Mass and Light in the Outskirts of Galaxy Clusters

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OUTLINE

- Infall regions of clusters: personal perspective.

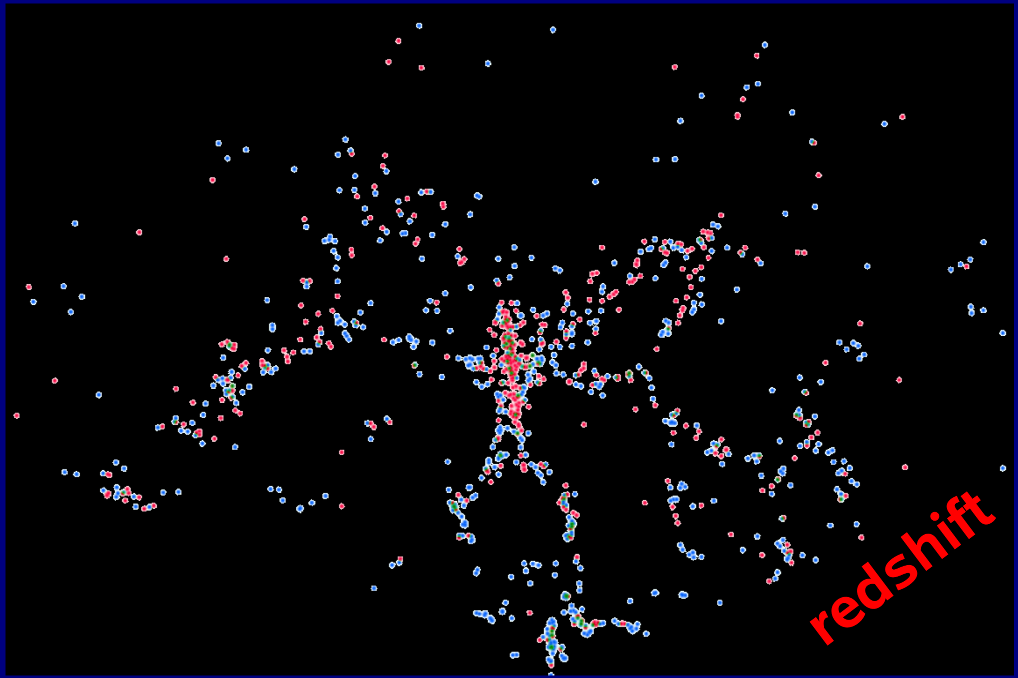
- Caustics in redshift space: the escape velocity.

- Measuring the mass in non-virialized regions: The caustic technique.

- Results, links and outlook.

INFALL REGIONS OF CLUSTERS: Prologue (1)

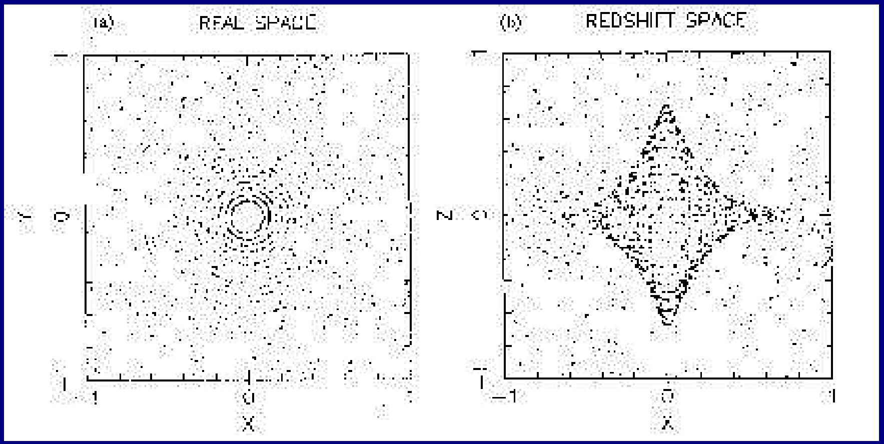
CfA slice



de Lapparent et al. 1986

redshift space distortion and the spherical infall model

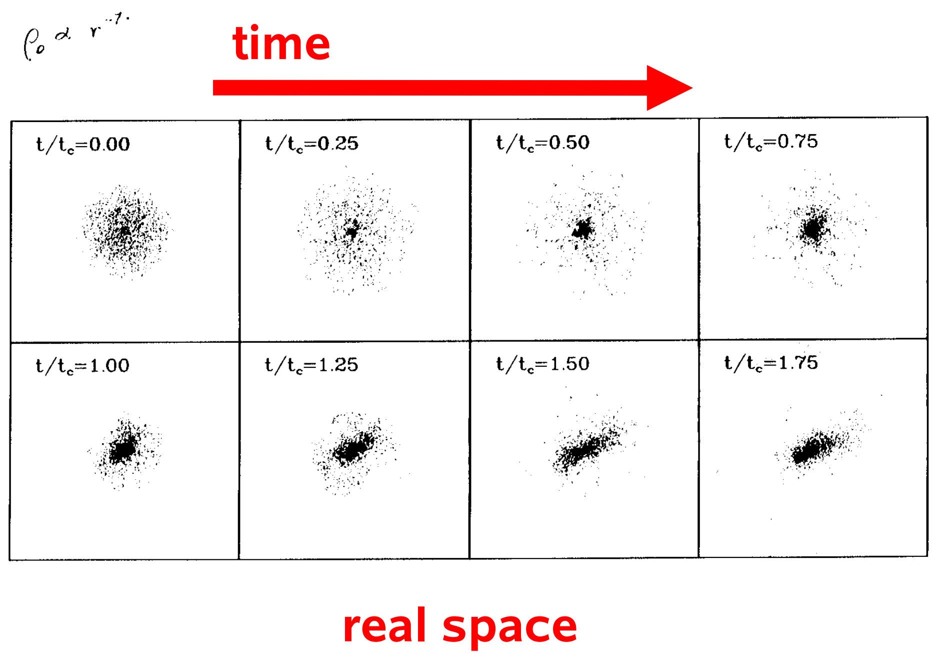
Real space Redshift space

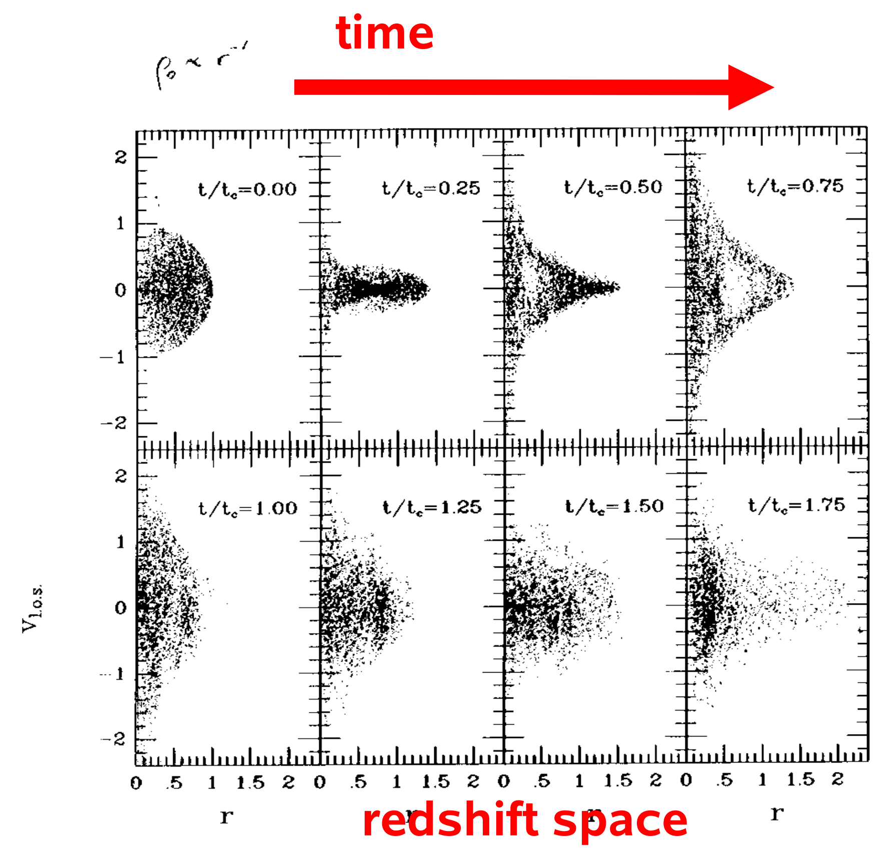


Kaiser 1987

INFALL REGIONS OF CLUSTERS:
Prologue (2)

Spherical infall model:
A primitive toy simulation





INFALL REGIONS OF CLUSTERS: Prologue (3)

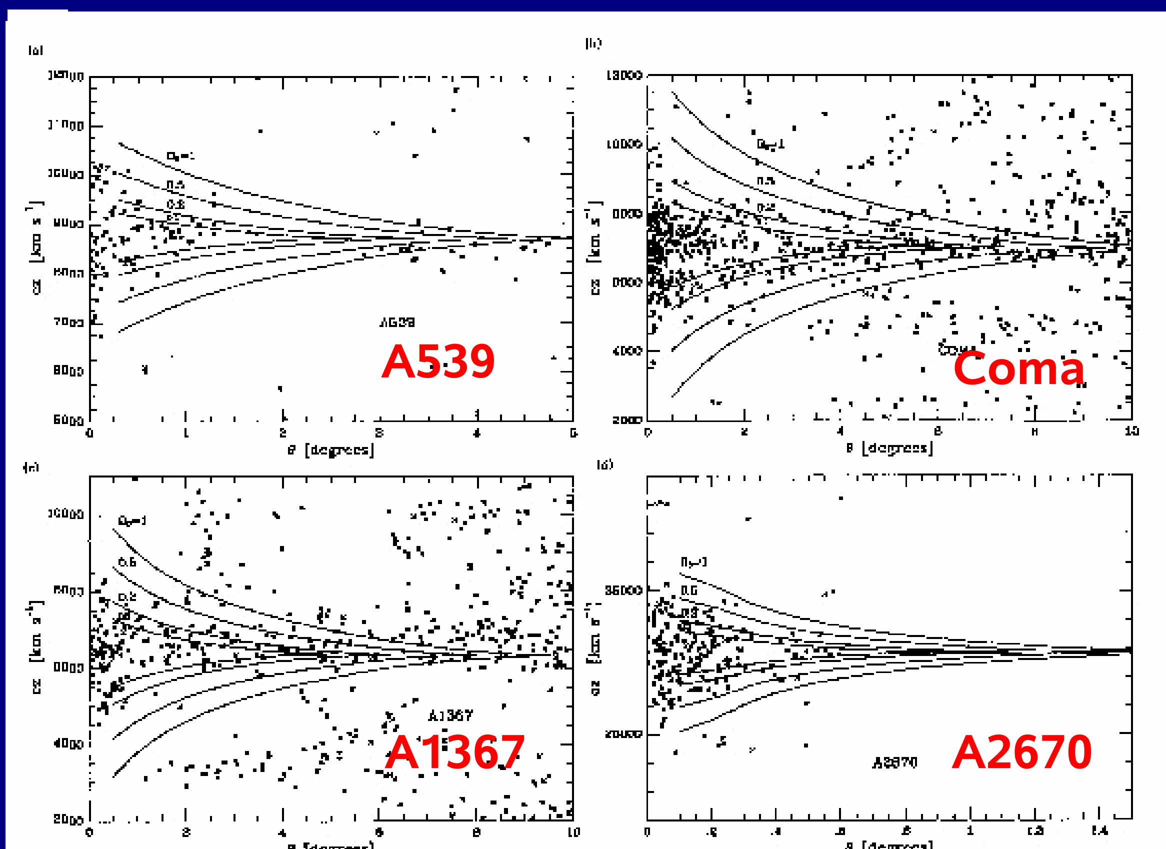
linear scales

$$\frac{v_{\rm pec}(r)}{H_0 r} = -\frac{1}{3}\Omega_0^{0.6}\delta_m(r)$$

mildly non-linear scales

$$\frac{v_{\rm pec}(r)}{H_0 r} = \frac{H_0^s}{H_0} - 1 \simeq -\frac{1}{3}\Omega_0^{0.6} f[\delta_m(r)]$$

cz



radius

Caustic amplitude

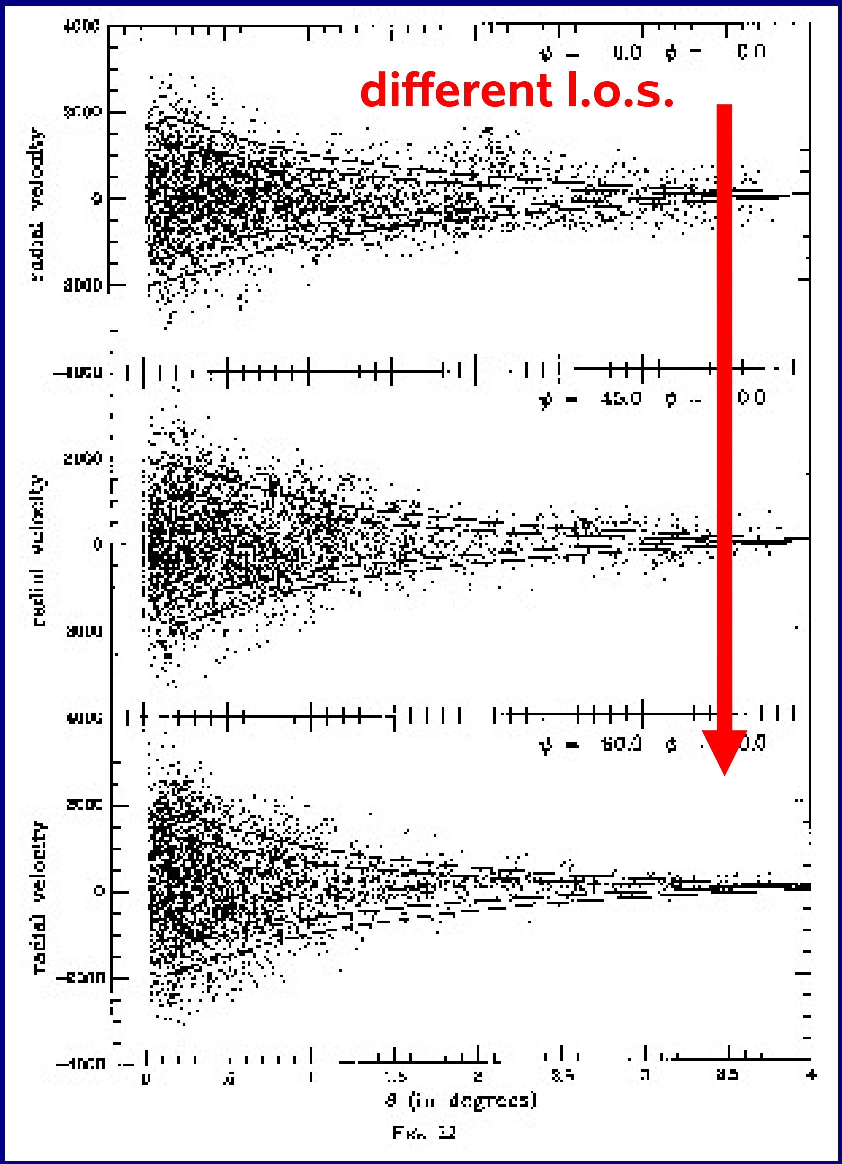
$$cz - \langle cz \rangle \cos\theta \propto \Omega_0^{0.6}\theta^{-\mu[\delta_m(r)]}$$

