Mon. Not. R. Astron. Soc. **386,** L82–L86 (2008) doi:10.1111/j.1745-3933.2008.00466.x

The mass–metallicity relation of interacting galaxies

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Accepted 2008 February 25. Received 2008 February 20; in original form 2008 January 8

ABSTRACT

We study the mass–metallicity relation of galaxies in pairs and in isolation taken from the Sloan Digital Sky Survey-Data Release 4 (SDSS-DR4) using the stellar masses and oxygen abundances derived by Tremonti et al. Close galaxy pairs, defined by projected separation $r_{\rm p} < 25\,{\rm kpc}\,h^{-1}$ and radial velocity $\Delta V < 350\,{\rm km\,s^{-1}}$, are morphologically classified according to the strength of the interaction signs. We find that only for pairs showing signs of strong interactions, the mass–metallicity relation differs significantly from that of galaxies in isolation. In such pairs, the mean gas-phase oxygen abundances of galaxies with low stellar masses ($M_* \lesssim 10^9\,{\rm M_\odot}\,h^{-1}$) exhibit an excess of 0.2 dex. Conversely, at larger masses ($M_* \gtrsim 10^{10}\,{\rm M_\odot}\,h^{-1}$) galaxies have a systematically lower metallicity, although with a smaller difference (−0.05 dex). Similar trends are obtained if g-band magnitudes are used instead of stellar masses. In minor interactions, we find that the less massive member is systematically enriched, while a galaxy in interaction with a comparable stellar mass companion shows a metallicity decrement with respect to galaxies in isolation.

We argue that metal-rich starbursts triggered by a more massive component, and inflows of low-metallicity gas induced by comparable or less massive companion galaxies, provide a natural scenario to explain our findings.

Key words: galaxies: abundances – galaxies: evolution – galaxies: formation – galaxies: interactions.

1 INTRODUCTION

Chemical features observed in galaxies can store fossil records of their history of formation since they are the result of different physical mechanisms acting at different stages of evolution (Freeman & Bland-Hawthorn 2002). Among them, galaxy interactions and mergers are considered important processes which can affect the star formation activity significantly as has been reported by numerous works (e.g. Sérsic & Pastoriza 1967; Tinsley & Larson 1978; Barton, Geller & Kenyon 2000; Lambas et al. 2003; Nikolic, Cullen & Alexander 2004; Alonso et al. 2006). The link of interactions and mergers with chemical properties have been recently started to be addressed (Donzelli & Pastoriza 2000; Márquez et al. 2002; Fabbiano et al. 2004; Kewley, Geller & Barton 2006). Recently, Kewley et al. (2006) found the metallicity in the nuclear regions of galaxies in very close pairs to be displaced to lower levels than those measured in more distant pairs and isolated galaxies. The authors claimed this effect to be caused by gas inflows triggering by the interactions.

In this Letter, we study the mass–metallicity relation (MZR; Lequeux et al. 1979) of close galaxy pairs as a tool to study the effects of interactions on metallicity. In the local Universe, Tremonti et al. (2004) have confirmed the dependence of metallicity on stellar mass with high statistical signal. Erb et al. (2006) has extended the study to high redshift finding a similar correlation, although displaced to lower metallicity (see also Maiolino et al. 2007). The luminosity–metallicity relation (LZR) has been also well estimated in local Universe when stellar masses are not possible to measure. However, it has been shown that luminosity is a less fundamental parameter than mass (e.g. Erb et al. 2006). Despite these new results, the origin of the MZR and its evolution remain unclear. Mergers and interactions could play an important role in shaping the MZR. Hence, a statistical analysis of the effects of interactions on chemical properties could help to shed light on this issue.

Numerical simulations showed how tidal interactions can trigger star formation activity and can modify the morphology of galaxies (e.g. Mihos & Hernquist 1996; Kennicutt et al. 1998 and references therein; Barnes 2004). Gas inflows generated during these

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interactions feed star formation activity (e.g. Barnes & Hernquist 1996; Tissera 2000). Tissera, De Rossi & Scannapieco (2005) showed that simulated galaxies in the concordance Λ cold dark matter (ΛCDM) cosmology reproduce the shape of the MZR but not its evolution. Part of the failure could be caused by the lack of supernova (SN) feedback in these simulations. In fact, Brooks et al. (2007), Finlator & Dave (2008) and Governato et al. (2007), resorting to ad hoc parametrizations for SN feedback model, claimed to be able to reproduce the observed MZR in a cosmological context.

