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A Redshift Survey of  
the Nearby Galaxy Cluster Abell 2107:  
Global Rotation of the Cluster and  
its Connection to LSS in the universe

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*Millennium simulation*

Clusters are generally formed in places where large-scale filaments from different directions meet.

31.25 Mpc/h



Thus, there is usually no preferred direction in the motion of matter in cluster, which ends up with overall random motions of cluster galaxies.

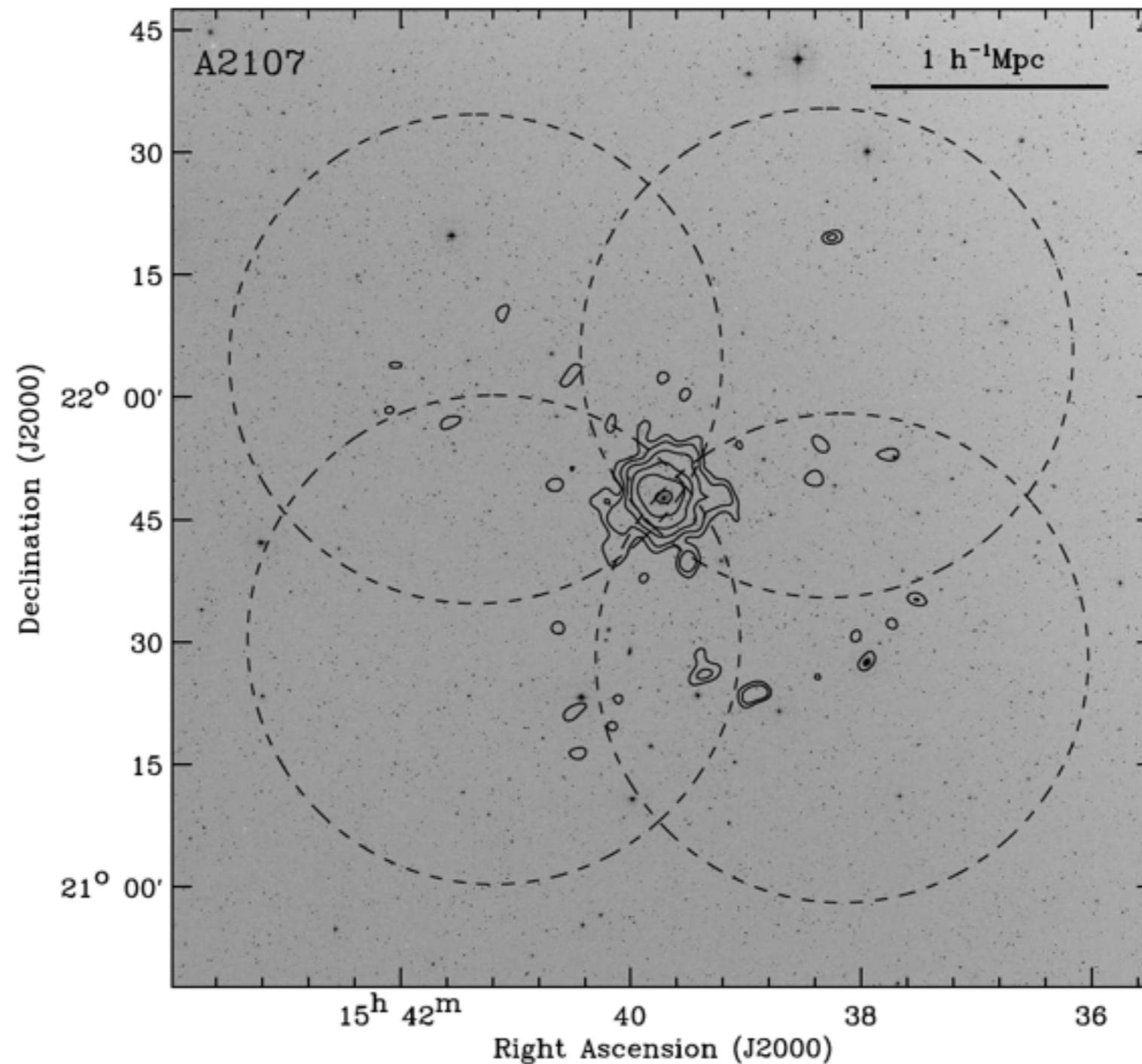
However,

# Abell 2107

- Nearby ( $z=0.04$ ), rich, X-ray bright galaxy cluster
- Known as a rotating cluster  
(e.g. Oegerle & Hill 1992, Kalinkov et al. 2005)
- **Dense sampling** is crucial to detect rotational motion clearly (cf. The previous studies were performed with  $\sim 70$  member galaxies only).
- **Large survey data** (i.e. SDSS) enable us to examine the cluster's rotational motion with its nearby LSS together.

6.5m telescope/300 fiber multi-object spectrograph

# A KIAS MMT/Hectospec survey



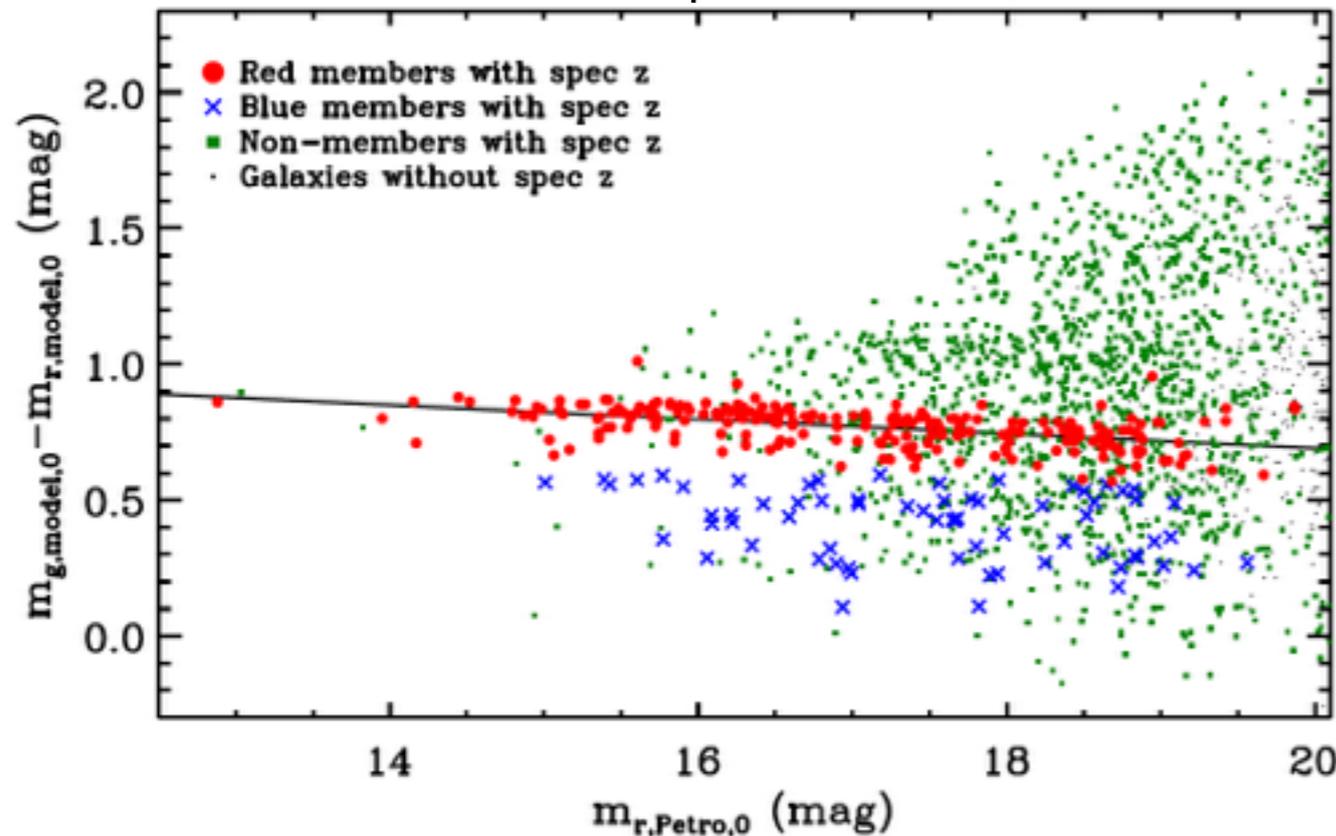
*dashed circles:*  
MMT/Hectospec FoV  
of 30' radius

*solid contours:*  
X-ray emission from  
Einstein/IPC

978 redshifts + 990 redshifts = **1968 redshifts (R<60')**  
(this survey) (literature)

