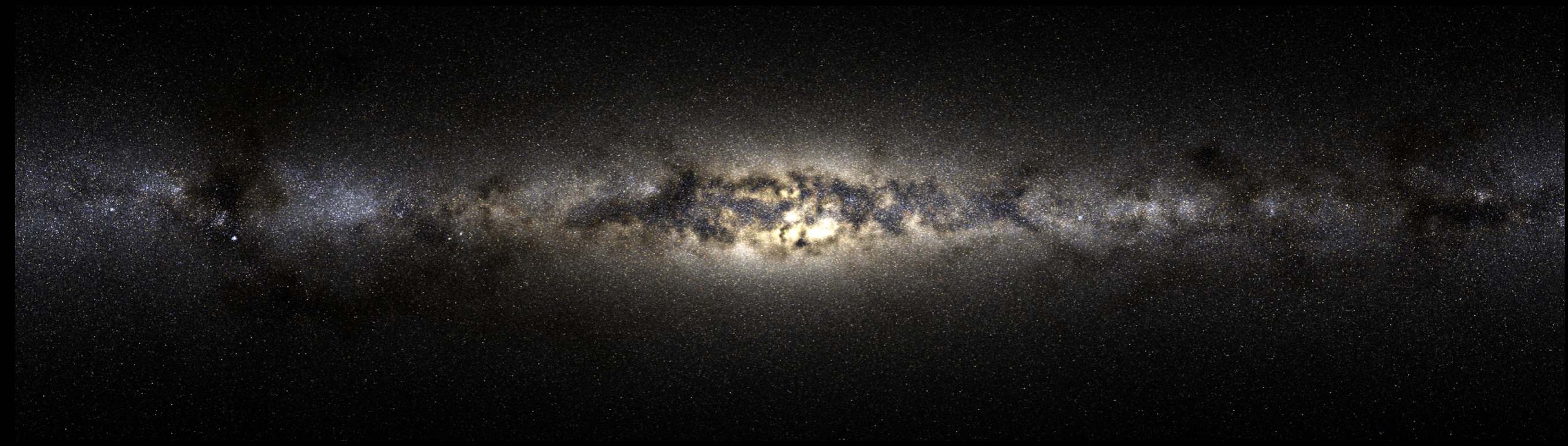


origin and location of the oldest and/or  
most metal-poor stars in the Milky Way



Andrew Wetzel

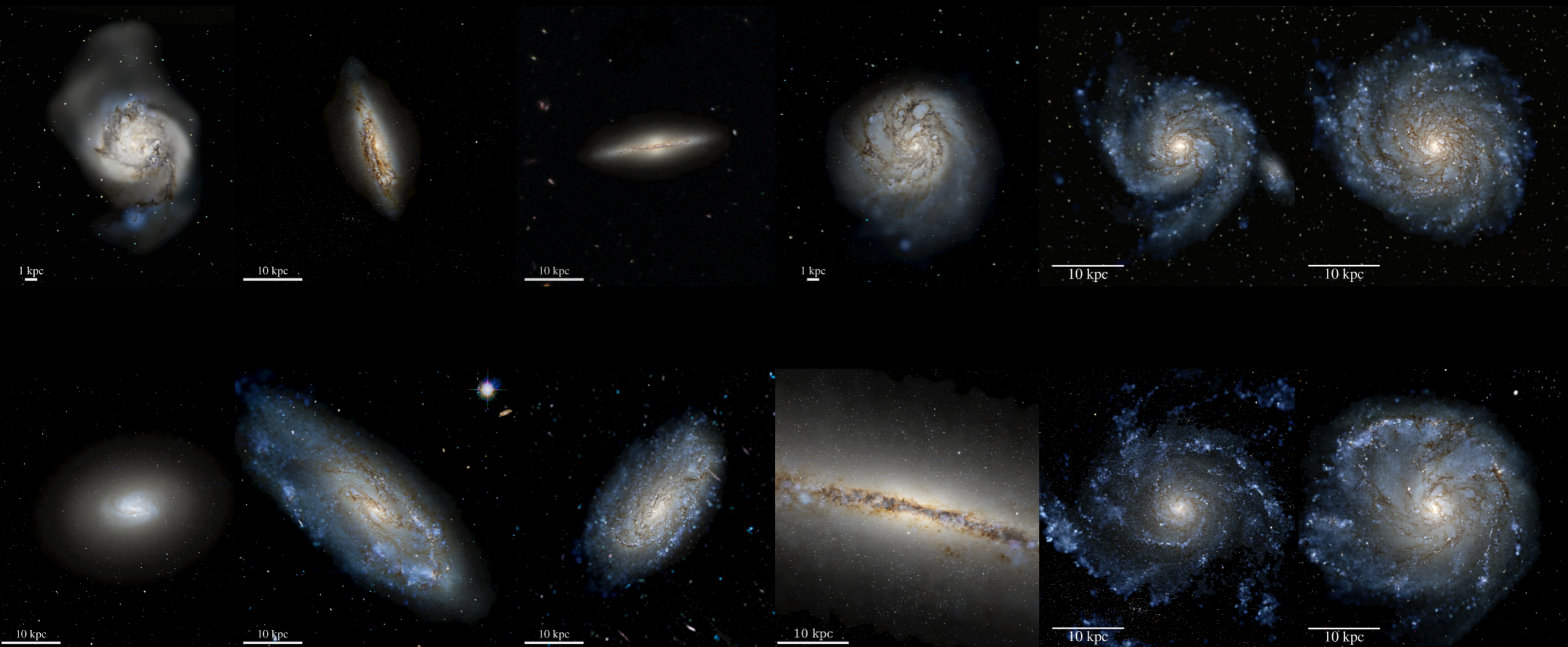
**UCDAVIS**  
UNIVERSITY OF CALIFORNIA



# simulation suite of MW-mass systems

Latte suite: 8 isolated MW-mass systems

ELVIS suite: 2 LG-like pairs (4 halos)



## Where are the most ancient stars in the Milky Way?

Kareem El-Badry,<sup>1★</sup> Joss Bland-Hawthorn,<sup>2,3,4</sup> Andrew Wetzel,<sup>5</sup> Eliot Quataert,<sup>1</sup>  
Daniel R. Weisz,<sup>1</sup> Michael Boylan-Kolchin,<sup>6</sup> Philip F. Hopkins,<sup>7</sup>  
Claude-André Faucher-Giguère,<sup>8</sup> Dušan Kereš<sup>9</sup> and Shea Garrison-Kimmel<sup>7</sup>



Kareem El-Badry  
(grad student @ UC Berkeley)

(see also Starckenburg et al 2017 using APOSTLE simulations)

