Galaxy evolution: Transformation in the suburbs of clusters

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University of Birmingham

ESO "Fornax, Virgo, Coma et al."
1 July 2011

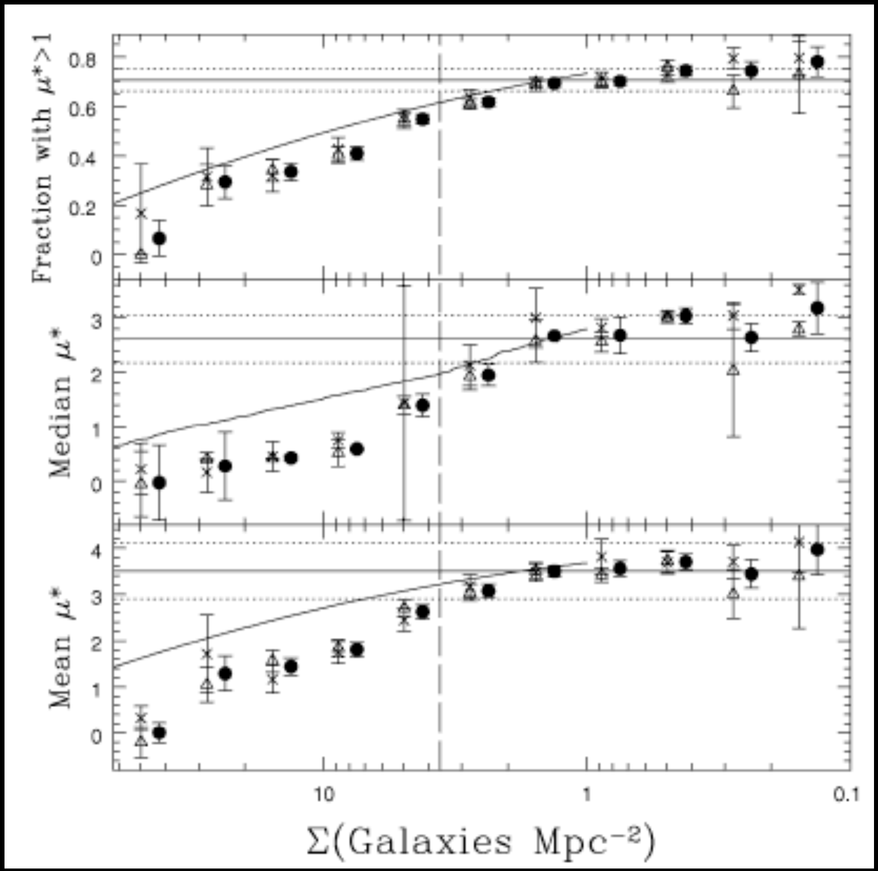
Plan of talk

- Star formation and galaxies in clusters
  - Trends with cluster-centric distance
  - Virgo outskirts: NGC 4472 (XMM and Chandra)
  - Coma –A1367 Supercluster: SDSS spectra/Spitzer MIPS
  - The supercluster-void network- clusters fed by filaments (2dFGRS and SDSS data)
- Shapley Supercluster: AAT spectra/GALEX/Spitzer MIPS

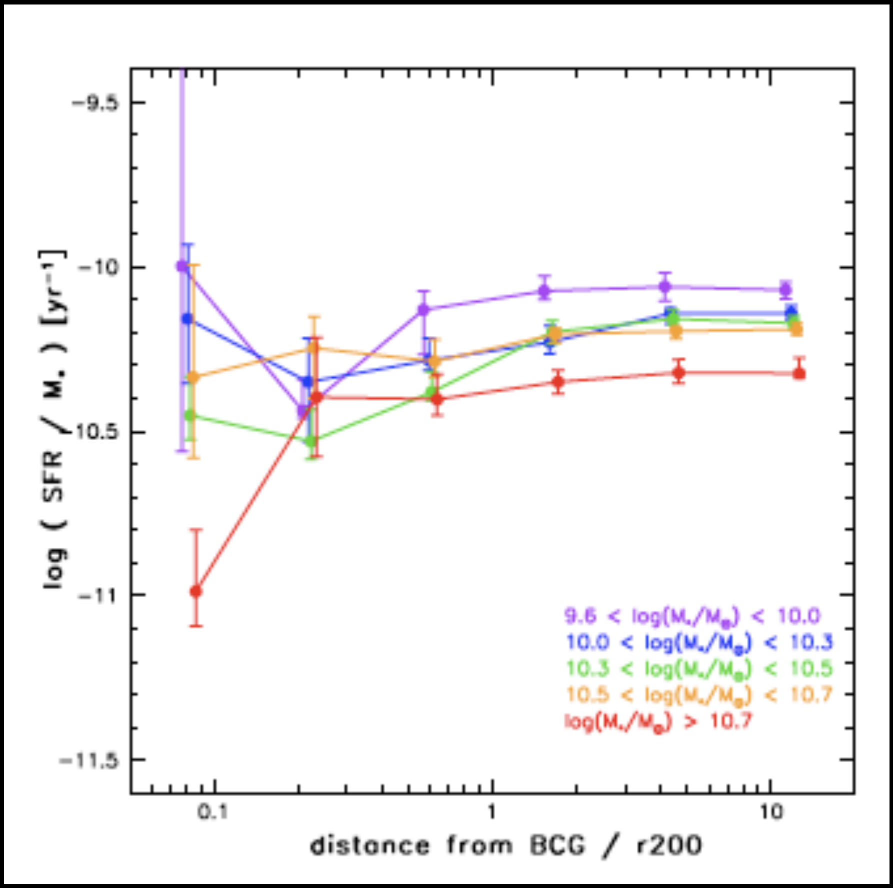
Contributions from:

- Smriti Mahajan, Scott Porter, Chris Haines (Birmingham)
- Kevin Pimbblet (Monash)
- N4472 Chandra-LP Team: Ralph Kraft (PI) , Bill Forman, Christine Jones, Paul Nulsen, Martin Hardcastle, Tom Maccarone, Greg Sivakoff, Craig Sarazin et al.

Star formation vs local density



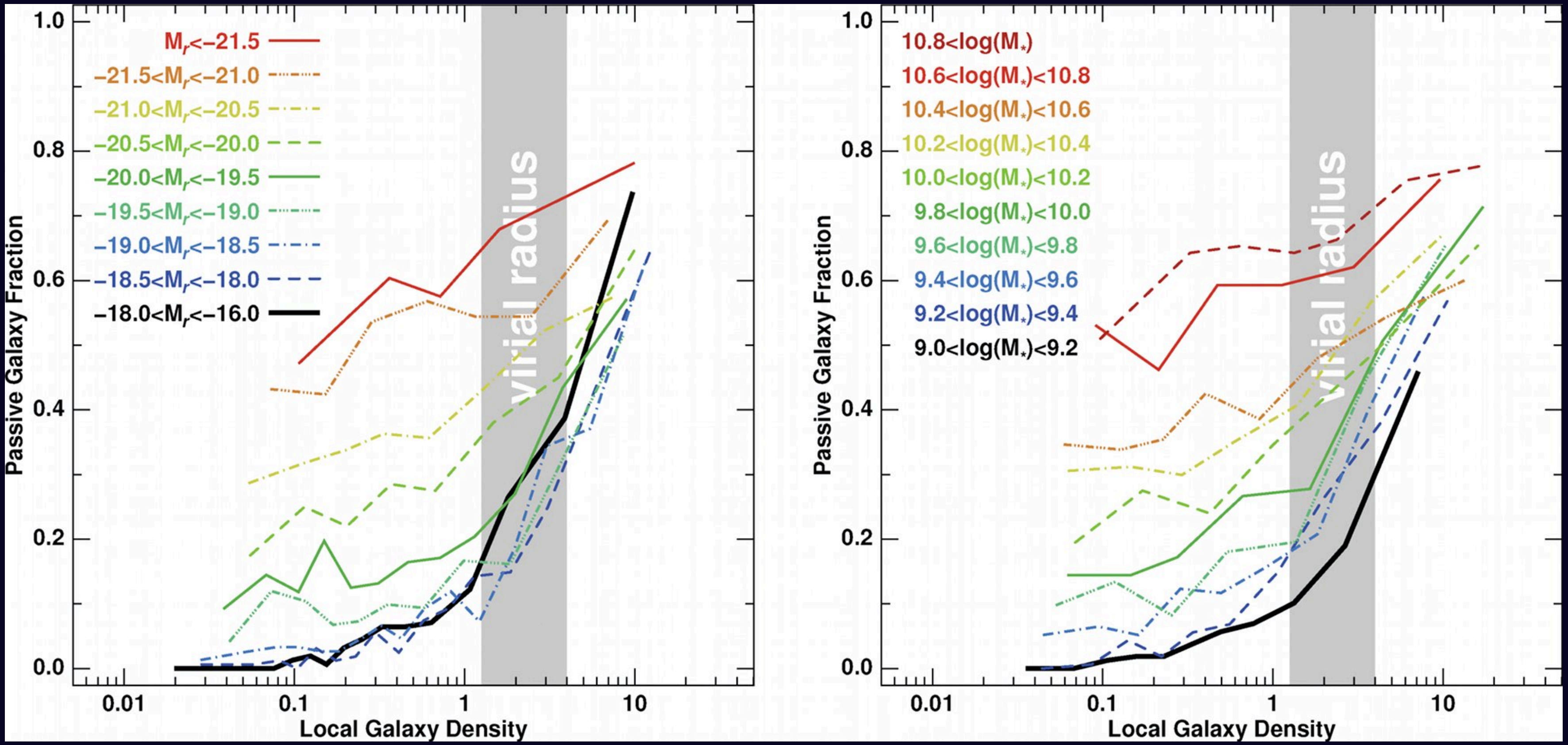
Lewis + (2002) : 17 clusters at 0.05<z<0.1 within 2dFGRS: M_b<-19



von der Linden + (2010) : >500 clusters at z<0.1 within SDSS

Note: definition of environment -- inadequate

In the field, almost all dwarfs are forming stars

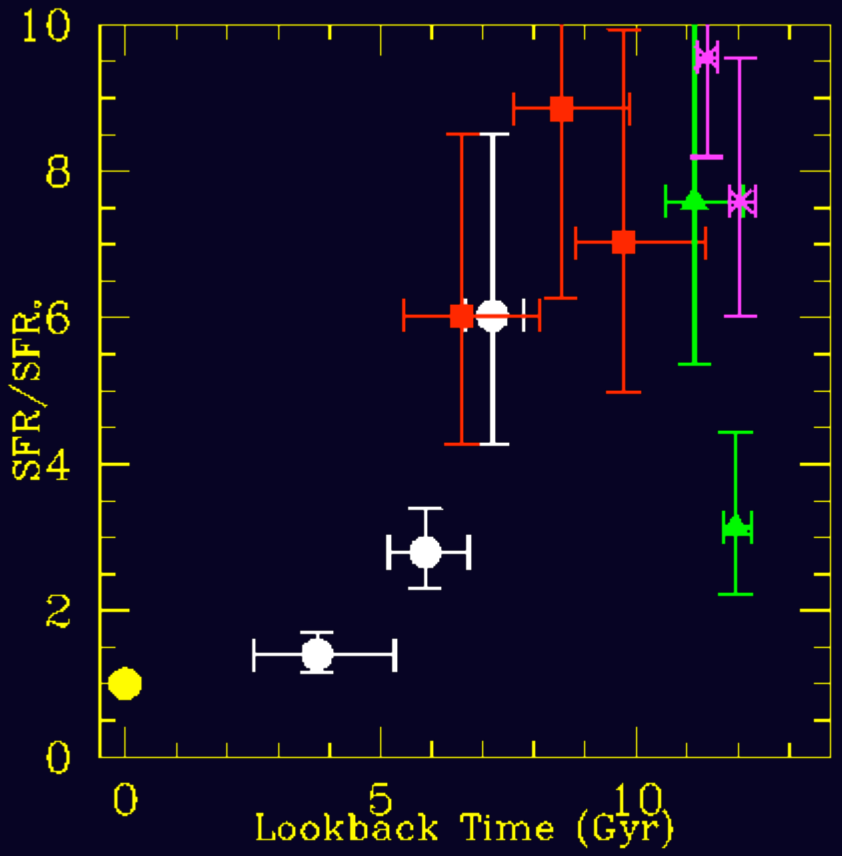


27,700 galaxies $0.005 < z < 0.037$

SDSS DR4 Haines+ 2007

Here definition of environment includes velocity dispersion

Why does star formation stop?



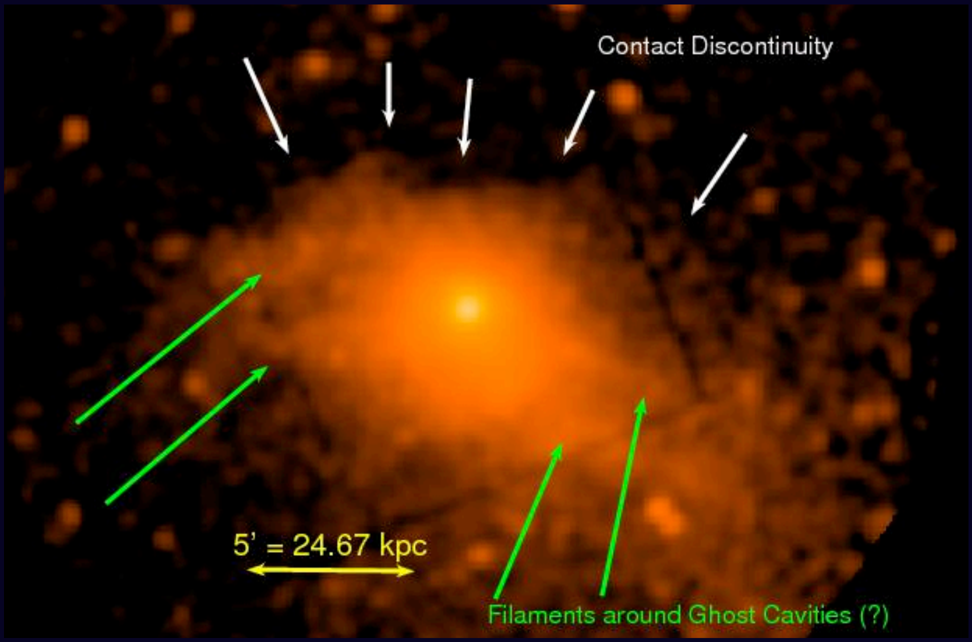
Steidel et al. 1999

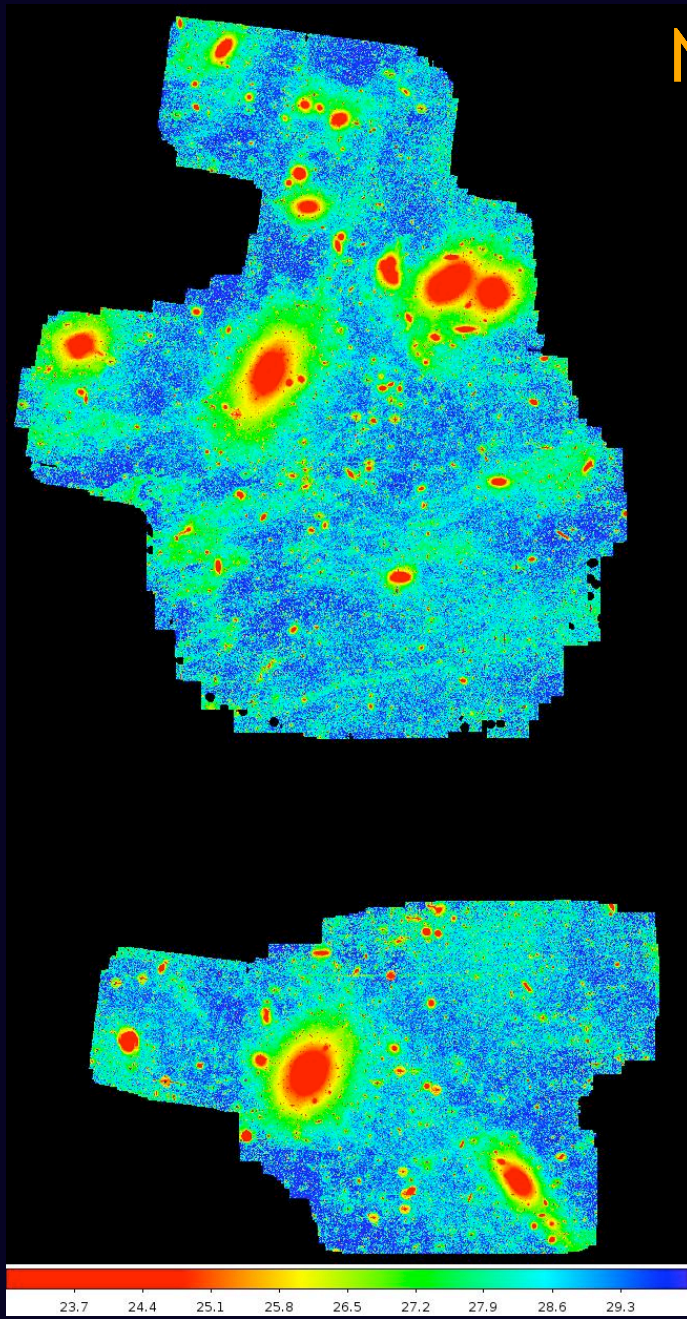
A) Internal? gas consumption and normal ageing

