Galaxy Systems in the Optical and Infrared

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Disclaimer:

No X-ray

Disclaimer:

No X-ray

No radio

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No X-ray

No radio

No lensing

Plan of the lectures:

I. Identification, global properties, and scaling relations

II. Structure and dynamics

III. Properties of the galaxy populations

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I. Identification, global properties, and scaling relations

II. Structure and dynamics

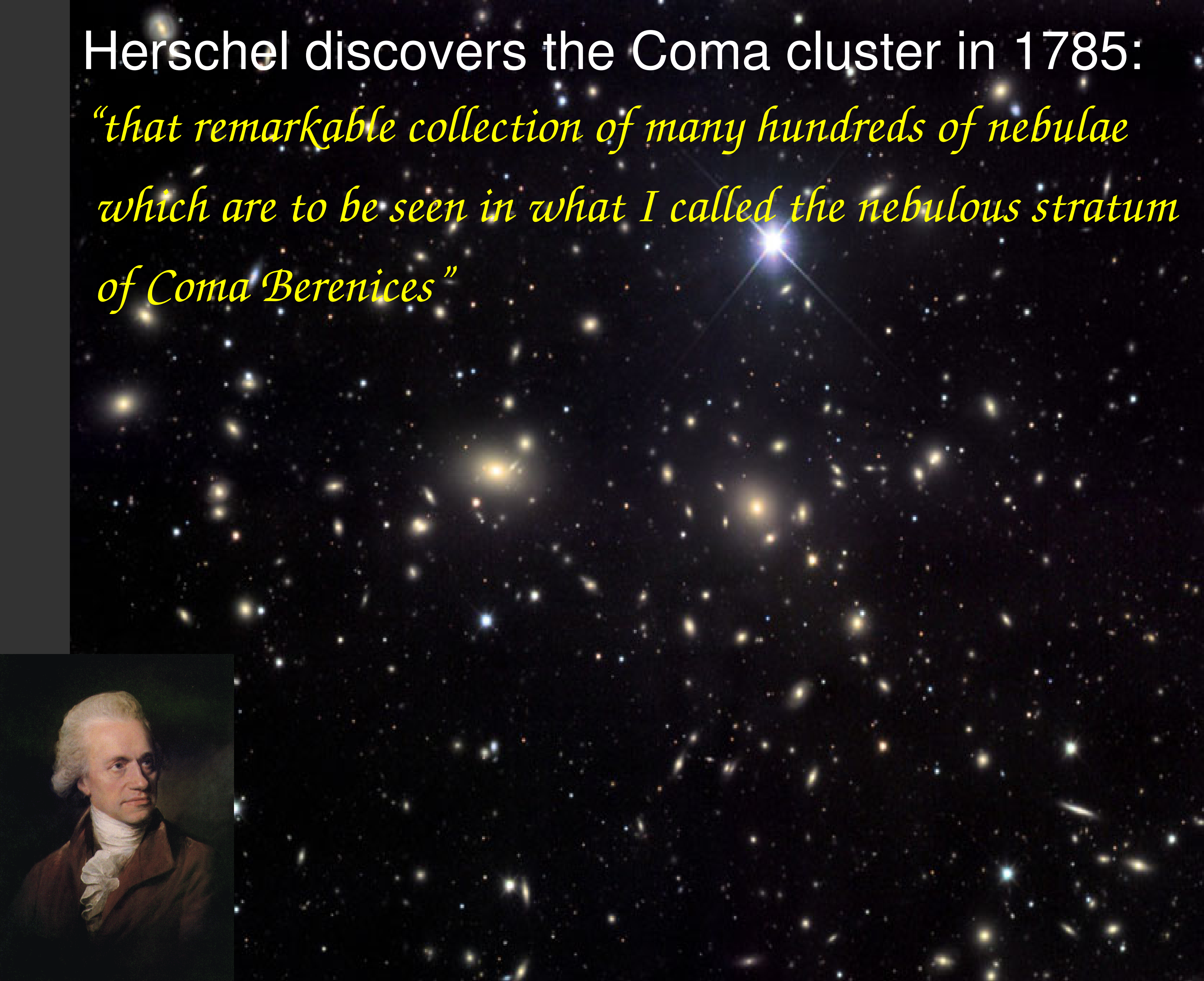
III. Properties of the galaxy populations

Identification


Messier discovers the Virgo cluster in 1784

Herschel discovers the Coma cluster in 1785:

"that remarkable collection of many hundreds of nebulae which are to be seen in what I called the nebulous stratum of Coma Berenices"



George Abell: First modern method of galaxy clusters identification (1958)

POSS photographic plates

m_{10} as a distance indicator

count galaxies from m_3 to m_3+2

within 2.13 Mpc radius

subtract counts from neighboring field

2712 clusters identified

(4073 w. southern extension)

Important reference catalog

(e.g. ENACS in 1989...)

but 2 main problems:

a) incompleteness

b) contamination (projection effects)

Ideally:

push incompleteness & contamination → 0

In practice:

estimate incompleteness & contamination on mock galaxy cluster samples

⇒ cluster identification must be:

AUTOMATED and OBJECTIVE

How to be a good identification method:

1) automatization

2) objectiveness

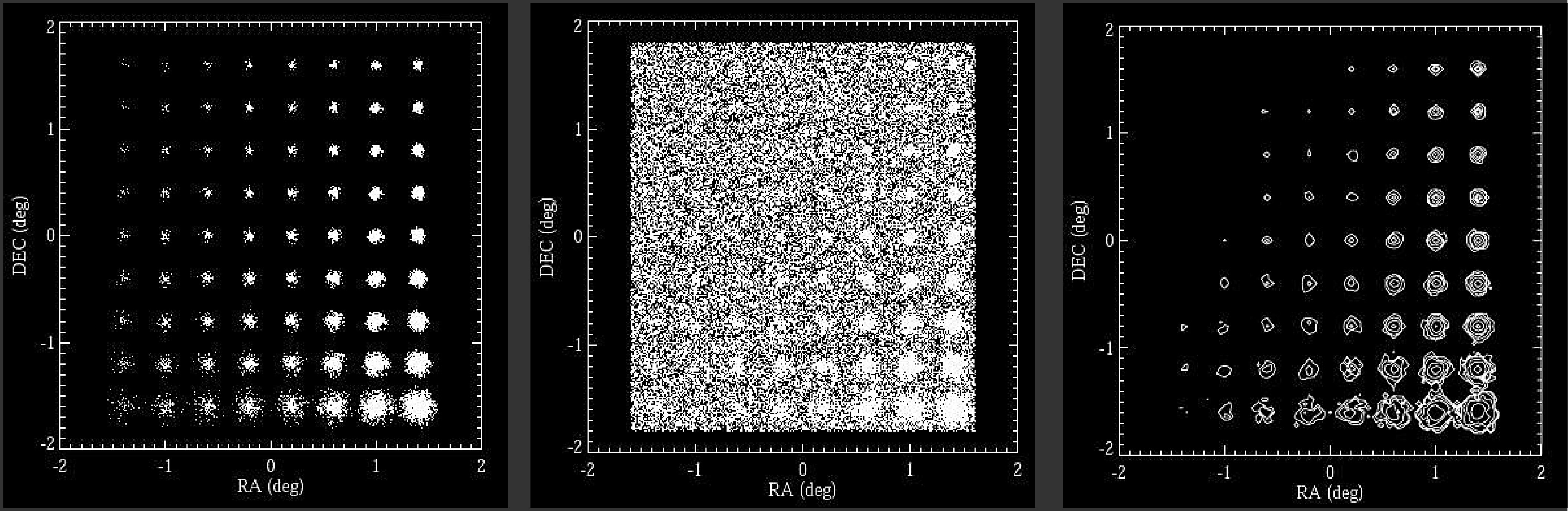
3) minimal constraints on cluster properties

4) well-understood selection function

5) provide cluster <z> and mass estimates

The Matched Filter method

(Postman+96, Kepner+99)



The Matched Filter method

Developed for photometric catalogs

$$D(r,m) = \text{background} + \text{cluster}$$

$$= b(m) + \Lambda_{\text{cl}} P(r/r_c)\,\phi(m - m^*),$$

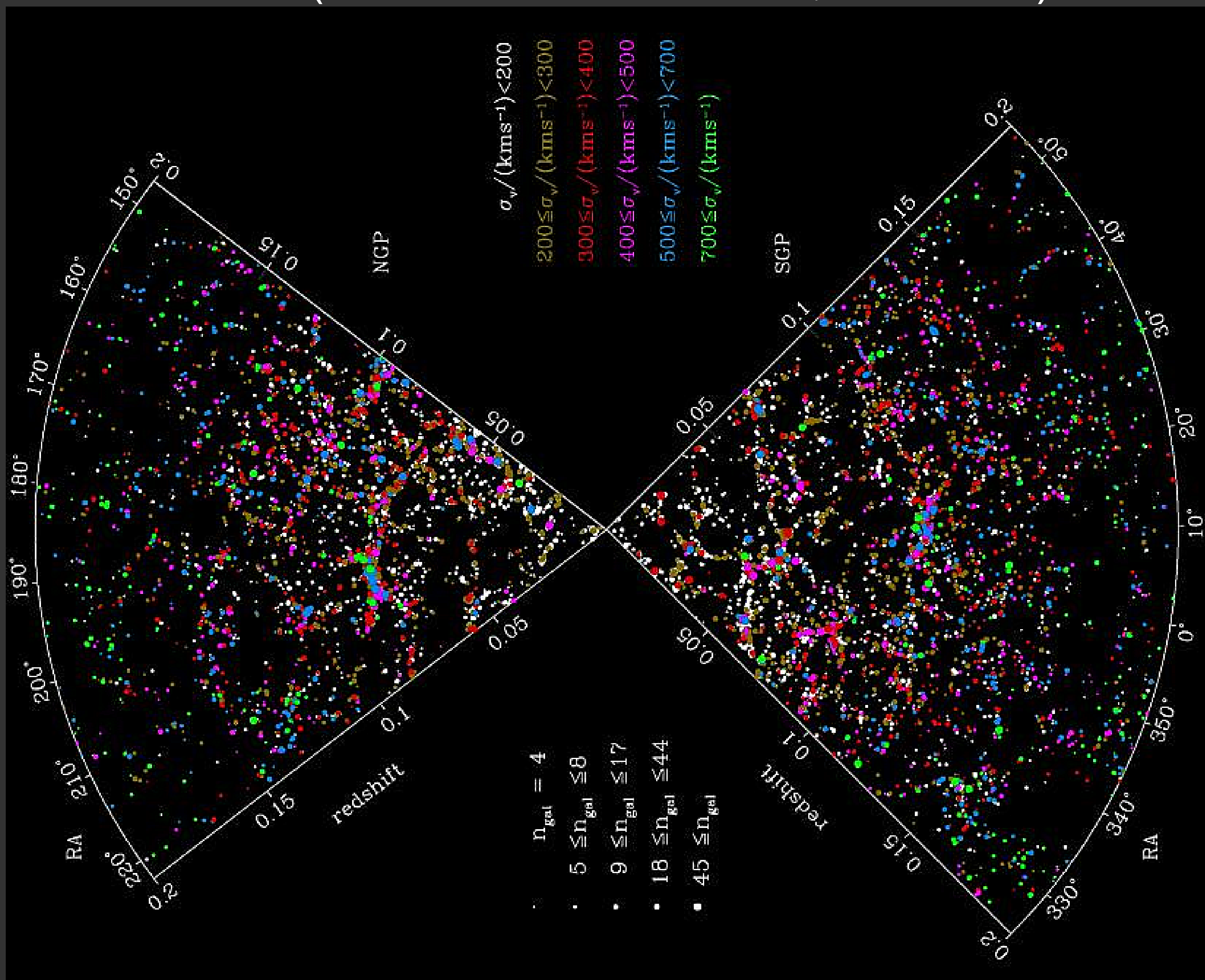
$$\ln \mathscr{L} \propto \int_{\text{Area},m} \ln \sigma$$

$$+ \int_{\text{Area},m} \frac{[b(m) + \Lambda_{\text{cl}} P(r/r_c)\,\phi(m - m^*) - D(r,m)]^2}{\sigma^2}.$$

$\sigma^2 = b(m)$

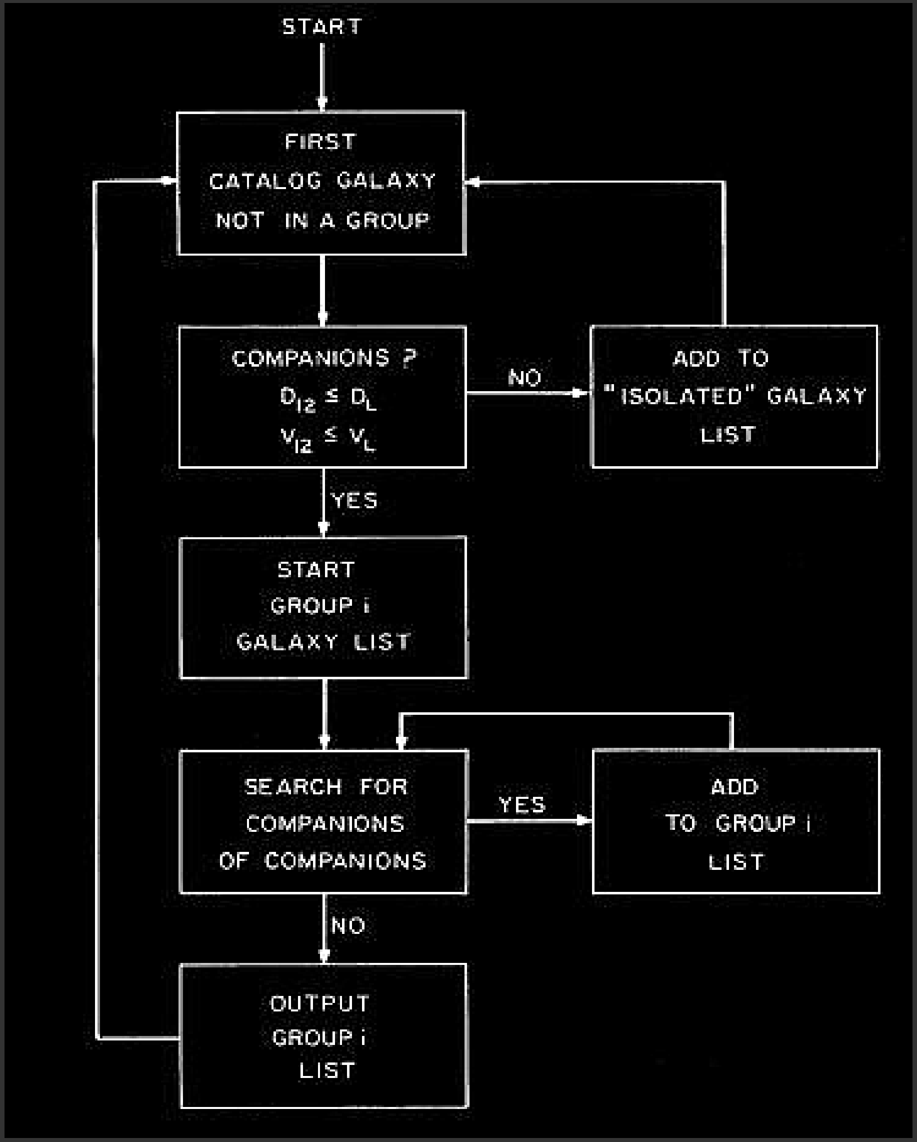
The Friends-of-friends method

(Huchra & Geller 82; Eke+04)



The Friends-of-friends method

Developed for spectroscopic catalogs



$$D_{12} = 2\sin(\theta/2)V/H_0 \le D_L(V_1, V_2, m_1, m_2),$$

$$V = (V_1 + V_2)/2,$$

$$V_{12} = |V_1 - V_2| \le V_L(V_1, V_2, m_1, m_2),$$

Systems are identified within physical overdensity

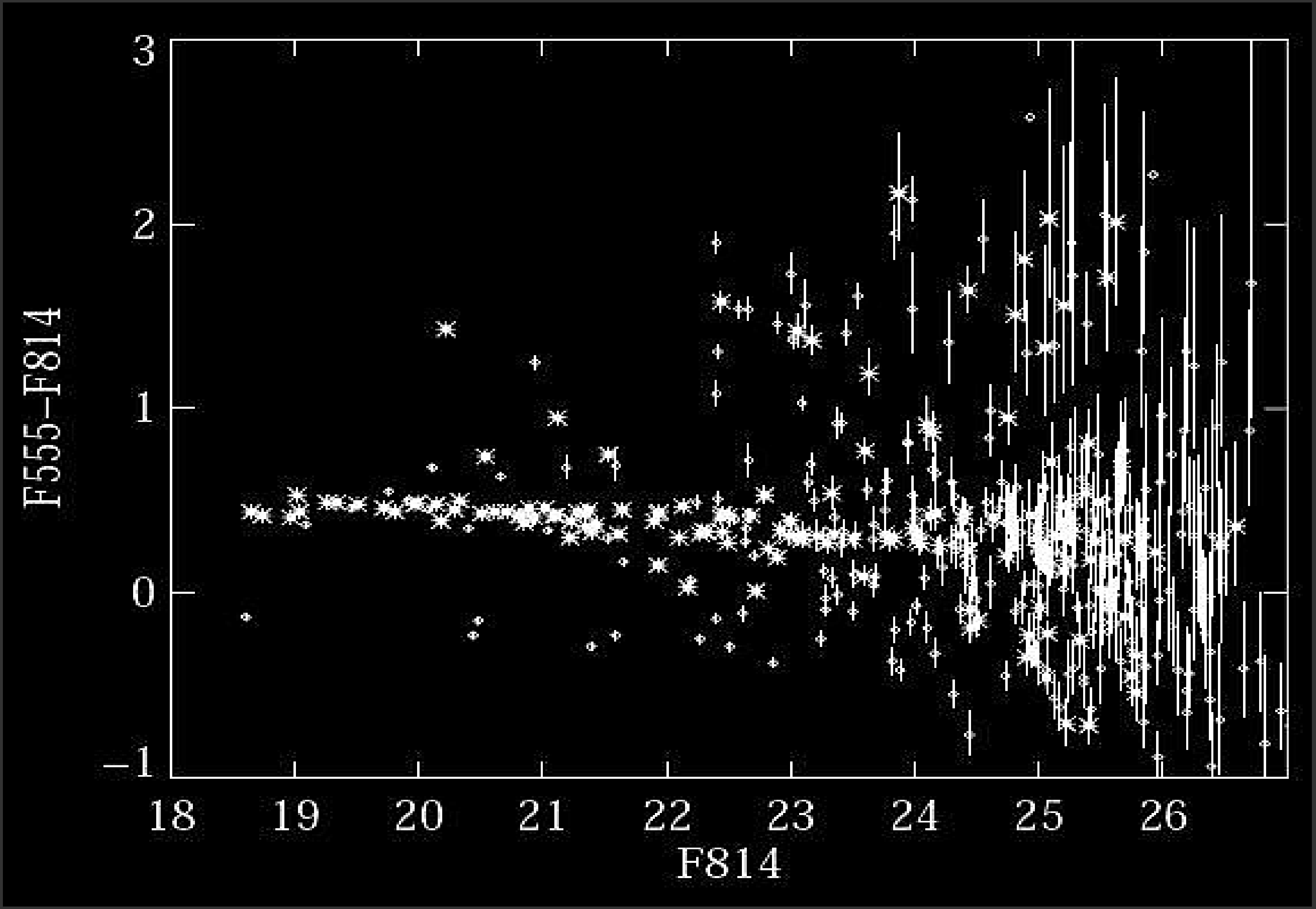
- MF applied to EIS, SDSS, 2MASS ...
- Clusters detected to z~1 down to 10^{14} $M_\odot$
- Completeness ~90% out to z~0.5

