Constraint on the nature of dark matter by high-resolution cosmological simulations and next generation spectroscopy observations

Tomoaki Ishiyama

Chiba University
(Institute of Management and Information Technologies)

18H04337 : JSPS Kakenhi Grant-in-Aid for Scientific Research on Innovative Areas (Why does the Universe accelerate? - Exhaustive study and challenge for the future)

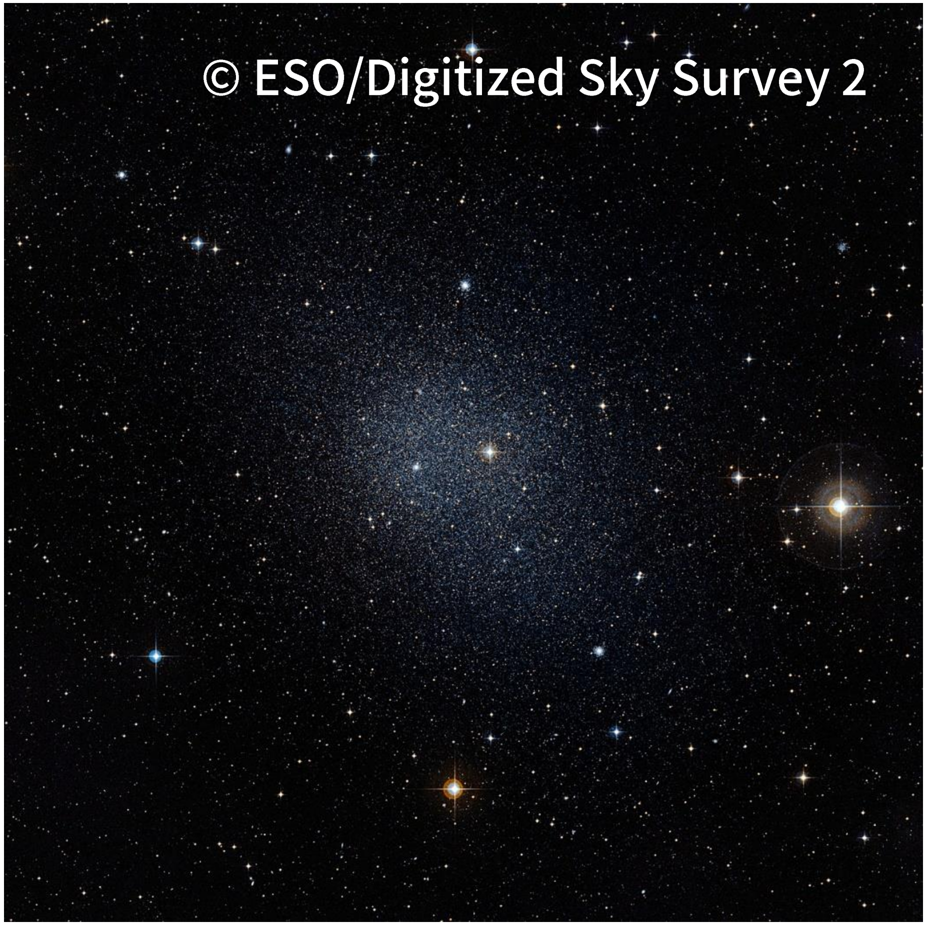
- Constraint on the nature of dark matter by high-resolution cosmological simulations and next generation spectroscopy observations
  - in prep

- Statistical properties of substructures around Milky Way-sized haloes and their implications for the formation of stellar streams
  - Morinaga and Ishiyama et al., MNRAS, 2019

Dwarf spheroidal galaxies (dSph)

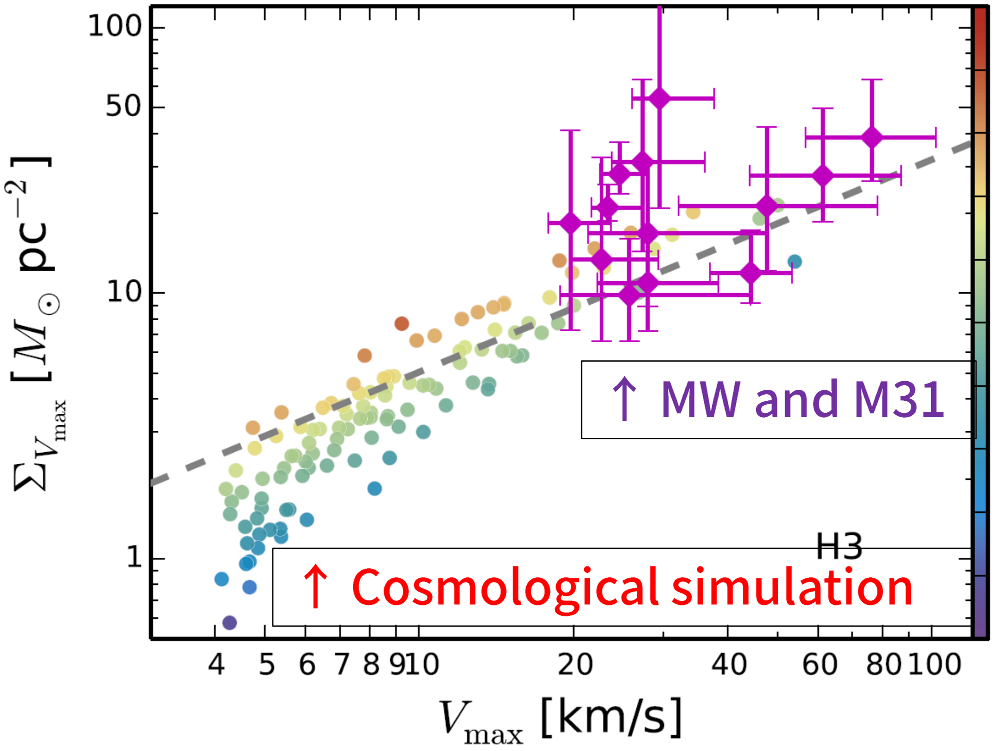
- Dark matter dominated
- Old stellar populations
- Little gas
- New (ultra-faint) dSphs have been discovering

