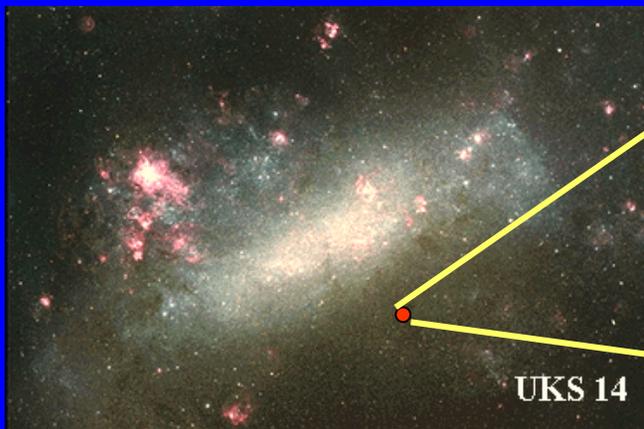


# Origin of the old globular cluster system in the LMC



UKS 14

(The LMC)



NGC 1850

(GC)

=

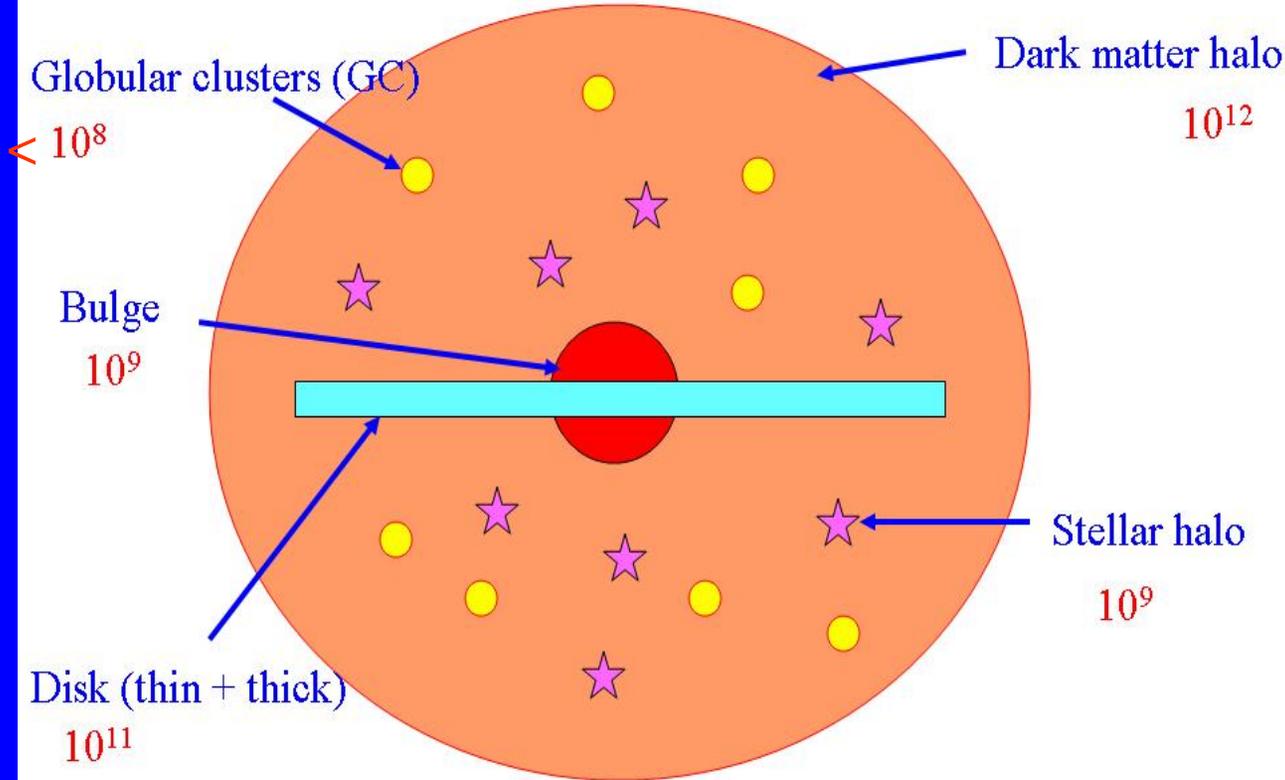


(The Rosetta Stone)

Kenji Bekki (UNSW, Australia)