Measure of Ω_0

Regös & Geller 1989

INFALL REGIONS OF CLUSTERS: Prologue (4)

cz



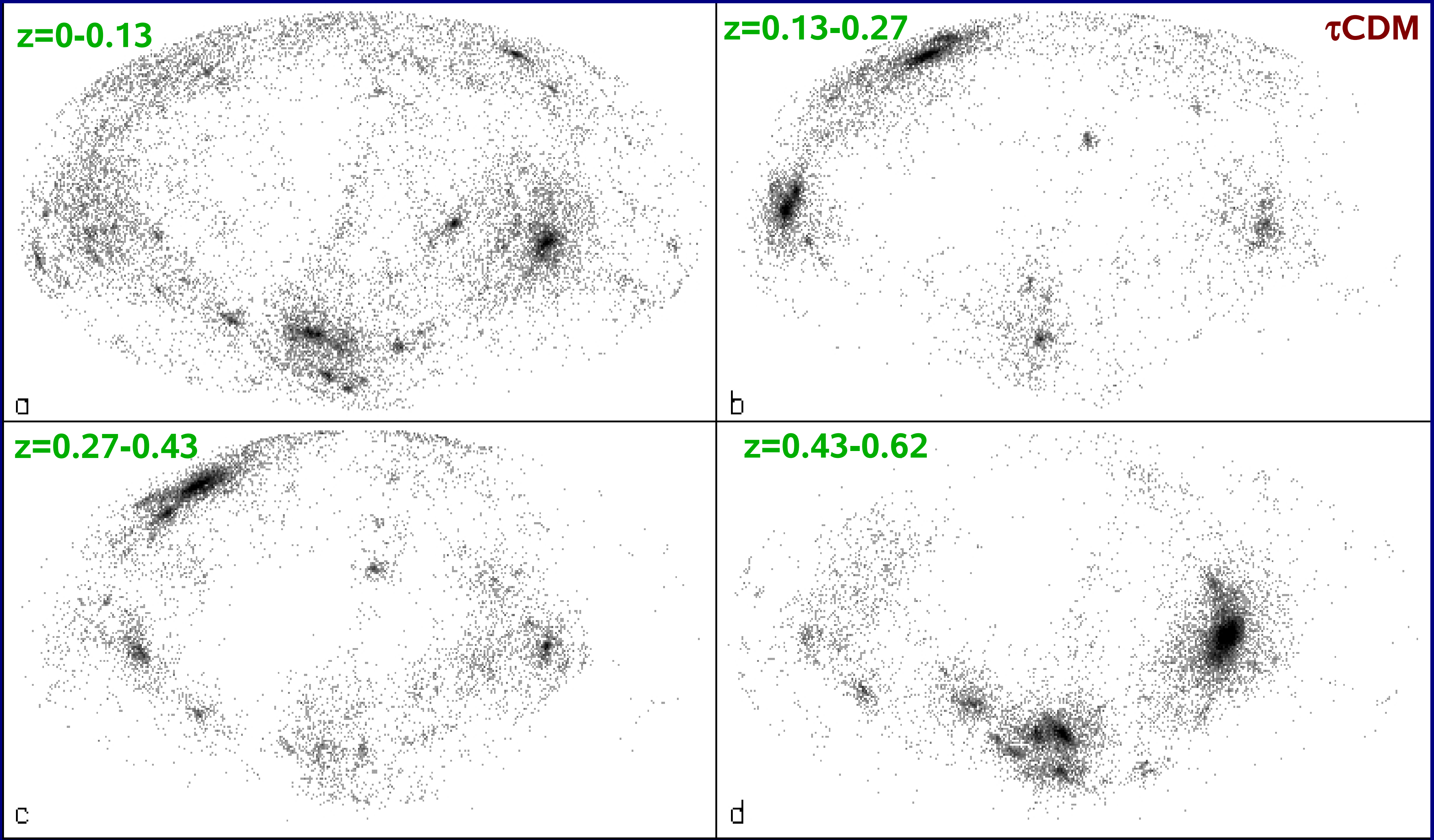
radius

Simulated cluster in a SCDM model

Merging and substructures affect the velocity field
<u>AND</u>
the caustic amplitude

van Haarlem & van de Weygaert 1993

Hierarchical clustering models:
anisotropic and episodic accretion

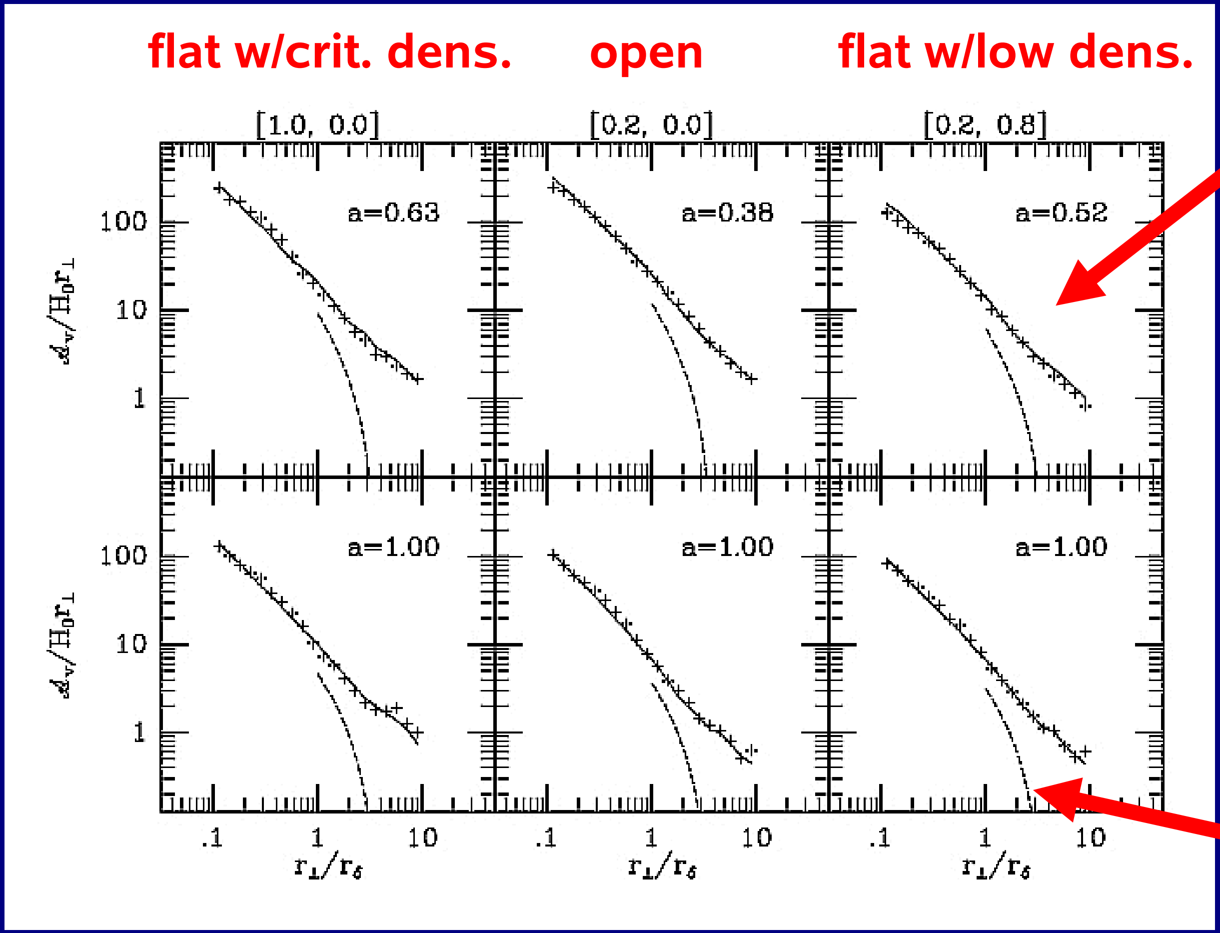


Colberg et al. 1999

INFALL REGIONS OF CLUSTERS

The caustic amplitude IS the escape velocity

cosmology →



$$\mathcal{A}^2(r) = v_{esc}^2(r)\frac{1-\beta(r)}{3-2\beta(r)}$$

clusters out of equilibrium

clusters in equilibrium

spherical infall model

caustic amplitude

radius

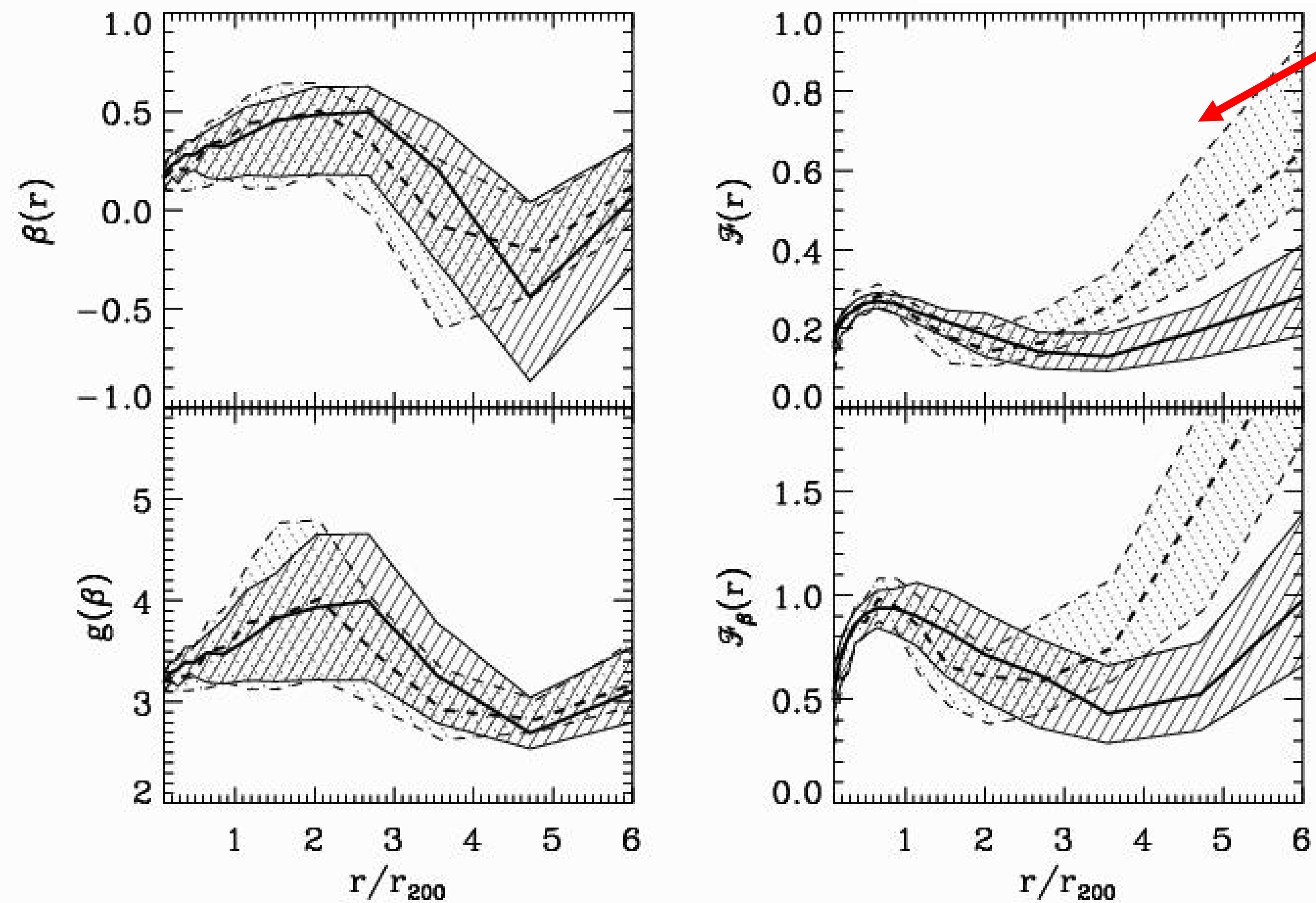
Diaferio & Geller 1997

INFALL REGIONS OF CLUSTERS

Connection to the mass profile

$$dm = -2\pi \langle v_{esc}^2 \rangle \frac{\rho(r) r^2}{\phi(r)} dr$$

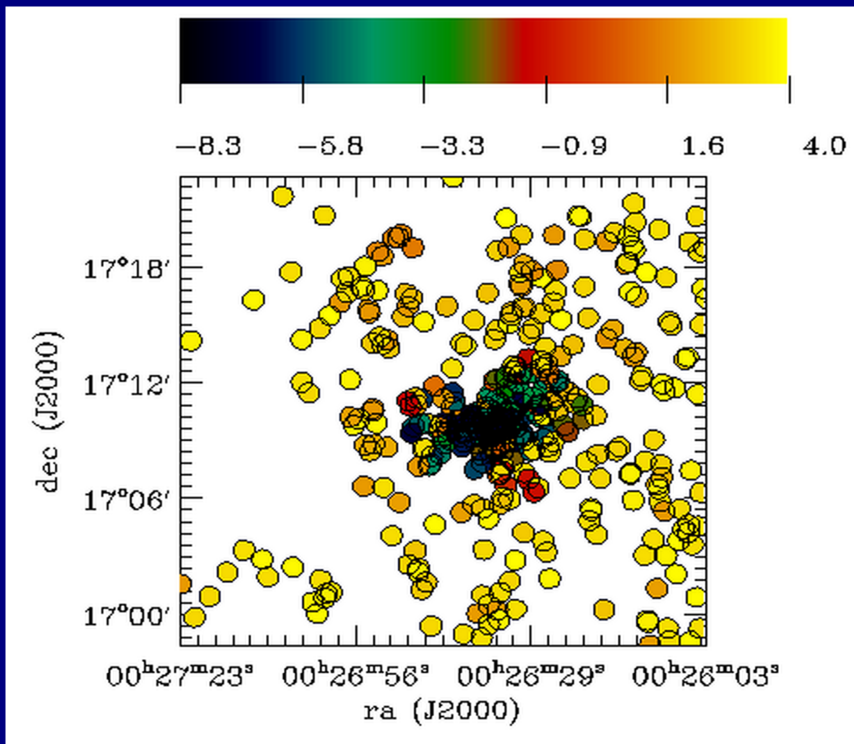
Relevant functions from simulated clusters



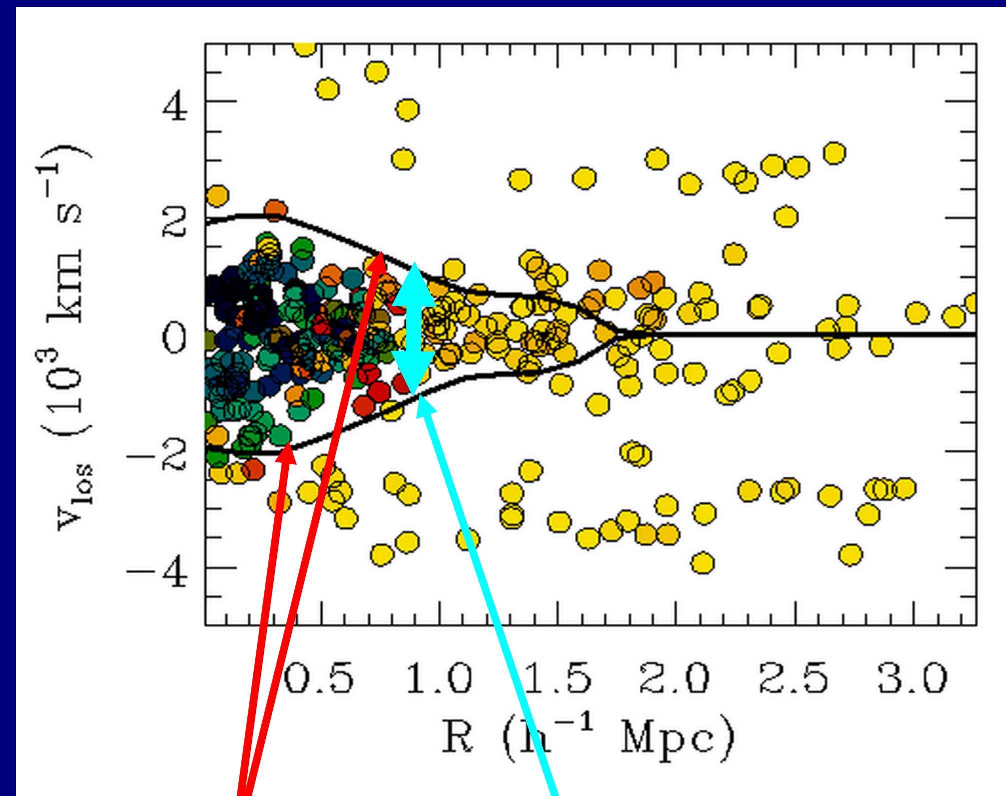
CAUSTIC TECHNIQUE: BASICS

Example: CL0024

Sky



Redshift diagram



Caustics

Caustic amplitude = escape velocity

MASS ESTIMATE:

$$GM(<r) = \frac{1}{2}\int_0^r \mathcal{A}^2(x)dx$$

(Diaferio & Geller 1997)