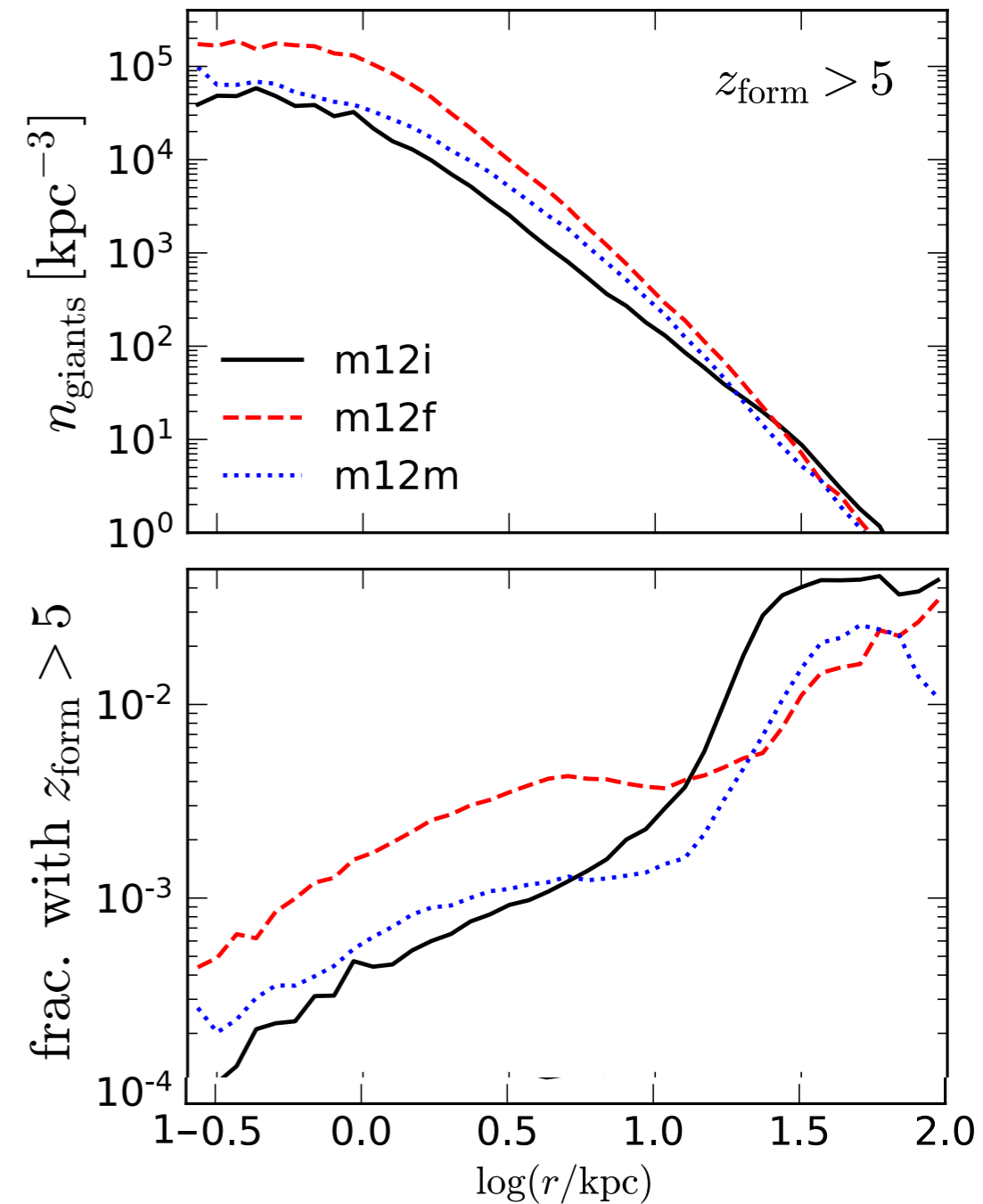
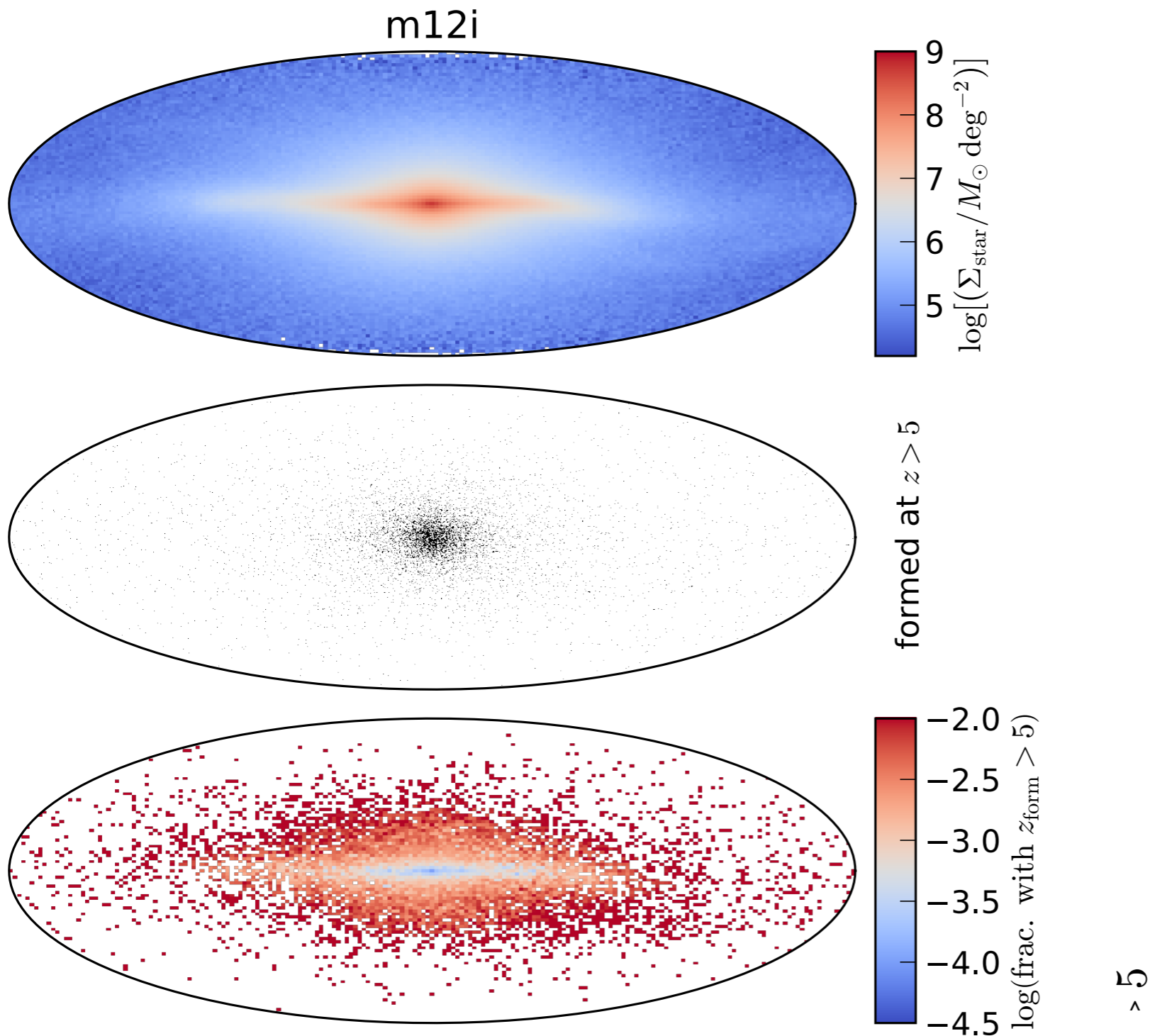
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'STANDARD' PICTURE OF  
GALAXY FORMATION:

GALAXIES GROW INSIDE-OUT,  
SO THE OLDEST STARS ARE  
NATURALLY IN THE CENTER

(RIGHT?)

# Where to find the oldest ( $z_{\text{form}} > 5$ ) stars?



only  $\sim 15\%$  of oldest stars are in bulge region ( $d < 2 \text{ kpc}$ )

# Why are the oldest stars less centrally concentrated?

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1. Most MW stars formed at  $z > \sim 3$  were accreted (ex-situ)
2. Stars that did form in-situ were heated to larger radii via stellar feedback (similar to DM core formation)

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WHEN DID THE MILKY WAY 'FORM'?

WHEN DID THE MAJORITY OF STARS  
FORM WITHIN THE MAIN PROGENITOR?

WHAT WERE ITS BUILDING BLOCKS?



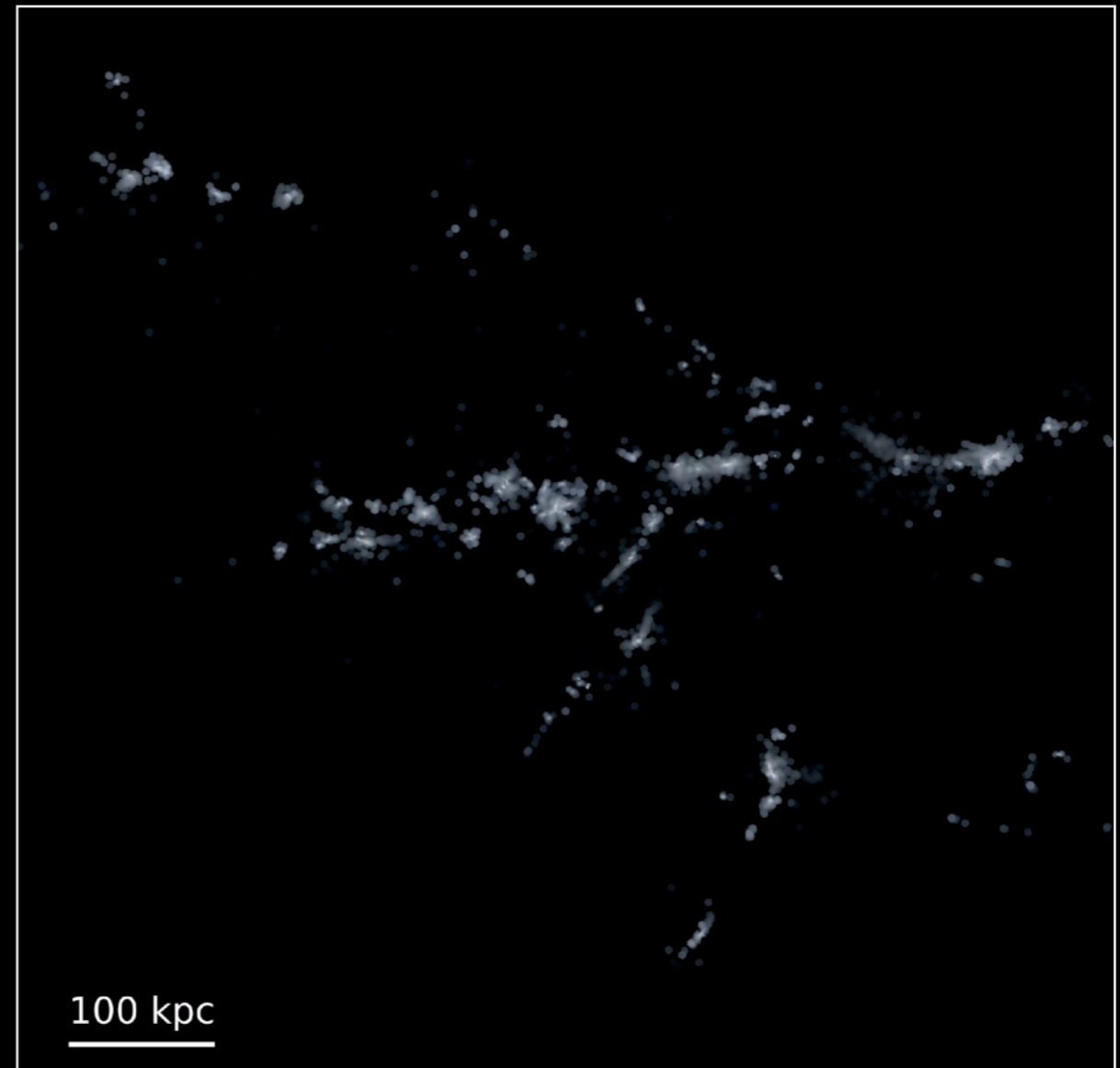
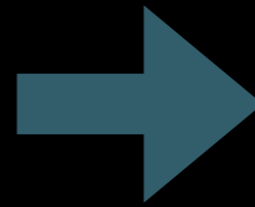
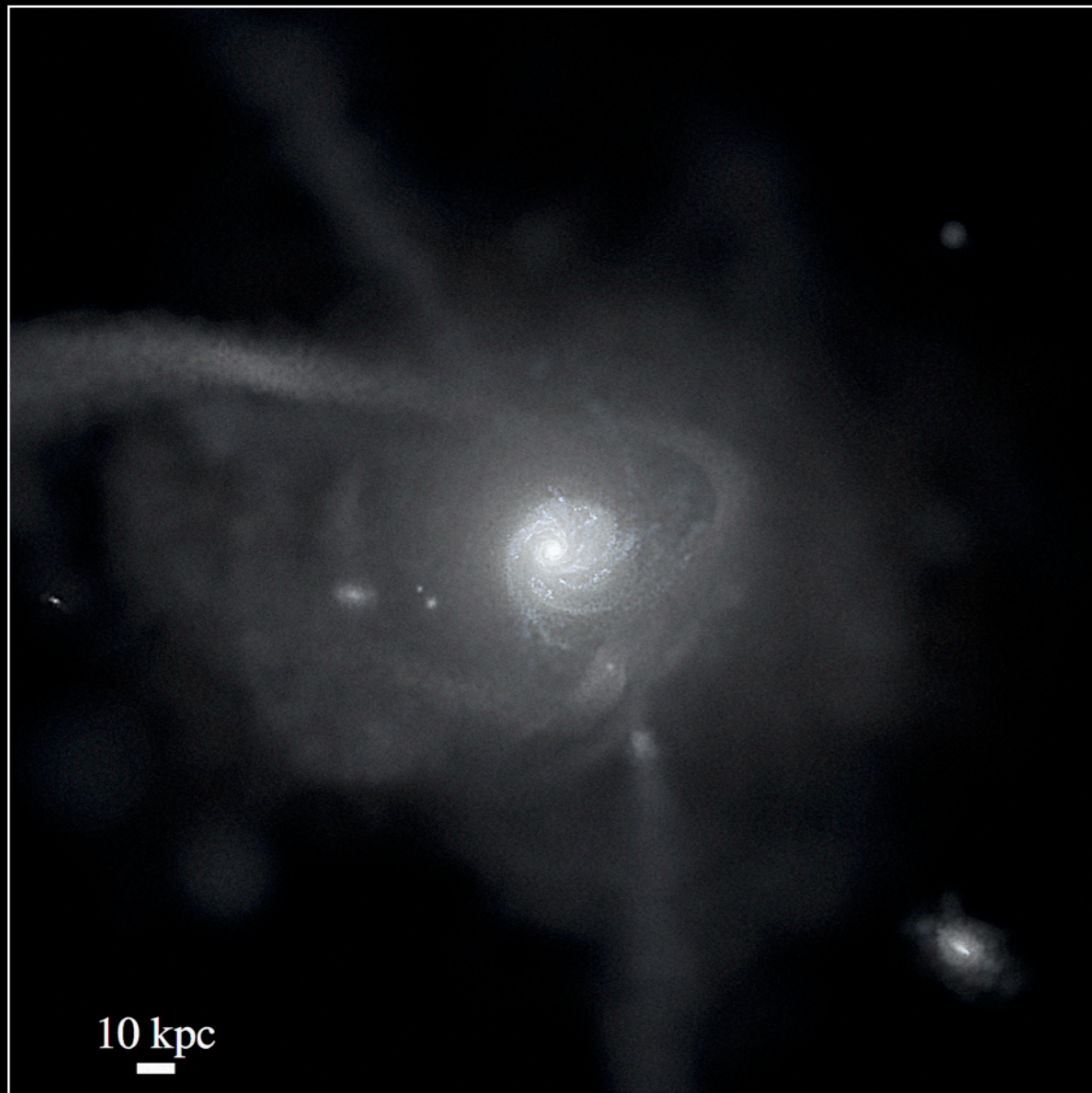
Isaiah Santistevan  
(grad student @ UC Davis)

