Stellar Spectroscopy

Image courtesy of European Southern Observatory

James Clerk Maxwell in 1873, on the subject of stars . . .

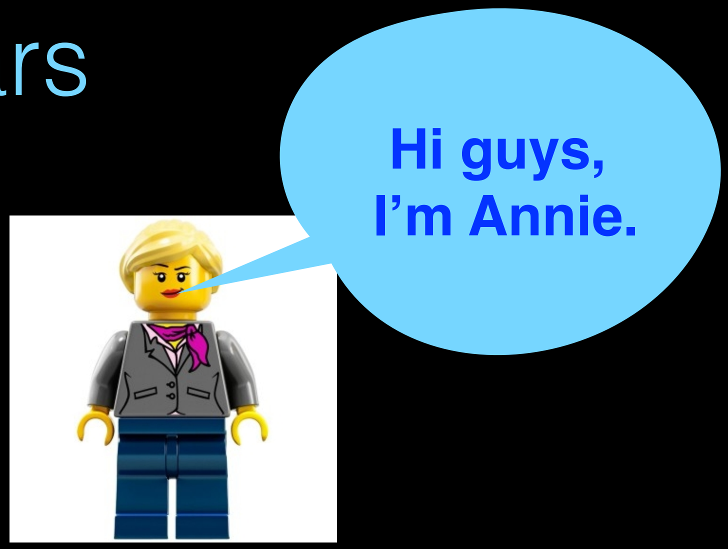
"But in the heavens we discover, by their light, ***and by their light alone*** *. . . . that each of them is built up of molecules of the same kinds as those which we find on earth".*

Examining the light from stars

We’ll look at what we can see with our own eyes, apply some intuitions of our own and re-trace the discoveries of earlier travellers on this road

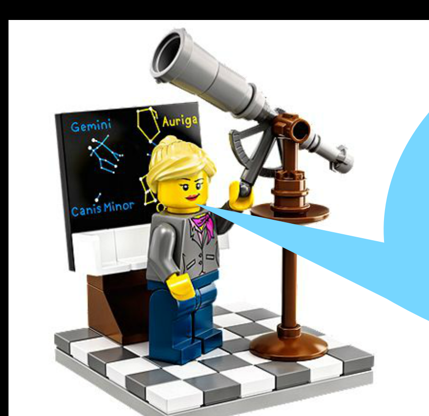
We will also look at how amateur astronomers can do their own spectroscopic investigations and at the spectra of some specific stars

. .and we’ll have a bit of help from my friends at the Lego Astrophysics Institute



What do we see in the night sky?

This star forming region, illustrates a variety of star types - everything from **red** stars through **orange / yellow** and even some with a **blueish** hue to them.



Hmm . . why so many colours?

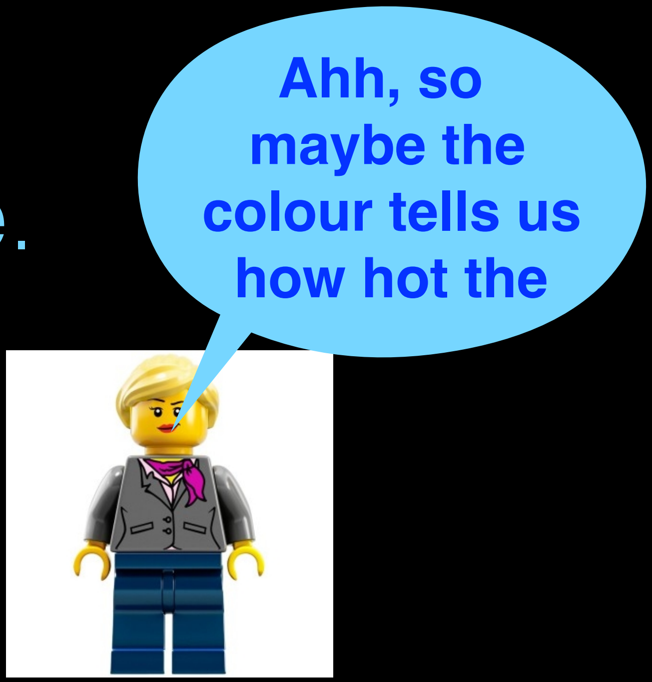
Image courtesy of European Southern Observatory

What might explain the colours?

Well, we know that -

- the Sun (a star 😉) is a long way away but feels warm so must be VERY hot
- we know that very hot things tend to change colour depending on how hot they are.

Lets run with that idea . . .



Colour = temperature?

If we increasingly heat these ceramic pots, they exhibit a range of colours. What is the connection between colour and temperature?

Annie: Ok, so much for metal pots. How does this relate to stars?

Isaac: Maybe I can be of assistance?

The rise of the science of light

Our understanding of light and colour begins with Isaac Newton in 1672.

He is the first to refract white light with a prism, resolving it into its component colours - a spectrum.

William Herschel

Apart from discovering Uranus, William Herschel made another dramatic discovery in 1800.

He directed sunlight through a prism and measured the temperature at several points in the spectrum.

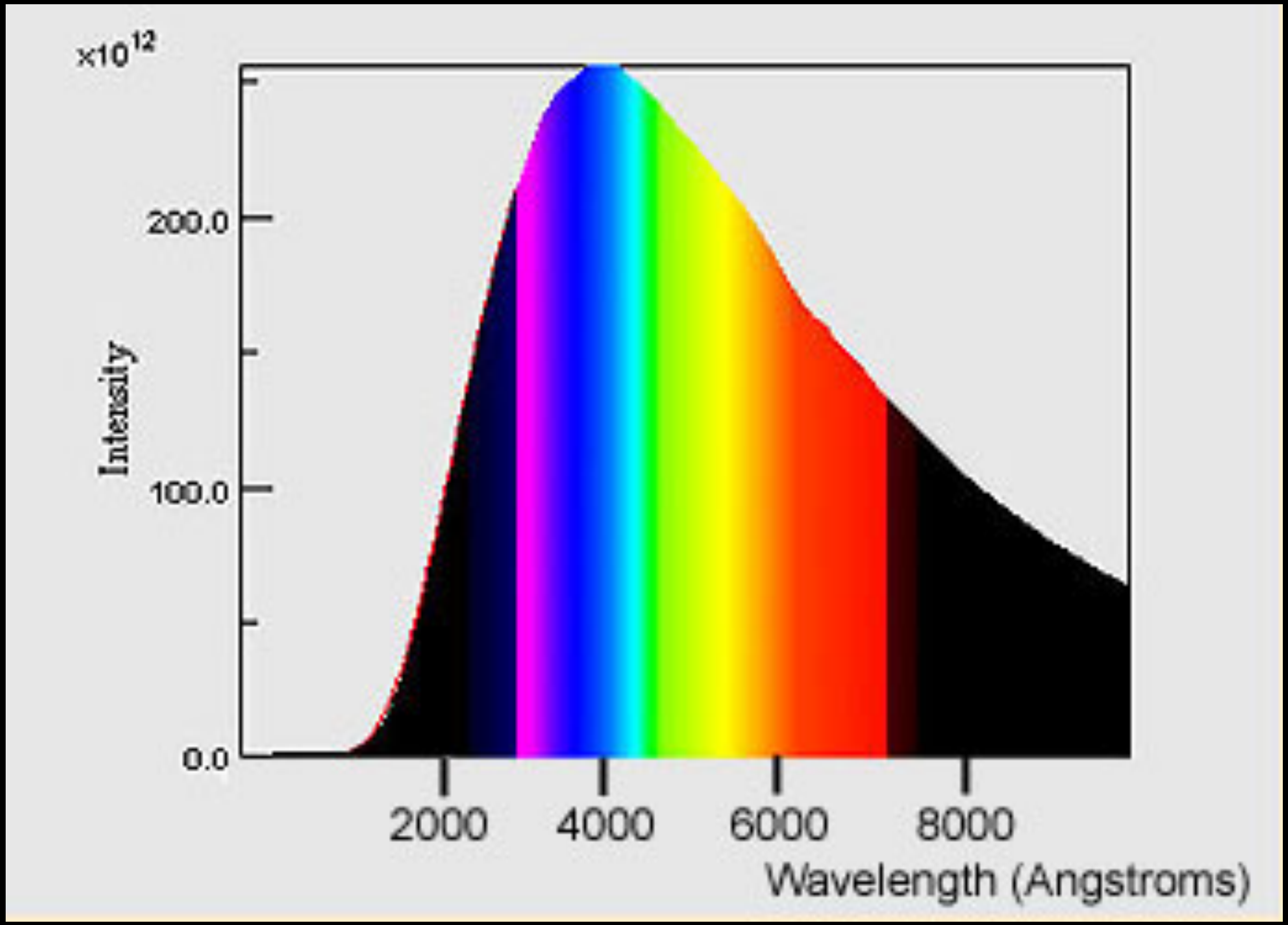
He noticed the temperature of a blank area just beyond the red portion had a higher temperature - he had discovered the infrared.

