Formation of Dwarf Spheroidal galaxies in LCDM simulations

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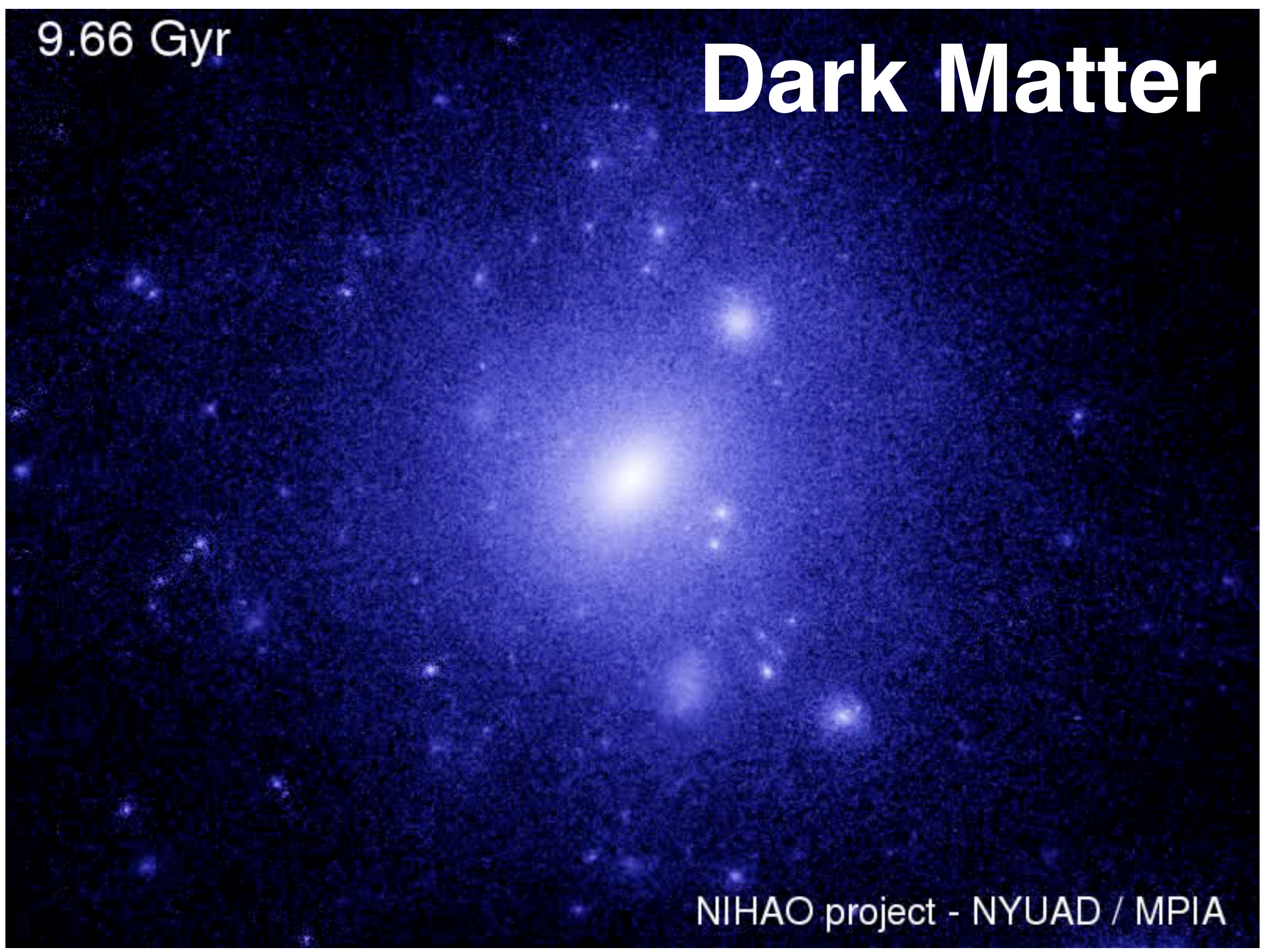
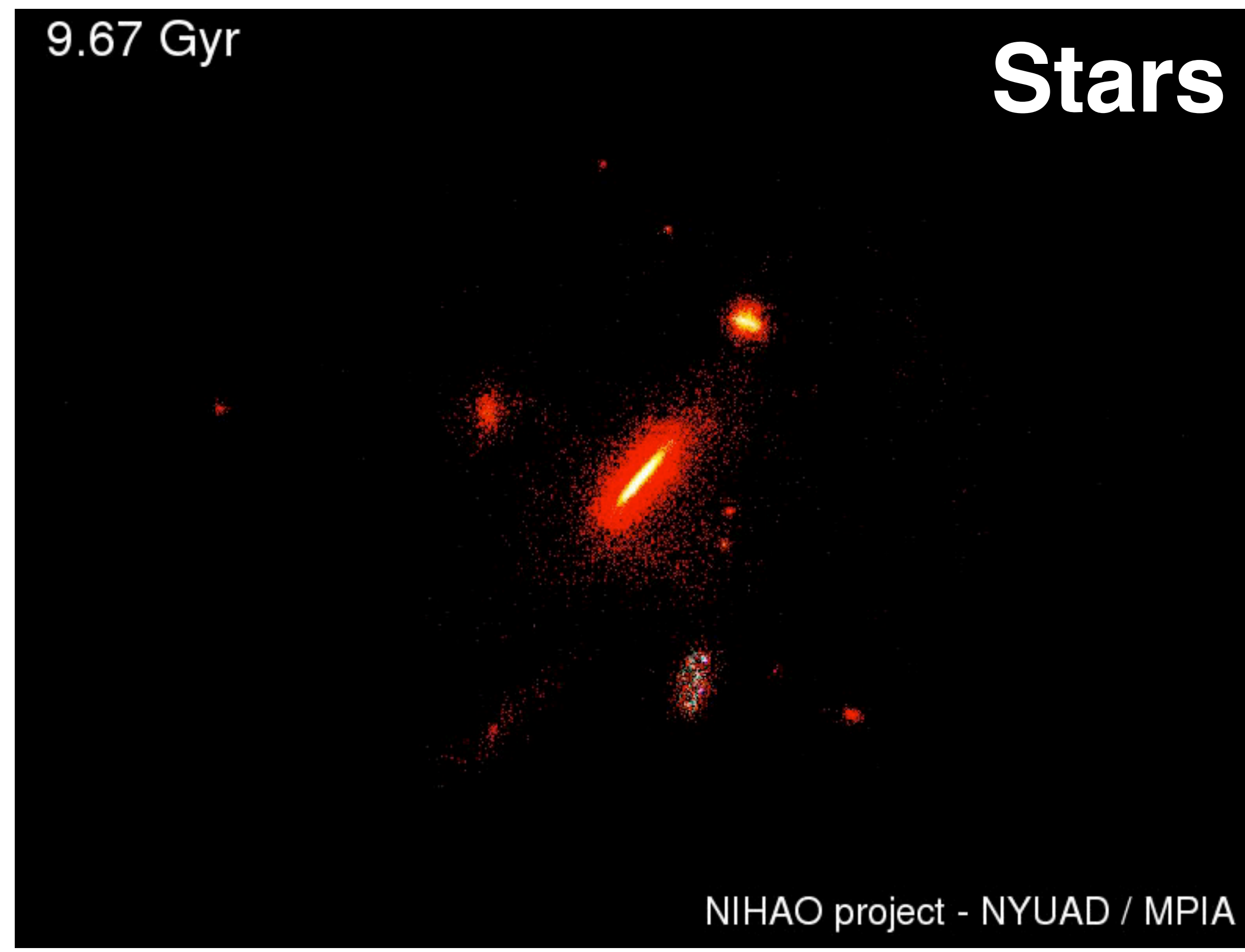




Barolo Astroparticle Meeting, September 2017


Norway
Finland
Baltic Sea
Estonia
Latvia
Lithuania
Moscow
Москва
North Sea
Denmark
United Kingdom
Ireland
Netherlands
London
Belgium
Germany
Poland
Belarus
Prague
Czechia
Paris
Slovakia
Ukraine
Austria
Moldova
Hungary
France
Romania
Croatia
Serbia
Black Sea
Italy
Bulgaria
Georgia
Caspian Sea
Barcelona
Rome
Madrid
Portugal
Spain
Tyrrhenian Sea
Istanbul
Greece
Turkey
Azerbaijan
Astana
Астана
Kazakhstan
Uzbekistan
Kyrgyzstan
Turkmenistan
Tajikistan
Afghanistan
Mediterranean Sea
Tunisia
Syria
Lebanon
Iraq
Iran
Morocco
Israel
Jordan
Pakistan
New Delhi
नई दिल्ली
Algeria
Libya
Egypt
Persian Gulf
Riyadh
الرياض
United Arab Emirates
Western Sahara
Mecca
مكة
Saudi Arabia
Red Sea
Oman
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Yemen
Mumbai
Burkina Faso
Gulf of Aden
Arabian Sea
Djibouti
Bengaluru
Google

Abu Dhabi is the capital of the UAE

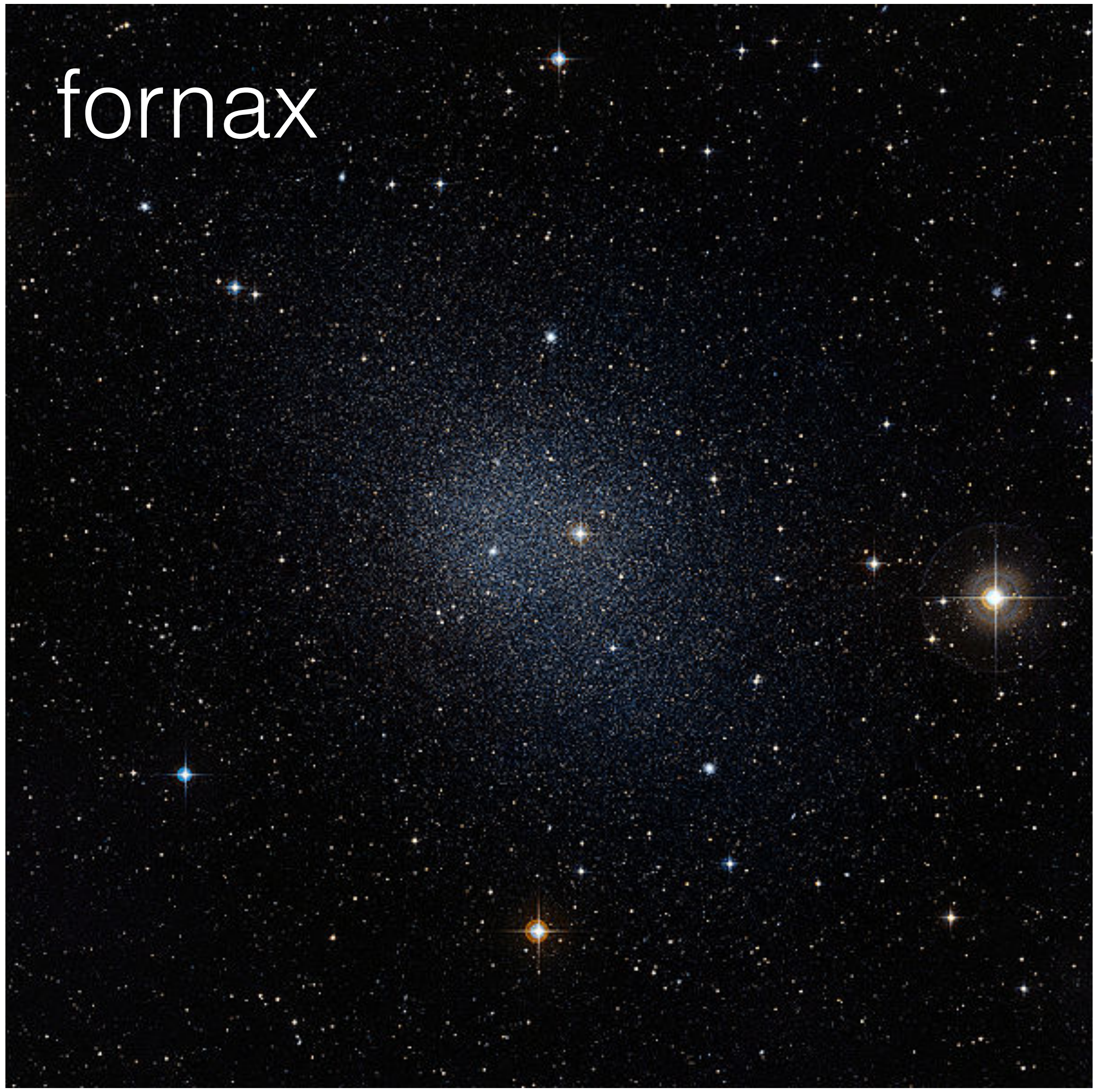
UAE = United Arab Emirates

Abu Dhabi is near Dubai

Burj Khalifa, tallest building in the world **0.828km**

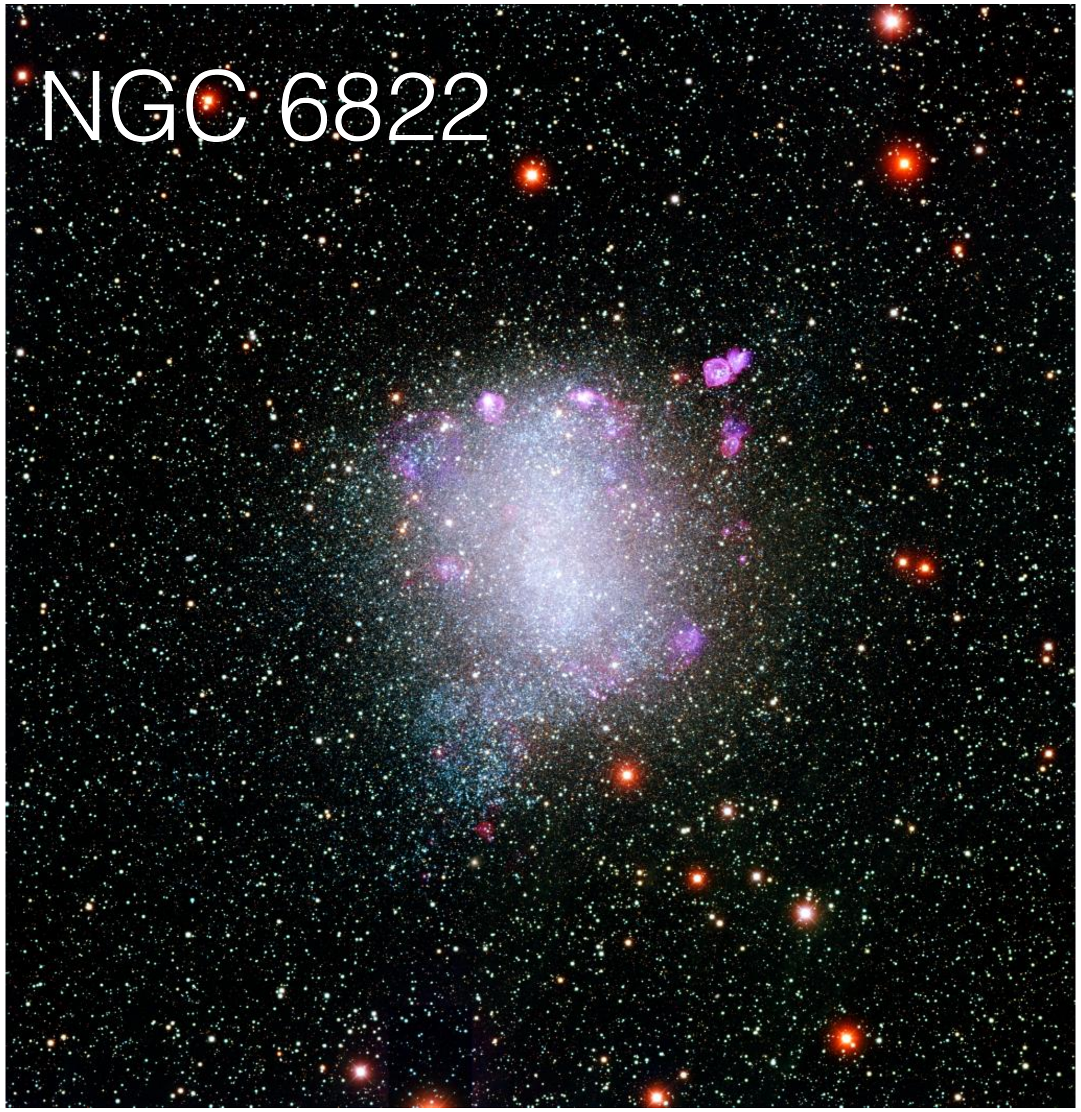
NYUAD
Saadiyat Beach
Corniche
Khor Faridah
Ba Al Ghaylam Island
جزيرة بالغيلم
Saadiyat Beach
E12
New York University Abu Dhabi - Saadiyat...
Ramhan Island
جزيرة رمحان
E12
Lulu Island
جزيرة اللؤلؤ
AL DANAH
Al Reem Island
جزيرة الريم
Umm Yifenah Island
Abu Dhabi Beach
Zeraa Island
Yas Island
جزيرة ياس
Bal Rumaid Island
جزيرة بالرميد
Khor Laffan
Ferrari World Abu Dhabi
Marina Mall
مركز المارينا
Corniche Beach
AL MANHAL
REISS
AL KHUBEIRAH
AL NAHYAN
AL ETIHAD
Khor Al Baghal
Massnoua Island
جزيرة مصموعة
AL BATEEN
EASTERN
Sas Al Nakhl Island
Samaliyah Island
جزيرة السمالية