# GCs and Globular cluster systems (GCSs)

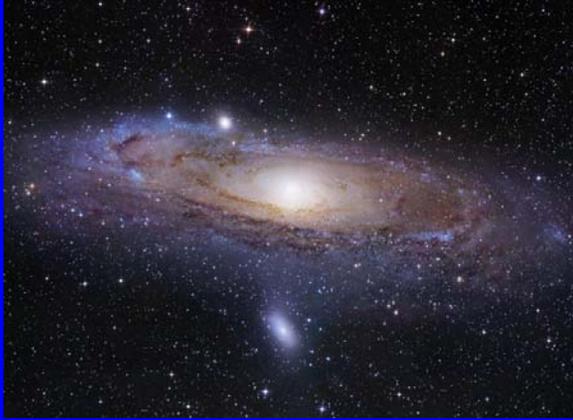
## Basic components of a galaxy



GC:47 Tuc

**GCS properties:**  
Space distributions,  
Kinematics,  
Metallicity.....

# Globular cluster systems (GCSs) in different Hubble types.



**Spiral: M31**



**Irregular: LMC**

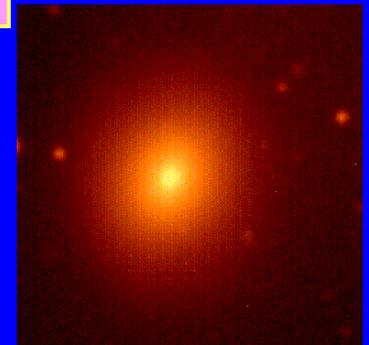


**Elliptical: M87**

**GC-less galaxies.**



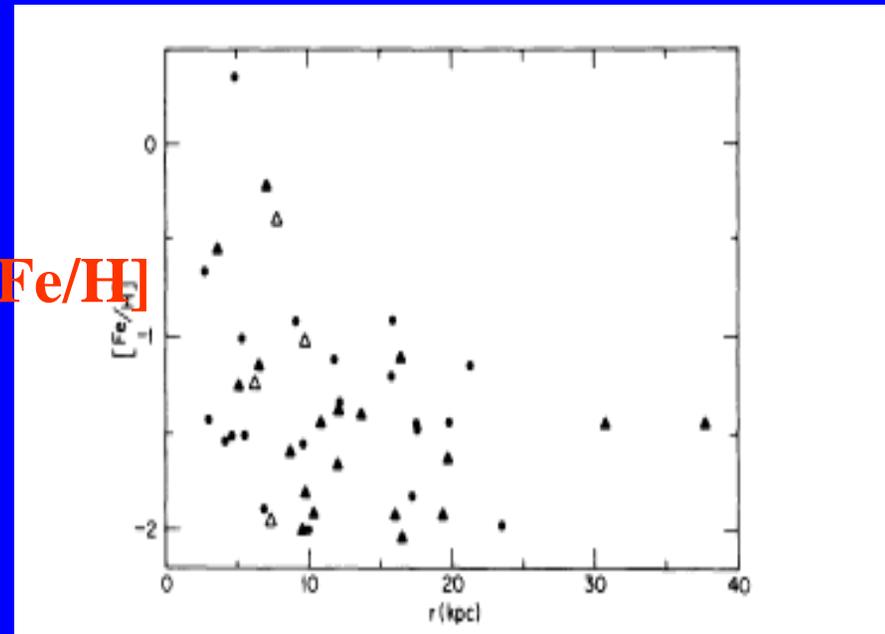
**Leo A**



**M32**

# Why merging/accretion in the Galaxy formation (Searle & Zinn 1978; SZ)?: GCs as fossil records of the Galaxy formation.

- No significant metallicity gradient in the Galactic GC.
- A possible broad range of age in the outer halo GCs etc... (SZ 1978).



**Radius (kpc)**

The chaotic merging/accretion  
scenario (Searle & Zinn 1978)

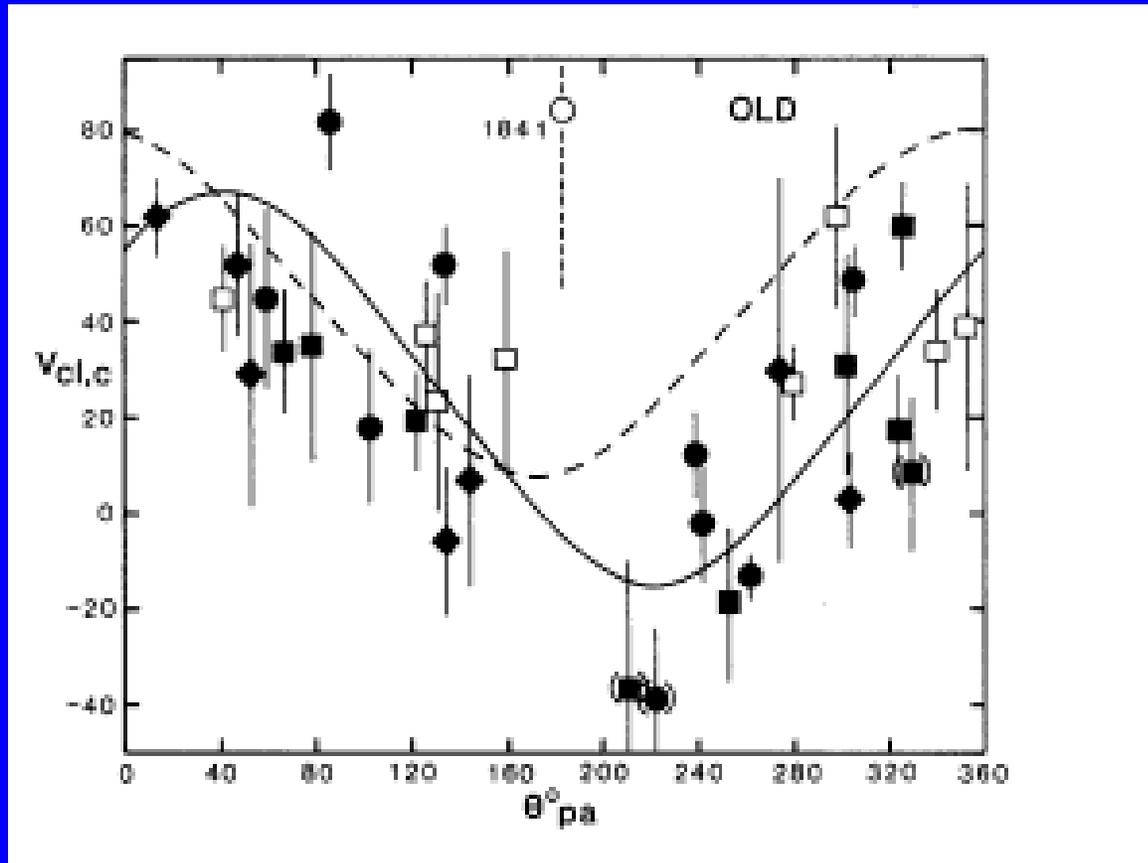
A big question:

What do physical properties of the  
GCS of the LMC tell us about the  
LMC formation ?

A specific question:

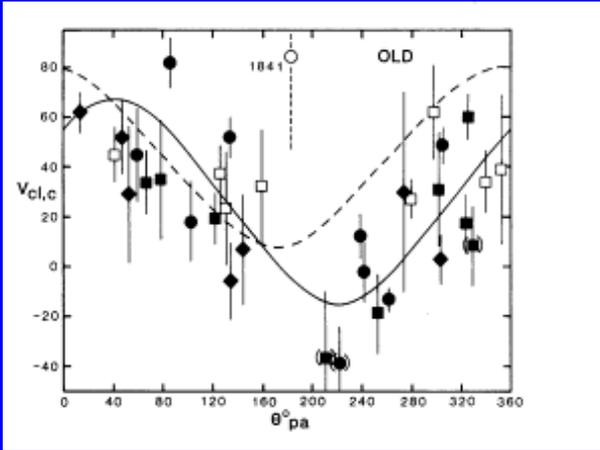
Origin of the observed kinematical differences between the stellar halo and the old GCS in the LMC.