THE CAUSTIC TECHNIQUE

1. Binary Tree
2. Cut the Tree: Thresholds
3. Galaxy Members: Caustic Location
4. Mass Profile

CAUSTIC TECHNIQUE (1): BINARY TREE

THE HIERARCHICAL METHOD

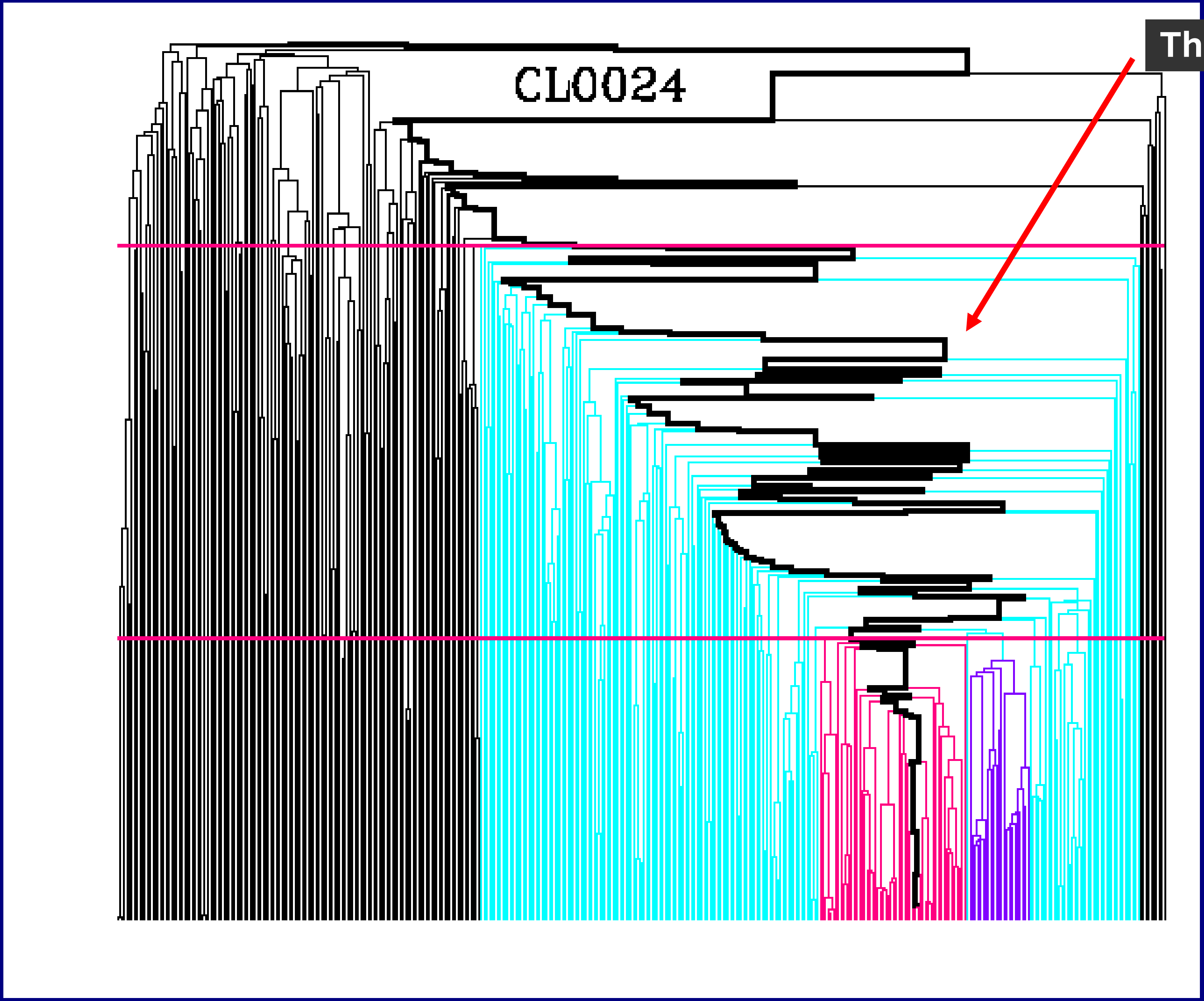
1. Arrange the galaxies in a binary tree based on the pairwise "projected" energy:

$$E_{ij} = -G\frac{m_i m_j}{R_p} + \frac{1}{2}\frac{m_i m_j}{m_i + m_j}\Pi^2$$

Projected separation

Line-of-sight velocity difference

THE BINARY TREE OF THE CL0024 FIELD



The main branch

633 galaxies

CAUSTIC TECHNIQUE (2): THRESHOLDS

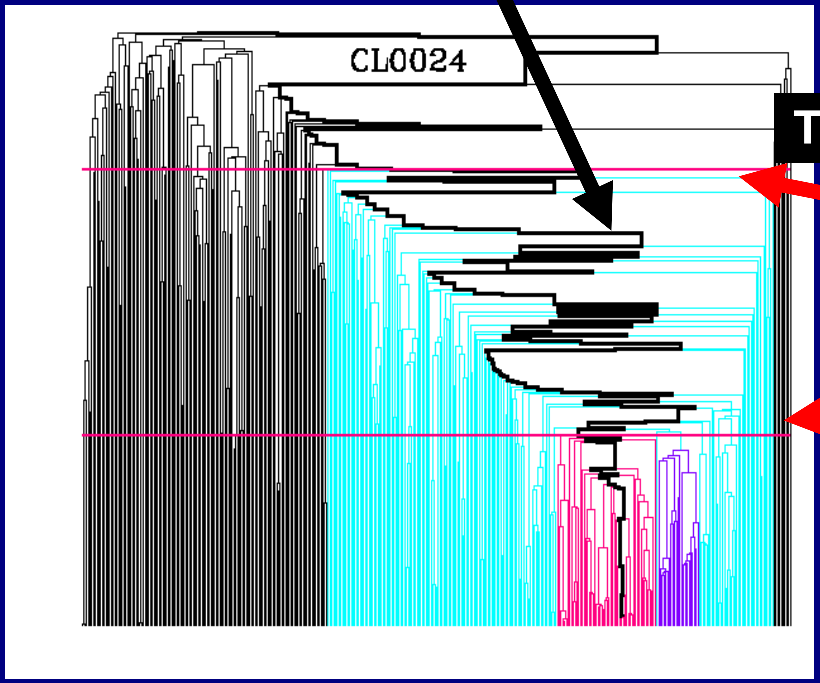
THE HIERARCHICAL METHOD

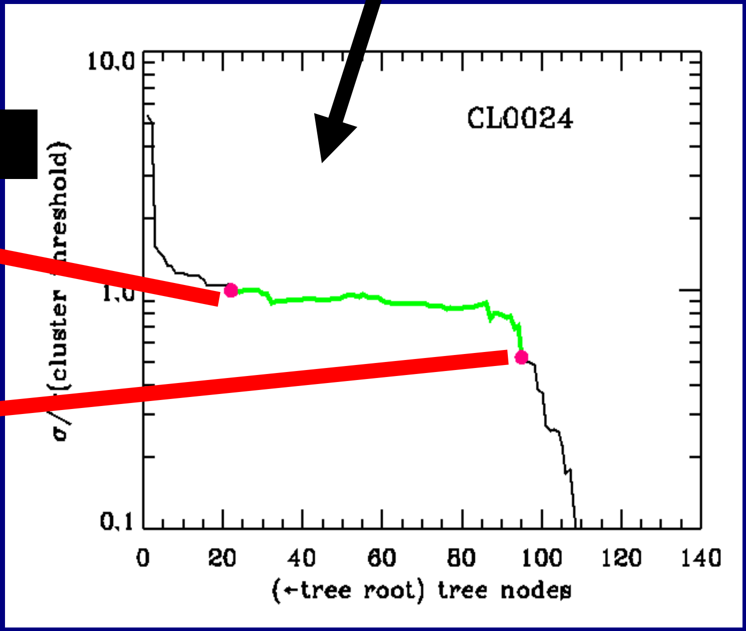
2. Move along the main branch and compute the galaxy velocity dispersion:

Main branch

Velocity dispersion along the main branch

Thresholds





CAUSTIC TECHNIQUE (3): LOCATION

Candidate cluster members determine:

1. the <u>cluster centre</u> → redshift diagram

Galaxy number density in the redshift diagram → $f_q(r, v) = \kappa$ ← <u>CAUSTIC EQUATION</u>

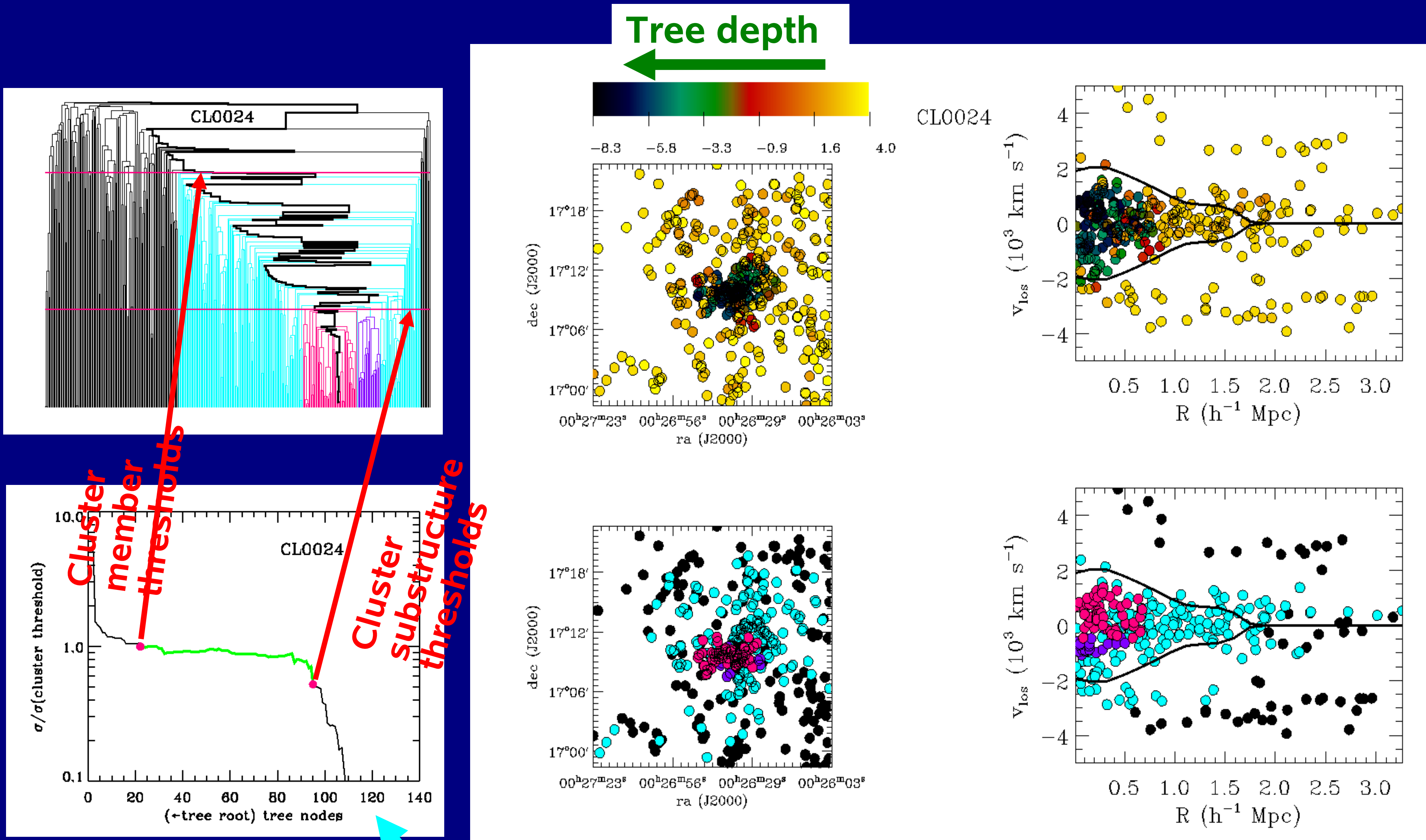
<u>Caustics from the zero of the function:</u>

$$S(\kappa, R) = \langle v^2_{esc} \rangle_{\kappa,R} - \langle v^2 \rangle_R$$

2. the <u>cluster radius</u>

3. the <u>cluster velocity dispersion</u>

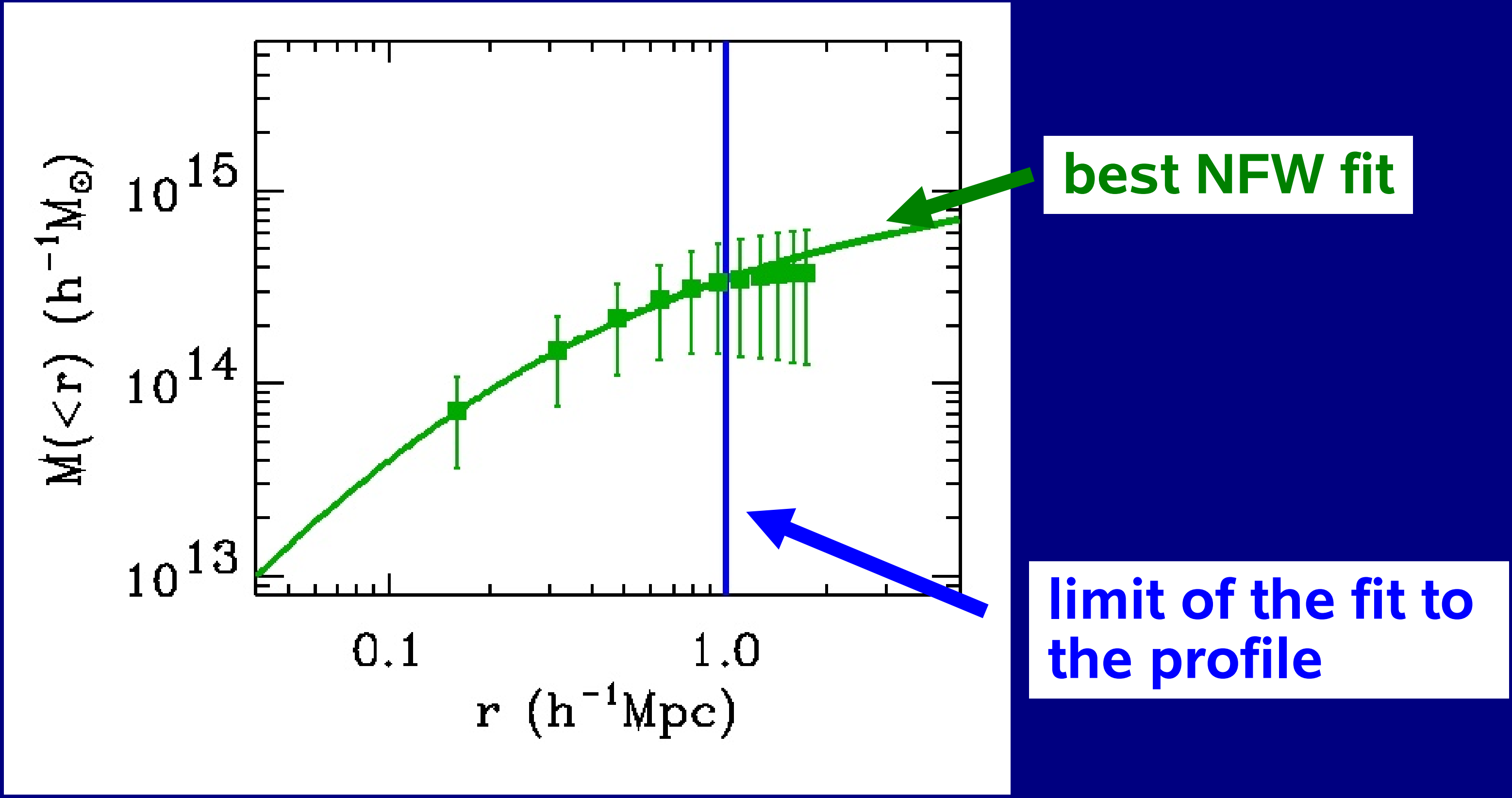
Members and substructures of CL0024



Galaxy velocity dispersion along the main branch

CAUSTIC TECHNIQUE (4):
MASS PROFILE OF CL0024

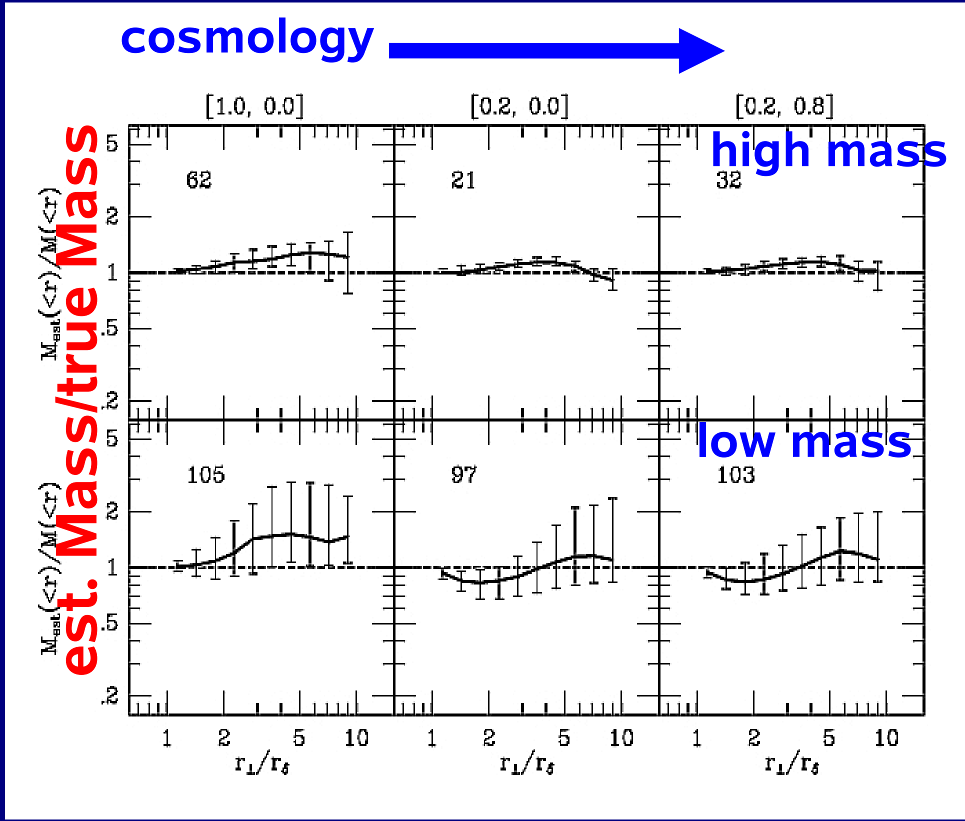
$$GM(<r) = \frac{1}{2}\int_0^r \mathcal{A}^2(x)dx$$



