



BAA
Variable Star Section
British Astronomical Association

Spectroscopy Workshop
N.L.O. 10th October 2015

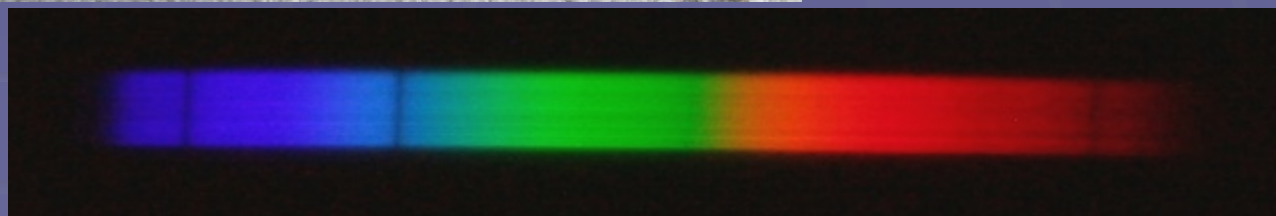
Download from dropbox at <http://tinyurl.com/NLO-workshop>

Low Resolution Slitless Spectroscopy

Robin Leadbeater

www.threehillsobservatory.co.uk

Objective grating spectrograph - Nothing simpler!

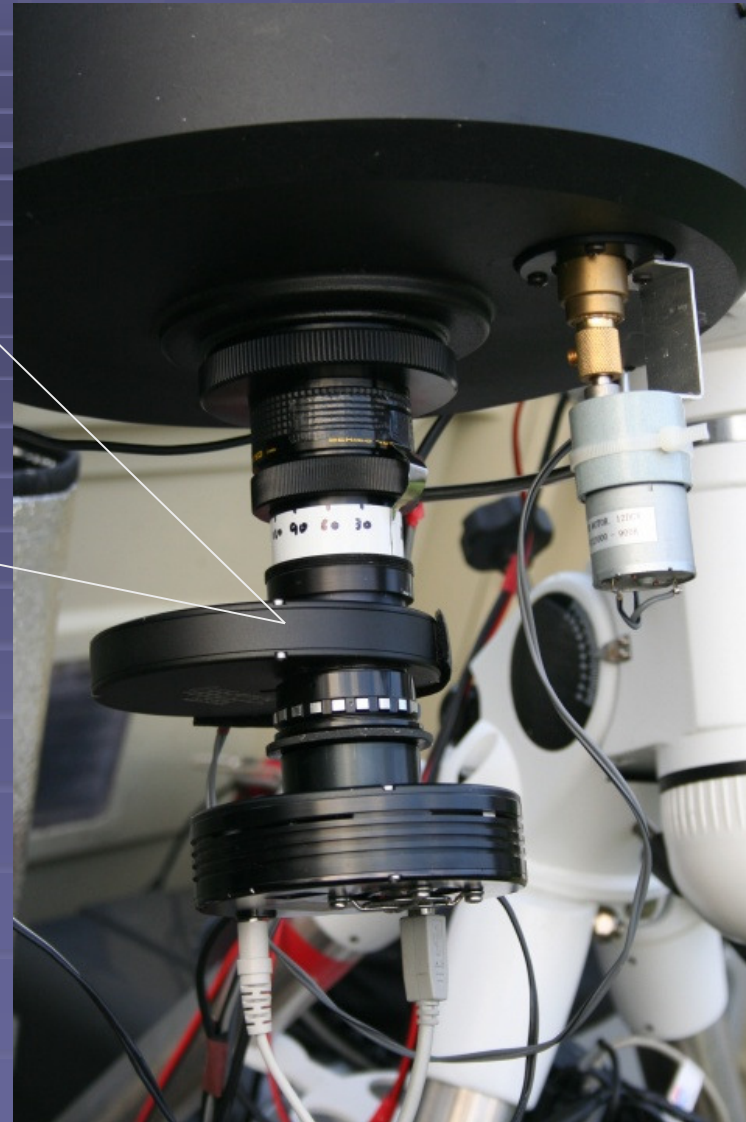


Altair

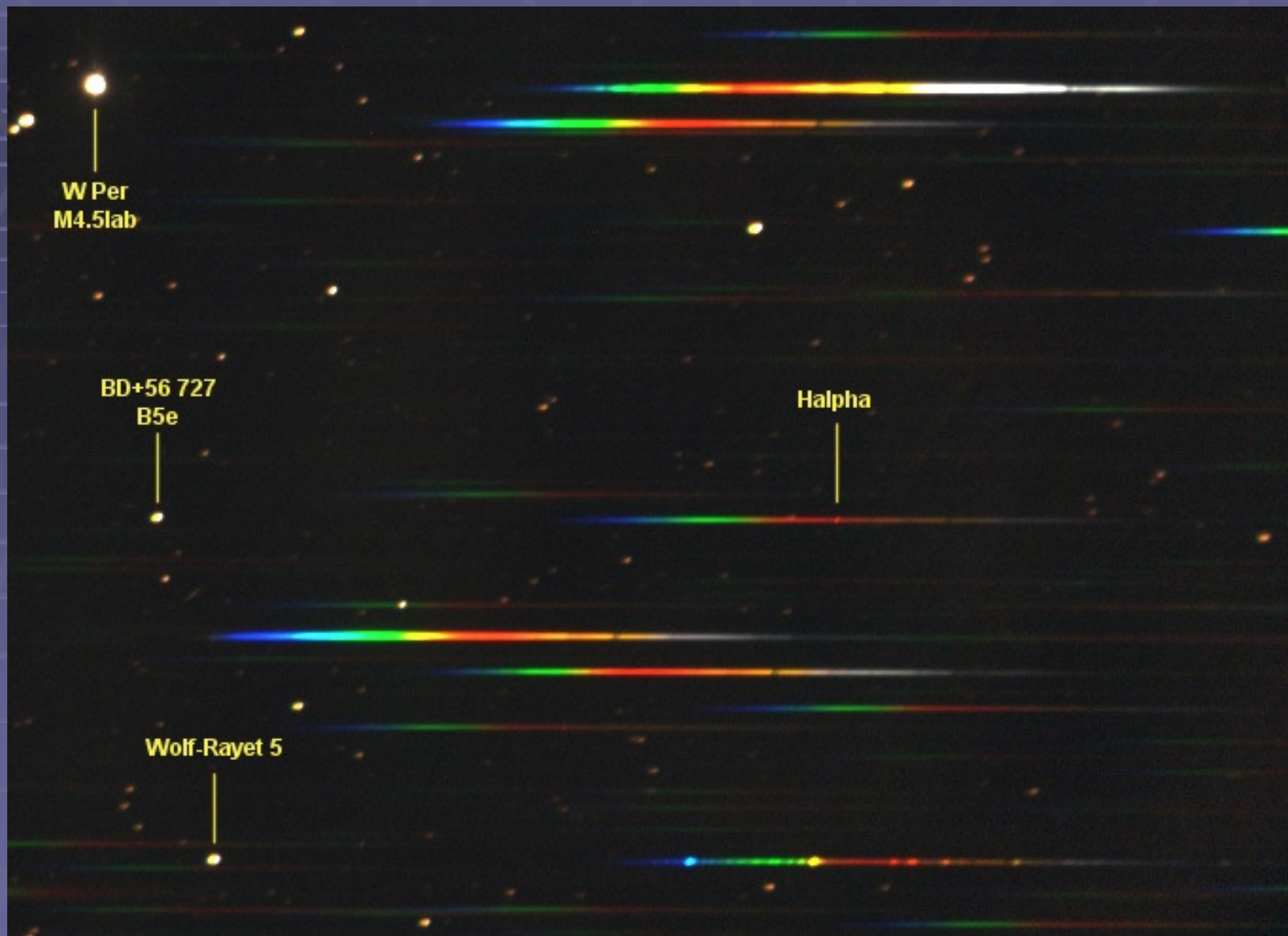
Non objective grating spectrograph



A 100 or 200 l/mm grating placed in the converging beam between telescope and camera sensor produces a low resolution spectrum typically 30-60Å resolution



A STELLAR “PICK AND MIX”



Measuring the spectra of MILES stars of various spectral types using a Star Analyser 100

The Equipment

Celestron C11 (280mm f10)

0.63 reducer

Rotating coupling with scale

Filter wheel with SA100 and photometric filters

ATK 16IC-S camera (782x8.3um pixels wide)



Measuring the spectra of MILES stars of various spectral types using a Star Analyser 100 2013-04-23

The Targets and observation details

star	spec type	Vmag	time	az	alt	air mass	exposure
HD60522	M0iii	4.1	21:18	259	41	1.5	10x0.5s
HD74721	A0v	8.7	21:23	232	39	1.6	10x5s
HD84937	F5iv	8.3	21:28	215	45	1.4	10x5s
HD79765	A3	7.0	21:32	230	46	1.4	10x5s
HD81192	G7iii	6.5	21:35	229	47	1.4	10x2s
HD83632	K2iii	8.1	21:41	230	54	1.2	9x5s

The MILES Library

~1000 bright stars with professionally measured spectra at 2.5Å resolution

MILES Population Synthesis for the 21st Century

MILES library

The library consist of ~1000 stars spanning a large range in atmospheric parameters. The spectra were obtained at the 2.5m INT telescope and cover the range 3525-7500 Å (Sánchez-Blázquez et al. 2006) at 2.5 Å (FWHM) spectral resolution (Falcón-Barroso et al. (2011)). The shape of the continuum for the stellar spectra has been carefully calibrated. A subset of the library, flux-calibrated in absolute terms, is available upon request.

NEW: The current version of the library (v9.1) present a number of improvements over the previous version (v9.0). We have corrected small errors in the radial velocities of the some stars and re-assessed the spectral resolution of the library. The newly estimated resolution in 2.5 Å. See the Falcón-Barroso et al. (2011) for details.

The complete library, in ASCII format, is available as a single tar file [here](#).

(a)

- $T_{\text{eff}}=8560\text{K}$
- $T_{\text{eff}}=5727\text{K}$ HD 74721, A0 V ($\log g=3.57$)
- $T_{\text{eff}}=4570\text{K}$ HD 4307, G2 V ($\log g=4.07$)
- $T_{\text{eff}}=3344\text{K}$ HD 1326, M1.5 V ($\log g=5.30$)

(b)

- $T_{\text{eff}}=7325\text{K}$ HD 2626, A7 III ($\log g=3.57$)
- $T_{\text{eff}}=5013\text{K}$ HD 2665, G5 III ($\log g=2.35$)
- $T_{\text{eff}}=4731\text{K}$ HD 221340, K0 III ($\log g=2.63$)
- $T_{\text{eff}}=3487\text{K}$ HD 184786, M4.5 III ($\log g=0.60$)

