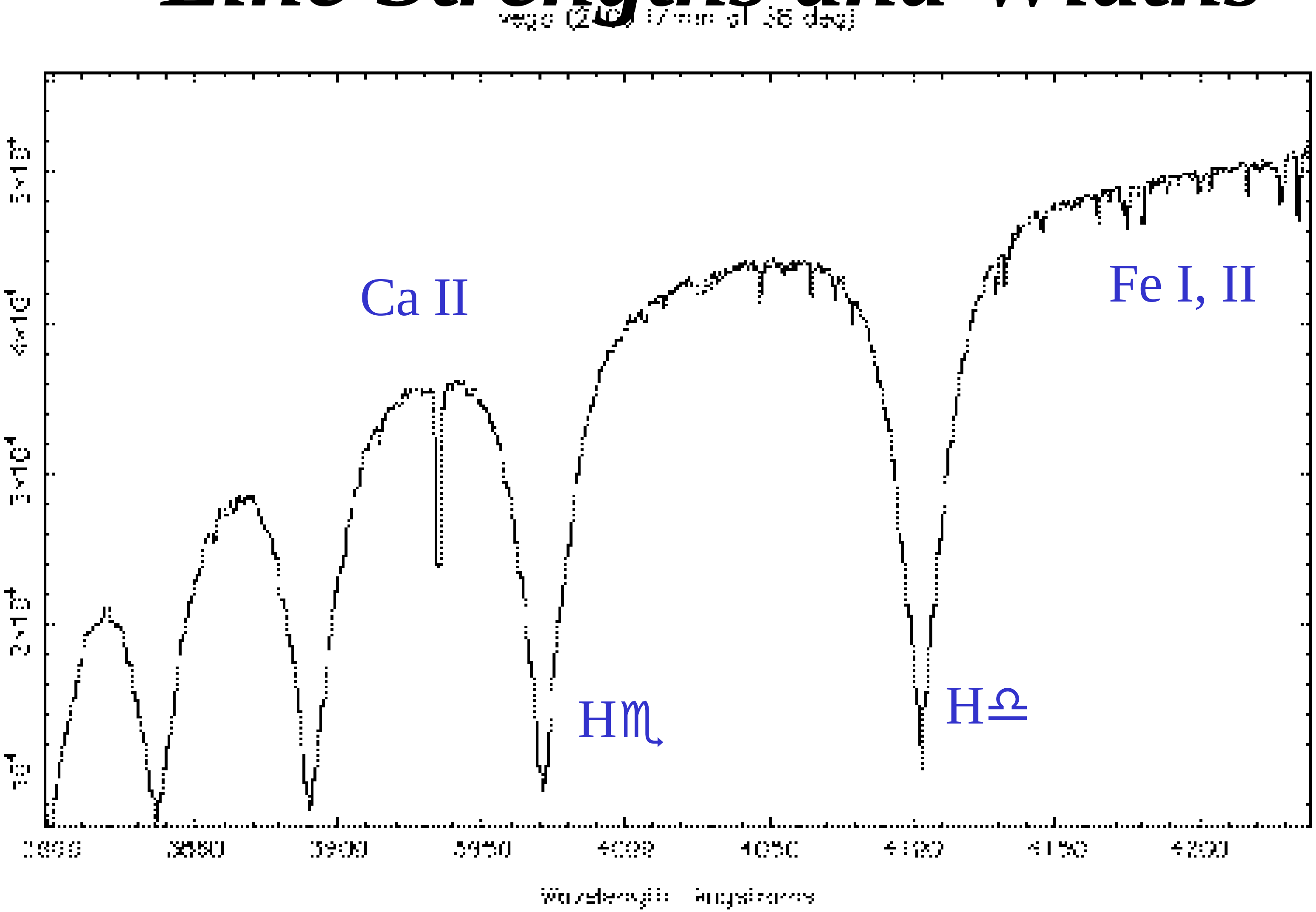
Line Strengths and Widths



each line has different strength (quantum mechanics)

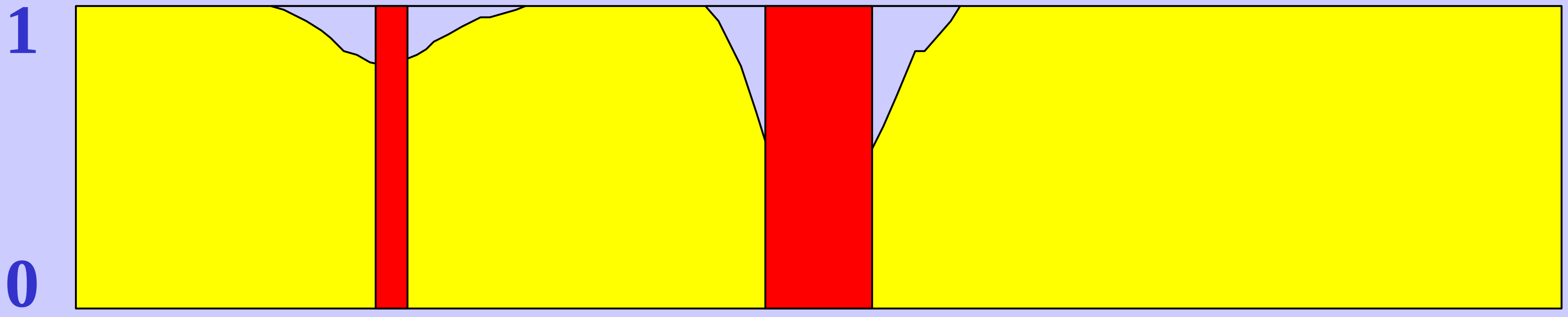
more ions --> stronger line

Equivalent Width

Measures line strength, NOT line width.

E.W. = width of rectangle with same area as line.

