Literatur zur Vorlesung Astronomische Spektroskopie:

The Theory of Stellar Spectra
Charles R. Cowley
Gordon and Breach Science Publishers, 1970

Lectures on spectral-line analysis: F,G, and K Stars
David F. Gray
The Publisher, 1988

Introduction to stellar atmospheres and interiors
Eva Novotny
Oxford University Press, 1973

The Observation and Analysis of Stellar Photospheres
David F. Gray
Cambride University Press, 2005

Atom- und Quantenphysik
Hermann Haken & Hans Chr. Wolf
Springer, Berlin, 2003

Physik der Sterne und der Sonne
Helmut Scheffler & Hans Elsaesser
Spektrum Akademischer Verlag, 2002

Abriss der Astronomie
Hans-Heinrich Voigt
Spektrum Akademischer Verlag, 2002

Stellar Atmospheres
Dimitri Mihalas
Freeman & Co., San Francisco, 1978

Spectrophysic: Principles and Applications
A. Thorne, U. Litzen, S. Johansson
Springer, 1999


Introduction

What is spectroscopy?

Study of the energy of a source at high resolution

$$R = \Delta\lambda / \lambda$$

very low resolution: R < 100, spectrophotometry

low resolution: R < 5 000, radial velocity distributions in galaxies

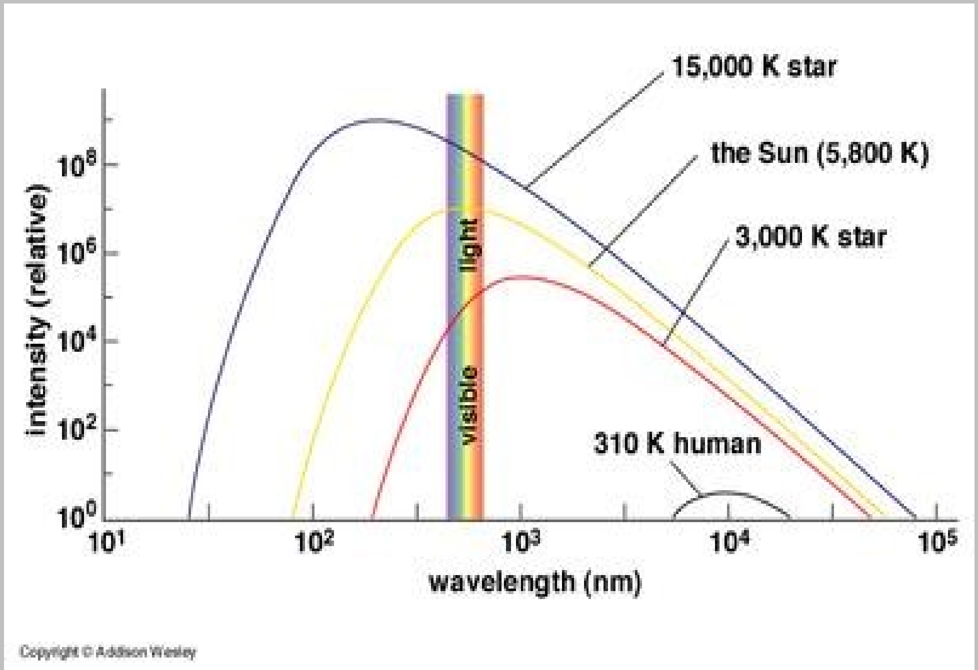
medium resolution: R < 30 000, rotation, radial velocities, elemental abundances, metallicity (age - PopI/II)

high resolution: R < 100 000, magnetic fields, pulsation, element distribution (horizontal and vertical), convection, high time resolution analysis, extrasolar planets

Blackbody = perfect radiator – hypothetical body that absorbs all incident EM radiation. At equilibrium temperature it re-radiates in pattern according to its temperature.

Wien's Law:

$$\lambda_{max} = 0.2897\text{cmK} / T$$



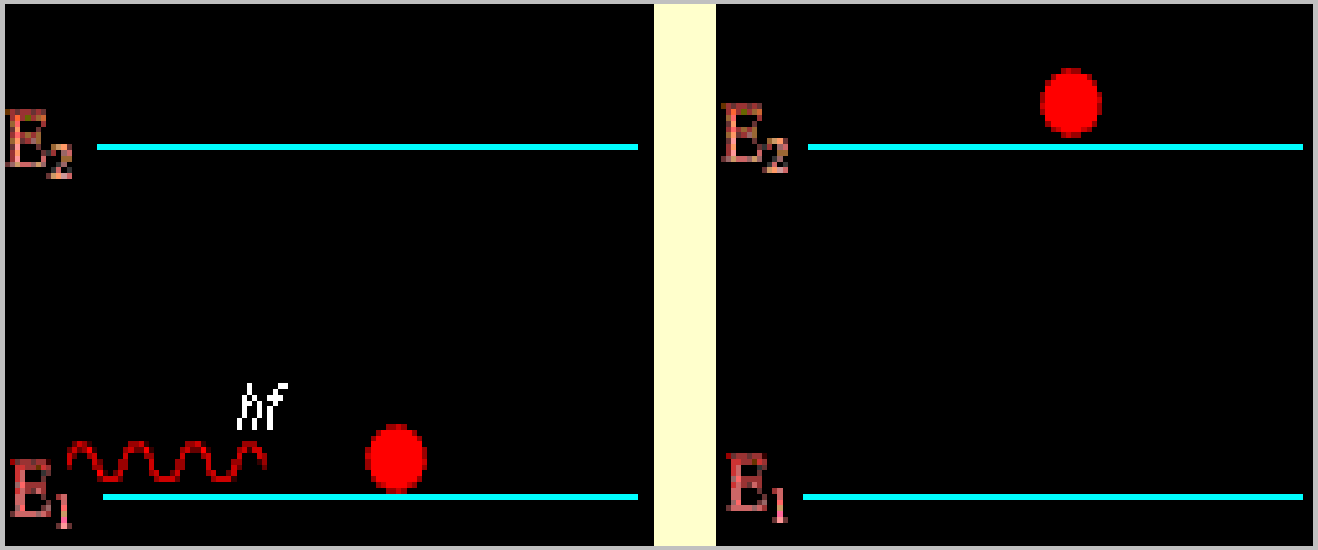
Stefan Boltzmann Law:

