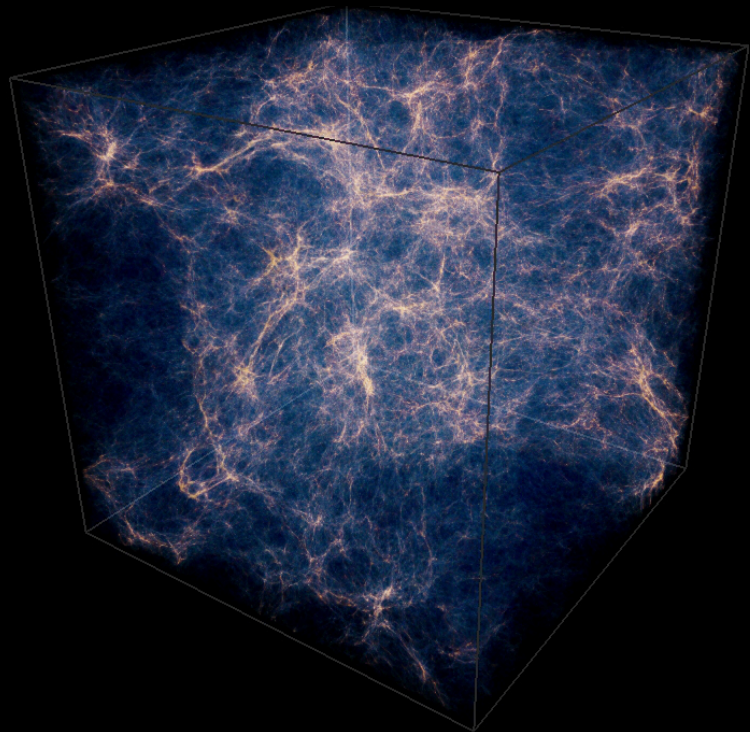
Dark Matter in the First Galaxies:

Cores or Cusps?



Andrew Davis

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TMoX Group

arXiv:1311.1109

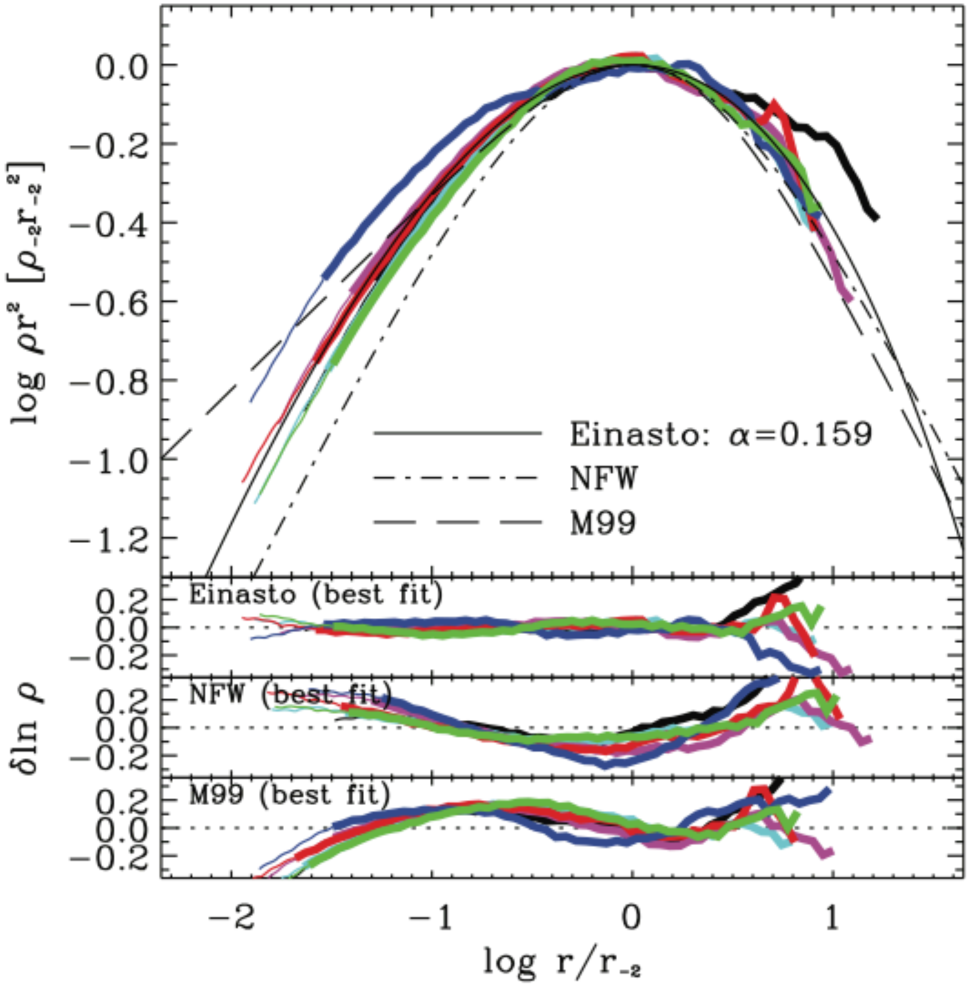
Build-up of the First Galaxies: Dark Matter Halo

- Universal density profile:

$$\rho(r) = \frac{\rho_s}{(r/r_s)(1+(r/r_s))^2}$$

- NFW profile has too little mass inside r_{-2} (e.g. Navarro et al. 2004, 2010; Gao et al. 2008)

Navarro et al. 10

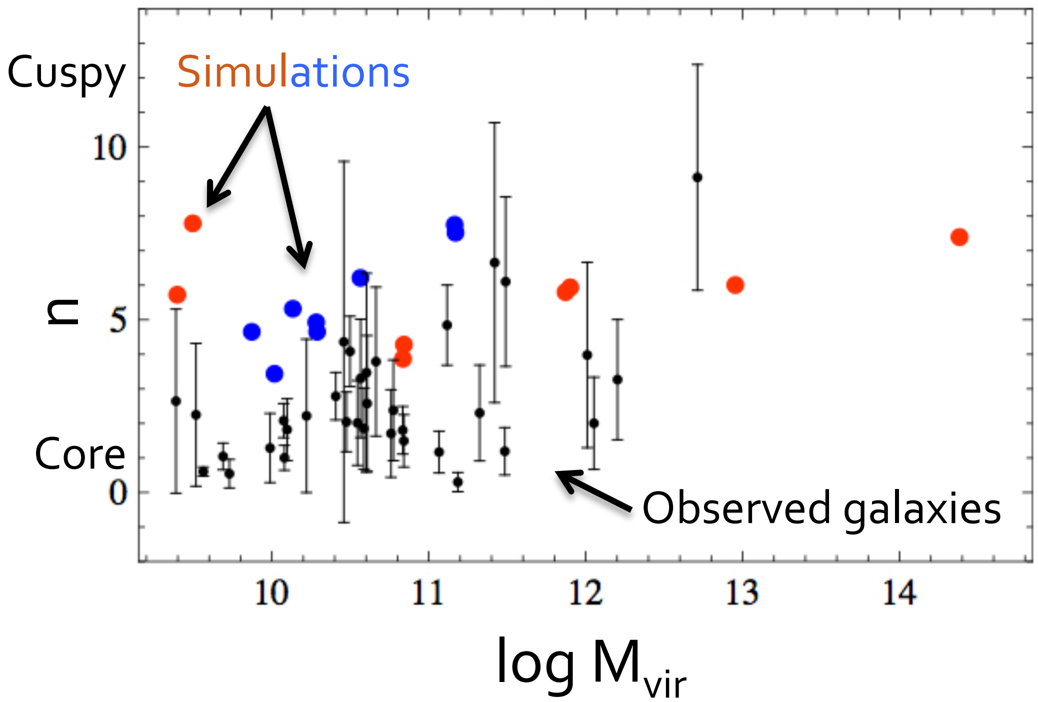


Build-up of the First Galaxies: Dark Matter Halo

- Dwarf galaxy rotation curves appear to have shallower dark matter profiles than simulations predict (e.g. Flores & Primack 1994, Moore 1994, Blok 2012, del Popolo et al. 2012, Amorisco & Evans 2012,…)
- No universal inner slope observed (e.g. del Popolo et al. 2012)

