Reconciling Dwarf Galaxies with LCDM Cosmology

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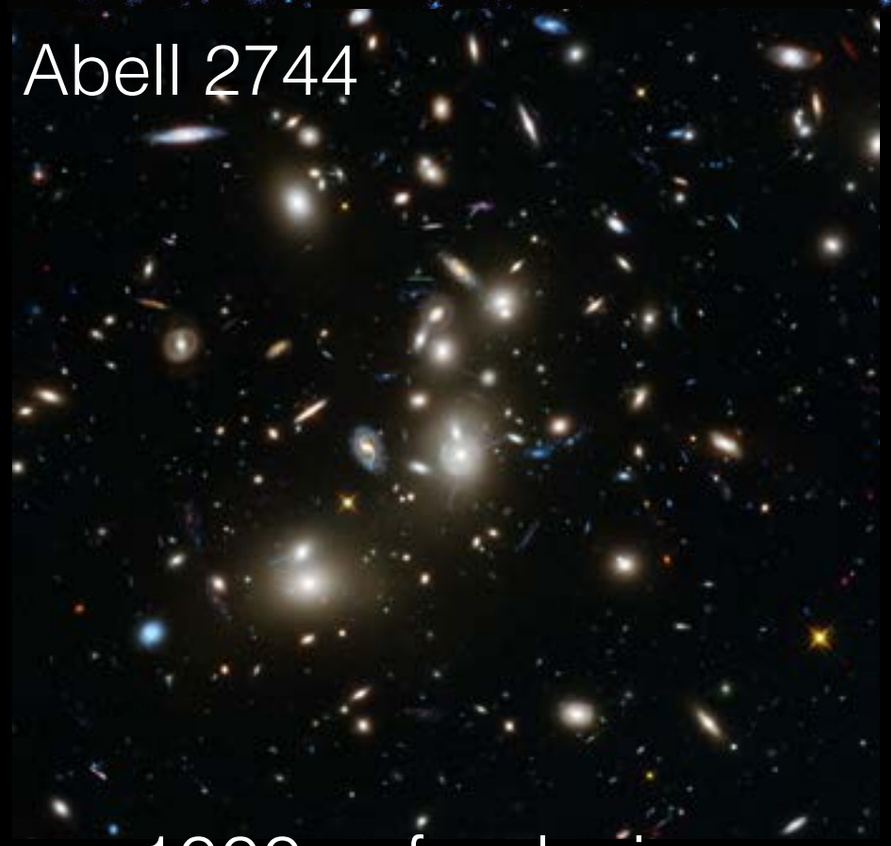
The Carnegie Observatories

dwarf galaxies:
the most significant challenges to the Cold Dark Matter (CDM) model

(nearly) self-similar structure formation in CDM

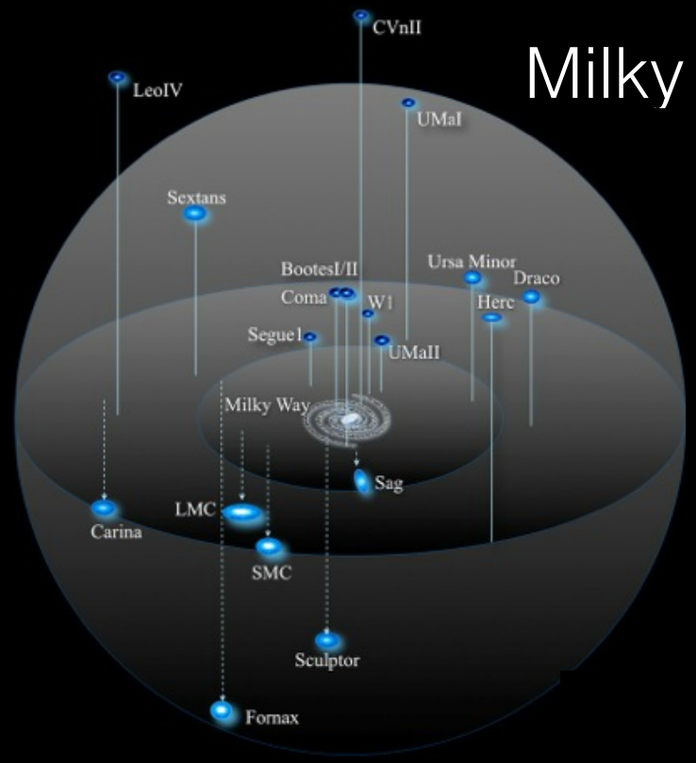
1000s of subhalos



Abell 2744

1000s of galaxies

Milky Way



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

dwarf galaxies: significant challenges to the Cold Dark Matter (CDM) model

“missing satellites” problem

CDM predicts **too many** dark matter subhalos compared with observed satellite galaxies

“too big to fail” problem

CDM predicts dark-matter subhalos that are **too dense** compared with observed satellite galaxies

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dwarf galaxies: significant challenges to the Cold Dark Matter (CDM) model

possible solutions

1. dark matter is not “standard” CDM
   examples: warm dark matter, self-interacting dark matter

2. standard CDM + baryonic physics

The Latte Project: the Milky Way on FIRE

simulating a Milky Way-mass galaxy with a realistic population of satellite dwarf galaxies in LCDM

Wetzel et al 2016, ApJL submitted, arXiv:1602:05957

The Latte Project: the Milky Way on FIRE

Flat White

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FIRE

Feedback In Realistic Environments

FIRE model for stellar feedback

Feedback In Realistic Environments

- High resolution to capture dense multi-phase inter-stellar medium
  - m_{gas} = 7070 M_{sun}
  - h_{gas} = 1 pc
  - h_{DM} = 20 pc

- Heating:
  - Supernovae: core-collapse (II) & Ia
  - Stellar Winds: massive (O) & AGB stars
  - Photoionization (HII regions)
  - Photoelectric heating

- Explicit Momentum Flux:
  - Radiation Pressure

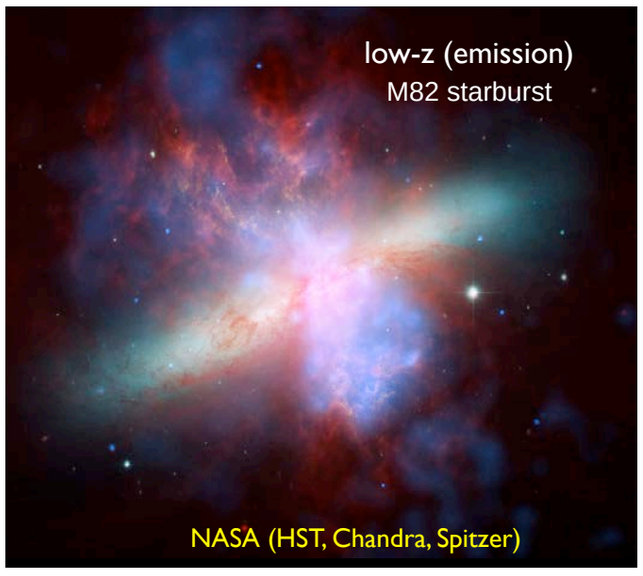
$$\dot{P}_{\rm rad} \sim \frac{L}{c}\,(1+\tau_{\rm IR})$$

  - Supernovae

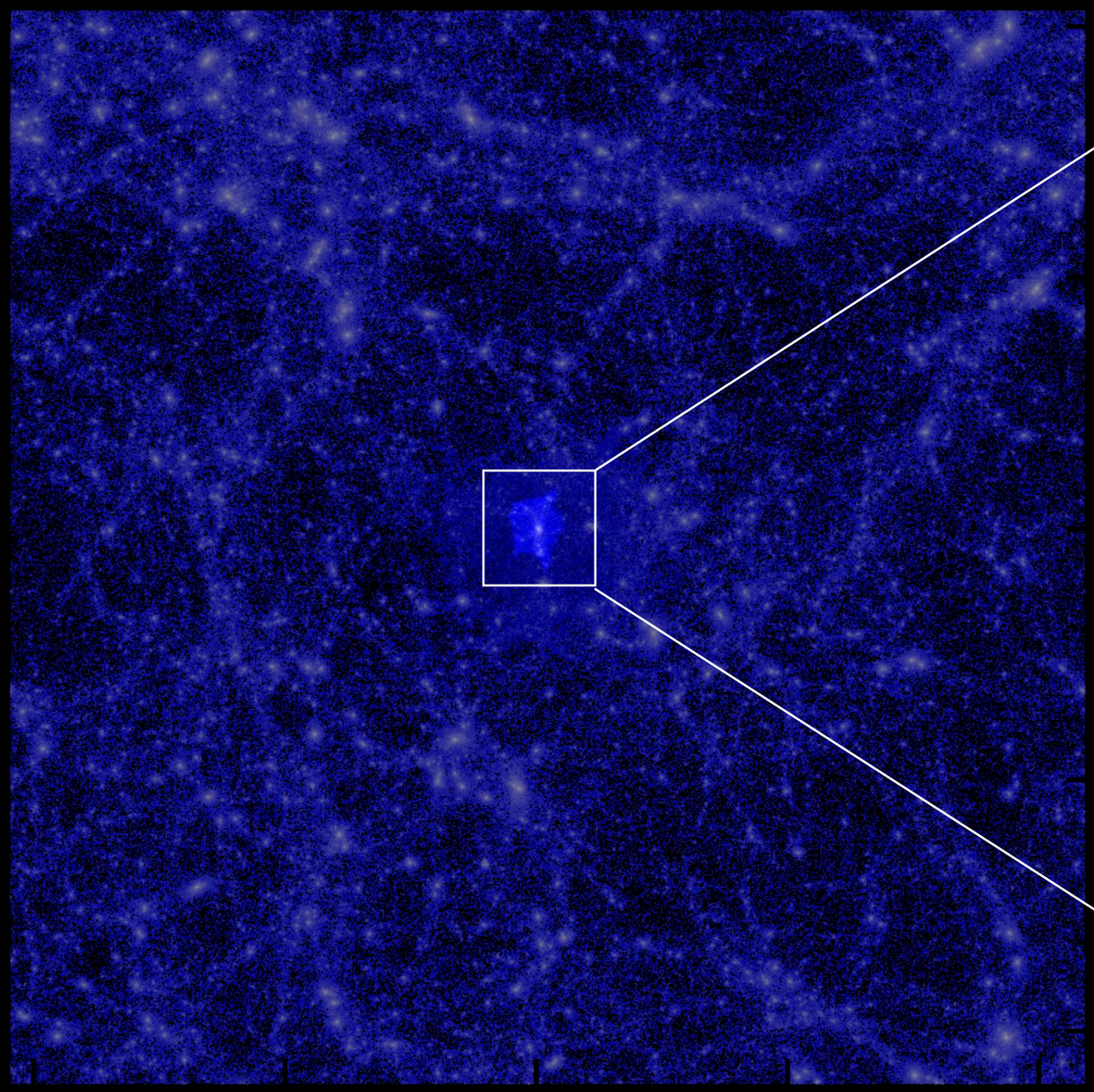
$$\dot{P}_{\rm SNe} \sim \dot{E}_{\rm SNe}\, v_{\rm ejecta}^{-1}$$

