Galaxies Lec 6

Galaxy Formation

Dark Matter Halo

The dark matter halo has some properties such as the virial radius and virial velocity

Virial radius ~ the "edge" effectively as the point where the halo's gravity has "won" against the expansion of the universe.

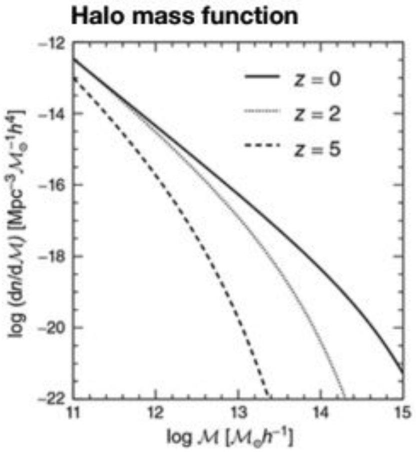
Virial velocities: how energetic a particle needs to be to support itself against gravity at the edge of the halo

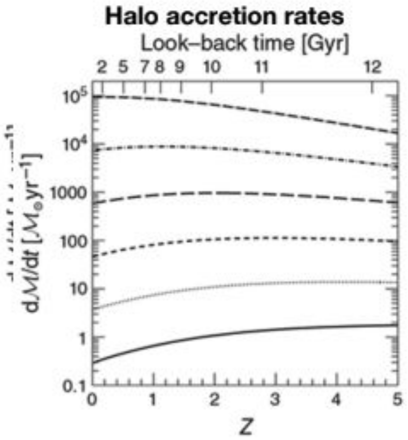
Virial radius + velocities give us virial temperature by relating gravitational potential to the temperature

$$r_{\rm vir} \simeq 259.0 \left(\frac{\mathcal{M}_{\rm vir}}{10^{12}\mathcal{M}_\odot}\right)^{1/3} \left(\frac{h}{0.7}\right)^{-2/3} \text{kpc}$$

$$v_{\rm vir} \simeq 128.9 \left(\frac{\mathcal{M}_{\rm vir}}{10^{12}\mathcal{M}_\odot}\right)^{1/3} \left(\frac{h}{0.7}\right)^{1/3} \text{km s}^{-1}.$$

$$T_{\rm vir} \equiv \frac{\mu m_{\rm p}}{2k_{\rm B}} v_{\rm vir}^2 \simeq 1.45 \times 10^6 \left(\frac{v_{\rm vir}}{200\,\text{km s}^{-1}}\right)^2 \text{K},$$





Virial Temperature: the temperature that remains bounded to a halo of that radius and mass.!

Together these affect the accretion rate of baryons to form galaxies.

To accrete matter requires us to **cool**.

Cooling

How long does it take to cool??

$$t_{cool} = \frac{3}{2}\left(\frac{n}{n_t}\right)\left(\frac{n}{n_e}\right)\frac{k_B T}{n\Lambda(T)} \approx \frac{6k_B T}{n\Lambda(T)},$$

$\longrightarrow$ $t_{cool} \propto 1/n$ with T and Z-dependence from $\Lambda(T)$

$n=n_t+n_e$

assuming fully-ionized gas

The top is the total energy budget.
The bottom is the derivative of internal energy

Similar to ISM Cooling curve!

We see that the cooling is dependent on density!

Cooling depends on **REDSHIFT**! Because of density! And hence efficiency should be coupled to redshift!

Heating

Traditionally we assume that the infalling gas would be **shock heated to virial** temperature as it falls and shock heats the cloud.

We see that the **virial velocity** vs. **sound speed** when they are comparable we have shock heating!

Also heating from:

- SNe
- First stars
- Compton CMB
- Maybe AGN later on?

