CosPa 2015

Investigating the evolution of massive galaxies using semi-analytic approaches

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KASI

Theoretical approaches to galaxy formation and evolution

Millennium Simulation
Virgo Consortium

Concept of galaxy formation in modern cosmology

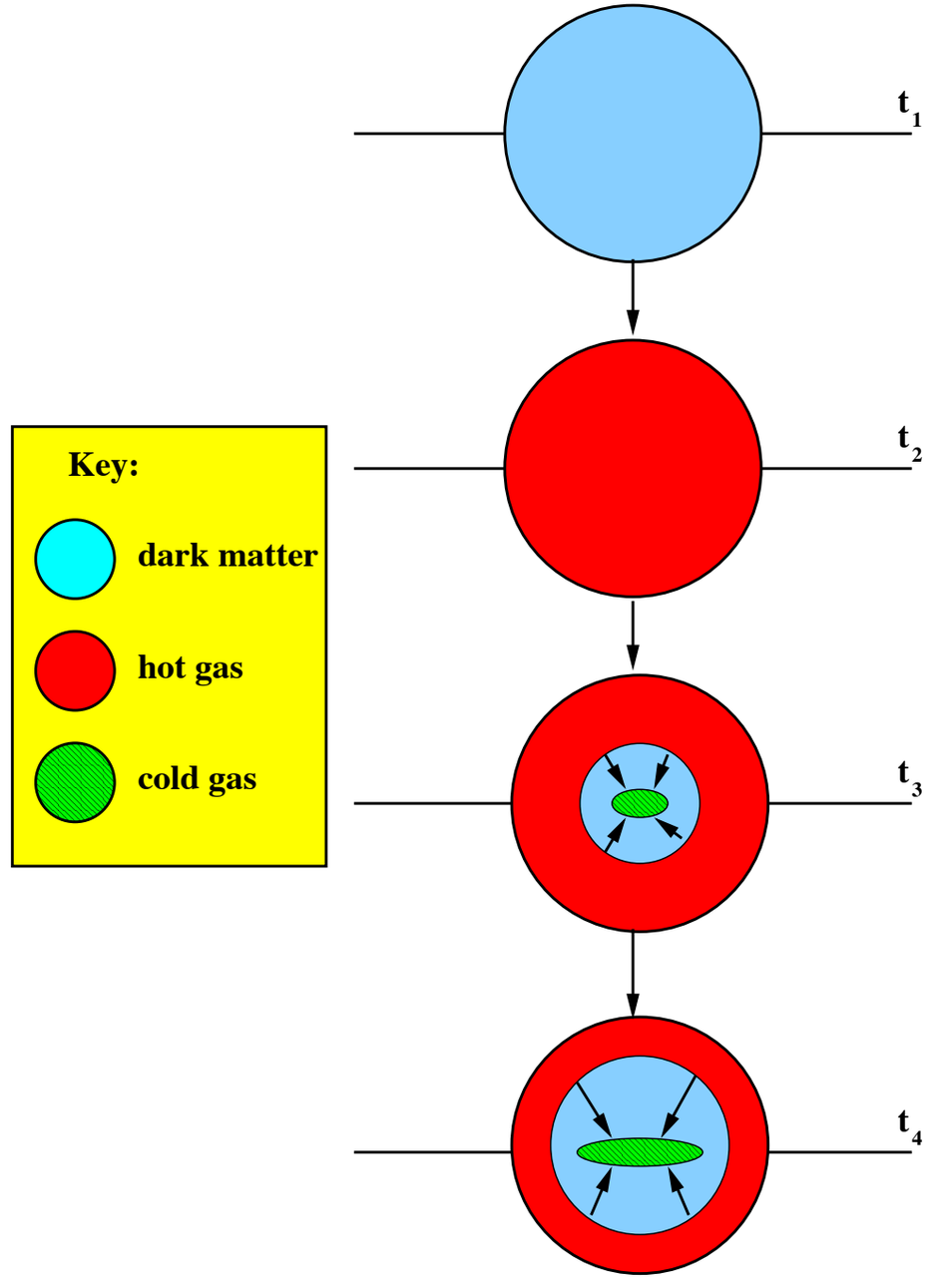
Dark matter haloes are essential in galaxy formation and evolution

1. Baryons fall into the gravitational potential well of the DM haloes

2. Baryons is heated by shock, reaching the viral temperature of DM haloes

3. The central part of the hot gas forms cold gas discs via cooling

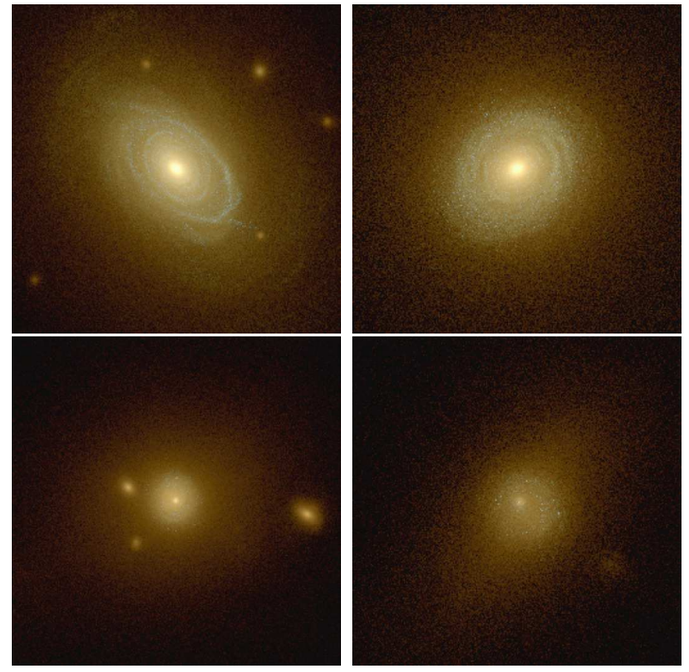
4. Stars are formed in the cold gas discs



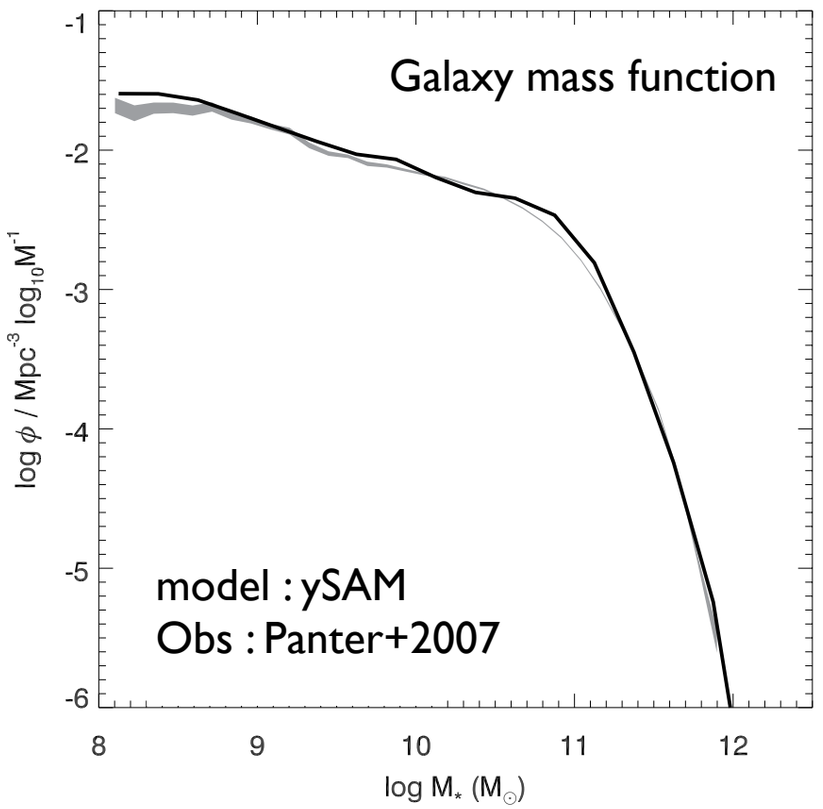
Baugh 2006

What tools are available?

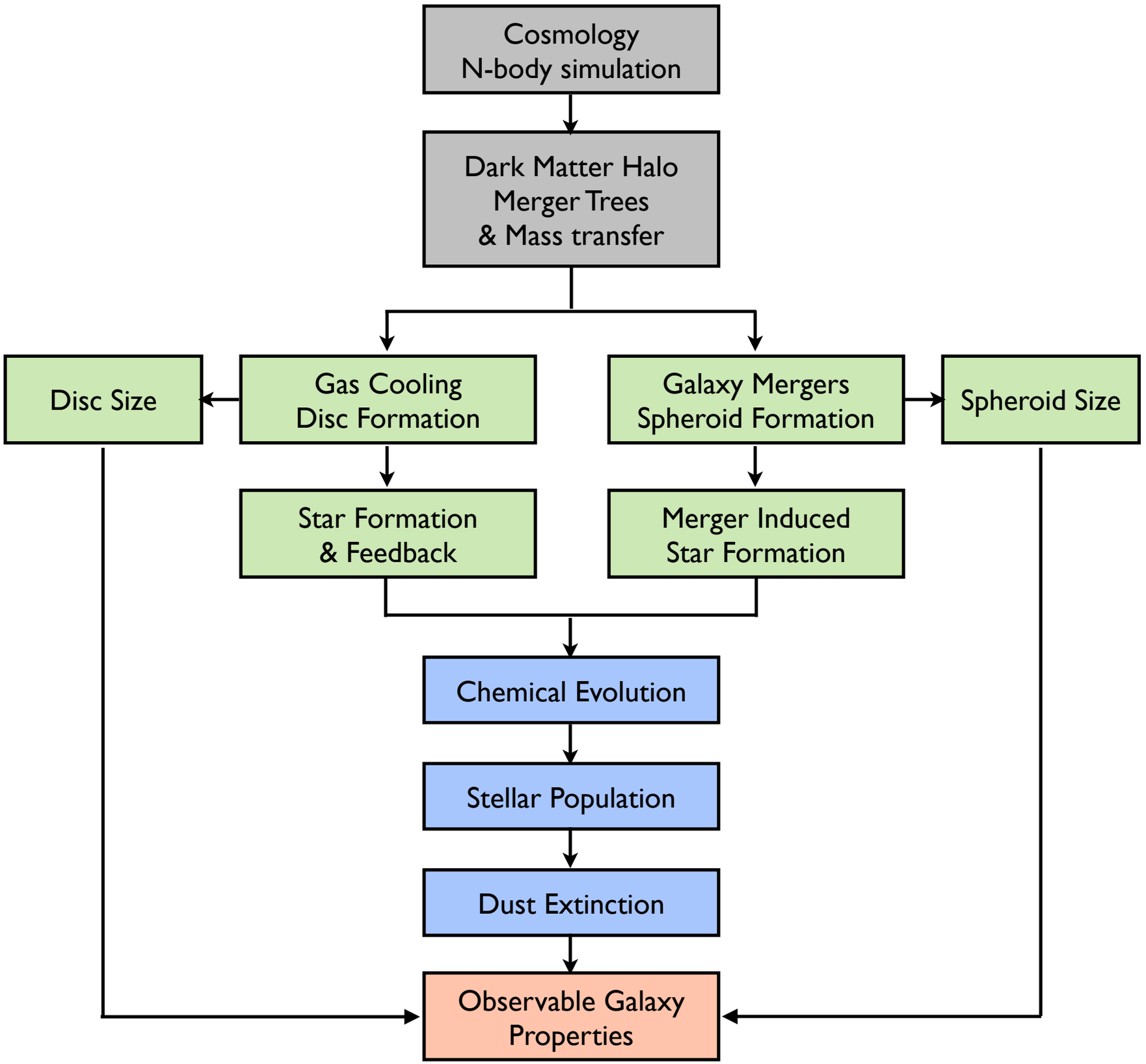
- Hydrodynamic simulation
  - Calculating hydrodynamics by directly solving differential equations for gas dynamics
  - Many technical challenges, time consuming
- Semi-analytic model (SAM) for galaxy formation and evolution
  - Based on a set of parameterised differential equations reduced from observation or numerical simulations
  - Much faster in calculating evolution of a large number of galaxies
  - Easy to test physical prescriptions



Dubois+2013



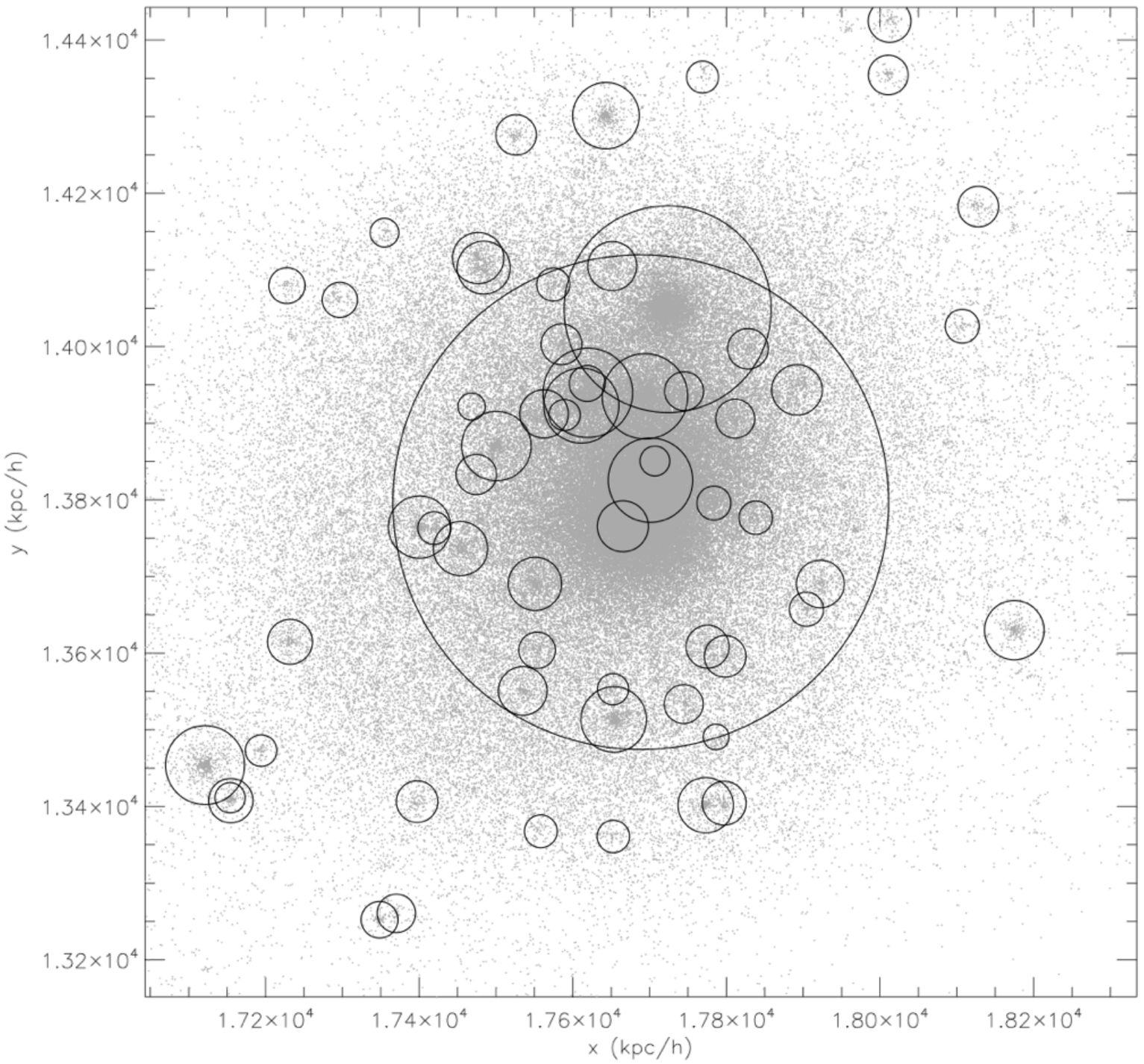
General Structure of Semi-Analytic Models