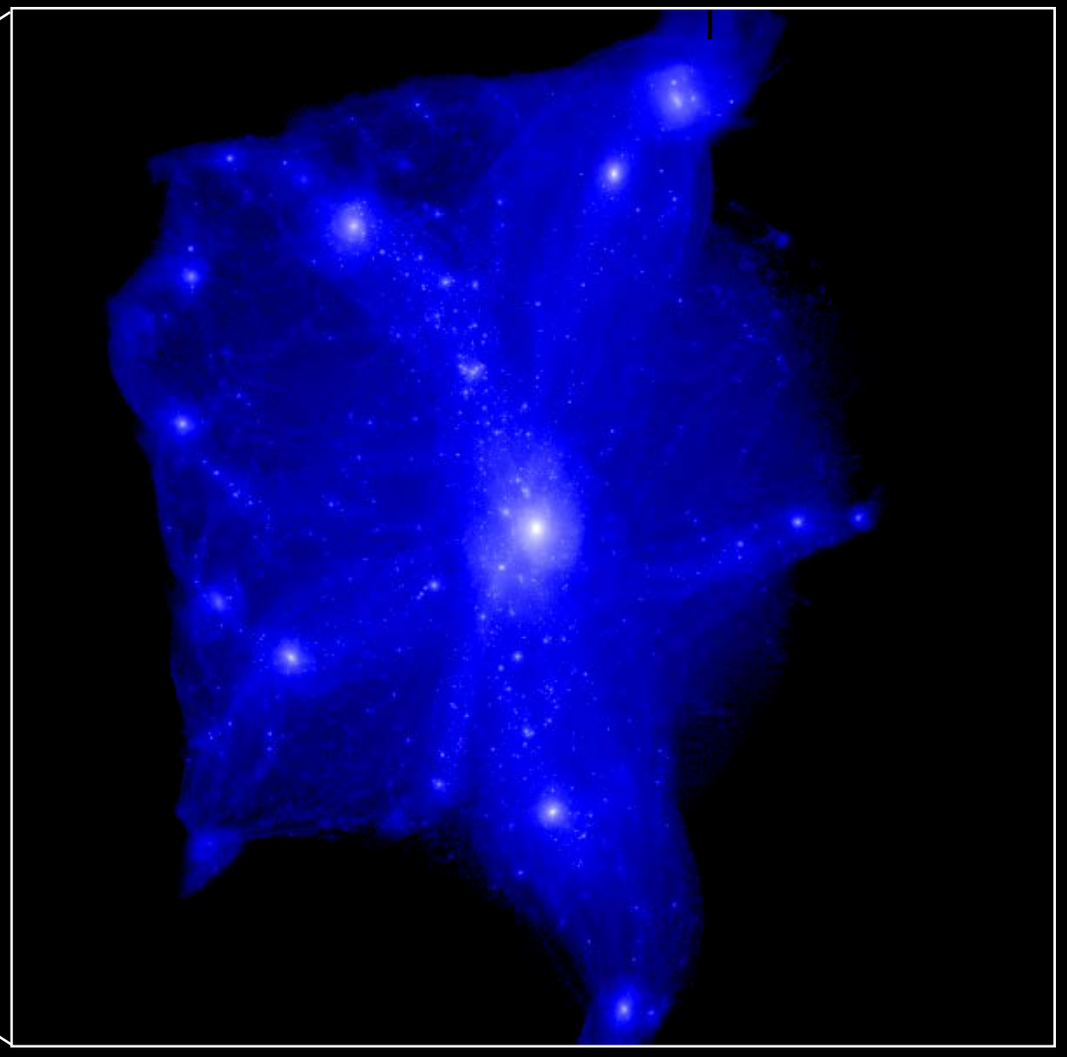
  - Stellar Winds

$$\dot{P}_{\rm W} \sim \dot{M}\, v_{\rm wind}$$

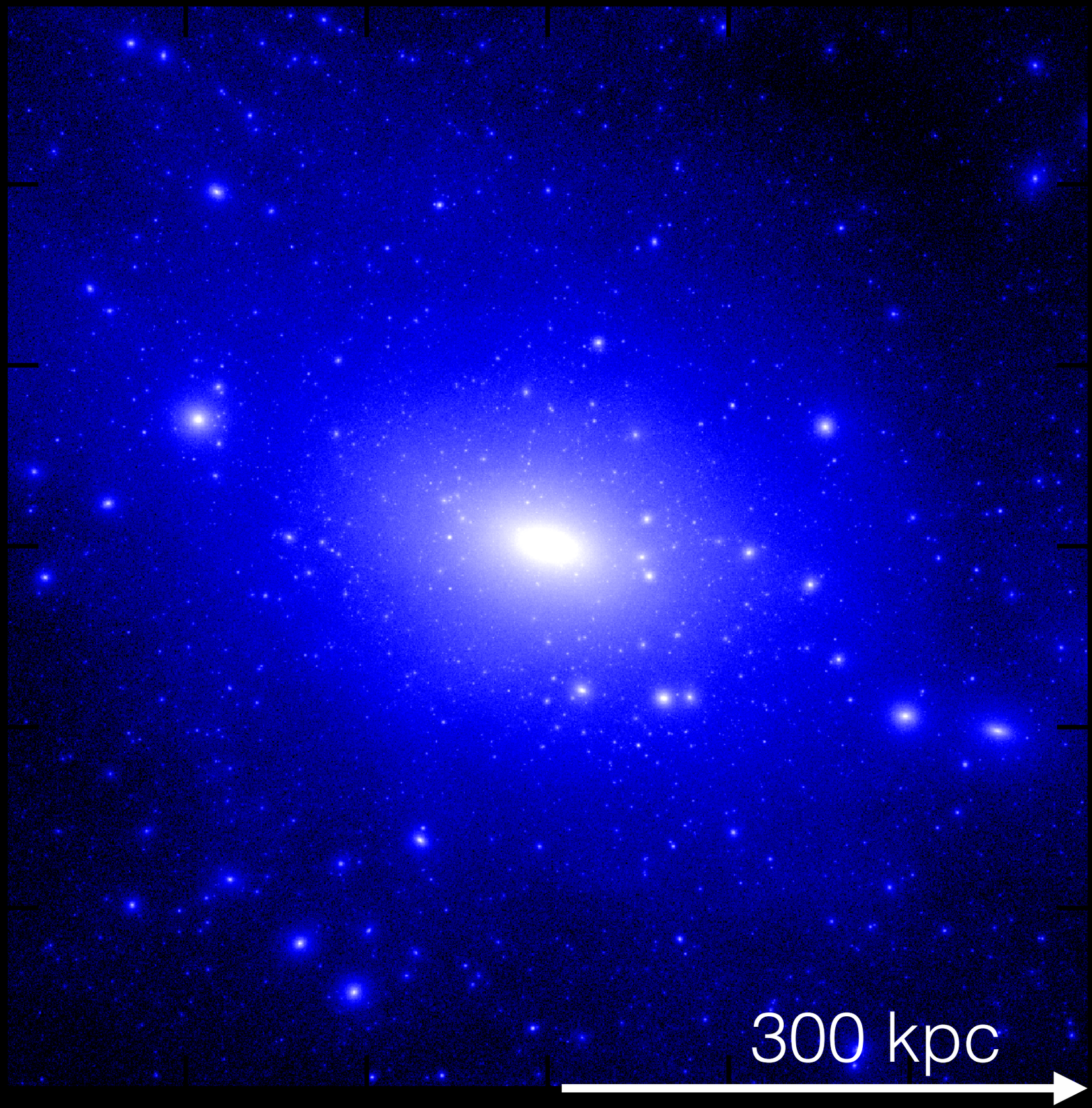


cosmological zoom-in simulation to achieve high resolution

