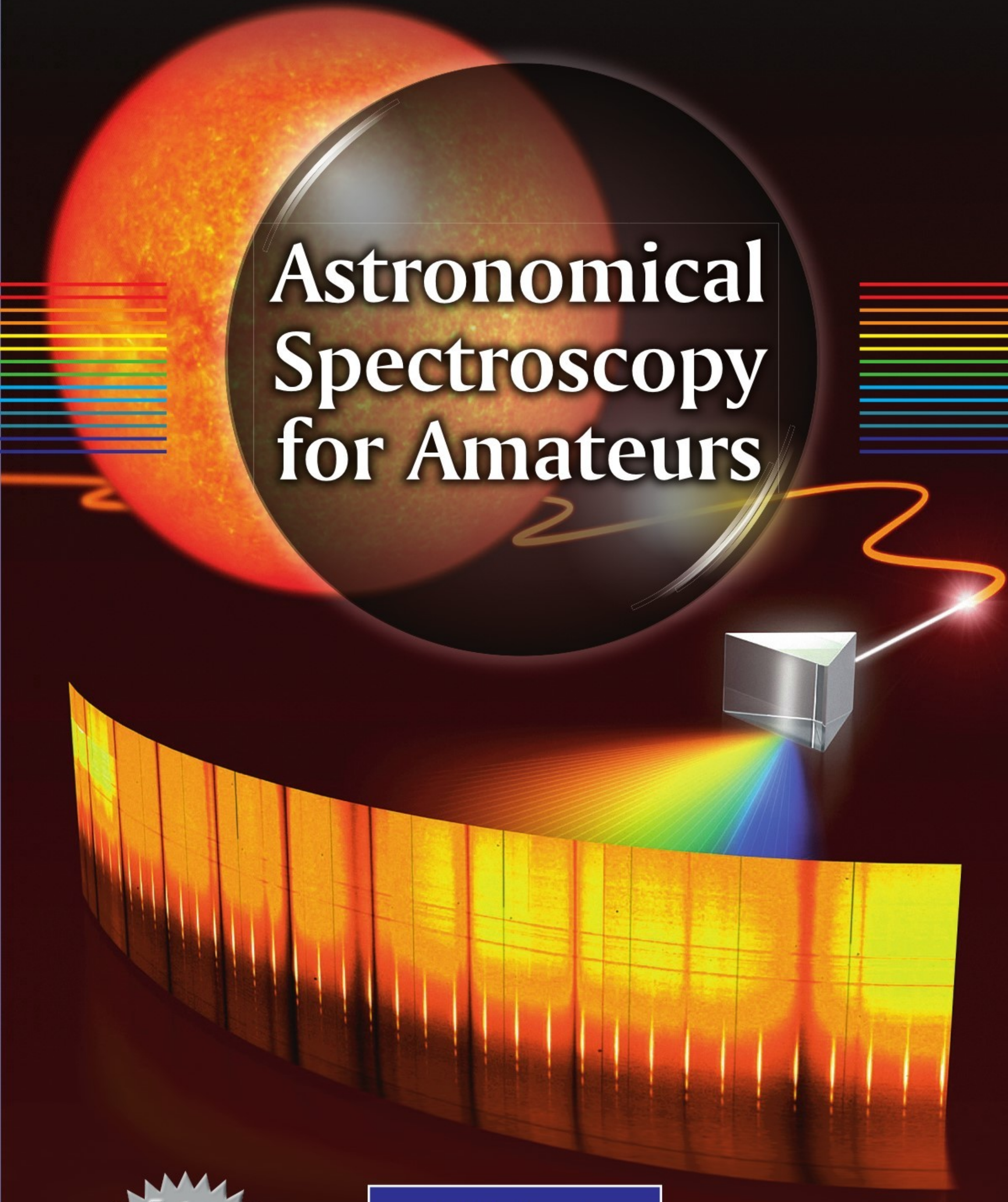
Ken M. Harrison

Astronomical Spectroscopy for Amateurs



Extra Materials
extras.springer.com

Patrick Moore's
Practical Astronomy
Series

Patrick Moore's Practical Astronomy Series

For other titles published in this series, go to
http://www.springer.com/series/3192

Astronomical Spectroscopy for Amateurs

Ken M. Harrison

Springer

Ken M. Harrison
Cobham, UK

Additional material to this book can be downloaded from http://extras.springer.com

ISSN 1431-9756
ISBN 978-1-4419-7238-5 e-ISBN 978-1-4419-7239-2
DOI 10.1007/978-1-4419-7239-2
Springer New York Dordrecht Heidelberg London

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Preface

There have been three significant milestones in the history of observational astronomy: the invention of the telescope, photography, and the spectroscope. The development of the spectroscope has contributed more to the science than any other telescope accessory. It has been said that 85% of all astronomical discoveries have been made with the spectroscope.

