We present the results of our analysis of the frequencies of galaxies with tidal tails and M51-type galaxies in several deep fields of the Hubble Space Telescope (HDF-N, HDF-S, HUDF, GOODS, GEMS). In total, we have found about seven hundred interacting galaxies at redshifts $z \leq 1.5$ in these fields. At $z \leq 0.7$, the observed space densities of galaxies with tidal structures and M51-type galaxies have been found to increase as $\propto (1+z)^m$, where $m \approx 2.6$. According to our estimates, over the last 6-7 Gyr, i.e., at $z \leq 0.7$, about a third of the galaxies with $M(B) \leq -18$ must have undergone strong gravitational perturbations and mergers and $\sim 1/10-1/5$ of the galaxies have accreted relatively low-mass nearby satellites typical of M51-type galaxies. The possible decrease in the timescale on which a distant galaxy appears peculiar with growing $z$ can increase considerably the estimated rate of mergers.

1. Introduction

The idea about the growth of stellar systems inside hierarchically merging dark haloes provides a basis for the present-day models of galaxy formation and evolution (see, e.g., White and Rees 1978; for a review, see the book by Mo et al. 2010). The process of halo mergers can be well described in terms of model calculations (Fakhouri and Ma 2008 and references therein); however, the connection of this process with the mergers of actually observed galaxies is not yet understood well enough (see, e.g., Kitzbichler and White 2008).

As a rule, two approaches are used when the galaxy merger rate is studied observationally. The first is based on analysis of the frequency of close galaxy pairs at various $z$ (Zepf and Koo 1989; Kartaltepe et al. 2007; de Ravel et al. 2011; and references therein). The weak points of this method are the small number of spectroscopically confirmed pairs at high $z$ and the assumption that all these pairs merge on a certain timescale (Kitzbichler and White 2008).

The second (morphological) approach is based on the frequency statistics of signatures of recent interactions and mergers in galaxies: structure distortions (Conselice et al. 2003 and references therein), the presence of tidal tails and bridges (Reshetnikov 2000a, 2000b; Bridge et al. 2010), polar rings (Reshetnikov 1997; Reshetnikov and Dettmar 2007), collisional rings (Lavery et al. 2004), etc. The main problem of this method is that the basic tracers of dynamical perturbations of galaxies, as a rule, have a low surface brightness and they are difficult to observe at high $z$. However, as was shown by Hibbard and Vacca (1997), such structures must be visible at least up to $z \sim 1$ on deep images of the Hubble Space Telescope (HST). The search for and statistics of tidal structures in galaxies in the HDF-N and HDF-S deep fields confirmed this conclusion (Reshetnikov 2000a, 2000b). Furthermore, as in the case of studying merging pairs, the connection of the dark halo merger rate derived from models with the complex processes of galaxy interactions and mergers acting on different mass and timescales is ambiguous. On the other hand, the advantage of the morphological approach is that very large samples of galaxies can be produced and investigated using it.

The results of the two approaches do not yet agree quite well quantitatively; however, the general conclusion is beyond question: the fraction of interacting and merging galaxies actually grows with $z$, as follows from theoretical expectations. At $z \leq 1.5$, this growth is commonly described by a power law, $(1+z)^m$, where the value of $m$ from the data of differ-
ent authors is, in most cases, within the range from 2 to 4 (see, e.g., Table 2 in Kartaltepe et al. 2007).

In this paper, we analyze the frequency statistics of galaxies with tidal structures and M51-type galaxies in several Hubble deep fields. All numerical values in the paper are given for the cosmological model with a Hubble constant of 70 km s\(^{-1}\) Mpc\(^{-1}\) and \(\Omega_m = 0.3\), \(\Omega_\Lambda = 0.7\).

2. Galaxies with tidal structures at \(z \sim 0.7\)

2.1. The sample of galaxies

The sample is based on the catalog of interacting galaxies in several Hubble deep fields (Mohamed and Reshetnikov 2011). This catalog was compiled on the basis of a visual classification of galaxies in the F814W (HDF-N and HDF-S fields), F775W (HUDF), and F850LP (GOODS and GEMS) filters. At \(z \sim 1\), these filters roughly correspond to the \(B\) band in the reference frame associated with the galaxies themselves. Our sample includes a total of 689 galaxies with tidal tails (the bridges have, on average, a lower surface brightness and they were not considered in our work) at redshifts \(z \leq 1.5\).

