The effect of environment in the early Universe: a comparison of protocluster and field galaxies at $z \sim 2$

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WHEN DOES ENVIRONMENT BEGIN TO AFFECT GALAXIES?

Need:
- a clean sample of protocluster galaxies
- a similarly selected field sample

Perform a NB survey targeting Hα emitters.
NOT CLUSTERS

Spiderweb Protocluster at z=2.2

Mass = $2 \times 10^{15} \text{ M}_\odot$ IF virialised $\rightarrow$ 4 x more massive than allowed by $\Lambda$CDM

Mortonson et al. (2011)

Predicted X-ray = $6 \times 10^{44} \text{ erg/s}$
Observed X-ray $\sim 1.5 \times 10^{44} \text{ erg/s}$ (Carilli et al. 2002)

Kuiper, NAH, et al. (2011)
SAMPLES

7.5' x 7.5'

UDS

COSMOS

GOODS-S

total area = 172 arcmin²

4C+10.48 (z=2.35)

2.5' x 2.5'

Spiderweb protocluster
(z=2.16; Kurk 2004)

2x 2.5' x 2.5'
SELECTING Hα EMITTERS

Hα emitters selected in exactly the same way in ALL fields
Emission line contaminants

- $P_\alpha$ at $z=0.15$
- [Fe II] at $z=0.34$
- $P_\beta$, $P_\gamma$....
- $[OIII]$ at $z=3.37$
- $H\alpha$ at $z=2$

- 55% of control field candidates are contaminants
- Surface density of contaminants $= 0.13 \text{ arcmin}^{-2}$
- <1 interloper in 4C+10.48 field
- <2 interlopers in Spiderweb

BzK criteria (Daddi et al. 2004)

- $z > 1.4$
- $z < 1.4$

LBG criteria (Steidel et al. 2003)

- $z > 3.1$
- $z < 3.1$
DISTRIBUTION OF HAES

- <1 interloper in 4C+10.48 field & <2 interlopers in Spiderweb
- less than 10% of candidates in protocluster fields are contaminants.
NUMBER DENSITY

Spiderweb and 4C+10.48 have very similar densities
13x more Hα emitters
COMPARING PROTOCLUSTER AND FIELD GALAXIES

• ~25 field galaxies
• ~35 protocluster galaxies

Hatch et al. (2011b) arXiv:1103.4364
$H\alpha$ LUMINOSITY FUNCTION

![Graph showing the $H\alpha$ luminosity function with field and protocluster data points.](image)
**Hα Luminosity Function**

- SFR of star forming galaxies is not affected by environment
  
  KS test 97%
  
  see also Tanaka et al. 2011; Tadaki et al. 2011
  
  and talks by Koyama & Hayashi
• SFR of star forming galaxies is not affected by environment

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• SFR of protoclusters = \( \rho \cdot \text{SFR(field)} \times 13 \cdot \text{Volume} \)

SFR of protoclusters \( \sim 3000 \, \text{M}_\odot/\text{yr} \) (1.5 Mpc)
Most protocluster galaxies are blue
Most protocluster galaxies are blue.

Galaxy colour is similar.
REST-FRAME R LUMINOSITY

protocluster

field
REST-FRAME R LUMINOSITY

KS test gives $P = 0.05$

![Graph showing luminosity distribution with labels for protocluster, field, and field x1.3.]
Star forming PC galaxies are 0.8 mag brighter than field galaxies.

- Star forming PC galaxies are 2 x as massive as field galaxies.
- Cluster galaxies always differed from field galaxies.

Similar results found in other studies: Steidel et al. (2003); Kuiper et al. (2010)
CONCLUSIONS

Environment does matter at $z > 2$

• No effect on SFR (of SF galaxies)
  - Total SFRs of protoclusters $\sim 3000 \text{M}_\odot/\text{yr}$

• Mass function of protocluster and field galaxies differ
  - Protocluster galaxies are twice as massive as their field counterparts