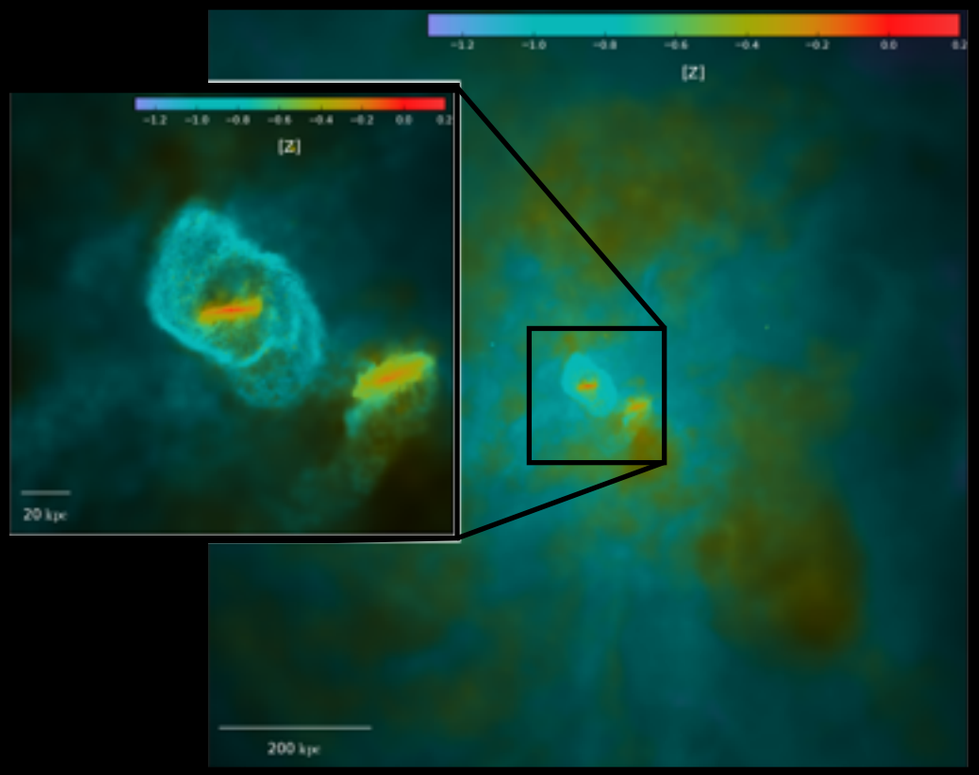
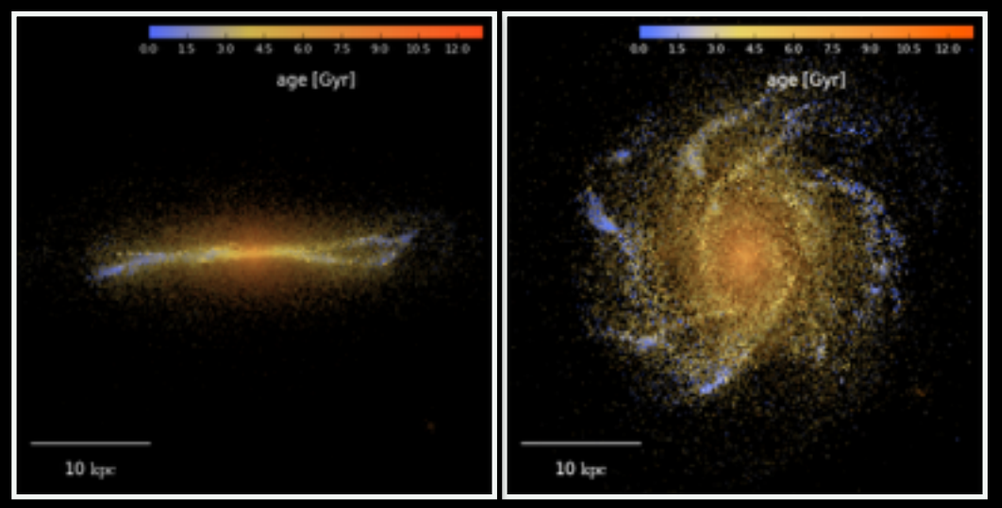
Convergence in a 2-phase Feedback Model and its Mass/Metal Budget



Bernhard Röttgers (MPA)

Ringberg Meeting
10 May 2016



Model

based on ***Marri & White (2003) & Scannapieco+ (2005,2006)*** -> ***Aumer+ (2013)***:

- **multi-phase gas model**
- **2-phase** thermal + kinetic stellar **feedback** *(from **SNe II**, **SNe Ia**, **AGBs**, and **radiation pressure** from massive stars)*
- **following 11 individual elements** (H, He, 8 most abundant metals + rest)
- **metal diffusion**
- **metal line cooling**
- redshift-dependent, const. **UV-background** (Haardt & Madau, 2001)
- **Schmidt-like star formation**: SFR=$0.04 \cdot \rho_{gas}/t_{dyn}$ *(with threshold of n=3cm^{-3} and over-density <2000)*

baryon resolution:

$m_{gas/stars} = \sim 7 \cdot 10^5\ M_\odot$

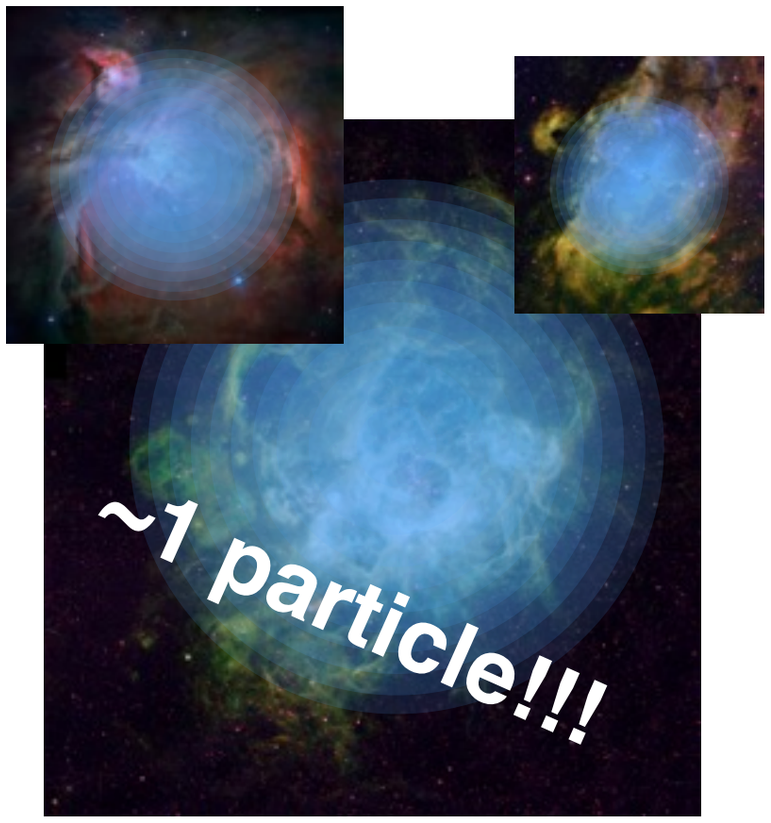
softening = 200 cpc/h_0

Multi-Phase SPH

- **two SPH particles i and k decouple** hydro-dynamically, if

    1. … their **entropic function are very different**: $\max(A_i/A_k, A_k/A_i) > 50$

    2. they do not approach faster than their sound speed: $-\mu_{ik} < c_{ik}$ (important in **shocks**)



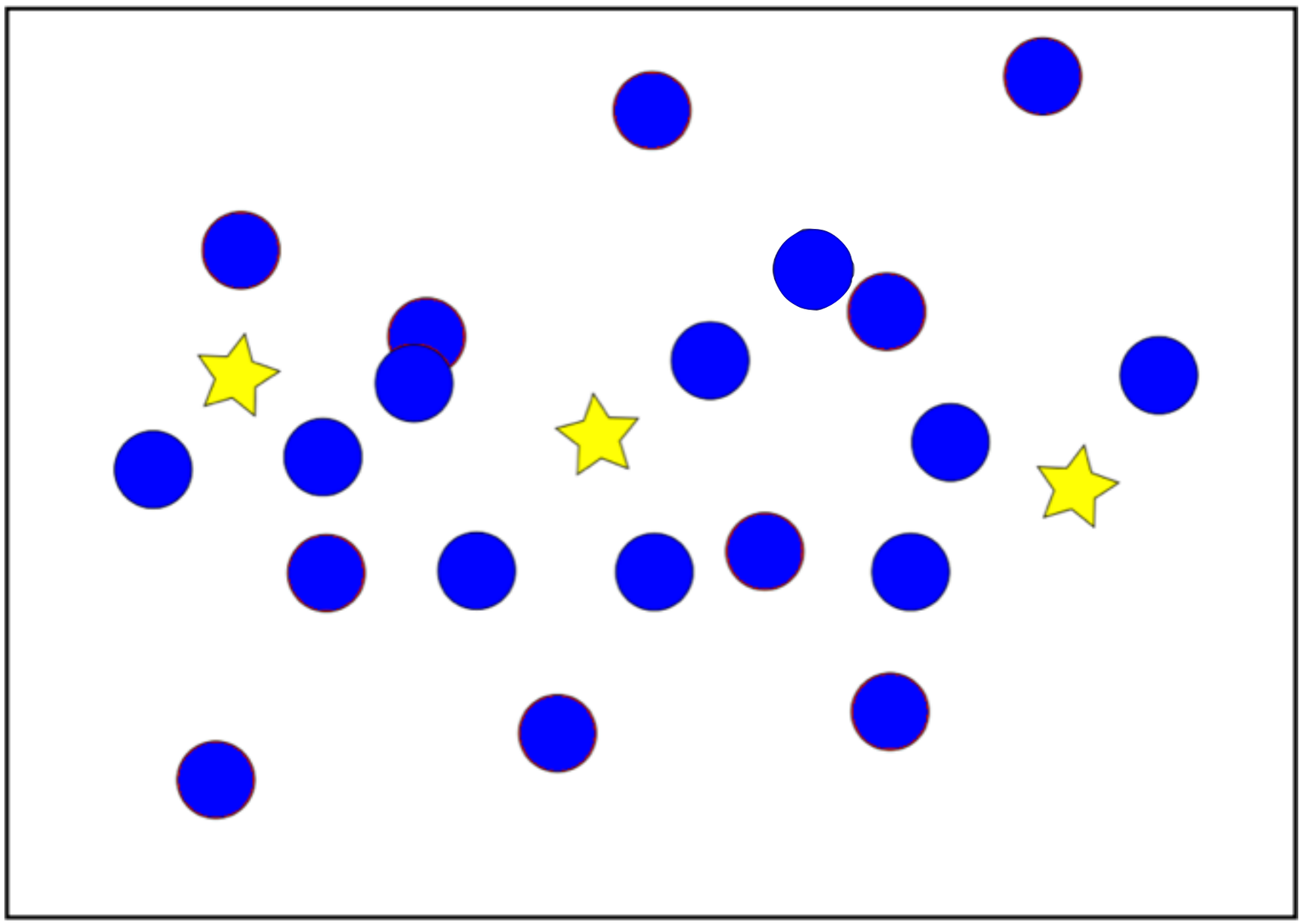
- allows for **spatial coexistence** of hot and cold gas

- **no ad-hoc scale** that separates phases!

Marri & White (2003), Scannapieco+ (2006)

Image credit:
NASA, ESA, M. Robberto (Space Telescope Science Institute/ESA) and the Hubble Space Telescope Orion Treasury Project Team
T.A.Rector (NRAO/AUI/NSF and NOAO/AURA/NSF) and B.A.Wolpa (NOAO/AURA/NSF)
NASA, Hui Yang University of Illinois ODNursery of New Stars

