From X-rays to Far Infrared: A multiwavelength view of environmental effects on cluster galaxy evolution

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ESAC. 03/12/2015

Talk outline

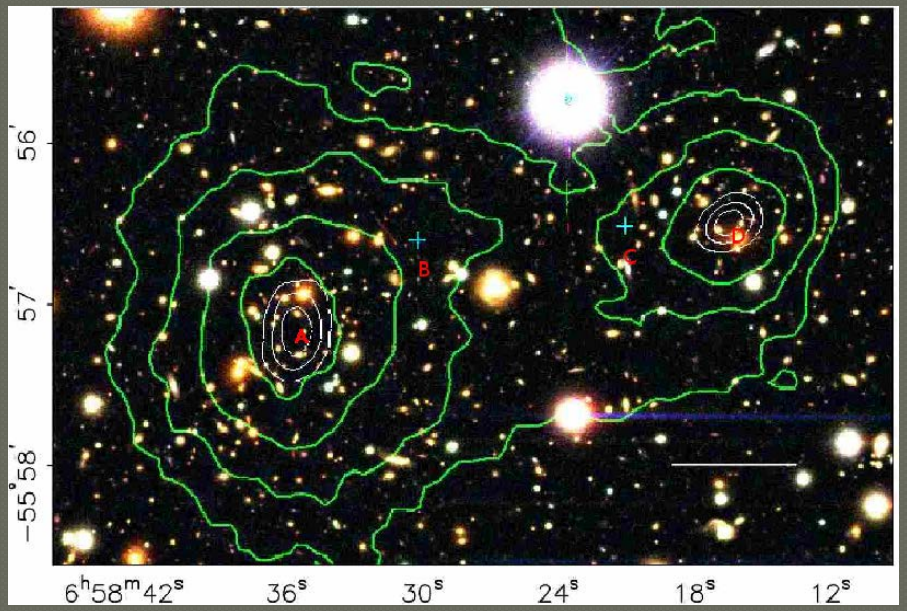
- Galaxy clusters overview
  - ZwCL0024+1652
- The multiwavelength catalogue
  - Data gathering
  - Xmatch
- Cluster populations
  - FIR
  - AGNs
  - SF/quiescent
- Environmental effects

Galaxy clusters overview

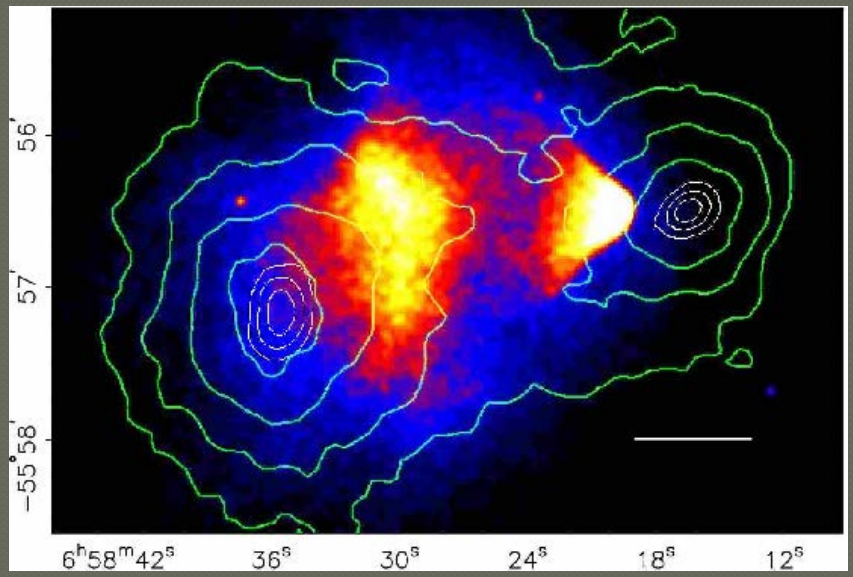
- Clusters are the largest gravitationally bound systems in the Universe
  - First identified by Messier (s. XVIII). Early studied by Zwicky and Abell (~30s-50s)
    - Abell catalogue (1958): ~ 2700 nearby clusters
    - Characterised by richness, concentration and virial mass.
  - Hierarchically formed
  - Xray extended emission (Uhuru, 70s)

Galaxy clusters overview

Different wavelengths provide different views:



The bullet cluster (z~0.3)



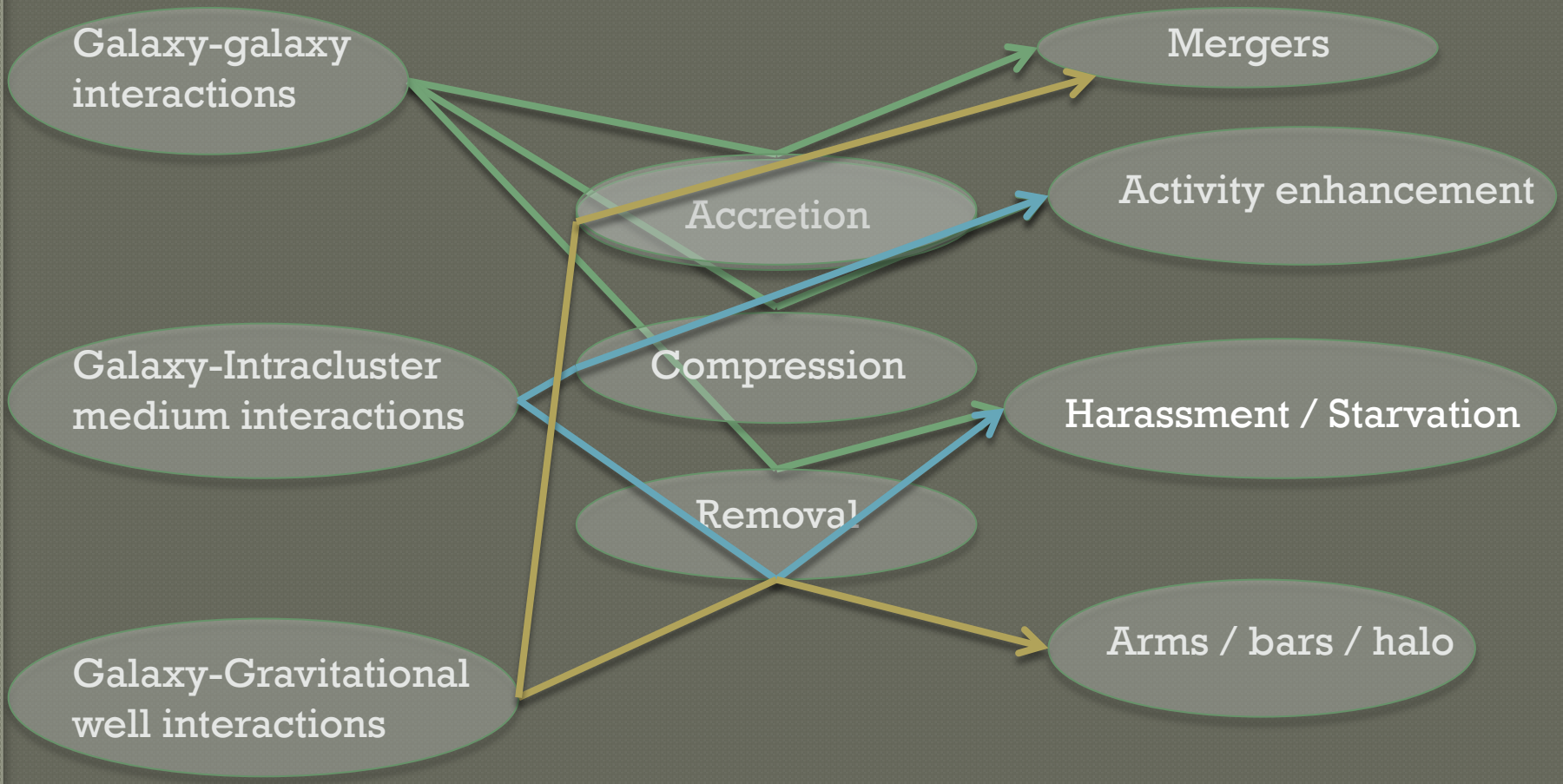
Mass discrepancy up to 70%. In some cases there is a mass agreement with no need of DM