# Rotational kinematics in the old GCS of the LMC (Freeman et al. 1983)?

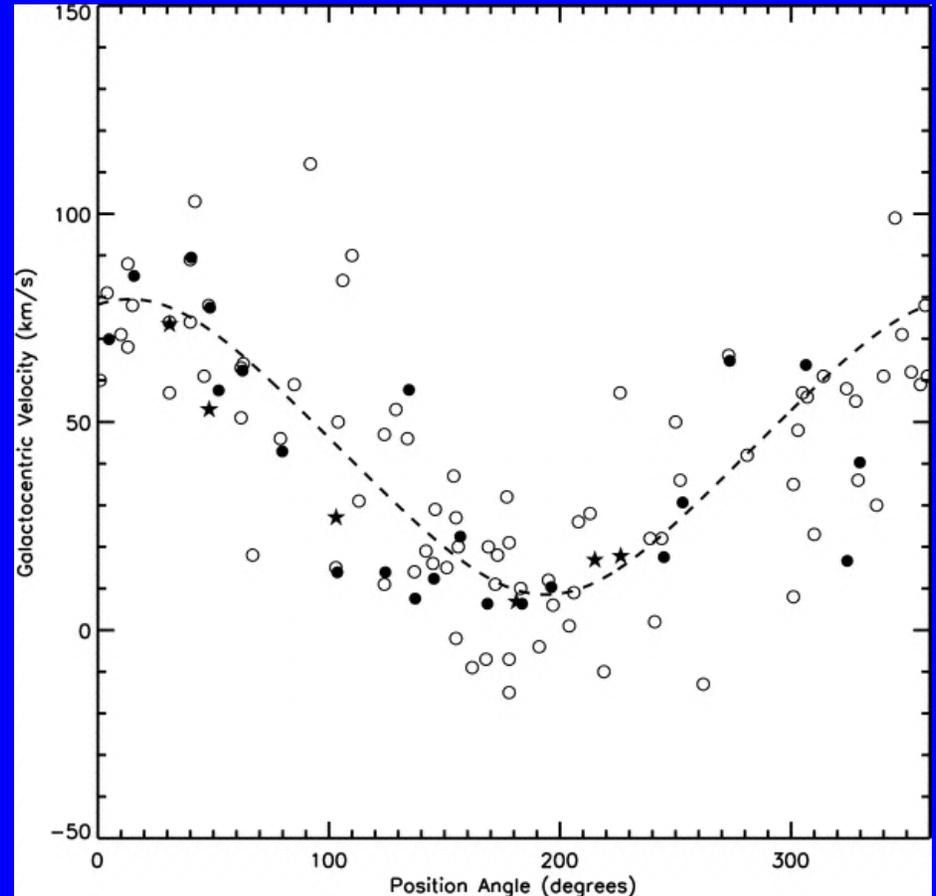


$$V_{rot} \sim 41 \text{ km/s}, \sigma \sim 17 \text{ km/s}, V/\sigma \sim 2.4$$

# Rotational kinematics in the LMC'S GCS.



(Freeman et al. 1983)



(Grocholski et al. 2006)

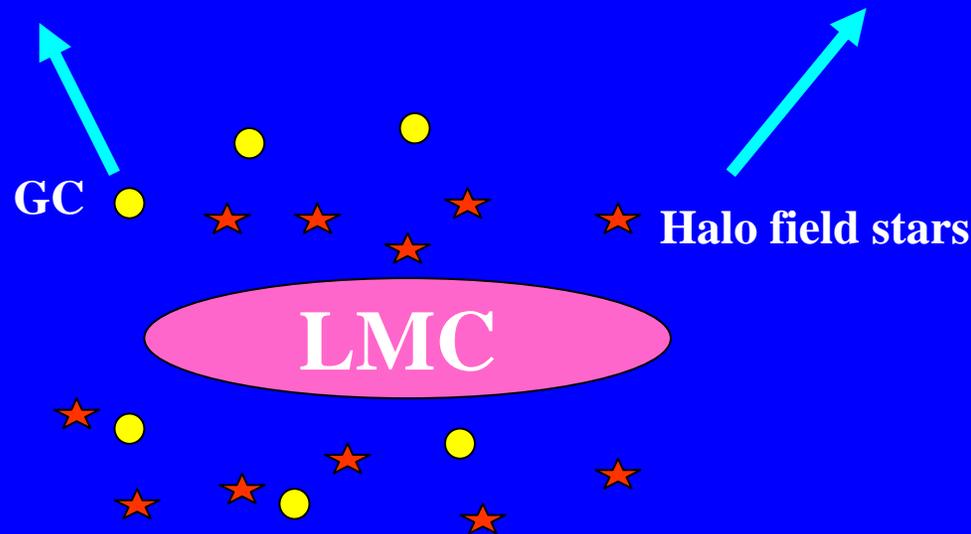
# The *old* stellar halo properties in the LMC.

- $V_{\text{rot}} < 10$  km/s for the stellar halo (for RR Lyrae stars),  $\sigma \sim 53$  km/s, and  $V/\sigma < 0.2$  (e.g., Minniti et al. 2003).
- An exponential (projected) radial density profile (e.g., Alves 2004).
- A flattened inner stellar halo (Subramaniam 2006) ?

The non-rotating stellar halo vs the rotating old GCS in the LMC ?

