1 Introduction	1.Giới thiệu
Technological advances like CCD cameras, but also affordable spectrographs on the market, actually cause a significant upturn of spectroscopy within the community of amateur astronomers. Further freeware programs and detailed instructions are available to enable the processing, calibrating and normalising of the spectra. Several publications explain the function and even the self-construction	Những bước tiến trong công nghệ CCD camera, cùng với những loại máy quang phổ vừa túi tiền hiện có trên thị trường đã góp phần nâng cao kiến thức quang phổ học trong cộng đồng các nhà thiên văn học nghiệp dư. Ngoài ra còn có những chương trình phần mềm miễn phí và các hướng dẫn chi tiết giúp người dùng xử lý, đo đạc và chuẩn hóa phổ. Một số công trình đã giải thích chức năng và thậm chí

of spectrographs and further many papers can be found on specific monitoring projects. The numerous possibilities however for analysis and interpretation of the spectral profiles, still suffer from a considerable deficit of suitable lit-erature.	cánh tự chế tạo các máy quang phổ và có nhiều công trình đề cập đến các hoạt động quan sát thiên văn cụ thể. Tuy nhiên vẫn chưa có nhiều tài liệu đề cập đến vấn đề phân tích và giải thích các loại phổ.
This publication is intended as an introduction to practical applications and the appropriate astrophysical backgrounds. Further the Spectroscopic Atlas for Amateur Astronomers [33] is available, which covers all relevant spectral classes by commenting most of the lines, visible in medium resolved spectral profiles. It is primarily intended to be used as a tool for the line identification. Each spectral class, relevant for amateurs, is presented with their main characteristics and typical features.	Tài liệu này nhằm giới thiệu các ứng dụng thực tiễn và các kiến thức thiên văn học hữu ích. Hơn nữa, hiện nay đã có Atlas quang phổ cho các nhà thiên văn học nghiệp dư [33], trong đó đã đề cập đến tất cả các loại phổ có liên quan bằng cách bình luận gần như toàn bộ các vạch phổ, có thể nhìn thấy được trong các biên dạng phổ có độ phân giải trung bình. Những tài liệu này chủ yếu được dùng làm công cụ xác định phổ. Mỗi lớp phổ, thích hợp cho những người không chuyên nghiệp được trình bày cùng với các đặc điểm chính và tính năng điển hình.
Further, Practical Aspects of Astro-Spectroscopy — Instructions and Information for Amateur Astronomers [30], is downloadable. It provides detailed instructions for operational aspects and data reduction of spectral profiles with the Vspec and IRIS software.	Hơn nữa, những khía cạnh thực tế về quang phổ học thiên văn, các hướng dẫn và thông tin dành cho các nhà thiên văn nghiệp dư [30] có thể tải về được. Nó đưa ra các hướng dẫn chi tiết về nguyên tắc hoạt động và cách rút ra dữ liệu từ các biên dạng phổ thông qua phần mềm Vspec và IRIS.
Spectroscopy is the real key to astrophysics. Without them, our current picture of the universe would be unthinkable. The photons, which have been several million years "on the road" to our CCD cameras, provide an amazing wealth of information about the origin object. This may be fascinating, even without the ambition to strive for academic laurels. Further there is no need for a degree in physics with, specialisation in mathematics, for a rewarding deal with this matter. Required is some basic knowledge in physics, the ability to calculate simple formulas with given numbers on a technical calculator and	Quang phổ học là nhân tố quan trọng giúp chúng ta tiếp cận được với vật lý thiên văn. Nếu không có chúng, chúng ta không thể hình dung được vũ trụ. Các photon đã tồn tại trong vài tỷ năm trước khi được ghi nhận bằng CCD camera, cho chúng ta nguồn thông tin tuyệt vời về nguồn gốc của các đối tượng. Vấn đề này rất thú vị, ngay cả cho những người không có tham vọng nghiên cứu chuyên sâu khoa học. Hơn nữa, không cần phải có bằng cấp vật lý cùng với chuyên môn về toán học để giải quyết vấn đề này. Chúng ta chỉ cần các kiến thức cơ bản về vật lý, khả năng tính toán các công thức đơn giản với một số lượng nhất định trình

finally a healthy dose of enthusiasm. Even the necessary chemical knowledge remains very limited. In the hot stellar atmospheres and excited nebulae the individual elements can hardly undergo any chemical compounds. Only in the outermost layers of relatively "cool" stars, some very simple molecules can survive. More complex chemical compounds are found only in really cold dust clouds of the interstellar space and in planetary atmospheres - a typical domain of radio astronomy. Moreover in stellar astronomy, all elements, except hydrogen and helium, are simplistically called as "metals". The share of hydrogen and helium of the visible matter in the universe is still about 99%. The most "metals", have been formed long time after the Big Bang within the first generation of massive stars, which distributed it at the end of their live in to the surrounding space by Supernova explosions or repelled by Planetary Nebulae. Much more complex, however, is the quantum-mechanically induced behavior of the excited atoms in stellar atmospheres. These effects are directly responsible for the formation and shape of the spectral lines. Anyway for the practical work of the "average amateur" some basic knowledge is sufficient. Richard Walker, CH 8911 -Rifferswil 2.1 Photons - Carriers of Information Photons are generated in stars, carrying valuable information over immense periods of time and unimaginable distances, and finally end in the pixel field	tính toán kỹ thuật và cuối cùng là một bầu nhiệt huyết. [redacted]

of our CCD cameras. By their "destruction" they deposit the valuable information, contributing electrons to the selective saturation of individual pixels - in fact trivial, but somehow still fascinating. By switching a spectrograph between the telescope and camera the photons will provide a wealth of information which surpasses by far the simple photographic image of the object. It is therefore worthwhile to make some considerations about this absolutely most important link in the chain of transmission.

