



Download from dropbox at <http://tinyurl.com/NLO-workshop>

# High Resolution Spectroscopy

## High precision Radial Velocity Measurement

Robin Leadbeater

[www.threehillsobservatory.co.uk](http://www.threehillsobservatory.co.uk)

# Convento group BRITE project

- The Canadian BRITE Constellation is a network of 6 Nano-Satellites measuring brightness variations in bright stars with high precision
- Amateur RV and H alpha line profile measurements coordinated with BRITE measurements of Deneb and P Cygni during summer 2014
- Objective is to better understand the relationship between the pulsations, the variations in the stellar wind and the brightness variations.

(Alpha-Cygni variables could potentially be used as “standard candles” for distance measurement)

<http://spektroskopieforum.vdsastro.de/viewtopic.php?t=4163>

## Planning the Observation

Measure the RV of Deneb from night to night over several months  
Using the Si II 6347, 6371 Å absorption lines

~10km/s range so need long term repeatability ~1km/s RV (0.02Å at 6000 Å)

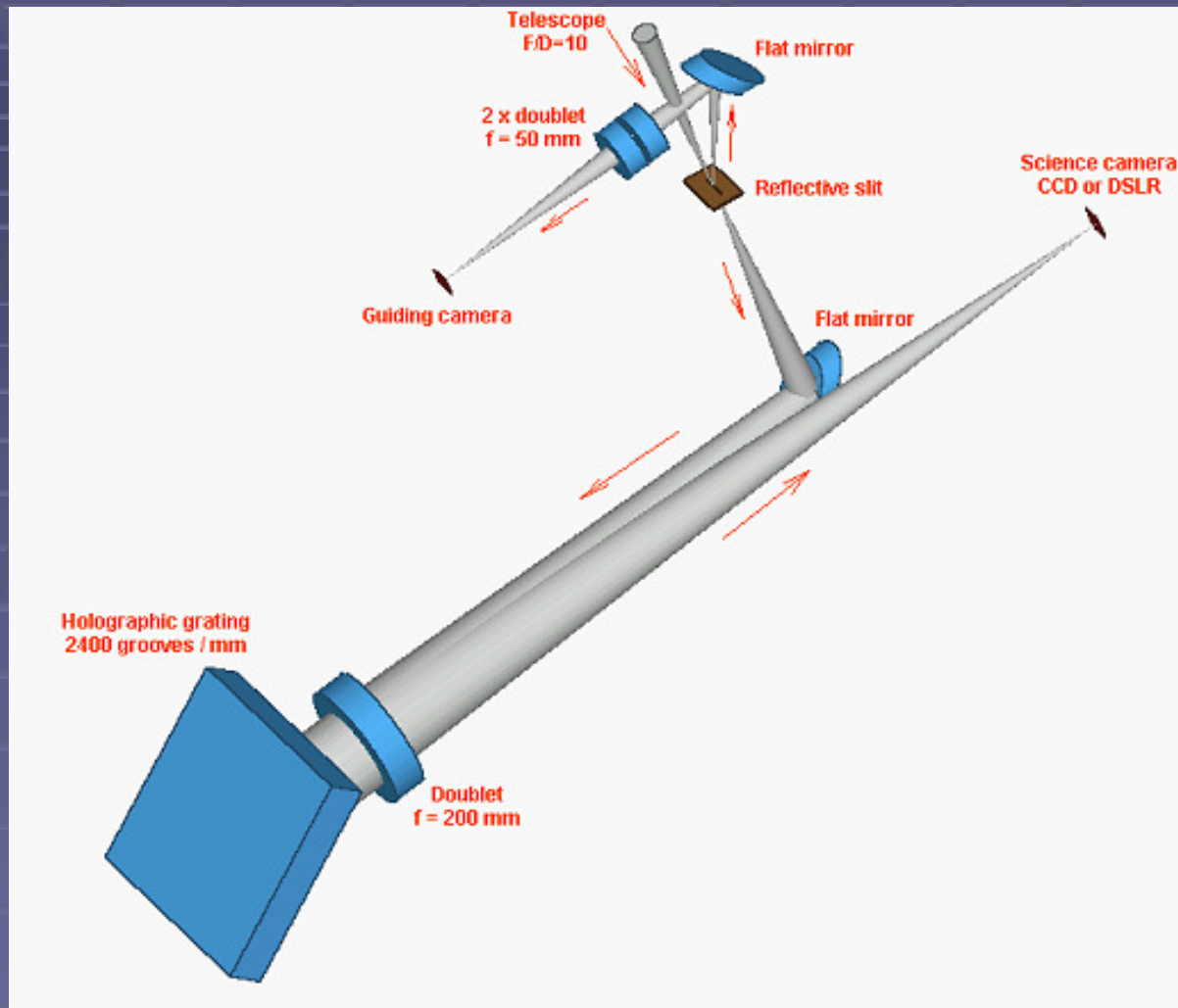
LHIRES III (2400 l/mm) = ~ 15Å/mm (~0.09Å/pixel ATK314L)  
measure the line with a precision and long term repeatability of ~1/5 pixel

Observers' data will be combined to give continuous coverage so  
reproduceability between observers needs to be of the same order

Flexure in LHIRES will potentially exceed this during an observation.  
Internal lamp spectra taken before and after star spectra is usual solution  
Lamp spectrum superimposed directly on the star spectrum for better precision

Also measure an RV reference star (Vega) to verify the precision and accuracy  
and allow data from different observers to be combined,

