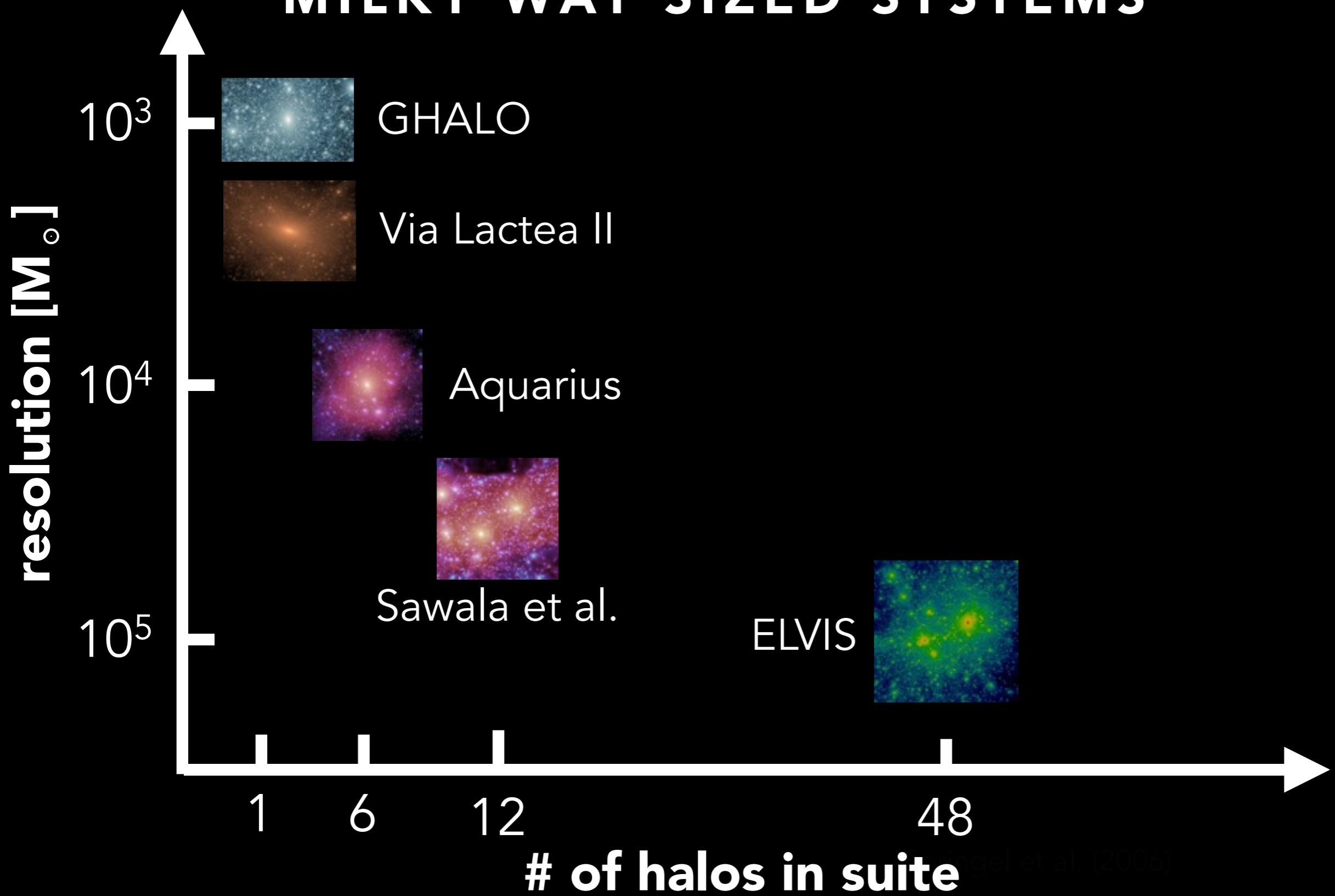


THE CATERPILLAR PROJECT

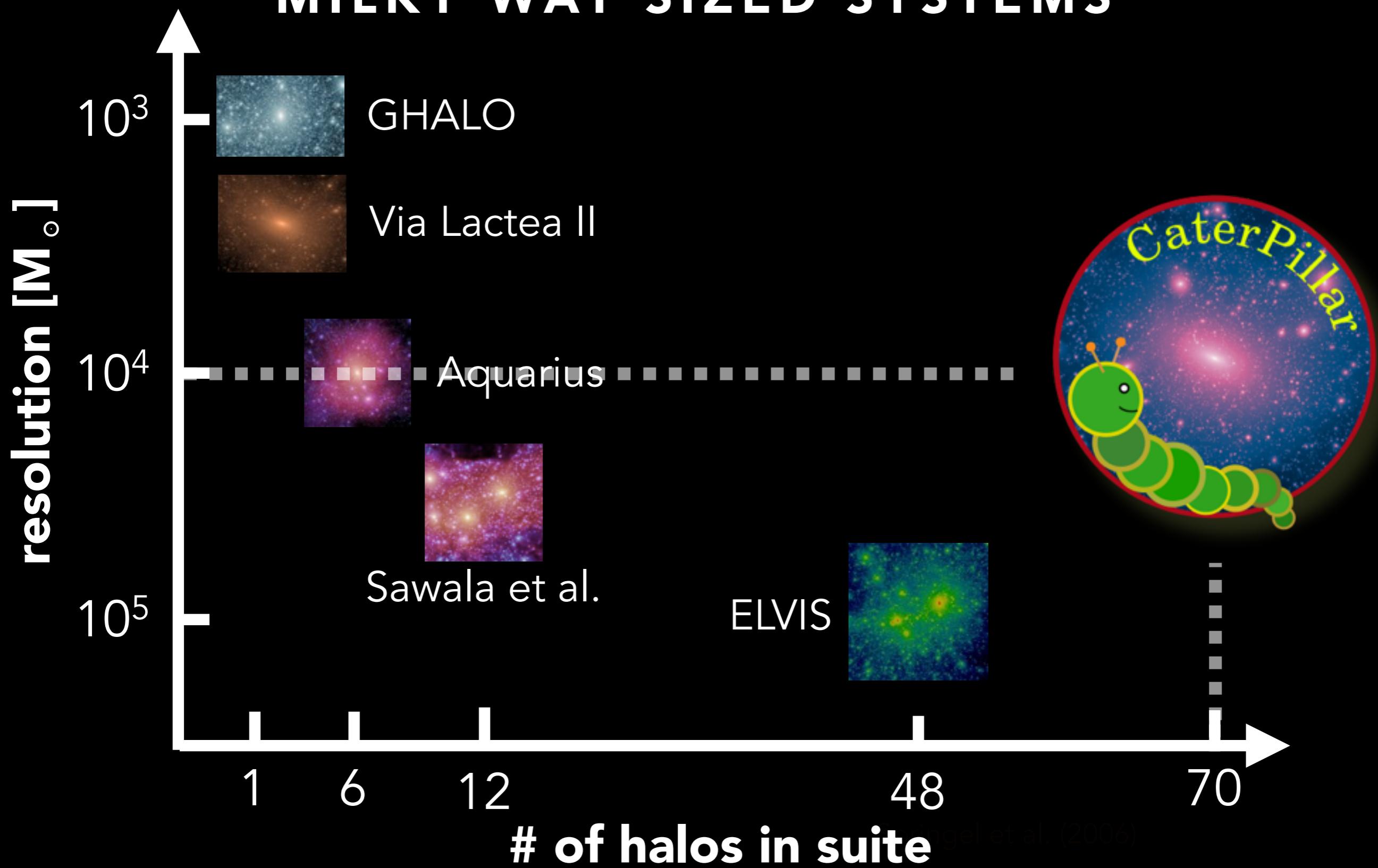


BRENDAN GRIFFEN
MIT

CURRENT STATE-OF-THE-ART: MILKY WAY SIZED SYSTEMS



CURRENT STATE-OF-THE-ART: MILKY WAY SIZED SYSTEMS



QUESTIONS

Can we probe the first stars/galaxies of the Milky Way?

What is the origin and evolution of the Milky Way satellites?

What was the environment of the Milky Way like at $z > 10$?



THE CATERPILLAR PROJECT

www.caterpillarproject.org



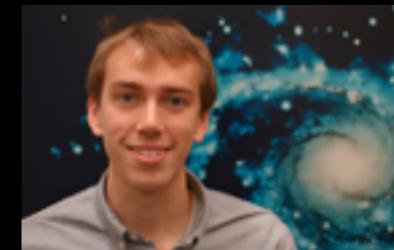
Anna Frebel



Brian O'Shea



Facundo Gómez



Greg Dooley



Alex Ji



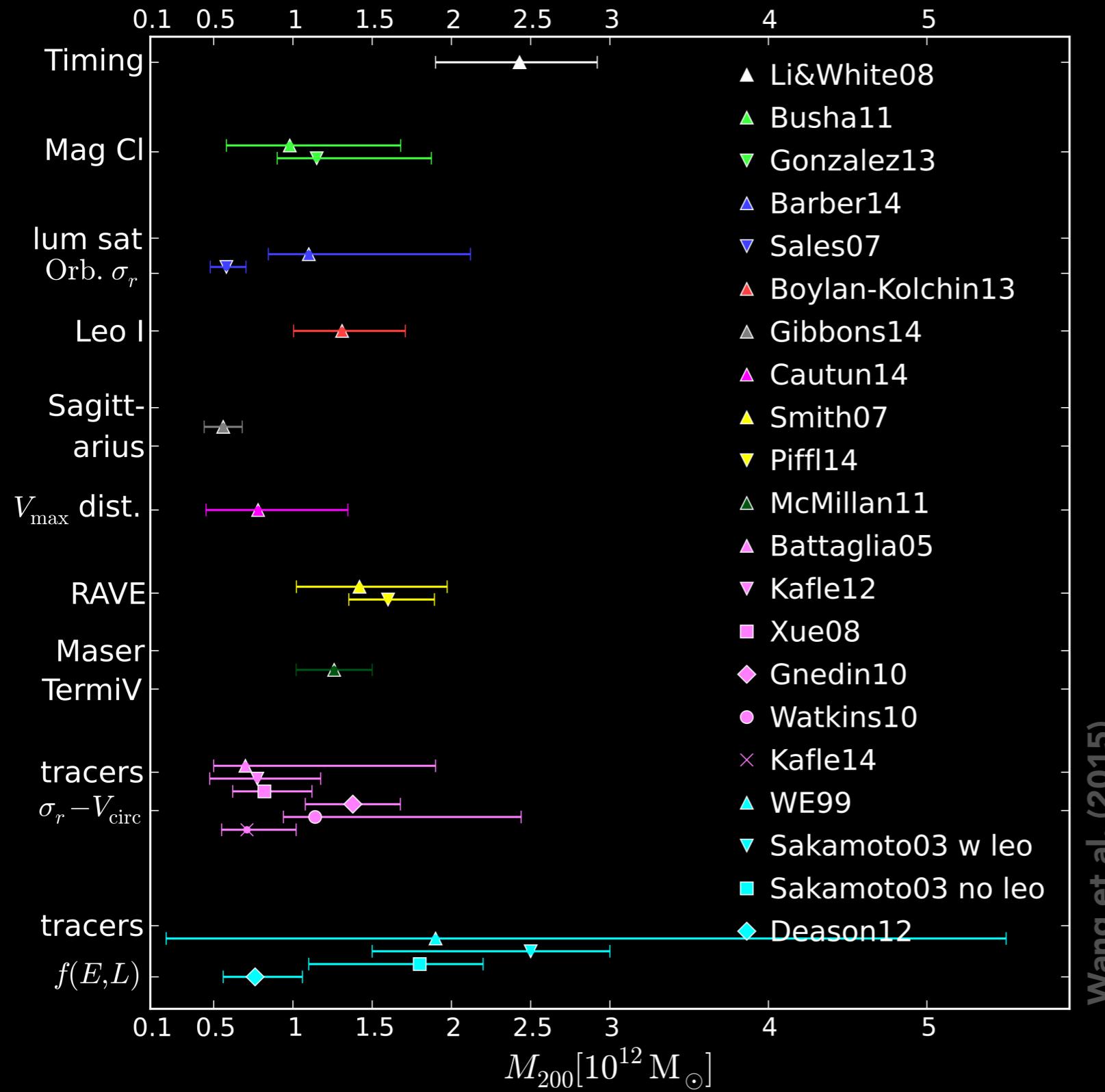
Mark Vogelsberger

mass of halos $0.7 - 3 \times 10^{12} M_{\odot}$ **number of halos**

70

cosmologyPlanck13: $\sigma_8 = 0.83$, $\Omega_m = 0.31$, $\Omega_{\Lambda} = 0.68$, $n_s = 0.96$, $h = 0.67$ **mass resolution** $\sim 10^4 M_{\odot}$ **spatial resolution** ~ 75 pc**temporal resolution**10 Myrs/snapshot to $z = 6$, then ~ 50 Myrs/snapshot**codes****MUSIC, Gadget-3/4, ROCKSTAR, SUBFIND****data product**4-6TB/halo ~ 325 TB total