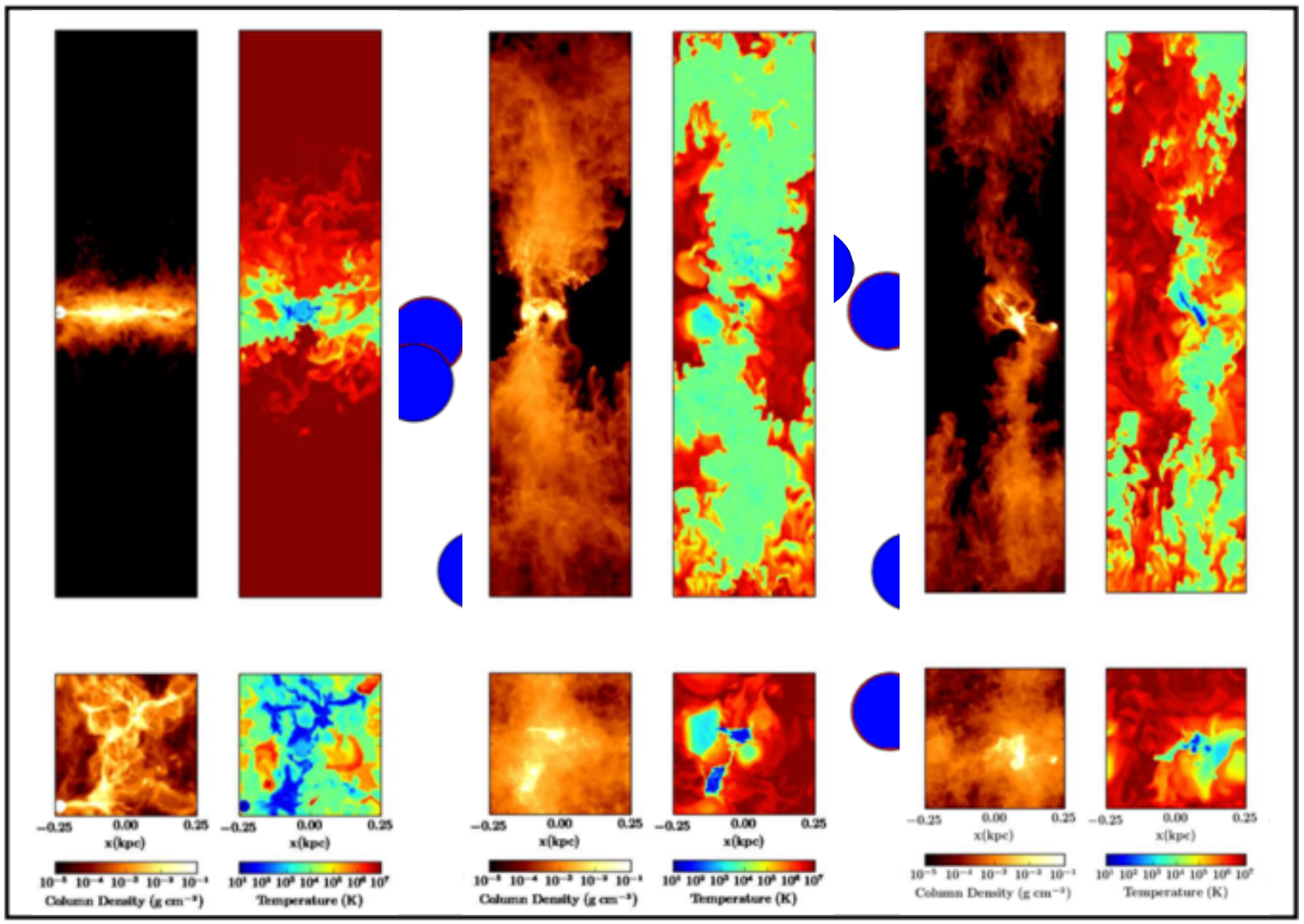
2-phase Feedback



star particles

SPH particles

2-phase Feedback



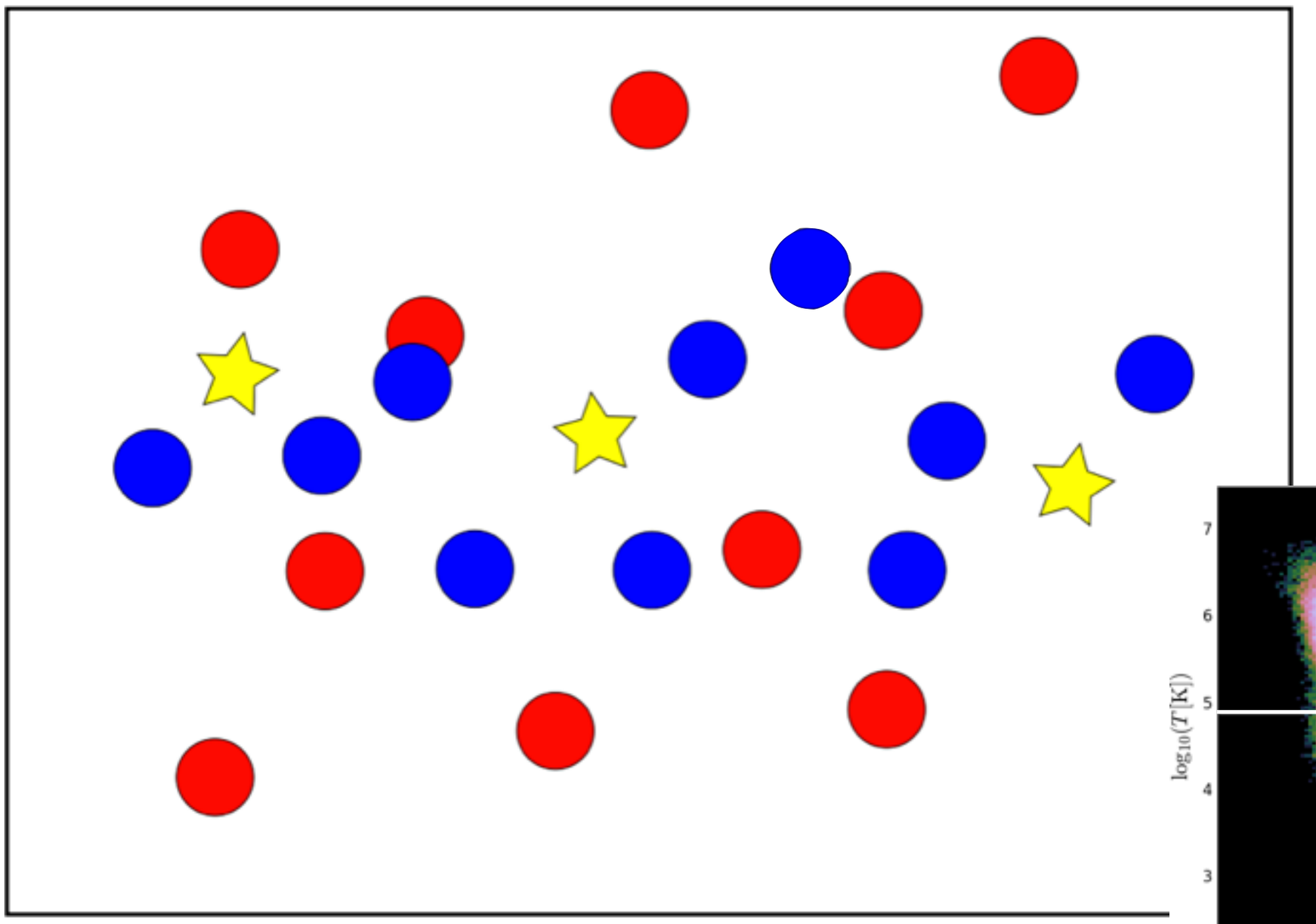
star particles

SPH particles

peak **random** **clustered**

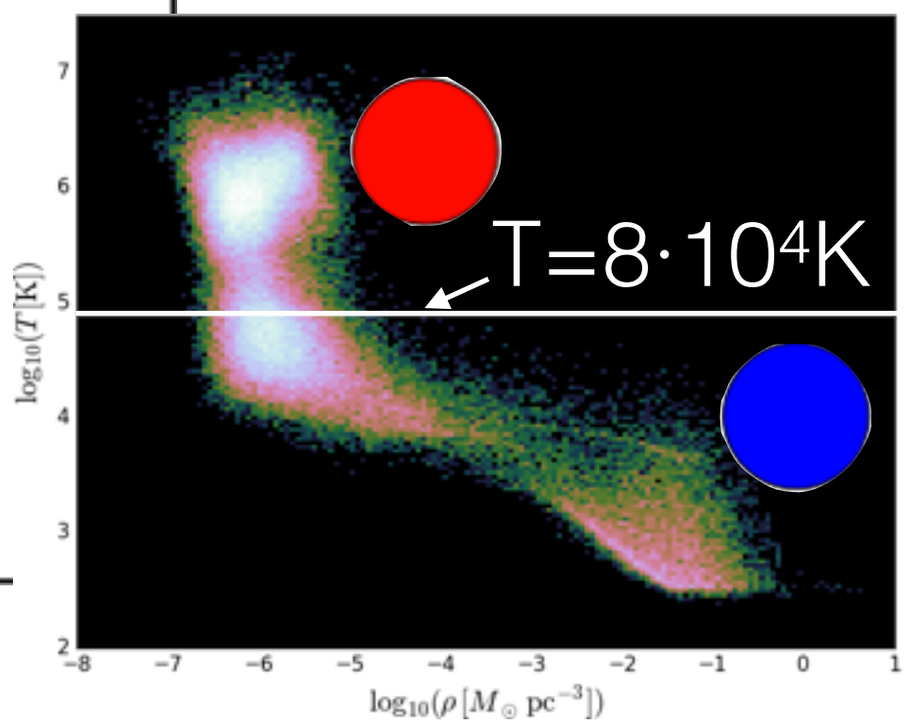
Walch+ (2015)

