Pillepich, Nelson, Hernquist, Springel et al. 2018, arXiv:1707.03406

The Stellar Mass (Assembly) of Groups and Clusters with the IllustrisTNG Simulations

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The TNG Team

■ Original Illustris Team + Debora Sijacki et al.

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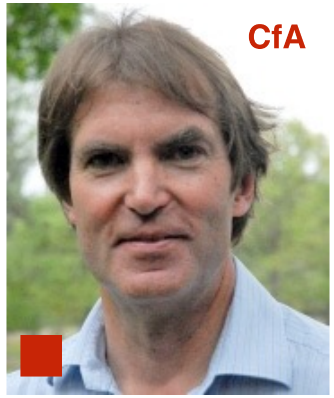

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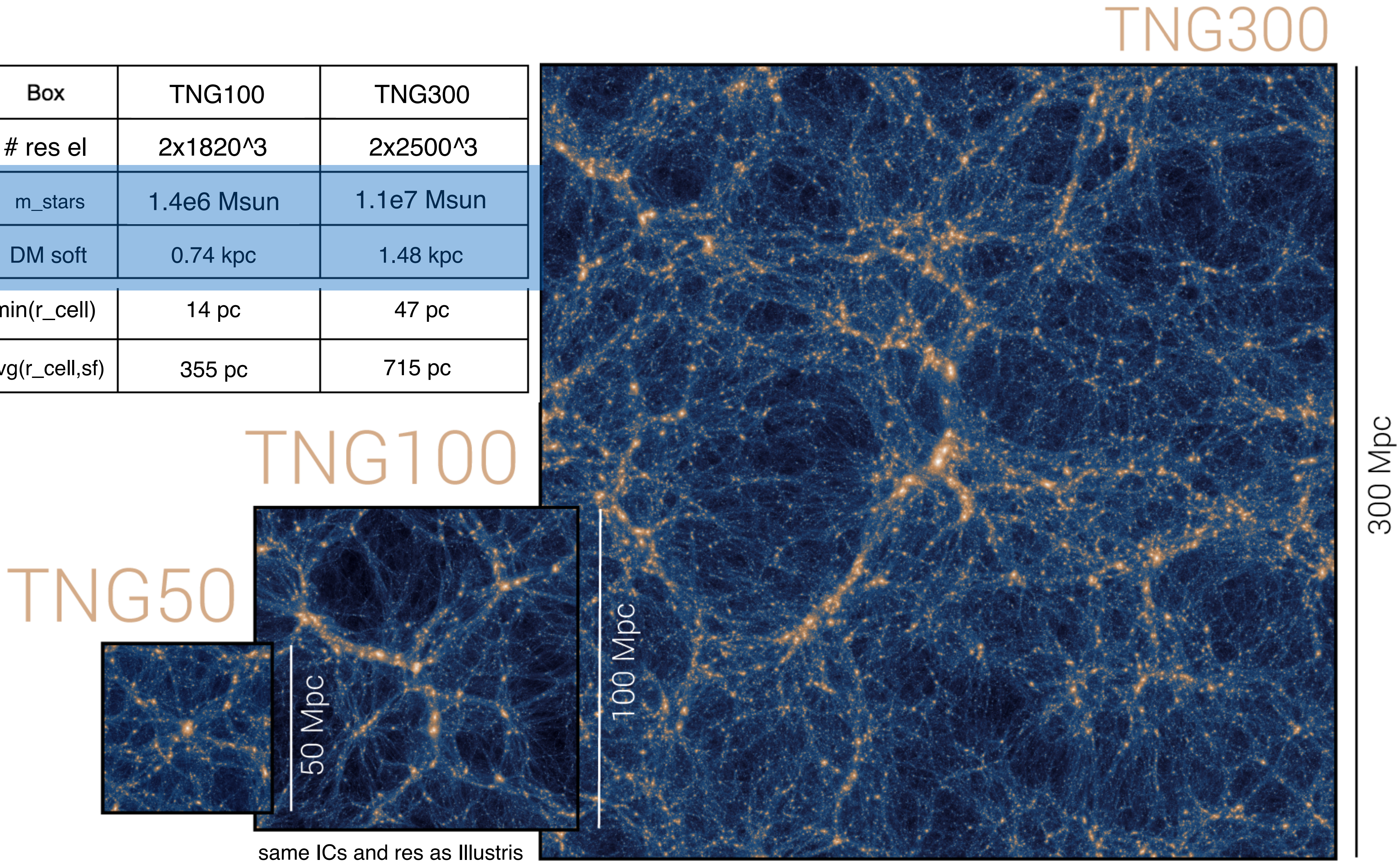
The TNG Suite

Box	TNG100	TNG300
# res el	2x1820^3	2x2500^3
m_stars	1.4e6 Msun	1.1e7 Msun
DM soft	0.74 kpc	1.48 kpc
min(r_cell)	14 pc	47 pc
avg(r_cell,sf)	355 pc	715 pc



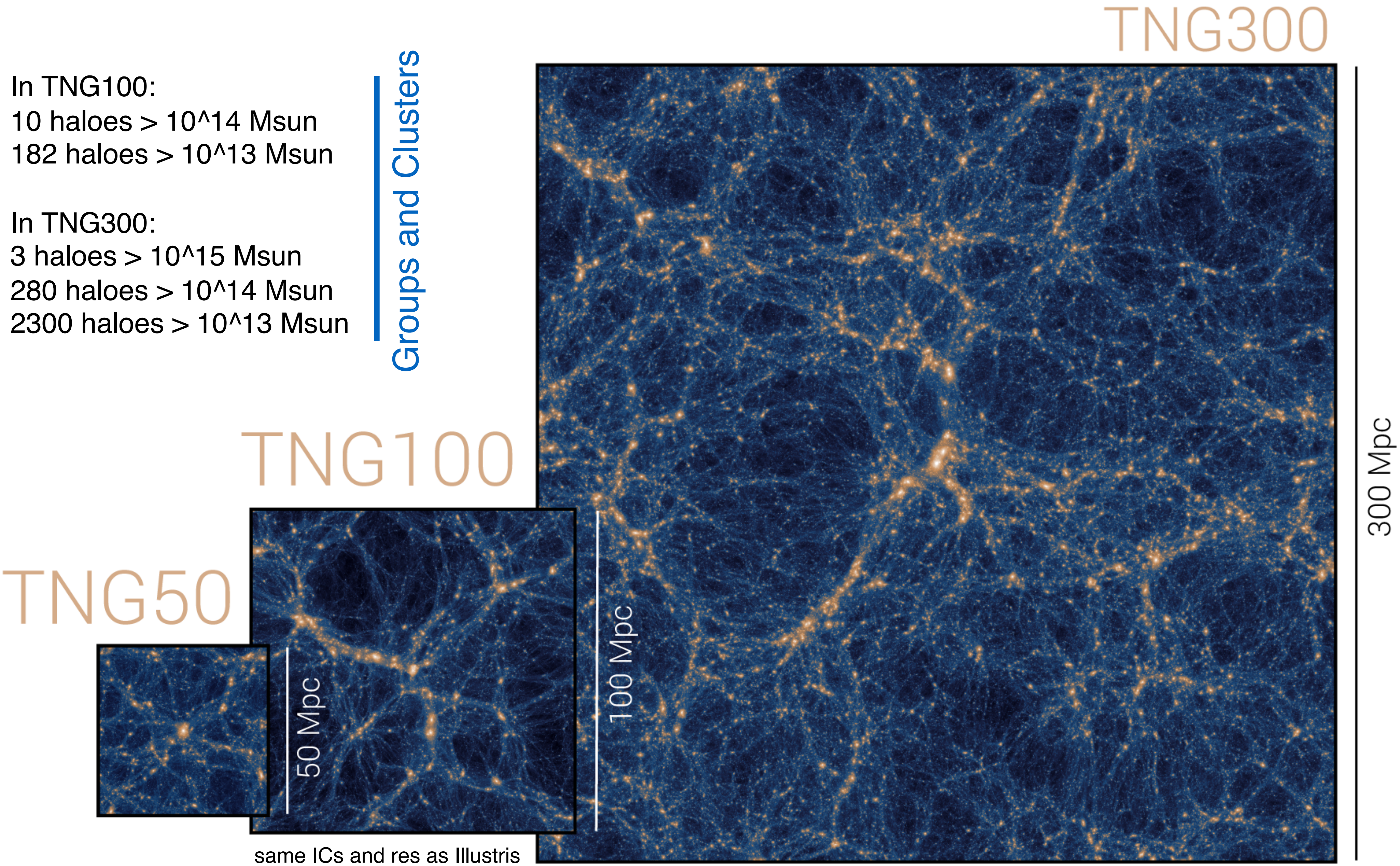
same ICs and res as Illustris

The TNG Suite

In TNG100:
10 haloes > 10^14 Msun
182 haloes > 10^13 Msun

In TNG300:
3 haloes > 10^15 Msun
280 haloes > 10^14 Msun
2300 haloes > 10^13 Msun