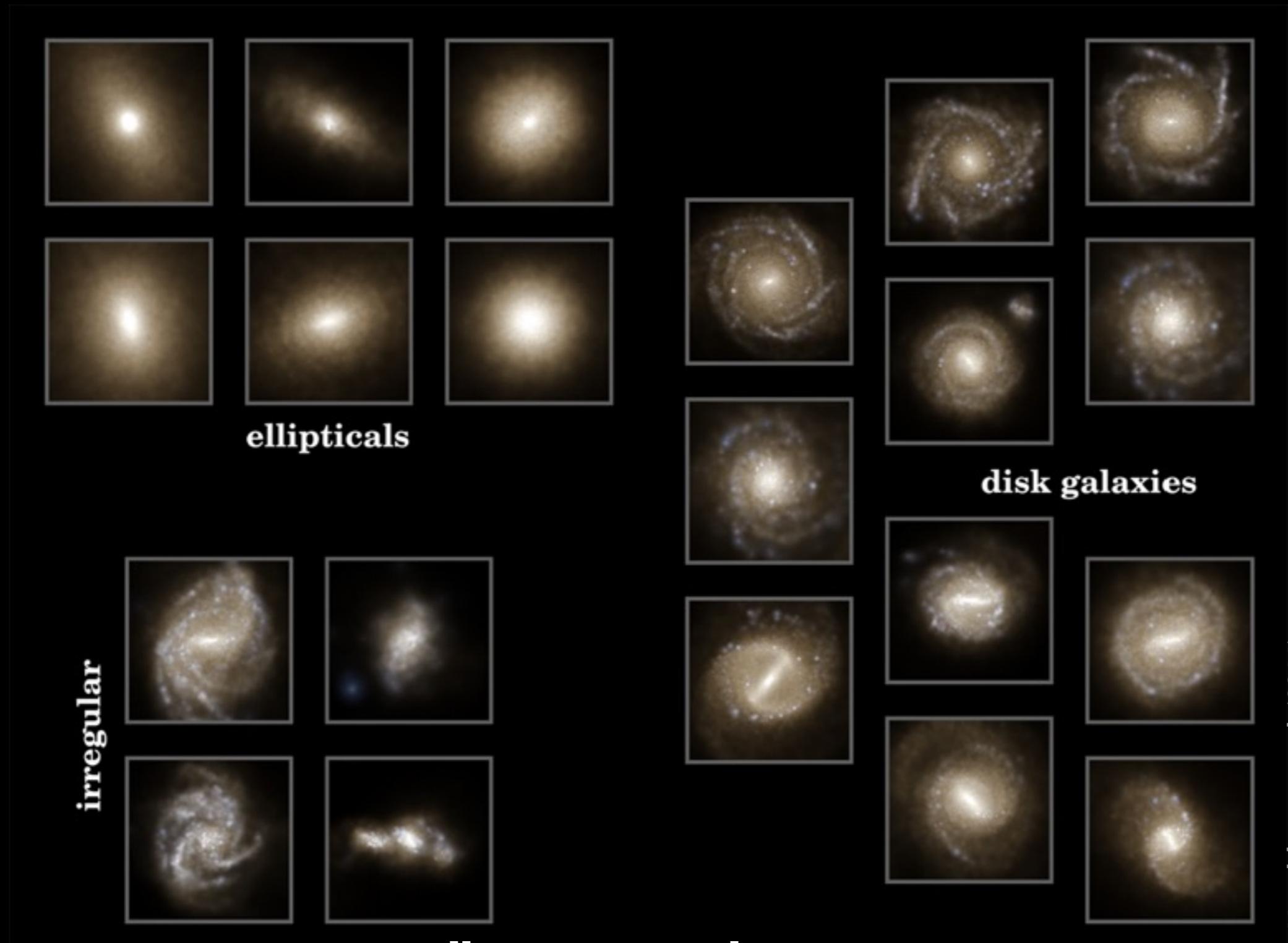
MASS OF THE MILKY WAY?



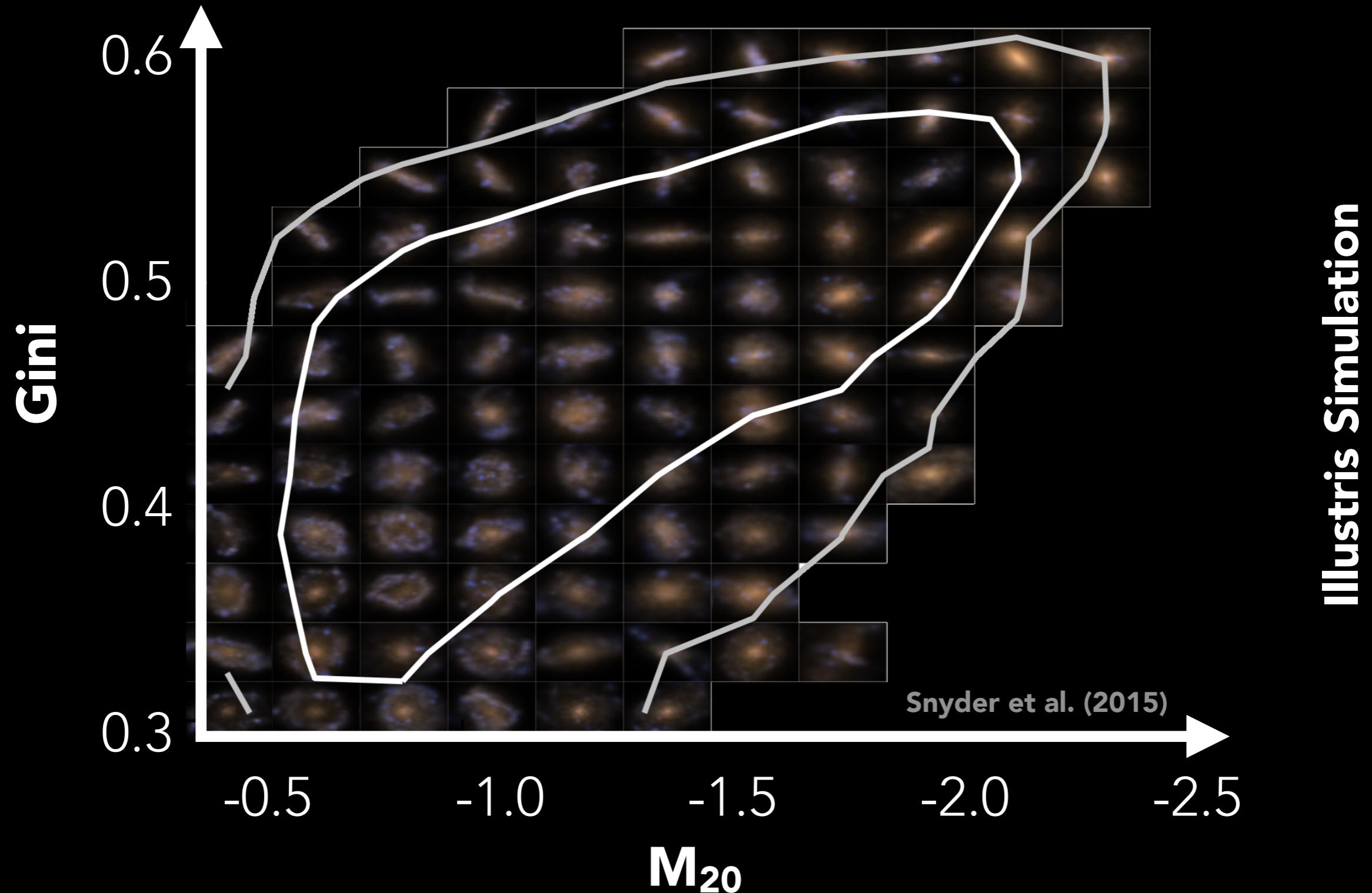
We need
many halos!

Wang et al. (2015)

