



Title:

*The colours of the Universe,
the amateur astronomical
spectroscopy.*

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1. Introduction

I have been interested in spectroscopy since one year, when I had a physics lesson about emission and absorption spectrum of chemical elements in different states of aggregation. It was interesting, in that simple way that I can independently receive substance's spectrum, make analyze and explore composition of substances. I had decided to get distinctive classes of spectrum: continuous emission and lines spectra. My observations were made by a digital camera with prism spectroscope. I made Continuous emission while I was observing a traditional bulb. When I was heating up salt, sodium chloride, I got emission of line spectra. However to get absorption of line spectra in the background of continuous emission, I decided to observe the Sun. I was trying many times, when I got continuous emission spectrum with Fraunhofer's lines.

In this year, I decided to make spectrum of other stars and objects, which we can see in the sky.

I made my observation by using digital camera Pentax K5 with 50 mm lens and diffraction grating Star Analyzer 100. Before I will present the results of my observations, I want to explain what the spectroscopy is and describe the methods which can be used to get spectrum of objects in the sky. Then I am going to write about methods which I used in my work to get the final effect of my observations.



2. Spectroscopy

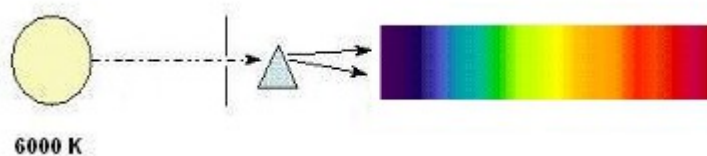
Spectroscopy is a science which deals with receiving and analysing spectrums which are made during fission of electromagnetic radiation, which is sent or absorbed by heated solid, chemical elements or compounds. Light emission is a mixture of electromagnetic waves in different wavelengths and frequencies. The range of wavelength which can be seen by the human eye is 380nm-720nm and it is received as a beam of white light.

Spectrum of the object can be received by be a refraction of light emitted by an object using prism or through decomposition using a diffraction grating. When the mixture of different wavelength passes through the prism it is refracted twice. As a results we can get a colourful rainbow or colourful lines, which we call spectrum emission of a tested object. Diffraction grating is a glass plate with scratches very close to each other. Every chemical element has characteristic lines spectrum, thereby we can clearly indentify it.

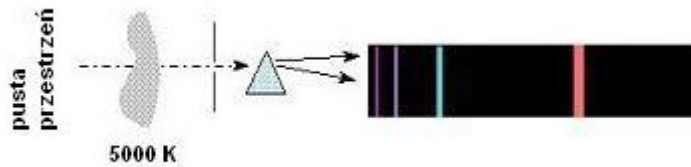
Isaac Newton in 1666 was the first who through prism diffracted sunlight and got a spectrum emission. He wrote his experience and observation in his book “Optics”, where he explains that creation of colour spectrum is related with the refractive index of glass, on this basis the prism is built.

If we get a spectrum, we can classify it according to kinds of substance emissions or absorption of analyzed light. We can distinguish two categories of spectrum: emission and absorption.

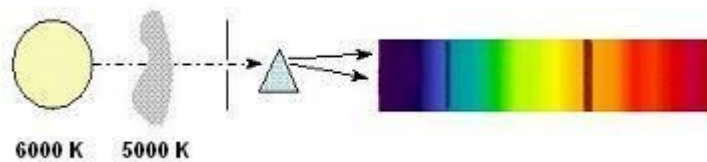
The continuous spectrum emissions is a colourful rainbow, which is received as a result of electromagnetic radiation emission of heat, liquid or solid substances. Thanks to the analyze of continuous spectrum of an object we can estimate its temperature.



The line spectrum emission is formed by the dispersion of light, which is emitted by heated chemical elements in the gaseous. The image of this spectrum is presented by simple, colourful lines. Every chemical element has a unique spectral lines and thanks to that we can clearly identify it.



Absorption spectrum is formed as a result of passing light, which is emitted by heated solid or liquid substance through colder gas. Thereby we can receive continuous spectrum emission of an object which, emits electromagnetic radiation. There are dark lines on this spectrum, which have characteristic frequencies of chemical elements located in the gas through which this light passes.



