From High Redshifts to Near-field Cosmology

~~*facts, "facts", opinions, slanderous accusations*~~

~~*A fair and balanced discussion*~~

Lots of questions, not many answers

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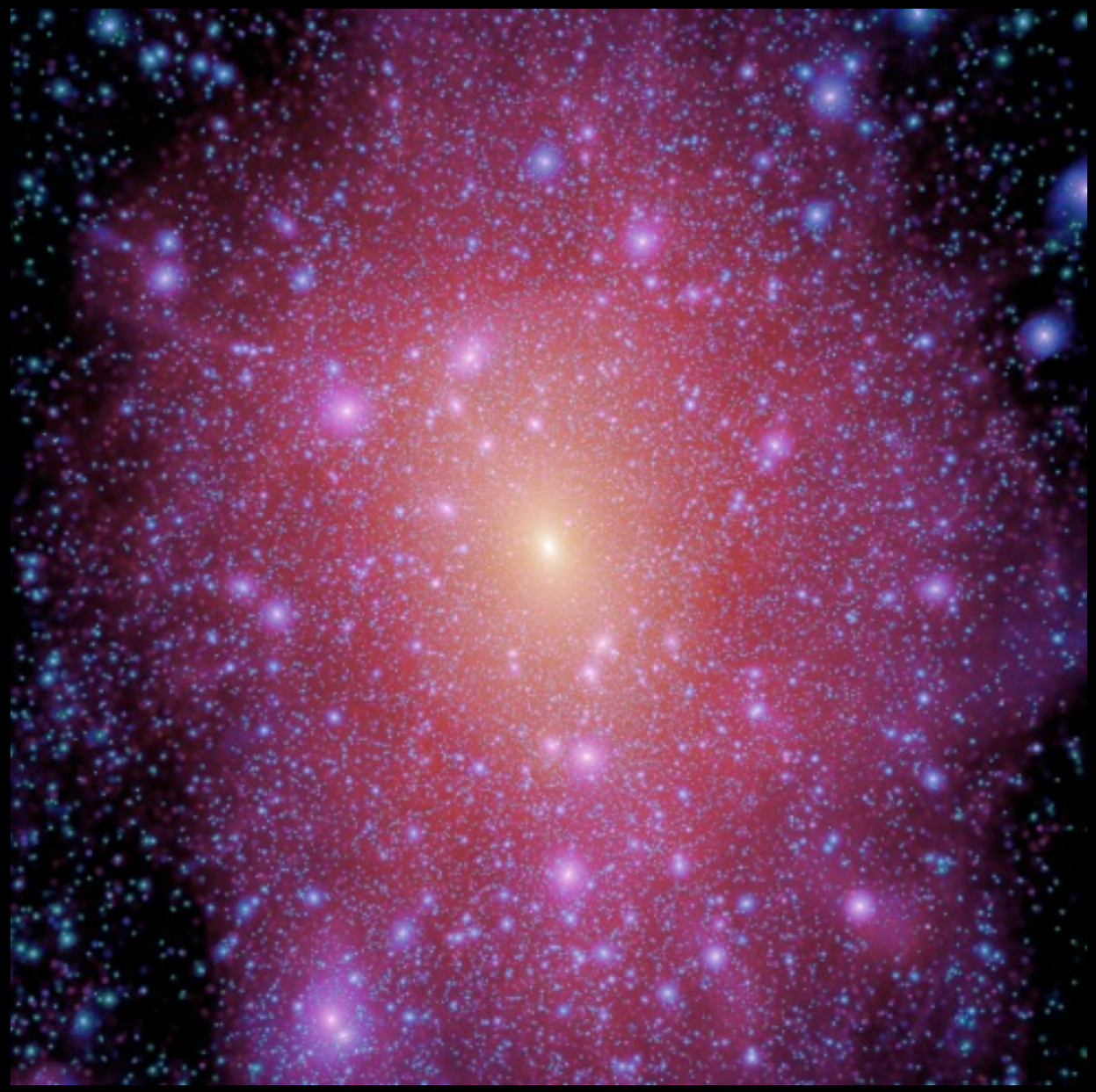
University of Maryland

UNIVERSITY OF MARYLAND

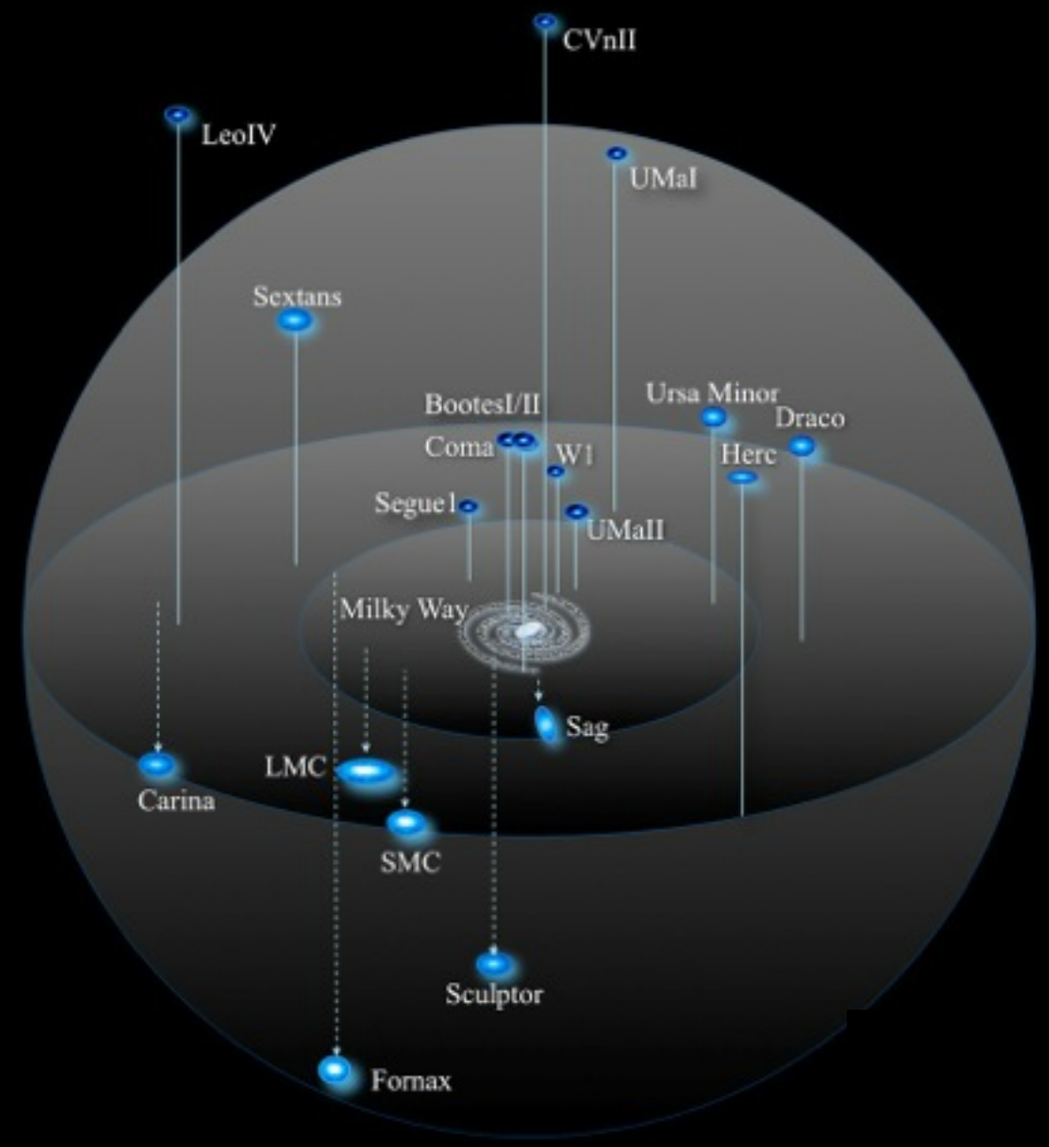
Near Field / Deep Fields Connection
Irvine, 13 February 2014

Context: Milky Way satellites and "crises" of ΛCDM



$>10^5$ identified subhalos

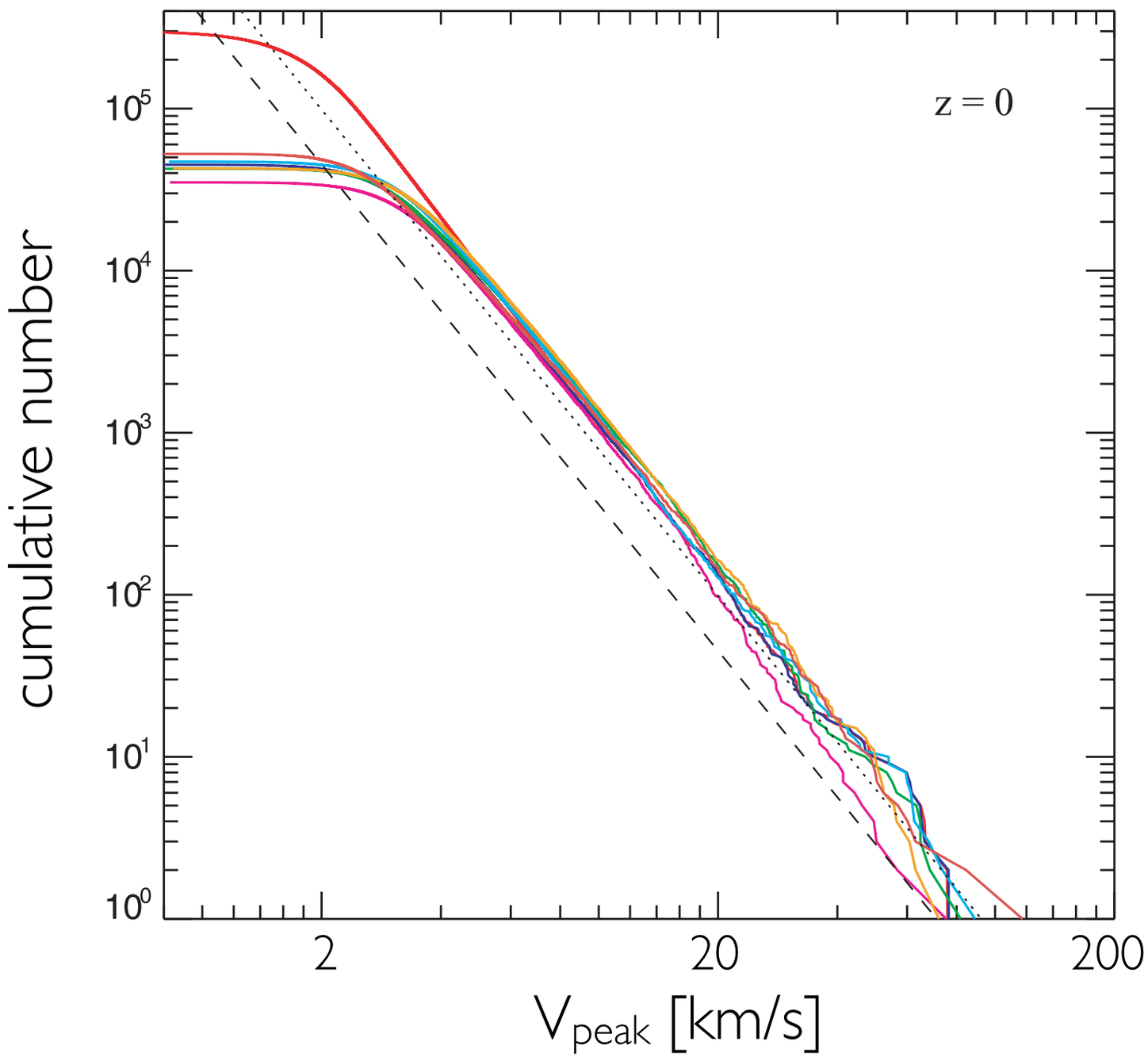
V. Springel / Virgo Consortium



12 bright satellites $(L_V > 10^5 L_\odot)$

J. Bullock

Standard Picture

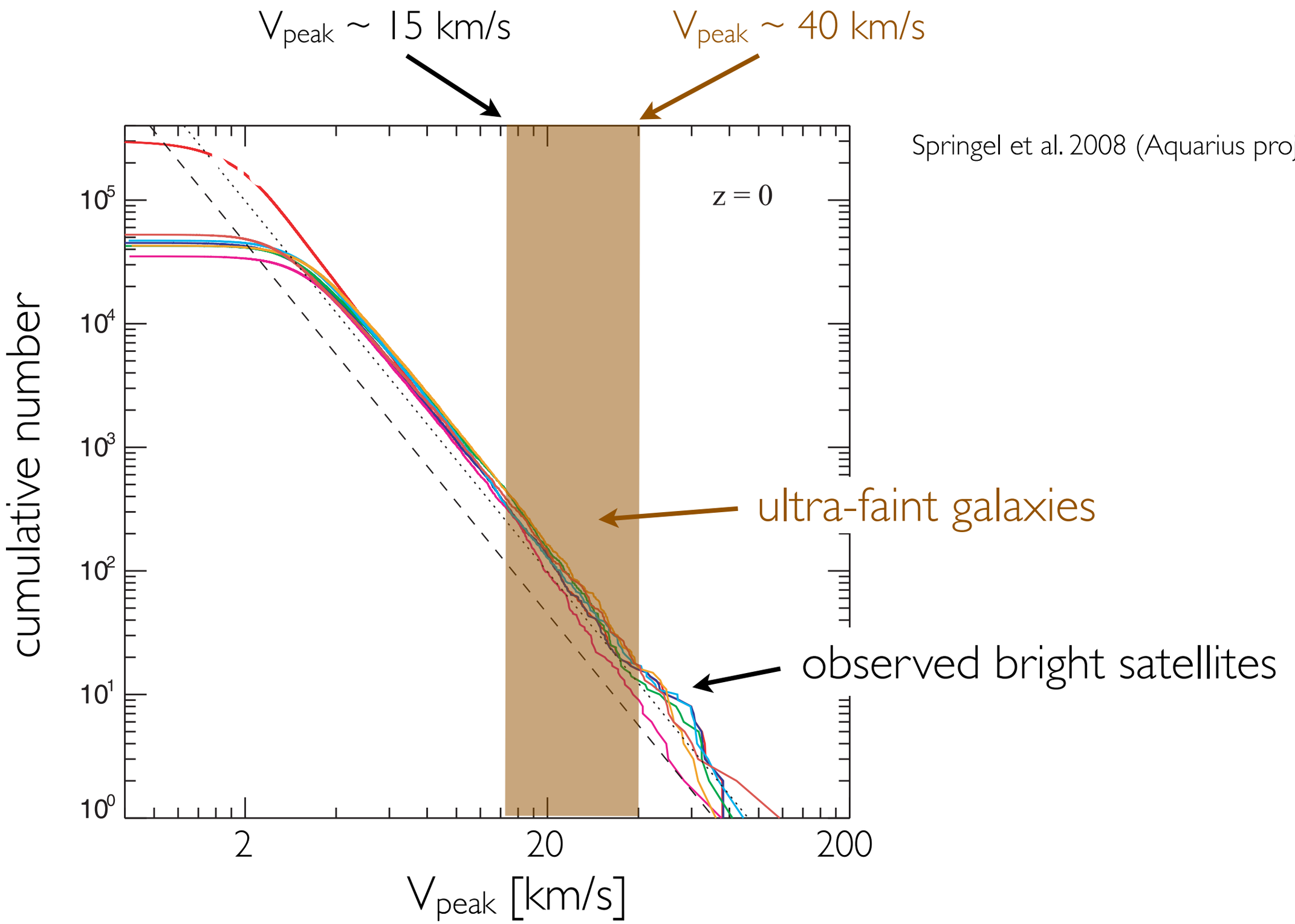


CDM:
power spectrum continues to $M \sim M_{earth}$ or $V_{max} < 1$ m/s.