Total energy emitted per second per cm² by a blackbody

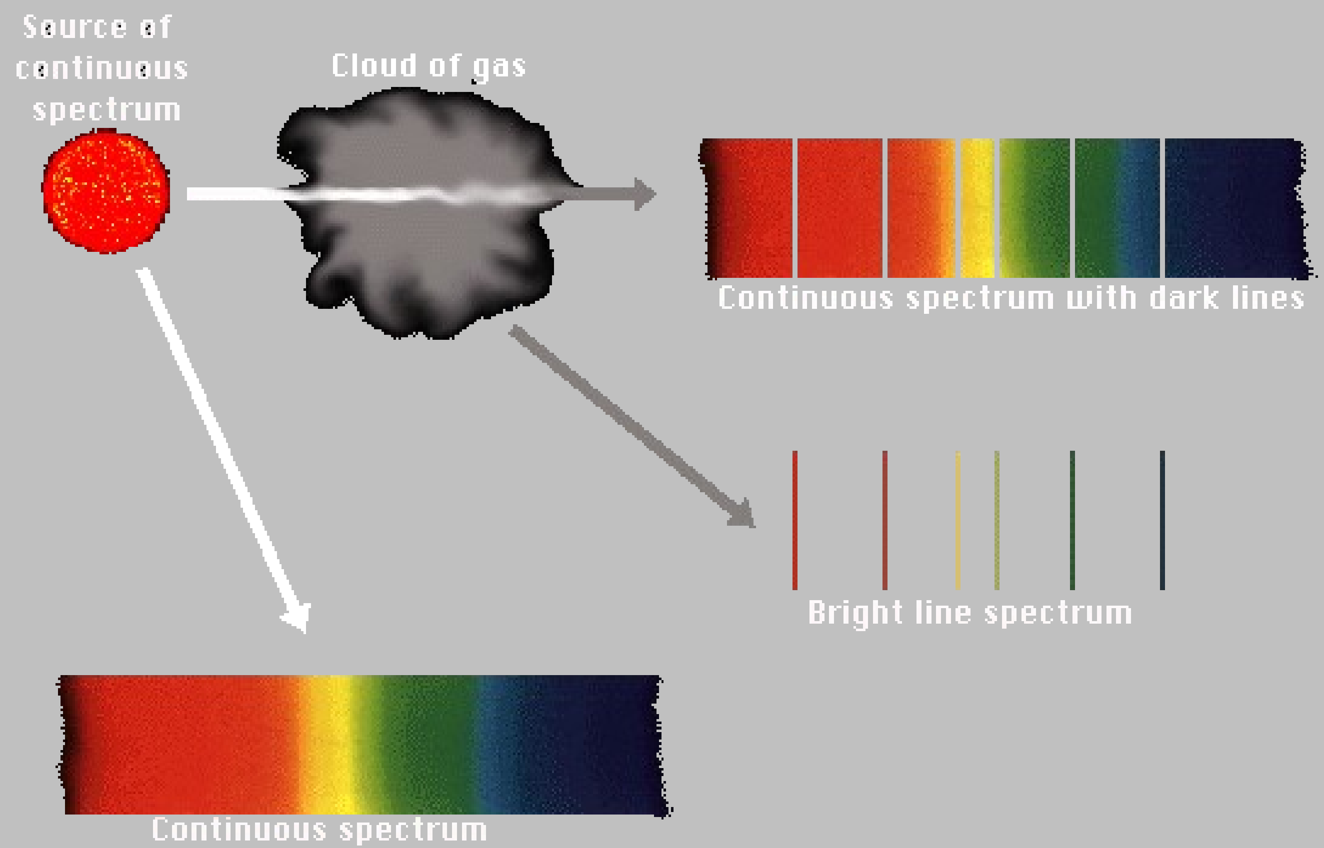
$$E(T)=\sigma T^4 \text{ (erg/s/cm}^2\text{)} \qquad \sigma=5.672 \times 10^{-5} \text{ erg/cm}^2\text{/K}^4\text{/s}$$

Gases in the atmospheres of stars perturb the continuous blackbody spectrum by introducing lines corresponding to electron transitions.

Absorption | Emission

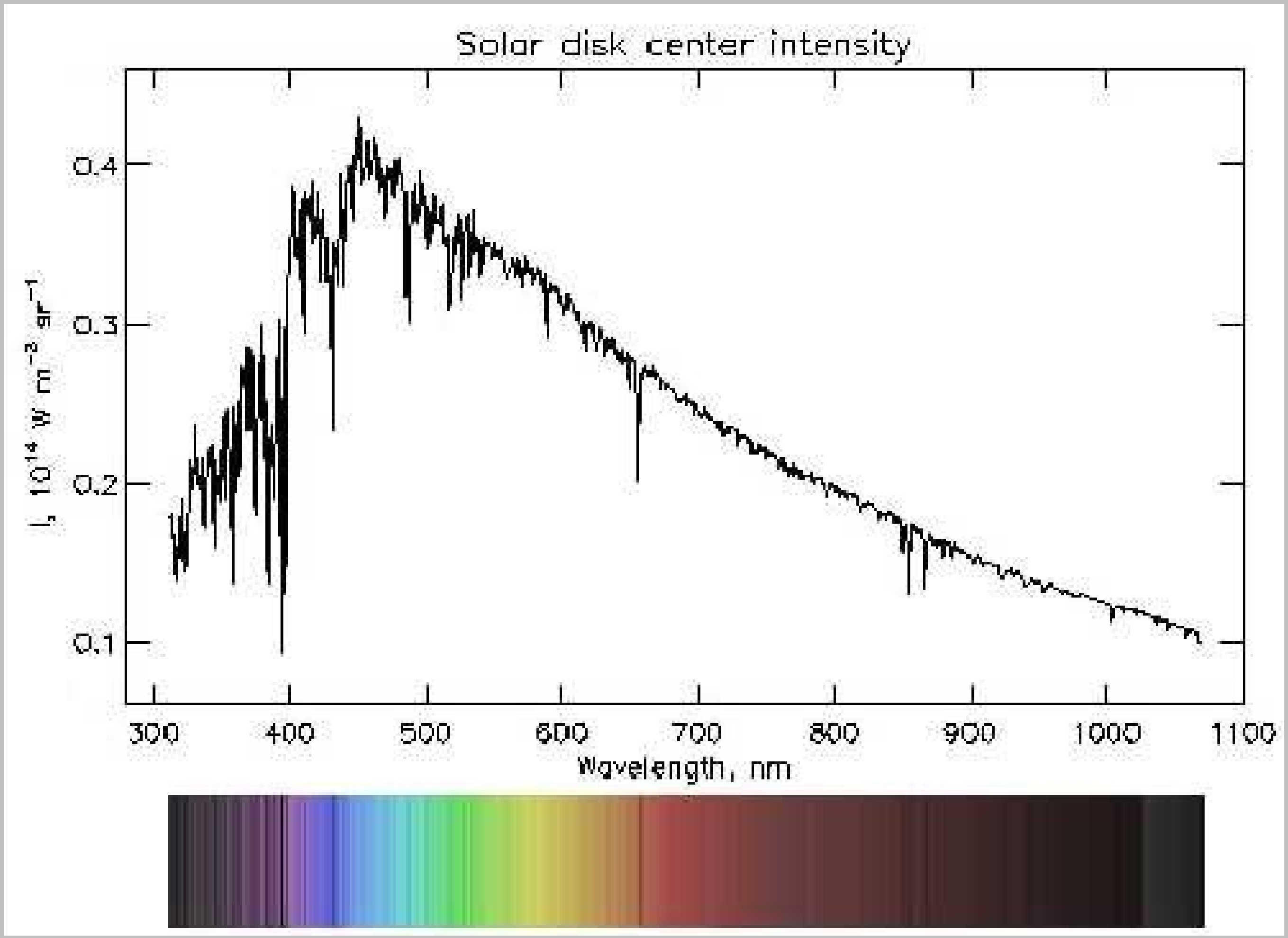


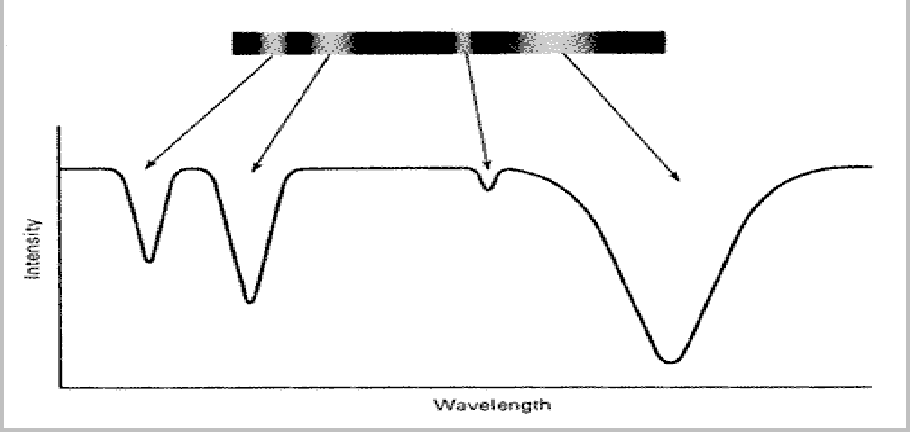
Question: What else can happen when energy is absorbed?



When light given off by hot gas is decomposed using a prism it is shown to be made up of colored lines (emission lines).