LMC

GCS:  $V/\sigma \sim 2.4$  Halo:  $V/\sigma \sim 0.2$



# The non-rotating stellar halo vs the rotating old GCS in the LMC

**LMC**

**GCS:  $V/\sigma \sim 2.4$  Halo:  $V/\sigma \sim 0.2$**

**The Galaxy**

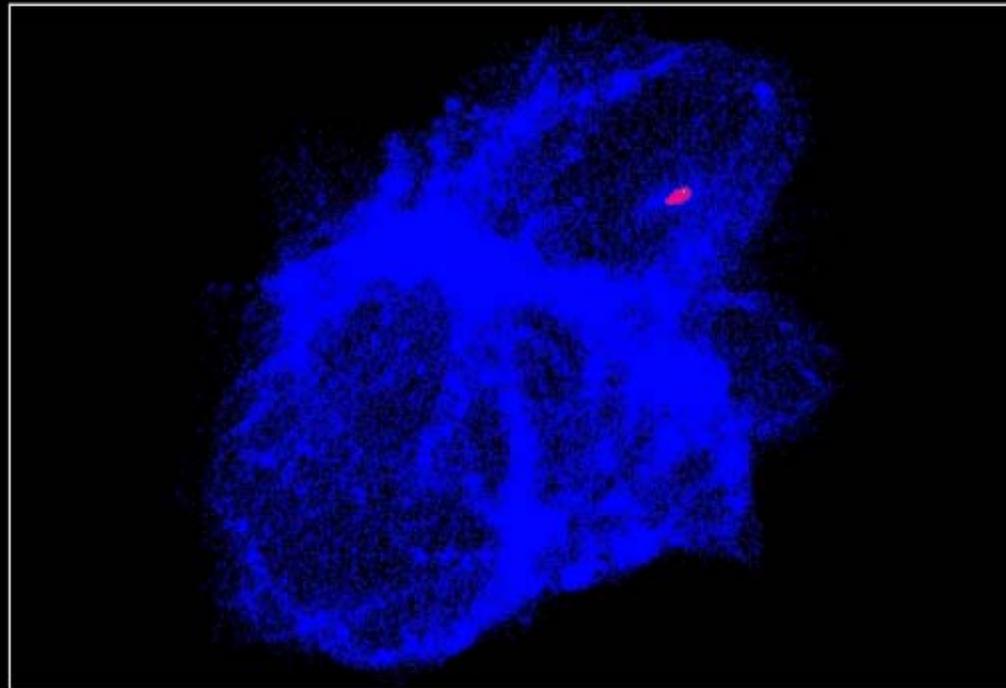
**GCS:  $V/\sigma \sim 0.3$  Halo:  $V/\sigma \sim 0.3$**

*(e.g., for  $\sigma_r/v$ ; Freeman 1993)*

Question:

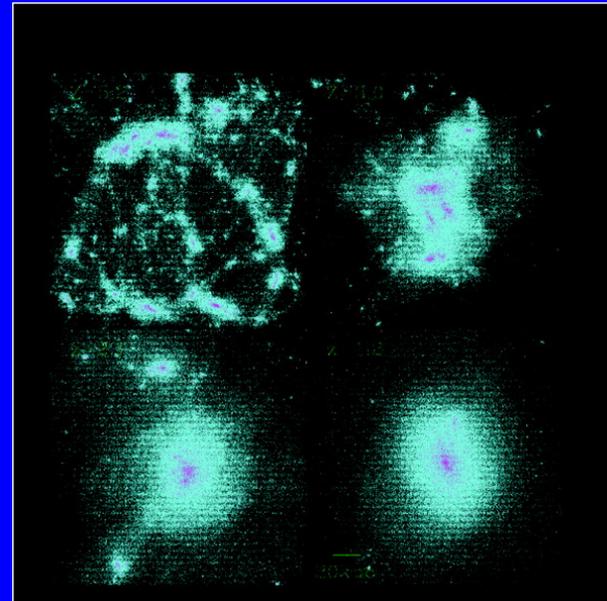
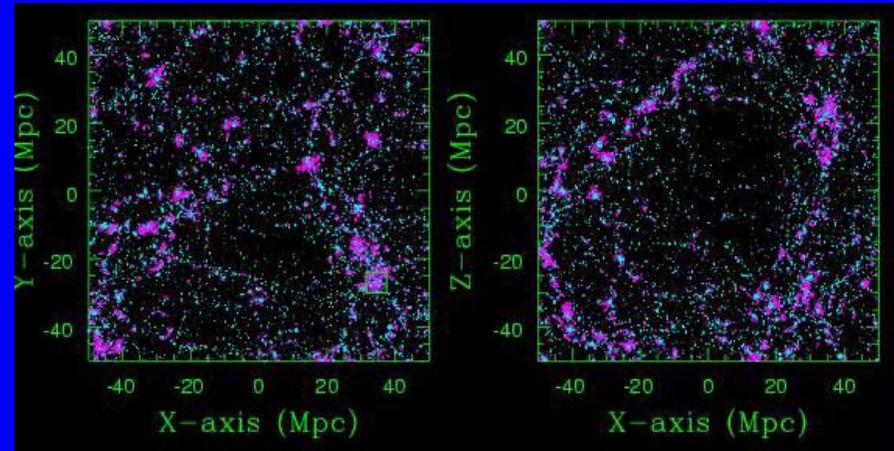
Are these kinematical properties consistent with the LMC formation model (based on the  $\Lambda$ CDM) ?

- (1) Bekki (2007): galaxy-scale simulations
- (2) Bekki & Yahagi (2007): Large-scale ones.