Emission lines of an analyzed object are in the same place as object's absorption lines.

We can also define stars' spectrum which is investigated by astronomical spectroscopy. By analyzing received spectrum and Fraunhofer's lines which are on it, we can define a spectral type of a star, spectral classes and chemical composition. Spectral distribution depends on the temperature and it is described as a black-body radiation. If we analyze Plank's law, we can estimate the surface temperature of a star.

A spectral type is a way of grouping stars by spectrum electromagnetic radiation which is emitted by an analyze object. The spectrum of a star depends on temperature, chemical composition and pressure of gas which are in star's atmosphere. The colour of stars depend on the star photosphere's temperature. Spectral types are named with letters: O, B, A, F, G, K and M. M stars are the coldest stars and O is the hottest stars.

A supplement of a spectral type is the spectral class. There are 8 spectral classes: 0- hipergiants, I-super giants, II- bright giants, III-normal giants, IV- sub- giants, V- main-sequence stars, VI- sub dwarfs, VII- white dwarfs.

3. Observations

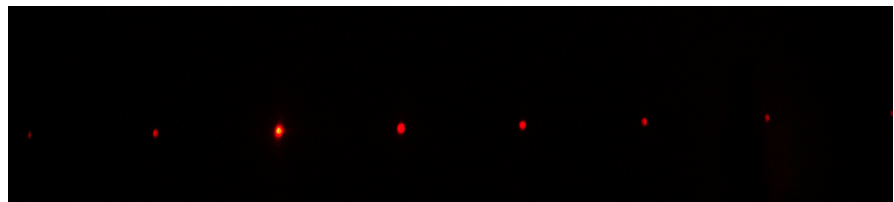
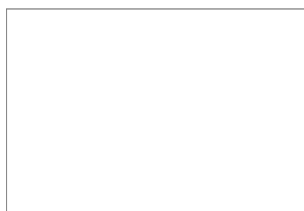
Orion Constellation – Betelgeuse – Mintaka – M42 – Comet C/2014 Q2 Lovejoy,

As the first object of my observation I have chosen Orion Constellation. After choosing appropriate setting of aperture, time exposure and ISO, I took series of photos by using my observation equipment. Then I made dark frames with the same settings. Received pictures were stacked in DeepSkyStacker. The photo on the left shows Orion Constellation, which was made by Pentax K5, while the photo on the right was made by the same camera together with diffraction grading.

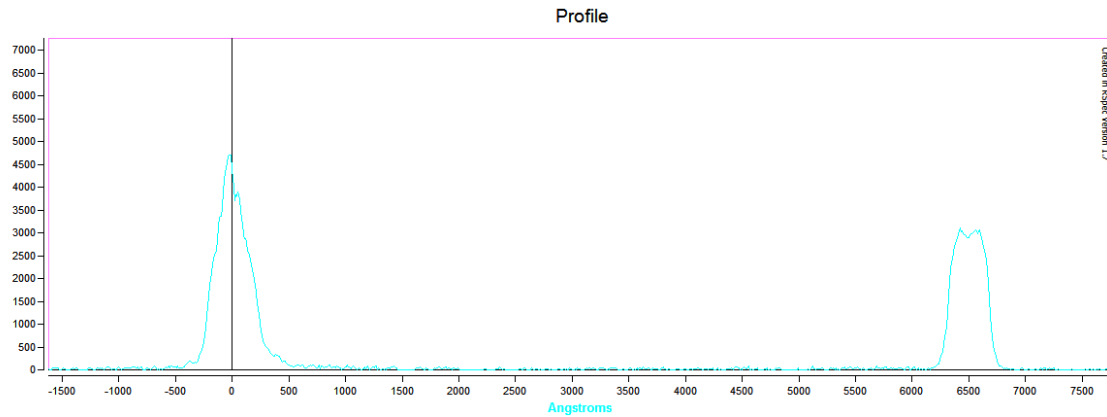


As the first star to analyze I have chosen Betelgeuse, which is the alpha star of Orion, but it isn't the brightest star of this constellation. It is Rigel, beta star of Orion. The photo, which was taken by using diffraction grading, I opened in the RSpec programme. At the beginning, after loading a picture I gained a graph which showed the dependence with the light intensity of the position of the picture (in pixels).

