TWIN BOOK PROJECT

ASTRONOMICAL

SPECTROSCOPY

By

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INTRODUCING THE AUTHORS

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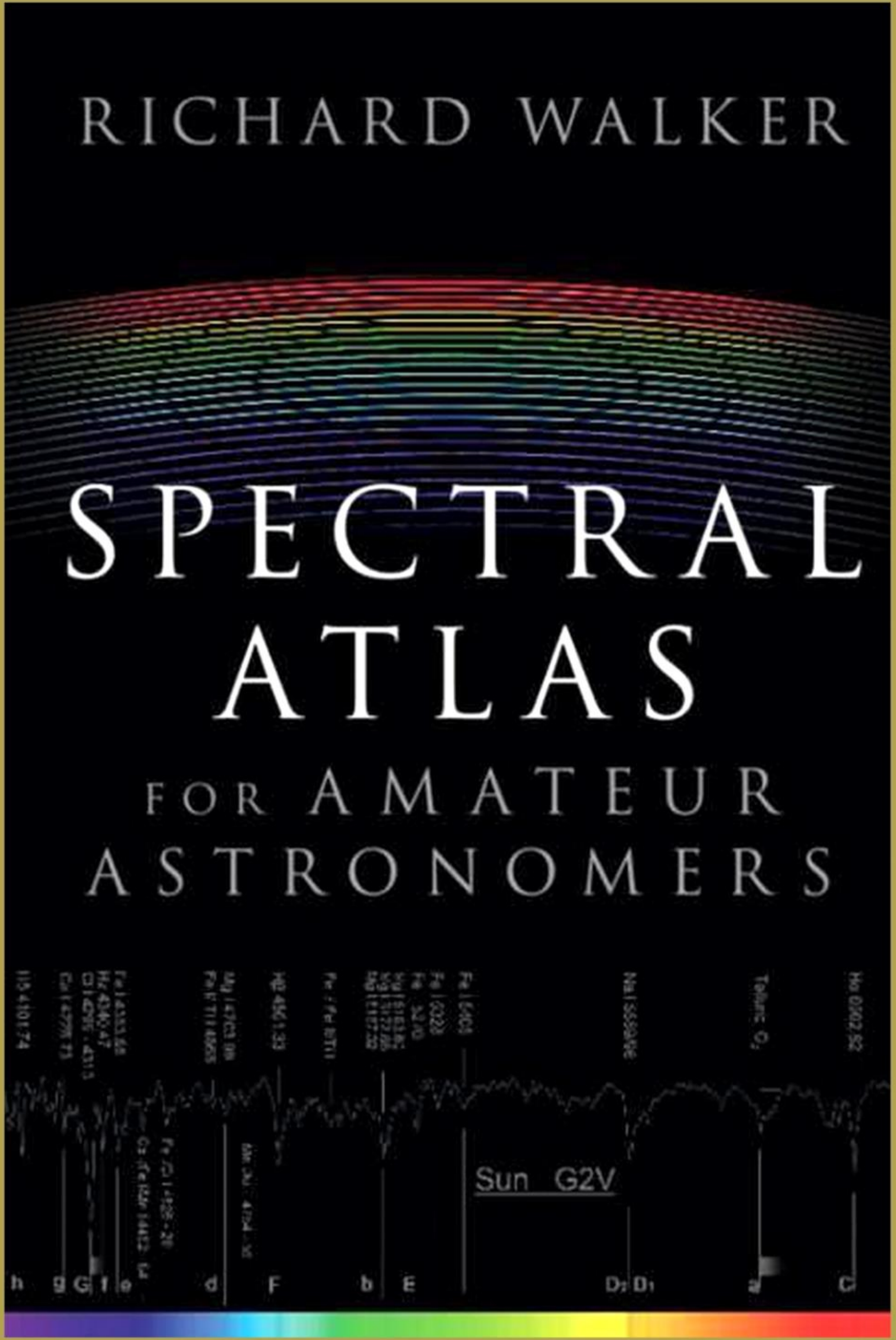
BOTH PASSIONATE ABOUT ASTRONOMICAL SPECTROSCOPY
and SUPPORTING ITS WORLDWIDE OUTSPREAD

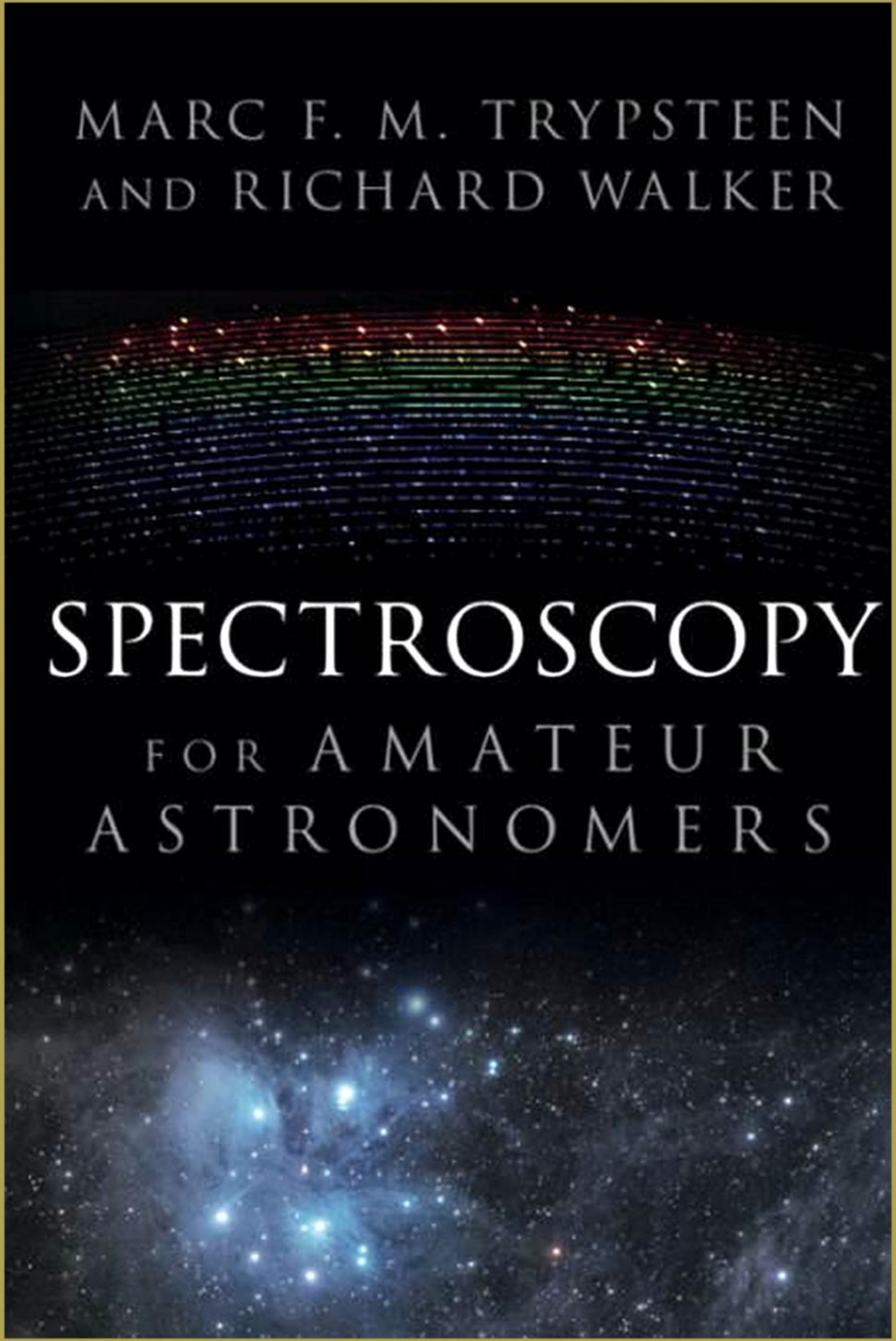
VOLUME 1: SPECTRAL ATLAS

VOLUME 2: THEORETICAL AND PRACTICAL SPECTROSCOPY HANDBOOK

for:

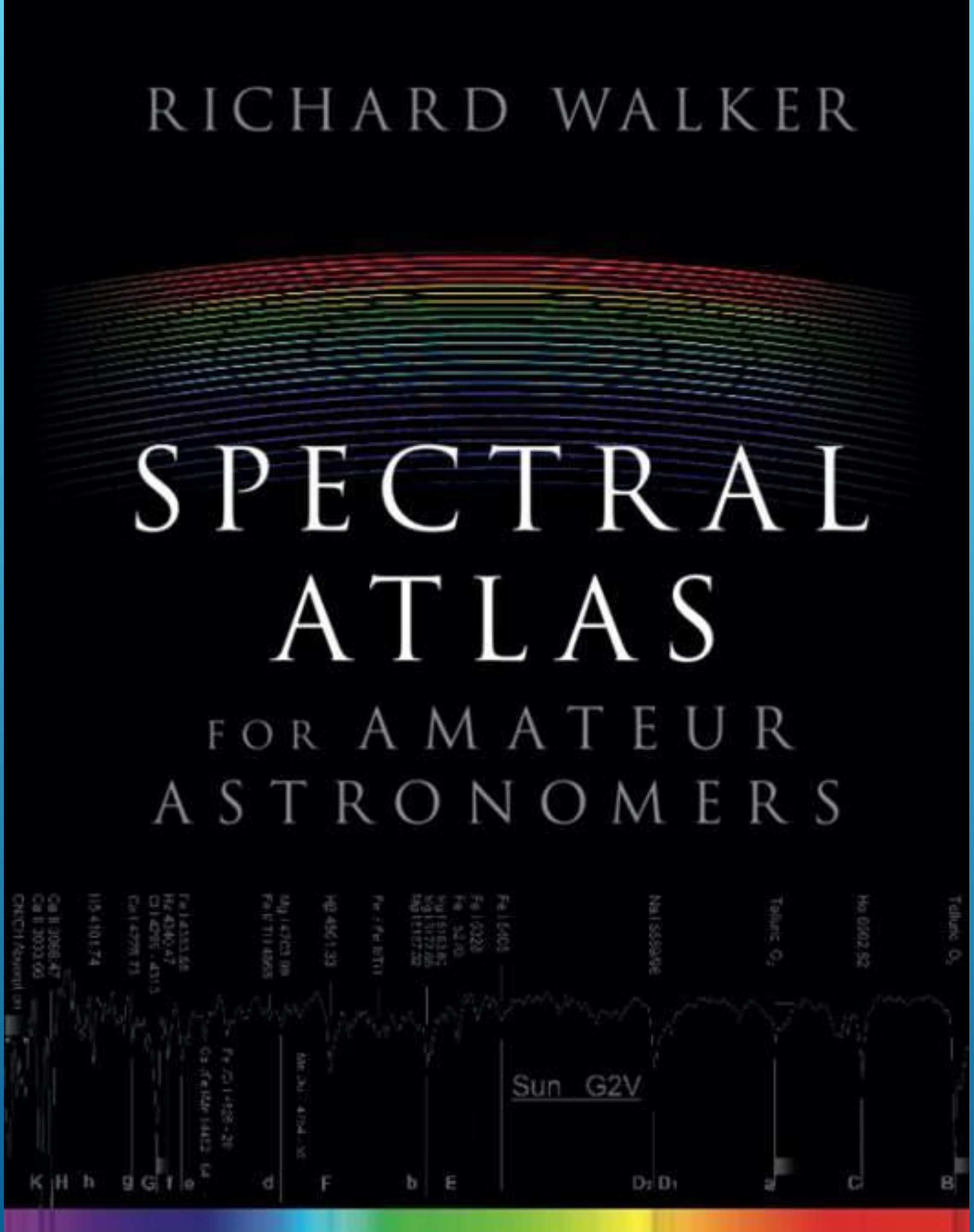
- AMATEUR ASTRONOMERS
- BSc/MSc STUDENTS
- TEACHERS IN ASTRONOMY CLUBS & OBSERVATORIES
- PARTICIPANTS in ProAm PROJECTS





Complete Spectroscopy for Amateur Astronomers

VOLUME 1


RICHARD WALKER
SPECTRAL ATLAS FOR AMATEUR ASTRONOMERS
Sun G2V
K H h g G f e d F b E D2 D1 a C B

- Acknowledgements
- The spectral atlas was launched in 2011 as a nonprofit project. The aim was first to provide an internet document with fully commented, low resolution spectra for amateurs, covering the seven basic spectral classes. At that time, this way also a significant publication gap should be reduced. Anyway first thanks deserve here Urs Flükiger, member of the Swiss Spectroscopic Group, convincing the author to publish the very first version of the atlas on his "Ursus Maior" homepage. Otherwise it could even be possible that the manuscript would still remain as "personal notes" in any folder on his Laptop.
- The following worldwide responses to the very first online version have been surprisingly numerous and so positive that the project was soon extended to further special classes. Thus further thanks are here addressed to all amateurs and even professionals, which have contributed with their valuable feed backs to the benefit of this atlas.
- Already 2011 Thomas Eversberg from DLR wrote a review in the VDS Journal Nr. 38 and was also the very first to propose, that this atlas should be published as a book. Anyway further five years have been required to record the spectra for all presently documented special classes and to collect the necessary background information for the description of the numerous objects. At this stage I got valuable support also by Martin Huwiler which assisted me with his immense optical knowledge, but also by discussing relevant spectroscopic and astronomical topics as well as by reviewing the text. In this respect I would like to include also Helen Wider. Further Erik Wischnewski helped me with the chapter about Novae and contributed excellent, self recorded spectra of Nova Delphini V339, which annoyingly erupted exactly during a time when the author was prevented from observing.
- 2014, during the NEAF convention near New York, Olivier Thizy of Shelyak Instruments met Vince Higgs from CUP and called his attention to the atlas project, which however was not yet finished at that time and required a further year to be completed. So Olivier made this way a small but nevertheless decisive contribution to the creation of this book. Further the excellent programs *Visual Spec* by Valerie Désnoux and *IRIS* by Christian Buil have been of great help, not only for analyzing of the recorded profiles but also for the illustration of the numerous colored plates in this atlas.
- While transferring the internet document into a book it became clear quite soon, that a separate publication would be necessary, supporting the atlas with practical and theoretical aspects. Anyway this required inevitably a co-author with complementary knowledge, for which fortunately Marc Trypsteen could be won. He contributed also valuable reviews and inputs to the atlas, not least a stunning reflectance-spectrum of the lunar eclipse from September 2015.
- Finally I generally want to express here again my warmest thanks to everyone who contributed in any kind to this atlas.
- Richard Walker