- When gas crosses virial radius, its infall speed is of order the halo circular speed

$$v_{\rm vir} \sim \sqrt{k_B T_{\rm vir}/(\mu m_p)}$$

- However its sound speed is lower than this, going roughly as

$$c_s \sim \sqrt{k_B T_{\rm pre}/(\mu m_p)}$$

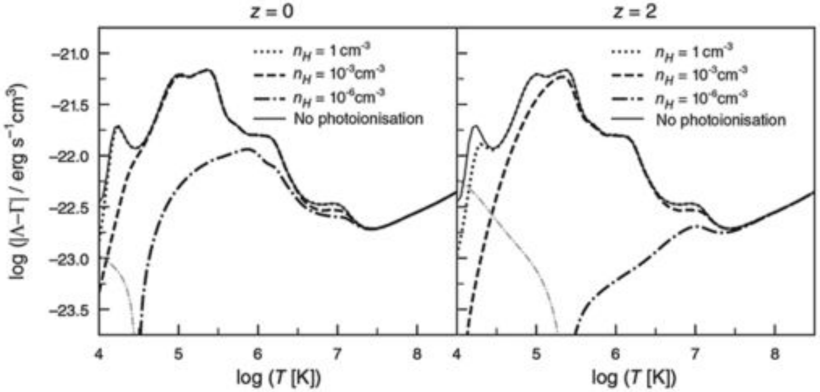
Criteria

Efficient!	1. $t_{cool} < t_{dyn}$	rapid cooling: gas cooling efficient -> rapid galaxy formation
Inefficient!	2. $t_H < t_{dyn} < t_{cool}$ Typo: should be t_dyn < t_cool < t_H	slow cooling: cooling takes long timescales, but will occur on lifetime of system
Doesn’t cool…	3. $t_{cool} > t_H$	cooling is unimportant, gas remains hot and galaxy formation will not happen

If the cooling time is faster than the mediums reaction time then it cools reallyyyy fast

If it is greater than the reaction time and the less than age of universe its slow.

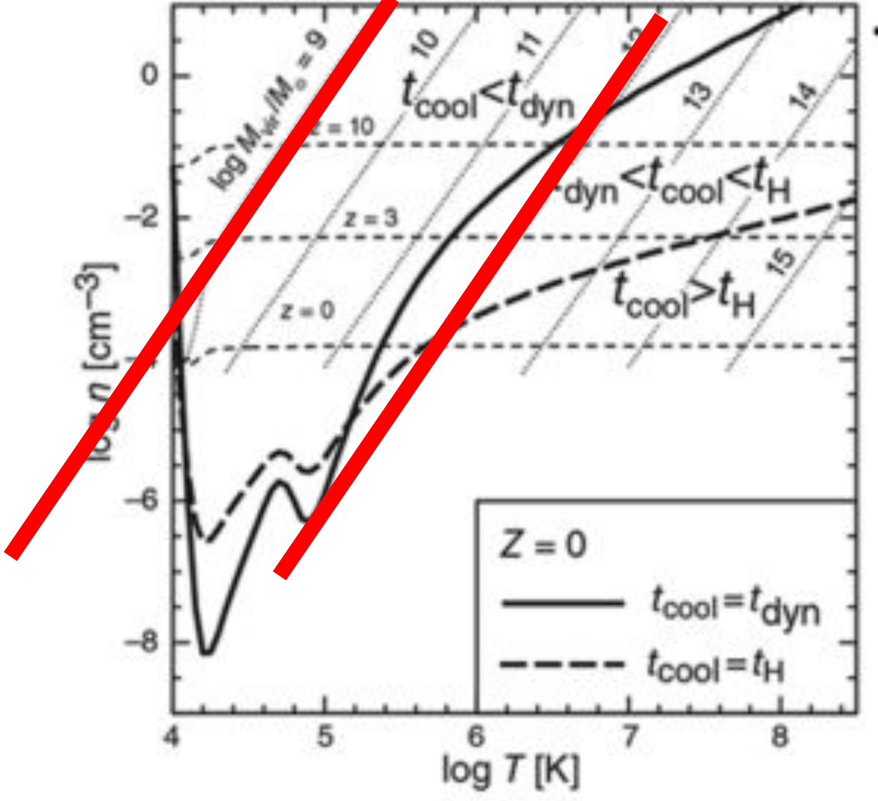
If greater than hubble then it never fully cools.



