A study on the relation between formation history and observables of galaxy clusters

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MOTIVATION & BACKGROUND

- Galaxy clusters(halos) were formed by gravitational collapse at high-density regions in the early universe

  ->Galaxy cluster statistics depend on the initial condition + evolution of the universe!

- Especially, halo number density per volume per mass is a good probe.

- one has to understand how to measure halo mass(cannot be 'observed'!) from 'observables'(X-ray, SZ signal, visible light …etc.)

- How to estimate halo mass from observables(THIS WORK)?
  ->
  Parametrize halo physics (baryon physics(BP) + mass growth(Diffmah)) and study halos in a parametrized way!

Virgo cluster
Credit: Chris Mihos(Case Western Reserve University)/ESO

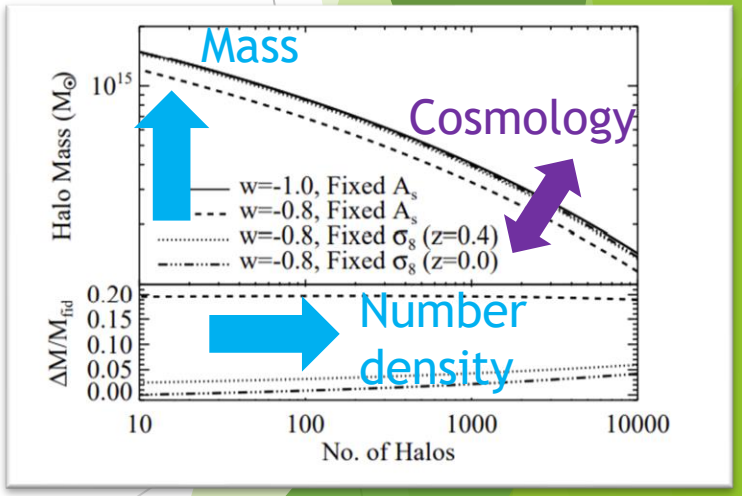
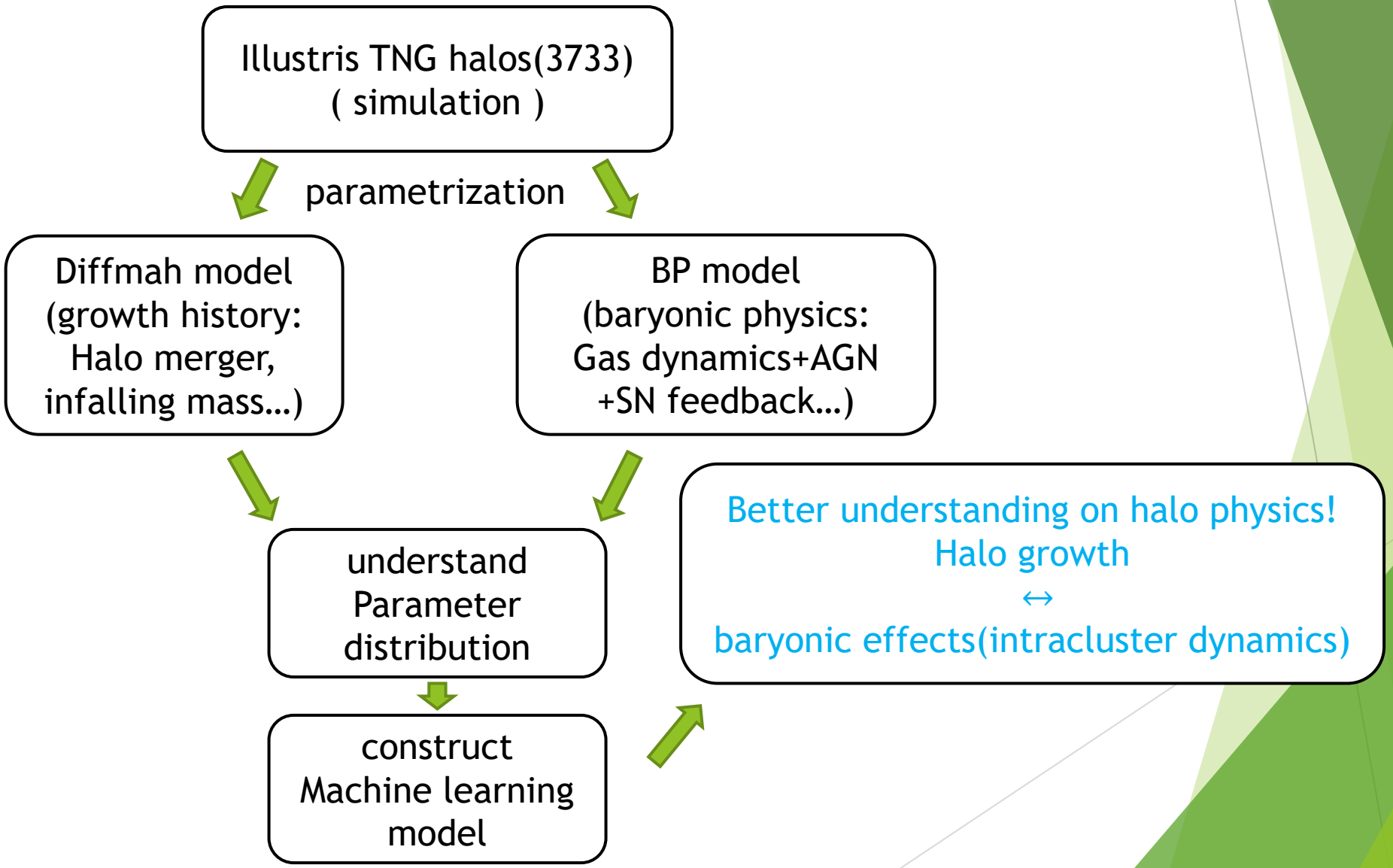


