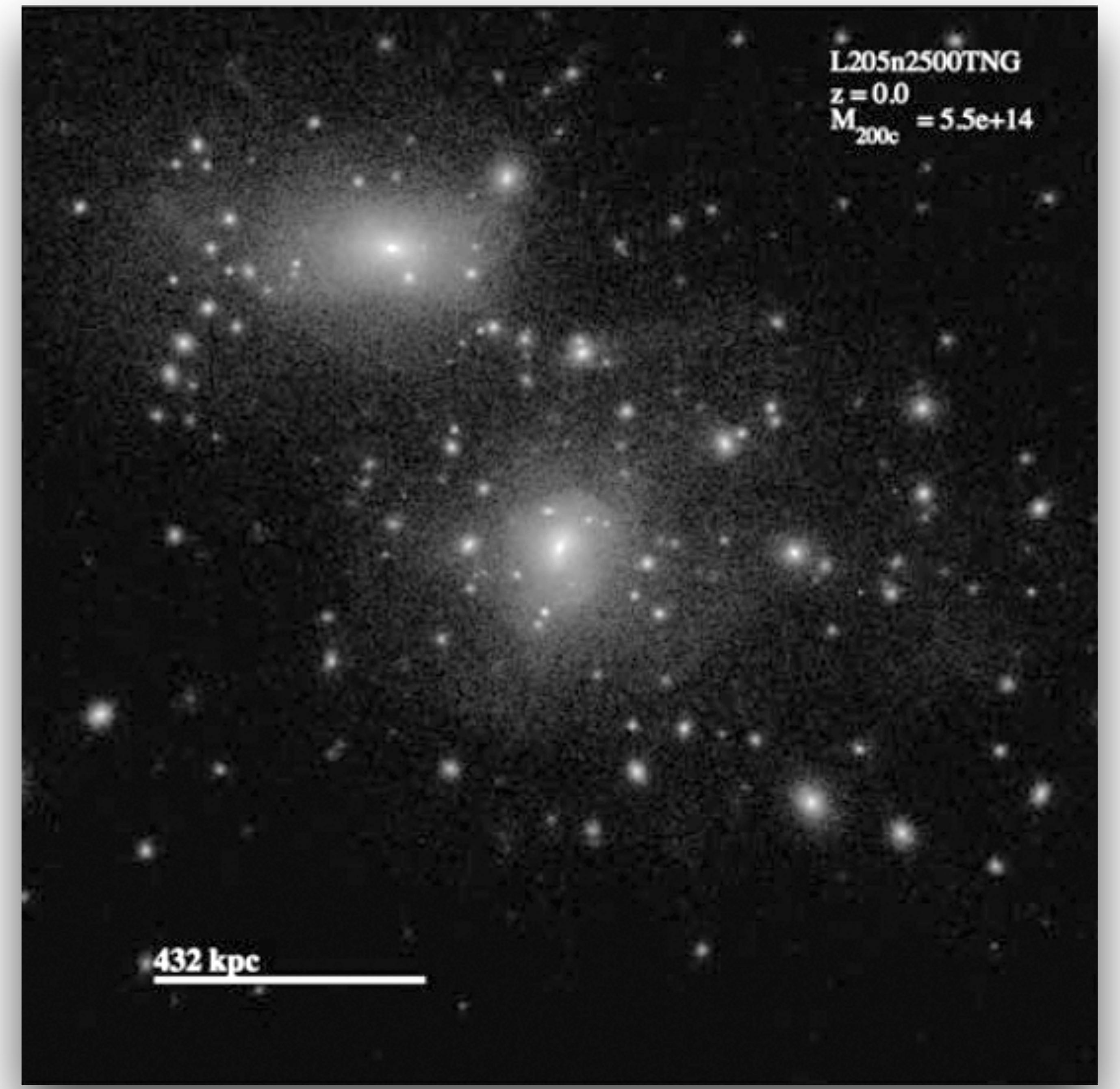
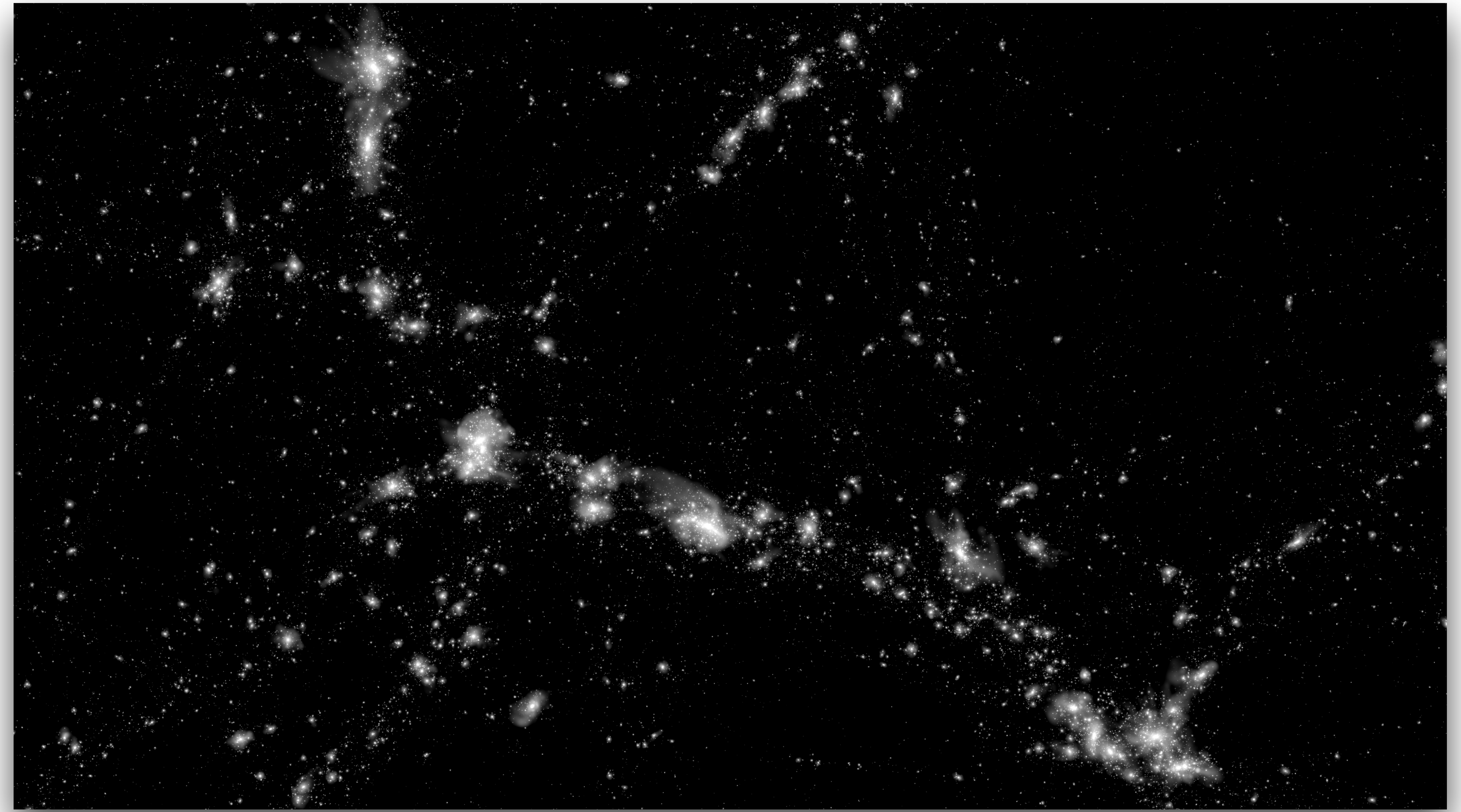


Credit: http://www.tng-project.org/



MARTINA DONNARI

MPIA Heidelberg

In collaboration with Annalisa Pillepich and the TNG team

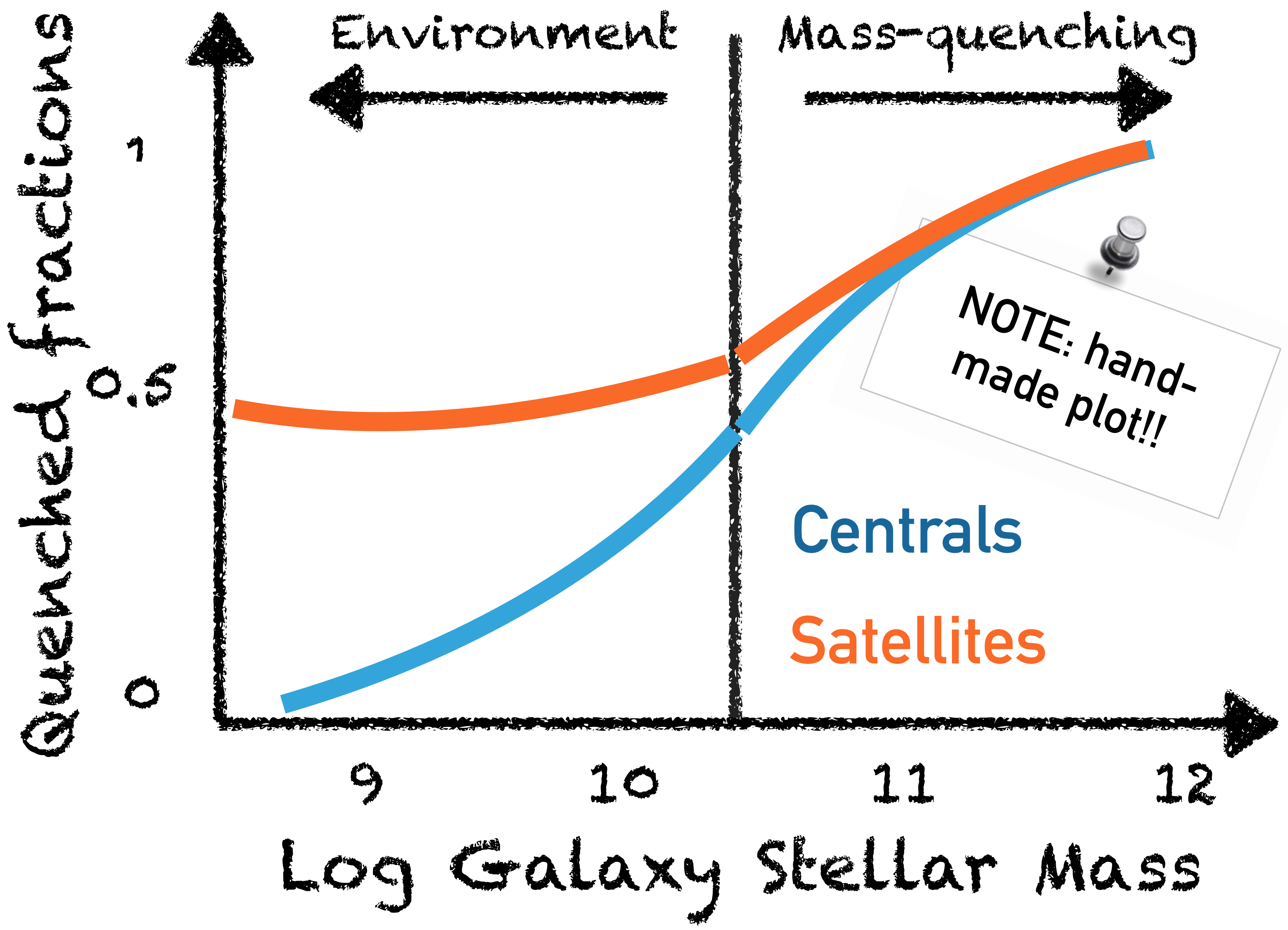
Quenched fractions in the IllustrisTNG simulations:

the roles of AGN feedback, environment, and pre-processing

Donnari, Pillepich et al. 2020 submitted to MNRAS

EAS 2020 - 30 June

Motivation of this work



Questions we address

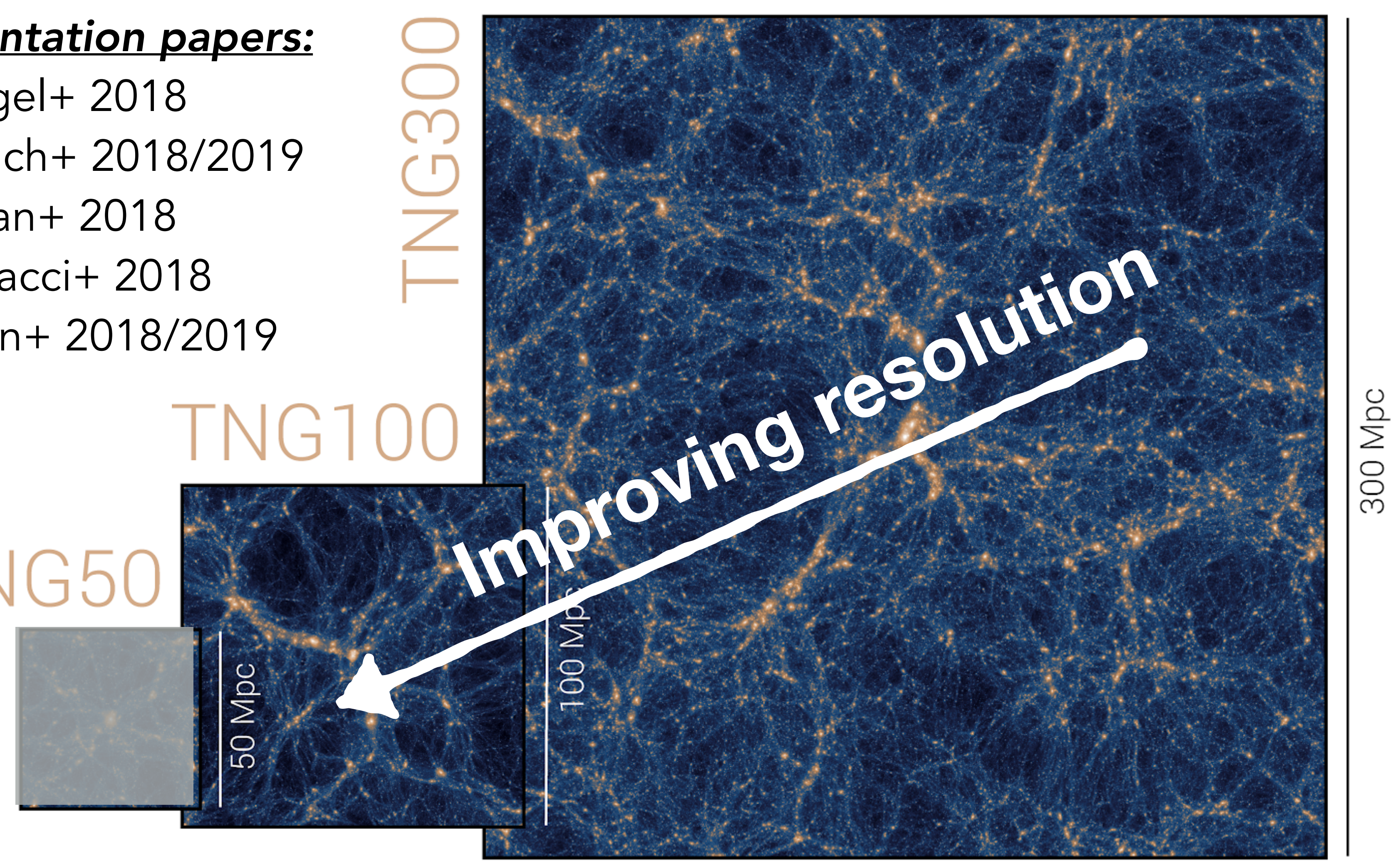
If we observe group and cluster galaxies today, when did they quench? and why?

- What is the role of pre-processing in quenching galaxies prior to their accretion onto their z=0 host?
- Do clusters quench their satellites more efficiently with respect to groups even when pre-processing is taken into account?

Tools: TNG simulations

large volume cosmological hydro-sims

Presentation papers:
Springel+ 2018
Pillepich+ 2018/2019
Naiman+ 2018
Marinacci+ 2018
Nelson+ 2018/2019

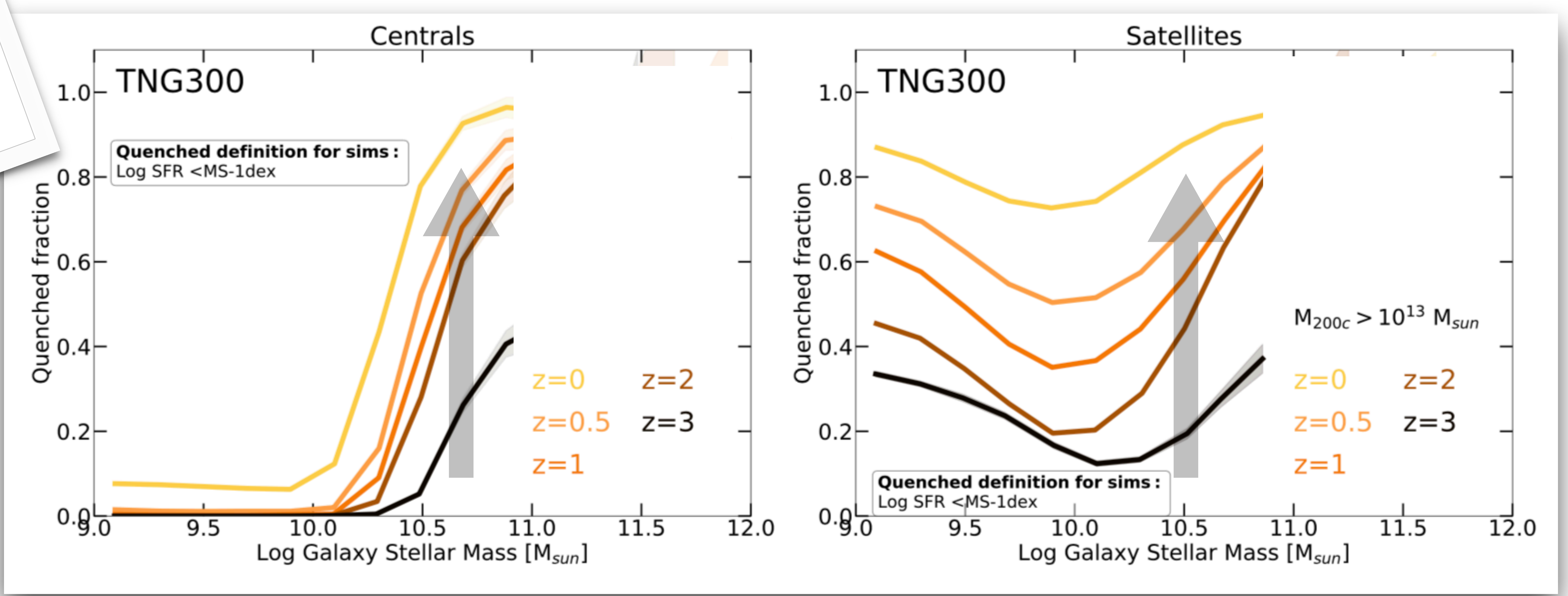


Number of objects in our sample selections

	TNG300	TNG100
All galaxies (M_{stars} > 10^9 M_{sun})	~253.000	~18.800
Groups and Clusters (>10^{13} M_{sun})	3733	182
Centrals	~149.000	~11.000
Satellites	~40.000	~2900

Trend with cosmic time

The quenching starts when the Universe was a few billion years old!



See also:

Glazebrook+17 (ZF-COSMOS-20115)
Forrest+20 (Keck/MOSFIRE)
Donnari+19 (TNG100/300)

$M_{stars} < 10^{10.5-11}$ M_{sun} At fixed Mstars, the fraction increases (by up to 80%) between z=3 and 0

$M_{stars} > 10^{10.5-11}$ M_{sun} The quenched fraction is about 80-90% regardless of redshift

Quenched fractions are lower at higher redshifts for both centrals and satellites

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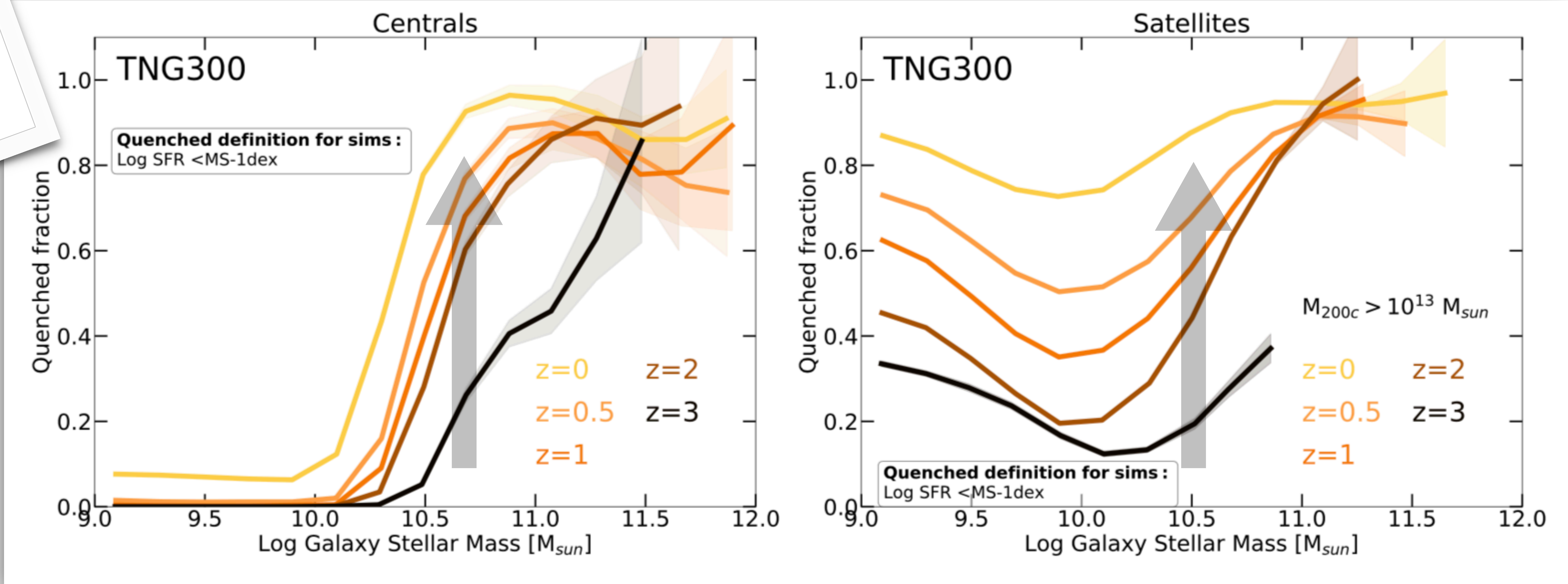

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Trend with 3D clustercentric distance

Also seen in observations

For similar results, see also:

Wetzel+12 (SDSS),
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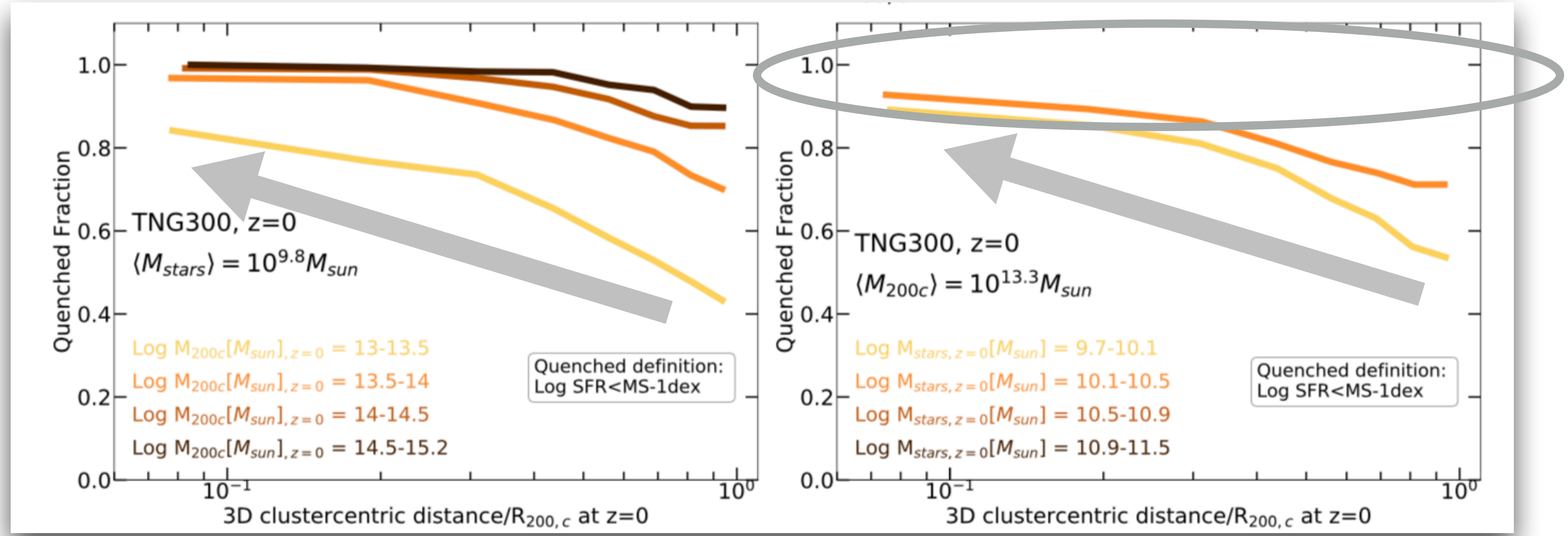

$M_{stars} < 10^{10.5-11}\ M_{sun}$ Quenched fraction higher closer to the host center

$M_{stars} > 10^{10.5-11}\ M_{sun}$ Quenched fractions 80-100% irrespective of the clustercentric distance

Role played by the environment in quenching low-mass satellites
and by internal processes in quenching massive satellites