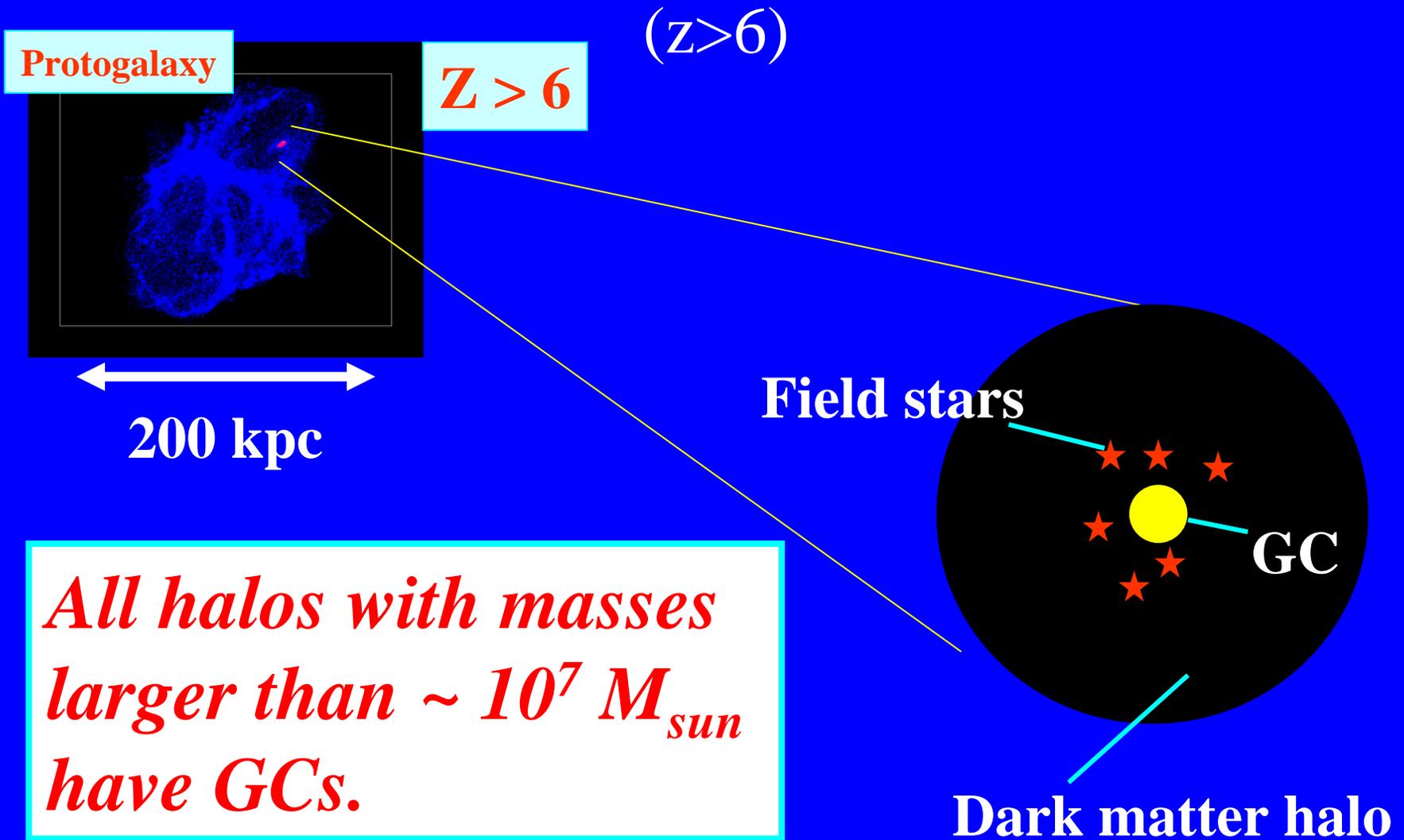


# The formation of the LMC's GCS.

- (1) GCSs from 100 Mpc-scale simulations (e.g., Yahagi & Bekki 2005)
- (2) GCSs from galaxy-scale simulations (Bekki 2007).



# GC/field star formation in low-mass galaxies embedded by dark matter halos at high redshifts



# Can we find a model with the GCS having $V/\sigma \sim 2$ ?

2 *K. Bekki*

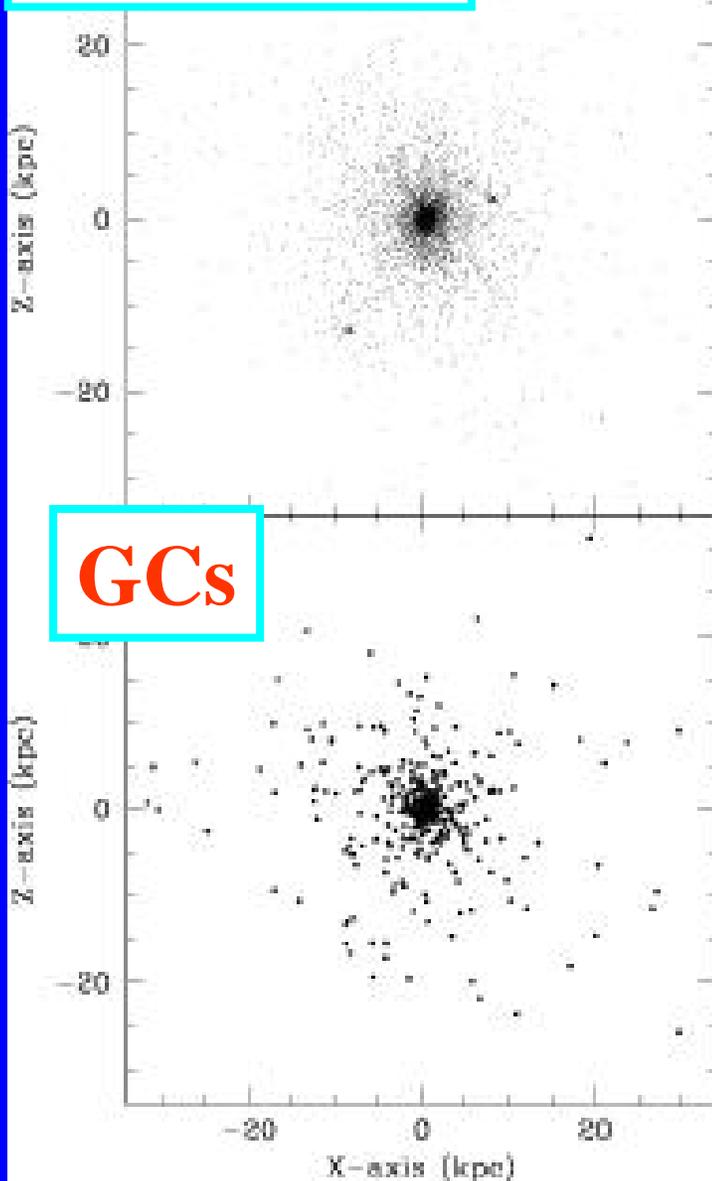
Table 1. Model parameters and a brief summary of results  $\lambda$   $\delta_i$   $Z_{\text{trun}}$

model	$M_V (\times 10^{10} M_{\odot})^a$	$\lambda^b$	$\delta_i^c$	$N_{\text{min}}^d$	$z_{\text{trun}}^e$	$(V/\sigma)_{\text{FS}}^f$	$(V/\sigma)_{\text{GC}}^g$
Standard	6.0	0.08	0.39	32	15	0.34	0.39
Low density	6.0	0.08	0.19	32	15	0.60	0.56
High threshold	6.0	0.08	0.39	1000	15	0.28	0.22
Low- $z$ truncation	6.0	0.08	0.39	32	10	0.19	0.21

