CHAPTER 5

DISCUSSIONS

As has been explained in Chapter 2, the spectroscopy of M-type red giant stars will give out certain characteristics. In this chapter, the analyzed data will be digested and discussed in detail in order to enlighten the idea of what has been stated in previous chapters. Depending on the objectives of the study, each part will be discussed either it is appeared as expected or not and the reasons of the occurrence.

5.1 Hα profile line

From now on, Table 4.1 is referred. There are many aspects to see this line profile. The first and foremost is the measurement of full width at half maximum which determine the line strength. It is stated that the greater the full width at half maximum, the stronger the lines. Presumably that earlier parts of subclasses is having a very strong compared to the later parts just like the overall spectrum scheme which we can see the variation of hydrogen alpha. However, the results show otherwise which among the M-type stars, the variation of full width at half maximum is almost identical with 0.239 Å for their average deviation. Also, by being compared to the main sequence star, α CrB which gives FWHM = 8.472 Å, the overall equivalent width for M-type star is relatively small.

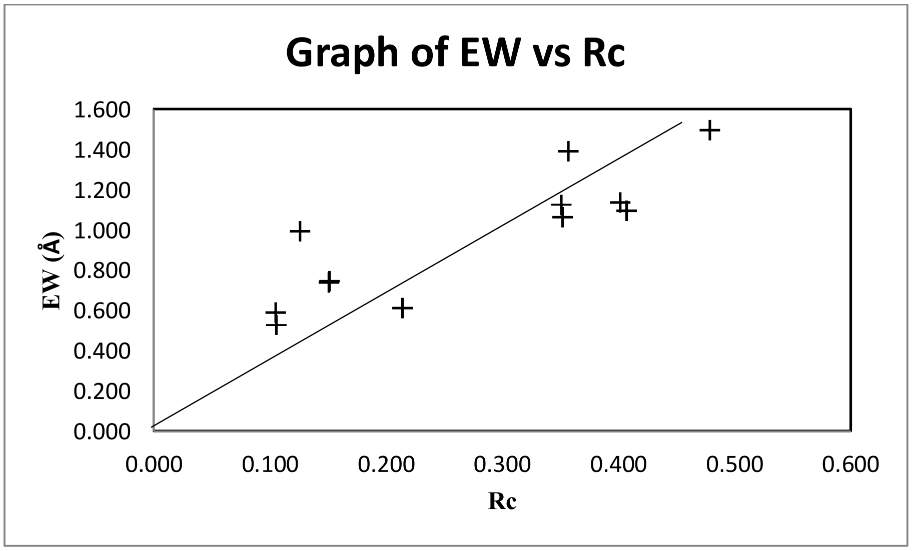
Also being noted is the equivalent width of α Lyn (M0), FWHM = 0.740 Å, which is slightly lower than 30 Her (M6), FWHM = 0.996 Å. By comparing the decimal subclasses of these two stars, they α Lyn is much hotter with 3,880 K (Massarotti et al.,

2008) than 30-Her which is just 3,000 K (Kaler, 2011) but being in the same spectral classes does not giving a very obvious pattern.

Another thing to take note is the two stars in same subclasses. Both of μ Gem and δ Vir are having FWHM = 1.139 Å and 0.591 Å respectively even though they both are in the same subclasses of M3 III. This comparison can be related perhaps due to the different temperature when μ Gem is 3,773 K (Mallik, 1999) while δ Vir is 3,999 K (Massarotti et al., 2008). Paradoxically, this comparison shows that cool star gives out high equivalent width of hydrogen alpha while hotter star gives out the lower value. One of the possible basis for this occurrence is δ Vir has small signal-to-noise ratio than μ Gem.

Equivalent width also can be used to tell what is actually happening for the same spectral type of giants. However, Table 4.1 shows that FWHM and EW do not really related to each other. Since FWHM is not the only factor contributes to the EW value, any lines with high EW value can have small FWHM and vice versa. For example is 30-Her which has EW = 0.996 Å but the value for FWHM = 8.002 Å. For all the observed M-type stars, the variation of FWHM value is about 1.371 Å.