# Latte simulation of MW-mass galaxy



# near-far connection

understanding the building blocks of the MW

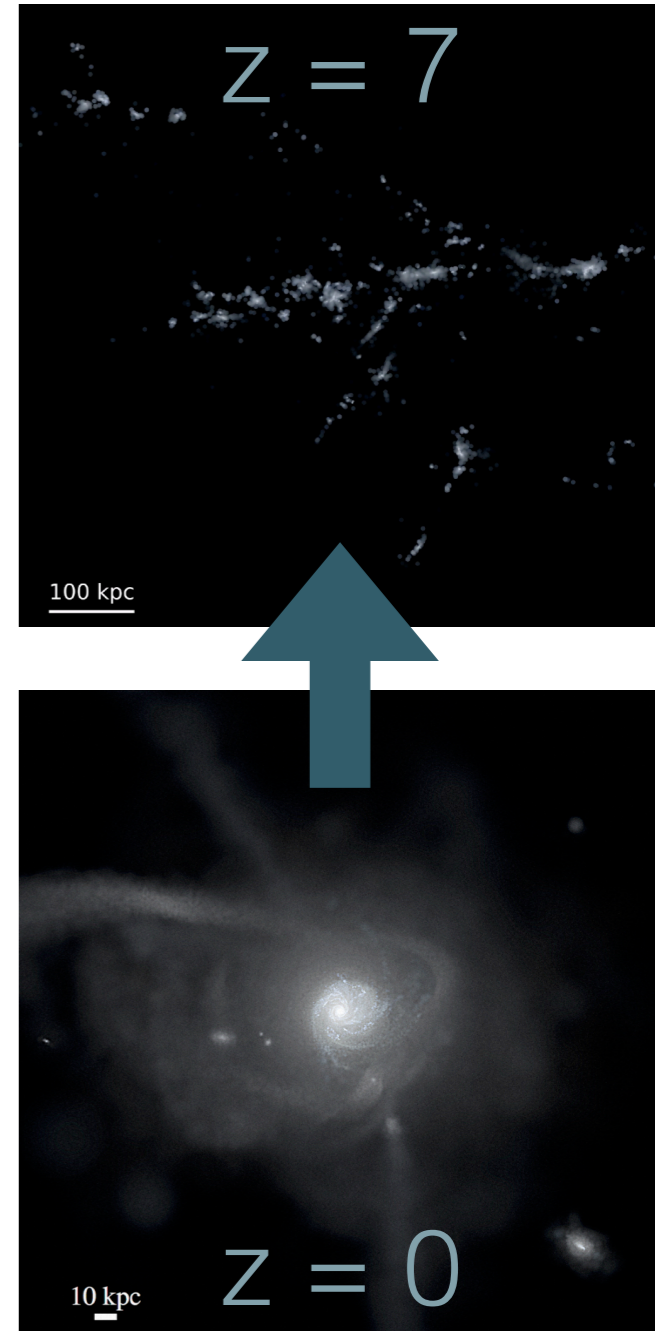
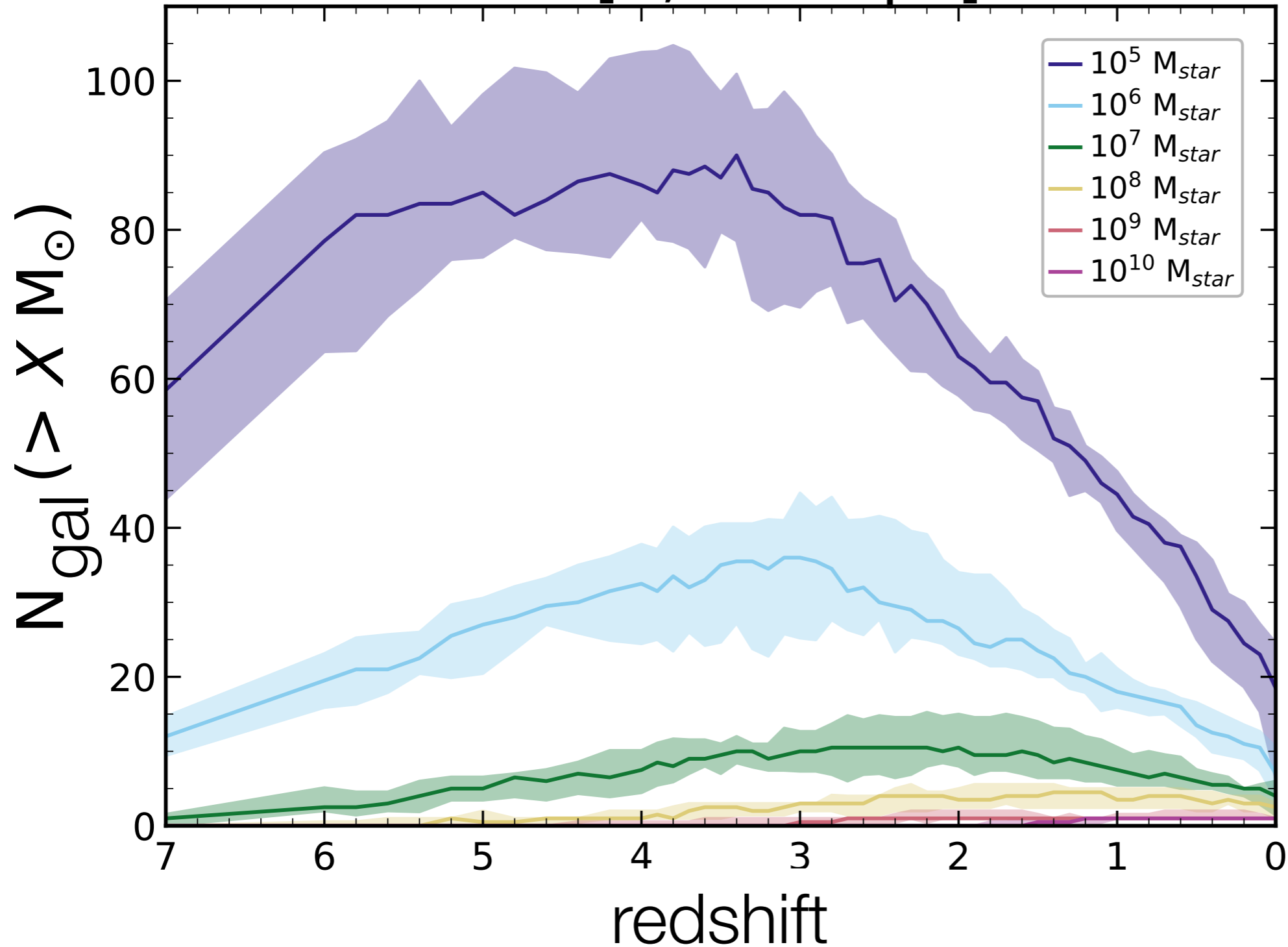