Figure 1 shows the \(z\) distribution of sample galaxies and their positions on the “rest-frame absolute magnitude – redshift” diagram. The dashed lines in the upper panel show the fits of the observed distributions by the empirical formula \(dN/dz \propto z^2 \exp\left(-\frac{z}{z_c}\right)^{1.5}\) proposed for describing the observational data for magnitude-limited samples with median redshift \(z_m = 1.412z_c\) (Baugh and Efstathiou 1993). As we see from the figure, the actual distributions agrees satisfactorily with the expected ones.

Figure 1 (bottom part) illustrates the obvious observational selection effect: we predominantly choose the brightest galaxies among more distant objects. The standard way of avoiding this selection is to consider only bright galaxies at various \(z\). Below, we will study the statistics of interacting galaxies for two subsamples: (1) for objects with absolute \(B\) magnitude from \(-18\) to \(-20\) and (2) for all galaxies with \(M(B) \leq -18\) (the stellar mass limit \(M \geq 4 \cdot 10^9\) \(M_\odot\) roughly corresponds to this luminosity restriction).

To estimate the completeness of our sample, we considered the differential counts of galaxies in comparison with those in the VIRMOS VLT F02 deep field (McCracken et al. 2003). According to McCracken et al. (2003), the differential counts for galaxies brighter than \(24\) in the \(I\) band have a slope of \(0.34 \pm 0.02\). (This result agrees well with the data on other deep fields as well; e.g., Metcalfe et al. 2001).

The objects in our sample of interacting galaxies follow this slope up to \(I \approx 21.5\) and then begin to deviate greatly from it. The median redshift for galaxies with \(I = 21.5\) is \(z = 0.67\) (this value is also close to that found from the analytical fit shown in Fig. 1) and below we take precisely this redshift as a completeness limit for the sample of interacting galaxies (both for galaxies with tidal tails and M51-type objects).

2.2. Estimating the evolution rate

To study the evolution of the frequency of galaxies with tidal structures, we used the same approach as that in Reshetnikov (2000a, 2000b). The meaning of this method is that, having fixed the space density of objects of some type at \(z = 0\), the expected number of such galaxies is estimated within the selected field.
in a given $z$ range for different space density evolution laws. By comparing the actual and expected numbers of objects, we can obtain a constraint on the density evolution law. Below, we assume that the space density of galaxies varies with $z$ as $n(z) = n_0 \times (1 + z)^m$ and estimate the exponent $m$.

An important stage in estimating the evolution rate is to determine the local density of galaxies $n_0$. Unfortunately, for galaxies with tidal structures, this quantity is known relatively poorly. In addition, it depends on the brightness level at which the structure is distinguished: for example, at a brightness level of $\sim 28^m/\sigma''$, more than 10% of spiral galaxies exhibit various kinds of external structures (Miskolezí et al. 2011). In our paper, we used the results of Nair and Abraham (2010), who performed a detailed visual classification of approximately 14000 galaxies from the Sloan Digital Sky Survey; they also provided the frequency statistics of galaxies with tidal tails (see Table 4 in their paper). According to Nair and Abraham, the visually distinguishable tidal tails are seen in 301 of 14034 galaxies, i.e., in about 2% of the galaxies. As the luminosity function of nearby galaxies, we take the results of the 2dF survey (Norberg et al. 2002) and assume that the fraction of galaxies with tidal tails in any luminosity range is 0.02.

When nearby and distant galaxies are compared, the possible evolution of their luminosity with $z$ should be taken into account. Studies of the Tully-Fisher relation and the luminosity function of distant galaxies show that the galaxies at $z \sim 1$ were approximately $1^m$ brighter (see, e.g., Gabasch et al. 2004; Miller et al. 2011). Therefore, to properly compare the space densities of galaxies at different $z$, this effect should be taken into account. As a model for the luminosity evolution of spiral galaxies, we used the results of Bicker et al. (2004). In the redshift range of interest ($z < 0.7$), the predictions of the model by Bicker et al. for the luminosity evolution of Sb-Sc spirals ($\Delta M(B) \propto (1^m - 1^m) \times z$) are close to the actually observed changes.