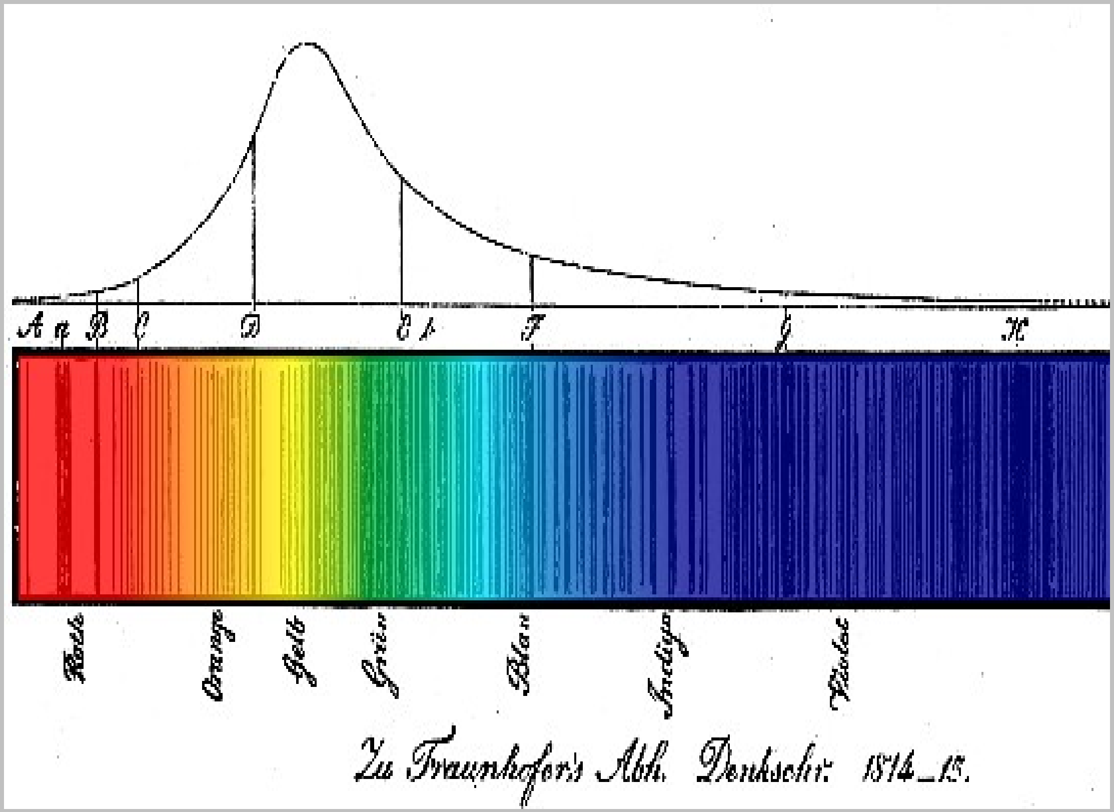
When white light shines trough a cold gas the resulting light, when decomposed is shown to have dark lines (absorption lines).


Solar disk center intensity
I, 10^{14} W m^{-3} sr^{-1}
0.1
0.2
0.3
0.4
300
400
500
600
700
800
900
1000
1100
Wavelength, nm


Intensity
Wavelength


The Sun

Solar Spectrum



Solar light decomposed by a prism exhibiting the emission and absorption lines.

Picture: one of the first measurements around 1817.

The curve above the lines denotes the intensity of the various colors (largest in the yellow).

Fraunhofer Lines

Set of absorption lines in the continuous (blackbody) spectrum of the Sun.

Discovered in 1802 by William Hyde **Wollaston**.

Named after **Fraunhofer** (1787-1826), who invented and used a diffraction grating and determined the relative positions of hundreds of lines. Did not know their origin.

Interpreted by **Bunsen** (1811-1899) and **Kirchoff** (1824-1887).

Names of the most prominent lines identified by Fraunhofer:

* Fraunhofer worked from red to ultraviolet, names go that direction.

A	7594	Molecular oxygen in earth's atmosphere
B	6867	Molecular oxygen in earth's atmosphere
C	6563	Halpha
D1*	5896	Sodium
D2*	5890	Sodium
E1	5270	Iron
Eb**	5183-5168	Magnesium
F	4861	Hbeta
G*	4308	Blend of band of methane and iron
H*	3968	Ionized calcium
K*	3933	Ionized calcium

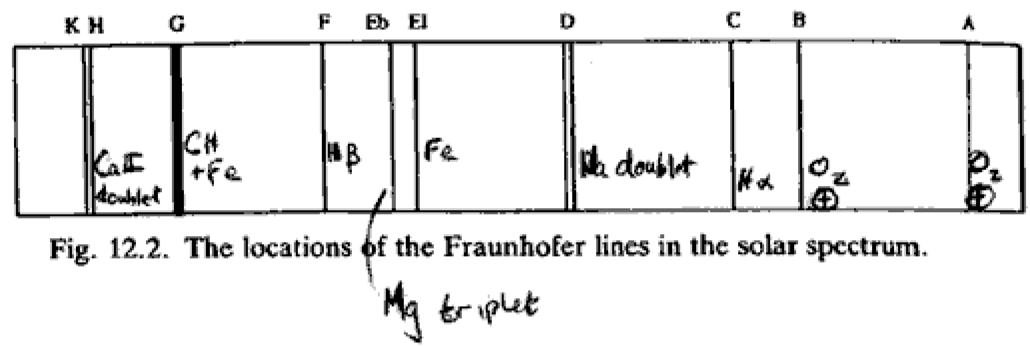
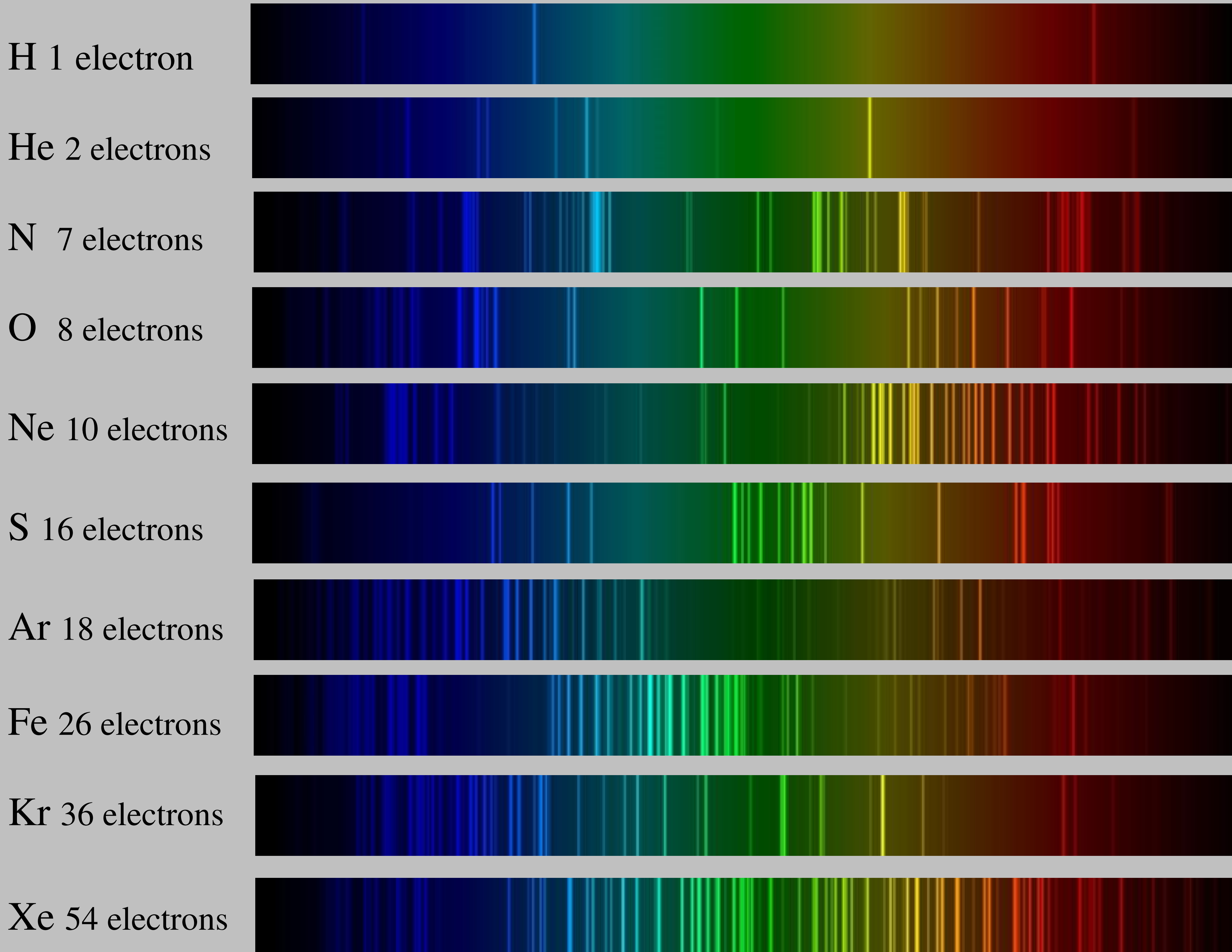


Fig. 12.2. The locations of the Fraunhofer lines in the solar spectrum.

