

Spectroscopy is a key tool for the professional trying to understand the mechanisms which cause variability in stars.

Amateur spectroscopists are rather thin on the ground however as it is generally seen as too difficult, expensive or both.

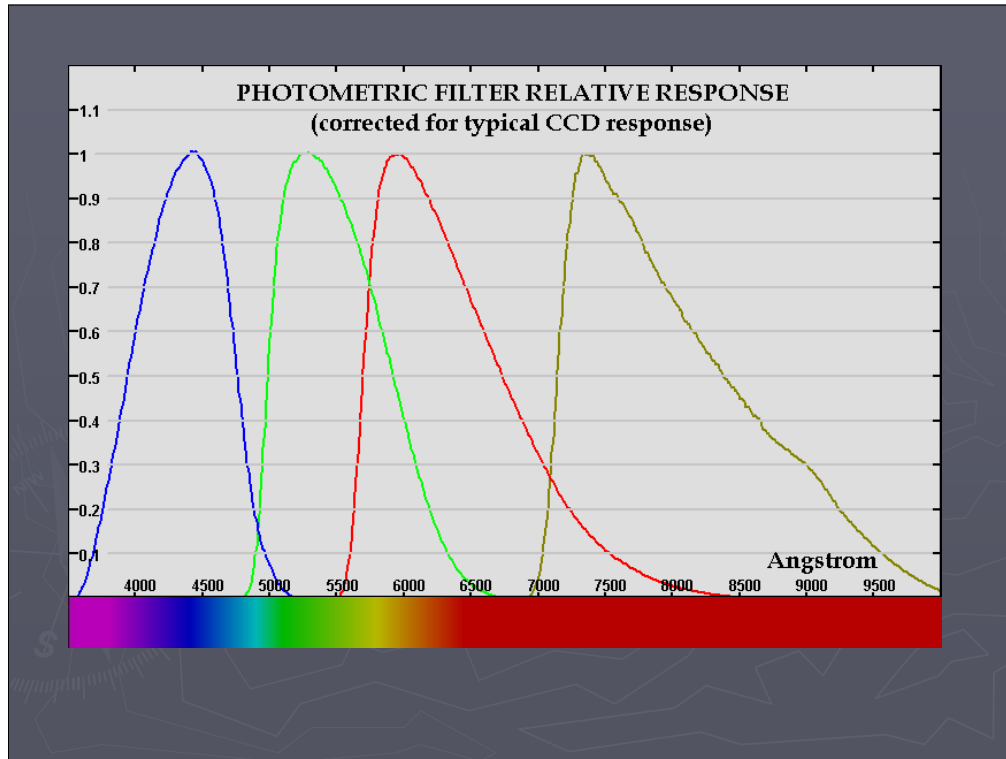
In practise however, anyone who is currently digital astro-imaging or doing photometry with a CCD camera can get into simple (but still scientifically interesting) spectroscopy without breaking the bank. Additionally an increasing number of amateurs are tackling the challenges of high resolution spectroscopy. So much so that the AAVSO are planning to develop a database for amateur spectra of variable stars.

VARIABLE STAR SPECTROSCOPY

- ▶ Equipment needed to do spectroscopy
- ▶ Examples of variable star phenomena which can be measured spectroscopically
- ▶ An example of the process of turning a spectrum image into useful scientific data
- ▶ Where to go for more information

In this workshop presentation I will:

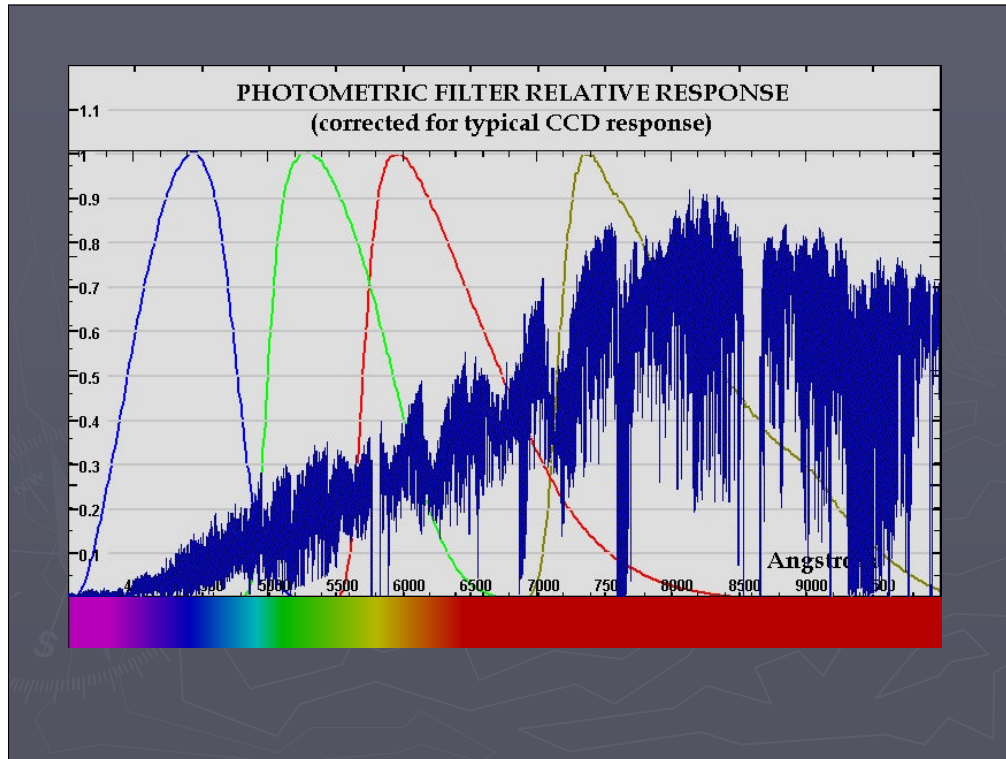
1. Describe the equipment I use to take low and high resolution spectra.
2. Give some examples of variable star phenomena which can be measured spectroscopically.
3. Walk through the procedure to turn a spectrum image into useful scientific data.
4. Give some sources of further information



The wavelength of light (which determines its colour) is usually measured in Angstroms or nanometres ($10\text{\AA} = 1\text{nm}$)

The standard BVRI photometric filters which cover the range of a typical CCD camera give us some quantitative information about the variation in colour of stars but only in four broad (about 1000\AA wide) bands.

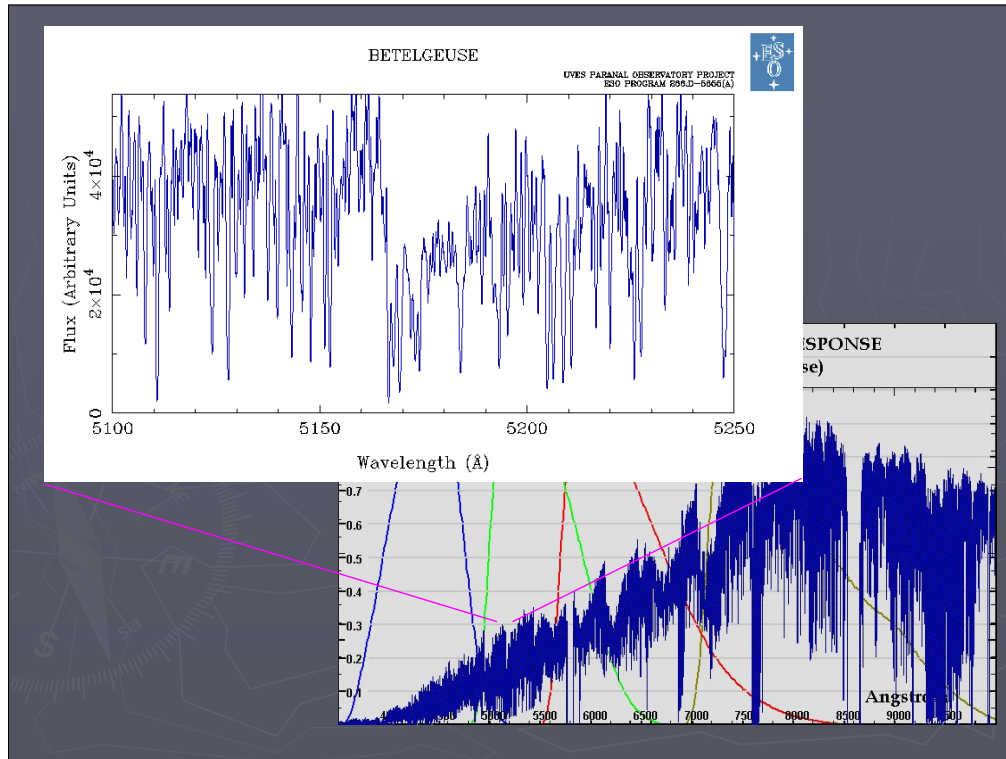
(Wavelengths in the Infra Red beyond about 7000\AA are invisible to the eye but are detectable by CCD cameras (provided they are not filtered out as they are in most digital cameras for general use))



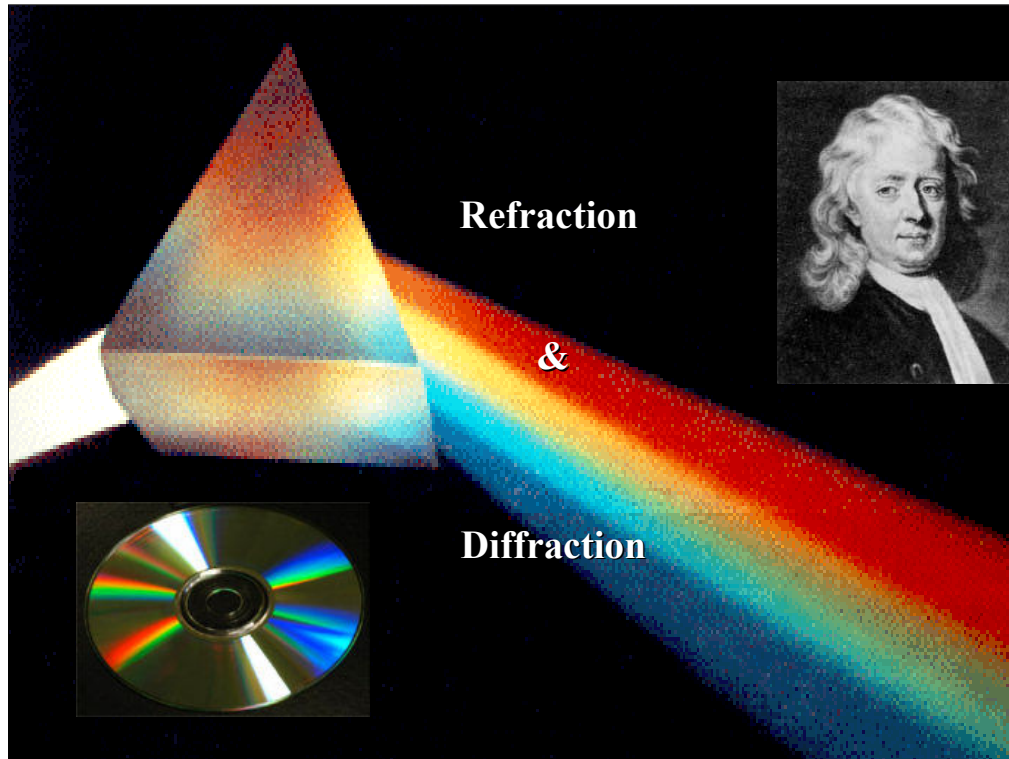
Here a high resolution spectra of Betelgeuse as been overlaid (Taken using the UVES spectrograph on the VLT)

Although the broad trend of the spectrum will be picked up by the photometric filters, (Betelgeuse is indeed a red star!) much of the detail is lost.

(Note also that Betelgeuse is much brighter in the IR than it is in the visible region.)



This level of detail continues as the resolution is improved. (The Resolution of this UVES spectrum $(R) = 80,000$ which means that detail of typically less than 0.1 Å can be resolved)



How are spectra produced?

Spectra are produced by two physical phenomena:

Refraction (through a prism) or

Diffraction either by reflection from or transmission through a grating with a pattern of fine (typically hundreds/mm) grooves.

Most modern spectrographs have a diffraction grating at their heart surrounded by various optics depending on the design, which are used to produce an image of the spectrum. They also often include a slit to sample a thin slice of the light from the object.



www.threehillsobservatory.co.uk

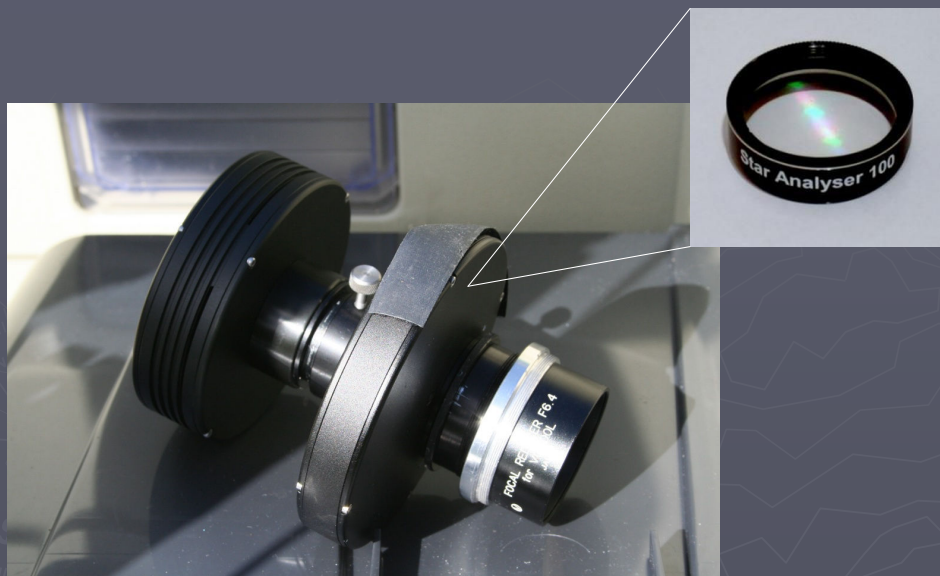
This is my setup. (A 200mm diameter Vixen VC200L on a GPDx mount controlled by a Skysensor 2000 GOTO system.) This photo shows my LHIRES III high resolution spectrograph mounted on the telescope. The rest of the equipment is there to allow semi-remote control and to control the climate of the "observatory" (A small plastic shed with a flip top roof)



By far the simplest way to get started in spectroscopy though is just to use a filter cell mounted diffraction grating positioned a few cm in front of the camera sensor to produce a low resolution spectrum ($R \sim 100$ or 50\AA), similar to those shown on the title slide. This particular grating is the Star Analyser which I should declare an interest in having developed it with the manufacturers Paton Hawksley here in the UK. A good alternative is the Rainbow Optics Star Spectroscope grating. (Beware of other manufacturers making unsubstantiated claims though. There are some inefficient poor quality gratings about and for astro work, we need the highest efficiency we can get.)

