The Starburst–AGN Connection
ASP Conference Series, Vol. 408, © 2009
Weimin Wang, Zhaoqing Yang, Zhijian Luo, and Zhu Chen, eds.

Interactions, Star Formation, and AGN Activity

Cheng Li

Max Planck Institut für Astrophysik, Karl-Schwarzschild-Strasse 1, 85748 Garching, Germany

MPA/SHAO Joint Center for Astrophysical Cosmology at Shanghai Astronomical Observatory, Nandan Road 80, Shanghai 200030, China

Abstract. We study the correlation of tidal interactions with star formation and AGN activity in galaxies using data from the Sloan Digital Sky Survey (SDSS). We show that specific star formation rates of galaxies are higher if they have close companions, but the accretion rate onto the black hole is not influenced by the presence or absence of companions. This indicates that star formation induced by a close companion and star formation associated with black hole accretion are distinct events. These events may be part of the same physical process, for example a merger, provided they are separated in time. In this case, accretion onto the black hole and its associated star formation would occur only after the two interacting galaxies have merged.

1. Introduction

Numerical simulations have demonstrated that interactions between galaxies can bring gas from the disc to the central regions of the galaxy, leading to enhanced star formation in the bulge. This has been known for more than thirty years and has been proved by many previous studies, both theoretical and observational.

Accretion of matter onto the central supermassive black hole of galaxies has also been assumed in many theoretical models to be closely linked to galaxy interactions since the discovery of a tight correlation between black hole mass and bulge mass or velocity dispersion in galaxies. However, there has been little clear observational evidence in support of this hypothesis. For instance, Li et al. (2006) investigated the small-scale clustering of active galactic nuclei (AGN) selected from the Sloan Ditigal Sky Survey (SDSS; York et al. 2000), and failed to yield any evidence that AGN activity is triggered by interactions with nearby companions.

We also know from previous work (e.g. Kauffmann et al. 2003) that galaxies with powerful AGN tend to have younger-than-average stellar populations. This establishes that there is a physical connection between accretion onto the central black hole and the presence of young stars in the inner galaxy.

It is thus clear that star formation enhancement is connected both to galaxy interactions and to AGN activity, but a third connection between galaxy interactions and AGN seems missing. In a set of two papers (Li et al. 2008a,b), we have recently used a variety of statistics to study the small-scale clustering properties of a sample of 10^5 star-forming galaxies as well as a similar number of narrow-line AGN, selected from the data release 4 of the SDSS (DR4;

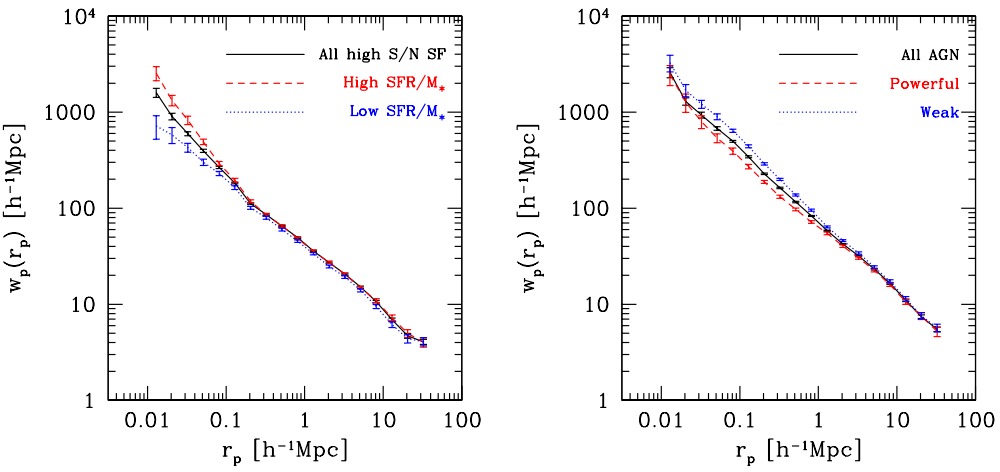

Figure 1. Projected redshift-space two-point cross-correlation functions $w_p(r_p)$ between all high S/N star-forming galaxies and our reference sample (left) and between all AGN and our reference sample (right). Different lines correspond to star-forming galaxies with different specific star formation rates, or to AGN with different accretion rates, as indicated.