2-phase Feedback

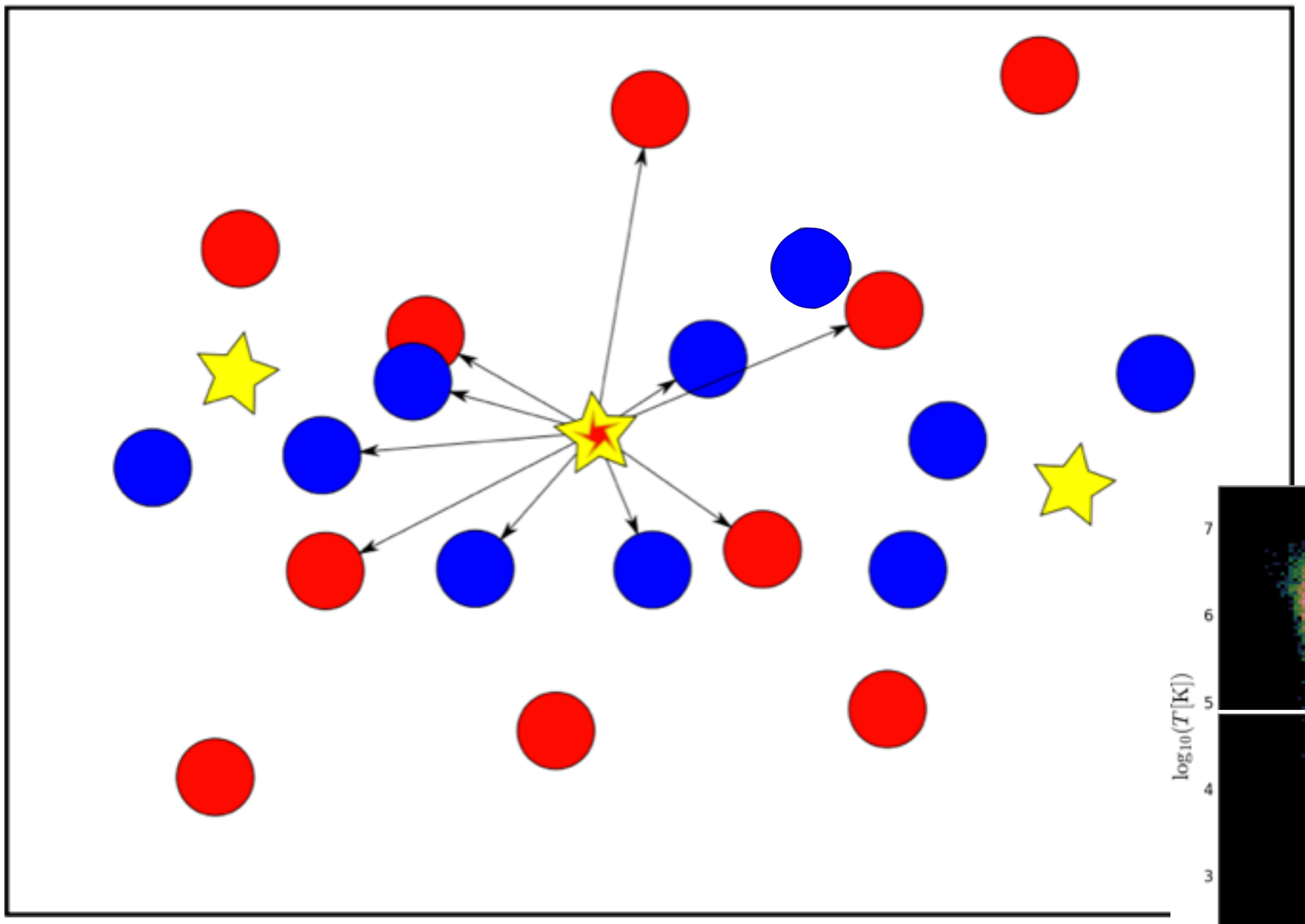


hot phase

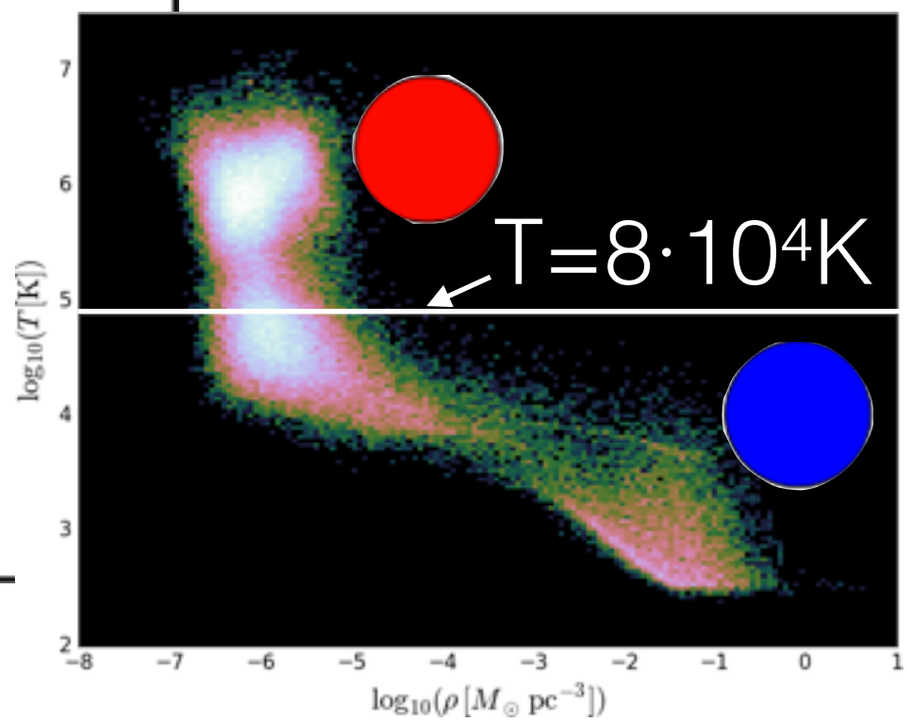
cold phase



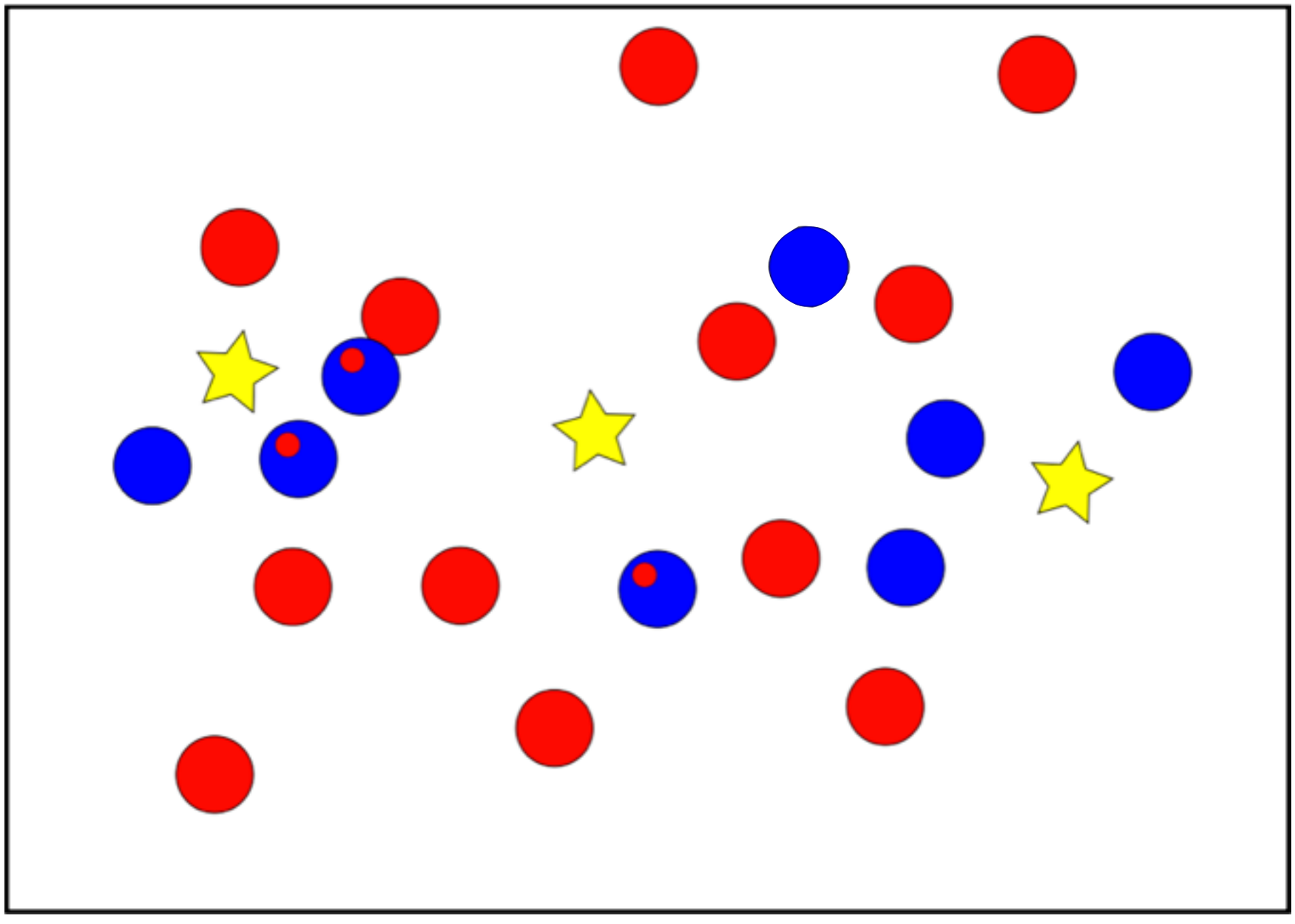
2-phase Feedback



5 nearest ngb's in each phase, the **hot phase** and the **cold phase**



2-phase Feedback



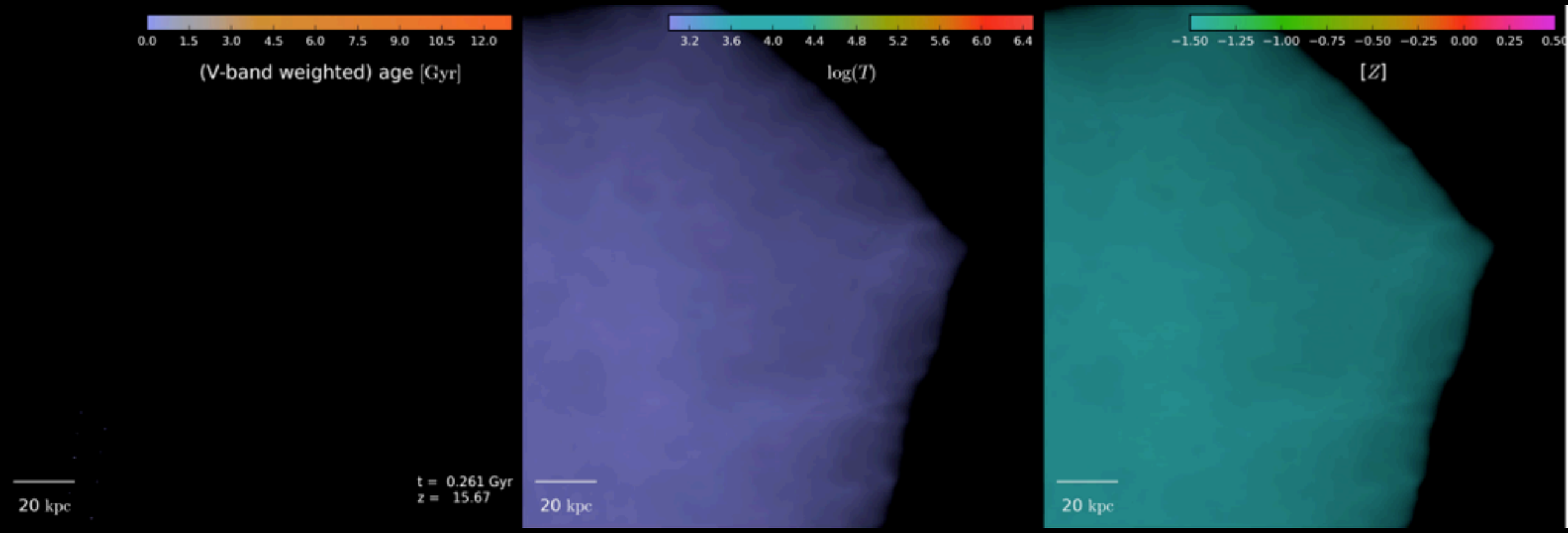
hot phase
($T>8\cdot10^4K$)

cold phase
($T<8\cdot10^4K$)

store thermal energy in reservoir, if not sufficient for promotion

M4323

resolution: ~$9 \cdot 10^4$ $M_\odot$ / 100 cpc/h

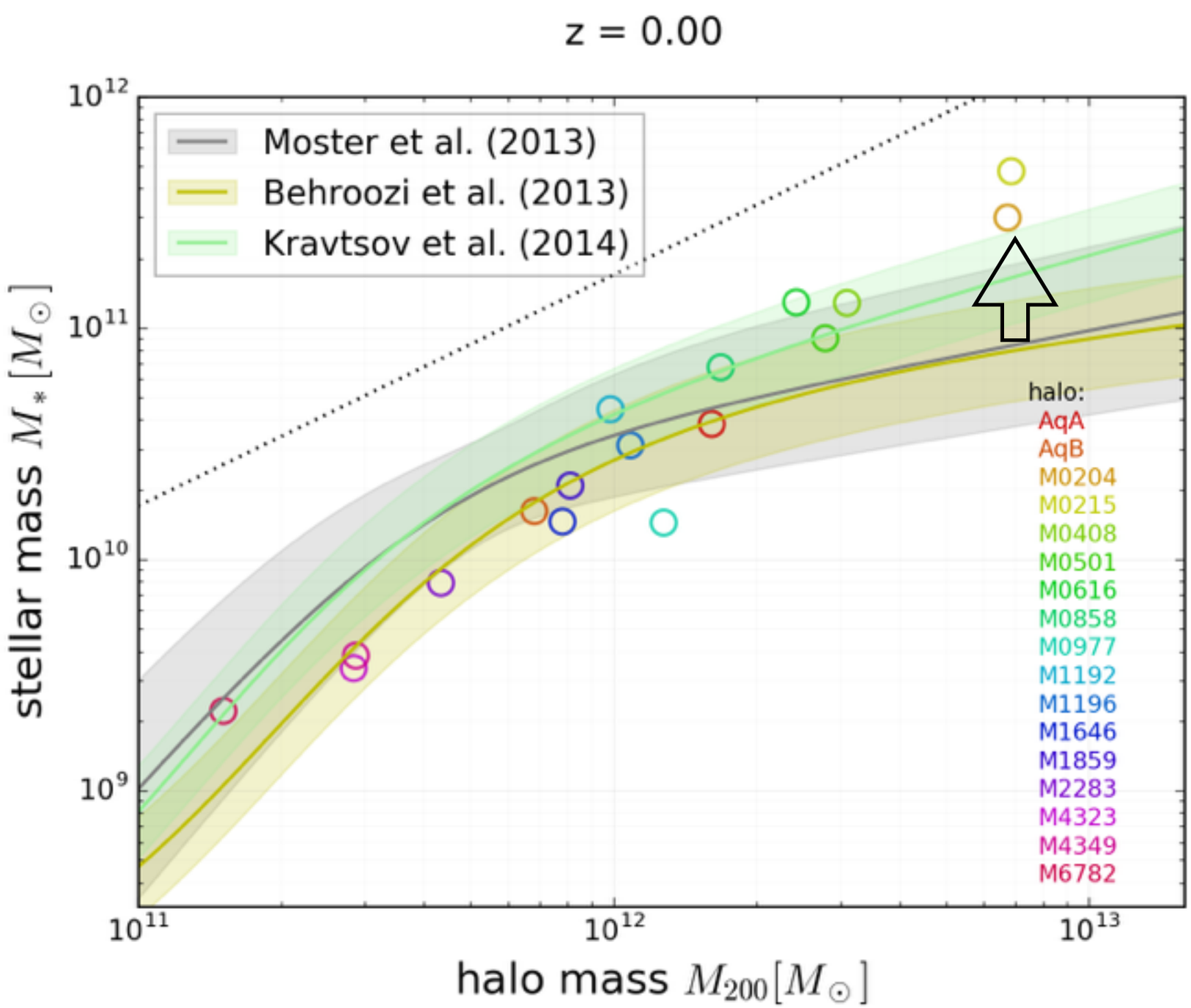


$M_{200}(z=0) = \sim 3 \cdot 10^{11}\ M_\odot$

$M_{stars}(z=0) = \sim 3 \cdot 10^{9}\ M_\odot$

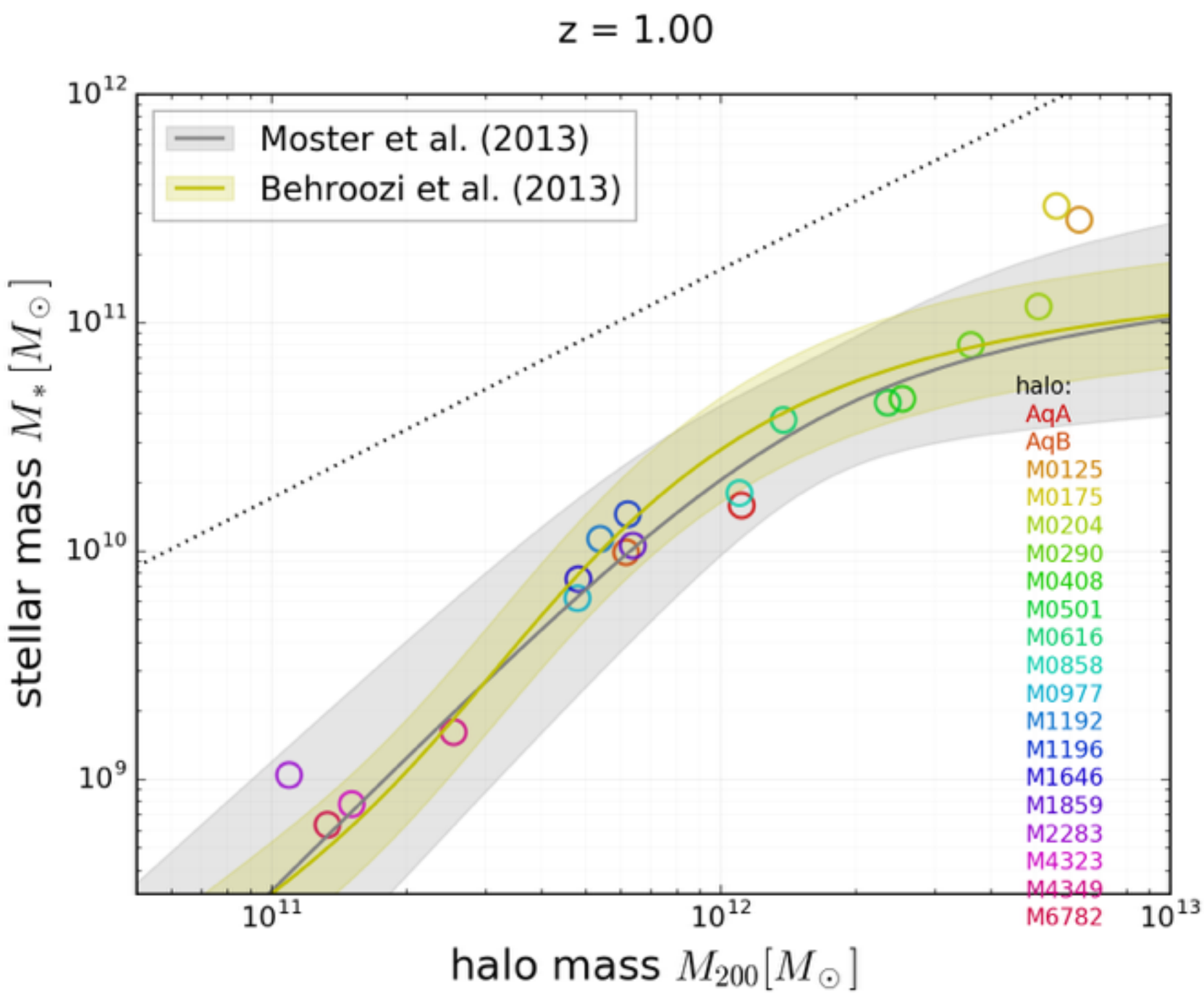
done with **pygad**:
https://bitbucket.org/broett/pygad