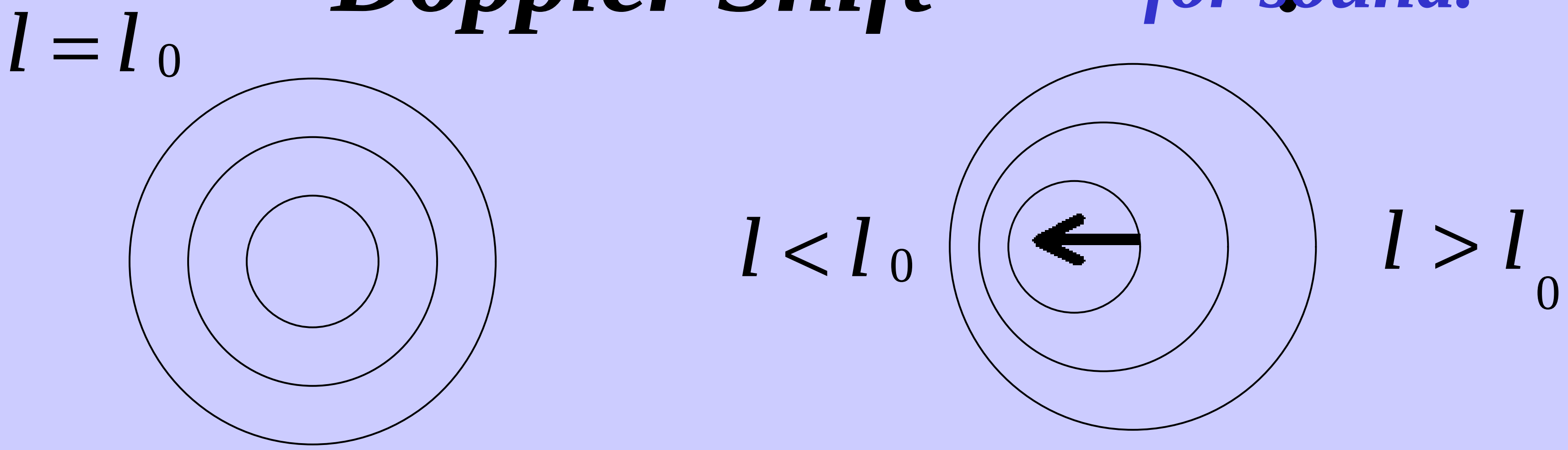
Units: nm



Same width, different equivalent width.

Doppler Shift

Doppler (1843) for sound.



rest wavelength: l_0 velocity: v

redshift: $$z = \frac{\Delta l}{l_0} = \frac{l - l_0}{l_0} \approx \frac{v}{c}$$

redshifted: $z > 0$ receding

blueshifted: $z < 0$ approaching

Doppler Shift

- ***Example:** v* **= 200 km s^{-1}, l$_0$ = 500 nm**

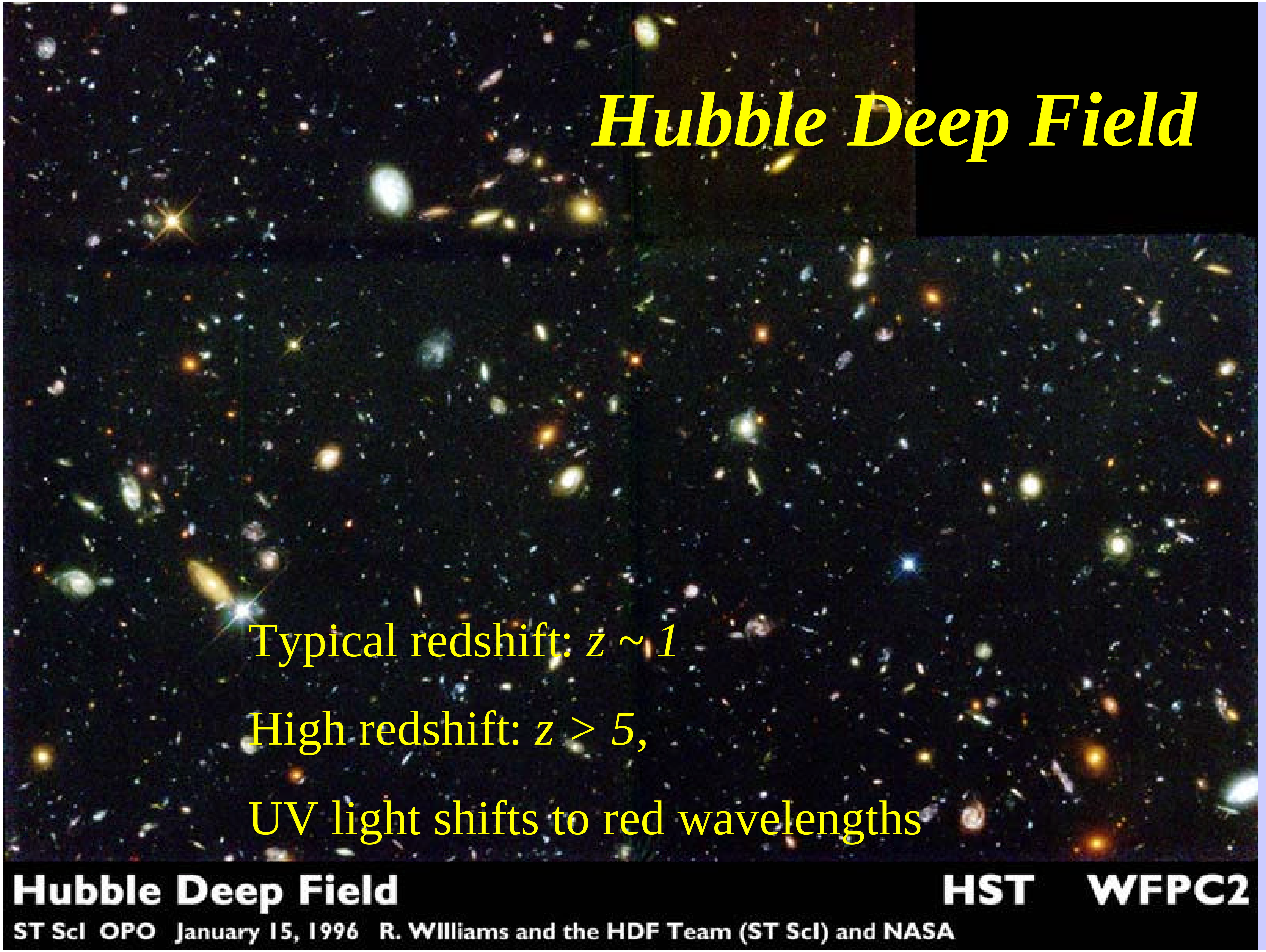
$$\Delta l = \frac{v}{c} l_0 = \frac{200 \text{ km s}^{-1}}{3\times10^5 \text{km s}^{-1}} \times 500 \text{ nm} = 0.3 \text{ nm}$$

