Why Does Environment Matter?

An Incomplete & Biased Guide

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Galaxy Zoo: Linear Clusters

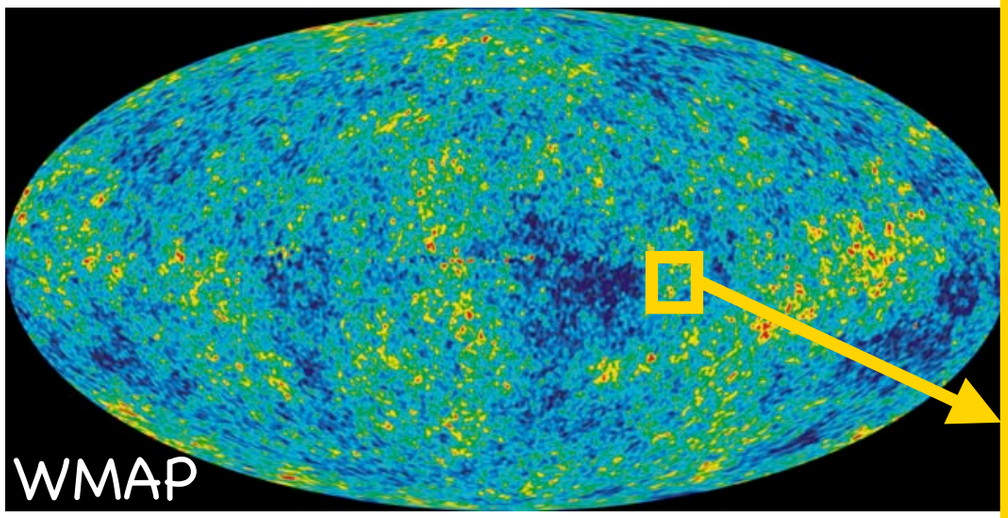
CAUTION! STRUCTURE
FORMATION IN PROGRESS

Thanks to S. Bamford

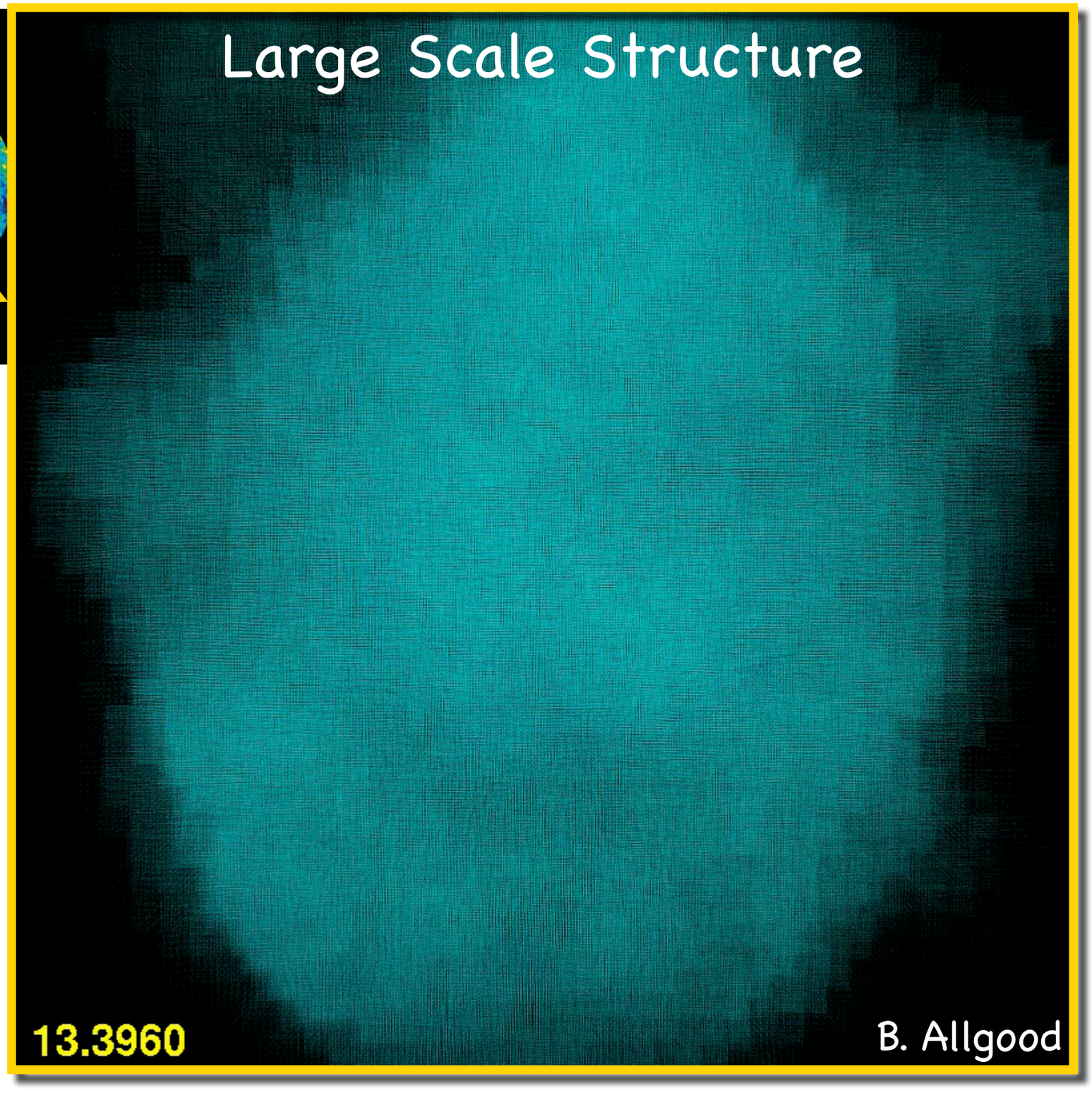
Outline

- Large-Scale Structure
- Observed Environmental Trends
- Merging & Red Sequence
- Gas Stripping
- Dynamical Friction & ICL

Hierarchical Formation



Primordial fluctuations to collapsed, bound structures (Peebles 1972):
Galaxies,
Galaxy Groups,
Galaxy Clusters



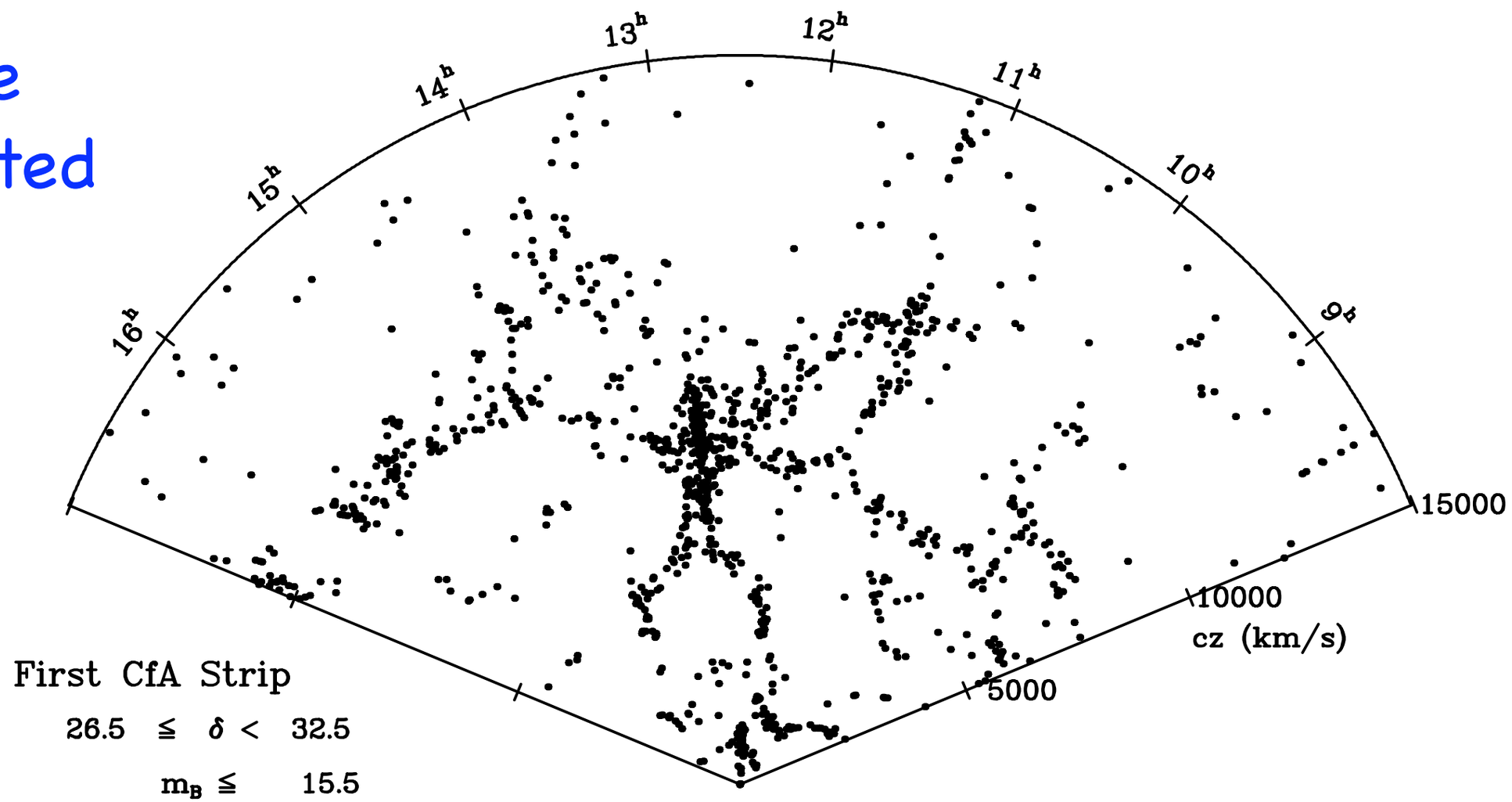
Redshift Surveys

CfA Redshift Survey (1980s)

First observational evidence of Large-Scale Structure

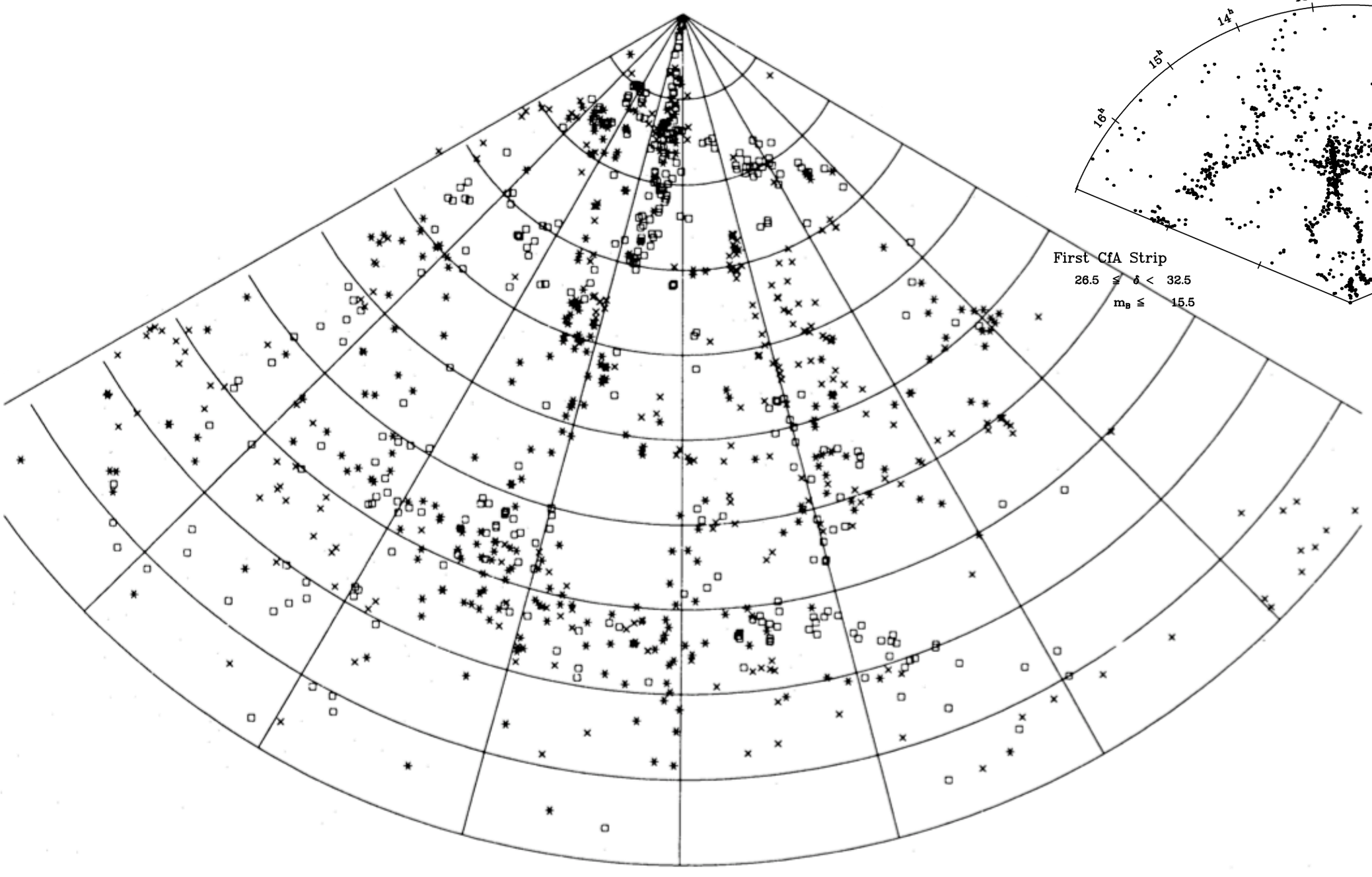
Davis, Huchra, Geller, Latham, Tonry

Galaxies are not distributed randomly



Redshift Surveys

Theory: Evolution of LSS in CDM Universe (Davis+85)



LSS: Local Universe

Las Campanas Redshift Survey (1990s)

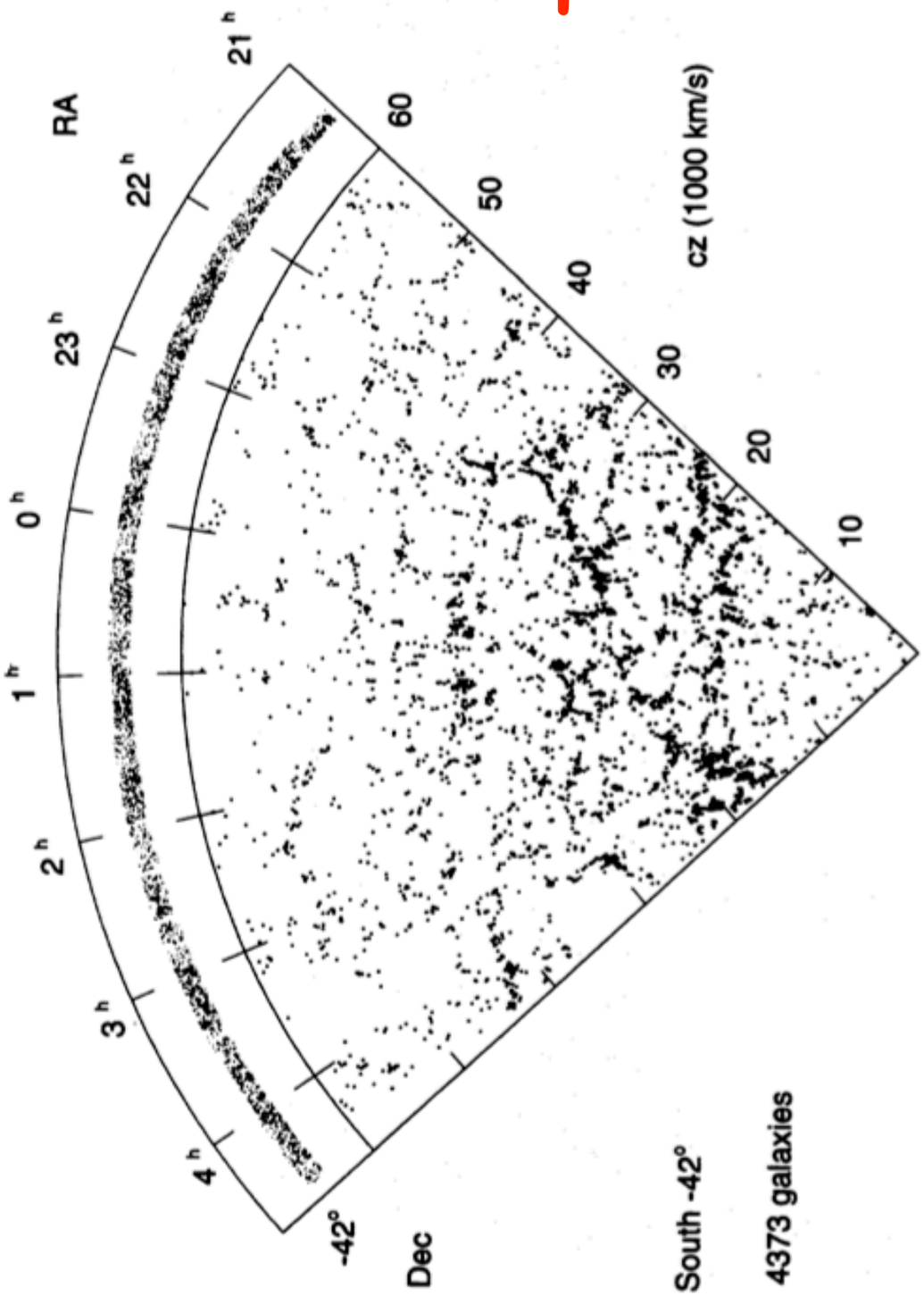


FIG. 8*e*

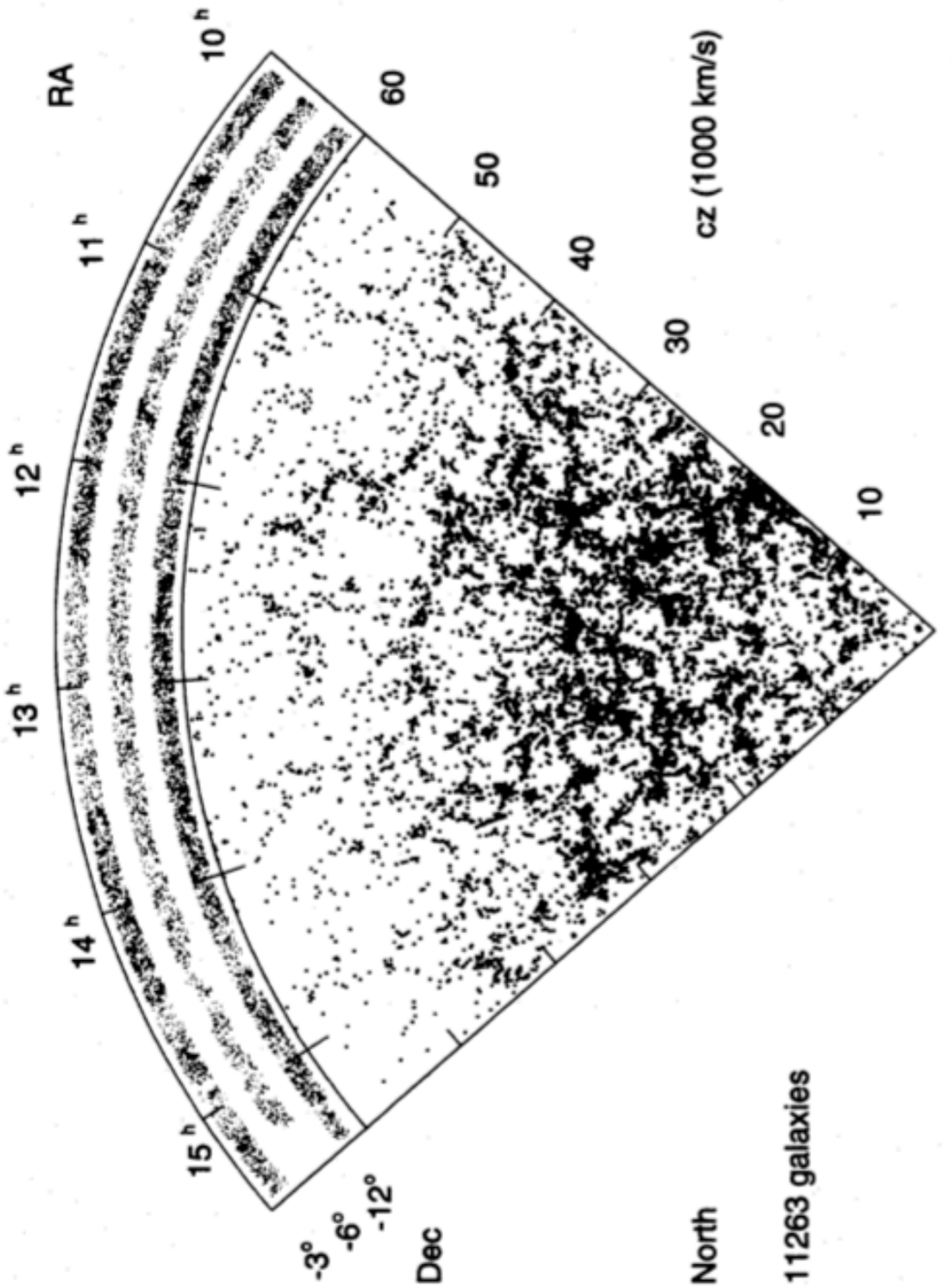
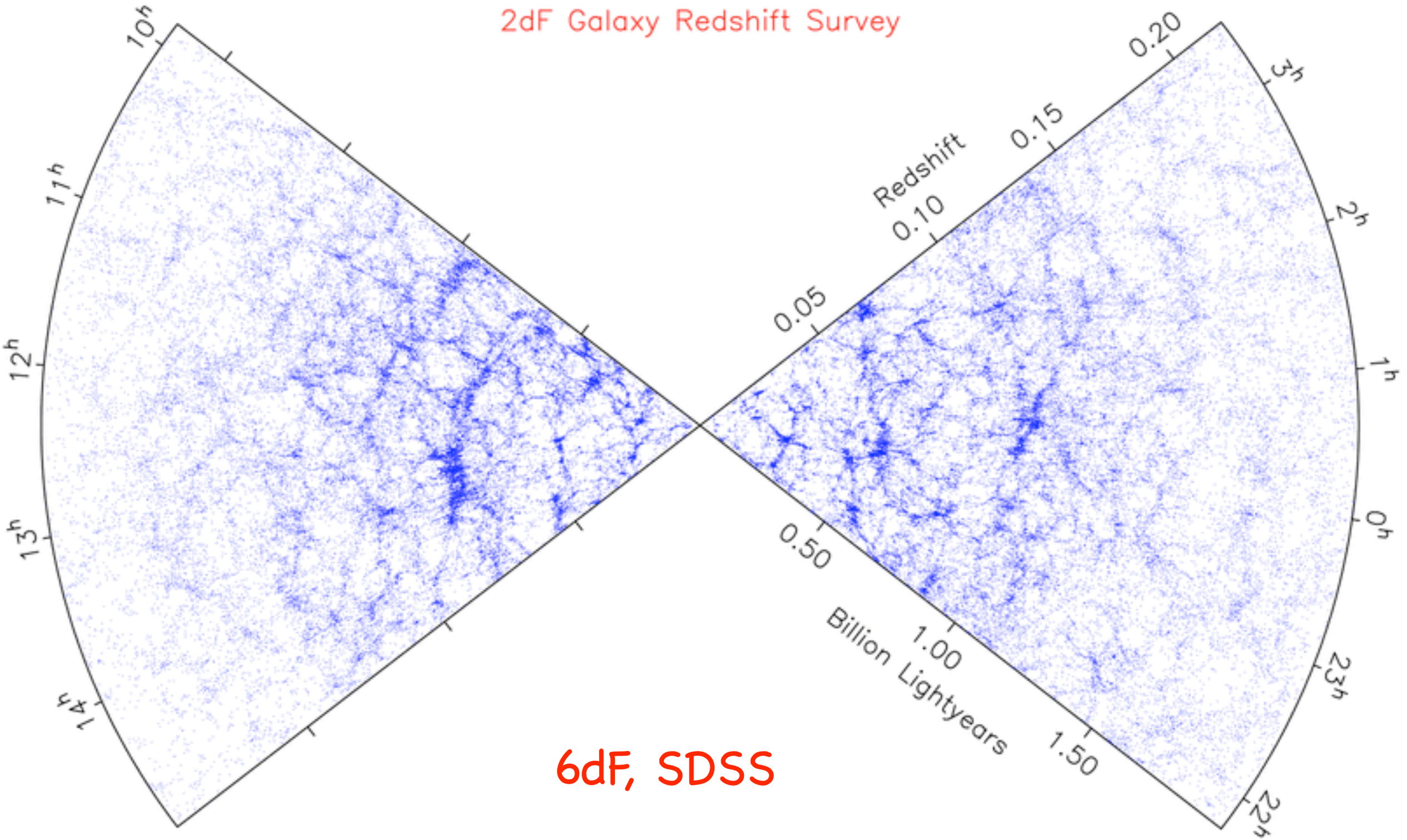