*Still commonly used name (e.g., “sodium D lines (NaD)”, “G band” and “calcium H and K lines (Ca II H+K)”.

** In this case the name has morphed from “Eb” into “Mgb” to indicate that magnesium is the source of the line.


H 1 electron
He 2 electrons
N 7 electrons
O 8 electrons
Ne 10 electrons
S 16 electrons
Ar 18 electrons
Fe 26 electrons
Kr 36 electrons
Xe 54 electrons


Applications

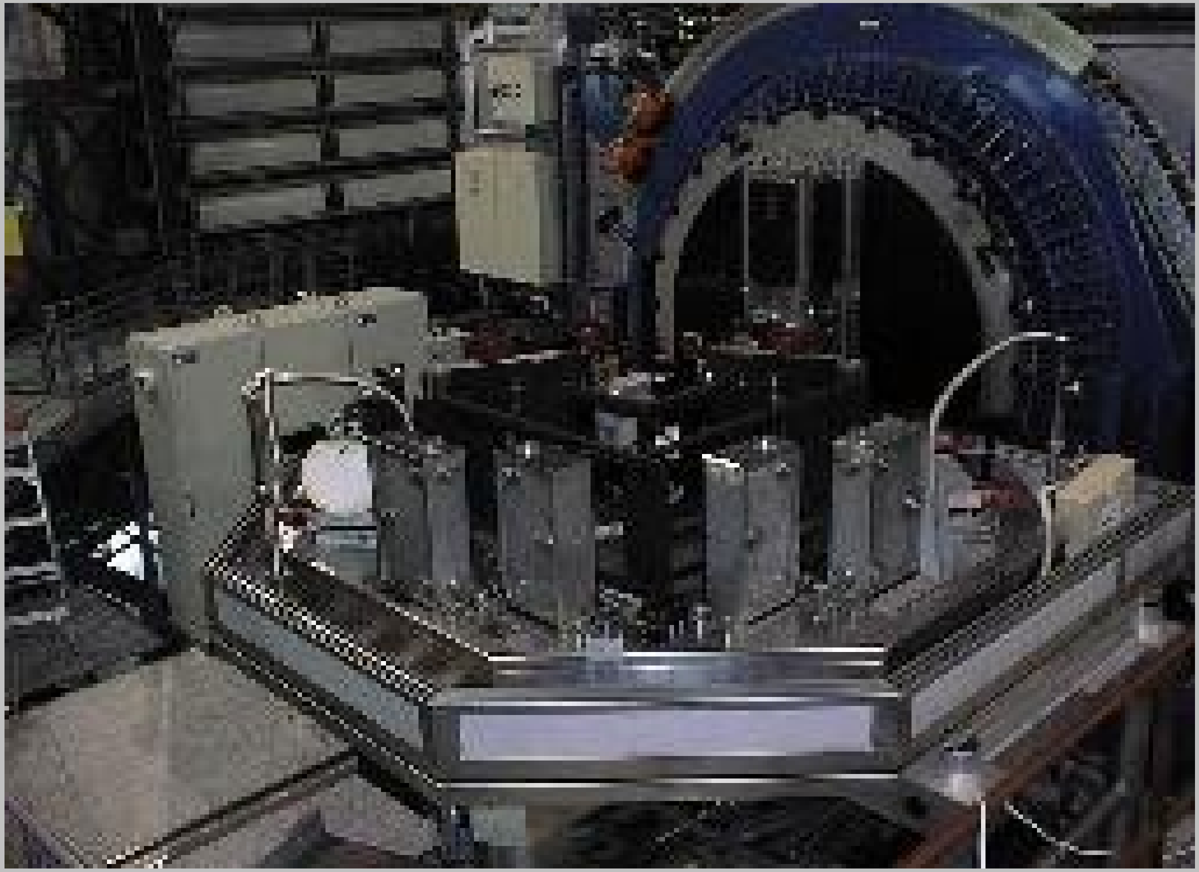
Obtaining a spectrum:

Observations with different types of spectrographs according to planned science (see VO Instrumente), e.g. high resolution echelle spectrograph, spectropolarimeter, long slit, ...

Example:

UVES (ultraviolet-visual echelle spectrograph), very high resolution

R~90 000-110 000, l~ 3000 – 10 000 Angstroms




1
2

Obtaining a spectrum:

Observations with different types of spectrographs according to planned science (see VO Instrumente), e.g. high resolution echelle spectrograph, spectropolarimeter, long slit, ...

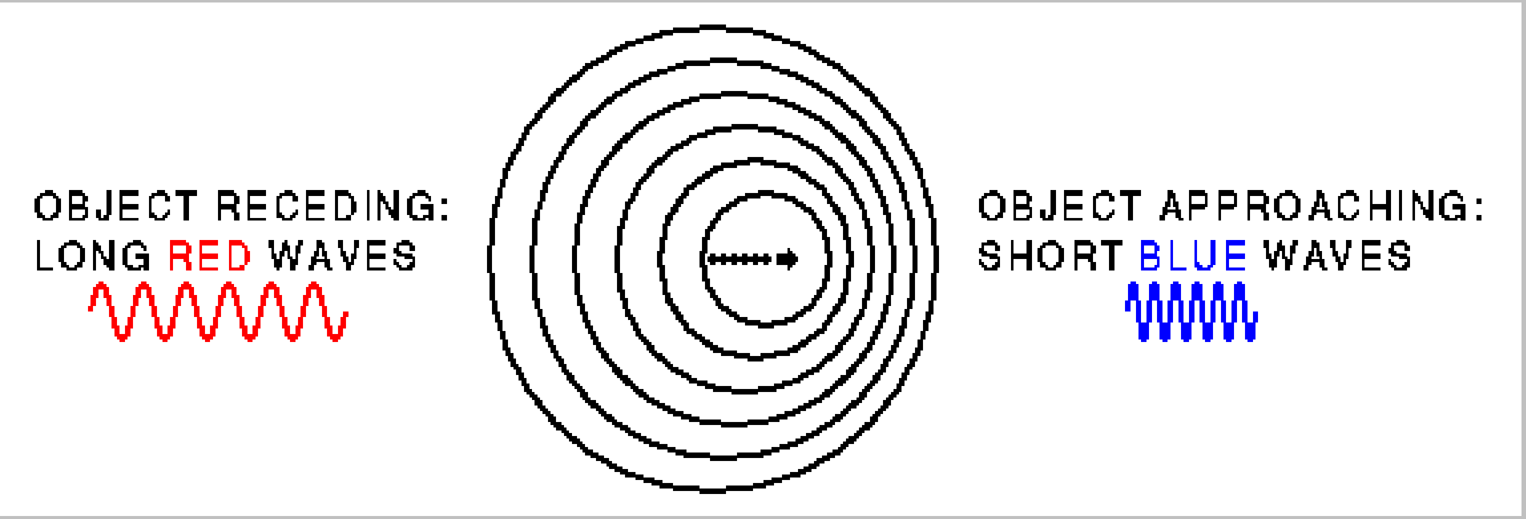
Data reduction: bias, flat field, wavelength calibration using comparison spectrum, continuum normalisation

Analysis:

measure **line positions, strengths, shapes, variations with time**
compare with models and synthetic spectra

