Cosmological formation of stellar streams

宇宙論的シミュレーションに基づいたストリームの構造形成

Morinaga et al. 2019, MNRAS, 487, 2718

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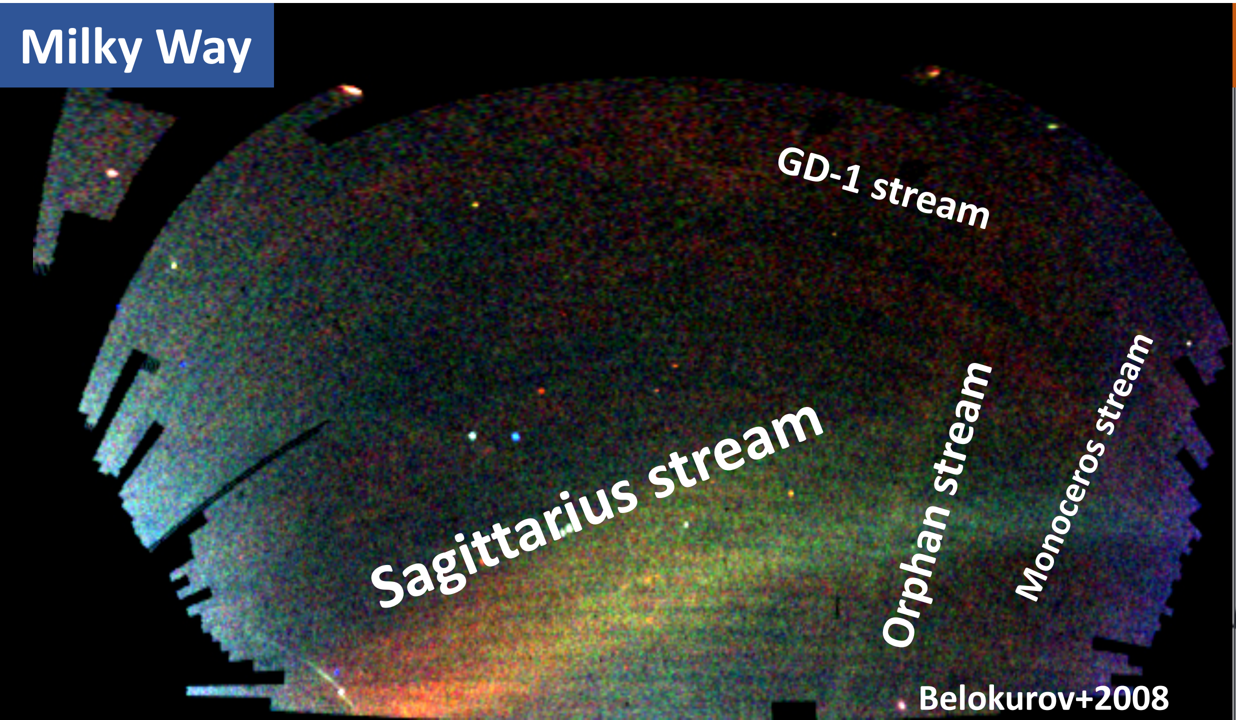
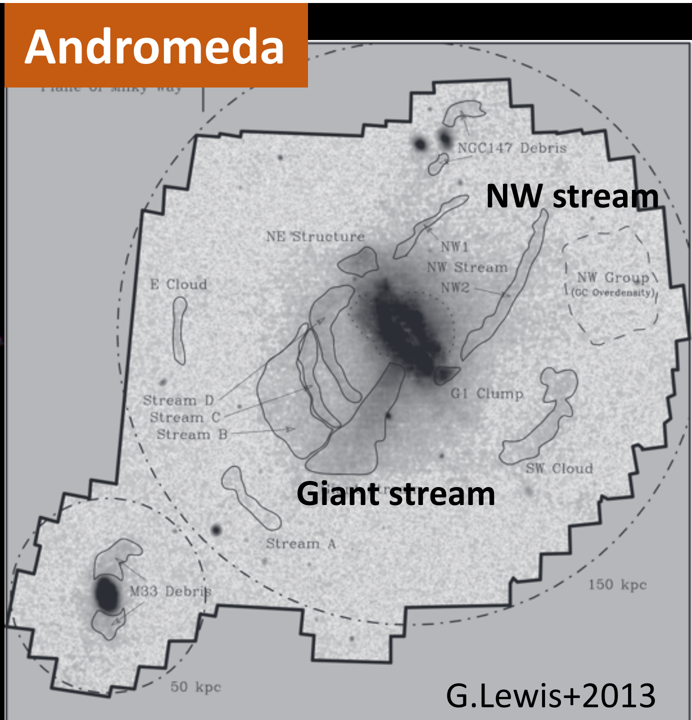
Background

- ➢Recent surveys have been discovering new faint stellar streams.
- ➢Structural properties of stellar streams depend on their progenitor orbits and the environments of their host galaxies
- ➢**Stellar streams are important clues to the formation histories and environments of galaxies**





Motivation

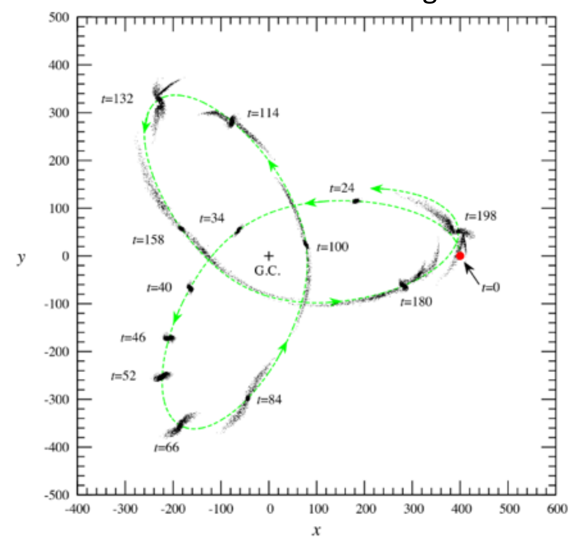
Many early studies…

- *N*-body simulations have been extensively used to reproduce the observed properties and the dynamical evolution of streams.

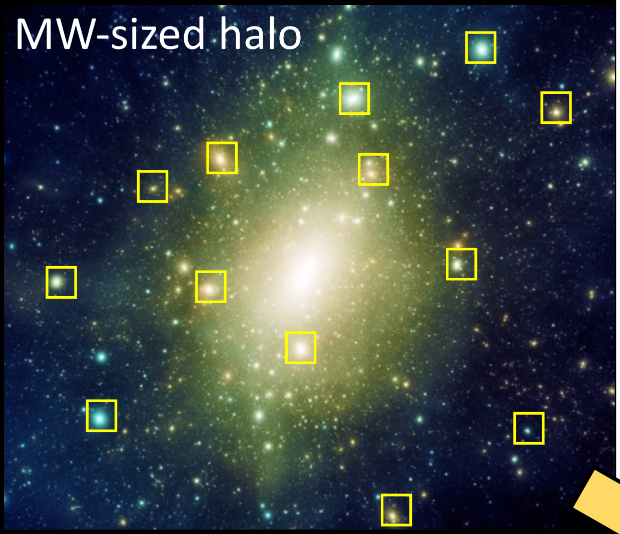
- However in a cosmological context, their dynamical evolution is affected by complicated physics…

For example
- ✦dynamical friction
- ✦multiple interaction
- ✦evolution history of host galaxies

