Phase-space Analysis of Halos around Large-scale Filamentary Structures

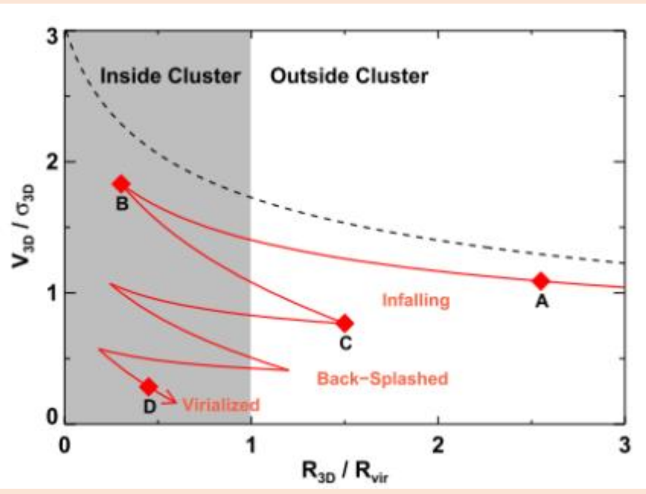
Hannah Jhee[1], Hyunmi Song[2], Rory Smith[3], Jihye Shin[3] and Inkyu Park[1]

[1]Department of Physics, University of Seoul, Seoul 02504, Republic of Korea
[2]Department of Astronomy, Yonsei University, Seoul 03722, Republic of Korea
[3]Korea Astronomy and Space Science Institute, Daejeon 34055, Republic of Korea

Abstract

It has been studied that galaxies evolve following a typical trajectory on the phase space under the influence of deep gravitational potential of galaxy clusters. Similarly, the large-scale filaments could also affect the evolution of galaxies before falling into the clusters. In this study, using a dark matter-only cosmological simulation, N-Cluster Run, we explore the evolution of galaxies on the phase space driven by large-scale filaments. We find that galaxies around the filaments form a common trajectory on the phase space as well as cluster galaxies do. We also examine how these trajectories change depending on various physical parameters such as galaxy mass, initial distance of galaxies from large-scale filaments, and cluster mass.

1. Introduction

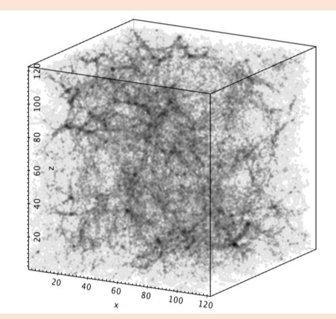


By Oman et al.(2013) and Rhee et al.(2017), halos falling into the clusters are shown to have typical trajectories on the normalized phase space. This implies that phase space analysis can be a tool to understand the evolutionary steps of a galaxy(see Fig 1). The question is: can similar work be done for filament galaxies too?

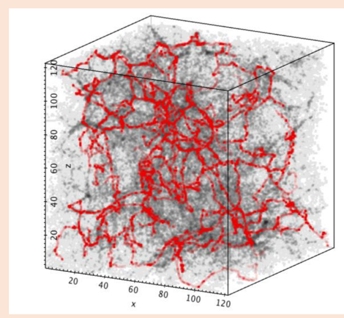
◀ ***Fig 1***. Typical tracks of galaxies on the phase space bound to the deep gravitational potential of a cluster.