It was on the threshold of the 20th Century, when it caused tremendous "headaches" to the entire community of former top physicists. This intellectual "show of strength" finally culminated in the development of quantum mechanics. The list of participants reads substantially like the Who's Who of physics at the beginning of the 20th century: Werner Heisenberg, Albert Einstein, Erwin Schrodinger, Max Born, Wolfgang Pauli, Niels Bohr, just to name a few. Quantum mechanics became, besides the theory of relativity, the second revolutionary theory of the 20th Century. For the rough understanding about the formation of the photons and finally of the spectra, the necessary knowledge is reduced to some key points of this theory.

2.2 The Duality of Waves and Particles

Electromagnetic radiation has both wave and particle nature. This principle applies to the entire spectrum. Starting with the long radio waves, it remains valid on the domains of infrared radiation, visible light, up to the extremely short-wave ultraviolet, X-rays and gamma rays.

Source: Wikipedia

For our present technical applications,

[redacted]

[redacted]

[redacted]

both properties are indispensable. For the entire telecommunications, radio, TV, mobile telephony, as well as the radar and the microwave grill it's the wave character. The CCD photography, light meter of cameras, gas discharge lamps (eg energy saving light bulbs and street lighting), and last but not least, the spectroscopy would not work without the particle nature.

[redacted]

2.3 The Quantisation of the Electromagnetic Radiation

It was one of the pioneering discoveries of quantum mechanics that electromagnetic radiation is not emitted continuously but rather quantised (or quasi "clocked"). Simplified explained a minimum "dose" of electromagnetic radiation is generated, called "photon", which belongs to the Bosons within the "zoo" of elementary particles.

[redacted]

2.4 Properties of the Photons

- Without external influence photons have an infinitely long life
- Their production and "destruction" takes place in a variety of physical processes. Relevant for the spectroscopy are electron transitions between different atomic orbital (details see later).

- A photon always moves with light speed. According to the Special Theory of Relativity (STR) it can therefore possess no rest mass.

2.5 Photons - Carriers of Energy

Each photon has a specific frequency (or wavelength), which determines its energy - the higher the frequency, the higher the energy of the photon (details see sect. 10.1).

3 The Continuum

[redacted]

3.1 Black Body Radiation and the Course of the Continuum Level

[redacted]

The red curve, hereafter referred to as continuum levelIc corresponds to the course of the radiation intensity or flux density, plotted over the wavelength, increasing from left to right. As a fit to the blue continuum it is cleaned by any existing absorption or emission lines (blue curve). The entire area between the horizontal wavelength axis and the continuum level Ic is called continuum [5].

[redacted]

Most important physical basis for the origin and course of the continuum is the so-called black body radiation. The blackbody is a theoretical working model which, in that perfection, doesn't exist in nature.

[redacted]

For most amateurs it is sufficient to know, that:

- The blackbody is an ideal absorber which absorbs broadband electromagnetic radiation, regardless of the wavelength, completely and uniformly.

[redacted]

- The ideal black body represents a thermal radiation source, which emits a broad-band electromagnetic radiation, according to the Planck's radiation law, with an exclusively temperature-dependent intensity profile.

[redacted]

- Stars in most cases may simplified be considered as black-body radiators.

[redacted]

3.2 Plank's Radiation- and Wien's Displacement Law

[redacted]

This theory has practical relevance for us because the intensity profile of the spectrum pro-vides information about the temperature of the radiator! The radiation distribution of different stars shows bell-shaped curves, whose peak intensity shifts to shorter wavelength, re-spectively higher frequency with increasing temperature (Planck Radiation law).

Wavelength [A]

With Wien's displacement law (German physicist Wilhelm Wien 1864-1928) and the given wavelength A,max [A] of the maximum radiation intensity Imax it is theoretically possible to calculate the atmosphere temperature T [K] of a star. This is also called "Effective temperature" Tef f or "Photosphere temperature".

[A]: Angstrom, 1 A = 10-10m [K]: Kelvin K « °Celsius + 273°

[redacted]

3.3 The Pseudo Continuum

By all stellar spectra, the course of the unprocessed continuum differs strongly from the theoretical shape of reference curves, regardless if recorded with professional or amateur equipments. The reasons are primarily interstellar, atmospheric and instrument-specific attenuation effects (telescope, spectrograph, camera), which distort the original intensity course of the spectral profile to a so called pseudo continuum Ps(A) (details see sect.8.2). Therefore, the Wien's displacement law, on the basis of the maximum profile intensity, can qualitatively only be observed. The following chart shows a superimposed montage of spectral profiles (pseudo continua) of all bright Orion stars, obtained with a simple transmission grating (200L/mm), a Canon compact camera (Powershot S 60) and processed with the Vspec software. Denoted are here the spectral classes, as well as some identified absorption lines.

