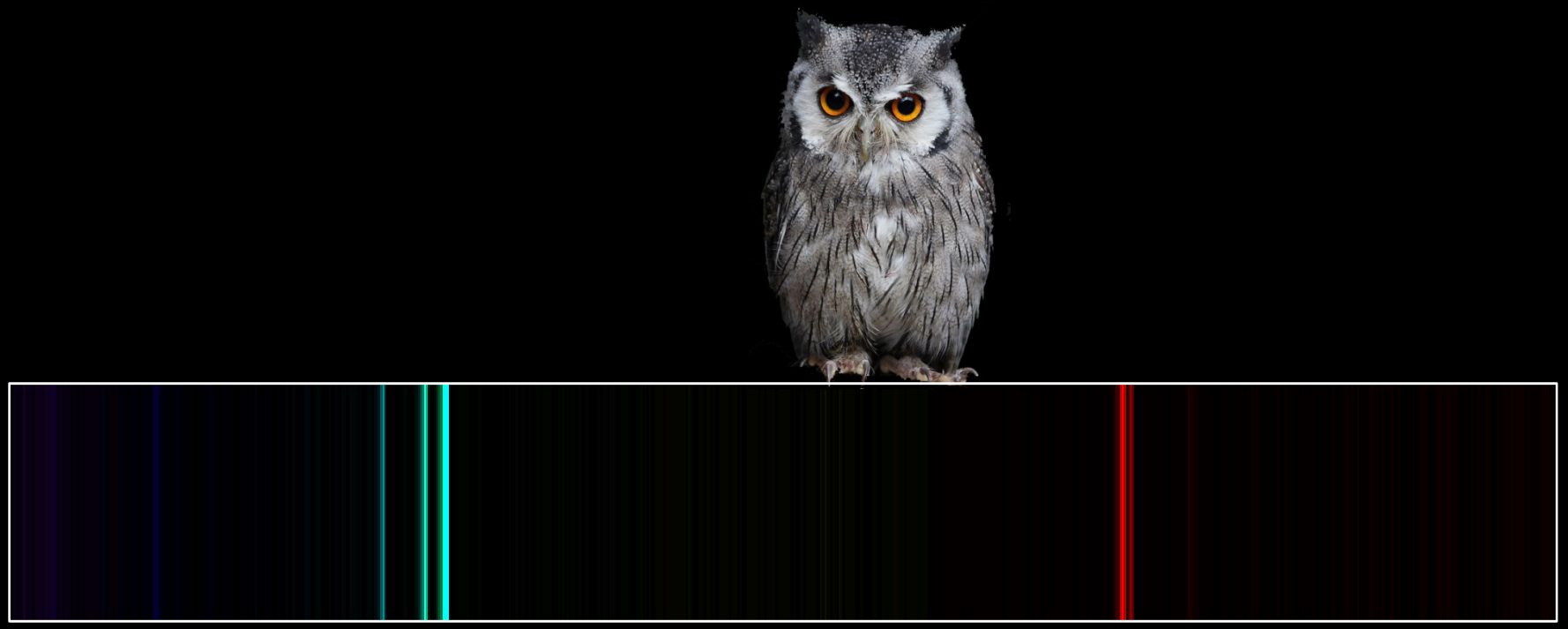
First steps in Spectroscopy



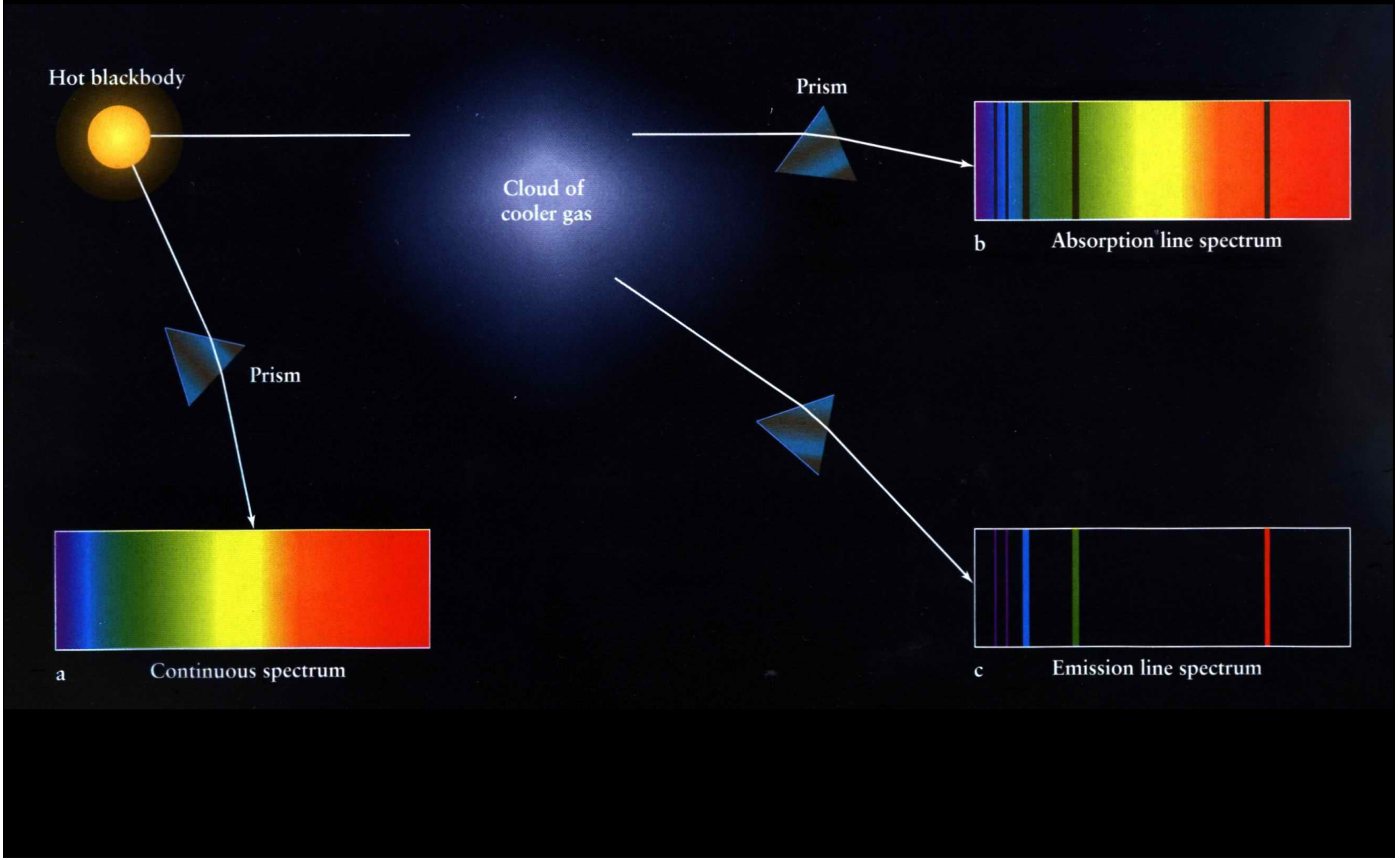
© David Boyd

Talk given at the BAA Winchester Weekend April 2014

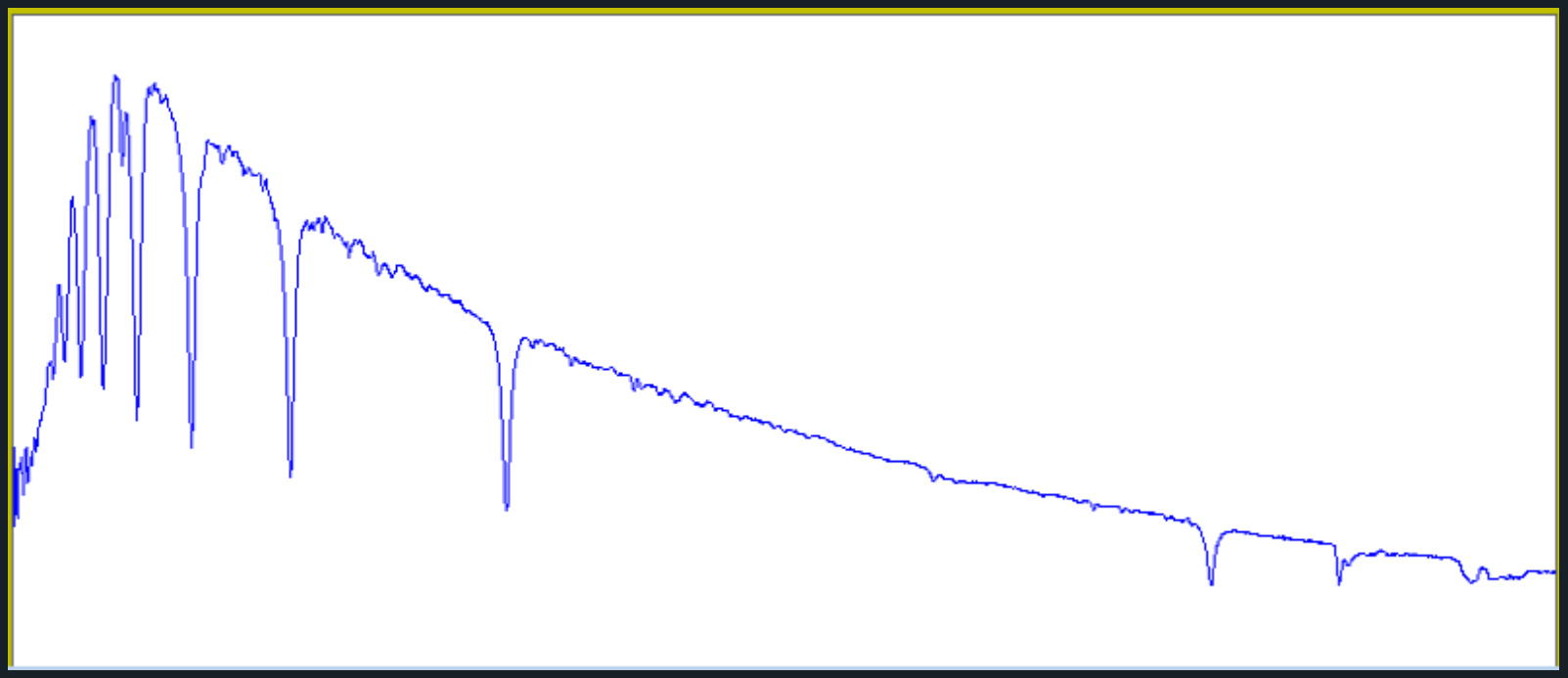
Outline of the talk

- Some basics of spectroscopy
- Slitless spectroscopy and analysis
- Slit spectroscopy and analysis
- Some examples

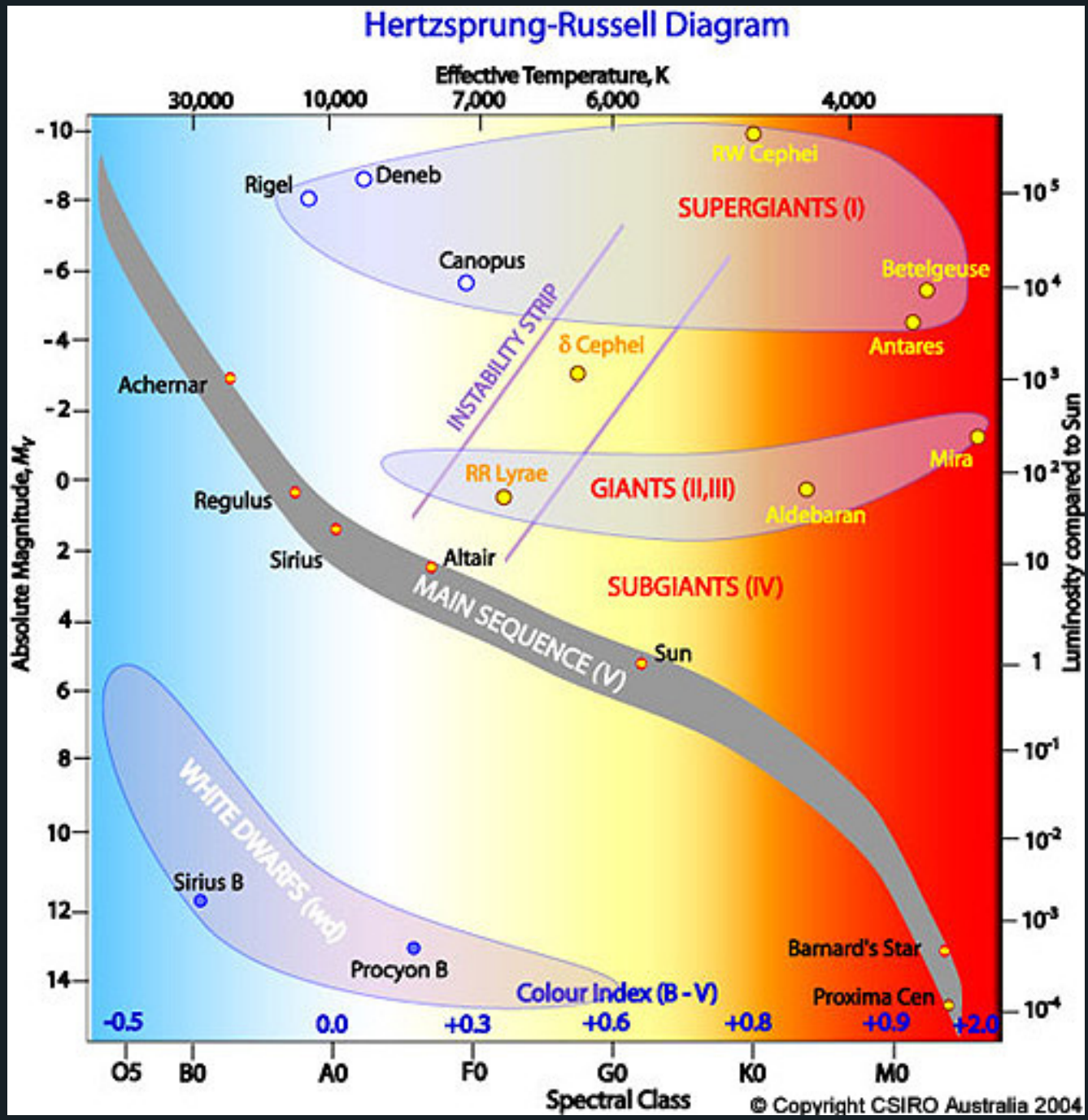
Different types of spectrum



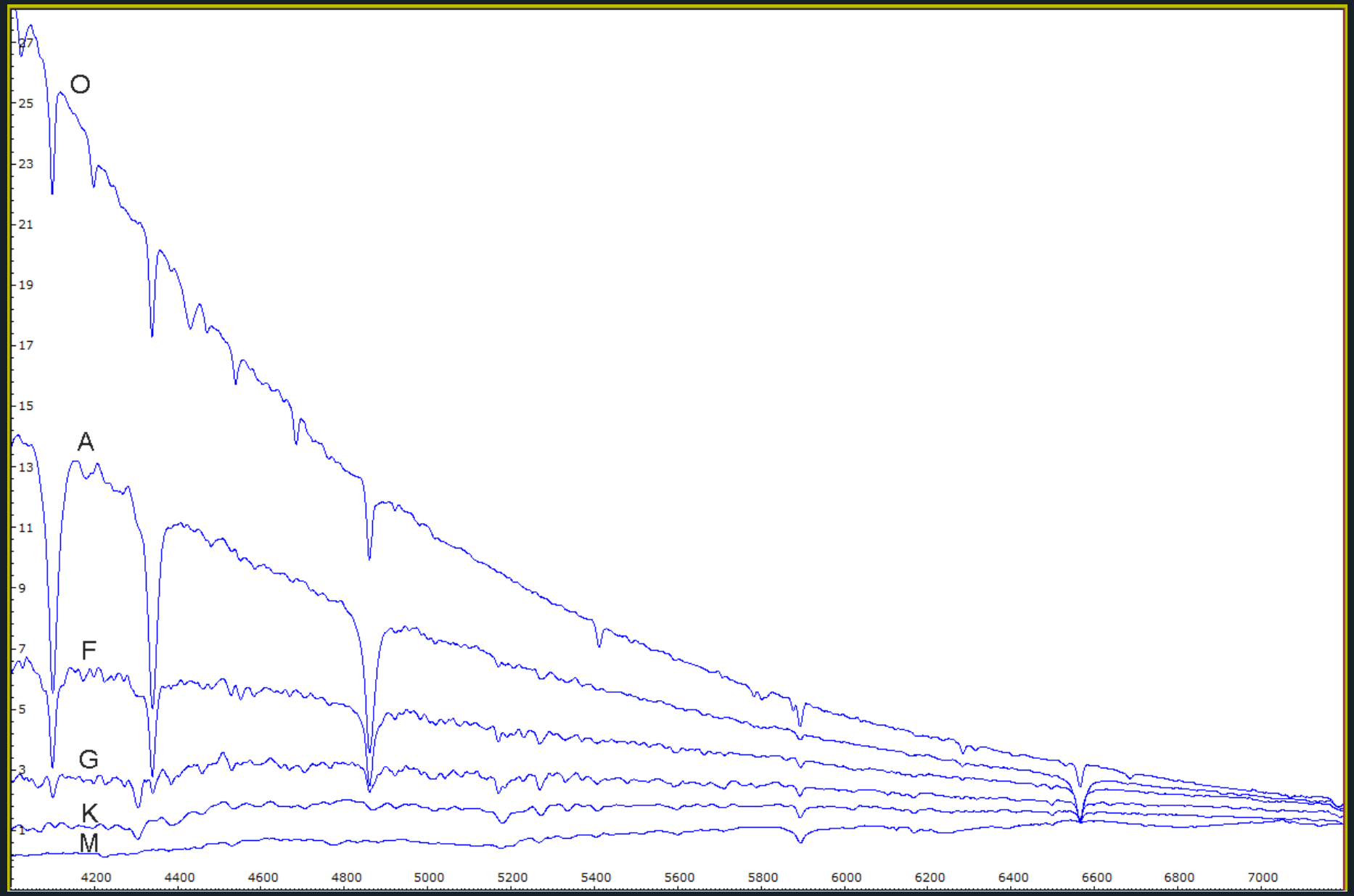
Different ways to look at a spectrum (HD85235 – spectral type A3IV)



