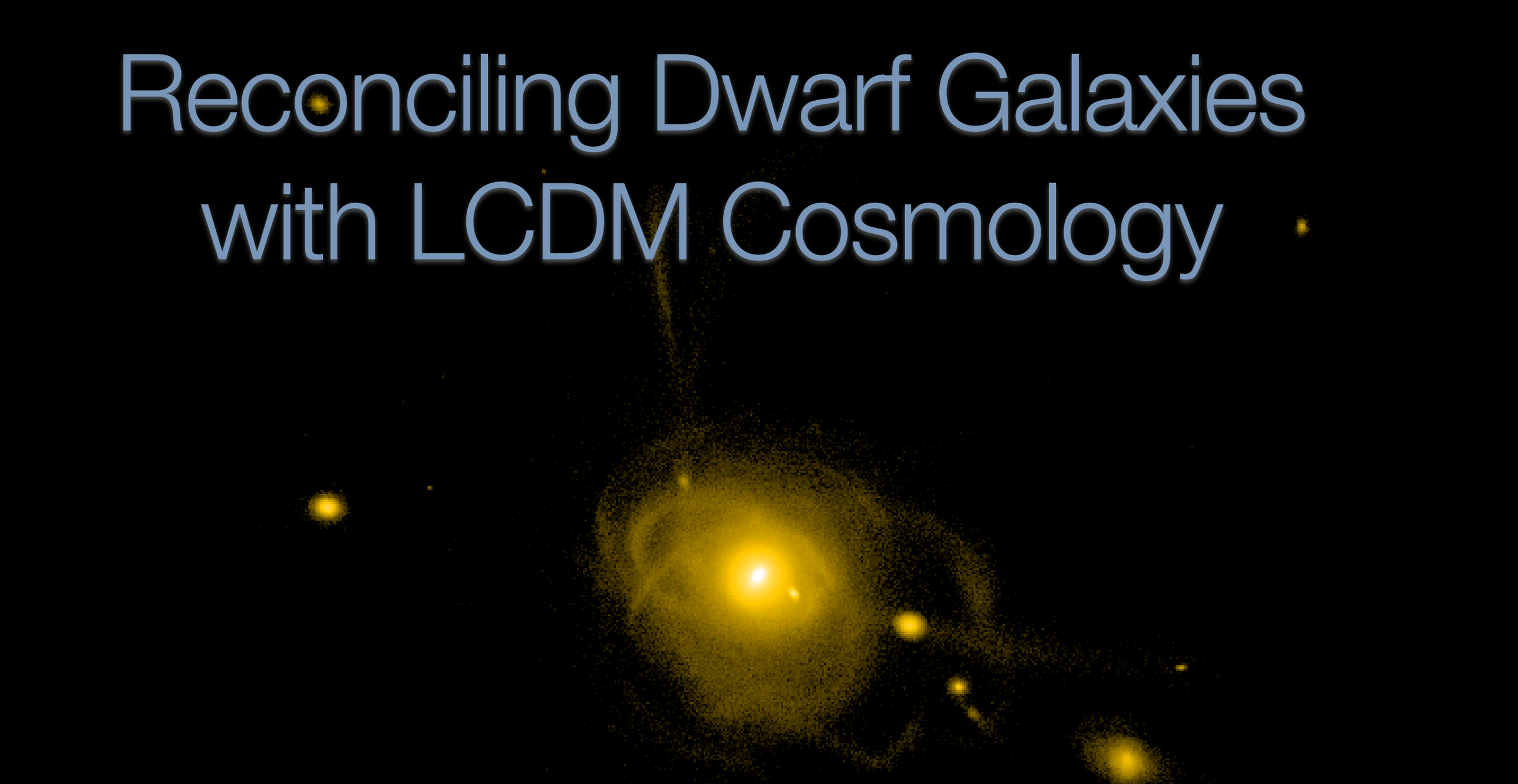
Reconciling Dwarf Galaxies with LCDM Cosmology



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The Carnegie Observatories

with the FIRE collaboration

Feedback In Realistic Environments

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

“missing satellites” problem
(probably) too few observed satellite galaxies compared with dark-matter subhalos in CDM

“too big to fail” problem
dark-matter subhalos in CDM are too dense compared with observed satellite galaxies

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

“missing satellites” problem

(probably) too few observed satellite galaxies compared with dark-matter subhalos in CDM

—> Can a CDM-based model produce a satellite stellar mass function as observed?

“too big to fail” problem

dark-matter subhalos in CDM are too dense compared with observed satellite galaxies

—> Can a CDM-based model produce a satellite dynamical mass (velocity dispersion) function as observed?

The Latte Project: the Milky Way on FIRE

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

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

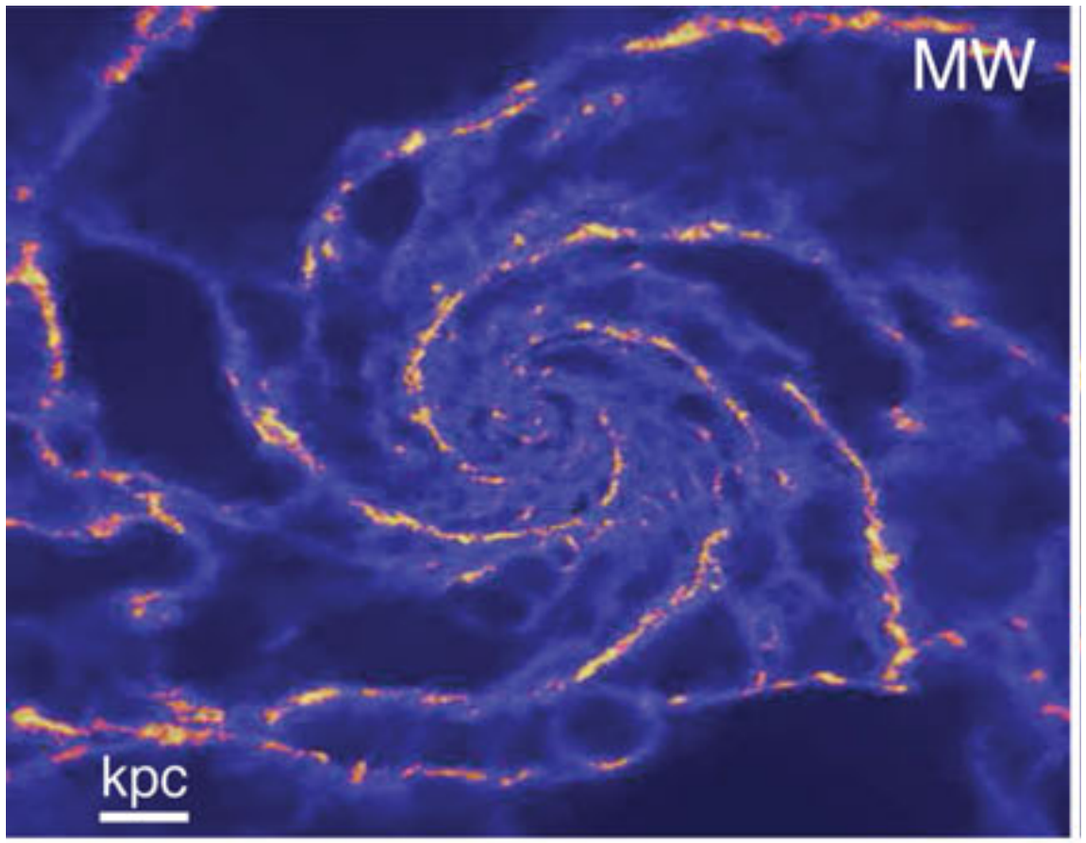
FIRE

Feedback In Realistic Environments

FIRE model for star formation

Feedback In Realistic Environments

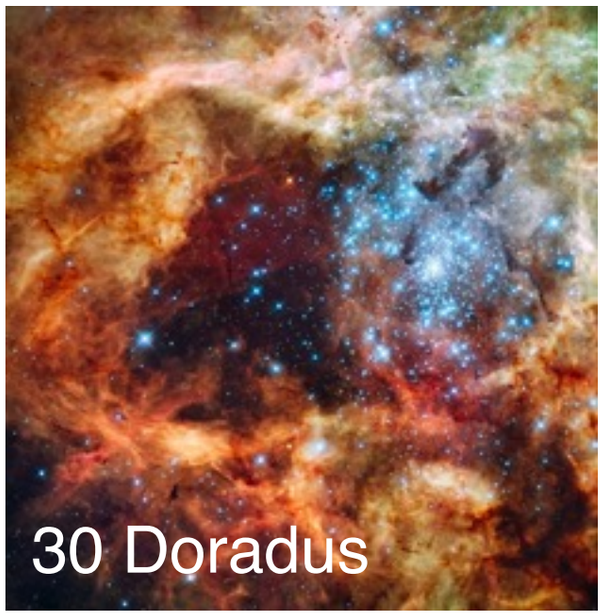
- High resolution to capture structure of multi-phase inter-stellar medium
  - m_{gas} = 7070 M_{sun}
  - h_{gas} = 1 pc (min), 25 pc (typical)
  - h_{dm} = 20 pc
  - $t_{step,min}$ = 180 yr



- Cooling from atoms, molecules, and 9 metals down to 10 K
- Star formation only in self-gravitating clouds

FIRE model for stellar feedback

Feedback In Realistic Environments



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

- Explicit Momentum Flux:
  - Radiation Pressure

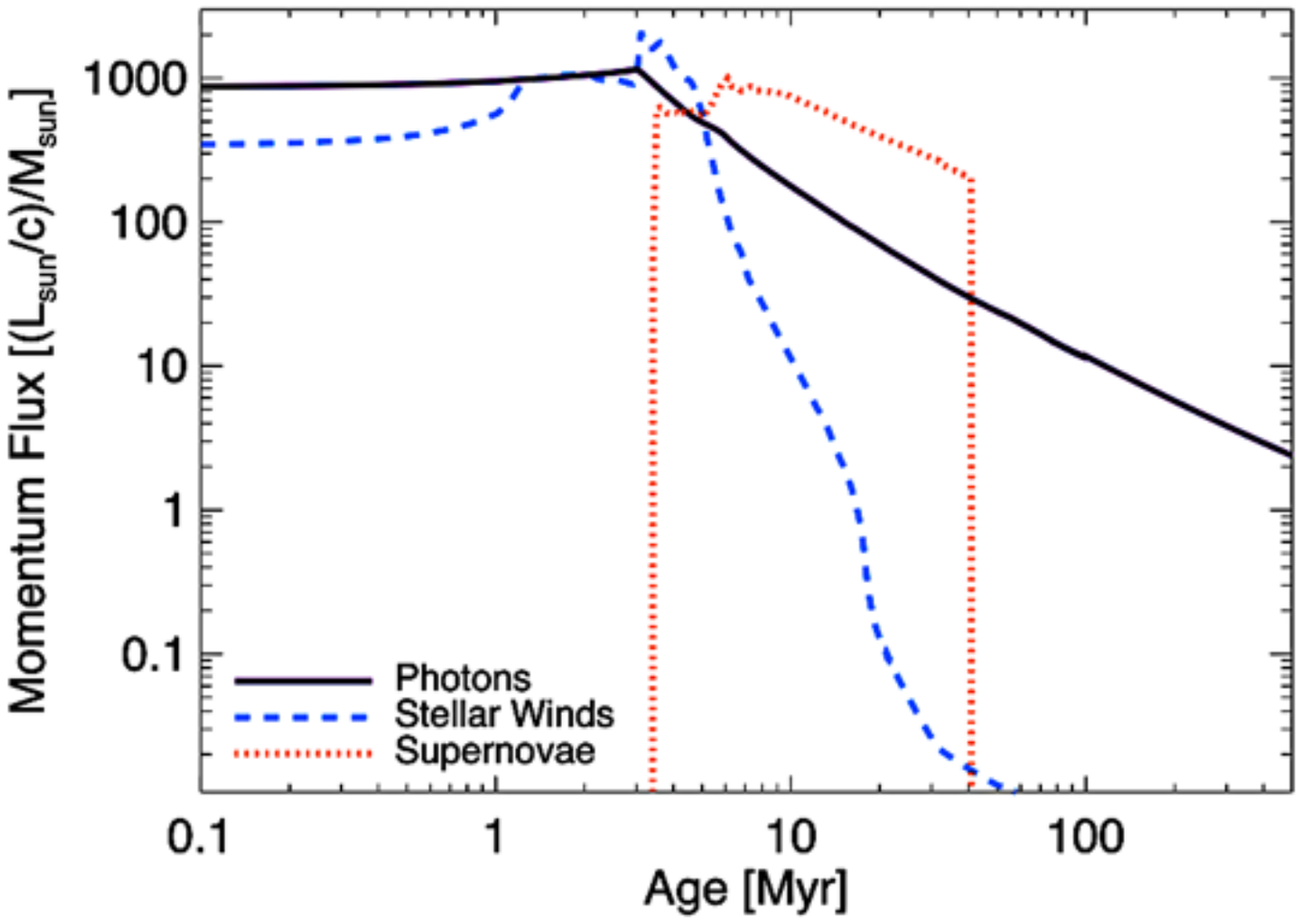
$$\dot{P}_{\rm rad} \sim \frac{L}{c}\,(1+\tau_{\rm IR})$$