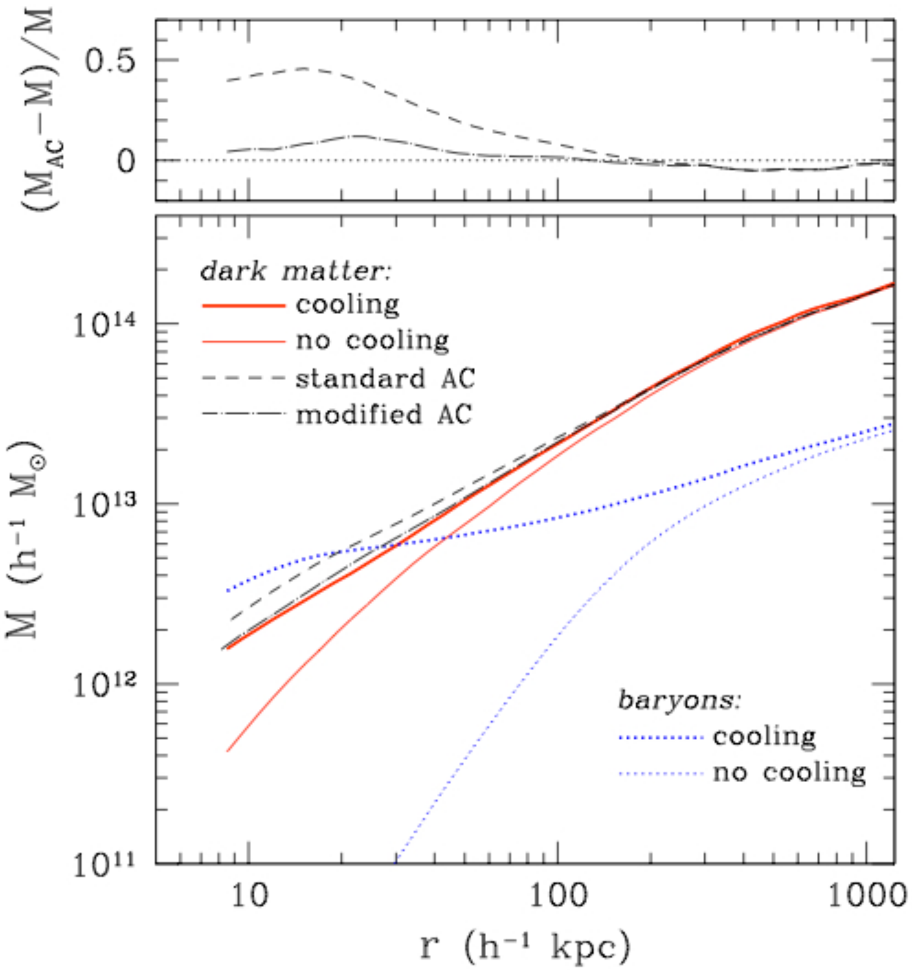
Einasto Profile:

$$\ln(\rho/\rho_s) = -2n[(r/r_s)^{1/n}-1]$$



del Popolo et al. 2012

Build-up of the First Galaxies: Baryonic Impact



Gnedin et al. 04

- Adiabatic Contraction (Blumenthal et al. 1986)
  - Leads to steeper cusp
- At least some galaxies (e.g. Sonnenfeld et al. 2012) and clusters (e.g. Cui et al. 2012) show evidence of adiabatic contraction

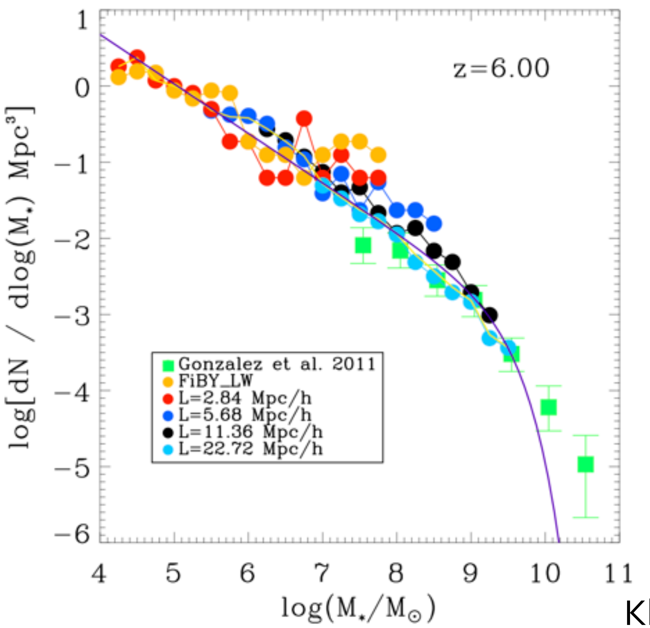
$$[M_{\rm dm}(r) + M_{\rm b}(r)]\, r = [M_{\rm dm}(r) + M_{\rm b}(r_f)]\, r_f$$

Build-up of the First Galaxies: Baryonic Impact

- Baryons can create a cusp via Adiabatic Contraction (e.g. Gnedin 2004)
- Baryons can also destroy a cusp
  - Clumpy infall (e.g. Tonini et al. 2006; Romano-Diaz et al. 2008; Pedrosa et al. 2009, 2010; Abadi et al. 2010; Dutton et al. 2011)
  - Outflows via stellar/AGN feedback (e.g. Ma & Boylan-Kolchin 2004, Mashchenko et al. 2008, Martizzi et al. 2012, Pontzen et al. 2012, Pawlik et al. 2013)
- Can these processes occur in a cosmological context?
- What is the DM profile in a statistical sample in the earliest galaxies?
  - How often do modifications happen?

FiBY: First Billion Years Simulation

- Modified Gadget-2 via OWLS
- 4, 8, 16, 32 Mpc (co) boxes
- In 4 Mpc box:
  - m_{DM} ~ 6000 M_o
  - m_g ~ 1250 M_o
  - ~ 800 halos with >5000 DM particles

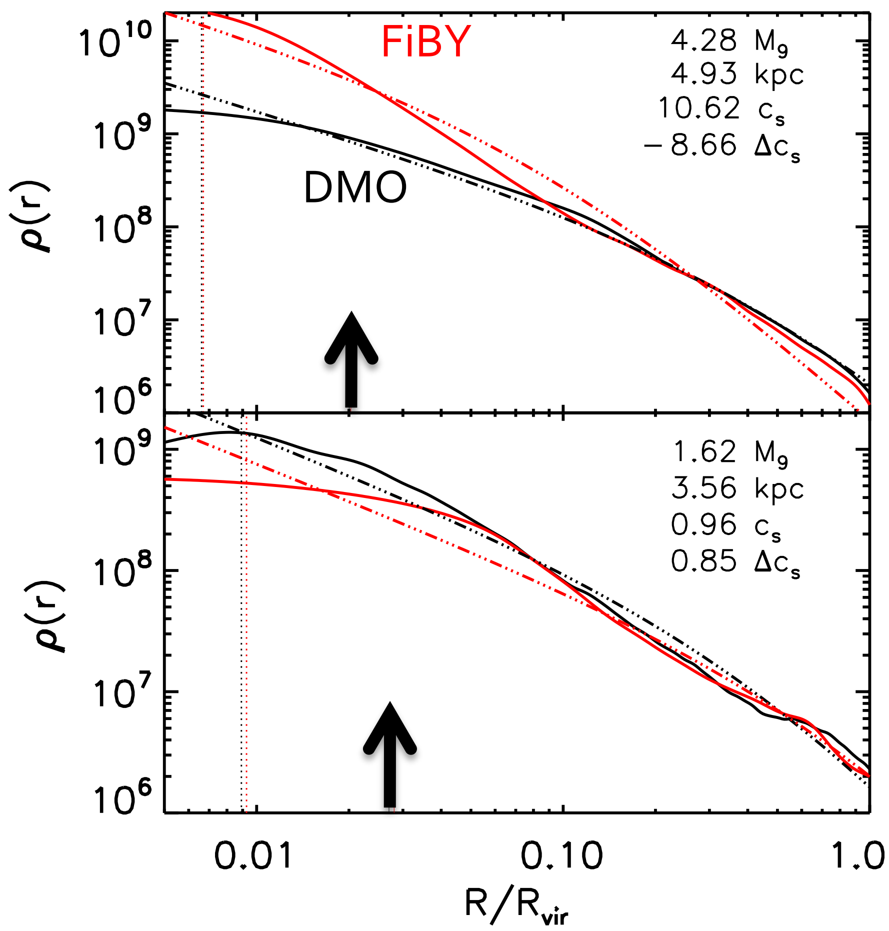


Gas Metallicity

Khochfar et al. 2014 (in prep)