Hozumi et al. 2014 Fig.1



This work – Cosmological *N*-body simulation

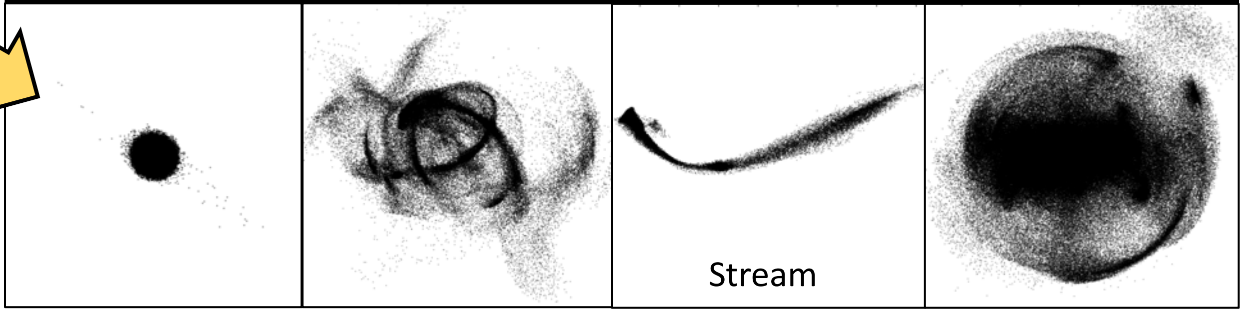


We use high-resolution and large cosmological simulations (Ishiyama et al)

Numerical parameters of cosmological simulations

N_p	L [h^{-1} Mpc]	m_p [$h^{-1}M_{\odot}$]	MW-sized halo
2048^3	8.0	5.13×10^3	9
4096^3	16.0	5.13×10^3	26

Various substructures in cosmological simulations



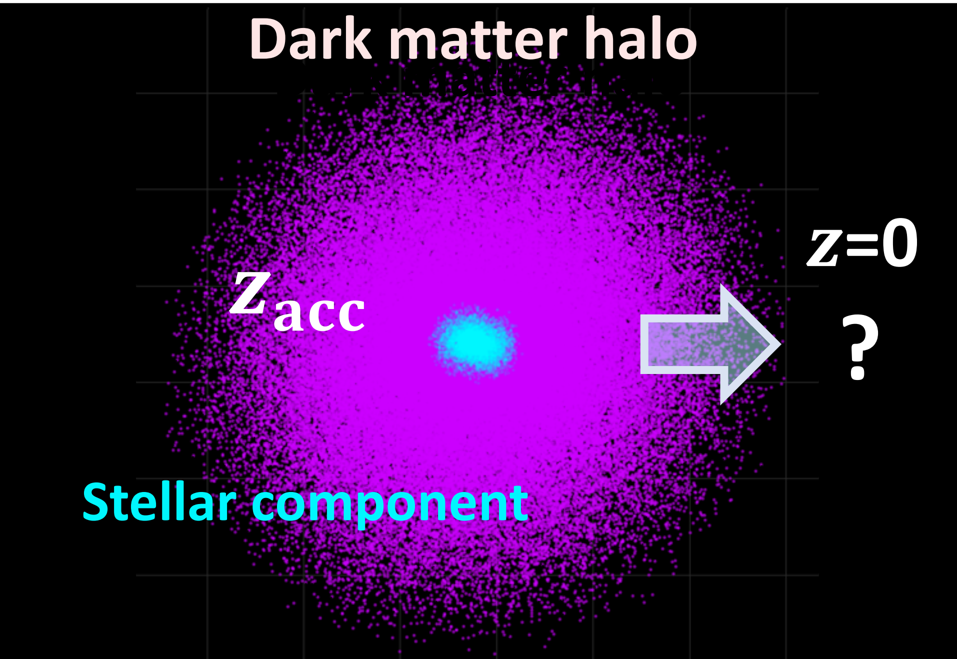
We investigate the relationship between **structural properties** of substructures at z =0 and **orbits** of their progenitors around MW-sized halos in a cosmological context

We also analyzed the relationship between the structural properties of **streams** (**orientation of tidal tails**) and **environments of their host halos** such as shape of underlying gravitational potential.

Semi-analytic model

Particle Tagging

(De Lucia et al. 2008)



z_{acc} ⇒ The redshift when the progenitor of substructure was accreted into the host halo

We treat 10 % of the most-bound DM particles in a progenitor halo at z_{acc} as the stellar component and trace it down to z=0.

A model to assign stellar mass

(Koposov et al. 2009)

$$M_* = \frac{f_* \times (M_{acc} - M_{rei})}{(1 + 0.26(V_{crit}/V_{circ}(z_{acc}))^3)^3} + f_* \times M_{rei}$$

for $V_{circ,r} < 10\ \mathrm{km\ s^{-1}}$

$$M_* = \frac{f_* \times M_{acc}}{(1 + 0.26(V_{crit}/V_{circ}(z_{acc}))^3)^3}$$

,where $V_{crit} = 30\ \mathrm{km\ s^{-1}}$, $z_{rei} = 11$

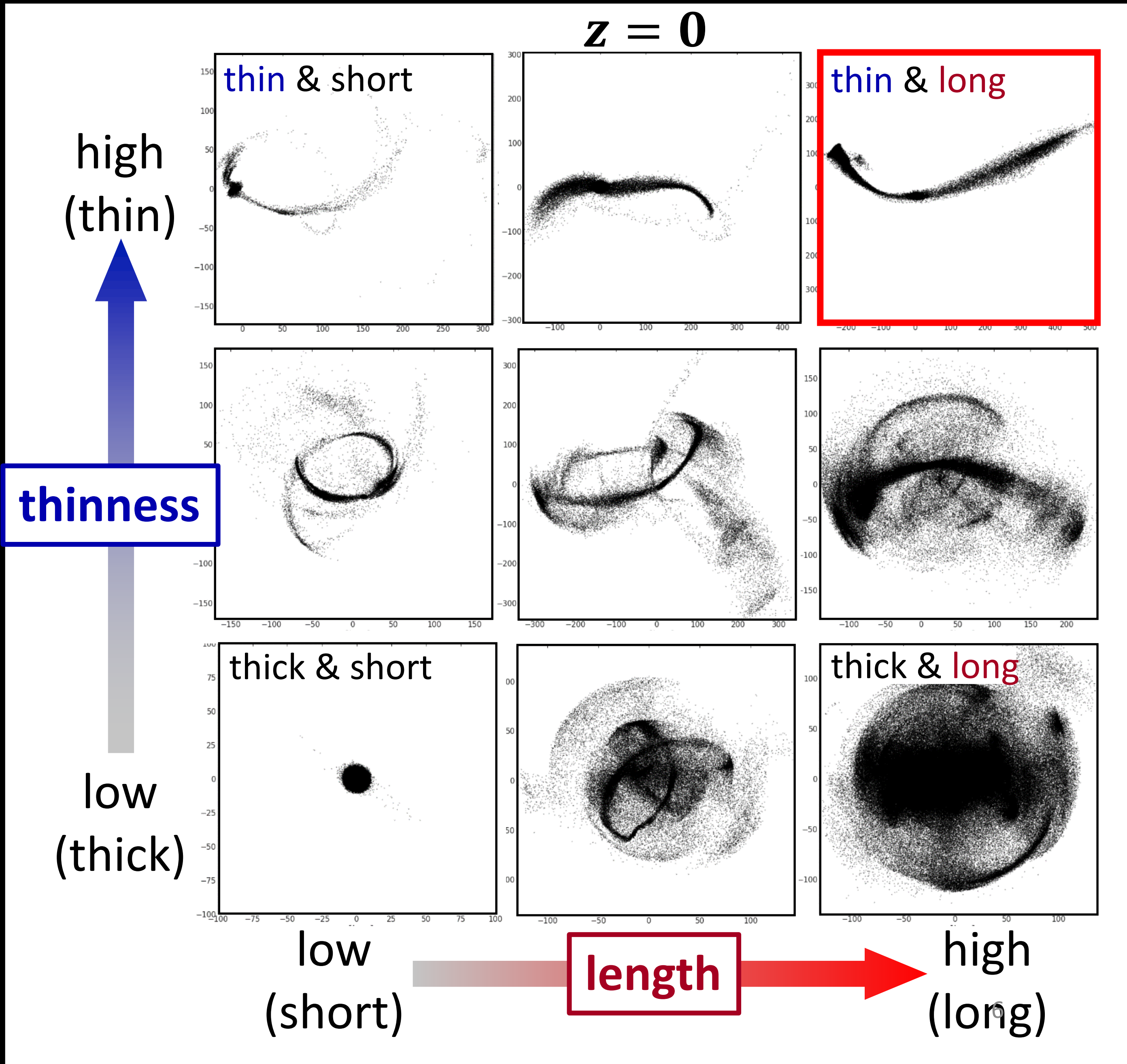
We reproduce the observed stellar mass functions in the MW and M31.
We analyze the substructures with $M_* > 10^4 M_\odot$.

