# Galaxy Collision and the Outer Density Profile in Andromeda Galaxy

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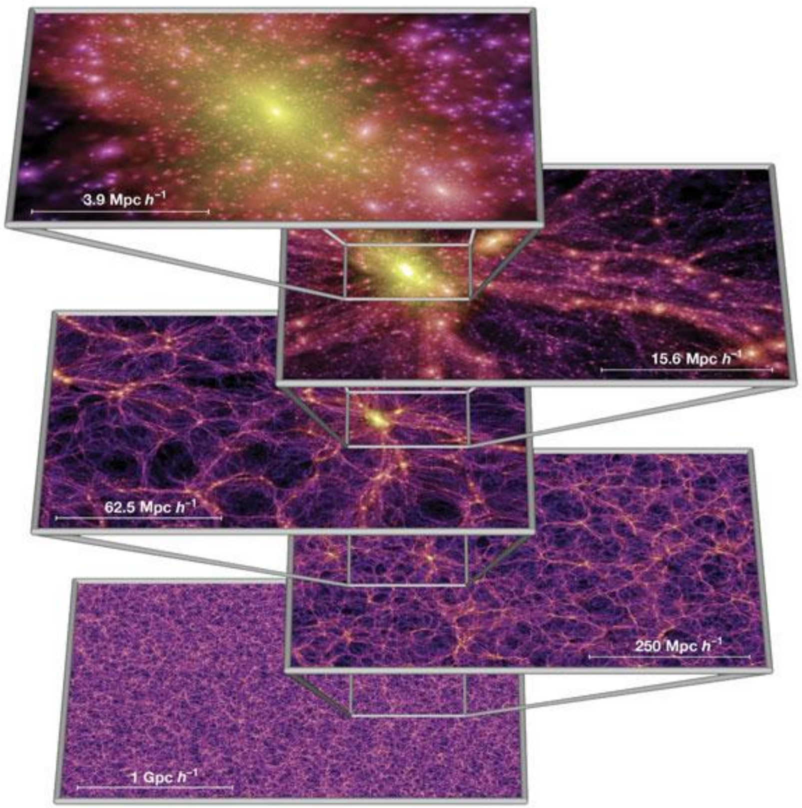
# Outline

- Structure formation in the universe
- Andromeda stellar stream
- Methods and parameters for simulation
- Numerical simulations
- Summary

# Theory of the structure formation



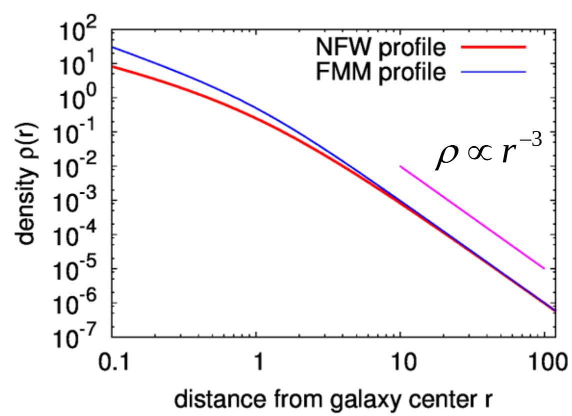

Springel, V et al. (2005)
structure formation in the universe
using cosmological *N*-body simulation

Recent cosmological simulations suggest that cold dark matter (CDM) halos have a universal mass-density profile (Navarro, Frenk & White 1995; Fukushige & Makino 1997; Moore et al. 1998).

Mass density of CDM outer halos decreases with the cube ( $\rho \propto r^{-3}$) of the distance from the galactic center.