Probably due to the perception that lots of mathematics and calculations are involved, plus the fact that it doesn't have the "Ohh" or "Ahh" impact of some of the spectacular astronomical images now being regularly distributed on the forums and websites, spectroscopy is an area that has been long overlooked and neglected by the amateur. By using amateur telescopes, mountings, and CCD cameras currently available, this book will show how, with the addition of a simple spectroscope we can observe and record spectra that reveal the temperature, composition, and age of stars, the nature of the glowing gases in nebulae, and even the existence of other exoplanets circling around distant stars.

The basic challenge facing the novice is where to start. What equipment will I need? Where can I find a spectroscope? How do I process the CCD image? How do I analyze my first spectrum? These questions and more are addressed in this book. Up to date information on equipment, spectroscopes, and methods available to the amateur, and more importantly "How to. . .".are all included in this book.

There are three basic sections in this book:

1. Introduction to Spectroscopy. This part provides a brief overview of the history of spectroscopy, the theory behind the spectrum lines, and types of spectroscopes.
2. Obtaining and Analyzing Spectra. Tells how to set up and use your spectroscope; describes different commercially available spectroscopes, cameras, and CCD's; explains how to analyze your spectra; and presents some interesting amateur projects.

3. Spectroscope Design and Construction. Here you will find basic spectroscope design ideas and how to construct your own spectroscope.

Each section is independent of the other, so if you want to jump straight into taking your first spectrum, go to the second section and get started!

"Spectroscope" is the generic term for visual spectroscopes, spectrographs (imaging), and spectrometers (linear CCD measuring devices). (Telescopes are not given different names when used with eyepieces, cameras, or filters, so why should spectroscopes?!)

Units of measure are always an issue of debate. Both the SI unit nanometer (nm) and Angstrom units (Å) are widely used in spectroscopy as a measure of wavelength, as are measurements and sizes in millimeters rather than inches.

As you gain practice and experience you may want to increase the resolution of your spectroscope, contribute to the ever-growing list of amateur and pro-am projects, or even construct your own spectroscope. The various sections in this book will guide you through the issues and hopefully answer your questions on all the different aspects of spectroscopy. It's a new and challenging field for amateurs, and with even the most basic of equipment it can be interesting, thought provoking, and most of all fun!

Cobham, UK
February 2010

Ken M. Harrison

Contents

About the Author

A keen amateur astronomer, Ken Harrison was born in Scotland where he trained as a mechanical engineer. He has been designing and building telescopes since the early 1960's and has built a series of spectroscopes for use on medium sized amateur telescopes. He was Section Director of the Astronomical Society of Victoria, Australia, Astrophotographic Section for 10 years and past President of the Society. Ken's university thesis (and his first publication) was *Design and Construction of the Isaac Newton 98-inch Telescope* (Strathclyde University, 1970). Since then he has published articles on optical design including "Blink Comparison" (BAA Journal Vol 87, p 94) and "Method of Radially Supporting Large Mirrors" (Vol 87, p 154). He has made contributions to the Astronomical Society of Victoria Newsletter and was for 3 years the Editor of the "N'Daba" newsletter of the Natal Centre, Astronomical Society of Southern Africa.

PART ONE

Introduction to Spectroscopy

CHAPTER ONE

Early Experiments in Spectroscopy

To the ancient Greeks and other philosophers around the world, light was all-pervasive and a medium connecting visible objects. Aristotle's view of light was something all bodies could have, similar to the element of fire. Early religions associated light with the Sun (as well as heat and life-giving energy) and accepted that it was a gift from the gods. Robert Grosseteste in the early thirteenth century declared light to be the "prima material," the original substance from which the universe was made, "for every natural body has in itself a celestial luminous nature and luminous fire."

