The Role of Tight Interactions in the Evolution of Galaxies

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Overview

- Tight interactions between galaxies provide unique insights into the processes which drive galaxy evolution
- I will focus on how galaxy properties are affected by ongoing or relatively recent tight interactions, such as:
 - star formation rates
 - morphologies
 - > metallicities
 - AGN fractions and accretion rates
 - > gas fractions
- I will not address the separate issue of the rate at which galaxies interact or merge
 - but stay tuned for talks this afternoon by Allison Man and Carlos López-Sanjuan

The Antennae (NGC 4038/4039)

NGC 4038-4039 • Antennae Galaxies



Hubble

Early Indications of Enhanced Star Formation in Interacting Galaxies



Larson and Tinsley (1978)





Paul Torrey Dave Patton Sara Ellison Trevor Mendel Jillian Scudder



Predictions From Simulations: Three Regimes

- 1) first infall
 - > no SFR enhancement (interaction has had no effect yet)
 - > some of these pairs are quite close
- 2) between first and second pericentre
 - moderately enhanced SFR
 - > pair separations range from very small to > 100 kpc
- 3) coalescing
 - strongly enhanced SFR
 - pair separations are small



Evidence for Enhanced Star Formation from Galaxy Pairs in Redshift Surveys



Close Galaxy Pairs in SDSS

-0.502	-0.435	-0.431	-0.417	-0.416
J163544.26+272912.7	J001828.3-003410.4	J084422.55+045509.6	J112546.79+470000.3	J132605.68+174953.4
-0.401	-0.393	-0.390	-0.387	-0.386
J152056.58+454305.2	J084950.41+452813.2	J113715.07+444611.9	J132423.52+652424.8	J130515.01+045227.3
-0.383	-0.382	-0.378	-0.371	-0.366
J132661.27+263528.4	J121554.48+263947.6	J120707.05+020351.7	J090823.32+195827.2	J135429.05+132757.2
-0.354	-0.354	-0.351	-0.342	-0.335
J102626,79+103918.8	J112957.8+545012.9	J171042.48+300053.3	J015808.07-090851.7	J130355.92+145425.9
-0.330	-0.329	-0.327	0.317	-0.310
J120924.63+324402	J095343.89-000524.6	J083101.79+040314.9	J124545.2+010447.5	J170437.26+603512.4

Patton et al. (2011)

Control Sample: Matching on Galaxy Type

- Many galaxy properties (e.g. SFR) depend strongly on stellar mass and redshift
- We therefore match each paired galaxy to a set of control galaxies, matching on stellar mass and redshift



Control Sample: Matching on Environment

- > Many galaxy properties also depend on environment
- > We therefore also match on:
 - N₂: the number of companions within 2 Mpc, 1000 km/s, and a stellar mass ratio within 1:10
 - > r_2 : the distance to the paired galaxy's 2^{nd} closest companion
 - \succ r₂ is matched to the control galaxy's closest companion



Enhanced Star Formation in SDSS Pairs



Comparison with Simulations



Centrally Enhanced Star Formation in SDSS



Patton et al. (in prep)

A Clearly Interacting Wide Pair

SFR enhanced by 5.6x

AGN

Separation: 91 kpc

Asymmetries

- Morphological disturbances provide a useful tool for confirming interactions and mergers
- Metrics include the following:
 - visual classification (by experts, Galaxy Zoo, etc.)
 - > asymmetry (e.g. Conselice et al. 2003)
 - ➢ Gini-M₂₀ (e.g. Lotz et al. 2008)
 - > presence of tidal tails (e.g. Bridge et al. 2007)
 - > shape asymmetry! (Milena Pawlik's talk this morning)
- Applying these metrics to samples of galaxy pairs has proven to be particularly effective
 - dependence on pair separation provides a truth test
 - comparison with control samples allows one to address visual bias, projection effects, poor de-blending, etc.

Earlier Results on Asymmetry in Pairs



de Propris et al. (2007)



Ellison et al. (2010)

Recent Results From GAMA



Casteels et al. (2014)

Recent Results From SDSS



Qamar et al. (in prep.)

A Low Bar Fraction for Galaxy Zoo 2 Pairs



Casteels et al. (2013)

Morphologies of Pairs in Galaxy Zoo 2



Casteels et al. (2013)

How do Interactions Influence the Mass-Metallicity Relation?



Tremonti et al. (2004)

Scudder et al. (2012)

The LZ and MZ Relation for Pairs





Ellison et al. (2008)

Metallicity Dilution in Pairs



Scudder et al. (2012)

Shallower Metallicity Gradients in Pairs





Kewley et al. (2010); see also Deise Rosa's poster

Do Interactions Trigger AGN?



Figure 1. The BPT diagram for control galaxies with strong emission lines. Black curves indicate the demarcation lines given by K01 (upper line), K03 (middle line) and S06 (lower line), see equations (1)–(3). Galaxies are colour coded for easy distinction: star forming (blue), composite (green) and AGN (red). QSOs not present in the MPA/JHU line flux catalogues are excluded from this figure.

Ellison et al. (2011)

Close Pairs and Post-mergers in SDSS

-0.502	-0.435	-0.431	-0.417	-0.416
J163544.26+272912.7	J001828.3-003410.4	J084422.55+045509.6	J112546.79+470000.3	J132605.68+174953.4
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587738947747053602	587732484342415393	588848900971888657	587725551741370430	587738409785557168
J101833.64+361326.6	J084344.98+354942	J094711.78+004209.6	J093551.6+612111.3	J093347.41+104842.3
				. 6
587736543096799321	587734948595236905	587732484897964080	567735666377949228	587741603112157297
J150517.88+080812.7	J104103.74+110546.2	J123040.3+510814.3	J134442.16+555313.5	J132505.73+273243.3
587725550135214193	587735967454247018	\$87728032776265859	587736580047914003	588017720639029387
J110213.01+645924.8	J142459.77+543106.2	J103631.87+022144	J155517.83+290621.2	J110654.44+404755
587726031175221368	587735349633351728	587739720296628334	567722983883407448	587732470387703859
J120359.57+012439	J095312.32+130803.4	J135831.05+272326.8	J112154.61+003344.8	J083818.43+333441.3
587732580977410186	588017605220171808	597739707951808602	588010880378404942	587741533323526200
J100049.35+534855.6	J120613.46+452001.3	J151151.35+230903.7	J131957.86+054828.3	J113507.51+295327.7
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Close galaxy pairs (Patton et al. 2011) Post-mergers (Ellison et al. 2013)



Obscured AGN in Pairs and Post-Mergers



Satyapal et al. (2014)

Enhanced AGN Accretion

optical

infrared



Satyapal et al. (2014)

Ellison et al. (2013)

Relating Star Formation and Gas



Saintonge et al. (2012)

HI Gas in SDSS Pairs and Post-mergers



Ellison et al. (submitted); see also Fertig et al. (submitted)

The HI Gas Fraction in Isolated Dwarf Pairs



Stierwalt et al. (in prep.)

Conclusions

- Galaxy pairs provide a sensitive probe of the influence of ongoing/recent tight interactions between galaxies
- Compared with their more isolated counterparts, interacting galaxies tend to have
 - enhanced central SFRs
 - increased asymmetries
 - diluted nuclear metallicities
 - higher AGN fractions and accretion rates
 - > similar HI gas fractions
- > Little is known about all of this at higher redshifts
- Much can be learned from comparison with and interpretation of cosmological hydro simulations
 - ➢ e.g., Illustris, Eagle