# Spectra & Stellar Classification

STELLAR CLASSIFICATION (MAIN-SEQUENCE)

SPECTRUM


| CLASS | COLOR | TEMP. (C°) | HYDROGEN | SIZE(SOLAR R) | % OF ALL |
|---|---|---|---|---|---|
| O | | >30,000 | WEAK | >6.6 | ~0.00003% |
| B | | 9,700 - 30,000 | MEDIUM | 1.8 - 6.6 | 0.13% |
| A | | 7,200 - 9,700 | STRONG | 1.4 - 1.8 | 0.6% |
| F | | 5,700 - 7,200 | MEDIUM | 1.1 - 1.4 | 3% |
| G | | 4,900 - 5,700 | WEAK | .9 - 1.1 | 7.6% |
| K | | 3,400 - 4,900 | VERY WEAK | .7 - .9 | 12.1% |
| M | | 2,100 - 3,400 | VERY WEAK | <.7 | 76.5% |

***Above = Harvard Classification***

Stellar classification = classification stars based on their spectral characteristics. Each line indicates particular chemical element or molecule, with the line strength indicating the abundance of that element. The strengths of the different spectral lines vary mainly due to the temperature of the photosphere, although in some cases there are true abundance differences. The spectral class of a star is a short code primarily summarizing the ionization state, giving an objective measure of the photosphere's temperature.

Most stars are currently classified under the Morgan–Keenan (MK) system using the letters O, B, A, F, G, K, and M, a sequence from the hottest (O type) to the coolest (M type). Each letter class is then subdivided using a numeric digit with 0 being hottest and 9 being coolest (e.g., A8, A9, F0, and F1 form a sequence from hotter to cooler). The sequence has been expanded with three classes for other stars that do not fit in the classical system: W, S and C. Some non-stellar objects have also been assigned letters: D for white dwarfs and L, T and Y for Brown dwarfs.

In the MK system, a luminosity class is added to the spectral class using Roman numerals. This is based on the width of certain absorption lines in the star's spectrum, which vary with the density of the atmosphere and so distinguish giant stars from dwarfs. Luminosity class 0 or Ia+ is used for hypergiants, class I for supergiants, class II for bright giants, class III for regular giants, class IV for subgiants, class V for main-sequence stars, class sd (or VI) for subdwarfs, and class D (or VII) for white dwarfs. The full spectral class for the Sun is then G2V, indicating a main-sequence star with a surface temperature around 5,800 K.

### Modern classification

The modern classification system is known as the Morgan–Keenan (MK) classification. Each star is assigned a spectral class (from the older Harvard spectral classification, which did not include luminosity) and a luminosity class using Roman numerals as explained below, forming the star's spectral type.

Other modern stellar classification systems, such as the UBV system, are based on colour indices—the measured differences in three or more colour magnitudes. Those numbers are given labels such as "U−V" or "B−V", which represent the colours passed by two standard filters (e.g. Ultraviolet, Blue and Visual).

