

UNIVERSITY COLLEGE LONDON

University Of London Observatory

PHAS1510 – Certificate in Astronomy 1213.01

PHAS1510-02: Classification of Stellar Spectra

Name: _____

An experienced student should aim to spend not more than 2 sessions on this experiment.

1 Objectives

The objectives of this experiment are to gain familiarity with the appearance of the spectra of stars and to learn the basic techniques and criteria used in stellar spectral classification. You will learn the identification of some spectral features.

2 Items required

You will need:

- access to a PC running MS-Windows and the CLEA/ULO ‘Classification of Stellar Spectra’ software. (Before running the CLEA/ULO program you should ensure that the MS-Windows default printer on the desktop of the ULO computer you are using is set to the ‘ULO-NWcolourprinter’. Ask a demonstrator to make the change for you if you are unsure how to do this.)
- (optionally) a small hand spectroscope.

(This practical is also available on the Certificate’s ULO Web site.)

3 Introduction

3.1 Historical background

A spectrum of light is the array of colours or wavelengths obtained when light is dispersed by a prism or diffraction grating. There are small hand spectroscopes in the classroom that can be used to examine the spectra of artificial light sources: please ask a demonstrator to show you where they are and how to use one. The basic purpose of spectral classification is to describe the appearance of any stellar spectrum by comparison with the spectra of *standard stars*. Through the use of detailed mathematical models, astronomers are able to calibrate these ‘spectral types’ in terms of the physical properties of a stellar atmosphere; usually these are temperature (T) and pressure (P). Other variables which affect the appearance of a stellar spectrum include: (1) projected rotational velocity, which broadens all stellar lines by the Doppler effect; (2) chemical composition; (3) large-scale motions in the atmosphere.

Nearly all stars have compositions that are roughly similar to the Sun’s, and are not rotating with extreme rapidity. This means that, for most stars, the gas pressure can be expressed in terms of a parameter representing surface gravity (via the equation of hydrostatic

equilibrium). If the stellar mass can be estimated, the radius R then follows, and hence the luminosity, since

$$L = 4\pi R^2 \sigma T_{\text{eff}}^4, \quad (1)$$

(where σ is the Stefan-Boltzmann constant and T_{eff} is the ‘effective temperature’ – roughly, the surface temperature). As a rule of thumb, low pressure is associated with low gravity and high luminosity.

Astronomers have studied stellar spectra systematically for more than 140 years. The earliest extensive work was done visually with eyepiece spectroscopes, before photography could be used. In the 1860s, Father Angelo Secchi, Director of the Observatory of the Roman College of Jesuits, classified approximately 4000 stars into four different spectral groups: stars like Sirius or Vega (our A-type stars), stars like the Sun and Capella (G and K stars), stars like Antares (M stars), and a rare group of fainter stars which we now recognize as the cool carbon stars. Secchi was also aware of another group which he called “Orion” stars, similar to the Sirius type, but differing from them; today we call them O and B stars. Secchi’s system was *morphological* (based on appearance), as was a later photographic scheme introduced by Edward Pickering and Annie Cannon at Harvard. They were the originators of the now famous* spectral sequence OBAFGKML and its subdivisions (where O stars are the hottest, and L the coolest brown dwarfs). At a very early date in the development of the Harvard system, moreover, Antonia Maury had recognized subtle differences between stars of the same type, which we now know are due to *luminosity effects*. In the 1930s and ’40s, Morgan, Keenan and Kellman developed the *MK system of spectral classification*, which includes luminosity criteria, and which is still in use today with only relatively minor revisions. (Kellman produced the photographic prints used in the paper, but made little further contribution to the scheme; we therefore refer to the ‘MKK Atlas’, but the ‘MK system’.)