FIG. 8*g*

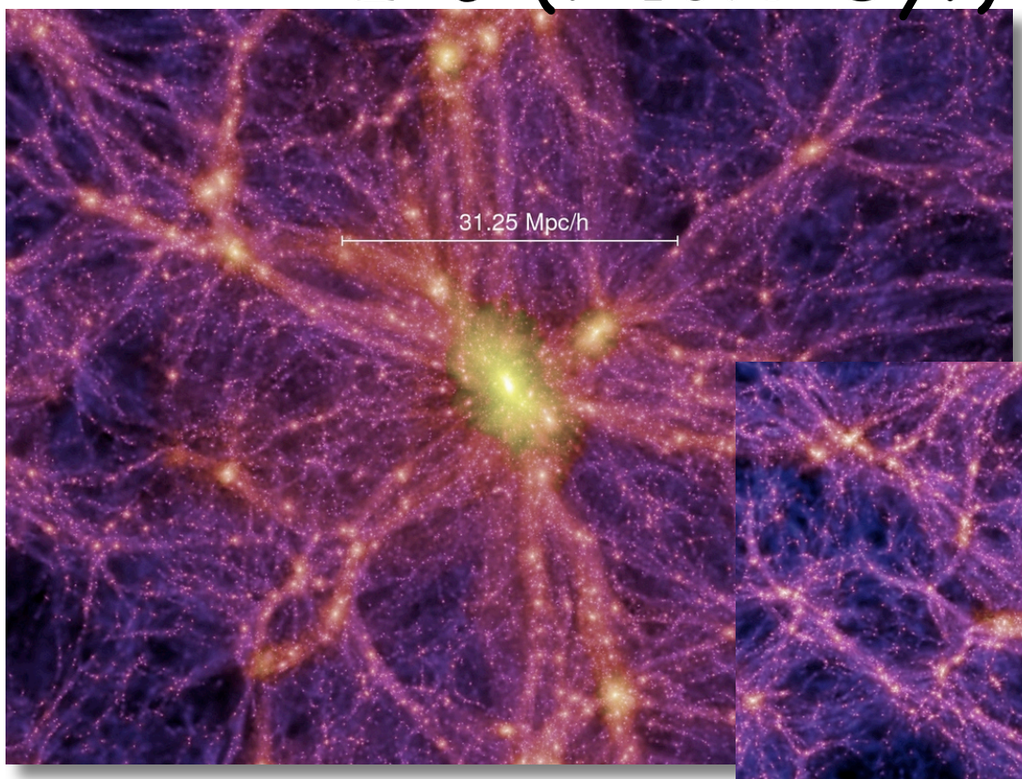
LSS: Local Universe



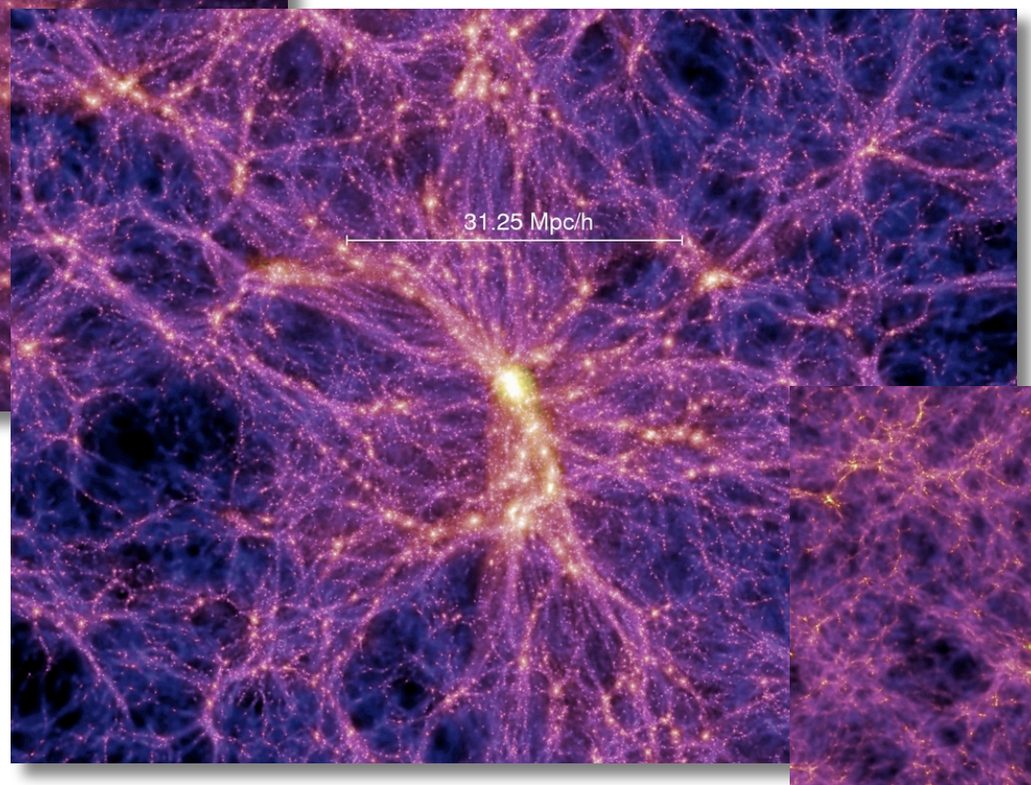
6dF, SDSS

LSS: Theory

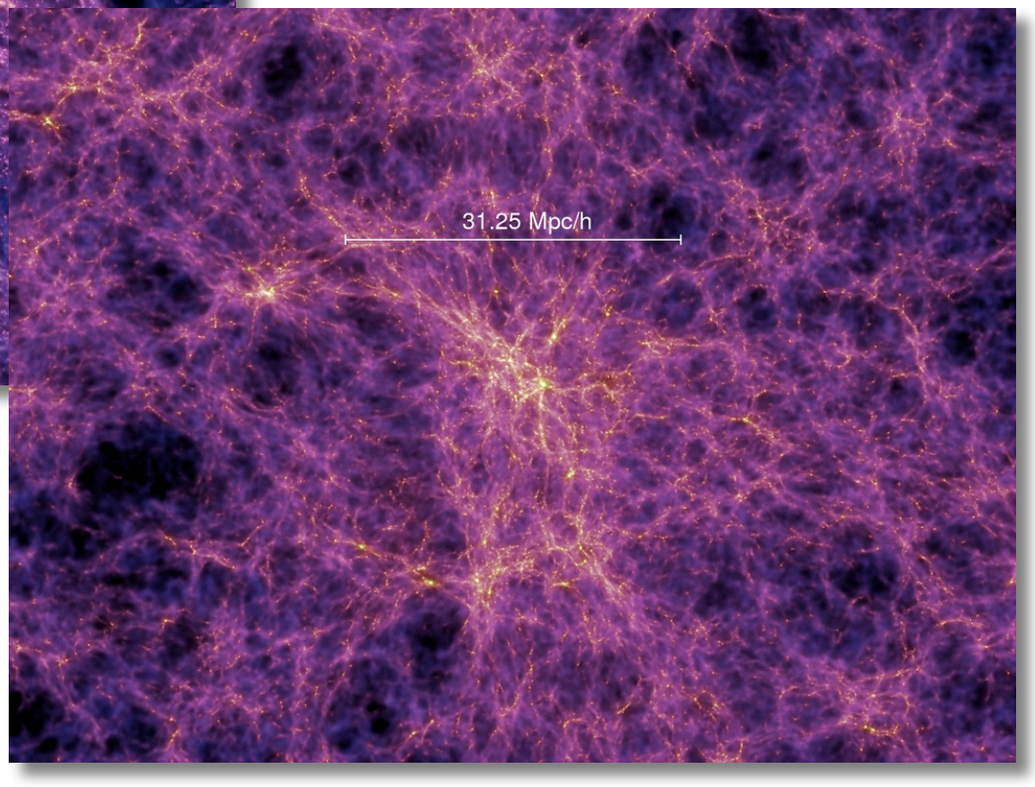
z=0 (t=13.6 Gyr)



z=1.4 (t=4.7 Gyr)



z=5.7 (t=1.0 Gyr)



Millenium Simulation

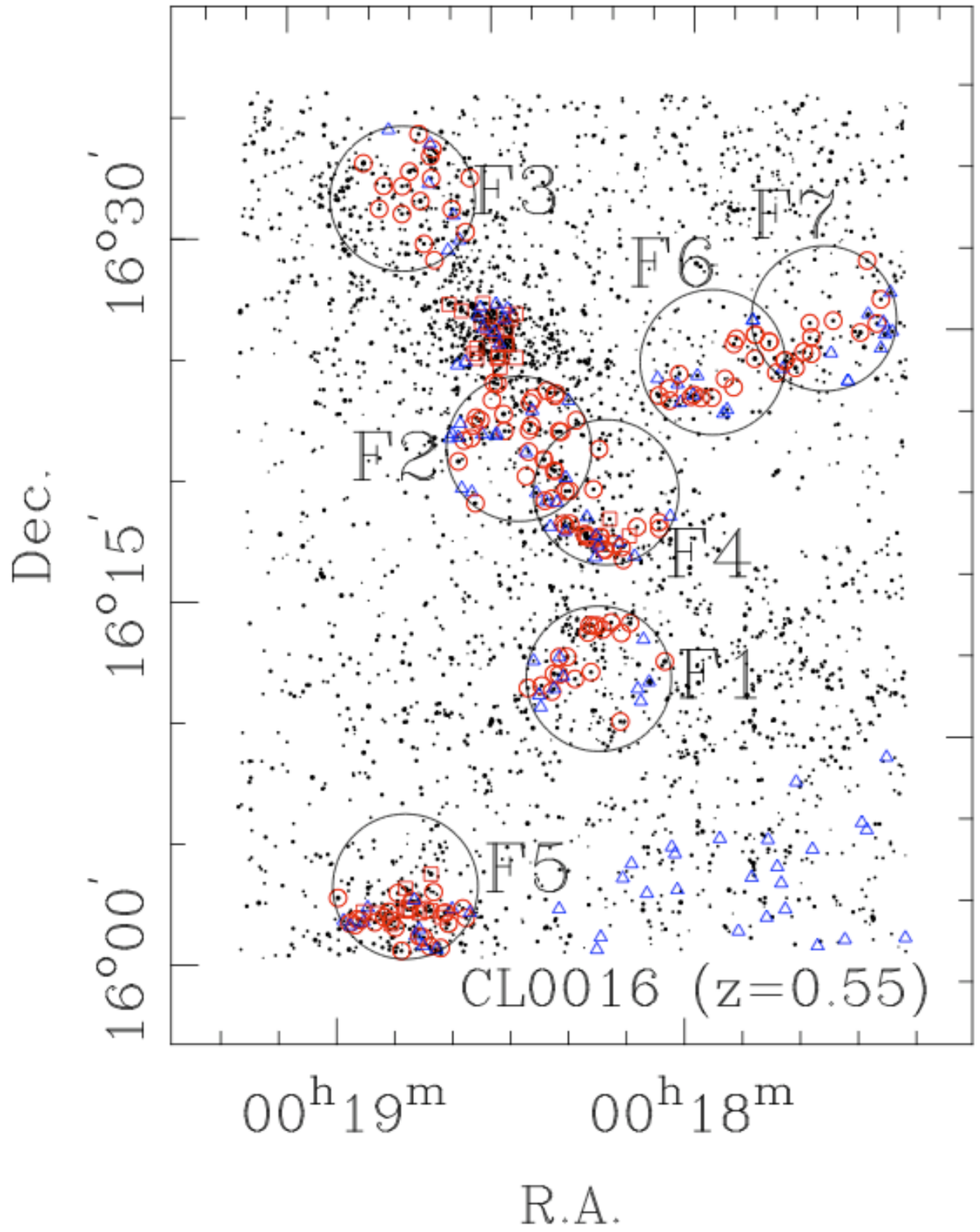
Springel+05

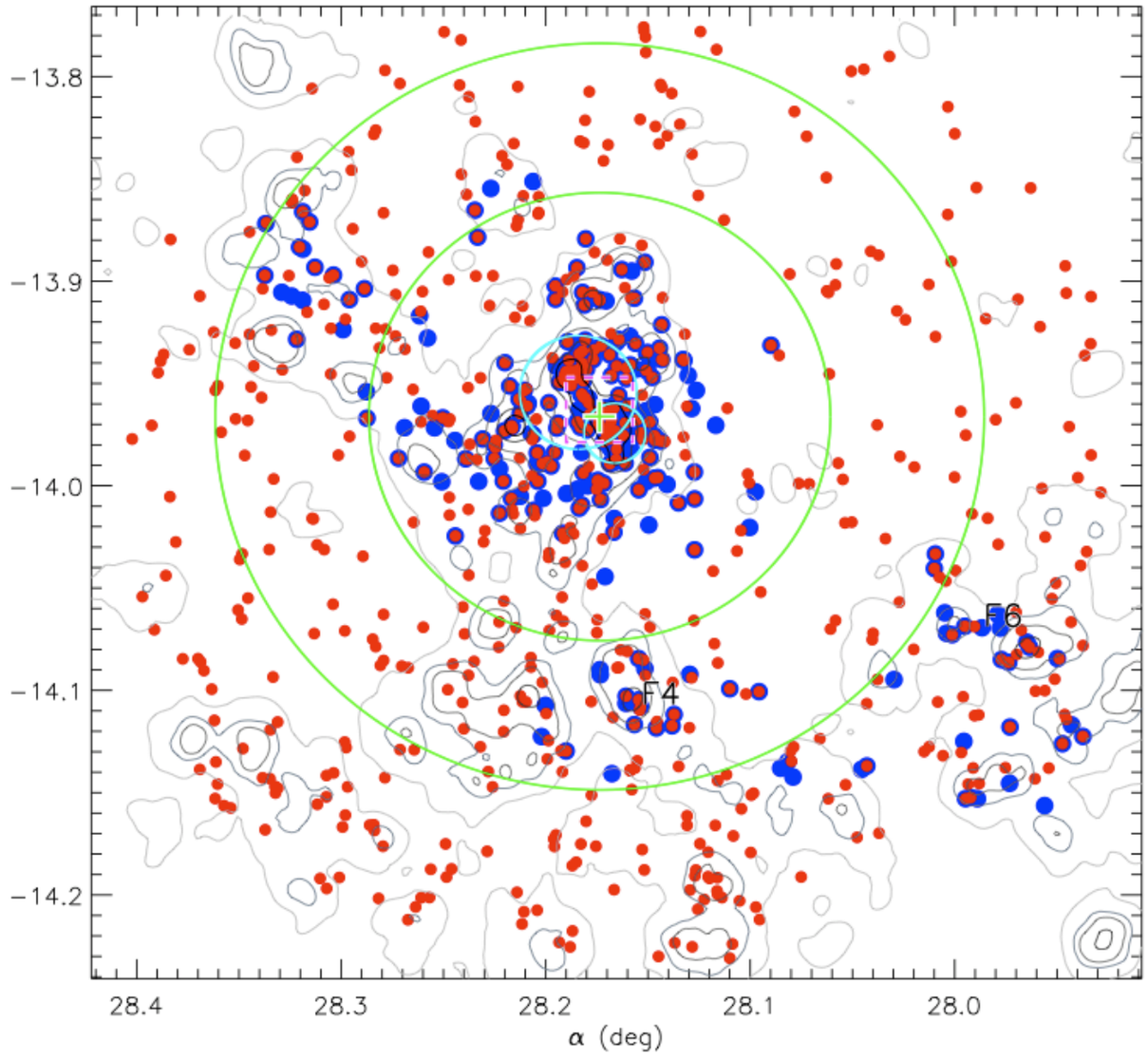
Abell 901/902 (z=0.16)
STAGES (M. Grey)

SG1120 (z=0.37)
Gonzalez, Tran+05

LSS: Intermediate Redshifts

Tanaka+05 (spec+photo-z's)

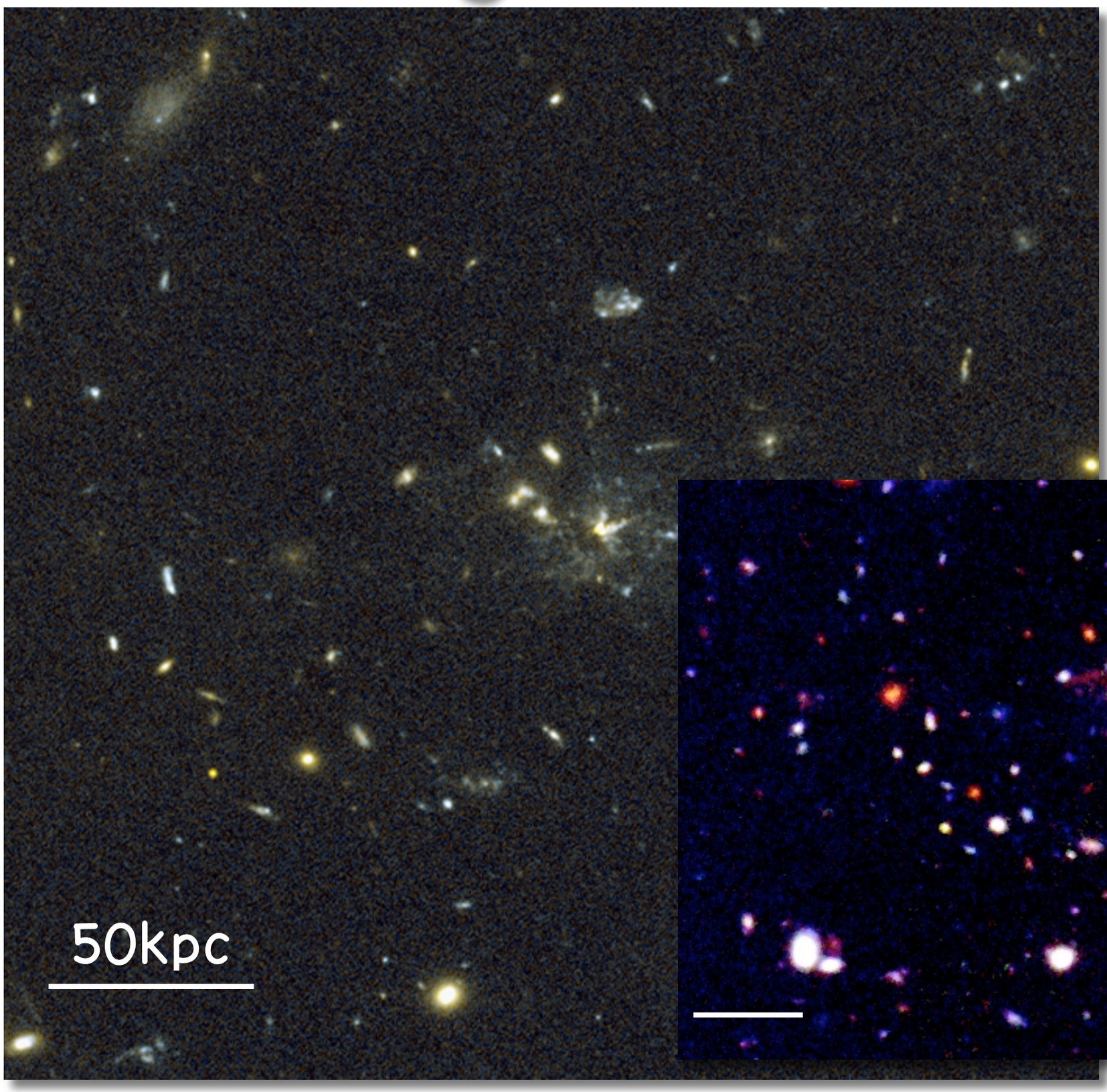




RX J0152 (z=0.83)

Patel+09 (>700 spec-z's)

High-z Protoclusters



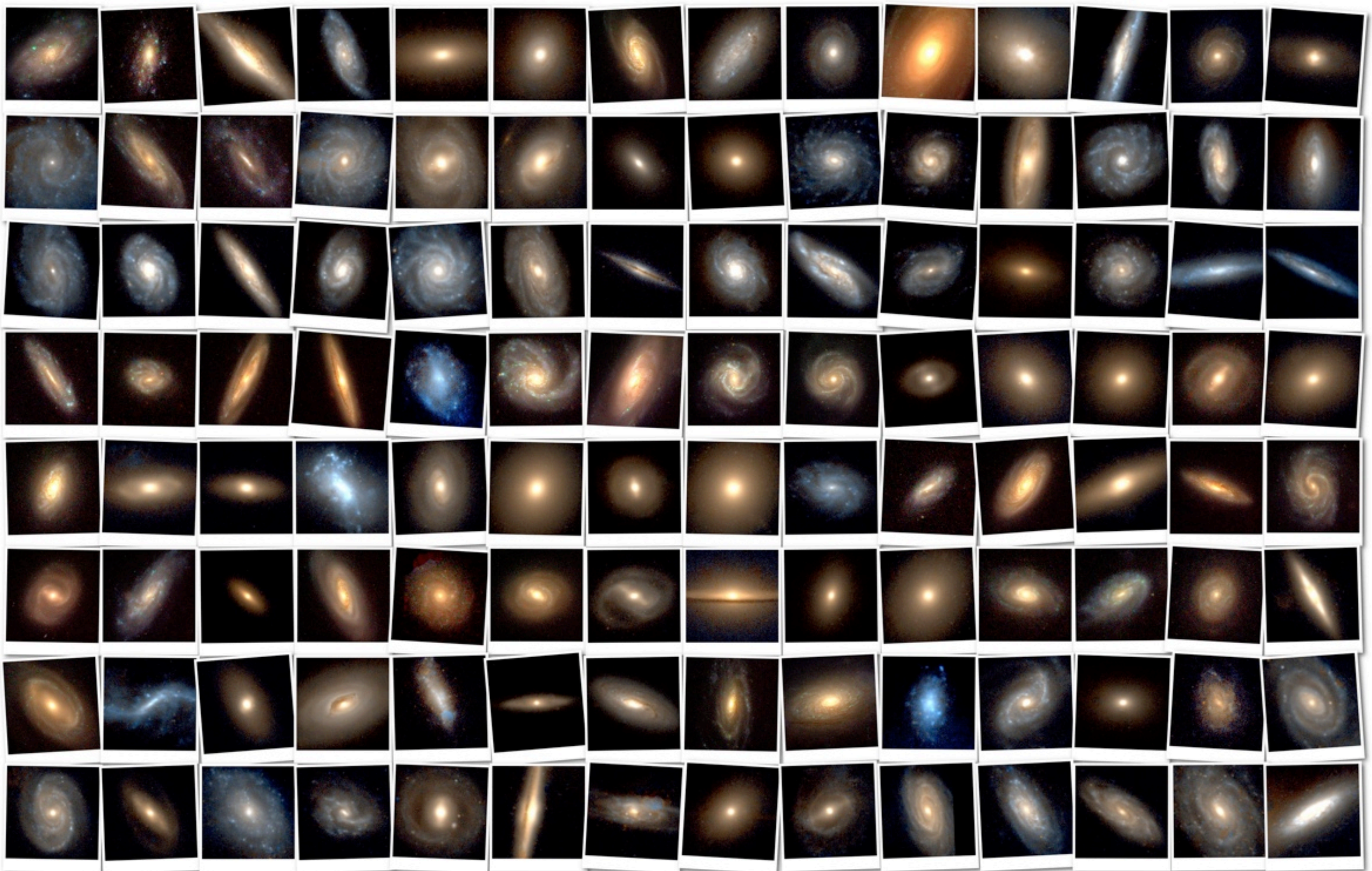
Spiderweb Galaxy
(z=2.2)

Miley+06

Hatch+09

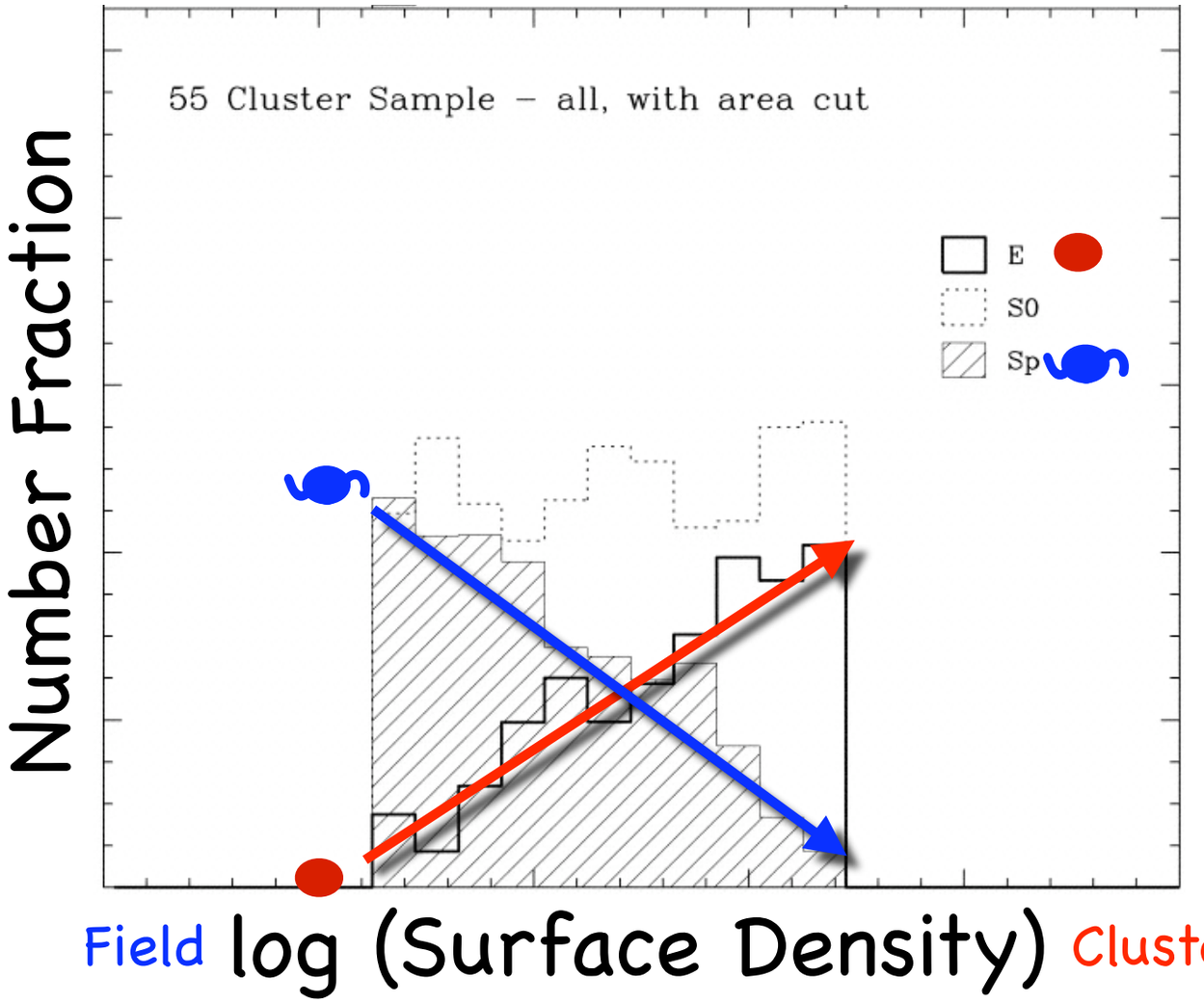
(see poster)