dwarf Spheroidal



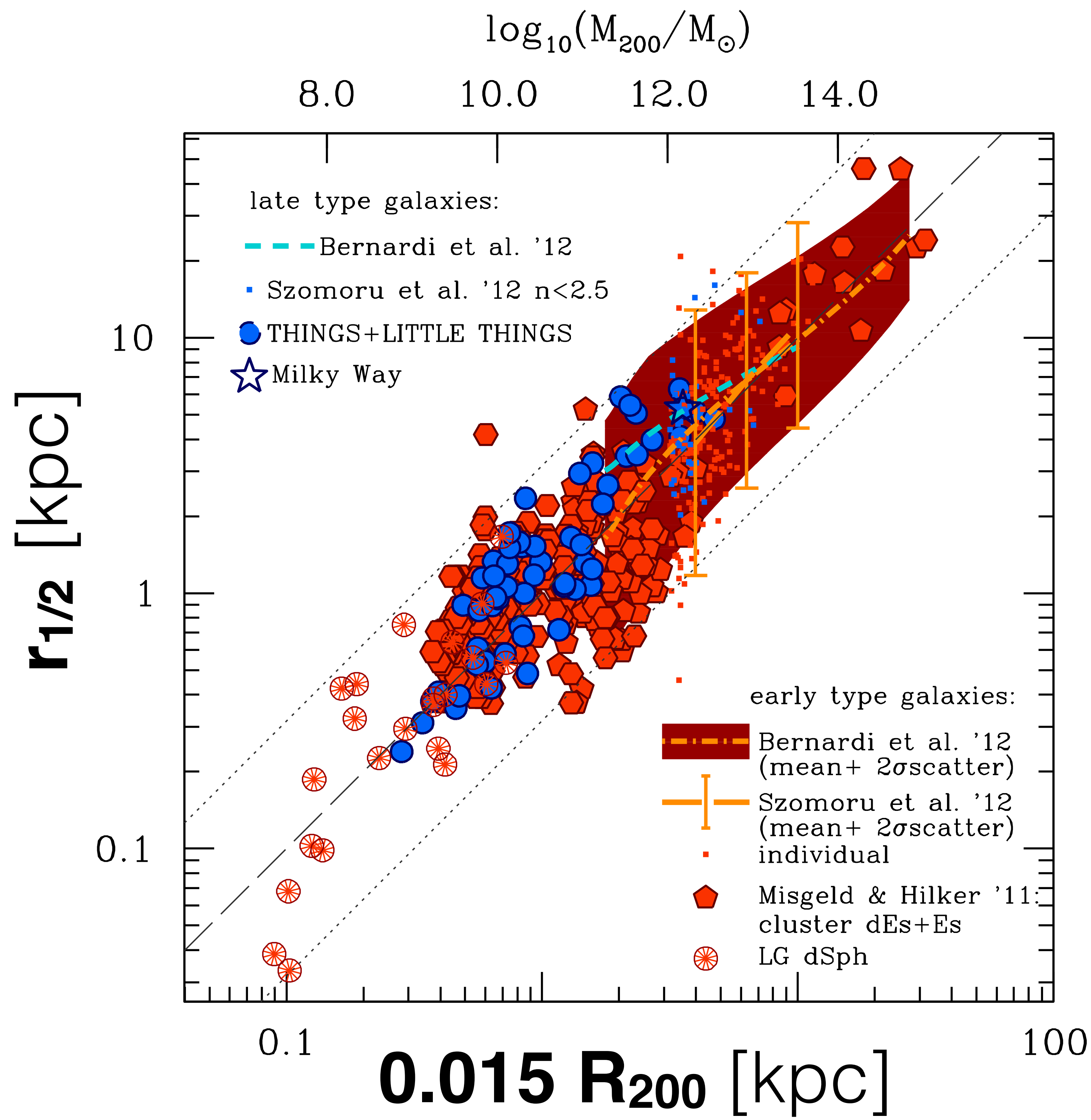
gas poor
passive
satellite

dwarf Irregular



gas rich
star forming
field

Half light radius $r_{1/2}$~1.5% halo virial radius

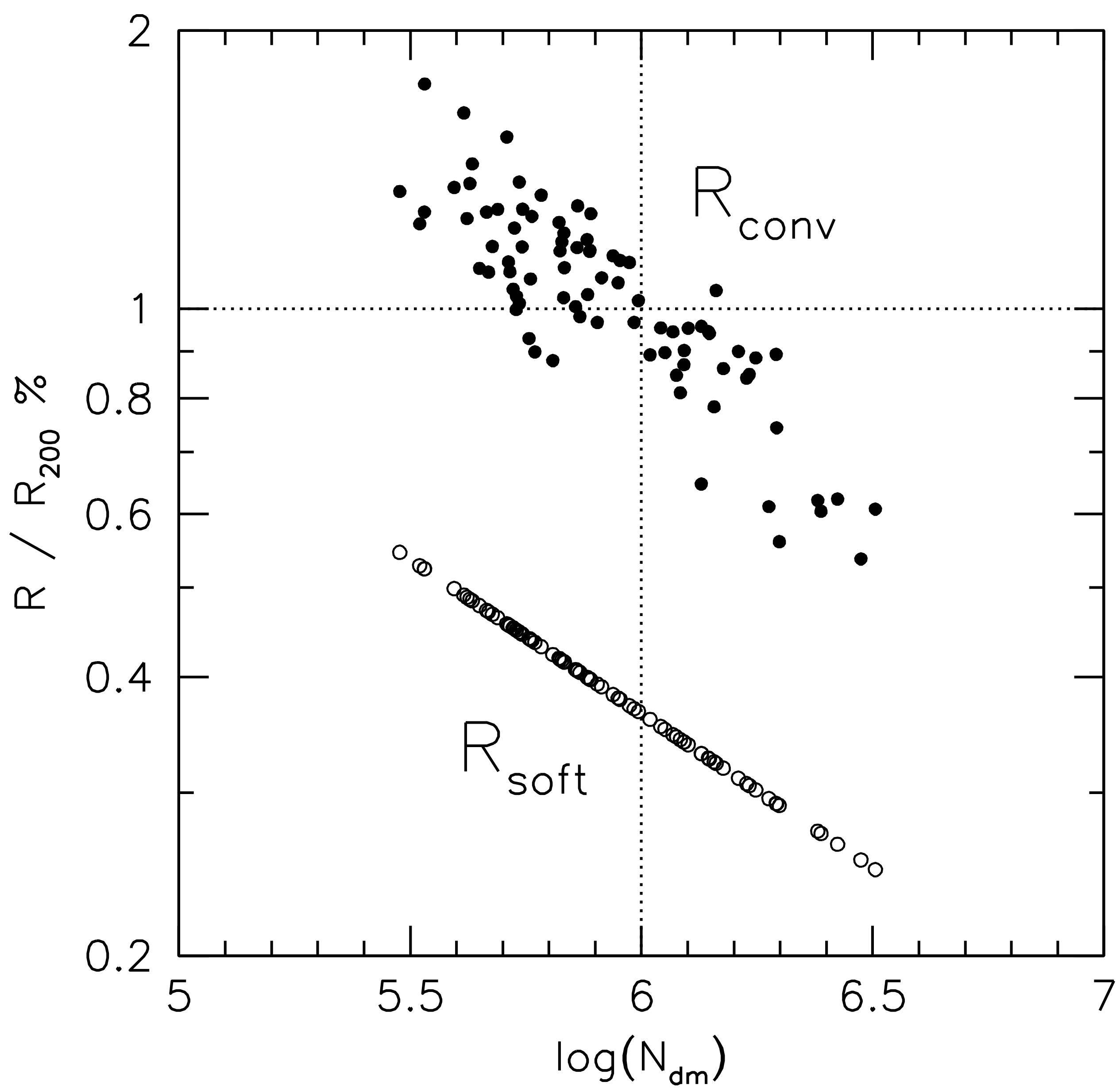


Kravtsov 2013

resolution = convergence in mass profile

$$\frac{t_{\rm relax}(r)}{t_{\rm circ}(r_{200})} = \frac{N}{8\ln N}\,\frac{r/V_{\rm c}}{r_{200}/V_{200}} = \frac{\sqrt{200}}{8}\,\frac{N}{\ln N}\left(\frac{\bar{\rho}}{\rho_{\rm crit}}\right)^{-1/2} > 0.6$$ 10% error

Power et al. 2003 convergence criteria

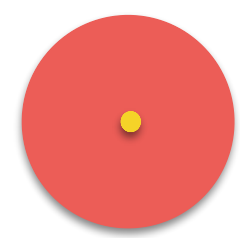


NIHAO simulations
Wang et al. 2015

Field dwarfs are "easy" to simulate

Required resolution: 1% of host halo (~**million** particles)

x10



Field halo

M_{halo}~**10^{10}** M_{sun}/h

R_{halo}~**35** kpc/h

Field galaxy

$R_{1/2}$~0.3 kpc/h

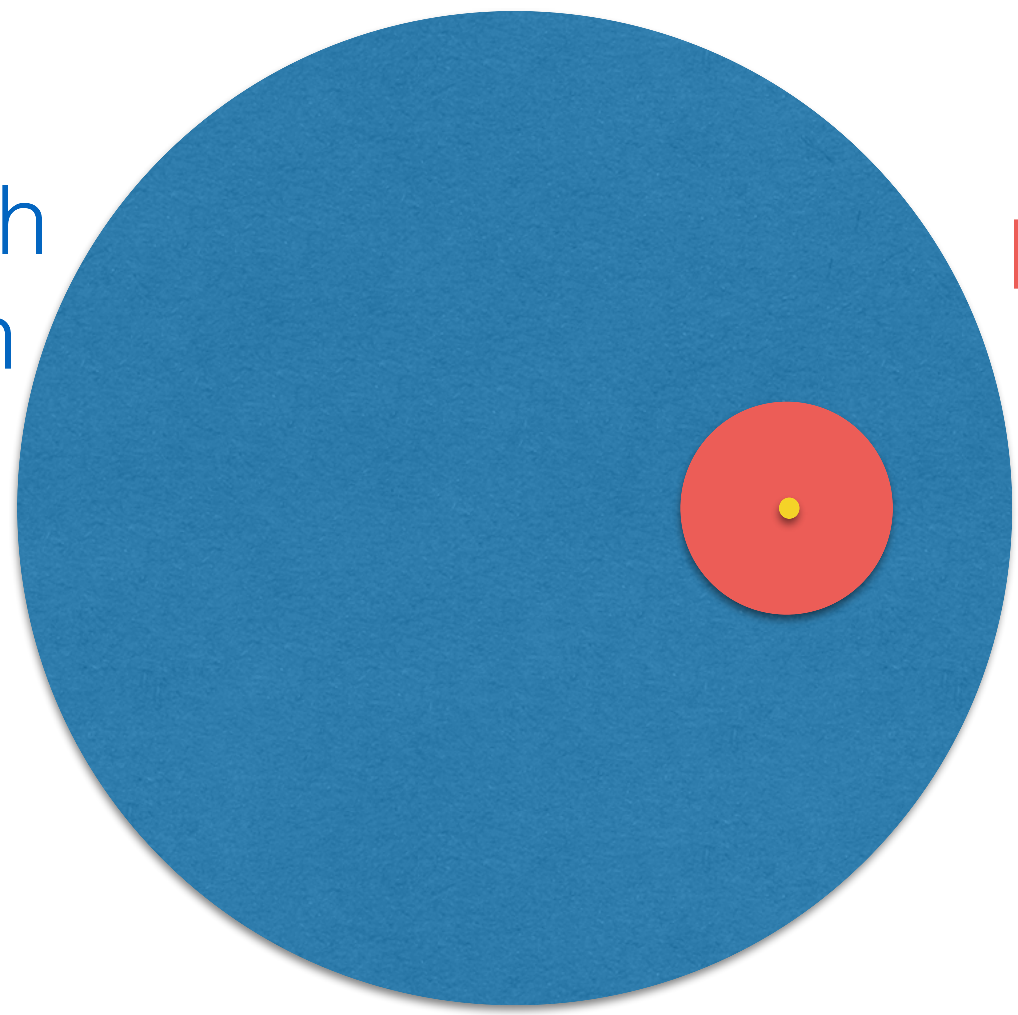
Environment is a challenge to simulate

Required resolution: 0.2% of host halo (~**120 million** particles)