- Good candidates to constrain the nature of dark matter by HSC and PFS


© ESO/Digitized Sky Survey 2

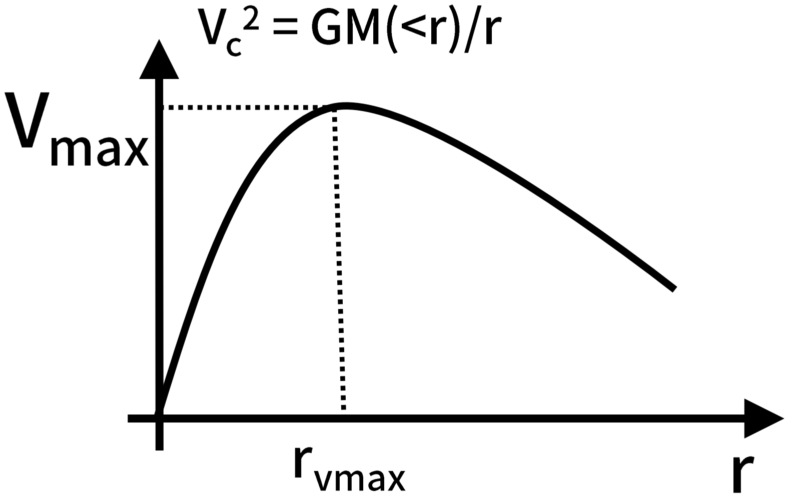
Fornax Dwarf Spheroidal

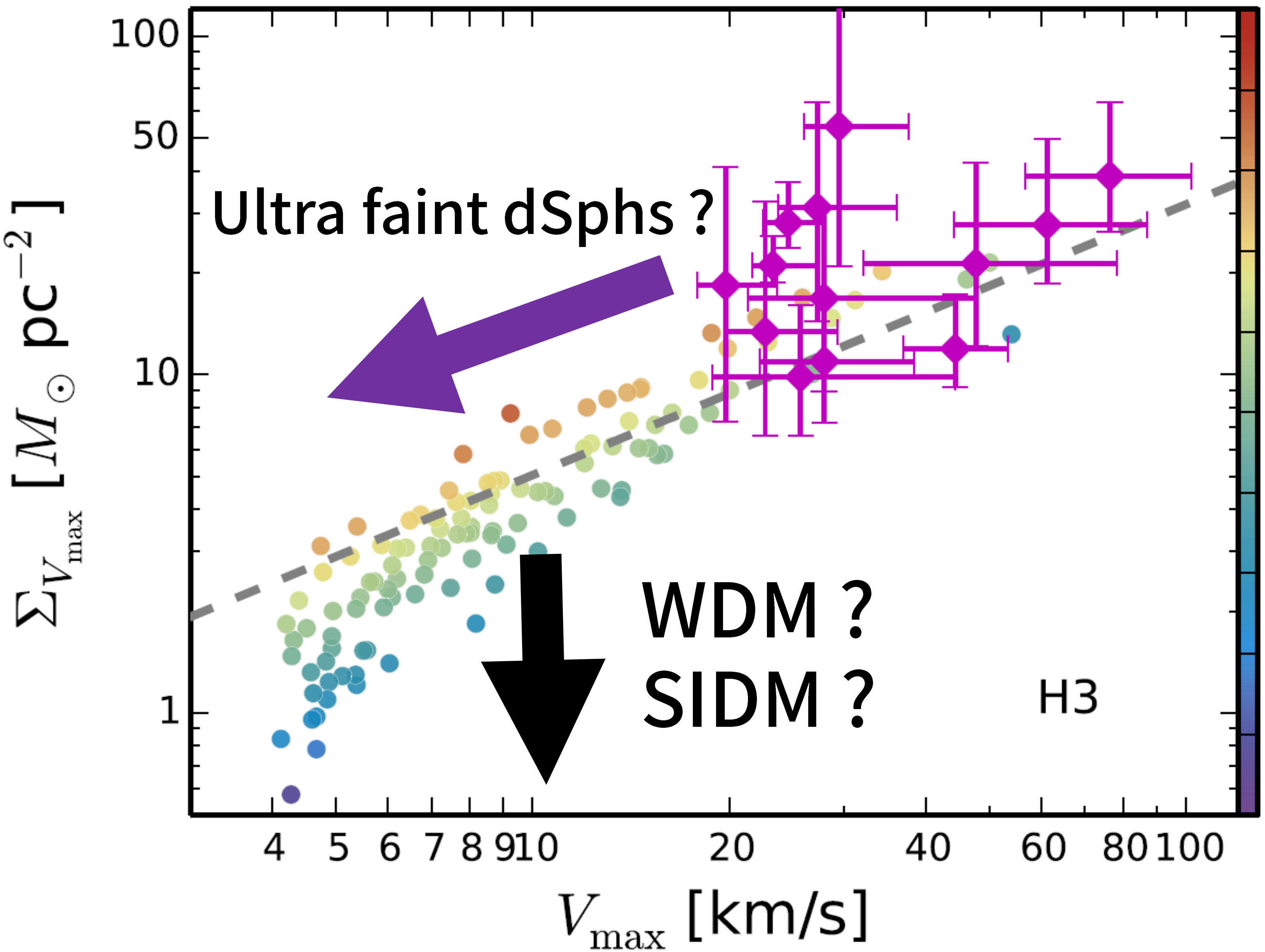
Universal Σv_{max} – V_{max} relation



Hayashi, Ishiyama et al., 2017,
See also Hayashi and Chiba 2015

- There is an universal scaling relation between dark halo surface density within a radius r_{vmax} and V_{max}
    - Both halos and "subhalos"
- Σv_{max} is insensitive to baryonic physics


$V_c^2 = GM(<r)/r$
V_{max}
r_{vmax}
r



Ultra faint dSphs ?

WDM ?
SIDM ?

Aim of our kakenhi project

- Quantifying the distribution and kinematics of dwarf-scale subhalos ($10^{7\text{-}9}$ Msun) using high-resolution cosmological N-body simulations
  - Inner profile (surface density)
  - Spatial distribution