### Harvard spectral classification

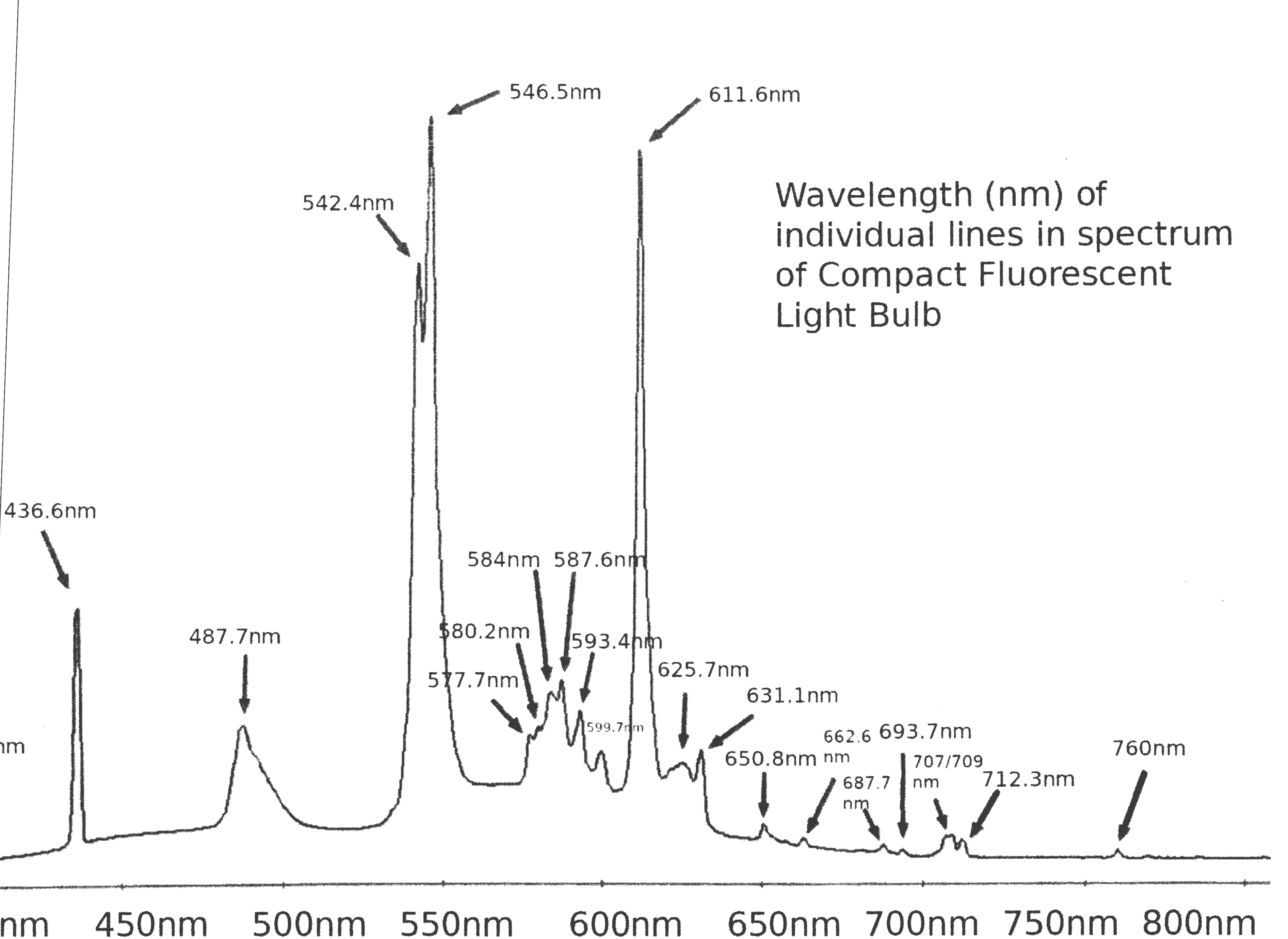
Harvard system = one-dimensional classification scheme by astronomer Annie Jump Cannon, who re-ordered and simplified the prior alphabetical system by Draper (see History). Stars are grouped according to their spectral characteristics by single letters of the alphabet, optionally with numeric subdivisions. Main-sequence stars vary in surface temperature from approximately 2,000 to 50,000 K, whereas more-evolved stars can have temperatures above 100,000 K. Physically, the classes indicate the temperature of the star's atmosphere and are normally listed from hottest to coldest.

