The build-up of massive galaxies &
the intracluster light since z=1
with Charlie Conroy (Princeton) and Andrey Kravtsov (Chicago)
Based on Conroy, Wechsler & Kravtsov 2007, astro-ph/this week
Evolution in the galaxy stellar mass function

Recent observations from $z=1 \rightarrow z=0$:

- total stellar mass in the universe roughly doubles
- however, very little evolution in the massive end of the GSMF
- evolution in the LF also consistent with ~passive evolution at the bright end
Evolution in the GSMF: a puzzle when compared with the halo mass function?

- No GSMF evolution; massive galaxies seem to be largely in place at $z \sim 1$
- However, strong evolution in the massive end of the DM halo MF from $z=1$ to $z=0$
- Because of the hierarchical nature of CDM, the halos hosting massive galaxies are still experiencing substantial merging.
- So why don’t their central galaxies grow? If LCDM paradigm is correct, growth of central galaxies in massive halos must be substantially weaker than the growth of their host halos -- where do the stars go?
But, not all the light ends up in galaxies!

When satellites halos merge:

- stars can get deposited onto the central galaxy
- stars can remain bound as satellite galaxies
- stars can get scattered out by tidal stripping or in mergers, and end up in the ICL

ICL in Virgo, Mihos et al 2005
Modeling the build-up of stellar mass since $z=1$

1) Start with a model for connecting $z=1$ galaxies with $z=1$ dark matter halos

2) Follow the build-up of galaxies with time using halo merger trees.

3) Ignore star-formation and other dissipative physics

4) Model the fate of stars during halo merging. Some combination of:
   - stars merge onto central galaxy
   - stars remain as bound satellites
   - stars end up in the ICL

5) Confront models with data
dark matter substructure
previous work: assign luminosities to subhalo circular velocities by matching \( n(>v_{\text{max}}) \) to \( n(>L) \)

here: in a similar spirit, we connect the stellar mass function to the halo mass function (including subhalos)

Conroy, Wechsler & Kravtsov 2006; Marin, Wechsler, Nichol & Frieman 2007
Distinct Halo Evolution

Subhalo Evolution

Accretion epoch

Wechsler et al 2002

\( V_{\text{max}} \times \text{mass}^{1/3} \)

\( \text{Time} \)

Constant increase

increase
decrease
same model reproduces galaxy-mass correlations (Tasitsiomi et al 04), 3pt statistics (Marin et al 07),
evolution of the close pair fraction (Berrirer et al 06), observed mass-light ratios (Tasitsiomi et al 07)
Modeling the build-up of stellar mass

1) Use the observed $z=1$ galaxy stellar MF to connect stellar mass to halo mass at $z=1$

2) Follow the build-up of stellar mass with time using halo merger trees.

3) Ignore star-formation and other dissipative physics
   - Appropriate for the most massive galaxies where $z_{\text{form,stars}}>2$
   - Provides a lower bound to stellar mass build-up

4) Track the evolution of each satellite galaxy along with its dark matter subhalo until the subhalo dissolves. When the subhalo dissolves, choose to:
   a) Keep the satellite galaxy $\text{KeepSat}$
   b) Put the satellite’s stars into the BCG $\text{Sat2Cen}$
   c) Put the satellite’s stars into the ICL $\text{Sat2ICL}$
   d) Equally split between 2) and 3) $\text{Sat2Cen+ICL}$

5) Confront models with data...
Evolution in the Galaxy Stellar MF

- Sample the observational uncertainties
- Model **Sat2Cen** ruled out by observed evolution in stellar MF
- Other models OK.
- $M_{\text{star}} / L_K = 0.72$

- Model Sat2Cen ruled out (again).

- Model Sat2Cen+ICL marginally ruled out.

- Implies that <50% of satellites from disrupted subhalos deposit their stars onto the central BCG
The Intracluster Light

- Model \textbf{Sat2ICL} (red points) reproduces observed total BCG+ICL luminosities.
- Model \textbf{KeepSat} (blue points) dramatically fails this test.
- We assumed that ICL is built-up at $z<1$ by major mergers, tidal stripping not important.
  (validated by hydro sims)

- Model \textbf{Sat2ICL} (red points) reproduces observed ICL light fraction better than model \textbf{Sat2Cen+ICL} (blue points).
- Depends on modeling of observed surface brightness profile and def’n of ICL.
- If substantial ICL buildup at $z>1$, room for more light going to the BCG
Implications for star formation

- Match z=0 stellar MF to the z=0 halo MF in the usual way.
- Compare z=0 “true” stellar mass to the z=0 stellar mass predicted by our dissipationless models.
- The difference should reflect the amount of star-formation since z=1.
- Galaxies in halos above $10^{13.5} \, M_{\odot}$ have had little star-formation.
- At lower masses, fraction of stars formed since z=1 decrease with increasing halo mass.
To resolve the apparent contradiction between the lack of evolution in the stellar MF and the strong evolution in the halo MF, one must put a substantial fraction of the light from disrupted satellites into the ICL (defined here as anything not included in galaxy photometric aperture).

Models which put all merging stars into the central galaxy fail, as do models which keep satellite galaxies after subhalos are destroyed.

In the most successful model, in massive halos ($>10^{13.5} \, M_{\odot}$), satellite galaxies dissolve when their associated subhalo dissolves, and the satellite stars are dumped primarily into the ICL.

This model is in agreement with a range of observations. Although there is weak evolution in the massive end of the GSMF, the model predicts strong evolution in the total (BCG+ICL) light since $z=1$ (very hard to observe this at $z=1$!)

Observations of the ICL provide crucial constraints on galaxy formation models -- models that match other observations while ignoring this component will either place too much stellar mass in resolved galaxies or will fail to produce enough stars globally.