B) External? Hierarchical build-up of structure inhibits star formation

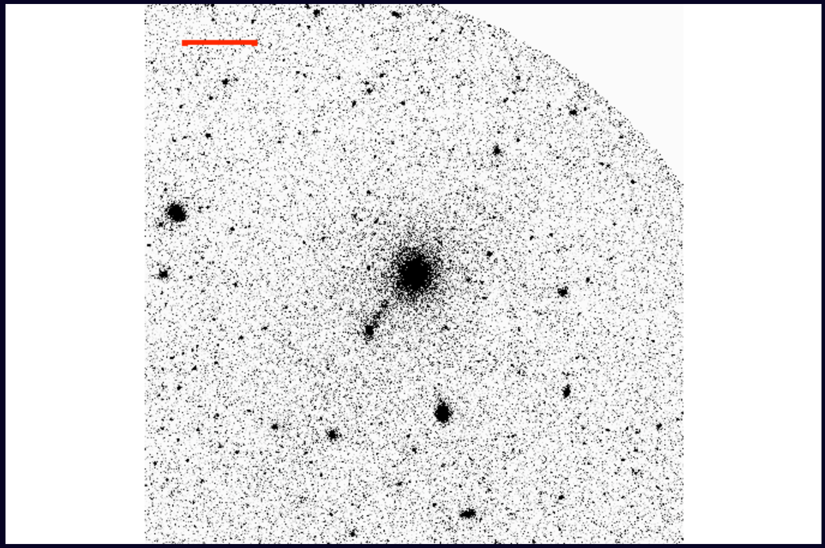
NGC 4472 = M 49

Kraft +, XMM, 2011





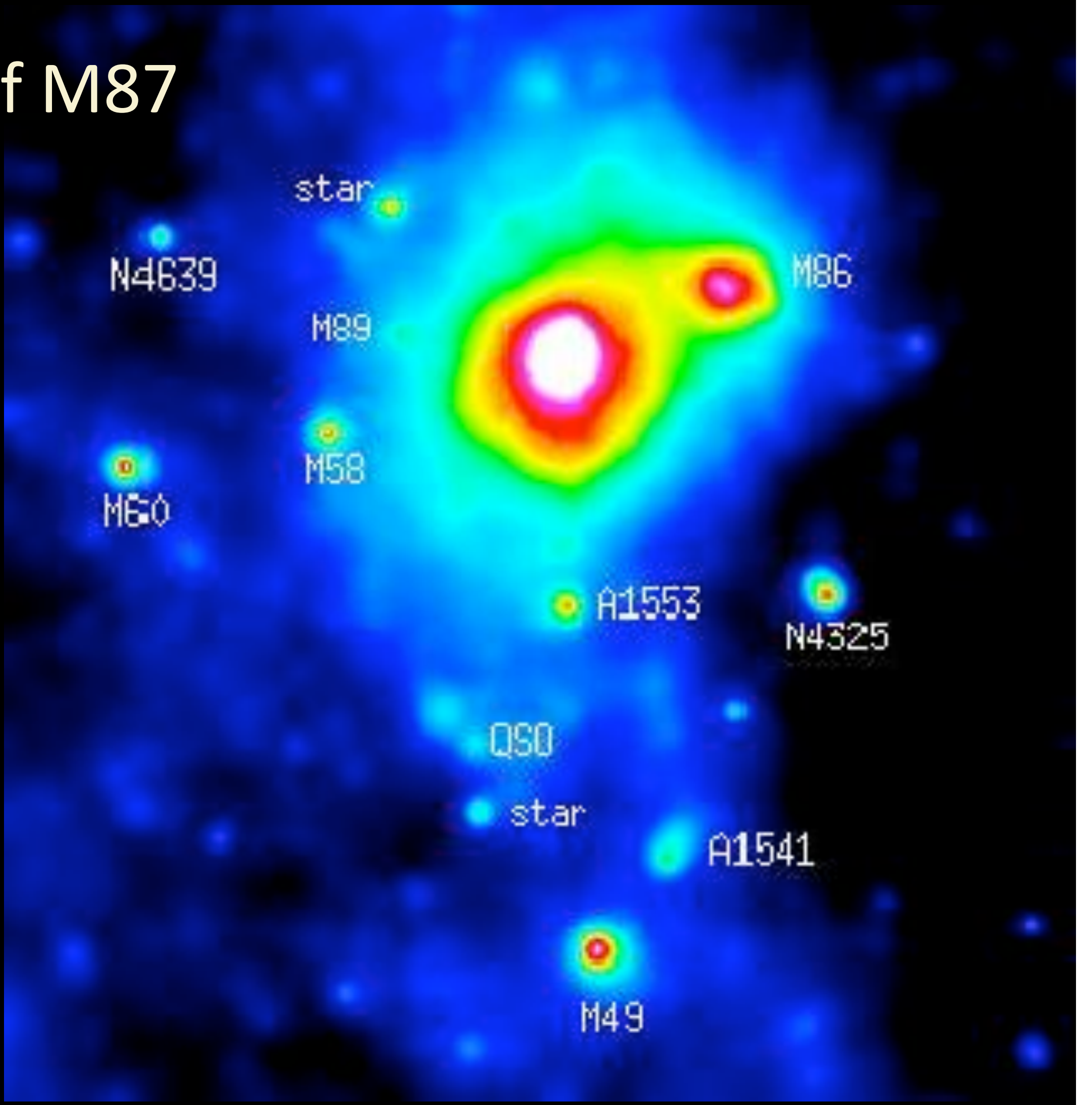
Mihos, this meeting



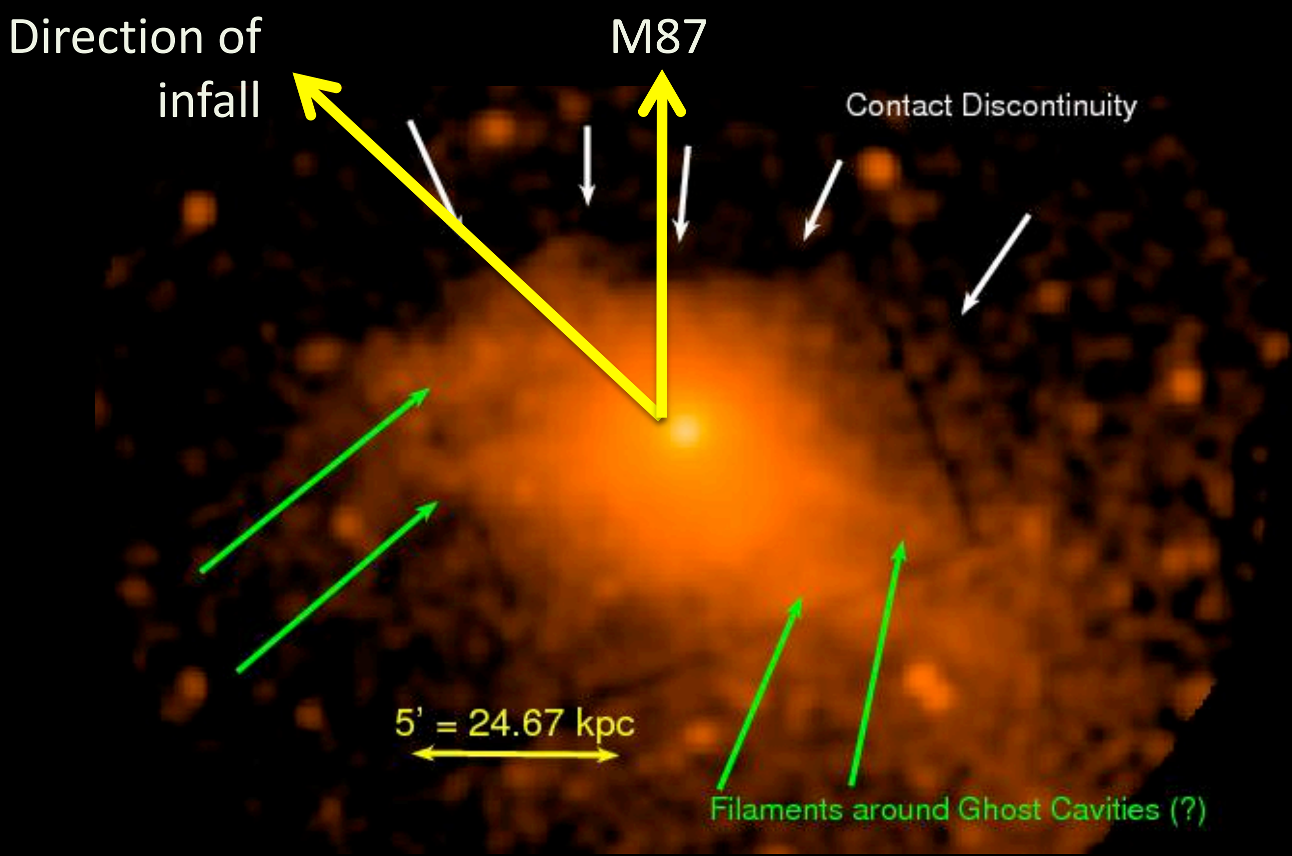
Arrigoni Battaia +, GuVICS, this meeting

M49, 1.2 Mpc south of M87

- NGC4472=M49 is the most optically luminous galaxy in the Virgo cluster (1”=80 pc)
- M_{SMBH}=6x10^{8} $M_{\odot}$
- Excellent example of group/ cluster merger in local Universe for detailed study
  - Proximity
  - Luminosity
  - Gas temperature (<1.5 keV)
- Chandra LP (380 ks total) received data few weeks ago



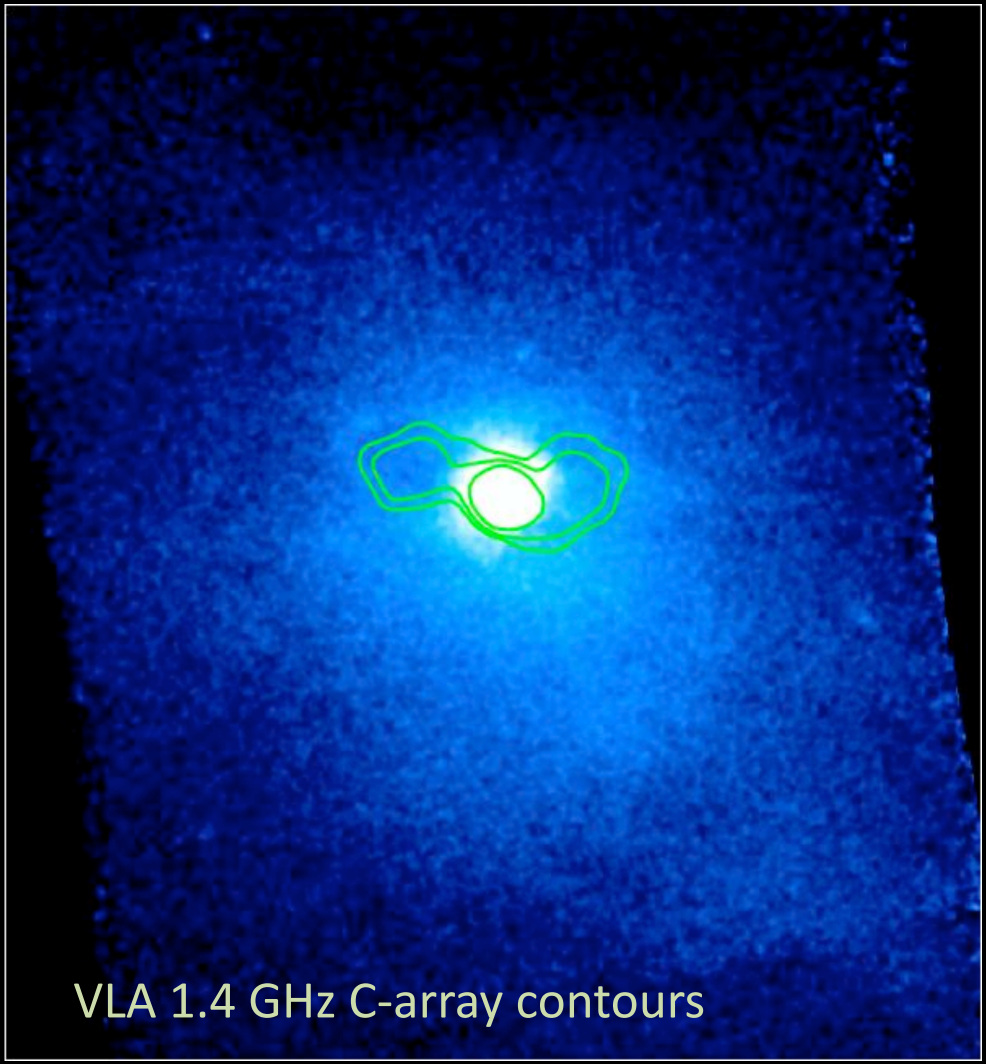
ROSAT PSPC mosaic of Virgo cluster (Bohringer *et al*. 1995)



(Biller+ 2004, Kraft+ 2011)

100 ks XMM-Newton MOS1+2 in 0.5-1.0 keV band

Broadband Chandra X-ray

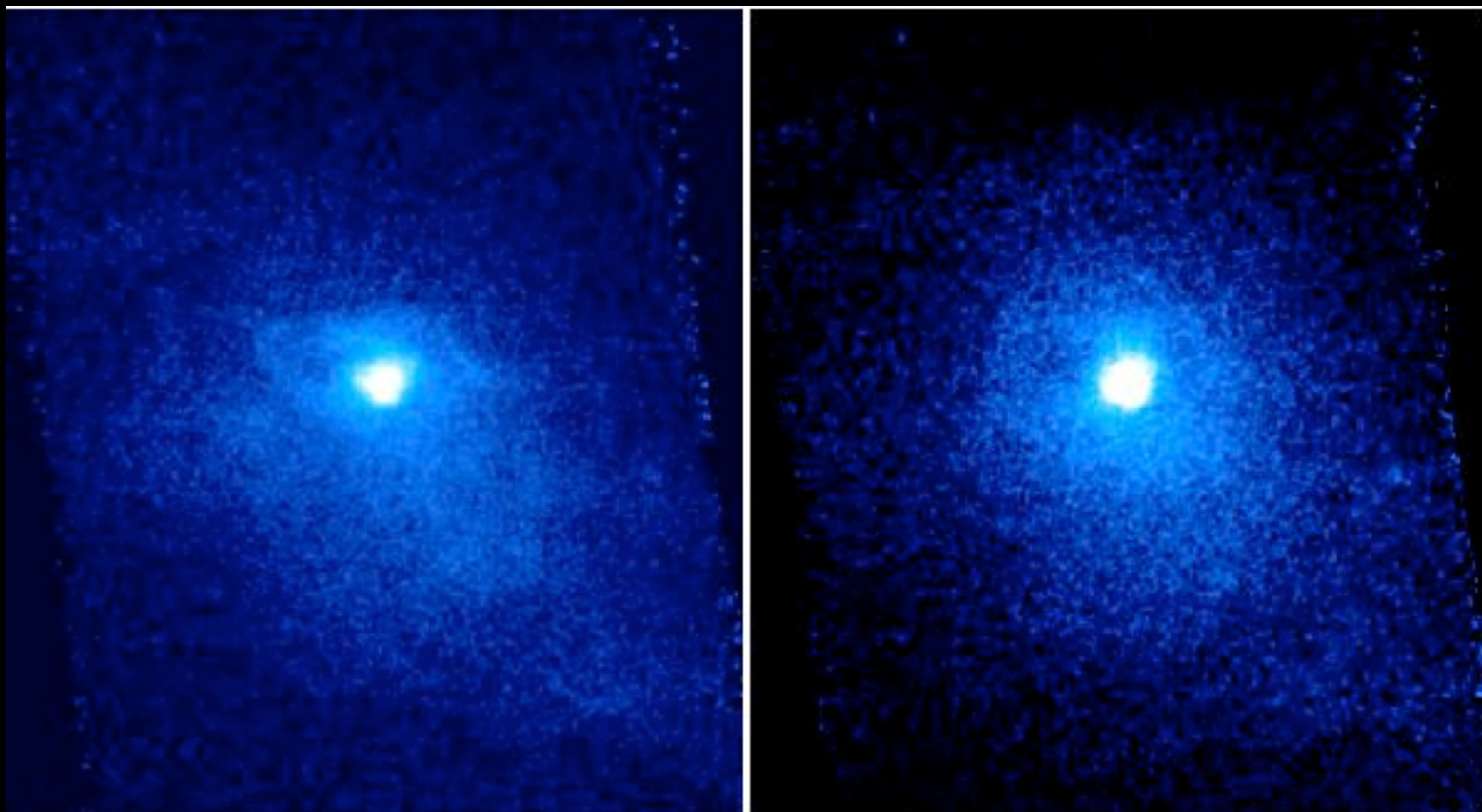


- •380 ks Chandra/ACIS-S
- •Smoothed (s=1.5''), exposure corrected
- •0.5-2.0 keV band
- •Point sources removed

Features of Interest

- •Multiple Surface Brightness Discontinuities
- •Filamentary Arms Around Radio Bubbles + cavities
- •Large scale X-ray filaments to the E and SW of the nucleus (seen by XMM)