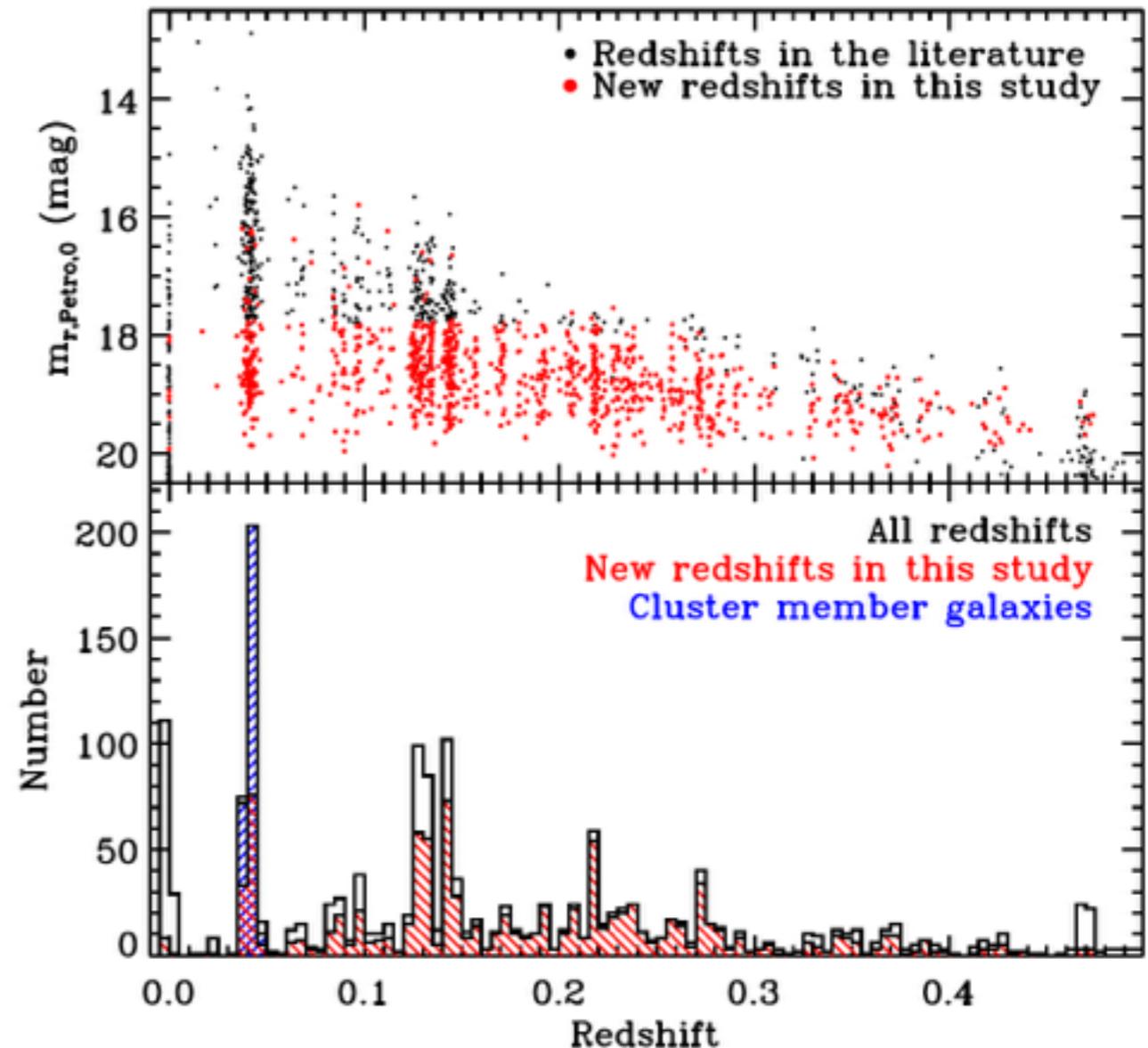
# A KIAS MMT/Hectospec survey

SDSS DR12 photometry



Color-magnitude diagram

Redshift distributions

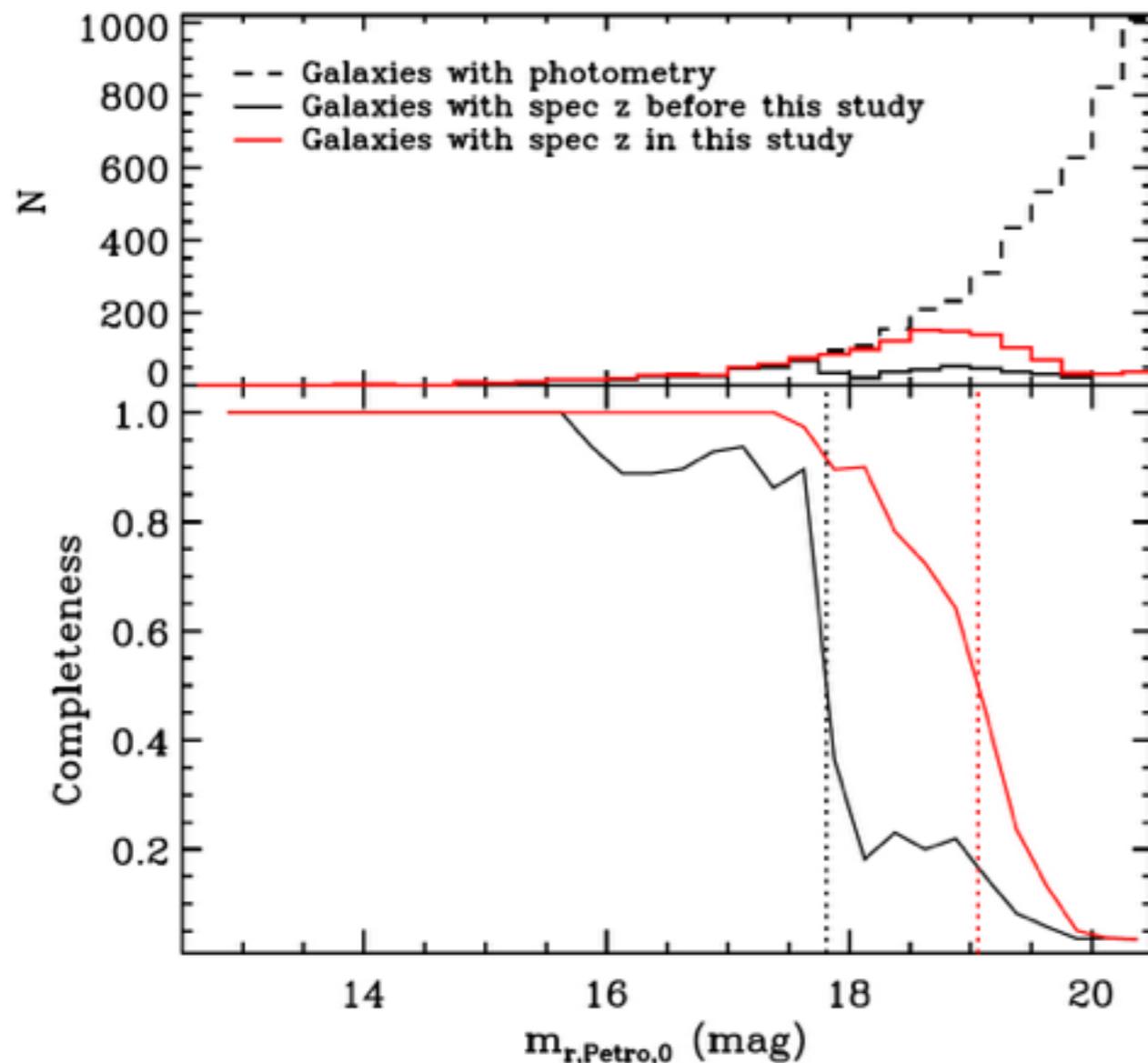


The resulting catalog shows **no selection bias** in color, magnitude, and redshift.

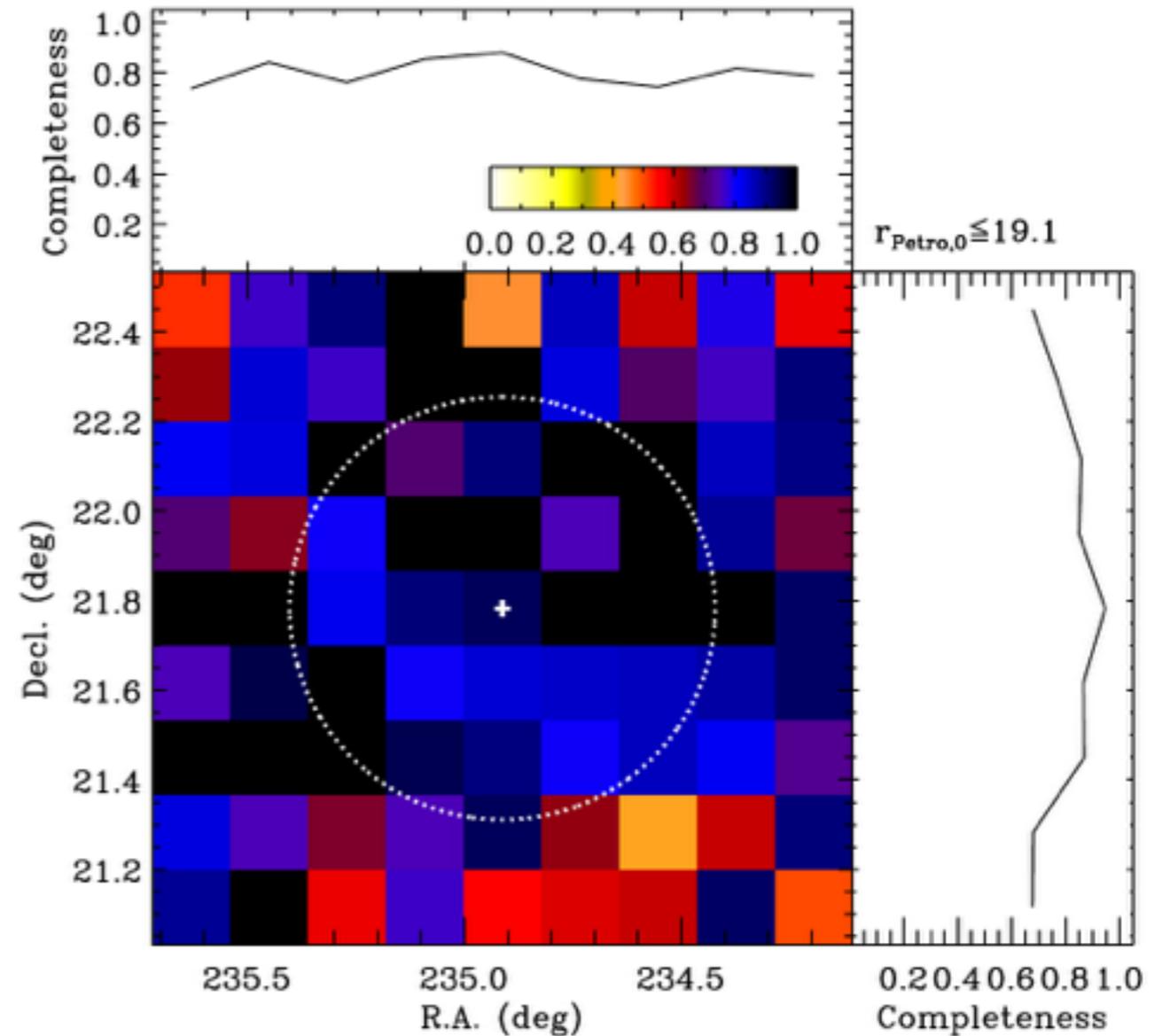
# A KIAS MMT/Hectospec survey

## Spectroscopic completeness

# of objects with redshifts/ # of photometric objects



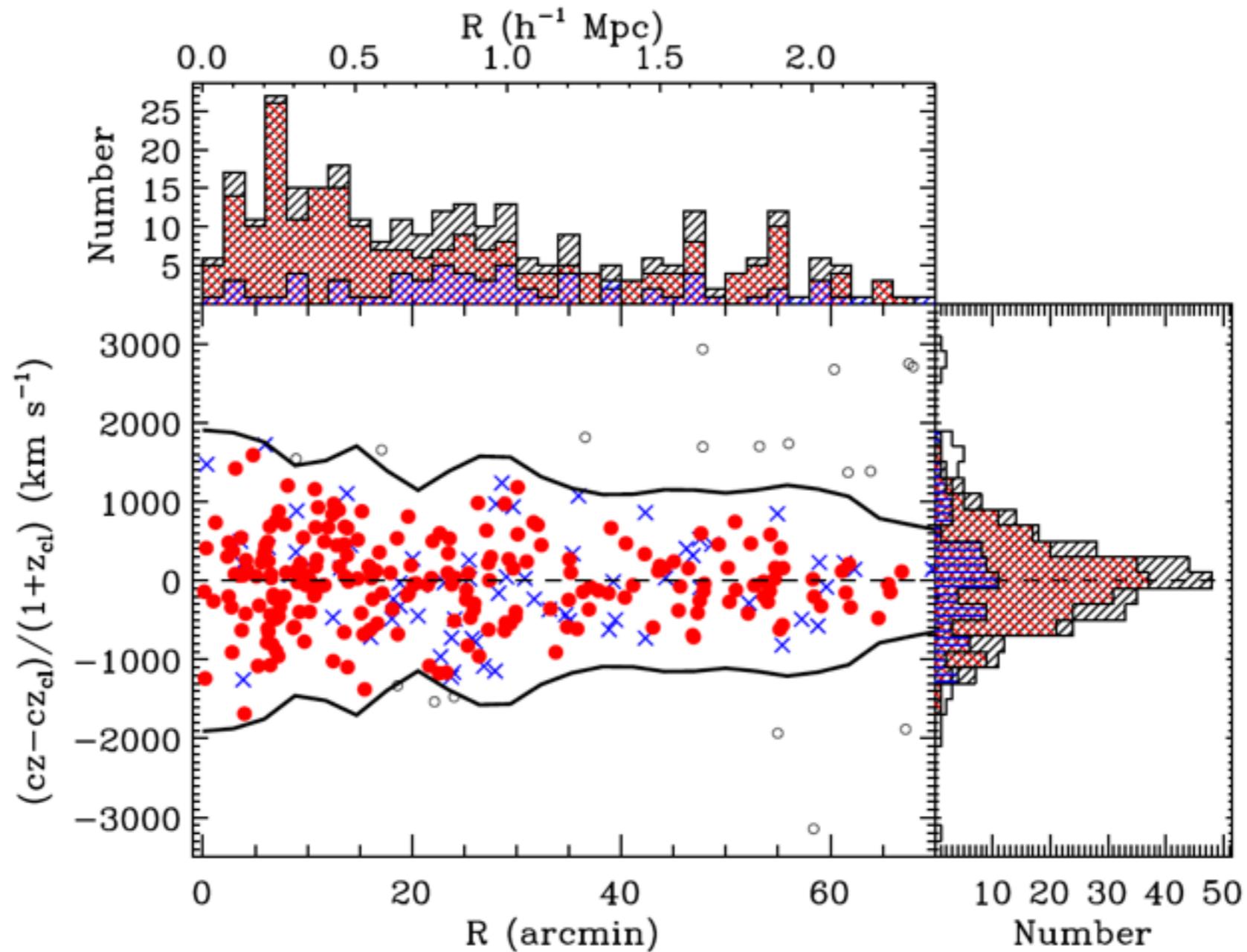
as a function of magnitude



as functions of R.A. and decl.