Table 1 presents the final results of determining the exponent $m$ from the statistics of galaxies with tidal tails within the deep fields we considered (their total angular area is $\Omega = 6.83 \times 10^{-5}$ sr) at $z \leq 0.67$. As the errors in $m$, the table provides the range of variation in the exponent in the case of a Poissonian error in the number of objects in the field ($\pm \sqrt{N}$); the total number of galaxies in a given luminosity range is given in parentheses ($N$); the first and second rows give the value of $m$ in the absence of luminosity evolution (only the $k$-correction was applied to the absolute magnitudes) and with its allowance. As we see from the table, allowance for the luminosity evolution changes the $m$ estimates, but not too much, approximately by 10%.

### Table 1. Results of the determination of the parameter $m$

| Sample                        | $-18^m \geq M_B \geq -20^m$ | $M_B \leq -18^m$ |
|-------------------------------|-------------------------------|------------------|
| Galaxies with tidal tails     | $2.56^{+0.17}_{-0.18}$ (198) | $2.93^{+0.14}_{-0.13}$ (278) |
| M51-type galaxies             | $2.97^{+0.43}_{-0.52}$ (27)  | $3.13^{+0.37}_{-0.46}$ (34)  |
|                               | $2.69^{+0.45}_{-0.56}$ (24)  | $2.48^{+0.43}_{-0.54}$ (26)  |

### 3. The frequency of M51-type galaxies

M51-type galaxies are binary systems that consist, as a rule, of a bright spiral galaxy with a relatively low-mass satellite located near the end of one of its spiral arms (Klimanov and Reshetnikov 2001). In the nearby Universe, such systems are relatively rare (only about 0.3% of all galaxies can be attributed to this type; see Klimanov 2003). However, they are convenient objects for studying a number of questions in the physics of galaxies (e.g., the spiral arms formed by tidal perturbations, the effects of satellites on the structure and star formation in galaxies).

As in the case of galaxies with tidal tails, the sample of M51-type galaxies is based on the catalog by Mohamed and Reshetnikov (2011); see the examples in Fig. 2. The sample includes 74 such binary systems (the distributions of galaxies in $z$ and $M(B)$ are shown in Fig. 1). Figure 3 compares the distributions of nearby (32 binary systems; see Klimanov and Reshetnikov 2001) and distant galaxies in ratio of the observed luminosity of the satellite to the luminosity of the main galaxy ($L_s/L_m$) and in relative distance to the satellite ($R/r$). As we see from the figure, the distributions are, on the whole, similar. The corresponding means are $\langle L_s/L_m \rangle = 0.19 \pm 0.21$, $\langle R/r \rangle = 1.34 \pm 0.48$ (nearby galaxies) and $0.22 \pm 0.18$, $1.26 \pm 0.53$ (distant galaxies).

The local space density $n_0$ of M51-type galaxies was found from their luminosity function. According to Klimanov (2003), the $B$-band luminosity function can be described by a Schechter function with the
4 V.P. Reshetnikov, Y.H. Mohamed: Interacting galaxies

4. Discussion

4.1. Galaxies with tidal tails

Let us consider how our data agree with the results of other works. Methodically, the closest work is the paper by Reshetnikov (2000b), in which it was found from the statistics of 25 galaxies with tidal tails in HDF-N and HDF-S that \( m = 3.6^{+1.2}_{-0.9} \). To properly compare the results, we should take into account the fact that Reshetnikov (2000b) assumed the galaxies with tidal tails to account for 1% of the field galaxies. If this estimate is doubled (see Sect. 2.2), then the \( m \) estimate will decrease approximately by a factor of 1.5 and will be consistent with our results. The results of several recent works, in which the morphological approach, i.e., the statistics of signatures of gravitational perturbations and mergers, was used to estimate \( m \) at \( z \sim 1 \) are summarized in Table 2 (see also references in these papers). The first, second, third, fourth, fifth, and sixth columns of this table give, respectively, the references, the type of objects (‘m’ for mergers, ‘rg’ for ring galaxies, ‘ts’ for tidal structures, ‘tt’ for tidal tails), the number of galaxies in the sample of interacting galaxies (if it is given in the original paper), the redshift range, the range of \( M(B) \) or another similar characteristic (the infrared luminosity, the mass of stars), and \( m \). Our results on M51-type galaxies were not included in Table 2, because they should be compared with the statistics of close pairs.

