Semi-analytic models (SAM)

Outline

- *What are Semi Analytic Models?*
- *History*
- *Recipe*
- *Details of the recipe*
- *Succeses and failures*

SAM

- *"Recipes for galaxy formation"*
- *Hierarchical clustering*
- *Statistical prediction of galaxy properties*

History of SAM

- *Three models*

- *“Munich”*
- *“Durham”*
- *“Santa Cruz”*

Differences between models are mainly in model parameters with normalization and details of SF, gas cooling and feedback.

Recipe

- *Cosmology*
- *Dark halos*
- *Gas cooling*
- *Star formation*
- *Feedback*
- *Normalization*

Cosmology

In the early days (beginning of the 1990s) people used $\boldsymbol{O_0 = O_m = 1}$ *with* $\boldsymbol{h = 0.5}$*. But all recent models use the WMAP results with* $\boldsymbol{O_m = 0.3}$ *and* $\boldsymbol{O_? = 0.7}$ *with* $\boldsymbol{h = 0.7}$*.*

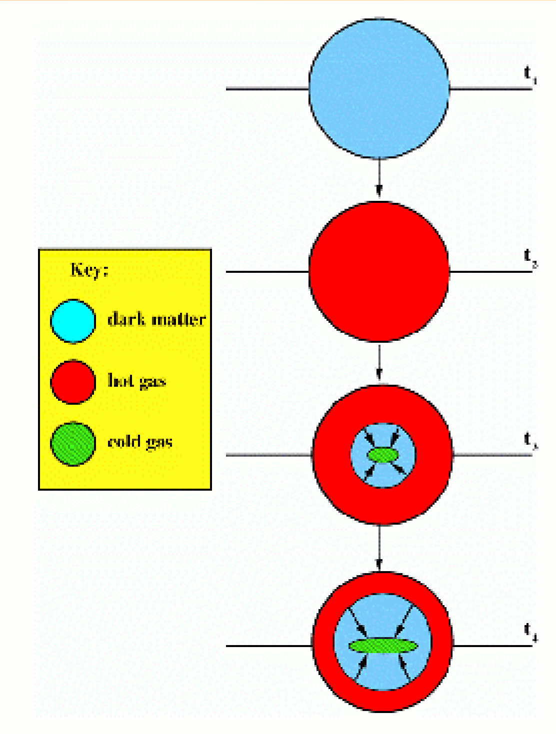
Because the CDM model is widely accepted this saves a lot of computing time since not all possible cosmologies have to be calculated anymore!

Dark halos

- *Basic process in galaxy evolution*
- *Historically described by PS formalism but nowadays N-body simulations*
- *Attention is now shifting to the details of star formation, gas cooling and feedback*

Gas cooling

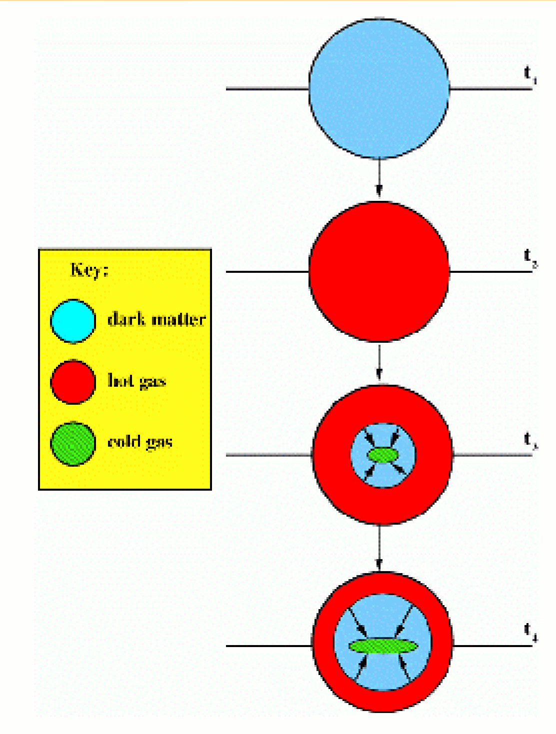
- *Models assume that the gas is initially spatially distributed as DM*
- *Shock heated as it falls in potential well of dark halo producing hot gas halo*
- *Gas attains virial temperature of the halo*



$$kT_{vir} = \tfrac{1}{2}\,\mu m_H V_H^2$$

Some more details on gas cooling

- Now gas can cool -> pressure drops
- Conservation of angular momentum means the cold gas forms a rotationally supported disk
- Cooling time depends on ionization (thus T), chemical composition and density (collision rate)
- Cooling rate depends on t_{cool} and t_{ff}