Groups and Clusters

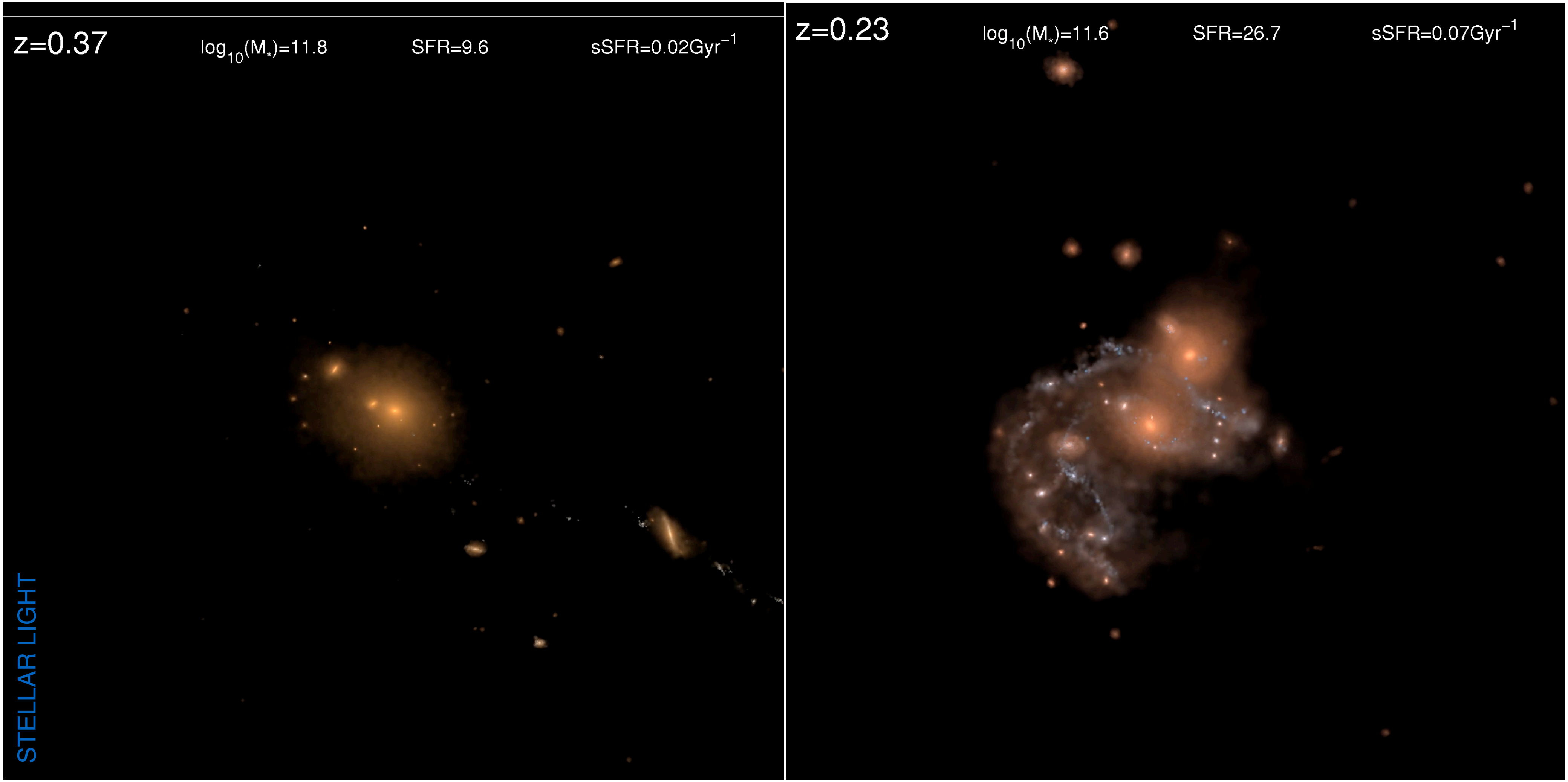


same ICs and res as Illustris

Primer on
Stellar Assembly and Ex-situ Stars

On the Hierarchical Growth of Galaxies

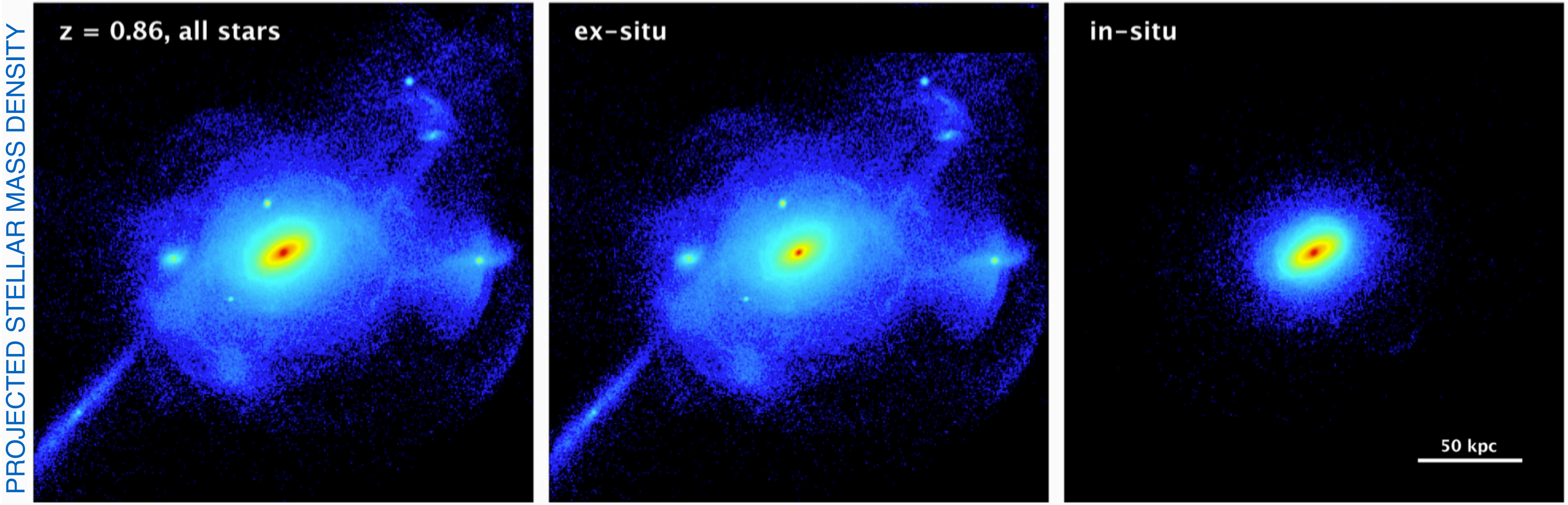
credits: Shy Genel & the TNG Team



THE HIERARCHICAL GROWTH OF GALAXIES, GALAXY MERGERS, COSMIC GAS ACCRETION INTO HALOES, TIDAL AND RAM PRESSURE STRIPPING, DYNAMICAL FRICTION etc ARE ALL “EMERGING” PROCESSES IN SIMULATIONS LIKE ILLUSTRIS/TNG

On the two channels to assemble stellar mass

credits: A. Pillepich
Evolution of Eris, a MW-like galaxy, in stellar density projection

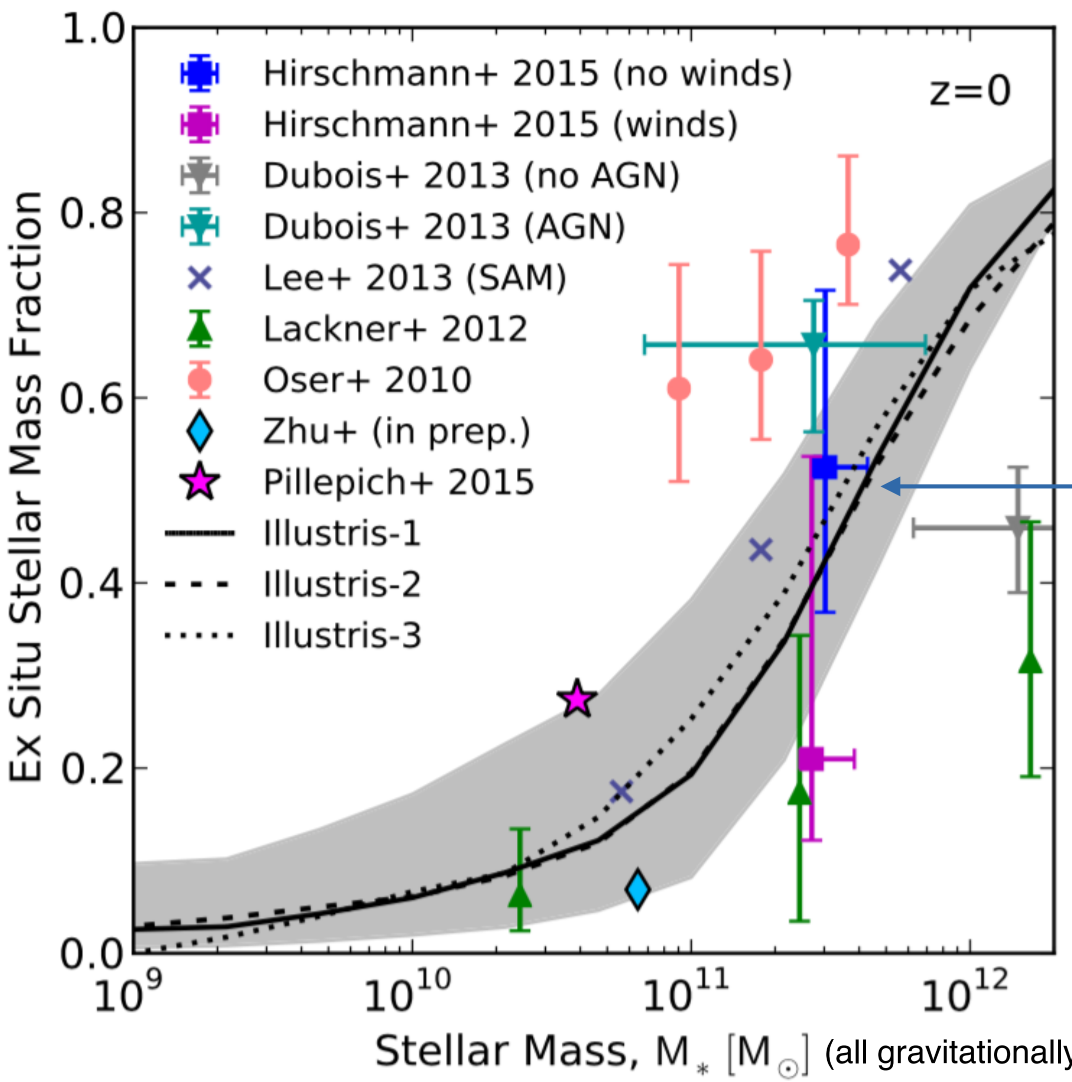


Simulations have clearly demonstrated that there are two channels to build up the galaxy stellar component:

