The Prolate dark halo of Andromeda galaxy

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ABSTRACT

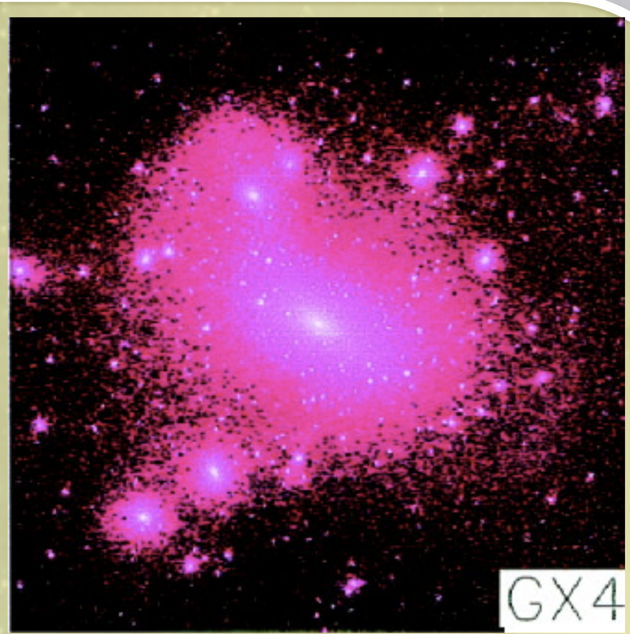
In order to obtain more realistic mass distribution of a dark halo in our nearest giant, we adopt axisymmetric mass models constructed by Hayashi & Chiba (2012) and apply these models to latest kinematic data of globular clusters and dwarf spherical galaxies in the halo of M31. Applying our model to Andromeda galaxy, we find that the most plausible cases for Andromeda yield not spherical but prolate shape for its dark halo. This result is profound in understanding internal dynamics of halo tracers in Andromeda, such as orbital evolutions of tidal stellar streams, which play important roles in extracting the abundance of CDM subhalos through their dynamical effects on stream structures.

1.Why Andromeda?

The Milky Way and its nearest neighbor Andromeda provide a unique laboratory to test Lambda-Cold Dark Matter (LCDM) theory of galaxy formation and evolution. In particular, LCDM models, as a current paradigm of structure formation in the Universe, predict universal density distribution for a galaxy-sized halo as well as the presence of numerous subgalactic halos in it, as a consequence of hierarchical assembly process of dark matter. It is thus of importance to derive how dark matter is actually distributed in a galaxy scale like the Milky Way and Andromeda, to get useful insight into the role of dark halos in galactic structure and evolution in the framework of LCDM models.

2.The motive of this study

Until now, most of existing mass models for Andromeda's dark halo have assumed spherical symmetry, for the purpose of simply estimating its total mass. However, LCDM models predict non-spherical virialized dark halos (right figure) in this galaxy scale. We thus need to consider more general models to set more realistic and new limits on global shape and profile of a dark halo.



LCDM predicted galaxy-sized dark halo by N-body simulation (Jing & Suto 2000)

3.Model

★Stellar density

$$\Sigma(x,y) \propto \left(x^2 + \frac{y^2}{q'^2}\right)^{-\gamma/2}$$

q' is a projected axial ratio. *γ=3.5* is best-fit power law value.

For axial ratio, q, we vary it between **0.6, 1, 1.4**, which can have presumable values, because it is so difficult to determine the shape of distribution of tracer populations.

★Dark halo

$$\rho(R,z) = \rho_0 \left(\frac{m}{b_{\rm halo}}\right)^{\alpha} \left[1 + \left(\frac{m}{b_{\rm halo}}\right)^2\right]^{\delta}$$