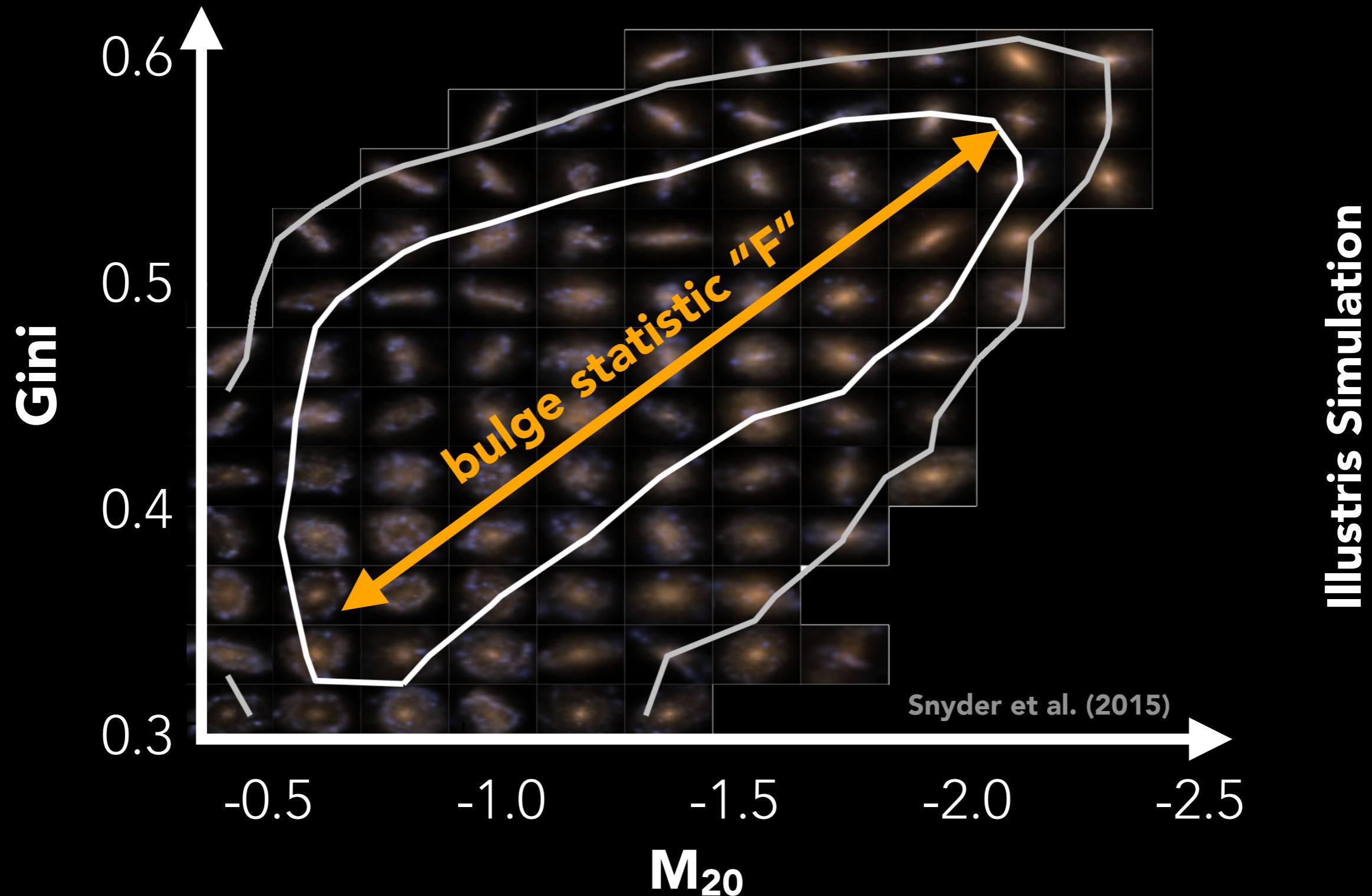
MORPHOLOGY & MERGER HISTORY



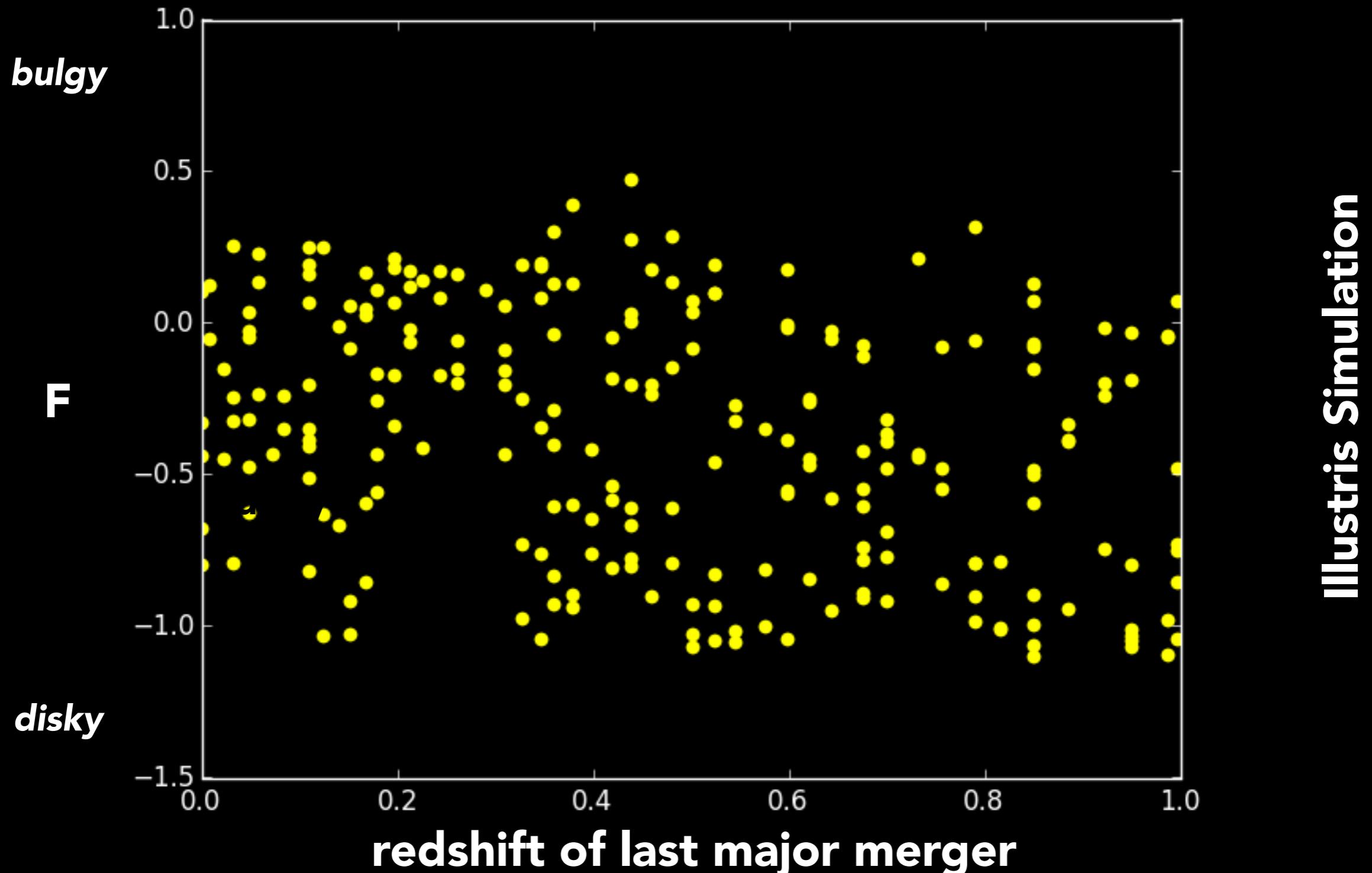
MORPHOLOGY & MERGER HISTORY



MORPHOLOGY & MERGER HISTORY



MORPHOLOGY & MERGER HISTORY



MORPHOLOGY & MERGER HISTORY

Not all major mergers are created equal:

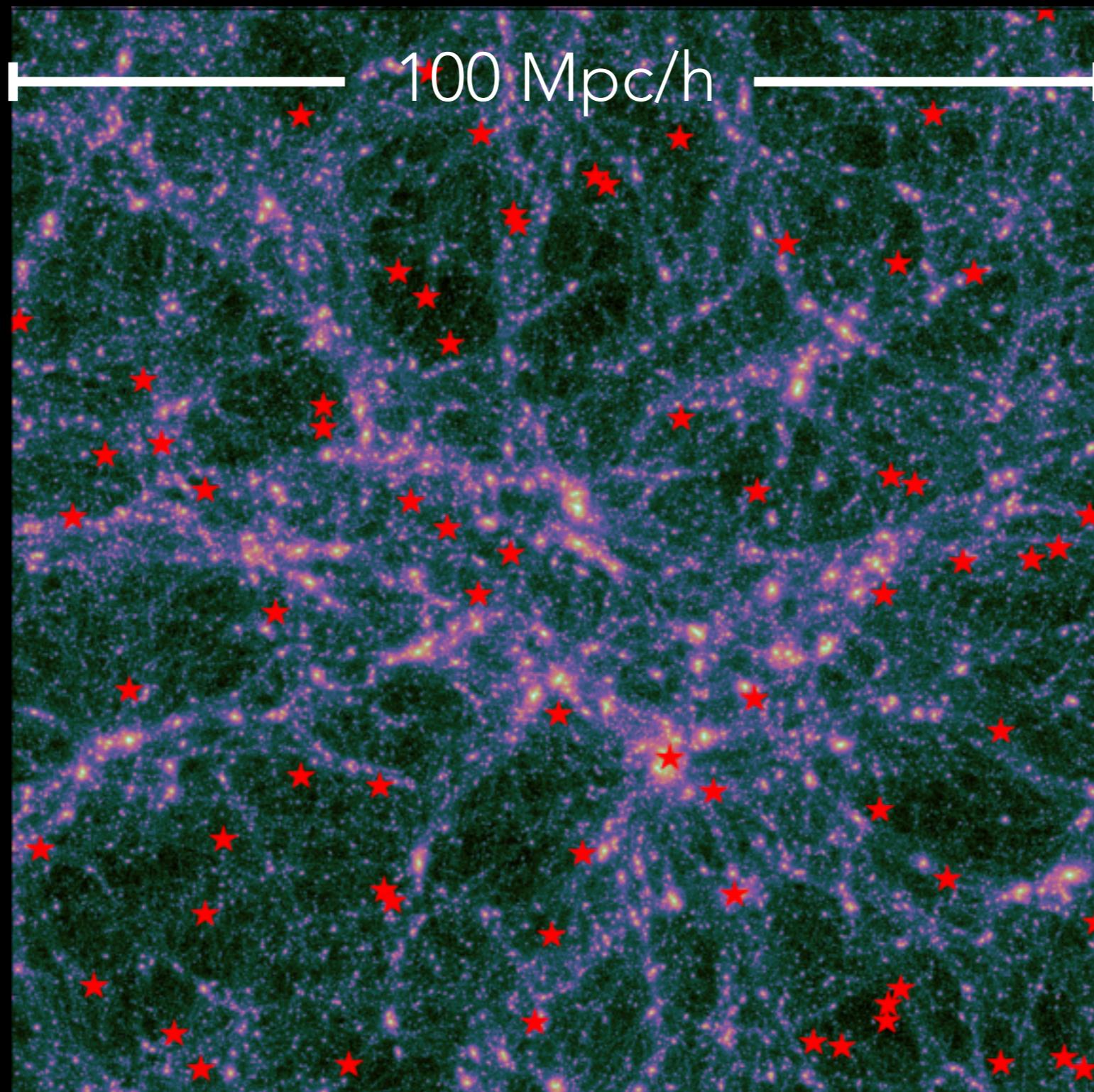
The morphology of MW analogues depends more on the nature of the merger (e.g. cold gas fraction), not necessarily that one occurred.

In other words:

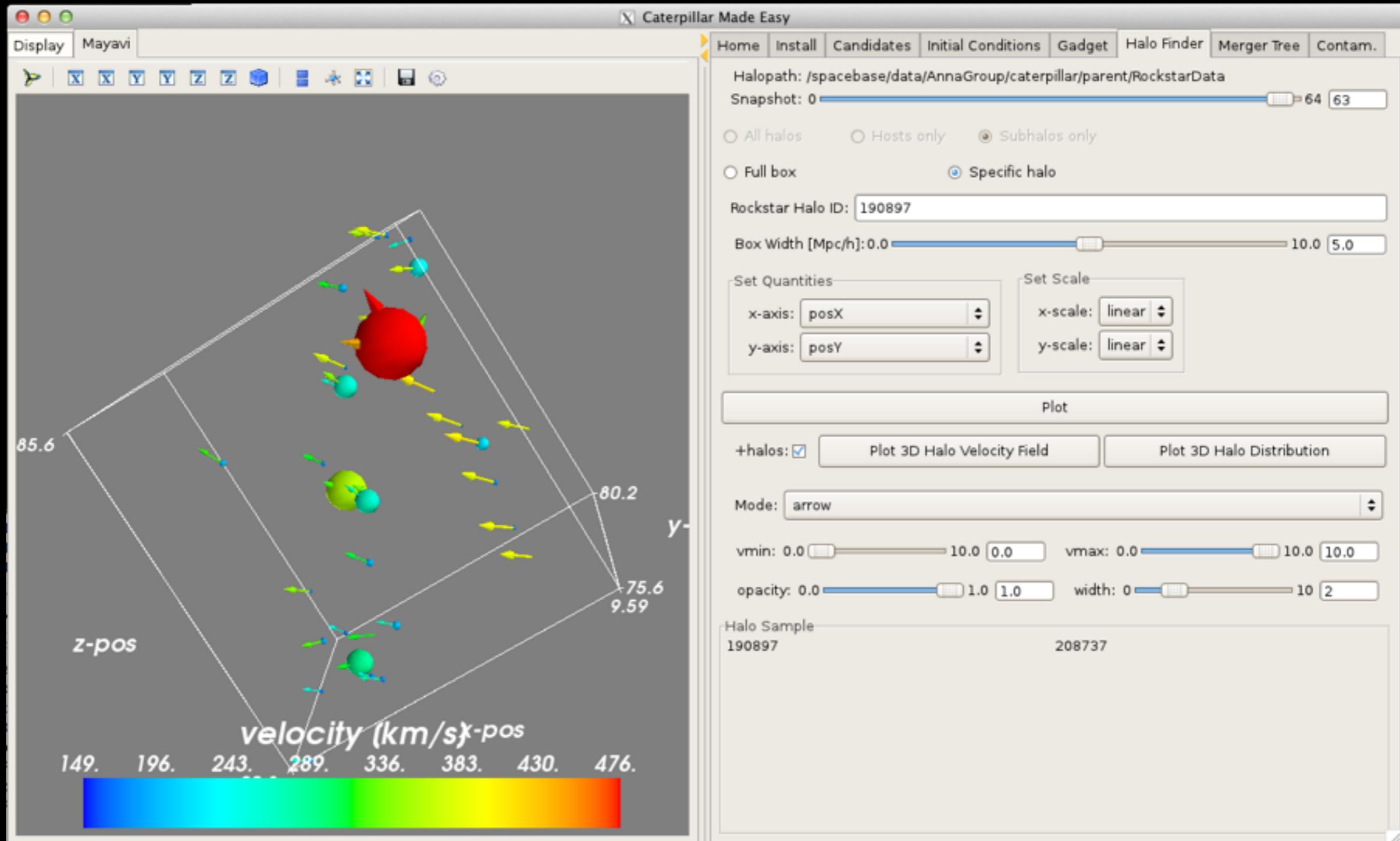
Ensuring your dark matter halo has no major mergers since $z = 1$ (as done previously), **doesn't guarantee** you'll get a nice disk galaxy at $z = 0$.

We need to sample wide range of merger histories!