DM Density Enhancement: η

DM Density profiles

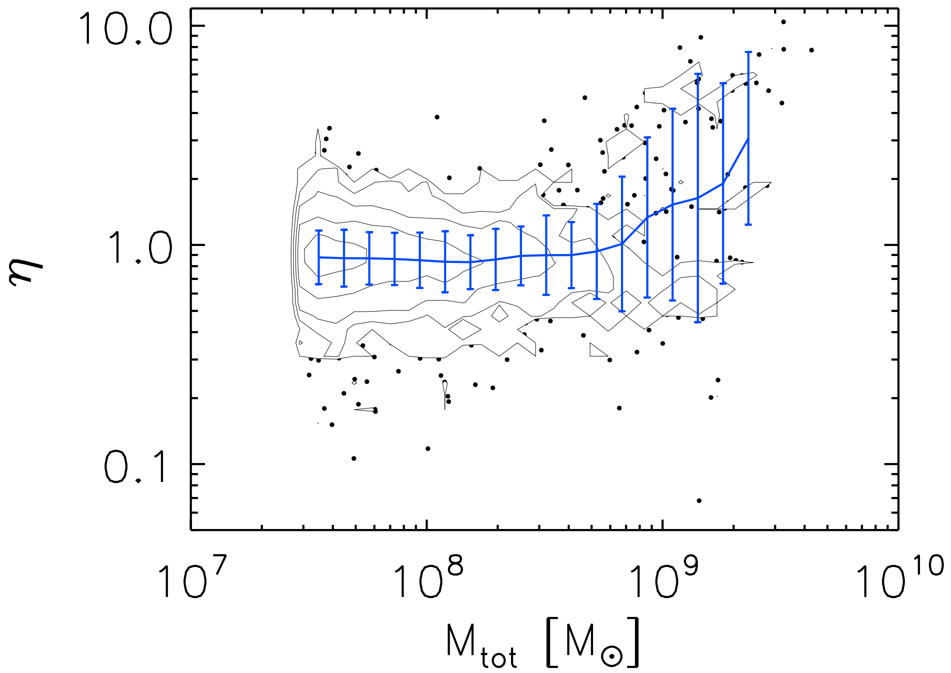


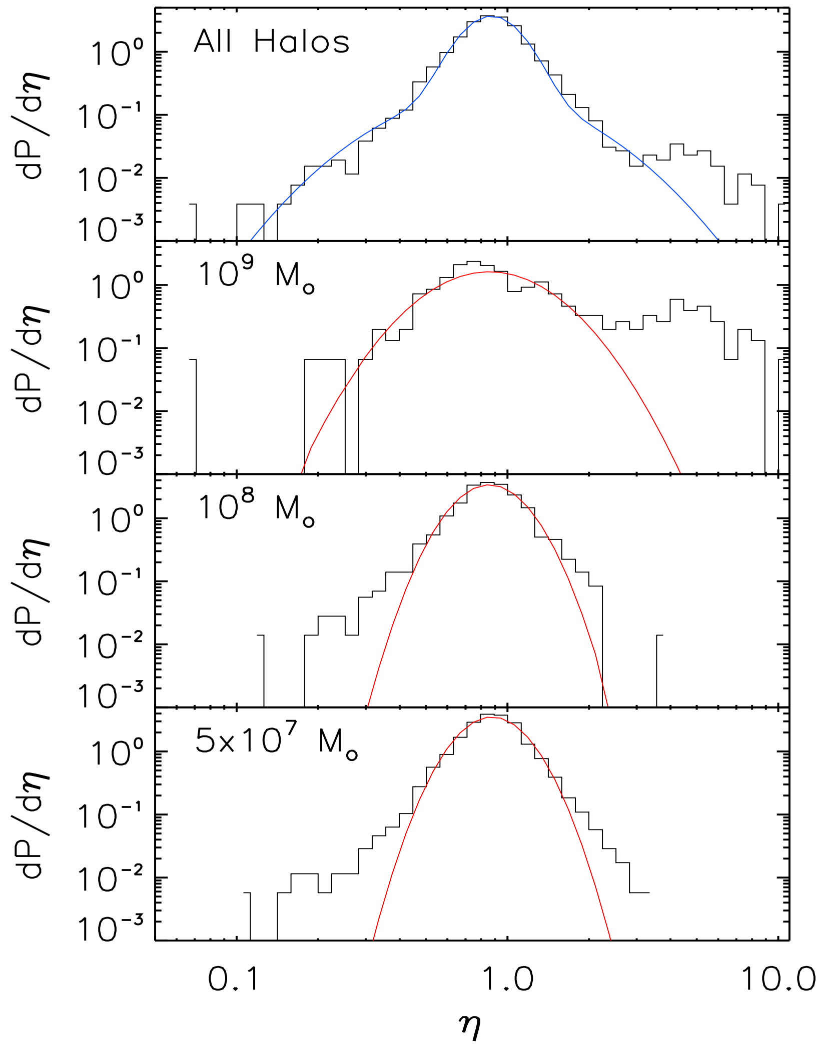
Davis et al. 2013

- Compare DM enclosed mass in FiBY versus DMO counterpart
  - Integral constraint
  - Correlates with difference in density slope

$$\eta = \frac{M_{\rm dm}^{\rm FIBY}(r < 100\,{\rm pc})}{M_{\rm dm}^{\rm DMO}(r < 100\,{\rm pc})} \left(\frac{\Omega_m}{\Omega_m - \Omega_b}\right)$$

