Southern African Large Telescope

Title:	**Stability of the HRS HS mode. The Blue arm data**
Author(s):	**Alexei Kniazev**
Doc. number:	**RSS0000024**
Version:	**2.0**
Date:	*November 5, 2020*
Keywords:	HRS, HS mode
Approved:	**Encarni Romero Colmenero** (AstOps Manager)

ABSTRACT

In this report I present results of my study of stability of the HS HRS mode. This analysis was done for the blue arm HS data only. The final result of this study shows ***that the HRS blue arm instrument drift is about 3 m/s without taking into account the temperature dependence. After correction for the temperature dependence the final number for the HRS blue arm instrument drift drops down to 0.000152 pixel that relates to the accuracy of about 40 cm/s at the wavelength of Hβ line (4861 Å).***

South African Astronomical Observatory, Cape Town 7925, South Africa

Contents

List of Figures

1 Introduction

I was requested to analyze HRS HS-mode stability in the way to check at what level do the object and sky/calibration fibers begin to deviate from one another. In this report I present my results of study of this item.

2 Data

HRS data in the High Stability (HS hereafter) mode were taken during two days of 2019 September 20-21, while nothing was happening at the telescope, but observations were done during the night in between. Altogether, 71 echelle spectra were taken.

3 HRS primary data reduction

First I was need to produce the primary data reduction that includes standard steps as (1) an overscan correction; (2) the master bias creation; (3) the master bias subtraction; (4) the gain correction. All primary data reduction was done with MIDAS programs that were created long-time ago specifically for the HRS primary data reduction. All primary reduction was done with use of a set of BIAS frames taken on 2019 September 21st.

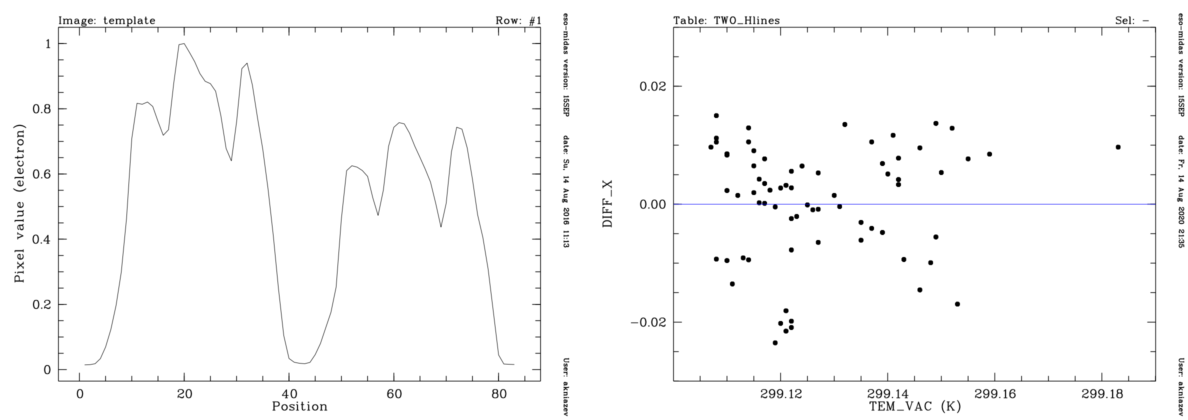

Figure 1: **Left panel:** The Y-direction profile for orders and lines. **Right panel:** An example of accuracy for the difference of X-positions.

4 The 2D-fit method

First, I have tried to use 2D-gaussian fit. Not successful. Very unstable because profile in Y-direction is very complex (see Figure 1).

5 Echelle method for selected lines

The second way I have tried was the same way I have used for the reduction of HRS data taken in LR, MR and HR modes. I have modified my programs in the following way:

1. to detect 40 echelle orders at the blue arm data as the first step. This step was done with use of five echelle flats taken in HS mode on September 21st;

2. 2d background was fitted and subtracted to remove scatter light in between orders;

3. all 40 orders for each fiber from all 71 echelle arcs were extracted;

4. in each extracted fiber for each spectrum all emission lines were detected with use of the standard selection method in the `echelle` package of MIDAS that uses criteria of the FWHM and the threshold. I need to note here that the MIDAS standard selection method gives the fast possibility to select lines, but since it does NOT produce the accurate gaussian fitting its line positions could be used as THE PRELIMINARY information in our case.