select stars in MW  
(galaxy or halo) at  $z = 0$

trace stars back to  $z > \sim 5$

# dwarf galaxy building blocks of entire MW system

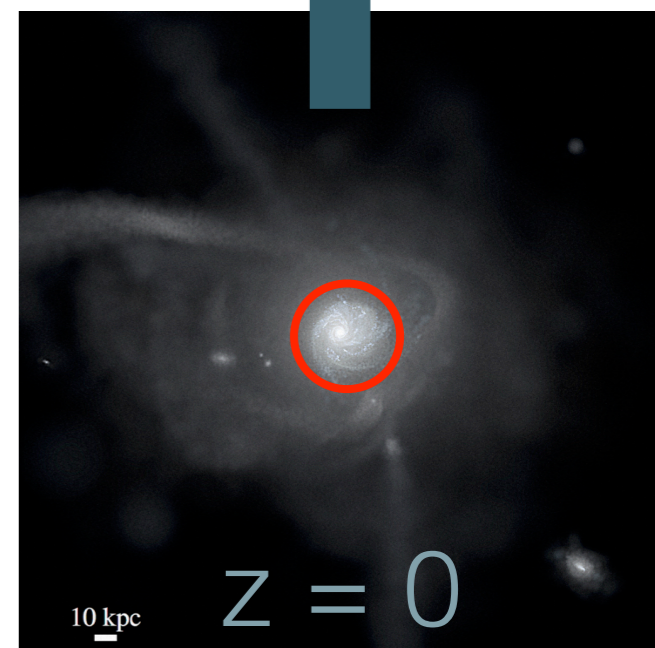
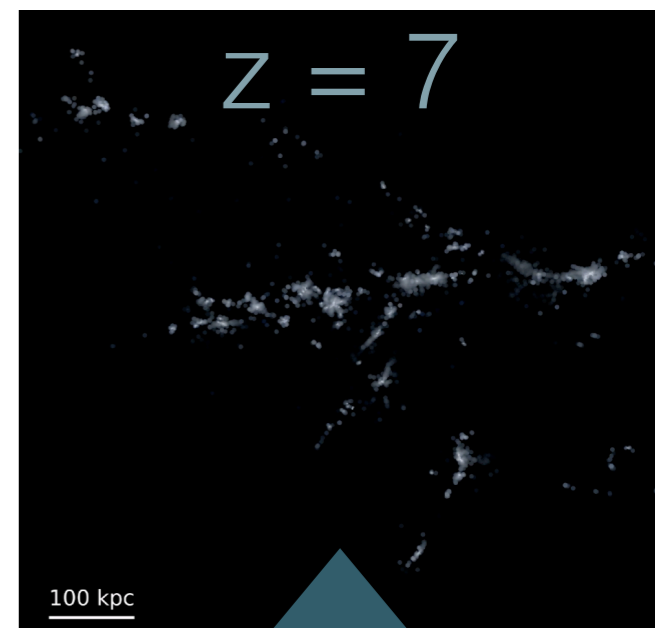
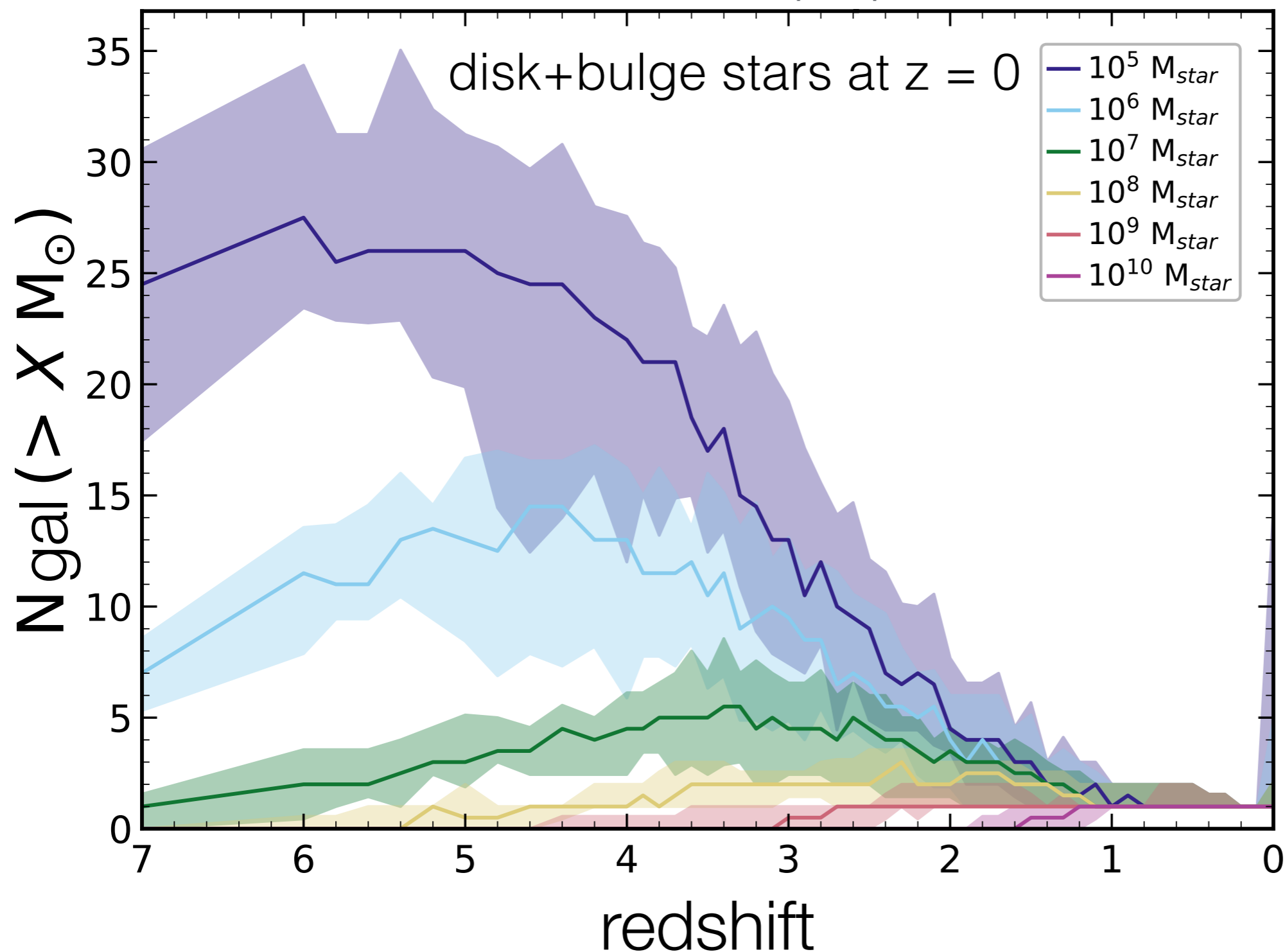
$d = [0, 300 \text{ kpc}]$

