the environmental dependence of galaxy properties at 0<z<2

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

7 – summary

Masayuki Tanaka

Before I start, let me introduce myself...

Fast Fact

Name : Masayuki Tanaka

Age : 25 ± 10

Hobbies: football, ski, guitar, ukulele, beer

Career :

1998 – 2002 : Undergrad. at Tohoku Univ.
2002 – 2006 : PhD at U-Tokyo (Hongo)
2006 – 2007 : JSPS PD fellow
2007 – 2009 : European Southern Observatory Fellow
2010 – : IPMU

Research interest : Galaxy properties as functions of environment, mass, and time.

Observing experience : >100 nights on 8m telescopes
Suprime-Cam, FOCAS, MOIRCS on Subaru
FORS2, VIMOS, HAWK-I, VISIR on VLT
GMOS on Gemini, WFCAM on UKIRT, ULBCAM on UH88

Skills : Observation + data reduction, spectral analysis, SED fitting

Welcome to the *real* Universe…

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

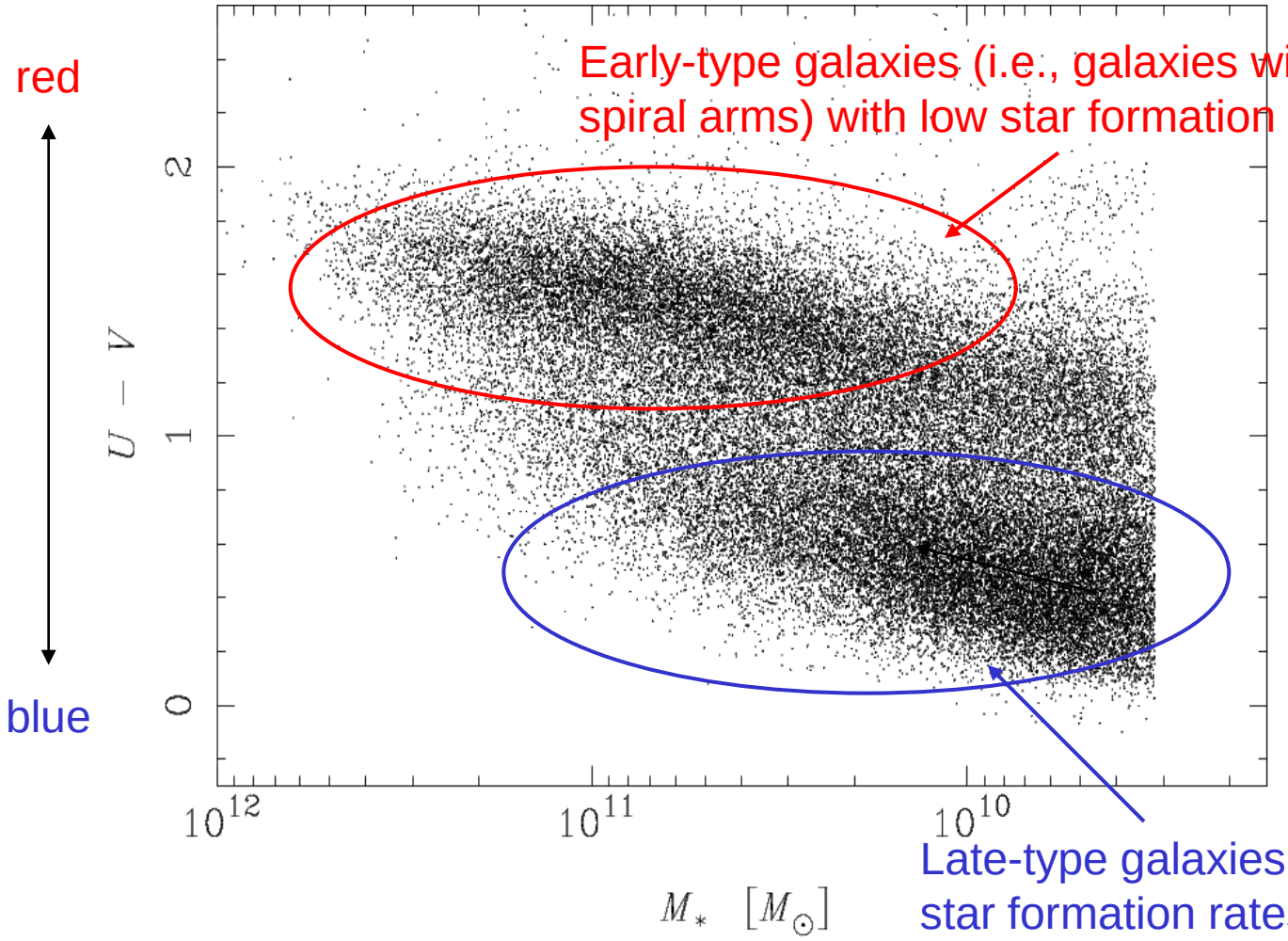
5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

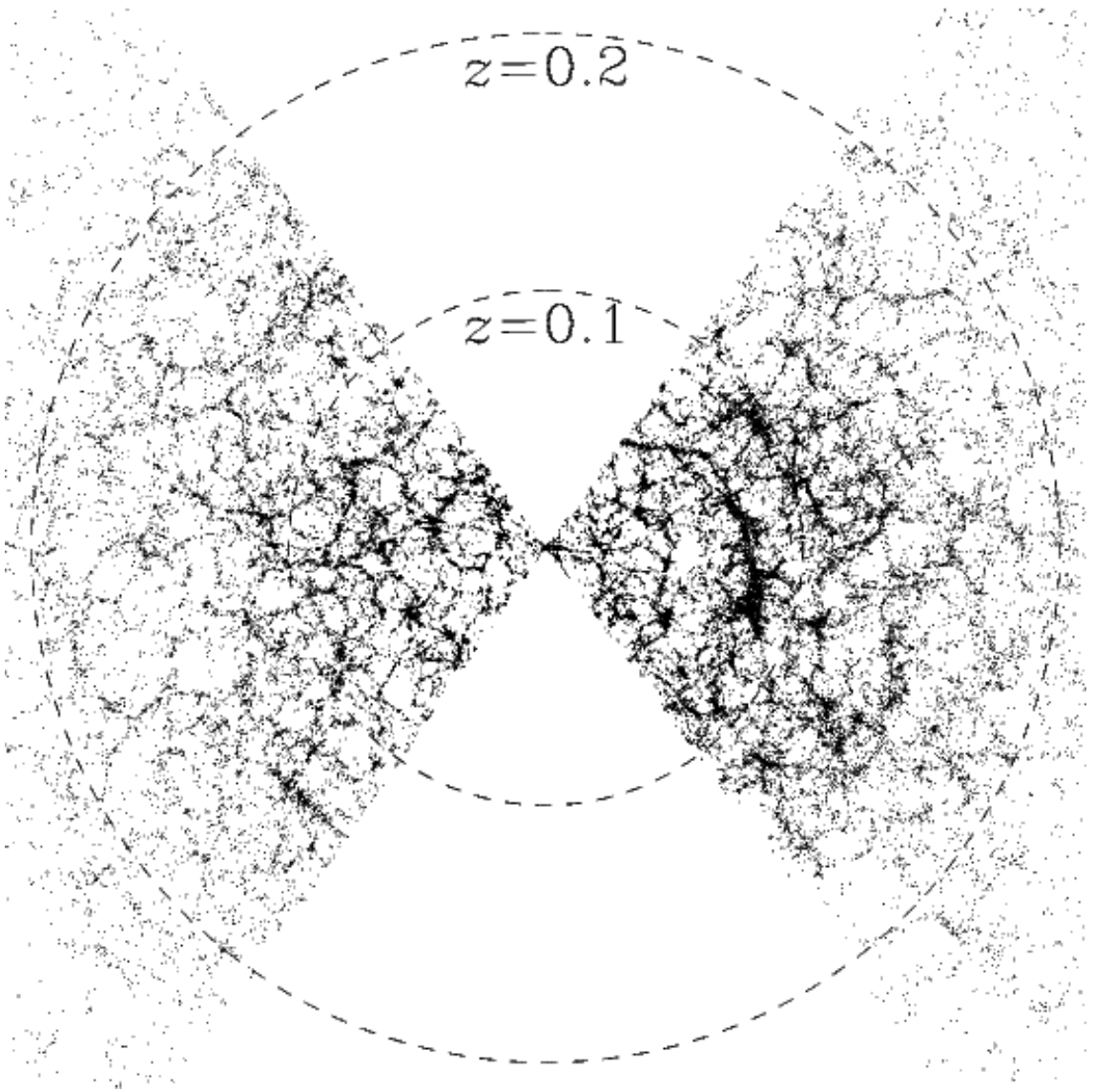
7 – summary

1 – Introduction

Galaxies come in two flavors



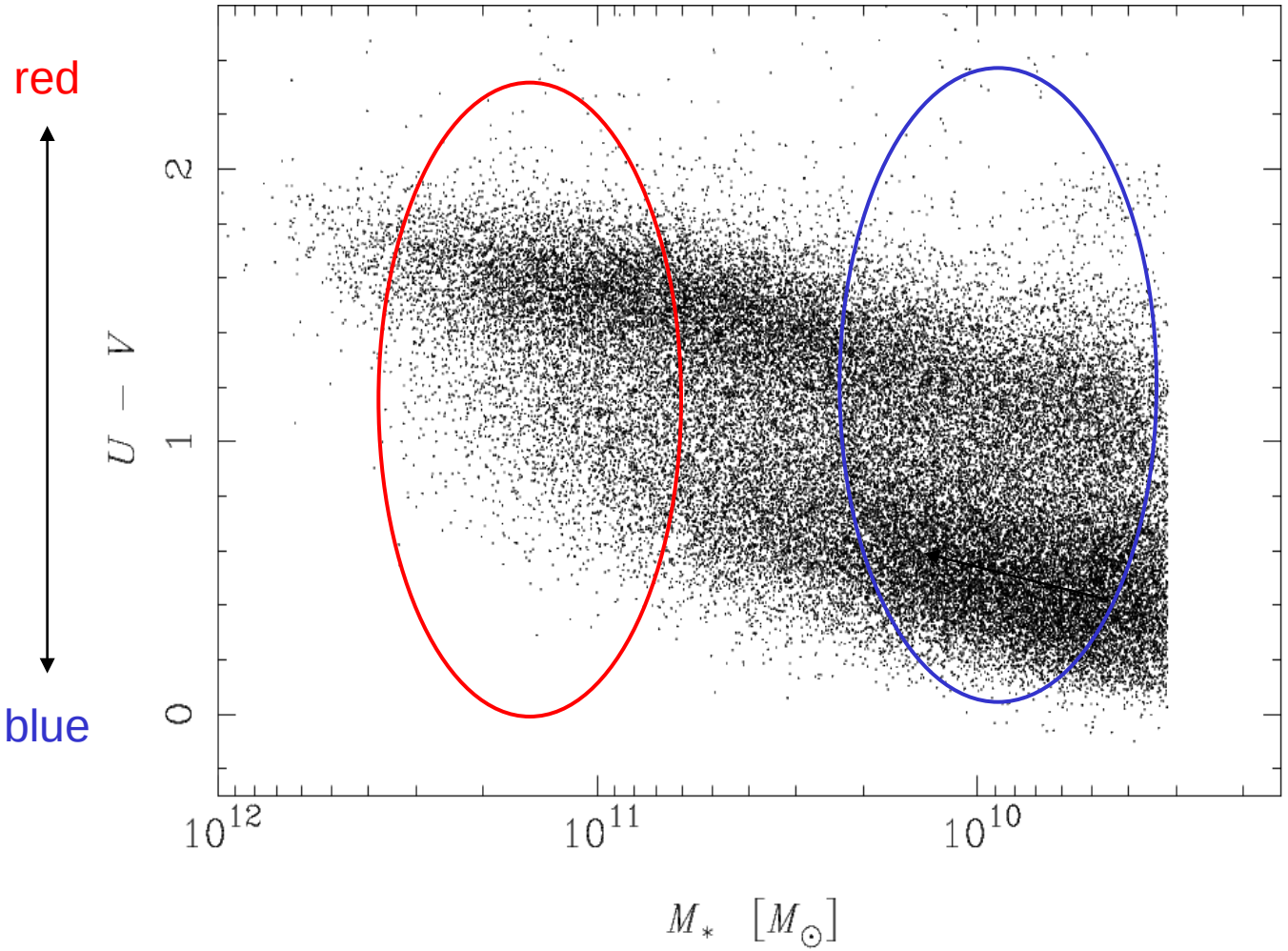
Cosmic large-scale structures probed by SDSS

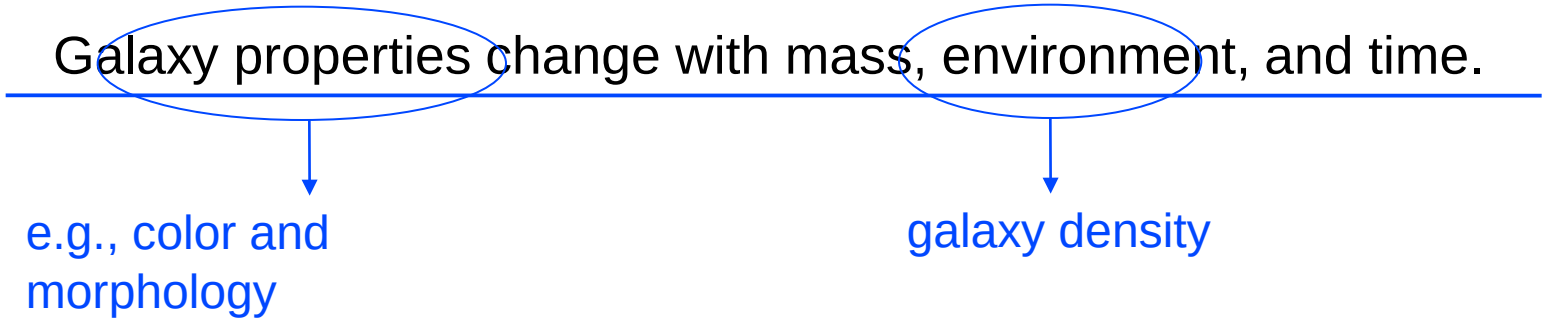



NGC5668


Coma cluster

Galaxies come in two flavors




Galaxy properties change with mass, environment, and time.
e.g., color and morphology
galaxy density

