# Statistical properties of substructures around MW-sized halos and their implications for the formation of stellar streams


Yu Morinaga (Chiba University, M2)

Collaborators: Tomoaki Ishiyama, Takanobu Kirihara, Kazuki Kinjo (Chiba University)


Based on:

Yu Morinaga et al, 2019 (accepted, MNRAS, arXiv 1901.04748)

6th Galaxy evolution workshop 2019 @ KAVLI IPMU - June 5th

# **Background –** Substructures around galaxies




国立天文台4次元デジタル宇宙プロジェクト

- Galaxies are formed via hierarchical mergers
- Tidally disrupted remnants including stellar streams are formed around galaxies

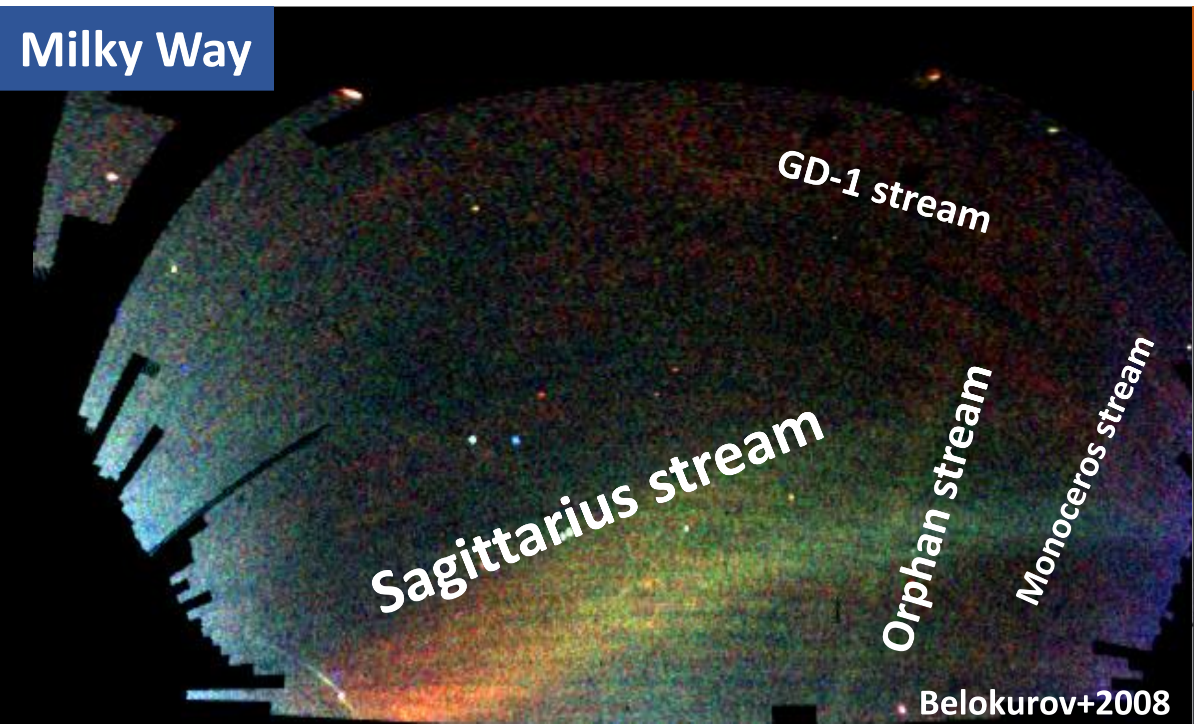
# **Background** – Substructures around galaxies

