

# Gas reservoirs and SF a function of environment at $z=0.2$

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**Min Yun & Ryan Cybulski (In this room!)**

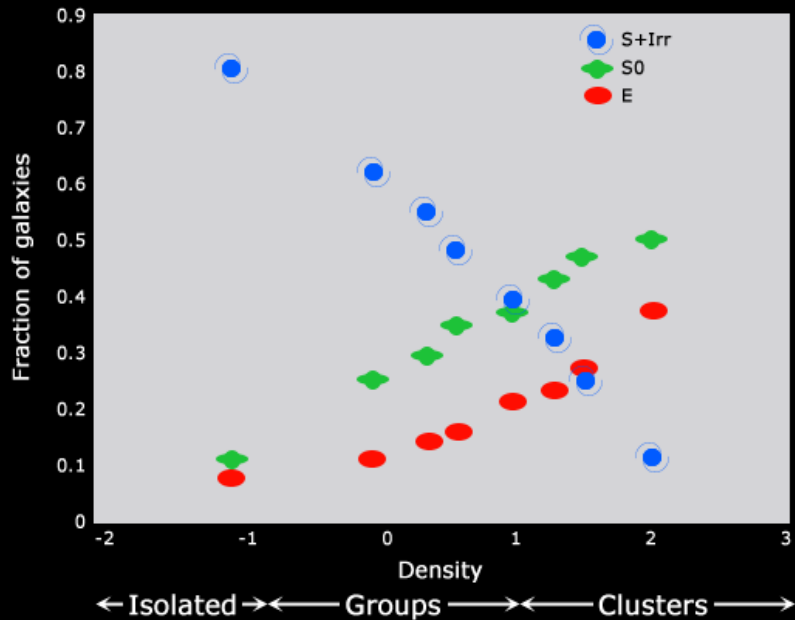
Aeree Chung, Maria Montero-Castaño

Glenn Morrison, David Schiminovich

K.S. Dwarakanath & Arpad Szomoru



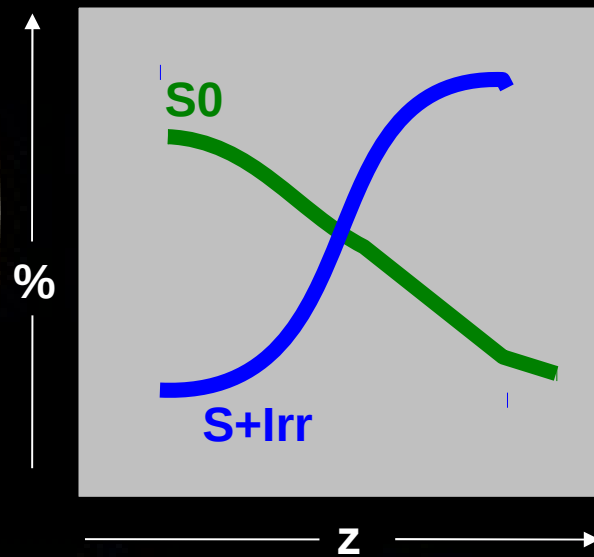
### Morphology Density Relation Dressler (1980)



(Graphic by A. Chung)

### Morphology Evolution

Dessai et al (2007); Dressler et al. (1997)



### $\Lambda$ CDM Cosmology



# Unsolved issues

What is the role of environment?

Which are the physical mechanisms transforming the galaxies in clusters?

- Ram-pressure stripping:

- of halo gas

(Larson et al. 1972, Bekki et al. 2002)

- of disk gas

(Gunn & Gott 1972, Quilis et al. 2000)

- Galaxy interactions:

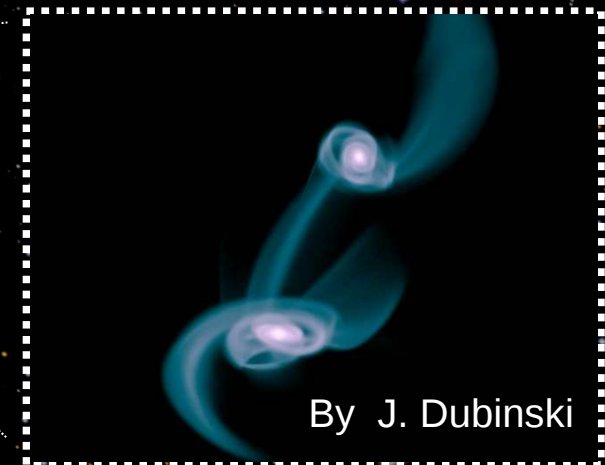
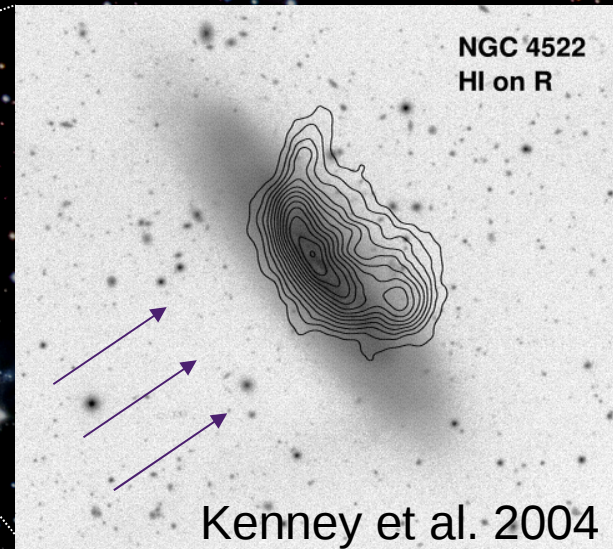
- unequal-M mergers

(Bekki 1998)

- harassment

(Moore et al. 1998)

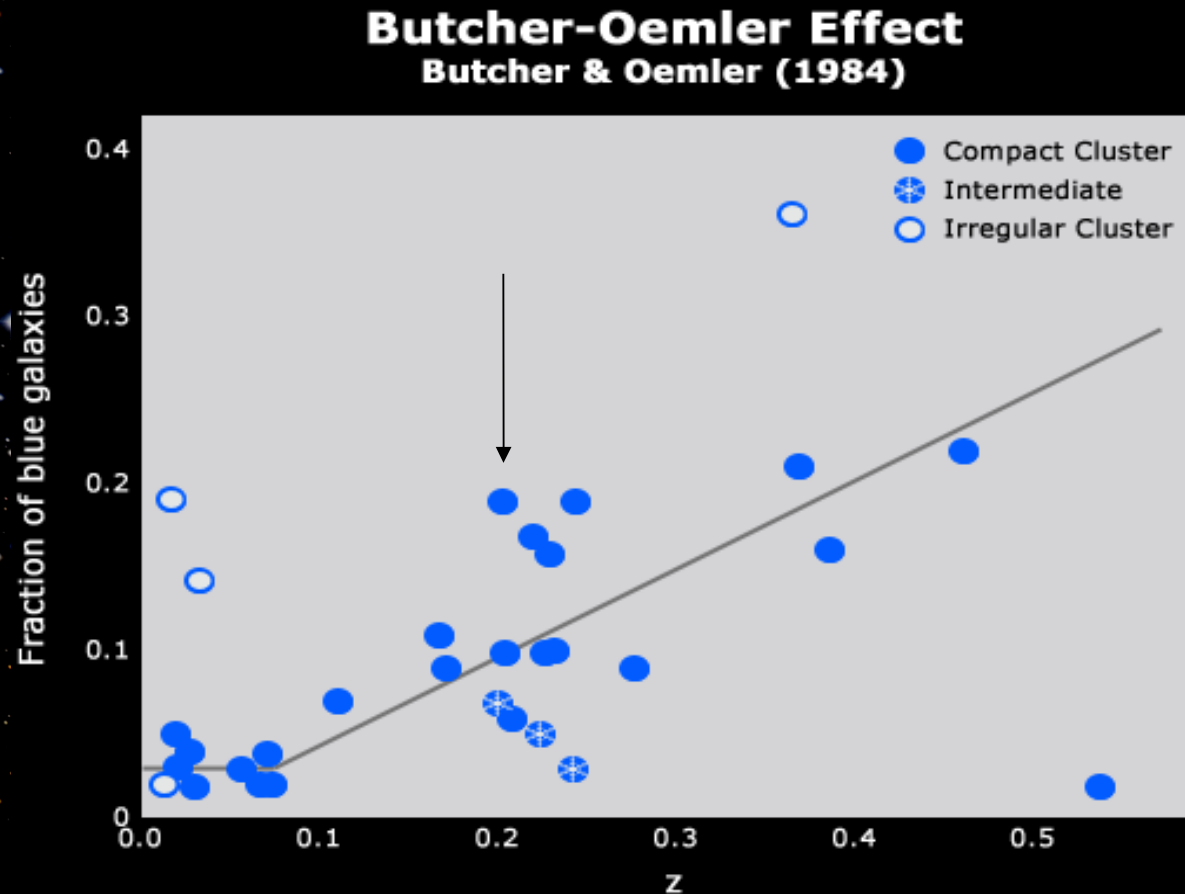
- Tidal stripping (Bekki 1999)



# Unsolved issues

## Evolution of the blue fraction

- Does the BO effect relate to
  - (i) the rate at which clusters accrete their members or
  - (ii) the accreted field pop. may be more gas rich @ higher  $z$ ?