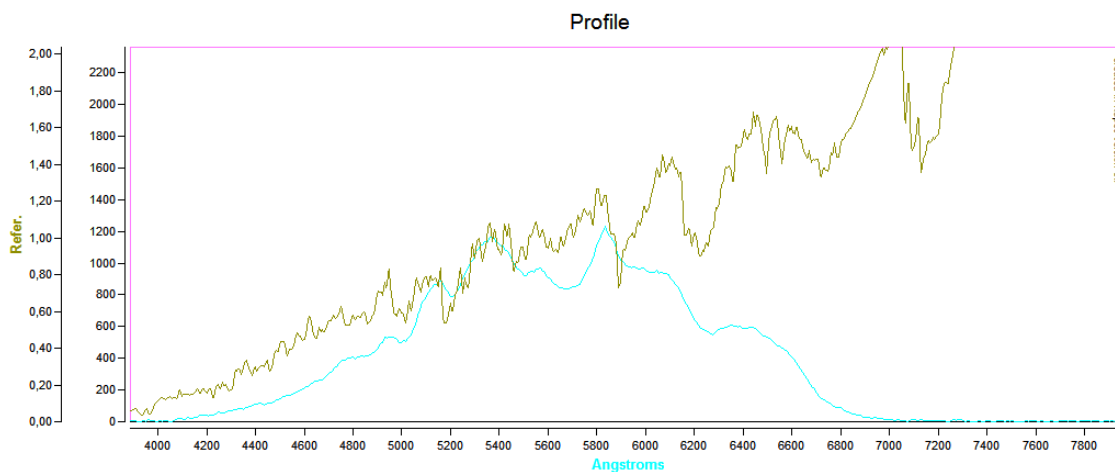
To be able to do a pre-calibration I took a picture of light emission by a red laser, which emits waves of known wavelengths 640-660 nm.



The received photo of laser's spectrum I loaded to a programme and made the calibration. I received value $9.52 \text{ \AA}/\text{Pixel}$ for my observation equipment.



The blue line is the graph, which was generated by my photo, while the brown line is the graph of spectral type of Betelgeuse – M2I, which can be found in the library of the RSpec.



The spectrum generated by my photo, values $4100\text{-}6800 \text{ \AA}$, because in a digital camera there are UV and IR filters. (Illustration 1.)

The Graph which I received is different from the graph of spectral type M2I because sensitivity of sensor CMOS isn't constant for all wavelengths. It is linked with sensitivity of individual sensor RGB at wavelengths. (Illustration 2.)