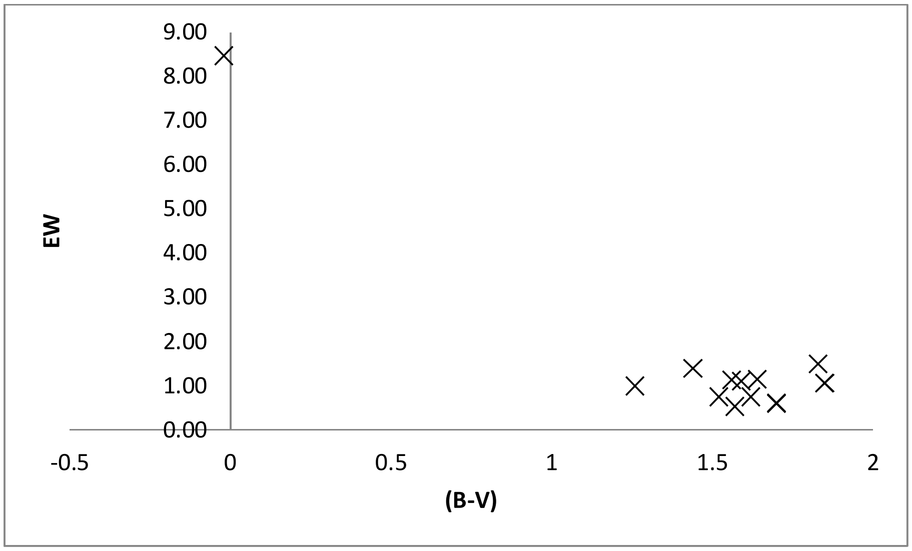
One other property that associated with the line strength is the value of R_c. Expectedly, the value of Rc is proportional with EW because both of them are showing the line strength property. The higher the value is, the stronger the line. So, graph 5.1 proves the relationship between EW and R_c values.



Graph 5.1: The proportionality of EW and R_c.

A further discussion is the relationship between these properties with colour index. Colour index is basically a numerical representation of colour for a celestial object. One colour index that is constantly being used is B-V index where B is the magnitude measure in blue star light which at a wavelength of 440 nm and V is the magnitude in greenish yellow light which is 550 nm of wavelength. The difference in magnitude gives the index which can be an indication of colour and temperature. Principally, most magnitude of stars is compared with Vega which globally taken as standard star. Hence, if the B-V index is higher than 0 which is positive value, the star is more red compared to Vega while if the B-V index is lower than 0 which is negative value, the star is more blue (Vitense, 1989).

In general, we can obviously see all M-type stars are positive value for B-V colour index with the average value of 1.61 and variation of just 0.12. Hence, it is verification that these stars are red.



Graph 5.2: The relationship of B-V colour index with EW of Hα spectral line profiles.

From graph 5.2, it is clearly shown of two distinguished region where the bottom right is packed with M-type stars while at the top left is where the α CrB is located. This pattern shows that the earlier spectral type belongs to the top left part where it more blue with strong line while later spectral type will bring together the stars at the bottom right.

Generally for Hα line profiles, on behalf of M-type red giants, they have an inhomogeneity or clear patterns among each other since they all together already in the same group with weak Hα absorption line if compared to the earlier spectral type. These characteristics also show that every star have different abundance of hydrogen even though they are in the same spectral type. This is due to the non-uniform space on where the stars were created and evolve.

This is also a possible reason to explain the case of μ Gem and δ Vir line profiles which is on the clear difference in Hα equivalent width even in the same spectral type.

5.2 Spectral broadening

Spectral broadening is one of the properties happens on spectral line. This occurrence is what makes the spectral line from photon is not exactly an extremely thin line but a wide line with a depth. This broadening effect is caused by many things. One is natural broadening. Natural broadening happens to every spectral line due to the inaccuracy of wavelength for each photon. Secondly is Doppler line broadening which happened by reason of the motion of the observed atoms in different velocities and directions. The other is pressure broadening which is due to the effects on the radiating neighbouring atom (Emerson, 1996).

