The Decline in Cosmic Star Formation: Is Environment to Blame?

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with

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1 Outline

There's been a lot of development recently in understanding how galaxies interact with their environment. In this talk I want to review some results derived from the SLOAN and 2dF-grs redshift surveys. Clearly the next step is to make a similar study at high redshift. With collaborators in Carnegie and Durham, I have been studying the properties of galaxy groups at z=0.4. I'll give a brief preview of some of the results, and then go on to consider how we could build an equivalent study with FMOS.

By studying the interaction between galaxies and their environment, and by studying how this evolves with redshift we can observationally determine how the present day properties of galaxies are shaped. In particular, we can determine whether the catastrophic down-turn in the global average star formation rate is driven by the growth of large scale structure or by evolution in the internal properties of galaxies (for example the consumption of their gas reservoir).

Some credits: the key people in the Sloan/2df-grs were Mike Balogh, Vince Eke, Chris Miller and Bob Nichol. Our work on the CNOC2 groups is down to a collaboration with Dave Wilman and MB in Durham, Ray Carlberg in Toronto and John Mulchaey and Gus Oemler at OCIW. The field study with which we compare is being led by Richard Wilman and Simon Morris at Durham.

2 Recent Results from the SLOAN and 2dF-GRS

We have made a joint analysis of 24968 galaxies selected from the SDSS and 2dFGRS, looking at how galaxy properties vary with environment (Balogh et al., 2004). The distribution of $EW[H\alpha]$ among these galaxies is bimodal, consisting of an active population of galaxies with $EW[H\alpha]> 4$ Å, and a quiescent population with no significant star formation at the present day (Fig 1). We use several different measures of environment to establish the scales and structures on which the present-day galaxy population depends. Our findings are best summarised as follows:

1. The distribution of Hα line strength for the star-forming population, selected on $EW[H\alpha]$ or $(g-r)$ colour, does not itself depend strongly on

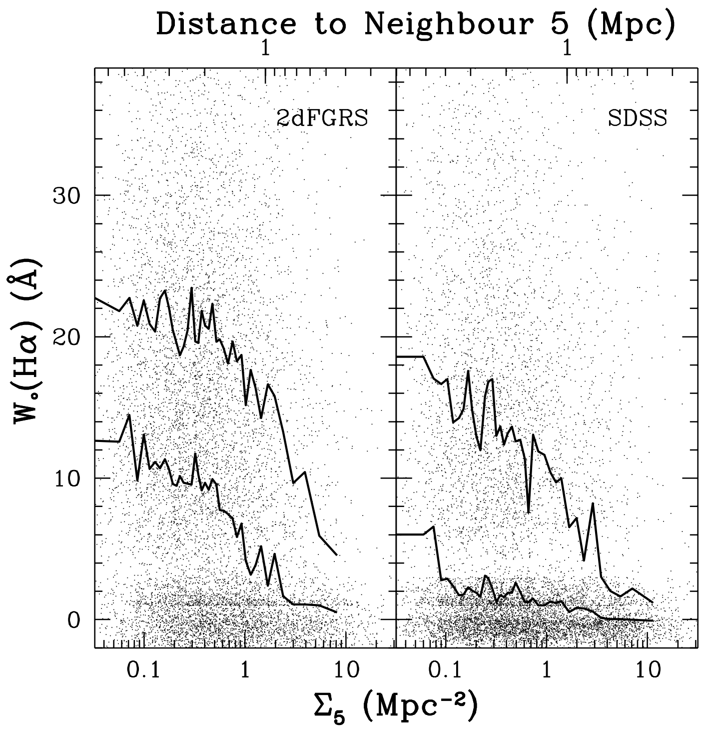

Figure 1: The dependence of $EW[H\alpha]$ on projected, local density for the 2dFGRS *(left panel)* and SDSS *(right panel)* samples. The top axis shows the distance to the 5^{th} nearest neighbour, from which Σ_5 is computed. The *solid lines* show the median and 75th percentile of $EW[H\alpha]$, in bins of 100 galaxies. Although we only plot the data for $EW[H\alpha]<$ 40Å, they extend to $EW[H\alpha]\sim$ 100Å. The Hα distribution is strongly bi-modal so that the factor that varies most between environments is the fraction of galaxies with active star formation.