Host halo

M_{halo}~**10^{12}** M_{sun}/h

R_{halo}~**160** kpc/h



Satellite halo

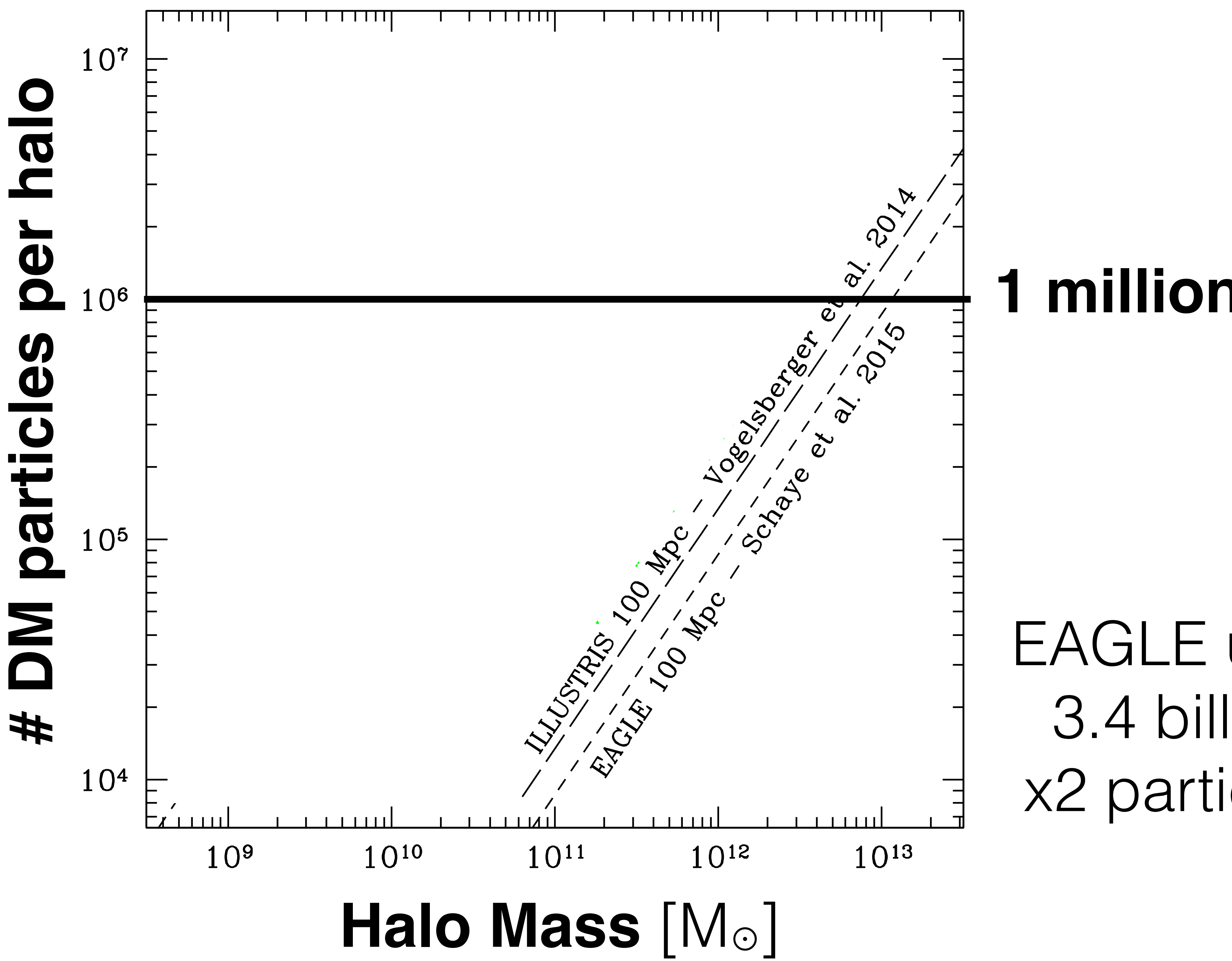
M_{halo}~**10^{10}** M_{sun}/h

R_{halo}~**35** kpc/h

Satellite galaxy

$R_{1/2}$~0.3 kpc/h

spatial resolution set by number of DM particles



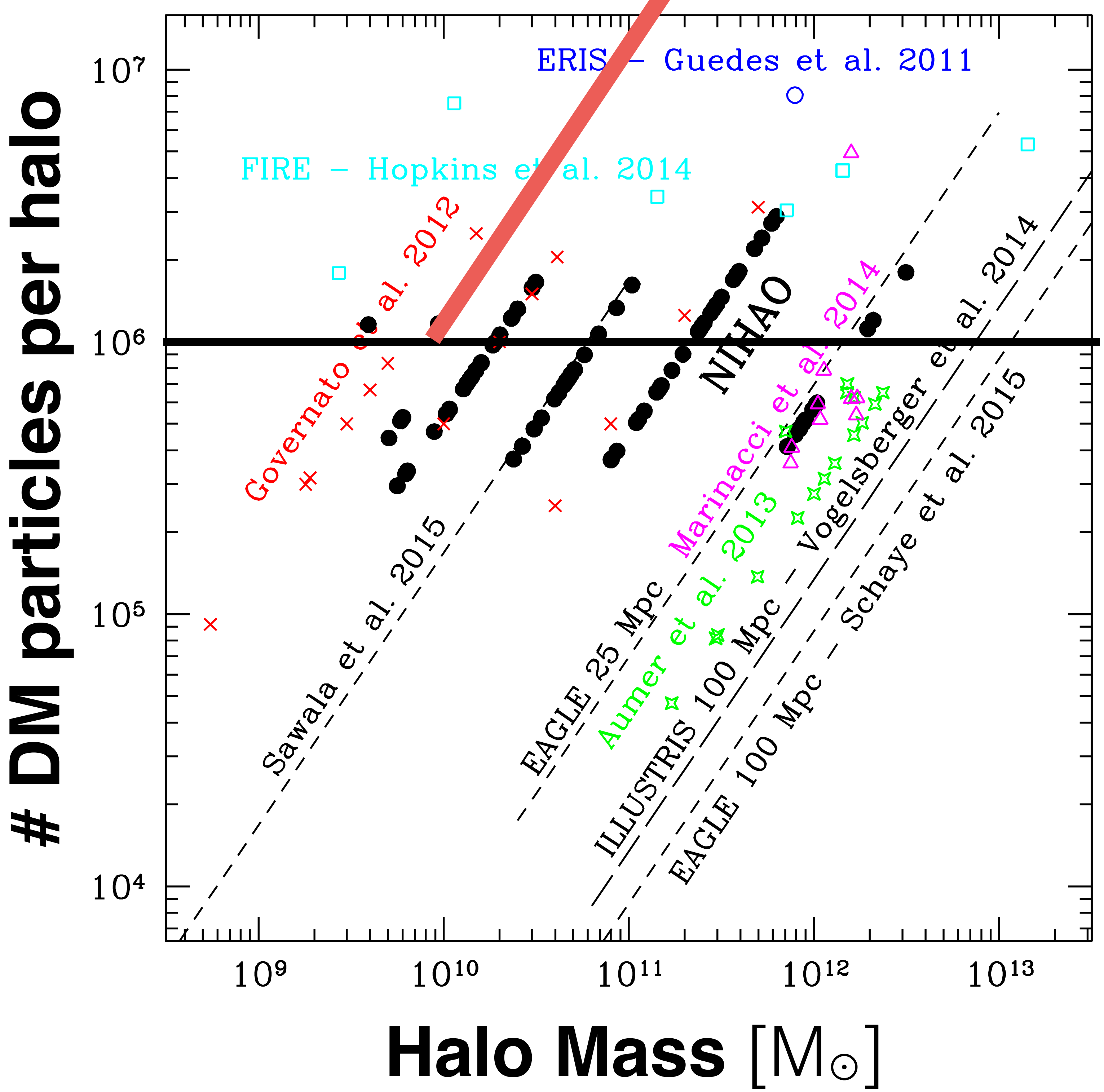
EAGLE uses 3.4 billion x2 particles

NIHAO I - Wang, Dutton et al. 2015

spatial resolution set by number of DM particles

100 million

Latte/FIRE - Wetzel et al. 2016



1 million

EAGLE uses 3.4 billion x2 particles

NIHAO I - Wang, Dutton et al. 2015

Full Cosmological

APOSTLE - Sawala et al. 2016
Latte - Wetzel et al. 2016

+ Fully cosmological

- Lower resolution

Isolated

Mayer et al. 2006
Kazantzidis et al. 2017

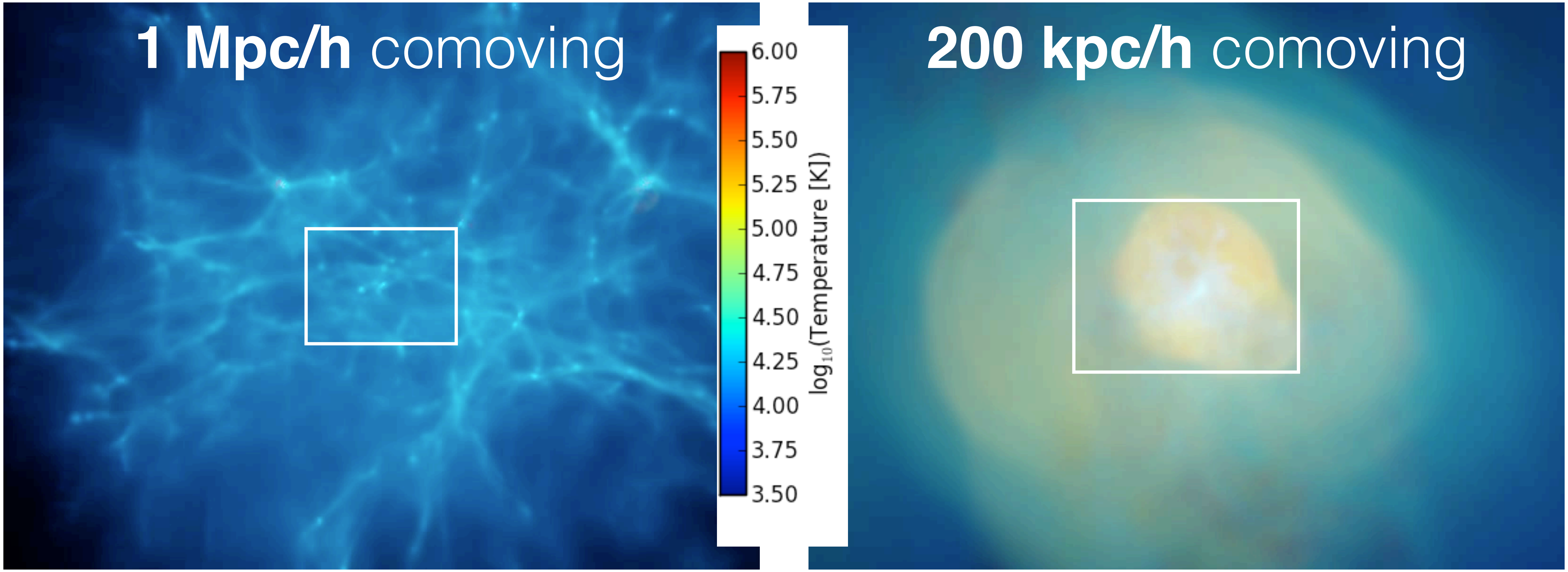
+ Higher resolution