Example 1: Rotation of a source

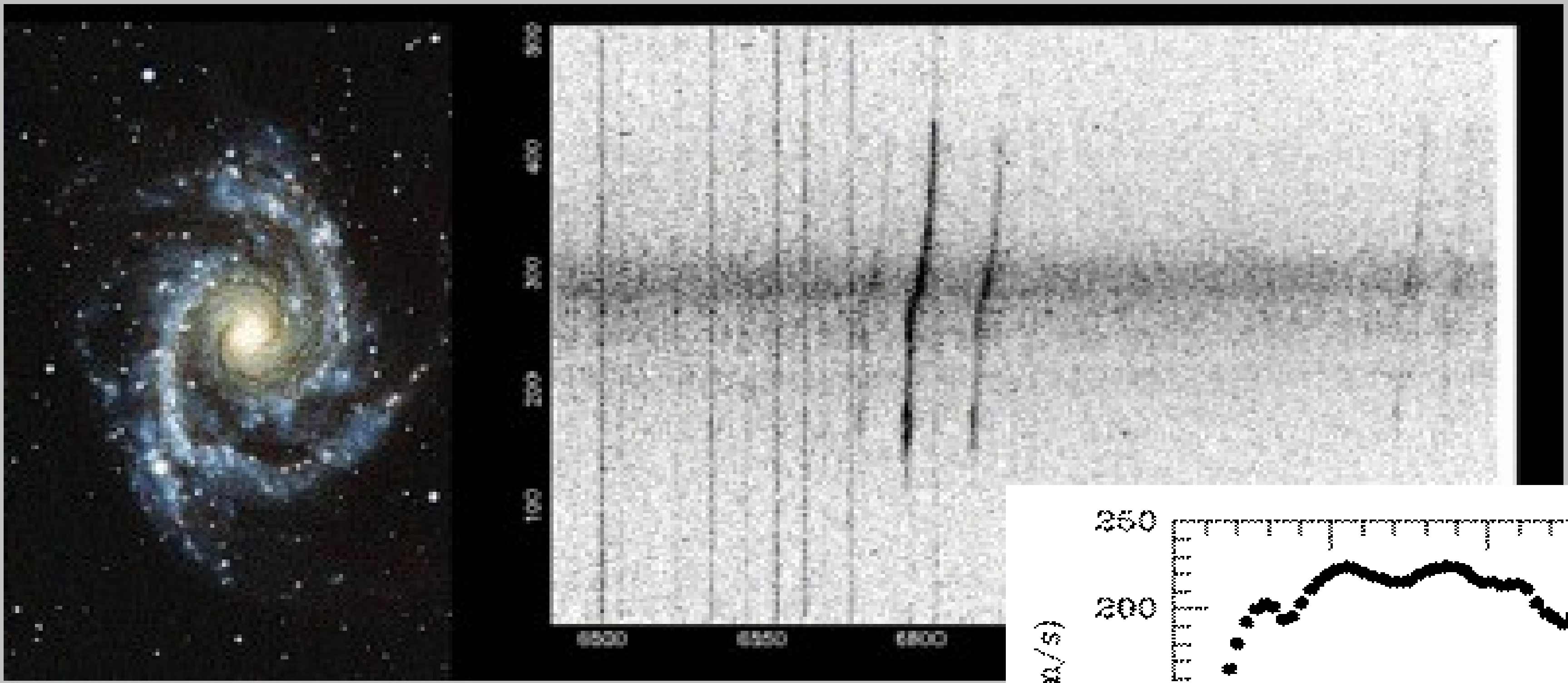
Seen as differential **Doppler shift** of spectral lines

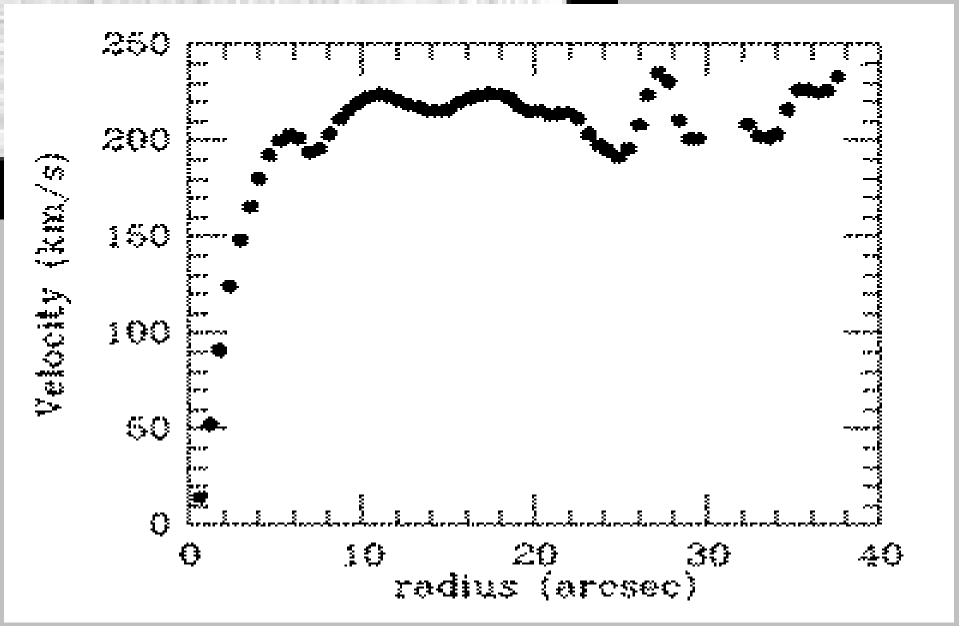


Question: What does the Doppler effect do to an absorption line from an unresolved source (stellar spectrum)?