  - Supernovae

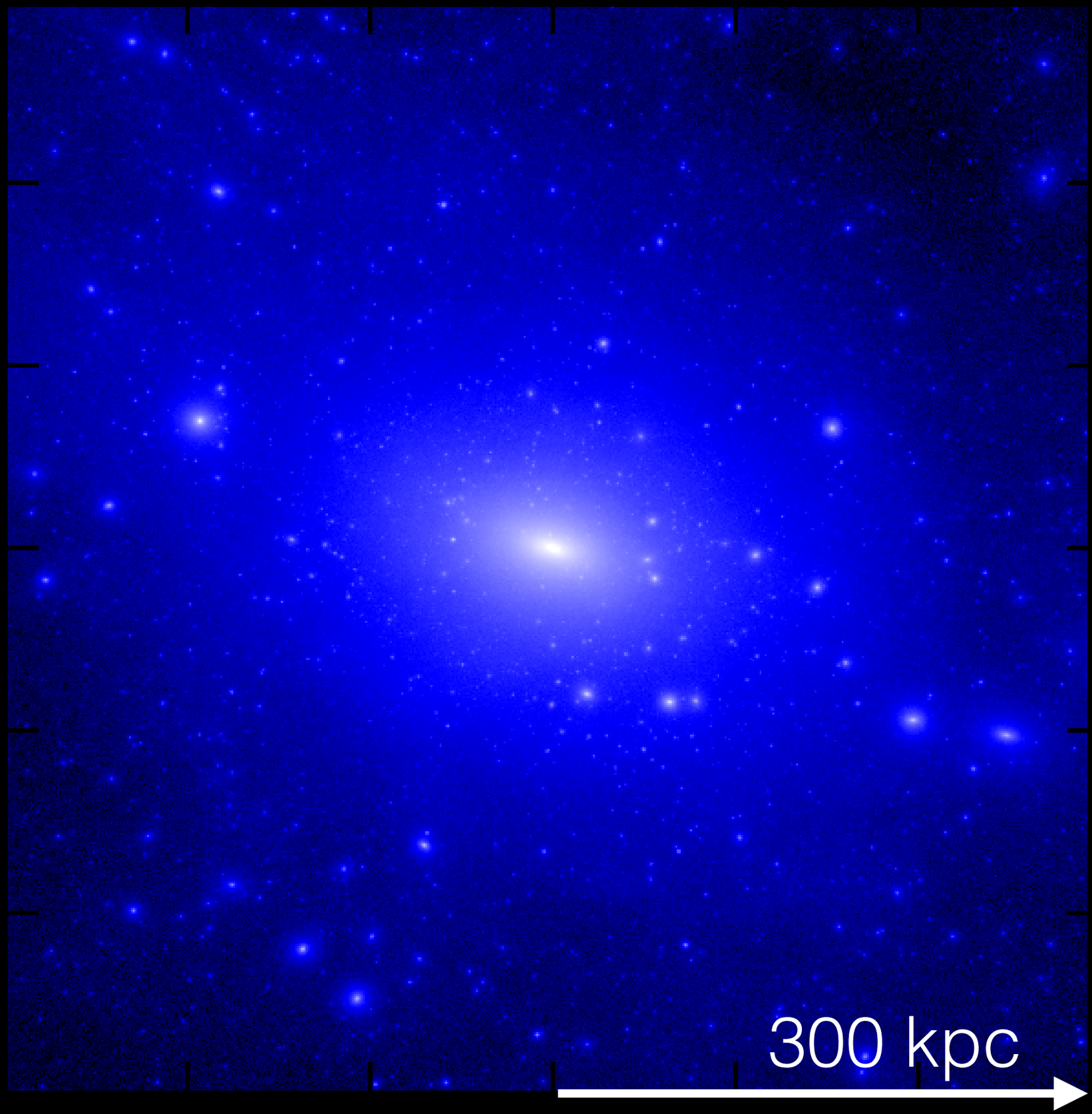
$$\dot{P}_{\rm SNe} \sim \dot{E}_{\rm SNe}\,v_{\rm ejecta}^{-1}$$

  - Stellar Winds

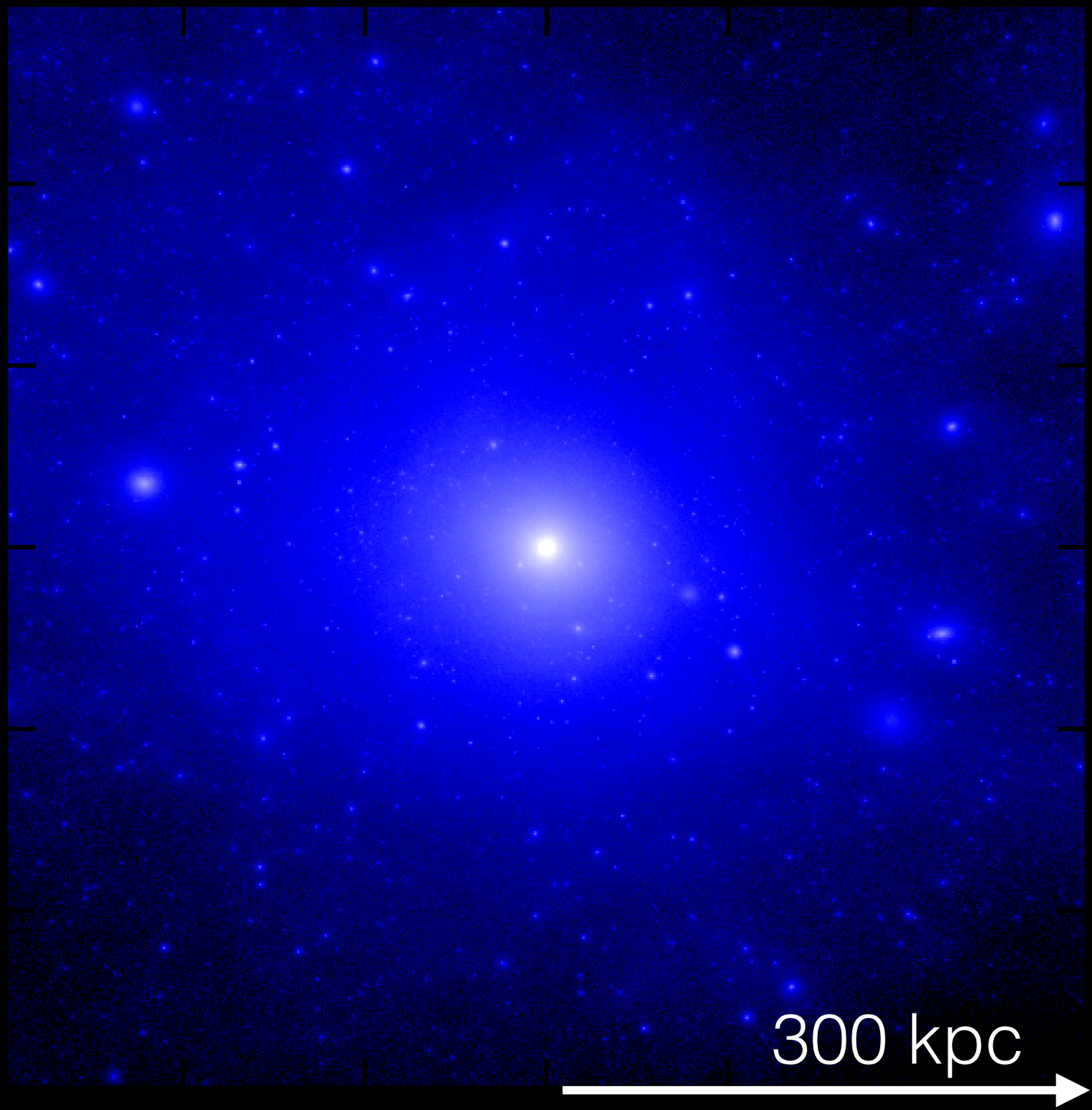
$$\dot{P}_{\rm W} \sim \dot{M}\,v_{\rm wind}$$