Simulations:
resolve 10^4 M_{sun} (2 km/s)

Subhalo mass functions from Springel et al. 2008 (Aquarius project)

Standard Explanation



Springel et al. 2008 (Aquarius project)

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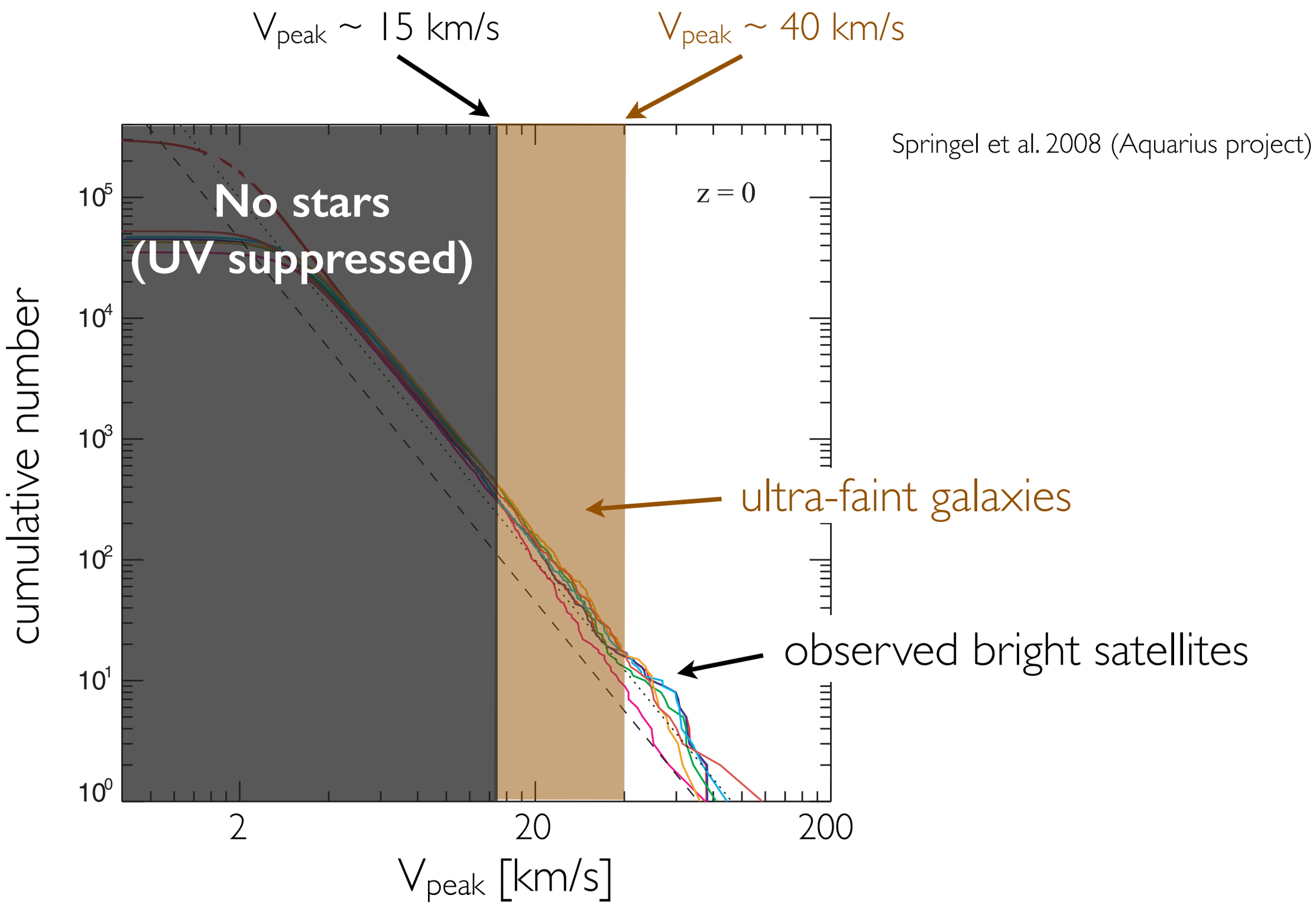


Springel et al. 2008 (Aquarius project)

Major Questions

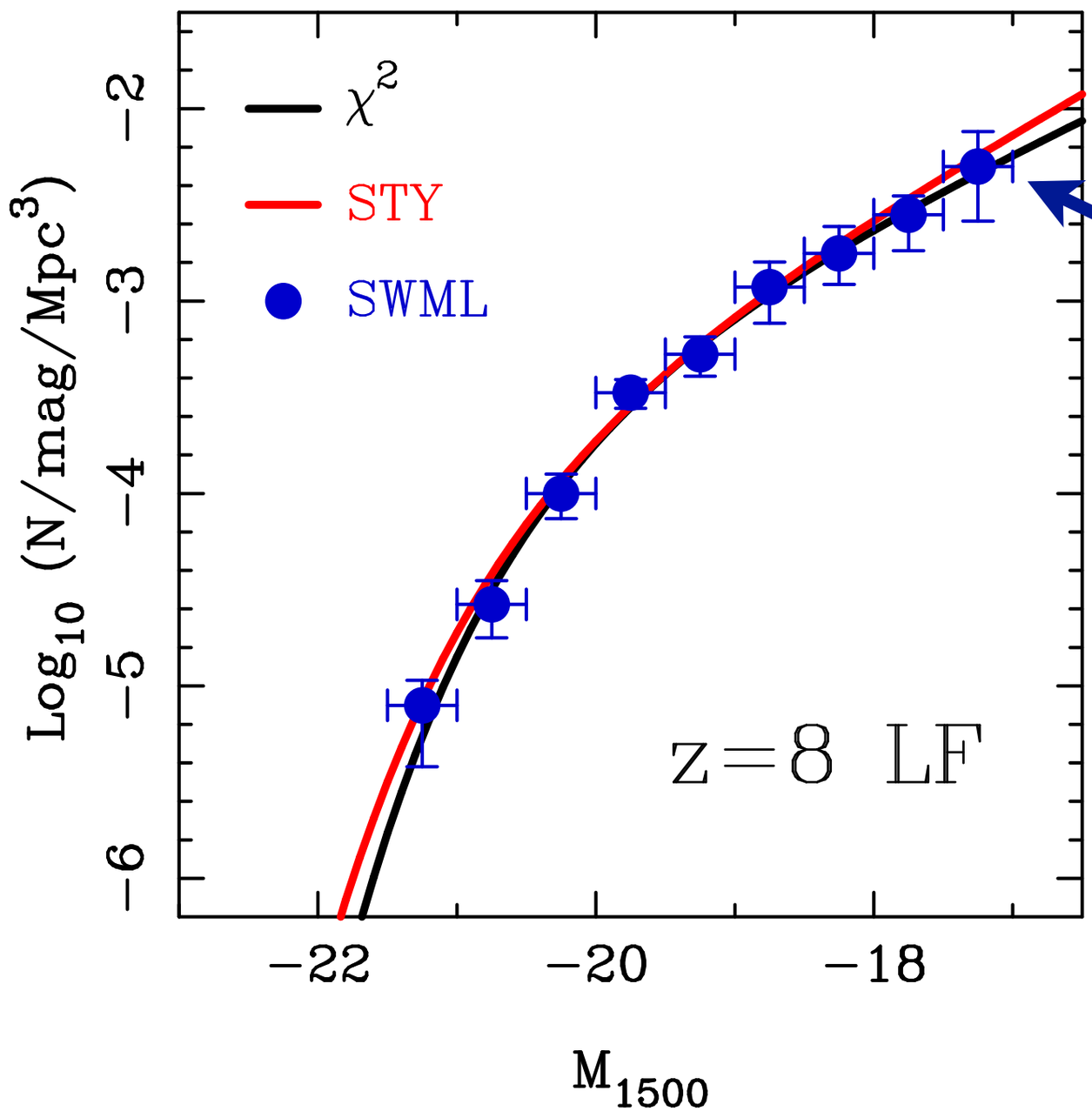
Are galaxies like the Milky Way satellites contributors to or victims of reionization?

When and how is star formation suppressed in low-mass galaxies?

Does ΛCDM + known physics explain the abundances, kinematics, and star formation histories of low-mass galaxies?

Galaxies at Cosmic Dawn

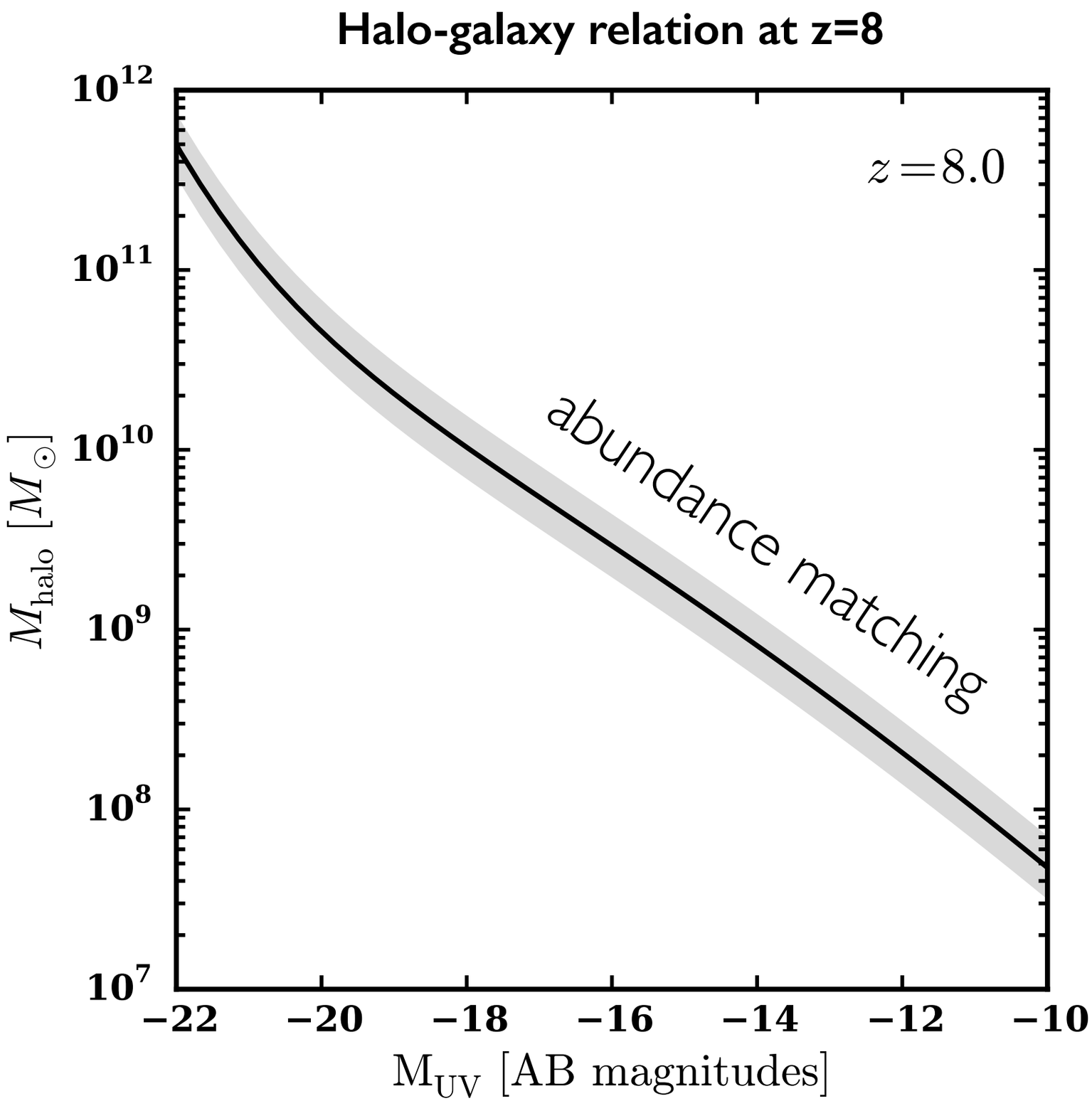
Hubble Ultra-Deep Field



dark matter halo mass of the hosts of these galaxies?

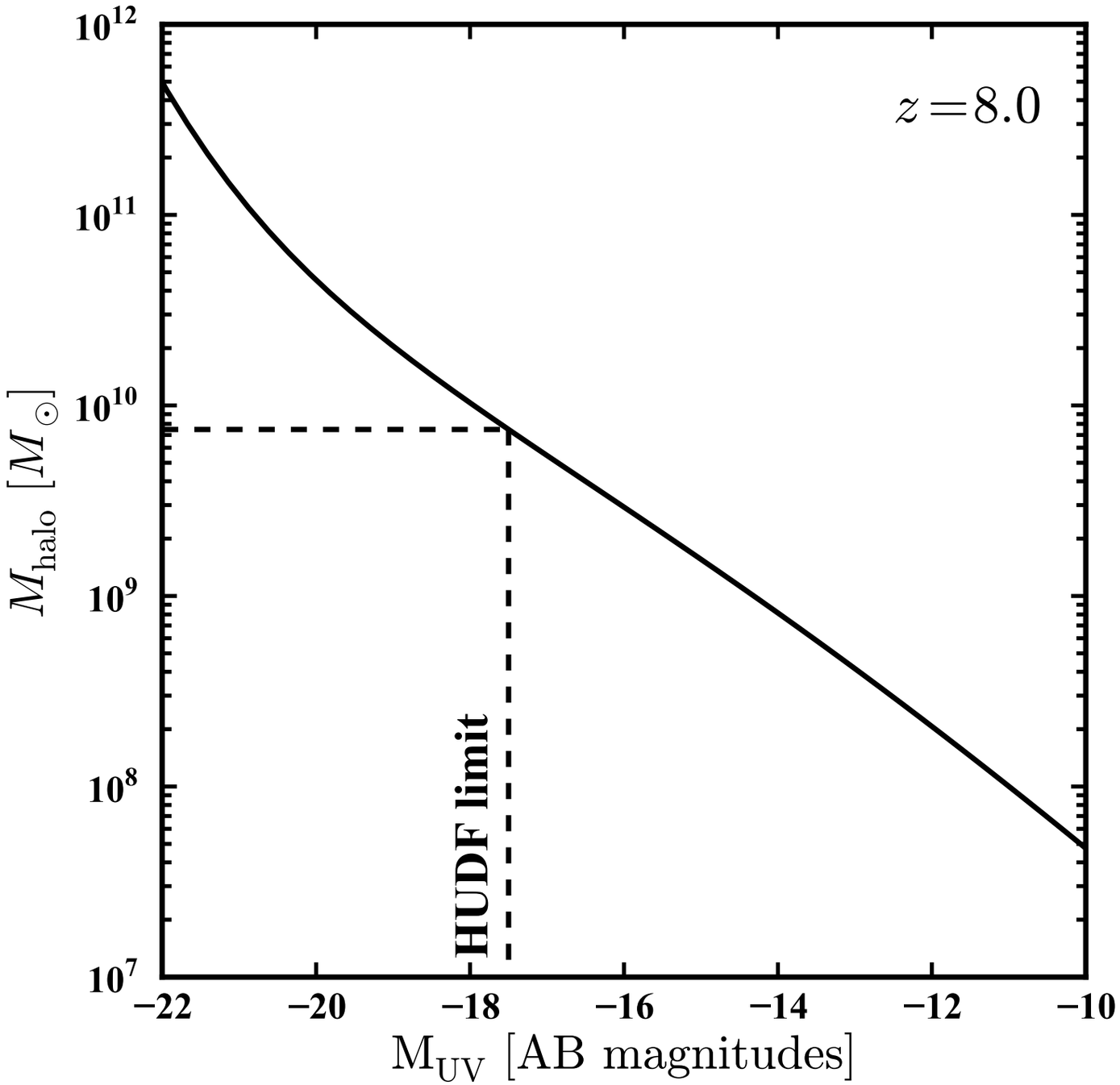
McLure et al. 2013; also Oesch et al. 2013, Illingworth et al. 2013