[redacted]

Here it is obvious, that the profile shapes and their maximum intensities of the late O- and early B-classes (sect. 1 3) are nearly identical. As expected, the maximum intensity in the green profile of

[redacted]

Rigel, a slightly lesser hot, late-B giant, and in stark extent in the orange profile of the cool M-giant Betelgeuse, is shifted to the right towards larger wavelengths. Theoretically and according to sect. 3.2, the maximum intensities of the O and B stars should be located far left, outside of the diagram in the UV range. On the other hand the maximum for the cold Betelgeuse should be also moved, but here to the IR range, on the right side, also outside of the diagram. Main causes for this error are the spectral selectivity of the CCD chip and the IR filter in the compact camera, pretending that all the peaks would be located within the diagram. Here is also clearly visible, that the absorption lines (sect. 5.2) are quasi "imprinted" on the continuum profile, similar to the modulation on a carrier wave. These lines carry the information about the object, the course of the continuum reveals only the temperature of the radiator. The profile of Betelgeuse shows impressively, that the spectra of cool stars are dominated by broad molecular titanium oxide (TiO) bands (sect. 5.4). The example also shows the dramatic influence of the spectral characteristics of the camera. In the blue wavelength range, the sensitivity of most cameras drops quickly. Astronomical cameras usually have easy removable/upgradable IR filters, exclusively used for the astrophotography and without them spectra can be recorded well in to the IR range.

[redacted]

4 Spectroscopic Wavelength Domains

4.1 The Usable Spectral Range for Amateurs

The professional astronomers nowadays study the objects in nearly the entire electromagnetic spectrum - including also Radio Astronomy. Also space telescopes are used, which are increasingly optimised

[redacted]

for the infrared region in order to record the extremely red-shifted spectra of objects from the early days of the universe (sect. 1 5.8-15.11). For the ground-based amateur, equipped with standard telescopes and spectrographs only a modest fraction of this domain is available. The usable range for us is, in addition to the specific design features of the spectrograph, limited mainly by the spectral characteristics of the camera including any filters. The Meade DSI III or Atik 314L+ e.g. achieves with the DADOS spectrograph useful results in the range of approximately 3800 - 8000 A, i.e. throughout the visible domain and the near infrared part of the spectrum. Here also the best known and best documented lines are located, such as the hydrogen lines of H-Balmer series and the Fraunhofer lines (see later).

[redacted]

4.2 The Selection of the Spectral Range

For high-resolution spectra, the choice of the range is normally determined by a specific monitoring project or the interest in particular lines. Perhaps also the calibration lamp emission lines have to be considered in the planning of the recorded section.

For low-resolution, broadband spectra mostly the range of the H-Balmer series is preferred (sect. 9). Hot O- and B- stars can be taken rather in the short-wave part, because their maximum radiation lies in the UV range. It usually makes little sense to record the area on the red side of Ha, except the emission lines of P Cygni, Be stars, as well as from emission line nebulae (sect. 22). Between approximately 6,200 - 7,700A (see picture below), it

[redacted]

literally swarms of atmospheric related (telluric) H2O and O2 absorption bands.

Apart from their undeniable aesthetics they are interesting only for atmospheric physicist. For astronomers, they are usually only a hindrance, unless the fine water vapour lines are used to calibrate the spectra! They can partly be extracted with the Vspec software or nearly completely with the freeware program SpectroTools by Peter Schlatter. [41 3].

By the late spectral types of K, and the entire M-Class (sect. 1 3), however, it makes sense to record this range, since the radiation intensity of these stars is very strong in the IR range and shows here particularly interesting molecular absorption bands. Also, the reflection spectra (sect. 5.8) of the large gas planets show mainly here the impressive molecular gaps in the continuum.

[redacted]

Useful guidance for setting the wavelength range of the spectrograph are eg the micrometer scale, the calibration lamp spectrum or the daylight (solar) spectrum, respectively. At night the reflected solar spectrum is available from the moon and the planets. A good marker on the blue side of the spectrum is the impressive double line of the Fraunhofer Hand K-Absorption (sect. 13.2.).

[redacted]

4.3 Terminology of the Spectroscopic Wavelength Domains

[redacted]

Terminology for wavelength domains is used inconsistently in astrophysics [4] and depends on the context. Furthermore many fields of astronomy, various satellite projects etc. often use different definitions.

Here follows a summary according to [4] and Wikipedia (InfraredAstronomy). Given are either the center wavelength A

[redacted]

of the corresponding photometric band filters, or their approximate passband.

Optical range UBVRI AA 3,300 - 10,000 (Johnson/Bessel/Cousins)

Center wavelength Astrophysical wavelength Required instruments
domain
A [|jm] A [A]
0.35 3,500 U - Band (UV) Most optical telescopes
0.44 4,400 B - Band (blue)
0.55 5,500 V - Band (green)
0.65 6,500 R - Band (red)
0.80 8,000 I - Band (infrared)

Further in use is also the Z-Band, some AA 8,000 - 9,000 and the Y-Band, some AA 9,500 - 11,000 (ASAHI Filters).