2. Data and Method

1. Simulation Data



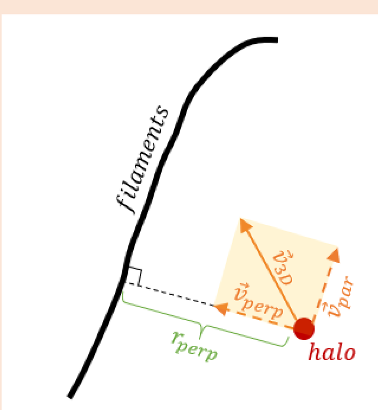
N-Cluster Run(run at KASI)
- Cosmological N-body Simulation
- Box size : 120 Mpc
- halo mass resol. : $\sim 2 \times 10^{10} M_{\odot}$
- WMAP7 Cosmology
- Only took central halos between $2R_{vir}$~$10R_{vir}$ from the cluster center



Amiga Halo Finder
- Finds gravitationally bound systems in cosmological simulations

DisPERsE
- **Dis**crete **Per**sistent **S**tructures **E**xtractor
- Applied to $R < 20R_{vir}$ around each halo to find filament structures

2. Perpendicular Method



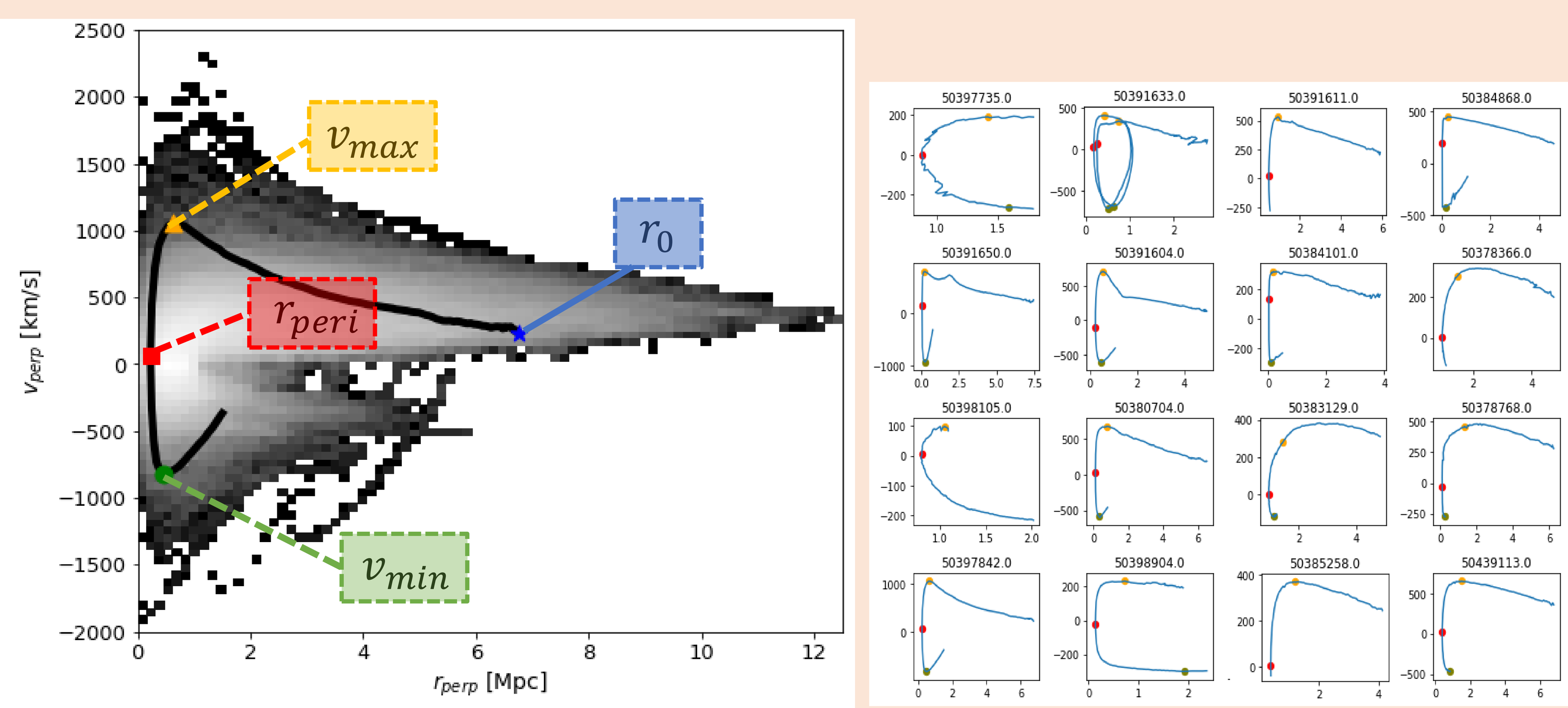
Perpendicular method finds the direction of a halo towards the nearest filaments as shown in Fig 2.

