Close pairs of galaxies with different activity levels

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Abstract. We selected and studied 180 pairs with $dV < 800\ km\ s^{-1}$ and $Dp < 60$ kpc containing Markarian (MRK) galaxies to investigate the dependence of galaxies integral parameters, star-formation (SF) and active galactic nuclei (AGN) properties on kinematics of pairs, their structure and large-scale environments. Projected radial separation Dp and perturbation level P are better measures of interaction strength than dV. The latter correlates with the density of large-scale environment and with the morphologies of galaxies. Both galaxies in a pair are of the same nature, the only difference is that MRK galaxies are usually brighter than their neighbors. Specific star formation rates (SSFR) of galaxies in pairs with smaller Dp or dV is in average 0.5 dex higher than that of galaxies in pairs with larger Dp or dV. Closeness of a neighbor with the same and later morphological type increases the SSFR, while earlier-type neighbors do not increase SSFR. Major interactions/mergers trigger SF and AGN more effectively than minor ones. The fraction of AGNs is higher in more perturbed pairs and pairs with smaller Dp. AGNs typically are in stronger interacting systems than star-forming and passive galaxies. There are correlations of both SSFRs and spectral properties of nuclei between pair members.

Keywords. galaxies: general, interactions, starburst, active, peculiar

1. Introduction

Interactions/mergers of galaxies are considered as important processes influencing morphological, stellar and chemical evolution of galaxies. Interactions/mergers can enhance star formation rates (SFRs) in galaxies as is revealed by numerous observations of close pairs (e.g. Larson & Tinsley 1978, Lambas *et al.* 2003, Li *et al.* 2008, Ellison *et al.* 2008, 2013, Hwang *et al.* 2010). The main physical processes responsible are gas inflow toward nuclear regions of galaxies due to global torques and, probably, gas fragmentation into massive and dense clouds and rapid SF therein (e.g. Mihos & Hernquist 1996, Hopkins *et al.* 2013). The triggering mechanism of AGN is often considered to be the same as that of the enhanced nuclear SF (e.g. Ellison *et al.* 2008, 2011, Wild, Heckman & Charlot 2010, Liu *et al.* 2012).

Large-scale environments, morphologies of both galaxies and mass ratios can affect on frequency and efficiency of enhanced SF and AGN triggering by interactions and merging (e.g. Sol Alonso *et al.* 2006, Hwang *et al.* 2010, Scudder *et al.* 2012, Li *et al.* 2008, Ellison *et al.* 2008, 2010, 2011, Cox *et al.* 2008, Lambas *et al.* 2012). The facts, that not all galaxies with high SFR are interacting ones, as well as that not all interacting galaxies have high SFR, support the hypothesis that internal properties of galaxies are also an important factor determining enhanced SF (Lambas *et al.* 2003, Sol Alonso *et al.* 2006).

The aim of this study is to investigate the connections between interaction with a close neighbor and nuclear activity and/or enhanced SF in galaxy pairs using the sample of close neighbors of MRK galaxies from Nazaryan *et al.* (2012). The complete study is presented in Nazaryan *et al.* (2014). A similar study of Second Byurakan Survey galaxies is presented in Nazaryan (2014).
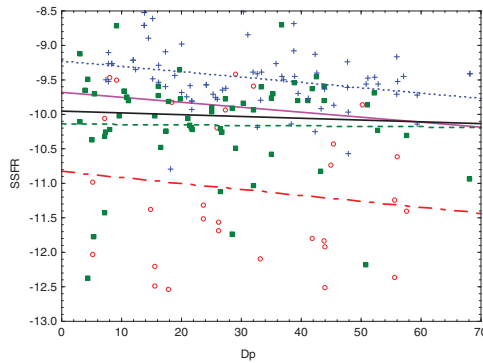
2. Sample

The starting point to create our sample of pairs is the catalog of MRK galaxies. The original catalog (Markarian *et al.* 1989) features 1545 bright galaxies mostly having starburst properties and/or AGNs. In Petrosian *et al.* (2007), homogeneously measured parameters of MRK galaxies are presented. Results of a close neighbors search for MRK galaxies are published in Nazaryan *et al.* (2012). For the current study, the subsample of 217 pairs of galaxies containing at least one MRK galaxy is selected. For this study, we classified morphologies of MRK galaxies and neighbors by using SDSS color images. We also classified sample pairs in terms of morphological perturbations (see e.g. Liu *et al.* 2012, Lambas *et al.* 2012) by 4 levels: $P = 0$: unperturbed pairs, $P = 1$: slightly perturbed, $P = 2$: highly perturbed, $P = 3$: mergers. We described the large-scale environments of each pair by average large-scale density Σ. For statistics we also included SFRs of galaxies and nuclear emission-line classification (BPT) of their SDSS spectra.

3. Statistics and discussions

The dependence of visually detected perturbation level P on dV and Dp is worthy to mention. Disturbance level P correlates only with Dp, while dV and Dp do not correlate with each other. The closer pairs are more disturbed. This is the result of different nature of Dp and dV. Pairs with larger dV correspond to environments with higher densities Σ. Therefore while Dp is a measure of interaction strength, the variation of dV mainly reflects change of large-scale environments. The SSFRs of barred galaxies do not differ from those of unbarred ones significantly.