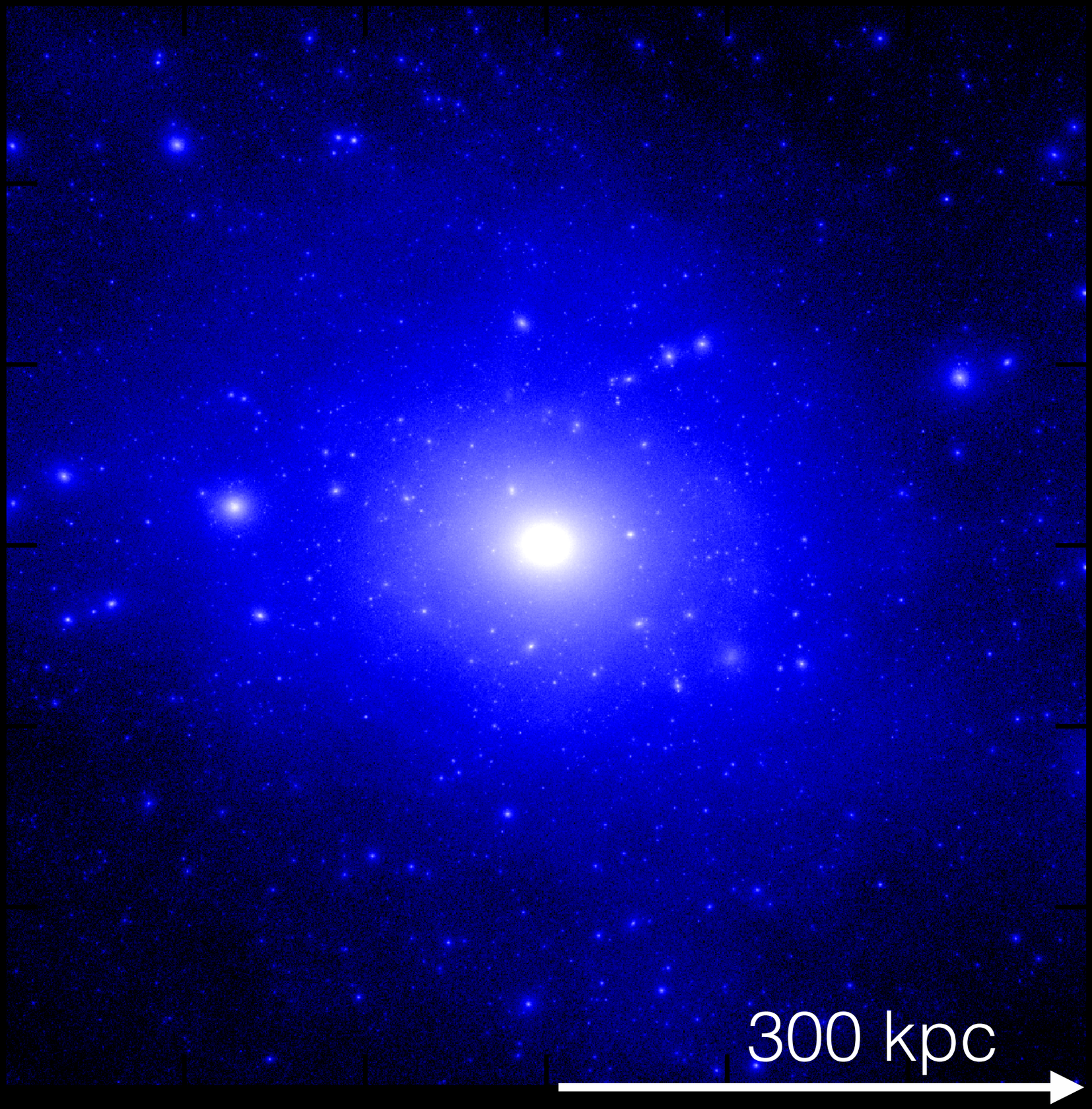




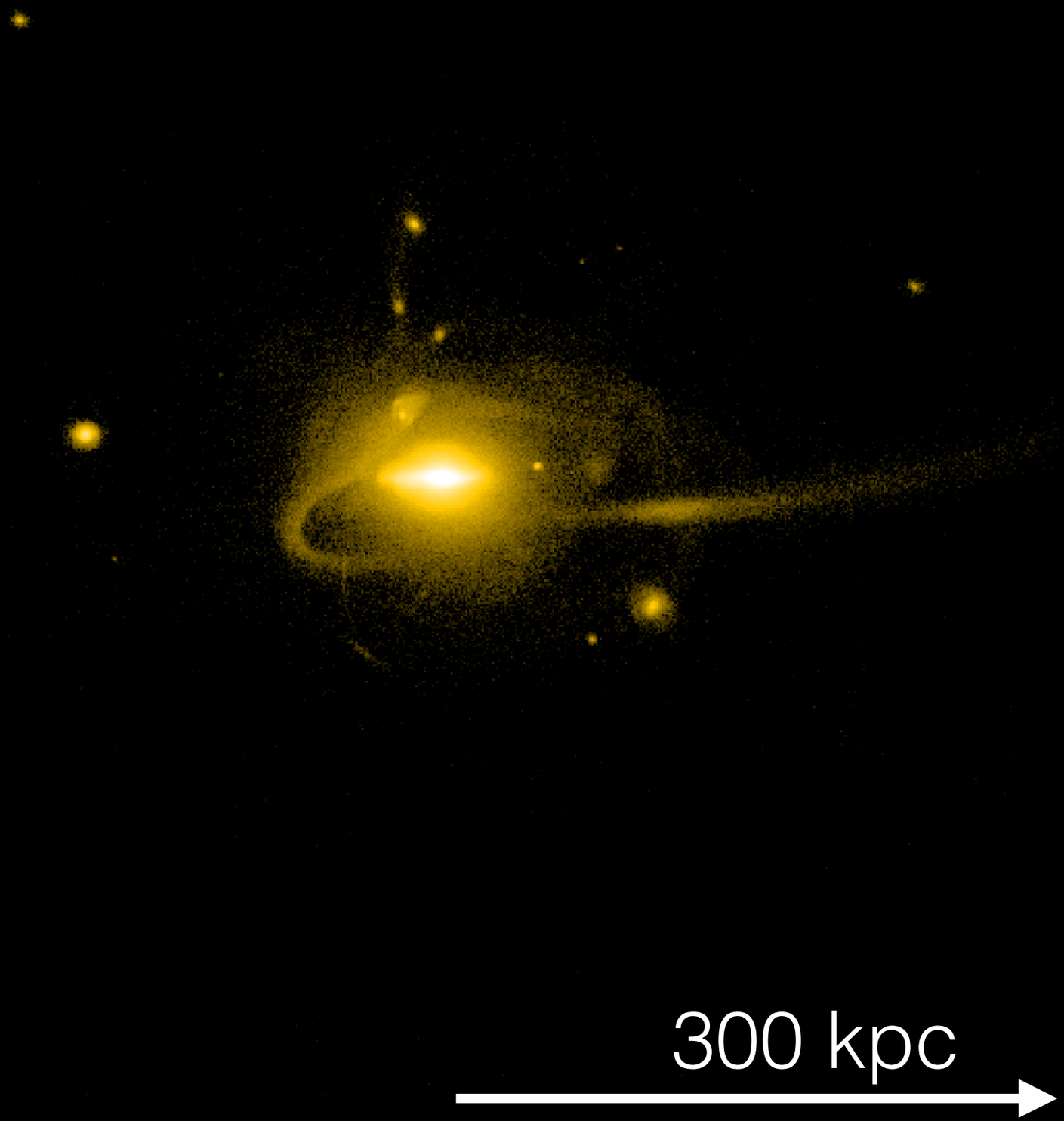
dark matter-only simulation



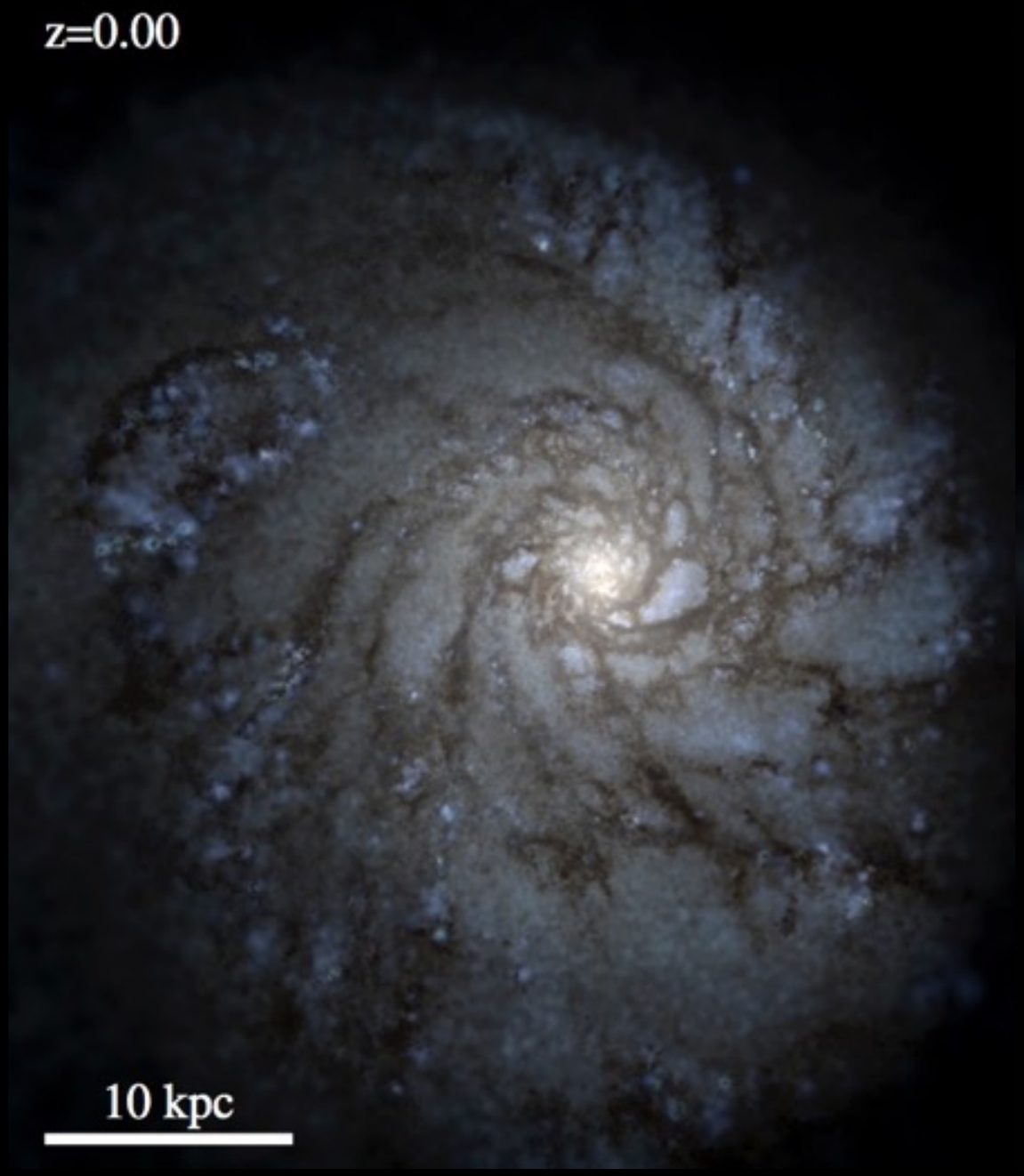