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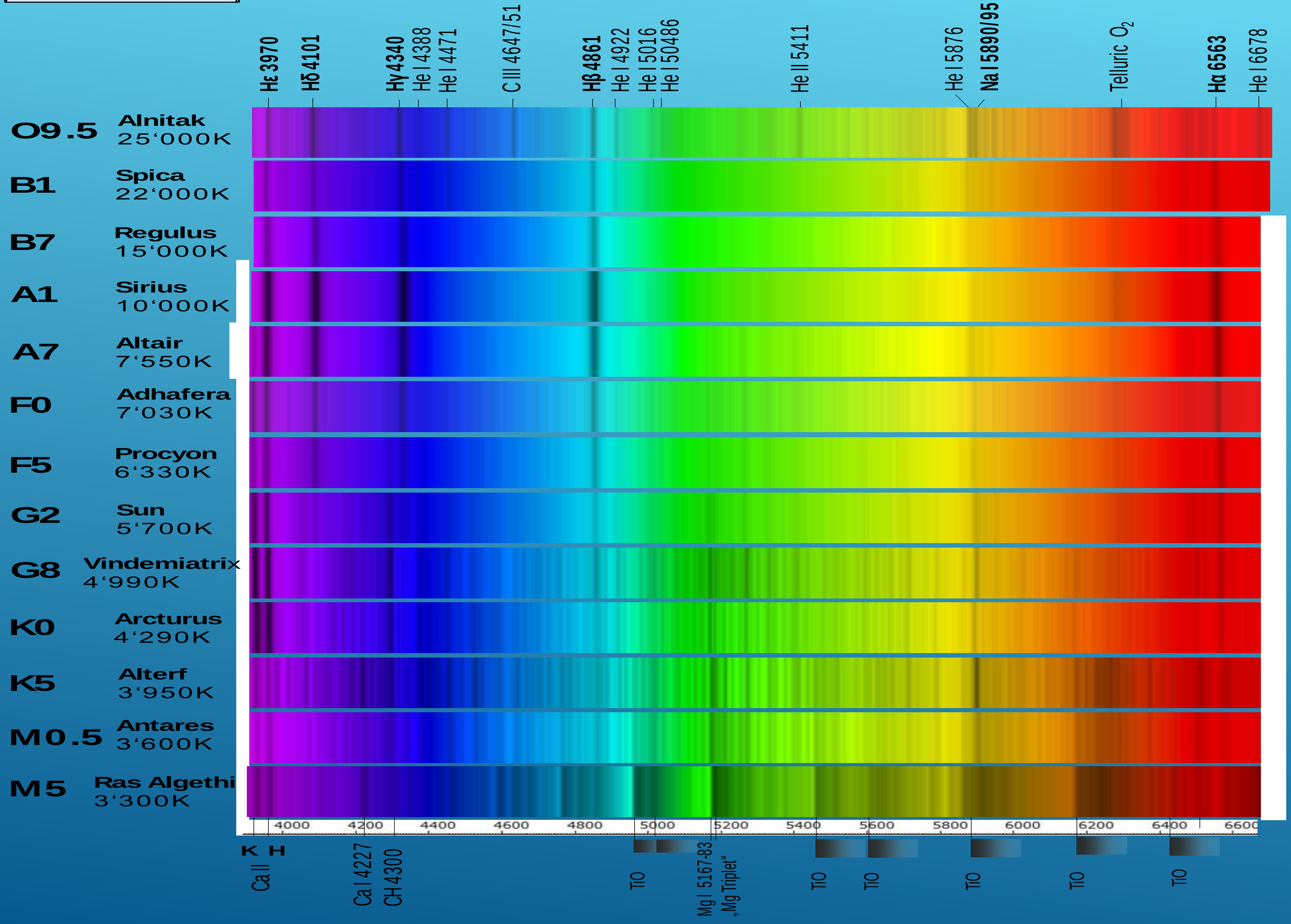
The spectral atlas covers a broad range of astronomical objects and interesting light sources

PLATE 1

Overview on The Spectral Classes



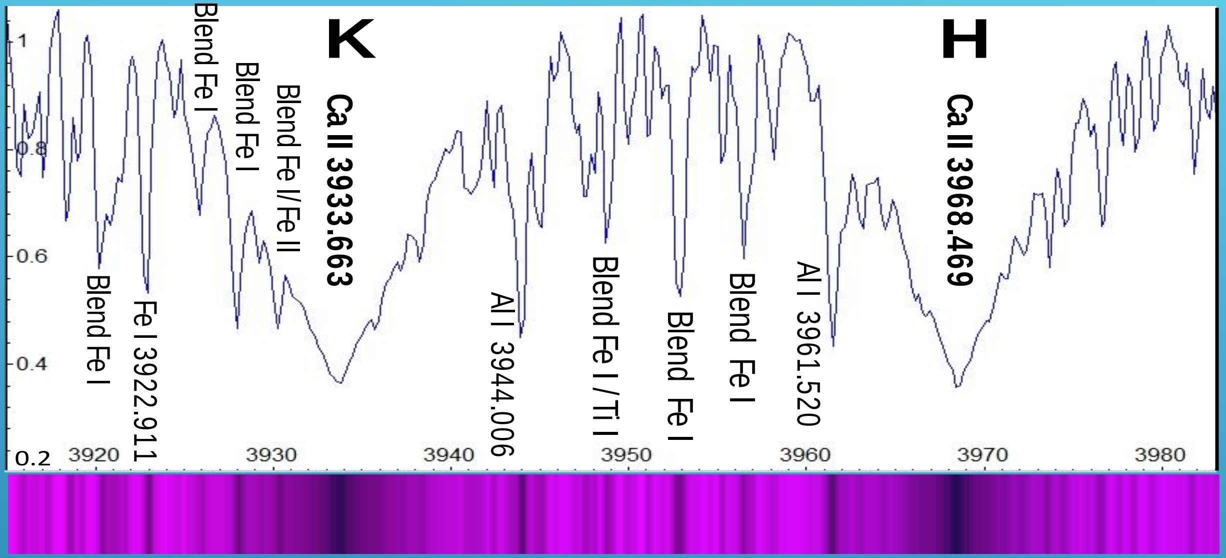
Presentation of recorded spectra ideally adapted to didactic teaching

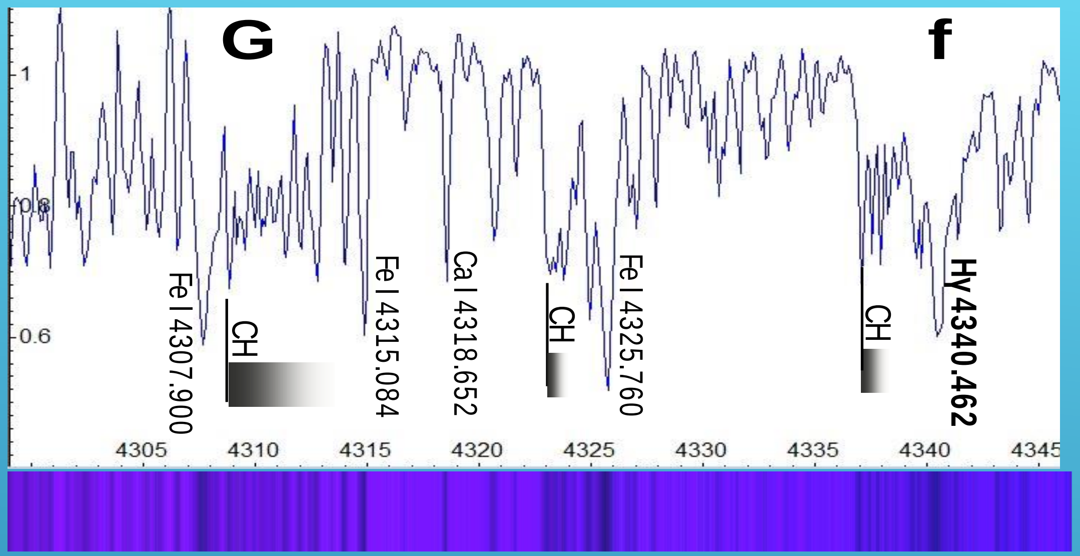
COMPLETE SPECTROSCOPY
For AMATEUR ASTRONOMERS

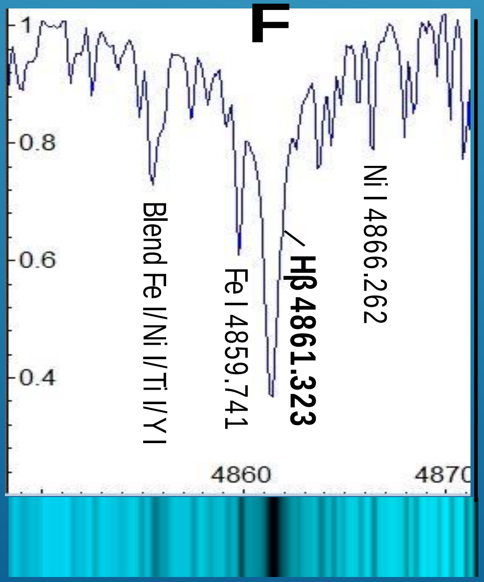
Sun G2V, Highly Resolved Fraunhofer Lines