- small shift, so no colour changes.
- unless *v* ~ *c* (near a black hole, or relativistic jet)
- Cosmological redshifts can be large:

$$l = l_0 (1+z) = (121 \text{ nm})\ (1+6) = 848 \text{ nm}$$

- Big Bang $T = \frac{T_0}{1+z} \approx \frac{3000\text{K}}{1100} \approx 2.7 \text{ K}$

Hubble Deep Field



Hubble Deep Field **HST** **WFPC2**

ST ScI OPO January 15, 1996 R. Williams and the HDF Team (ST ScI) and NASA

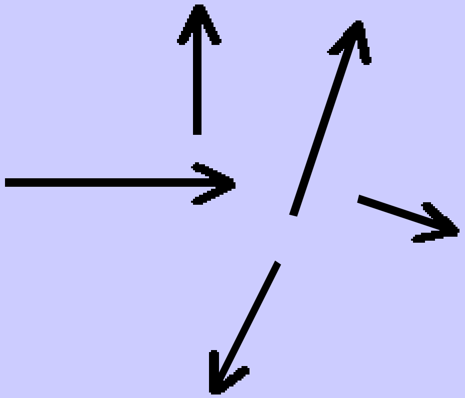
Typical redshift: $z \sim 1$

High redshift: $z > 5$,

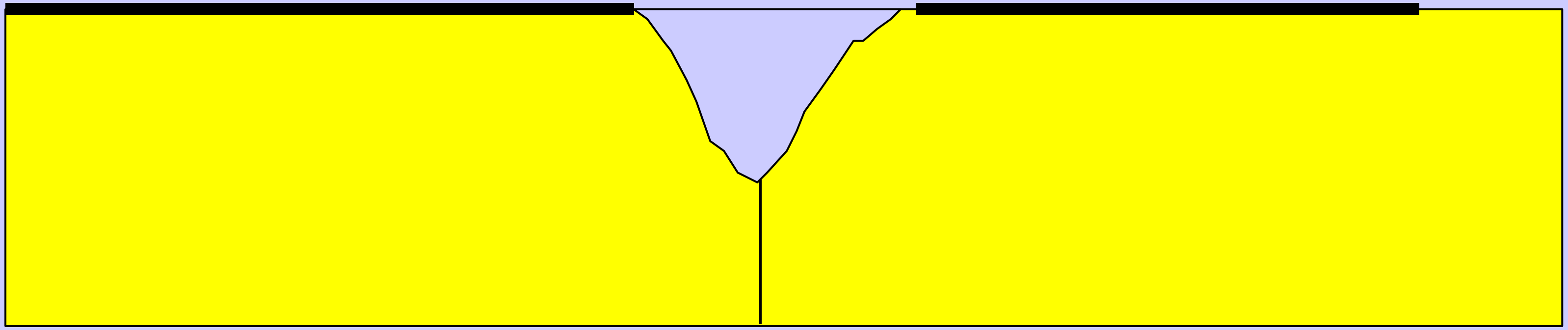
UV light shifts to red wavelengths

Thermal Broadening

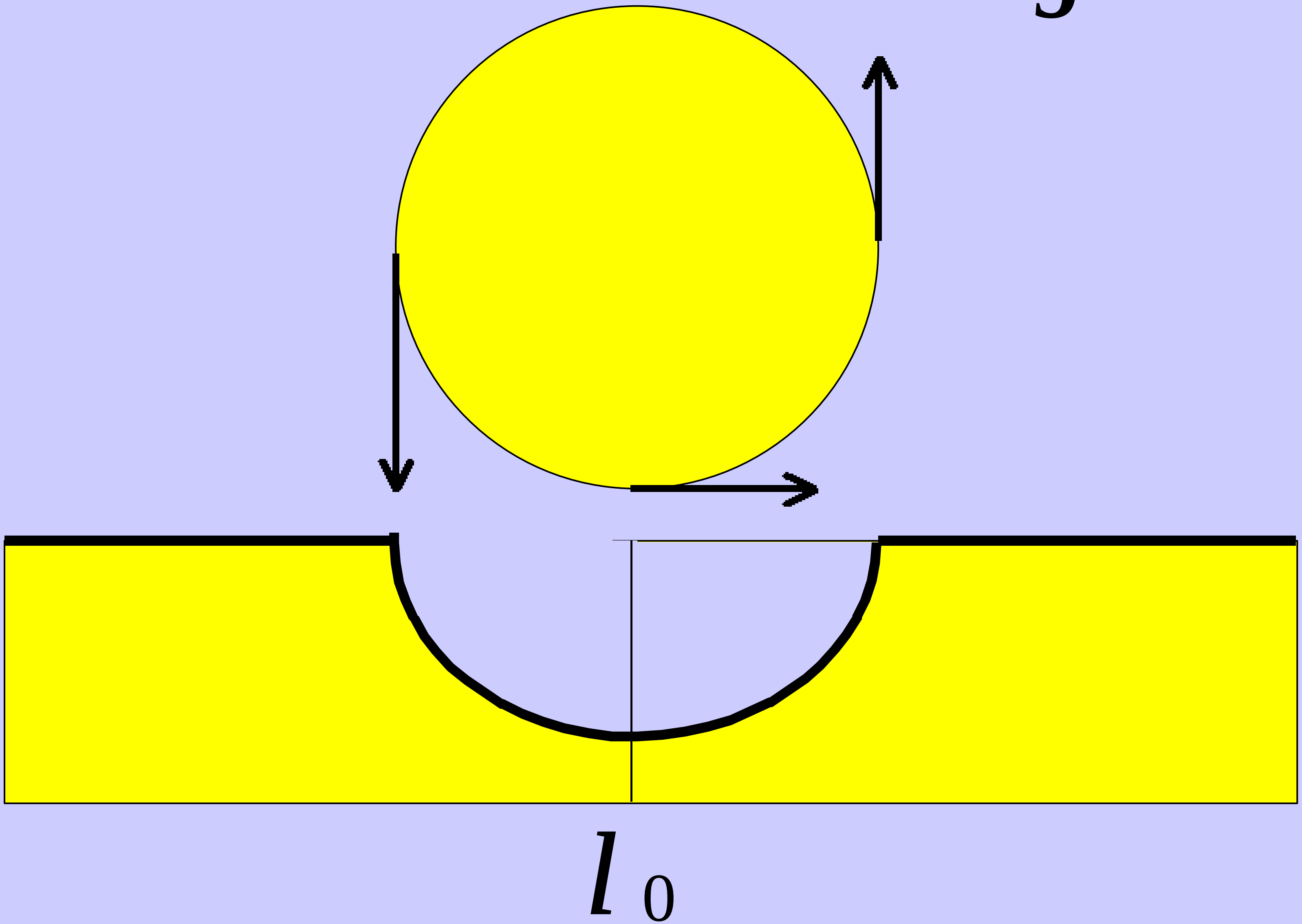
$$\frac{mv^2}{2} \approx kT$$



random motions of atoms

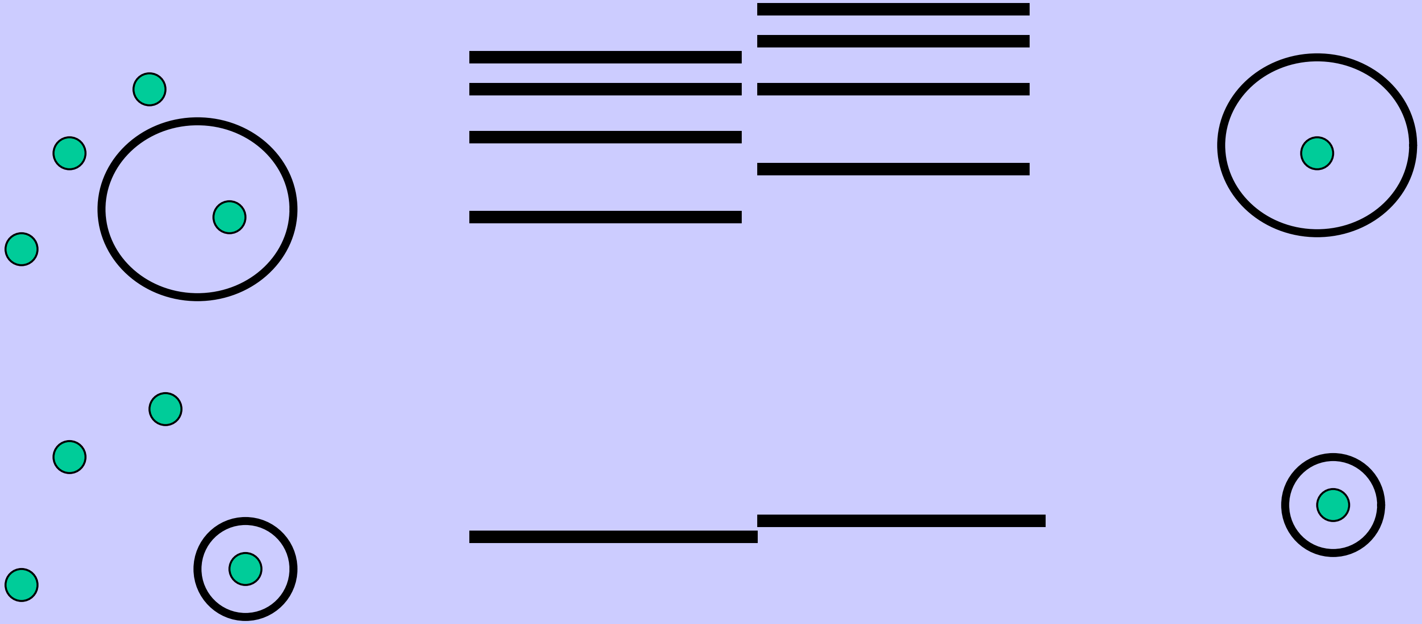


Rotational Broadening



Pressure Broadening

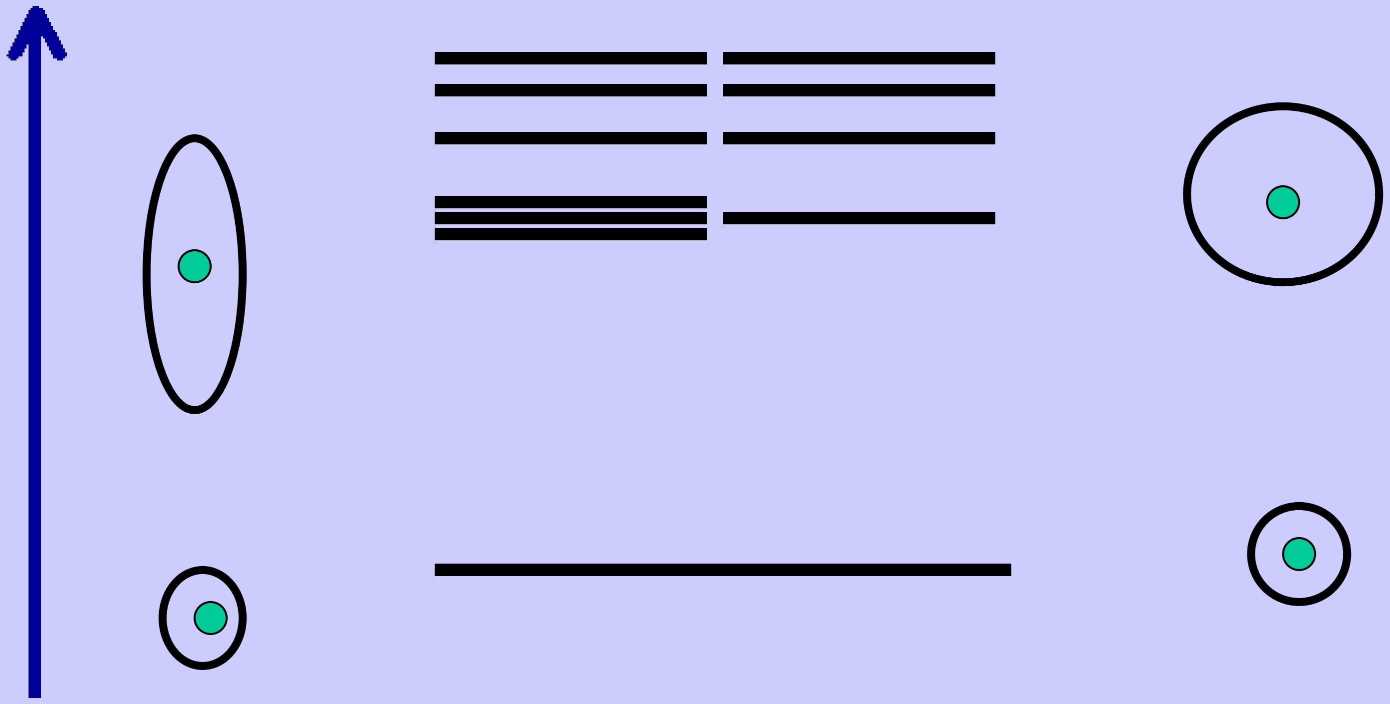
Energy levels shift when particles are nearby