The rainbow should have given philosophers cause to ponder more about the nature of light. Instead they rationalized it to be a sign from the gods. For Christians, it was God's covenant that never again would there be a flood like that experienced by Noah (see Fig. 1.1).

Al Farisi and Theodoric of Freiberg around A. D. 1300 showed how the geometry of the raindrop could produce a rainbow, but it wasn't until much later, in 1670, that Isaac Newton (1642–1727) applied his scientific reasoning to the analysis of the Sun's spectrum. He allowed a small beam of sunlight to go through his prism and produce a spectrum. With this he showed that white light is made up of many colors. The original red, yellow, green, blue, and violet were augmented by orange and indigo (to make up a "perfect seven"). ROY G BIV has become our rainbow ever since.

With his experiments in "refraction" Newton concluded that lenses would never give a color-free image (chromatic aberration) and went on to develop his reflecting telescopes as an alternative (see Fig. 1.2).

After Newton there was a hiatus in the scientific use of prisms, and it wasn't until 1750 that a Scot, Thomas Melvill (1726–1753) noted that by adding "burning spirit" to his candle, his prism showed a band of yellow light. At about the same time, John

K.M. Harrison, *Astronomical Spectroscopy for Amateurs*, Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4419-7239-2_1,

Figure 1.1. *A Lesson In The Rainbow,* late fourteenth-century manuscript of "De proprietatibus rerum." (On the Property of Things) by Bartholomaeus Anglicus.

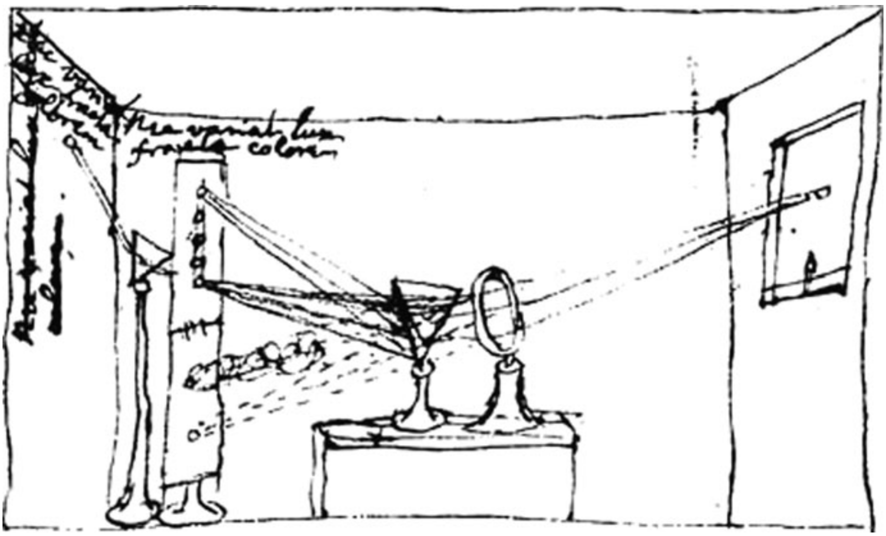


Figure 1.2. Newton's prism experiments. (Courtesy New College Library.)

Dollond (1706–1761), an English optician, appreciated that not all glass dispersed light by the same amount; he found (in 1758) that by combining a clear crown glass and a leaded flint glass that the chromatic aberrations could be significantly reduced. Here we have the first evidence of appreciation that the spectrum produced by different types of glass was different enough to be useful.

There is very little recorded evidence of other spectral experiments in the 1700's until William Herschel (1738–1822) was finally persuaded by his colleague William Watson (1715–1787) to experiment with a prism to view the spectra of the brighter stars. In 1797 he recorded the distribution and intensity of the various colors in the spectra, but did not pursue the interest.

William Hyde Wollaston (1766–1828) improved his view of the solar spectrum by adding an "elongated crevice, 1/20″ wide" between the prism and the Sun. This showed him seven distinct dark lines in the spectrum (1802); these he associated with the "natural boundaries" between the colors. Such was the state of knowledge in the early 1800's.