(Graphic by A. Chung)

# **BUDHIES: Blind Ultra-deep Distant HI Environmental Survey** (a deep HI imaging study of two clusters at $z \sim 0.2$ with WSRT)

## Why neutral Hydrogen?

- Basic ingredient in the formation process of galaxies
- Sensitive to physical processes such as ram pressure stripping

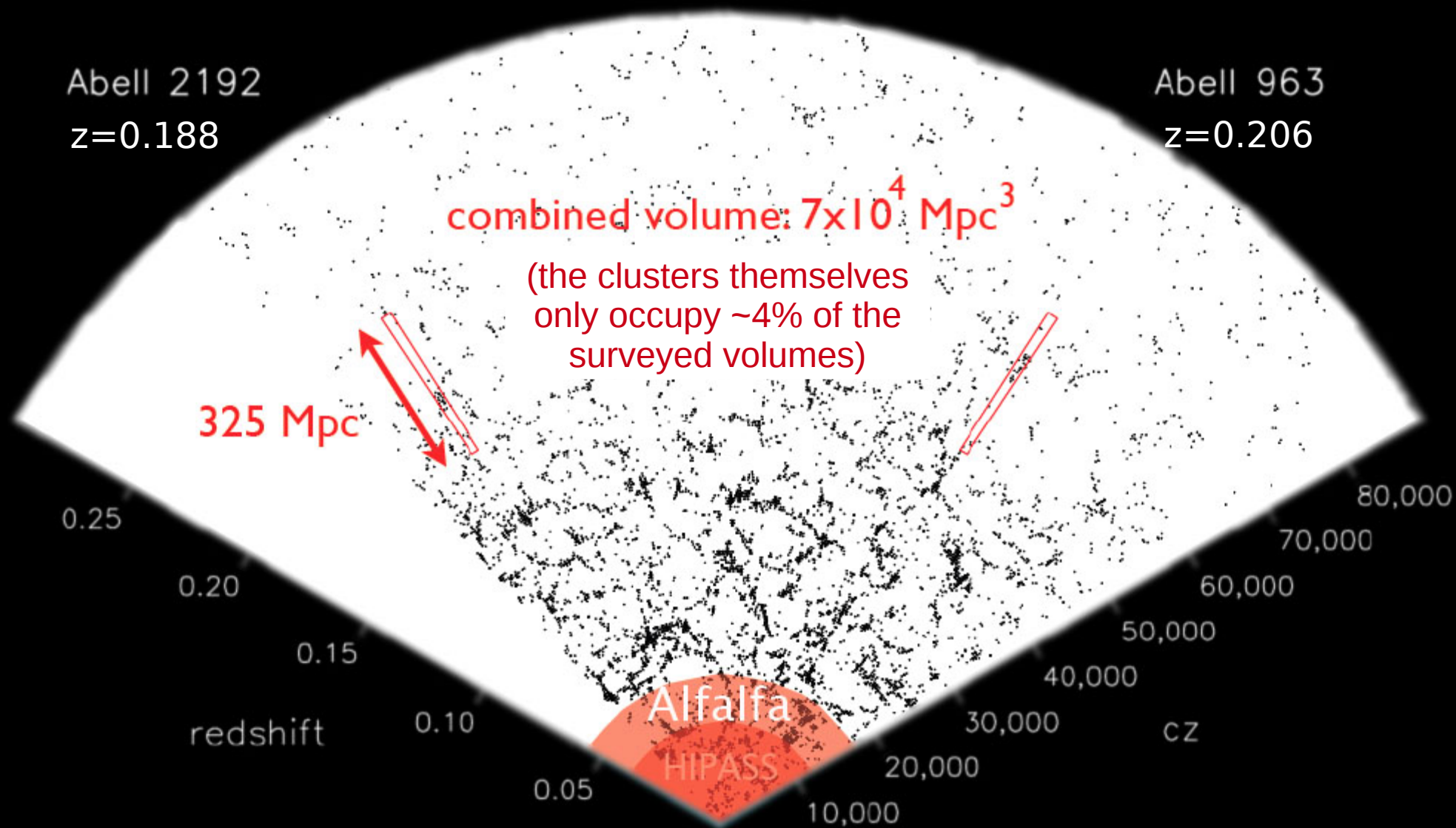
## Why $z=0.2$ ?

- Highest  $z$  for practical HI imaging with existing arrays
- Lowest  $z$  where evolutionary effects are seen
- **ONLY  $z \sim 0$  STUDIES HAD BEEN DONE UP TO NOW**