  ~50% out to z~1.5 for 10^{15} $M_\odot$
- Miss <10% X-ray selected clusters

- FoF applied to SDSS, 2dFGRS, 2MRS
- Several 1000 systems, low-z, mostly groups (σ_V~200 km/s, ~10^{13} $M_\odot$)
- Essentially complete

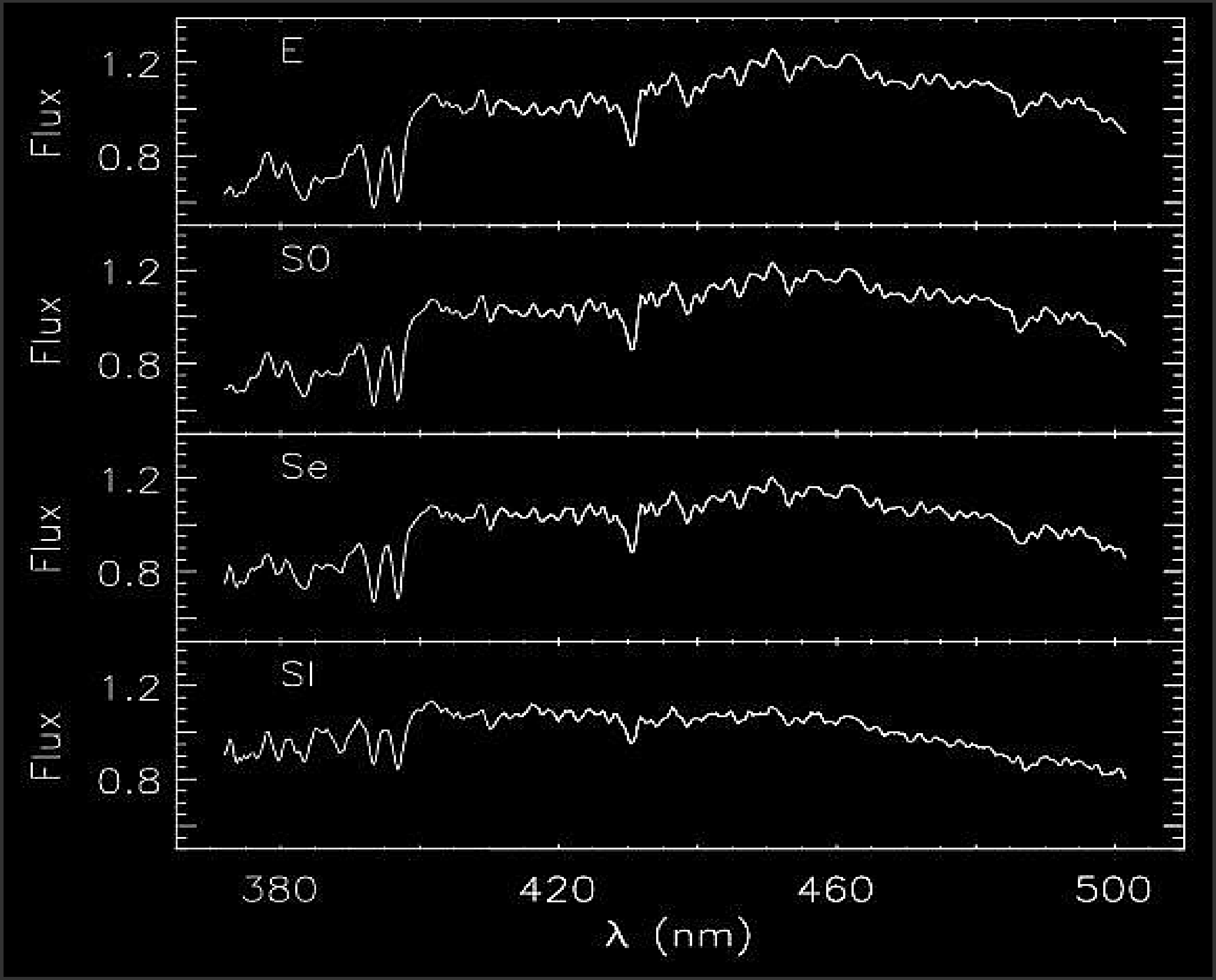
The Cluster Red Sequence method:

(Gladders & Yee 00)



The Cluster Red Sequence method

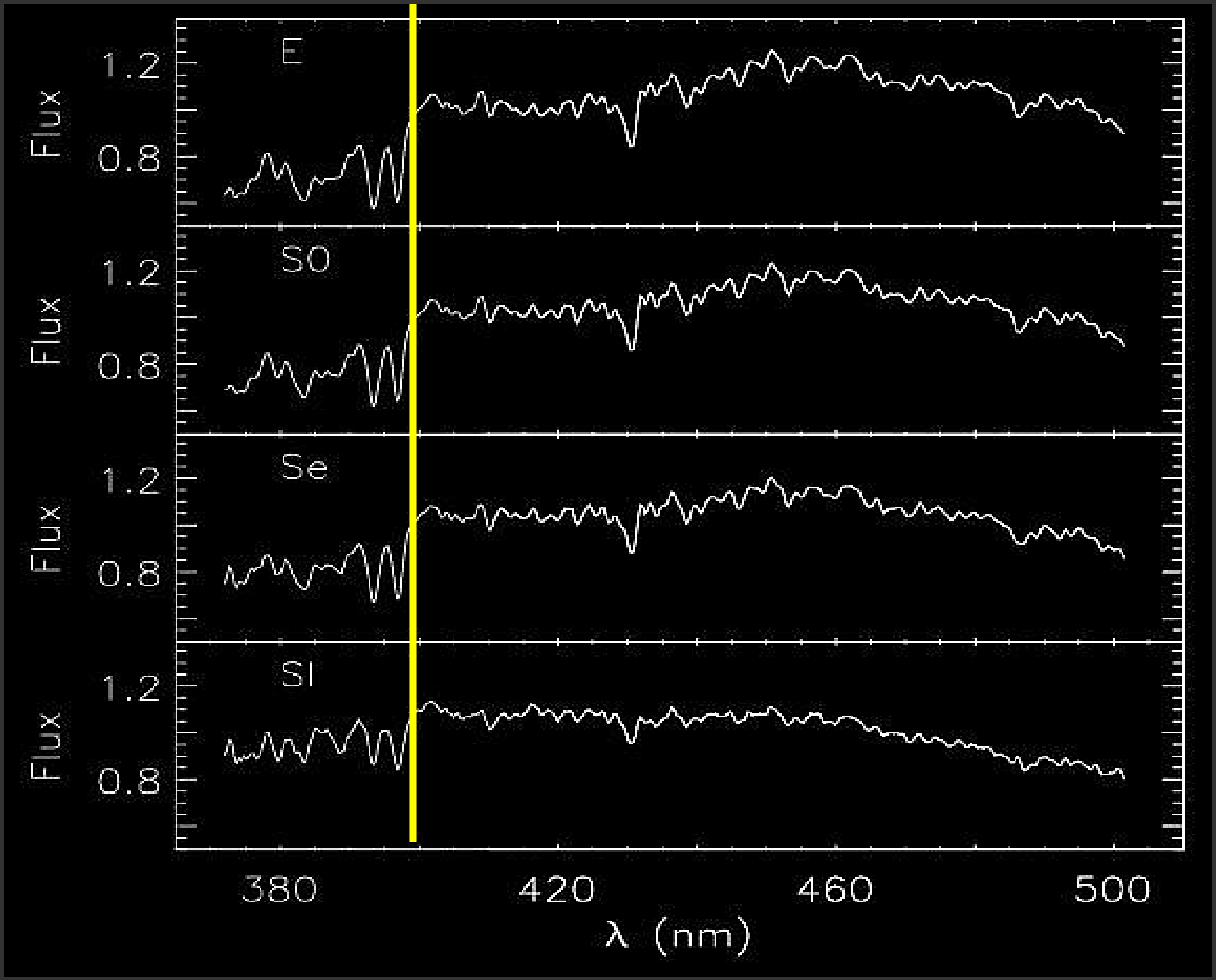
Developed for photometric catalogs



(from Thomas & Katgert 06)

The Cluster Red Sequence method

Developed for photometric catalogs



The Cluster Red Sequence method

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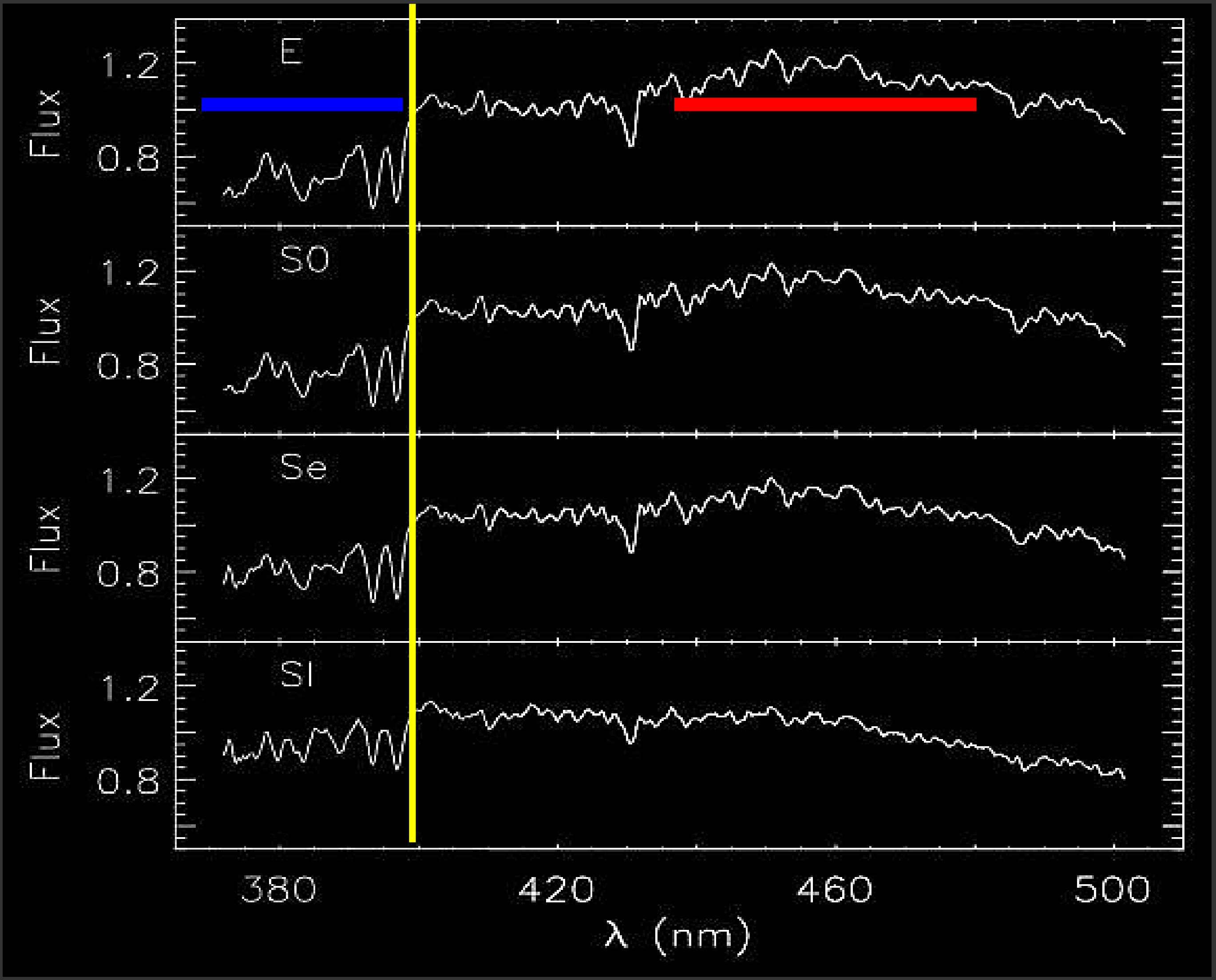
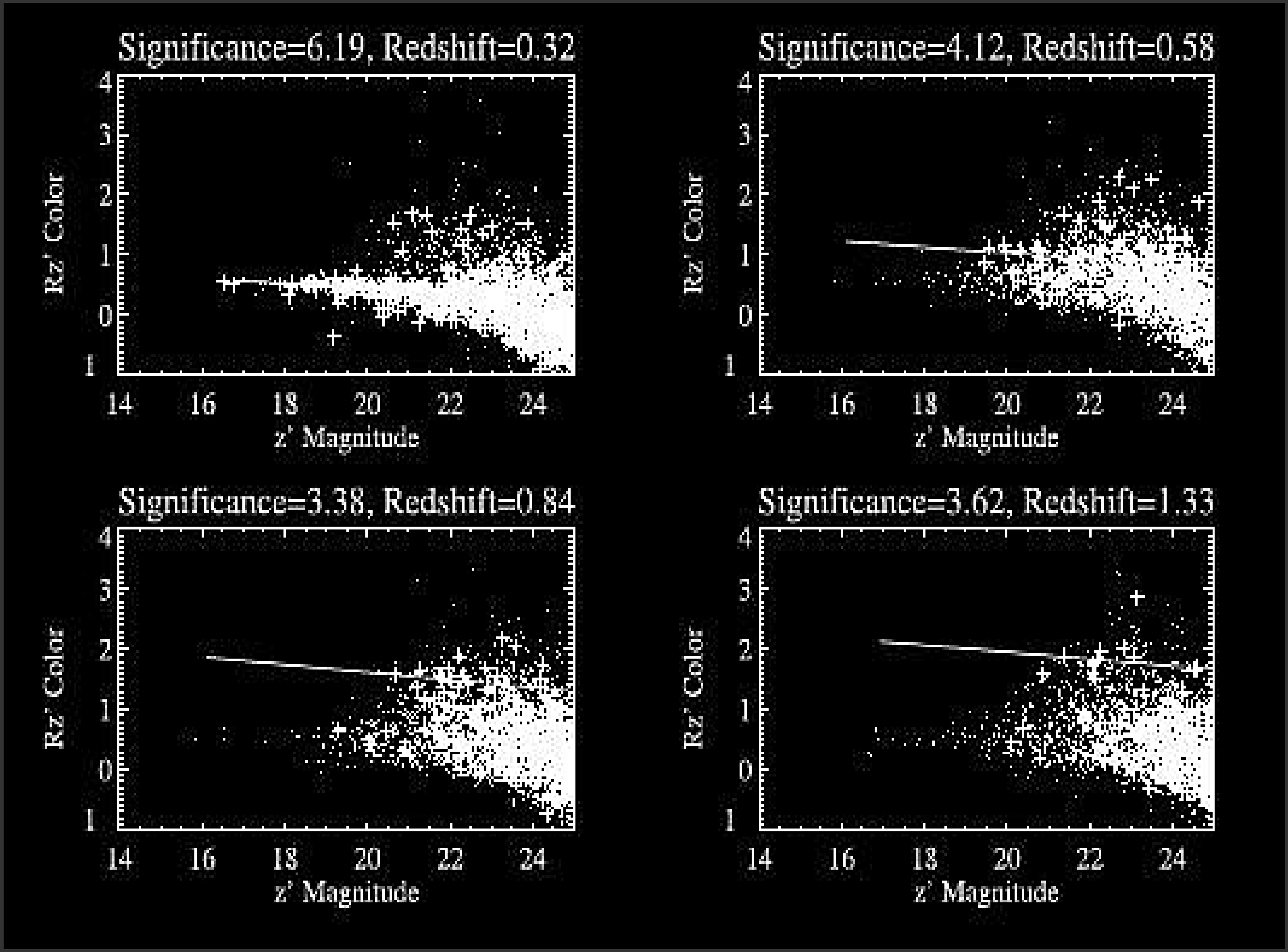


The Cluster Red Sequence method:



The Cluster Red Sequence method:

1) Slice a catalog in color,

2) compute galaxy surface density of the slice,

3) identify significant overdensities.