- STARS FORMED WITHIN THE MAIN HOST ⟶ **in-situ stars!**
- STARS STRIPPED and ACCRETED FROM SATELLITE GALAXIES ⟶ **ex-situ stars!**

ERIS: Pillepich, Madau & Mayer 2015

On the two channels to assemble stellar mass



(all gravitationally bound stars)

More massive galaxies have assembled more than half of their stars by accreting satellites and merging rather than making star formation

Large galaxy-to-galaxy variation, but not random:

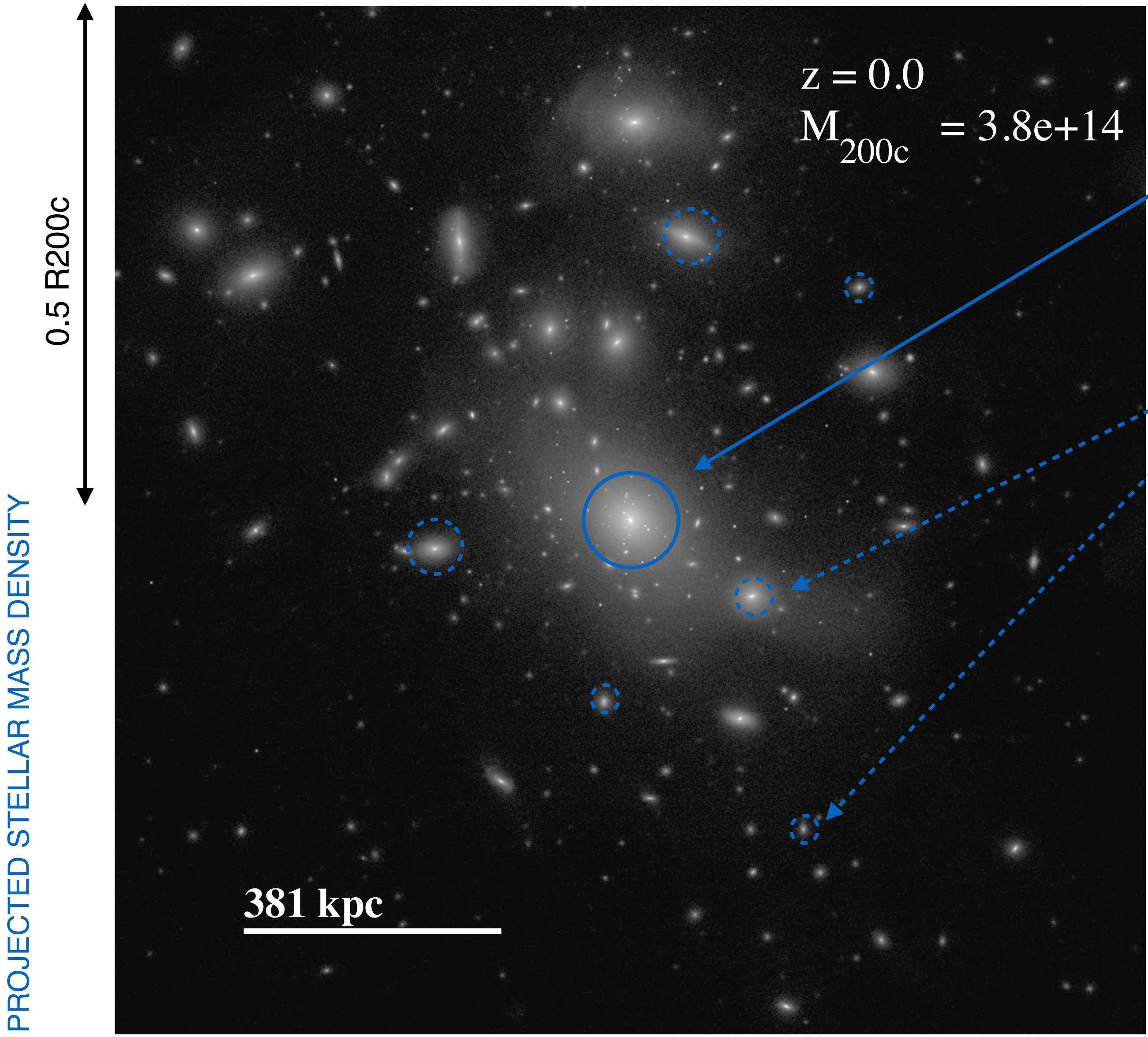
At a fixed stellar mass, **elliptical** galaxies and those formed at the centres of **younger haloes** exhibit **larger fractions** of *ex situ* stars than disc-like galaxies and those formed in older haloes.

CAREFUL: THE DEFINITION OF IN-SITU/EX-SITU MATTERS!

ILLUSTRIS: Rodriguez-Gomez, Pillepich, Genel et al. 2016

Massive Galaxies and Groups and Clusters with TNG (at z=0)

The setup and definitions



central galaxy/BCG

= galaxy at the minimum of the potential well

satellite galaxies

= all galaxies within e.g. R200c (3D)

stellar haloes/ICL

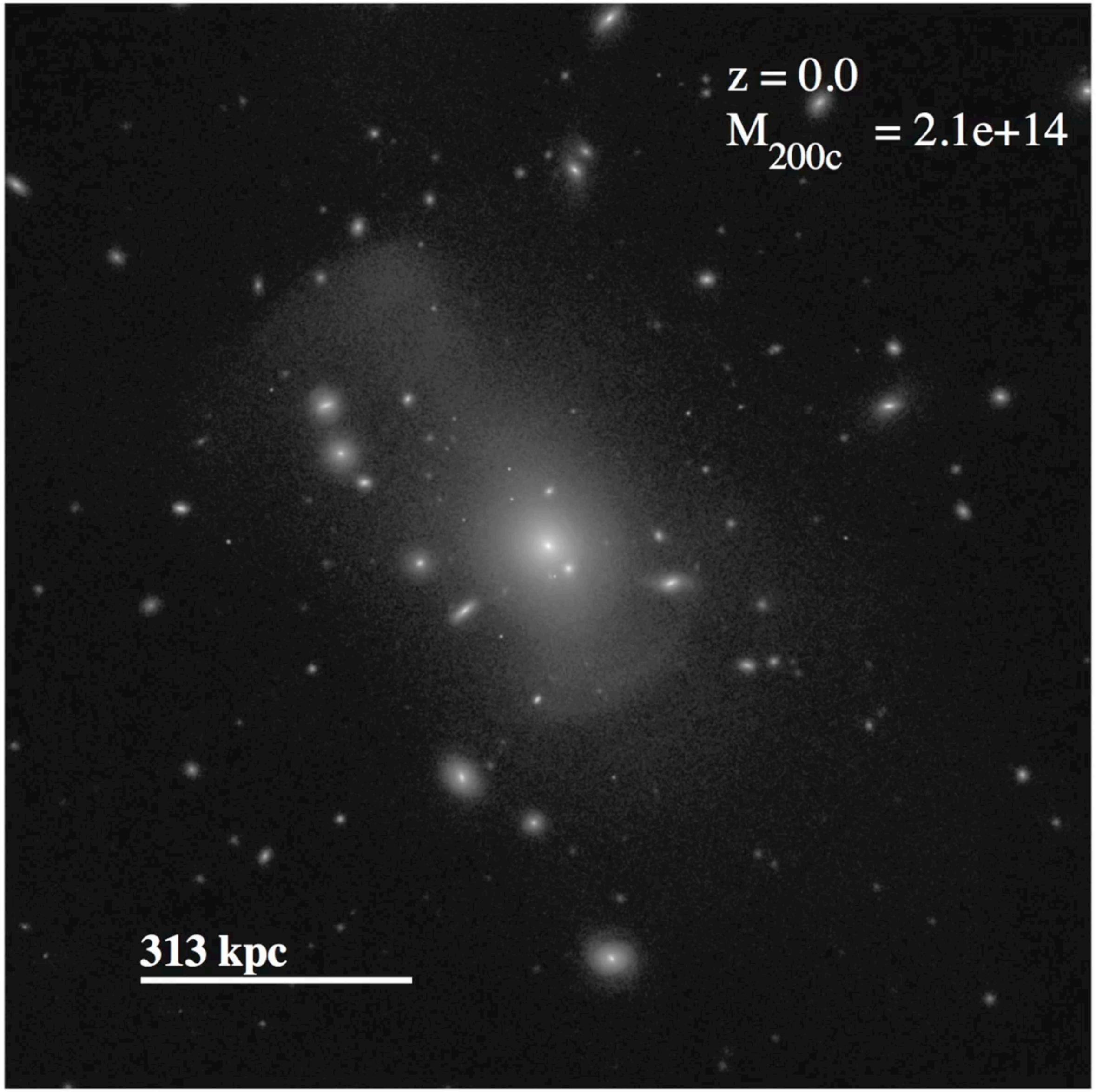
= all stellar mass beyond a given 3D radius from the centre — excising satellites