  - Kinematics (Line-of-sight, tangential velocities)
- Previous works are limited in a few MW halos and poor mass resolution (> 10^5 Msun)
  - Improve to a few tens halos and ~$10^{3\text{-}4}$ Msun resolution
    -> Ultra faint dwarf scale
- Constructing big theoretical templates to compare with future observations
  - Not only CDM, but WDM and SIDM

Simulation suite

All simulations are terminated at z=0
halo/subhalo identification: Rockstar (Behroozi+ 2013)
http://hpc.imit.chiba-u.jp/~ishiymtm/db.html

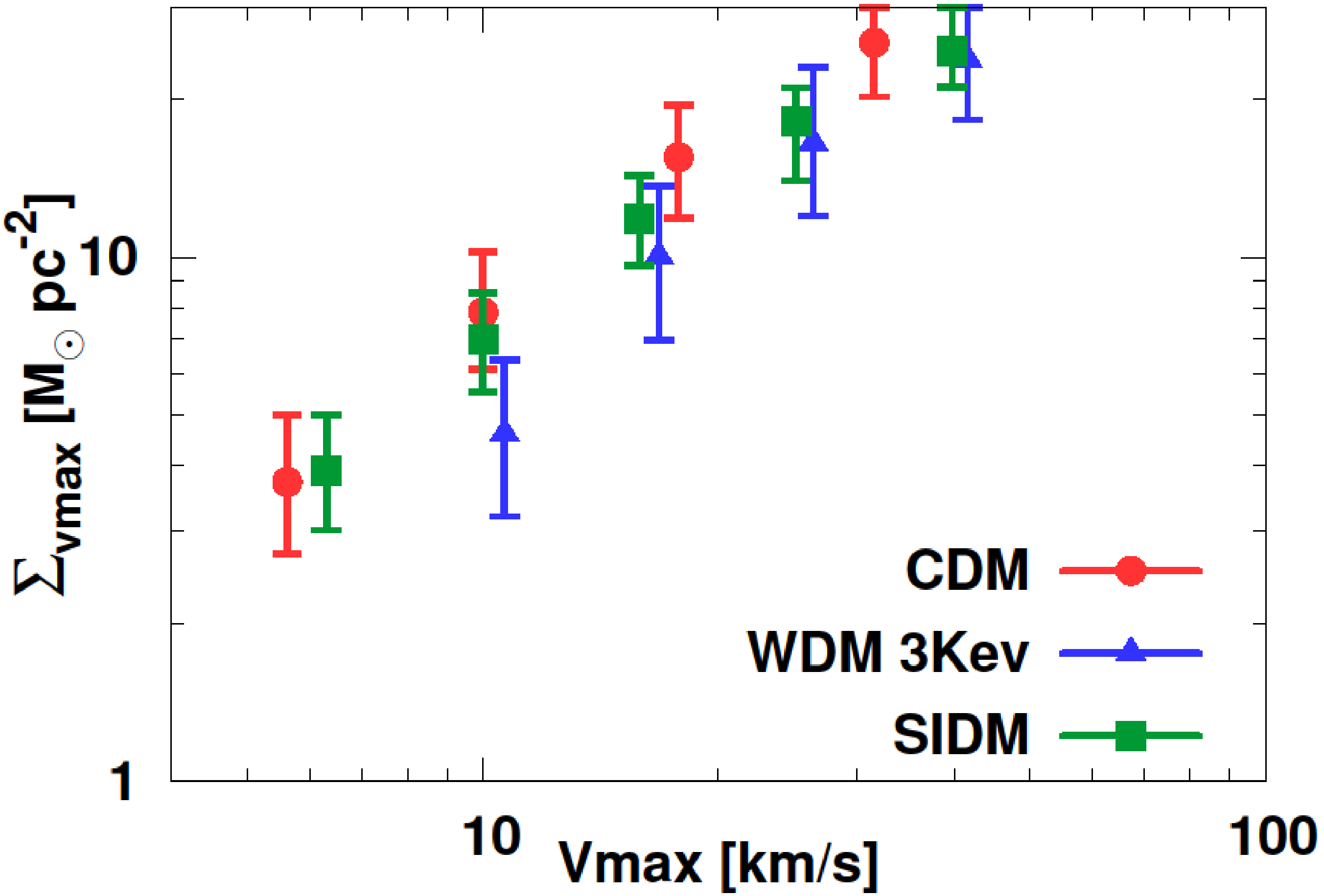
Name	Model	N	L (Mpc/h)	m_p(Msun/h)	#MW halos
CDM16L	CDM	4096^3	16	5.1×10^3	20~30
CDM8L	CDM	2048^3	8	5.1×10^3	5~10
WDM8L3kev	WDM 3kev	1024^3	8	4.1×10^4	5~10
WDM8L5kev	WDM 5kev	1024^3	8	4.1×10^4	5~10
WDM16L3kev	WDM 3kev	2048^3	16	4.1×10^4	20~30
SIDM8L1S	SIDM*	1024^3	8	4.1×10^4	5~10