# LHIRES III Optical Design

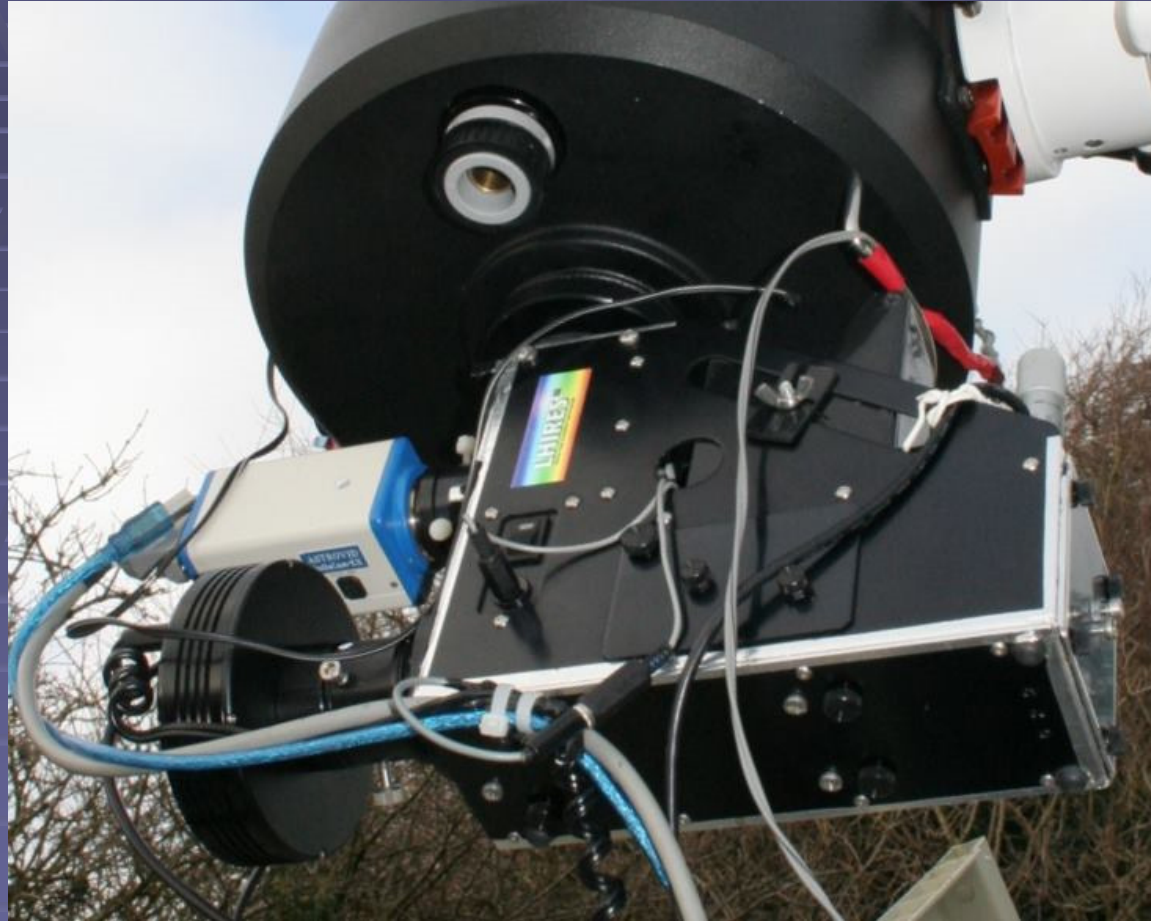


# LHIRES III Installation Three Hills Observatory

Celestron  
C11

Guider  
Camera

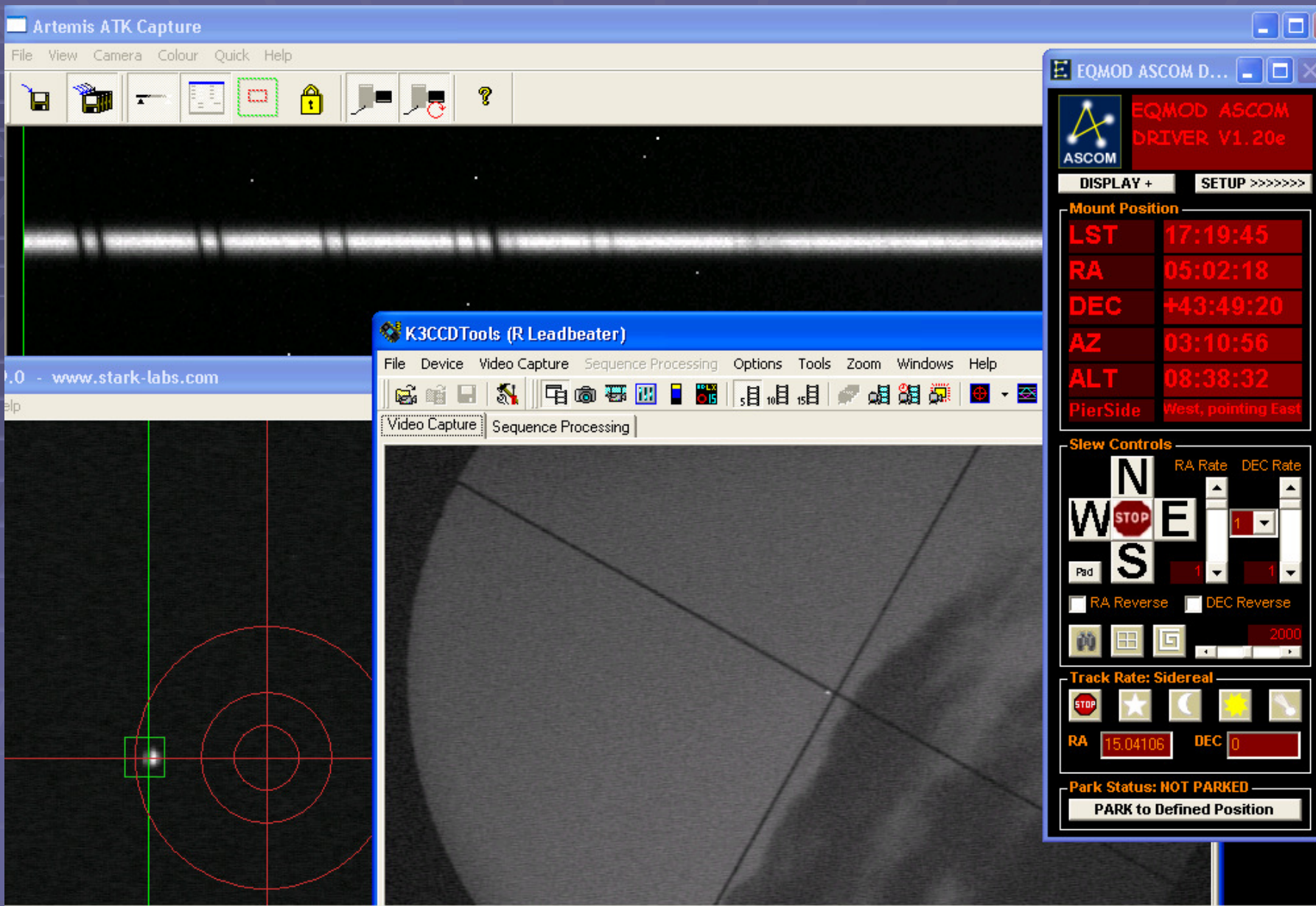
Imaging  
Camera



LHIRES III

$R \sim 15000$  (0.4A) with 2400 l/mm grating





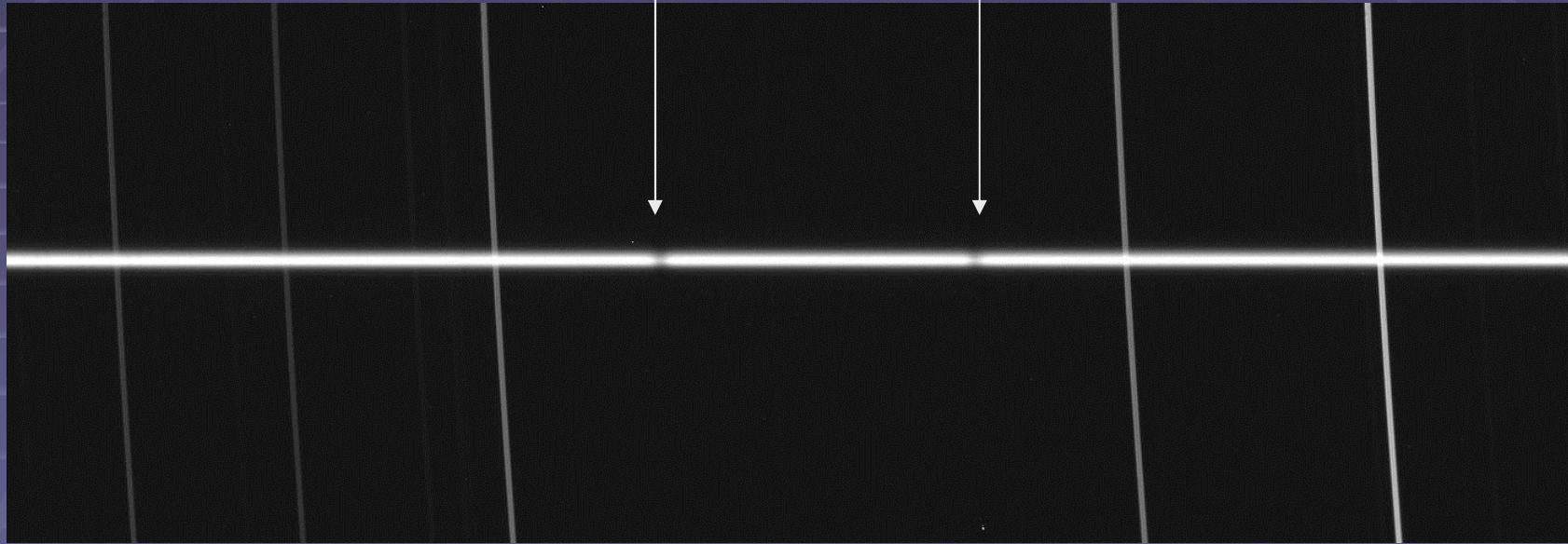
Habitat “Filly Dot” lamp mounted in front of aperture in line with slit



Calibration lines superimposed on star spectrum

# Deneb spectrum image

Si III star lines



Ne lamp lines



# Wavelength Calibration using ISIS "file mode"

## Mean of all star+lamp exposures used for calibration image

ISIS - V5.5.1

1. Image | 2. General | 3. Calibration | 4. Go | 5. Profile | 6. Grunplot | Masters | Tools | Misc | Instruments | Settings

Root name : **deneb** ... Object : **Deneb** **Auto** **Next**

Images to process

Generic name : **deneb\_** ... Number : **8** ...

Calibration : **deneb\_mean** ...  Spectral calibration

Offset : **bias\_ATK314\_20140912** ... Dark : **120s\_thermal\_ATK31420140** ...

Flat : **flat\_LHIRES2400\_ATK314\_2014** ...

General parameters

Pixel size (microns) : **6.45** ...  Fixed Y value for sequence

Cosmetic file : ...  Sky not removed

Instr. responsivity : ...  Wavelength registration

Wavelength shift (A) : **0** ...  Cosmic rays filter

Heliocentric radial velocity correction ...  Optimal binning

Auto atmosphere AOD : **0.13** ... Rejection coef. : **50**

Atmo. transmission : ...  Automatic air mass computing

Spectral calibration

Predefined mode **ALPY 600 ( calibration module )** ...

Predefined dispersion equation ( see "Dispersion" tool in "Profile" tab )

File mode : **\_Sill\_4Ne\_isis\_filemode** ( type xxx.lst )

Output

Instrument : **C11\_LHIRES\_2400\_ATK314** ...

Observatory : **THO robin@threehillsobservatory.co.uk** ...

Observer : **Leadbeater** ...