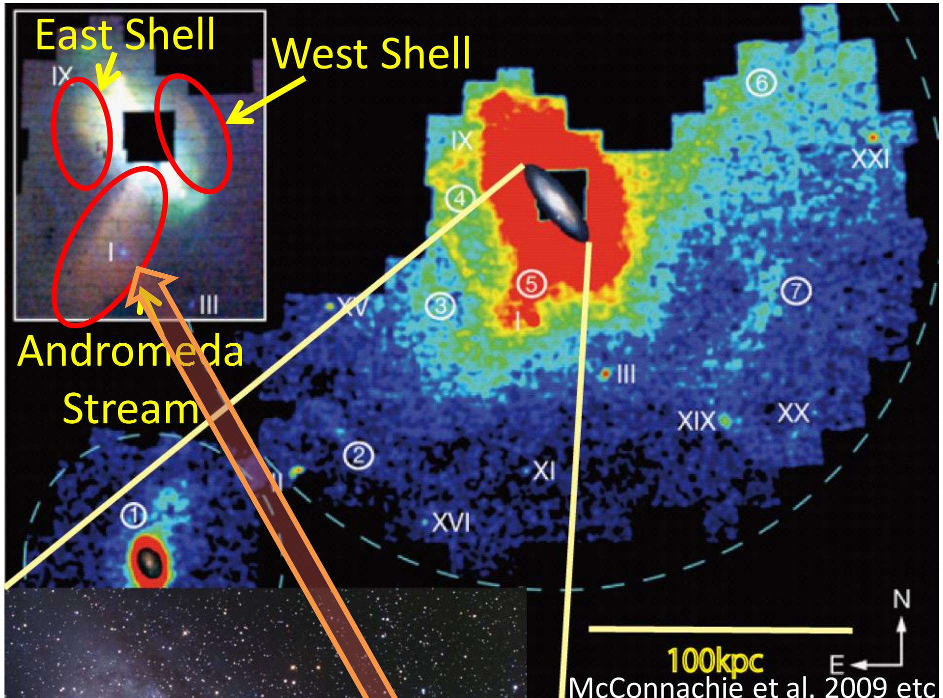
**However**

**So far, observational verification of this theoretical prediction is not yet sufficient**



# Andromeda stellar stream

Stellar density map around M31




- Andromeda stellar stream extends over 100kpc from the center of M31.
- Its spatial and velocity structure have been observed in detail (Ibata et al. 2001,2004; McConnachie et al. 2009).

*N*-body simulations of the galaxy collision between dwarf satellite galaxy and M31 nicely reproduced these structures.

Orbit, mass and other properties of the progenitor have been examined (Fardal et al. 2007; Mori & Rich 2008; Miki et al. 2010).

This giant stellar stream provides an attractive window to explore the structure of outer CDM halo in the M31.

# Methods and parameters for simulation

- Models of progenitor dwarf galaxy as an *N*-body system
  - Number of particles is 49,512
  - Other conditions are taken from Fardal et al.(2007)
- M31 is treated as the fixed potential
  - With the Hernquist bulge, the exponential disk and the DM halo
- Mass density profile of DM halo of M31

$$\rho_{DMhalo}(r) = \frac{\rho_{0,a}}{(r/r_{s,a})(1+r/r_{s,a})^{a}}$$

$\rho_{0,a}$ : the scale density
$r_{s,a}$ : the scale length
of the DM halo respecting M31

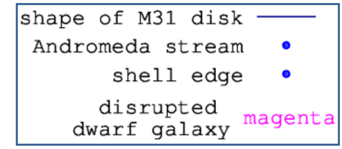
We change the power-low slope ***a*** **(1.5≦a≦4.0)**

※ a=2 ($\rho \propto r^{-3}$): the profile of the DM outer halo corresponds to the prediction of CDM model

⟹ examine the range of parameter ***a*** which reproduces the giant stream and shells with *N*-body simulations of galaxy collision