SIDM: $\sigma/m=1.0\ \mathrm{cm^2g^{-1}}$ velocity independent
CDM run with the same initial phase also exists

Aterui-II
© CfCA, NAOJ

京
K computer
TOP500リストで世界No.1獲得
K Computer
(c) RIKEN,

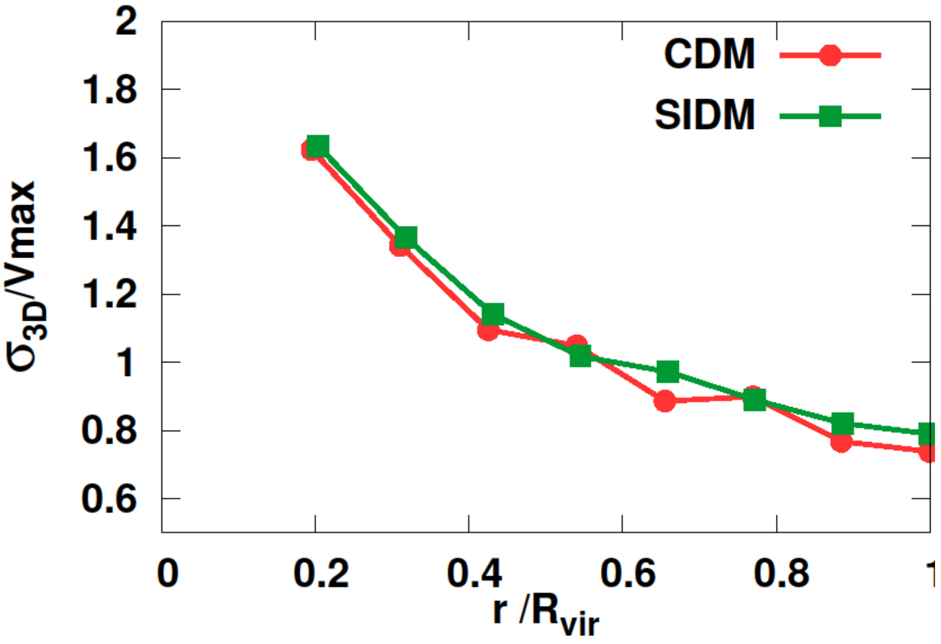
Σv_{max} – V_{max} relation in MW halos

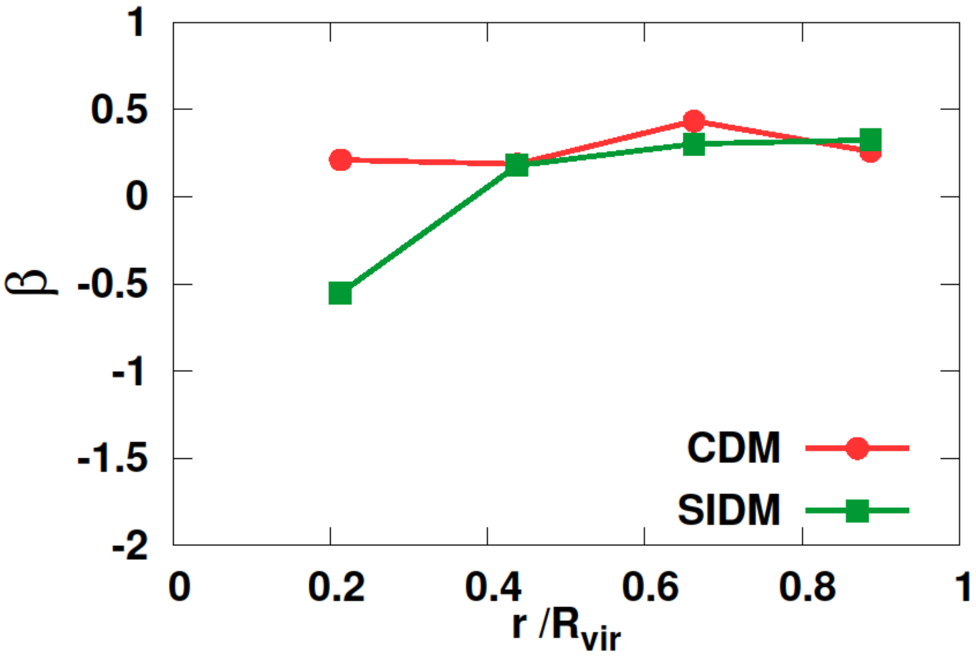


- WDM simulations show lower surface density at V_{max} < 20km/s
- Factor ~1.5 difference in Σv_{max} between CDM and WDM at V_{max}~10km/s
- No significant difference between CDM and SIDM (σ/m=1, velocity independent)

How to distinguish CDM and SIDM ?