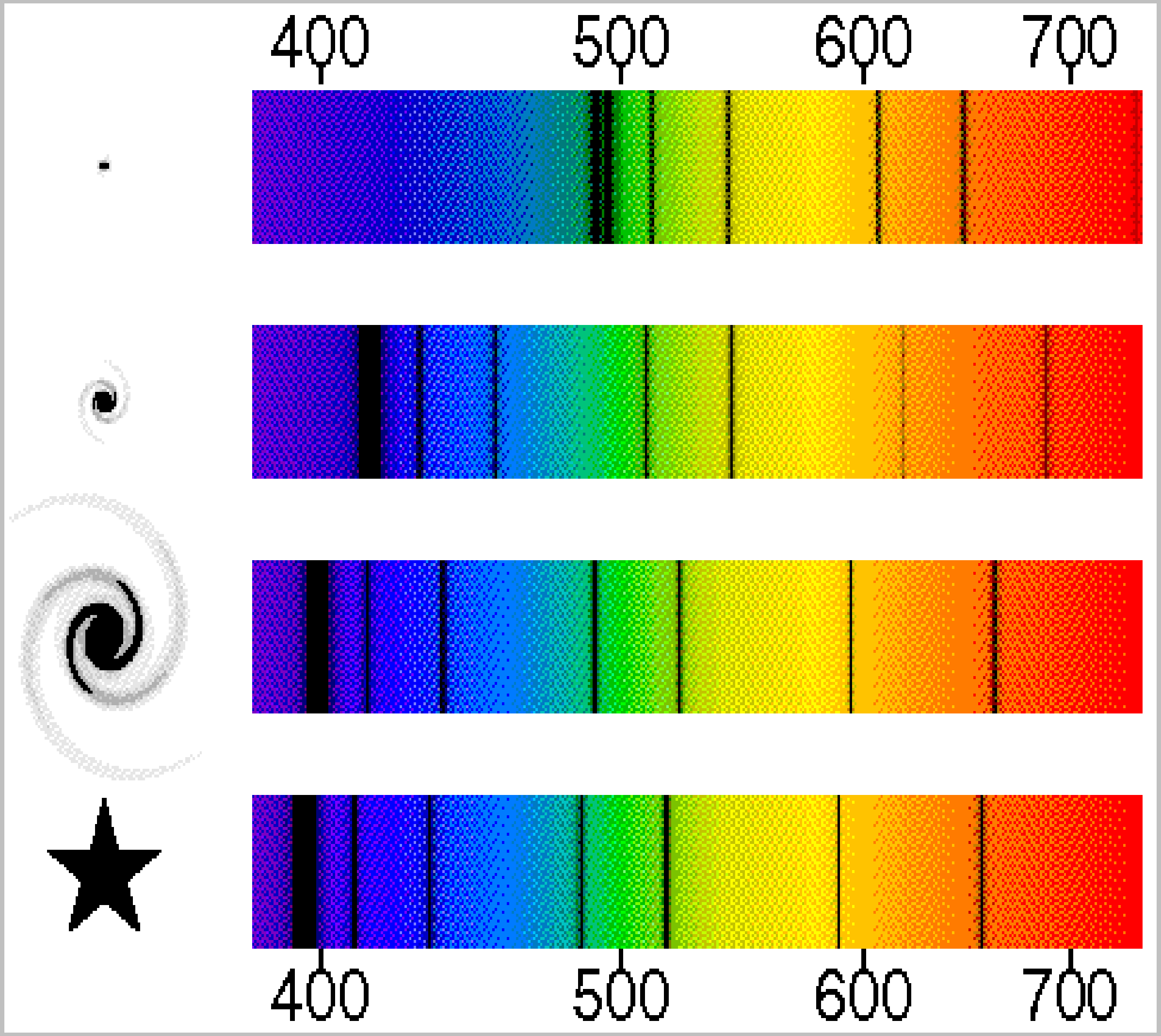
Example 1: Rotation of a source

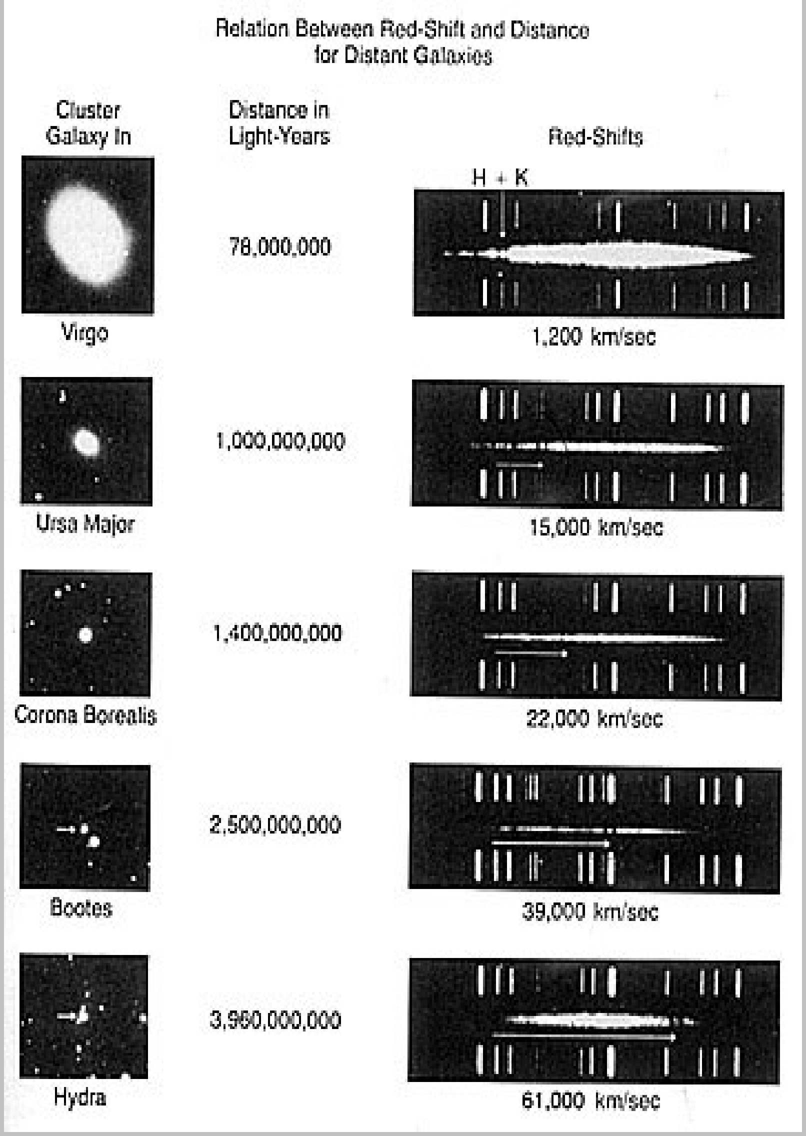
Example for extended source: galaxy rotation curve





Example 2: Redshift as distance indicator for galaxies





Example 3: Expansion of a Source

different parts of the source will have different relative velocities than other parts

Novae, Supernovae, Cepheids, RR Lyrae, ...

in unresolved sources this leads to smearing out of spectral lines

some unresolved sources show emission and absorption lines at the same time resulting in spectral features called P-Cygni profiles