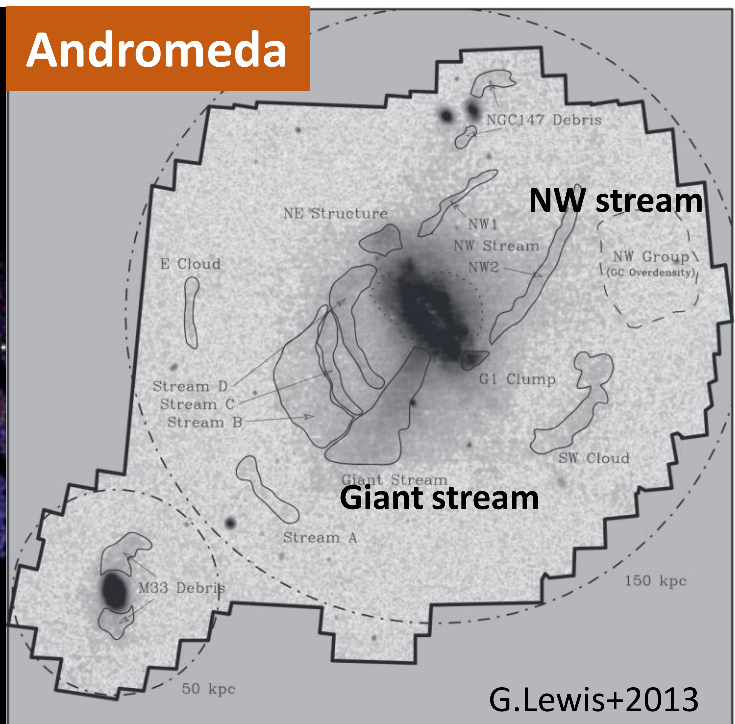


- Recent surveys have been discovering new faint stellar streams.

- Tidally disrupted remnants including **stellar streams** inform us their accretion history.

- **Stellar streams are important clues to galaxy formation history**



# Motivation

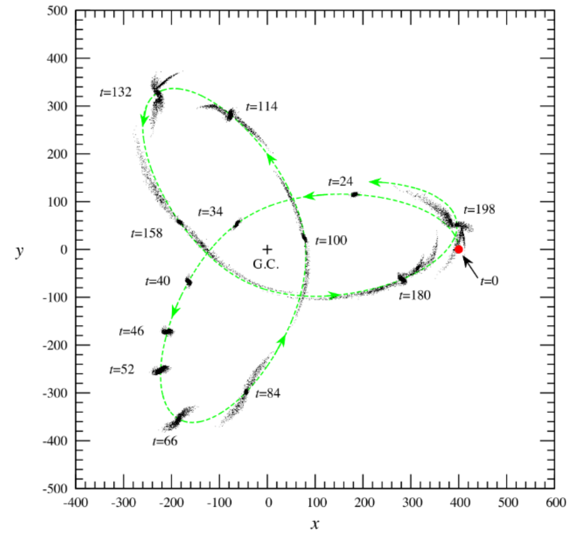


## Many early studies…

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




**We need to investigate the relationship between structural properties of substructures and orbits of their progenitors within**