Galaxies at Cosmic Dawn



MBK et al. (in preparation)

Galaxies at Cosmic Dawn



HUDF limit:
Schenker et al. 2013
$\sim 10^{10}\, M_\odot$

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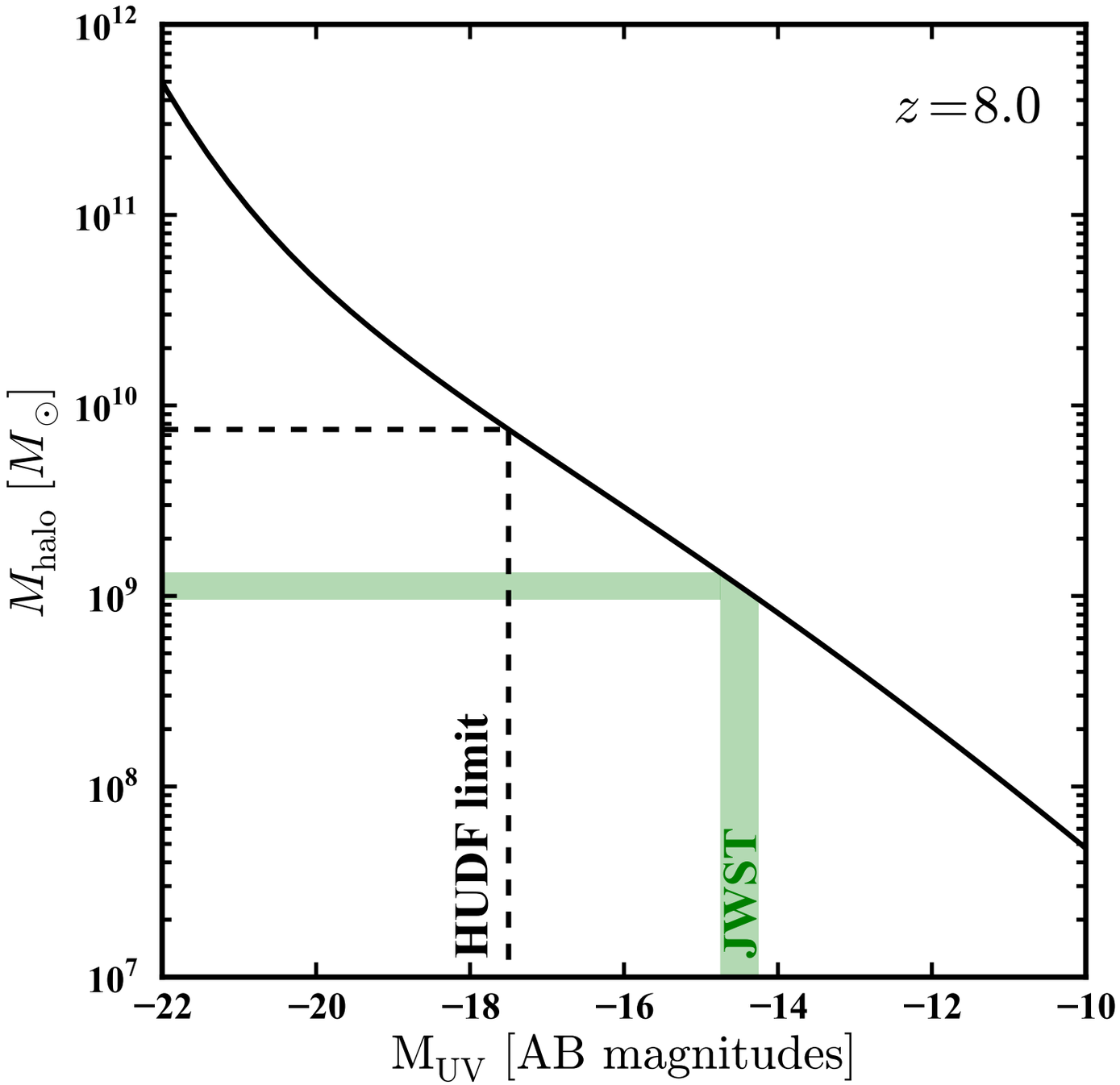

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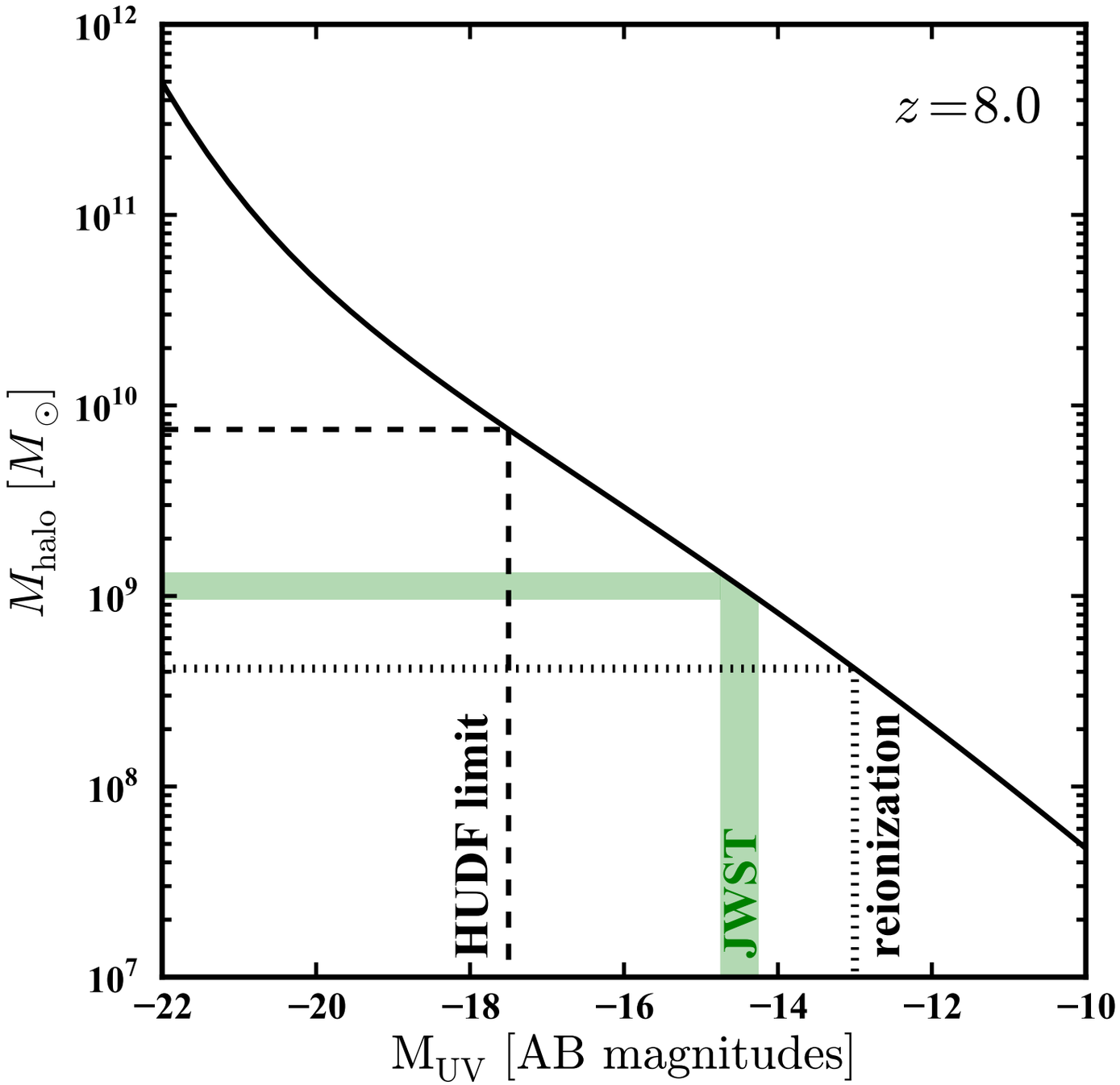
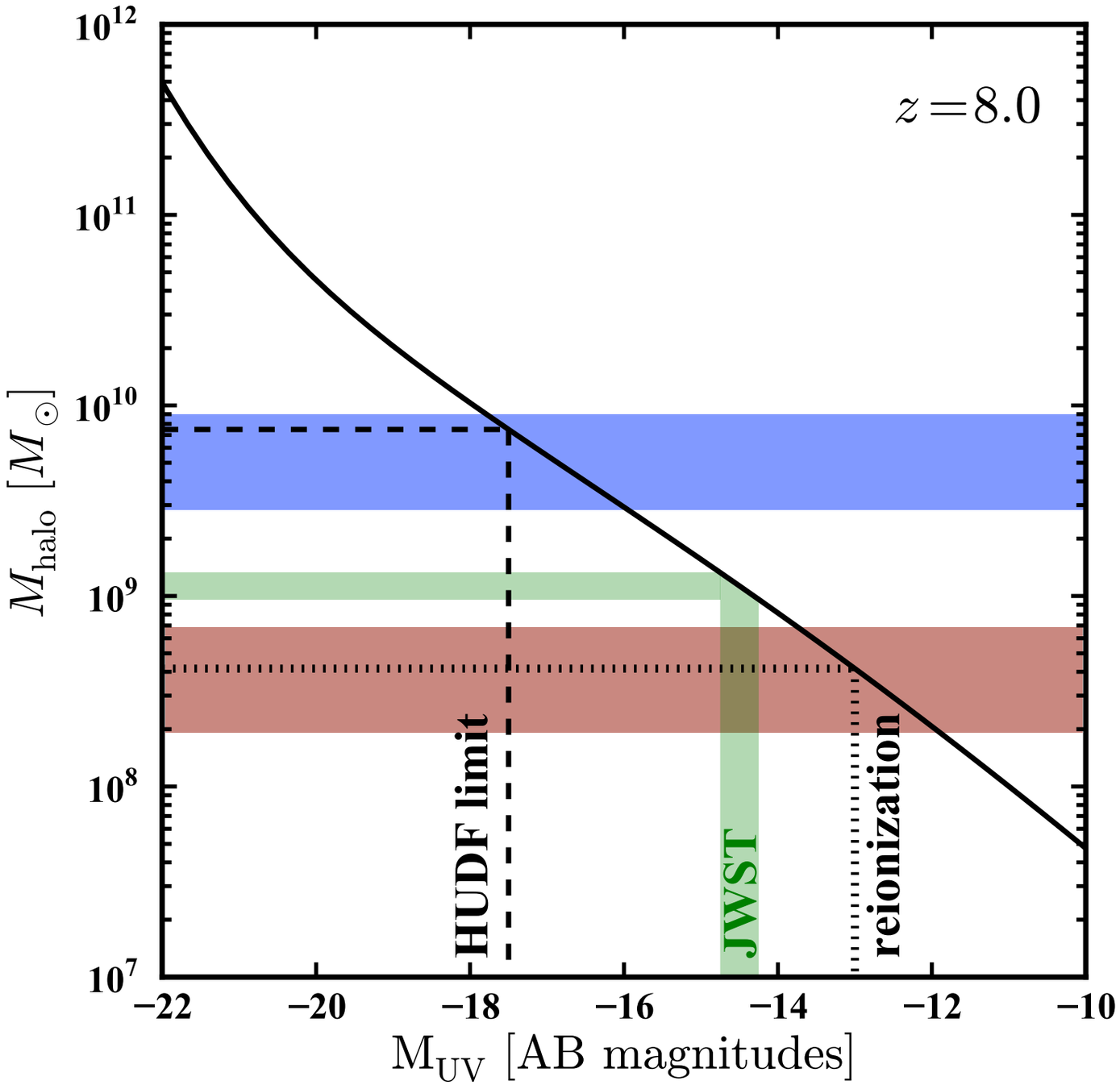


HUDF limit:
Schenker et al. 2013
$\sim 10^{10}\ M_\odot$

Reionization limit:
Robertson et al. 2013
$(4 - 40) \times 10^{7}\ M_\odot$

MBK et al. (in preparation)

Galaxies at Cosmic Dawn



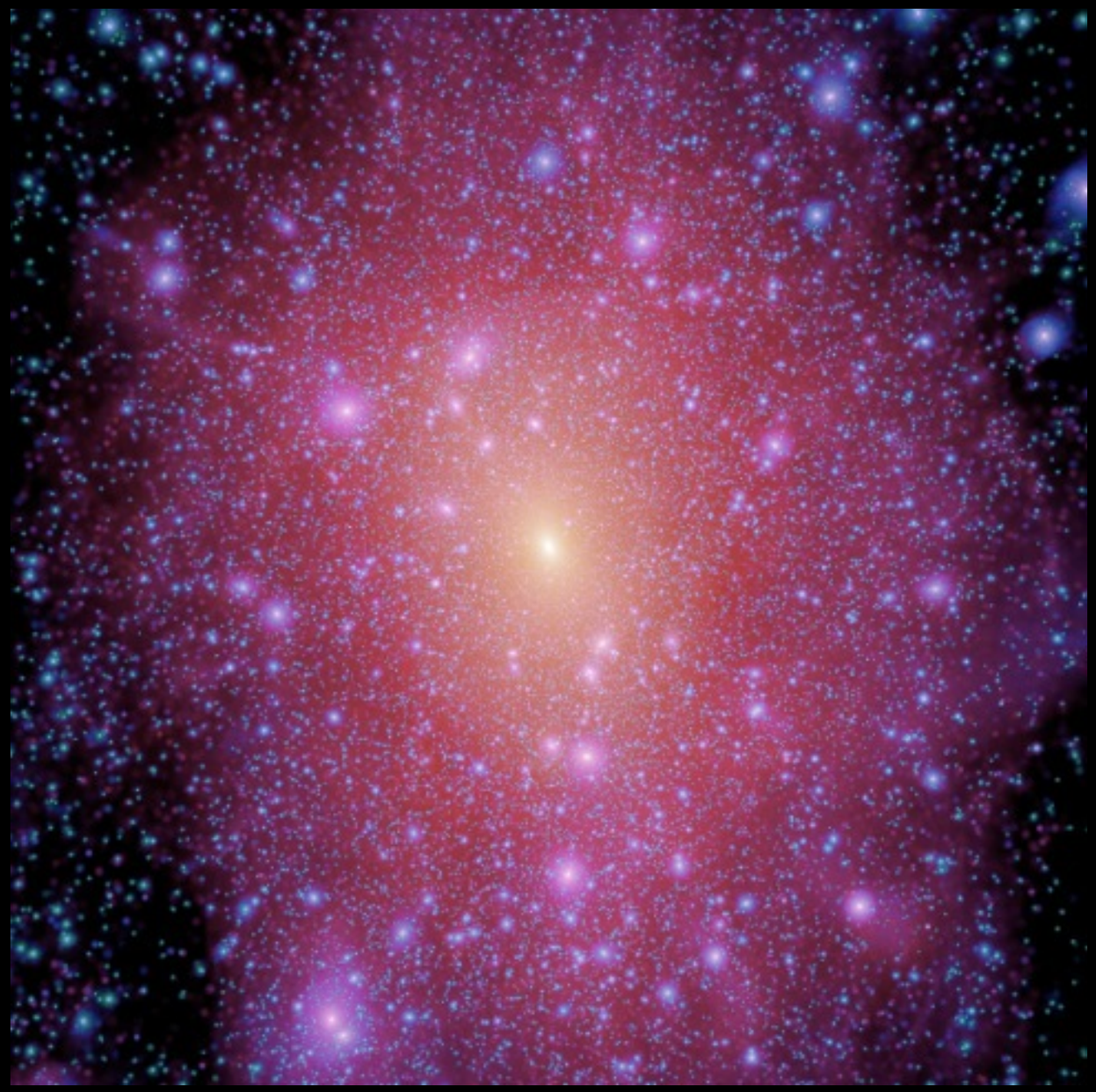
Main progenitor of the Milky Way

Main progenitors of classical MW satellites (~10 remnants at z=0)