- Idealized initial conditions

Hybrid

Macciò et al. 2017
Frings et al. 2017

+ Higher resolution (m_{dm} ~ 2000 M_{sun})
+ Fully cosmological before infall



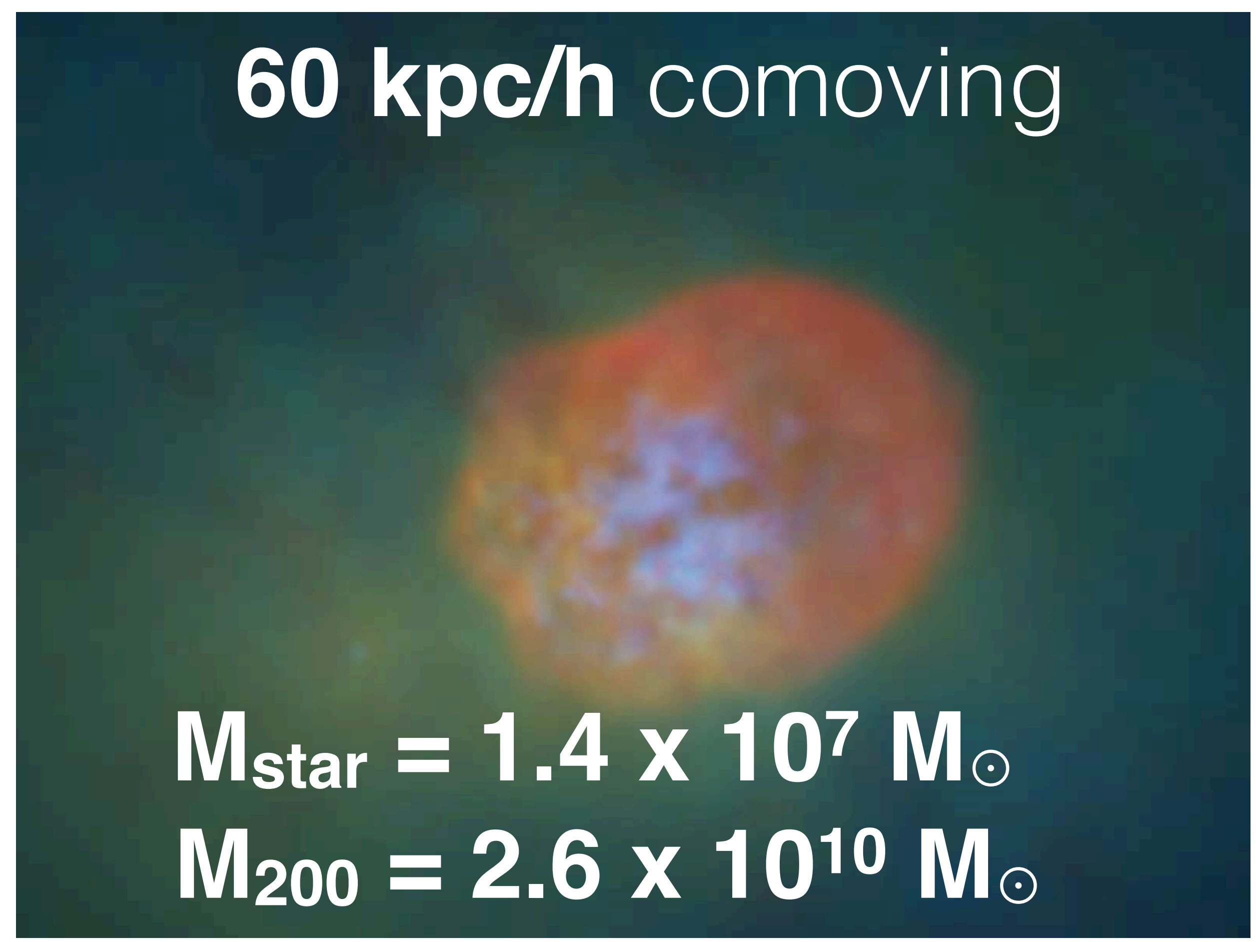
Cosmological zoom-in simulations

Gasoline - SPH

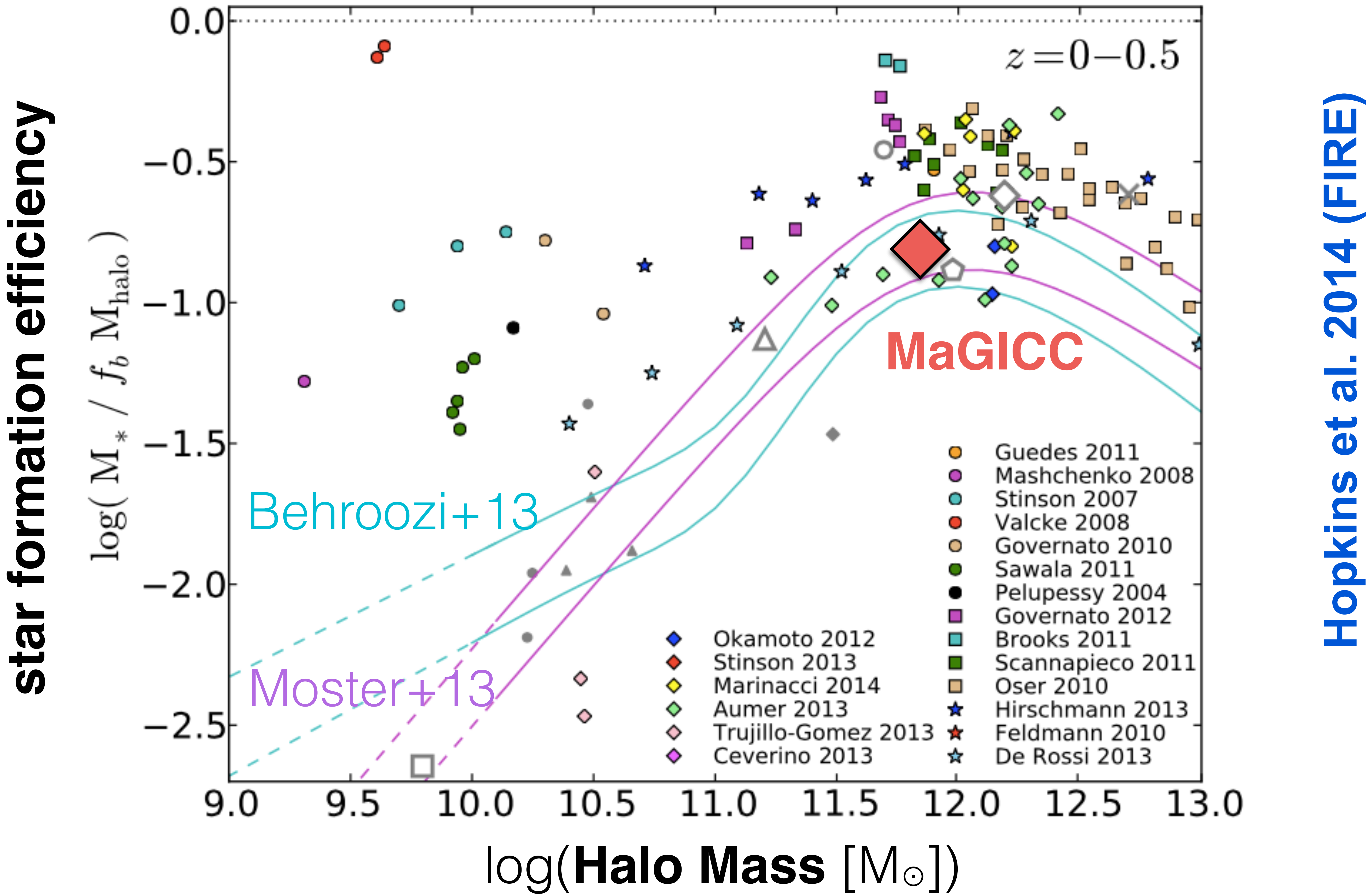
Wadsley et al. 2004

MaGICC sub-grid model

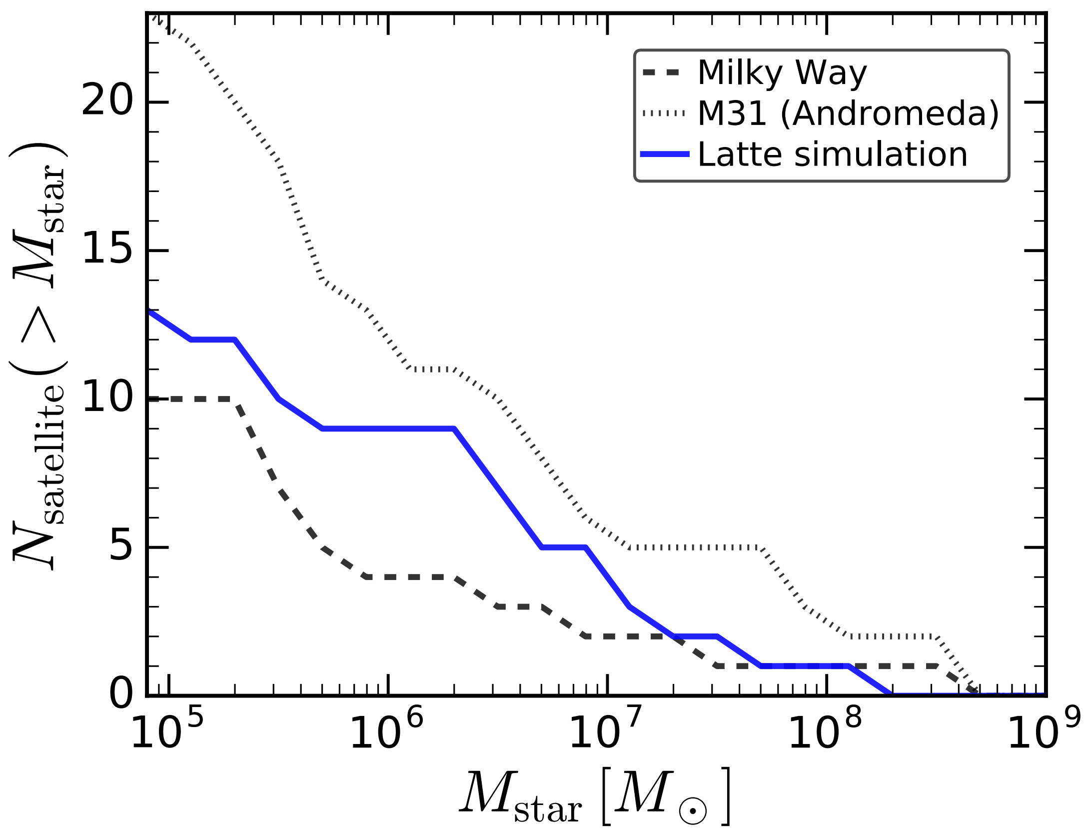
Stinson et al. 2013

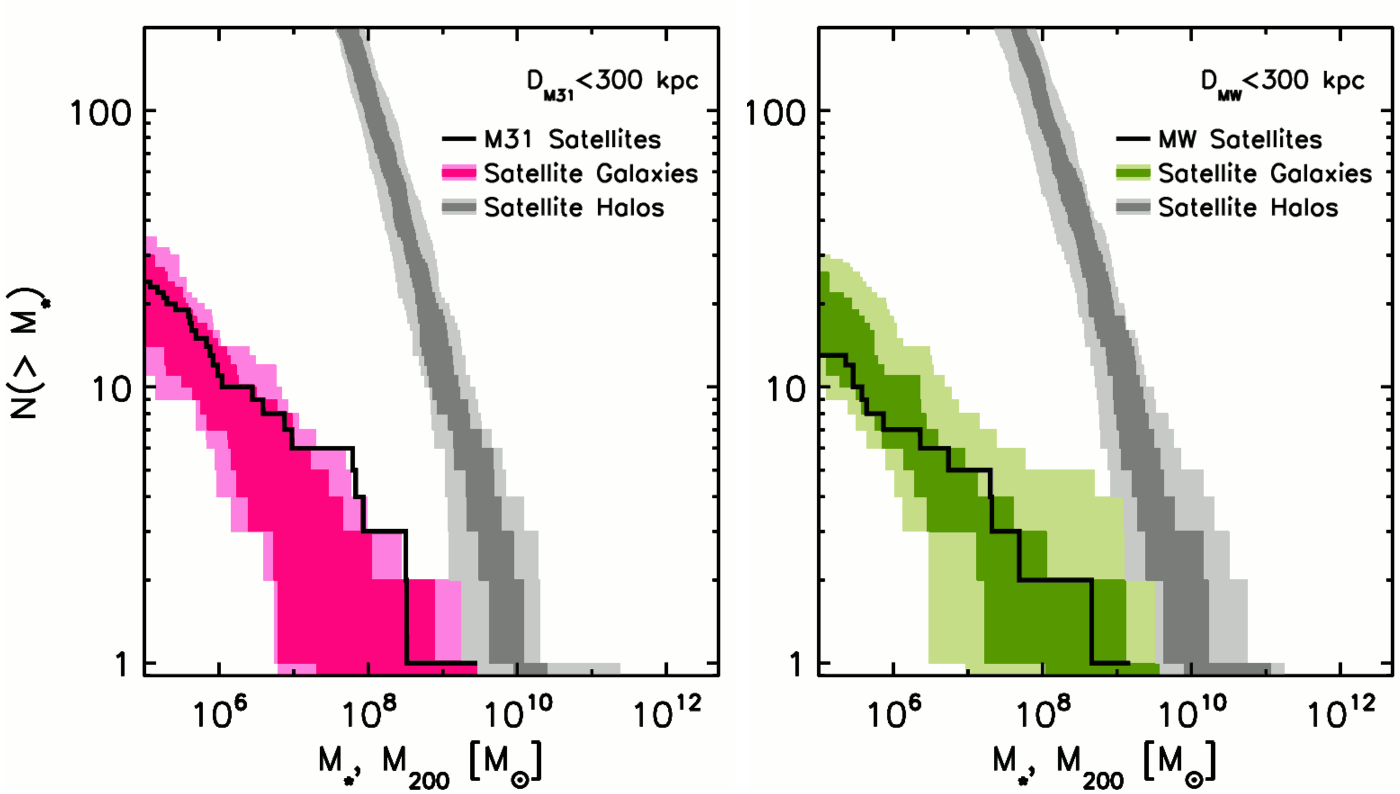


Most hydro sims over-produce stars @ z~0



New simulations match stellar mass function

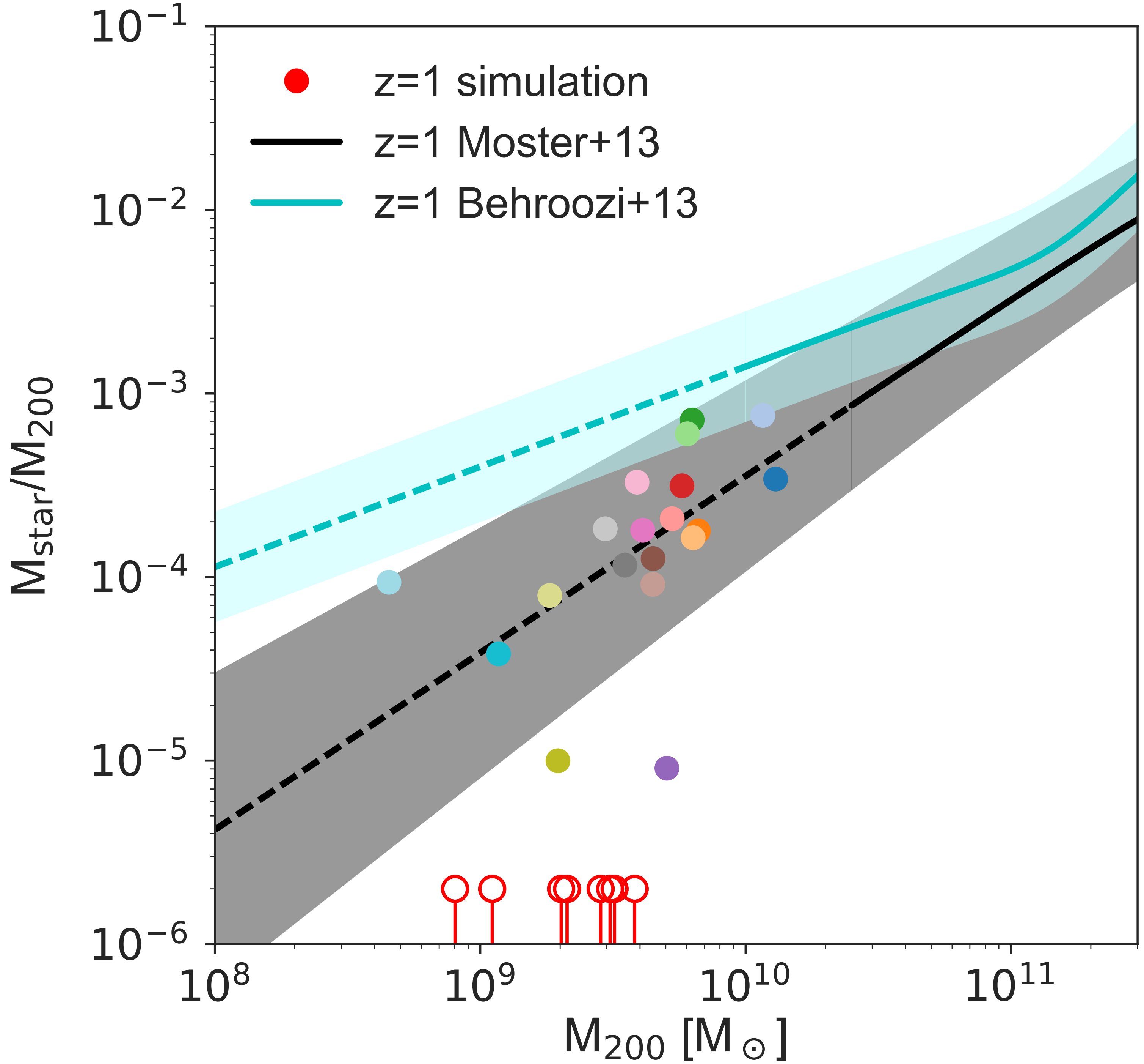




Latte
Wetzel et al. 2016

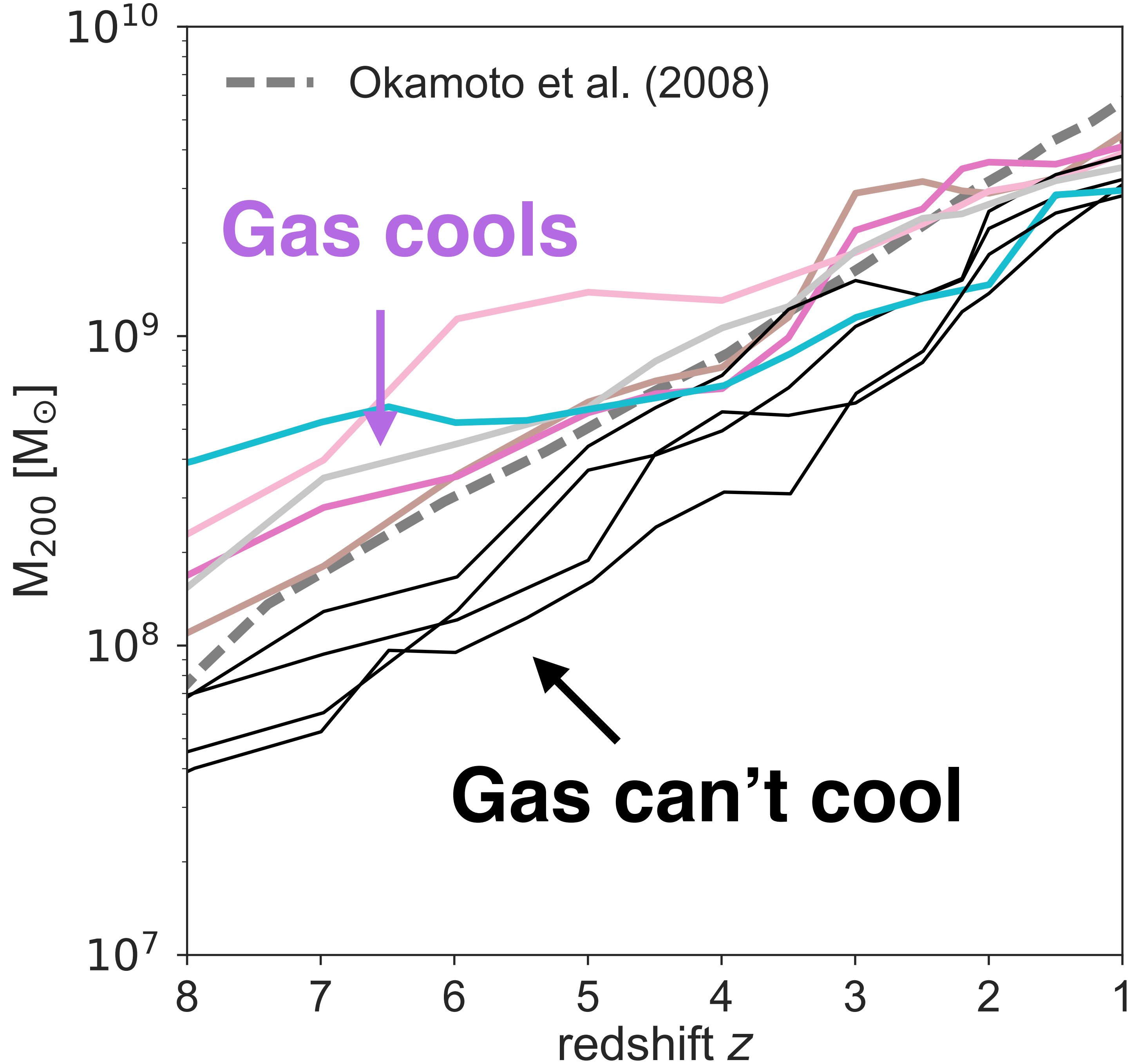
APOSTLE
Sawala et al. 2016

Results Before Infall: z=1



Macciò et al. 2017, arXiv 1707.01106

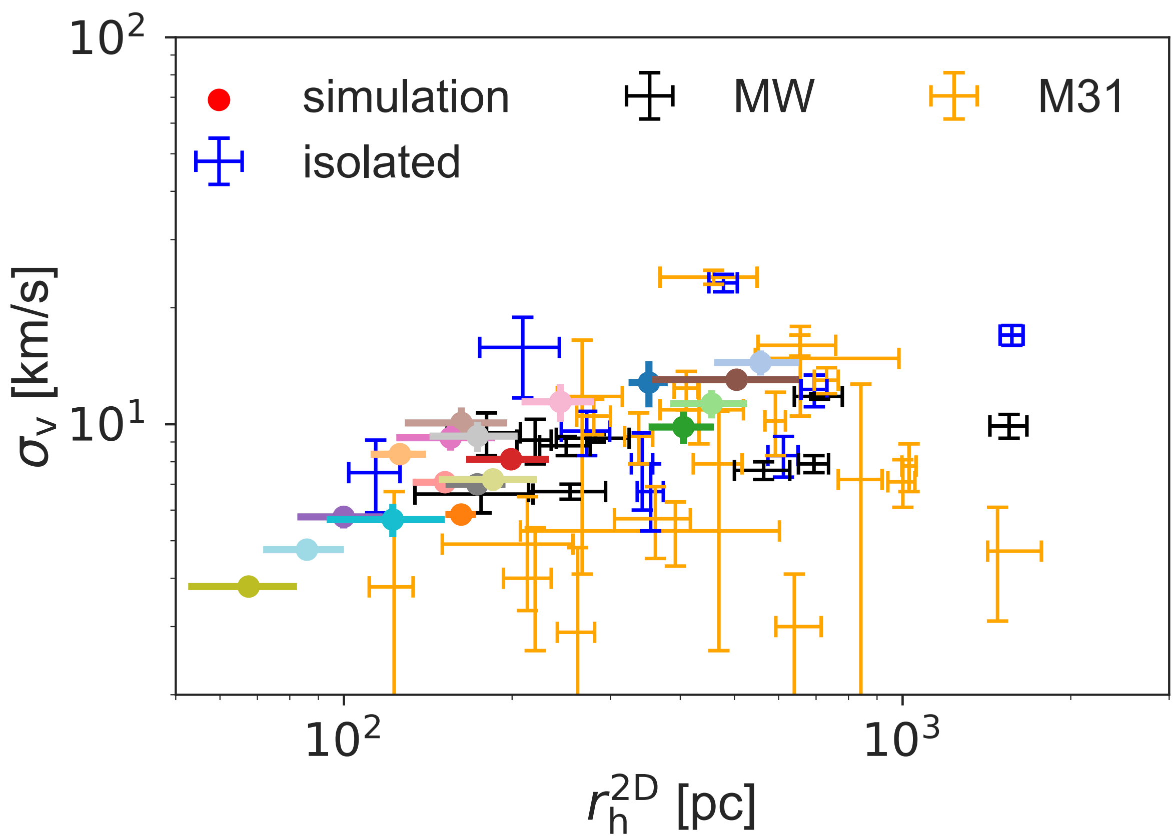
Dark Halos: UV background prevents cooling