Fraunhofer Lines

Label	Wavelength (nm)	Source
A-band	759.4–762.1	Atmospheric O_2
B-band	686.7–688.4	Atmospheric O_2
C	656.3	Hα
a-band	627.6–628.7	
D1	589.6	Na I
D2	589.0	Na I
E	526.9	Fe I
b1	518.4	Mg I
b2	517.3	Mg I
c	495.8	Fe I
F	486.1	Hβ
d	466.8	
e	438.3	Fe I
f	434.0	Hγ
G	430.8	Ca/Fe (430.77/430.79)
g	422.7	Ca I
h	410.2	Hδ
H	396.8	Ca II
K	393.3	Ca II

Josef von Fraunhofer (1787–1826) took up the challenge to measure the dispersion of the glass he was producing. At this time there was very little scientific analysis carried out in the manufacture of glass; making glass was an art, not a science. There was a degree of trial and error every time!

By making small prisms from each batch of glass and measuring and recording the dispersion, Fraunhofer could quickly ensure that the process was giving the outcome he needed. This allowed him to manufacture the best objectives of the time, and his large telescopes were the envy of all astronomers. He designed and built the 9.5″ Great Dorpat Refractor in 1824, mounting it on his new "German Equatorial mount."

To improve his measuring device, which he called a "spectroscope," he added a slit in front of the collimating lens; this gave a cleaner image of the spectrum. He also noticed that sunlight, when dispersed by his prisms, always seemed to have dark lines in the same positions, and eventually, in 1815, he mapped some 324 lines; the more prominent ones are still called "Fraunhofer lines". See Fig. 1.3. Although he didn't understand how these lines were produced, he made good use of them as "standard wavelengths" for his optical testing.

Figure 1.3. Fraunhofer's spectrum. (Photo courtesy of NASA.)

Fraunhofer also placed a prism in front of his telescope objective (in 1823) and observed the stars and planets. He noted that similar lines appeared in the stellar spectra. This very first objective prism is currently on display in the Deutsches Museum in Munich. See Fig. 1.4.

To further improve his spectral measurements he developed the diffraction grating. Early examples were made by winding fine wire around a frame. With these

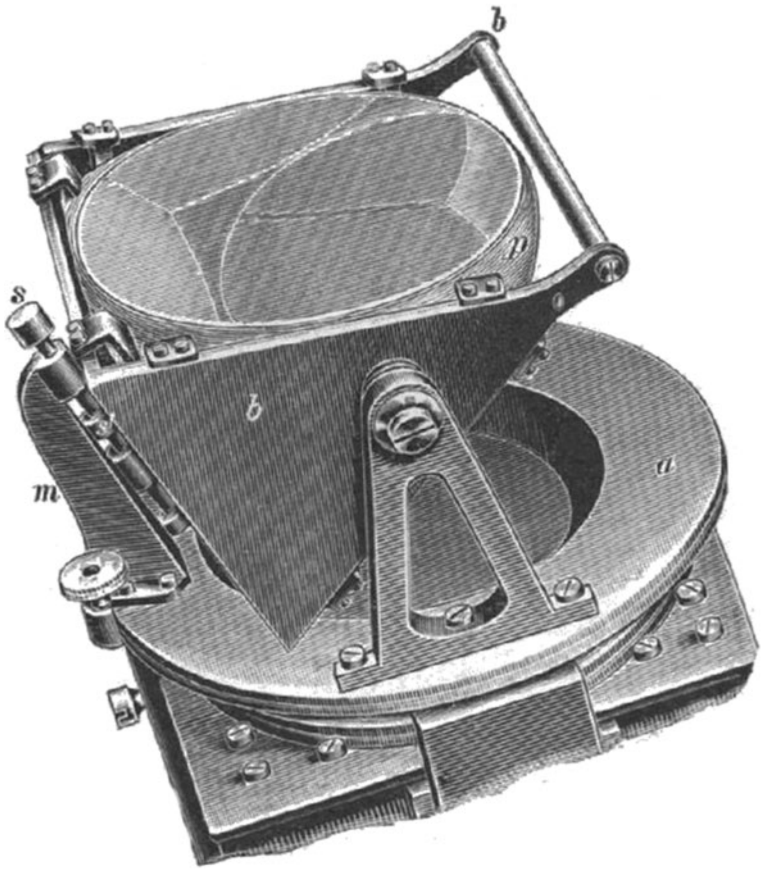


Figure 1.4. Fraunhofer's early objective prism. (From Dr. L. Ambronn, "Handbuch der Astronomischen Instrumentenkunde- II Band",1899.)

gratings, which gave the spectrum a more uniform scale, it was easier to accurately measure the position of the various dark lines.