This eventually led to the notion of the broader electromagnetic spectrum.

Measuring the light from stars

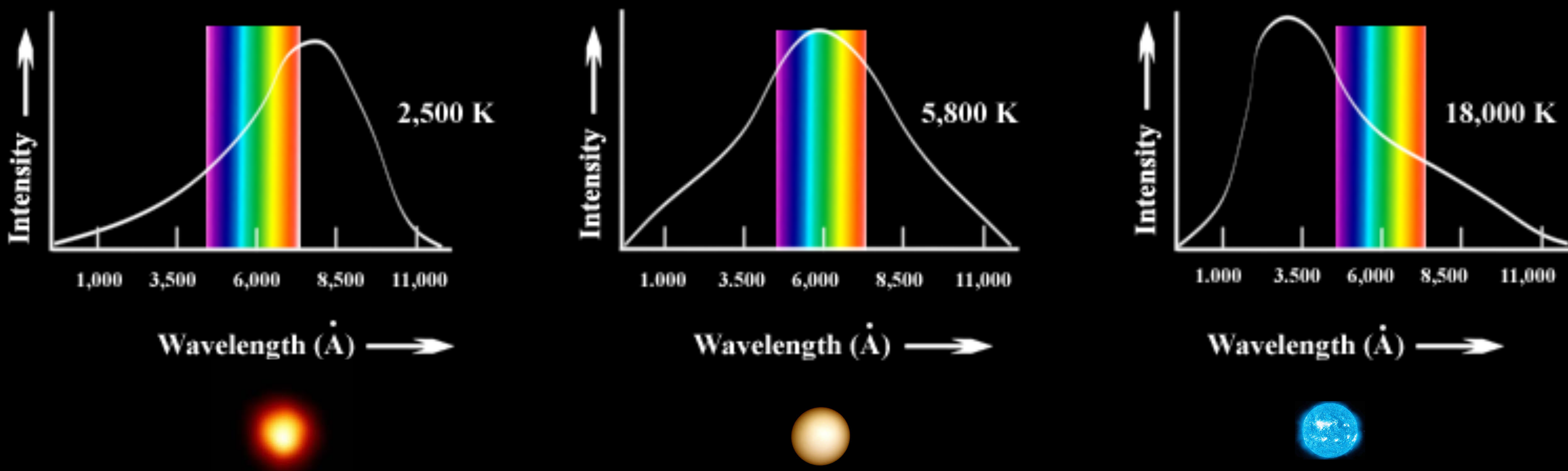
Each star gives off light across a broad spread of wavelengths (both visible and otherwise)

Plotting a graph of light intensity at each wavelength creates a profile - a sort of 'fingerprint' - which reveals much important information



Don't forget stars also radiate energy outside the visible spectrum - the black regions above

. . so, applying this to stars



The wavelength of maximum intensity can be used to compute the effective surface temperature of the star using Wien's Law

It's even an easy calculation - $T_{eff} = b / \lambda_{max}$

where T_{eff} is the 'effective' surface temp K

'b' is Wein's constant = 2.8978×10^{-3}

and λ is wavelength of max intensity (m)

Joseph Fraunhofer

Joseph von Fraunhofer studied the solar spectrum (in 1814) and noticed over 800 dark lines lines in it.

Bunsen and Kirckhoff subsequently revealed these lines were associated with various chemical elements by burning them in a flame

Neils Bohr explained the lines were a result of the quantum nature of the electron energy levels which underpins the science of spectroscopy.

Dark lines appear when atoms absorb energy and push electrons to higher energy levels.

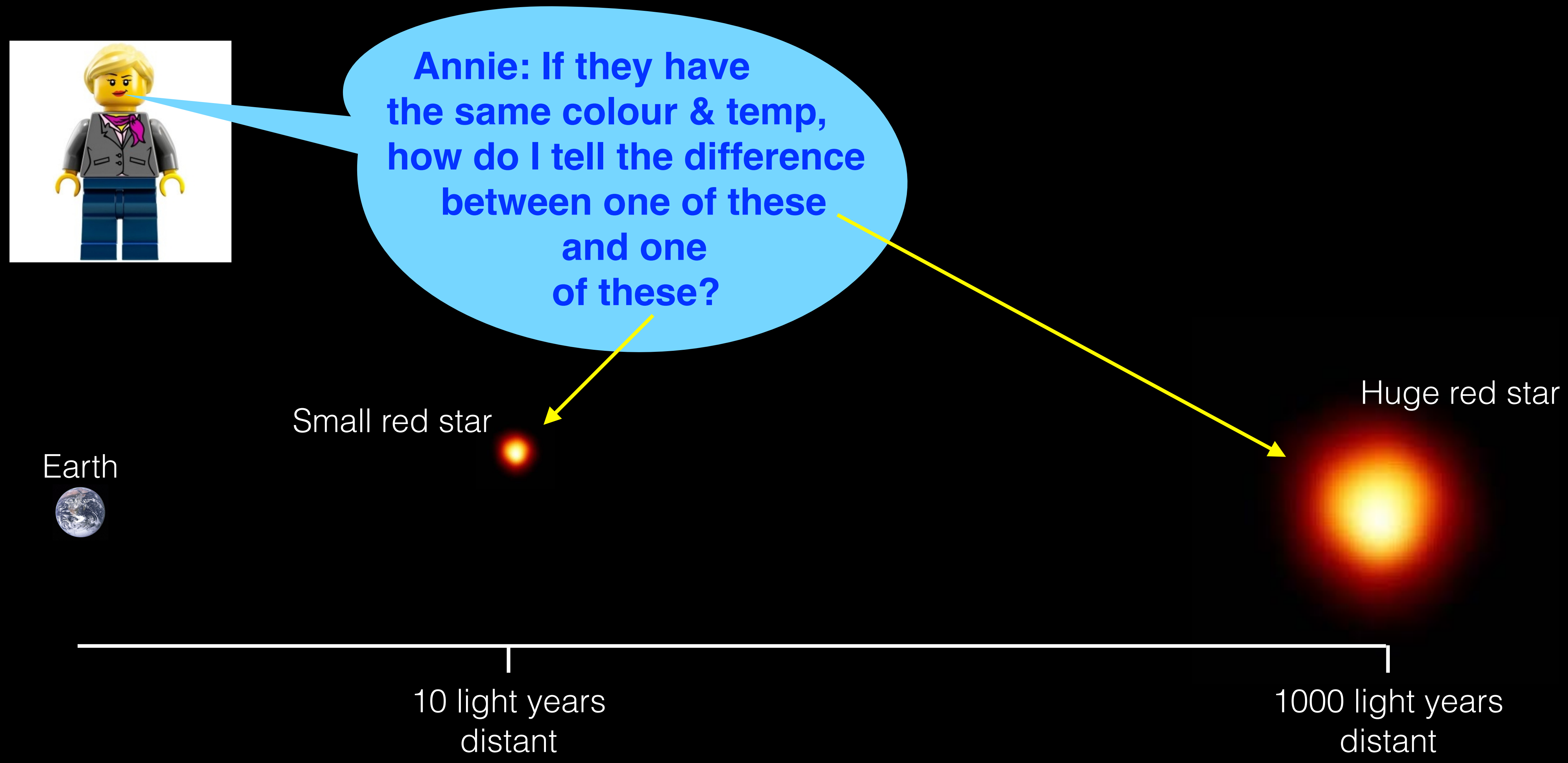
Bright lines appear when electrons drop to a lower energy level and light of a wavelength specific to the element and energy level is emitted

