Southern African Large Telescope

Title: **HRS pipeline for LR blue-arm data with MIDAS**

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Doc. number: **HRS0000005**

Version: **1.0**

Date: *August 17, 2016*

Keywords: HRS, Pipeline

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ABSTRACT

In this report I present a pipeline for the High Resolution Spectrograph (HRS) blue-arm data taken in Low Resolution (LR) mode. This pipeline was implemented using standard system of astronomical data reduction MIDAS. All programs were written in MCL (MIDAS Command Language) and were developed and debugged by me within a total time of **about four hours**. *MCL programs are based on the standard MIDAS echelle packages* `FEROS` *and* `ECHELLE`. *I present here results of my work.*

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LT. JERRY MOUSE

1 Introduction

After making MIDAS working to reduce HRS red-arm data in all modes I make an experiment will it be possible for me to reduce HRS blue-arm data taken in LR mode. I modified all procedures for work with LR blue-arm mode. It took a total time of about four hours. In the current report I will display shortly results of this work.

2 HRS LR blue-arm data reduction implementation

2.1 Order Definition

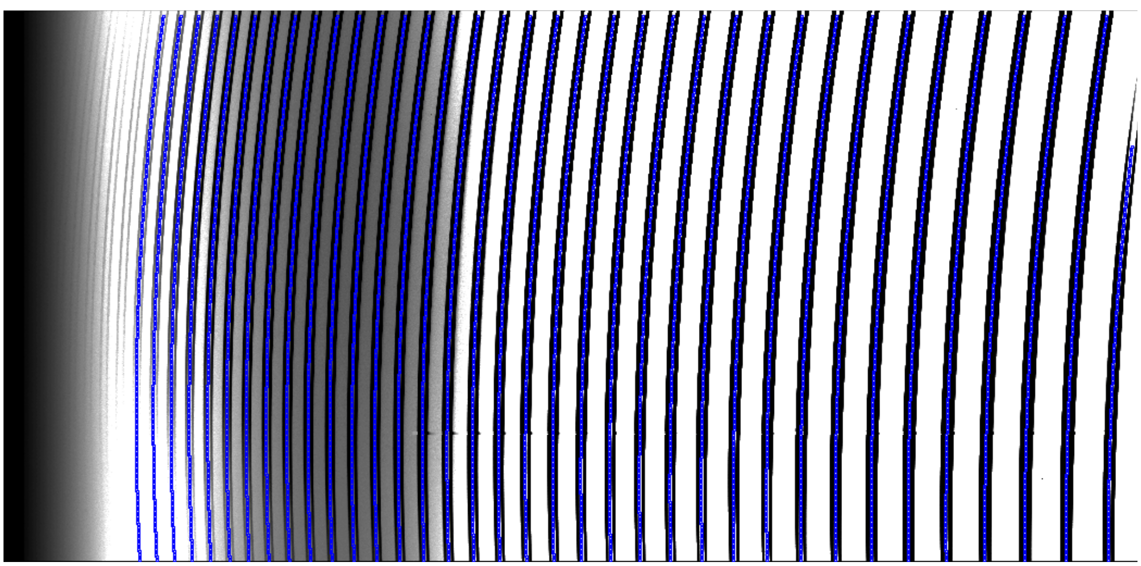


Figure 1: An example of order definition with `DEFINE/FEROS` procedure for HRS LR blue-arm flat-field image. The whole image is shown.

It is absolutely similar to LR red-arm mode. Template was created using FLAT image for HRS LR blue-arm data. With this template `FEROS` package program `DEFINE/FEROS` found 36 echelle orders in FLAT data up to the echelle order with absolute number 119. There are more blue orders is posible to define potentially, but only using not very red QTH lamps, but very blue star like white dwarf. The result of work of `DEFINE/FEROS` procedure is shown in Figure 1.

2.2 Background Definition

It is absolutely similar to all modes with red-arm data.