It can therefore be said that Fraunhofer was certainly the father of spectroscopy. He invented and developed the spectroscope to the stage that it could be used as a scientific tool to view and measure spectra.

Giovanni Amici (1786–1863), director of the Florence Observatory in Italy, employed a combination of crown and flint prisms in his dispersion prism arrangement that effectively gave a straight through, undeviated spectrum. This "Amici prism" design was widely used in subsequent Direct Vision star spectroscopes.

It was in 1859 that Gustav Kirchhoff (1824–1887) and Robert Bunsen (1811–1899) finally solved the problem of the dark (and bright) lines in the spectrum. Their experiments showed conclusively that various elements gave rise to their own unique bands (always in the same position) in the spectrum. With this connection now established many chemists took up the challenge and established a database of element lines.

Kirchhoff, in furthering his investigations, developed his three laws:

(1) An incandescent solid or a gas under high pressure will produce a continuum spectrum.
(2) An incandescent gas under low pressure will produce an emission-line spectrum.
(3) A continuous spectrum viewed through a low-density gas at low temperature will produce an absorption-line spectrum.

The era of scientific research had begun. No more rainbows!

For Further Reading

Abbott, D. (Ed.), *The Biographical Dictionary of Scientists-Astronomers.* Blond Educational (1984).

Web Pages

http://home.vicnet.net.au/~colmusic/clario2.htm

CHAPTER TWO

A History of Astronomical Spectroscopy

The publication of Kirchhoff's and Bunsen's work brought the awareness of the spectroscope, and what it could reveal, to a wider audience, including astronomers. The obvious question was, how could this new instrument be used to analyze the light from the Sun and stars?

Auguste Comte (1798–1857), a French philosopher stated this in 1835: "We may in time ascertain the mean temperature of the heavenly bodies: but I regard this order of facts as for ever excluded from our recognition. We can never learn their internal constitution, nor, in regard to some of them, how heat is absorbed by their atmosphere." He was about to be proved wrong!

One of the first astronomers to apply the spectroscope to his telescope was William Huggins (1824–1910), an English amateur. To quote from his later book:

> I soon became a little dissatisfied with the routine character of ordinary astronomical work, and in a vague way sought about in my mind for the possibility of research upon the heavens in a new direction or by new methods. It was just at this time ... that the news reached me of Kirchhoff's great discovery of the true nature and the chemical constitution of the sun from his interpretation of the Fraunhofer lines.
>
> This news was to me like the coming upon a spring of water in a dry and thirsty land. Here at last presented itself the very order of work for which in an indefinite way I was looking – namely, to extend his novel methods of research upon the sun to the other heavenly bodies. A feeling as of inspiration seized me: I felt as if I had it now in my power to lift a veil which had never before been lifted; as if a key had been put into my hands which would unlock a door which had been regarded as for ever closed to man – the veil and the door behind which lay the unknown mystery of the true nature of the heavenly bodies.

K.M. Harrison, *Astronomical Spectroscopy for Amateurs*, Patrick Moore's Practical Astronomy Series, DOI 10.1007/978-1-4419-7239-2_2,

For the next 40 years he and his wife Margaret dedicated their time and resources to observing the sky with the spectroscope.

Huggins designed and built all his prism spectroscopes and pioneered new techniques such as providing a reference spectrum from an electric spark and a reflection slit to improve guiding the spectroscope on a star. See Fig. 2.1.