Structural properties of substructures

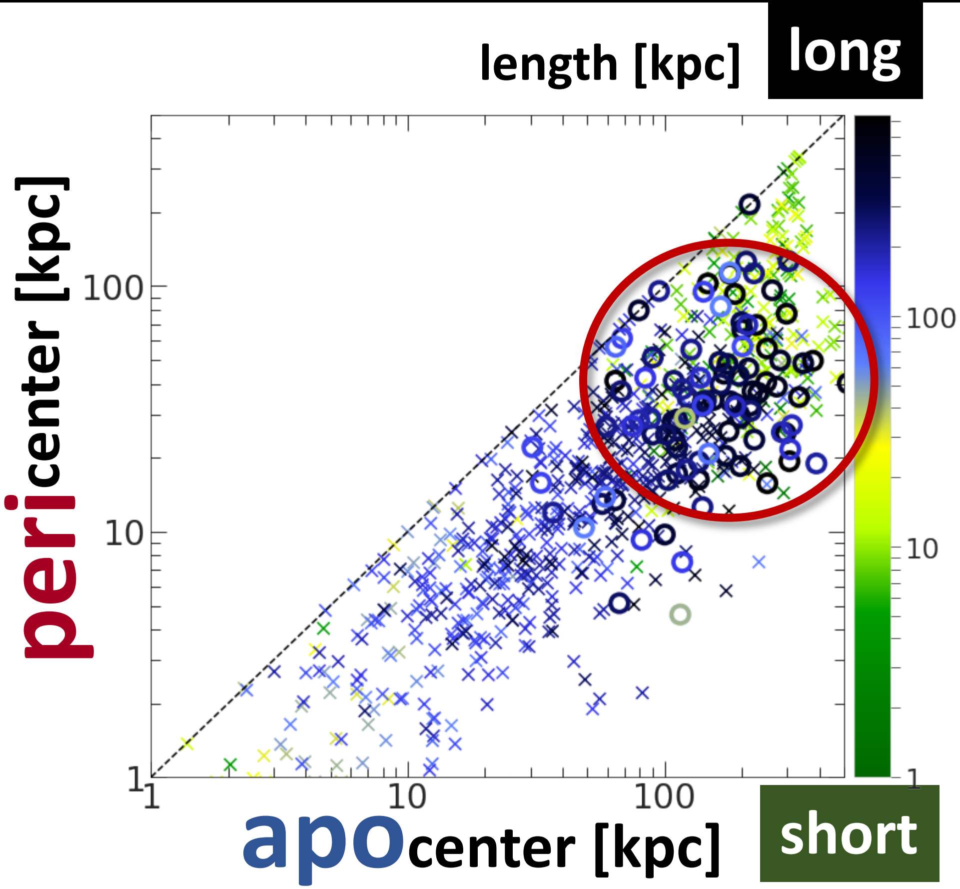
Quantifying structural properties
(Morinaga et al. 2019)