Adelman-McCarthy et al. 2006). The purpose was to bring our results on star-forming galaxies and AGN together. We analyzed star-forming galaxies and AGN in exactly the same way, using the same set of statistics, and we compared and contrasted the results that are obtained for the two kinds of galaxy. We then discussed the implications of our results for understanding the connection between star formaion, AGN activity and galaxy interactions.

We present here the main results of these studies and refer the reader to Li et al. (2006), Li et al. (2008a) and Li et al. (2008b) for details.

2. Results

In Figure 1, we compare projected redshift-space 2-point cross-correlation functions (2PCCF) $w_p(r_p)$ for our sample of star-forming galaxies (left) and AGN (right), with respect to a same reference sample of galaxies drawn from the SDSS DR4. Results for the whole sample are plotted in black. Results for the 25% of galaxies with the smallest values of SFR/M_* and L[O III]/M_{BH} are plotted in blue. Results for the 25% of galaxies with the highest values of SFR/M_* and L[O III]/M_{BH} are plotted in red. The left panel shows that galaxies with high specific star formation rates are more strongly clustered than galaxies with low specific star formation rates on scales less than 100 h^{-1} kpc and that the difference in clustering amplitude increases as one goes to smaller values of r_p. The right panel shows that AGN display quite different behaviour. AGN with the highest values of the Eddington parameter L[O III]/M_{BH} are *more weakly* clustered on scales between 30 kpc and 1 Mpc. At the smallest values of r_p, the clustering amplitude exhibits no dependence on AGN power.

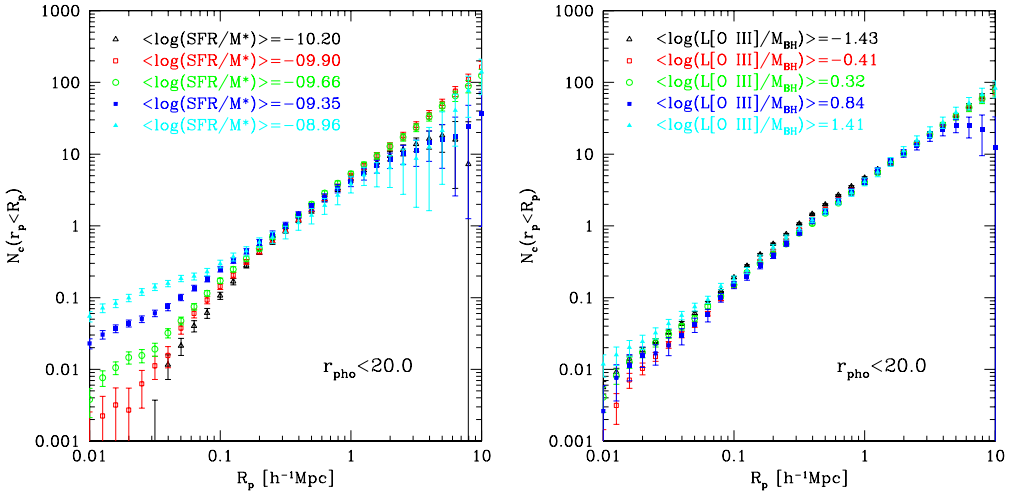

Figure 2. Average counts of galaxies in the photometric sample to an r-band limiting magnitude of $r_{lim} = 20$ within a given projected radius R_p from the star-forming galaxies (left) and from the AGN (right). Different symbols are for star-forming galaxies in different intervals of $\log_{10} SFR/M_*$ or for AGN in different intervals of $\log_{10}(L[\mathrm{O\ III}]/\mathrm{M}_{BH})$, as indicated.