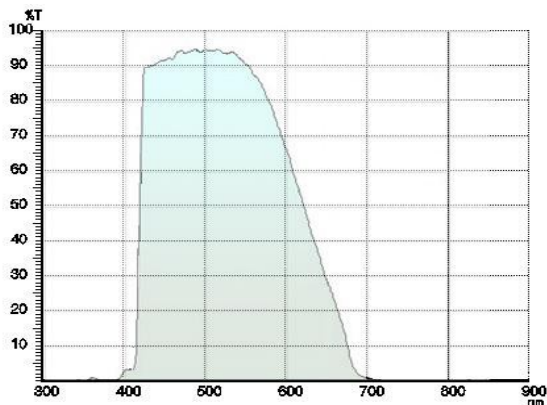


Illustration 1

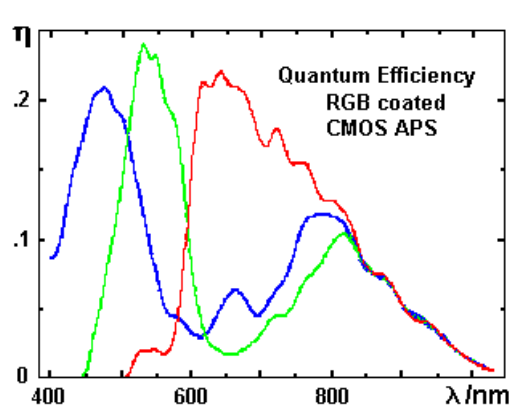
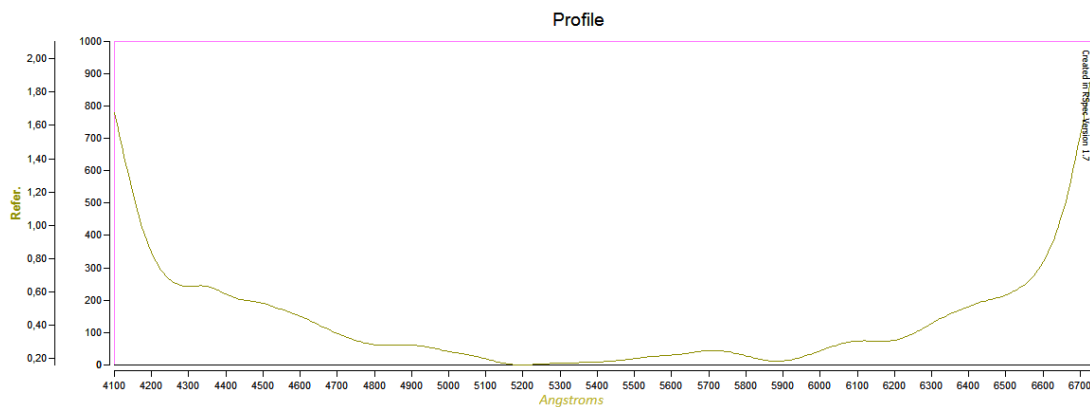


Illustration 2

To obtain a graph of sensor's sensitivity I divided graphs from Rspec's library by graph generated from my photo. The graph of sensitivity, which I received is shown below. I will use it in calibration of other spectrum objects, which I will analyze.



The final spectrum of an analyzed star I received by multiplying obtained spectrum of a star from the photo and the obtained graph of sensor sensitivity. Then I compared them with the graph of M2I. I have done it in order to check if the process of calibration was done in a correct way. The spectrum which was made is very similar to the graph from the library. It means that calibration was made correctly and I can start analyzing of the obtained spectrum.

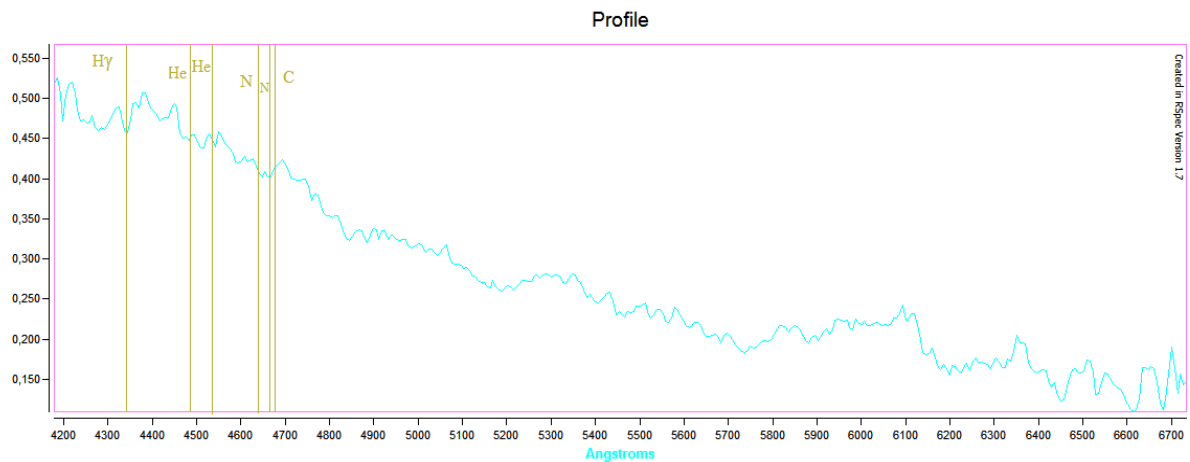


During the graph analyzing we can see, that the bigger part of the spectrum is in red, it means that it is a cold, red coloured star. Its spectral class informs us that it is a supergiant. I compared Betelgeuse graph with a Planck graph and I estimated the temperature of the star at about 3100 K.