SELECTING CATERPILLAR HALOS



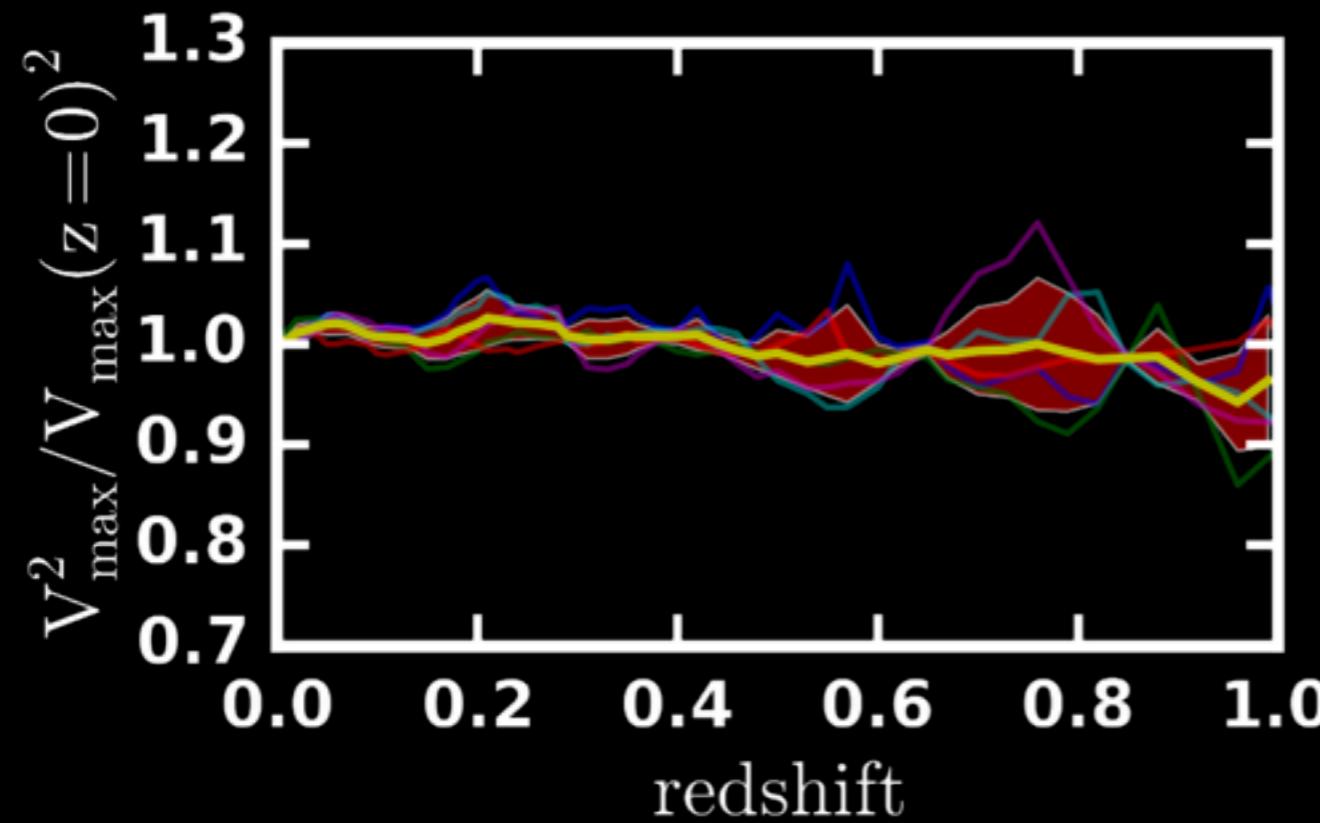
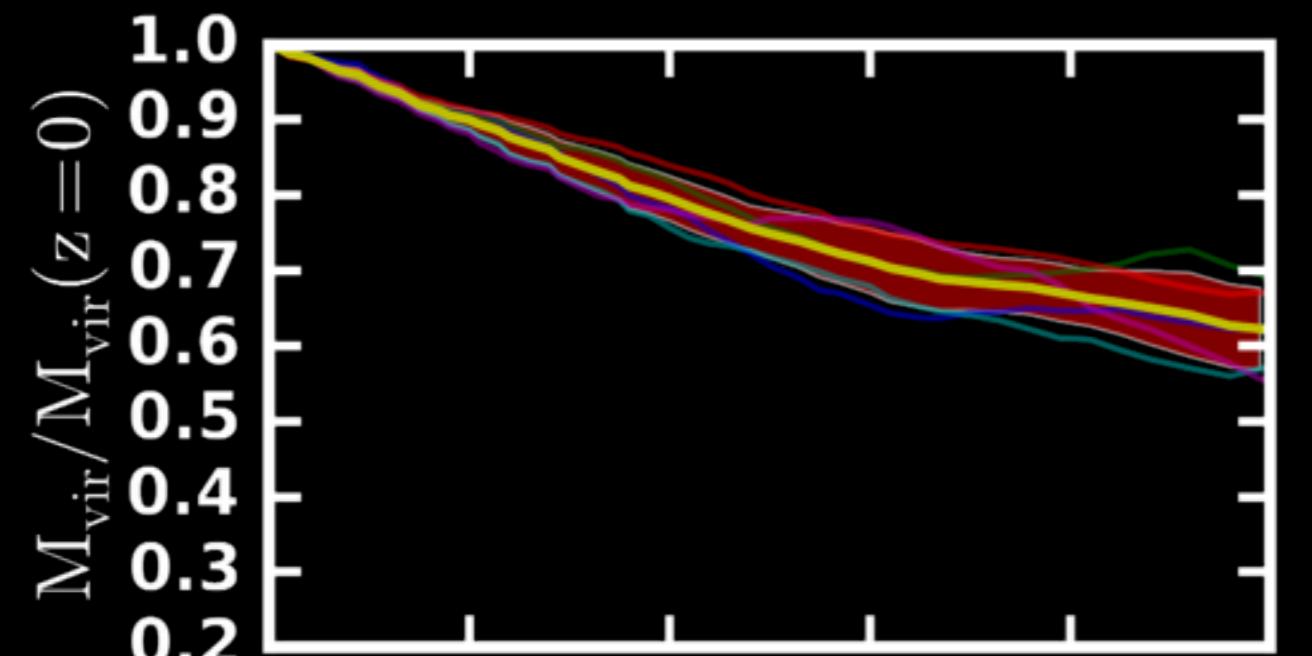
CME: CATERPILLAR MADE EASY