high pressure gas

Zeeman Shift

Energy levels shift and split in Magnetic field



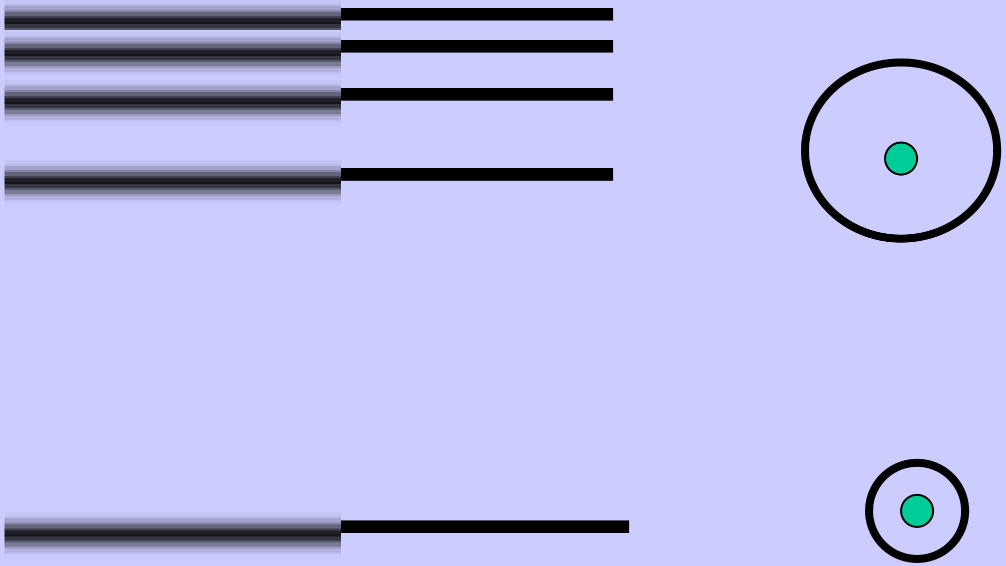
magnetic field

Quantum Uncertainty

“fuzzy” energy levels

short visit

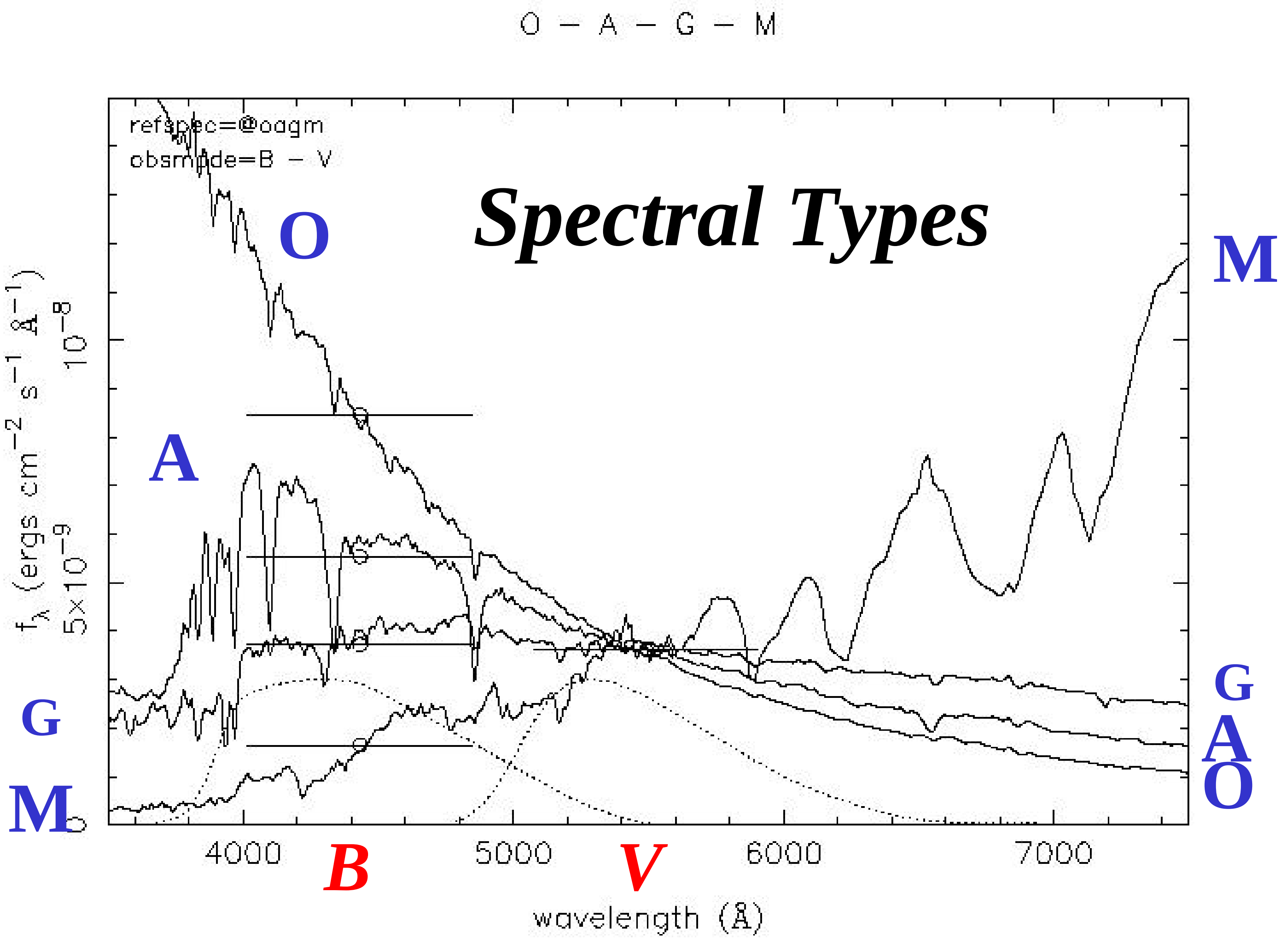
-> uncertain E



$$\Delta E \, \Delta t \approx h$$

$$h = 4.1 \times 10^{-15} \text{ eV sec}$$

Spectral Types



Why spectra differ

- Line strengths (EW ratios)
  change mainly due to
  SURFACE TEMPERATURE
  (hot-> high ionisation and excitation
  cool-> neutral atoms and molecules)
- Some line widths and ratios change with LUMINOSITY
- Very little range of abundances

  (74% H + 24% He 2% everything else)

Spectral Classification

- 1890s first photographic spectra
- 1918-24 Henry Draper Catalogue "spectral classes" of ~ 225,300 stars !!! (star names HD 35311, HD 209458, etc)
- original classification: A,B,… R,S from simple to complex lines
- many letters later dropped or merged.
- 1920s photometry (colour indices) revealed correct temperature sequence
- confirmed by atomic physics
- 1940s Morgan & Keenan (MK spectral types)

- handout:
  - spectral classes provide a "short-hand" description of the appearance of a stellar spectrum.

Spectral Types

hot cool