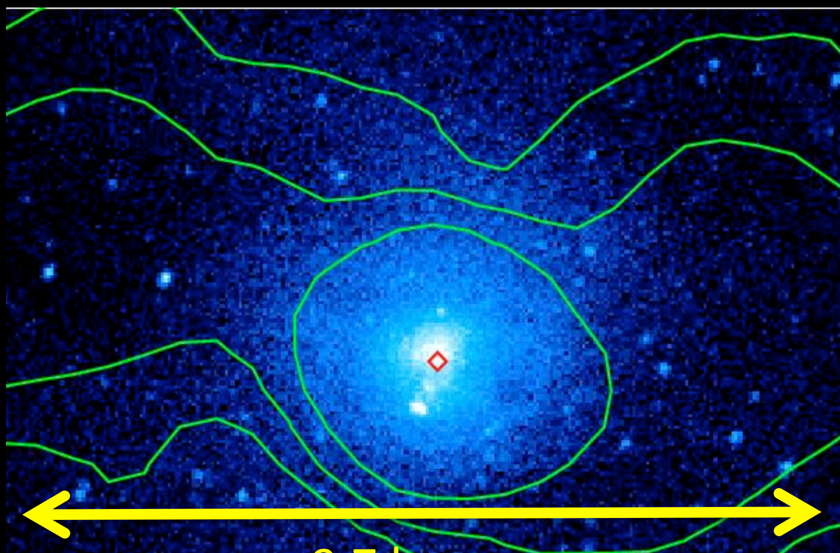
Broadband Chandra X-ray



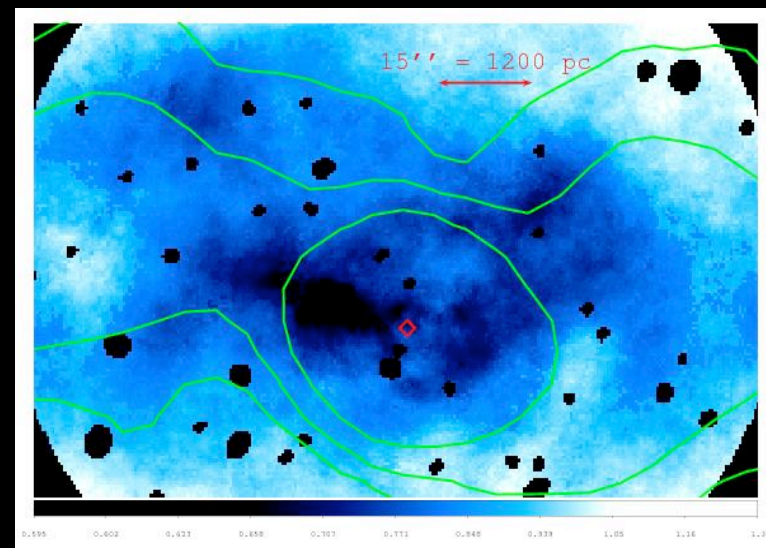
0.7-0.9 keV   1.1-1.5 keV

M49 Core Region

Soft X-ray image with radio contours overlaid



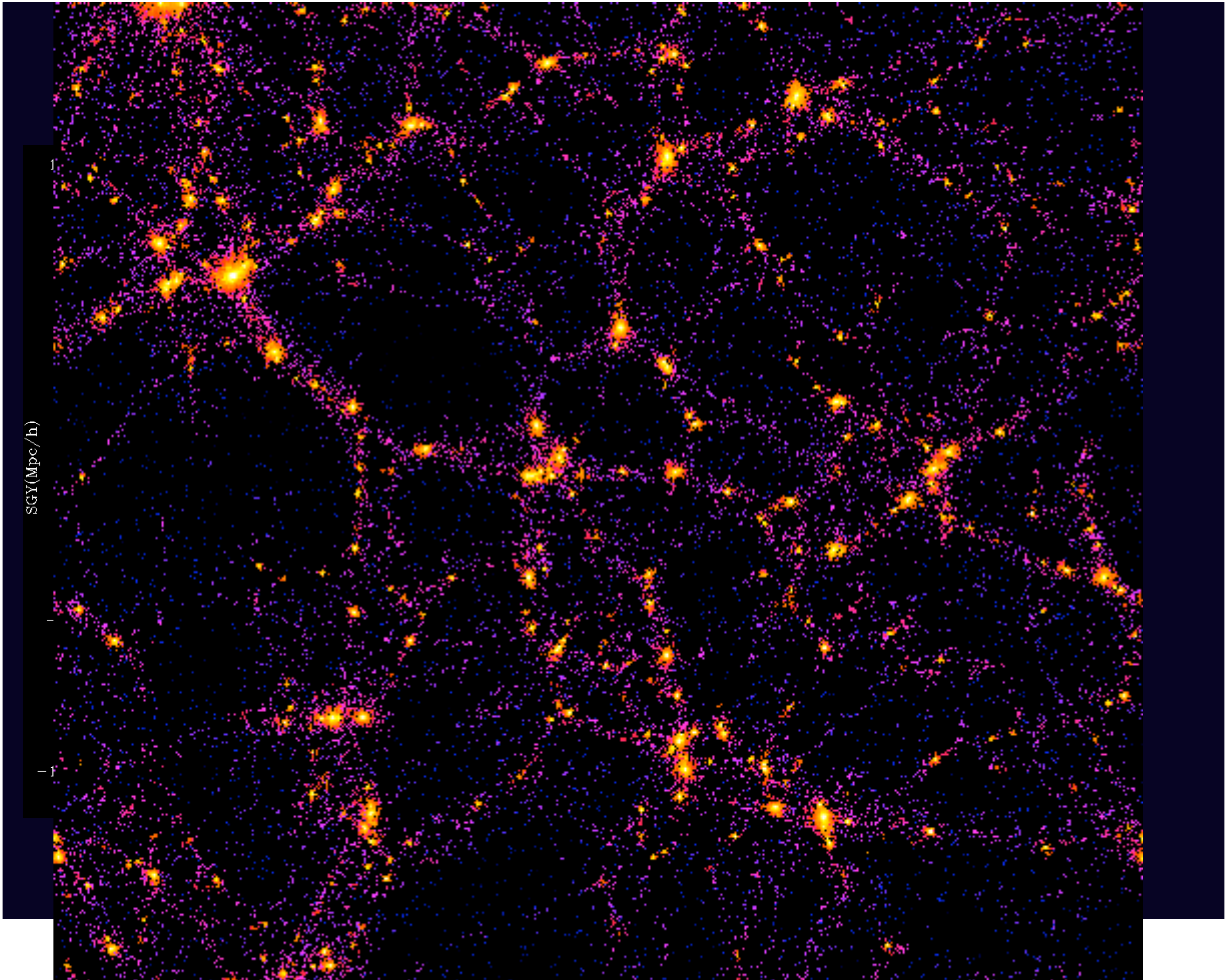
Randall



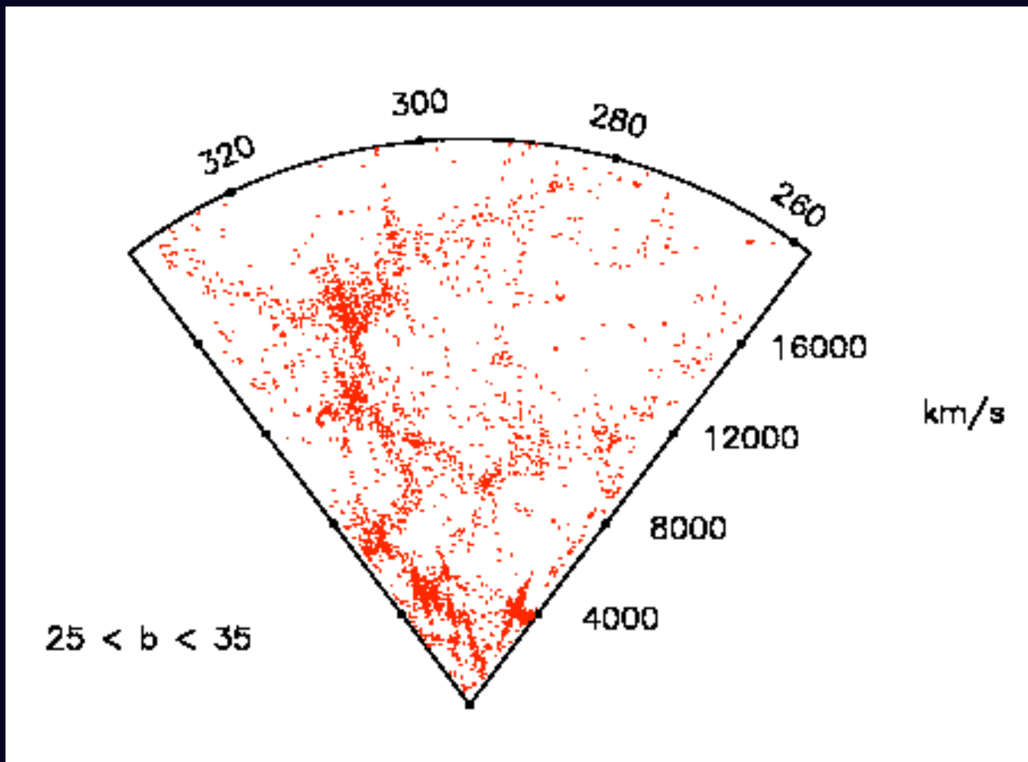
0.5 keV 1.5 keV

Temperature map with radio contours overlaid

- Gas core is clearly sloshing
- Complex temperature structure aligned with radio lobes: suggests entrainment

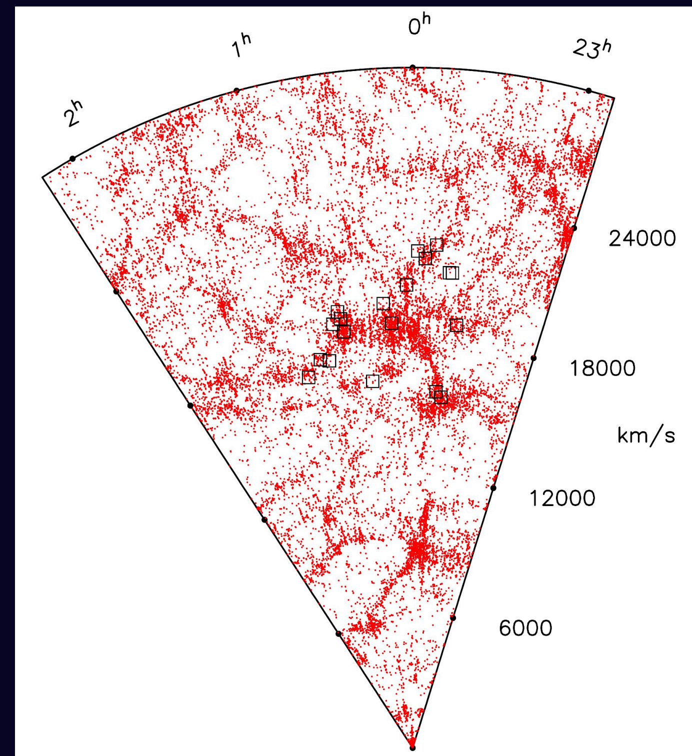

SGY(Mpc/h)

Nearby Superclusters in redshift space



Shapley Supercluster

Kaldare Raychaudhury Colless Peterson 2003

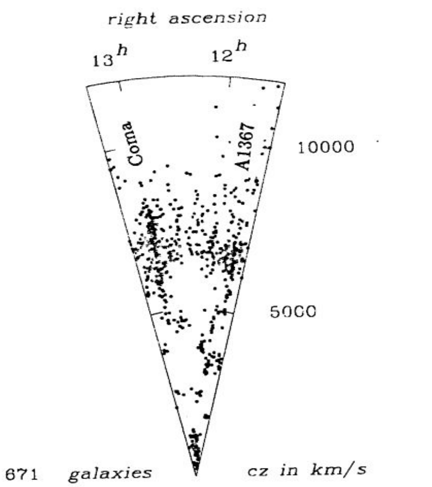


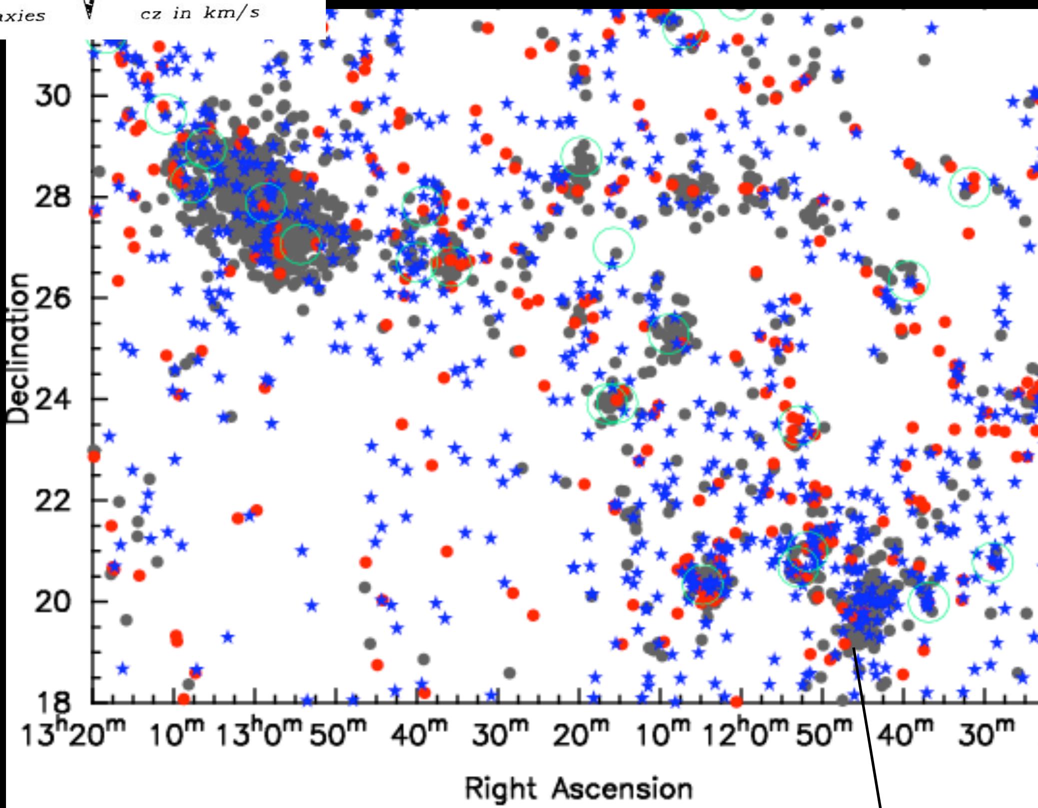
Pisces-Cetus Supercluster

Porter & Raychaudhury 2005

Each with >25 Abell clusters connected by a network of filaments

The Coma "supercluster" (z=0.023)





- Around 500 sq. degrees on sky
- One of the richest nearby Large-scale structures

· Red: AGN hosts

· Blue: SF galaxies (EW Hα>2.5A)

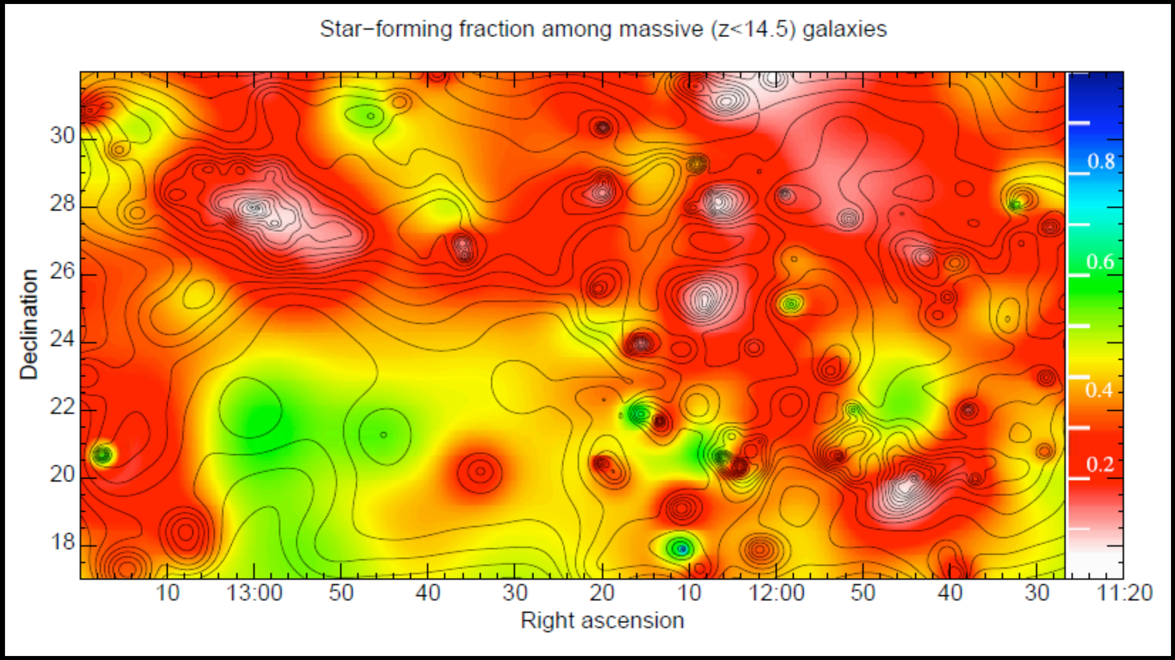
· Green: groups of galaxies

Mahajan, Haines SR 2010

Abell 1367

Data from SDSS DR7

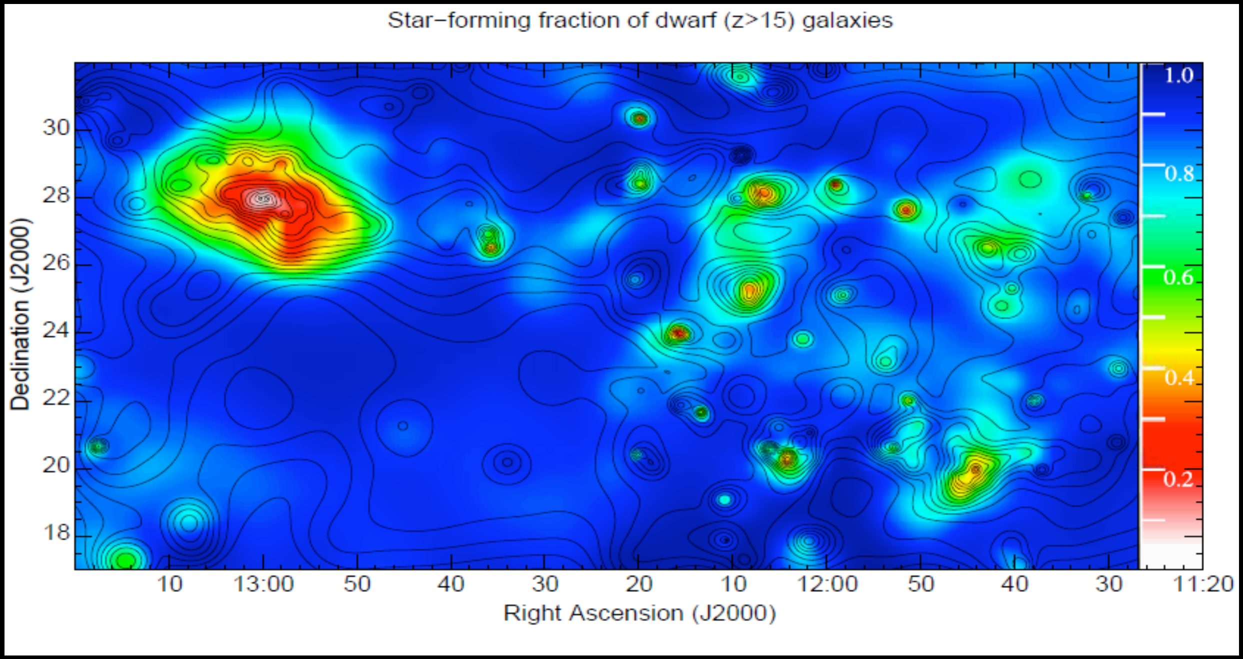
Mahajan, Haines, SR 2010



Star forming: EW(Hα)> 2 Å

Giants are passive irrespective of their environment

Dwarf galaxies are star-forming everywhere, except in the cores of clusters and groups