We can get a NET cooling curve that looks like this

We see the dip of 10^4-10^6 K this corresponds the diagonals with 10^9 and 10^12 halo masses!

And thus most efficient => corresponds to 10^9-10^13 viral mass!



We can get a temperature density plot like this

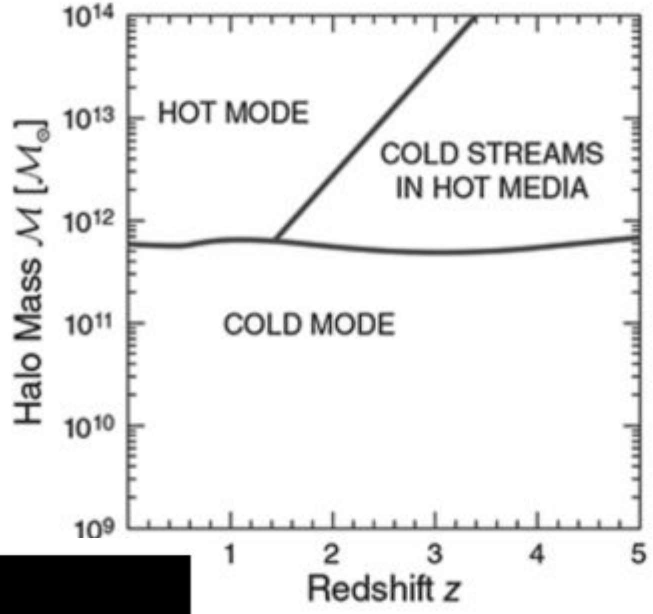
New Developments

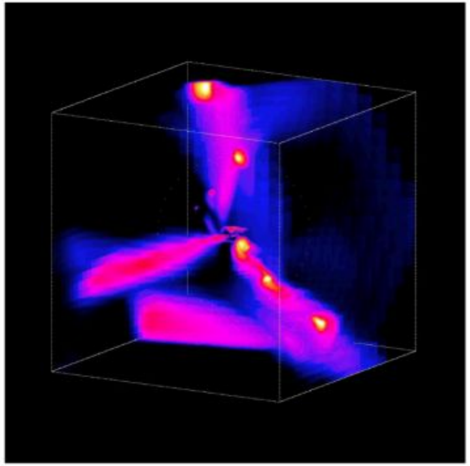
We used to think all gas falling into a halo got shock-heated to the virial temperature (becoming hot) and then had to cool down to form stars. Now its not always true.

Cold mode: The gas stays cold the whole way down. It crashes directly onto the galaxy disk without ever heating up to millions of degrees. This is very efficient for star formation.
(more dense universe higher shock)

Hot mode: In these massive halos, the gas is dense and falls in fast, but the cooling is inefficient so it gest quenched.

Cold streams: Older massive ones It falls along filaments of the Cosmic Web. Happens in earlier universe because web was dense enough? (less dense universe lower shock)





Star formation efficiency!

We see that redshifts can affect star formation rates!

High Redshifts (BEFORE)