2.3 Order Extraction

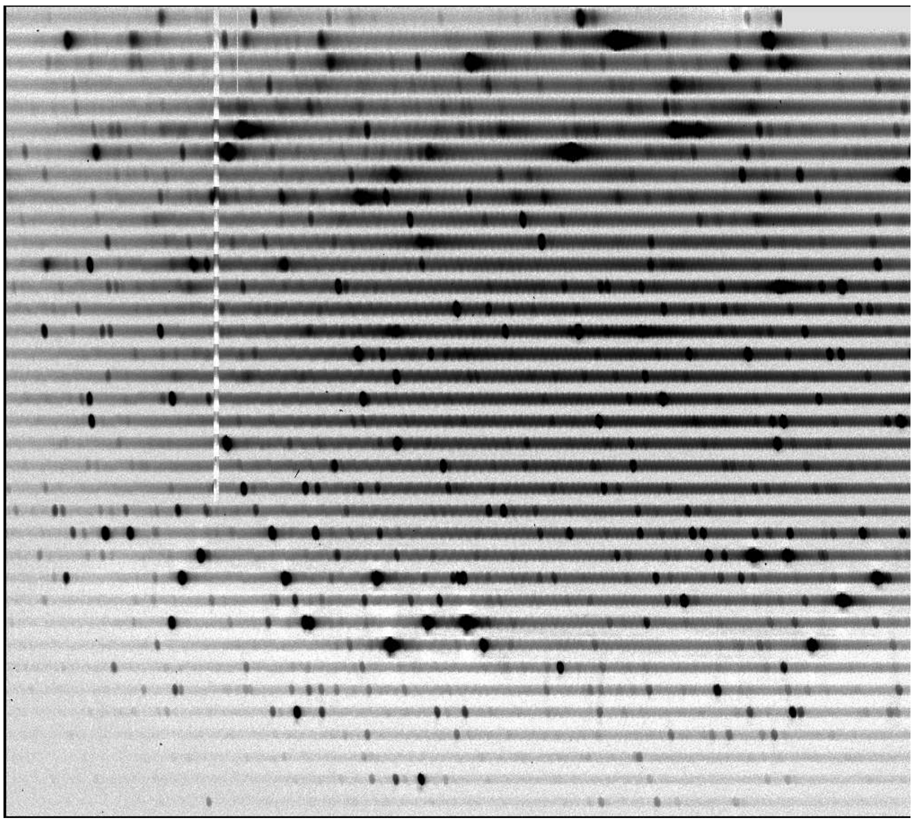


Figure 2: Rectified ThAr+Ar ARC spectrum from Sky fiber. There is bunch of bad columns is located at the top-left part of the image. Each blue-arm 2D spectrum has this feature.

It is absolutely similar to all modes with red-arm data. An example of the work of this procedure is shown in Figure 2. All defined 36 orders are visible.

2.4 Flat Field Correction

I did the flat-field correction for all objects from HRS data after their orders were extracted. This step is absolutely similar to LR red-arm mode.

2.5 Wavelength Calibration

`SEARCH/ECHELLE` command finds ∼650 lines in all 36 orders for each extracted fiber in case of HRS LR blue-arm data.

I use the TWO-D method with initial interactive identification for the same 14 different not bright lines, which are located more or less uniformly across 2D ARC frame as I did for LR red-arm mode. Final solution was saved after that with `SAVE/ECHELLE` procedure for each fiber and used for all next wavelength calibrations in GUESS mode, where new found line positions in extracted ARC spectra are cross-correlated with previous solution, identified and new solution is found automatically.

An examples for such solution for both object and sky fibers are shown in Figures 3,4,5 and 6. This is the standard output from `IDENTIFY/ECHELLE` procedure. It shows the absolute number of spectral order, amount of finally used lines to build wavelength solution, calculated starting and final wavelengths as well as the standard deviation. I present here two types of solutions – the global 2D solution only and mode, when after the global 2D solution, the coefficients are computed independently for each order. In the second mode, when the amount of finally identified lines is less than required the global bivariate polynomial solution is used for these orders.

Figure 7 shows the distribution in wavelength of residuals for each finally used lines from ARC. Blue lines show the standard deviation level.

Figure 8 shows quality of the wavelength calibration in the way that edges of two adjacent orders are shown in the blue and red parts of spectra.

2.6 Order Merging

It is absolutely similar to all modes with red-arm data.

Figures 9 and 10 show examples of the final reduction for one candidate to LBV star and the central star SAO 244567 of young planetary nebulae from my observational programs after all 36 orders were merged in one spectrum. For orders bluer of ∼4300 Å correction for the FLAT gives very bad result, where for the redder orders it looks very nice. *Different reasons could be for that and this question needs to be studied carefully.*

2.7 The Final Sky Subtraction

The sky subtraction was done in the same manner as it was explained in the previous report. Fortunately, there is no any sky input in data for sky fiber. For that reason sky subtraction is useless and only data for the object fiber have to be used in most data.

```
 POLYNOMIAL DEGREE :   3
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
         ORDER                                  ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1       119         2   3889.62   3941.10    0.00368 *FROM 2D SOLUTION*
      2       118         0   3922.63   3974.43   99.99999 *FROM 2D SOLUTION*
      3       117         2   3956.21   4008.33    0.00986 *FROM 2D SOLUTION*
      4       116         4   3990.36   4042.82    0.00566 *FROM 2D SOLUTION*
      5       115         2   4025.11   4077.91    0.00208 *FROM 2D SOLUTION*
      6       114         2   4060.46   4113.62    0.00271 *FROM 2D SOLUTION*
      7       113         4   4096.44   4149.96    0.00533 *FROM 2D SOLUTION*
      8       112         3   4133.07   4186.96    0.00621 *FROM 2D SOLUTION*
      9       111         6   4170.35   4224.62    0.00896 *FROM 2D SOLUTION*
     10       110        11   4208.30   4262.97    0.00655 *FROM 2D SOLUTION*
     11       109         8   4246.95   4302.03    0.00914 *FROM 2D SOLUTION*
     12       108        10   4286.32   4341.81    0.00724 *FROM 2D SOLUTION*
     13       107        15   4326.42   4382.34    0.00591 *FROM 2D SOLUTION*
     14       106        11   4367.27   4423.63    0.00449 *FROM 2D SOLUTION*
     15       105        11   4408.90   4465.72    0.00624 *FROM 2D SOLUTION*
     16       104        11   4451.33   4508.61    0.00901 *FROM 2D SOLUTION*
     17       103        12   4494.57   4552.34    0.00942 *FROM 2D SOLUTION*
     18       102         8   4538.66   4596.93    0.00600 *FROM 2D SOLUTION*
     19       101         8   4583.62   4642.41    0.00774 *FROM 2D SOLUTION*
     20       100         5   4629.48   4688.79    0.00471 *FROM 2D SOLUTION*
     21        99         8   4676.26   4736.11    0.00558 *FROM 2D SOLUTION*
     22        98         8   4723.99   4784.40    0.00509 *FROM 2D SOLUTION*
     23        97         7   4772.70   4833.69    0.00519 *FROM 2D SOLUTION*
     24        96         9   4822.42   4884.01    0.00697 *FROM 2D SOLUTION*
     25        95         5   4873.18   4935.38    0.00820 *FROM 2D SOLUTION*
     26        94         7   4925.01   4987.85    0.00811 *FROM 2D SOLUTION*
     27        93         4   4977.95   5041.45    0.00798 *FROM 2D SOLUTION*
     28        92         3   5032.04   5096.22    0.00360 *FROM 2D SOLUTION*
     29        91         4   5087.32   5152.19    0.00974 *FROM 2D SOLUTION*
     30        90         5   5143.81   5209.40    0.01240 *FROM 2D SOLUTION*
     31        89         3   5201.57   5267.90    0.00970 *FROM 2D SOLUTION*
     32        88         2   5260.63   5327.73    0.00649 *FROM 2D SOLUTION*
     33        87         2   5321.04   5388.94    0.00934 *FROM 2D SOLUTION*
     34        86         5   5382.85   5451.57    0.00911 *FROM 2D SOLUTION*
     35        85         1   5446.11   5515.67    0.00959 *FROM 2D SOLUTION*
     36        84         0   5510.86   5581.30   99.99999 *FROM 2D SOLUTION*
 ---------------------------------------------------------
       MEAN RMS:   0.00701
** TOTAL NUMBER OF LINES :    208 **
Set parameter SAMPLE=0.0424258187
```