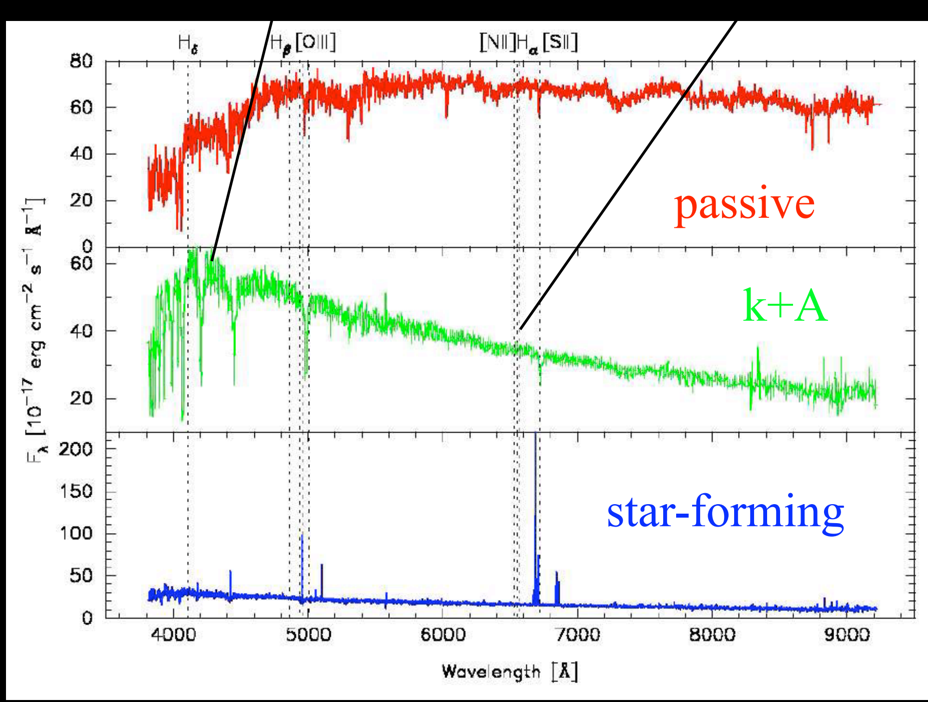


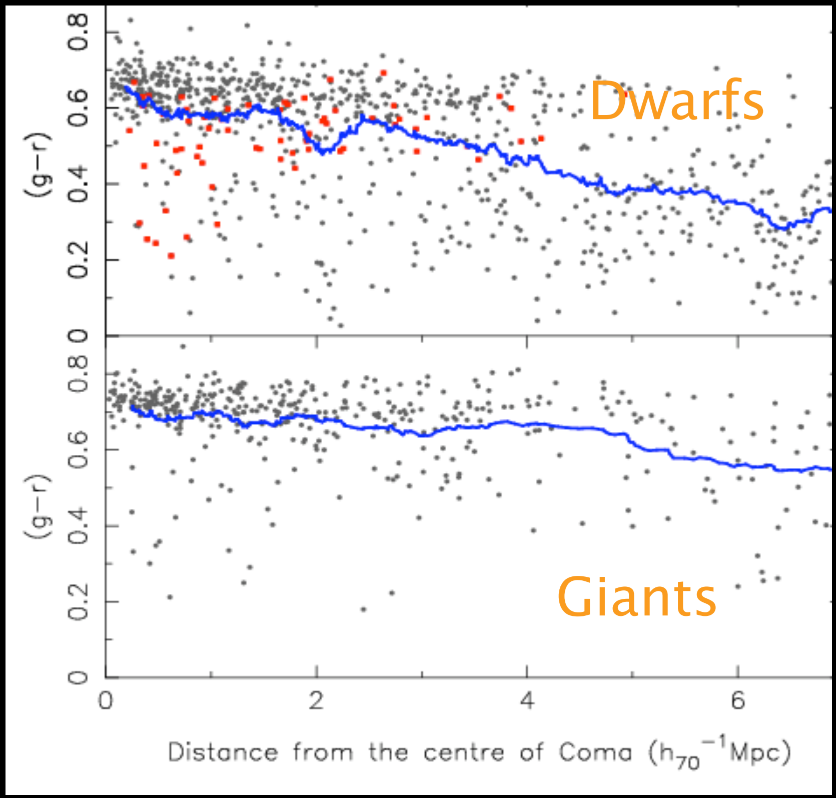
Contour: SDSS z-band luminosity-weighted galaxy density

The post-starburst (k+A) galaxies

Mahajan, Haines, SR 2011

(Red dots) k+A: Strong Hδ absorption and no Hα emission

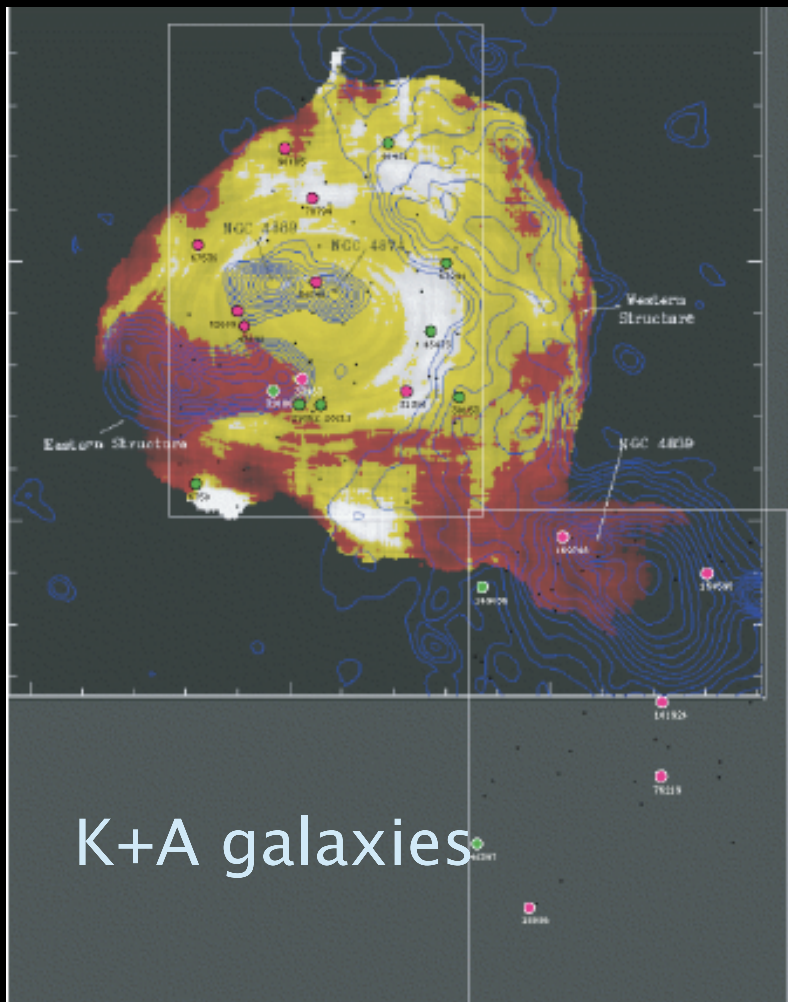


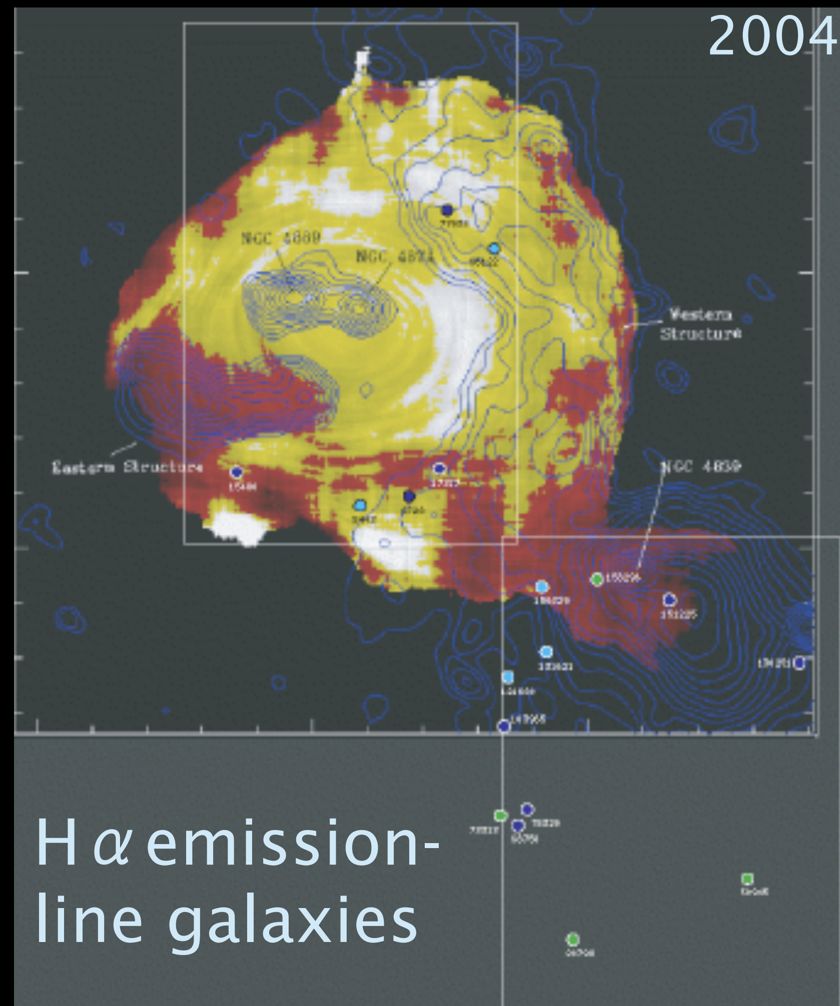


- The mean colour of dwarfs changes by ~0.4 mag between thrice the radius of the cluster and its centre
- Almost all k+A dwarf galaxies are found within 1.5 times the radius of the cluster

A COMPARISON OF THE GALAXY POPULATIONS IN THE COMA AND DISTANT CLUSTERS: THE EVOLUTION OF k + a GALAXIES AND THE ROLE OF THE INTRACLUSTER MEDIUM[1]

Bianca M. Poggianti,[2] Terry J. Bridges,[3] Y. Komiyama,[4] M. Yagi,[5] Dave Carter,[6] Bahram Mobasher,[7] S. Okamura,[4] and N. Kashikawa,[5]





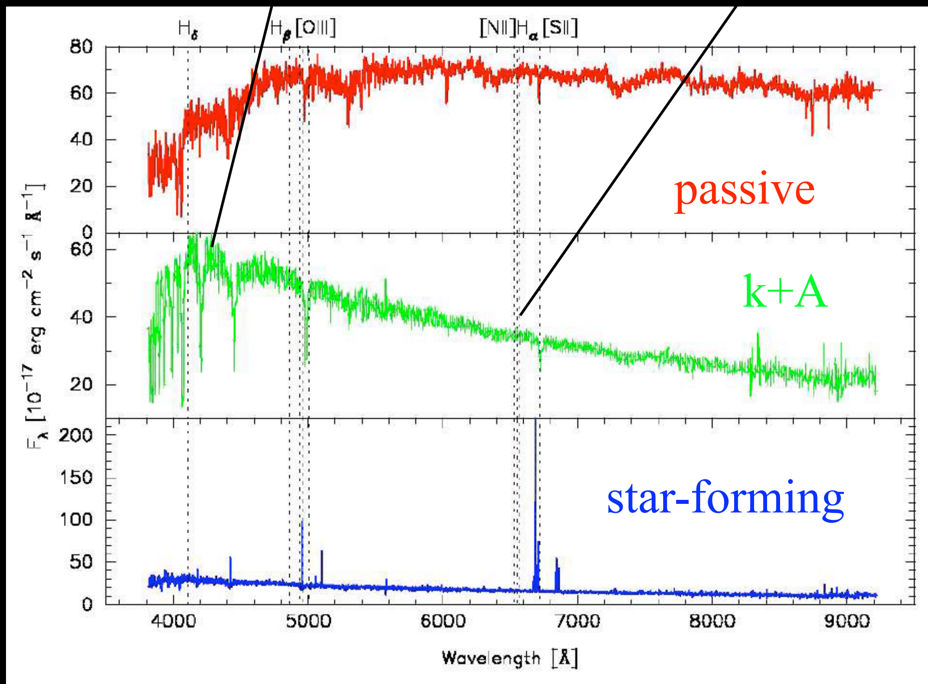
X-Ray: Neumann et al 2003 XMM

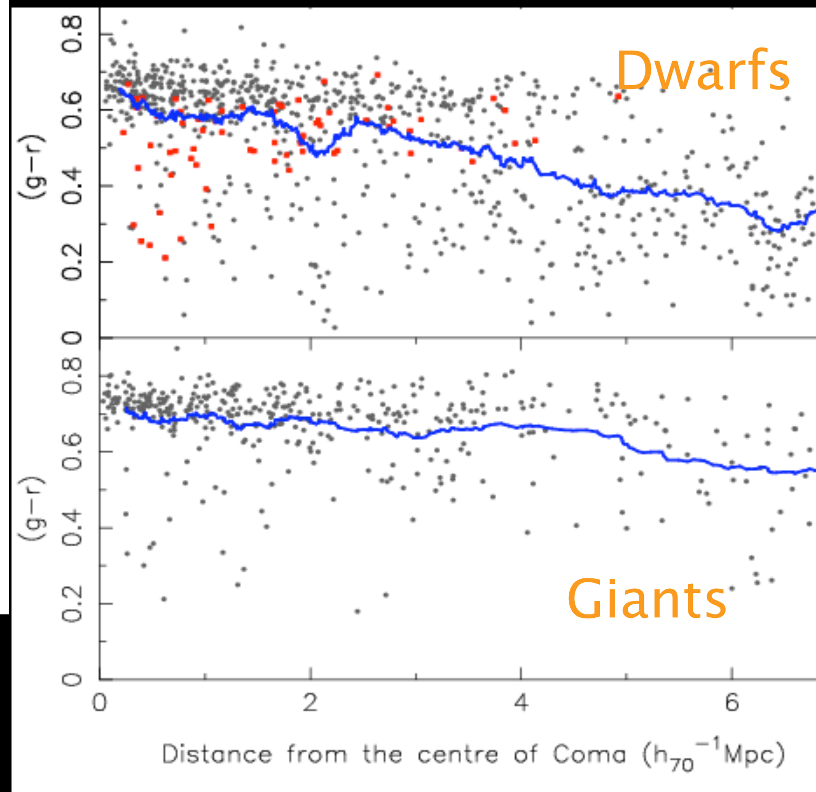
The post-starburst (k+A) galaxies

Mahajan, Haines, SR 2011

k+A: Strong Hδ absorption and no Hα emission

No K+A giants in Coma





K+A dwarfs

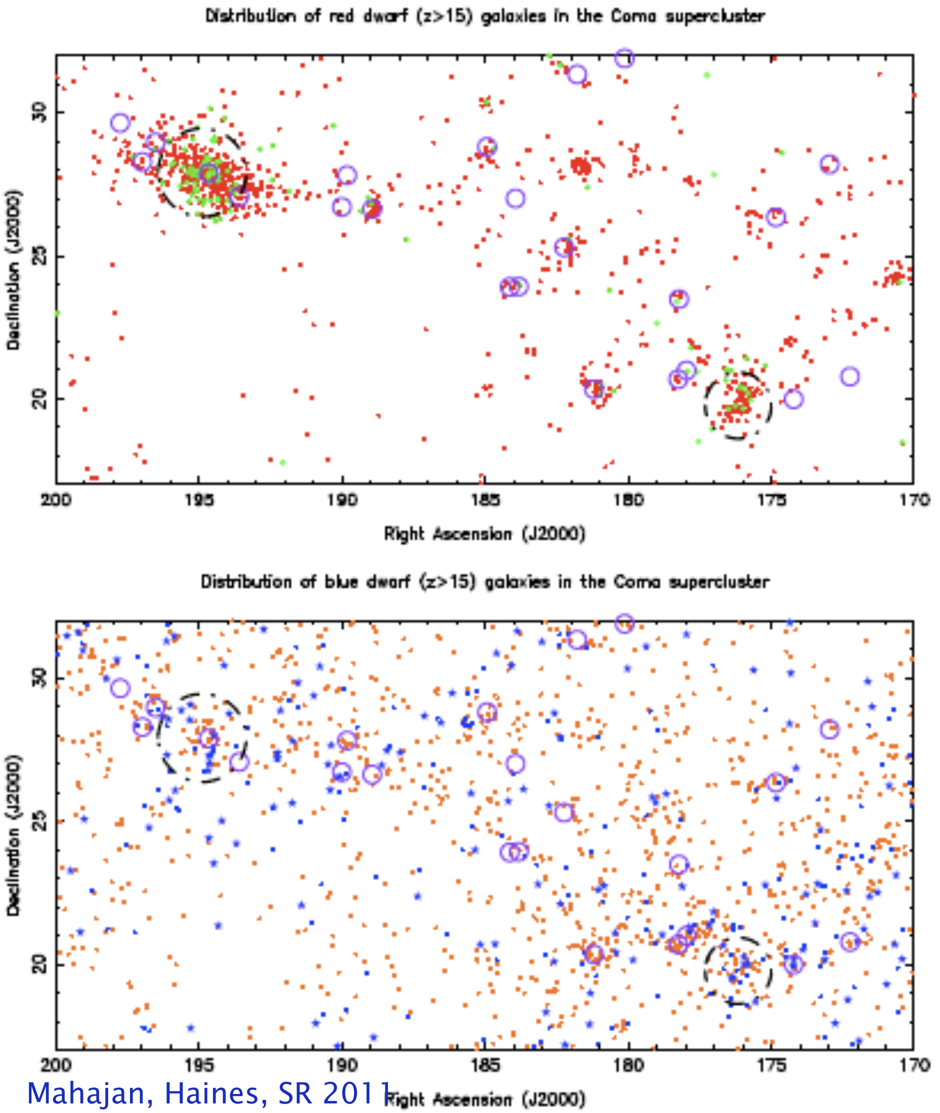
< 2A H alpha em

> 3A H delta abs

> M_Z >-20, z>15

Also see Gavazzi+ 2010

Dwarfs in Coma (z'>15)