**Deep and uniform** redshift catalog obtained

# Cluster membership with Caustics

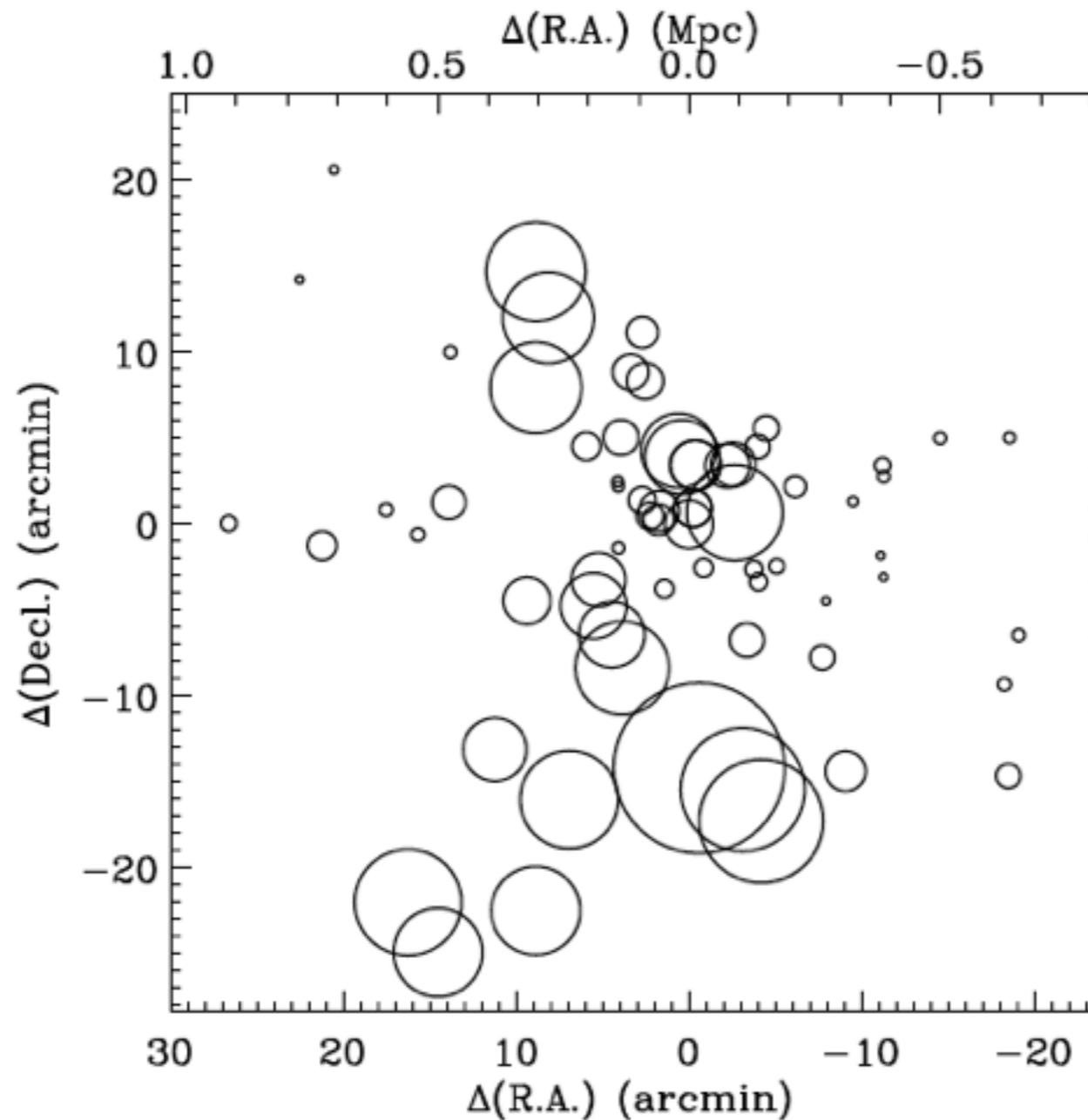


285 members at  $R < 60'$

(doubled compared to previous studies for the same area)

# Dressler-Shectman diagram

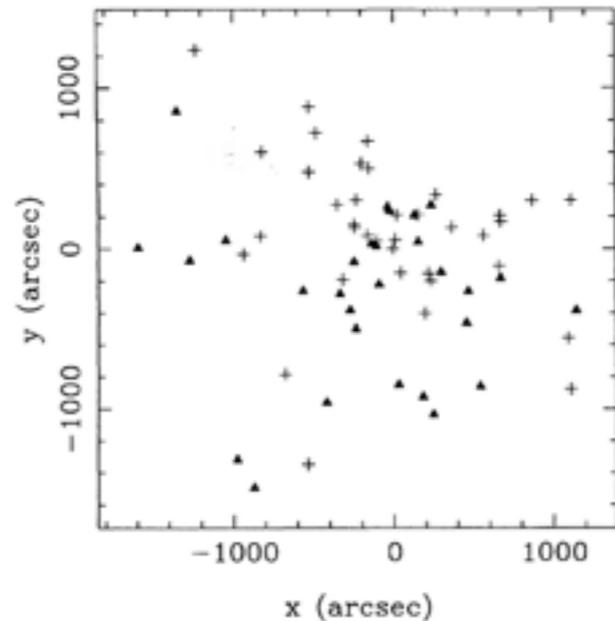
size of circle proportional to  $\delta^2 = (N_{nn}/\sigma_{cl}^2) [(\bar{v}_{local} - \bar{v}_{cl})^2 + (\sigma_{local} - \sigma_{cl})^2]$