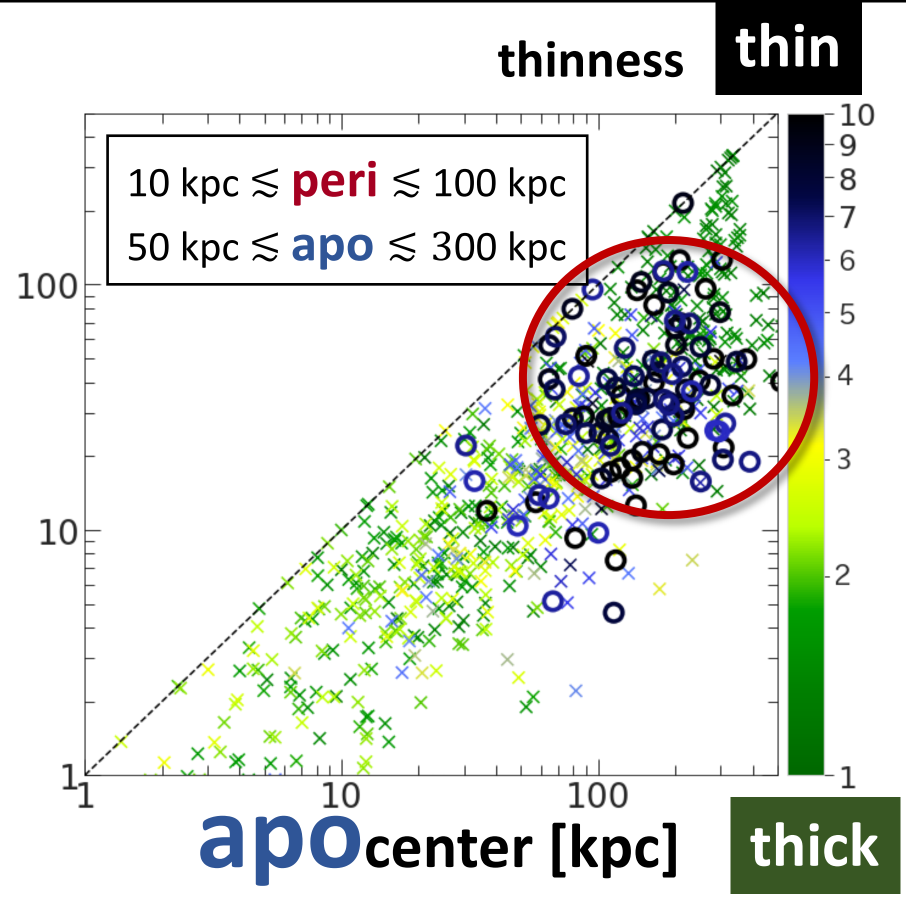
① Length
High ⇒ long
Low ⇒ short

② Thinness
High ⇒ thin
Low ⇒ thick



Orbits - Structures

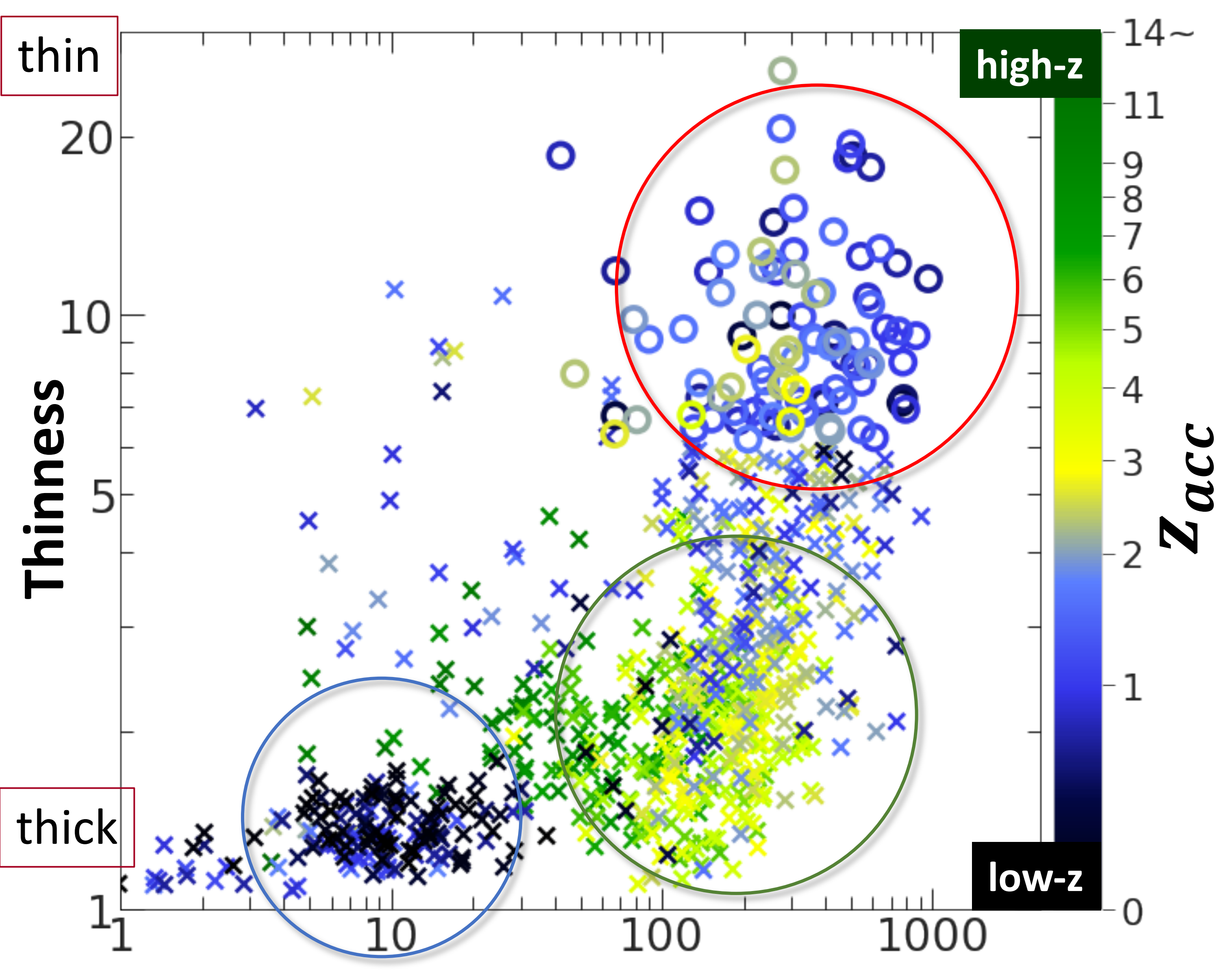


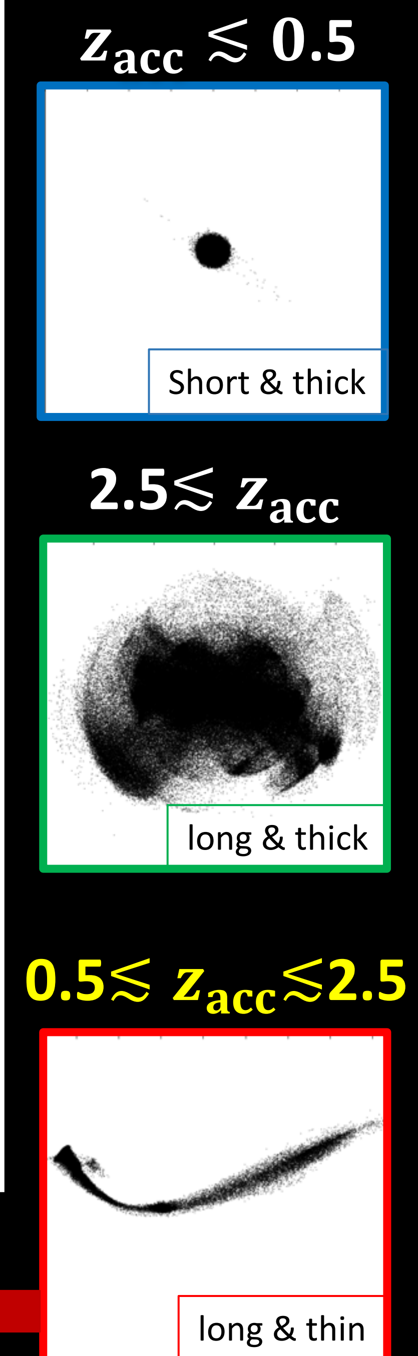


✦It is clear that substructures observed like streams are concentrated in the rather narrow region of the pericenter (10-100 kpc) and apocenter (50-300 kpc) plane.

✦small pericenter and apocenter (< 10 kpc) ⇒ largely disrupted because of strong perturbation

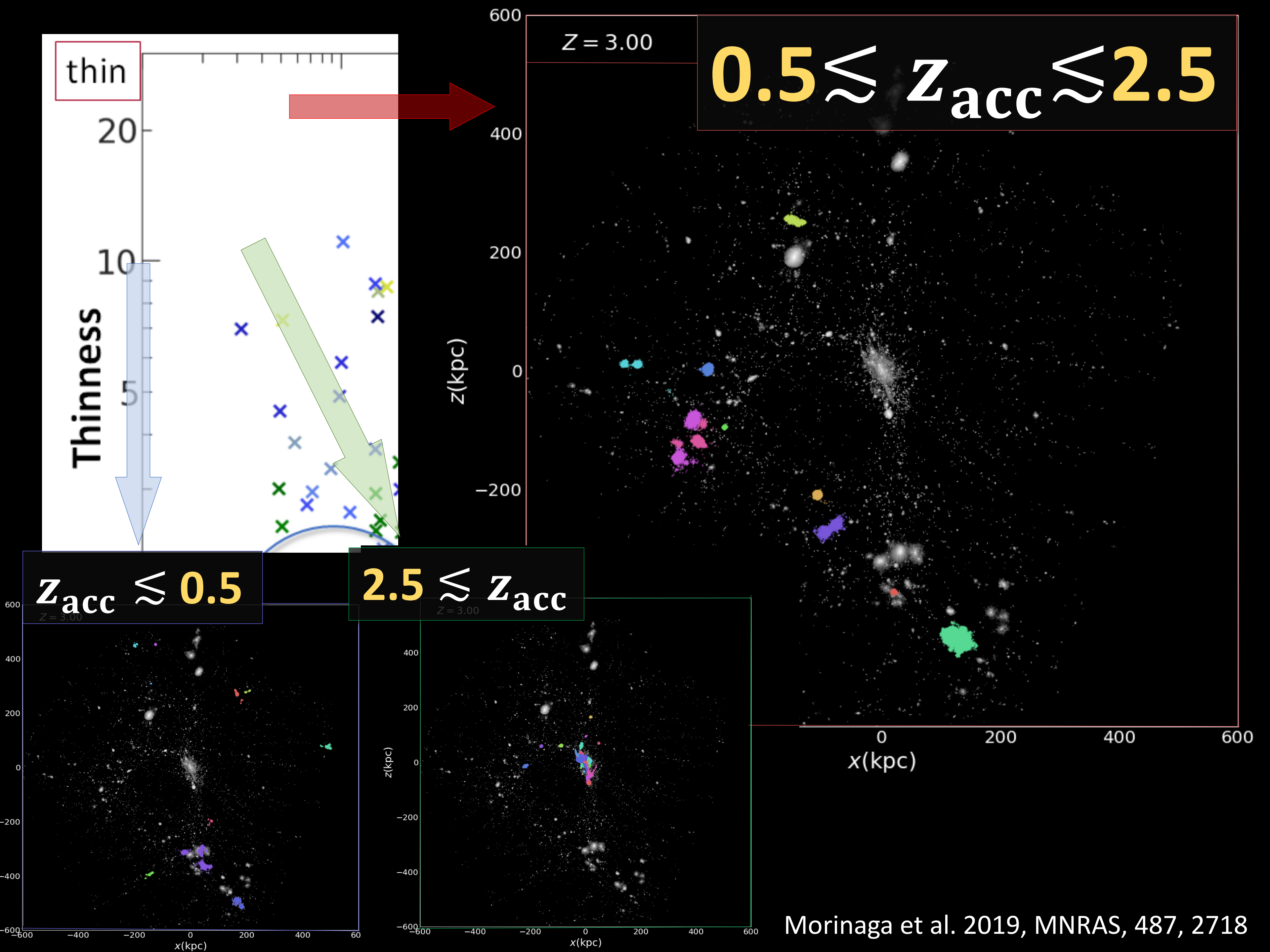
✦large percenter (> 100 kpc) ⇒ less affected by tidal force and keep gravitationally bounded structure





