Stellar Atmospheres

Lecture 12

VITALY NEUSTROEV

ASTRONOMY RESEARCH UNIT
UNIVERSITY OF OULU

2019

Syllabus

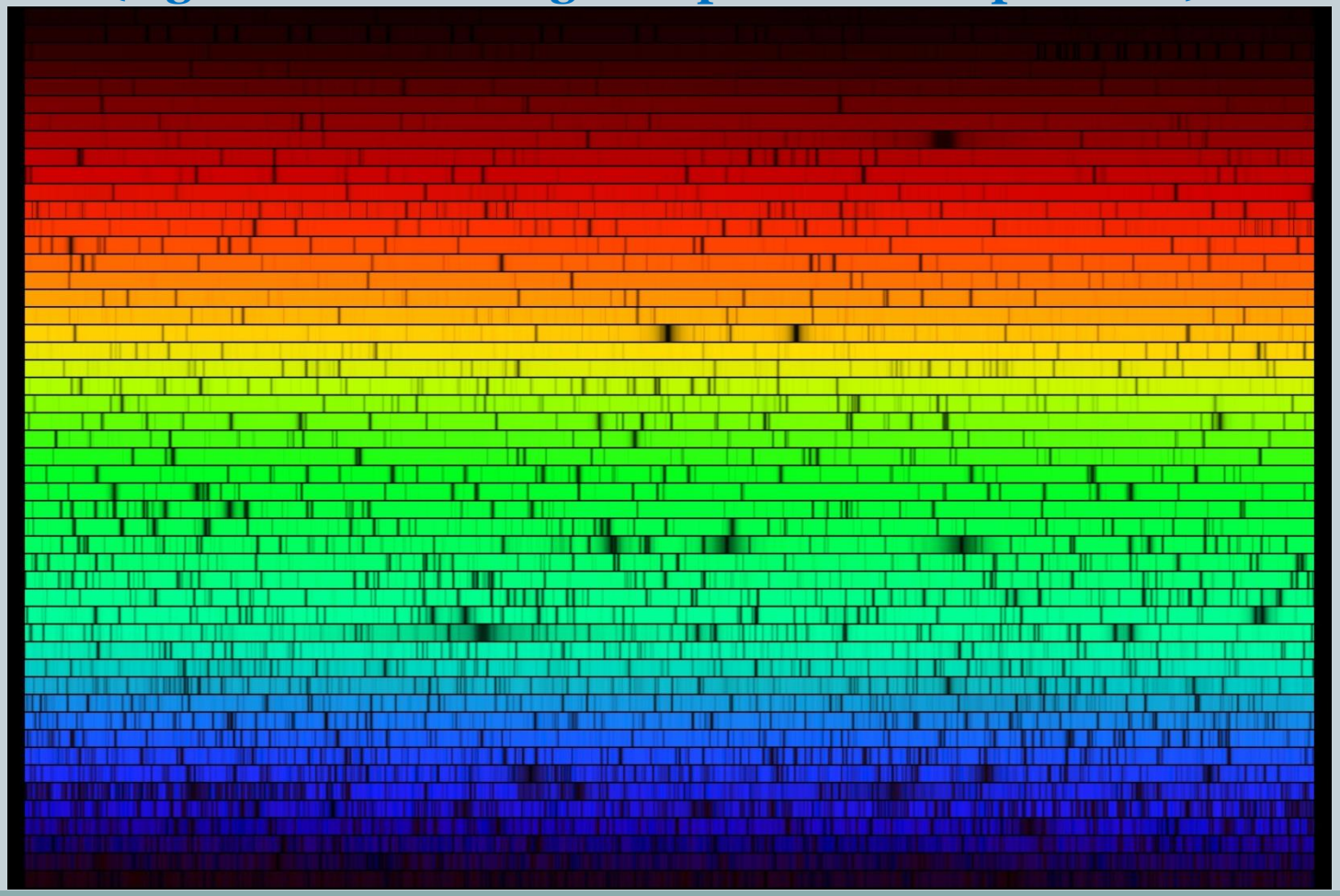
1. **Introduction:** What is a stellar atmosphere? Spectral Types, Luminosity Classes, Magnitudes, Bolometric Flux and Bolometric Correction
2. **Radiation terms:** Blackbody radiation, Effective Temperature, Specific Intensity, Flux, Optical depth, Source function
3. **LTE:** Maxwellian distribution, Boltzmann and Saha equations
4. **Radiation transfer equation:** basic definitions and solutions
5. **Radiative Transfer:** Parallel ray and plane-parallel transfer equation, surface intensity, limb darkening, Eddington-Barbier relation, Eddington approximation, grey atmosphere, radiative equilibrium
6. **Continuous absorption:** bound-bound, bound-free, free-free, opacity, atomic H, H- ion, He, metals, molecules, Thompson & Rayleigh scattering
7. **Temperatures and pressures of stars:** Direct determination of radii, T_{eff} and P from discontinuities, hydrostatic equilibrium, electron pressure from gas pressure using Saha equation, radiation pressure, Eddington limit, electron degeneracy pressure
7. **Line formation:** Equivalent widths, line broadening, spectroscopic notation, optically thin and thick lines, curve of growth, abundances
8. **Deviations from LTE:** level populations, Einstein coefficients, statistical equilibrium equations
9. **Stellar winds:** Solar wind, diagnostics and mechanisms of mass-loss from late- and early-type stars
10. **Recent developments:** Spectroscopic observations & models for supernovae, brown dwarfs
11. **Interstellar Medium**
12. **Accretion disks:** Emission and absorption spectra
13. **Etc.**