<https://github.com/bgriffen/cme>

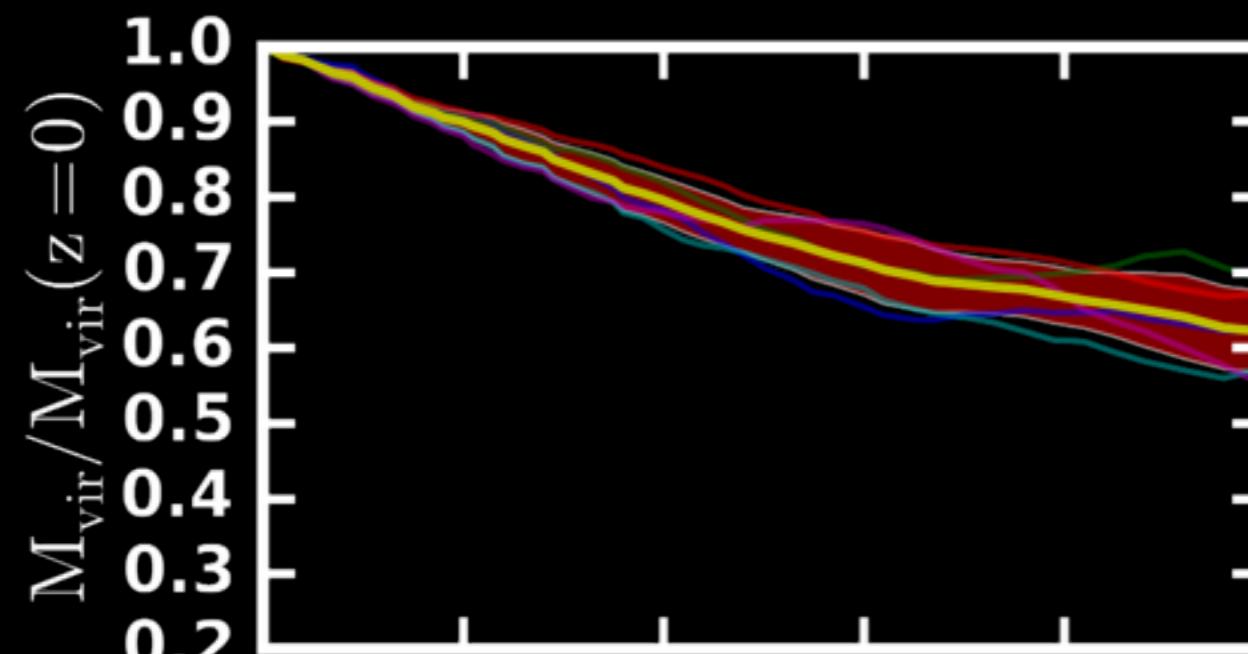
ACCRETION HISTORY

Aquarius

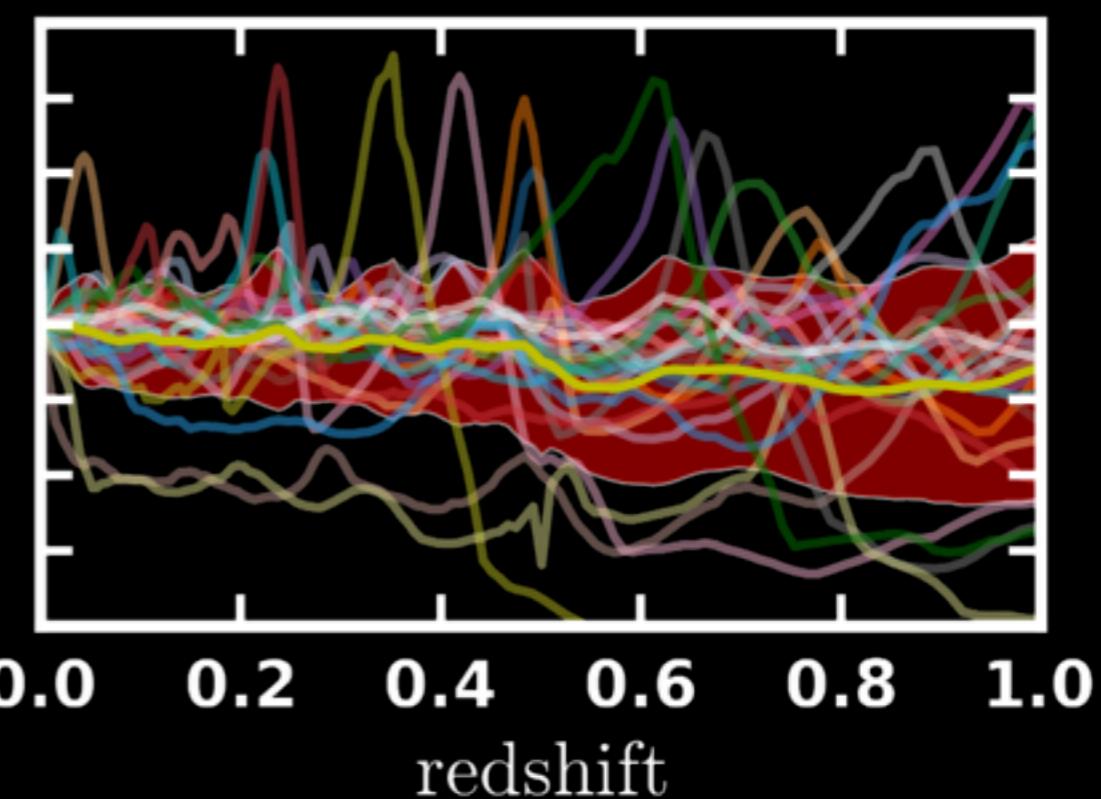
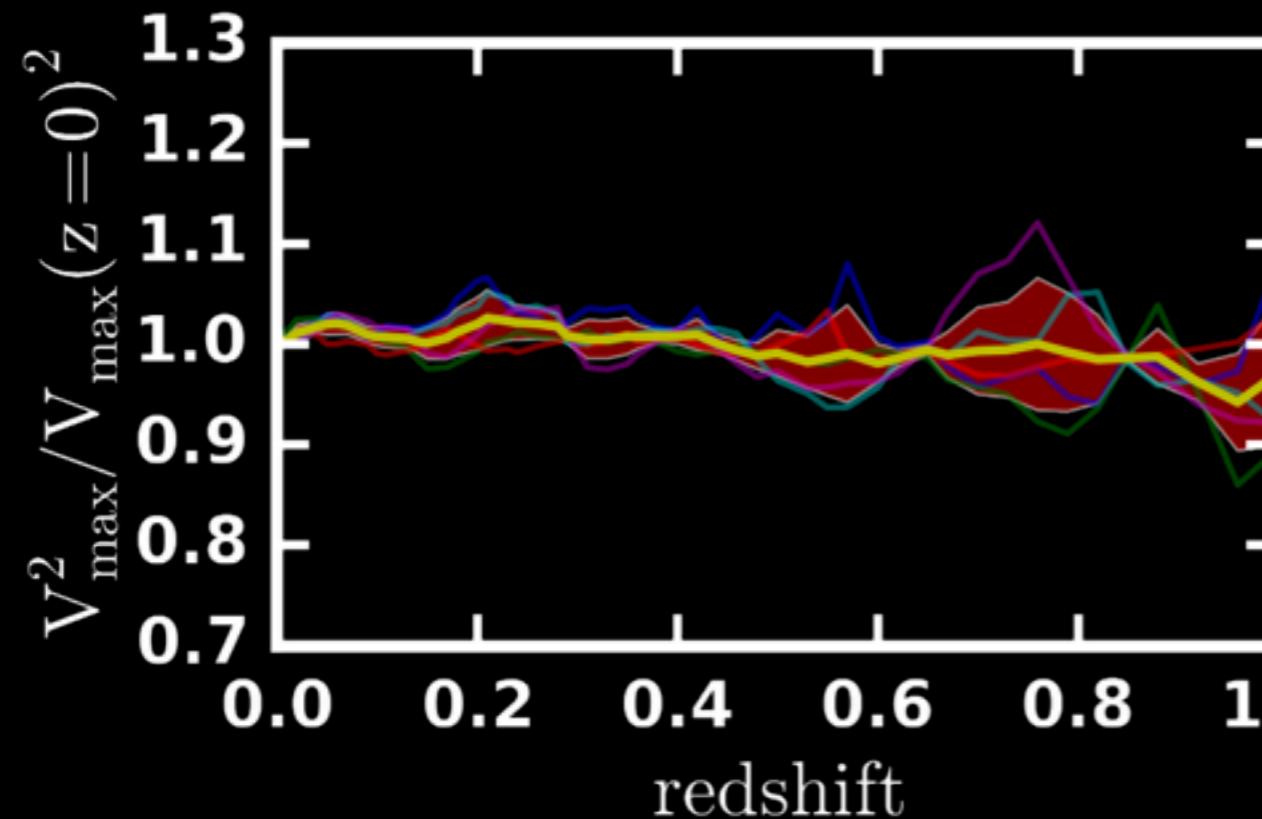
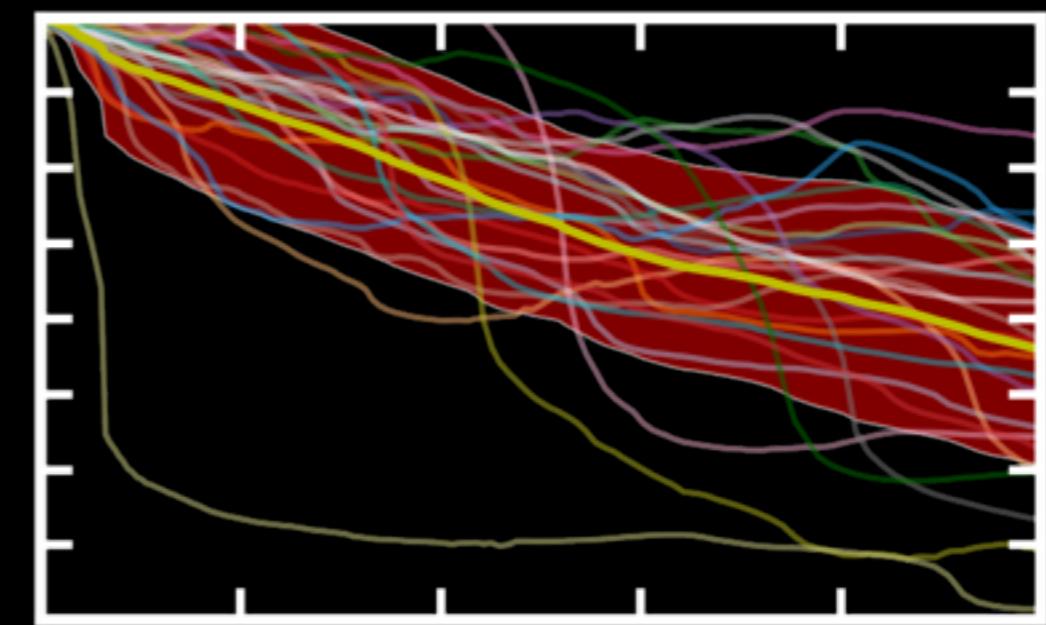


ACCRETION HISTORY

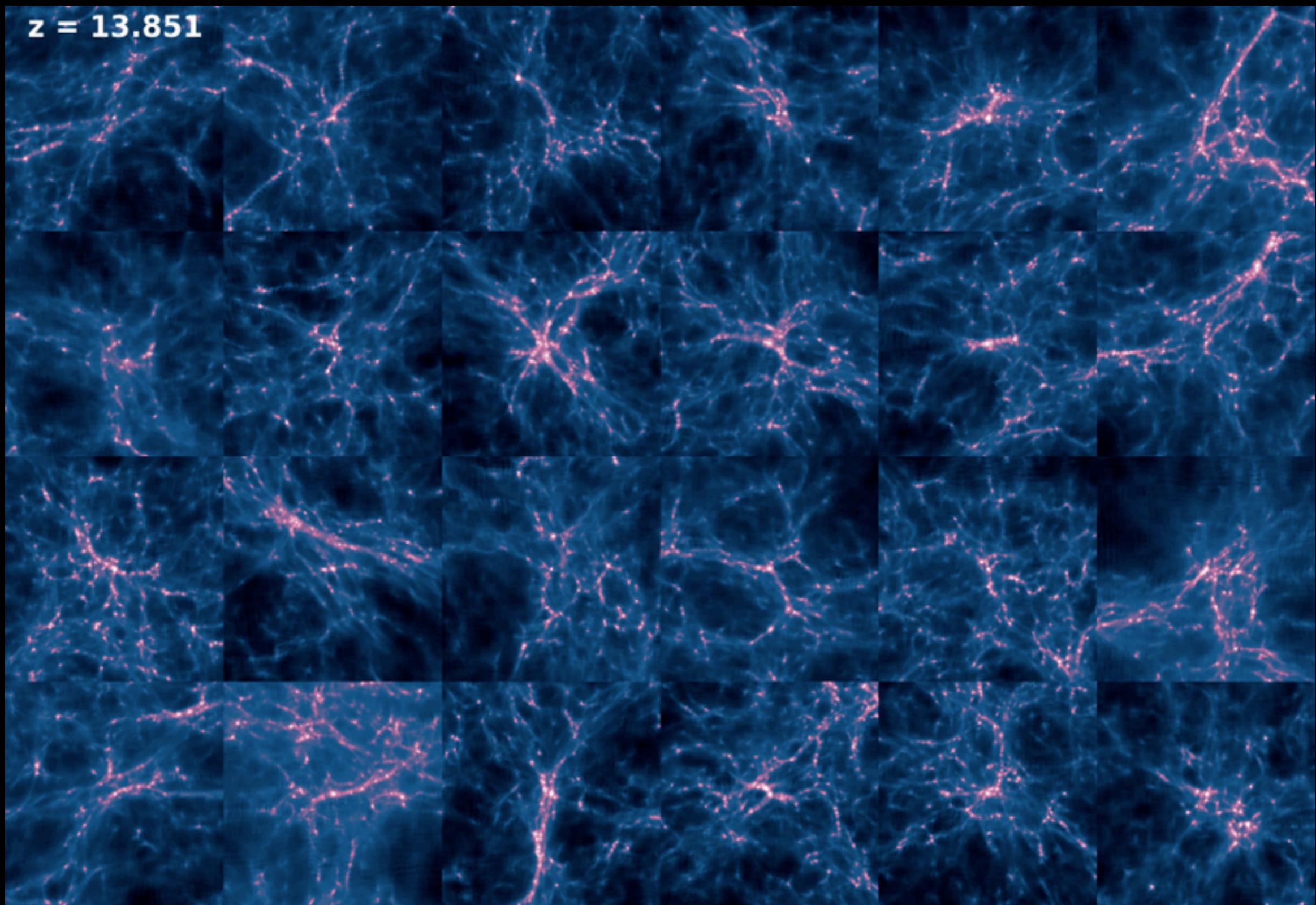
Aquarius



Caterpillar



FIRST 24 CATERPILLAR HALOS



Springer et al. (2009)

CATERPILLAR & FIRST STARS/GALAXIES

Converged to $V_{\max} \sim 5 \text{ km/s}$

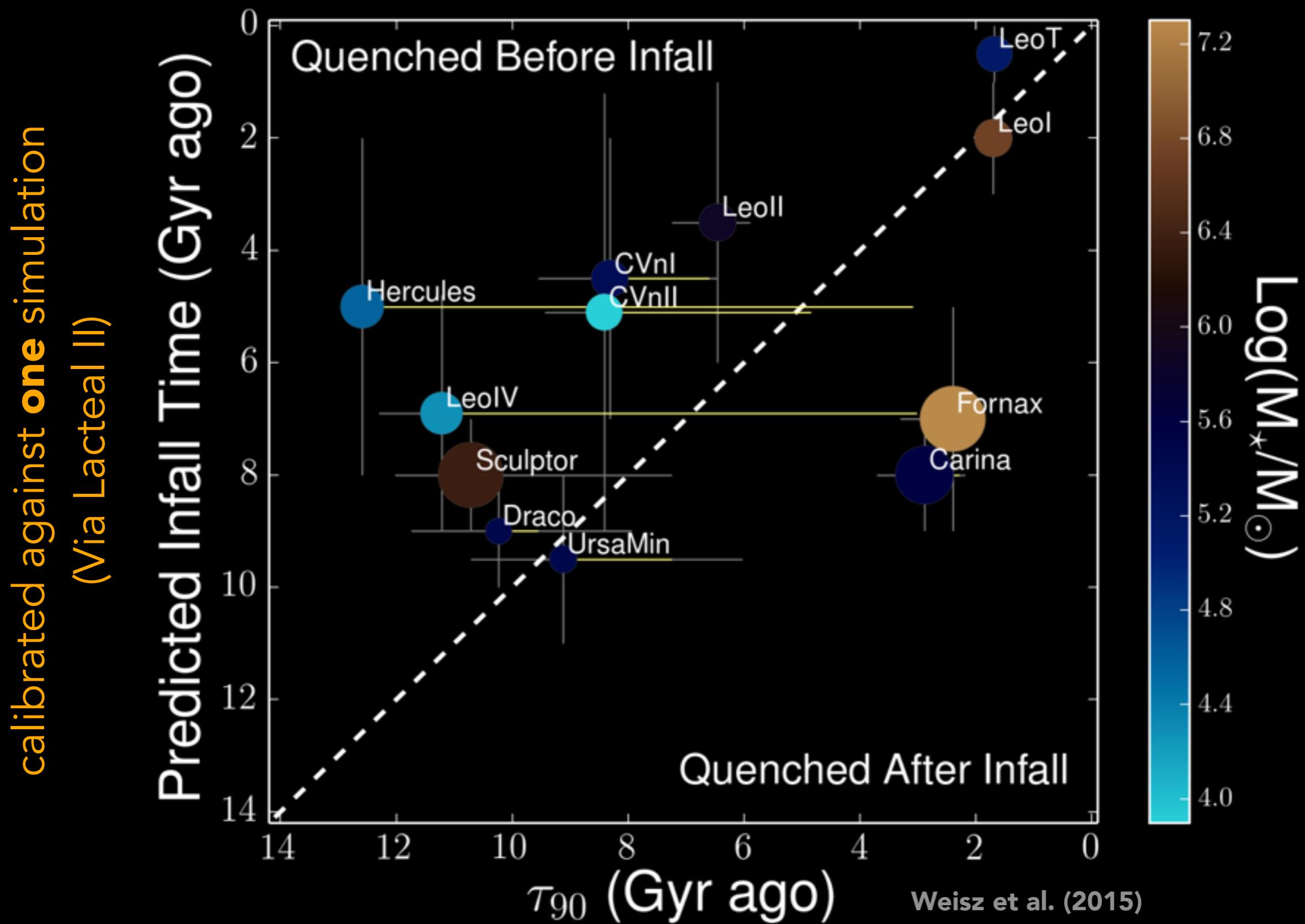
We can locate sites of Pop. III star formation in halos with
 $T_{\min} \sim 1100\text{K}$ ($M_h \sim 10^6 M_\odot$) — where are they today?