In received spectrum of Betelgeuse, in the background of continuous spectrum, which is created in photosphere of a star, we can see more absorption lines. They are created by absorbing certain wavelengths by chemical elements and chemical compounds, which are in colder gas than photosphere, which creates chromospheres of a star. Thanks to the presence of these lines we can estimate the composition of star's atmosphere. The chemical elements or compounds belonging to it: Balmer's hydrogen spectral series, sodium, titanium oxide, vanadium oxide and silicon carbide (IV).

The next star which I have chose to observe was Mintaka, the star in Orion constellation. According to a compared spectrum which was gained and the graph in Rspec's library, I was able to identify a spectral type of the star as O9II.

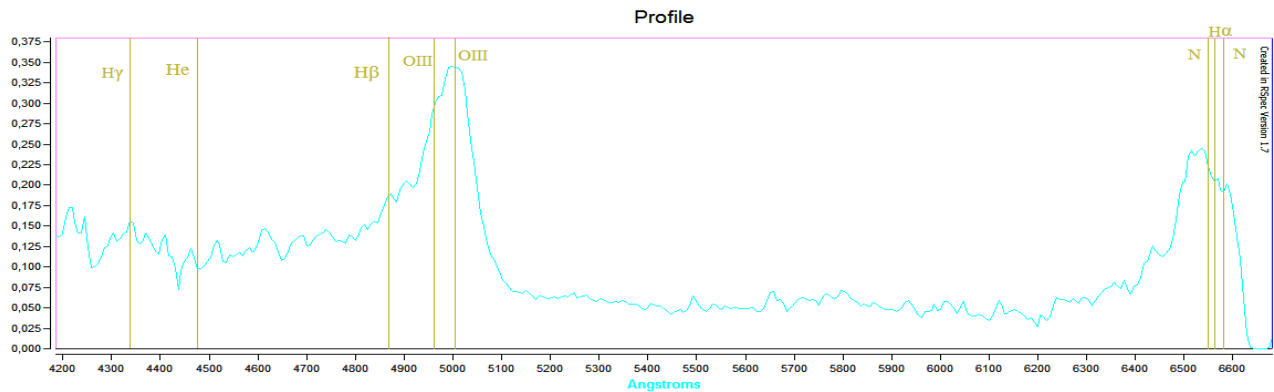


Mintaka's spectrum is located mainly in the ultraviolet. It is a hot star, according to Planck's law we can estimate its temperature at about 25 000 K. Its lightness class is II, white coloured, bright giants. On the graph of this there star are presented some absorption lines of chemical elements such as: Balmer's hydrogen spectral series, helium, nitrogen and carbon, which prove their presence in the Mintaka's chromospheres. In the stars of high temperature, spectral type O, there are ionized atoms, because at such a high temperature bonds between the atomic nucleus and the electrons are destroyed. The characteristic chemical elements of this spectral type is helium, because it has the strongest atomic bonds.

In the Orion constellation I investigated the spectral analysis of Great Nebula in Orion. It is a nebula diffuse, it means that the light emission is created by stimulating gas which forms nebula glow by the star which is nearby.

The following graph presents clear emission lines of hydrogen - Balmer's hydrogen spectral series, OIII lines – double ionized oxygen, nitrogen and helium. The above mentioned chemical elements are present in the gas of the nebula. Due to the presence of helium in Orion Nebula we can observe its pink colour.

OIII emission lines are called as forbidden emission lines in a visible spectrum because we can't get them, even in a laboratory. If we want to gain them, we need extreme physics conditions e.g. low density.