Spectral lines

EQUIVALENT WIDTH
FWHM
FWZI

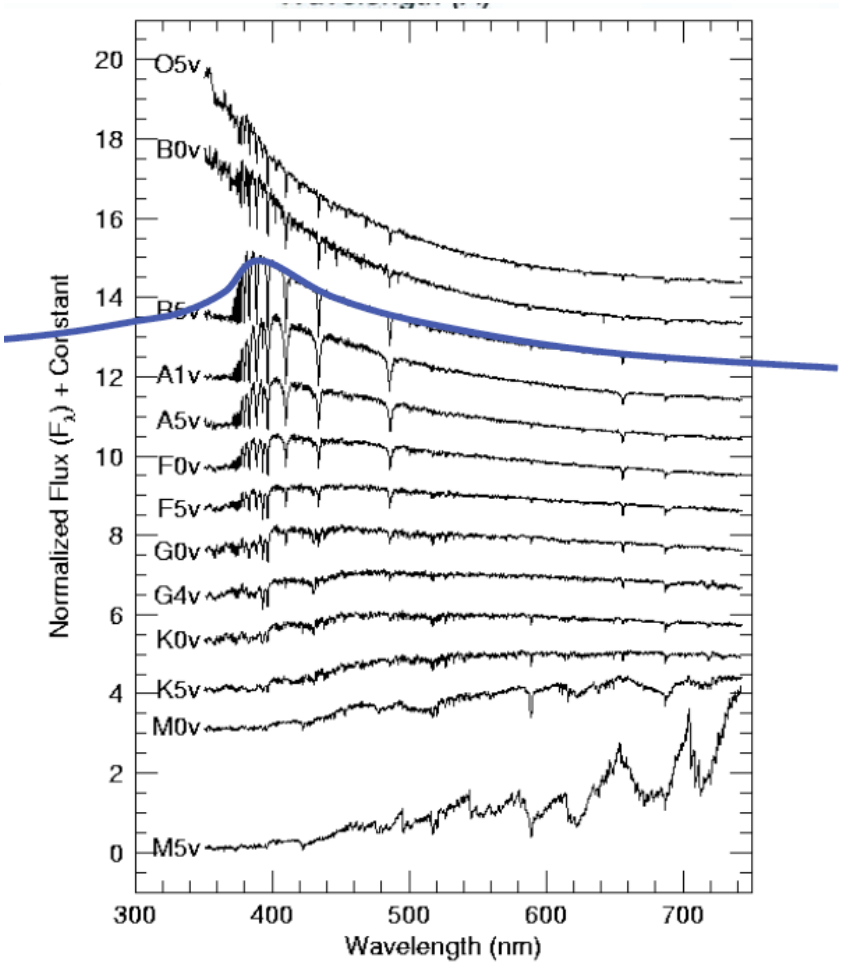
Spectral Lines

(e.g. 2D echelle image of optical Solar spectrum)