dark matter with effects of baryons

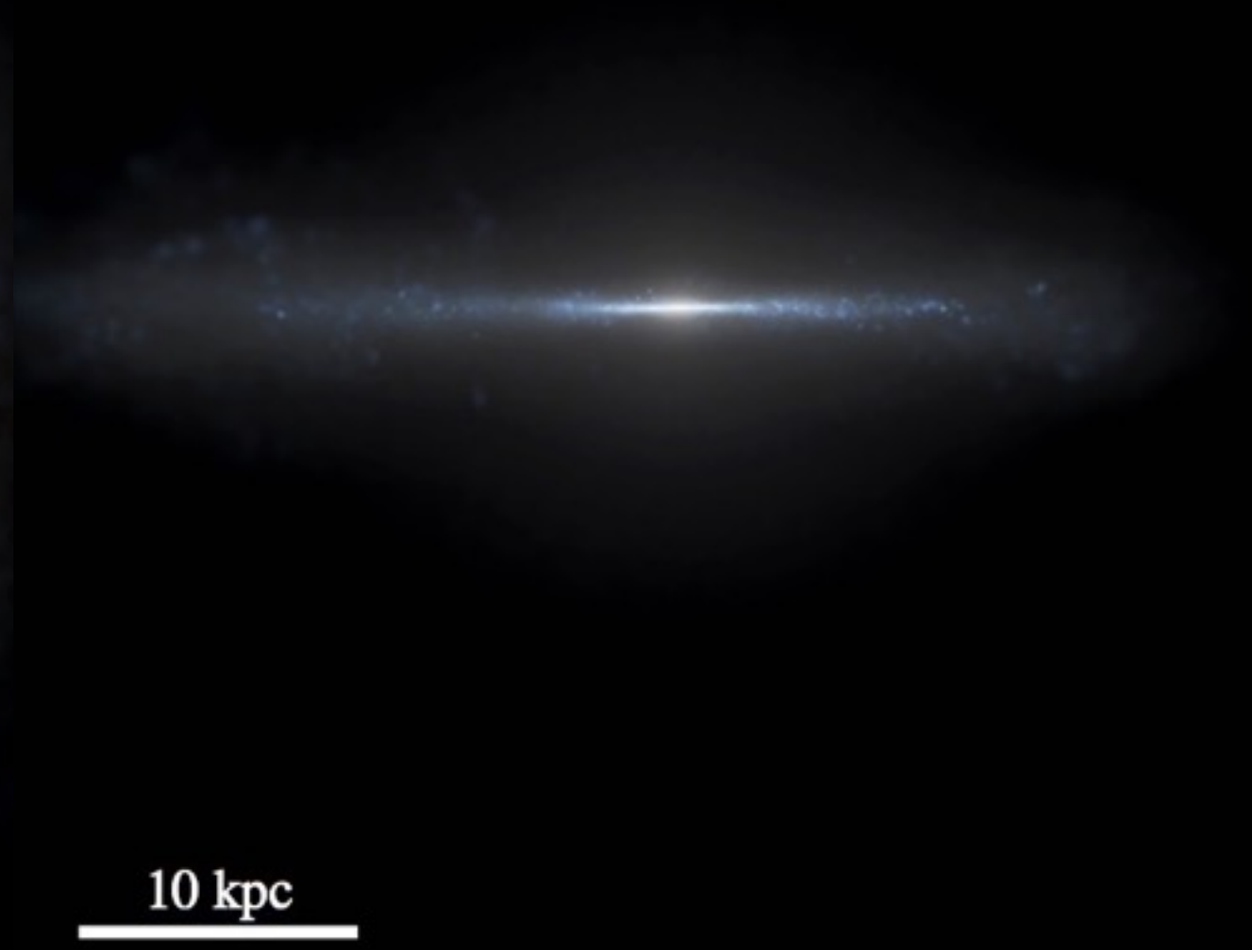


stars



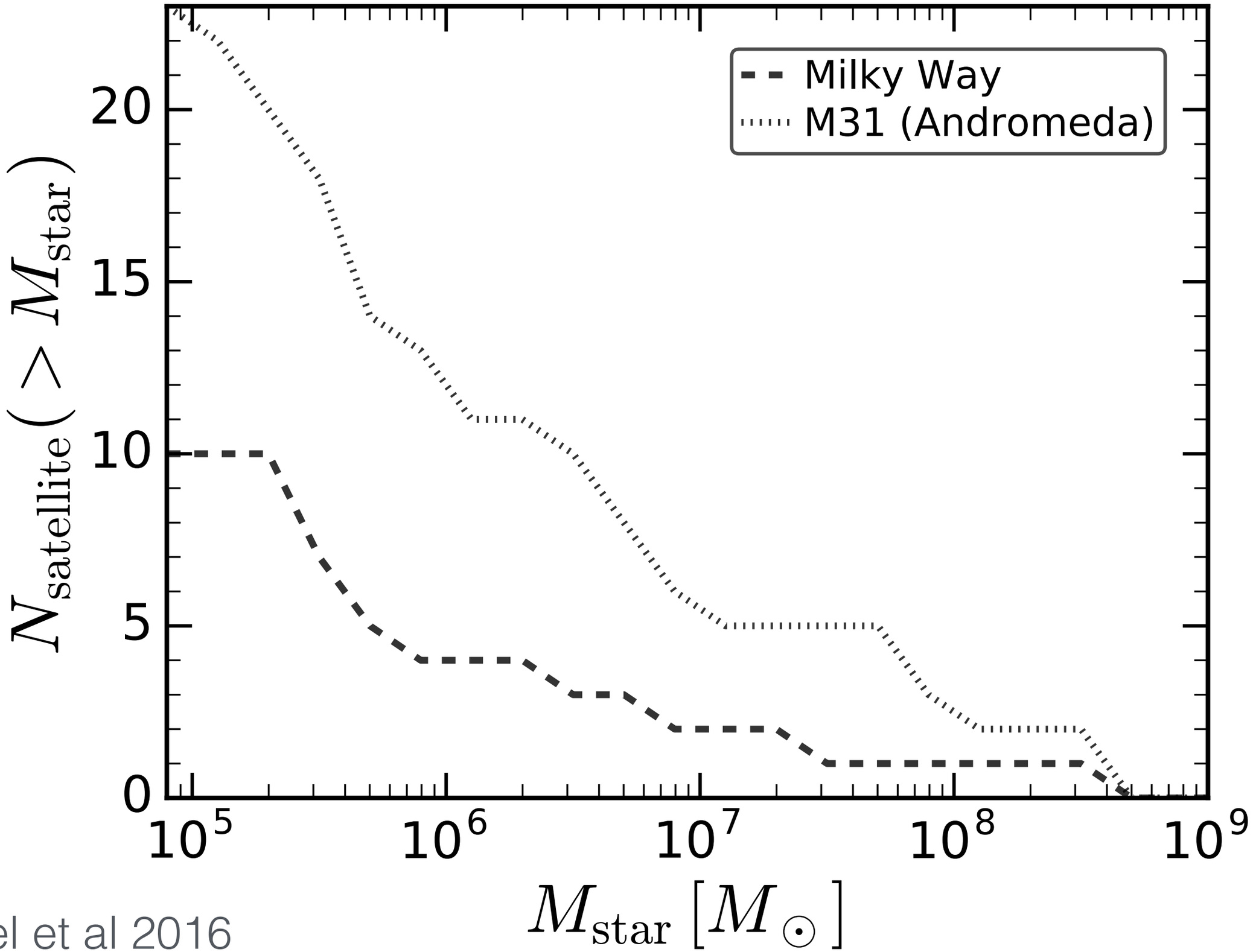
host galaxy at z = 0





$M_{star} = 7x10^{10} M_{sun}$