Spectral types and luminosity classes



Examples of spectra of the main spectral types

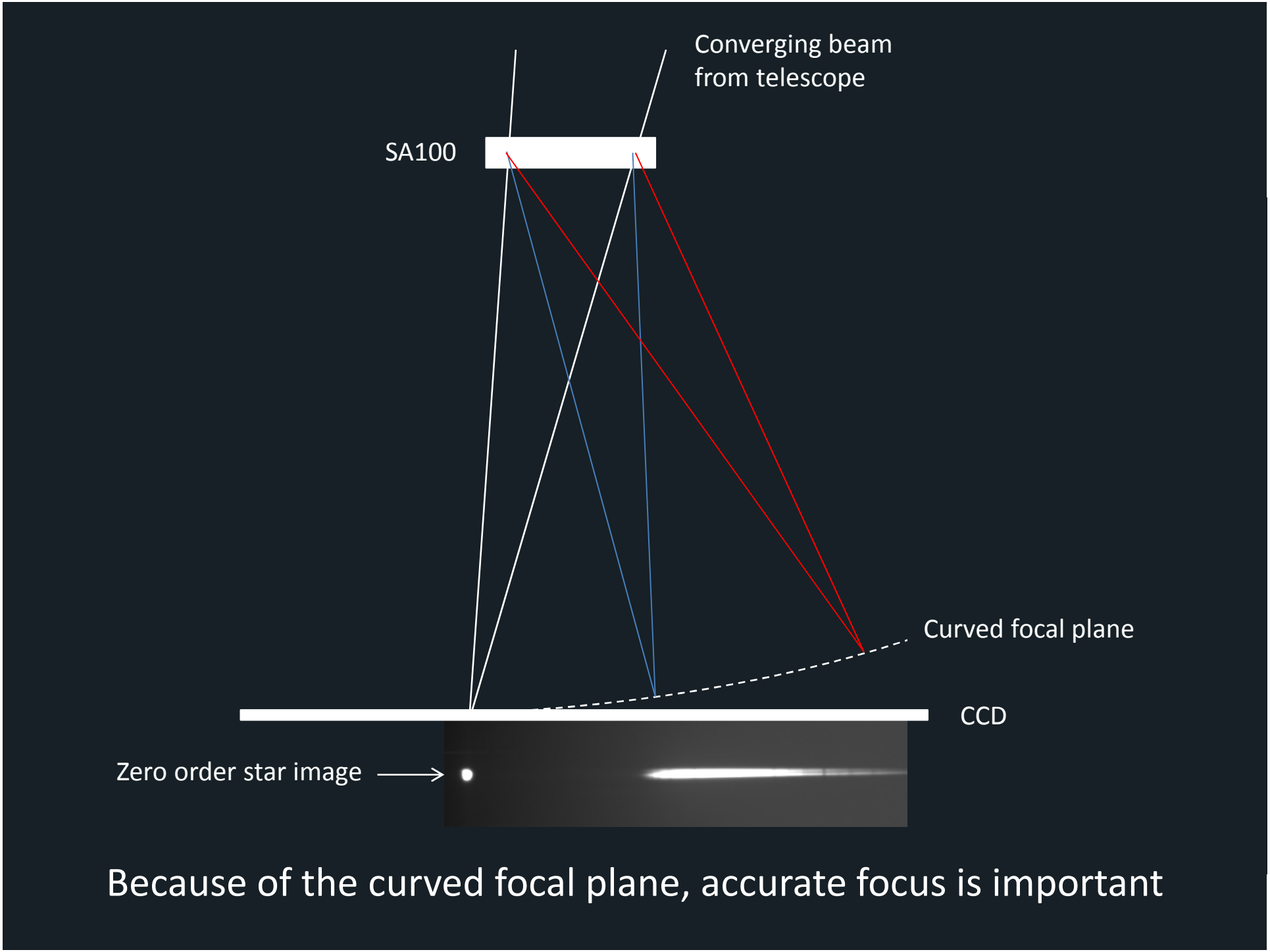


A good starting point

Slitless spectroscopy using the
Star Analyser SA100

(manufactured by Paton Hawksley)

- 100 lines/mm transmission diffraction grating in 1¼” holder
- designed to be screwed into a camera nosepiece or filter wheel
- blazed so one 1st order spectrum is much brighter
- important to get correct spacing between grating and CCD
- orient grating so spectrum is parallel to long dimension of CCD



Because of the curved focal plane, accurate focus is important

- Initially focus on sharp emission or absorption lines in a bright star
  - this puts the first order star image out of focus

- Then move to your target and, if necessary, rotate grating and camera to avoid other stars or spectra overlapping the target
- Take a series of exposures without saturating spectrum
- Dark subtract and median combine these images using suitable software (eg Astroart)

We also need to observe a star with bright Balmer emission or absorption lines close to and at the same altitude as our target for two reasons:

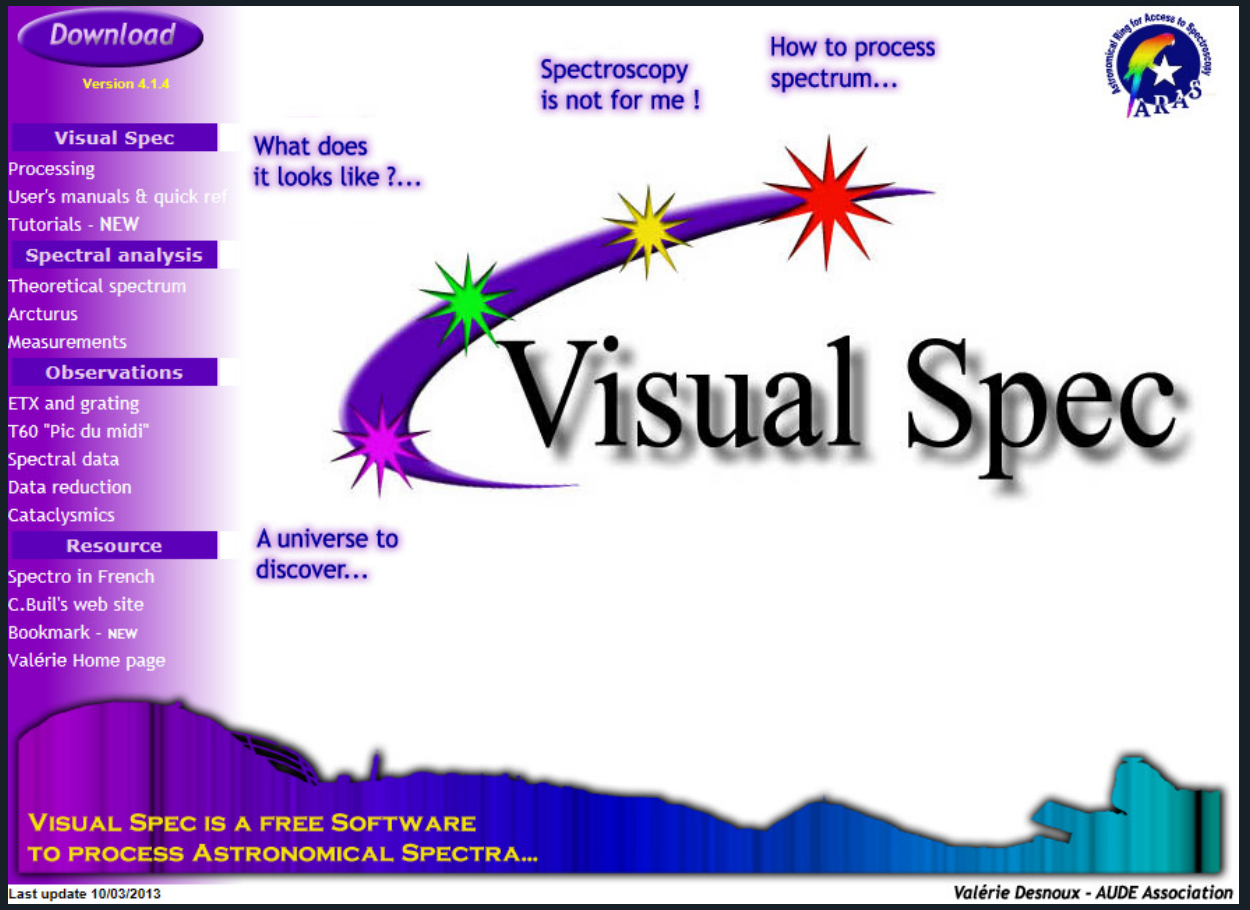
a) to find the dispersion of our equipment in Å/pixel so we can convert pixel number in the X-direction into wavelength units

b) to find the combined effect of the spectral response of our equipment and atmospheric extinction in that direction so we can correct our measured spectrum for both these effects

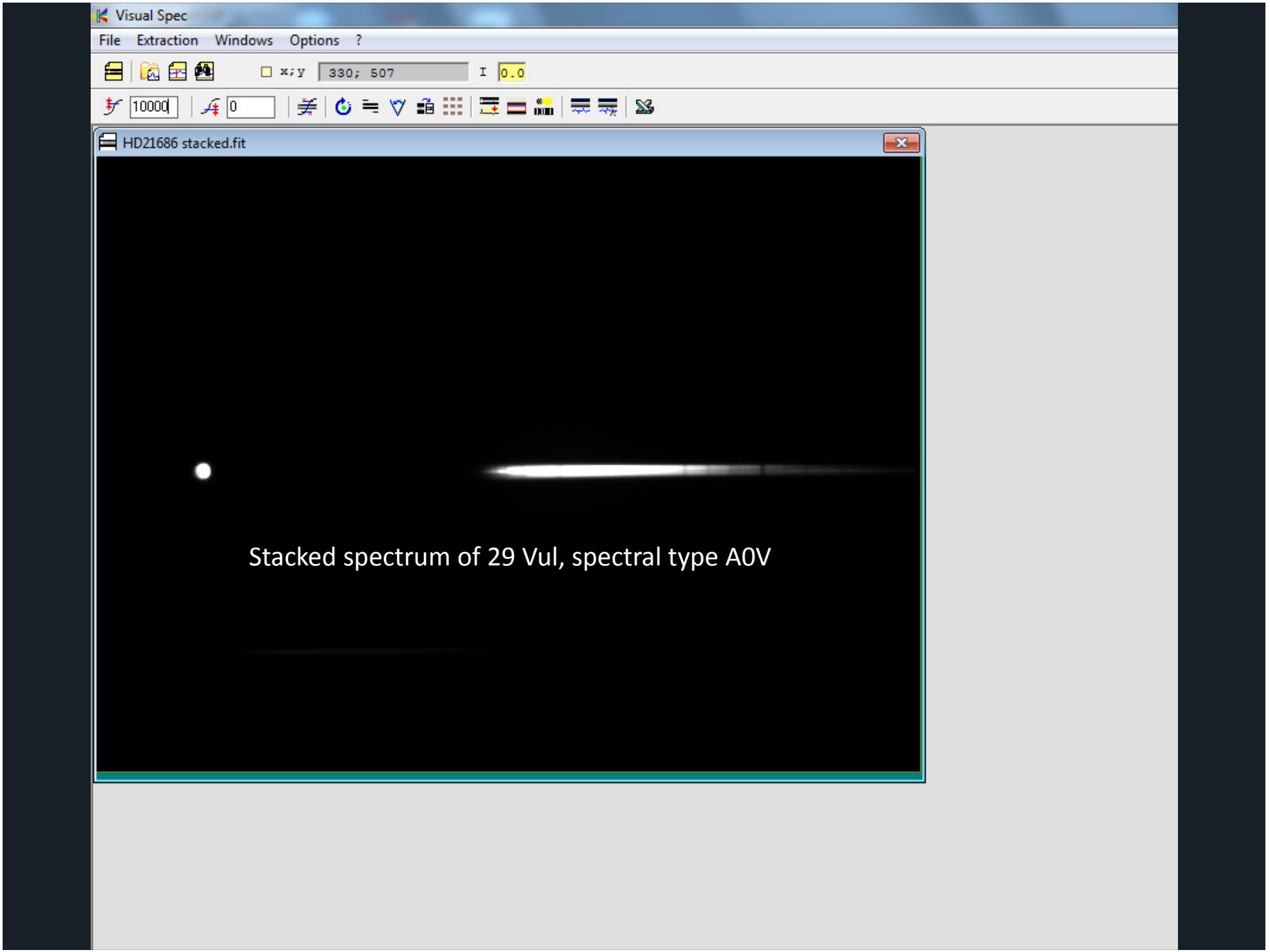
Analysing your spectra

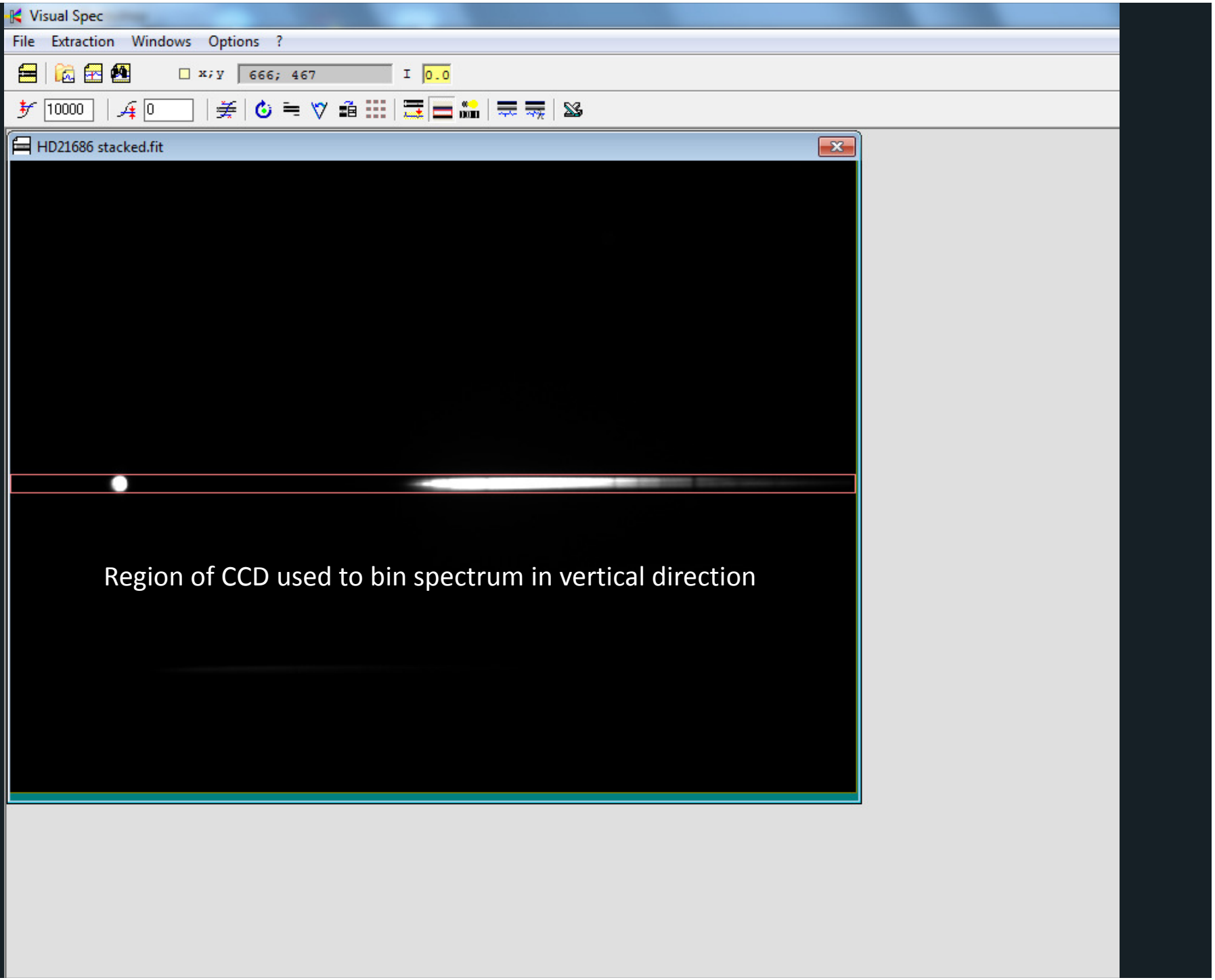
Visual Spec or Vspec is free software which provides an excellent starting point for analysing spectra