$(V/\sigma)_{\text{FS}} ?$

$(V/\sigma)_{\text{GC}} ?$

## Stellar halo



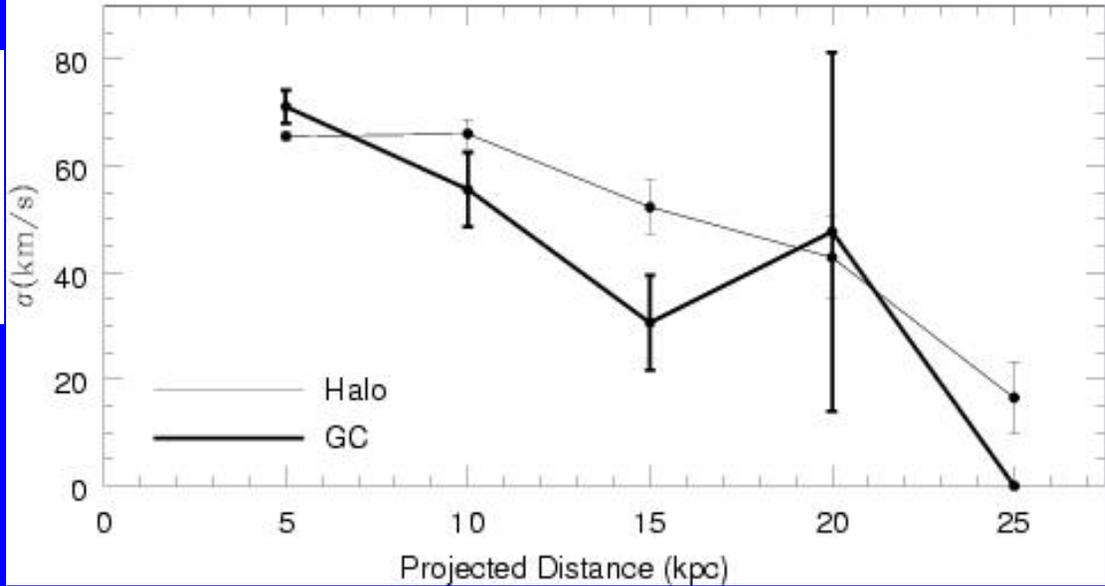
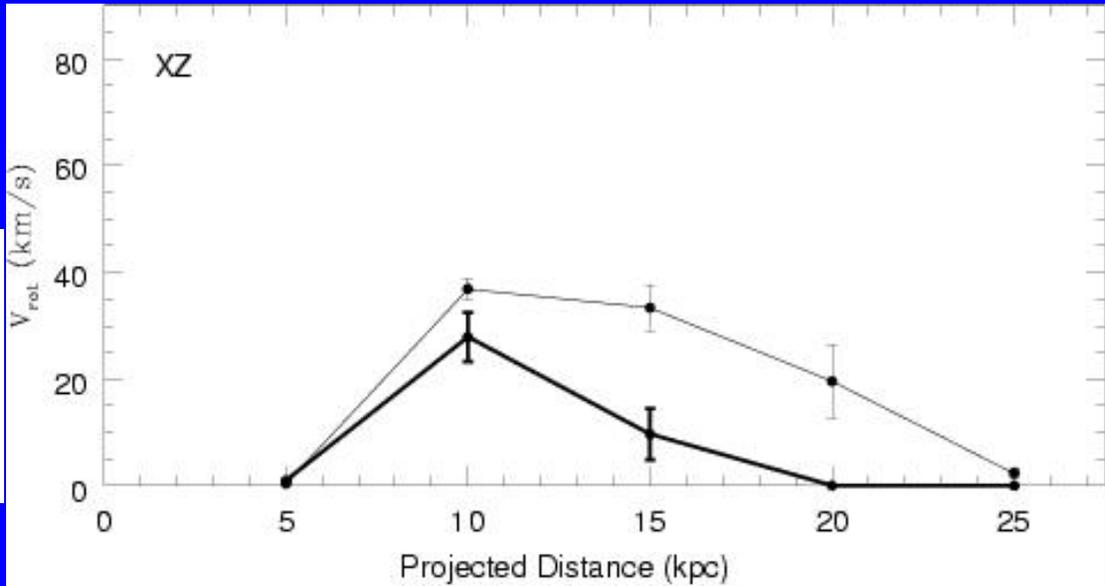
## GCs

Results:  
Spatial distributions of  
the stellar halo and the  
GCs in the LMC

# Kinematics

$V_{\text{rot}}$   
(km/s)

$\sigma$   
(km/s)