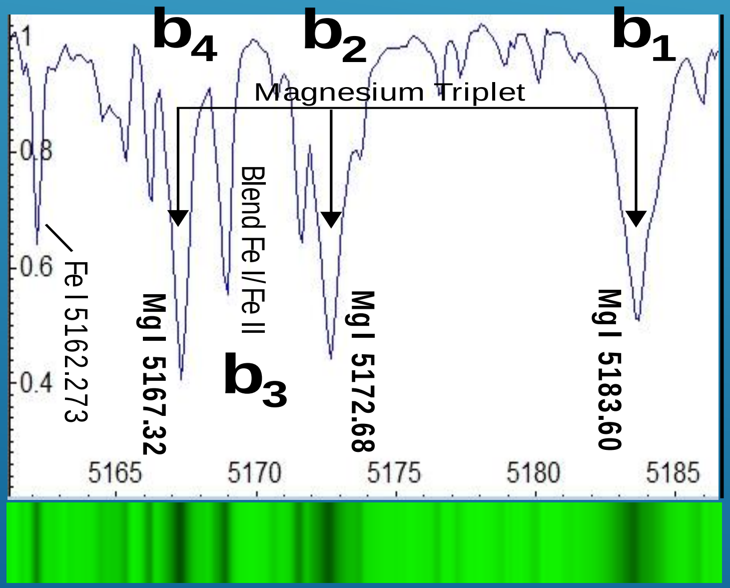
SQUES Echelle Spectrograph

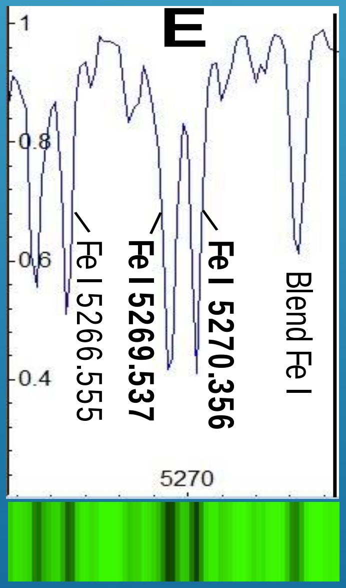
⊗ Telluric Absorption

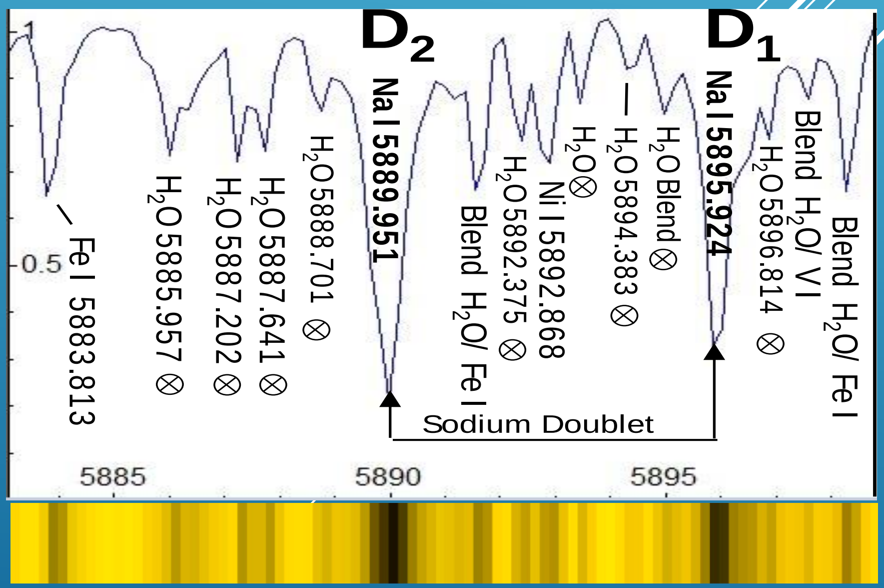






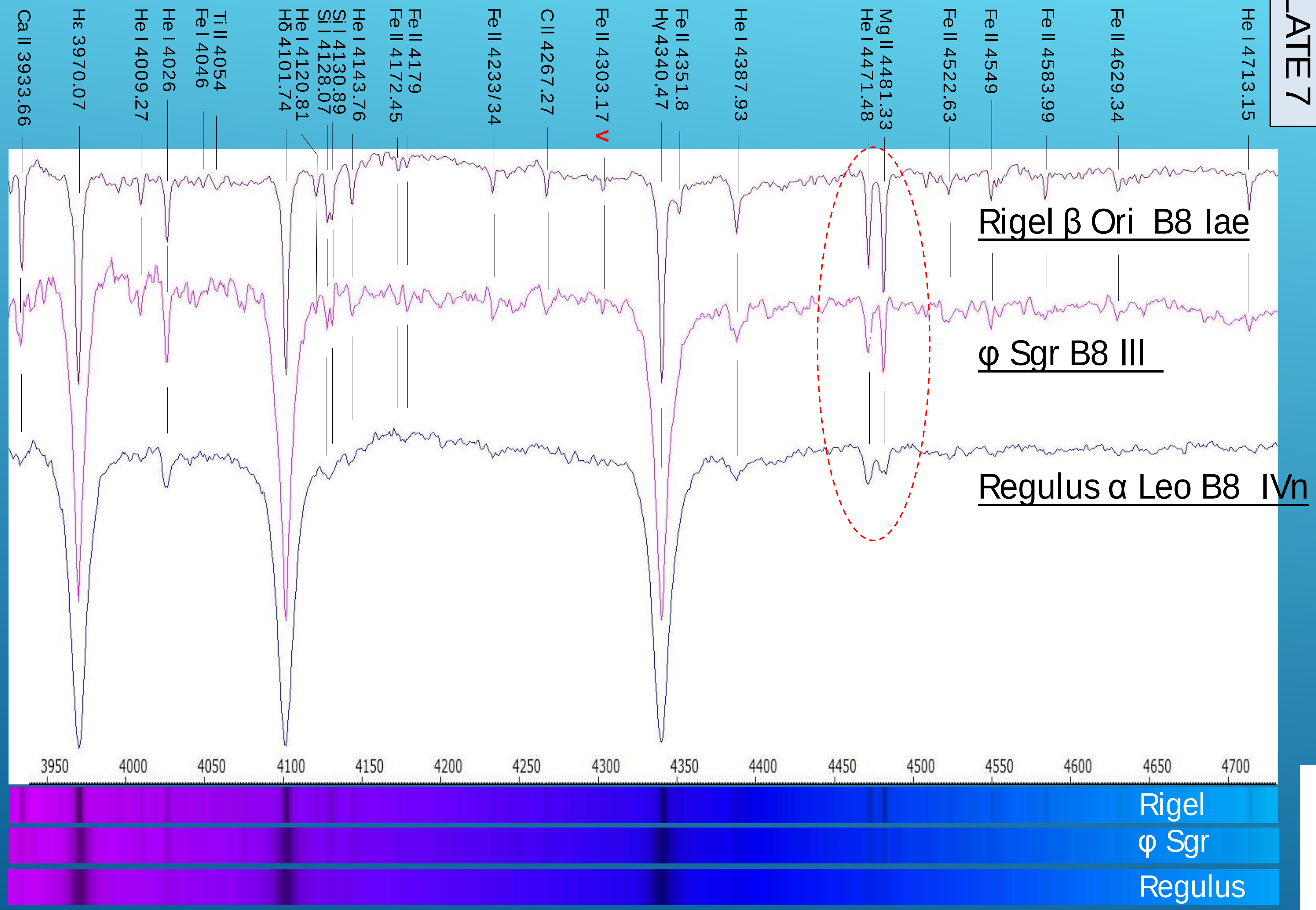






Effect of the Luminosity on Spectra of the B-class

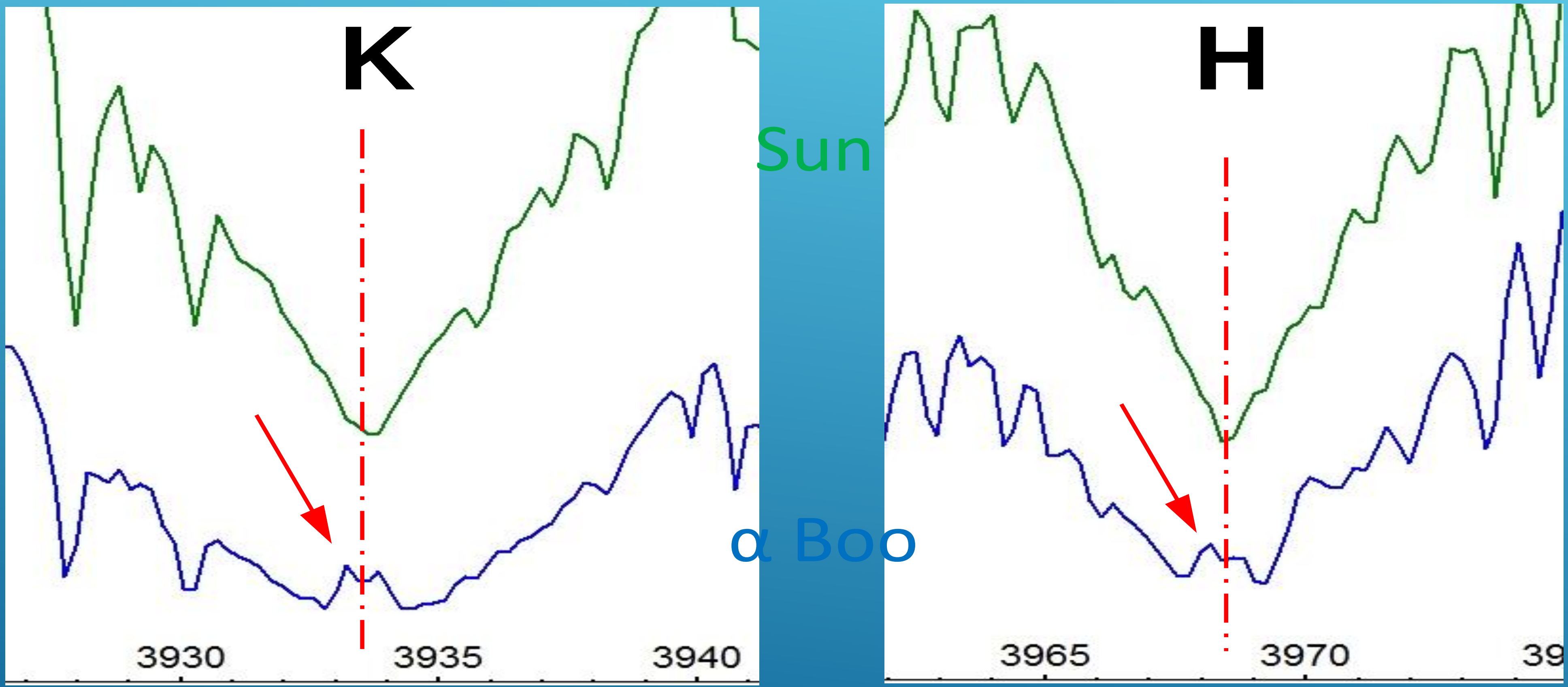
PLATE 7



Instructive way of presenting effects such as:

- **Negative Luminosity Effect**
- **Rotational Broadening**
- **Collisional / Pressure broadening**

WILSON –BAPPAU EFFECT



Detailed visualisation of specific effects observed in recorded higher resolution spectra

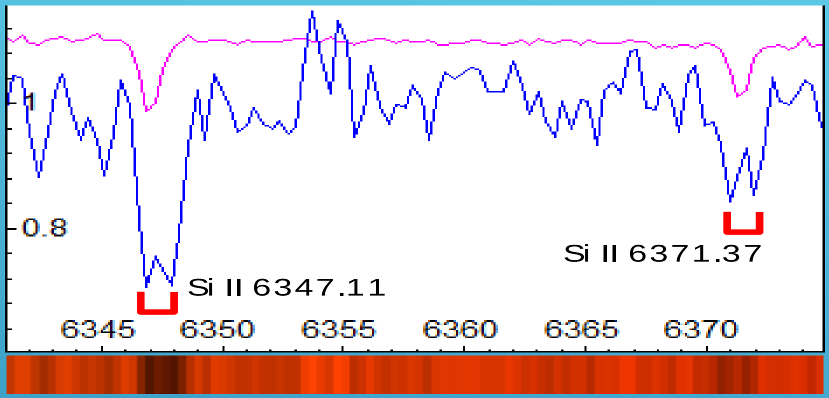
Babcock's Star HD 215441 Mean Magnetic Field Modulus

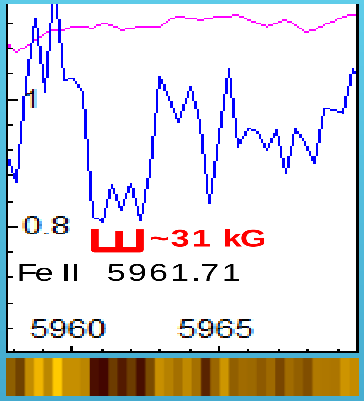
PLATE 45

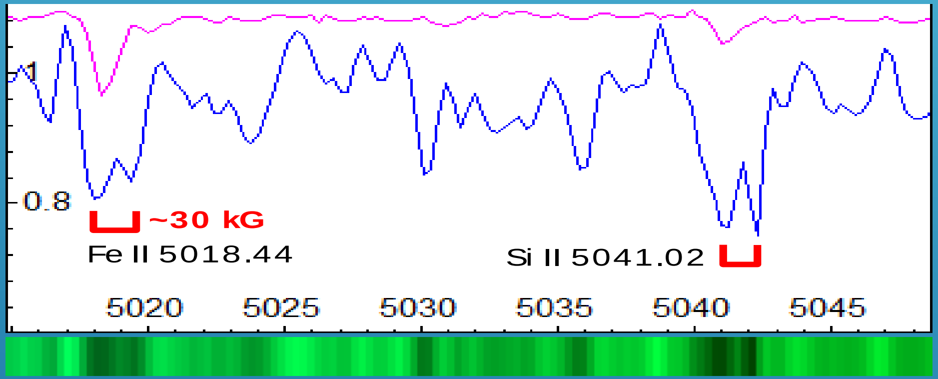
Vega A0V 🟪

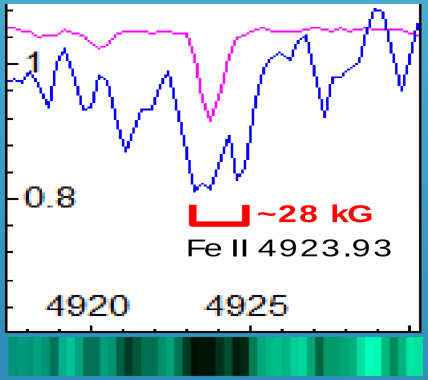
HD215441 B9p Si 🟦

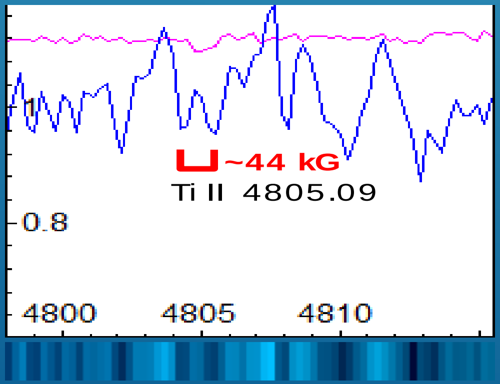
SQUES Echelle Spectrograph
slit width 70µm, JD2456984.4

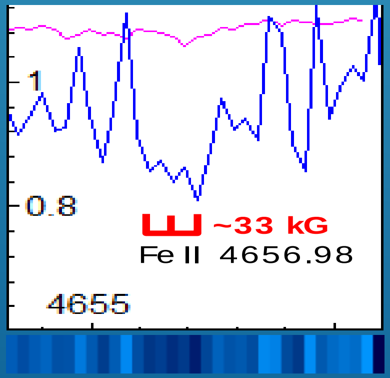


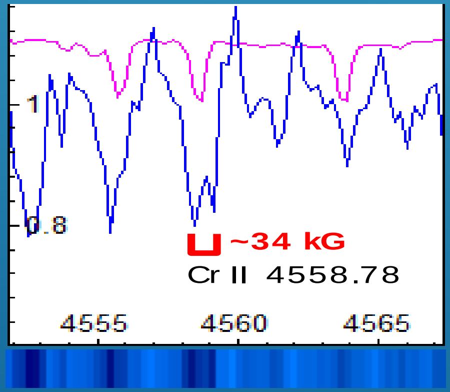










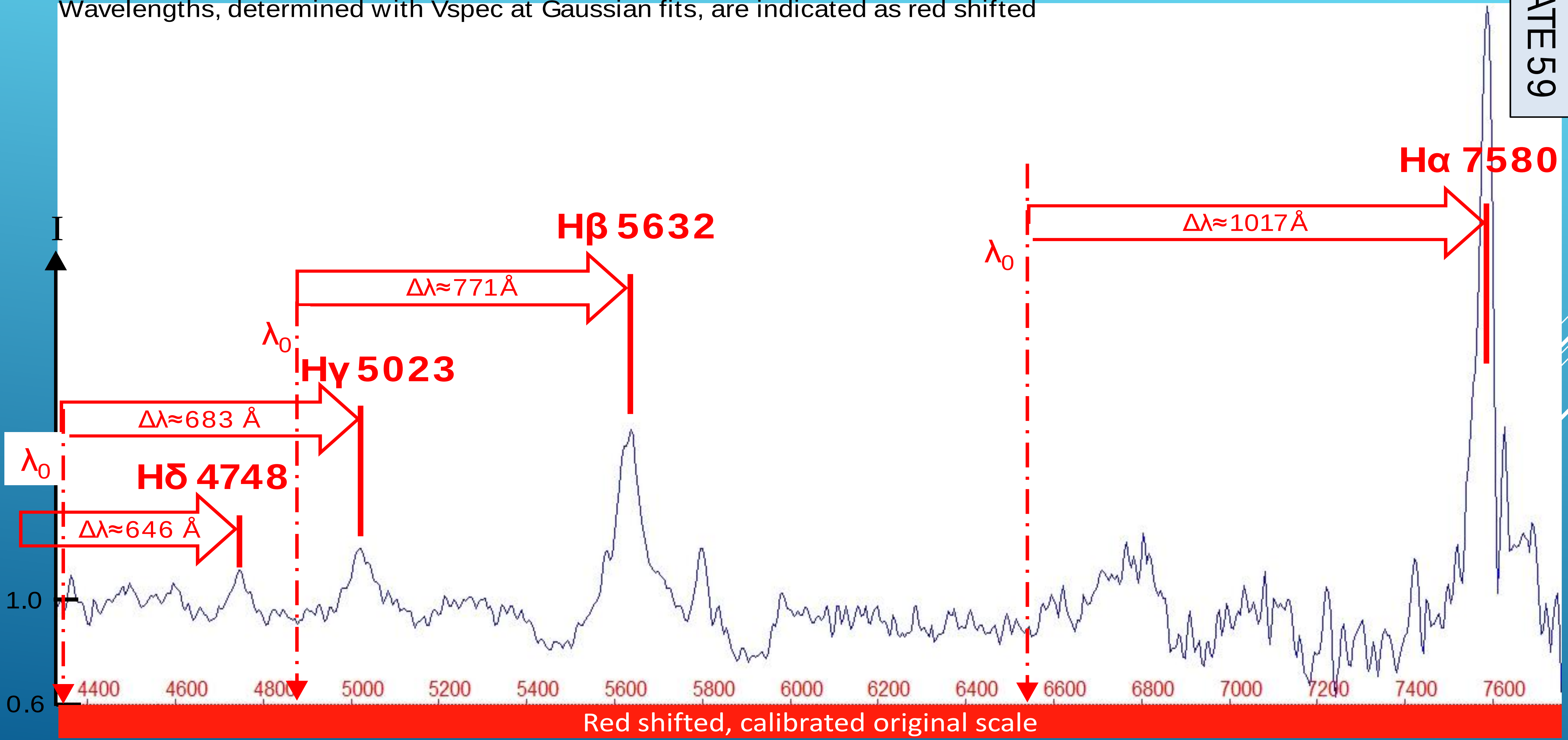


Estimation of the flux density B of the mean magnetic field modulus from the Zeeman splittings of HD 215441:

Ion	Landé Factor	B
Fe II λ5962	1.2	31 kG
Fe II λ5018	1.9	30 kG
Fe II λ4924	1.7	28 kG
Ti II λ4805	1.2	44 kG
Fe II λ4657	1.7	33 kG
Cr II λ4559	1.2	34 kG
Measured mean value:		~33 kG
H. Babcock, 1960:		~34 kG

Quasar 3C273, Redshift of the Hydrogen Balmer Lines

Wavelengths, determined with Vspec at Gaussian fits, are indicated as red shifted

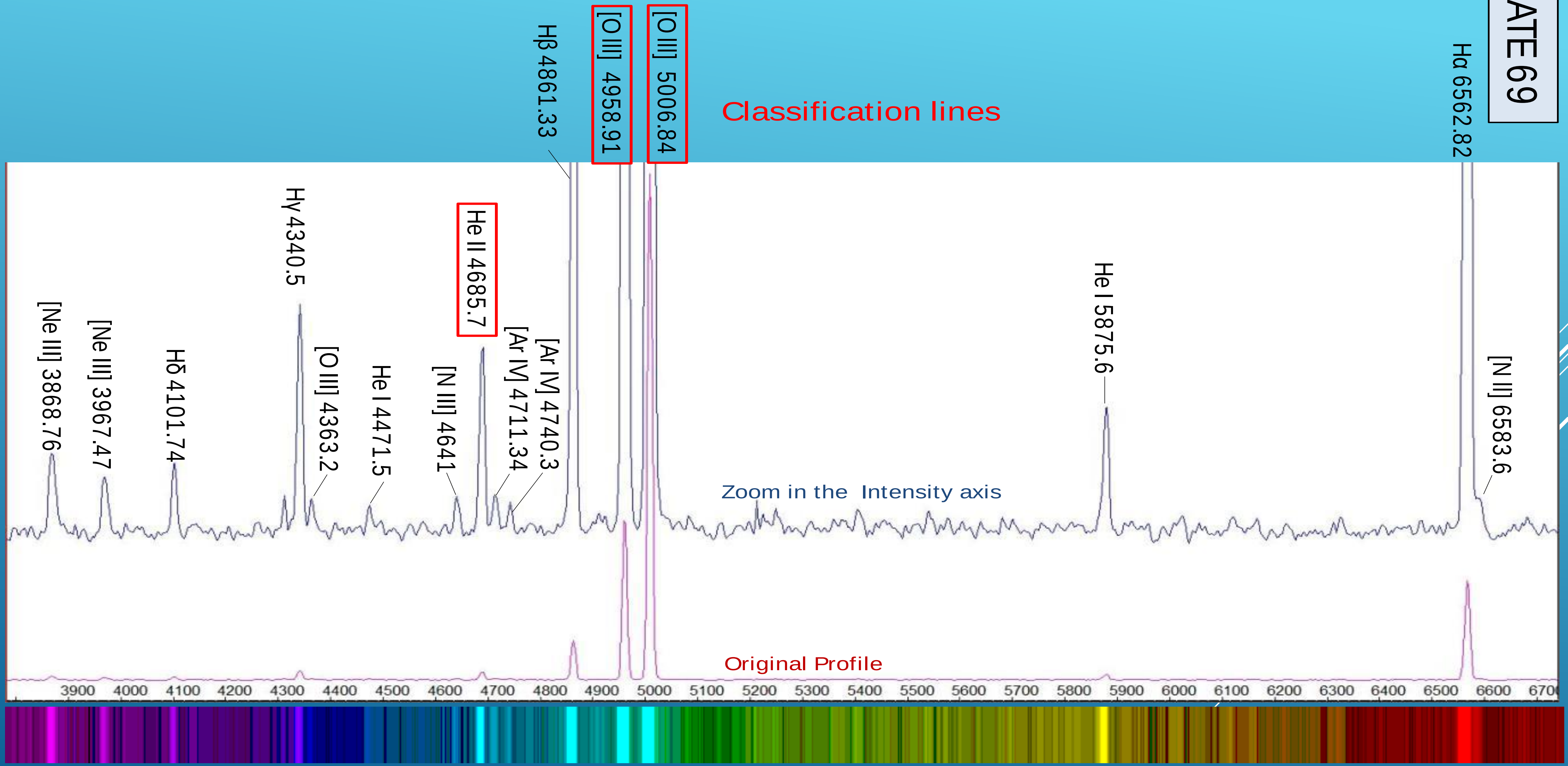


COMPLETE SPECTROSCOPY
For AMATEUR ASTRONOMERS

Saturn Nebula NGC 7009

Criterion log $(I_{N1+N2} / I_{He\ II\ (4686)}) \approx 1.9$ → Excitation class E8

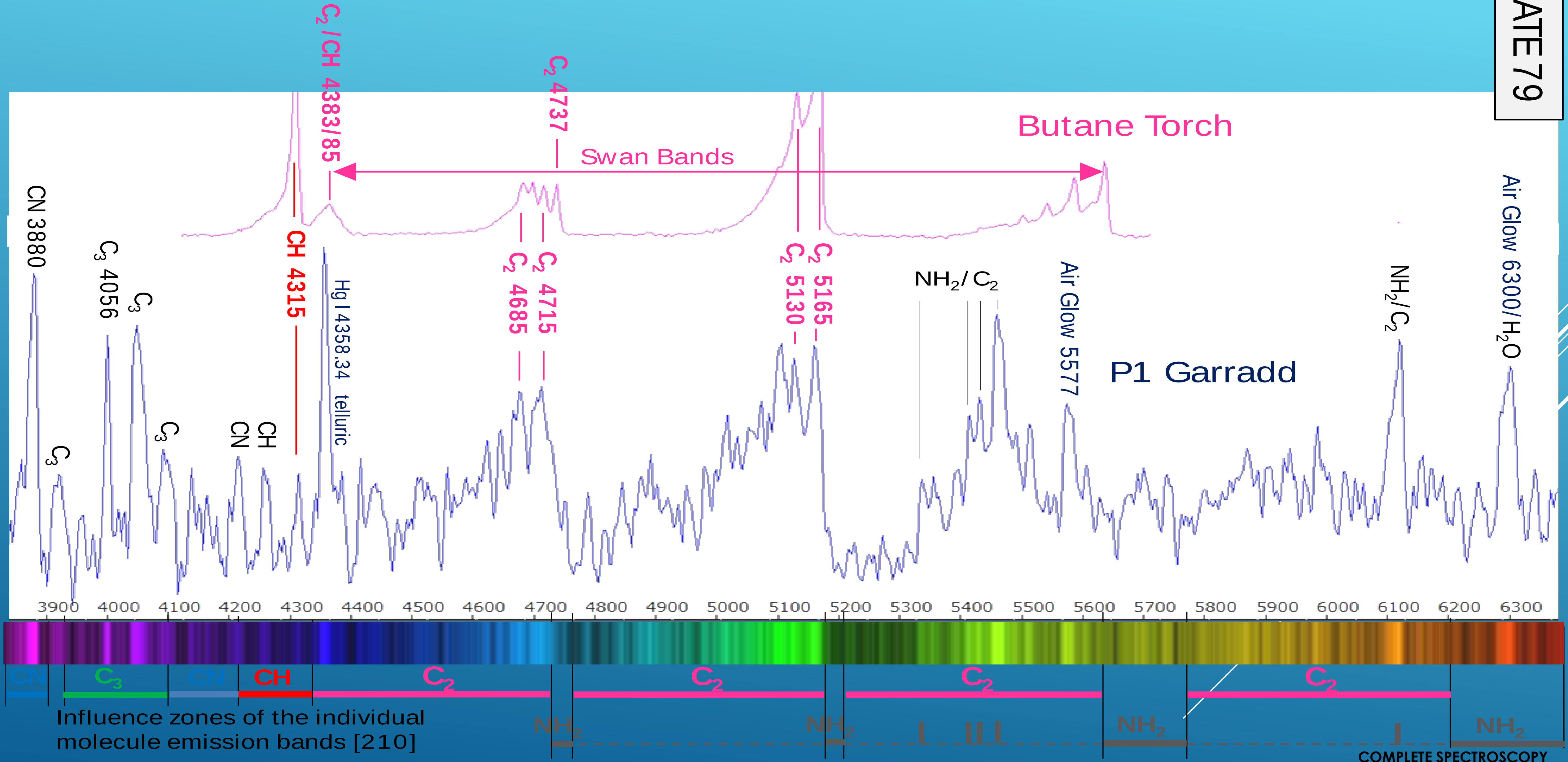
PLATE 69



COMPLETE SPECTROSCOPY
For AMATEUR ASTRONOMERS

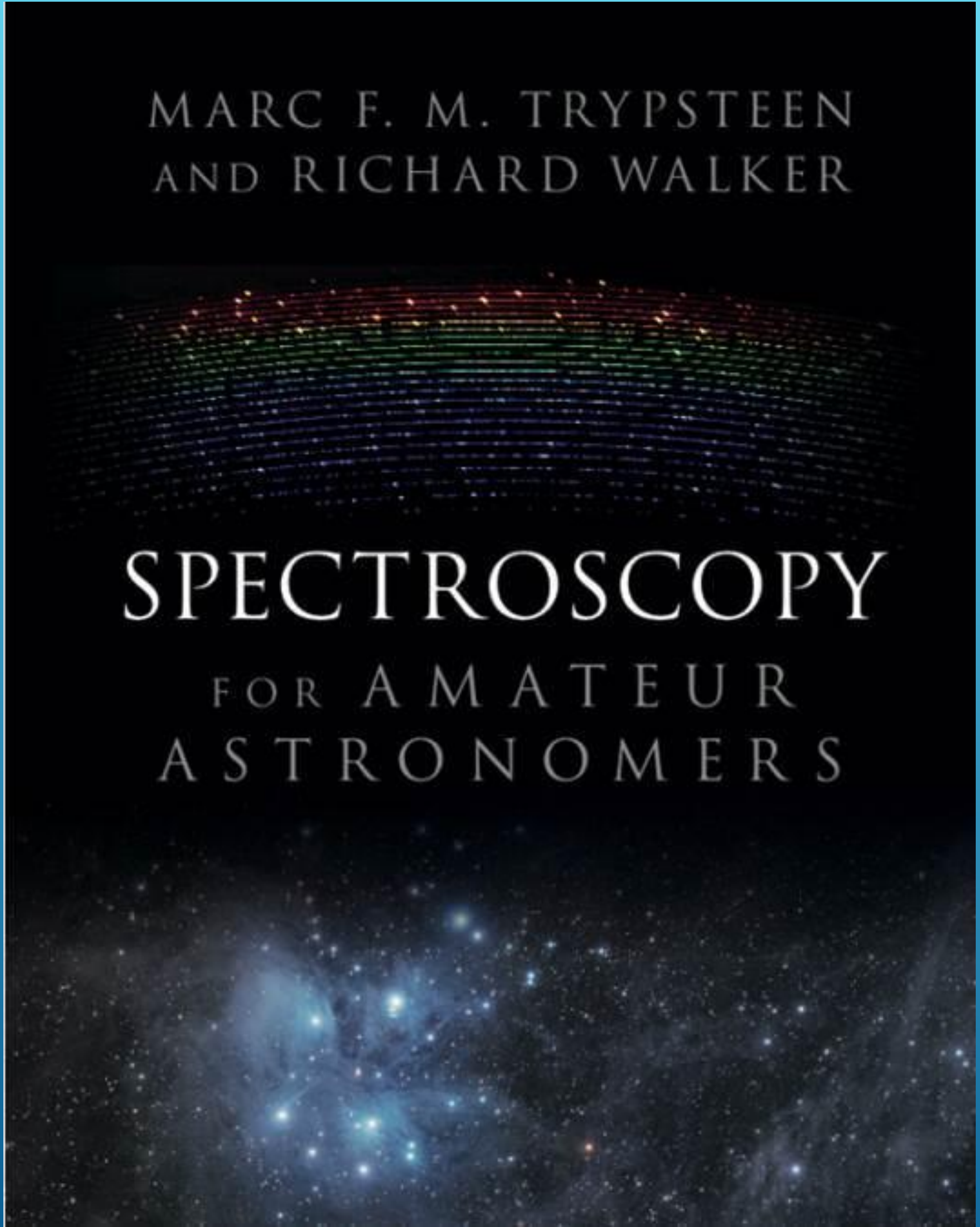
Coma-Spectrum Comet C/2009 P1 Garradd

PLATE 79



Influence zones of the individual
molecule emission bands [210]

VOLUME 2


MARC F. M. TRYPSTEEN
AND RICHARD WALKER

SPECTROSCOPY
FOR AMATEUR
ASTRONOMERS

- Acknowledgements
- While working for the Spectral atlas quite soon the necessity for a separate book became obvious, which would relieve the atlas from theoretical and practical matters. This way the amateur astronomer has at his disposal a second book, which provides supplementary information and interesting astrophysical applications, customized to his specific needs. Parallel to the atlas it fills the gap between theoretical knowledge and practical astronomical spectroscopy, simultaneously opening the way to a more professional approach, a "conditio sine qua non" for a successful participation in Pro-Am spectroscopy projects. For this multidisciplinary task we wish to thank all people involved for their valuable advices and cooperation. The numerous e-mails between us and colleagues, amateurs, professionals, companies and friends have been a tremendous help for the fine-tuning of this work. Therefore the many persons, already involved and mentioned in this context with respect to the realization of the spectral atlas, deserve here our acknowledgement. Anyway we hope for understanding if not all are here mentioned individually again.
- Special thanks go to the company representatives or manufacturers of astronomical spectrographs, being : Johannes & Thomas Baader (Baader Planetarium, Germany), Martin Huwiler (Eagle Owl Optics, Switzerland), Terry Platt (Starlight Xpress, UK), Daniel Sablowski Astro Spectroscopy Instruments, Germany), Olivier Thizy (Shelyak, France), Mark Woodward & Ken Harrison (JTW astronomy, The Netherlands) for their willingness to provide detailed technical information and illustrations on their spectrographs. We are also grateful for their continuous efforts to offer entry level and research grade spectrographs for personal, educational and scientific cooperative projects. Additionally a special recognition is headed here to Martin Huwiler, who substantially contributed to chapters, containing optical and/or practical aspects.
- An especially high effort required the search for information about the calibration of the spectral flux density, revealing here a lack of appropriate publications, treating this topic not just fragmentary but rather comprehensively. To provide here a somewhat reasonable overview, tailored to the needs of the amateur, the information had tediously to be gathered from numerous sources. In addition further supplementary inputs had to be obtained, and many points to be clarified, by intense and sometimes even controversial discussions with many amateurs and even some professionals. Thus specific thanks deserve here all, having proofed patience and contributed in any kind to this chapter.
- Our deepest gratitude goes to our wives, children and other family members for their support, interest and patience during all phases before and under the editorial process. Finally of course we generally want to express our warmest thanks to everyone who contributed in any kind to this book.
- Marc Trypsteen
- Richard Walker