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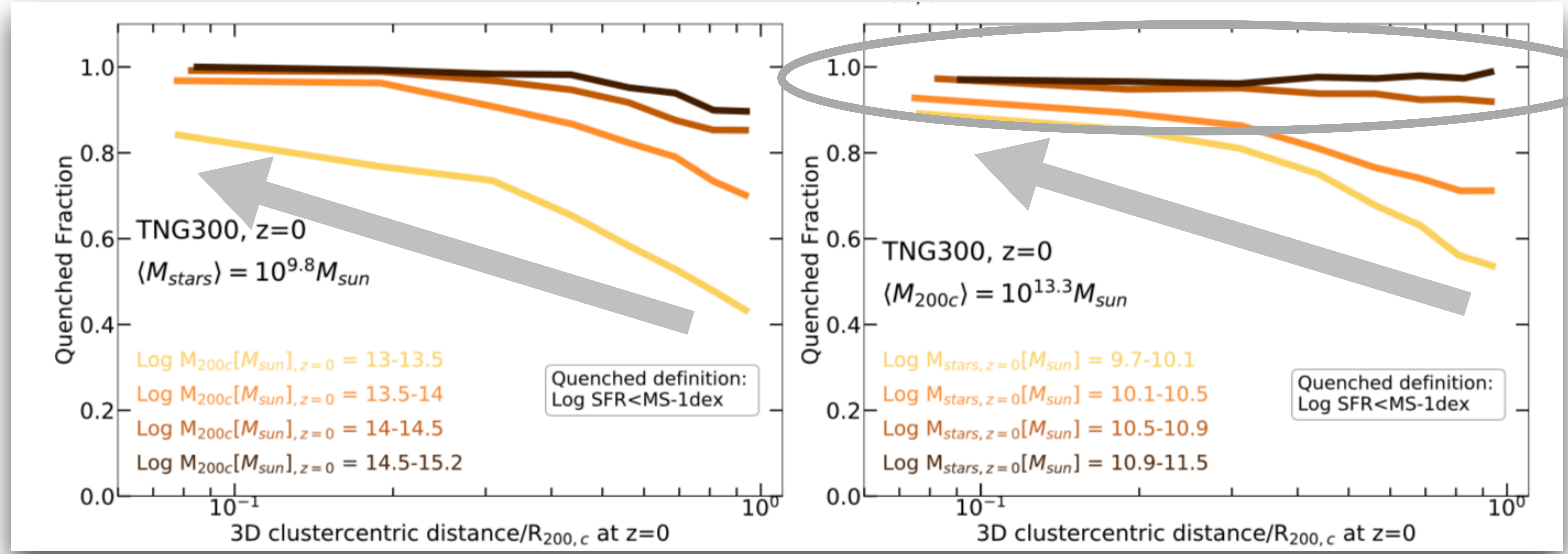

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Trend with stellar mass and host mass

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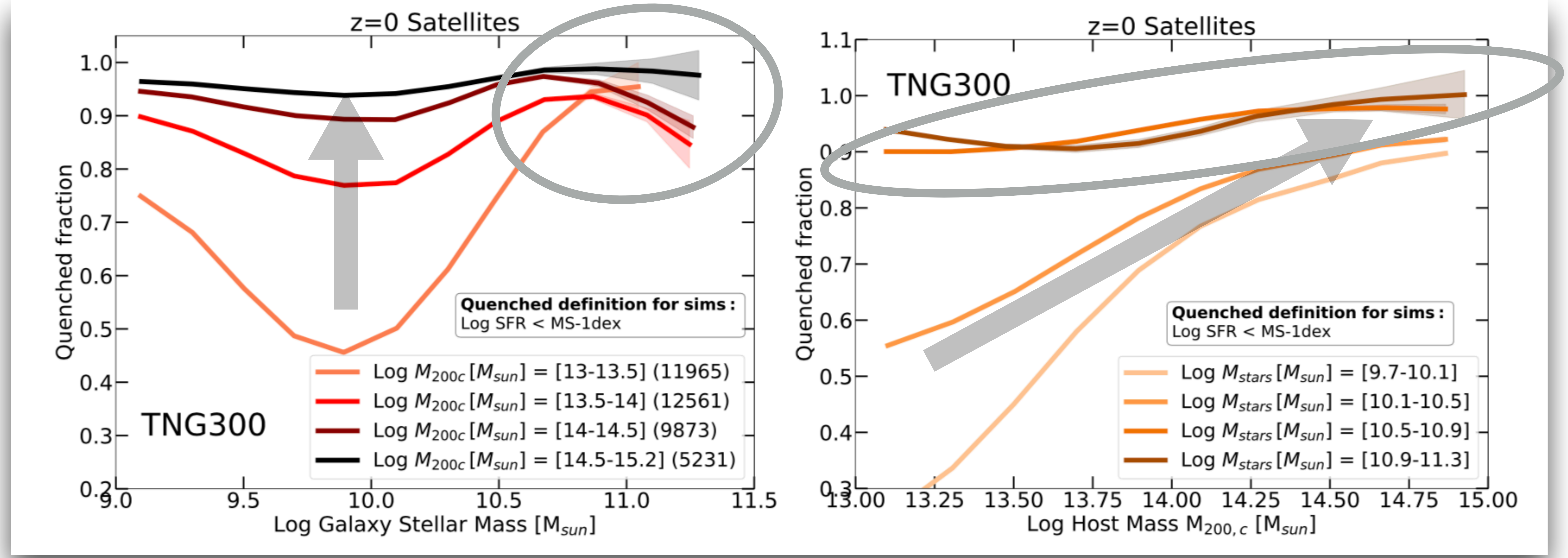

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Quenched fraction is 90-100% at any host mass:

mostly due to internal processes

Quenched fractions higher in clusters than in groups

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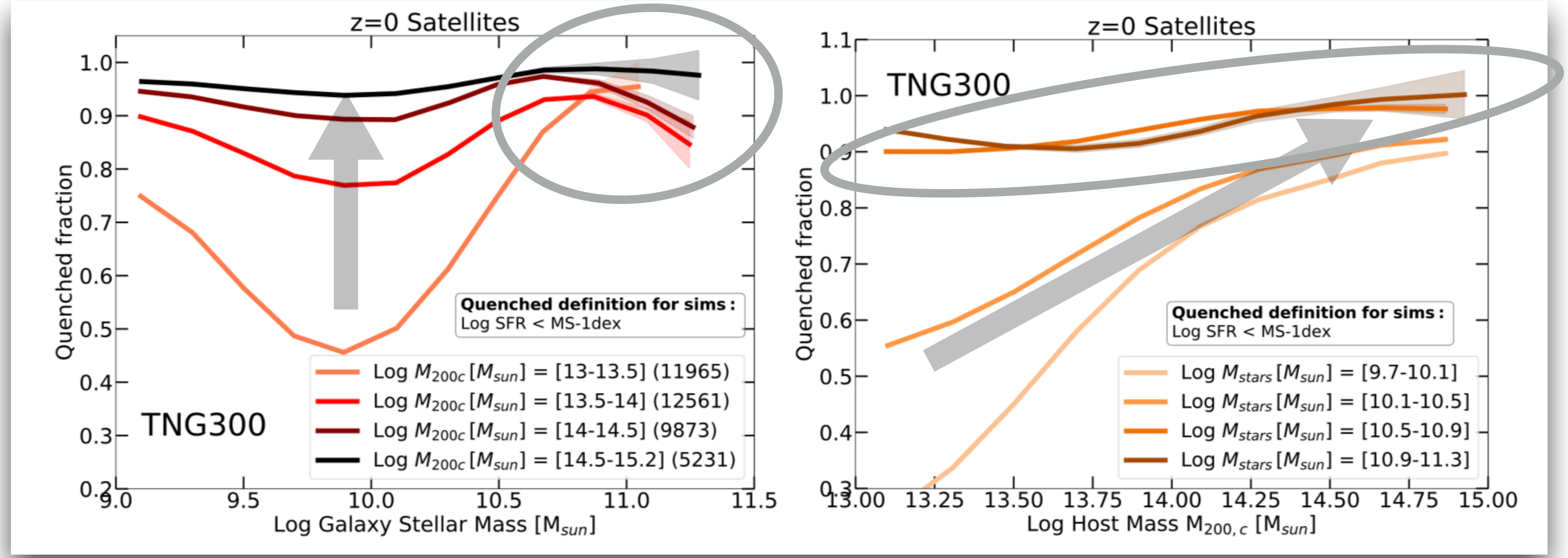

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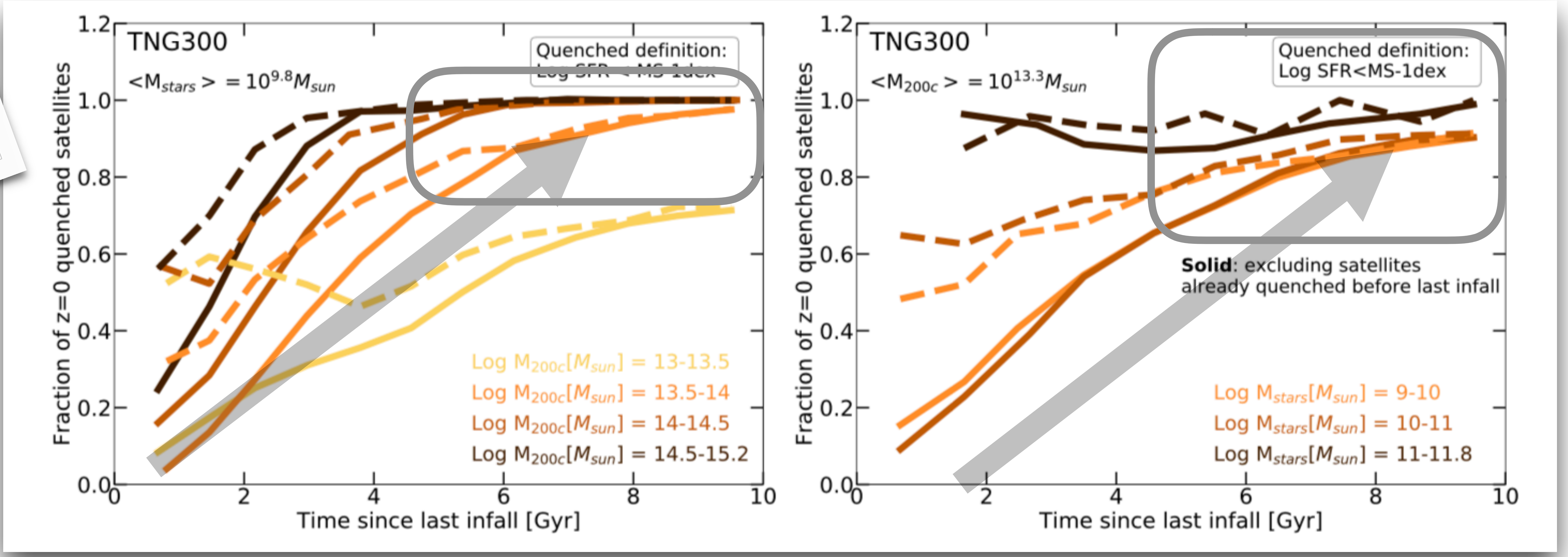
Trend with the time since infall

Hard to prove with observations, that's why we have simulations!



Early infallers are more likely to be quenched compared to recent infallers

Flat at 80-100% for satellites accreted > 4-6 Gyr ago: upper limit for the quenching to occur

Quenched fractions in the IllustrisTNG simulations

First take home

Low-mass
$M_{stars} < 10^{10.5}\ M_{sun}$

- ***Centrals are rarely quenched —> environmentally-driven quenching***

High-mass
$M_{stars} > 10^{10.5}\ M_{sun}$

- ***Internal processes (AGN), regardless of whether they are centrals or satellites***
- ~80-100% of quenched galaxies regardless of host mass, cosmic time ($z<0.5$), cluster-centric distance, and time since infall.

The power of theoretical models

stellar streams

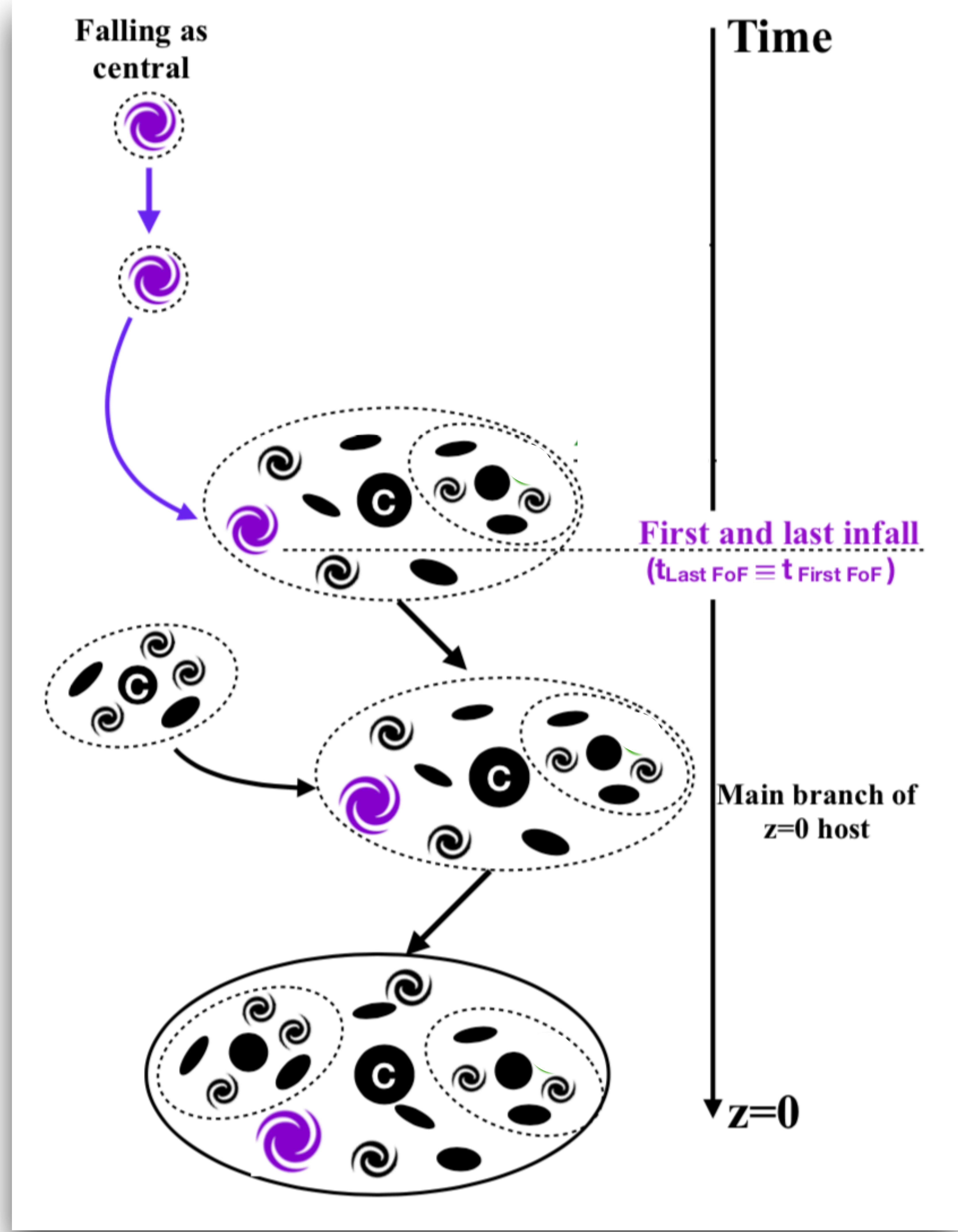
merging galaxies

tidal tails

shells

We can follow the evolution of galaxies across cosmic time back to their infall into clusters

Stellar distribution of a forming cluster at z<1 in TNG50



How does a galaxy become satellite?