<http://www.iac.es/proyecto/miles/pages/stellar-libraries/miles-library.php>

<http://www.spectro-aras.com/forum/viewtopic.php?f=6&t=207>

<http://www.spectro-aras.com/forum/viewtopic.php?f=6&t=207&start=30#p2162>

HD60522 M0iii



Typical
spectrum images

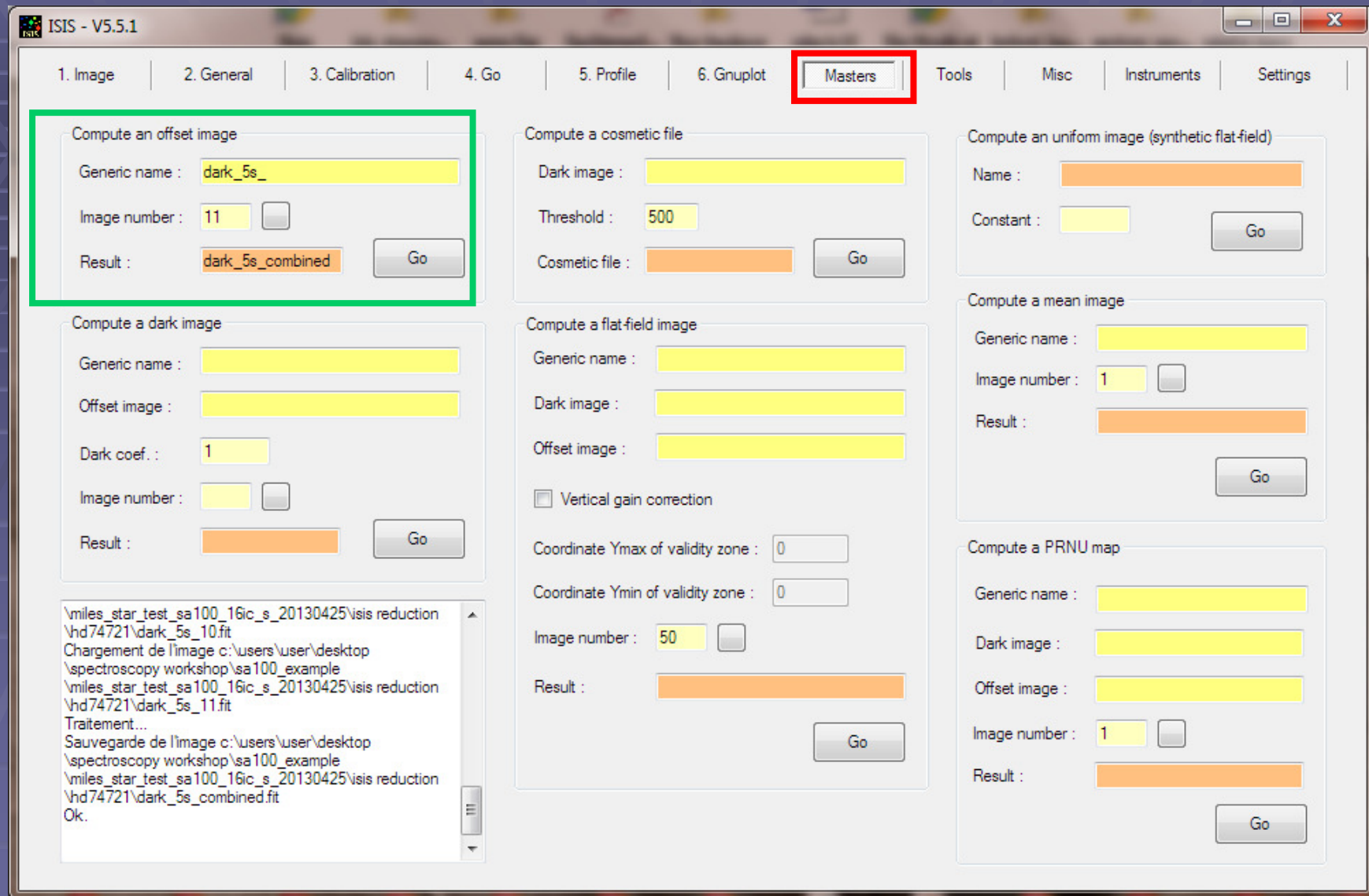
HD74721 A0v



Preprocessing (using ISIS)

http://www.astrosurf.com/buil/isis/isis_en.htm

Compute the master offset



(no separate thermal or flat correction used in this example)

Dark correct the star 10 exposures

The screenshot shows the ISIS V5.5.1 software interface. The 'Tools' menu is highlighted with a red box. The 'Preprocessing' tool is selected and highlighted with a green box. The configuration for the 'Preprocessing' tool is as follows:

- Input generic name: `hd74721_`
- Offset image name: `dark_5s_combined`
- Dark image name: (empty)
- Flat-field image name: (empty)
- Cosmetic file name: (empty)
- Output generic name: `hd74721_preproc_`
- Image number: `10`

The 'Register' tool configuration is as follows:

- Input generic name: `hd74721_preproc_`
- X1: `216`, Y1: `136`
- X2: `1`, Y2: `1`
- X3: `1`, Y3: `1`
- Search zone size: `20`
- Output generic name: `hd74721_preproc_aligned_`
- Image number: `10`

The 'Add a constant' tool configuration is as follows:

- Input image: (empty)
- Output image: (empty)
- Constant: `0`

The 'Remove sky background' tool configuration is as follows:

- Input image: `hd74721_preproc_aligned_sum`
- Output image: `74721_preproc_aligned_sum_bgsub`
- Order: `3`
- Threshold: `7000`

The 'Addition of a sequence' tool configuration is as follows:

- Input generic name: `hd74721_preproc_aligned_`
- Image number: `10`
- Sum image: `hd74721_preproc_aligned_sur`
- Rejection: (unchecked)
- Threshold: `500`

The command line at the bottom shows the following commands:

```
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\@mask.fit
Pointing number = 4747
Processed image : c:\users\user\desktop\spectroscopy workshop\sa100_example
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\hd74721_preproc_aligned_sum_bgsub.fit
Ok.
```

Align the 10 star exposures

The screenshot shows the ISIS V5.5.1 software interface with the 'Tools' tab selected. The 'Images processing 2' sub-tab is active, and the 'Register' section is highlighted with a green box. The 'Preprocessing' section on the left has the following fields: Input generic name: hd74721_, Offset image name: dark_5s_combined, Dark image name: (empty), Flat-field image name: (empty), Cosmetic file name: (empty), Output generic name: hd74721_preproc_, and Image number: 10. The 'Register' section (highlighted) has: Input generic name: hd74721_preproc_, X1: 216, Y1: 136, X2: 1, Y2: 1, X3: 1, Y3: 1, Search zone size: 20, Output generic name: hd74721_preproc_aligned_, and Image number: 10. The 'Add a constant' section has: Input image: (empty), Output image: (empty), and Constant: 0. The 'Remove sky background' section has: Input image: hd74721_preproc_aligned_sum, Output image: 74721_preproc_aligned_sum_bgsub, Order: 3, and Threshold: 7000. The 'Addition of a sequence' section has: Input generic name: hd74721_preproc_aligned_, Image number: 10, Sum image: hd74721_preproc_aligned_sur, Rejection: (unchecked), and Threshold: 500. The command line at the bottom shows the file path and processing steps.

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

Images processing 1 | Images processing 2 | Image processing 3 | Spectra processing 1 | Spectra processing 2 | Spectra processing 3 | Command line

Preprocessing

Input generic name : hd74721_
Offset image name : dark_5s_combined
Dark image name :
Flat-field image name :
Cosmetic file name :
Output generic name : hd74721_preproc_
Image number : 10 [Go]

Register

Input generic name : hd74721_preproc_
X1 : 216 Y1 : 136 One star
X2 : 1 Y2 : 1 Three stars
X3 : 1 Y3 : 1
Search zone size : 20
Output generic name : hd74721_preproc_aligned_
Image number : 10 [Go]

Add a constant

Input image :
Output image :
Constant : 0 [Go]

Remove sky background

Input image : hd74721_preproc_aligned_sum
Output image : 74721_preproc_aligned_sum_bgsub
Order : 3 Threshold : 7000 [Go]

Addition of a sequence

Input generic name : hd74721_preproc_aligned_ Image number : 10
Sum image : hd74721_preproc_aligned_sur Rejection Threshold : 500 [Go]

```
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\@mask.fit  
Pointing number = 4747  
Processed image : c:\users\user\desktop\spectroscopy workshop\sa100_example  
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\hd74721_preproc_aligned_sum_bgsub.fit  
Ok.
```

Sum the 10 aligned star exposures

The screenshot shows the ISIS V5.5.1 software interface. The 'Tools' tab is active, and the 'Addition of a sequence' dialog box is highlighted with a green border. The dialog box contains the following fields and controls:

- Input generic name: `hd74721_preproc_aligned_`
- Image number: `10`
- Sum image: `hd74721_preproc_aligned_sur`
- Rejection:
- Threshold: `500`
- Go button

The background interface shows the 'Preprocessing' and 'Register' sections. The 'Preprocessing' section has the following fields:

- Input generic name: `hd74721_`
- Offset image name: `dark_5s_combined`
- Dark image name:
- Flat-field image name:
- Cosmetic file name:
- Output generic name: `hd74721_preproc_`
- Image number: `10`
- Go button

The 'Register' section has the following fields:

- Input generic name: `hd74721_preproc_`
- X1: `216`, Y1: `136`
- X2: `1`, Y2: `1`
- X3: `1`, Y3: `1`
- Search zone size: `20`
- Output generic name: `hd74721_preproc_aligned_`
- Image number: `10`
- Go button

The 'Add a constant' section has the following fields:

- Input image:
- Output image:
- Constant: `0`
- Go button

The 'Remove sky background' section has the following fields:

- Input image: `hd74721_preproc_aligned_sum`
- Output image: `74721_preproc_aligned_sum_bgsub`
- Order: `3`
- Threshold: `7000`
- Go button

The command line at the bottom shows the following text:

```
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\@mask.fit  
Pointing number = 4747  
Processed image : c:\users\user\desktop\spectroscopy workshop\sa100_example  
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\hd74721_preproc_aligned_sum_bgsub.fit  
Ok.
```


Sky Background Removal

ISIS - V5.1.3

1. Image | 2. General | 3. Calibration | 4. Go | 5. Profile | 6. Gnuplot

Image to process :

Tilt angle : Slant angle : Spectrum vertical coordinate :

X coordinate of line at wavelength A = (pixels) Emission line

Definition of area zone for sky evaluation and spectrum bi...

1 2 3 4 Predefined values

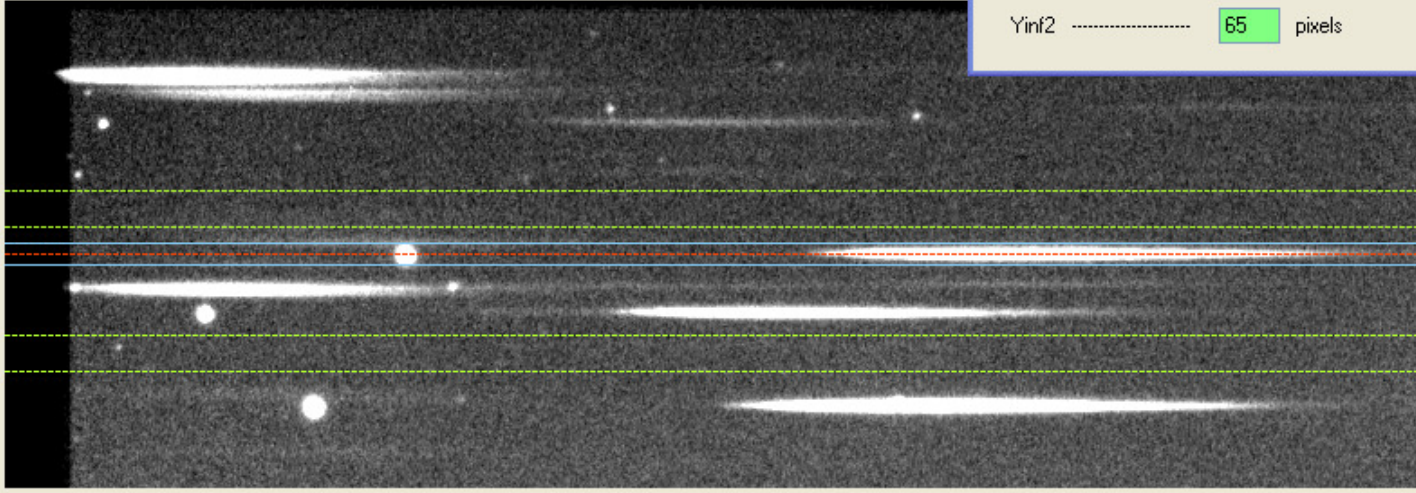
Ysup2 pixels Display sky zone

Ysup1 pixels

Y0 ===== Spectrum position - Binning height :

Yinf1 pixels

Yinf2 pixels



X : 8
Y : 326
I : 204

Displayed image : c:\documents and settings\user\desktop\astronomy current\recent ob: 2012-12-10T12:10:57 sign\observations\t_tauri_campaign_20121210_dn_tau' Domain

Seuil haut :

Seuil bas :

Remove the sky background (using a 2D 3rd order fit to the sky)

The screenshot shows the ISIS V5.5.1 software interface with the 'Tools' tab selected. The 'Remove sky background' tool is highlighted with a green box. The configuration for this tool is as follows:

- Input image: `hd74721_preproc_aligned_sum`
- Output image: `74721_preproc_aligned_sum_bgsub`
- Order: `3`
- Threshold: `7000`

The 'Preprocessing' section is also visible, with the following settings:

- Input generic name: `hd74721_`
- Offset image name: `dark_5s_combined`
- Dark image name: (empty)
- Flat-field image name: (empty)
- Cosmetic file name: (empty)
- Output generic name: `hd74721_preproc_`
- Image number: `10`

The 'Register' section has the following settings:

- Input generic name: `hd74721_preproc_`
- X1: `216`, Y1: `136` (One star selected)
- X2: `1`, Y2: `1`
- X3: `1`, Y3: `1`
- Search zone size: `20`
- Output generic name: `hd74721_preproc_aligned_`
- Image number: `10`

The 'Add a constant' section has the following settings:

- Input image: (empty)
- Output image: (empty)
- Constant: `0`

The 'Addition of a sequence' section has the following settings:

- Input generic name: `hd74721_preproc_aligned_`
- Image number: `10`
- Sum image: `hd74721_preproc_aligned_sur`
- Rejection: (unchecked)
- Threshold: `500`

The command line at the bottom shows the following command:

```
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\@mask.fit  
Pointing number = 4747  
Processed image : c:\users\user\desktop\spectroscopy workshop\sa100_example  
\miles_star_test_sa100_16ic_s_20130425\isis reduction\hd74721\hd74721_preproc_aligned_sum_bgsub.fit  
Ok.
```

Configure ISIS to reduce the spectrum

ISIS - V5.5.1

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

Root name : ... Object :

Images to process

Generic name : ... Number :

Calibration : ... Spectral calibration

Offset : ... Dark : ...