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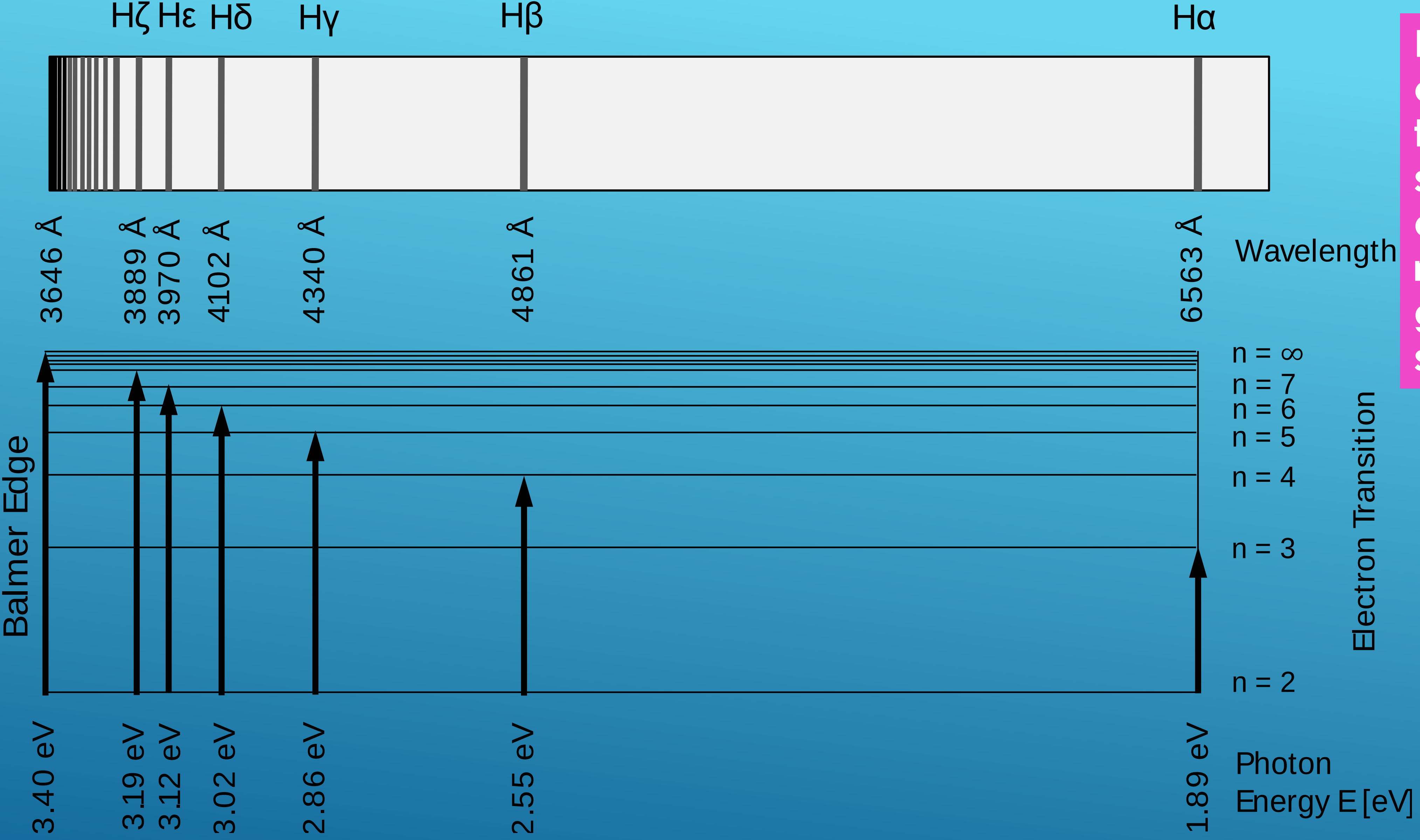
This work covers broad theoretical background- and practical approaches necessary for a successful recording and interpretation of astronomical spectra. The perfect companion of the Spectral Atlas and additionally filling the gap with professional environment



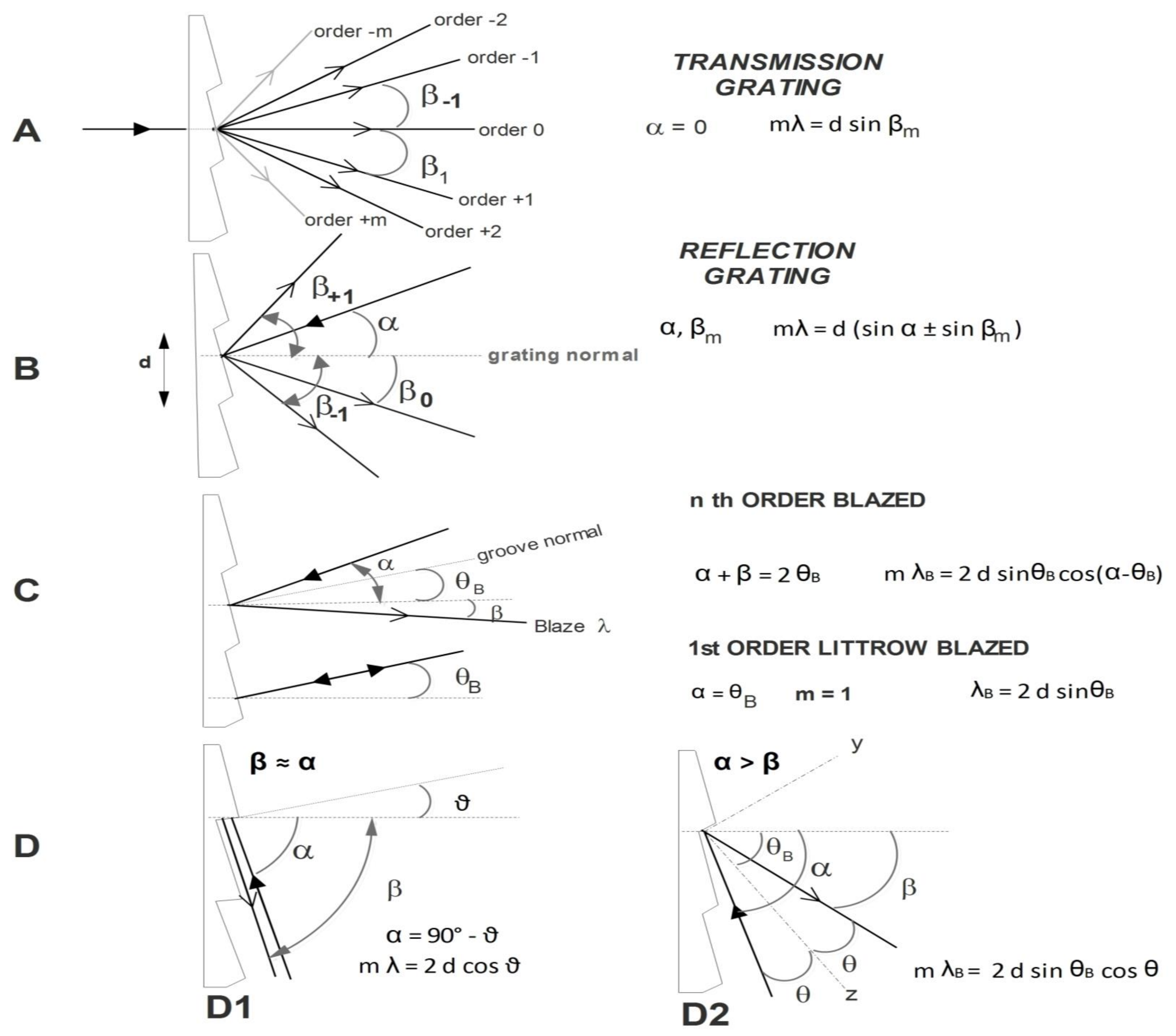
Direct visualisation of the link between the recorded spectrum and the electron transitions responsible for the generation of the spectrum

Dispersion	By Refraction	By Diffraction
Bending	Blue side > Red side	Red side > Blue side
Causing Mechanism	Push/Pull on electrons Absorption/Re-emission	λ versus slit opening Dimension difference
Examples	Rainbow, Prism spectrographs	Transmission-/Reflective grating spectrographs

Clear overviews by tables for a quick insight and memorization

ALL-IN-ONE ILLUSTRATIONS RESULTING IN:

- Better insight
- Direct comparison
- Instant overview of different possibilities



TRANSMISSION GRATING

$\alpha = 0$ $m\lambda = d \sin \beta_m$

REFLECTION GRATING

α, β_m $m\lambda = d\,(\sin \alpha \pm \sin \beta_m)$

n th ORDER BLAZED

$\alpha + \beta = 2\,\theta_B$ $m\,\lambda_B = 2\,d\,\sin\theta_B \cos(\alpha - \theta_B)$

1st ORDER LITTROW BLAZED

$\alpha = \theta_B$ **m = 1** $\lambda_B = 2\,d\,\sin\theta_B$

$\beta \approx \alpha$

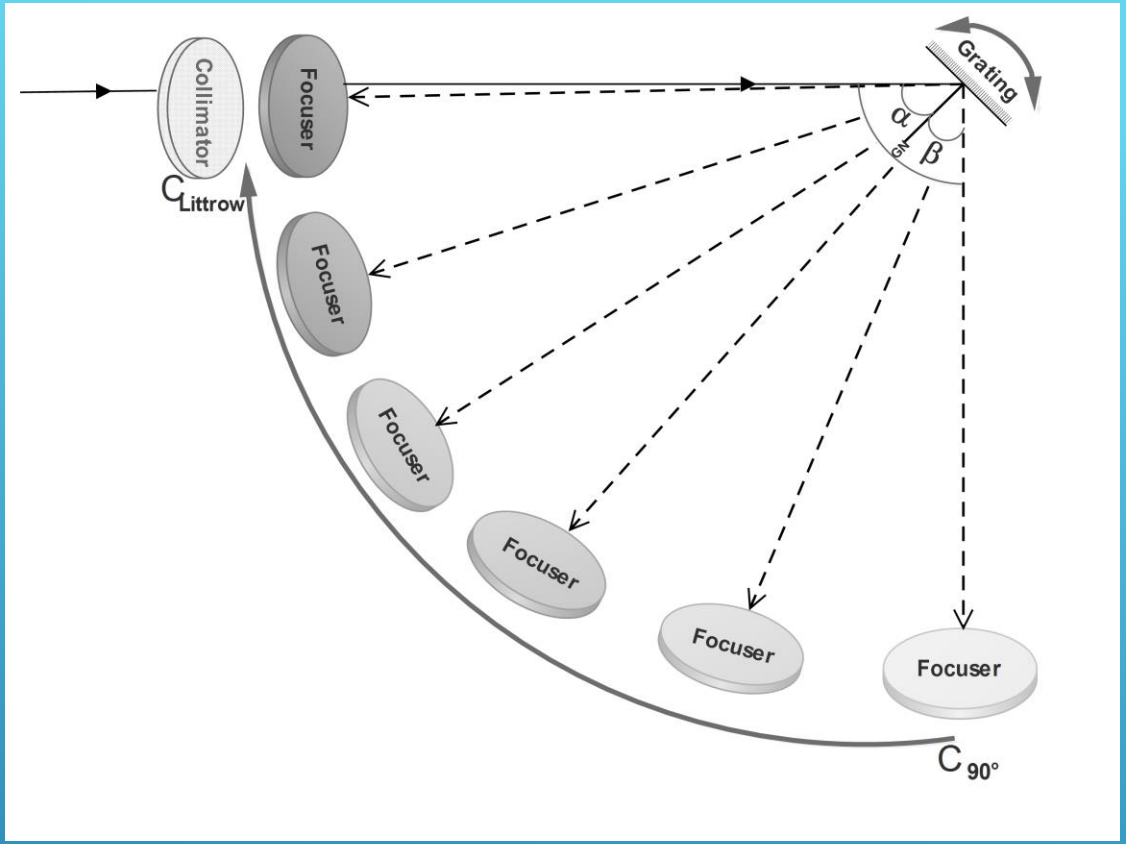
$\alpha = 90° - \vartheta$

$m\,\lambda = 2\,d\,\cos\vartheta$

$\alpha > \beta$

$m\,\lambda_B = 2\,d\,\sin\theta_B\,\cos\theta$

At the starting position the sum of both angles is $\alpha + \beta = 90°$. Depending on the chosen or desired geometry the value of $\alpha \pm \beta$ is a typical parameter of the spectrograph. As a result this total angle between the incident rays at the collimator and the diffracted rays collected by the focuser can be fixed going from 90° to a small angle value indicated in Fig. 5.3 from $C_{90°}$ to C_{Littrow}, where C corresponds to type C from Fig. 4.10. The selected configuration influences the overall performance but also the limitations of the spectrograph. Turning the focuser to the left so that the angle to the grating normal becomes $\beta < \alpha$, empirically improves the spectral resolution. At the endpoint the focuser and the collimator are working together representing the idea of the small angle Littrow configuration ($\lambda_B = 2d \sin \Theta_B$ in Fig. 4.10). Which concept can finally be used depends on the optical design of collimator and focuser, the blaze angle of the grating and the resulting linear dispersion. It depends further on the intended area of astronomical applications.