We performed a statistical analysis of the chemical properties of galaxies in pairs selected from the Sloan Digital Sky Survey-Data Release 4 (SDSS-DR4), focusing on the MZR. Since it is already clear that proximity is the main parameter associated to important increases in the star formation activity, hereafter we will centre our analysis on close galaxy pairs. These pairs have been reclassified according to the level of morphological disturbances detected by inspection of their images in merging, tidal and non-perturbed (Alonso et al. 2007). Merging pairs are those exhibiting the higher level of star formation activity.

This Letter is organized as follows. In Section 2 we described the galaxy samples. Section 3 discussed the results. Section 4 summarized the main findings.

2 DATA

The main SDSS galaxy sample is essentially a magnitude limited spectroscopic sample $r_{\rm lim} < 17.77$ with most of the galaxies spanning a redshift range $0 < z < 0.25$ with a median redshift at 0.1 (Strauss et al. 2002). Following Alonso et al. (2006, and references therein), we selected galaxy pairs by requiring members to have a relative projected separation $r_{\rm p} < 100\,{\rm kpc}\,h^{-1}$ and a relative radial velocity $\Delta V < 350\,{\rm km\,s^{-1}}$.

In order to properly assess the significance of the results obtained from the pair catalogue, we defined a control sample by a Monte Carlo algorithm that selects for each galaxy in a pair, two galaxies with similar redshift and r-band luminosity but without a close companion within the adopted relative velocity and separation thresholds. This procedure assures that the control catalogue has the same selection effects than the pair sample, and consequently, it can be used to estimate the actual difference between galaxies in pairs and in isolation.

Alonso et al. (2006, 2007) discussed possible effects of aperture and incompleteness, which were found to have no significant consequences in the analysis. Active galactic nuclei (AGNs) could contribute to the emission spectral features affecting our interpretation. Hence, AGNs had not been included in either the control or the pair catalogues.

As mentioned above, we focus our analysis on the close galaxy pairs defined as those with a relative projected separation $r_{\rm p} < 25\,{\rm kpc}\,h^{-1}$. These pairs are subclassified accordingly to the level of morphological disturbances in non-disturbed (N-type), tidal (T-type) and merging (M-type) pairs as discussed by Alonso et al. (2007). M-type pairs show clear and strong signals of interactions and have active star formation. For completeness, we have also included the estimations for more distant pairs, $50 < r_{\rm p} < 100\,{\rm kpc}\,h^{-1}$ (D-type).

For the SSDS-DR4, Tremonti et al. (2004) estimated gas-phase oxygen abundance, 12 + log O/H, and derived stellar masses (M_*). In Table 1, we show the numbers of pairs and galaxies in the different samples which have oxygen abundances measured for both members or for only one member. Pairs with only one member with oxygen estimations have been used to improve the statistics, when possible.

Table 1. Number of pairs and galaxies in the different samples used in this work ($N_{\rm p}$ total number of pairs; $N_{\rm p}^1$ number of pairs with oxygen abundances measured for both members; $N_{\rm g}$ number of galaxies with oxygen abundances estimated for at least one member).

Sample	M	T	N	D	C
$N_{\rm p}$	383	686	536	4982	–
$N_{\rm p}^1$	94	142	124	679	–
$N_{\rm g}$	284	454	410	1358	6034

3 ANALYSIS AND RESULTS

In Fig. 1, we show the mean MZR and LZR for galaxies in M-, T-, N- and D-type pairs and the control sample. We also plot the fit to the observed MZR given in equation (3) by Tremonti et al. (2004), and the mean value of the observed LZR (also given by Tremonti et al. 2004). It can be appreciated that our different samples are in general agreement with these mean relations except for M-type pairs. For this sample, at low stellar mass, or low luminosity, there is a significant excess in the gas-phase metallicity with respect to the other samples and mean observed values of Tremonti et al. (2004). Conversely, at high mass (or high luminosity), we find M-type pairs galaxies to have slightly smaller metallicity. This behaviour is in agreement with the results reported by Kewley et al. (2006). These authors found a decrease in the metallicity in the nuclear region of galaxies in close pairs which had members with luminosities consistent with our high luminosity end.

