Gas flows in galaxies: mergers versus bars.

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How galaxies respond to their environments

High density (Abell 1689)  Low density (NGC3190)
How galaxies respond to their environments

Classic morphology density relation as shown by Dressler et al. (1980).
Larson & Tinsley (1978) showed that `peculiar’ galaxies in the Arp catalogue have a larger colour scatter, with a trend towards bluer colours than `normal’ galaxies in the Hubble atlas.
Metal-poor gas flows to galaxy centre and triggers star formation. Star formation is accompanied by dilution of metallicity in galaxy centre before eventual enrichment.

Simulation by Paul Torrey, in Scudder et al. (in prep).
The dataset and tools of the trade

~ one million galaxies in the SDSS DR7. From the image catalogue: colours, bulge fractions, asymmetries and local densities.

~ 700,000 galaxies with spectra in the SDSS DR7: redshifts, line fluxes, stellar masses, metallicities, SFRs, dust extinction, Lick indices, AGN classification.
DR7 pairs sample: Projected separation <80 kpc and $V < 300$ km/s, Mass ratio 0.1 - 10.

Yields: ~16,000 pair galaxies, plus x10 matched control.
Several improvements made to SDSS photometry, which tends to give colours that are too red in crowded environments:

- Sextractor deblending
- Local sky determination
- Simultaneous \( r+g \) fits

Public catalog available: Simard et al. (2011)
Poor background determination can lead to extended disks:

Simard et al. (2011)

Poor object definition leads to spuriously red colours:
Divide galaxies into “blue”, “red” and those that are extreme. Construct a control sample that is matched in mass and redshift.
Red pairs slightly redder than control, likely due to environment.

Blue galaxies get bluer than their controls at small separations, dominated by changes in their central regions: star formation is nuclear. 

Patton et al. (2011)
Fraction of pairs with extreme colours vs. separation.

Patton et al. (2011)

Excess of extremely blue galaxies at close separations .....
Improved photometry is crucial for close pairs!

Patton et al. (2011)

....... but previously reported excess of very red galaxies was spurious.
Star Formation Rates

Early results from DR4. SFRs as function of projected separation and mass ratio.

SFR enhancement significant within 40 kpc.

Highest enhancements in major mergers.

Possible enhancement at wide separations.

Ellison et al. (2008a)
High SFRs at wide separations confirmed with larger sample → SFRs stay high out to at least 80 kpc.

Scudder et al. (in prep)
In addition to mass ratio, star formation rate enhancements depend on the environment of the pair.

Pairs in regions of high density (log $\Sigma < -0.55$) show no enhancement in star formation, whereas pairs in low density environments show a factor of $\sim 2$ enhancement in SSFR.

Ellison et al. (2010).
Bluing of bulge colours is also confined to low densities, but pairs in both low and high densities are more asymmetric. Ellison et al. (2010)
Metal-poor gas flows to galaxy centre and triggers star formation. Star formation is accompanied by dilution of metallicity in galaxy centre before eventual enrichment.

Simulation by Paul Torrey, in Scudder et al. (in prep).
The (luminosity) mass-metallicity relation

Luminosity

Metallicity ($Z$) vs. $12 + \log(O/H)$

LZR

Stellar mass

Metallicity ($Z$) vs. $\log(M_*)$

MZR

Tremonti et al. 2004
The stellar-mass-metallicity relation shows a much smaller offset than the LZR, indicating that changes in metallicity only account for about 50% of the shift. I.e. the offset in the LZR is caused by both lower metallicities and brighter magnitudes.

Ellison et al. (2008a)
Metallicity dilution goes hand-in-hand with SFR enhancement. Agreement with simulations (Scudder et al. in prep).
Ellison et al (2008b) found that (at fixed mass) higher SFR galaxies had lower metallicities. Mannucci et al (2010) extended this to the “fundamental metallicity relation”.
In addition to changes in star formation and metallicity, expect that gas inflows may trigger AGN: find up to 2.5 times more AGN in close pairs. Ellison et al. (2011b).
In addition to the expected increase in star-forming fraction, and our detection of increase in AGN fraction, we find the biggest increase is in the fraction of composite galaxies.
Fraction of double AGN is twice what we would expect from a random occurrence.

Calculate what fraction of the double AGN can be accounted for from a random occurrence and hence what fraction are correlated. Excess of correlated pairs at small separations: SYNCHRONIZED AGN TRIGGERING.

Ellison et al. (2011b).
Two main mechanisms for gas inflow to galactic centre to trigger star formation.

- **Galaxy-galaxy mergers** (e.g. the mice)
- **Galaxy bars** (e.g. NGC 1300)
311 visually selected bars with z<0.1, g<16 from DR4 spectroscopic sample (Nair & Abraham 2010).
Metallicities in barred galaxies

Barred galaxies more metal-rich at all masses. Bars sufficiently long lived to show enrichment, even after SF.
Star formation rates in bars

60% enhancement in fibre SFR in barred galaxies with \( \log M > 10 \ M_\odot \).

Ellison et al. (2011a)
Mass of $10^{10} \, M_{\text{sun}}$ corresponds to morphological transition

Low mass bars are mostly late-types (Sc and Sd)

High mass bars are mostly early-types (SO-Sb)

Nair & Abraham (2010)
\[ \epsilon_{b/p} > 3, \text{ i.e. at least 3 times more central star formation comes from bars than pairs.} \]

Ellison et al. (2011a)
Summary

• Powerful dataset - large size, imaging and spectroscopy with improvements in SDSS photometry (which otherwise lead to spurious results). Public catalogue of all DR7 GIM2D photometry.

• Pairs of galaxies in all environments may show signs of interaction, but triggered star formation is strongest in blue galaxies/low density environments/equal mass pairs. Star formation is centrally located.

• Galaxies in pairs have low metallicity for their mass due to gas inflows. Offsets in both metallicity and SFR persist out to at least 80 kpc.

• Mergers trigger AGN (factor ~3 enhancement), and the triggering can happen in both galaxies simultaneously.

• Barred galaxies also have enhanced SFRs, but (in contrast to pairs) their metallicities are also enhanced. The abundance of barred galaxies means they contribute ~3 times more to additional central star formation.