Galaxy clusters overview

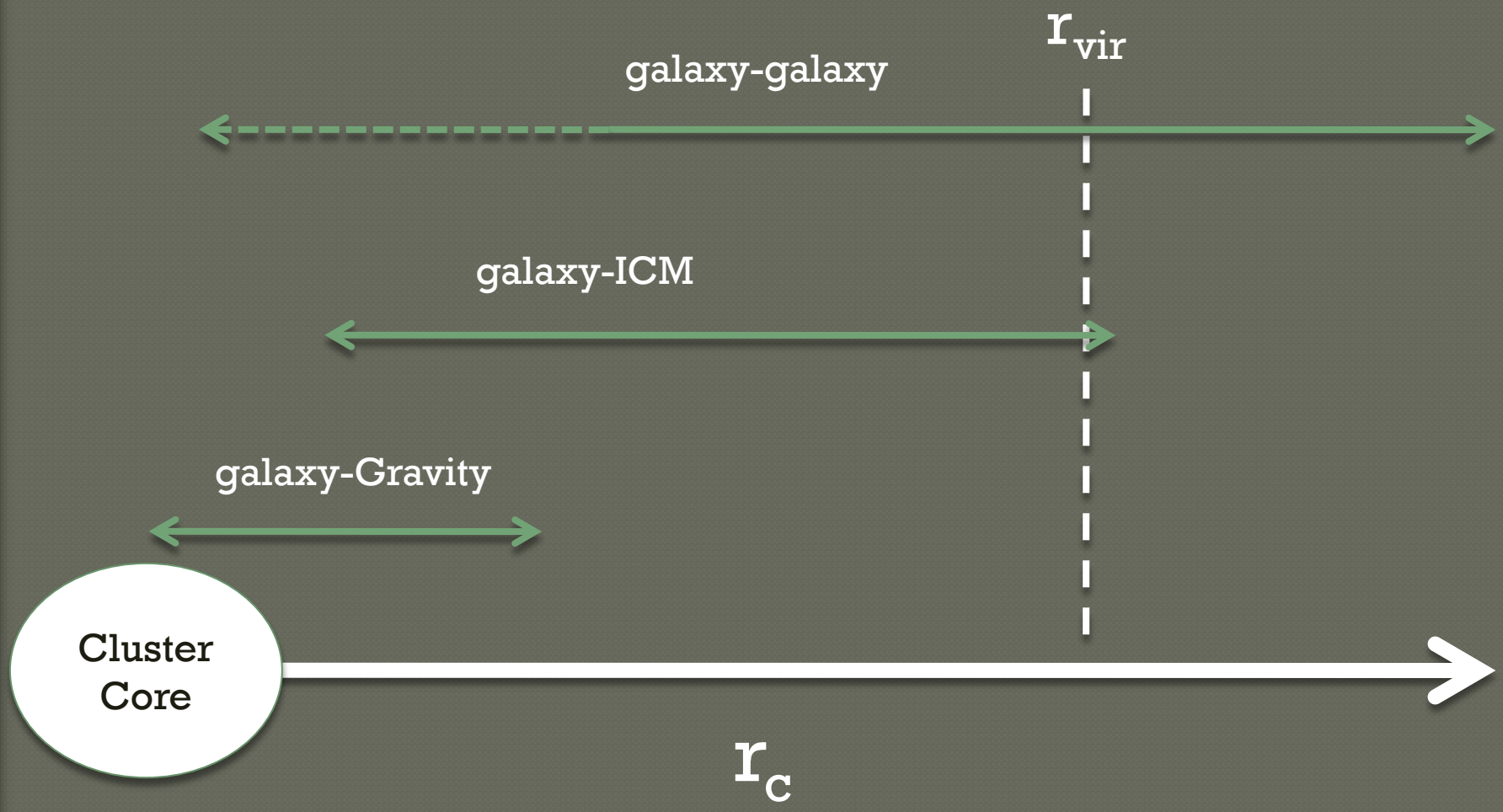
- Cluster components:
  - Galaxies (~1%)
  - Hot intracluster gas (ICM) (~10%)
  - Dark Matter (~90%)
- Cluster members:
  - Dominance of red, passive, elliptical galaxies
  - Blue fraction evolution (Butcher & Oemler, 74)
  - Morphology / luminosity – density (Dressler+80)

Galaxy clusters overview

Environmental effects:



Galaxy clusters overview



ZwCL0024+1652

- Massive, rich cluster at z = 0.395
  - $M_{200} = 5.9 \pm 0.3 \times 10^{14}\ h_{70}^{-1}\ M_{\odot}$
  - $r_{200} = 1.7 \pm 0.1\ h_{70}^{-1}$ Mpc
- Intermediate L_x
  - $L_x = 2.9 \pm 0.1 \times 10^{44}\ h_{70}^{-2}$erg s^{-1}
  - $M_{200} = 2.3 \pm 0.1 \times 10^{14}\ h_{70}^{-1}\ M_{\odot}$
  - T ~ isothermal sphere (r<1.5arcmin) & power law $\Gamma = 0.98$ (r>1.5arcmin)

Sanchez-Portal+2015, Zhang+2005

The multiwavelength catalogue

Data gathering

- Optical data
  - Hα+[NII] (SanchezPortal+15) and Hβ (OSIRIS@GTC, GLACE)
- Infrared data
  - Spitzer
    - 3.6, 4.5, 5.8 & 8 μm (IRAC) and 24μm (MIPS)
  - Herschel
    - 100, 160 μm (PACS) and 250, 350, 500 μm (SPIRE)
- X-rays
  - XMM/Newton
    - 0.5-7 KeV (EPIC)

Data gathering

- Archival catalogues
  - CSC (Chandra)
  - 3XMM-DR4 (XMM/Newton)
  - UV GR7 (GALEX)
- Published catalogues
  - B, V, R, F814W, I, J, K (Moran *et al* 2005 ApJ, 634, 977) (M05)

Multiwavelength Catalog

- 25 photometric points from 12 different instruments in 8 telescopes.
- Robust Xmatch algorithms needed
- M05 chosen as master catalog
  - Best astrometry accuracy
  - Best completeness and depth
  - Largest area covered

Likelihood ratio and reliability

$$LR(m,r) = \frac{q(m)f(r)}{n(m,r)}$$

Probability function of a true match be at distance r:

$$f(r) = \frac{1}{2\pi\sigma^2}\exp\left(\frac{-r^2}{2\sigma}\right)$$

$$\sigma = \sqrt{\sigma_{NO}^2 + \sigma_{Opt}^2}$$

Surface density of background sources: $n(m,r)$

Likelihood ratio and reliability

Probability distribution of true matches:

$$q(m) = \frac{real(m)}{\Sigma_m real(m)} Q$$

$$real(m) = total(m) - \pi r_0^2 n(m, r)$$

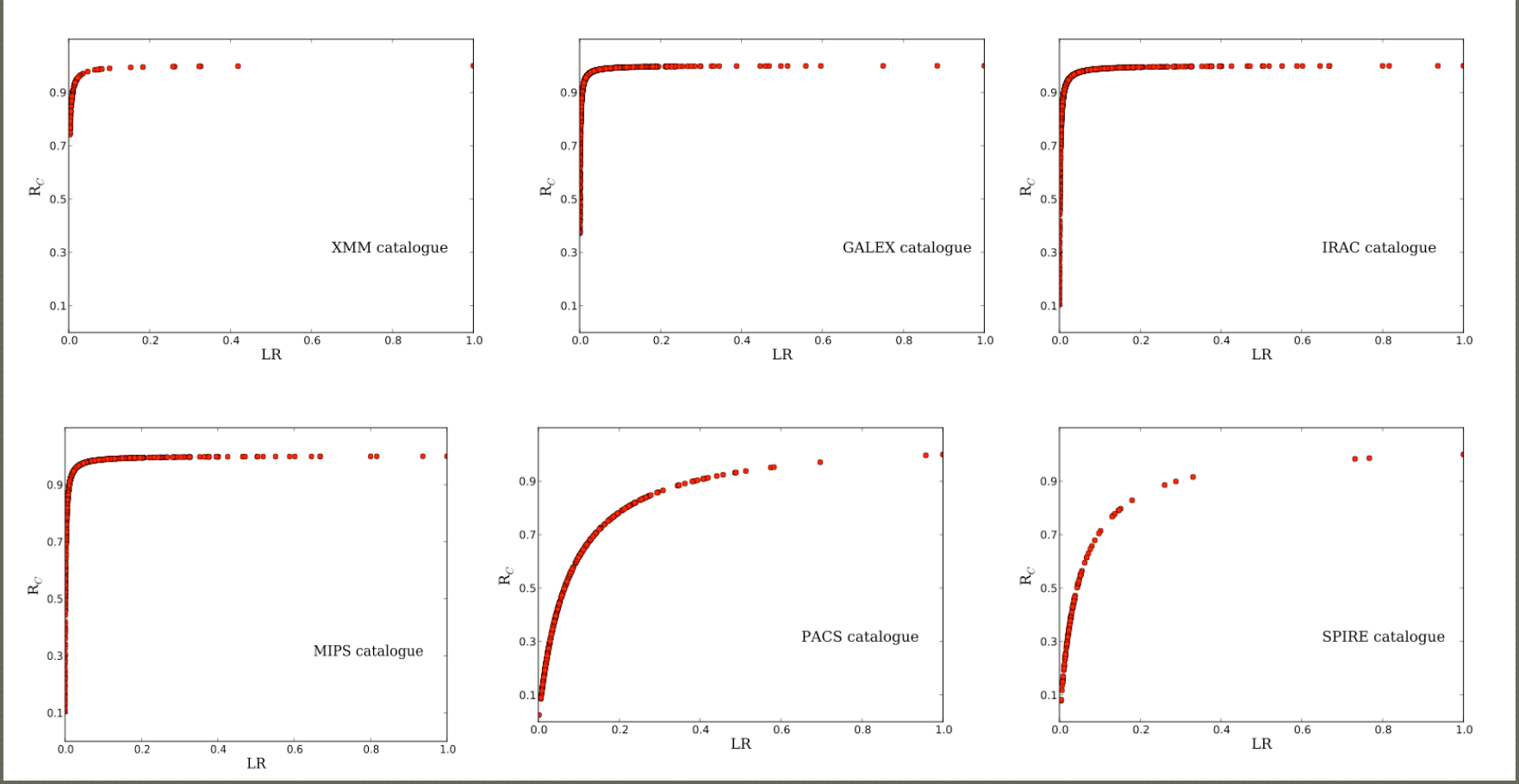
$$Q = \int_{-\infty}^{m_{lim}} q_m dm.$$