Cole+2000

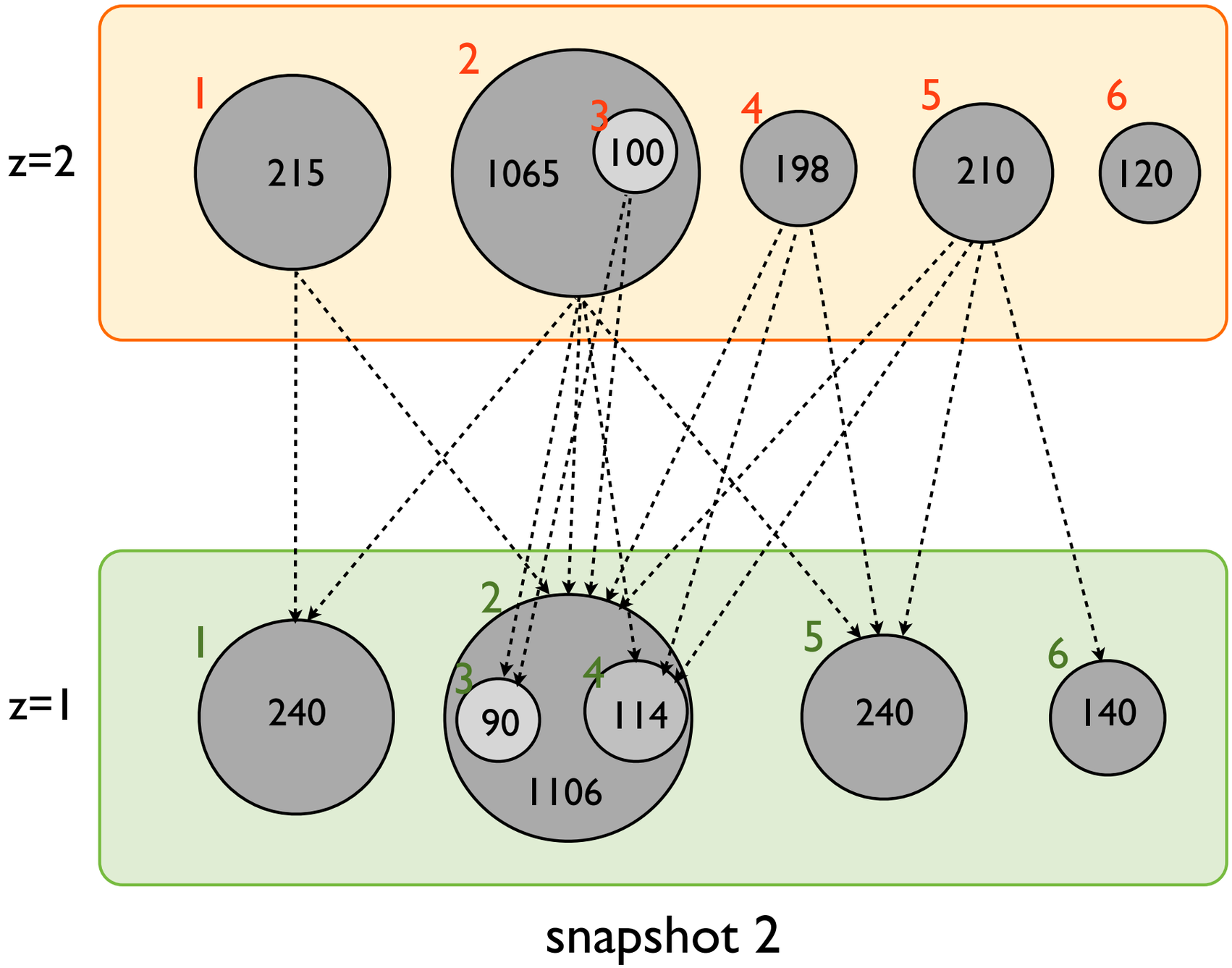
Tree building process from N-body simulations (1)

Particle distribution in an N-body volume
and haloes identified by halo finders

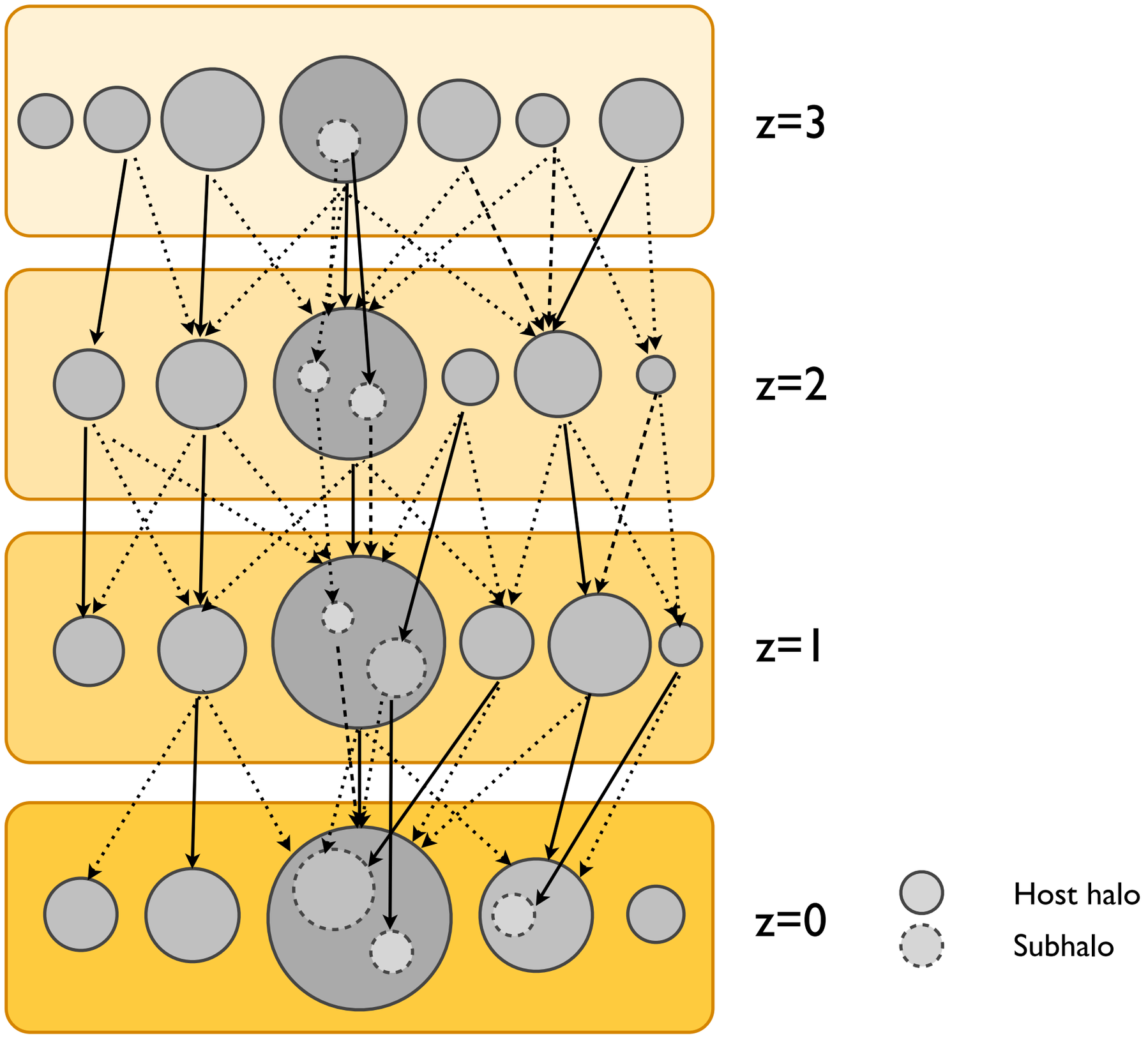


Tree building process from N-body simulations (2)

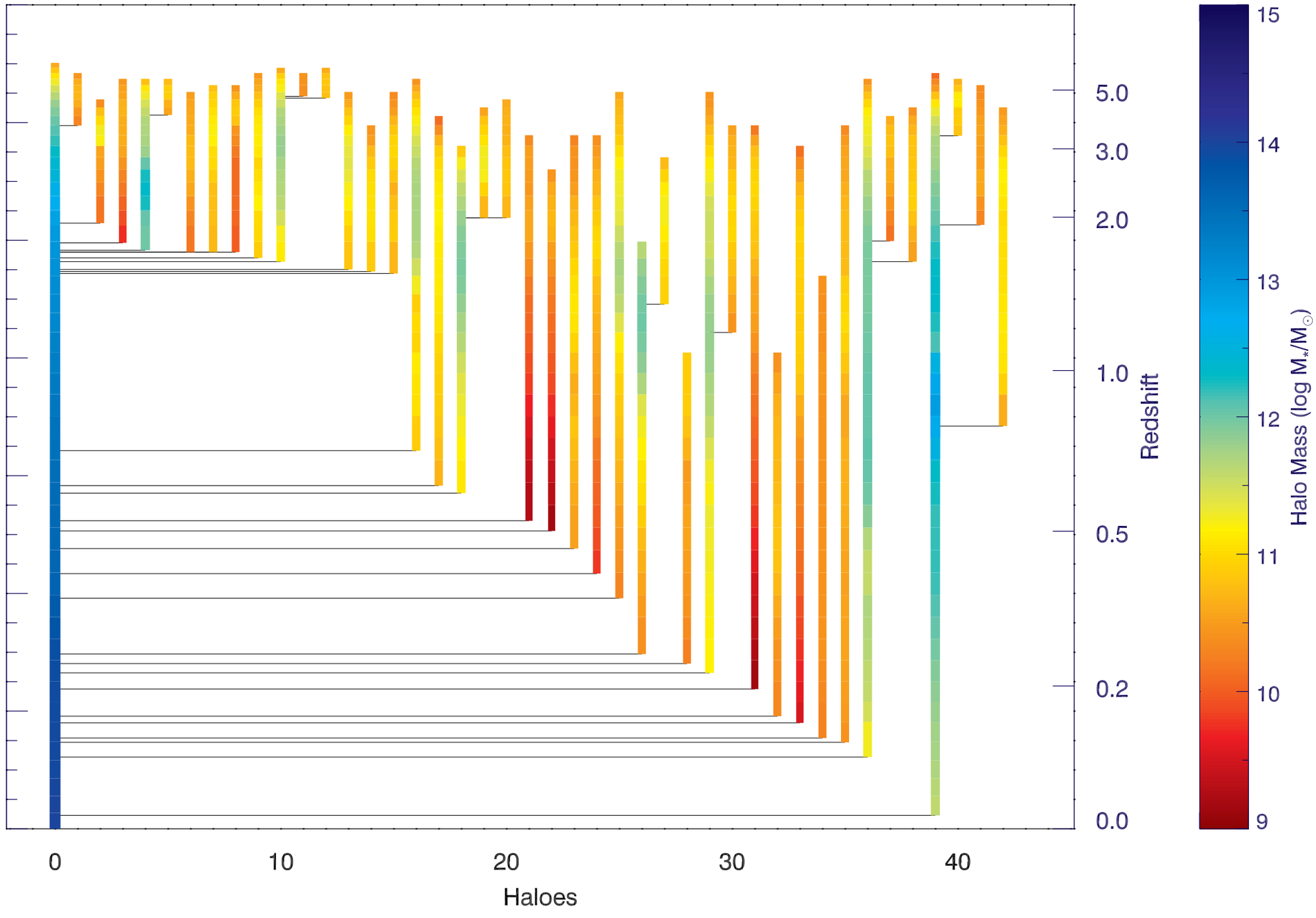
Tracking particle exchange histories between haloes
in two snapshots.



Tree building process from N-body simulations (3)



Tree building process from N-body simulations (4)

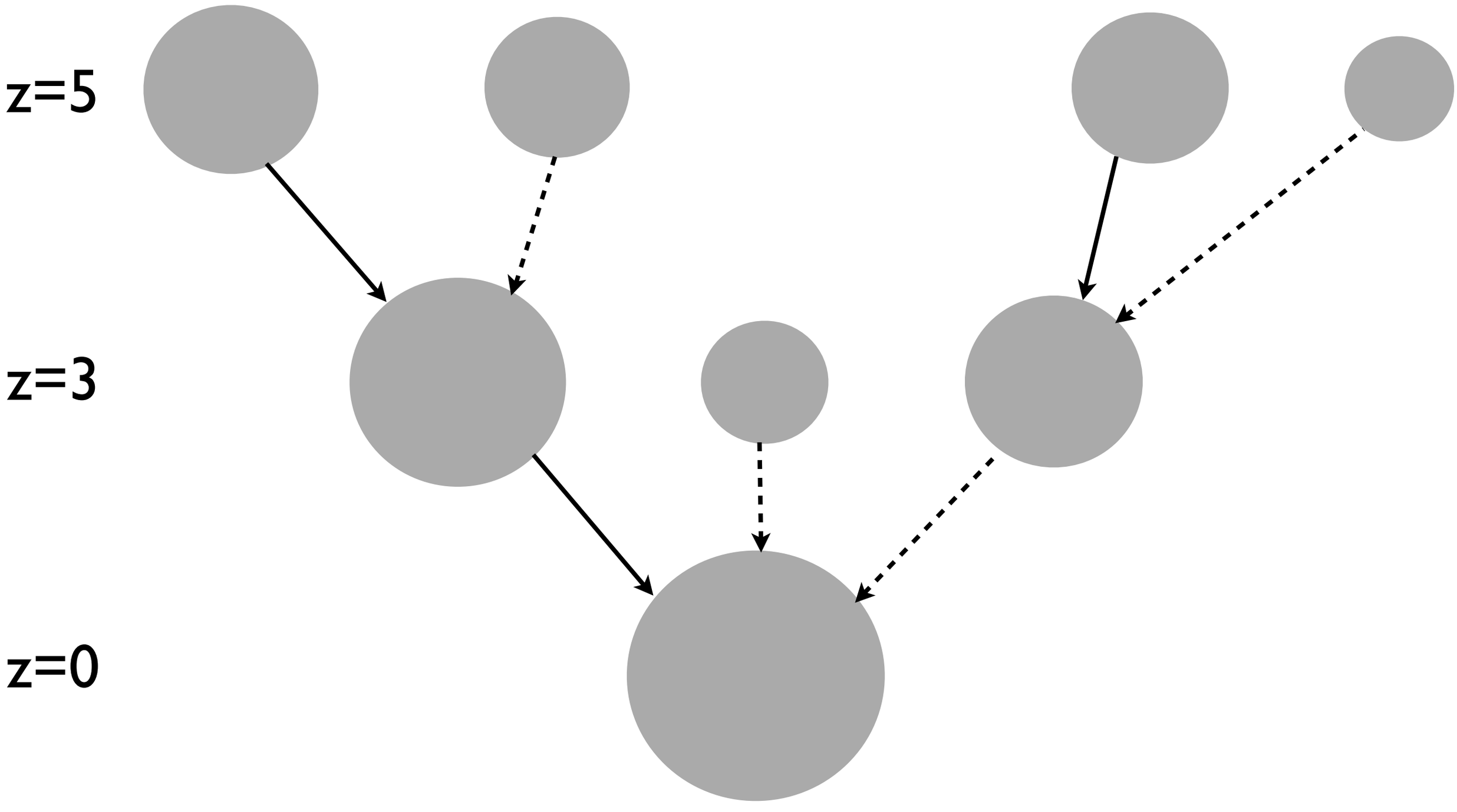


Physical ingredients in Semi-Analytic Model

- Halo merger trees and mass transfer histories from N-body simulations
- Gas cooling and star formation
- Stellar population evolution
- Chemical evolution of gas and stars
- Galaxy mergers and starbursts
- Scatter of stellar components due to galaxy mergers
- Tidal and ram pressure stripping of hot gas
- AGN and supernova feedback

