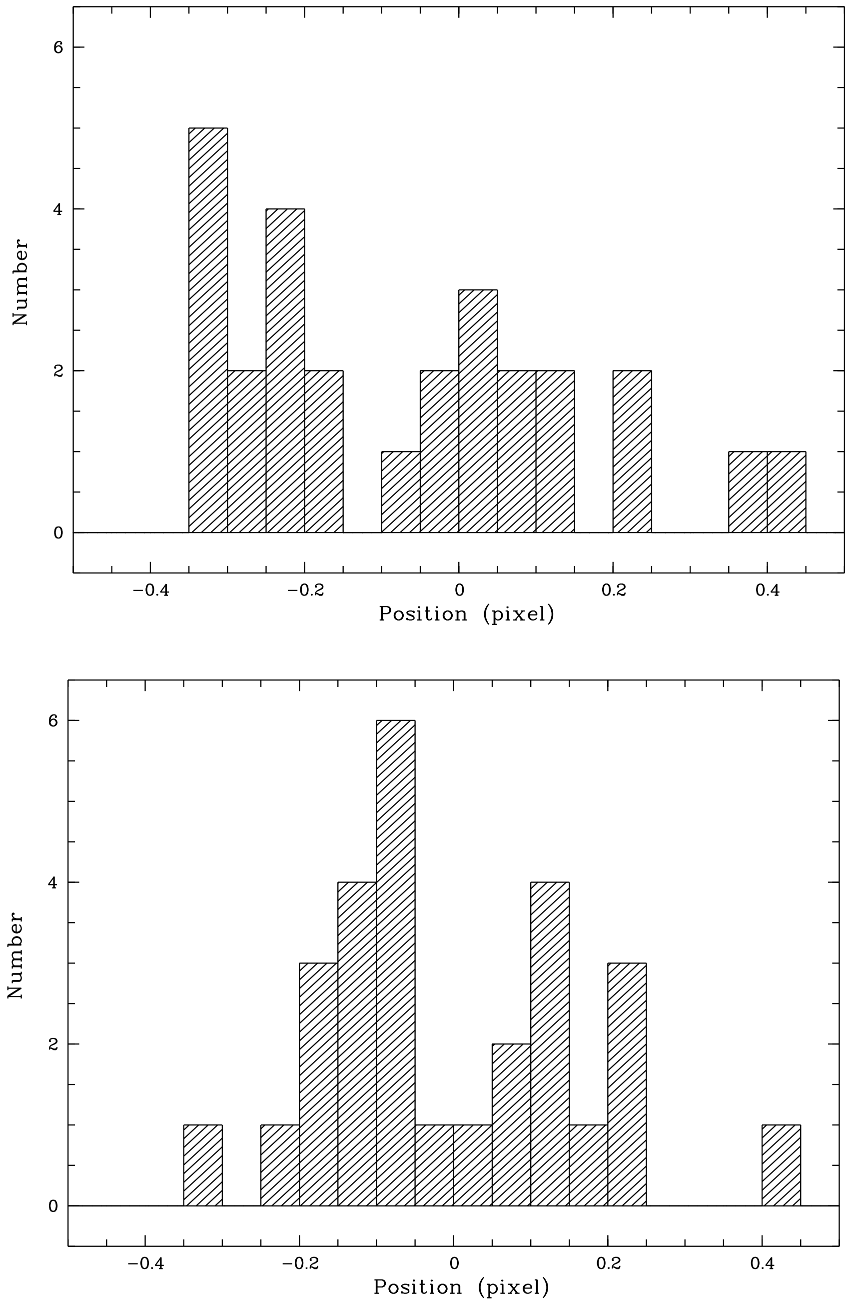

Figure 4: **Top panel:** The histogram of all measured drifts for the 5577 night-sky line. The standard deviation for this distribution is 0.25 pixels. **Bottom panel:** The same histogram after correction for azimuthal and rho angle. The standard deviation for this distribution is 0.17 pixels.