We have also explored the dependence of the MZR on galaxy concentration for the samples analysed finding a similar behaviour irrespective of galaxy concentration (here concentration is defined as the ratio of Petrosian 90–50 per cent r-band light radii). Since the concentration parameter is well correlated to morphology (see, however, Ellis et al. 2005 for a detailed discussion of the relation of morphology and other galaxy properties), this result indicates that our findings are not merely a morphology-induced effect.

The change in the slope of the MZR of M-type pairs as a function of M_* shown in Fig. 1 suggests a possible dependence of the effects of interactions on the stellar mass of the members. Hence, we splitted the pair samples into minor and major interaction subsamples by adopting a ratio of 0.20 between the corresponding stellar masses. We studied the MZR and star formation activity for each component in major and minor interactions in the four defined pair samples.

As shown in Fig. 2, two cases depart considerably from the global relation given by Tremonti et al. (2004). Galaxies in major interactions (Fig. 2a), which show a lower metallicity, and the small component of minor interactions (Fig. 2c) with strong disturbances (M-type), which exhibit a significantly larger mean metallicity at a given stellar mass.

These results suggest that in major interactions, there is an efficient inflow of pristine gas from the external regions of the halo. We argue that the lack of an effect for the large component (M_2^*) in minor interactions may reside on the relatively weak perturbation these galaxies are subject to. On the contrary the small component (M_1^*) of minor interactions are the ones mostly disturbed by the interactions and therefore those subject to major episodes of star formation and metallicity enhancement.

We argue that the ratio between the stellar masses of the galaxies involved in an interaction is an important parameter in setting the metallicity content of galaxies. To explore this, we show in Fig. 3 (upper panel) that the metallicity difference (Δ) between the less massive and the most massive components in M-type minor

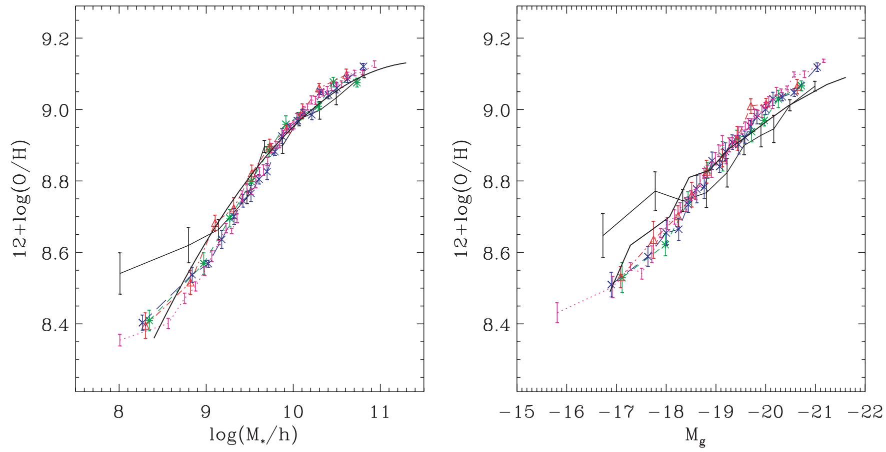

Figure 1. MZR (left) and LZR (right) for galaxies in M-type (black solid lines), T-type (green dashed lines), N-type (red dotted–dashed lines) and D-type (blue long-dashed lines) pairs, and in the control sample (magenta dotted lines). The thick solid line corresponds to Tremonti et al. mean values. Error bars have been estimated by applying the bootstrap resampling technique.