Frei Catalog of Local Galaxies



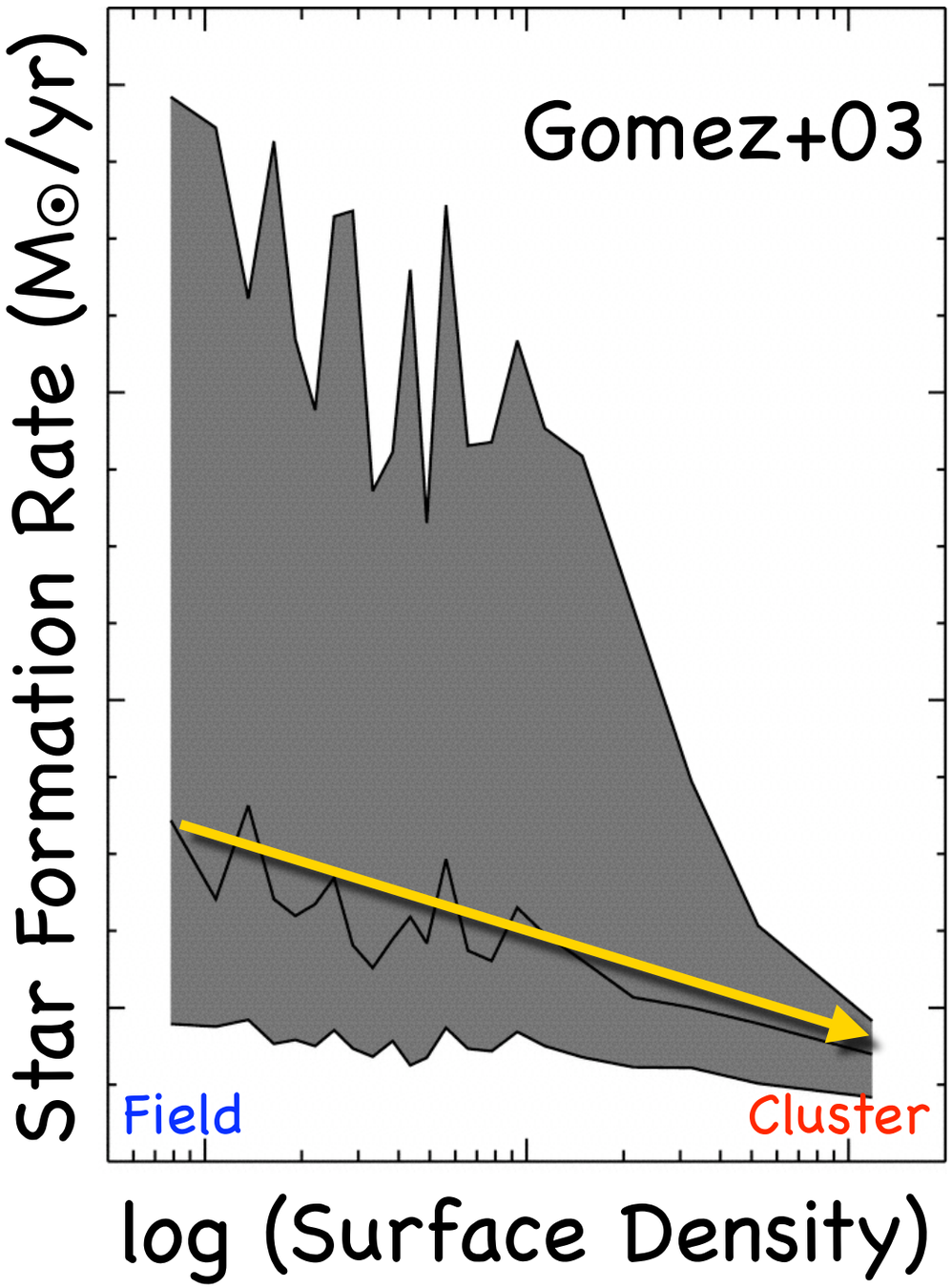
Observed Environmental Trends

Changes in Morphology



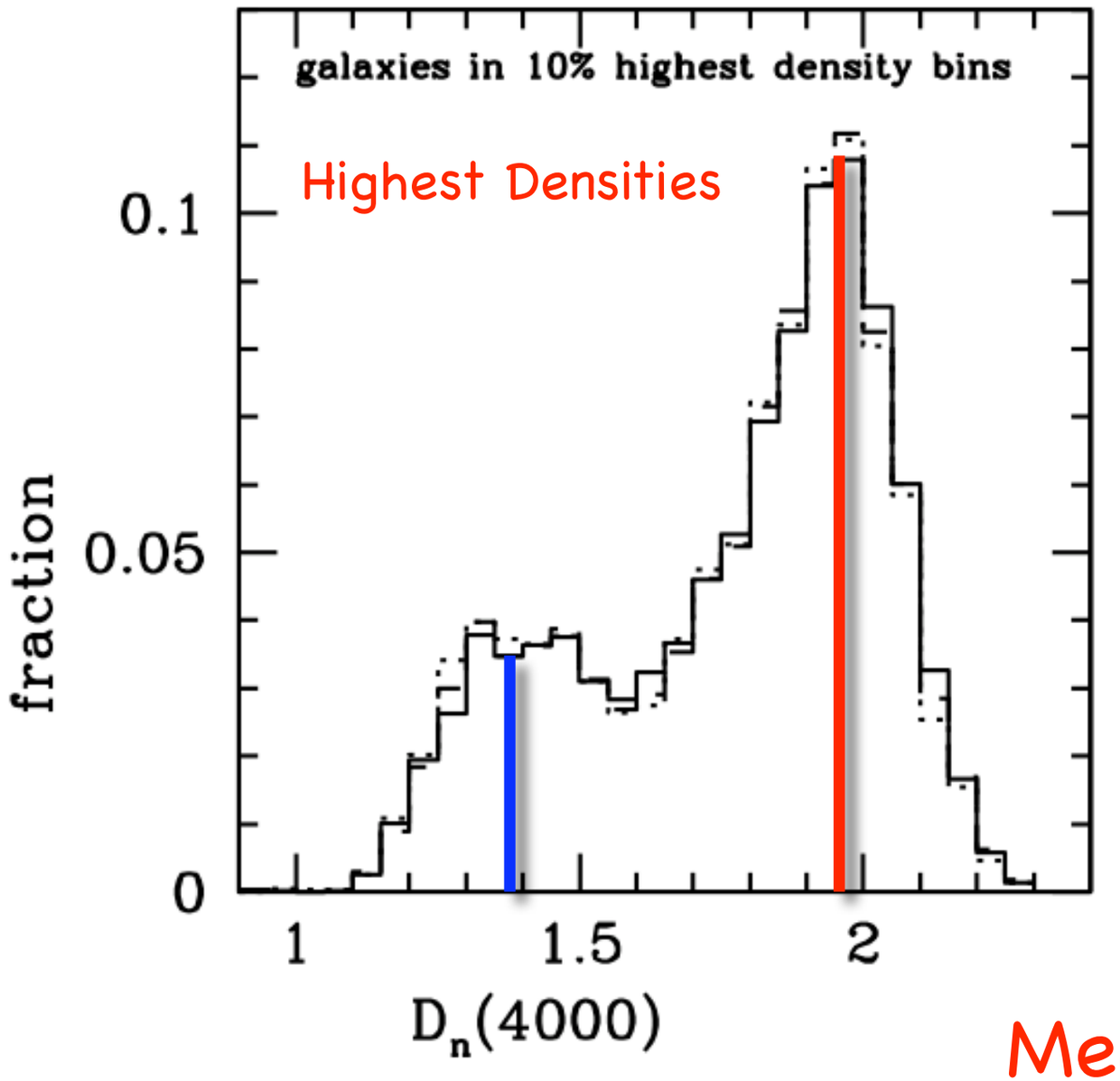
Dressler+1997

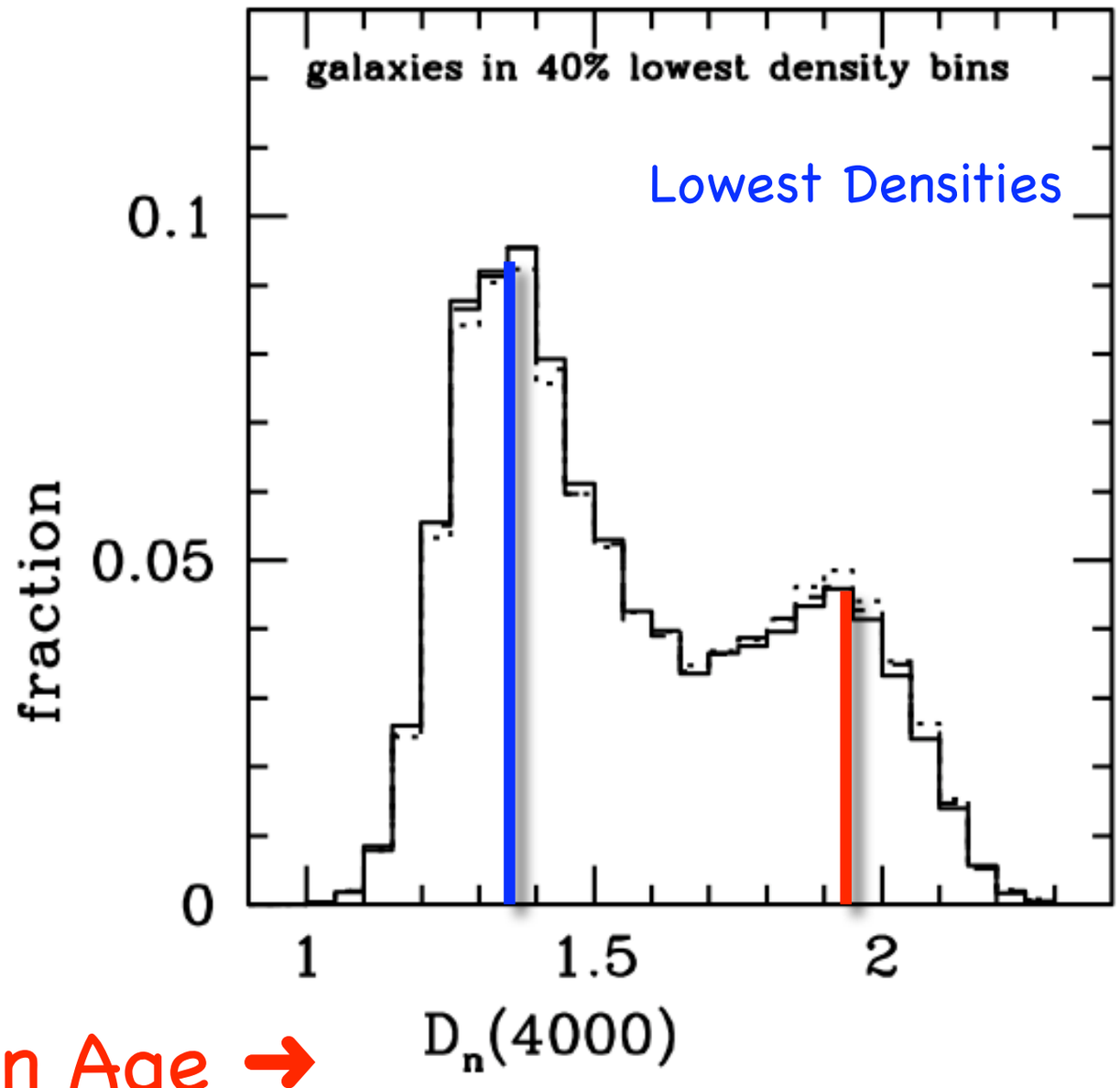
Changes in Star Formation



Observed Environmental Trends

Kauffmann+04 (SDSS): Star formation history is the galaxy property most sensitive to environment (Poggianti also)

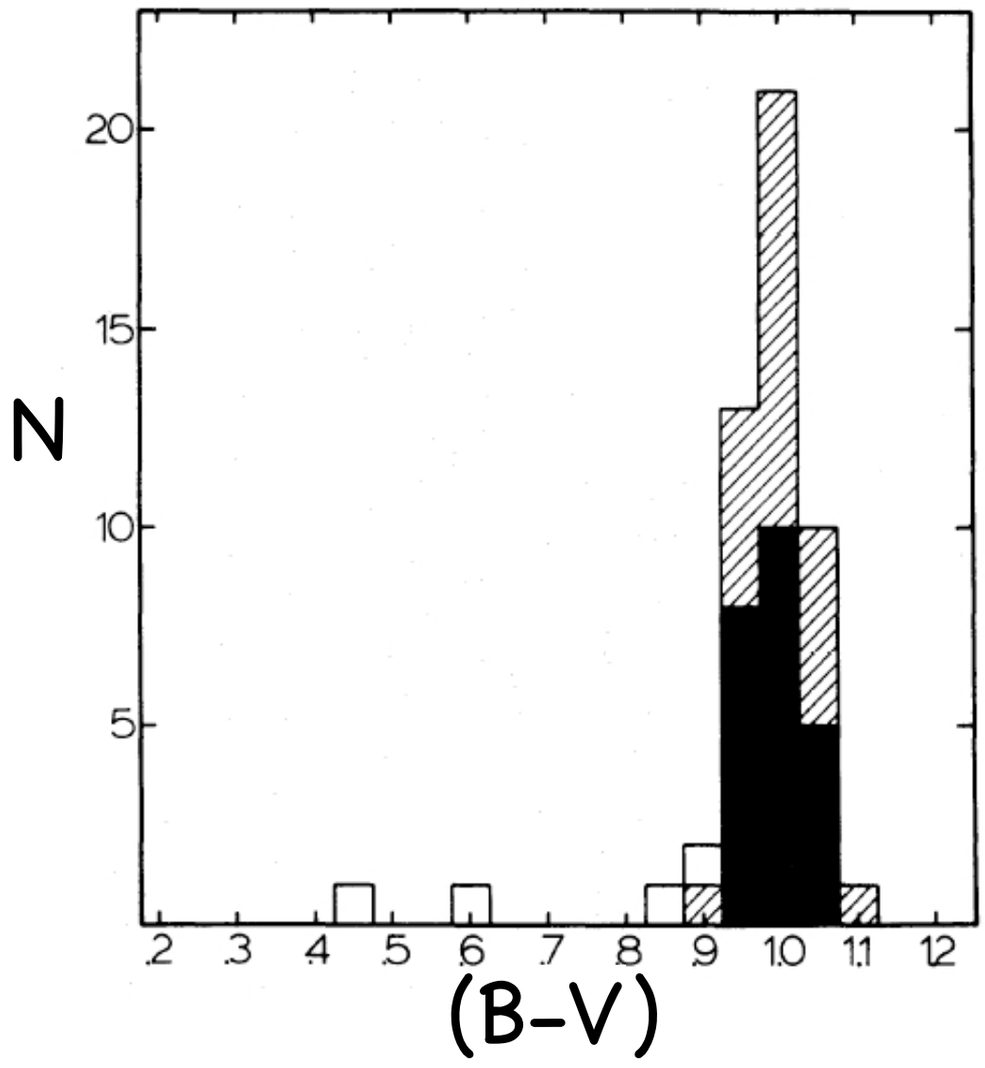




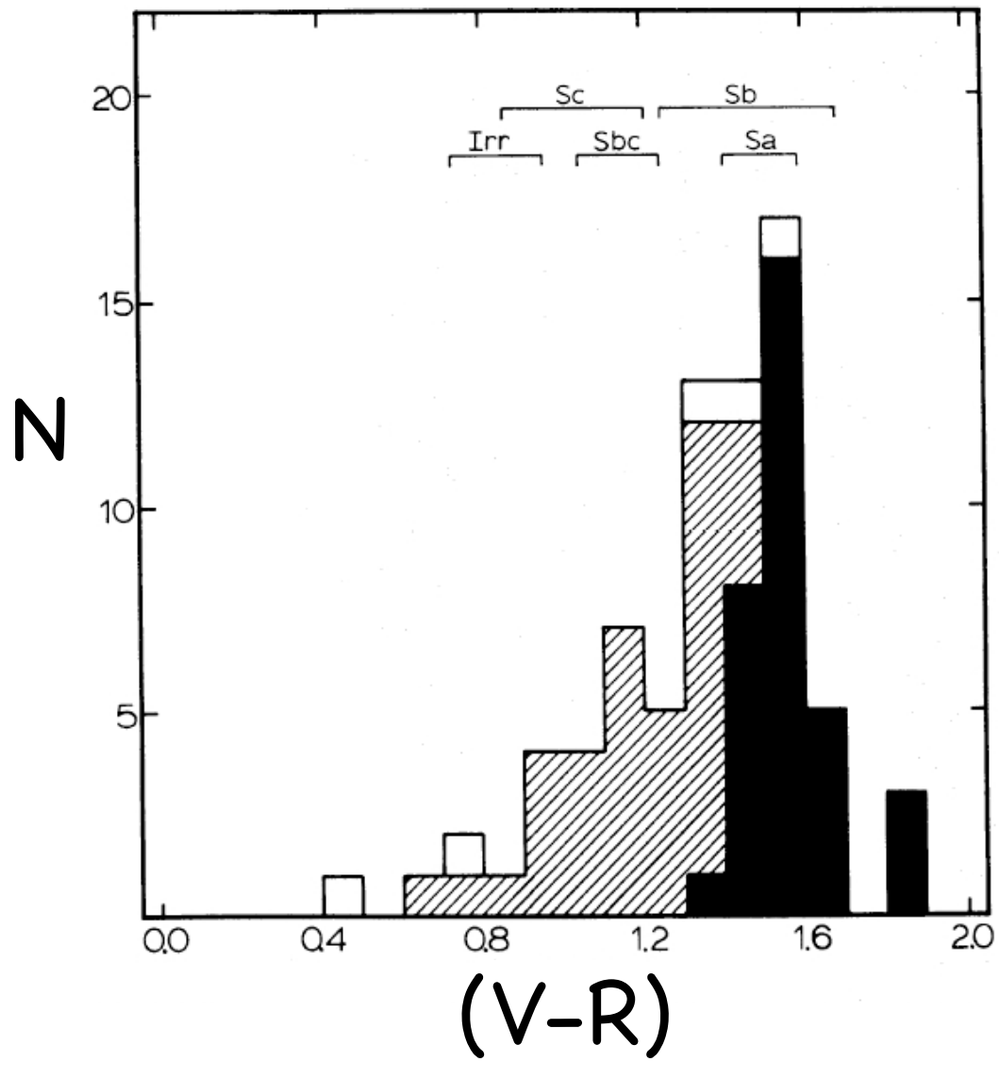
Mean Age →

Butcher-Oemler Effect

Coma (z=0.02)



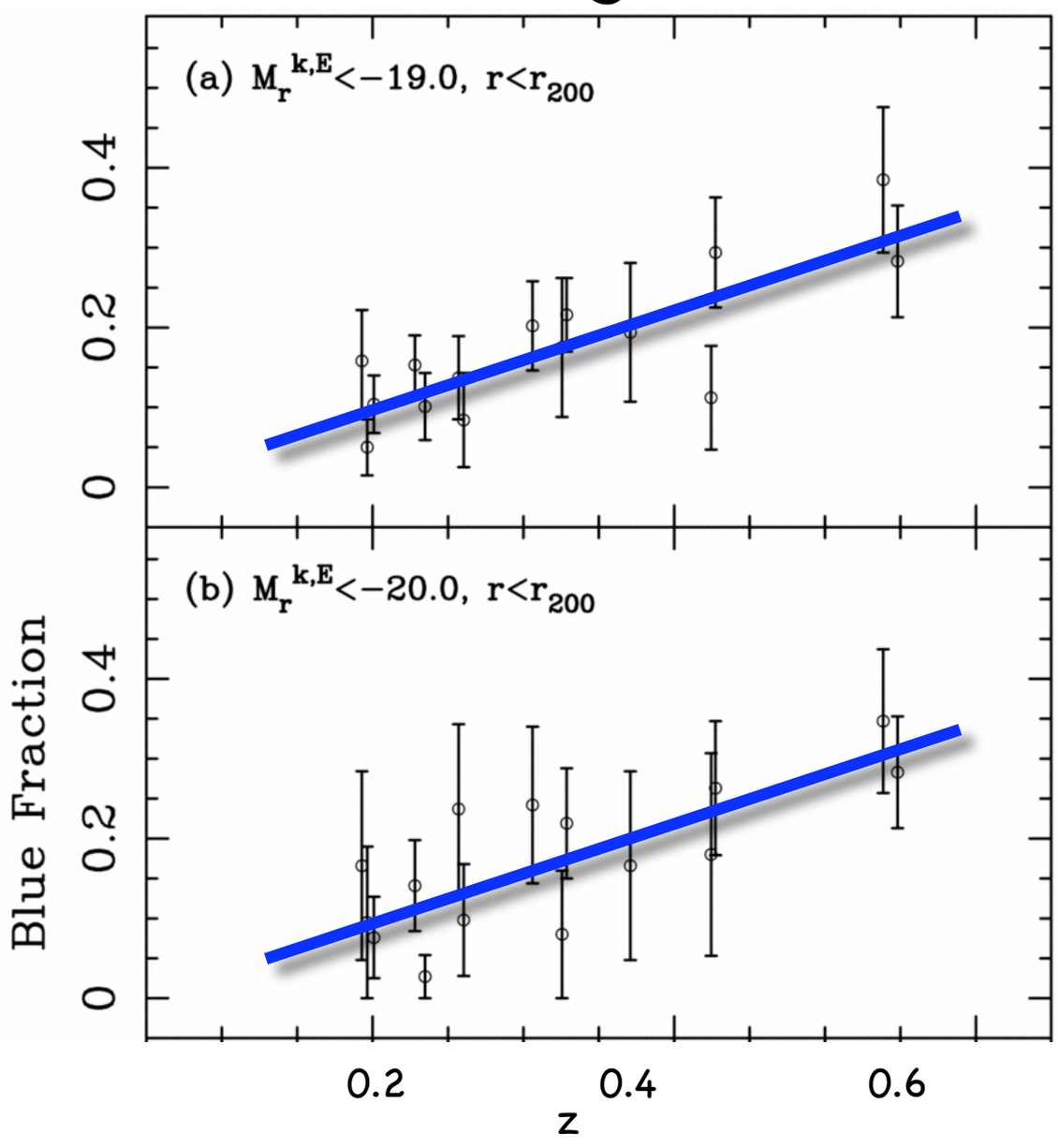
CL 0024 (z=0.39)



Butcher & Oemler (1978, 1984)

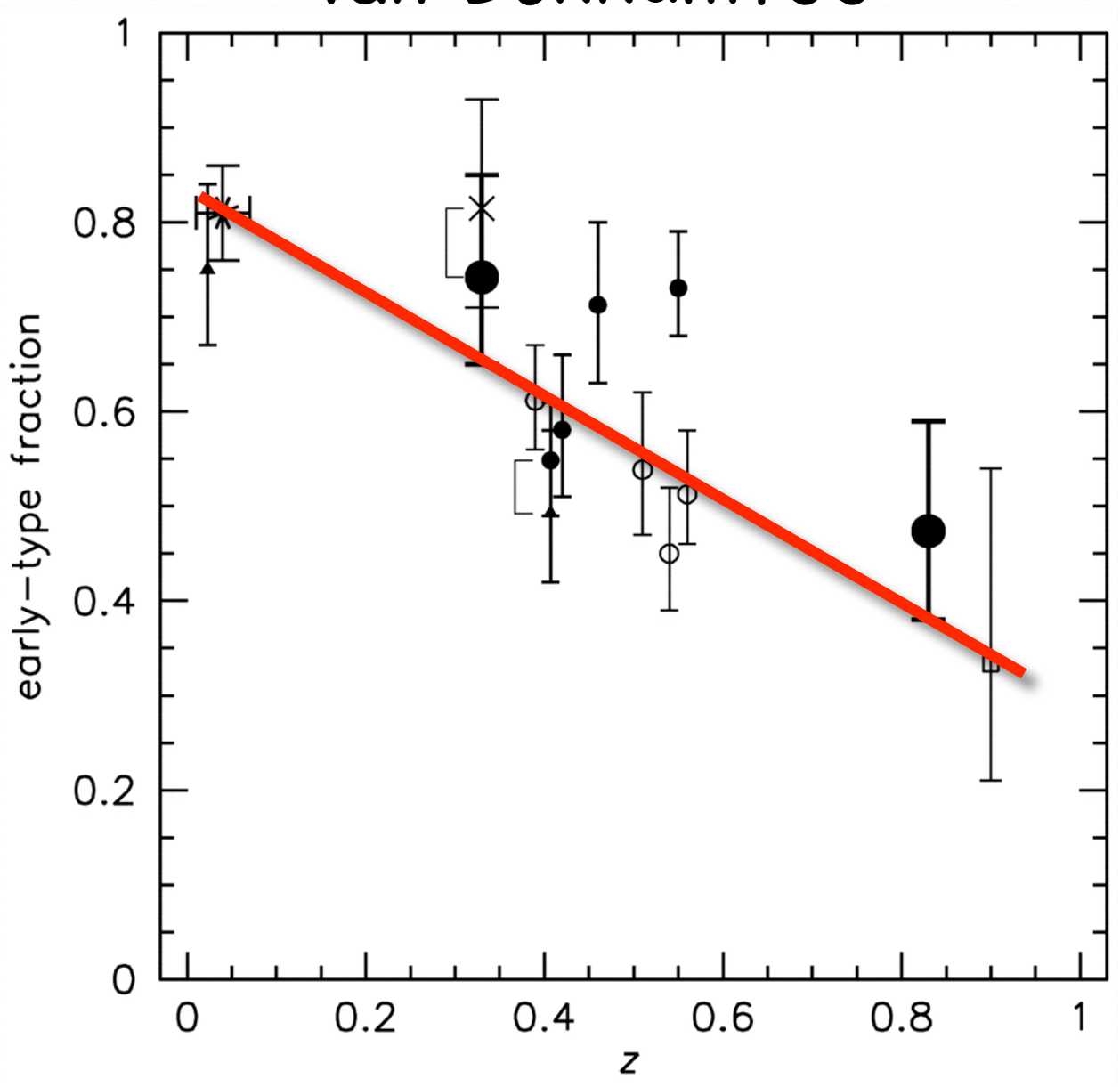
Evolving Early-Type Fraction

Ellingson+01



Increasing fraction of blue/star-forming members

van Dokkum+00



Decreasing fraction of red/early-types

Observables

Galaxies:

masses (stellar & gas), sizes, luminosities, metallicities, star formation histories (ages), kinematics (scaling relations)