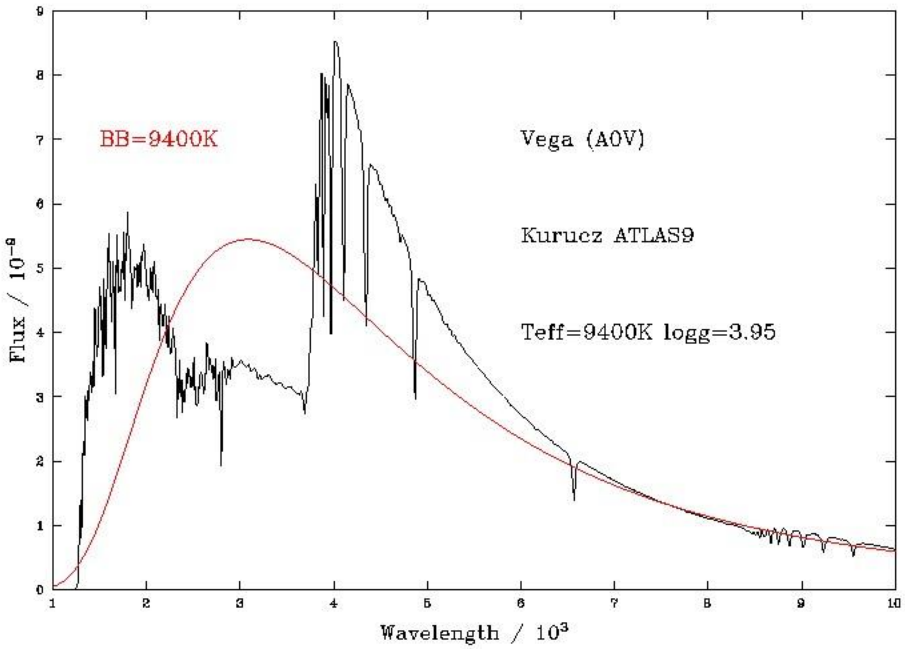


Continuous Energy Distribution

Dwarf Stars

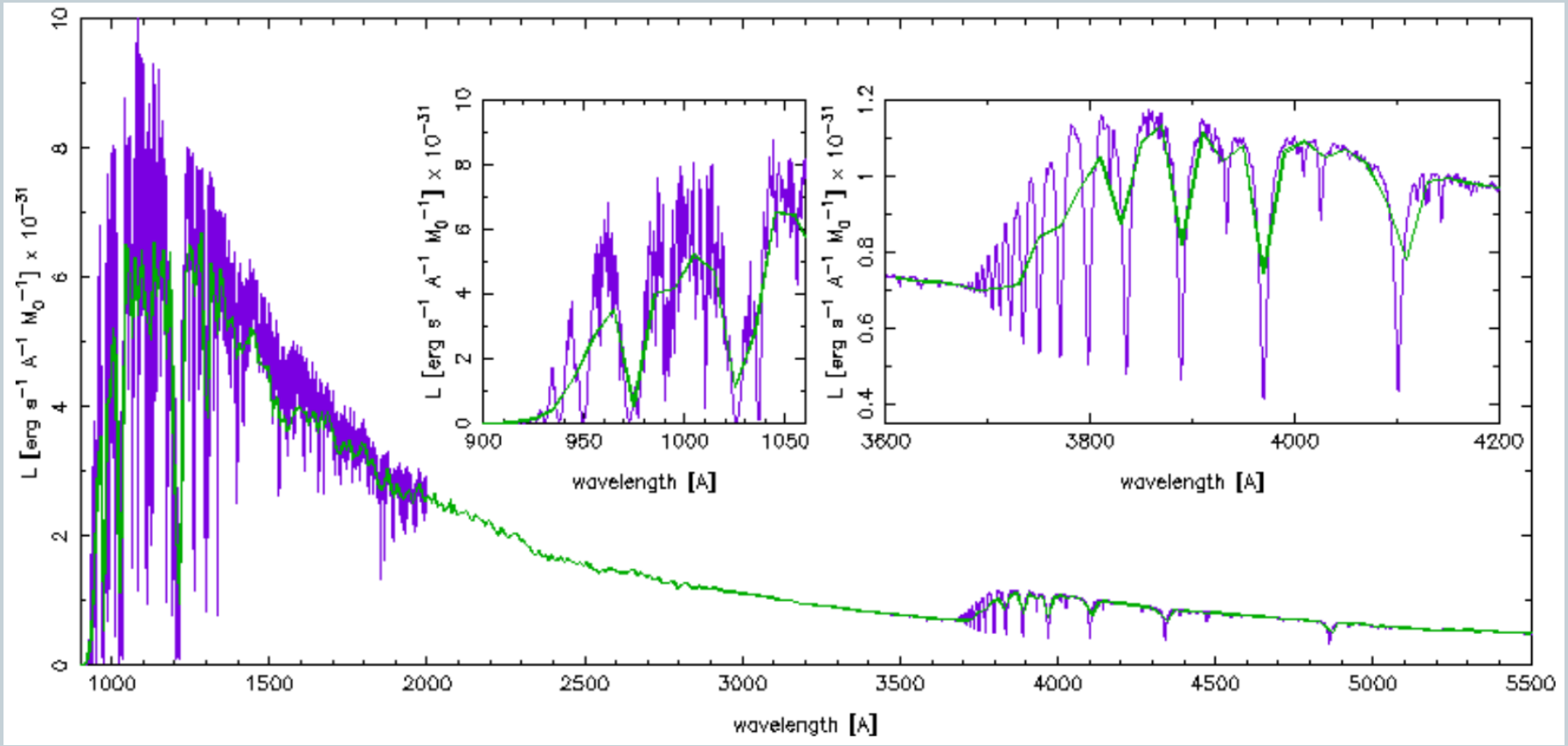


Vega

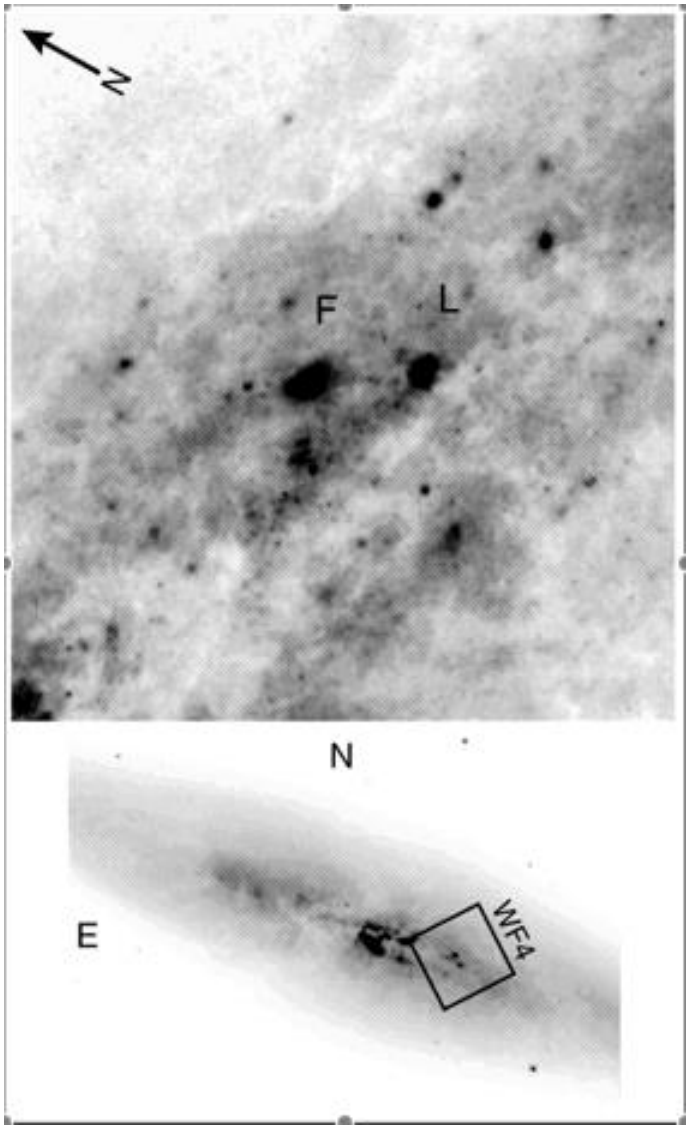


Spectral Lines

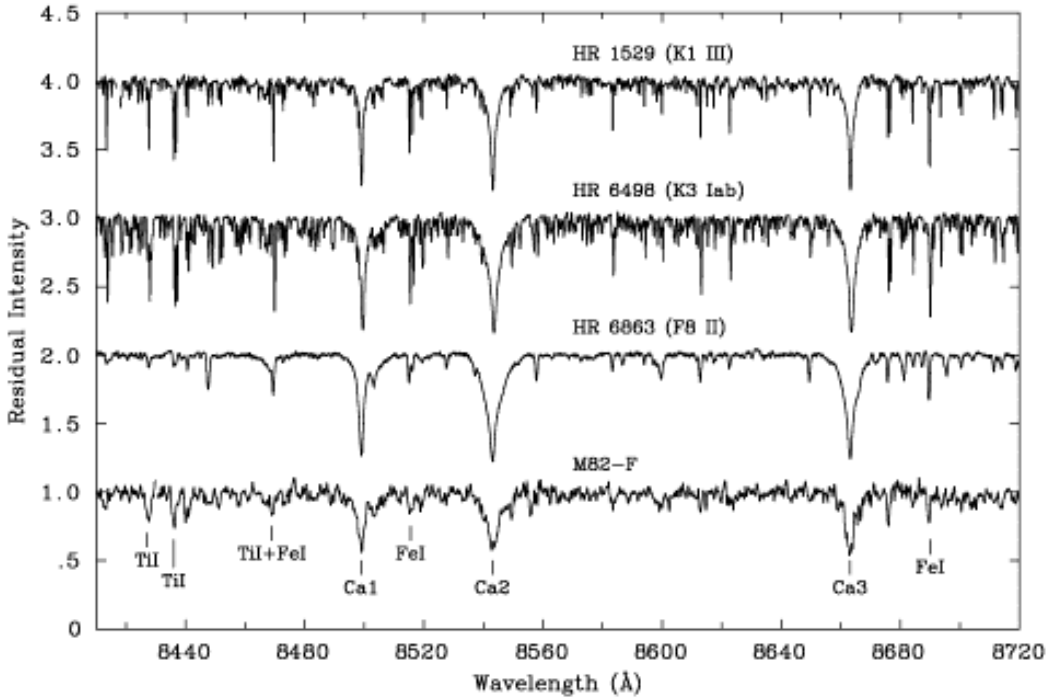
Impact of Spectral Resolution