Springel et al. (2006)

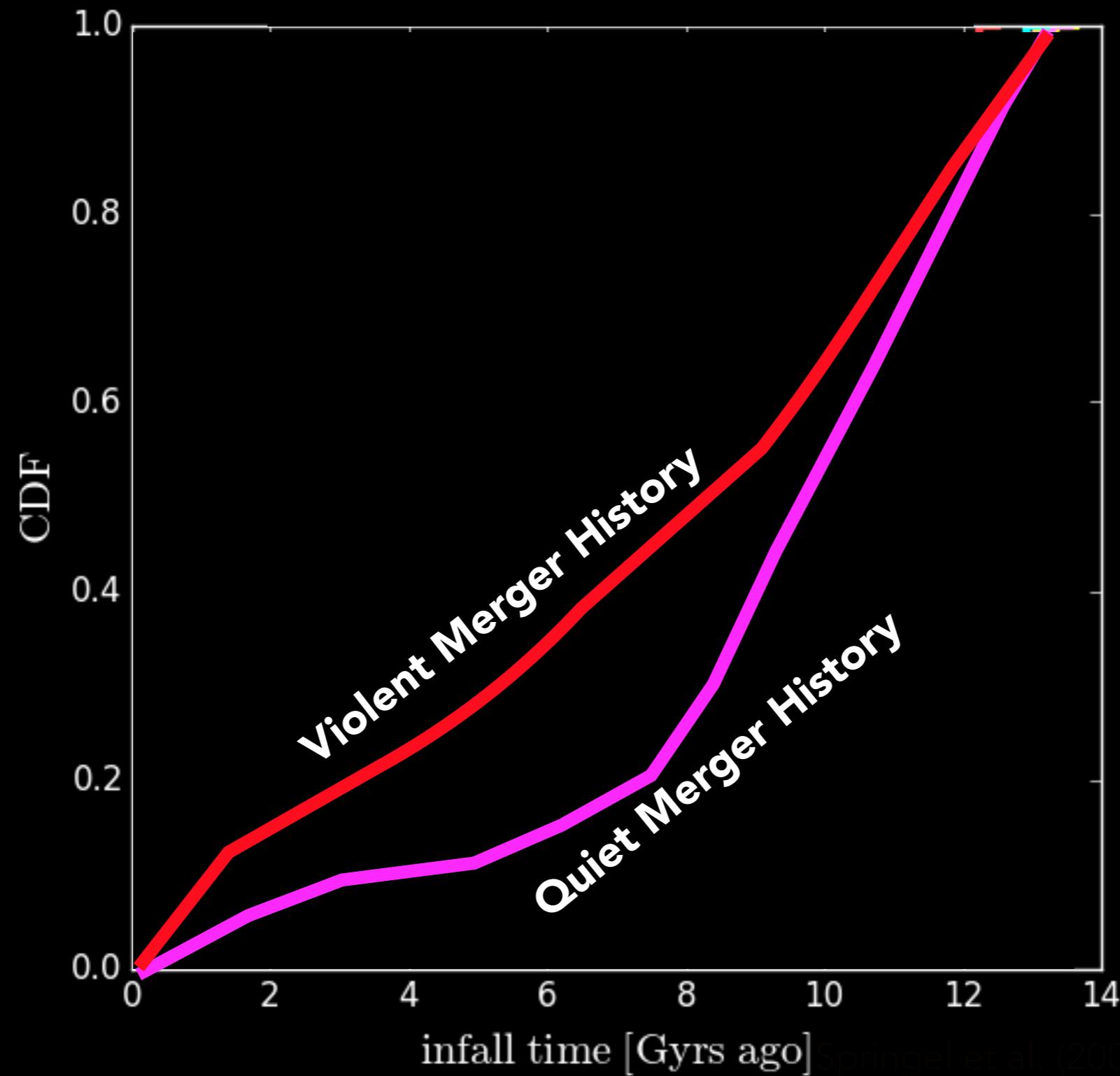
PRELIMINARY RESULTS

- 1. Infall times of satellites**
- 2. Pop. III formation sites**

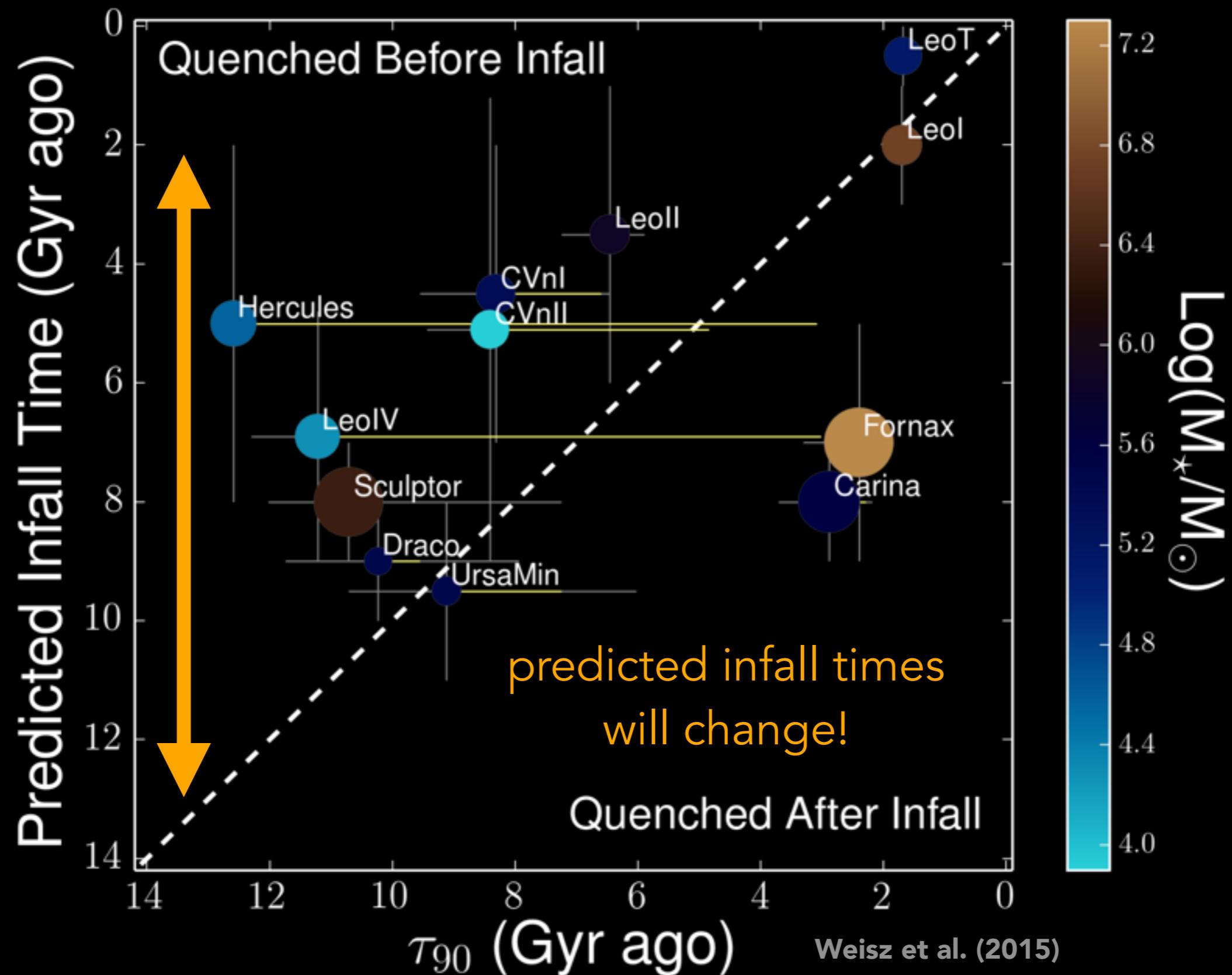
INFALL TIMES & MERGER HISTORY



INFALL TIMES & MERGER HISTORY



INFALL TIMES & MERGER HISTORY



CATERPILLAR & FIRST STARS/GALAXIES

Inferred infall times depend on assembly history!

We need more simulations to understand the full scatter.

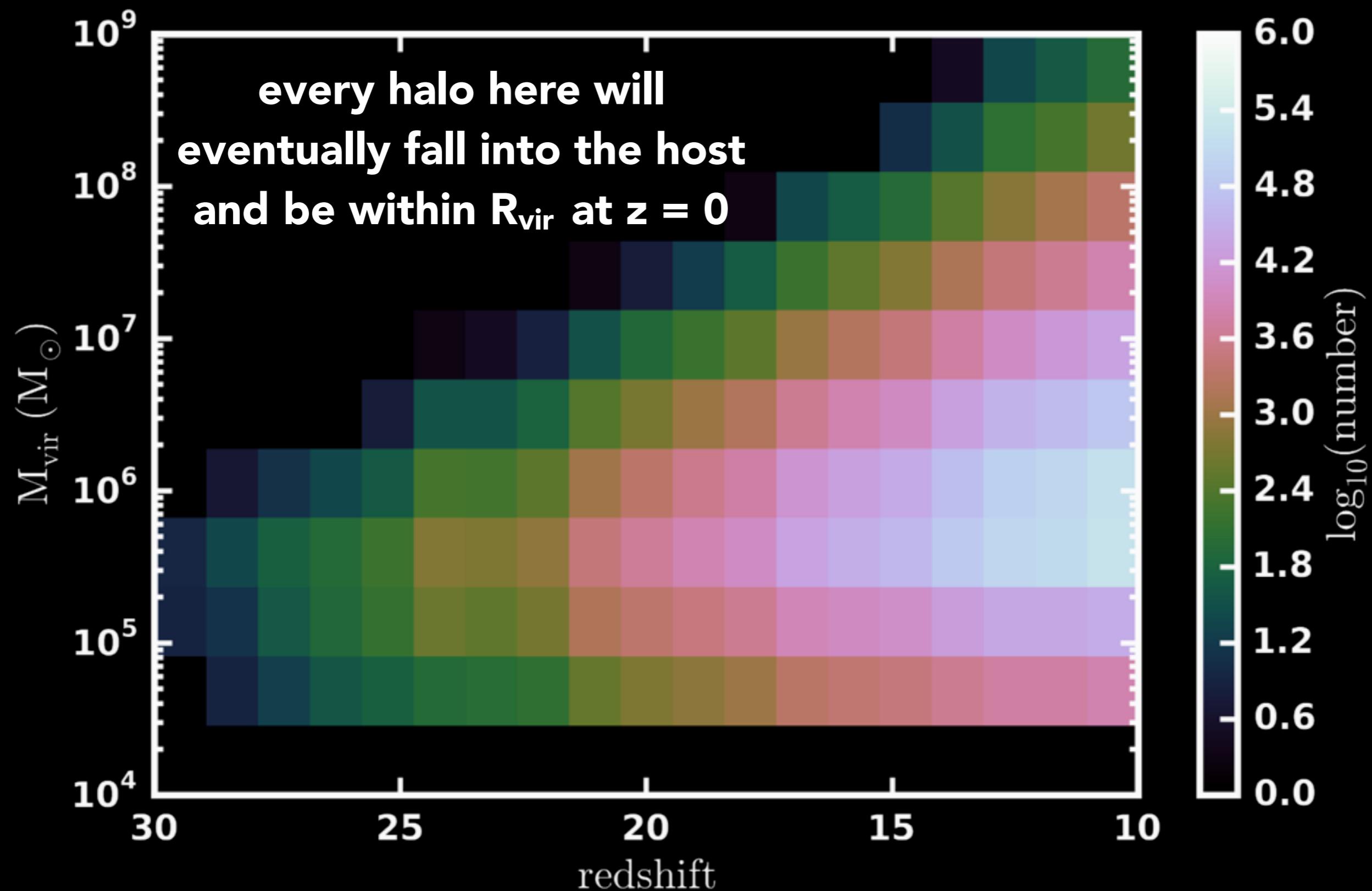
Hopefully we can constrain the assembly history from other observations (e.g. profile of the stellar halo, streams) to better determine infall times.

