Interstellar Medium

What is it?

It's the gas & Dust inside galaxies and contains material that has not formed stars but may do so. It's made of H and He mostly.

→ It's the raw material for star formation.

Process in ISM:
1. Gas flows from cosmic web into DM halos.
2. If it cools, it settles into a galaxy disk and forms ISM.
3. Inside ISM, when cooling further, gas becomes very dense.
4. Radiative cooling lowers temperature to create molecular clouds.
5. Molecular clouds are the coldest and densest regions of ISM.
6. In these regions, stars form!

→ Stars form within dense molecular clouds in the ISM where gas cooled sufficiently through radiative cooling processes.

However, cold gas doesn't shine inherently, but nearby massive stars emit strong UV radiation, which excites atoms in the gas.

Emission Line Nebulae
1. UV excites atoms.
2. Electrons fall to low energy level.
3. photons are emitted at specific λ.
4. We get emission lines.

Applications:

Allows measurement:
- Gas composition;
- Gas temperature;
- Star formation rate;

- Each element has a spectral line, therefore emission lines act as fingerprints.

Important Interpretation

Note: **Emission lines indicate recent star formation because the lines are coming from the gas but the gas is lit up by massive stars (young)!**

best way to measure rate:

Strength of Emission Lines in Galaxies tells us rate of star formation. Strong lines → active star formation

- Ellipticals: Have hot gas – formation
- Spirals: hot & cold gas
- Irregular: Cold gas + formation

Note: Young galaxies have little dust since no heavy elements.

Dust in Space

(From heavy elements)

Forms from metals in ISM.
Types: carbonaceous, silicate

why it matters? It absorbs, scatters & emits energy.

Growth & Destruction

Formation In:
- Planetary nebulae
- Supernova remnants

Aka dying stars

Destroyed by:
- high temperatures
- UV radiation
- Shock waves.

Dust Reddening: dust scatters blue light, often appearing redder!

ALSO

Dust Re-Processes (re-emits absorbed energy at longer wavelengths)

→ So it can look redder even though the stars are mostly young. (Important)

Additional Info:

Galaxy mergers trigger starbursts by compressing gas and increasing star formation.

Why can a Galaxy be Redder?

Galaxy Evolution

What is expected for an Early Galaxy:
- → Fewer in number
- → Smaller, younger, bluer
- → More star forming

} Due to Idea of Hierarchical structure formation!

→ Why? Galaxies have not had enough time to grow & interact

Hence, @ higher redshift, the n° of high mass galaxies is much lower. Observations confirm that early galaxies are generally less massive, more star-forming, less evolved, supporting hierarchical galaxy growth.

morphology:

Early Galaxies were predominantly irregularly shaped, since they were frequently colliding and merging, creating distorted shapes.

EXAM CONCEPT:

Mergers were more common since the Universe was denser and galaxies were closer together, increasing the likelihood of collisions.

& Early Univ. was highly gas-rich, which explains why there's not many ellipticals.

- Gas-poor → disk destroyed → ellipticals
- Gas-rich → disk can regrow → spiral/disk

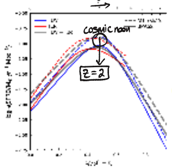
Star Form. & Quiescent Galaxies

(quenched)

when it actively converts gas into new stars. → High redshifts (Early)

When it has little to no ongoing star formation → Low redshifts (Modern)

Madau Plot



Interpretation: why does star formation fall?
- → Universe becomes less dense, and gas accretion slows down.
- → Cooling becomes less efficient
- → Dark Energy causes accelerated expansion, making it harder for material to fall into galaxies.

Cosmic Dawn → Epoch of Reionisation → Cosmic Noon

Cosmic Dawn: First stars & galaxies formed (have z > 6, so hard to observe)

Epoch of Reionisation: Radiation ionises hydrogen again, forming ionised bubbles that grow and overlap until Universe became fully ionised.

Cosmic Noon: peak star formation

Reionisation depends on whether early galaxies can produce enough escaping radiation to ionise hydrogen faster than it recombines.

→ Hence, Early Galaxies likely drove reionisation by producing UV photons.

Stellar-Halo Connection

We know that all stars form within DM halos, but not all halo mass becomes stars.

Stellar-to halo mass relation: $SHMR = \frac{M_{star}}{M_{halo}}$

→ Gives us how efficiently DM halos convert baryonic matter into stars.

- We expect the maximum SHMR to be ≈16% when taking into account Ω_b and Ω_m.
- However, when taking into account Infall Time (time it takes for gas to fall into galaxy), we get ≈13%.

→ This SHMR ≠ is due to the fact that gas infall delays reduce maximum expected to be less.

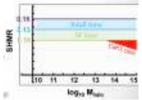
But then there's another issue, because it takes time trying to form a star, giving us SHMR ≈ 0.10.

→ This further ≠ is due to star-formation inefficiency.

At large values of M_{halo}, we expect a decline in maximum because in very massive halos, long cooling times reduce star formation efficiency a lot!

hence, we expect SHMR ≈ 0.10

→ So, 60% baryons should become stars.

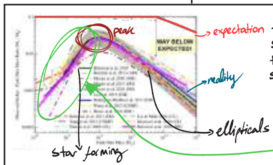


How to measure halo masses? Gravitational lensing, studying velocities of galaxies orbiting DM halo, etc.

but!

Observed / Reality SHMR turned out to be ≈2%.

→ So reality is that baryon conversion is inefficient in comparison to what expected!



→ The peak of SHMR is the transition between star-forming galaxies and ellipticals

Galactic Feedback injects energy into gas, heating gas and supress star formation!
- I. Ejective feedback: gas enters then gets expelled.
- II. Preventive feedback: gas never enters at all.

must explain:

Supernova Feedback

Supernova explosions inject energy into galaxies, regulating star formation and explaining low SHMR.

Context: Life & Death of Massive stars.
- → 8 $M_\odot$ stars explode when fusion reaches iron, causing stellar core to collapse.
- → Undergoes a giant explosion.

Reason it's so energetic: Core bounce mechanism!
- In less than a second, material hits dense core and is rapidly flung outwards and outer layers are expelled ⟹ explosion.

→ Think of dropping a tennis ball with a basketball. Momentum transfer causes top (tennis ball) to be FLUNG OUT fast.

This creates:
1. Leaves a supernova remnant
2. Turns to a hot, expanding bubble
3. When joined with others, makes a superbubble.
4. Remove/push gas outside of galaxies.

(It's so hot that it boils the gas) out of the galaxy

Meanwhile...

Supernova keep enrich the Universe with heavy metals essential for life on earth.

To stop star formation, feedback must un-bind halo gas.

$$E_{minimum\ (to\ eject\ gas)} = G \cdot \frac{M_{halo} \cdot M_{gas}}{R_{halo}}$$

So, $E_{supernova} > E_{gravitational\ binding}$

Supernova feedback was much stronger in early universe because galaxies formed stars faster. It's strongest in low-mass galaxies because they are weakly bound!

Explains shape of SHMR graph since it's ineffective for larger halos and smaller halos.
- → Larger halos: Gravity is too strong, so doesn't cool properly (explained by something else)
- → Smaller halos: Weakly bound so gas is easily removed.

Additional Note

When gas is expelled, it creates galactic winds which