MBK et al. (in preparation)

ΛCDM vs. the Milky Way, Round 1: **Missing Satellites**

Klypin et al. 1999, Moore et al. 1999



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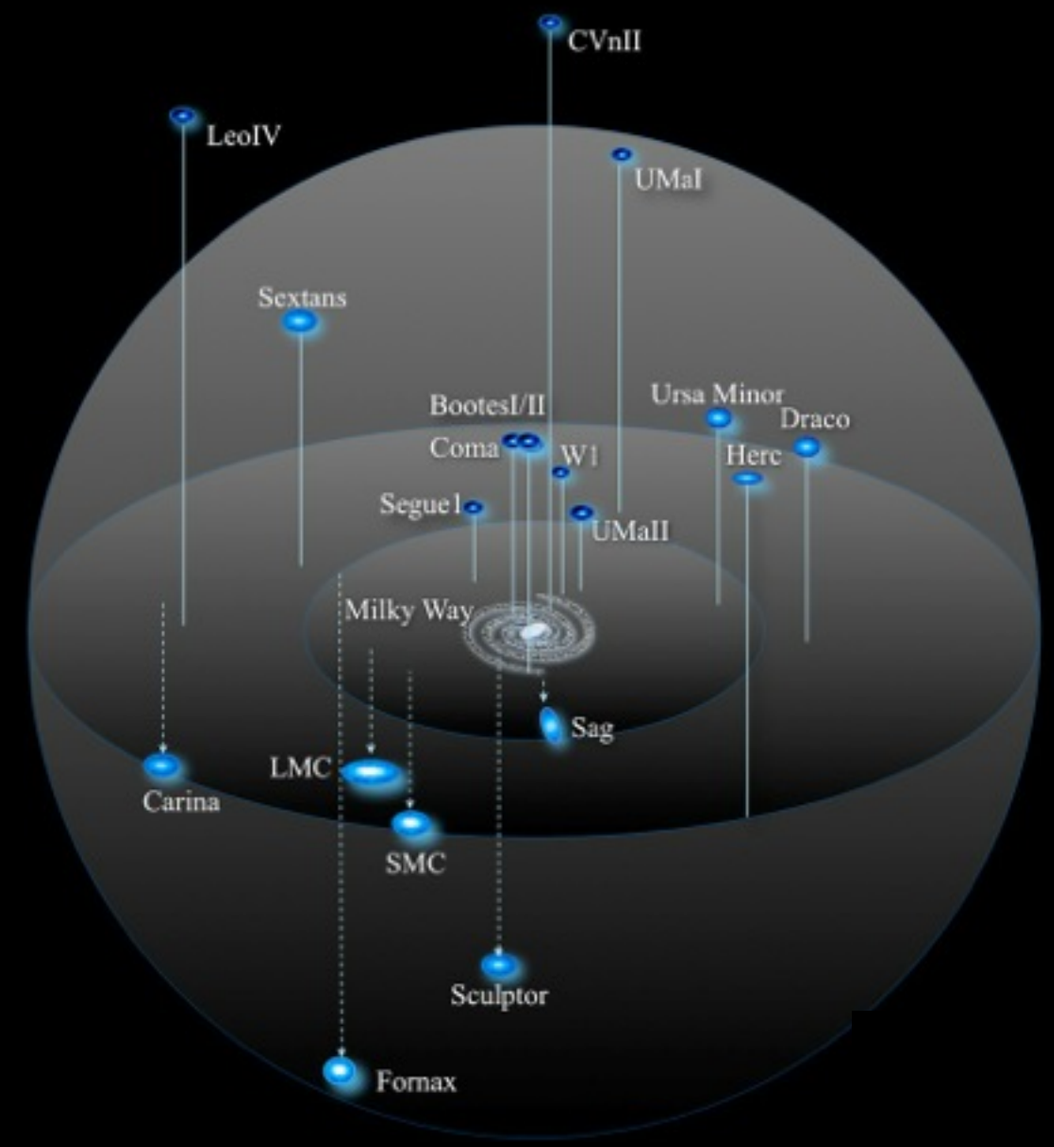

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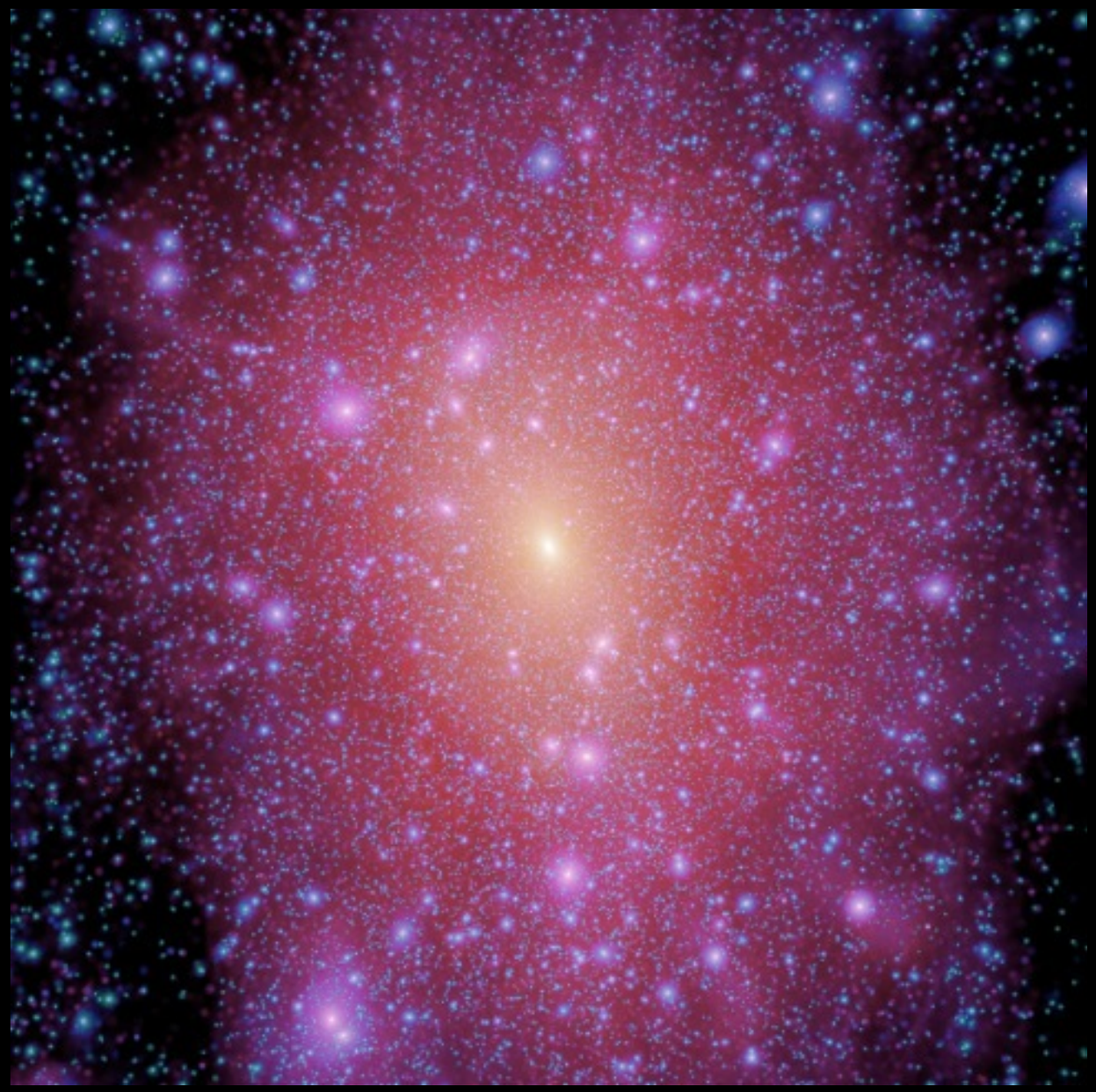
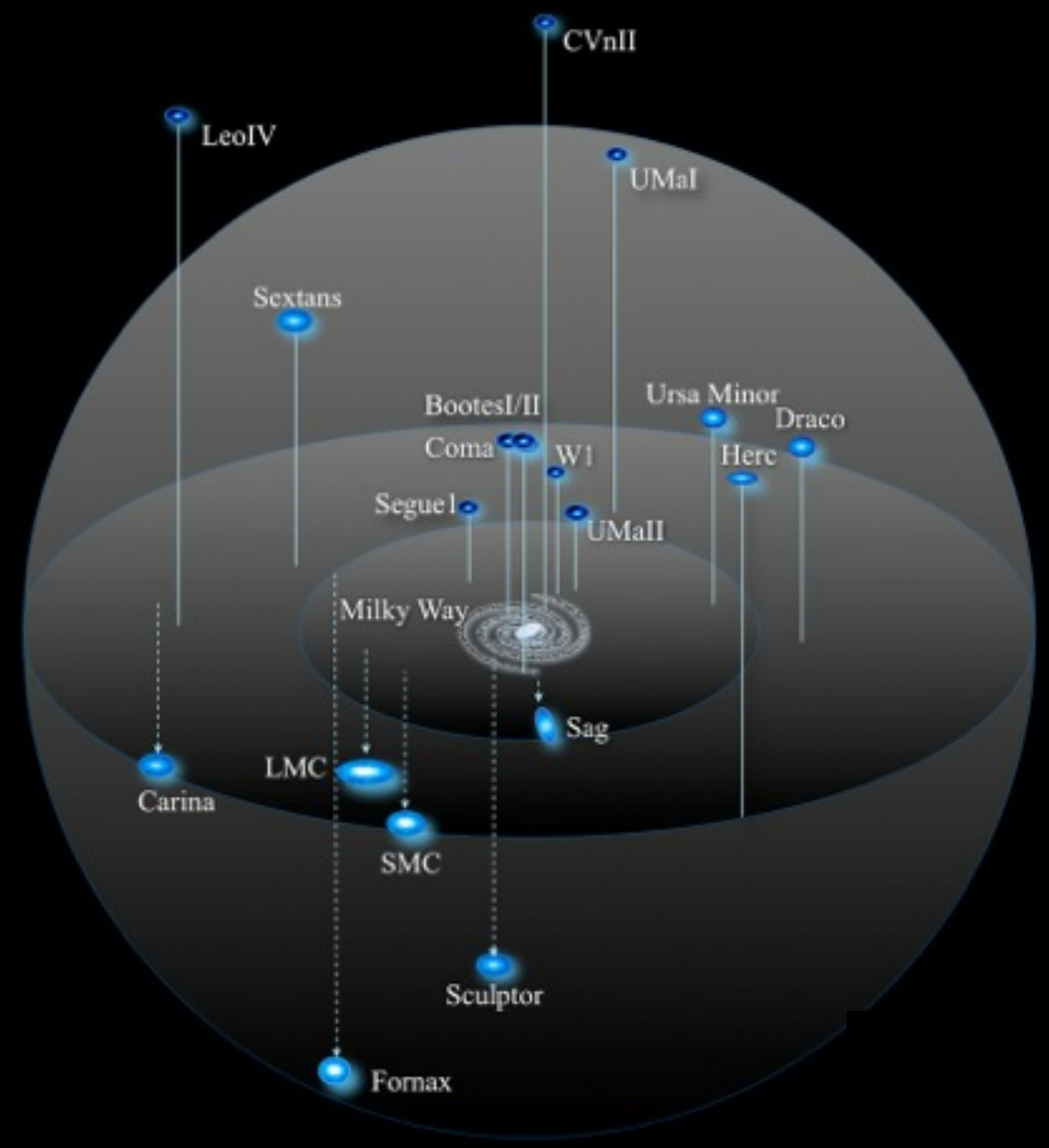
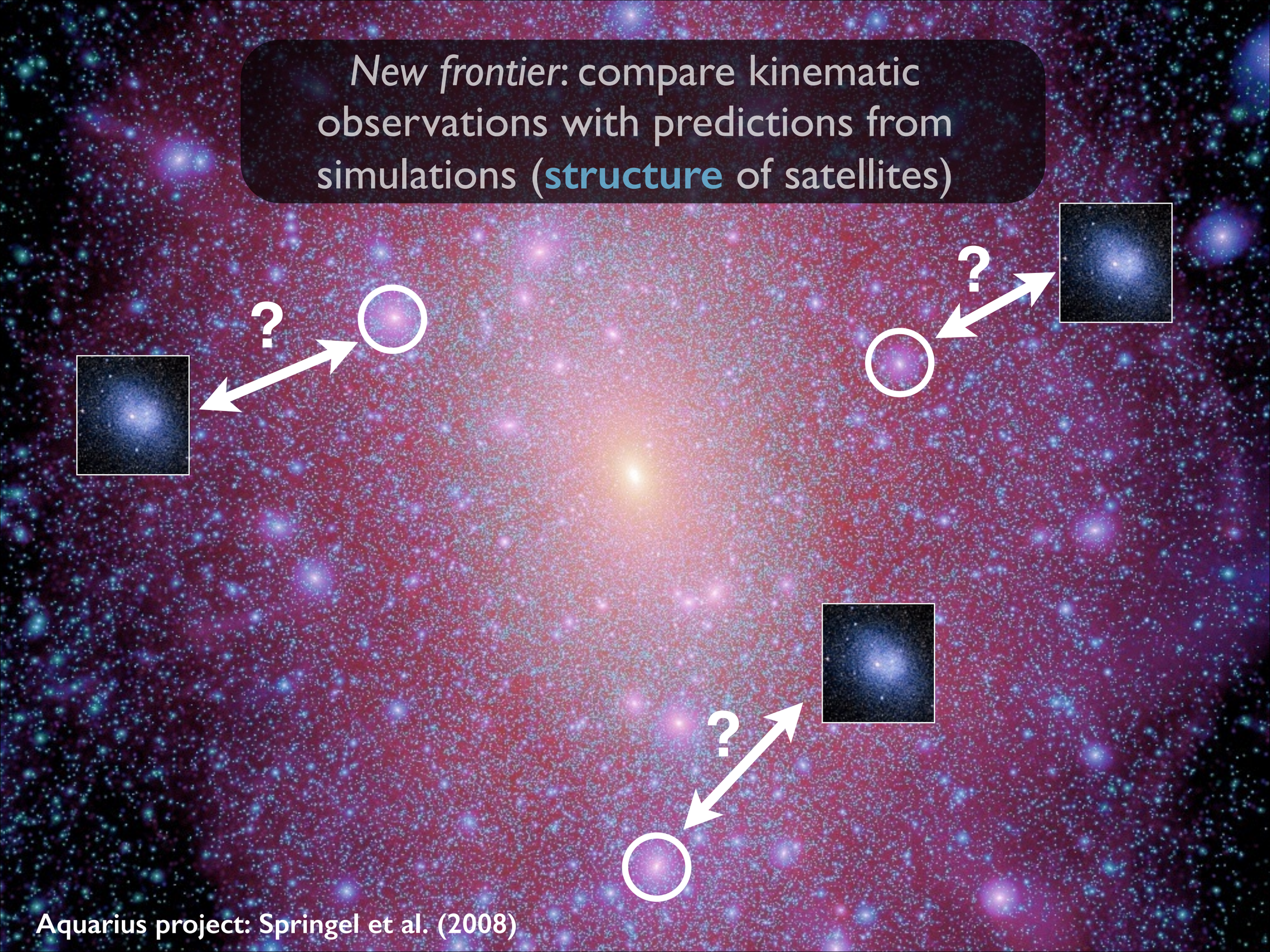




Number mismatch: can be explained through (1) additional ultra-faint satellites and (2) galaxy formation processes (supernova feedback, reionization)???