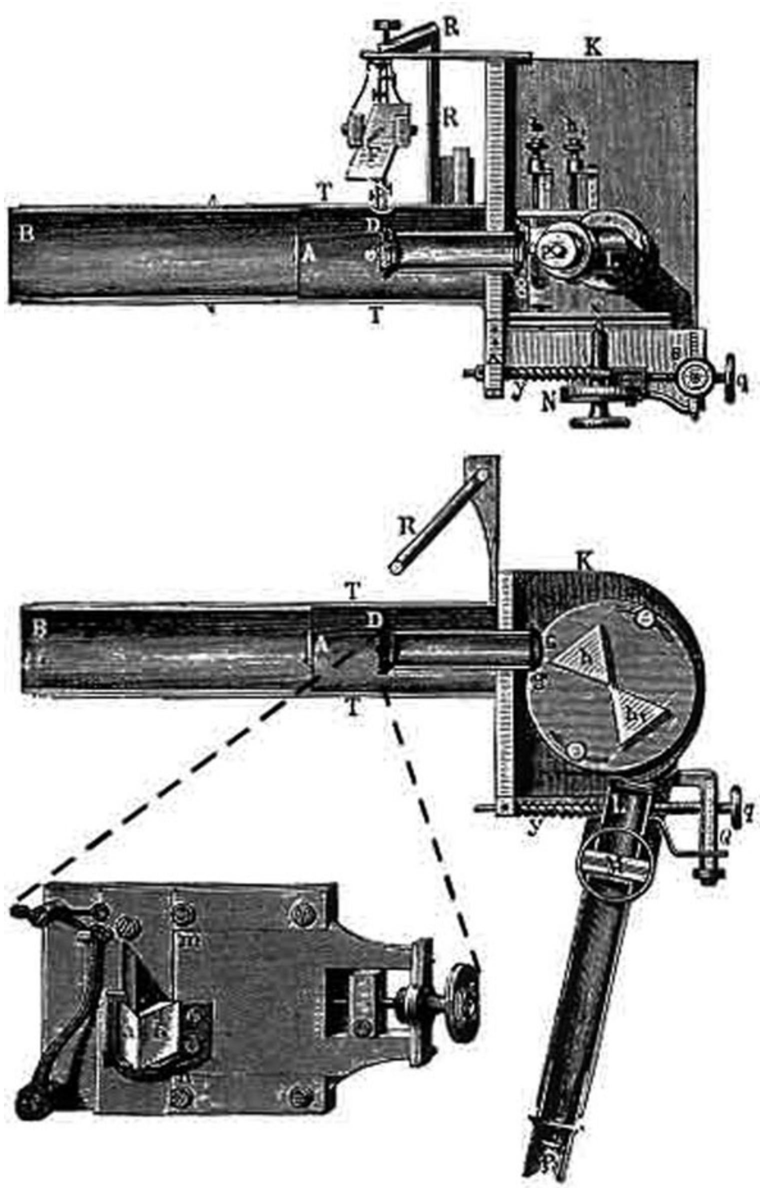


Figure 2.1. Huggins spectroscope. (WIKI.)

From his observatory at Tulsa Hill just outside London, Huggins was the first to observe emission lines in the spectra of nebulae; he also correctly applied Doppler's principle to his spectra to determine the radial velocity of a star (Sirius). In 1869, Huggins developed a technique to allow the observation of solar prominences without the need for a solar eclipse. He later also correctly identified the ultraviolet lines of hydrogen on photographic plates.

Another active observer at the time was Father Angelo Secchi (1818–1878) of the Vatican Observatory. Secchi observed the spectra from over 4,000 stars and developed a stellar classification system that was used for almost 50 years.

In 1863 he announced his Class I (strong hydrogen lines) and Class II (weaker hydrogen lines with numerous metallic lines) stars; by 1866 he had added Class III (bands stronger towards the blue, plus metallic lines), and in 1868 Class IV (deep red stars with bands opposite to Class III). He later added Class V (emission spectra). See Fig. 2.2.

The Mertz 12° objective prism 162 mm diameter (made in 1872) used by Secchi for his later research, was displayed at the 2009 ASTRUM exhibition in Rome.

Anders Jonas Angstrom (1814–1874), using an early grating spectroscope, mapped the solar spectrum with greater accuracy than had been done previously. In 1868 he published an atlas of over 1,000 lines, their positions recorded in units of 10^{-10} m. This is now known as Angstrom Units (Å) and is still widely used.