Infrared range according to Wikipedia (InfraredAstronomy)

Center wavelength Astrophysical wavelength domain Required instruments
A [|jm] A [A]
1.25 10,250 J - Band Most optical- and dedicated
1.65 16,500 H - Band infrared telescopes
2.20 22,000 K - Band
3.45 34,500 L - Band Some optical- and dedicated
4.7 47,000 M - Band infrared telescopes
10 100,000 N - Band
20 200,000 Q - Band
200 2,000,000 Submilimeter
Submilimeter telescopes

For ground based telescopes mostly the following terminology is in use [A]:

- Far Ultraviolet (FUV):
- Near Ultra Violet (NUV):
- Optical (VIS):
- Near Infrared (NIR):
- Infrared or Mid-Infrared:
- Thermal Infrared:

[redacted]

- Submilimeter:

A <3000 A 3000 - 3900 A 3900 - 7000 A 6563 (Ha) - 10,000 A 10,000 - 40,000 (J, H, K, L - Band 1 A 40,000 - 200,000 (M, N, Q - Band 4 - A >200,000 (200 |jm)

5 Typology of the Spectra

5.1 Continuous Spectrum

Incandescent solid or liquid light sources emit, similar to a black body radiator, a continuous spectrum, eg Bulbs. The maximum intensity and the course of the continuum obey the Plank's radiation law.

[redacted]

5.2 Absorption Spectrum

An absorption spectrum is produced when radiated broadband light has to pass a low pressure and rather cool gas layer on its way to the observer. Astronomically, the radiation source is in the majority of cases a star and the comparatively "cooler" gas layer to be traversed, its own atmosphere. Depending on the chemical composition of the gas it will absorb photons of specific wavelengths by exciting the atoms, ie single electrons are momentarily lifted to a higher level. The absorbed photons are ultimately lacking at these wavelengths, leaving characteristic dark gaps in the spectrum, the so-called absorption lines. This process is described in more detail in sect. 9.1. The example shows absorption lines in the green region of the solar spectrum (DADOS 900L/mm).

[redacted]

5.3 Emission Spectrum

An emission spectrum is generated when the atoms of a thin gas are heated or excited so that photons with certain discrete wavelengths are emitted, eg neon glow lamps, energy saving lamps, sodium vapor lamps of the street lighting, etc. Depending on the chemical composition of the gas, the electrons are first raised to a higher level by thermal excitation or photons of exactly matching wavelengths -

[redacted]

or even completely released, where the atom becomes ionised. The emission takes place after the recombination or when the excited electron falls back from higher to lower levels, while a photon of specific wavelength is emitted (sect. 9.1). Astronomically, this type of spectral line comes mostly from ionised nebulae (sect. 22) in the vicinity of very hot stars, planetary nebulae, or extremely hot stars, pushing off their gaseous envelops (eg, P Cygni). The following picture (DADOS 200L/mm) shows the emission spectrum (Ha, HP, HY, He, [O III]), of the Planetary Nebula NGC6210, which is ionised by the very hot central star (some 58'000K), [33].

[redacted]

5.4 Absorption Band Spectrum

Band spectra are generated by highly complex rotational and vibrational processes, caused by heated molecules. This takes place in the relatively cool atmospheres of red giants. The following spectrum originates from Betelgeuse (DADOS 200L/mm). At this resolution it shows only a few discrete lines. The majority is dominated by absorption bands, which are here mainly caused by titanium oxide (TiO) and to a lesser extent by magnesium hydride (MgH). In this case, these asymmetric structures reach the greatest intensity on the left, short-wave band end (called bandhead), and then slowly weaken to the right. The wavelength of absorption bands always refers to the point of greatest intensity ("most distinct edge").

[redacted]

But also several of the prominent Fraunhofer lines in the solar spectrum are caused by molecular absorption. The

[redacted]

following picture, taken with the SQUES Echelle spectrograph [400], shows a high-resolution O2 band spectrum of the Fraunhofer A line (sect. 4.2 and 13.2).

[redacted]

……………………………………

5.5 Band Spectrum with Inversely Running Intensity Gradient 5 h 50

The following picture (DADOS 200L/mm) shows C2 carbon molecular absorption bands in the blue-green region of the spectrum of the carbon star ZPiscium [33]. Generally at some carbon molecules (eg CO, C2), the intensity gradient of the absorption bands runs in the opposite direction as with titanium oxide (TiO) or O2.

Already in the middle of the 19th Century this effect has been recognised by Father Angelo Secchi (Sect. 13.3). For such spectra, he introduced the "Spectral type IV".

[redacted]

5.6 Mixed Emission- and Absorption Spectrum

[redacted]

There are many cases where absorption and emission lines appear together in the same spectrum. The best known example is P Cygni, a textbook object for amateurs. To this un-stable and variable supergiant of the spectral type B2 Ia numerous publications exist. In the 17th Century, it appeared for 6 years as a star of the third magnitude, and then "disappeared" again. In the 18th Century it gained again luminosity until it reached its current, slightly variable value of approximately +4.7m to +4.9m. The distance of P Cygni is estimated to ca. 5000 - 7000 ly (Karkoschka 5000 ly).

The picture below shows the expanding shell, taken with the Hubble Space Telescope (HST). The star in the center is

[redacted]

fully covered. The diagram right shows the typical formation of the so-called P Cygni profiles, which are shown here in the violet region of the spectrum (DADOS 900L/mm).

In the area of the blue arrow a small section of the shell, consisting of thin gas, is moving exactly toward Earth and generating blue-shifted absorption lines (Doppler Effect). The red arrows symbolise the light, emitted by sections of the shell, expanding sideward, producing emission lines. In the combination results a broad emission line and a generally less intense blue-shifted absorption line. P Cygni profiles are present in almost all spectral types and are a reliable sign of a massive radial motion of matter ejected from the star.