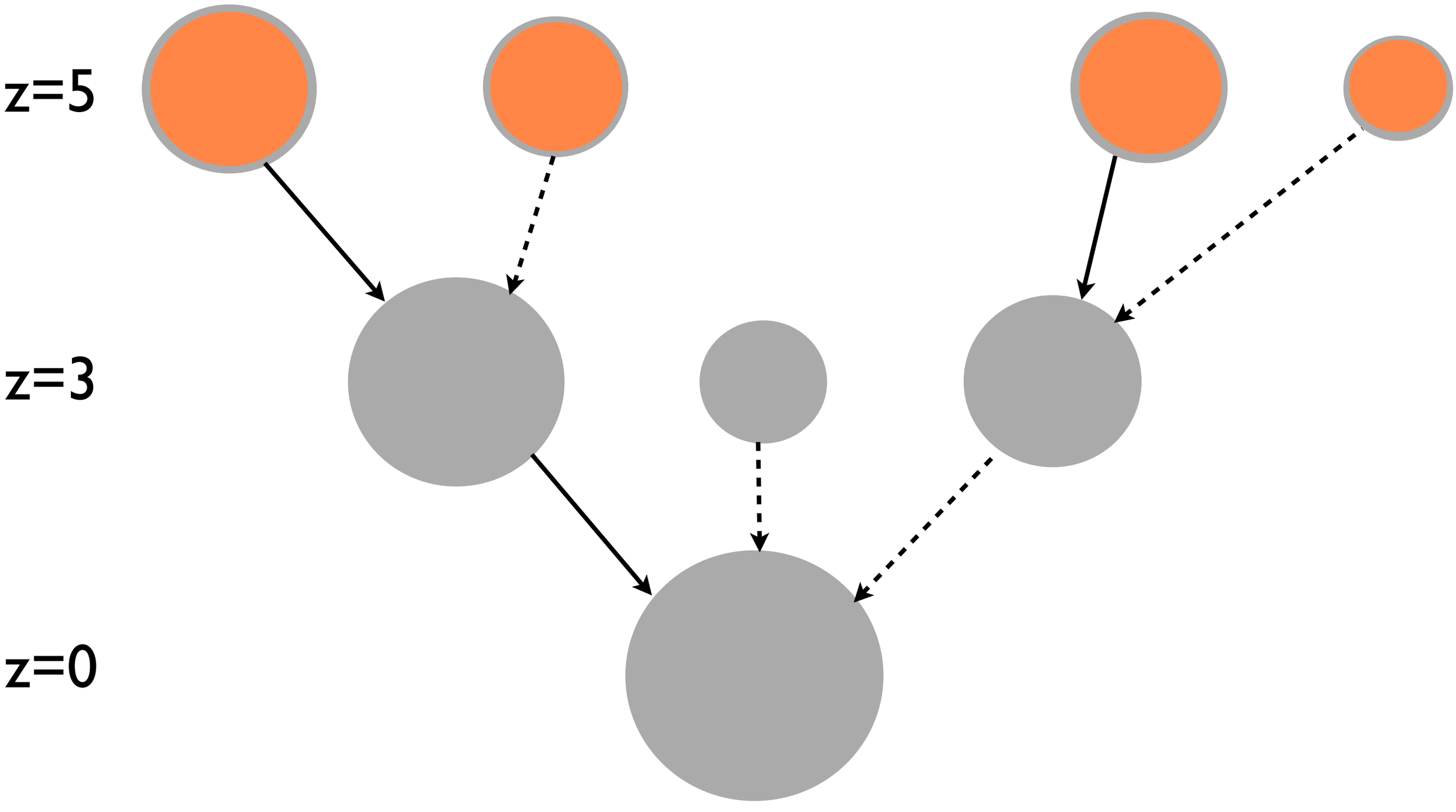
How SAM Works

1. Constructing DMH merger trees from N-body simulations



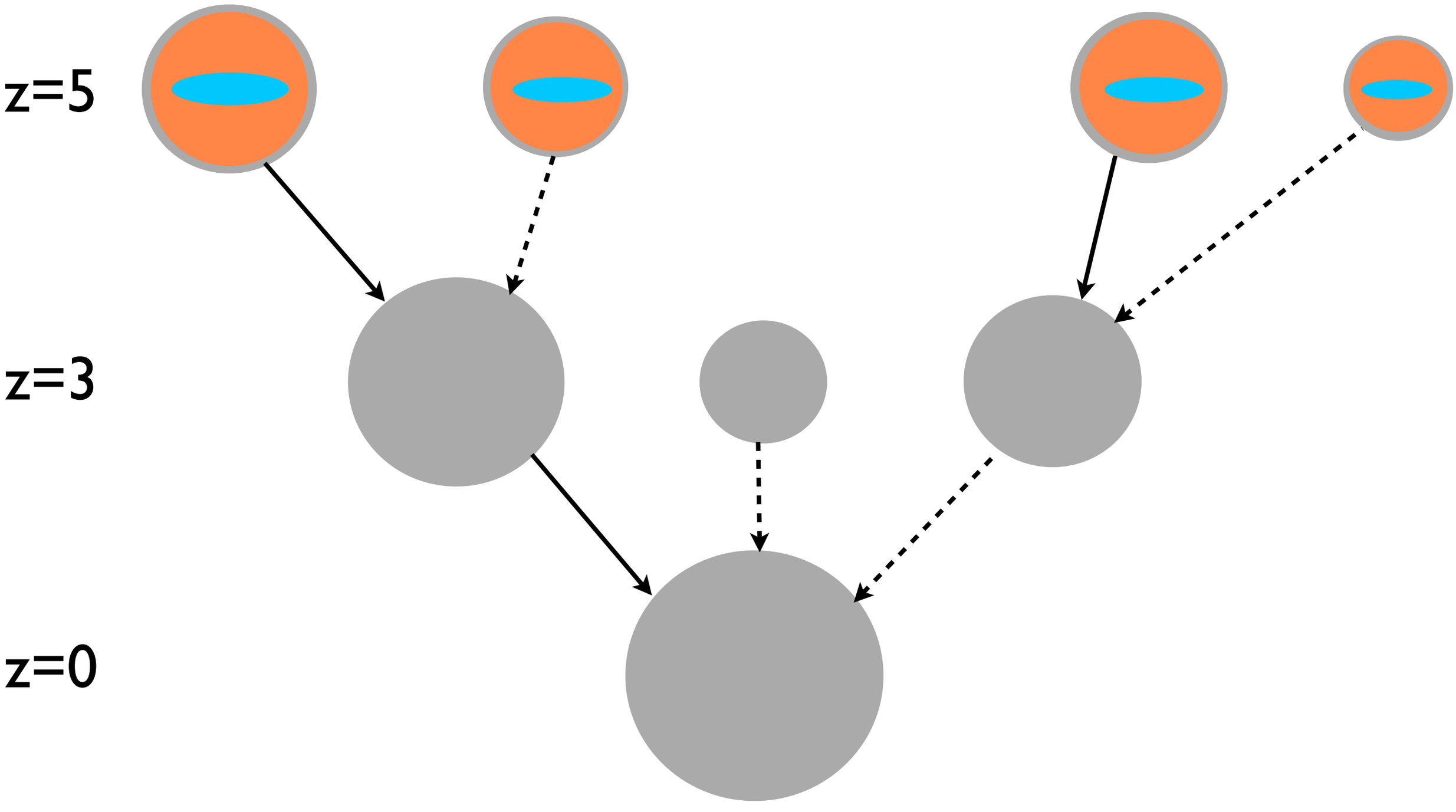
How SAM Works

2. Putting baryon as 'hot gas' into DMHs



How SAM Works

3. Forming cold gas discs via cooling



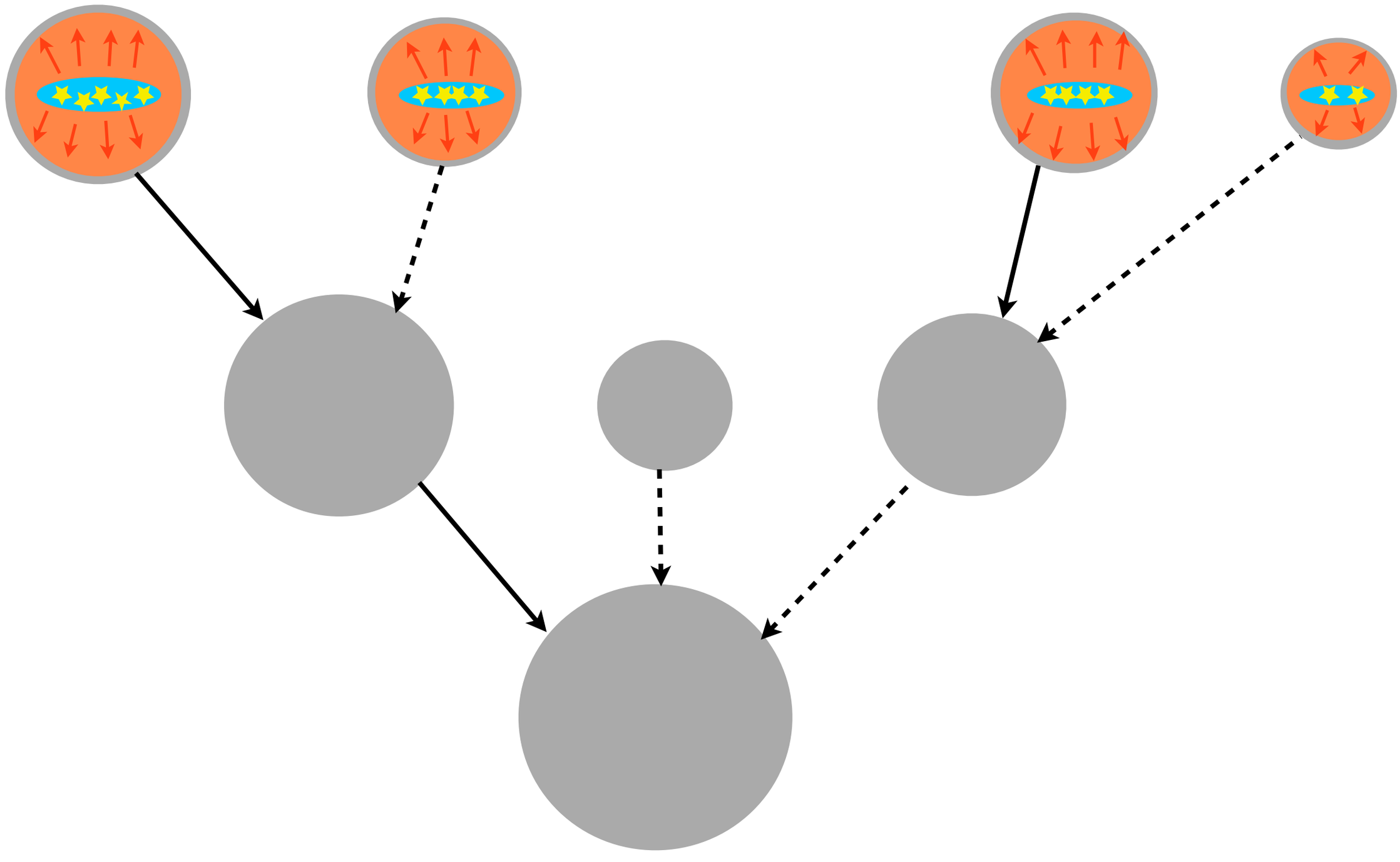
How SAM Works

4. Star formation on disks
Stellar feedback from new stars

z=5

z=3

z=0



How SAM Works

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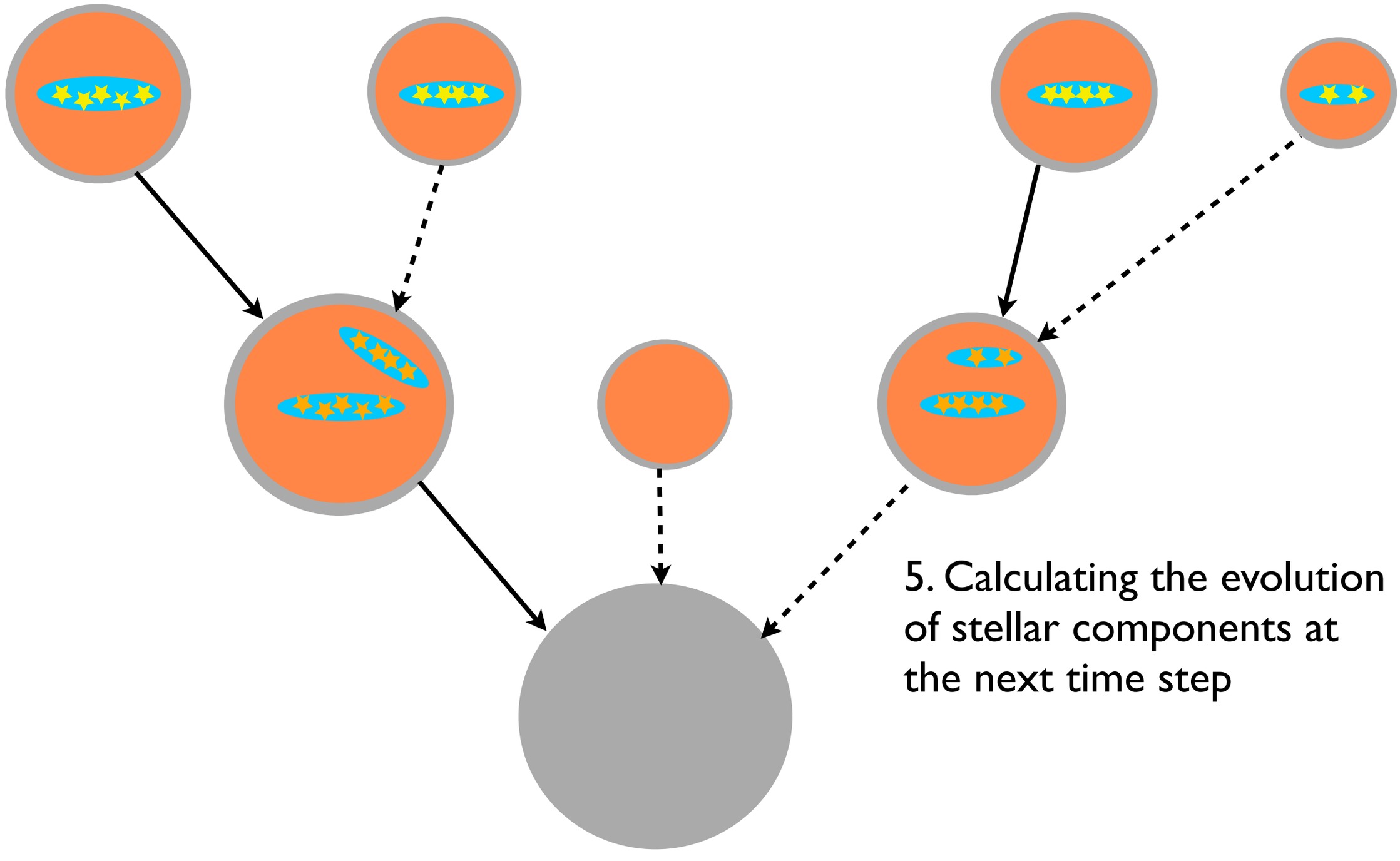


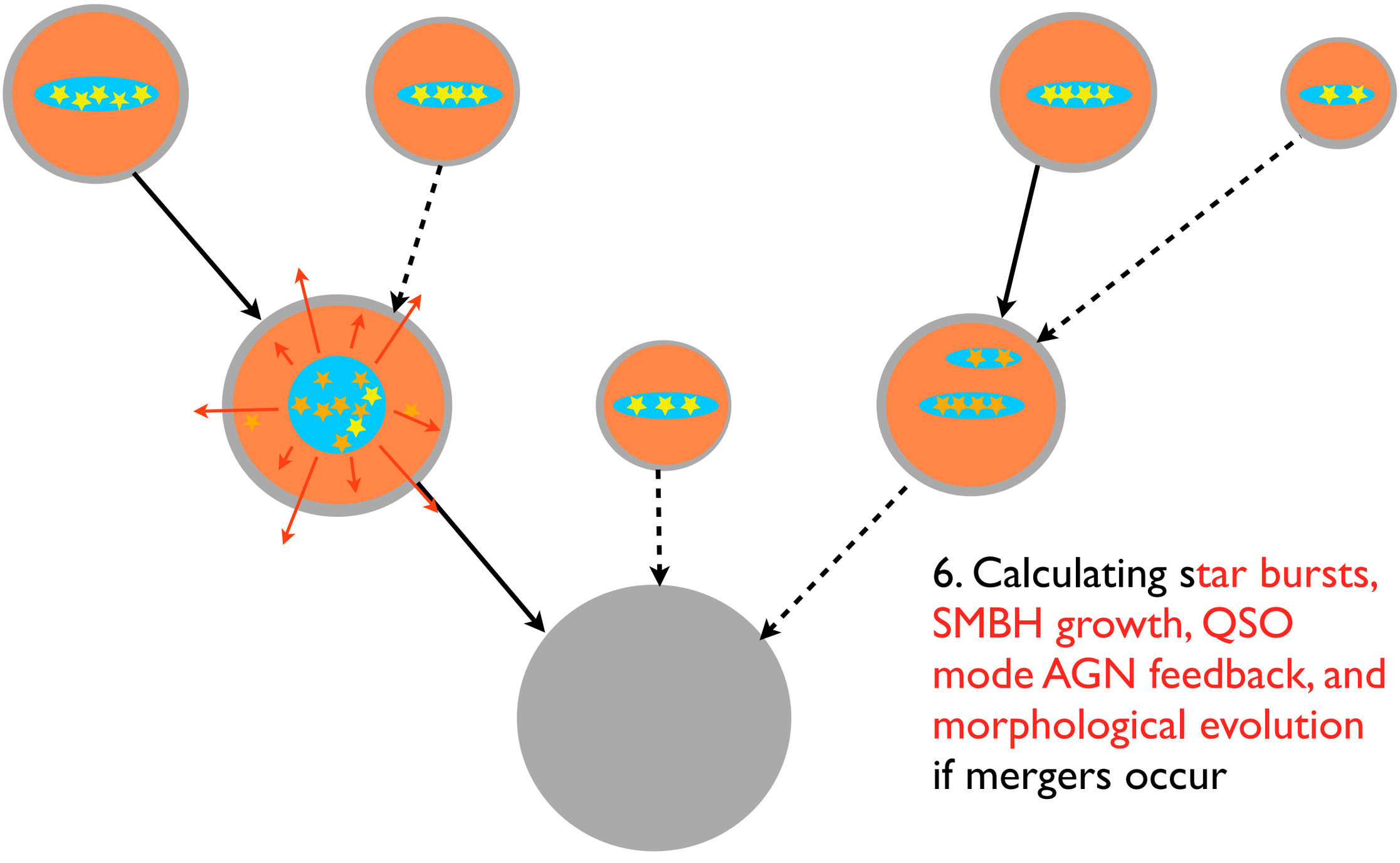
5. Calculating the evolution of stellar components at the next time step