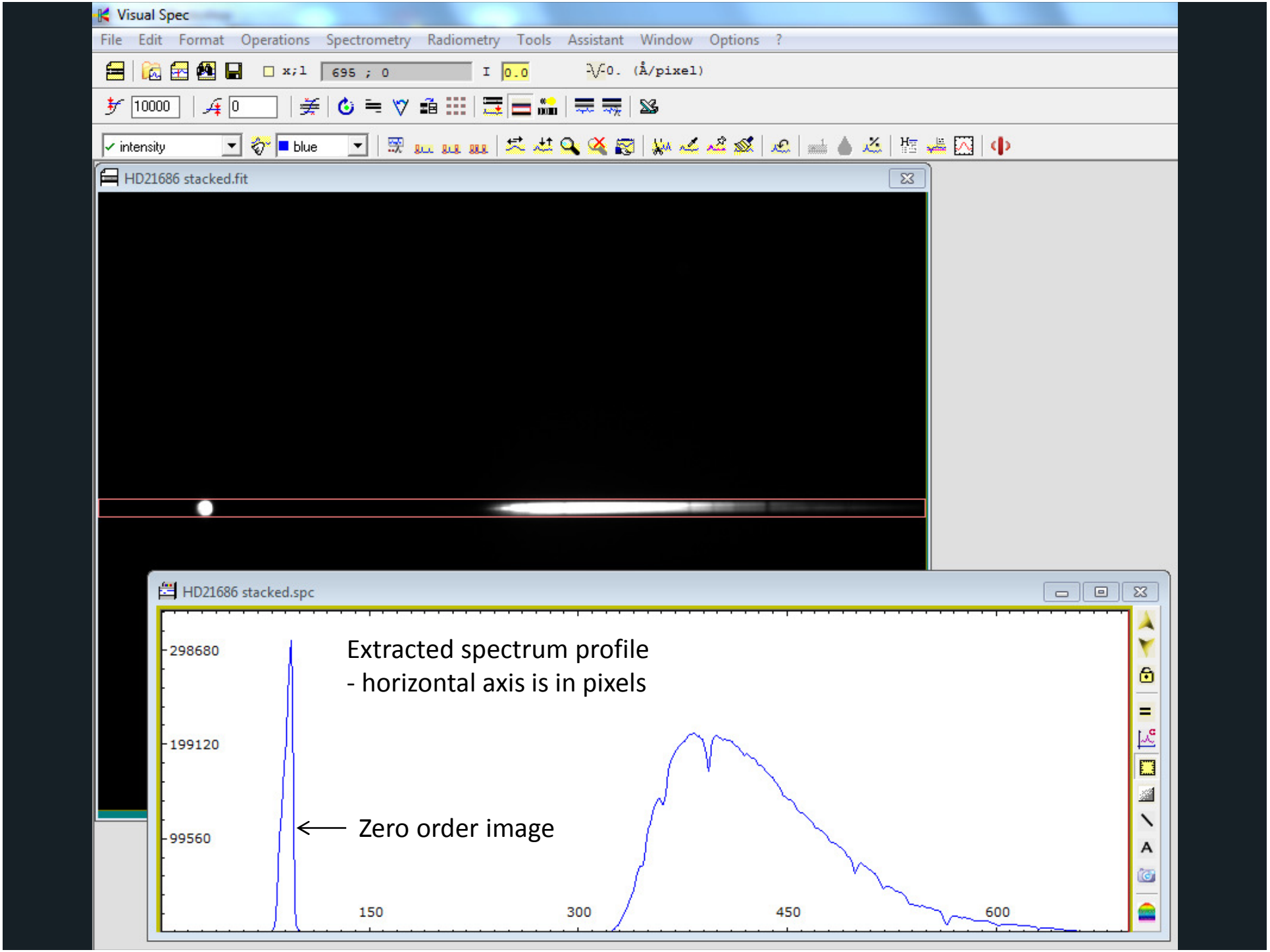
It's a good example of the lead which French amateurs have taken in driving spectroscopy forward

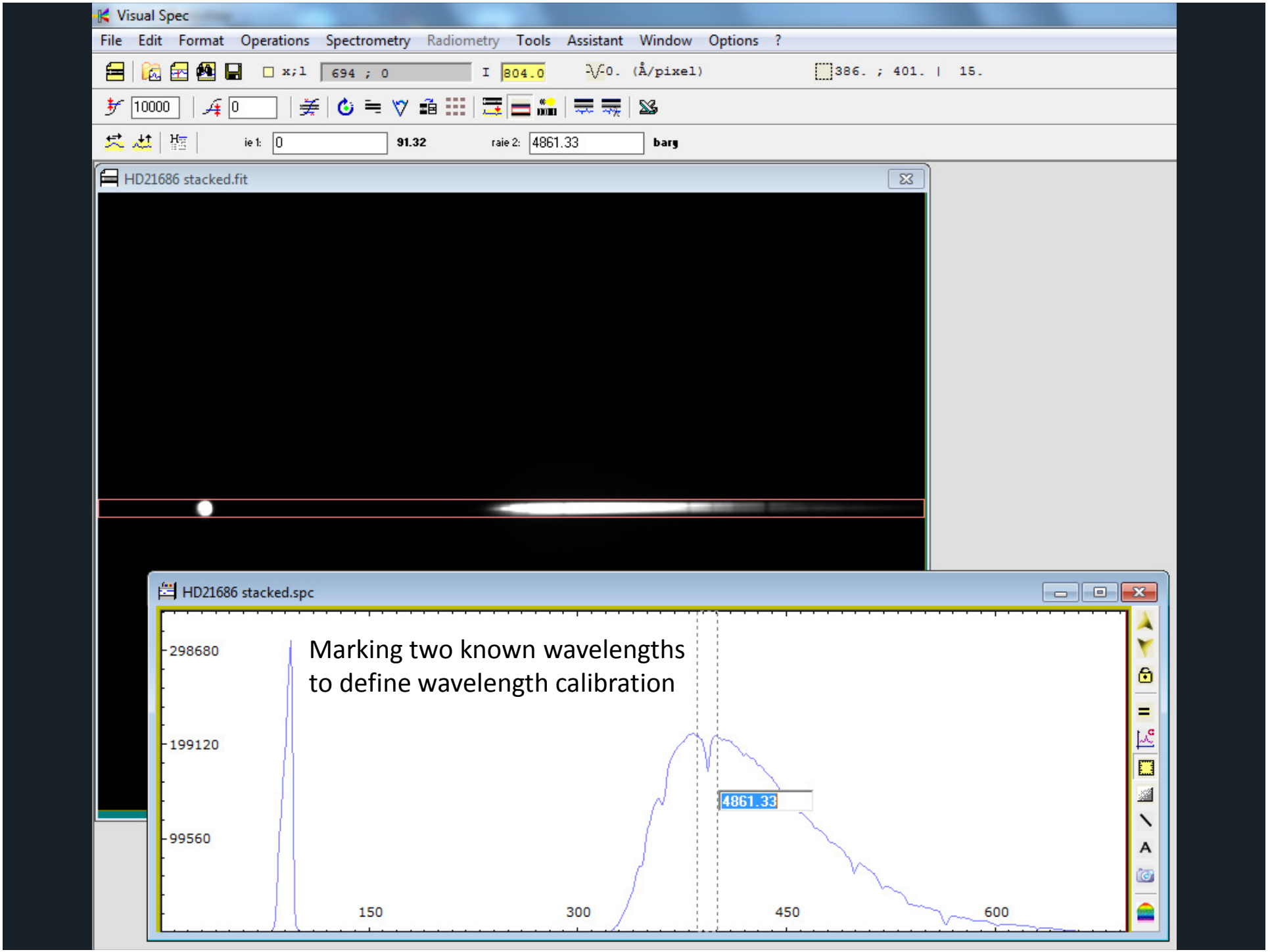


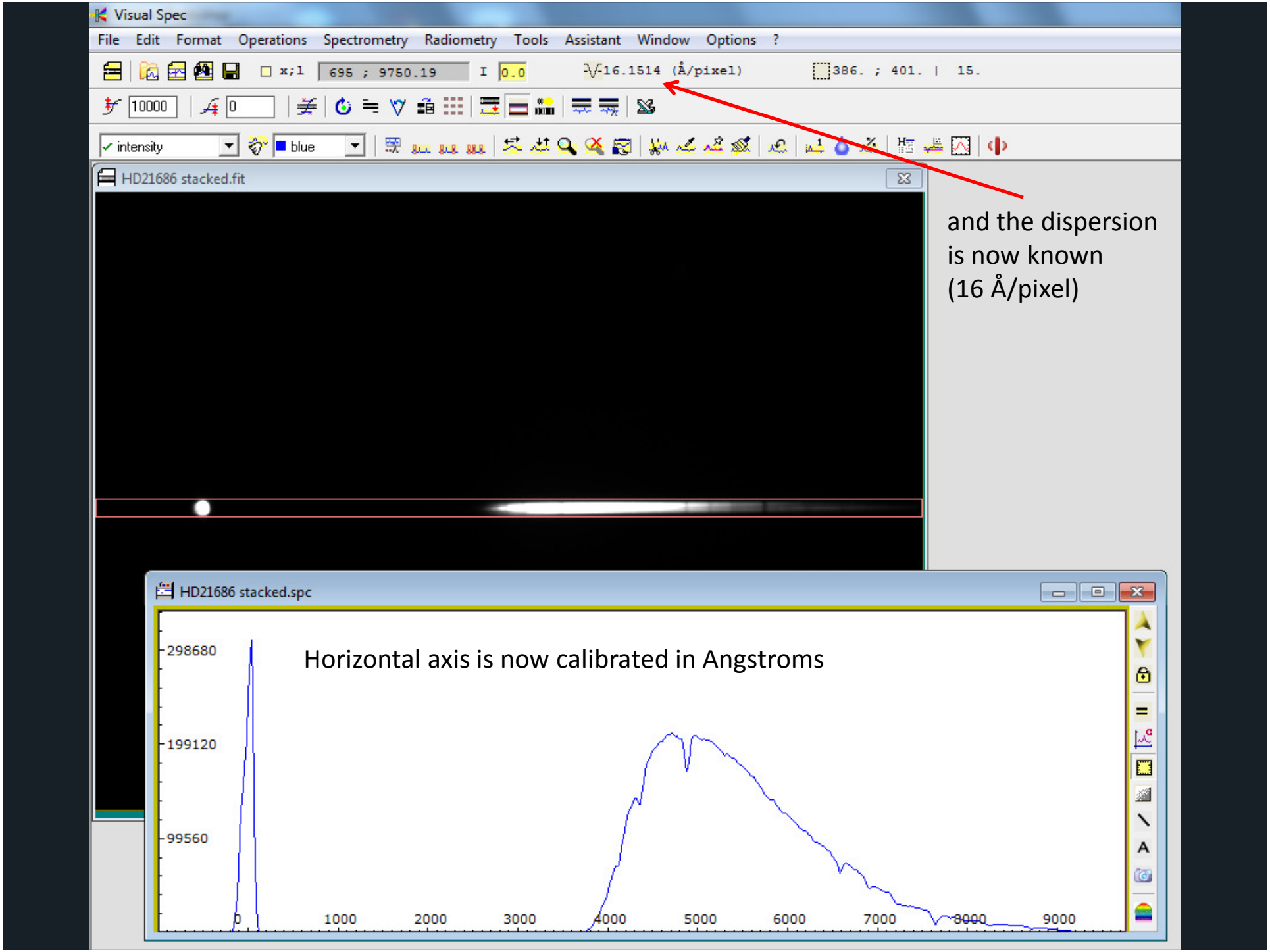
http://www.astrosurf.com/vdesnoux/

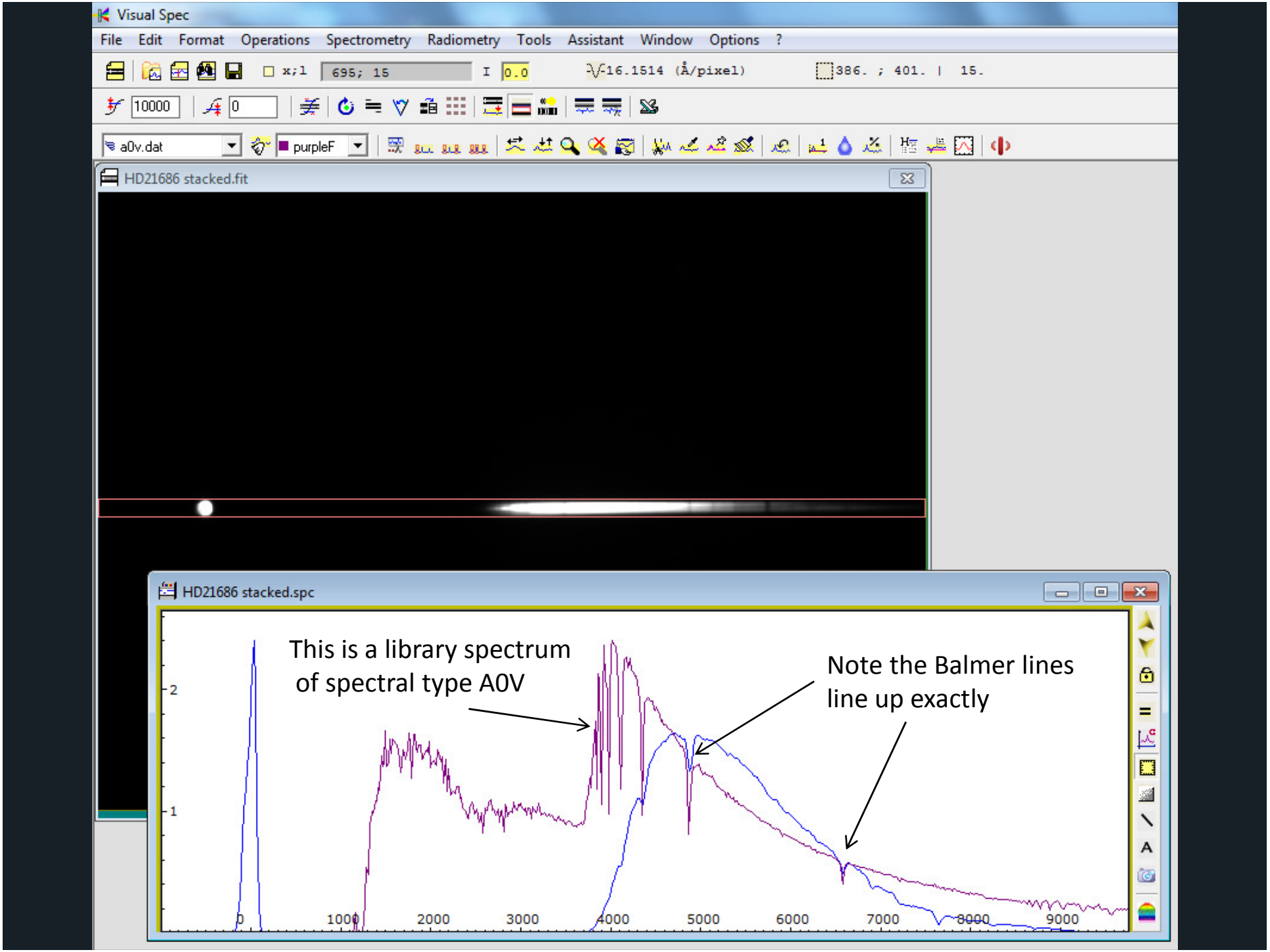

Visual Spec
File Extraction Windows Options ?
x;y 330; 507 I 0.0
10000 0
HD21686 stacked.fit
Stacked spectrum of 29 Vul, spectral type A0V