stellar mass-halo mass relation

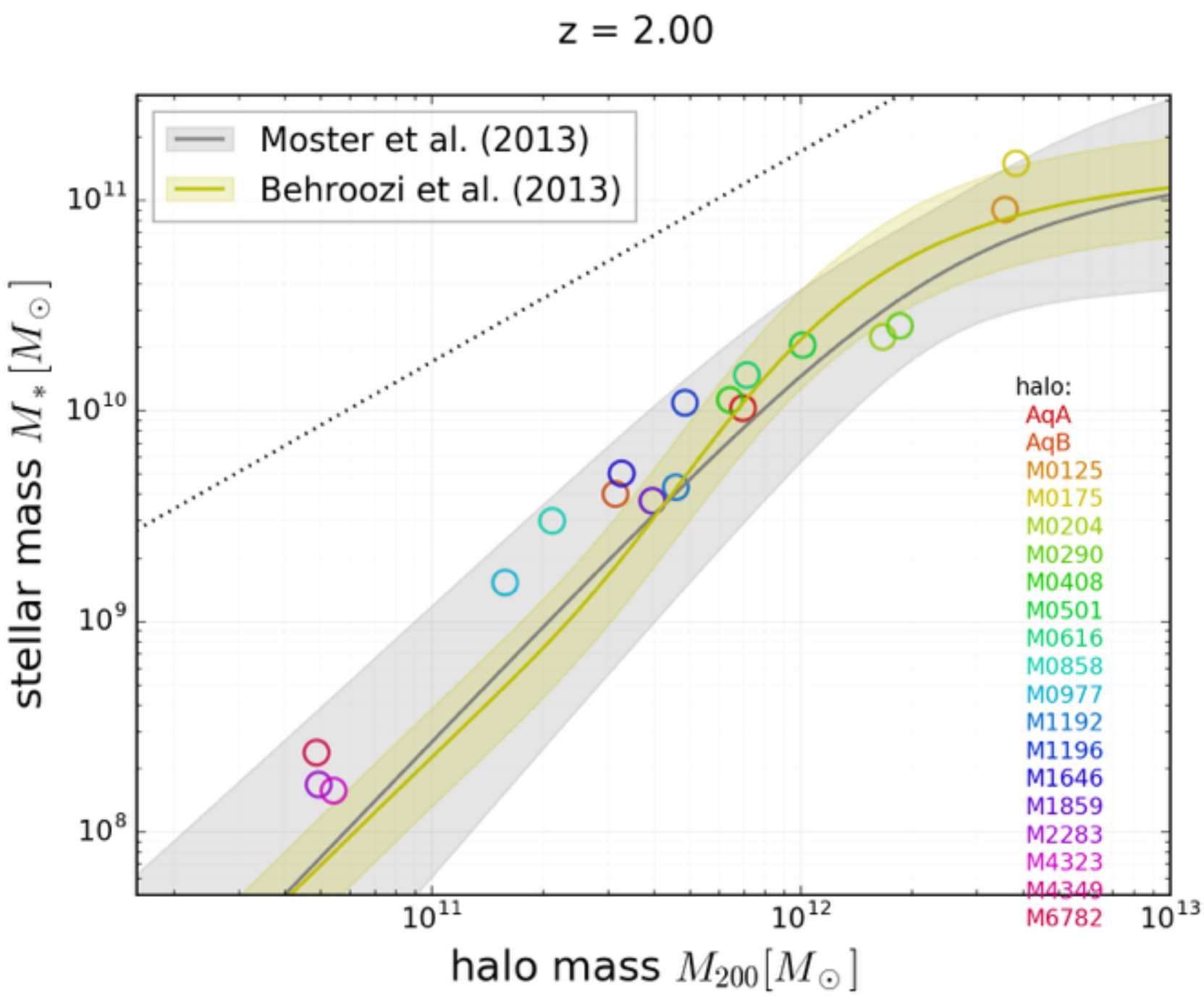


missing AGNs(?)