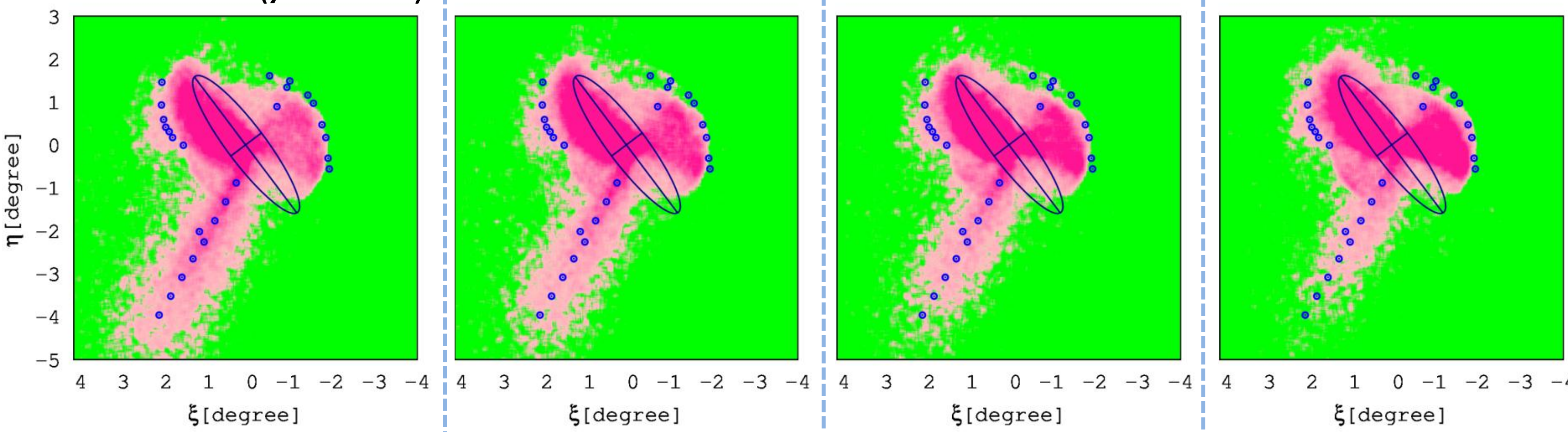
⟹ **examine the theoretical prediction of the profile of the DM outer halo**

# Results

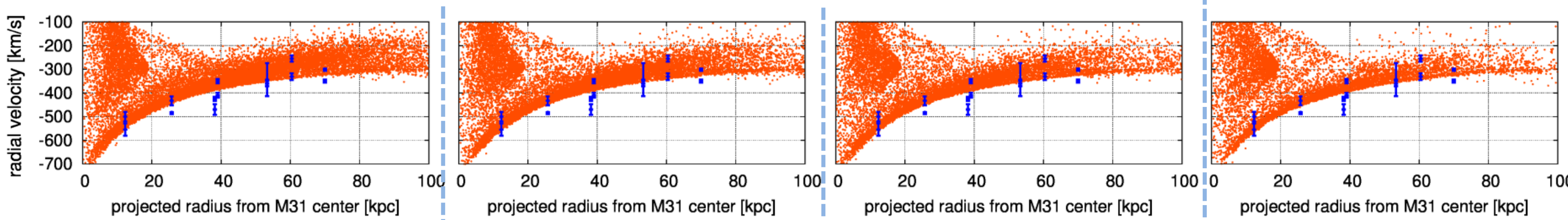



## ① Spatial structure of disrupted dwarf satellite galaxy in present-day

a=2.0 ($\rho \propto r^{-3}$) a=2.5 a=3.0 a=3.5



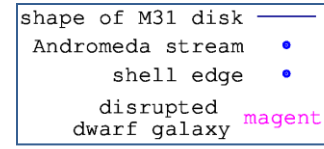

## ② Radial velocity structure of the Andromeda stream




Velocity distribution in simulation is consistent with the observation (Trethewey et al. (in prep.)) in all parameters.


(Trethewey et al. (in prep.))