[redacted]

Direction toward earth

[redacted]

Based on the wavelength difference between the absorption and emission part of the line, the expansion velocity of the envelope can be estimated using the Doppler formula (sect.1 5). This object is further described in sect. 1 7, where also the estimation of the expansion velocity is demonstrated.

5.7 Composite Spectrum

Superimposed spectra of several light sources are also called "composite"- sometimes also "integratedspectra". The English term “composite"was coined in 1891 by Pickering for composite spectra in binary systems. Today it is often used also for integrated spectra of stellar clusters, galaxies and quasars, which consist from hundreds of thousands up to several hundred billions superposed individual spectra.

[redacted]

5.8 Reflectance Spectrum

The objects of our solar system are not self-luminous, but only visible thanks to reflected sunlight. Therefore, these spectra always contain the absorption lines of the solar spectrum. The continuum course is however coined, because certain molecules in the atmospheres of the large gas planets, eg CH4 (methane), absorb and/or reflect the light differently strong at specific wavelengths.

[redacted]

The following chart shows the reflection spectrum of Jupiter (red), recorded with the DADOS spectrograph and the 200L/mm grating. Superimposed (green) is generated by dawn light, previously captured in the daylight- (solar) spectrum. Before rectifying, both profiles have been normalised on the same continuum section [30]. In this wavelength range, the most striking intensity differences are observed between 6100 and 7400 A.

[redacted]

5.9 Cometary Spectrum

Such can be considered as a special case of the reflectance spectra. Comets, like all other objects in the solar system, reflect the sunlight. However on its course into the inner solar system core material increasingly evaporates, flowing out into the coma, and subsequently into the mostly separated plasma- and dust tails. The increasing solar wind, containing highly ionised particles (mainly protons and helium cores), excites the molecules of the comet. Thus the reflected solar spectrum gets more or less strongly overprinted with molecular emission bands, chiefly due to vaporised carbon compounds of the cometary's material. The most striking features are the C2 Swan bands Further frequently occurring emissions are CN (cyan), NH2 (Amidogen

[redacted]

Radicals), and C3. Sometimes also Na I lines can be detected. Only slightly modified appears the solar spectrum, recorded from sunlight, which has exclusively been reflected by the dust tail. All these facts and the associated effects, create complex composite spectra. The influence of the possible components depends primarily on the current intensity of the core eruptions, as well as on our specific perspective, regarding the coma, as well as the plasma- and dust tail. Further details see [33].

6 Form and Intensity of the Spectral Lines

6.1 The Form of the Spectral Line

The chart on the right shows several absorption lines with the same wavelength, showing an ideal Gaussian-like intensity distribution but with different width and intensity. According to their degree of saturation, they penetrate differently deep into the continuum, maximally down to the wavelength axis. The red profiles are both unsaturated. The green one, which just touches the deepest point on the wavelength axis, is saturated and the blue one even oversaturated [5]. The lower part of the profile is called "Core", which passes in the upper part over the "Wings" in to the continuum level. The short- wavelength wing is called "Blue Wing", the long-wave- "Red Wing" [5].

Emission line profiles, in contrast to the presented absorption lines, always rise upwards from the continuum level.

6.2 The Information Content of the Line Shape

There hardly exists any stellar spectral line, which shows this ideal shape. But in the deviation from this form a wealth of

[redacted]

[redacted]

[redacted]

[redacted]

information is hidden about the object. Here are some examples of physical processes which have a characteristic influence on the profile shape and become therefore measurable:

[redacted]

- The rotational speed of a star, caused by the Doppler Effect, flattens and broadens the line (rotationalbroadening), see sect. 1 6.
- The temperature and density/pressure of the stellar atmosphere broaden the line (tem- perature/pressure-/collision broadening), see sect. 13.12.
- Macro turbulences in the Stellar Atmosphere, caused by the Doppler Effect, broaden the line, see sect. 1 6.6.
- Instrumental responses broaden the line (instrumentalbroadening)
- In strong magnetic fields (eg sunspots) a splitting and shifting of the spectral line occurs due to the so-called Zeeman Effect.
- Electric fields produce a similar phenomenon, the so-called Stark Effect.

The combined effects of pressure- and Doppler broadening result in the so-called Voigt pro-files.

6.3 Blends

Stellar spectral lines are usually more or less strongly deformed by closely neighbouring lines - causing this way so-called "blends". The lower the resolution of the spectrograph, the more lines appearing combined into blends.

[redacted]

6.4 The Saturation of an Absorption Line in the Spectral Diagram

The following spectral profile is generated with Vspec, based on the course of an 11 - step gray-scale chart, running parallel to the wavelength axis. The maximum possible range from black to white, covered by Vspec, comprises 256 gray levels [411]. The Profile section in the

[redacted]

black area is here, as expected, saturated to 100% and runs therefore on the lowest level, ie congruent with the wavelength axis. The saturation of the remaining gray values decreases staircase-like upward, until on the continuum level, it finally becomes white. If an underexposed spectral stripe was prepared in advance with IRIS [410] [30], the gray scale is stretched, so that the highest point on the chart becomes white. Thus, a maximum contrast is achieved. Continuum Level = white	[redacted]
So far remains the theory, covering the electronic recording and the data reduction level. According to [11] however, in astronomical spectra, an absorption line reaches already full saturation before it touches the wavelength axis. In fact the "Wings" in the upper part of an oversaturated line profile, appear massively broadened, without penetrating much further into the continuum (sketch according to [11]).	[redacted]
7 The Measurement of the Spectral Lines	[redacted]
7.1 Methods and Reference Values of the Intensity Measurement Depending on the specific task, the line intensity is determined either by simple relative measurement, or quite complexly and time consuming, with absolutely calibrated dimensions. Here we focus exclusively on the relative measurement which is sufficient for most amateur purposes, and is supported by the analysis software (eg Vspec). As a reference or unit usually serves the local or normalised continuum level lc (sect. 8) but possibly also values of a linear, but otherwise arbitrary scaling of the intensity axis. 7.2 Metrological Differences between	[redacted]

Absorption and Emission Lines

For measurements of spectral lines the following differences must be noted.