A large part of **streams** $(\sim 90\%)$ is accreted by their hosts within

$$0.5 \lesssim z_{acc} \lesssim 2.5$$



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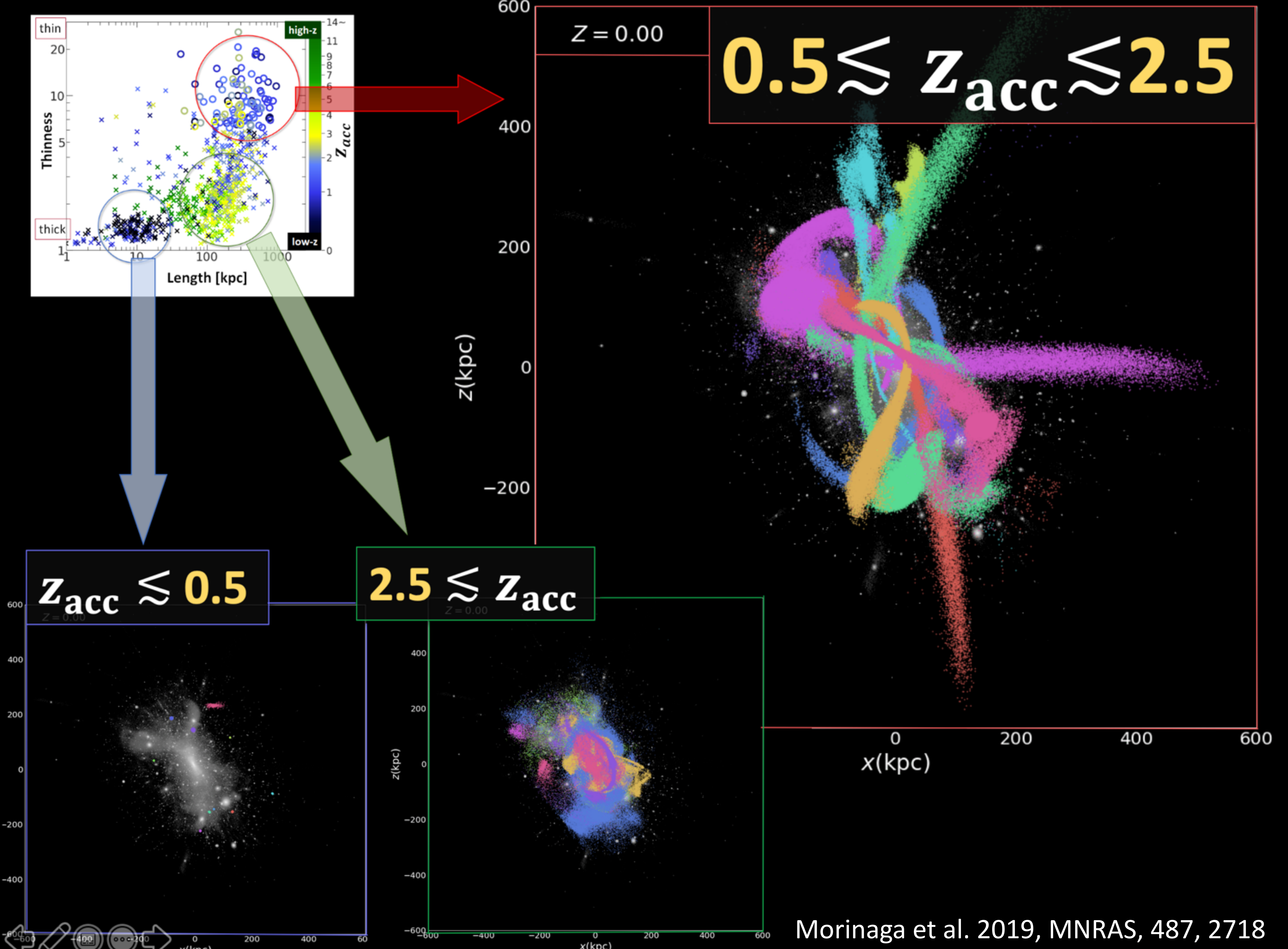

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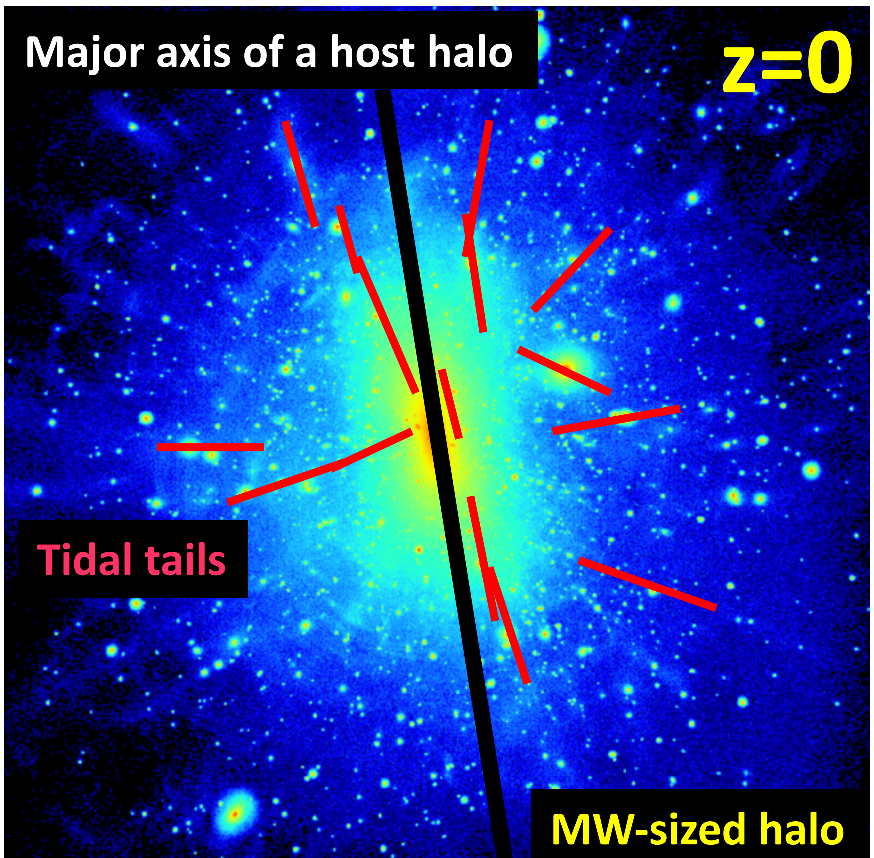
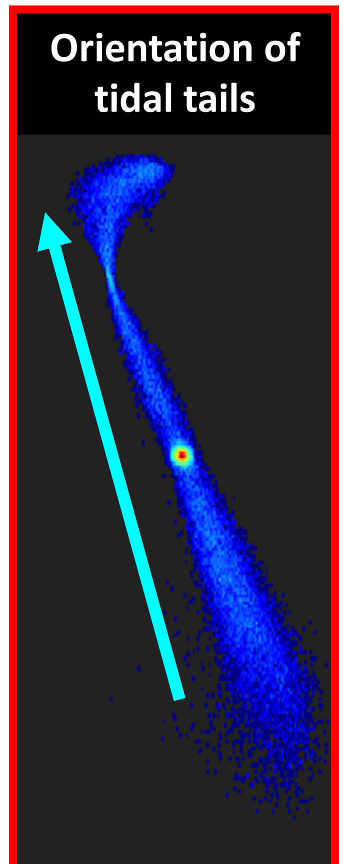
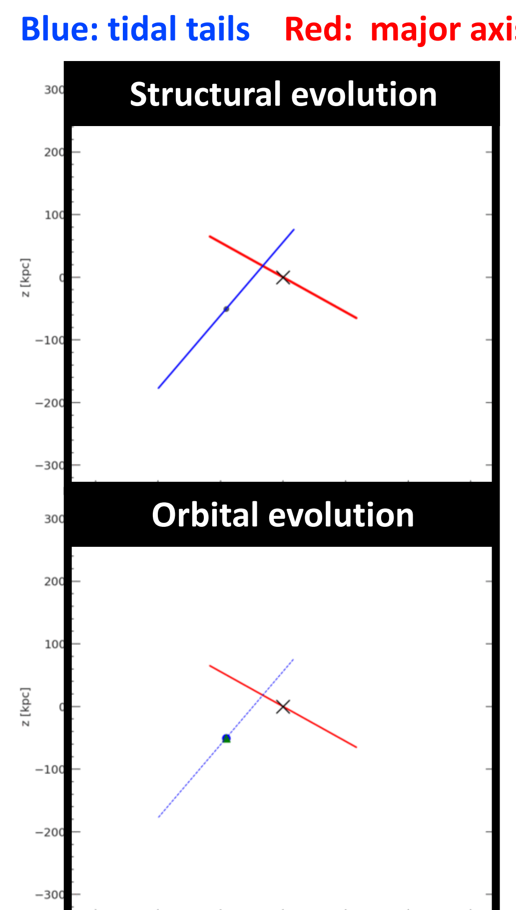
Relationship between the major axis of host halos and tidal tails of streams