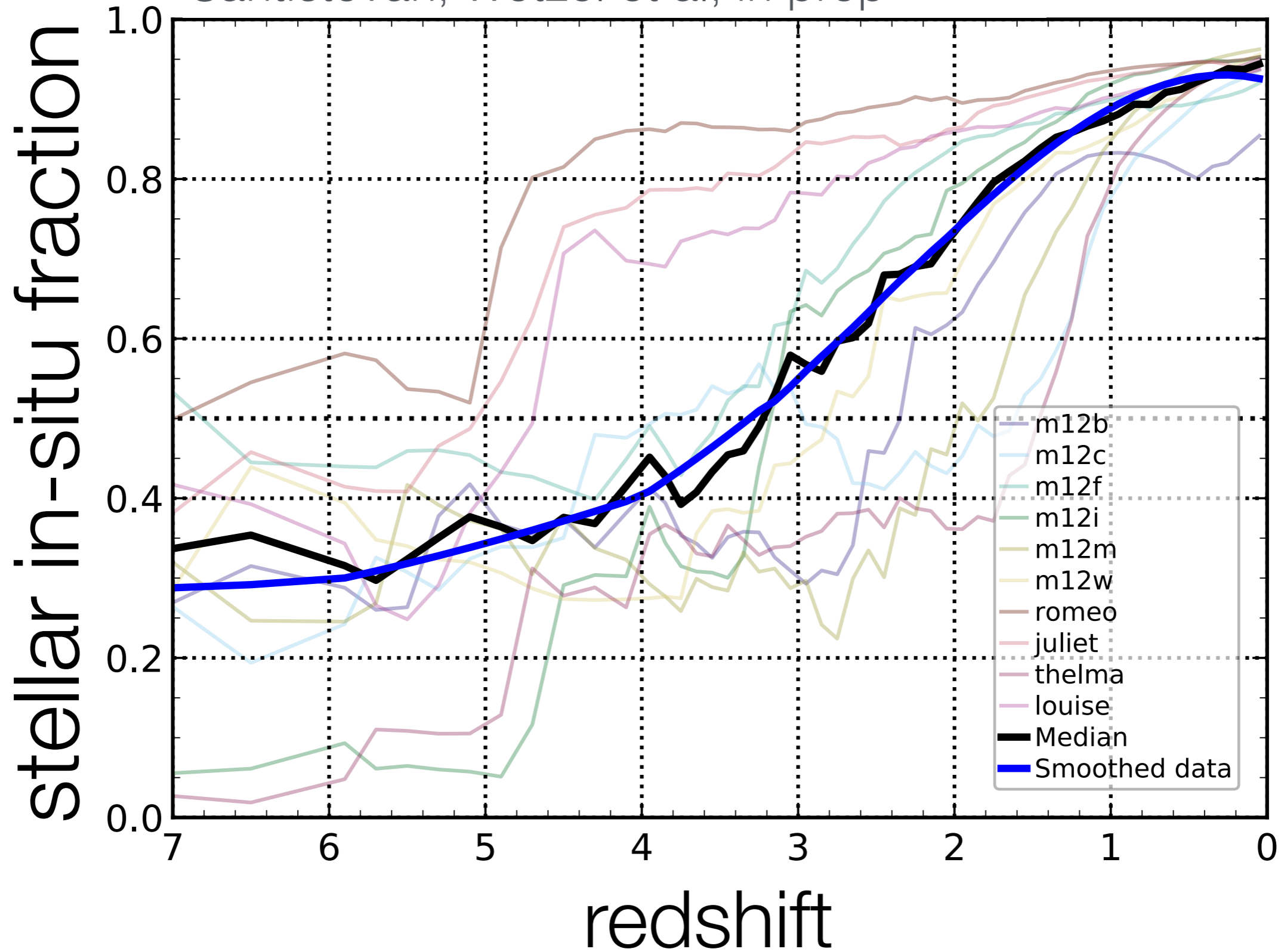


current population is highly incomplete census of dwarfs that built MW

# dwarf galaxy building blocks of MW stellar disk

Santistevan, Wetzel et al, in prep





transition to in-situ star formation:  $z < \sim 3$

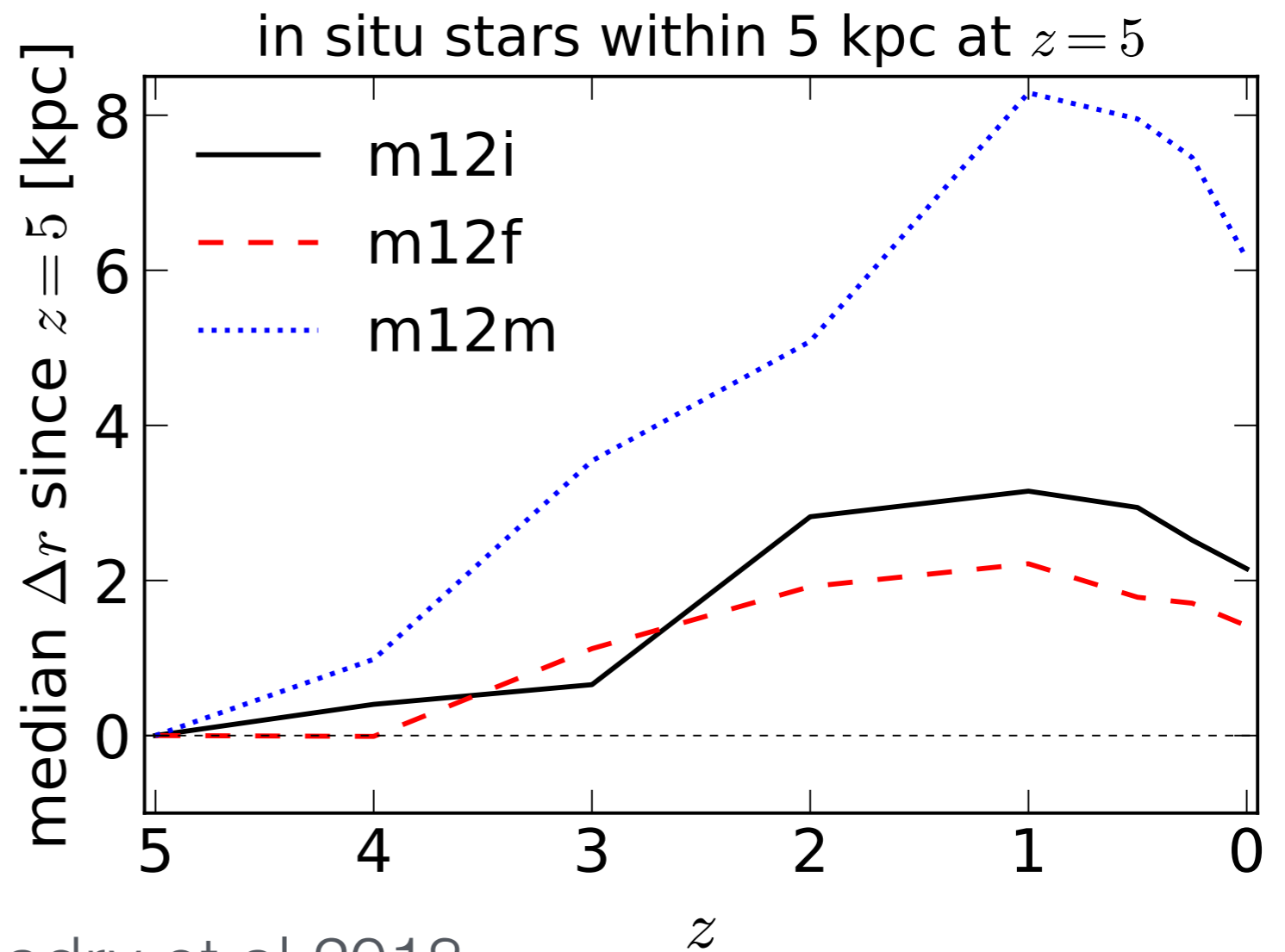
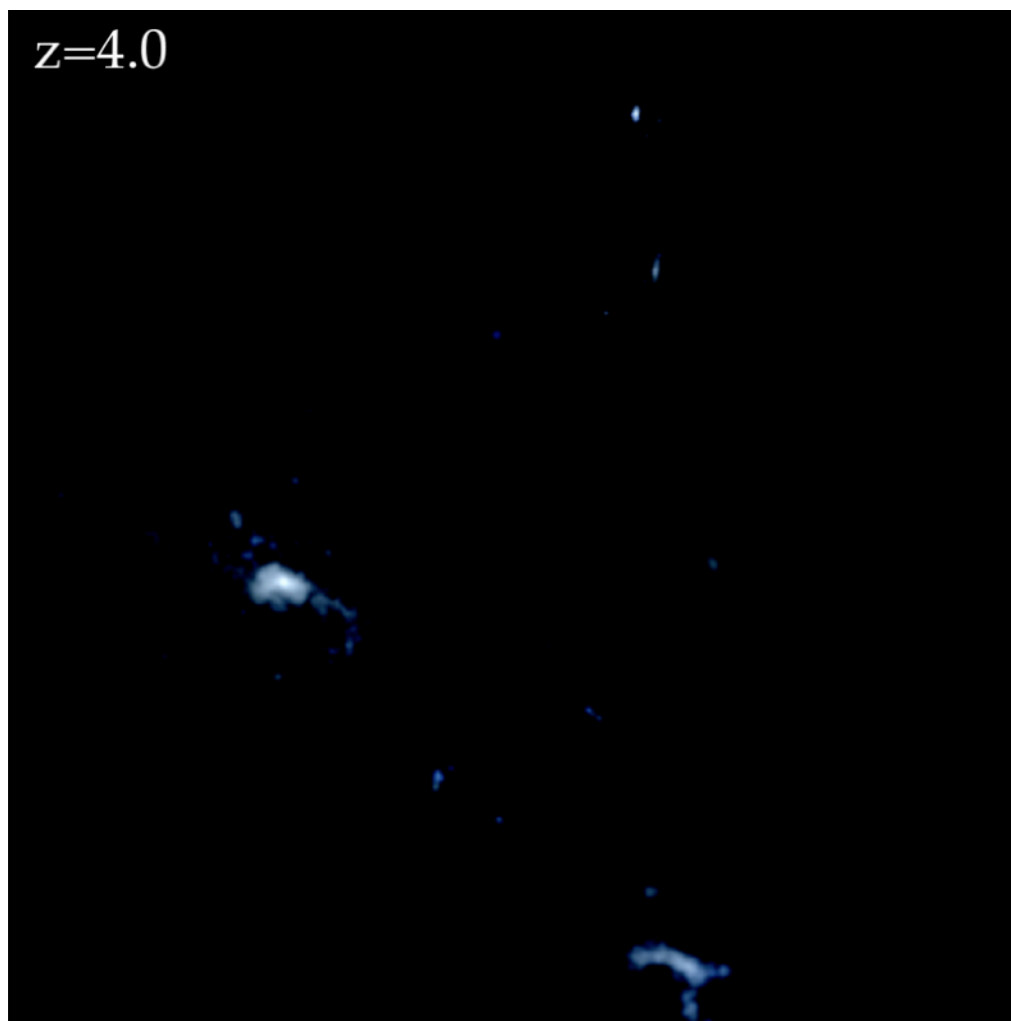
# Why are the oldest stars less centrally concentrated?