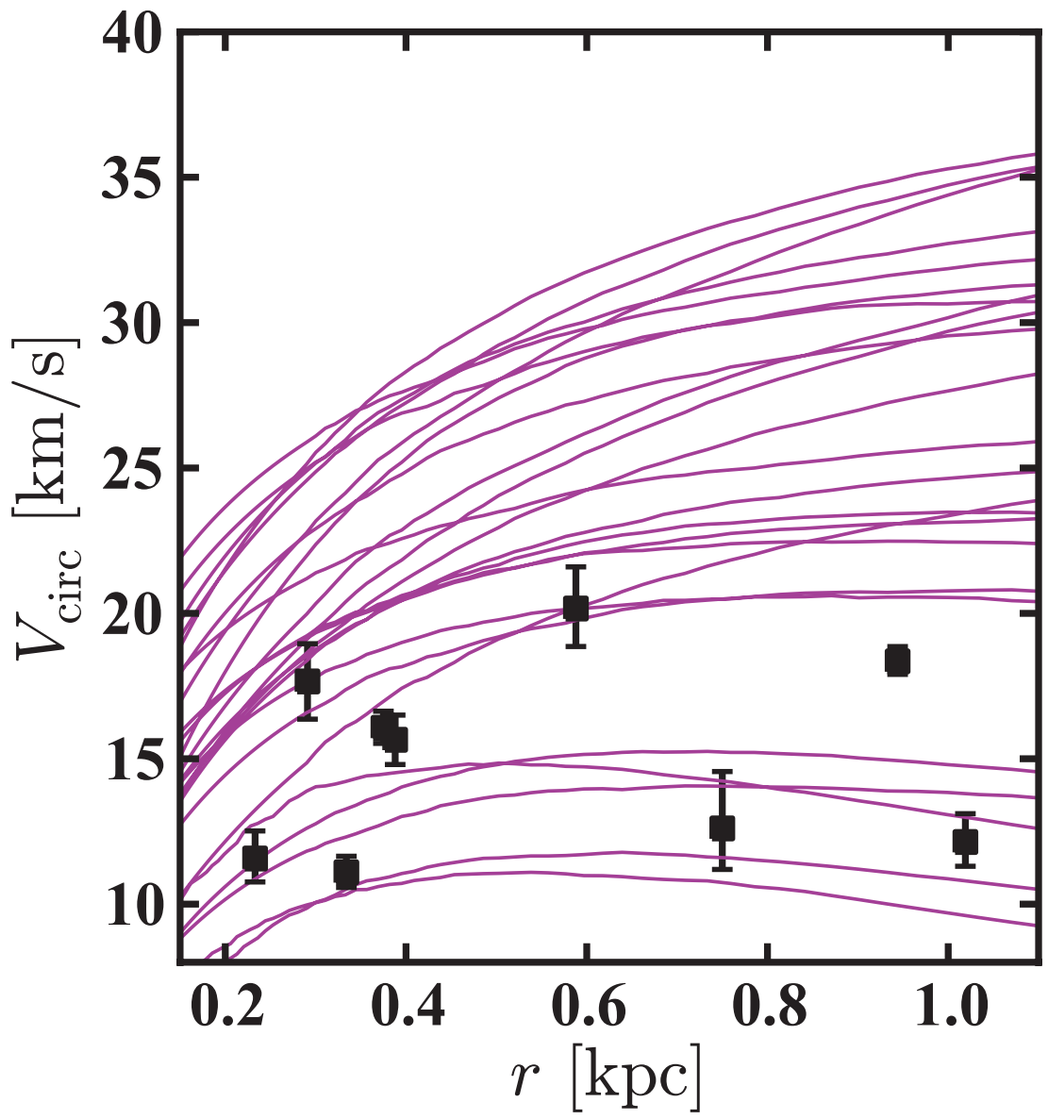
New frontier: compare kinematic observations with predictions from simulations (**structure** of satellites)

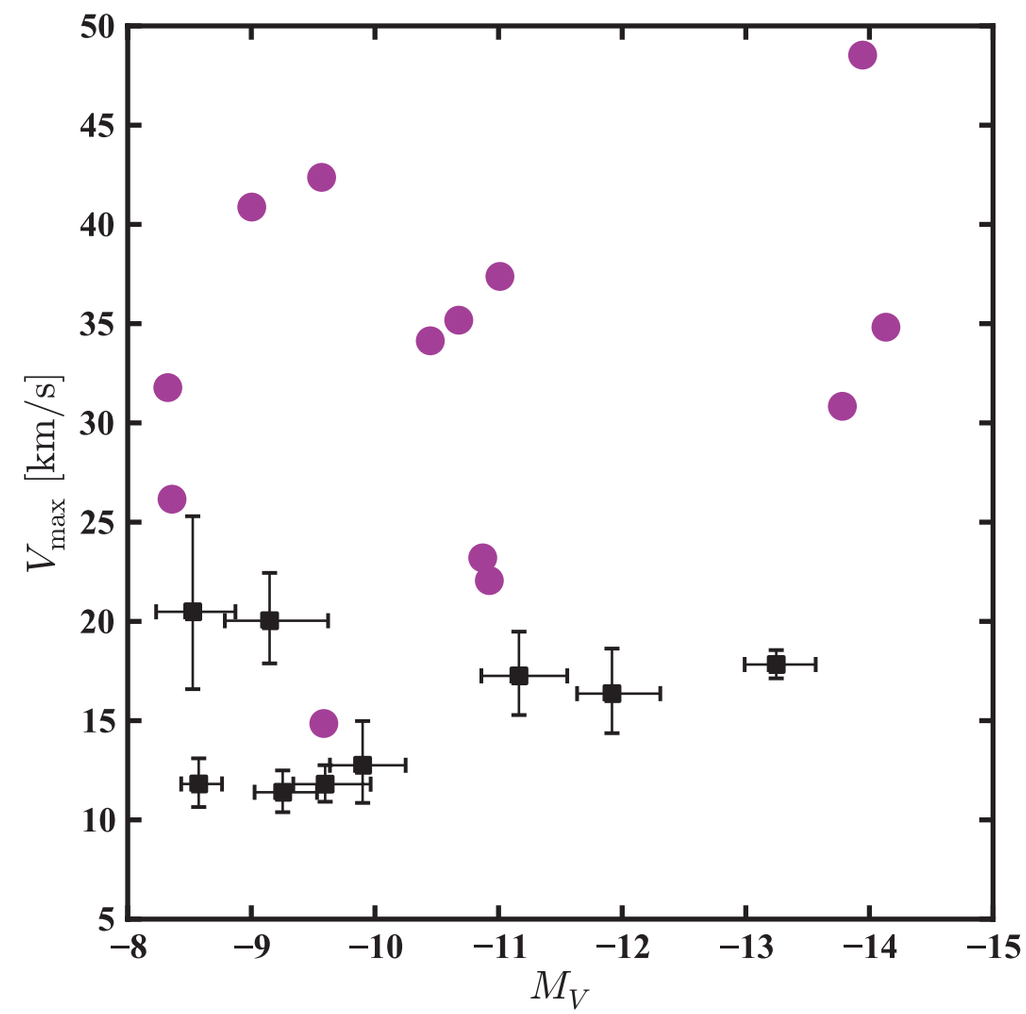


Aquarius project: Springel et al. (2008)

Problems are not just in abundances

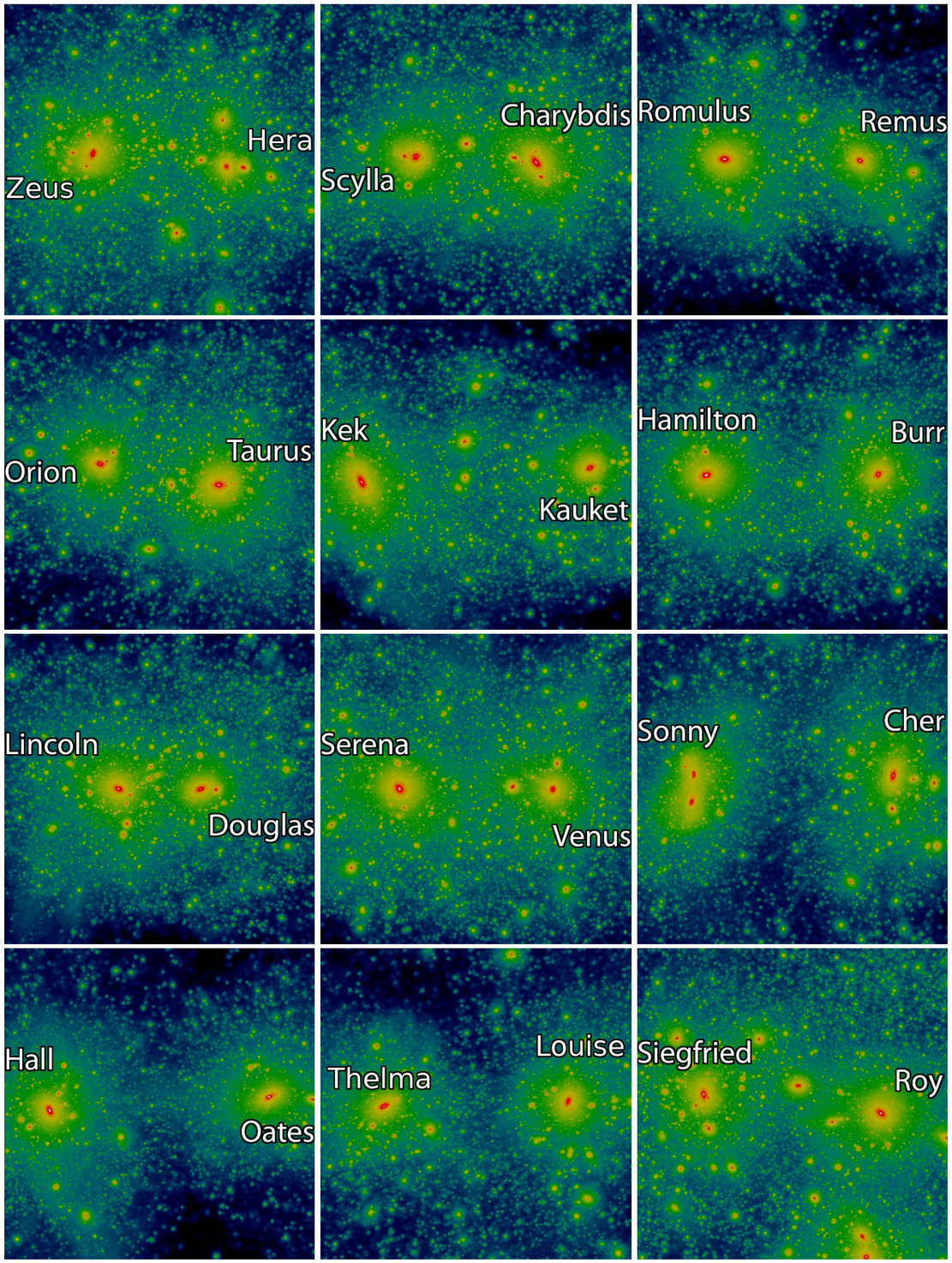
"*Too big to fail*": too much mass in centers of the ***most massive*** simulated DM subhalos relative to observations





MBK, Bullock, & Kaplinghat 2011, 2012

Statistics for TBTF:



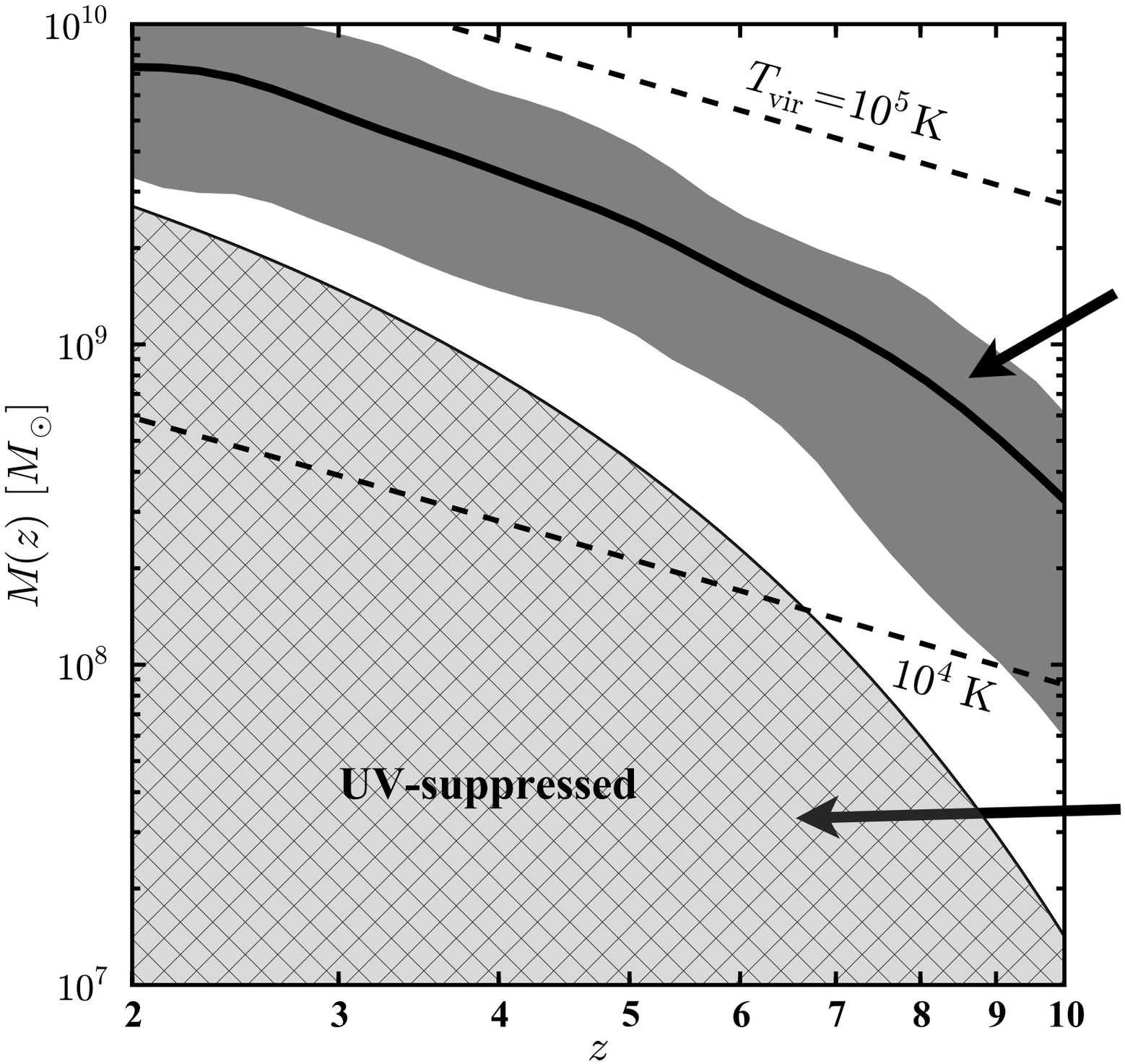
ELVIS suite (Garrison-Kimmel, MBK, Bullock, Lee 2014):

- 24 MW-mass halos in Local Group analogs
- 24 isolated MW-mass halos
- WMAP-7 cosmology

Approximately **15** TBTF subhalos per host
(Garrison-Kimmel, MBK, Bullock, Kirby 2014)

(*an aside:* MW satellites are not a good data set for precision cosmology)