Spectra of stars, clusters, galaxies…



Spectral lines and continuum energy distributions provide temperatures and metallicity of individual stars, plus ages of clusters & galaxies (since the highest mass stars are visually the brightest), e.g. here for cluster F in M82 (60Myr, $10^6 M_\odot$)



Line depth

We now turn from the continuous energy distribution to the line spectrum.

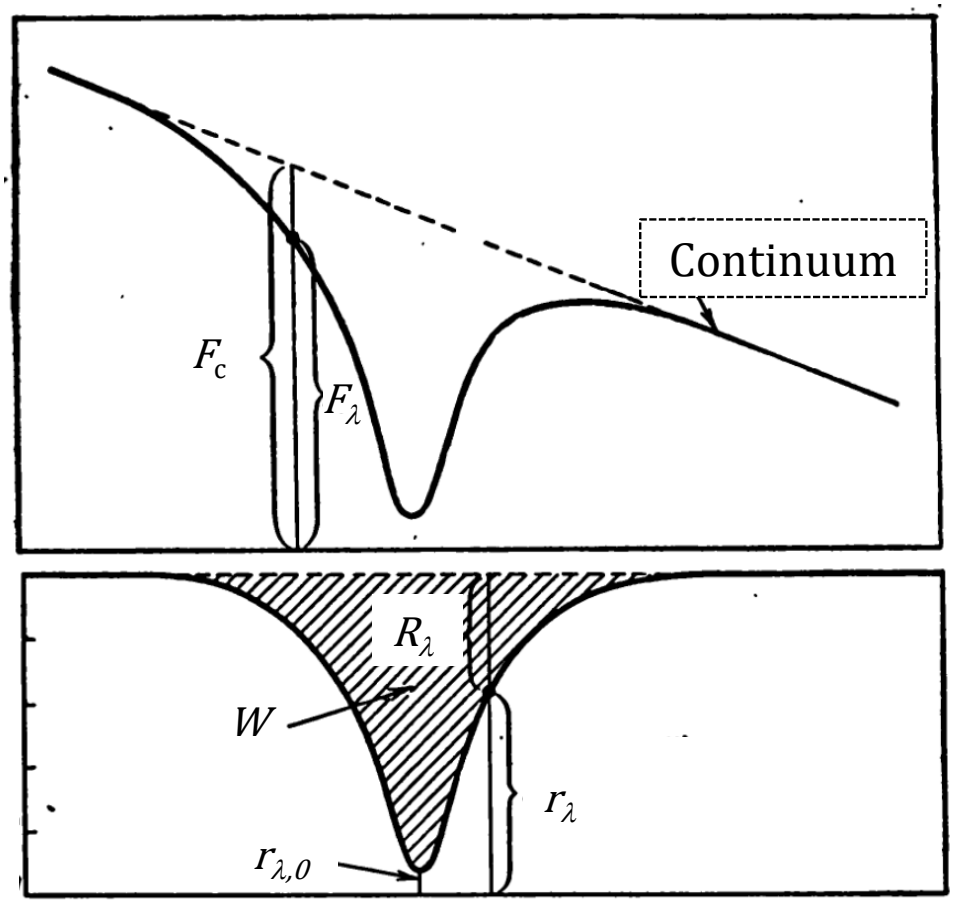
Relative intensity r_λ (*not very common term, usually applied to emission lines*):