$$m^2 = R^2 + \frac{z^2}{Q^2}$$

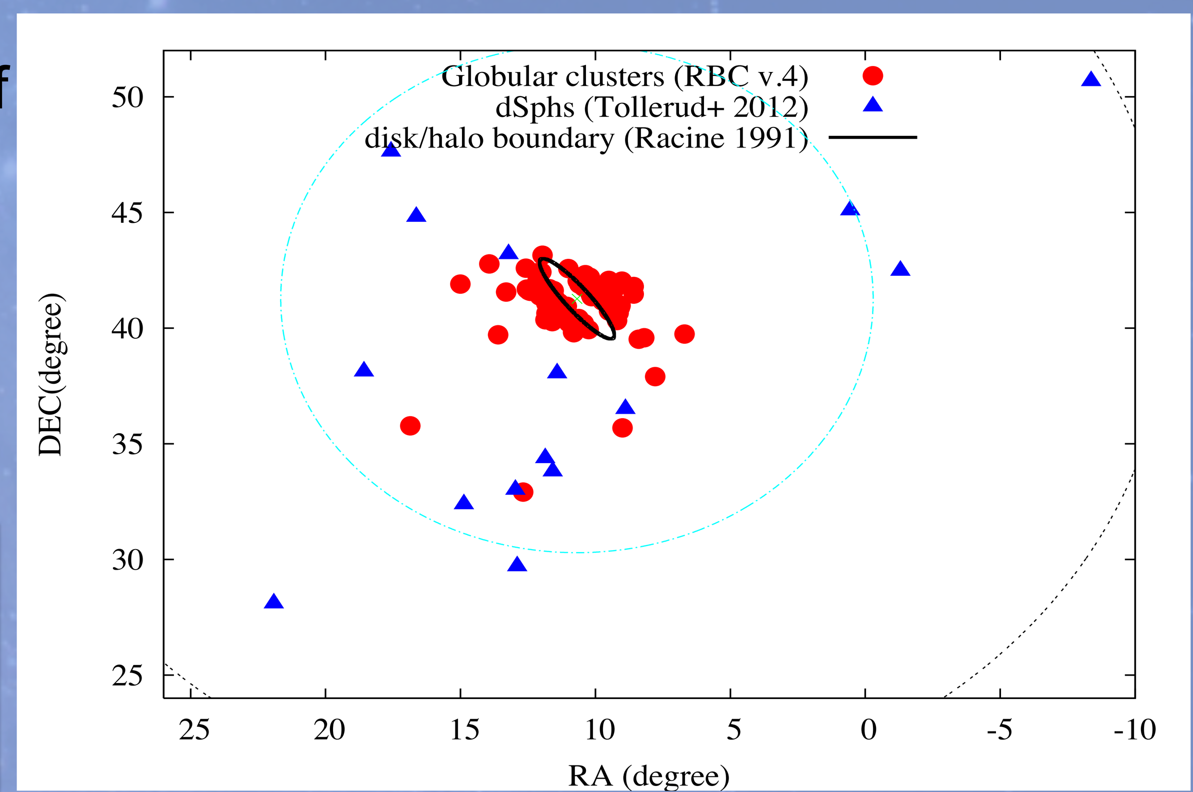
Q is an axial ratio, b_{halo} is scale length and ρ_0 is a scale density. For ρ_0, We replace it with ***M(<200 kpc)***, which is mass within 200 kpc. *These are free parameters.*

For (α,δ): We confine ourselves to plausible density profiles: **SIS with (α,δ)=(-2,0)** and **NFW with (α,δ)(-1,-1)**.

4.Data analysis

We use a sample of 91 globular clusters and 15 dwarf galaxies in the halo of Andromeda.

For the kinematic data of GCs and dSphs, we adopt **Revised Bologna Catalogue** of M31 GCs and **Tollerud+ 2012**, respectively.



・Maximum likelihood analysis

To obtain halo parameters of our mass models by comparing with observational data, we employ a maximum likelihood method.

$$P(\mathbf{v}_{\rm los}|u,\sigma_t) = \prod_{i=1}^{N} \frac{1}{\sqrt{2\pi\sigma_i^2}} \exp\left[-\frac{1}{2}\frac{(v_{{\rm los},i}-u)^2}{\sigma_i^2}\right]$$

u : systemic velocity of M31

$$\sigma_i^2 = \sigma_{t,i}^2 + \sigma_{m,i}^2 \quad \begin{cases} \sigma_{t,i}^2 : \text{theoretical dispersion} \\ \sigma_{m,i}^2 : \text{measurement uncertainty} \end{cases}$$

5. Prolate dark halo in M31

5-1. Results of Maximum likelihood analysis

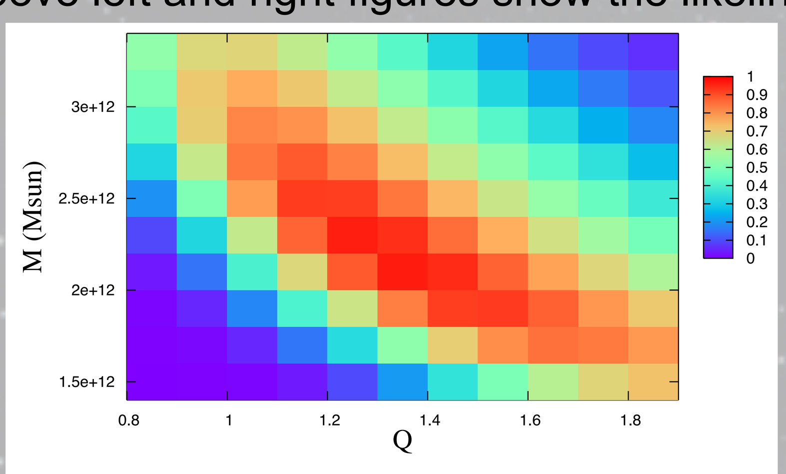
For axial ratio which we set 0.6, 1.0, 1,4, in comparing the results of fitting, we find that unity q' fits much better than non-unity one.