Two main pathways!

Falling as centrals
"Direct infallers"

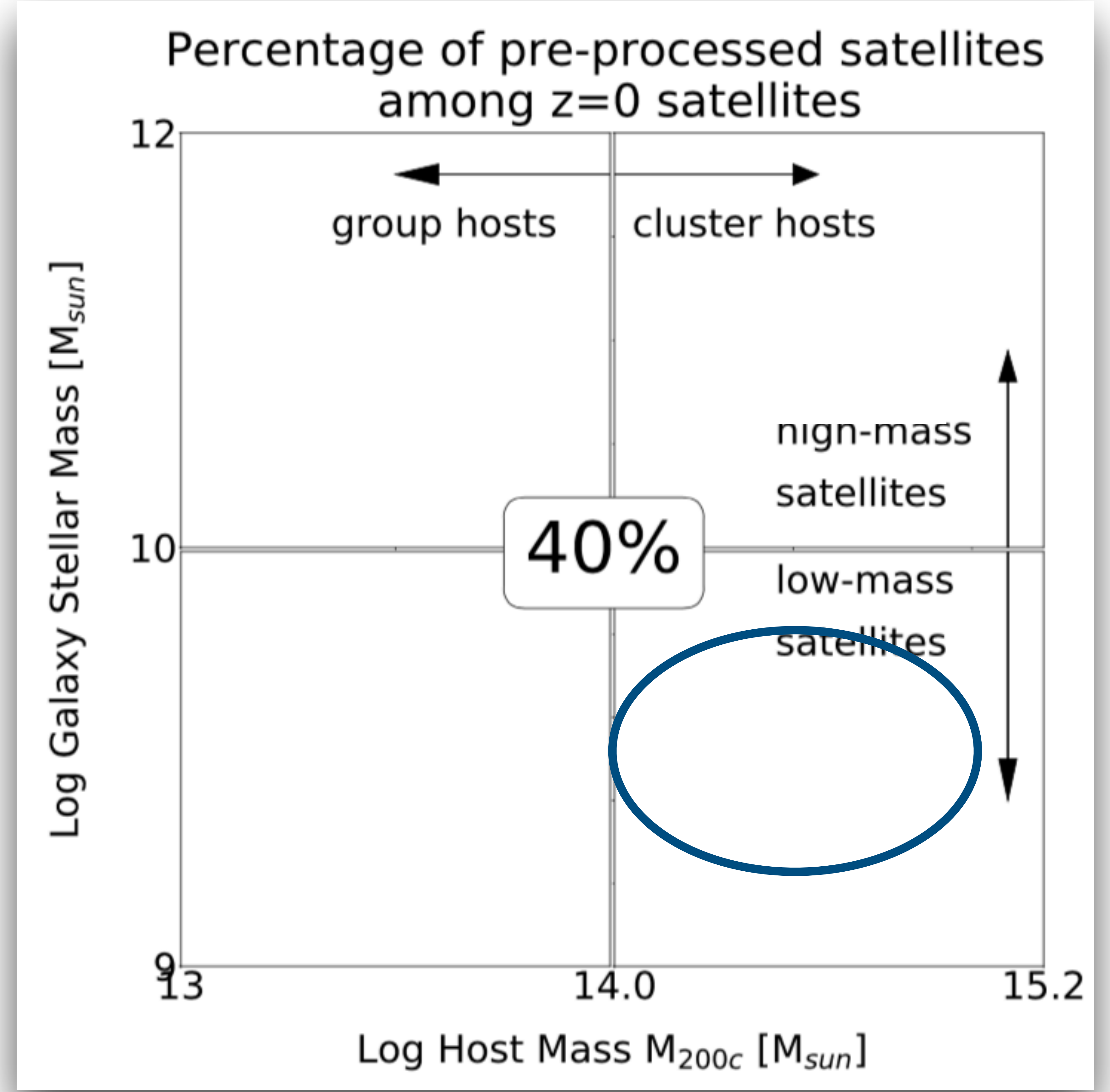
A galaxy might be directly accreted into the main branch of the z=0 host and thus have only one infall time.

Falling as satellites
"Pre-processed"

A galaxy might first fall into a subgroup which in turn will merge in the final z = 0 host.

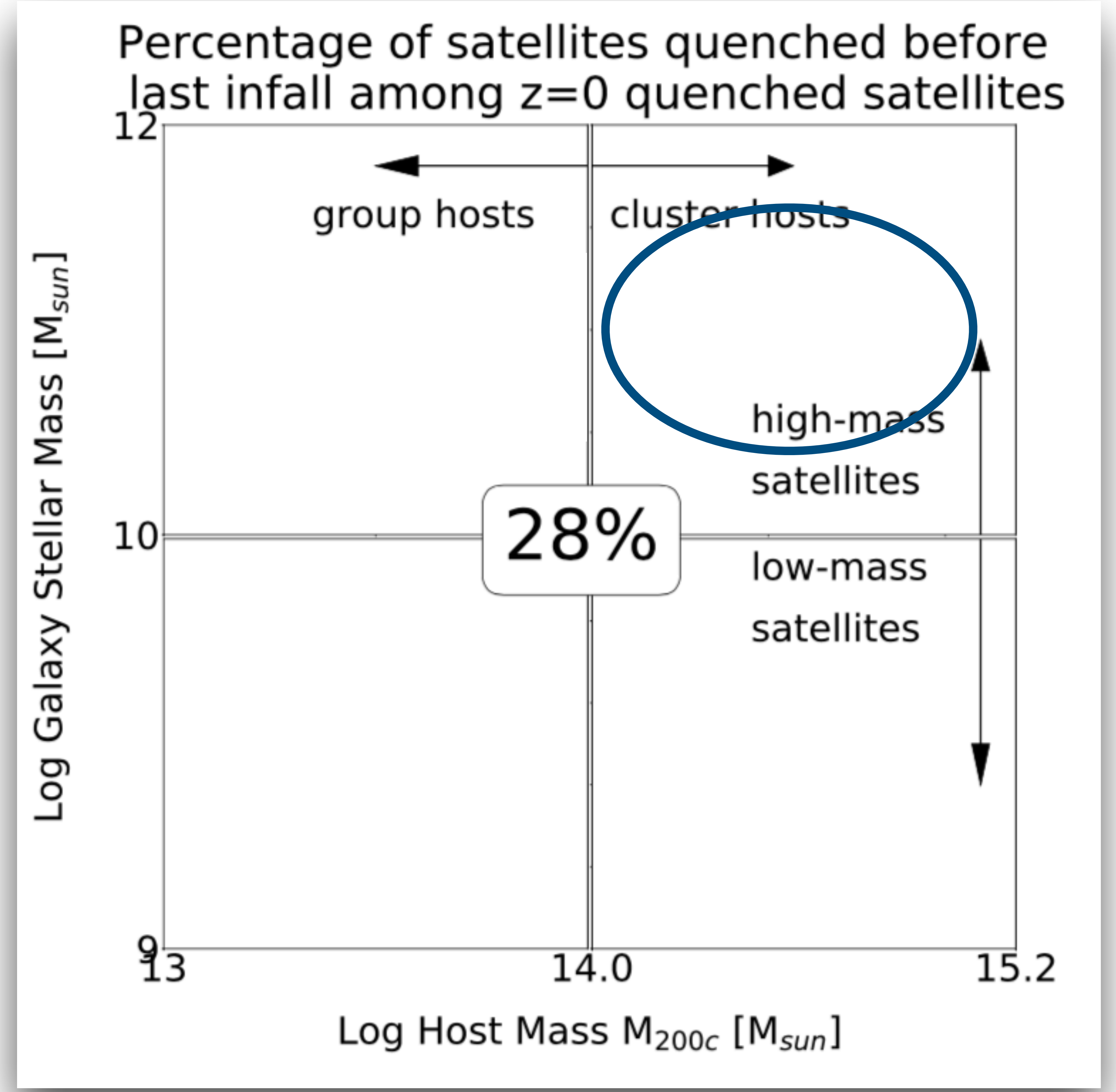
How many z=0 satellites have been pre-processed?

Pre-processing statistics for group and cluster satellites



How many z=0 satellites have been pre-processed?

How many z=0 quenched satellites fall into their current host already quenched?



- ~40% of pre-processed satellites
- Pre-processing is predominant in clusters: ~54-57% of low mass satellites

For similar results: Bahe'+17/+19

- ~28% of pre-quenched satellites
- ~35-37% of satellites > 10^{10} Msun in clusters

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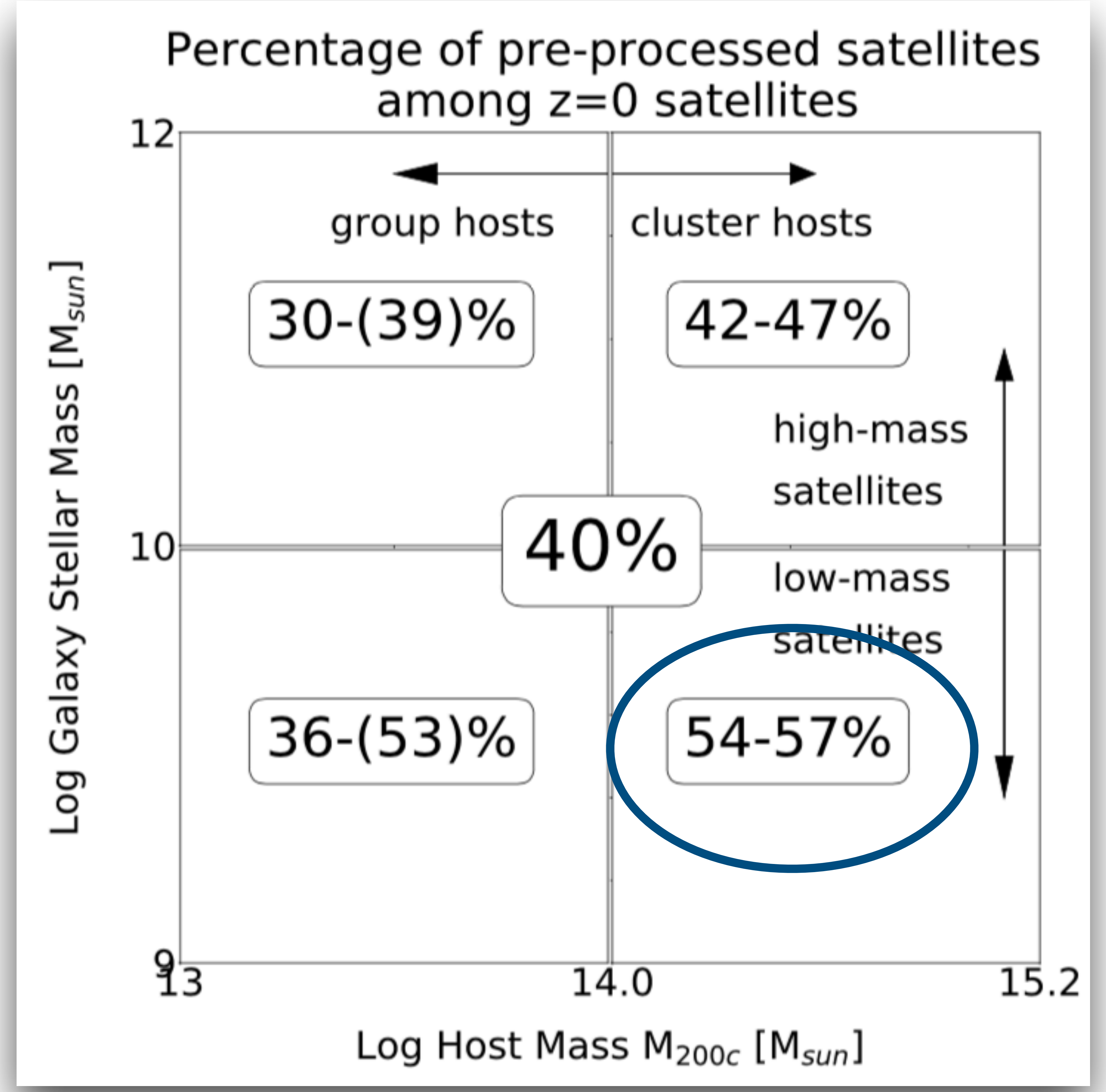