Cooling mechanisms

- *Inverse Compton scattering (very early Universe)*
- *Collisions of molecular hydrogen cause excitation of rotational and vibrational energy levels which subsequently decay (halos with T_{vir} below 10^4 K)*
- *Collisions between partially ionized atoms and electrons which subsequently decay (10^4 K < T_{vir} < 10^6 K)*
- *Bremstrahlung in massive clusters ($T_{vir} \sim 10^7$ K)*

Modifications to cooling model

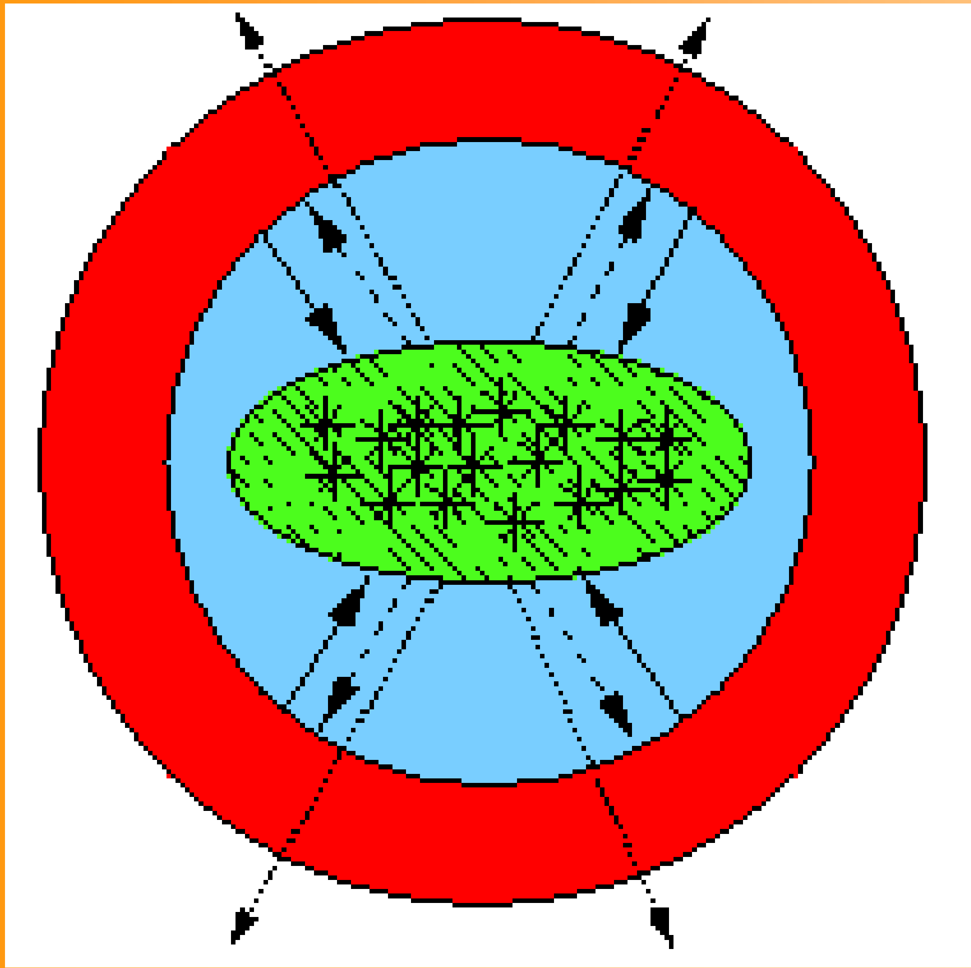
There are several mechanisms which reduce the gas cooling in either low-mass or massive halos. More or less all of these depend on feedback mechanisms which I will discuss later.