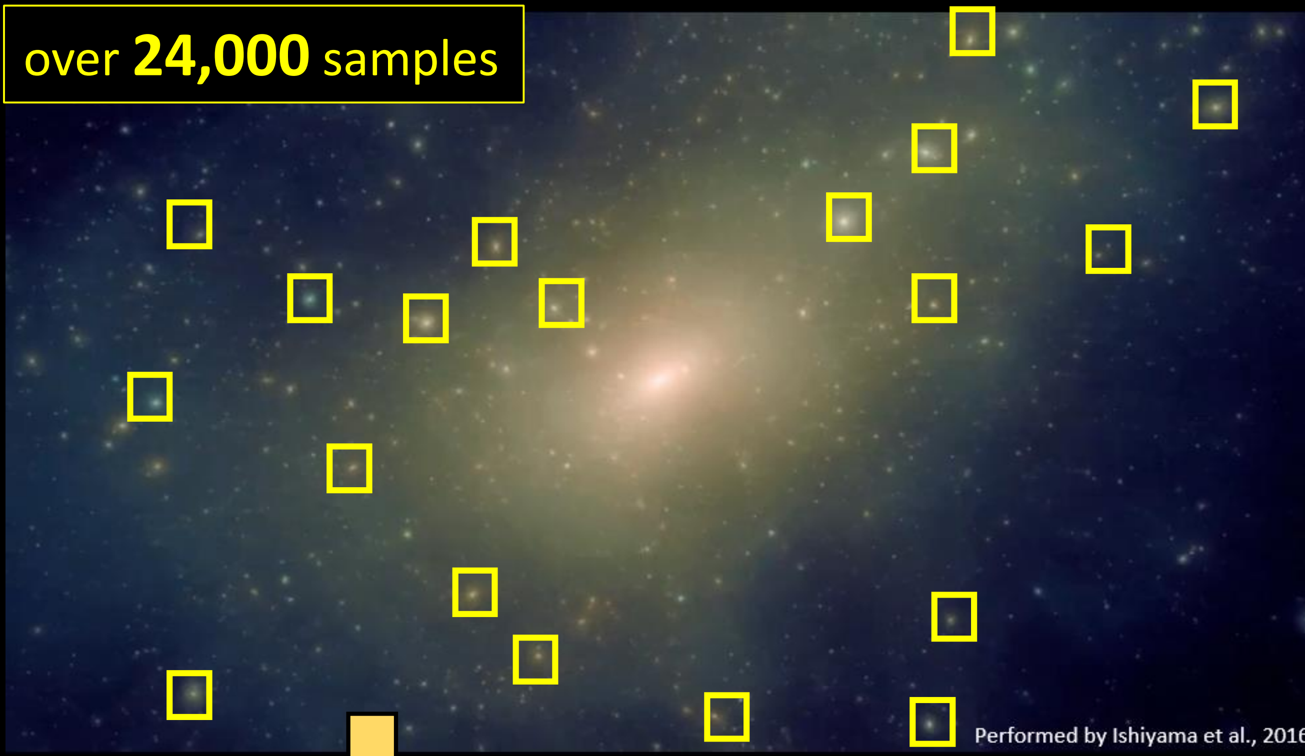
**Cosmological context**

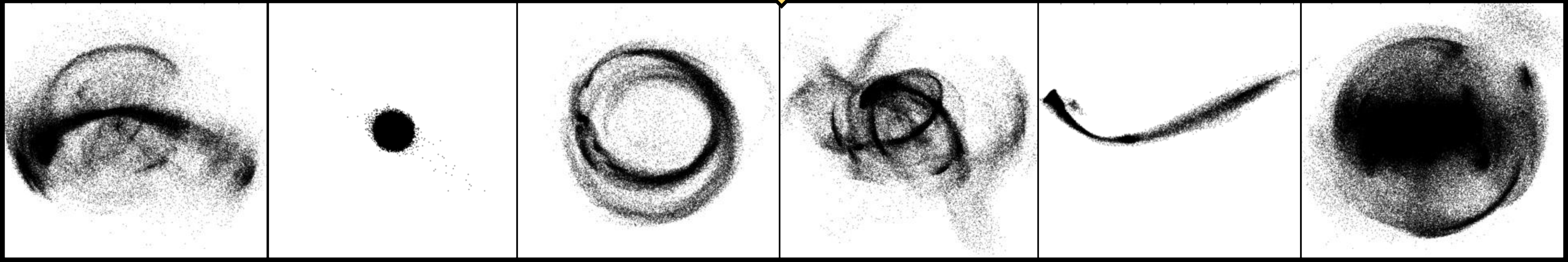
# This work – Cosmological N-body simulation



We use a high-resolution cosmological simulation (Ishiyama et al. 2016)

- Particles: $2048^3$
- Boxsize: 8 Mpc/h
- $m_{\mathrm{p}}$: $5.13 \times 10^3$ Msun/h
- Softening: 120 pc/h
- Nine MW-sized halos