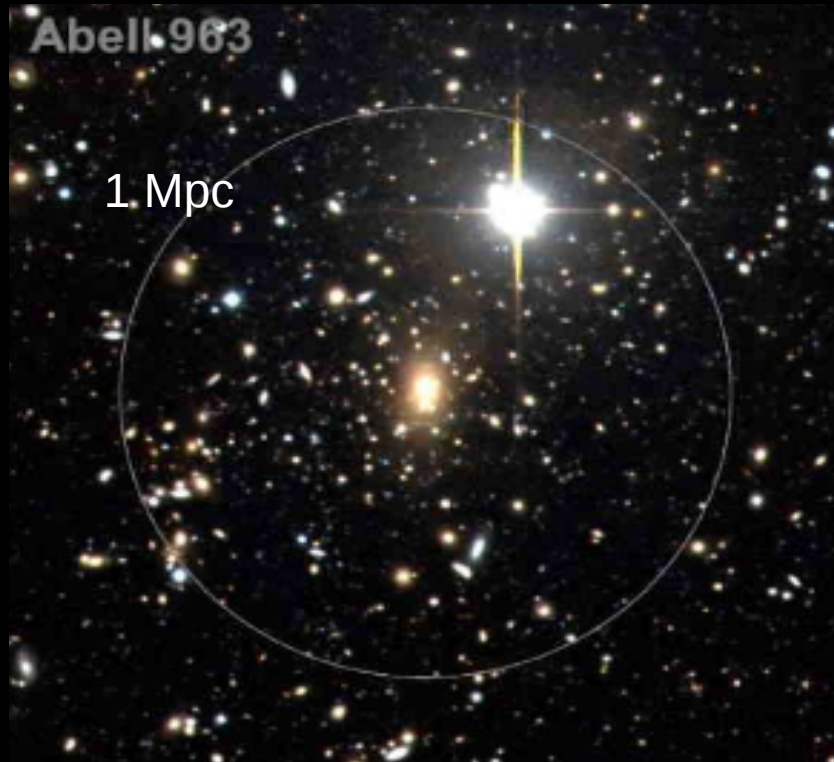


The Westerbork Synthesis Radio Telescope

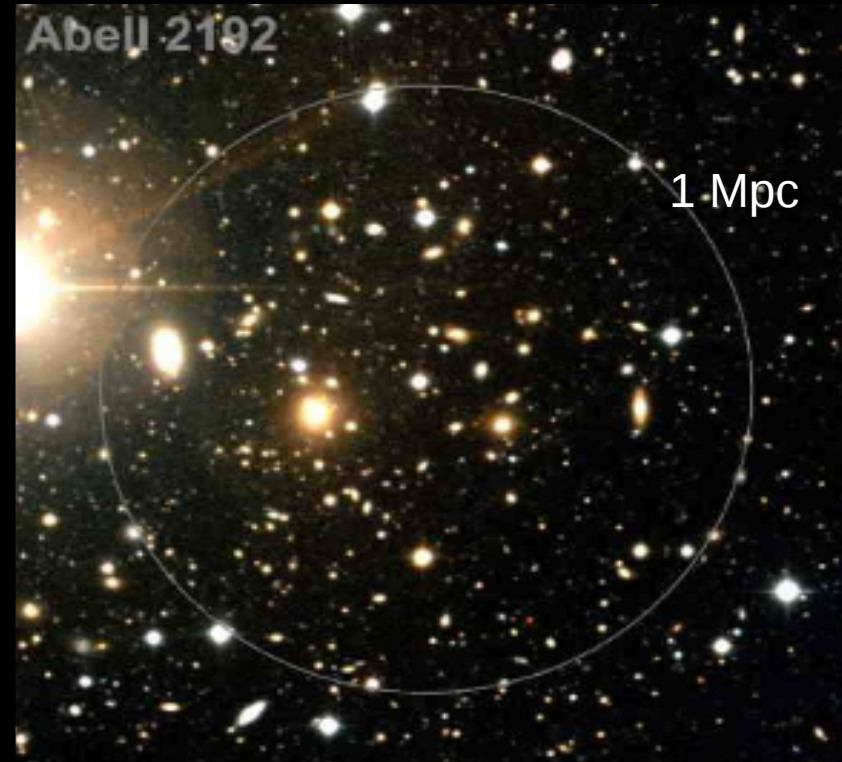
# BUDHIES: Blind Ultra-deep Distant HI Environmental Survey (a deep HI imaging study of two clusters at $z \sim 0.2$ with WSRT)



## A tail of 2 clusters:



Massive lensing cluster at  $z=0.206$   
Strong B-O effect & unusually large fb  
 $\sigma_{\text{vel}}=1350$  km/s  
Bright and regular X-ray source, centered  
on BCG (low level of substructure)



Less massive and more diffuse cluster  
at  $z=0.188$   
fb is yet unknown  
 $\sigma_{\text{vel}}=650$  km/s  
Barely detected in X-rays



WHT

# The Data

- Ultra deep WSRT observations (HI)
- Optical Photometry:

Deep B and R-band with WFC/INT + SDSS photometry

- Optical spectroscopy:

from WIYIN, SDSS but mostly AF2/WYFFOS at WHT

- Spitzer imaging (3.6, 4.5, 5.6, 8, 24 and 70 micron) → Ryan Cybulski
- Galex near and far UV
- Radio continuum
- Herschel → See Min Yun's poster!
- CO (in the oven: Nobeyama Radio Obs.)



# Ultra deep HI observations with WSRT

(Verheijen et al. 2007; Deshev et al. in preparation)

- $M_{\text{HI}} > 2 \times 10^9 M_{\text{sun}}$
- Redshift range:  $0.164 < z < 0.224$
- Combined volume:  $7 \times 10^4 \text{ Mpc}^3$
- 20 Km/s velocity resolution
- Exposure times:  
78 x 12h for A2192 (at  $z=0.188$ )  
117 x 12h for A963 (at  $z=0.206$ )  
Total = 1620 h !!!

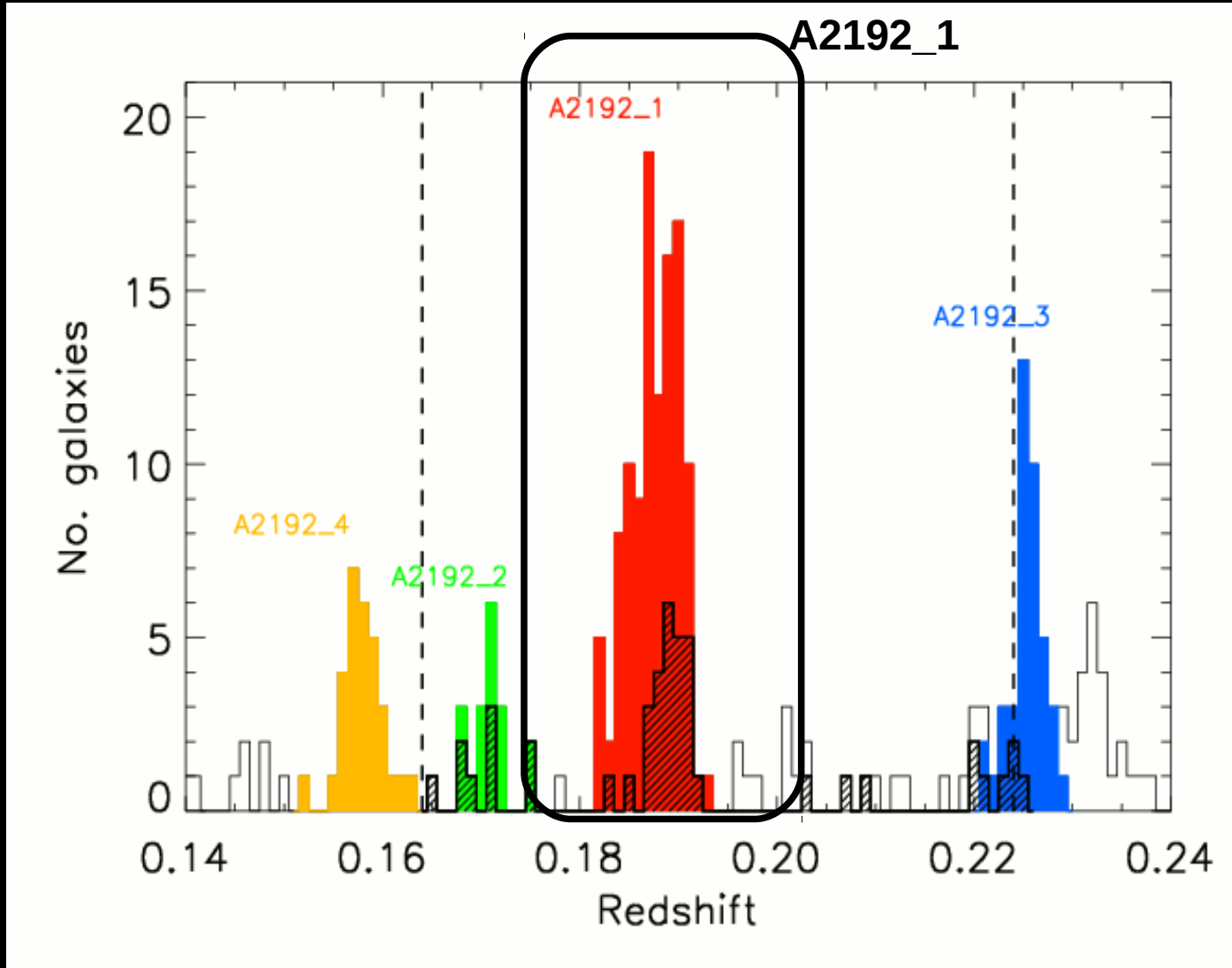


**RESULT:** HI emission from >150 individual galaxies at  $z=0.2$   
**CONCLUSION:** The HI-universe at  $z=0.2$  is under reach !