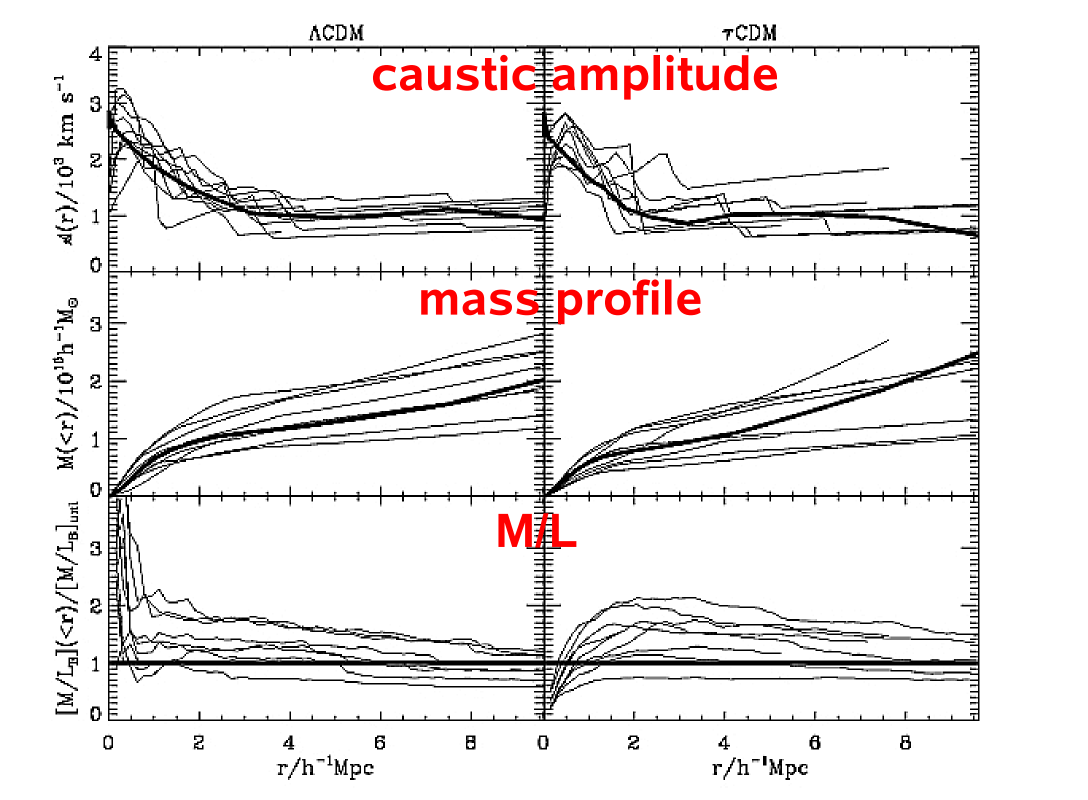
CAUSTIC TECHNIQUE (6): MASS PROFILE

DOES IT WORK?

Comparison with N-body simulations



radius

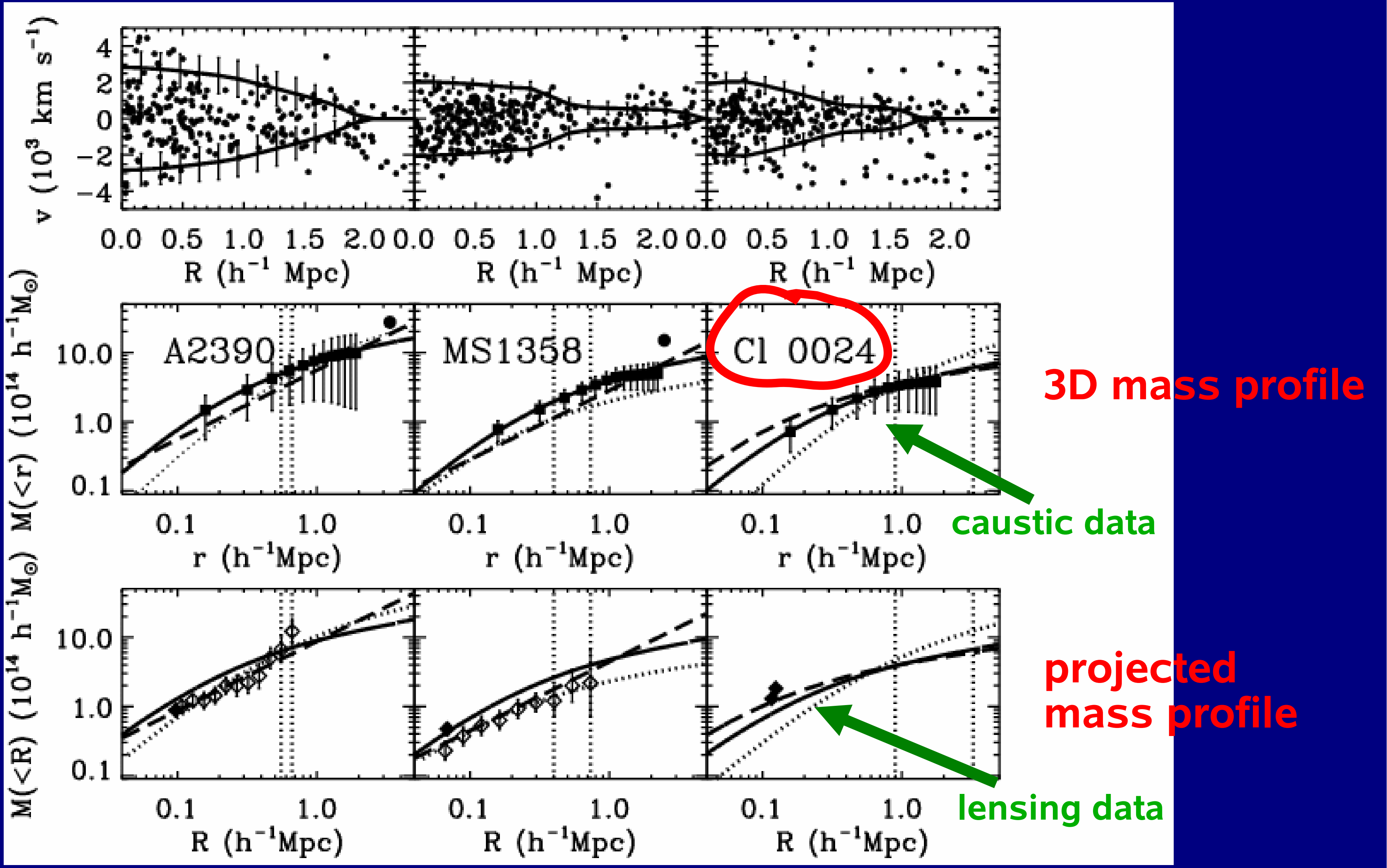


radius

Diaferio & Geller 1997

Diaferio 1999

CAUSTIC TECHNIQUE (5):
CAUSTICS VS. LENSING

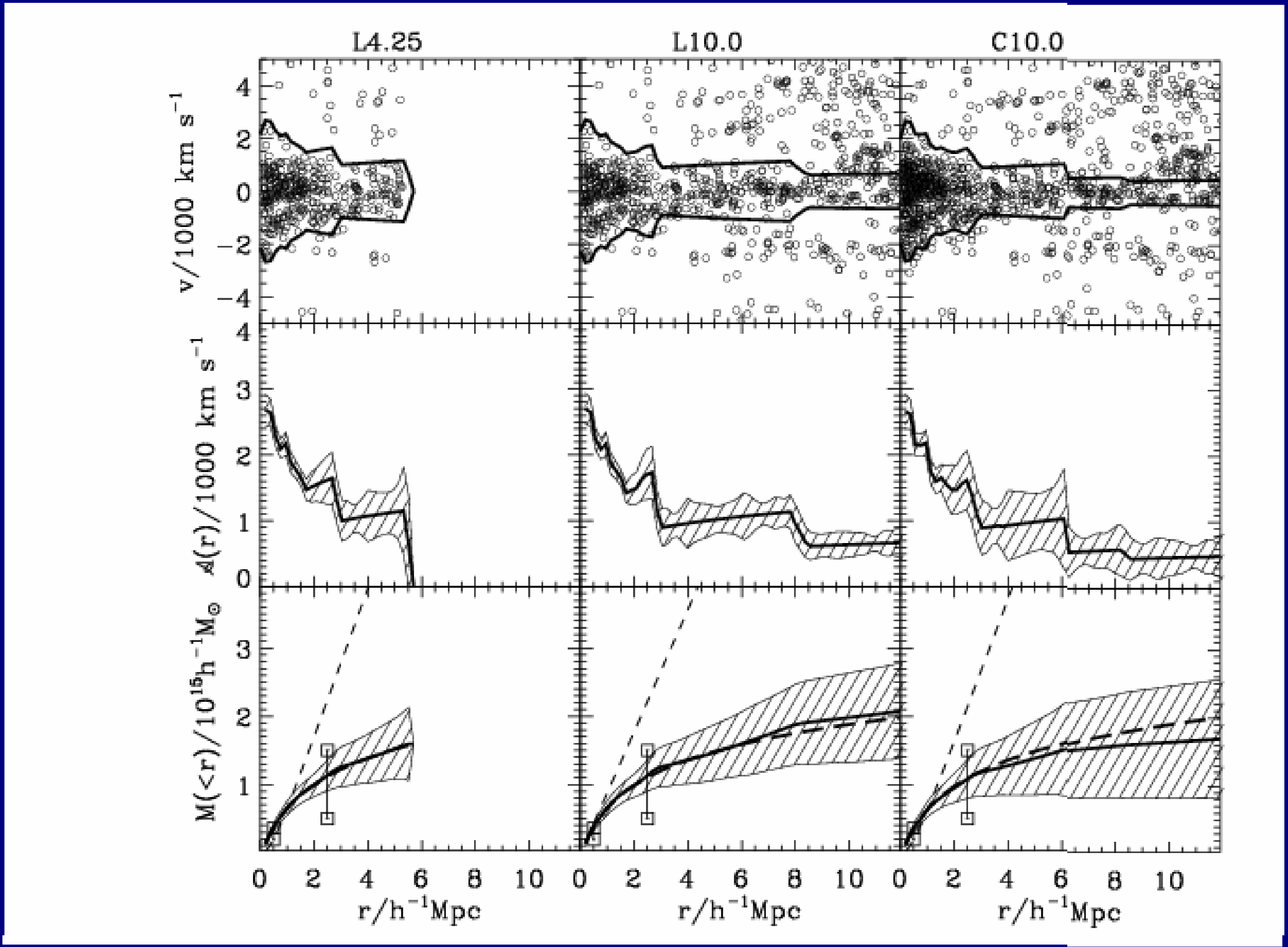


Diaferio et al. 2005

CAUSTICS VS. LENSING

CAUSTICS	LENSING
Requires:	***Requires***:
➔ Wide-field redshift survey	➔ Wide-field photometric survey
➔ Sufficiently dense survey	➔ Redshift where signal is sufficiently strong
Yields:	***Yields***:
➔ 3D mass profile (affected by projection effects)	➔ Mass projected along the line of sight