Example 3: Expansion of a Source

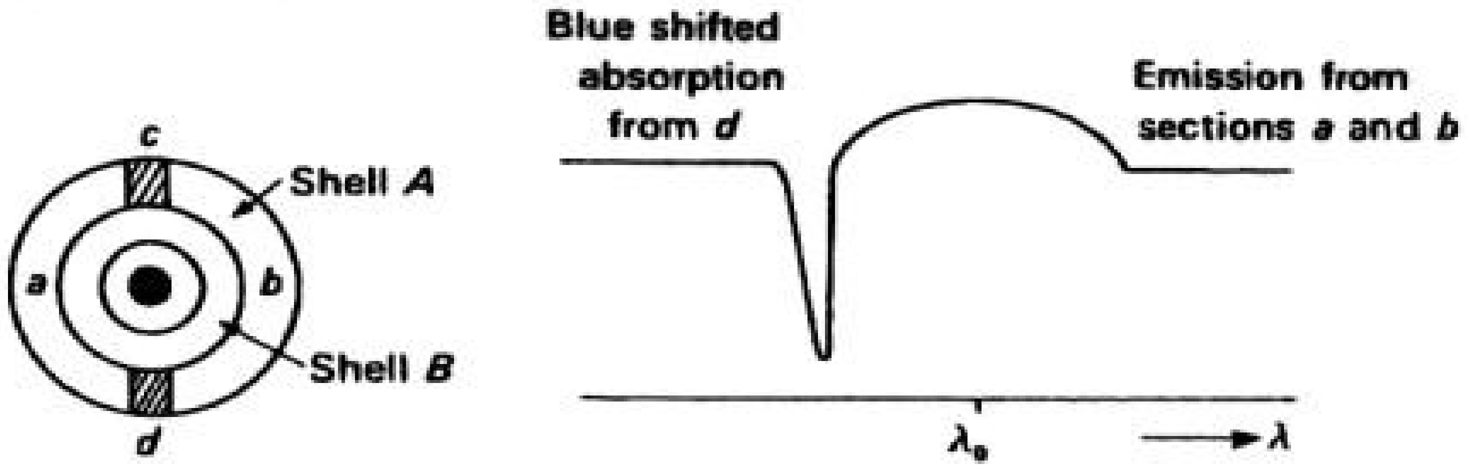
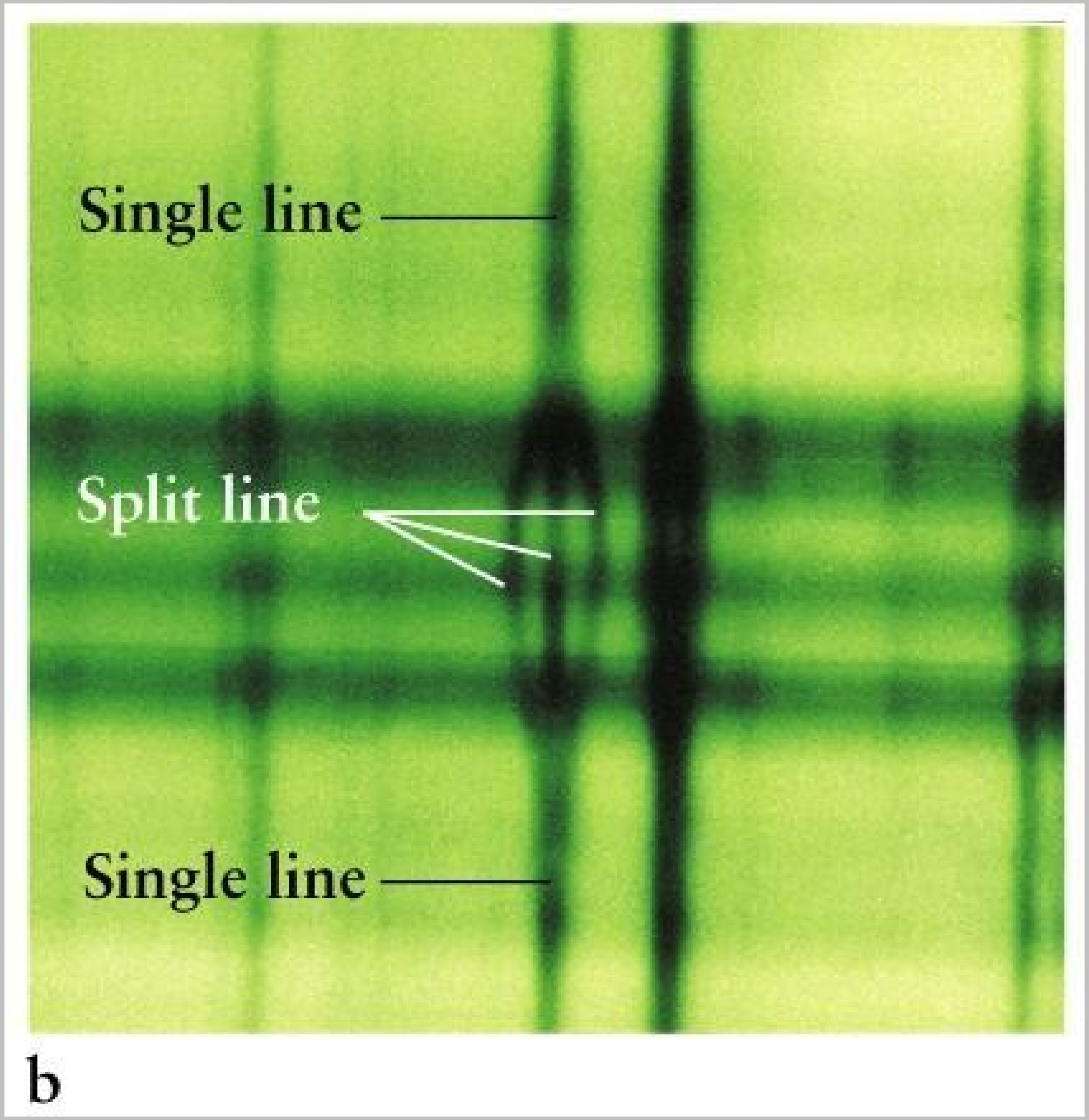
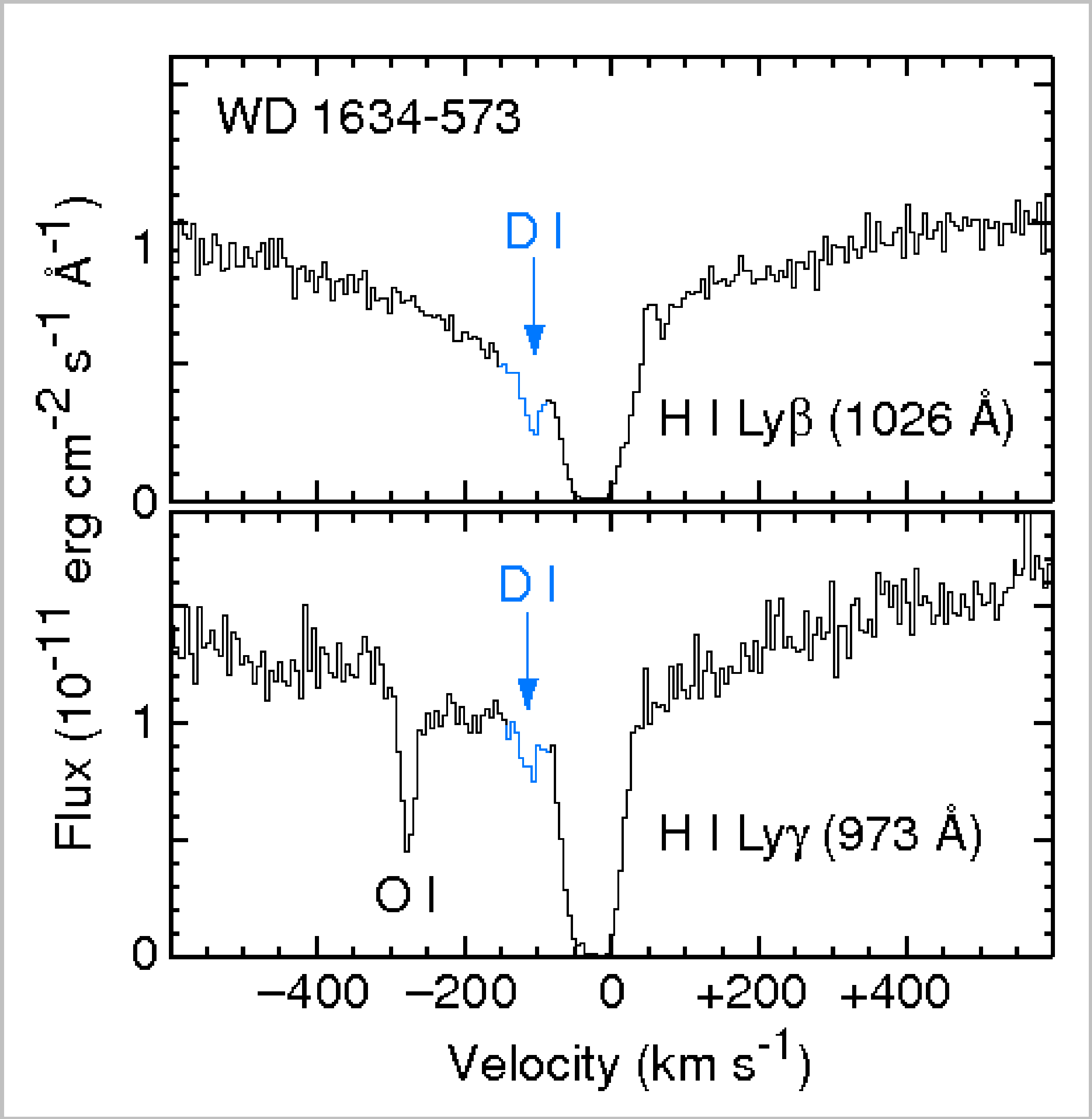


Fig. 17.8. In the beginning of the supernova expansion the material in the outer shell (shell *A*) is rather dense. There is much material in section *d* in front of the star to absorb light from the deeper layers, causing a blueshifted absorption line. Sections *a* and *b* cannot contribute to the absorption line; they can only emit light, giving rise to an emission line. These sections move on average transverse to the line of sight; the emission line is therefore only broadened but not shifted. Redshifted emission lines are emitted from section *c* but are obscured by the star. The expected absorption–emission line profile is shown on the right side of the figure. These types of line profiles were first observed for the star P Cygni (which is not a supernova) and are therefore called P Cygni lines.