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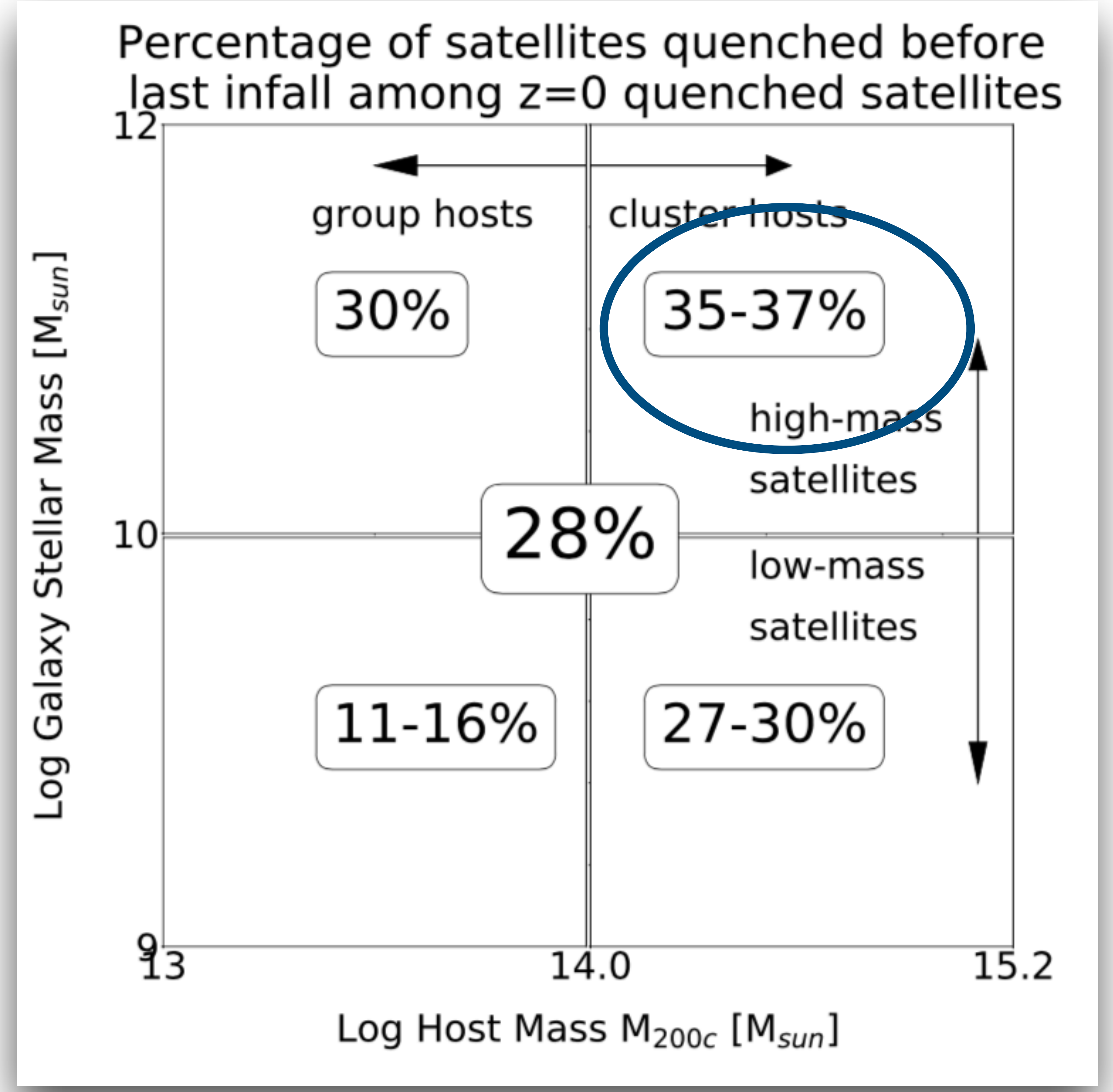

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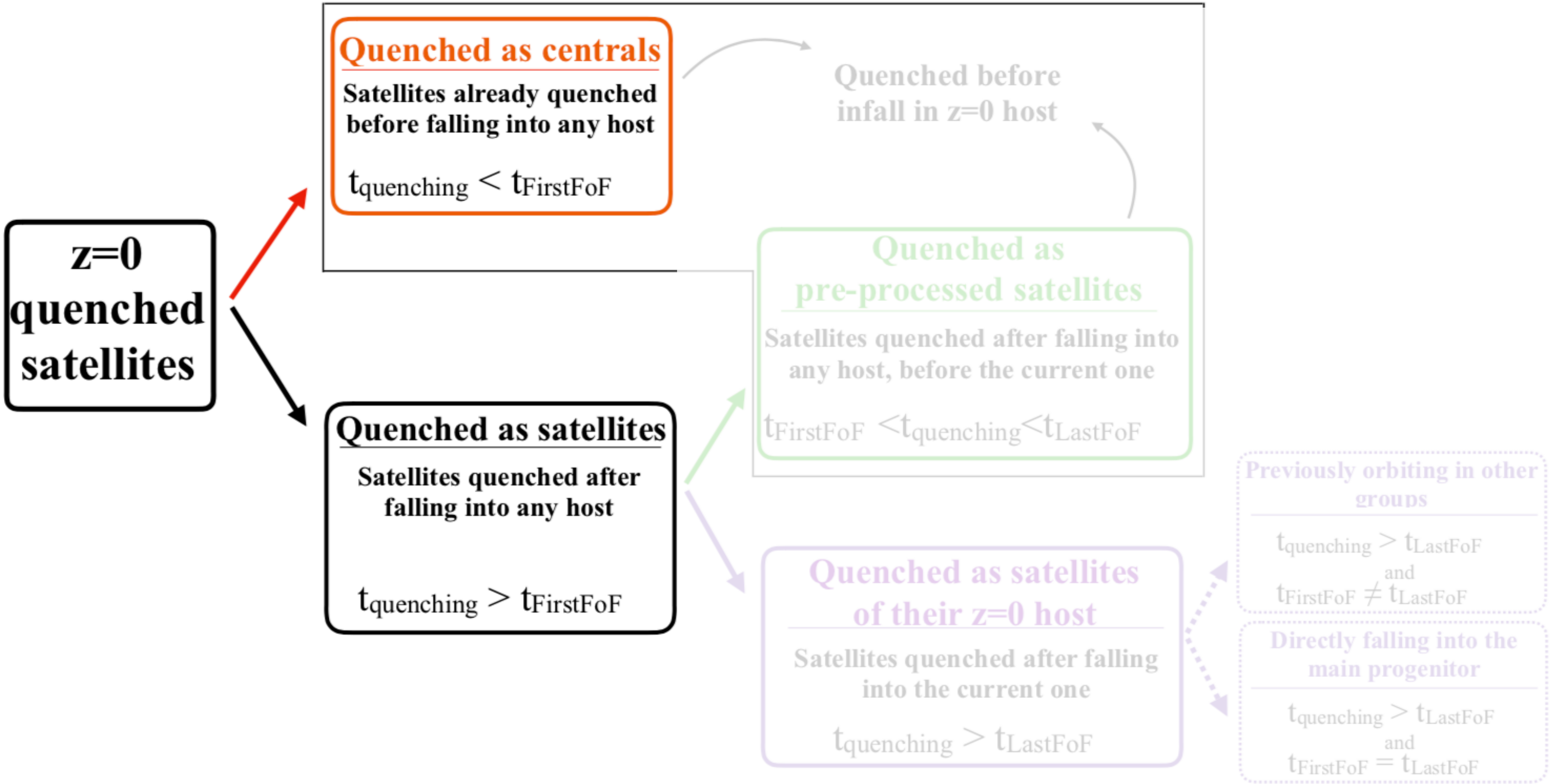

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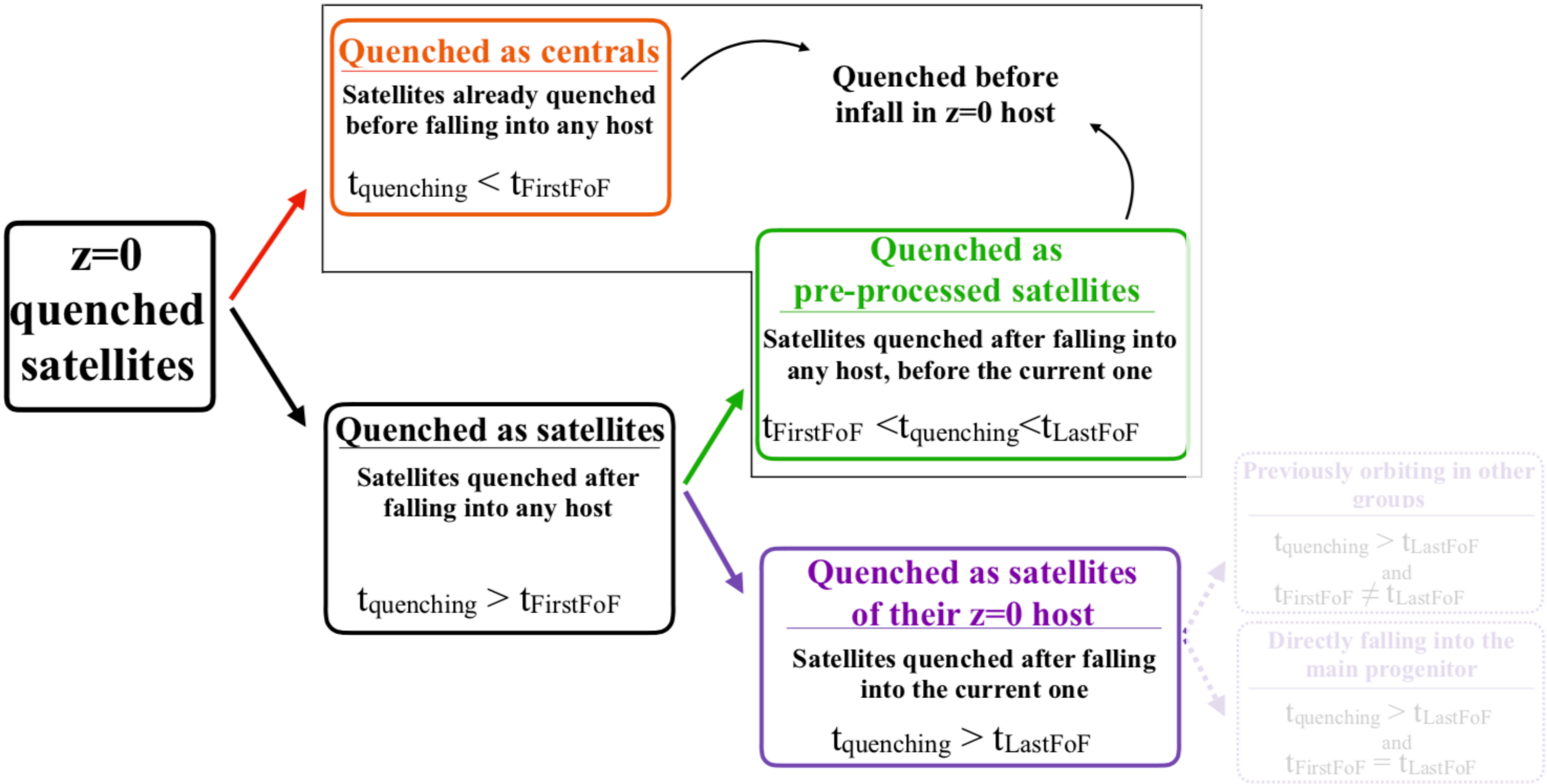