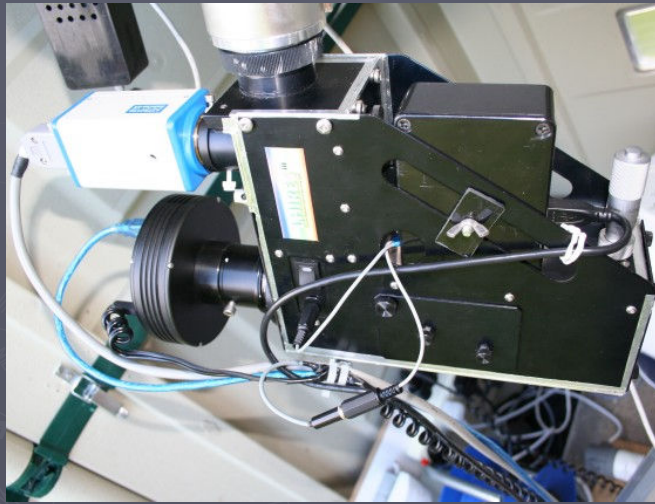
Although there are some compromises in resolution in this simple design, this is more than compensated for by the ease of use, important if you are just starting out in spectroscopy.

Low Resolution Spectrograph



I have a Star Analyser Grating mounted in my filter wheel alongside photometric filters so I can switch easily from photometry to taking a low resolution spectrum.

High Resolution Spectrograph



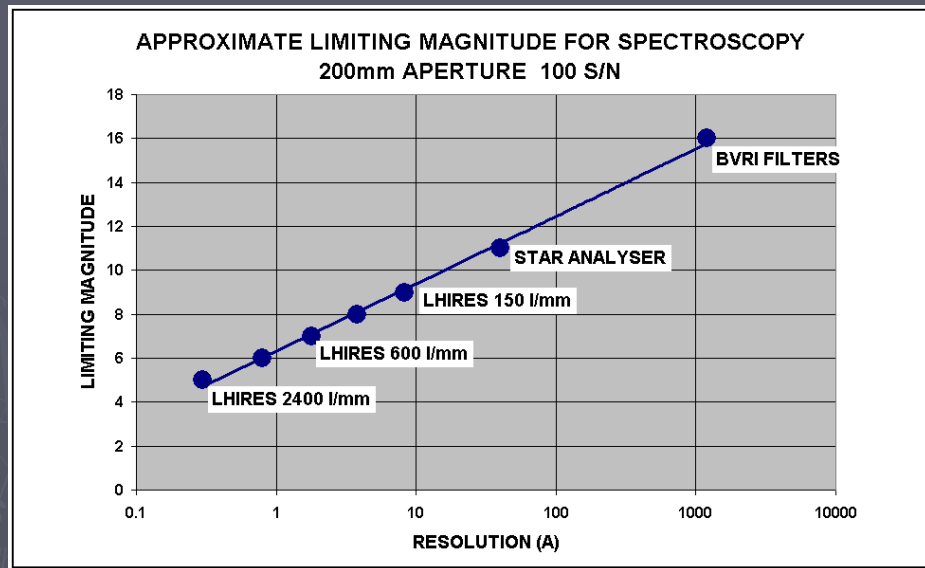
LHIRE III - Vision Oleron 2003 Reality 2006

At the other end of the resolution scale is my LHIRE III high resolution spectrograph. Designed and manufactured by a group of French amateurs, it is capable of a range of resolutions up to the highest available commercially to the amateur. ($R \sim 17000$ or 0.3\AA) Although not exactly cheap, it offers good value alongside the other major spectrograph supplier, SBig and appears to be becoming the standard amateur instrument, certainly here in Europe at least with several hundred sold

Self build is an alternative route if you have the skills and there are many designs out there (including the complete drawings for the LHIRE) but if you do go this route, make sure you design in structural stability, ease of use and some means of guiding the star on a $20\mu\text{m}$ wide slit – not trivial tasks but essential if you are going to end up with an instrument which you can use year in year out to produce pro quality data.

In the picture you can see the ATIK 16IC imaging camera (lower left) the Stellacam guide camera (upper left) and on the right, the micrometer adjustment to adjust the grating angle to select the required wavelength range. On the front is a switch for the built in neon calibration lamp. (The black box held on with the wing nut is my own addition and contains a servo control to remotely swing the calibration lamp in and out of the beam)

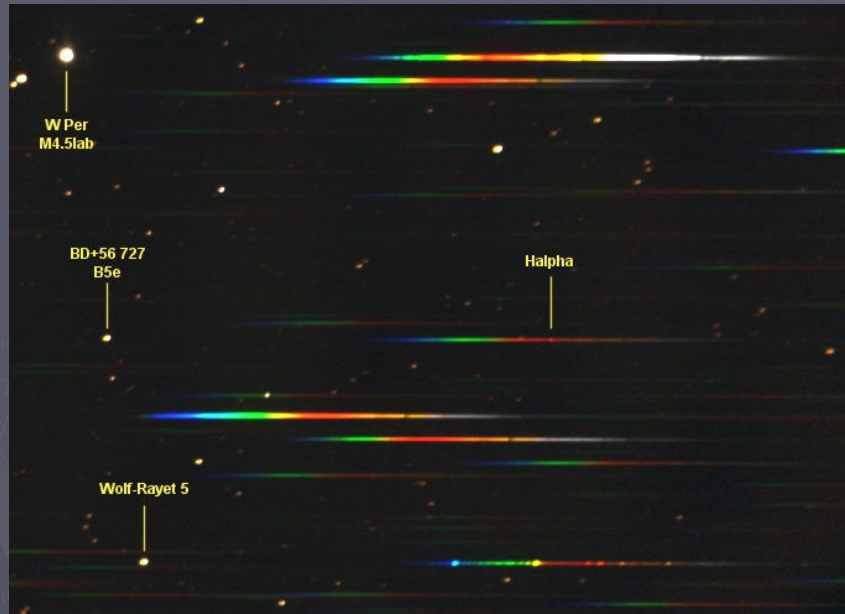
Spectrograph Performance



The downside of spreading starlight ever more thinly to get higher resolution is the inevitable loss of sensitivity. (Getting good spectra of faint objects is a major reason why pro telescopes are so large aperture)

This graph shows the approximate limiting magnitude of my equipment to produce a low noise spectrum (In practise useful, if rather noisy spectra can still be produced at 2-3 magnitudes fainter than in this graph)

A STELLAR “PICK AND MIX” (Star Analyser & DSLR)



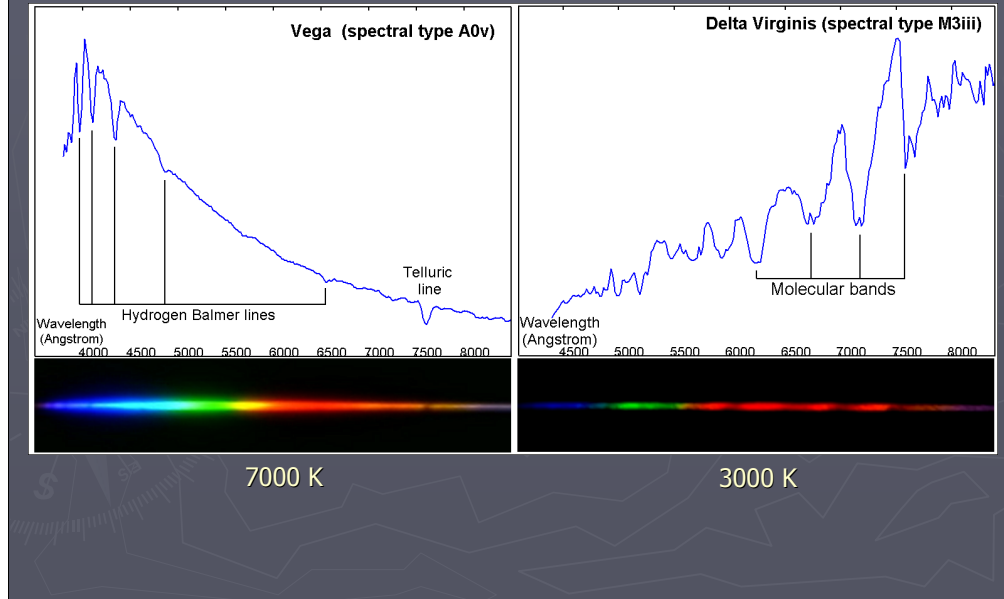
Christian Buil

Now let's have a look some of the characteristics of variable stars which can be measured spectroscopically, starting with the low resolution instrument.

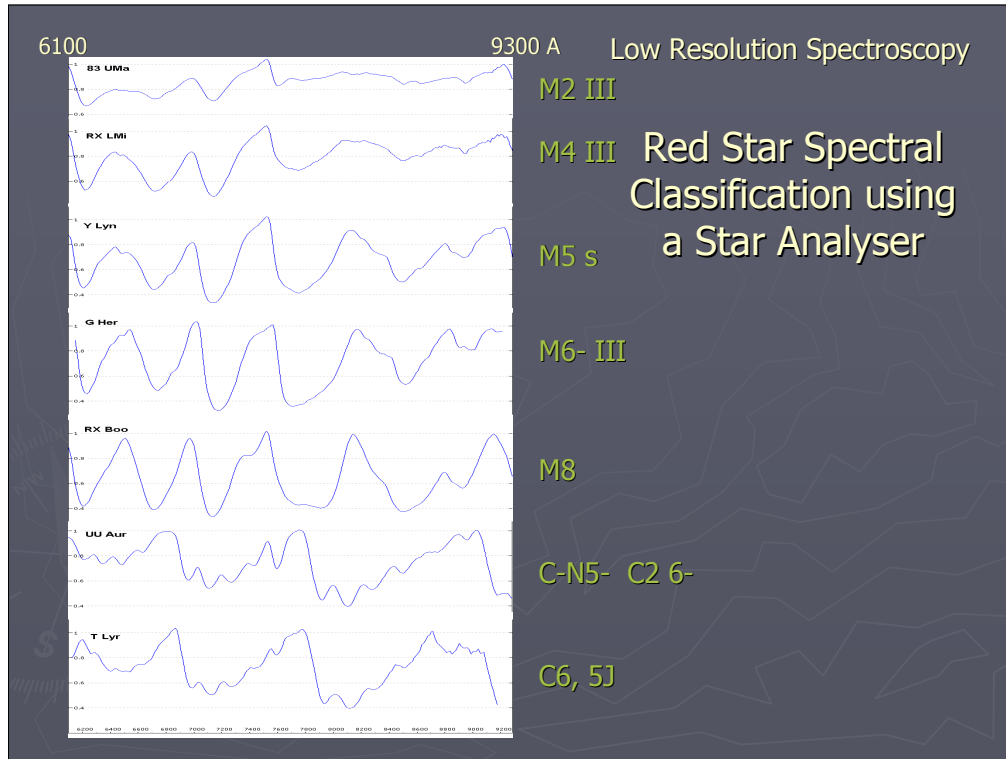
This was taken by French amateur spectroscopist Christian Buil using a Star Analyser with a Canon 350D, modified with the IR block filter removed to improve IR response.

In just this one field we can see Semi Regular variable supergiant W Per, very bright in the IR, Be Star +56 727 with the disk of gas surrounding it glowing at the Hydrogen alpha wavelength, and a Wolf Rayet star WR5 with bright emission lines in the powerful stellar wind.

The effect of temperature

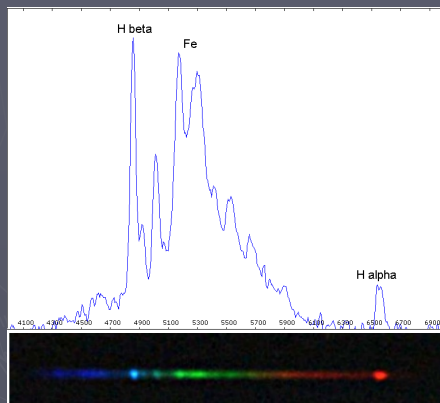


The first thing you notice about a low resolution spectrum is the broad shape of the continuum which gives information about the temperature. This can be confused by interstellar dust however which tends to redden the colour of a star. The finer features however give us more information about the temperature. The narrow absorption lines of Hydrogen seen here in Vega only appear within a certain band of temperatures, and the broad molecular lines in delta Virginis only form in cool red stars.



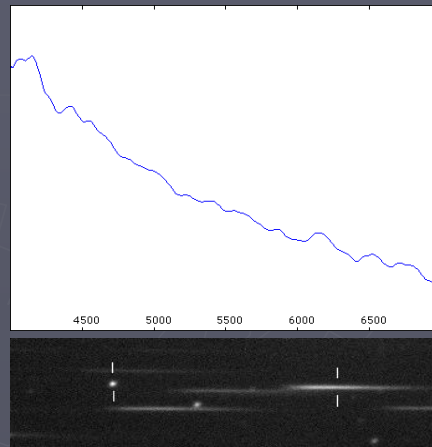
More detailed analysis of the lines can help define the exact spectral type as in these red stars measured in the red/IR.