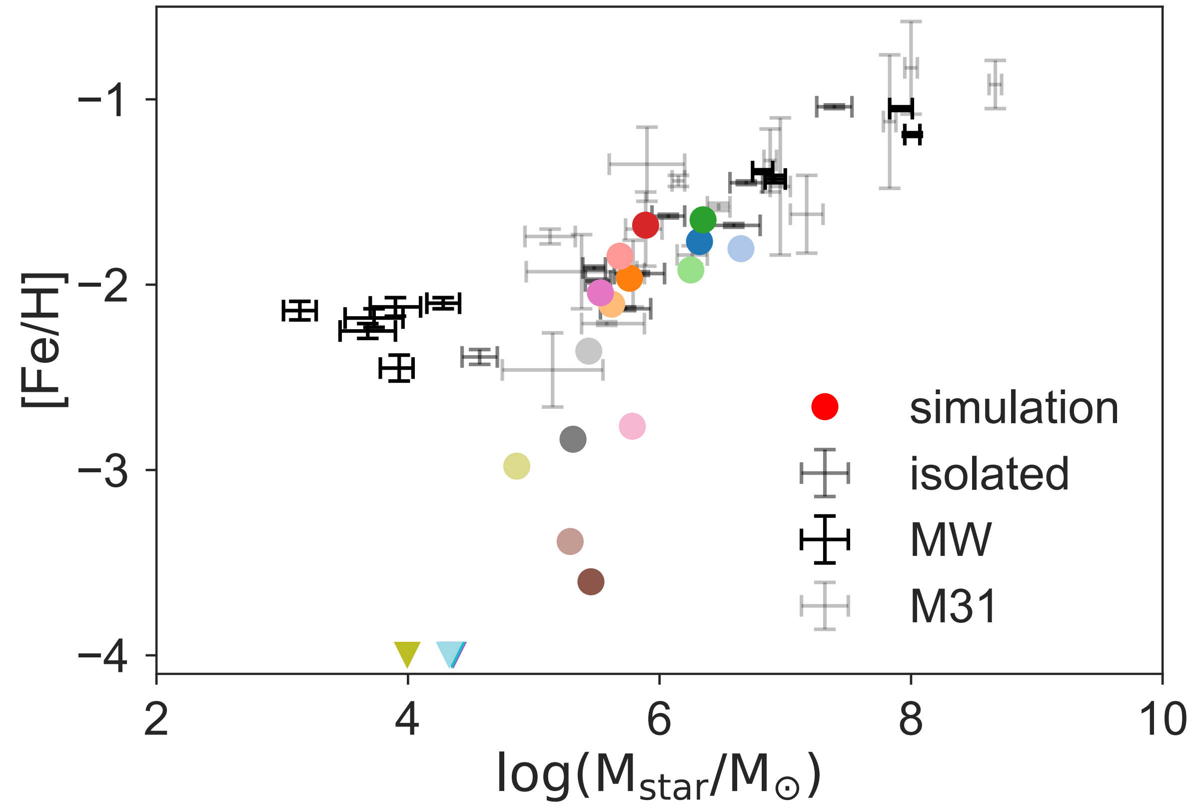


Macciò et al. 2017, arXiv 1707.01106

Simulations z=1, Observations z=0

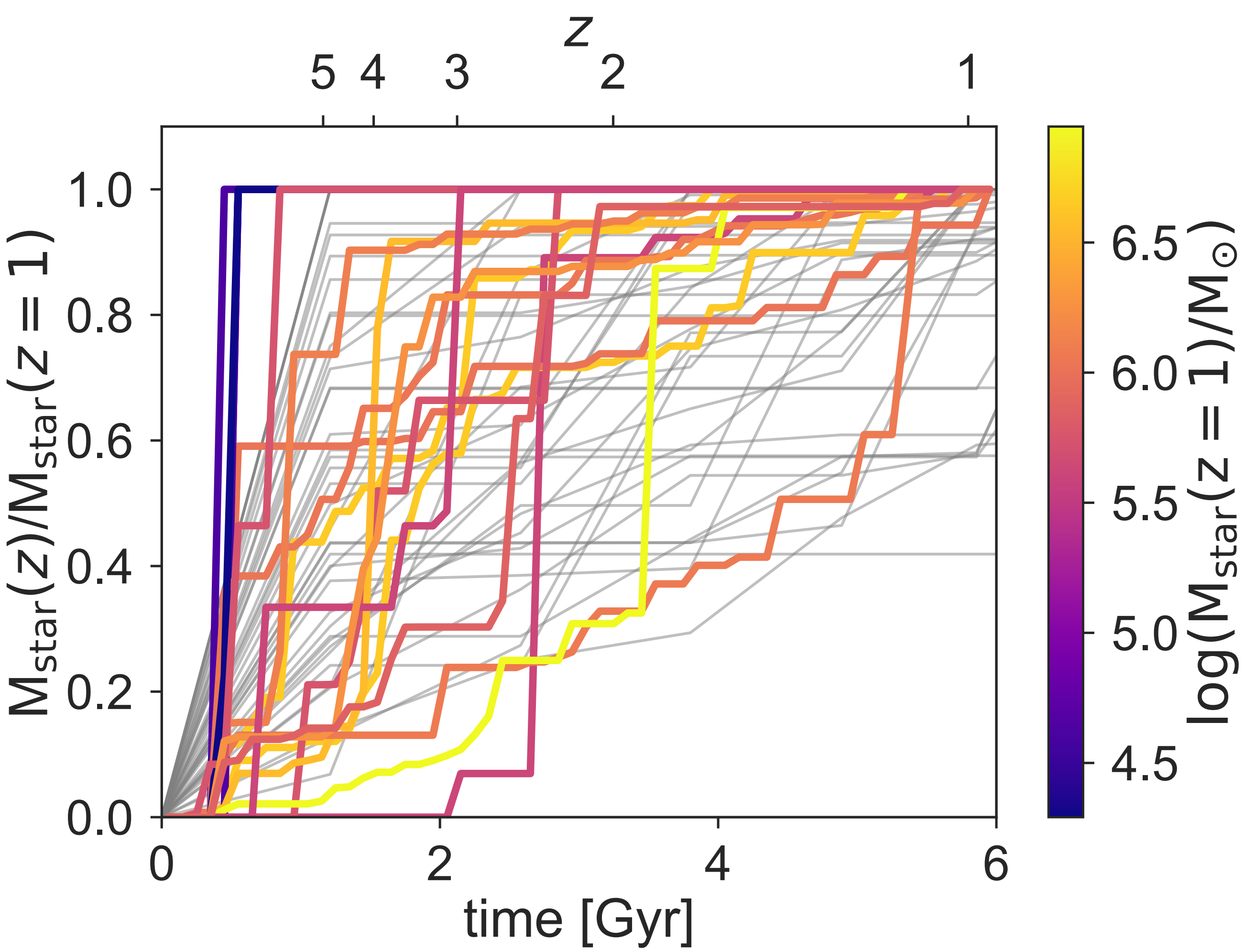
scaling relations largely in place by z=1

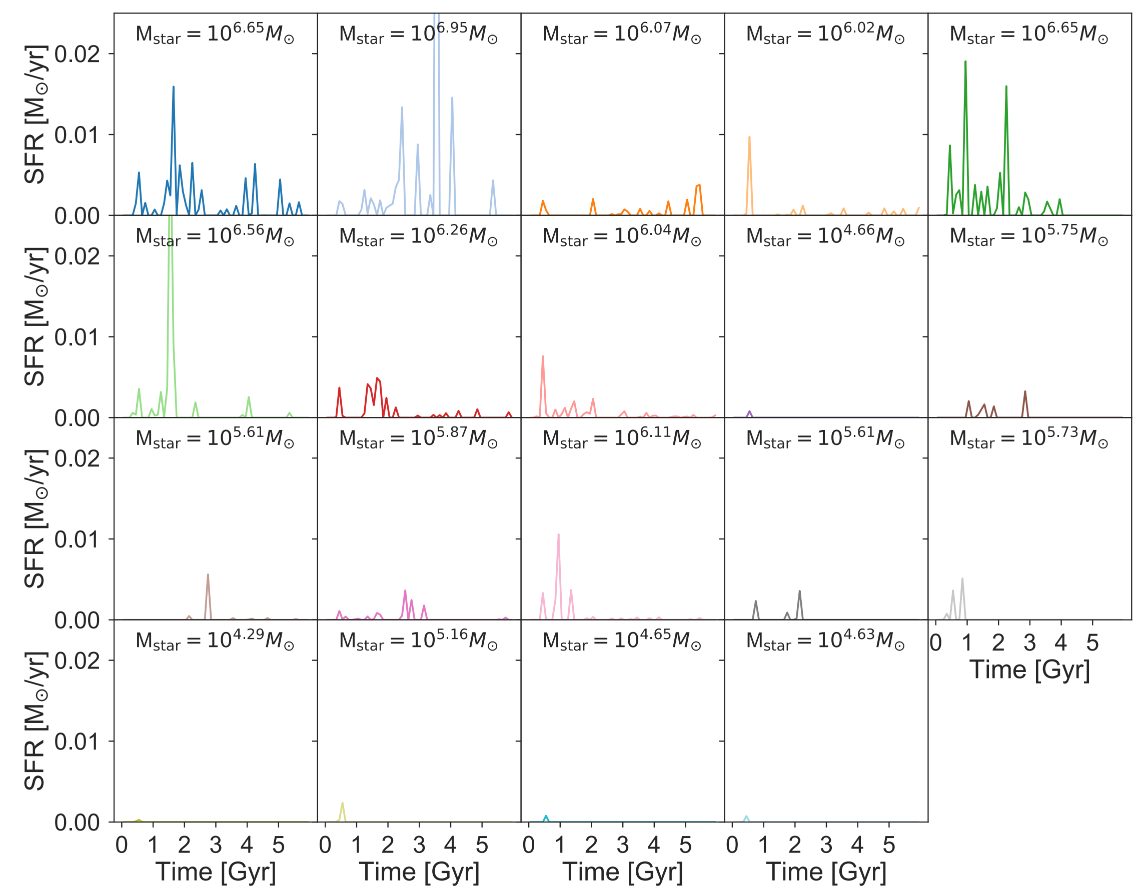




Macciò et al. 2017, arXiv 1707.01106

Diverse and Bursty Star Formation Histories

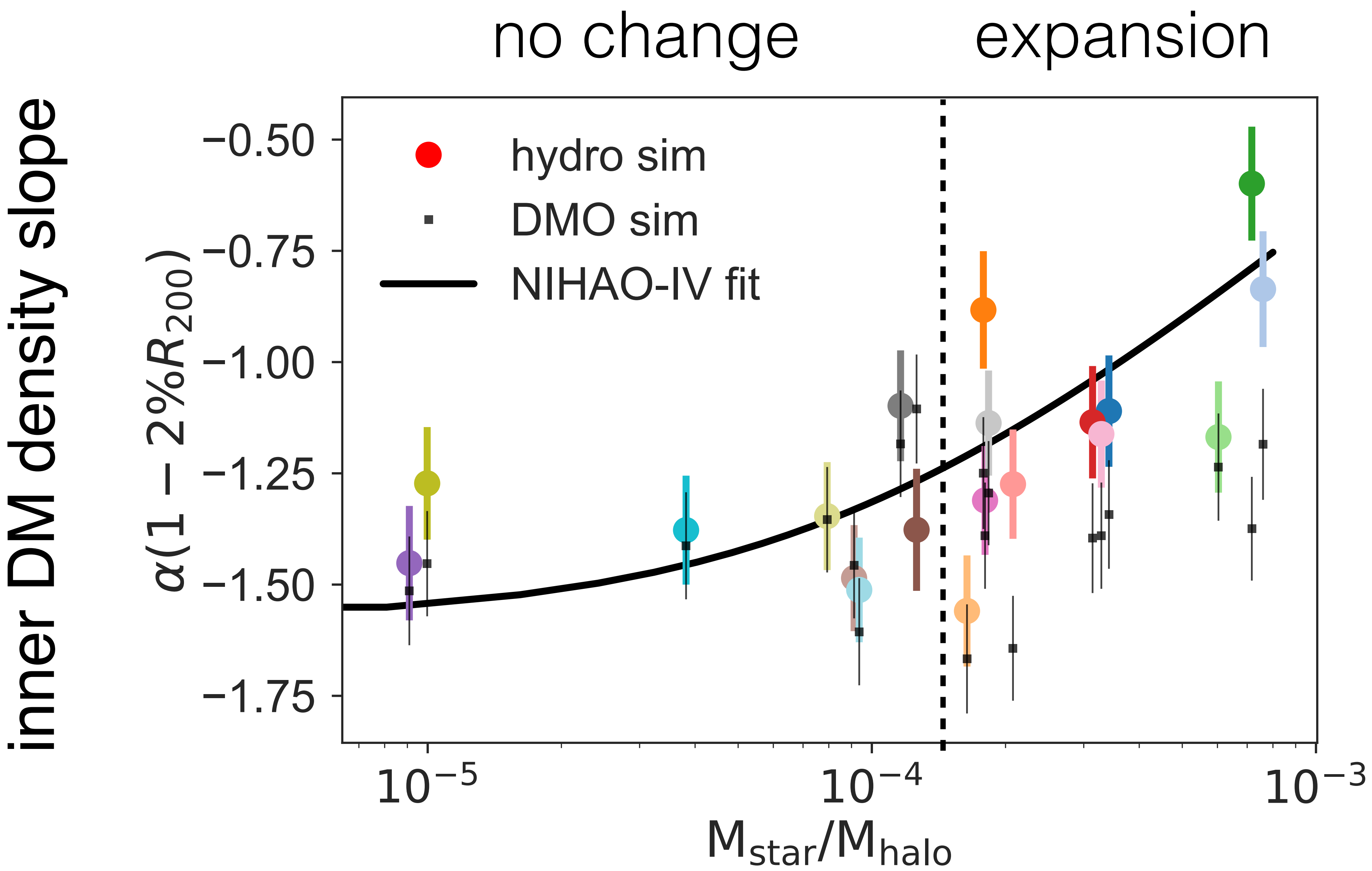




Observations: Weisz et al. (2014)