stellar mass function of satellites



Wetzel et al 2016

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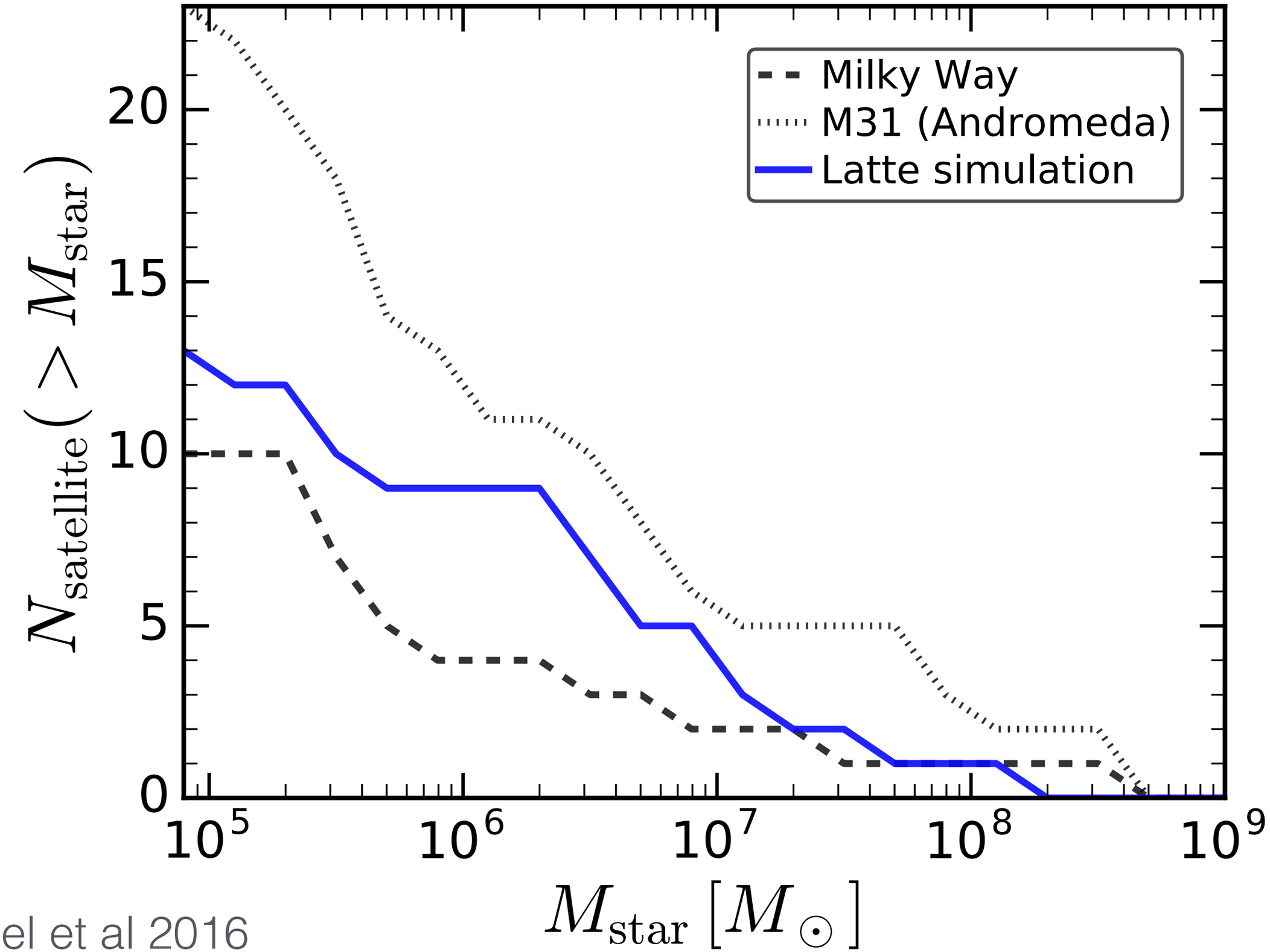
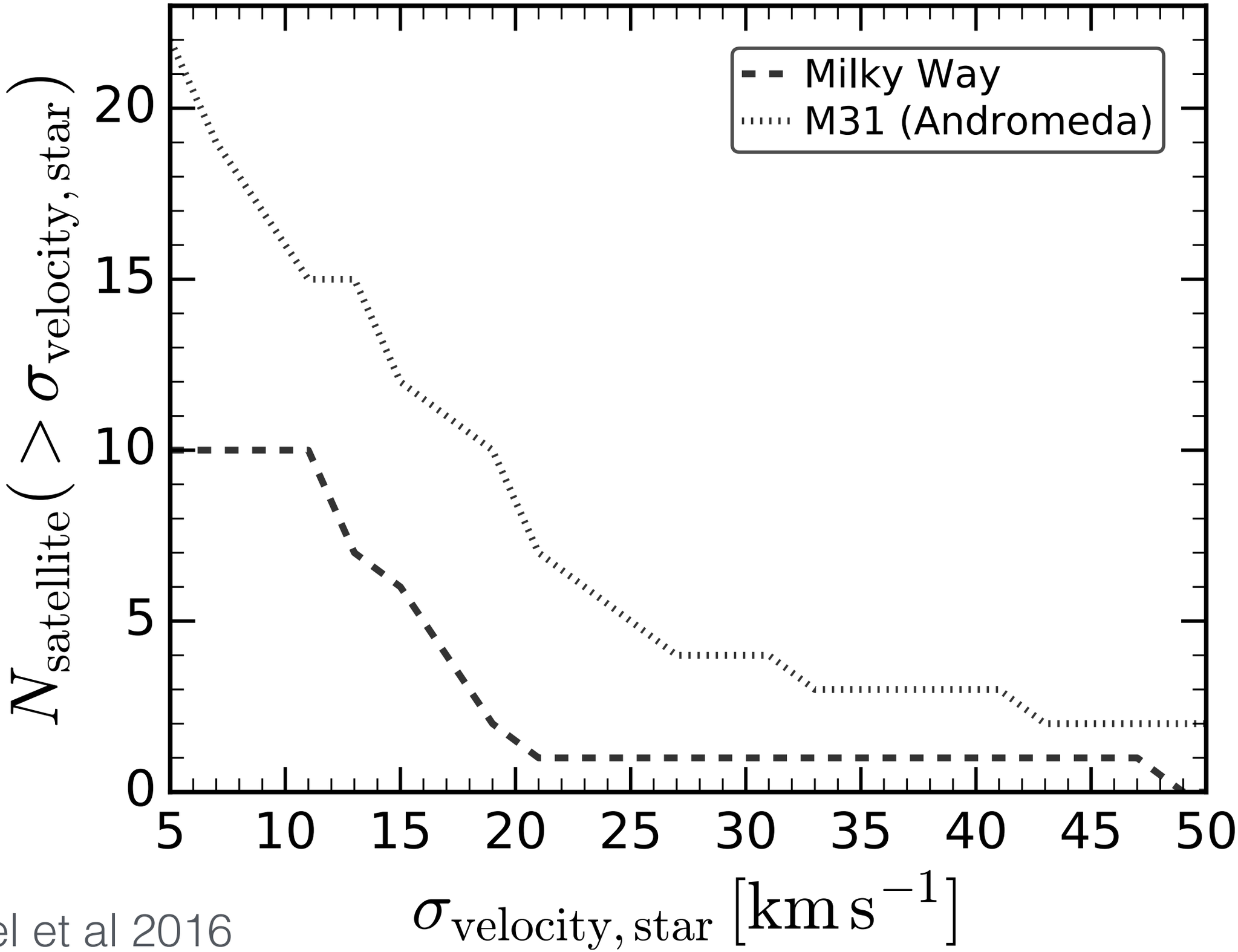