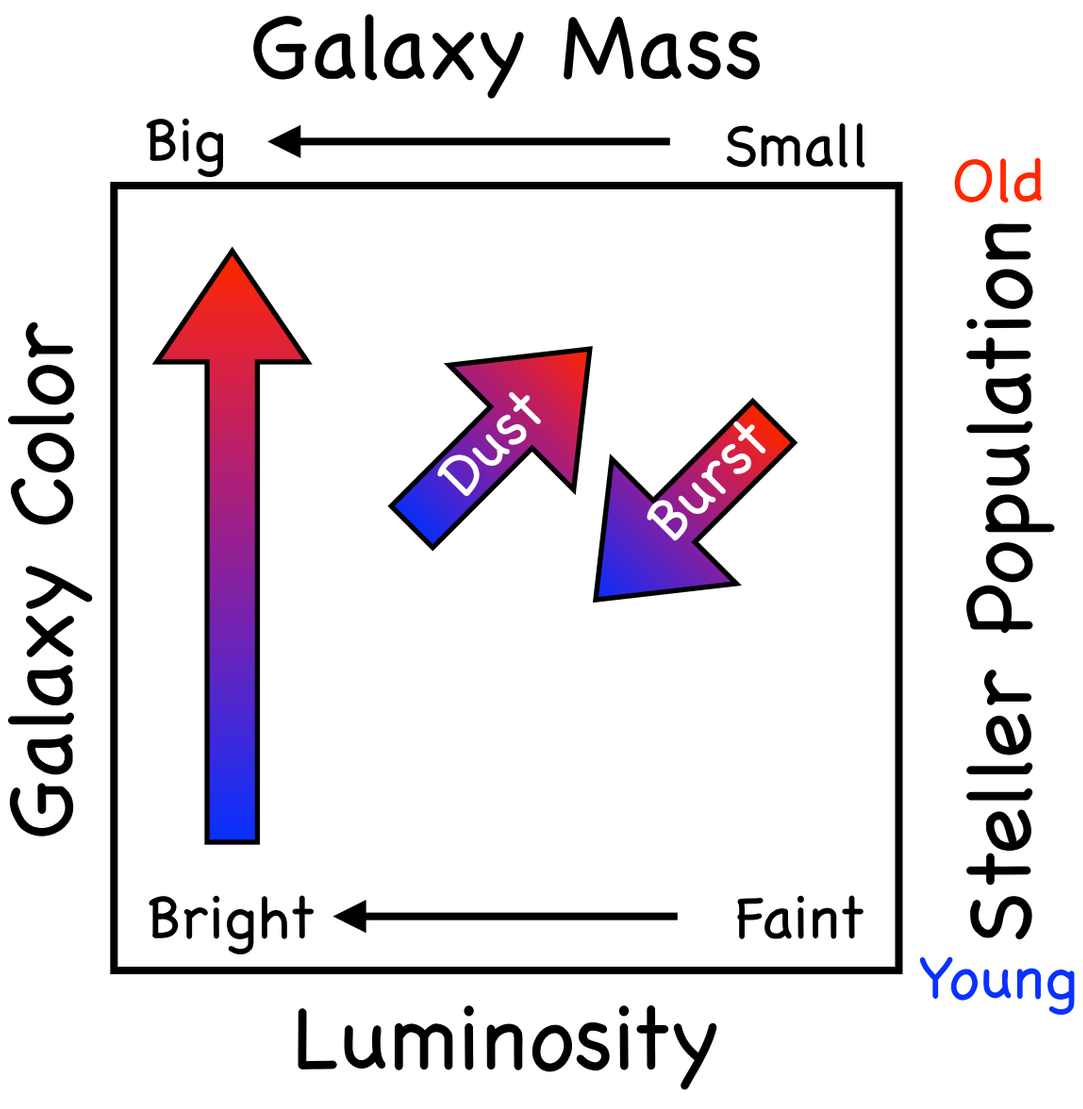
Intra-cluster/group medium:

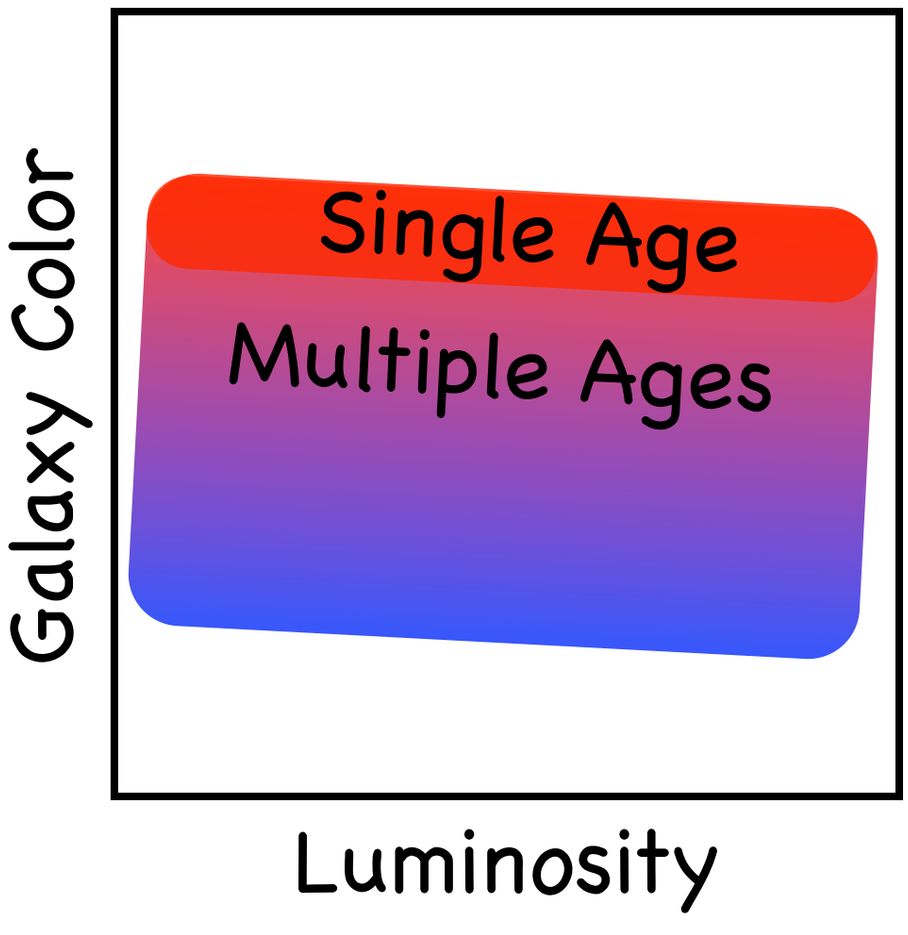
masses (stellar & gas), sizes, luminosities, metallicities, star formation histories (ages), kinematics, temperatures (X-ray)

Dark Matter:

mass & distribution via lensing & galaxy kinematics

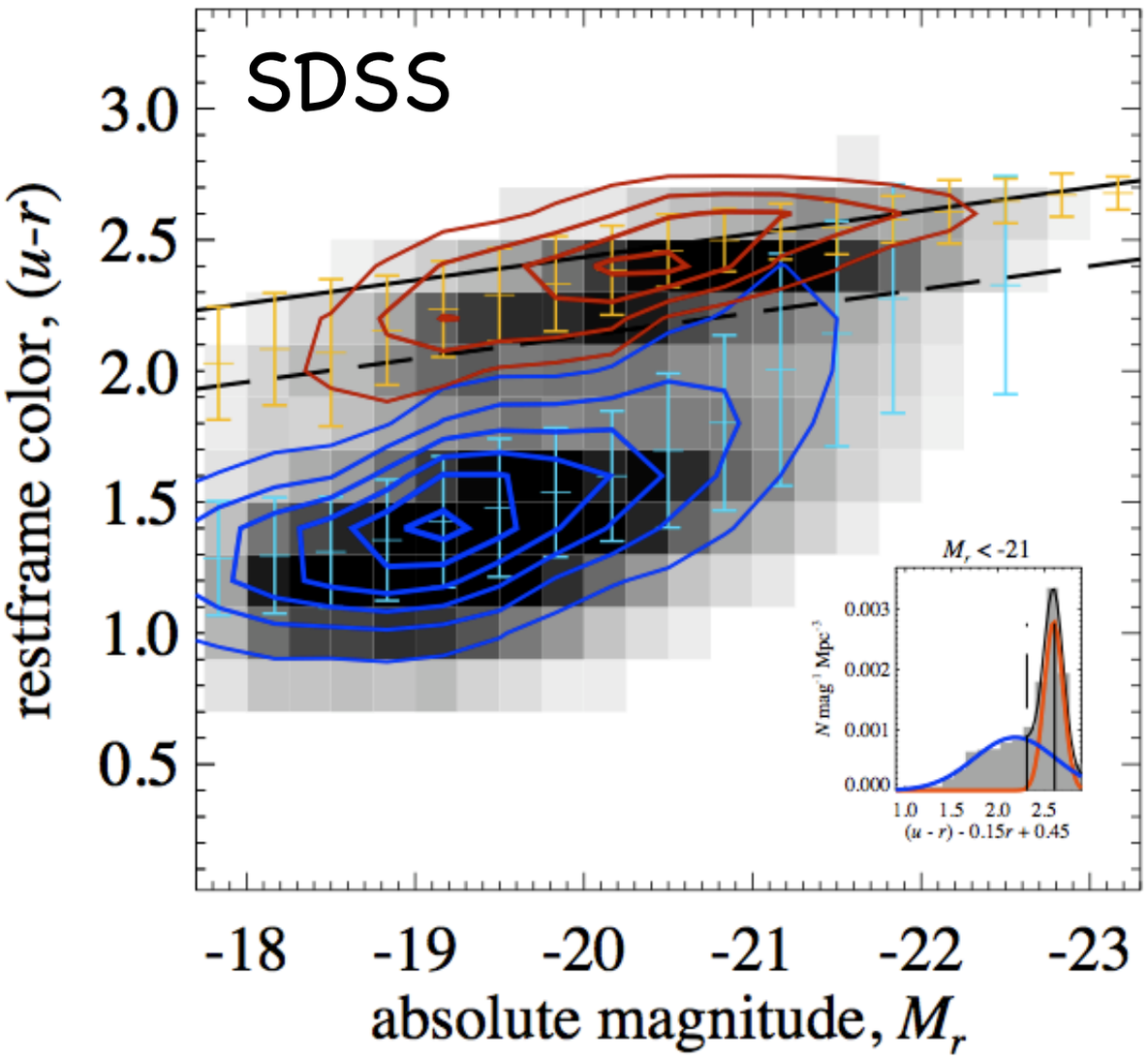
Color-Magnitude Diagram

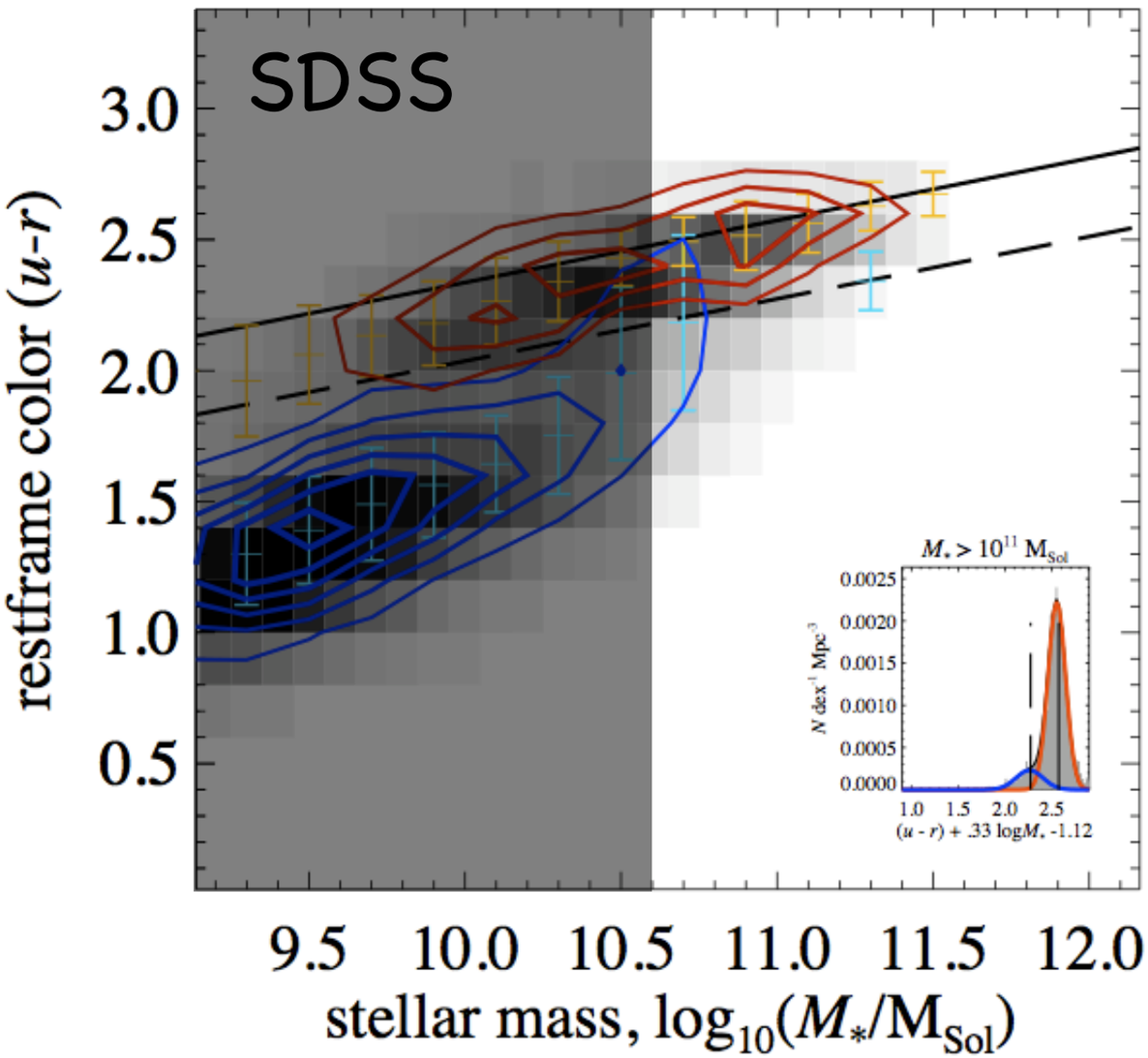




Color-Stellar Mass Diagram

Taylor+09 (see poster)





Lost in Translation

Are we even talking about the same quantities?

Observational studies limited by observations, e.g. how do we define an E+A?

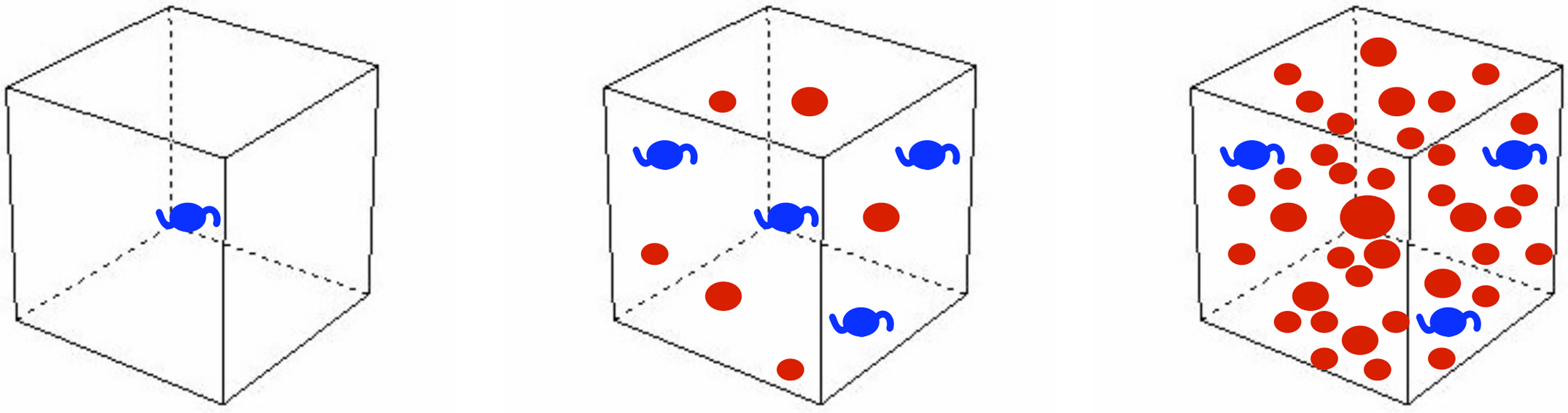
Theoretical results require prescriptions so they can be compared to the observations, e.g. converting particle masses to galaxy luminosities by assuming mass-to-light ratios.

Defining Environment

Group:

~10 L* Galaxy/Mpc^3

δ(velocity)~200-300 km/s



Field:

~1 L* Galaxy/Mpc^3

cz=Hubble Expansion

Cluster:

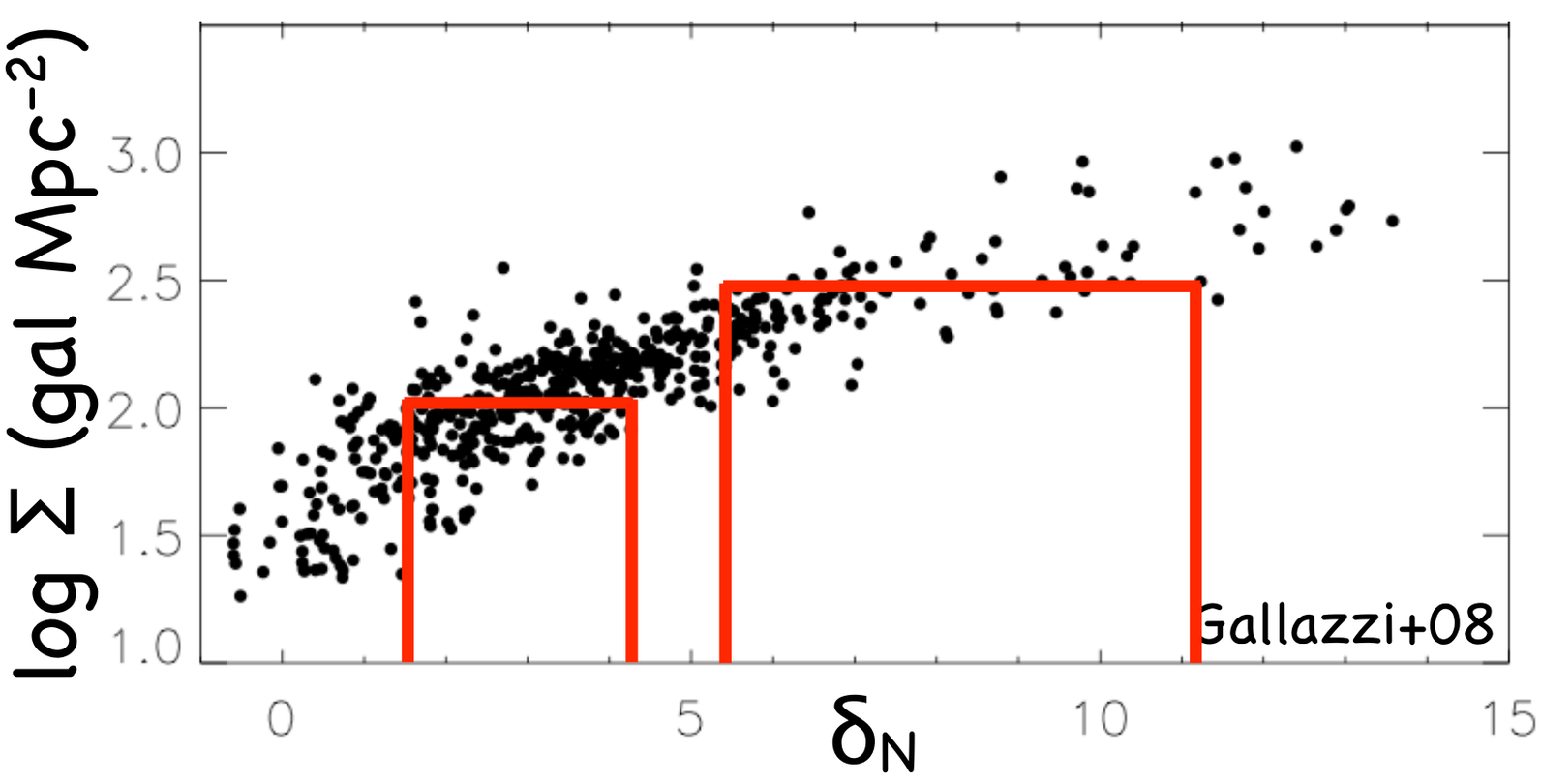
~10^2-10^3 L* Galaxy/Mpc^3

δ(velocity)~1000 km/s

Defining Environment

In practice, harder to define:

- count # galaxies in comoving cylinder/cube
- count distance to nearest n^{th} neighbor
- spectroscopic vs. photometric samples (interlopers)
- weak-lensing mass distribution (sheet degeneracy)



theoretical (halos & subhalos) vs. observational

Post-starburst Galaxies

Will the real E+A galaxies please step up?

Dressler & Gunn 1983: HδΥβ > (7-8) Å

Zabludoff+96

"E+A"s are selected to have the strongest Balmer absorption lines (the average of the equivalent widths of Hβ, γ, δ is >5.5 A) and weakest [O II] emission-line equivalent widths (<2.5 A, which corresponds to a detection of [O II] of less than 2 σ significance)

Fisher+98

galaxies with average Balmer absorption line strengths [(Hδ + Hγ + Hβ)/3] greater than 4.0 Å and [O II] 3727 Å emission less than 5 Å. The Balmer

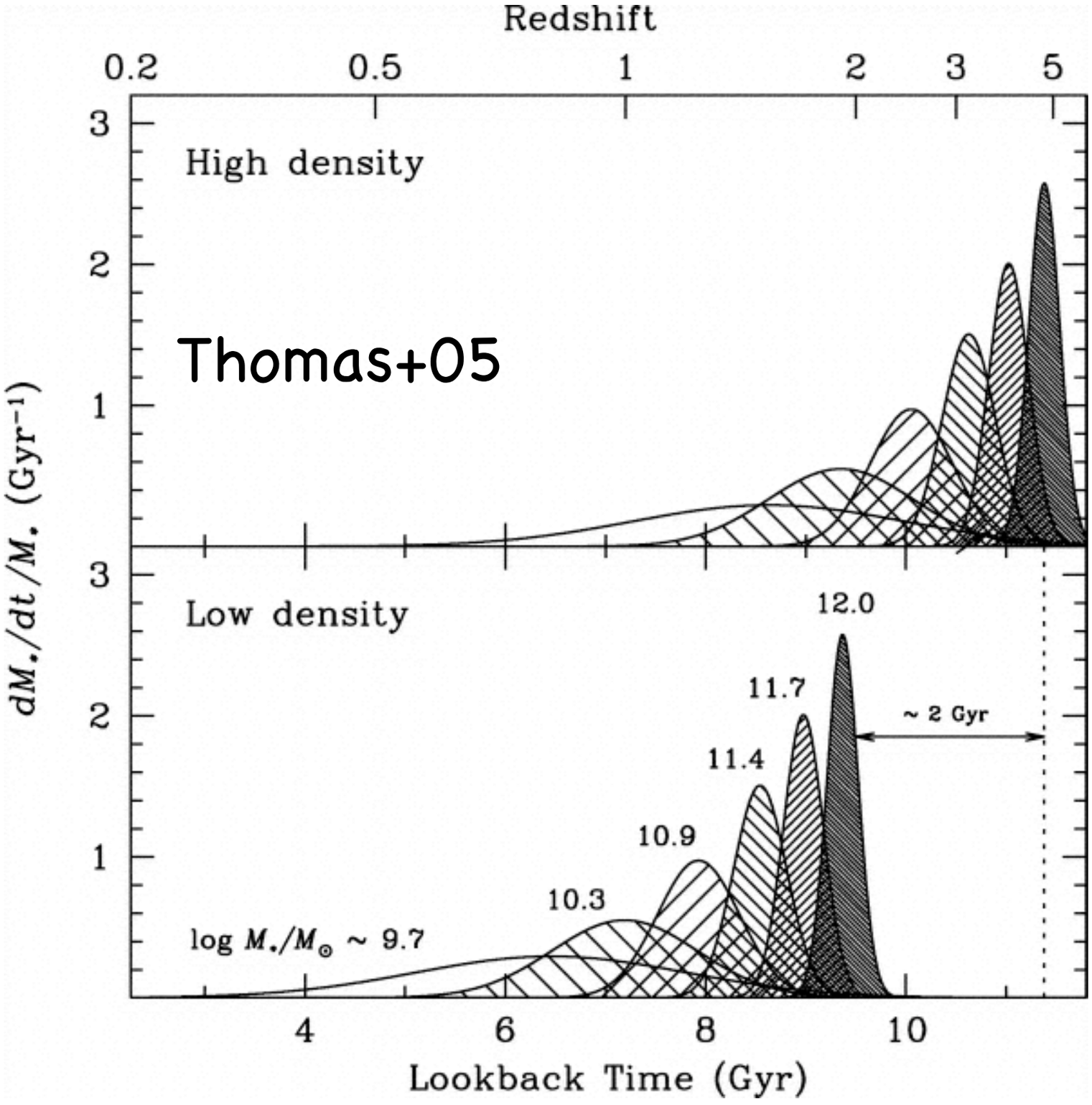
Poggianti+99

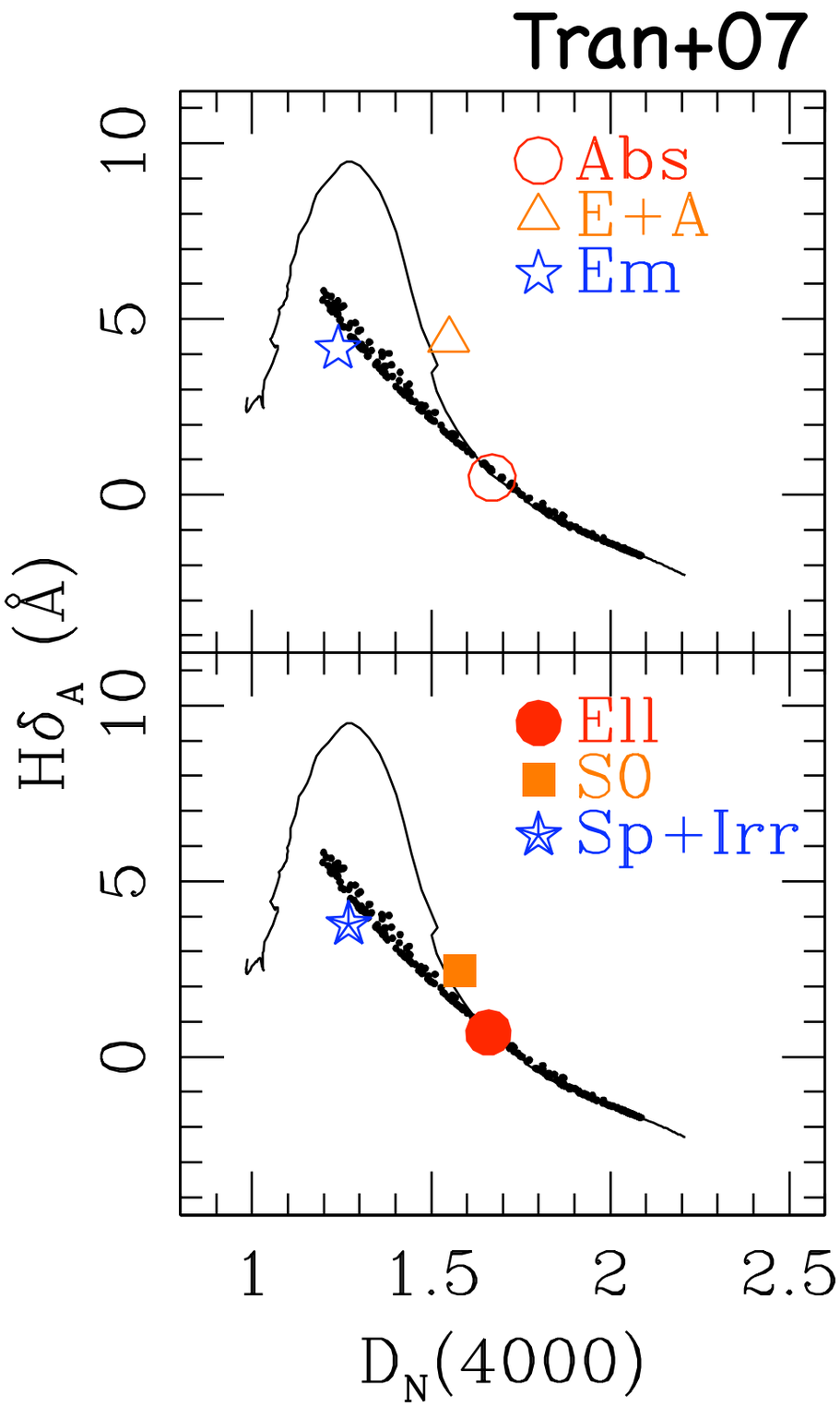
Class	EW [O II] λ3727 (Å)	EW Hδ (Å)	Color
k...	absent	<3	...
k + a...	absent	3–8	...