We also compute the number of galaxies in a photometric reference sample in the vicinity of star-forming galaxies and AGN and we make a statistical correction for the effect of chance projections with the help of a set of 10 random samples that have the same selection effects as the reference sample. We have trimmed the AGN and star-forming samples so that they each have the same distribution in redshift and stellar mass. In Figure 2 we plot the average background-subtracted neighbour count within a given value of the projected radius R_p. Results are shown for star-forming galaxies in different intervals of SFR/M_* and AGN in different intervals of $\log_{10}(L[\mathrm{O\ III}]/\mathrm{M}_{BH})$. The photometric reference sample is always limited at r_{pho}= 20.0. We see a clear trend for an increase in the average number of close neighbours around the most strongly star-forming galaxies, but not around the most powerful AGN.

Finally, we compute the background-corrected, neighbour-count-weighted enhancement, as a function of projected neighbour distance, both in specific star formation rate for our star-forming galaxies and in the level of nuclear activity, as measured by the quantity $\log \mathrm{L[O\ III]}/\mathrm{M}_{BH}$, for the AGN in our sample. The results are shown in Figure 3. The top panels show the enhancement functions as function of projected separation r_p, while in the bottom panel the separation is scaled by dividing by R_{90}, the radius that encloses 90% of the r-band light of the galaxy. As can be seen, AGN behave very differently to star forming galaxies. Accretion onto the black hole is *suppressed* for galaxies with companions with projected separations between $\sim$ 100 kpc – 1 Mpc, and there is no evidence that the nuclear activity level is enhanced above the mean at small neighbour separations. The most plausible explanation for the suppression on intermediate scales is that the majority of AGN with close neighbours are located in groups and clusters and the suppression of nuclear activity is a larger-scale environ-