Wetzel et al 2016

stellar velocity dispersion function of satellites



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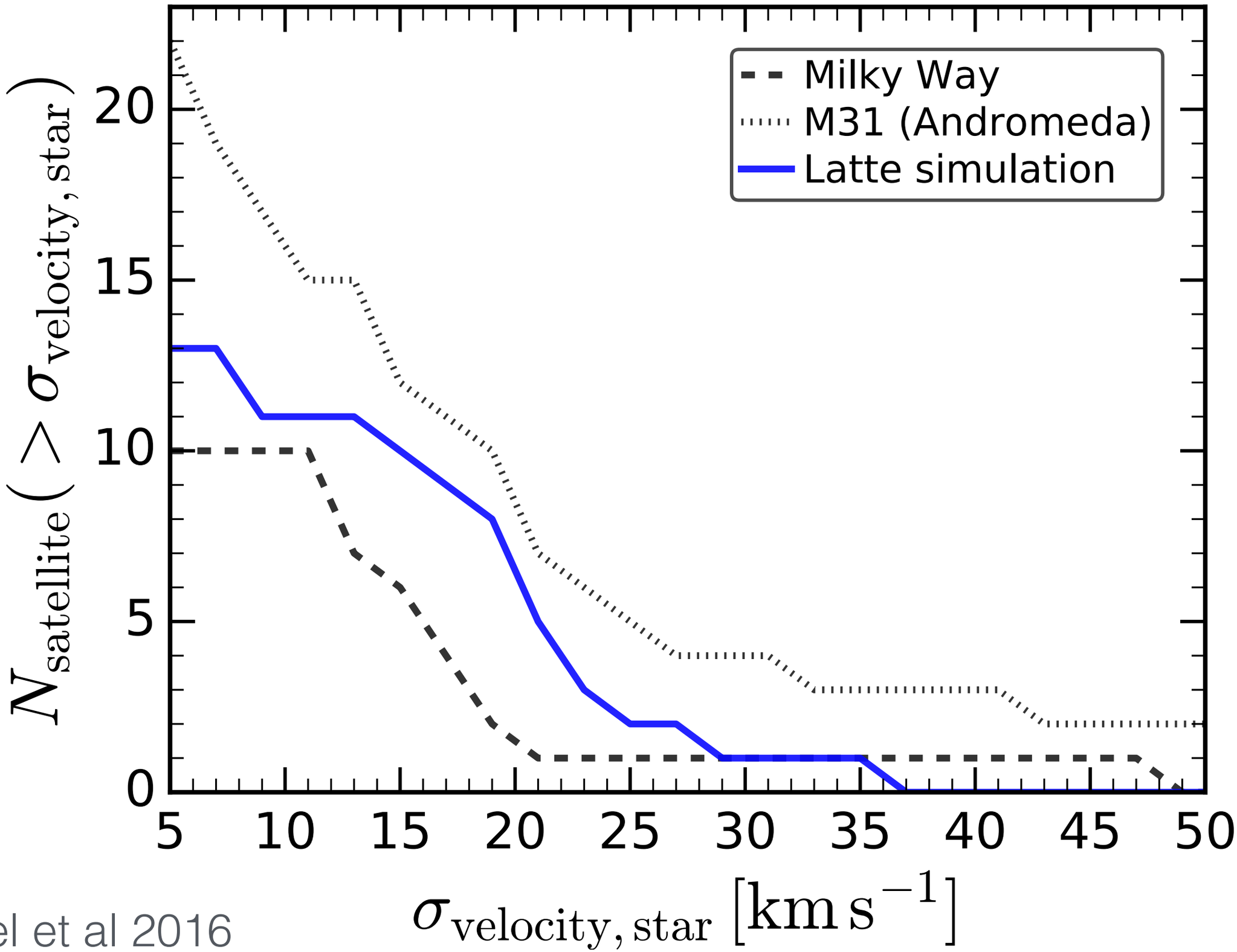
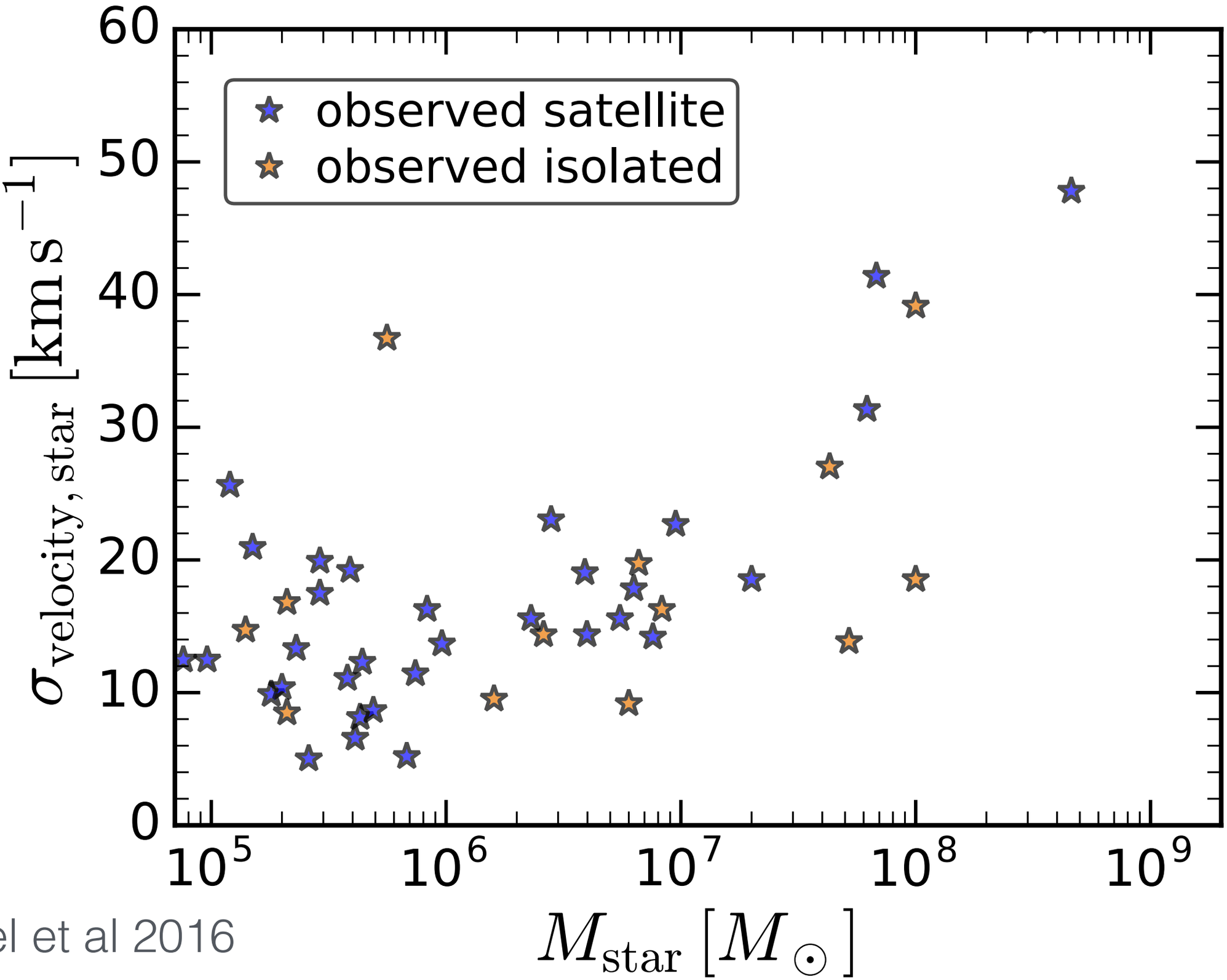


Wetzel et al 2016

velocity dispersion - mass relation



Wetzel et al 2016

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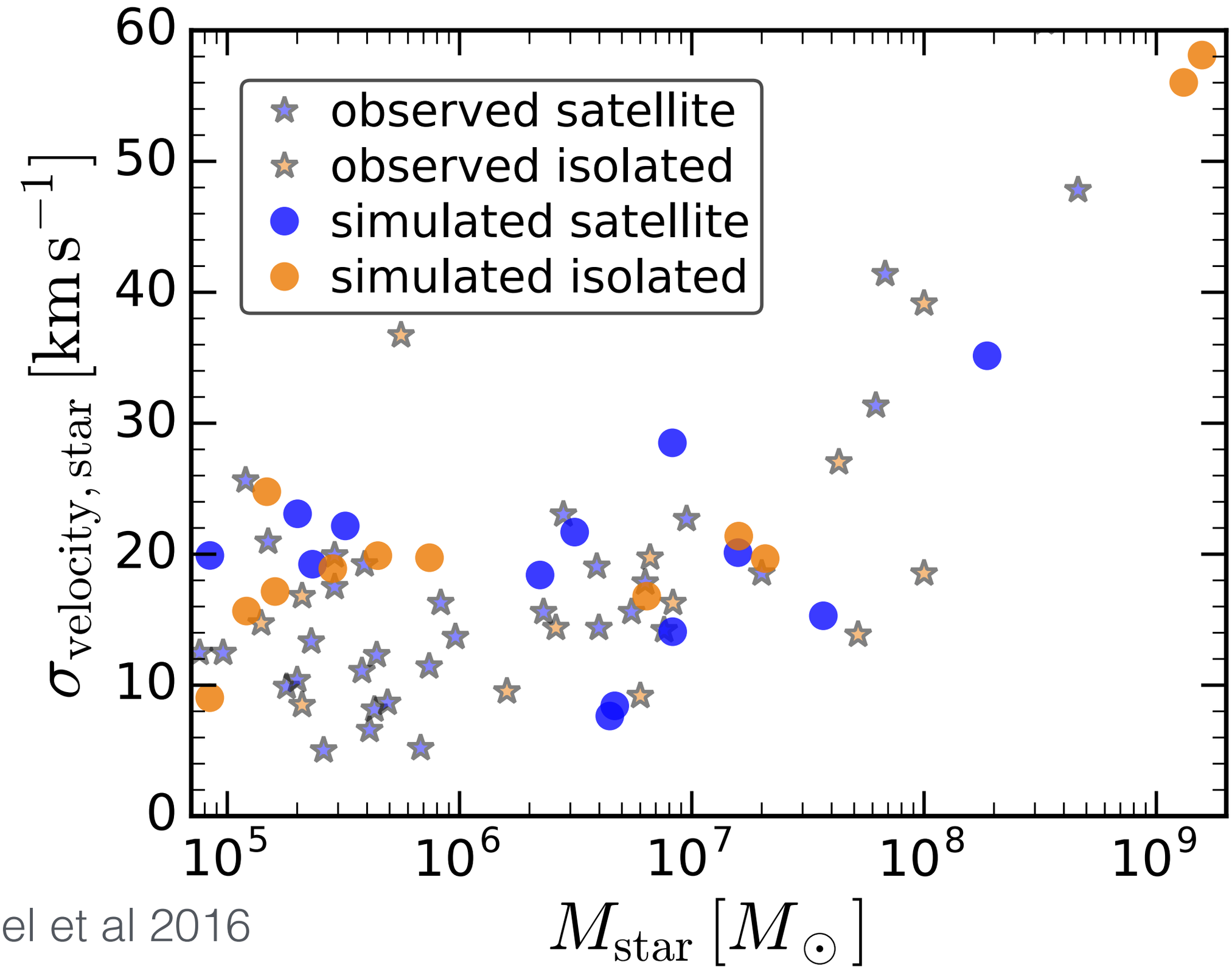