Balogh+99

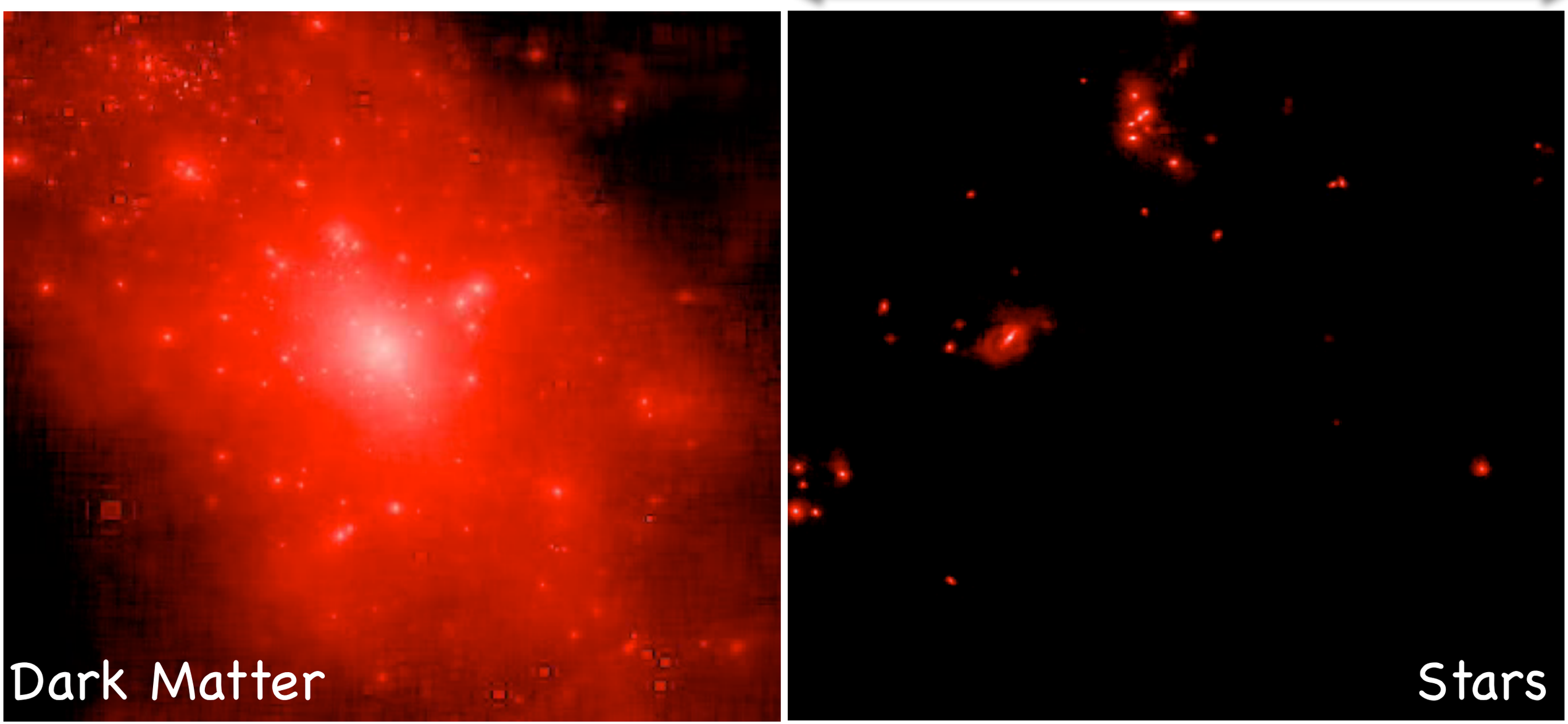
Type	W_0(O II) (Å)	W_0(Hδ) (Å)	D4000	Interpretation
K+A...	<5	>5	...	T, TSB

Post-starburst Galaxies





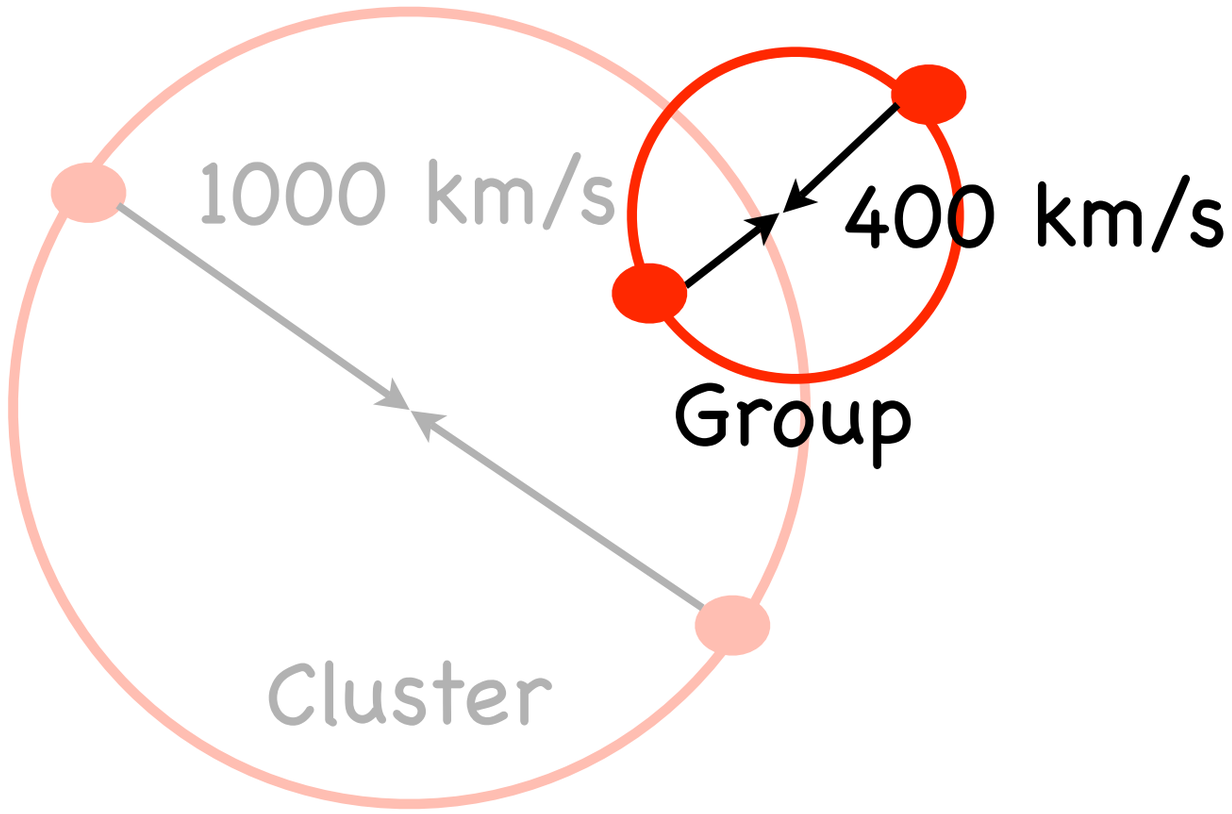
#1: Merging & Red Sequence



Bryan+08: ENZO AMR, 10^{15} M_{sun} cluster

Galaxy-Galaxy Merging

Direct merging infrequent?



Group environment is conducive to galaxy-galaxy merging.

Need groups and assembling galaxy clusters

Galaxy-Galaxy Merging: MS1054

MS 1054-04 (z=0.83, lookback time 7 Gyr)

~16% bound galaxy pairs (spectroscopically confirmed)

Tran+05b

van Dokkum+99

SG1120 (z=0.37)

2

3

1

4

not a pair!

Tran+08

BGG-4

BGG-3

BGG-2

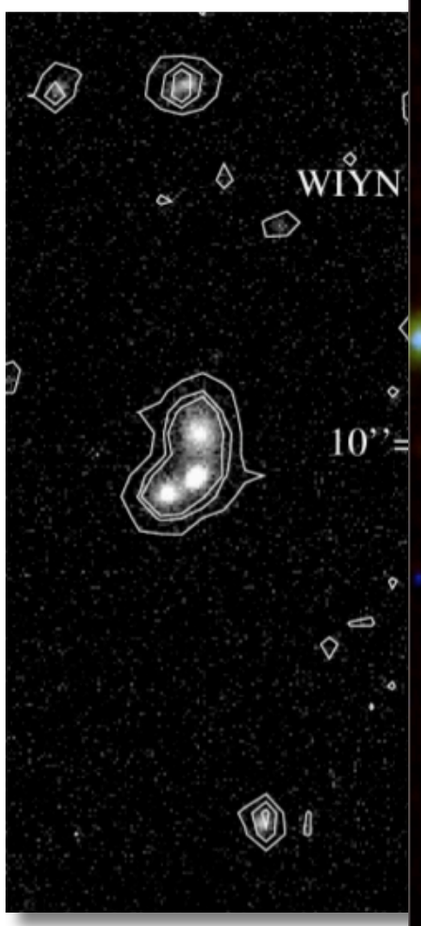
BGG-1

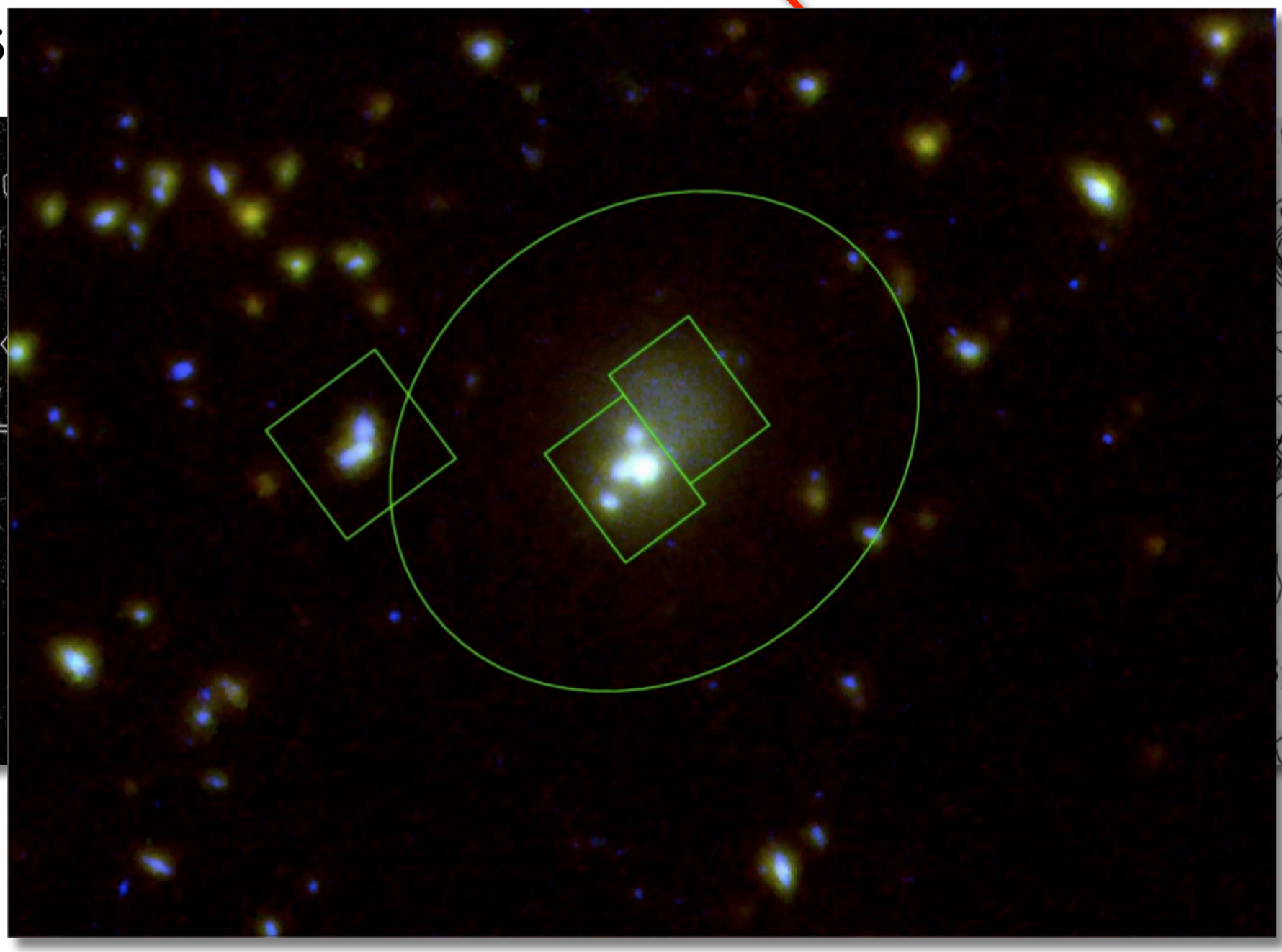
Brightest Cluster/Group Galaxy

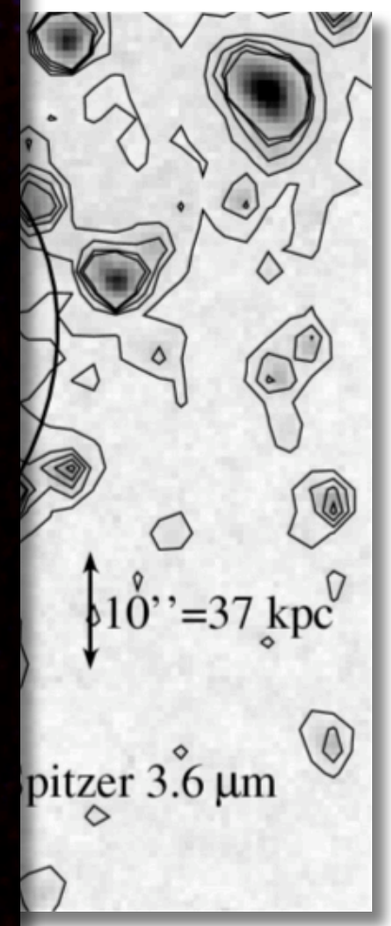
Growing the BCG and ICL via dry merging

Rines+07 (z=0.39)

s





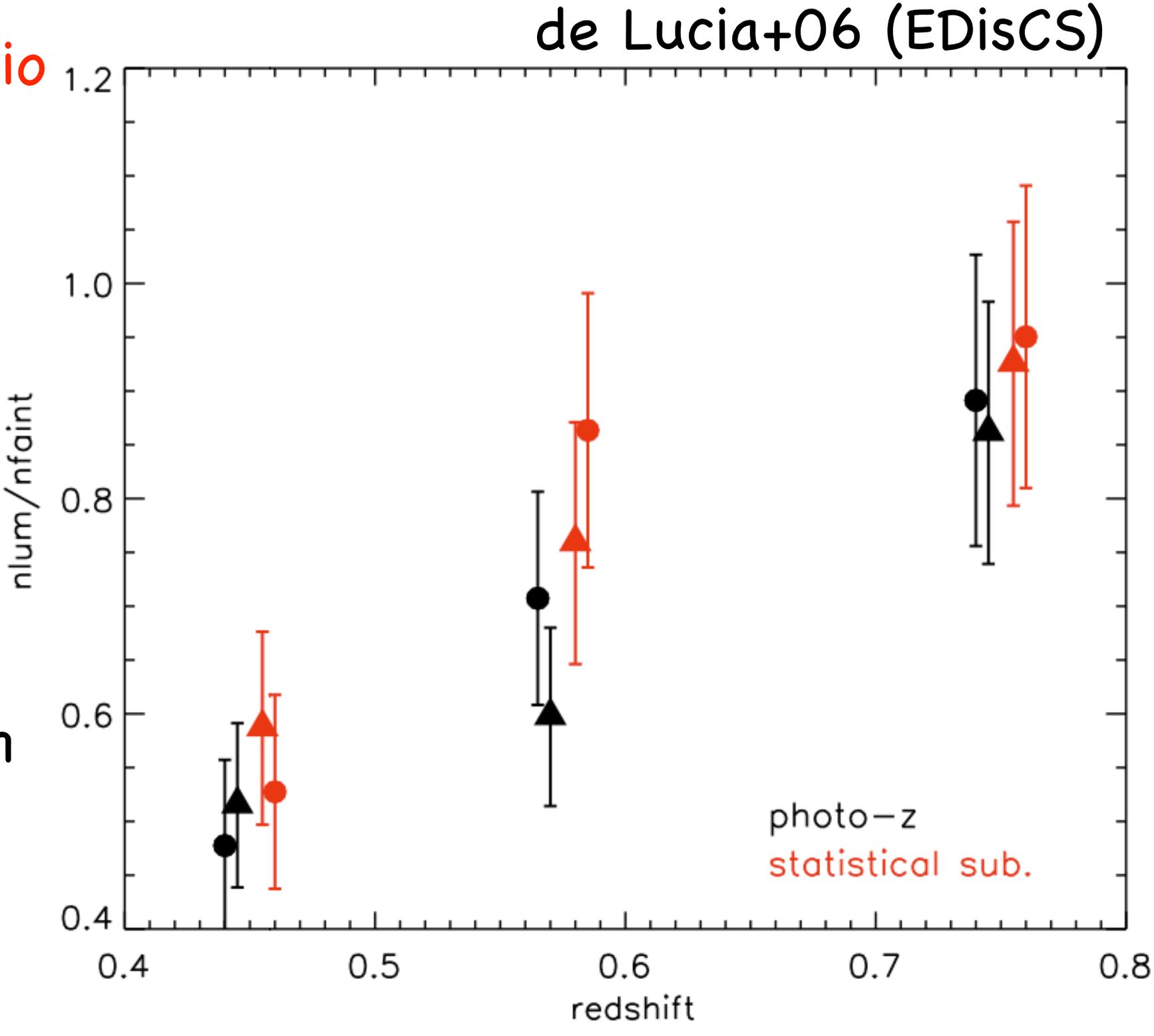


Building up the Red Sequence

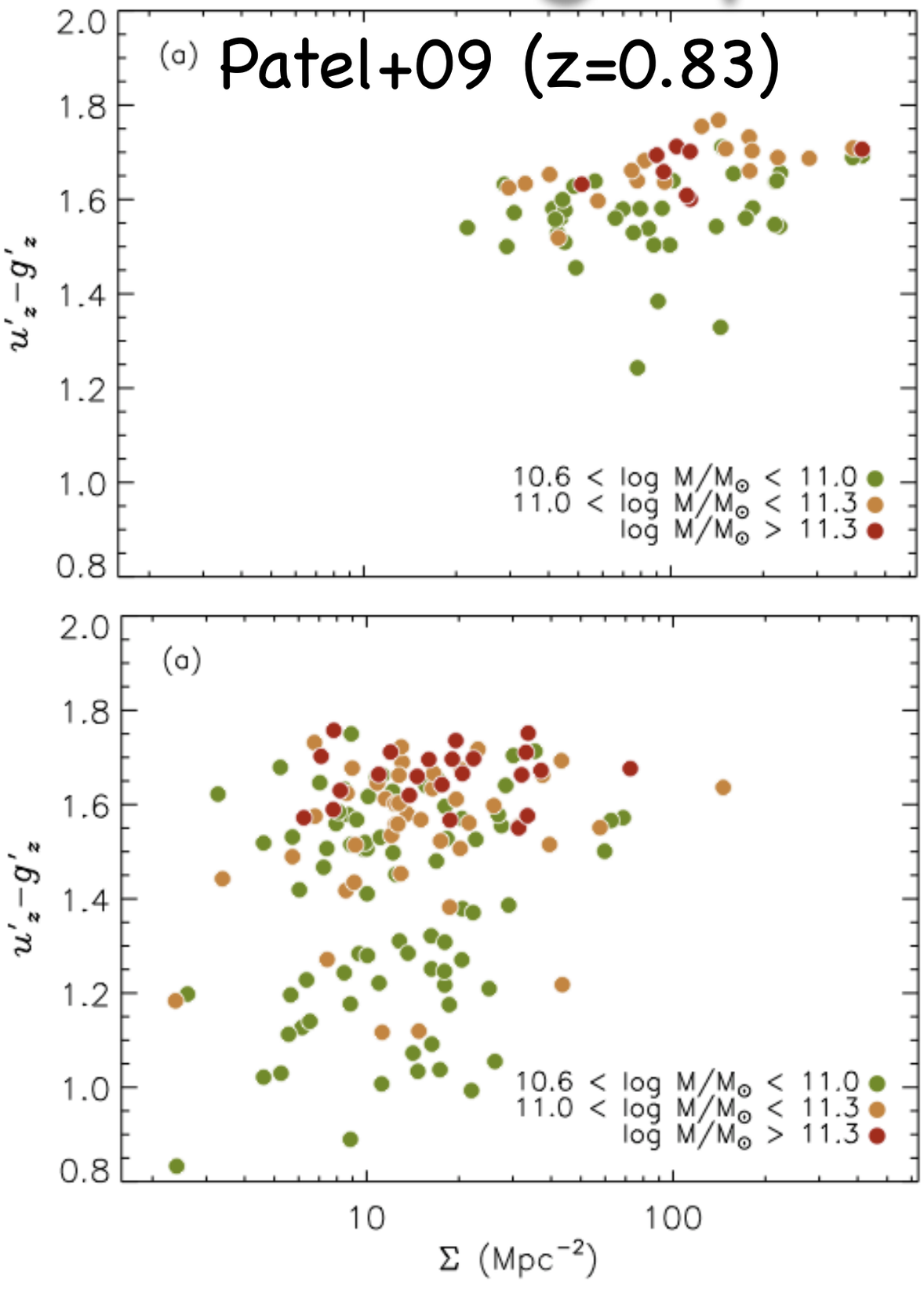
Giant to dwarf ratio in clusters evolves (Koyama+07 c.f. Crawford+08)

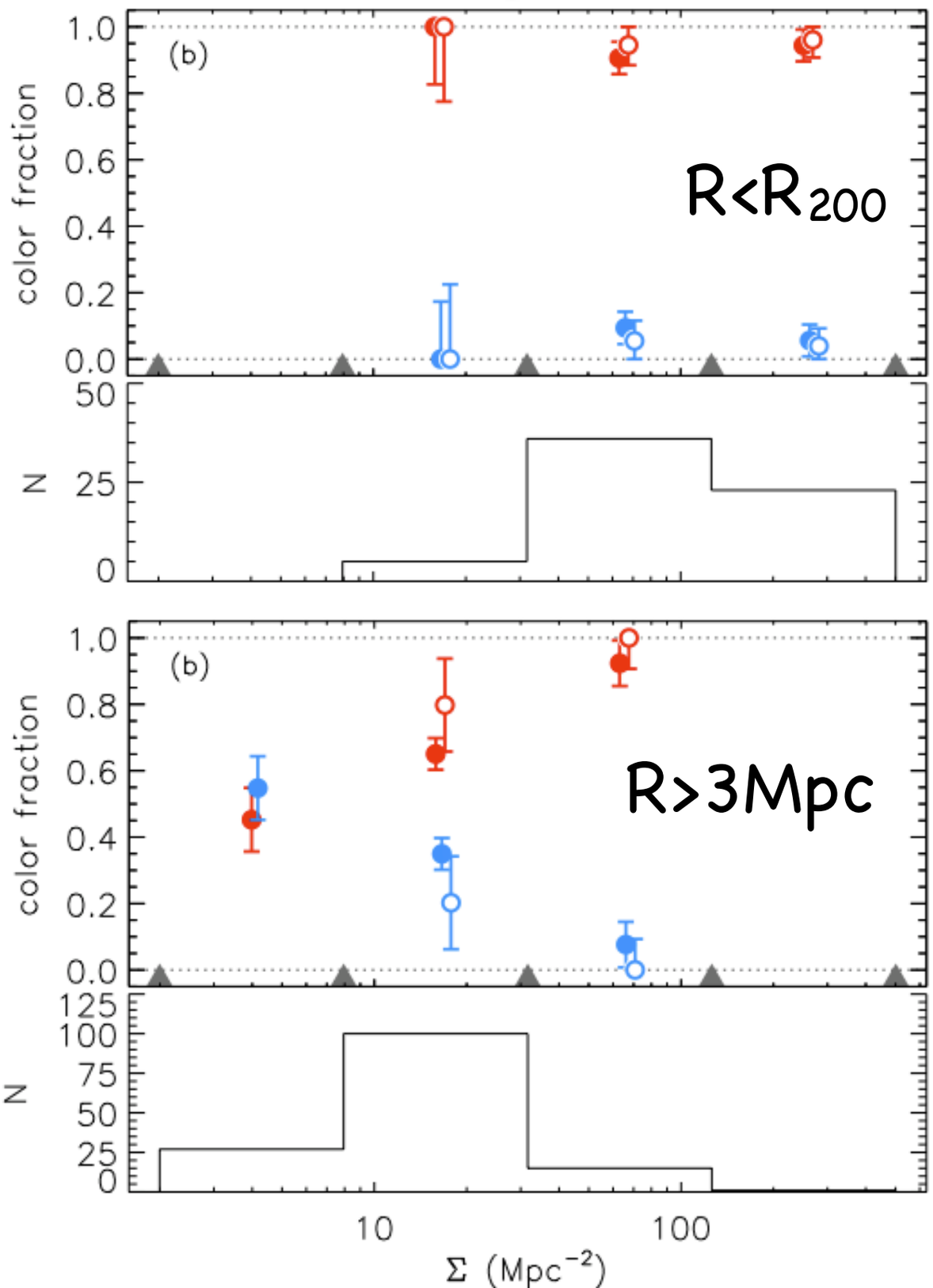
Dependent on cluster richness? (Tanaka+07)

Field contamination of photo-z's?