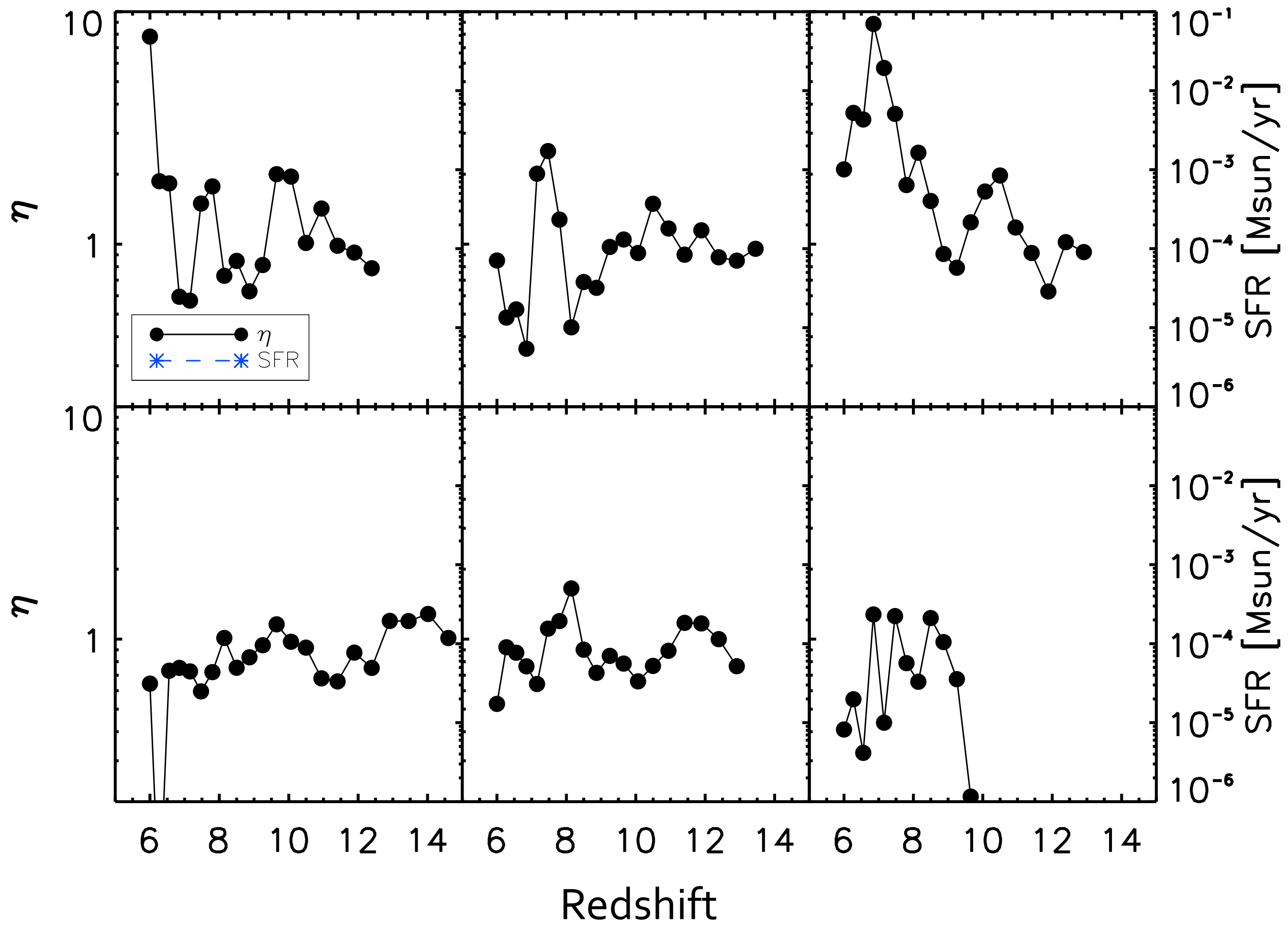
Distribution of η





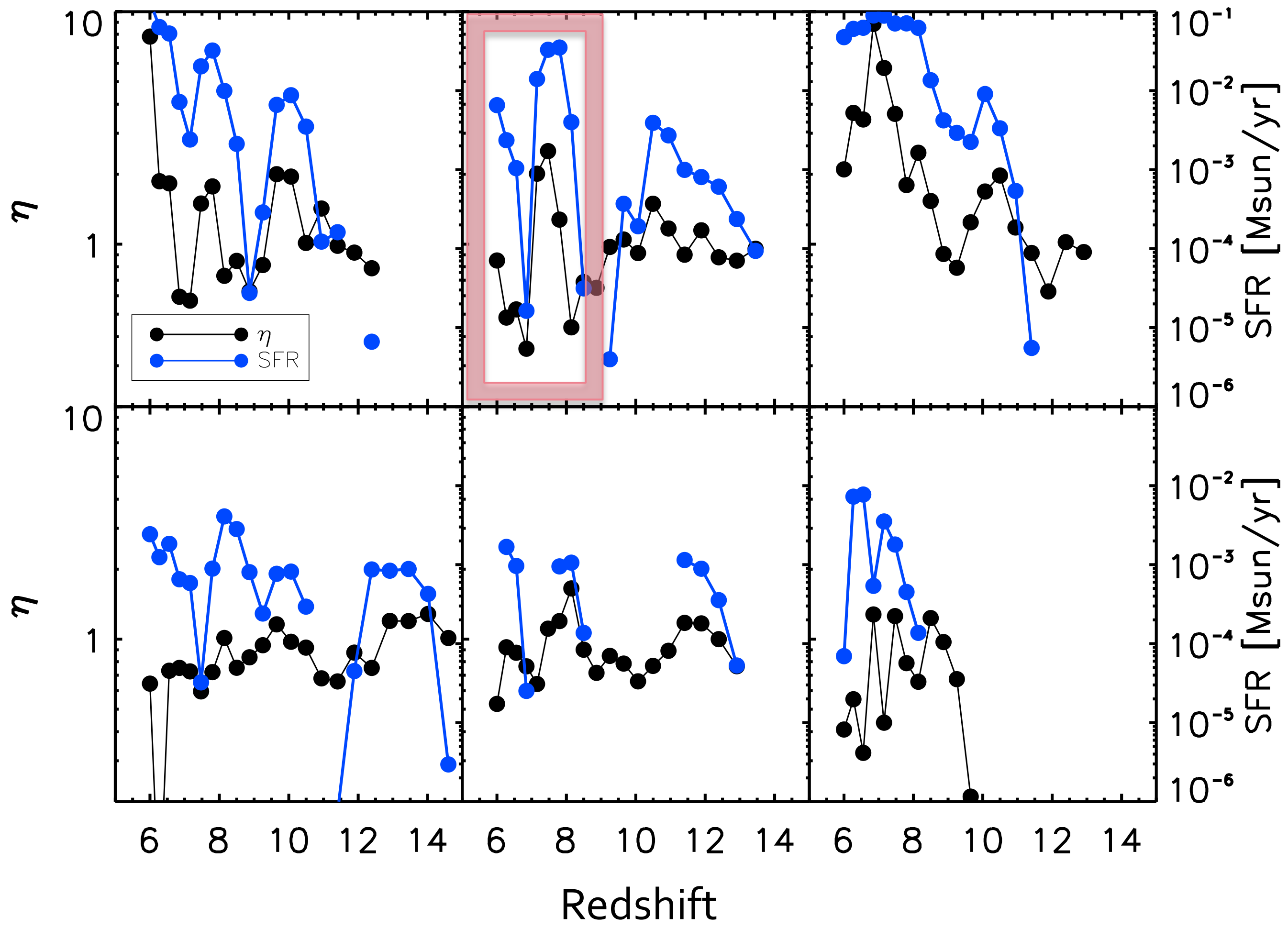
Davis et al. 2013

Time Evolution of η



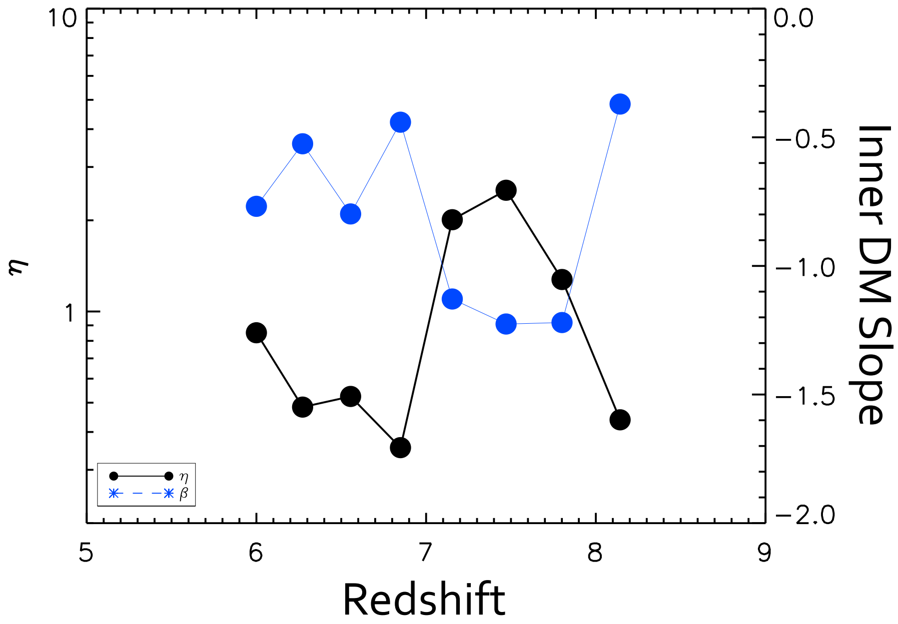
Davis et al. 2013

Time Evolution of η

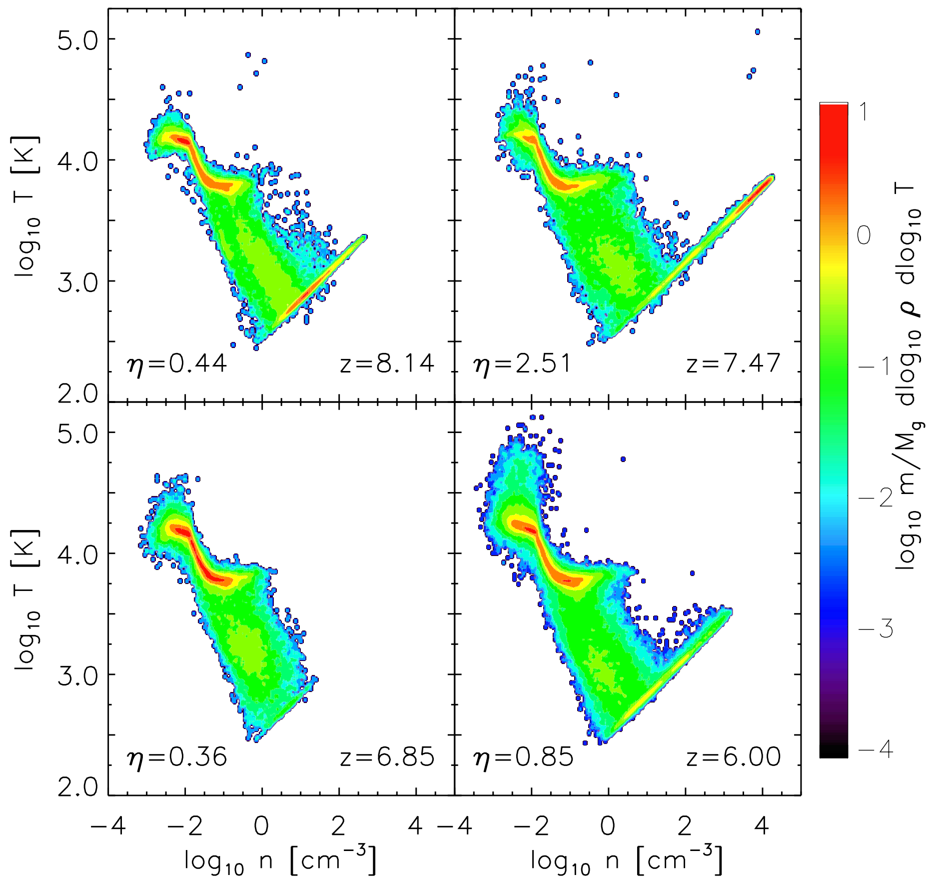


Davis et al. 2013

Sample Halo Cycle