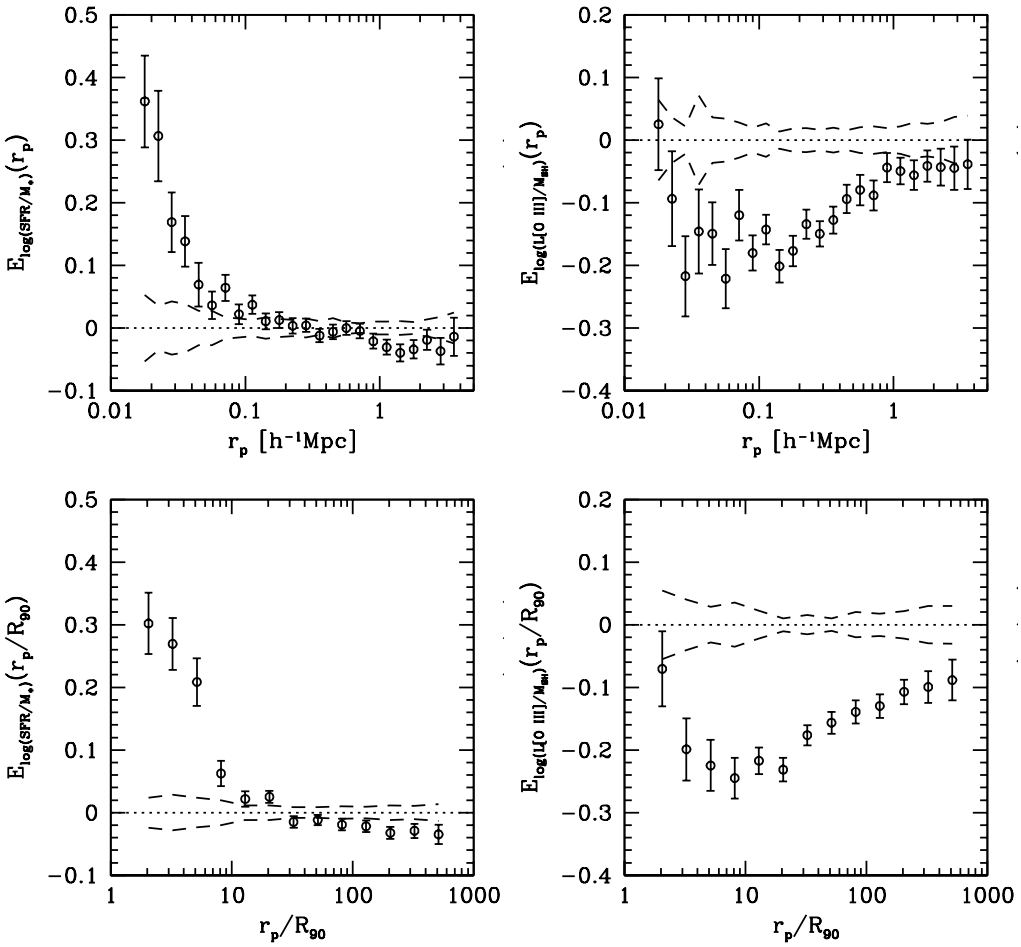

Figure 3. Enhancement in $\log_{10} SFR/M_*$ for high S/N star-forming galaxies (left) and in $\log_{10} L[\mathrm{O\ III}]/M_{BH}$ for AGN (right), as a function of the projected separation r_p (top) and as a function of the scaled separation r_p/R_{90} (bottom). Here $r < 17.6$ for the central star-forming galaxies and AGN, while $r < 19.0$ for the reference sample of galaxies from the photometric catalogue.

mental effect, similar to the morphology-density or SFR-density relations. This hypothesis is in accord with the AGN clustering model of Li et al. (2006), in which AGN activity is suppressed in satellite galaxies relative to central galaxies.

3. Summary

We have explored the connections between galaxy interactions, star formation and AGN activity by applying a variety of statistics to SDSS data. A strong connection between galaxy interactions and enhanced star formation is found no matter what statistic we employ. However, we fail to find any corresponding relation between enhanced AGN activity and interactions. These results appear to support the hypothesis that there is a significant time delay between the onset of the interaction and the phase in which the black hole is able to accrete. This delay hypothesis can be tested by using empirical measures of galaxy morphology that are more sensitive to the later stages of the merging event.

A major caveat in all the analysis is the assumption that the extinction-corrected [O III] luminosity is a reasonably robust indicator of the bolometric luminosity of the central black hole. This is the only indicator of accretion that is available to us for our sample of AGN from the Sloan Digital Sky Survey. It will be extremely important to check the results presented in this paper using indicators of AGN activity at other wavelengths.

Acknowledgments. This work was supported by the Joint Postdoctoral Programme in Astrophysical Cosmology of Max Planck Institute for Astrophysics and Shanghai Astronomical Observatory. CL thanks the conference organizers for invitation and hospitality.

References

Adelman-McCarthy J. K., Agüeros M. A., Allam S. S., Anderson K. S. J., Anderson S. F., Annis J., Bahcall N. A., Baldry I. K., et al.,, 2006, ApJS, 162, 38

Kauffmann G., Heckman T. M., Tremonti C., Brinchmann J., Charlot S., White S. D. M., Ridgway S. E., Brinkmann J., et al., 2003, MNRAS, 346, 1055

Li C., Kauffmann G., Wang L., White S. D. M., Heckman T. M., Jing Y. P., 2006, MNRAS, 373, 457

Li C., Kauffmann G., Heckman T. M., Jing Y. P., White S. D. M., 2008a, MNRAS, 385, 1903

Li C., Kauffmann G., Heckman T. M., White S. D. M., Jing Y. P., 2008b, MNRAS, 385, 1915

York D. G., Adelman J., Anderson Jr. J. E., Anderson S. F., Annis J., Bahcall N. A., Bakken J. A., Barkhouser R., et al., 2000, AJ, 120, 1579