Novae Spectra



Alain Lopez
(Uncorrected for instrument response)

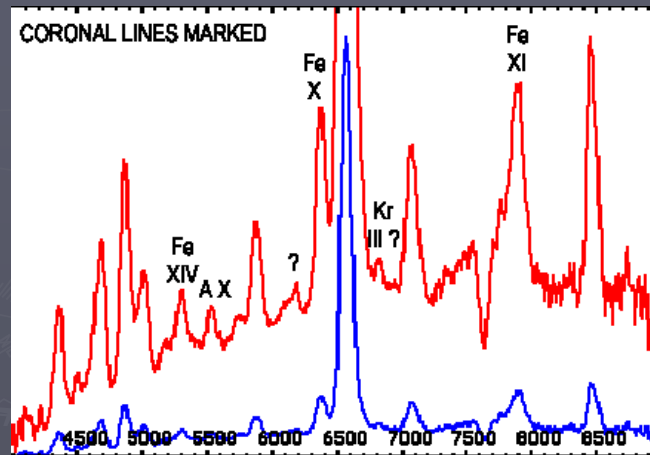
Nova Cyg 08
(N V2468 Cyg)



Nova And 08
(UGWZ V466 And)

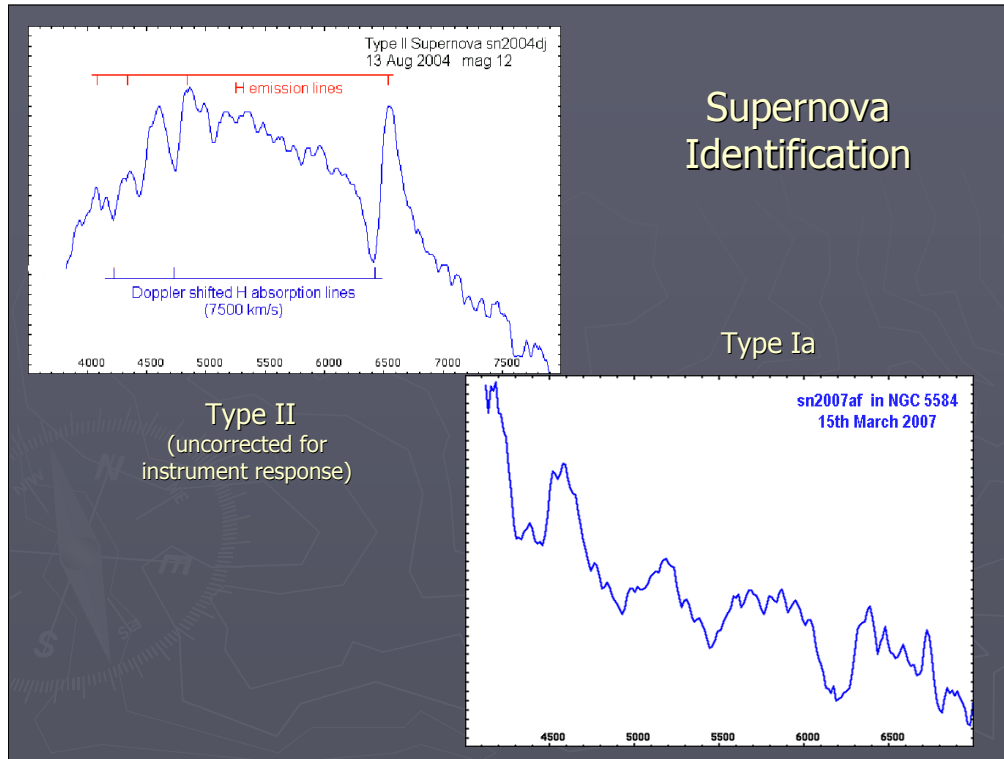
Specific types of variable show particular characteristics in their spectra. The spectra of classical and dwarf novae in outburst for example are quite different. The rather pretty spectrum of Nova Cyg 08 taken by Alain Lopez using an unmodified Canon DSLR shows clear emission lines from Hydrogen and Iron whereas the spectrum of dwarf nova And 08 is very blue but virtually featureless (Taken by me when Vmag 14)

Recurrent Nova RS Oph April 2006



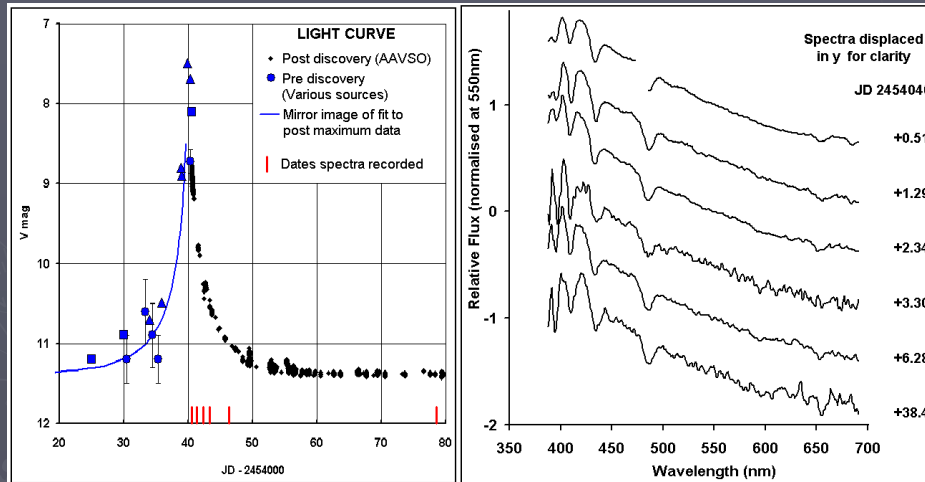
70 days post outburst (vmag 10)
Emergence of coronal lines

This spectrum taken during the last outburst of recurrent Nova RS Oph shows some exotic emission lines from highly ionised Iron and other elements as the high velocity gas from the explosion hits the stellar atmosphere of the secondary star.

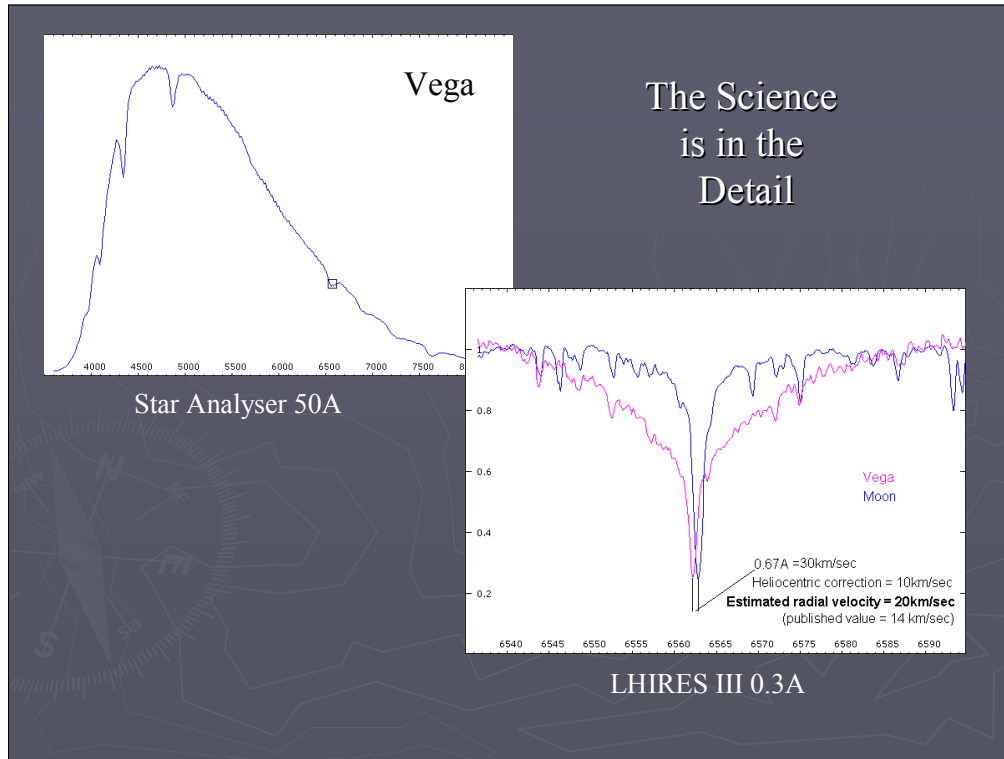


Supernovae also have characteristic spectral features which allows the type to be determined. A few each year are brighter than mag 14 and can be recorded spectroscopically using a modest amateur setup.

Var Cas 06 - A gravitational microlensing event ?

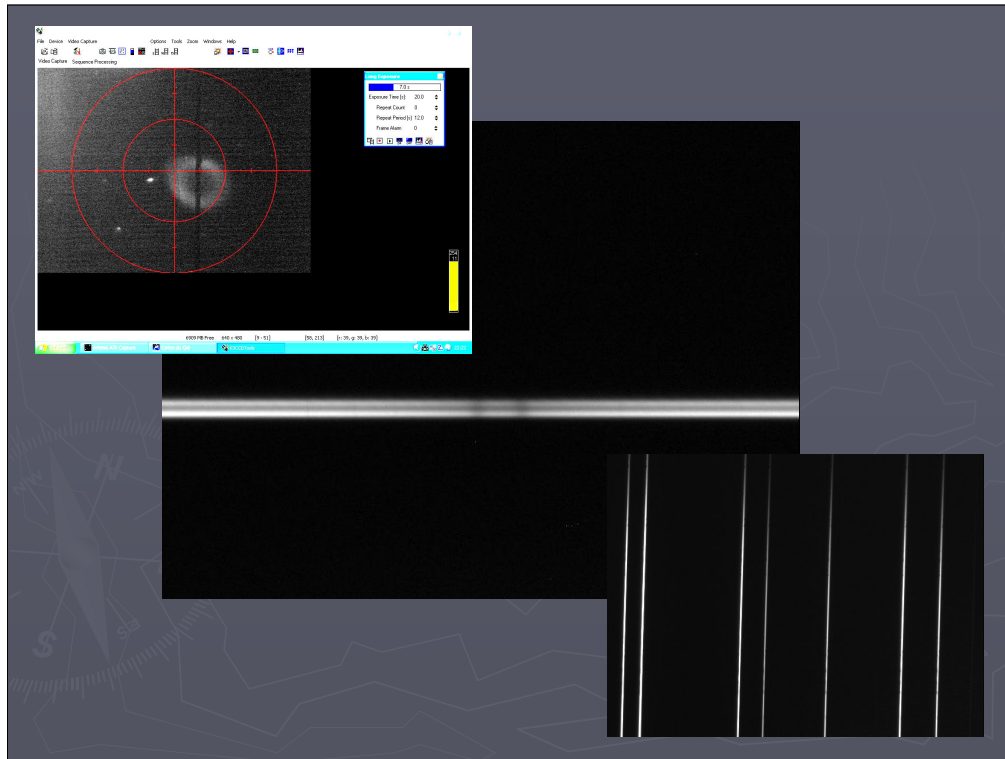


Then there are the once in a lifetime events like this apparent microlensing event characterised by the spectrum remaining unchanged despite the considerable temporary brightening of this star.



By moving to higher resolution we can see different phenomena, particularly effects due to temperature and pressure and the velocity (both along the line of site and rotational) of the objects or the material that they consist of, which can be measured by the red or blue Doppler shift.

Here the tiny 50A part of the Vega spectrum containing the Hydrogen alpha line (which is equivalent the resolution achieved by the Star Analyser) is expanded to the full width of the camera field using the LHIRES III at maximum resolution of 0.3A, some 150x higher. Now we can see the broadening of the line due to the higher temperature and pressure of Vega compared to the reflected sunlight from the moon and also the blue doppler shift due to the velocity of Vega relative to us (which is partly due to the velocity of the earth round the sun)

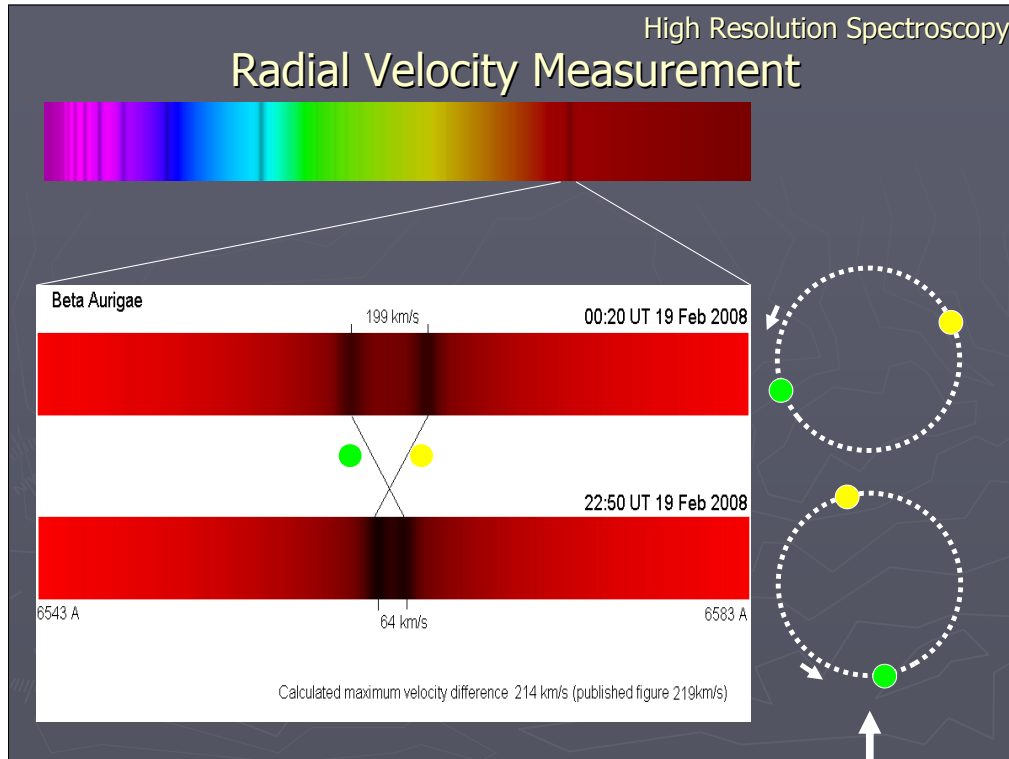


Here is some examples of the raw information from the LHIRES III spectrograph.

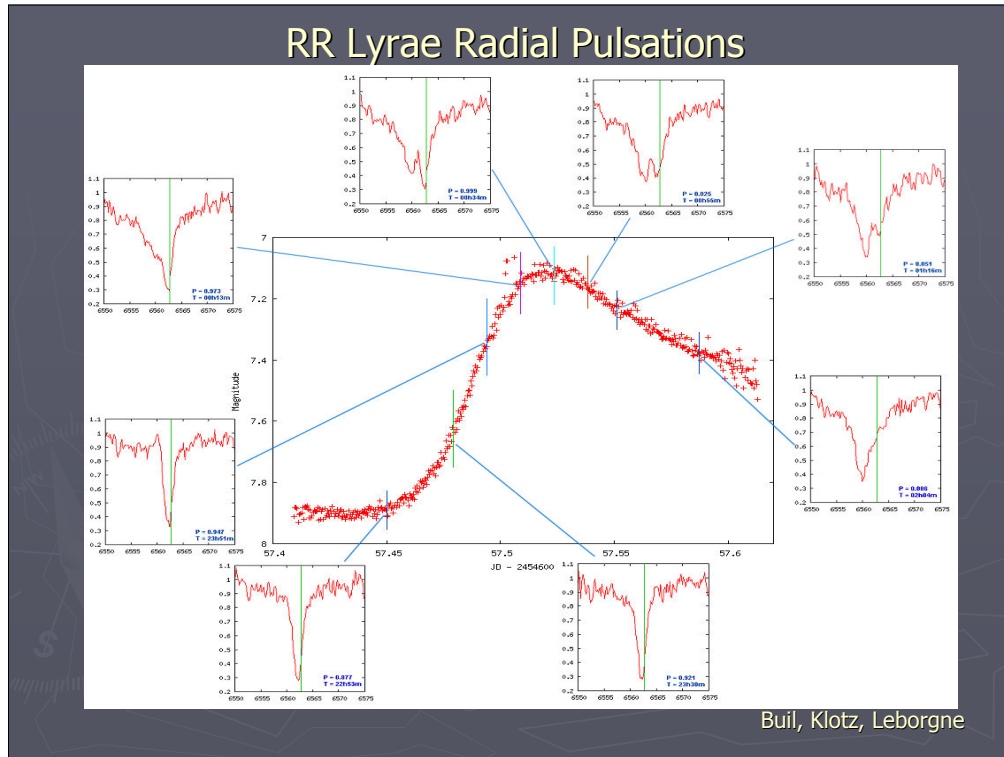
Top left - A shot from the guide camera showing the reflective slit and the target (in this case M57) The light which passes through the slit is processed by the spectrograph.