Flat : ...

General parameters

Pixel size (microns) : Fixed Y value for sequence

Cosmetic file : ... Sky not removed

Instr. responsivity : ... Wavelength registration

Wavelength shift (Å) : Cosmic rays filter

Heliocentric radial velocity correction Optimal binning

Auto atmosphere AOD : Rejection coef. :

Atmo. transmission : ... Automatic air mass computing

Spectral calibration

Predefined mode

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

File mode : (type xxx.lst)

Output

Instrument :

Observatory :

Observer :

Hour shift : R :

Files name prefix and suffix

Object suffix :

Calibration suffix :

Calibration prefix :

In this case just to produce an uncalibrated spectrum

Make geometric correction(1deg tilt) and set binning zone height

The screenshot shows the ISIS V5.5.1 software interface. The '3. Calibration' tab is selected and highlighted with a red box. The main window displays the following parameters:

- Image to process: `hd74721_preproc_aligned_sum_bgsub_1`
- Tilt angle: `1`
- Slant angle: `0`
- Vertical coordinate: `136`
- X coordinate of line at wavelength: `5852.49`
- A = `0` (pixels)
- Emission line

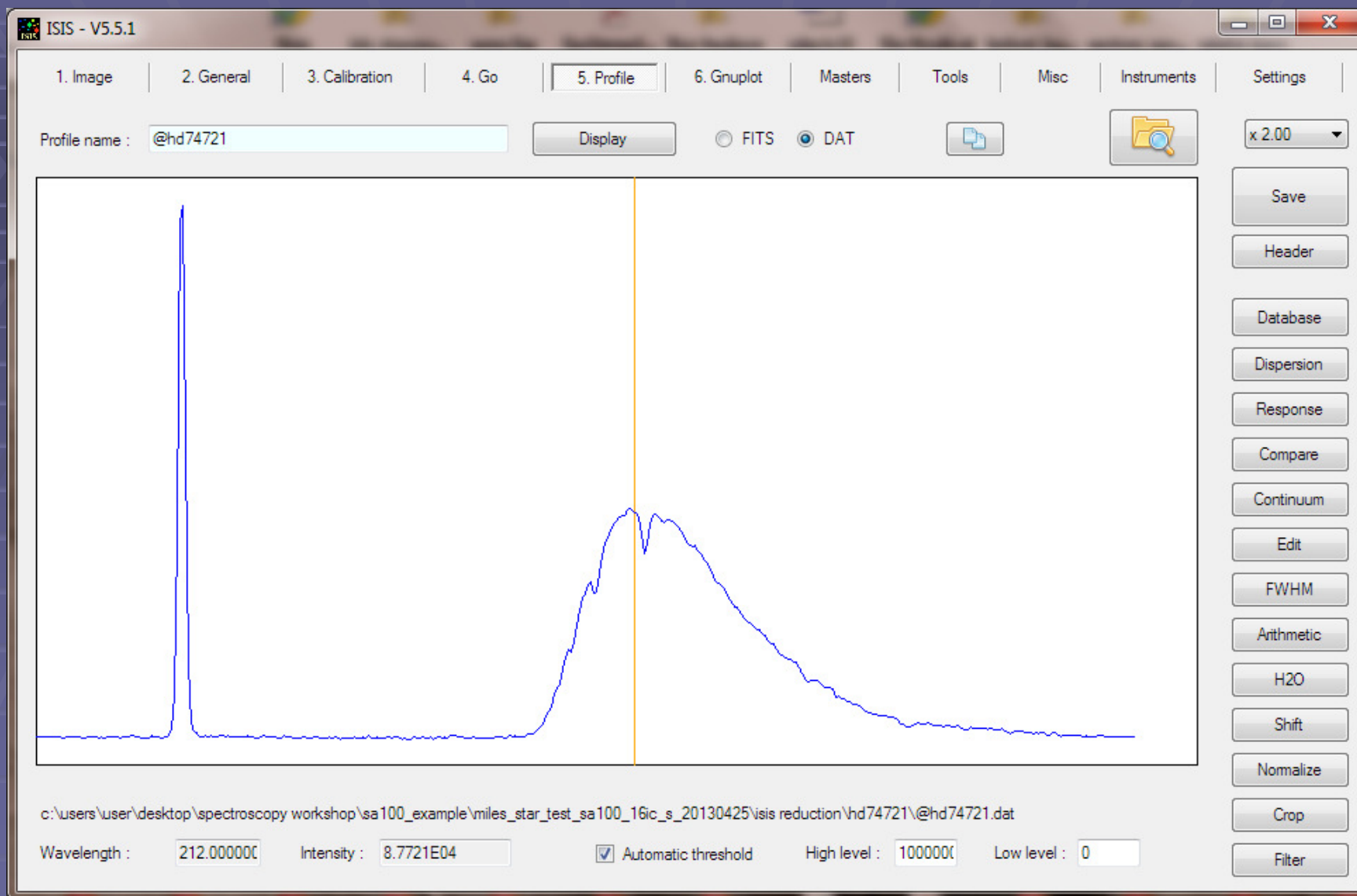
A dialog box titled 'Definition of area zone for sky evaluation and spectrum binning' is open, showing the following settings:

- Radio buttons 1, 2, 3, 4: 1
- Predefined values
- Ysup2: `35` pixels
- Ysup1: `15` pixels
- Y0: ===== Spectrum position - Binning height: `12`
- Yinf1: `15` pixels
- Yinf2: `35` pixels
- Display sky zone
- Close button

The background image shows a spectrum with several horizontal dashed lines indicating the binning zones. The 'Seuil haut' and 'Seuil bas' sliders are visible at the bottom of the main window.

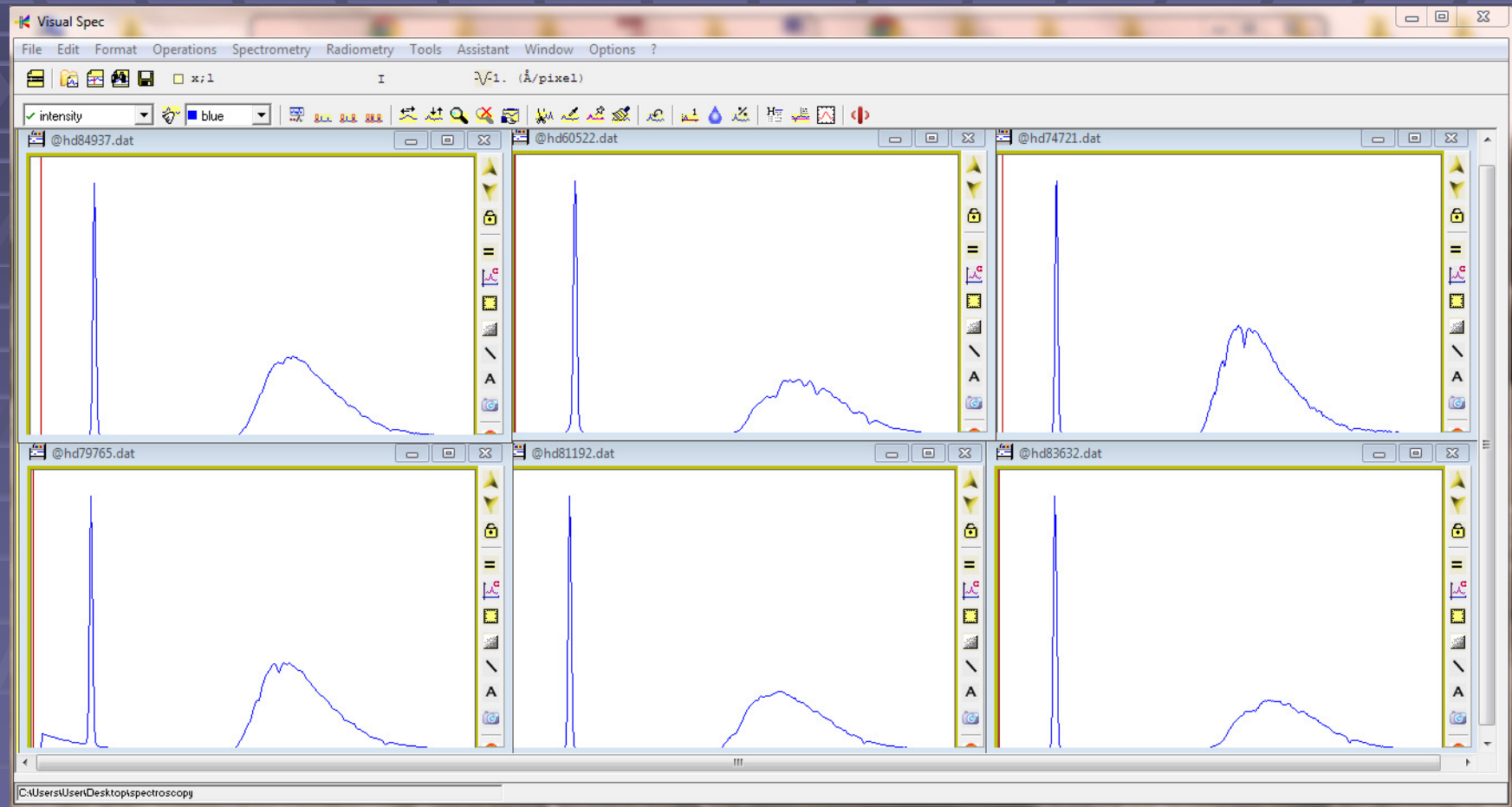
(The background binning zones are not used as the sky has already been subtracted)

The binned spectrum (X = pixels, Y = total counts)



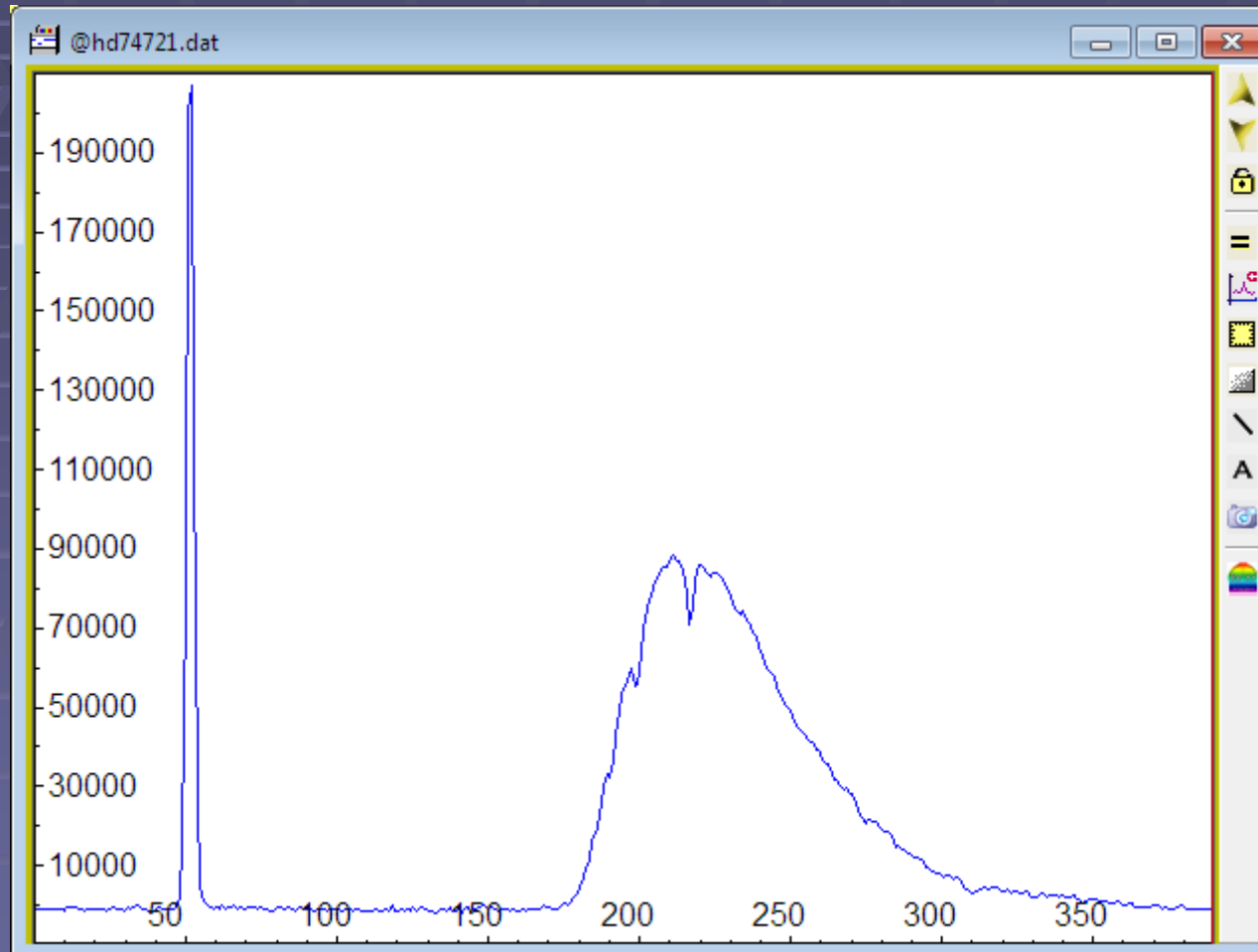
Wavelength and Flux calibration (using Visual Spec)