As we see from Table 2, the works on the statistics of tidal structures (this paper and the paper by Bridge et al. 2010) yield very similar results. Bridge et al. performed a visual classification of about 27 000 galaxies with \( i \leq 22.77 \) in a sky region with an area of 2\(^\circ\) (the CFHTLS-Deep project). As a result, they identified more than a thousand interacting galaxies with \( z \) from 0.1 to 1.2. Comparing the number of
Table 2. Values of $m$ from different sources

| Reference                     | Type of objects | $N$ | $\Delta z$ | $\Delta M(B)$ | $m$     |
|-------------------------------|-----------------|-----|-------------|----------------|---------|
| Conseilce et al. (2003)       | m               | 25  | $\leq 1$    | $\leq -18^m$   | $2.5 \pm 0.3$ |
| Lavery et al. (2004)          | rg              | 25  | 0.1–1.0     | $L_{IR} > 5 \cdot 10^{10} L_\odot$ | $5.2 \pm 0.7$ |
| Bridge et al. (2007)          | m               | 64  | 0.2–1.3     | $\leq -19^m$   | $3.8 \pm 1.2$ |
| Kampczyk et al. (2007)        | m               | 68  | $\leq 0.7$  | $\leq -18.94 – 1.3z$ | $0.23 \pm 1.03$ |
| Lotz et al. (2008)            | m               | 402 | 0.2–1.0     | $> 10^9 M_\odot$ | $2.3 \pm 0.4$ |
| Conseilce et al. (2009)       | m               |     | 0.2–1.2     | $\leq -20^m$   | $2.9 \pm 0.8$ |
| López-Sanjuan et al. (2009a)  | m               | 25  | 0.35–0.85   | $< 20^m$       | $1.8 \pm 0.5$ |
| López-Sanjuan et al. (2009b)  | m               | 61  | 0.2–1.1     | $< 20^m$       | $2.56 \pm 0.24$ |
| Bridge et al. (2010)          | ts              | 1075| 0.25–1.0    | $> 10^{9.5} M_\odot$ | $2.60^{+0.15}_{-0.16}$ |
| This paper                    | tt              | 243 | $\leq 0.67$ | $< -18^m$      | $2.71^{+0.16}_{-0.17}$ |

Fig. 3. Top: Ratio of the luminosity of the satellite to the luminosity of the main galaxy for the samples of nearby (black solid line) and distant (red dashed line) M51-type galaxies. Bottom: Ratio of the distance to the satellite ($R$) to the radius of the main galaxy ($r$) for M51-type galaxies (the notation is the same).

The derived dependence is described by the exponent $m = 2.25 \pm 0.24$; however, if the least reliable intervals near the beginning and the end of the investigated $z$ range are eliminated, then $m = 2.56 \pm 0.24$ (this value is given in Table 2). Note also that Bridge et al. (2010) considered galaxies with stellar masses $> 10^9.5 M_\odot$ (Table 2). Our approach to estimating $m$ and the observational data used were completely different, but the results turned out to be close.

The paper by Lavery et al. (2004) on collisional ring galaxies gives a very large value of $m$. However, the sample of galaxies they used is small. In addition, the type of interaction itself in which one of the galaxies passes through the center of the other at a high velocity is so rare that the local space density of such objects and, consequently, the value of $m$ are known poorly.