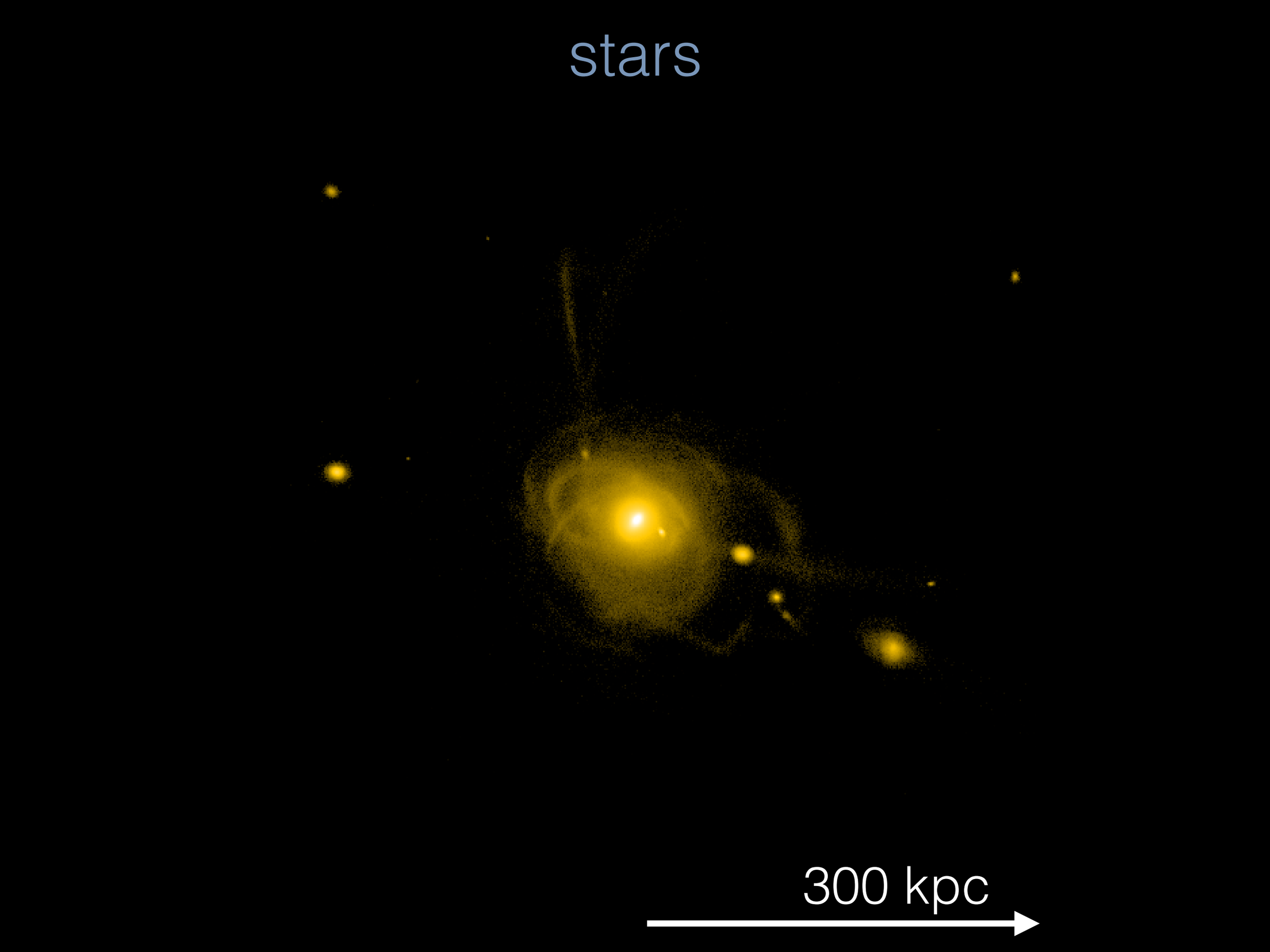
dark matter-only simulation

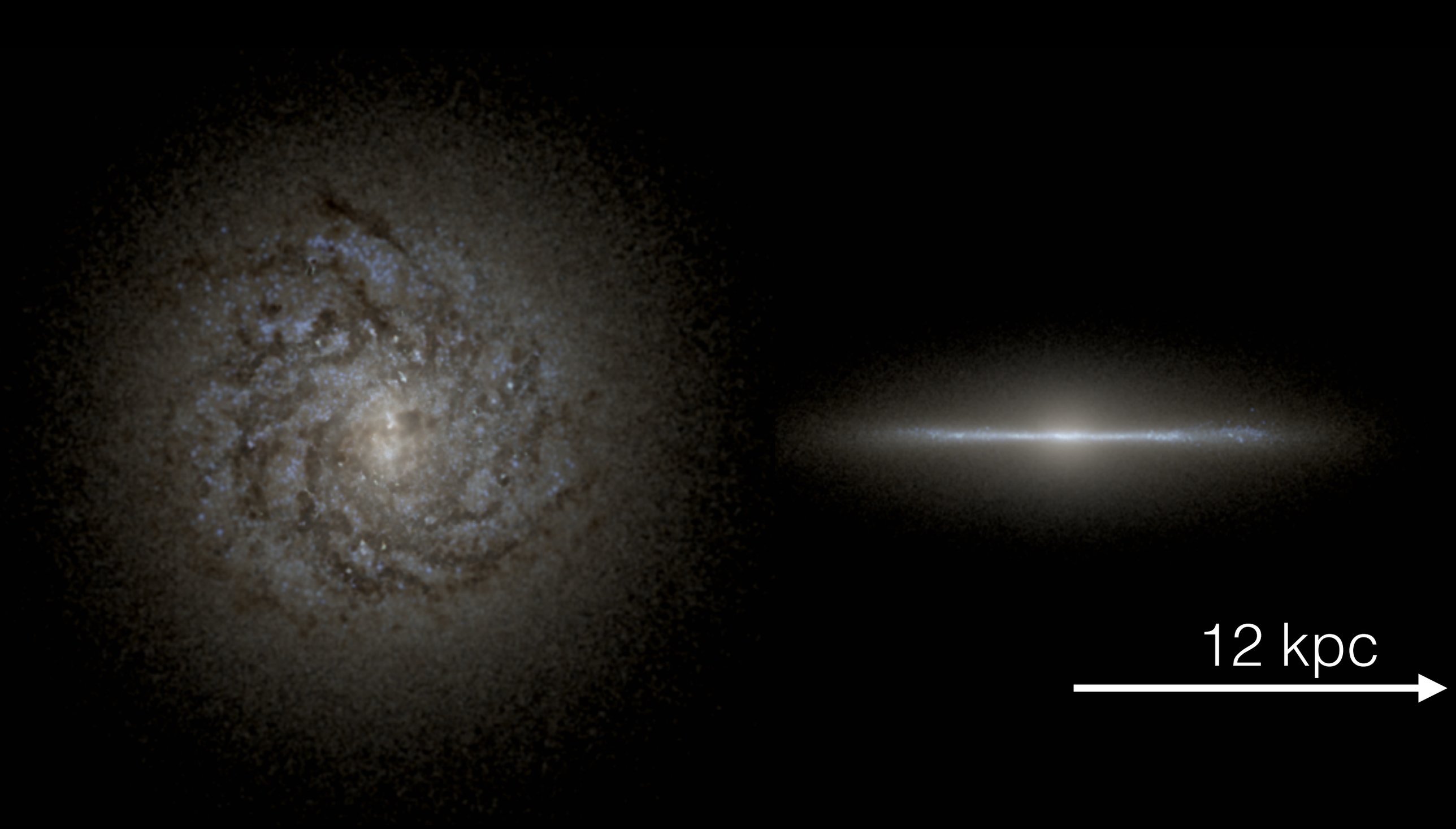


dark matter with effects of baryons



stars

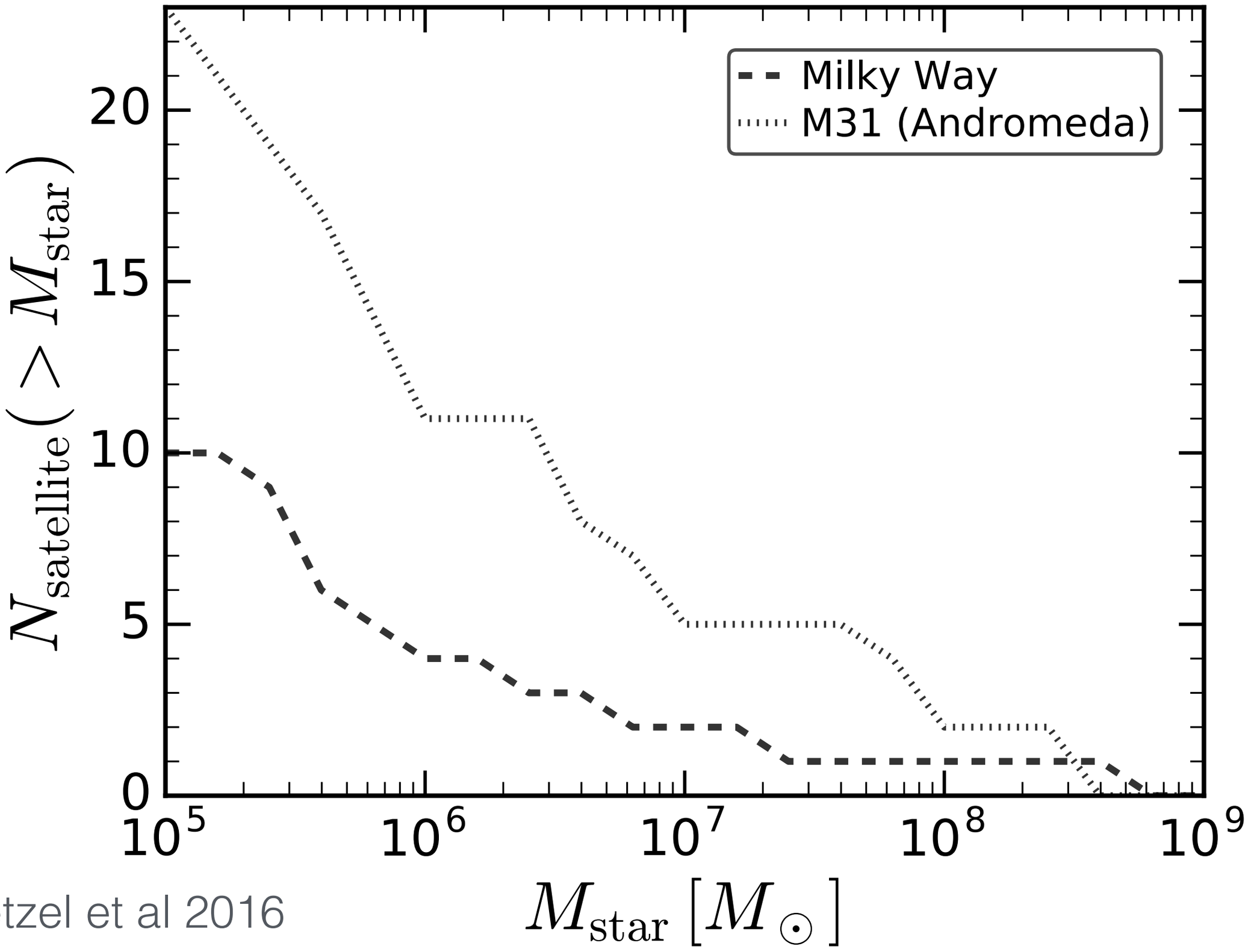




$M_{star} = 9x10^{10}\,M_{sun}$

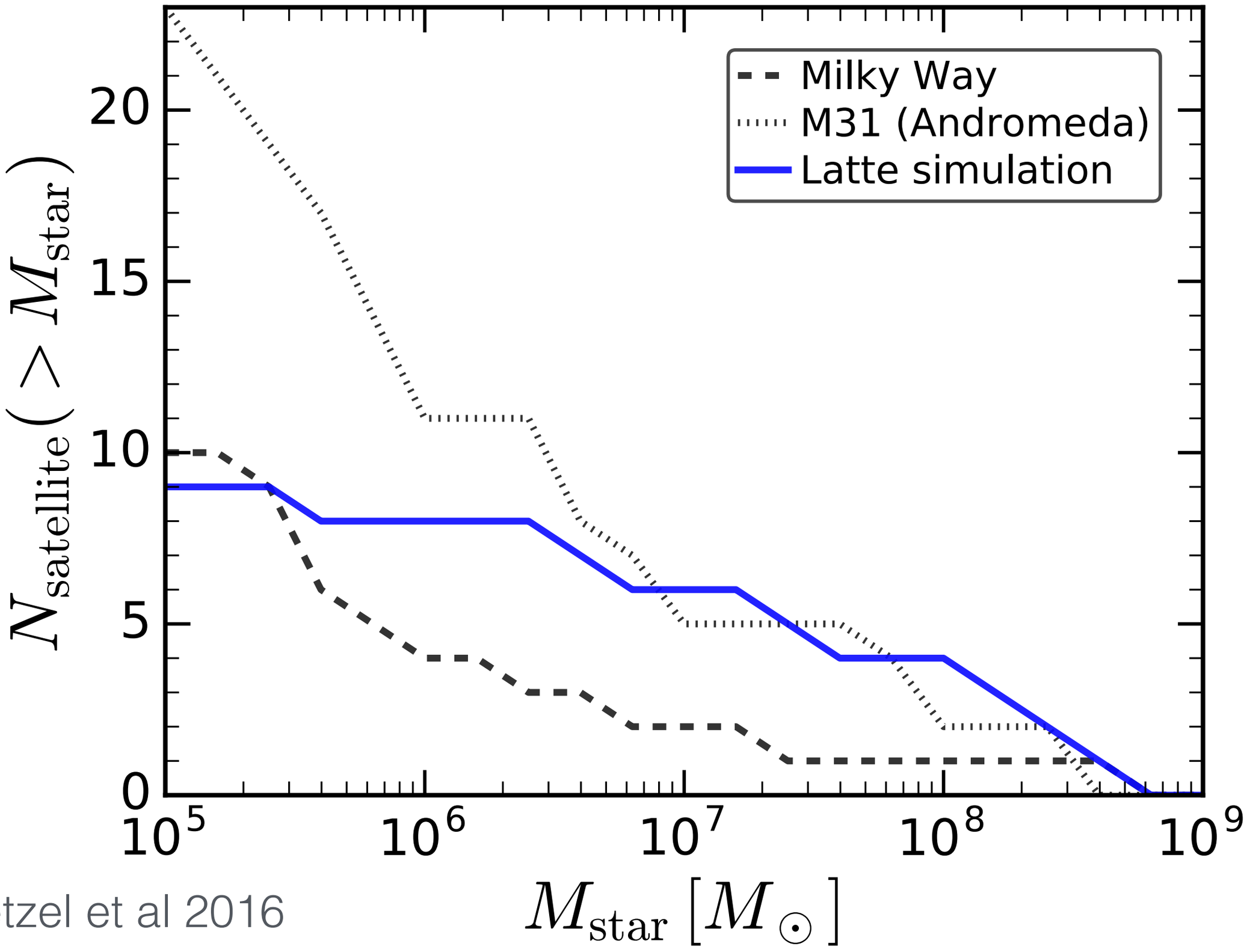
$SFR = 3.4\,M_{sun}/yr$

stellar mass function of satellites



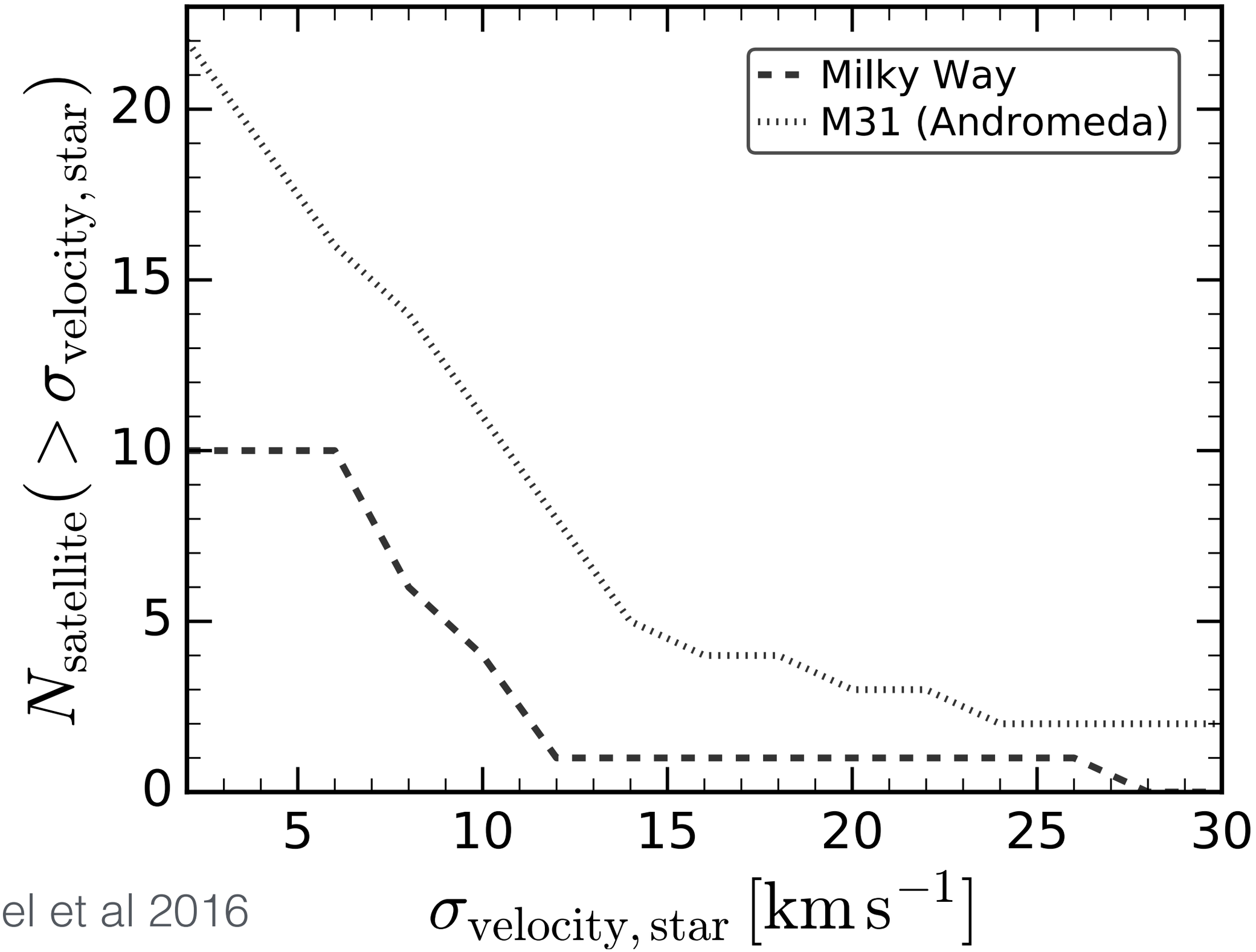
Wetzel et al 2016

stellar mass function of satellites



Wetzel et al 2016

stellar velocity dispersion function of satellites



Wetzel et al 2016

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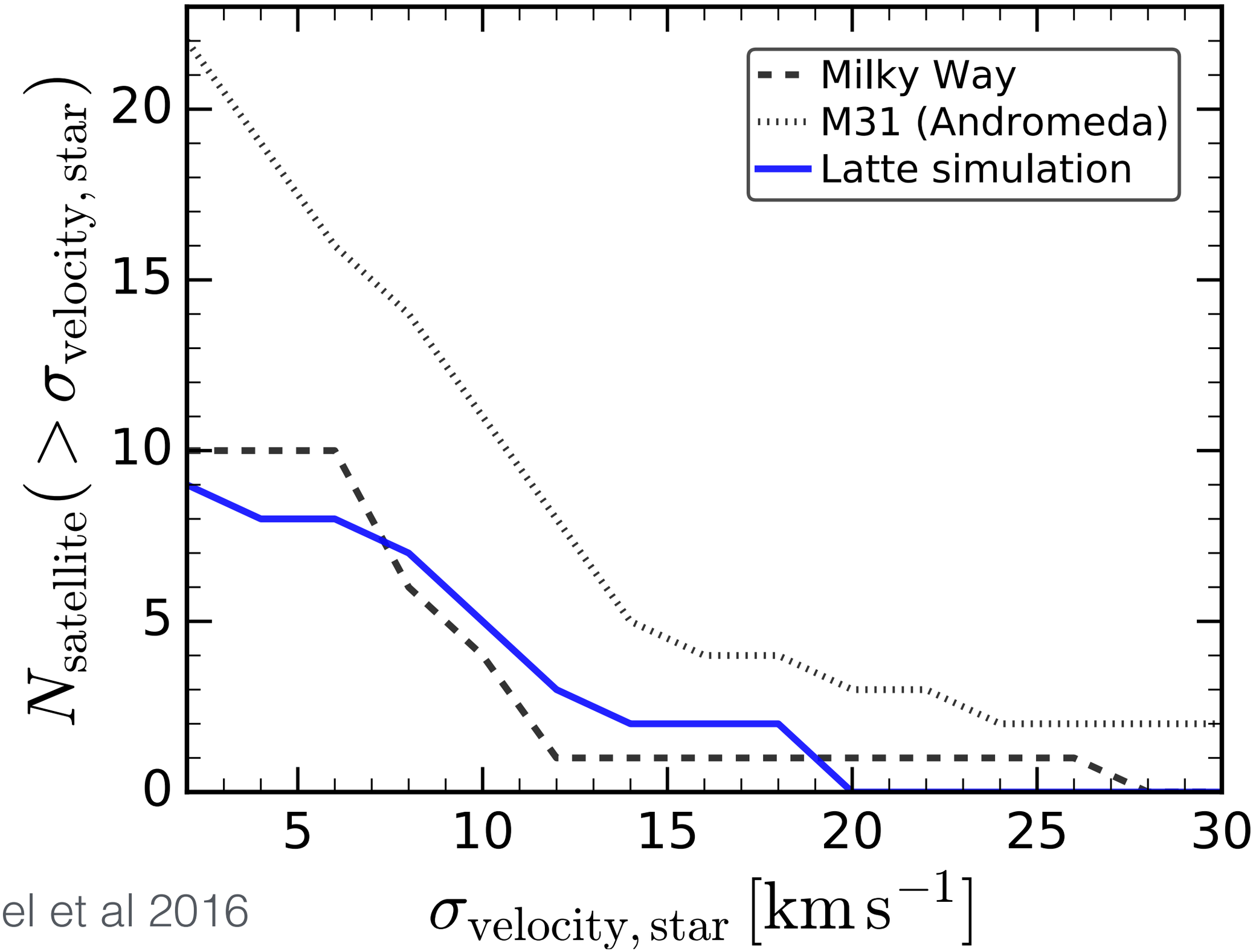
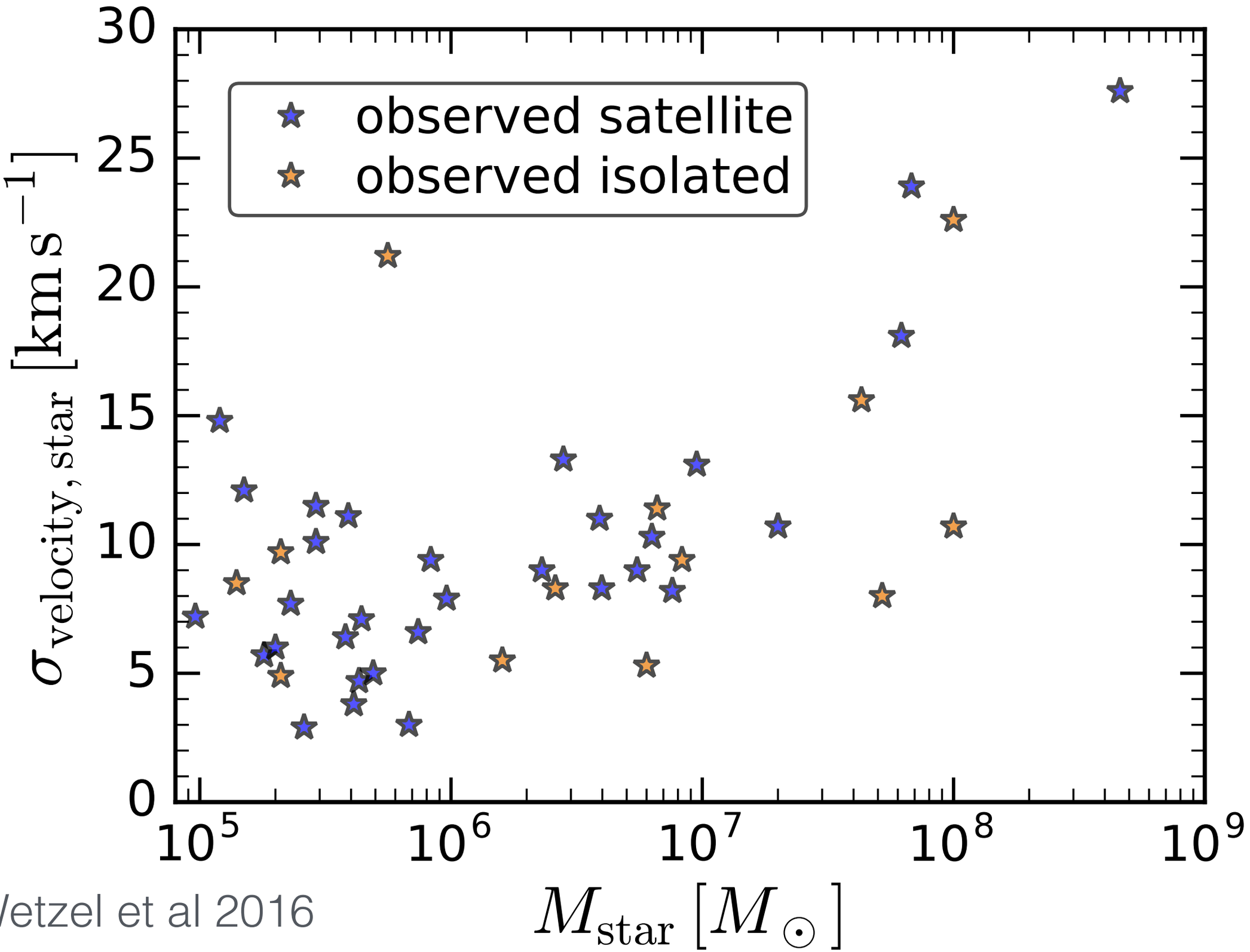