<http://www.astrosurf.com/vdesnoux/>

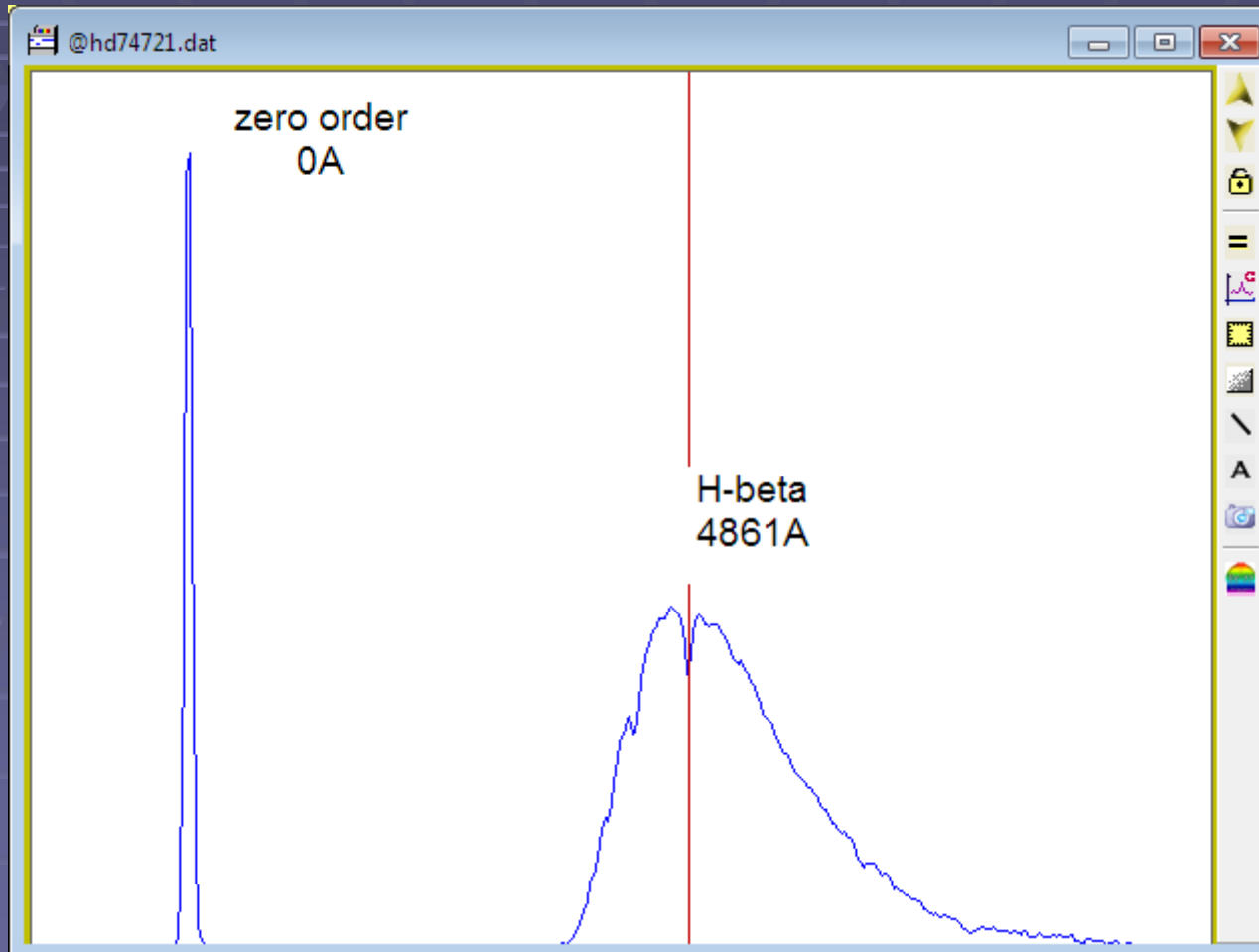


The raw binned data from ISIS for the 6 MILES stars measured

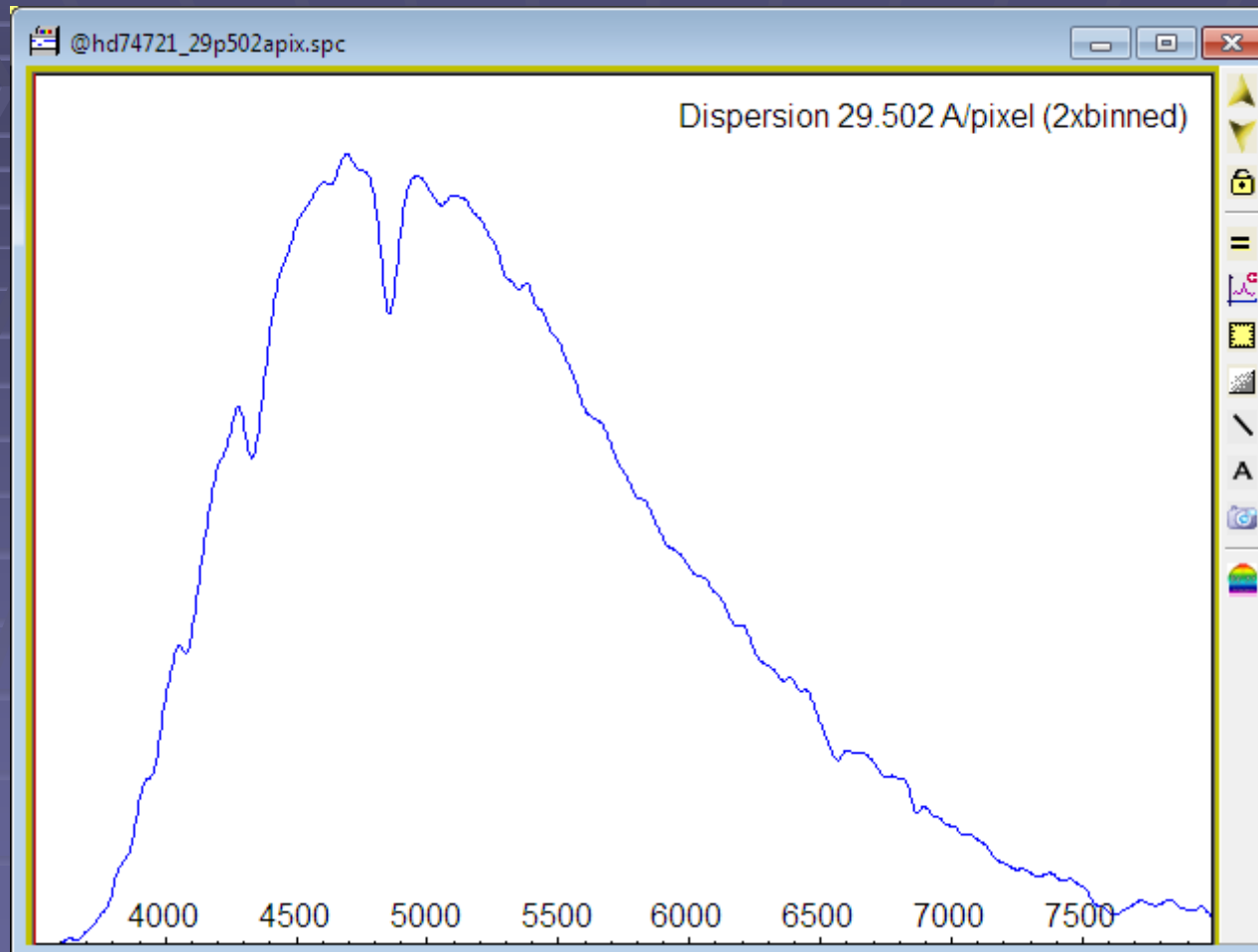
HD74721 X - pixels Y - total counts
Note some clear absorption lines



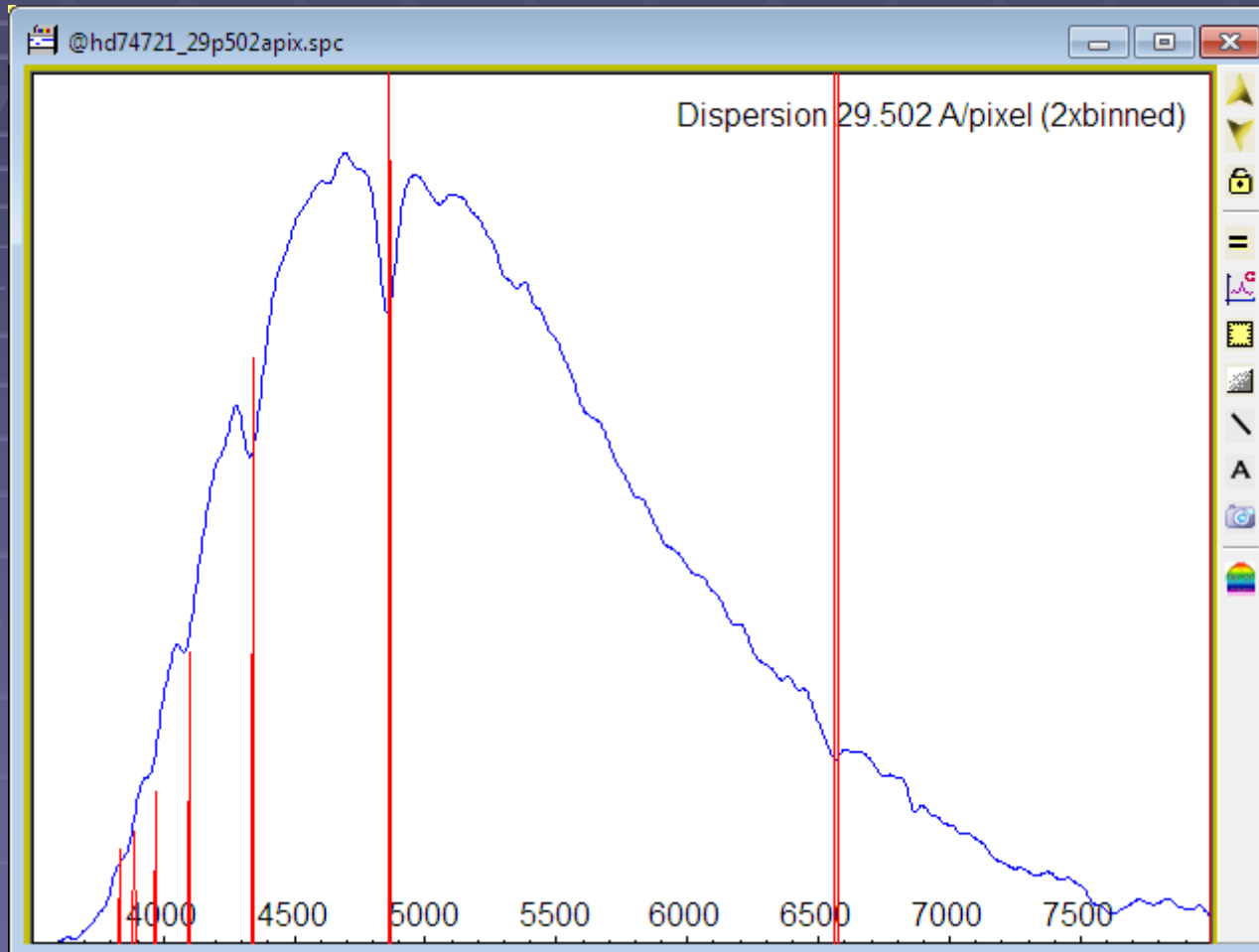
HD74721 is a hot main sequence star with an A0v type spectrum showing strong Hydrogen Balmer absorption lines. We can use the zero order and the H beta line to calibrate the X axis in wavelength