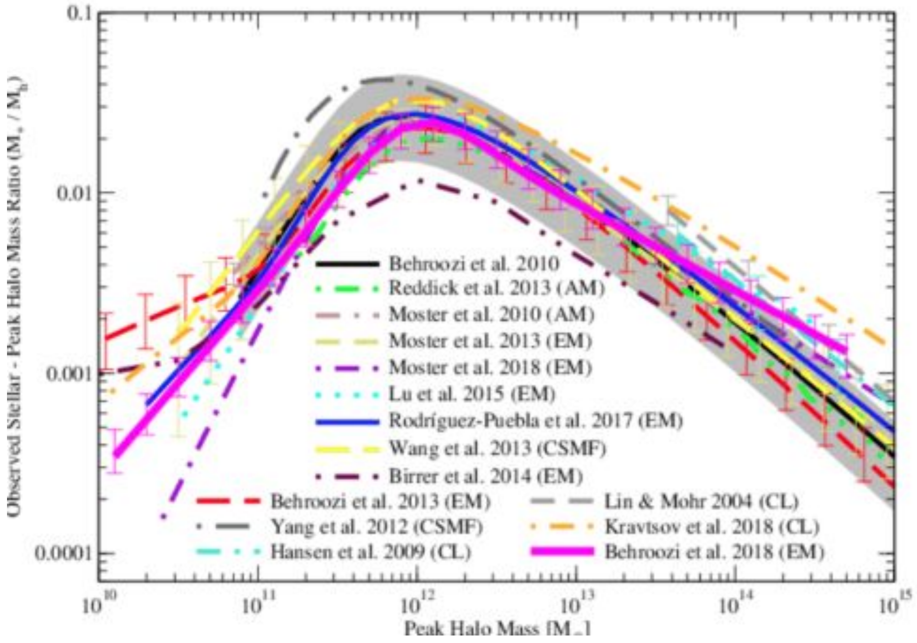
- Halos are smaller mass (inefficient accretion)
- Cold accretion (small halos)
- Denser universe (more efficient cooling curve) (1+z)^3
    - Low total SFR

Medium Redshifts (OPTIMAL)

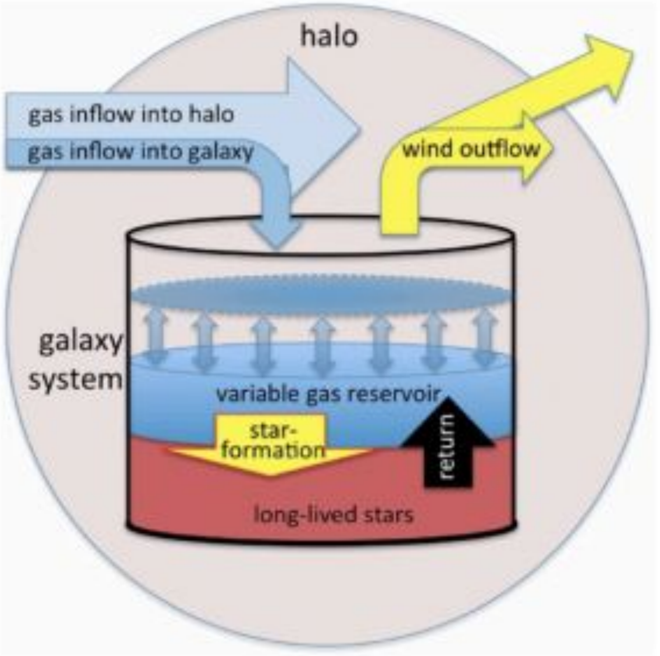
- Halos reach large sizes (Efficient)
- Reasonable density radiation to cool
- Cold stream accretion
    - Large SFR

Low redshifts (NOW)

- Massive halos (helps with accretion)
- Hot accretion (large halos)
- Less dense and cooling is harder
    - Small SFR



Star formation in this environment



Regulator Models

We model the star formation with this

M_Gas = M_in - m_out - SFR

All time derivatives!

This equation is a mass conservation law for the gas reservoir in a galaxy.

Explains the High sSFR fast build ups!

Explains why there is a Mass metallicity

Conditional Luminosity function

A luminosity function conditioned on mass of the central object and the mass of the satellites.