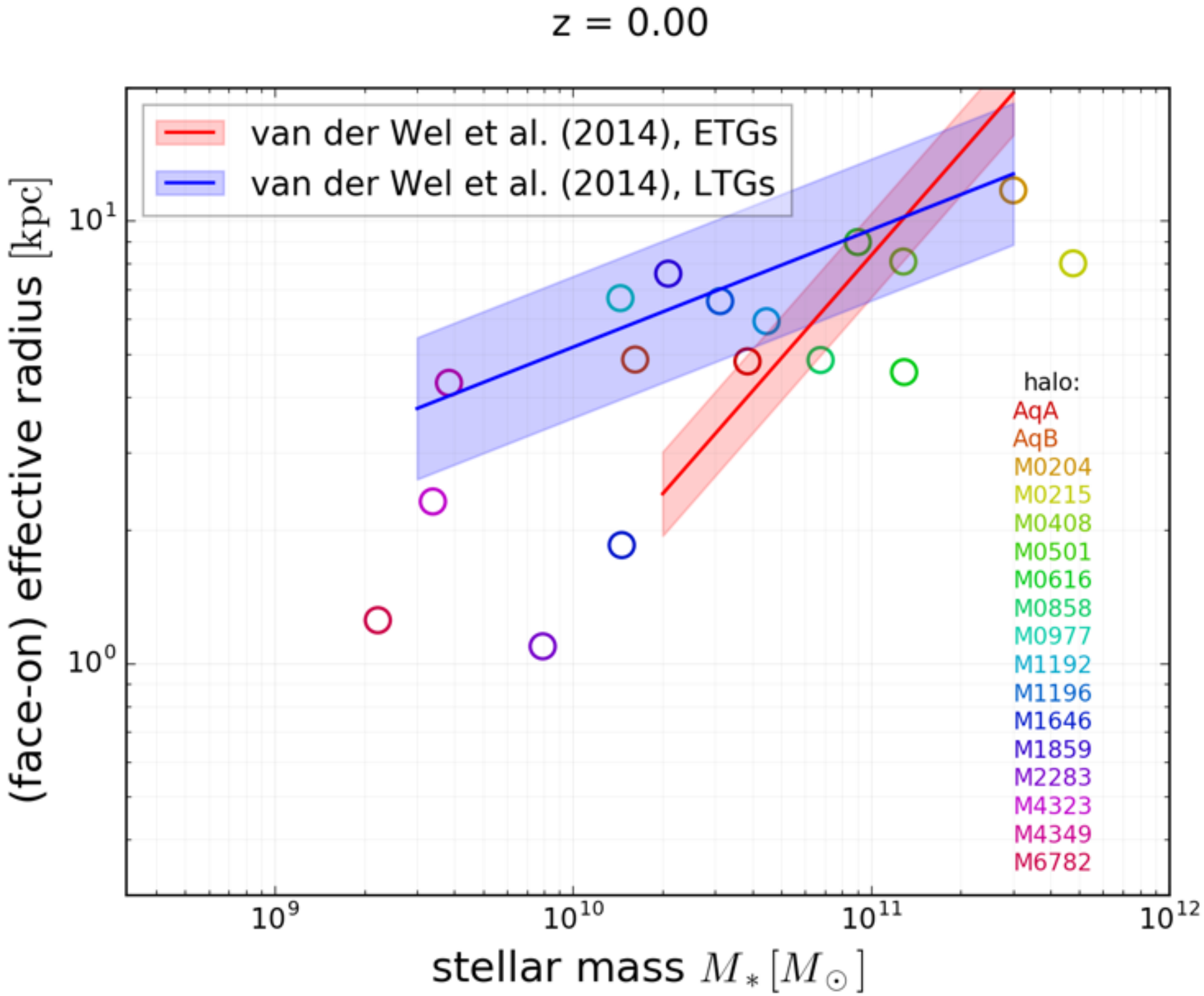
stellar mass-halo mass relation



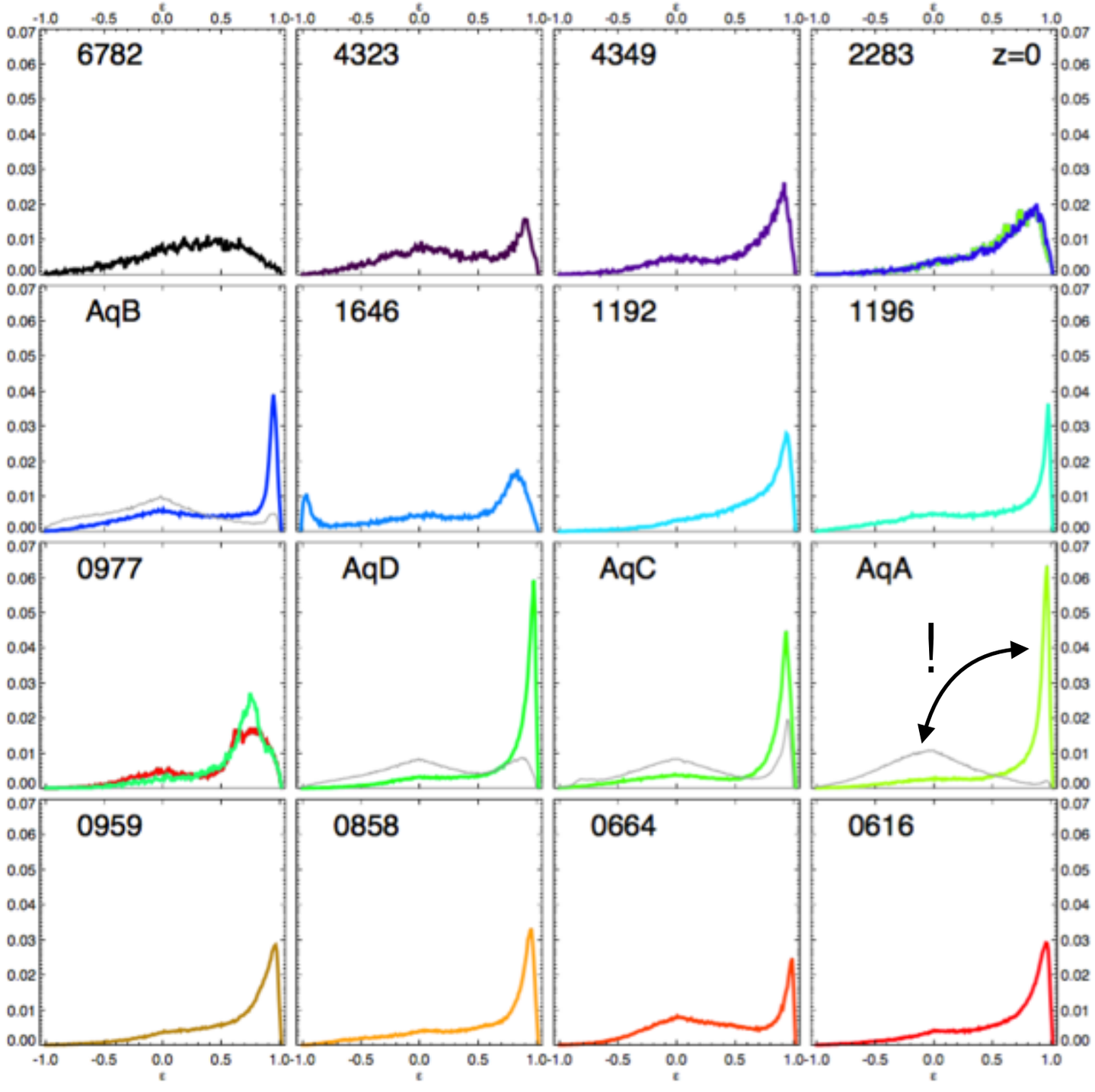
stellar mass-halo mass relation



Galaxy Sizes



Disc Fractions



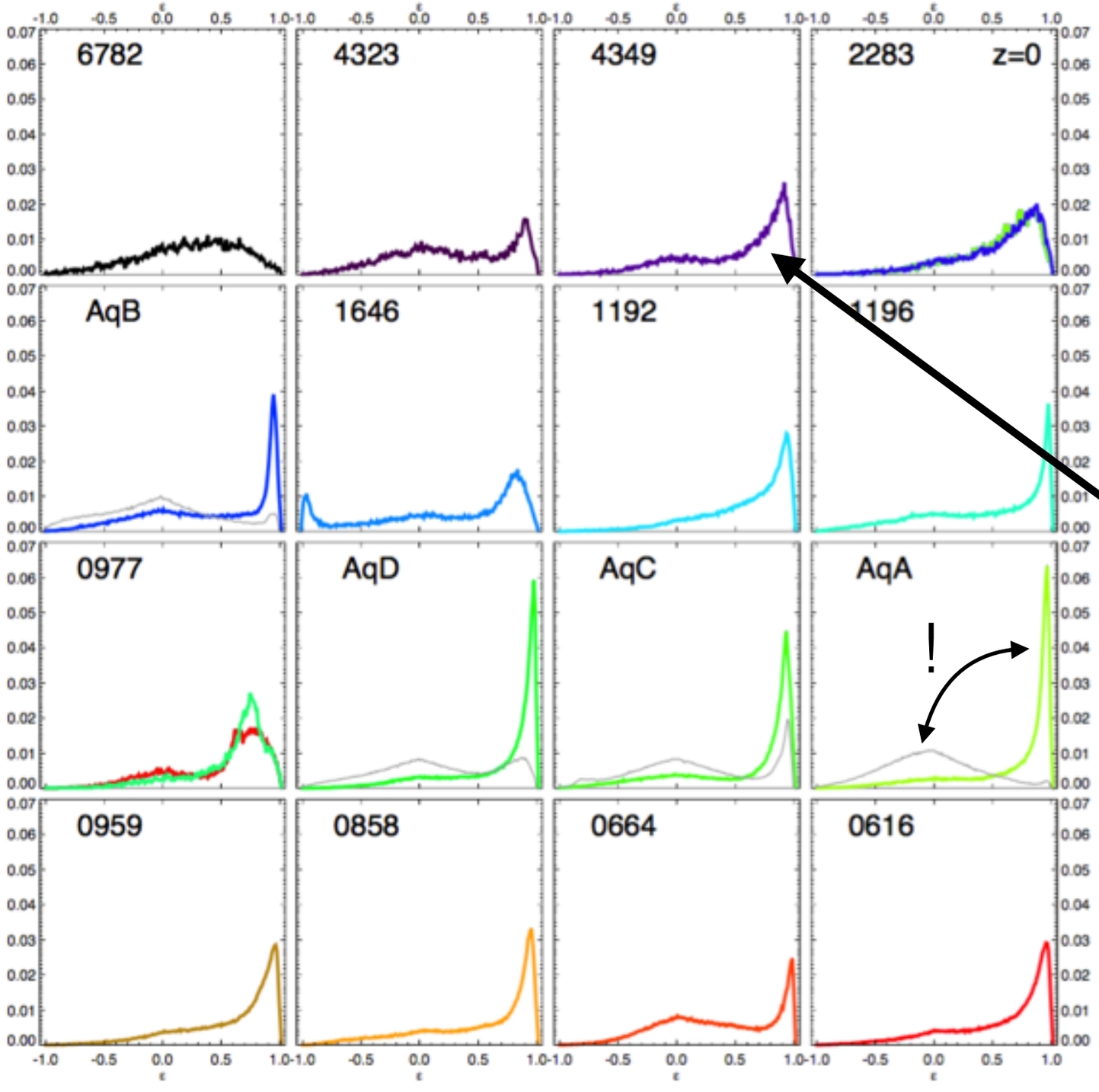
a measure of the circularity of a particle:

$\varepsilon := j_z/j_c$

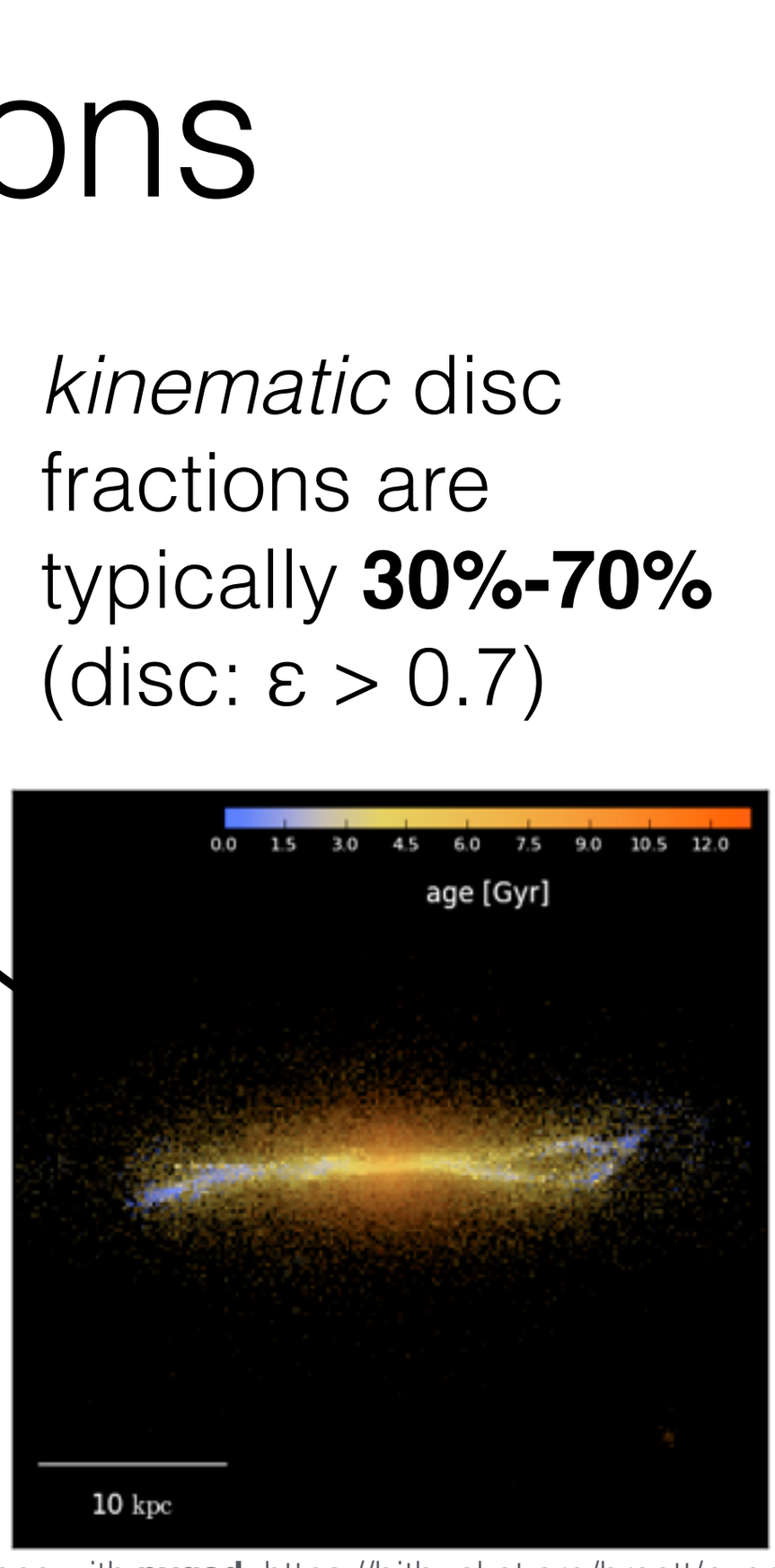
j_c: angular momentum of a particle with the same energy but on a circular orbit

Aumer+ (2013)

Disc Fractions



kinematic disc fractions are typically **30%-70%** (disc: ε > 0.7)



done with **pygad**: https://bitbucket.org/broett/pygad

Aumer+ (2013)

Convergence Study

- typically **re-calibration** of parameters needed for different resolution (*strong* vs. *weak* convergence)

- is the 2-phase feedback resolution independent?