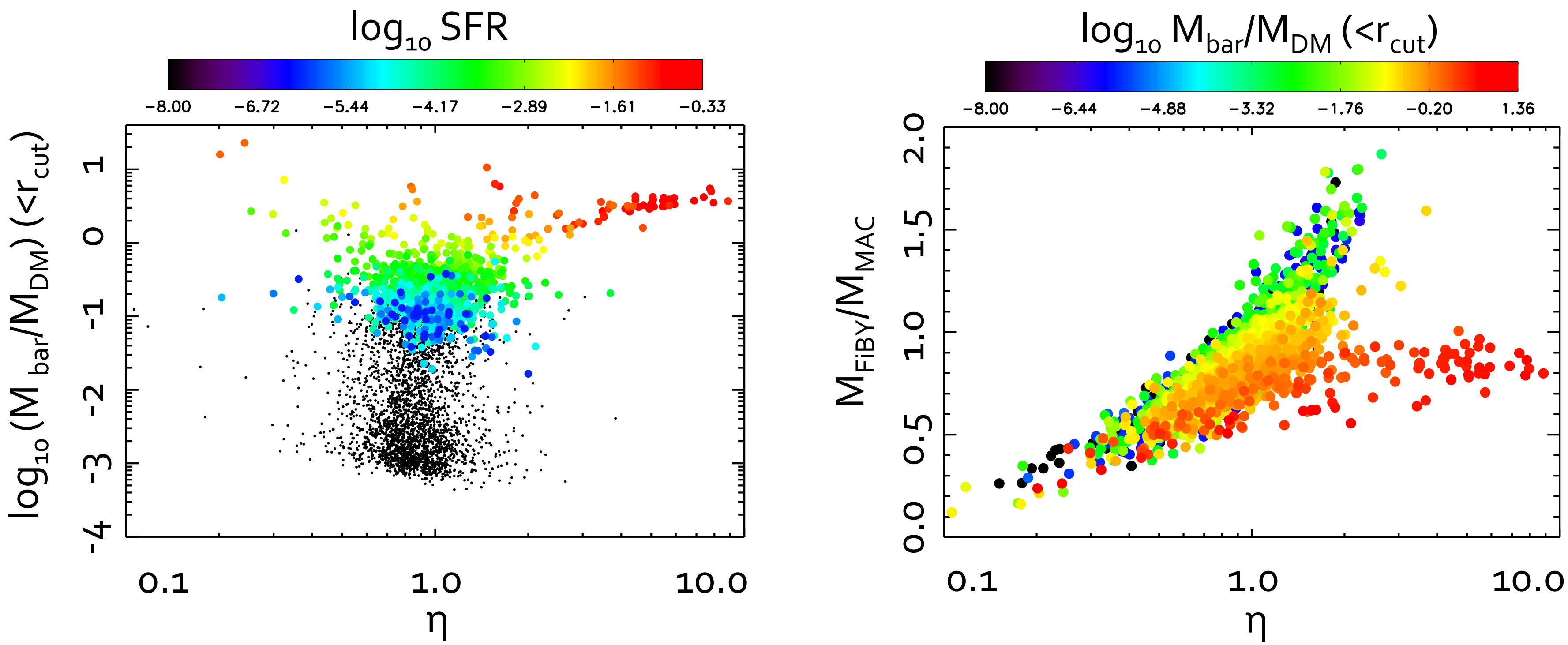


- Steeper slope with increase η
- Never reaches a true flat core
- Cycle tied to gas phase



Davis et al. 2013

Cusps via Adiabatic Contraction



- Adiabatic contraction explains high η halos with large baryon fractions
- No evidence for adiabatic expansion

