① Summary – <u>The Milky Way</u>

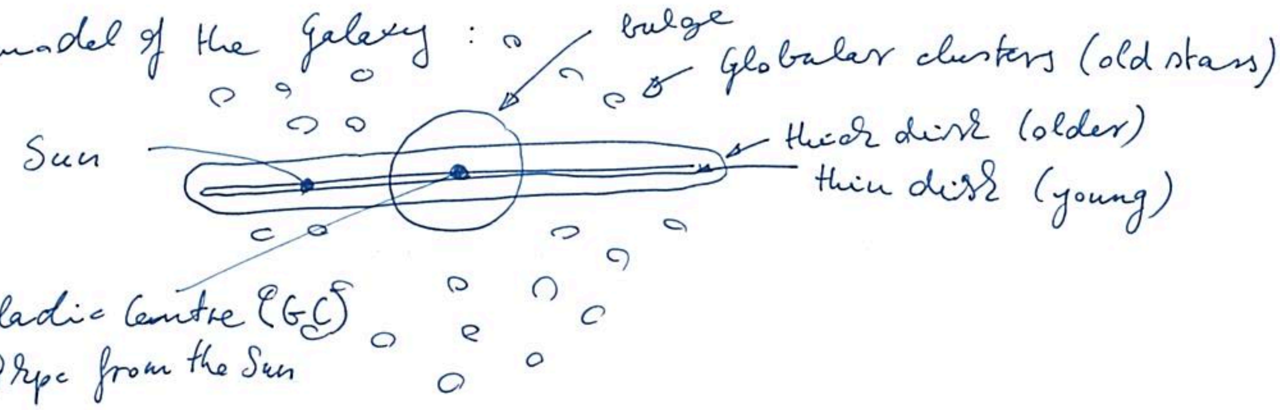
How do we know in what type of a galaxy we live in?
- → mapping the distribution of stars
- → mapping the distribution of gas

} spiral galaxy

Mapping the distribution of stars – Malmquist bias
↳ we only see bright stars at large distances

Measuring distances:
- parallax – only very nearby stars within the Galaxy
  ↳ Gaia is pretty good at this
- variable stars (Cepheids, RR Lyrae)
  ↳ period-luminosity relation
  ↳ on the red giant branch on the HR diagram

⇒ model of the Galaxy:



Galactic Centre (GC)
~ 8 kpc from the Sun

+ stellar streams in the halo – from shredded dwarf galaxies

+ the Small and Large Magellanic Clouds

Components of the Galaxy:
- stars
- dust
- gas
- dark matter

} these are <u>most of the mass</u>
+ small mass of planets, black holes etc....

<u>Interstellar extinction</u> – or reddening
↳ dust absorbs some of the star light
→ more absorption of shorter wavelengths (blue light) → reddening

$$m = M + 5\log_{10} d - 5 + \underline{A_\lambda} \leftarrow \text{extinction}$$

$E(B-V)$ – reddening

→ dust is confined in a layer of about ± 150 pc in the midplane
zone of avoidance

(2) Galactic rotation:

2 types of motion in the Galaxy:

- rotation (centrifugal force) - disk
- random motions - halo, bulge

How does the Sun move → compare to far away globular clusters

↳ rotates around the Galactic Centre

$\Theta_0 = 220$ km/s

→ we can estimate the dynamic mass inside a radius based on how the stars move at that radius $M \sim 10^{11} M_\odot$

→ How do other nearby stars move?

↳ compare to the solar motion

↳ express v_R and v_T with the Oort constants (A, B)

→ v_R has sinusoidal pattern

→ measure the Oort constants from the motion of other stars (e.g. Gaia satellite measurments)

A → shearing motion in the disk near the Sun

B → angular momentum gradient near the Sun

→ building a rotation curve → flat rotation curve → dark matter

→ Do stars actually orbit on circular orbits? - No

reference frame: Local Standard of Rest (LSR) - the Suns position moving with Θ_0 speed on a circular orbit around the GC.

→ stars move on an ellipse with respect to the LSR, while the LSR is revolving around the GC. → epicyclic motion

→ the Sun's motion with respect to the LSR is called solar motion

Stellar populations: Population I: metal-rich, young stars, interstellar gas → disk

Population II.: metal-poor, old stars, no interstellar gas

→ globular clusters, bulge, halo stars

Population III: theorethically the first stars in the Universe

3. <u>The interstellar medium (ISM)</u>

How can we detect it? → absorption lines in stellar spectra → thermal broadening, narrow lines → cold gas
→ direct detection of gas (HI, CO) etc...

<u>neutral hydrogen (HI)</u> – chemistry denotation
→ spin-flip transition at 21cm (1.4 GHz)
→ can observe HI in the galaxy
→ spectral line → dopler shift → motion of the gas ≈ distance
↳ maps the disribution of the gas in the Galaxy
↳ spiral structure

→ HI is desributed in a disk around the stars
↳ the HI disk is larger (more extended) than the stellar disk

→ gas cycle in the galaxy: gas gets heated and cooled by various processes → a dynamic system

<u>Emission and absorption in the ISM</u>
→ no thermodynamic ~~eqy~~ equilibrium (TE) → using the Einstein coefficients of radiative transition
— spontaneous transition A_{ul}
— induced transition B_{ul} B_{lu}

⇒ can expres the emission j_ν and absorption α_ν coeficients as a function of the Einstein coeficients
↳ these relations come from the fundamental atomic transitions
↳ true in all cases (no TE required)

→ in TE we get the relations discussed earlier

<u>Phases of the ISM</u>:
- cold HI: average 80K, clumpy gas clouds, denser, observed as absorption lines
- warm HI: average 8000 K, less dense, more extended HI, observed as emission lines

absorption lines give the integral: $\int \frac{n_H}{T} ds$ (number density; path; temp)

emission lines give the integral $\int n_H ds$

} by combining the two we can estimate the temperature

calculate the HI mass ⇐ ↳ directly gives the colum density

(4) Molecular gas

- cold dense regions of the ISM
- 10-30 K
- ~1 % in volume, ~40 % of the mass of the ISM
  ↳ in dense clumps
- observe with molecular lines in the radio e.g. CO

rotational line transition

→ most abundant species is H_2, but difficult to observe } observe CO instead

→ CO maps of the Galaxy → gas is in a thin disk
→ gas is in molecular clouds
↓
stars form in molecular clouds

Masers: very bright OH emission
- microwave amplification by stimulated emission of radiation
- same as a laser
→ stimulated spectral line emission
- molecular clouds, AGN, planetary atmospheres, stellar atmospheres

HII regions:

- bubble shaped regions of ionised hydrogen
- around O, B stars → associated with star formation regions
  ↳ lots of UV photons → ionise gas
- visible in many wavelengths: optical, radio
- can also contain other partially ionised elements, C, O, N etc...

Hot halo gas: $T \sim 10^6$ K, low density gas

Galactic magnetic field:
- can map with polarization measurments of star light or radio continuum emission → provides direction
- most modern map: from the Planck satellite
- strength of the field from pulsar data (dispersion + Faraday rotation)
- syncrotron radiation from cosmic rays → indication of magnetic field
- origin: turbulent motion of plasma (most likely)