    - feedback always 50:50 between hot (sparse) & cold (dense) phase

Convergence Study

$M_{200}=3\cdot10^{11}M\odot$, $M_{stars}=2\cdot10^{9}M\odot$

2x
400 pc
$6\cdot10^{6}$ $M_\odot$

4x
200 pc
$7\cdot10^{5}$ $M_\odot$

8x
100 pc
$9\cdot10^{4}$ $M_\odot$

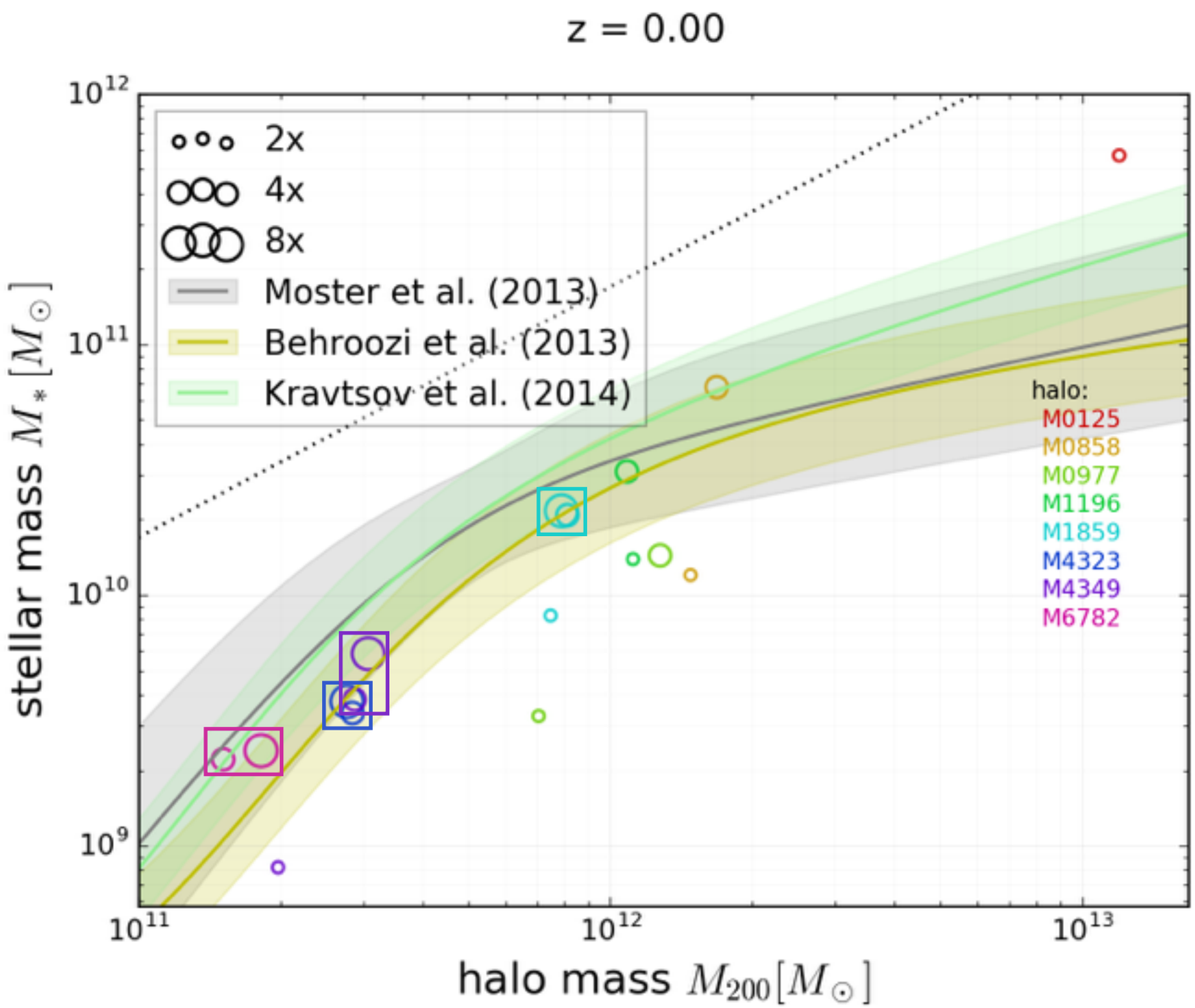
x8 in particles

x8 in particles

done with **pygad**: https://bitbucket.org/broett/pygad

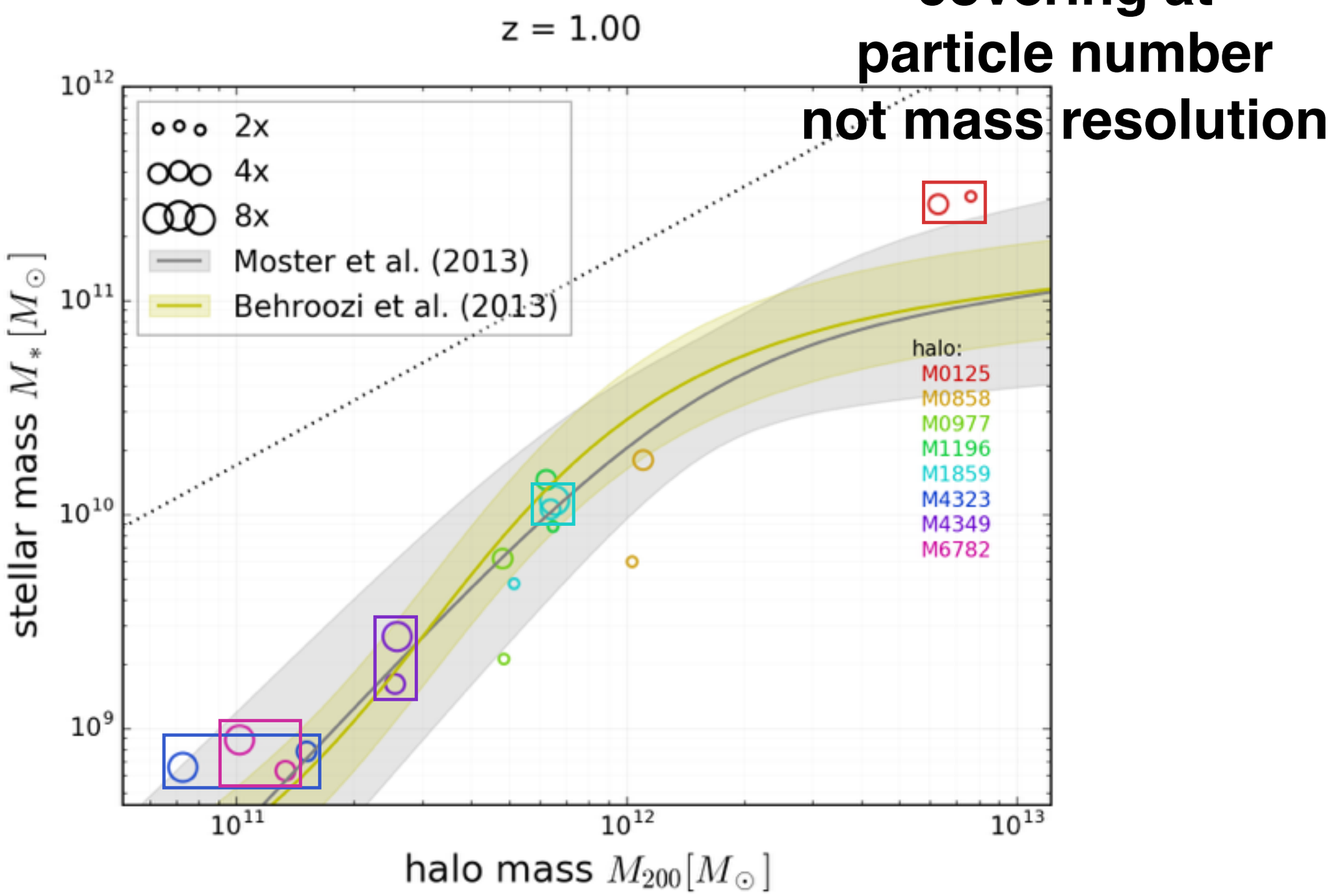
- **zoomed in sim's**
- exact same code: **no adjustment of feedback parameters!**
- only gravitational softening lengths are adapted

Stellar Mass-Halo Mass Relation

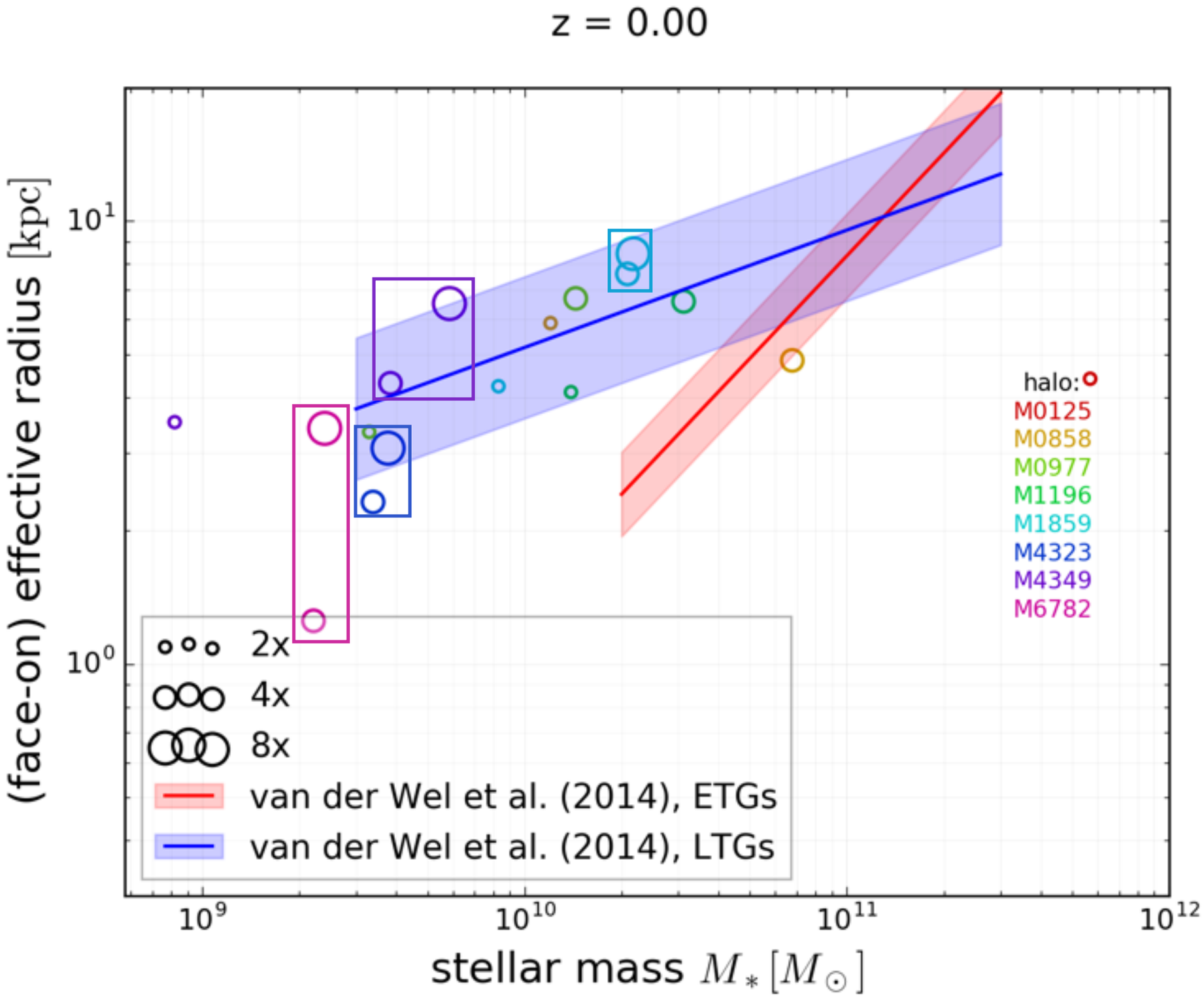


Stellar Mass-Halo Mass Relation

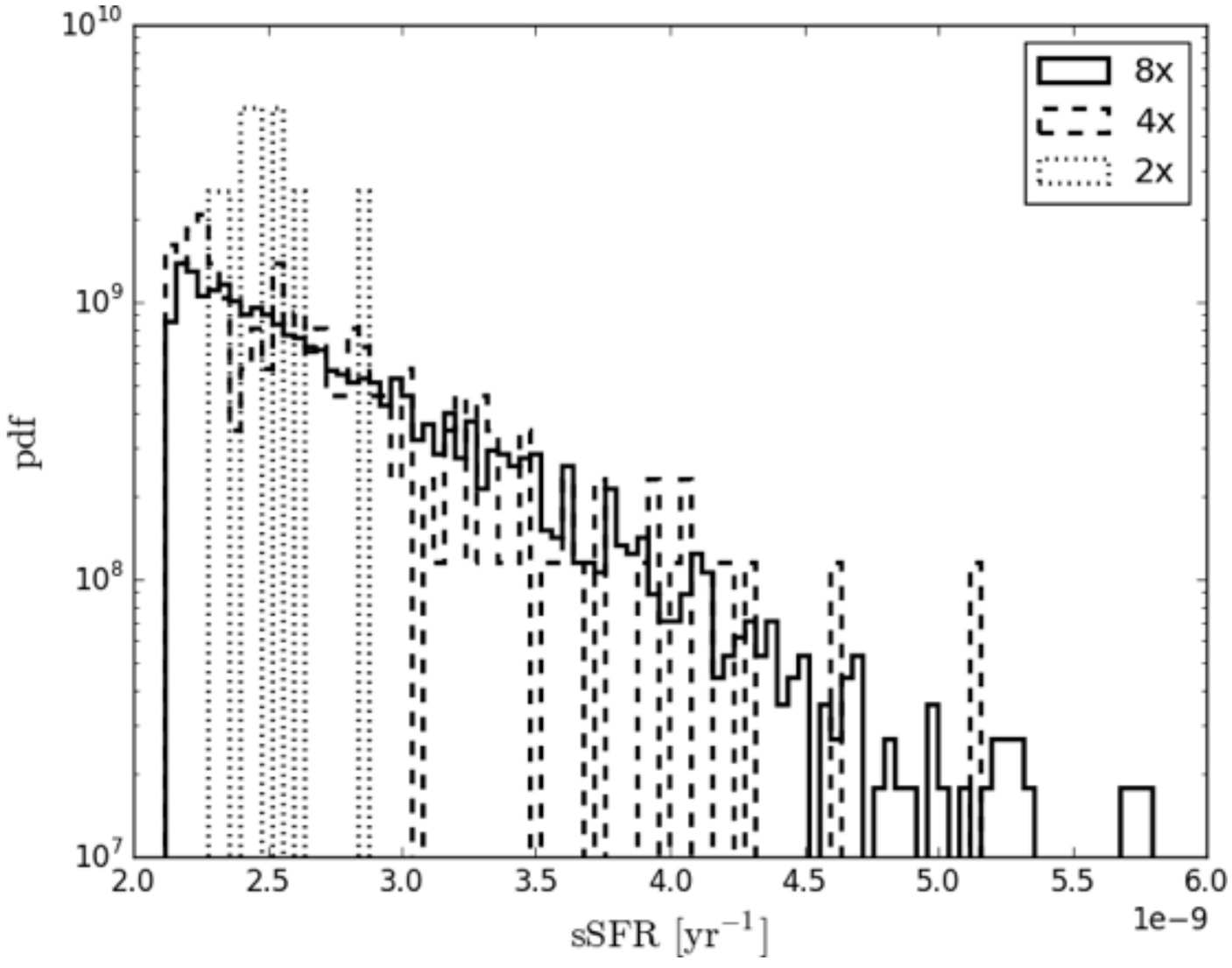
covering at particle number not mass resolution



Galaxy Sizes



Stochasticity



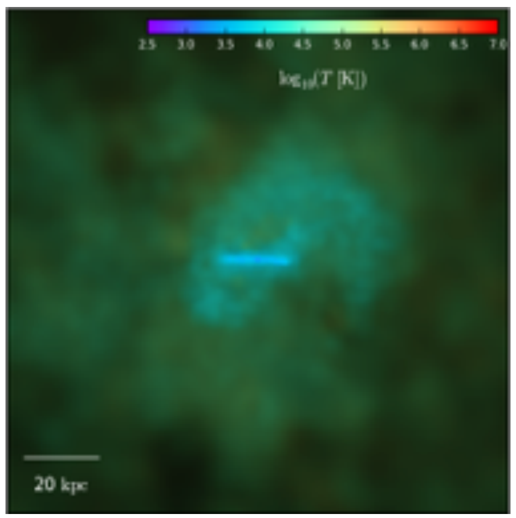
- **sampling a pdf**

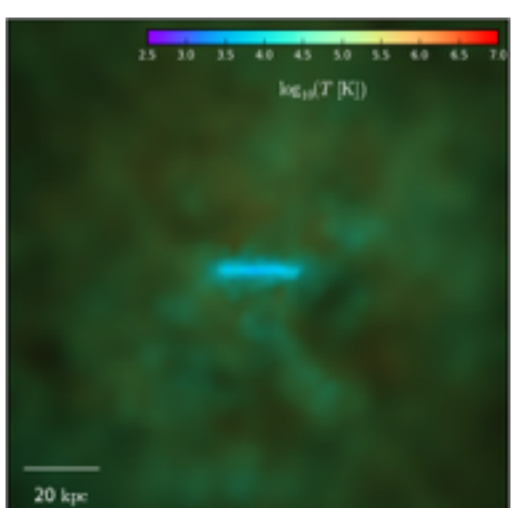
star-forming gas particles:

- 2x: 10
- 4x: ~200
- 8x: >2000

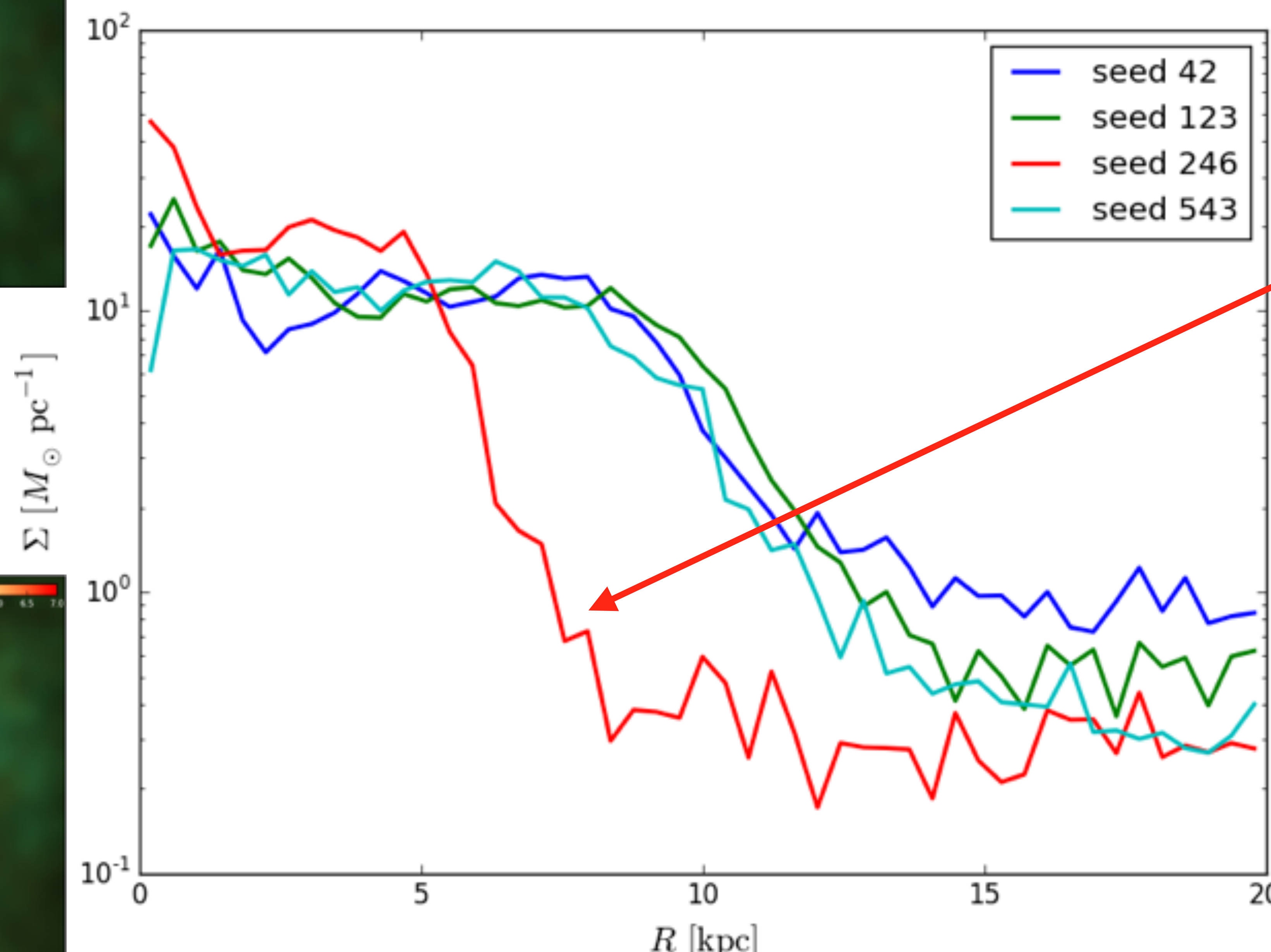
- a single event feedback is strong, when there are few particles

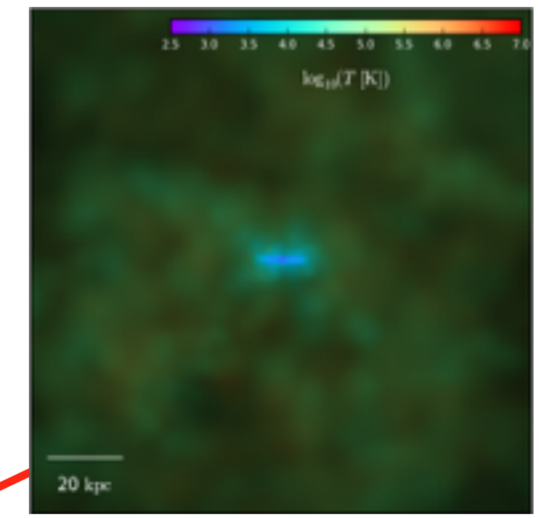
Effects of RNG Seed

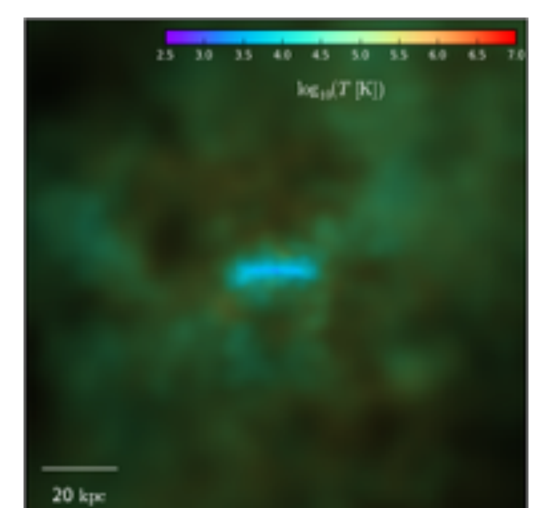




same ICs, same code!