With the Star Analyser a simple linear dispersion gives a good approximate calibration. Here the dispersion is 29.5 Angstrom/pixel

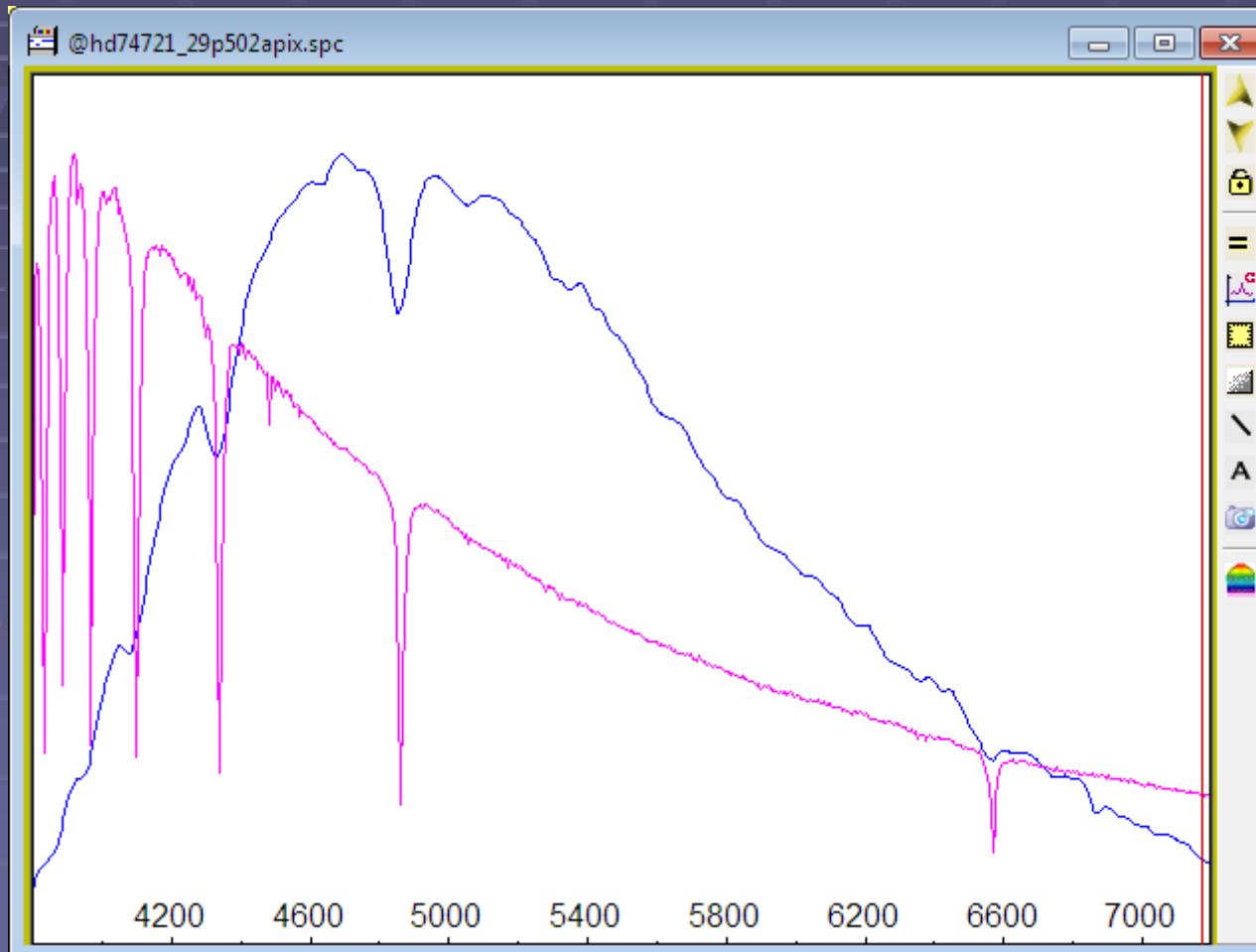


The Hydrogen Balmer line wavelengths overlaid (in red)

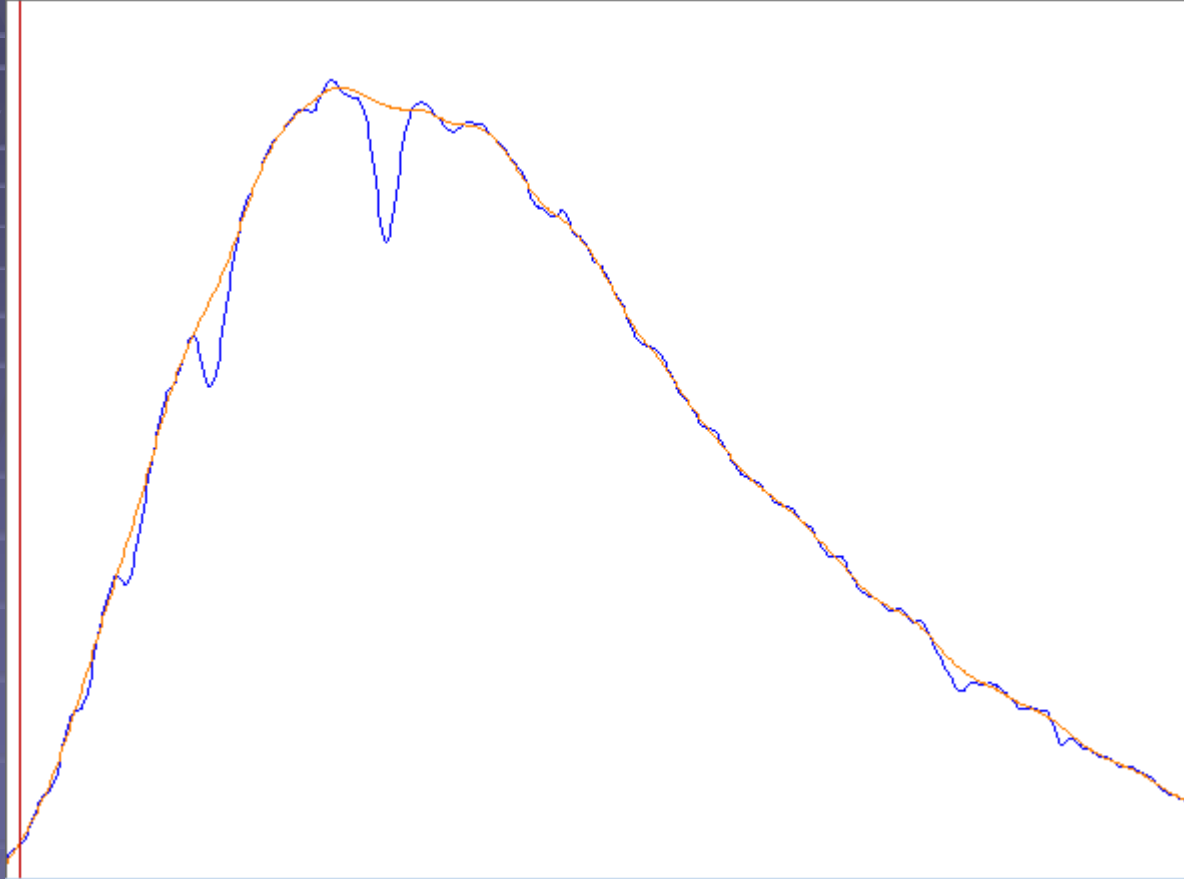


Comparison with spectrum in MILES database

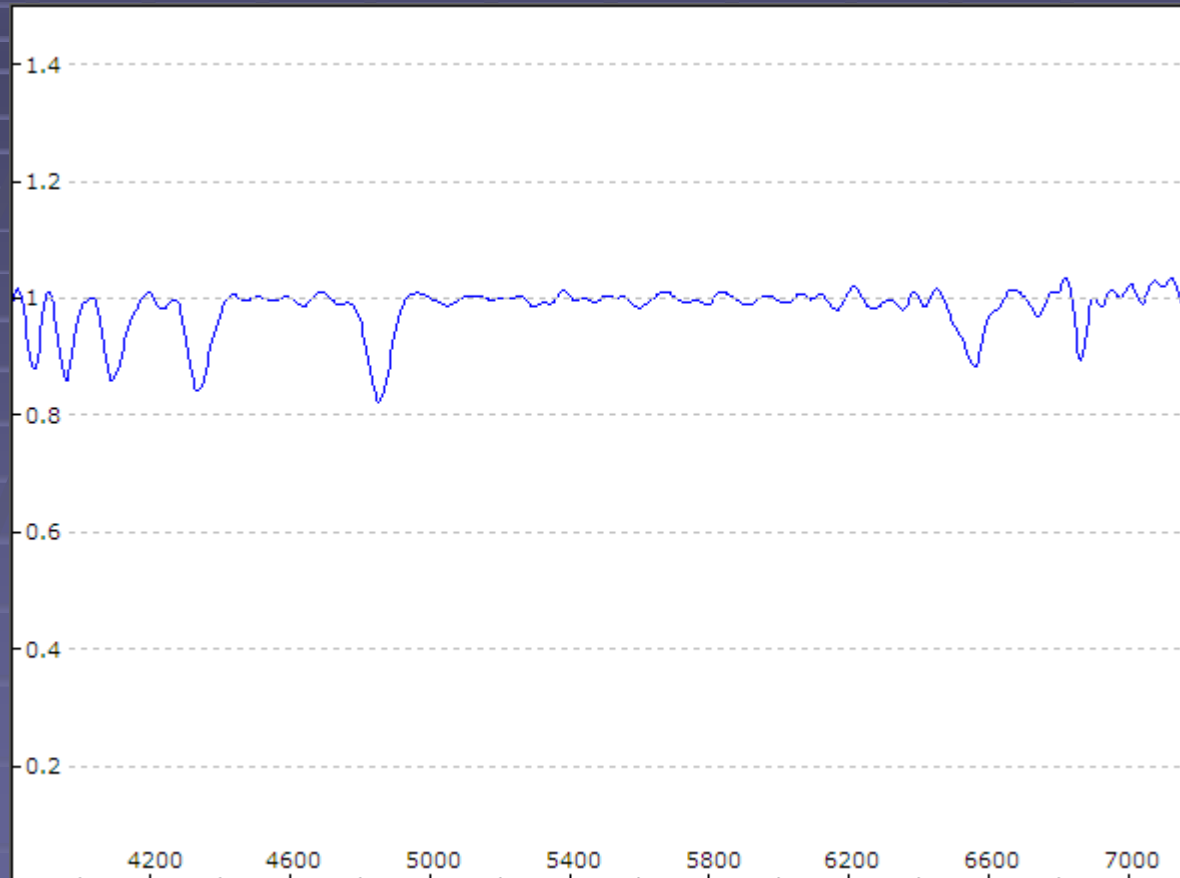
Different resolution (2.5Å v 60Å) and continuum shape (instrument response)



Rectify spectrum by dividing by a smooth fit to continuum



Rectified spectrum
(Continuum normalised to 1 at all wavelengths)