Reliability and Completeness:

$$R_c = \frac{LR}{\Sigma LR + (1 - Q)}$$

$$C = \frac{\Sigma R_c}{N_{NO}}$$

Likelihood ratio and reliability



Likelihood ratio and reliability

Table 3.1: Crossmatch of NonOpt and Optical sources.

Catalog	Depth	σ_{NO}	R	C	N_X	N_{ID}	N_{mult}
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
XMM–Newton	1.2×10^{-13}	1.33	0.89	0.64	148	107	0
Chandra	1.0×10^{-13}	0.7	0.61	0.55	31	20	6
GALEX	25.3	0.5	0.88	0.44	3748	872	23
IRAC	23.6	0.18	0.94	0.64	2337	1529	0
MIPS	19.6	1.0	0.86	0.73	1549	956	0
PACS	20.6	2.0	0.47	0.39	408	330	0
SPIRE	19.6	3.0	0.41	0.31	3211	126	0

Multiwavelength Catalog

Sample (1)	N_{obj} (2)	% (3)	Z range (4)
Objects with redshift	19670	100	full
Objects with reliable redshift	9117	46	full
Objects with photometric redshift	7753	39	full
Objects with spectroscopic redshift	1364	7	full
Total cluster members	1262	6	ZwCl0024+1652
z_{phot} cluster members	735	4	0.395 ± 0.09
z_{spec} cluster members	527	3	0.395 ± 0.03

SED fitting (*Le Phare*)

- SED fitting
  - Optical: population synthesis models by Bruzual & Charlot, 2003. IMF: Chabrier, 2003
  - Infrared: Chary&Elbaz, 2001
- Obtained: L(UV), L(IR), Age and Mass
- Double run approach
  - 500 instances of same object (free model)
  - 500 instances of same object (best model)

CLUSTER POPULATIONS

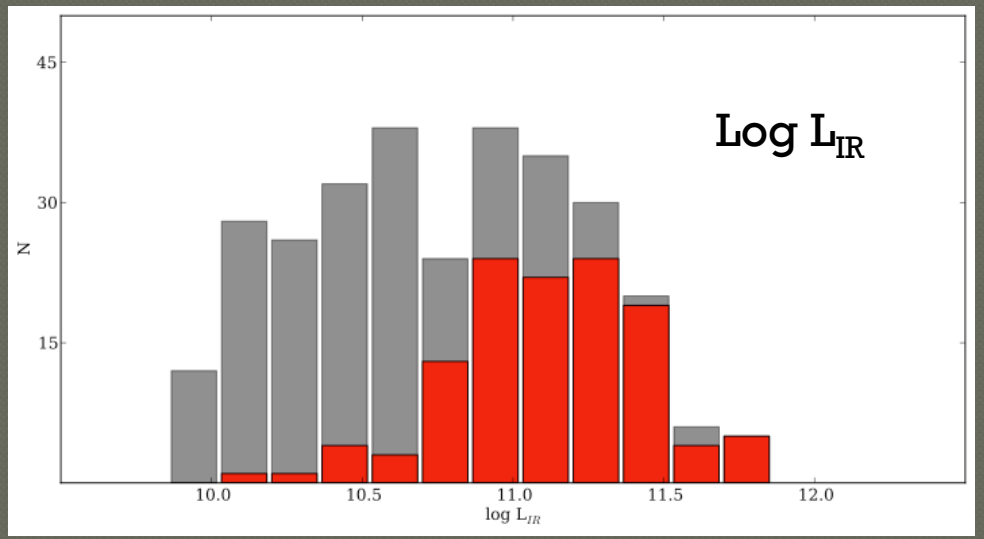
Cluster populations: FIR

	Total (1)	All instrument band (2)	Common with MIPS (3)
100 μm	87	79	74
160 μm	97	79	68
250 μm	41	21	29
350 μm	36	21	26
500 μm	21	21	13
Total (*)	122	24	85