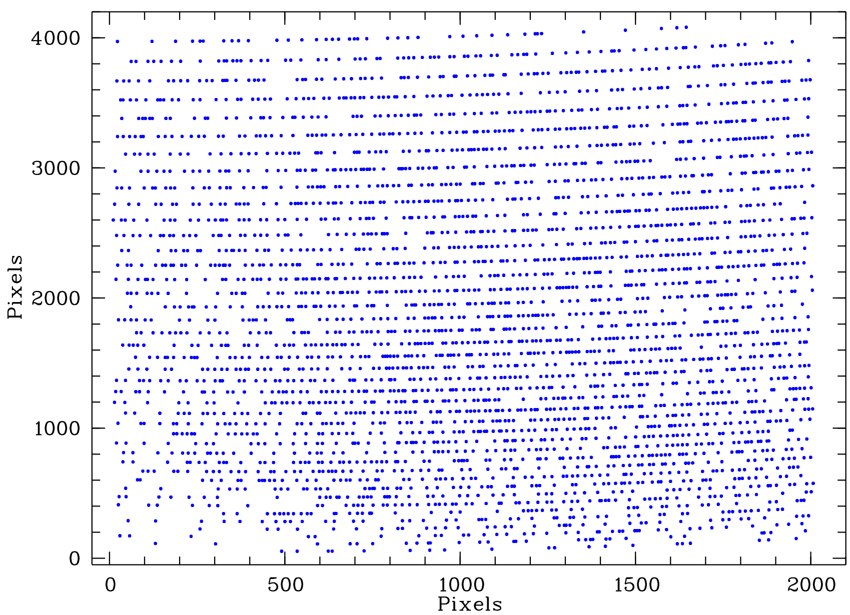

Figure 2: The XY-distribution of all found $\sim$ 3000 emission lines in the arc spectrum of the first fiber. Found lines from the second fiber are not shown because the difference in Y-coordinate is very small.

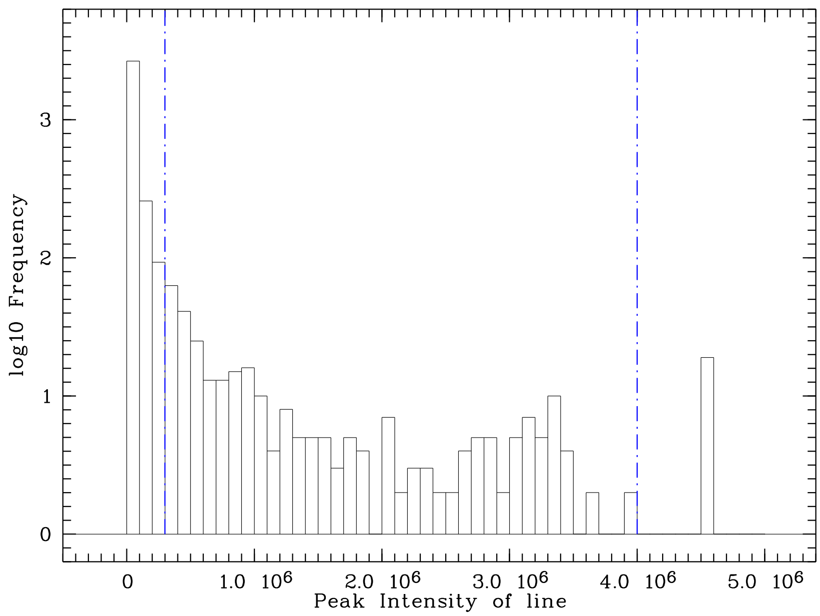

Figure 3: The range of the peak intensities for all found ~ 3000 emission lines. 307 lines were selected finally with the selection criterion of the peak intensities $1 \cdot 10^5 - 4 \cdot 10^6$ counts. This range of the peak intensities is shown with vertical blue lines.