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

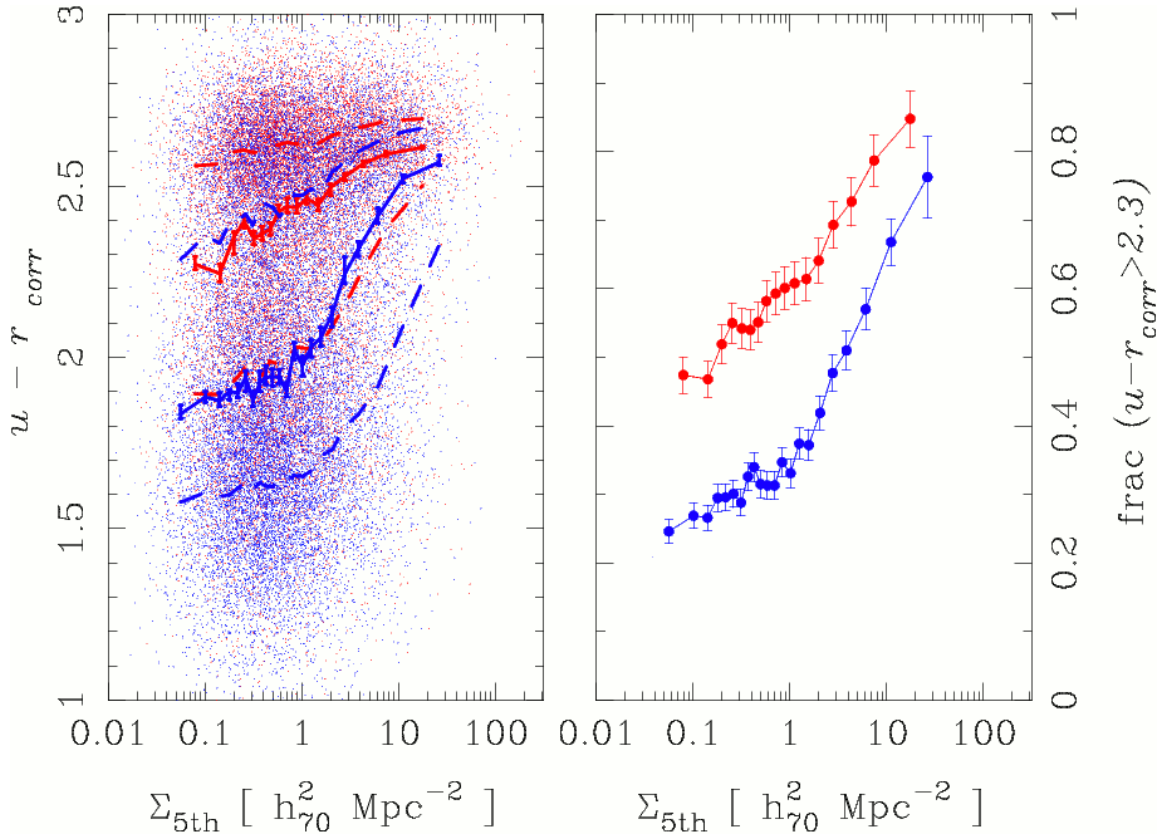
5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

7 – summary

2 – Galaxies today

Color-density relation

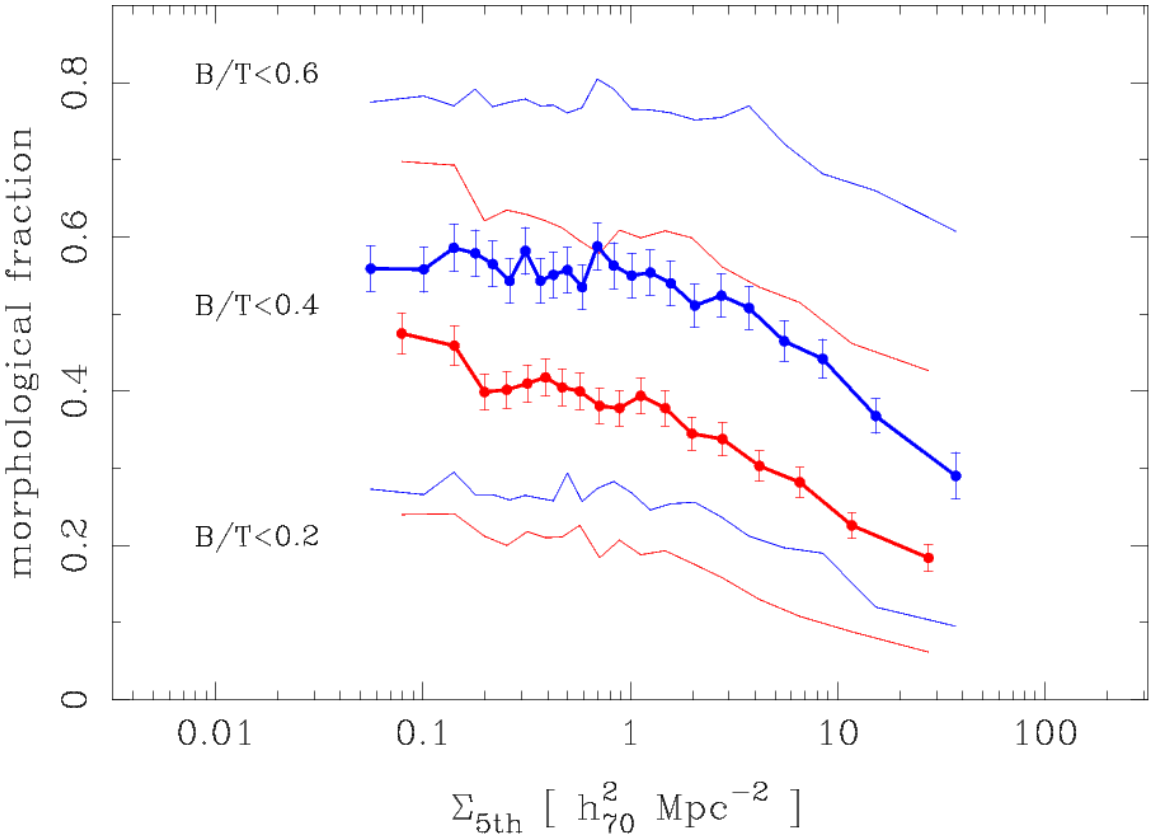


Mr<Mr*+1

Mr*+1<Mr<Mr*+2

Tanaka et al. 2004

Morphology-density relation



Mr<Mr*+1

Mr*+1<Mr<Mr*+2

Tanaka et al. 2004

Why are galaxy properties dependent on environment?

Galaxy formation and evolution must be closely linked to the structure evolution of the Universe.

⟶ Observe galaxies in all environments at all redshifts.

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

5 – cluster hunting at 1.5<z<2.0

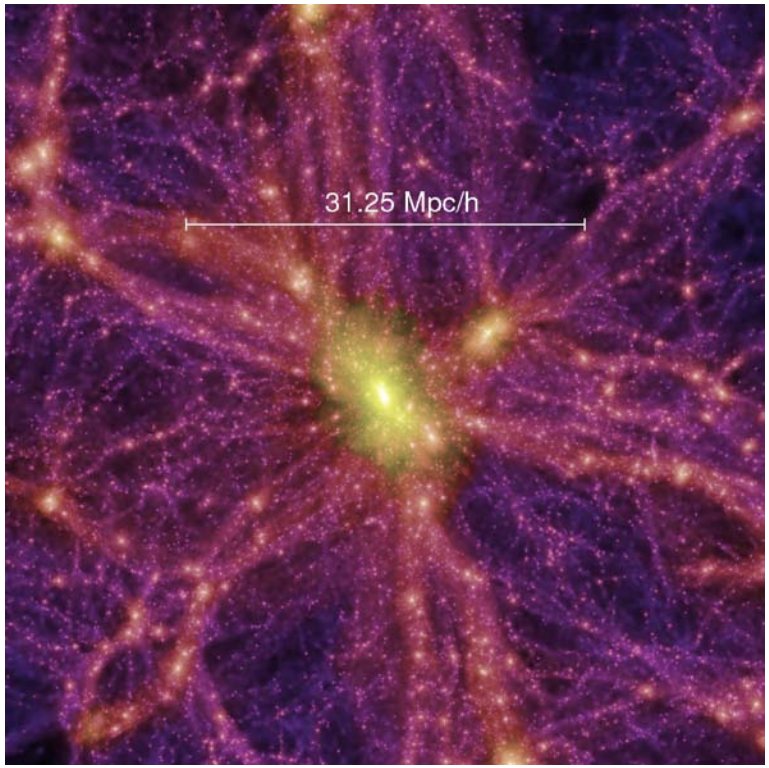
6 – forming clusters at z=2

7 – summary

3 – Observing strategy and large-scale structures

The strategy

We want to observe galaxies in a wide range of environments and at a wide range of redshifts.

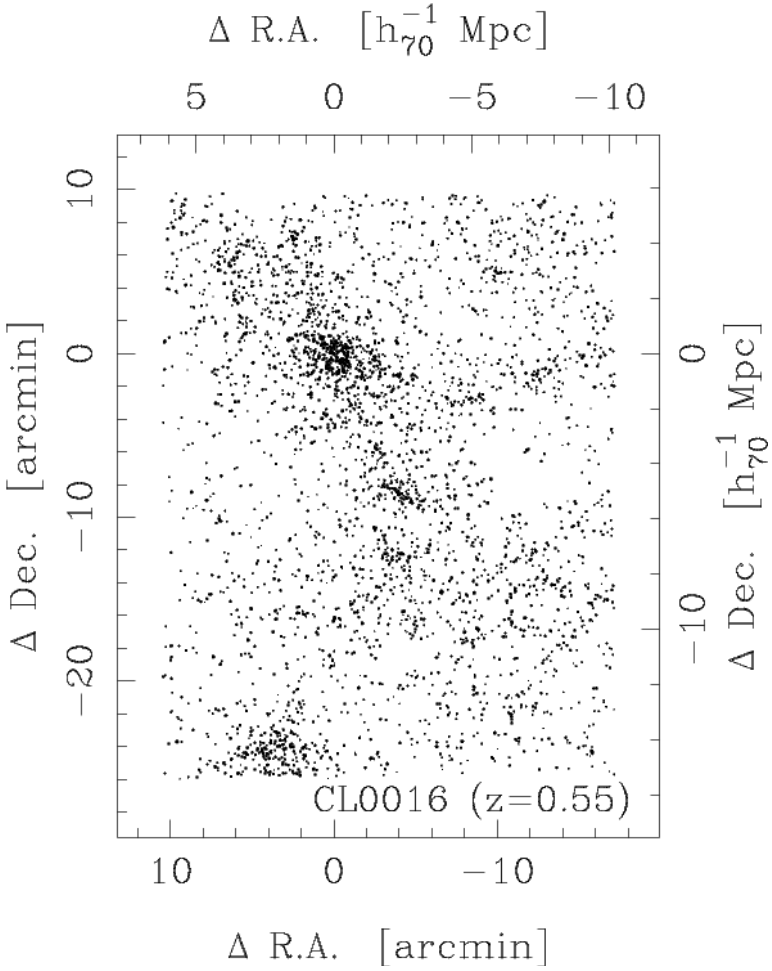


→ Wide-field observations of rich clusters with 8m telescopes.

Strategy :

1 – observe rich clusters with wide-field instruments
2 – find structures around them
3 – confirm them spectroscopically
4 – then, look into galaxy properties as functions of env., mass, and time

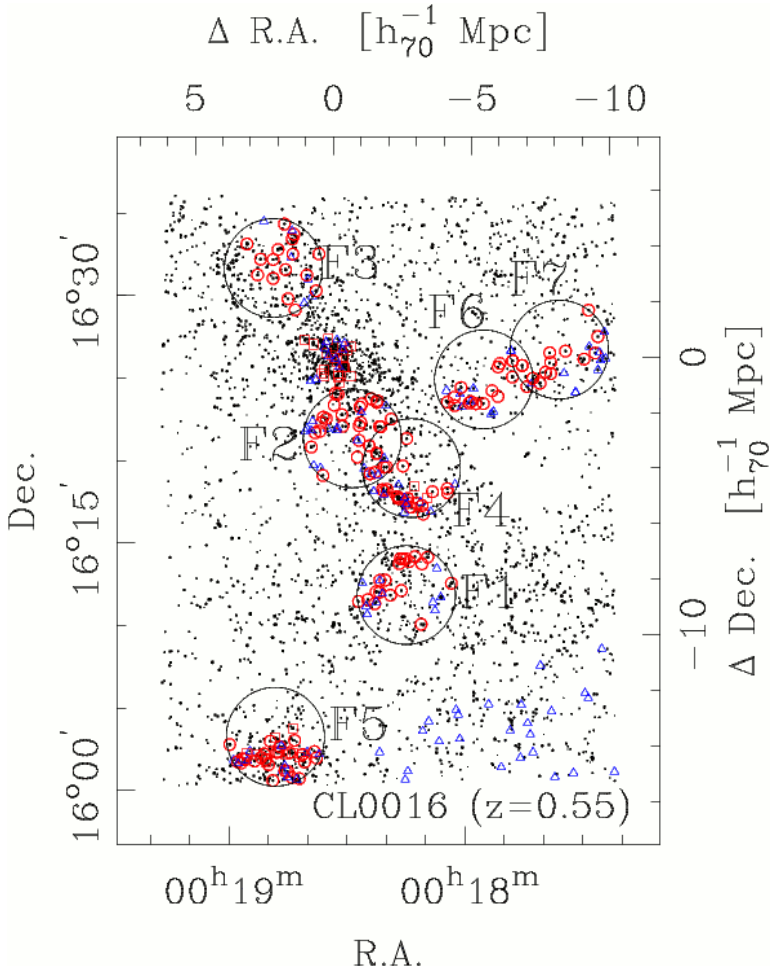
... and that's a right strategy!



CL0016 at z=0.55

Tanaka et al. 2007 MNRAS

... and that's a right strategy!