Figure 3: Wavelength solution in 2D mode, when the coefficients are derived from a global 2D solution. Solution for the fiber with object (fiber number two in LR mode) is shown.

```
 POLYNOMIAL DEGREE :   3
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
         ORDER                                  ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1       119         3   3889.62   3941.10    0.05177 *NOT ENOUGH LINES*
      2       118         3   3922.63   3974.43    0.15177 *NOT ENOUGH LINES*
      3       117         3   3956.21   4008.33    0.03512 *NOT ENOUGH LINES*
      4       116         6   3990.03   4042.86    0.00389
      5       115         9   4025.14   4077.89    0.00809
      6       114        11   4060.50   4113.59    0.00767
      7       113         7   4096.39   4150.25    0.00324
      8       112         7   4133.38   4186.88    0.00412
      9       111         8   4170.35   4224.61    0.00557
     10       110        13   4208.32   4262.97    0.00607
     11       109        12   4246.92   4302.02    0.00708
     12       108        10   4286.31   4341.79    0.00645
     13       107        20   4326.38   4382.36    0.00542
     14       106        15   4367.23   4423.67    0.00534
     15       105        12   4408.84   4465.74    0.00581
     16       104        11   4452.35   4508.38    0.00932
     17       103        12   4494.49   4552.37    0.00663
     18       102        11   4538.64   4596.95    0.00782
     19       101        10   4583.59   4642.41    0.00719
     20       100         9   4629.43   4688.82    0.00676
     21        99        11   4676.24   4736.11    0.00776
     22        98        12   4723.95   4784.24    0.00774
     23        97        13   4772.67   4833.66    0.00742
     24        96        17   4822.37   4884.00    0.00600
     25        95        10   4873.13   4935.40    0.00910
     26        94         8   4924.99   4987.85    0.00331
     27        93         7   4977.90   5041.52    0.00268
     28        92         6   5031.99   5096.41    0.00385
     29        91         8   5087.36   5152.17    0.00989
     30        90        10   5143.82   5209.58    0.00264
     31        89         9   5201.62   5267.92    0.00947
     32        88         6   5260.71   5327.53    0.00811
     33        87         5   5321.12   5388.98    0.01528
     34        86         8   5382.95   5451.36    0.00992
     35        85         6   5446.17   5515.85    0.00906
     36        84         0   5510.86   5581.30   99.99999 *NOT ENOUGH LINES*
 ---------------------------------------------------------
       MEAN RMS:   0.00689
** TOTAL NUMBER OF LINES :    328 **
Set parameter SAMPLE=0.0424258187
```

