Dark Matter and Galaxy Formation

Section 4: Semi-Analytic Models of Galaxy Formation

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Overview

• Success of modern semi-analytic models (SAMs)
• Getting the star formation rate (SFR) correct
• Narrow halo mass range for efficient star formation
• Evolution of galaxies
• Extragalactic background light (EBL) predictions
Modern SAMs

Processes: Extended Press-Schechter theory of halo merging
Gas cooling by radiation
Gas heating by gravitational collapse
Stellar feedback

Assumptions: Most star formation occurs in galactic discs
Galactic spheroids form only in major mergers
Gas cools only onto the central galaxy in any halo
Star formation and feedback parameters set by local data

Reproduced Observations:
Trends in galaxy luminosity, gas content, morphology
Early-type galaxies populate higher density environments
Most halos do not host galaxies

Somerville and Primack (1999)

Galaxy formation is efficient only for halos roughly in the mass range $10^8 - 10^{12} \, M_\odot$
### Additional SAM processes

<table>
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<th>Process or Assumption</th>
<th>Helps to</th>
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<tr>
<td>Dust extinction</td>
<td>Reproduce observed luminosity functions</td>
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<td>AGN feedback</td>
<td>Not overproduce very luminous galaxies</td>
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<td>Radio-mode AGN feedback</td>
<td>Quench star formation</td>
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<tr>
<td>Supernova feedback</td>
<td>Reproduce galaxy color bimodality</td>
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<tr>
<td>Critical halo mass ( M_{\text{shock}} \approx 10^{12} , M_{\odot} )</td>
<td>Quench star formation</td>
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\[
M_h < M_{\text{shock}} \quad \text{halos} \\
\text{Gas can enter in cold streams and form stars efficiently}
\]

\[
M_h > M_{\text{shock}} \quad \text{halos at } z < 2 \\
\text{Entering gas is shock-heated and cannot form stars efficiently}
\]

Somerville et al. (2008)
Importance of quenched star formation

The central galaxies are all red, which is consistent with observations.
Inconsistency between SFR and stellar mass densities

Possible Solutions
- Stellar initial mass function (IMF) could be evolving:
  Producing a higher fraction of high-mass stars with increasing $z$
- SFR in the left plot might have been overestimated for higher $z$
Narrow halo mass range for efficient star formation

Assumptions

- SF only efficient for ΛCDM halos in $M_{\text{min}} - M_{\text{shock}} = 1.5 \times 10^{12} \, M_\odot$
- $\text{SSFR} \approx f_b \times (\text{halo mass accretion rate})$

SSFR (specific SFR): SFR per unit stellar mass
Satellite galaxies
Star formation quenches
Gas accretion ceases
Become red

Central galaxies
Join the red sequence if either:
- Form a supermassive black hole
- Halo mass exceeds $M_{\text{shock}}$
- Become satellite galaxies in clusters

Dry mergers
Most massive reds
Form through mergers of reds
(Blues are not massive enough)
Extragalactic background light predictions
Summary

• Modern SAMs reproduce many observed galactic features

• Remaining problems:
  – Solving the inconsistency between SFR and stellar mass density
  – Getting star formation right in small galaxies
  – Getting black hole accretion history right

• SAMs that assume a narrow halo mass range for efficient star formation are successful

• Upper EBL limits constraint the cosmic SFR history and therefore are a testable prediction of SAMs