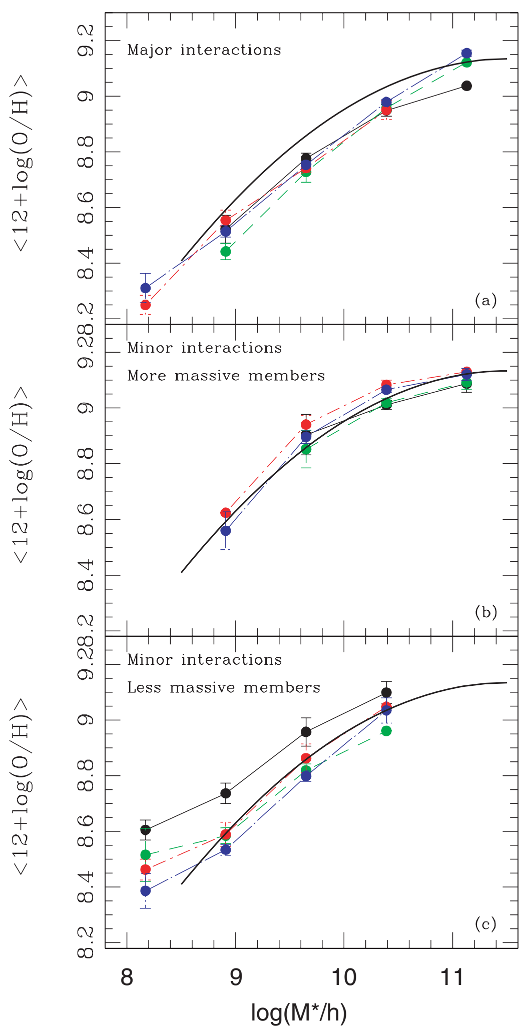

Figure 2. MZR for the different type pairs: M-type (black), T-type (green), N-type (red) and D-type (blue); in major interactions ($M_2^*/M_1^* > 5$) (a) and in minor interactions ($M_2^*/M_1^* < 5$) (b: massive components; c: less massive components). The thick solid line corresponds to Tremonti et al. (2004) fit. Error bars have been estimated by applying the bootstrap resampling technique.

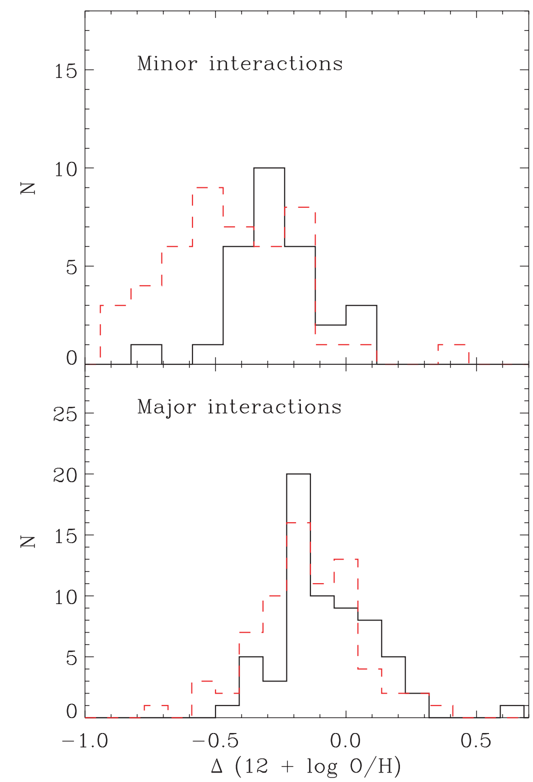

Figure 3. Distribution of oxygen abundance differences between the less massive and the most massive components in M-type (black solid lines) and N-type (red dashed lines) pairs in minor (upper panel) and major (lower panel) interactions.

interactions is significantly reduced in comparison to that of galaxies in N-type pairs (similar to D-type pairs). Members of major interactions in M-type pairs have similar metallicity differences than those of N-type pairs (lower panel in Fig. 3).