"We don't know the potential of the Milky Way" - Else Starkenburg

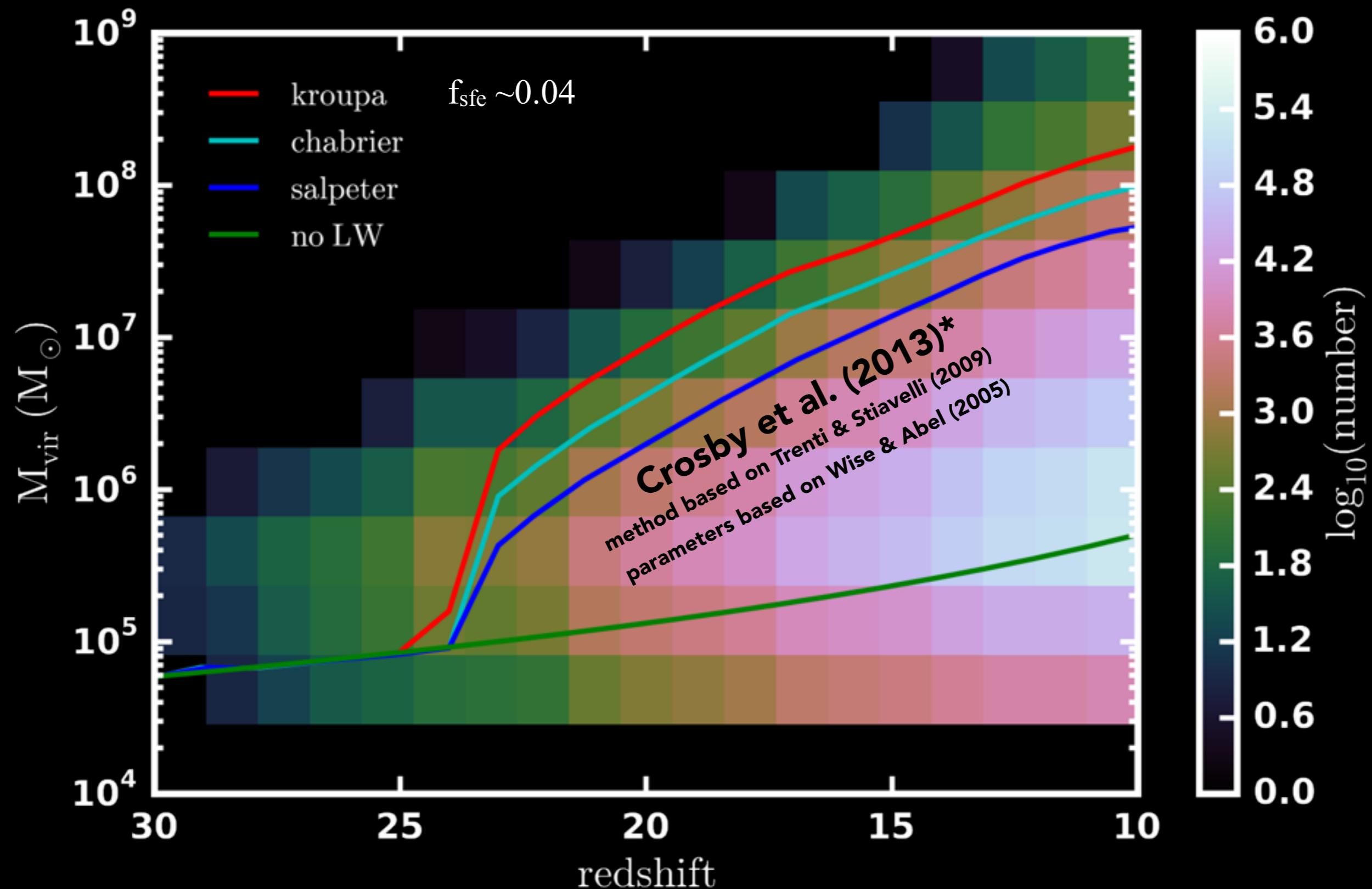
"LMC perturbs potential of Milky Way" - Gomez et al. (2015)

Springel et al. (2006)