We can classify stars by their colour/temperature

In 1901 Annie Jump Cannon extended the original classification of Henry Draper.

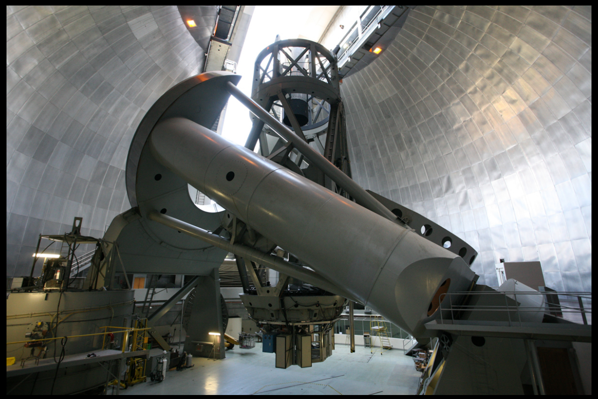
She combined earlier criteria with the surface temperature information and spectral lines and this led to the well known **O**h, **B**e **A**, **F**ine, **G**irl, **K**iss, **M**e classification.

But colour isn't the whole story

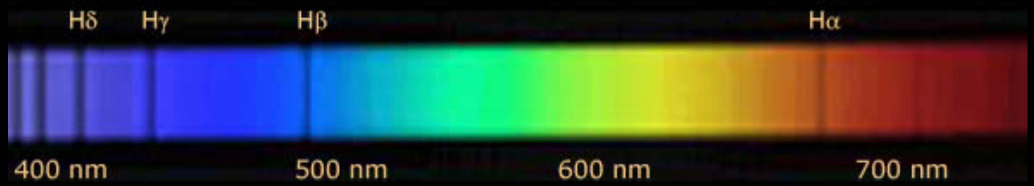


A more complete picture required more information

Improved distance info from better telescopes gives us Absolute magnitude and Luminosity allowing us to distinguish between stars with the same temperature but which have vastly different physical size.



Morgan, Keenan & Kellman also used spectroscopic techniques to define '**luminosity classes**' to distinguish Dwarf, Giant & Supergiant stars from main sequence stars of similar colour and temperature.



We can combine the temperature classification ('OBAFGKM') with these Luminosity classes to give us the classifications and the H-R diagrams we use today.

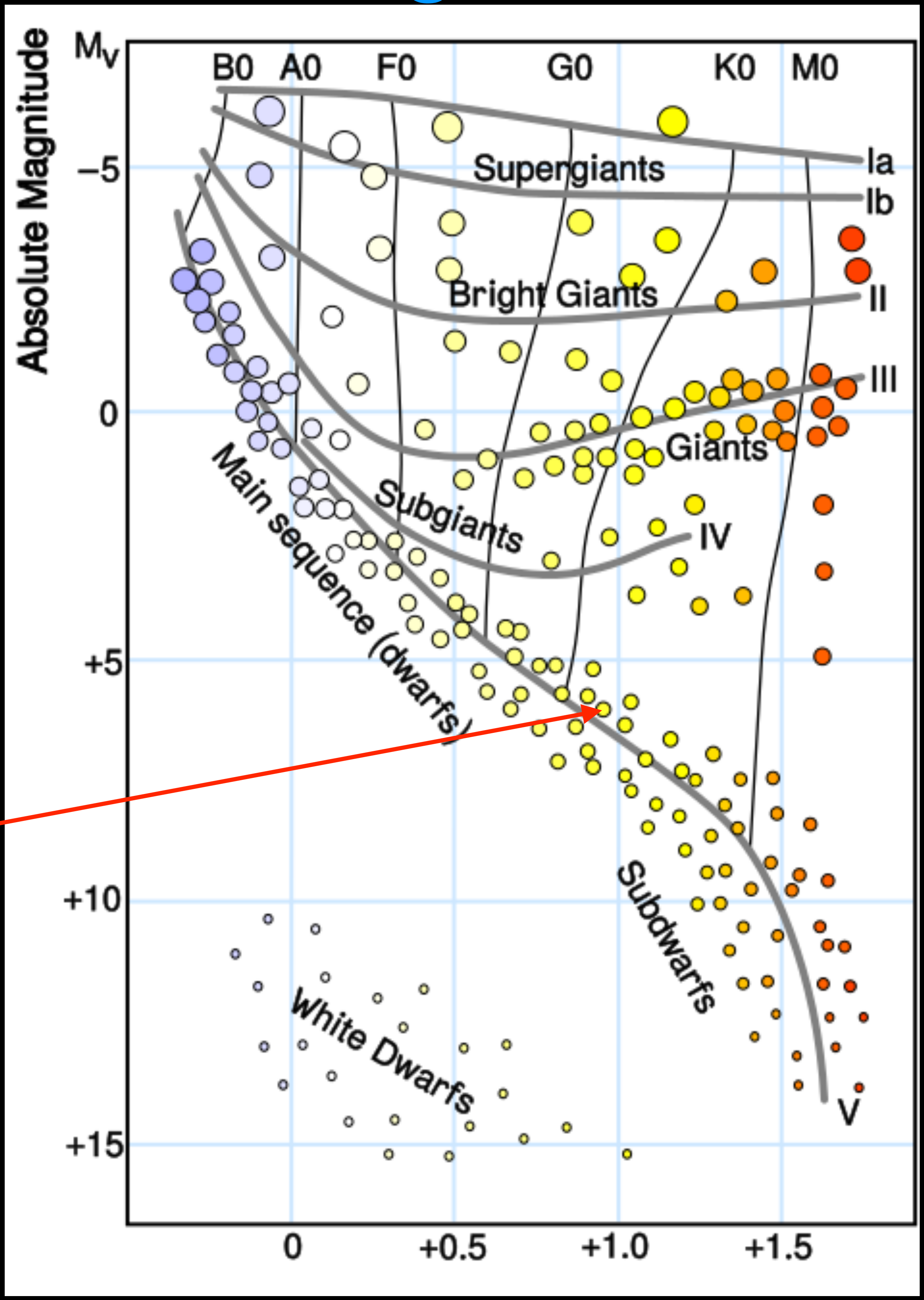
The modern classification of stars - the Hertsprung-Russel diagram

The **OBAFGKM** scale provides the temperature info (hot on left, cool on right) at all stages of their lifecycle

Absolute mag and the **luminosity classes** distinguish -
I/Ia - Supergiants
II- Bright Giants
III - Giants
IV - Sub-giants
V - Dwarfs & Sub-dwarfs (Main Sequence)

Our Sun is a G2V star.