$$r_\lambda = \frac{F_\lambda}{F_c}$$

The line depth R_λ:

$$R_\lambda = \frac{F_c - F_\lambda}{F_c} = 1 - \frac{F_\lambda}{F_c}$$

The largest $R_{\lambda,0}$— the central line depth

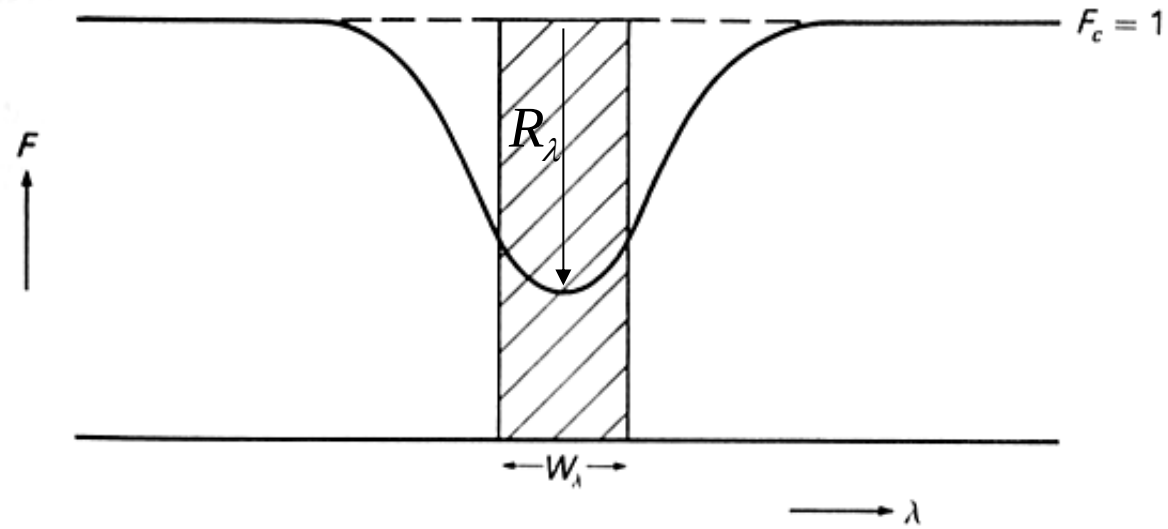


Equivalent Width

- The total area in a spectral line divided by the continuum flux F_c is called the line **equivalent width**, i.e. an integral over a line **depth R_λ**