---

1. Most MW stars formed at  $z > \sim 3$  were accreted (ex-situ)
2. Stars that did form in-situ were heated to larger radii via stellar feedback (similar to DM core formation)

# Why are the oldest stars less centrally concentrated?

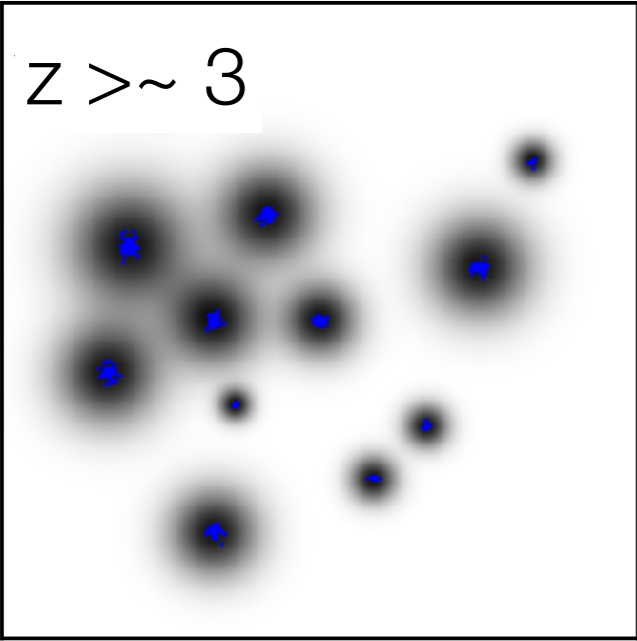
stars that did form in-situ were heated to larger radii via stellar feedback-driven gas outflows



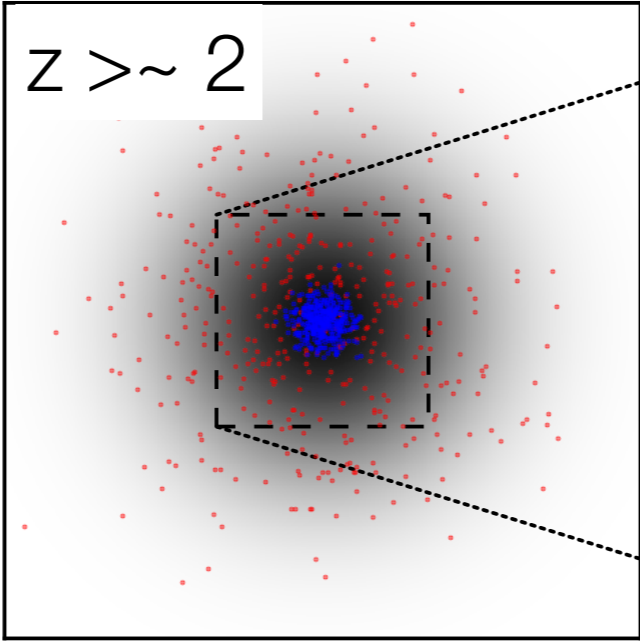
El-Badry et al 2018

# diagram of MW formation

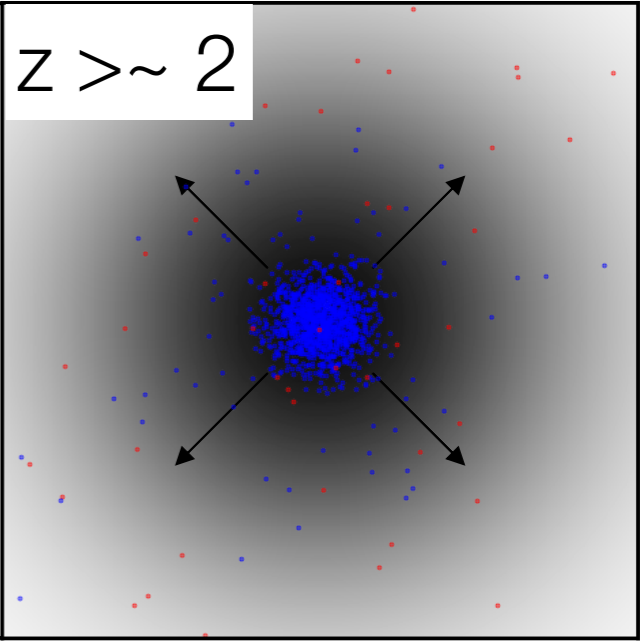
1) First stars form across many low-mass halos.



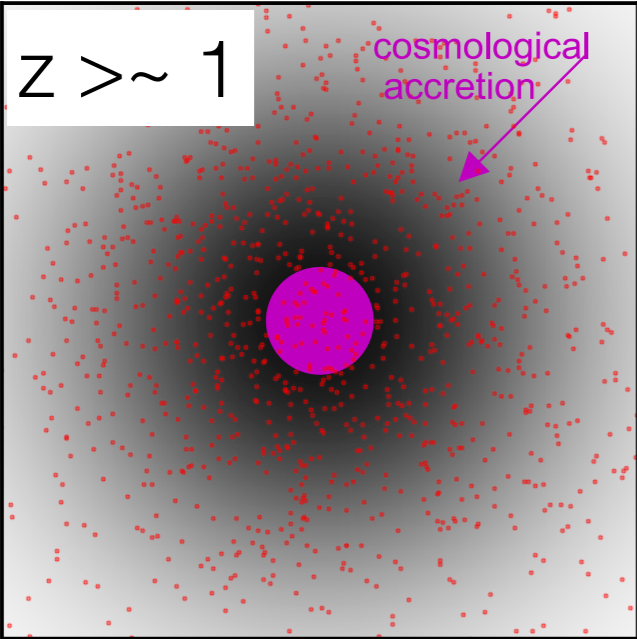
2) Mergers deposit old stars throughout halo. More stars form in center.



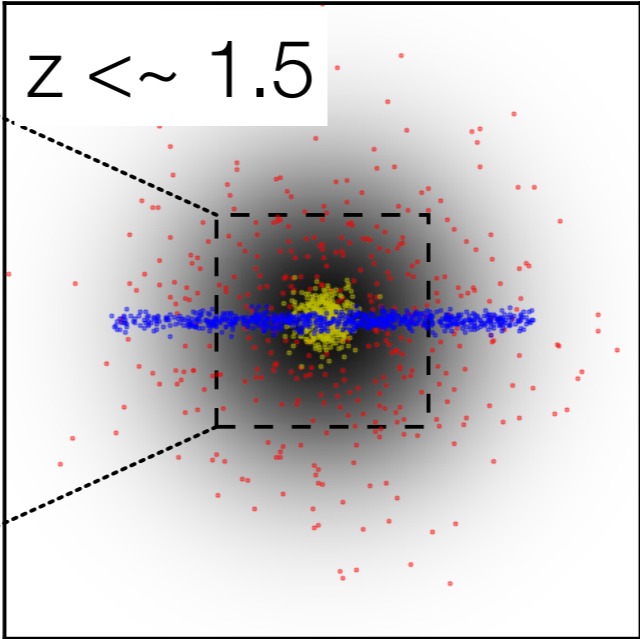
3) Gas-driven potential fluctuations drive central stars outward.



4) As mass is accreted, fluctuations weaken. Potential contracts.



5) Bulge and disk form. Old stars remain in outer bulge and halo.