An analysis of the star formation activity indicates that metal-rich less massive members in M-type pairs are in general exhibiting a high star formation activity, at a given stellar mass. This somewhat expected result reinforces the idea that minor components in strong

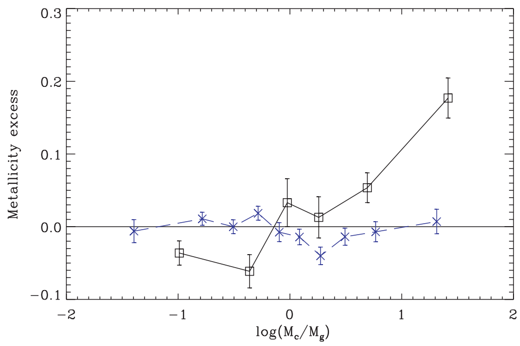

Figure 4. Metallicity excess of a given galaxy with respect to galaxies in the control sample with similar stellar mass as a function of mass ratio between the companion galaxy and the given one for M-type (solid line) and D-type (long-dashed line) pairs. Error bars correspond to the mean standard deviation.

interactions are likely to have experienced strong gas shocks leading to star formation and enrichment.

In order to further assess the role of the relative mass ratio of the galaxy members on the mean gas-phase metallicity, we calculated the metallicity excess (ϵ) as the difference between the oxygen abundance of a given galaxy in a pair and the mean abundance of galaxies in the control sample with similar stellar mass as a function of the ratio between the stellar mass of the companion (M_c) galaxy and the stellar mass of the given galaxy (M_g). We estimated ϵ for all subsamples. In Fig. 4, we display the results corresponding to pairs in the M- and D-type subsamples since these galaxies set the range of variation. As it can be appreciated, in M-type pairs, galaxies with massive companion ($\log M_c/M_g > 0$) have significantly enhanced their metallicity with respect to galaxies in the control sample with the same stellar mass. The opposite occurs for galaxies with a less massive companion ($\log M_c/M_g < 0$) where the metallicity is lower. Conversely, D-type pairs exhibit a remarkable consistency with the control sample. The behaviour of M-type pairs stresses that the relative mass ratio plays a major role in determining the metallicity properties in galaxies in strong interactions.

4 DISCUSSION AND CONCLUSIONS

We analyse the effects of interaction on the metallicity properties of galaxies. For this aim we have studied pairs of galaxies with projected separation $r_p < 25\,\mathrm{kpc}\,h^{-1}$ and radial velocity $\Delta V < 350\,\mathrm{km\,s^{-1}}$ from the SDSS-DR4 and oxygen abundances from Tremonti et al. (2004). Using the visual classification of pairs into M-, T-, N- and D-type pairs of Alonso et al. (2007), we find that pairs undergoing a strong interaction differ significantly on the MZR in comparison to other pair categories and a control sample. In the low mass range ($M_* \lesssim 10^9\,\mathrm{M}_\odot\,h^{-1}$) the mean metallicity of galaxies in M-type pairs is 0.2 dex greater. On the contrary, at large masses ($M_* \gtrsim 10^{10}\,\mathrm{M}_\odot\,h^{-1}$), M-type pair galaxies have a systematically lower metallicity, although with a smaller difference (−0.05 dex).

When dividing the pairs into minor ($M_2^*/M_1^* > 5$) and major ($M_2^*/M_1^* < 5$) interactions, we find that the less massive members in strong minor interactions are always enriched irrespective of their mass. The interactions of galaxies of comparable stellar mass content have a systematically lower metallicity content, suggestive of an inflow of unenriched material from the external regions.

We notice that the finite size of the fibre might affect the results in the sense that the smaller the angular size of the objects the larger the region where metallicity is derived. Nevertheless, in this work we have considered galaxies of similar stellar masses and redshifts differing only on the presence of a companion. In order to analyse this effect on the MZR into more detail, we have considered separately large and small angular size galaxies (Petrosian 90 per cent r-band light radius $\leqslant 8$ arcsec) for the samples in Fig. 1. We find that the trends obtained in this work remain unchanged regardless of the apparent angular size of the galaxies. Therefore, the results are robust against a combination of observational aperture and metallicity gradient in the galaxies.

We may interpret our results in terms of a combination of the effects of a metal-rich starburst induced by a massive component and the pristine gas inflow triggered by comparable or less massive companion galaxies. These two effects are expected naturally in current galaxy formation and evolution scenarios, so our findings may help to understand the origin and evolution of the MZR.