Wetzel et al 2016

velocity dispersion - mass relation



Wetzel et al 2016

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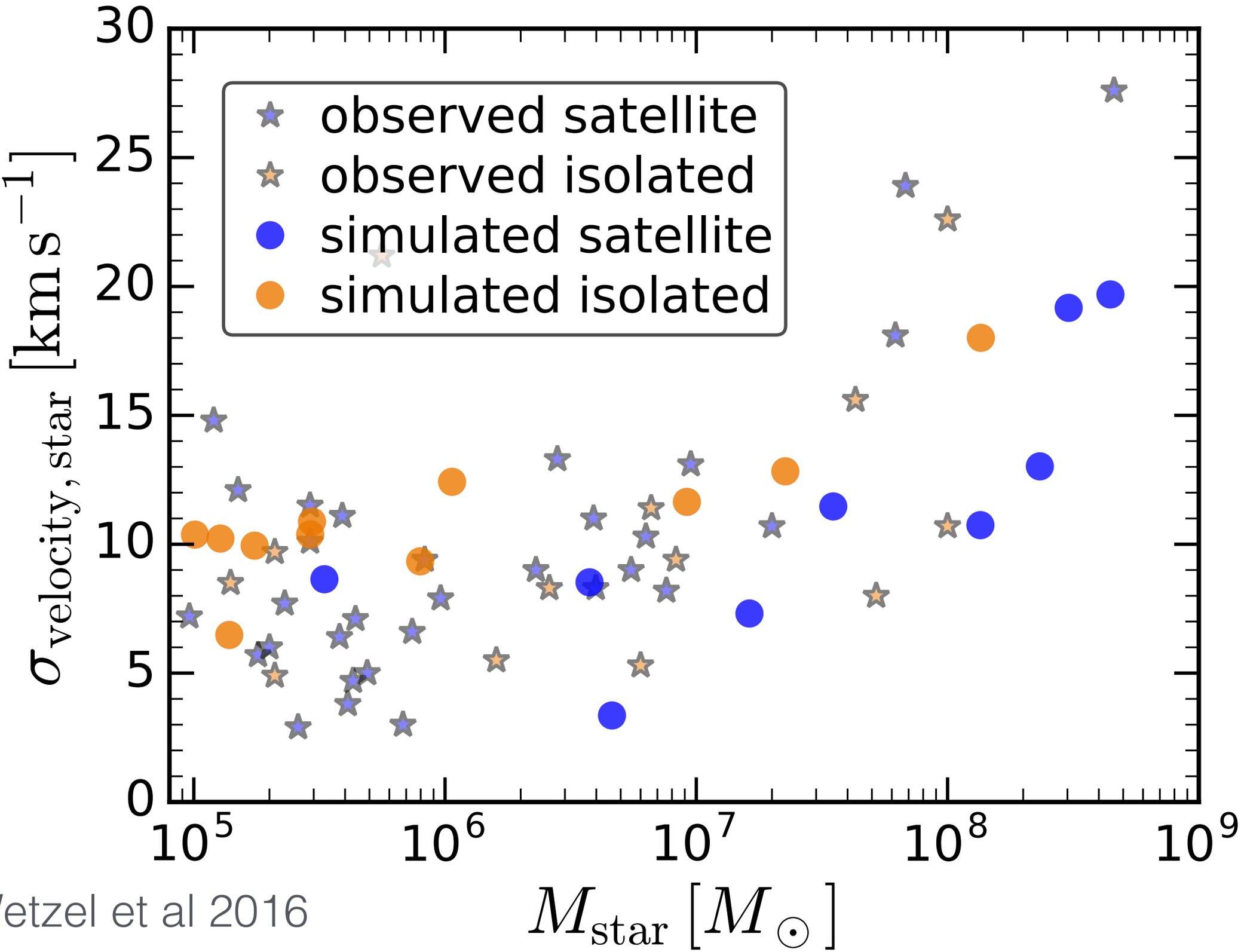
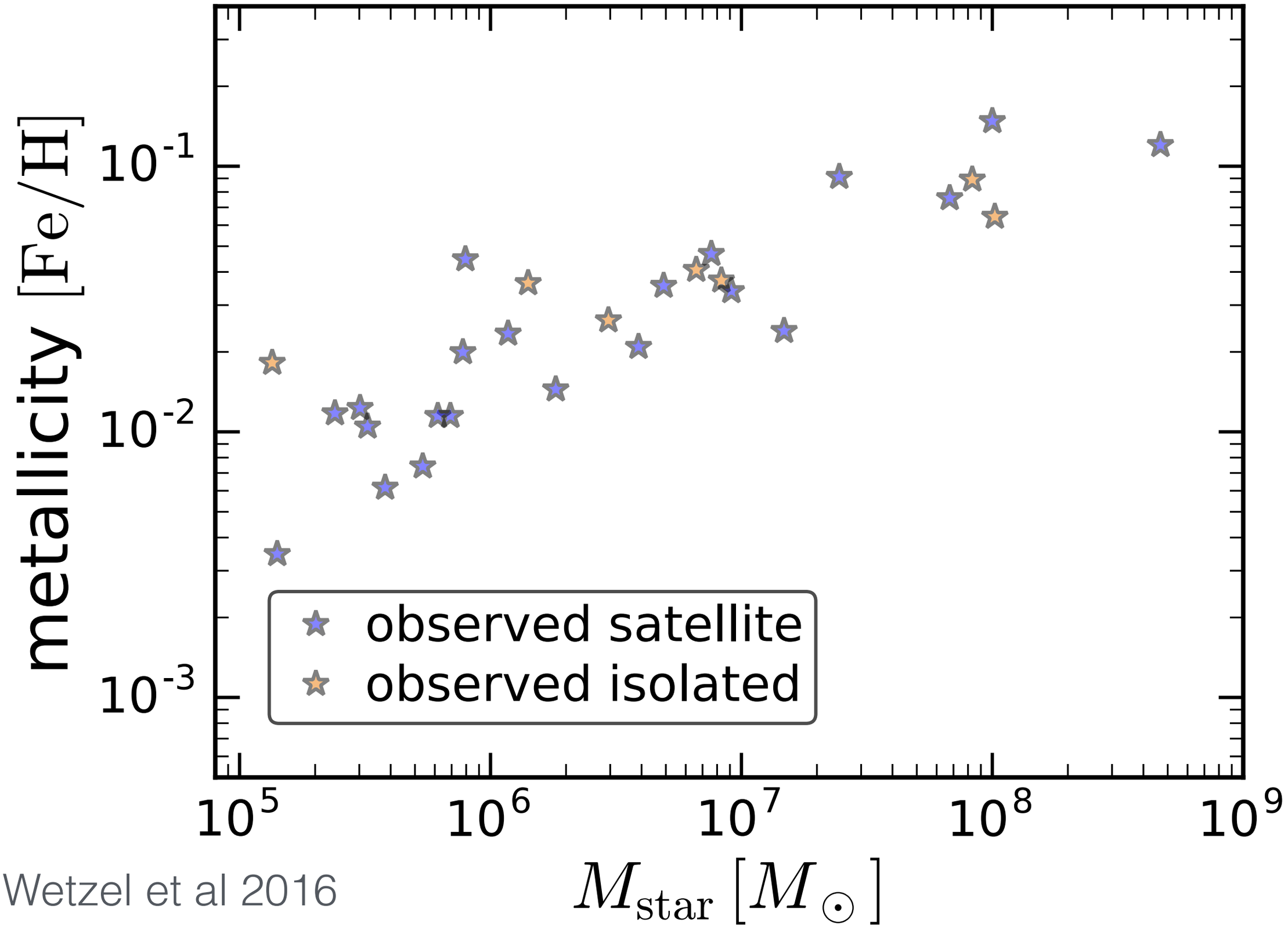


Wetzel et al 2016

mass - metallicity relation



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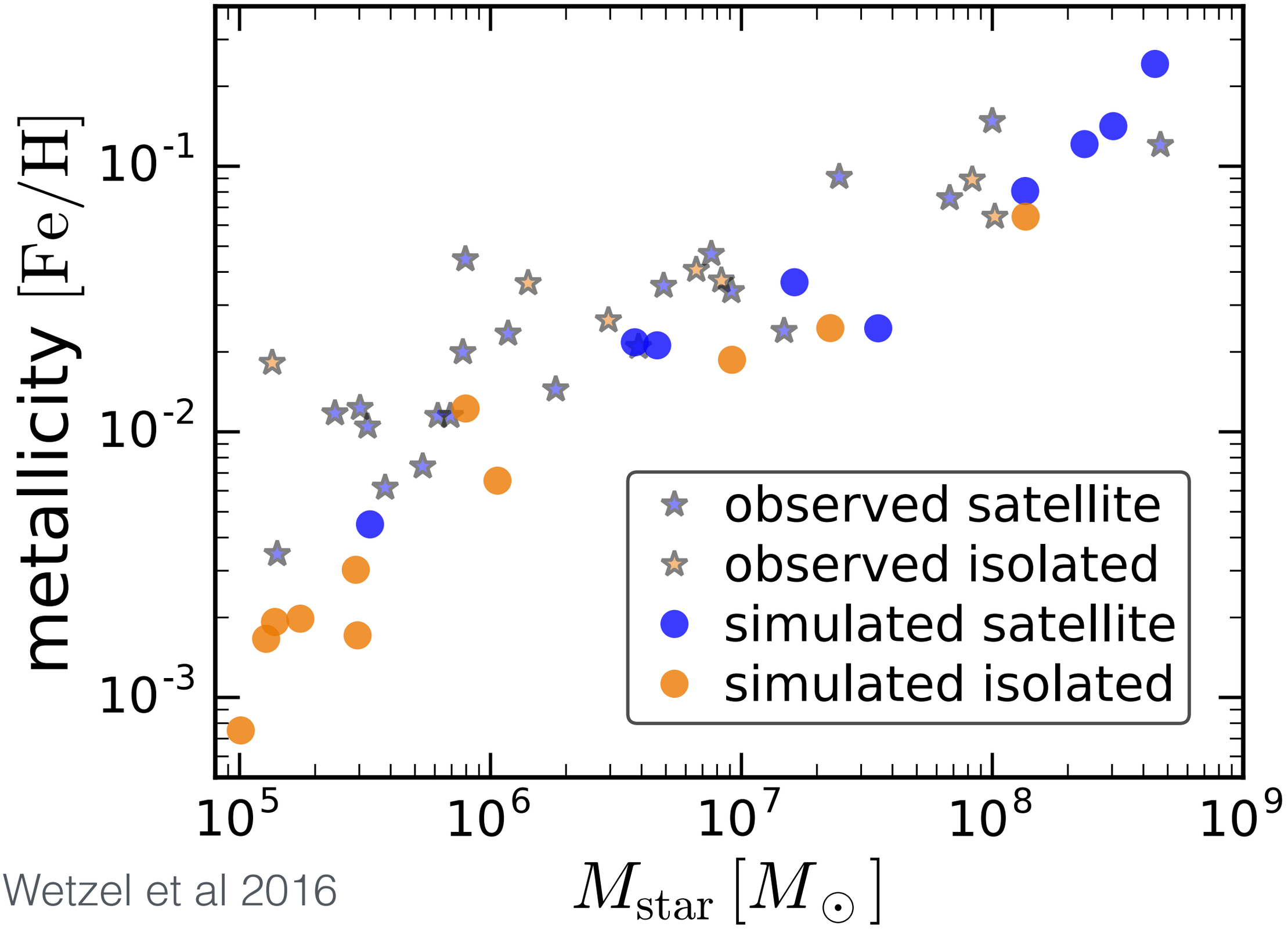
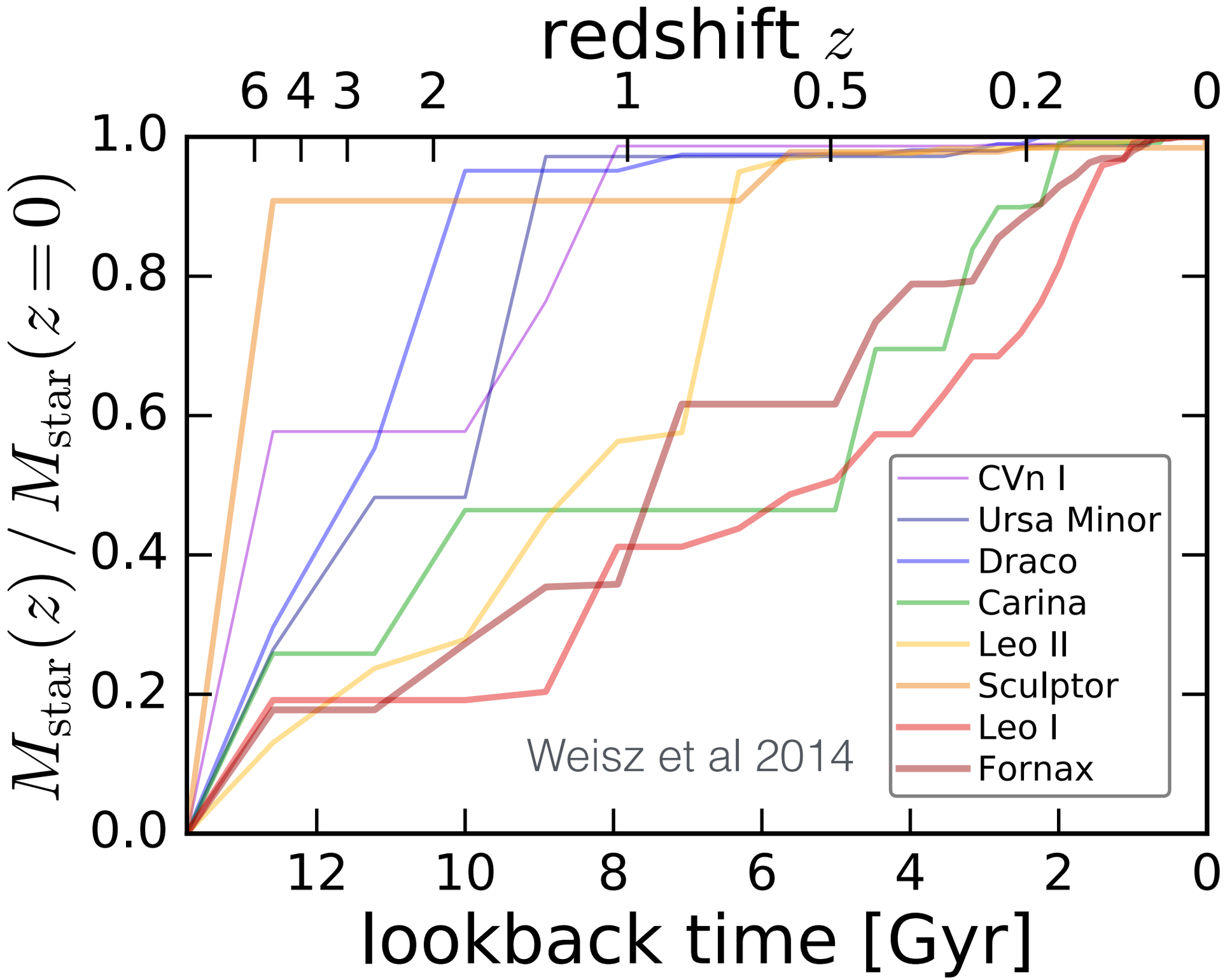