Building up the Red Sequence

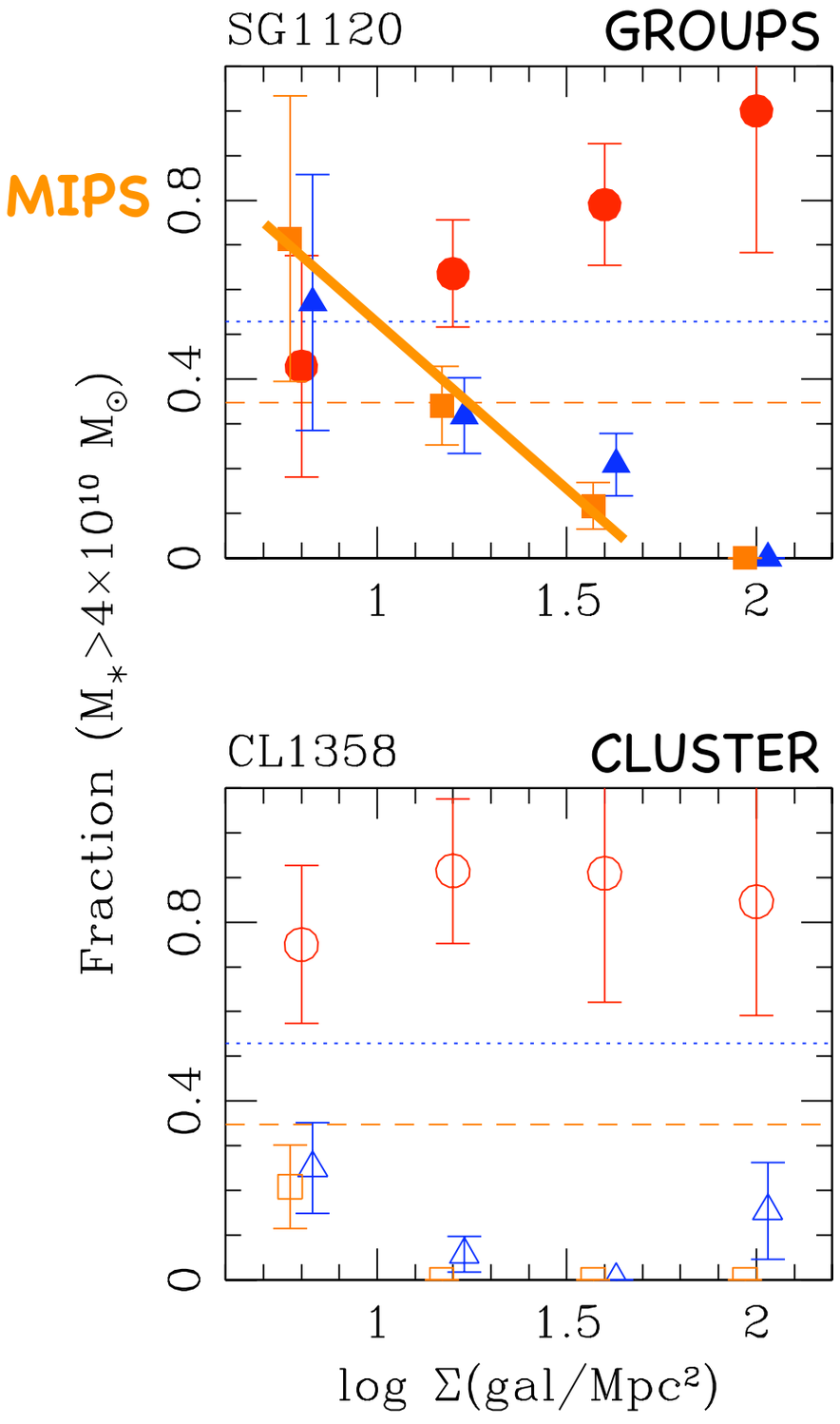




Building up the Red Sequence

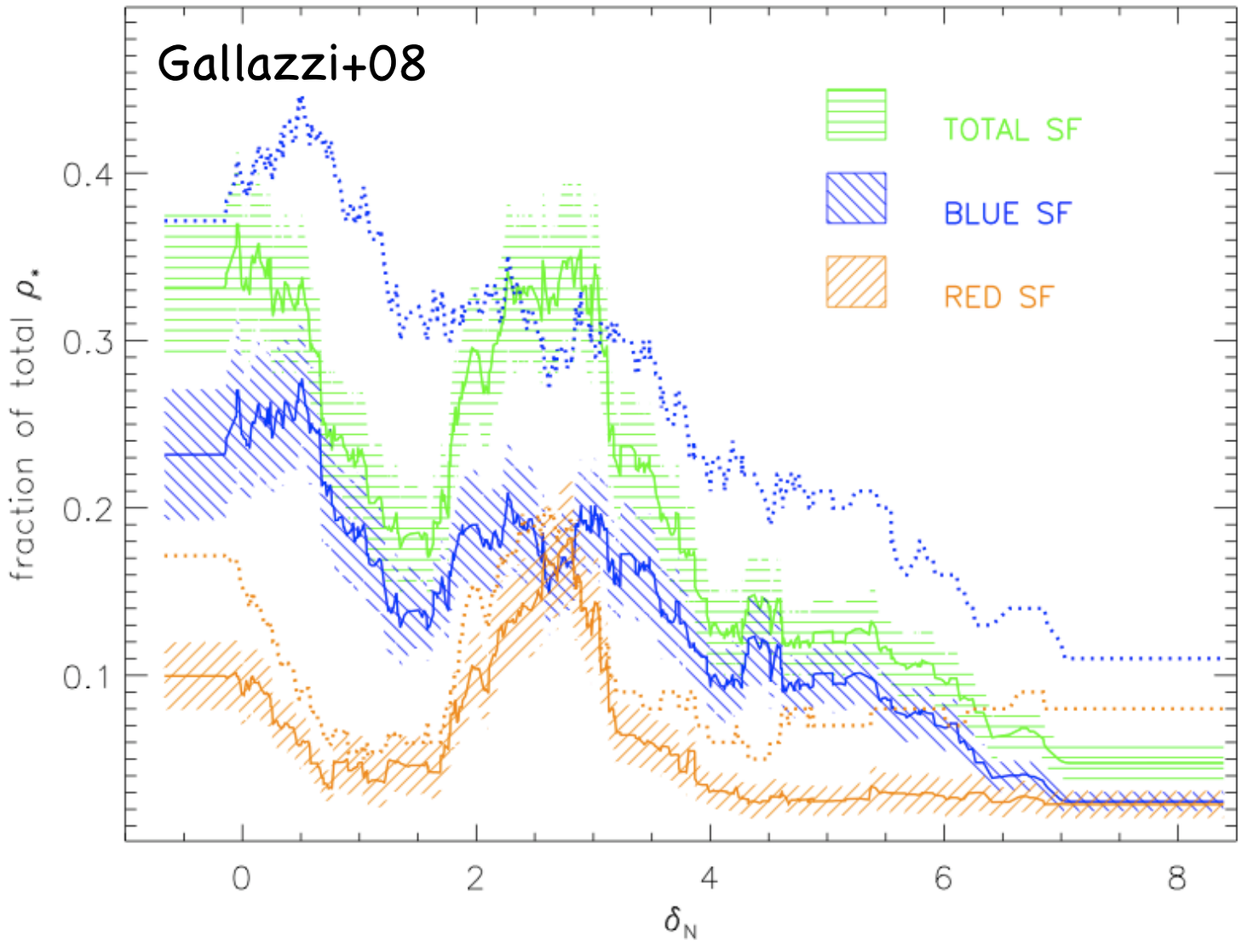
Tran, Saintonge in prep

MIPS



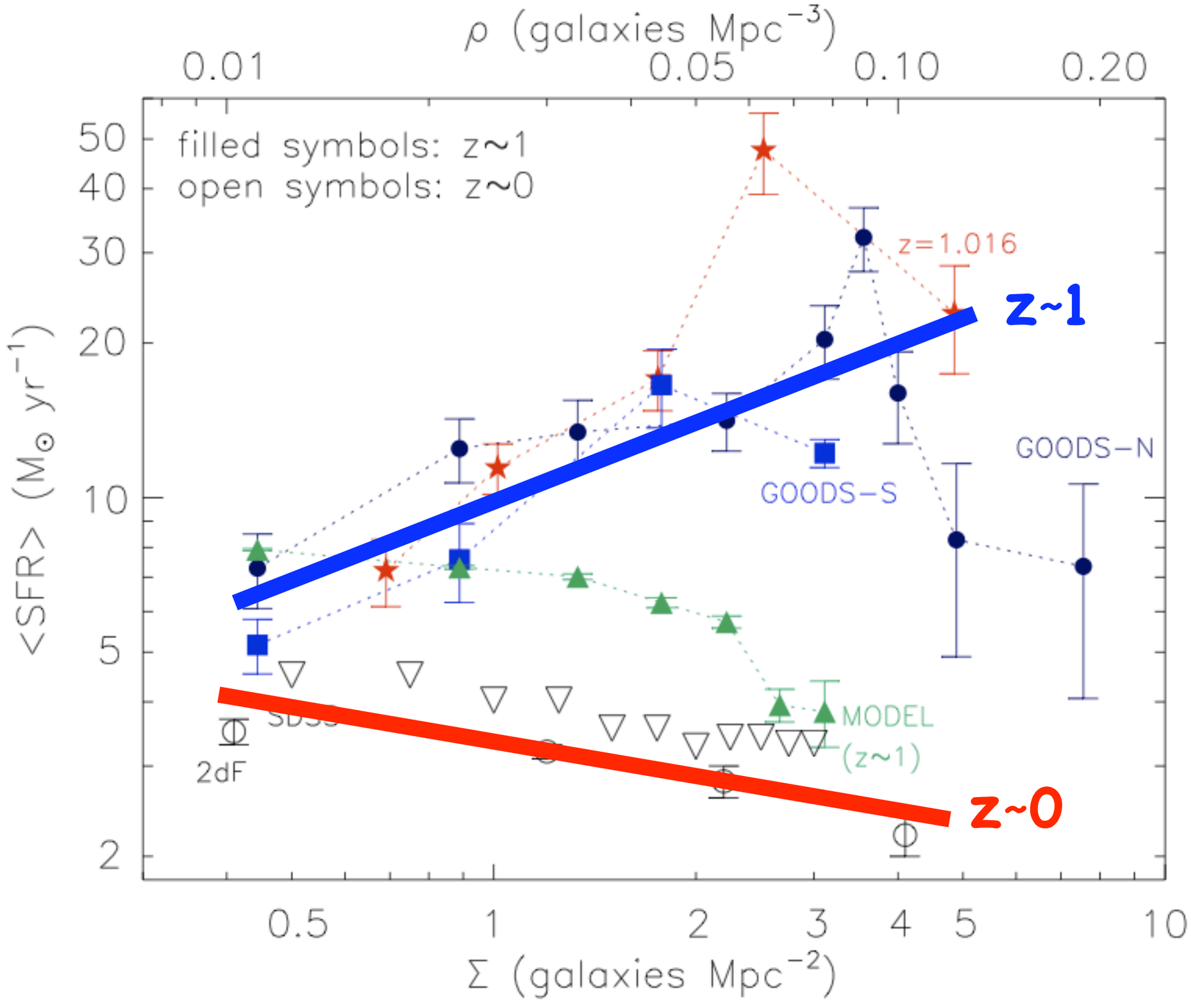
Higher Dusty SF % at intermediate densities

(Koyama poster)