Hour shift : **0** ... R : **500**

Files name prefix and suffix

Object suffix : **\_**

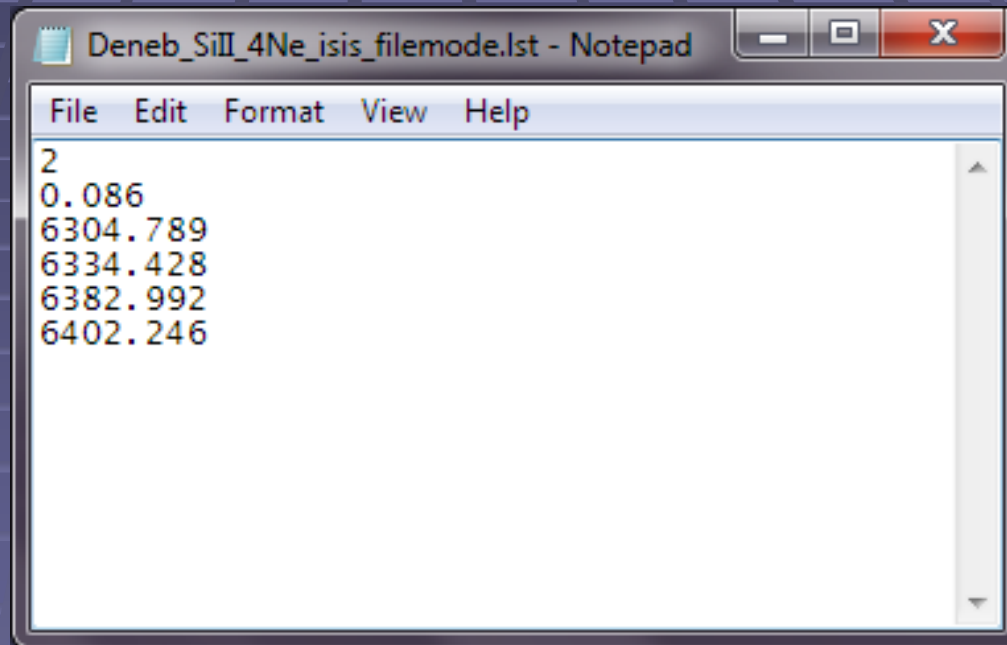
Calibration suffix : **\_**

Calibration prefix : **\_**

ISIS calculates Heliocentric RV correction using SIMBAD coordinates, fits header time and obs coordinates. Note instrument correction not required for this project.

“File mode” file (4 Ne lines 2<sup>rd</sup> order)

order of fit  
dispersion A/pix  
line wavelengths



The image shows a Notepad window titled "Deneb\_SiII\_4Ne\_isis\_filemode.lst - Notepad". The window contains a list of parameters for a spectral fit. The parameters are: order of fit (2), dispersion A/pix (0.086), and four line wavelengths (6304.789, 6334.428, 6382.992, and 6402.246).

```
2  
0.086  
6304.789  
6334.428  
6382.992  
6402.246
```

## Set binning and sky background zones

ISIS - V5.5.1

1. Image | 2. General | 3. Calibration | 4. Go | 5. Profile | 6. Grunplot | Masters | Tools | Misc | Instruments | Settings

Image to process : deneb\_1    Display    < >    Next   

Calibration image : deneb\_mean    Display

Tilt angle : -0.02    Slant angle : 3.29    Vertical coordinate : 539     Auto    Binning zone adjustment

X coordinate of line at wavelength 6304.789    A = 99 (pixels)

Displayed image : c:\users\user\desktop\spectroscopy\_workshop\lhires\_isis\_example\lhires\_2014-10-04T18:36:51\_b\_20141004\deneb\deneb\_1.fit 30.0 s

Seuil haut :     Domain

Seuil bas :    

Graticule

FWHM

Statistic

Tilt

Slant

Smile

Line PSF

X : 760  
Y : 409  
I : 302

Correct tilt and slant and enter wavelength and coordinate of first lamp line

## Run the calibration and check the quality of the fit

ISIS - V5.5.1

1. Image | 2. General | 3. Calibration | **4. Go** | 5. Profile | 6. Grunplot | Masters | Tools | Misc | Instruments | Settings