$$r_{perp} = |\hat{u} \cdot \vec{D}_{halo}|$$
$$v_{perp} = |\hat{u} \cdot \vec{v}_{3D}|$$
$$v_{par} = |\vec{v}_{3D} - \hat{u}v_{perp}|$$

◀ ***Fig 2***. The schematic view of measuring perpendicular direction. The direction has been calculated at every snapshot.

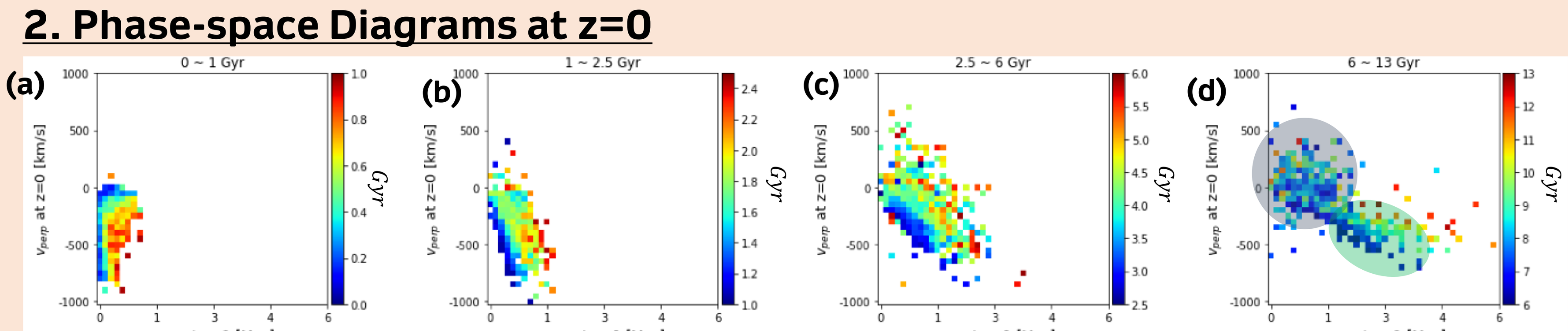
3. Results

1. Shape of the Phase-space Diagrams



▲ ***Fig 3***. (a) The accumulated phase-space diagrams and (b) the individual cases.