Fig 21, Weinberg et al. 2013

STUDY OUTLINE



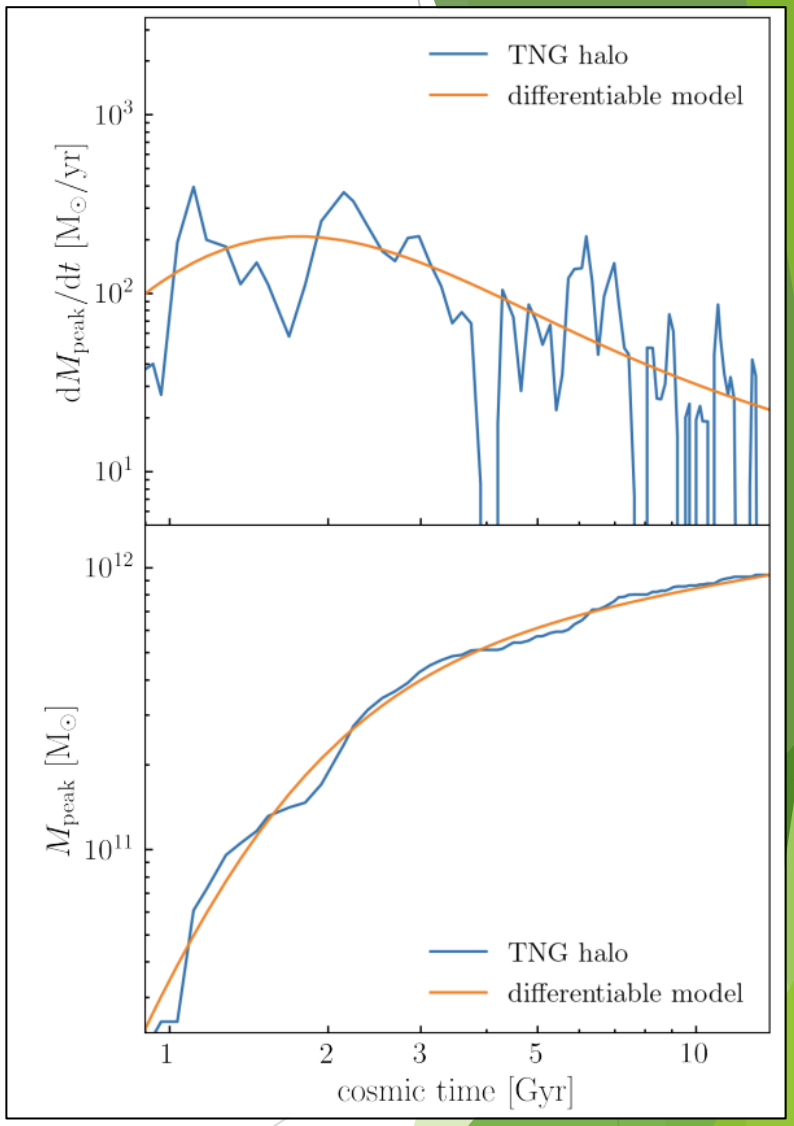
Diffmah model

- According to previous studies,
  galaxy clusters in common, have two growth phase
  (rapid growth(first phase) + slow growth(second phase)).

- we adopt Diffmah model(hearin et al. 2021)
  to describe growth of galaxy clusters.

$$M_{peak}(t) = M_0 \left(\frac{t}{t_0}\right)^{\alpha(t)},$$

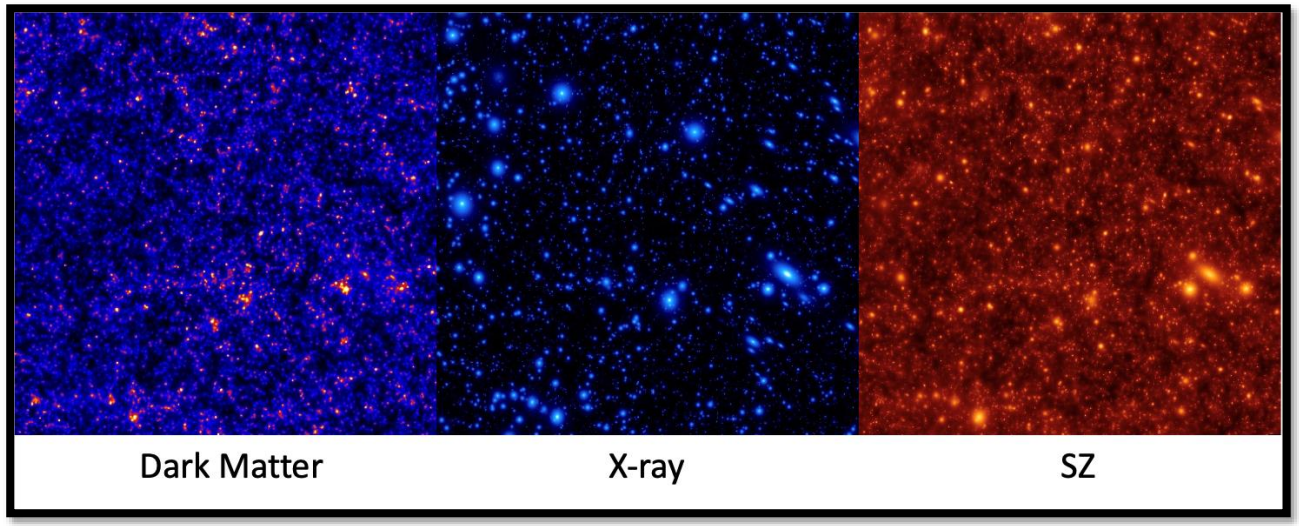
$$\alpha(t) = \alpha_{early} + \frac{\alpha_{late} - \alpha_{early}}{1 + \exp(-3.5(log_{10}t - log_{10}t_c))},$$



An example mass accretion history from simulation
and the corresponding diffmah fit
fig 2, hearin et al. 2021

BP(Baryon Pasting) model

- Baryonic physics is modeled by using BP model.



Left:dark matter map from N-body simulation
Middle:mock X-ray map ‘pasted’ onto the N-body simulation
Middle:mock SZ map ‘pasted’ onto the N-body simulaion

Basic inputs for a halo
We want to generate:
M,z

↓

Physical models(Ostriker et al. 2005, Shaw et al., 2010…)
(gas physics, stellar feedback..)