Wetzel et al 2016

diverse range of star-formation histories of satellite dwarf galaxies



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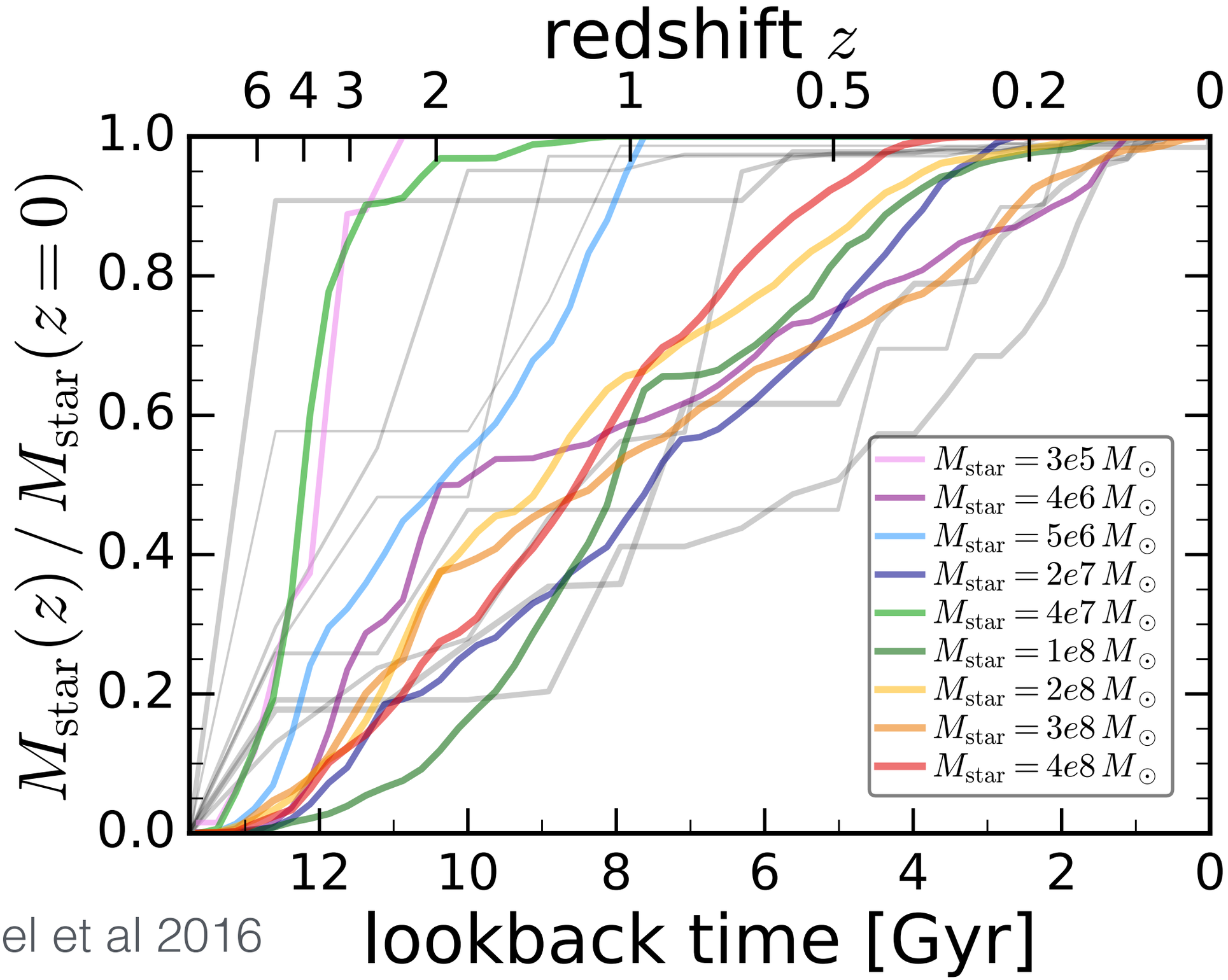
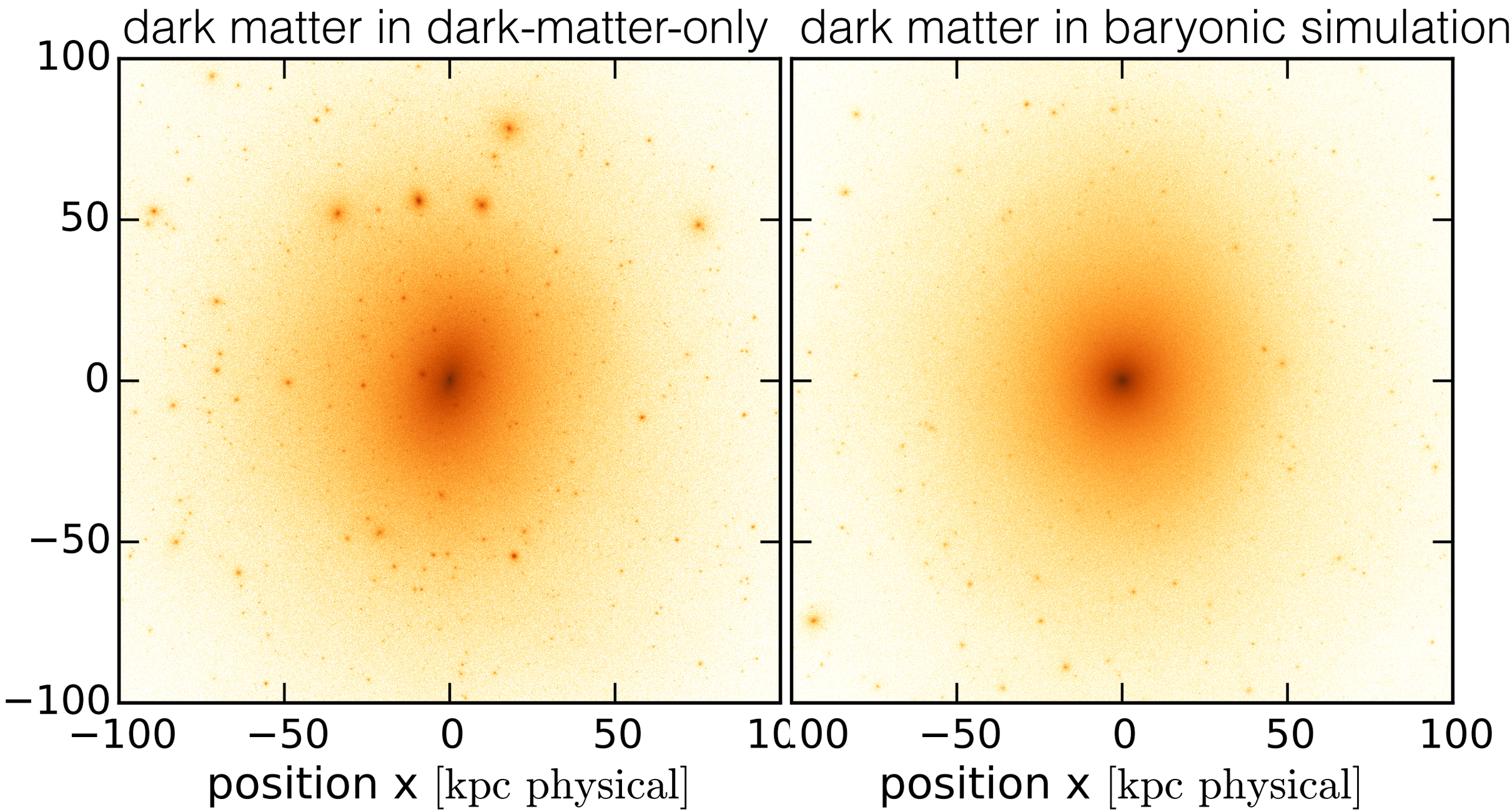