- young stars
- older stars

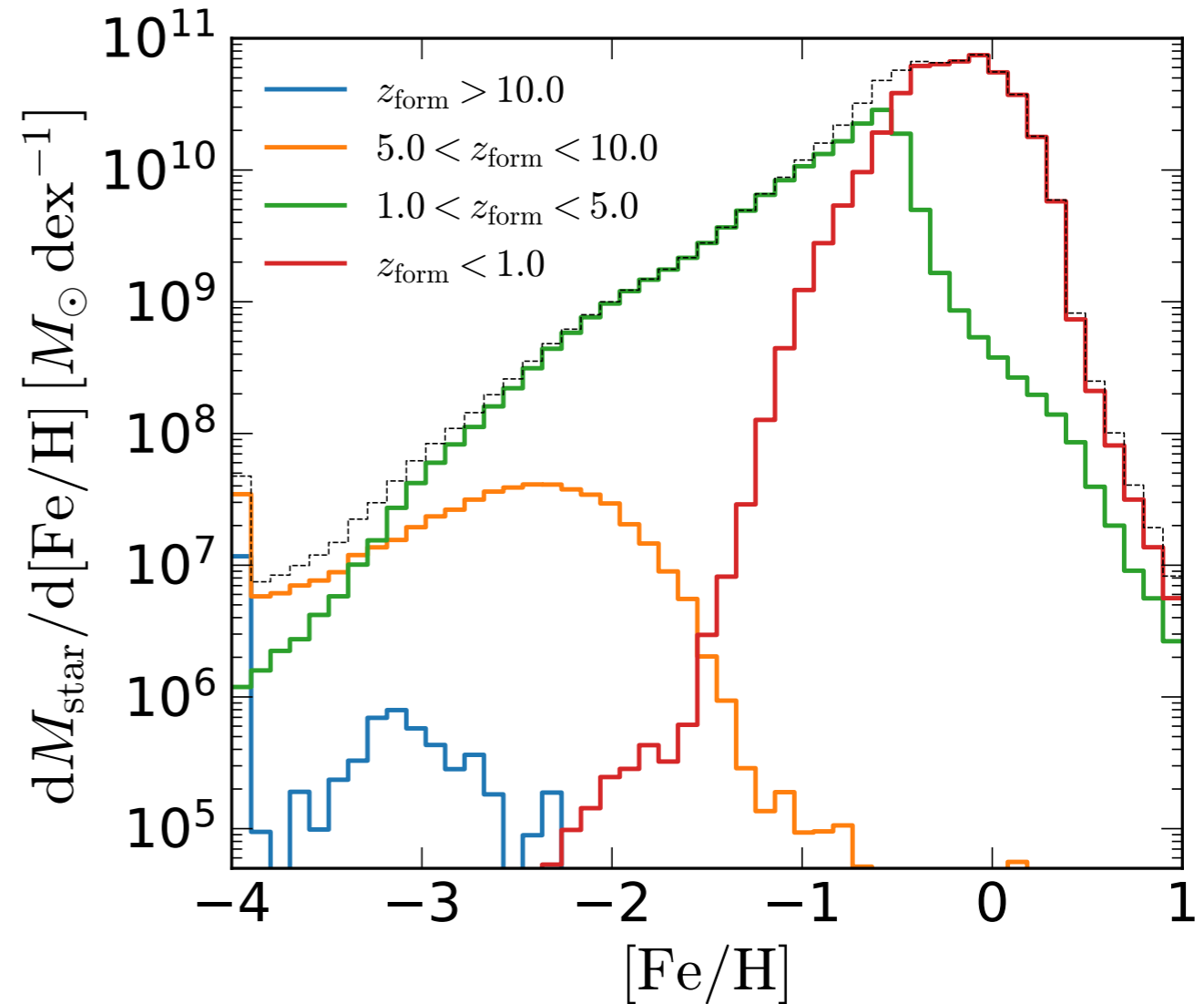
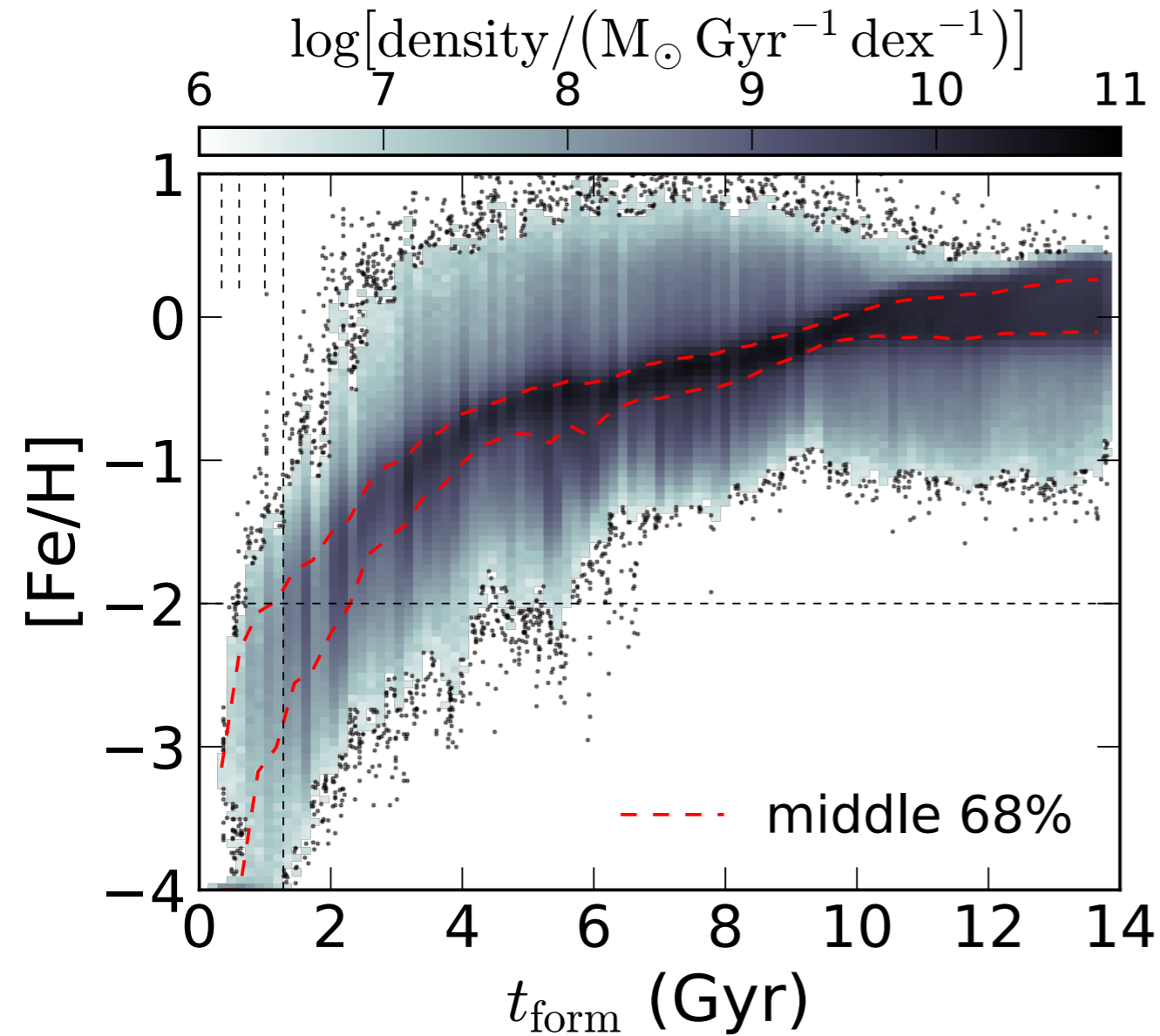
El-Badry, Bland-Hawthorn, Wetzel et al 2018

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WHAT IS CONNECTION  
BETWEEN OLDEST AND MOST  
METAL-POOR STARS?

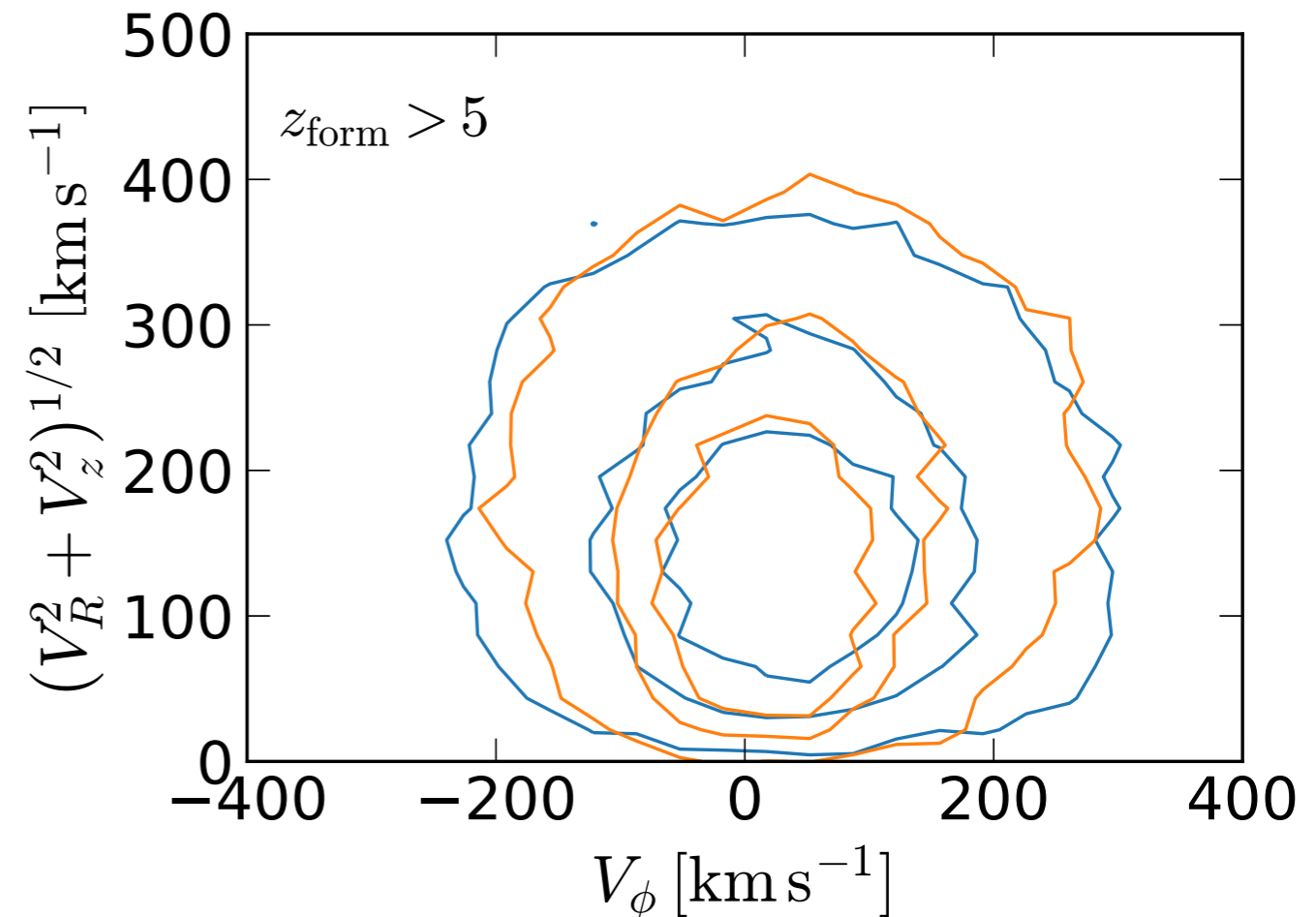
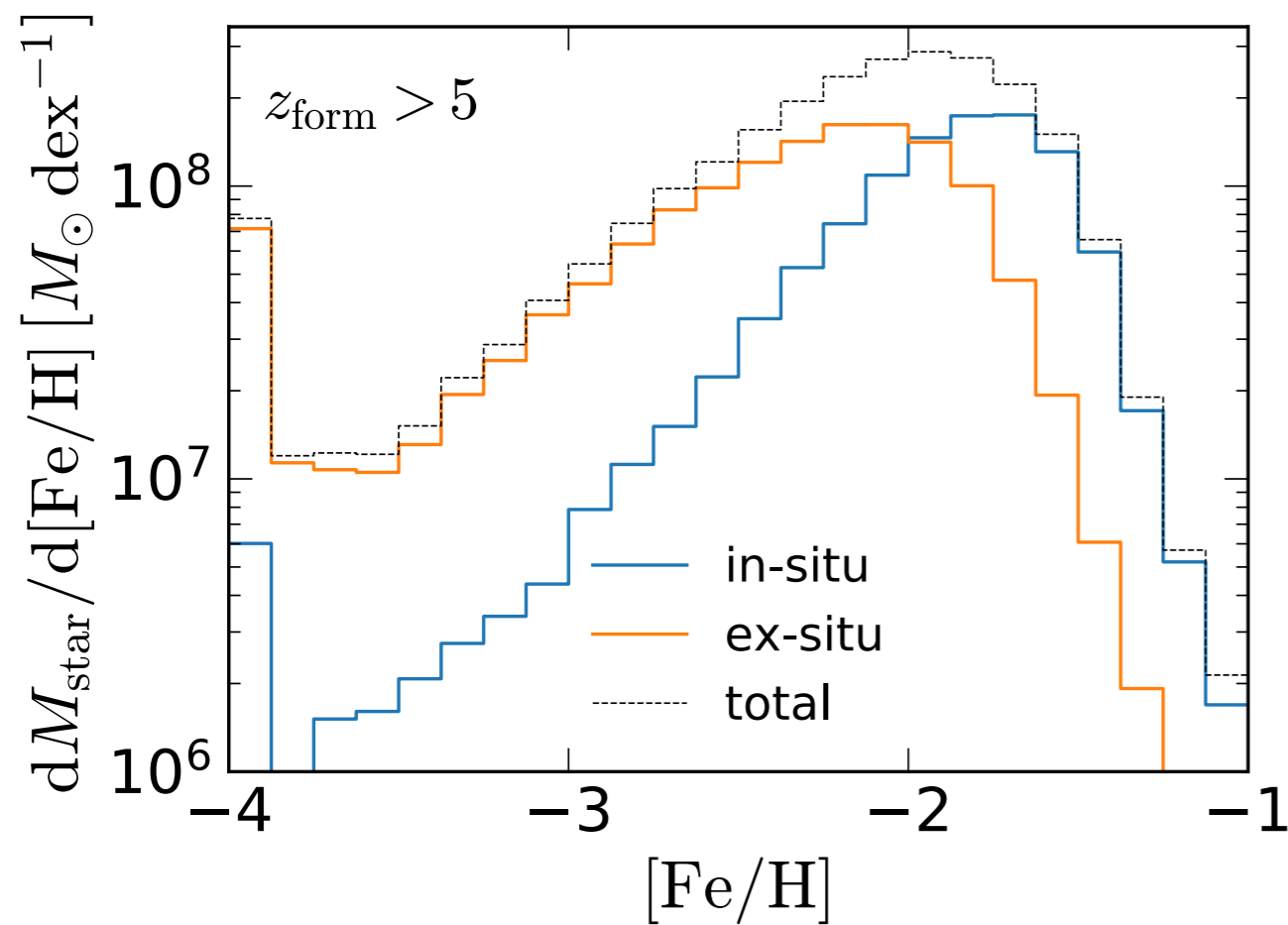


