AS1001:Extra-Galactic Astronomy

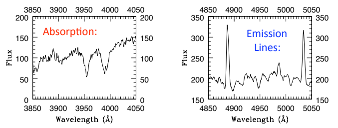
Lecture 4: Galaxy Spectra

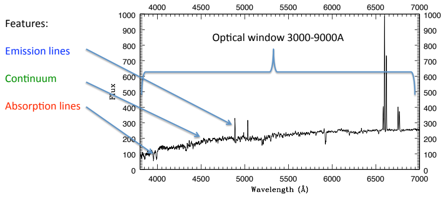
Galaxy Spectra

- The combined light from ~10^{10} **stars** plus many **molecular clouds** and **star-forming regions**.
- The spectra tell us:
  - The galaxy's **velocity** (or redshift, hence distance)
  - The **mass** (from internal velocities)
  - The **star-formation rate** (emission lines)
  - The average **age** of the stellar population (blue/red)
- 3 Aspects of Spectra:
  - **Continuum**
  - **Absorption Lines**
  - **Emission Lines**

Galaxy Spectrum

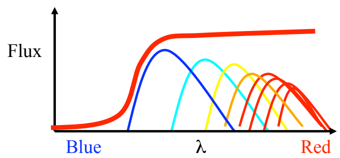
Example galaxy spectrum:





The Continuum

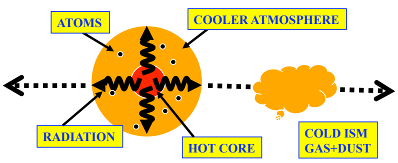
- The combination of many Black-Body spectra from stars spanning a range in temperatures



- Red colour => lack of blue (hot young) stars => old stellar population
- Blue colour => ongoing star formation

Absorption Lines

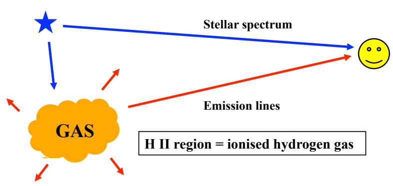
- Atoms/Molecules in a star's atmosphere absorb light at specific wavelengths



- Cold gas in the interstellar medium (ISM) absorbs light at specific wavelengths.
- (ISM's cold dust absorbs ~ 1 mag / kpc)

Emission Lines

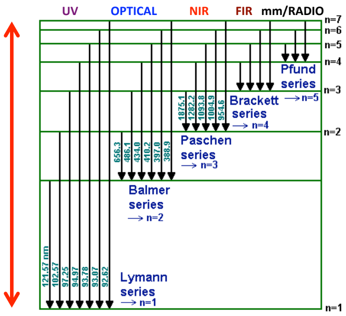
- Young stars are initially embedded in gas.
- Hot (high-mass) young stars ionise nearby gas.
- Gas emits at specific wavelengths as the free electrons recombine.



Hydrogen Energy Levels

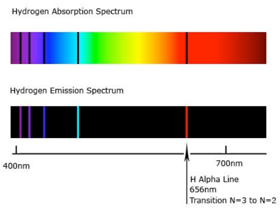
Ionisation Potential
$h\nu = 13.6$ eV
$\lambda = 912$ Angstroms
UV photons ionise.
Recombinations then produce emission lines

$$\frac{1}{\lambda} = R\left(\frac{1}{n_l^2} - \frac{1}{n_u^2}\right)$$
$$R = 1.097\times10^{7}\ m^{-1}$$
$$= 1/(\,912\ \text{A}\,)$$
$$H\alpha: n_u = 3 \quad n_l = 2$$



Rydberg Formula for Hydrogen Lines

$$\frac{1}{\lambda} = R_\infty\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$



hot star atmosphere

H II region

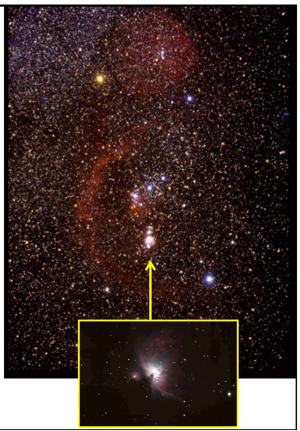
Orion Nebula

Hydrogen is ionized by photons with E > 13.6 eV or λ < 912 A.
1eV = 1.602E-19 J;
E = h ν = h c / λ

Four bright O stars emit most of the ionizing photons that produce the **Orion Nebula H II region**

Neutral hydrogen: H^0 = H I
Ionized hydrogen: H^+ = H II

Similarly for other atoms/ions, e.g. MgII, OIII, …



HST View of Orion Nebula

Electrons recombine, cascade thru energy levels, emitting line photons.