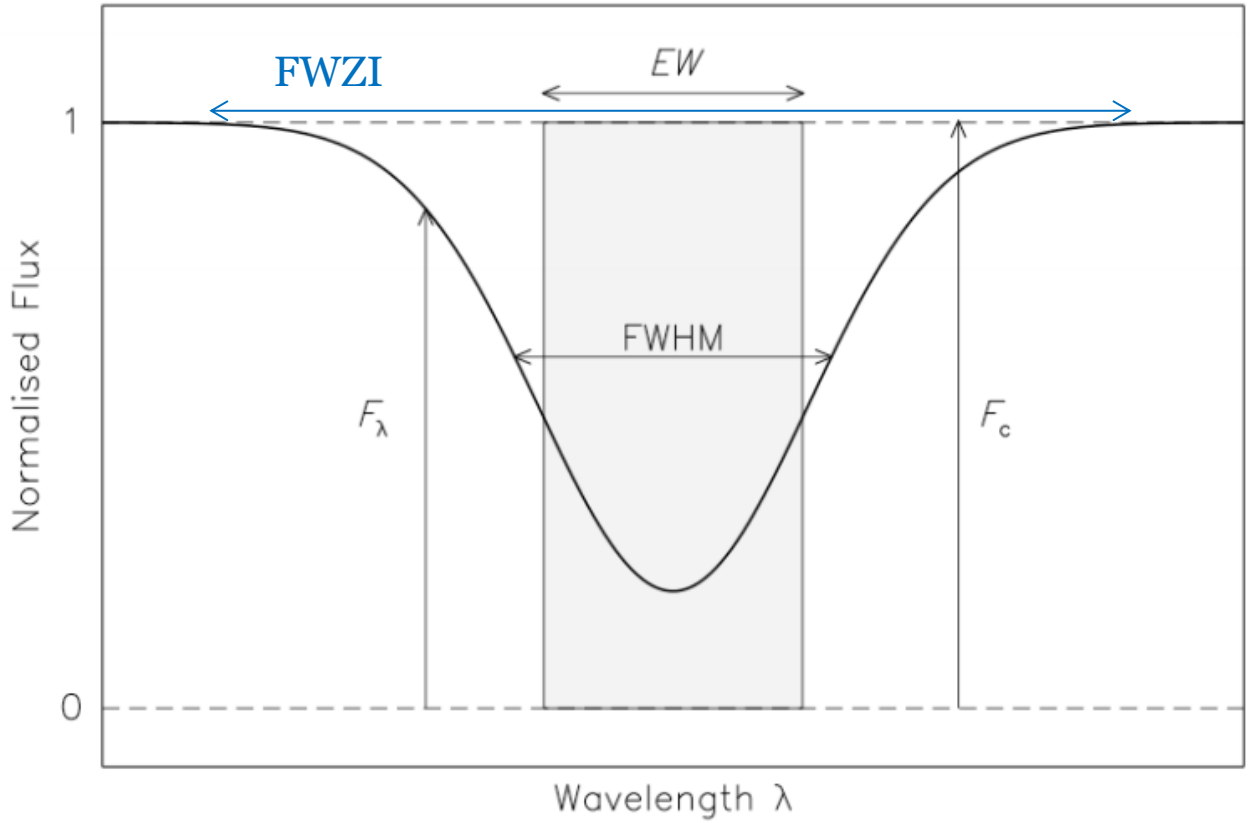
$$W_\lambda = \int \frac{F_c - F_\lambda}{F_c} d\lambda = \int R_\lambda d\lambda$$

- The division by the continuum flux means that this is a measurement of the flux in units of the continuum – the equivalent width is identical to a rectangular line of width W_λ.
- EW of absorption lines is positive, emission lines have negative EWs, and are measured in Ångströms (at optical wavelengths).