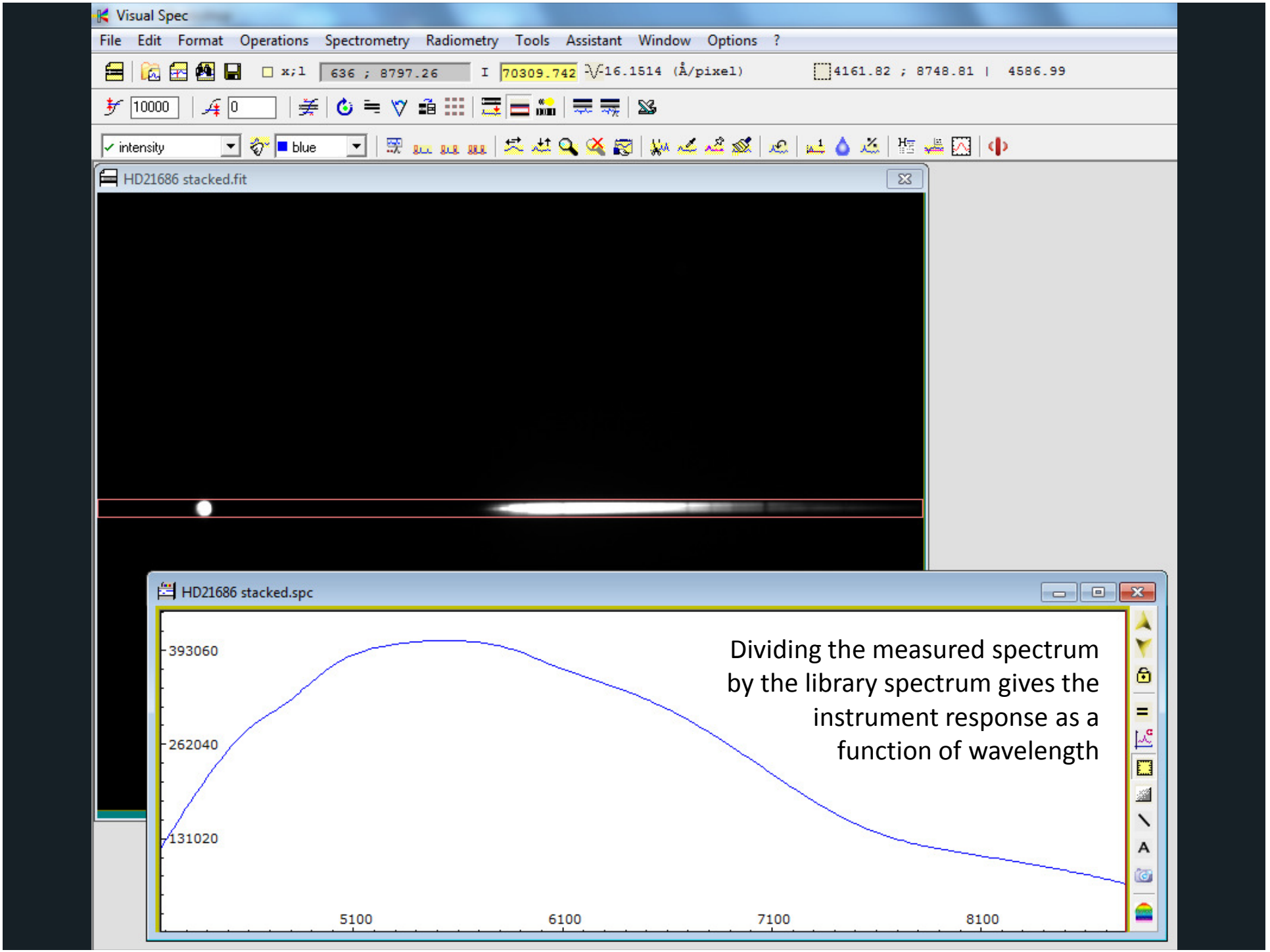

Visual Spec
File Extraction Windows Options ?
x;y 666; 467 I 0.0
10000 0
HD21686 stacked.fit
Region of CCD used to bin spectrum in vertical direction


Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
695 ; 0
10000
0
intensity
blue
HD21686 stacked.fit
HD21686 stacked.spc
298680
199120
99560
150
300
450
600
Extracted spectrum profile
- horizontal axis is in pixels
Zero order image


Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
694 ; 0
I 804.0
0. (Å/pixel)
386. ; 401. | 15.
10000
0
ie 1: 0
91.32
raie 2: 4861.33
barg
HD21686 stacked.fit
HD21686 stacked.spc
Marking two known wavelengths
to define wavelength calibration
298680
199120
99560
150
300
450
600
4861.33

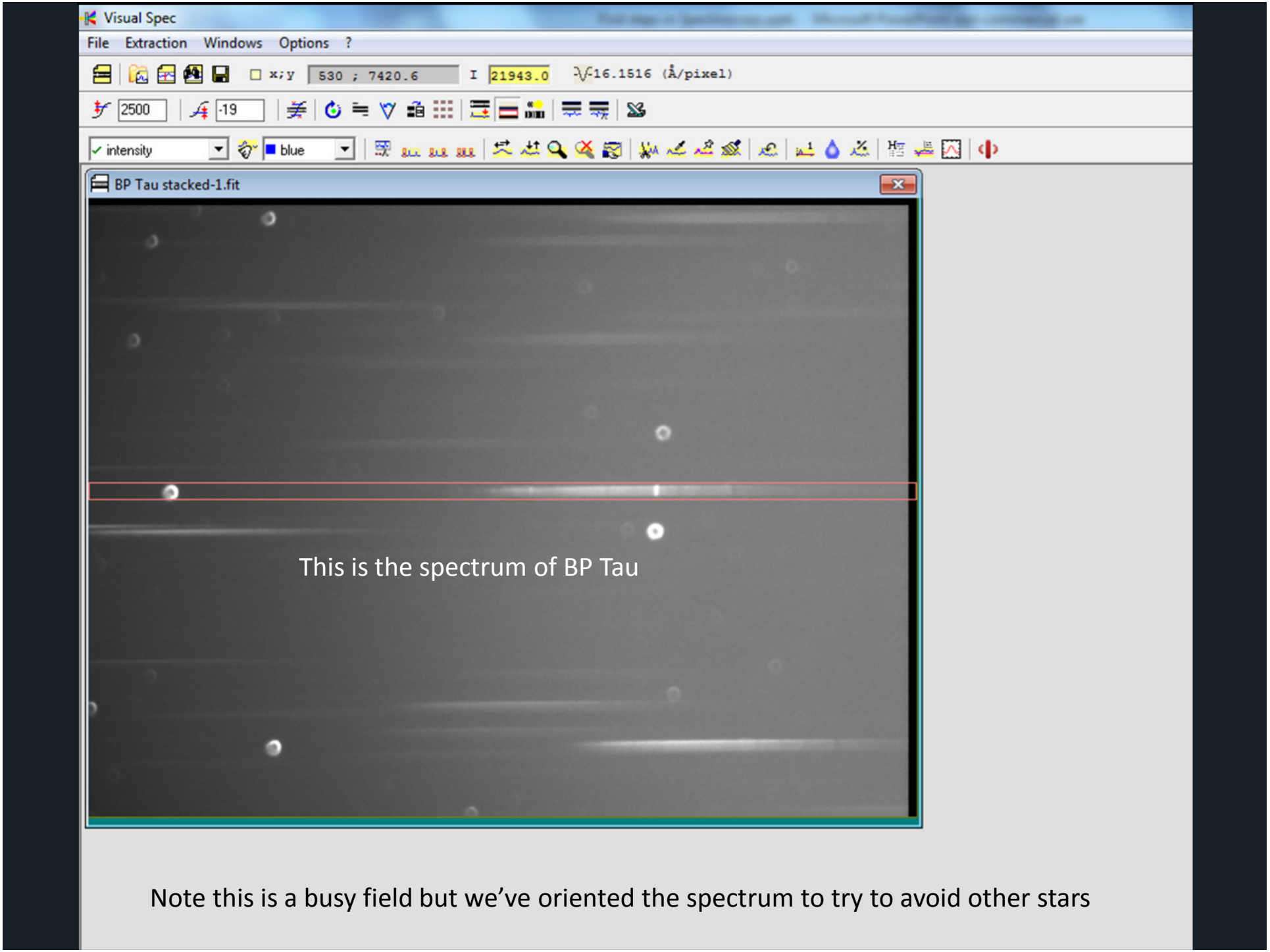

Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
695 ; 9750.19
16.1514 (Å/pixel)
386. ; 401. | 15.
HD21686 stacked.fit
and the dispersion is now known (16 Å/pixel)
HD21686 stacked.spc
Horizontal axis is now calibrated in Angstroms
298680
199120
99560
0
1000
2000
3000
4000
5000
6000
7000
8000
9000


Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
16.1514 (Å/pixel)
a0v.dat
purpleF
HD21686 stacked.fit
HD21686 stacked.spc
This is a library spectrum of spectral type A0V
Note the Balmer lines line up exactly
2
1
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

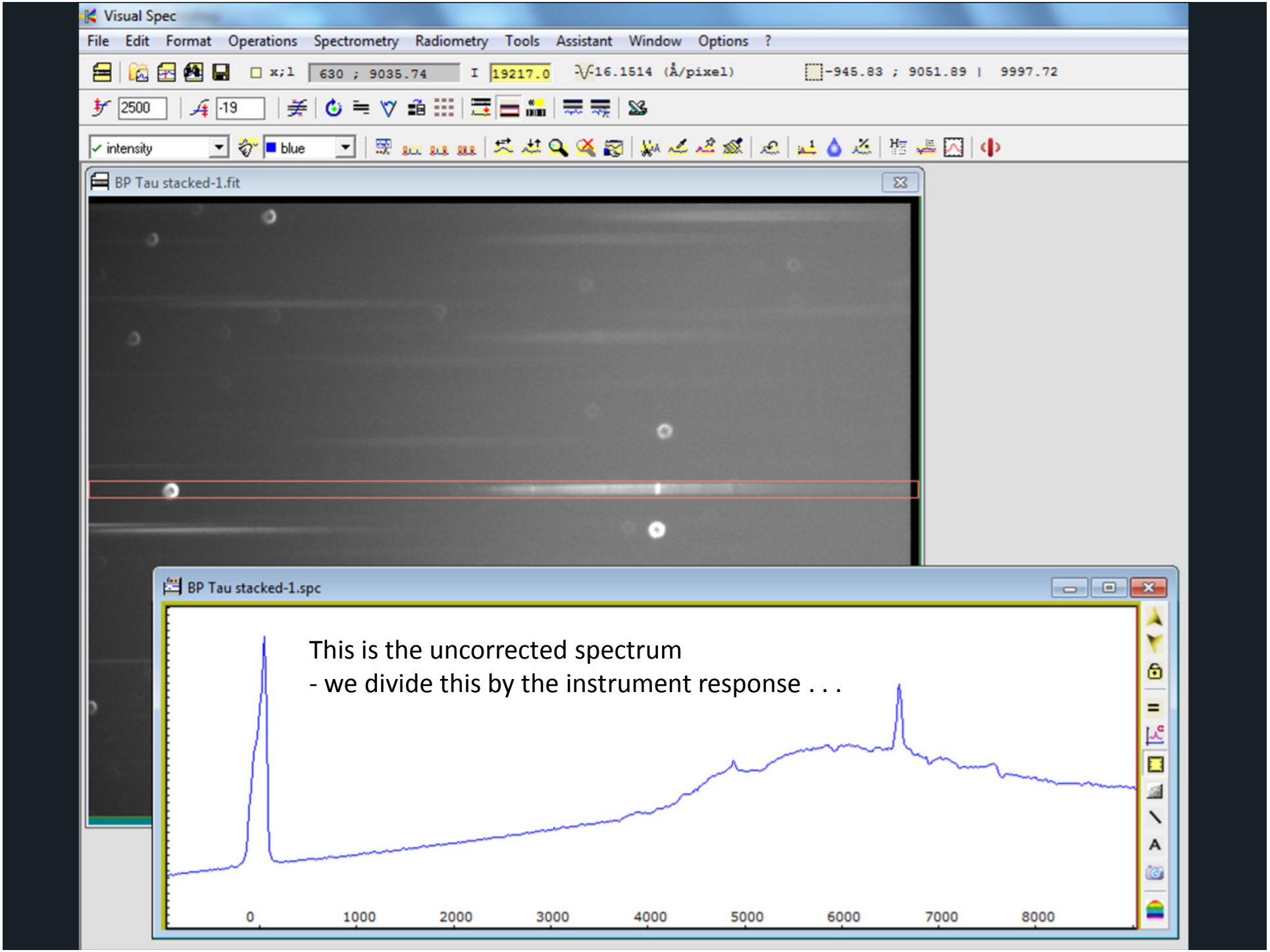

Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
636 ; 8797.26
70309.742
16.1514 (Å/pixel)
4161.82 ; 8748.81 | 4586.99
10000
0
intensity
blue
HD21686 stacked.fit
HD21686 stacked.spc
393060
262040
131020
5100
6100
7100
8100
Dividing the measured spectrum by the library spectrum gives the instrument response as a function of wavelength

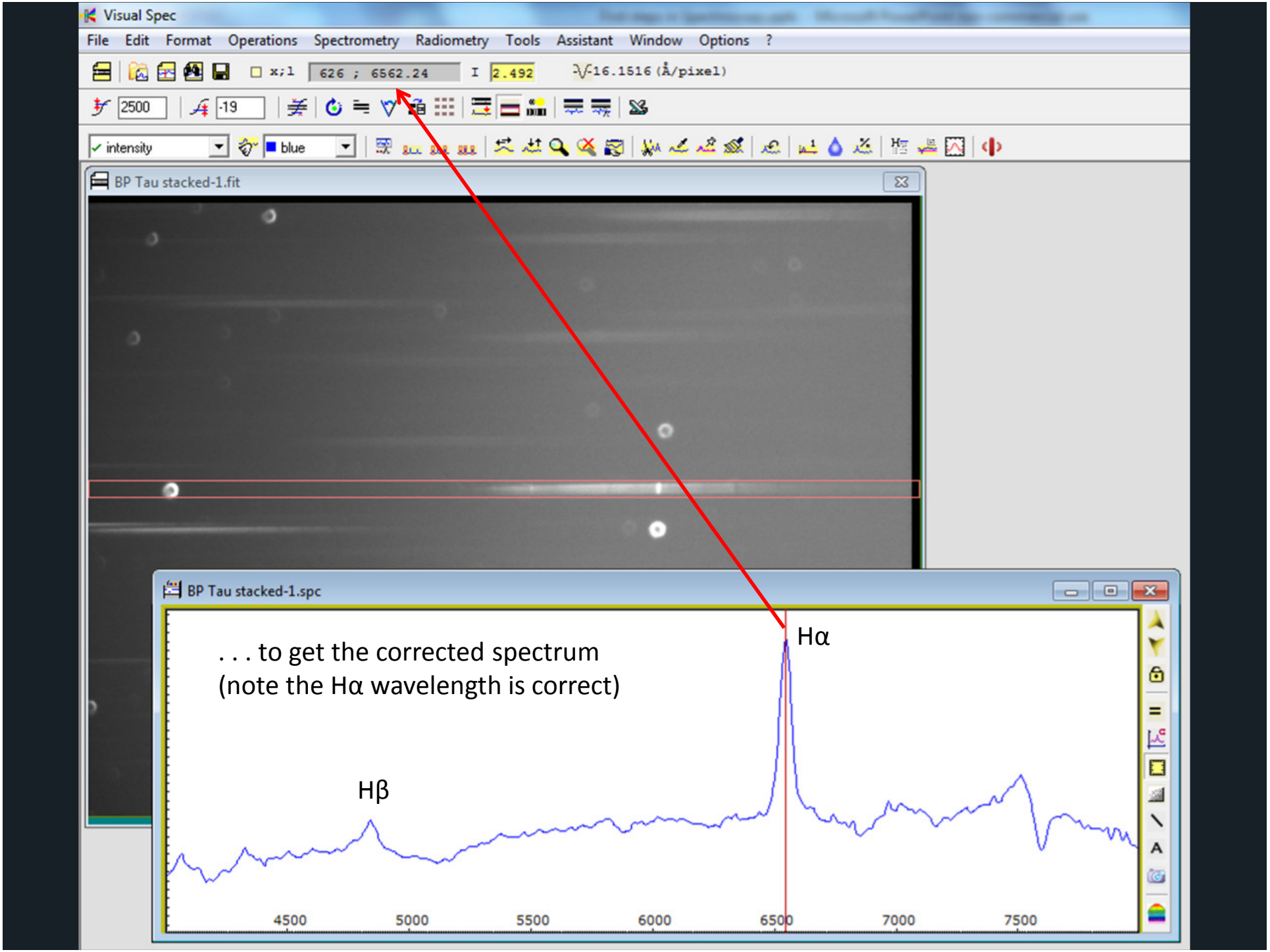
We now have everything we need to process the spectrum of our target, in this case the T Tauri star BP Tau

NB. If your target is faint, it is important to have a dark sky



Note this is a busy field but we've oriented the spectrum to try to avoid other stars


Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
630 ; 9035.74
19217.0
16.1514 (Å/pixel)
-945.83 ; 9051.89 | 9997.72
2500
-19
intensity
blue
BP Tau stacked-1.fit
BP Tau stacked-1.spc
This is the uncorrected spectrum
- we divide this by the instrument response . . .
0
1000
2000
3000
4000
5000
6000
7000
8000


Visual Spec
File Edit Format Operations Spectrometry Radiometry Tools Assistant Window Options ?
626 ; 6562.24
2.492
16.1516 (Å/pixel)
2500
-19
intensity
blue
BP Tau stacked-1.fit
BP Tau stacked-1.spc
. . . to get the corrected spectrum
(note the Hα wavelength is correct)
Hα
Hβ
4500
5000
5500
6000
6500
7000
7500

How good is slitless spectroscopy?

Because there is no slit, wavelength resolution depends on the star image size and the scale of the images

These in turn depend on the focal length of the optical system and the seeing

3.5” FWHM seeing with 1.2”/pixel => 3 pixels FWHM
dispersion of 16 Å/pixel => $\Delta\lambda$ = 50Å
resolution R = $\lambda/\Delta\lambda$ = ~100-120

Backgrounds are higher because of superposition of images

Flat subtraction is difficult for the same reason (so is best ignored)

So overall, slitless spectroscopy is a good way into spectroscopy

- hardware relatively inexpensive (~£100)

- software to analyse results is free

- good way to gain experience of processing spectra

- also a good way to find out if you like spectroscopy!

Plus - several novae have first been spectroscopically classified by amateurs using SA100 gratings!