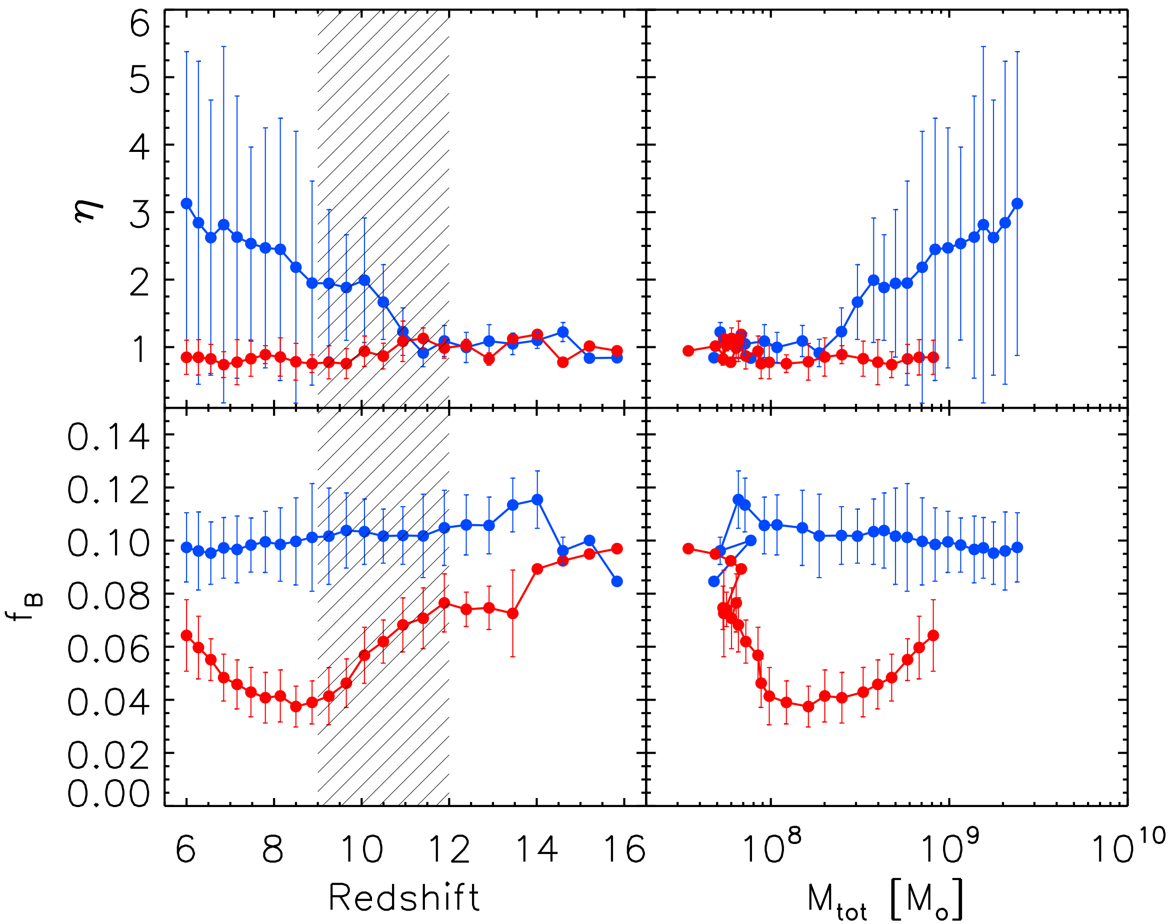
Davis et al. 2013

Impact of Reionization

Blue: Halos with $M_{tot} > 1.5e9\ M_o$ at z=6

Red: Halos with $6.5e8 < M_{tot} < 1.5e9\ M_o$

Errors show 1-sigma spread

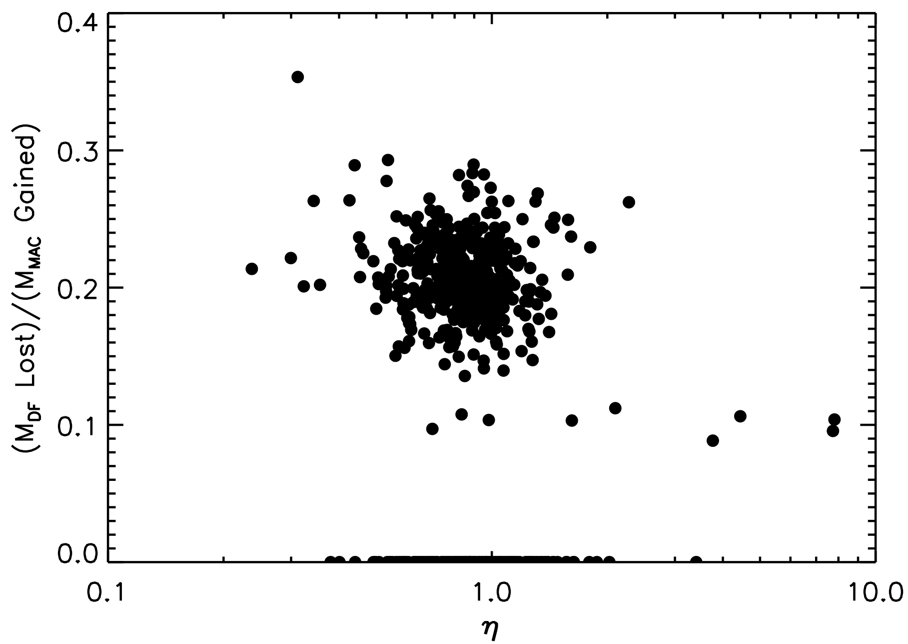


- Mean evolution of η affected by photoheating during reionization
- DM density profile not just a function of halo mass

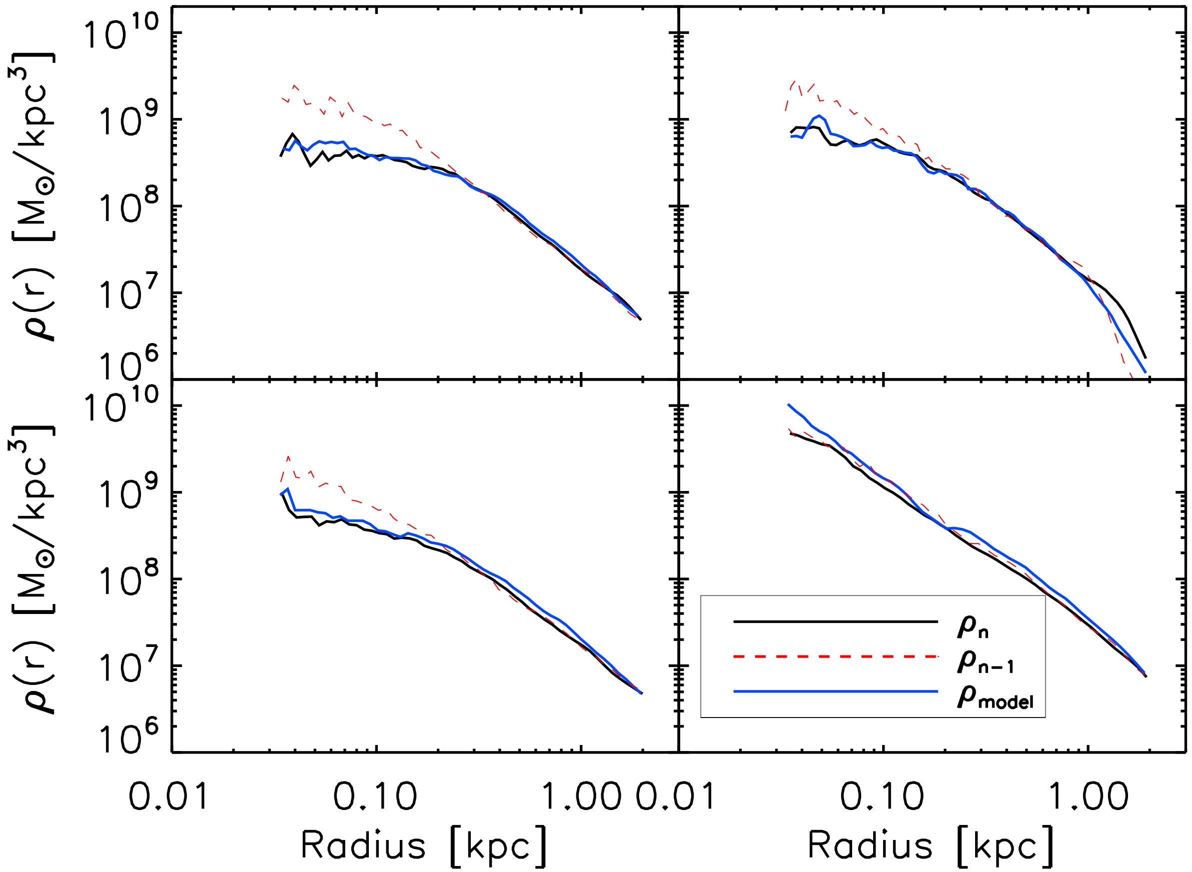
Davis et al. 2013

How Not to Create a Core

- Using model of Lackner & Ostriker (2010), predict mass lost due to dynamical friction via infalling stellar clumps
- $M_{DF} < M_{MAC}$
- Dynamical friction via baryon infall plays only small role in η