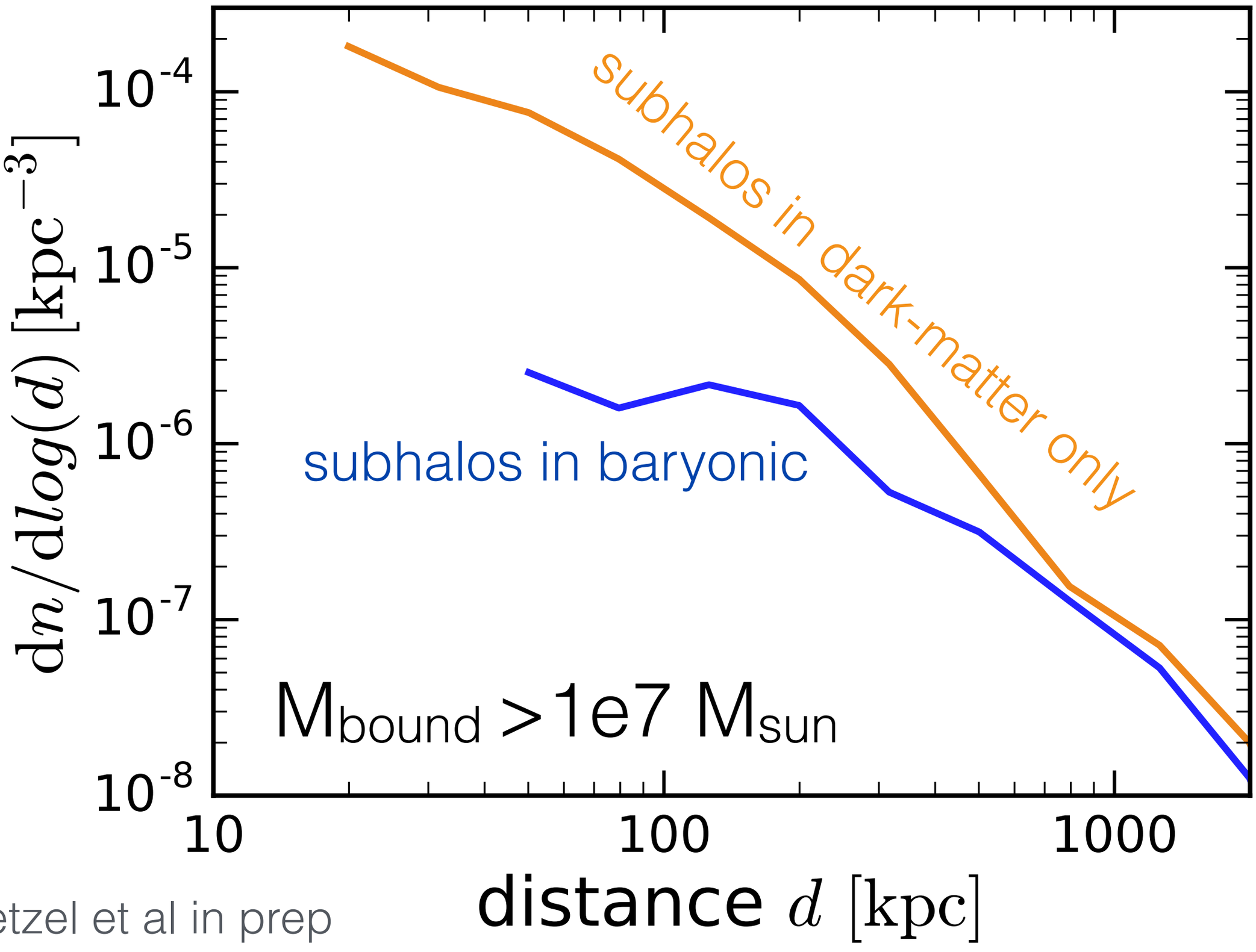
Wetzel et al 2016

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

inclusion of baryons destroys dark-matter subhalos

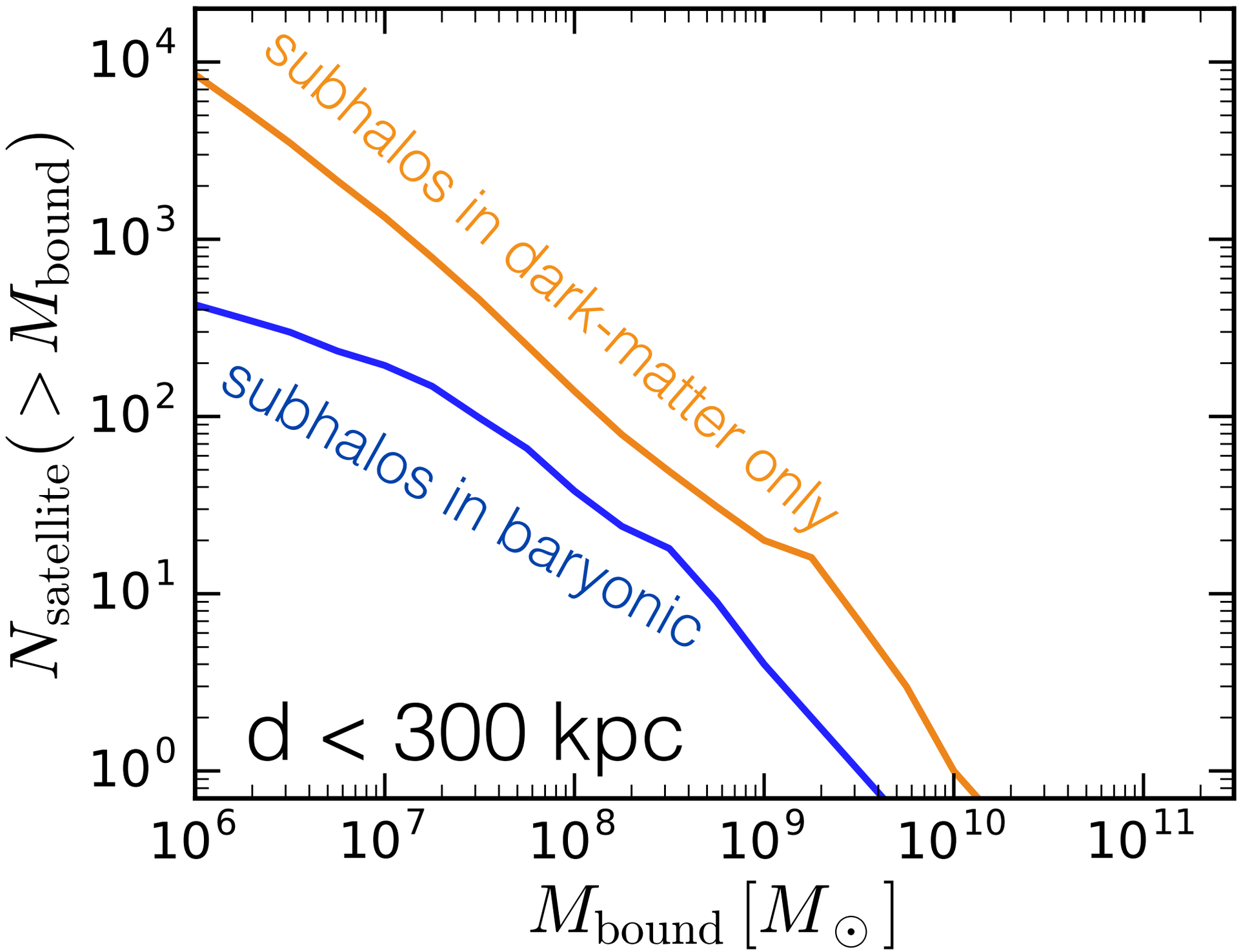


subhalo number density profile



Wetzel et al in prep

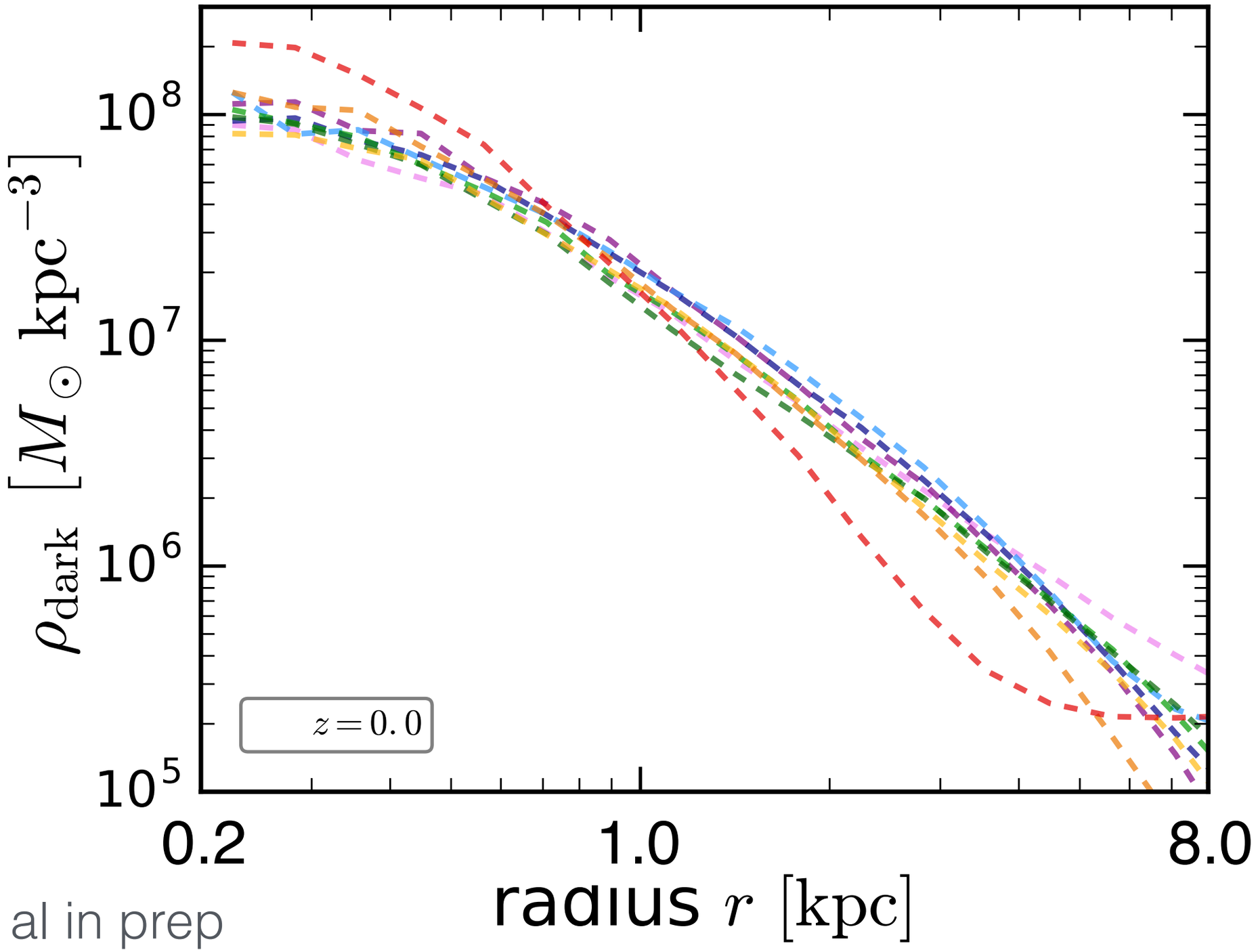
dark-matter subhalo mass function



Wetzel et al in prep

see also, e.g., Zhu et al 2016, Sawala et al 2016

stellar feedback drives gas outflows/inflows that can produce dark-matter cores



Wetzel et al in prep

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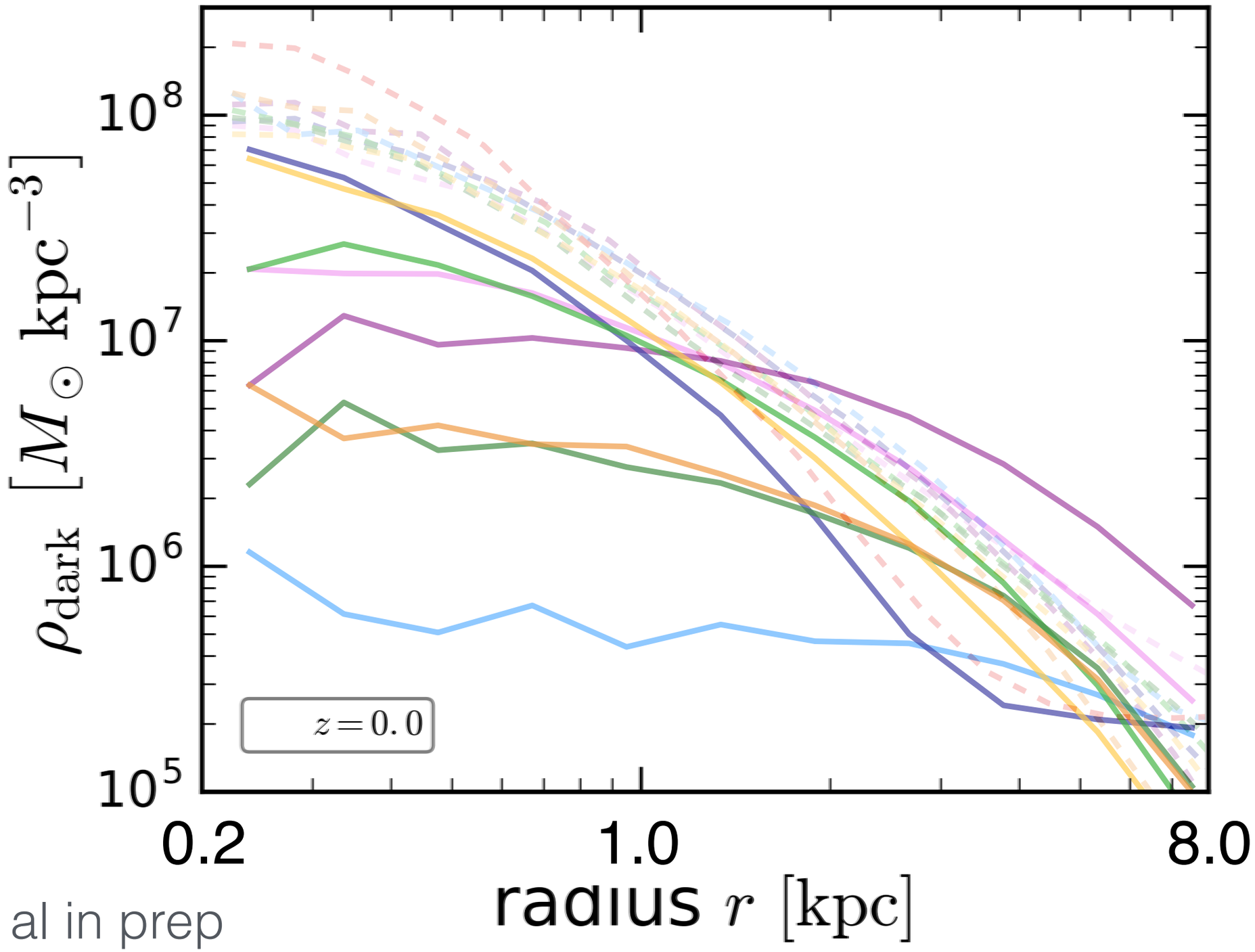
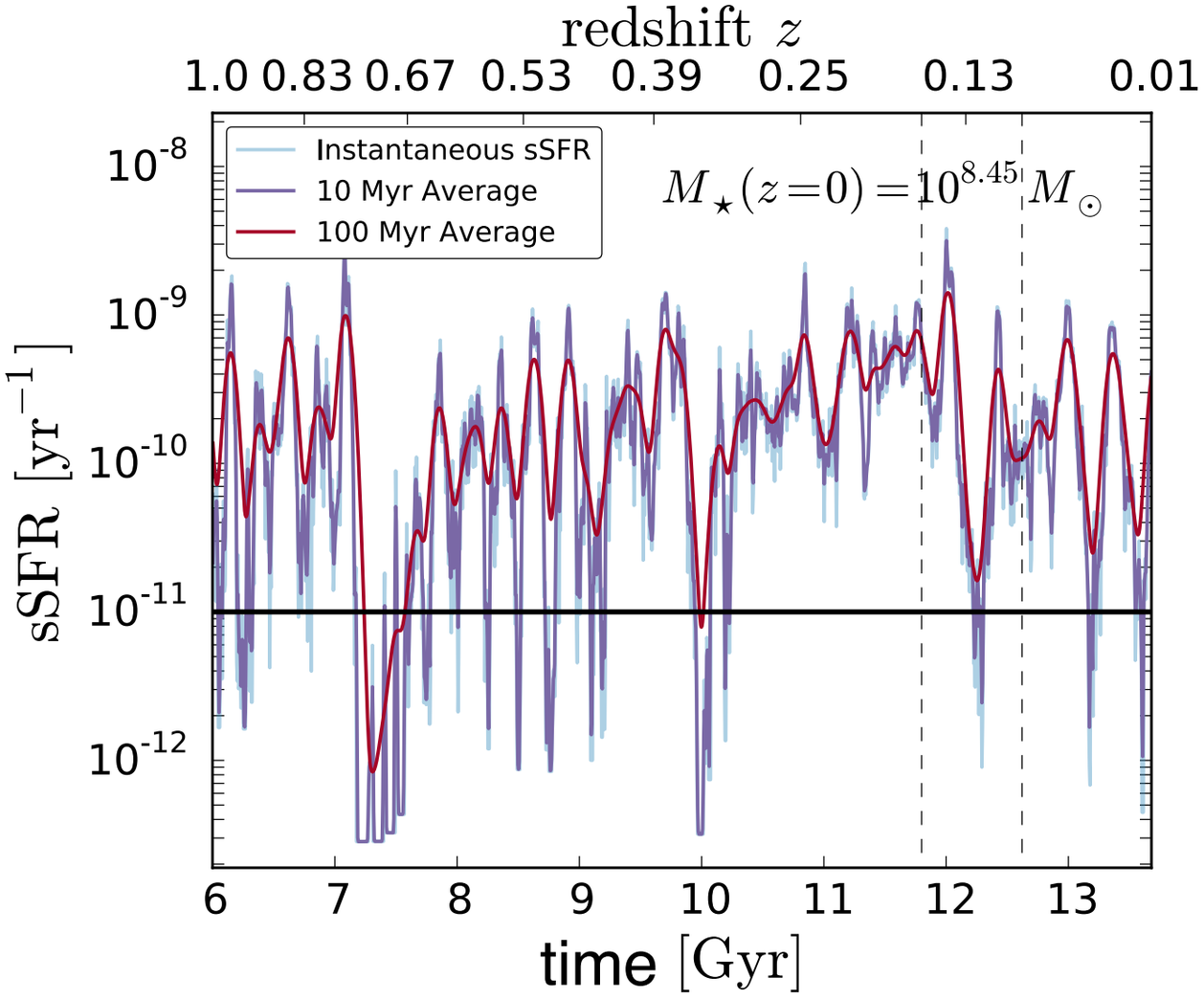
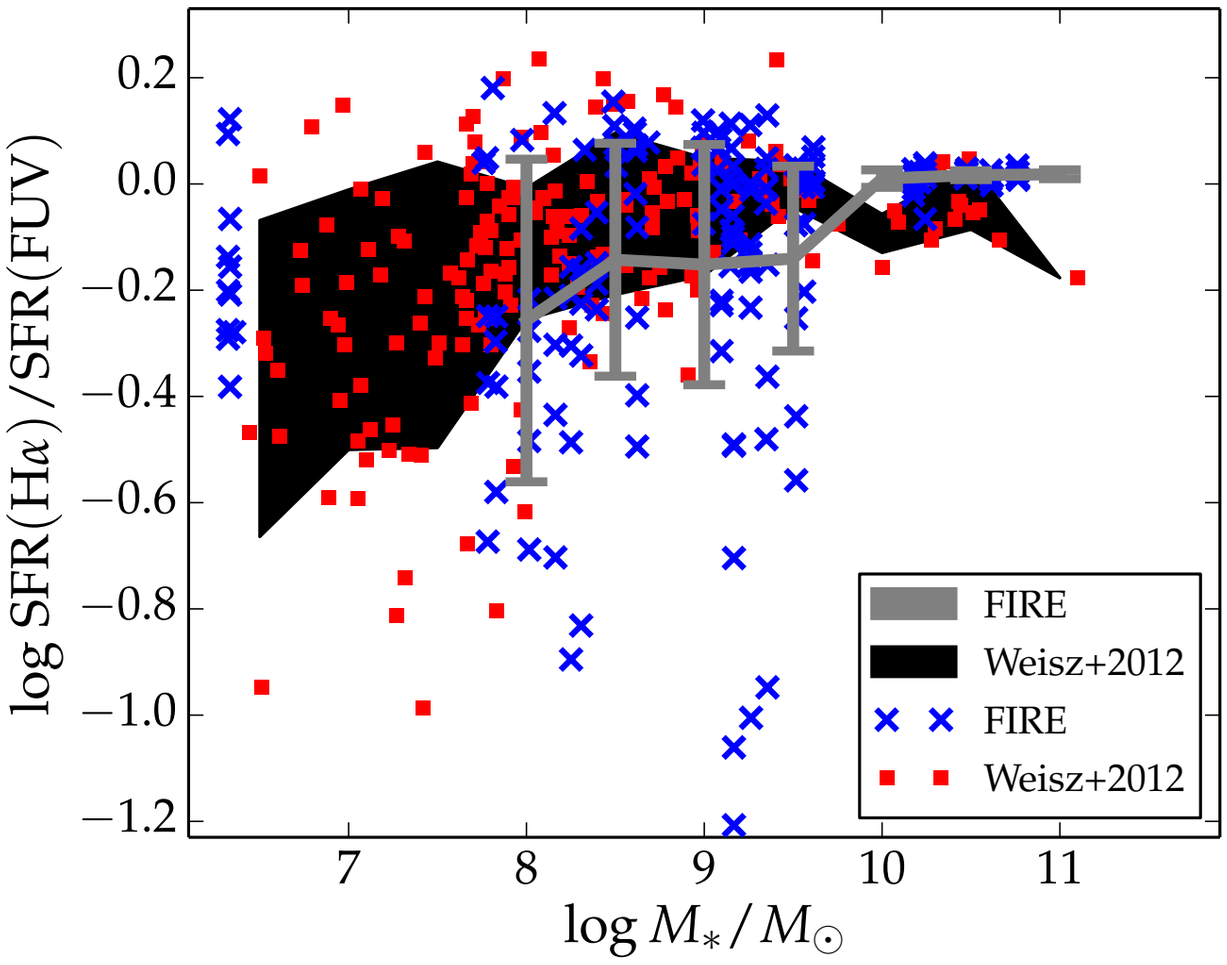