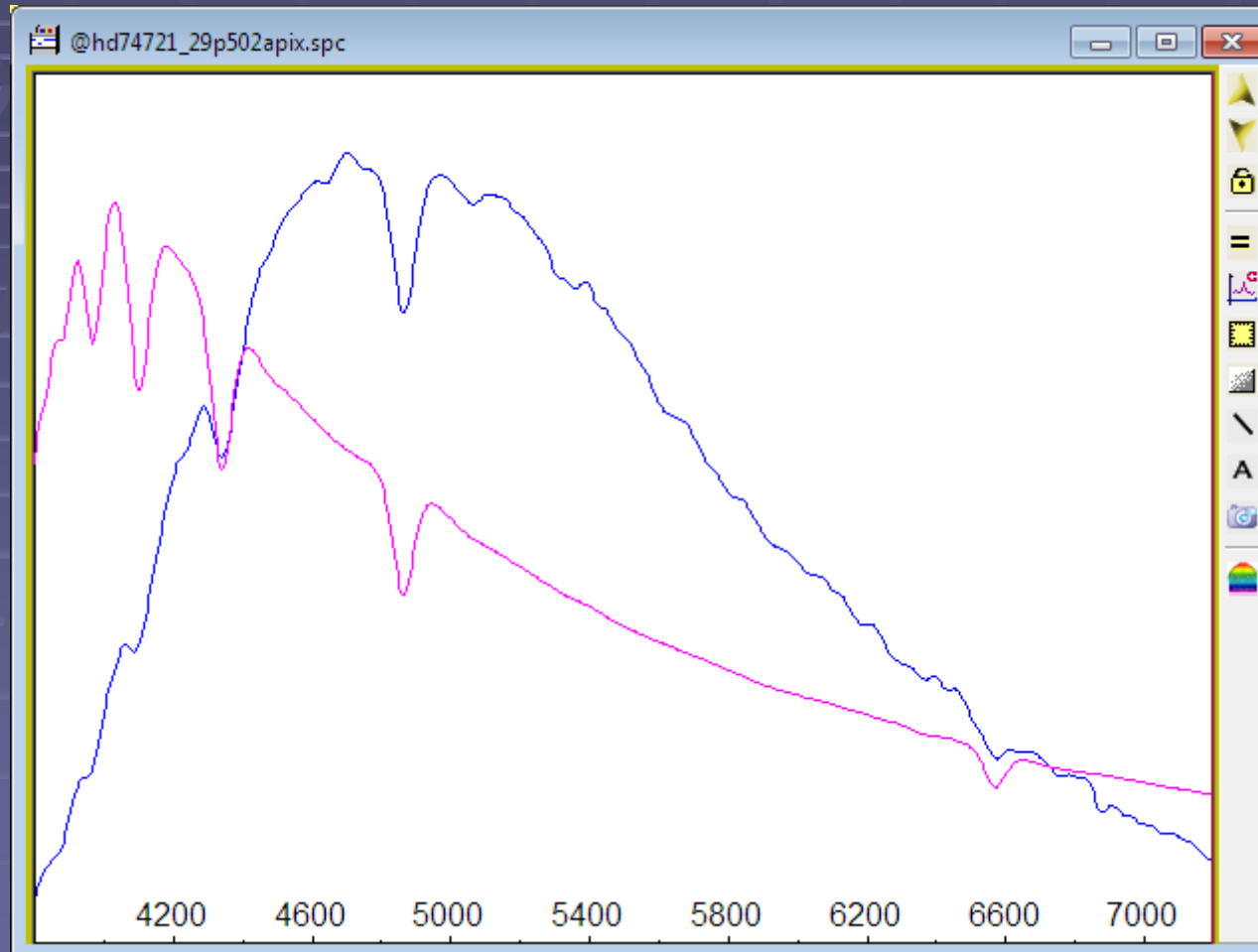


Shows relative strength of absorption lines correctly but not correct for emission lines

A pseudo colour “classical” spectrum image
can be generated from the rectified spectrum

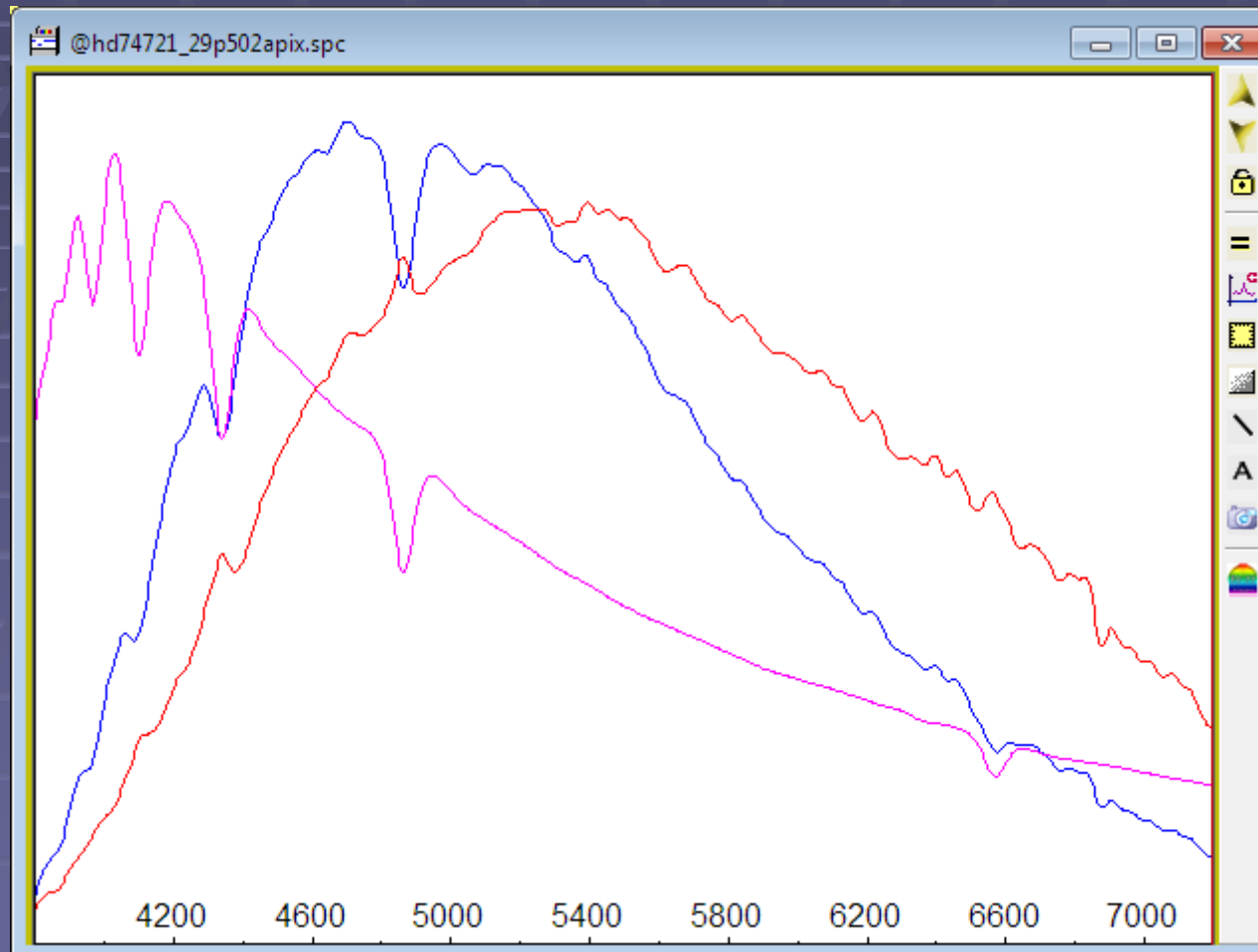


Measure the instrument response



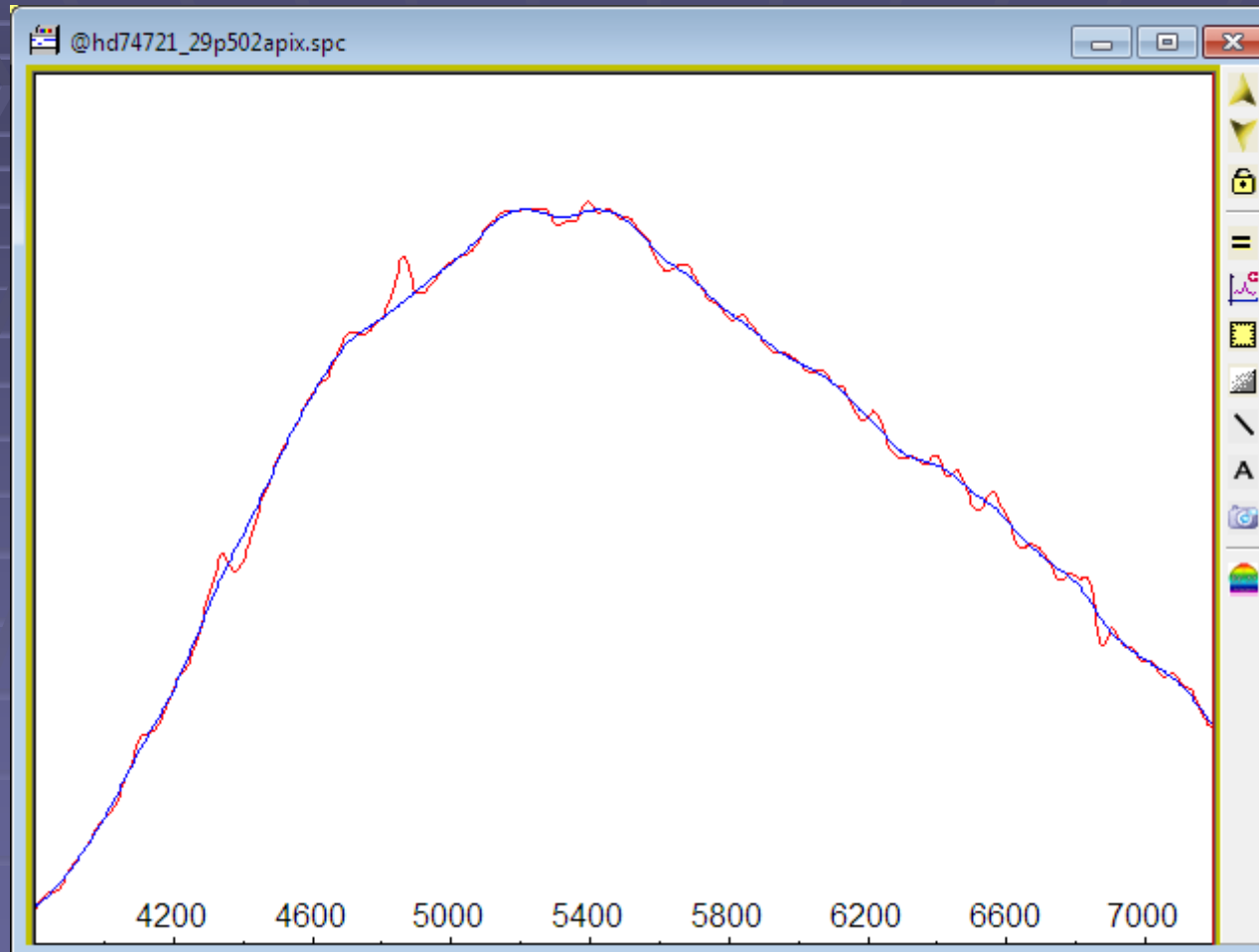
Filter the reference spectrum to match the resolution of the measured spectrum

Divide the measured spectrum (blue) by the reference spectrum (pink)



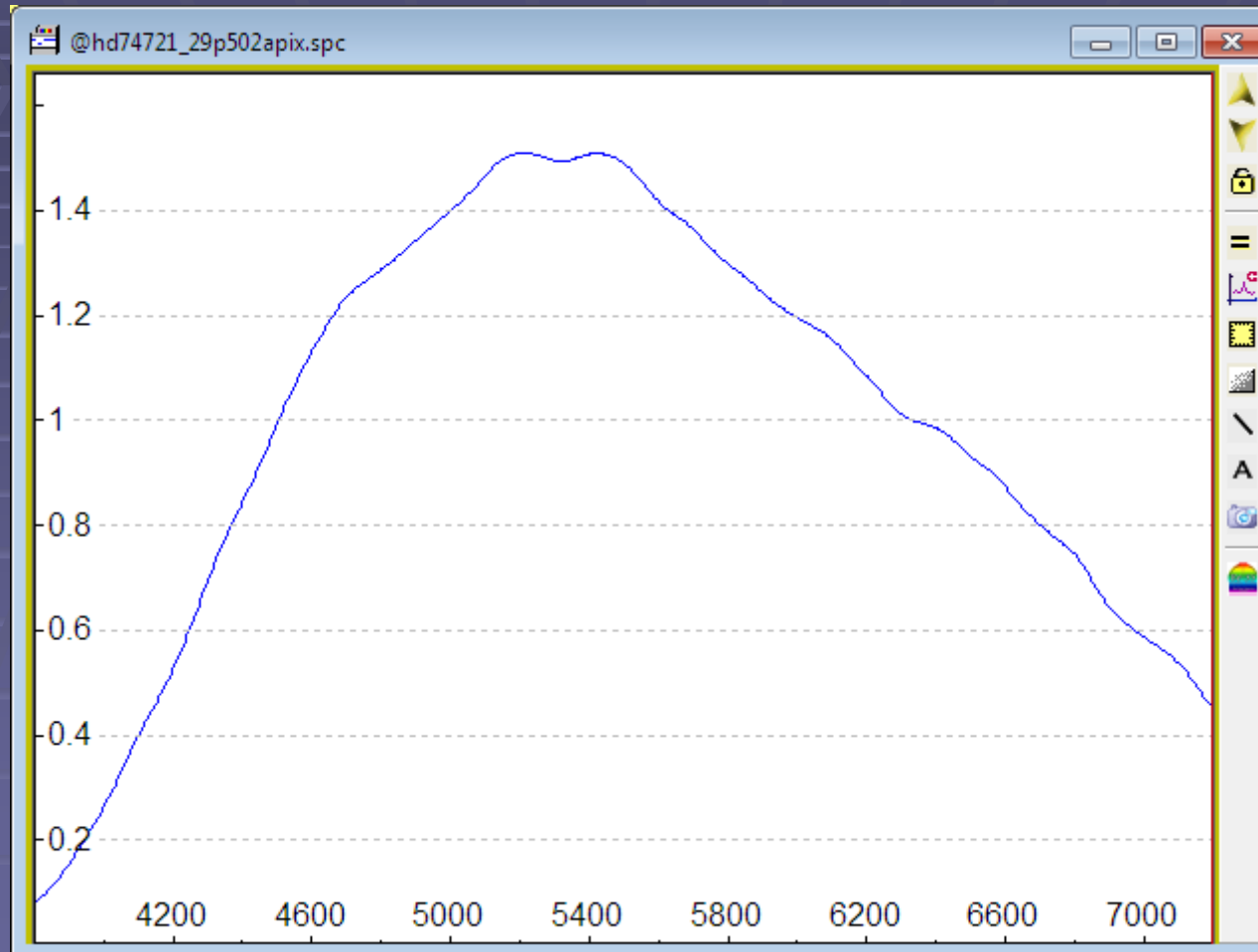
The result (red) is the raw instrument response