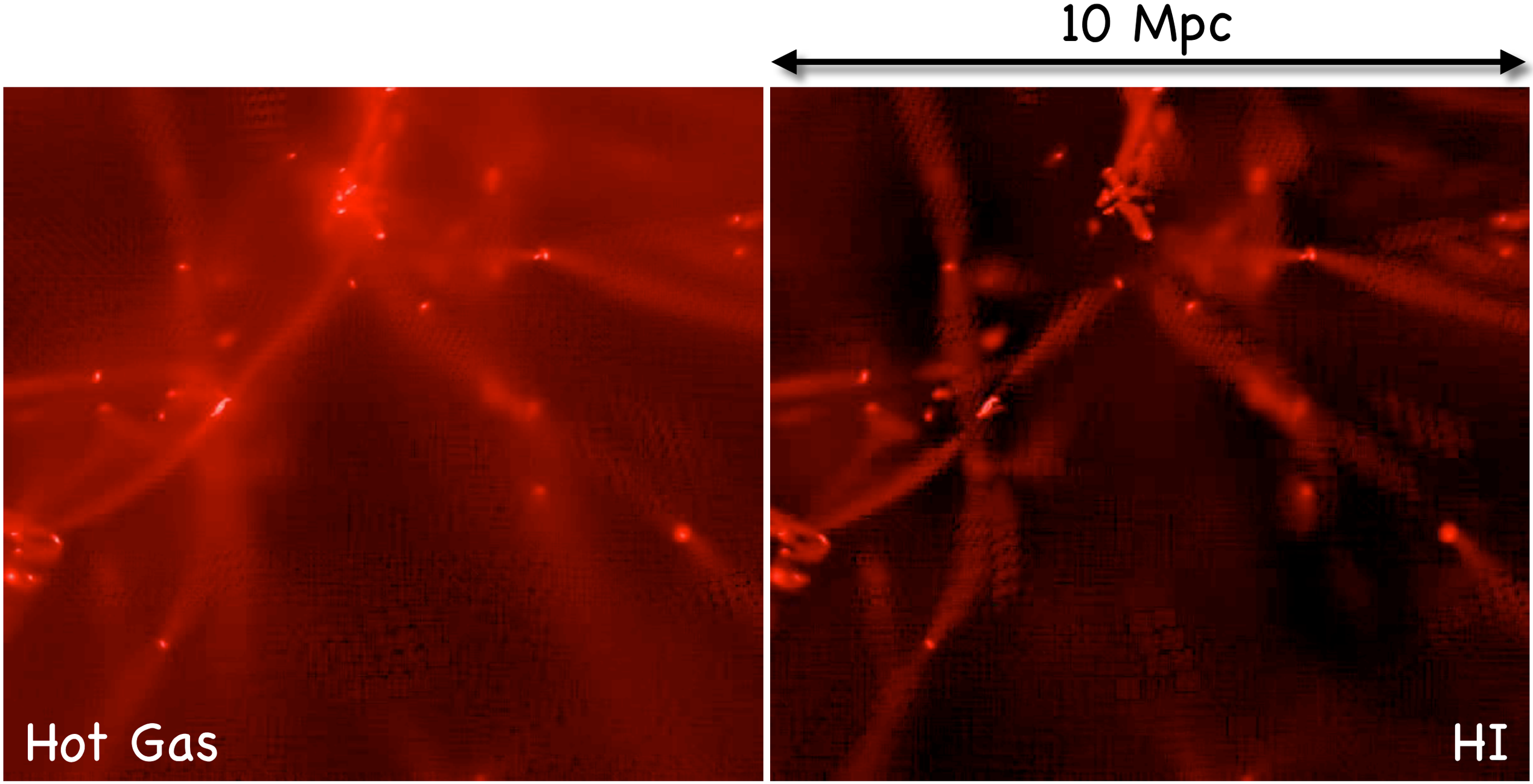


Building up the Red Sequence

Elbaz+07: GOODS



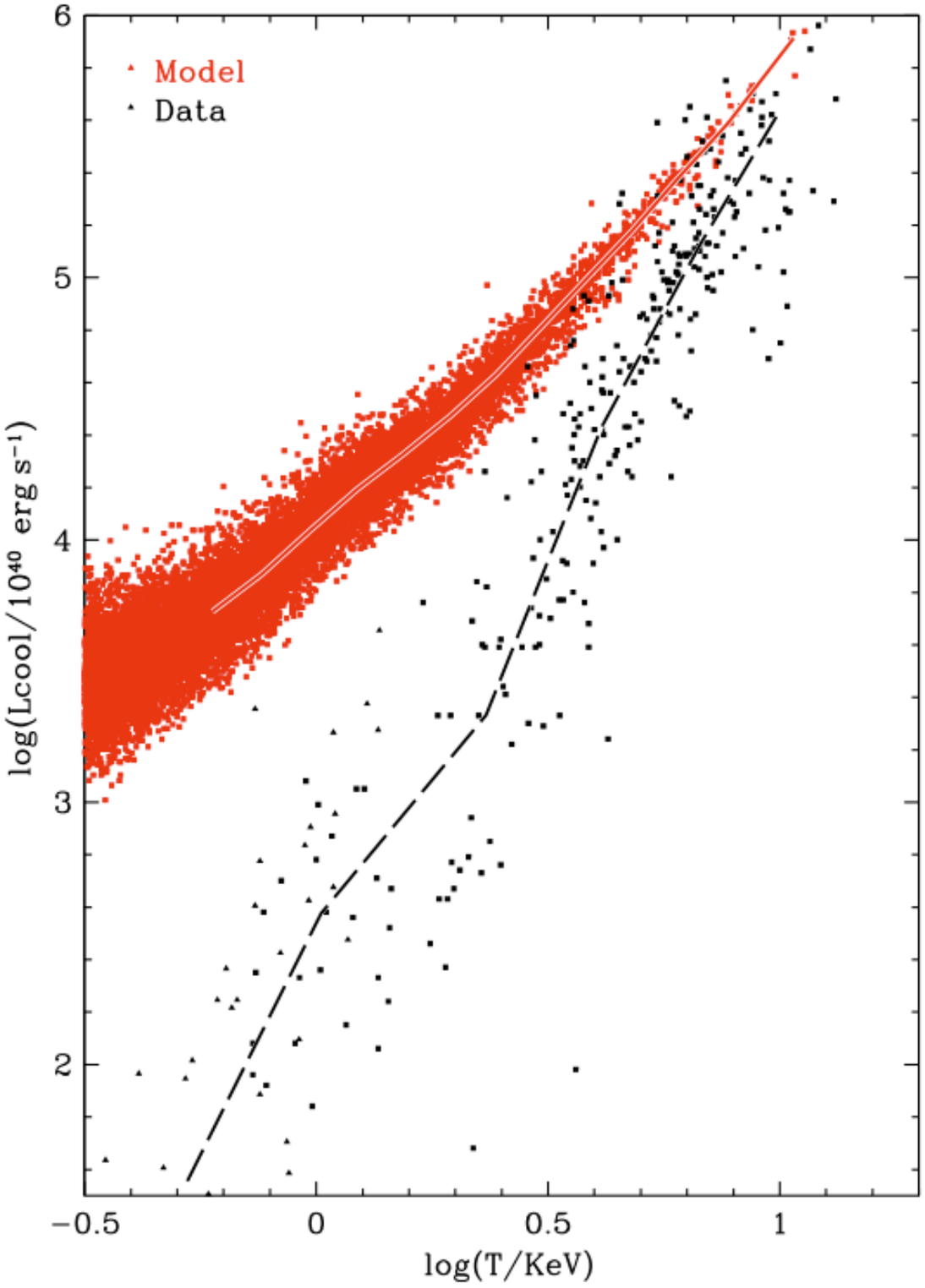
#2: Gas Stripping

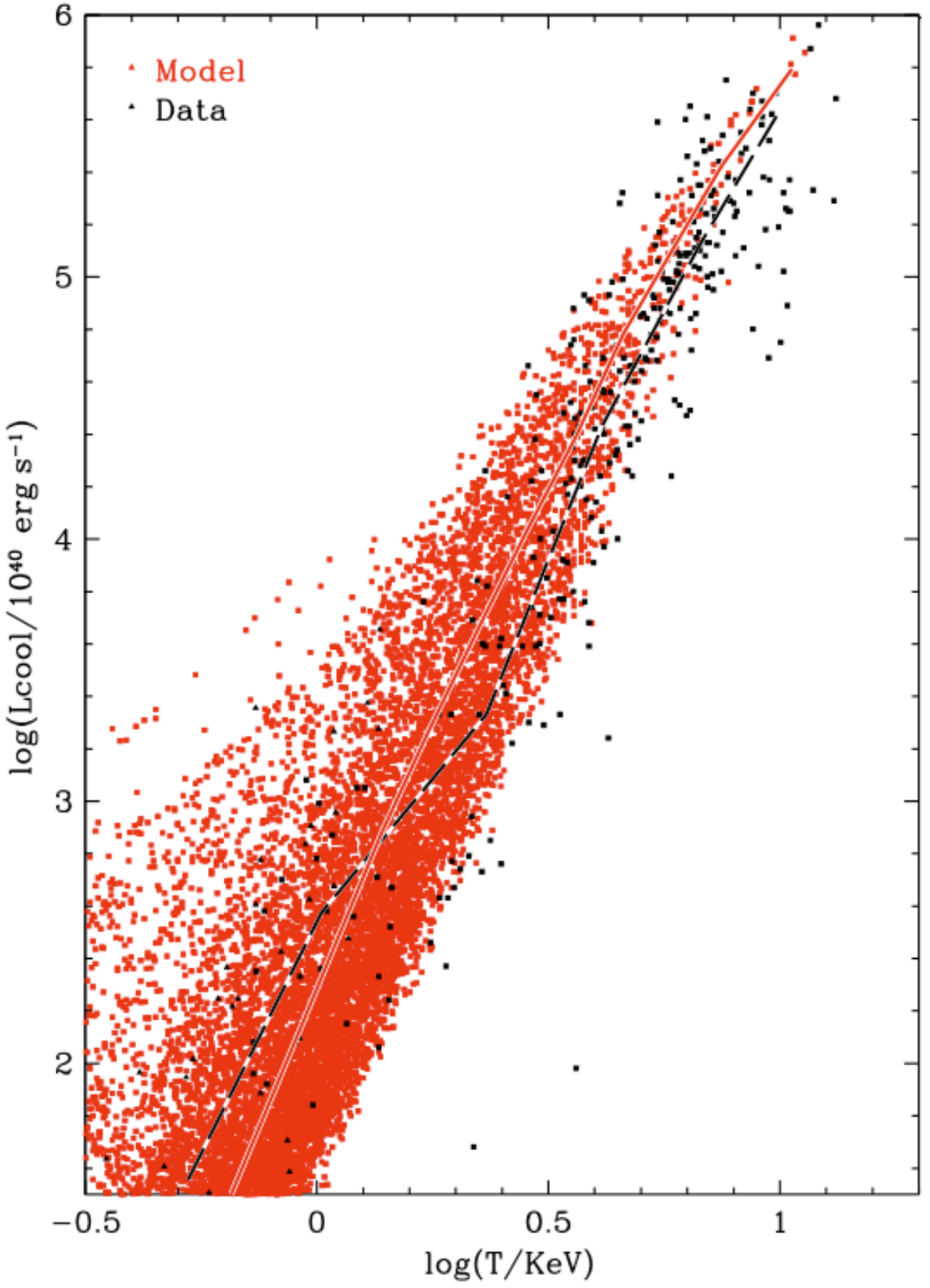


Tonnesen & Bryan 2007, 2009

X-ray Gas

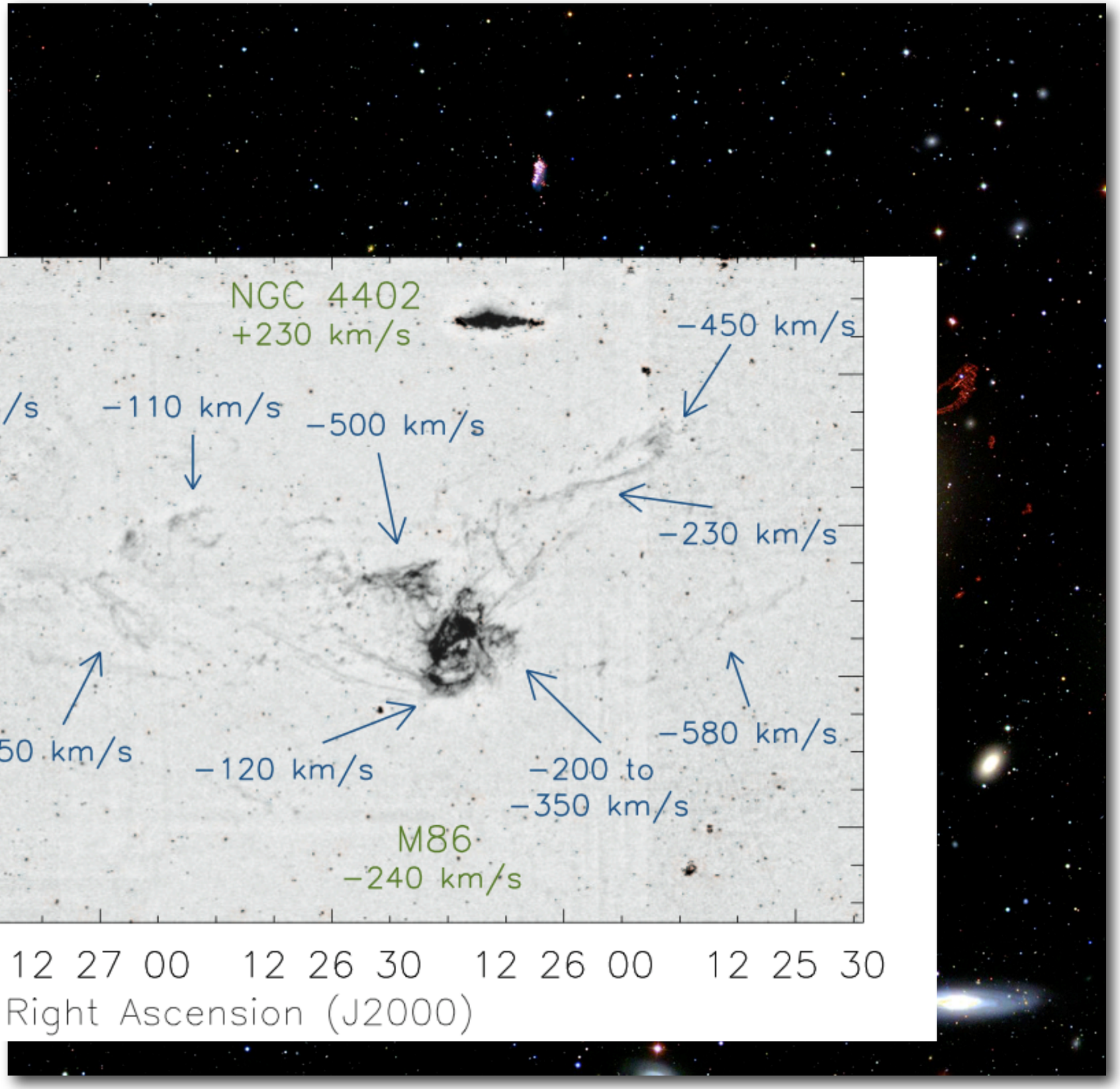
Bower+08





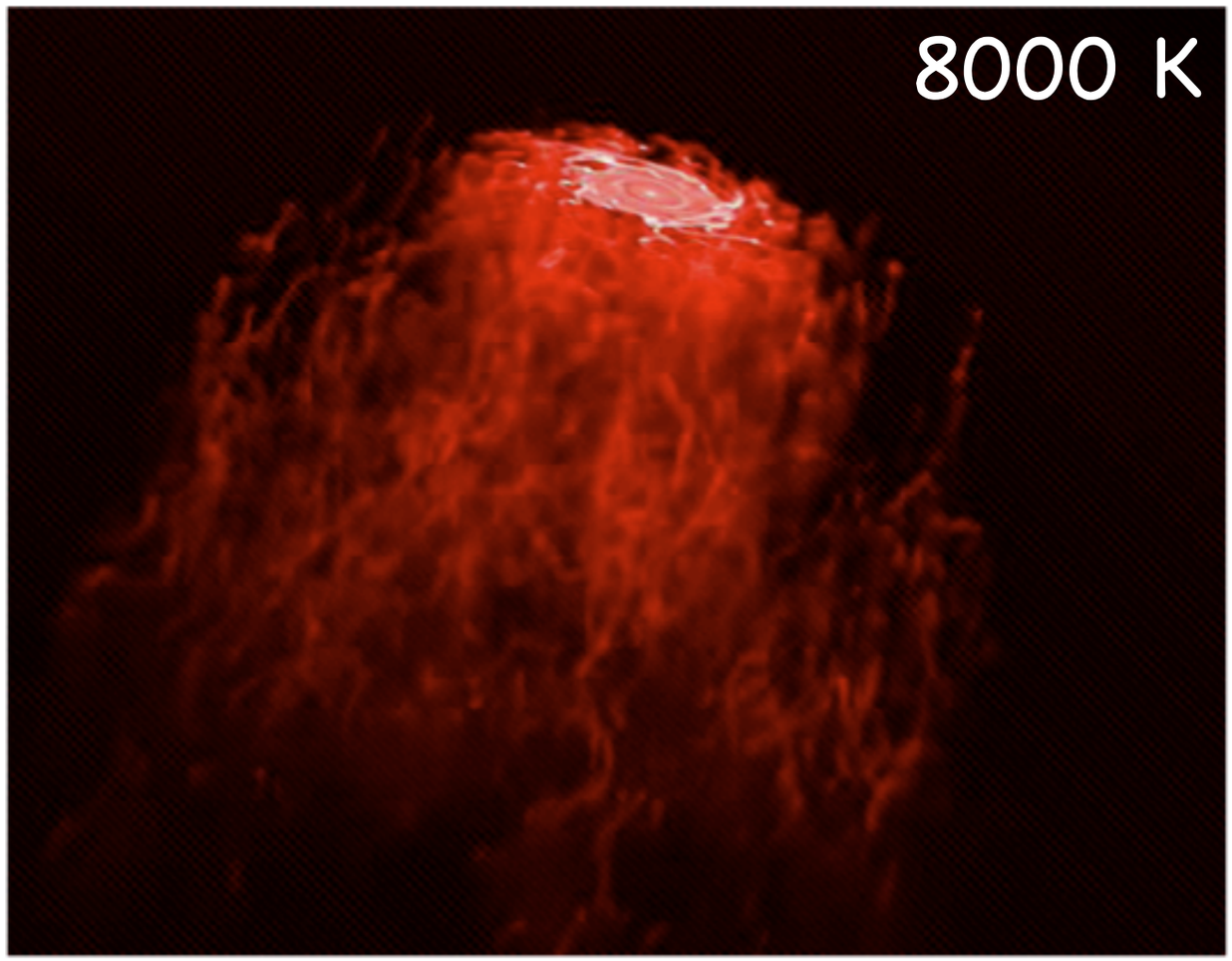
Virgo Cluster

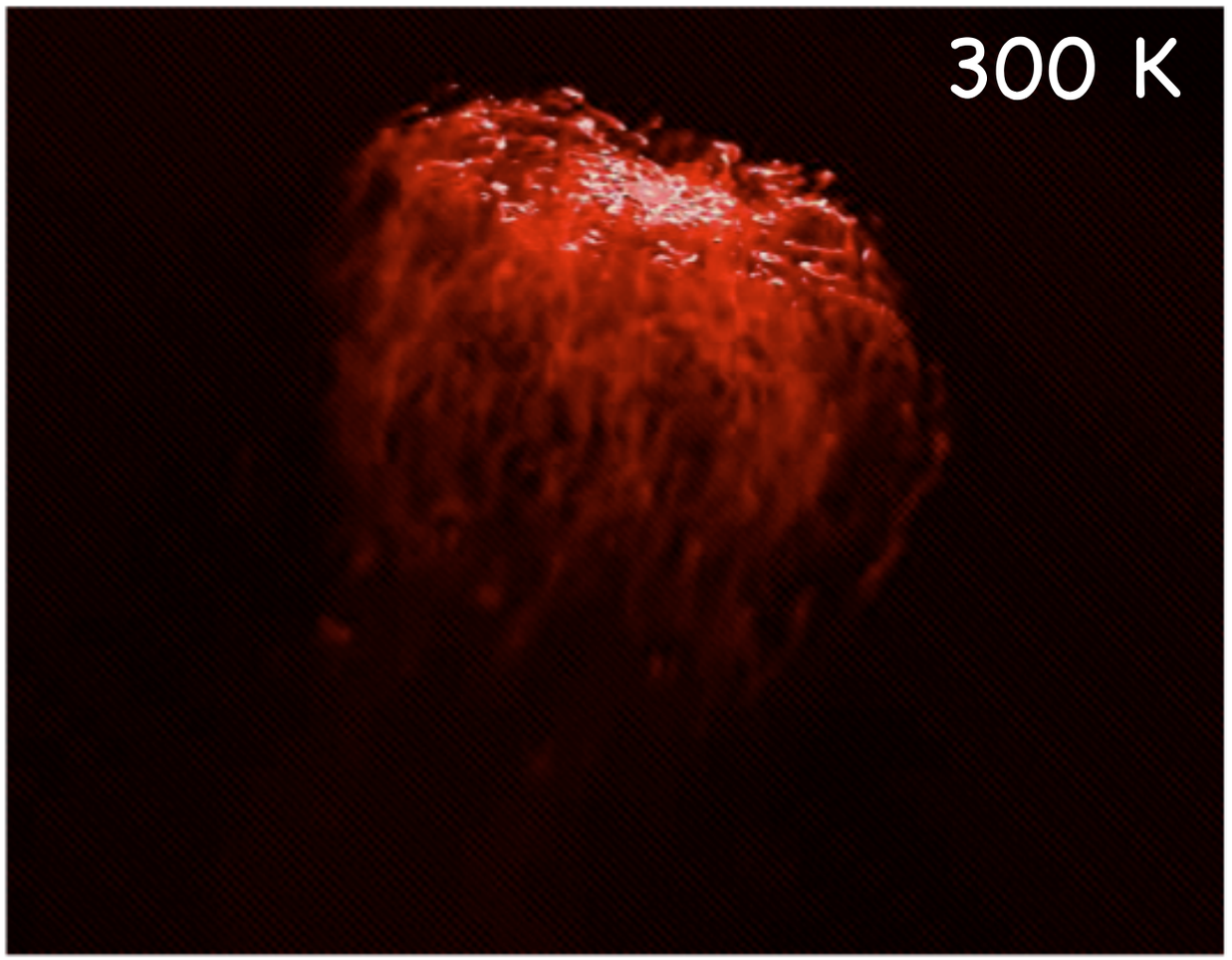
Intracluster Hα
Bulk motion



Kenney+08

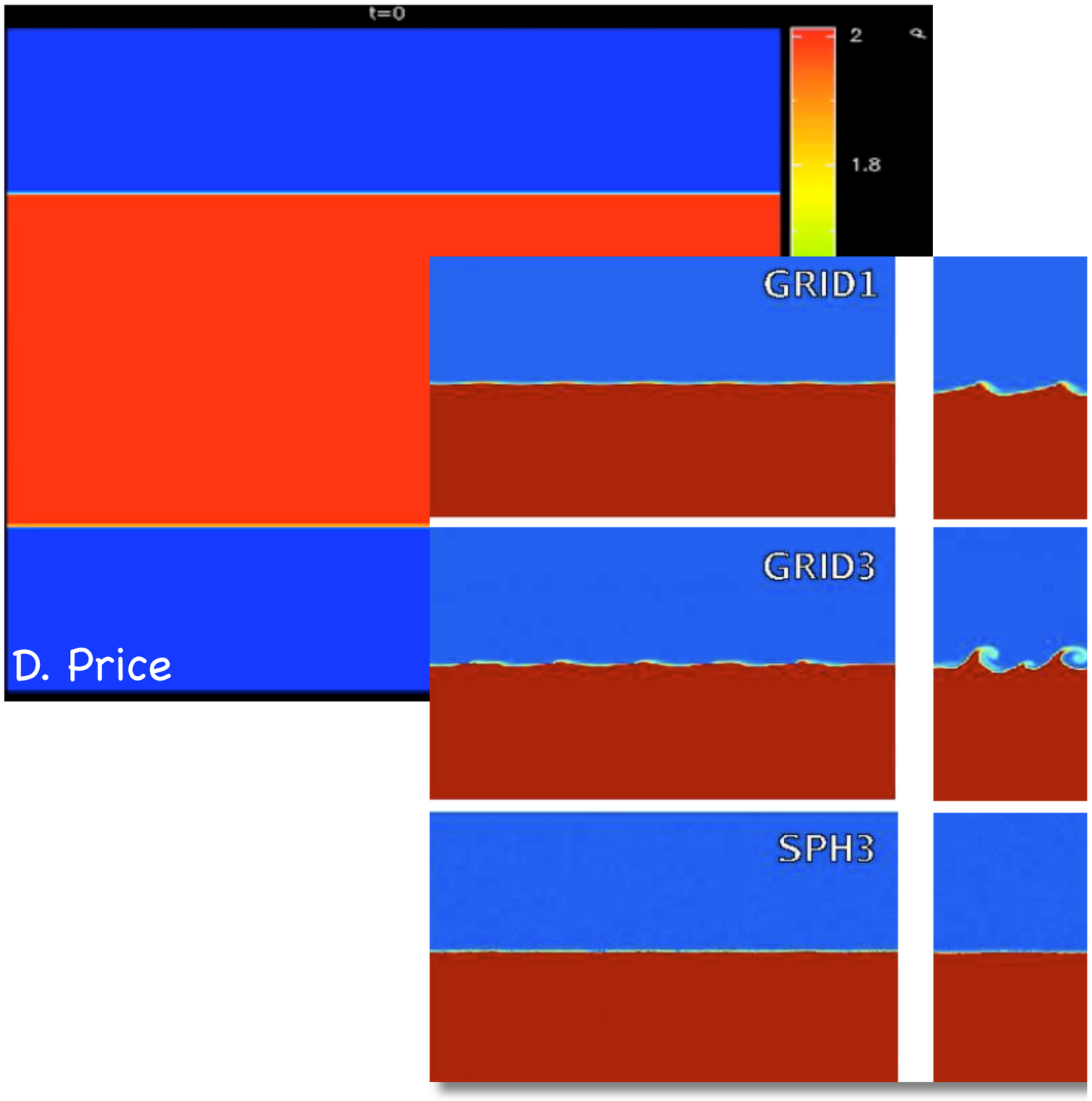
Galaxy Simulations

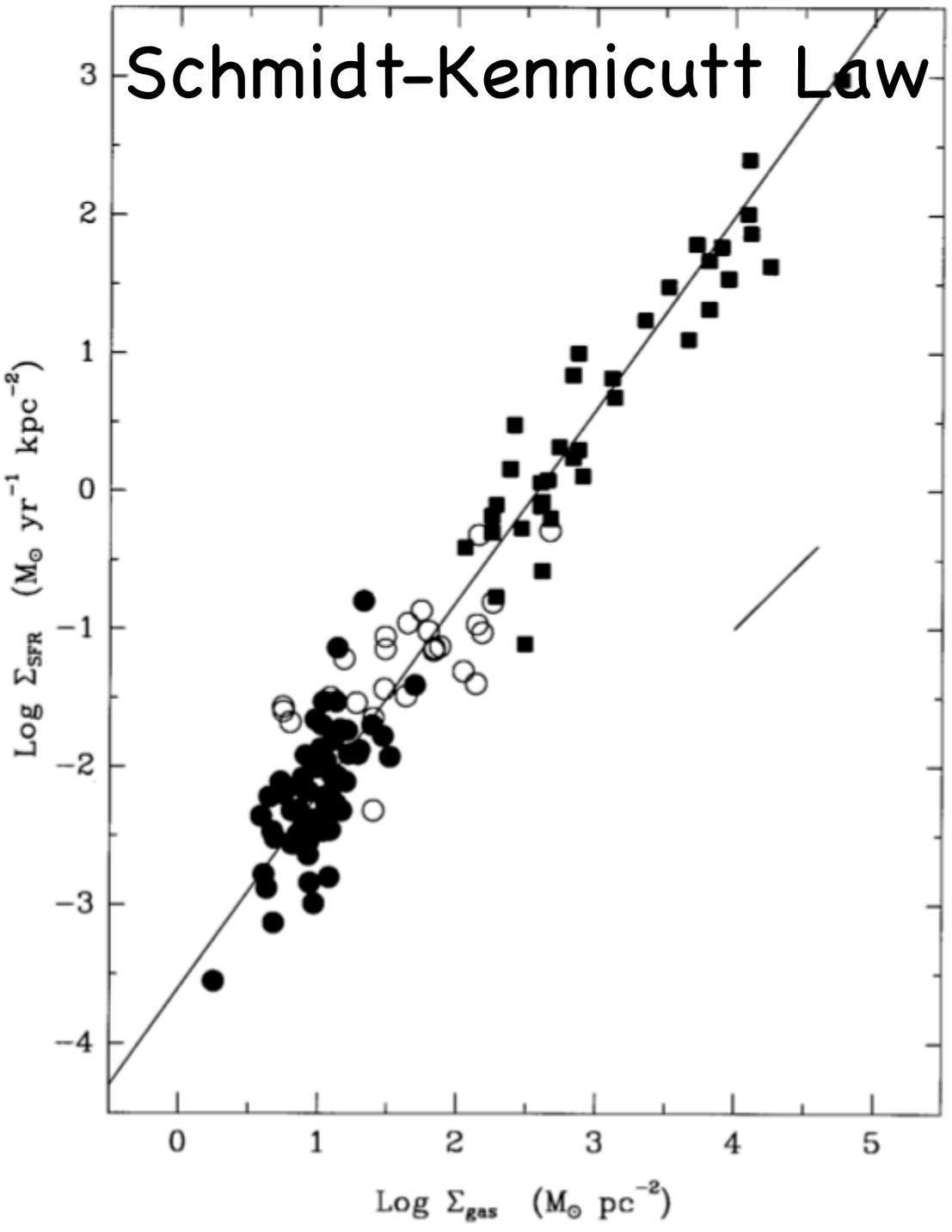




Tonnesen & Bryan 2009
Gas stripping in multi-phase medium

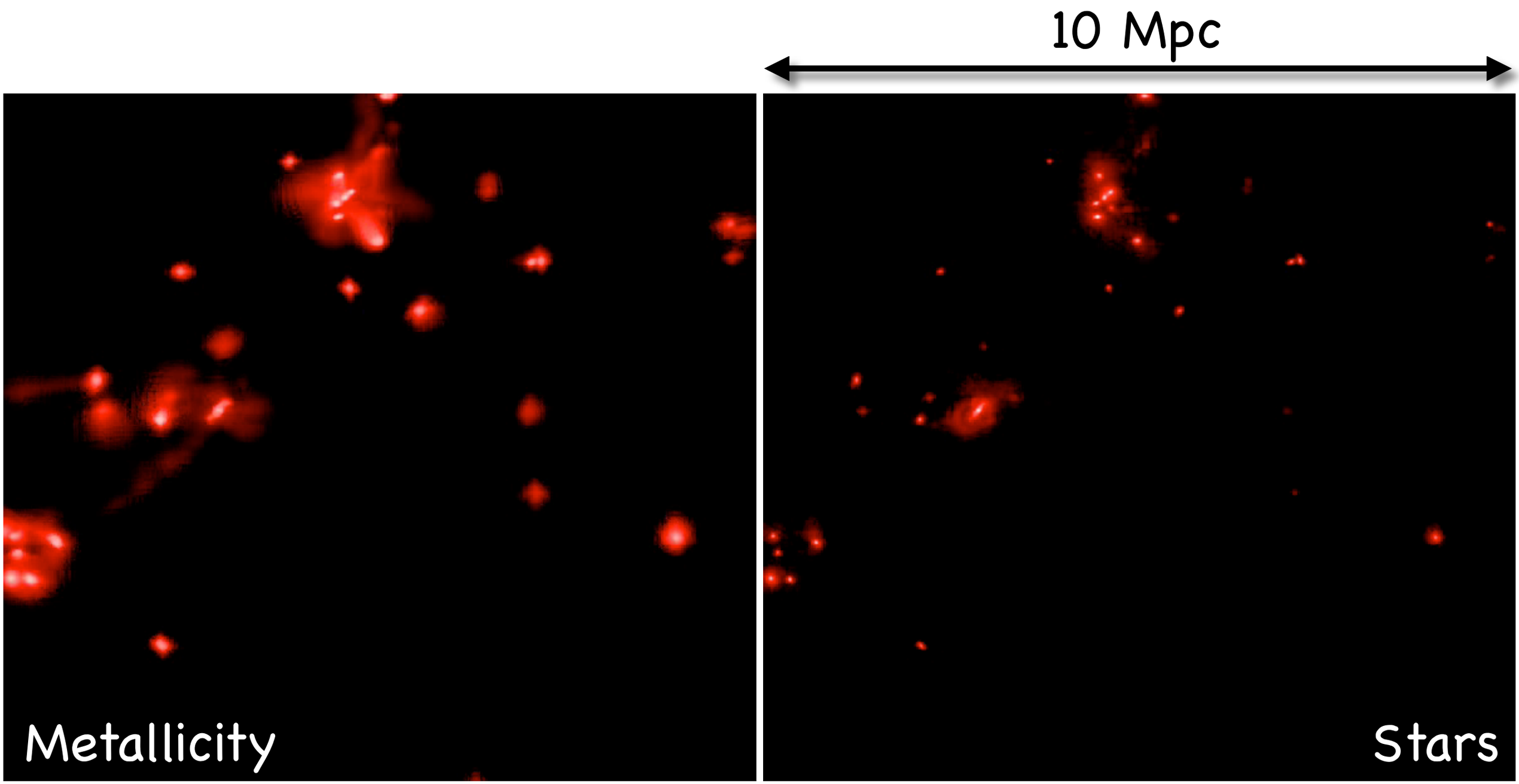
Galaxy Simulations





Modeling the gas physics correctly is hard.