Wetzel et al in prep

simulated dwarf galaxies have bursty star formation



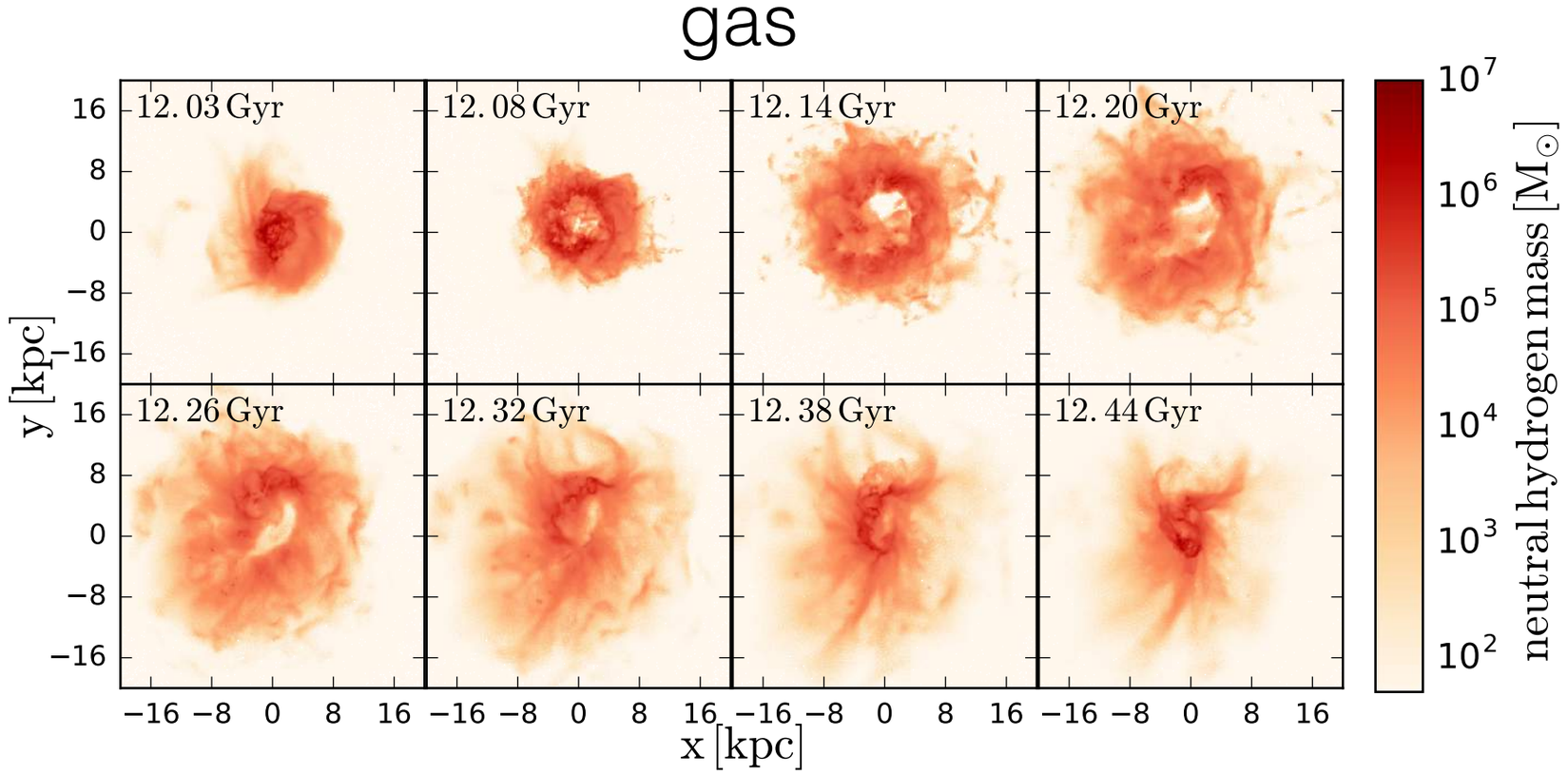
El-Badry, Wetzel et al 2015



Sparre et al 2015

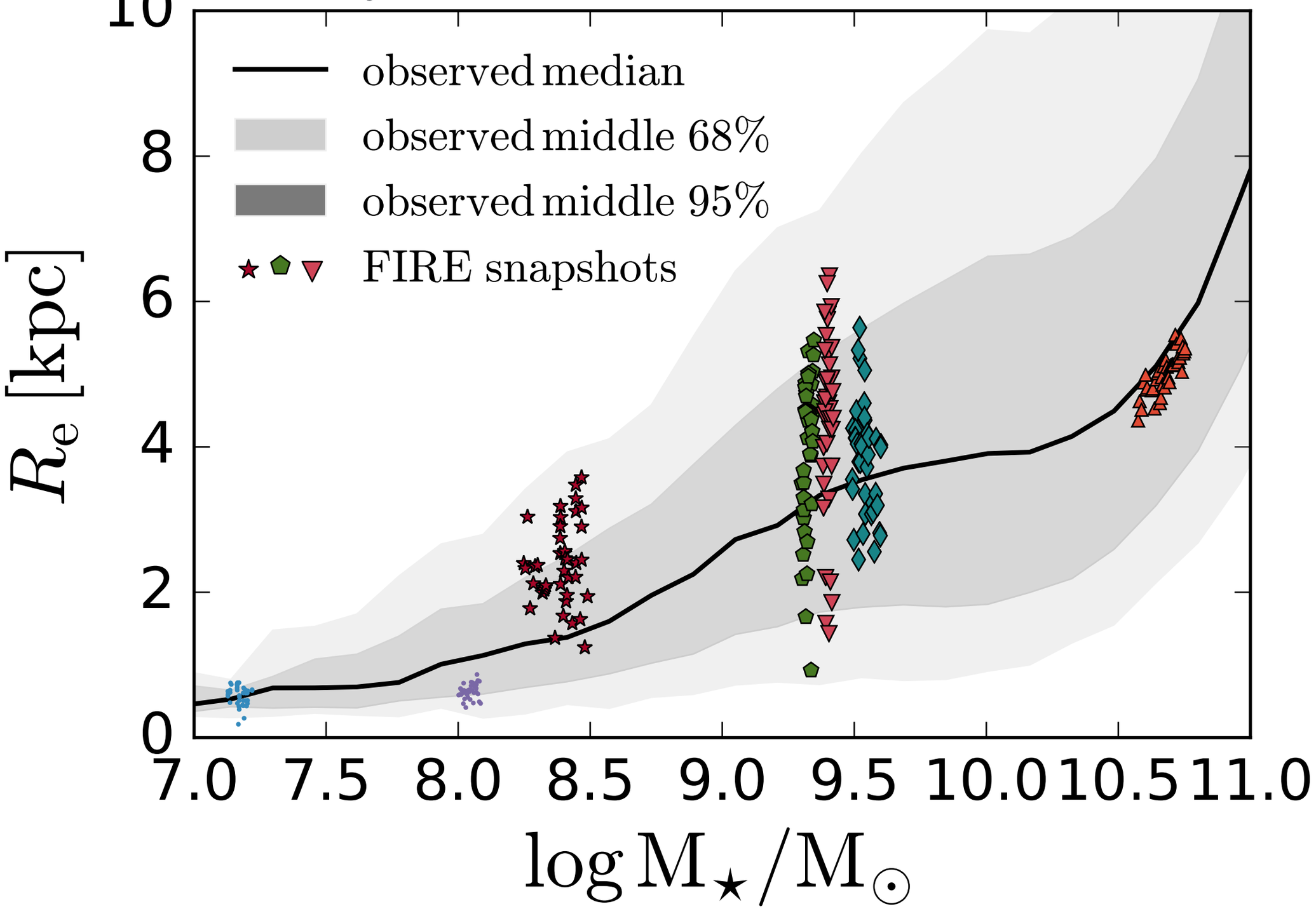
feedback-driven gas outflows in dwarf galaxies