Remove residual line artifacts and smooth the result



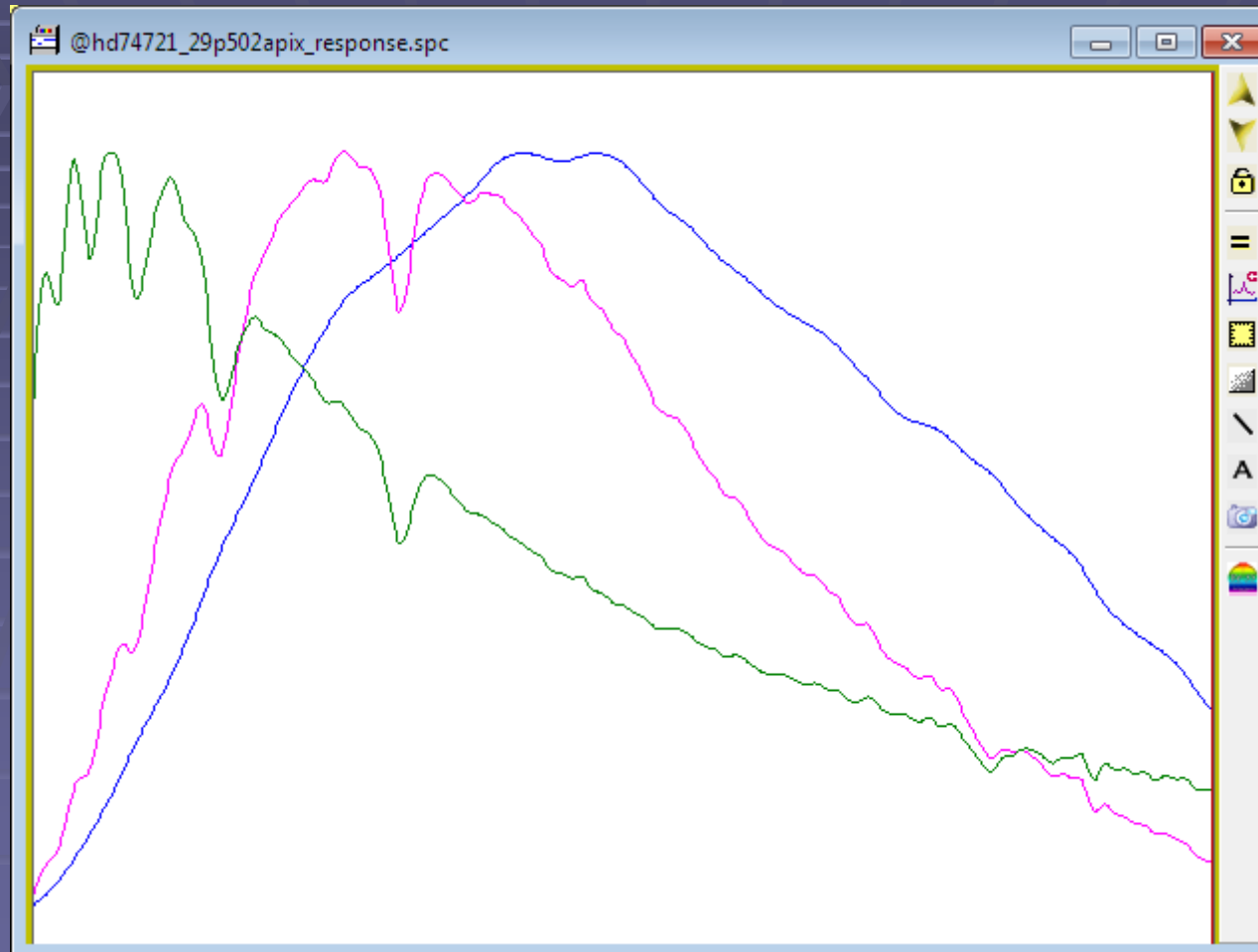
Take care not to over smooth, particularly at the blue end where sensitivity is low

The resulting instrument (+ atmospheric extinction) curve



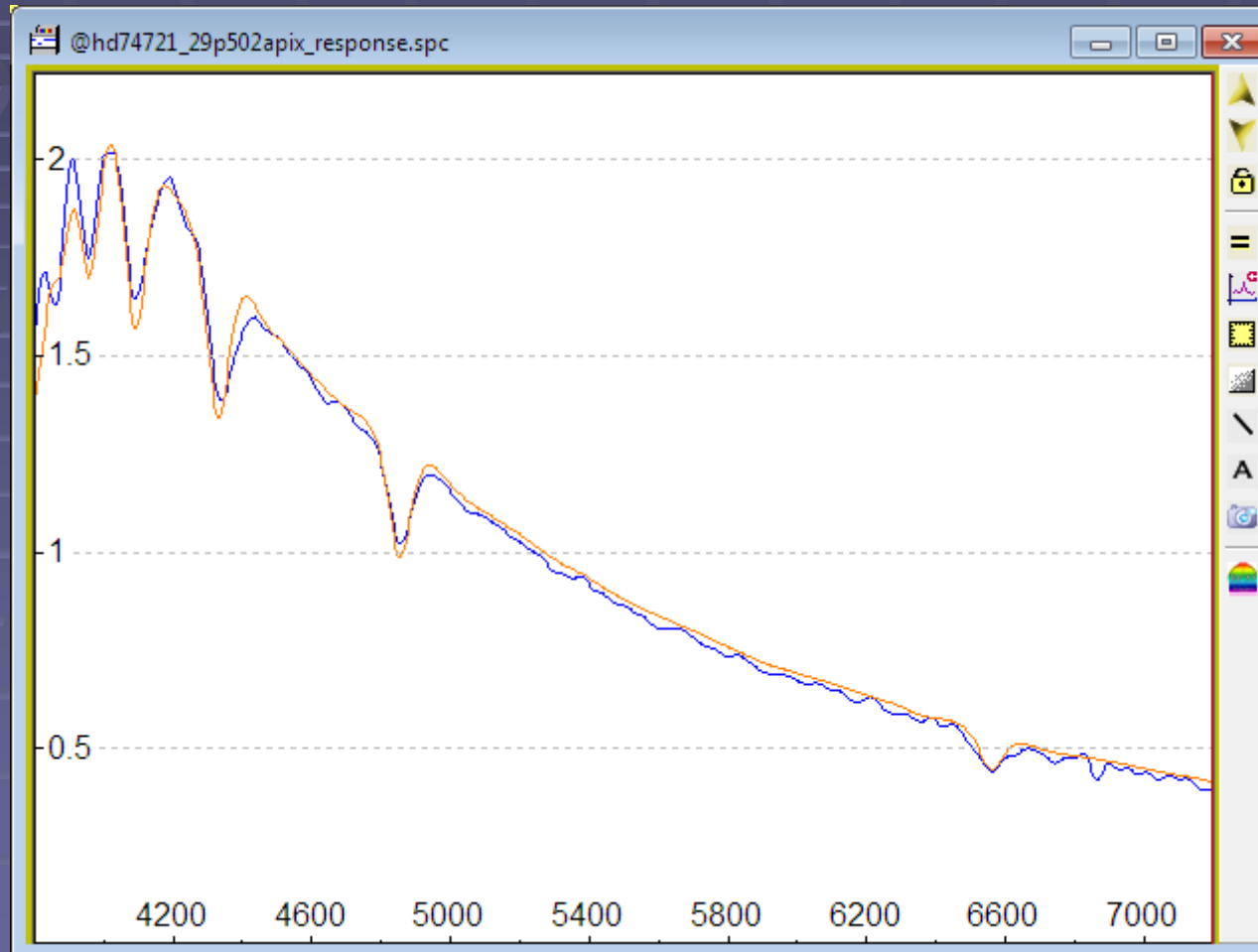
(normalised)

As a check, apply it to the uncorrected spectrum

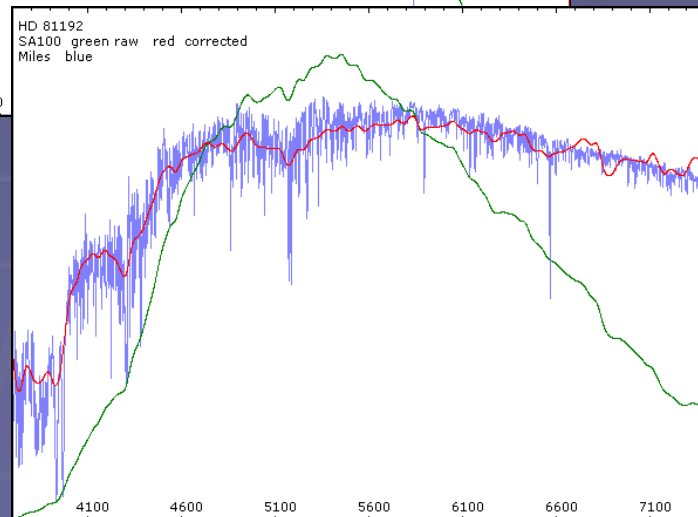
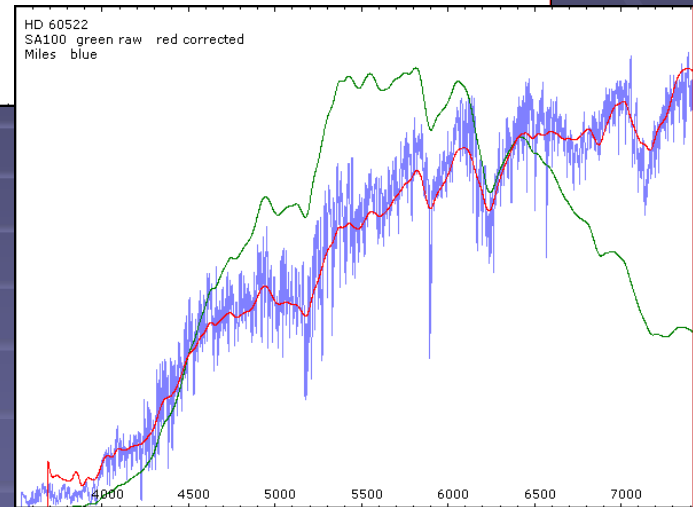
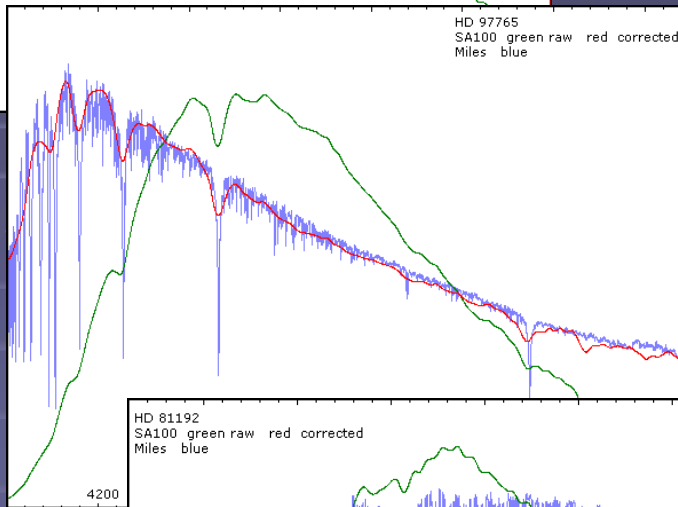
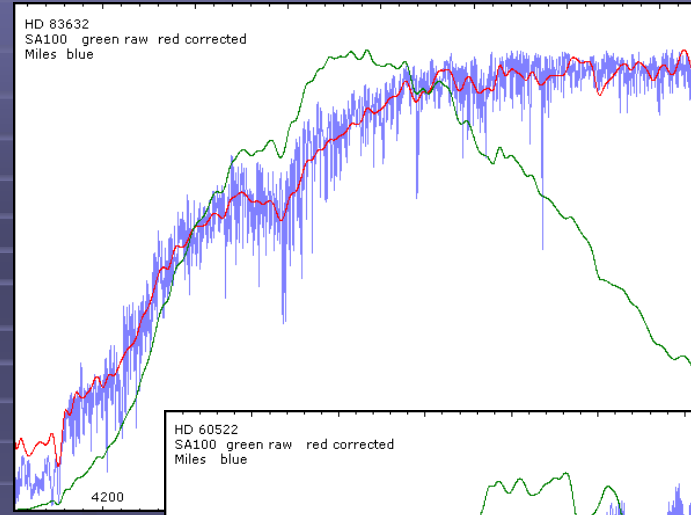
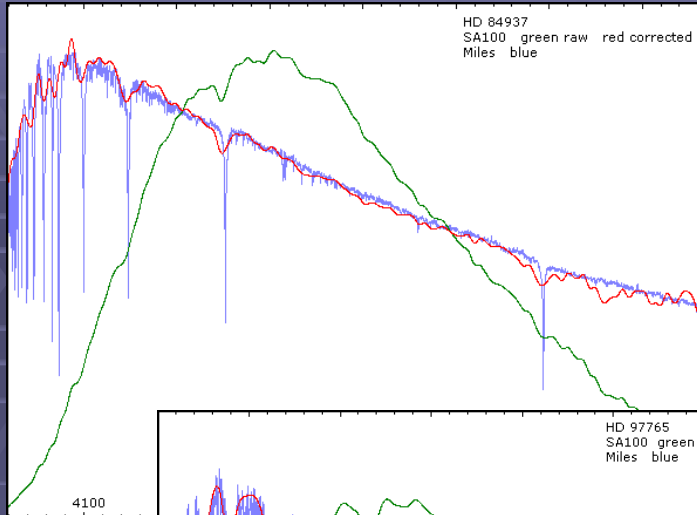