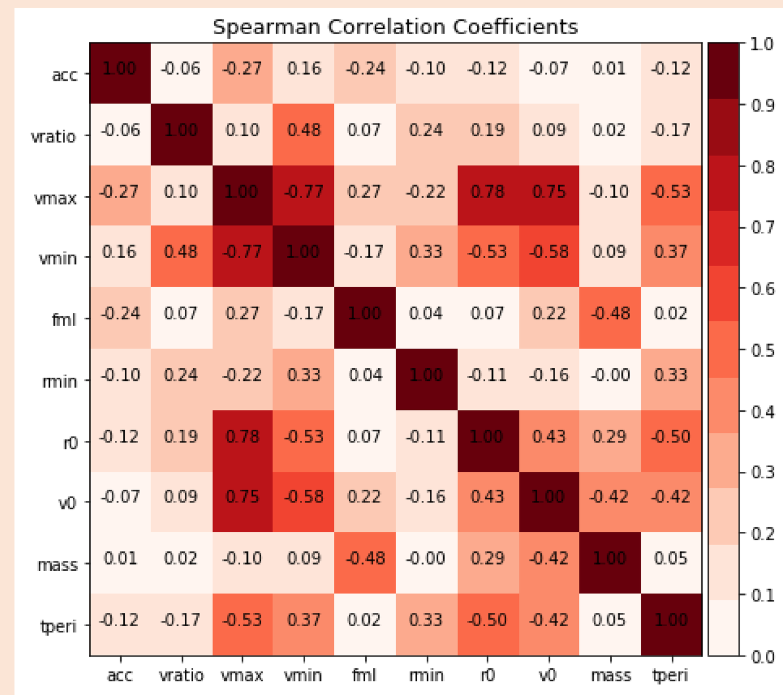
2. Phase-space Diagrams at z=0



▲ ***Fig 4***. Phase-space diagrams at z=0 subsampled by t_{peri} and color-coded also by t_{peri}, where t_{peri} indicates the time since infall in Gyr. The bins are such as (a) [0, 1), (b) [1, 2.5), (c) [2.5, 6), (d) [6, ∞). Color bars are not equal for all bins for better identification of the gradients.

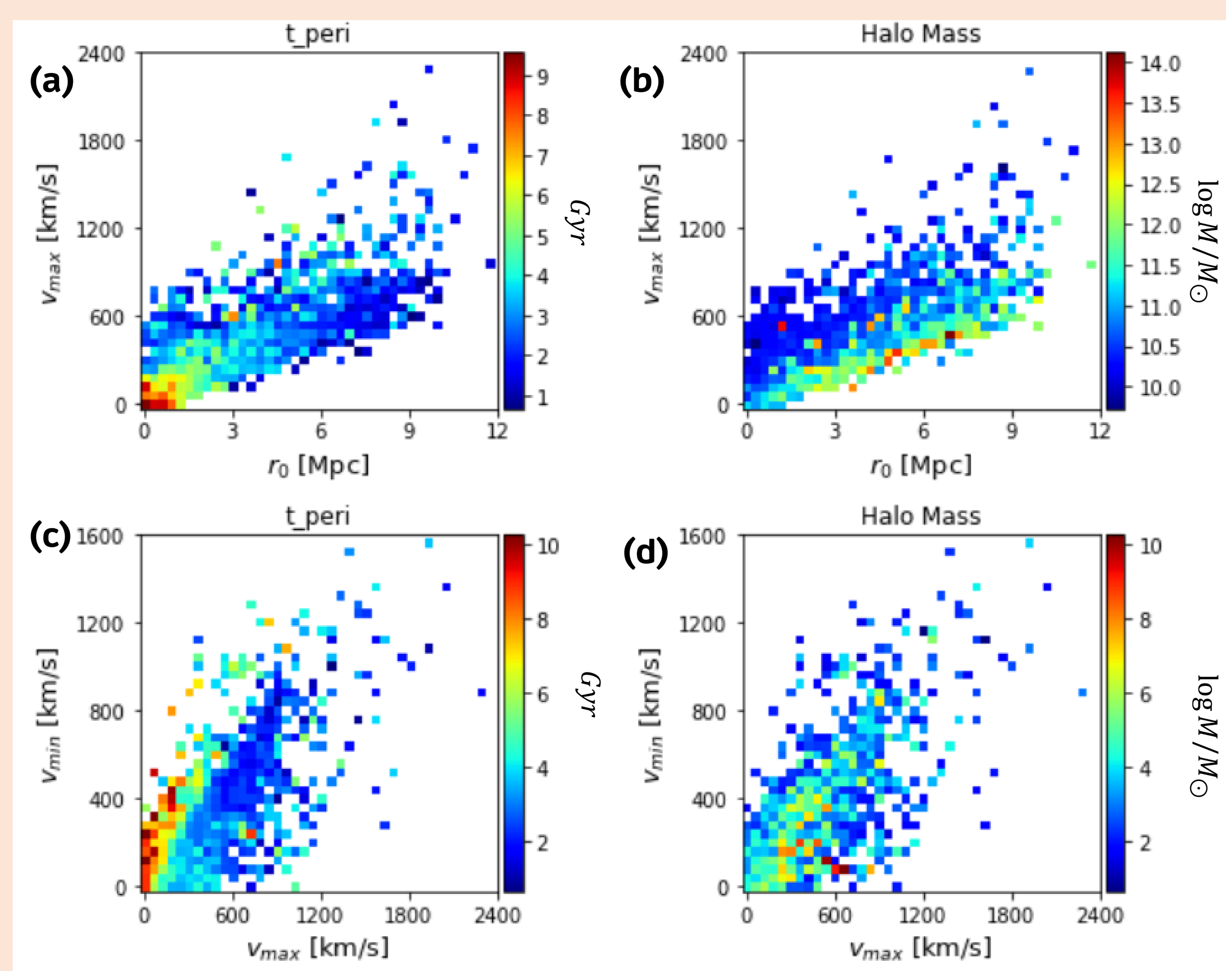
Subsampling halos by t_{peri} and then plotting the phase space diagrams at z=0 color-coded also with t_{peri}, one can see that the larger the values of t_{peri} are, the fainter the gradient is, which indicates the virialization of halos. In the right panel, the bounded body objects(grey) show clear virialization while tail objects(green) are still showing the gradients.