The absorption lines lA can simplified be considered as the product of a "filtering process". The photons of a specific wavelength A, which, in most of the cases are absorbed in a stellar photosphere, cause a gap in the continuum of defined area, shape and penetration depth.

Therefore, the parameters of the absorption remain always proportionally connected to the continuum-intensity lc(2) .

[redacted]

The emission lines lE are generated independently of the continuum by recombination and/or electron transitions (sect. 9). Because this process is mostly also excited by the stellar radiation, it results a certain strongly object-dependent, time related degree of coupling to the continuum radiation. For instance at P Cygni these lines are generated directly in the turbulent expanding gas envelope - at the Be stars (sect. 1 6) mostly in the relatively nearby circumstellar gas disk - and in the cases of the HII regions or Planetary Nebulae PN, even up to some ly away, where almost regular laboratory conditions exist!

The combination of emission lines and continuum radiation results in a superposition ltotai of the two intensities:

hotal=W) + W) {3}

[redacted]

Due to the physically, and often even locally, different generation, as well as may fluctuate independently of each other. The continuum-level is dependent on the specific radiation density, which the star generates at the wavelength . To this level, the emission intensity lE (2) is adding up independently.

[redacted]

The combination of emission lines and absorption lines results also in a superposition of the two intensities.	[redacted]
hotcii = UW + IEW {3a}	
At Be-stars, the slim hydrogen emission line is produced in the circumstellar disk or -shell, and appears superimposed to the rotation- and pressure-broadened H-absorption of the stellar photosphere. The resulting spectral feature is therefore called "Shell Core" [4]. The H- absorption of such a spectral feature may also originate from the photosphere of a hot O-star and the emission line from the surrounding HII region, see eg the HP line of Q1Ori C/M42 [33].	[redacted]
7.3 The Peak Intensity P The Line Intensity I The intensity I offers the easiest way to measure a spectral line in a linear but otherwise arbitrarily scaled intensity axis.. However this measure is only significant in a radiometrically corrected or absolutely calibrated profile as described in section 8.10 - 8.12. The Peak intensity P In a pseudo-continuum, but also in a just rectified profile according to sect. 8.9, the intensity I gets only comparable with other lines if related to its local continuum level Ic. This is expressed as the dimensionless Peak intensity P. P = I/Ic {4} The Peak intensity P at absorption lines P is here also called LD for "Line Depth". Related to the continuum level Ic, the peak intensity P of the absorption line, corresponds to the maximum intensity I or flux density F R e i, which is removed from the continuum radiation by the absorption process. This further corresponds to the photon energy per time, area, the considered wavelength interval and related on the level Ic (units see sect.	[redacted]

8.12). In addition, it qualitatively shows the degree of absorption, or the share of photons, which is absorbed in the peak of the absorption line with the penetration depth I.

[redacted]

The Peak intensity P at emission lines

If the upwards striving and independently generated emission lines appear superimposed on a continuum {3}, they are, just as a pure makeshift, sometimes also related to the independent continuum-levelIc {4}, eg for investigations of individual lines. Related to the independent continuum-levelIc, the peak intensity P of the emission line corresponds to the maximum intensity I or flux density FR e i. This further corresponds to the photon energy per time, area, the considered wavelength interval and related on the level Ic.

[redacted]

7.4 FWHM Full Width at Half Maximum Height

[redacted]

The FWHM value is the line width in [A] at half height of the maximum intensity. It can be correctly measured even in non-normalised spectral profiles. The width of a spectral line is inter alia depending on temperature, pressure, density, and turbulence effects in stellar atmospheres. It allows therefore important conclusions and is often used as a variable in equations, eg to determine the rotational velocity of stars (sect. 1 6.6).

This line width is specified in most cases as wavelength- difference AA. For the measurement of rotational and expansion velocities, FWHM is also expressed as a velocity value according to the Doppler principle. For this purpose FWHM [A] is converted with the Doppler formula {1 6}

[redacted]

v = FWHM ■ cl A to a speed value [km/s] (sect. 1 5).

The FWHM value, obtained from the spectrum [30] has now to be corrected from the in-strumental broadening.

FWHMkorr = J FWHM2measured FWHM instrument}

FW H M Instrument corresponds to the theoretical maximum resolution A25 [A] of the spectrograph, ie the smallest dimension of a line detail, which can be resolved.

The resolution is limited on one side by the optical design of the spectrograph (dispersion of the grating, collimator optics, slit width, etc.). It can normally be found in the manual of the spectrograph as so-called R-Value R = A/AAS which is valid for a defined wavelength range (A = considered wavelength) [302].