!!! In this talk, all stellar masses are in 3D fixed apertures

With TNG100+TNG300, we have three thousands haloes >10^13 Msun

PROJECTED STELLAR MASS DENSITY

0.5 R200c



… with their

central galaxy,

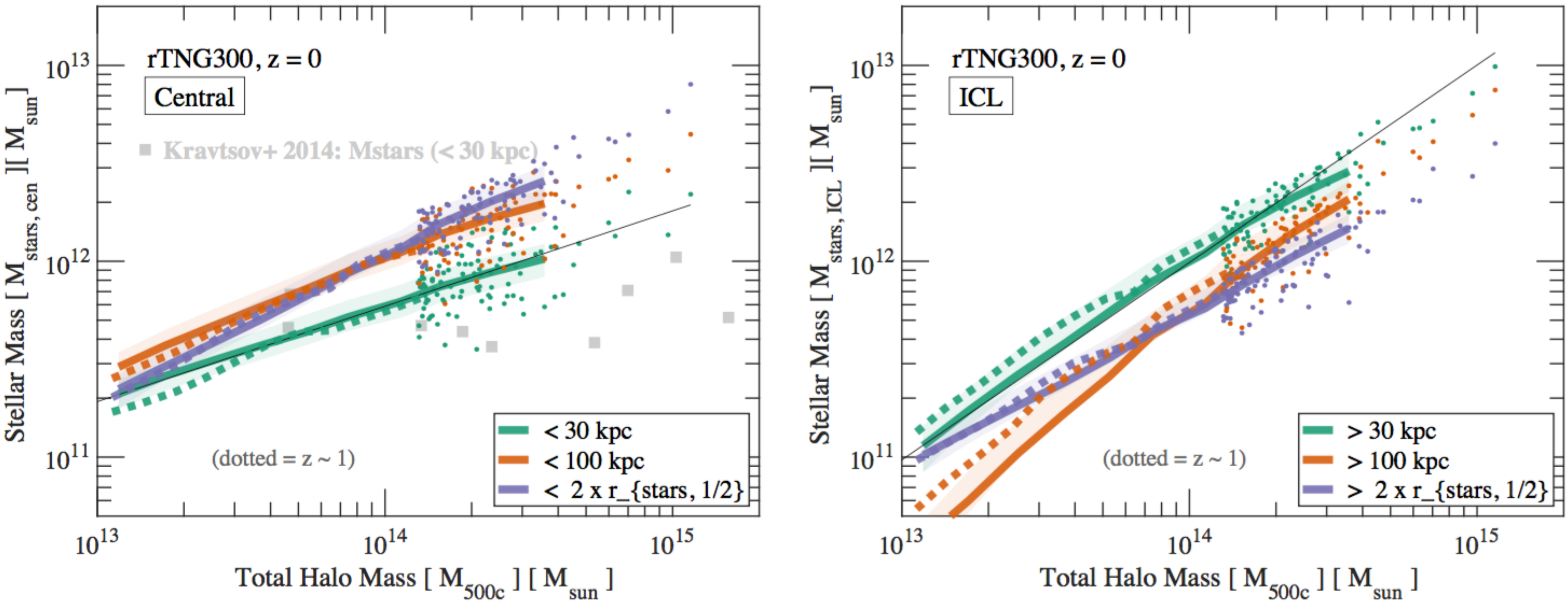
satellite systems,

diffuse stellar light,

low-surface brightness features

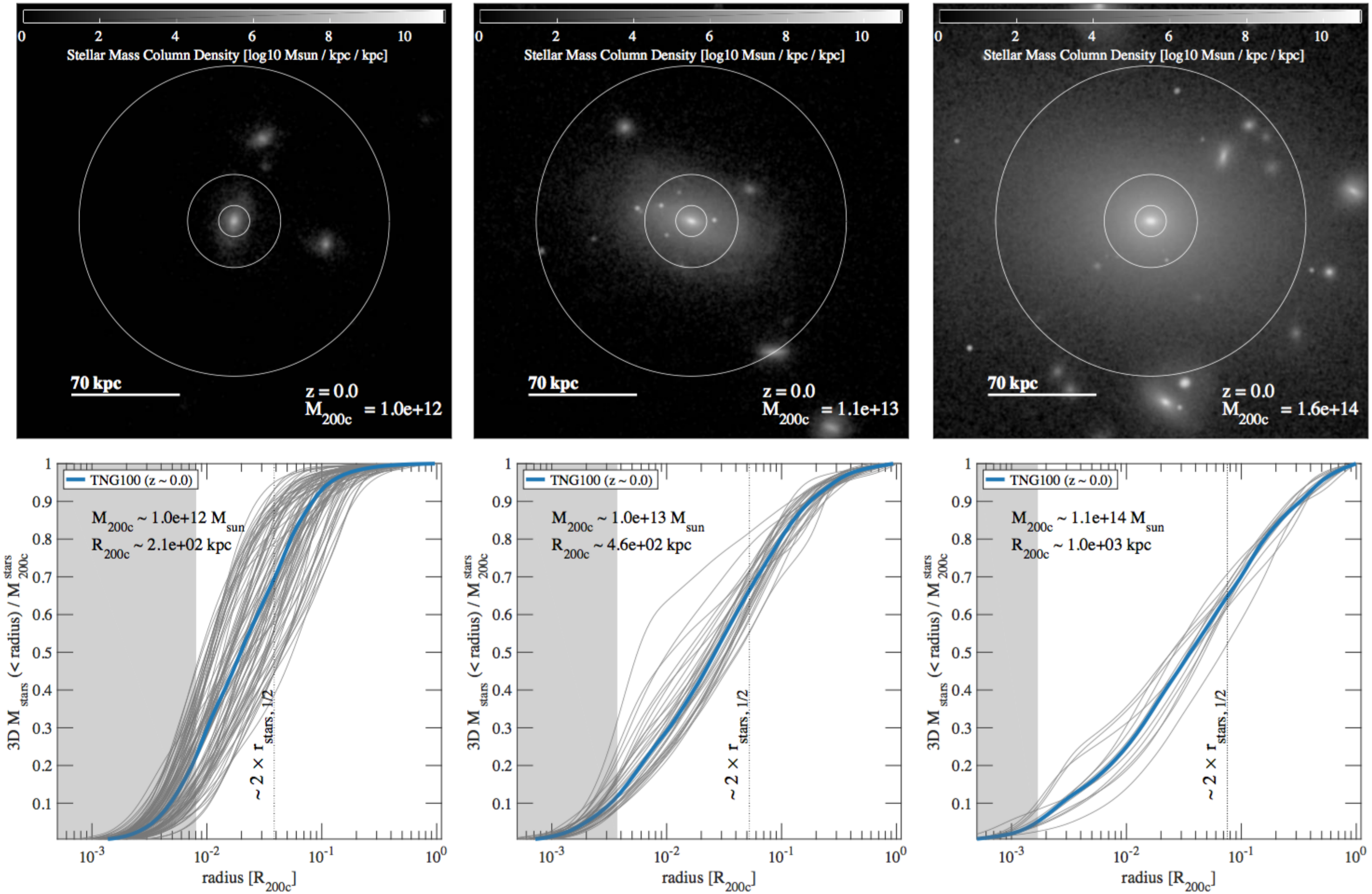
like shells and streams,…

Results #1: Halo mass predicts stellar mass (not a novelty)

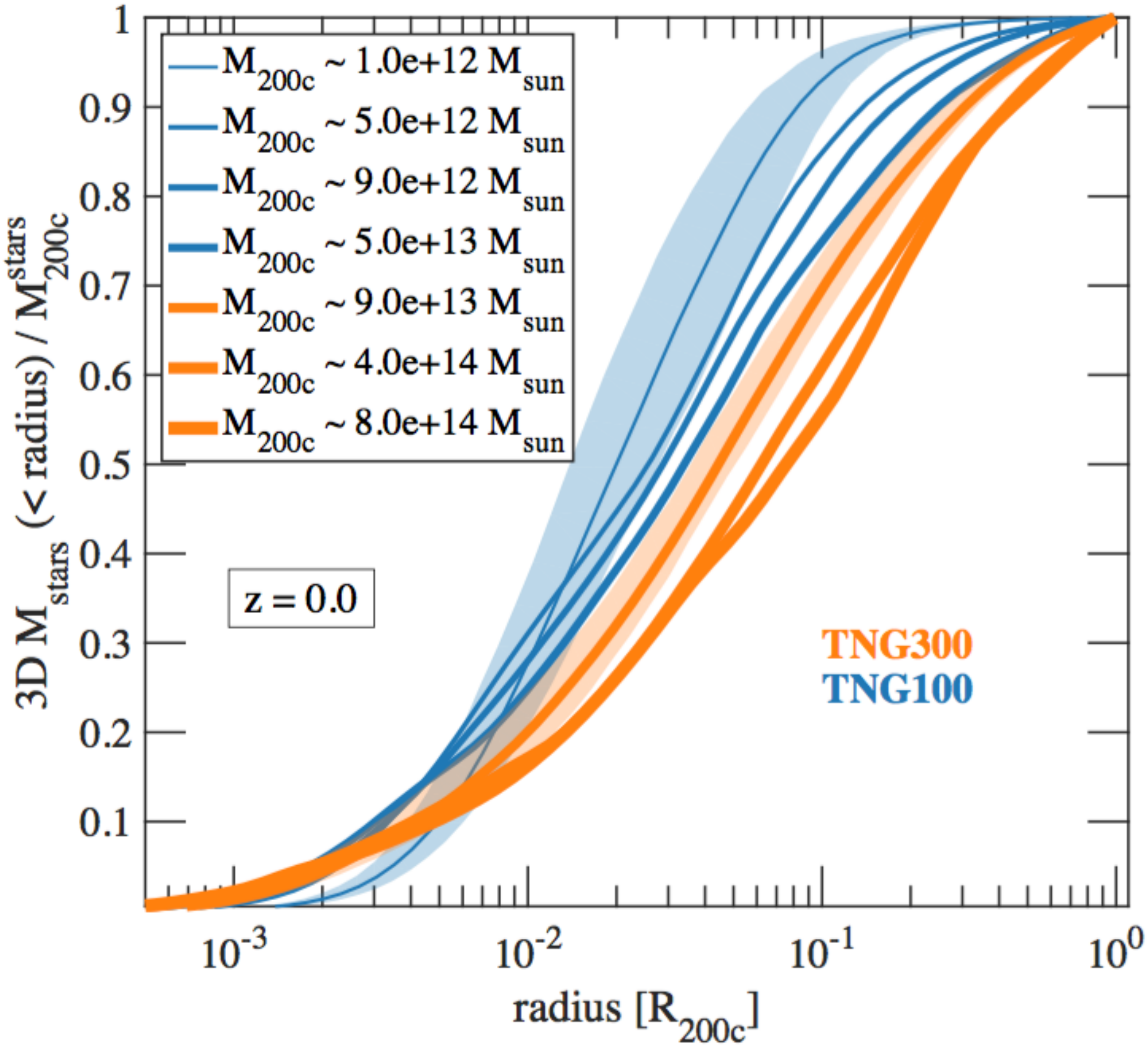


For galaxies in haloes > 10^13 Msun,
1. M_stars = f(MHalo) at better than 0.1-0.2 dex uncertainty
2. The slope of the relation depends on the aperture for the stellar mass definition
3. The mass in the ICL is a steeper function with halo mass than the mass in the central
4. The relations do not vary much between z=1 and z=0