The spectral type is probably the most important thing to know about a star



What did we conclude

Our understanding of the astrophysics of stars is, quite literally, illuminated by their light !

Spectroscopy is a cornerstone technology for understanding not just stars but the wider universe.

It lets us gauge galactic distance by measuring the red shift of stars in other galaxies - thats cosmology folks!

What next then ?

Spectroscopy isn't just a technique
for professional astronomers.

Time to unleash your inner ‘astrophysicist’ !!

What kit do we need?

Pretty well any telescope

Imaging camera - anything from cheap webcam or DSLR to high end CCD will do

Software to capture images on the camera and analyse the spectrum

How do we create the spectrum?

Most spectroscopy is done using diffraction gratings - does the same job as Newton and Herschel's prisms did!!

A diffraction grating is a piece of glass with very fine groves cut in it - 100/mm in this case.

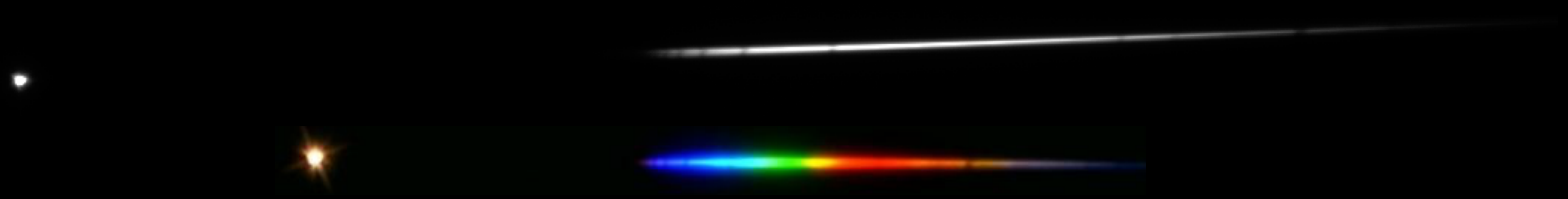
Packaged like a 1.25" filter it just needs mounting in the optical path to your imaging camera.

You can even mount it on the front of a DSLR lens

How do we do the imaging?

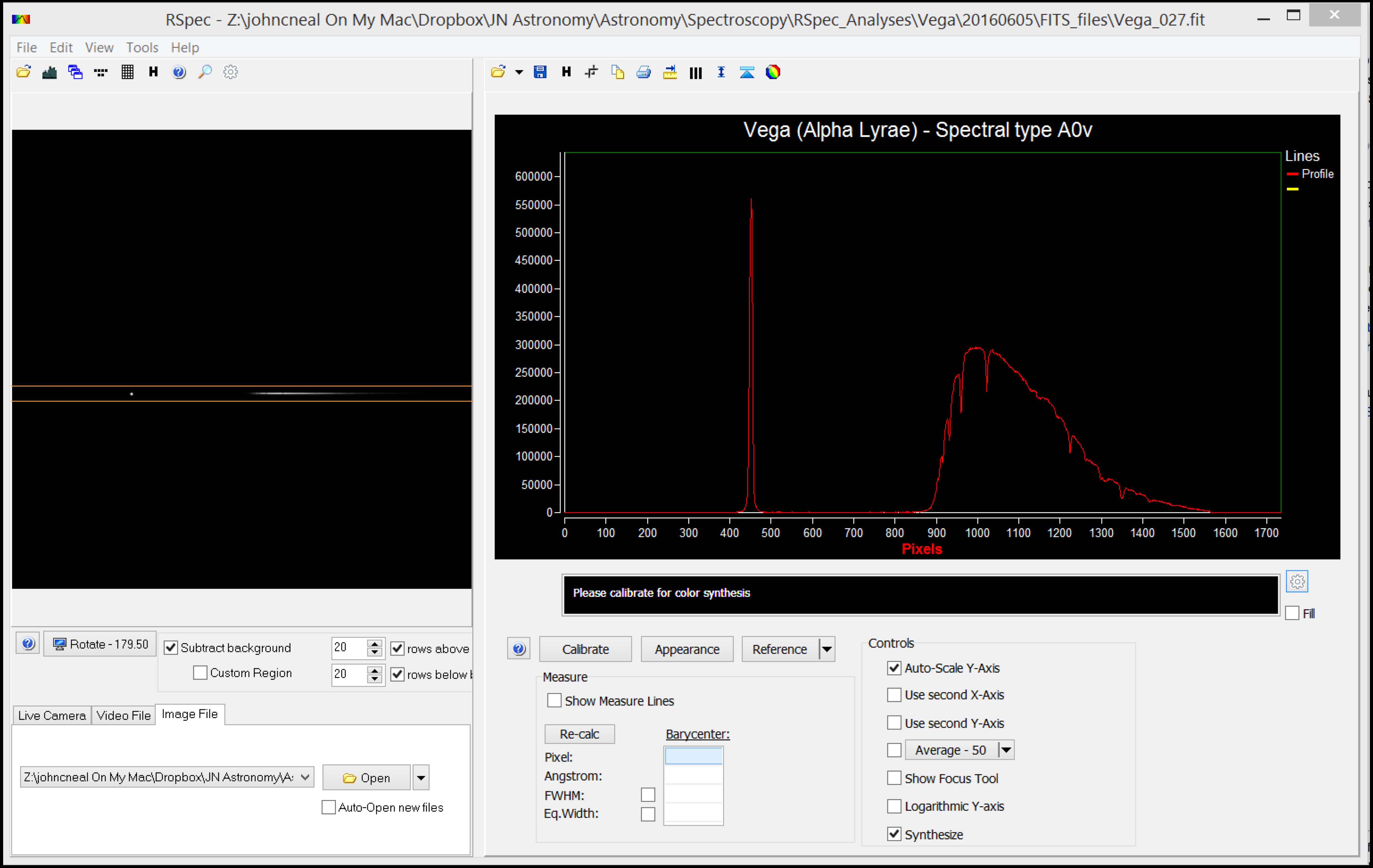
Pretty much the same as any other astro imaging.
Need to consider -

- Focus
- Exposure (you don't want the spectrum part saturated)
- Alignment - you want the spectrum horizontal
- Still or video and either colour or mono can be used