Resolving Power R	Spectral Information
150 – 2000	Wide field spectroscopic surveys eg by objective prisms General determination of spectral features eg emissions or absorptions Spectral Energy Distribution (SED curves) Redshift of very faint Quasars and Galaxies General Stellar Spectral Classification Classification of faint Novae and Supernovae Excitation class of emission nebulae
2000 – 9000	Details for Stellar Spectral Classification Spectral details of brighter galaxies Quasars and Supernovae Identification of molecules and elements Analysis of element abundance and metallicity
10,000 – 20,000	Detailed analysis of line profiles eg for disks of Be stars Rotation velocities of planets and stars Stellar temperature, analysis of particular sensitive lines
20,000 – 50,000	Detailed analysis of line profiles (eg for Wilson Bappu effect) High precision measurements of radial velocities Analysis of solar and stellar magnetic fields by Zeeman effect
50,000 – 100,000	For very large telescopes: Doppler analysis and mapping of winds, circumstellar and proto-planetary disks, flares, interstellar medium
> 100,000	For very large telescopes: Atmospheric structures, Thermal broadening, Analysis of Interstellar lines, Chemical composition of exoplanetary atmospheres. For solar telescopes: Detailed analysis of solar surface and granulation

Each of the discussed spectrographs has its own characteristics and applications. Depending on which astronomical object will be studied the resolving power of the spectrograph plays a key role in the choice. An important turning point to be able to analyze line profiles and Doppler shifts is a value of R=10,000. Such details are highly demanded by professional astronomers. Therefore high resolution spectrographs are essential for Pro-Am collaborative projects. Tab. 5.4 represents a rough overview of the type of spectral information that can be found in the recorded spectrum with increasing resolving power R [8].

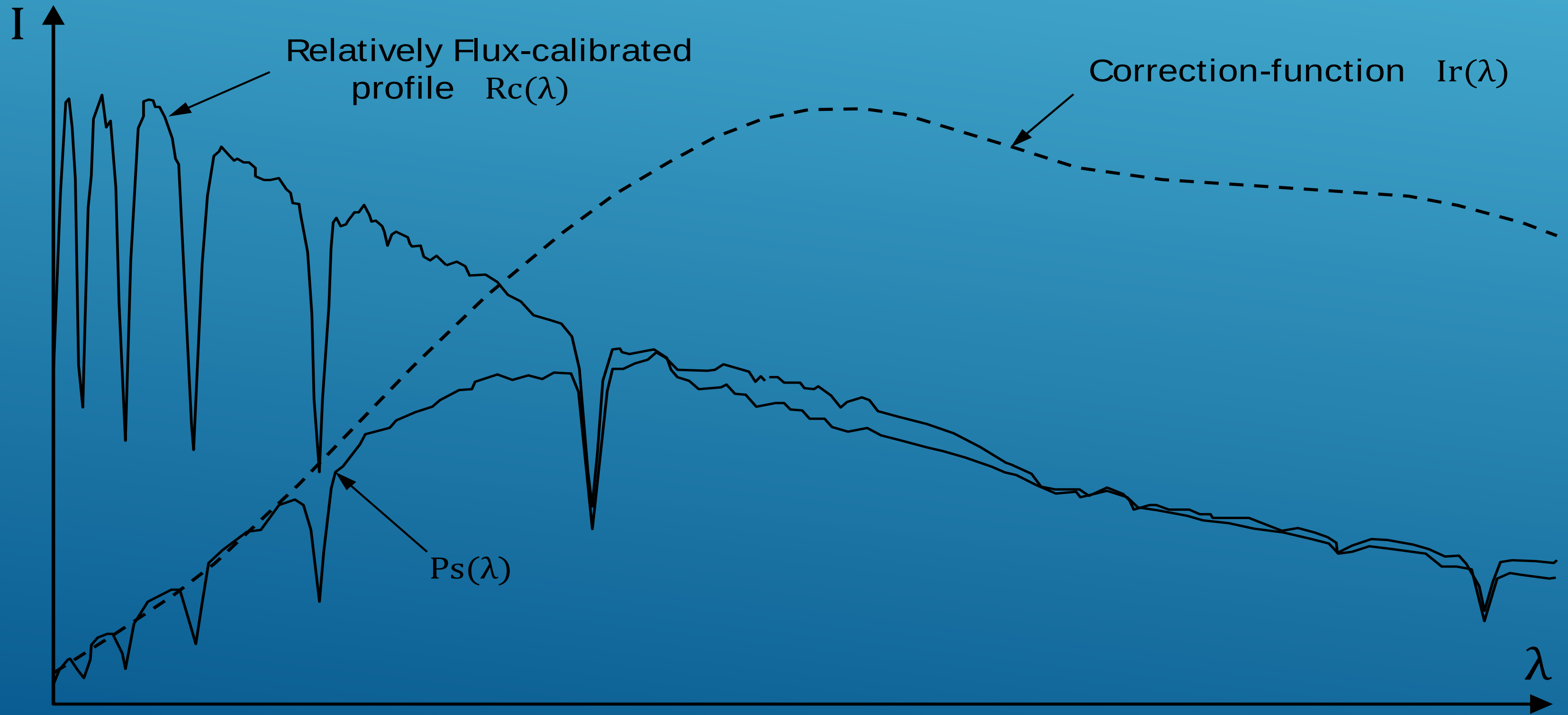
However it makes no sense in any case to strive for the highest possible resolution. As a general rule: The higher the resolving power the longer the required exposure time. Thus for high resolution analysis of faint objects accordingly large professional telescopes are needed. Even with such equipment, for extremely distant and accordingly faint Quasars and Supernovae, low resolution spectrographs are applied. Further for rough stellar classification lowly resolved broadband spectra are preferred, displaying on a glance all relevant, spectral features.

In a rough approximation $\mathbf{Ir}(\lambda)$ corresponds here to the "attenuation-function" $D_{Tot}(\lambda)$, according eq. {8.1} and {8.2}.

$$\mathbf{Ir}(\lambda) \approx D_{Tot}(\lambda) \qquad \{8.11\}$$

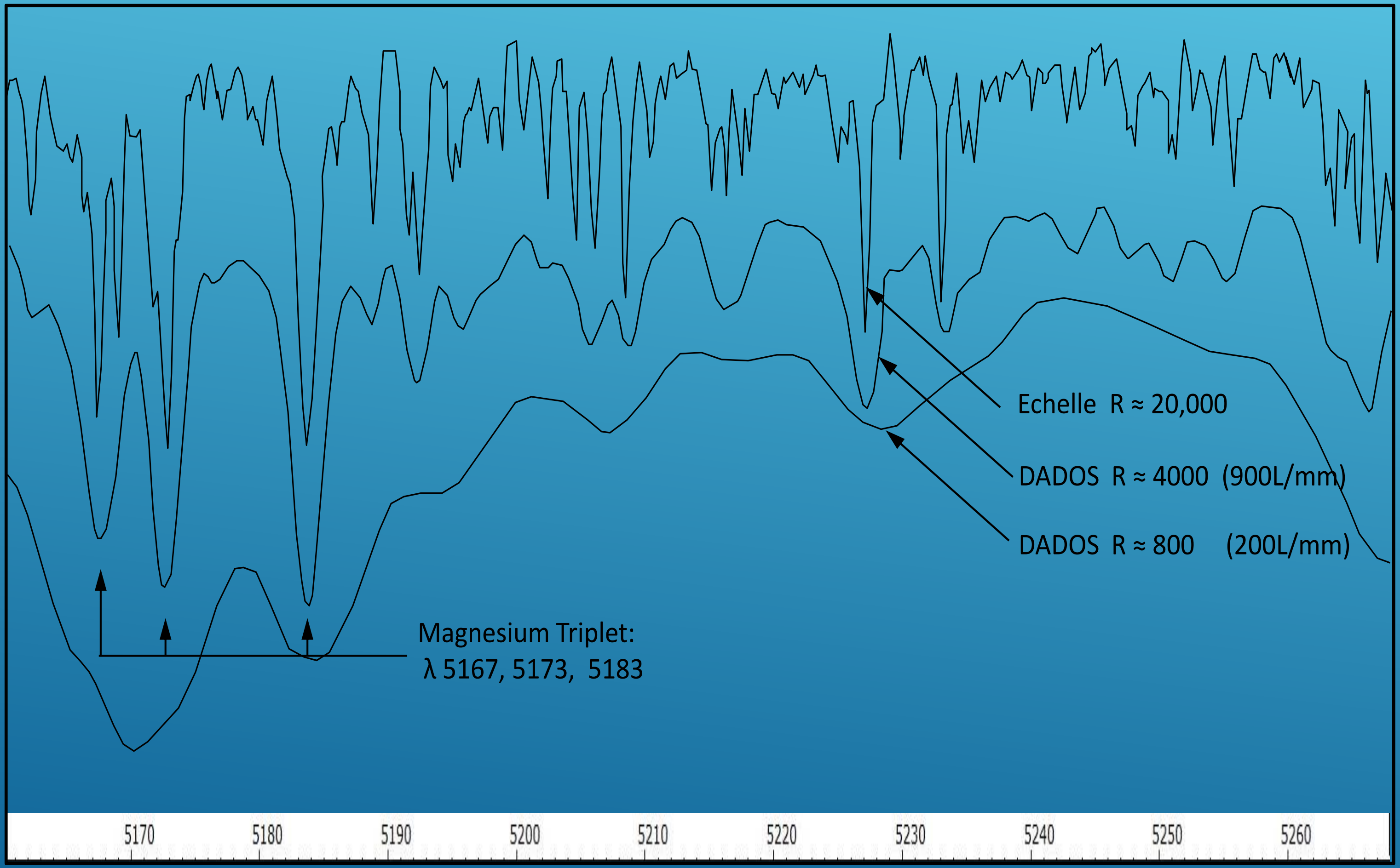
Finally the division of the pseudo-continuum $\mathbf{Ps}(\lambda)$ by the correction-function $\mathbf{Ir}(\lambda)$, results in the relatively flux-calibrated profile $\mathbf{Rc}(\lambda)$. It shows now the same continuum course like the smoothed reference profile $Ms_{Fit}(\lambda)$ in Fig. 8.6, but appears now overprinted with the accordingly scaled lines of the recorded profile.

$$\mathbf{Rc}(\lambda) = \mathbf{Ps}(\lambda)/\mathbf{Ir}(\lambda) \qquad \{8.12\}$$



Influence of the Spectrograph Resolution on the FWHM- and EW Values

The spectral profiles of the Sun in Fig. 9.7, recorded with differently high resolutions show the influence on the recorded spectral lines. The R-values are here within a range of approximately 800 – 20,000.



Influence of the spectral resolution on the recorded spectral lines (Huwiler / Walker)

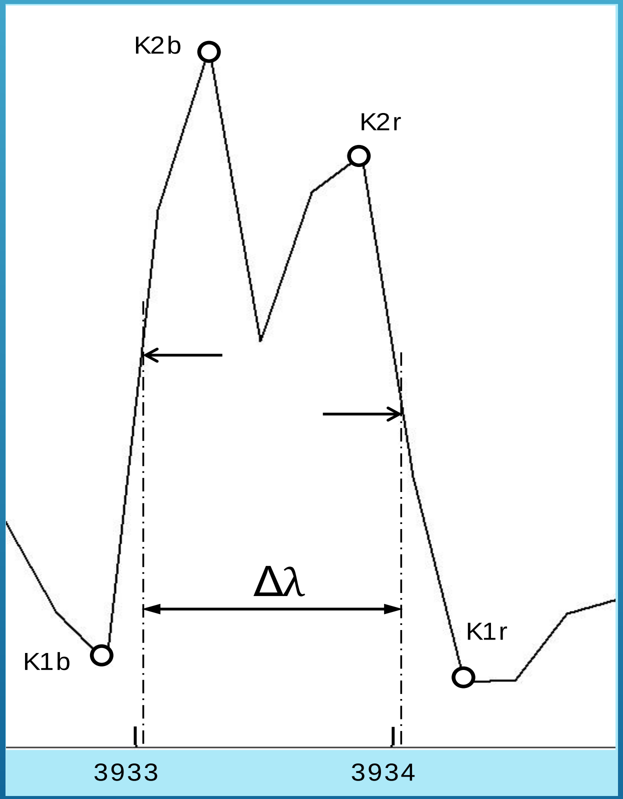
Wilson-Bappu Effect

A possible way to use also giants from the spectral classes G –M for the spectroscopic distance estimation is to apply the Wilson-Bappu effect. Already 1957 O. Wilson and K. Bappu discovered a remarkable correlation between the measured width of the small emission in the core of the Ca II K-line (λ3933.66) and the absolute visual magnitude of Giants. For amateurs with high resolution spectrographs (R~20'000) this is an interesting field for experiments. Fig. 10.9 shows a strong zoom on the according emission core of Arcturus, fully displayed in the spectral atlas [1]. It shows how the width Δλ is measured, i.e. on each side of the line at half intensity between K1 and K2. Here follows, in a long sequence since the 1960ies, the most recent calibration [128] of this empirical law:

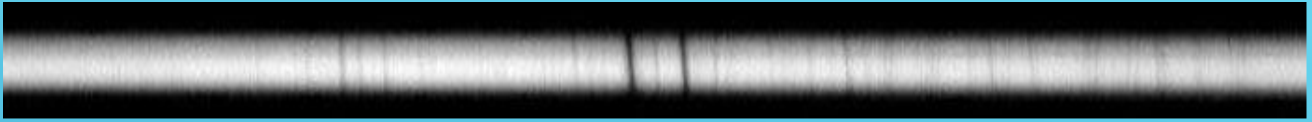
$$Mv=33.2-18\cdot\log W0 \qquad 10.1 \qquad \text{where} \quad W0=\Delta\lambda/\lambda0\cdot c$$

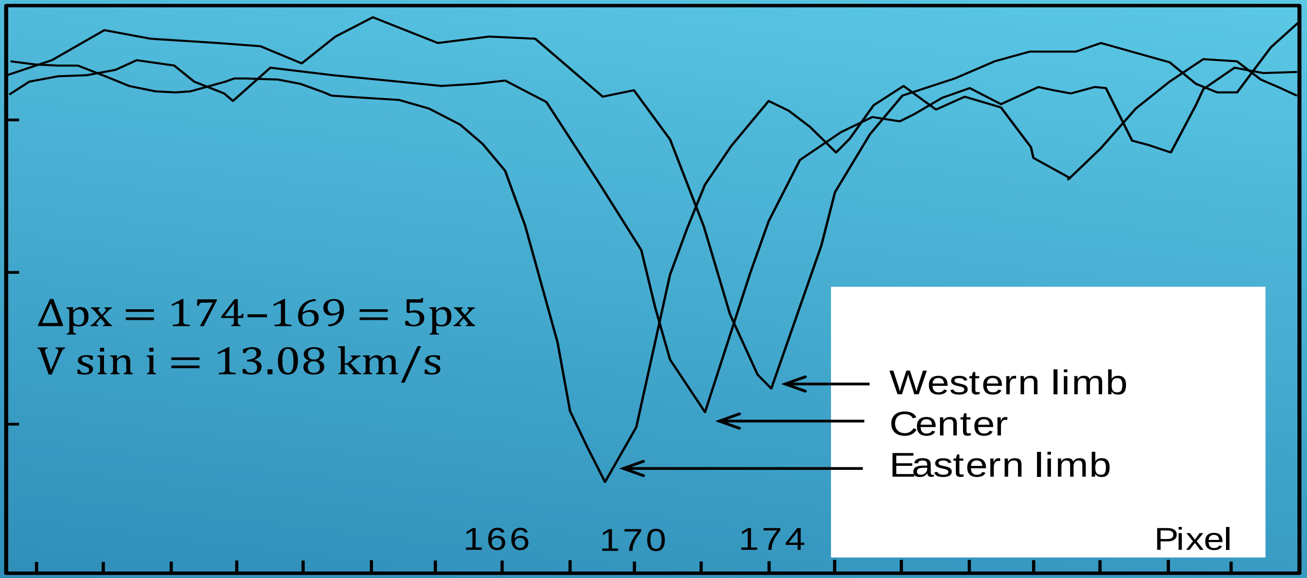
Ca II K-line is preferred for this analysis because it has been revealed that in high resolution spectroscopy the Ca II H-line is often contaminated by other adjacent lines.