Kinematics



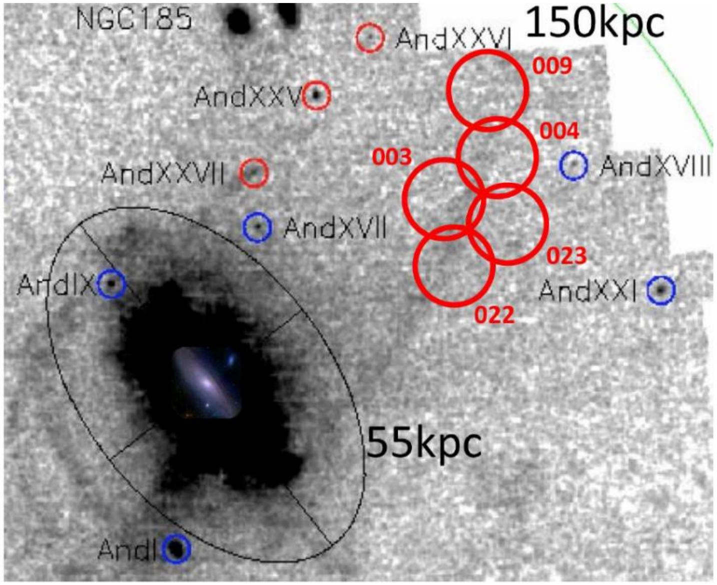


- Can not see significant difference in 3D velocity dispersion
- In the inner part, velocity anisotropy is different?
  - Caution: the number of subhalos in the inner halo is not large
  - See also Nadler+ 2020

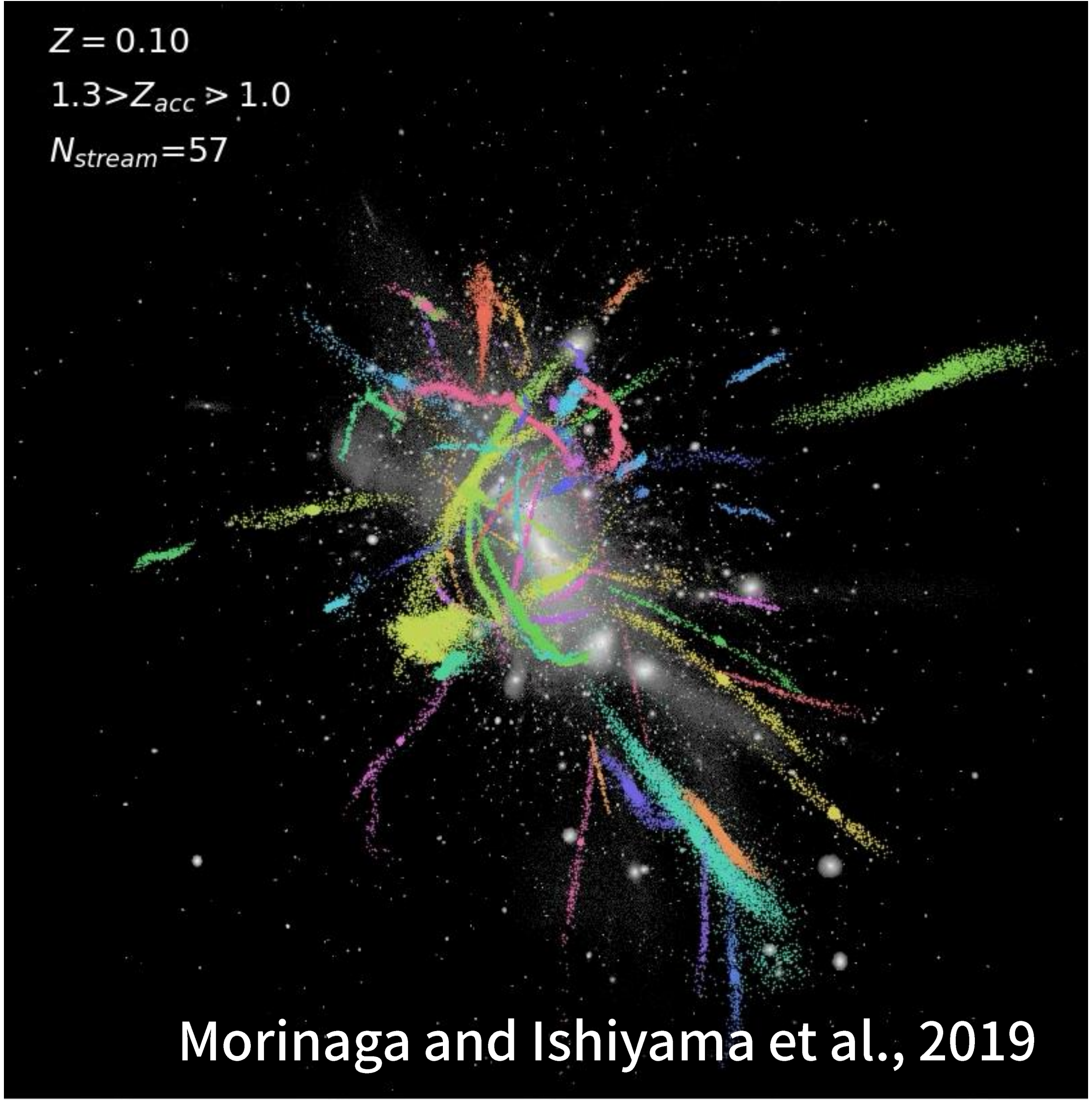
Reproducing stellar stream in cosmological context