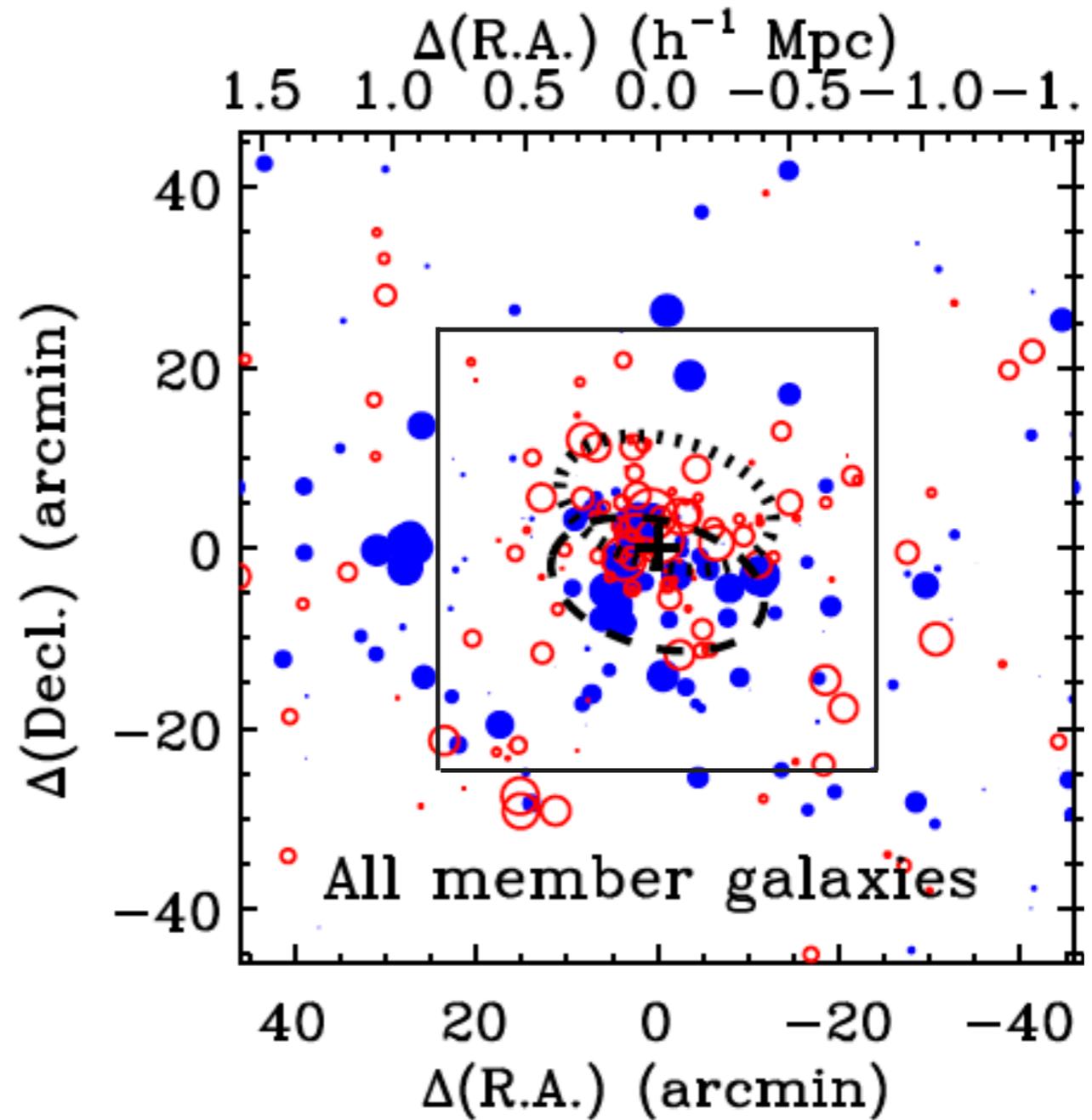
*Oegerle & Hill (1992)*

*this study*

# Spatially segregated velocity distribution



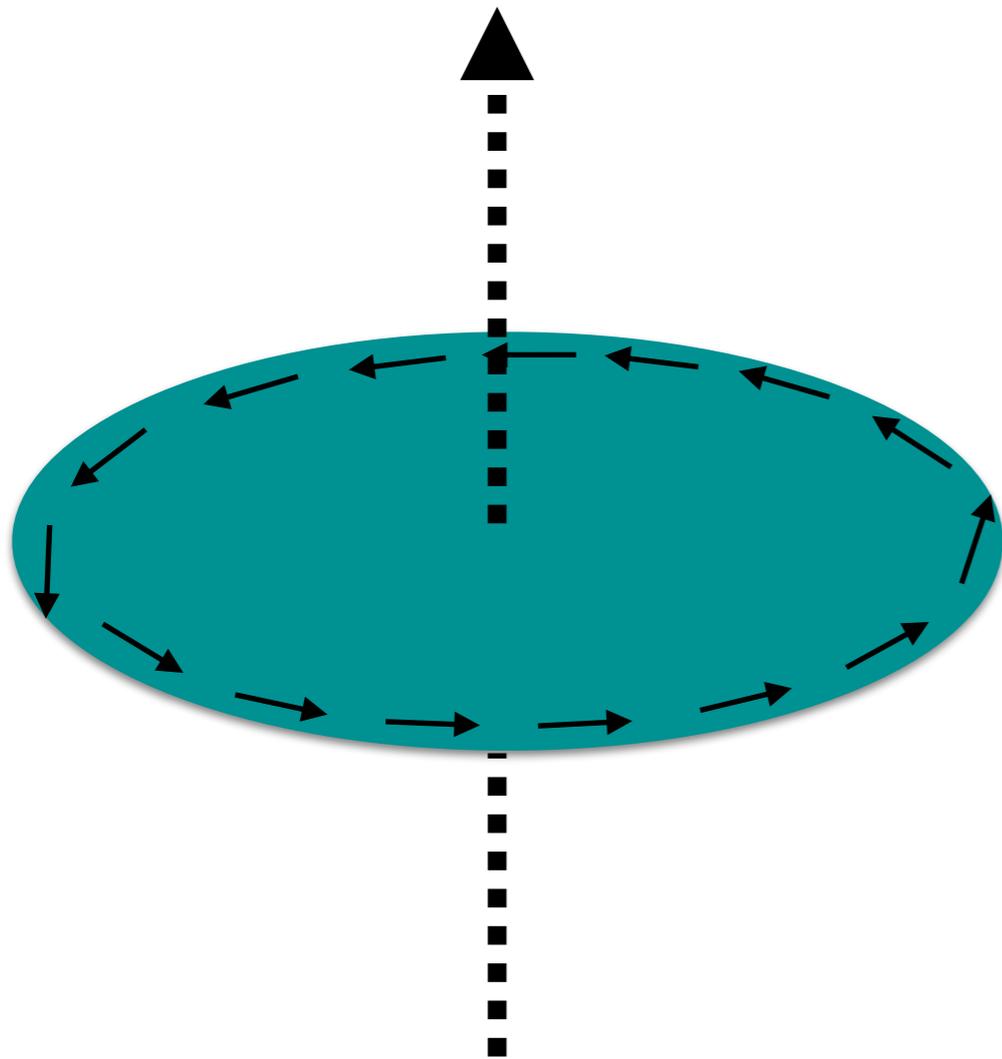
*Oegerle & Hill (1992)*



*this study*

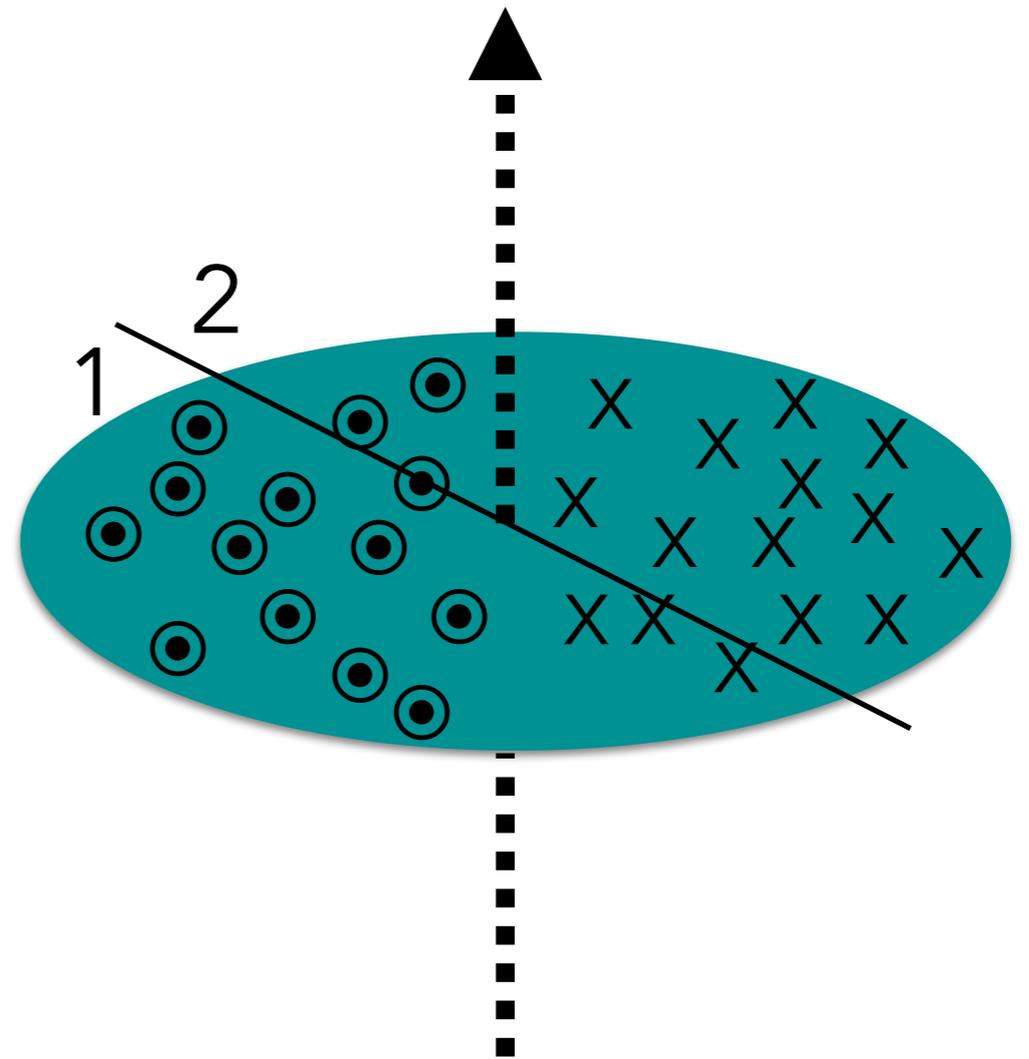
▲/blue for negative velocity (approaching to us)  
+ /red for positive velocity (receding from us)

# How to quantify rotational motion?



*Hwang & Lee (2007)*

$$v_{\text{los}} = v_{\text{cl}} - \mathbf{v}_{\text{rot}} \sin(\Theta - \Theta_0)$$



*Manolopoulou & Plionis (2017)*

$$\mathbf{v}_{\text{diff}} = \langle v_{\text{los}} \rangle_1 - \langle v_{\text{los}} \rangle_2 = f(\Theta)$$

$$\min(v_{\text{diff}}) \sim v_{\text{rot}}$$

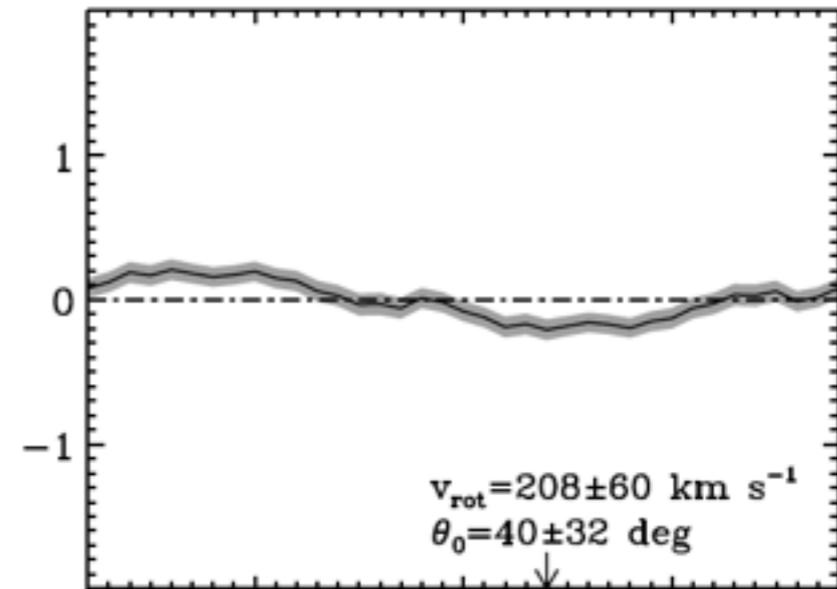
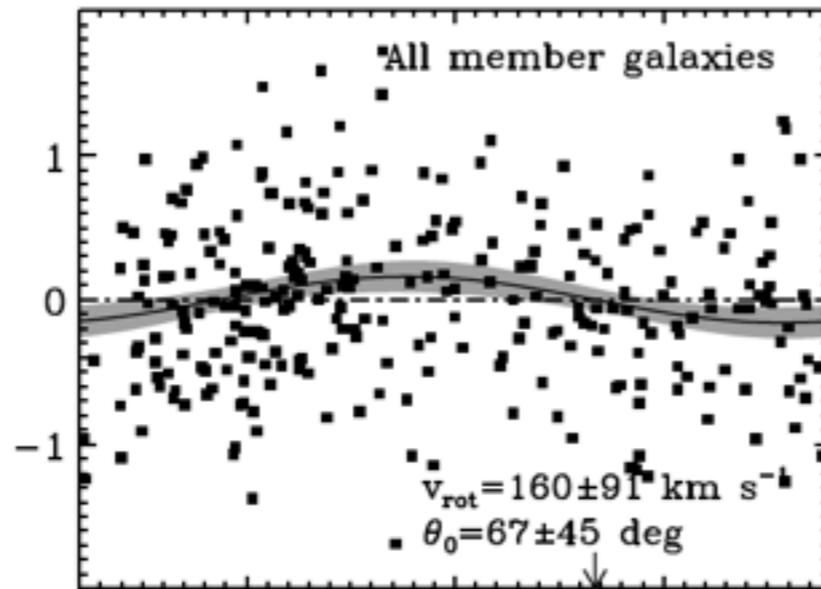
Hwang & Lee (2007)