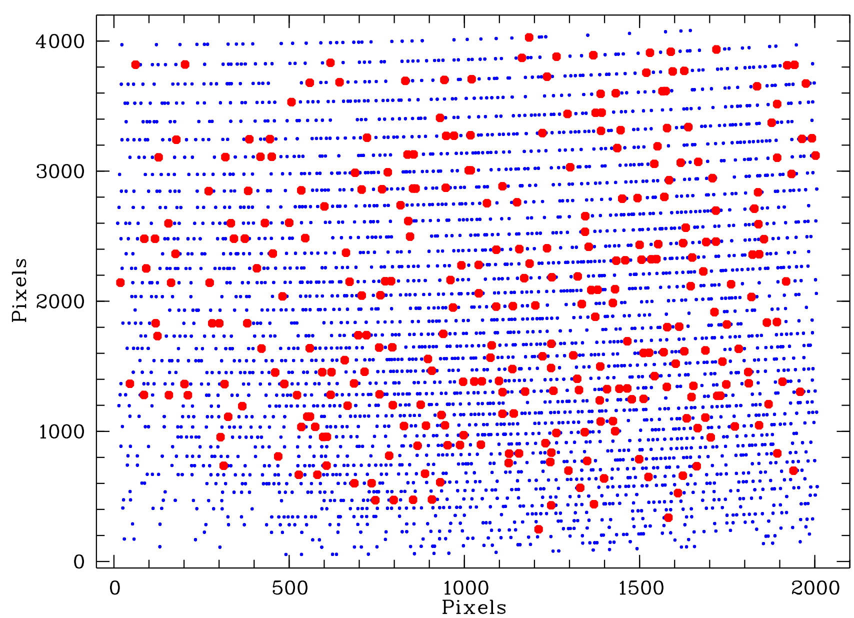

Figure 4: The distribution of finally selected lines is shown with red filled circles.

All ~ 3000 emission lines detected in the first fiber of one 2D ThAr spectrum are shown in Figure 2. The distribution of the peak intensities of these detected lines is shown in Figure 3. All lines with the peak intensities in between $1 \cdot 10^5 - 4 \cdot 10^6$ counts were selected for the following analysis. Finally, 307 lines were selected with this criterion.

The X-Y pixel distribution of all finally selected 307 ThAr lines is shown in Figure 4 with red filled circles.

5. For each line of the finally selected 307 lines in each order for all 71 spectra the Gaussian fit was done and 307 tables were formed.

   The difference between X-positions of each line detected at the first and second fibers was calculated. Since this X-difference depends on the order and the order position, the mean value for the X-differences was subtracted for each line that gives a possibility to compare the stability of X-difference for all 307 lines detected for both fibers. Figure 5 shows such a difference for one line.

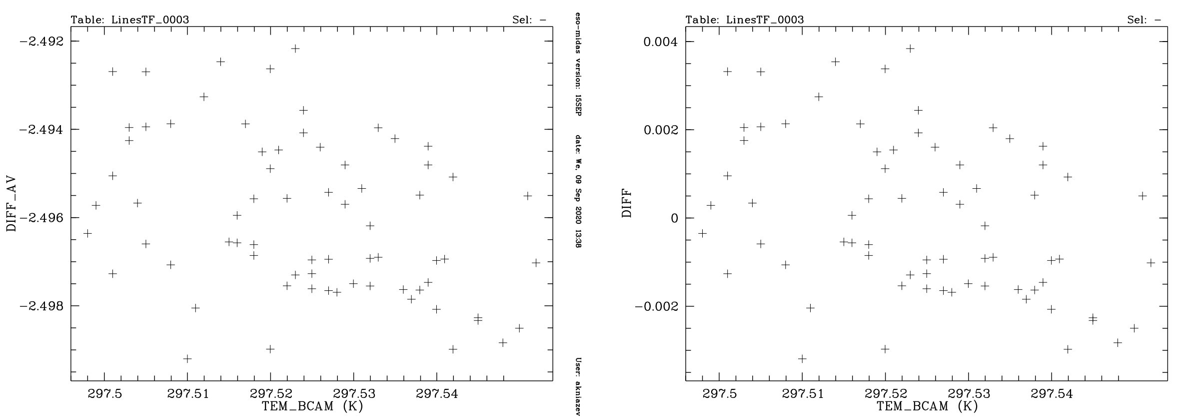

Figure 5: **Left panel:** The difference of X-positions of the same line detected at the first and second fibers for all 71 spectra. **Right panel:** The same distribution after subtraction of the mean value.