Wetzel et al 2016

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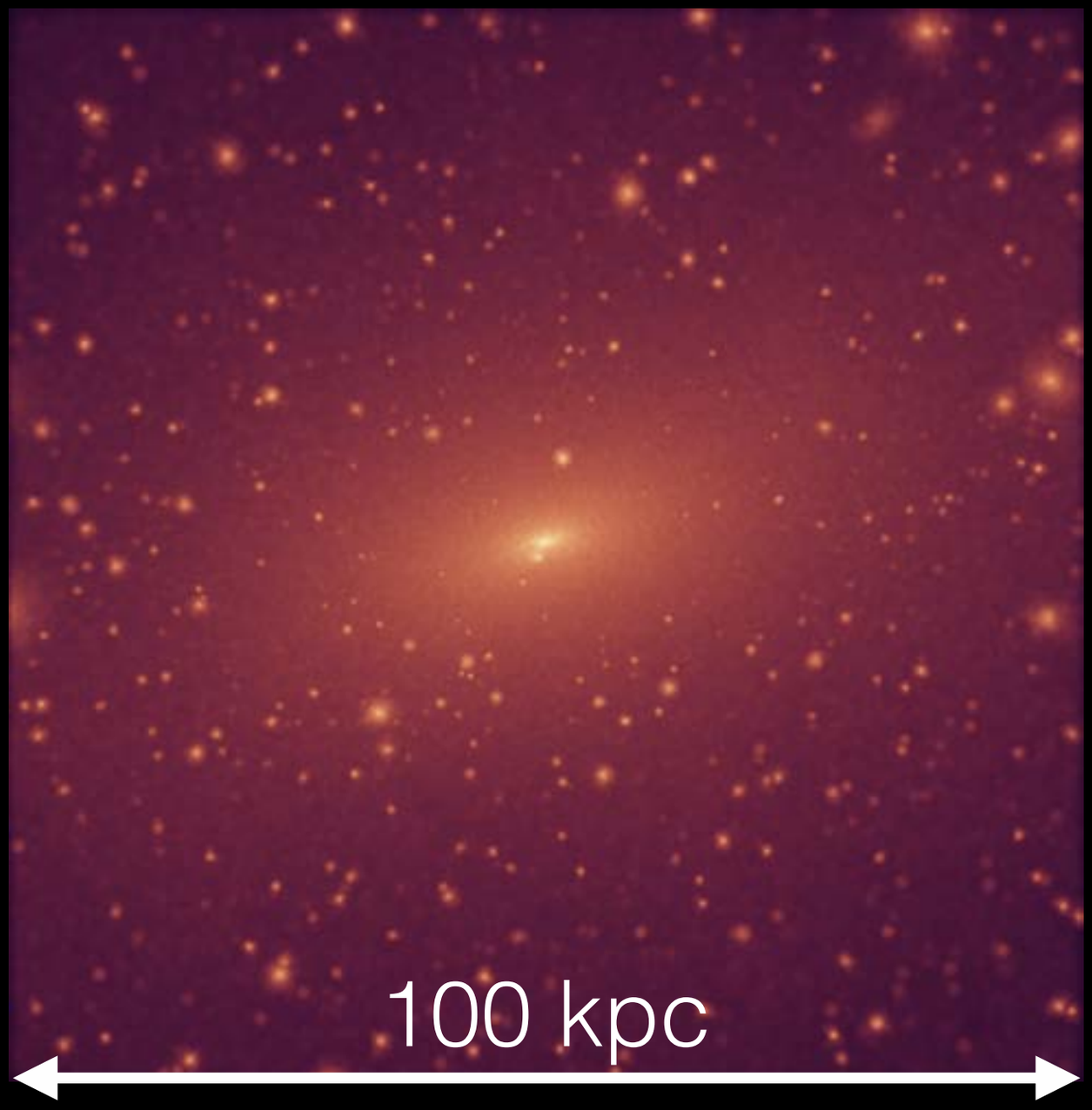
What causes the lack of (massive) satellite dwarf galaxies around the Milky Way-mass host?

1. Stellar feedback drives significant gas outflows that dynamically heat dark matter, reducing inner density of dark matter (cores)

2. Stellar disk of the Milky Way-mass host galaxy destroys satellites (via tidal shocking, etc)

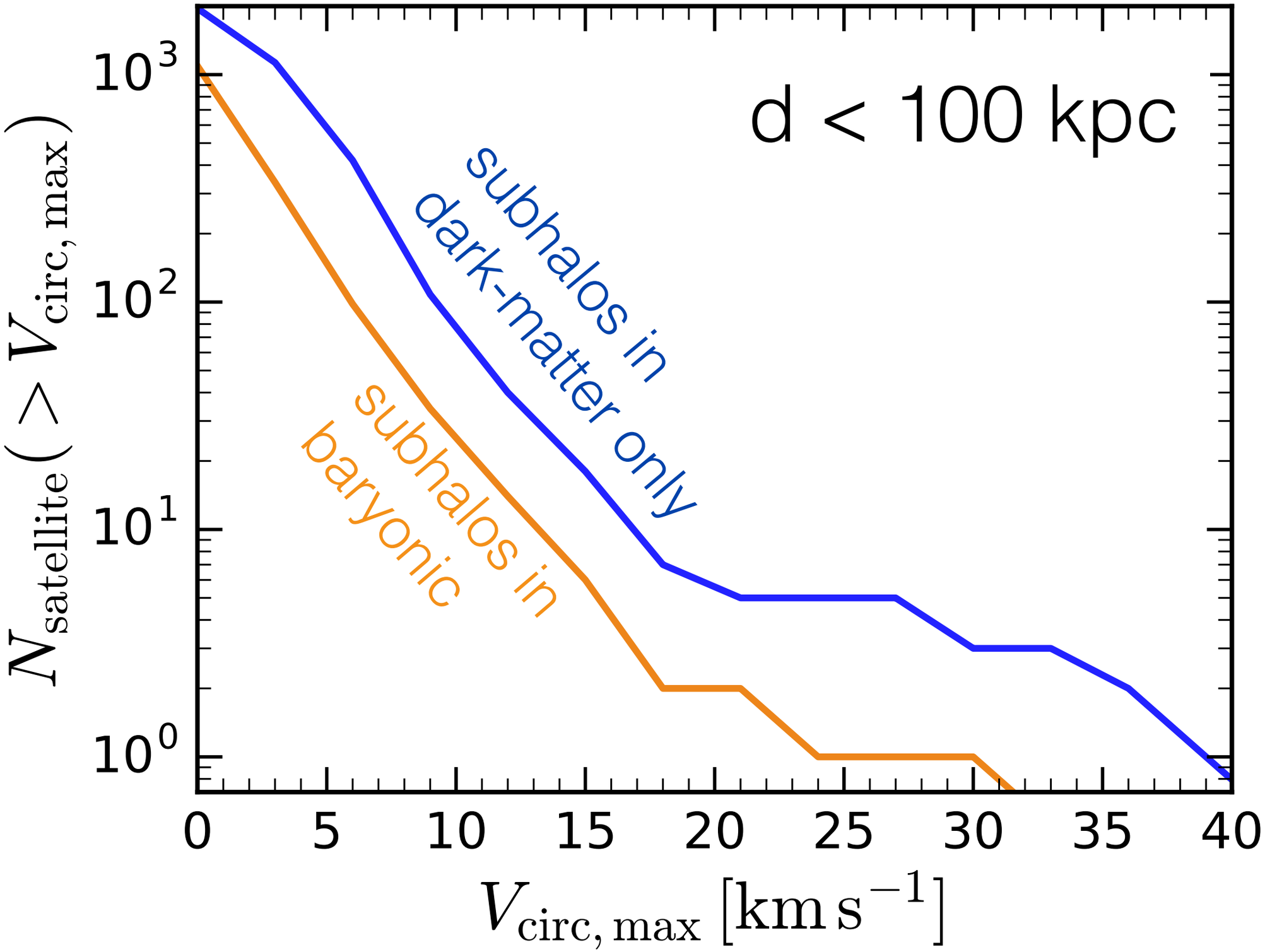
inclusion of baryons (stellar disk) destroys dark-matter subhalos