↓

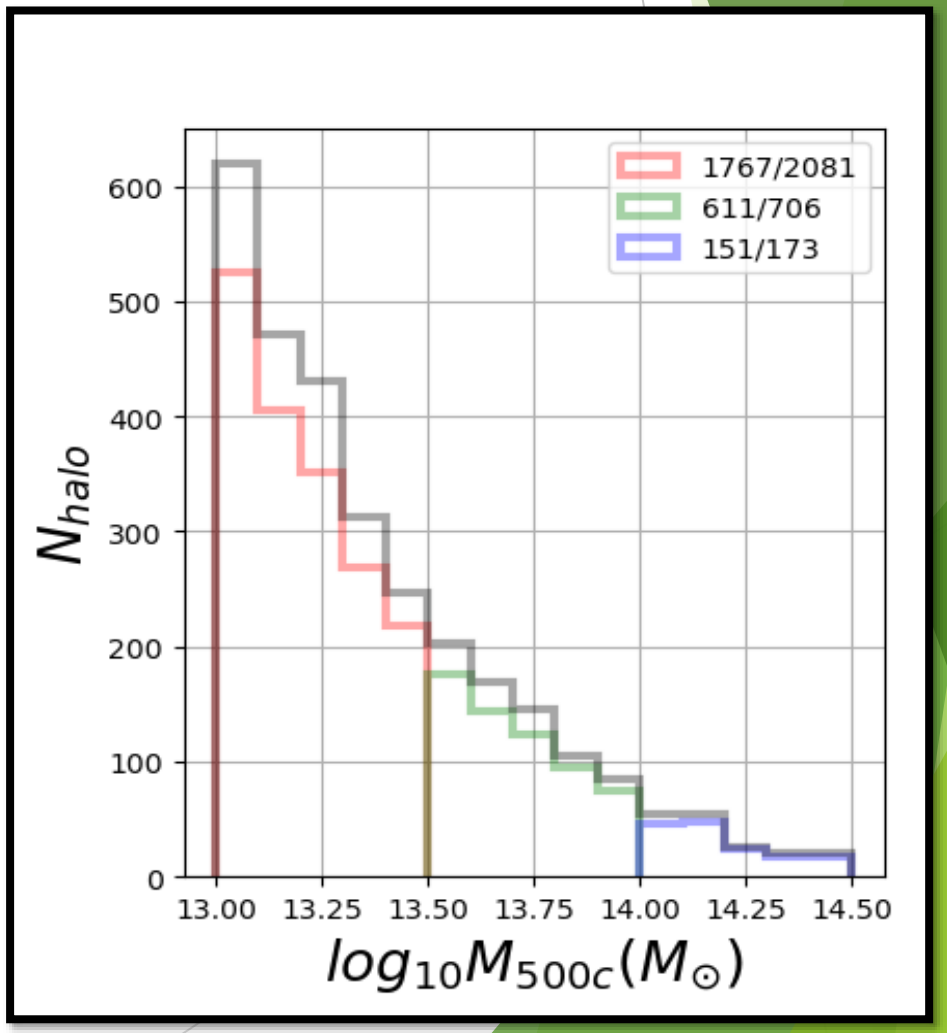
A ‘Plausible’ halo
(ρ_{gas}, L_X, Y_{SZ} …)

Halo pop. (Filter from hearin et al.2021)

- We mask outliers with extreme mass accretion histories. (to justify Diffmah parametrization)