| Class | Effective temperature[3][4] | Vega-relative chromaticity[5][6][a] | Chromaticity (D65)[7][8][5][b] | Main-sequence mass[3][9] (solar masses) | Main-sequence radius[3][9] (solar radii) | Main-sequence luminosity[3][9] (bolometric) | Hydrogen lines | Fraction of all main-sequence stars[c][10] |
|---|---|---|---|---|---|---|---|---|
| O | ≥ 33,000 K | blue | blue | ≥ 16 $M_{\odot}$ | ≥ 6.6 $R_{\odot}$ | ≥ 30,000 $L_{\odot}$ | Weak | 0.00003% |
| B | 10,000–33,000 K | bluish white | deep bluish white | 2.1–16 $M_{\odot}$ | 1.8–6.6 $R_{\odot}$ | 25–30,000 $L_{\odot}$ | Medium | 0.12% |
| A | 7,300–10,000 K | white | bluish white | 1.4–2.1 $M_{\odot}$ | 1.4–1.8 $R_{\odot}$ | 5–25 $L_{\odot}$ | Strong | 0.61% |

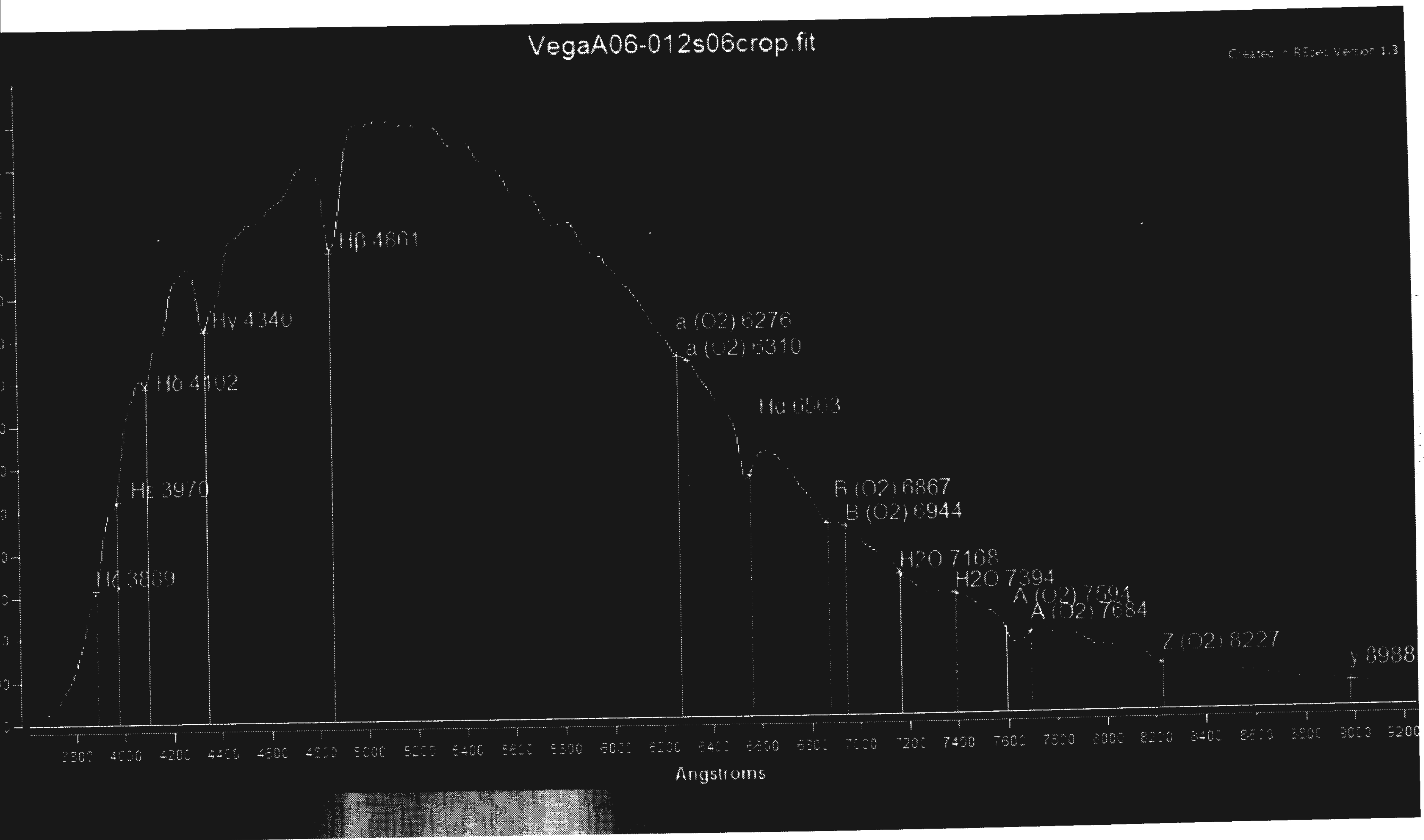
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| F | 6,000–7,300 K | yellowish white | white | 1.04–1.4 $M_\odot$ | 1.15–1.4 $R_\odot$ | 1.5–5 $L_\odot$ | Medium | 3.0% |
| G | 5,300–6,000 K | yellow | yellowish white | 0.8–1.04 $M_\odot$ | 0.96–1.15 $R_\odot$ | 0.6–1.5 $L_\odot$ | Weak | 7.6% |
| K | 3,900–5,300 K | light orange | pale yellowish orange | 0.45–0.8 $M_\odot$ | 0.7–0.96 $R_\odot$ | 0.08–0.6 $L_\odot$ | Very weak | 12% |
| M | 2,300–3,900 K | orangish red | light orangish red | 0.08–0.45 $M_\odot$ | ≤ 0.7 $R_\odot$ | ≤ 0.08 $L_\odot$ | Very weak | 76% |