The statistics of merging galaxies (mergers) also, on the whole, is indicative of relatively large ($\approx 2–4$) $m$ (Table 2). The only exception is the paper by Lotz et al. (2008); however, there are several factors (e.g., a strong dependence of the result on the data in two bins with the lowest $z$) that may explain this discrepancy (for a discussion, see Bridge et al. 2010). As a result, we may conclude that the works of recent years give a relatively consistent picture of the growth of the frequency of morphological signatures of interactions and mergers up to $z \sim 1$. Most of the results agree, within the error limits, with $m \approx 2.6$. The statistics of binary systems, including M51-type galaxies (this paper), also yields similar results, $m \sim 3$ (Le Fèvre et al. 2000; Kartaltepe et al. 2007; de Ravel et al. 2011).
The conversion from the observed fraction of interacting and merging galaxies to the galaxy merger rate \(R_{\text{mg}}\) is usually accomplished through the timescale \(t_v\) on which the galaxies appear morphologically peculiar (e.g., exhibit distinguishable tidal structures): 
\[ R_{\text{mg}}(z) = \delta(z)/t_v, \]
where \(\delta(z)\) is the fraction of interacting galaxies at redshift \(z\). For galaxies with tidal tails, we assumed that \(\delta_0 = 0.02; \) at \(m = 2.6\) for galaxies with \(M(B) \leq -18^m\) (Table 2), we then obtain \(\delta(z = 0.7) = 0.08\). As the time during which the galaxies exhibit noticeable tidal tails, we take, according to Bridge et al. (2010), \(t_v = 0.8\) Gyr. (Of course, this estimate is very uncertain, because it depends, in particular, on the mass ratio of the interacting galaxies, the gas fraction in them, the method of identifying tidal structures, etc.) For the galaxy merger rate at \(z = 0.7\), we then obtain \(R_{\text{mg}} \approx 0.1\) mergers per galaxy during 1 Gyr. This estimate agrees well with the data of other authors obtained by different methods (see Fig. 11 in Bridge et al. 2010). If we pass to a unit volume, then the merger rate is \(\sim 10^{-3}/(\text{Gyr} \times \text{Mpc}^3)\).

Using the above numbers, we can estimate the averaged history of interactions for the galaxies of our sample. Integrating the fraction of interacting galaxies at different \(z\) by taking into account the timescale \(t_v\) (see Eq. (3) in Bridge et al. 2010), we found that a typical galaxy with \(M(B) \leq -18^m\) in the \(z\) range from 0.7 to 0.0 (a time of 6–7 Gyr corresponds to this range) underwent \(\sim 0.35\) mergers or close encounters accompanied by the formation of extended tidal tails. In other words, a third of bright galaxies have undergone strong gravitational perturbations and mergers in the last 6–7 Gyr.

In the above simple estimates, there is one, previously almost undisputed uncertainty: the timescale \(t_v\) can depend on \(z\). As was shown by Mohamed et al. (2011), the tidal structures in distant galaxies, on average, appear shorter than those in nearby objects. One of the possible causes is observational selection due to the cosmological brightness dimming and the influence of the \(k\)-correction. As a result of this selection, in distant galaxies we predominantly observe a relatively early evolutionary stage of the tails, when they have a high surface brightness, while in nearby galaxies we see, on average, “older” and longer structures.

To quantitatively estimate the influence of this effect on \(R_{\text{mg}}\), we used the results of the calculations by Mihos (1995). Mihos showed that the tidal tails should be visible in the HST exposures only for \(\sim 150\) Myr at \(z = 1\) and for about 350 Myr at \(z = 0.4\). Assuming that \(t_v = 800\) Myr for \(z = 0\) (see above), we can obtain the following simple approximation for the \(z\) dependence of \(t_v\): 
\[ t_v = a \exp(-z/b) + c, \]
where \(a = 0.7, \ b = 0.4, \ c = 0.095,\) and the timescale \(t_v\) is in Gyr. For \(z = 0.7\), it follows from this approximation that \(t_v = 0.22\) Gyr and, accordingly, \(R_{\text{mg}} \approx 0.36\) mergers per galaxy during 1 Gyr. For the full history of mergers between \(z = 0.7\) and \(z = 0.0\), we obtain an estimate of \(\sim 0.75, \) i.e., \(3/4\) of all galaxies with \(M(B) \leq -18^m\) must have undergone mergers in the last 6–7 Gyr.

4.2. M51-type galaxies

Let us now consider M51-type galaxies. As we showed in this paper, their space density at \(z \leq 0.7\) evolves with \(m = 2.5 – 2.7\) (Table 1). Assuming that \(m = 2.6\) and \(\delta_0 = 0.003\) (Klimanov 2003), we can estimate that the relative fraction of such galaxies is 0.012 at \(z = 0.7\) and 0.014 at \(z = 0.8\). Recently, López-Sanjuan et al. (2011) presented the results of direct counts of faint satellites (with luminosities from 0.1 to 0.25 of the luminosity of the central galaxy) for various distances from the main galaxy for galaxies with \(M(B) \leq -20^m\) at \(z = 0.5\) and \(z = 0.8\) based on the VIMOS VLT data (VVDS-Deep survey). Extrapolating these counts to 15 kpc (most of the satellites in our sample of M51-type galaxies are within this distance), we can estimate that the fraction of such galaxies at \(z = 0.8\) is \(\approx 0.02\). Given the large errors in such estimates (different methods of identifying objects, different constraints on their luminosity, etc.), the agreement between the estimates of the fraction of galaxies with relatively low-mass satellites at \(z = 0.8\) may be recognized to be satisfactory.