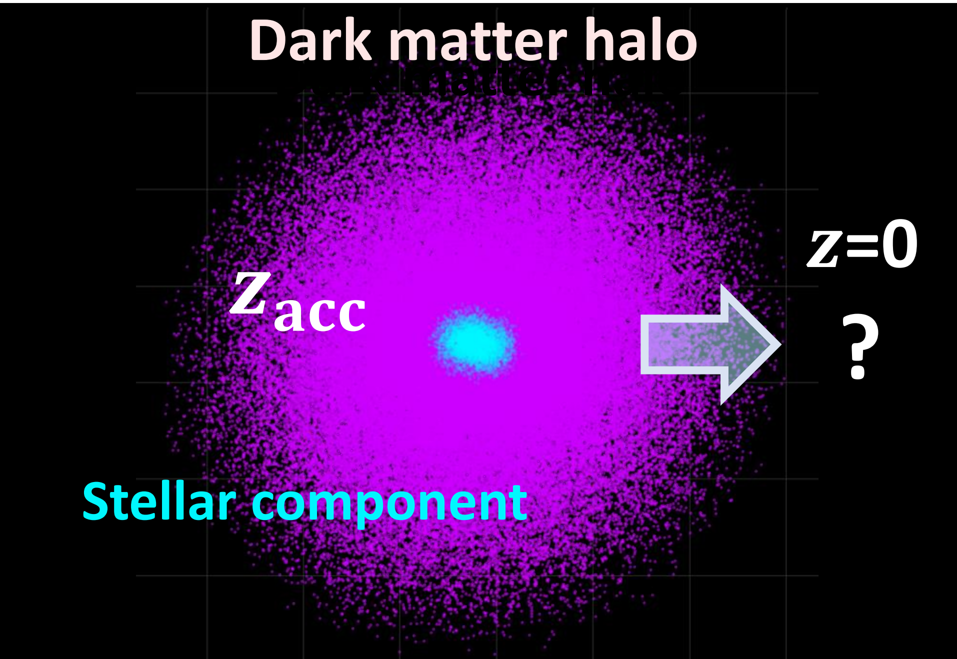
We investigate the relationship between **structural properties** of substructures at z =0 and **orbits** of their progenitors

# 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 $V_{circ,r} < 10 \text{ km s}^{-1}$

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

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

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

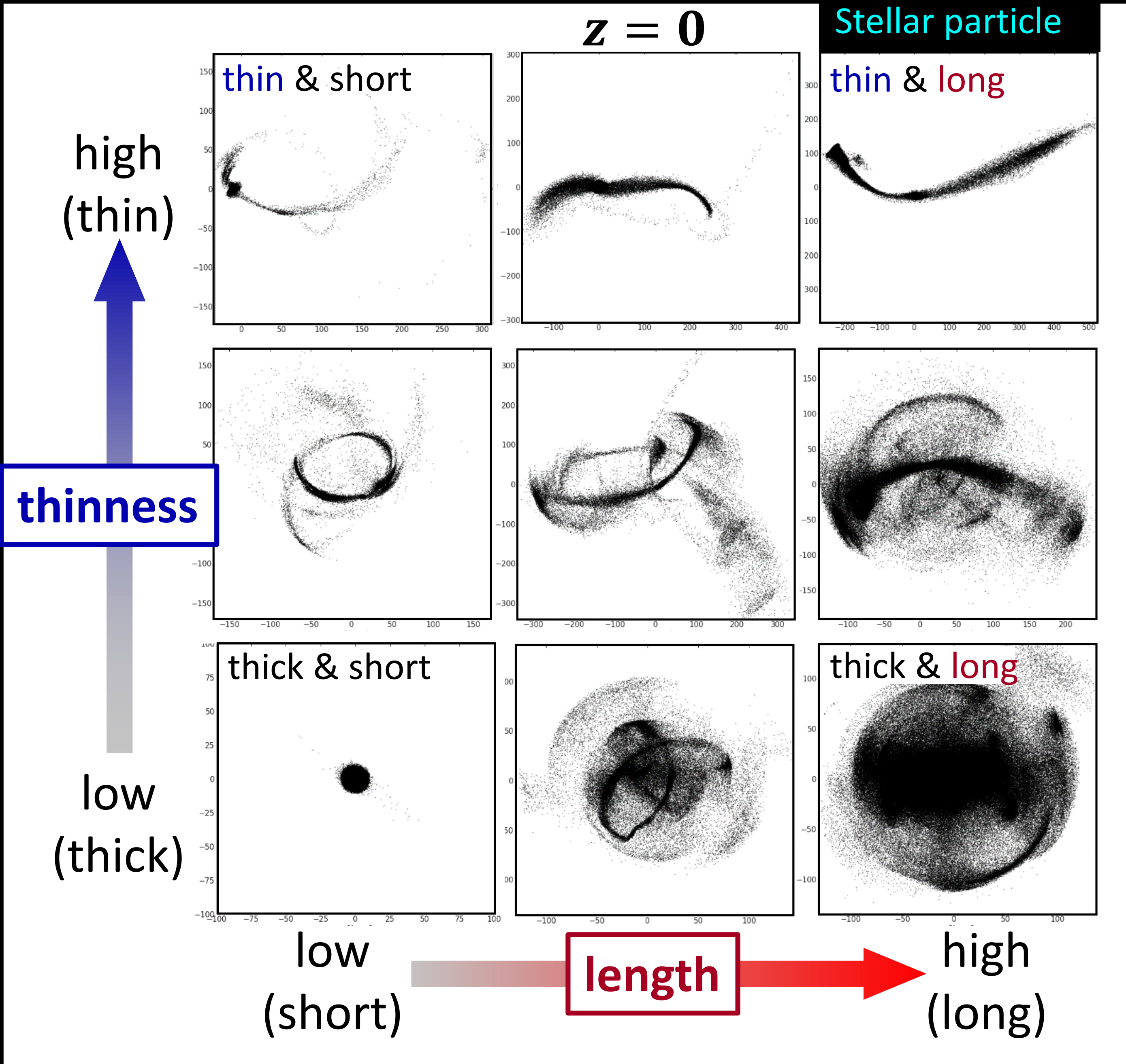
# Structural properties of substructures