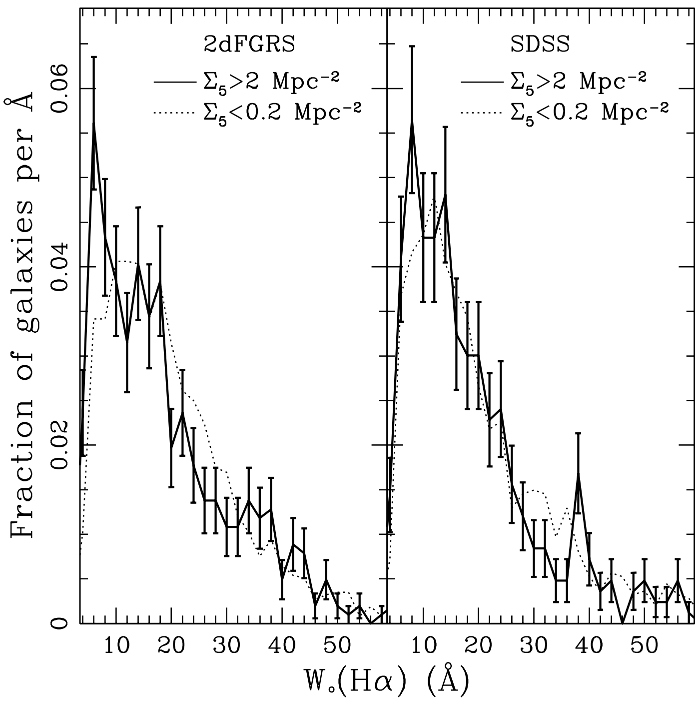

Figure 2: The $EW[H\alpha]$ distribution for galaxies in the 2dFGRS *(left panel)* and SDSS *(right panel)* with $EW[H\alpha]> 4$Å, in low-density environments ($\Sigma_5 < 0.2$ Mpc^{-2}, *dotted line*) and high-density environments ($\Sigma_5 > 2$ Mpc^{-2}, *solid line*). We show Poisson-distributed error bars on the high-density subsample, which is the smaller of the two. The distribution of star formation rate among these galaxies varies little between the two environments.

environment (Fig 2. Thus, it is unlikely that SFRs are gradually decreasing in a substantial number of star-forming galaxies in or near dense environments today.

2. The fraction of galaxies with $EW[H\alpha]> 4\text{Å}$ decreases steadily with increasing local density (Fig **??**). There is evidence that it decreases more strongly at densities exceeding $\Sigma_5 \sim 1$ Mpc^{-2}, or $\rho_{1.1} > 0.05$ Mpc^{-3}. The persistence of this correlation at low densities means that ram–pressure stripping, at any redshift, cannot be the dominant physical mechanism at work.

3. The fraction of galaxies brighter than $M^* + 1$ with $EW[H\alpha]> 4\text{Å}$ is never more than ~ 70 per cent, even in the least dense environments explored here. We have shown that this means the recent decline in globally-averaged star formation rate cannot be wholly due to the growth of large scale structure.

4. The emission-line fraction of a galaxy population appears to depend both on the local environment (on $\sim$ 1 Mpc scales) *and* on the large-scale structure as parameterised by the density ~ 5.5 Mpc scales. There is little further dependence on the velocity dispersion of the group or cluster in which the galaxy is embedded. This result suggests that the composition of the galaxy population today is likely related *indirectly* to its present environment.

The most likely physical explanations for the correlation between $EW[H\alpha]$ distribution and environment at $z = 0$ are those which are effective over a large range of environment, affect the SFR on short ($<$ 1 Gyr) timescales, and were much more effective in the past. As suggested by previous authors, one good candidate is starbursts induced by galaxy interactions, since close pairs of galaxies are the only environment known to directly provoke a physical transformation. Such interactions will likely be more common at high redshift, and will have had more time to influence galaxies that end up in high density environments.

3 Towards Higher Redshifts: groups at $z \sim 0.4$

Using the Magellan telescope, we have been able to study the properties of galaxies in groups at $z \sim 0.4$. The initial group catalogue was constructed from the CNOC2 survey by finding galaxy overdensities in redshift space (Carlberg et al., 2001). Using Magellan we have filled in the missing galaxies and extended the measurements to fainter luminosities. This data-set allows us to measure how the properties of galaxies in groups evolve with redshift.

We first compare the fraction of galaxies with $EW[OII]$ greater or less than $5\dot{A}$. Figure 3 shows us that in all samples, the fraction of passive galaxies ($EW[OII] < 5\dot{A}$) is a strong function of luminosity with fainter galaxies far