R = A/AA$ {5 a} FWHMjnstrument = — {5ft}

This value is determined by FWHM measurements at thinnest possible spectral lines, eg atmospheric H2O absorptions or somewhat less accurate, at emission lines of calibration light sources [11], [123], [302]. In the laboratories for example emissionlines, generated by microwave excited mercury lamps are used, in order to minimise temperature broadening. Such profiles are called "instrumental profile" or "5-function response" [11]. The resolution may further be limited by the pixel grid of the connected camera [A/pixel], if this value is greater than AAS of the spectrograph. For a wavelength-calibrated profile, this value is shown in the head panel of the Vspec screen. Compared to monochrome-, with color CCD cameras, a significant loss of resolution must be accepted.

7.5 EW, Equivalent Width

[redacted]

[redacted]

[redacted]

The EW value at absorption lines

As sketched above and related to the continuum-level Ic, EW corresponds to the measure of the total radiation flux FL Rei, which the entire absorption line removes from the continuum radiation. This further corresponds to the photon energy per time, area and related on the continuum-levelIc (common units see sect. 8.12). The EW value is for absorption lines an absolute measure, because they are inseparably and proportionally linked to the continuum level.

The EW value at emission lines

The EW value of the just relatively to the independent continuum level Ic related emission lines, corresponds to the measure of their entire radiation flux FLRei. This further corresponds to the photon energy per time, area, and relatively related on the independent levelIc. In contrast to the absorptions the EW value is for the emission lines not an absolute measure, because the relation to the independently generated continuum is always relative, just by makeshift, but never absolute.

Measurement and signs of the EW values

EW values of absorption lines are by definition always positive (+), those of emission lines negative ( ).

Since the EW value is always measured at a continuum level, normalised to Ic = 1 , it is neither influenced by the course of the continuum, nor by the absolute radiation flux.

Should EW be measured in a non rectified profile, the continuum must be normalised immediately at the base of the spectral line to Ic = 1 !

In scientific publications EW is also

[redacted]

[redacted]

designated with the capital W. Wa designates the equivalent width of the Ha Line.	[redacted]
Somewhat confusing: In some publications I have also found the FWHM value expressed as W. The conclusion: One must always simply check which value is really meant. 7.6 Normalised Equivalent Width Wx Rather rarely the normalised EW value W\ is used [1 28]:	[redacted]
This allows the comparison of EW -values of different lines at different wavelengths A, taking into consideration the linearly increasing photon energy towards decreasing wavelength A, according to formula {8}. Anyway, in astrophysics this is not applied by most of the mainly empirical formulas and procedures. 7.7 FWZI Full Width at Zero Intensity Rather rarely the FWZI value of a spectral line is applied. The Full With at Zero Intensity cor-responds to the integration range A2 — At of the definite integral according to formula and chart {6a}:	[redacted]
FWZI = A2-A1 {6 bj	
7.8 Influence of the Spectrograph Resolution on the FWHM- and EW Values	[redacted]
The above outlined theories about FWHM- and EW must realistically be relativated. This need is dramatically illustrated by the following spectral profiles of the Sun, taken with different highly resolving spectrographs (M. Huwiler/R. Walker). The R-values are here within a range of approximately 800 - 80,000.	[redacted]
o Sun Spectrum X 5160 - 5270 A Comparison Prototyp Echelle- with DADOS Spectrograph 900- and 200 L	

mm-1	
The comparison of these graphs shows the following:	[redacted]
• If the resolution (R) is increased it becomes clearly evident that in stellar spectra practically no "pure" lines exist. Apparent single lines almost turn out as a "blend" of several sub lines, if considered at higher resolutions.	[redacted]
• Striking is also the so-called "Instrumental Broadening" effect. Even relatively well- insulated seeming lines broaden dramatically with decreasing resolution (R), due to the instrumental influences. This affects the measured FWHM or the half-width of a line.	[redacted]
• The EW value, related to the profile area, remains theoretically independent of the resolution. At higher resolutions, the area of the slimmer line profile is compensated by a higher peak-value P.	[redacted]
7.9 Practical Consequences for the FWHM and EW Measurements	[redacted]
• FWHM values must always be corrected in respect of the "Instrumental Broadening", applying the formulas {5} to {5b}.	[redacted]
• The comparability of the EW values, obtained with different resolutions, remains purely theoretical and is limited to discrete and well isolated single lines. Assuming the case of a blended absorption line, a high-resolution spectrograph measures, in an ideal case, the EW value of only one, well-defined single line. However, at low resolution and the same wavelength, a substantially larger value is measured due to a blend of several inseparable lines. In this case, only EW - values are seriously comparable, if they	[redacted]

have been obtained from profiles with similar resolution. This necessarily requires a declaration of the R-value.

- According to formula {6a}, the EW -value is clearly defined. However to determine this value e.g. for strongly deformed, broad emission lines, possibly even with a double peak, remains a serious problem. With Gaussian fits in such cases reasonably reproducible, albeit relatively imprecise results may result. The profile fit with Spline filter, or similar algorithms is perhaps more accurate, but the result is subjectively influenced by the investigator.
- For amateur monitoring projects it is important, that all participants work with similarly high resolutions and the recording and processing of the spectra is clearly standardised. A problem with the EW values poses the standardisation of the integration area A2 — At (FWZI) of formula {6a}, since the width of the line base may change significantly with varying intensity. Further the section of the continuum must be specified, on which the profile is to normalise. This is unavoidable at least for the later spectral classes, which exhibit a rather diffuse continuum. When monitoring emission lines one must always keep in mind that the measured EW values are related to a possibly independently fluctuating continuum level (sect. 7.2).