Object name : Deneb

Instrument : C11\_LHIRES\_1200\_ATK314

Observatory : THO robin@threehillsobservatory.co

Observer : Leadbeater

**Go for process**

Go Stop

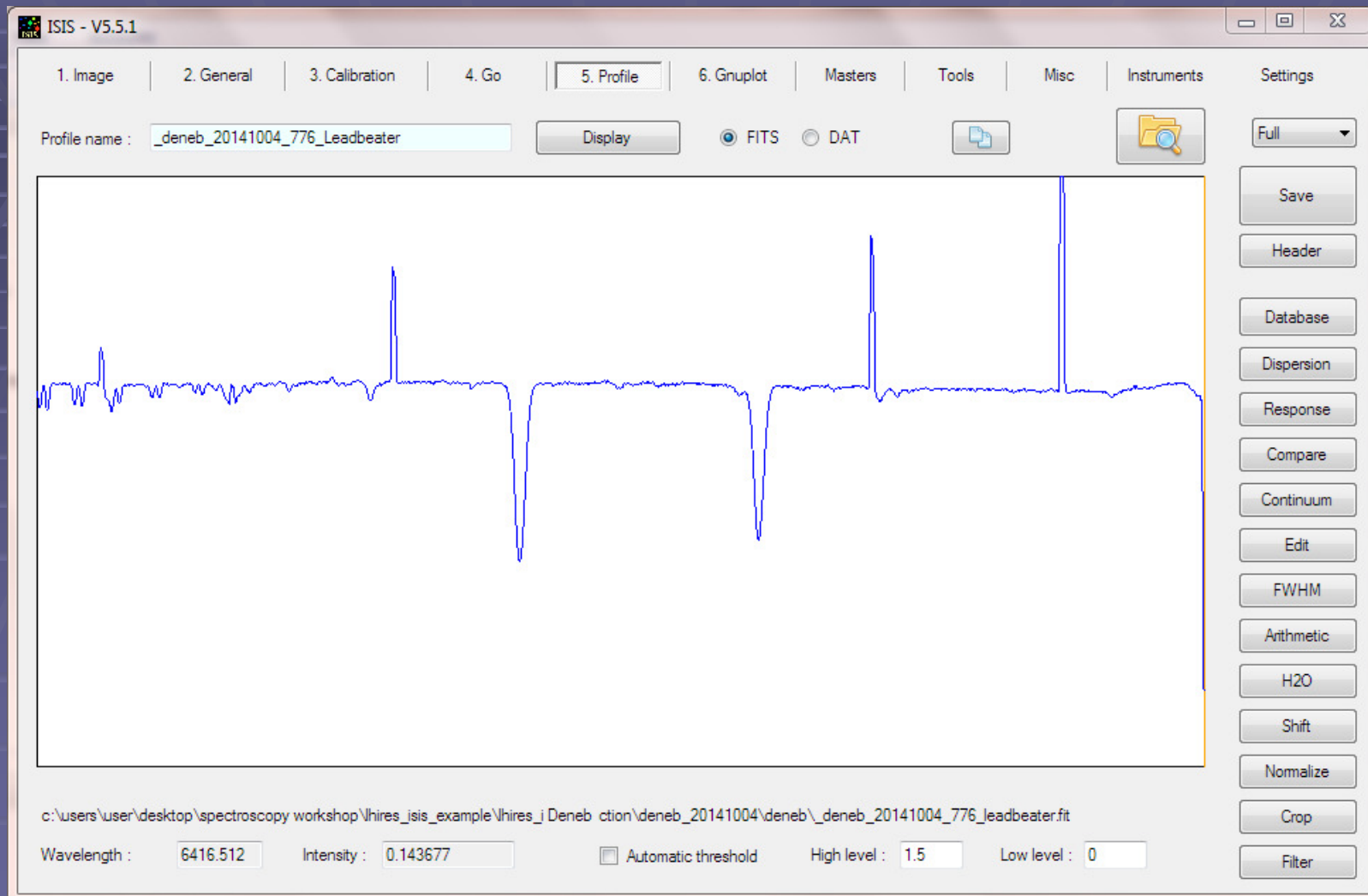
```
\hires_isis_example\hires_isis_reduction\deneb_20141004\deneb\deneb_mean.fit
Dark coefficient (calibration) : 0.7512
Save image : c:\users\user\desktop\spectroscopy workshop\hires_isis_example
\hires_isis_reduction\deneb_20141004\deneb\@calib.fit (2D image)
Save spectral profile : c:\users\user\desktop\spectroscopy workshop
\hires_isis_example\hires_isis_reduction\deneb_20141004\deneb\@calib.dat
Spectral calibration
-----
Wavelength fitting error
Line #1 x = 97.992 lambda = 6304.789 dlambda = 0.002
Line #2 x = 434.739 lambda = 6334.428 dlambda = -0.004
Line #3 x = 995.386 lambda = 6382.992 dlambda = 0.005
Line #4 x = 1221.041 lambda = 6402.246 dlambda = -0.003
-----
Wavelength file : c:\users\user\desktop\spectroscopy workshop
\hires_isis_example\hires_isis_reduction\deneb_20141004\deneb
\Deneb_Sill_4Ne_isis_filemode.lst
Coefficient a4 : 0.000000E00
Coefficient a3 : 0.000000E00
Coefficient a2 : -1.587702E-06
Coefficient a1 : 0.08888
Coefficient a0 : 6296.093
-----
RMS : 0.006743
-----
Warning : The spectral profiles are not normalized.
-----
Radial velocity : -8.906 km/s
-----
```

Display image Display profile Plot

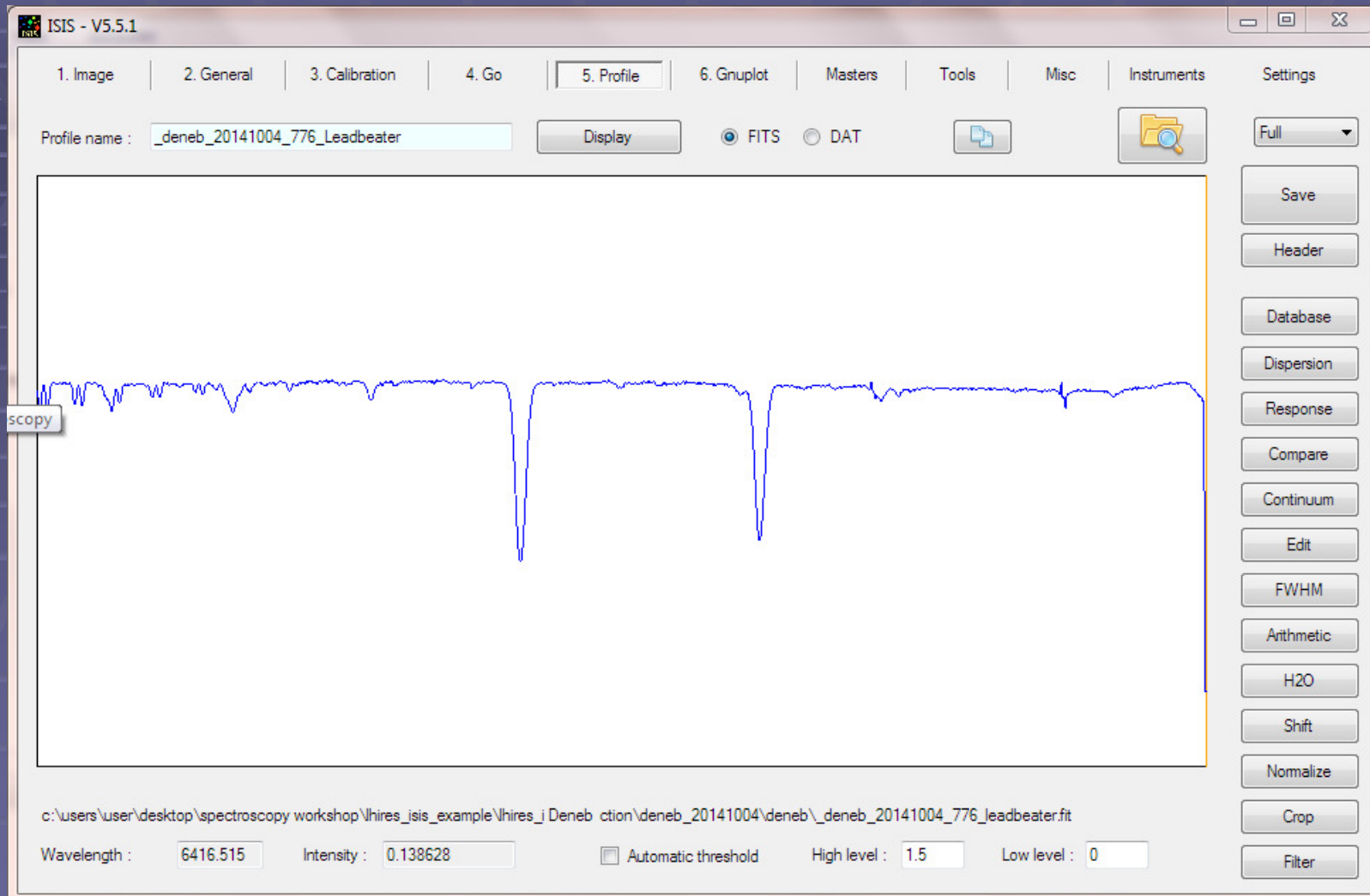
Residual errors well within target 0.02Å precision