Tested on spectroscopic samples using only photometry:

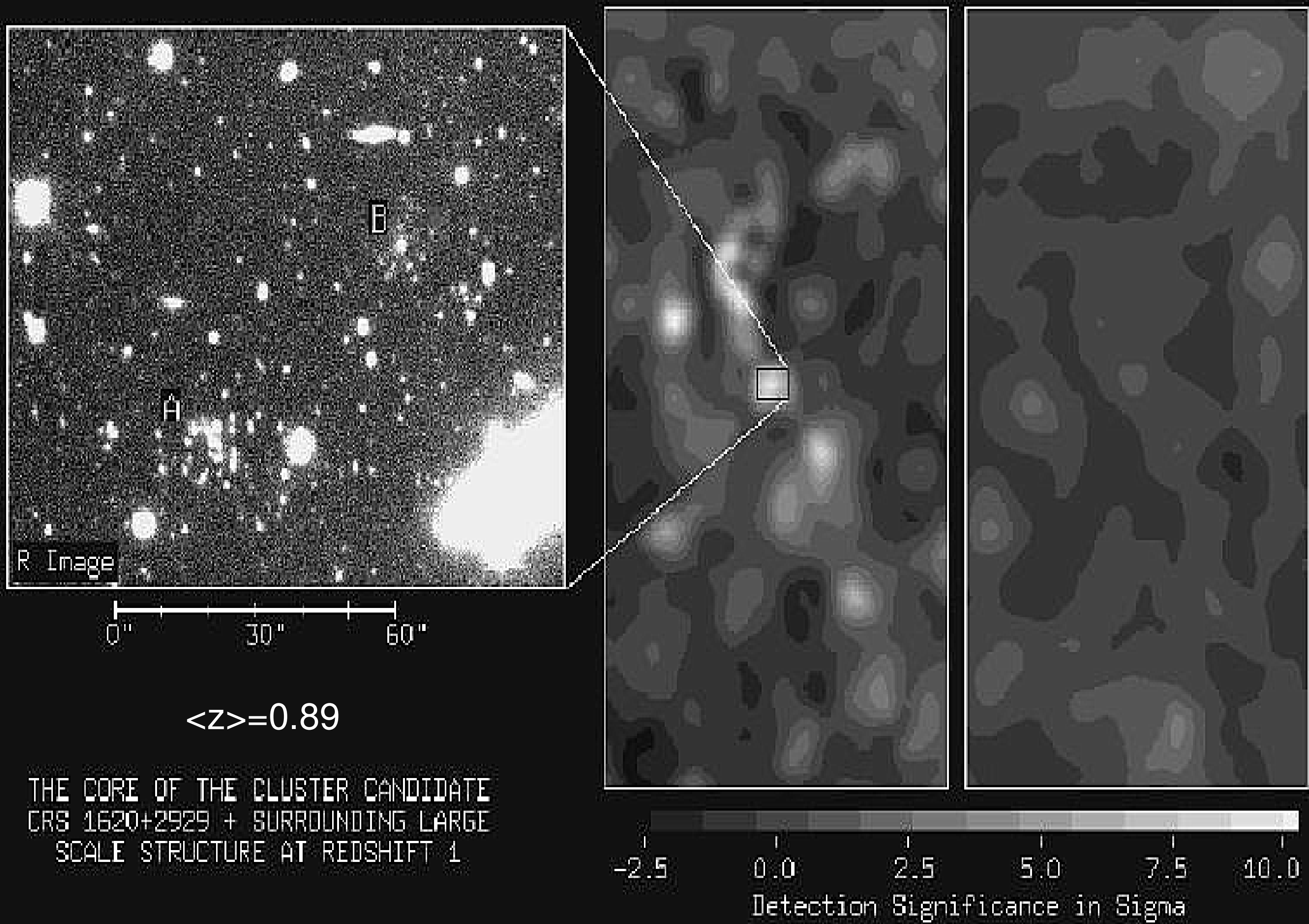
⇨ only 1/23 clusters missed out to z=0.5

<z> estimates accurate to Δz~0.03

Tested on Millennium simulations:

⇨ 80-90 % detected systems unaffected by strong projection effects

The Cluster Red Sequence method:



<z>=0.89

THE CORE OF THE CLUSTER CANDIDATE CRS 1620+2929 + SURROUNDING LARGE SCALE STRUCTURE AT REDSHIFT 1

The Cluster Red Sequence method

CFHT and CTIO large-format camera data

⇨ Red Sequence Cluster survey

~1000 cluster candidates (100 @ z~1)

IR needed to find 1<z<2 clusters with CRS:

Spitzer SWIRE data: 70 candidate clusters

Beyond the red sequence:

maxBCG (Bahcall+03)

Relies also on presence of central BCG

Cut & Enhance (Goto+02)

C4 (Miller+05)

Use all colors in SDSS, not only 2 bands

maxBCG applied to SDSS:

13823 clusters $z<0.3$, $\Delta z \sim 0.01$, $\sigma_V > 400$ km/s

Mocks ⇒ 90% pure, 85% complete, $>10^{14}\ M_\odot$

maxBCG vs. MF:

~80% overlap

imperfect matching due to substructures

and presence of false positives

IR searches for z>1 clusters

(Brodwin+08, Eisenhardt+08, Elston+08, Stanford+05)

7.25 sq deg Spitzer IRAC Shallow survey

z_{phot} slices, overdensity selection

→ 335 candidates, ~10^{14} $M_{\odot}$

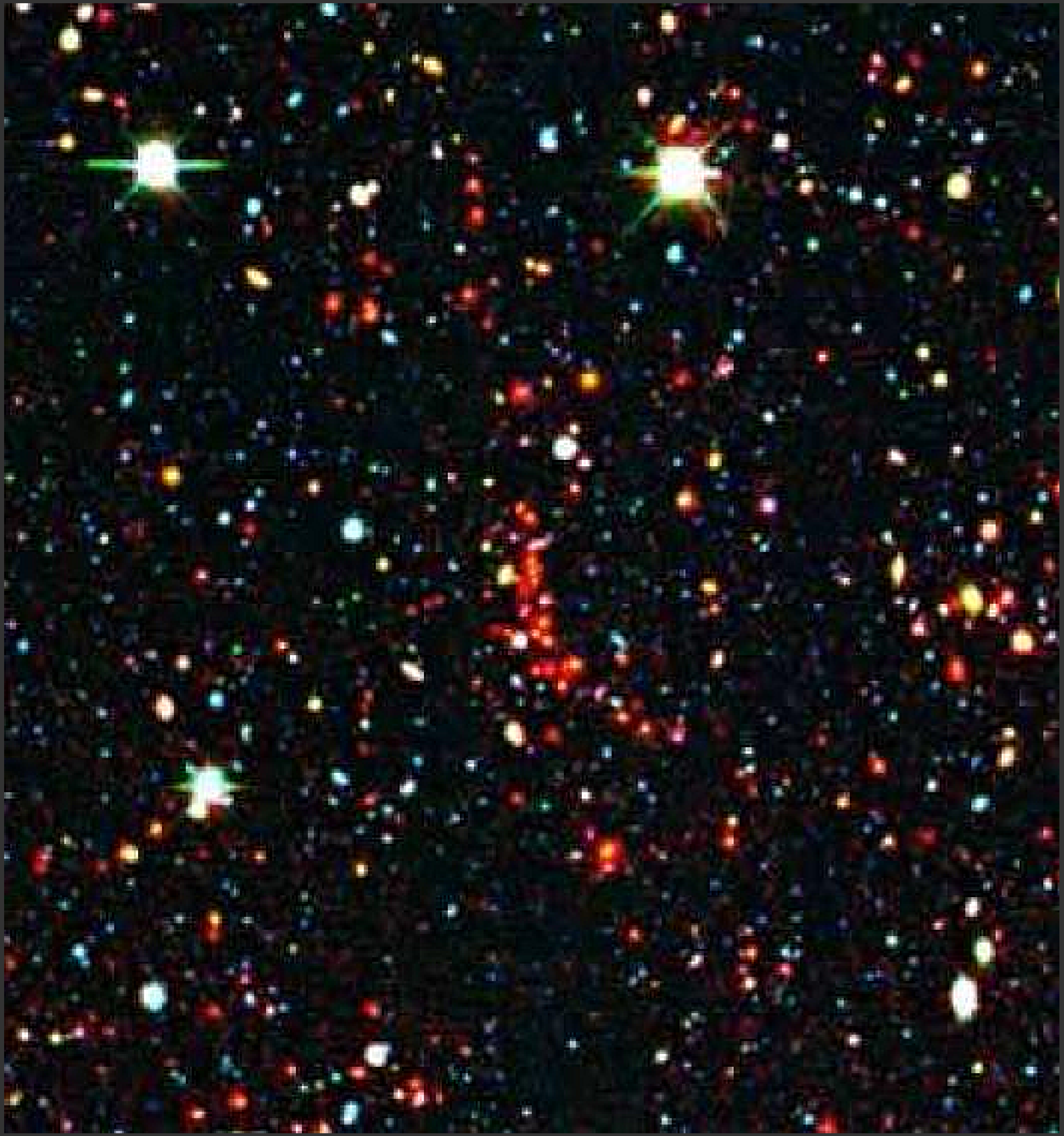
100 z>1 (12 confirmed so far) ~10 at z>1.5

IR searches for z>1 clusters

$z_p = 1.24$

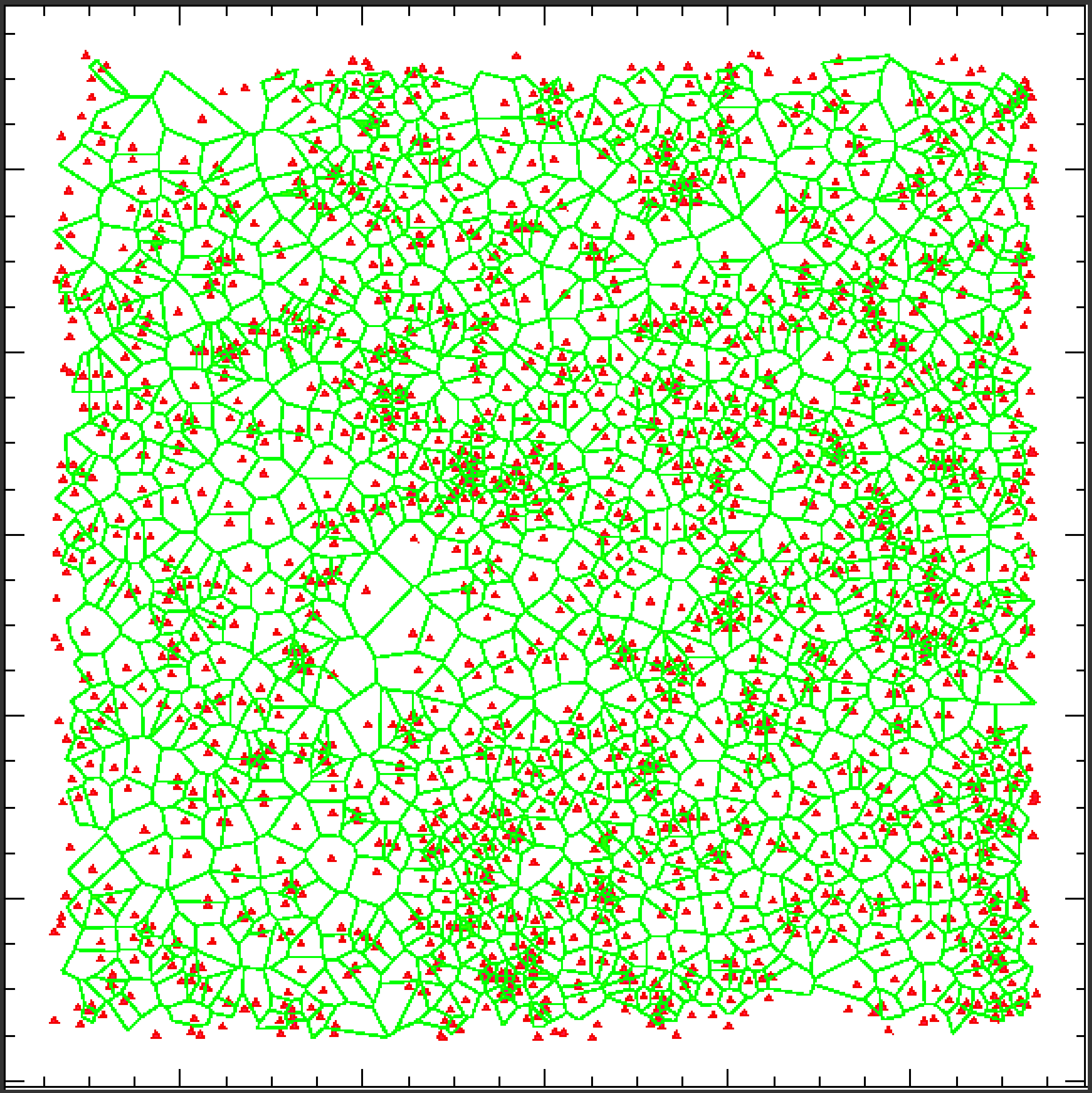
5' x 5'

2.5 x 2.5 Mpc^2



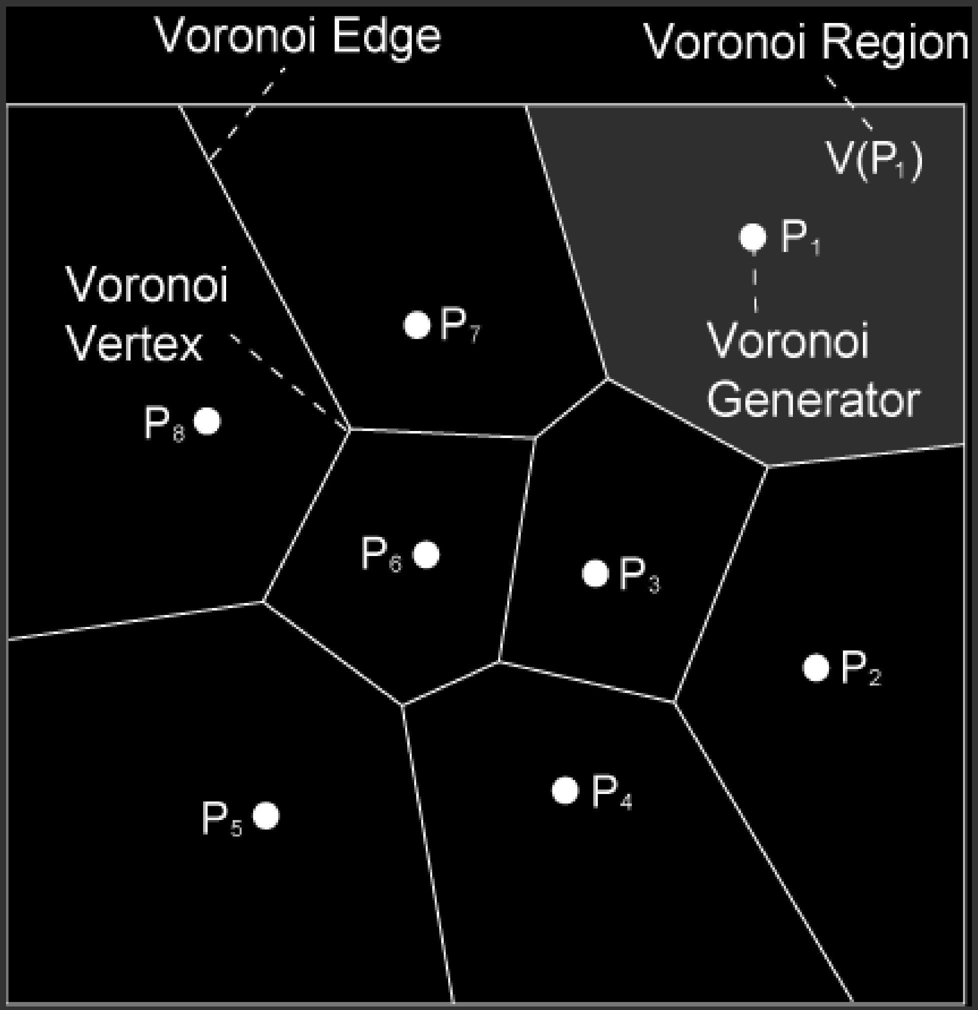
The Voronoi Galaxy Cluster Finder

(Ramella+01)



The Voronoi Galaxy Cluster Finder

Developed for photometric catalogs



Galaxies = Voronoi generators

1/Area(Voronoi Region) = density

Clusters = ensembles of adjacent cells with density > threshold

The Voronoi Galaxy Cluster Finder

Non-parametric

Imposes no constraints on cluster shape

Using z_{phot} slices ➔ z~1 detections

Using spectroscopic catalogs (DEEP2 GRS)

➔ 105 systems z~0.9, σ_V~500 km/s

One step up in the cosmic hierarchy: superclusters

FoF and overdensity techniques
using clusters rather than galaxies

LSS statistical characterization
(e.g. the **genus** statistics:
~ *the number of holes a surface has*)

Global properties:

richness, luminosity, mass

Cluster catalogs + cluster masses

➔ cosmology

Cluster catalogs + cluster masses
➔ cosmology

When direct Mass measurements too expensive,

Cluster catalogs + cluster masses
➔ cosmology

When direct Mass measurements too expensive, use M-proxies:

1) richness (multiplicity), N
2) total luminosity of cluster galaxies, L

N and L:

- count galaxies,
  sum galaxy luminosities;