But its real science potential is limited

The logical step up is into slit spectroscopy

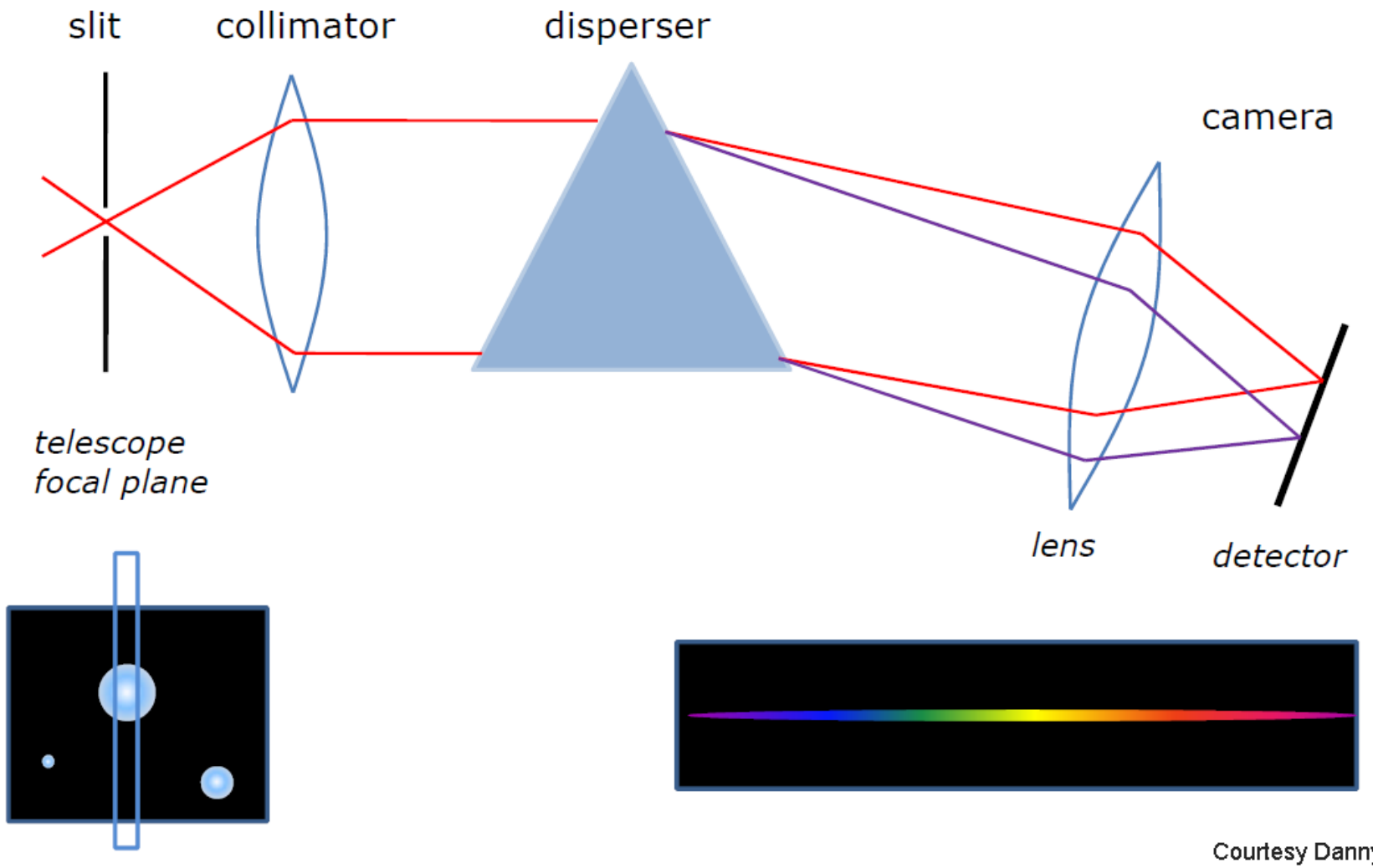
Resolution is now defined by the width of the slit

Background is much lower as only light coming through the slit is recorded

Much higher resolutions are achievable, but a choice has to be made:

- higher resolution means the light is spread out more so wavelength coverage is smaller and only brighter targets can be recorded with amateur scopes in reasonable times
- lower resolution means wider wavelength coverage and fainter targets can be observed but less spectral detail is recorded

The basic spectrograph



Courtesy Danny Steeghs

Examples of the spectrographs available

Shelyak LHIRES
Ken Harrison's L200
Baader DADOS

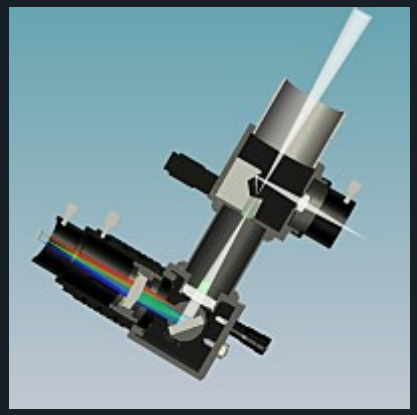
} these have interchangeable gratings with multiple resolutions available

Shelyak LISA 1000
Shelyak ALPY 600
Ken Elliot's CCDSPEC

} these have fixed gratings giving pre-defined resolutions

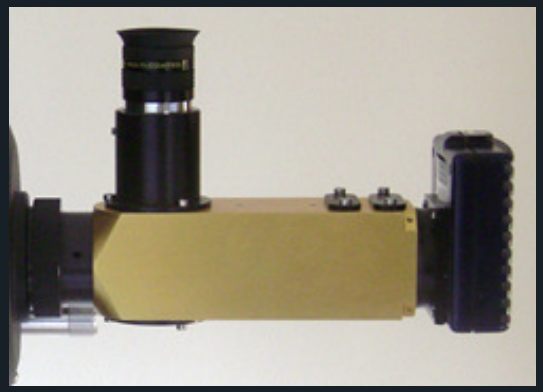
Spectrographs can usually be fitted with various slit widths according to stellar image size and seeing

You want most of the starlight to go through the slit but without reducing the resolution too much

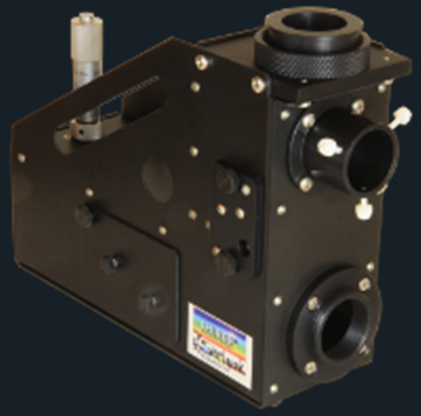


DADOS

L200



CCDSPEC

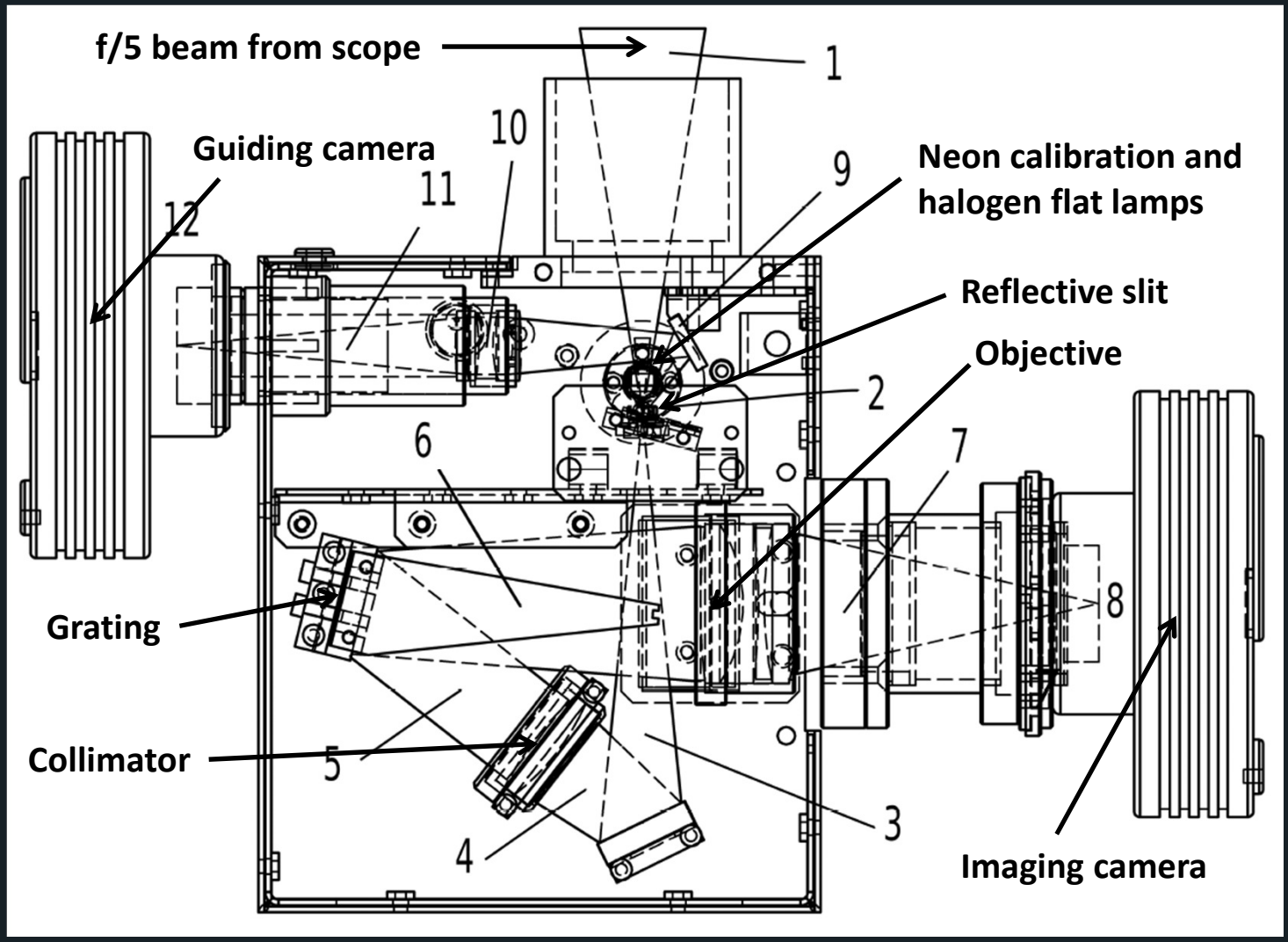


LHIRES

ALPY

LISA

I have a LISA spectrograph so I'll use that as an example



My imaging camera is a SXVR-H694 and the guider is an EX-view

The LISA is designed for a f/5 input beam

This is reduced to f/3.4 by the internal optics

I usually operate the camera binned 2x2 to improve S/N

This gives the following operational parameters:

3.5” FWHM seeing with 1.8”/pixel => 2 pixels FWHM

dispersion of 3.4 Å/pixel => $\Delta\lambda$ = 6.8Å

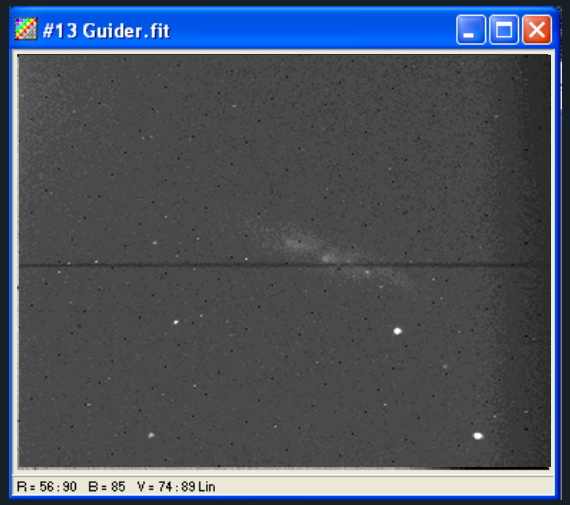
resolution R = $\lambda/\Delta\lambda$ = ~800-1000

Guiding

A major issue with slit spectrographs is keeping the star image on the slit

This is very difficult to do using a separate guide scope

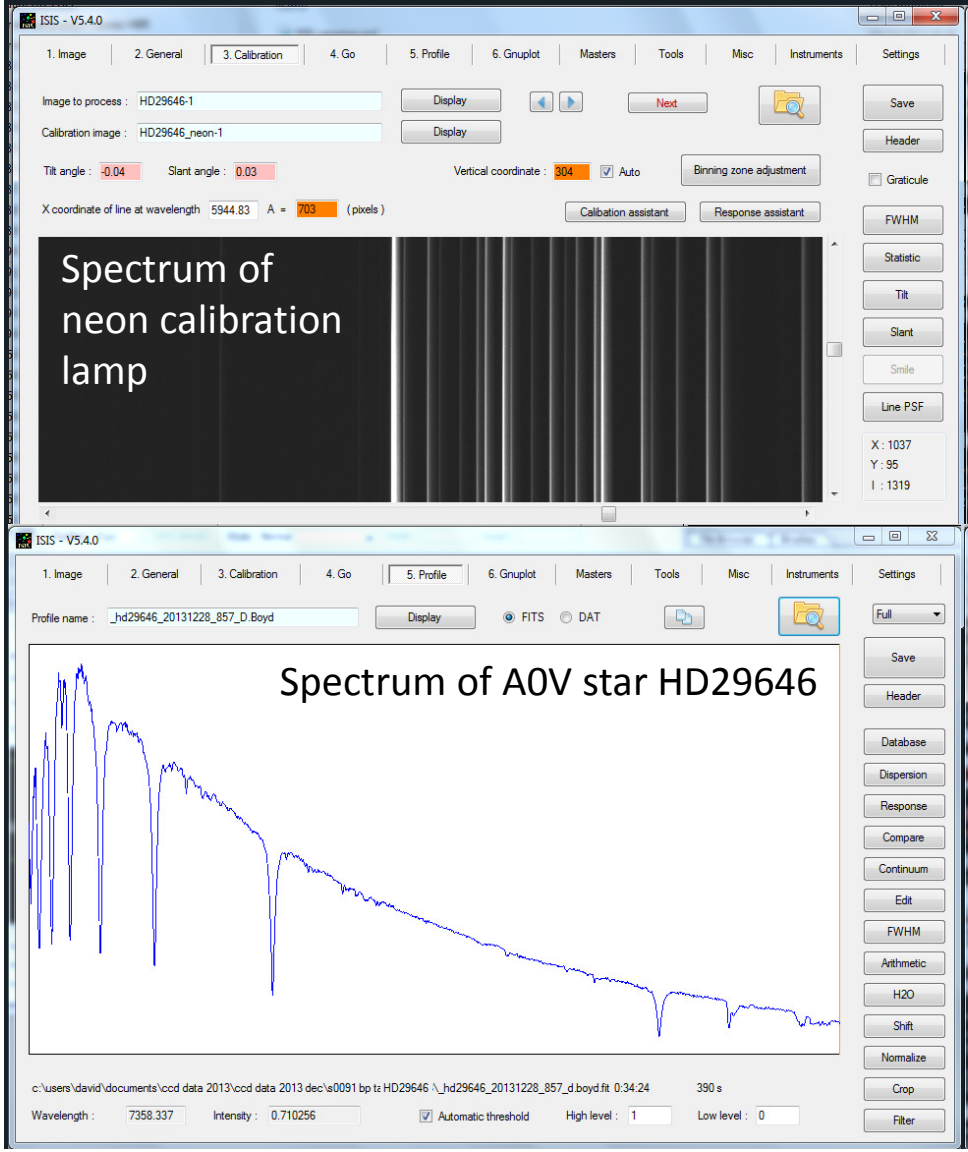
The best method is to use a reflective slit with a guide camera looking at a reflected image of the sky around the target