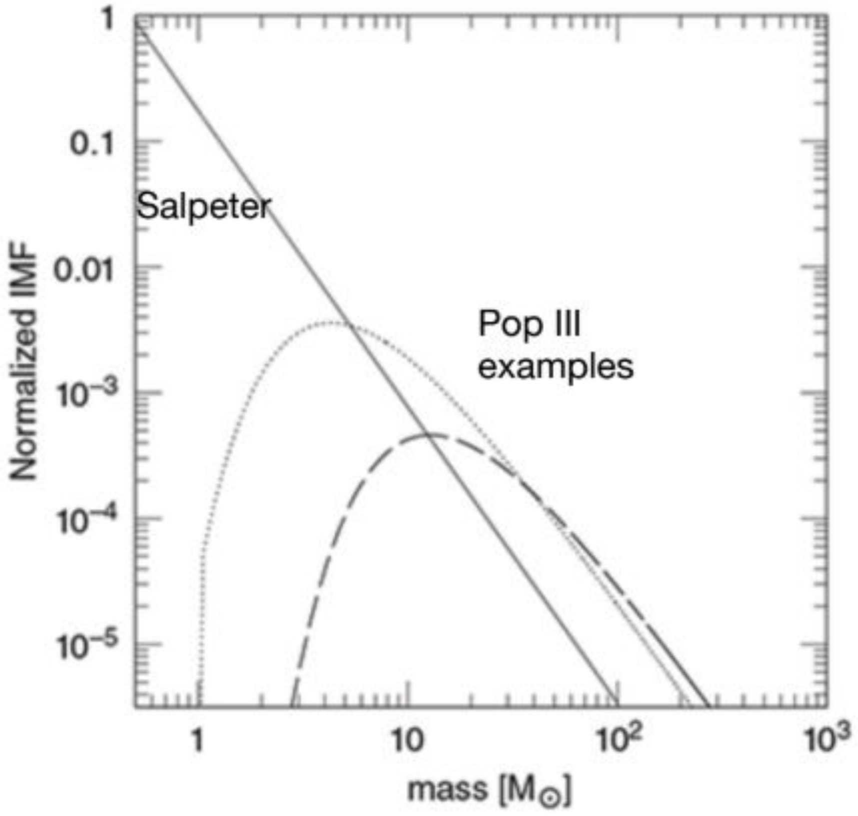
Distribution functions are obtained via Observation? Calculate the Global Luminosity Function and the spatial clustering (2-Point Correlation) of real galaxies using large-scale survey data? Simulations?

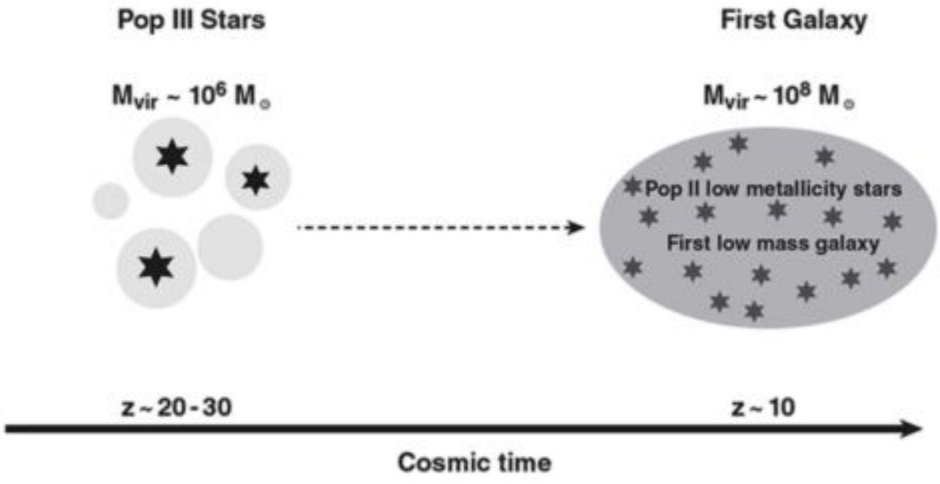
Successful in reproducing the peak in SFR/halo peak at 10^12 solar masses

$$\Phi(L \mid M_h) = \Phi_c(L \mid M_h) + \Phi_s(L \mid M_h)$$

First Stars!

First stars were more massive!
They are expected to be more massive because of metallicities (harder to cool metal lines) and hotter universe (needing larger jeans mass to cool)





First galaxies from z~10ish

Why? Needed time to form large halos so that gas doesn't get unbounded from the first SNe.