# Fe $\sim$ age, but Fe $\neq$ age

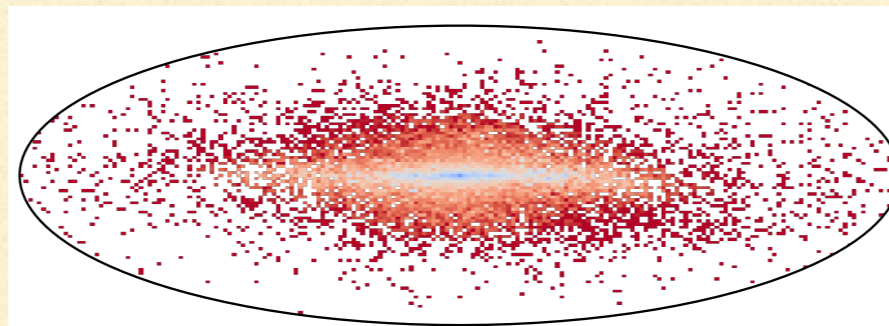
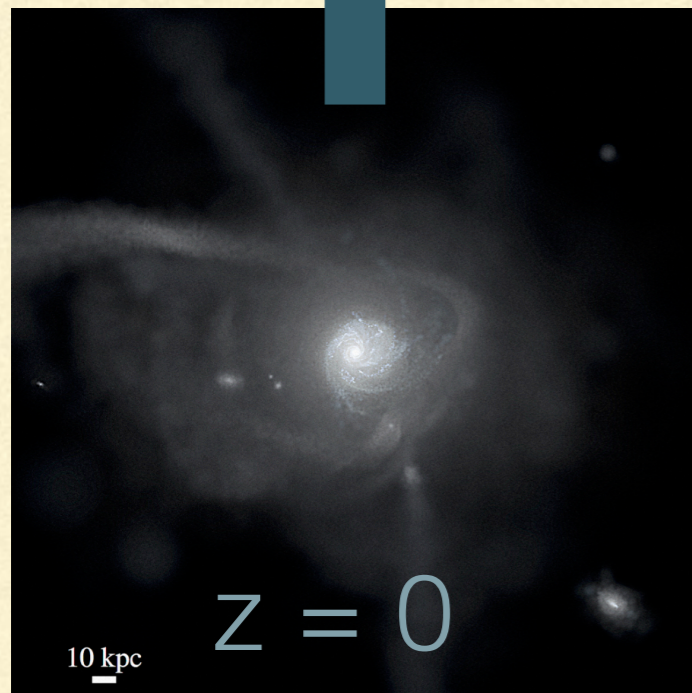
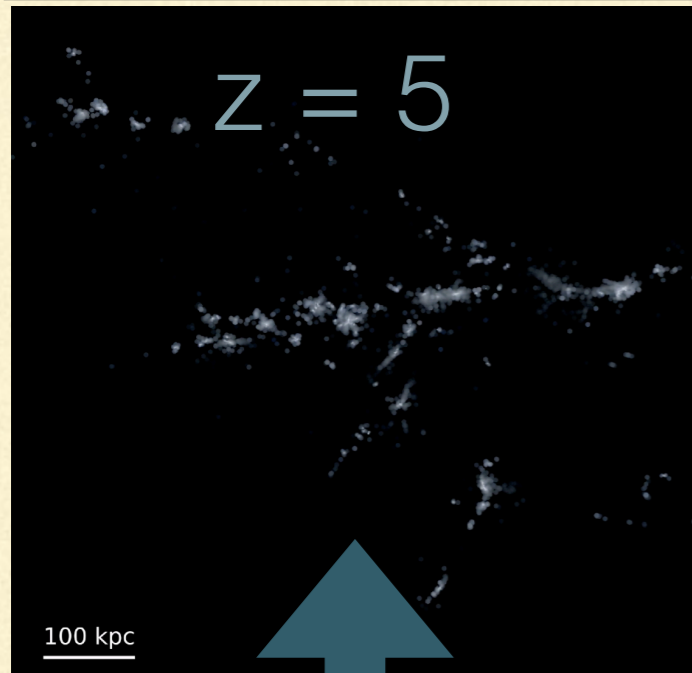


most 'old' stars have  $[\text{Fe}/\text{H}] > \sim -2$

determining origin of old stars:  
abundances are useful (mostly)  
kinematics are not

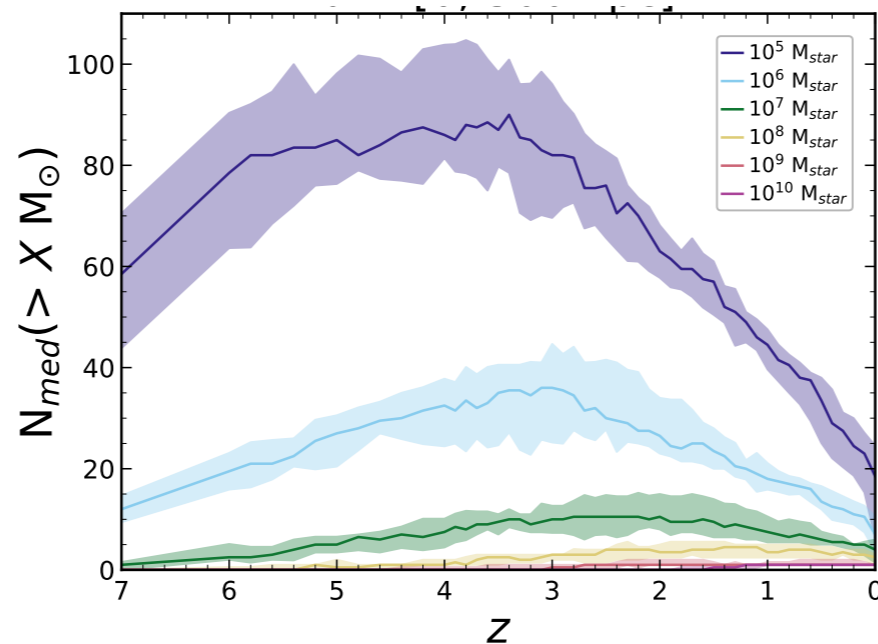


# THE MILKY WAY ON FIRE

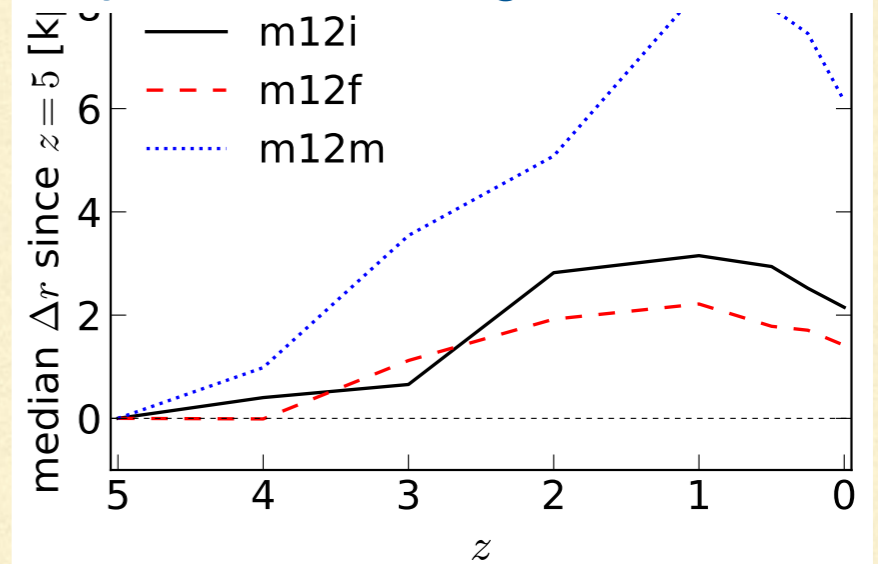


location of oldest stars today

dwarf gal building blocks of MW



dynamical heating of old stars



ex-situ dominates @  $z > \sim 3$