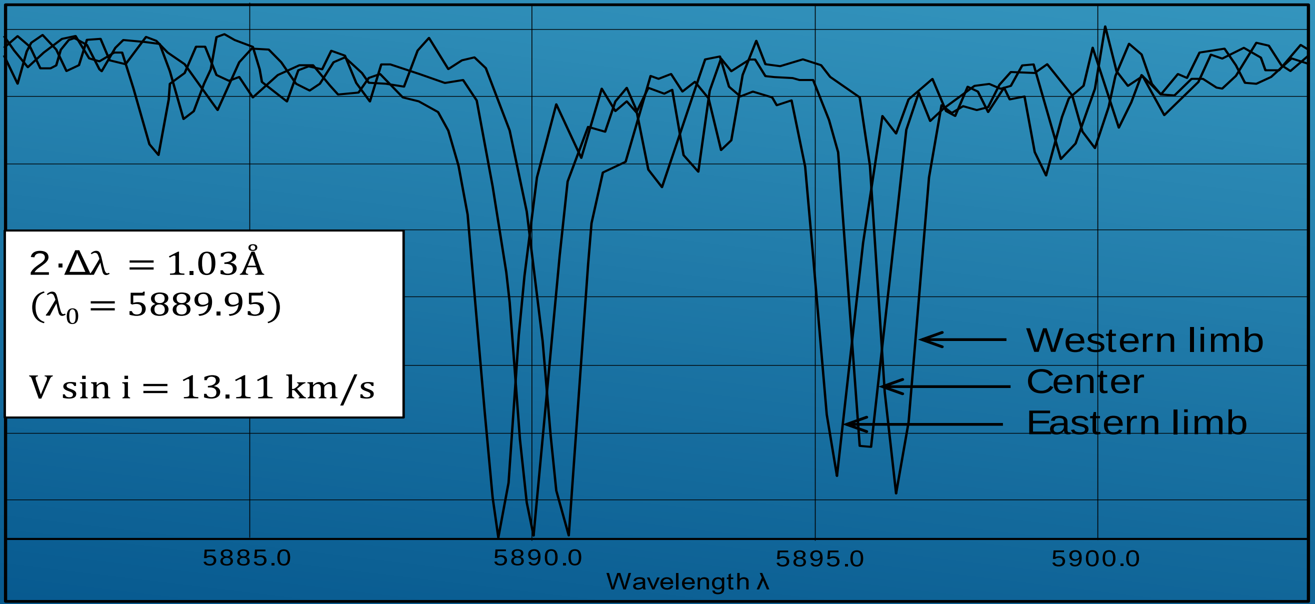
Synchronised with the Spectral Atlas, Volume 2 focuses in detail on the theory behind the observed effects and their useful practical applications

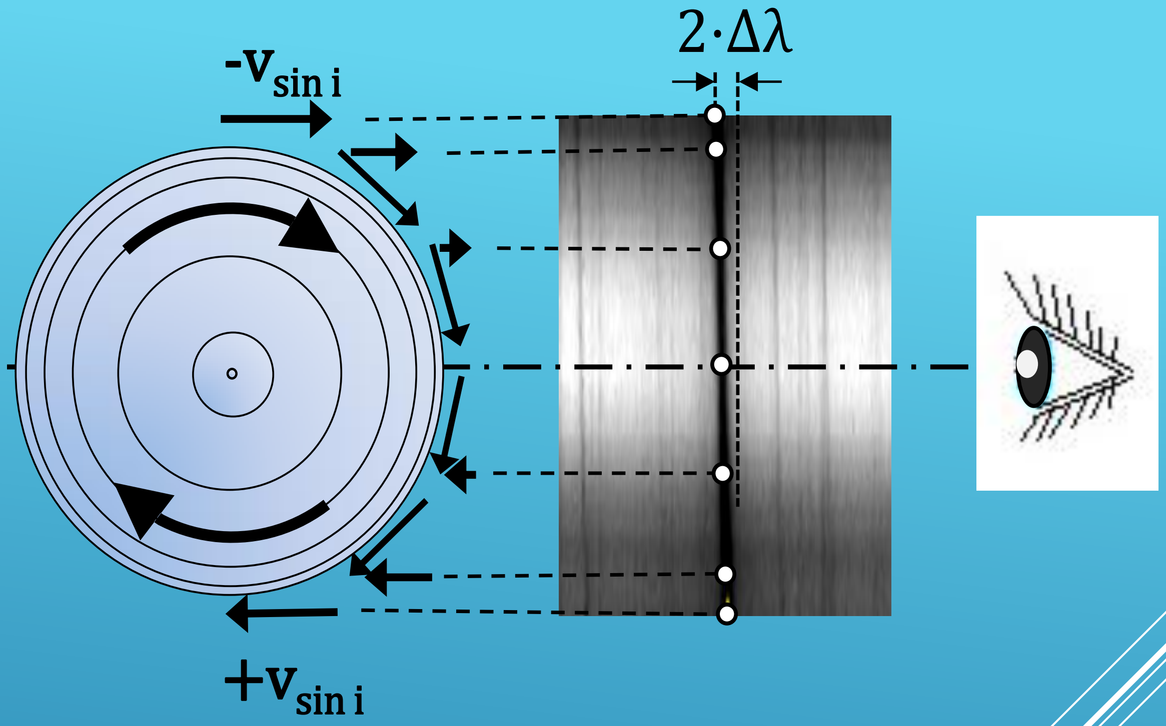


DIRECT VIEW SKETCHES AND ILLUSTRATIONS FOR PROFOUND INTERPRETATION OF THE RECORDED SPECTRUM



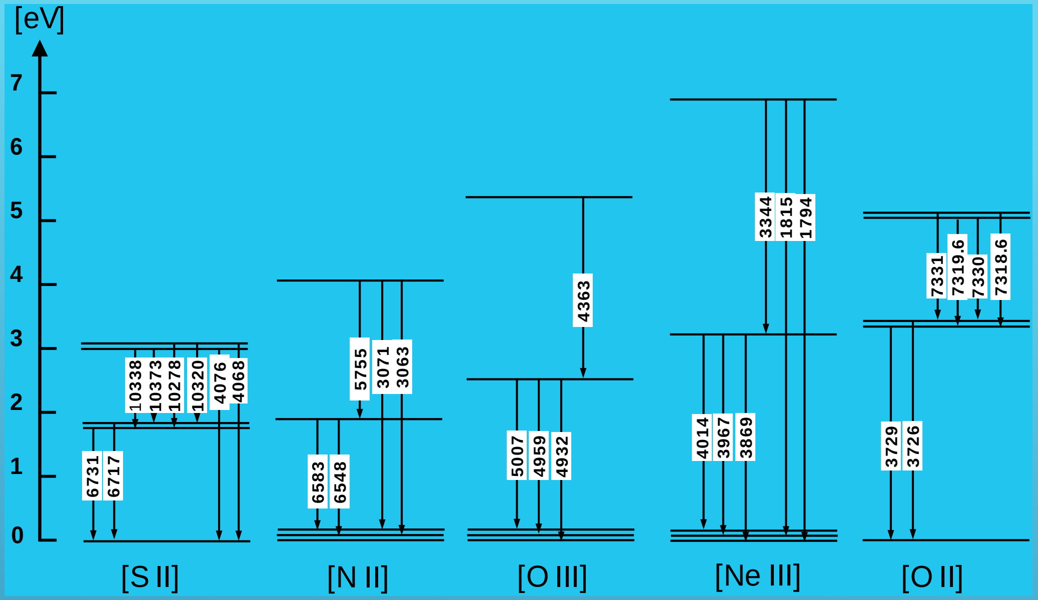


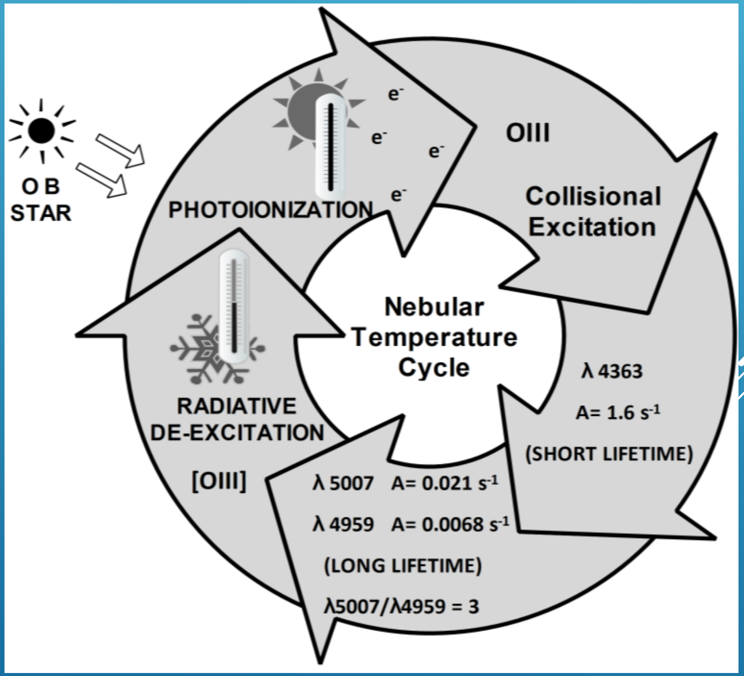


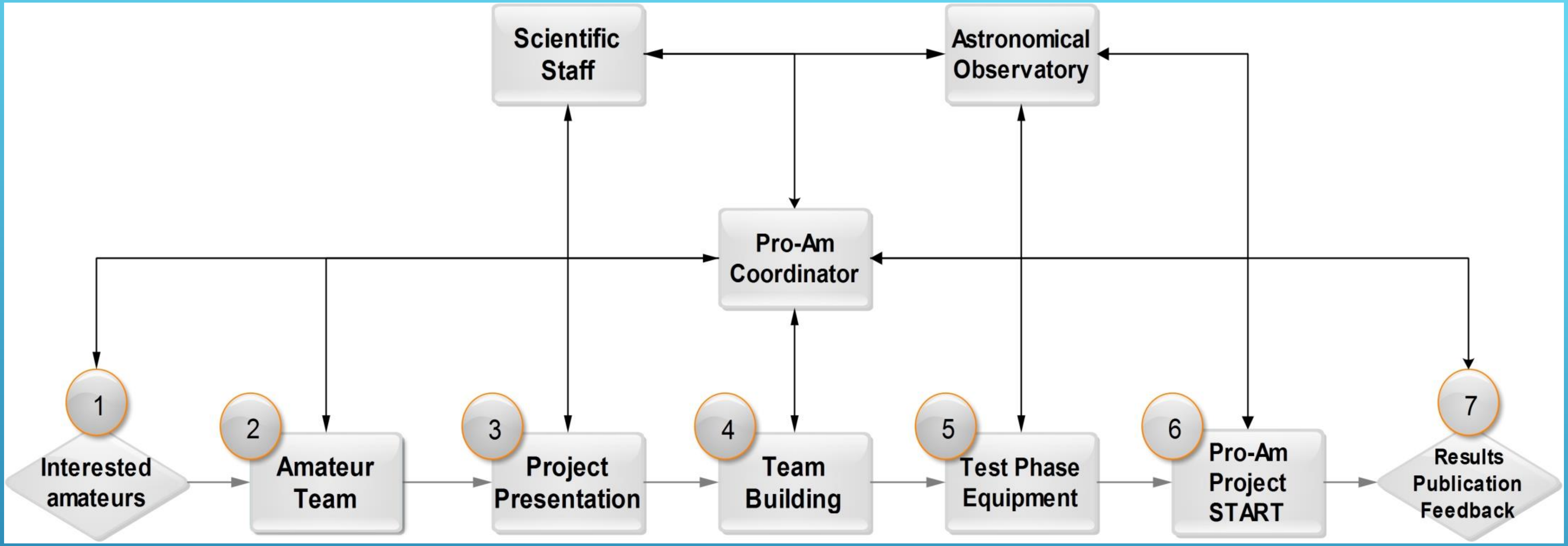


Cooling Mechanism by Forbidden Transitions

- Here, at the example of the [O III] transitions, the important contribution of the forbidden transitions to the cooling mechanism in emission nebula is considered more closely. The scheme in Fig. 14.8 shows the nebular temperature cycle, displaying the photoionization of the hydrogen atoms by a neighboring OB type star, causing a fast rise of the electron temperature. The generated free electrons collide with already ionized metals such as O III (O^{++}). As mentioned above the kinetic energies of the free moving electrons are within the rough range of the differences 2.5 and 2.8 eV, indicated in Fig. 14.6, causing collision-excitation up to the higher metastable energy levels $^1S_0$ and $^1D_2$. Depending on their electron population radiative de-excitation occurs which ends on one of the of the fine-structure levels of O III (O^{++}). This way observable emission lines are generated in the visible wavelength range. In the Spectral Atlas [1] most profiles of the numerous documented emission nebulae show the intense [O III] lines at λ5007 and λ4959, whereas λ4363 appears as a very tiny bump just in the highly excited Planetary Nebula NGC 7009. Therefore the emissions at λ5007 and λ4959 are here the main cooling forces. As a result of consecutive radiative emissions the electron temperature drops and an efficient "cooling" mechanism is activated. After several cycles a thermal equilibrium is reached and the electron temperature stabilizes (Fig. 14.7 and 14.8).