Manolopoulou & Plionis (2017)

gray band:  
1sigma error obtained  
from bootstrapping  
resampling method

# Rotation diagram

$(cz - cz_{el}) / (1 + z_{el})$  (1000 km s<sup>-1</sup>)



all

red

blue

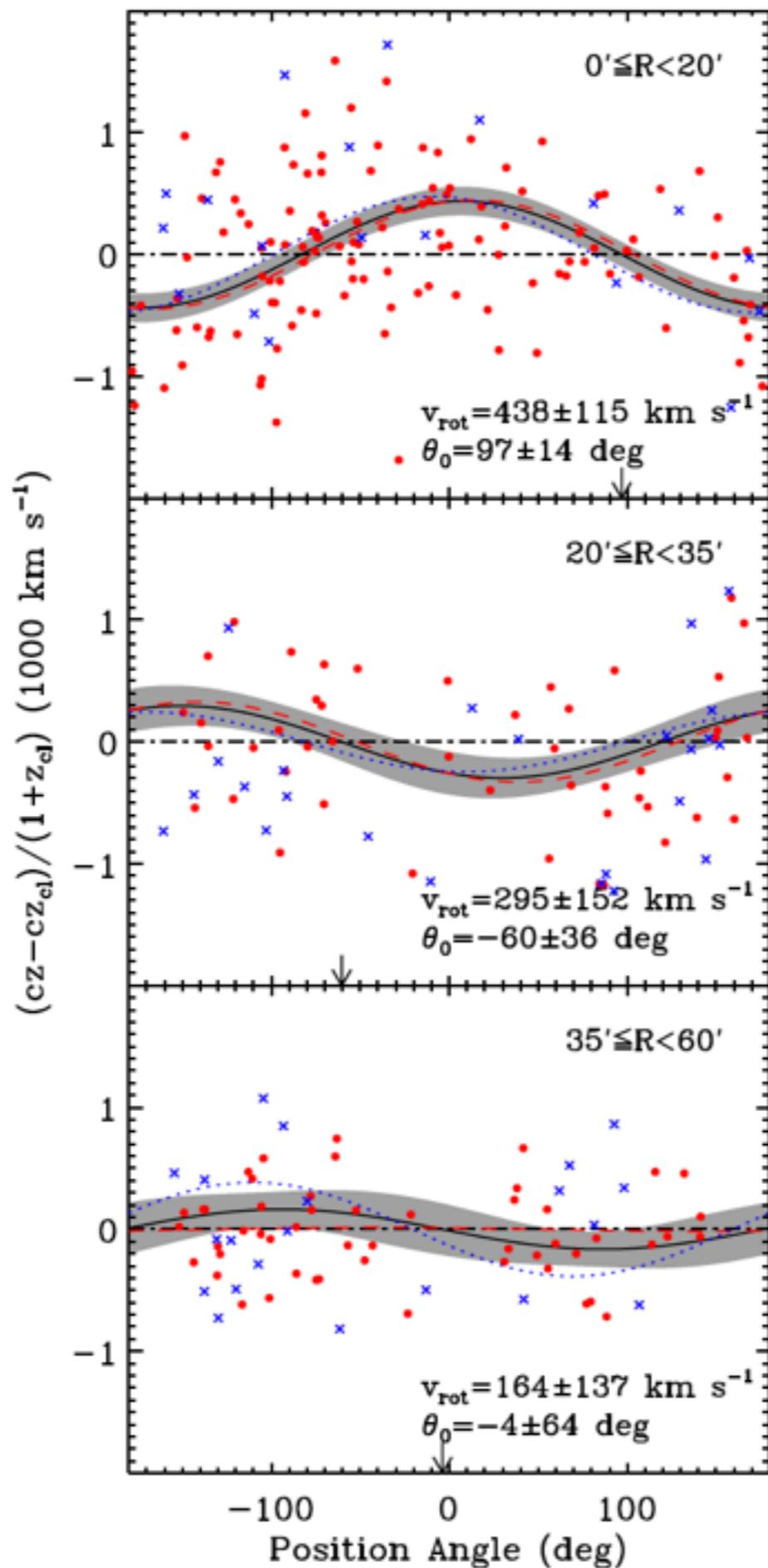
-100 0 100  
Position Angle (deg)

-100 0 100  
Position Angle (deg)

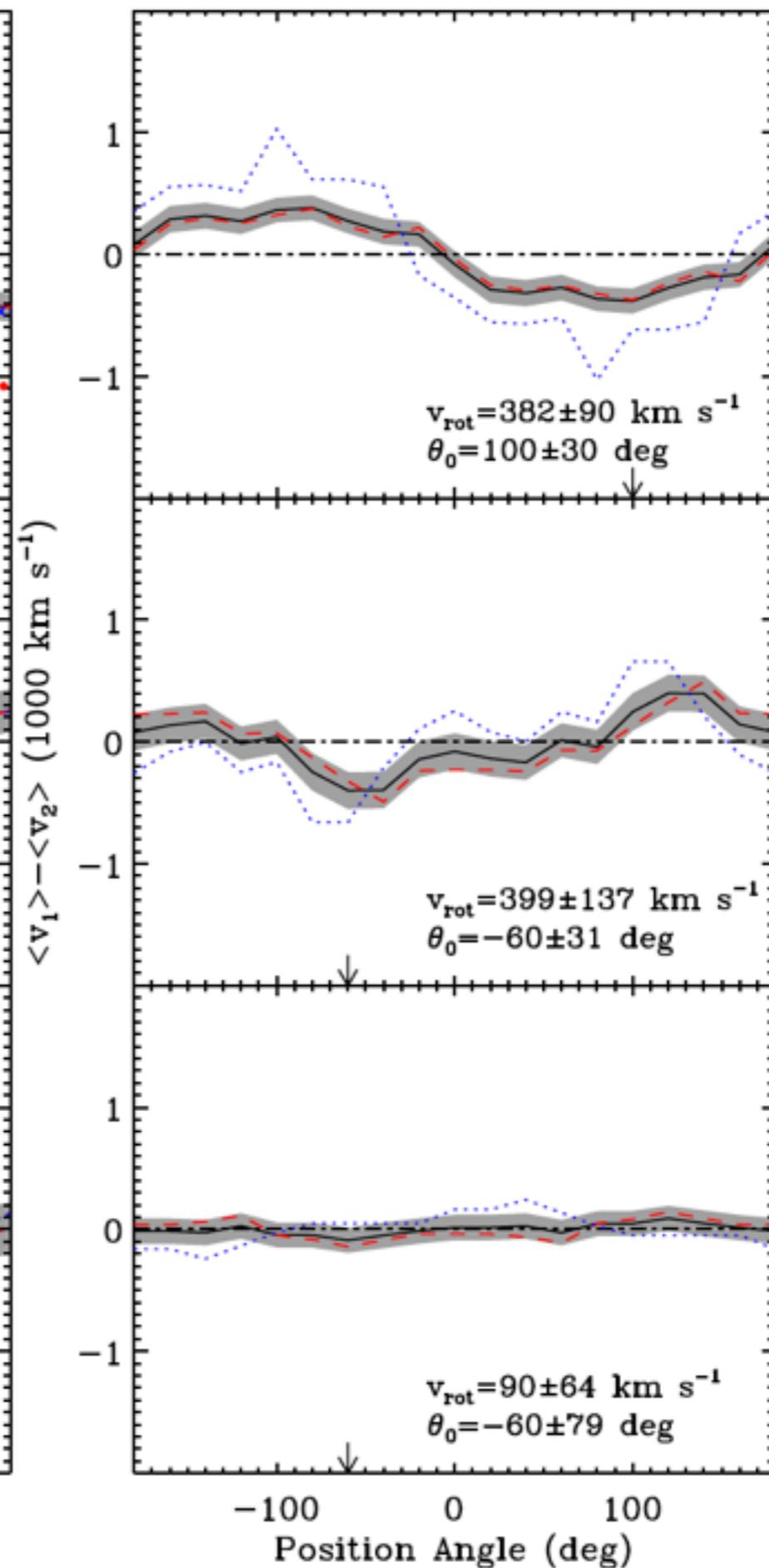
Hwang & Lee (2007)

Manolopoulou & Plionis (2017)