# Results

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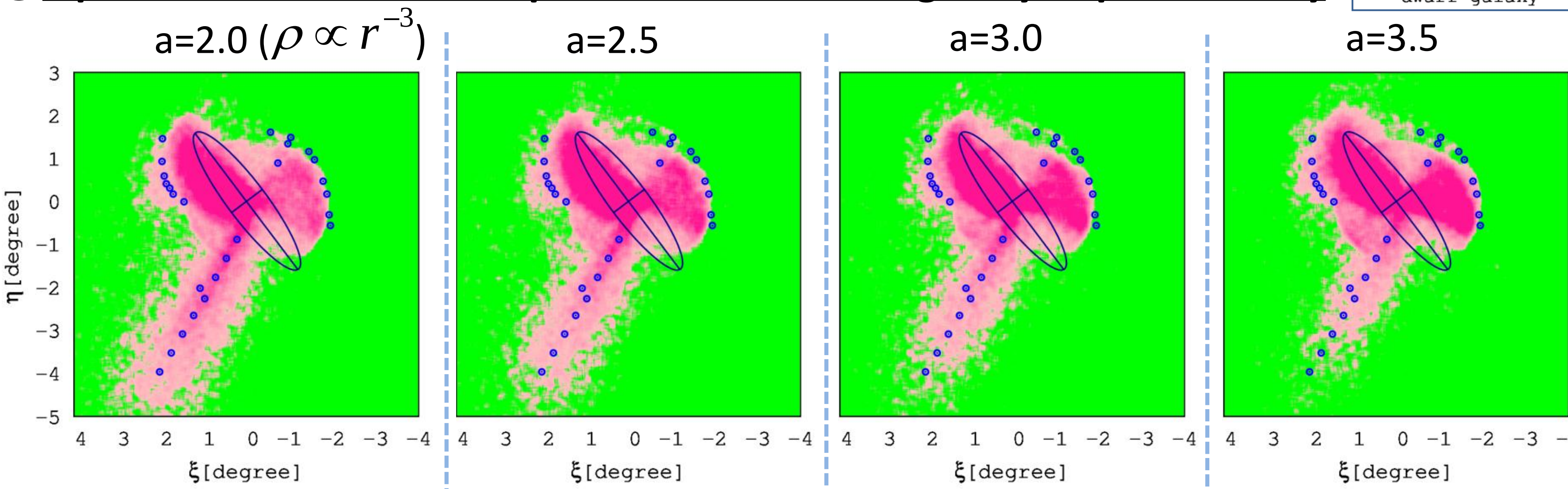
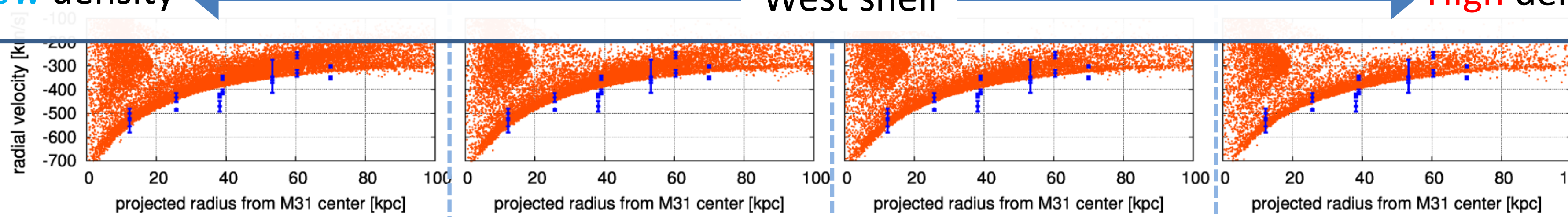
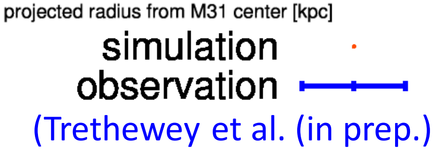