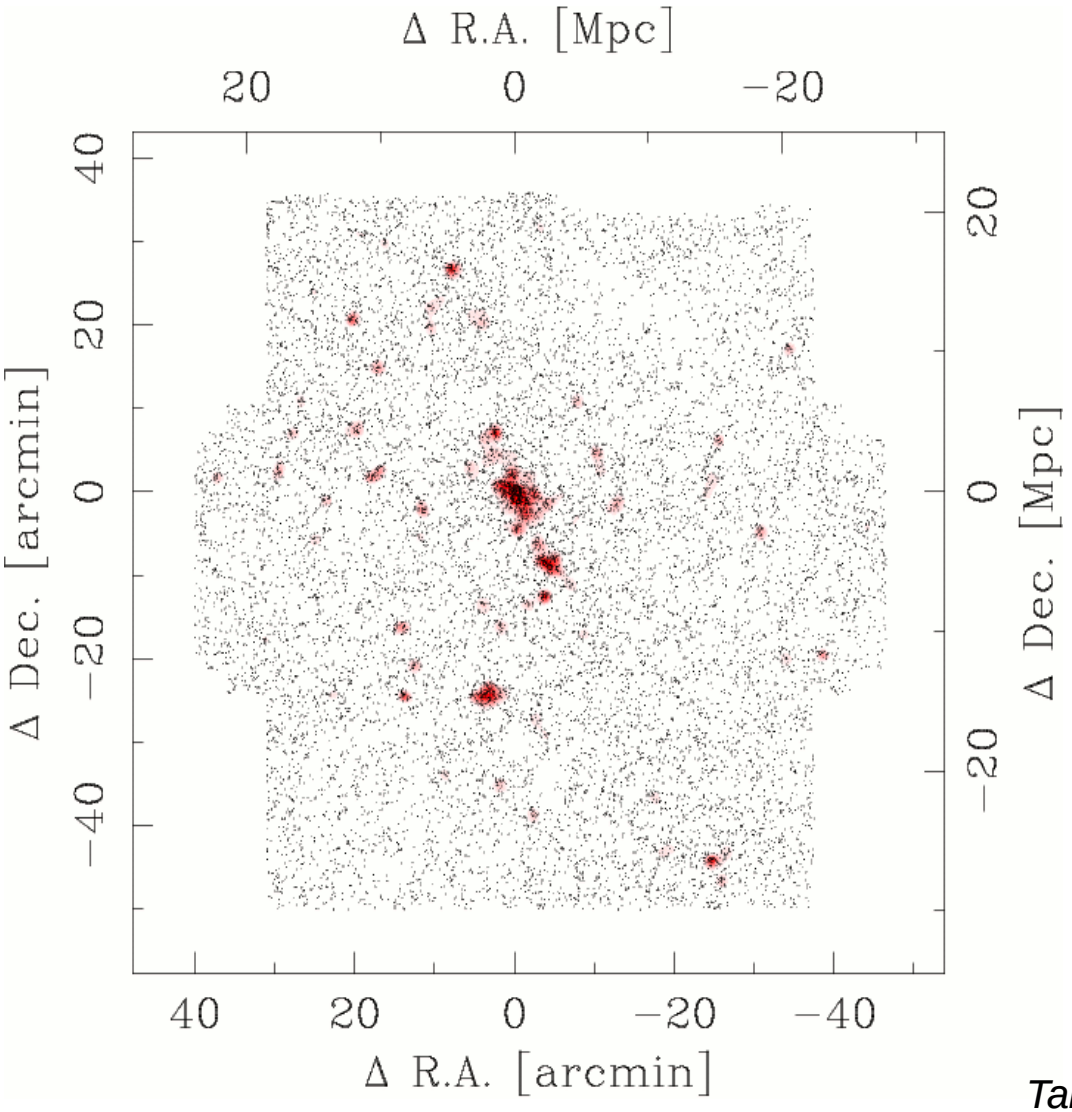
Structure members

Fore-/Background galaxies

CL0016 at z=0.55

Tanaka et al. 2007 MNRAS

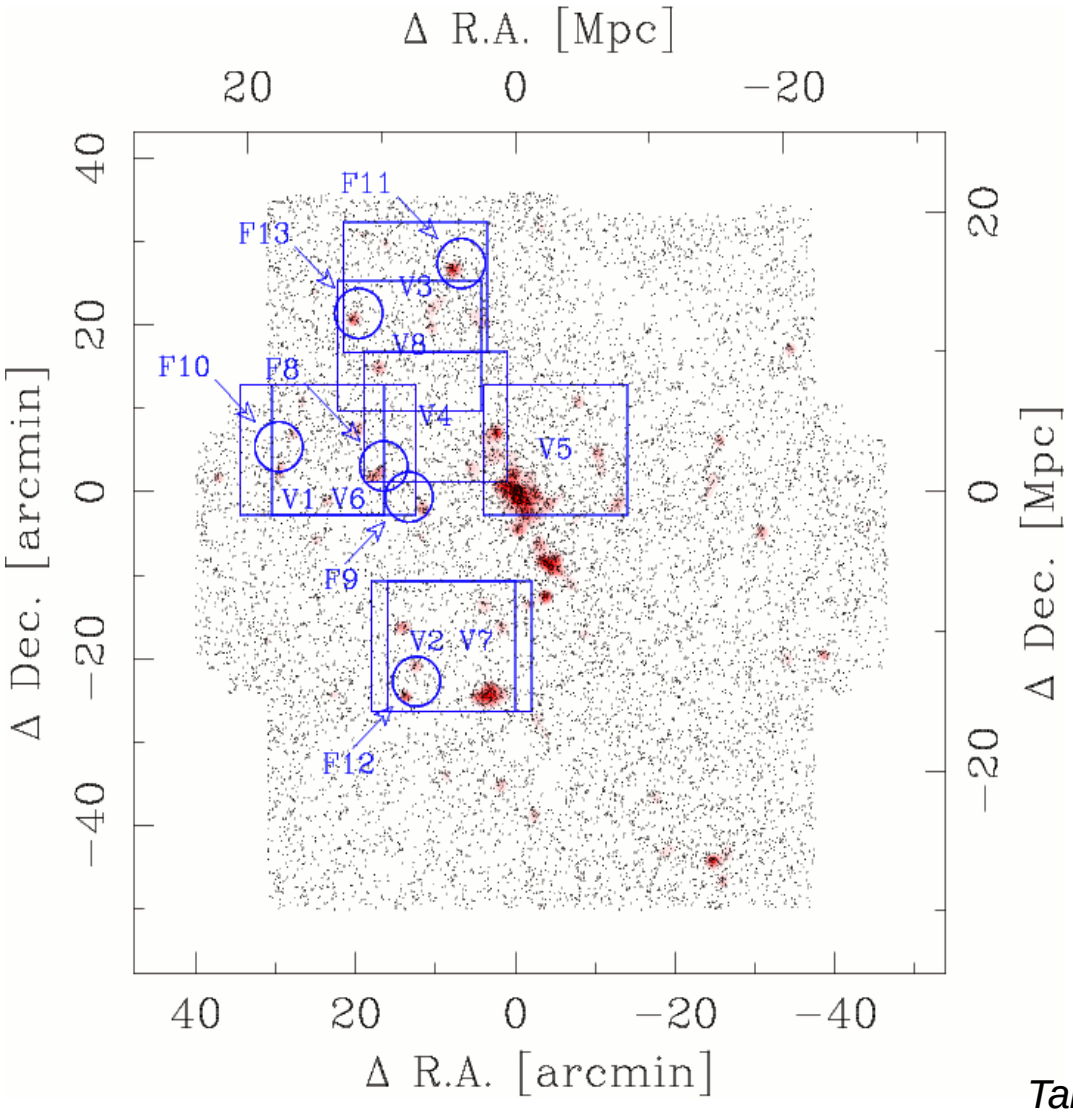
... and that's a right strategy!



CL0016 at z=0.55

Tanaka et al. 2009 A&A

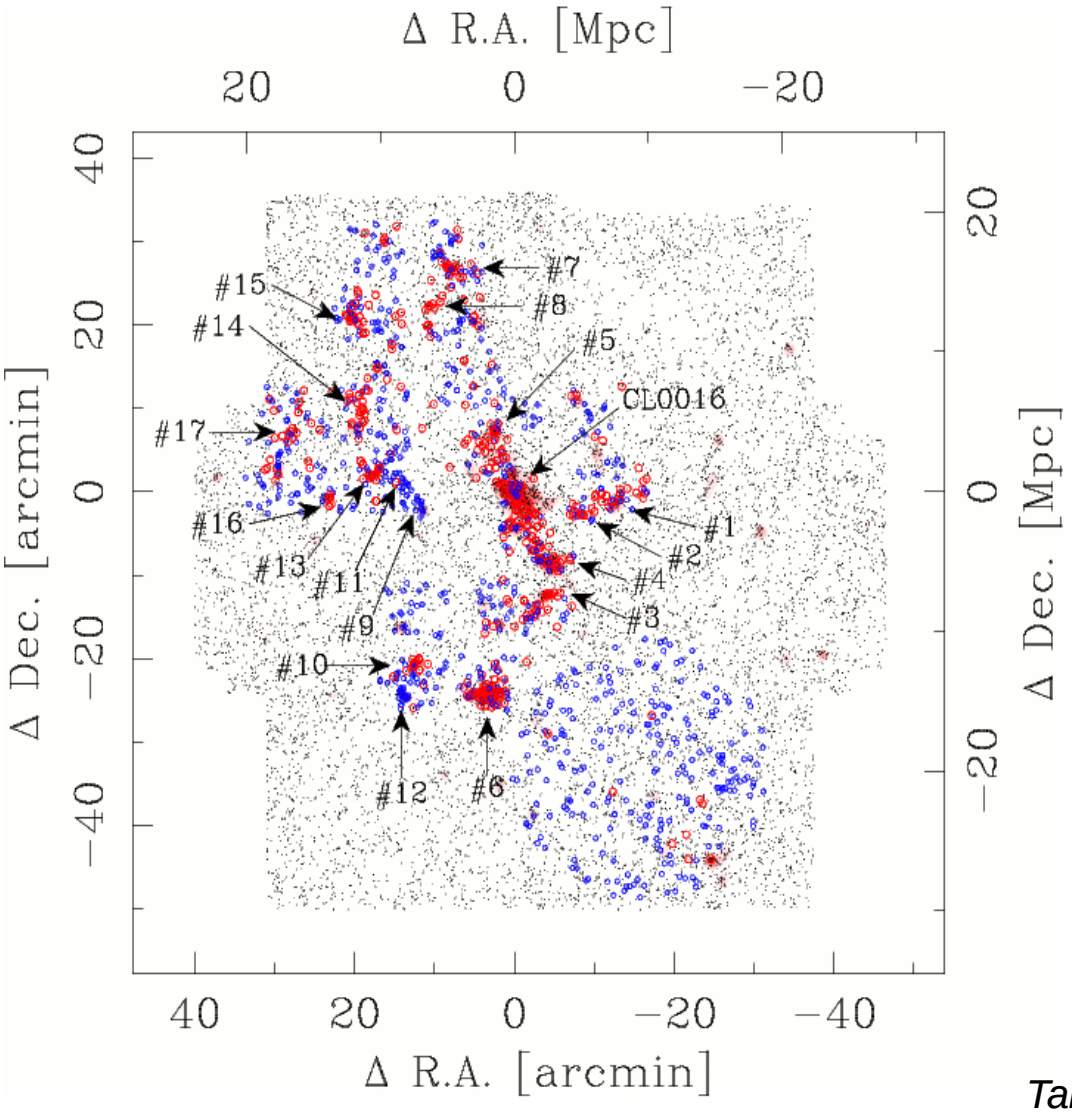
... and that's a right strategy!



CL0016 at z=0.55

Tanaka et al. 2009 A&A

... and that's a right strategy!



Structure members

Fore-/Background galaxies

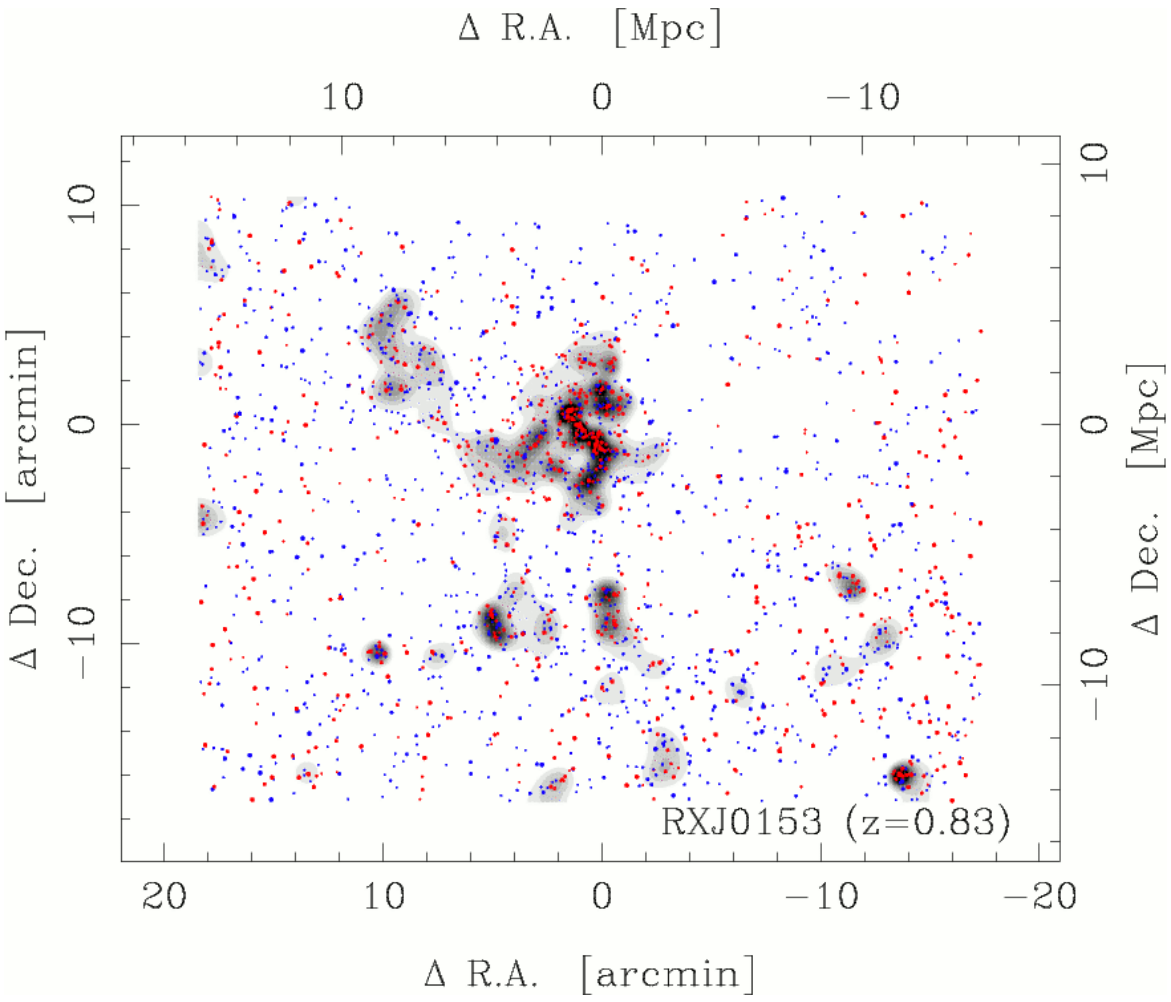
CL0016 at z=0.55

Tanaka et al. 2009 A&A

RXJ0152 at z=0.83

(Suprime-Cam *VRiz* + FOCAS)