Bottom right – the calibration lines produced by the internal neon lamp

Centre – The 50Å wide spectrum centred on 6563Å (H alpha) of eclipsing binary star Beta Aurigae. Look carefully and you can see two absorption lines in the centre, one from each of the two stars, Doppler shifted by their orbital velocity.



Here are two spectra of Beta Aur taken less than one day apart. The change in position of the two lines as the stars orbit each other is clear. This data together with the light curve can be used to identify the size and mass of the stars and their orbital parameters.



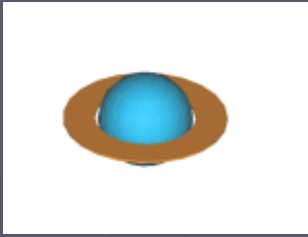
Some variable stars show regular radial pulsations (ie they breath in and out), changing luminosity and temperature as they do so. Cepheids and RR Lyrae stars are examples of this phenomenon.

This set of spectra high resolution of RR Lyrae were taken at 10min intervals in coordination with high precision photometric measurements by a French team at the time in the light curve when the star was changing from contraction to expansion.

<http://www.astrosurf.com/~buil/rrlyr/obs.htm>

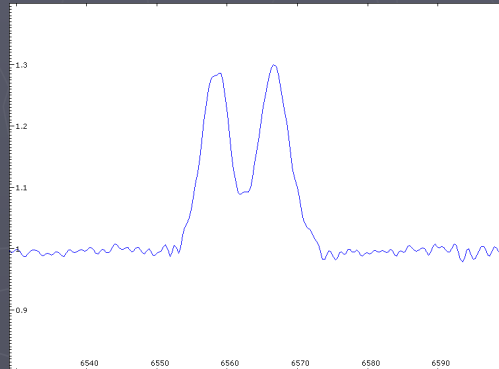
The shift in the H alpha absorption line towards the blue is evident. Note how not all the star starts expanding at the same time, producing a split line and evidence of interactions between the expanding and contracting areas, producing an emission hot spot.

Be Stars



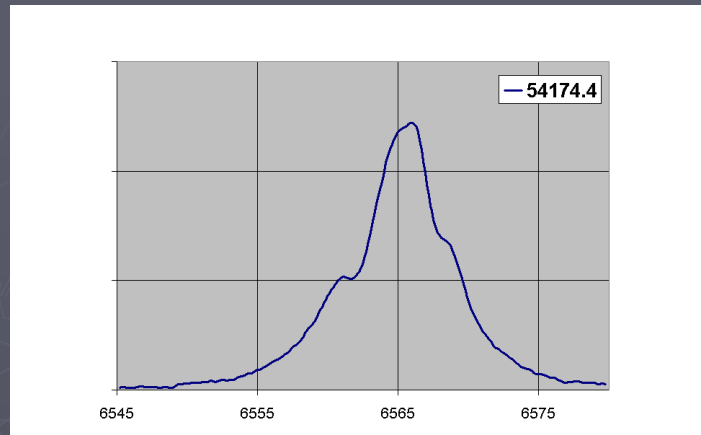
A hot (B spectral class) rapidly spinning main sequence star with a disc of circumstellar material

Pi Aqr Aug 2007



Be Stars are main sequence hot (B type) stars which show emission lines, particularly at H alpha from discs of circumstellar material. These discs are generally unstable and build and decay with time. The mechanisms of disc formation and decay are only approximately understood. This is a typical line profile of a Be star. The emission from the left and right portions of the disc are shifted to the blue and red respectively due to the rotation of the disc.

Be Star Zeta Tau Sep 2003-Apr 2006



Confirmed 1471 day and found new 69 day periods in V/R

E Pollmann IBVS 5813

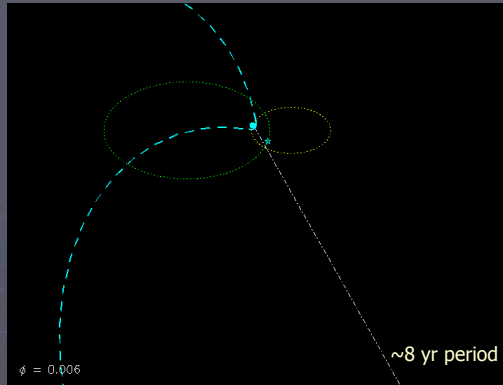
Here is an example of Be star H α emission line variability over 2.5 years by German amateur Ernst Pollmann.

Long term monitoring of many Be stars is currently a major Pro Am project.

WR140 periastron Jan 2009^{Pro-Am Campaigns}

Pro: Mike Moffat University of Montreal

Am: Thomas Eversberg VdS



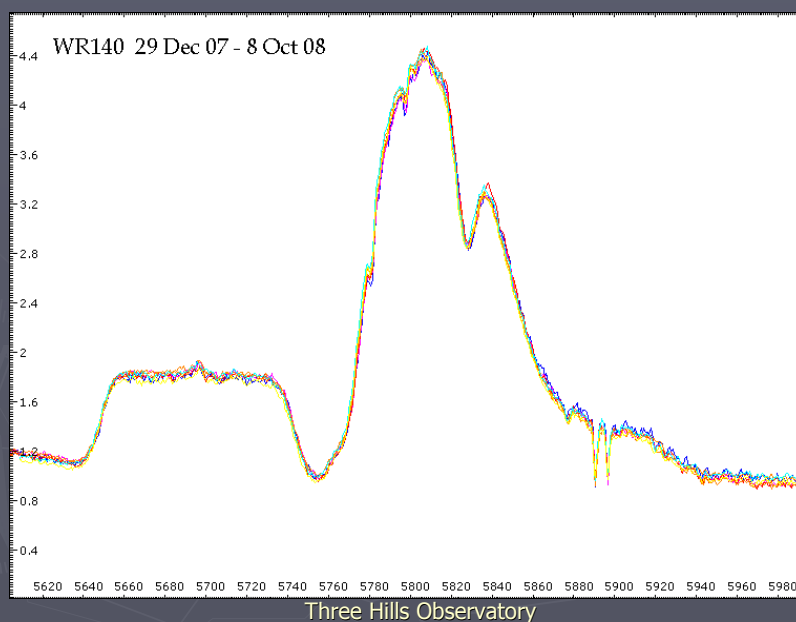
Amateur teams plan to observe continuously Dec 08-Mar 09 using home observatories and the 0.5m MONS telescope on Teneriffe

Also looking for
multi filter photometry

Another Pro-Am project currently under way is the interaction between stellar winds of components of the binary Wolf Rayet star system WR140 during periastron early next year (2009).

WR140 periastron Jan 2009 Pro-Am Campaigns

Practice run outside periastron period



In order to measure the phenomena during periastron a repeatability of better than 2% is needed.

These are eight spectra of the area of interest covering several months pre periastron as a base line.

Eps Aur eclipse 2009-11

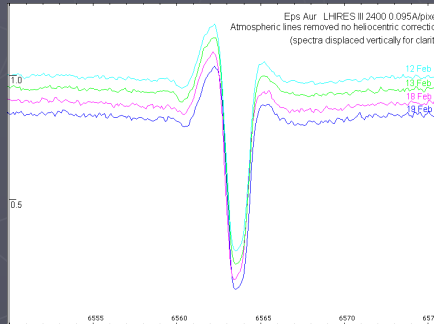
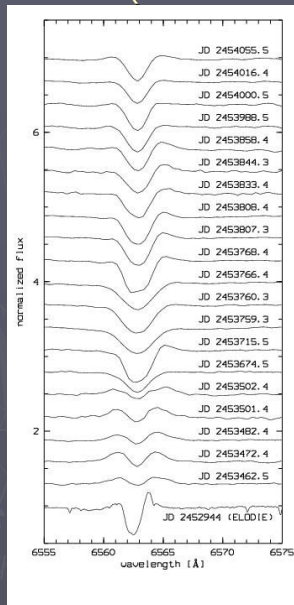
(Coordinator: Jeff Hopkins)

Pro-Am Campaigns



Apr 05- Nov 06
Lothar Schanne VdS
(IBVS 5747)

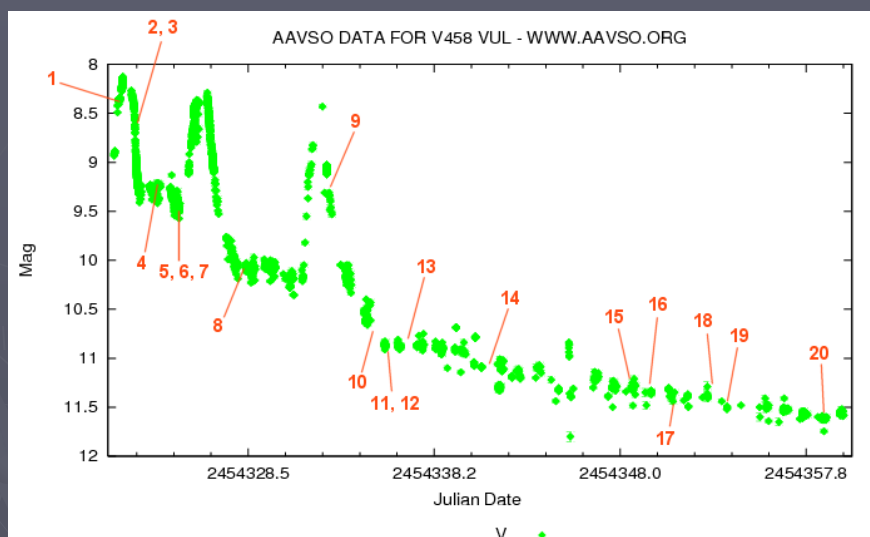
27yr period



Three Hills Observatory

The exact nature of the object orbiting Eps Aur and causing an eclipse every 27 years is not well understood. A Pro-Am campaign which will include high resolution spectroscopic measurements hopes to add to the existing knowledge during the 2009-11 eclipse. One problem is the variability outside eclipse which needs to be understood if the in eclipse data is to be interpreted correctly.

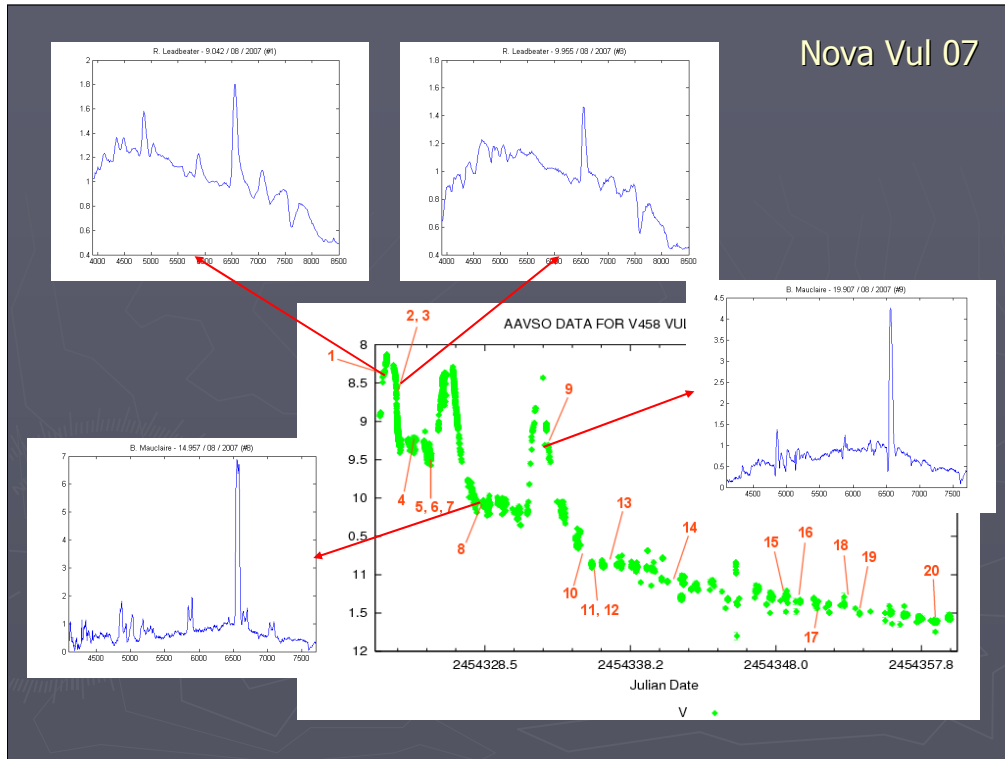
Nova Vul 07



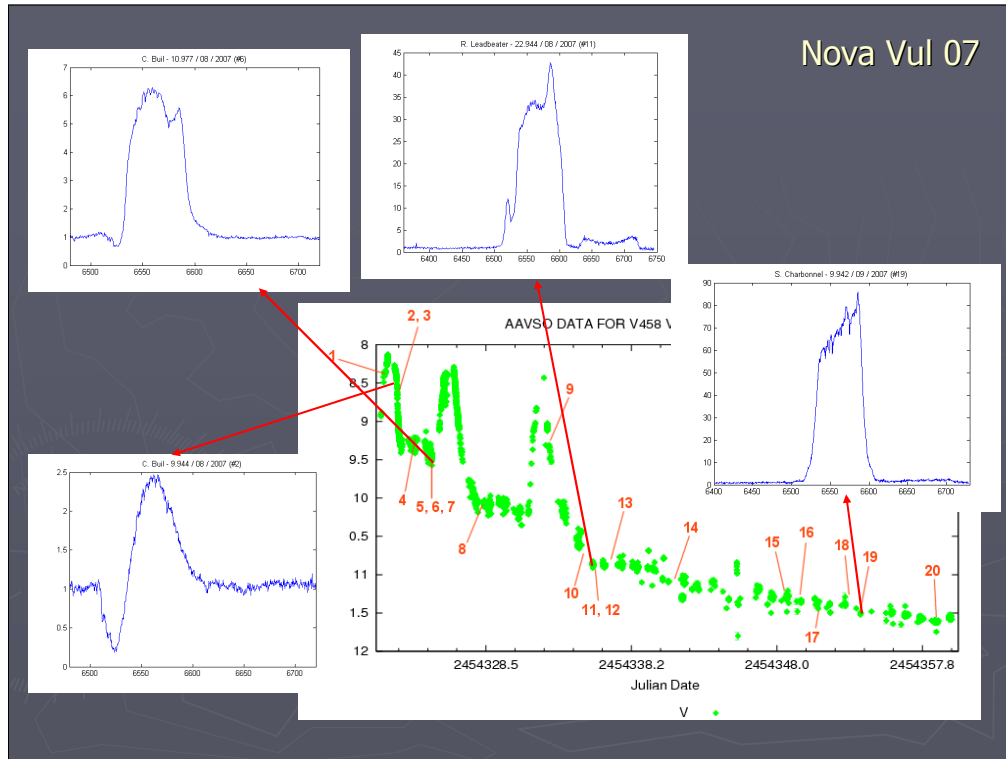
Spectra from 7 observers: Leadbeater, Buil, Mauclaire, Desnoux, Benson, Barbotin, Charbonnel