Mahajan, Haines, SR 2011

- Red: Passive (70%)
- Circles: groups
- Green: k+A galaxies

- Red dwarfs in high density regions (trace giant passive galaxies)
- k+A galaxies also in clusters and groups

Mahajan, Haines, SR 2011
Also see Gavazzi+ 2010

- Red: EW Hα< 50 A
- Blue: EW Hα>50 A
- Circles: groups

- Blue dwarfs are all over the entire supercluster

k+A galaxies in Coma

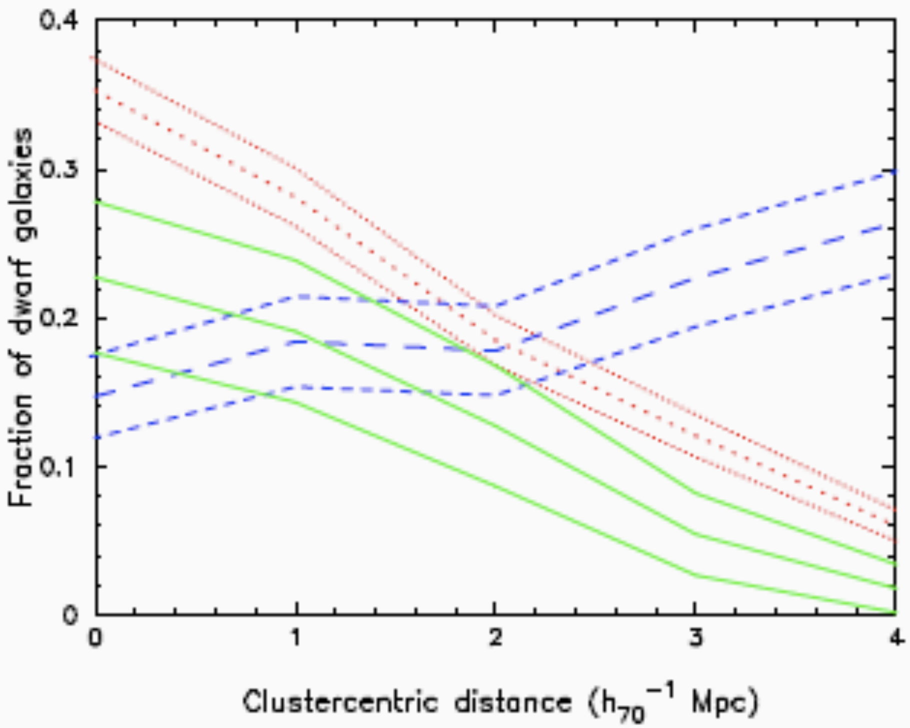


Figure 5. This figure shows the distribution of the red (*red dotted line*), blue (*blue dashed line*) and k+A (*green solid line*) galaxies as a function of clustercentric radius from the centre of the Coma cluster. 525, 157 and 67 galaxies contribute to each of the 3 curves respectively. The *thin lines* corresponding to each distribution represent the $\pm 1\sigma$ scatter, assuming binomial statistics. All curves are individually normalized to unity.

K+A dwarfs

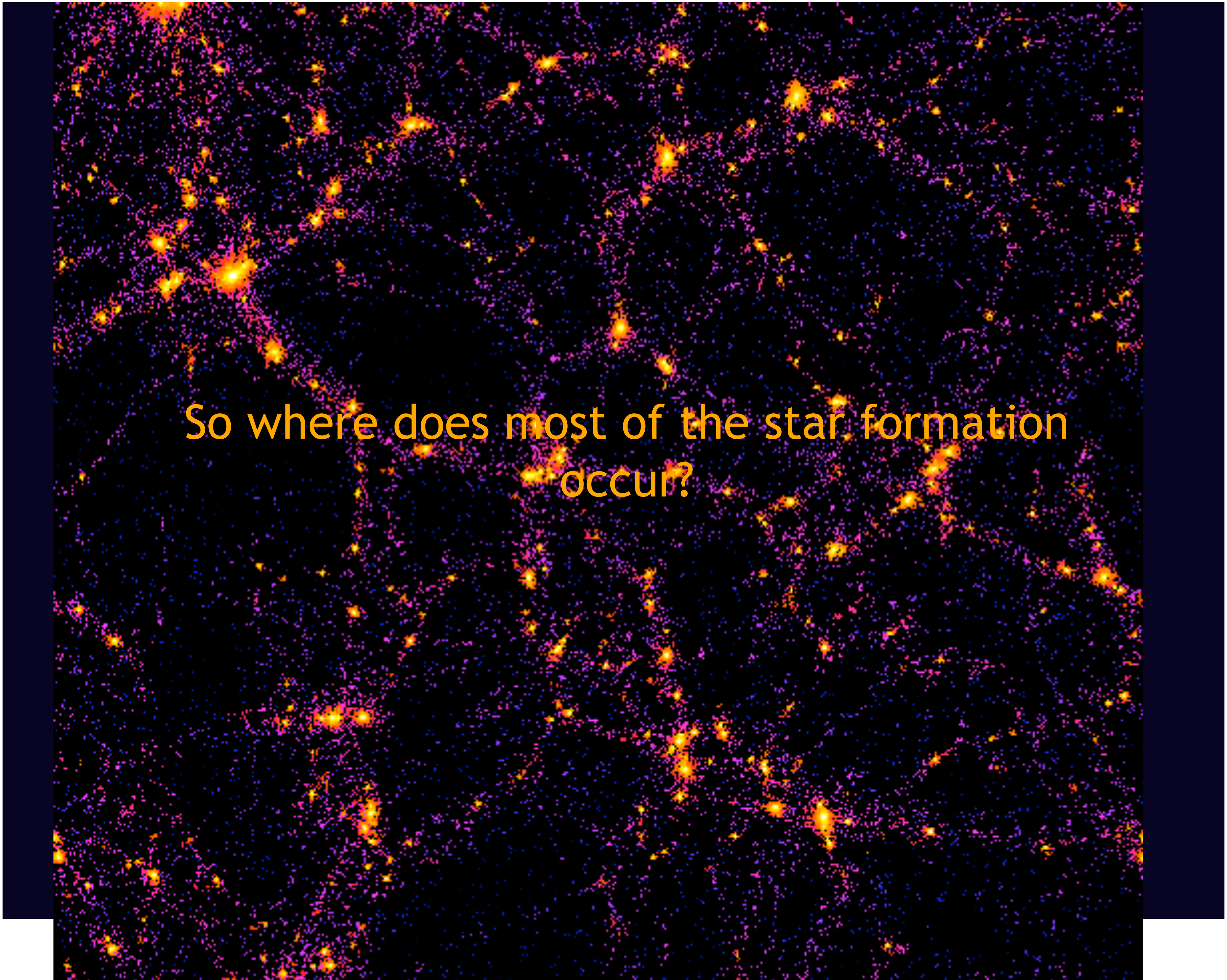
< 2A H alpha em

> 3A H delta abs

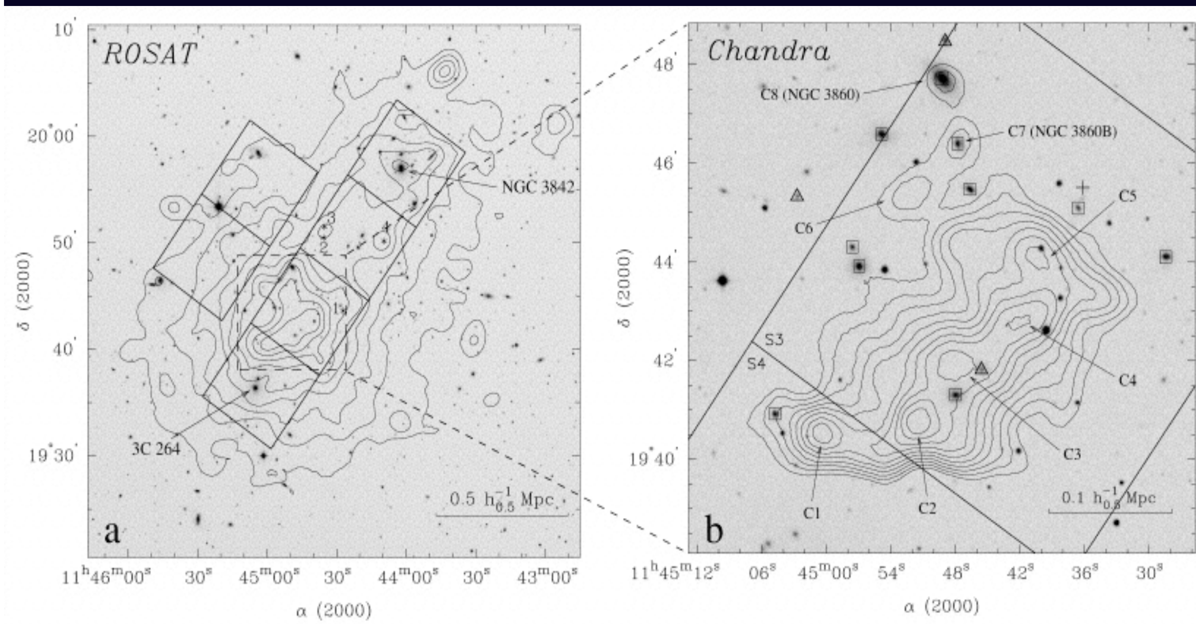
> M_Z >-20

To create the k+A phase (which lasts < 1 Gyr), we need sudden quenching of star formation- so need groups, clusters

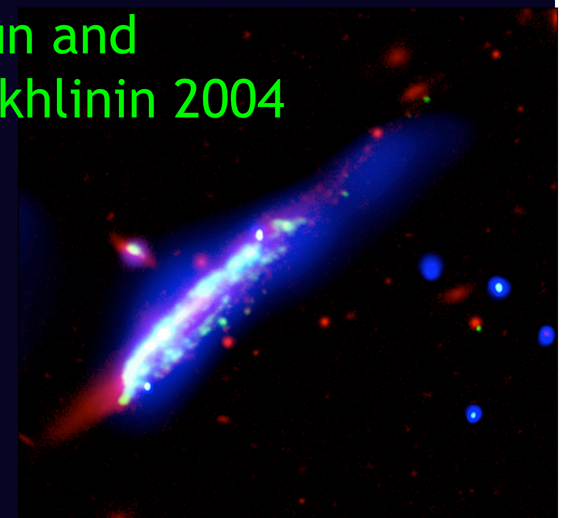
Mahajan, Haines, SR 2011

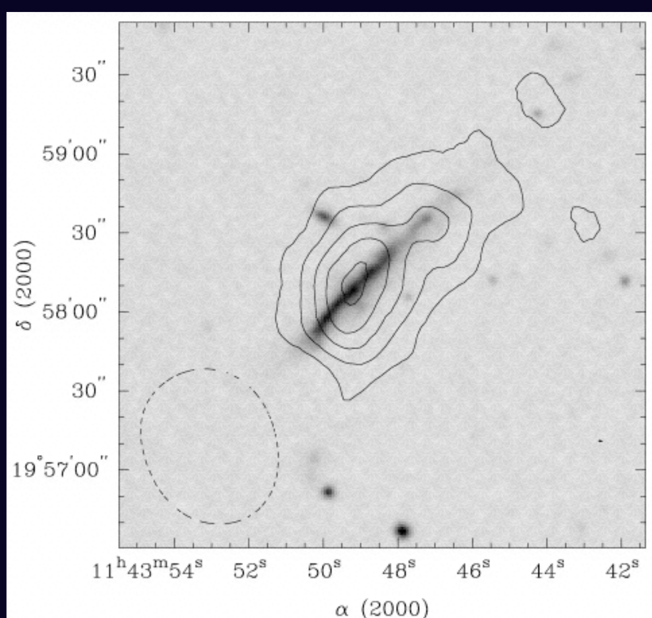

So where does most of the star formation occur?