$0' < R < 20'$

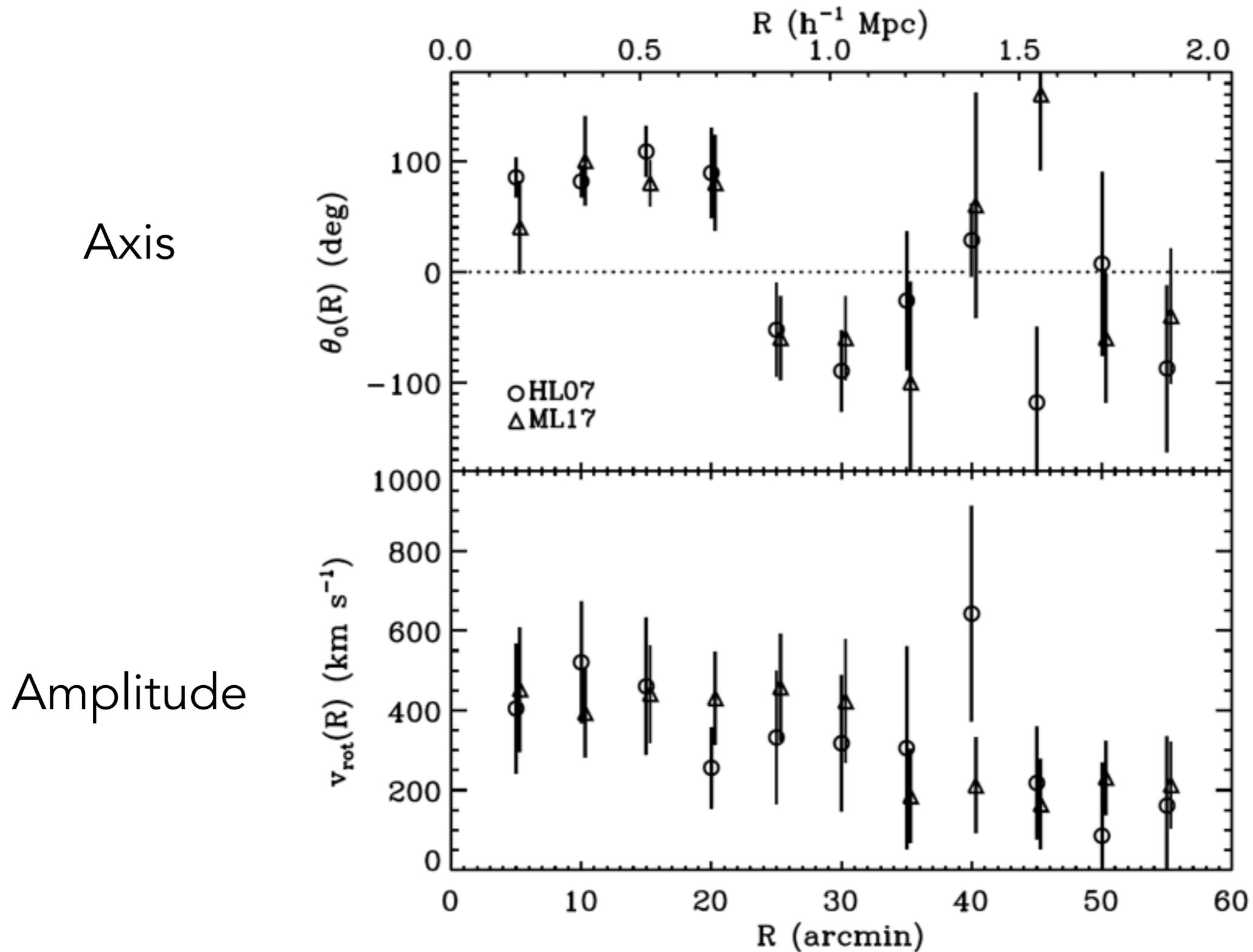


$20' < R < 35'$



$35' < R < 60'$

# Rotation parameters as a function of R

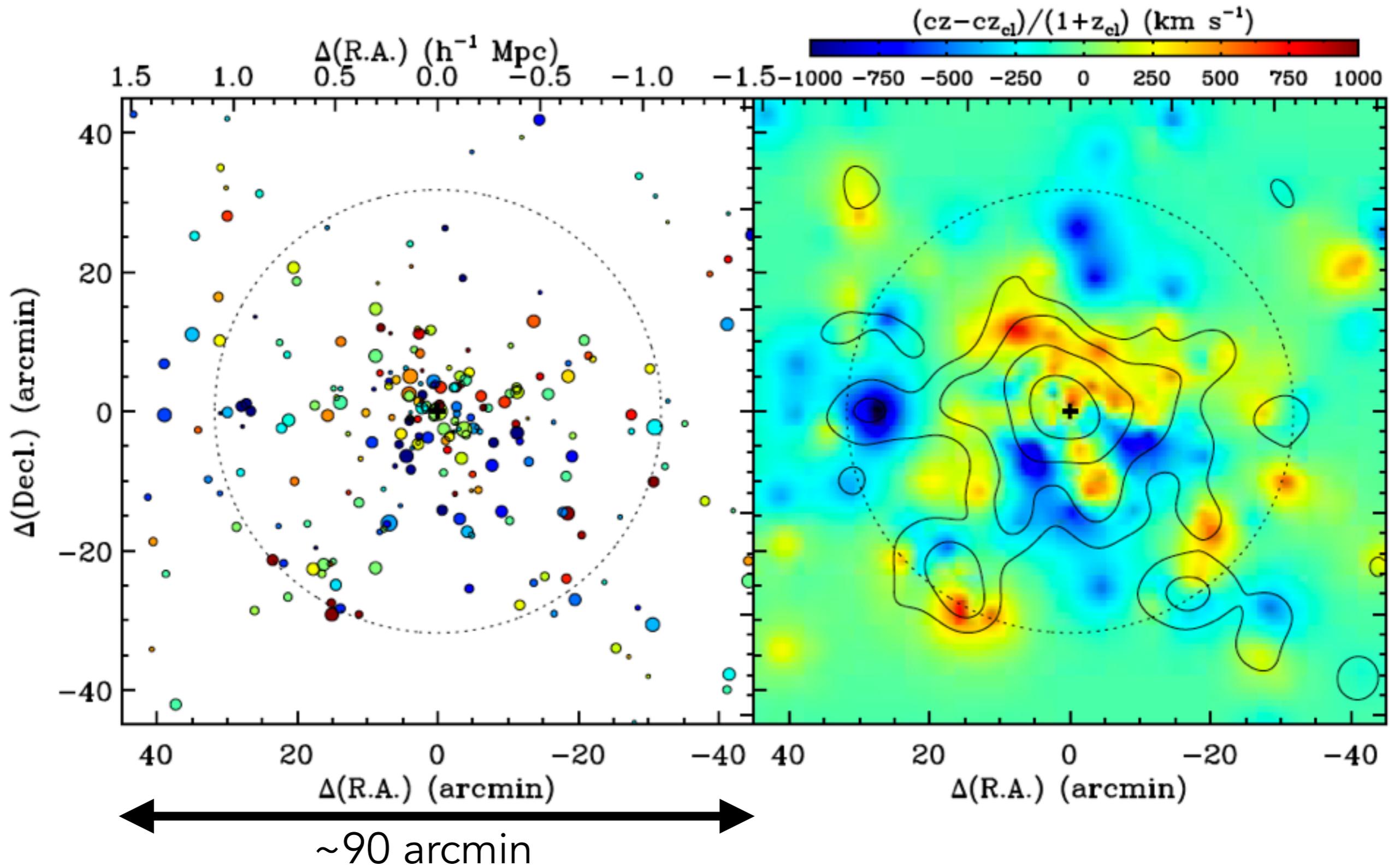


# What causes this rotational motion?

- Off-axis merging two clusters  
(Peebles 1969, Ricker 1998, Takizawa 2000, Roettinger & Flores 2000)
  - two density peaks? merging feature in X-ray?
- Global rotation of the universe (Li 1998, Godlowski et al. 2003)
  - correlation between the angular momentum and the mass?
- Inflow from nearby LSS
  - well configured connections between nearby LSS and the cluster?

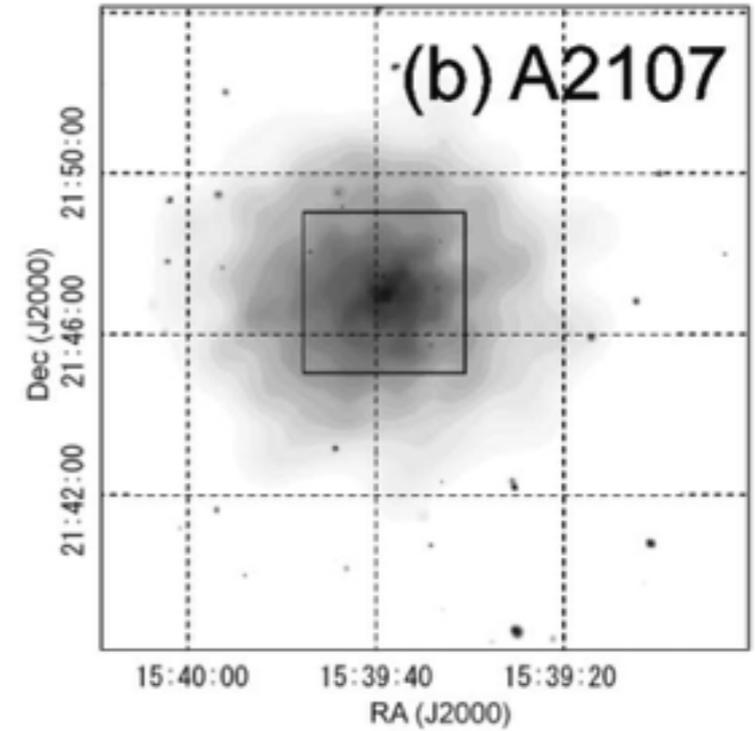
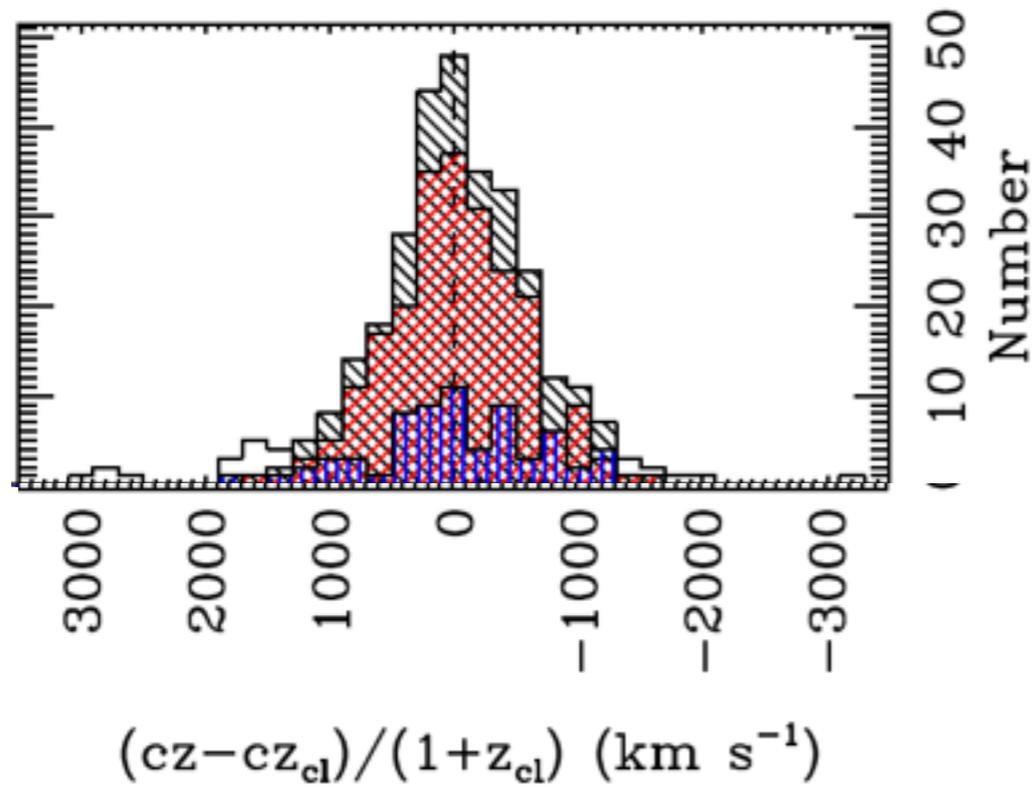
# Merging clusters?

*member galaxies only*

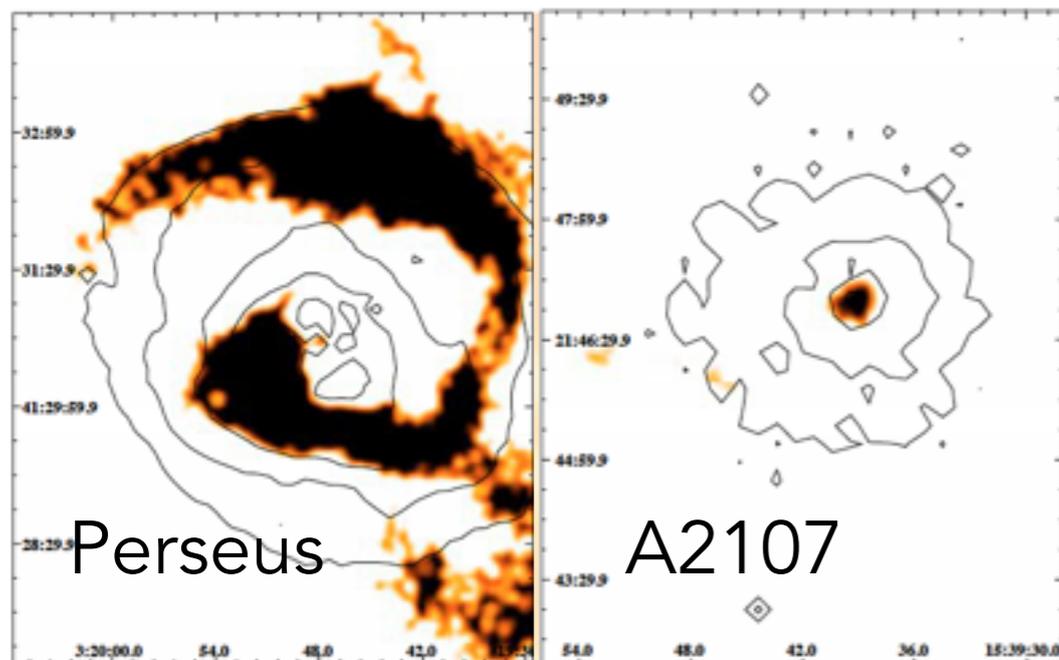


# Merging clusters?

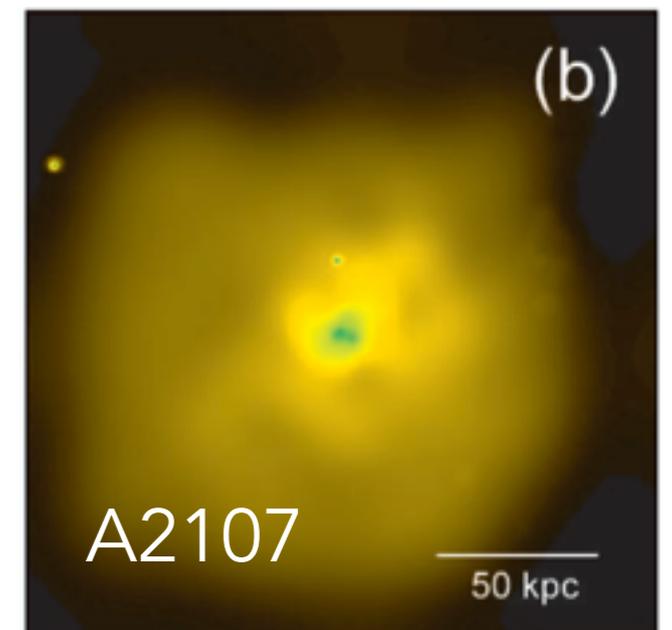
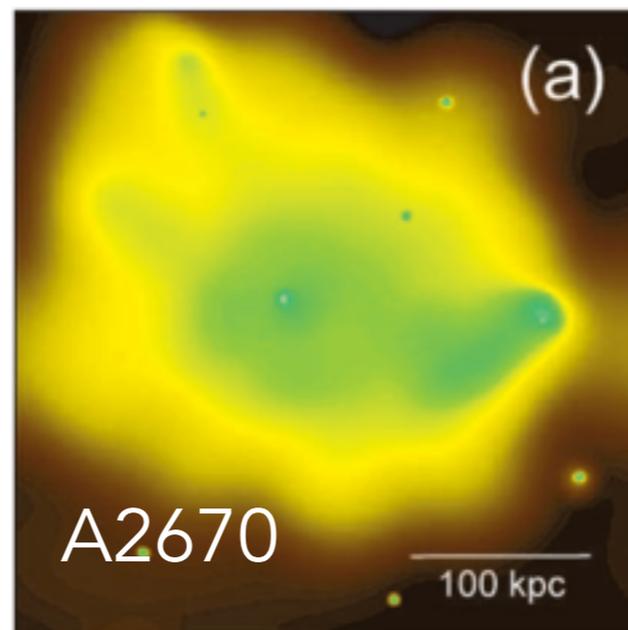
Gaussian velocity distribution