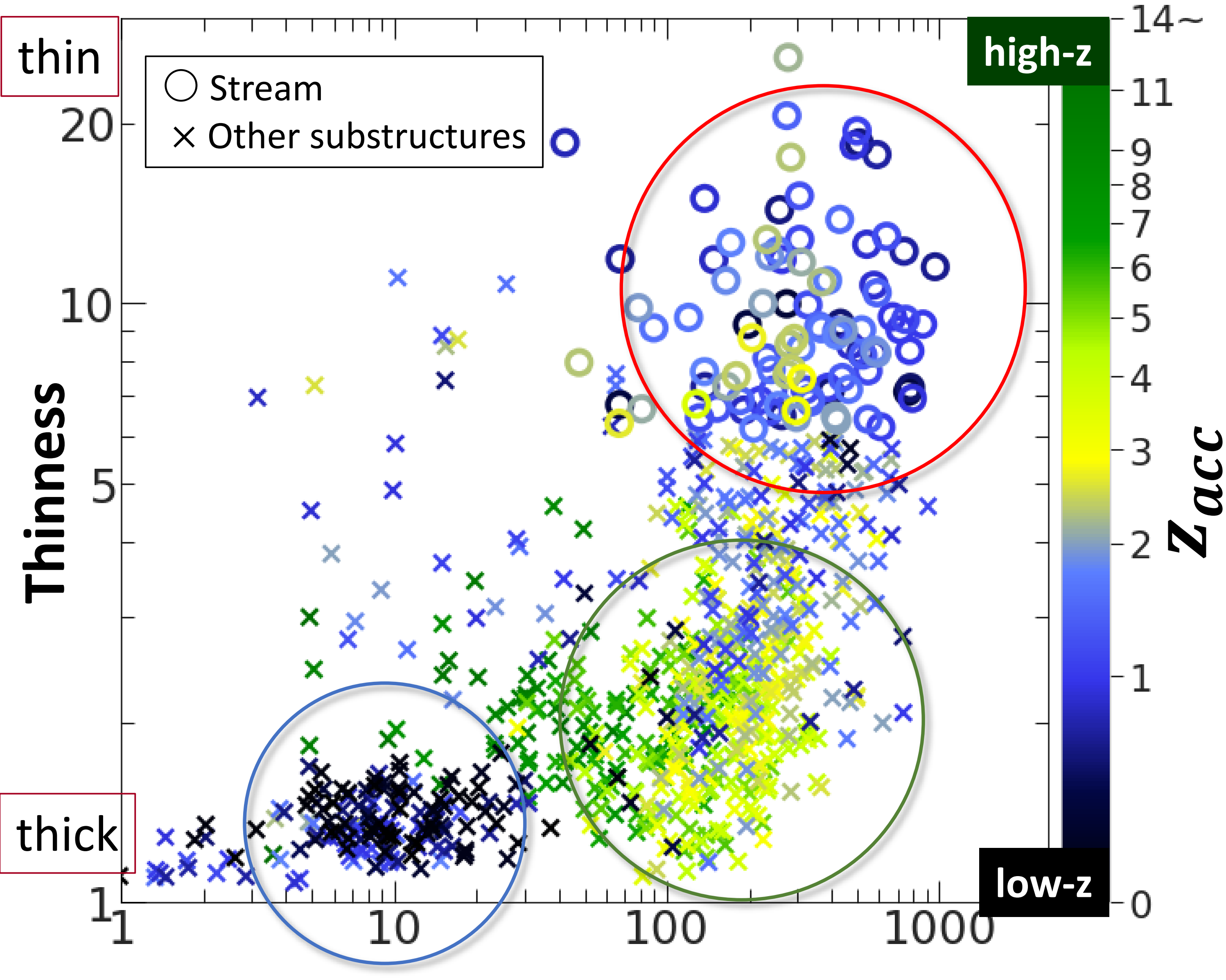
Quantifying structural properties with

**① Length**
High ⇒ long
Low ⇒ short

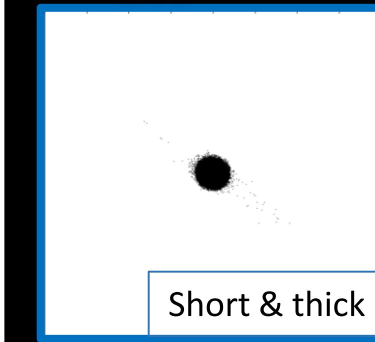
**② Thinness**
High ⇒ thin
Low ⇒ thick



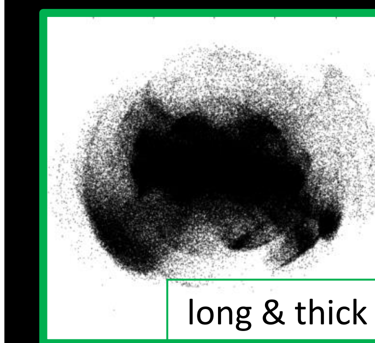
# Result




$z_{acc} \lesssim 0.5$



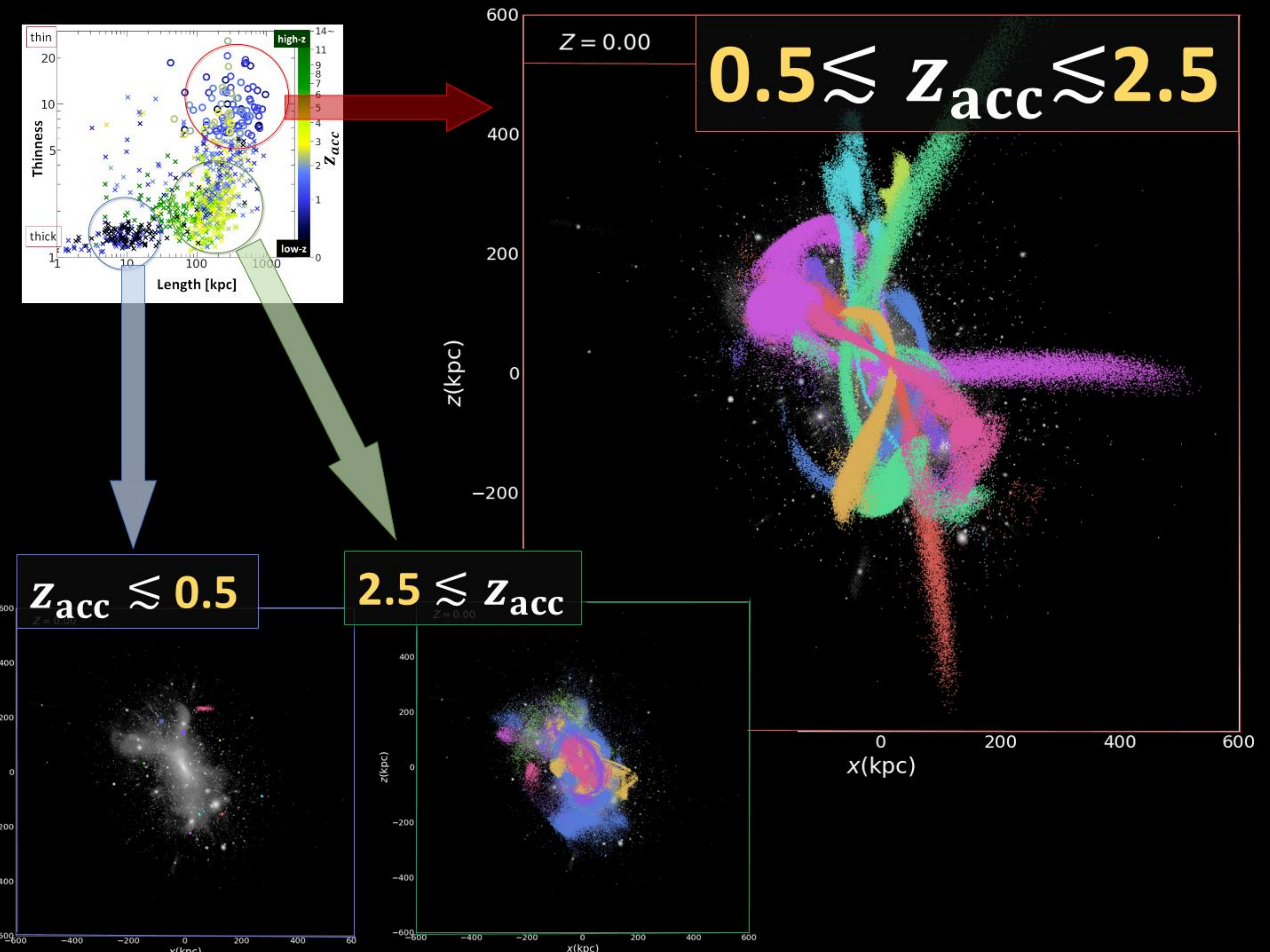

$2.5 \lesssim z_{acc}$




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