An example of the potential benefits of cooperation between amateur spectroscopists and photometrists. The first spectra were taken within a few hours of the announcement of Nova Vul 07

Nova Vul 07

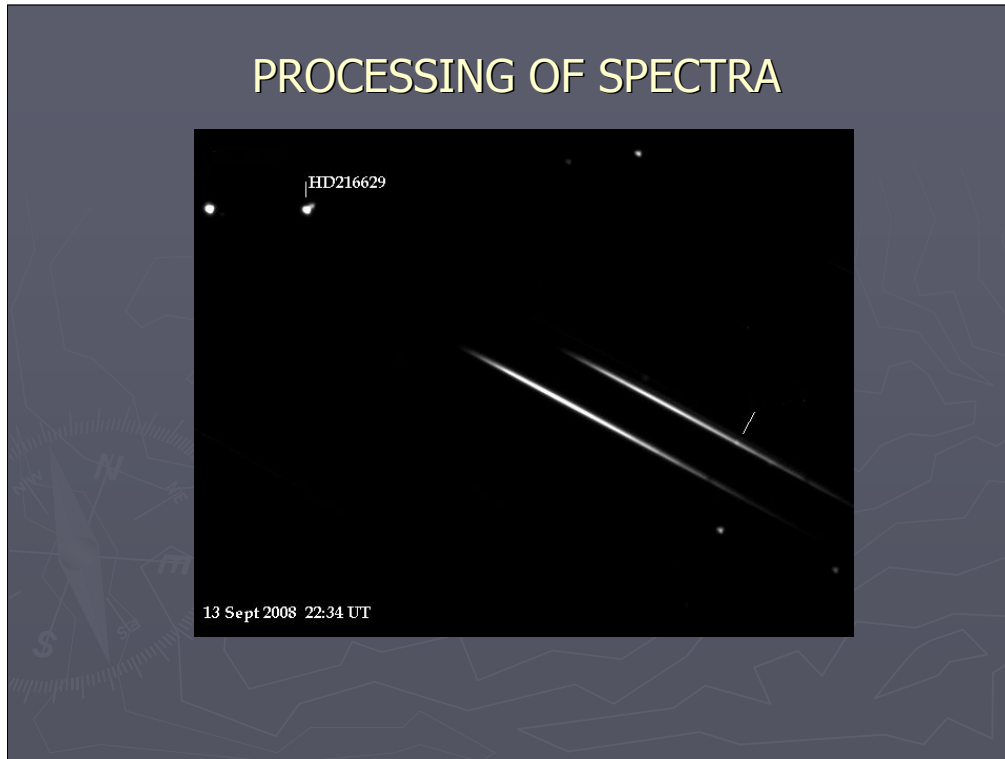


Examples of low resolution spectra. Note the marked changes in the spectrum within the first few hours.



Examples of high resolution spectra of H alpha region. Note the dramatic changes in shape which contain information about the velocity and distribution of the ejected material.

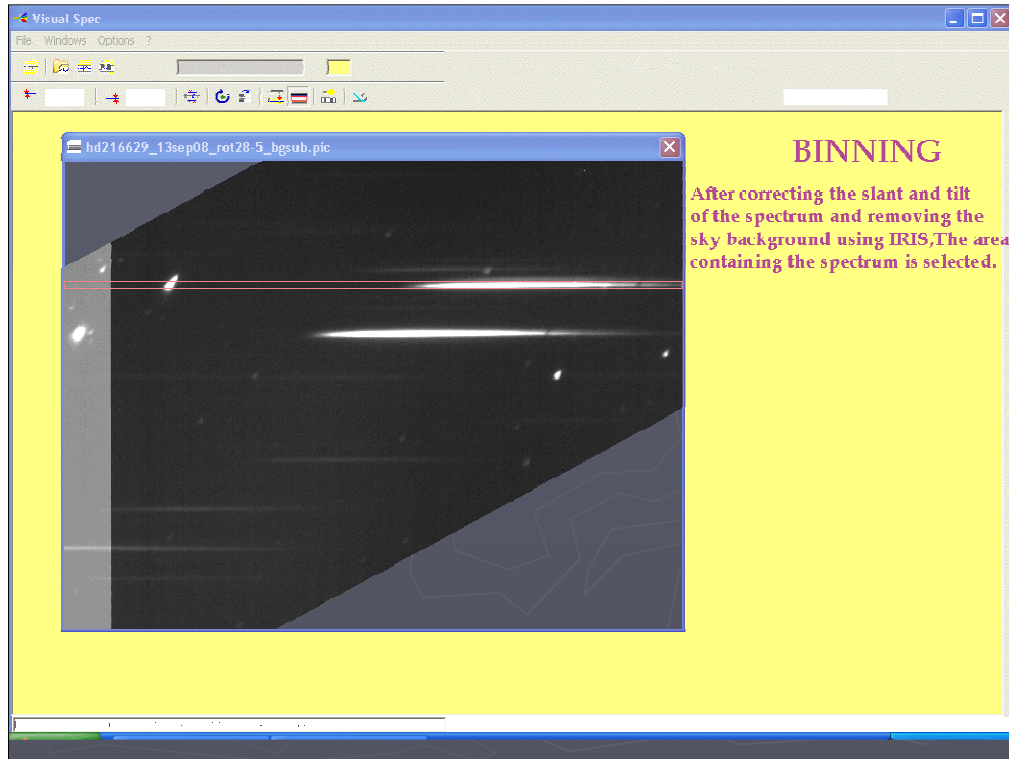
PROCESSING OF SPECTRA



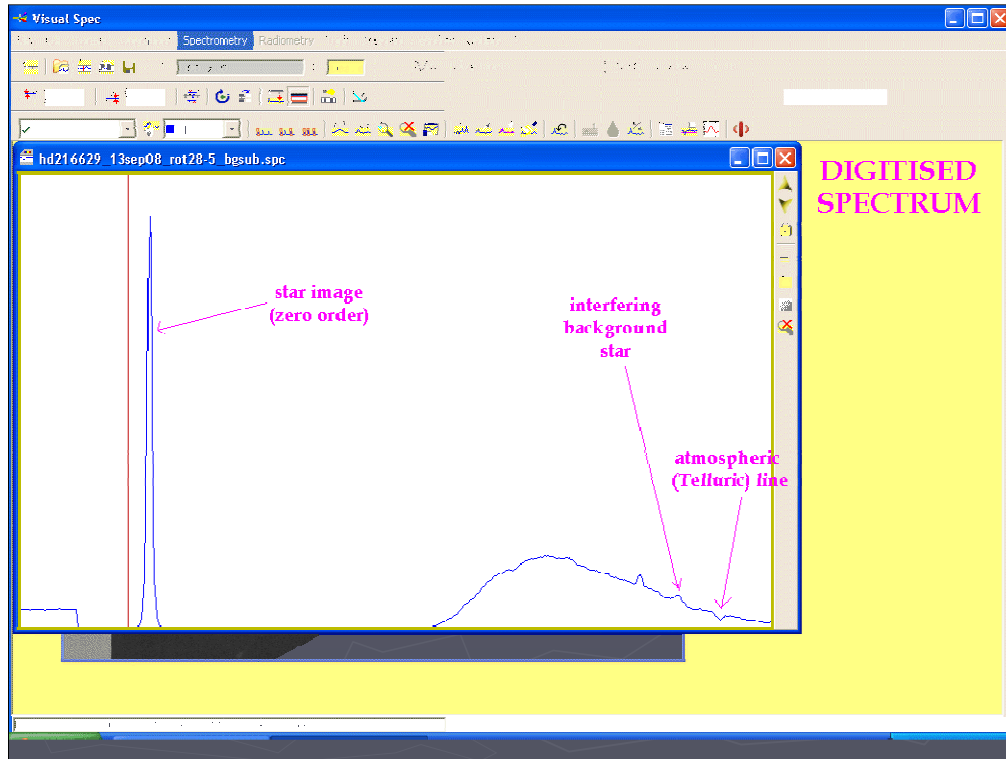
Raw images of spectra are processed to generate useful scientific data.

This is the raw image of the spectrum of 9th magnitude Be star IL Cep (HD216629) Taken using a Star Analyser (The grating was rotated so that the fainter close companion could be separated out).

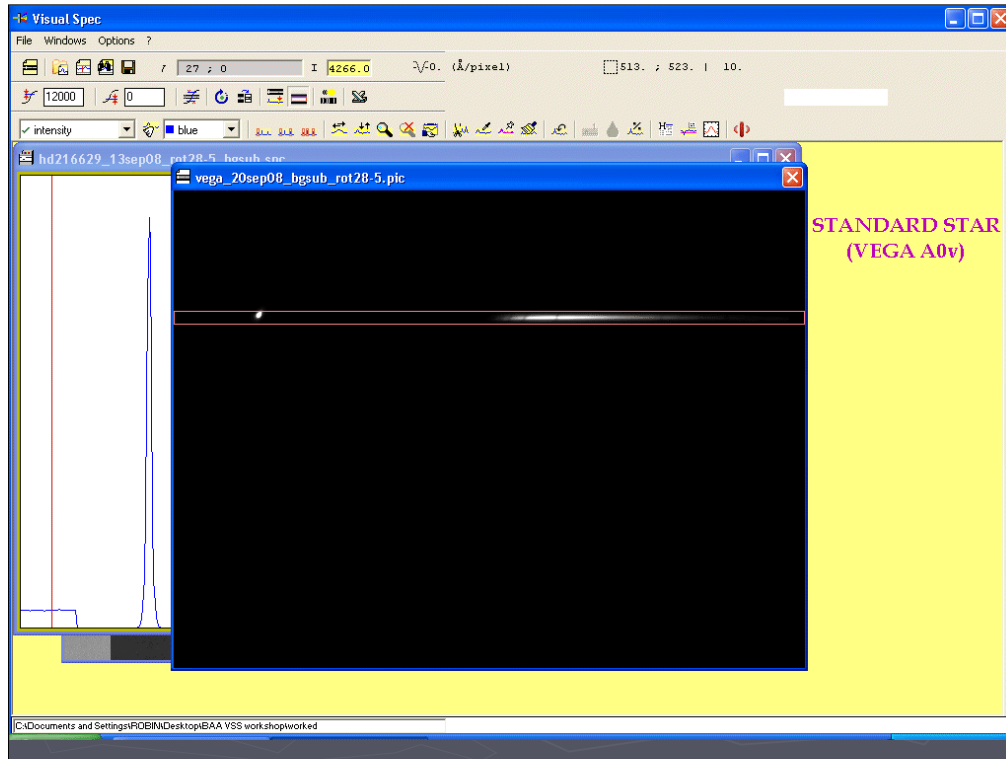
The image was corrected for darks and flats in the normal way before being rotated to make the spectrum horizontal and the background subtracted using special features designed for manipulation of spectroscopic images in the freeware program IRIS.



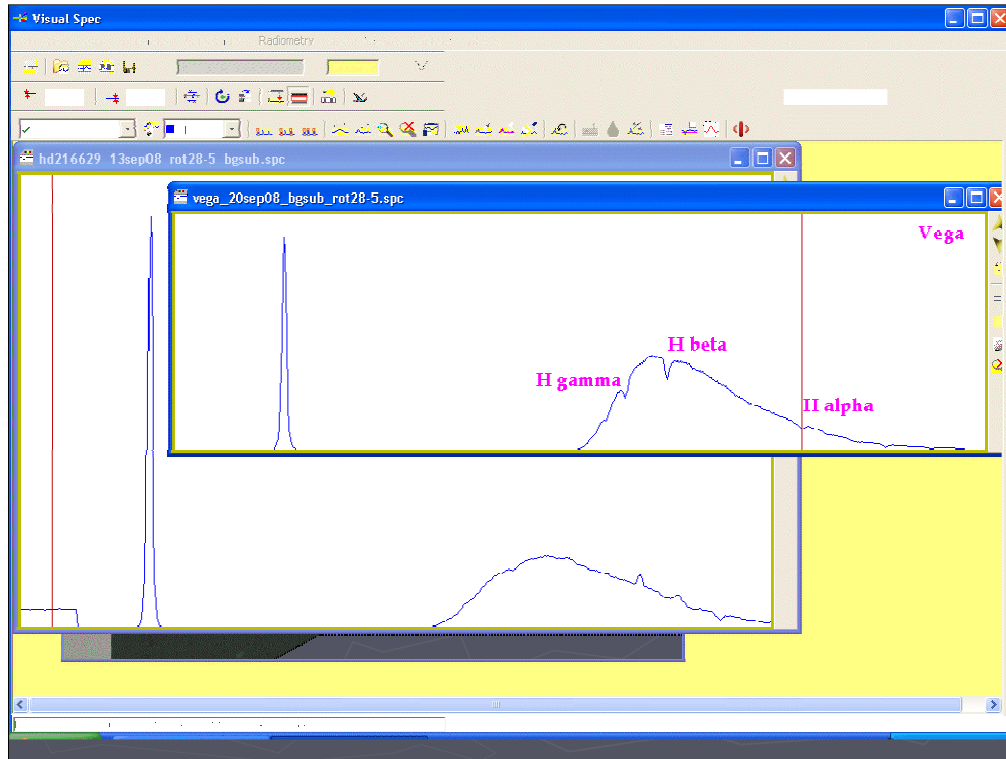
The resulting image was loaded into Visual Spec, a powerful and highly graphical spectral analysis freeware program. The spectrum of interest is selected and converted into a digital graph of brightness v pixel position along the x axis. (binning)



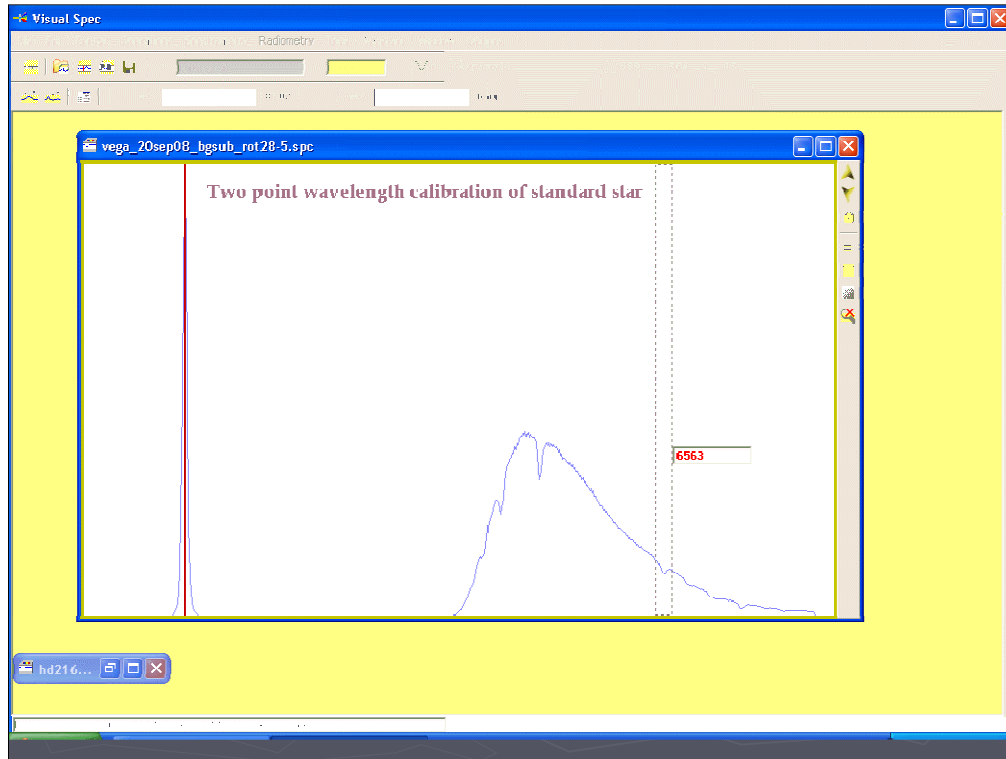
Note the zero order (the starlight which passed straight through the grating), a small blip from an interfering star (identified by careful study of a DSS image of the field) and the strong absorption band due to the Earth's atmosphere.



