Statistical properties of substructures around MW-size halos and their implications for the formation of stellar stream

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Stellar Archaeology as a Time Machine to the First Stars
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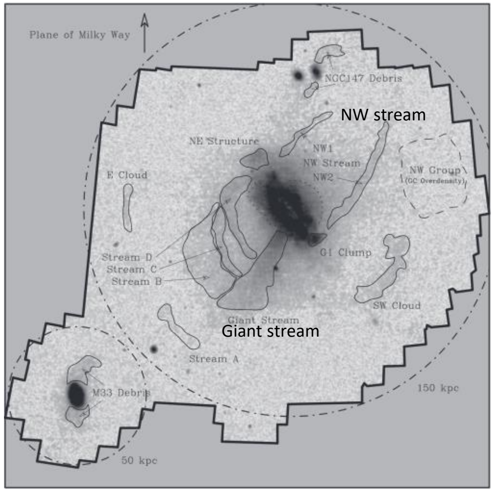
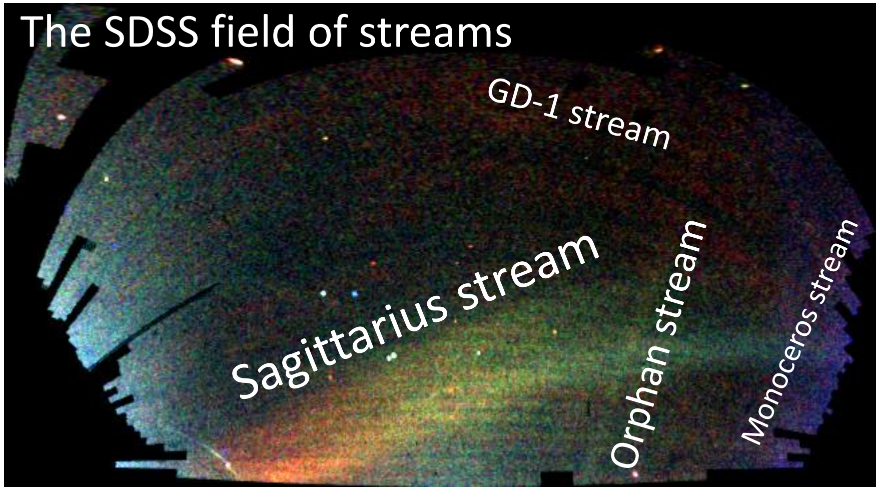
Introduction