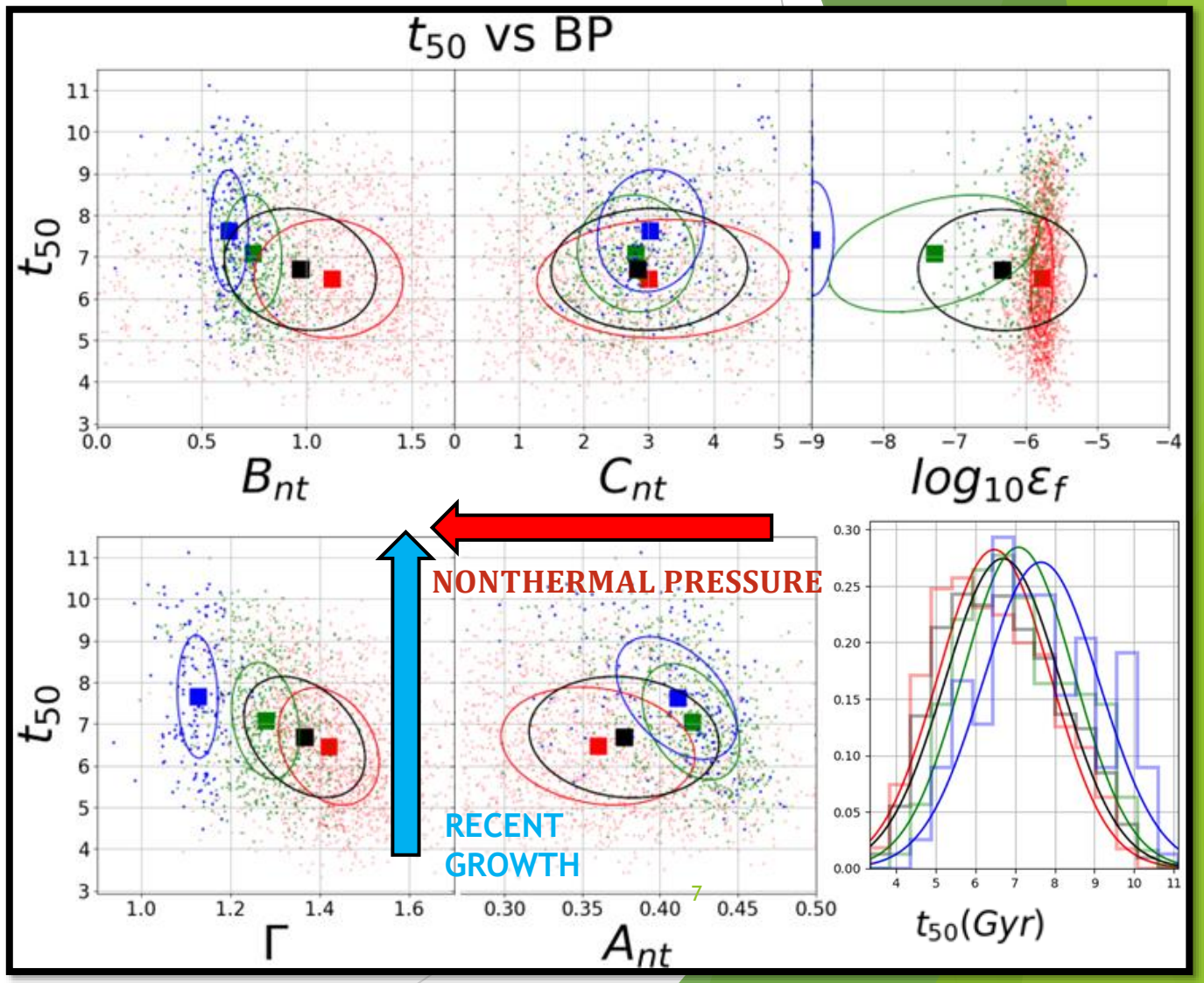
- We divide halos into three groups to take halos' mass dependency into account.

$$\log \frac{M_{500c}}{M_{sun}} \rightarrow 13\sim13.5$$
$$\log \frac{M_{500c}}{M_{sun}} \rightarrow 13.5\sim14$$
$$\log \frac{M_{500c}}{M_{sun}} \rightarrow 14\sim14.5$$