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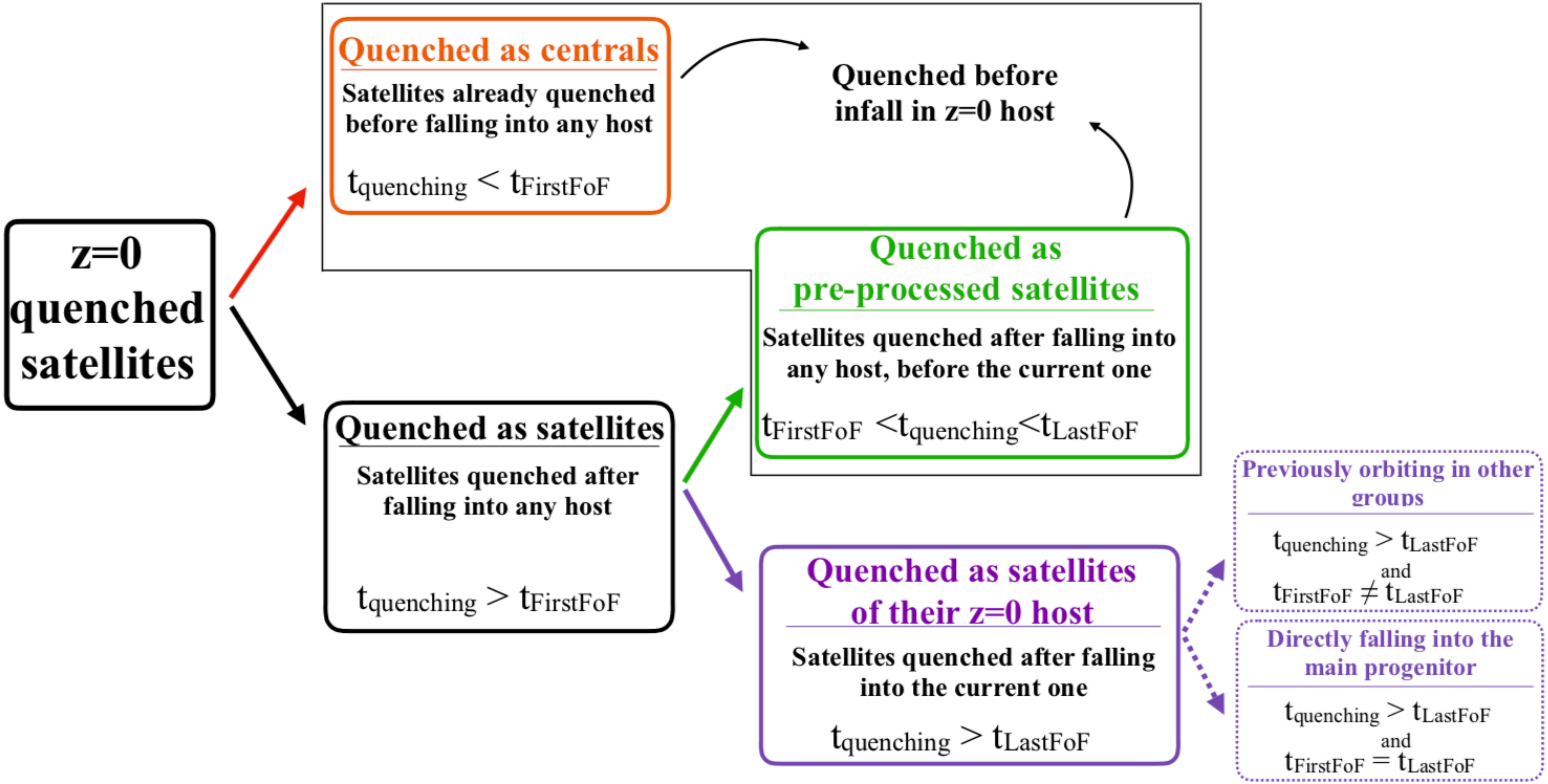

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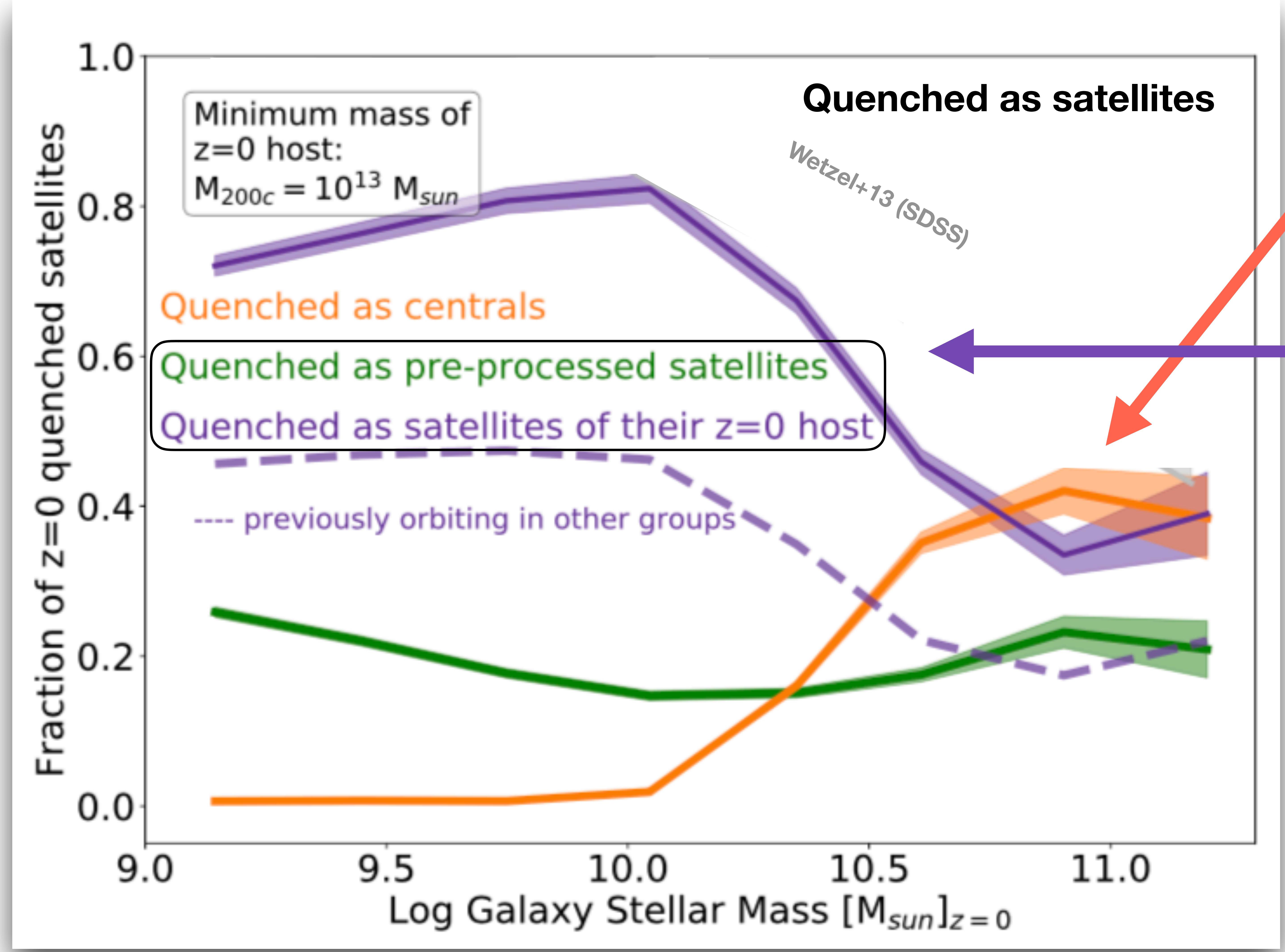

Quenched as centrals: only > 10^{10} Msun today quench when they were centrals
—> AGN feedback

Satellites that were quenched within their current host exhibit a strong correlation with Mstars

$M_{stars} < 10^{10.5-11}$ M_{sun}

The build up of the z = 0 quenched population is dominated by the environmental effects

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Quenching as a central is almost as frequent as quenching as a satellite

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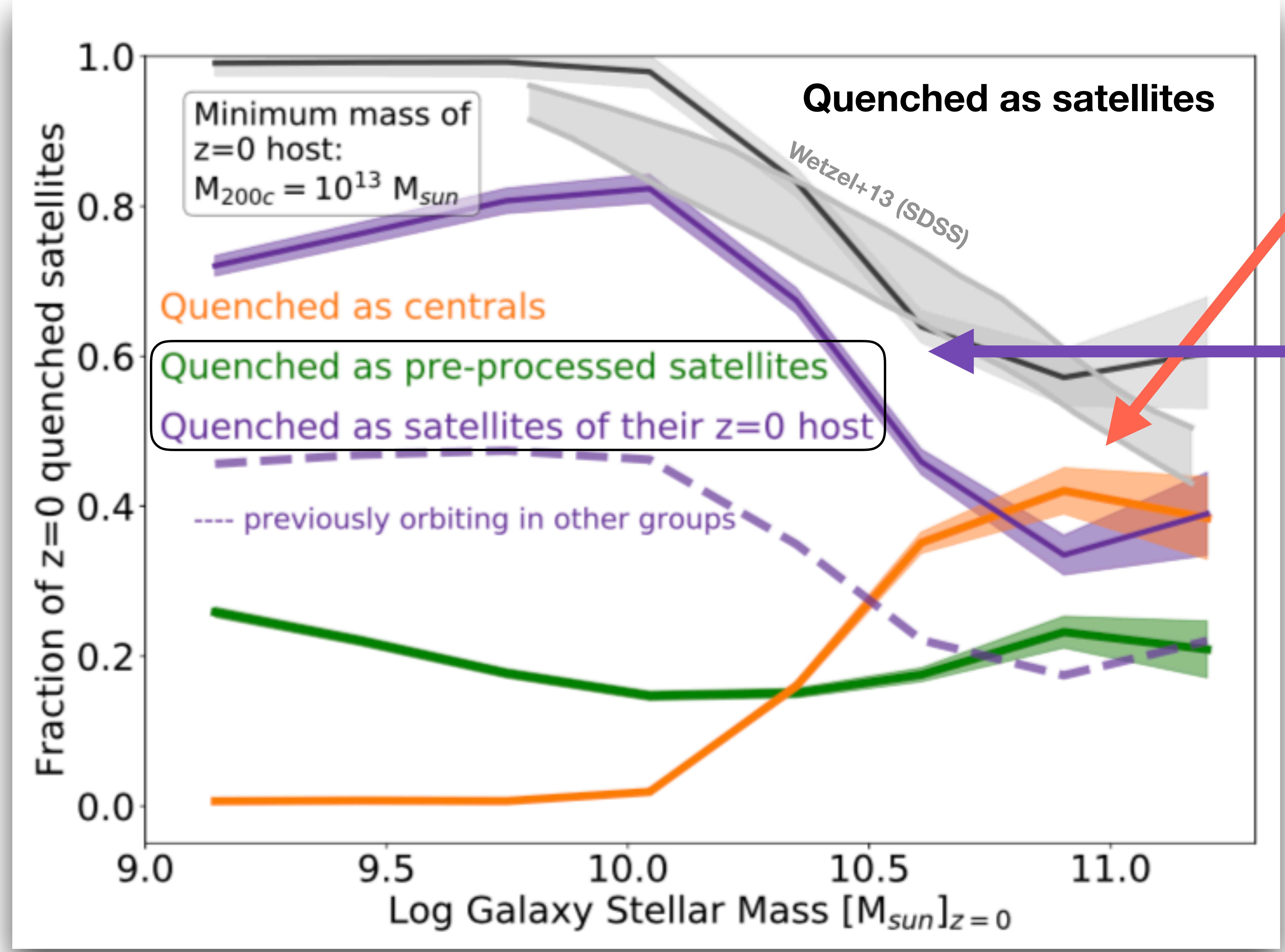

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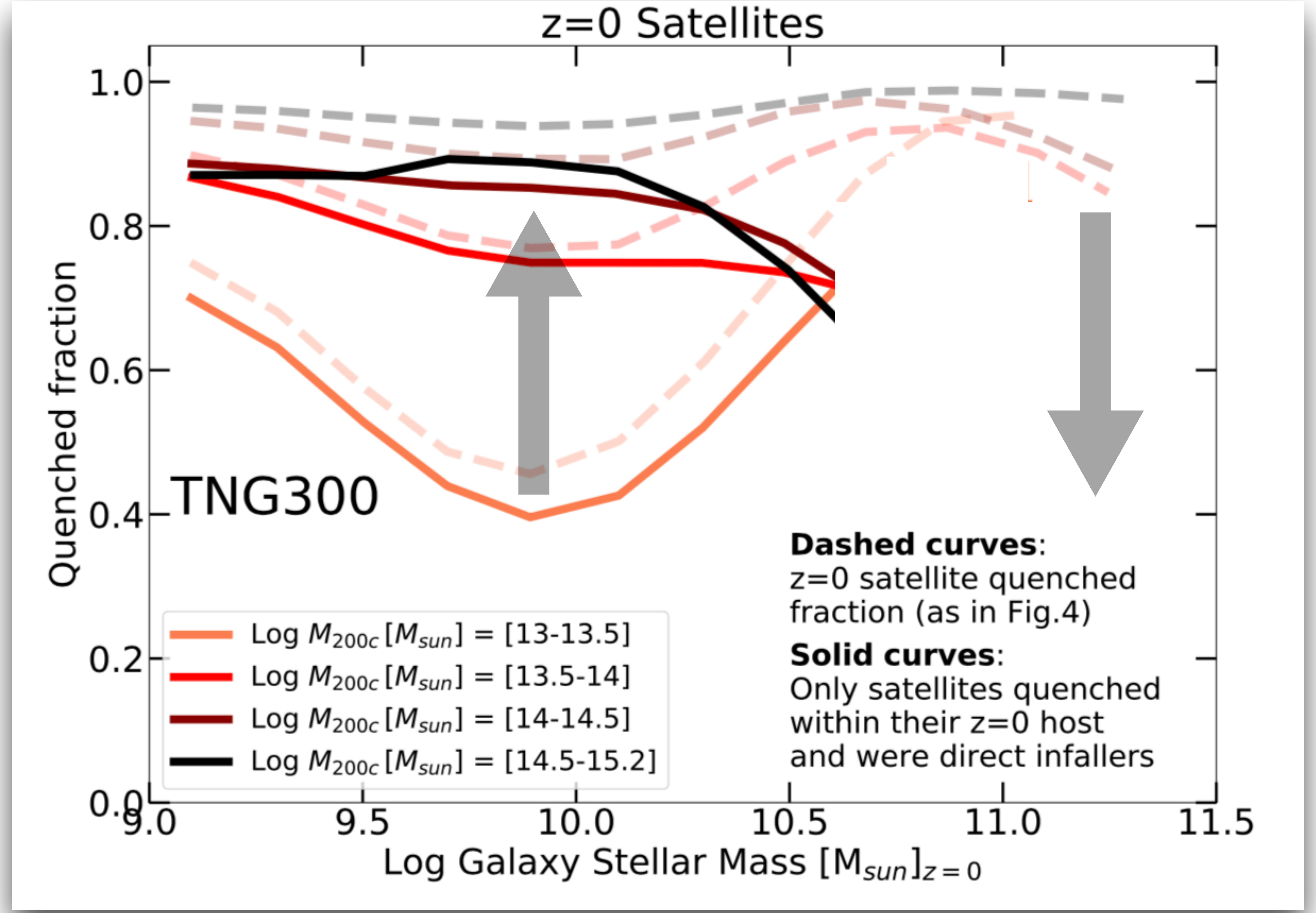
Ranking of host efficiency