5.2.1 Natural broadening

This type of broadening results from the intrinsic width of energy level due to the property of atoms. No matter how static or isolated the atom is, the lines still cannot be distinctly sharp. This is due to the Heisenberg's uncertainty principle which stated that the intrinsic uncertainty of the results decreases when the time for the measurement taken increases. An excited electron occupies its orbital only for a brief second, Δt, thus the orbital energy cannot have a precise value. Hence, the uncertainty in the energy of the orbital can be stated as:

$$\Delta E \approx \frac{h}{\Delta t} \qquad \text{-------- (5.1)}$$

This 'bleary' energy level is where the transition of electrons occurs. So, the absorption and emission of energy produce an uncertainty in wavelength. The uncertainty in energy of the photon involved is associated with the wavelength uncertainty which can be expressed as:

$$\Delta\lambda \approx \frac{\lambda^2}{2\pi c}\left(\frac{1}{\Delta t_i} + \frac{1}{\Delta t_f}\right) \qquad \text{-------- (5.2)}$$

where Δt_i= the lifetime of the electron in its initial state
Δt_f= the lifetime of the electron in its final state

5.2.2 Doppler broadening

Doppler broadening was the consequence of Doppler Effect where the line broadens due to the motion of individual radiating atom in a hot gas. In the gas, each individual atom is in random motion and very fast due to the high temperature. The frequency of a line, υ, emitted from a moving atom with velocity, v_r, in the line of sight can be changed by the Doppler Effect which is:

$$\Delta\upsilon = \upsilon - \upsilon_0 = -\left(\frac{v_r}{c}\right)\upsilon_0 \qquad \text{-------- (5.3)}$$

where υ_0= the line rest frequency
c= the speed of light

When v_r is positive, the atom is moving away from the observer and hence the $\Delta\upsilon$ is negative. Hence, the photon is not detected ate the exact wavelength predicted but the wavelength is a little bit longer (the spectrum moves towards red region which is called red shifted). This shifting is proportional to the velocity away from the observer. Likewise, if the v_r is negative which is towards the observer, the light detected is at shorter wavelength.

Atoms are in constant thermal movement in a cloud of gas which contains of atoms mowing towards and away from the observer. Some are moving transverse to observer's line of sight and unaffected by the Doppler Effect. Hence, in that space region, atoms move in every possible direction and make the atom to emit and absorb energy at somewhat different wavelength than the normal wavelength during the rest.

Atoms largely have small thermal velocities in cloud. So, only most atom have this Doppler Effect while a very little others have large shifts. Hence, the center of spectral line is much dominant rather than it side edge thus giving a bell-shaped spectral line.

The spread of Doppler motion becomes larger of the temperature of the gas increases and give affect on the width of the line.

The full width at half maximum of the line profile can be related to the Doppler width, $\Delta\lambda_D$, by this equation:

$$\mathrm{FWHM} = 2\sqrt{\ln 2}\,\Delta\lambda_D \qquad \text{-------- (5.4)}$$

Table 4.1 shows the values of Doppler width of Hα. According to the equation above, the value of FWHM is proportional to the Doppler width. Hence, the variation of Doppler width shows the same outline with FWHM.

Atom movement is not the only causing the Doppler broadening. Turbulence is the other cause. The stellar atmospheres are scorching and wavy. The most important thing is that it is not static. Hence, the motion can cause spectral line Doppler shifting as well. However, this broadening is rather similar to the thermal broadening but the mechanism is not related with temperature at all.

Doppler broadening also is caused by the rotation of the stars. Since the star is relatively tiny and we just look at the entire star instead of looking directly at the rotation pole, the spectral detected is from both approaching and recessing side. Hence, the faster the rotation, the broadening is greater.

5.2.3 Pressure broadening

This type of broadening is caused of high density of atoms which causing the energy levels in each atom to be slightly tarnished. If electrons are transferring between the orbital while the atom is colliding with another atom, the energy of the absorbed or emitted photos is a little changed. Thus, the spectral lines become blur due to this mechanism. This occurrence happens most often in dense gas.

However, for most red giant stars, these star already expanding especially the outer layer thus the radius of the stars is increasing. Thus, the density becomes less and the broadening due to pressure becomes small.

5.3 Radial velocity

By finding the difference of the observed wavelength with the rest wavelength position of Hα, the radial velocity of the star can be determined. In table 4.1, v_r shows the variation of both positive and negative values. The positive value means that the object is moving away from the observer due to the distance between those two is increasing. On the contrary, the negative value means that the star is moving towards us and the distance between the star and the observer is decreasing.

Most of the stars are having positive value. This is due to the expansion of the universe (Riess et al., 1998) which everything in the universe is actually moving away from each other on a definite accelerating rate. Hence, the stars observed are all red shifting.