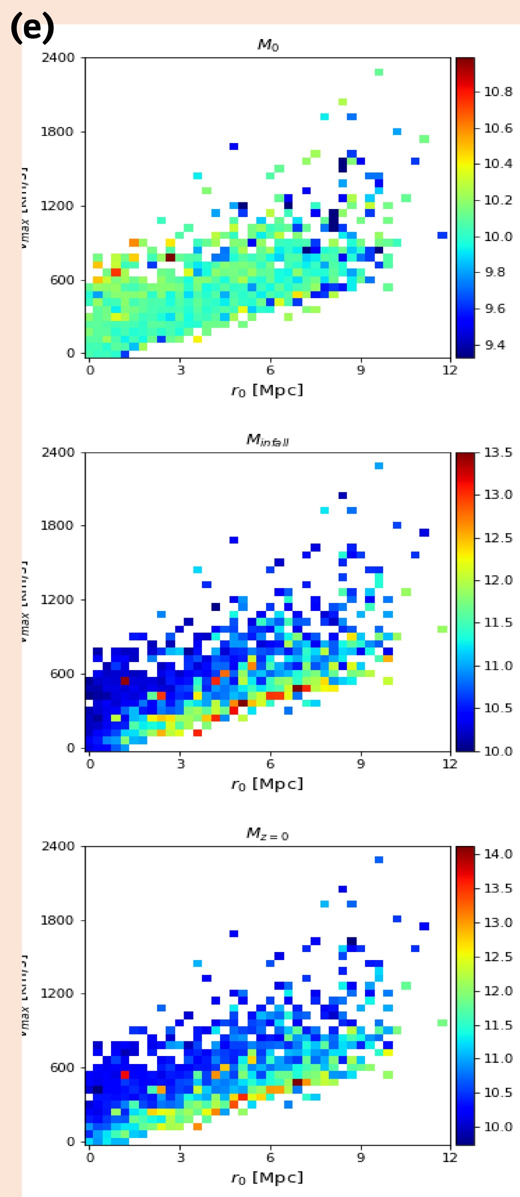
2. Parameter Correlations



Parameter	Configuration
acc (a)	Acceleration right after hitting the 1st v_{max}
vratio (Γ_v)	$\Gamma_v = v_{min}/v_{max}$
vmax (v_{max})	1st maximum velocity
vmin (v_{min})	The absolute value of 1st minimum velocity
fml (f_{ML})	$f_{ML} = 1 - M_{now}/M_{peak}$
rmin (r_{min})	r_{perp} at 1st pericenter($v_{perp} = 0$)
r0 (r_0)	Initial r_{perp}
v0 (v_0)	Initial v_{perp}
mass (M_{halo})	Halo mass at $z = 0$
tperi (t_{peri})	Time since the 1st pericenter