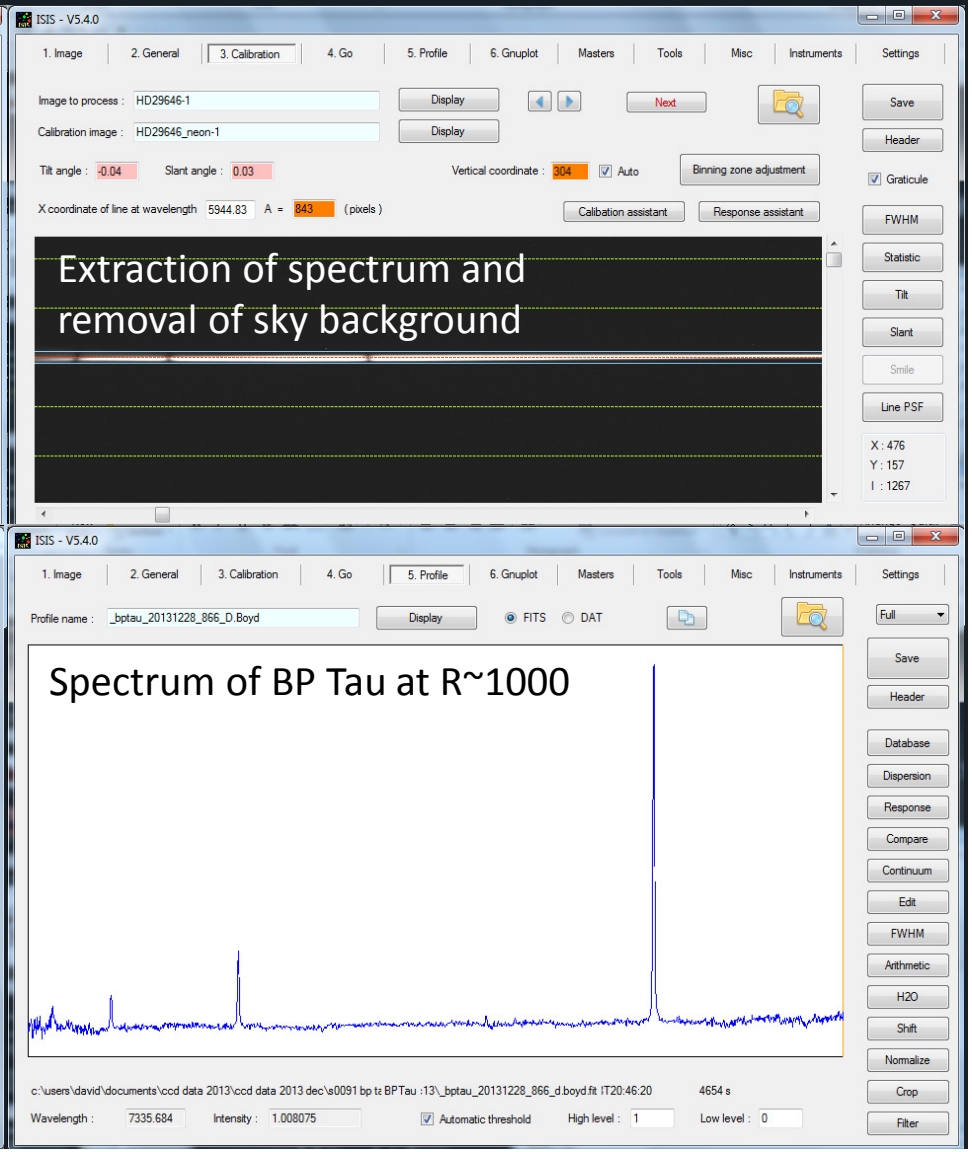


Most good guider software such as PHD or Astroart now has clever ways of putting targets in the slit and guiding on them

Software for analysing slit spectroscopy

Probably the most comprehensive software for processing slit spectra is ISIS written by Christian Buil

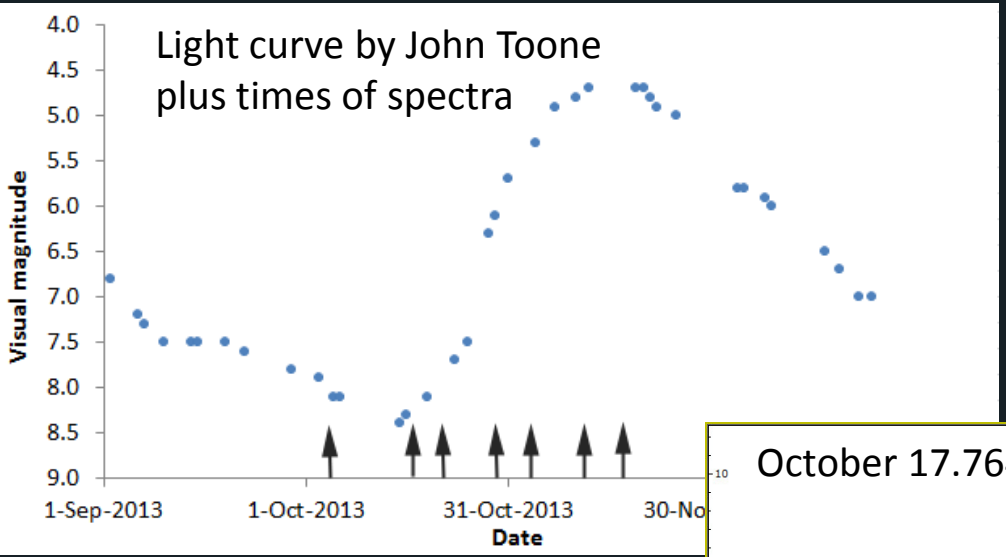




Some examples of the use of slitless spectroscopy

The following examples were recorded using a LISA spectrograph attached to a C11 scope on a Losmandy G11 mount

R Scutum – rising from a deep minimum in October 2013

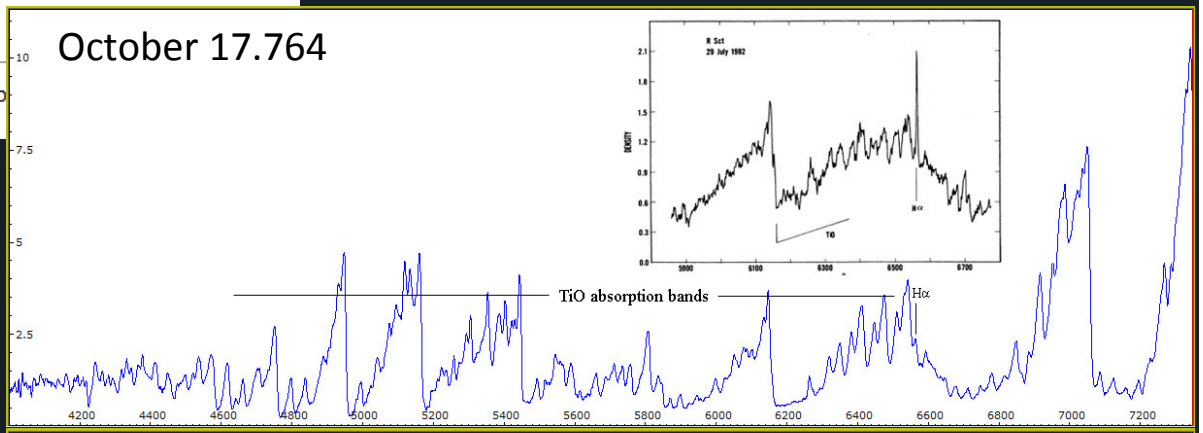


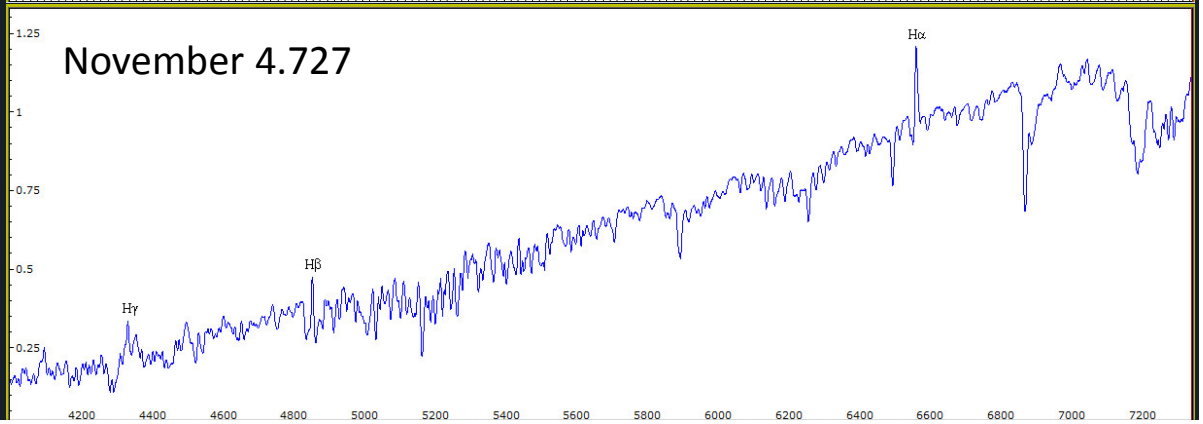
R Sct is believed to be a large, radially-pulsating, post-AGB star

I took a series of spectra as the star rose from a deep secondary minimum while John Toone observed it visually

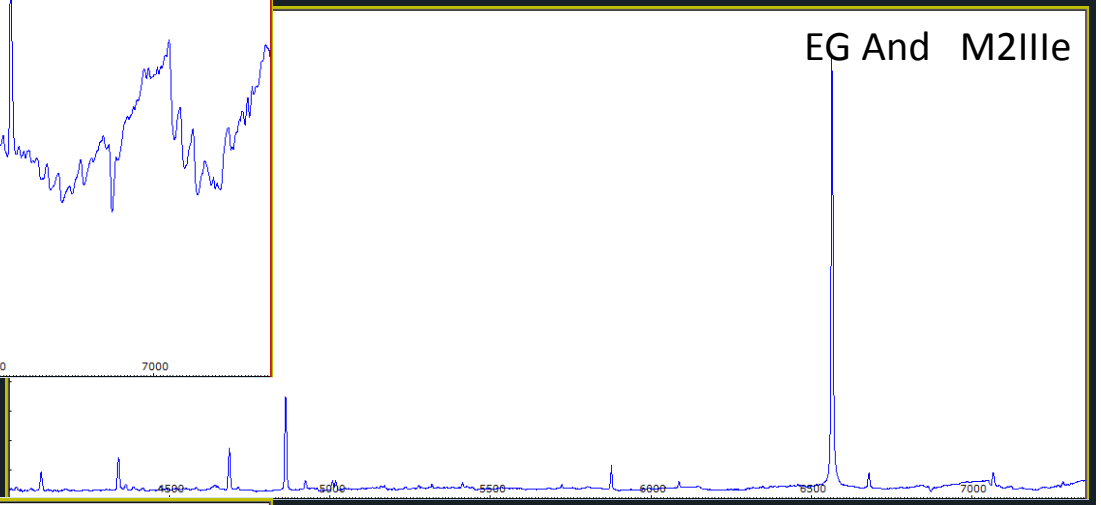
The spectrum on Oct 17 at minimum light is that of a cool M-type star showing TiO absorption bands

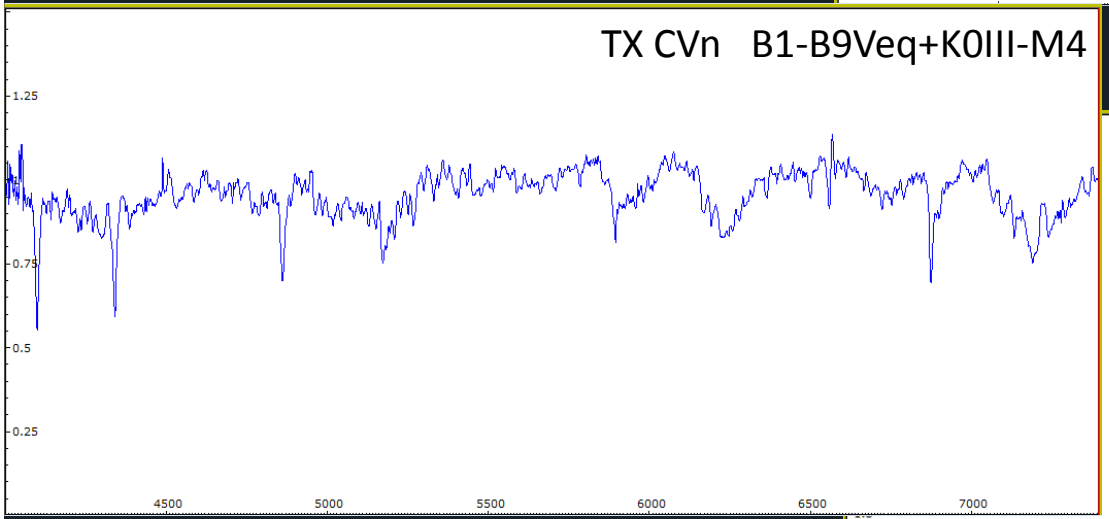
As the star brightens and gets hotter, the spectral type moves earlier and hydrogen emission lines appear

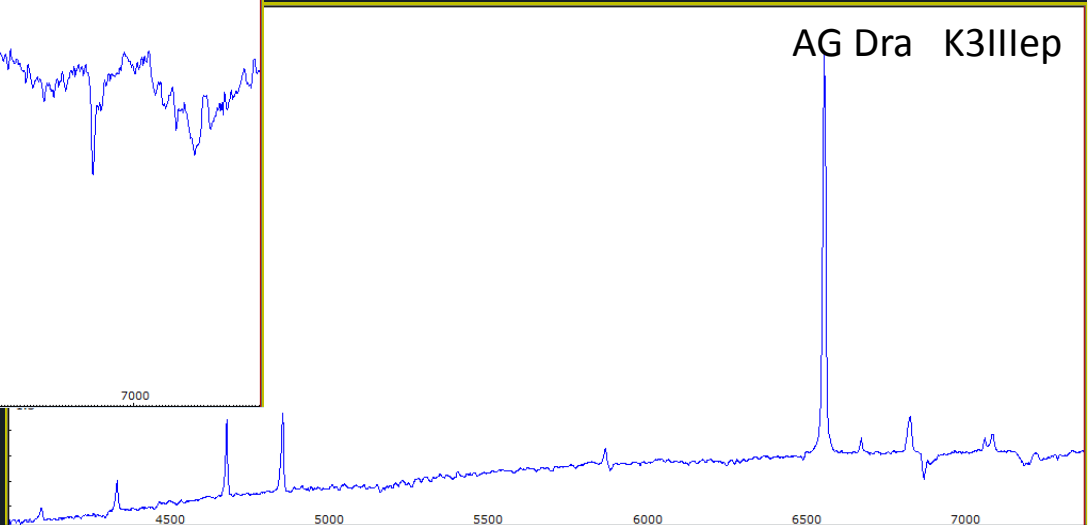




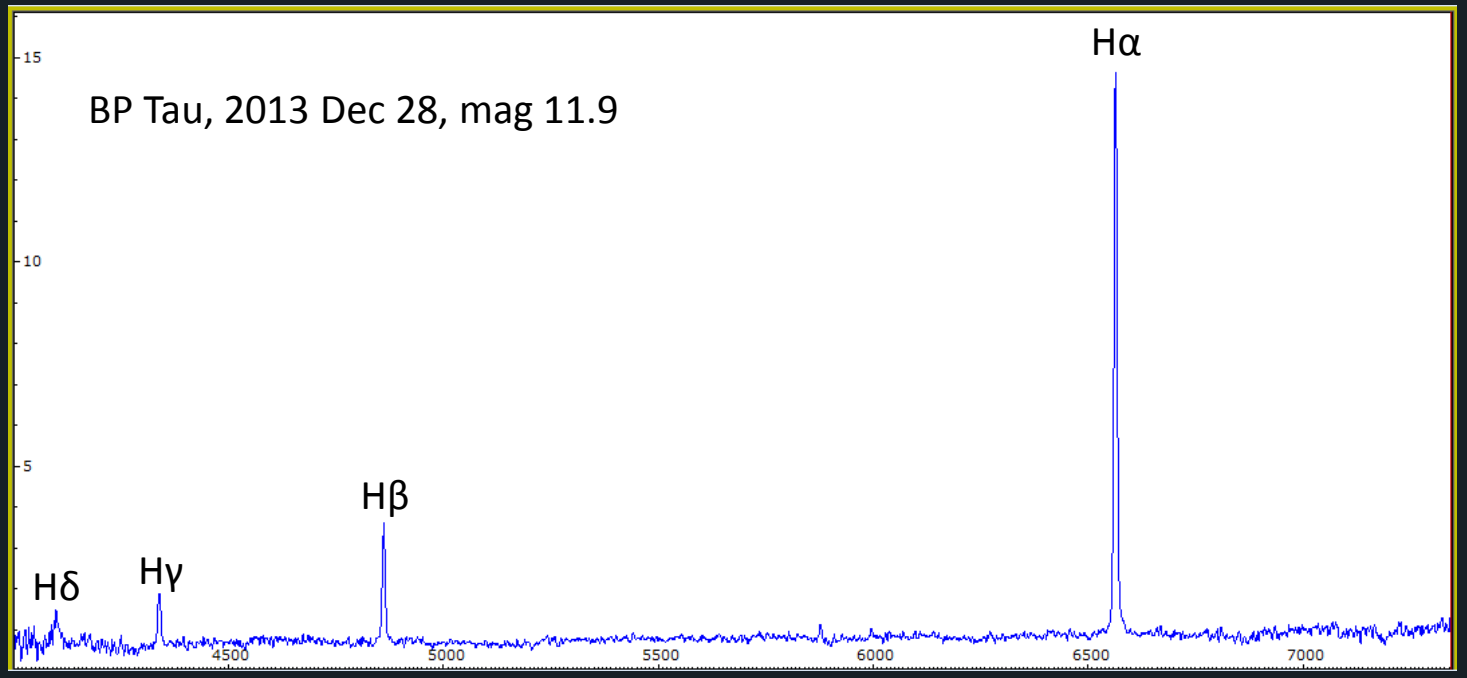
Symbiotic stars – binaries containing WD and a cool giant star