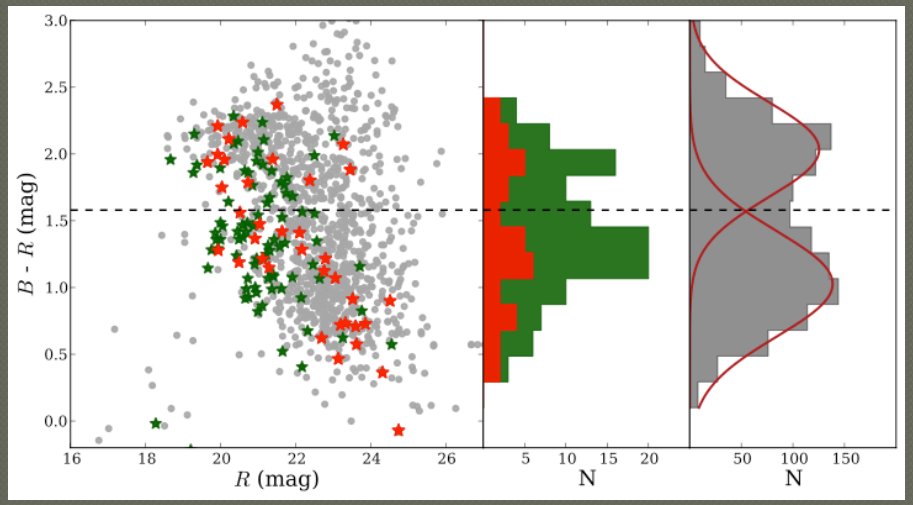
Mean L(IR) =

$1 \times 10^{11.24 \pm 0.02} L_{\odot}$

57 LIRGs

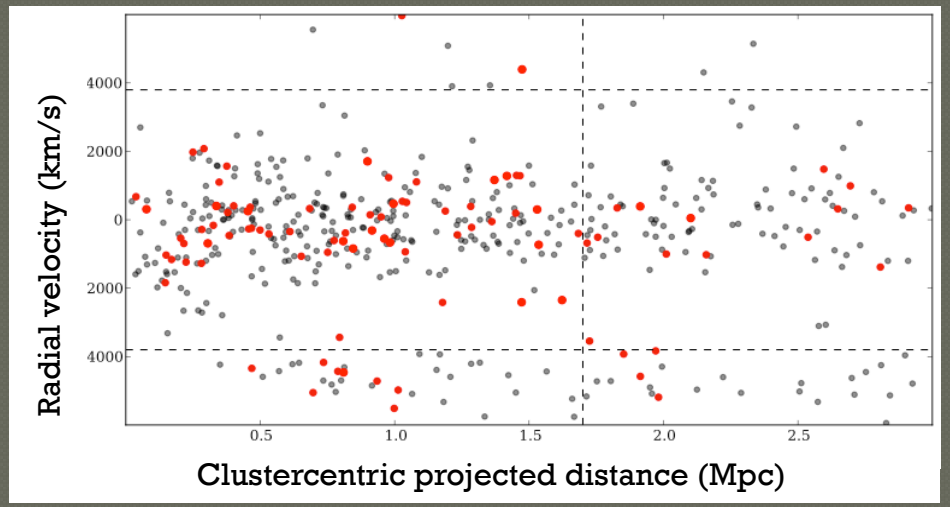


Cluster populations: FIR



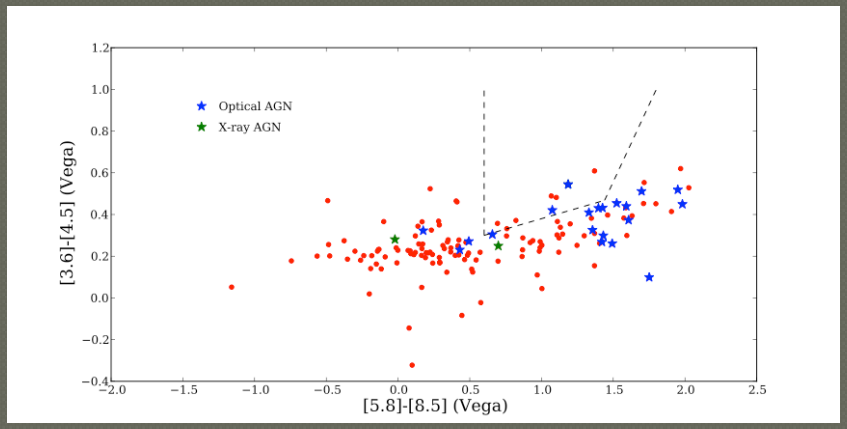
FIR population loci:
red sequence & green valley (extinction)

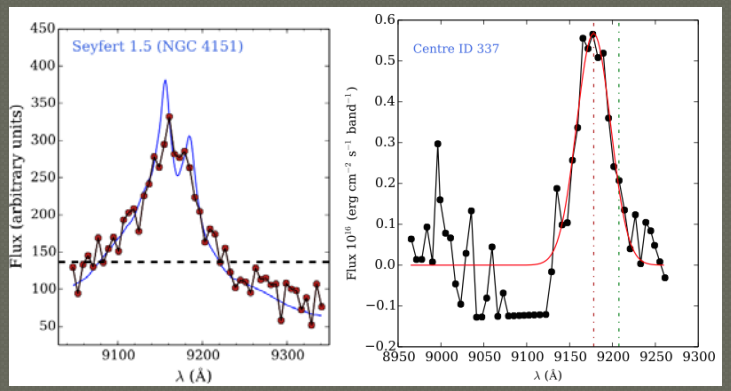
FIR fraction favours the main structure by a factor of 2