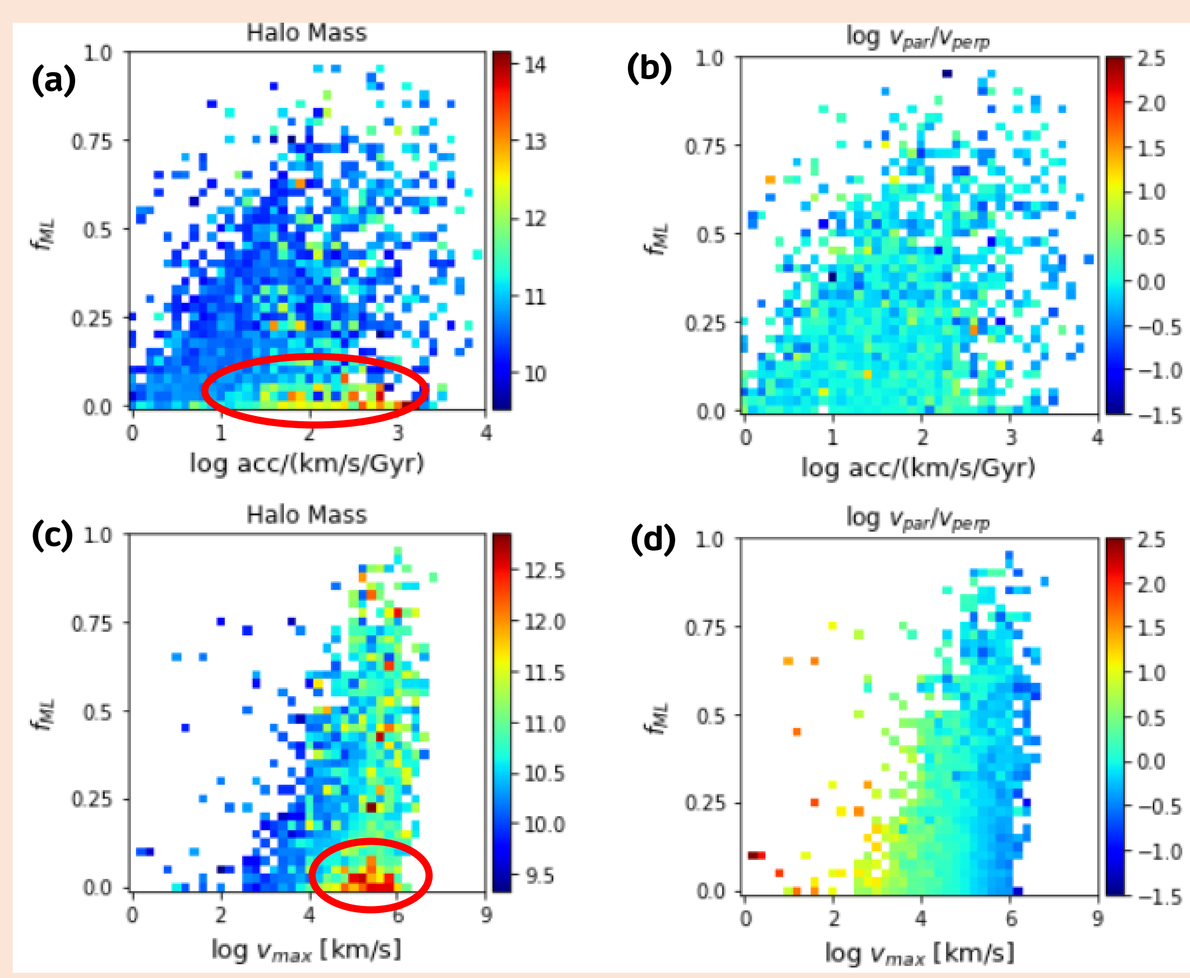
◀ ***Fig 5***. The heatmap of Spearman Correlation Coefficients among various parameters.