Figure 4: Wavelength solution in 1D mode shown, when after the global 2D solution, the coefficients are computed independently for each order. Solution for the fiber with object (fiber number two in LR mode) is shown.

```
 POLYNOMIAL DEGREE :   3
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
          ORDER                                  ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1       119         2   3889.69   3940.91    0.00174 *FROM 2D SOLUTION*
      2       118         0   3922.67   3974.26   99.99999 *FROM 2D SOLUTION*
      3       117         0   3956.22   4008.17   99.99999 *FROM 2D SOLUTION*
      4       116         5   3990.35   4042.67    0.00370 *FROM 2D SOLUTION*
      5       115         3   4025.07   4077.77    0.00538 *FROM 2D SOLUTION*
      6       114         6   4060.41   4113.49    0.00532 *FROM 2D SOLUTION*
      7       113         3   4096.38   4149.84    0.00590 *FROM 2D SOLUTION*
      8       112         4   4132.98   4186.84    0.00695 *FROM 2D SOLUTION*
      9       111         6   4170.25   4224.50    0.00786 *FROM 2D SOLUTION*
     10       110        11   4208.20   4262.86    0.00543 *FROM 2D SOLUTION*
     11       109        10   4246.84   4301.92    0.01006 *FROM 2D SOLUTION*
     12       108        11   4286.20   4341.70    0.00570 *FROM 2D SOLUTION*
     13       107        15   4326.29   4382.23    0.00421 *FROM 2D SOLUTION*
     14       106        12   4367.14   4423.52    0.00730 *FROM 2D SOLUTION*
     15       105        10   4408.76   4465.61    0.00607 *FROM 2D SOLUTION*
     16       104         9   4451.19   4508.50    0.01103 *FROM 2D SOLUTION*
     17       103         7   4494.43   4552.23    0.00567 *FROM 2D SOLUTION*
     18       102         7   4538.53   4596.81    0.00534 *FROM 2D SOLUTION*
     19       101         7   4583.49   4642.28    0.00704 *FROM 2D SOLUTION*
     20       100         8   4629.34   4688.67    0.00791 *FROM 2D SOLUTION*
     21        99         7   4676.13   4735.99    0.00673 *FROM 2D SOLUTION*
     22        98         7   4723.86   4784.27    0.00619 *FROM 2D SOLUTION*
     23        97         7   4772.57   4833.56    0.00505 *FROM 2D SOLUTION*
     24        96        11   4822.29   4883.87    0.00621 *FROM 2D SOLUTION*
     25        95         8   4873.05   4935.25    0.01072 *FROM 2D SOLUTION*
     26        94         8   4924.89   4987.72    0.00872 *FROM 2D SOLUTION*
     27        93         4   4977.83   5041.32    0.00669 *FROM 2D SOLUTION*
     28        92         3   5031.92   5096.08    0.00628 *FROM 2D SOLUTION*
     29        91         6   5087.20   5152.06    0.01099 *FROM 2D SOLUTION*
     30        90         5   5143.69   5209.28    0.01004 *FROM 2D SOLUTION*
     31        89         3   5201.44   5267.78    0.00895 *FROM 2D SOLUTION*
     32        88         5   5260.50   5327.62    0.01035 *FROM 2D SOLUTION*
     33        87         2   5320.90   5388.84    0.00470 *FROM 2D SOLUTION*
     34        86         3   5382.70   5451.48    0.00851 *FROM 2D SOLUTION*
     35        85         2   5445.94   5515.60    0.00403 *FROM 2D SOLUTION*
     36        84         0   5510.68   5581.25   99.99999 *FROM 2D SOLUTION*
 ---------------------------------------------------------
       MEAN RMS:   0.00666
** TOTAL NUMBER OF LINES :    217 **
Set parameter SAMPLE=0.0429698974
```

Figure 5: Wavelength solution in 2D mode, when the coefficients are derived from a global 2D solution. Solution for the fiber with sky (fiber number one in LR mode) is shown.

```
 POLYNOMIAL DEGREE :   3
 SEQ.NO  SPECTRAL  NO.LINES  WL START    WL END  STD. DEV.
           ORDER                                 ANGSTROEM
 ------  --------  --------  --------    ------  ---------
      1       119         3   3889.69   3940.91    0.05336 *NOT ENOUGH LINES*
      2       118         3   3922.67   3974.26    0.16078 *NOT ENOUGH LINES*
      3       117         1   3956.22   4008.17    0.06603 *NOT ENOUGH LINES*
      4       116         7   3990.94   4042.58    0.00801
      5       115         8   4025.19   4077.70    0.00424
      6       114        12   4060.36   4113.49    0.00682
      7       113         7   4096.33   4150.09    0.00220
      8       112         7   4133.28   4186.77    0.00321
      9       111         8   4170.24   4224.50    0.00541
     10       110        12   4208.19   4262.87    0.00482
     11       109        13   4246.81   4301.90    0.00847
     12       108        11   4286.19   4341.69    0.00471
     13       107        19   4326.27   4382.24    0.00337
     14       106        14   4367.11   4423.54    0.00561
     15       105        11   4408.75   4465.61    0.00541
     16       104         9   4452.25   4508.43    0.00328
     17       103        10   4494.38   4552.26    0.00556
     18       102         9   4538.52   4596.82    0.00667
     19       101         9   4583.46   4642.30    0.00576
     20       100         9   4629.32   4688.68    0.00621
     21        99        10   4676.15   4735.98    0.00254
     22        98        12   4723.82   4784.10    0.00762
     23        97        12   4772.54   4833.52    0.00594
     24        96        18   4822.25   4883.87    0.00714
     25        95        11   4873.01   4935.27    0.00744
     26        94        10   4924.86   4987.71    0.00752
     27        93         7   4977.80   5041.31    0.00407
     28        92         7   5031.79   5096.28    0.00538
     29        91         9   5087.23   5152.08    0.00730
     30        90         9   5143.69   5209.48    0.00625
     31        89         7   5201.71   5267.77    0.00147
     32        88         9   5260.60   5327.32    0.00852
     33        87         5   5320.99   5388.82    0.00639
     34        86         7   5382.76   5451.43    0.00402
     35        85         5   5446.04   5515.68    0.00440
     36        84         0   5510.68   5581.25   99.99999 *NOT ENOUGH LINES*
 ---------------------------------------------------------
       MEAN RMS:   0.00628
** TOTAL NUMBER OF LINES :    320 **
Set parameter SAMPLE=0.0429698974
```

Figure 6: Wavelength solution in 1D mode shown, when after the global 2D solution, the coefficients are computed independently for each order. Solution for the fiber with sky (fiber number 0, LR mode) is shown.