O B A F G K M

(Oh! Be A Fine Girl, Guy, Kiss Me!)

("early-type" "late-type")

– sub-class 0 - 9 *e.g.* B0, B9, G2

Spectral Types

hot cool

O B A F G K M

(Oh! Be A Fine Girl Guy, Kiss Me!)

("early-type" "late-type")

– sub-class 0 - 9 *e.g.* B0, B9, G2

(N R S (No Romeo, Scram))

✶ one example of a luminosity criterion:

- H lines of Balmer series are affected strongly by pressure broadening

- pressure gradient ∝ surface gravity of star *g*

$$g = \frac{GM}{R^2}$$

(M = mass, R = radius, G = gravitational constant)

- dwarf star, small *R*, large *g* ⇒ broadened H lines
- giant star, large *R* (~100×), small *g* ⇒ narrow H lines
    - (handout: spectra showing luminosity effects)

Luminosity Classes

✶	– main-sequence	**V**	most common
	– subgiants	**IV**	
✶	– red giants	**III**	common
	– bright giants	**II**	rare
	– supergiants (blue to red)	**I**a,b	very rare
	– white dwarfs	DA	quite common
	–	DB,DO	

MK Spectral Types

– *e.g.*	Sun	G2 **V**
	Vega	A0 **V**
.	Betelgeuse	M2 **I**ab
	Rigel	B8 **I**a
	Aldebaran	K5 **III**

Review

- Multicolour Photometry
  - Use filters (e.g. *U B V R I*)
  - measure *flux densities* : (f_B, f_V, ...)
  - apparent magnitudes : (*B*, *V*, …)
  - colour indices :