3.2 The MK system of spectral classification

The MK system contains two parameters (that is, it is a ‘two-dimensional’ classification scheme), associated with temperature and luminosity. The temperature sequence is:

O, B, A, F, G, K, M, L

with ‘decimal’ subdivisions – *e.g.*, ... B8, B9, A0, A1, A2... A9, F0...[†] The hottest, OB, stars are commonly referred to as ‘early-type’ objects, with the coolest stars referred to as ‘late-type’; this nomenclature does *not* imply an evolutionary sequence.

The luminosity class completes the MK classification, and is indicated by the Roman numerals I–V (with further subdivisions in some cases). Class V corresponds to ordinary main-sequence stars, like our Sun; class III to giants; and class I to supergiants.

The subdivisions of the MK system are such that a skilled classifier can consistently distinguish the difference between stars in two adjacent classes, while two independent classifiers will usually agree to within one subtype.

It is important to remember that, although physical interpretations of stellar spectra can and do change with the passage of time (due to improved model atmospheres, for example), the MK spectral classification system itself does not change in any fundamental way, because

*Well, famous among stellar astronomers...

[†]The sequence is fundamental to stellar astrophysics, and you may want to try to commit to memory; one common mnemonic is ‘Oh, Be A Fine Girl/Guy, Kiss Me, Love’.

it is strictly defined by standard stars. For example, a new determination of the luminosities and temperatures of, say, B3 V stars might be published someday, but the stars themselves are still going to be called B3 V in the MK system.

3.3 The physical background to spectral classification

In stellar atmospheres, different atoms become ionized (i.e., they lose electrons) at different temperatures. This results in differing spectral lines appearing in spectra at different temperatures. One element can produce a variety of ‘species’ at different wavelengths which lead to lines according to the number of electrons lost; *e.g.*, the He I spectrum is produced by neutral helium (no electrons removed), while the He II spectrum is produced by singly ionized helium (one electron removed; as can be seen from these examples, Roman numerals are used to denote the spectra produced by different ionization stages of a given element). For different ranges of spectral types, from the hottest (OBA) to the coolest stars (KML), there are specific lines that are particularly useful when judging the classifications.

4 Classifying the Stellar Spectra

In this experiment, you will classify at least 14 stars of ‘unknown’ spectral type, by comparing their spectra with those of standard stars. You will only determine the temperature class, for main-sequence (luminosity class V) stars. (A full classification which includes the luminosity class as a free parameter is somewhat more difficult.) You should pay particular attention to key absorption lines which, for certain spectral types, are useful diagnostics of the stellar temperature of main sequence stars. The software closely simulates the visual appearance of photographs of stellar spectra, by which stars have traditionally been classified.[‡]

4.1 Displaying the spectra

The PC should already be switched on. If the ‘Classification of Stellar Spectra’ program is not already running, find its icon and double-click the left mouse button to start the program. (In this script an unspecified ‘click’ means you should use the left mouse button; some of the features of the software require use of the right mouse button and this will always be specified.)

To begin the experiment, click on **Run**; do *not* ‘Log in’. Then click on **Classify Spectra**. When the classification window has opened, click on **Config|Display|Grayscale ‘Photo’**.[§]

Select **Load|Atlas of Standard Spectra**, click, and then click **OK** if ‘Standard Stars’ is highlighted. (If ‘Standard Stars’ is not visible, inform an instructor (Dr Furniss) who will help sort out the problem.) When all is well a small window will appear with plots of spectra. Minimize this window, as you will not be using it for this script. Two standard spectra will also appear in the main window, looking like positive photographs.

Select **Load|Unknown Spectrum|Program List**. Click **OK** for the first star: 48 Cet. (You will need to reload this way for each of the other ‘unknown’ spectra you choose to classify. This can be done by using **Load|Unknown Spectrum|Next on List**, unless you need to go back to check a previous classification.)

[‡]The last few years have, naturally, seen an increasing trend towards classification of digital data.

[§]This means click on the ‘**Config**’ menu, then select ‘**Display**’ from the options offered, followed by **Grayscale ‘Photo’** (with apologies for American spelling). In this script, instructions in **this font** always indicate options on the computer screen.