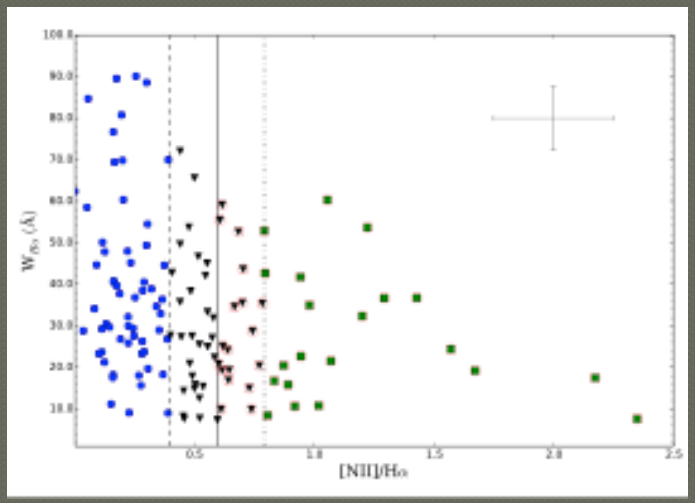


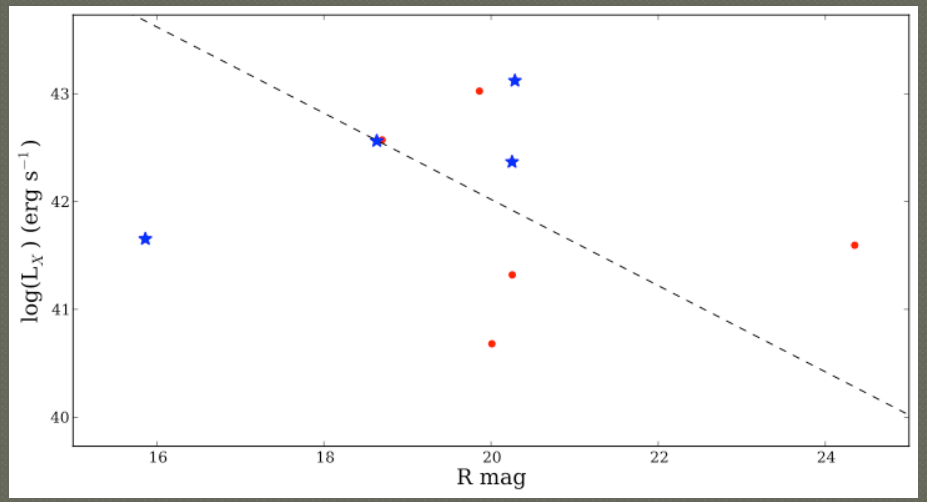
Cluster populations: AGNs

- Selection: EWαN2 + Broad Lines + IRAC colors + X/O = 72

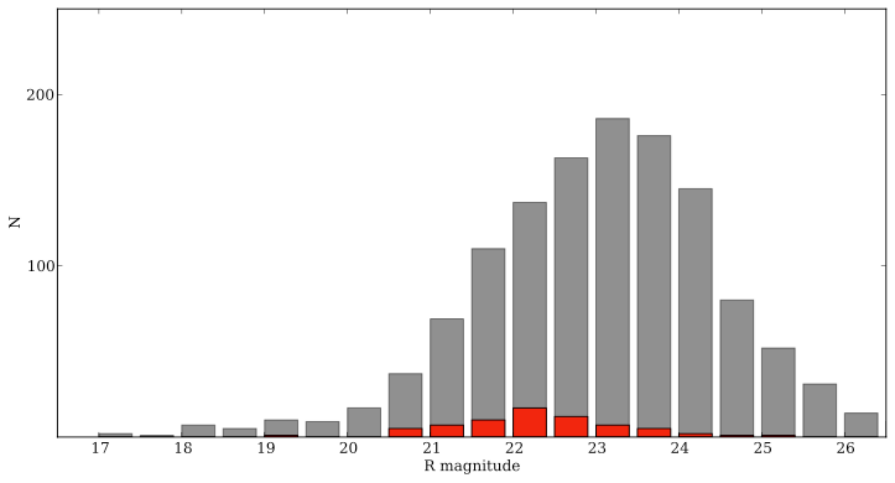






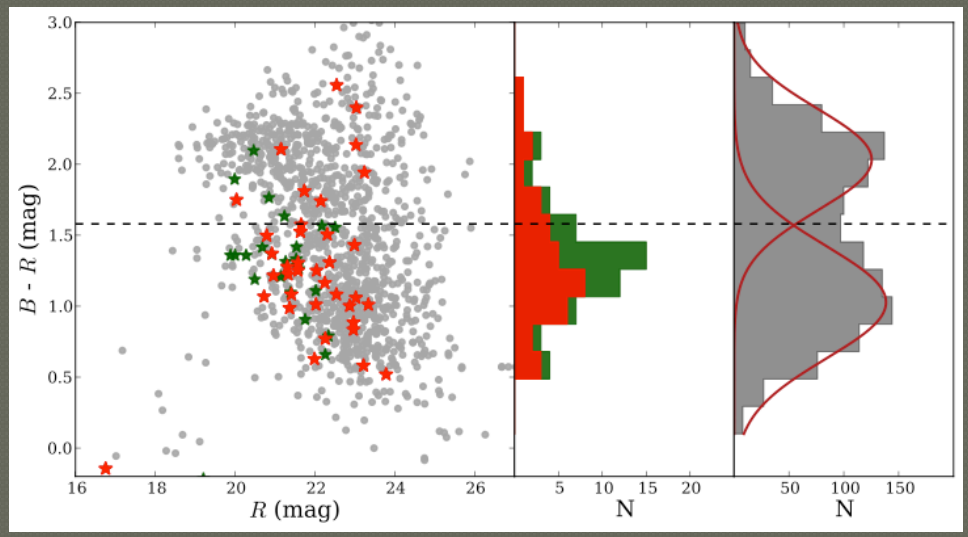


Cluster populations: AGNs

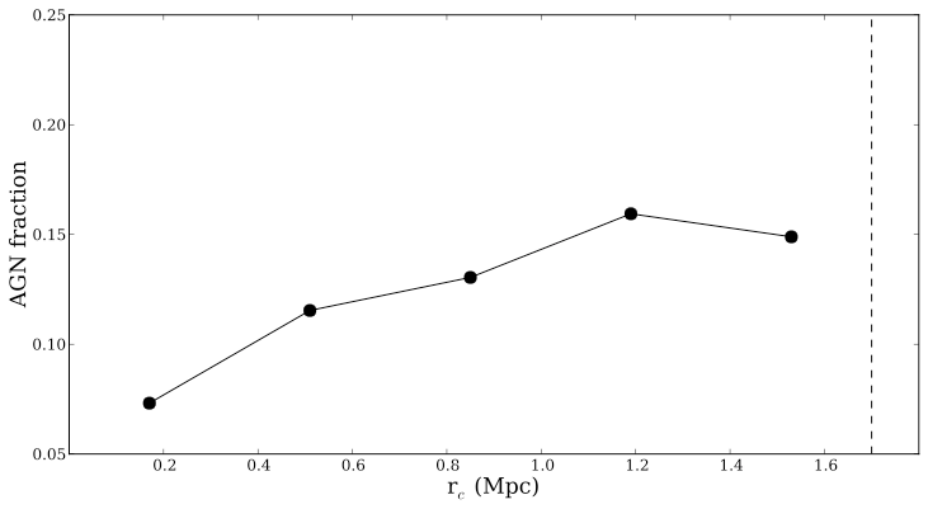


AGN fraction wrt cluster pop. (R band)

AGNs mainly in the green valley
(Green: NLAGNs. Red: BLAGNs



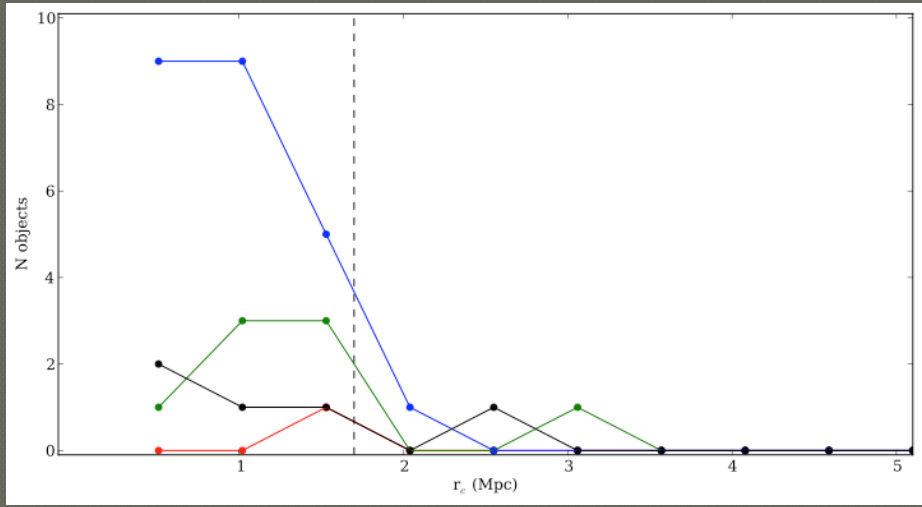
Cluster populations: AGNs



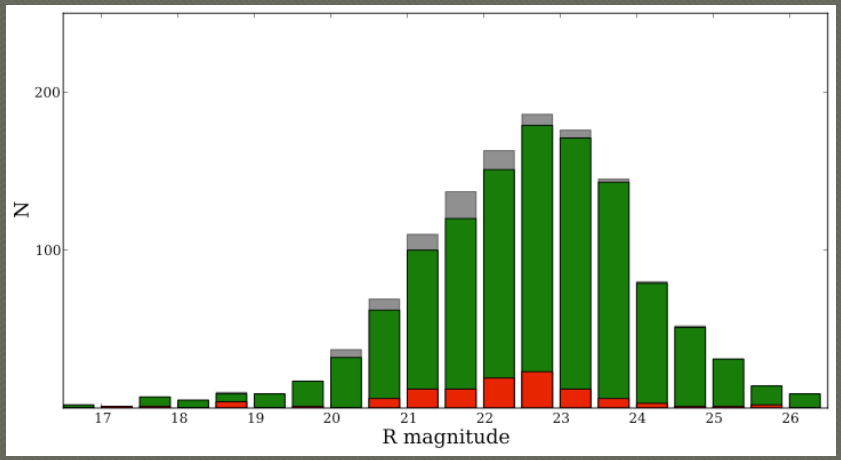
Peak at 0.7 r_{vir} (2.4 σ)

Subrepresentation at 0.2 r_{vir} (3.1 σ)

Red: Elliptical.
Green: Disk.
Blue: Spirals.
Black: Irregulars

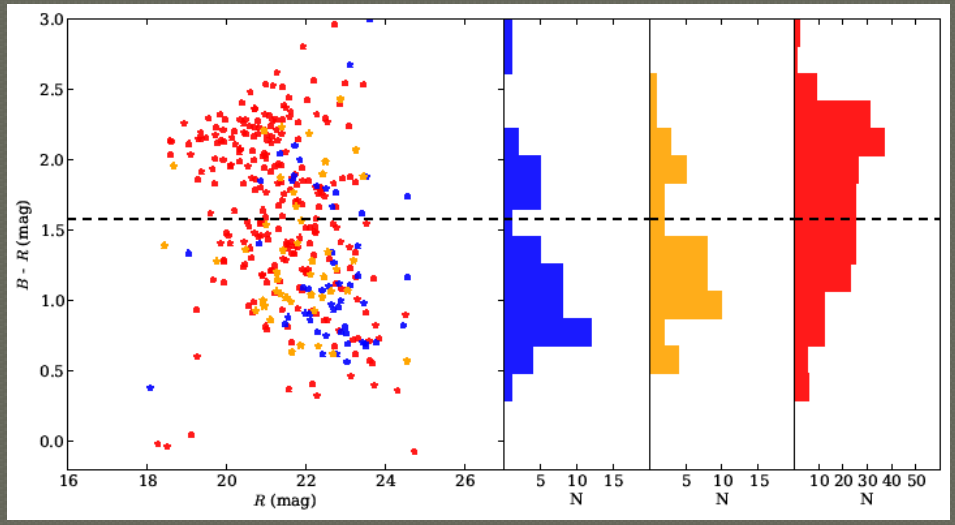


Cluster populations: SFs/quiescent



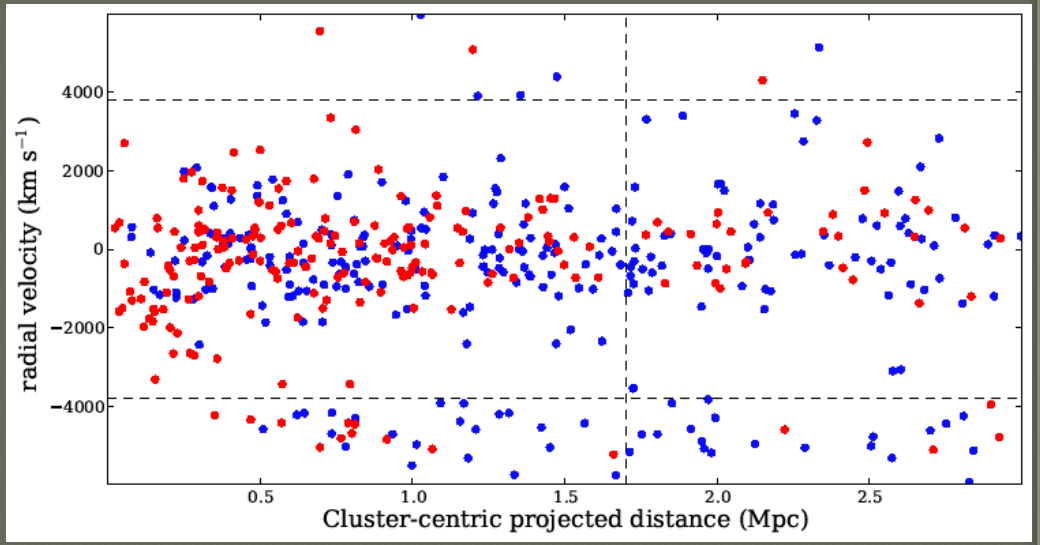
Star forming galaxies traces the overall cluster population (Red bars: ELGs)