6. I have selected 307 lines without any additional analysis about their position, possible blending etc. The following analysis shows that some of them could be easily rejected because their FWHM is very large etc. Simple criteria were applied to reject bad lines and only 252 lines out of 307 were used for the final analysis.

5.1 Results

Now I can analyze all X-difference distributions for the finally selected lines. The difference in the X-positions of the same line detected in both orders could be plotted as it was done in Figure 5, where X-axis could be time or any temperature. Such distributions for each analyzed line do not show any obvious dependencies and could be characterised by its mean value and by the standard deviation. Since the mean value depends on the 2D wavelength transformation of echelle spectra, I removed it from my analysis. So, finally, I assume that the standard deviation of the distribution of the difference in the X-positions of the same line detected in both orders shows to me as an accurate such a difference could be **statistically** measured for **the each particular line**.

For that reason **the distribution** of standard deviations for all analyzed lines give me **the final accuracy** of the stability of HS mode.

The first result is shown in Figure 6, where I plotted the final distribution of standard deviations for all analyzed lines. We can see that the mean value for such a distribution is about 0.002 pixel, where the tail of the distribution goes far to the right and it is logic to suggest that the tail consist of problematic lines for some reason and could be rejected from the final analysis.

In the suggestion that the uniform wavelength step is about 0.04 Å for HRS we can transform the value 0.002 pixel into the final accuracy of about 5 m/s at the wavelength of Hβ line (4861 Å). In reality, it could be slightly better, since this step is less for the blue arm.

Figure 7 presents the distribution of standard deviations from the peak intensity of our analyzed lines. For the each intensity range plotted with blue lines I show the median value plotted with a red filled circle.

This distribution obviously shows that the final accuracy depends on the intensity of analyzed line that is logic. The accuracy for centers of faint lines is the worst because any random factor changes the measured position of their centers drastically. So, the median value is about 0.0026 pixel that is about 1.5 time worse of the mean for the whole distribution. The more intensive line is the more stable center position it shows and there is a range of line intensities exist where accuracy could be as high as about 0.0012–0.0016 pixel. However, starting from some intensity lines started to be saturated and accuracy started to be worse again.

I have plotted with the green line some level of the standard deviations (accuracy), which I was never able to reach with my method of analysis. **This level is about 0.0009 pixel or about 2.2 m/s for Hβ line.**

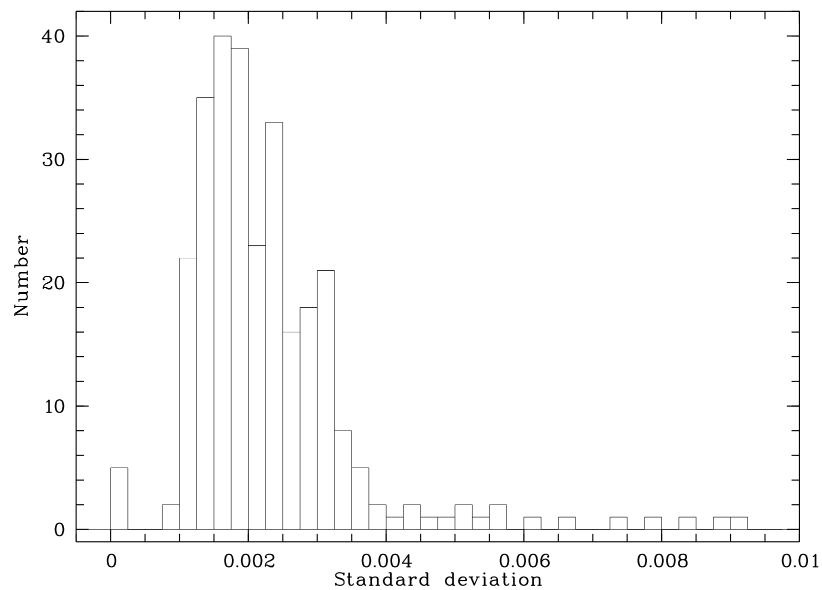

Figure 6: The histogram of the distribution of standard deviations for all analyzed lines. The mean value for such a distribution is about 0.002 pixel.