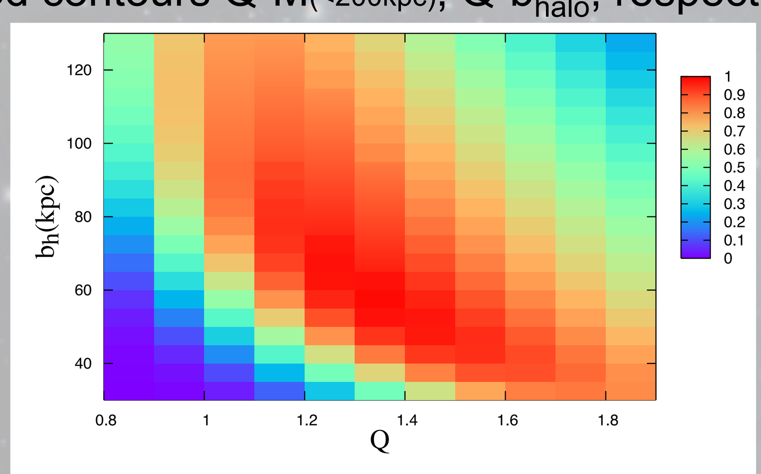
Case of $q'=1$	Halo Model	Q	$b_{\rm halo}$ (kpc)	$M_{\le 200{\rm kpc}}$ $(10^{12}\times M_\odot)$
	SIS	$1.38^{+0.29}_{-0.33}$	80.5^{+65}_{-45}	$2.59^{+0.95}_{-0.57}$
	NFW	$1.18^{+0.50}_{-0.21}$	$35.2^{+8.7}_{-8.2}$	$4.26^{+1.74}_{-0.20}$

We find that the most plausible cases for Andromeda yield not spherical but prolate shape for its dark halo.

5-2. Q vs. M(<200 kpc) and Q vs. b_{halo} with SIS model

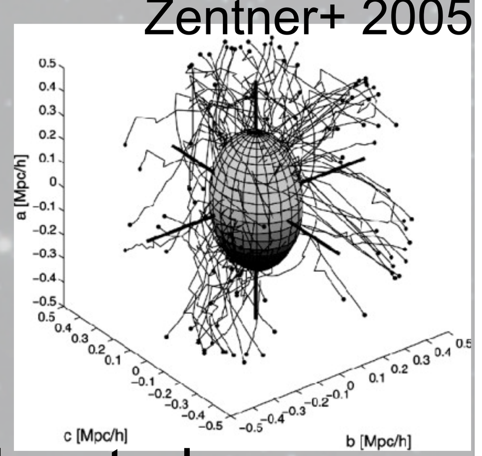
Above left and right figures show the likelihood contours Q-M(<200kpc), Q-b_{halo}, respectively.





These results suggest that prolate dark halo would be significant results, although it is difficult to determine the shape parameter, Q.

5-3. Comparison with LCDM simulation



Zentner+ 2005

In this work, we find that dark halo in M31 is elongated along the pole of the its disk. This result is consistent with prediction from LCDM based N-body simulation (e.g. Zenter+ 2005).

In particular, Zenter+ 2005 found that subhalos are distributed anisotropically and preferentially located along the major axes of the triaxial their host halos. Therefore, ***our result may contribute valuable evidence for interpreting spatial distribution of dwarf satellites in Andromeda.***

6. Summary

- We adopt axisymmetric models constructed by Hayashi & Chiba (2012) and apply these models to latest kinematic data of globular clusters and dwarf spheroidal galaxies in the halo of Andromeda.
- We find that the best fitting cases for Andromeda's dark halo yield prolate shape and are elongated along perpendicularly to the plane of the its disk.
- This result is profound in understanding internal dynamics of halo tracers in Andromeda, such as orbital evolutions of tidal stellar streams, which play important roles in extracting the abundance of CDM subhalos through their dynamical effects on stream structures.
- In the near future, planned surveys of Andromeda's halo using HSC and PFS will enable us to discover new halo objects (globular clusters, dwarf galaxies and tidal streams) and measure their accurate kinematic data, thereby allowing us to obtain tighter limits on the dark halo distribution in Andromeda.