# Final spectrum without background subtraction



# Final spectrum with background subtraction



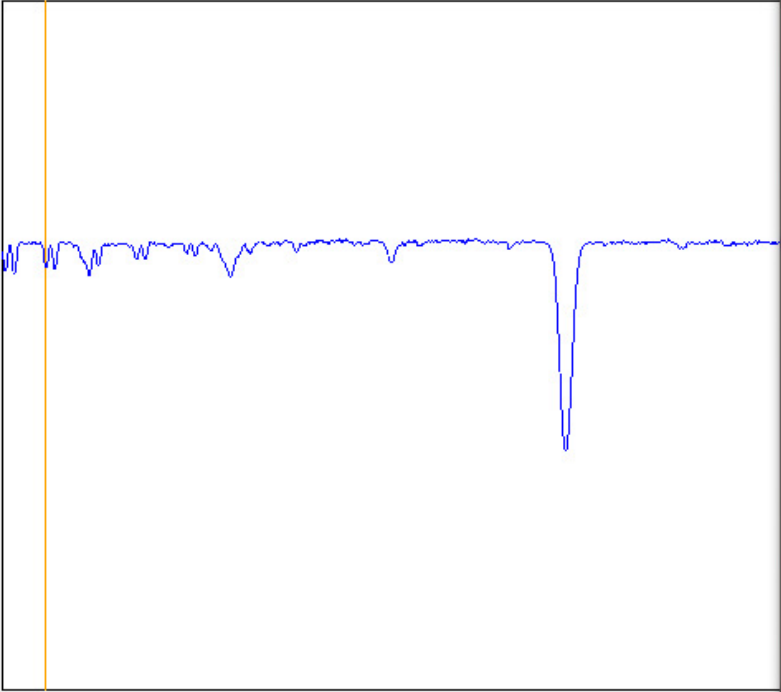
Some sign of small residual features from the lamp lines but these do not interfere with the star lines to be measured

# The fits header which includes the heliocentric correction

ISIS - V5.5.1

1. Image | 2. General | 3. Calibration | 4. Go | 5. Profile

Profile name :



c:\users\user\desktop\spectroscopy workshop\lhires\_isis\_example\lhires\_j Deneb ction\deneb\_20141004\_776\_Leadbeater

Wavelength :  Intensity :   Automatic fit

FITS header (profile)

BITPIX :	<input type="text" value="-32"/>	CRPIX1 :	<input type="text" value="1"/>
NAXIS :	<input type="text" value="1"/>	CUNIT1 :	<input type="text" value="Angstrom"/>
NAXIS1 :	<input type="text" value="2758"/>	CTYPE1 :	<input type="text" value="Wavelength"/>
CRVAL1 :	<input type="text" value="6298.0934196004"/>	OBSERVER :	<input type="text" value="Leadbeater"/>
CDELTA1 :	<input type="text" value="0.043"/>	BSS_VHEL :	<input type="text" value="-8.906"/>
OBJNAME :	<input type="text" value="Deneb"/>	BSS_COSM :	<input type="text" value="Removed"/>
DATE-OBS :	<input type="text" value="2014-10-04T18:36:51"/>	BSS_TELL :	<input type="text" value="None"/>
EXPTIME :	<input type="text" value="740.145"/>	BSS_NORM :	<input type="text" value="None"/>
EXPTIME2 :	<input type="text" value="8x 90 s"/>	VERSION :	<input type="text" value="ISIS V5.5.1"/>
BSS_INST :	<input type="text" value="C11_LHIRES_1200_ATK314"/>	OBJRA :	<input type="text"/>
BSS_ESRP :	<input type="text"/>	OBJDEC :	<input type="text"/>
BSS_SRPW :	<input type="text"/>	OBJBMAG :	<input type="text" value="0"/>
BSS_ITRP :	<input type="text"/>	OBJVMAG :	<input type="text" value="0"/>
BSS_SITE :	<input type="text" value="THO robin@threehillsobservat"/>	SPTYPE :	<input type="text"/>
BSS_ORD :	<input type="text"/>	OBJRV :	<input type="text" value="0"/>
SPE_RPOW :	<input type="text" value="16003"/>	GEO_LAT :	<input type="text" value="54.746"/>
GEO_LONG :	<input type="text" value="-3.241"/>	JD-OBS :	<input type="text" value="2456935.2756"/>
GEO_ELEV :	<input type="text" value="135"/>	JD-HEL :	<input type="text" value="2456935.2822"/>
JD-OBS :	<input type="text" value="2456935.2756"/>	COMMENT :	<input type="text"/>
JD-MID :	<input type="text" value="2456935.2799"/>	COMMENT :	<input type="text"/>

# Removal of Telluric lines using template

The screenshot displays the ISIS V5.5.1 software interface. The main window shows a spectral profile with several telluric absorption lines. A dialog box titled "Remove H2O telluric lines" is open, allowing the user to adjust parameters for line removal. The dialog box includes sliders for FWHM, Intensity, and Shift, along with input fields for Max, Step, and Shift (A). The "Na" checkbox is checked, and the "Manual" checkbox is also checked. The "Shift (A)" field is set to 0. The "OK" and "Cancel" buttons are visible.