Reionization: not effective for these halo masses



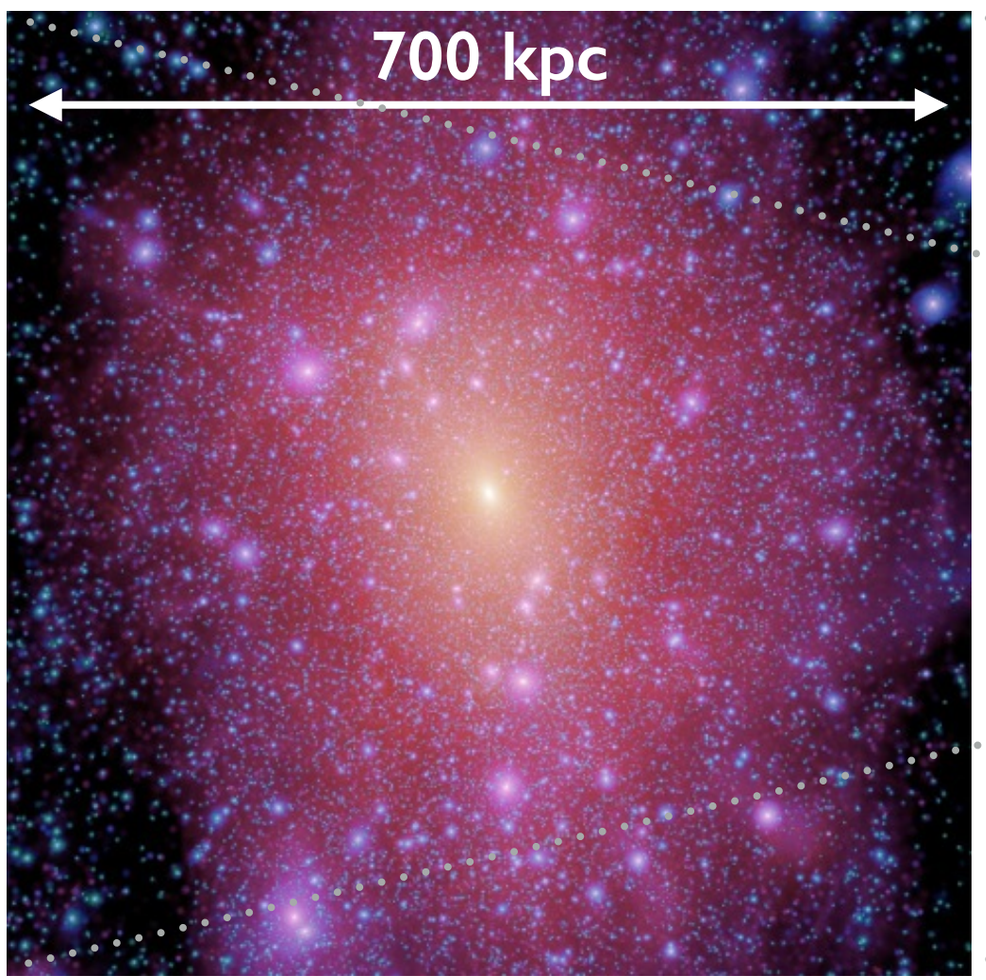
Median mass for subhalos with V_{peak} > 30 km/s

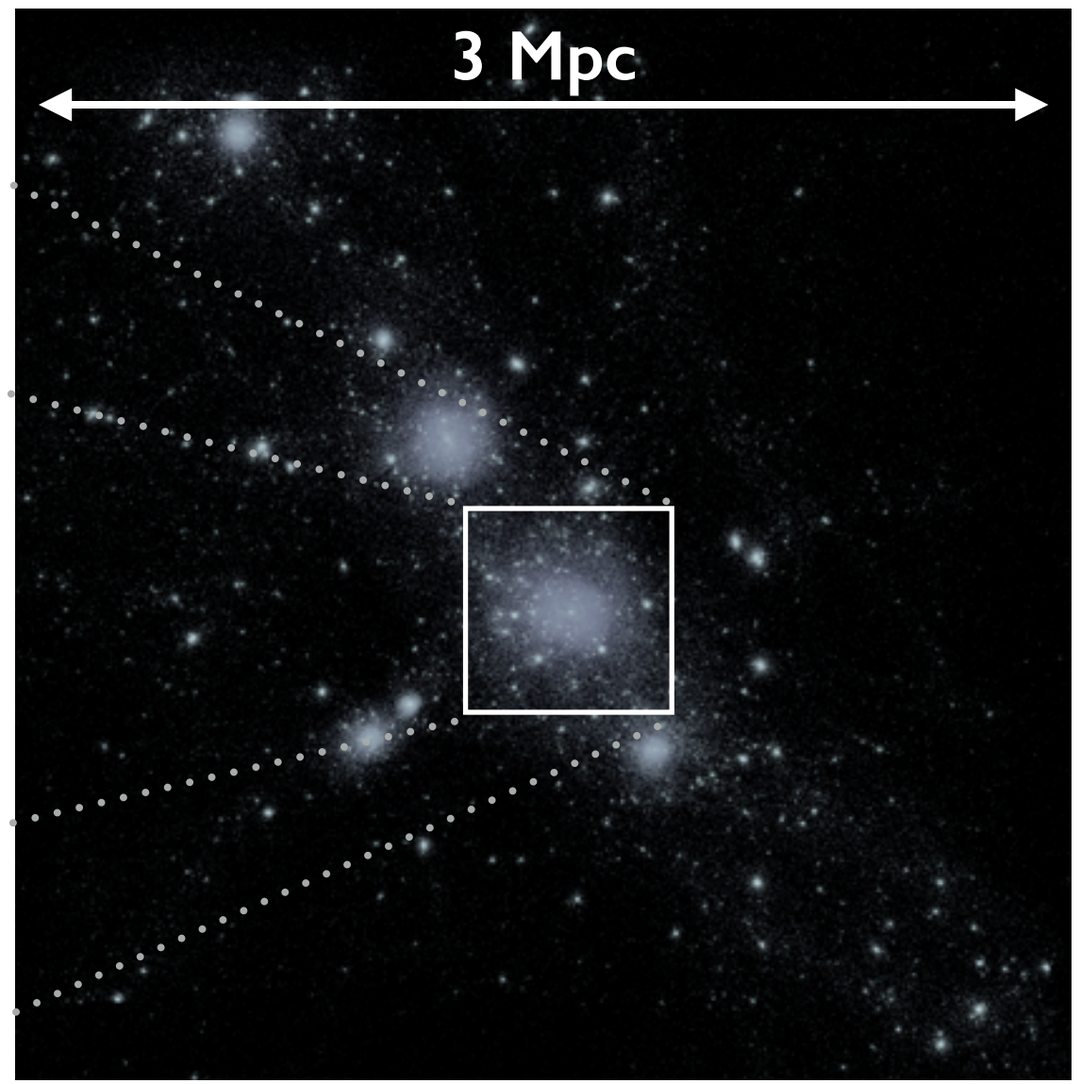
Suppressed by UV background
(Okamoto et al. 2008)

MBK, Bullock, & Kaplinghat 2012

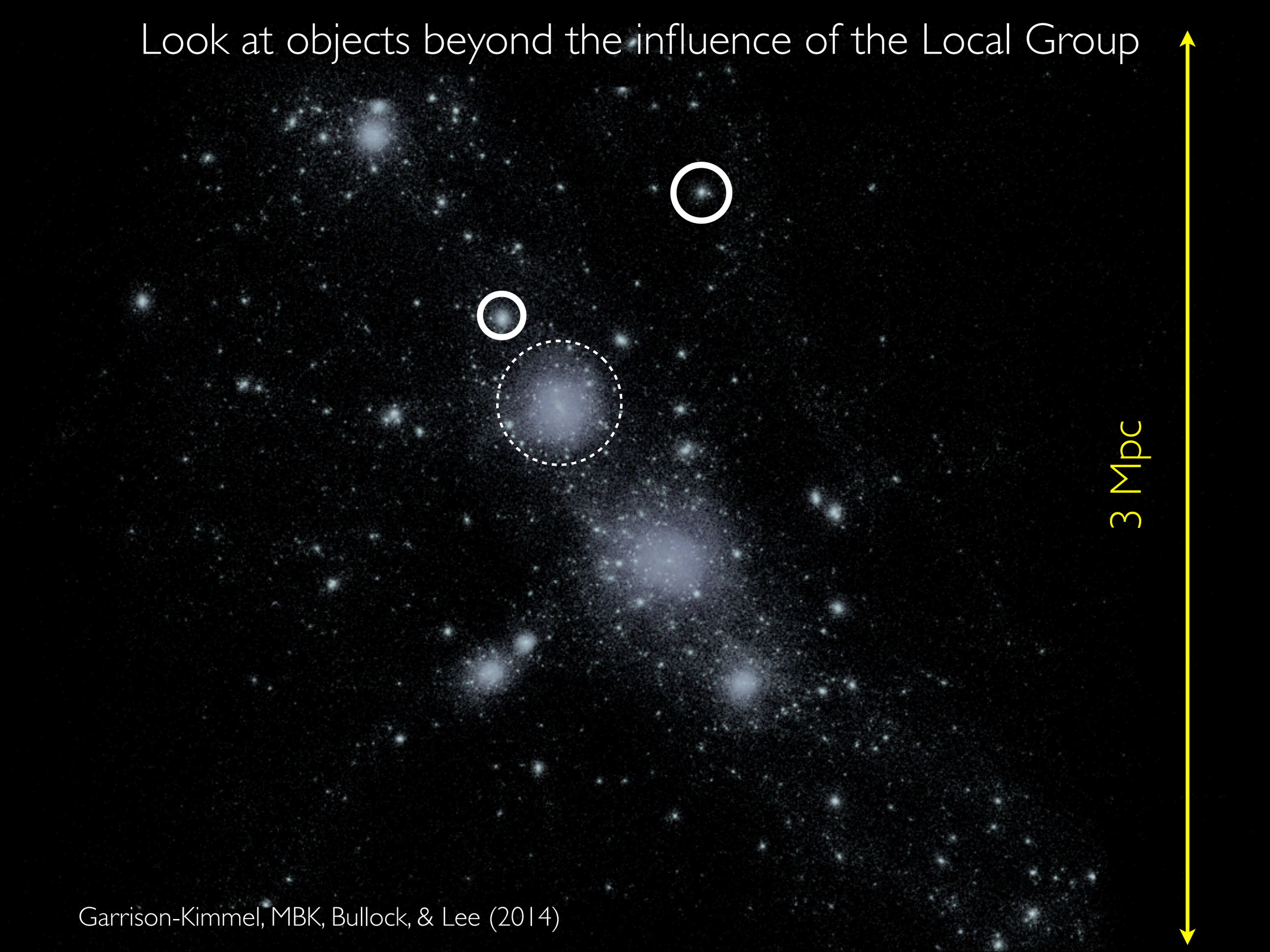
Baryonic solution to Too Big to Fail?

- UV suppression not effective; star formation feedback?
- Simulations, analytic estimates agree on mass scale: $M_\star = (3\text{-}10)\times10^6\ M_{sun}$
  Governato++, Onorbe++, Penarrubia++, Garrison-Kimmel++
- **But**: *require* environmental influences to reduce MW satellite densities
  (Zolotov et al. 2012; Arraki et al. 2013)



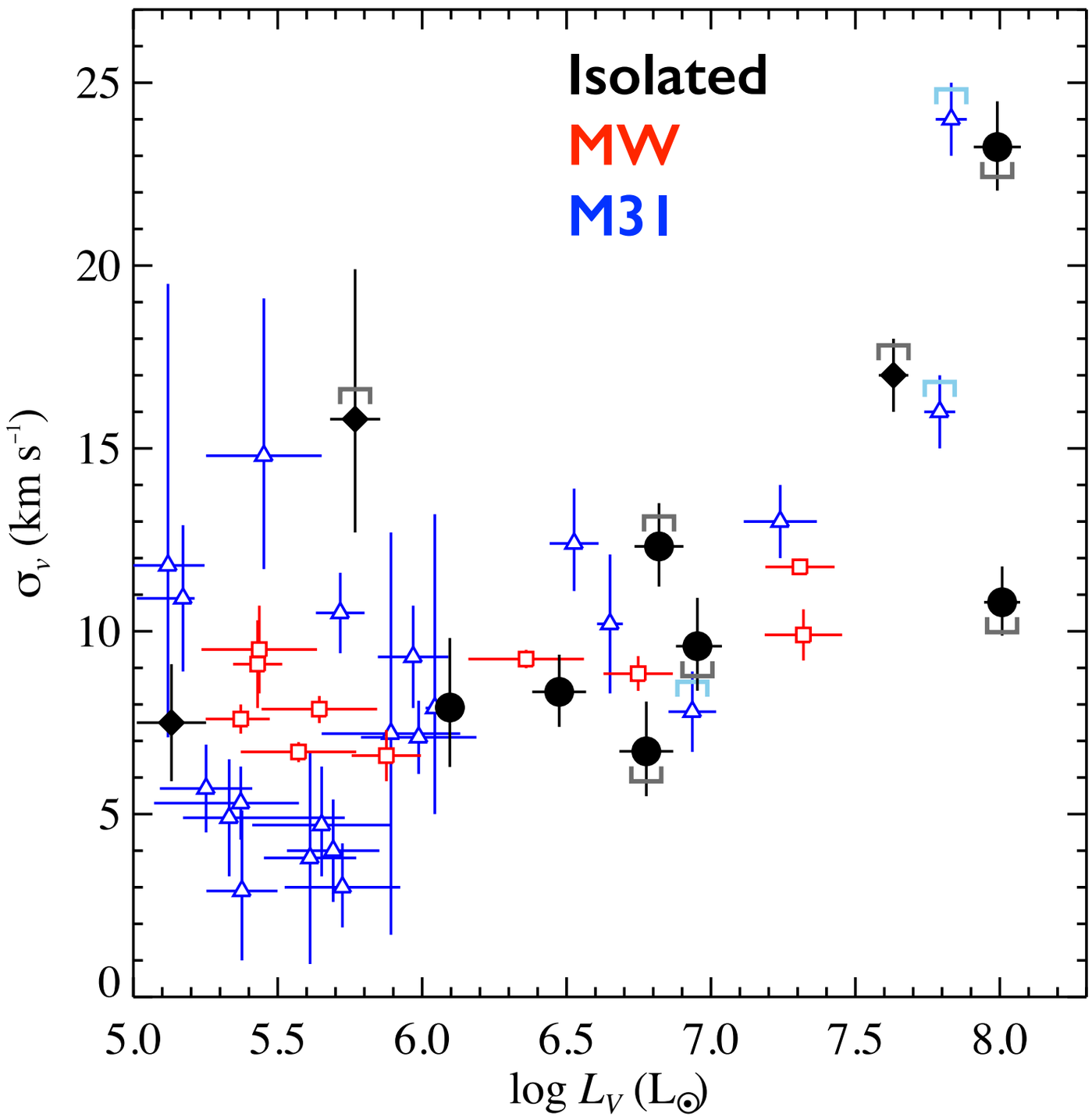


Look at objects beyond the influence of the Local Group



Garrison-Kimmel, MBK, Bullock, & Lee (2014)

