What are Protoclusters?

Stuart Muldrew
Overview

• How to define a protocluster?

• Is the main progenitor halo an accurate representation?

• Why are low mass galaxies absent in emission line observations of protoclusters?

Collaborators:

Nina Hatch and Elizabeth Cooke (Nottingham)
How to define a protocluster?
Cluster Formation

Sembolini et al. (2014)
Merger Tree

Lacey & Cole (1993)
Protocluster Definition

Sembolini et al. (2014)
Cluster Definition

- Millennium Simulation (Springel et al. 2005) —> 500 h\(^{-1}\) Mpc
- Guo et al. (2011) Semi-Analytic Model
- Clusters defined as haloes with \(M_{200} > 10^{14}\) h\(^{-1}\)M\(_{\text{sun}}\) at \(z=0\) —> 1,938 clusters
- Protoclusters are defined as all the haloes at a given redshift that will merge to make the \(z=0\) cluster —> At \(z=2\), 1,938 protoclusters made of 639,253 haloes
$M_{200}^{z=0} = 10^{15.4} \, h^{-1} M_\odot$

$M_{200}^{z=0} = 10^{14.8} \, h^{-1} M_\odot$

$M_{200}^{z=0} = 10^{14.0} \, h^{-1} M_\odot$
Protocluster Size

![Graph showing the relationship between protocluster size and redshift (z). The graph includes different line styles and labels for different mass ranges.]

- $1 \leq M_{200}^{z=0} < 4 \times 10^{14} \, h^{-1}M_\odot$
- $4 \leq M_{200}^{z=0} < 10 \times 10^{14} \, h^{-1}M_\odot$
- $M_{200}^{z=0} \geq 10^{15} \, h^{-1}M_\odot$
Protocluster Size

\[ \tau_{\text{physical}}/ (h^{-1}\text{Mpc}) \]
Protocluster Size

![Graph showing the relationship between angular size (\(\tau_{\text{angular}}/\text{arcmin}\)) and redshift (\(z\)) for different mass ranges. The graph includes three curves, each representing a different mass range:

- Black curve: \(1 \leq M_{200}^{z=0} < 4 \times 10^{14} h^{-1} M_\odot\)
- Red curve: \(4 \leq M_{200}^{z=0} < 10 \times 10^{14} h^{-1} M_\odot\)
- Blue curve: \(M_{200}^{z=0} \geq 10^{15} h^{-1} M_\odot\)
Protocluster Size
Protocluster Galaxy Membership
Cluster Assembly

$1 \leq M_{200}^{z=0} < 4 \times 10^{14} h^{-1} M_\odot$

$4 \leq M_{200}^{z=0} < 10 \times 10^{14} h^{-1} M_\odot$

$M_{200}^{z=0} \geq 10^{15} h^{-1} M_\odot$

$M / M_{200}^{z=0}$ vs $z$
Main Halo at $z=2$
Hatch et al. (inc. Muldrew; in prep.)
Why are low mass galaxies absent from protoclusters in emission line observations?
Observed Mass Function

Cooke et al. (inc. Muldrew; 2014)
Model Mass Function

\[ \log \left| \frac{\Phi}{(h^3 \text{Mpc}^{-3} \text{dlog}(M))} \right| \]

\[ \log \left[ M_*/(h^{-1} M_\odot) \right] \]

Legend:
- All Galaxies
- Protocluster
- Field
Star Forming Fraction

![Graph showing the Star Forming Fraction vs. log(M*/(h⁻¹M☉)) for different clusters and field conditions.](image)
Star Forming Fraction

![Graph showing Star Forming Fraction](image)
Conclusions

• Protoclusters are very extended (up to $45h^{-1}$ Mpc comoving; 41 arcmin at $z=2$).

• Main Halo dominated protoclusters are only a small subsample.

• Modelling predicts that low mass galaxies are lost from emission line observations due to quenching.

• Measuring accurate overdensities is difficult due to completeness and hence is a poor proxy predictor of mass.

• Ratio between largest haloes is a better predictor of evolution.

• More details in Muldrew, Hatch & Cooke (2015)
What are Protoclusters?

Stuart Muldrew
Protocluster Size - $R_{\text{vir}} \, z=0$