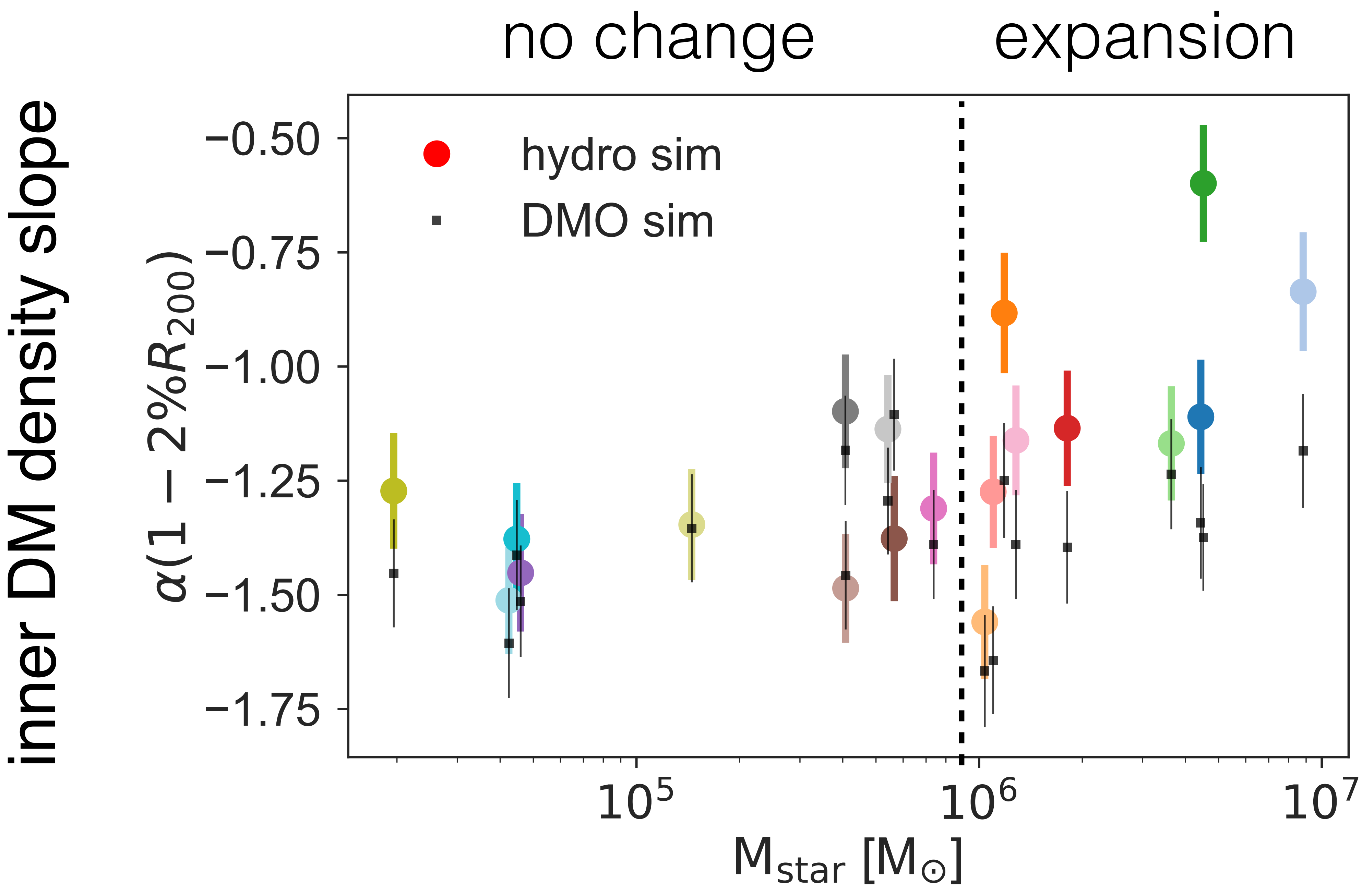
Macciò et al. 2017, arXiv 1707.01106

Dark Halo Response



Macciò et al. 2017, arXiv 1707.01106

Dark Halo Response



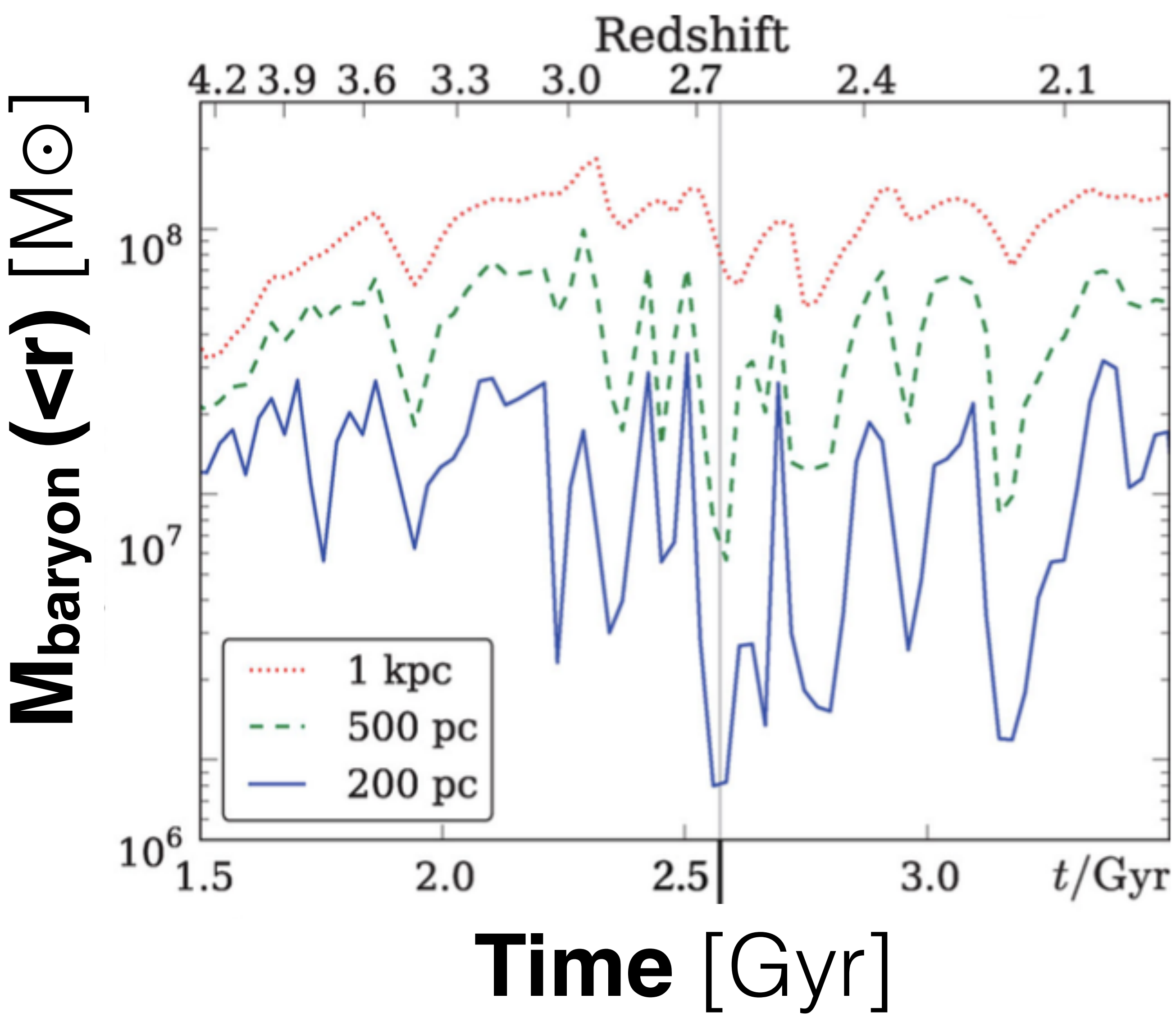
Macciò et al. 2017, arXiv 1707.01106

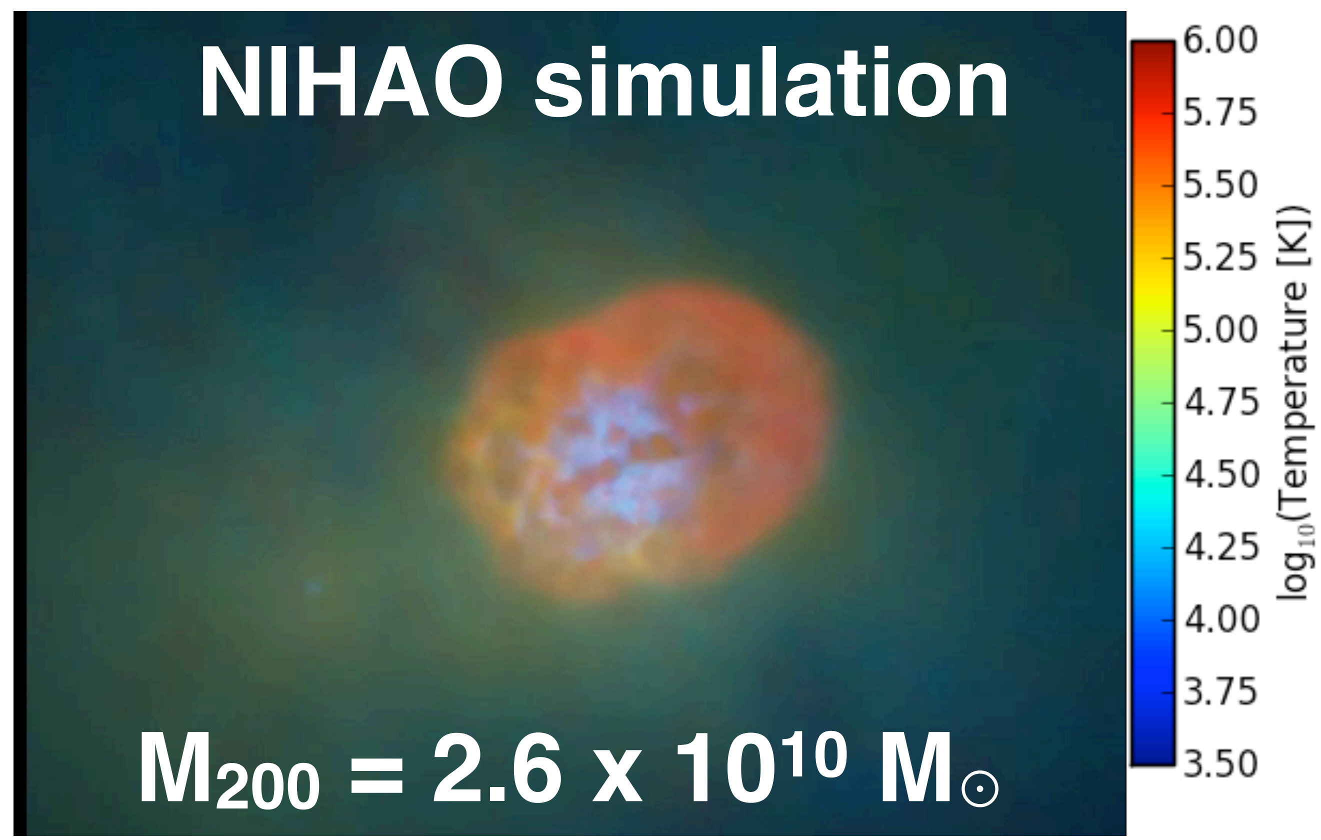
Halo expansion driven by SN feedback

particles moving in a rapidly fluctuating potential gain energy

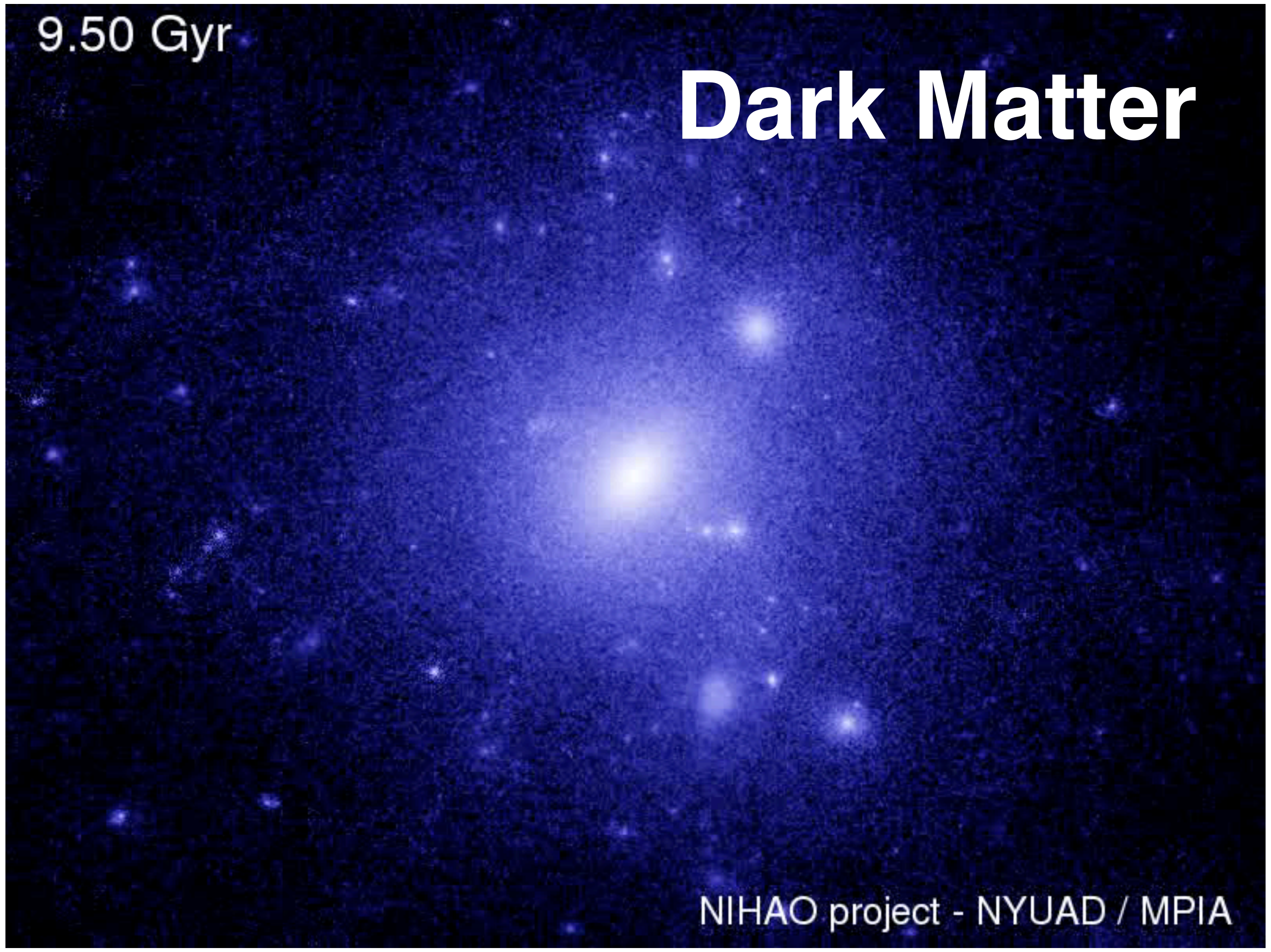
Pontzen & Governato 2012

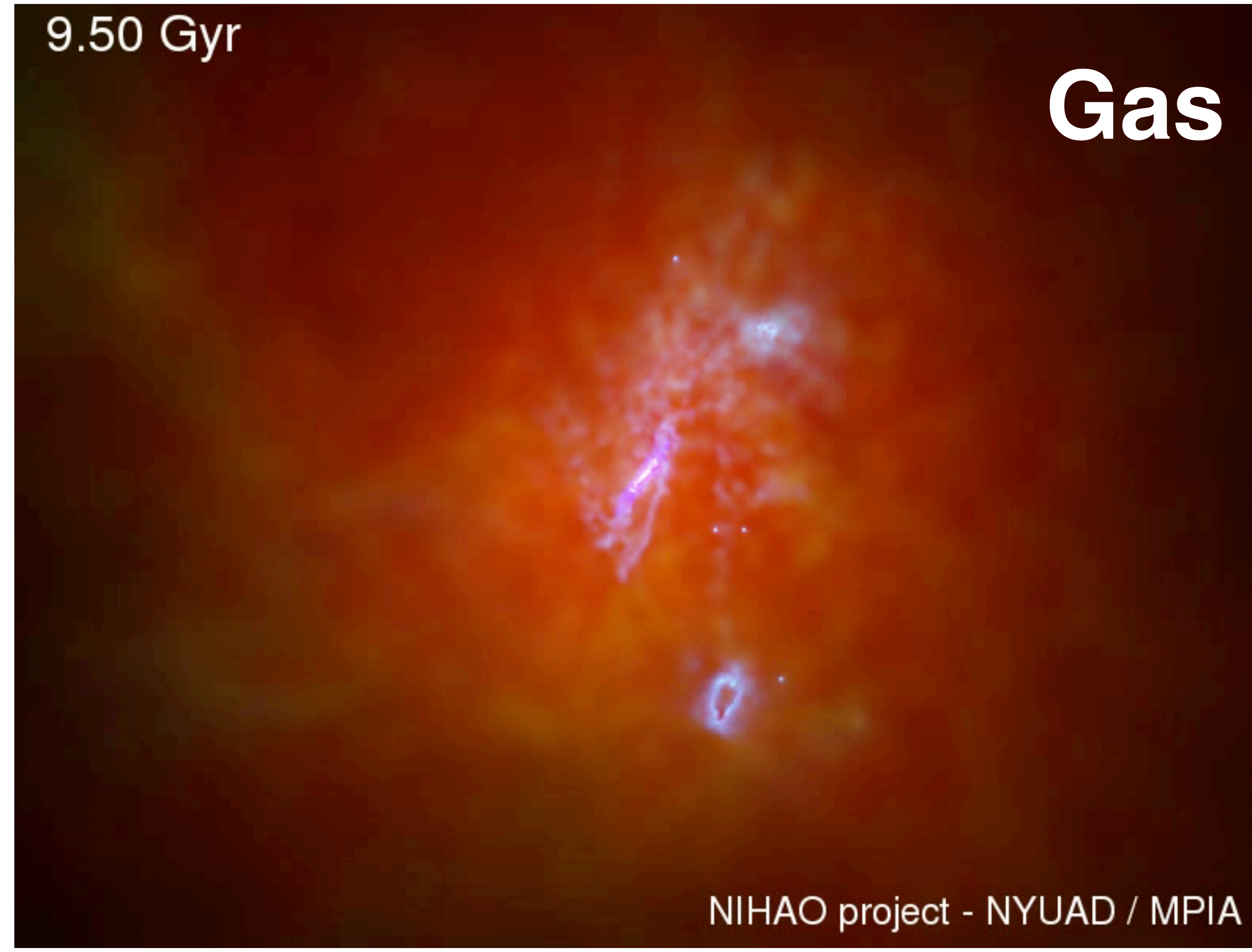
$$r_f/r_i \approx 1 + f^2_{out} + \ldots$$





(see also Navarro, Eke, Frenk 1996; Read & Gilmore 2005; Mashchenko et al. 2008, NIHAO IX)