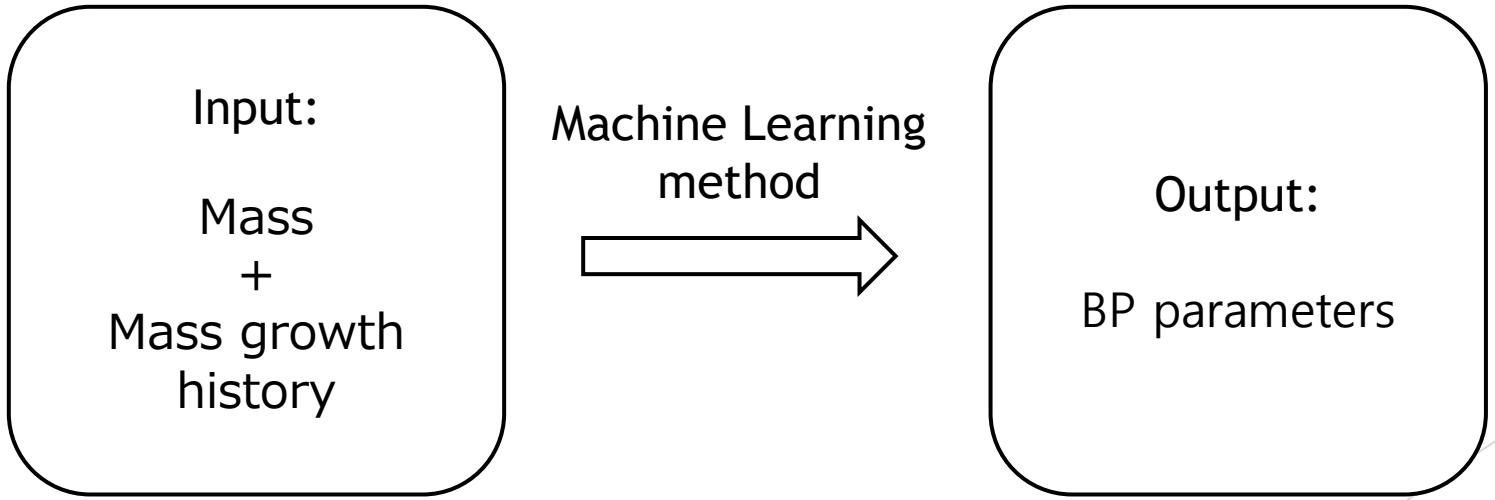
t_{50}-BP RELATION

- Halos with Recent mass growth events tend to be nonthermal pressure-dominated (Very natural!)



MACHINE LEARNING METHOD

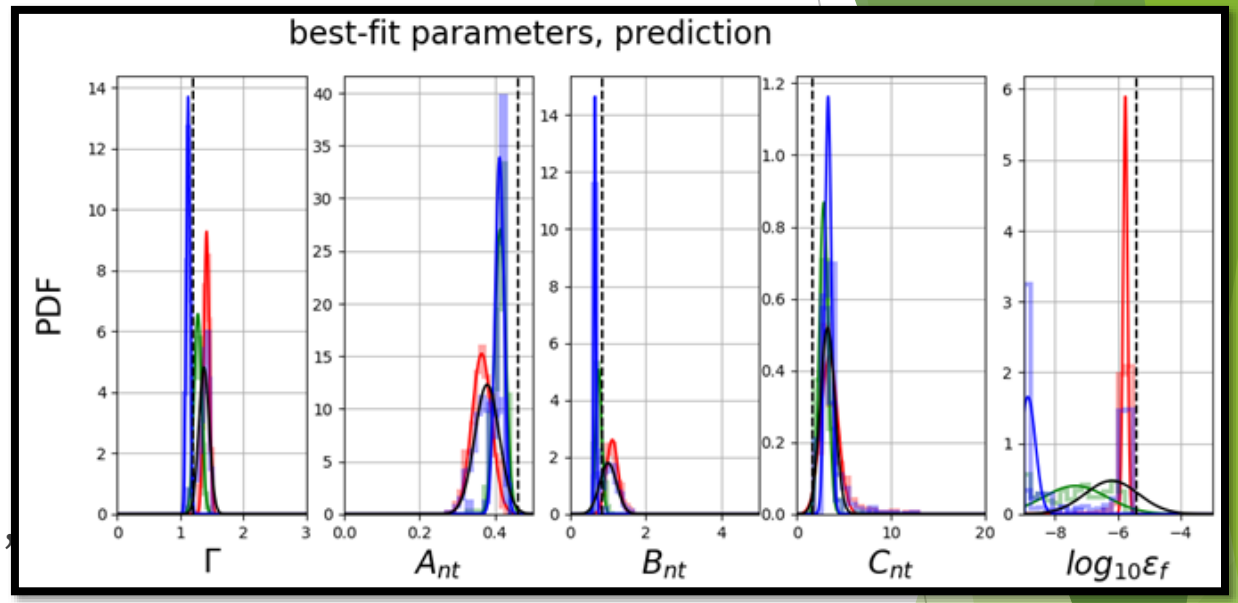
- The relation between diffmah(growth) & BP(baryonic physics) is not trivial.
- Introducing machine learning method(we use JAX library),
  we visualize the complicated relation between the two different phenomena.
- In our study, we aims to reproduce (predicted)BP parameters
  by using Diffmah parameters.
  ($\theta_{Diffmah} \rightarrow \theta_{BP}$)