Profile name :    FITS  DAT

Remove H2O telluric lines

FWHM

Intensity

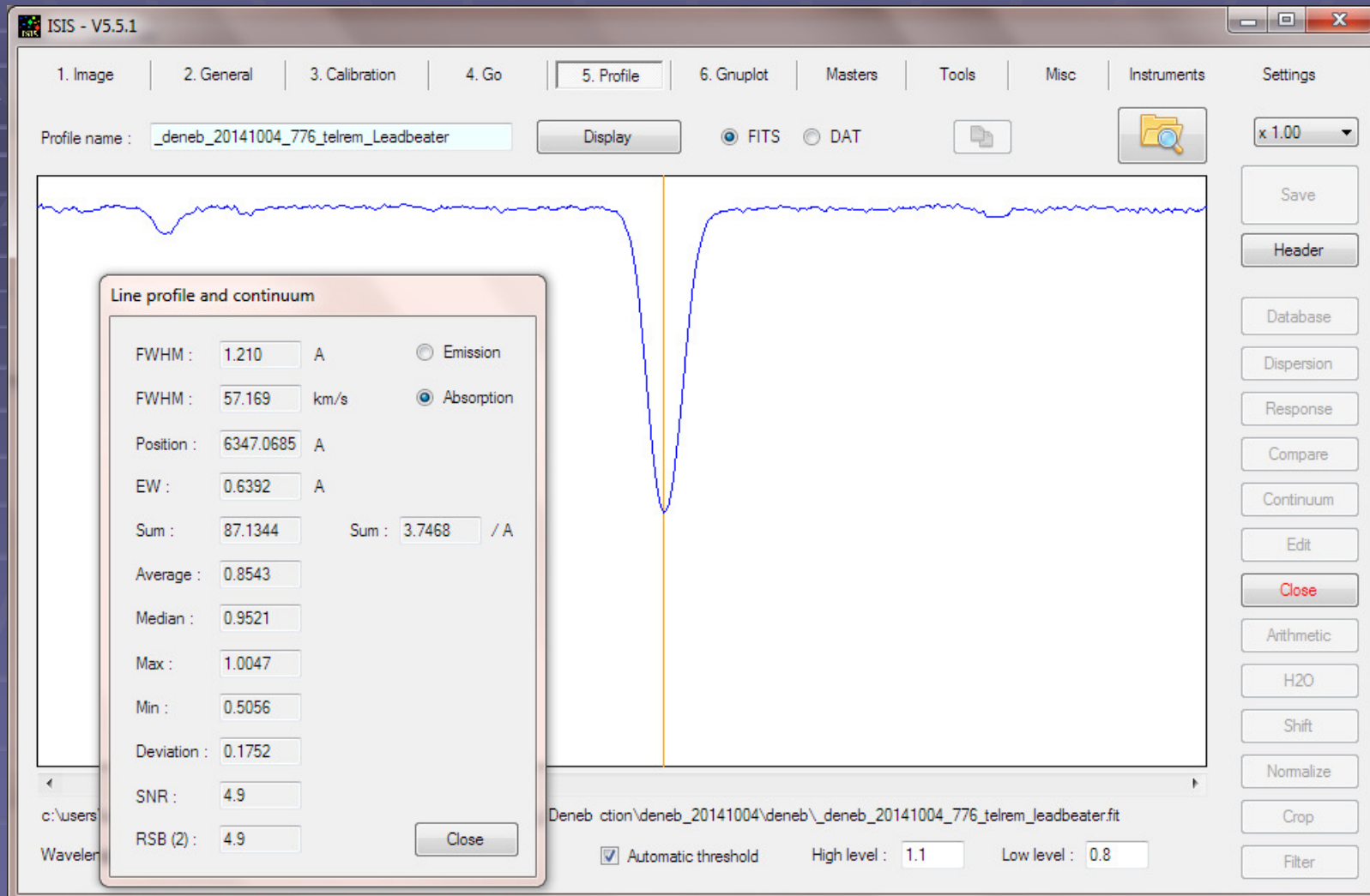
Shift   A

Na  Manual

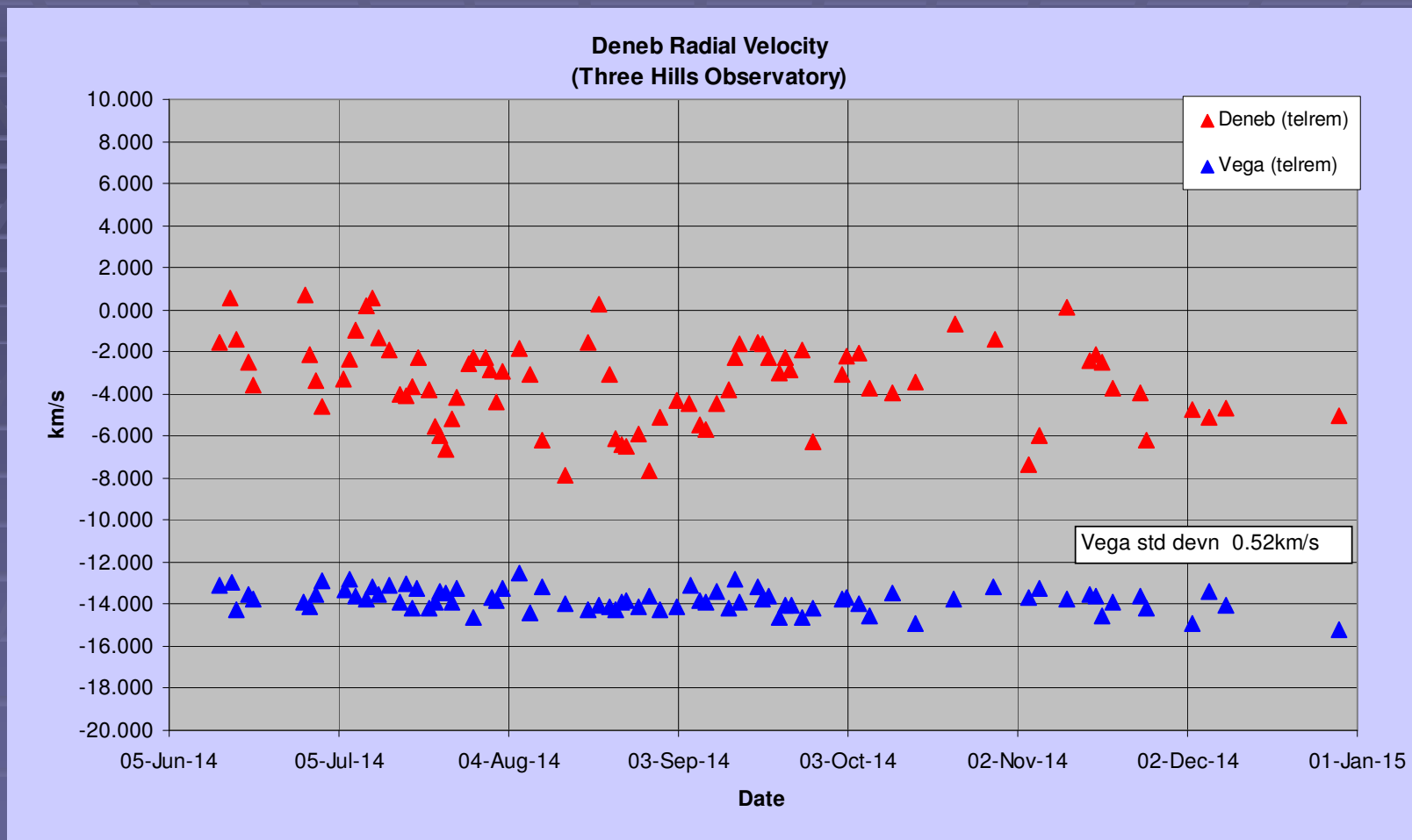
Wavelength  level : 0.8



Measure the line wavelength to 0.005Å ~1/20 pixel precision

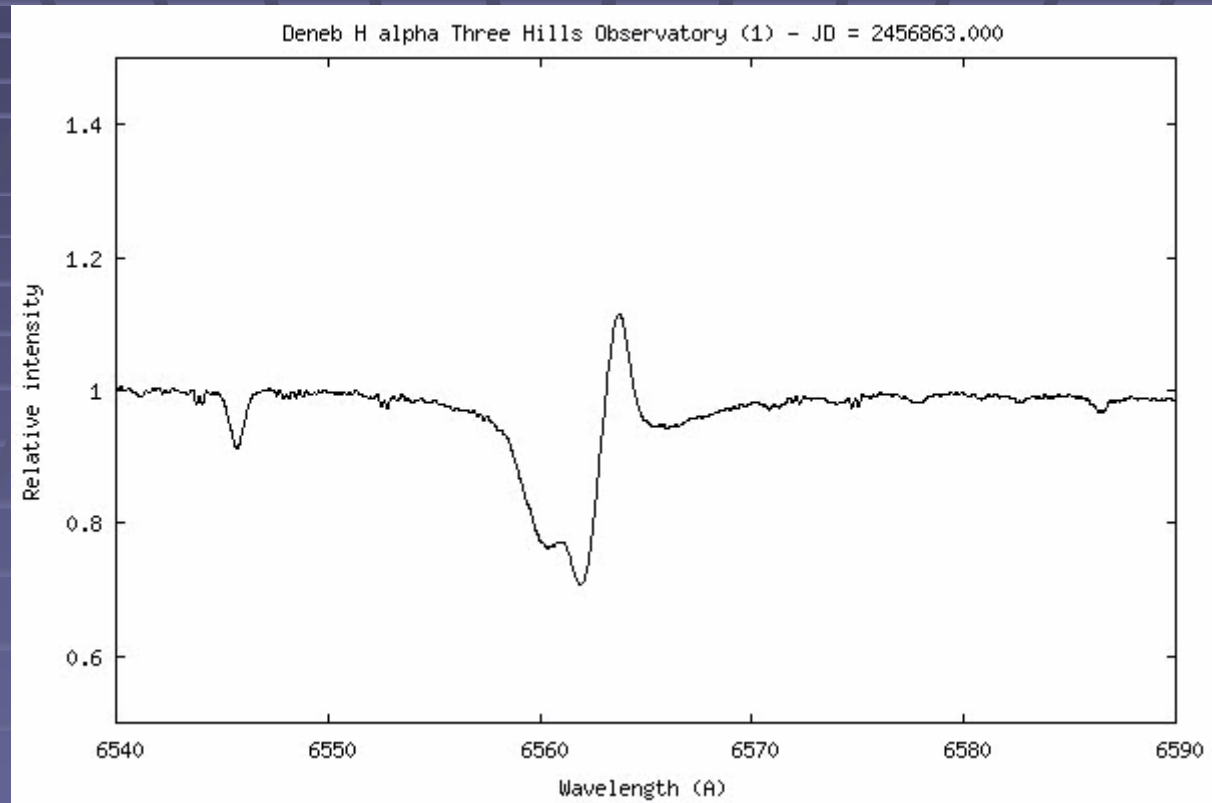


Using Barycentre or Gaussian fit gives a much higher precision than the pixel size or line width might suggest possible.



Observations on ~50% of nights June – Sept  
(bright target made observing possible in thin cloud and short breaks)

# Deneb H alpha line profile evolution 2014-07-23 - 2014-12-28



Generated from 48 observations