No merger features in X-ray



Lagana et al. (2010)

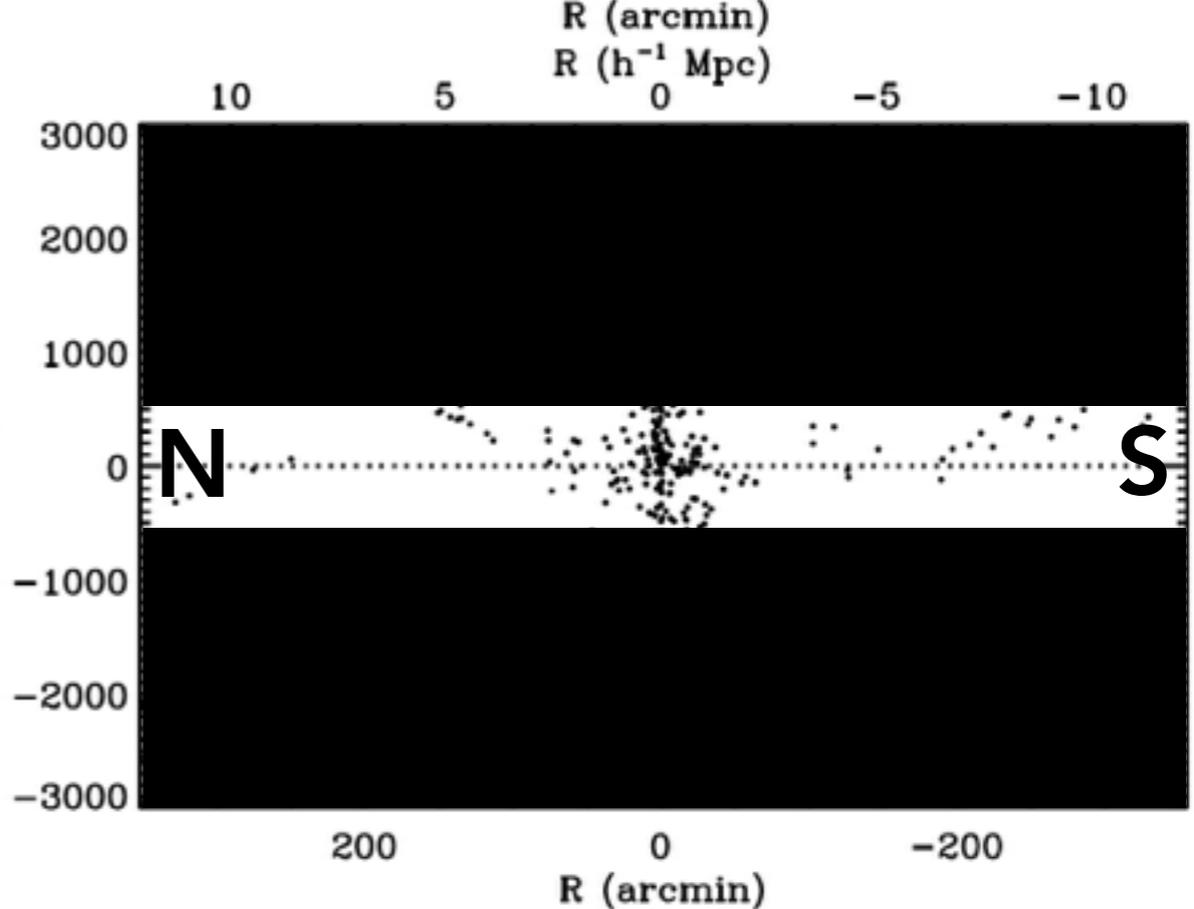
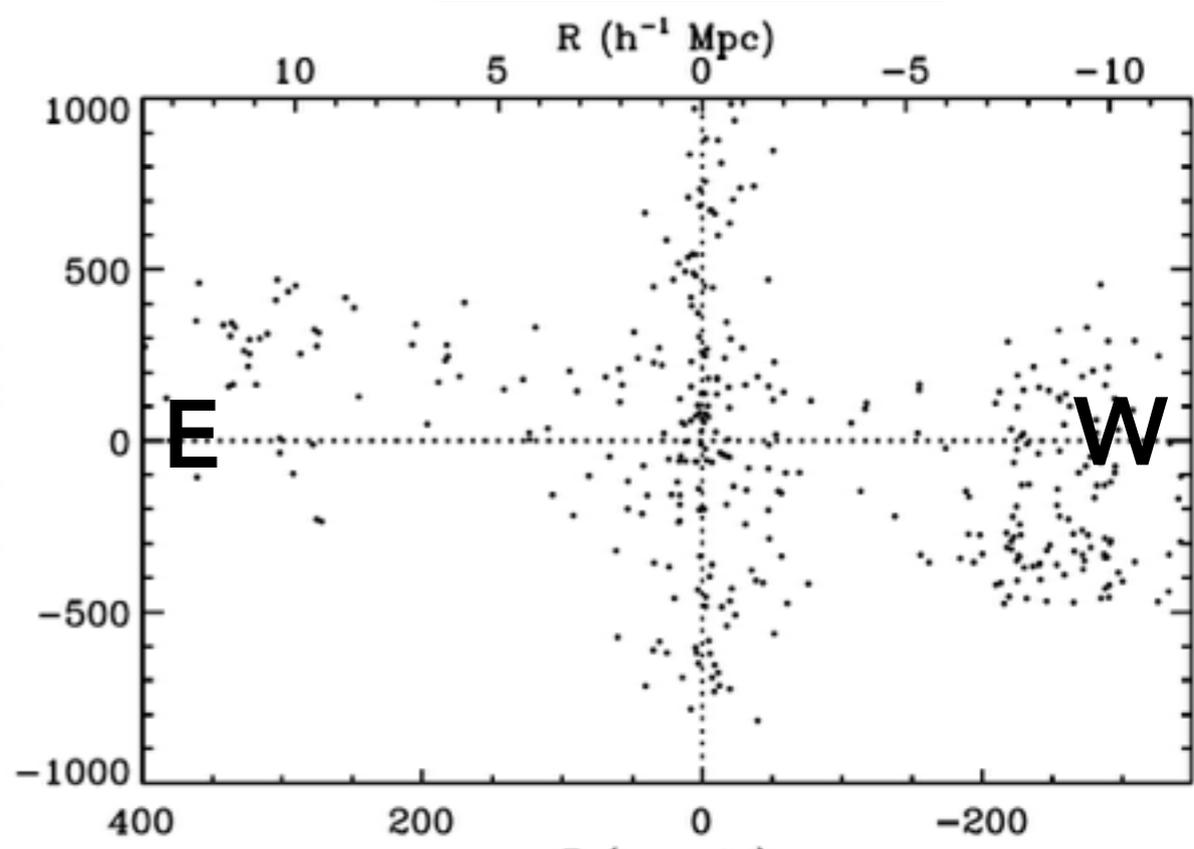
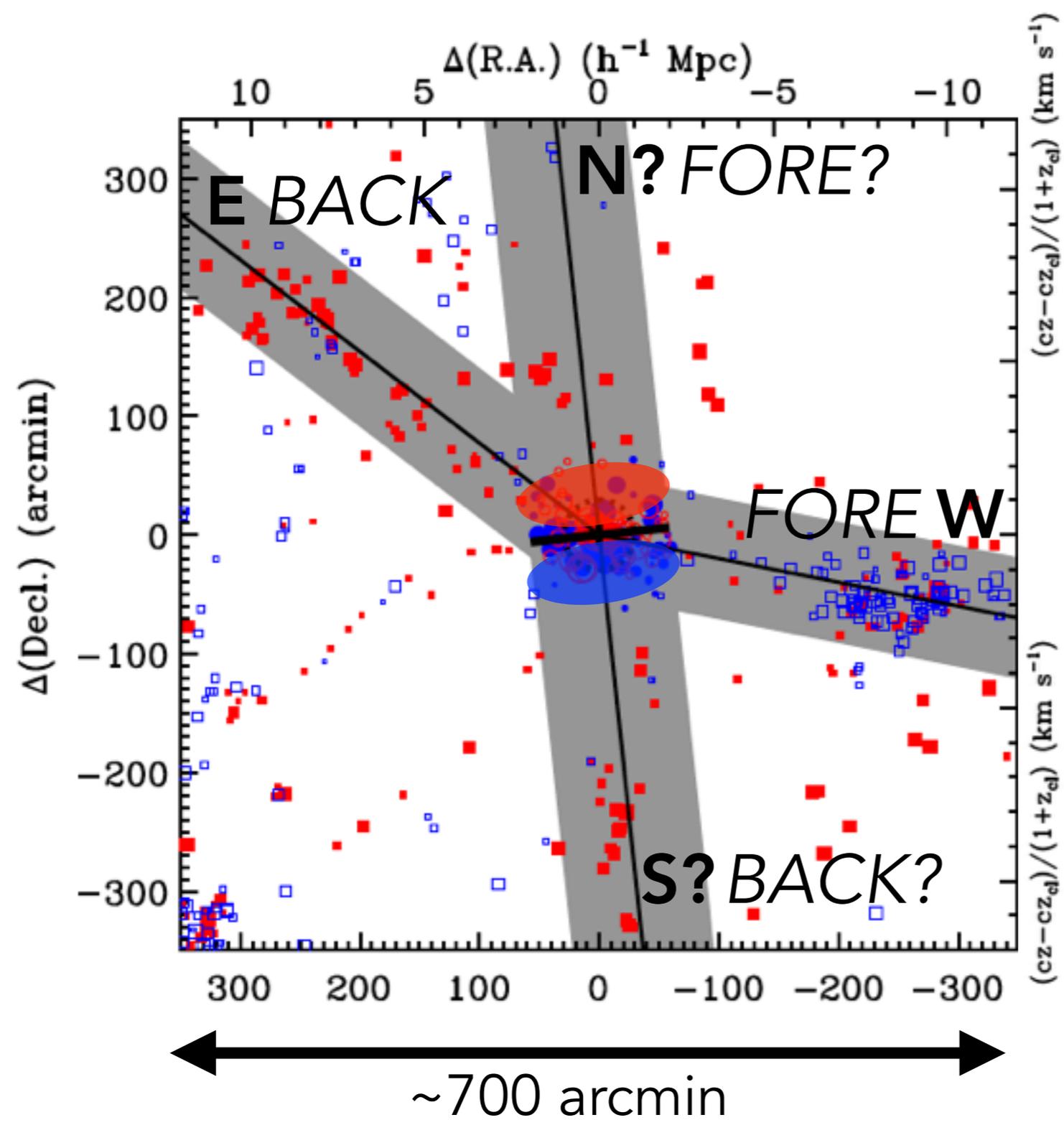