- Identifying the major axis of MW-sized haloes at z=0
- Picking up only streams from various substructures and Identifying the orientation of tidal tails by using the stellar particles of the streams at z=0
- Quantifying the angle between the major axis of host and tidal tails of streams



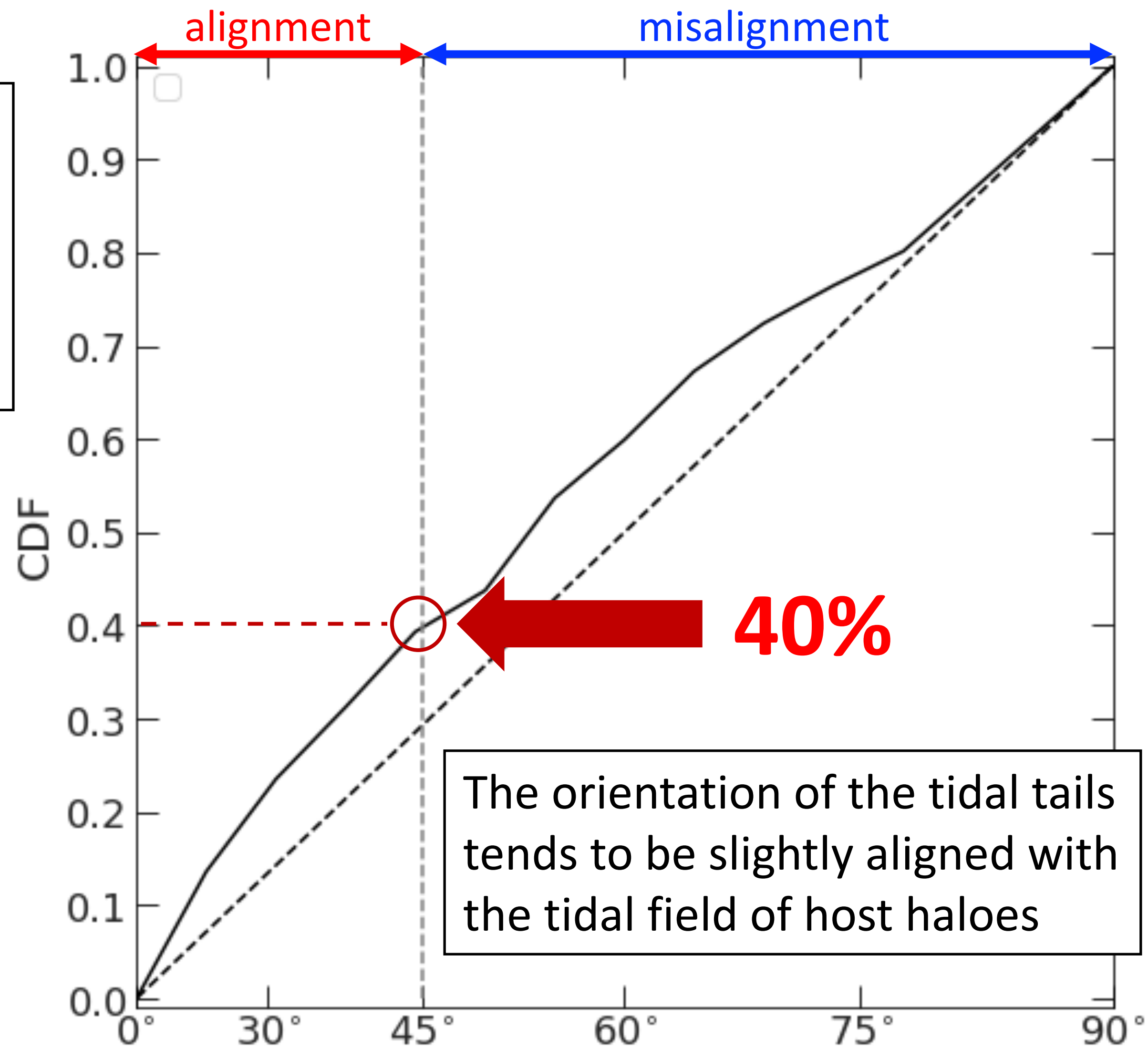




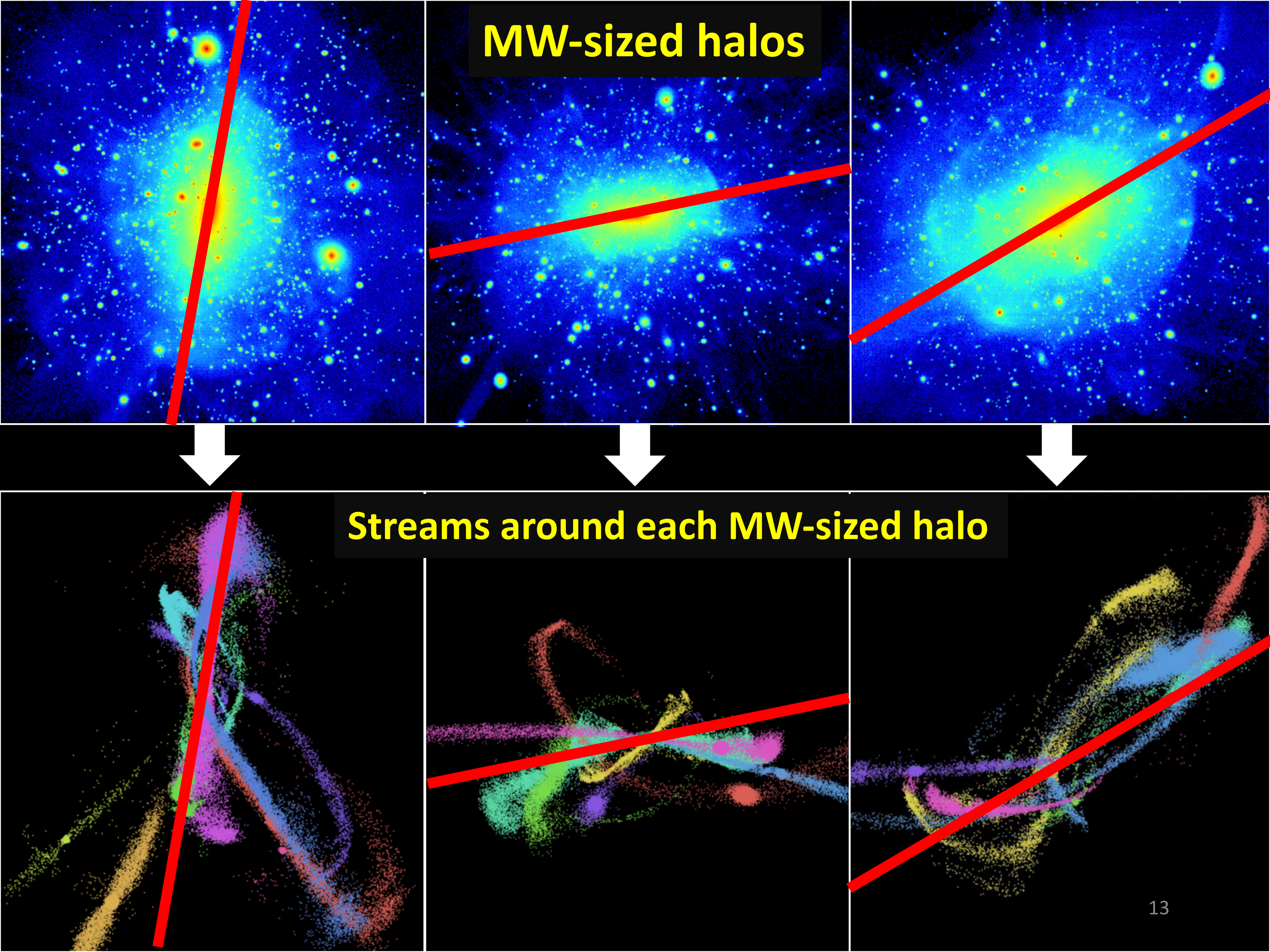
Stream alignments with major axis of host haloes