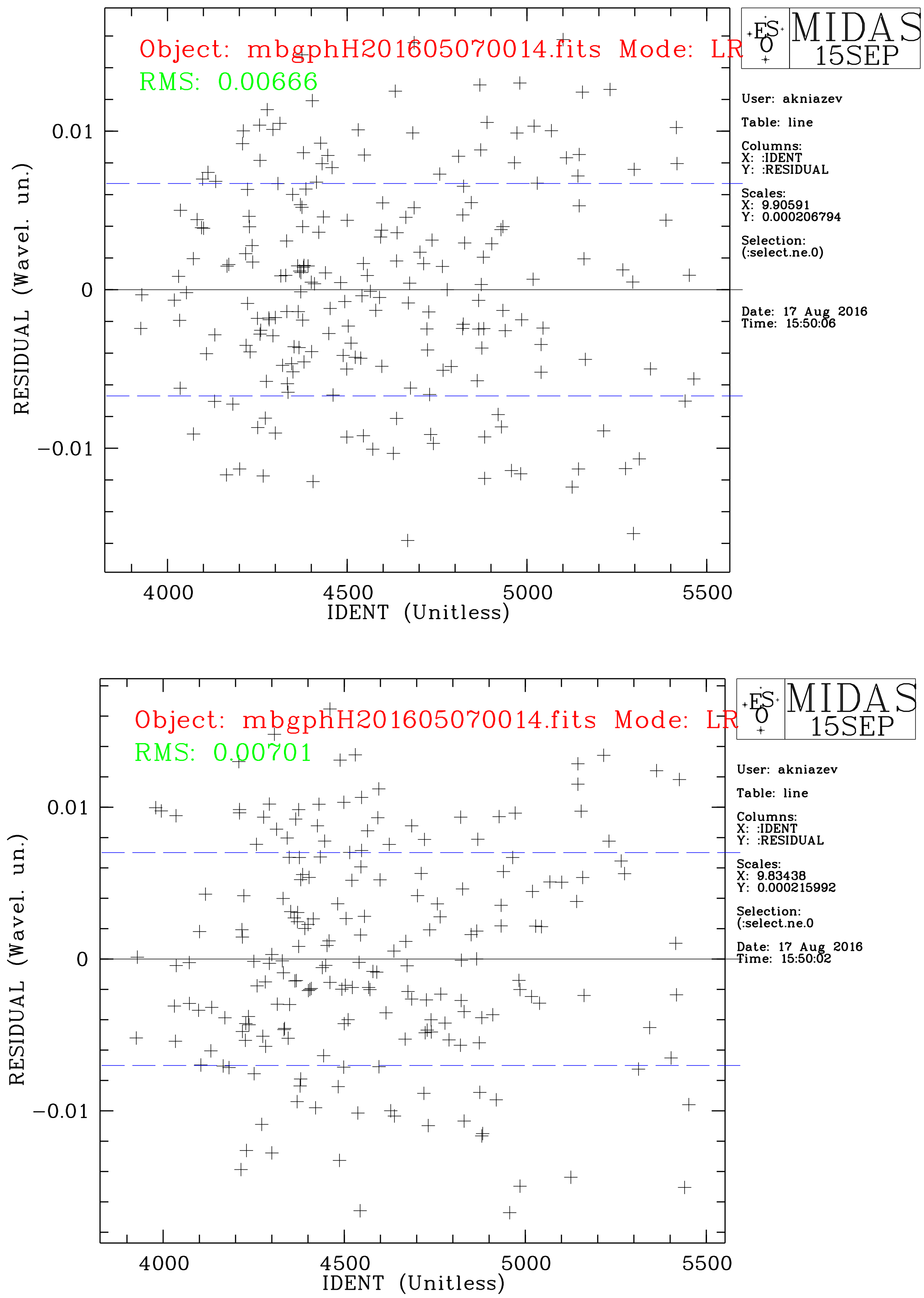


Figure 7: The distribution in wavelength of residuals for each finally used lines from ARC. Blue lines show the standard deviation level. The top panel shows this distribution for the first fiber and the bottom panel shows is for the second fiber. Both pictures are for the 2D solution only.