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



G.Lewis+2013



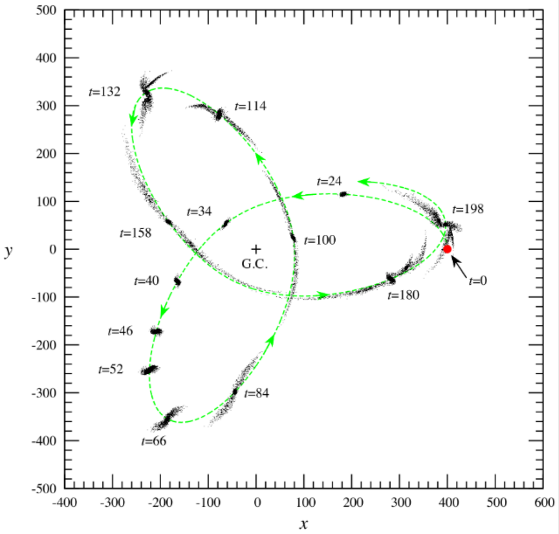
Belokurov+2008

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**



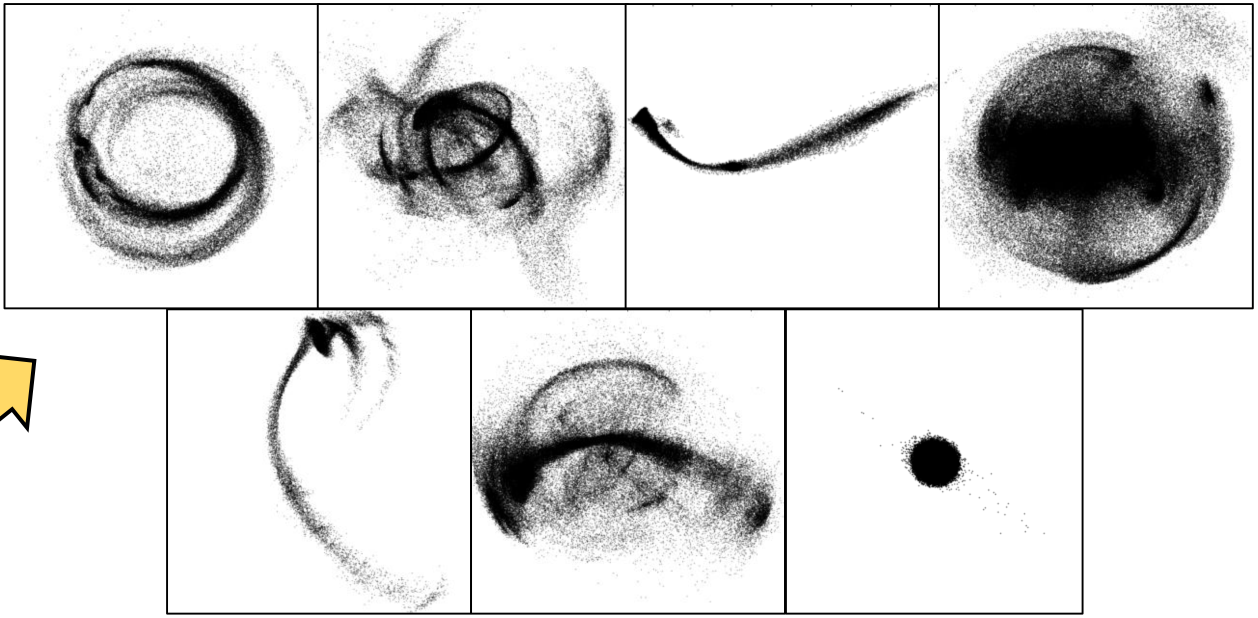
Hozumi et al. 2014 Fig.1

This work

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

- **Particles: 2048^3**
- **Boxsize: 8 Mpc/h**
- **m_p: 5.13×10^3 Msun/h**
- **Softening: 120 pc/h**
- **Nine MW-sized halos**

How are these various substructures formed until z=0 in cosmological simulation?



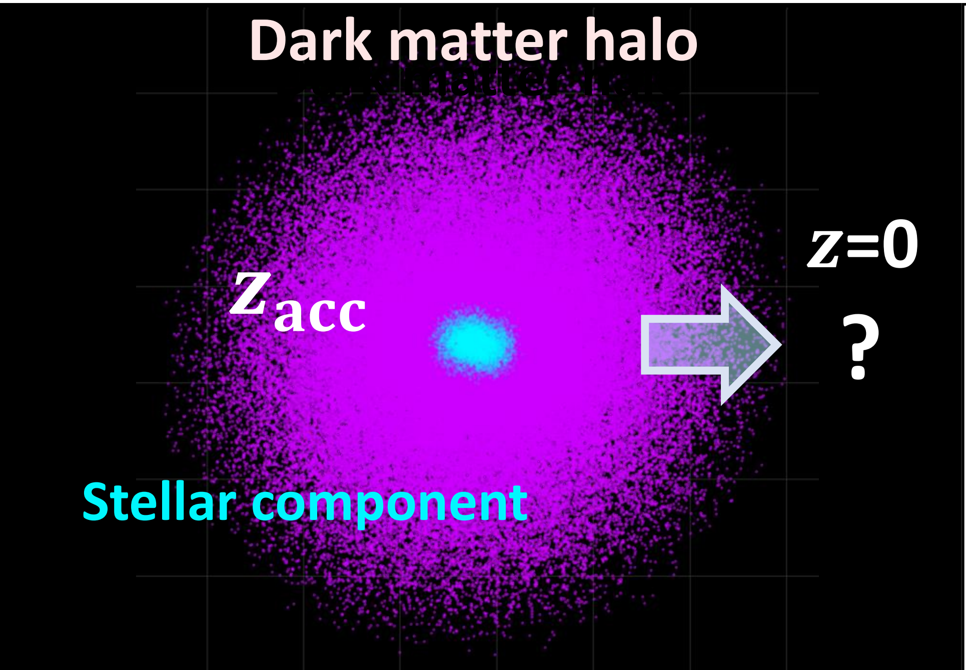
over **24,000** samples

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.