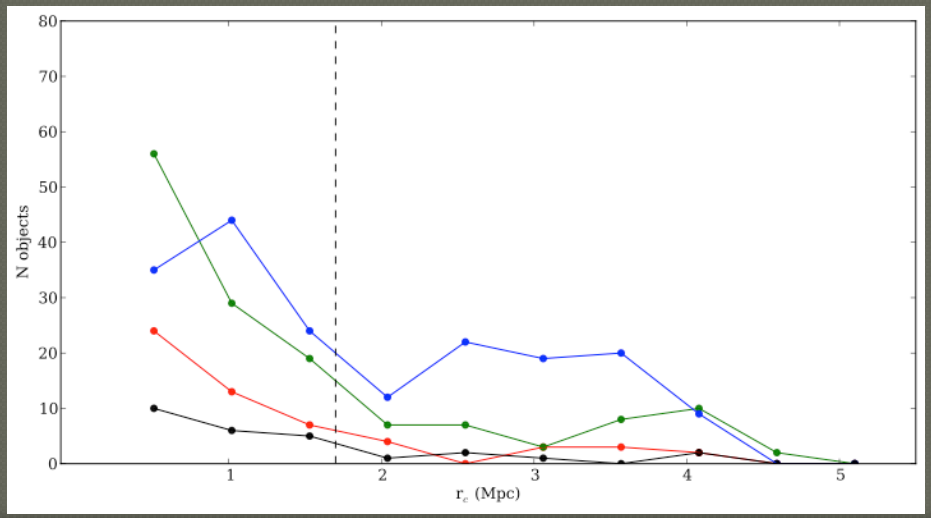
Blue: ELGs w/o IR emission
Orange: ELGs with IR emission
Red: noELGs with IR emission



Cluster populations: SFs/quiescent

Red: Red sequence.
Blue: Blue cloud
Blue galaxies dominate at larger clustercentric distances and in the secondary structure

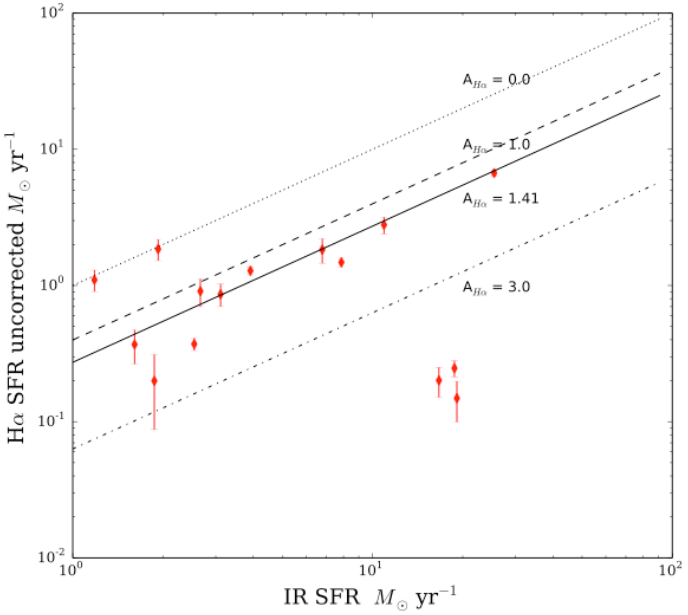


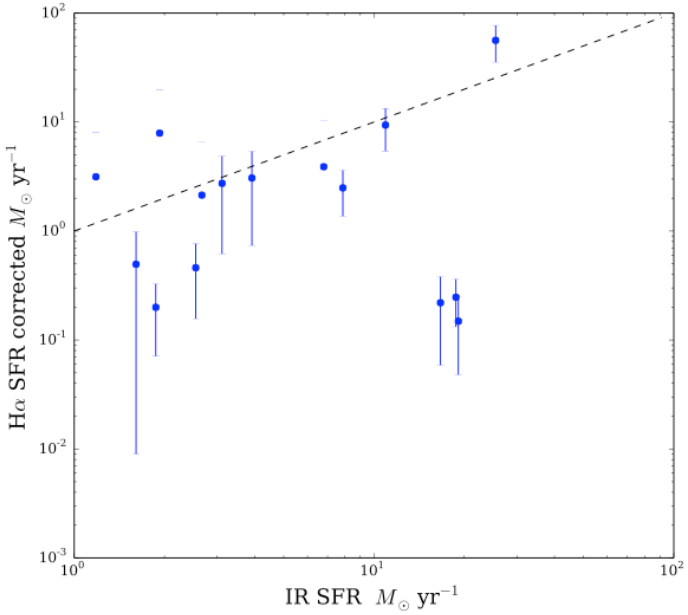


Dominance of disk-like galaxies in the core

Red: Elliptical.
Green: Disk.
Blue: Spirals.
Black: Irregulars

Cluster populations: SFs/quiescent





Environmental effects

Environmental effects

- Mass profile from X-rays

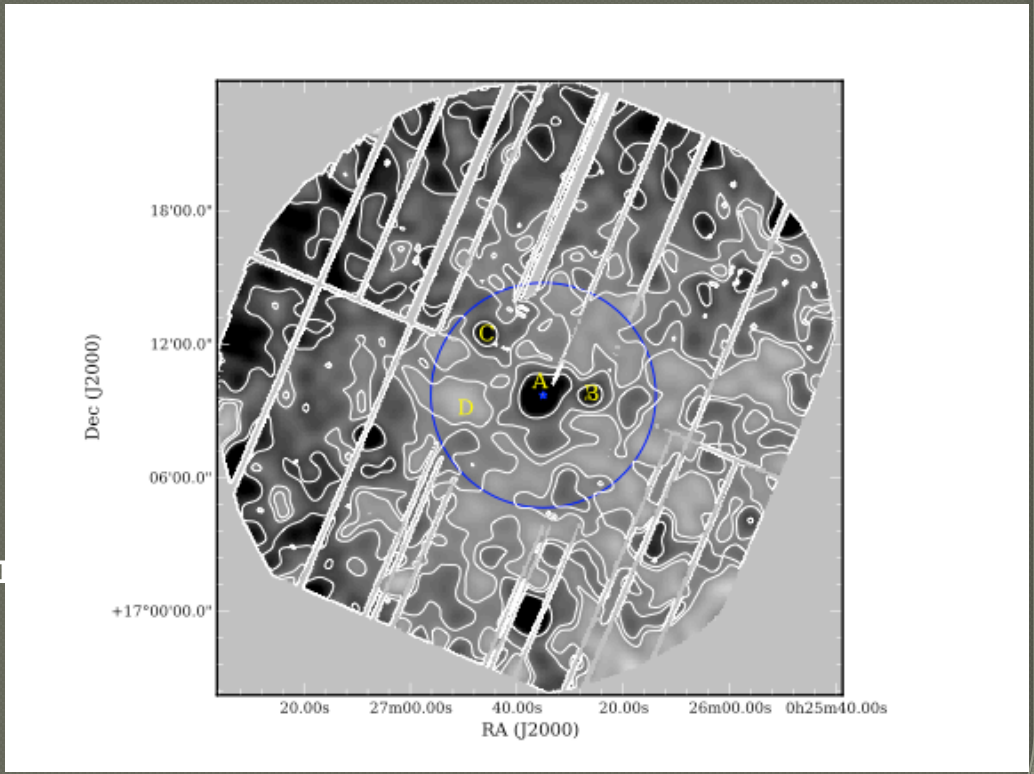
$L_{xrays} = 2.9 \pm 0.1 \times 10^{44}\ h_{70}^{-2}$ erg s^{-1}

$\beta \approx 0.56 \pm 0.02$, $r_c \approx 0.3 \pm 0.03$

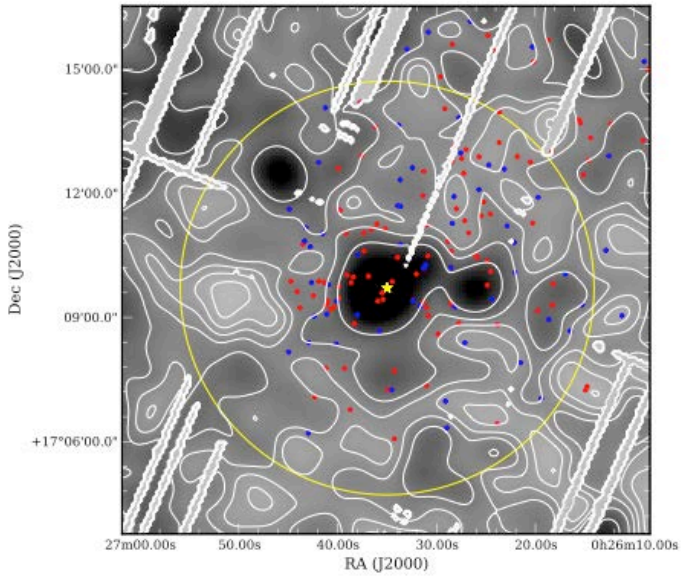
Isothermal sphere r < 1.5 arcmin
Power law $\Upsilon \approx 0.98$ r > 1.5 arcmin