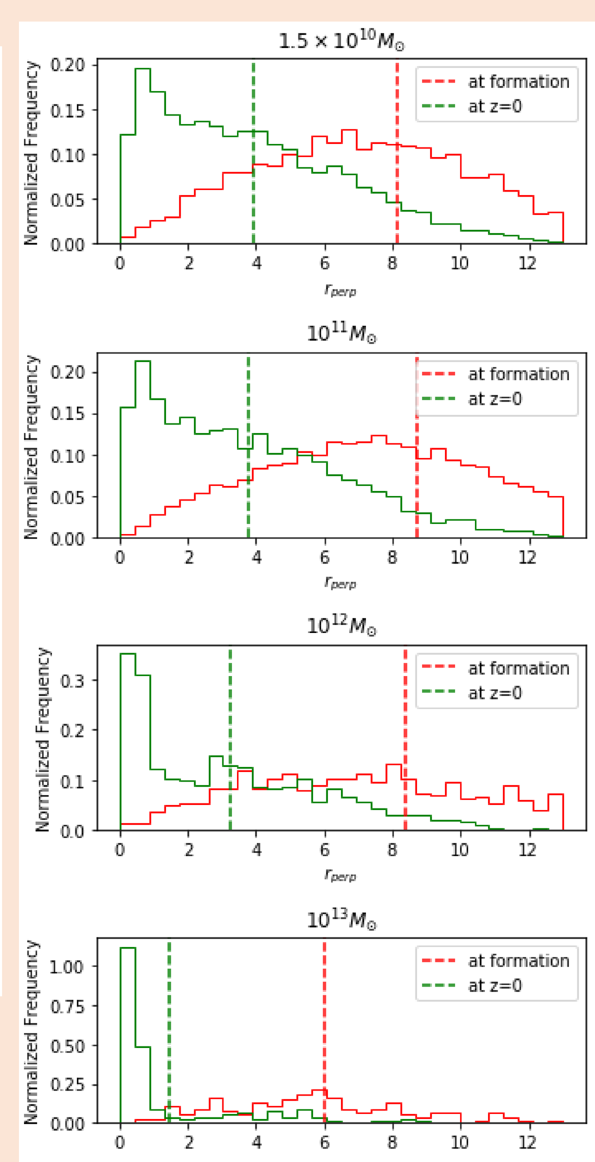
▲ ***Fig 7***. r_0-v_{max} and v_{min}-v_{max} relations color-coded with (a), (c) t_{peri} and (b), (d) halo masses. (e) r_0-v_{max} relation with M_0, M_{infall}, M_{now} coloring.

3. Mass Evolution of Halos



▲ ***Fig 8***. The relation between a and v_{max} at infall time and fractional mass loss, color-coded by (a) halo mass at the infall and (b) the ratio of v_{par} over v_{perp}.

- Higher mass halos lose masses less due to their own gravity.
- For a given halo mass, larger acceleration and larger v_{max} makes larger mass loss.
- Why are higher mass halos observed closer to the filaments?
  → Higher mass halos are formed closer to the filaments.
  → They have lower peak velocities(Fig 7.(b))
  → They suffer less mass loss(Fig 8.(c),(d))
  → They stay in high mass.



▲ ***Fig 9***. The distribution of r_{perp} at z=0 (green) and at formation(red), with mass subsampling: $[1.5 \times 10^{10}, 10^{11})$, $[10^{11}, 10^{12})$, $[10^{12}, 10^{13})$, $[10^{13}, \infty)$ $M_{\odot}$.

4. Conclusion & Future Works

1. Halos falling into the gravitational potential of the large-scale filamentary structures show common trajectories on the phase-space.
2. Lower mass halos have higher peak velocities and this started from the infall moment.
3. Higher mass halos don't lose their masses much, possibly due to their own gravitational force.
4. Higher mass halos end up closer to the filaments.
5. Mass evolution steps should be related to halos' motion after their infall, such as whether they are bound to the filaments or just passing by it.