40% of all streams are aligned with the major axis of their host halos

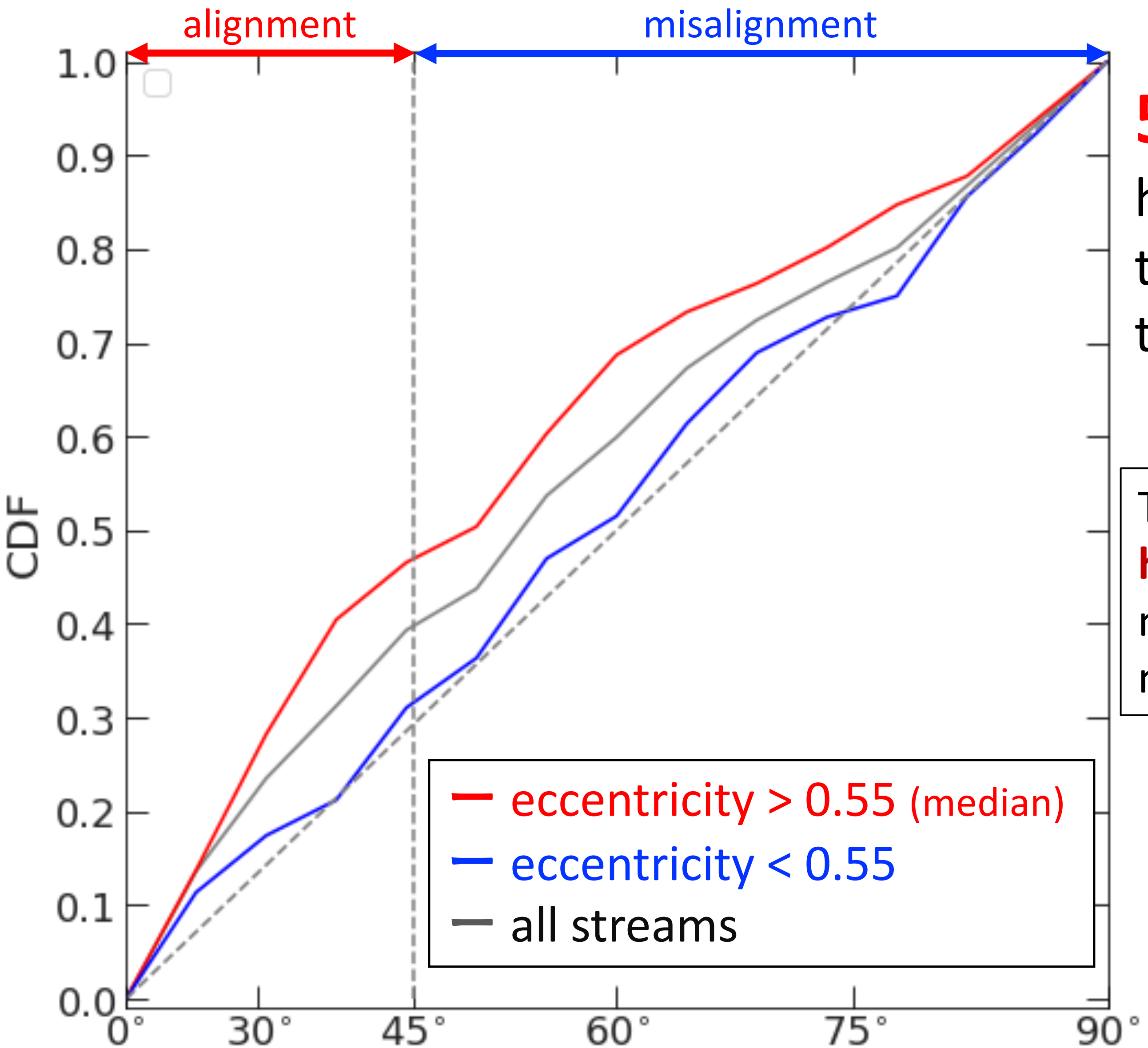
Sample size:
282 streams around
26 MW-sized haloes
in a cosmological simulation
at z=0