On the right side of the main classification window there are some buttons. You can scroll through the standard stars using the **Up** and **Down** buttons. You can also **Zoom In** or **Zoom Out** to get better resolution; zooming is useful if measuring wavelengths, but is not recommended when deciding the overall classification of an unknown. (When zoomed in, it is possible to pan left (\leftarrow) or right (\rightarrow) to look at all parts of a spectrum.) The **Reset** button returns the display to $1\times$.

4.2 Classification procedure

To classify a star's spectrum, you may find it helpful first of all to decide the *approximate* temperature class, by scrolling through the standard star spectra which bracket the unknown spectrum until spectra of about the right temperature class are displayed. Try to find a pair of standard spectra which give a reasonable match to the strengths of the spectral lines in the programme star. The unknown spectrum may appear to match exactly one of the standard star spectra, or the line strengths may make it appear to fall in the interval between the two.

To make a precise classification, or if there is any ambiguity, you should concentrate on the features listed in Table 1.

Table 1: Useful features for classification

Spectral Type	Species and wavelength (Å)	Temperature (K)
O	He II 4199.83, He I 4026.19, 4387.93, 4471.68 H I 3970.07, 4101.75, 4340.48	$\leq 50,000$
B	He I and H I (as above) but no He II	$\leq 25,000$
B \rightarrow A0 transition	H I, He I (weakens and vanishes) Mg II 4481.20	25,000–10,000
A	H I, metals, Ca II 3933.68	$\leq 10,000$
F, G	H I weakens, Ca II (<i>H&K</i>), metal lines (Fe I 4045.82, 4143.88, 4383.56), <i>G</i> band, 4300–4310	8,000–6,000
G, K, M	metals, Ca I 4226.74, TiO molecular bands	6,000–3,000

(H = hydrogen, He = helium, Mg = magnesium, Ca = calcium, Fe = iron, TiO = titanium oxide.)

Approximate wavelengths can be found from the display by referring to the scale at the bottom of the window. As the pointer is moved across the window with the left button held down, the wavelength, shown at the bottom of the window, is updated continuously. Clicking (or releasing the button) displays the wavelength and other information. You can add a red marker during measurement of any feature by double-clicking. To remove this red line, click once anywhere inside the spectral display area.

Lines can be identified by using the Spectral Line Identification Library, opened by using **Load|Spectral Line Table**. This opens a small window. To move up and down in the table, click once in the spectral region of the image display which you wish to examine, or use the scroll bar on the side of the table's window. A single dashed red line usually appears when you click. But if the wavelength selected is listed, it will be bracketed by two dashed red lines. Finally, the table can be used to swiftly locate spectral features. Double-clicking on a table entry (e.g., 4340.48 H I) highlights the entry and marks it with a red line (but

does not update the entry in the “measured” box). Double clicking a table entry with the right mouse button opens an information window that gives more details on the line. You may find this feature very useful.

Experiment with these controls for a few minutes before beginning. As an example, take the first programme star, 48 Ceti. The strengths of the hydrogen Balmer lines place it in temperature class A. The strengths of the calcium K (Ca II 3933Å)[¶] and ionized magnesium (Mg II 4481Å) lines further place it between A0 and A5, though it matches neither perfectly. However, the changing strength of these lines allows one to interpolate the spectral type with reasonable accuracy, say to within one or two sub-types. The overall appearance of other, weaker metal lines is a further clue.

Classify the next 14 spectra (ω^1 Sco to α Dra). The programme stars can be loaded by clicking on **Load|Unknown Spectrum|Program List** and choosing a star by clicking on it. You should spend up to a half-hour doing the first one or two, but you should get faster with practice, and the final spectra should take only a few minutes each. You should assume that each spectral class has subdivisions 0, 1, 2...9, so that, for example, B9 is immediately followed by A0. Whenever it seems necessary, you should interpolate between the standard stars to the best of your ability.