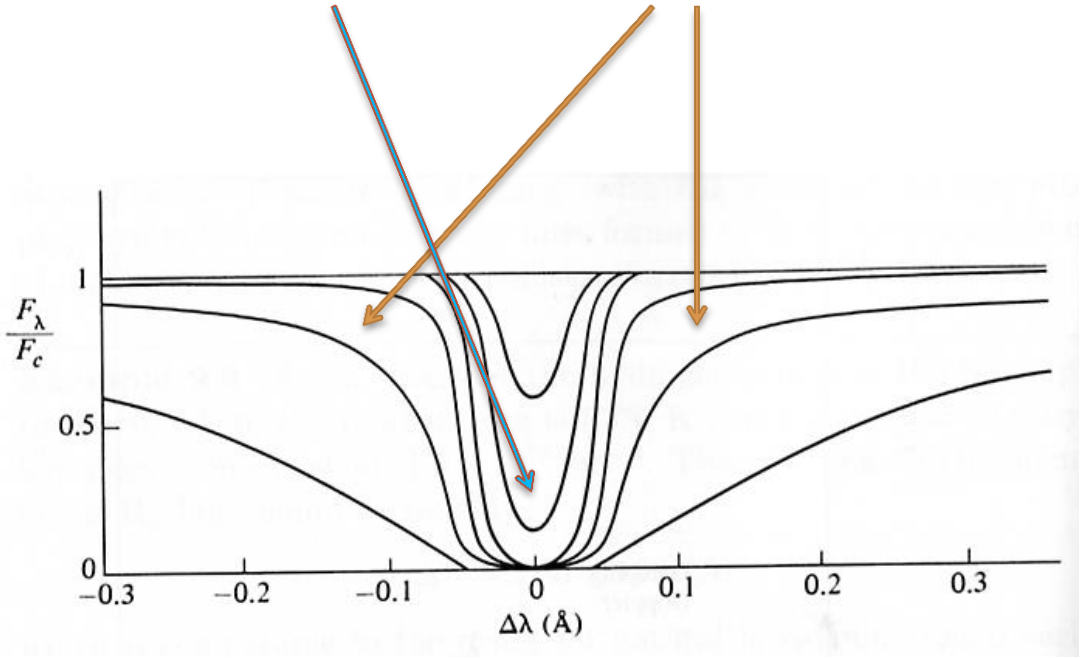
FWHM and FWZI

- Other measures of the line width are the **Full Width at Half Maximum (FWHM)**, the distance between the half line depth from blue to red, i.e. $(\Delta\lambda)_{1/2}$, and the **Full Width at Zero Intensity (FWZI)**,



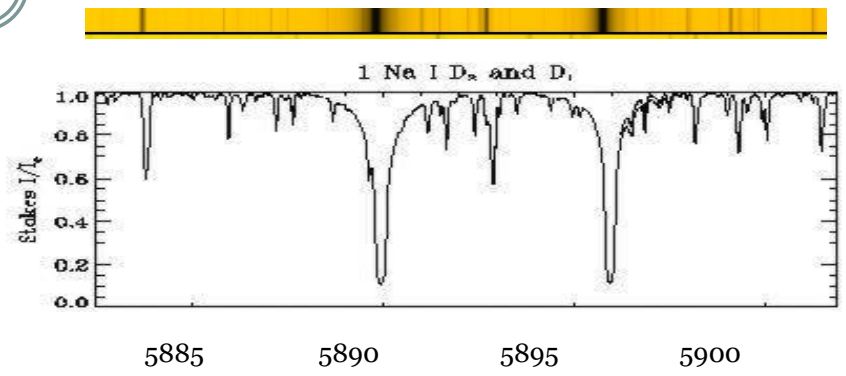
Line core and the wings

- We denote **optically thick** (**thin**) lines as those in which the line core is (not) saturated, i.e. reaching zero intensity. In reality, zero intensity is only reached for lines in non-LTE.
- The region close to the centre of the spectral line is referred to as the line **core**, whilst the **wings** sweep up the local continuum.



Example: Solar spectrum

λ	Element	W(Å)	Name
4920.51	Fe I	0.43	
4957.61	Fe I	0.45	
5167.33	Mg I	0.65	b_4
5172.70	Mg I	1.26	b_2
5183.62	Mg I	1.58	b_1
5232.95	Fe I	0.35	
5269.55	Fe I	0.41	
5324.19	Fe I	0.32	
5238.05	Fe I	0.38	
5528.42	Mg I	0.29	
5889.97	Na I	0.63	D_2
5895.94	Na I	0.56	D_1
6122.23	Ca I	0.22	
6162.18	Ca I	0.22	
6562.81	H_α	4.02	C
6867.19	O_2	tell	B
7593.70	O_2	tell	A
8194.84	Na I	0.30	
8498.06	Ca II	1.46	
8542.14	Ca II	3.67	
8662.17	Ca II	2.60	
8688.64	Fe I	0.27	
8736.04	Mg I	0.29	



Strong spectral lines in the Solar spectrum typically have equivalent widths $W_\lambda \approx 1$Å, such as the Na I D lines in the yellow. In other stars, line equivalent widths can reach tens or even hundreds of Angstroms. EWs are by definition measured relative to the continuum strength, unlike line fluxes.

Formation of absorption lines

- We obtained earlier that the emergent flux from the stellar surface is π times the Source function at an optical depth of 2/3:

$$F_\lambda(0) = \pi S_\lambda(\tau_\lambda = 2/3) = \pi B_\lambda(T(\tau_\lambda = 2/3))$$

LTE

- In spectral lines, the opacity is much larger, thus we see much higher layers at these wavelengths. These layers have a lower temperature and so B_λ is smaller, leading to a smaller F_λ in the line than F_c, the continuum flux in the neighbourhood of the line.
- In the following, we will study theory of line formation, but before it we need some practice in measuring line parameters.

Software

- We will need some software to measure parameters of spectral lines.
  - Linux: IRAF
  - Windows: DECH