A common mnemonic for remembering the order of the spectral type letters, from hottest to coolest, is "Oh, Be A Fine Guy/Girl: Kiss Me!", or another one is "Our Bright Astronomers Frequently Generate Killer Mnemonics!".

The spectral classes O through M, as well as other more specialized classes discussed later, are subdivided by Arabic numerals (0–9), where 0 denotes the hottest stars of a given class. For example, A0 denotes the hottest stars in class A and A9 denotes the coolest ones. Fractional numbers are allowed; for example, the star Mu Normae is classified as O9.7. Sun = classified as G2.



Wavelength (nm) of individual lines in spectrum of Compact Fluorescent Light Bulb
546.5nm
611.6nm
542.4nm
436.6nm
487.7nm
584nm
587.6nm
580.2nm
593.4nm
577.7nm
599.7nm
625.7nm
631.1nm
662.6 nm
693.7nm
650.8nm
707/709 nm
687.7 nm
712.3nm
760nm
nm
450nm
500nm
550nm
600nm
650nm
700nm
750nm
800nm

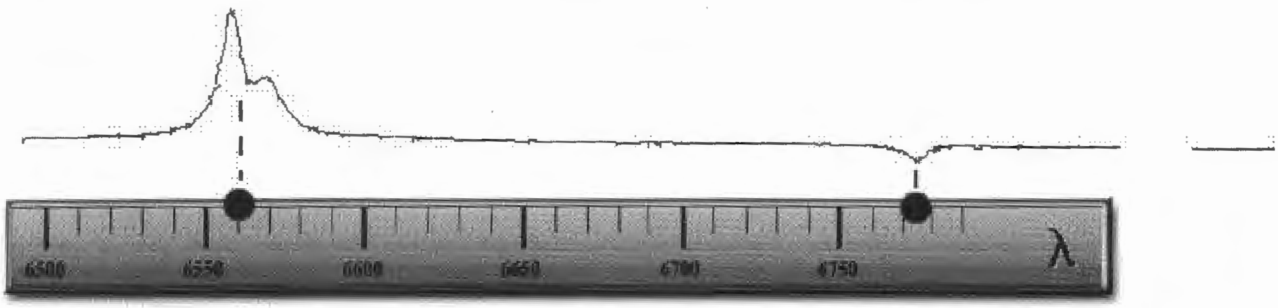

VegaA06-012s06crop.fit
Hε 3889
Hε 3970
Hδ 4102
Hγ 4340
Hβ 4861
a (O2) 6276
a (O2) 6310
Hα 6563
B (O2) 6867
B (O2) 6944
H2O 7168
H2O 7394
A (O2) 7594
A (O2) 7684
Z (O2) 8227
y 8988
Angstroms

## *From pixel to wavelength*

Once the intensity curve is obtained, through binning, the next operation consists of establishing a relationship between pixel and wavelength.