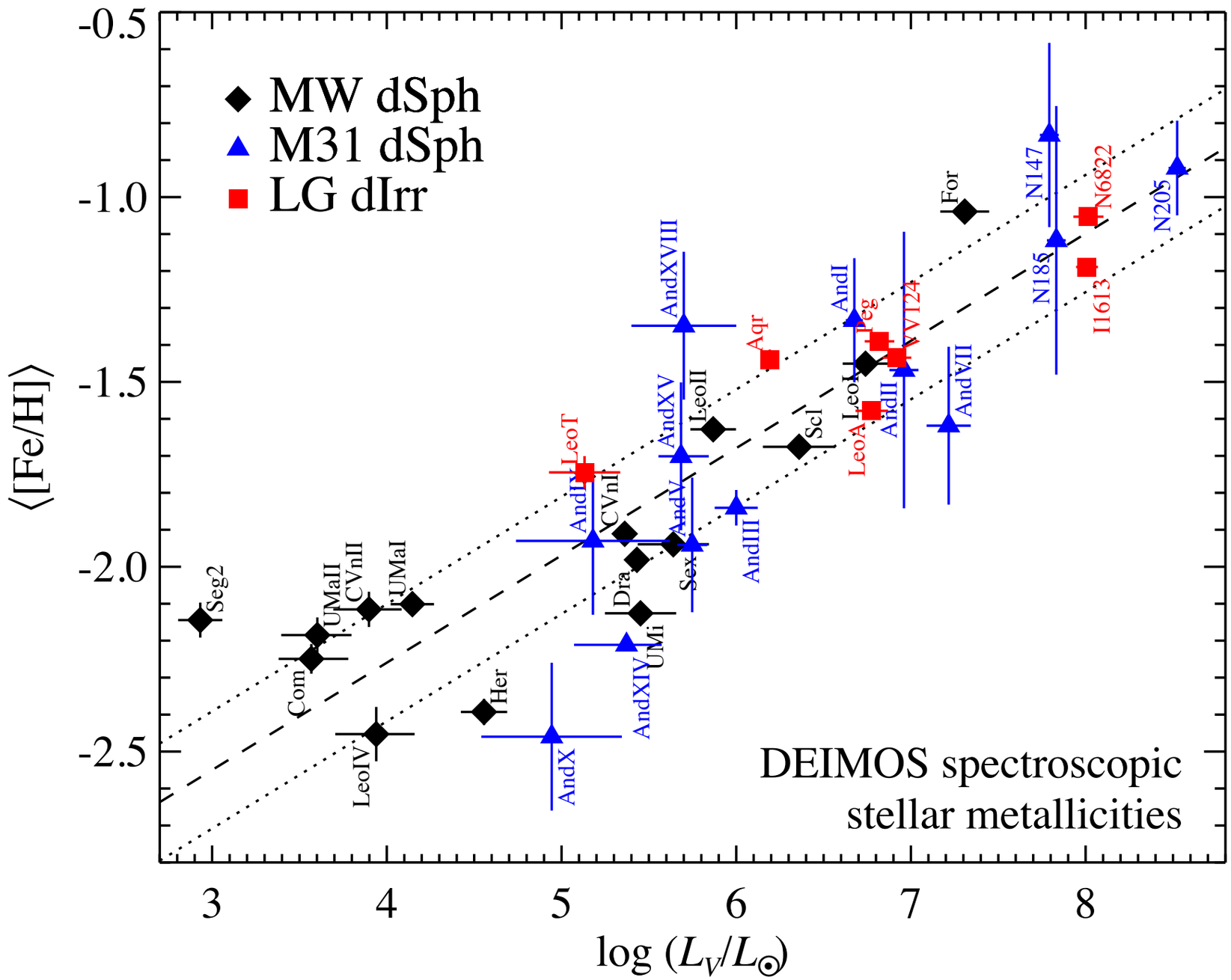
Isolated galaxies look just like satellites



No signs of reduced densities in denser environments

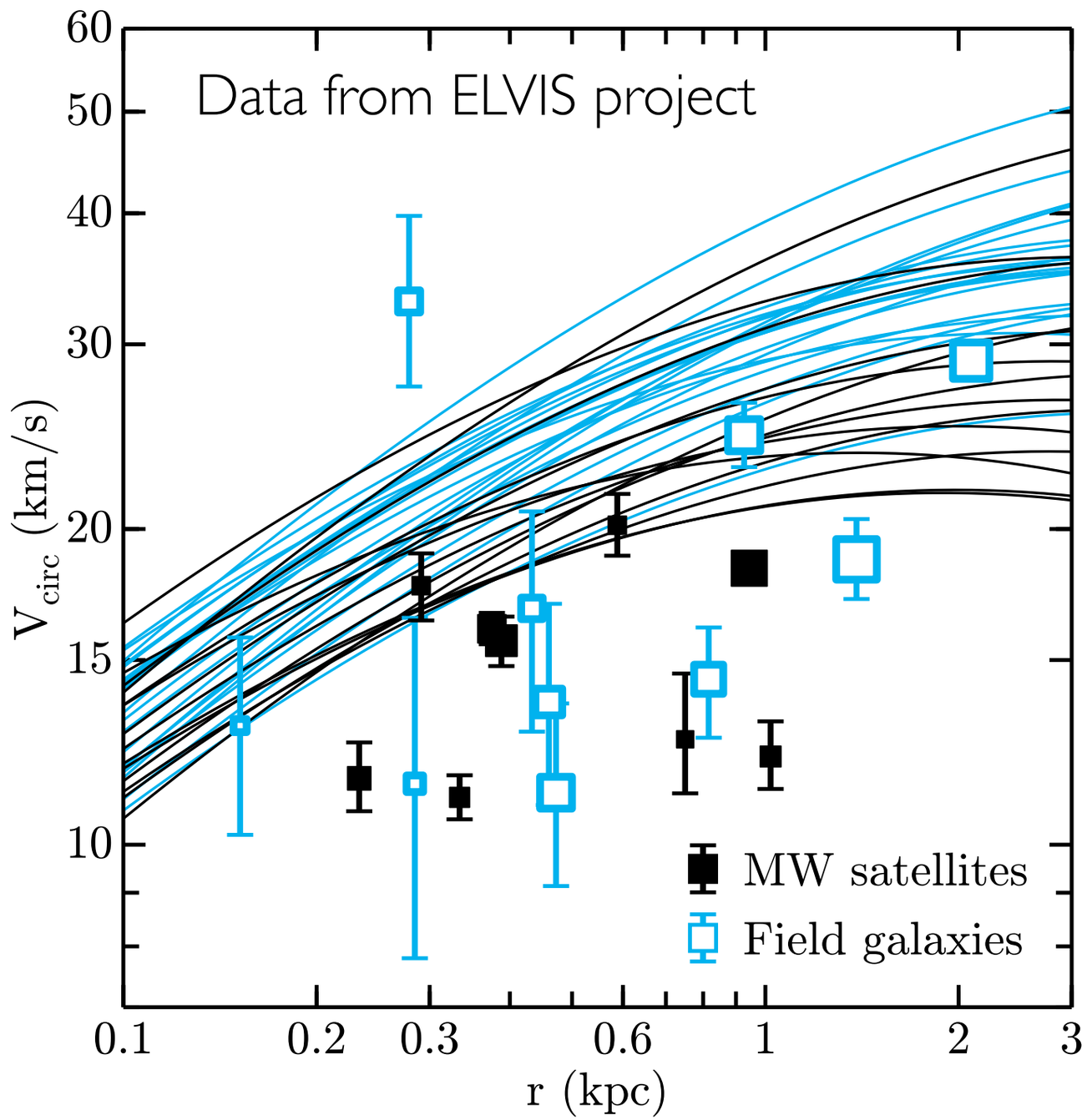
Kirby, Bullock, MBK et al. (2014)

Universal stellar mass — stellar metallicity relation



Kirby et al. 2014

Comparing MW and nearby field to simulations



V_{peak} > 30 km/s

TBTF subhalos

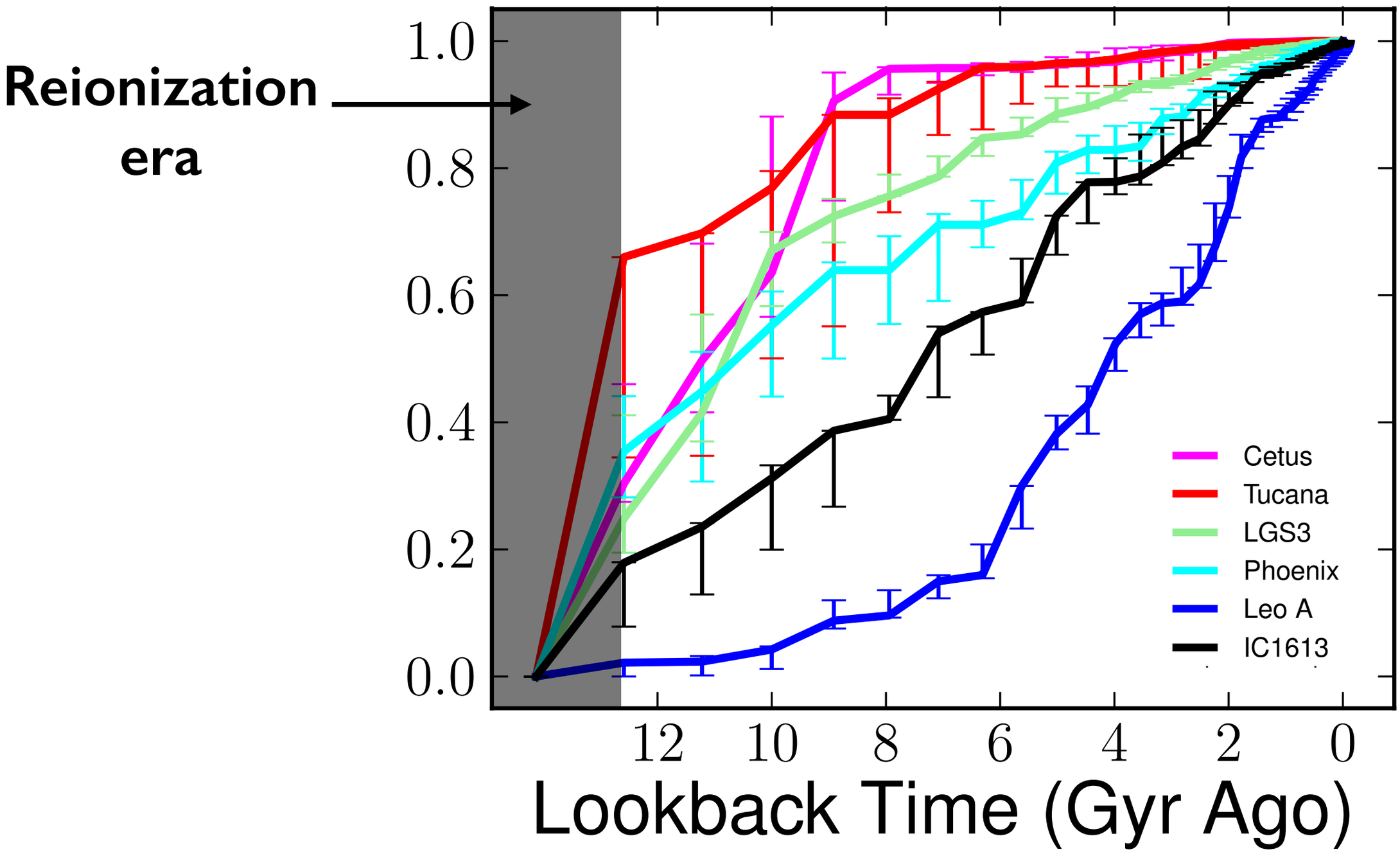
TBTF field halos

Garrison-Kimmel, MBK, Bullock, & Kirby, in preparation

Field vs. satellite galaxies

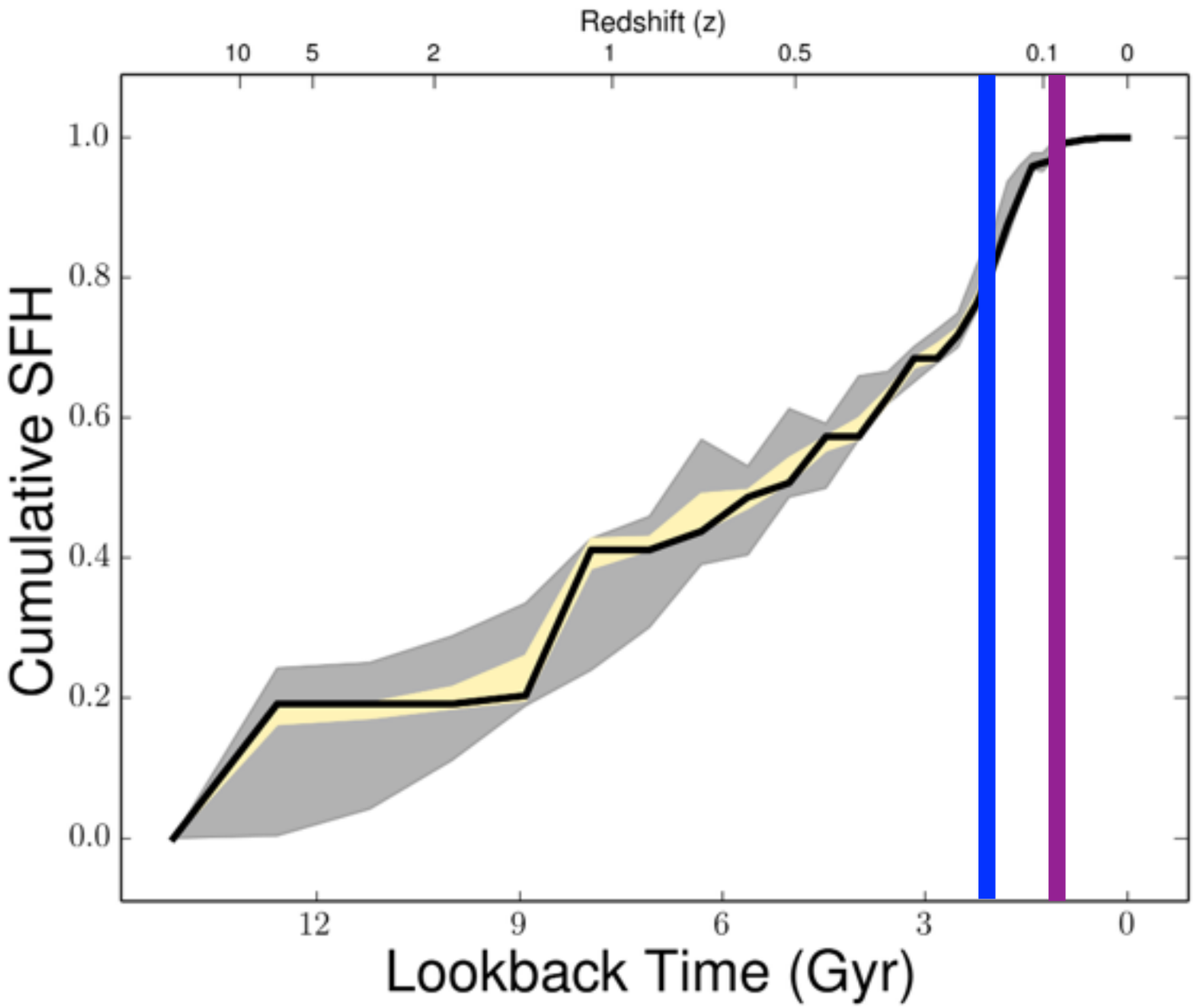
- Similarities:
  - stellar metallicities (as a function of stellar mass)
  - location in size / luminosity / velocity dispersion space
  - total enclosed masses
- Differences
  - gas content
  - star formation histories

Diverse star formation histories



Skillman et al. 2014 (ApJ, submitted) — ACS LCID project

Star formation truncation in Leo I



HST proper motion of Leo I: strong constraints on SF truncation mechanisms

Sohn et al. 2013, MBK et al. 2013

HSTPROMO collaboration (R. van der Marel's talk later today)