Background dominated r > 5 arcmi

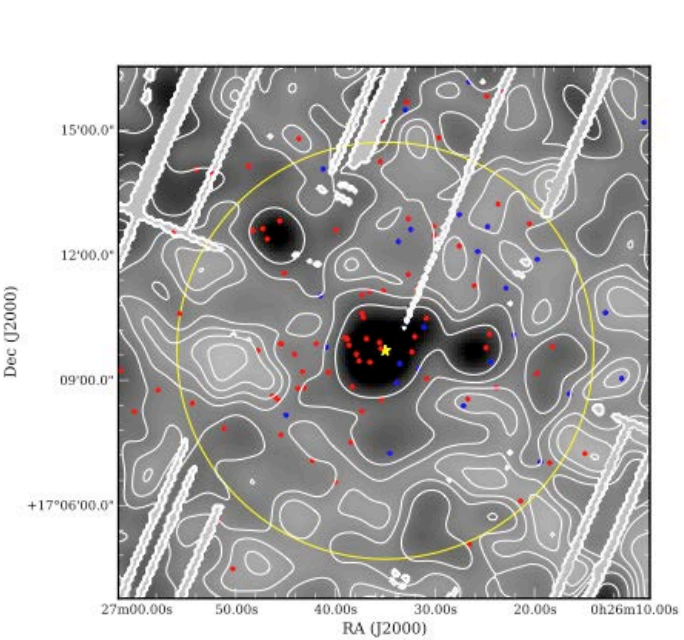
Zhang+05



Environmental effects



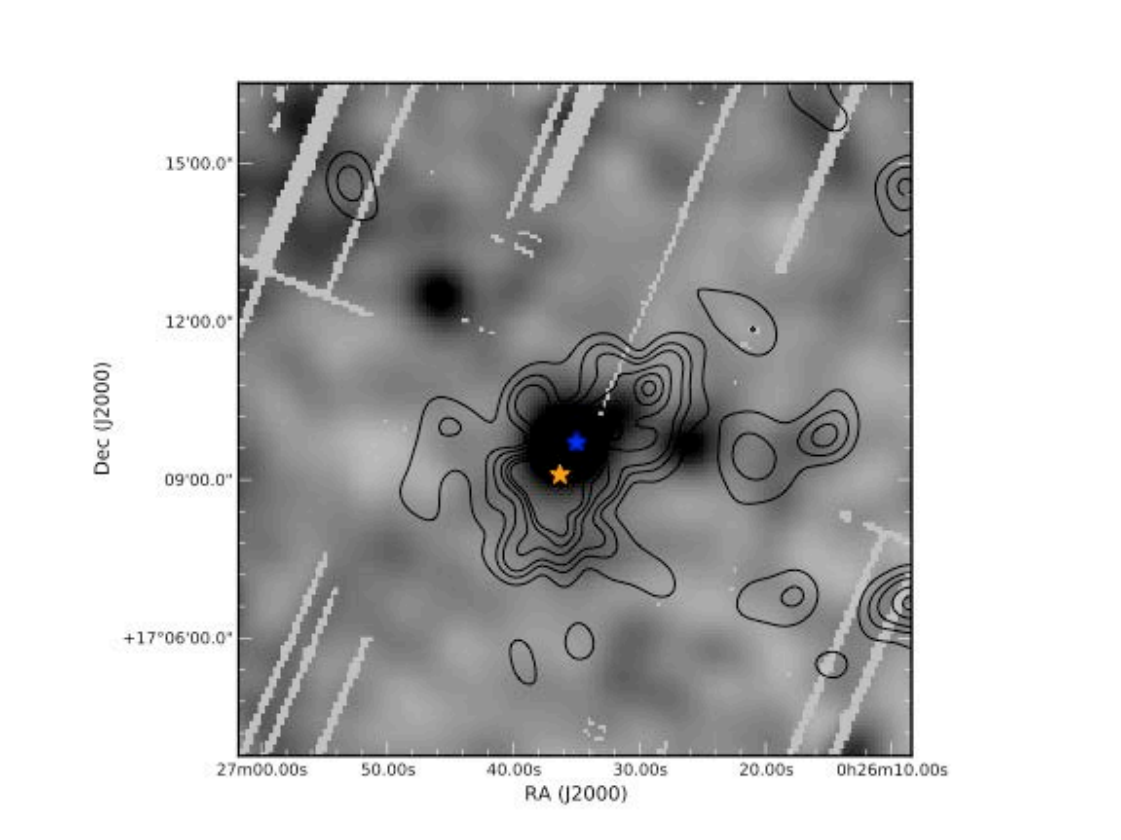
ELGs (red). AGNs (blue)



FIR objects (red). AGNs (blue)

Environmental effects

Optical vs X-rays substructures



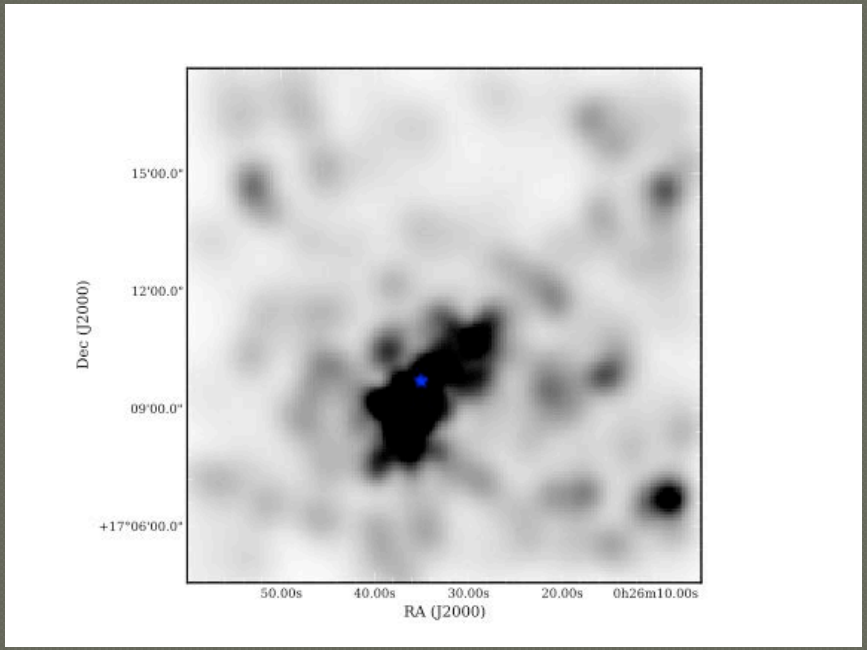
Blue star: Xray centre. Yellow star: BGC