The composition of the light has been spread out by the spectroscope device according to wavelength. Depending of the mounting chosen, this relationship can be close to linear: an equal number of pixels correspond to an equal domain of wavelength.

### *Theory of operations*




An equation links the pixel number to a specific wavelenght :

```
Wavelenght = a*Pixel_number + b
```

Once this relationship is established for the optical combination of the spectroscope, this is more or less valid for all the spectra recorded with this very same combination.

The "a" coffecient is the sampling of your system. The higher it is, the highest resolution you have, this mean the more easy it will be to separate lines when they close to each other.

However, it is strongly recommended to recompute the relation for each spectrum in order to eliminate small variations like mounting/dismounting, small mechanical displacements, telescope equilibrium, atmospheric transparency.

### *How to identify which intensity correspond to which wavelenght ?*

Several options shall be considered:

- **The spectrum itself shows easely identifiable lines which allow self-calibration**
- **A spectrum of a well-known star which exhibits recognizable lines is recorded before or after the studied spectrum**
- **The spectroscope assembly includes a calibration lamp**

The usage of a calibration lamp is the most accurate way to calibrate spectra. On the opposite, using the spectrum itself does not work properly in all cases and show low precision as it cannot account for doppler measurements. But this is probably the easiest one to start with.

### **Wavelength calibration with the spectrum itself...**

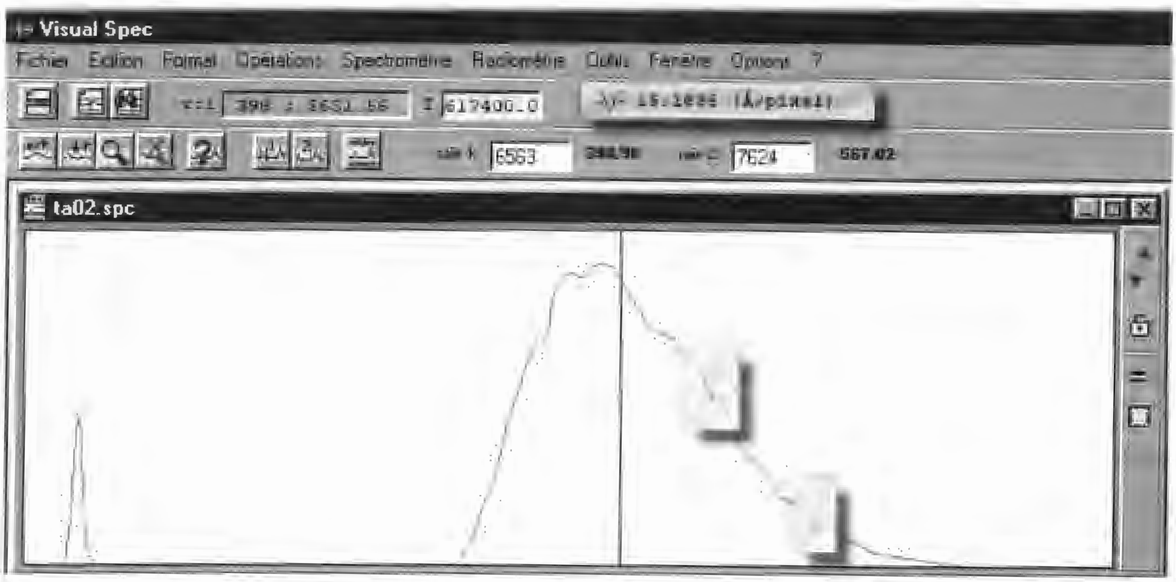
This method works properly if at least two lines are easely identifiable. To calibrate the profil, you need to assign the right wavelength to each of the two lines and Visual Spec will do the rest by computing the linear fit for each pixels. As a result, each pixel will correspond to a wavelength and by dragging the cursor over the profil you will see dispayed the corresponding wavelenght.