How SAM Works

z=5

z=3

z=0



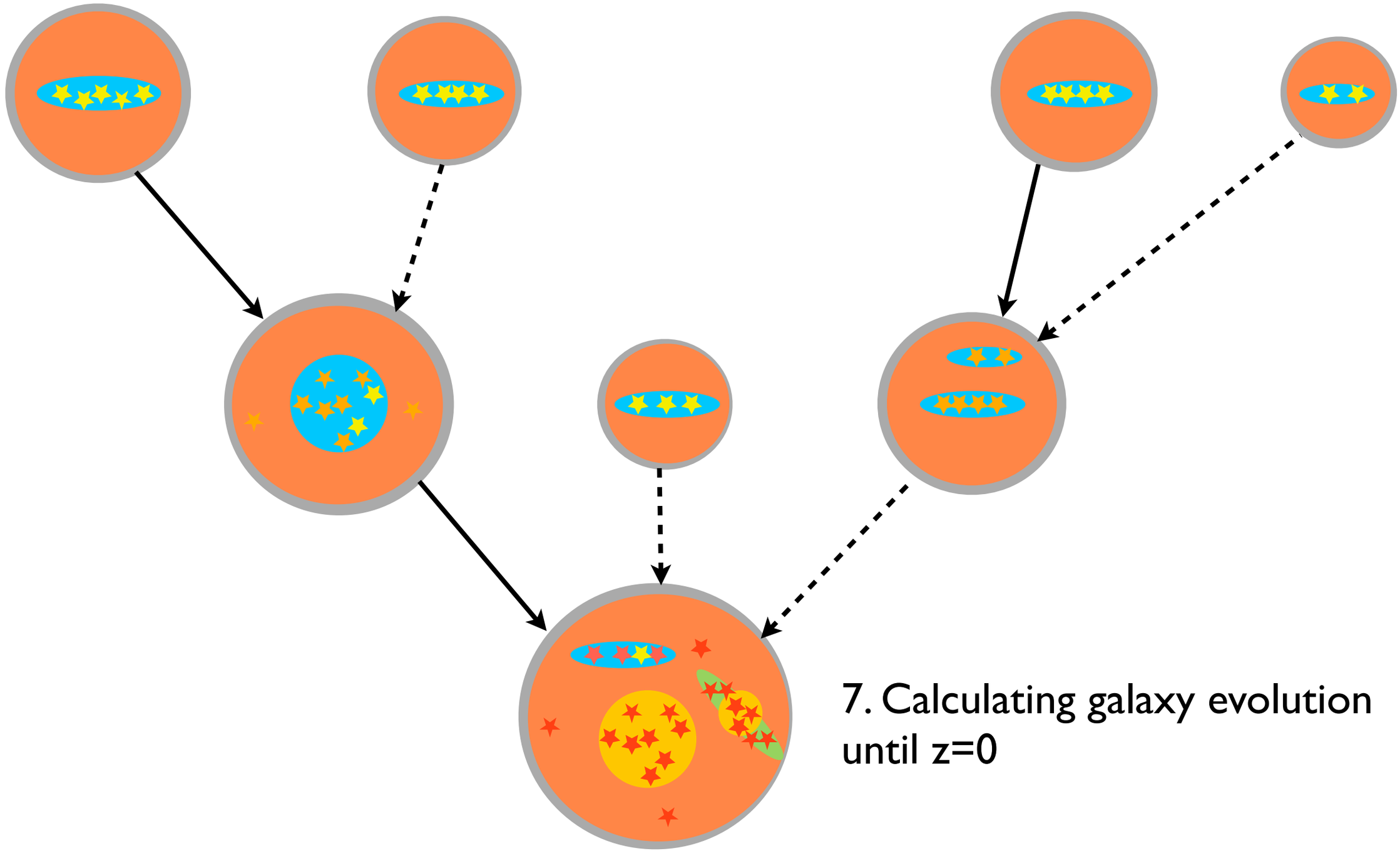
6. Calculating star bursts, SMBH growth, QSO mode AGN feedback, and morphological evolution if mergers occur

How SAM Works

z=5

z=3

z=0



7. Calculating galaxy evolution until z=0

The role of mergers in the growth of massive galaxies

NGC1132
Hubblesite.org

- Massive galaxies are the end product of the hierarchical Universe

  - Clues from observations

    High disturbed fraction in red early types in the local Universe due to recent mergers (Van Dokkum 2005; Sheen et al. 2012)

    High pair fraction of massive (log M/M>11) red spheroidal at z~1 (Bundy et al. 2009)

    Downsizing trends (e.g. Cowie et al. 1996; Glazebrook et al. 2004)

  - Theoretical view

    Stellar component fraction assembled via mergers (Oser et al. 2010; Lackner et al. 2012; Lee & Yi 2013)

    Formation history of massive galaxies (Kauffmann 1996; Baugh et al. 1996; De Lucia et al. 2006; De Lucia & Blaizot 2007; Almeida et al. 2008; De Lucia & Borgani 2012)

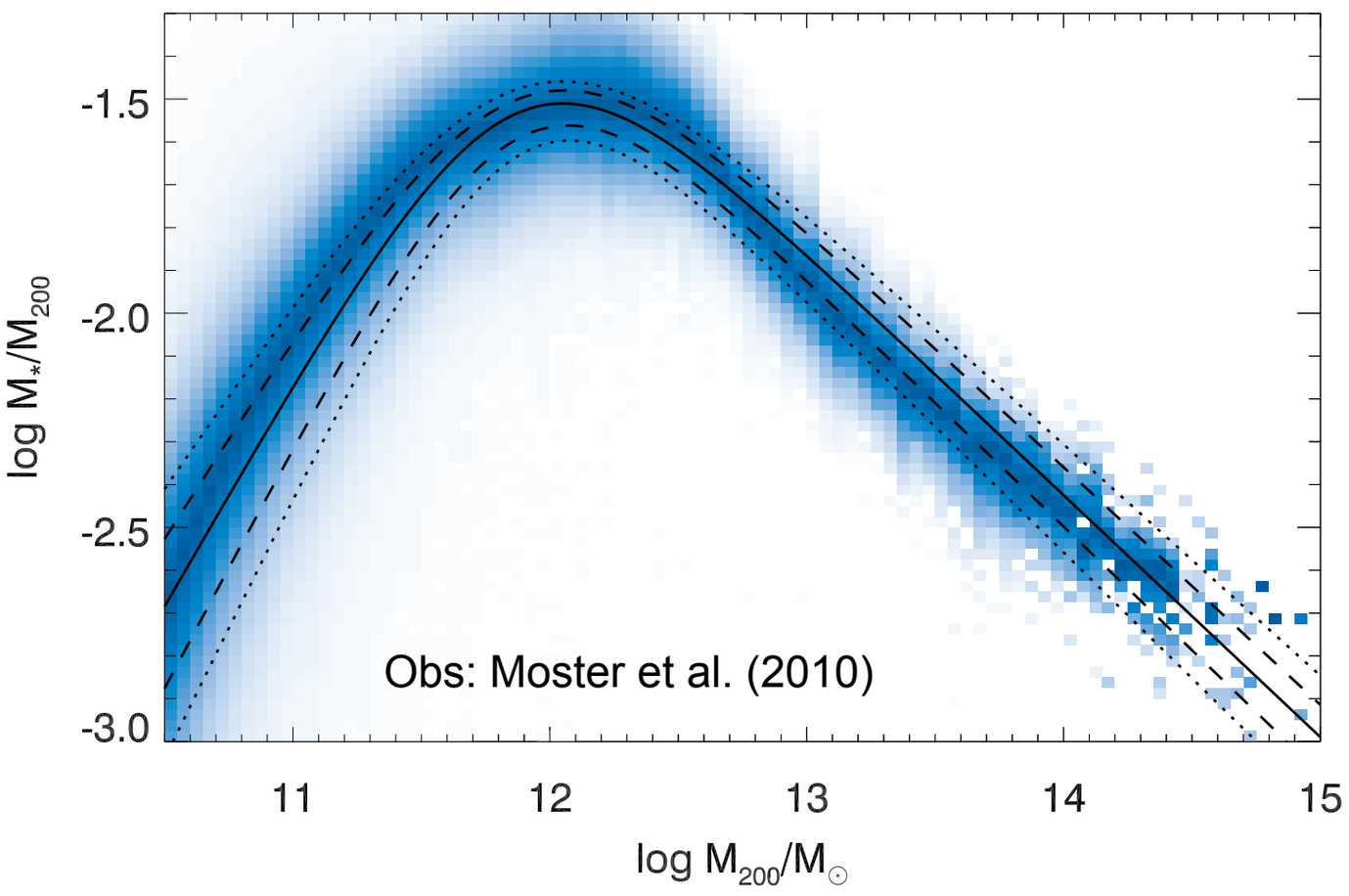
    Downsizing trend in SAMs (e.g. De Lucia et al. 2006; Lee & Yi 2013)

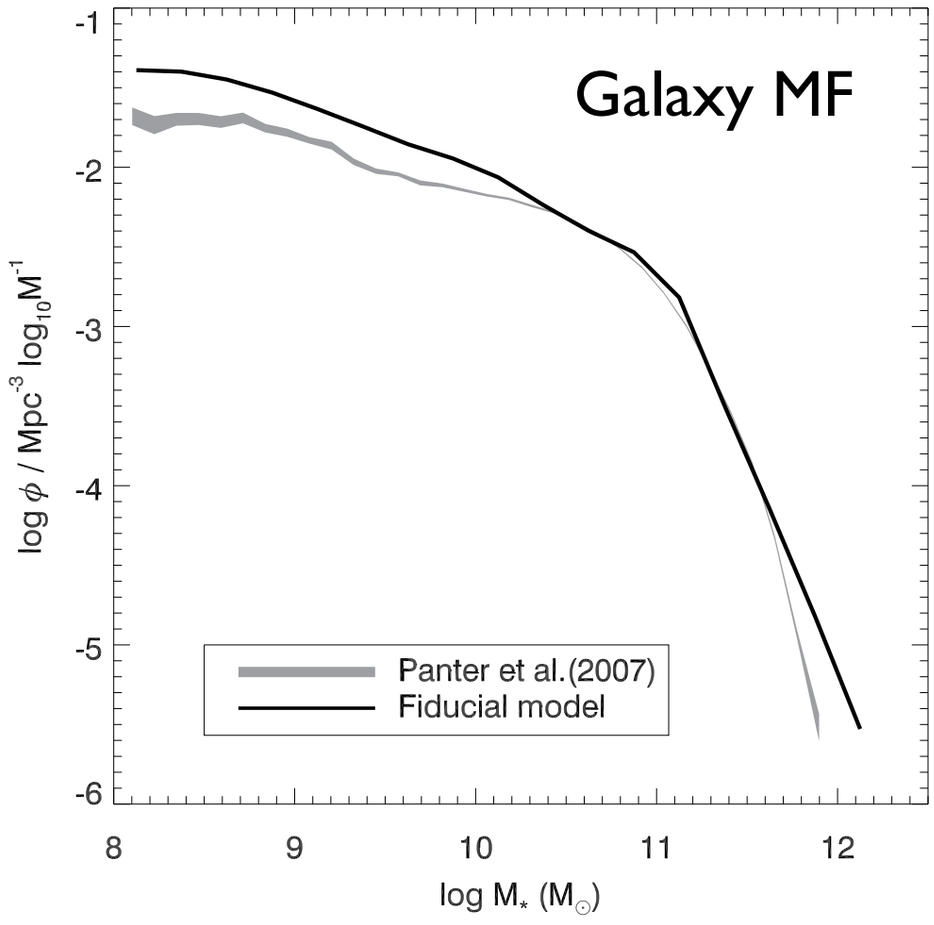
- Key questions
  - How does galaxy stellar mass grow as a function of halo and galaxy mass?
  - How many stars are coming from outside via mergers?
  - When is merger dominant?

- Semi-analytic model for galaxy formation and evolution
  - The simplest approach to investigate the evolution histories of massive galaxies in large volumes

- Simulation
  - ySAM (Lee & Yi 2013)
  - 1024^3 particles in a $(200 Mpc/h)^3$ volume (min $M_{200} \sim 10^{10.5} M_\odot$)

Stellar-to-halo mass relation





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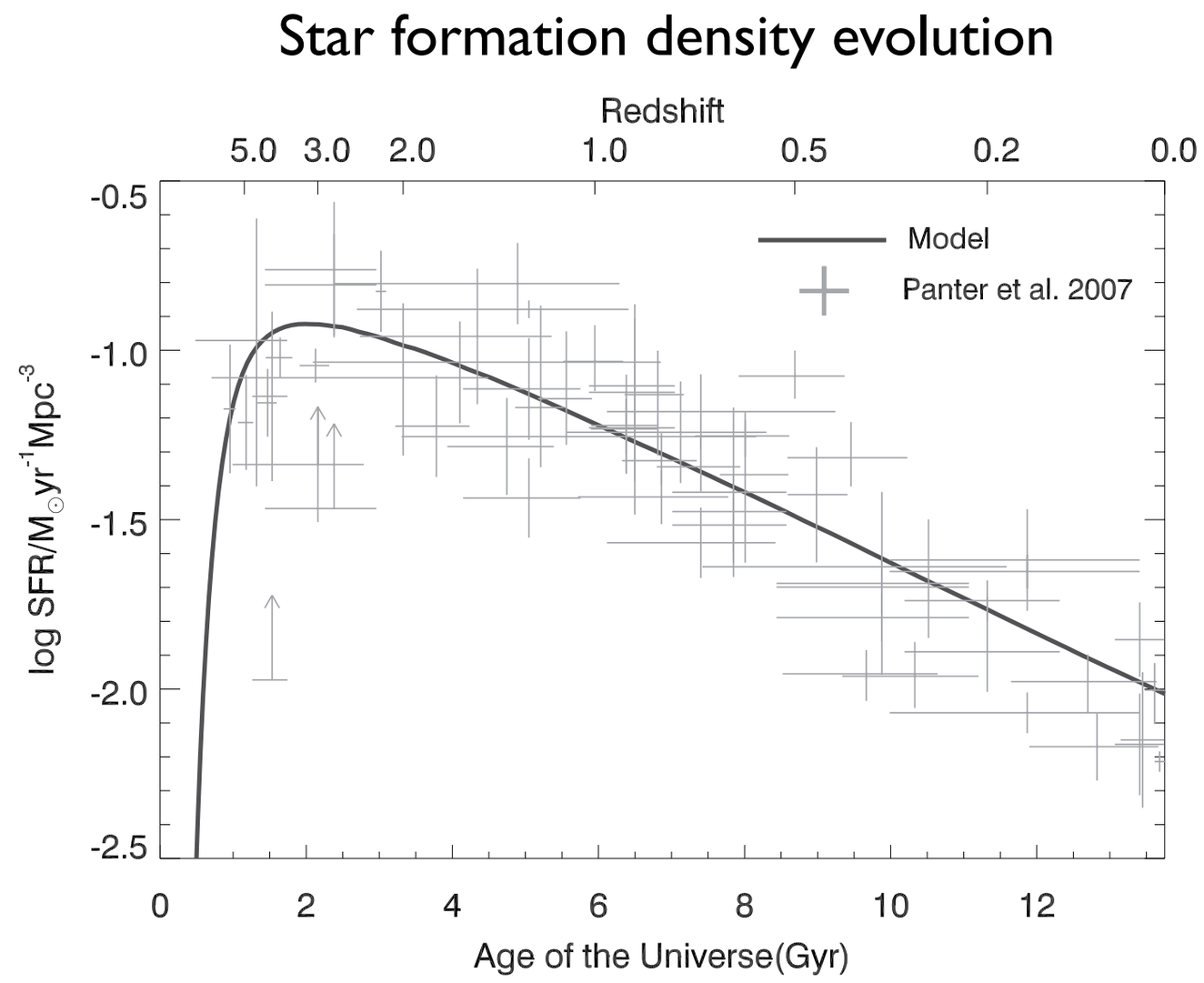