#3: Dynamical Friction & ICL

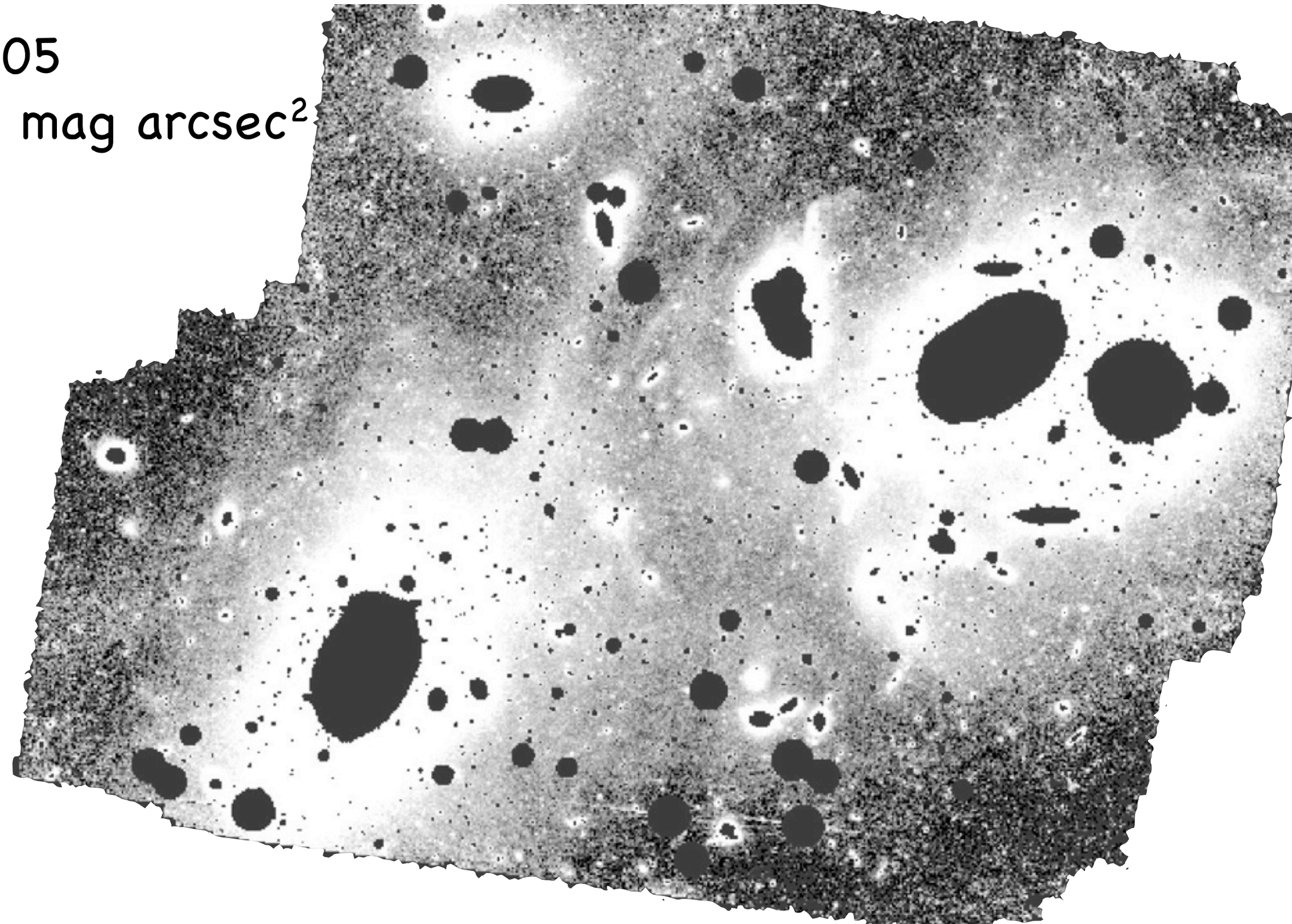


Bryan+08: ENZO AMR, 10^{15} M_{sun} cluster

Intracluster Light: Virgo

Mihos+05

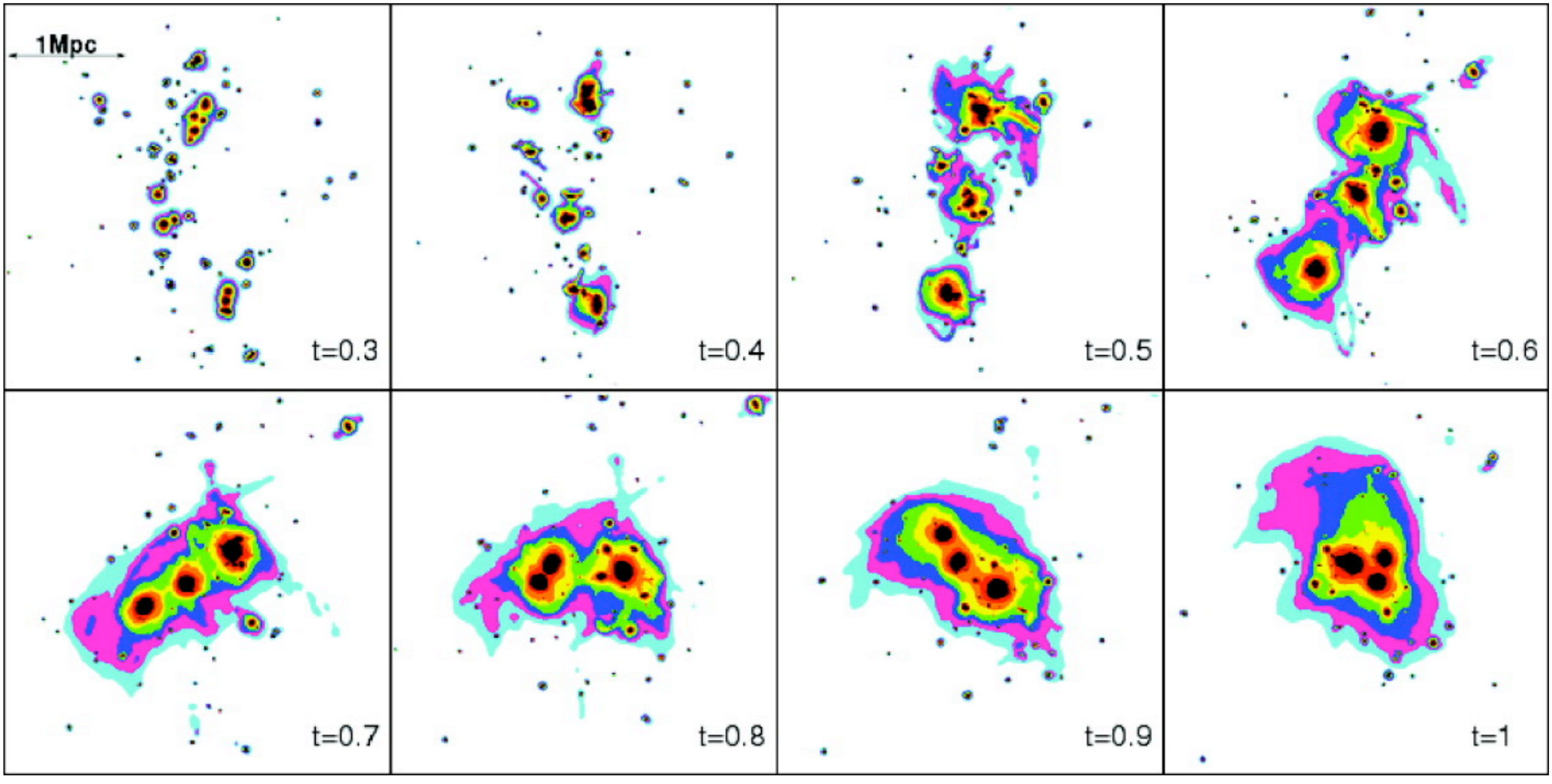
$\mu > 26.5$ mag arcsec^2



Intracluster/group Light

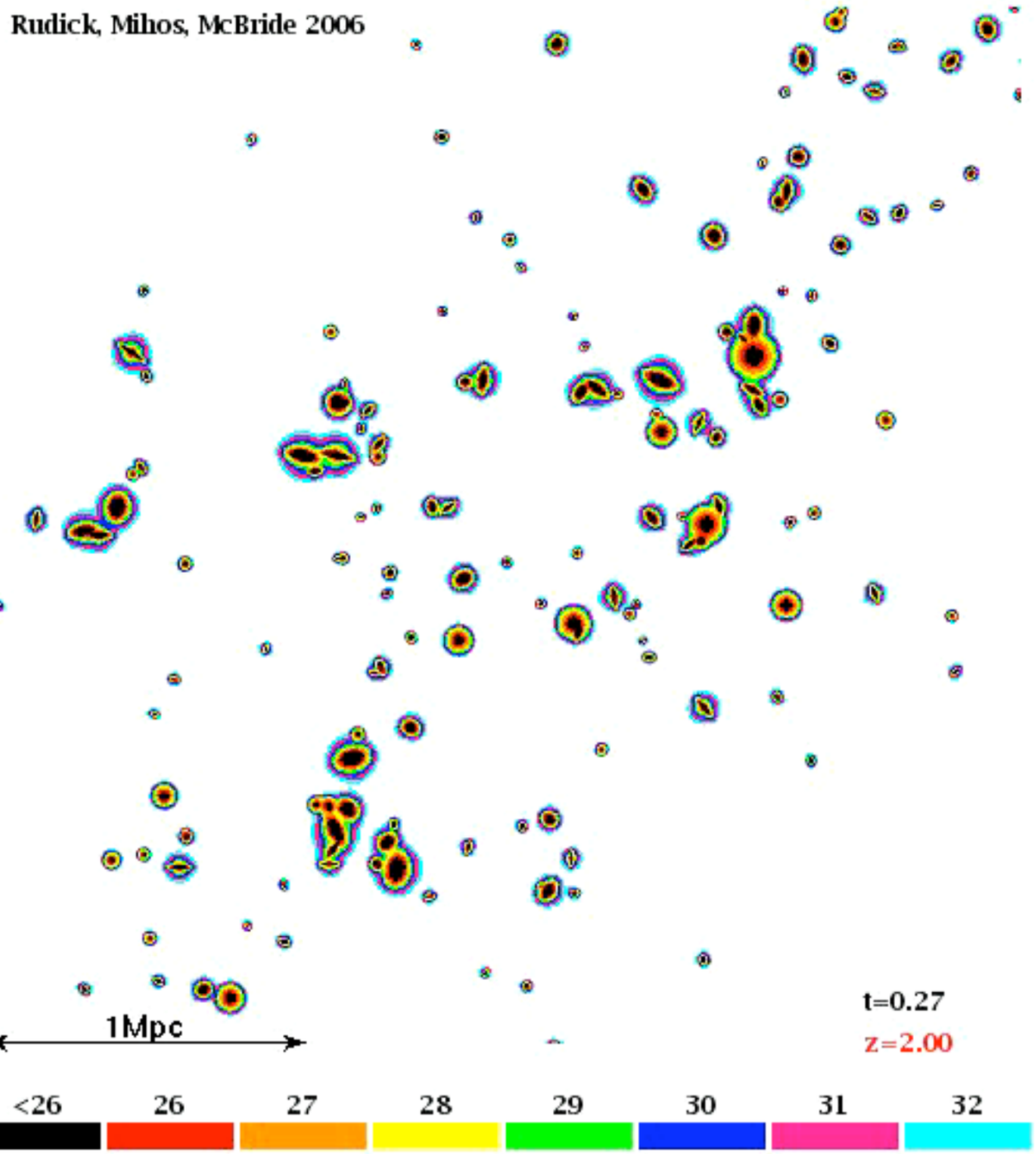
Rudick+06 (Models): ICL structure evolves

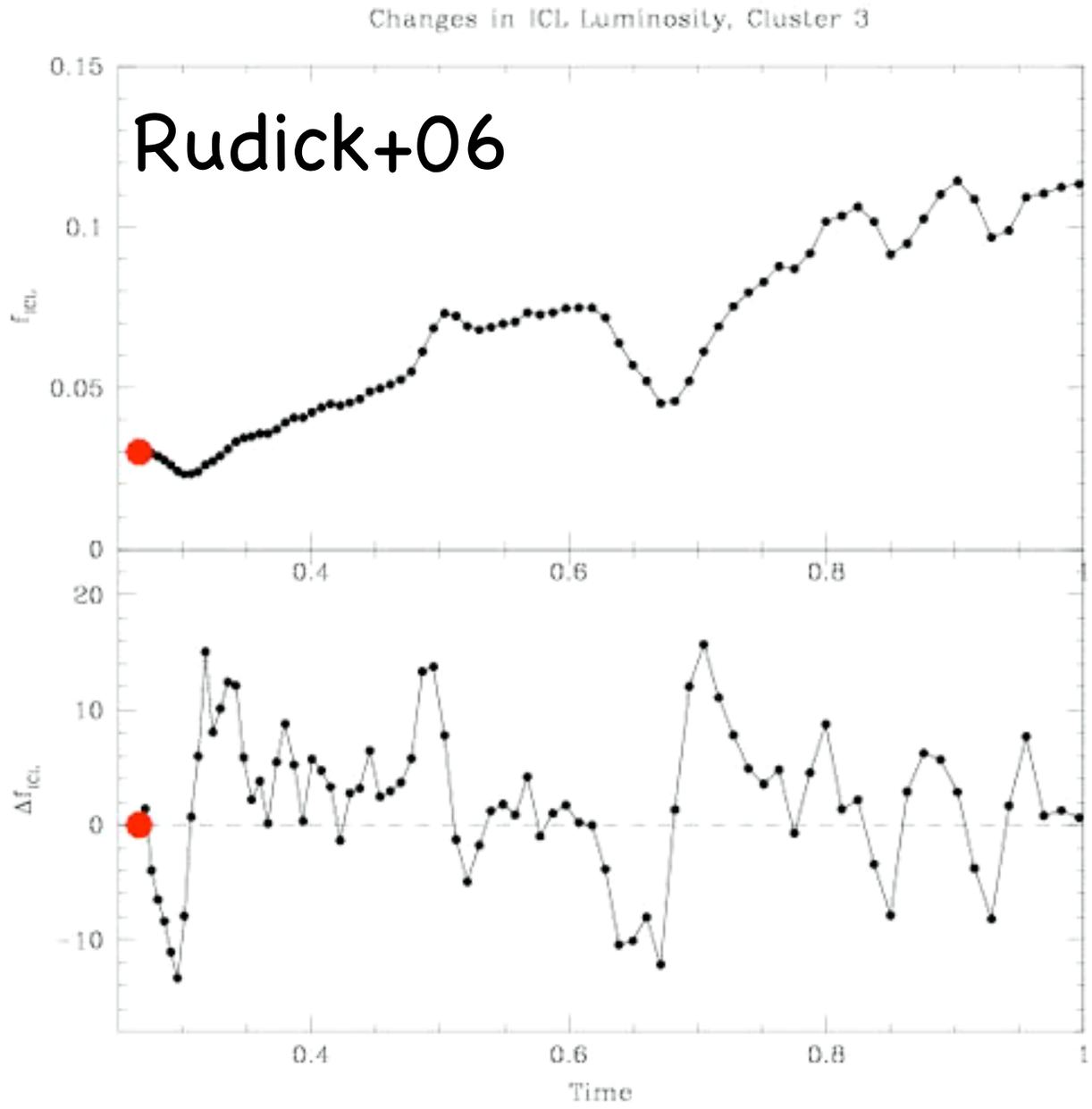
➜ fossil record of cluster assembly



Intracluster/group Light

Build-up of ICM linked to accretion of galaxy groups



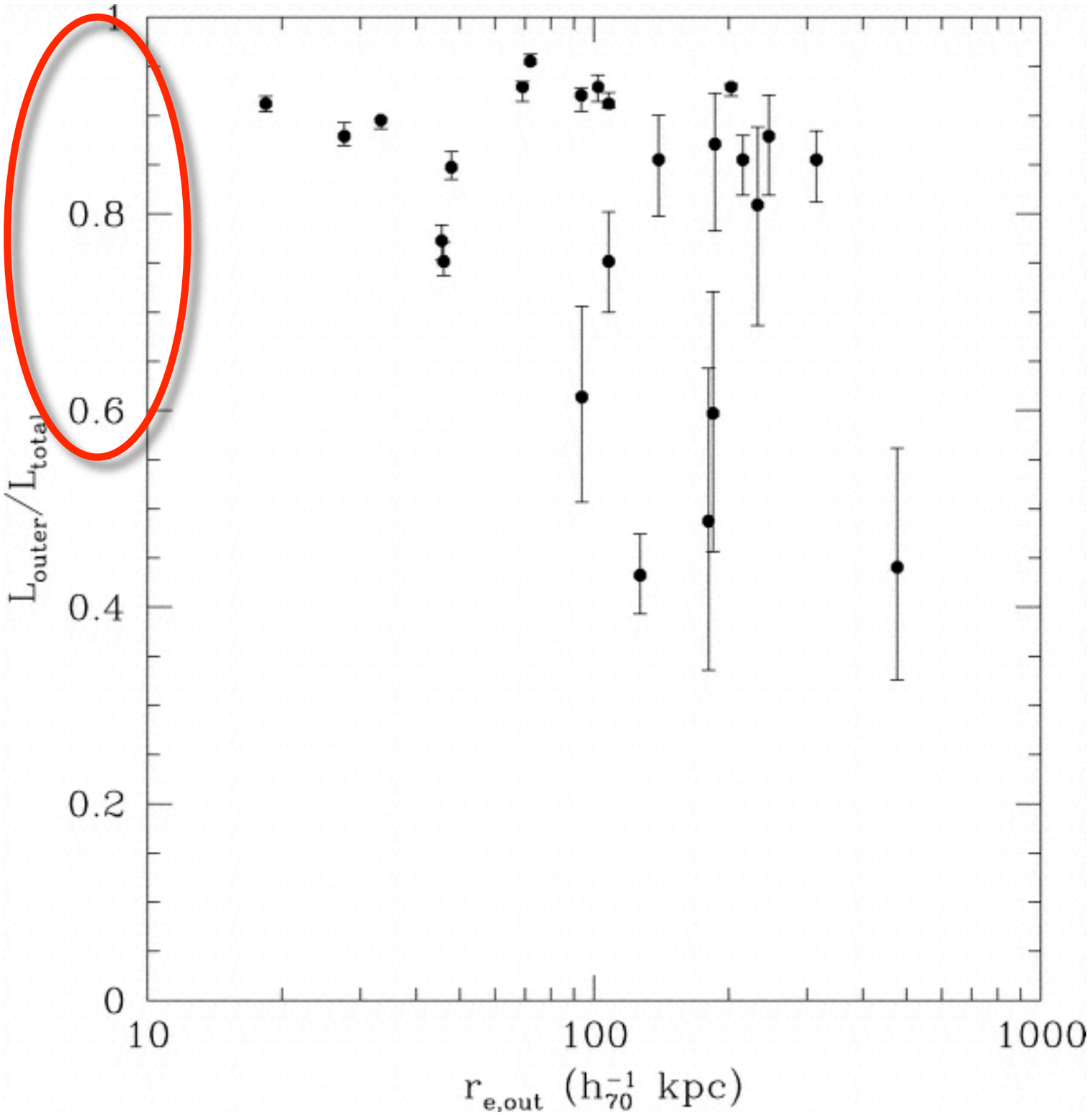


Intracluster/group Light

Gonzalez+05:
BCGs (inner)
ICL (outer)

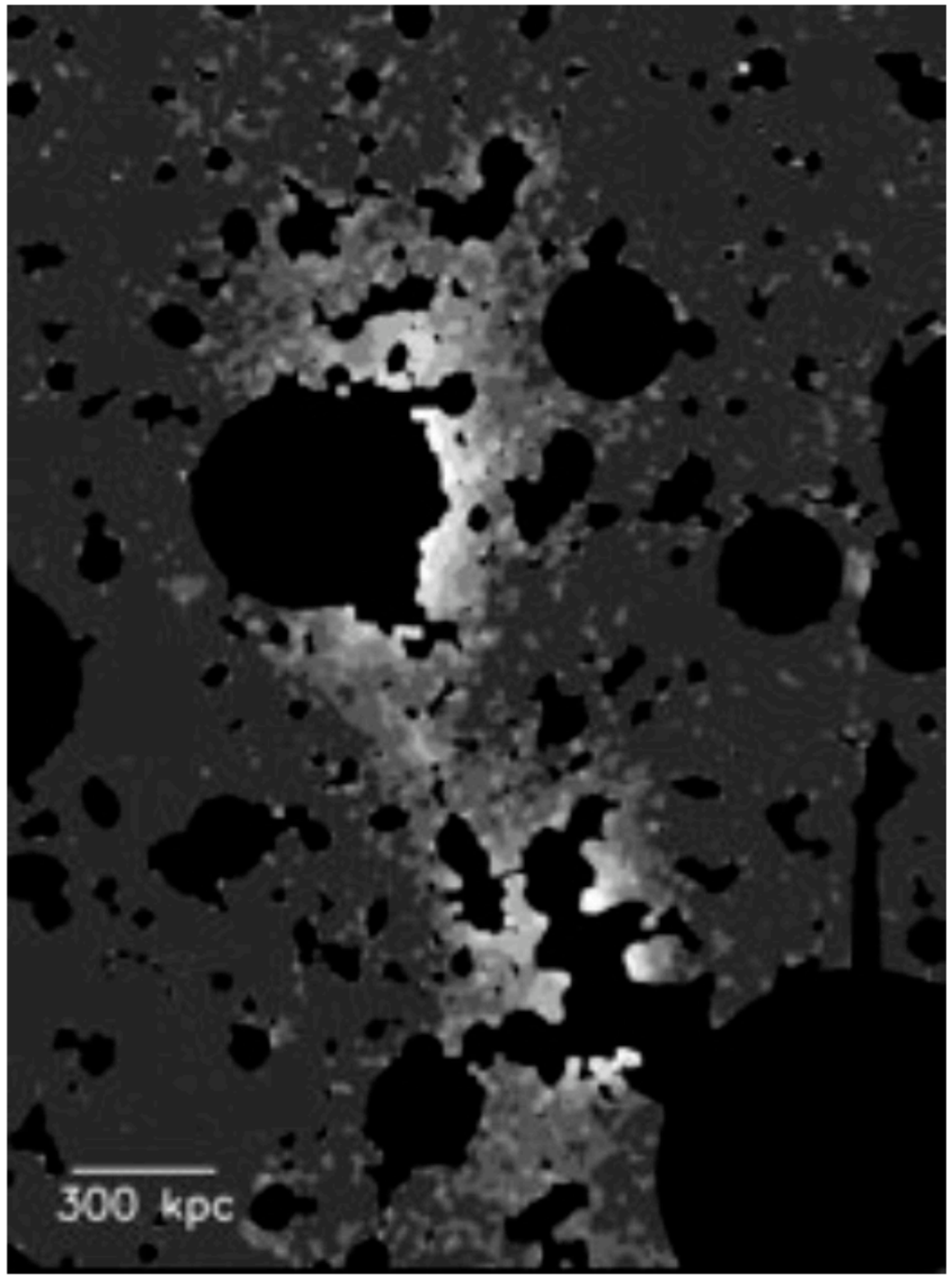
ICL has >80% of total stellar light (inner+outer)

c.f. Zibetti+05



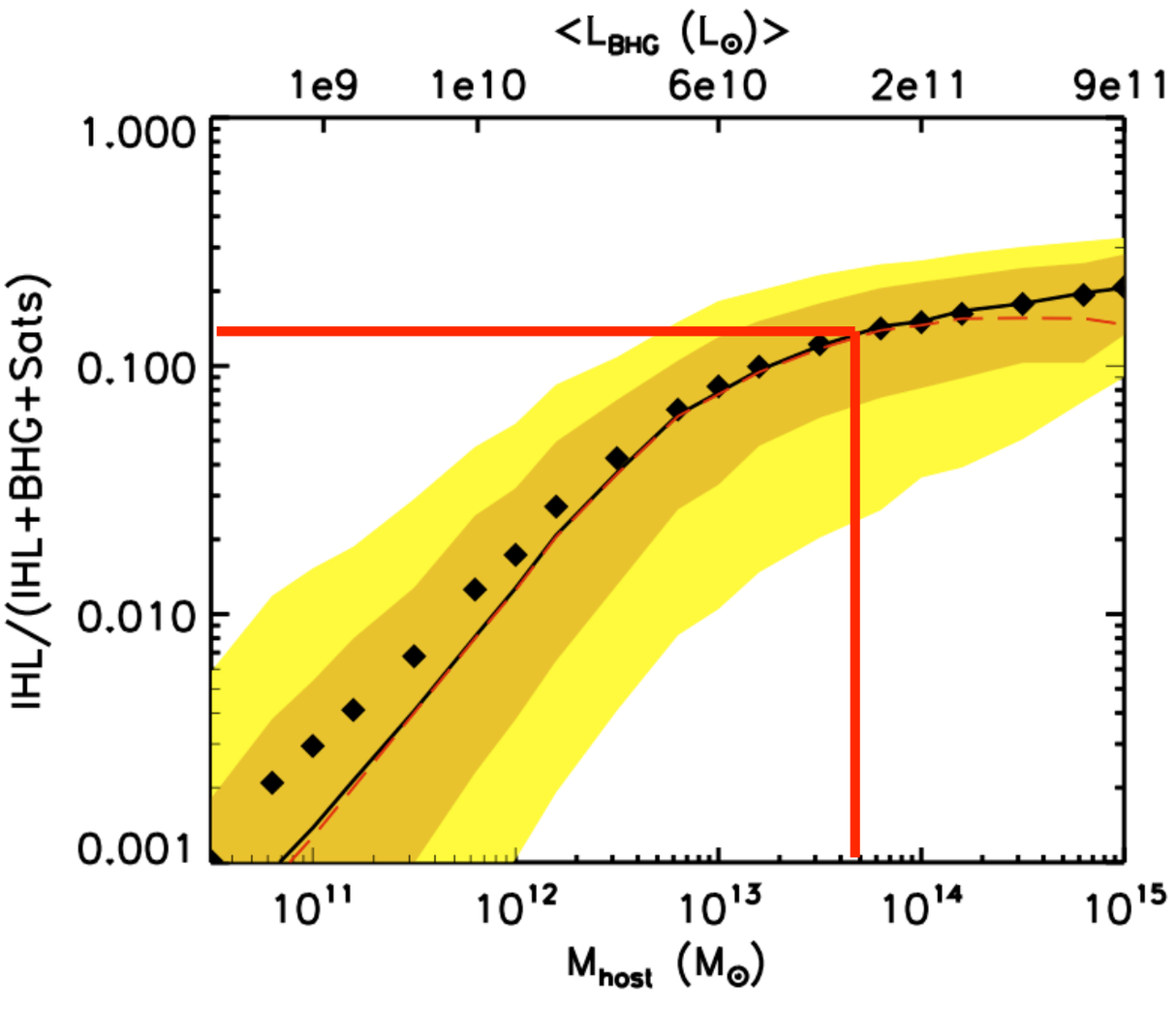
Intracluster/group Light

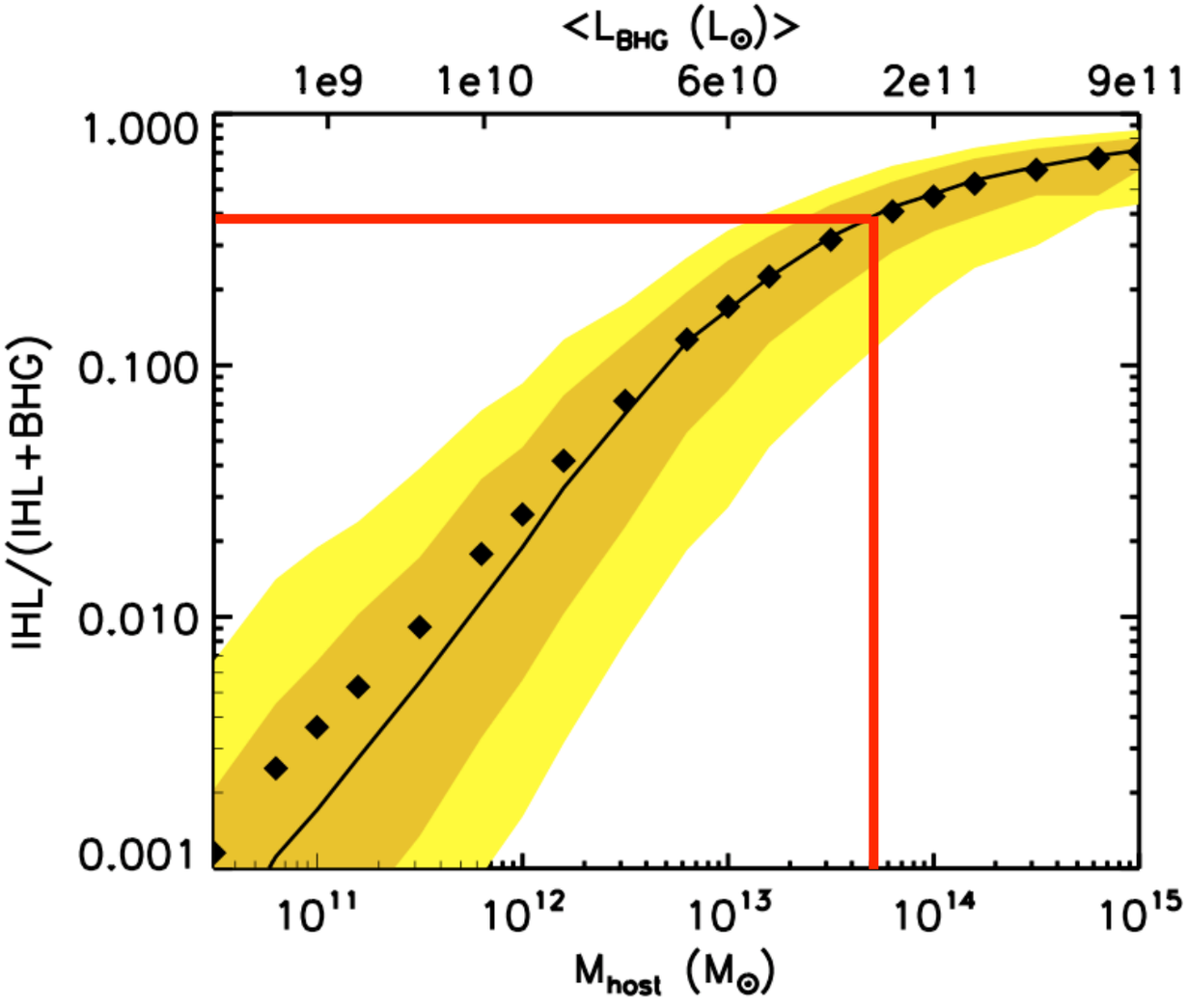
Krick & Bernstein 07: 10 Abell clusters@z<0.3



Intracluster/group Light

Purcell+07 (Models): Intra-halo Light is 20-30% of total stellar mass in groups and clusters





Summary

Rise of the galaxy group environment
(big shift from even 5 years ago)

Holistic view of galaxy evolution:
Galaxies & Intra-Halo Light/Medium
(e.g. Mulchaey, Owers, Bower)

Synergy between observations & theory
(better translate b/w theory observations,
e.g. satellites & centrals)

Thanks for making this such a stimulating conference!