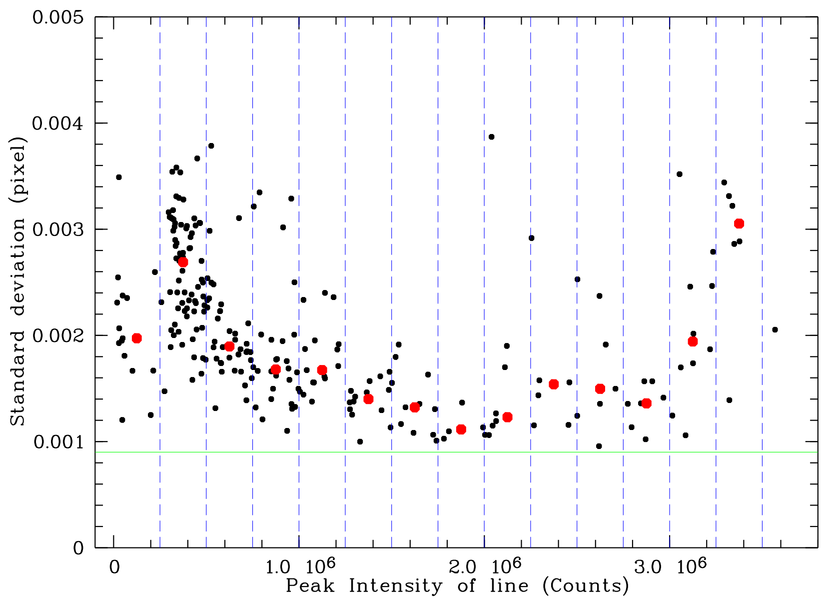

Figure 7: The final distribution of standard deviations of all analyzed lines depending on the Peak Intensity of line. For the each intensity range plotted with blue lines the median value is plotted with the red filled circle.

6 Stability by the frame-by-frame analysis

The second way I have tried was suggested by Dr. Arpita Roy and consist of the general idea to check the stability of the whole system of lines from one fiber relatively to another and check this stability with time for the whole system of our set of data.

The general algorithm of this test could be explained in the following steps:

1. I used all analysis results explained in Section 5 for the selection of 252 lines, positions of which could be measured very accurate, since they are separate and not blended lines in the very good range of their intensities.

2. The first frame was assign as a reference frame.

3. I calculated the difference in line position between each frame and the reference frame for all selected lines of the first fiber, and take the median and/or mean value of that. This is the absolute drift of the first fiber.

4. Repeat above step for the second fiber. This is the absolute drift of the second fiber. This absolute drift of the mean position is plotted in Figure 8 and shows that each fiber has absolute drift of the mean value at about 0.04 pixel during these two days of tests or about 2.5 km/s at the wavelength of Hβ line (4861 Å). The plot of the median value shows absolute the same tendency and amplitude.

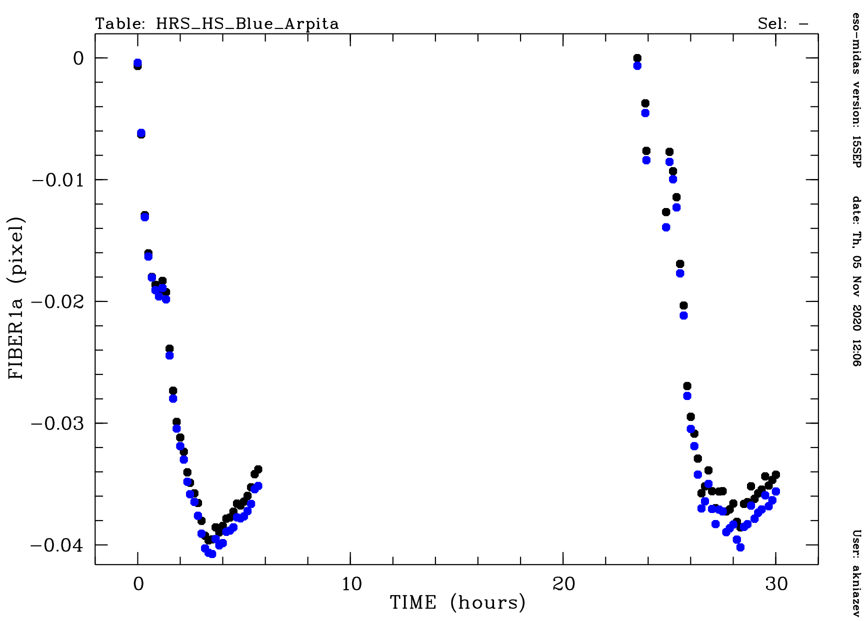

Figure 8: The absolute drift of the mean (median shows the same) position with time of each fiber. The mean position for the first fiber is shown with black symbols and for the second fiber is shown with blue symbols. Time is shown in hours and covers two days with night of observations in between them.