El-Badry, Wetzel et al 2015



fluctuations in galaxy radius at fixed M_{star}

El-Badry, Wetzel et al 2015



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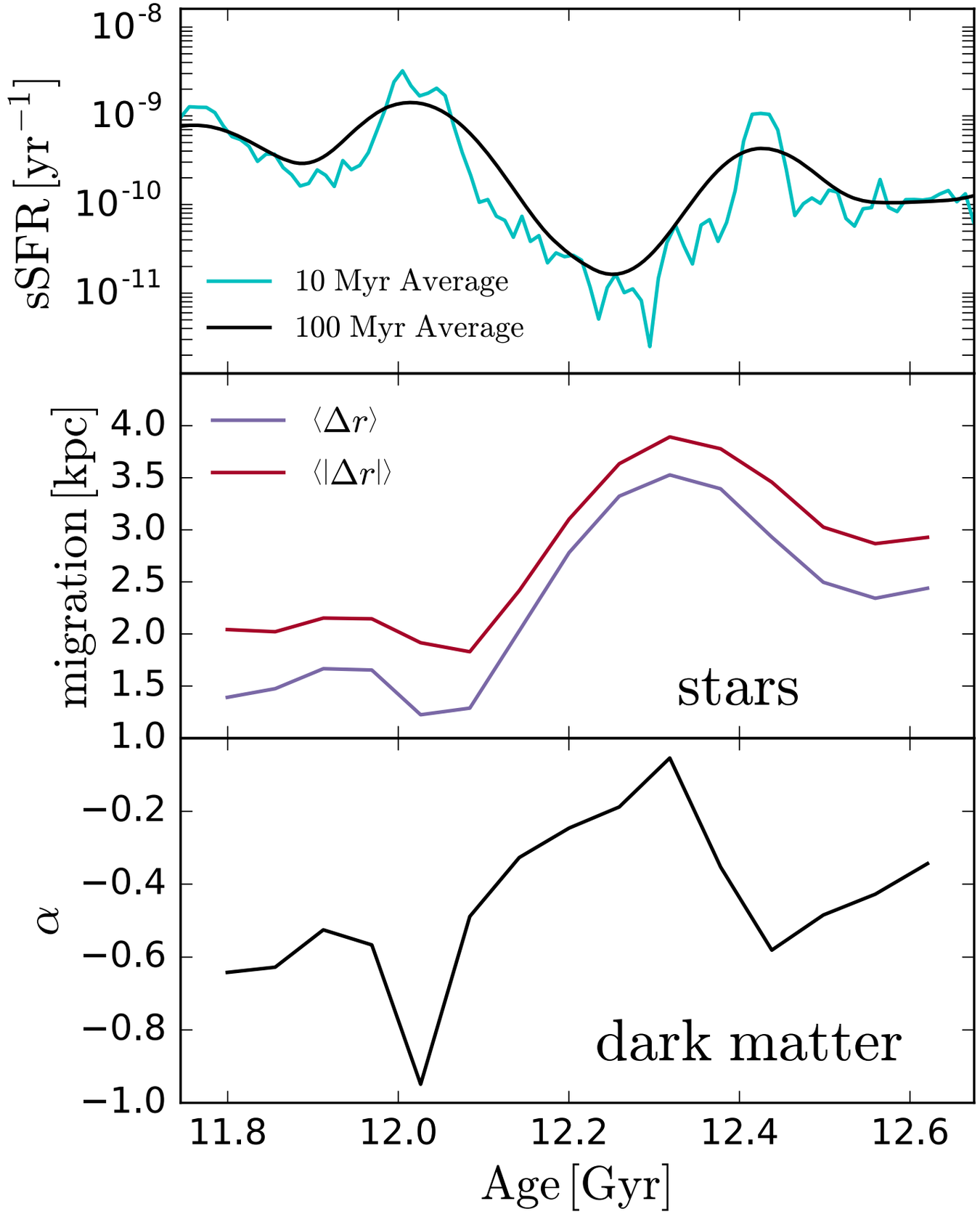
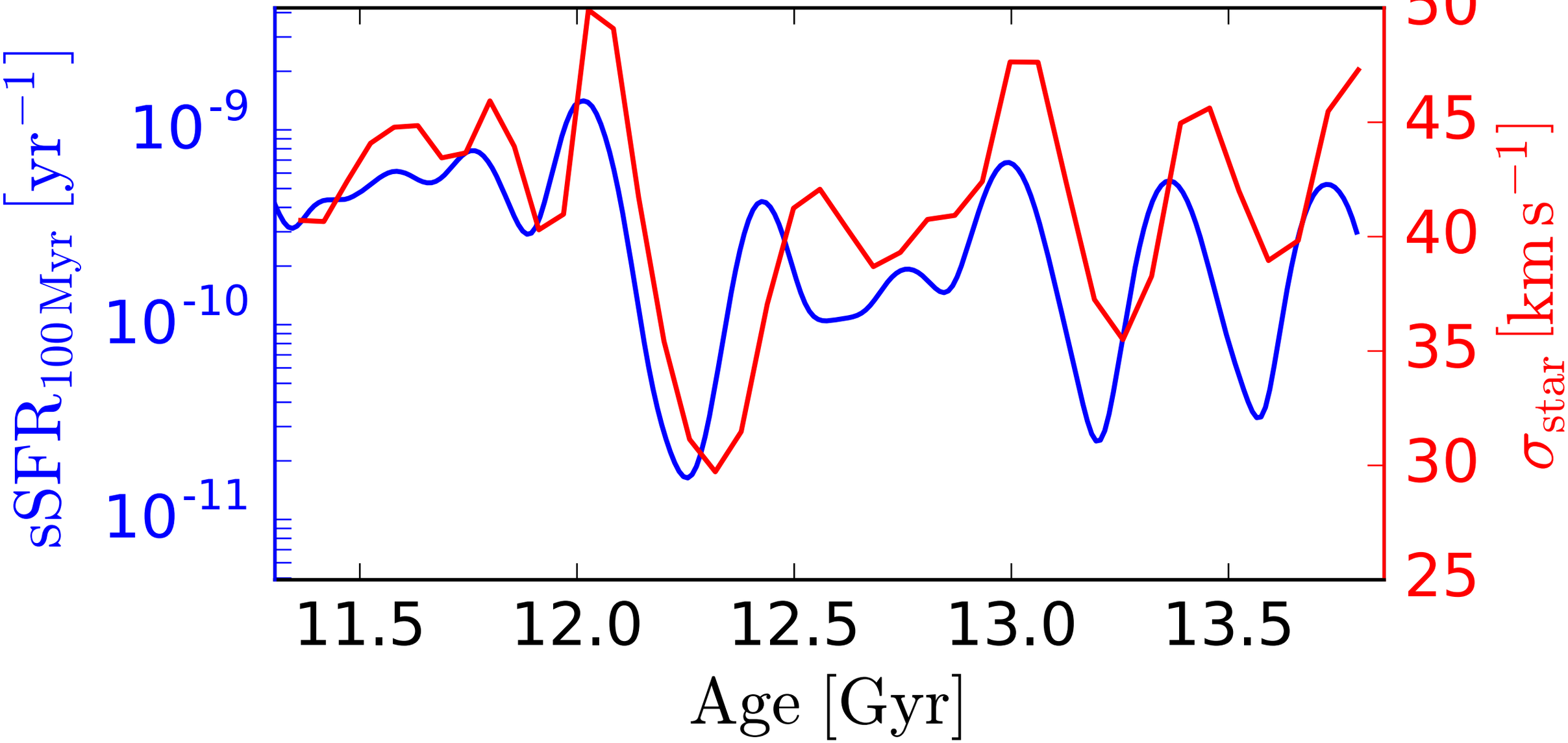
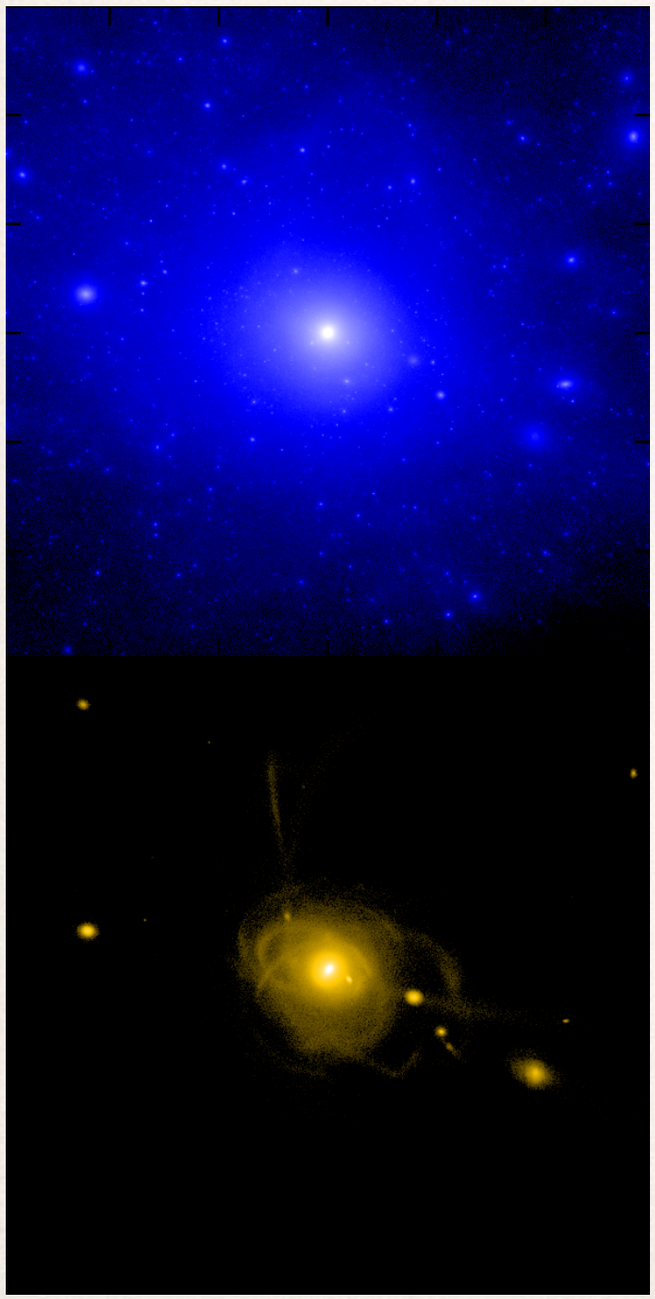


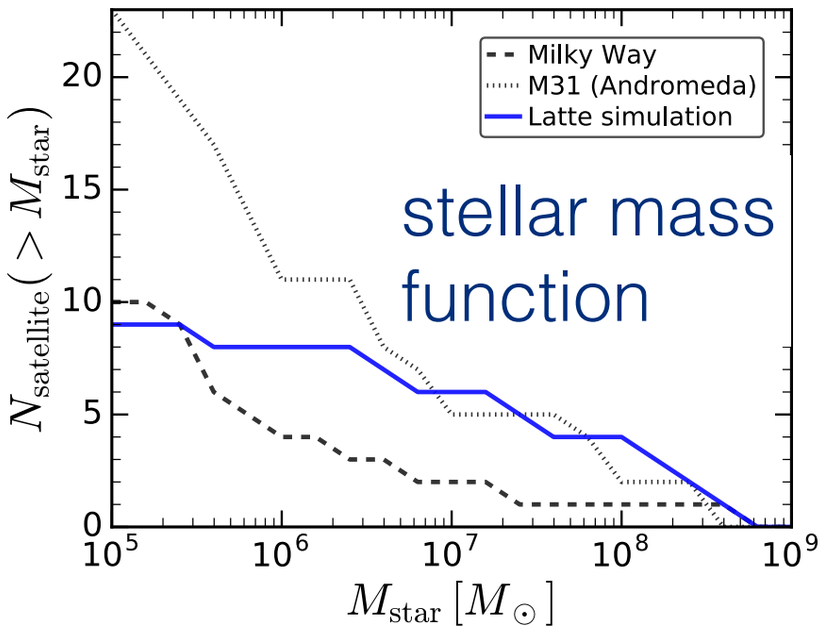
El-Badry, Wetzel et al, in prep

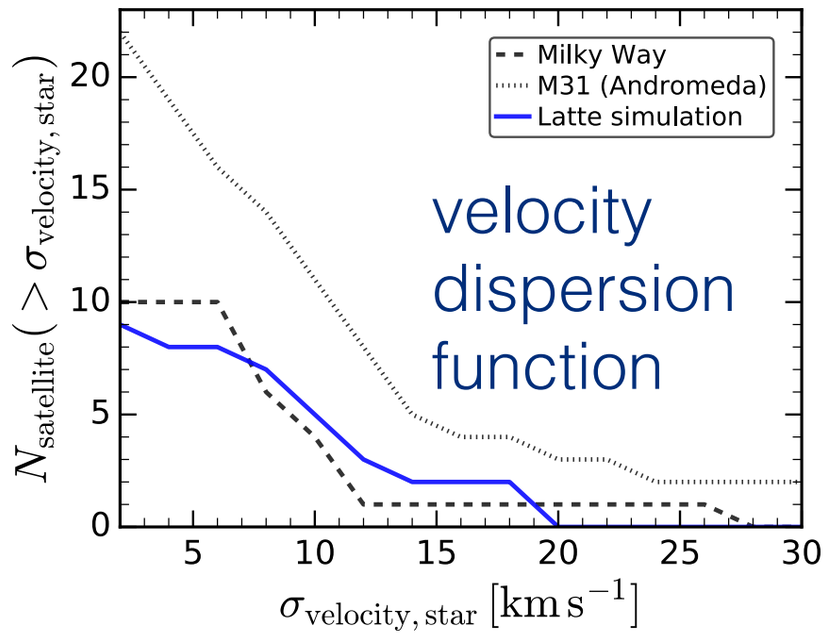


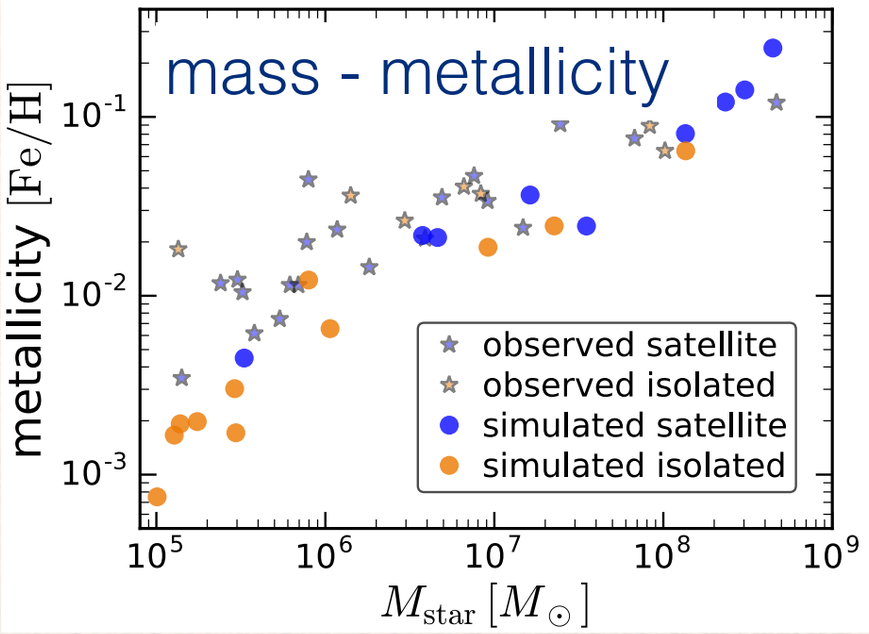
detailed stellar (and gas) kinematics in dwarf galaxies will provide **robust** tests of feedback models and the nature of dark-matter coring

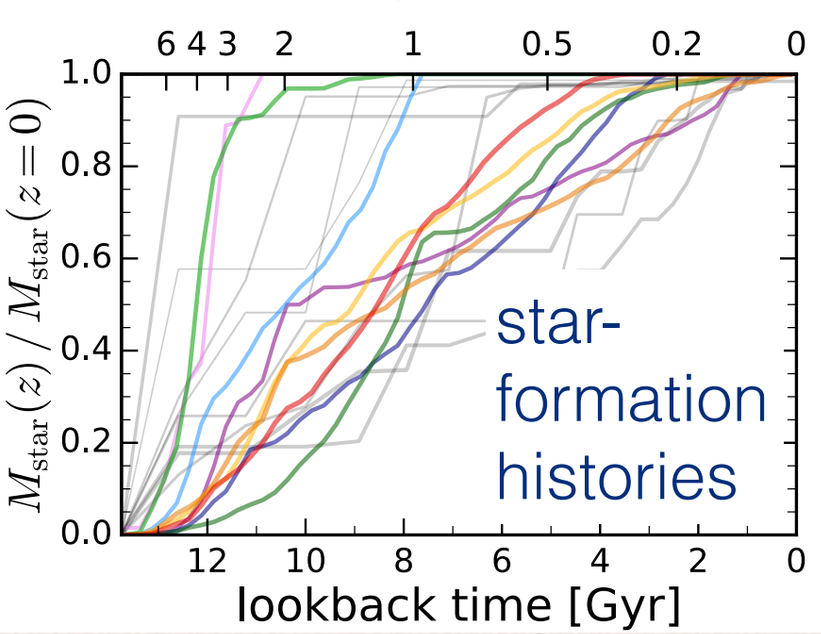
The Latte Project: the Milky Way on FIRE











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