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

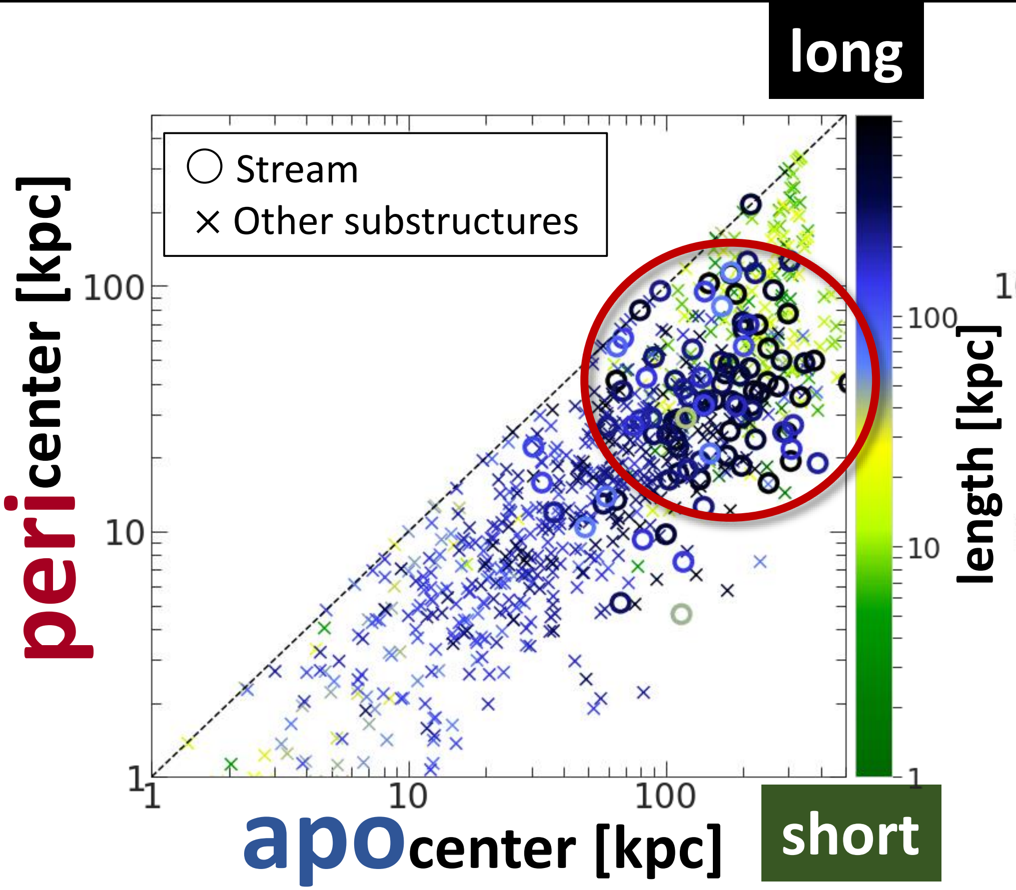
**$0.5 \lesssim z_{acc} \lesssim 2.5$**

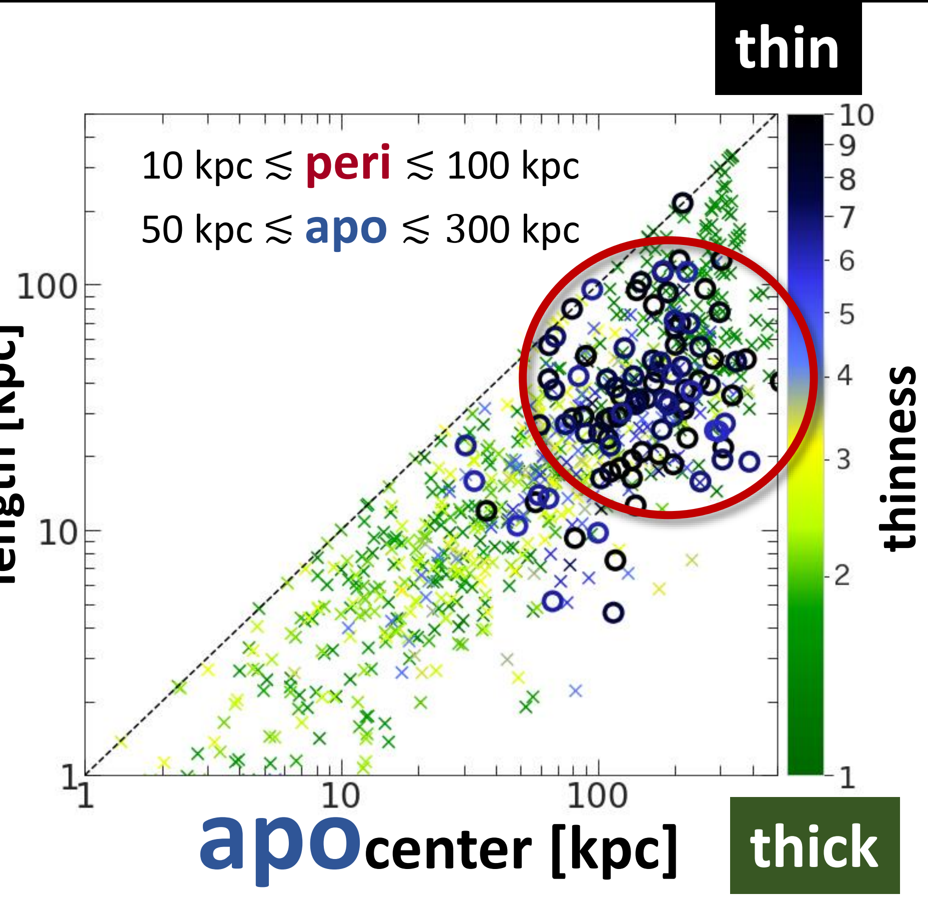


thin
thick
Thinness
Length [kpc]
high-z
low-z
$z_{acc}$
Z = 0.00
$0.5 \lesssim z_{acc} \lesssim 2.5$
z(kpc)
x(kpc)
$z_{acc} \lesssim 0.5$
$2.5 \lesssim z_{acc}$

# 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 pericenter (> 100 kpc) ⇒ less affected by tidal force and keep gravitationally bounded structure

# Summary



We can infer the evolution of properties of substructures in terms of accretion redshift and orbital parameters by using cosmological simulation.

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

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

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

✦ Substructures with high-$z_{\mathrm{acc}}(> 2.5)$ suffer from strong tidal forces
⇒ They are entirely disrupted and their stellar components are well-mixed

✦ Substructures with low-$z_{\mathrm{acc}}(< 0.5)$ are less affected by the tidal forces and keep larger pericenter and apocenter
⇒ They also keep their gravitational bound structures

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