5. Now, plot the drift of the first fiber minus drift of the second fiber. This is the instrument drift and it is plotted in Figure 9.

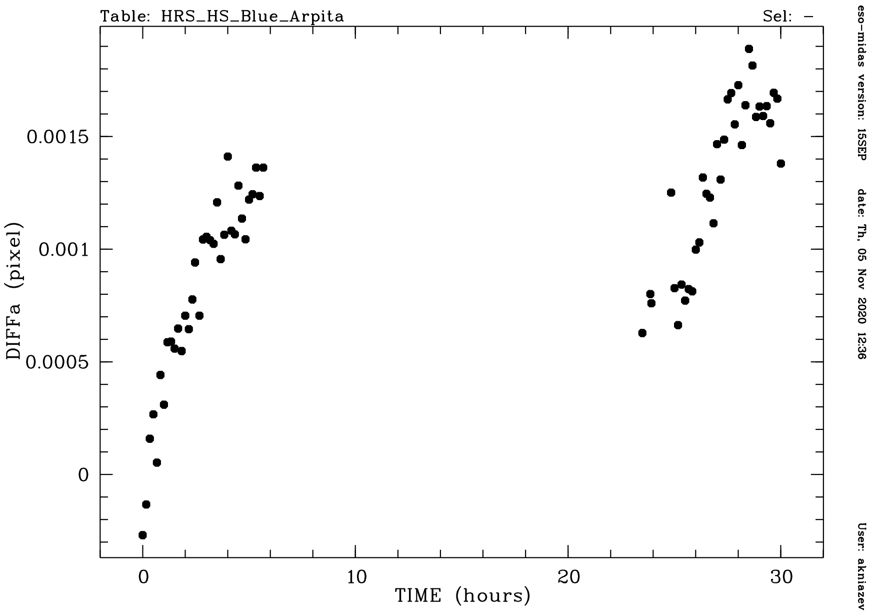

Figure 9: The instrument drift calculated for the set of test data.

6.1 Results

As it is possibly see in Figure 9 we have the final accuracy very close to the described one in Section 5. The current result shows that the absolute drift of the HRS blue arm is **below** of 0.002 pixel or could recalculated as about 5 m/s at the wavelength of Hβ line (4861 Å). All data **below of that level** obviously show some systematic trend.

Can we remove this trend out of our data? I analyzed this dependency on the different temperatures specified in FITS-headers for all HRS data: (1) SDSU controller temperature, (2) HRS environment air temperature, (3) Blue camera temperature, (4) Collimator mount temperature, (5) Echelle mount temperature, (6) Optical bench temperature, (7) Vacuum chamber wall temperature. All these parameters shows about the same dependence and finally I have selected "Blue camera temperature" as the most obvious for me. Such a dependence and its approximation with the second order polynomial is shown in Figure 10. Point from two different days of tests are plotted with different color to show that all data belong to the same dependence. The rms of approximation is 0.000152 pixel.

The final Figure 11 shows the instrumental drift (black symbols) and the same drift after I subtracted the temperature dependence approximation from it (blue symbols). The final distribution has mean value as zero with very high accuracy and rms 0.000152 pixel that means is is dominated by the accuracy of approximation of the temperature dependence. The rms 0.000152 pixel relates to the accuracy of about 40 cm/s at the wavelength of Hβ line (4861 Å).