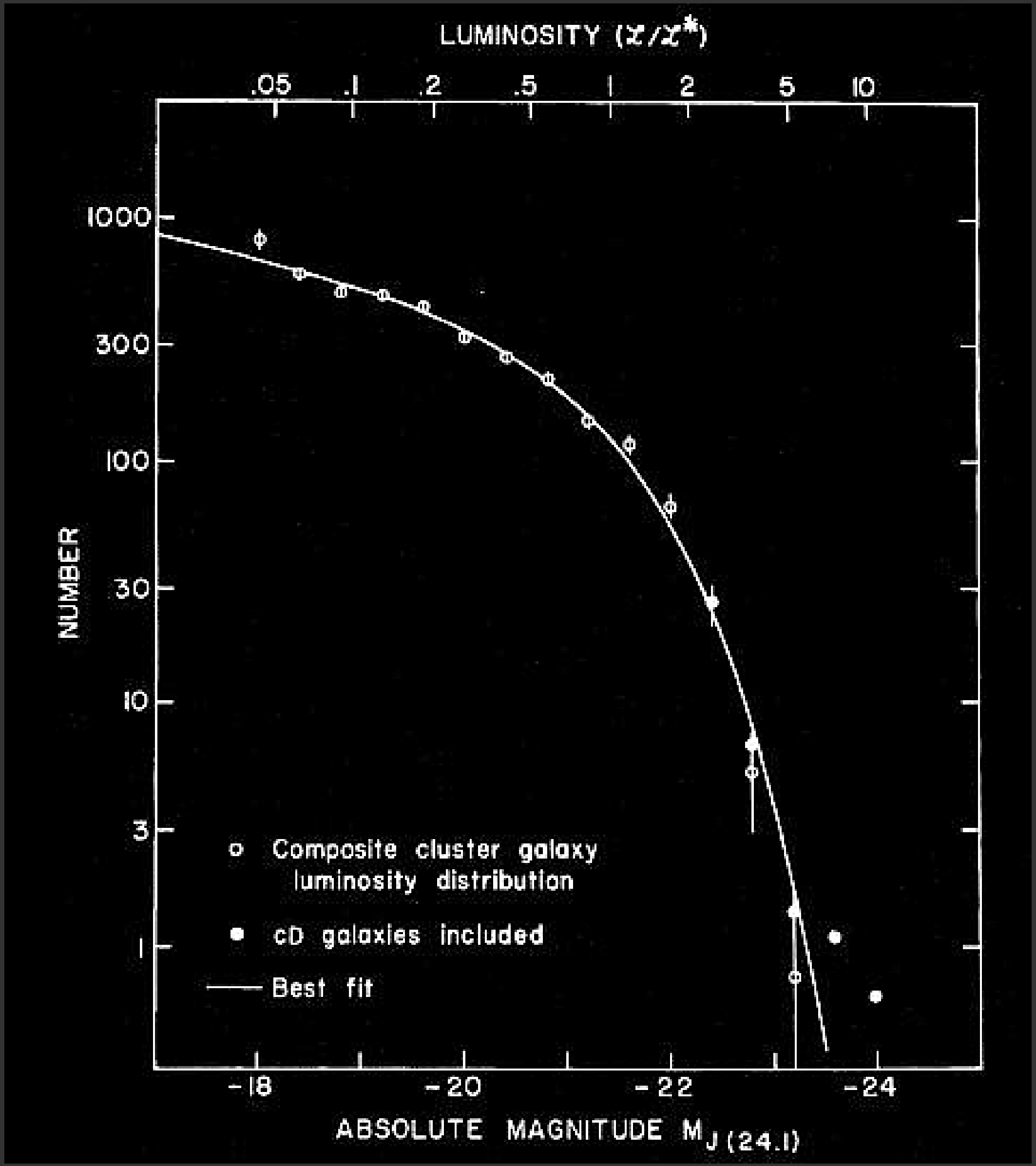
- correct for incompleteness;

- subtract field contribution;

L only:

- fit analytic function;

- extrapolate beyond m_c



Schechter (1976) function:

$$\phi(L)dL = \phi_\star \left(L/L_\star\right)^\alpha \exp(-L/L_\star)\, d(L/L_\star)$$

An alternative richness estimate: B_{gc}

(Yee & López-Cruz 2003)

Amplitude of 3-d spatial correlation function between the cluster center and cluster galaxies,

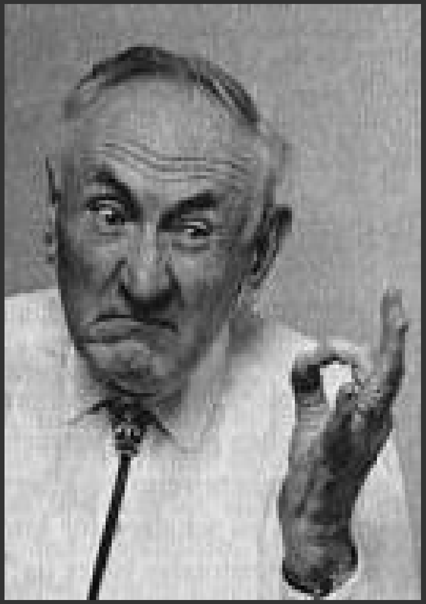
$$\xi(r)=B_{gc}\, r^{-\gamma}$$

Requires background correction and luminosity function (LF)

Robust vs. change of: assumed LF
spatial aperture
limiting magnitude

Direct M estimate from the virial theorem

(Zwicky 33, 37; Smith 36)



$$M = 3\pi \, f_{sp} \, \sigma_p^2 \, R_h / G$$

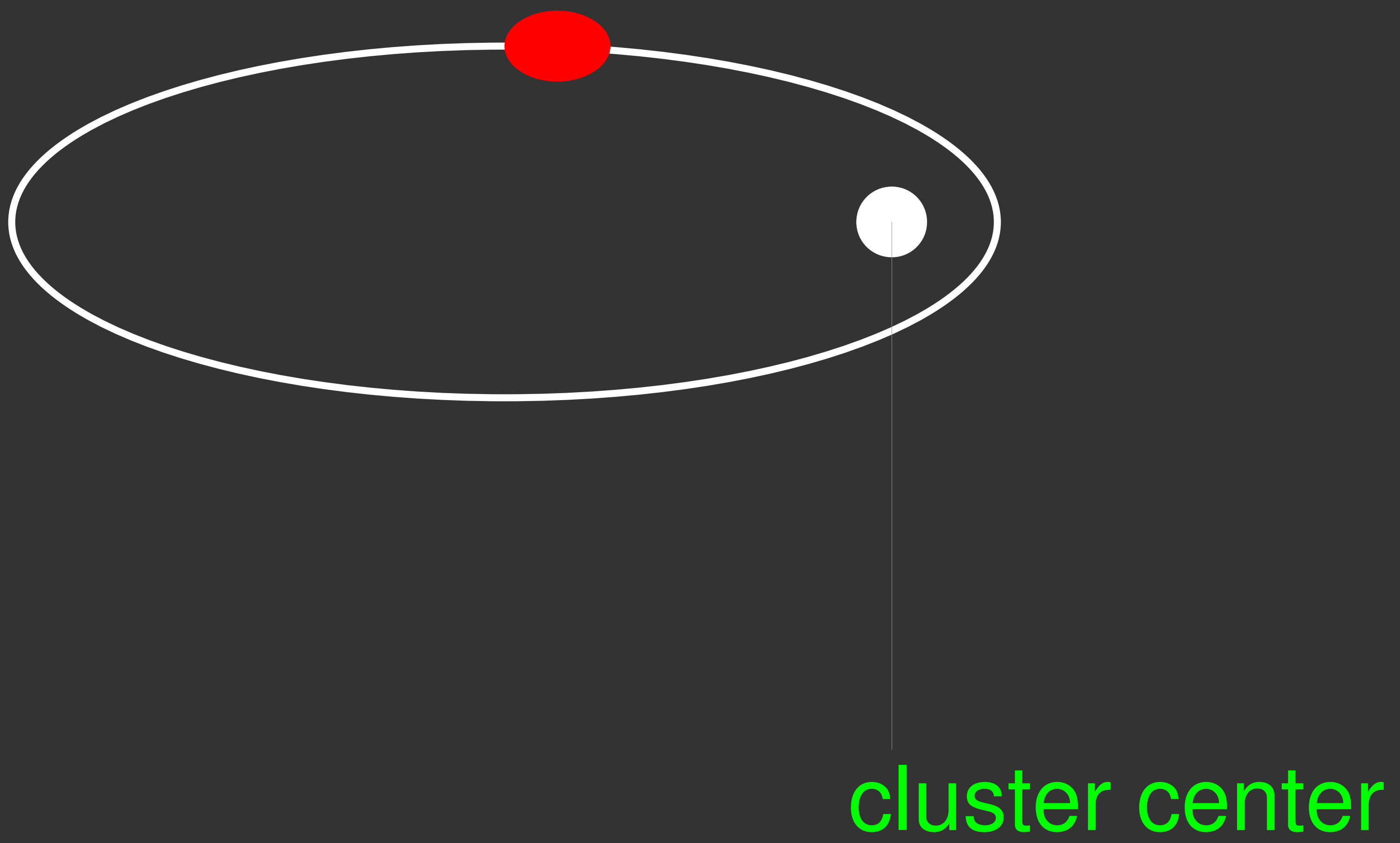
$$R_h = \frac{1}{2} \frac{N(N-1)}{\sum_{i>j} R_{ij}^{-1}}$$

$$f_{sp} = 1 - 4\pi r_l^3 \frac{\rho(r_l)}{\int_0^{r_l} 4\pi x^2 \rho dx} \frac{\sigma_r^2(r_l)}{\sigma^2(< r_l)}$$

$f_{sp} \approx 0.8\text{-}0.9$ at $r_l \approx r_{200}$

Direct M estimate from the virial theorem:

The surface pressure term



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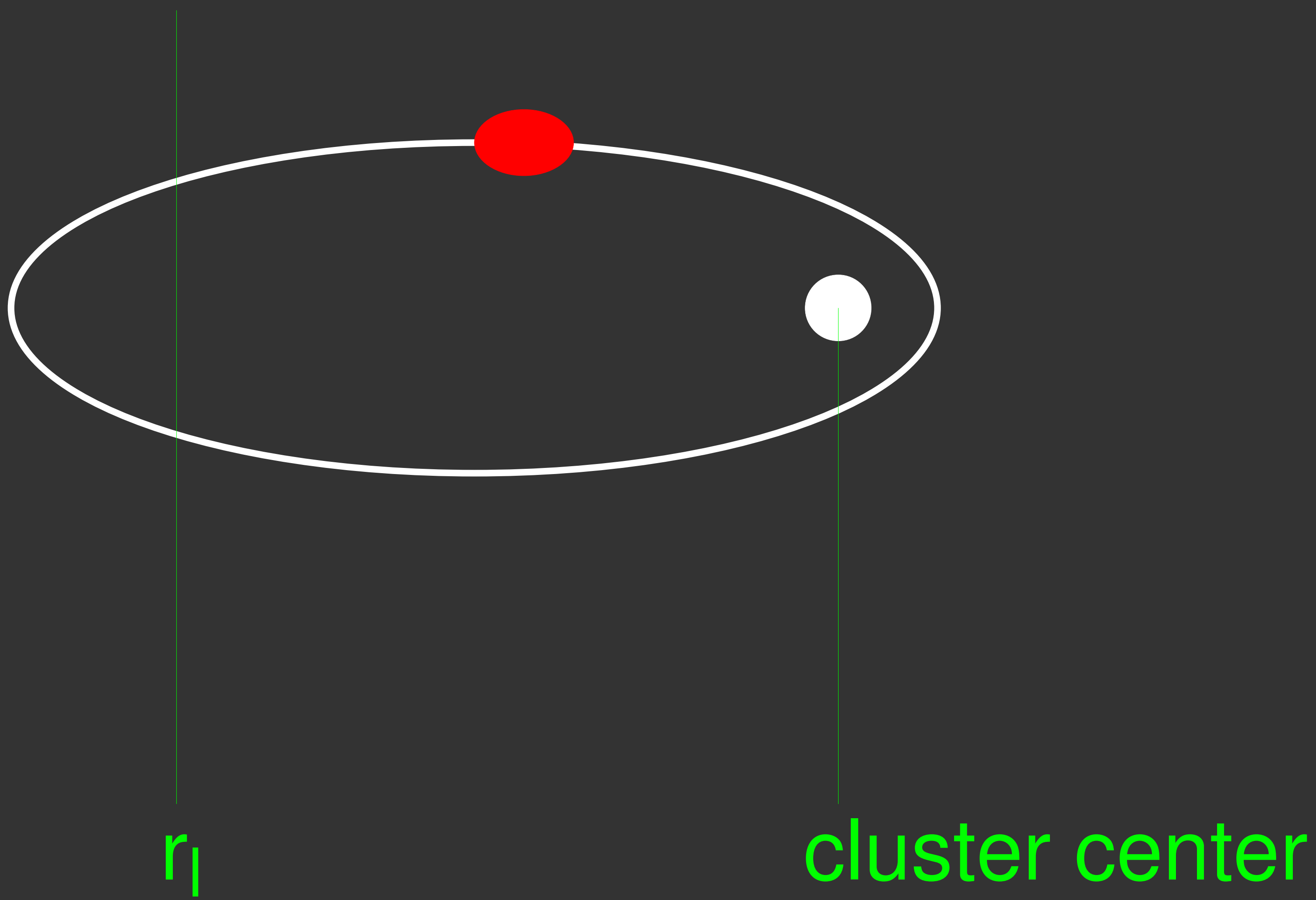

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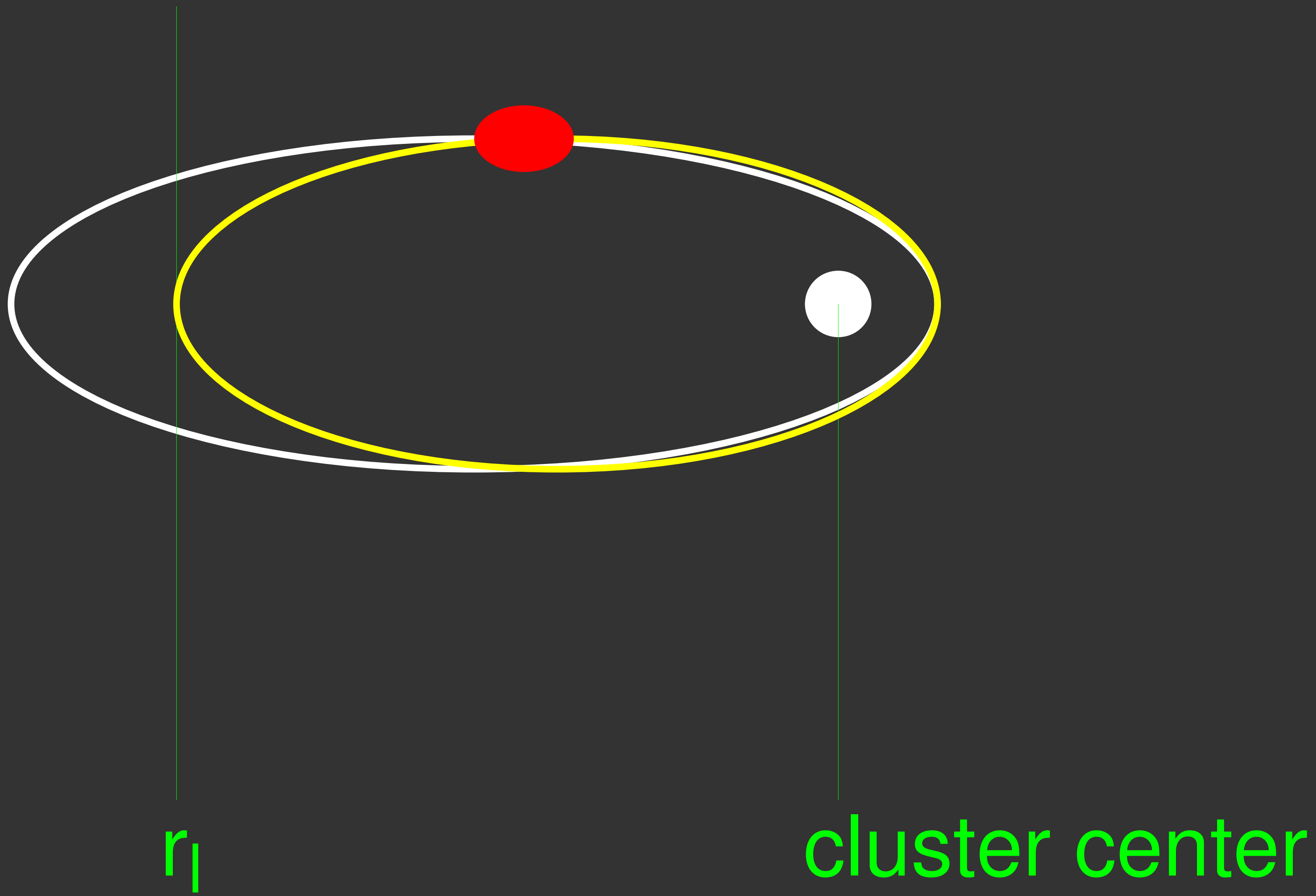