Fill in the worksheet at the end of the script with the star name, your classification, and brief notes of the particular criteria which you used to derive these classifications. If a spectrum is very similar to a standard spectrum, it is sufficient to state this as your reasoning. Note in particular any peculiarities which may have made the classification more difficult;^{||} for example, if the hydrogen lines seem to give a result inconsistent with the calcium K line.

When you have completed the exercise (see Worksheet), click on **Back** and answer yes to **Return to Main Window**. Then click **Quit** and exit the program. Additional credit will be given for any extra spectral classifications made at the end of the exercise.

5 References and Background Reading

1. Zeilik, M. & Gregory, S. *Introductory Astronomy and Astrophysics*, (4th edition). The 3rd edition, by Zeilik, Gregory & Smith, is very similar.
2. Freedman, R.A. & Kaufmann, W.J., *Universe*, 7th edition; Chapter 19, especially §19–5.
3. Abt, H.A., Meinel, A.B., Morgan, W.W. & Tapscott, J.W., *An Atlas of Low-Dispersion Grating Stellar Spectra*.

[¶]The strongest features in the solar spectrum were first systematically recorded by Fraunhofer, who labelled them $A, B...N$ (red to blue). These ‘Fraunhofer lines’ have subsequently been identified with specific atoms, ions, molecules, or blends of features. The nomenclature has, perhaps surprisingly, survived in part; thus astronomers still refer to ‘Calcium $H\&K$ ’, ‘the G -band’, and ‘the sodium D lines’.

^{||}There are some ‘peculiar’ stars with spectra that don’t fit into a single, temperature-dependent spectral sequence. This is because, in practice, there is a third parameter, in addition to temperature and luminosity, which influences the spectrum: the abundances of the elements in the stars’ atmospheres. The great majority of stars have compositions very similar to that of our Sun, but a few stars show significant deviations. You should check that different classification criteria give consistent results. [Hint: pay particular attention to BD+36 4864, should you classify that star.]

Classification of Stellar Spectra: Worksheet

No.	Star Name	Classification	Reasons for Classification
e.g.	48 Ceti	A1	Between A0 & A5; Ca <i>HK</i> slightly stronger than A0; metal lines also slightly stronger
1			
2			
3			
4			
5			
6			
7			

No.	Star Name	Classification	Reasons for Classification
8			
9			
10			
11			
12			
13			
14			

Questions

1. Refer to the displayed spectra and the line information window to answer the following:
 - (a) At what spectral type do the hydrogen Balmer lines (3970, 4101, 4340Å) reach maximum strength?
 - (b) At what spectral type do the neutral-helium lines (*e.g.*, 4026, 4388, 4471Å) reach maximum strength?
 - (c) As one proceeds from hotter to cooler stars, at what spectral type does the *G*-band (4300–4310Å, primarily due to the molecule CH) first make its appearance?
 - (d) What happens to the *G*-band as you move towards cooler temperatures?
 - (e) As one proceeds from hotter to cooler stars, at what type does the Ca II *K* line at 3933Å first appear?
 - (f) As you can see, *K* grows rapidly in strength towards cooler temperatures, and soon becomes equal in strength to the adjacent line, which is a blend of a hydrogen line and another line due to ionized calcium, the Ca *H* line. At what spectral type does the Ca *K* line become equal in strength to the Ca *H* line?
 - (g) Can you devise an alternative mnemonic for the OBAFGKML sequence? (No marks, but it might help you remember the sequence!)
2. Ceres is not a star. It is a minor planet (asteroid). It reflects sunlight rather than producing its own light. Does its spectral type agree with what we might expect?

If you have time, classify some further spectra for extra credit – but note that most marks are awarded for careful classification of the main sample.

No.	Star Name	Classification	Reasons for Classification
15			
16			
17			
18			
19			
20			
21			
22			
23			