Balmer lines in optical
Recombinations to n = 2
Hα: 6563A (red)
O[III] 5007 A (green)

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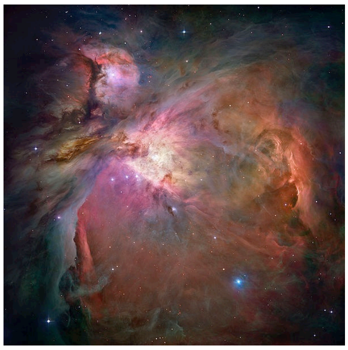
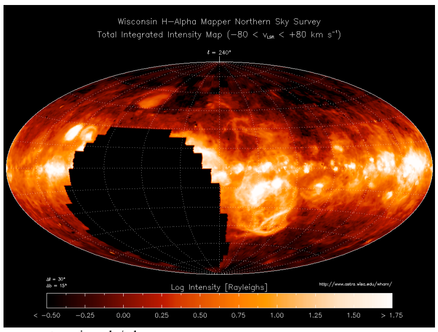


Hα map of Milky Way's Ionised Gas

Gas layer ~1 kpc thick. Ionized by O & B stars in the Galactic disc.



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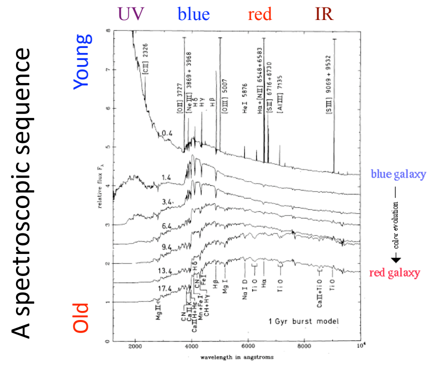
Emission nebulae (H II regions) along the spiral arms.

Why are H II regions pink?

Why are H II regions along the spiral arms?

Model Spectra for a Starburst

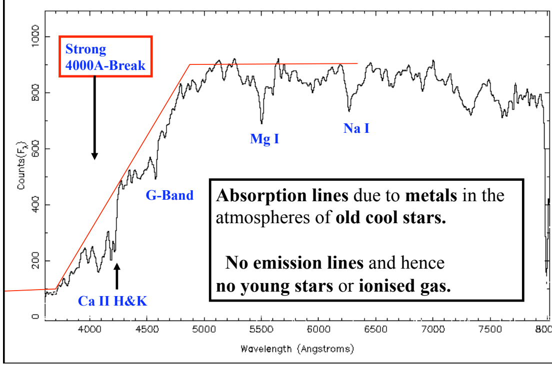


Absorption / Emission Lines

- Absorption Lines
  - hot: H, He cool: metals
  - Formed by atoms/molecules absorbing light
  - in stellar atmospheres
  - by cold gas in the ISM
- Implies
  - Metal lines from cool stars
    => old stellar population
    => old galaxy
- From
  - Ellipticals
  - Spiral Bulges

- Emission Lines
  - Gas ionised by UV photons from nearby O and B type stars
- Implies
  - Newly formed stars
    => star-forming ongoing
    => young galaxy
- From
  - Spiral Disks
  - Irregulars