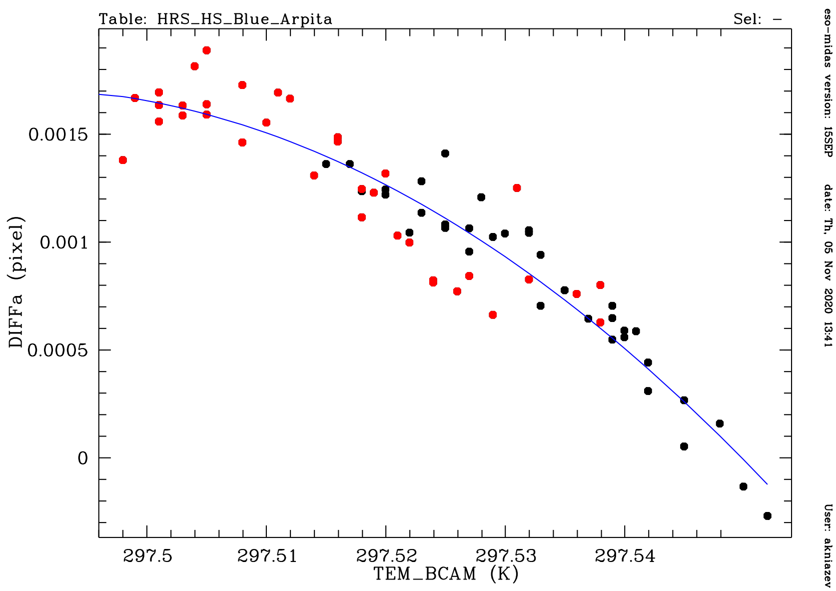

Figure 10: The dependence of the instrument drift on the blue camera temperature for the HRS blue arm data. Black and red points shows data taken during two different days of tests, where night time observations were taken in between. Blue curved line shows approximation with the second order polynomial.

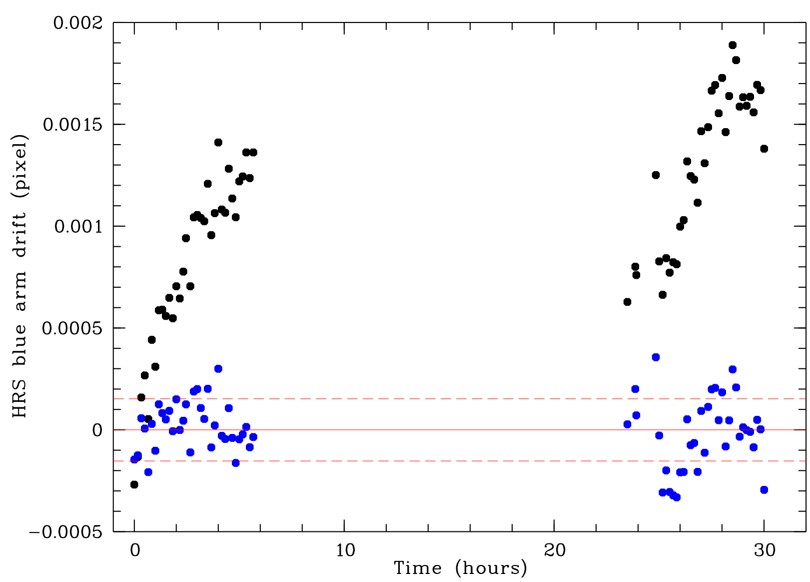

Figure 11: The final result which shows the instrumental drift (black symbols) and the same drift after I subtracted the temperature dependence approximation from it (blue symbols). The final distribution has mean value as zero with very high accuracy and rms 0.000152 pixel that means is is dominated by the accuracy of approximation of the temperature dependence.

7 Conclusions

I see some conclusions as the result of my analysis:

1. The average accuracy in the optimal region of ThAr line intensities is close to 0.0015 pixel or 3.5–3.7 m/s at the wavelength of Hβ line.

2. The HRS blue arm instrument drift is about 3. m/s without taking into account the temperature dependence.

3. After correction for the temperature dependence that could be approximated by the second order polynomial, I found that **the final number for the HRS blue arm instrument drift is 0.000152 pixel that relates to the accuracy of about 40 cm/s at the wavelength of Hβ line (4861 Å)!**

8 Postscriptum

I think that the most important next step of the HRS Stability data analysis has to be the analysis of all taken HRS High Stability data for the Reference Fiber to check the general existence and stability of the temperature dependence described in the Section 6.1 since take it into account could improve the instrument drift down to 40 cm/s.