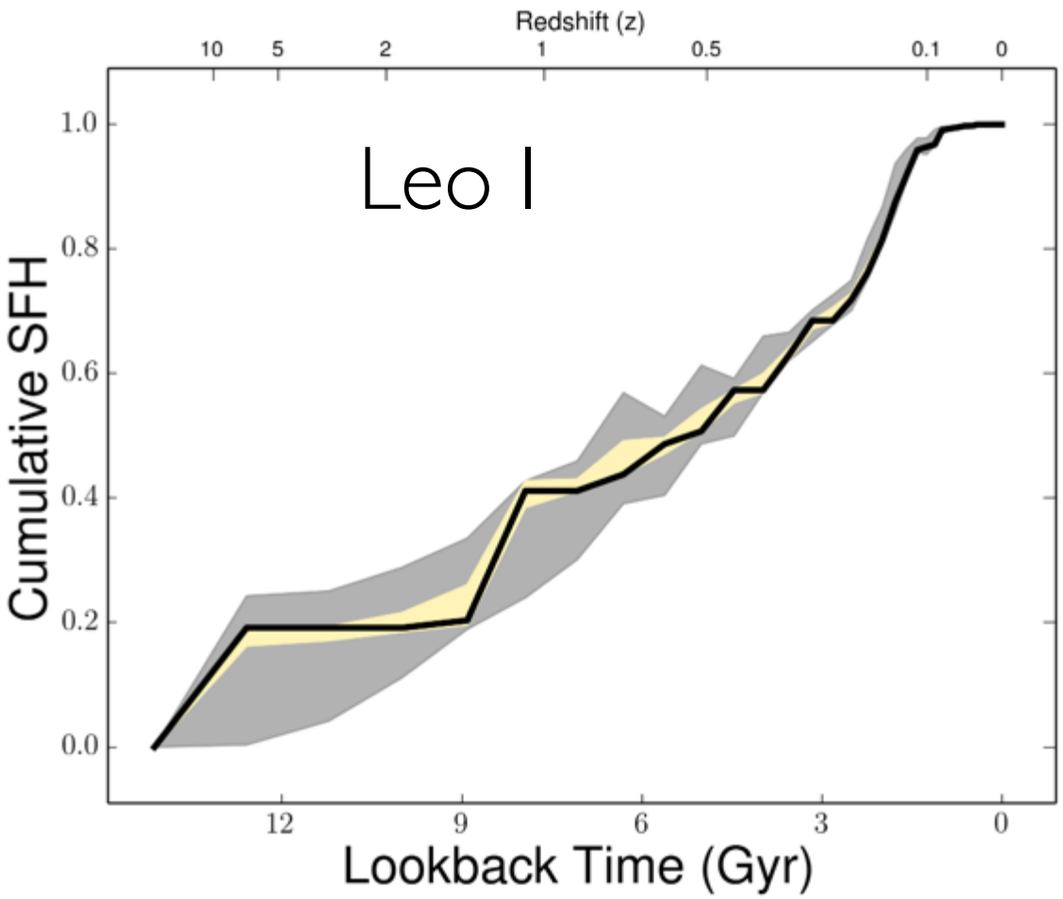
First R_{vir} crossing (2.3 Gyr)

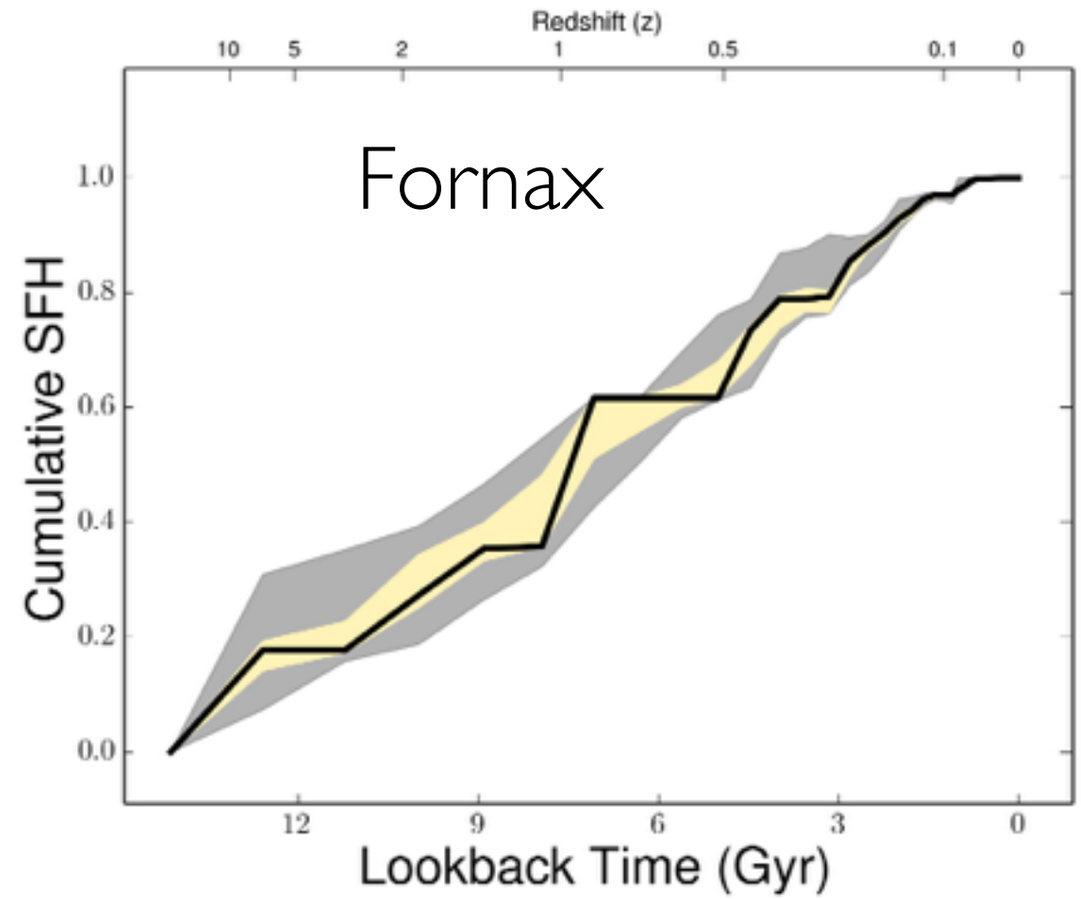
First pericenter (1.0 Gyr)

Proper motion:
$M_{vir,MW} > 10^{12} M_{sun}$

Weisz et al. 2014b

Leo I vs. Fornax



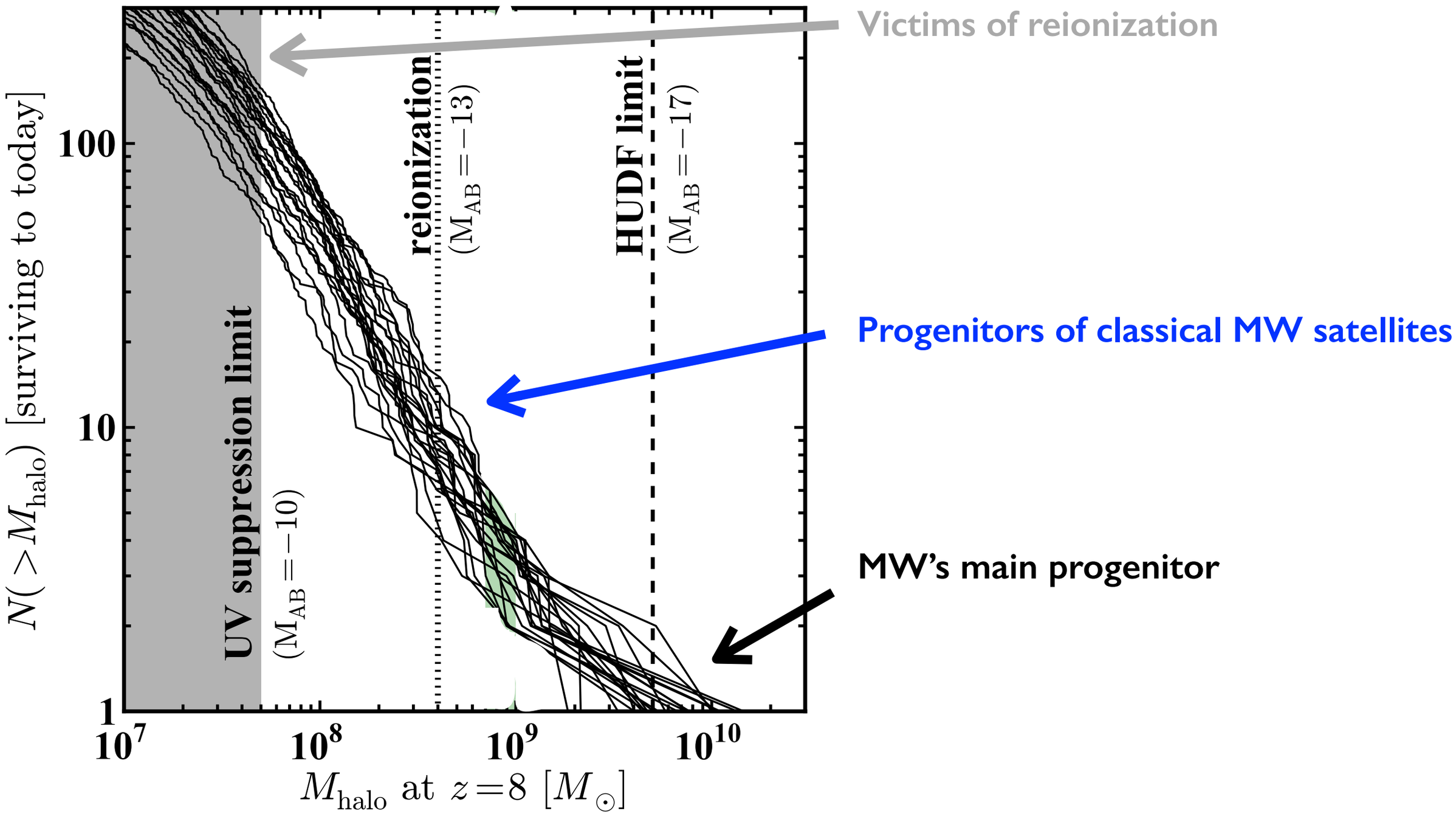


$M_{star}=6\times10^{6}\ M_{sun}$
$R_{peri}=90$ kpc
Highly eccentric orbit

$M_{star}=3\times10^{7}\ M_{sun}$
$R_{peri}=110$ kpc
Nearly circular orbit

Weisz et al. 2014b

The near field / deep fields connection



Data from ELVIS (Garrison-Kimmel, MBK, Bullock)

MBK et al. (in preparation)

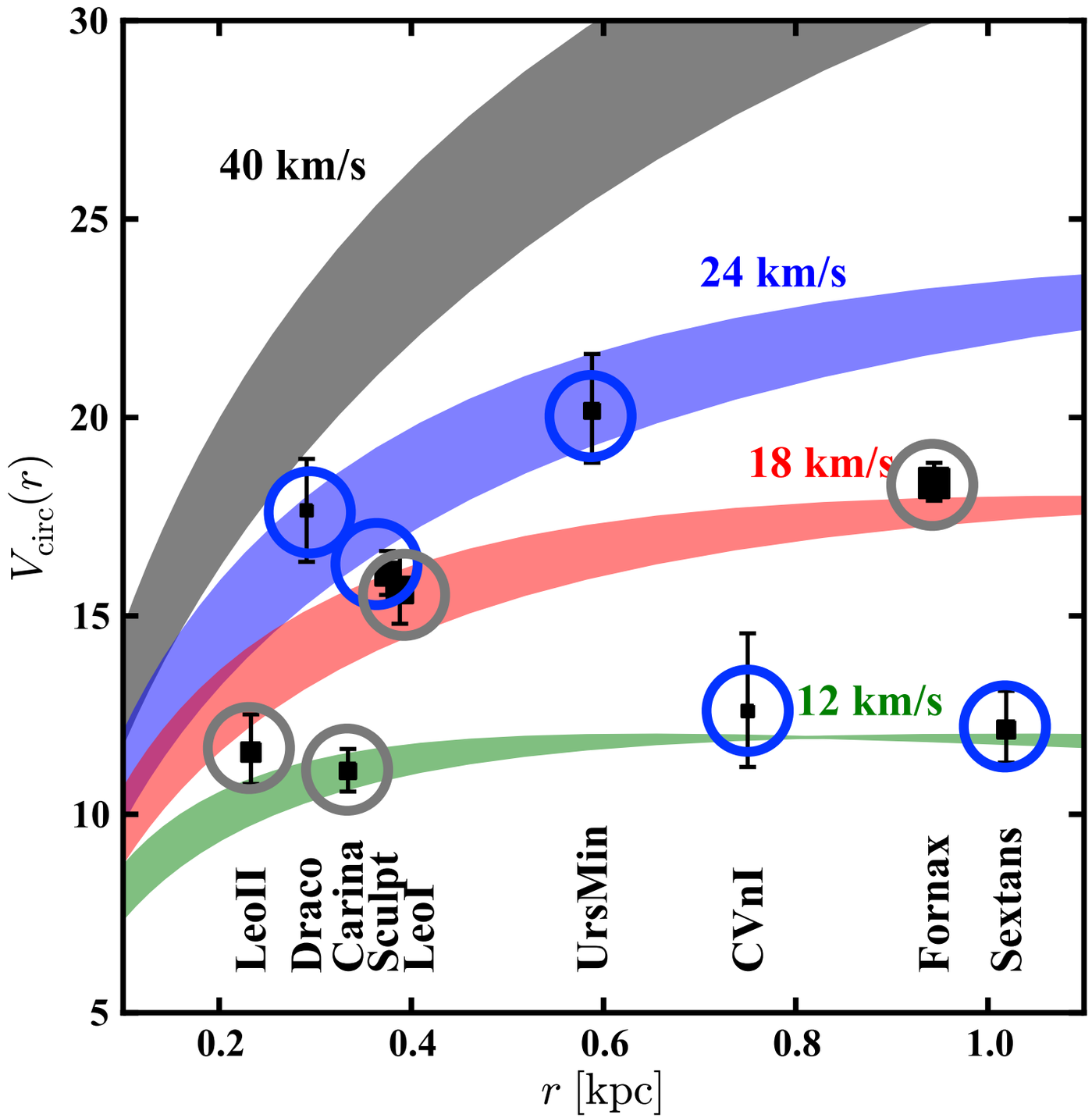
More questions than answers

- How do we reconcile tension between requirements for reionization (substantial star formation in very low mass halos) and near-field observations (low abundance of faint galaxies)?
- What is expected signature of reionization on SFHs of low-mass galaxies? (Existing cold gas isn't affected, so some SF can continue.)
- Why are some properties of nearby dwarfs so uniform while others have large scatter? How do we connect stellar masses to halo masses / gravitational potentials?
- What can combined SFHs + proper motions tell us about SF truncation mechanisms and CGM structure around the MW?

Conclusions

- There are strong near field / deep field connections
  - Faintest galaxies in HDFs are likely progenitors of MW-mass galaxies
  - Faintest galaxies in JWST blank fields ~ progenitors of **classical** MW satellites
  - Simple models of reionization require galaxies a factor of 5-10 fainter; should be hundreds of these in the MW's virial volume today. Is this model correct?
- Near-field cosmology: issues on small scales persist
  - **Too big to fail**: many (~15) such subhalos per simulated host
  - equivalent problem exists in field, where models predict differences in galaxy evolution (lesser impact of tides, ram pressure)
- Star formation histories: orbit for Leo I from HST proper motion
  - consistent with rapid quenching due to single pericenter pass at ~90 kpc.
  - future proper motion-based orbits will be shed light on quenching processes and question of reionization "fossils".

Correlations in density, SF histories



Most SF at early times: Draco, UMi, CVnI, Sculptor,

Significant SF at late times: Leo I, Leo II, Carina, Fornax

MBK, Bullock, & Kaplinghat 2011, 2012