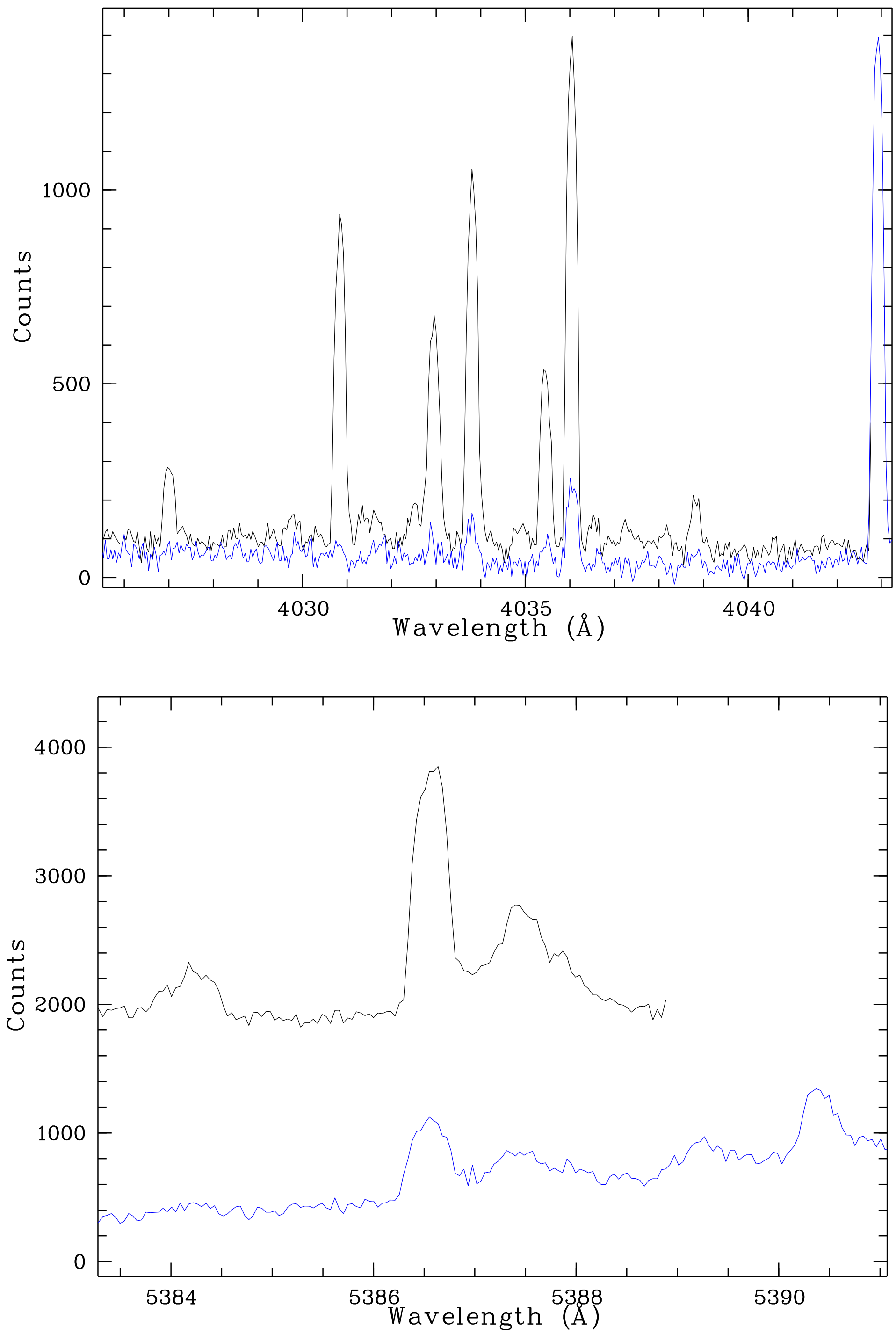
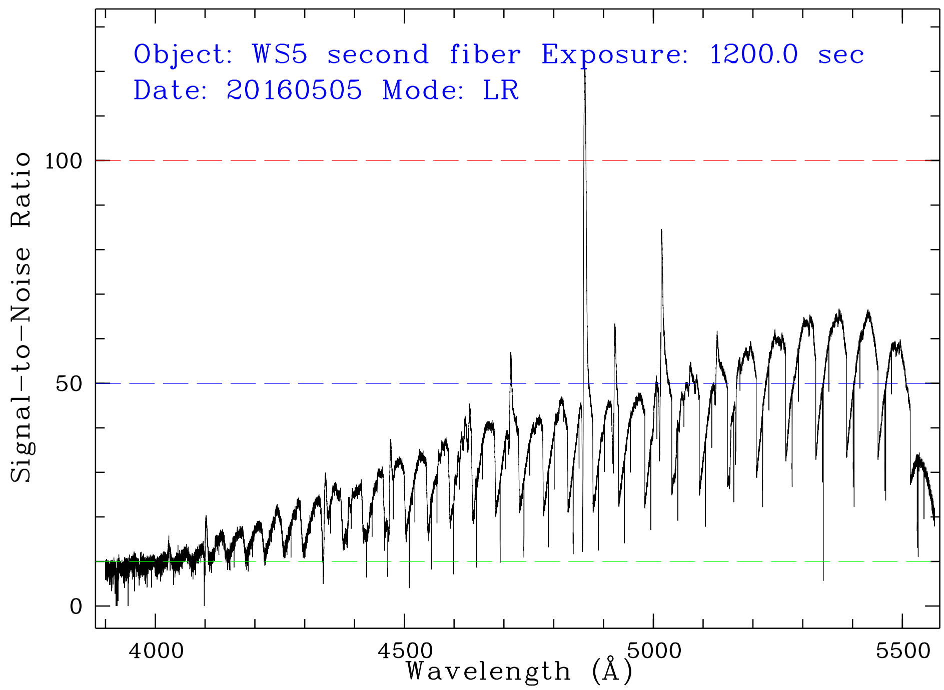


Figure 8: Two examples of edges for adjacent orders from wavelength calibrated ARC spectrum. Different orders are shown with different color. Blue (top) and red (bottom) spectral regions are shown.