raw spectrum (pink) / instrument response (blue) = flux calibrated spectrum (green)

...and compare the result against the filtered reference spectrum (orange)



(scaled in relative flux = 1 at 5200Å)



raw
calibrated
MILES

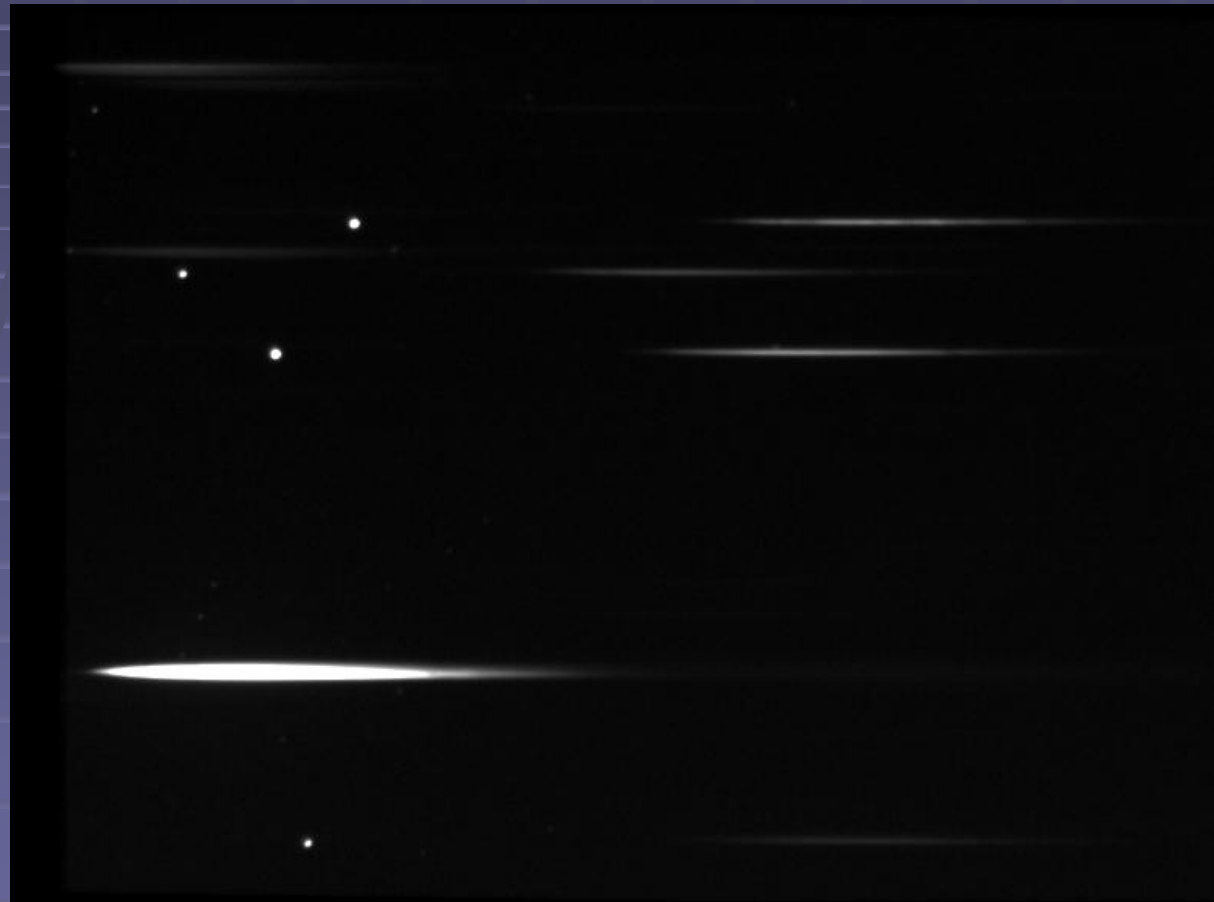
A spectrum of any object can be calibrated using the dispersion and instrument response measured using a reference star

High Cadence Differential Spectroscopy

A fast transient in the spectrum of T Tauri star DN Tau 2012-12-09

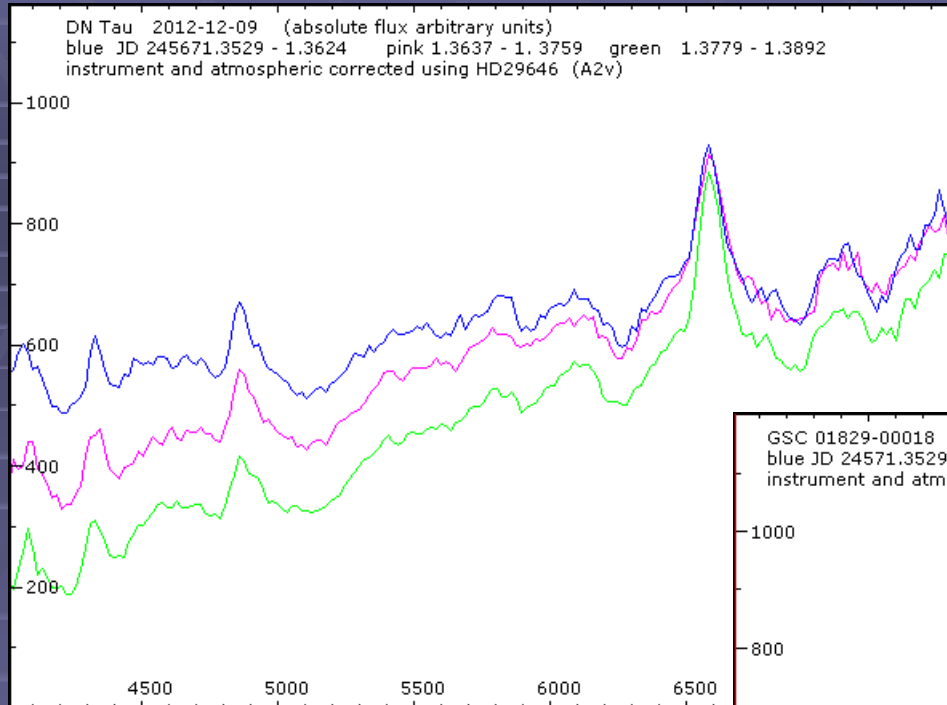
DN Tau (mag 12)

GSC 01829-00018



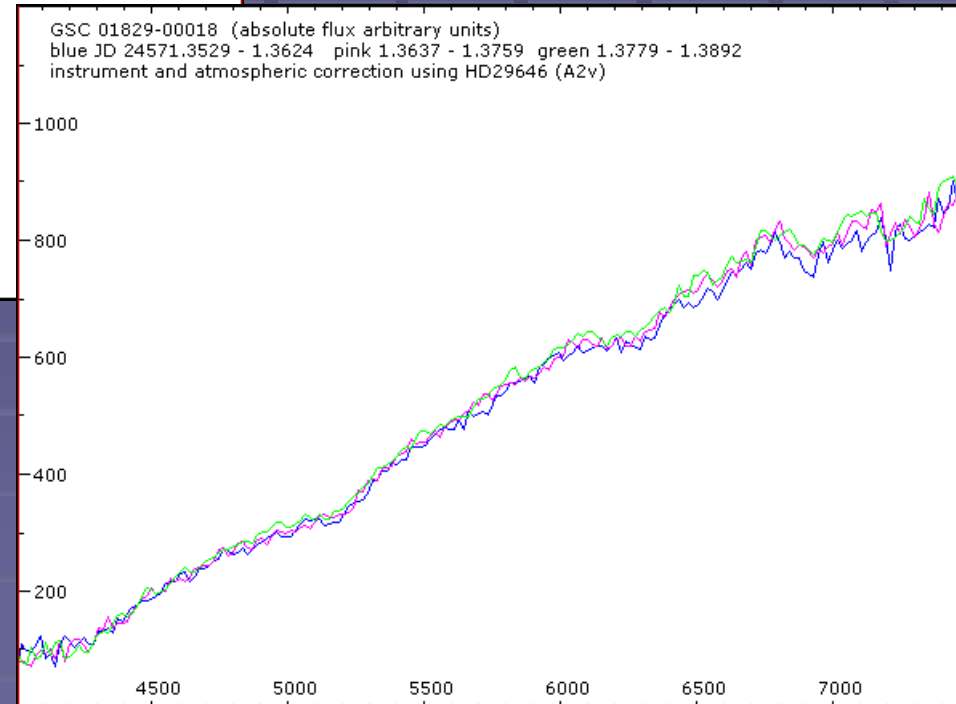
Monitoring request by Darryl Sergison University of Exeter

High Cadence Differential Spectroscopy

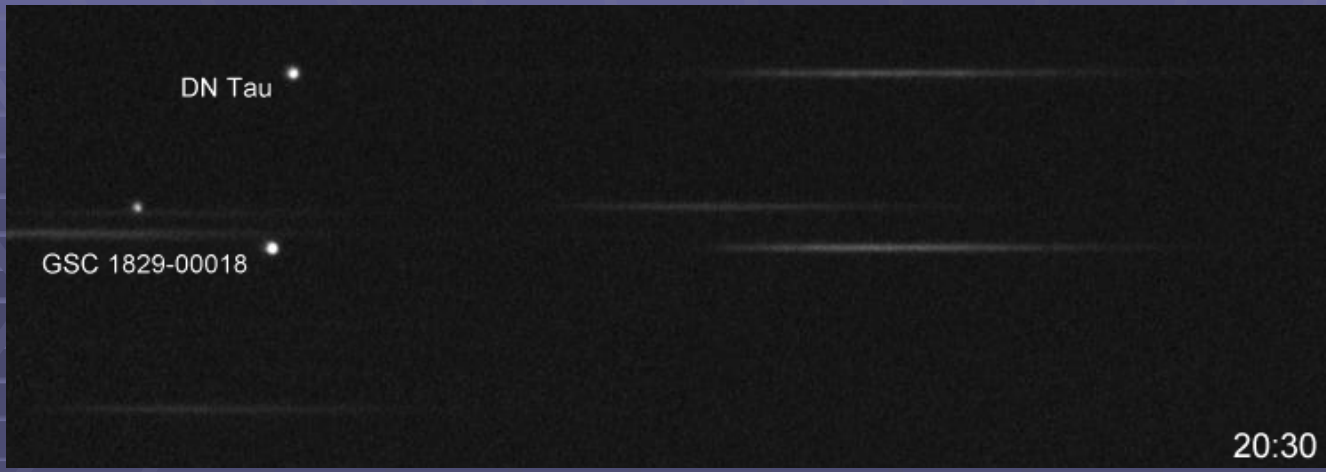


Target spectra

Spectra every 15 min,
each a mean of 30x 20 sec



Comparison star spectra



Individual
20 sec exposures