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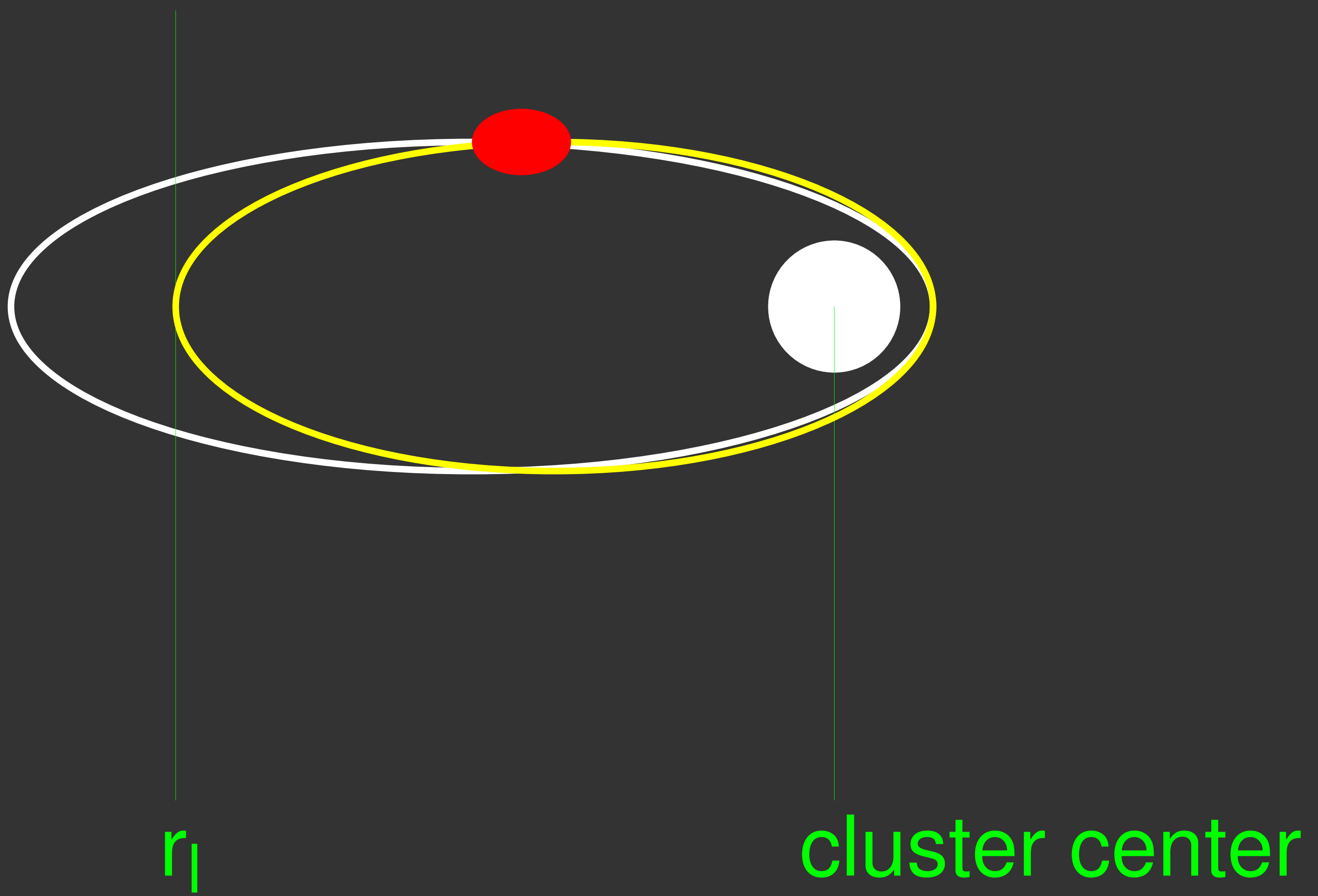
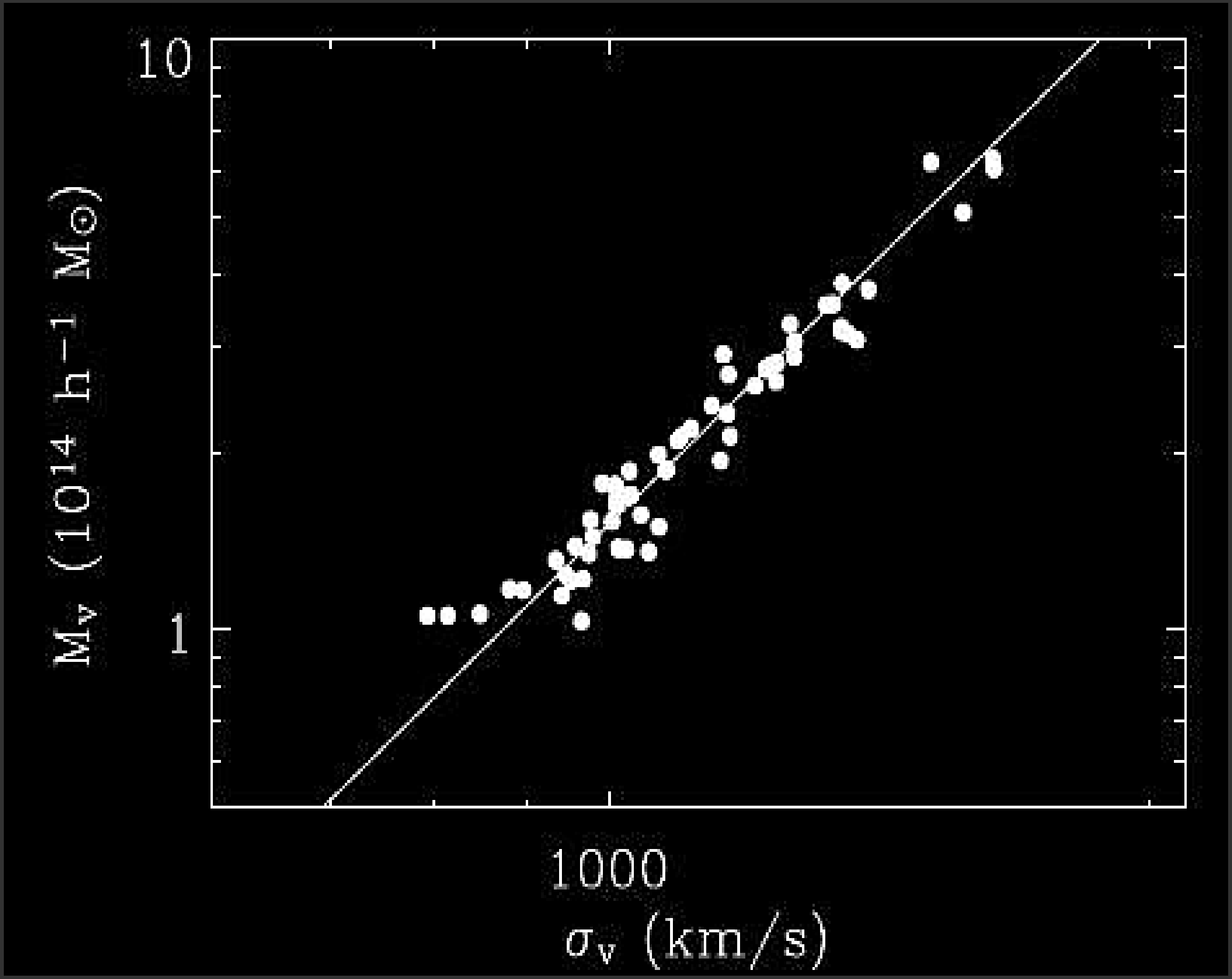


Direct M estimate from the virial theorem:

The surface pressure term

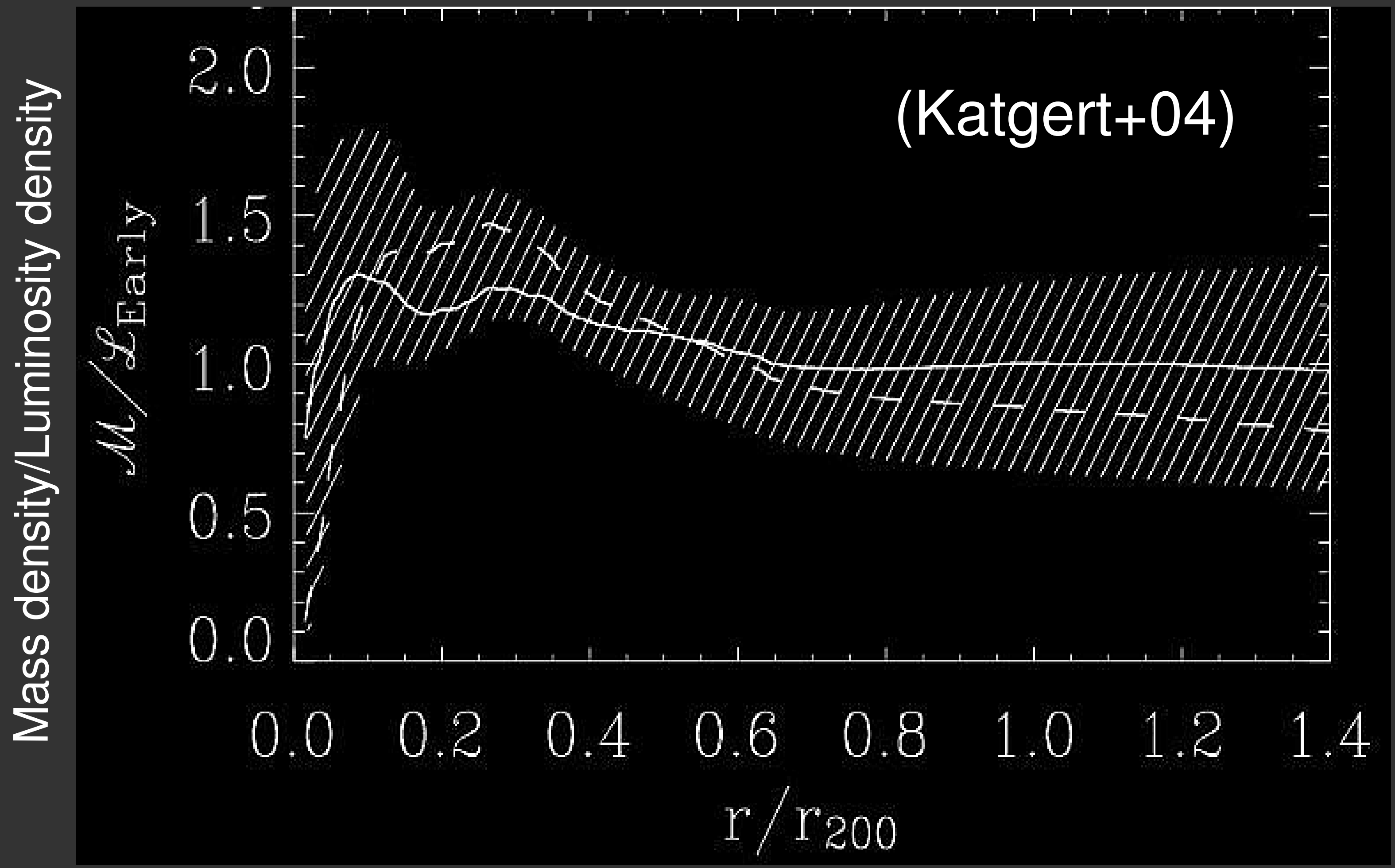
Direct M estimate from velocity dispersion

(from numerical SPH simulations; Biviano+06)



Direct M estimate:

are the tracers distributed like the mass?

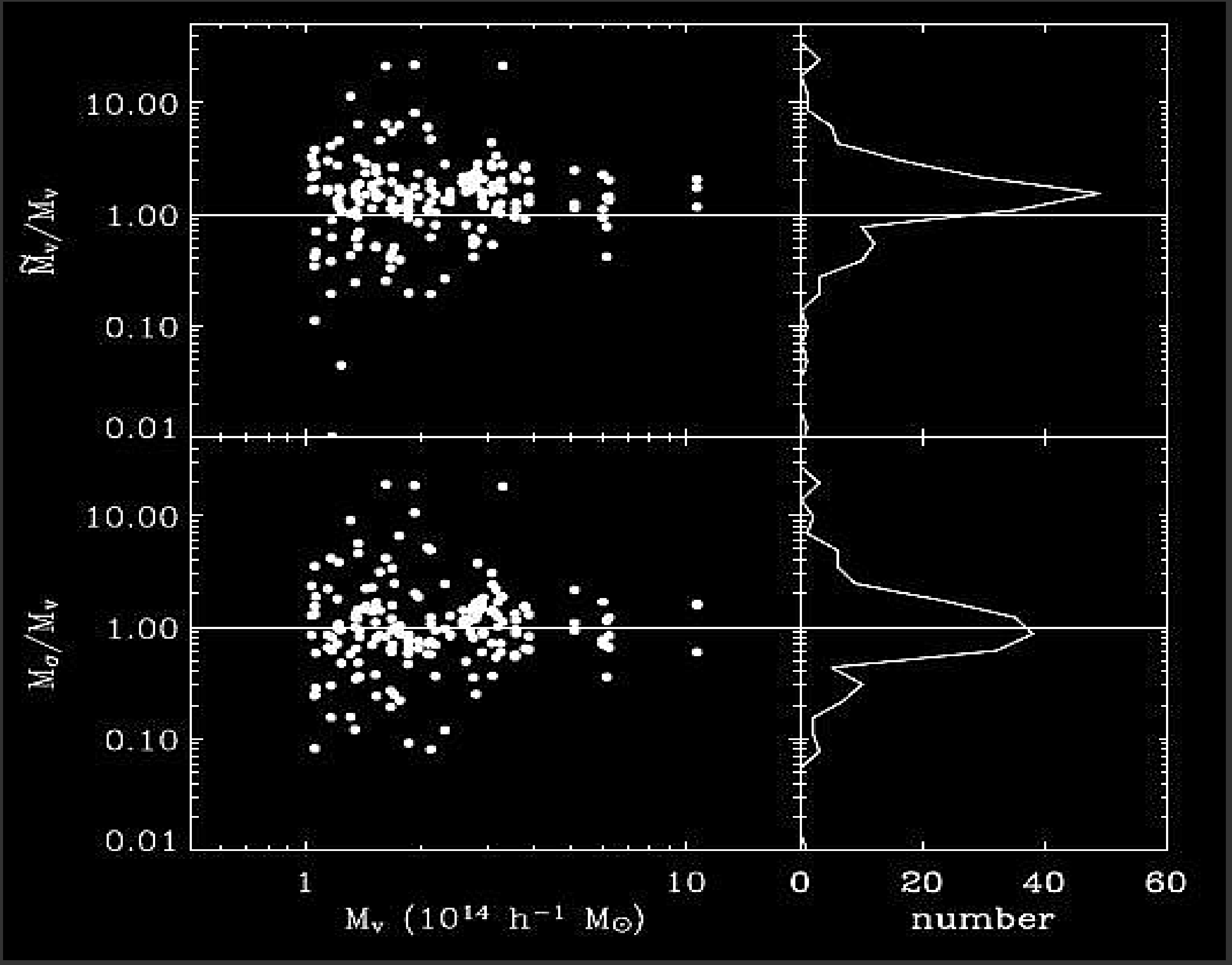


Yes, if tracers = ETG;   using LTG ⇨ M overestimate

Direct M estimate:

reliability (from numerical SPH simulations; Biviano+06)

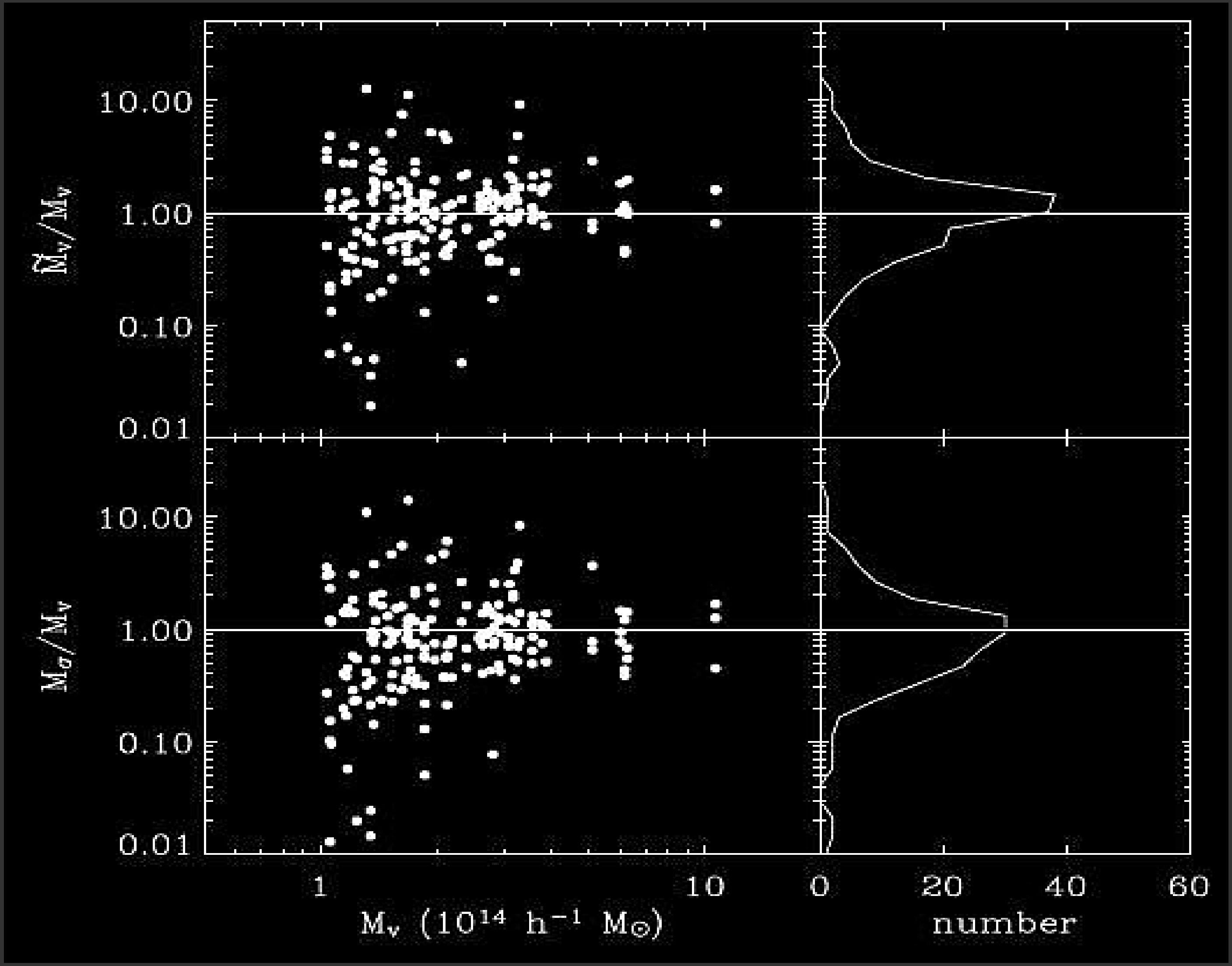
All galaxies



Direct M estimate:

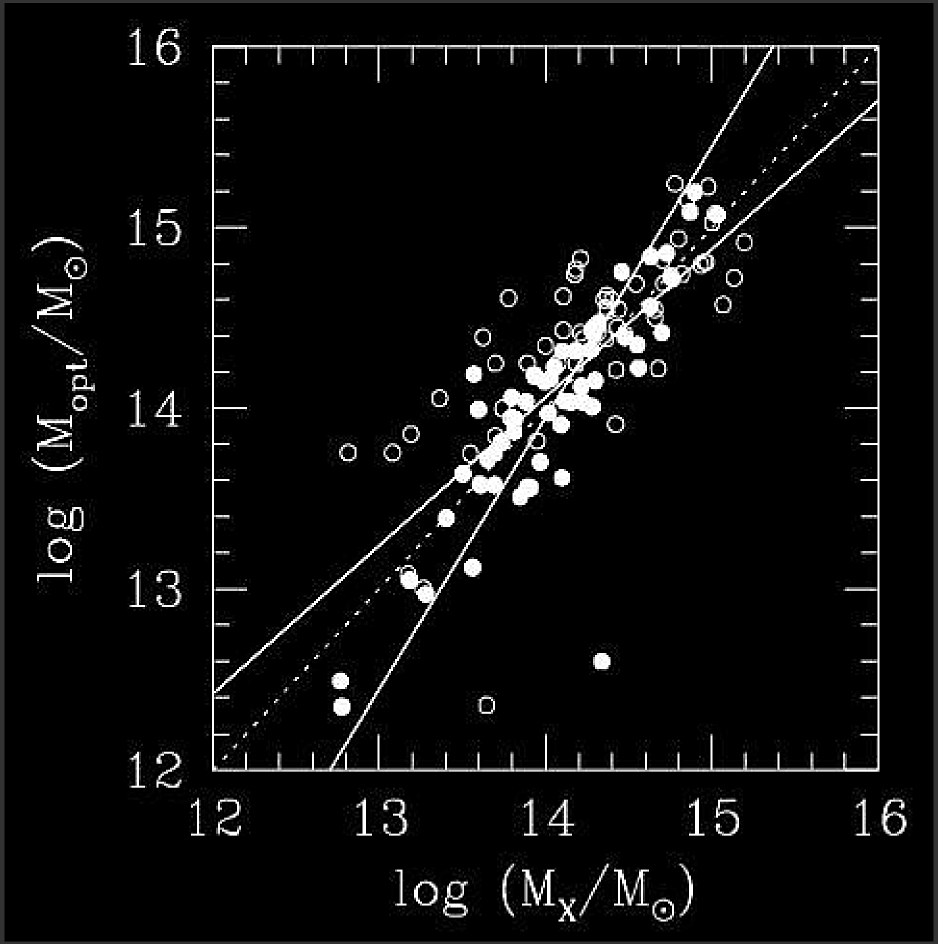
reliability (from numerical SPH simulations; Biviano+06)

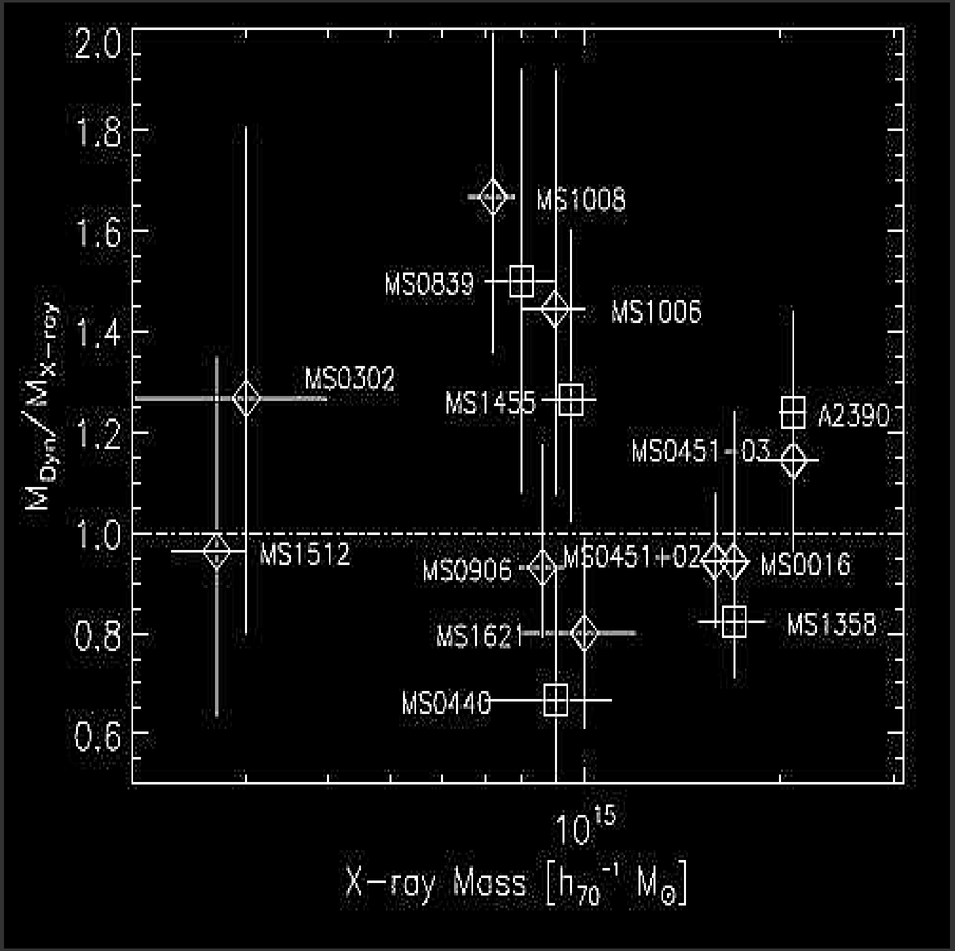
ETG only



Direct M estimate:

comparison with X-ray estimates





Nearby clusters (Girardi+98)

Medium-z clusters (Hicks+06)

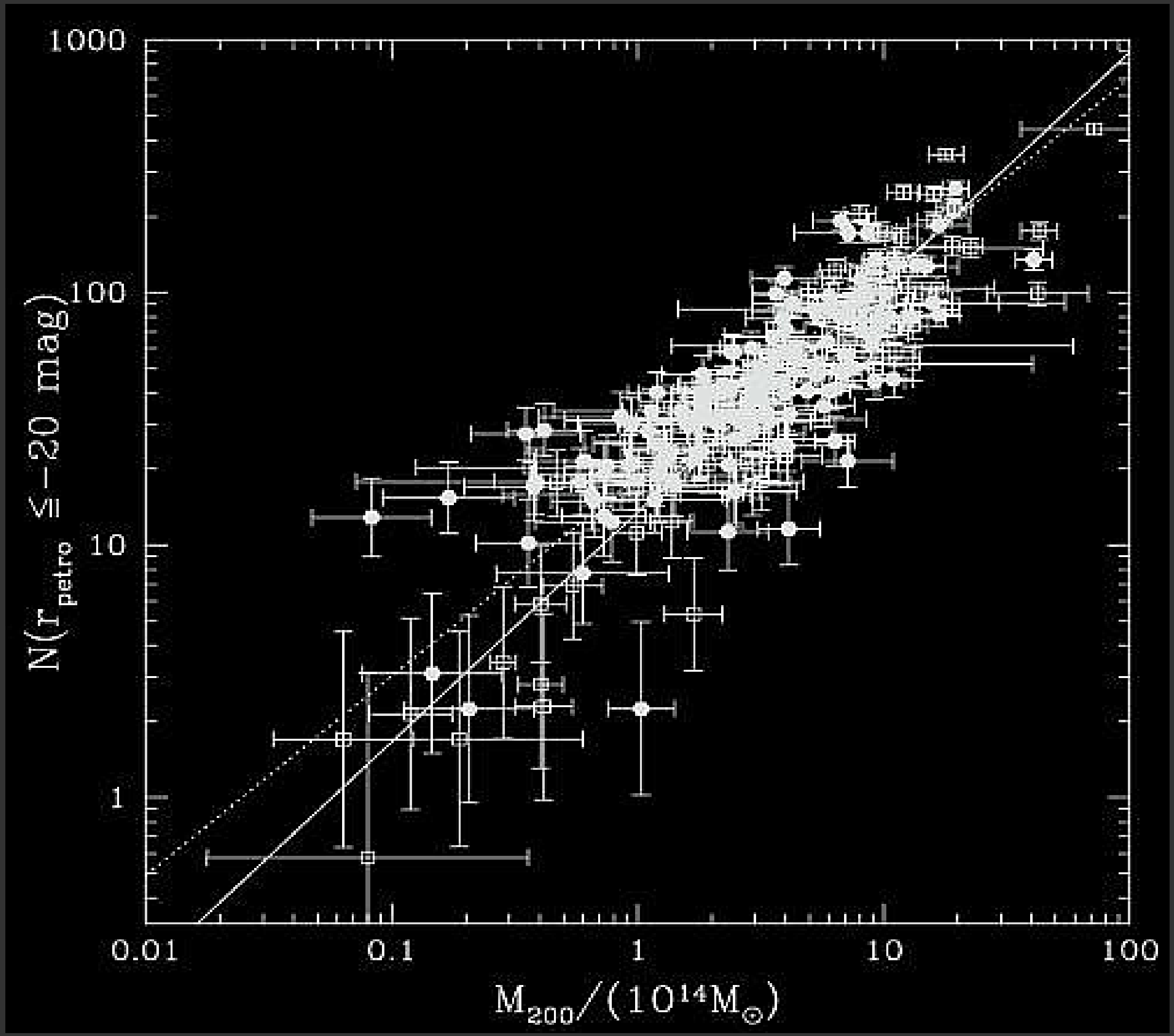
Scaling relations:

richness & luminosity vs. mass

N, L ⇨ M
with 30-40 %
accuracy
≈ Lx ⇨ M
accuracy

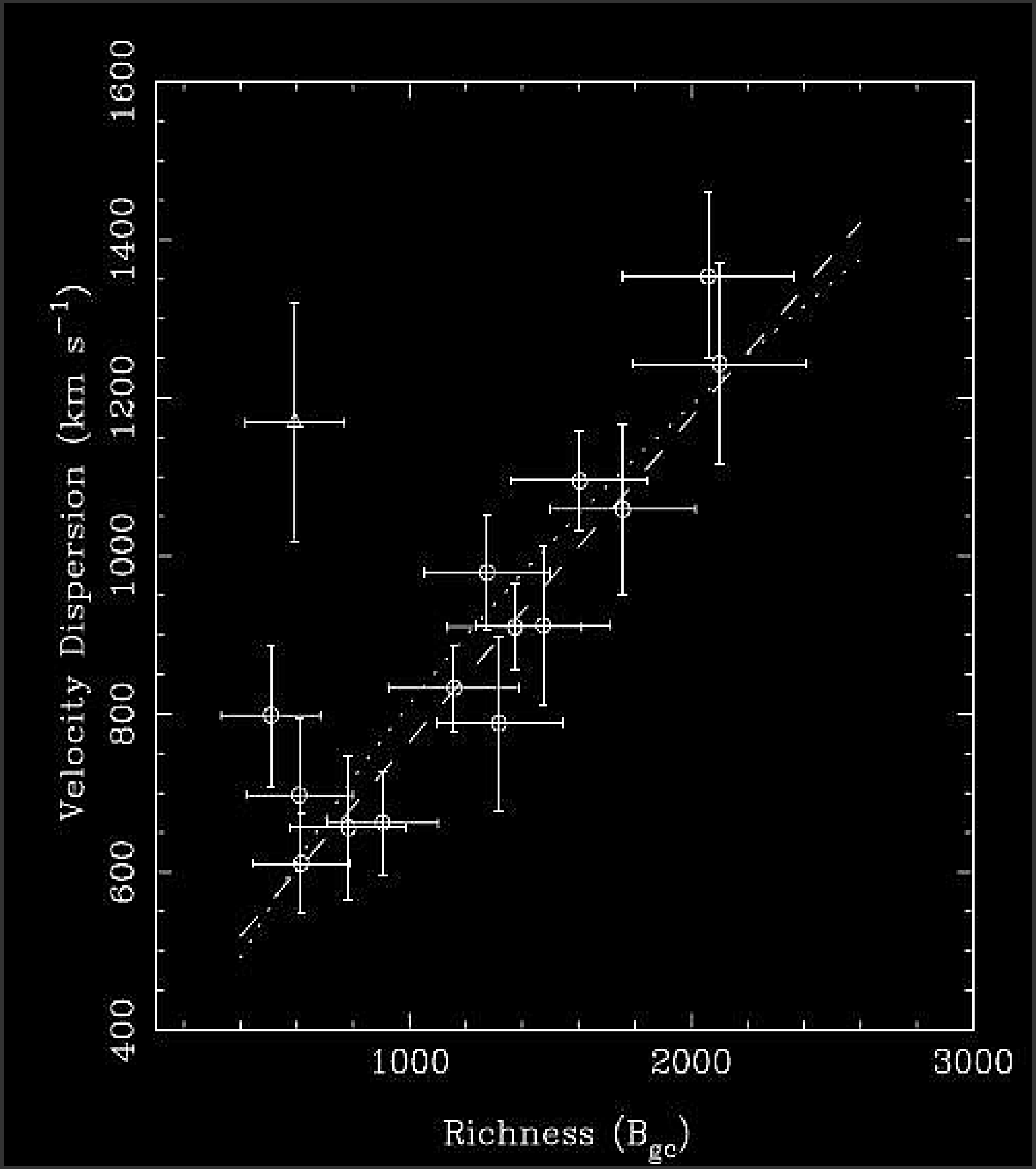
M ↑ scatter ↓

Scatter ↓
in more regular clusters



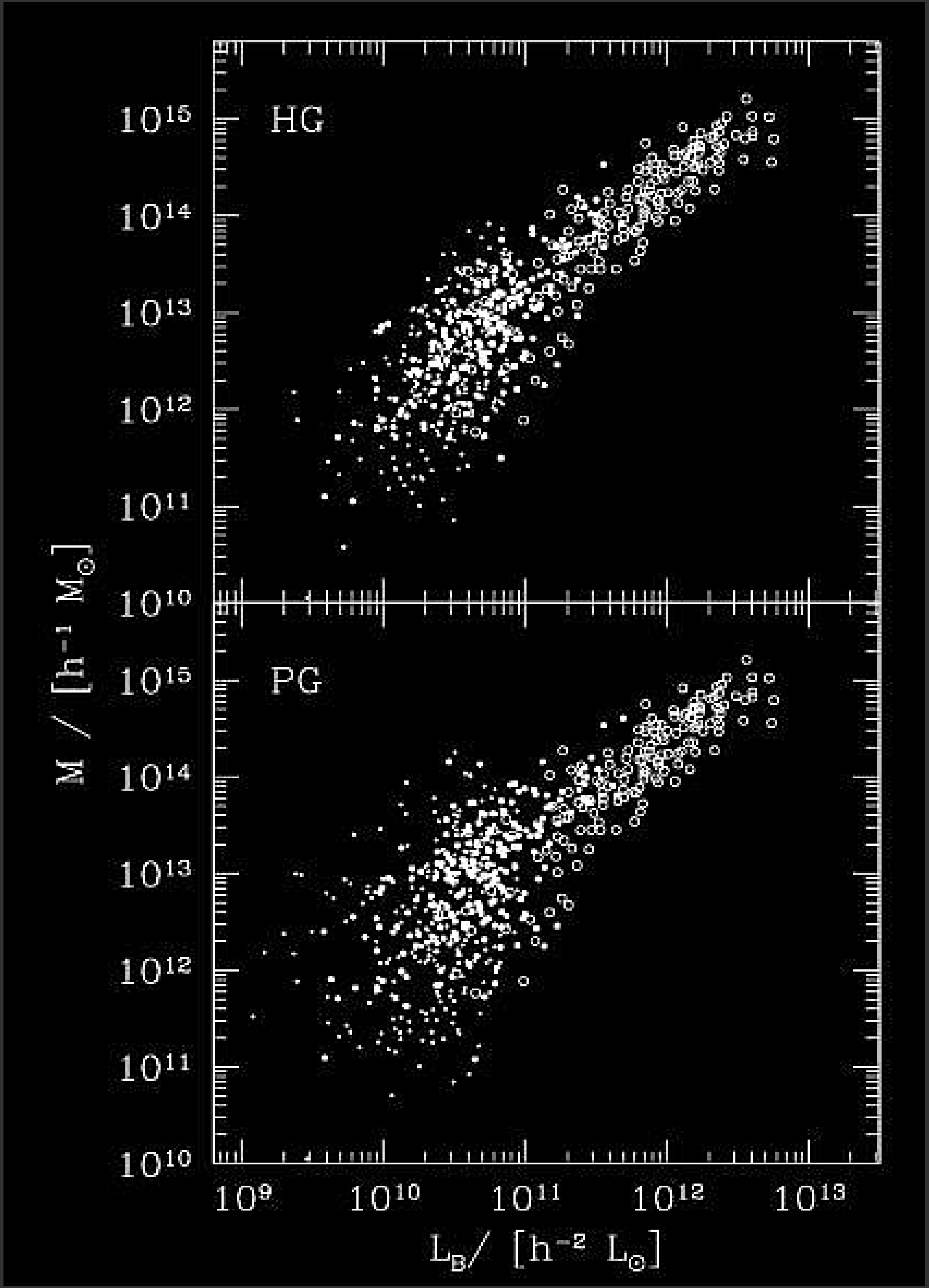
(Popesso+07)

Linear relation on cluster scales



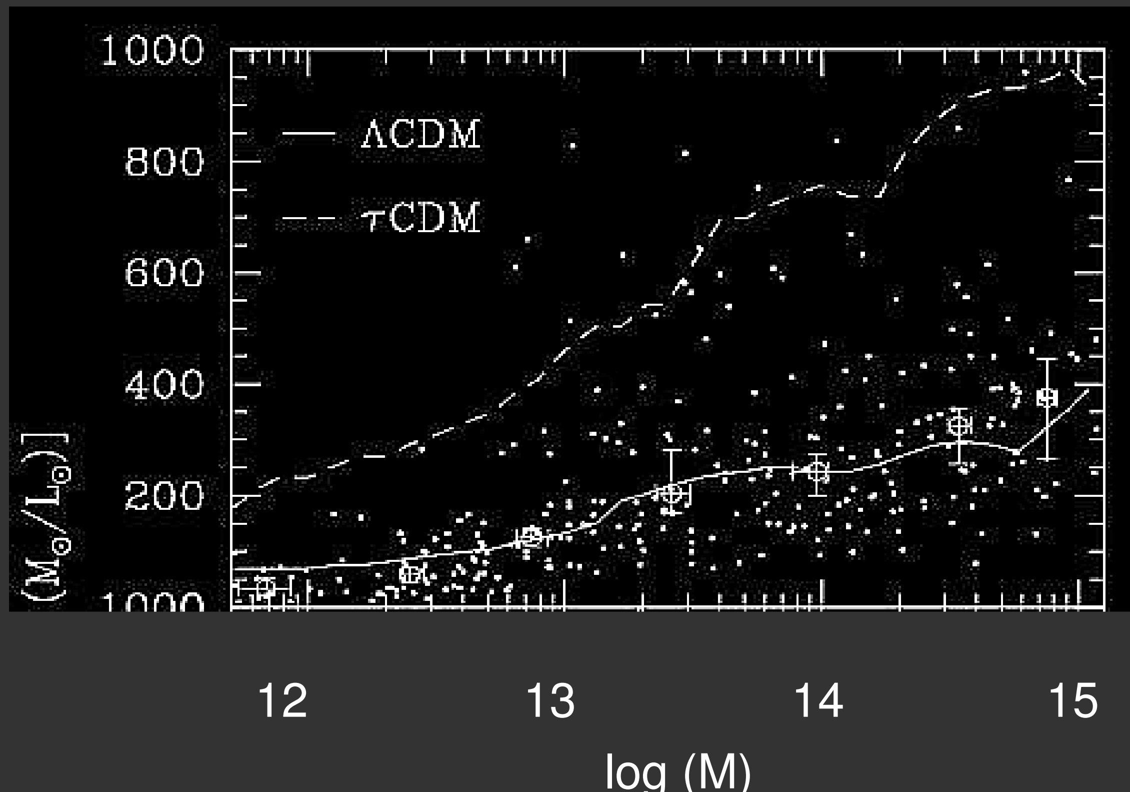
(Yee & Ellingson 03)