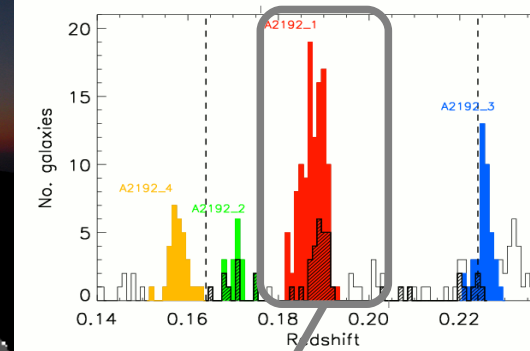
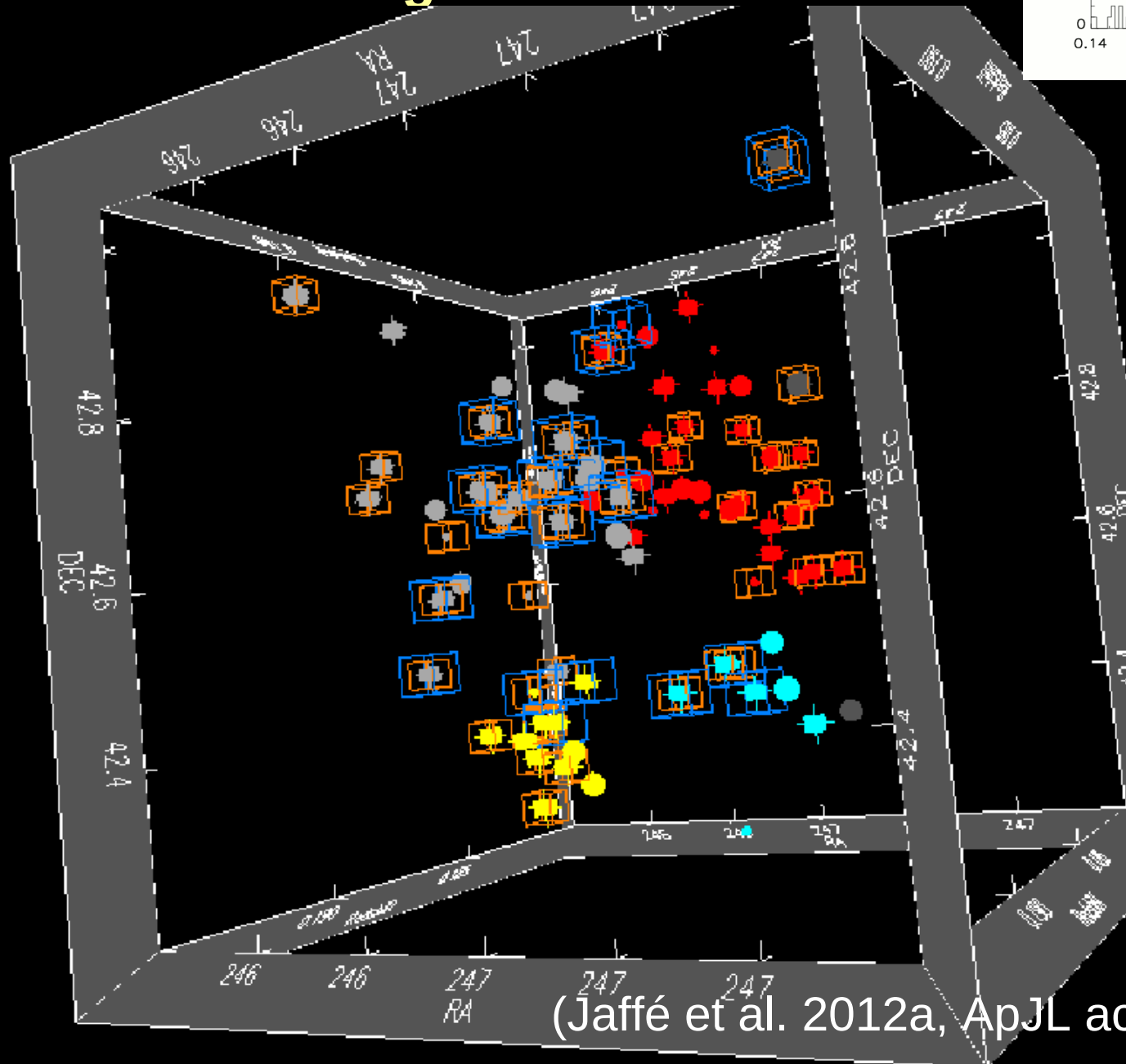
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# Optical spectroscopy: (Jaffé et al 2012b, in prep)












# Defining environment in 3D

- HI
- OII
- ETG
- LTG
- ?
- Sub-structures
- structures



(Jaffé et al. 2012a, ApJL accepted)

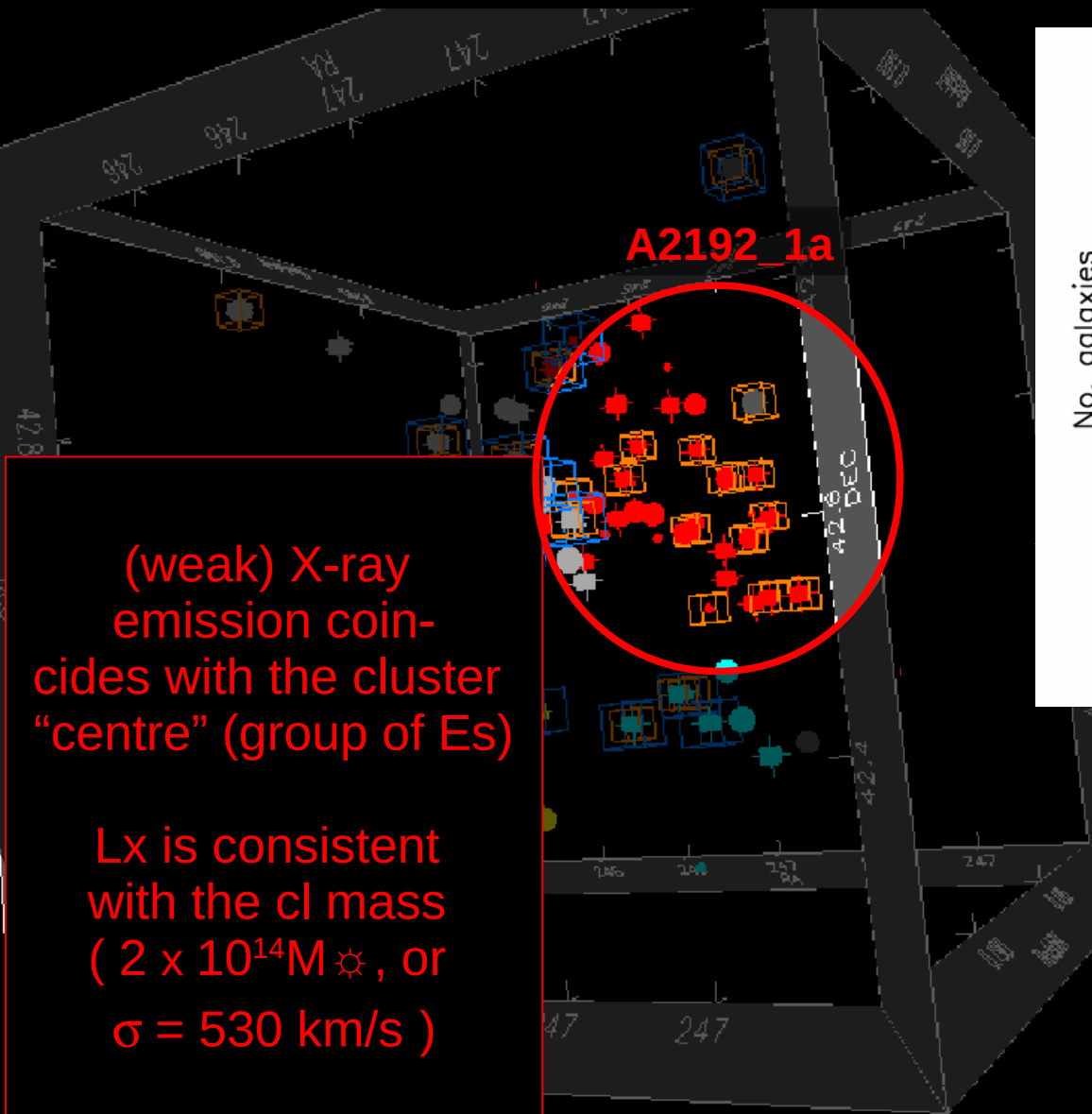
# Defining environment in 3D

-  HI
-  OII
-  ETG
-  LTG
-  ?
- 
-  Sub-
-  structures
- 

Movie available at:

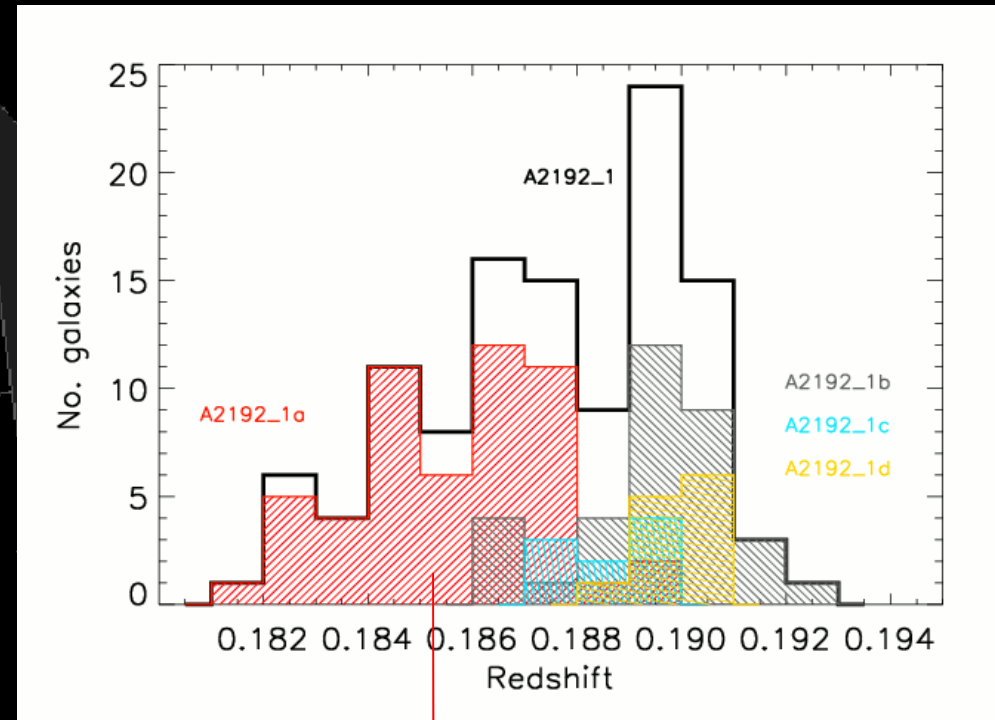
[http://www.nottingham.ac.uk/~ppxyj/Jaffe\\_ApJL\\_2012\\_Fig2\\_movie.mpeg](http://www.nottingham.ac.uk/~ppxyj/Jaffe_ApJL_2012_Fig2_movie.mpeg)

# Defining environment in 3D



(weak) X-ray emission coincides with the cluster "centre" (group of Es)

$L_x$  is consistent with the cl mass ( $2 \times 10^{14} M_{\odot}$ , or  $\sigma = 530 \text{ km/s}$ )



A baby cluster at  $z=0.186$

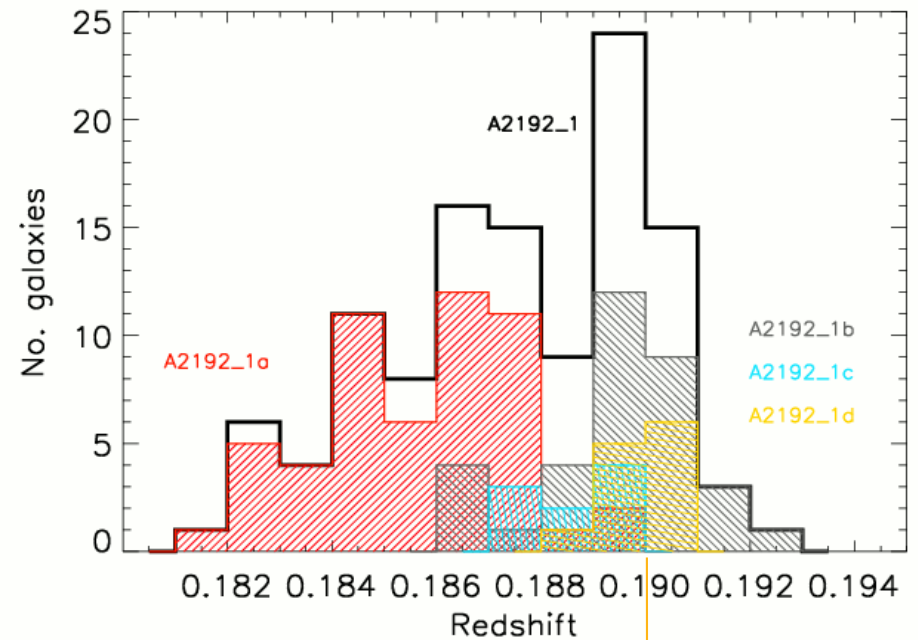
Already devoid of HI !!

SF still happening in the outskirts

# Defining environment in 3D

Compact group  
inside the  
turnaround radius  
of A2192\_1a !

A2192\_1d

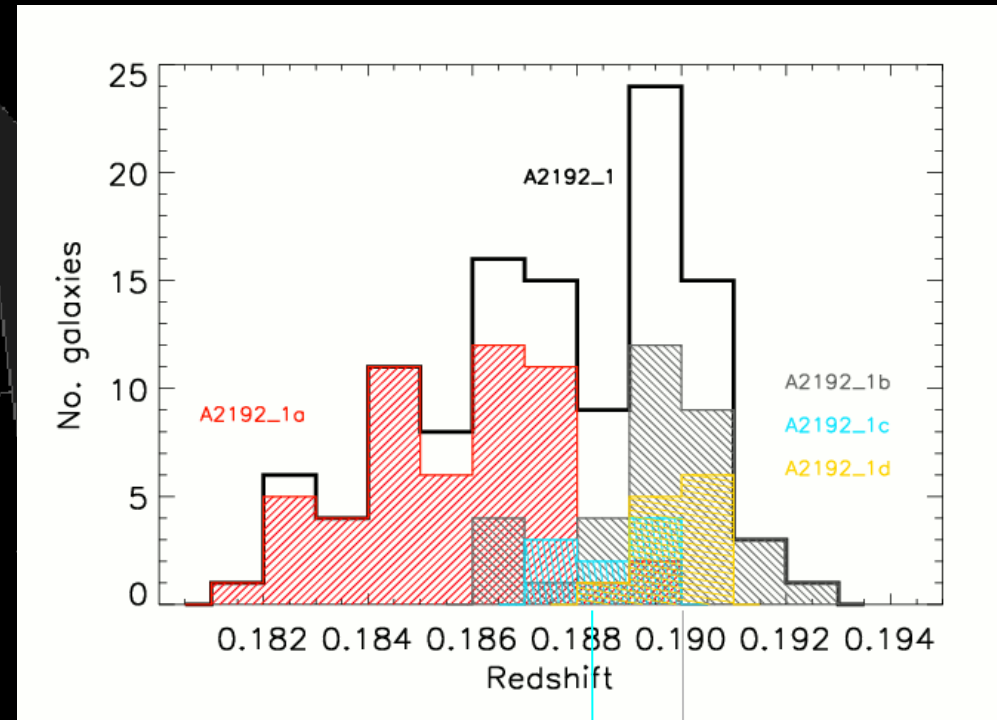
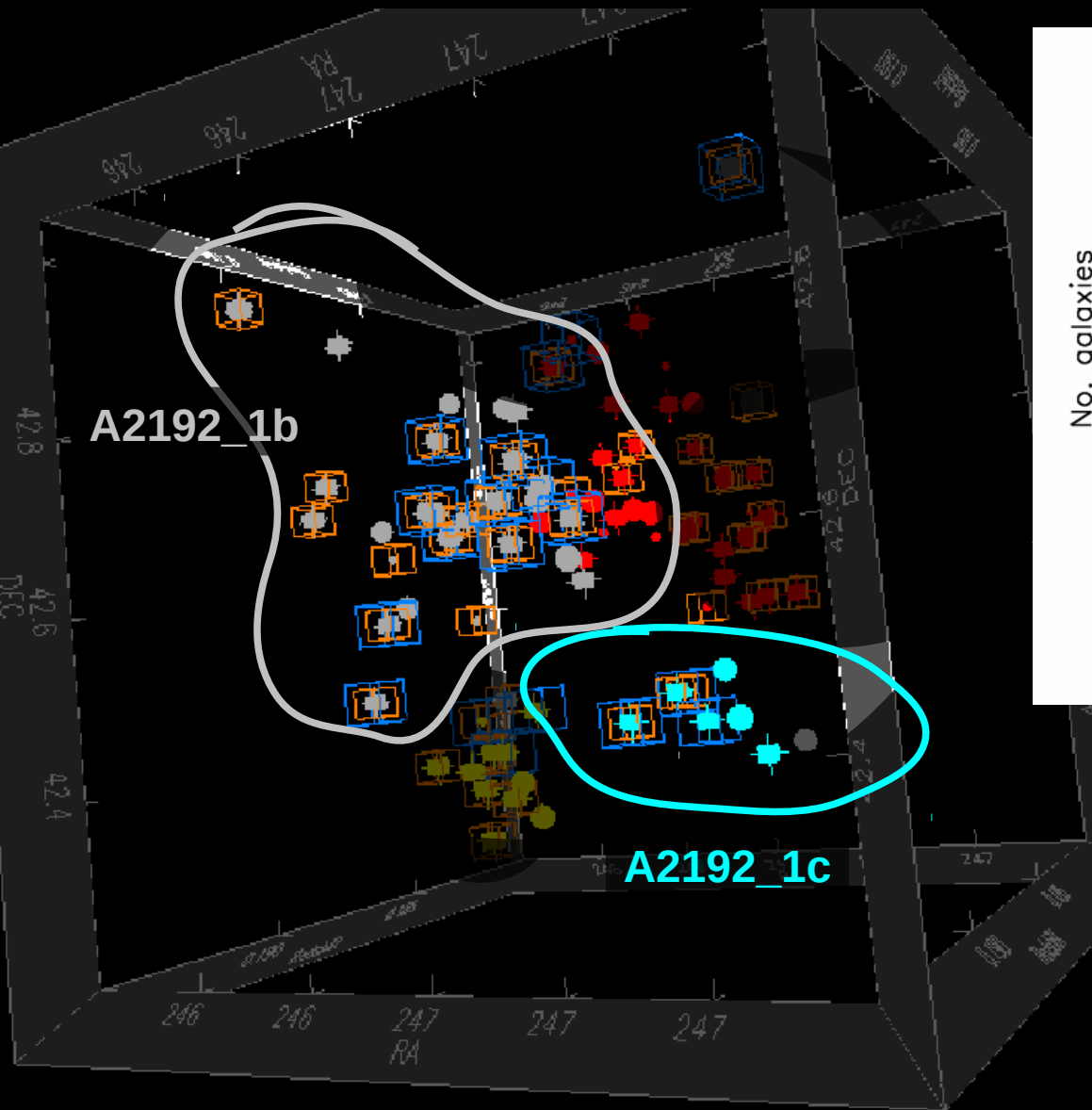