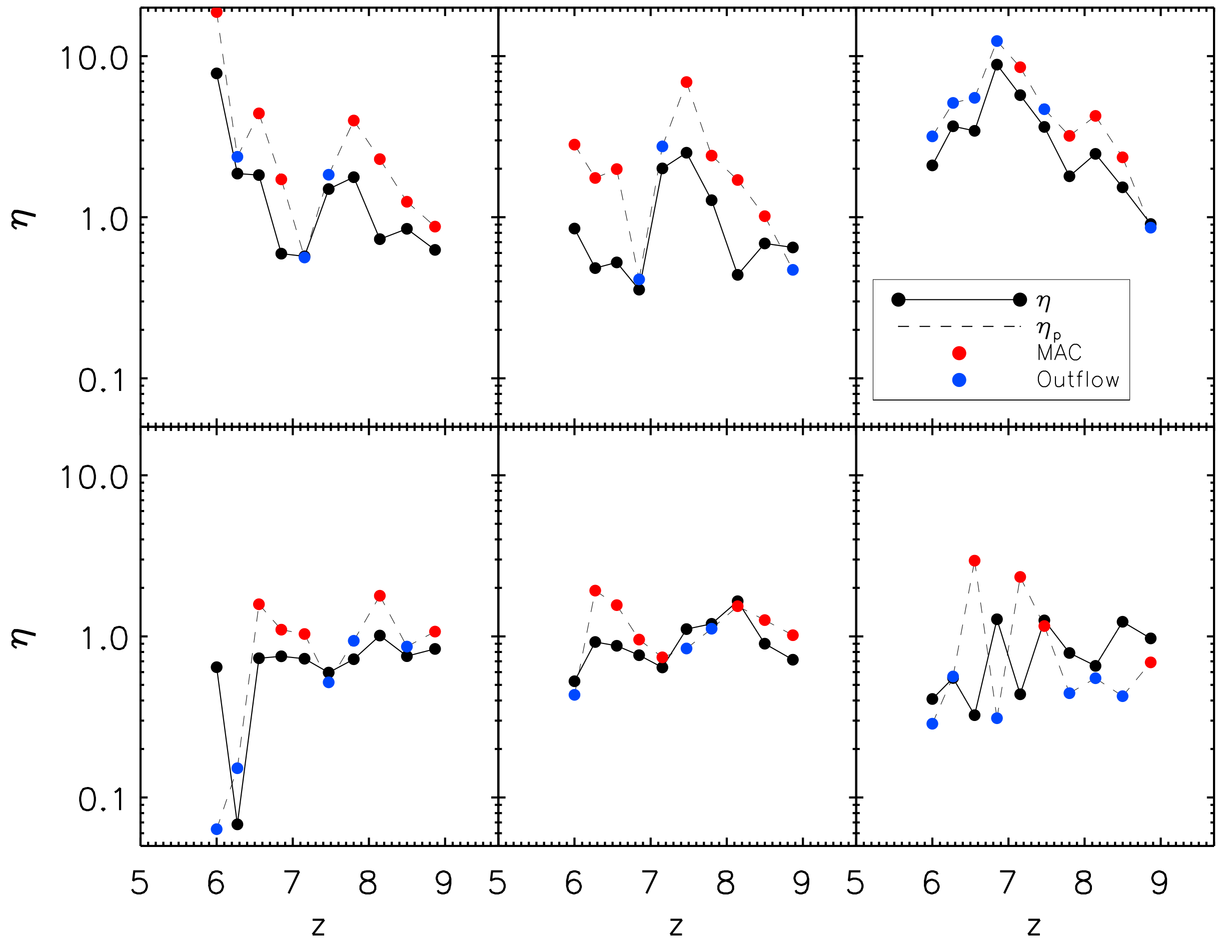
Cores via Explosive Feedback



- As gas is expelled, the DM responds to the new potential
  (e.g. Pontzen et al. 2012)