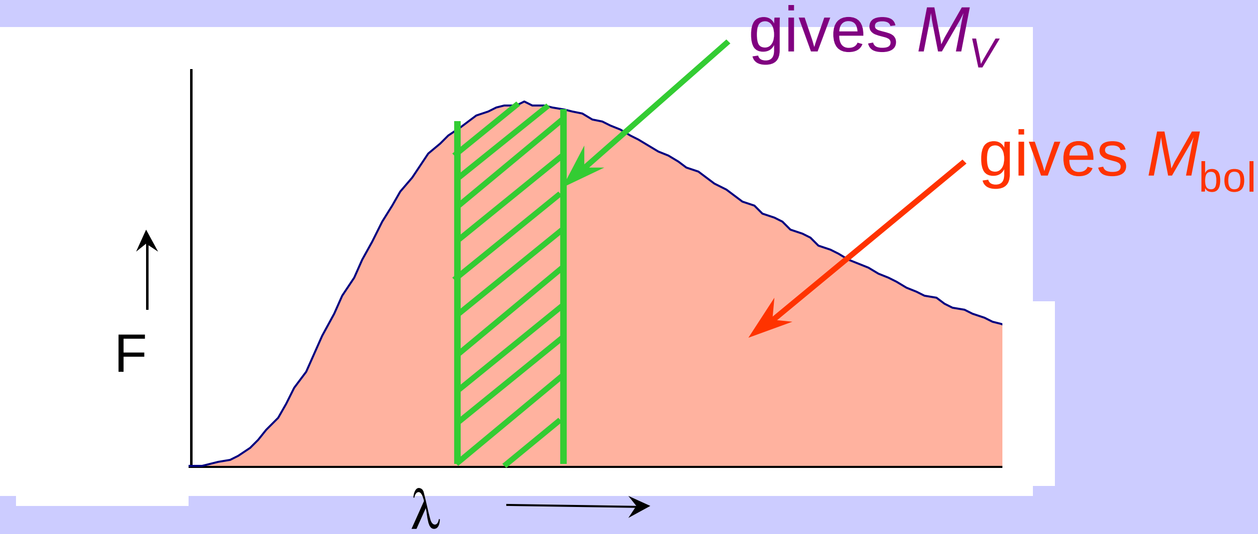
$$(B - V) = -2.5 \log \left[f_B / f_V \right] + \text{constant}$$

  - absolute magnitudes (*d* from parallax):

$$M_V = V - 5 \log(d / 10 \text{ pc})$$

Bolometric Magnitude

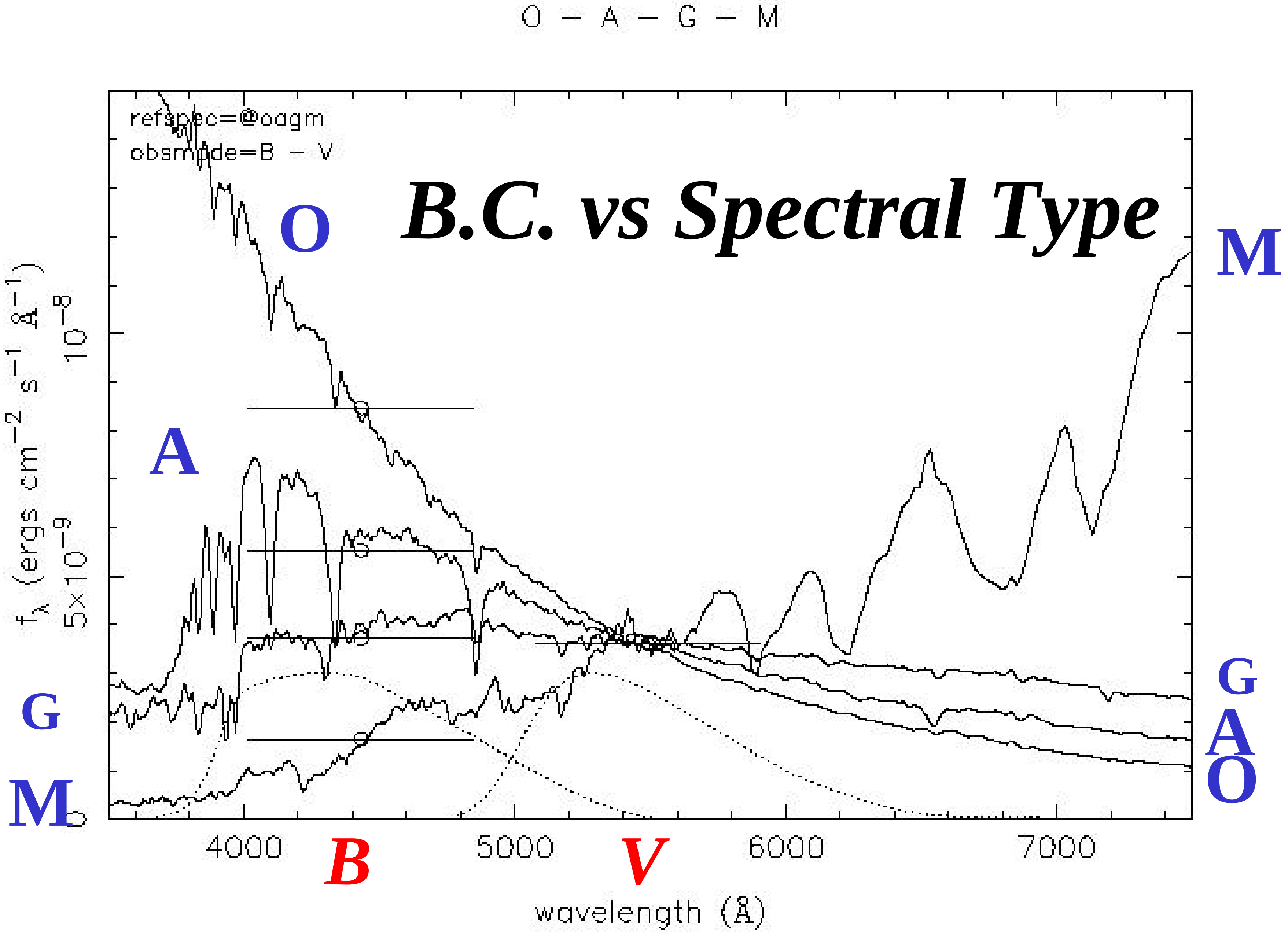
M_{bol} = absolute bolometric magnitude
total flux over the entire spectrum.