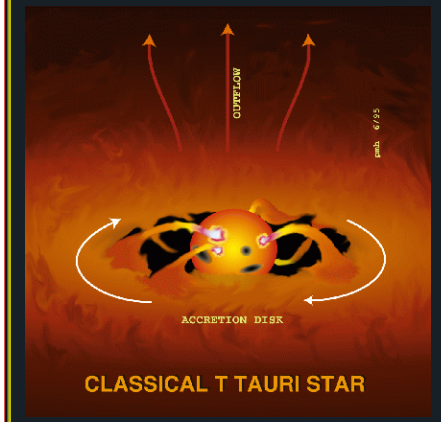


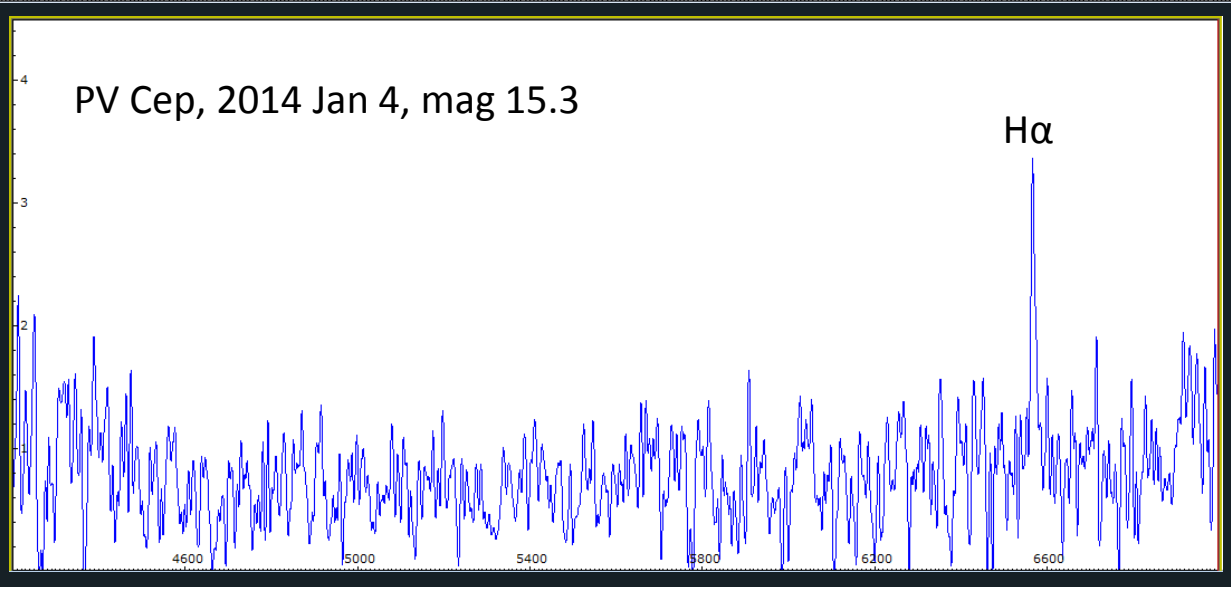


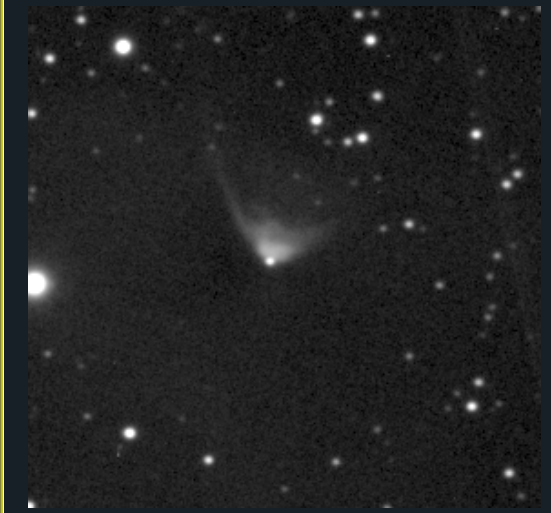


T Tauri stars – young pre-main-sequence stars





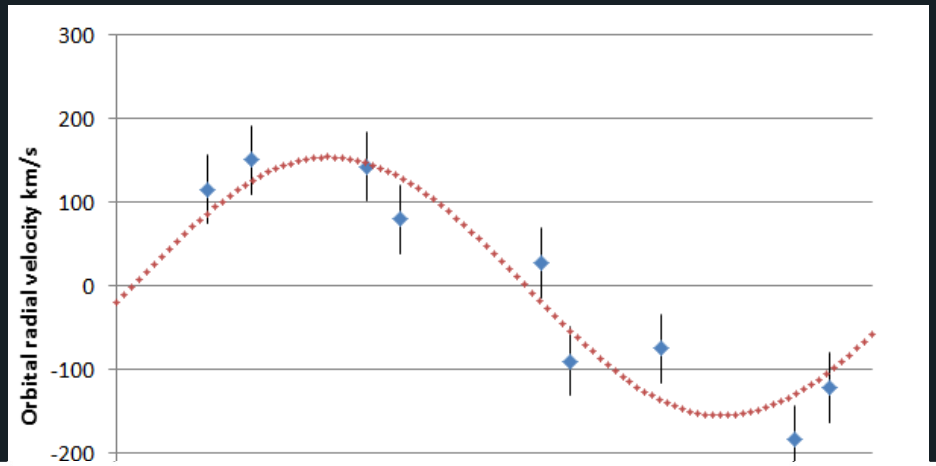




Measuring the radial velocity of an eclipsing binary

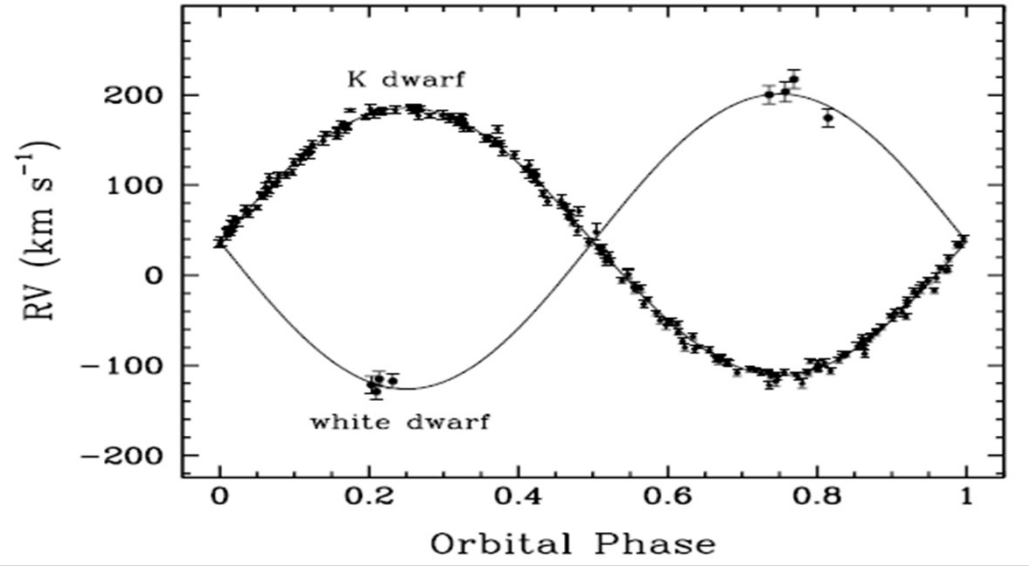
V471 Tau is a WD/MS eclipsing binary with a 12.5 hr orbital period
It is considered to be a pre-CV before mass transfer has begun

Relative radial velocity of the K-type MS star was measured by cross-correlating spectra taken at different orbital phases

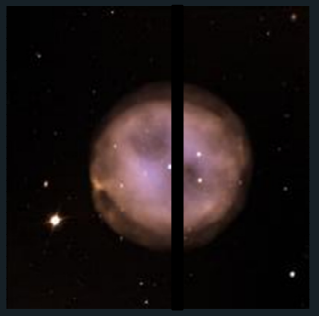


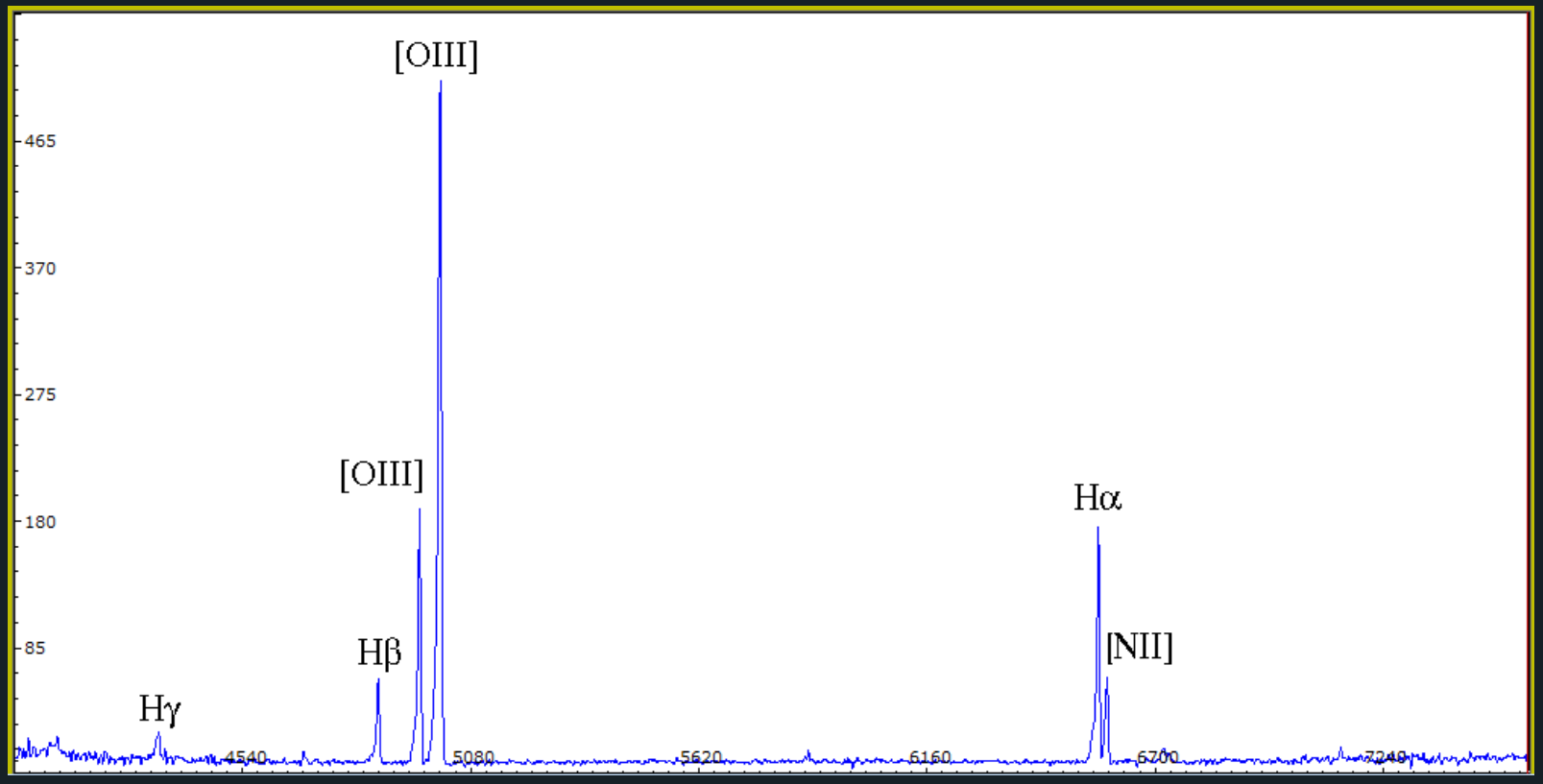
The best fit sine curve has the correct amplitude and phase compared to published RV measurements

The theoretical RV resolution is ΔV ~300 km/s, but my rms uncertainty is ~40 km/s



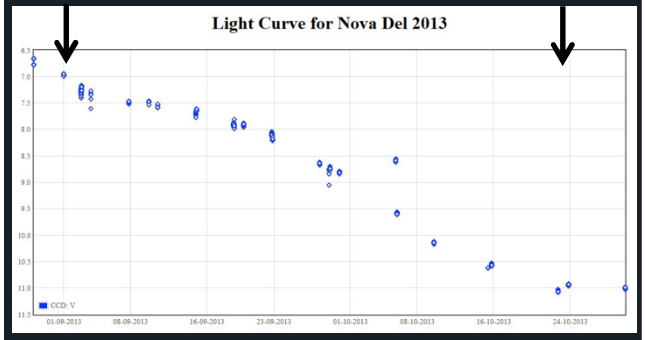
Spectrum of planetary nebulae



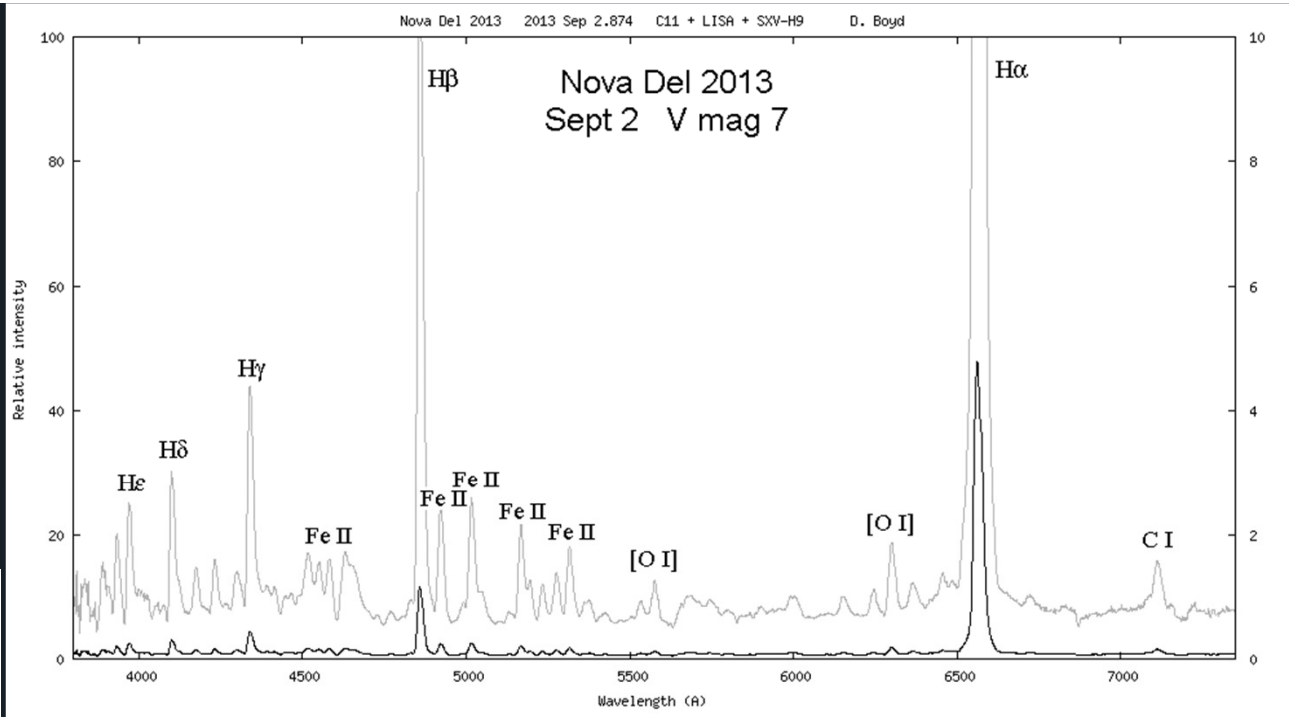


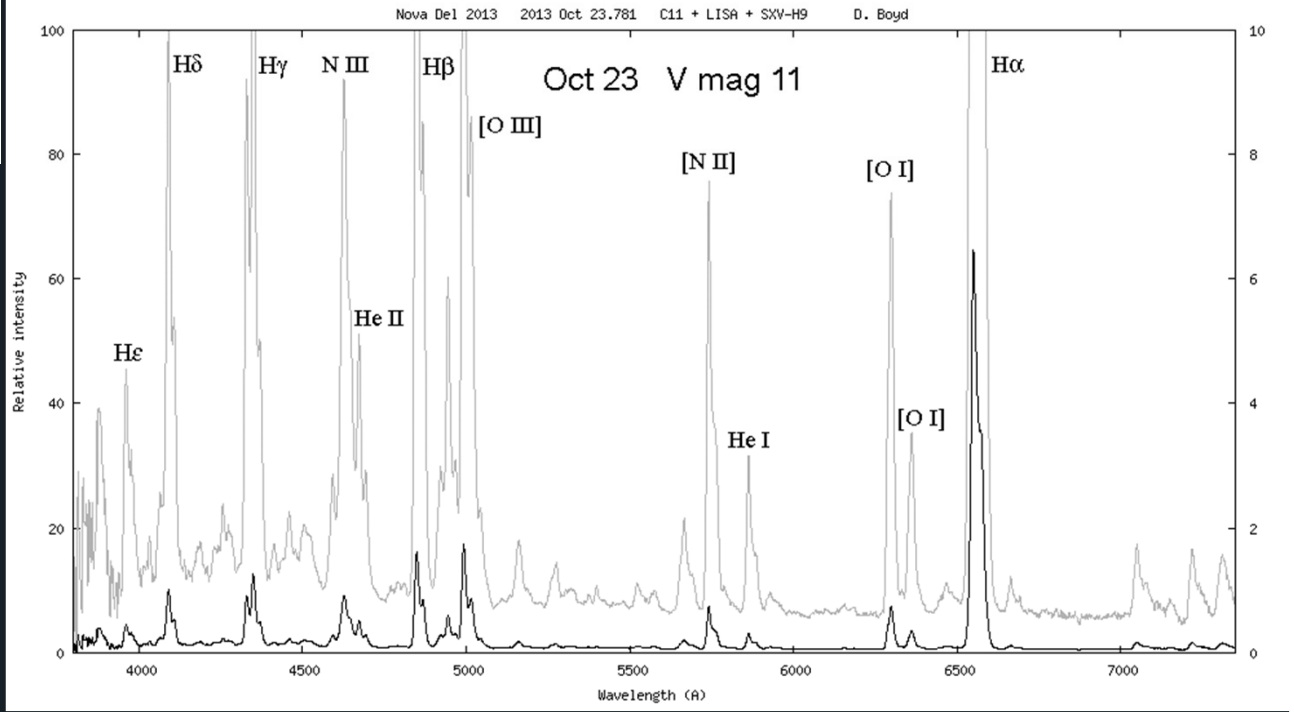
Nova Del 2013 – spectral evolution

Initially the spectrum consisted mainly of hydrogen and iron emission lines

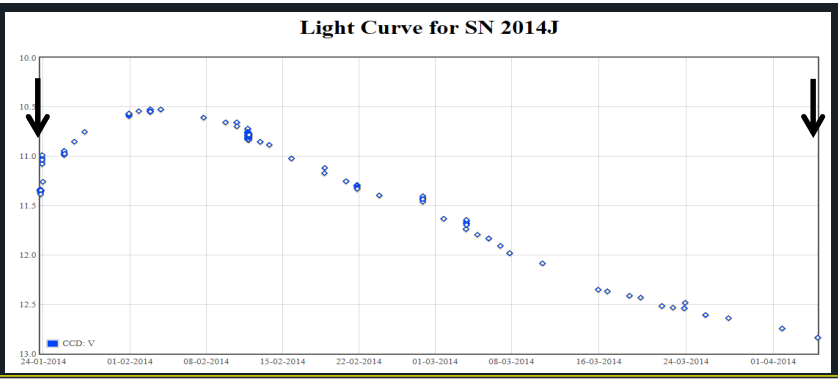


As the nova faded, many other emission lines appeared from deeper in the expanding debris from the explosion