The satellites near the outer boundary of the stellar disks in the main galaxies must be rapidly swallowed. The characteristic merger timescale is \(\sim 0.2–0.4\) Gyr (see, e.g., Lotz et al., 2010). Consequently, the merger rate estimate for M51-type galaxies at \(z = 0.7\) is \(R_{\text{mg}} \approx 0.03 – 0.06\) per galaxy brighter than \(M(B) = -18^m\) in 1 Gyr. López-Sanjuan et al. (2011) give a similar value: the minor merger rate at \(z = 0.5 – 0.8\) is 0.0045–0.034 (Table 8 in their paper). The total expected number of mergers per galaxy at \(z < 0.7\) is \(0.1–0.2\). Therefore, M51-type galaxies make a noticeable and non-negligible (compared to major mergers) contribution to the galaxy merger rate at \(z = 0.7\). Of course, this conclusion is very sensitive to the satel-
lite merger timescale. If, for instance, it is close to 1 Gyr (Kitzbichler and White 2008), then the merger rate through M51-type galaxies decreases by several times.

5. Conclusions

Based on a large sample of distant galaxies with tidal tails and M51-type galaxies (spiral galaxies with a relatively low-mass satellite located near the end of one of the spiral arms), we estimated the evolution of the space densities of objects of these types up to $z = 0.7$. It turned out that their observed densities increase with redshift approximately as $(1 + z)^{2.6}$.

At $z = 0.7$, the merger rate leading to the formation of extended tidal tails is $\approx 0.1$ per galaxy brighter than $M(B) = -18^m$ in 1 Gyr. The corresponding merger rate for M51-type galaxies is approximately a factor of 2–3 lower.

In the last 6–7 Gyr, i.e., at $z \leq 0.7$, about a third of the galaxies with $M(B) \leq -18^m$ must have undergone strong gravitational perturbations and mergers; $\sim 1/10$–1/5 of the galaxies swallowed nearby satellites with $L_s/Lm \approx 0.1$–0.2. Such processes are capable of radically changing the characteristics of galaxies (Toomre, 1977) and stimulating the processes of star formation and nonthermal activity of the nuclei (see, e.g., Keel et al. 1985).

The estimates of the galaxy merger rate depend strongly on the adopted timescale on which they appear peculiar ($t_v$). For instance, allowance for the possible redshift dependence of $t_v$ (the identification time of tidal structures decreases with increasing $z$) can increase the above merger rates by several times.

The high galaxy merger rates found from observations of distant objects clearly suggest that gravitational interactions and mergers were among the most important processes that determined the individual properties of the galaxies surrounding us. Furthermore, they affect the evolution of the "luminous" matter in the Universe as a whole, because mergers change the luminosity function of galaxies, the luminosity density produced by them, and other characteristics.

Acknowledgments

This work was supported in part by the "Bourse de la Ville de Paris" programme.