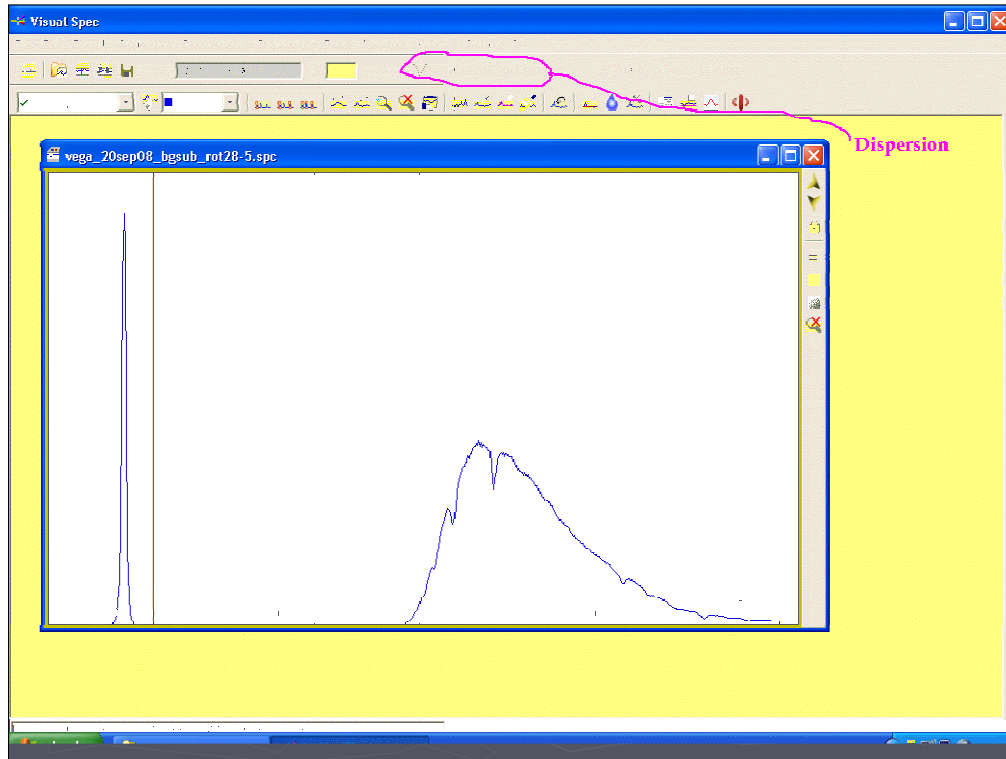
In order to calibrate the spectrum both in wavelength and to correct for the spectral response of the instrument (camera/grating/telescope optics) a standard star A type star (in this case Vega) was also taken on the same night.



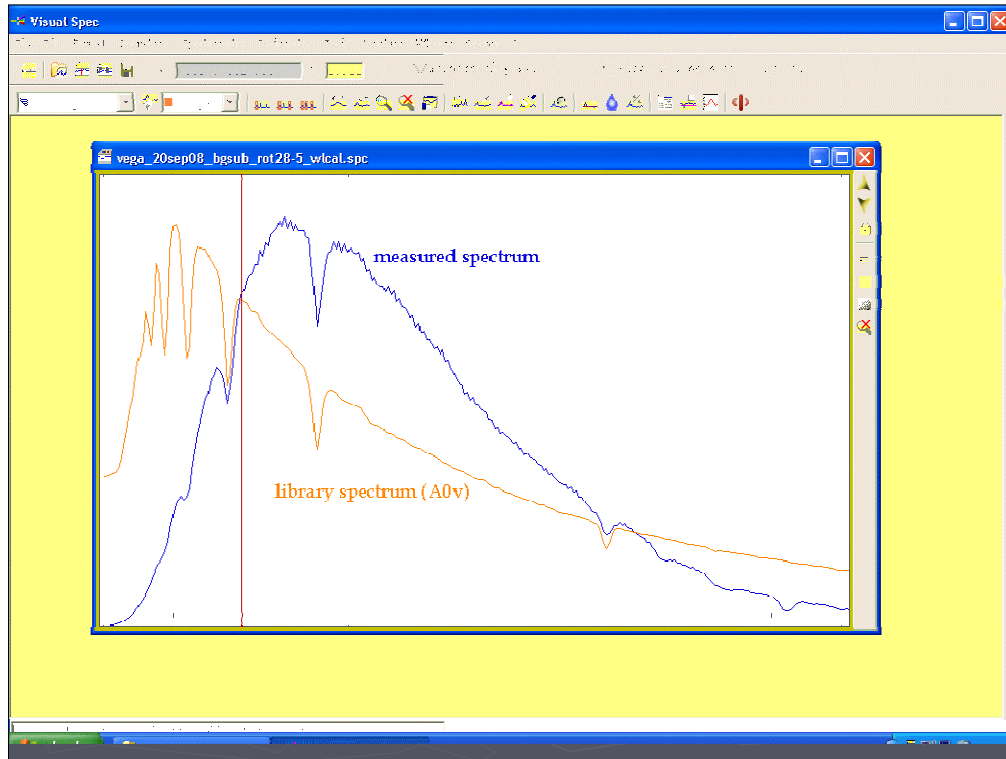
The spectrum was digitised in the same way. The Hydrogen lines which fall at known wavelengths are easily identified and can be used to wavelength calibrate the spectrum



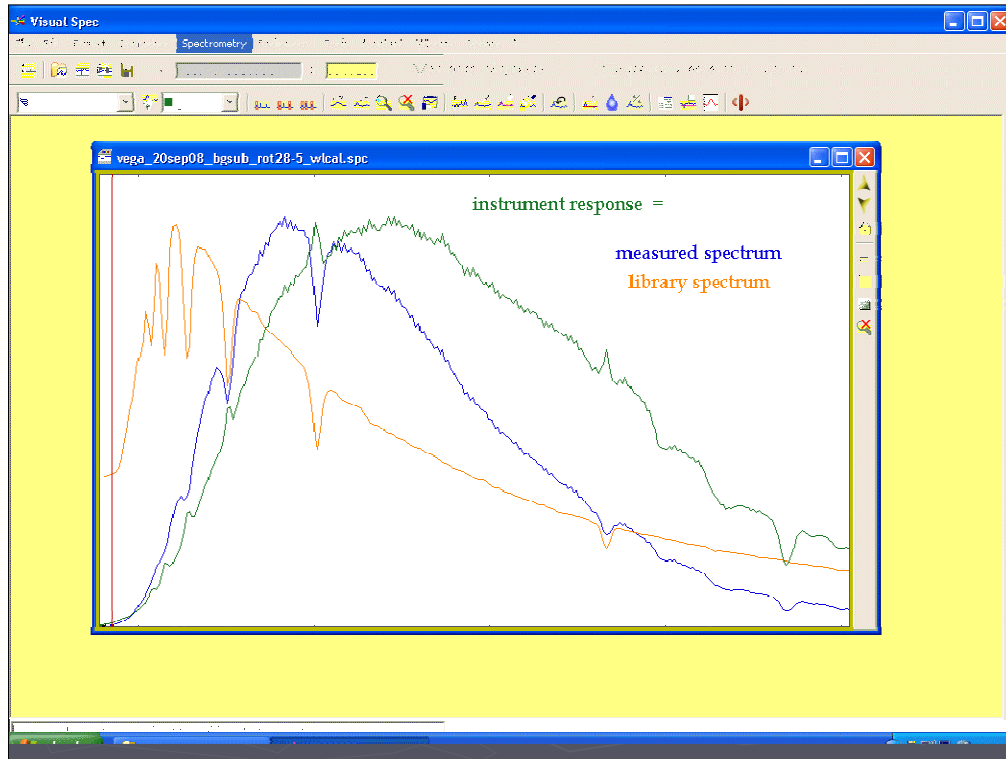
Two wavelength calibration points are used. "0A" the zero order and "6563A" the Hydrogen alpha line. (With this low diffraction angle type setup the calibration is very close to linear so two points are sufficient)



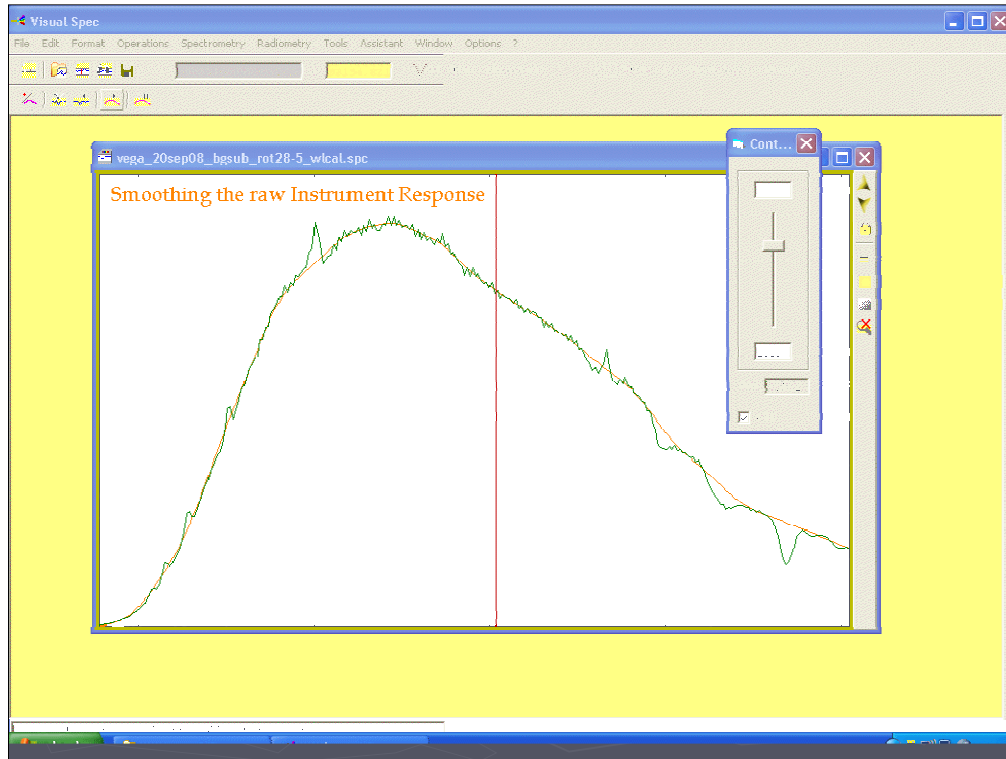
This is the resulting wavelength calibrated spectrum of Vega. We can use the dispersion figure obtained to calibrate any spectra taken using the same configuration.



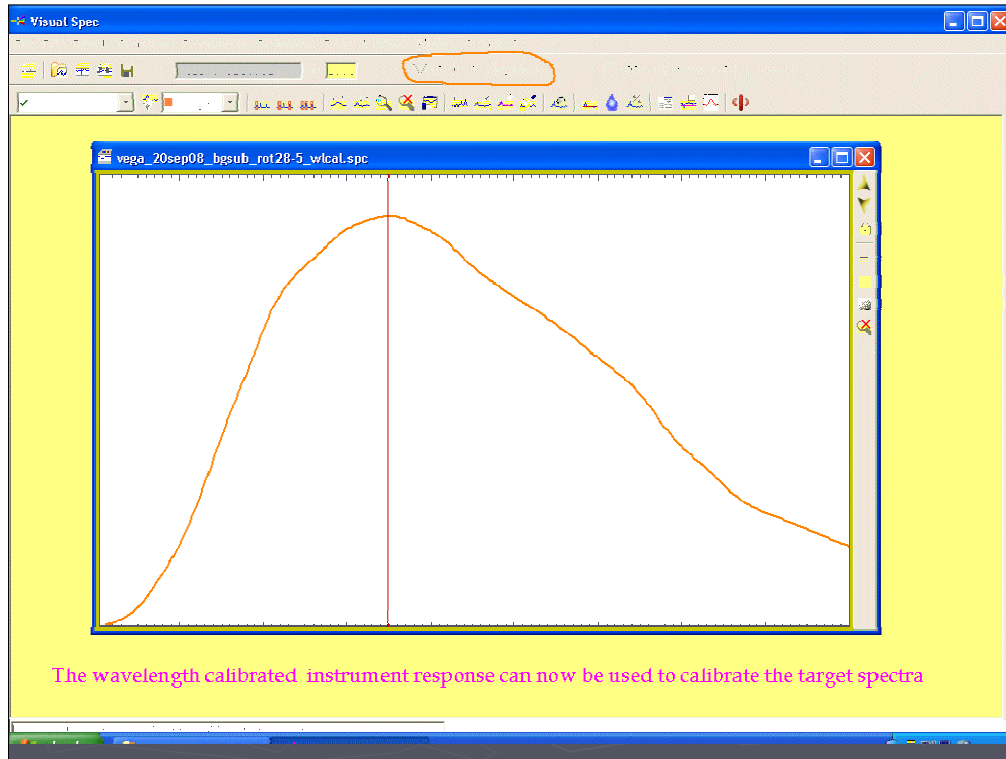
Visual Spec has a library of standard spectra. If we overlay type A0v (Vega) we see the Hydrogen lines line up but the overall shape is very different. This is because of the spectral response of the instrument (mainly due to the CCD response)