Semi-analytic model

Particle Tagging

(De Lucia et al. 2008)



$z_{\rm acc}$ ⇒ 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 $z_{\rm acc}$ as the stellar component and trace it down to z=0.

A model to assign stellar mass

(Koposov et al. 2009)

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

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

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

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

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**

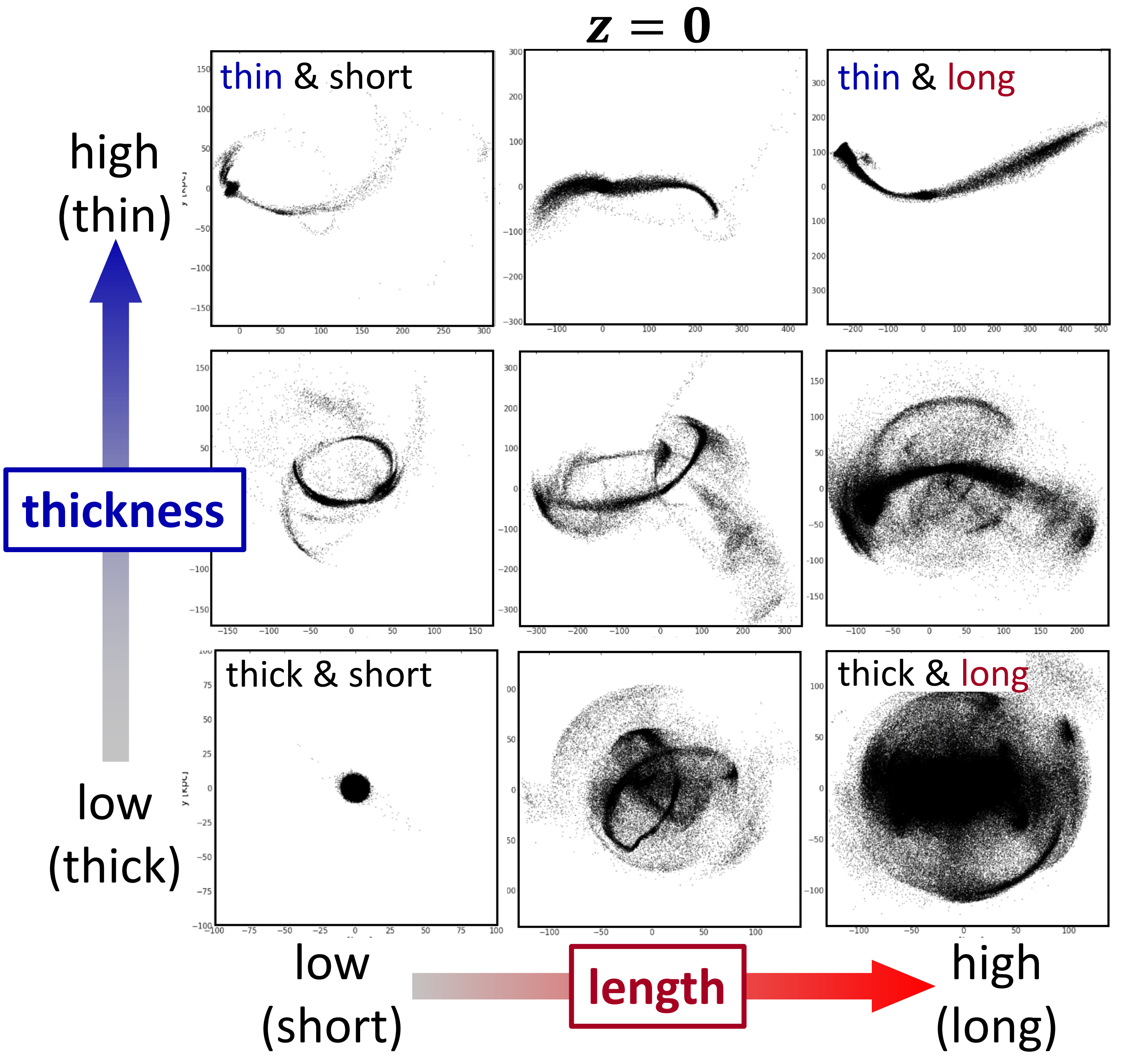
High ⇒ long

Low ⇒ short

② **Thickness**

High ⇒ thin

Low ⇒ thick



$z = 0$

high (thin)