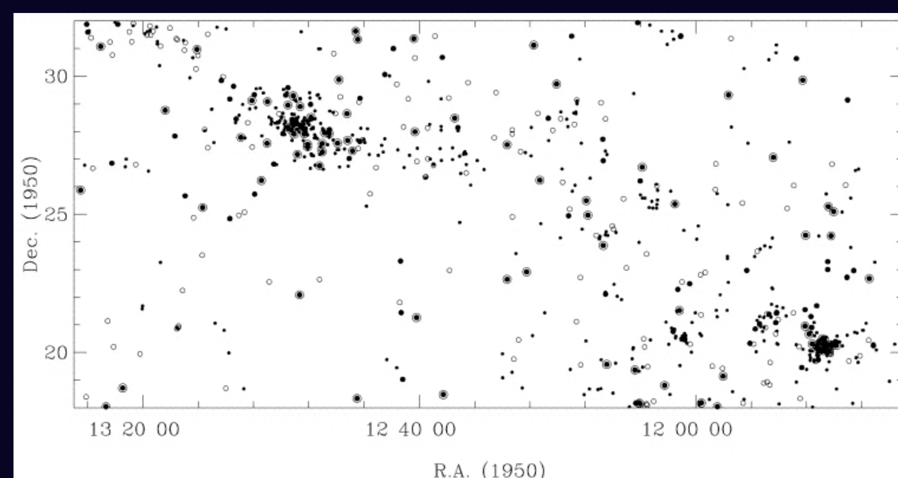
Abell 1367 Chandra



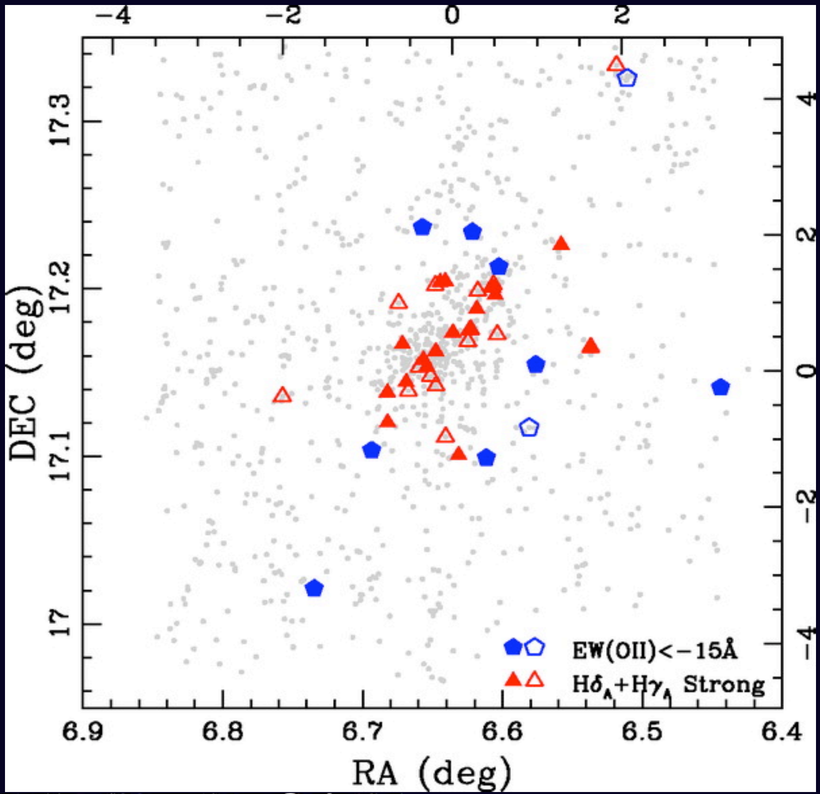
Sun and Vikhlinin 2004

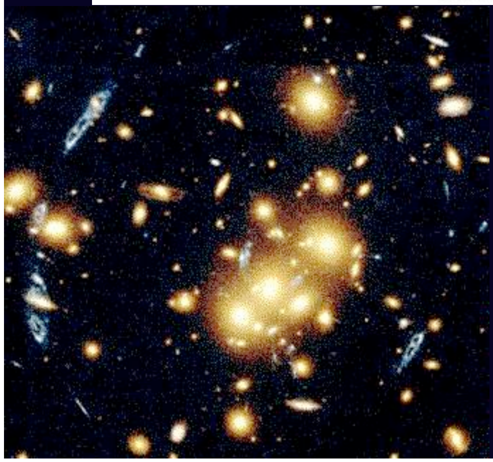


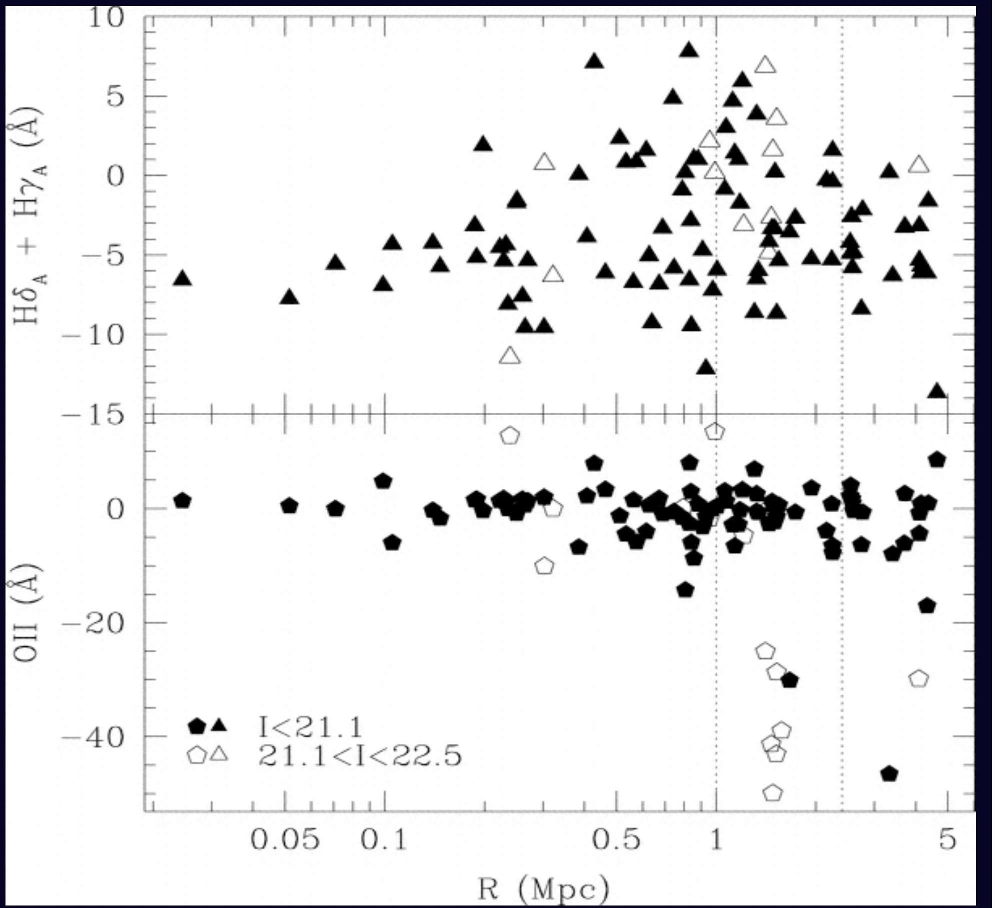




CL0024: Rich cluster at z=0.39







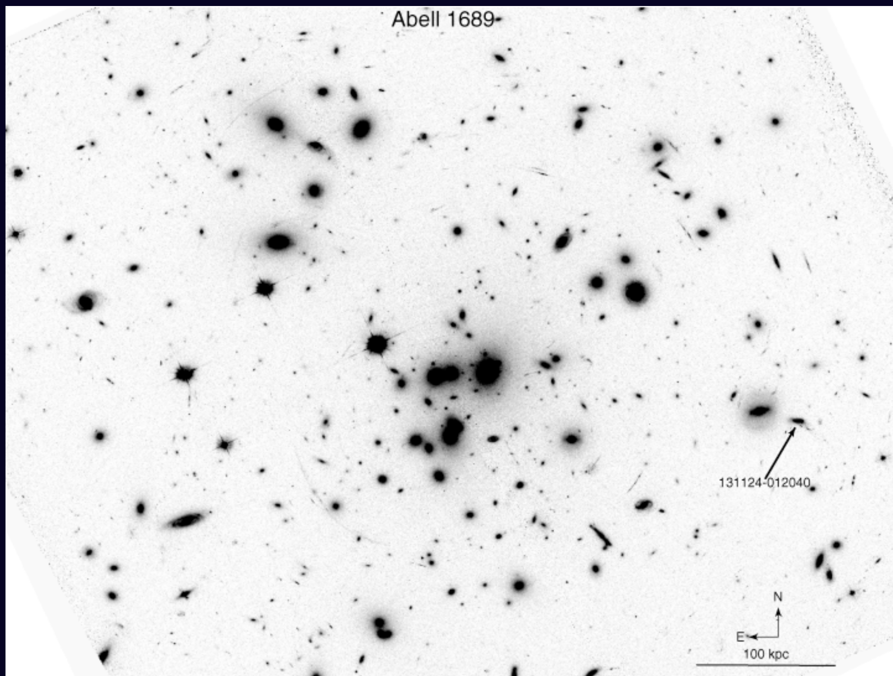
Star forming dwarfs between 1-2 Mpc from centre

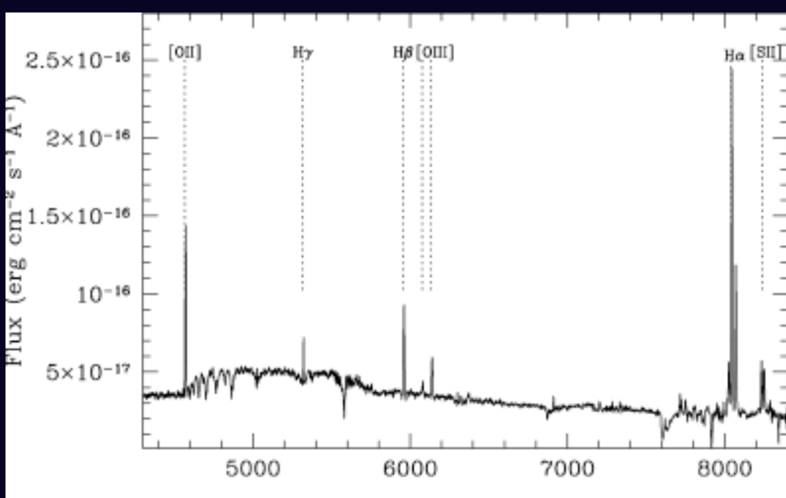
- Moran et al 2005

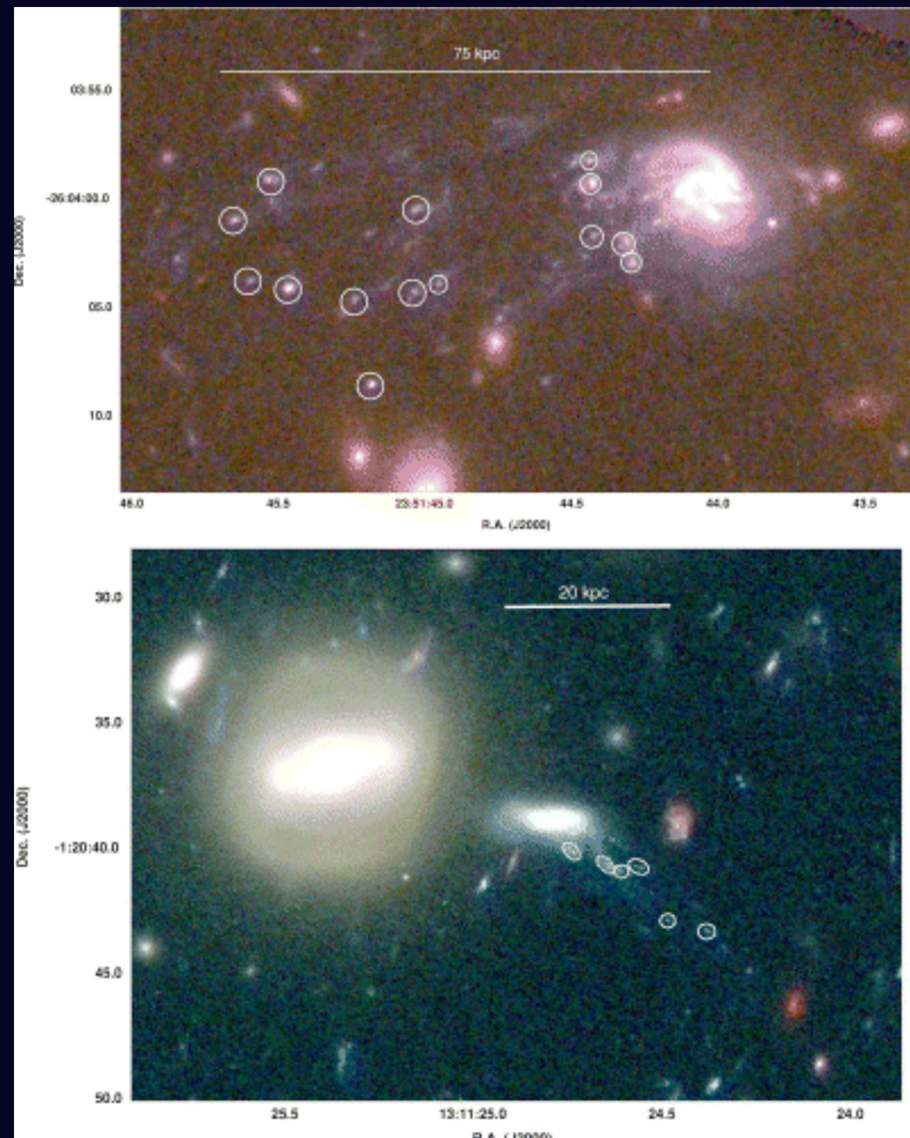
What do these galaxies look like?

Abell 1689 & 2667

Cortese et al 2006

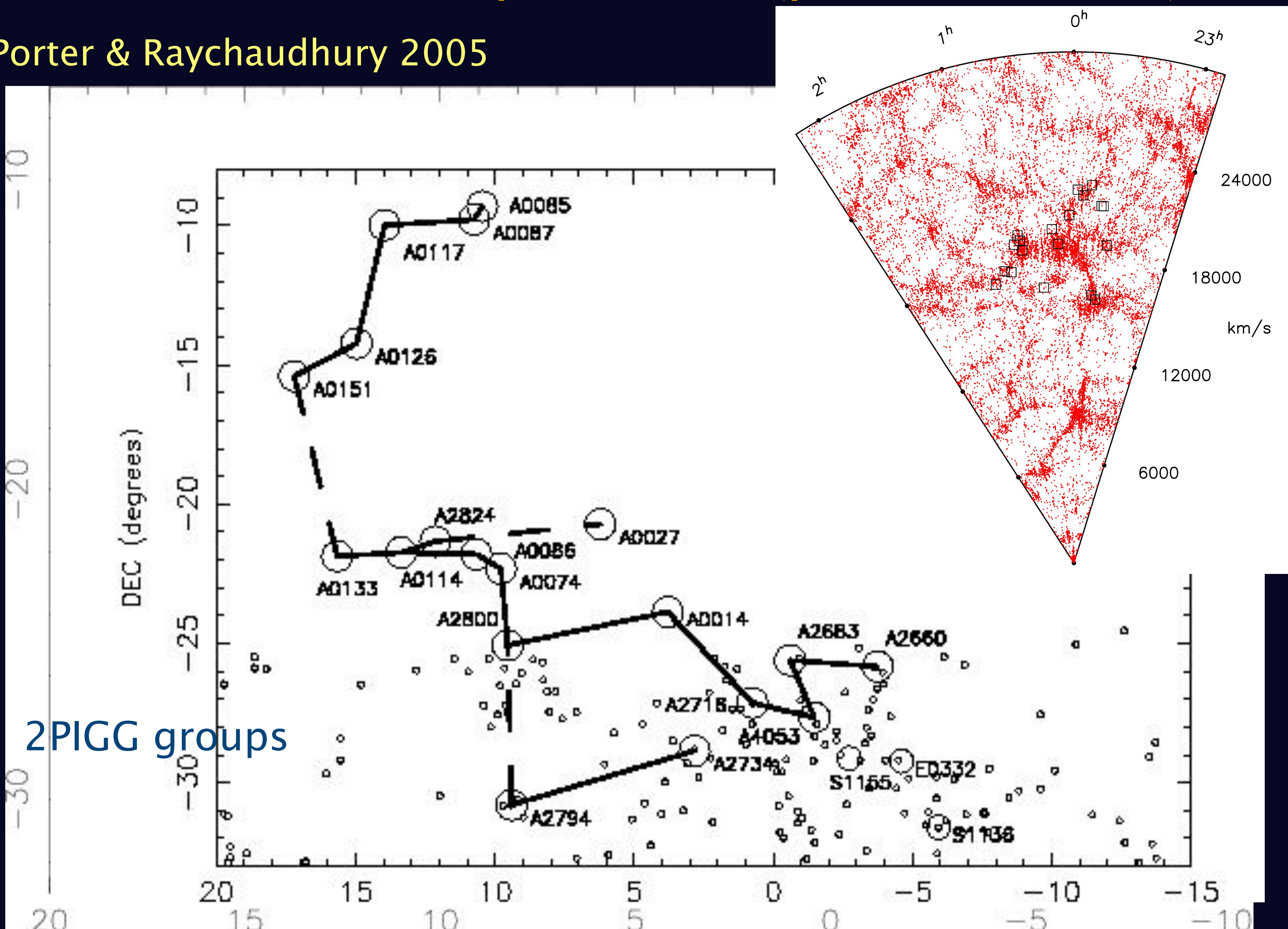






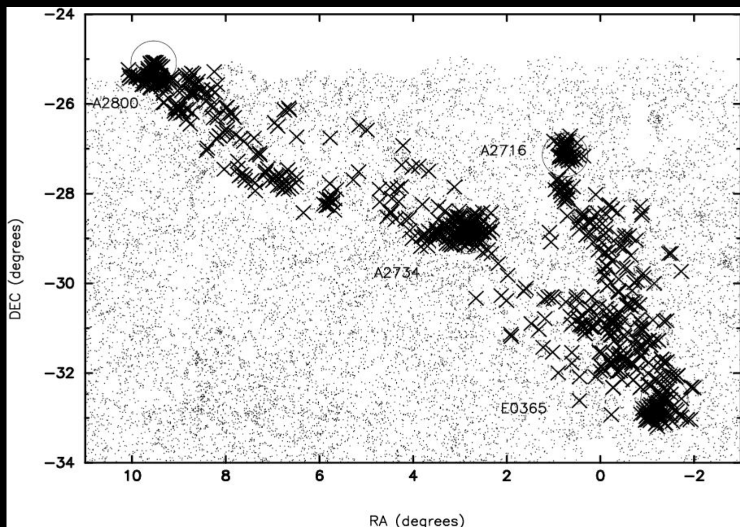
Pisces-Cetus Supercluster (part of 2dFGRS)

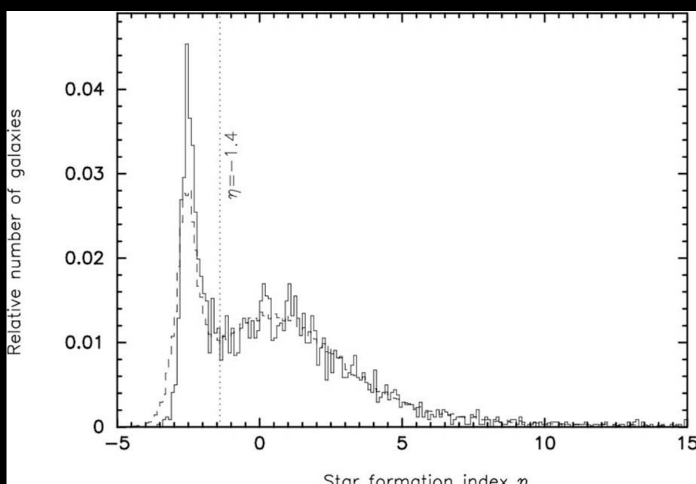
Porter & Raychaudhury 2005



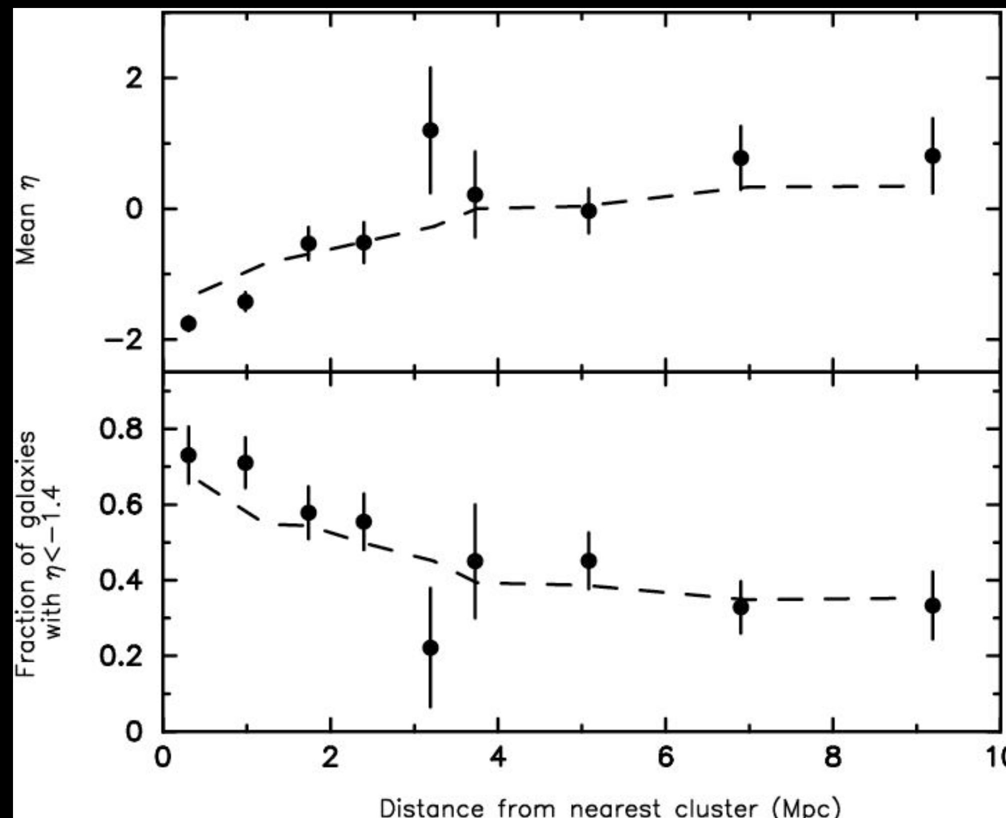
Star formation in supercluster filaments:

3 Pisces-Cetus filaments from 2dFGRS





Porter and SR 2007



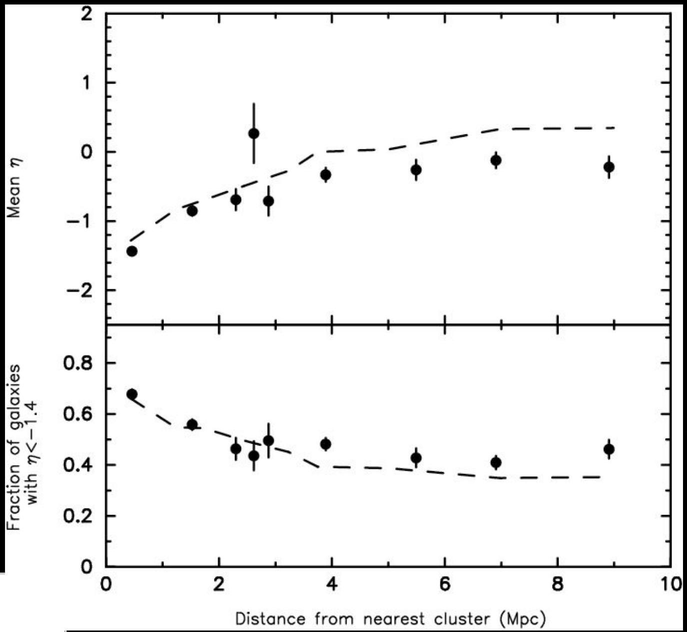
Star formation in superclusters

Porter SR Pimbblet Drinkwater 2007

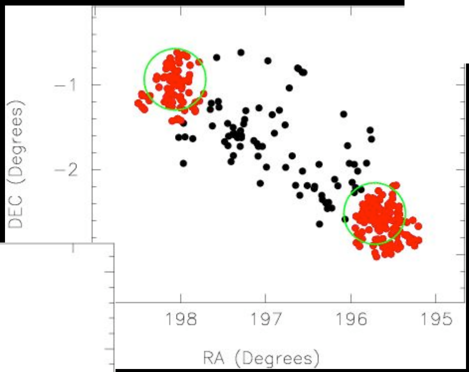
Try again on much bigger sample:

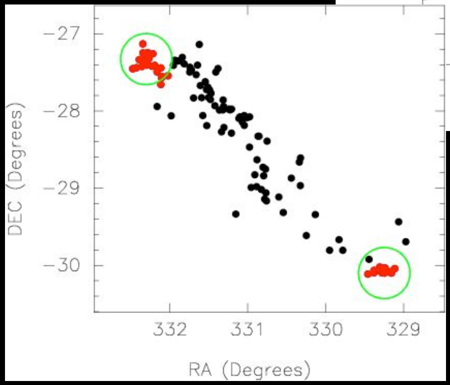
52 2dF filaments

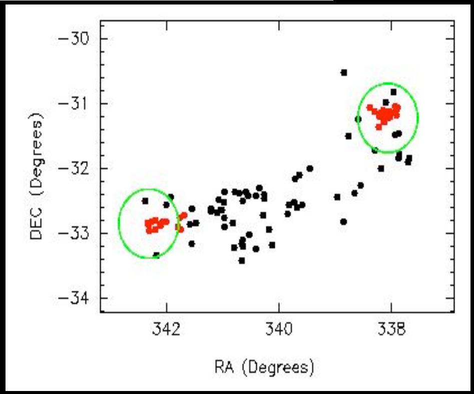
from Pimbblet et al

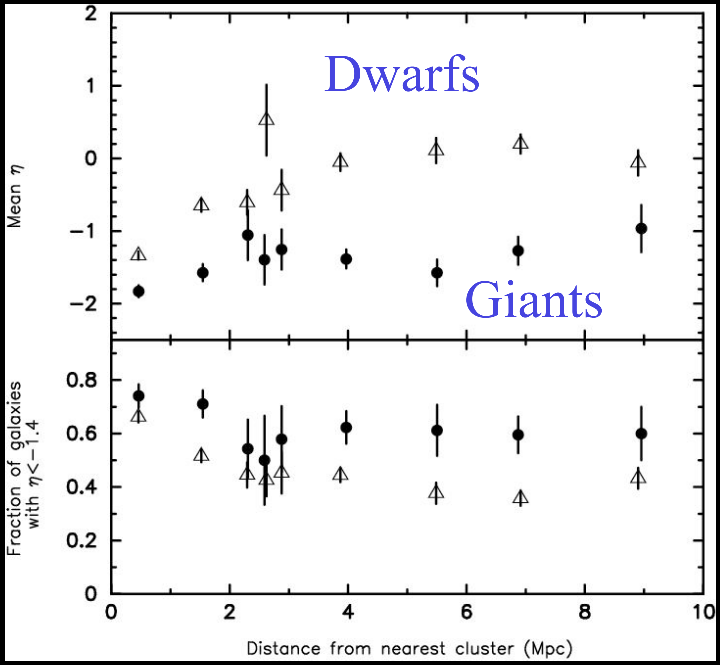


Galaxies in filaments vs all galaxies in 2dFGRS







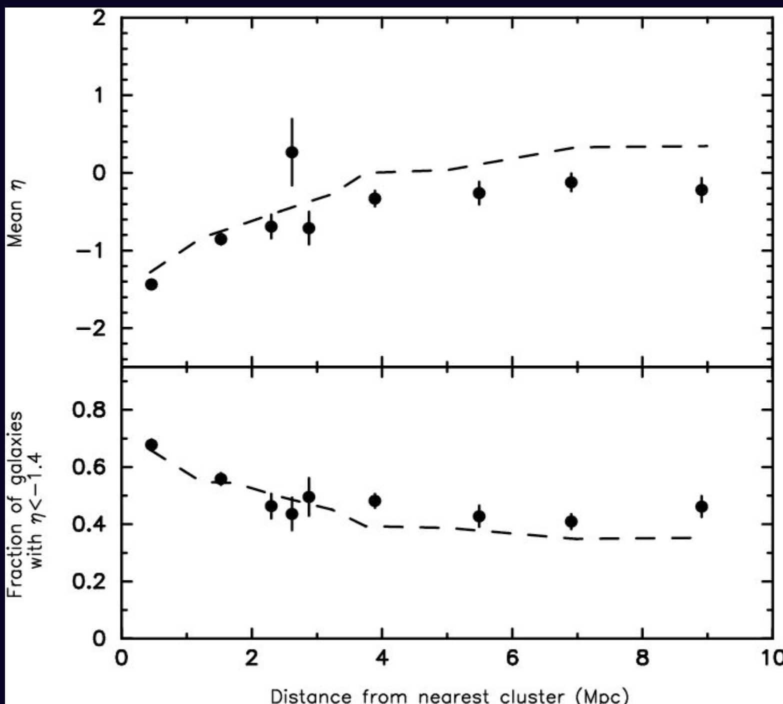


CL0024 lensing cluster at z=0.39

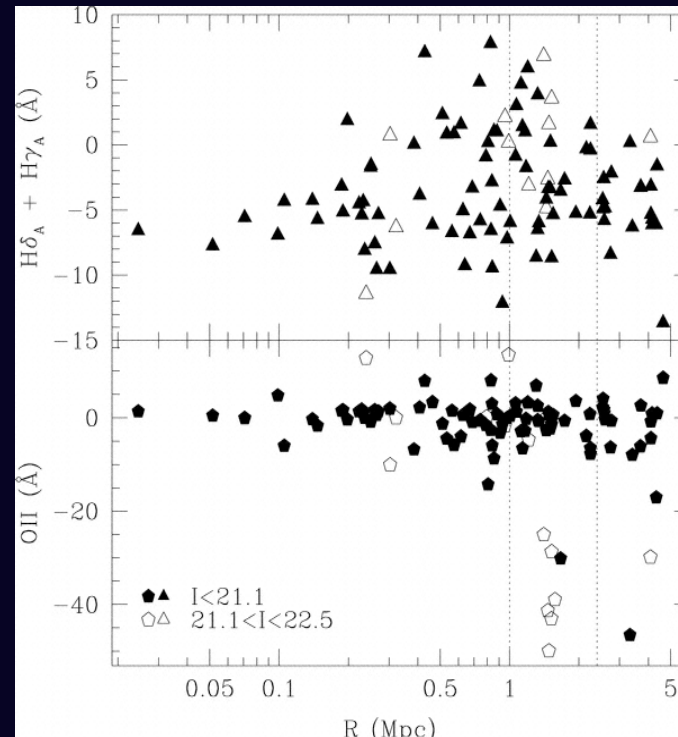
Star forming dwarfs between 1-2 Mpc from centre

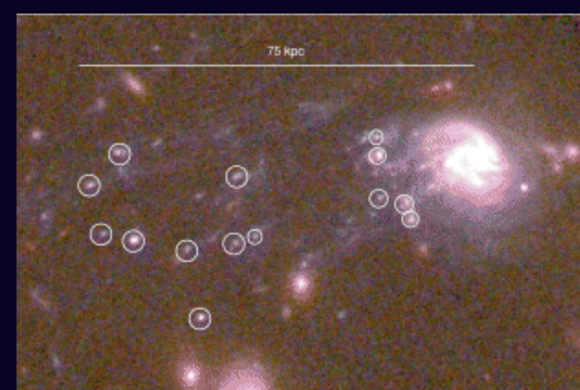
Moran et al 2005

- Compare:



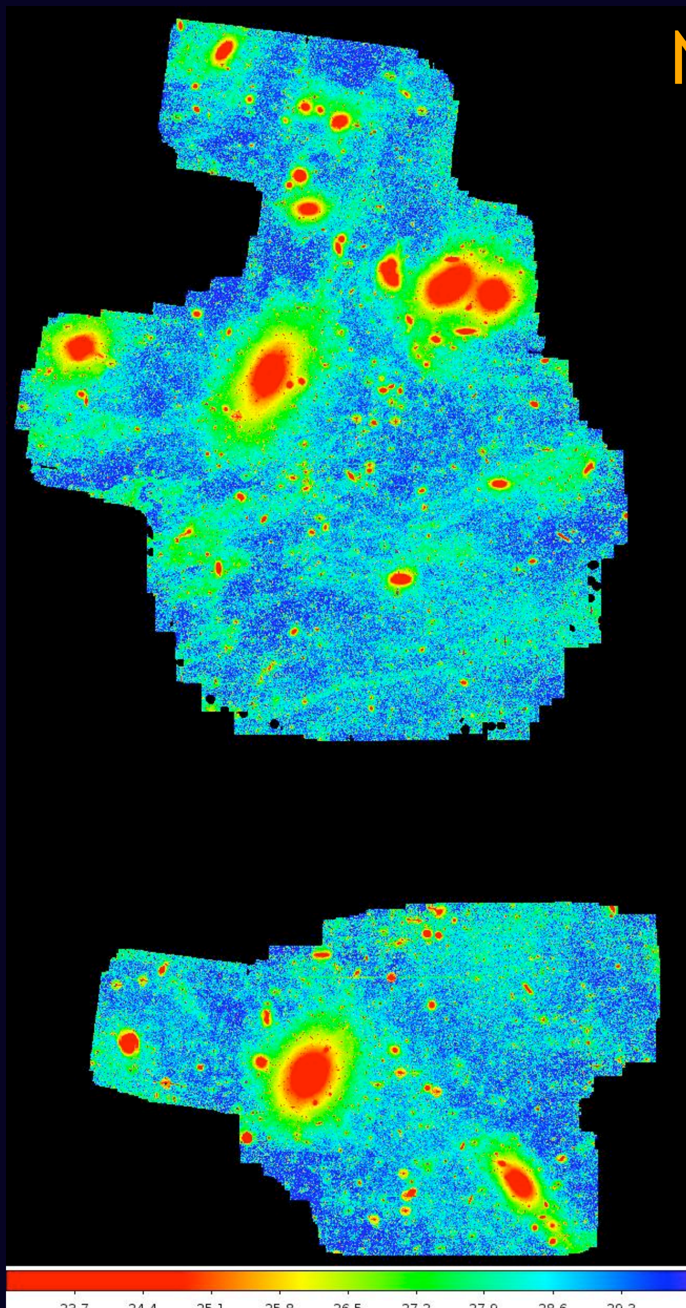
- Porter Raychaudhury Pimbblet Drinkwater 2007





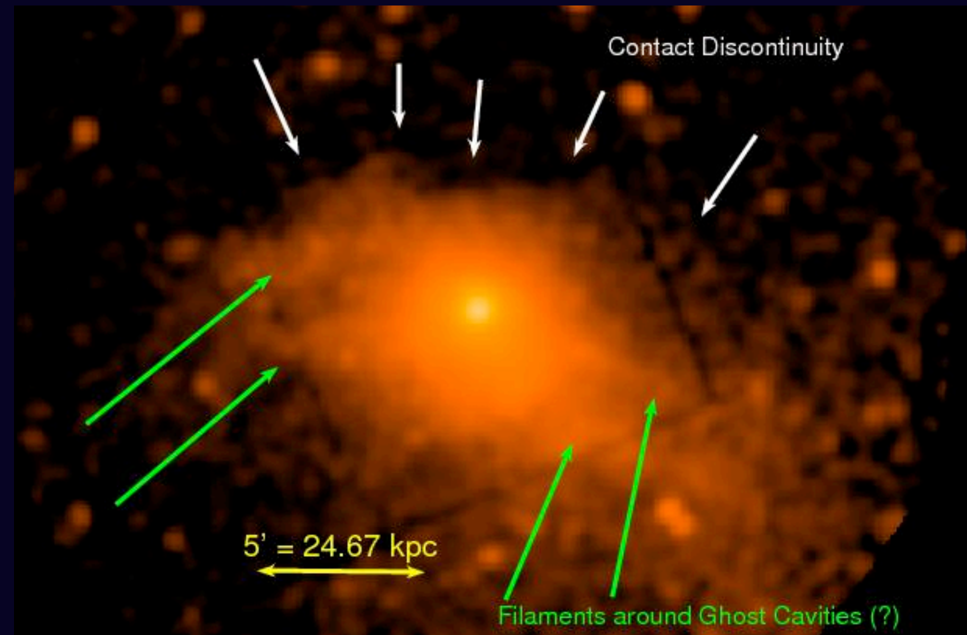
What's going on here?

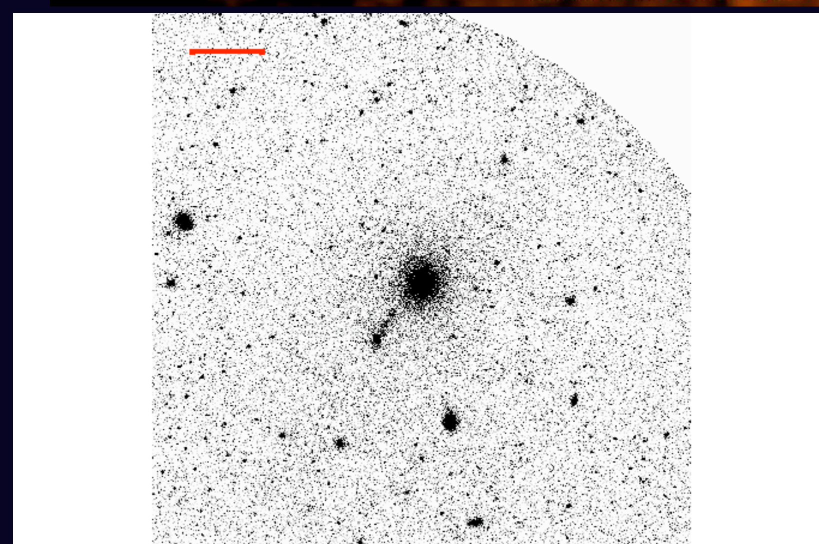
NGC 4472 = M 49



Mihos, this meeting

Kraft +, XMM, 2011

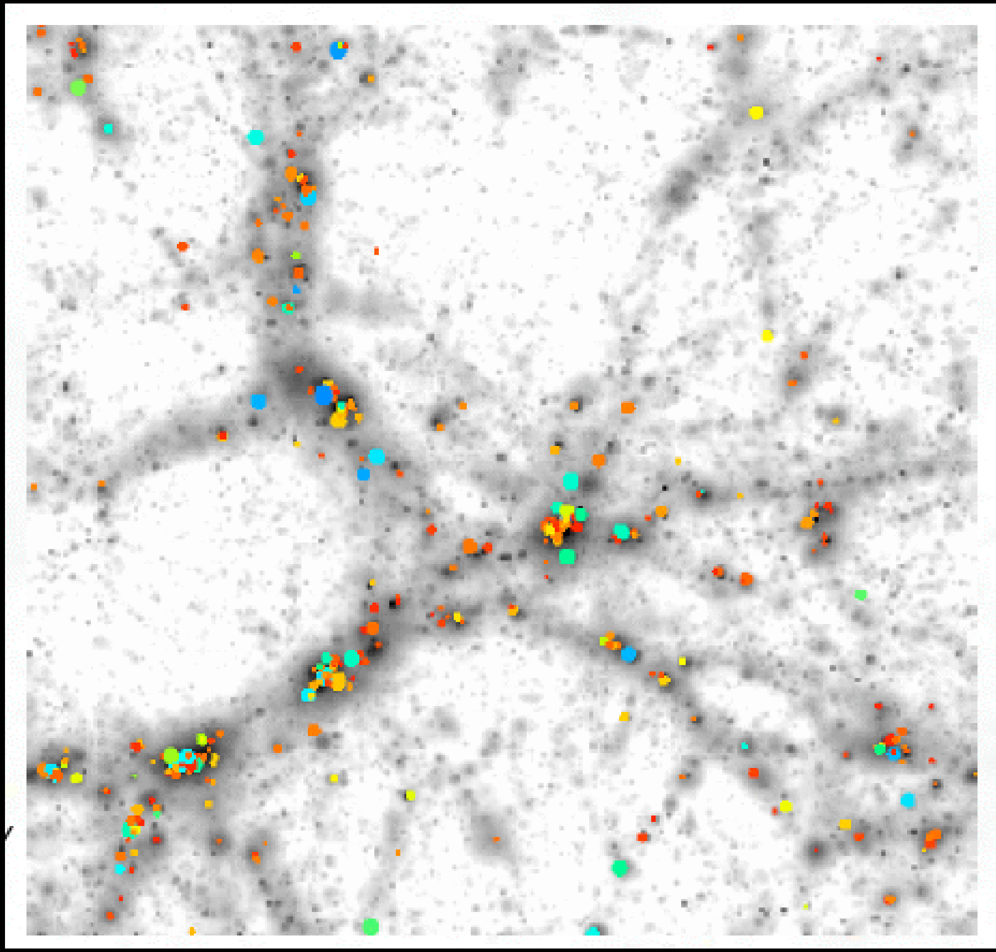




Arrigoni Battaia +, GuVICS, this meeting

As galaxies fall into clusters...