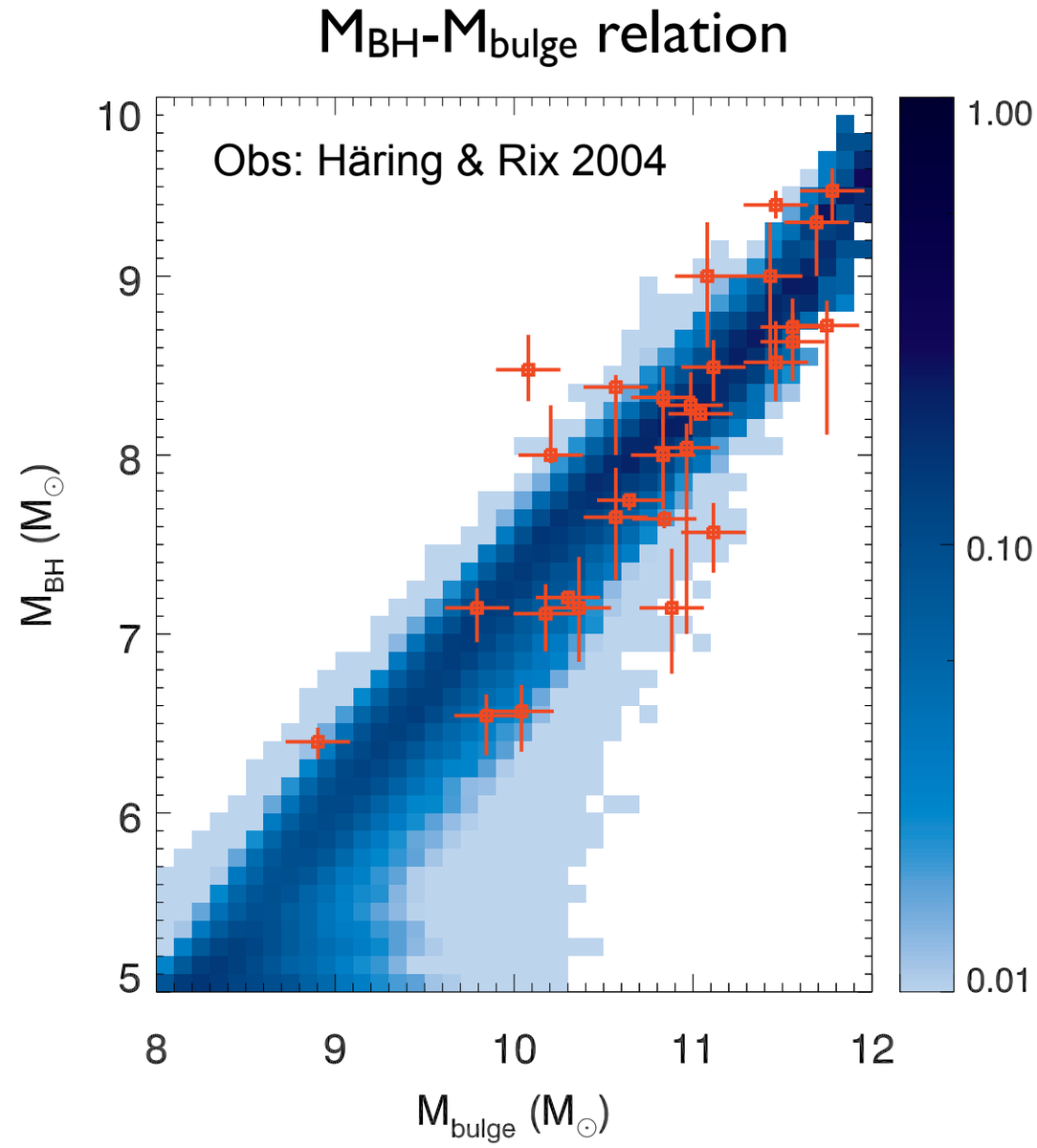

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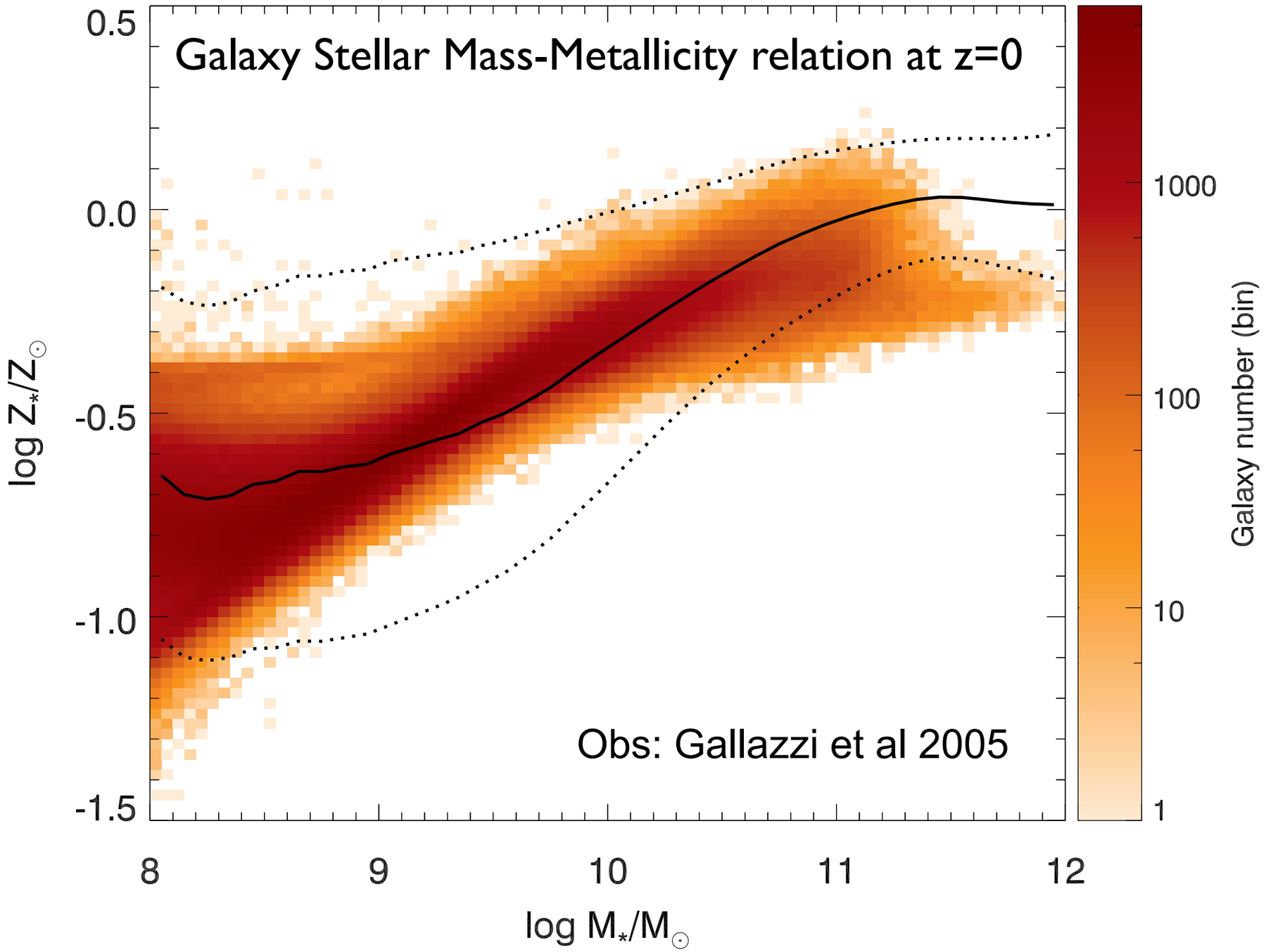
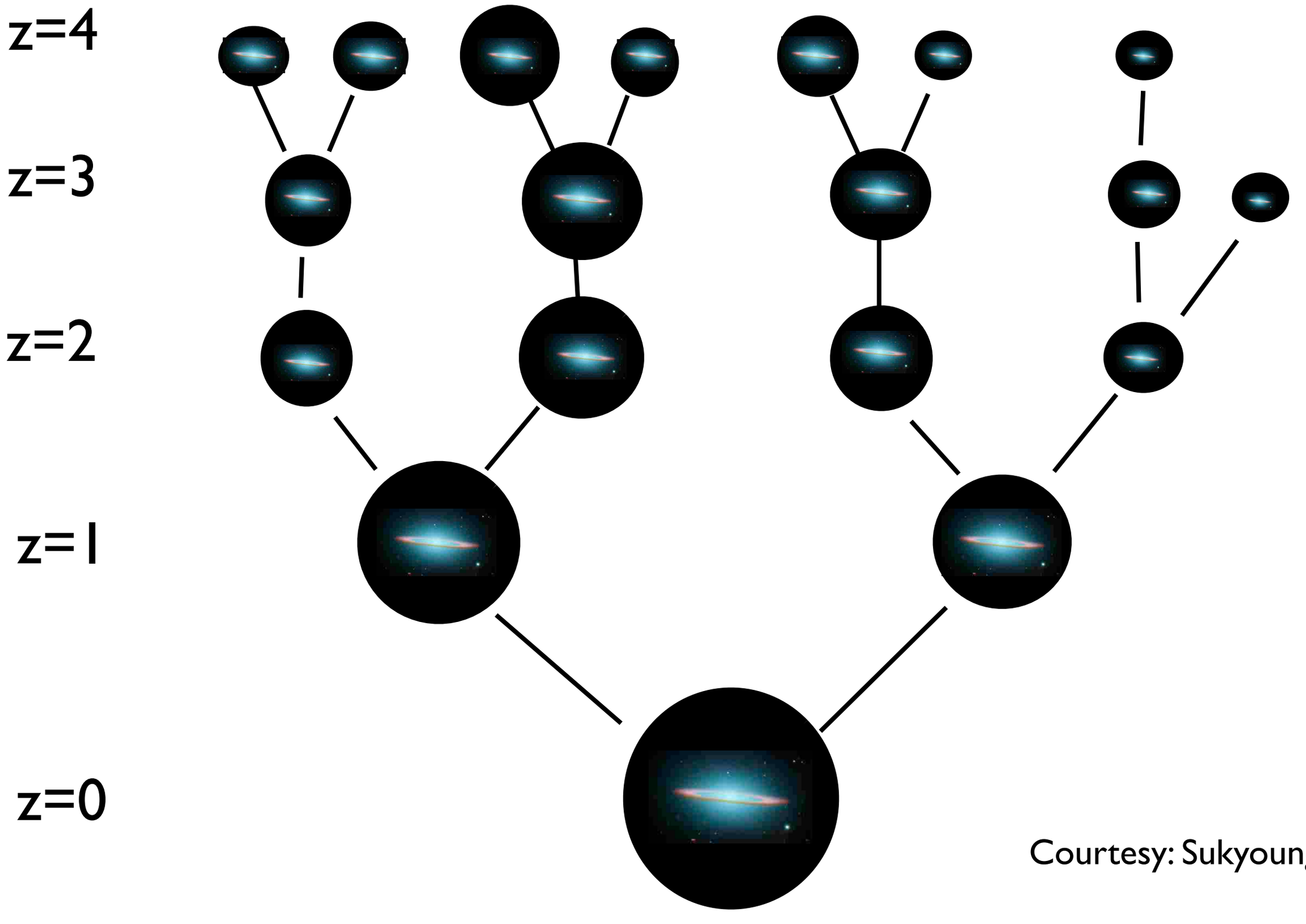
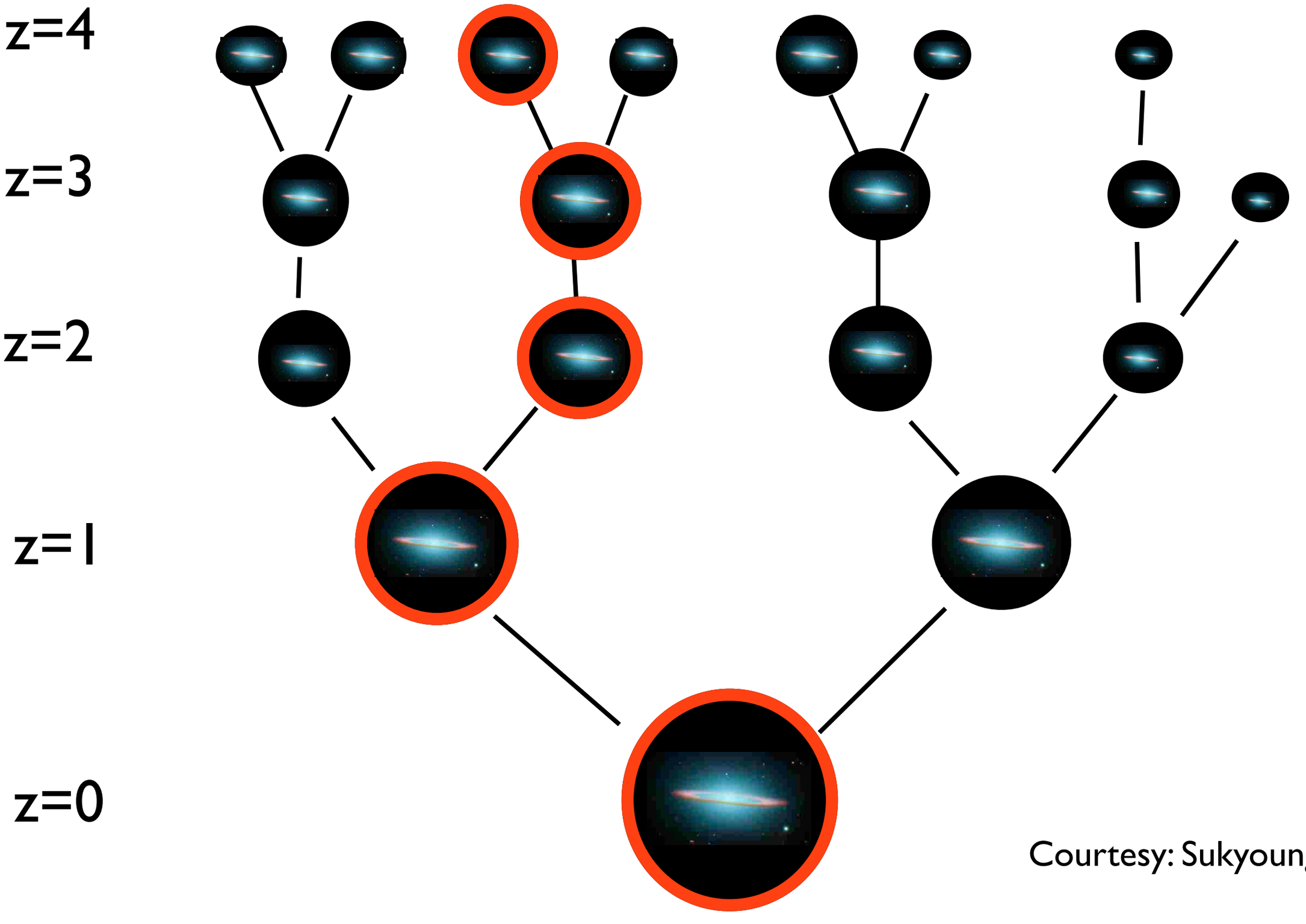


- Galaxy evolution in the hierarchical universe



Courtesy: Sukyoung Yi

- Mass growth history of direct progenitors



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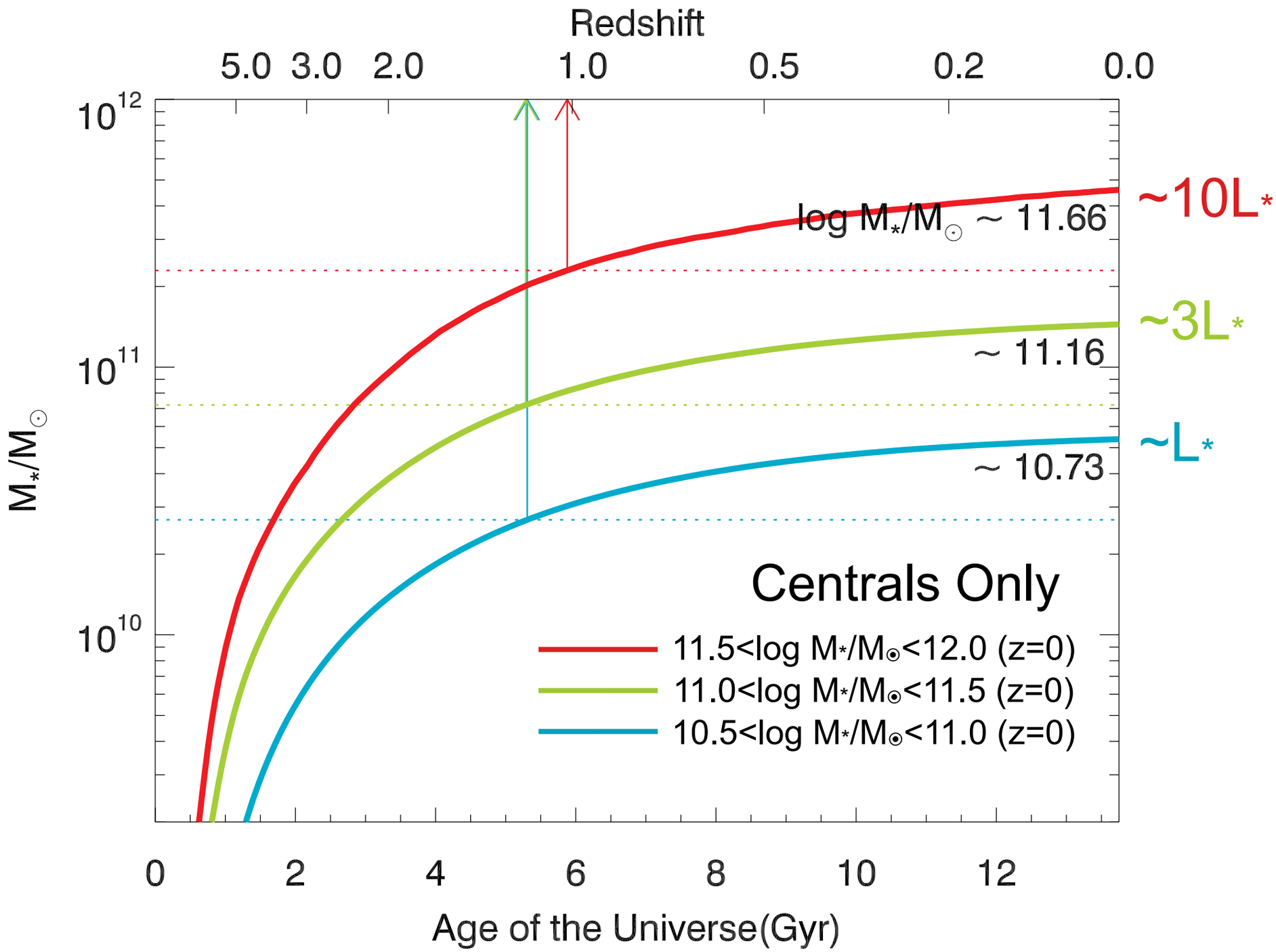
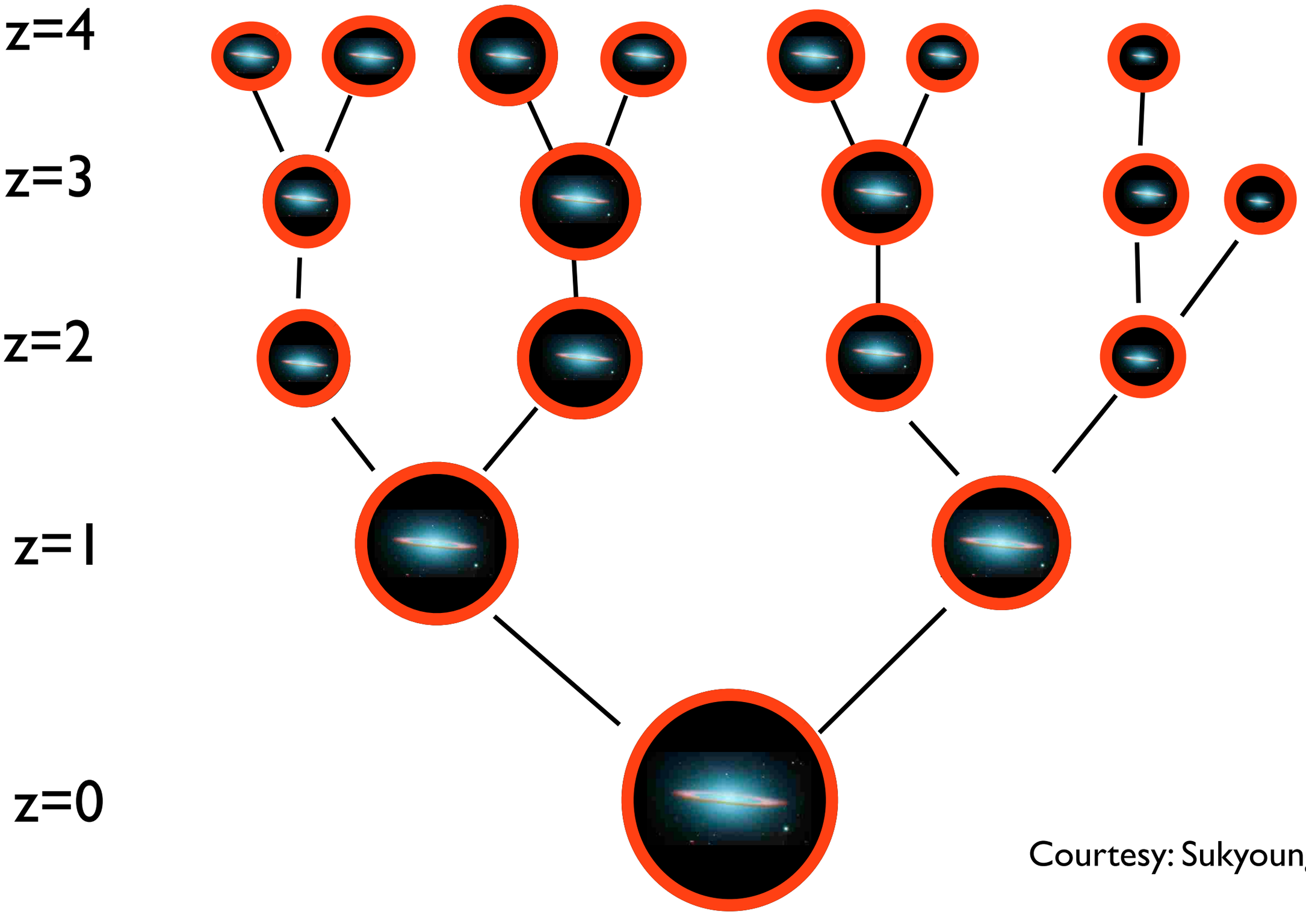