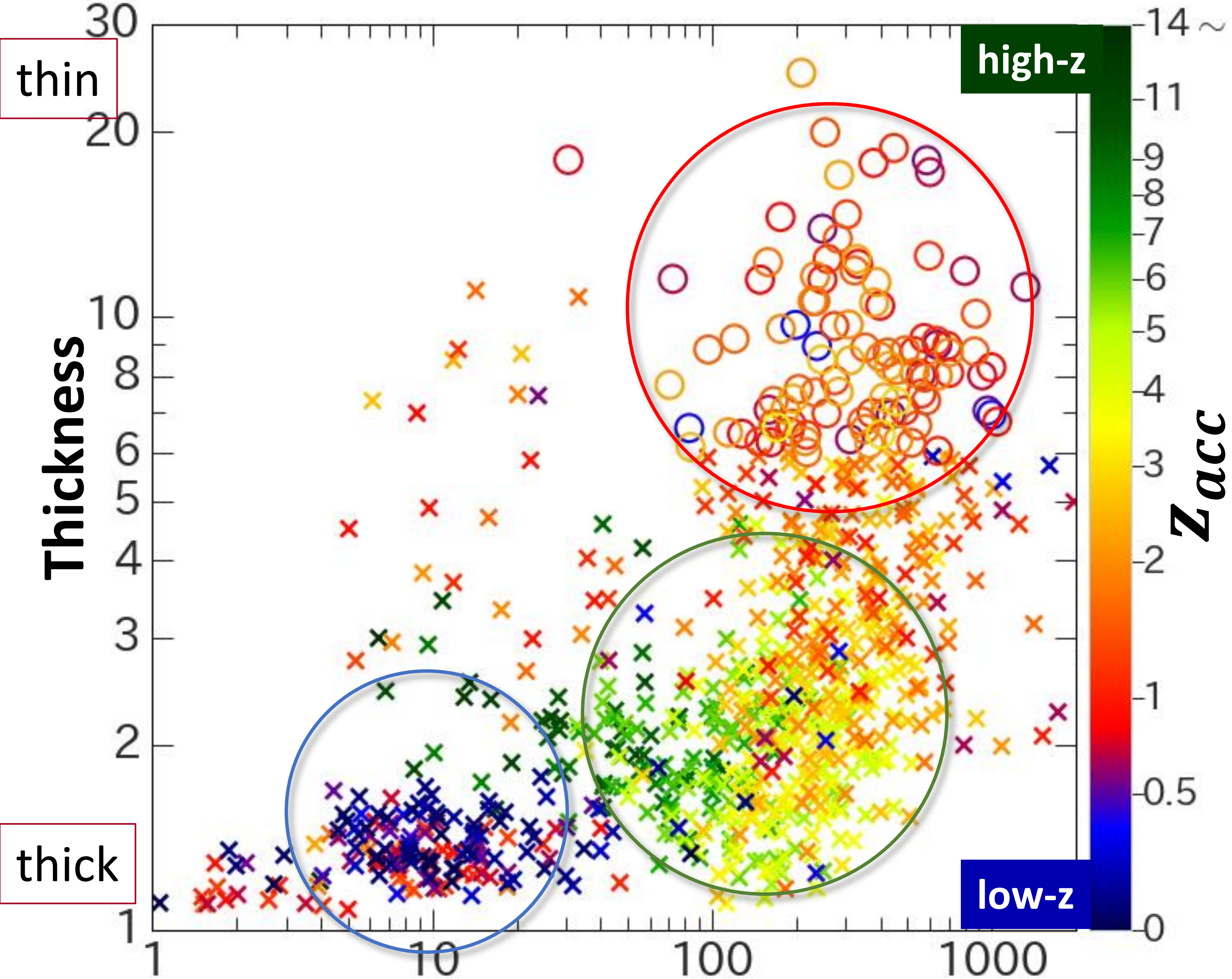
thickness

low (thick)

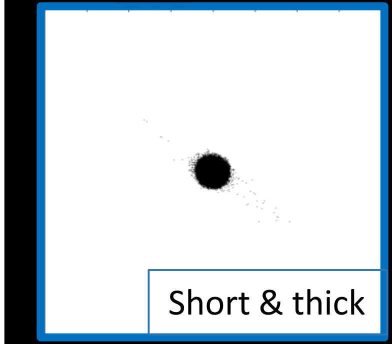
low (short)

length

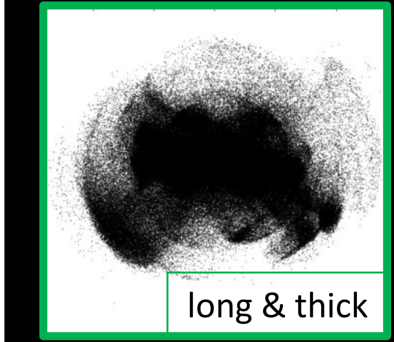
high (long)