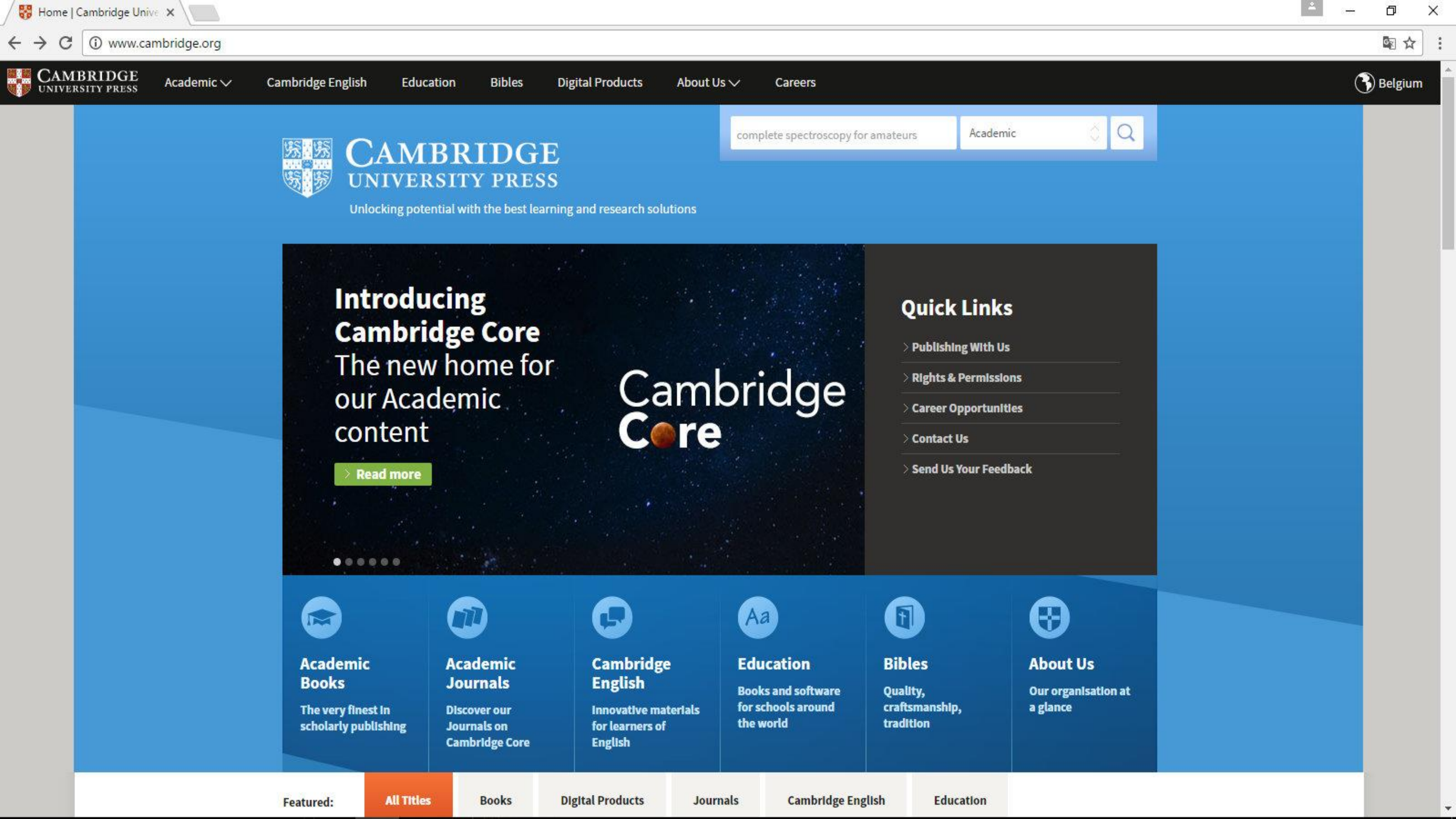






Phase 1: Interested amateurs

An Important message to all interested amateurs that must be clear at the very beginning is that a Pro-Am collaboration is a high quality science project. The primary goal of this collaboration is to make a contribution to scientific work which can be a (funded) local or cross-border project. Sometimes it can also be organized as a contribution to a PHD or postdoctoral teamwork. The first task for the Pro-Am coordinator is to thoroughly inform interested amateurs about the philosophy of the Pro-Am collaboration to avoid overall deception afterwards.



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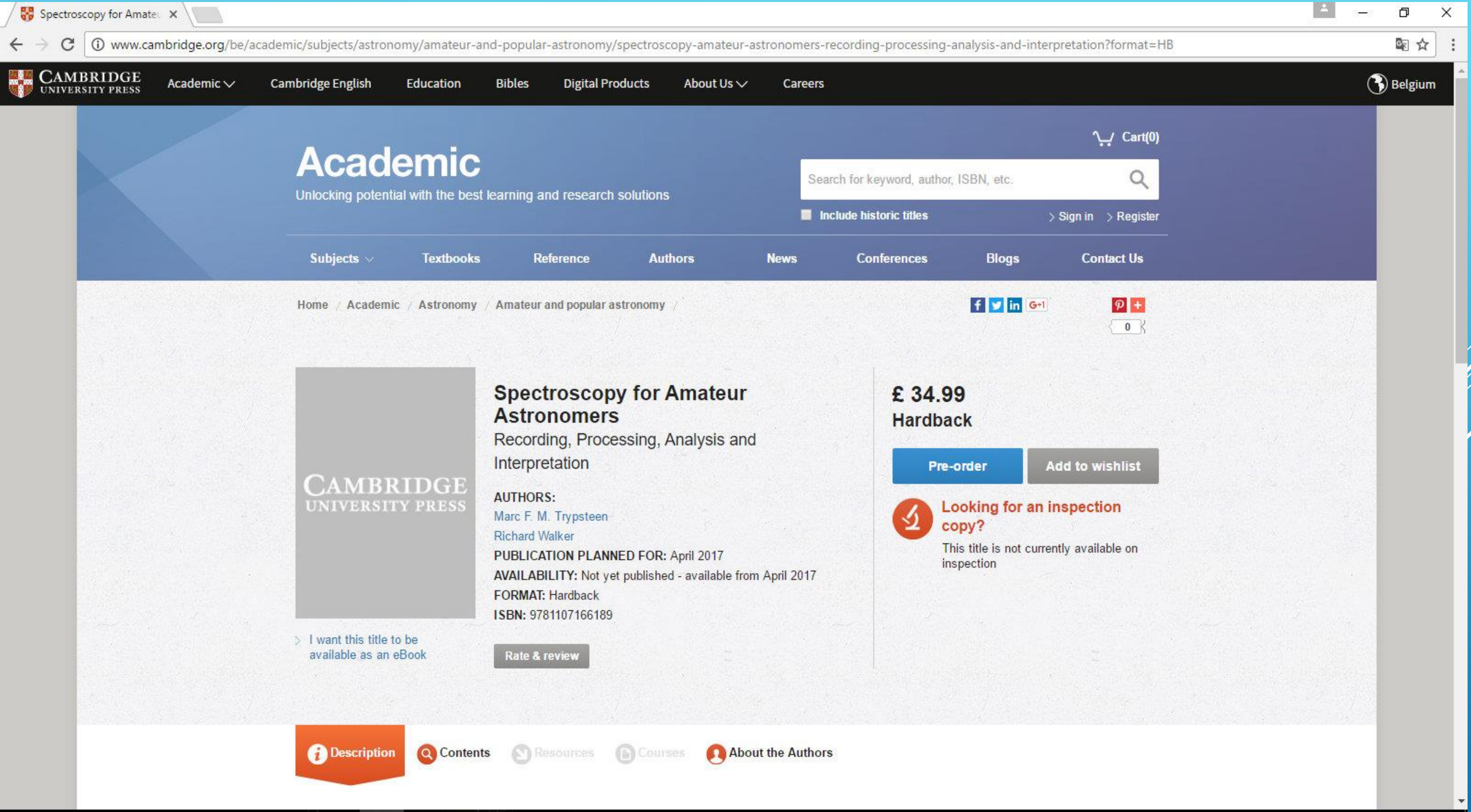

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Spectroscopy for Amateur Astronomers

Recording, Processing, Analysis and Interpretation

AUTHORS:

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Richard Walker

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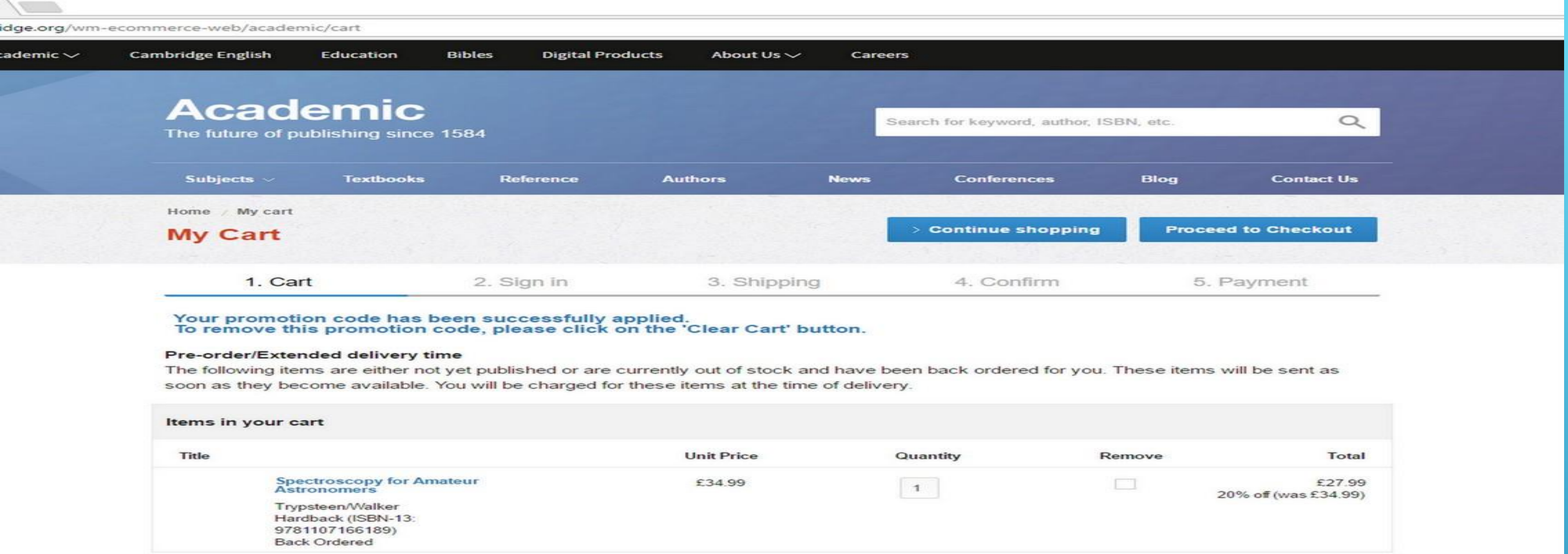

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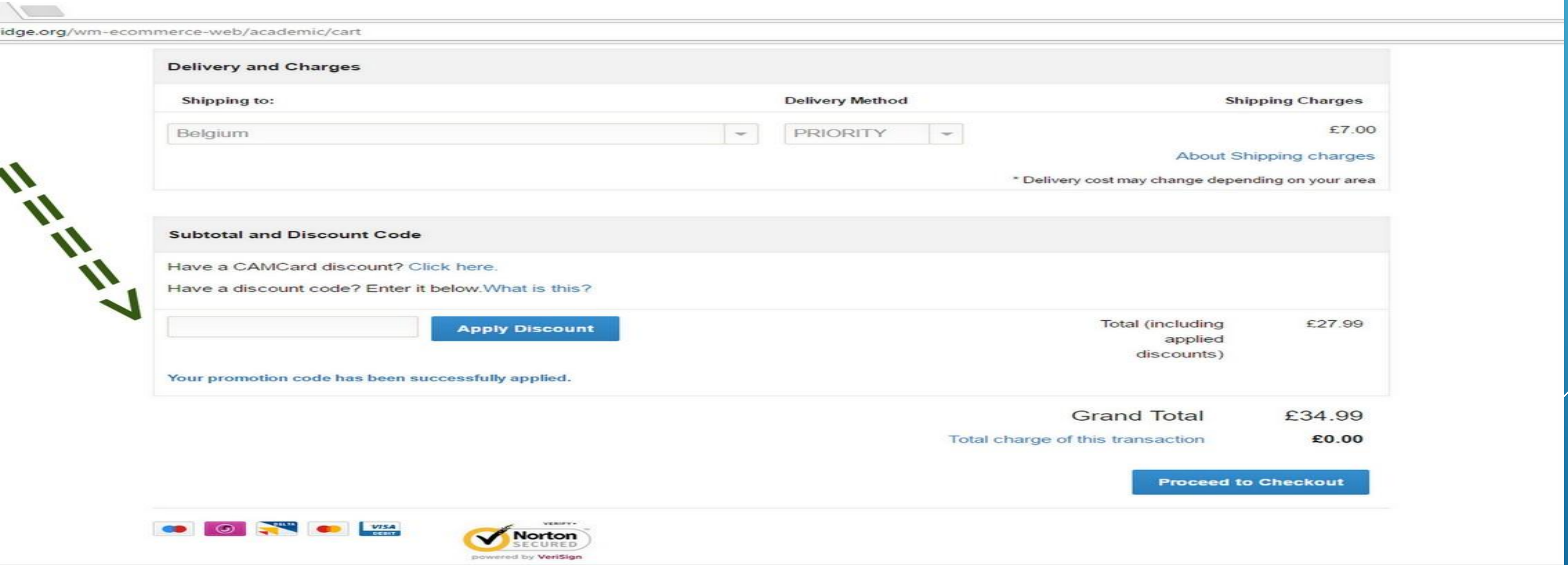

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