[redacted]

7.10 The Measurement of the Wavelength

The wavelength of a spectral line (Nanometer [nm] or Angstrom [A]) can be obtained in a wavelength calibrated spectrum directly via Gaussian fit (Vspec) or by positioning of the cursor at the peak of the line. Which method is better, depends upon whether a strongly asymmetric blend or an isolated single-

[redacted]

line is present.

7.11 Additional Measurement Options

Depending on the applied analysis software, further information can be obtained from the calibrated spectral profile. In Vspec these are, among other, e.g. the signal to noise ratio SNR and the dispersion in A/pixel, etc. For details see the respective manuals.

8 Calibration, Normalisation and Radiometric Correction

8.1 The Calibration of the Wavelength

Usually spectra are plotted as course of the radiation intensity over the wavelength. In principle, both dimensions can be calibrated. For most applications, only the calibration of the wavelength is required. This can be done relatively easy with lines of known wavelength within the spectrum, or absolutely with appropriate spectral calibration lamps. These procedures are well documented in literature eg [30], [411].

8.2 The Selective Attenuation of the Continuum Intensity

The intensity profile of the undisturbed stellar original spectrum 0r(A) is determined mainly by the black body radiation characteristics of the star and its effective temperature Teff (sect. 3.2). On the long way to the unprocessed raw spectrum the continuum of 0 r (A) becomes deformed by the following damping influences into a so called pseudo-continuum (continuum chuẩn, gần giống continuum) Ps (A) (sect. 3.3).

1. The Attenuation by the Interstellar Matter DISM(A) is mainly caused by scattering effects of dust grains and gas. Thereby the intensity is selectively much stronger dampened in the blue short wave part of the spectrum. Thus the maximum of the continuum radiation is shifted in to

[redacted]

[redacted]

the red, long-wavelength range, which is called "Interstellar Reddening" (sect. 21). The extent of this effect depends on the object-distance, the direction of the line of sight and is, as expected, most intensive within the galactic plane. It can roughly be estimated with a corresponding 3D model by F. Arenou et al. [209], [201].

2. The Attenuation in the Earth's Atmosphere DATM(A) acts similarly. Well known effects are the reddish sunsets. The modelling of the atmospheric transmission is mainly applied in the professional sector. It is rather complex and depends inter alia on the zenith-distance z (or the complementary elevation angle) of the observed object, the altitude of the observation site and the meteorological conditions [303].

3. The Attenuation by Instrumental Influences DINST(A) of the system telescope- spectrograph-camera follows at the very end of the transmission chain. This can be determined quite precisely, eg by comparison with the exactly known radiation distribution of a continuum light source (eg special calibration lamps) [11], [300], [31 3], [315], [316],
[480].

[redacted]

The resulting attenuating effect does:
DfotW = DISM(A) ■ Datm(A) ■ DINST W {7}

The empirical function provides to any wavelength the correction factor between the continuum-intensity of and .
DTot(X) = Ps(A)/0r(A) {7 b}

[redacted]

This empirical scaling- or "correction function" DTot (A) can be determined as a rough ap-proximation only. The intensity profile of the original stellar spectrum can

[redacted]

be simulated just on a theoretical basis and the individual factors can just very roughly be estimated. Similar approaches with empirical functions can be found in [300] and [303]. The practical calculation with profiles is normally enabled - including all basic operations - by the software of the analysis tools. At Vspec this feature is to find under Operations/Divide-, /Multiply,- /Add-, or /Subtract profiles by a profile.

[redacted]

8.3 Relationship Between Original-Continuum O r (X) and Pseudo-Continuum Ps (X)

The following diagram shows two identical sections of the same spectrum: on the left the undisturbed original profile 0 r (2) and on the right the recorded raw spectrum with the pseudo-continuum Ps (2) . It shows each an absorption and an emission line. Within this fictional spectral section, the course of DTot(2) , 0r(2) and Ps(2) is assumed to run horizontally.

The following relationships and its consequences can be derived:

- Due to the selective attenuation, at a certain wavelength 2, the continuum-intensity of the recorded profile Ps(2) appears to be reduced by AIc, compared with the original- spectrum .

{7c}

[redacted]

8.4 Attenuation of Absorption Lines

The continuum intensity and the penetration depth of the absorption line , are attenuated equally proportional.

Ic = Ico'DrotW {7^}

Ia = Iao ' DTot(X) {le}

[redacted]

As an example the following graph shows the Sirius spectrum with the virtual original profile 0r(2) and the recorded pseudo-continuum Ps(2). The absorption lines always remain proportionally and

[redacted]

inseparably connected to the continuum. Therefore the -related measurement categories - Peak Intensity PA = I/Ic, and Equivalent width EW - cannot be changed by a simple division or multiplication by.	[redacted]
Anyway the example of the Hy line also shows that the relative line intensity of IA, which is measured independently of the continuum-level, appears strongly attenuated, compared with IA0. At 0 r (A) , IA0 corresponds to the intensity of the original profile. U < IAO {7g]	[redacted]
Further in the original profile 0 r (A) of Sirius, spectral class A2V, it gets clearly evident, that the absolute energy flux FL,(sect. 8.12) which is absorbed by the Hy-line and is not related to the continuum-level Ic, is much higher, compared to the Ha - Absorption. FL Hy Sirius ^ Ha Sirius	[redacted]