**Halo:**  $V/\sigma \sim 0.57$

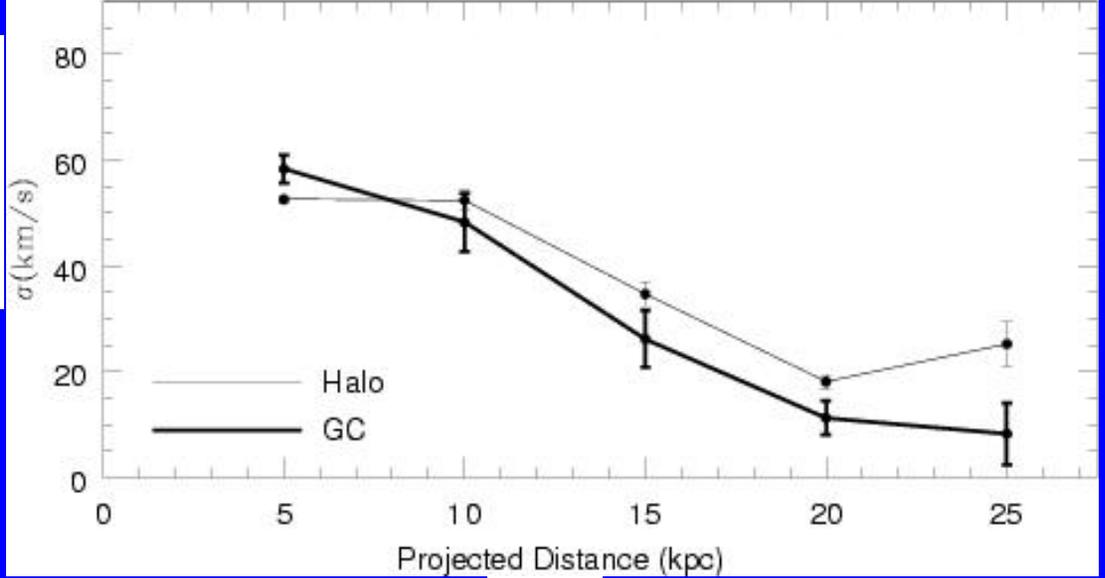
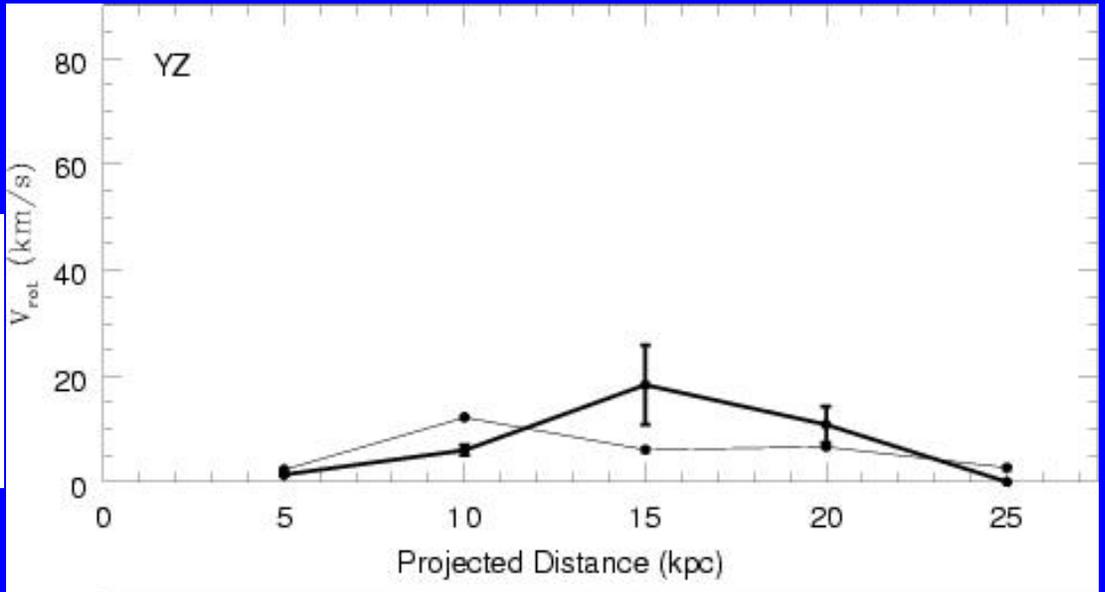
**GC:**  $V/\sigma \sim 0.60$

**R**  $\longrightarrow$

# Kinematics

$V_{\text{rot}}$   
(km/s)

$\sigma$   
(km/s)

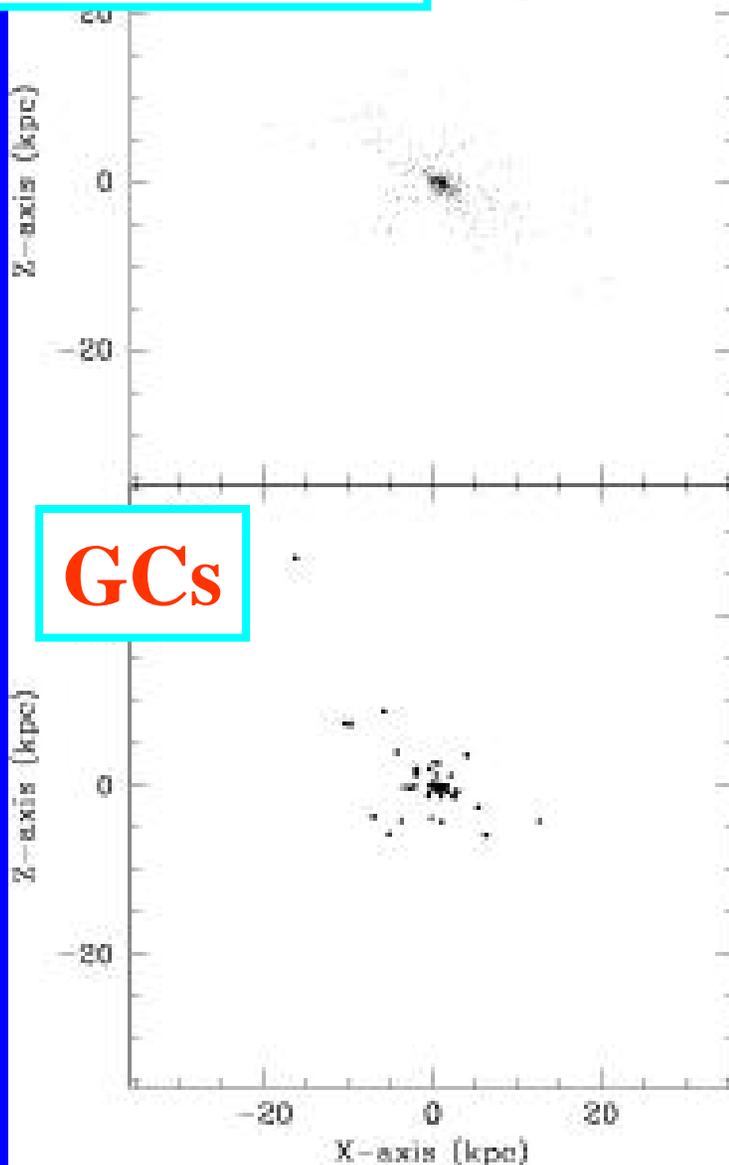


**Halo:**  $V/\sigma \sim 0.21$

**GC:**  $V/\sigma \sim 0.31$

**R**  $\longrightarrow$

## Stellar halo



Spatial distributions  
of the low- $\sigma$  (initial  
low density) model.