A small compact infalling group

$$\sigma = 161 \text{ km/s}$$

$$(M = 6 \times 10^{12} M_{\odot})$$

# Defining environment in 3D

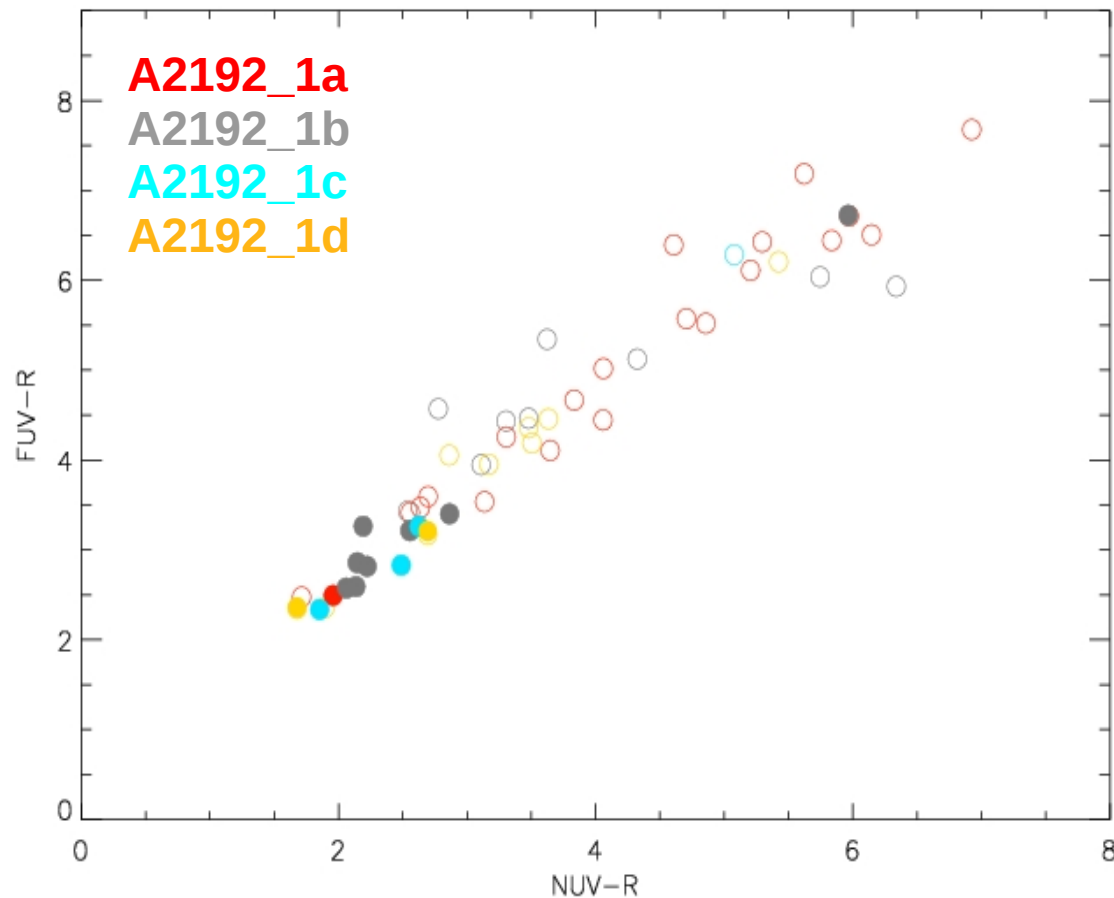


Infalling field population  
of galaxies

HI-rich, full of SF!

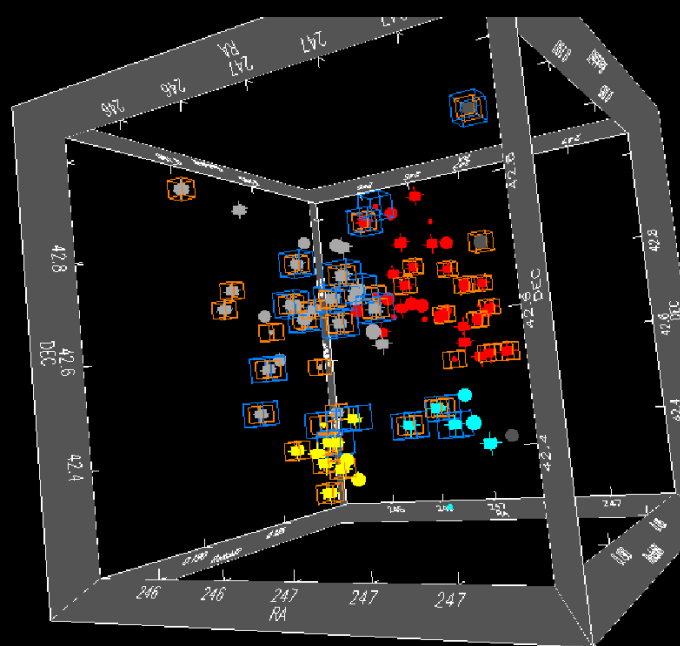
# The UV view:

- HI-detected
- Non detected in HI



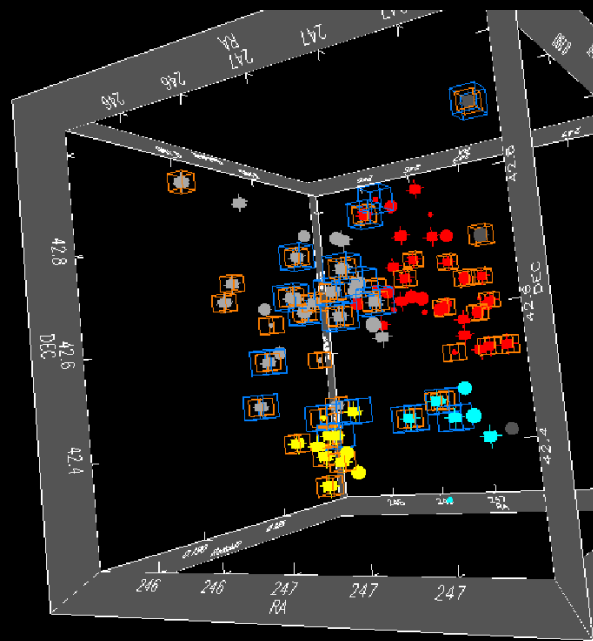
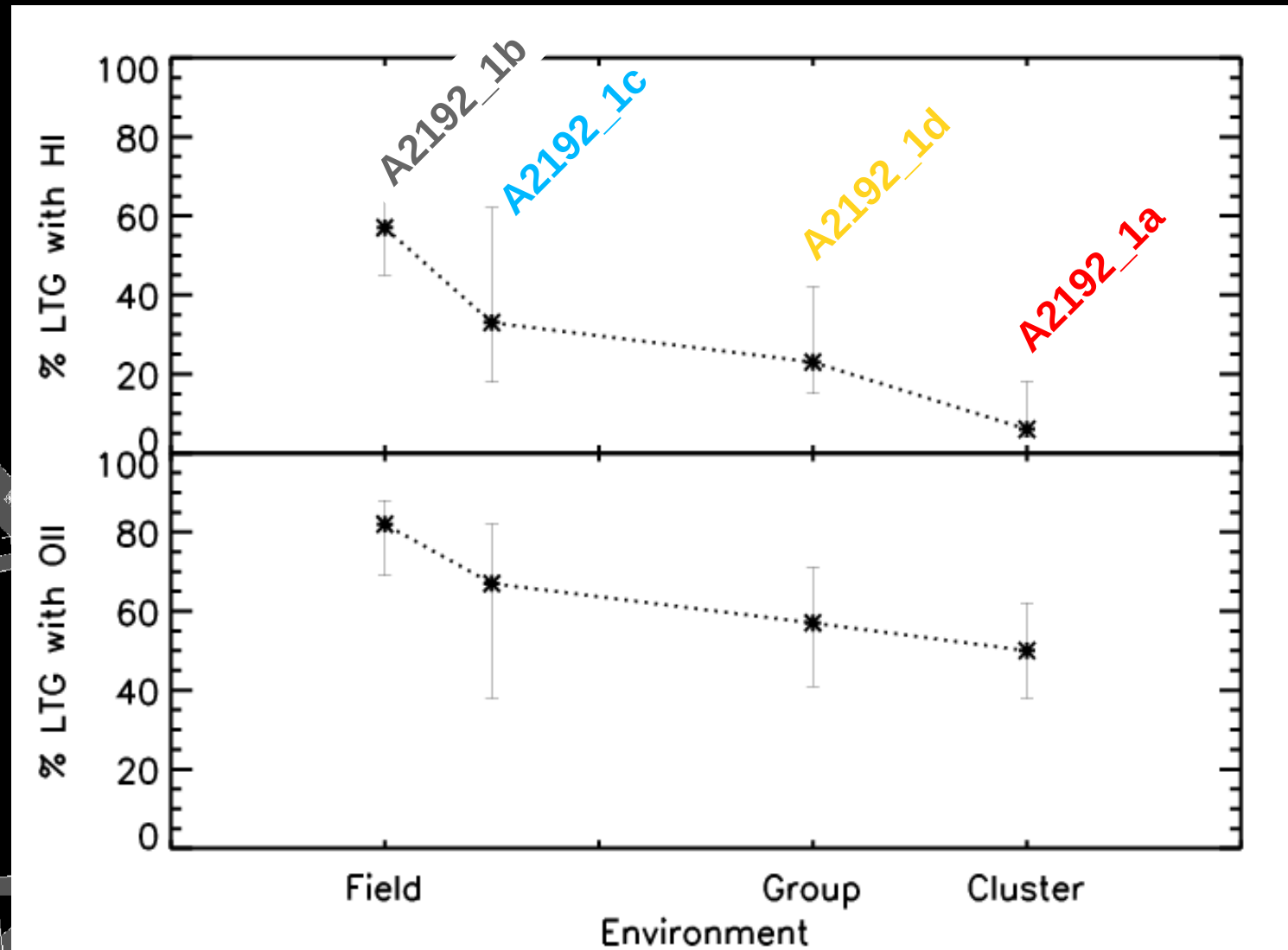
The substructures are also distinct in UV-optical colors!

(Montero-Castaño et al. in prep.)





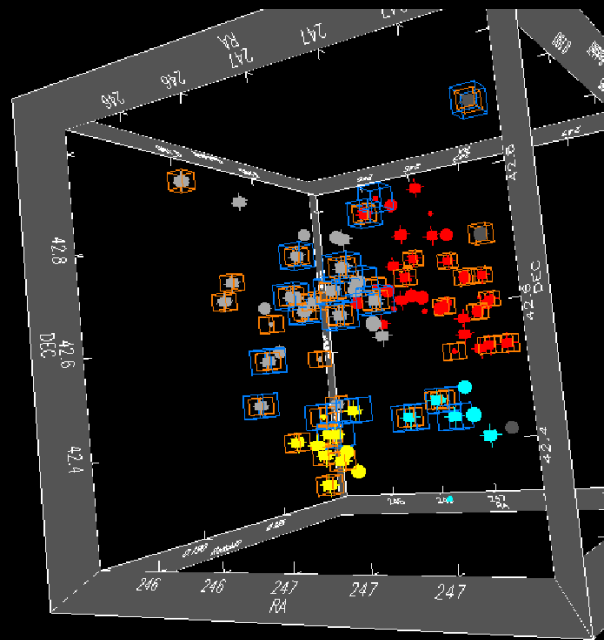
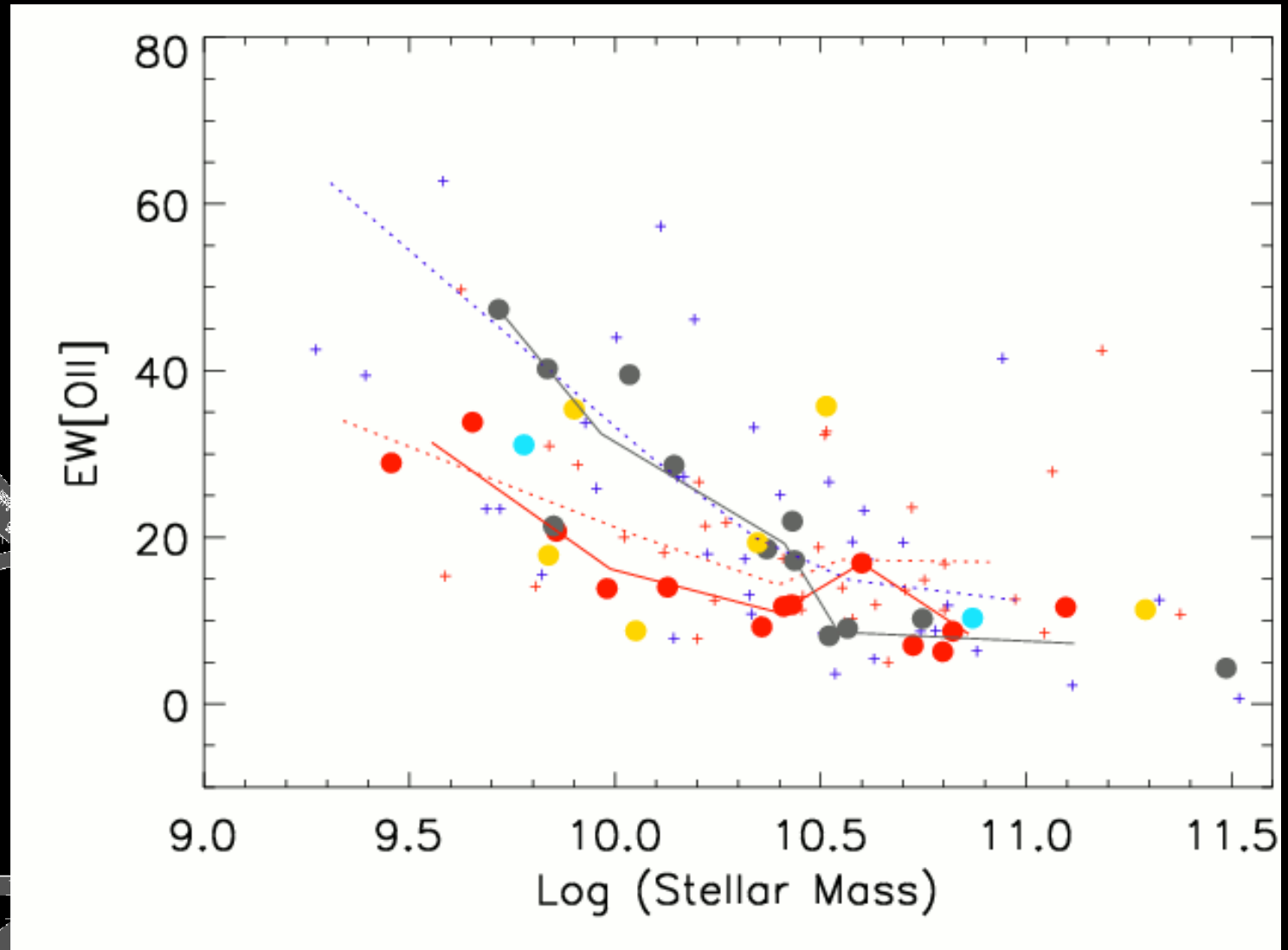
# Where is the HI and the SF present?