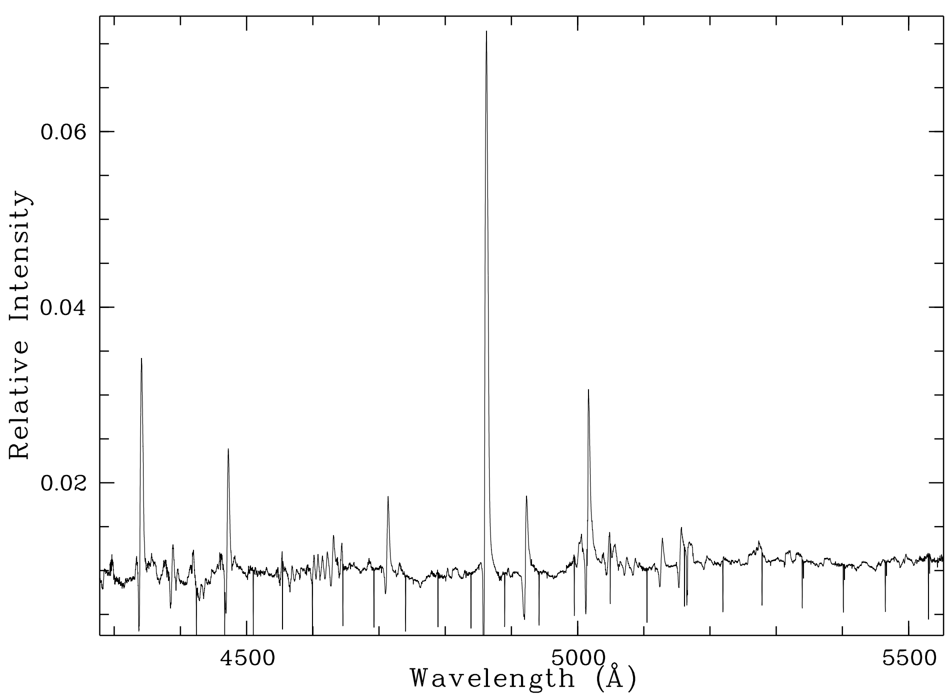


Figure 9: *Top:* Merged spectrum of new LBV candidate star without flat-field correction. *Bottom:* The same spectrum, but after flat-field correction. For orders bluer of ∼4300 Å correction for the FLAT gives very bad result and these orders are not included in the plot.

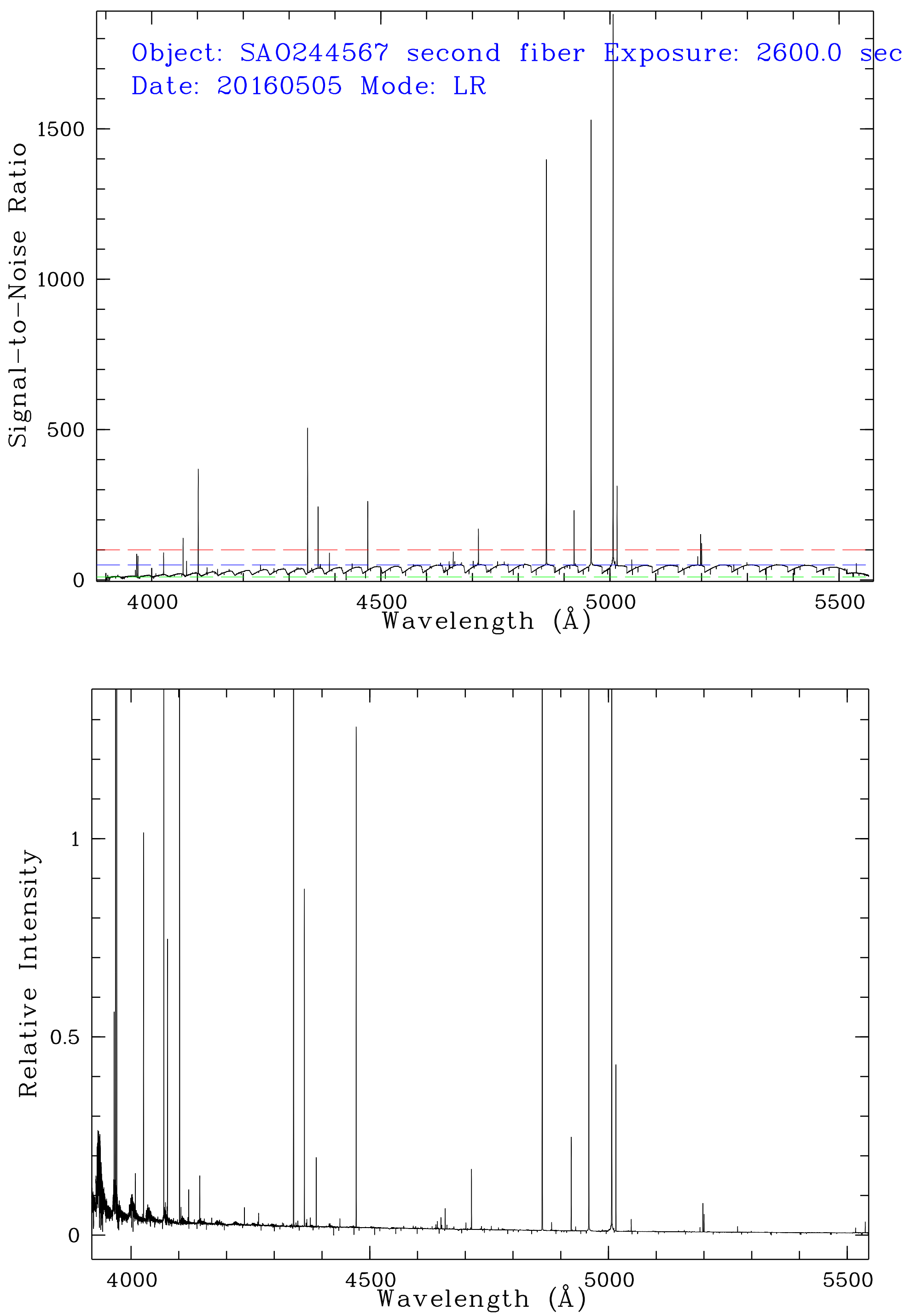


Figure 10: *Top:* Merged spectrum of the central star SAO 244567 of young planetary nebulae from my observational program without flat-field correction. *Bottom:* The same spectrum, but after flat-field correction.

3 MIDAS pipeline for HRS LR blue-arm data

All programs are written in MCL. The total length of the code is 520 MCL strings excluding comments. All steps are summarised into three main procedures:

1. **FLAT reduction**
   During this step FLAT image is reduced. The output of this procedure consist of extracted and smoothed flats for both fibers and file with their ratio.

2. **ARC reduction**
   During this step ARC image is reduced. The output consist of all tables, which are necessary for wavelength calibration of both fibers and extracted, calibrated and merged ThAr+Ar spectra for both fibers.