Example 4: Magnetic Fields



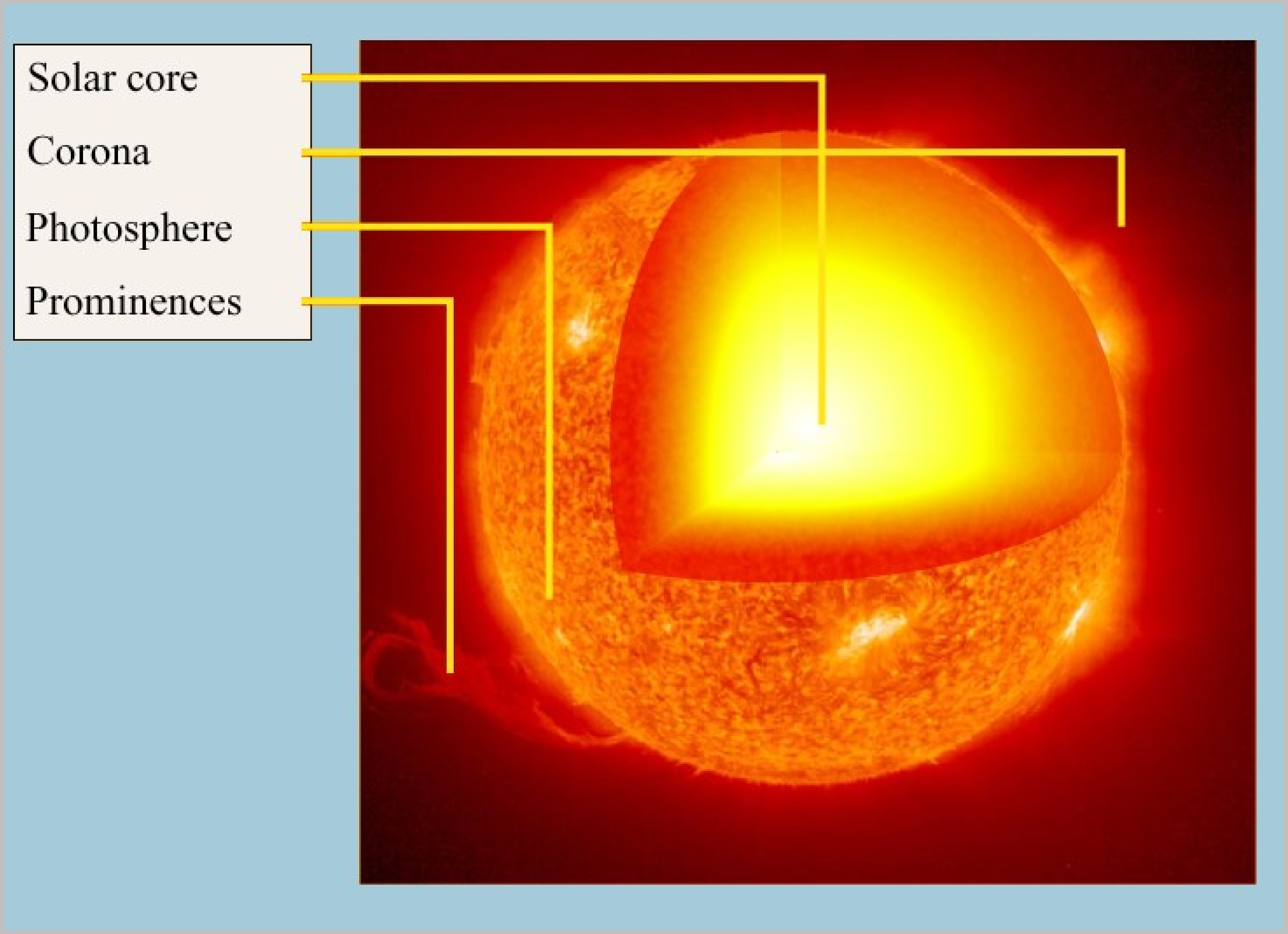
Example 5: Isotopes



A small portion of the FUSE spectrum of the white dwarf star WD 1634-573. Each panel shows the spectral region near a hydrogen absoprtion line. The blue regions indicate the spectral fingerprint of deuterium (marked "D I"). The depth and shape of these fingerprints compared to others such as oxygen and regular hydrogen, tells astronomers the relative abundance of deuterium in the gas being sampled on the sight line to the star. Note that the x-axis has been converted from wavelength into a velocity scale. (Graphic courtesy of JHU FUSE project.)


Stellar Atmospheres

Stellar atmosphere = outer region of the volume of a star, lying above the stellar core, radiation zone and convection zone.



What information can we derive using spectroscopy?

Physical state of the gas (= stellar atmosphere):

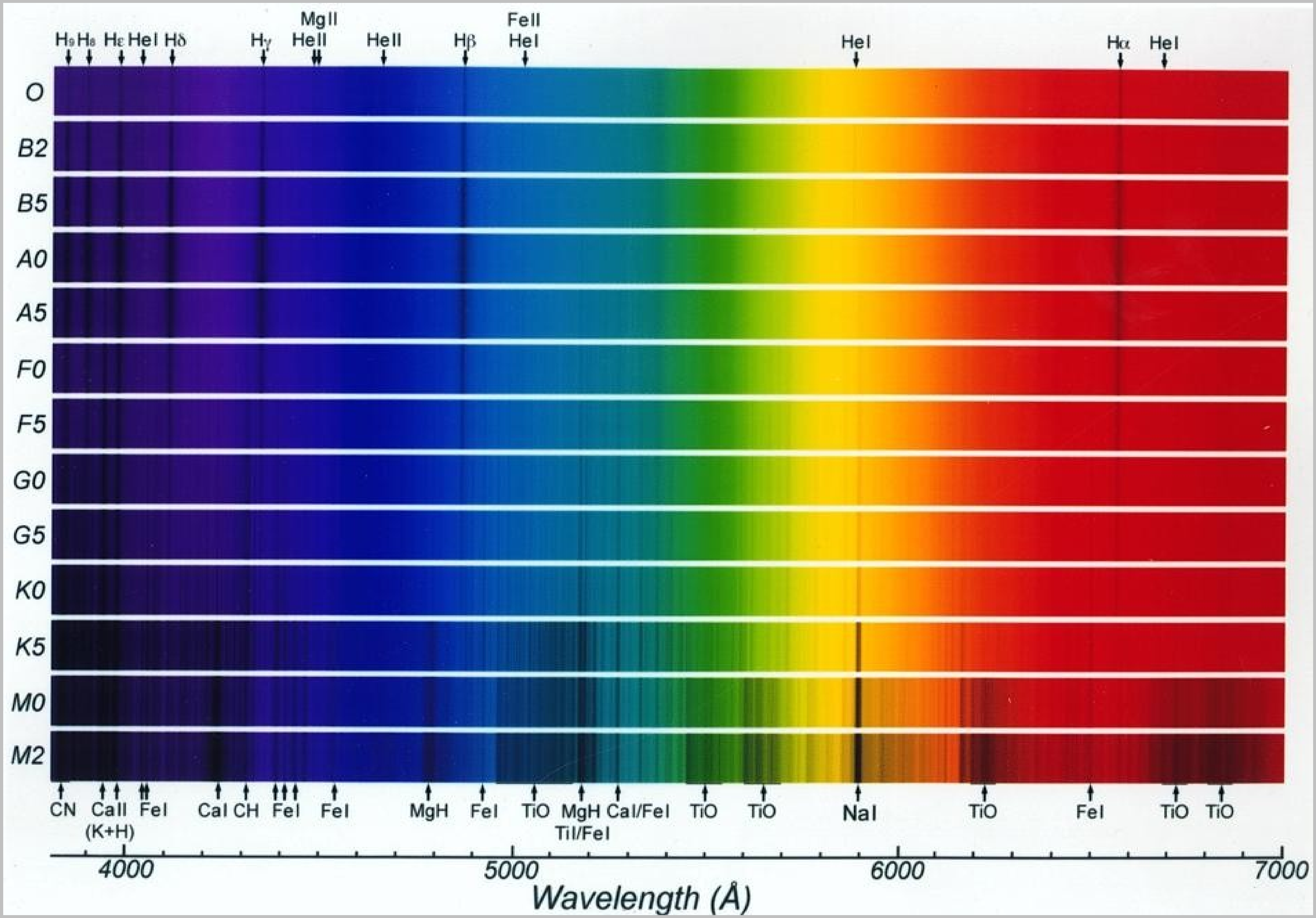
- Degree of excitation or ionization
- Number of excited or ionized atoms (abundances)
- Temperature of the gas

  Hotter gas -- greater degree of ionization, molecular dissociation, and excitation

- Density/pressure of the gas

  Higher density/pressure -- greater degree of excitation

=> the strength of an absorption line depends not only on total abundance of species but on the *fraction of those atoms in the correct state of ionization and excitation* to produce the line.



H9 H8 Hε HeI Hδ Hγ MgII HeII HeII Hβ FeII HeI HeI Hα HeI
O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN CaII (K+H) FeI CaI CH FeI FeI MgH FeI TiO MgH TiI/FeI CaI/FeI TiO TiO NaI TiO FeI TiO TiO
4000
5000
6000
7000
Wavelength (Å)

What information can we derive using spectroscopy?

- chemical composition/anomalies:

  e.g. Ap stars with overabundant rare-earth-elements, ...

- spectrum variability due to rotation, chemical spots, magnetic field geometry, and
- dynamics of the gas:

  pulsation ("wiggling" of lines in time series spectra)

  convection (line bisectors)

- binarity: multiple lines of same element but with different radial velocities

More on all this during the rest of the semester!


Now it's time for your questions, comments and brilliant ideas!