ACKNOWLEDGMENTS

We thank the referee for helpful comments and suggestions. This work was partially supported by the Consejo Nacional de Investigaciones Científicas y Técnicas, Agencia de Promoción de Ciencia y Tecnología and Secretaría de Ciencia y Técnica de la Universidad Nacional de Córdoba. Funding for the SDSS and SDSS-II has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, the U.S. Department of Energy, the National Aeronautics and Space Administration, the Japanese Monbukagakusho, the Max Planck Society, and the Higher Education Funding Council for England. The SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions. The Participating Institutions are the American Museum of Natural History, Astrophysical Institute Potsdam, University of Basel, Cambridge University, Case Western Reserve University, University of Chicago, Drexel University, Fermilab, the Institute for Advanced Study, the Japan Participation Group, Johns Hopkins University, the Joint Institute for Nuclear Astrophysics, the Kavli Institute for Particle Astrophysics and Cosmology, the Korean Scientist Group, the Chinese Academy of Sciences (LAMOST), Los Alamos National Laboratory, the Max-Planck-Institute for Astronomy (MPIA), the Max-Planck-Institute for Astrophysics (MPA), New Mexico State University, Ohio State University, University of Pittsburgh, University of Portsmouth, Princeton University, the United States Naval Observatory, and the University of Washington.

REFERENCES

Alonso M. S., Lambas D. G., Tissera P., Coldwell G., 2006, MNRAS, 367, 1029
Alonso M. S., Lambas D. G., Tissera P., Coldwell G., 2007, MNRAS, 375, 1017
Barnes J., 2004, MNRAS, 350, 798
Barnes J., Hernquist L., 1996, ApJ, 471, 115
Barton E. J., Geller M. J., Kenyon S. J., 2000, ApJ, 530, 660
Brooks A. M., Governato F., Booth C. M., Willman B., Gardner J. P., Wadsley J., Stinson G., Quinn T., 2007, ApJ, 655, L17
Donzelli C. J., Pastoriza M. G., 2000, AJ, 120, 189
Ellis S. C., Driver S. P., Allen P. D., Liske J., Bland-Hawthorn J., De Propris R., 2005, MNRAS, 363, 1257
Erb D. K., Shapley A. E., Pettini M., Steidel C. C., Reddy N. A., Adelberger K. L., 2006, ApJ, 644, 813
Fabbiano G. et al., 2004, ApJ, 605, L21
Finlator K., Dave R., 2008, MNRAS, in press (doi:10.1111/j.1365-2966.2008.12991.x) (arXiv:0704.3100)
Freeman K., Bland-Hawthorn J., 2002, ARA&A, 40, 487

Governato F., Willman B., Mayer L., Brooks A., Stinson G., Valenzuela O., Wadsley J., Quinn T., 2007, MNRAS, 374, 1479
Kennicutt R. C., Jr, Schweizer F., Barnes J. E., Friedli D., Martinet L., Pfenniger D., 1998, in Saas-Fee Advanced Course 26, Galaxies: Interactions and Induced Star Formation. Springer-Verlag, Berlin
Kewley L. J., Geller M. J., Barton E. J., 2006, AJ, 131, 2004
Lambas D. G., Tissera P. B., Alonso M. S., Coldwell G., 2003, MNRAS, 346, 1189
Lequeux J., Peimbert M., Rayo J. F., Serrano A., Torres-Peimbert S., 1979, A&A, 80, 155
Maiolino R. et al., 2007, preprint (arXiv:0712.2880)
Márquez I., Masegosa J., Moles M., Varela J., Bettoni D., Galletta G., 2002, A&A, 393, 389
Mihos J. C., Hernquist L., 1996, ApJ, 464, 641
Nikolic B., Cullen H., Alexander P., 2004, MNRAS, 355, 874
Sérsic J. L., Pastoriza M., 1967, PASP, 79, 152
Strauss M. et al., 2002, AJ, 124, 1810
Tinsley B. M., Larson R. B., 1978, ApJ, 221, 554
Tissera P. B., 2000, ApJ, 534, 636
Tissera P. B., Domínguez-Tenreiro R., Scannapieco C., Sáiz A., 2002, MNRAS, 333, 327
Tissera P. B., De Rossi M. E., Scannapieco C., 2005, MNRAS, 364, 38
Tremonti C. A. et al., 2004, ApJ, 613, 898

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