3. **Object reduction** The output consist of extracted, calibrated and merged spectra for both fibers and result of subtraction of the sky fiber from the object fiber as well as extracted, calibrated but not merged spectra for both fibers.

The output of all procedures is mostly FITS-files except configuration files, which are saved by system in the internal MIDAS format.

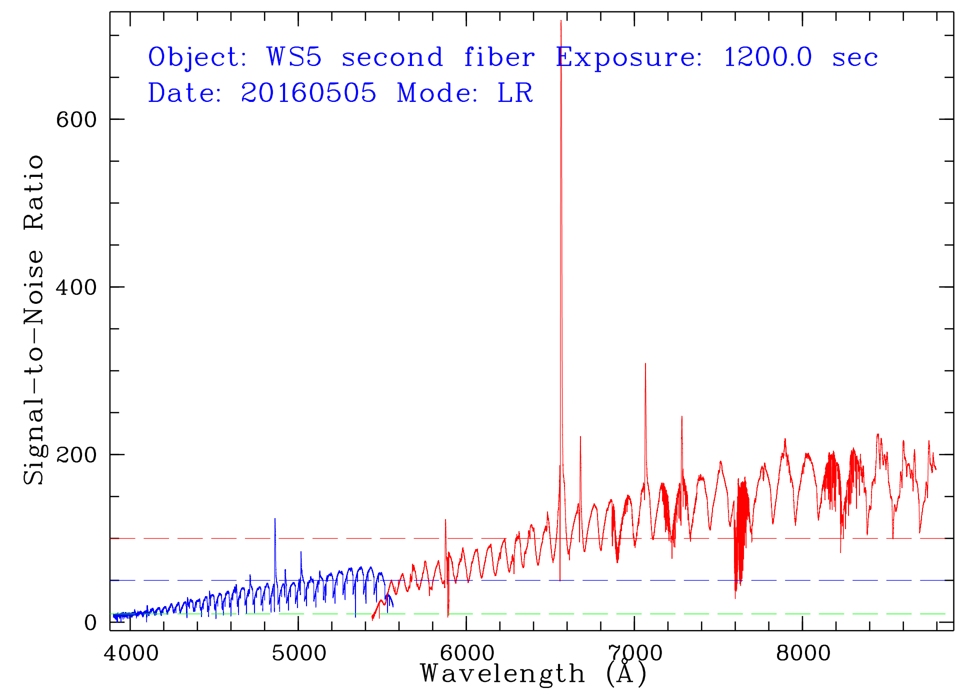
Each procedure has as minimum two modes of work: (1) **visualization mode**, when practically after each step user has a possibility to see and check the result of step, and (2) **silent mode**, when procedures work without any graphical output. Only the ARC reduction procedure has one more interactive mode for the possibility of re-identification of the reference spectrum.

Since the low level programs are implemented with `C` and `FORTRAN` code, reduction works very fast.

4 Conclusions

HRS pipeline for **ALL** HRS LR data is created in MIDAS and works.

Figures 9 and 10 show examples of the final reduction for one candidate to LBV star and the central star SAO 244567 of young planetary nebulae. Data for both blue and red channels are shown.



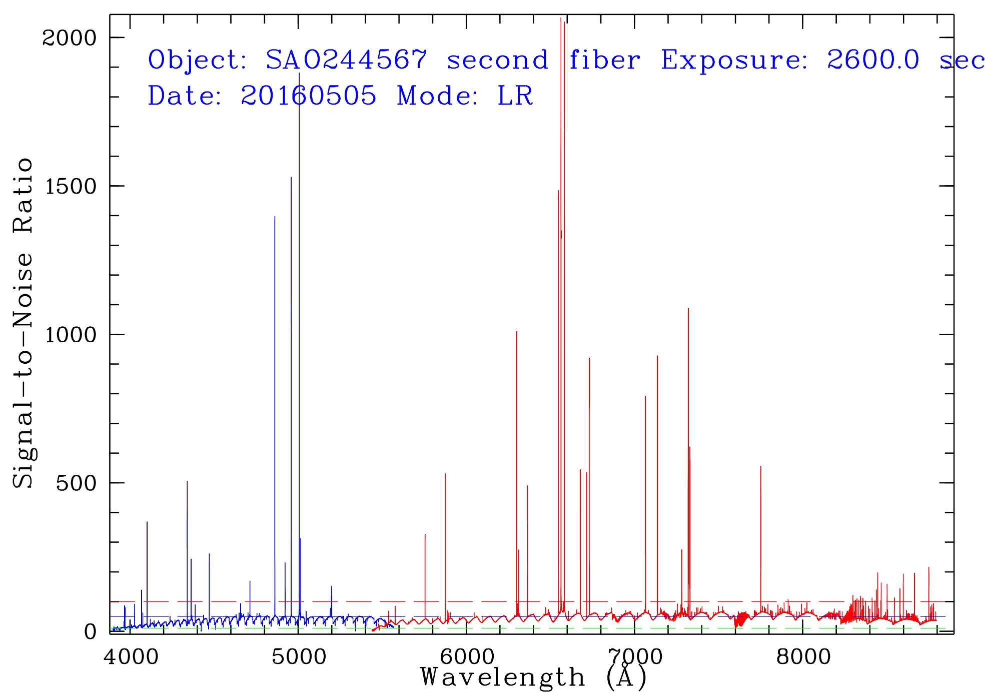


Figure 11: *Top:* The merged spectra of new LBV candidate star without flat-field correction for both blue and red channels data. *Bottom:* The merged spectra of the central star SAO 244567 of young planetary nebulae without flat-field correction for both blue and red channels data.