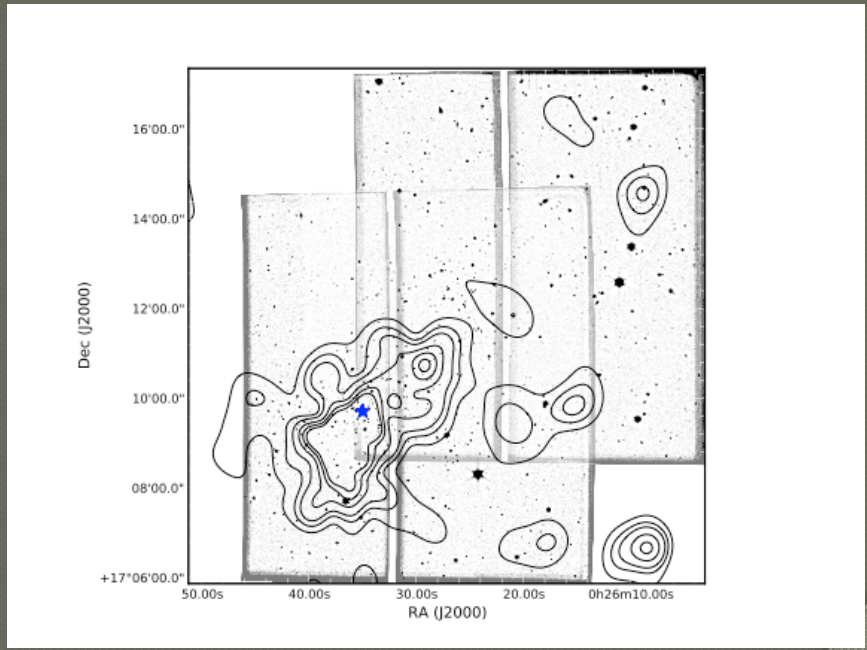
Environmental effects

- Local density: $\Sigma_k = \frac{k+1}{\pi R_k^2}$

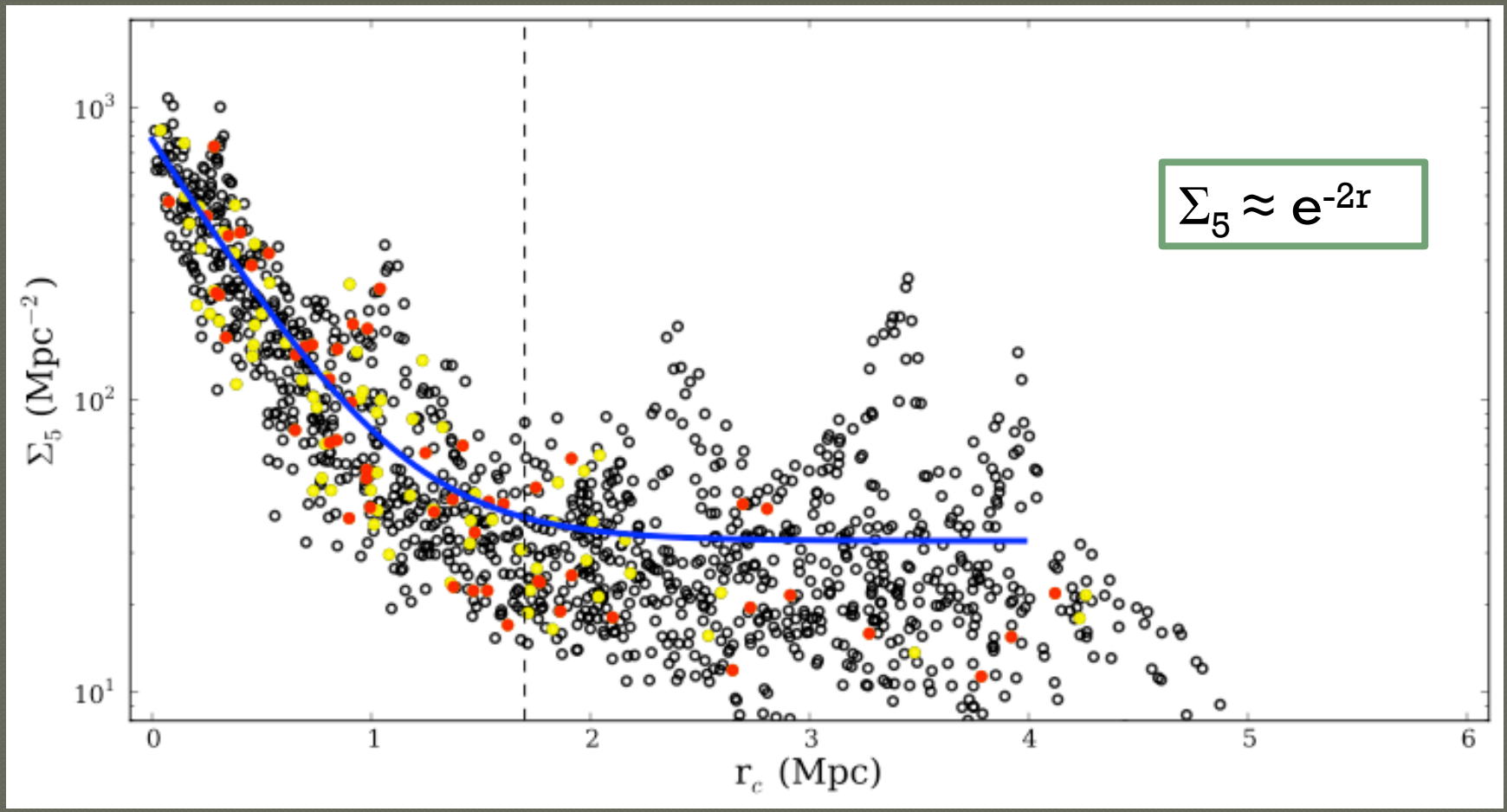
Each source in the FoV was weighted:

- $W(z_{spec}) = 1$
- $W(z_{phot}) = W_0 + K_D \times D$
- $W(\text{no z}) = D$



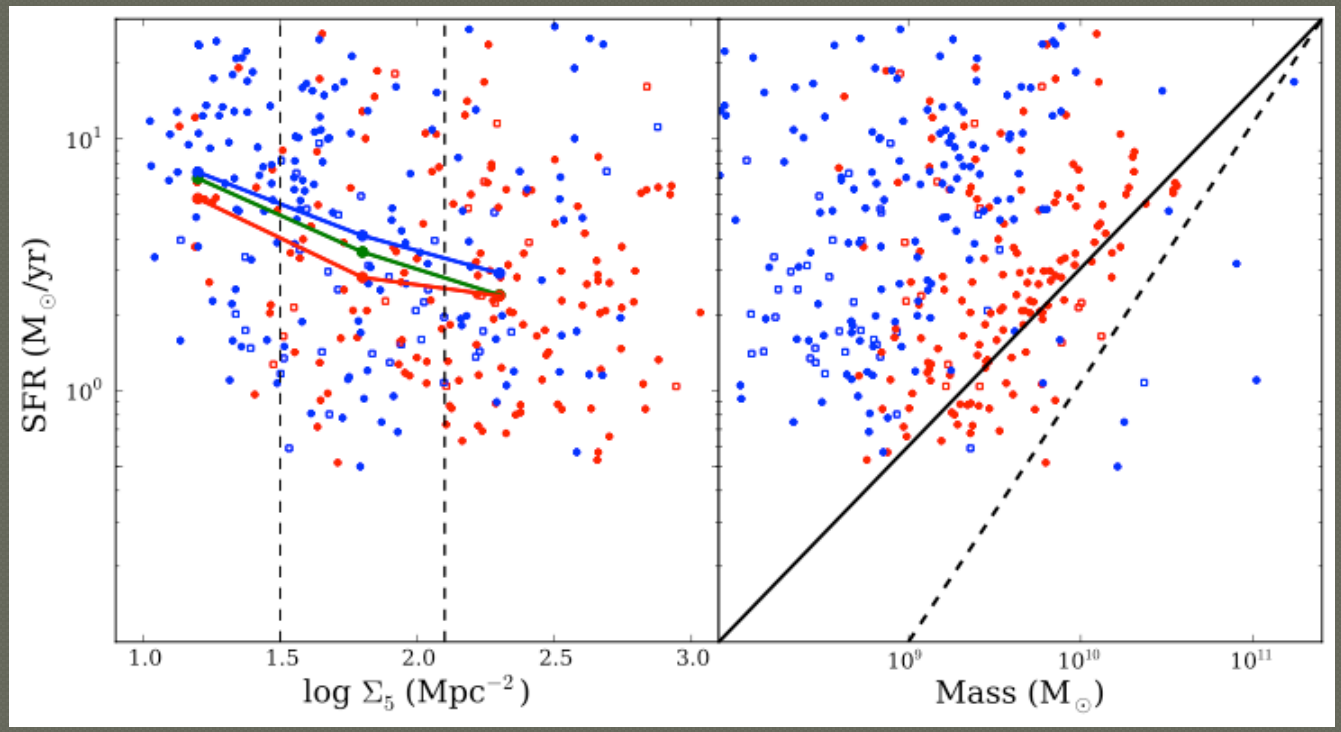


Environmental effects



Environmental effects

SFR and Mass vs local surface density



Black line: MS from Koyama+13 (z≈0.4)
Dashed line: MS from Winter+12 (local)

Conclusions

- Newly studied FIR sources:
  - 10% of the cluster population
  - Favours main cluster structure
  - Mainly in the blue cloud and green valley
  - $L(IR) \approx 10^{11.24 \pm 0.02} L_{\odot}$
  - 43% LIRGs

Conclusions

- AGNs:
  - Largest sample of AGNs in a cluster at this z
  - 15% of the cluster population (inline - slightly below expected)
  - Avoid higher density areas && Favours 0.7 r_{vir}
  - Typical green valley objects
- SF / SFR
  - Average extinction correction from Balmer decrement: 1.41 mag
  - SFR(IR) larger than SFR($H\alpha_{corr}$) (larger extinctions)

Conclusions

- Environmental effects:
  - Xray structure shows and unrelaxed cluster.
  - FIR, AGNs and SFs follow the Xray structure
  - Local surface density correlates with r_c

$$\Sigma_5 \approx e^{-2r}$$

  - SFR decreases with Σ5
  - Red sequence follows SFR / Mass relation (MS)