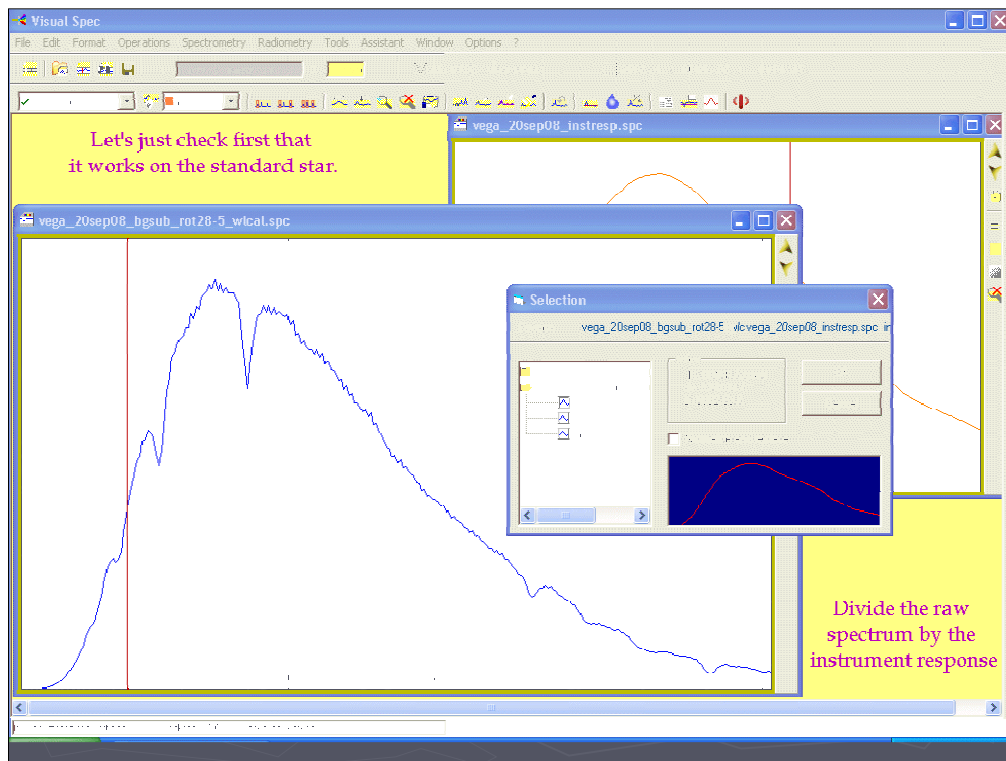
We can calculate this response by dividing the measured spectrum by the library spectrum (green line)



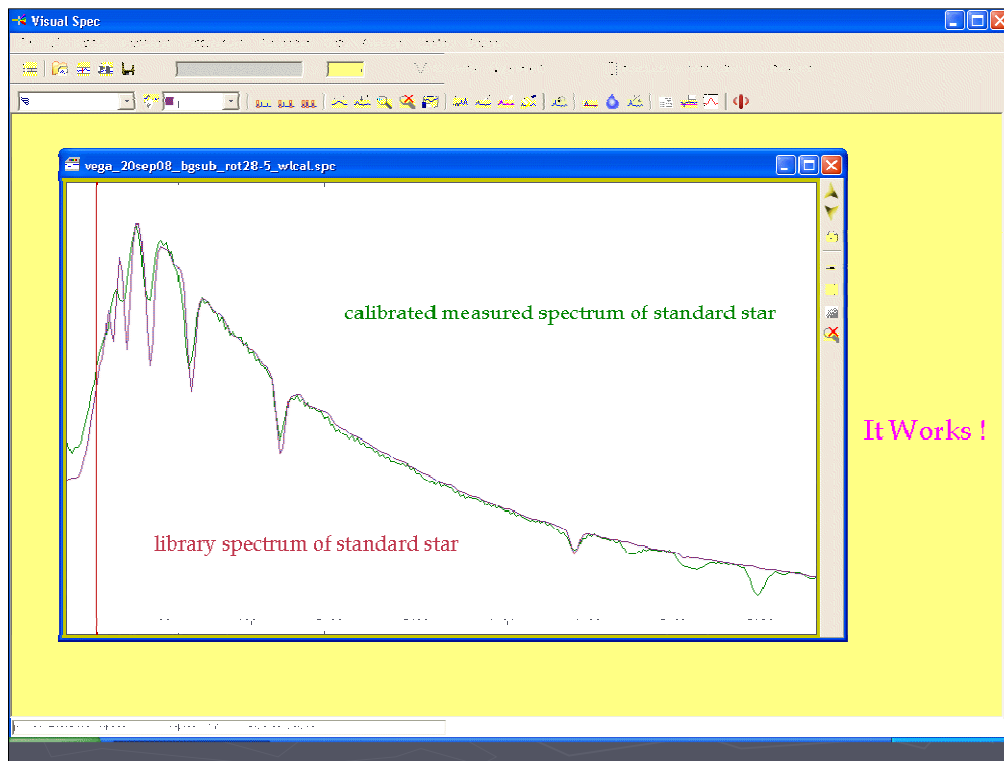
The result is “tidied up” and smoothed to get rid of artifacts due to inaccuracies in division of the narrow absorption lines and the telluric lines.



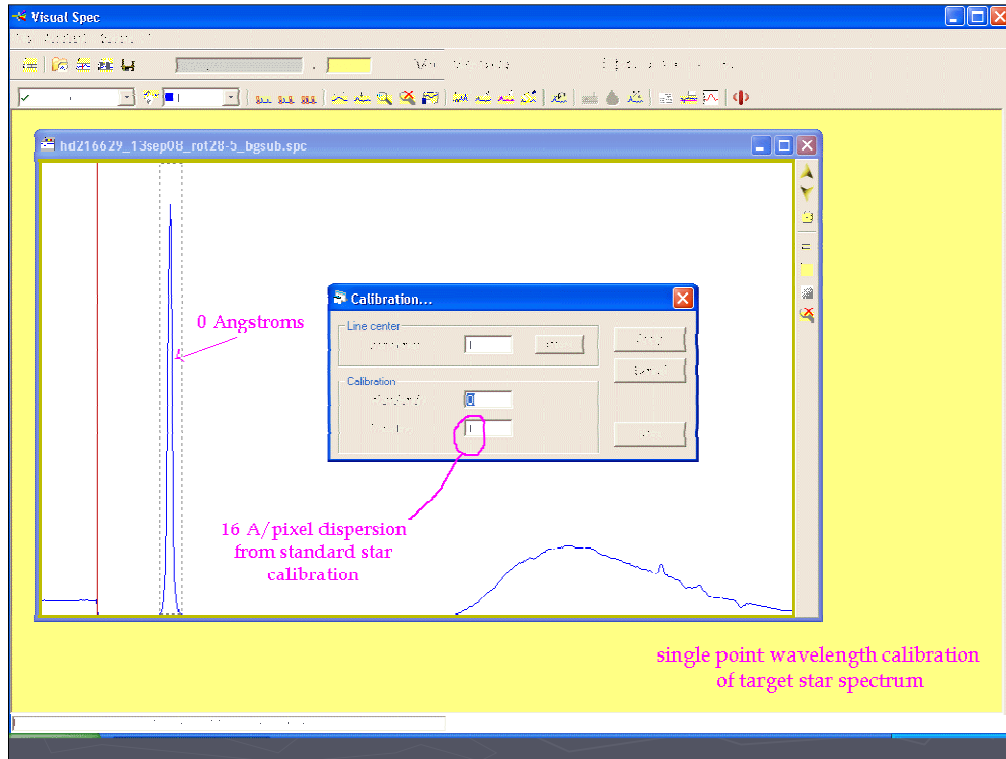
The result is our instrument response curve which we can use to calibrate the target spectra



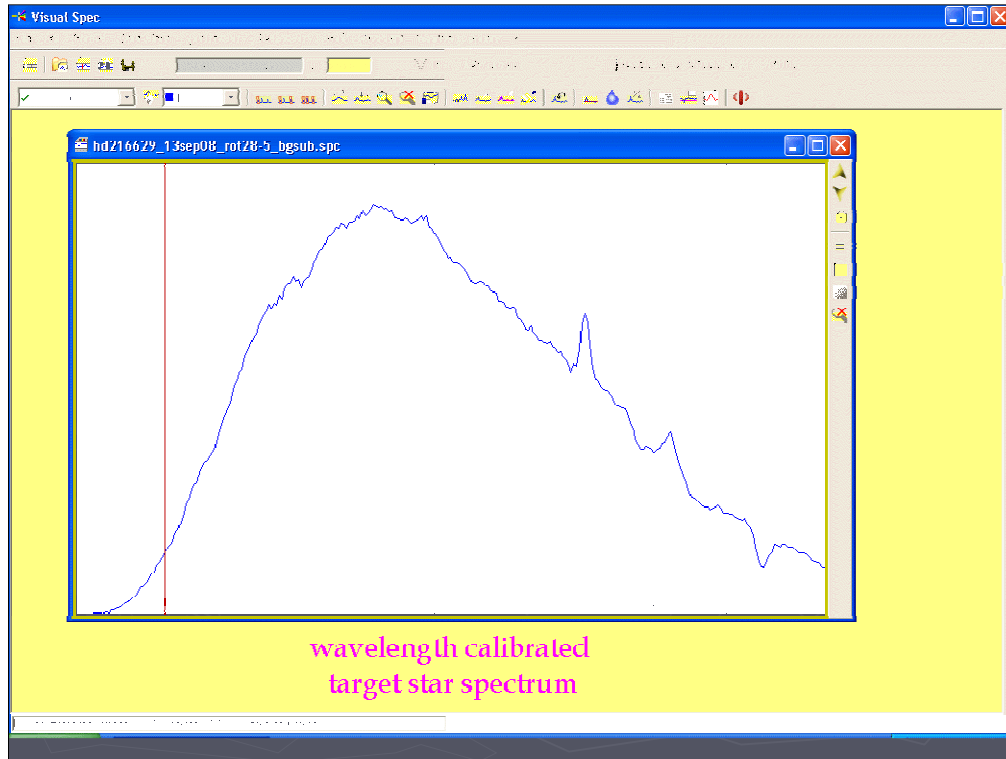
A quick check to make sure it works ok by dividing the raw Vega spectrum by the instrument response curve.



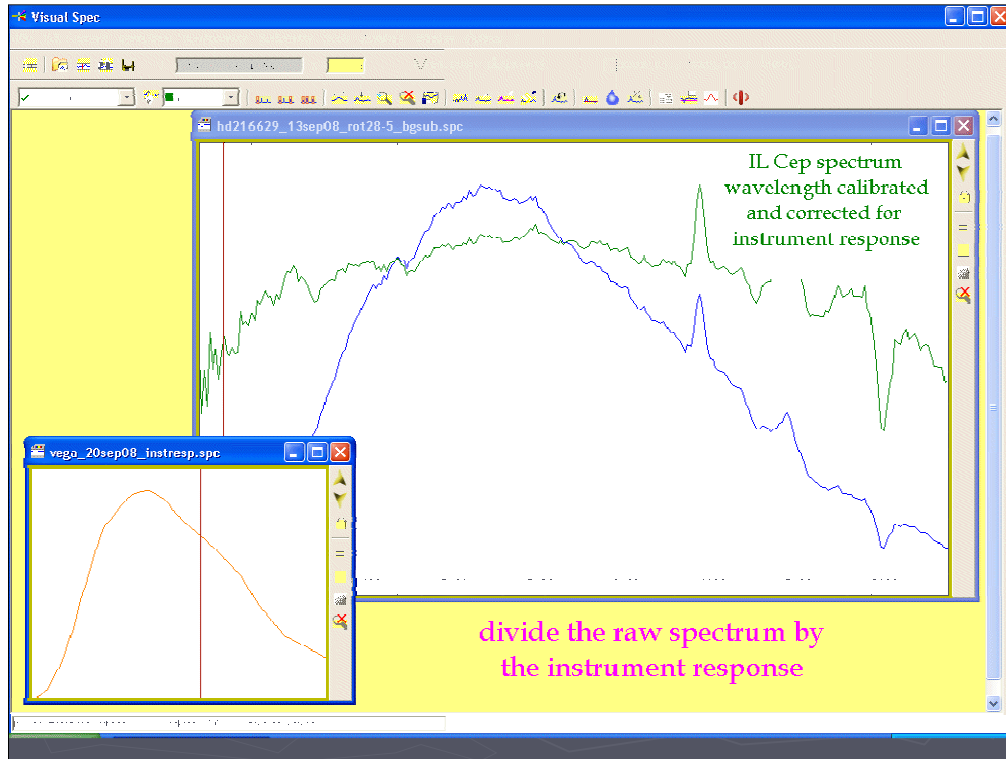
It works!