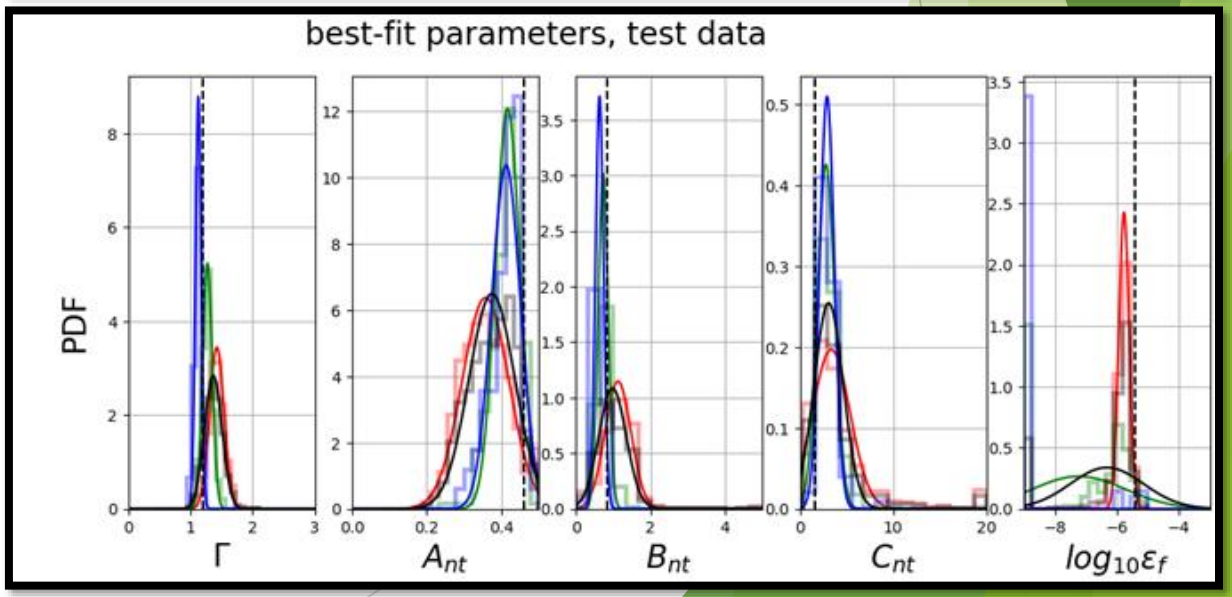


MACHINE LEARNING METHOD

- Current state:

  pipeline to find best-fit model parameters
  looking into the relation between parameters
  (in traditional ways! ex:1D parameter histogram, 2d parameter distribution(correlation))
  +
  wrote machine learning code(using jax)
  better understanding on $\theta_{\mathrm{Diffmah}}$-> θ_{BP}
  (expected to be very complicated!)