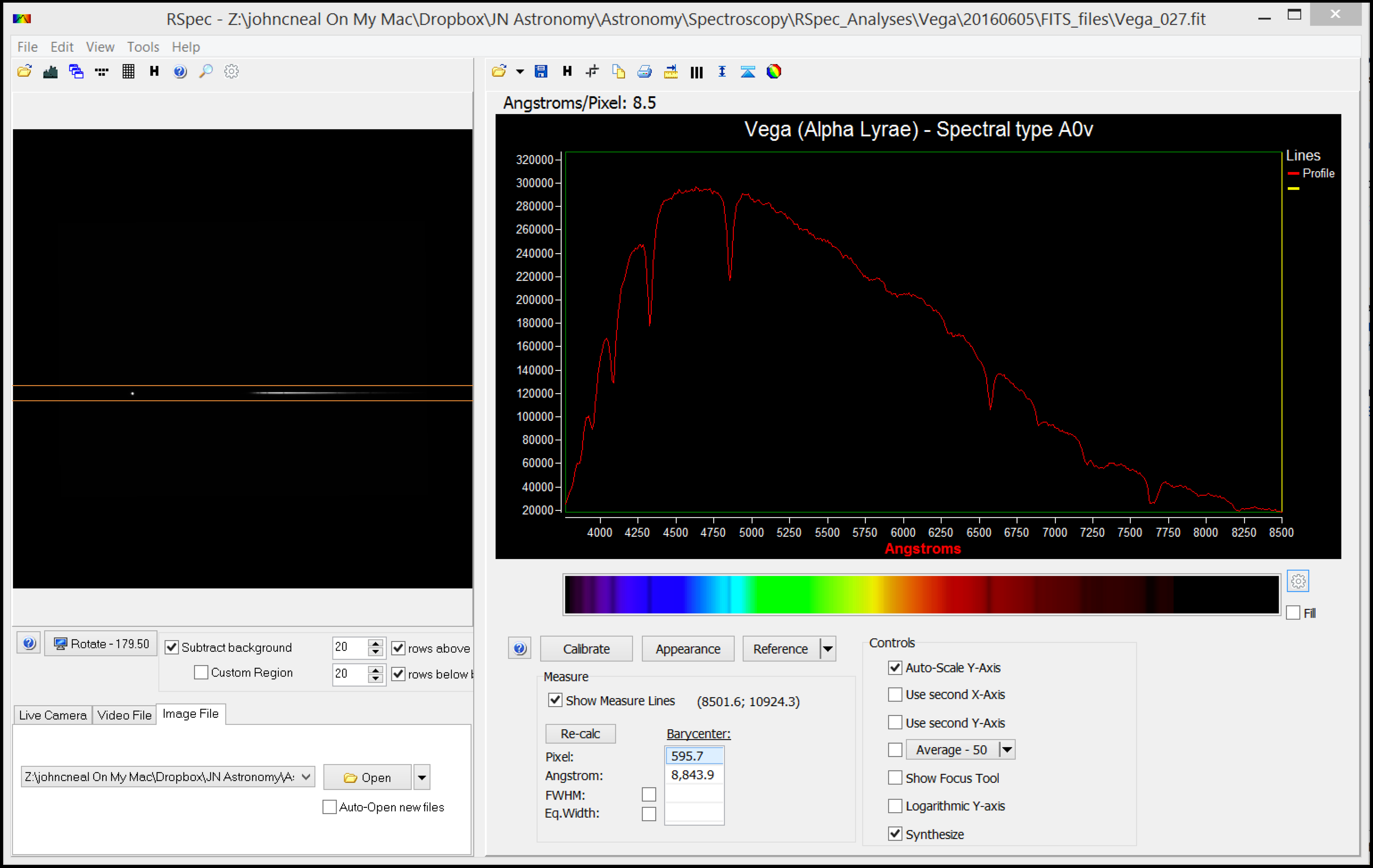


Once we have the images captured, like other astro-images - we need to process them . . .

Analysing the spectrum with RSpec

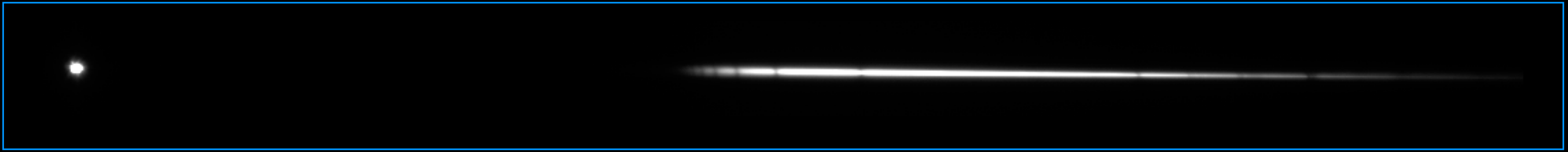


Analysing the spectrum with RSpec



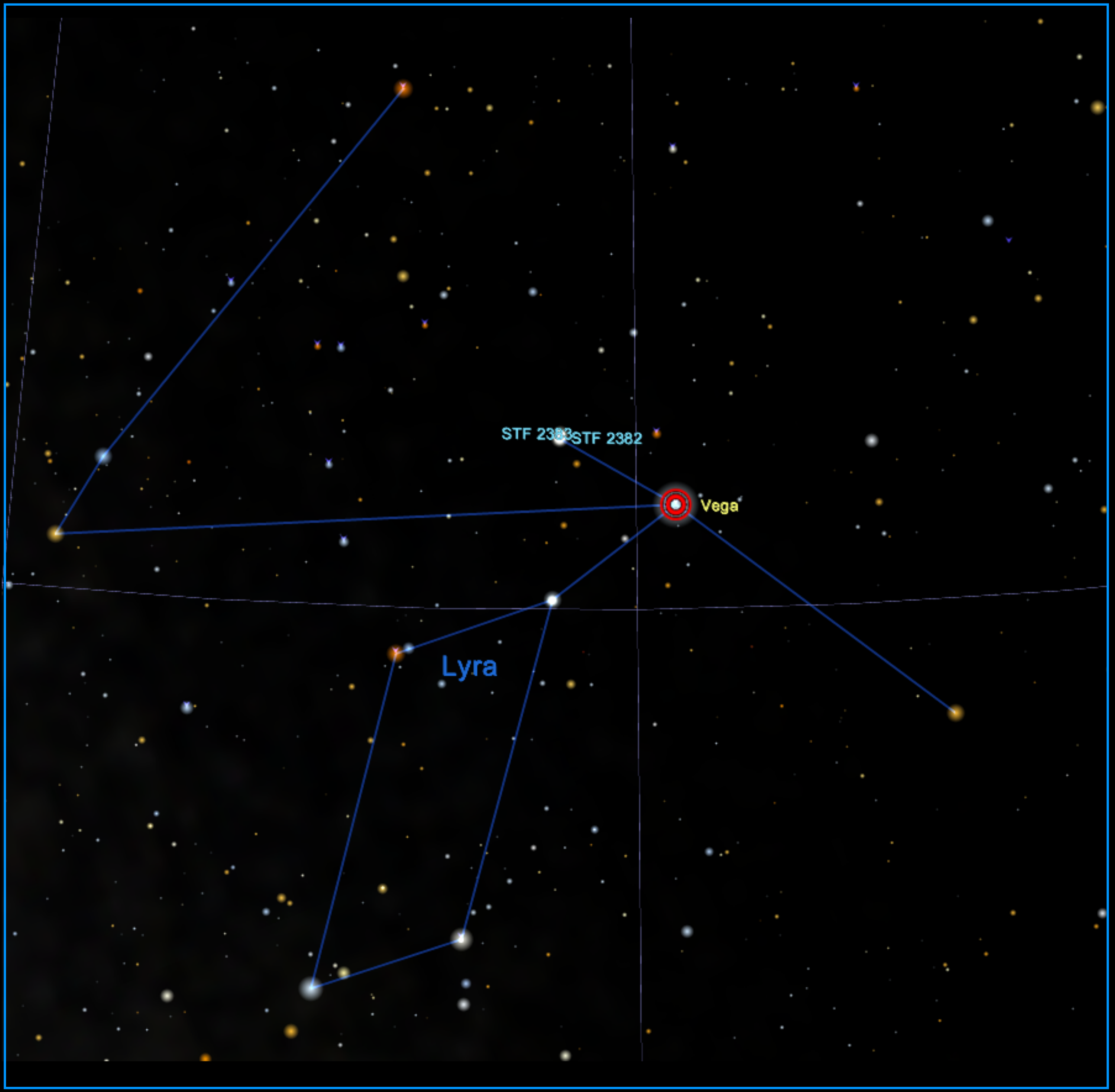
Lets see what sort of objects we
can investigate with DIY spectroscopy . . .