We compared properties of neighbors with those of MRK galaxies. Mean absolute r mag of neighbors is fainter by 0.9 mag than that of MRK galaxies. Morphologies of neighbors correlate significantly with those of MRK galaxies and are slightly later. Neighbor galaxies have the same distributions by SSFRs, BPT types and colors, and the same fraction of barred galaxies as MRK galaxies. This is a result of a correlation between properties of galaxies in pairs. However, because of magnitude limitation of Markarian survey, MRK galaxies are usually the brightest members of pairs.

The main parameters describing interactions are dV, Dp, and P. Without considering morphologies, there is a 0.7 dex increase of SSFRs from larger dV to smaller ones. However the variance of SSFRs because of morphologies is much larger (more than 2.5 dex). In Ellison *et al.* (2010), it was shown that pairs in denser environments have larger dV. Because of morphology–density relation, dV is also biased by morphologies: early-type galaxies have about 3 times more dV than irregulars, so most of the SSFR vs. dV dependence is because of morphology–SSFR dependence and does not reflect pure interaction. Therefore, it is essential to take into account morphologies of galaxies when discussing their SSFRs and interactions. Grouping by morphologies weakens SSFR vs. dV relation, but there still remains some variance, maximal for early spirals $(0.4 - 0.5$ dex). This result is in agreement with modeling, e.g. Di Matteo *et al.* (2008) showing that strong starbursts during interactions are rare and that typical enhancement of SFR is less than 5 times. Figure 1 shows the dependence of SSFR on Dp of a pair in AGN–removed

Figure 1. SSFR vs. Dp for subsamples of early-types (red blank circles, dashed-dotted line), early spirals (green filled squares, dashed line), and late spirals and irregulars (blue crosses, dotted line). Two best-fit lines for all galaxies (black bottom solid line) and AGN–removed sample (purple upper solid line) are drawn.
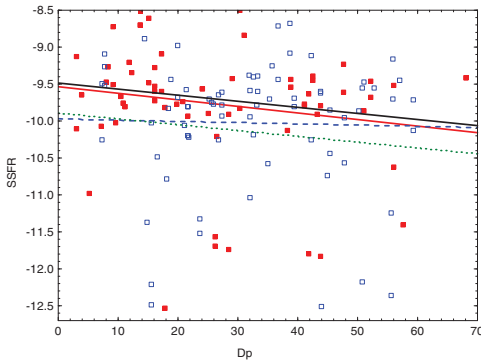
Figure 2. SSFR vs. Dp for major interactions (red filled squares, solid line best fit), minor interactions (blue blank squares, dashed line), brightest components of major interactions (black upper solid line), and brightest components of minor interactions (green dotted line).
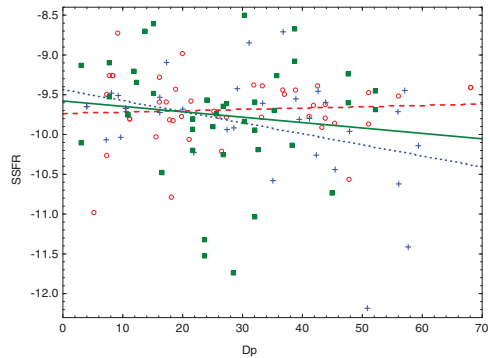
Figure 3. SSFR vs. Dp for galaxies with relatively earlier type neighbors (red blank circles, dashed line), same type neighbors (green filled squares, solid line), and relatively later type neighbors (blue crosses, dotted line).

sample. In our sample Dp is not biased by morphologies compared to dV. After grouping by morphologies we have about 0.5 dex increase of SSFRs in closer pairs.

We studied the impact of the luminosity ratio of pair members on SSFR increase by considering major ($log(L_{\mathrm{bright}}/L_{\mathrm{faint}}) \leqslant 0.6$) and minor (the rest) pairs. The major interactions are more effective in triggering SF than minor ones (see Fig. 2), there is a 0.5 dex increase of SF in major interactions, while there is no trend among minor interactions. This results are in agreement with both observational and modeling data (Lambas *et al.* 2003, 2012, Cox *et al.* 2008) suggesting that the merger mass ratio is an important parameter defining the effectiveness of the tidal forces.

The impact of morphology of neighbor galaxy on SSFR is shown in Fig. 3. Earlier-type neighbors do not increase of SSFR, while the same- and later-type neighbors increase SSFR. The extra SSFR is maximal if the neighbor is of later morphological type (0.8 dex). Previous papers, e.g. Hwang *et al.* (2010), also obtained similar result, supporting the

scenario where neighbor of later type can not only trigger gas inflow in earlier type galaxy, but also be an additional source of gas fuel.

The fraction of AGN galaxies in less separated pairs is larger than that in more separated pairs. Fraction of AGNs increases by about 7 times when going from unperturbed pairs ($P = 0$) to mergers ($P = 3$). This result indicates that while both AGN and SF can be triggered by interactions, AGNs "prefer" stronger interactions. Different timings of starbursts and AGN events can explain this result (Ellison *et al.* 2008, Wild *et al.* 2010, Hopkins 2012). The fraction of AGNs in major interactions is about 4 times larger than that in minor ones.

We studied BPT–BPT correlations between pair members. There is a tendency to have an increased probability of a neighbor with the same BPT type. Especially that is noticeable regarding passive galaxies and AGNs: passive galaxies are more likely to be found near another passive galaxy, AGNs are more probable to be near another AGN. We explain these correlations between BPT types as a result of two main factors: first, the correlation between morphologies of galaxies, and, second, the increased likelihood of pair members to have nuclear activity of same types when interacting strongly.

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