Results #2: The stellar mass profiles are shallower at larger masses



Results #3: Halo mass predicts … the whole stellar mass profiles (*)



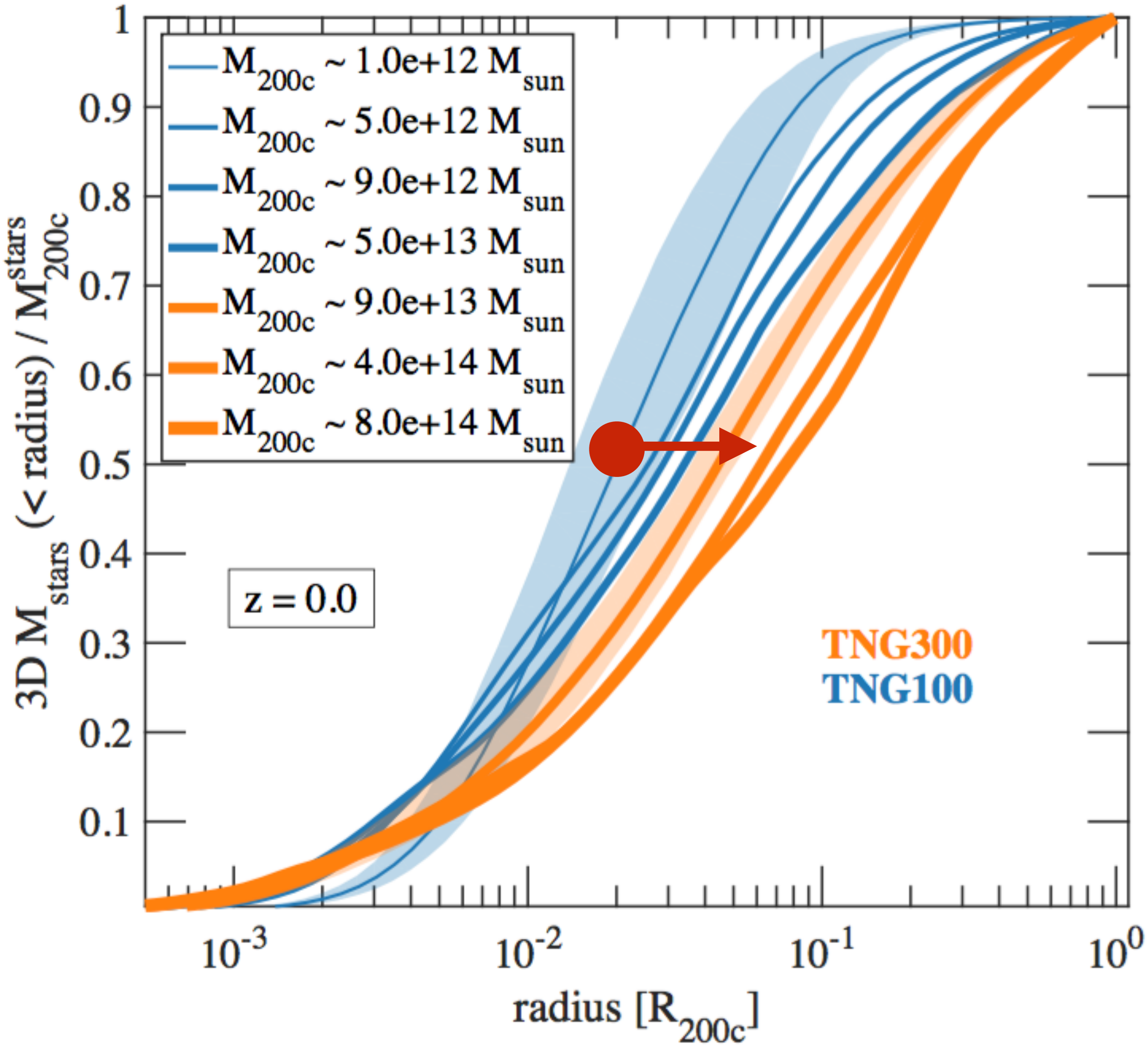
For galaxies in haloes > a few 10^12 Msun & beyond a few kpc from the centers:

1. The "normalized" stellar mass profiles are sigmoids (**)

(*) = of the diffuse component, centrals +ICL (excising satellites)

(**) for the stacks and the average profiles

Results #3: Halo mass predicts … the whole stellar mass profiles

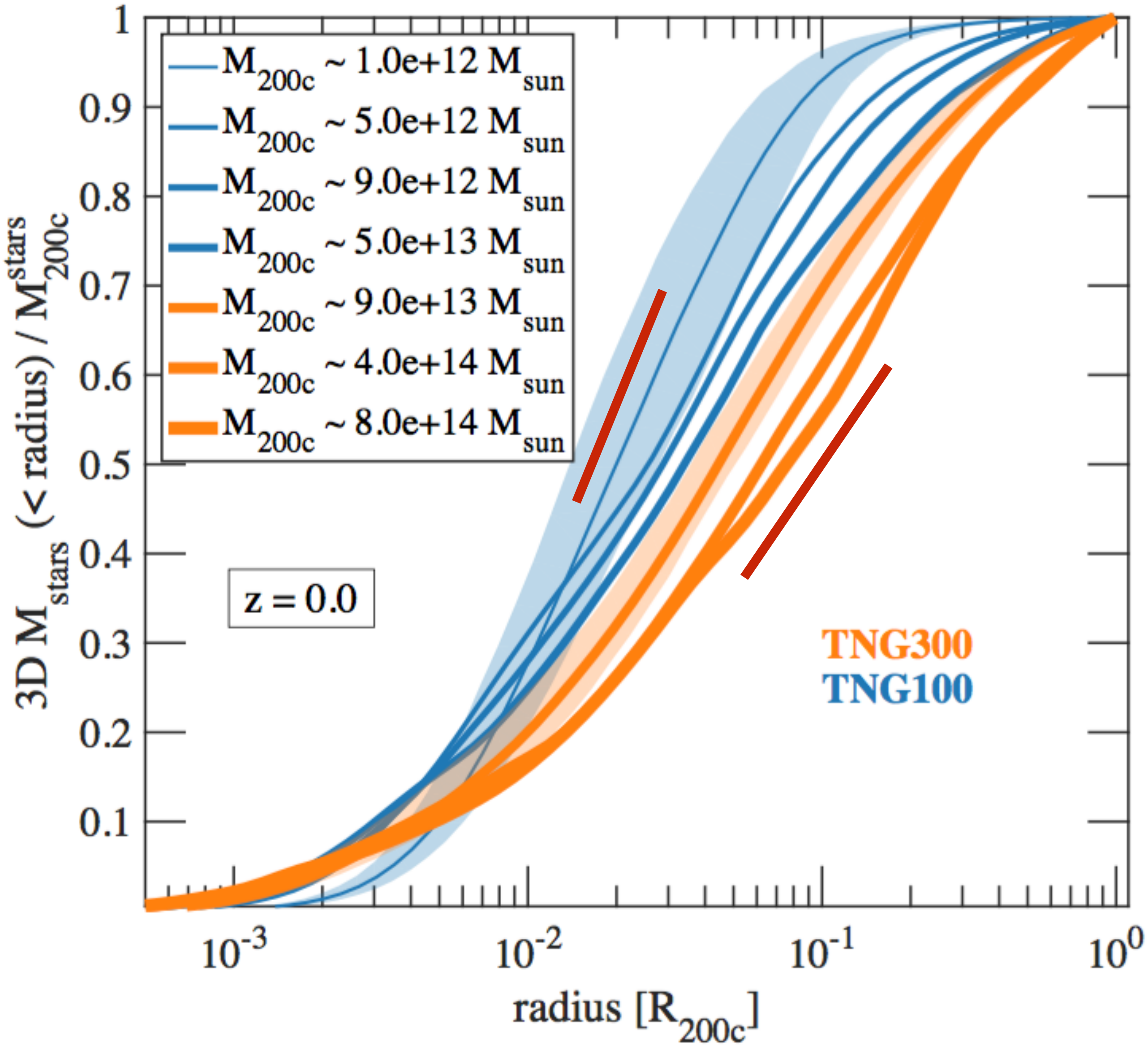


For galaxies in haloes > a few 10^12 Msun & beyond a few kpc from the centers:

1. The "normalized" stellar mass profiles are sigmoids

2. The mid points move to larger distances for larger halo masses

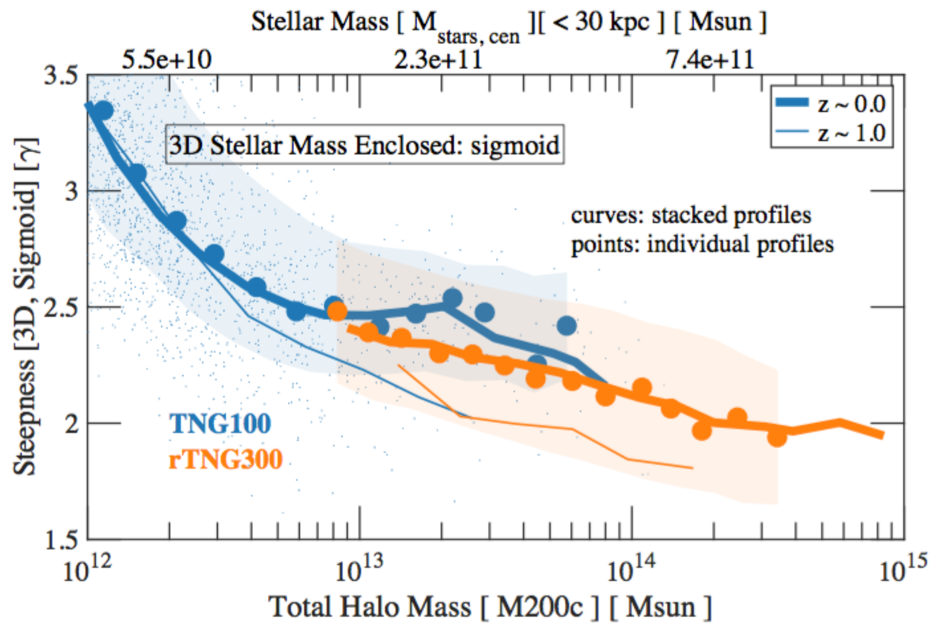
Results #3: Halo mass predicts … the whole stellar mass profiles

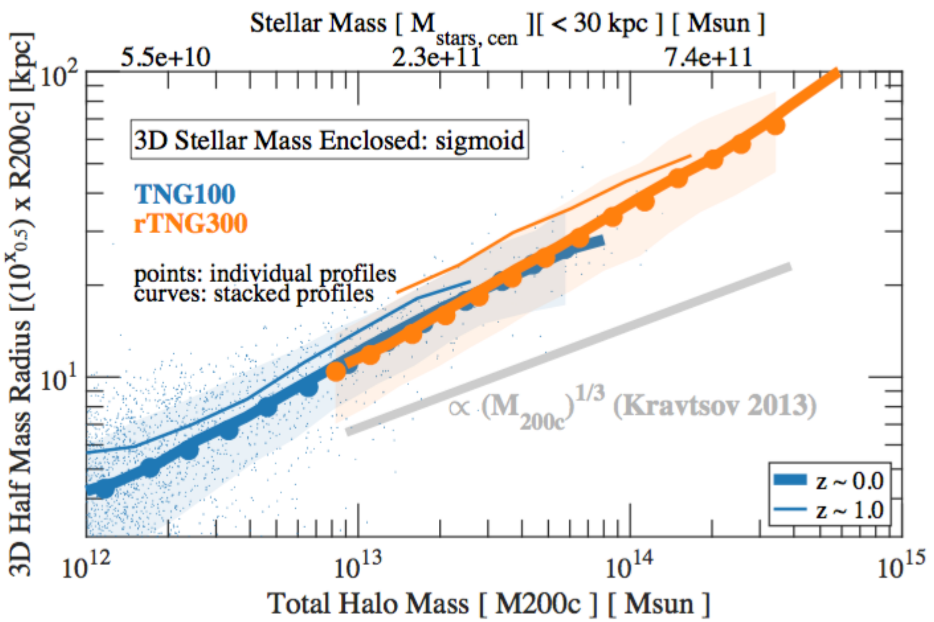


For galaxies in haloes > a few 10^12 Msun & beyond a few kpc from the centers:

1. The "normalized" stellar mass profiles are sigmoids
2. The mid points move to larger distances for larger halo masses
3. The curves get shallower for larger halo masses

Results #3: Halo mass predicts … the whole stellar mass profiles

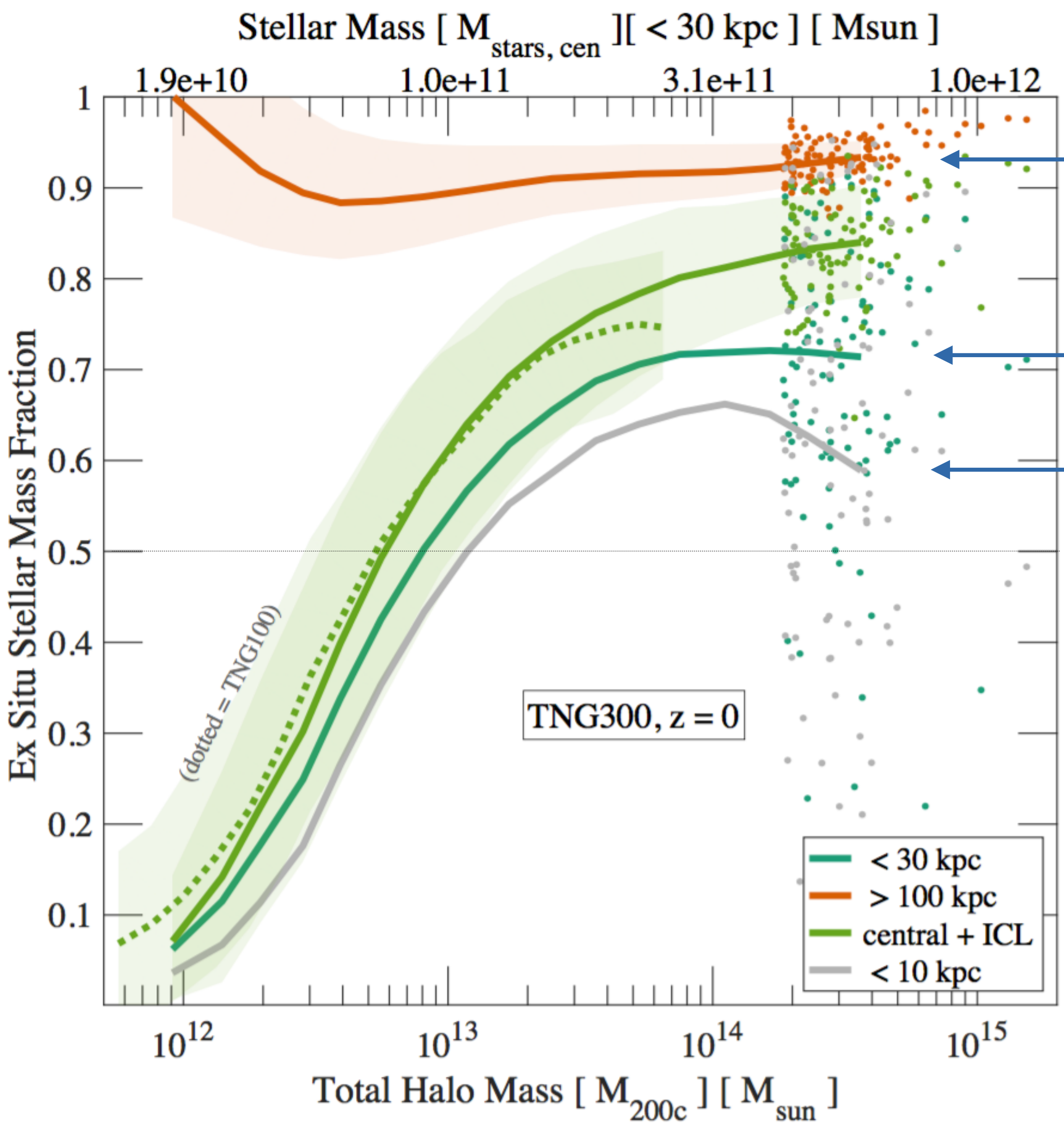




For galaxies in haloes > 10^13 Msun, the stellar mass profile parameters are a power-law function of halo mass, with small scatters

Given a halo mass, you can reconstruct the **whole 3D diffuse stellar mass distribution** around massive central galaxies, from a few kpc to the viral radius!!!

Results #4: the BCGs are mostly ex-situ!

