The rise of galaxy groups in the Carnegie-Spitzer-IMACS (CSI) redshift survey

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Another redshift survey, why!?

• Which environments matter for building the quiescent galaxy population at $z<1$?
  • Connection between decline in cosmic SFRD and growth of structure?

• Addressing this question requires a survey with…
  • **High quality redshifts** - link galaxies into groups
  • **Large area** - sample massive halos at low number density
  • **Low stellar mass limits** - account for bulk of stellar mass
CSI’s area and IRAC selection \(\rightarrow\) large volume, and low stellar mass limit compared to optically-selected spectroscopic surveys.
15 sq. deg over 3 CSI fields: ELAIS-S1, CDFS, XMM-LSS
Multiplexing with **IMACS prism** spectroscopy

Popular observing mode for environmental studies: Patel+09ab,+11,+12, PRIMUS, EDisCS, etc.
Groups in CSI

- Group catalogs with FoF
- Produced mock catalogs to characterize completeness and contamination in group finder
Groups in **CDFS**: $M_{200}$ from deep X-ray imaging

M$_{200}$ from Finoguenov+15

Patel et al. 2015
Stellar mass - halo mass relation

(a) 0.5<z<1

Slope:
CDFS+COSMOS: 0.84
+GCLASS: 0.72

M_{200} from Finoguenov+15

Patel et al. 2015
Evolution in the **stellar mass density**

![Graph showing the evolution of the stellar mass density](image)

- Factor of ~2 growth for galaxies above log \(M/M_\odot > 10.5\) since \(z \sim 1\)

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**Figure 65** (top) shows the distribution of high-quality CSI redshifts for galaxies with stellar masses \(1 < M/M^* < 2\) and \(1/2 < M/M^* < 1\). (A color version of this figure is available in the online journal.)

- Open circles come from Ilbert et al. (2010)
- Open triangles are derived from the mass functions of Pozzetti et al. (2010)
- Filled triangle at \(z = 1\)
- The large filled circles at \(z = 2\) reach out to \(\sim 1\) (orange thick line)

**Figure 66** (bottom) dissects the sample into two stellar mass bins. The points are the same as in (top), and the agreement with these past results is generally good. Above these redshifts, the flux limits explicitly exclude galaxies from the selection and respectively; these limits are shown as hatched regions with the respective color. Above these redshifts, the faint optical magnitude limit of the current analysis cuts the sample.

- Open squares derive from the mass functions of Brammer et al. (2010)
- Solid squares at \(z = 1\)
- Closed circles at \(z = 2\)

**Figure 67** shows approximately Factor of \(~2\) growth for red galaxies (the hatched regions tracing the thick solid line; Marchesini et al. 2013)

- Closed triangles at \(z = 1\)
- Solid triangles at \(z = 2\)

**Figure 68** illustrates the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

**Figure 69** illustrates the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

**Figure 70** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

**Figure 71** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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We conclude our discussion of the survey by presenting a broad overview of the CSI sample. Using the sample directly we can estimate the completeness functions derived earlier, we can estimate that the magnitude density if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 1** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 2** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 3** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 4** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 5** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 6** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 7** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)

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**Table 8** shows the relative insensitivity of our redshift errors on spectral type (or line-of-sight linking lengths) encompass both red and blue densities if care is not taken to ensure that velocity windows are not correlated with spectral type will bias estimates of local galaxy properties as a function of environment.

- Closed circles at \(z = 1\)
- Solid circles at \(z = 2\)
Evolution in **stellar mass density** for different halos

- SDSS points from Baldry +12 and Moustakas+13

**Preliminary!**
Evolution in **stellar mass density** for different halos
Evolution in **stellar mass density** for different halos

- **Hierarchical growth**: stronger evolution for more massive halos
- **Factor of ~2** growth in stellar mass in groups above $\log M_{200}/M_\odot > 13.4$ over $0.25 < z < 1$
- **Fraction of overall stellar mass density increase occurring in groups**: $\sim 20\%$

Preliminary!
Quiescent galaxies

- Factor of ~2.5 growth over 0.25<z<1
- Accounts for ~75% of overall stellar mass density growth since z=1
Preliminary!

**Quiescent galaxies**

- More gradual increase for QG mass density in groups: ~40% over 0.25<z<1, accounting for only 10% of the overall growth in QGs

- More of the overall QG mass density growth since z=1 occurs in lower mass groups and/or field!

- Dominant quenching mechanism(s) operate in those environments
Summary

• Carnegie-Spitzer-IMACS (CSI) Redshift Survey
  • Infrared selection for spectroscopy (IRAC 3.6 μm)
  • Magellan IMACS prism spectra for ~120,000 galaxies over 15 deg²
  • $\sigma_z/(1+z) \approx 0.01$ to $z=1$

• Key take away points
  • Factor of ~2 growth in stellar mass density in groups above $\log(M_{200}/M_\odot) > 13.4$ since $z=1$: accounts for ~20% of global stellar mass density growth
  • Most of the QG stellar mass density growth occurs in lower mass groups and/or the field at $z<1$

• Looking ahead
  • 2 more CSI fields (ELAIS-S1, CDFS) - will triple the current analysis area
  • SFRs from [OII], mid-IR: group contribution to cosmic SFRD