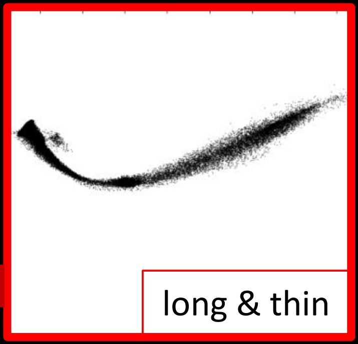
$z_{acc} \lesssim 0.5$



$2.5 \lesssim z_{acc}$

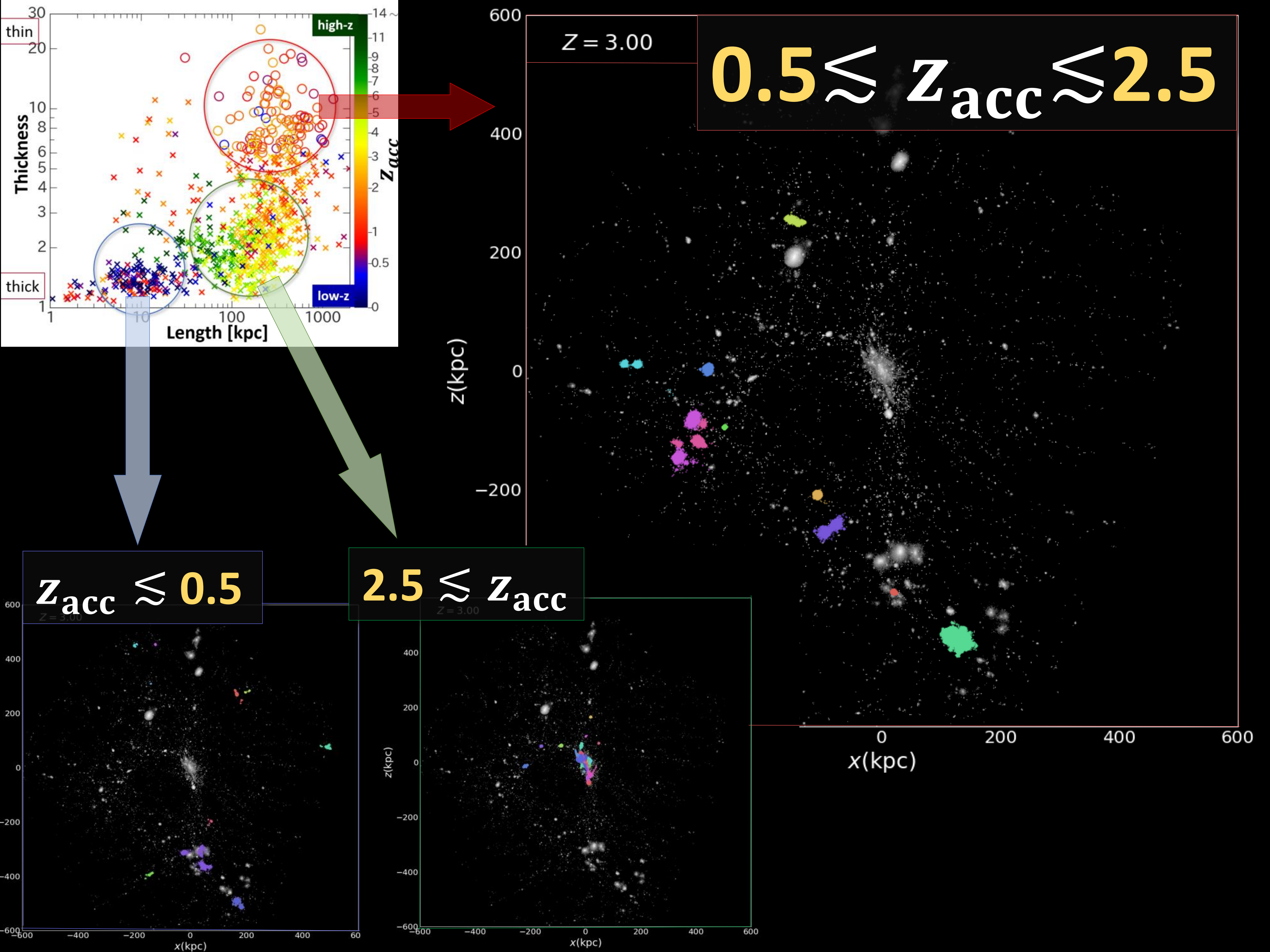


$0.5 \lesssim z_{acc} \lesssim 2.5$



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

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