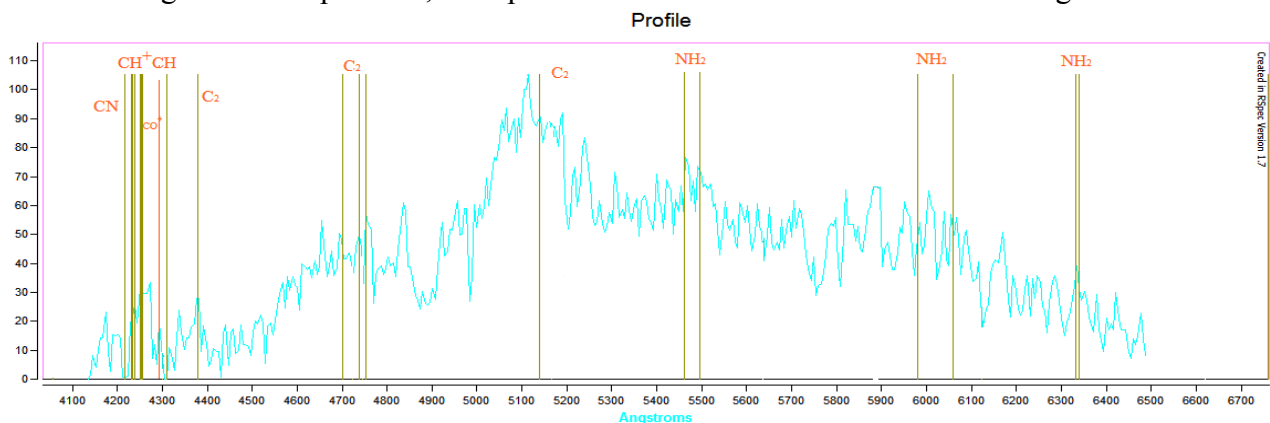


Examining different objects I couldn't resist to take a spectrum of the object which was currently hosted on our night sky – comet C/2014 Q2 Lovejoy. It is a long-period comet, discovered in the second half of August 2014 by Terry Lovejoy. It is brightened to roughly magnitude 3.9 and is visible by an eye. Through a telescope or binoculars you could see that it is green.

The spectrum of a comet is a continuous spectrum, which is created by reflected sunshine. This light is emission lines of chemical elements and chemical compounds which it coma is built, caused by the phenomenon of fluorescence. The comet's nucleus consists of a mixture of dust and small shards of rock and ice which are built of water ice, solid carbon dioxide, carbon and ammonia.



After I gained a photo of comet's spectrum, I applied characteristic spectral lines for comets from Rspec's library at the graph which was generated in RSpec program. The main emission lines in my comet's C/2014 Q2 Lovejoy spectrum are spectral lines C₂, CN, NH₂, CH⁺, CH, CO⁺. Clearly visible are molecular carbon lines C₂ and cyanide CN, which are located near 4700 i 5100 Å, which are responsible for the green colour comet. The presence ions carbon monoxide (II) CO⁺, in the blue region of the spectrum, is responsible for the blue colour of the comet's gas tail .



4. Summary

In that lecture I have presented the results of my observation of spectrum of different objects, which we can observe in the sky: Betelgeuse, Mintaka, Great Nebula in Orion and Comet C/2014 Q2 Lovejoy.

To obtain spectrums to analyze, I had to learn how to make calibration for my observation equipment. Initially I tried to make it by comparing the received spectrum with the graph from Rspec's library, however, the minimums weren't explicit. It turned out that a red laser was much easier to use.

After calibration the received graphs were still significantly different from those of library program, books or Internet. While I was looking for information, I found out that sensitivity of the CMOS sensor, which is presented in a digital camera, is different for the following wavelengths sensitivity. In addition, the filter UV and IR which are present in digital cameras affect the range of the resulting spectra.

While analyzing Betelgeuse and Mintaka's spectrum I discovered them anew. I have learned that the stars owe their colour to temperature: red coloured are cold stars, blue coloured are warm stars. The ionized gas atoms dominate in warm stars, while in cold stars atoms of chemical elements dominate, even molecule might be present.

When I was observing the Great Orion Nebula, I saw that it owes its beautiful pink colour the presence of hydrogen in the nebula's gas. Due to the presence of spectrum emissions lines, OIII, double ionized oxygen, I have learned about the exceptional conditions existing in the nebula.

On the graph of C/2014 Q2 Lovejoy comet's spectrum I have noticed clear emission lines of molecular carbon C_2 and cyanide CN, which are located near 4700 i 5100 Å, and which are responsible for the green colour of a comet, while ionized carbon monoxide (II) CO^+ , in the blue region of the spectrum, is responsible for the blue colour comet's gas tail.

In the nearest future I am going to improve my observation methods, so as to increase the resolution and continue to explore the colours of the Universe.

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