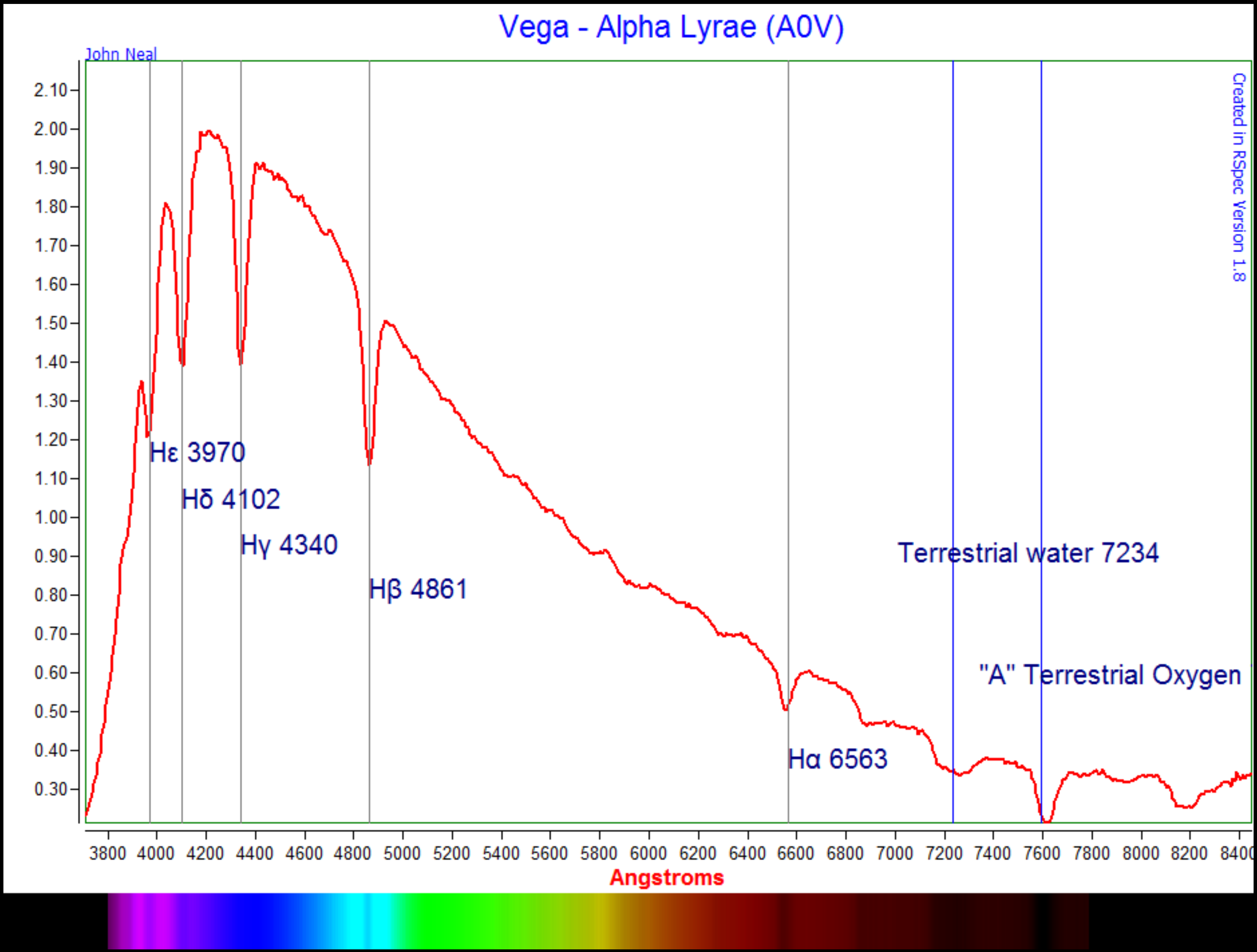
Vega - Alpha Lyrae



Vega is an excellent reference star for those new to spectroscopy.   Its an **A0V** main sequence star - so towards the hotter end of the sequence.

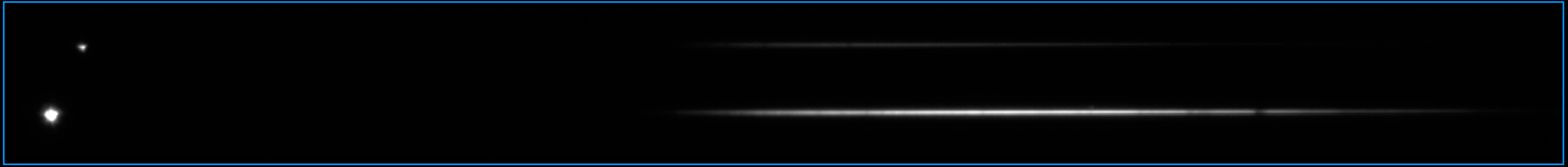
‘A’ type stars show the strongest Hydrogen Balmer absorption lines which make its spectrum easy to calibrate.

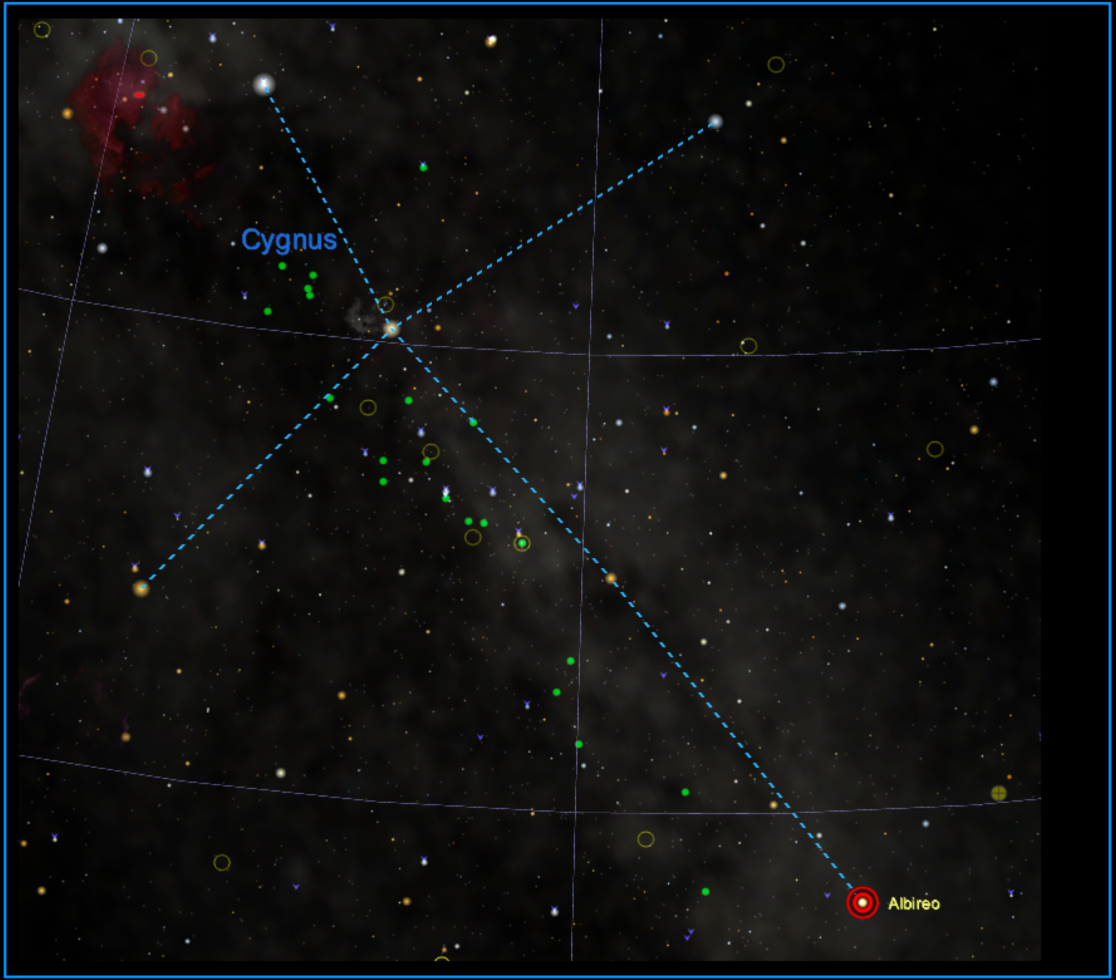




Vega - Alpha Lyrae (A0V)
John Neal
Created in RSpec Version 1.8
2.10
2.00
1.90
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
Hε 3970
Hδ 4102
Hγ 4340
Hβ 4861
Hα 6563
Terrestrial water 7234
"A" Terrestrial Oxygen
3800 4000 4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000 7200 7400 7600 7800 8000 8200 8400
Angstroms