REFERENCES

1. C.M. Baugh and G. Efstathiou, Mon. Not. R. Astron. Soc. 265, 145 (1993).
2. J. Bicker, U. Fritz–v. Alvensleben, et al., Astron. Astrophys. 413, 37 (2004).
3. C.R. Bridge, P.N. Appleton, C.J. Conselice, et al., Astrophys. J. 659, 931 (2007).
4. C.R. Bridge, R.G. Carlberg, and M. Sullivan, Astrophys. J. 709, 1067 (2010).
5. Ch.J. Conselice, M.A. Bershady, M. Dickinson, and C. Papovich, Astron. J. 126, 1183 (2003).
6. Ch.J. Conselice, C. Yang, and A.F.L. Bluck, Mon. Not. R. Astron. Soc. 394, 1956 (2009).
7. O. Fakhouri and Ch.-P. Ma, Mon. Not. R. Astron. Soc. 386, 577 (2008).
8. A. Gabasch, R. Bender, S. Seitz, et al., Astron. Astrophys. 421, 41 (2004).
9. J.E. Hibbard and W.D. Vacca, Astron. J. 114, 1741 (1997).
10. P. Kampeczyk, S.J. Lilly, C.M. Carollo, et al., Astrophys. J. Suppl. Ser. 172, 329 (2007).
11. J.S. Kartaltepe, D.B. Sanders, N.Z. Scoville, et al., Astrophys. J. Suppl. Ser. 172, 320 (2007).
12. W.C. Keel, R.C. Kennicutt, E. Hummel, and J.M. van der Hulst, Astron. J. 90, 708 (1985).
13. M.G. Kitzbichler and S.D.M. White, Mon. Not. R. Astron. Soc. 391, 1489 (2008).
14. S.A. Klimanov, Astrofizika 46, 191 (2003).
15. S.A. Klimanov and V.P. Reshetnikov, Astron. Astrophys. 378, 428 (2001).
16. R.J. Lavery, A. Remijan, V. Charmandaris, et al., Astrophys. J. 612, 679 (2004).
17. O. Le Fèvre, R. Abraham, S. J. Lilly, et al., Mon. Not. R. Astron. Soc. 311, 565 (2000).
18. C. López-Sanjuán, M. Balcárs, C.E. García-Dabo, et al., Astrophys. J. 694, 643 (2009a).
19. C. López-Sanjuán, M. Balcárs, P.G. Pérez-Ganzále, et al., Astron. Astrophys. 501, 505 (2009b).
20. C. López-Sanjuán, O. Le Fèvre, L. de Ravel, et al., Astron. Astrophys. 530, A20 (2011).
21. J.M. Lotz, M. Davis, S.M. Faber, et al., Astrophys. J. 672, 177 (2008).
22. J.M. Lotz, P. Jonsson, T.J. Cox, and J.R. Primack, Mon. Not. R. Astron. Soc. 404, 575 (2010).
23. H.J. McCracken, M. Radovich, E. Bertin, et al., Astron. Astrophys. 410, 17 (2003).
24. N. Metcalfe, T. Shanks, A. Campos, et al., Mon. Not. R. Astron. Soc. 323, 795 (2001).
25. J.Ch. Mihos, Astrophys. J. 438, L75 (1995).
26. S.H. Miller, K. Bundy, M. Sullivan, et al., Astrophys. J. (2011, in press); arXiv:1102.3911v1.
27. A. Miskolczi, D.J. Bomans, and R.-J. Dettmar, Astron. Astrophys., (2011, in press); arXiv:1102.2905v1.
28. H. Mo, F. van den Bosch, and S.D.M. White, Galaxy Formation and Evolution (Cambridge Univ. Press, Cambridge, 2010).
29. Y.H. Mohamed and V.P. Reshetnikov, Astrophysics 54, 155 (2011).
30. Y.H. Mohamed, V.P. Reshetnikov, and N.Ya. Sotnikova, Astron. Lett. 37 (2011); arXiv:1108.6155v1.
31. P.B. Nair and R.G. Abraham, Astrophys. J. Suppl. Ser. 186, 427 (2010).
32. P. Norberg, Sh. Cole, C.M. Baugh, et al., Mon. Not. R. Astron. Soc. 336, 907 (2002).
33. L. de Ravel, P. Kampczyk, O. Le Fèvre, et al., Astron. Astrophys. (2011, in press); arXiv:1104.5470v1.
34. V.P. Reshetnikov, Astron. Astrophys. 321, 749 (1997).
35. V.P. Reshetnikov, Astron. Lett. 26, 61 (2000a).
36. V.P. Reshetnikov, Astron. Astrophys. 353, 92 (2000b).
37. V.P. Reshetnikov and R.-Yu. Dettmar, Astron. Lett. 33, 222 (2007); arXiv:astro-ph/0703784v1.
38. A. Toomre, Evolution of Galaxies and Stellar Populations, Ed. by B.M. Tinsley and R.B. Larson (Yale Univ. Observ., New Haven, 1977).
39. S.D.M. White and M.J. Rees, Mon. Not. R. Astron. Soc. 183, 341 (1978).
40. S.E. Zepf and D.C. Koo, Astrophys. J. 337, 34 (1989).