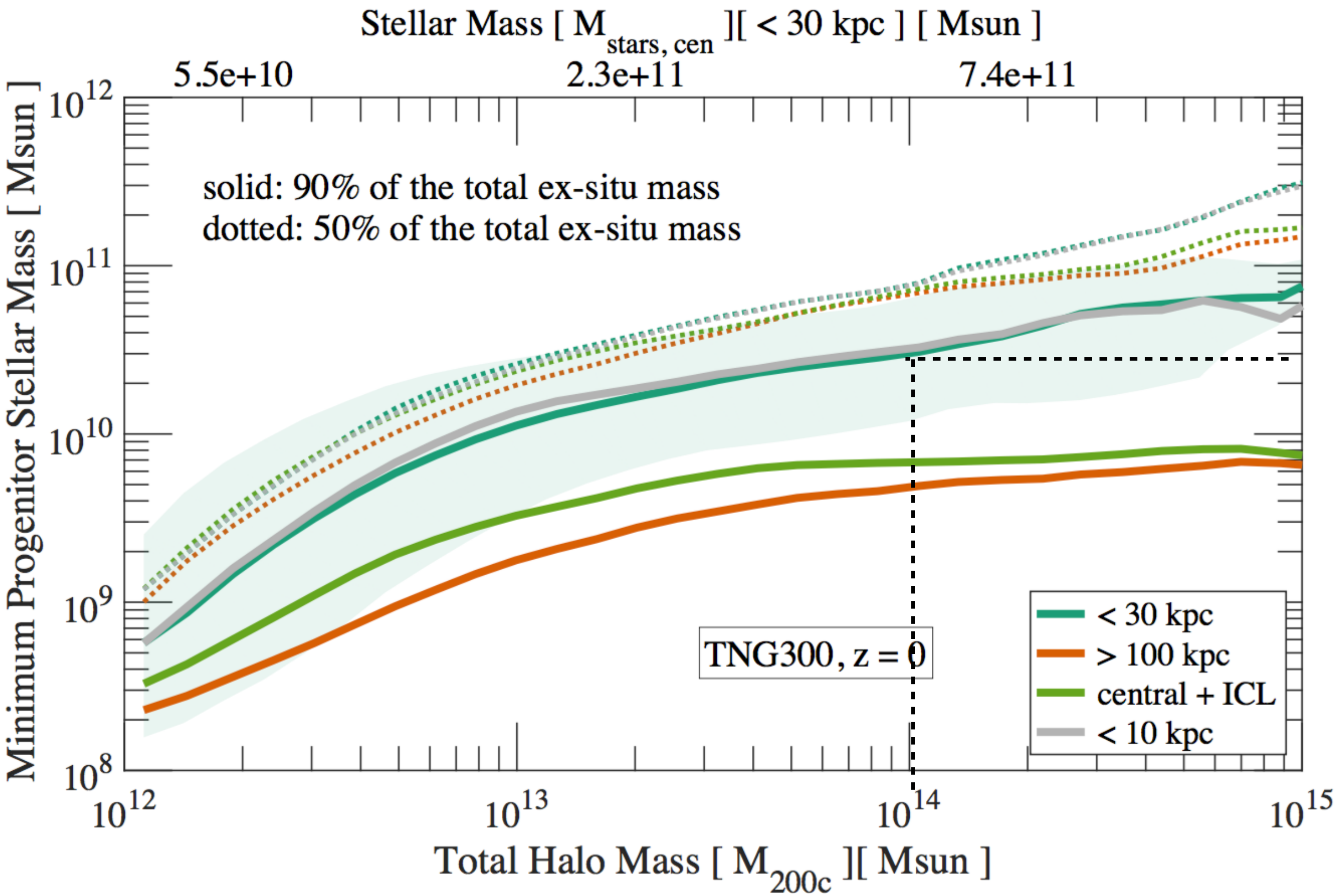


At larger galactocentric distances, all stellar mass is accreted at all masses (aka stellar haloes/ICL)

Also within 30 kpc (and even within only 10 kpc!) from the center, galaxies > 10^11 Msun have assembled **more than half of their stars by accreting satellites and merging** rather than making stars themselves

Results #4: the BCGs are mostly ex-situ!

What galaxies/mergers have brought in such amount of stellar mass?



90% of the stellar mass (< 30 kpc) in galaxies that sit in haloes > 10^14 Msun has been brought in by galaxies at least as massive as a few 10^10 Msun!

#1: Implications on e.g. the AGN feedback

At the very high mass end, ~70-80% of the stars are accreted and of those 90% come from galaxies more massive than a few 10^10 Msun

=>

At the highest mass end, not only it is important to identify the right quenching mechanisms of the central (in-situ) galaxy, but it becomes even more relevant how the mechanisms that regulate star formation act across the whole spectrum of accreted galaxies at all *relevant* times

To identify the "right" quenching/sf regulation mechanism(s) is of the essence, at all masses and times!

(For BCGs, in particular, for galaxies in 10^12-10^13 Msun haloes)

#2: Implications on BCG vs. ICL separation

At the high mass end, stellar mass **accretion** is the dominant mechanism for the build up of both the inner and the most distant stellar components of a cluster.

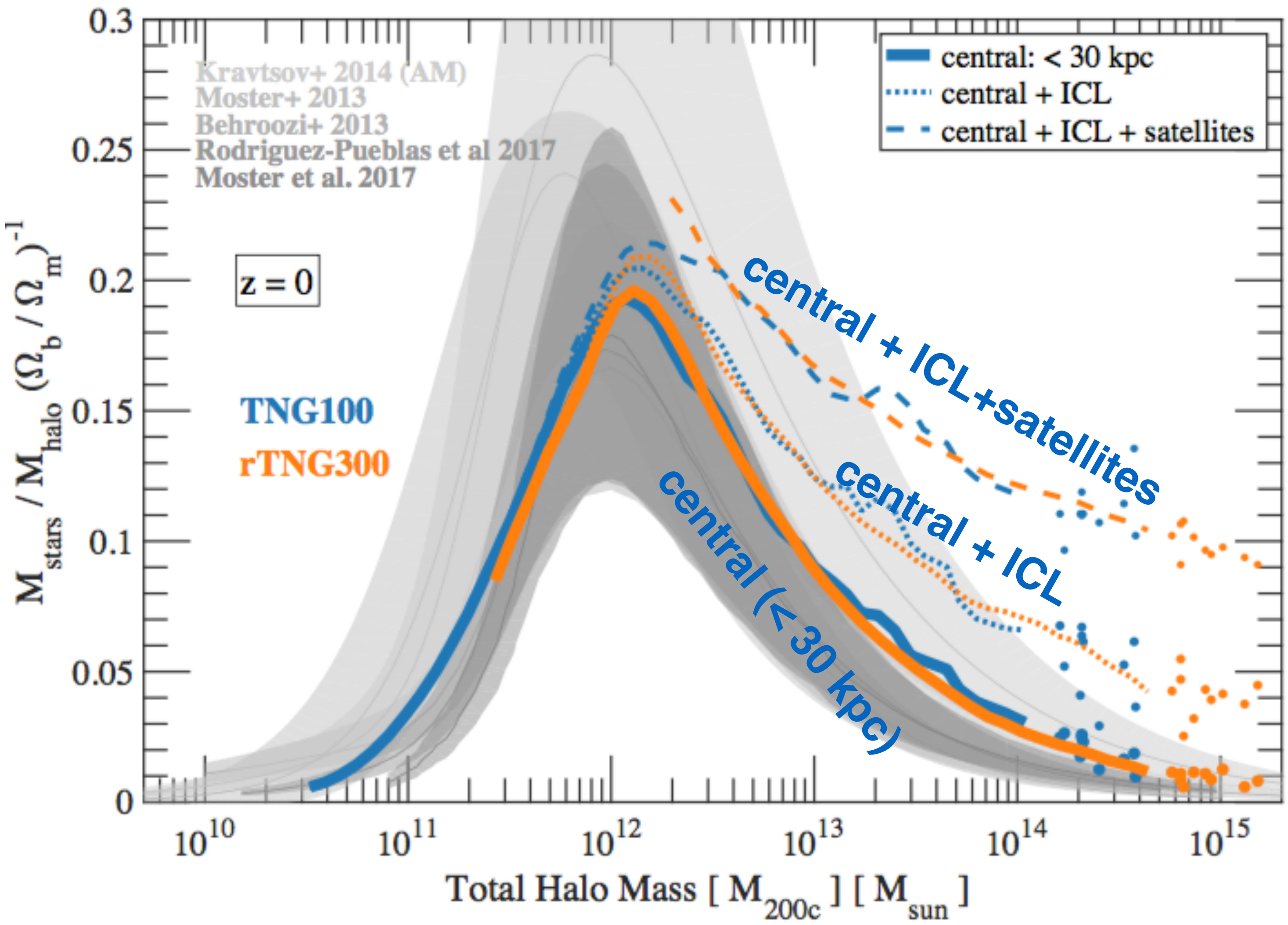
This makes the distinction between

a central galaxy and its stellar halo/ICL conceptually arbitrary.

(From the stellar mass profiles and looking at populations of galaxies, we could not identify any optimal, qualitative or generalized physical transition between the inner bright regions of galaxies and their lower surface brightness envelopes)

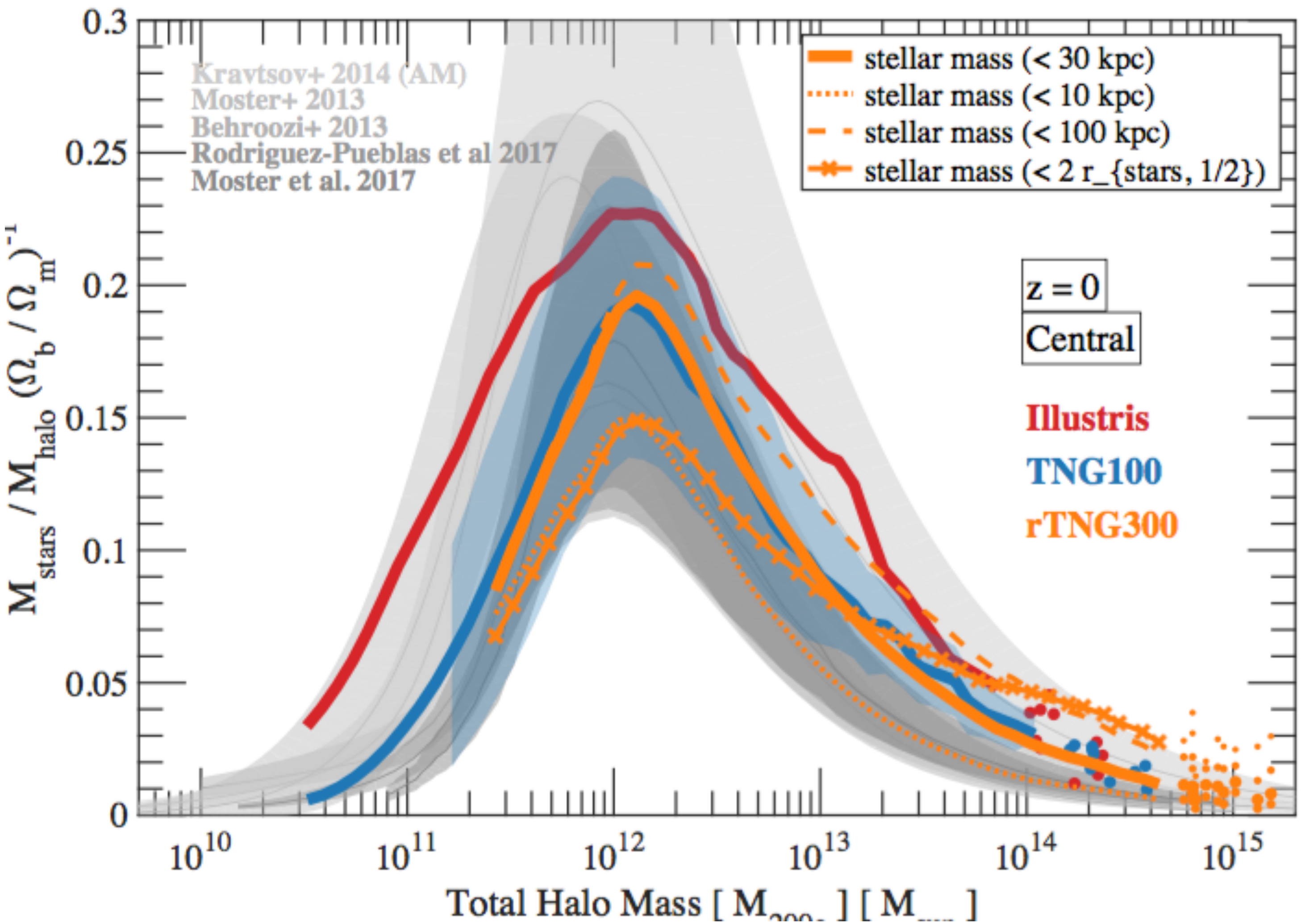
Fixed apertures, although arbitrary, are the least confusing pragmatic separation