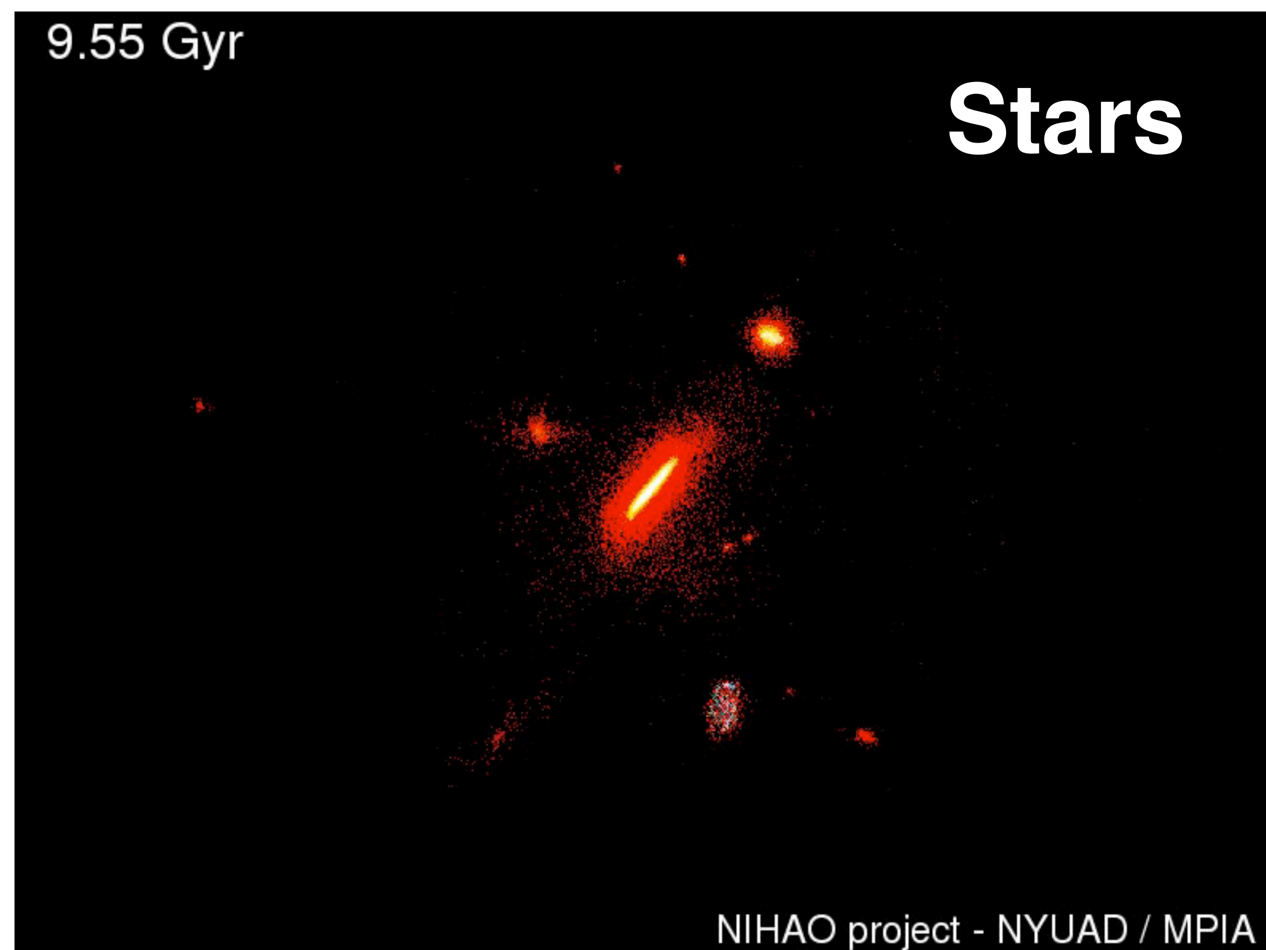




NIHAO 你好
Galaxy Simulations

Wang, Dutton et al. 2015

600x450 kpc/h
comoving



SN driven halo expansion requires high star formation threshold

expansion

MaGICC/NIHAO
n=10 cm^{-3}

Di Cintio et al. 2014
Tollet et al. 2016

FIRE
n=100 cm^{-3}

Chan et al. 2015

no change

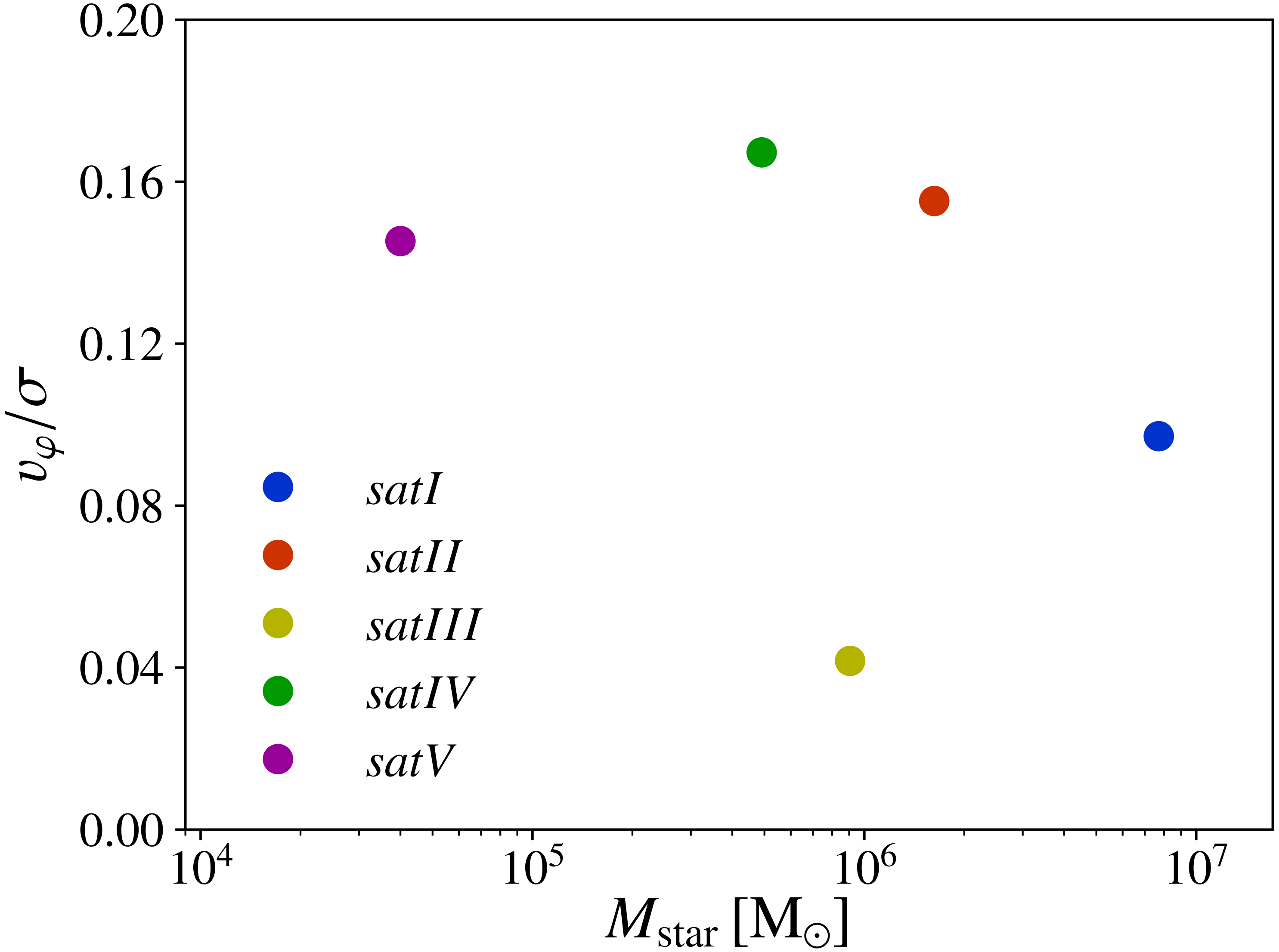
APOSTLE/EAGLE
n~0.1 cm^{-3}

Schaller et al. 2015

Dispersion dominated at infall

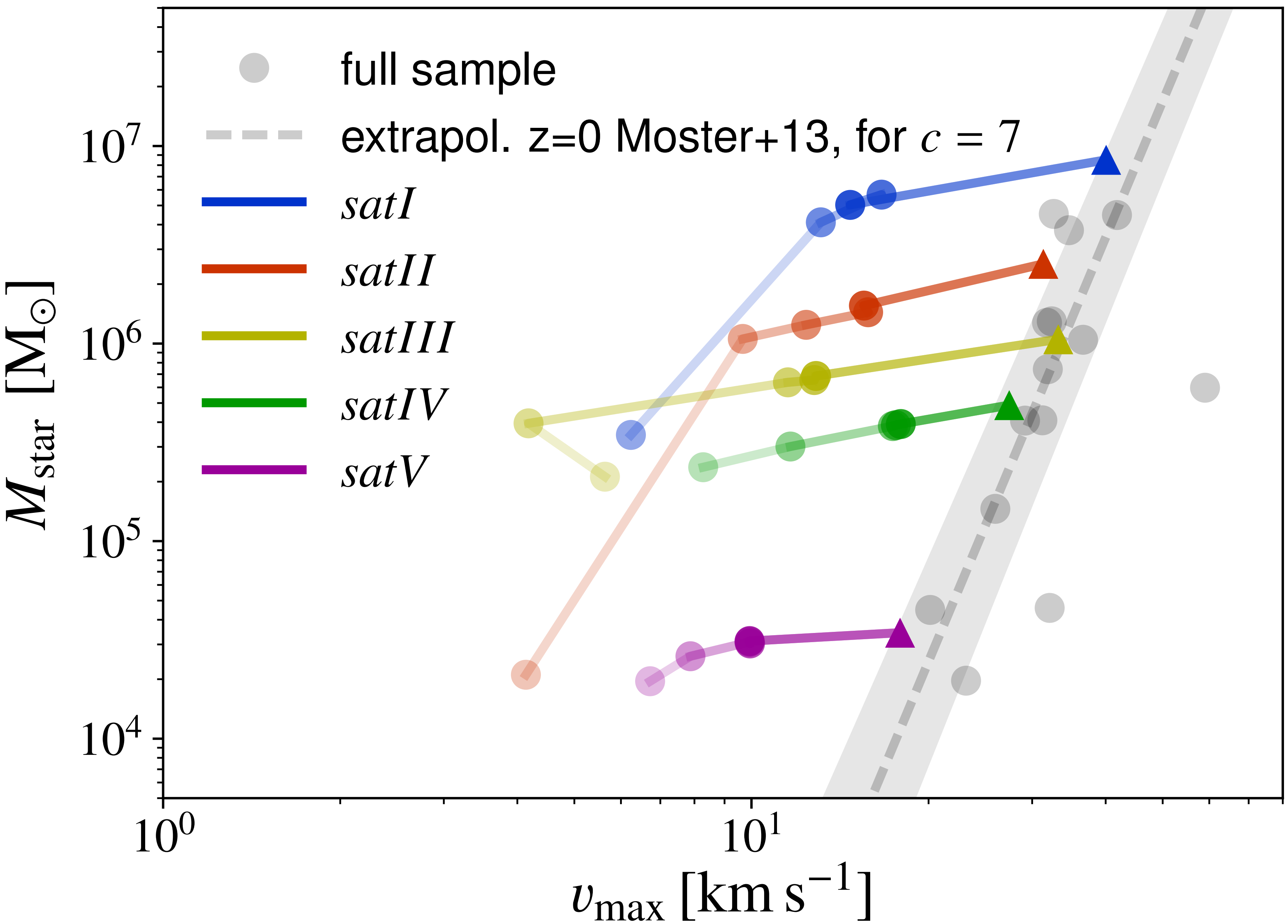
- no need for “morphological transformation”