- Mass growth history of all progenitors



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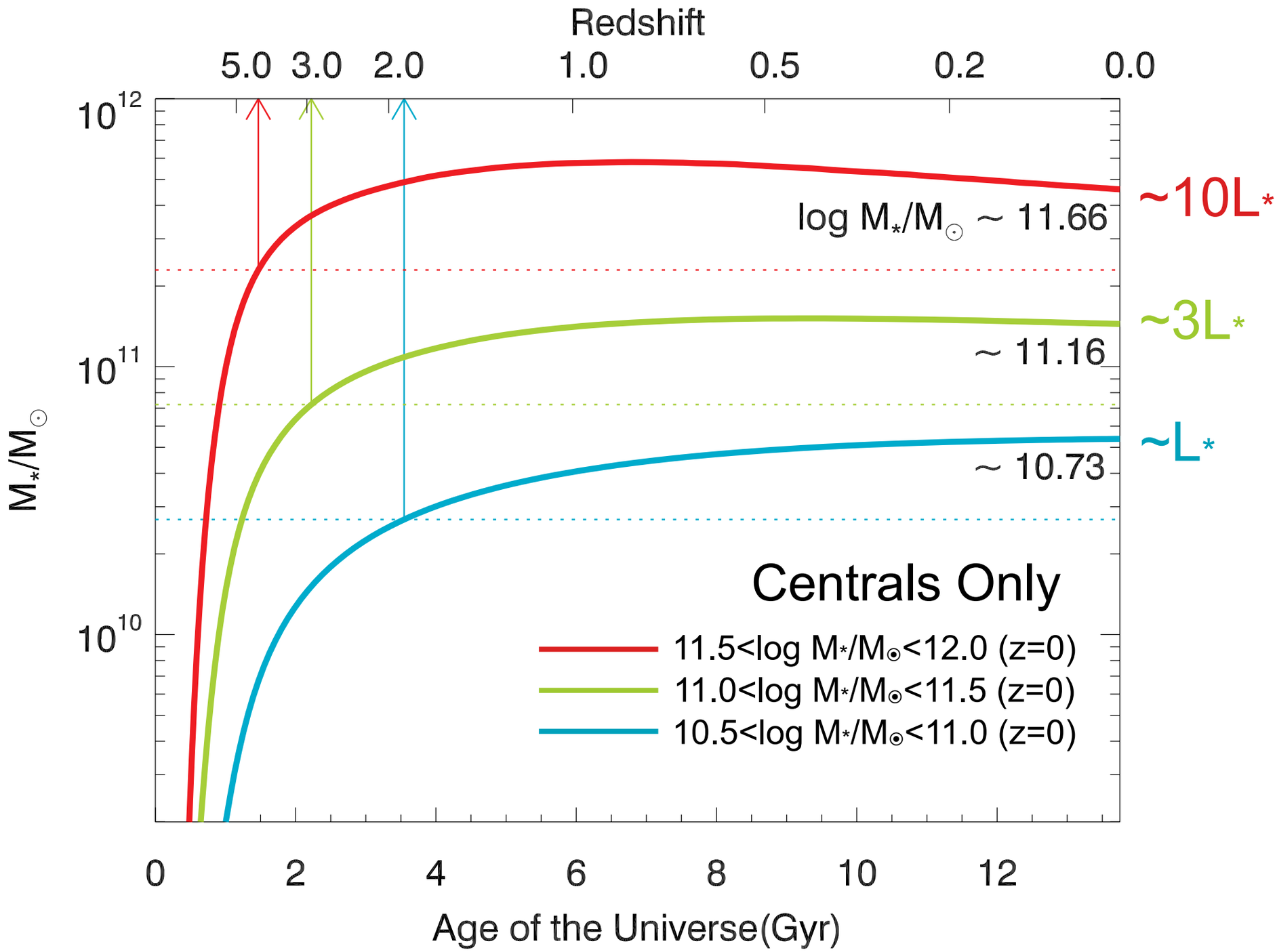
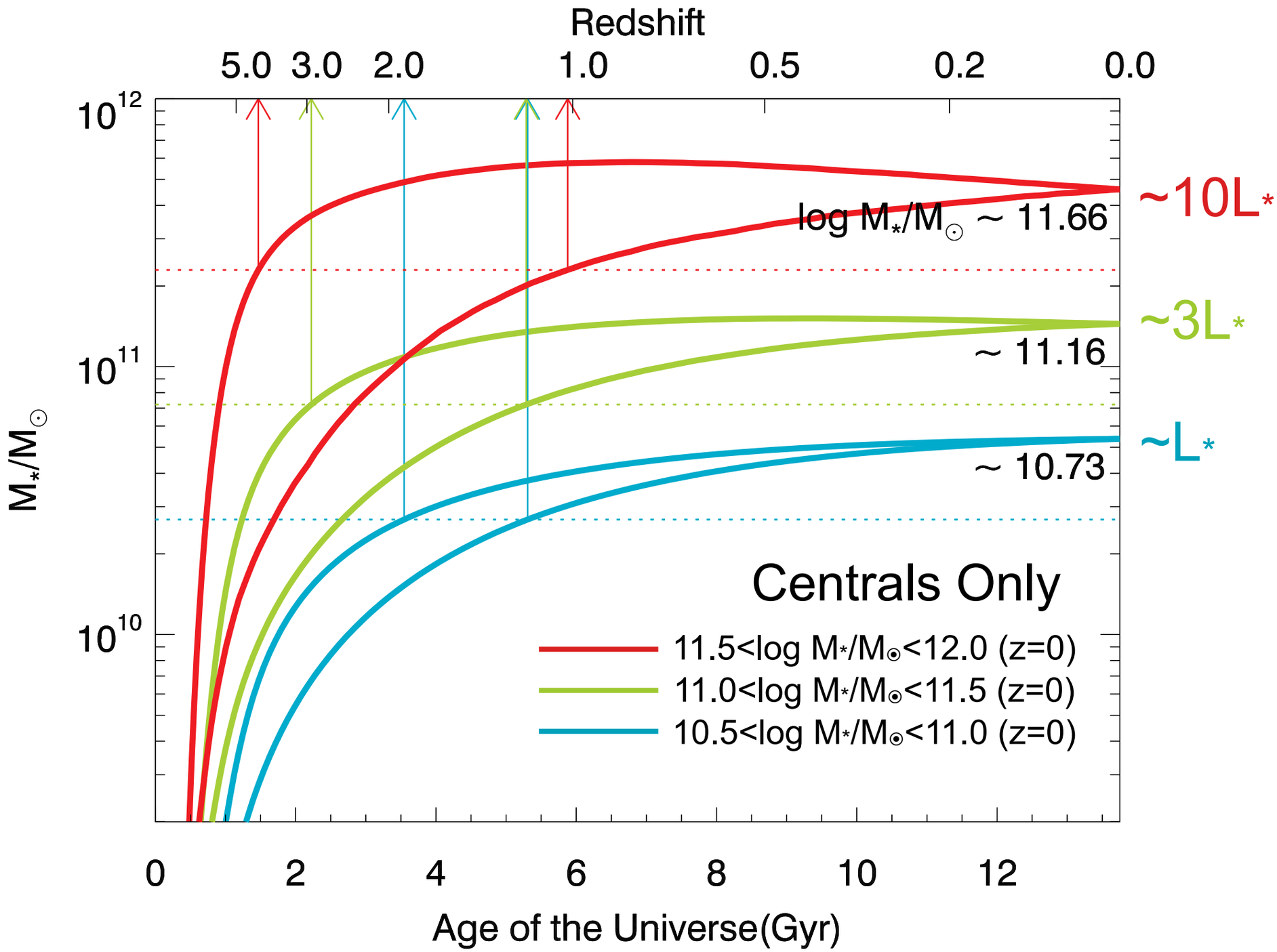
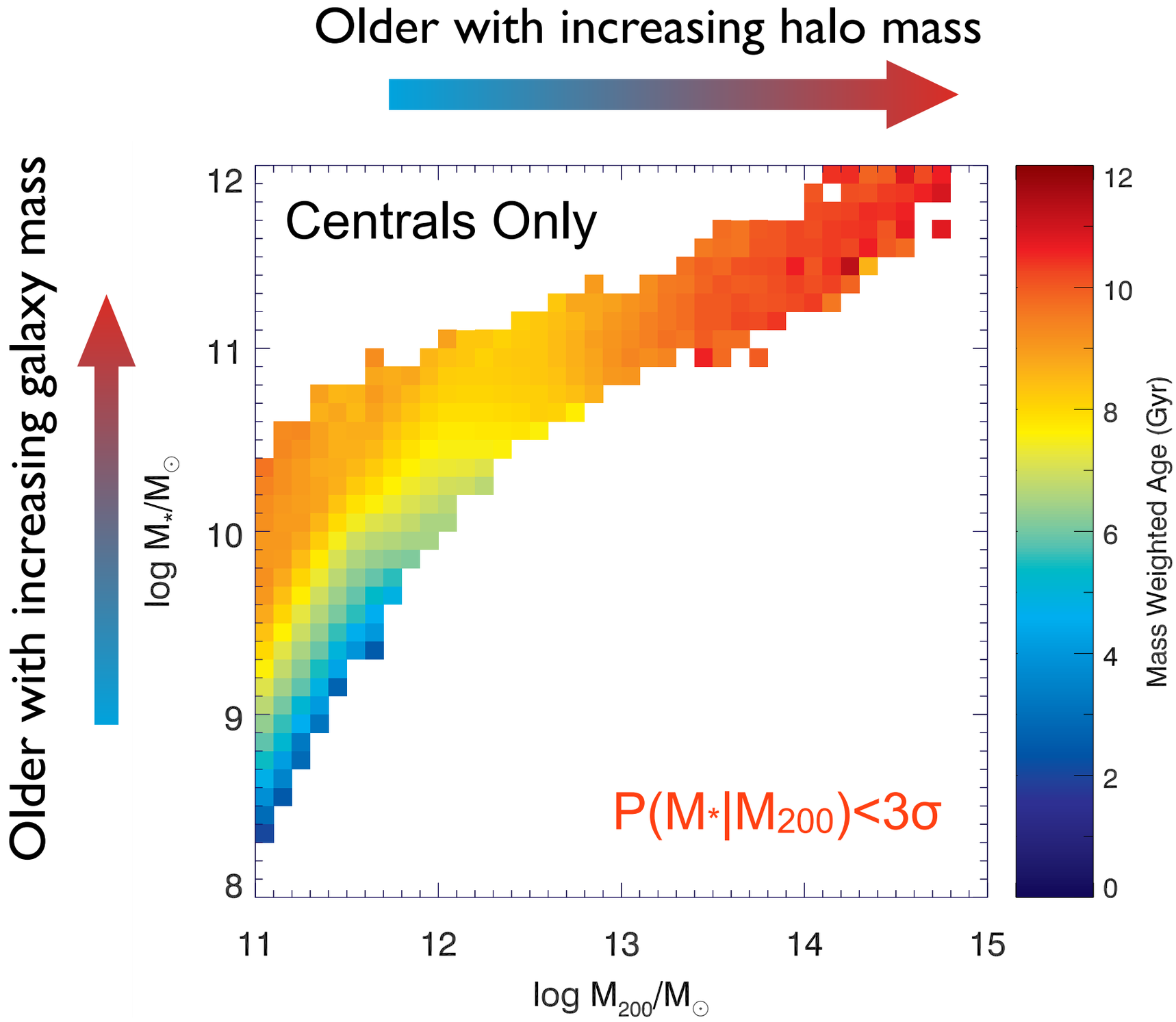


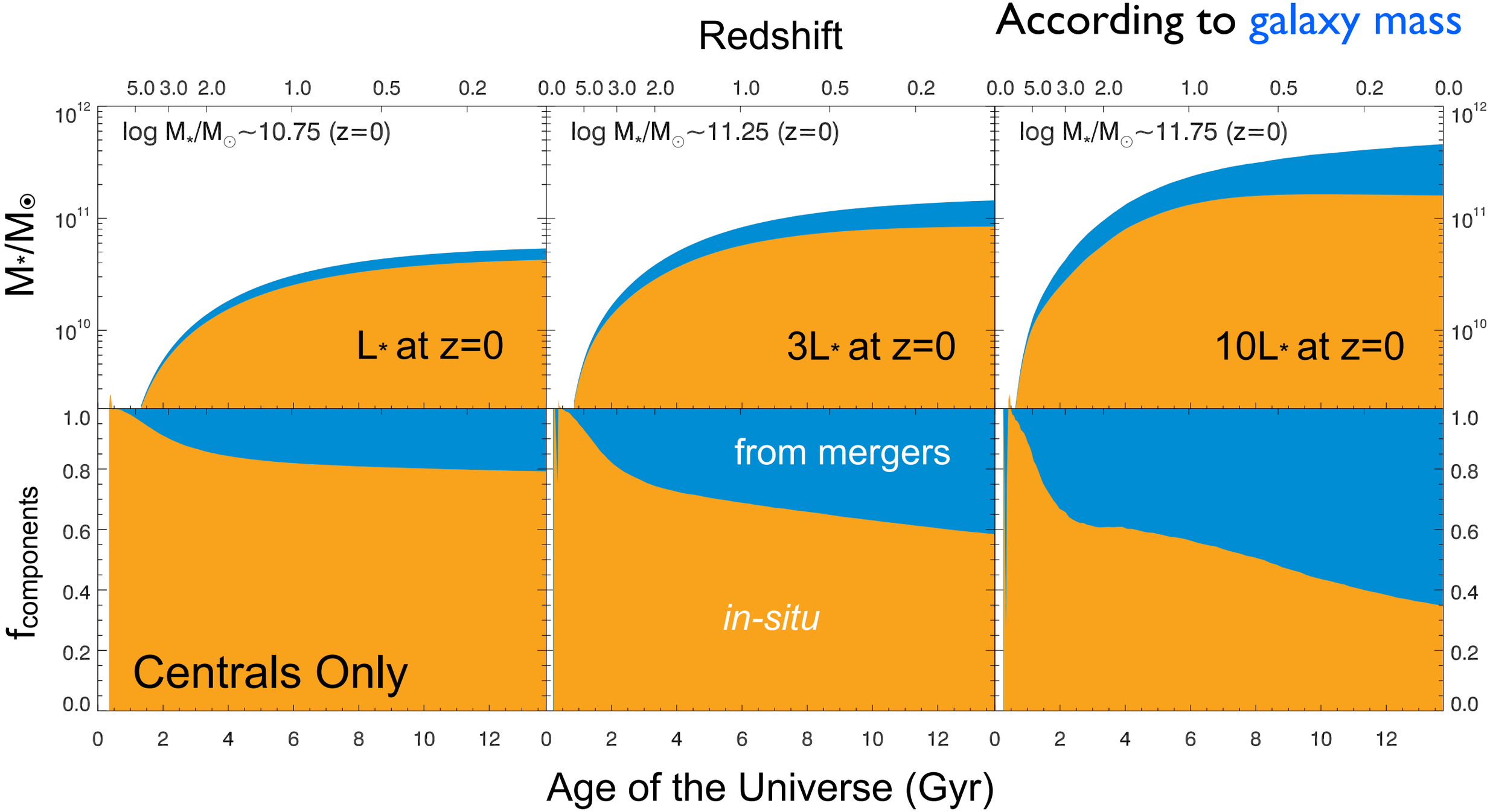
- All progenitors vs. direct progenitors