#3: Implications on the stellar mass budget



For 10^15 Msun haloes, there can be up to **ten times** more stellar mass beyond 30 kpc (in the ICL and in satellites) than in the central galaxy

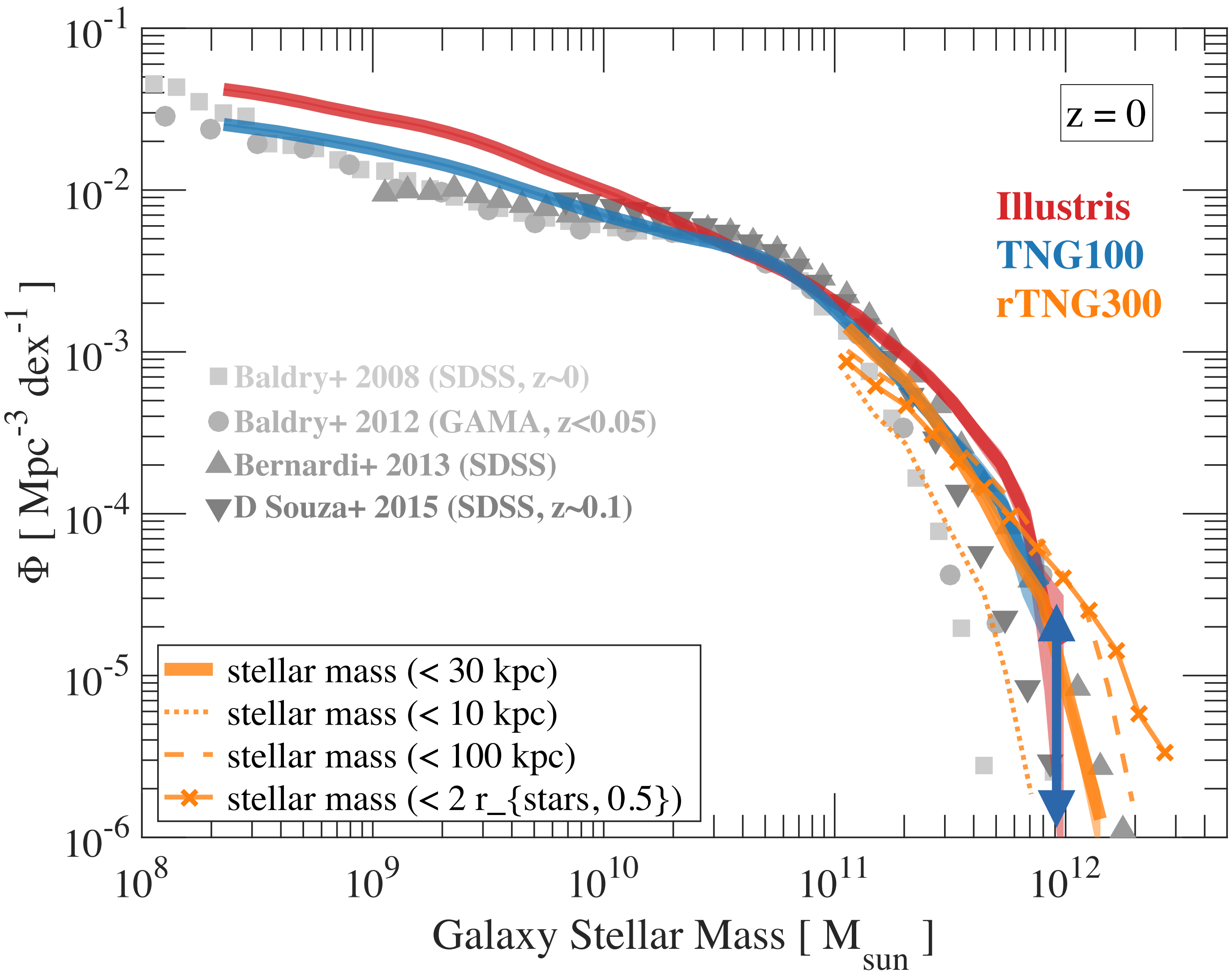
#4: Implications on the "shape" of the high mass end



The aperture choice affects the SHAPE of the stellar-mass to halo-mass relation

This is more relevant for more massive galaxies, because of their more extended stellar bodies

#4: Implications on the “shape” of the high mass end



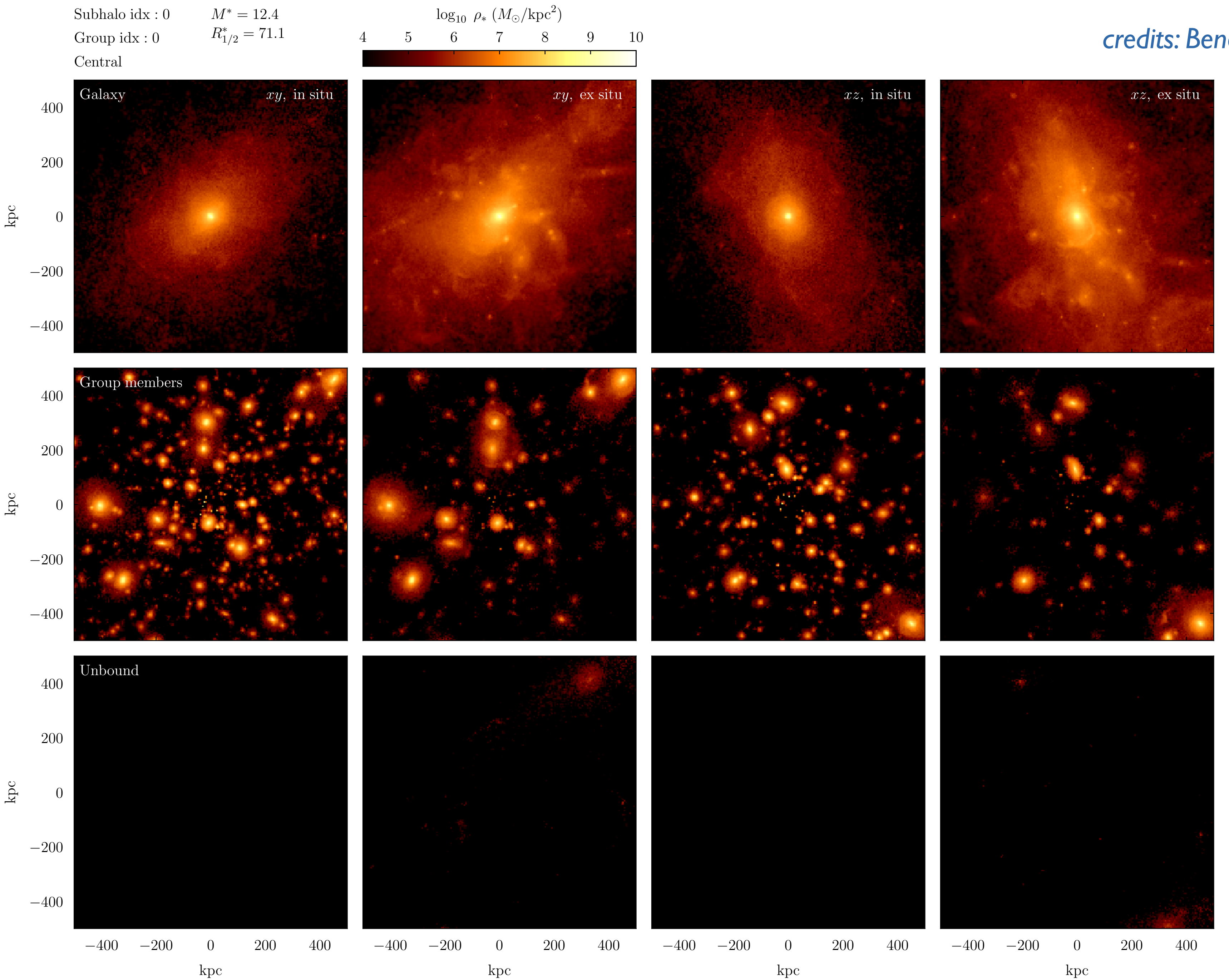
The aperture choice affects the SHAPE of the galaxy stellar mass function after the knee: differences up to factors of 10 at Mstars = 10^12 Msun

Quantitative comparisons to observations require exquisite care

MPIA 2018 Conference

July 2-6, 2018
House of Astronomy, Heidelberg

“The stellar outskirts of galaxies: from our Galaxy to the most massive galaxy clusters”



credits: Benedikt Diemer