Fujita et al. (2006)

# Inflow from LSS?

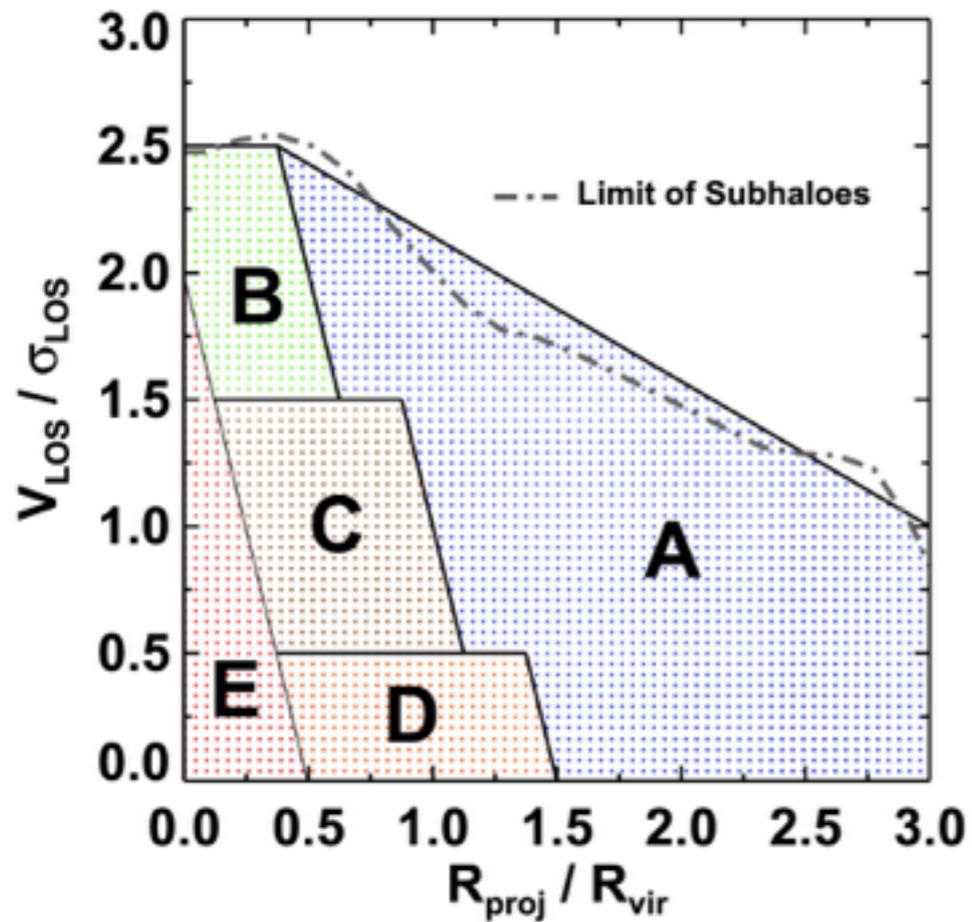
*R-v diagrams*

*cluster members and galaxies with  $l(cz-cz_{cl})$*

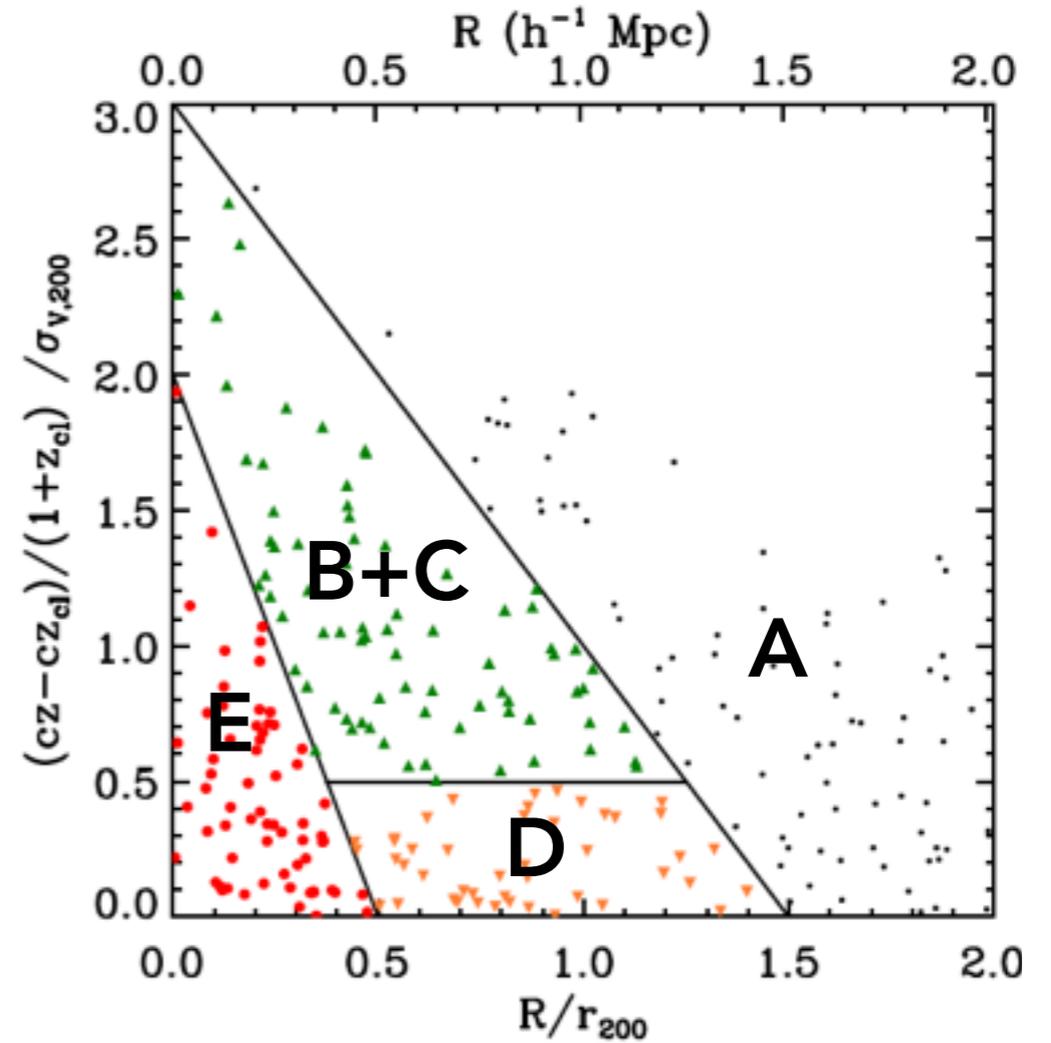


# Cluster phase-space analysis

Rhee, Smith et al. (2017)



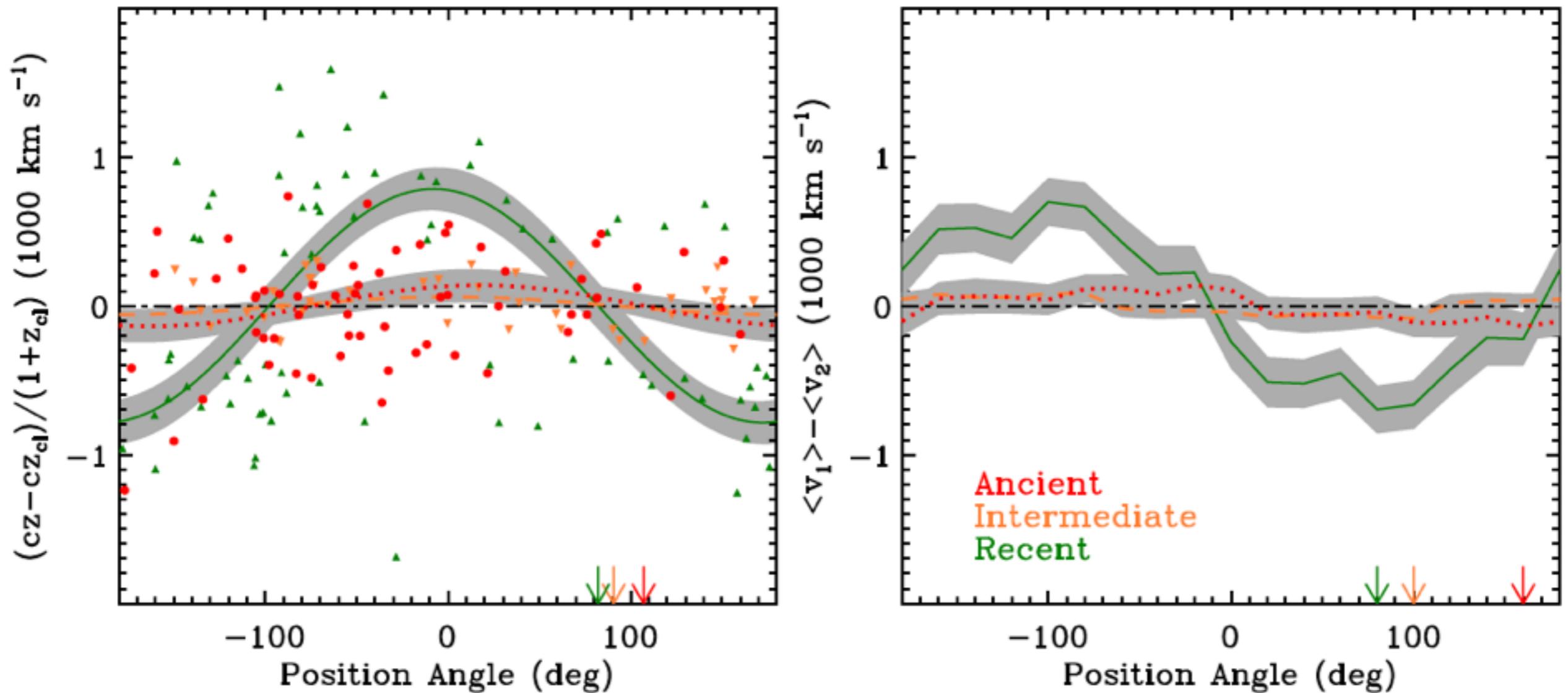
15 YZiCS clusters



A2107

Infallers :  
 E ancient  
 D intermediate  
 B+C recent  
 A first

# Rotation diagrams for ancient/intermediate/recent infallers



**More recent** infallers show **more significant** rotational signals.

# SUMMARY

- We conduct a redshift survey in the field of A2107 at  $R < 60'$  using MMT/Hectospec.
- We confirm the spatial segregation of radial velocities of member galaxies, suggesting global rotation of A2107.
- We quantify the global rotation using two independent methods. Both methods suggest that there is strong rotation of 380-440 km/s with  $4\sigma$  significance at small radii of  $R < 20'$ .
- We find five large-scale structure candidates connected to A2107, and examine their velocity fields and their connections to the cluster.
- More recent infallers show more significant rotational motion.
- The rotational motion detected in A2107 may originate from its surrounding LSS.