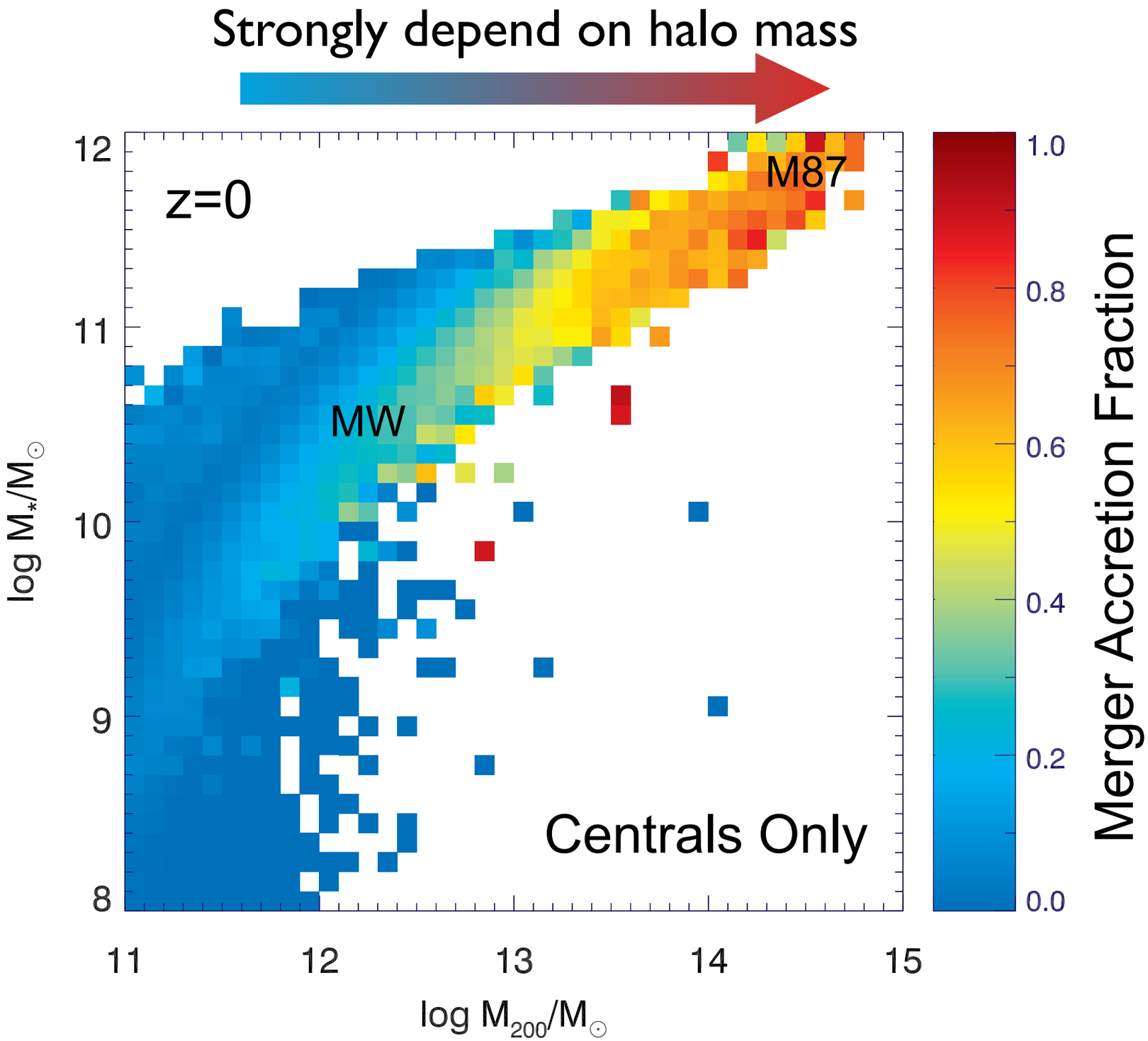
- How does <u>mass weighted age</u> evolve according to halo and galaxy mass?



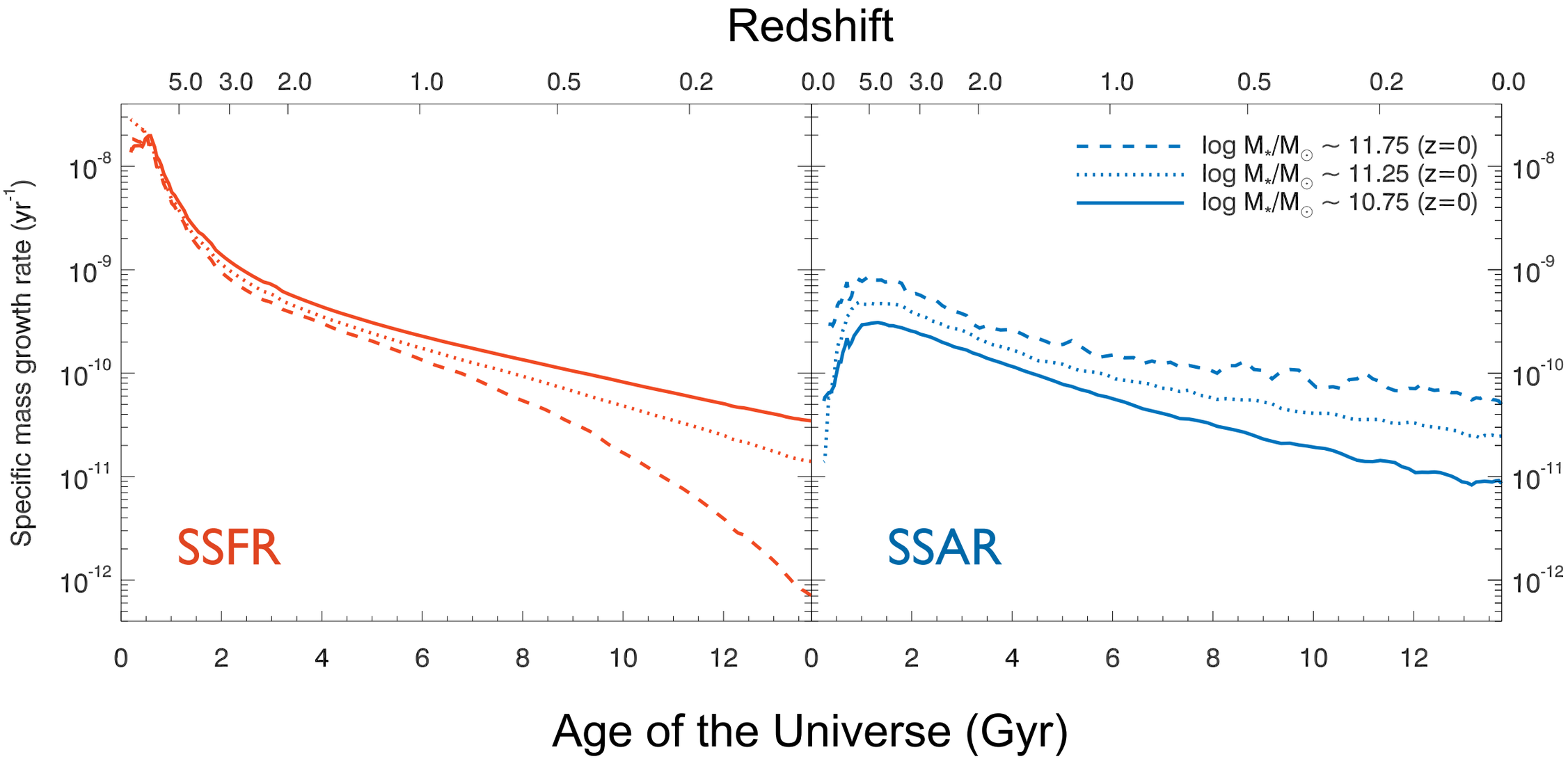
- Origin of stellar components - *in situ* vs accreted via mergers



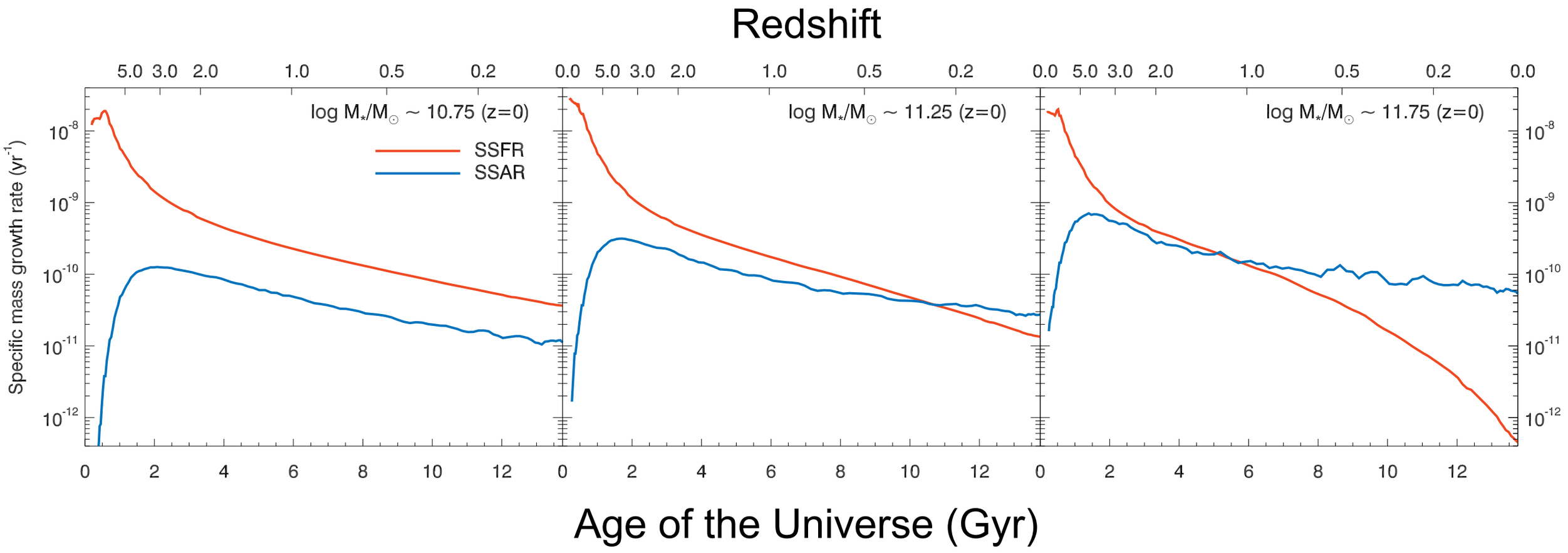
- The fraction of stellar components accreted via galaxy mergers



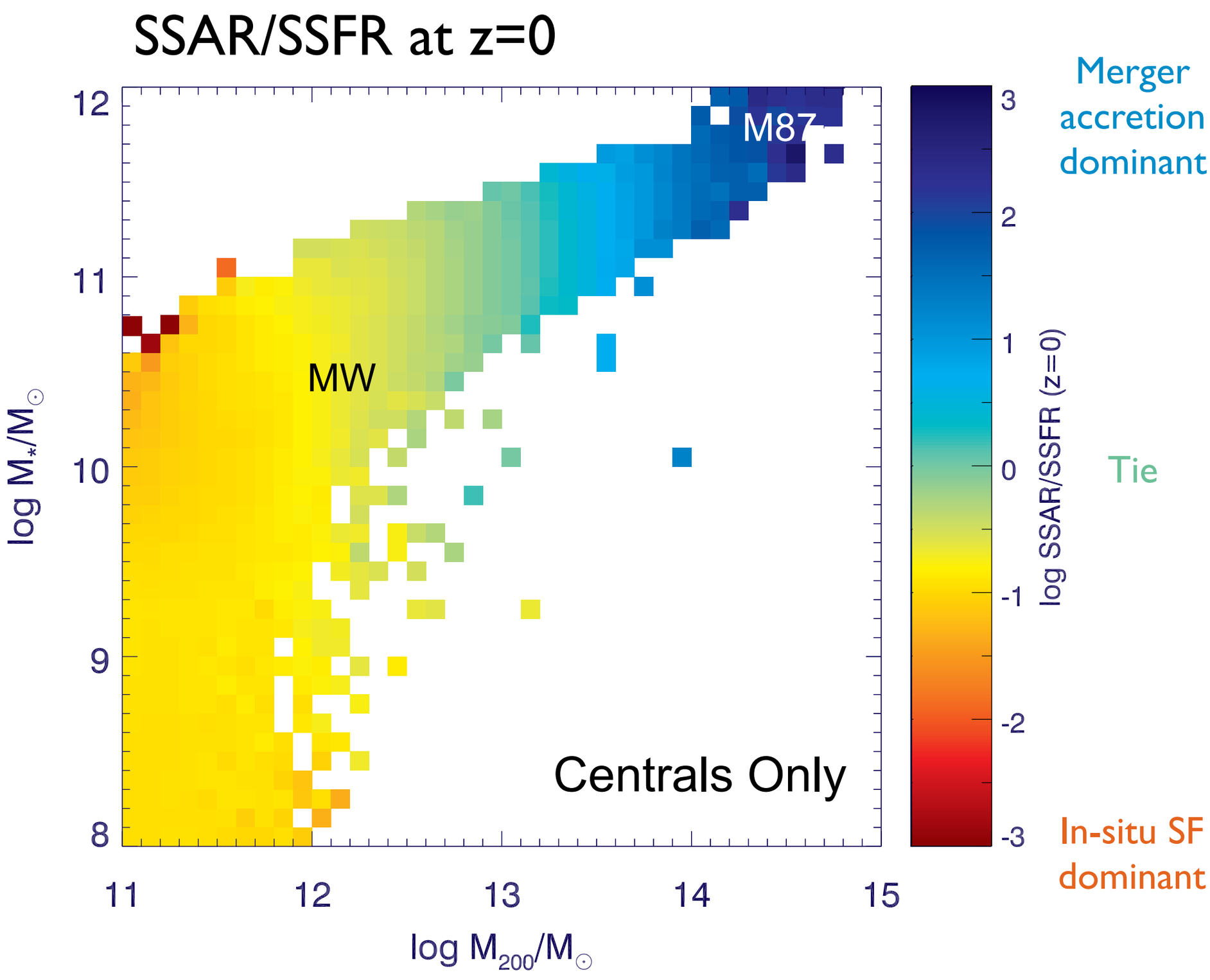
- Specific mass growth rate channels
  - Specific Star Formation Rate $= \dfrac{\mathrm{SFR}}{M_*}$
  - Specific Stellar mass Accretion Rate (via Mergers) $= \dfrac{\dot{M}_{\mathrm{acc}}}{M_*}$



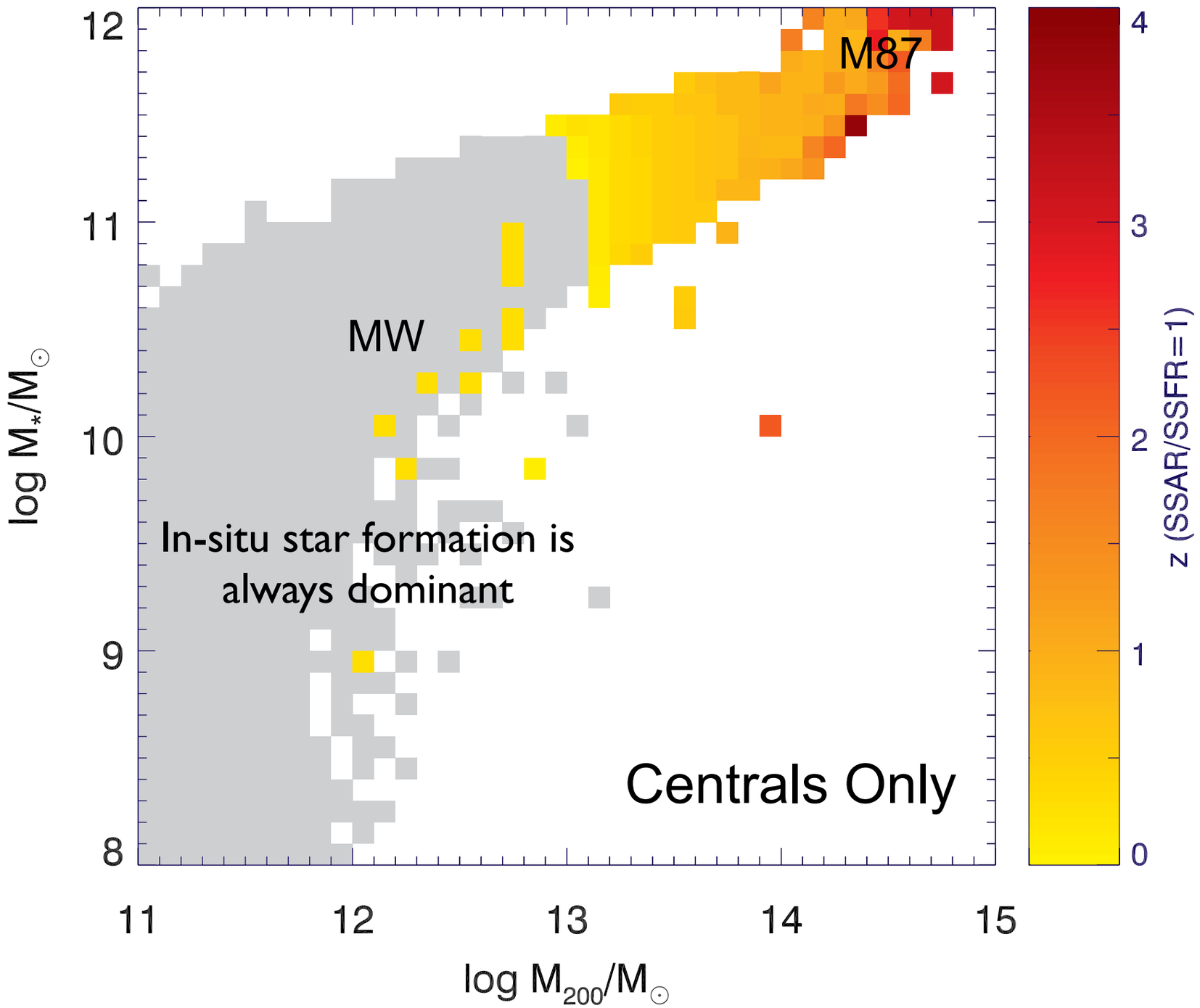
- When is merger dominant?
  - SSAR decays more slowly than SSFR



- When does merger become dominant?