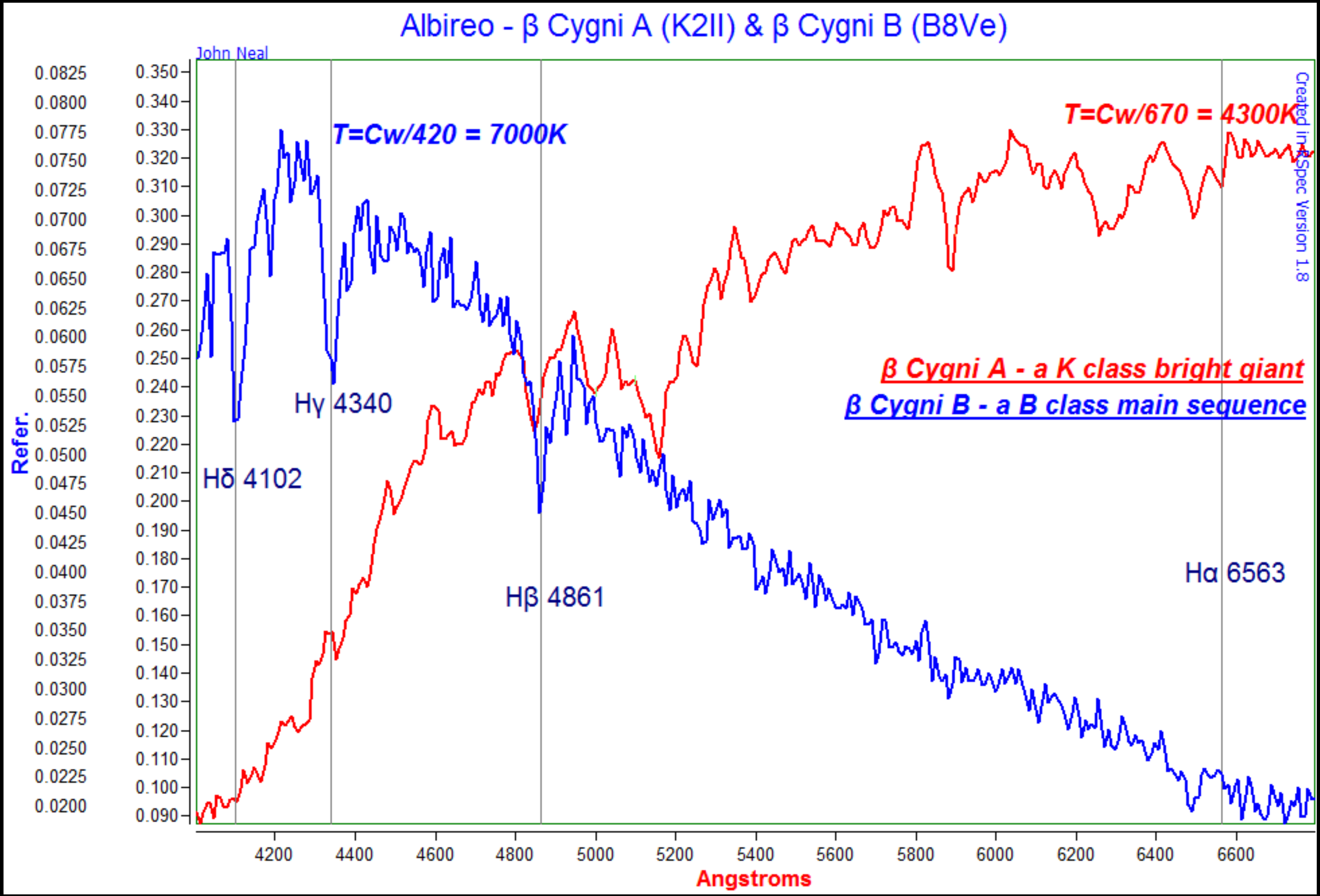
Albireo - Beta 1 Cygni





Albireo is a beautiful binary system in Cygnus resolving to reveal two components* - 'A' being a cool **K2II** (red giant) and 'B', a hot **B8V**.

*In fact 'A' is a double itself though there is ongoing debate as to whether it is a binary - if it is, then it has an orbital period of some 213 years.