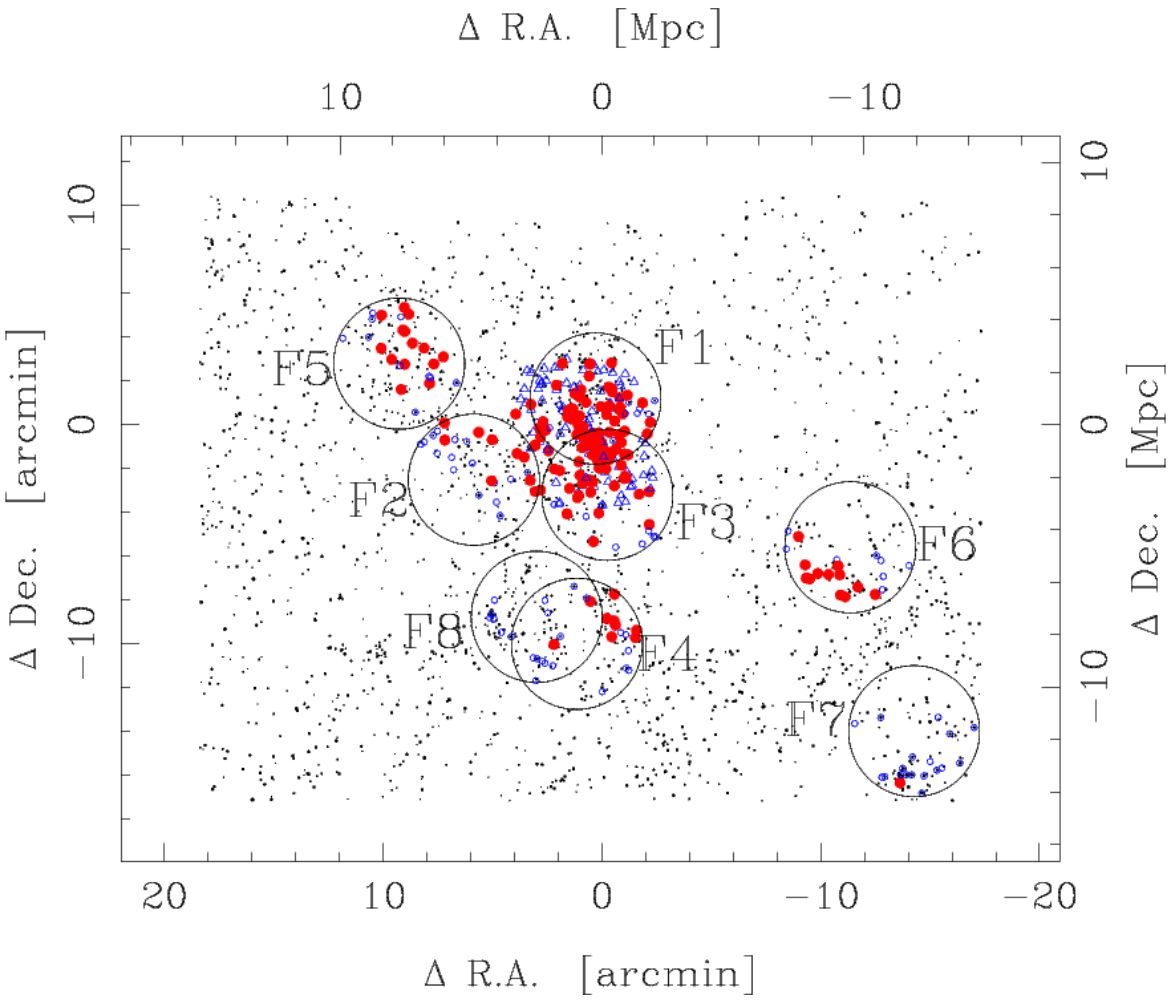
Large-scale structure at z=0.8



RXJ0152 at z=0.83

Tanaka et al. 2006 MNRAS

Large-scale structure at z=0.8



Structure members

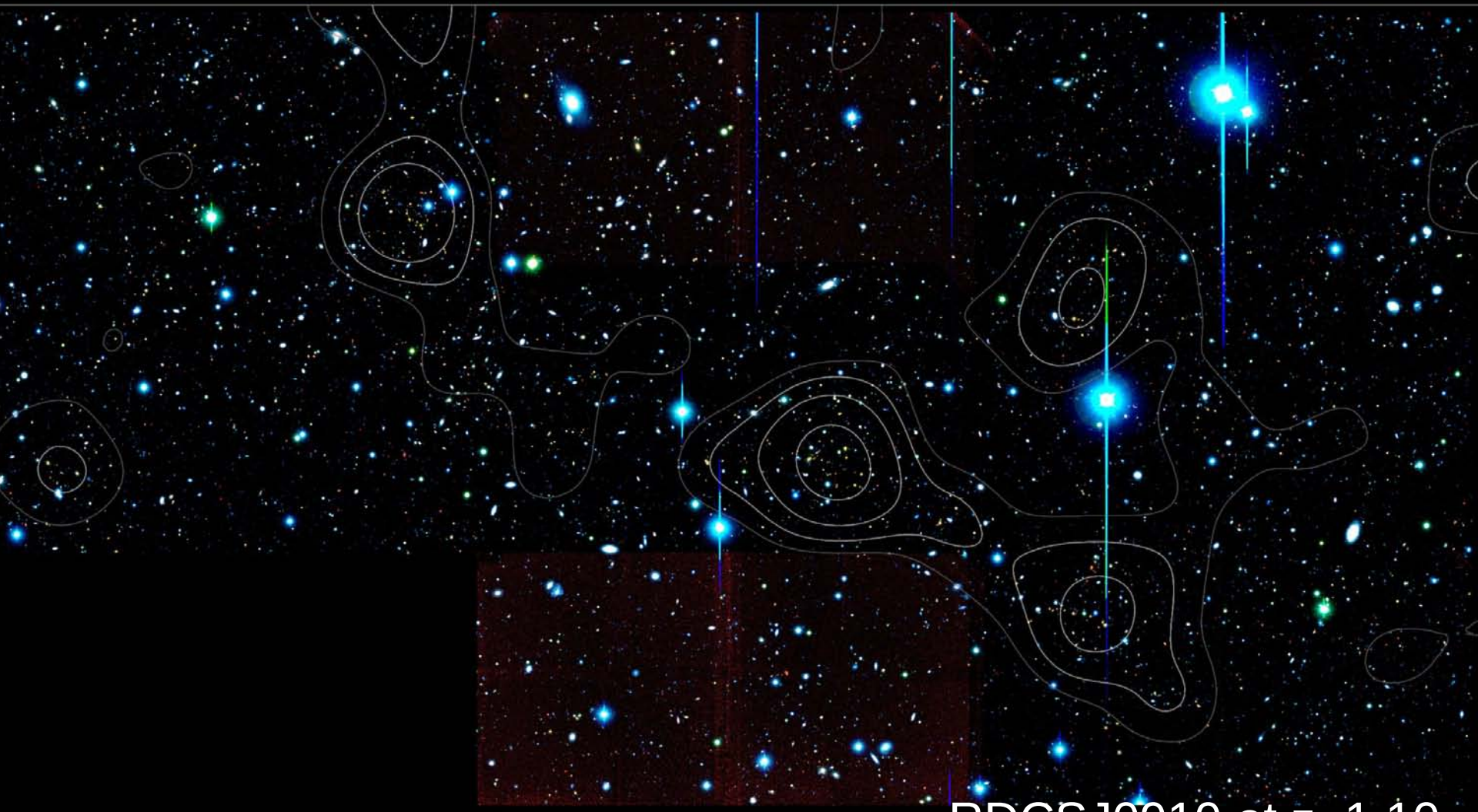
Fore-/Background galaxies

RXJ0152 at z=0.83

Tanaka et al. 2006 MNRAS

RDCSJ0910 at z=1.10

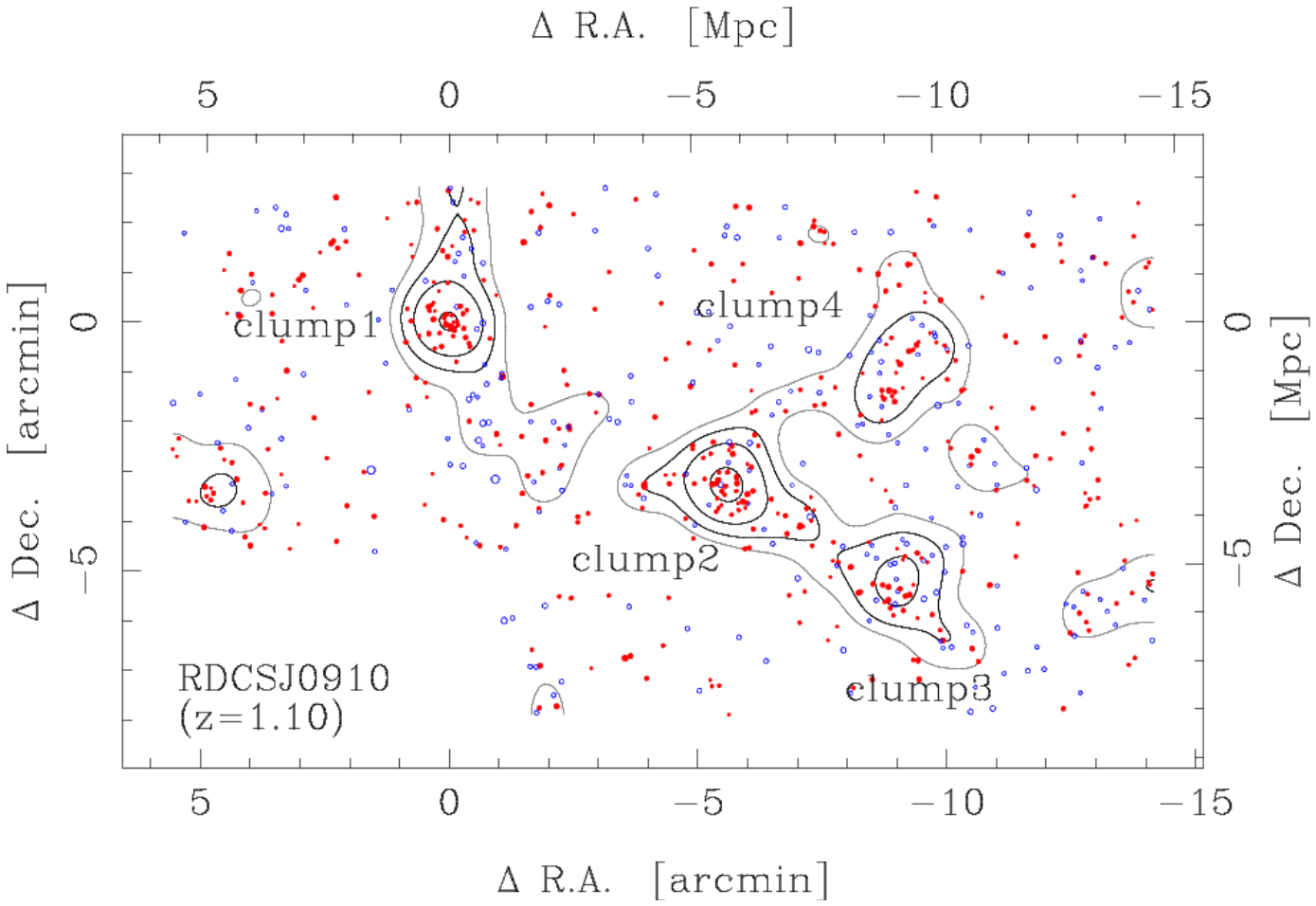
(Suprime-Cam *VRiz* + MOIRCS *Ks*)



RDCSJ0910 at z=1.10

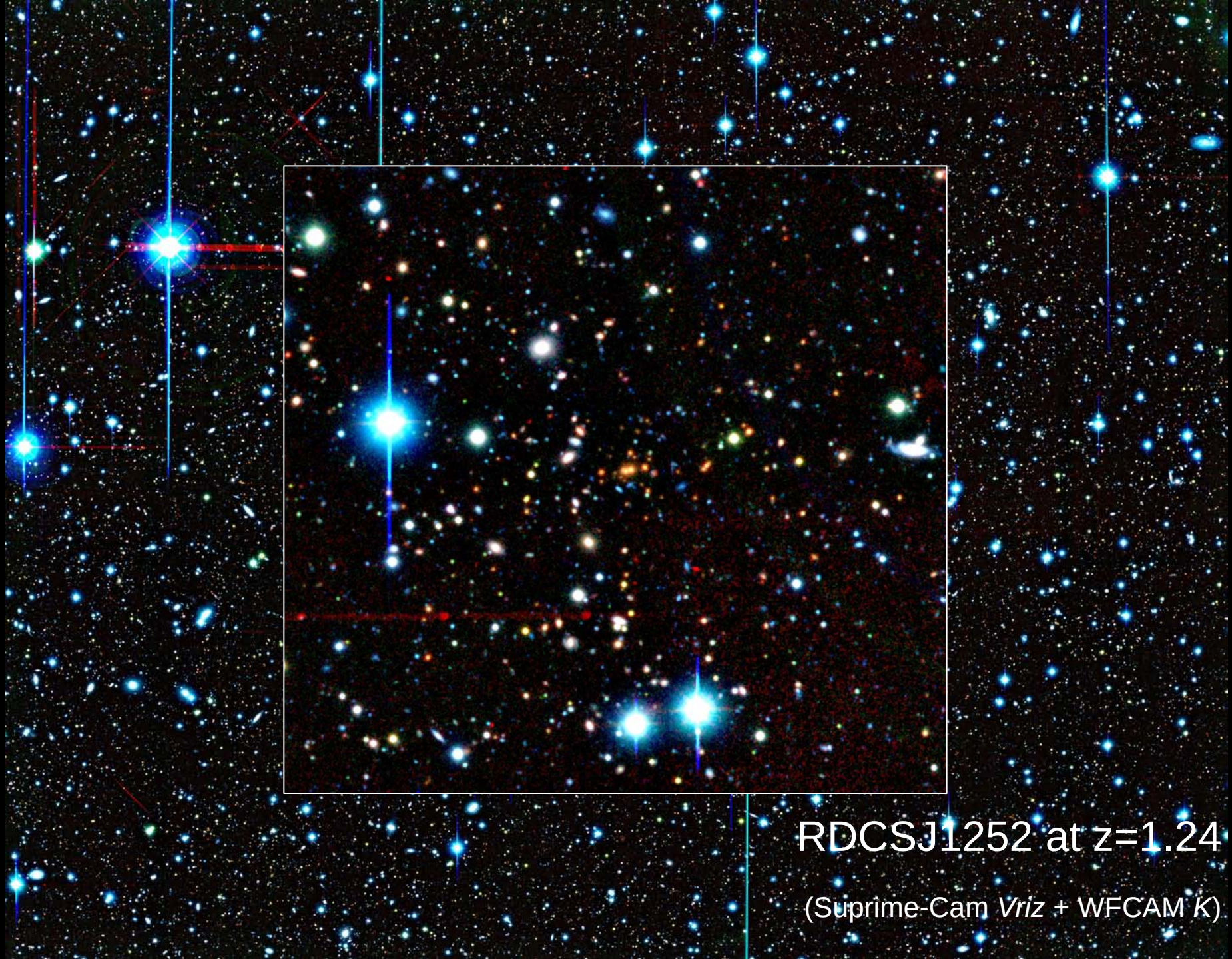
(Suprime-Cam *Vriz* + MOIRCS *Ks*)

Large-scale structure at z=1.1

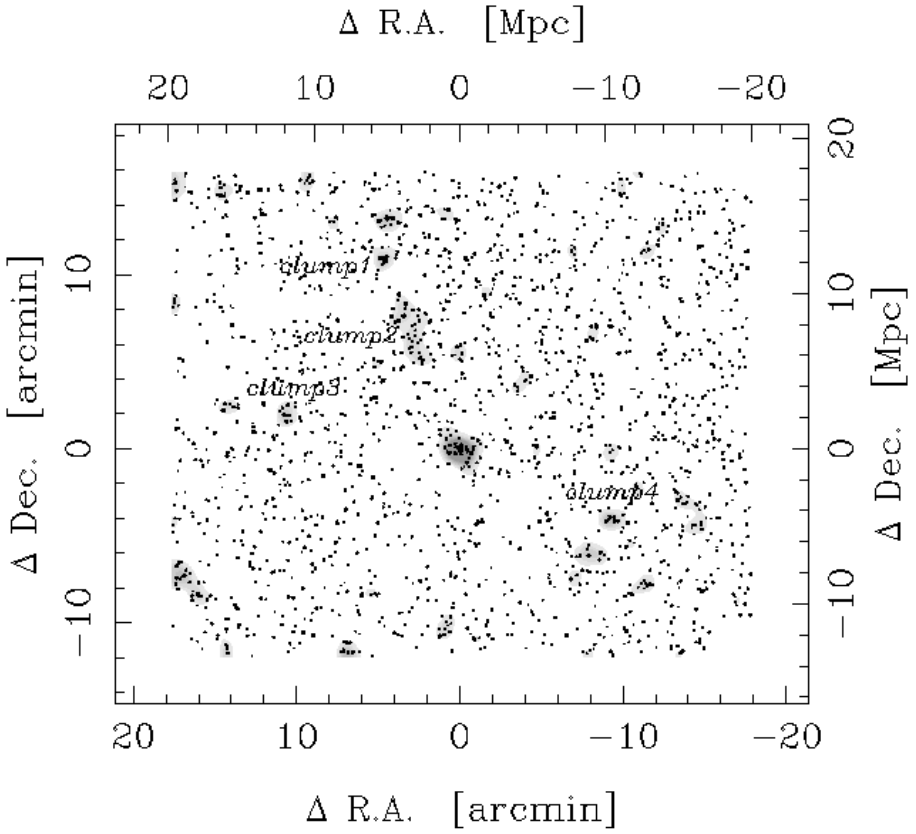


RDCSJ0910 at z=1.1

Tanaka et al. 2008 A&A


RDCSJ1252 at z=1.24
(Suprime-Cam *Vriz* + WFCAM *K*)