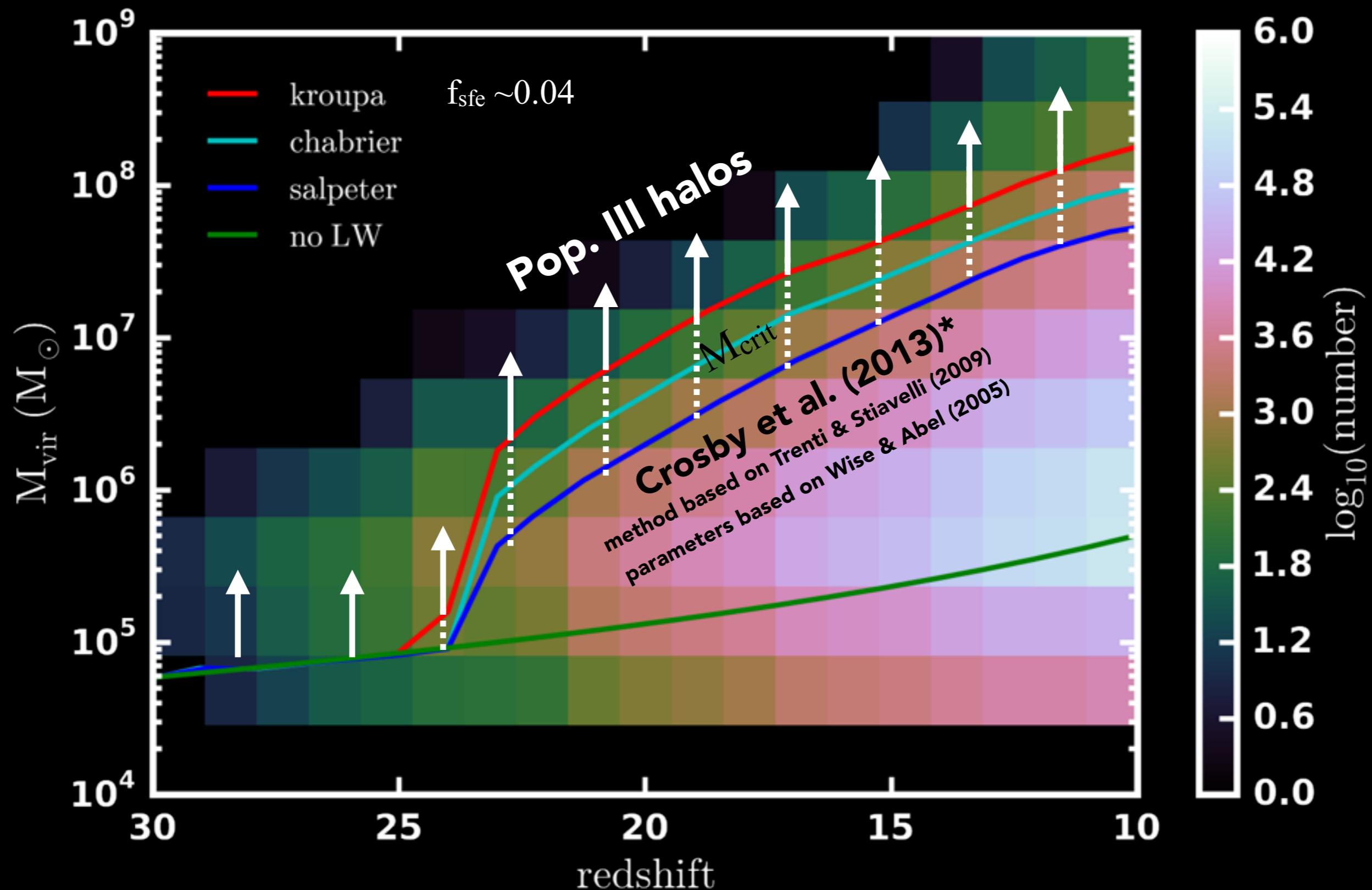
POP. III HALOS IN CATERPILLAR



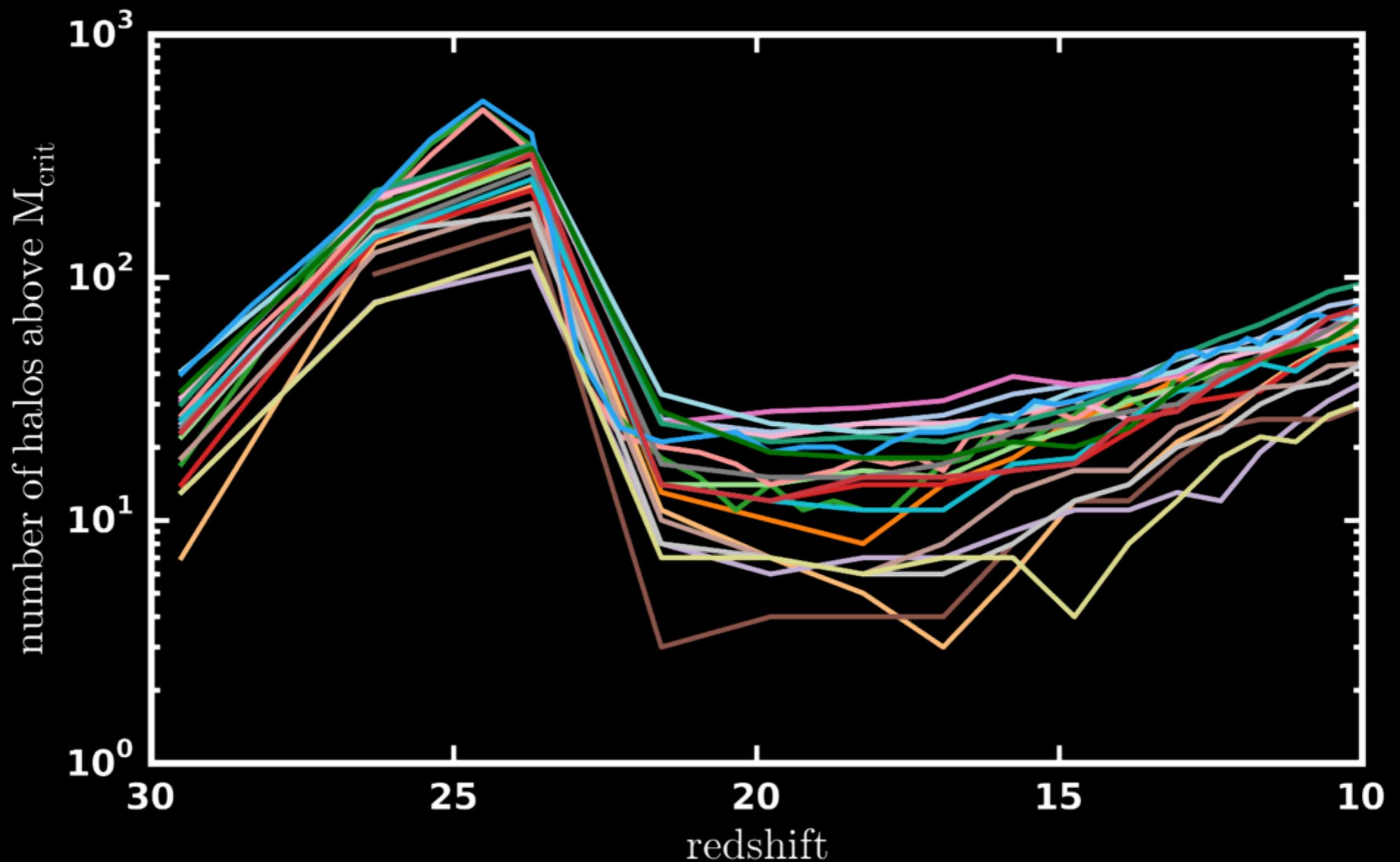
POP. III HALOS IN CATERPILLAR



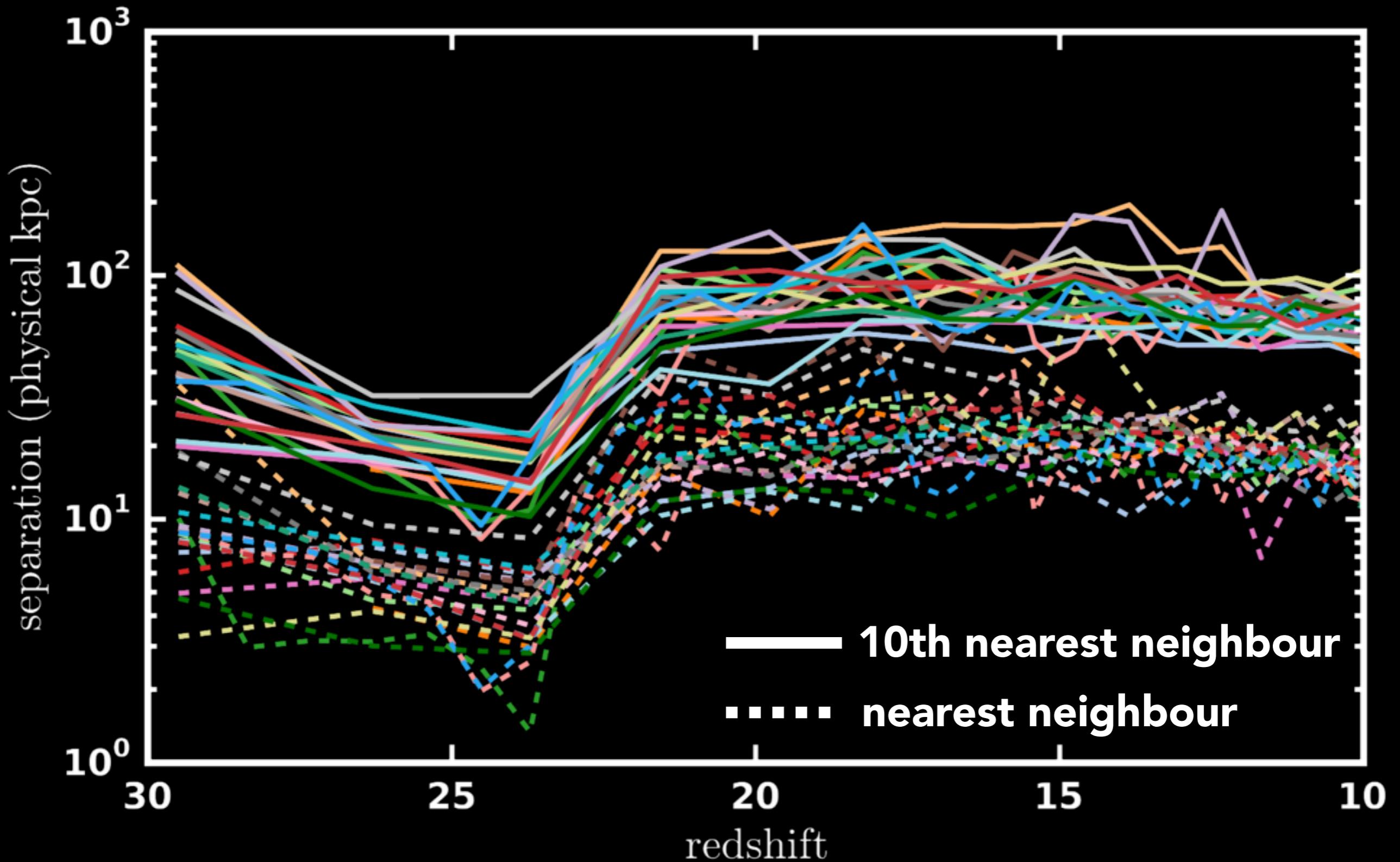
POP. III HALOS IN CATERPILLAR



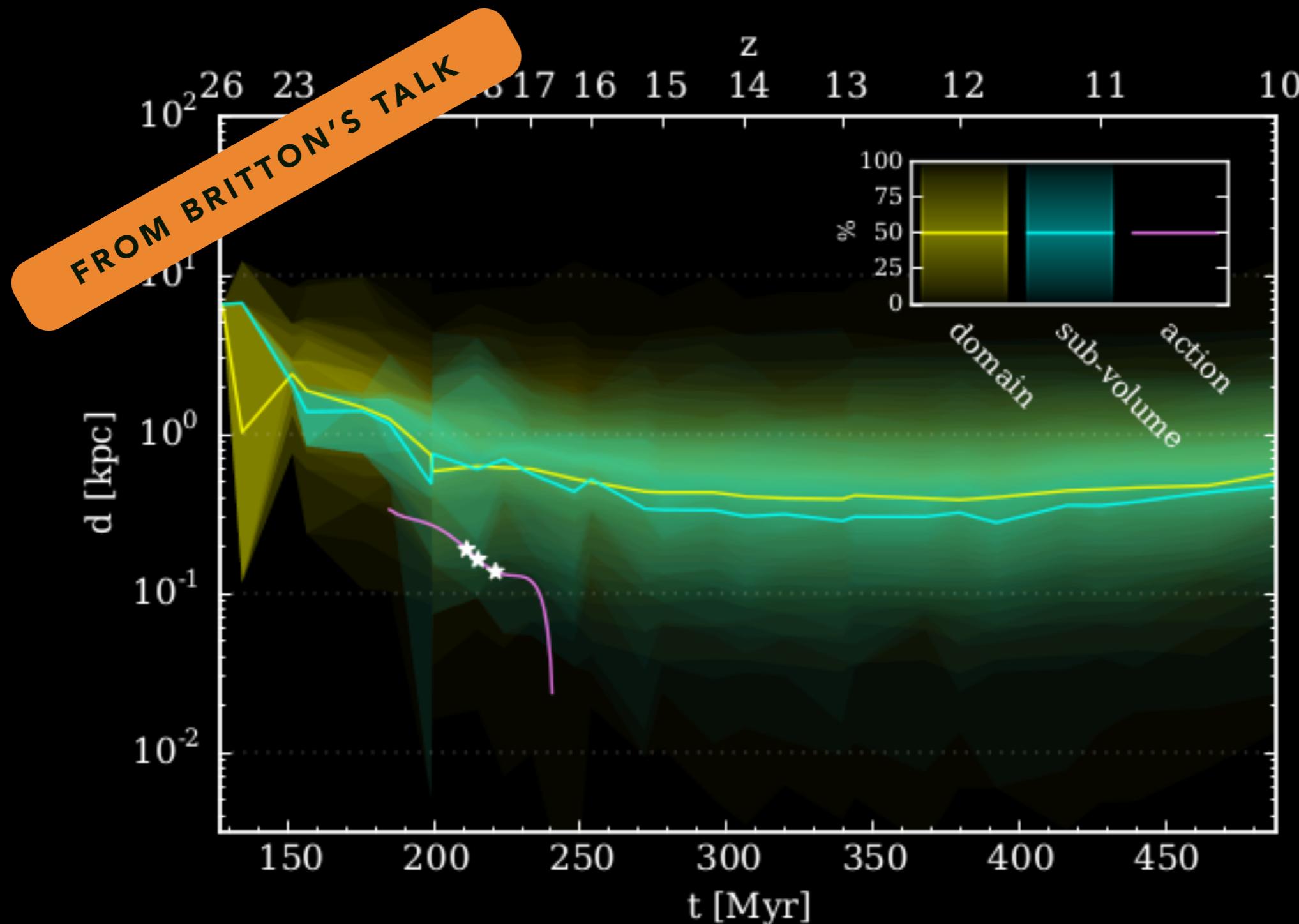
POP. III HALOS IN CATERPILLAR



POP. III HALOS IN CATERPILLAR

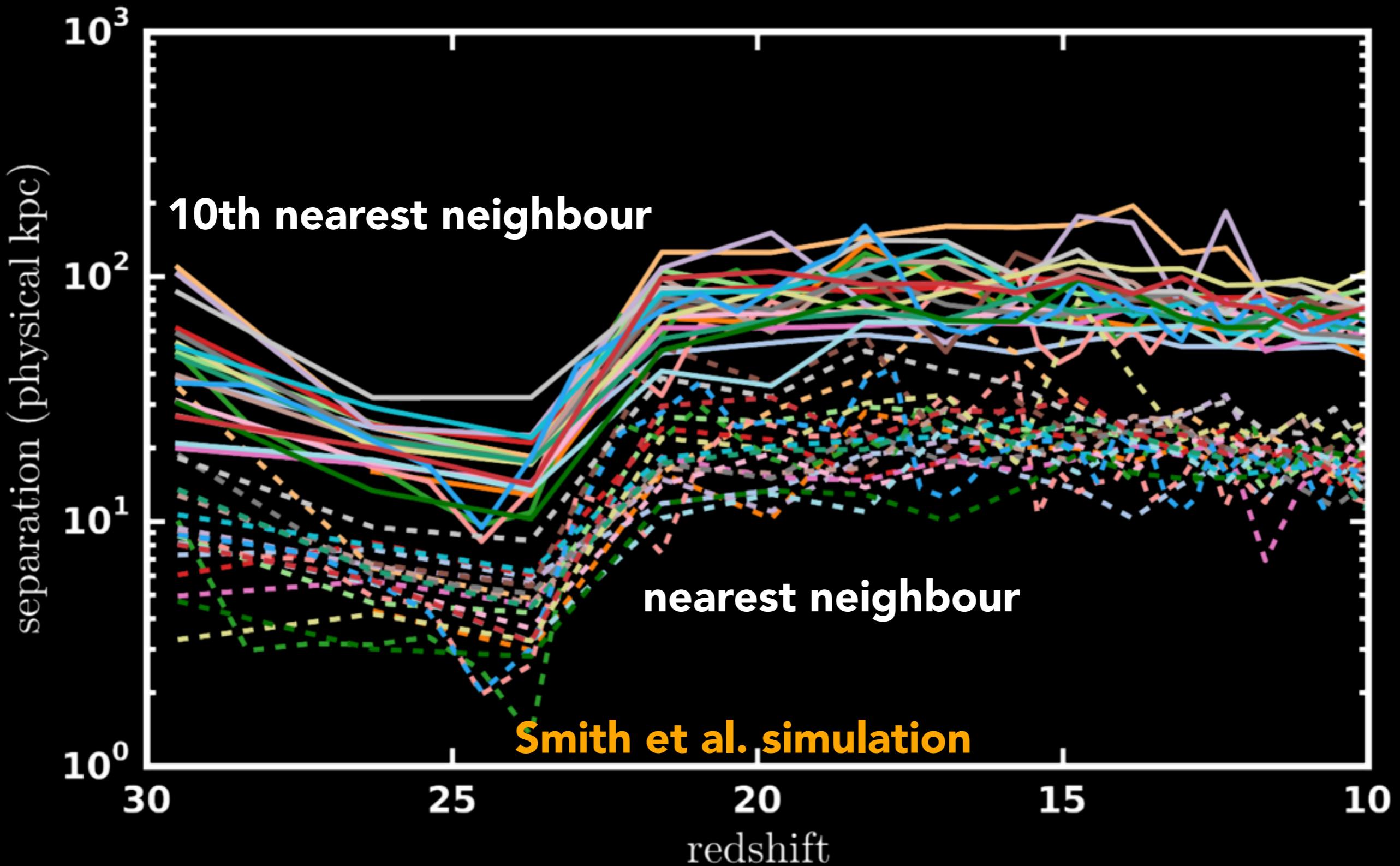


CLUSTERING COMPARISON TO HYDRO



Britton: “nearby mini-halos can be externally enriched by blast-waves washing over them if the conditions are just right”. e.g. highly clustered

MINI-HALOS IN CATERPILLAR



TOY MODEL CONCLUSION

Simply toy model for identifying mini-halos in merger tree of Milky Way sized halos does not exclude external enrichment from having occurred. However, the Milky Way's progenitor Pop. III halos are less clustered than current hydro simulations and so external enrichment is perhaps less common.

"Externally enriched star formation is rare for ~MW sigma peak region" - John Wise talk

Springel et al. (2006)

www.caterpillarproject.org



Do you want halo catalogues and/or merger trees for your first star/galaxy SAMs?
e.g. substitute our trees for your EPS trees...

Or test your other models?

Come talk to me later!

www.caterpillarproject.org

New High Resolution Simulation Suite Of Milky Way Sized Halos

70 halos, available at end of 2015

$m_p \sim 10^4 M_\odot$ reliably resolve: $M \sim 10^6 M_\odot$

contamination free zones: 1 - 2 Mpc from host

Status: On-going

24 completed, continually running, $10^3 M_\odot$ high-z runs planned, hydro late 2015

Converged mass functions, assembly histories & halo profiles

(Einasto: $\alpha \sim 0.16 \pm$ depends on assembly)

Take Home Science Messages From Preliminary Results:

Infall times of satellites depends on the assembly history of the host.

External enrichment likely occurred very rarely in the less clustered environments of the Milky Way mini-halo Pop. III progenitors.