Supernova SN2014j in M82



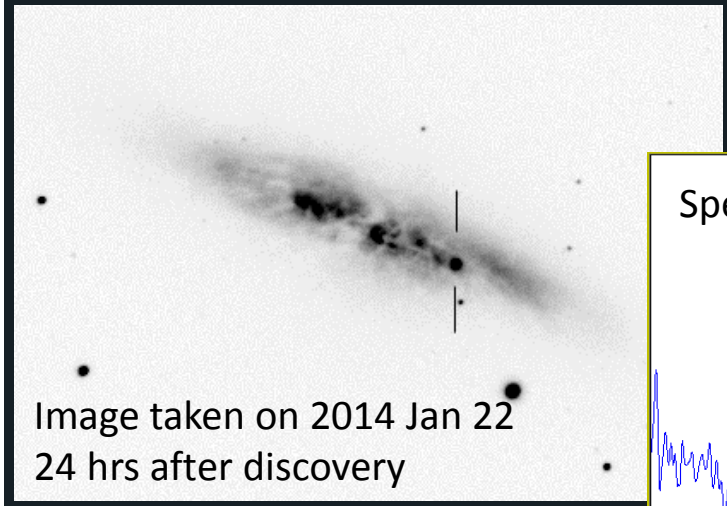
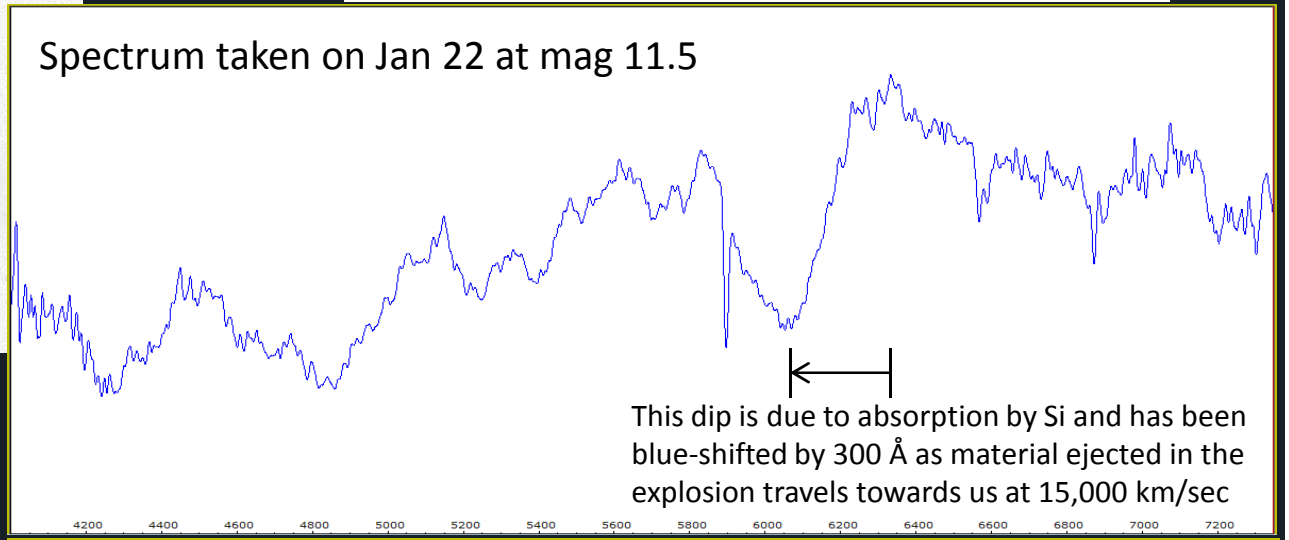
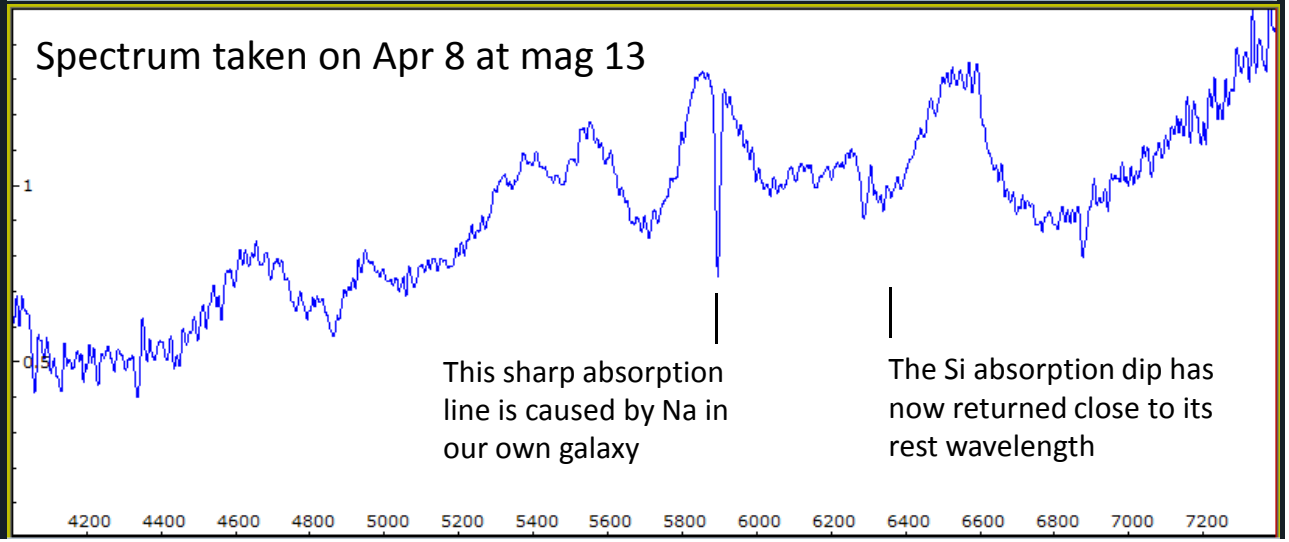
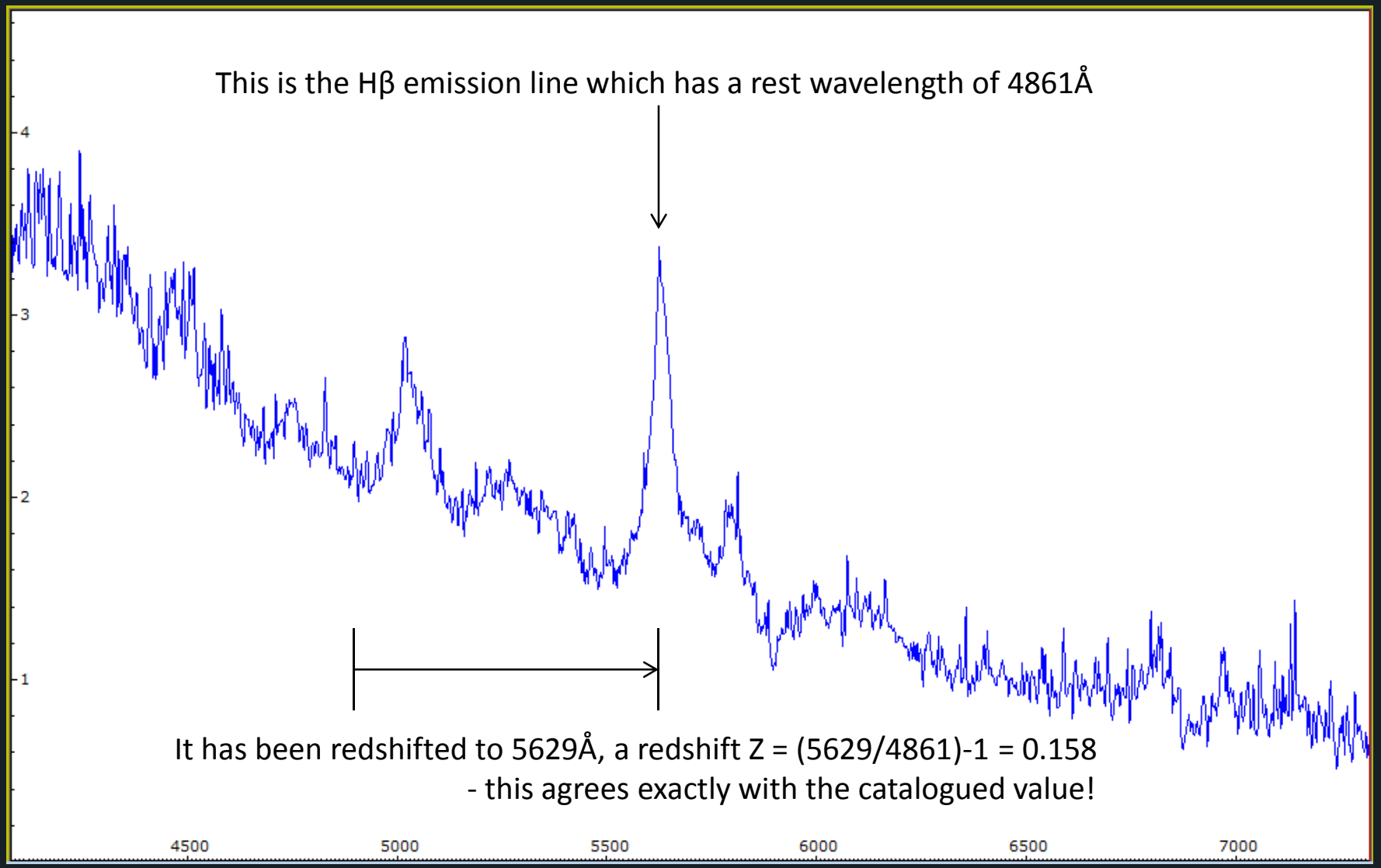


Image taken on 2014 Jan 22
24 hrs after discovery





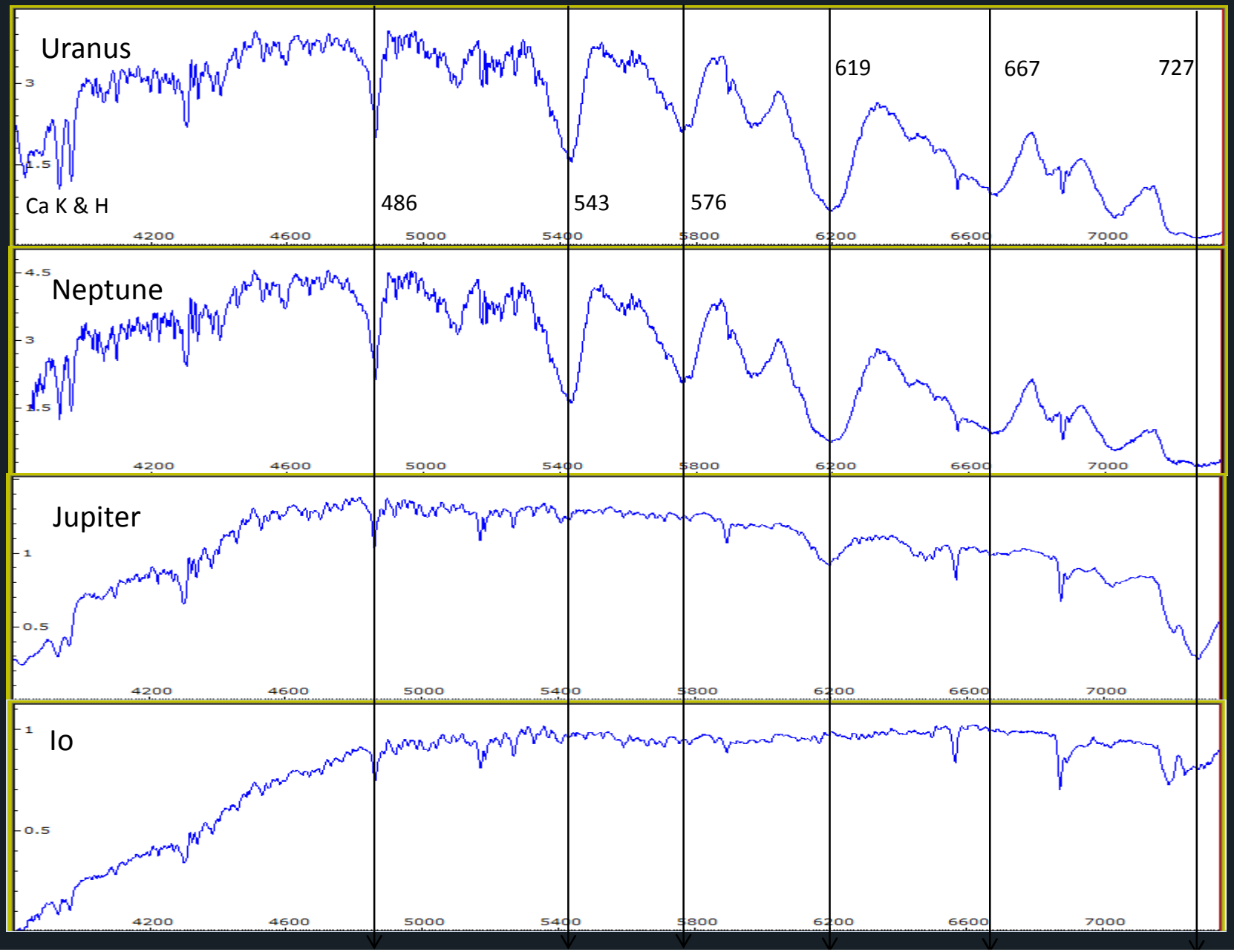
3C 273 – brightest quasar has a catalogued redshift of 0.158



It has been redshifted to 5629Å, a redshift Z = (5629/4861)-1 = 0.158
- this agrees exactly with the catalogued value!

The gas giant planets

The methane bands are marked in nm



So what do you do with your new spectrum?

- Currently there are few places which archive amateur spectra
- Nor is there general agreement on the format to be used
- The main variable star organisations have not moved into spectroscopy (yet?)
- Most activity in this area is centred in France and Germany
- The ARAS organisation in France is both active and advanced
- Similarly VdS in Germany coordinates amateur activity there

Spectroscopy is the new frontier in amateur astronomy

- It opens up new ways for amateurs to make a scientifically useful contribution
- It complements photometry and provides additional insight into the behaviour of variable stars and many other objects
- It takes time to learn but can be very rewarding and lots of fun
- If you are so inclined, give it a try!

Some useful links

Vspec: http://www.astrosurf.com/vdesnoux/

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

ARAS: http://www.astrosurf.com/aras/

Shelyak: http://www.shelyak.com/

Robin Leadbeater's webpage:
http://www.threehillsobservatory.co.uk/astro/spectroscopy.htm

Christian Buil's webapge: http://www.astrosurf.com/buil/

Francois Teyssier's webpage: http://www.astronomie-amateur.fr/

ARAS Forum: http://www.spectro-aras.com/forum/

Yahoo groups: staranalyser, spectro-l, astronomical_spectroscopy