- The epochs when merger exceeds star formation

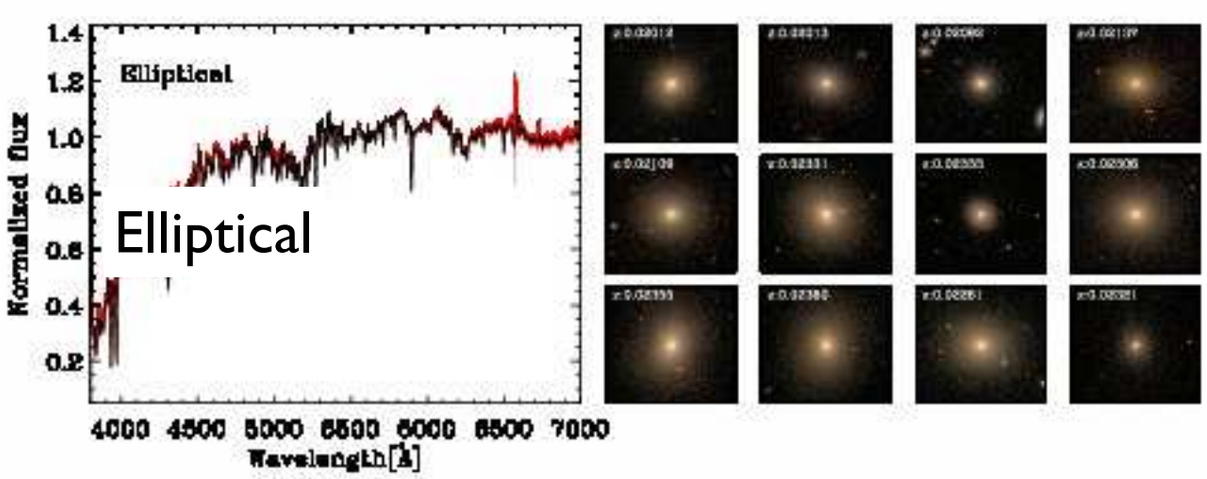


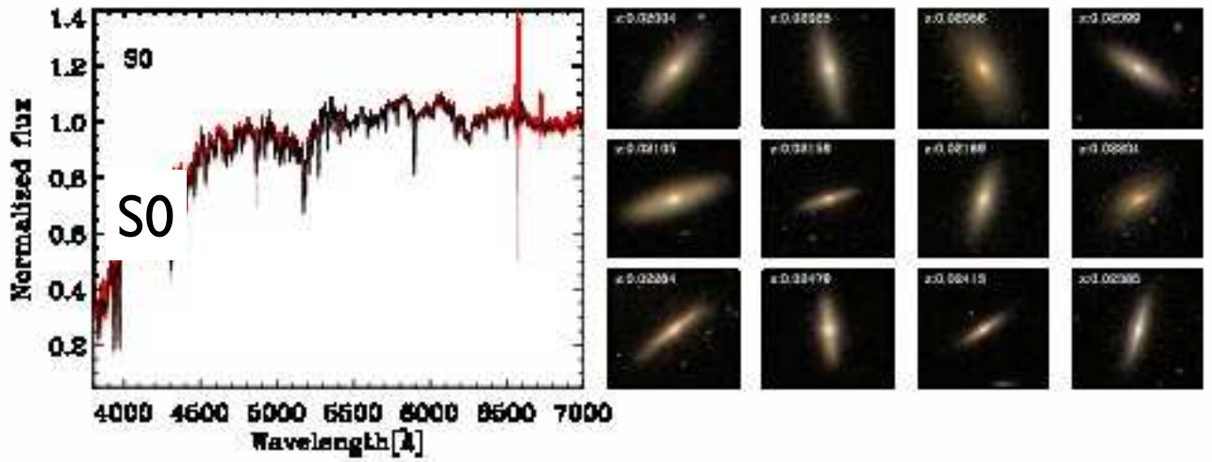
Future work

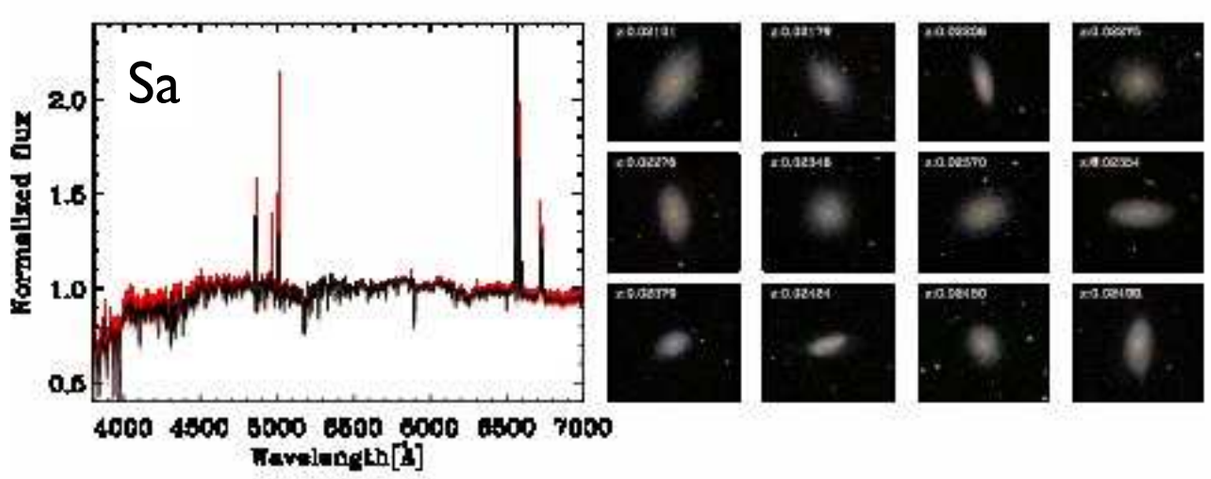
Model SED catalogues from a SAM

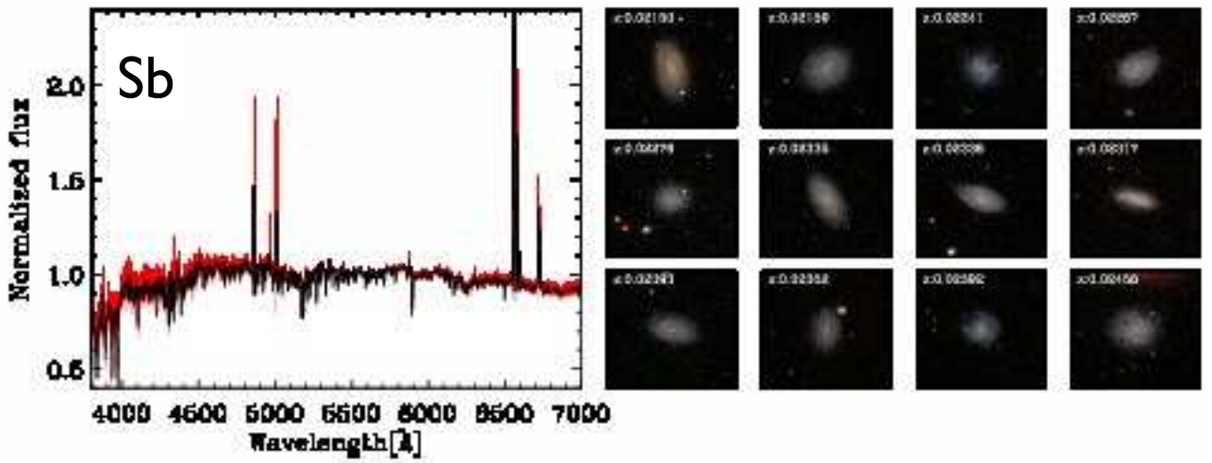
Carina Nebula
ESO VLT

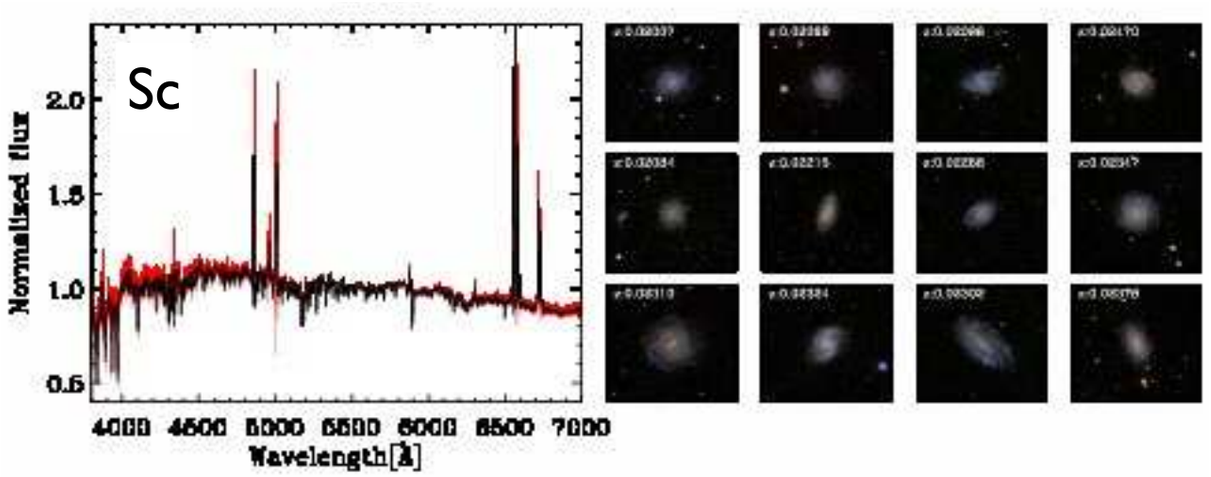
- Constructing the SED catalogues of model galaxies using ySAM









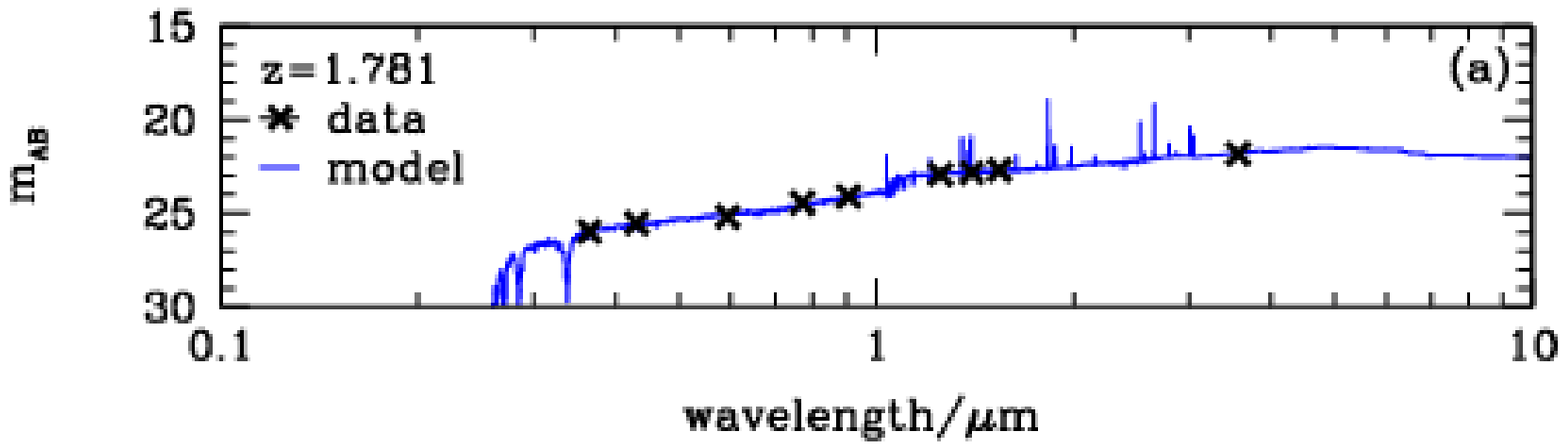


SDSS DR7 data

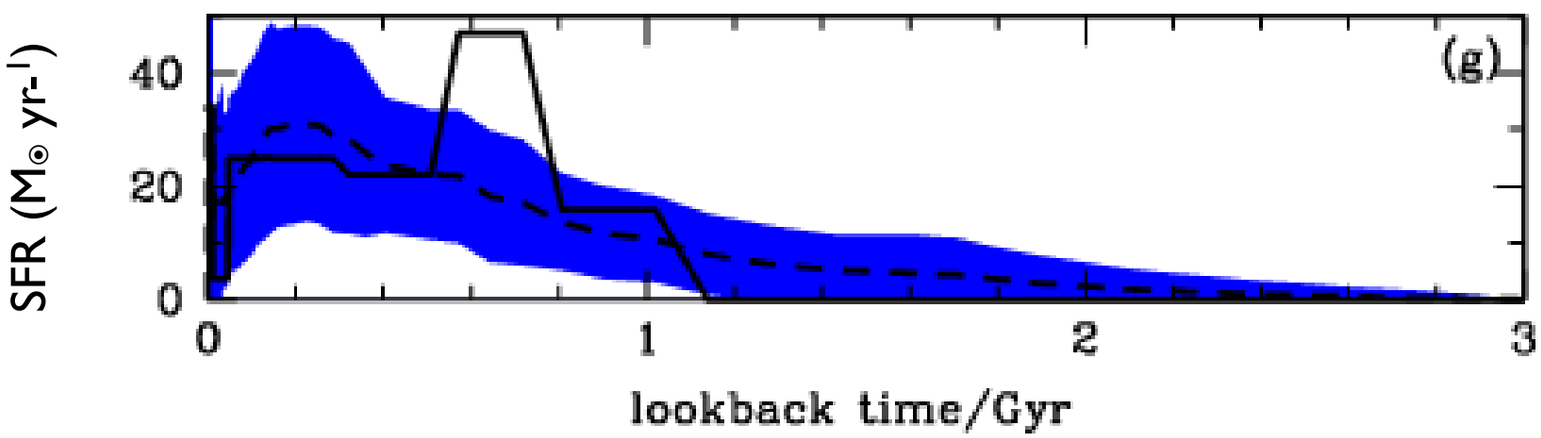
Oh et al. 2011

- An application of the mock SED catalogue

  - Searching similar model SEDs



- Estimating most-likely star formation histories of observed galaxies



Pacifici et al. 2015

- Summary & Discussion
  - SAM is the most effective approach to investigate massive galaxy evolution yet.
  - The fraction of stellar mass in central galaxies accreted via mergers strongly correlates with halo mass. Central galaxies in haloes more massive than $10^{13.5}M_{\odot}$ gain more than half their stellar mass from mergers
  - The contribution of mergers to stellar mass growth decays slower than that of in-situ star formation
  - The redshifts at which merger becomes dominant for mass growth increase with increasing halo mass. But, In central galaxies of haloes less than $10^{13}M_{\odot}$, star formation is always dominant.
  - Constructing model SED catalogues is under way