CAUSTIC TECHNIQUE (6): APPLICATIONS

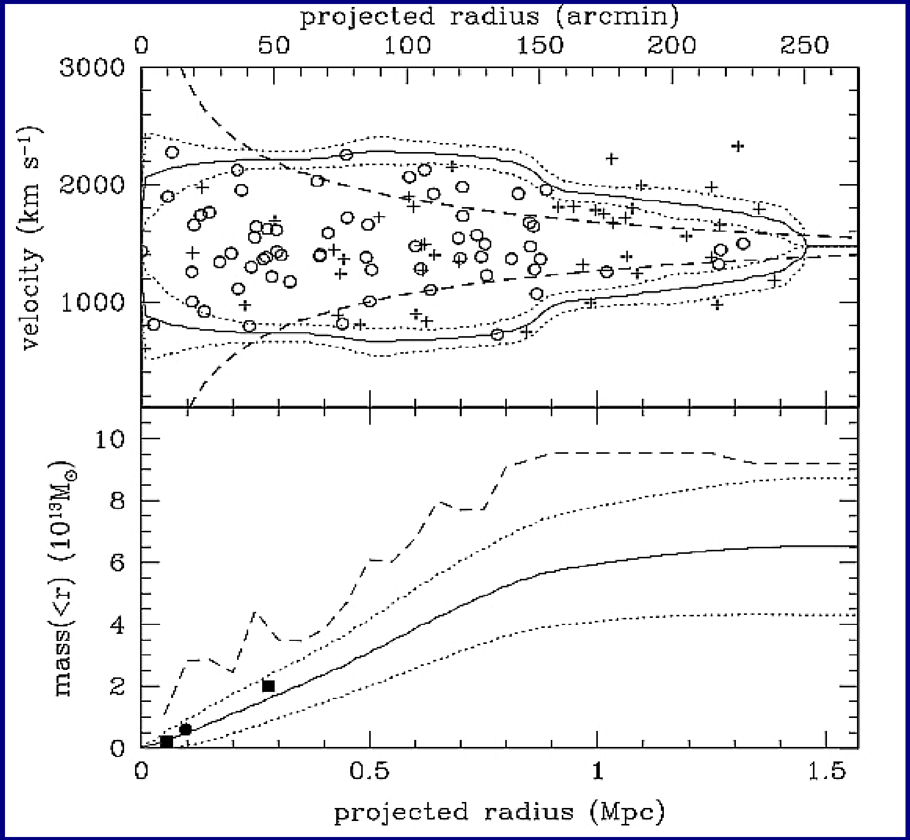


Coma

Geller et al. 1999

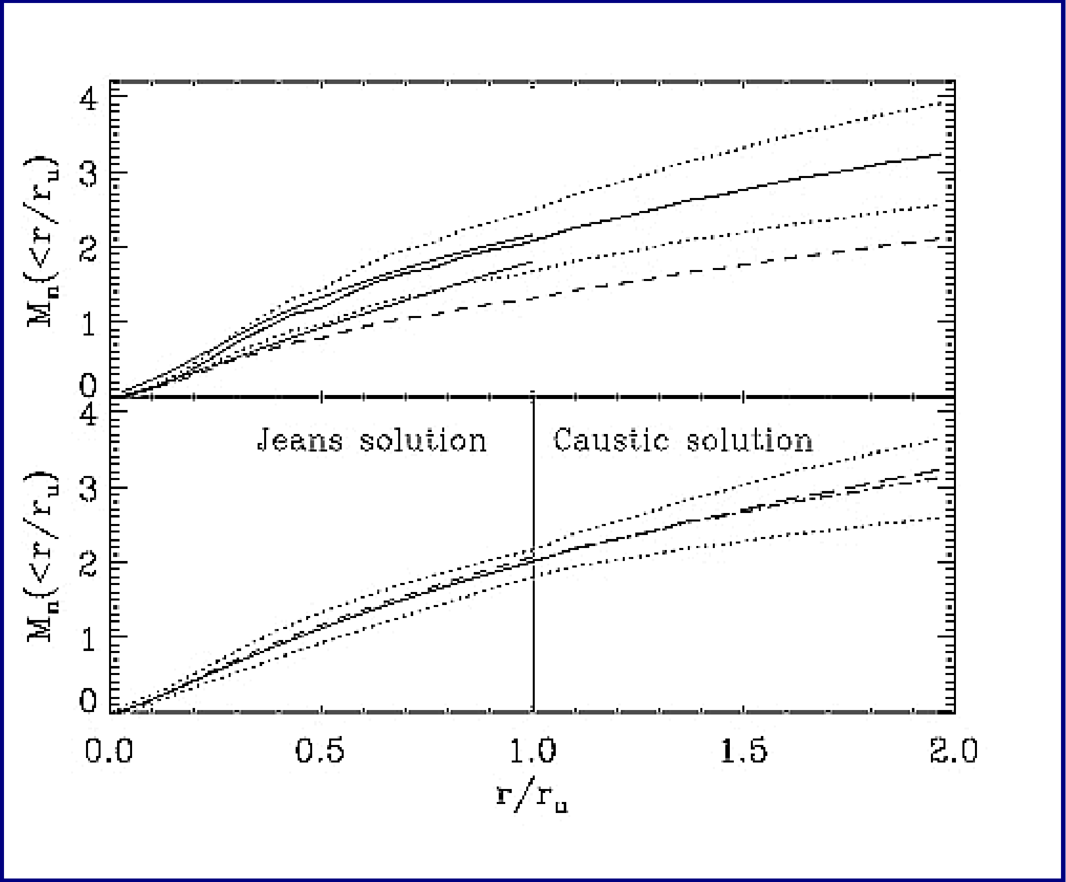
CAUSTIC TECHNIQUE (7): APPLICATIONS

Fornax cluster



Drinkwater et al. 2001

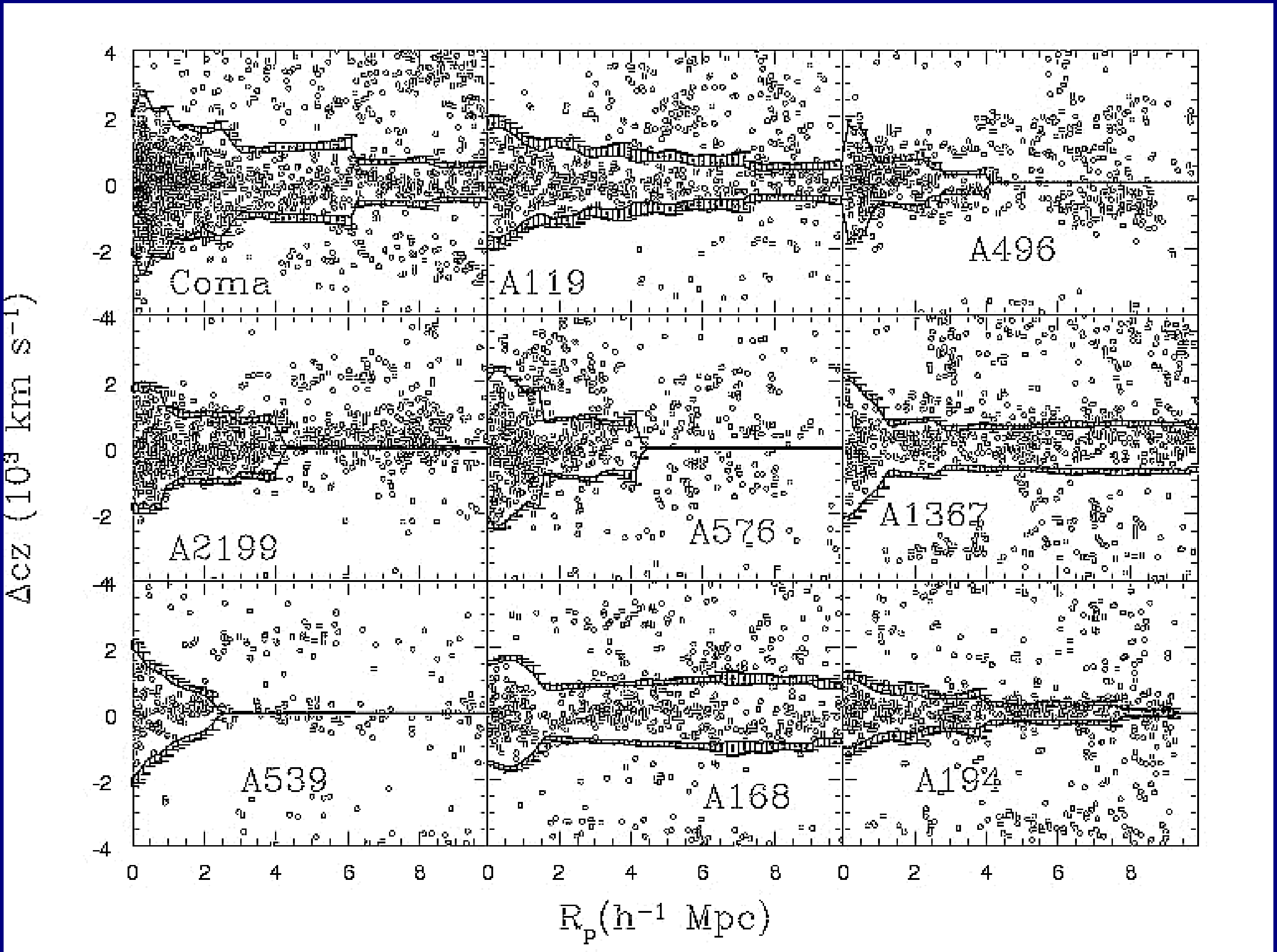
43 stucked clusters from the 2dF



Biviano & Girardi 2003

CAIRNS:
Cluster And Infall Region Nearby Survey

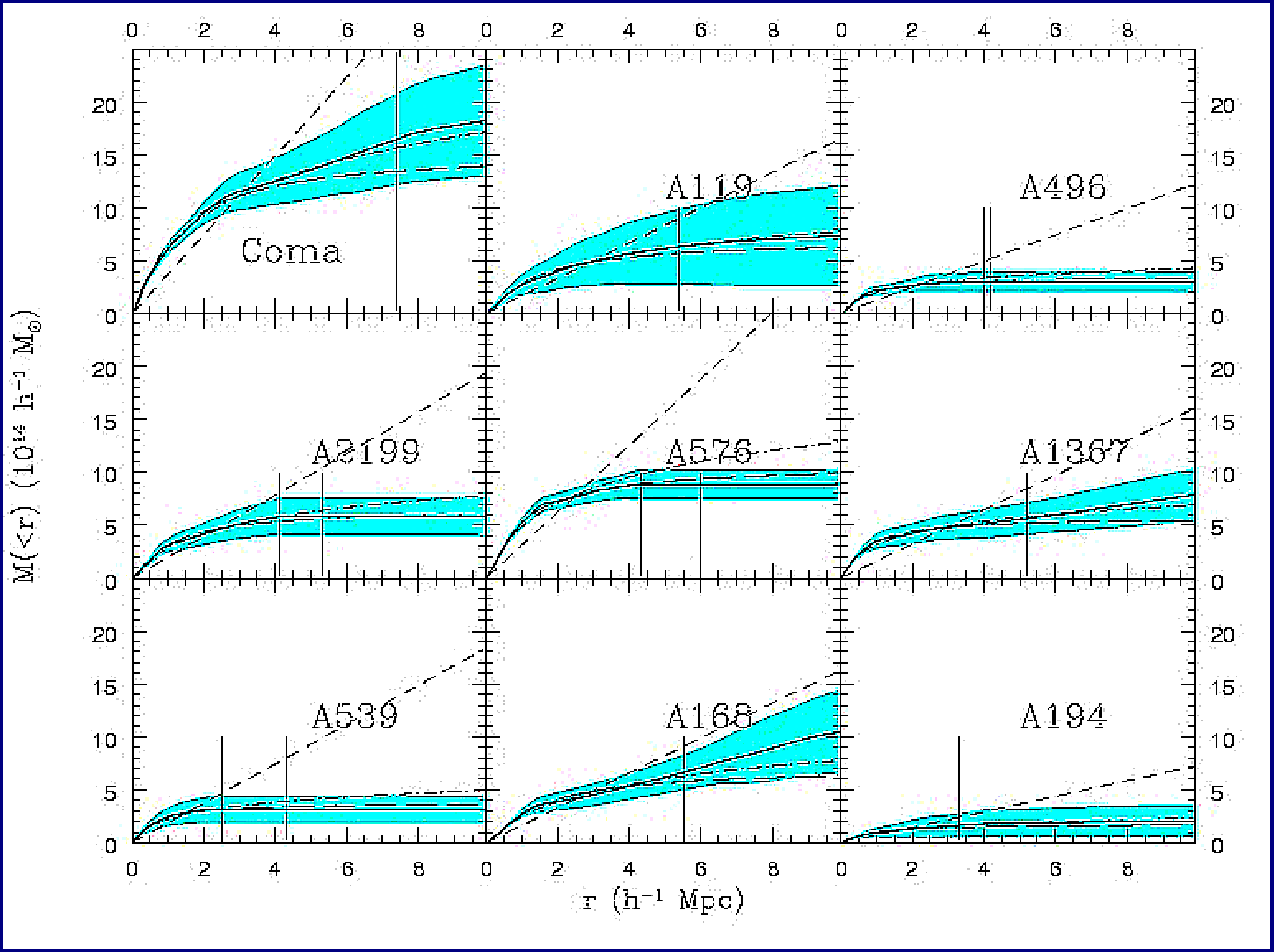
8+1 nearby clusters (cz<15,000 km/s), 15,654 galaxy redshifts