After excluding satellites quenched before their last infall:

$M_{stars} < 10^{10.5}$ M_{sun}

More massive clusters are indeed more efficient at quenching their satellites

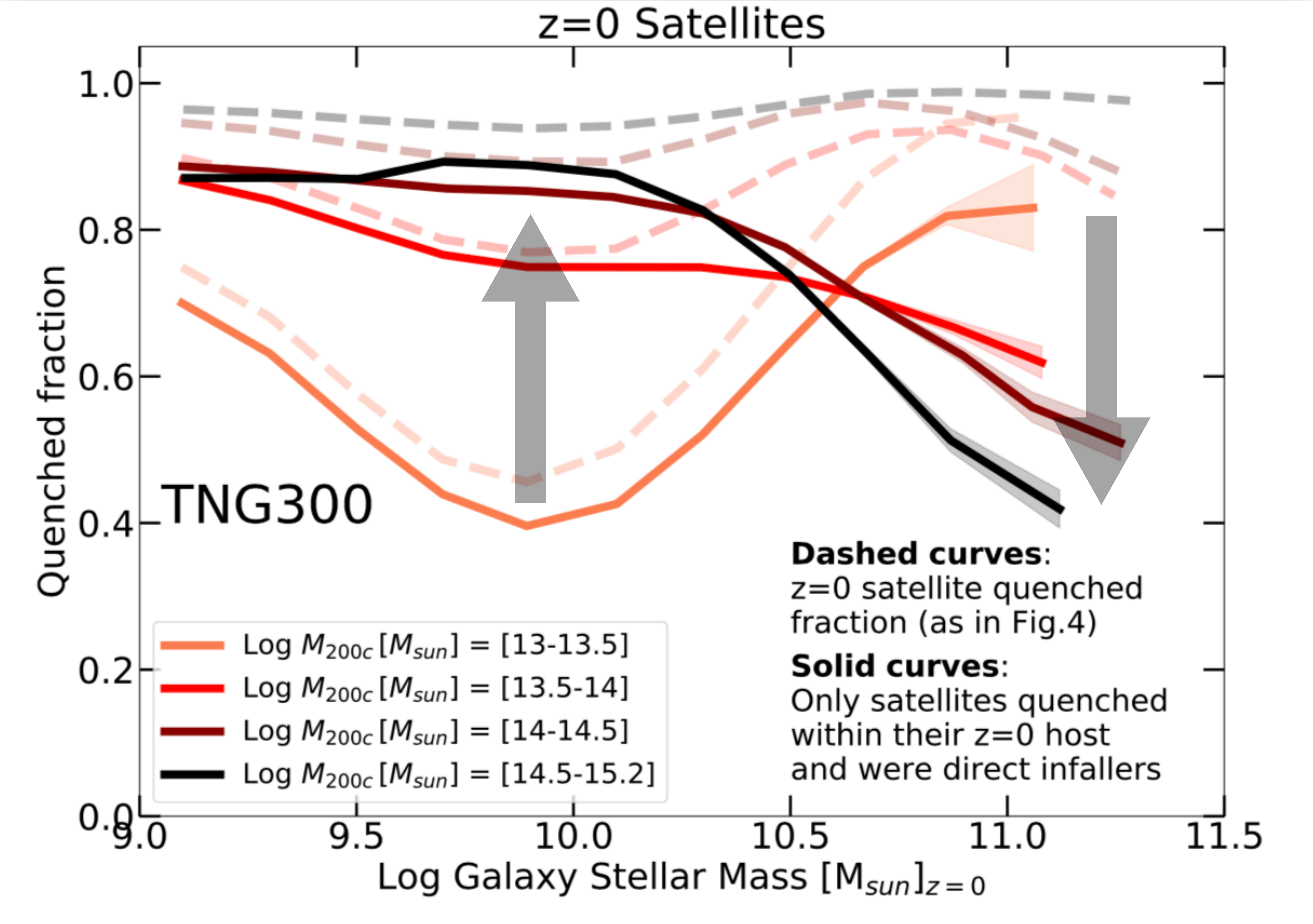
$M_{stars} > 10^{10.5}$ M_{sun}

An inversion of the trend with host mass: quenched fractions are lower in clusters than in groups

Main culprits for their quenching are secular and internal processes (AGN feedback in TNG)

See Joshi's talk (S6f - July 3rd)

Ranking of host efficiency



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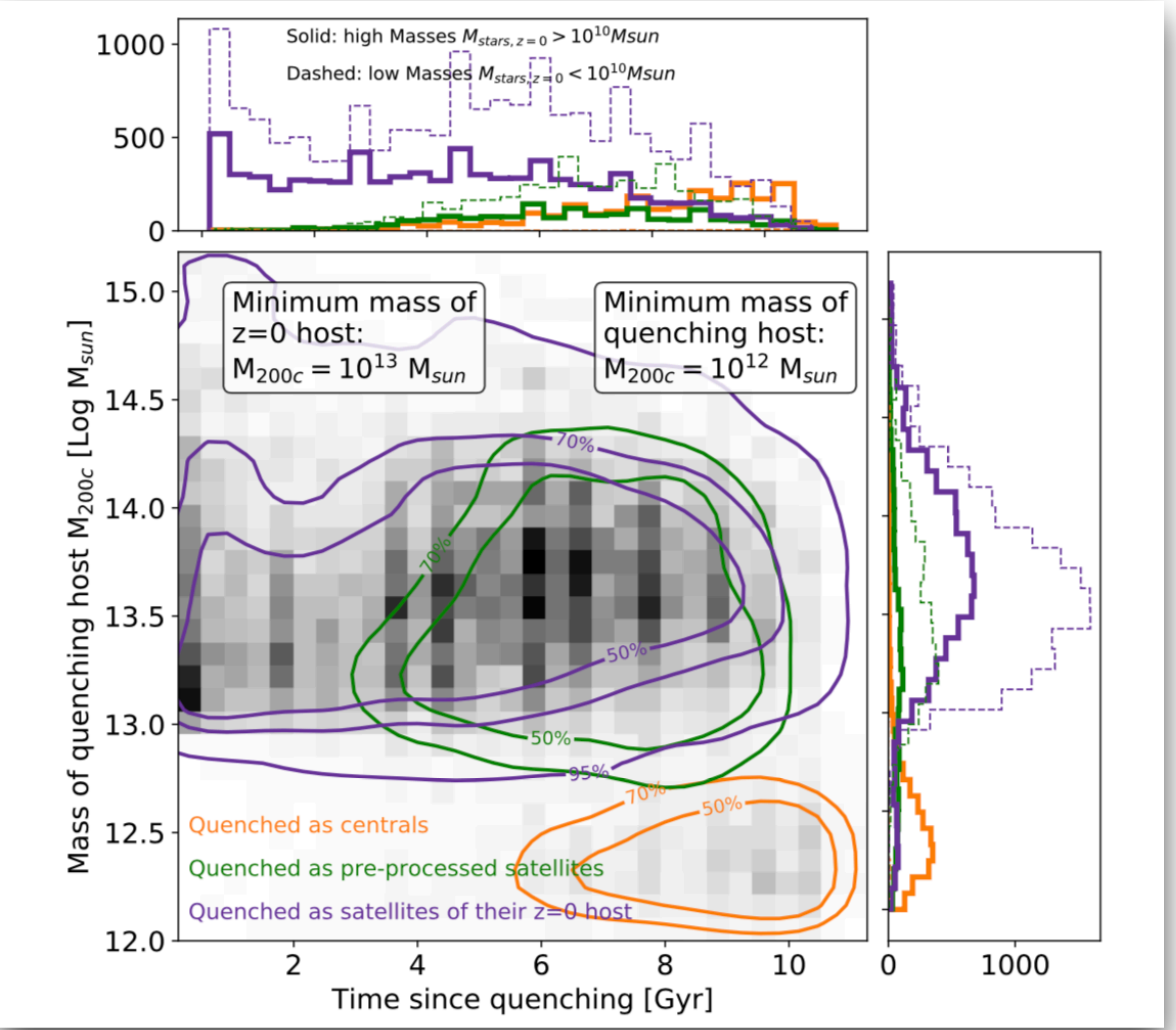
Distribution of the mass of quenching hosts and the time since quenching



Quenching hosts

Satellites quenched as satellites

10^{13-14} Msun

Satellites quenched as centrals

$10^{12-12.6(*)}$ Msun

(*) refers to their own dark matter haloes

Time since quenching

Satellites quenched as pre-processed satellites:

6 to 8 Gyr ago

Satellites quenched within their z=0 host:

1 to 7 Gyr ago

Only massive satellites quench as centrals

6 to 10 Gyr ago

Quenched fractions in the IllustrisTNG simulations

Take home

Take home

Environmental processes in hosts more massive than about 10^{13} M_{sun} are already in place at z~1-3

Low-mass
$M_{stars} < 10^{10.5-11}$ M_{sun}

- Centrals: are rarely quenched —> environmentally-driven quenching scenario
- Satellites: quenched fractions is higher in massive hosts, closer to the host center, and for early infallers
- Satellites: ~ 30% were already quenched before infalling into z=0 host
  —> entirely due to environmental effects during pre-processing,

High-mass
$M_{stars} > 10^{10.5-11}$ M_{sun}

- Internal processes (AGN), ***regardless of whether they are centrals or satellites***.
- ~90-100 % of quenched galaxies regardless of host mass, cosmic time (z<0.5), cluster-centric distance, and time since infall.
- Satellites: quenching as a central is almost as frequent as quenching as a satellite, but even as satellites, they quench because of their BHs

Overview of the IllustrisTNG project

	TNG300	TNG100	TNG50
Gas mass [M_{sun}]	1.1×10^7	1.4×10^6	8.5×10^4
DM mass [M_{sun}]	5.9×10^7	7.5×10^6	4.5×10^5
MHD	yes	yes	yes

Number of objects in our sample selections

	TNG300	TNG100
All galaxies (M_{stars} > 10^9 M_{sun})	~253.000	~18.800
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Centrals	~149.000	~11.000
Satellites	~40.000	~2900

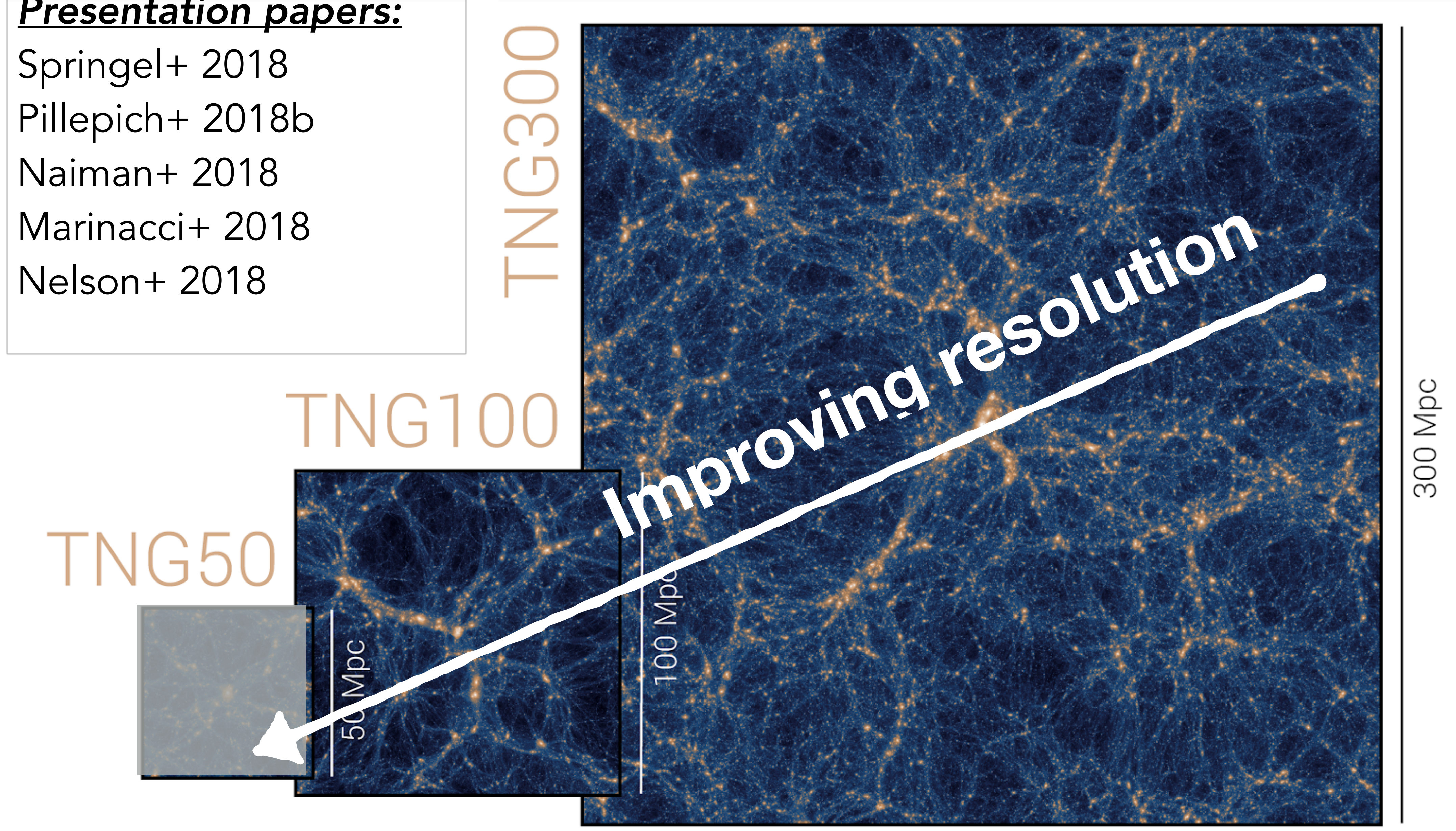
Pillepich+ 2018a, Weinberger+ 2018

The physical ingredients in TNG

- Star-formation
- Stellar feedback (galactic wind)
- BH seed and growth
- BH feedback (high & low accretion modes, i.e. **thermal dump and kinetic BH driven winds**)
- Gas cooling/heating
- Stellar evolution
- Metal enrichment