The angle between tidal tails and major axis of host haloes


MW-sized halos
Streams around each MW-sized halo

The effect of eccentricity on stream alignment

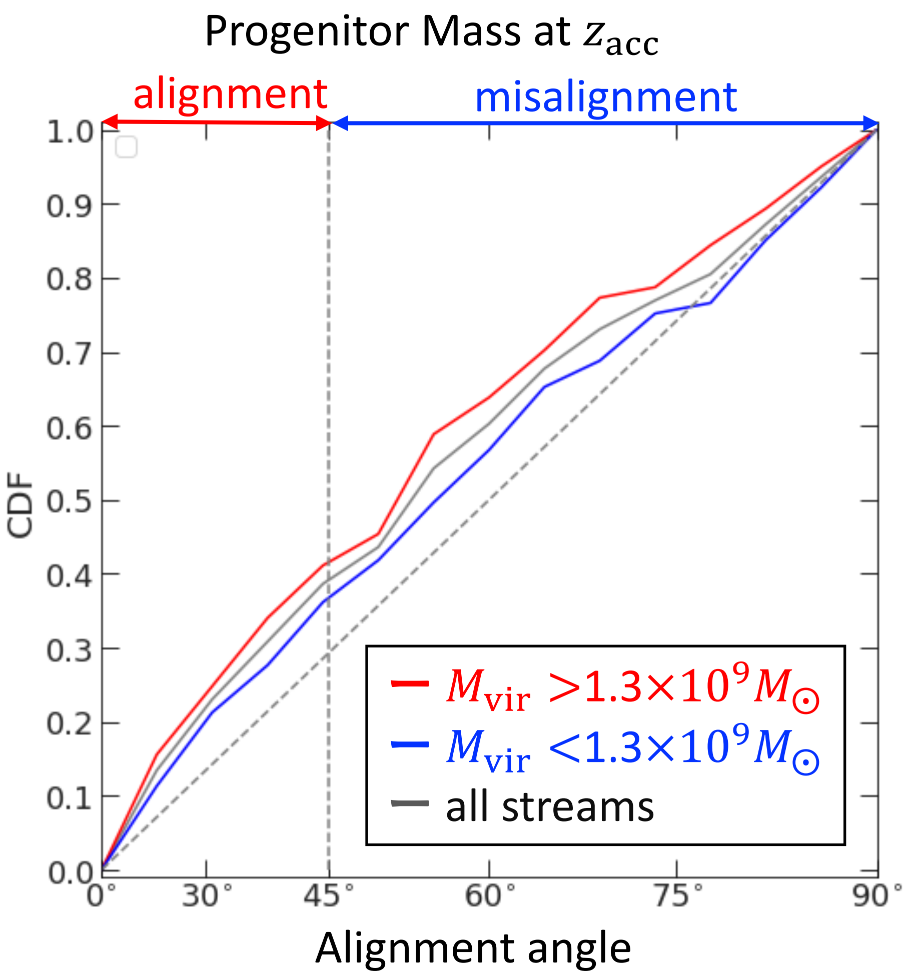


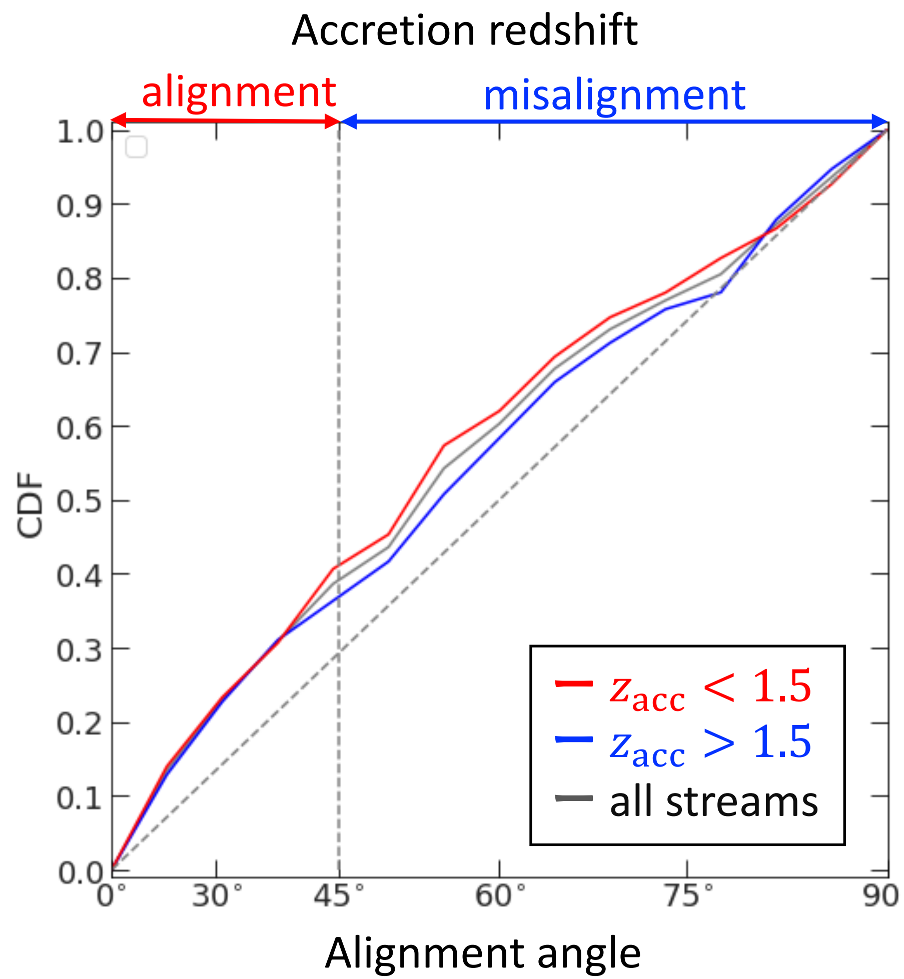
The angle between tidal tails and major axis of host haloes

50% of streams with high-eccentricity tend to be aligned with their host halos

Tidal tails of streams on **high-eccentricity orbits** are more strongly aligned with major axis of host halos

The effect of mass and accretion redshift on stream alignment





Streams with **high-mass** or **low-z_{acc}** are more strongly aligned with major axis

The effect of cosmic filament on stream alignment

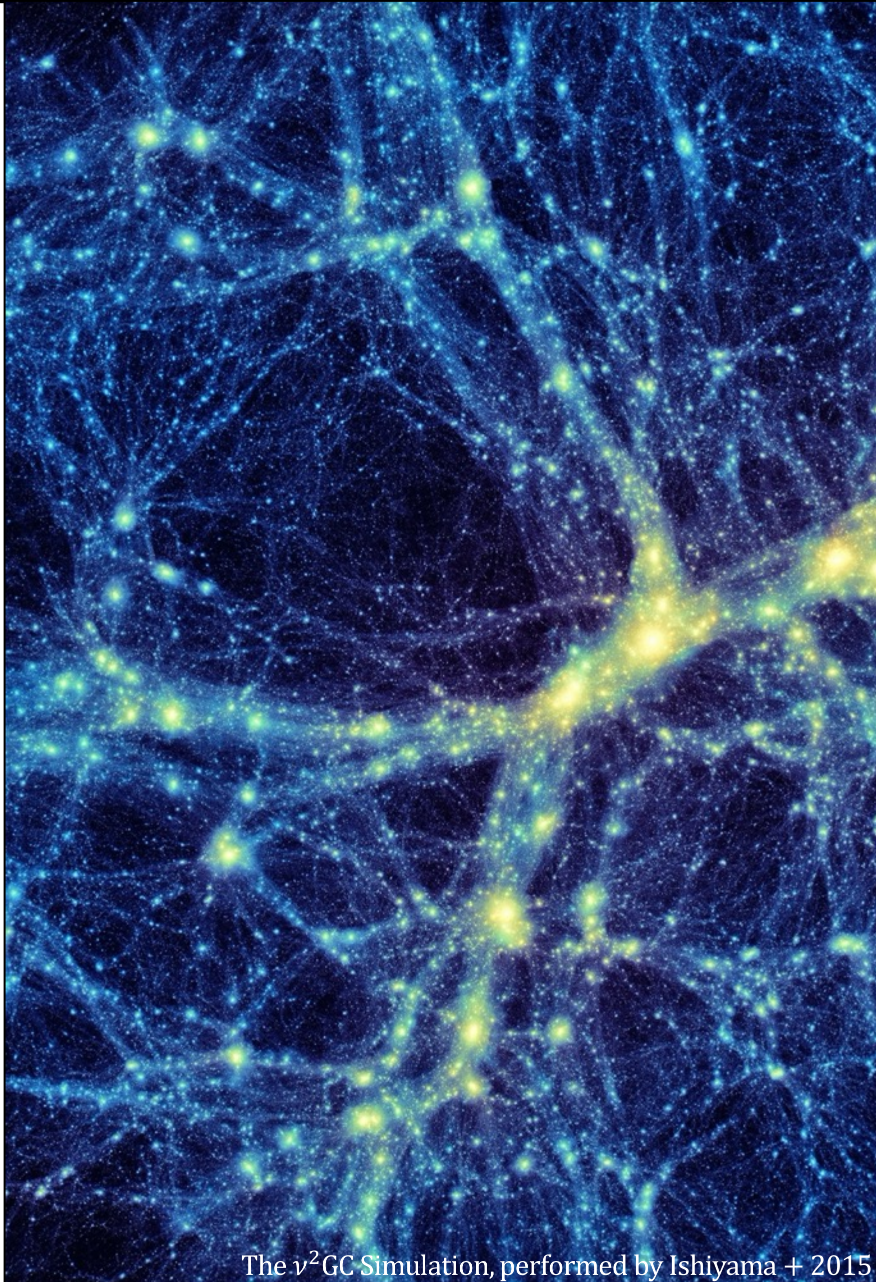
Some properties of subhalos accreted into a host halo along cosmic filaments

- Their entry points tend to be aligned with the major axis of their host halos
- Their orbits tend to be more eccentric
- Accretion redshift tends to be low
- Masses tend to be high

(Libeskind+2014,Gonzalez+2016, Veena+2018…)

In this work, streams originating in progenitors with such properties are preferentially aligned with major axis of their host haloes.

⇨ Cosmic filaments may affect the stream alignment with shape of their host haloes



The ν^2GC Simulation, performed by Ishiyama + 2015

Summary

We can infer the evolution of properties of stellar streams in terms of accretion redshift, orbital parameters and the relationship with environments of their host haloes in cosmological simulations.

✦ A large part of streams **($\sim$90%)** is accreted by their host within **$0.5 \lesssim z_{\mathrm{acc}} \lesssim 2.5$.**

✦ Streams are concentrated in the narrow region of **pericenter (10-100 kpc)** and **apocenter (50 – 300 kpc)** plane

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✦ **40%** of all streams are aligned with the major axis of their host halos

✦ Streams with **high-eccentricity**, **high-mass** or **low- z_{acc}** are preferentially aligned with the major axis of their host halos

※z_{acc} ⇒ The redshift when the progenitor of substructure is accreted into their host