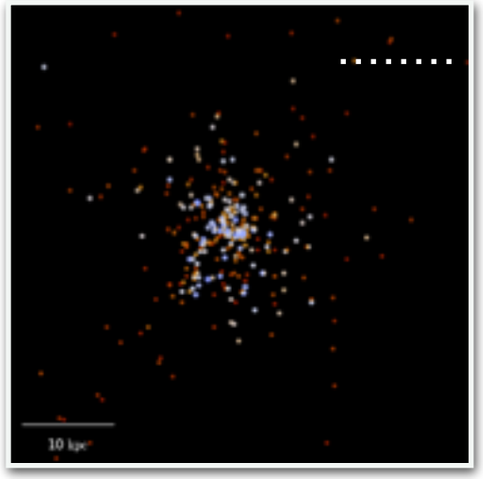




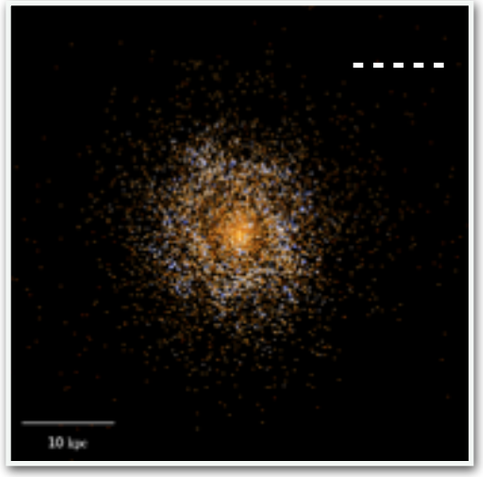


Formation Histories

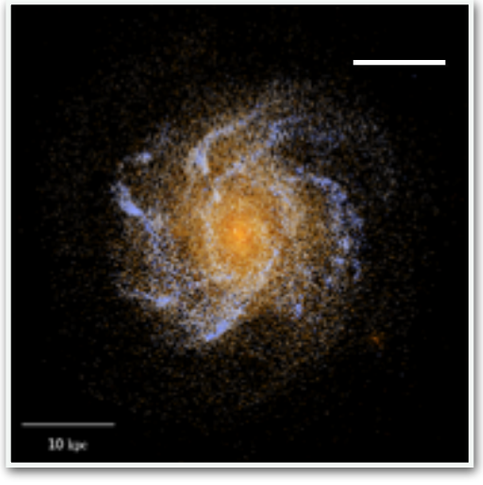
2x
400 pc
$6 \cdot 10^6$ $M_\odot$

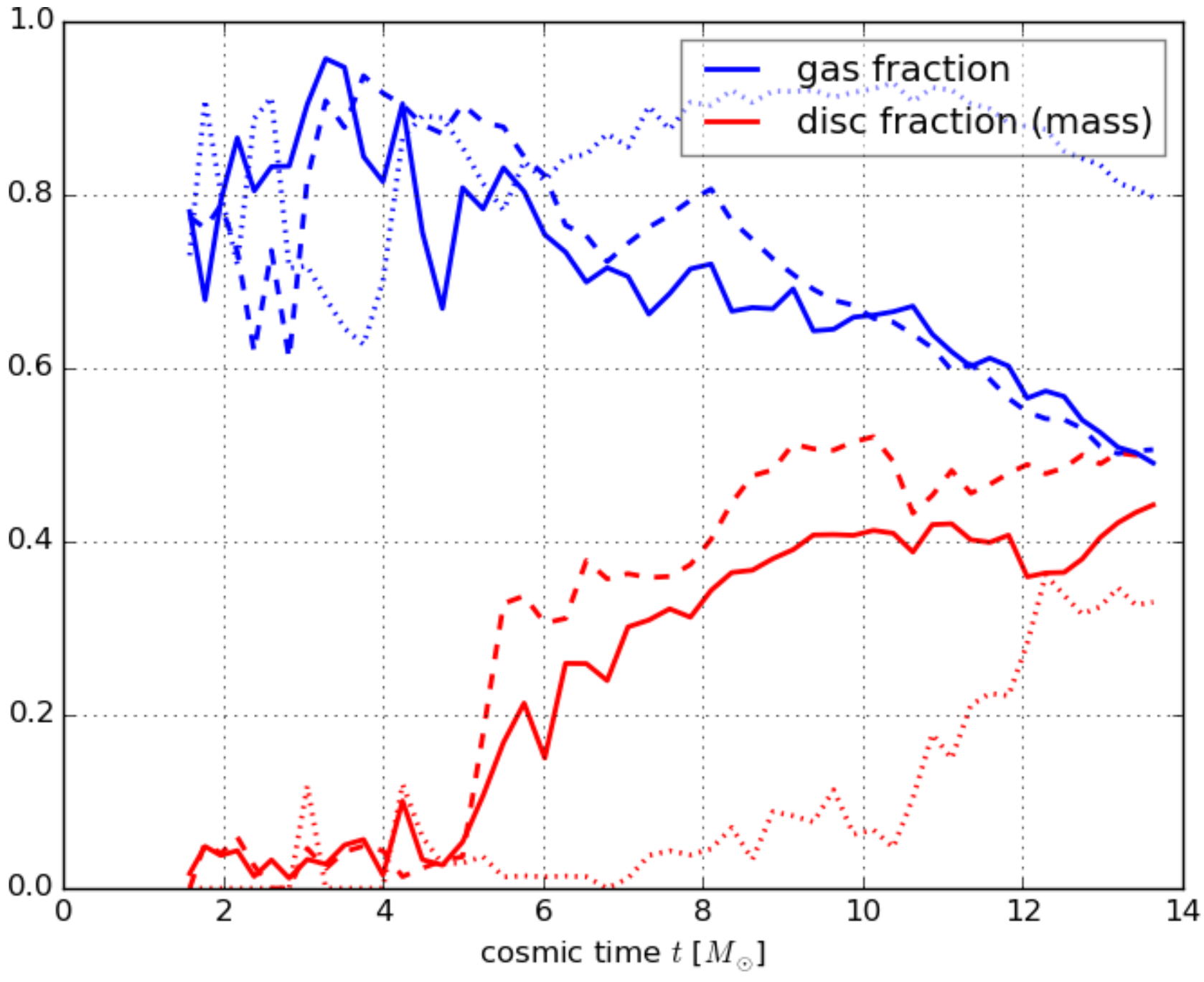


4x
200 pc
$7 \cdot 10^5$ $M_\odot$



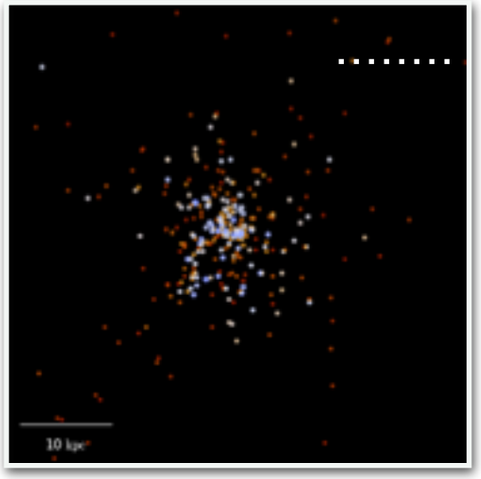
8x
100 pc
$9 \cdot 10^4$ $M_\odot$



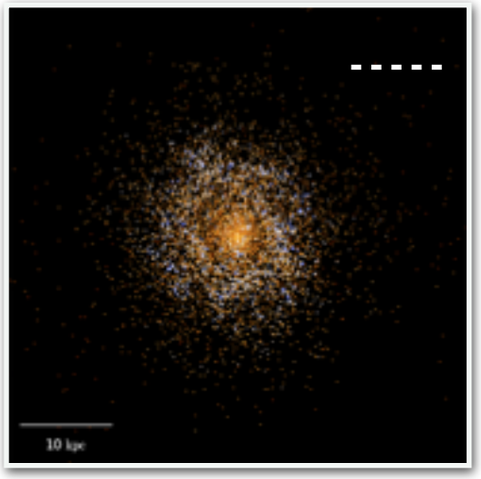


SFR History

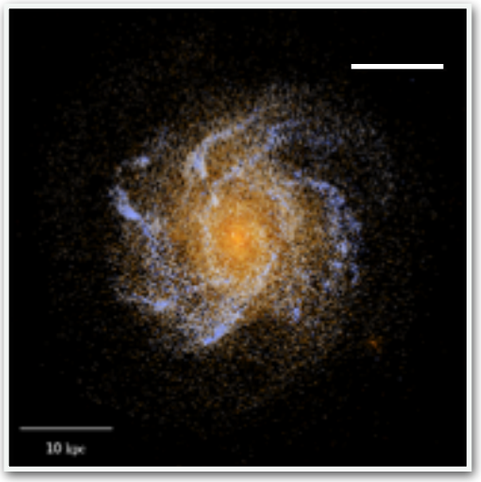
2x
400 pc
$6 \cdot 10^6$ $M_\odot$

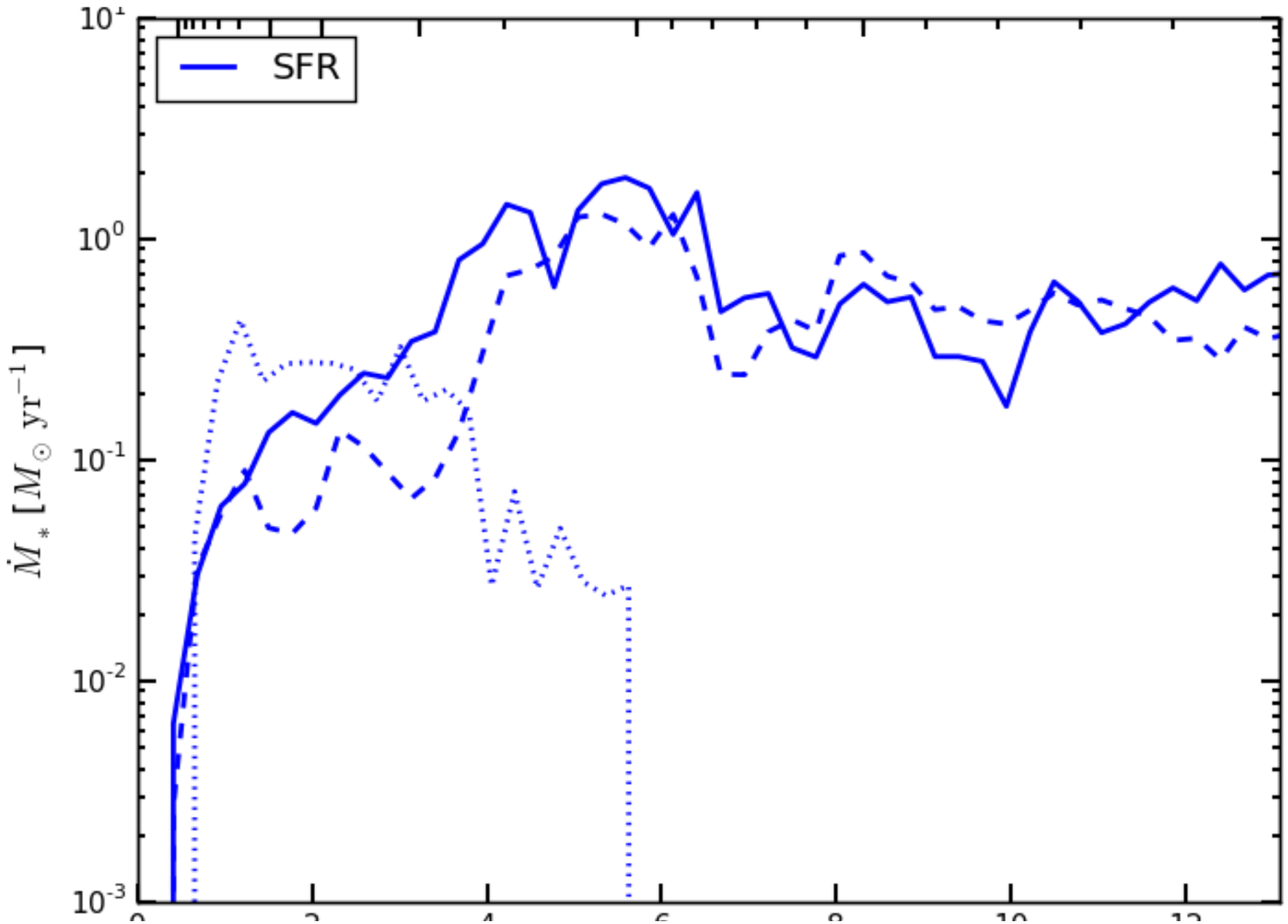


4x
200 pc
$7 \cdot 10^5$ $M_\odot$

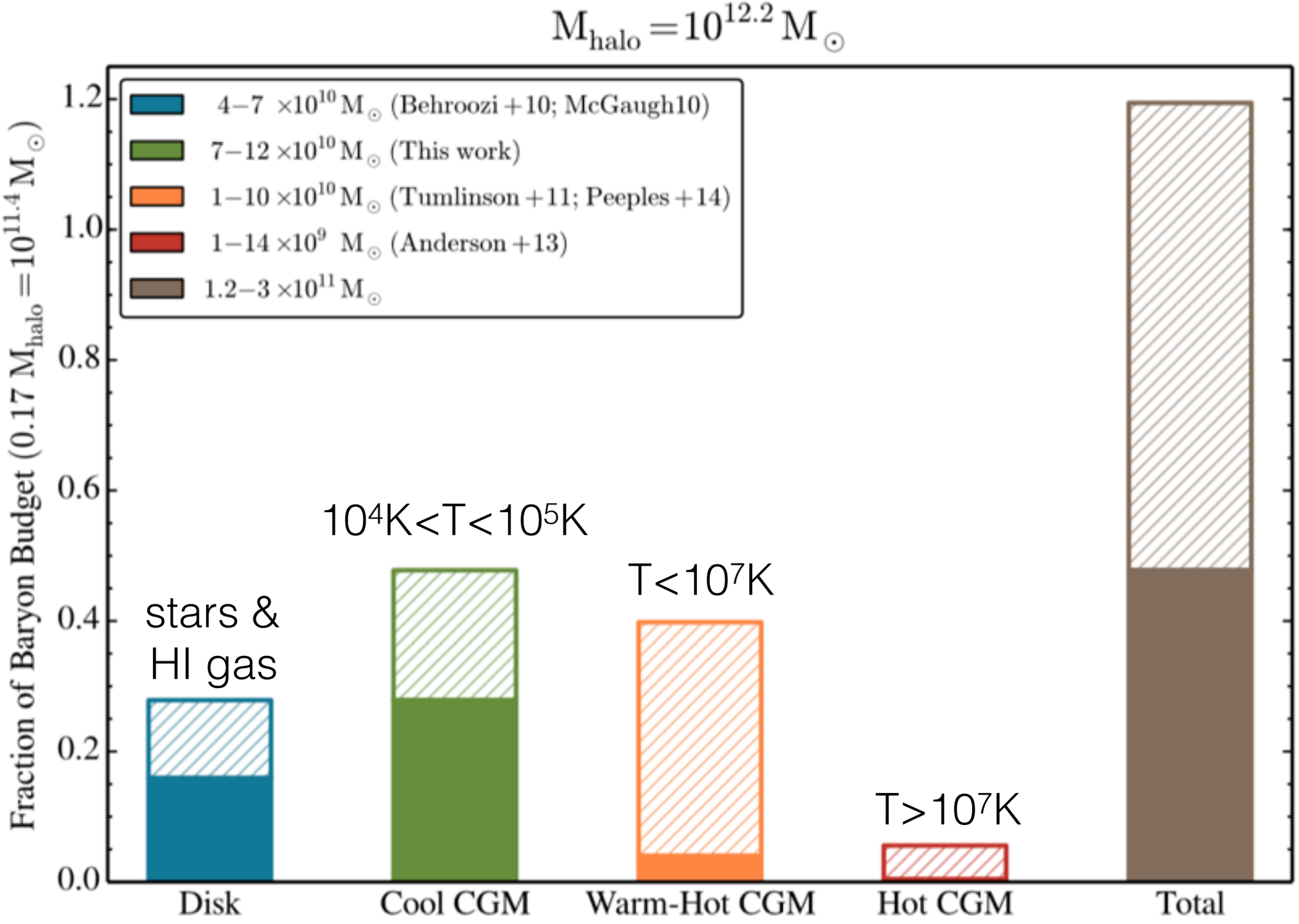


8x
100 pc
$9 \cdot 10^4$ $M_\odot$





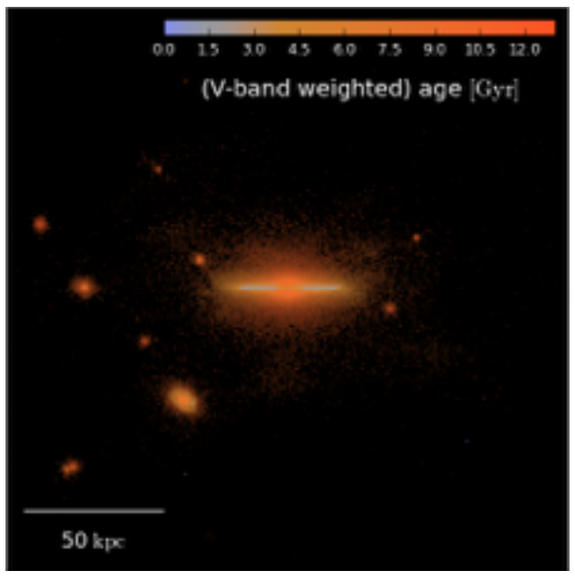
Mass Budget

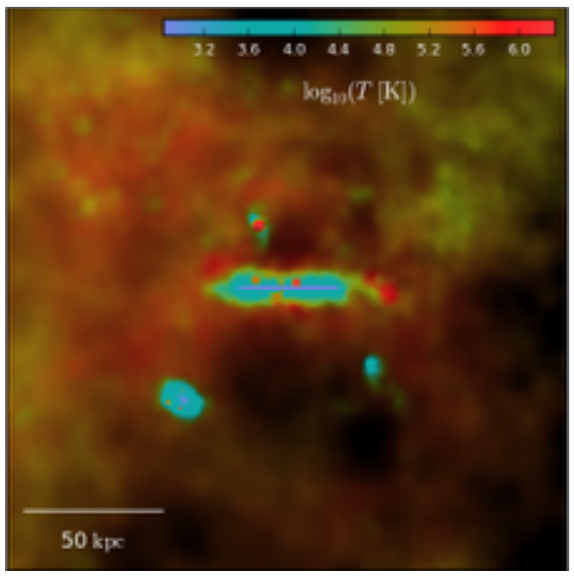


Werk+ (2014)

Mass Budget

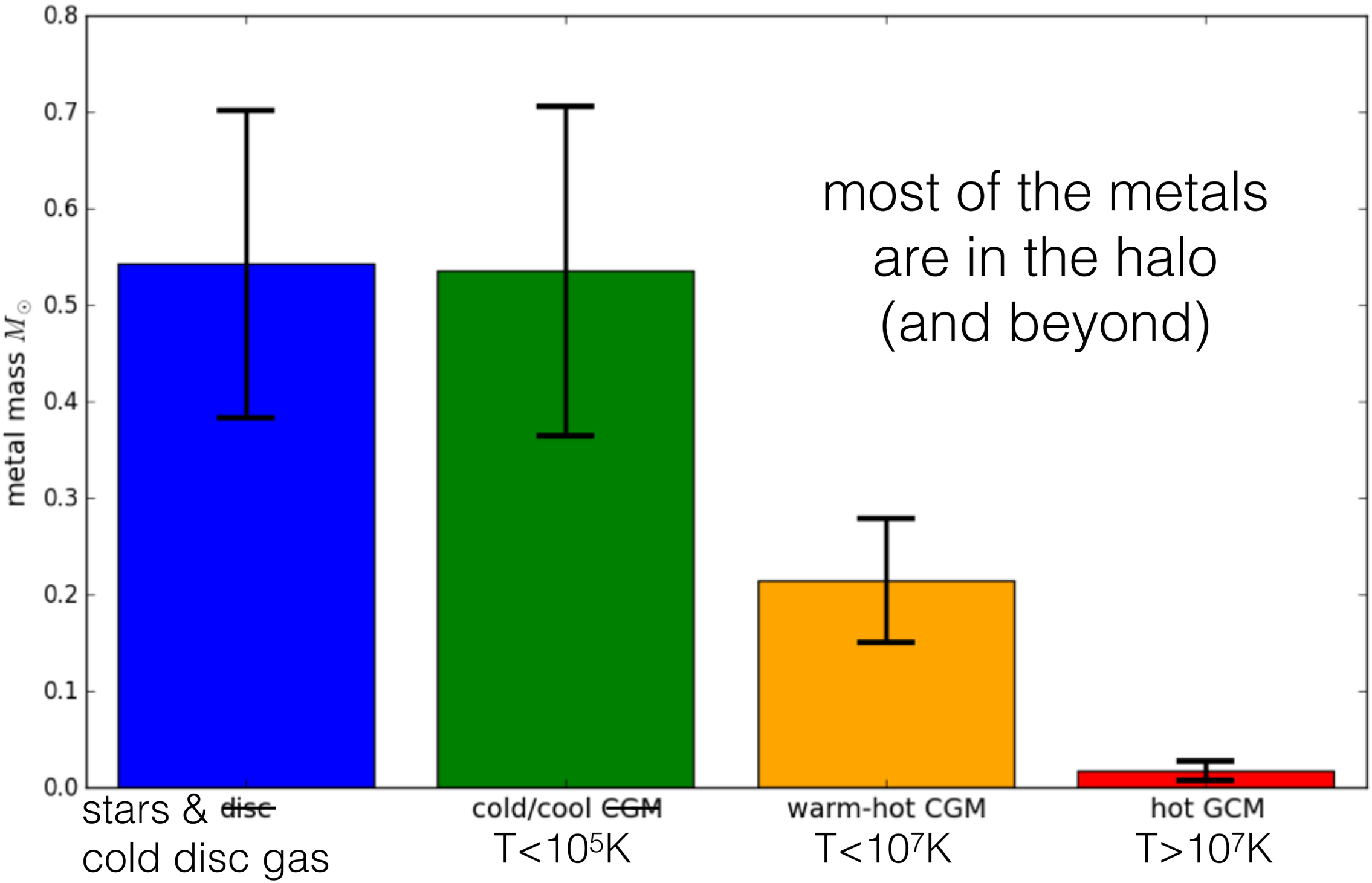
9 sims @z=0.0 $M_{halo} \approx 10^{12.2\pm0.3}\ M_\odot$





Metal Budget

9 sims @z=0.0 $M_{halo} \approx 10^{12.2\pm0.3}\ M_\odot$



Summary

- We have **missing baryons**…
- Typically **>50% of the metals** are ***not*** **in the galaxy.**
- **Multi- / 2-phase model** is promising in terms of **convergence.**
- Be aware of the **stochasticity of SN** (also in smaller / early structures) and hence the feedback! Need for ≳10,000(?) baryon particles per structure.