(c) NAOJ

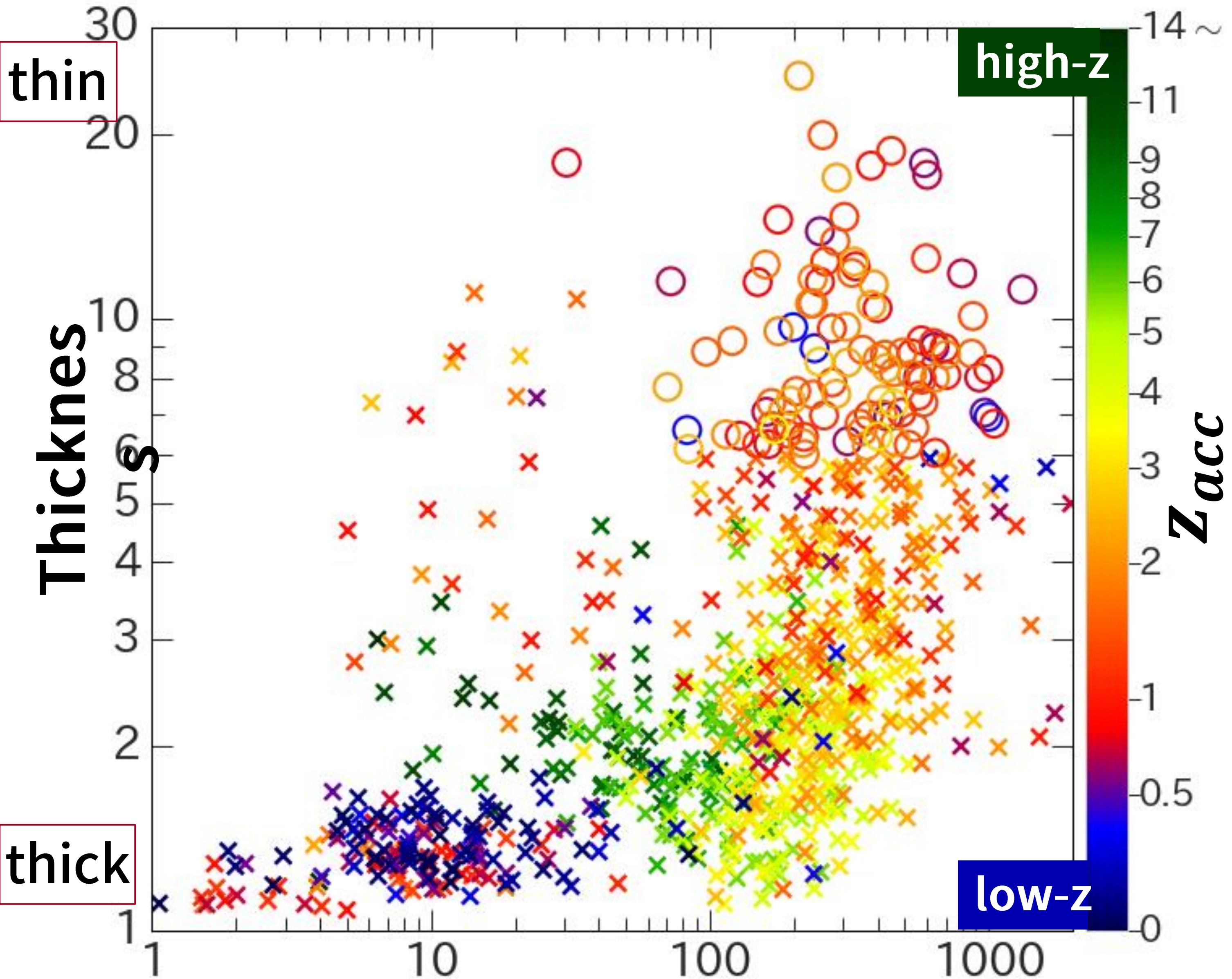
- Progenitors of streams are accreted at z=0.5-2.5


NGC185
AndXXVI
150kpc
009
AndXXV
004
003
AndXVIII
AndXXVII
AndXVII
023
AndIX
AndXXI
022
55kpc
AndI