*As the spectrum is calibrated by respect to itself, it will not be possible to measure doppler effact as it needs to take into account wavelength shift versus the absolute value which you do not have.*

## Wavelength calibration with a reference star...

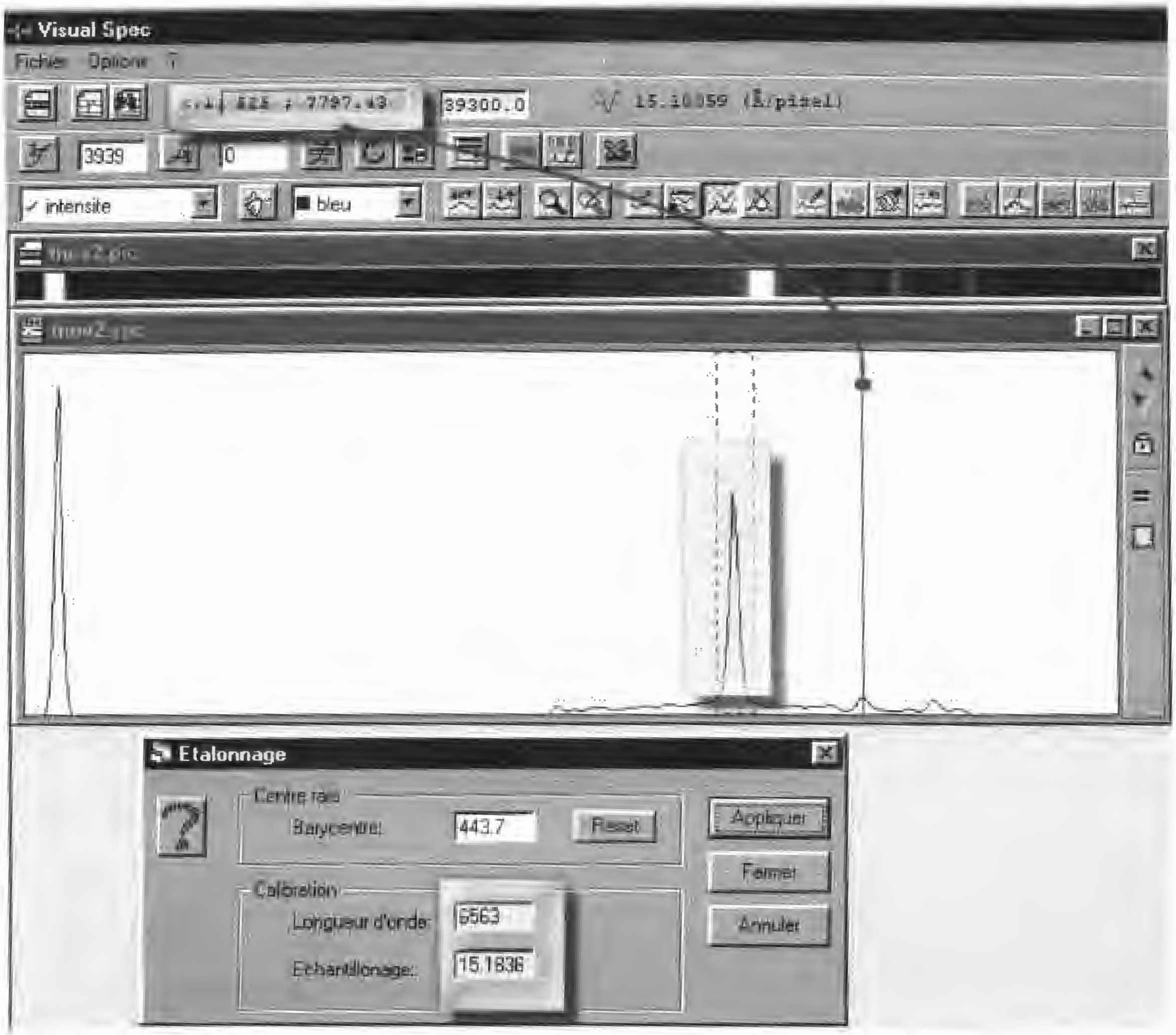
To calibrate the spectrum of the reference star, you need to identify two lines and to assign through Visual Spec their corresponding wavelength. Once this is done, you have to load the spectrum you want to calibrate. It is mandatory that this spectrum has been recorded in the very same conditions to not introduce errors. The assumption is that the sampling coefficient will be the same for both spectra.