However, there are two stars which are experiencing blue shift namely δ Vir and γ Eri. The blue shift phenomena can be assumed more a bit peculiar than the other observed stars which follow the nature of the expanding universe. One possible reason of this Doppler Effect is due to the existence of stellar wind on the stars. These stellar winds were ejected from the stars and are moving away from the origin stars towards the earth. Hence, the motion of the stellar winds is giving out the blue shift effect (Ryden & Peterson, 2009).

5.4 Photospheric Ca I and Fe I lines profile

From Table 4.1, the full width at half maximum values, the equivalent values and the depth line values are already tabulated in order to see the variation of these two well-known photospheric lines.

As seen in the table, α CrB does not have both spectral lines. This is because of the star is still in main sequence phase which does not have much abundance of heavier element to be detected. Though, for M-type red giants, Ca I can be detected for all of the stars in this type. On the other hand, Fe I is not detected in μ Gem and δ Vir. One of the reasons is that the spectral line is too weak to be measured. The underdeveloped of the lines shows that the Fe element is not dominant in the stars even though Ca I is already detected. Furthermore, Fe is heavier element than Ca, so, fusing or producing Ca in the star is much less complex and faster rather than Fe.

Nevertheless, the existence of these two lines is already being a proof of the existence of heavier elements which showing that these stars are already at the late stage of stellar evolution if seen from chemical aspect.

5.5 TiO molecular bands

Figure 4.15 to 4.25 shows the same frame region which is from about 6950 to 7700 Å. The pattern to recognized this band is to take a look at 7055 Å which the spectrum drops drastically and forming a wide and deep band instead of shallow and spiky absorption. This is the identification characteristic of TiO molecular band in this frame region. From the spectral variation shown in chapter 4, it is clearly noted that the TiO molecular band can be identified starting from α Sco which is M1.5 onwards. As the stars getting to the later part of the subclass, the molecular band feature becomes more dominant. This is because of the subclasses within spectral type are arranged according to their temperature. The temperature is cooler as it goes into the later subclasses. Hence, the possibility of producing titanium oxide molecule is increasing because the excessive heat that able to break the molecular bond is already reduced.

Let's take a look at figure 4.15 to 4.25 closely and since the spectrum range for these figures are about the same, the similar identity can be discussed further. Let's start at figure 4.15, spectrum of HD 139006 which is a standard star with spectral type A0 V, there are two regions with obvious bands which are telluric bands. This characteristic occur due to the existence of elements in Earth atmosphere and since telescope is capturing light that travels from the star passing through the Earth atmosphere before reaching the instruments, all these elements is also captured in the spectrum. This feature also can be seen in other spectrum.

Starting from figure 4.16 onwards, the spectrums of M-stars are arranged according to their subclasses. M0 is the earlier part; M1 is the later; and so on. The focus to study the abundance of TiO is at the range of 7000 to 7400 Å. As a rough comparison to the spectrum of HD 139000 (A0 V), spectrum of HD 80493 (M0 IIIvar) is not very much different with HD 139006. This is due to the lack of abundance for TiO molecules in M0 stars compared to the latter subclasses. However, if the spectrum pattern to be looked closely, there are a few small bands that form like a downward steps from starting from 7000 Å that can be seen at figure 4.15 onwards. This pattern has to do with the existence of TiO. As we go through star spectrums from M0 onwards, the depth of absorption band in the range of 7000 to 7400 Å is becoming obvious. At the last figure, figure 4.25, which is spectrum for star HD148783 (M6 IIIvar), TiO band can be seen to be very dominant and forming a deep-well shape instead of just few ditches.

The results from figure 4.15 to 4.25 showing that even earlier subclass can show TiO molecular band feature unlike what J. Lee et al. stated (1947). The possible reason of this is due to the usage of CCD camera instead of photographic plate which has some limitation in resolution. CCD which is a superior version of imager has more sensitivity than the photographic plate and the data captured is much more precise than previous method.

In addition to the fact above, it is also known that across the same classes, M0 is much hotter than M1 and so on. Hence, the lower temperature of the latter subclasses is the reason of the existence and also abundance of TiO. This is due to the fact that heat will break up the molecular bond between atoms. Hence, lack of heat in colder stars make possible for the molecule to form in the stars itself. So, the colder the stars, or as the stars being in the latter part of the M class, TiO abundance will increase accordingly.