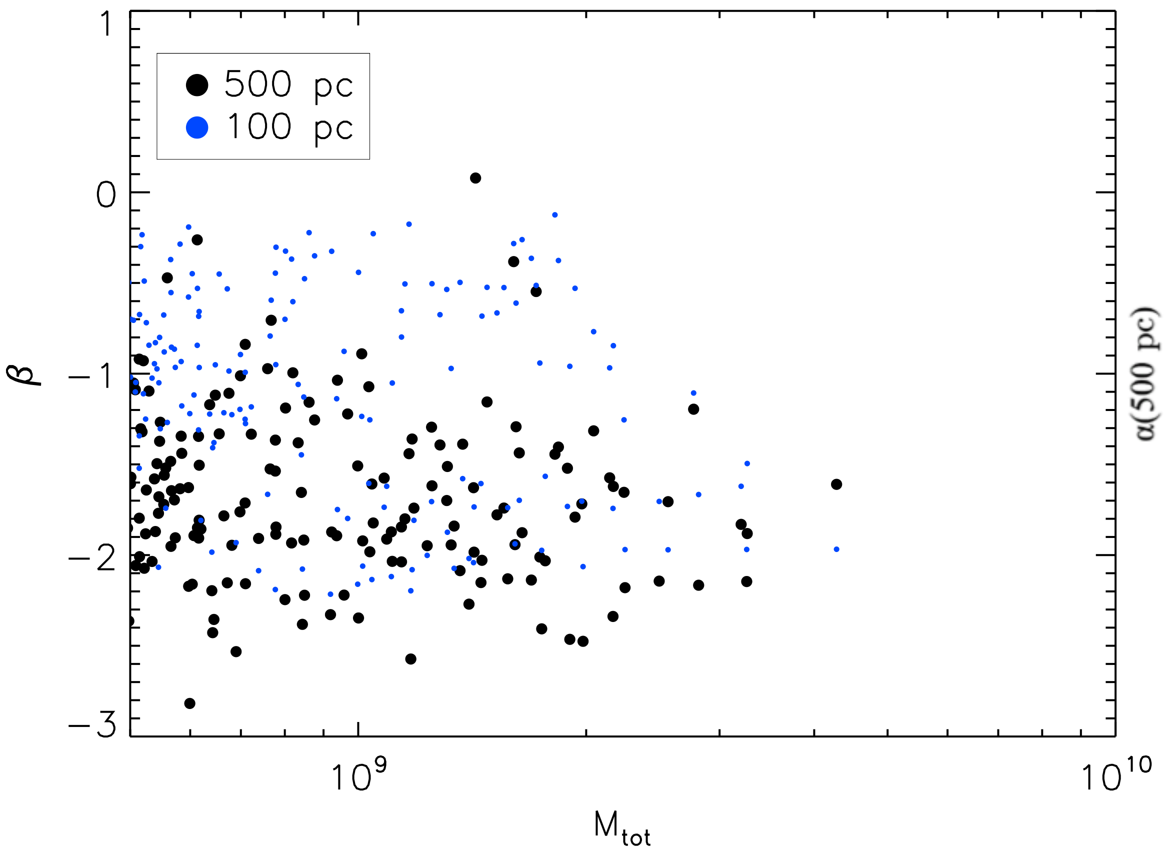
Davis et al. 2013

Predicting the Evolution of η



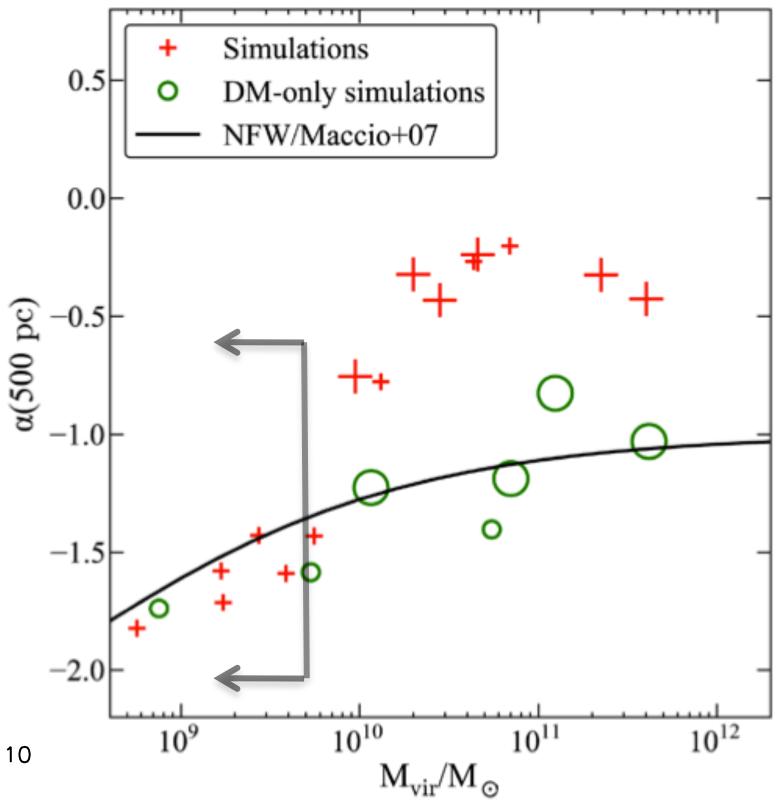
- The two models are able to reproduce the evolutionary trends in η

Future work: inner slope

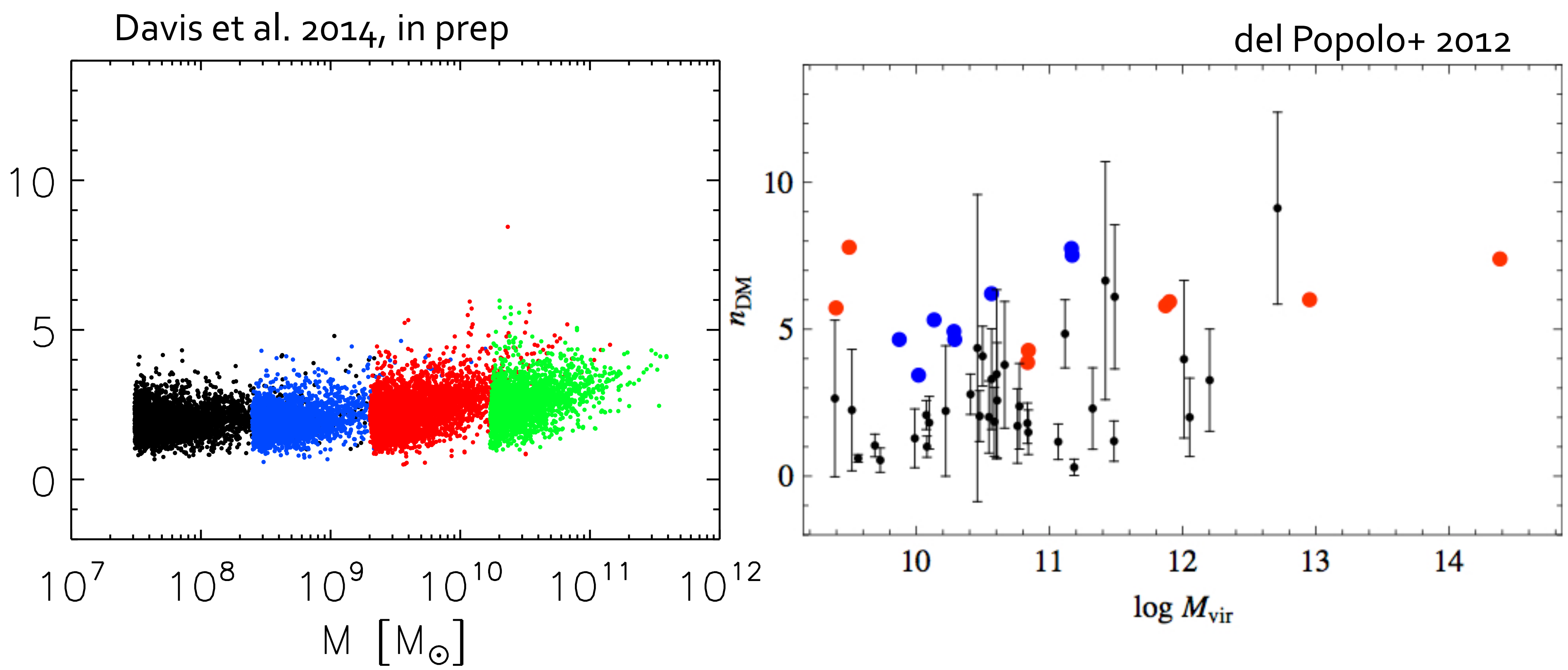


Davis et al. 2014, in prep

Governato+ 2012



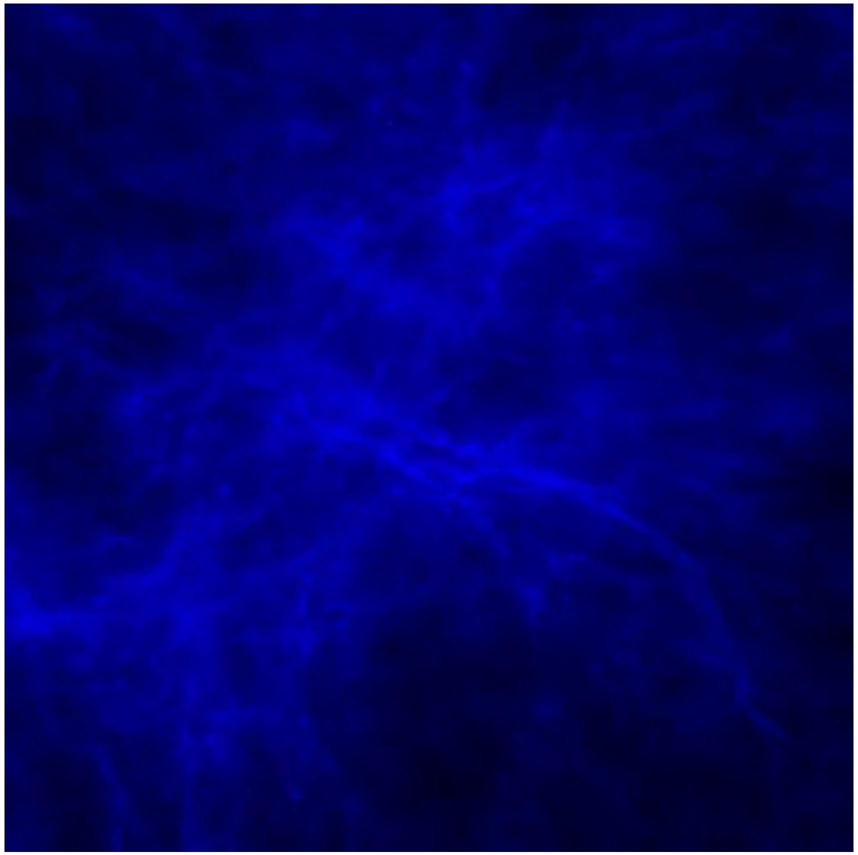
Future work: comparison with observations



- Are local dwarf cores due to Nature or Nurture?
- FiBY halos can reproduce inner slope and scatter

Conclusions

- No universal level of enhancement (or decrement) due to baryons
  - No universal inner profile
- In halos with cold, dense gas adiabatic contraction explains cuspy center
  - Reionization inhibits cusp formation
- Cyclical evolution of η tied to star formation bursts and feedback driven outflows to create a core



Gas density