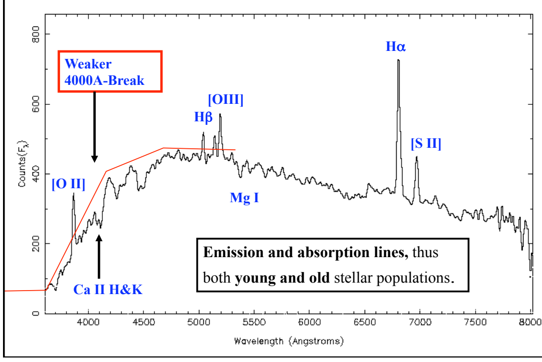
Example Spectrum: Elliptical



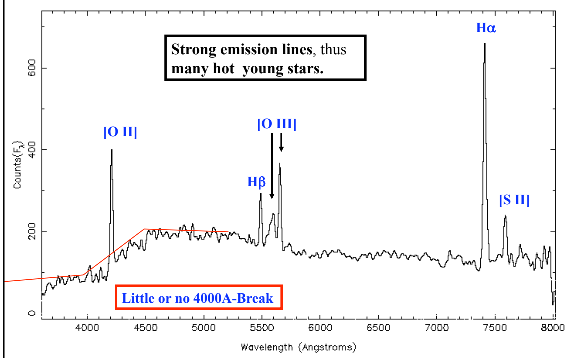
The "4000A-break"

- 4000 Angstrom = 400 nm
- Caused by:
  - **Absorption** (many overlapping lines with λ < 4000A) by **metals** in the atmospheres of cooler stars
  - **lack of hot blue stars** (type O,B)
- Hence:
  - Ellipticals => Strong 4000A-Break
  - Spirals => Weak 4000A-Break
  - Irregulars => Little or no 4000A-Break

Example Spectrum: Spiral



Example Spectrum: Irregular

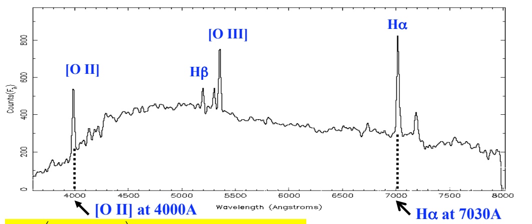


Radial Velocities

- Most galaxy spectra are **REDSHIFTED**.
- Observed wavelengths of spectral lines are longer than wavelengths measured for gasses in the lab.
- Interpret this as a DOPPLER shift.
- Most galaxies are moving away.
- v > 0 : RECEDING
- v < 0 : APPROACHING
- z = **redshift** (z = v / c for z << 1)
- **Distance** from Hubble's law: d = v / H_0 (H_0 = 72 km/s/Mpc)

$$\frac{\lambda_{\mathrm{OBSERVED}}}{\lambda_{\mathrm{LAB}}} \equiv 1 + z = 1 + \frac{\mathrm{v}}{\mathrm{c}} \quad \text{or} \quad z = \frac{\Delta\lambda}{\lambda} = \frac{\mathrm{v}}{c}$$

Example Radial Velocity



$$\mathrm{v} = c\left(\frac{\lambda_{\mathrm{OBS}} - \lambda_{\mathrm{LAB}}}{\lambda_{\mathrm{LAB}}}\right)$$

$$= (3 \times 10^5 \text{ km/s})\left(\frac{4000 - 3727}{3727}\right) = 21{,}974 \text{ km/s}$$

$$\mathrm{v} = c\left(\frac{467}{6563}\right) = 21{,}500 \text{ km/s}$$

GALAXY IS MOVING AWAY AT ABOUT 21,750 km/s

CLASS EXERCISE

- Work in groups of 2-3
- Collect an example spectrum
- Identify spectral features
- Measure the wavelengths of the spectral lines
- Calculate the radial velocity (km/s)
- Use Hubble's law (d = H_0 v) to find the distance (H_0 = 72 km/s/Mpc)

Typical Spectral Features

- Absorption
  - Ca II (K) = 3933.7 A
  - Ca II (H) = 3968.5 A
  - G-band = 4304.4 A
  - Mg I = 5175.3 A
  - Na I = 5894.0 A
- Emission
  - [O II] = 3726.7 A
  - Hδ = 4101.7 A
  - Hγ = 4340.5 A
  - Hβ = 4861.3 A
  - [O III] = 4958.9 A
  - [O III] = 5006.8 A
  - Hα = 6562.8 A
  - [S II] = 6716.0A

1 Angstrom = 0.1 nm = 10^{-10} m

Brackets (e.g. [O III]) mean "forbidden lines", emitted only at very low gas densities.