High density ← Stream → Low density

Low density ← West shell → High density

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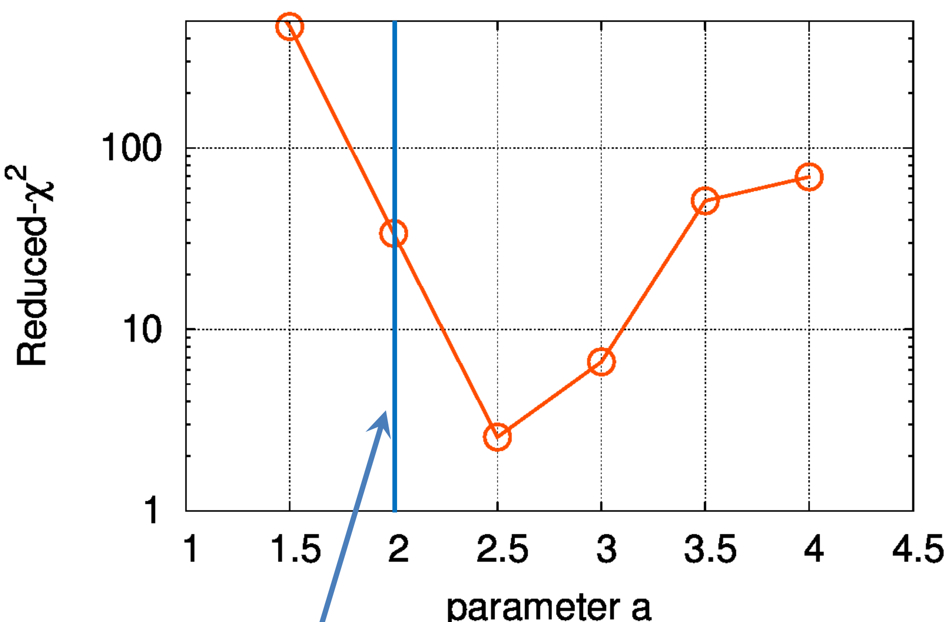
# Discussion

What makes this discrepancy between prediction of CDM model and our result?

- -Triaxiality of the CDM halo
  (e.g. Milky Way (Deg & Widrow. 2012))
- -Tidal effect by galaxies such as M33 and/or Milky Way
- -Morphology of the infalling galaxy

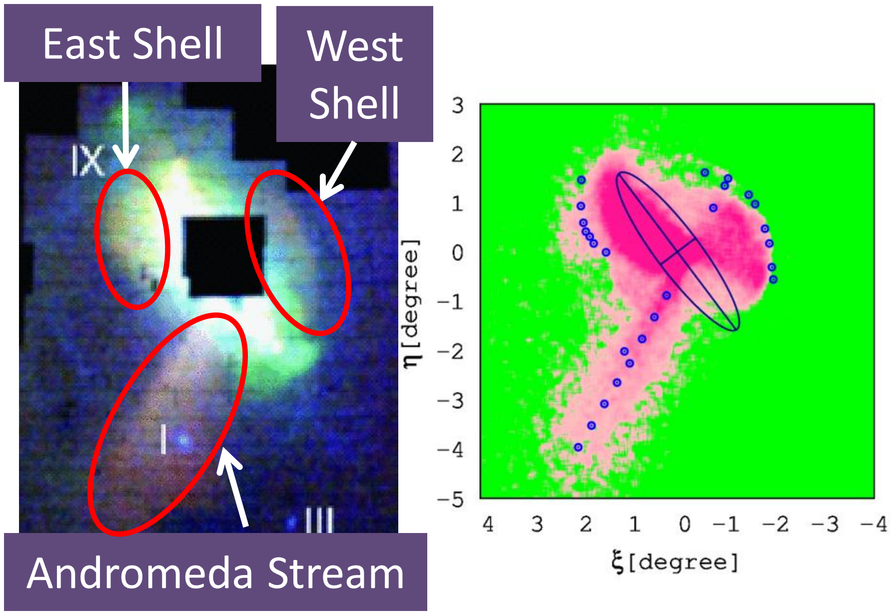
# Analysis

③ $\chi^2$ **analysis of the surface density ratio of stream and 2 shells between simulation and star count map of observation**




DM density profile suggested by cosmological *N*-body simulation $\rho \propto r^{-3}$

a=2 can't reproduce apparent structures




Only for the DM outer halo with a density power-law slope of **-2< a <-3.5**, the results of simulations successfully reproduce the giant stream and the apparent shell structures that are observed in the star count map.

# Summary

- We examined the mass density profile of DM halo of M31 using *N*-body simulation of galaxy collision.
- DM density profile suggested by cosmological *N*-body simulation can't reproduce apparent stream and shell structures.
- Our result indicates that the density profile of the DM outer halo of the Andromeda galaxy is steeper than the prediction of the CDM model.

## ***Future Works***

➢ Investigating the effect of the triaxiality halo and tidal effect by galaxies such as M33 and Milky Way

➢ Collisions between disk dwarf galaxy and M31 to explain asymmetric structure of the Andromeda stream (ongoing)