Presentation papers:
Springel+ 2018
Pillepich+ 2018b
Naiman+ 2018
Marinacci+ 2018
Nelson+ 2018

Credit: http://www.tng-project.org/



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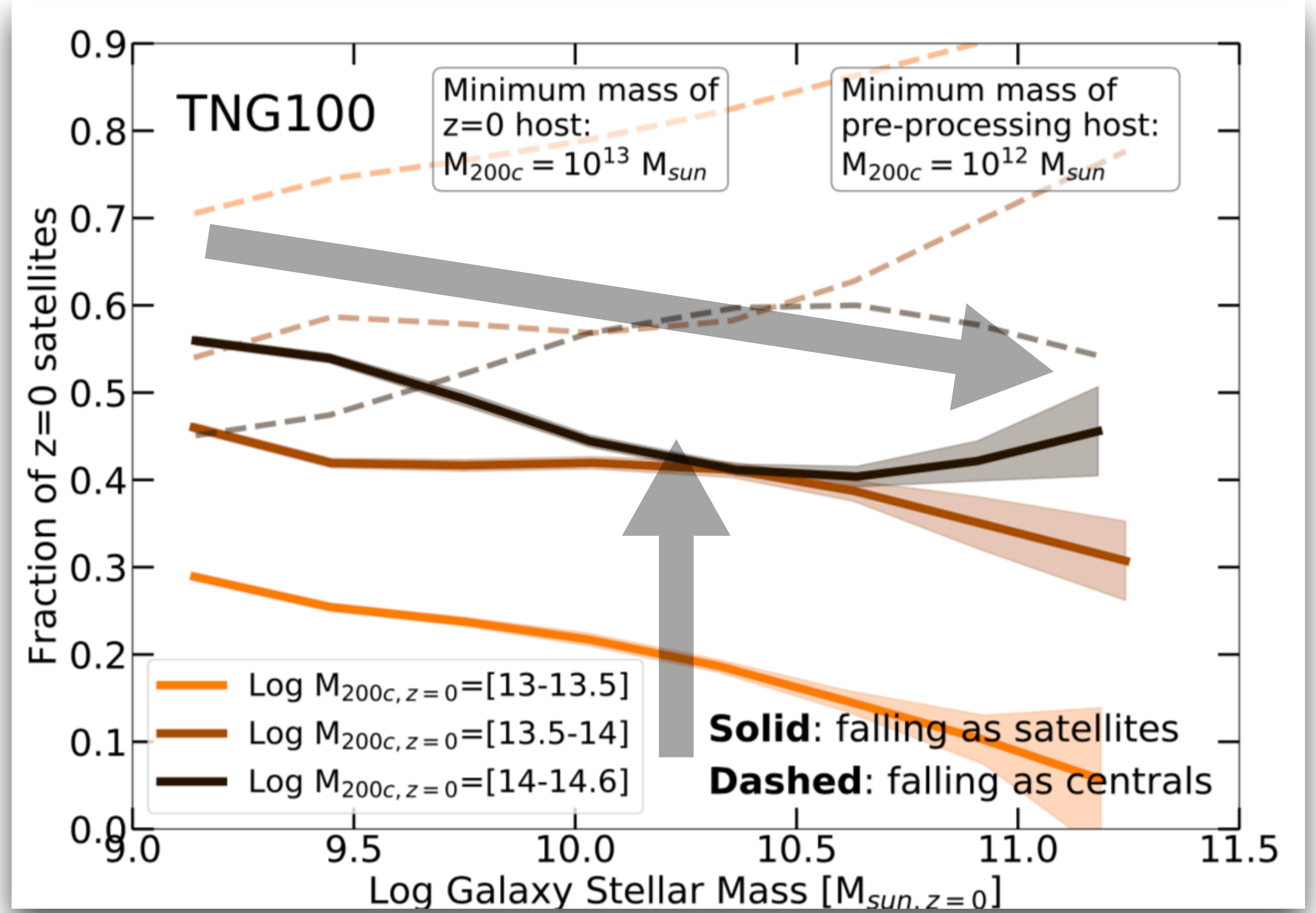


At fixed stellar mass:
the fraction increases with the host mass

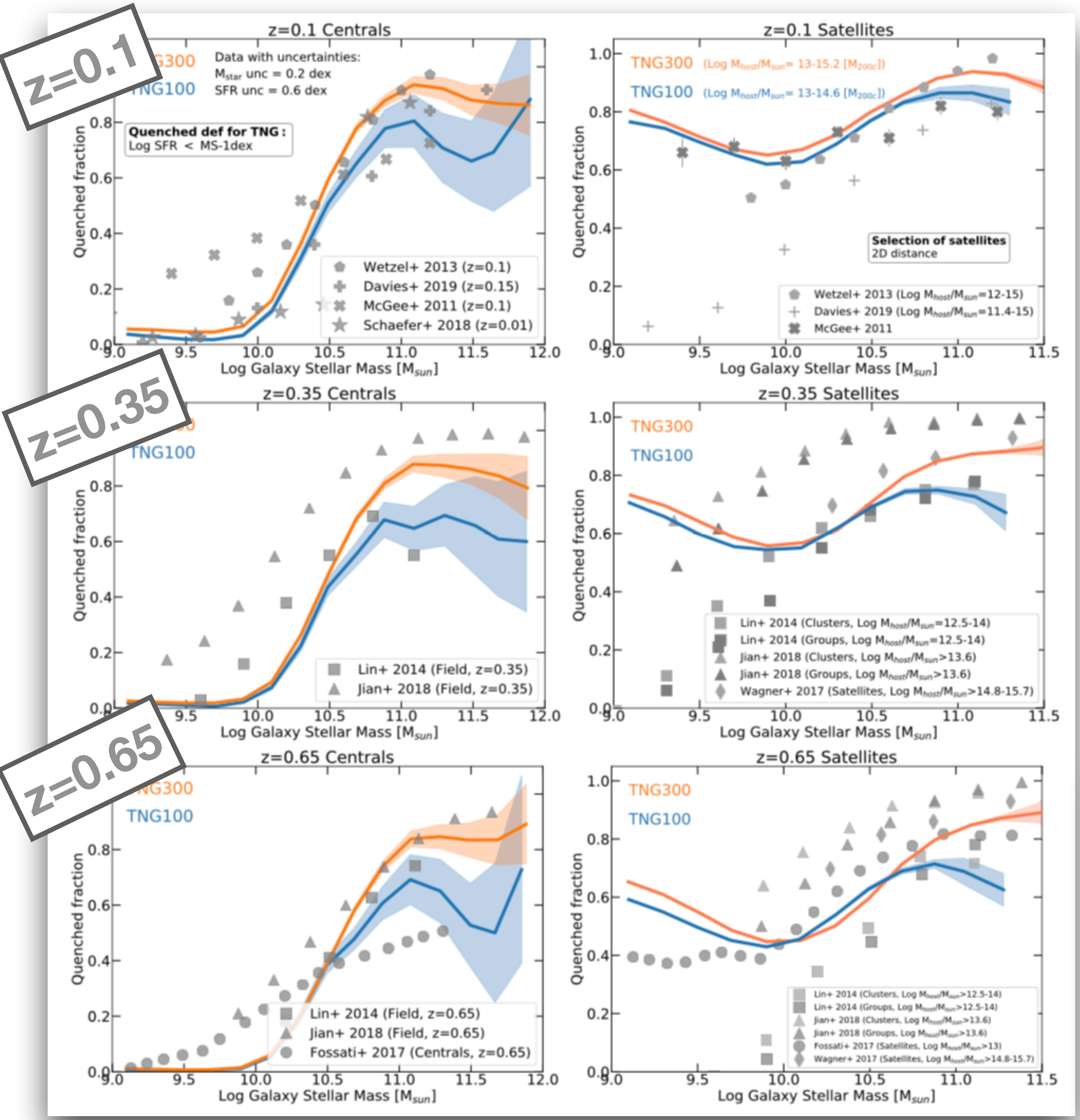
At fixed host mass:
the fraction decreases with the stellar mass

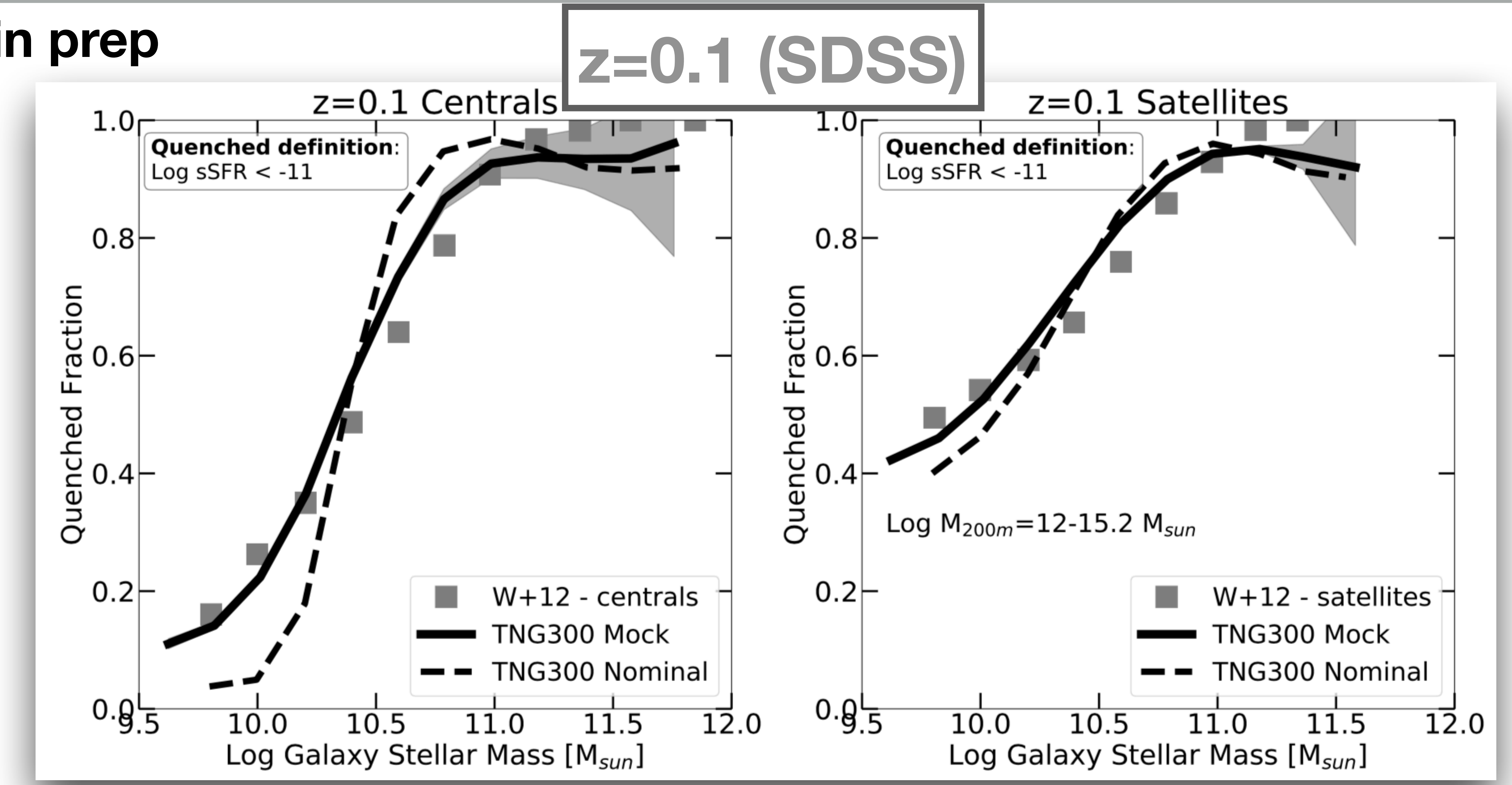
Pre-processing is predominant in clusters compared to low-mass groups and slightly decreases with increasing galaxy stellar mass.

How many z=0 satellites have been pre-processed?

Comparison to observations: validation of the TNG model

Donnari+ in prep





Donnari+ 2019