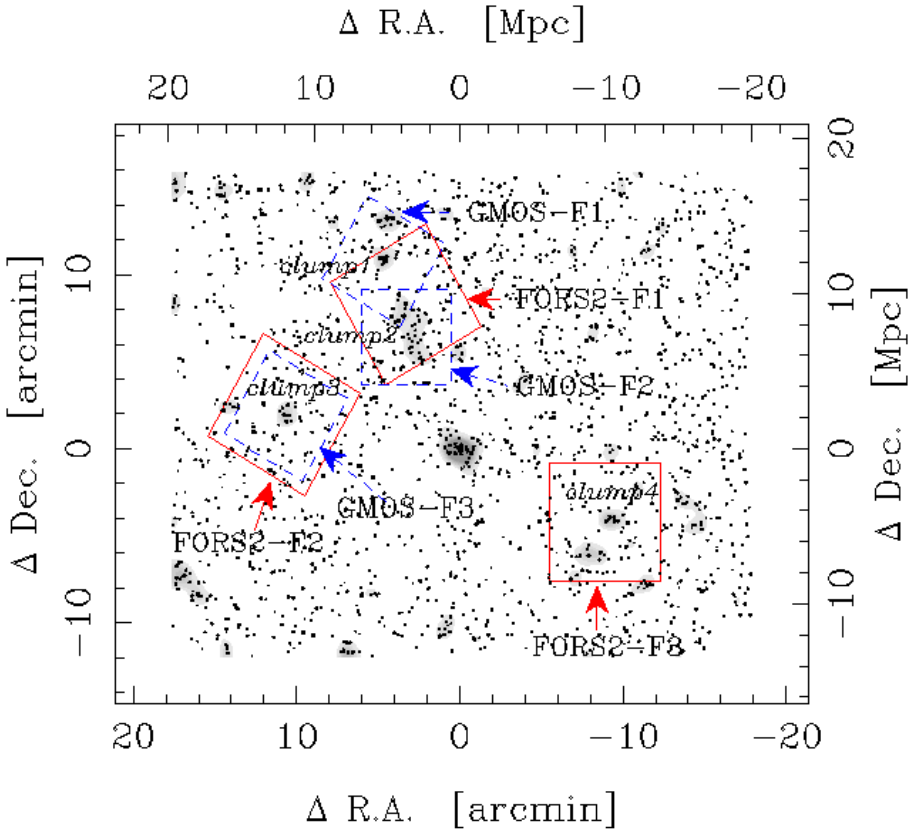
Large-scale structure at z=1.2



points : photo-z selected galaxies shades : galaxy density

Tanaka et al. 2007 MNRAS

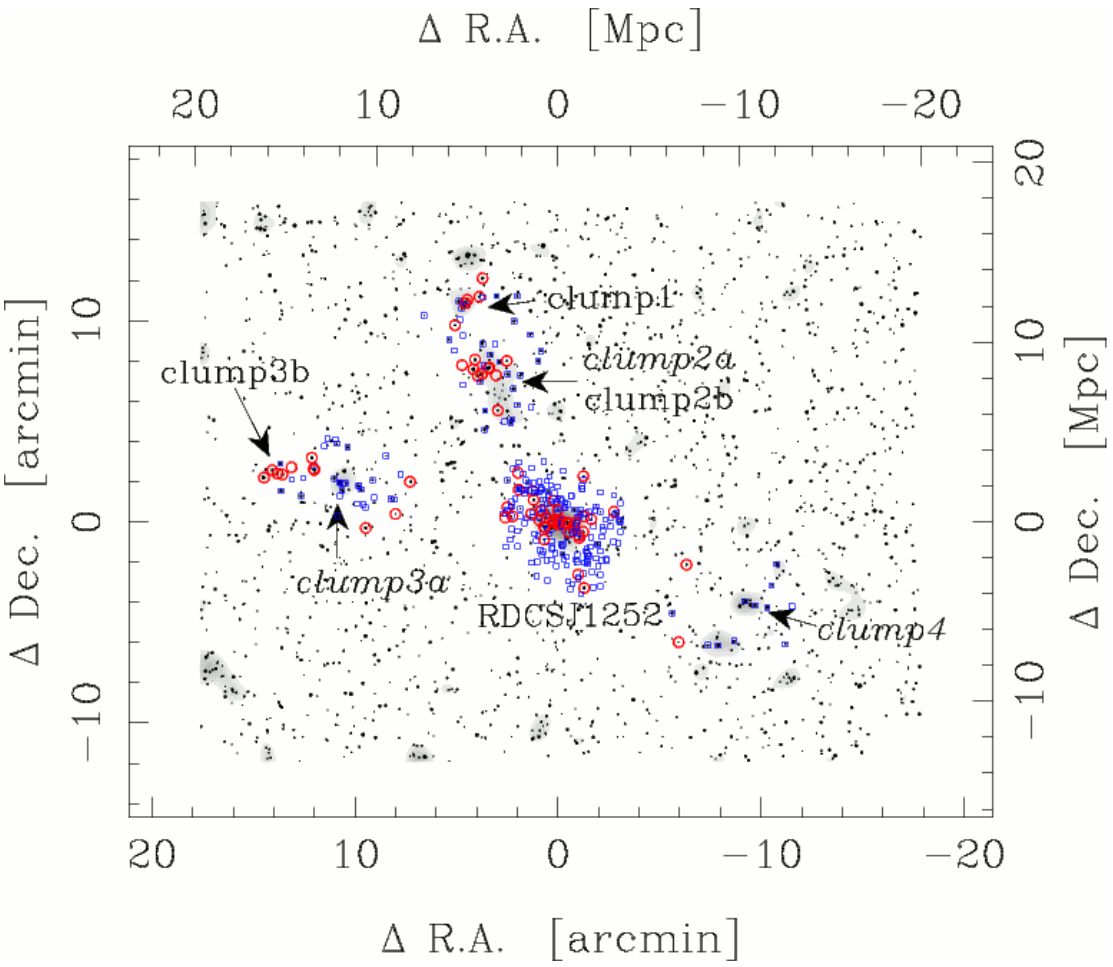
Large-scale structure at z=1.2



points : photo-z selected galaxies shades : galaxy density

Tanaka et al. 2009 MNRAS

Large-scale structure at z=1.2



points : photo-z selected galaxies shades : galaxy density

Tanaka et al. 2009 MNRAS

Strategy :

1 – observe rich clusters with wide-field instruments
2 – find structures around them
3 – confirm them spectroscopically
4 – then, look into galaxy properties as functions of env., mass, and time

(Probably biased) View of the current status of the environment business :

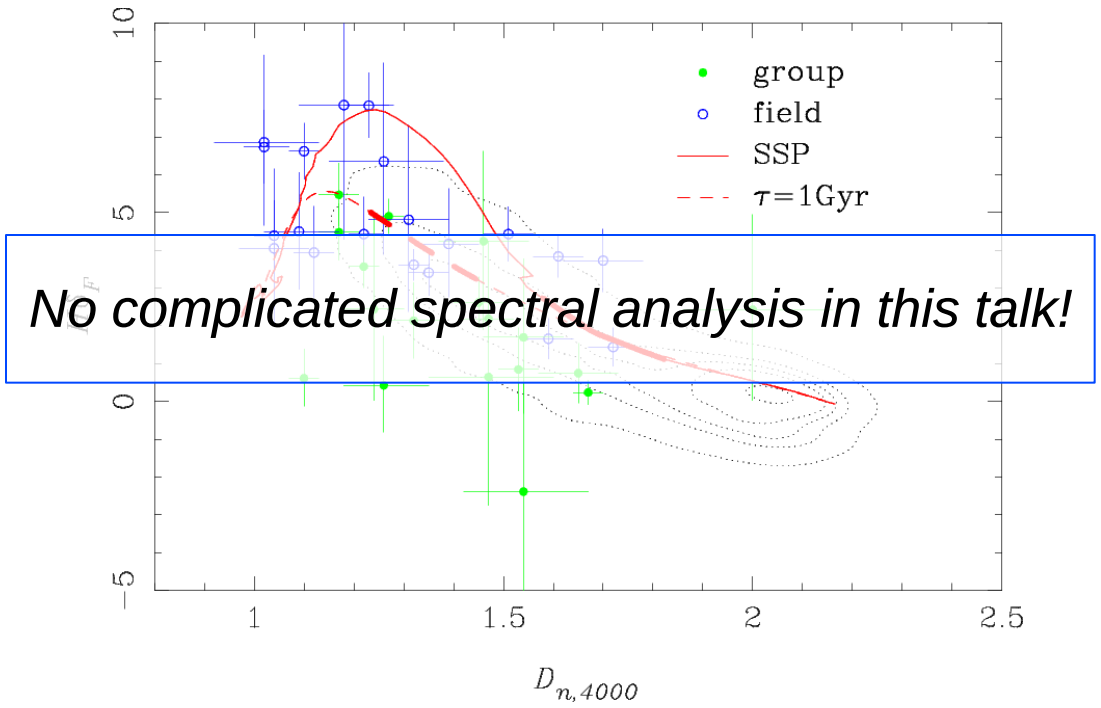
z=0 : done by SDSS

0<z<1.0 : done by many people, many confirmed clusters and structures

1.0<z<1.5: now it's time for statistical studies

1.5<z<2.0: no confirmed clusters known

2.0<z : epoch of forming clusters



No complicated spectral analysis in this talk!

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

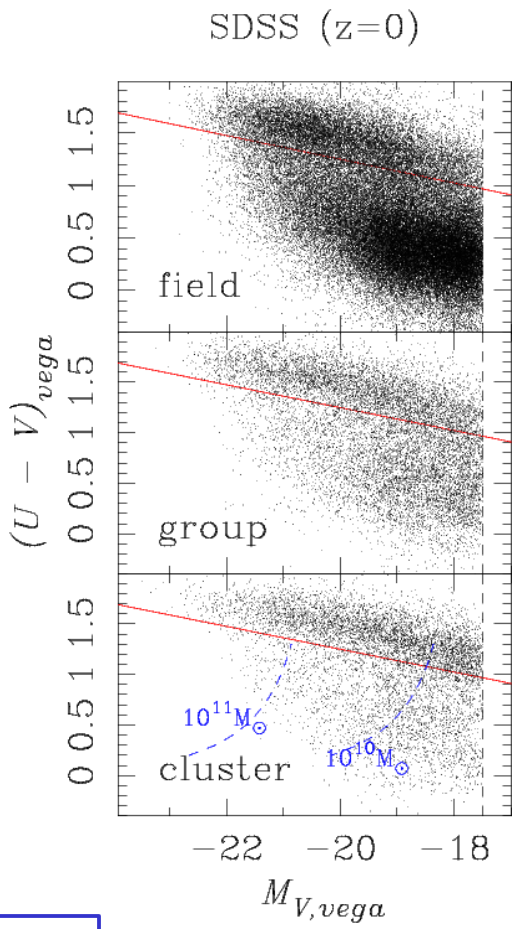
4 – galaxy properties at 0<z<1.5

5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

7 – summary

4 – Galaxy properties at 0<z<1.5



outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

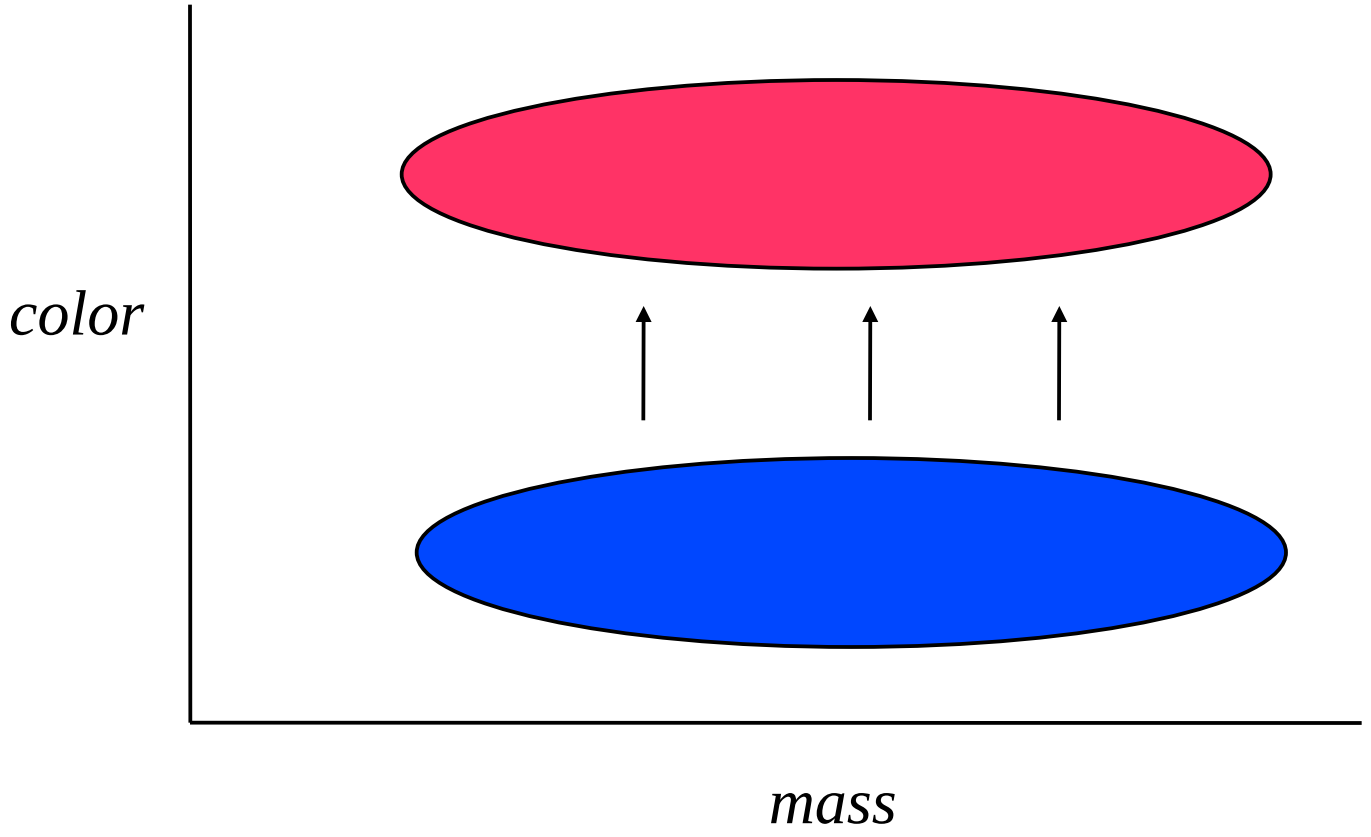
5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