Albireo - β Cygni A (K2II) & β Cygni B (B8Ve)
John Neal
T=Cw/420 = 7000K
T=Cw/670 = 4300K
Created in RSpec Version 1.8
β Cygni A - a K class bright giant
β Cygni B - a B class main sequence
Hδ 4102
Hγ 4340
Hβ 4861
Hα 6563
Refer.
Angstroms
0.0825
0.0800
0.0775
0.0750
0.0725
0.0700
0.0675
0.0650
0.0625
0.0600
0.0575
0.0550
0.0525
0.0500
0.0475
0.0450
0.0425
0.0400
0.0375
0.0350
0.0325
0.0300
0.0275
0.0250
0.0225
0.0200
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0.190
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0.170
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0.150
0.140
0.130
0.120
0.110
0.100
0.090
4200
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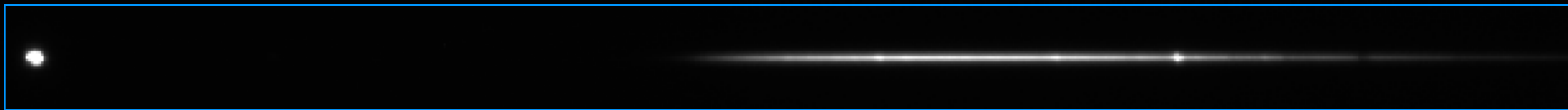
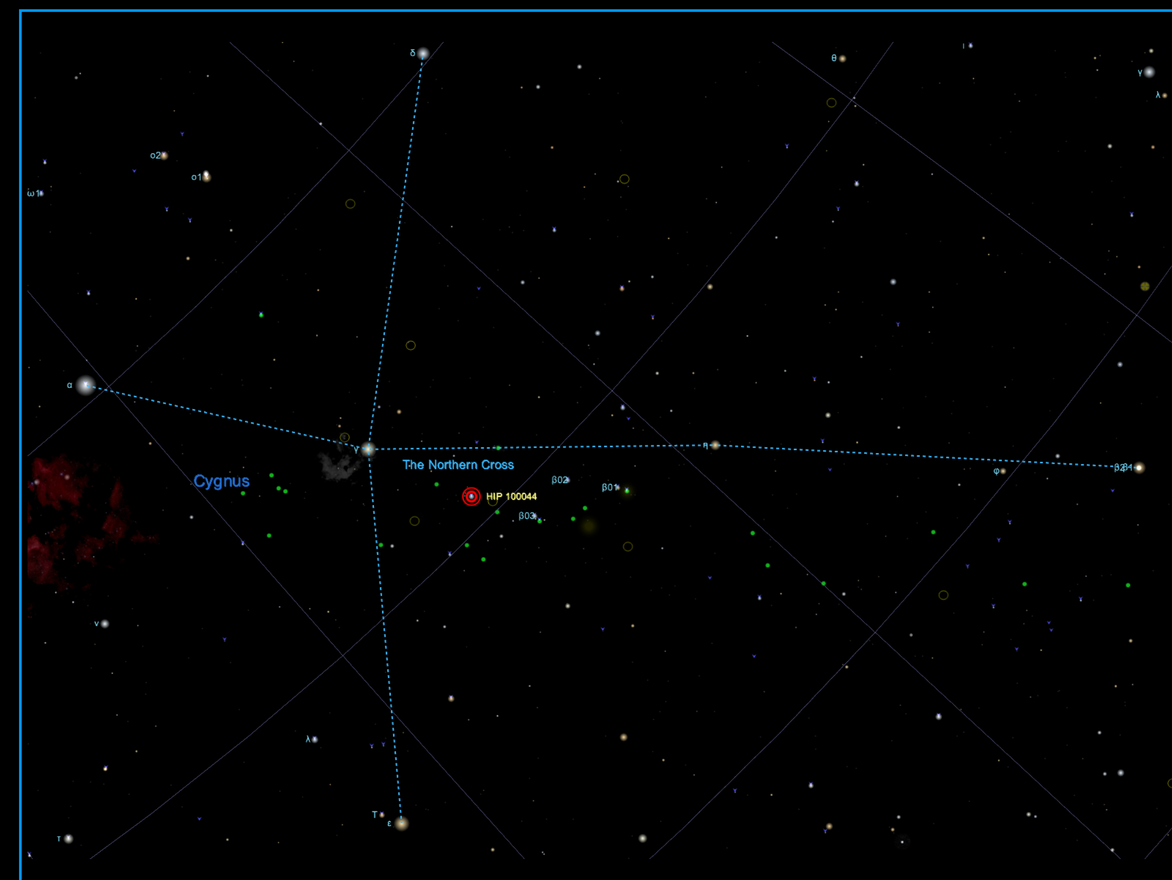
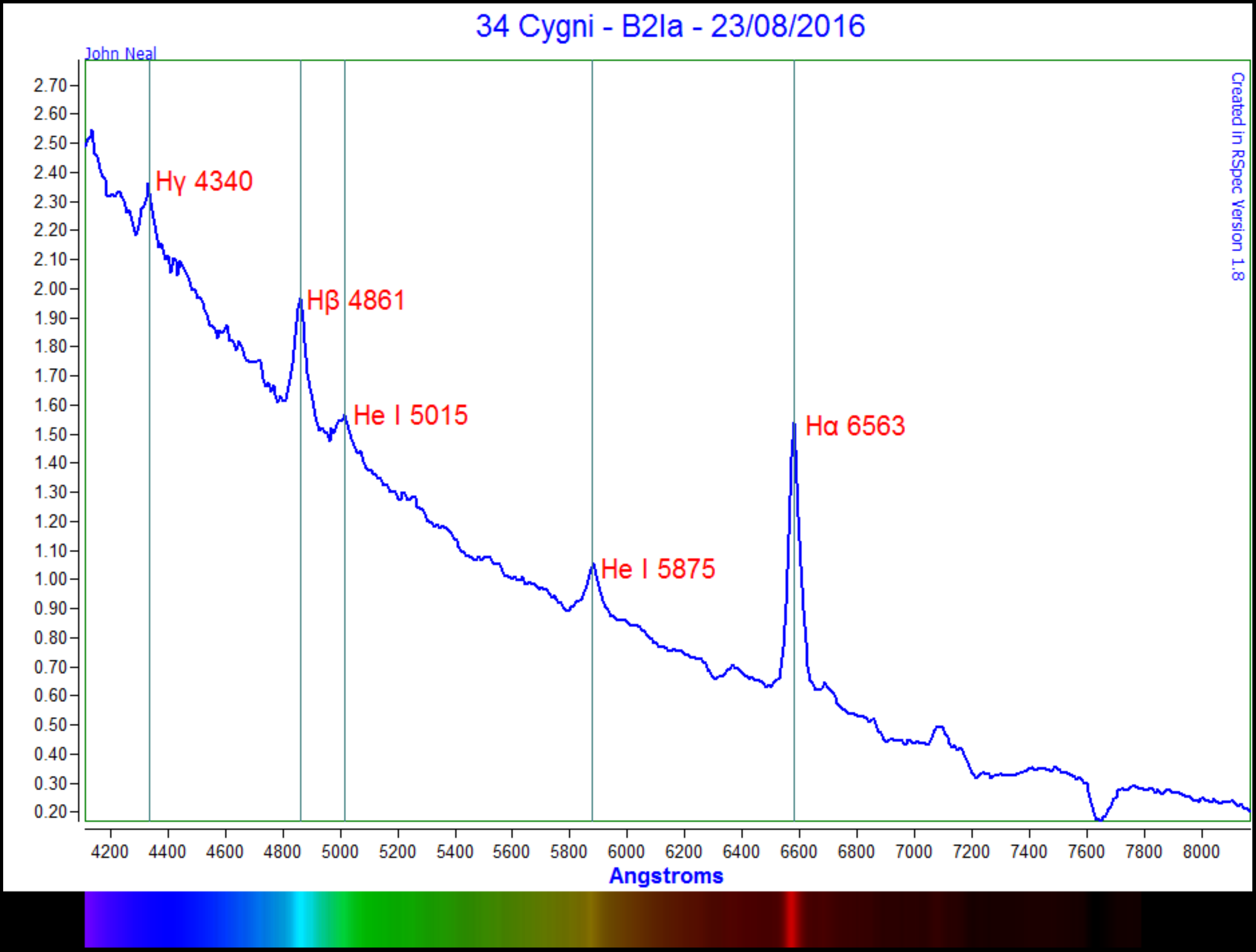
4600
4800
5000
5200
5400
5600
5800
6000
6200
6400
6600

P34 Cygni



Whats wrong with this picture ?




34 Cygni - B2Ia - 23/08/2016
John Neal
Created in RSpec Version 1.8
Hγ 4340
Hβ 4861
He I 5015
He I 5875
Hα 6563
2.70
2.60
2.50
2.40
2.30
2.20
2.10
2.00
1.90
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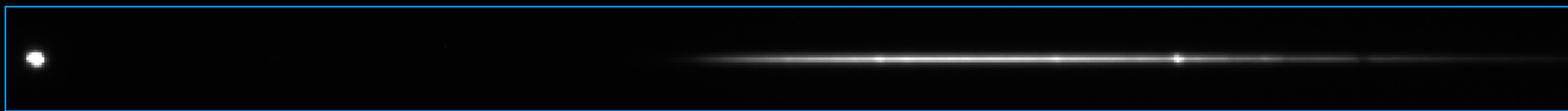
4200 4400 4600 4800 5000 5200 5400 5600 5800 6000 6200 6400 6600 6800 7000 7200 7400 7600 7800 8000
Angstroms

P34 Cygni



34 Cygni is an LBV star - a Luminous Blue Variable. Take a look at its stats and you will see its a huge star.

At magnitude 4.8, it is presently just visible to the naked eye but since its discovery in 1600 it has flared and faded unpredictably.

It is also rotating rapidly and in the process its stellar wind is shedding material in an expanding gaseous envelope around the star. This highly energetic material emits light as it loses energy.

Apparent magnitude (m_V)	4.82 (3 to 6)
Absolute magnitude (M_V)	-7.9
Spectral type	**B2Iape**
Distance	1,700 pc
Mass	**30 $M_\odot$**
Radius	**76 $R_\odot$**
Luminosity	**610,000 $L_\odot$**
Temperature	18,700 K
Rotational velocity	**35 km/s**

Questions?

The lifecycle of stars