Linear relation
on cluster scales
...not on group scales



(Girardi+02)

M/L vs. M and theoretical predictions



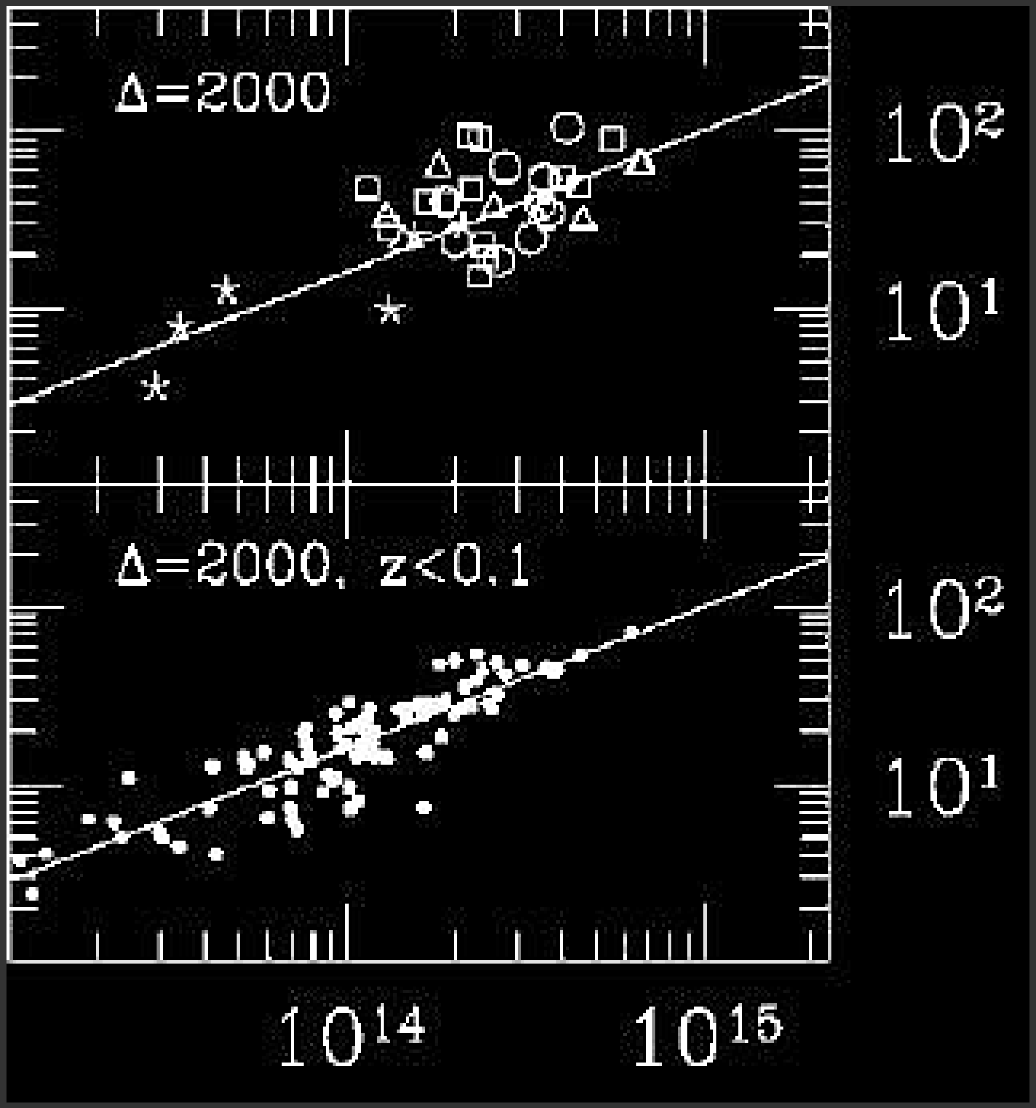
(Girardi+02)

Agreement with SAM:

SF efficiency regulated by cool gas reheating (small scales) and (long) cooling time of hot gas (large scales)

N vs. M does not evolve out to z=0.9

N

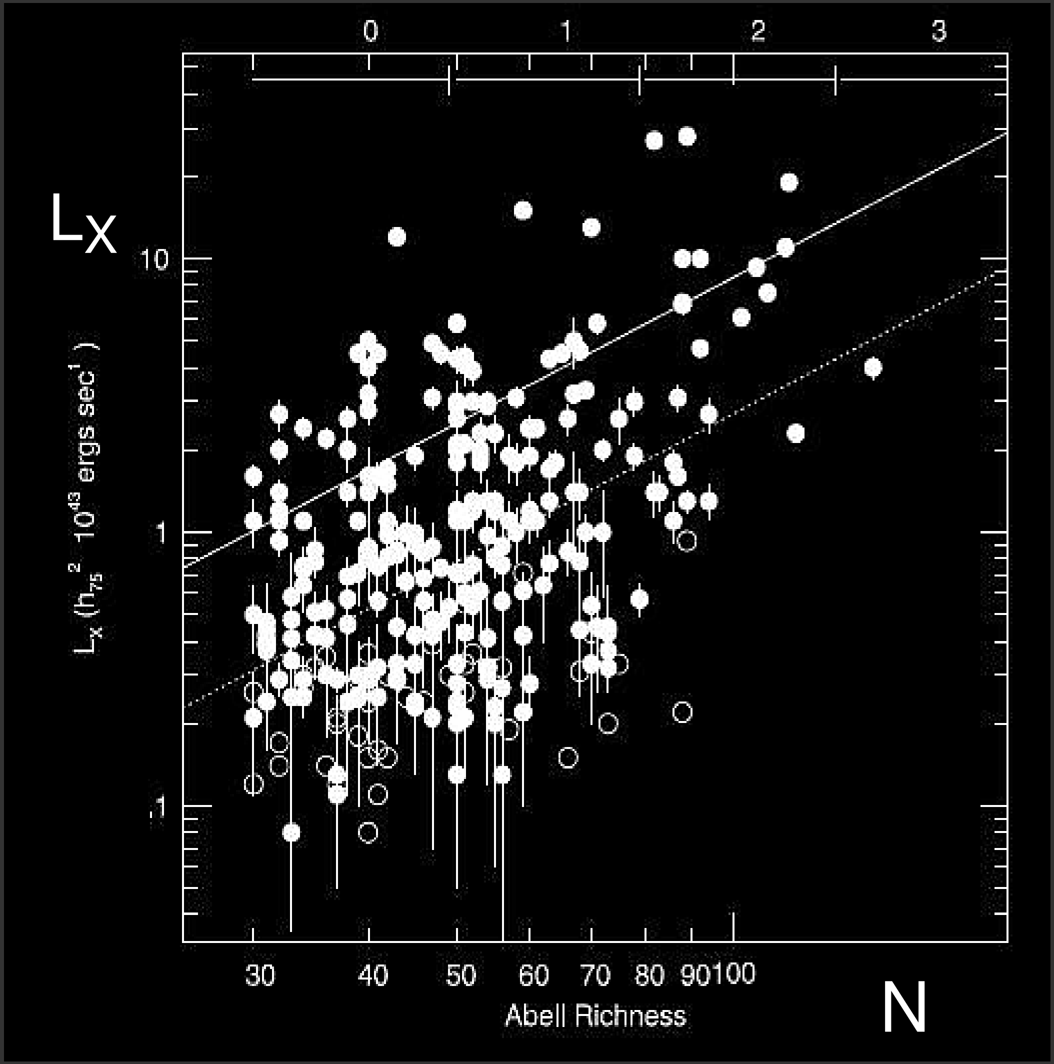


(Lin+06)

M

Biases in cluster selection?

Compare different M proxies



L_X

N

(Ledlow+03)

Low-L_X clusters

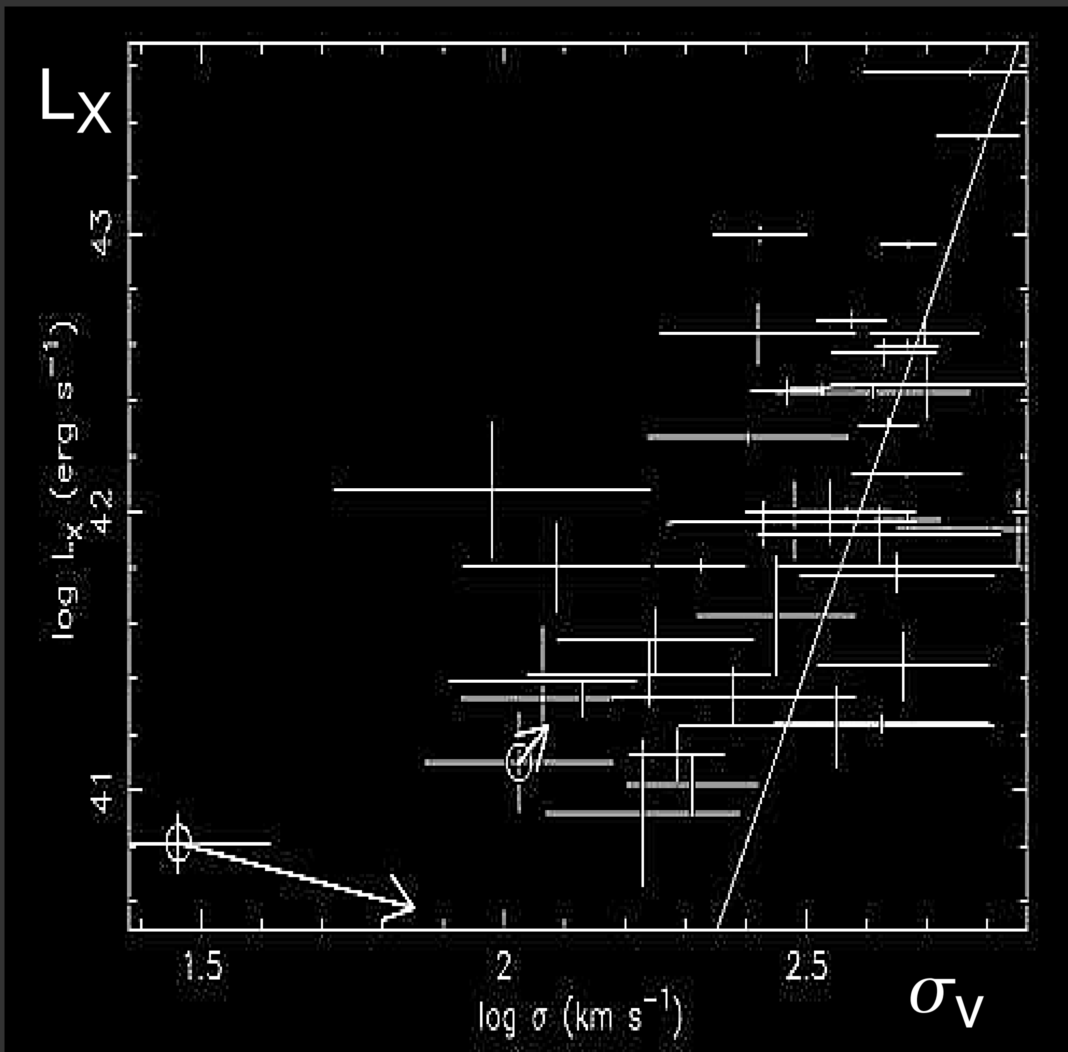
at given N:

systems in formation

or projection effects?

Biases in cluster selection?

Compare different M proxies



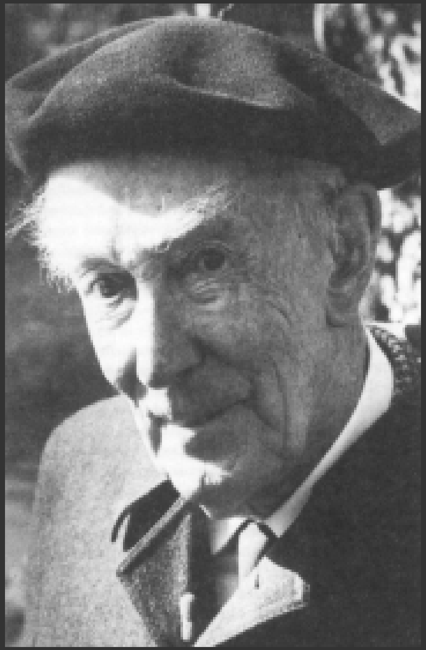
(Ledlow+03)

Low-σ_V groups at given L_X:

dynamically evolved (dynamical friction) or projection effects?

Cosmological constraints

The Oort technique: $\Omega_m = \langle M/L \rangle \, \rho_L / \rho_c$



Cluster $\langle M/L \rangle \sim$ Universal value

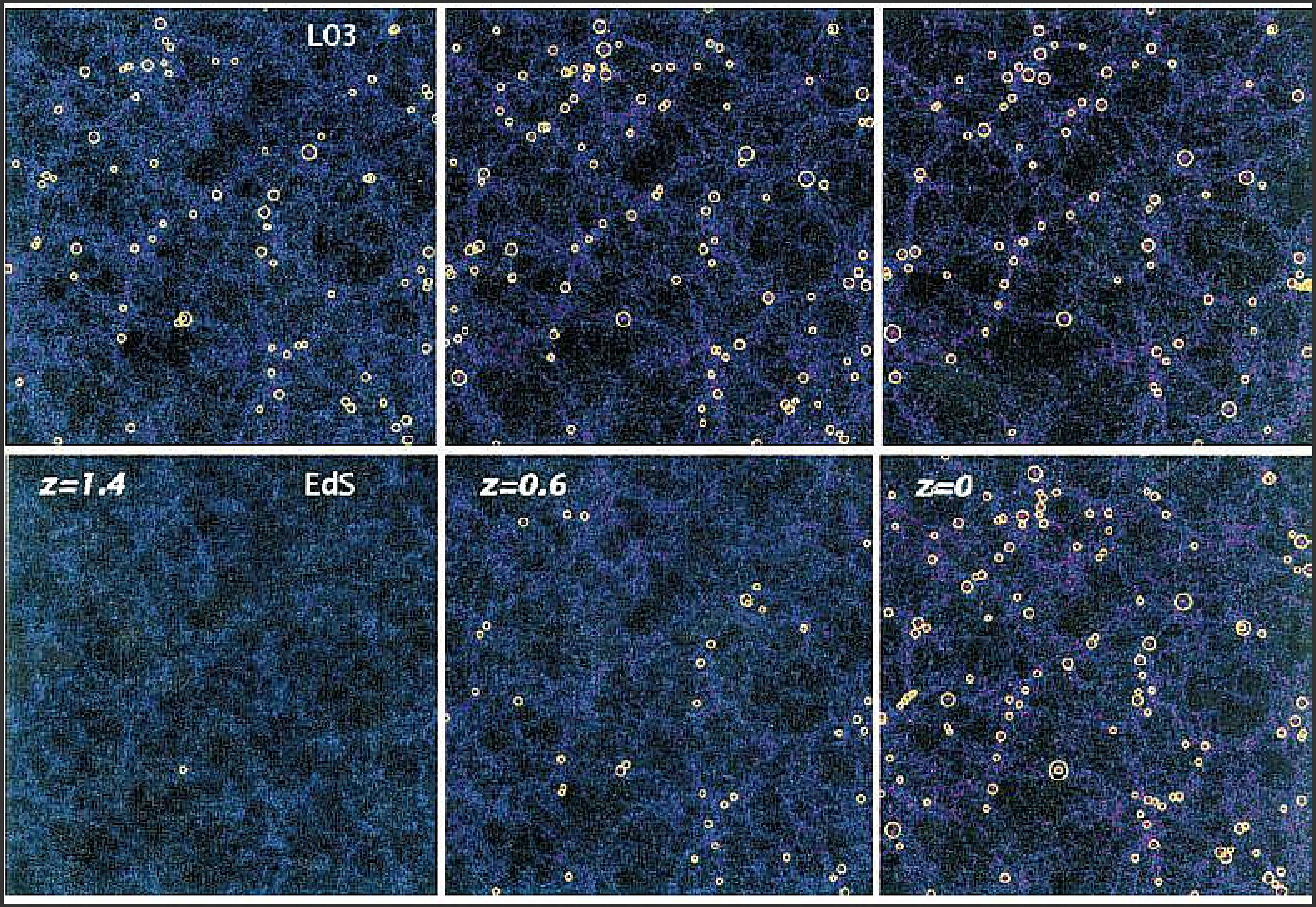
(assembled from regions >10 Mpc)

Abell 65: 1st result, $0.1 < \Omega_m < 1.0$

The cluster mass function, n(M,z)

Constrains Ω_m and σ_8

(Borgani & Guzzo 01)