Rines et al. 2003

CAIRNS:
Cluster And Infall Region Nearby Survey

Mass profiles

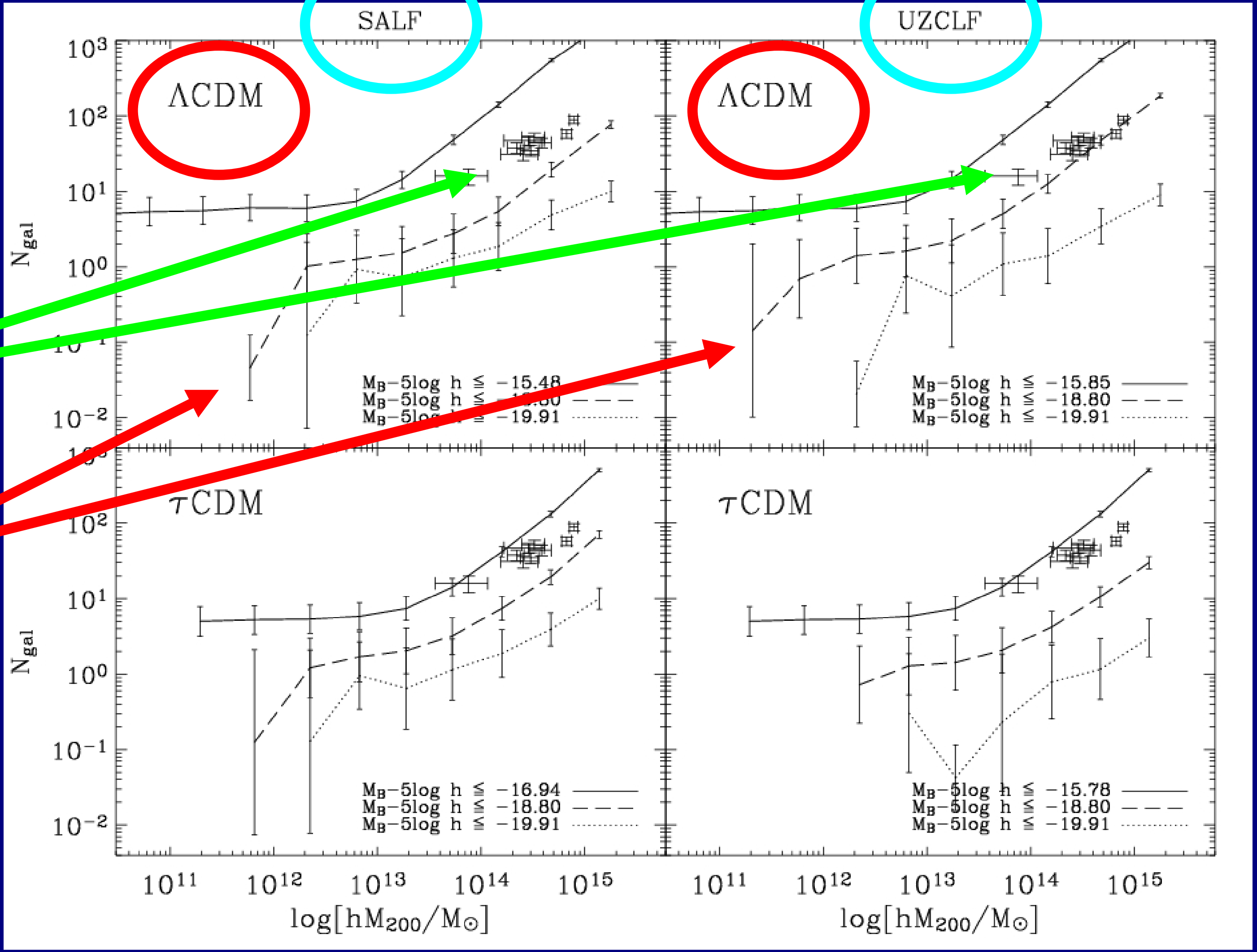


CAIRNS:
Cluster And Infall Region Nearby Survey

Halo Occupation Number

DATA

GIF



Mass

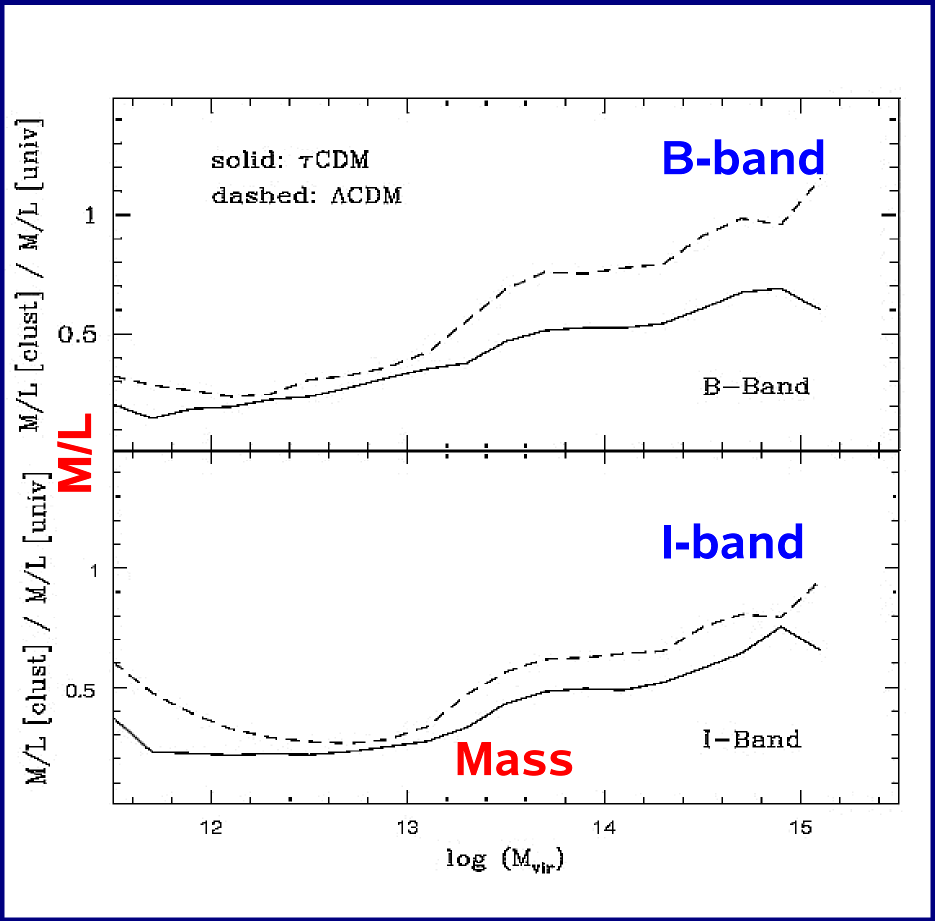
Casagrande & Diaferio 2006

THE MASS-TO-LIGHT RATIO

$$\Omega_0 = \left\langle \frac{M}{L_B} \right\rangle \frac{j_B}{\rho_{crit}}$$

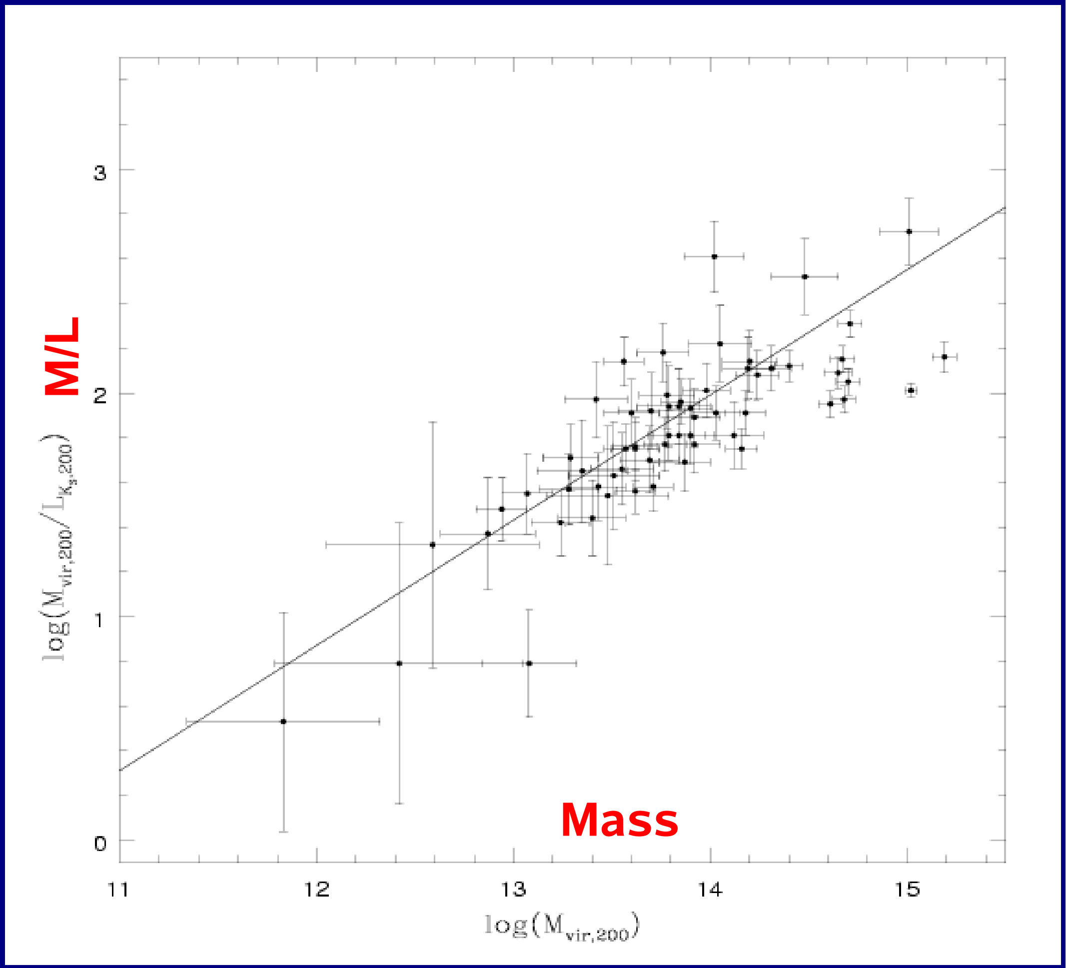
M/L increases with scale

Simulations



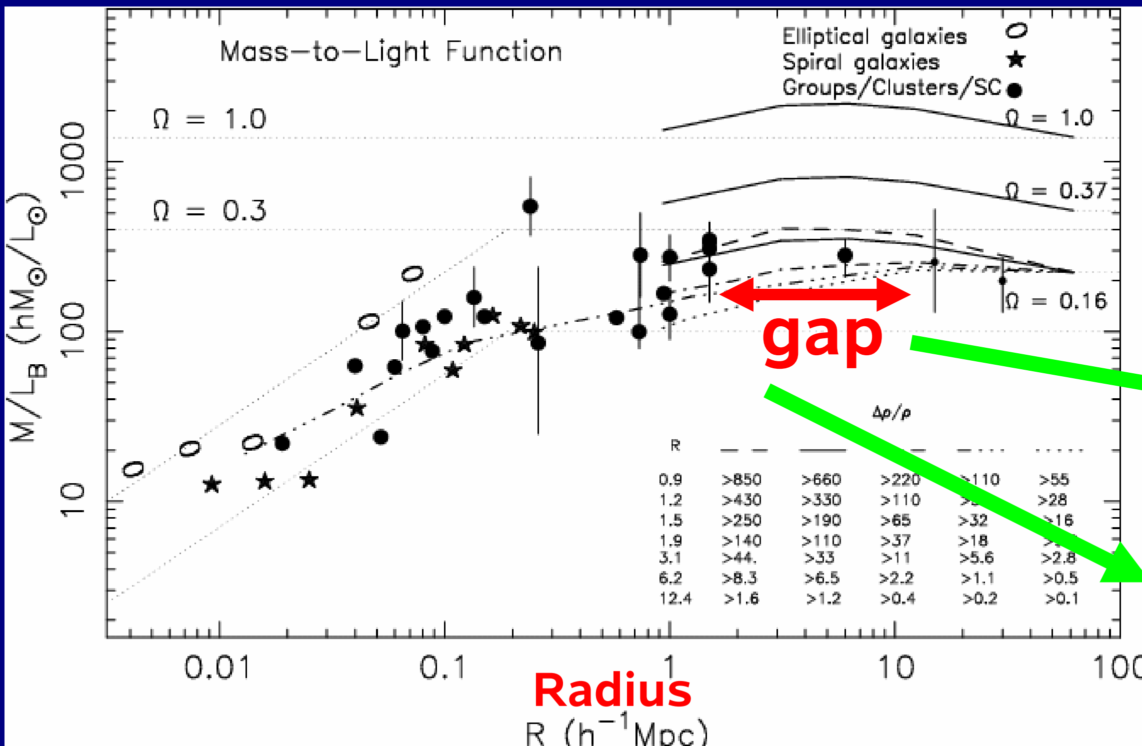
Kauffmann et al. 1999 (GIF sims.)

Observations



Ramella et al. 2004 (2MASS groups)

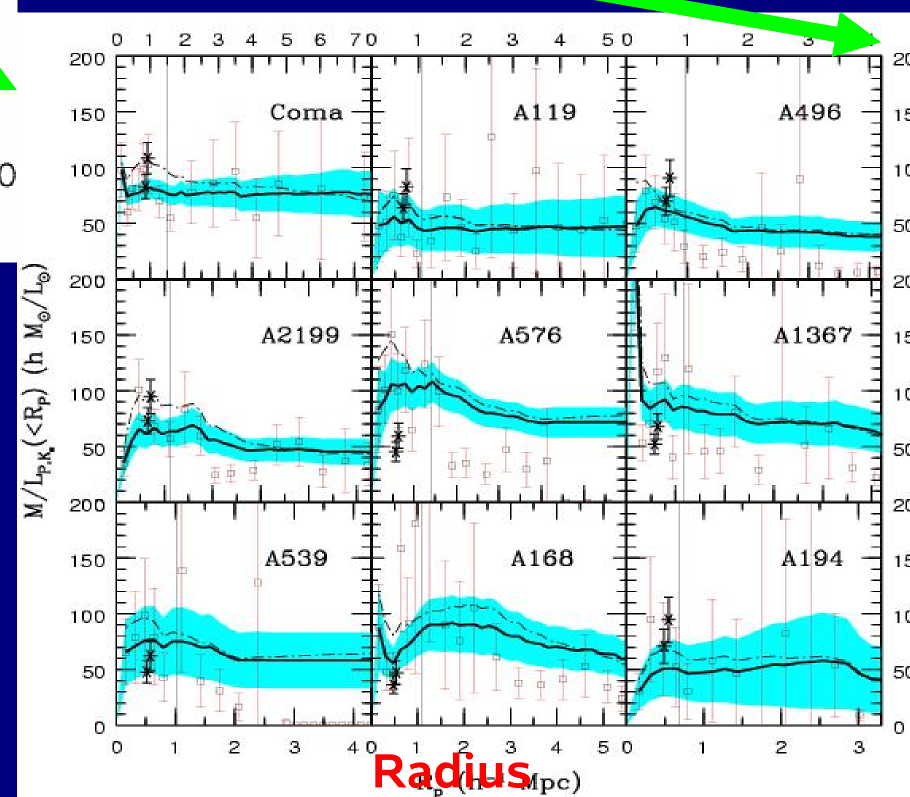
M/L: MEASURES



B-band

Bahcall et al. 2000

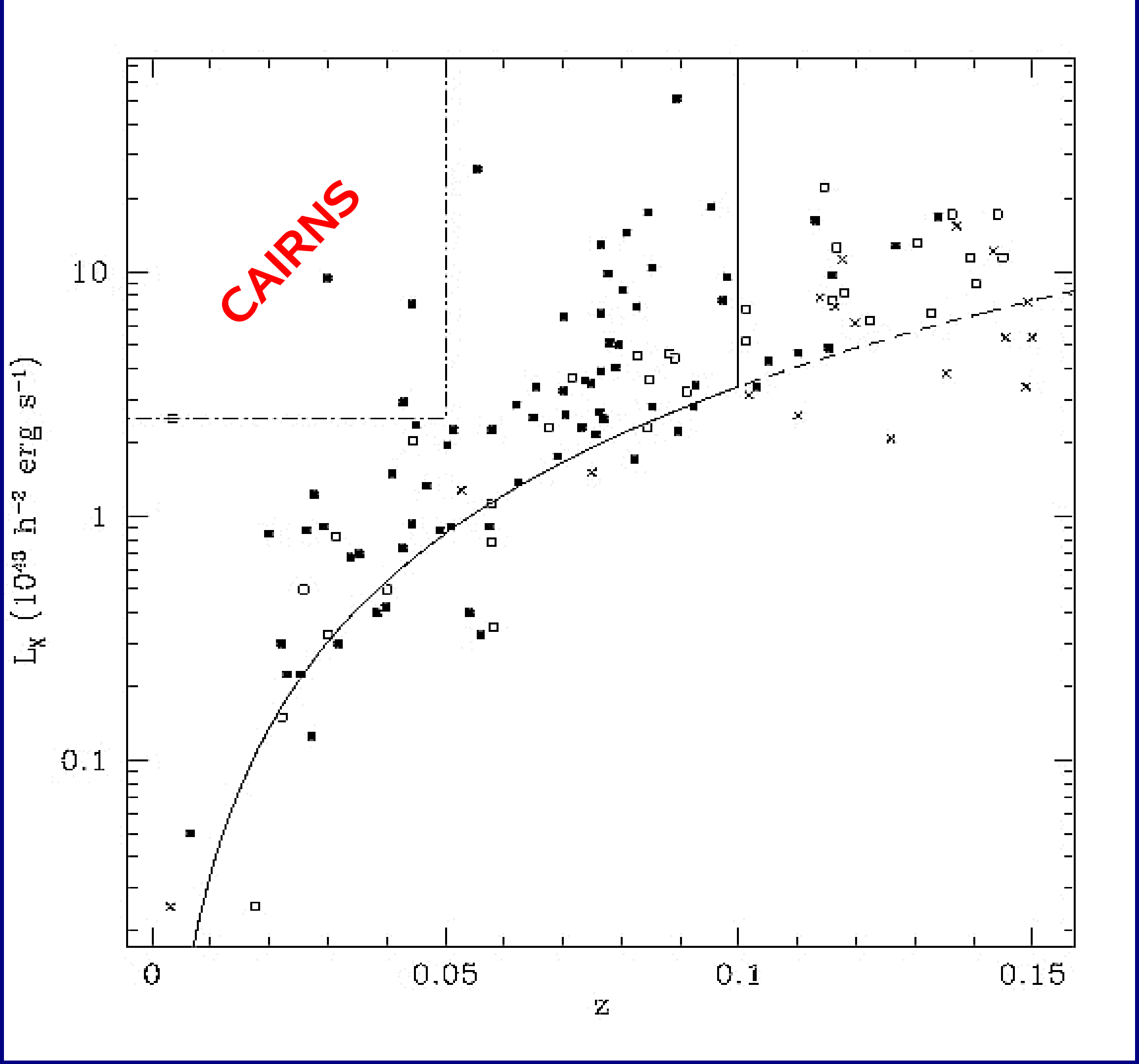
K-band



Rines et al. 2004

CIRS:
Cluster Infall Regions in the SDSS

72 X-ray selected clusters combined with the 4th SDSS data release



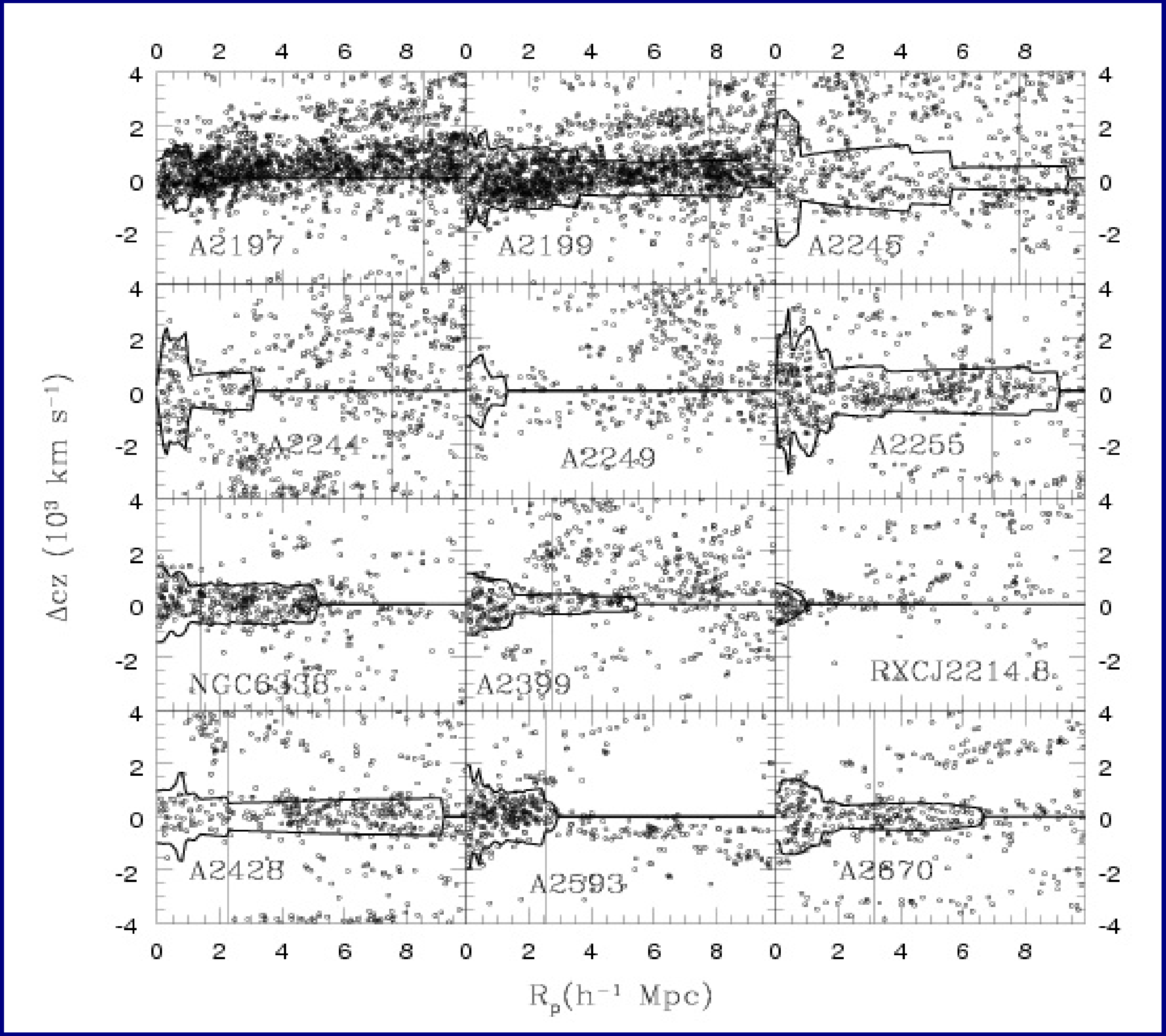
X-ray luminosity

redshift

Rines & Diaferio 2006

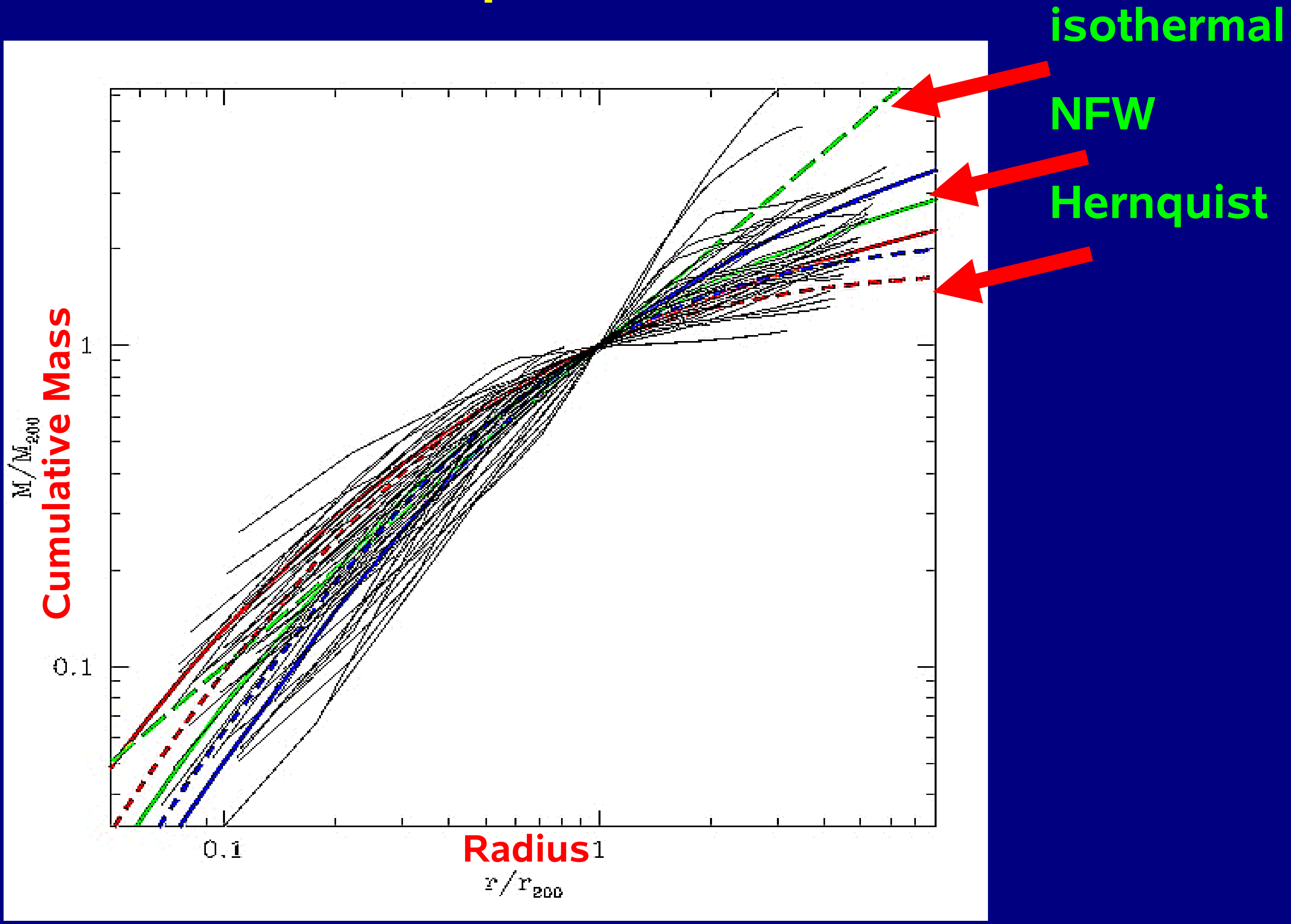
CIRS:
Cluster Infall Regions in the SDSS