Difficult to measure M_{bol}.

Easy to measure M_V .

B.C. vs Spectral Type



Bolometric Corrections

- B.C. = M_{bol} - M_V < 0 to make star brighter.
- Sun: $M_V = 4.83$, B.C. $= -0.14$ $M_{\text{bol}} = 4.69$
- F0**V** B.C. = 0 (most optical)

. O5**V** $= -3.8$ (mostly UV

M8**V** $= -4.0$ mostly IR)

$$\frac{L}{L(\text{sun})} = 10^{-0.4\left(M_{bol} - M_{bol}(\text{sun}) \right)}$$

$$M_{bol} - M_{bol}(\text{sun}) = -2.5 \log\left(\frac{L}{L(\text{sun})} \right)$$

Calibrations

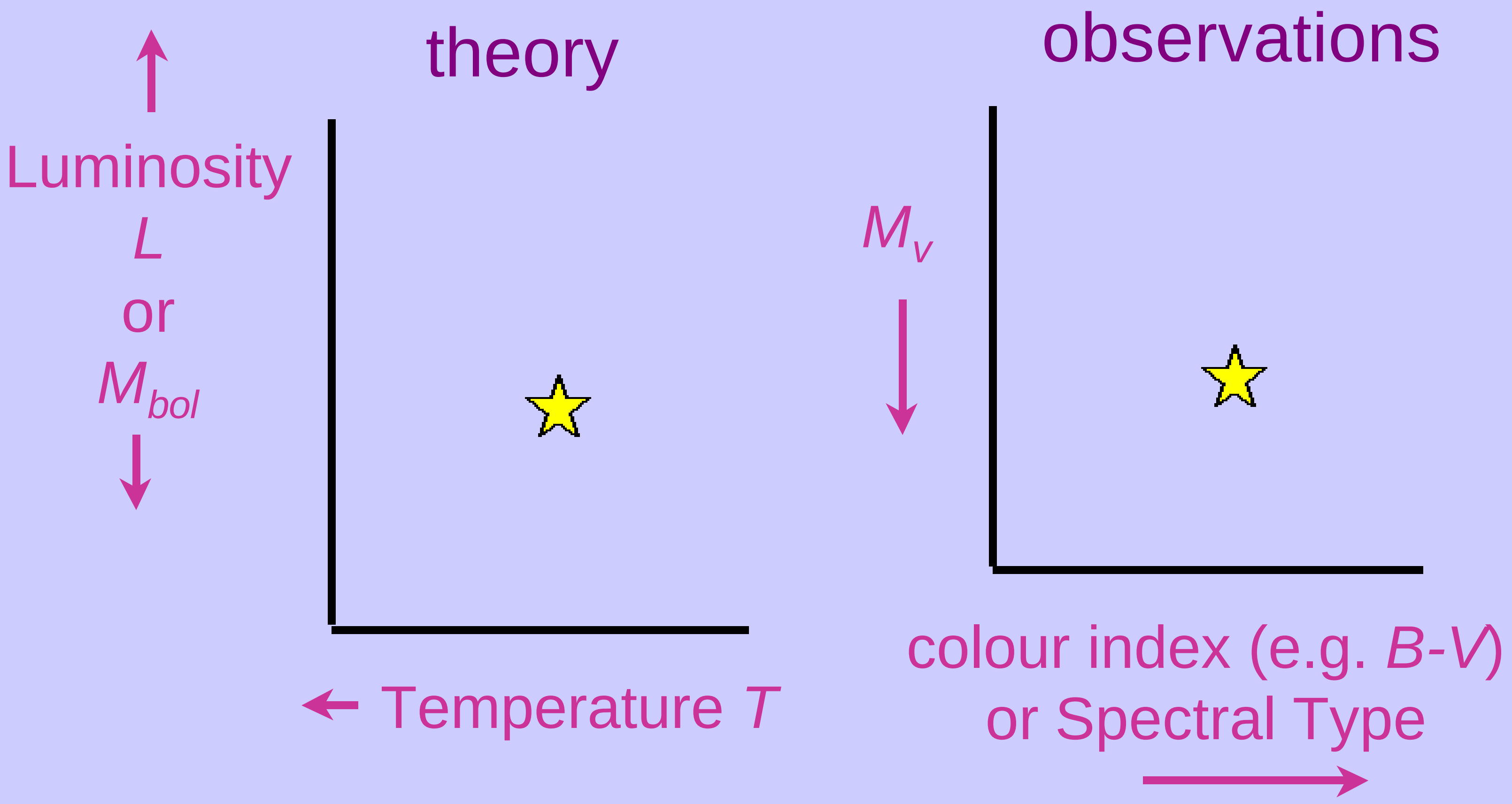
- Calibrations of colour indices, temperatures, absolute visual magnitude (M_V), and (less precise) spectral types
  - very well defined for <u>most</u> main-sequence stars (5,000 ≤ T ≤ 30,000 K)
  - less so for hotter O stars (> 40,000 K)
  - and cooler M stars (< 2,500 K)

(handout: example of relevant calibrations)

- The Hertzsprung-Russell (HR) Diagram
  - first presented independently by H (1911) and R (1913) to show links between spectral types (or colours) of stars and absolute magnitudes
  - now recognised as one of the most important diagrams for all astronomy, because of its importance for understanding the evolution (ageing) of stars
    - (handout: HR diagram)

Theory vs Observations

- Alternative versions of the H-R diagram:



theory

Luminosity

L

or

M_{bol}

← Temperature T

observations

M_v

colour index (e.g. B-V)
or Spectral Type