*More flattened...*

# Kinematics

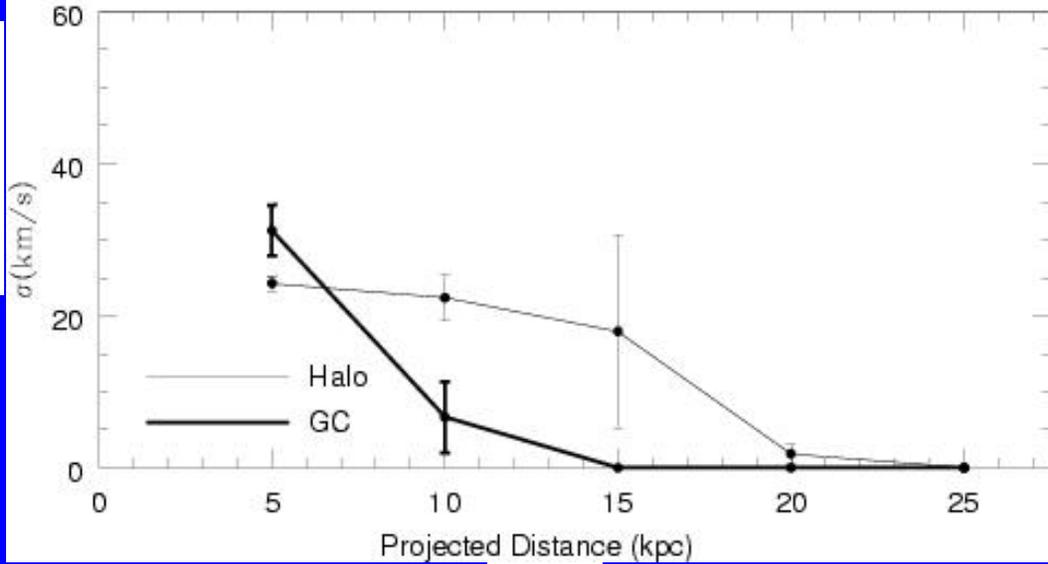
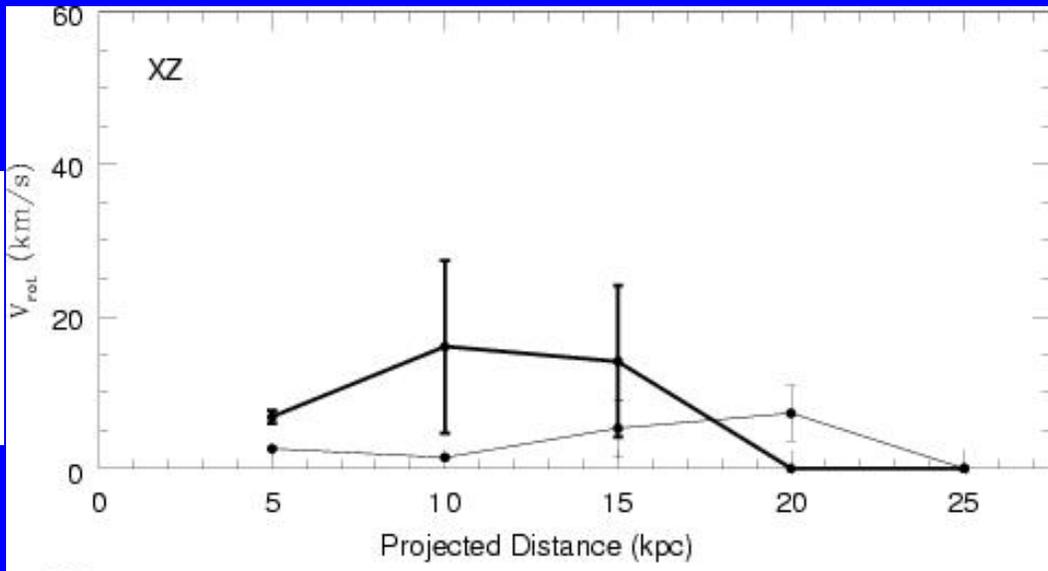
$V_{\text{rot}}$   
(km/s)

$\sigma$   
(km/s)

*Mean of three projections*

**Halo:**  $V/\sigma \sim 0.60$

**GC:**  $V/\sigma \sim 0.56$



**R**  $\longrightarrow$

Inconsistency between simulations  
and observations.

$$(V/\sigma)_{GC}$$

**Obs:  $V/\sigma \sim 2.4$    Sim:  $V/\sigma \sim 0.3$**

## Discussions: Lessons from unsuccessful models.

- No/little GC formation in low-mass halos at high- $z$  ( $>6$ ) : the presence of the threshold halo mass for GC formation ?
- ``Dissipative'' GC formation at the very early epoch of the LMC's disk formation : The LMC's GC are slightly younger than the Galactic counterparts ?

## Discussions: Two related problems.

- Why do less luminous galaxies have GCSs with rotation (e.g., Olsen et al. 2004 for galaxies in the Sculptor group) ?
- Why do the GCS/stellar halo in the Galaxy appear to show no/little kinematical differences ?

# Conclusions: Still mysterious GCS kinematics in the LMC

- Failures of the present LMC formation models in reproducing the rotational kinematics of the LMC's GCS.
- A possible threshold halo mass for GC formation and GC formation at the very early epoch of the LMC's disk formation ??