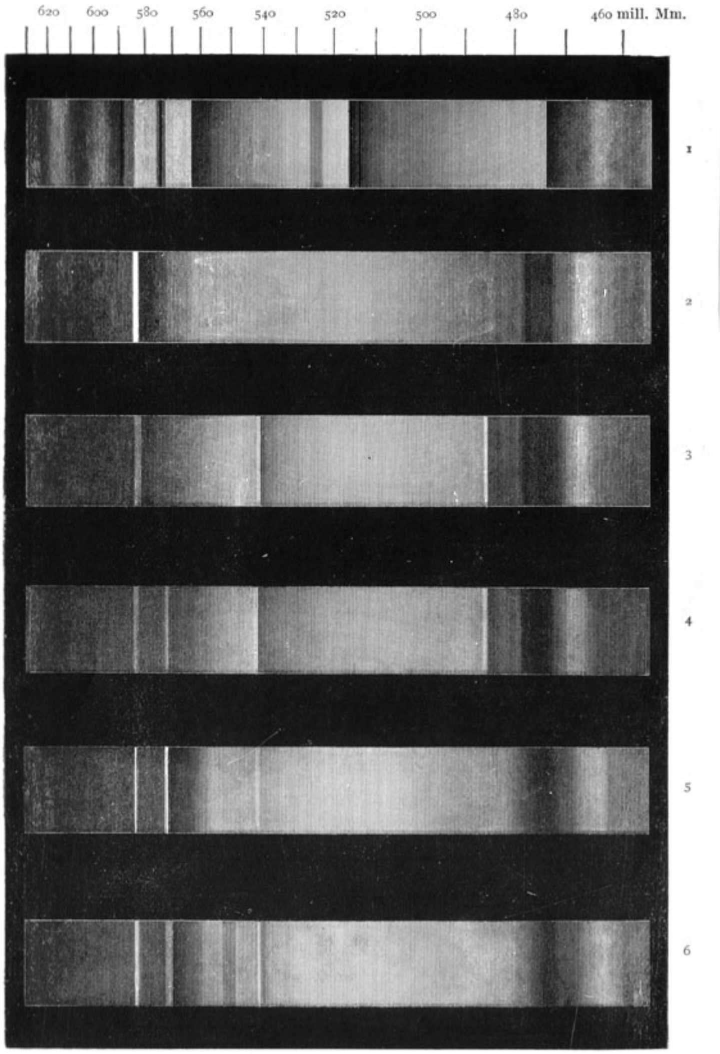
Henry Draper (1837–1882) succeeded in obtaining a photograph of the spectrum of Vega, which clearly showed the hydrogen absorption lines (1872). The advent of the dry photographic plate in the mid-1880s allowed early investigators to carry out the long exposures required to record spectra (Harvard Observatory obtained the first spectrum of a meteor in 1897). The use of these dry plates and later photographic film heralded the beginning of the transfer of spectroscopy from amateurs to professional astronomers.

With monies from the Henry Draper Memorial Fund, Edward Pickering (1846–1919) and his team at Harvard Observatory followed the work of Secchi in recording and cataloging stellar spectra. Using an objective prism mounted in front of the telescope objective he was able to quickly amass large amounts of low resolution spectra (He used objective prisms with angles from 5 to 7° mounted on telescopes up to 13″ aperture to obtain the spectra). The subsequent "Henry Draper Catalogue" of stellar spectra was based on separate classes and sub classes; W O B A F G K M. Updated and enhanced versions of this catalog are still used today.

The work of Henry Rowland (1848–1901) in perfecting his grating ruling engine in 1882 allowed the production of large diffraction gratings that gradually took over from prisms in professional spectroscopes.

By the turn of the century the era of the amateur scientist was drawing to a close; larger and larger spectroscopes and telescopes were producing scientific results that would determine the direction of astrophysics for the next 100 years.

The interested amateur could acquire spectroscopes made by John Browning (1835–1925). These were small direct-vision Amici prism instruments (D-V) for stellar observing, and they established the trend for the next 40 years. Being a dedicated visual instrument, the results were limited to viewing spectra of the Sun, brighter stars, and nebulae.



VISUAL SPECTRA TYPE V COMPARED WITH TYPE IV (VOGEL).
1. Y Can. Ven.; 2. XVIII^{h} 3^{m}, S. 21° 16′; 3. VI^{h} 51^{m}, S. 23° 49′; 4, 5, 6. Wolf-Rayet, Nos. 1, 2, 3, Cygnus.

Figure 2.2. Visual spectra of Secchi Type IV and V by Vogel. (From Preface to Webb's Celestial Objects for Common Telescopes, 1917.)

Commercial D-V instruments continued to be produced by Adam Hilger, Ltd., among others and examples by GOTO (Japan) and LaFeyette (USA) were widely used by amateur astronomers in the 1950's and 1960's (see Fig. 2.3).