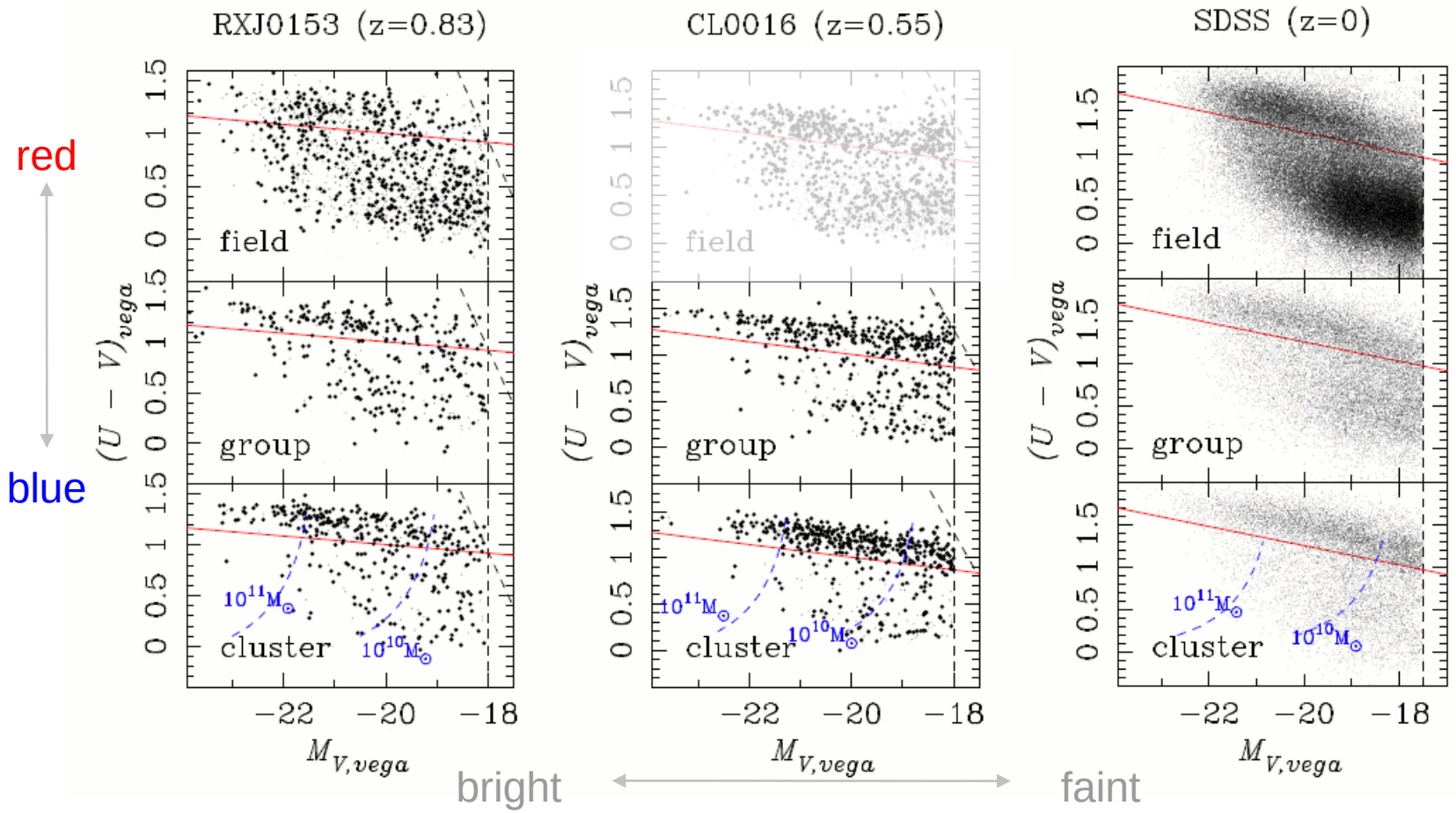
7 – summary

4 – Galaxy properties at 0<z<1.5

Red sequence tells us when/where/how galaxies die

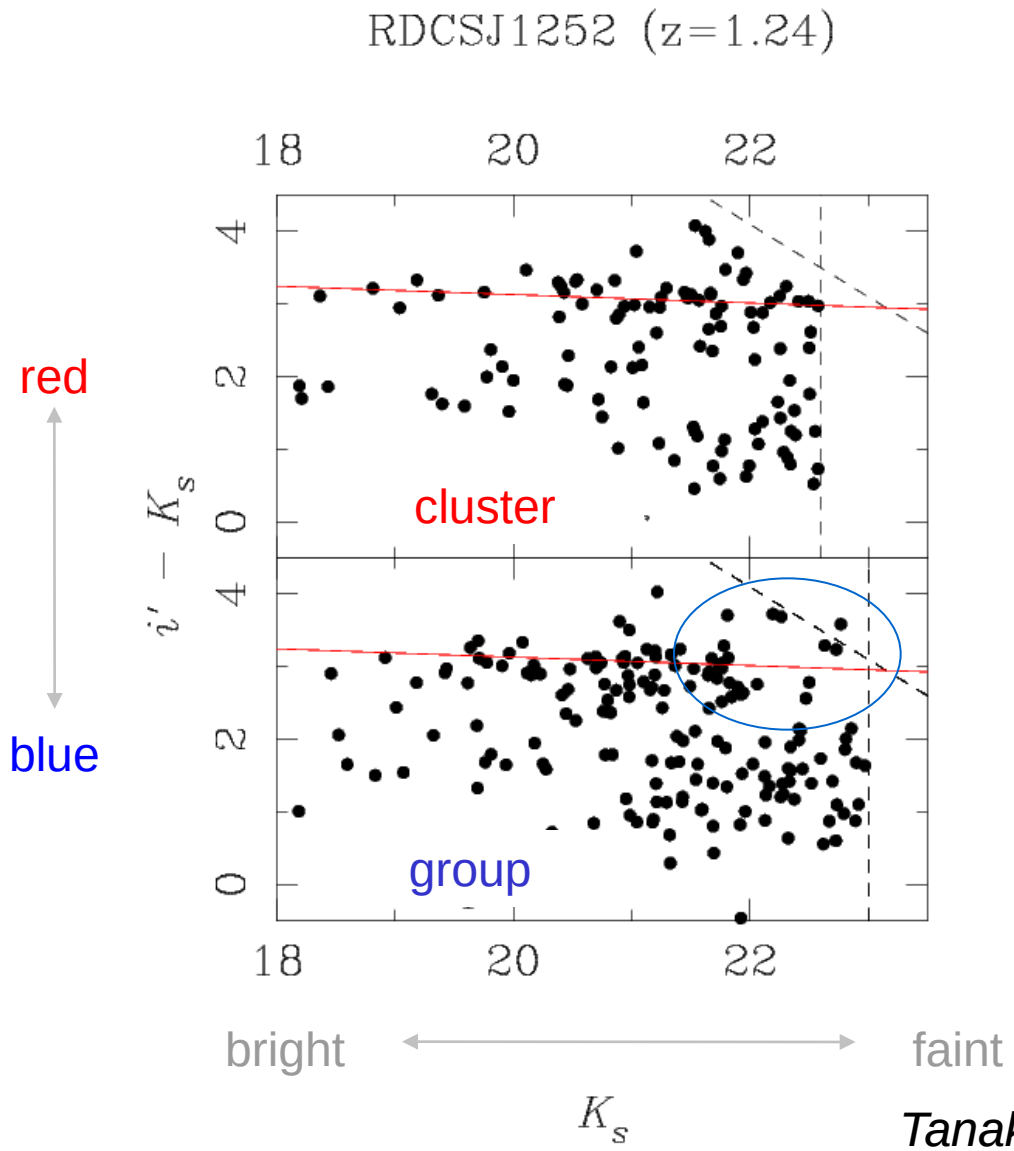


The build-up of the red sequence



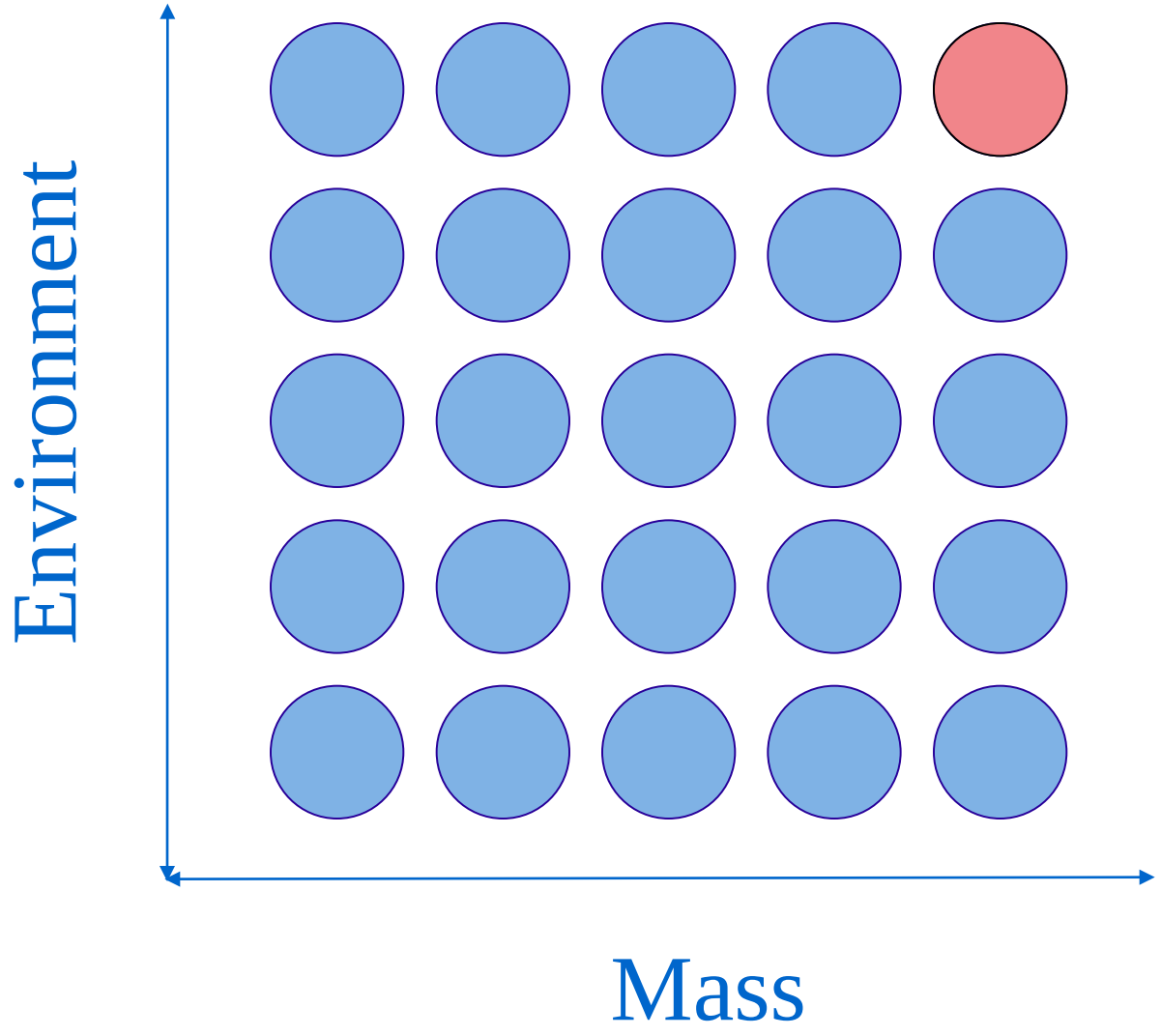
Tanaka et al. 2005 MNRAS

The build-up of the red sequence

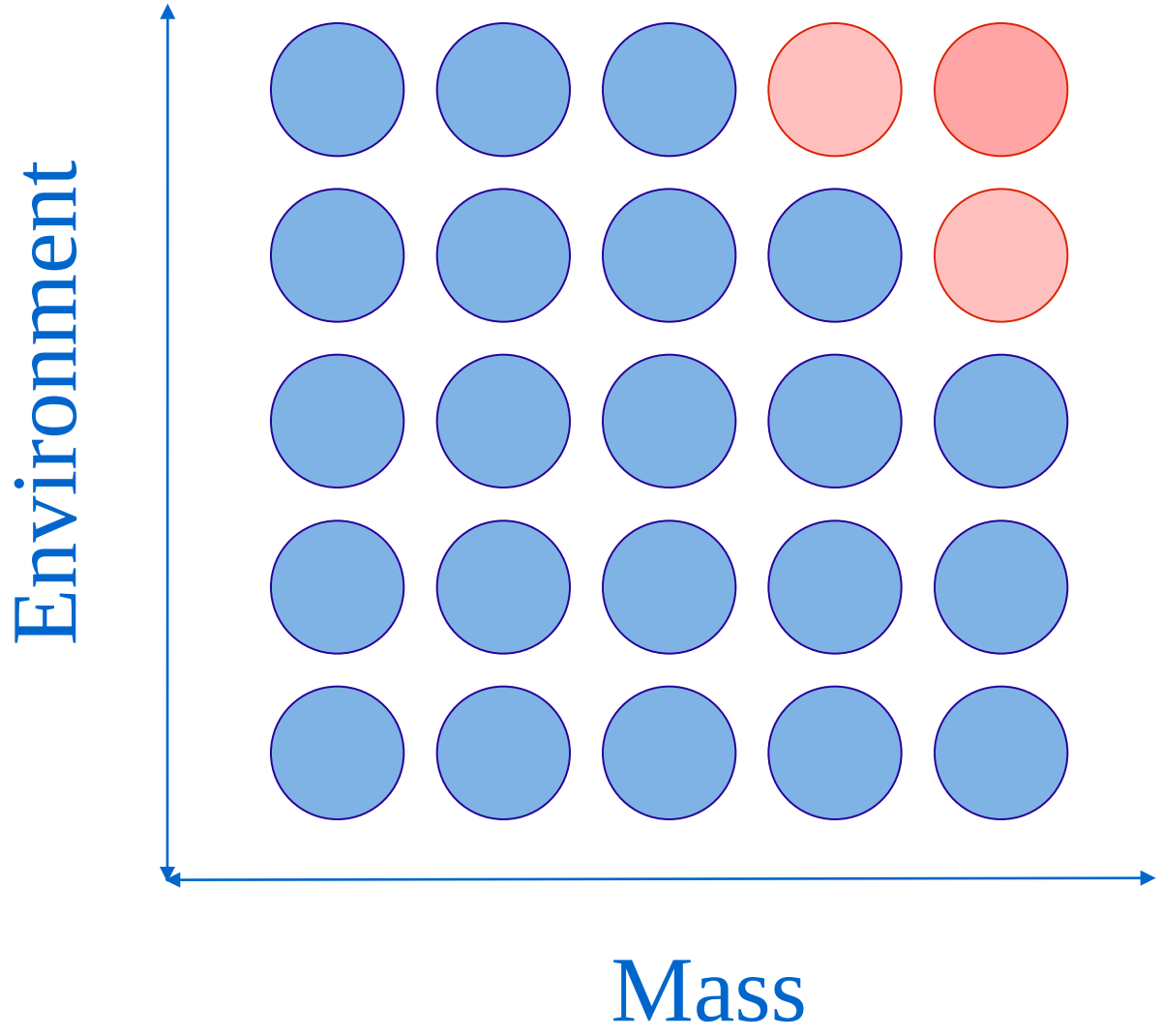


Tanaka et al. 2007 MNRAS

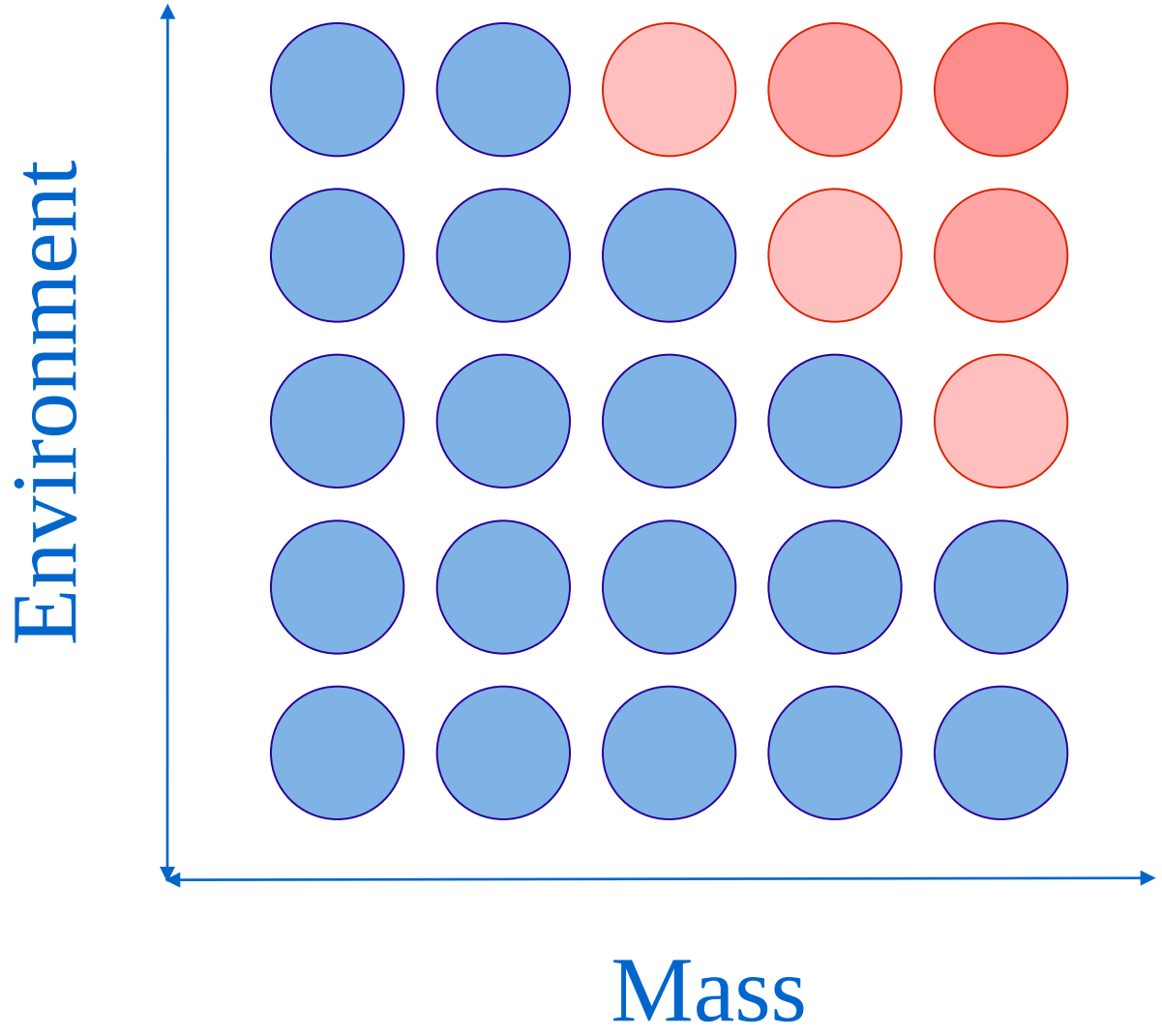
Schematic view of the build-up of the red sequence



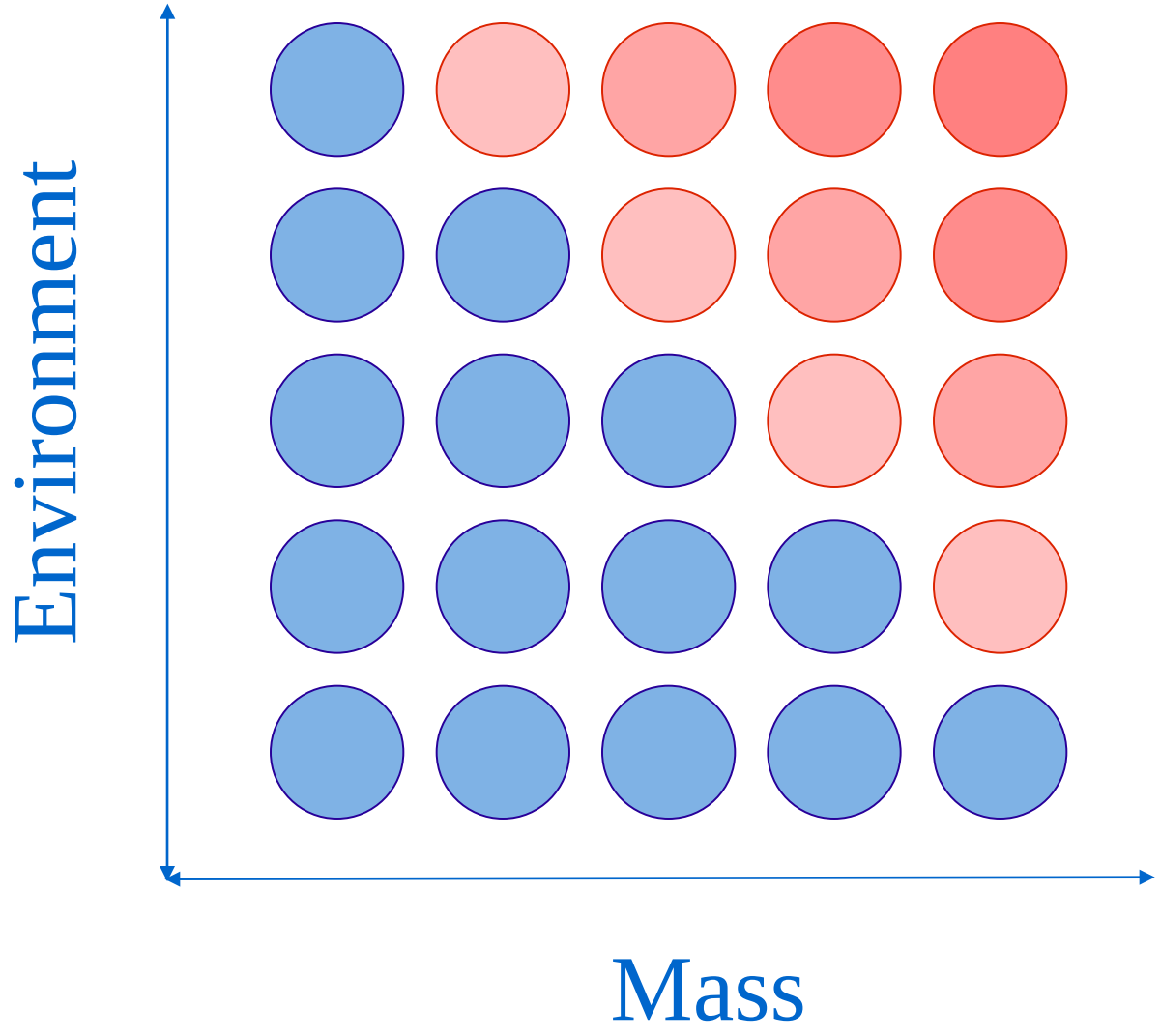