see Also Wheeler et al. 2017



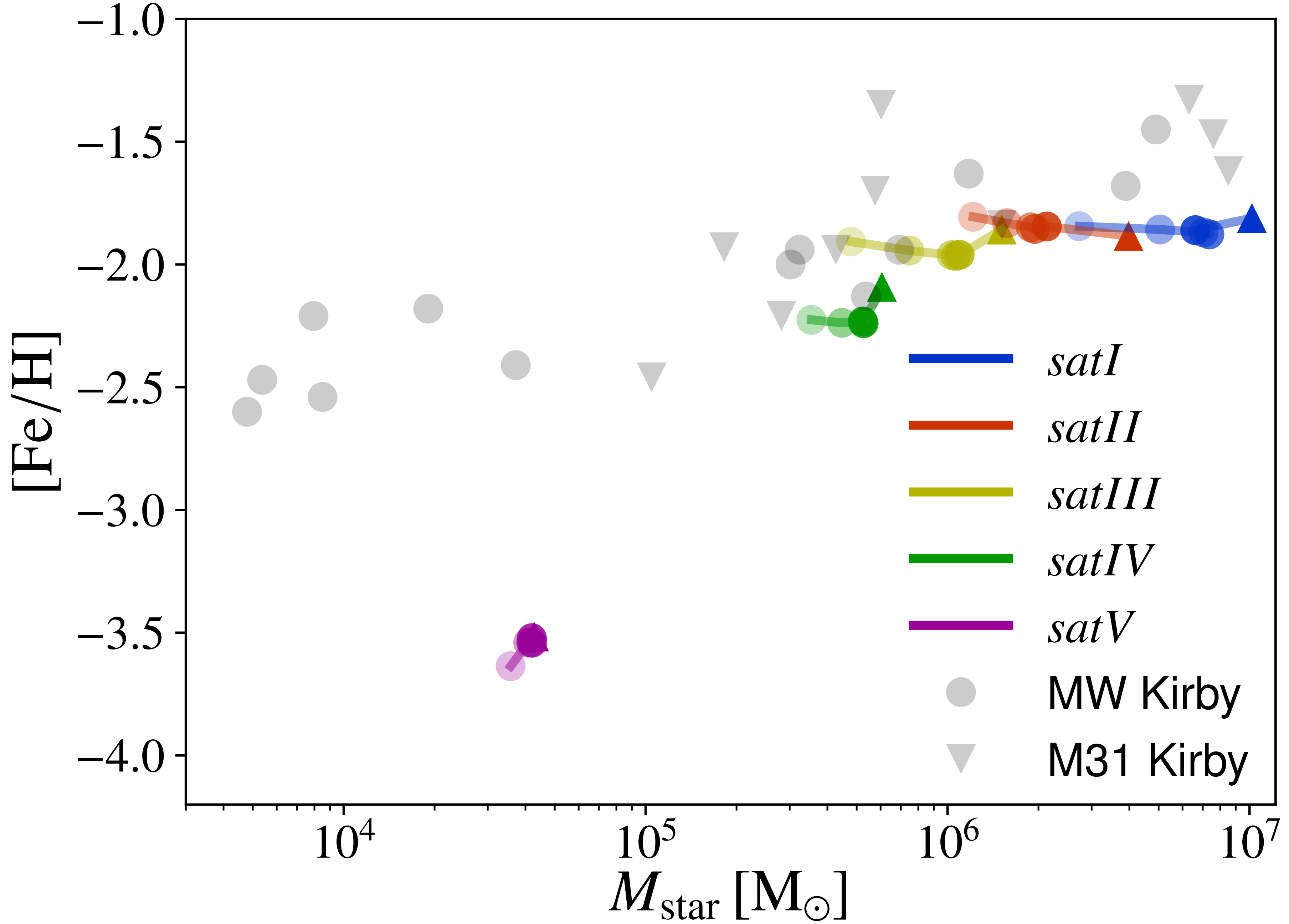
Frings et al. 2017, arXiv 1707.01102

Results After Infall: z=0



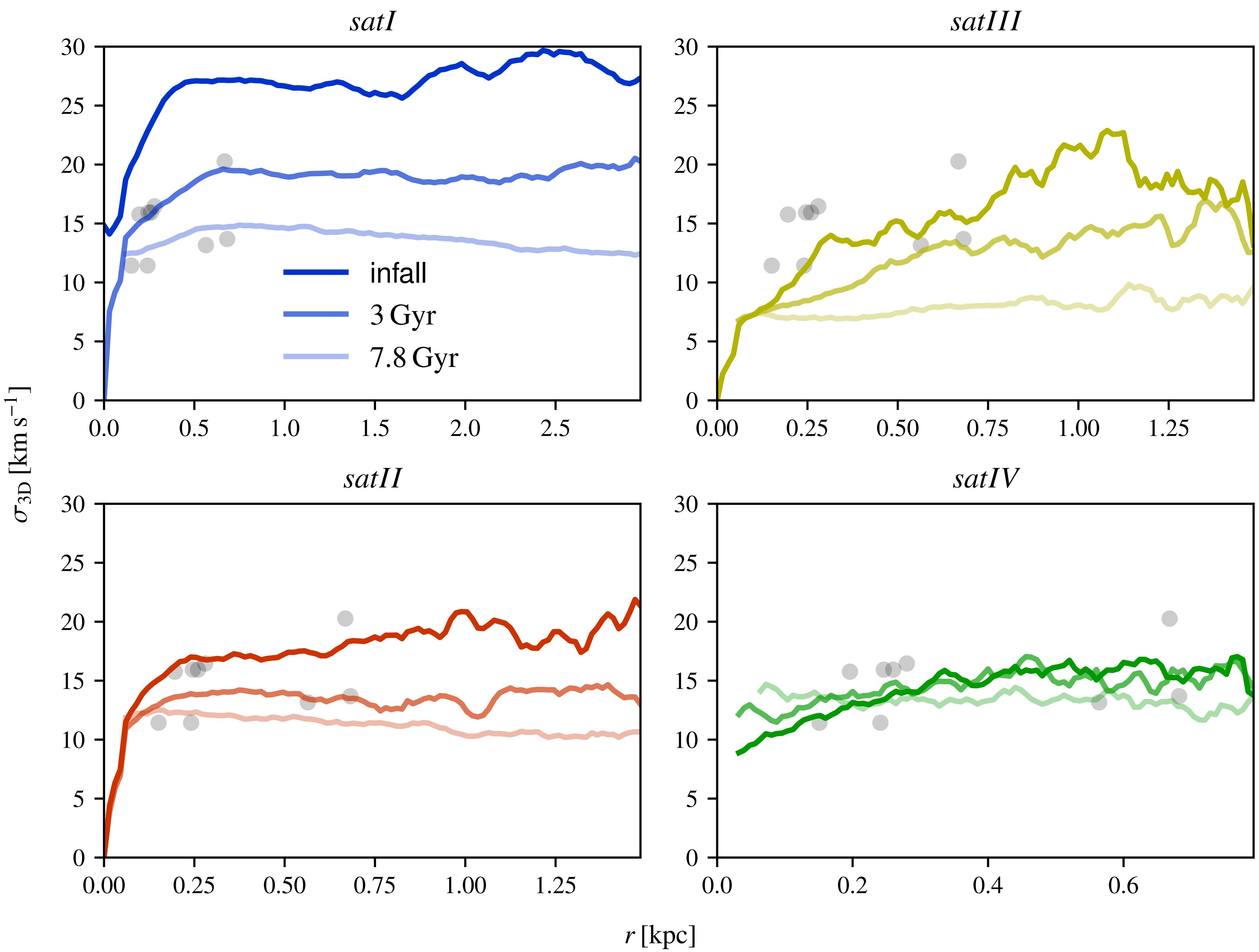
Frings et al. 2017, arXiv 1707.01102

stellar mass loss ~ constant metallicity



Frings et al. 2017, arXiv 1707.01102

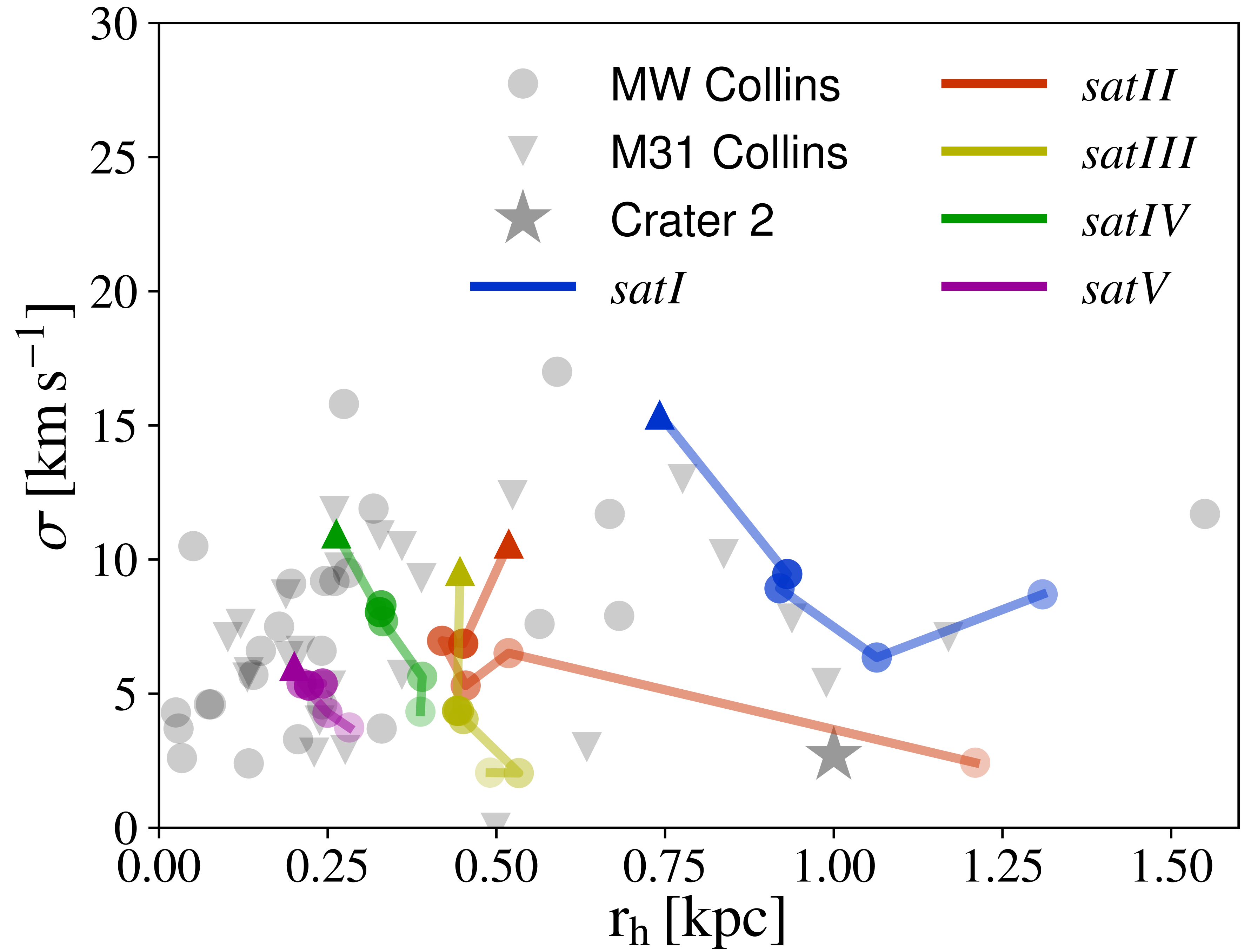
Velocity dispersion profiles:
lower normalization and flatter



Frings et al. 2017, arXiv 1707.01102

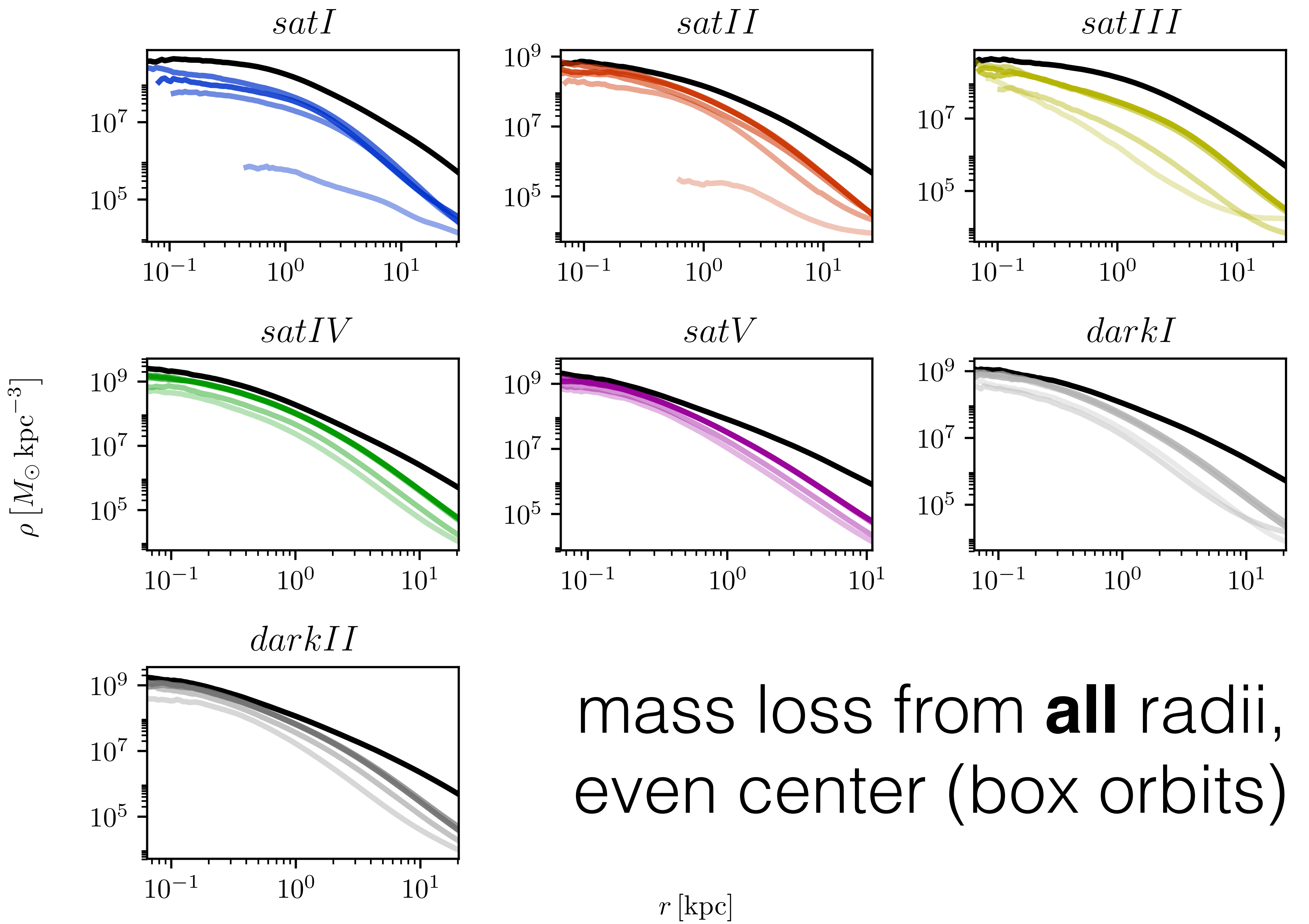
Velocity dispersion drops, sizes increase

different orbits fill out parameter space



Frings et al. 2017, arXiv 1707.01102

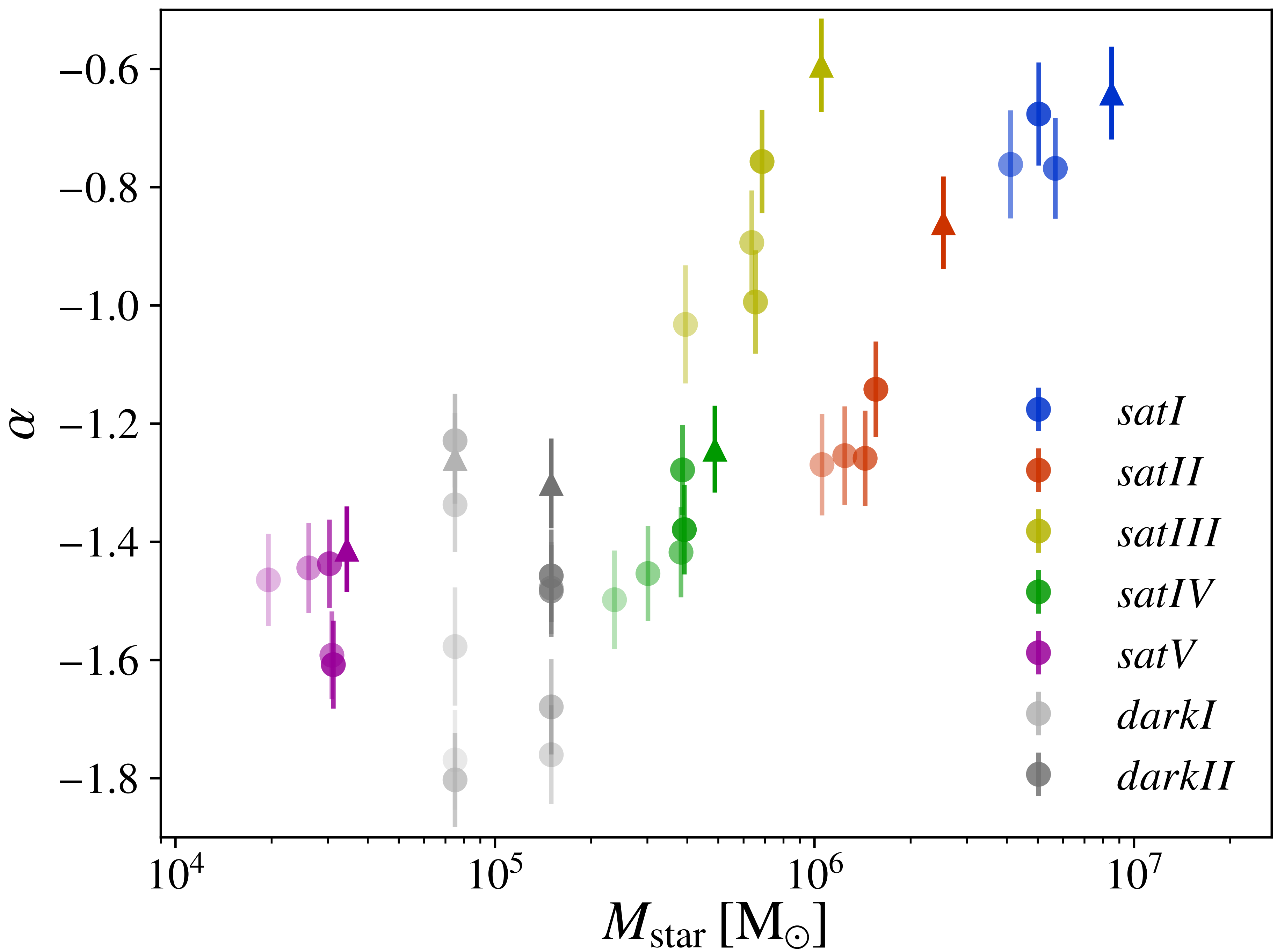
Dark Matter Haloes become cuspier!



mass loss from **all** radii, even center (box orbits)

Frings et al. 2017, arXiv 1707.01102

Dark Matter Haloes become cuspier!



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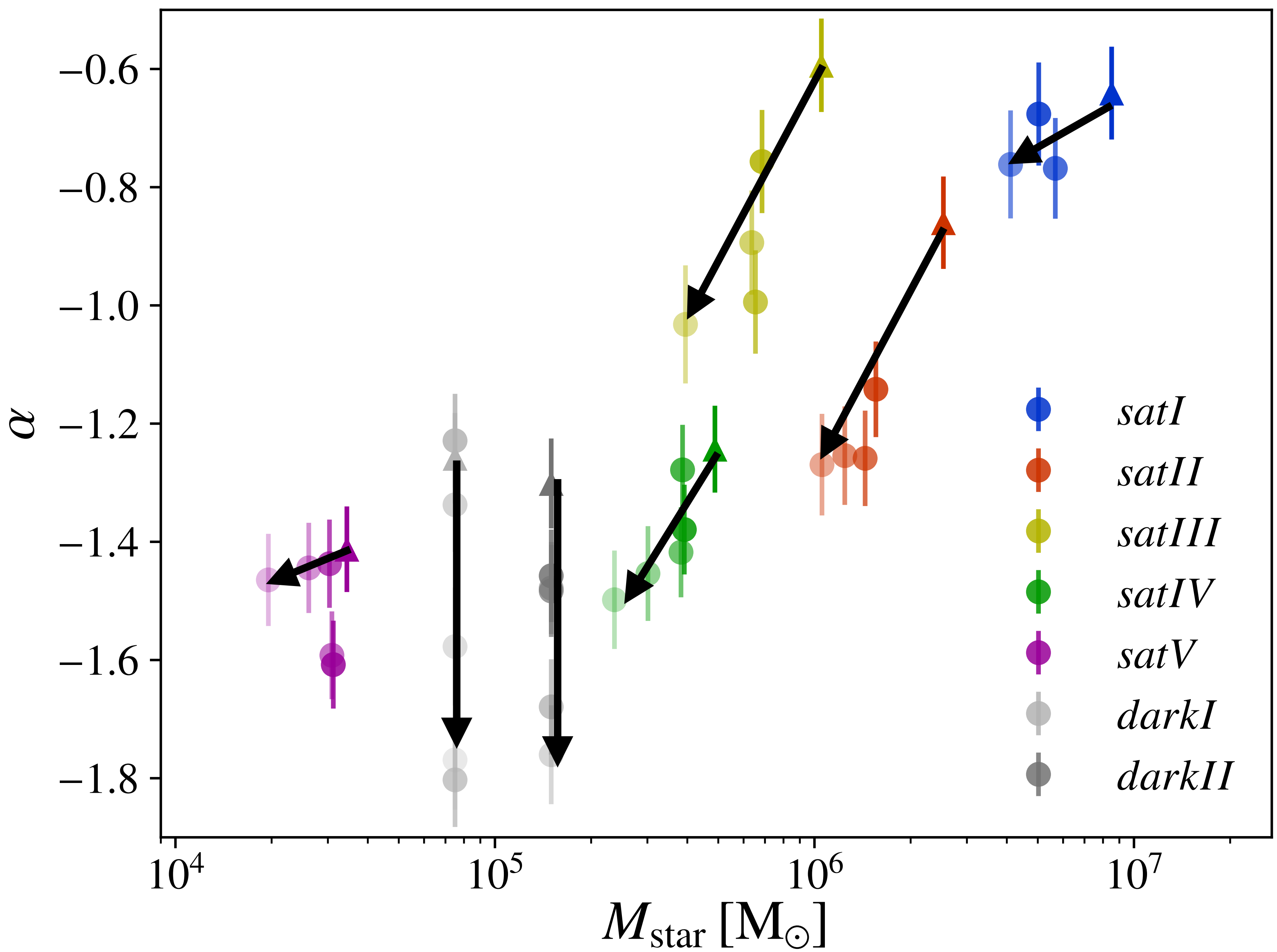

Frings et al. 2017, arXiv 1707.01102

Nature vs Nurture

Before infall: SF and SN feedback (internal process):
- sets stellar mass
- sets metallicity
- sets low v/sigma
- lowers DM density, shallower density profile

After infall: Stripping (external process):
- lowers DM density, steeper density profile
- lowers stellar velocity dispersion
- increases galaxy size

Macciò et al. 2017, arXiv 1707.01106

Frings et al. 2017, arXiv 1707.01102