dark matter in dark-matter-only



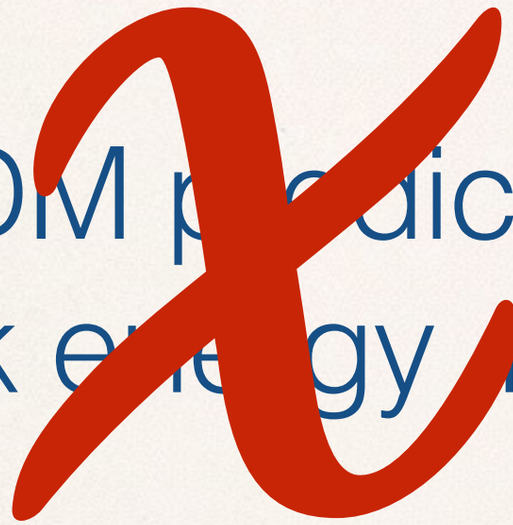
dark matter in baryonic simulation

dark-matter subhalo mass function



Garrison-Kimmel, Wetzel et al in prep

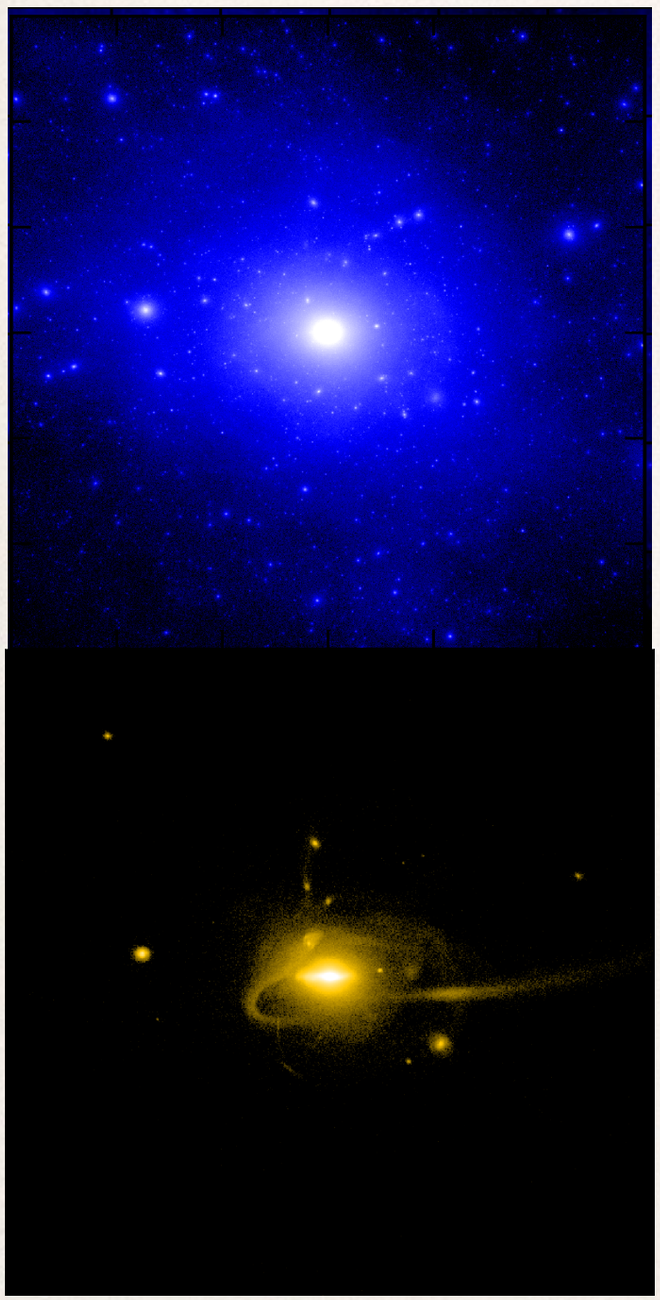
A Modest Proposal

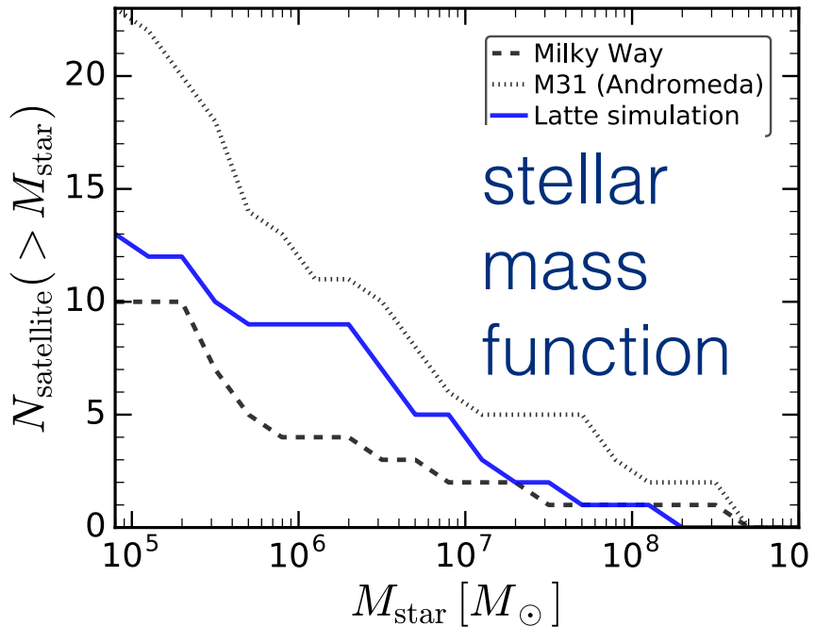


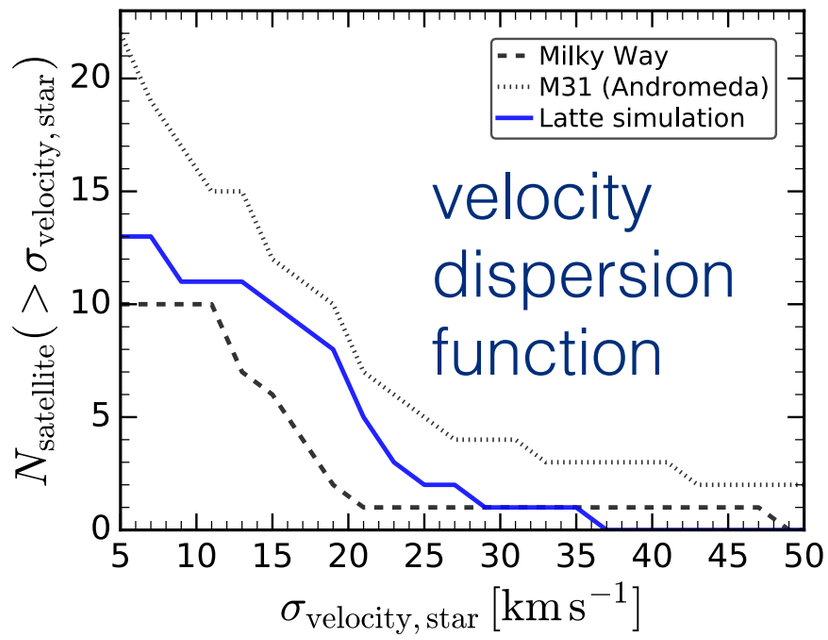
"LCDM predicts…"
(dark energy + cold dark matter)

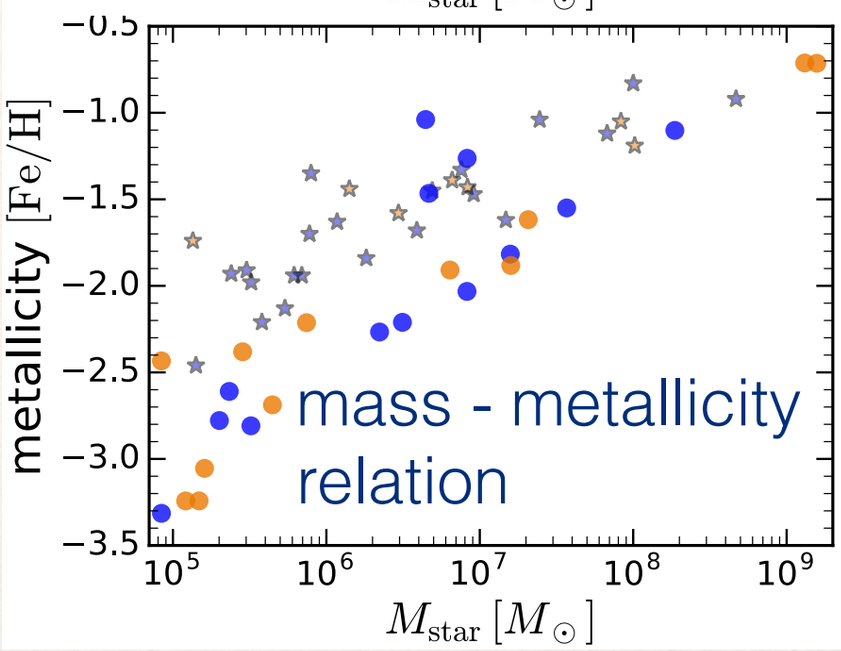
"LCDMB predicts…"
(dark energy + cold dark matter + baryons)

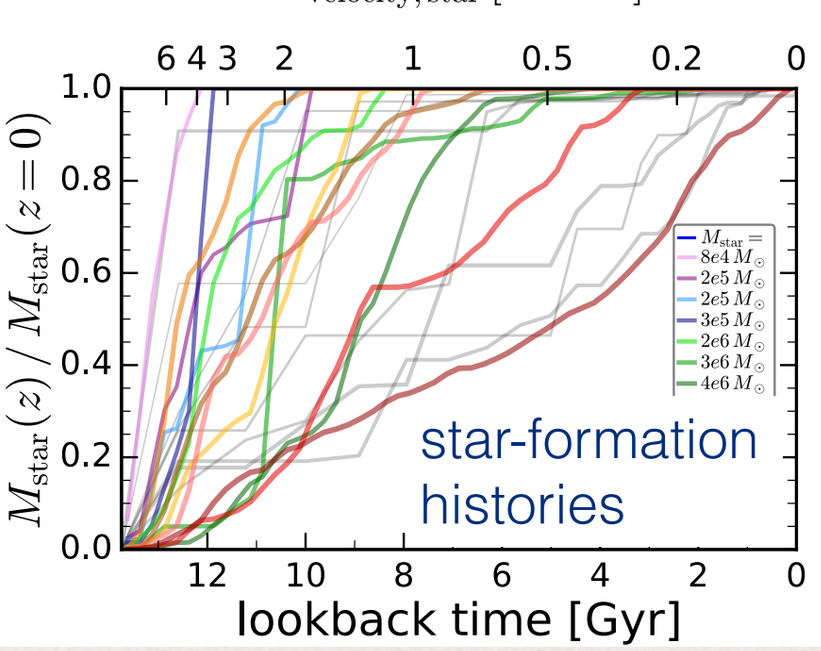
The Latte Project: the Milky Way on FIRE











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