Schematic view of the build-up of the red sequence



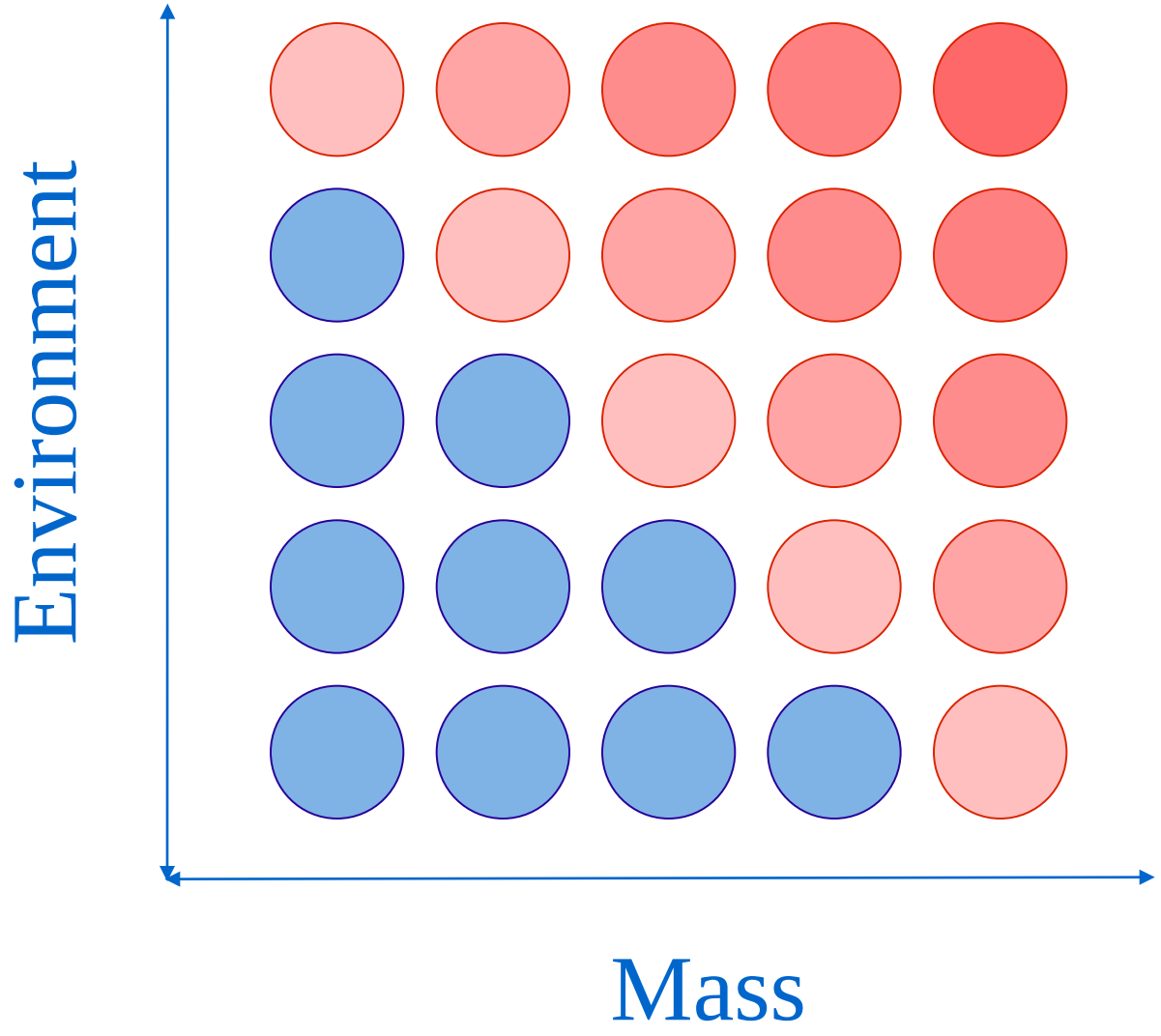
Schematic view of the build-up of the red sequence



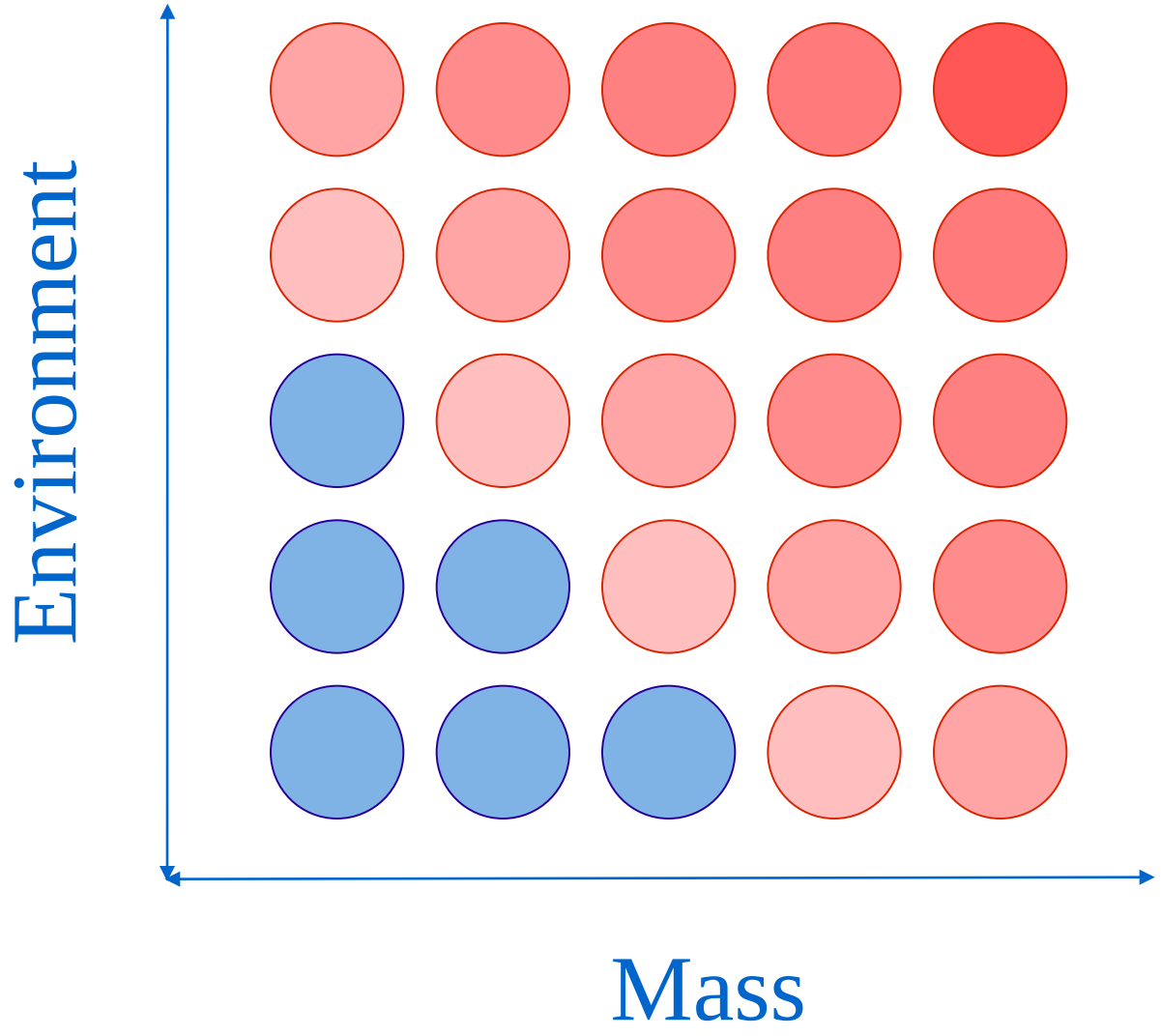
Schematic view of the build-up of the red sequence



Schematic view of the build-up of the red sequence



Schematic view of the build-up of the red sequence



The origin of the environmental dependence…

We have identified when and where galaxies die.
The remaining question is *how* they die.