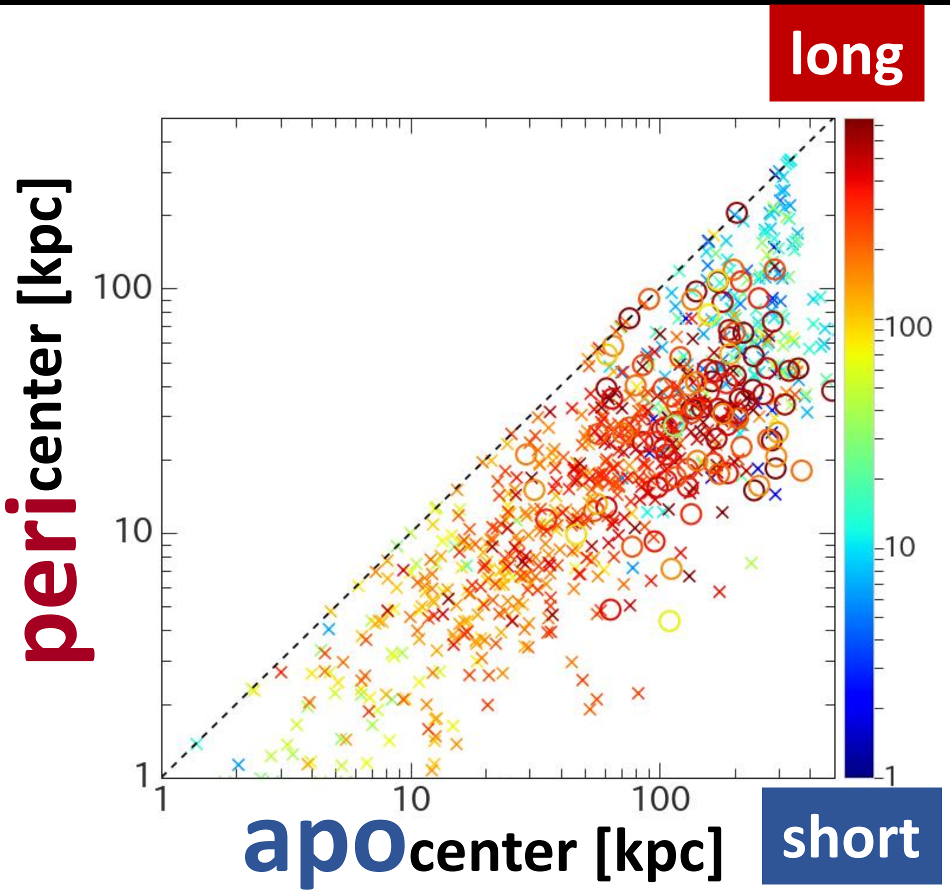


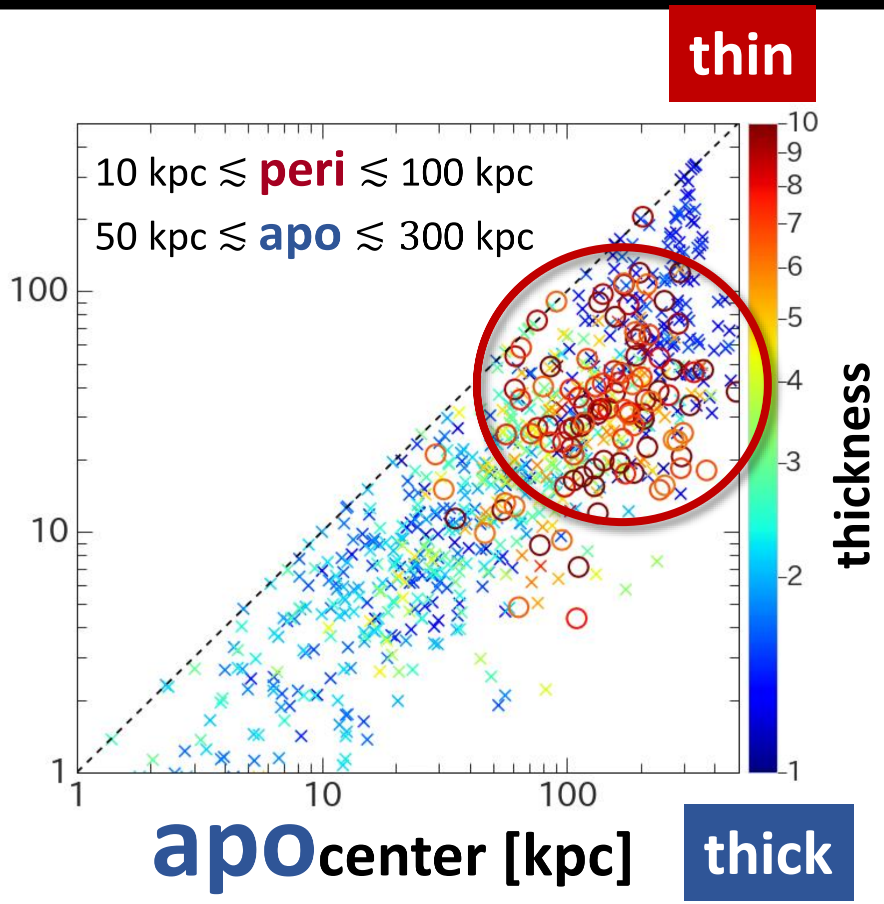
$0.5 \lesssim z_{acc} \lesssim 2.5$

$z_{acc} \lesssim 0.5$

$2.5 \lesssim z_{acc}$

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 percenter (> 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

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

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

✦ 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

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