We now return to target spectrum and wavelength calibrate it using the zero order and the dispersion calculated from the Vega spectrum



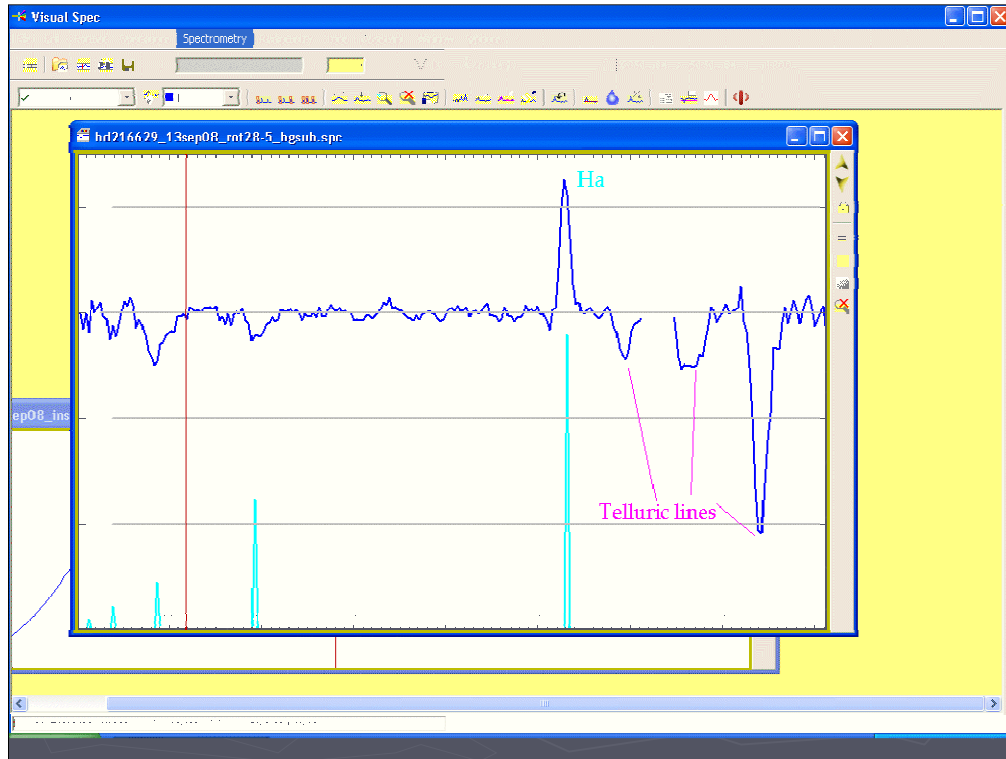
The wavelength calibrated spectrum



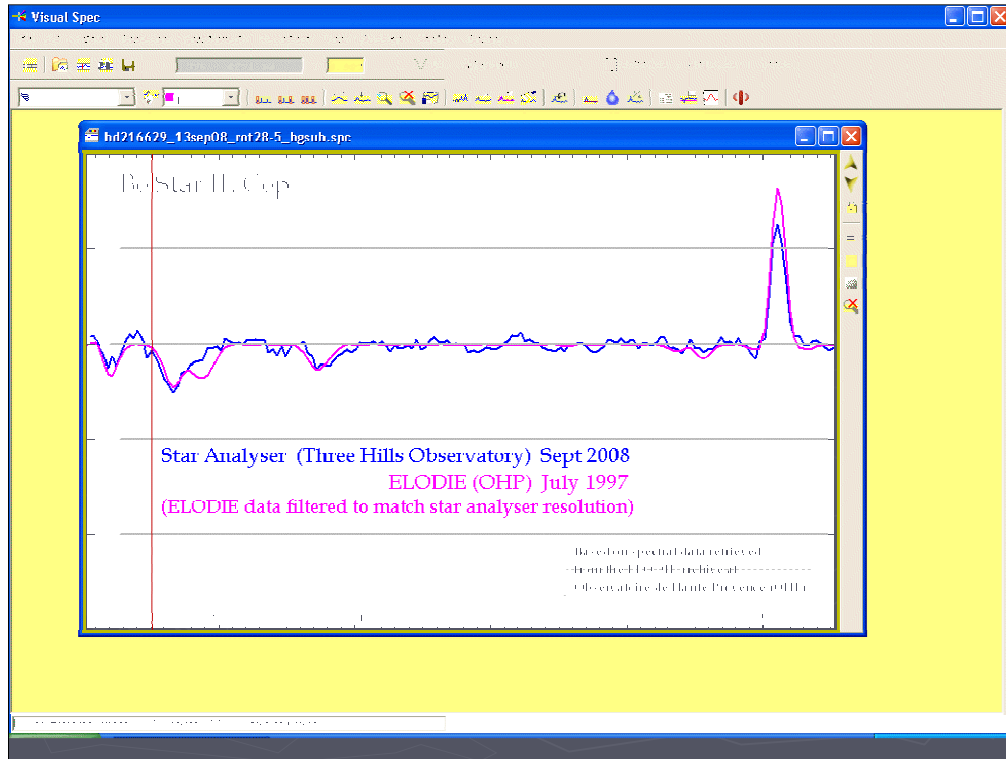
Now divide by the instrument response to produce the fully calibrated spectrum
(The portion containing the background star has been eliminated)



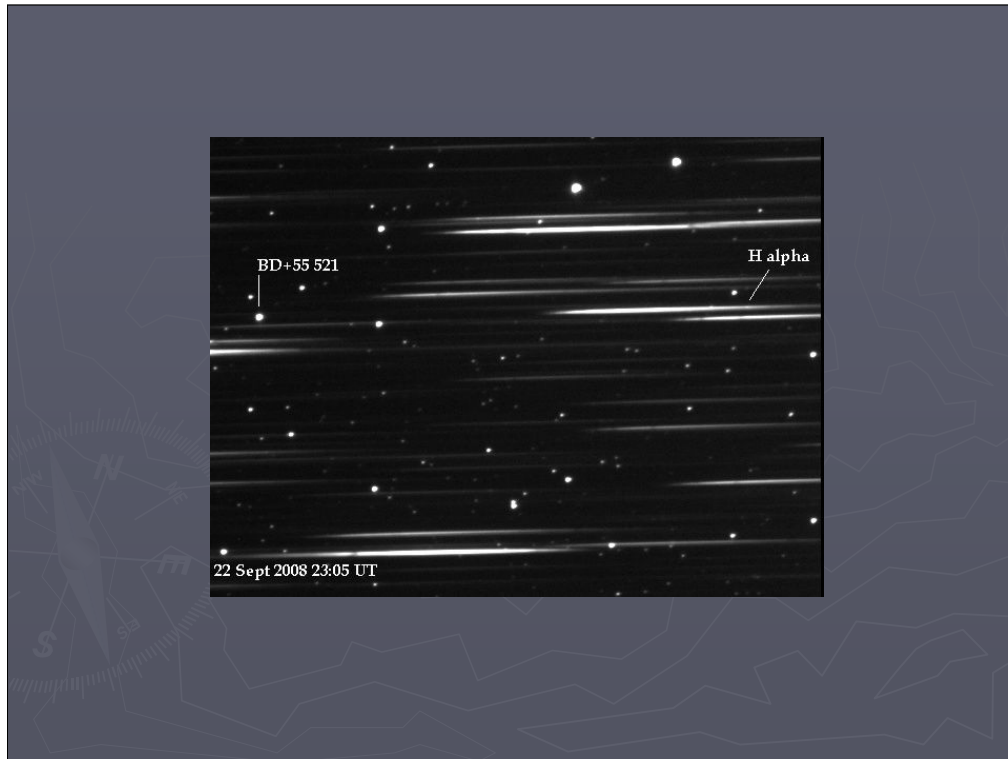
To make measurement of the intensities of the absorption and emission lines clearer, it is common practise to “normalise to the continuum” to get rid of the broad background shape. A smooth fit to the continuum is produced and the spectrum is divided by it. The spectrum is then scaled so the continuum = 1 where there are no spectral lines.



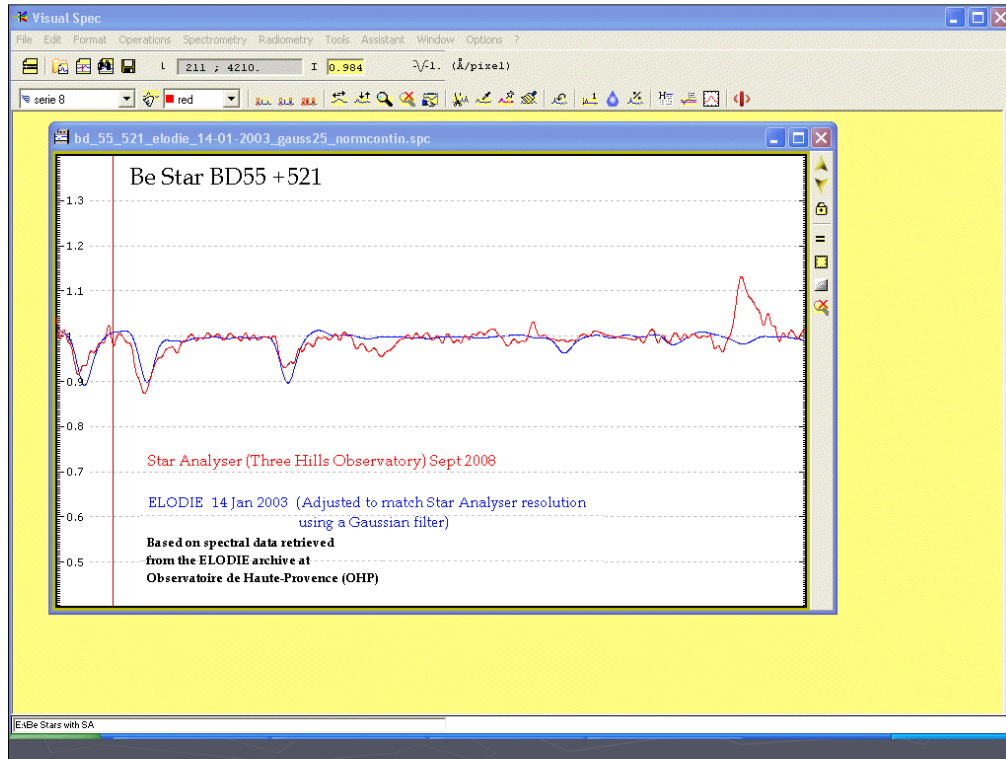
This is the final result. The Hydrogen lines are clear (identified by the cyan lines from the visual spec library of elements) Hydrogen Alpha is in emission. beta, gamma, delta are in absorption. Three Telluric bands can also be seen in the IR



Overlaying the previous spectrum (dated 1997) from the database of the ELODIE spectrograph at the Observatoire Haute Provence (Incidentally the device which was used to discover 51Peg-b, the first exoplanet), we can see that the low resolution spectrum of this star is very similar to the last one 11 years. (The ELODIE spectrum is heavily filtered to match the resolution of the Star analyser spectrum)

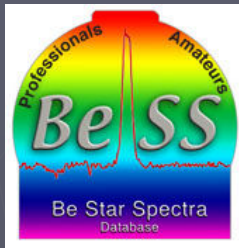


This is not always the case however. A few nights later I measured this Be Star BD +55 521



and found evidence of increased emission at H alpha compared with 5 years previously. I now need someone with a big telescope and high resolution spectrograph to confirm what has happened

Databases



Joint amateur and professional database for Be star spectra only.

Open to all after registration (contributions are "moderated")



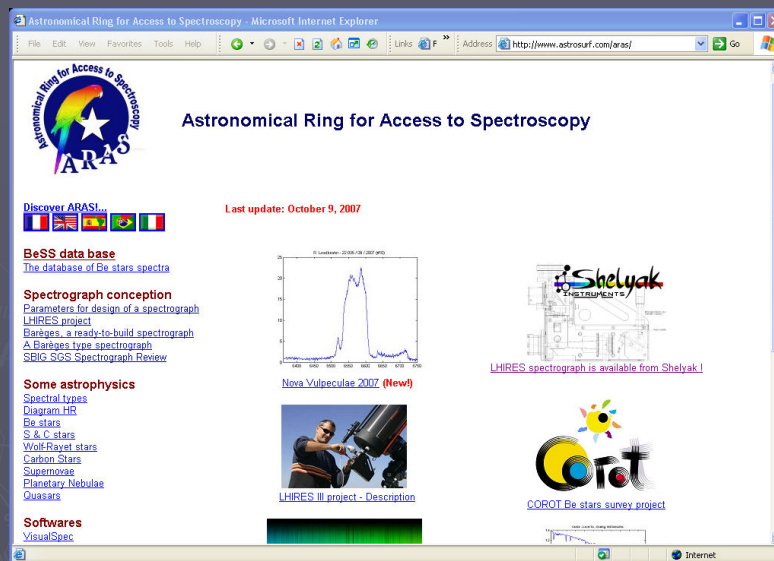
Small informal database for all targets run by Dr Otmar Stahl



AAVSO database for spectra in 2009?

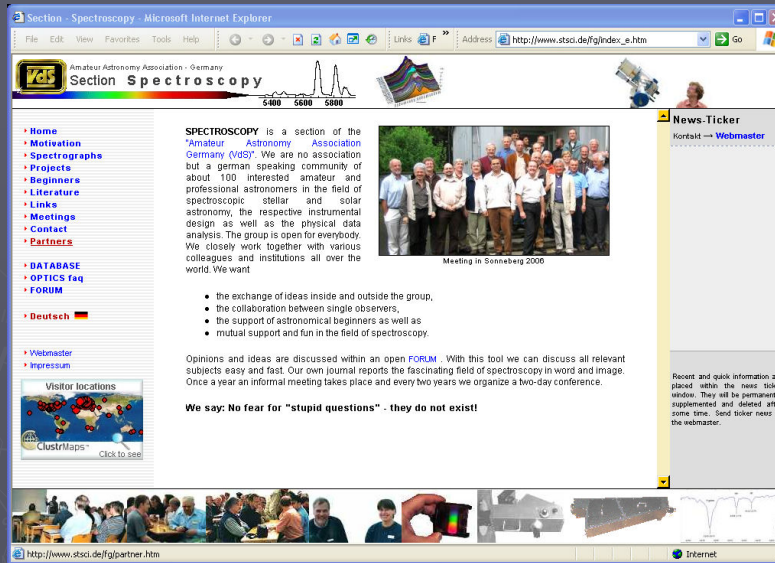
There are a couple of public databases which accept amateur spectra but the most exciting news is that AAVSO are planning to develop a database for spectra of variable stars, possibly next year.

Astronomical Ring for Access to Spectroscopy



Useful sources of further information on amateur spectroscopy are the French sponsored website ARAS

VdS Spectroscopy Group



and the website of the spectroscopy section of the German society VdS



Other useful websites are:

| | |
|------------------|---|
| Robin Leadbeater | www.threehillsobservatory.co.uk |
| Christian Buil | www.astrosurf.com/~buil |
| Maurice Gavin | www.astroman.fsnet.co.uk |
| Ernst Pollman | http://spektroskopie.fg-vds.de/pollmann |
| Dale Mais | http://mais-ccd-spectroscopy.com |

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|-------------------|--|
| ARAS | www.astrosurf.com/aras |
| Vds Spectro group | www.stsci.de/fg/index_e.htm |

| | |
|---------------------|--|
| Star Analyser | www.patonhawksley.co.uk/staranalyser.html |
| Rainbow Optics | www.starspectroscope.com/ |
| LHIRES III | www.shelyak.com |
| Sbig Spectrographs | www.sbig.com/dss7/dss7.htm |
| | www.sbig.com/sbwhtmls/spectrometer2.htm |
| Baader spectrograph | www.baader-planetarium.de/produktankuendigungen/produkt.htm |

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|-------------|--|
| IRIS | www.astrosurf.com/~buil/us/iris/iris.htm |
| Visual Spec | www.astrosurf.com/vdesnoux/ |

| | |
|---------------|---|
| BeSS Database | http://basebe.obspm.fr |
| | http://arasbeam.free.fr/?lang=en |
| VdS Database | www.stsci.de/fg/data.htm |

| | | |
|------------------|--|--|
| WR140 Periastron | www.stsci.de/wr140/wr140.htm | www.roe.ac.uk/~pmw/Wr140int.htm |
| Eps Aur Eclipse | www.hposoft.com/Campaign09.html | www.du.edu/~rstencel/epsaur.htm |

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|--------------|---|
| Yahoo groups | http://tech.groups.yahoo.com/group/staranalyser |
| | http://tech.groups.yahoo.com/group/spectro-l http://tech.groups.yahoo.com/group/amateur_spectroscopy |