Star Formation

- *First generation of stars (very massive? z~50?)*
- *IMF (process for determining mass?)*
- *Conditions for SF in galactic disks and starbursts (lack of accurate theory)*
- $M_* = M_{cold}/t_*$

All ignorance is in t_*

Feedback



- *"Want to make the low-mass end of luminosity function more vulnerable to disruption" (White & Rees 1978)*
- *Cold gas is heated and removed from galactic disk*
- *Cooling rate is suppressed*

Feedback(2)

- *Initially strong supernovae winds to explain faint end slope*
- *Nowadays CDM cosmology*
- *Photo-ionizing background*
- *Unexceptional amount of SN wind*
- *Faint end matches the observations (e.g. Croton et al. 2006)*

Feedback(3)

- *Recently attention has shifted to bright end of luminosity function*
- *Kauffmann et al (1993) turn off SF*
- *Cole et al (2000) hot gas has constant density core i.s.o. following DM profile*
- *Around those times a baryon density of 0.02 was assumed (conveniently) which we now think to be too low*

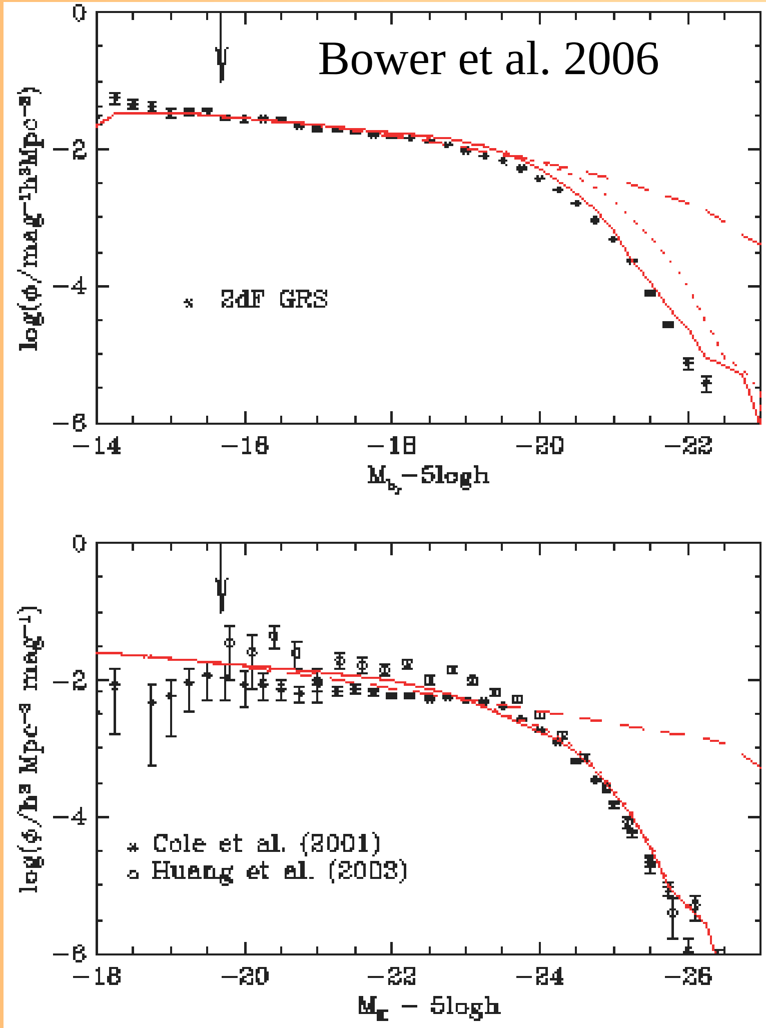
Feedback (4)

Possible explanations to bring the bright end down (Benson et al 2003)

- *Excessive amounts of SN feedback (galactic disks would get bigger than observed)*
- *Thermal conduction in hot halo (unphysically large)*
- *Superwinds (requires too efficient energyconversion from SN to driving gas out)*
- *BUT maybe energy comes from accretion onto BH*

AGN feedback examples

- *Croton et al (2006) 'quasar mode' and 'radio mode'*
- *Bower et al (2006) calculate Eddington limit and compare it to the gas cooling rate*
- *All seem to match fairly well*



Other parameters

- *Chemical evolution (cooling, luminosity and color, optical depth)*
- *Galaxy size*
- *Mergers (shock heating, timescales, morphological evolution)*

Normalization

- MW properties (Tully-Fisher normalization for a MW sized halo
- Luminosity density of the Universe

- The first models used the luminosity density to normalize
- Over the past decade the TF normalization was favored
- It seems most models are back to the luminosity density normalization

Succeses and failures

- *"Satellite problem"*
- *"Cuspy core problem"*
- *WDM or self interacting DM?*

- *Faint end of luminosity function is well matched by good feedback and photo ionization.*
- *Bright end more challenging (AGNs seem important).*