Redshift diagrams (12 out of 72)



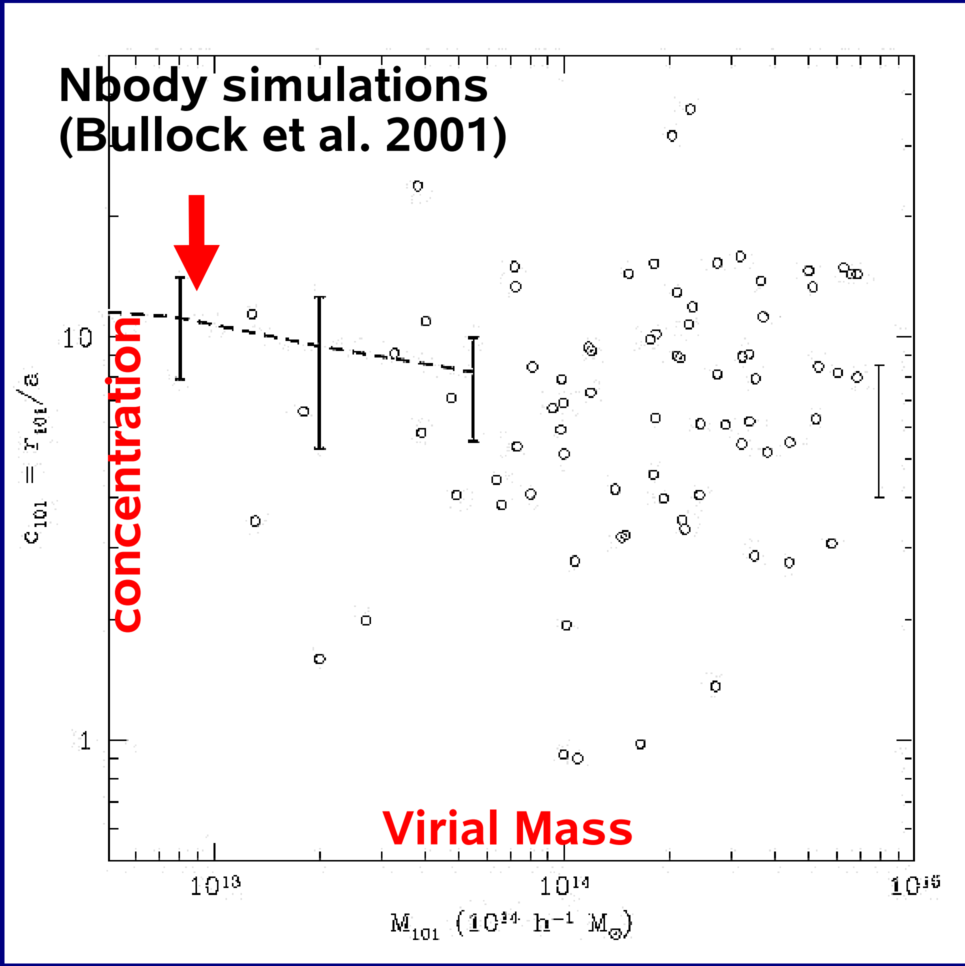
CIRS:
Cluster Infall Regions in the SDSS