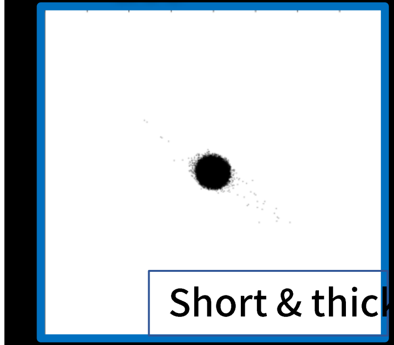
Andromeda stream by HSC (Komiyama+ 2018)


$Z = 0.10$
$1.3 > Z_{acc} > 1.0$
$N_{stream} = 57$

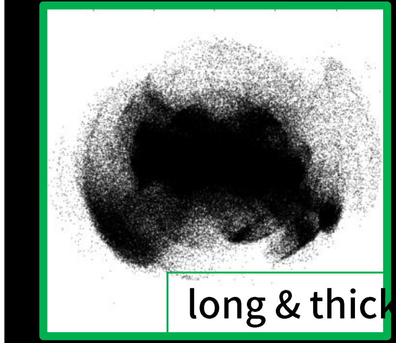
Morinaga and Ishiyama et al., 2019



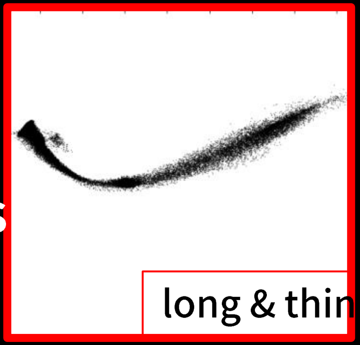
$z_{acc} \lesssim 0.5$


Short & thick

$2.5 \lesssim z_{acc}$

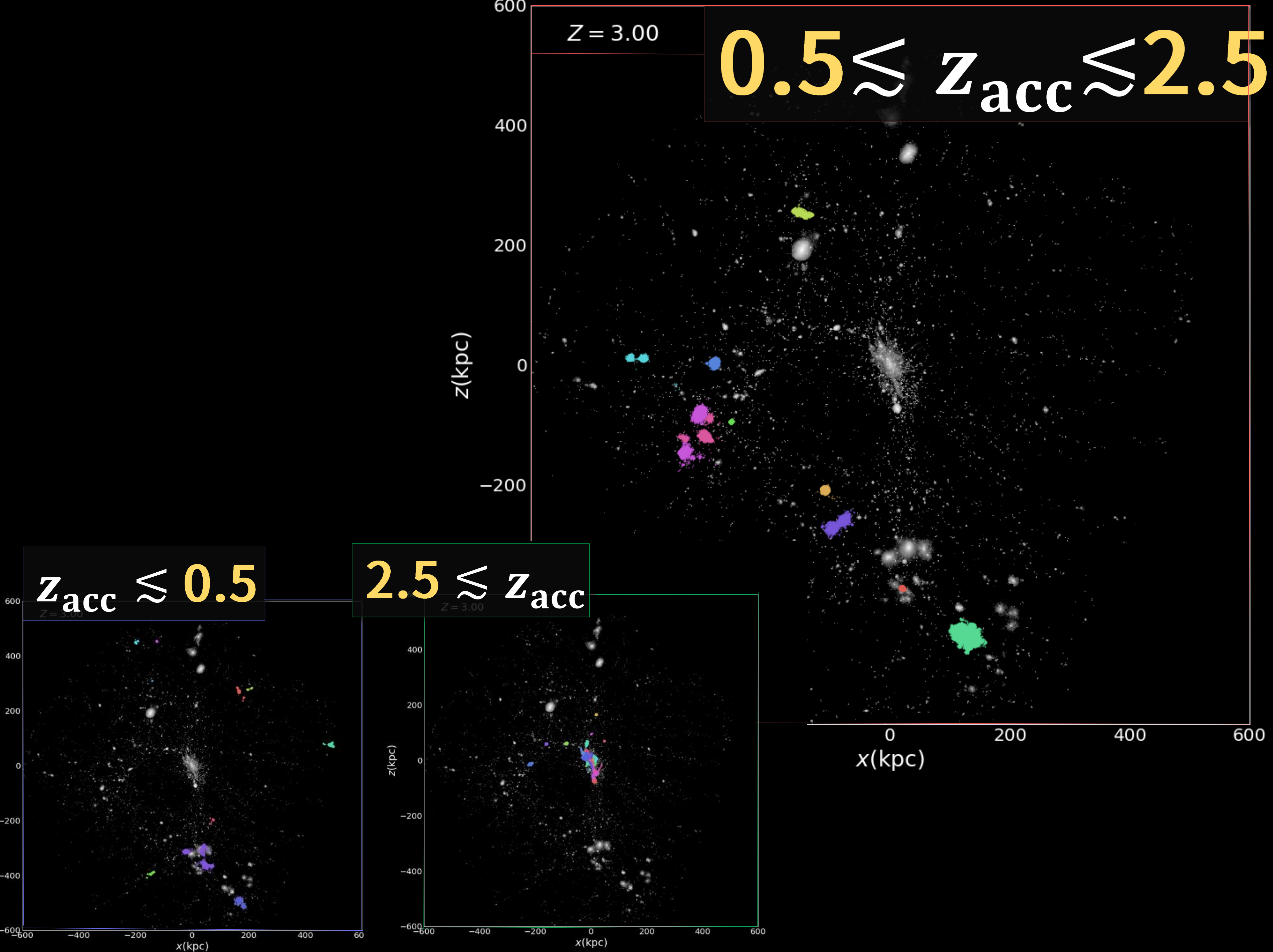


$0.5 \lesssim z_{acc} \lesssim 2.5$



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

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

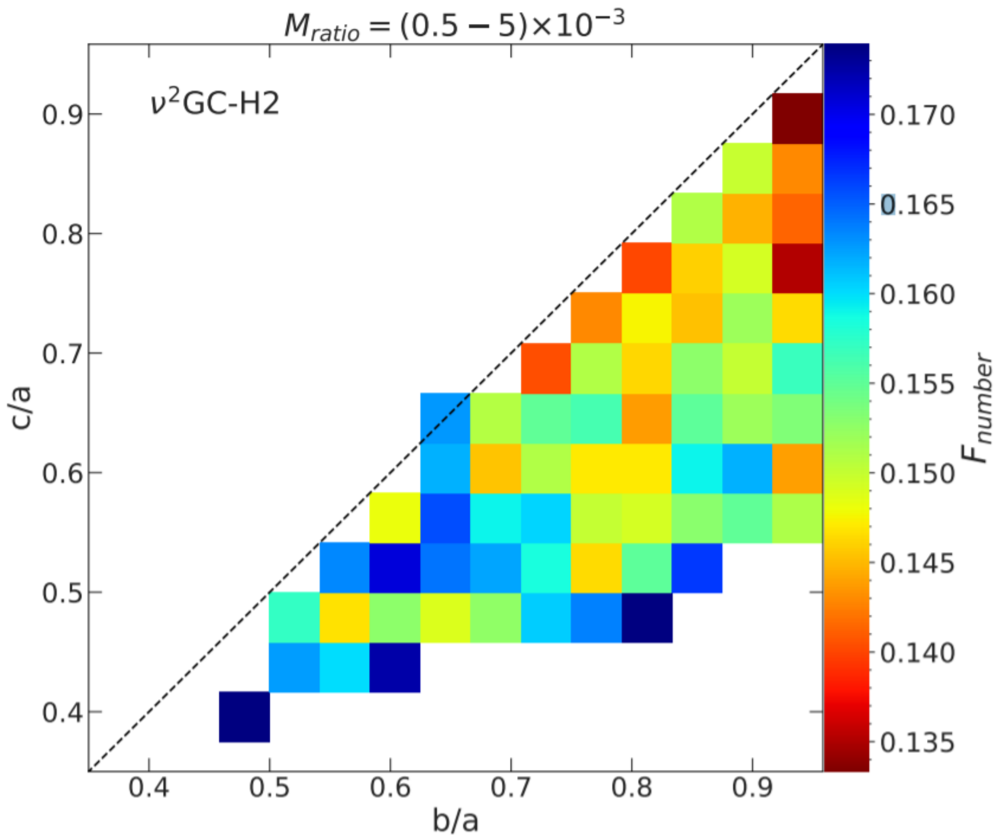


$0.5 \lesssim z_{\rm acc} \lesssim 2.5$

$z_{\rm acc} \lesssim 0.5$

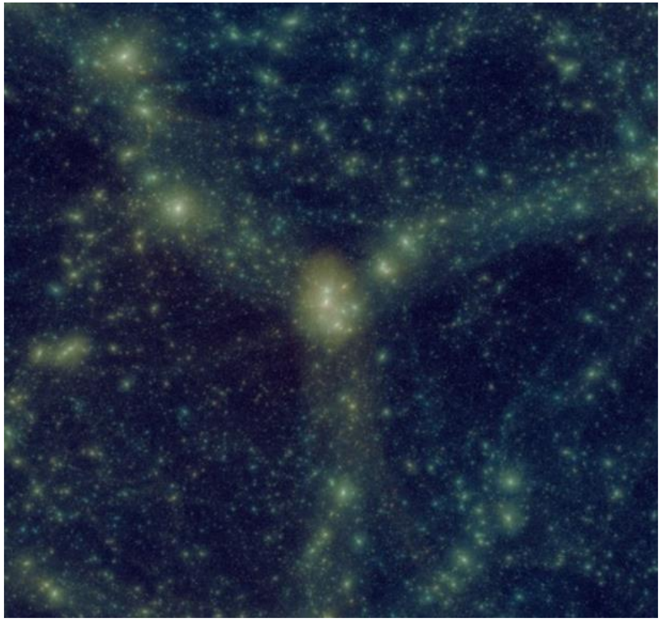
$2.5 \lesssim z_{\rm acc}$

The impact of filamentary accretion of subhaloes on the shape and orientation of haloes



Morinaga and Ishiyama, arXiv:1912.11647

- Haloes with highly anisotropic accretion become more prolate or triaxial, while haloes with isotropic accretion become more spherical or oblate



Summary and future

- By high resolution cosmological N-body simulations, we are testing whether (how) we can use dSphs to constrain the nature of dark matter

- $\Sigma v_{max} - V_{max}$ relation can possibly distinguish CDM and WDM if high precision observations of a number of dSphs are conducted
- To distinguish CDM and SIDM, satellite kinematics plays a key role? But there are large variations in SIDM

- Future:
  - Higher resolution simulations by Fugaku supercomputer
  - Larger parameter space
  - Can we use stellar streams to constrain the nature of DM?