- More starbursts will be found on filaments feeding clusters
- Cluster mass not directly important
- Group membership will be relevant
- Observationally, projection effects will need to be modelled



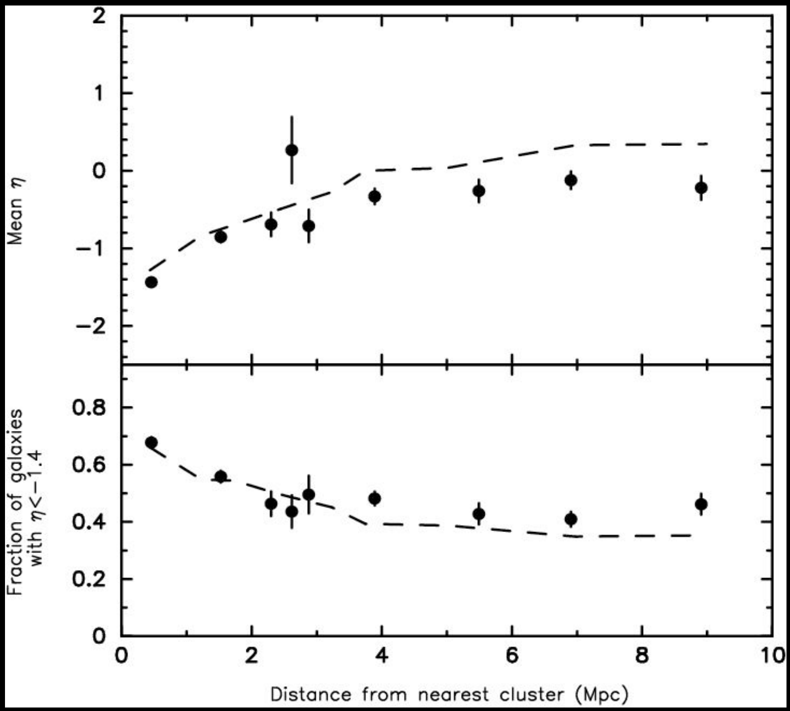
Strong interaction between galaxies along filaments

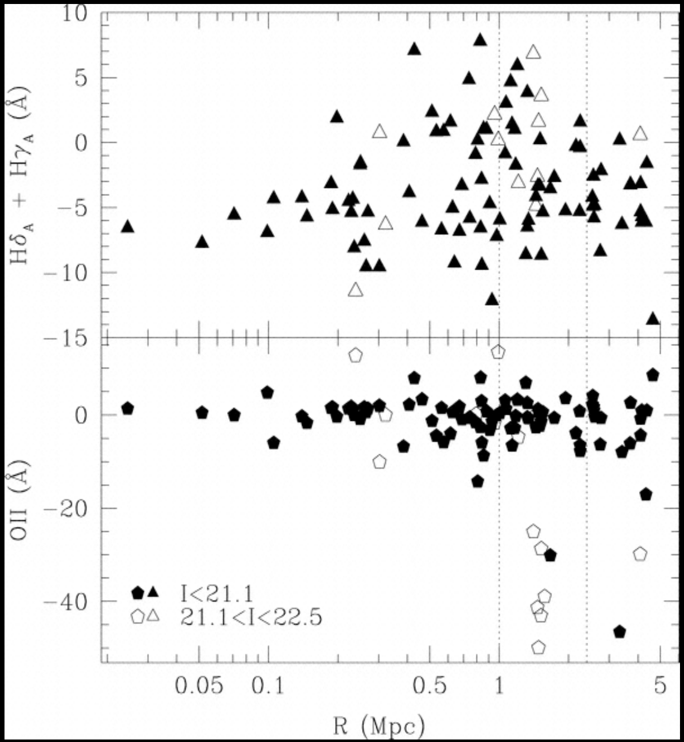
CL0024 lensing cluster at z=0.39

Star forming dwarfs between 2-3 Mpc from centre

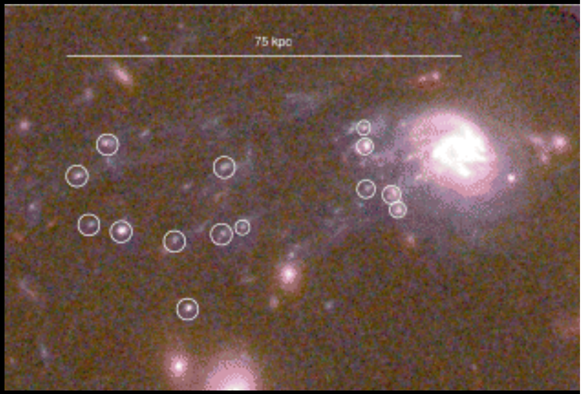
Moran+ 2005

Compare:



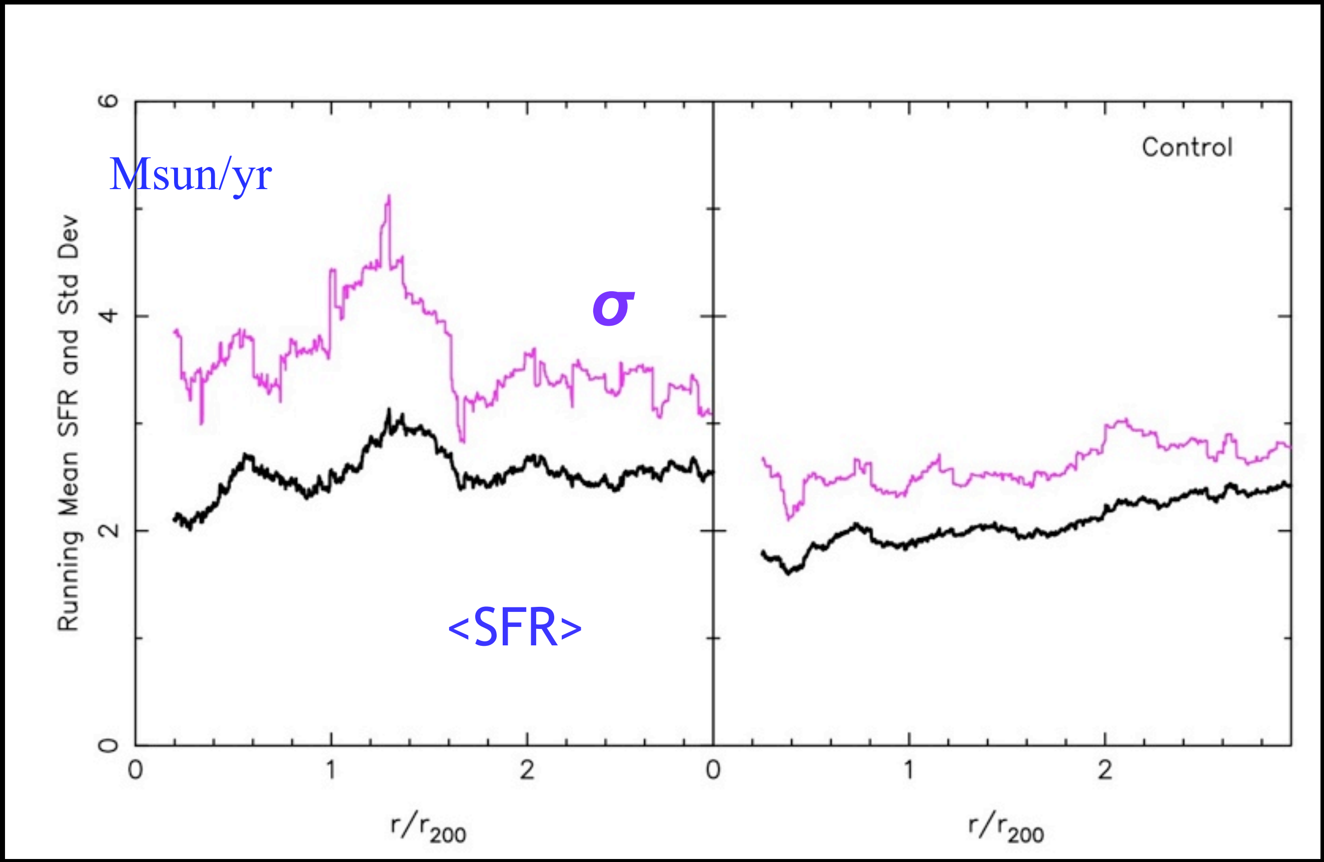


Porter SR + 2007



This sharp peak is most likely due to galaxy-galaxy harassment

SDSS Clusters with Starburst galaxies



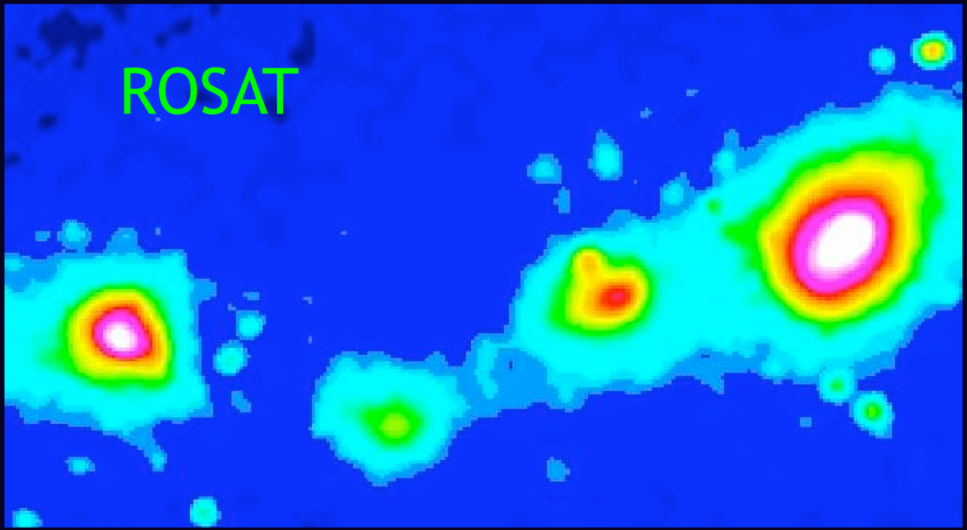
50 clusters each, z=0.02-0.15, >4000 galaxies in each sample

Clusters with (from BPT) non-AGN galaxies with SFR >10 M⊙ & log SFR/M* > -10.5 yr^{-1} within $3r_{200}$ of the cluster centre

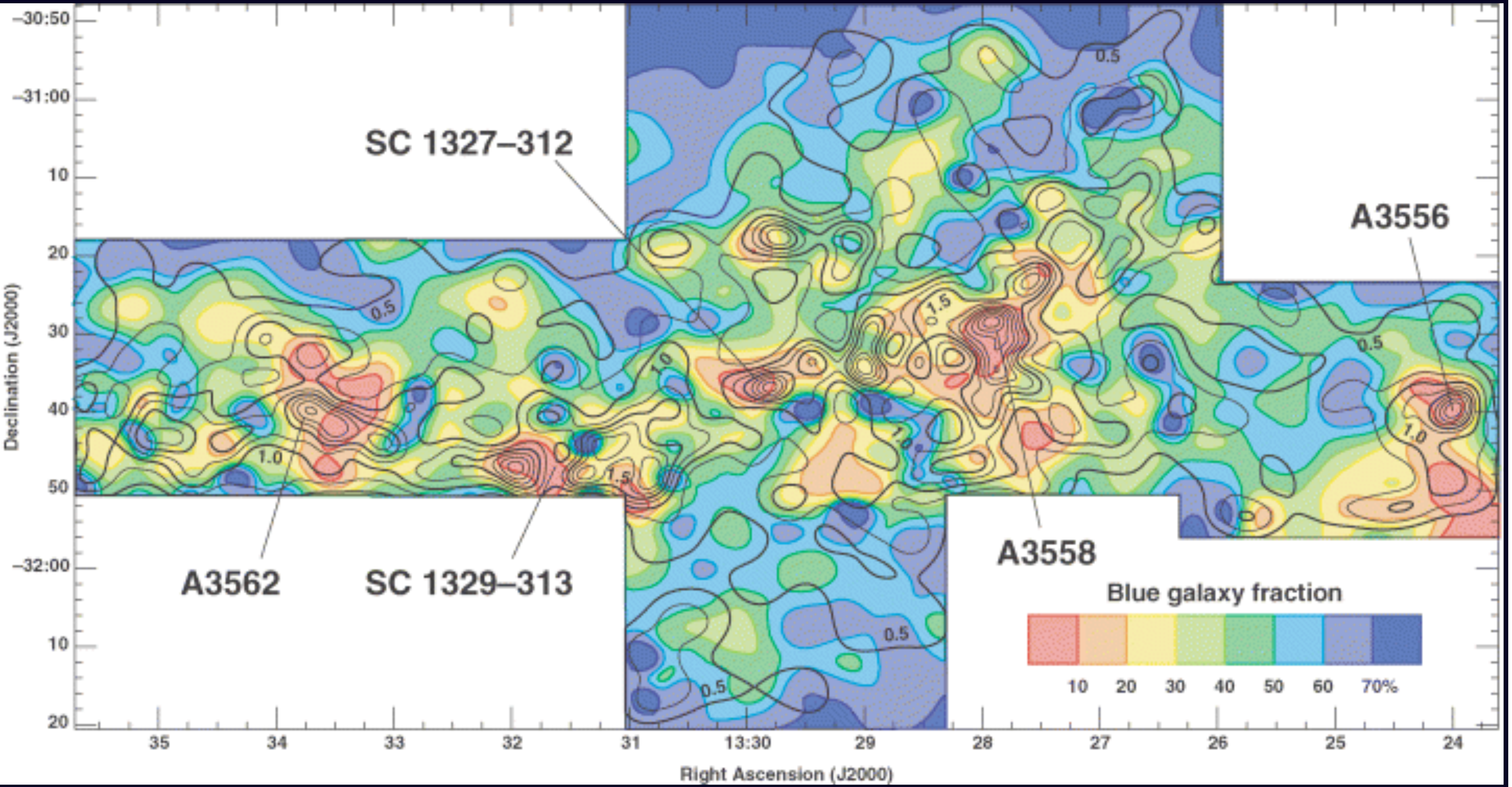
Note: cluster-centric scaled distance

Smriti Mahajan, PhD thesis

The Shapley Supercluster



Breen et al 94

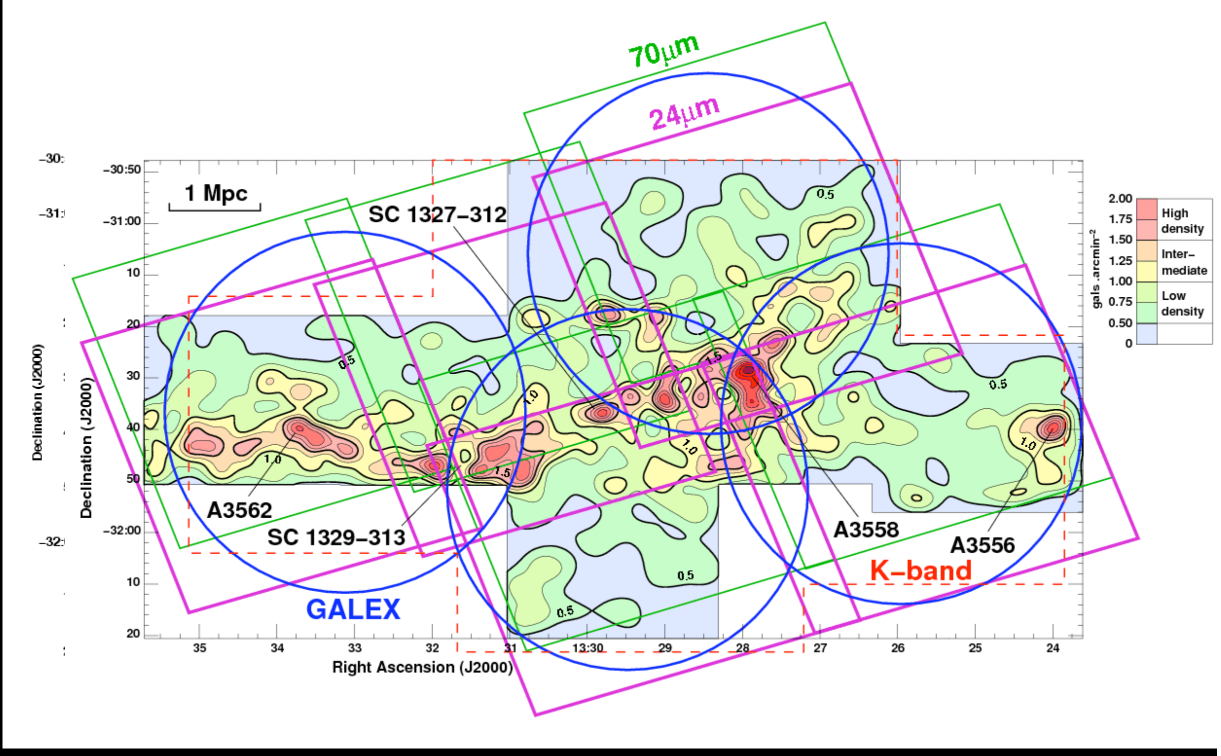


Haines et al 2005

ACCESS (Shapley): Available Data

- Optical-NIR (*BRK*) photometry to M*+6 (morphologies, stellar masses)
- >800 redshifts of supercluster members to M*+3 (AAOmega, 6dF)
- FUV/NUV GALEX photometry, published VLA 1.4GHz radio catalogue
- New Spitzer/MIPS 24/70μm photometry sensitive to SFRs~0.05$M_\odot yr^{-1}$
- Most extensive MIR coverage of z<0.1 cluster environment
- Follow up of few starbursts with WIFES

ACCESS (Shapley) Team: Chris Haines, Paula Merluzzi, Gianni Busarello, Amata Mercurio, Mike Dopita, Somak Raychaudhury, Russell Smith, Graham Smith et al.



Summary

- Star formation occurs mostly in quiescent galaxies falling into clusters
- Ram pressure stripping is efficient in quenching star formation near the cores of clusters where the hot ICM is present.
- Galaxies spend most of their star forming lives out on the cosmic web. As they fall into clusters, tidal fields and ram pressure strip their gas and quench SF.
- As they fall into clusters along the network, those on narrow filaments experience galaxy-galaxy interactions in the infall regions. This may inspire starbursts, if the galaxy still has its gas reservoir.
- This happens more in dwarfs, which eventually turn into passive dwarfs after going through a k+A phase.
- Study of star formation along supercluster filaments and on the outskirts of clusters is essential for the study of galaxy transformations.