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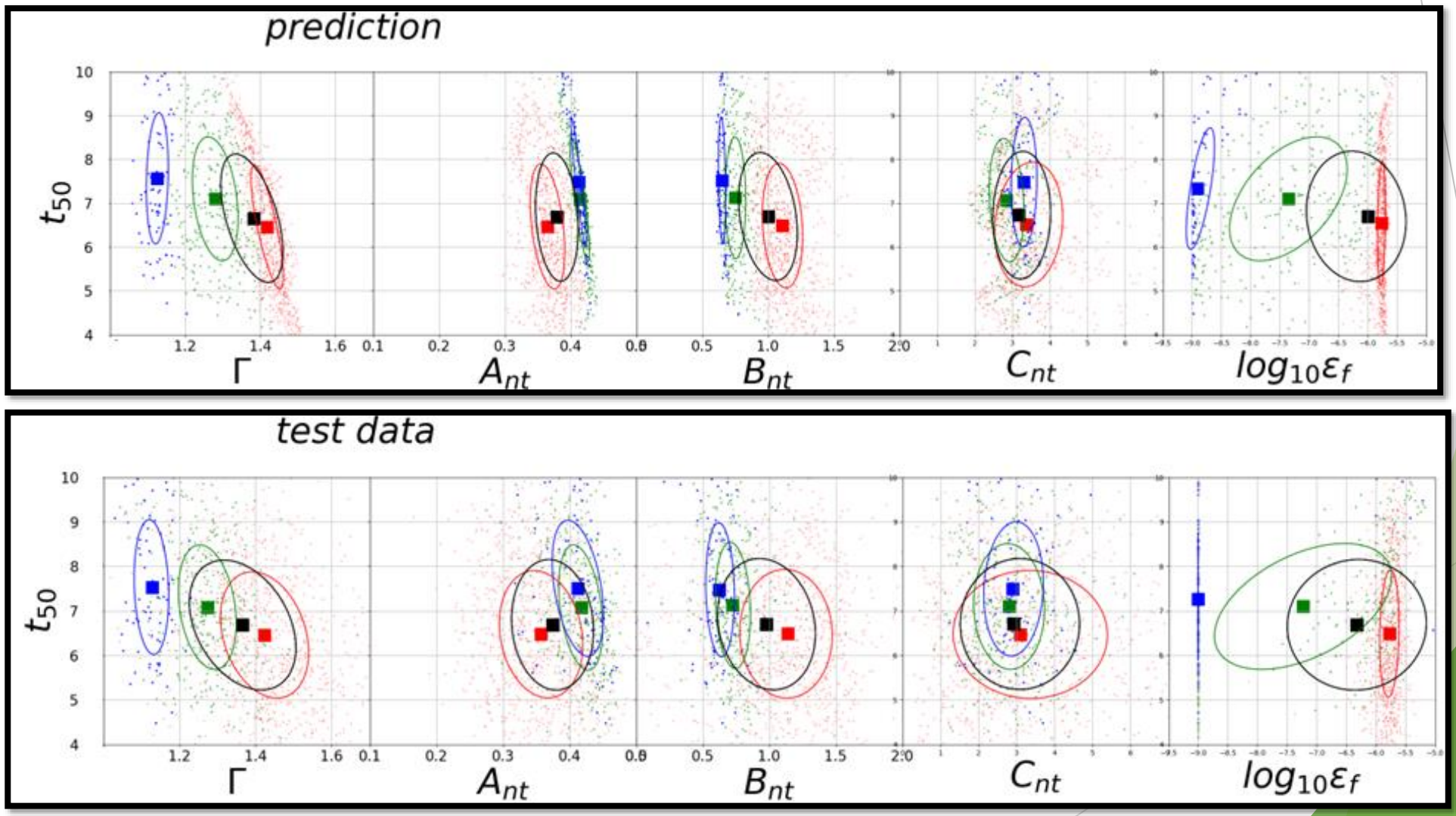

SUMMARY

- Cosmological models can be constrained by measuring number density of galaxy clusters. However, to do this, one should understand cluster physics well.

- We parametrized the two main factors affecting cluster physics, baryon physics(BP model) and mass growth of clusters(Diffmah model)

- We visualized the relation between model parameters.
  (traditional 1d histogram & 2d scatter plot)
  also, we wrote machine learning code which reproduce $\theta_{Diffmah} \rightarrow \theta_{BP}$ mapping well