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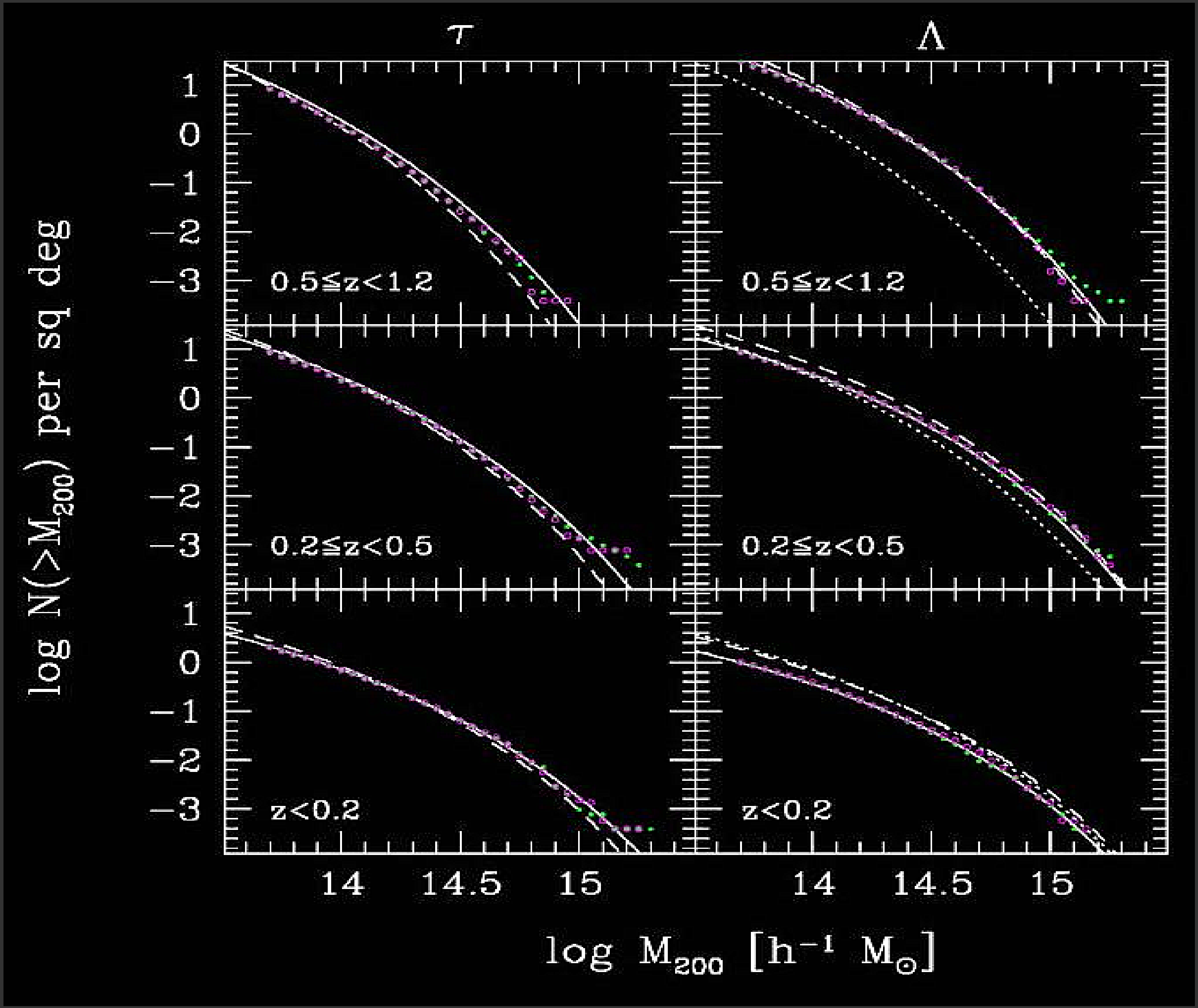
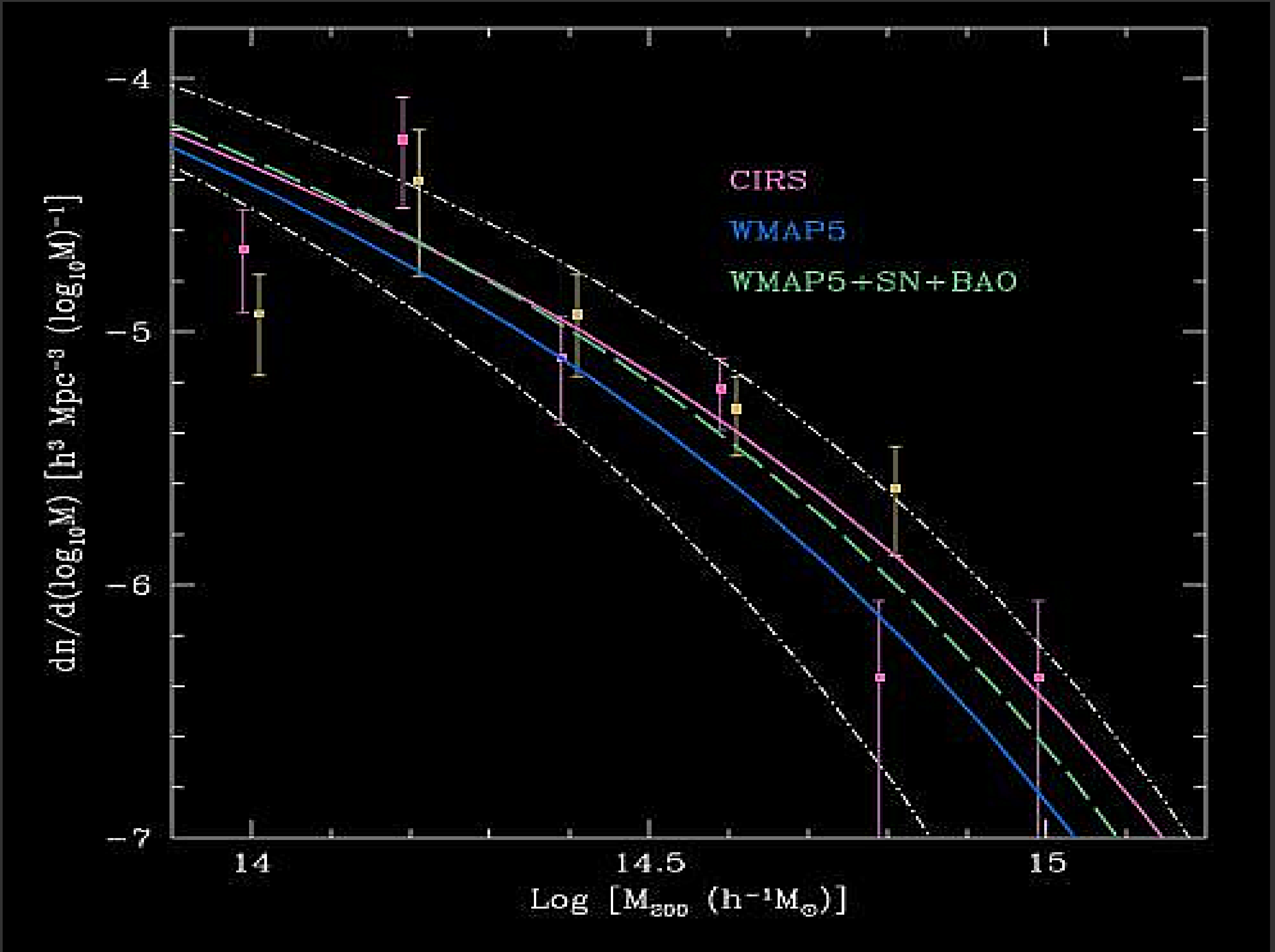


(Evrard+02)

E.g.: The CIRS virial mass function (Rines+08)

72 nearby clusters with accurate M determination



Too many massive superclusters?

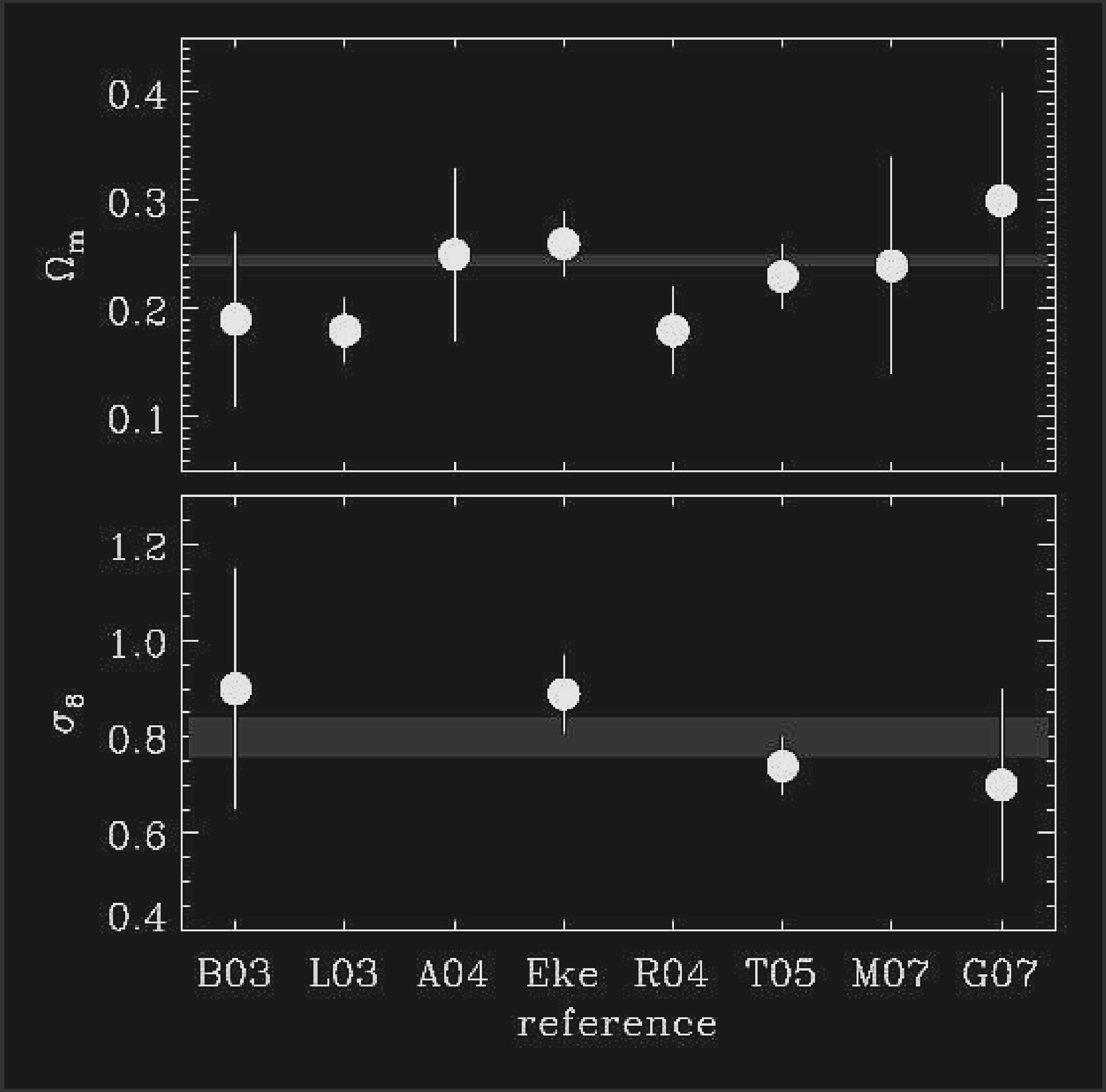
Millennium simulation lacks very rich superclusters cmpd to real Universe

(Einasto+07)

RCS1-discovered z=0.9 massive supercluster <9% probability in WMAP5 Universe

(Gilbank+08)

Summary of current constraints



Shaded regions: WMAP5 (Dunkley+08)

Perspectives:

forthcoming/planned optical/IR

spectroscopic and photometric surveys

from the ground and from space

Cluster-dedicated photometric survey:

CFHT MegaCam

1000 deg^2

g'=25.3, r'=24.8, z'=22.5

detection out to z~1

constrain Ω_m to ± 0.02, σ_8 to ± 0.05, and w to 10%

(Yee+07)

Other photometric surveys:

Univ Hawaii Inst Astronomy:

1200 deg^2, g=27, 4 bands

KiDS

1500 deg^2, 5 SDSS bands

VLT Survey Telescope

2 mag deeper than SDSS

CTIO 4m wide-field camera:

5000 deg^2, 4 bands

Spectroscopic surveys:

BOSS,

Baryon Oscillation Spectroscopic Survey

10000 deg^2 1.5 million z's ($z \leq 0.7$)

Part of SDSS-III, 1^{st} DR in 2011

1 million z's in 100 nights

Surveys from space:

Warm mission: ~10^4 hrs observations

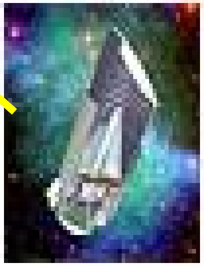
3.6, 4.5 μm ⇒ more IR-selected z>1 clusters (e.g. Papovich 08)

JDEM, NASA+DoE

joint dark energy mission

Advanced Dark Energy Physics Telescope (ADEPT)

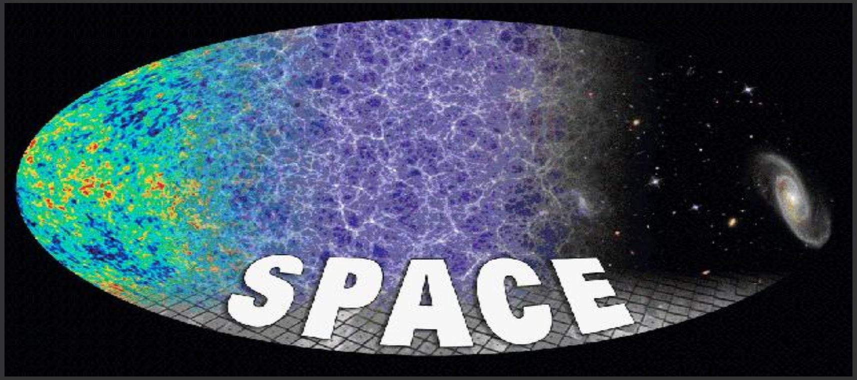
Dark Energy Space Telescope (Destiny)



SuperNova/Acceleration Probe-Lensing (SNAP-L)

Surveys from space:

+



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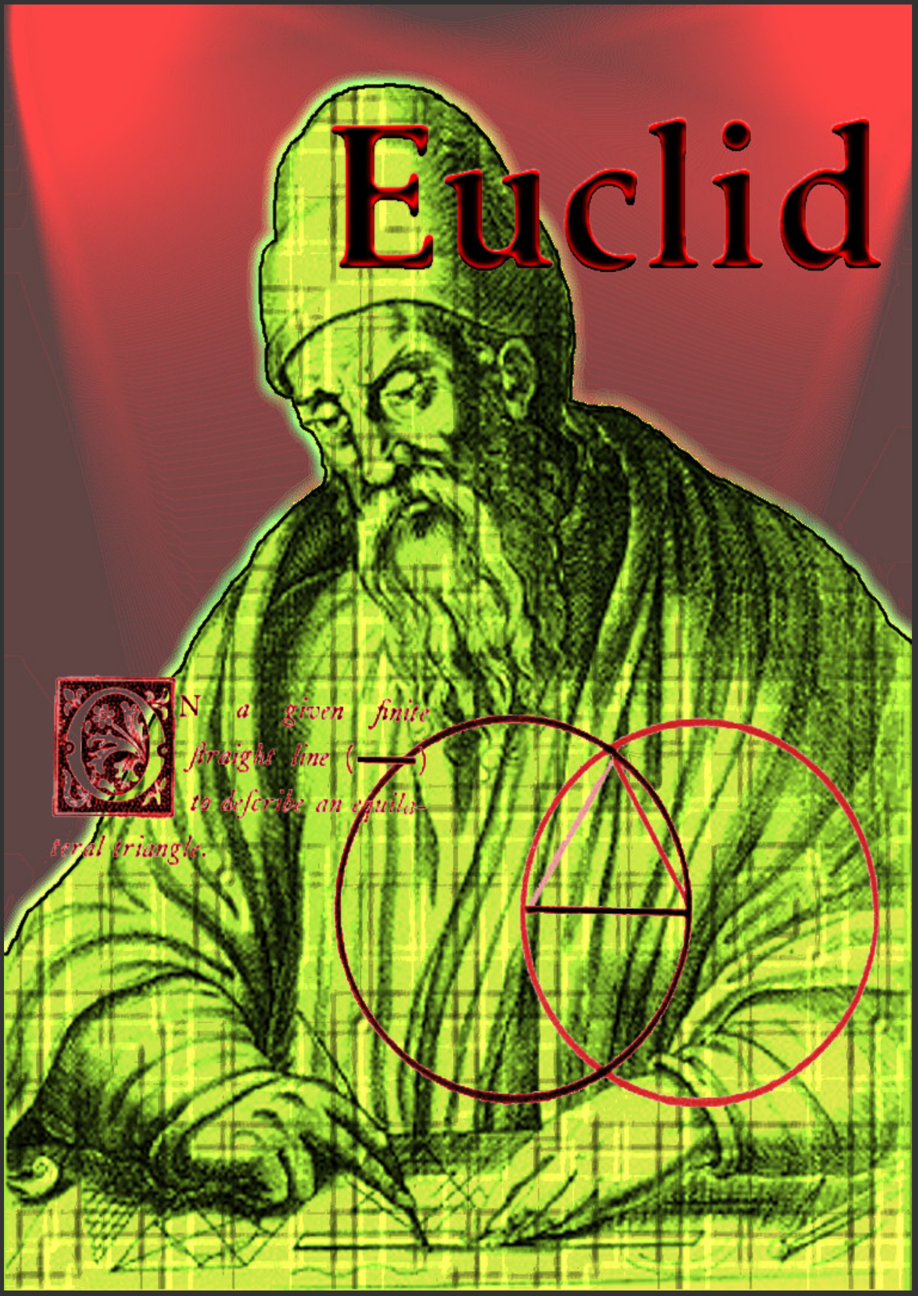

ESA M-class mission

20000 deg^2, H=22, R$\approx$400

~150 million z's

~ 2 billion galaxies z~2