(Jaffé et al. in preparation)

# SF vs mass and environment

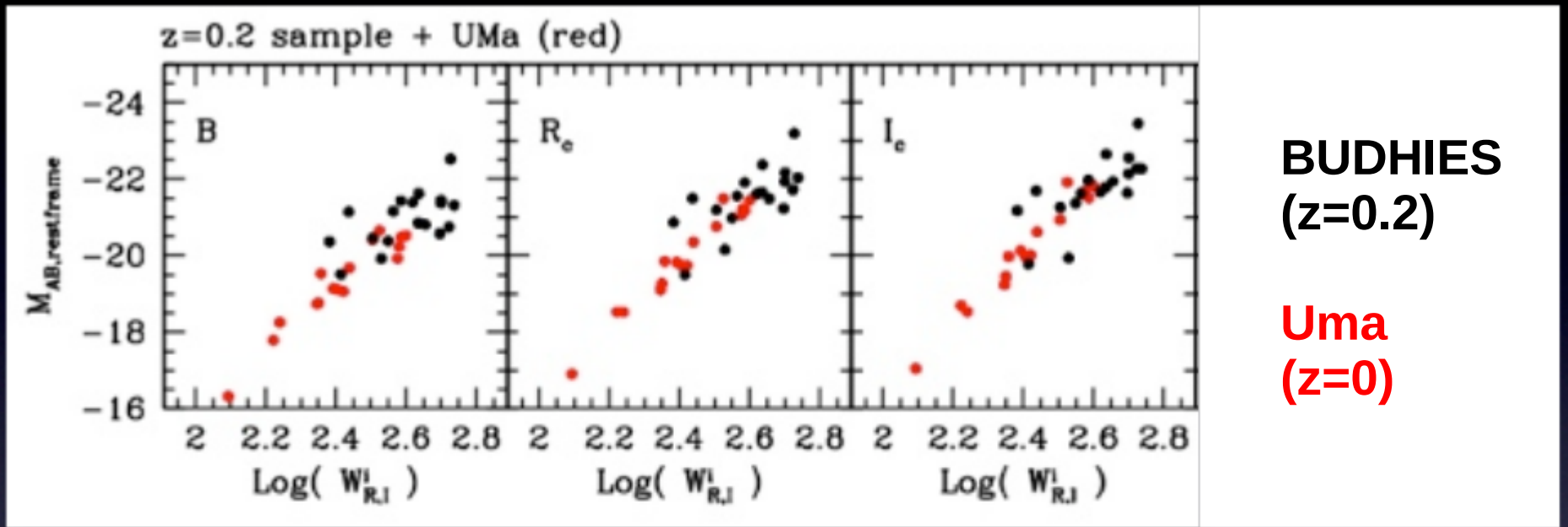
- A2192\_1a ———
- A2192\_1b ———
- A2192\_1c ———
- A2192\_1d ———
- + Other clusters ····
- + All field ····



(Jaffé et al. 2012A, ApJL accepted)

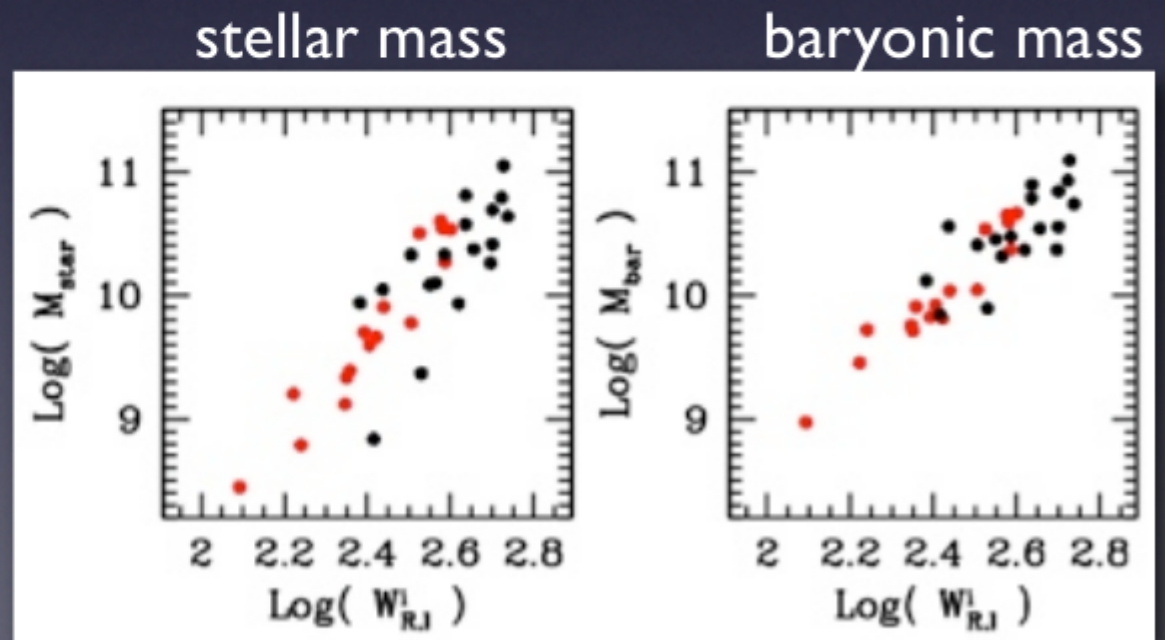
# The HI TFR at $z=0$ vs. $z=0.2$

(Verheijen et al. in preparation)



- larger scatter
- no appreciable offset

error/statistical  
analysis is pending



## Conclusions so far (on A2192)

- HI gas and the SF correlate with morphology and environment at  $z \sim 0.2$
- The fraction of HI-detections is significantly affected by environment
- The effect starts to kick in in low mass groups that pre-process the galaxies before they enter the cluster
- By the time group galaxies fall into the cluster, they are already devoid of HI

( Jaffé et al. 2012a, ApJL accepted)

A silhouette of a landscape with hills and mountains against a sunset sky with orange and blue tones.

## In the oven:

- Global and local environment analysis in the 2 clusters
- T-type vs. Stellar mass vs. HI-content vs. environment
- $\Omega_{\text{HI}}$
- Photometric and spectroscopic blue fractions
- Star-formation rates (From Galex, Spitzer and radio cont.)
- CO observations

# Example detection – state of the art imaging