I haven’t reached any clear conclusion yet….
(ref : Tanaka et al. 2009 A&A)

(Probably biased) View of the current status of the environment business :

z=0 : done by SDSS
0 <z<1.0 : done by many people, many confirmed clusters and structures
1.0<z<1.5: now it's time for statistical studies
1.5<z<2.0: no confirmed clusters known
2.0<z : epoch of forming clusters

outline

5 – cluster hunting at 1.5<z<2.0

The most distant cluster known to date – XMMUJ2215 at z=1.45

outline

1 – introduction

2 – galaxies at z=0

3 – observing strategy and large-scale structures

4 – galaxy properties at 0<z<1.5

5 – cluster hunting at 1.5<z<2.0

6 – forming clusters at z=2

7 – summary

5 – cluster hunting at 1.5<z<2.0

How to find high-z systems

Ask me later if you are interested.


SXDS-XCL63 at z~1.6

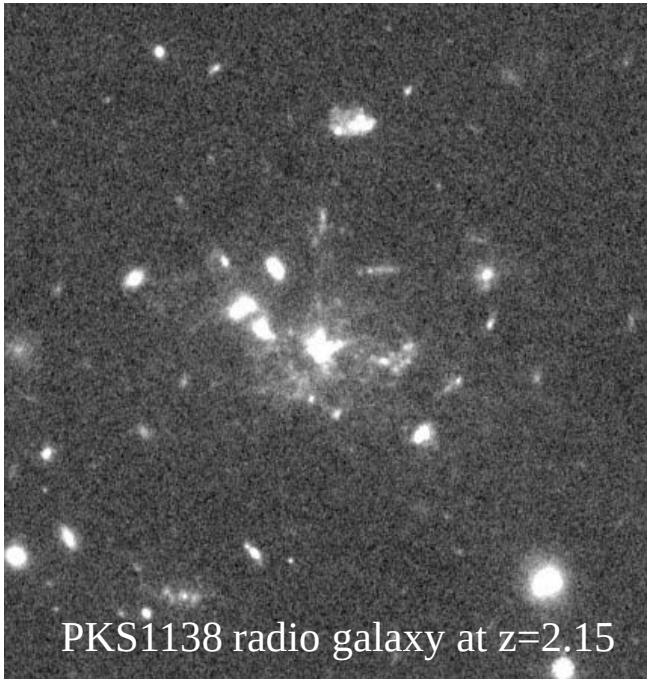
There are a few candidates of forming clusters at z>2.

It seems the environmental dependence of galaxy properties are partly in place as early as z~2.

Tanaka et al. A&A submitted

outline

6 – forming clusters at z=2



PKS1138 at z=2.15

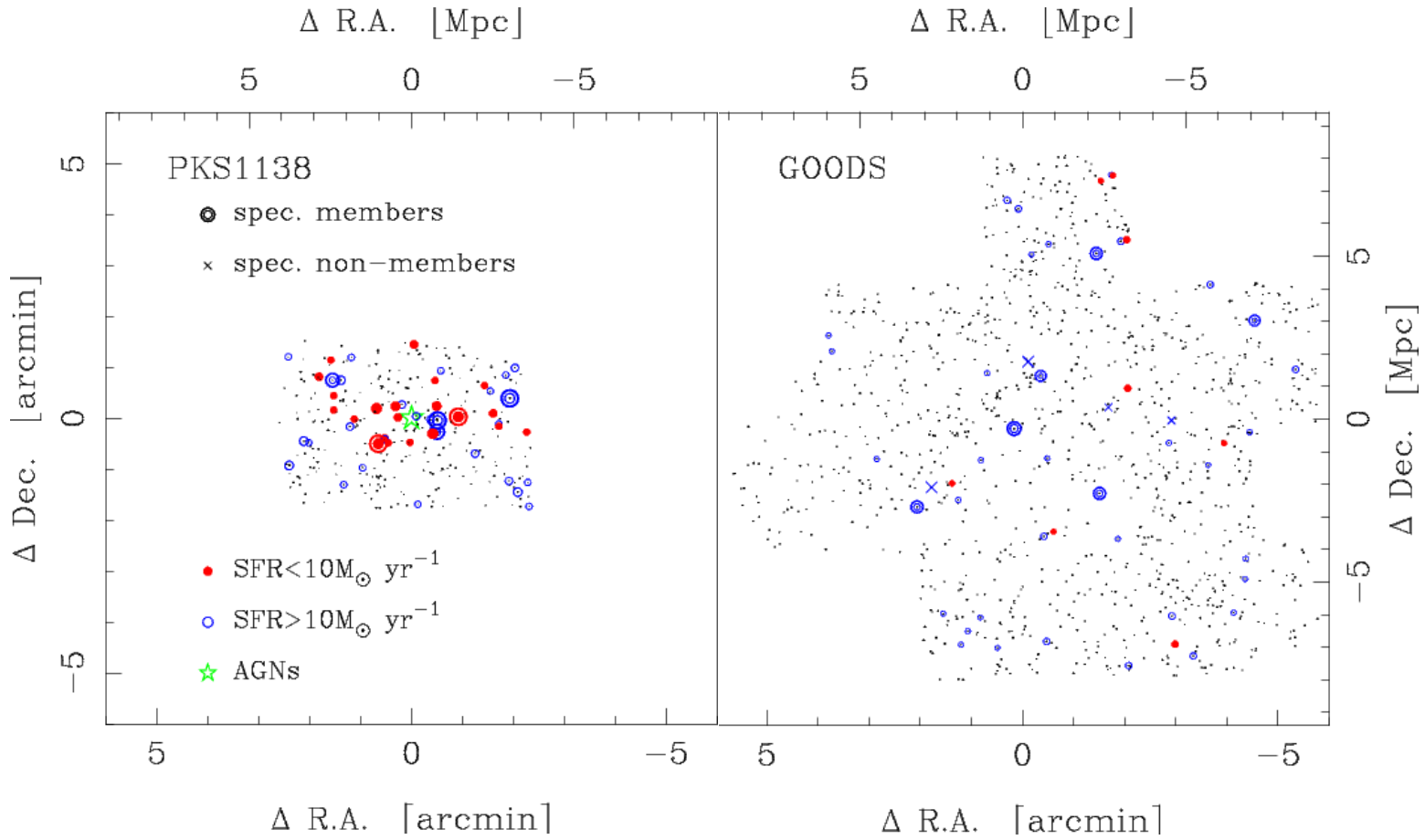
- is a powerful radio galaxy
- has several lines of evidence for galaxy over-density around it
- is one of the most promising (proto-)clusters at z>2

outline

6 – forming clusters at z=2

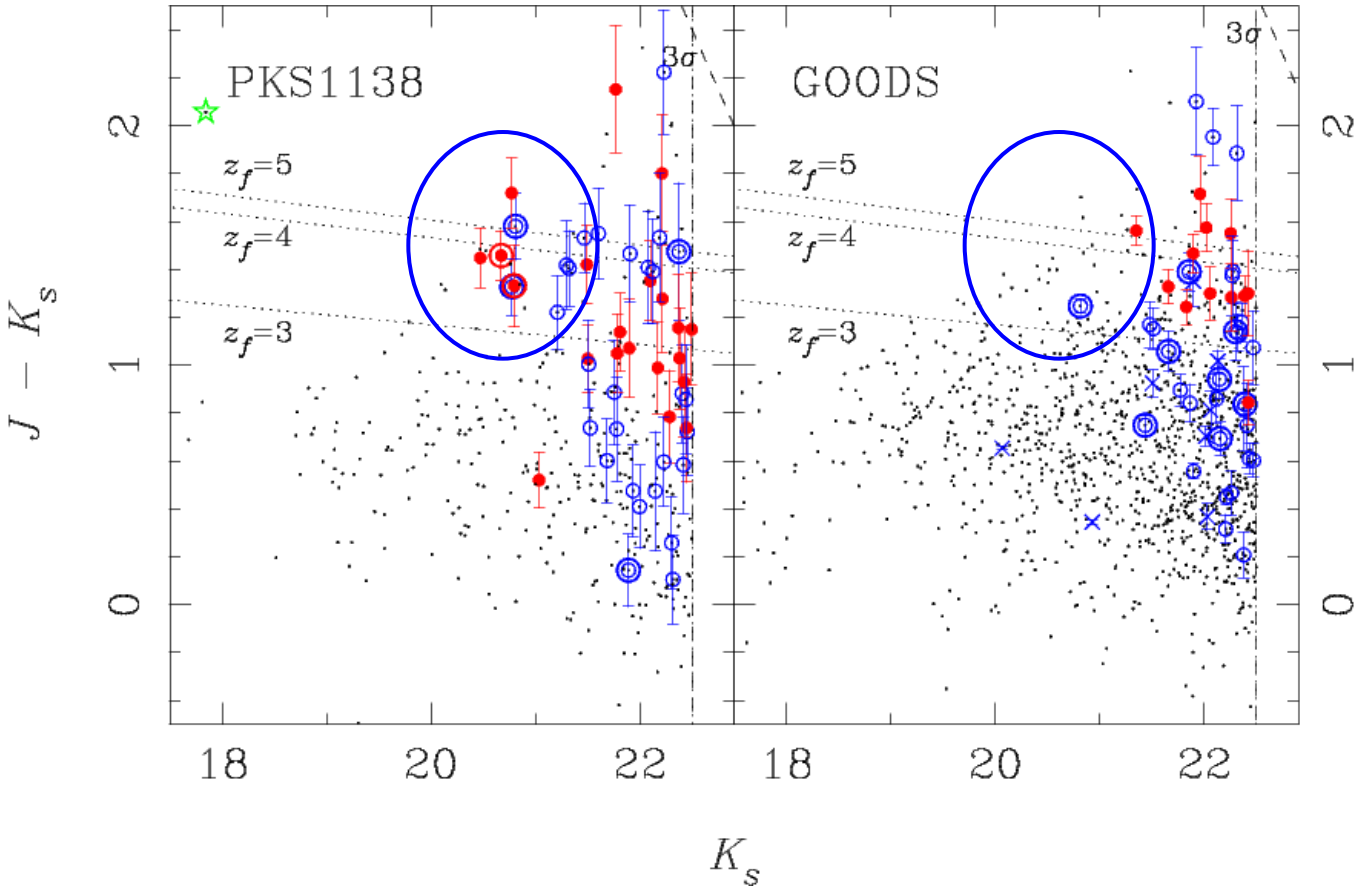
PKS1138 at z=2.15

Galaxy distributions at z=2.15



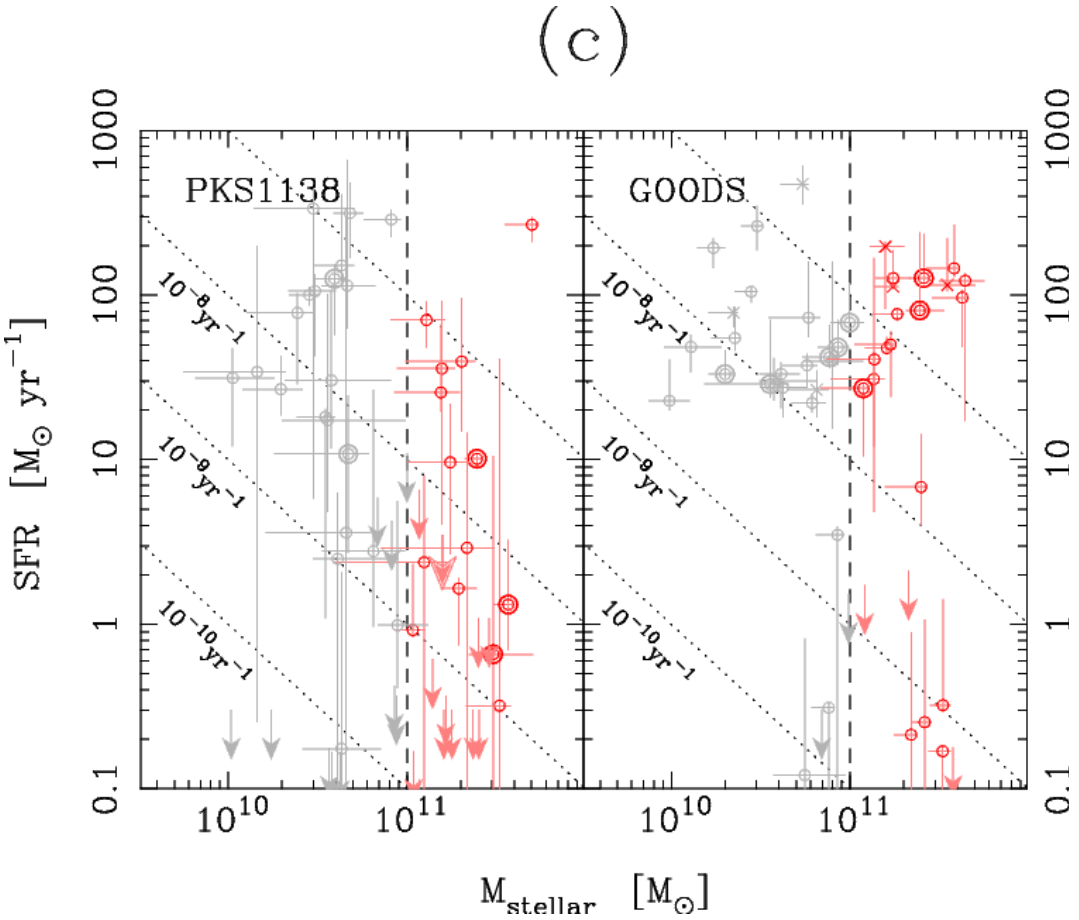
A factor of >10 over-density around the vicinity of the radio galaxy.

Color-magnitude diagrams



PKS1138 is likely a forming cluster.

*Age / tau / **SFR** / dust*



frac (SFR<10): 0.62 +- 0.20 0.29 +- 0.13

At z~2, we observe galaxies with lower star formation rates in higher density environments, where we see clearer red sequence.

This is a qualitatively similar trend to what we observe locally.

Some galaxies are dying in forming cluster. Maybe the environmental dependence partly comes from initial conditions of galaxy formation…?

7 – Summary

Summary

- Galaxy properties depend on environment at z=0. More red early-type galaxies in higher density environments.

- We observed the build-up of the red sequence, i.e., the formation of the environmental dependence.

- The environmental dependence is already partly in place in forming clusters at z=2.15.

- The dependence may partly originate from initial conditions of galaxy formation.