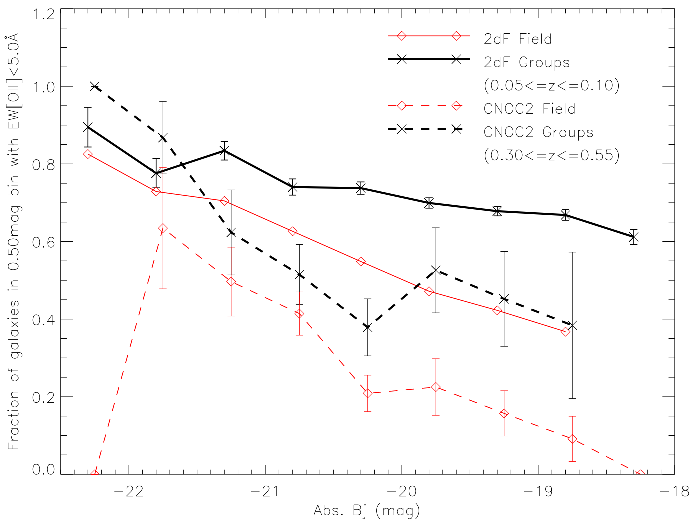

Figure 3: Fraction of galaxies with EW[OII]$< 5\dot{A}$ in the CNOC2 groups and field (at $z \sim 0.4$). We compare this with equivalent local data from the 2df-GRS. The fraction of non-star forming objects is plotted as a function of rest-frame Bj luminosity. The Figure that the fraction of passive galaxies is much greater at low redshift than in equivalent environments at $z \sim 0.4$. This is true for galaxies in both the field and in groups.

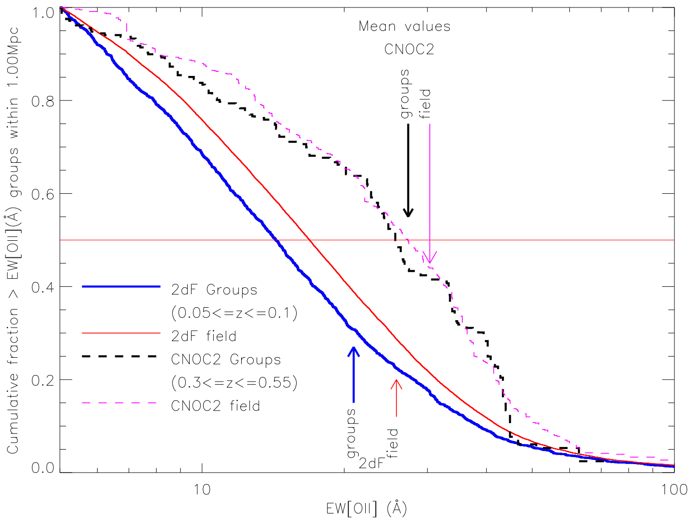

Figure 4: Cumulative distributions of EW[OII] of the field and group galaxies in 2dF ($0.05 \leq z \leq 0.1$) and CNOC2 ($0.3 \leq z \leq 0.55$) samples, in log space. The arrows indicate the mean values of EW[OII] for star forming galaxies in each sample. There is some evolution in the average star formation rate among the active population, but the overall evolution in the volume averaged star formation rate is dominated by the change in the relative fraction of active and passive galaxies.

more likely to be star forming than their brighter cousins. The crucial point, however, is that this fraction is significantly greater in the galaxy groups than in the field at both low and intermediate redshift (right across the luminosity range investigated) and that this fraction is strongly redshift dependent. Both the field and the galaxy groups show a similar trend for a decreasing fraction of passive galaxies at higher redshift.

Figure 4 looks at the properties of the star forming population with $EW[OII] > 5\dot{A}$. We'll refer to these as the 'active' galaxies. The figure shows the cumulative distribution of EW[OII] in star active galaxies in the 2dF and CNOC2 group and field samples. At $z \sim 0.4$, the distribution shows a definite enhancement in highly star forming galaxies ($EW[OII] > 30\dot{A}$) relative to the 2dF galaxies in both groups and the field. The average values for each sample are indicated by the arrows in figure 4. It is clear that whilst the shape of the EW[OII] distribution is clearly evolving, the average value is relatively insensitive to this evolution.

4 Prospects for FMOS

The FMOS instrument will offer us a powerful opportunity to extend this analysis to higher redshifts. This will provide us with crucial data point covering the range $1 < z < 2$, the epoch when most of the stars in the universe are formed. This will allow us to compare the properties of galaxies as a function of environment between this epoch, intermediate redshift and the local universe. We can imagine a number of outcomes. For example, are the average star formation rates enhanced over the present-day galaxies in similar environments? Do groups still have lower star formation rates than the field, or do the interactions between galaxies actually promote star formation? If so, how and why?

What we should aim for is a large, comprehensive survey. Our experience with the SLOAN and 2dF data-set has given us an unprecedented, clear view of galaxy properties in the local universe. Large numbers of galaxies are essential if we are to analyse galaxies in a multi-dimensional space of redshift, luminosity and environment. They also allow us to build representative samples of rare objects such as star burst galaxies. A large survey of galaxies at $1 < z < 2$ can give us the same clarity of vision at the most crucial epoch in the history of the universe.

Bibliography

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