- First step is to record the spectrum of a known star for reference, with lines easely identifiable. Then, this spectrum shall be calibrated. Once done, the sampling coefficient shall be recorded on a piece of paper.




*If the assembly does not allow to image domain beyond 6600 angstrom, it will not be possible to use atmospheric lines as they will no show up on the spectrum.*

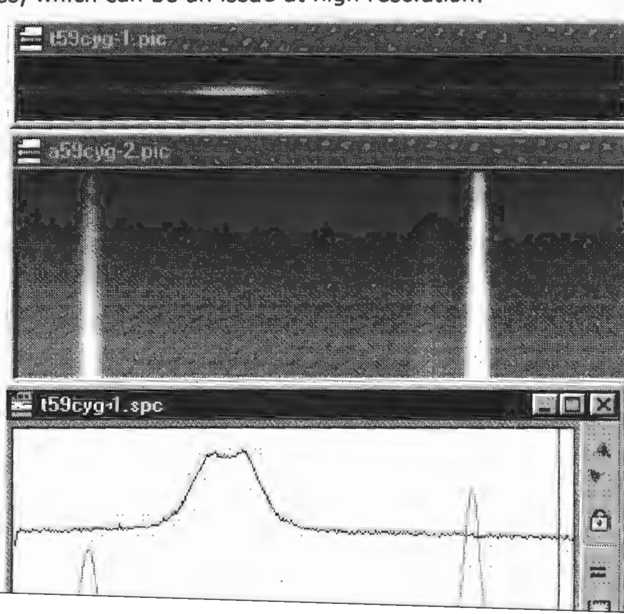
- Now,the spectrum to calibrate is loaded, and it is sufficient to identify only one line. By entering the same sampling coefficient, the new spectrum will be calibrated as well, and by dragging the cursor over the spectrum, wavelength will be displayed




## Wavelength calibration with a calibration lamp...

The method is the same as for the reference star. But instead of using a star spectrum, this method use the artificial light from a lamp which exhibits emission lines. By knowing the composition of the lamp, you can easely identify key lines and find in tables their wavelenght.
In my past experience I used Argon lamp, but Neon lamp shall work as well. You just need to take care that the type of lamp you are using exhibits lines in the wavelength domain you are observing. In Infrared, Argon lamp does not have a lot of lines, which can be an issue at high resolution.

This is the technic used by professionals. It will works for all types of spectra, in all type of optical combination.




Once the two spectra has been recorded, they shall be both reduced by binning into the same profile. As they were acquired in the same conditions, the Argon spectrum can be superimposed on the object spectrum, and Argon calibration will apply too.
It is easiest to calibrate the Argon one, as emission lines can be found in laboratory tables. In Visual Spec, a library of such lines are indudes.

In this very special case, there is few lines present. The first aproximation is done by knowing by construction which spectral domain is targeted. Usually, spectroscope indudes such control, the rotation angle of the camera versus the grating is a first indication of the spectral domain.

The second approximation is that by shooting in the H-alpha region, the strong line in emission shown on the star which is a Be star is likely to be the H-alpha line.

By looking at which lines are around 656.3 nm on the

After wavelength calibration on the Argon spectrum, one checks that star emission line is well set at 656.3nm...

**The argon spectrum as per laboratory tables**