Mass profiles

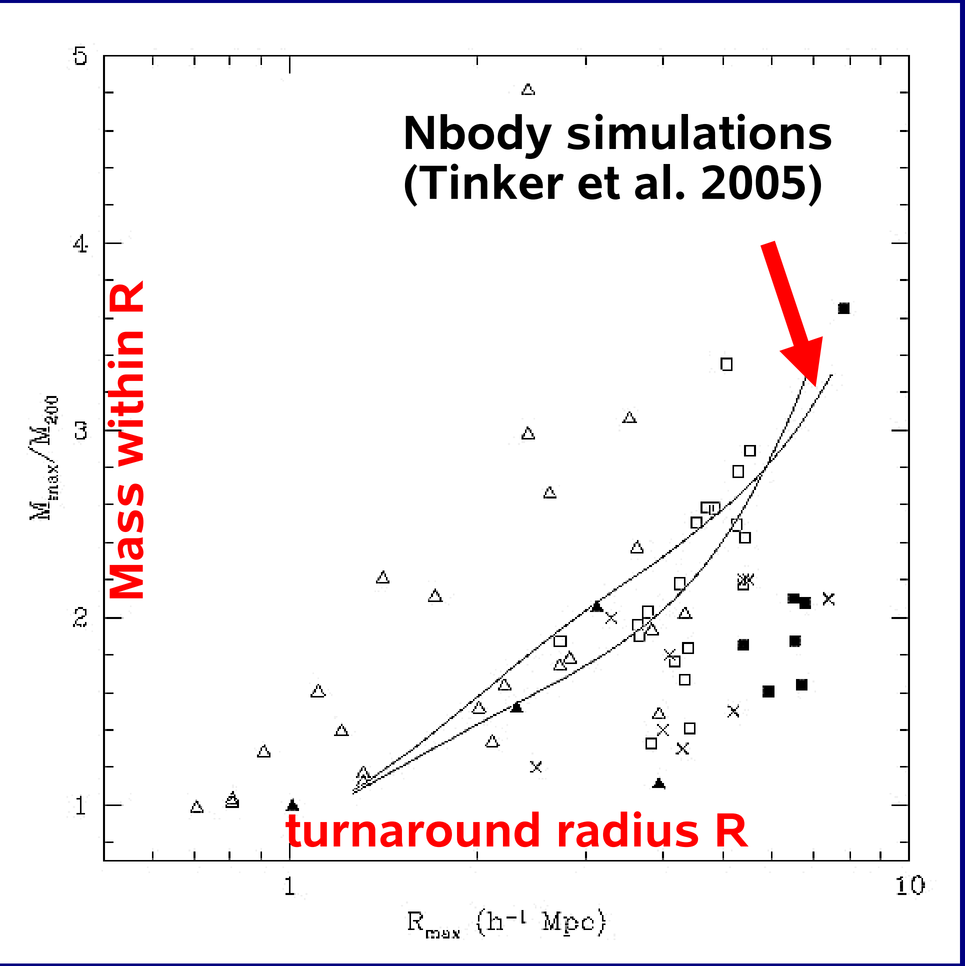


CIRS:
Cluster Infall Regions in the SDSS

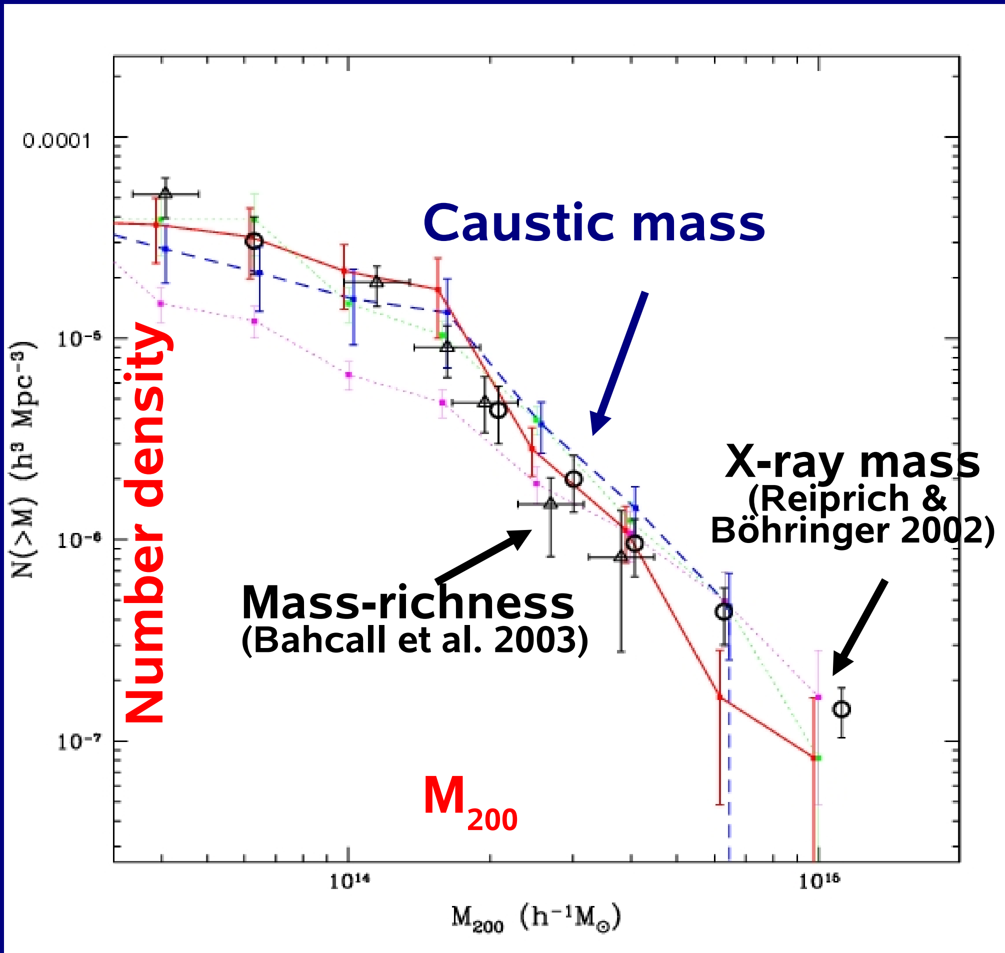
Concentrations

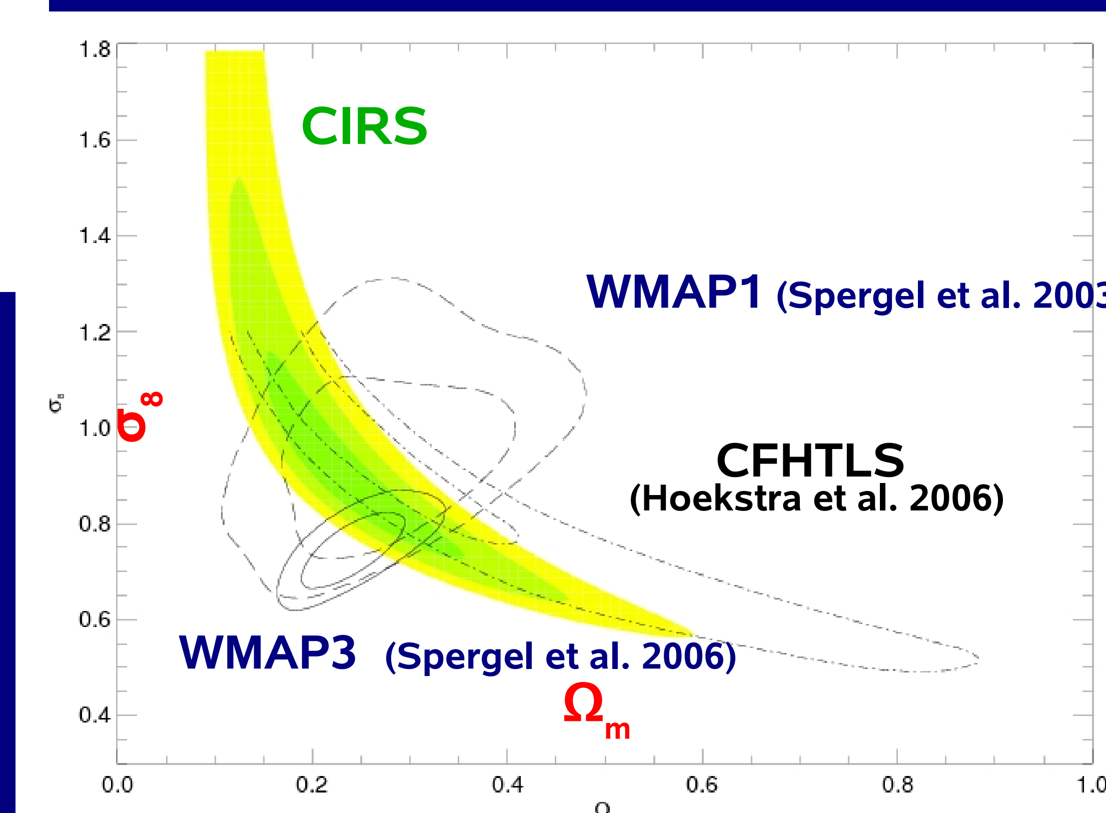


Mass in the infall region



THE CIRS MASS FUNCTION AND THE COSMOLOGICAL PARAMETERS



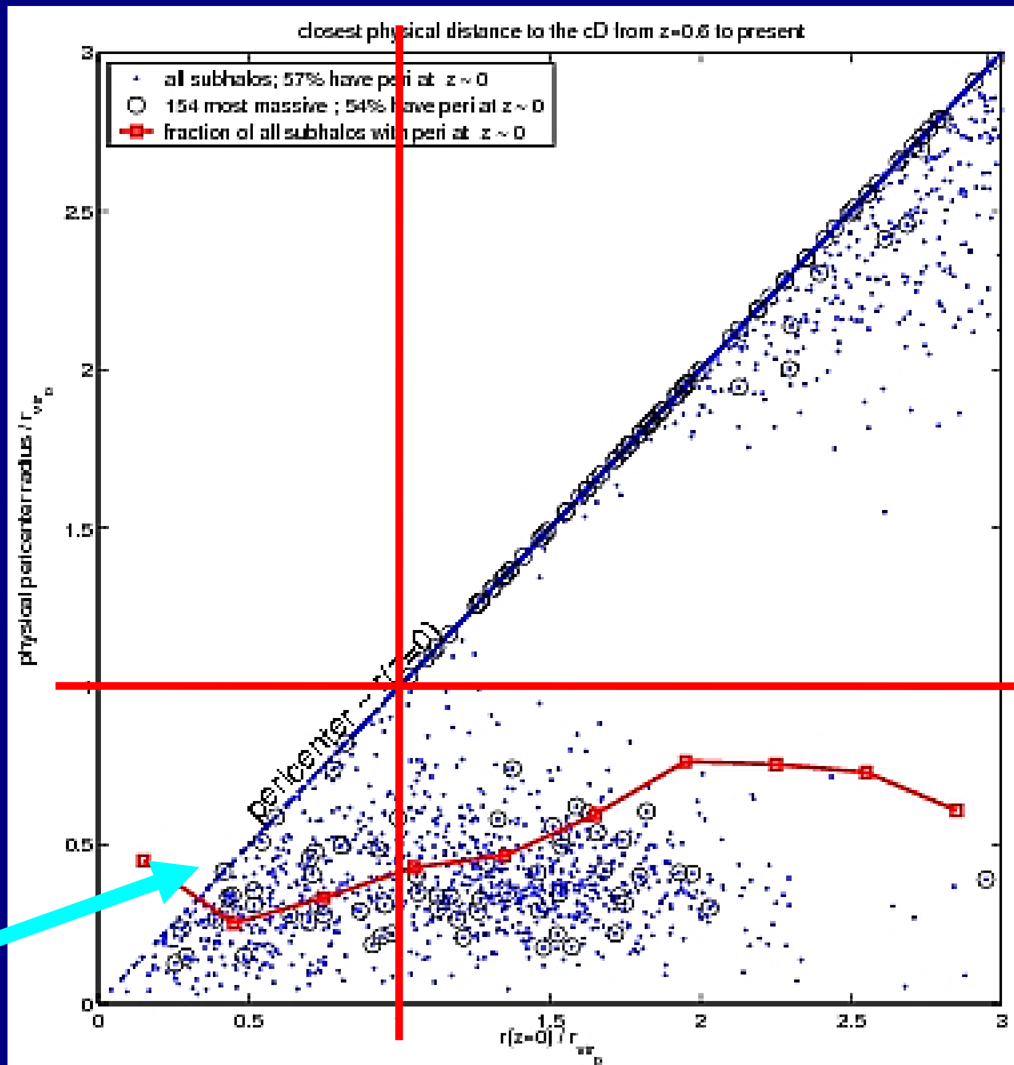


$\Omega_m = 0.24^{+0.14}_{-0.09}$

$\sigma_8 = 0.92^{+0.24}_{-0.19}$

Rines et al. 2006

THE GALAXY-LSS CONNECTION



pericenter

virial region

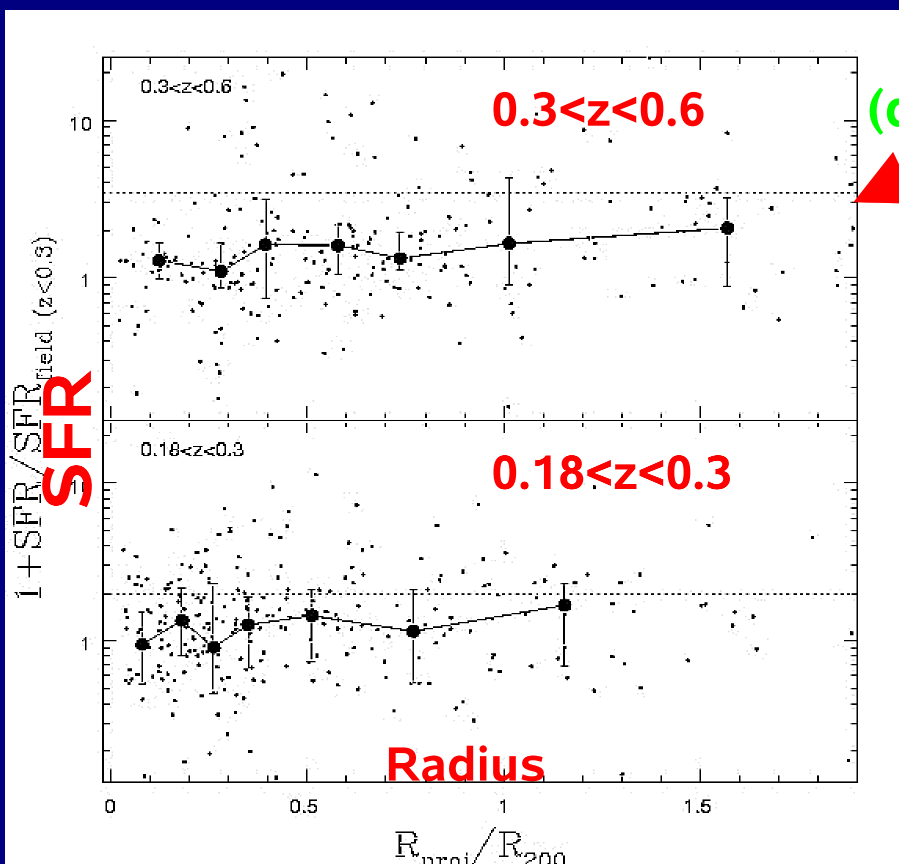
position at z=0

Moore et al. 2004

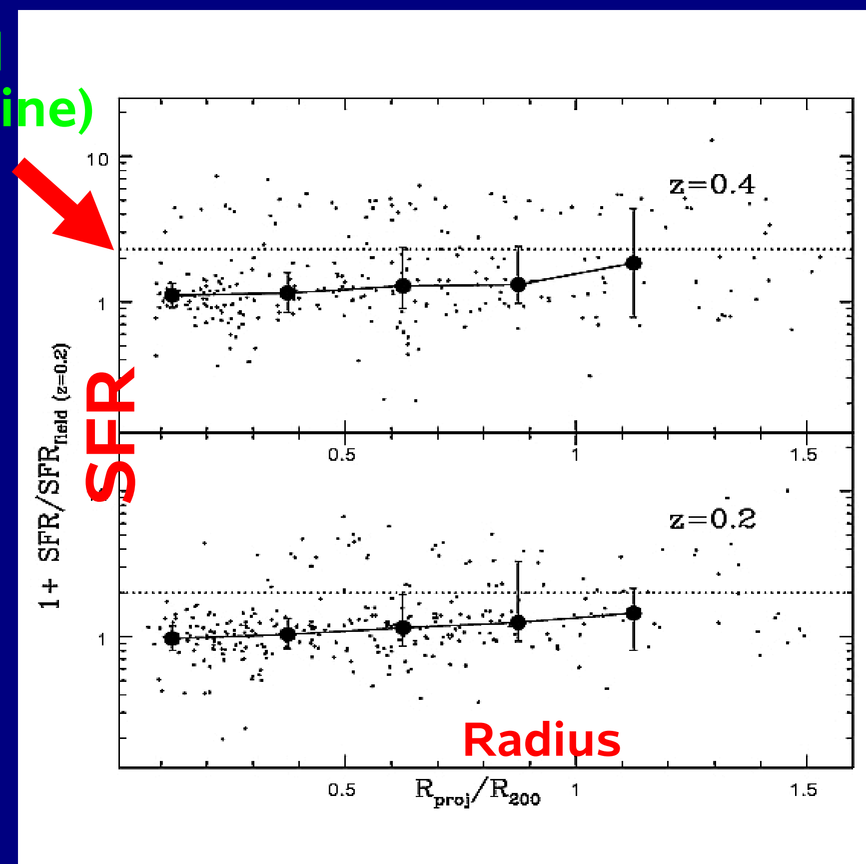
SFR vs. RADIUS

CNOC

N-body+semi-analytic model



Field (dotted line)

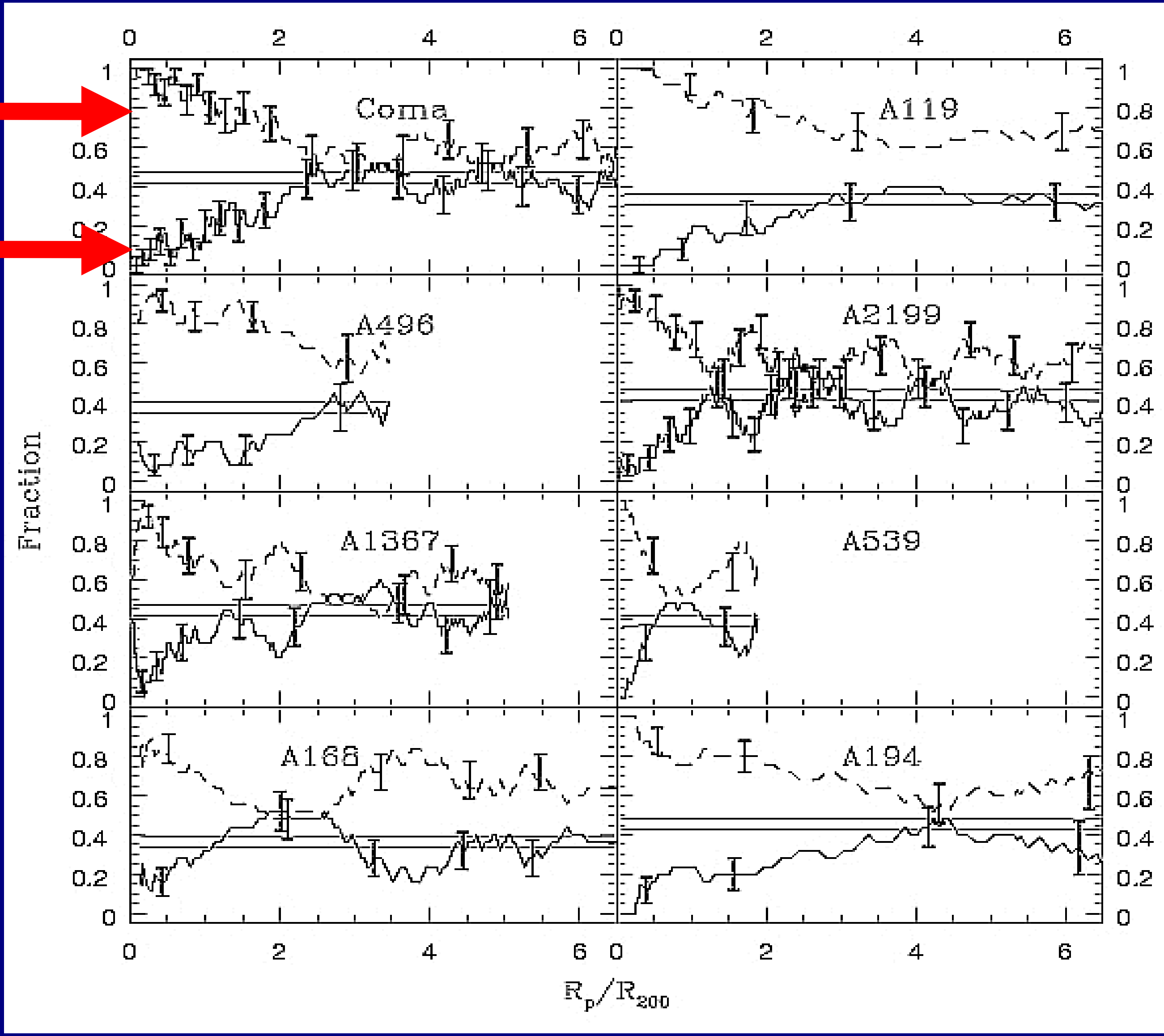


Diaferio et al. 2001

CAIRNS:
Hα vs. radius

Non emission-line

Emission-line



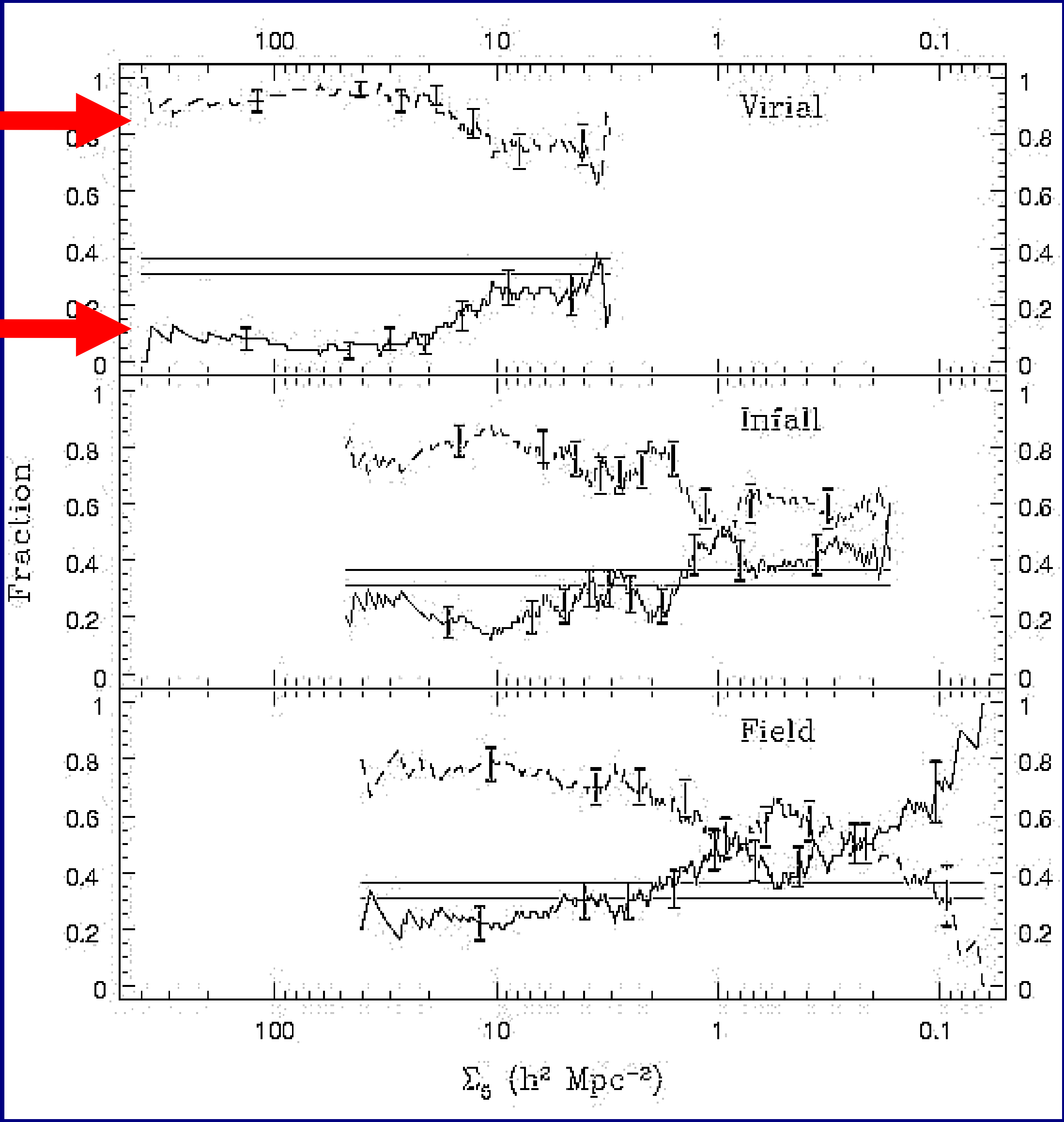
galaxy fraction

radius

CAIRNS:
Hα vs. local density

Non emission-line

Emission-line



galaxy fraction

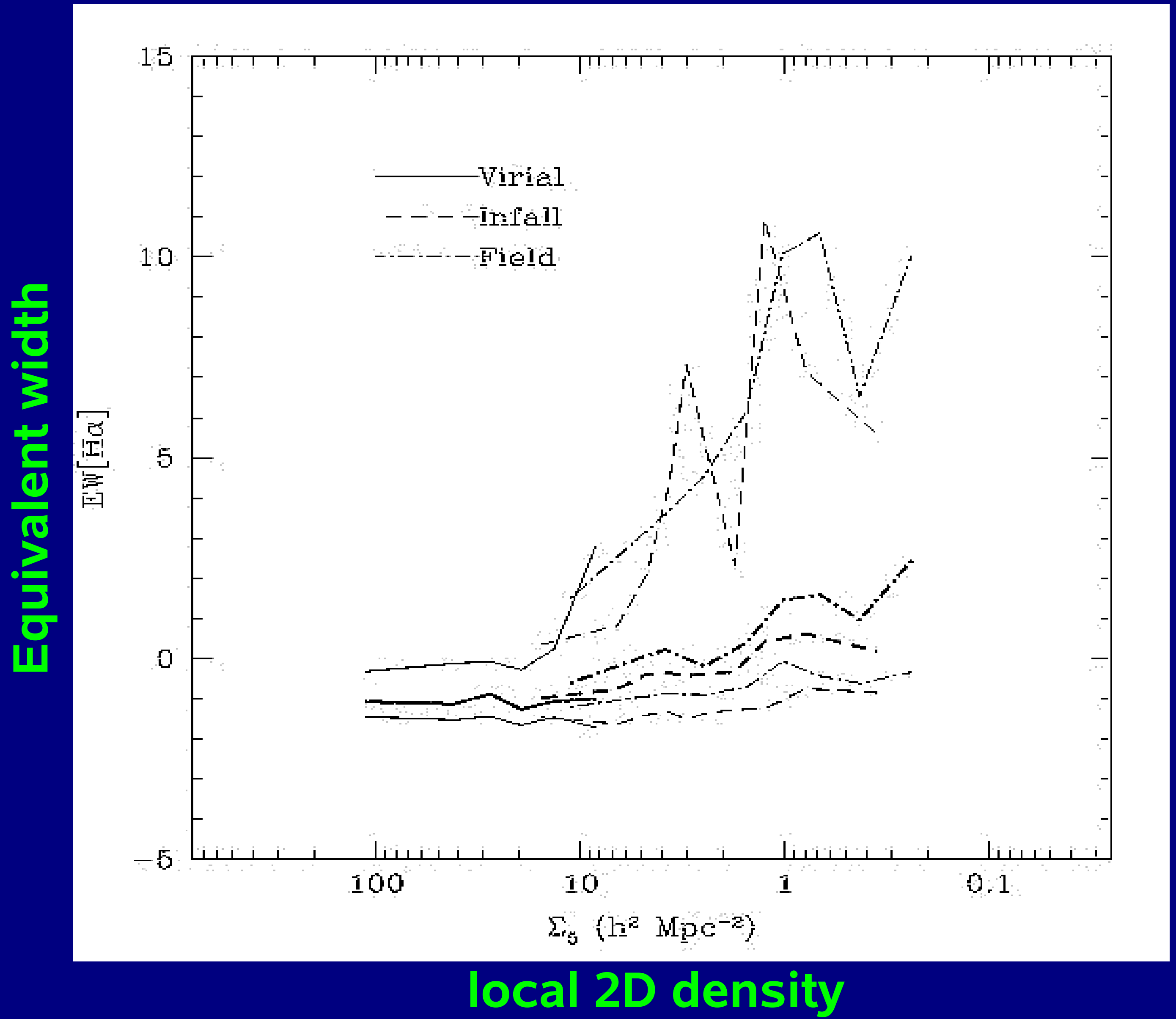
Virial region

Infall region

Field

local 2D density

CAIRNS:
EW[Hα] distribution vs. density



CONCLUSION

- The caustic technique: A mass estimator for the outer regions of clusters
- Results from the CAIRNS and CIRS cluster surveys
- Mass-to-light ratio profiles out to ~4 R_{200} for 9 clusters
- NFW/Hernquist best fits to the mass profiles out to 4-5 R_{200} for ~80 clusters!
- Mass function yields Ω_m-σ_8 consistent with other estimates
- The galaxy-environment connection: local density