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2016 Res. Astron. Astrophys. 16 003

(http://iopscience.iop.org/1674-4527/16/5/003)

RAA 2016 Vol. **16** No. **5**, 72 (8pp) doi: 10.1088/1674–4527/16/5/072
http://www.raa-journal.org *http://iopscience.iop.org/raa*

Research in Astronomy and Astrophysics

An isolated compact galaxy triplet

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Received 2015 June 23; accepted 2015 December 4

Abstract We report the discovery of an isolated compact galaxy triplet SDSS J084843.45+164417.3, which is first detected by the LAMOST spectral survey and then confirmed by a spectroscopic observation of the BFOSC mounted on the 2.16 meter telescope located at Xinglong Station, which is administered by National Astronomical Observatories, Chinese Academy of Sciences. It is found that this triplet is an isolated and extremely compact system, which has an aligned configuration and very small radial velocity dispersion. The member galaxies have similar colors and show marginal star formation activities. These results support the opinion that the compact triplets are well-evolved systems rather than hierarchically forming structures. This serendipitous discovery reveals the limitations of fiber spectral redshift surveys in studying such a compact system, and demonstrates the necessity of additional observations to complete the current redshift sample.

Key words: galaxies: group — galaxies: interaction — galaxies: star formation — galaxies: evolution

1 INTRODUCTION

A galaxy triplet constitutes the simplest galaxy group and the smallest N-body system that cannot be modeled analytically. In general, triplets have not received much attention in contrast to close pairs or rich groups of galaxies. So, the basic scenario describing their formation and evolution is still ambiguous. According to the popular hierarchical structure formation theory, it is naturally presumed that a triplet is formed through a close galaxy pair accreting a third remote galaxy. However, some recent evidence suggests that for lots of triplets, their member galaxies have similar properties and are supposed to be the remains of a long evolved dynamical system within a common dark matter halo (e.g. Duplancic et al. 2015 and Aceves 2001).

The first catalog of galaxy triplets was compiled by Karachentseva et al. (1979) and Karachentsev et al. (1988), which contains 84 isolated galaxy triplets from the northern hemisphere. These triplets were selected by visual inspection of Palomar Sky Survey plates, whose member galaxies have apparent magnitudes brighter than 15.7. About 64% of these targets were considered to be physical triplets with $\Delta v_{ij} < 500\ \mathrm{km\ s^{-1}}$ (Karachentsev & Karachentseva 1981, hereafter the K-sample). Based on this catalog, the basic properties of the galaxy triplets, e.g. integrated luminosity, diameter, velocity dispersion, as well as the spatial configuration, dynamics and dark matter content, have been estimated and discussed in detail (Karachentseva & Karachentsev 1982; Karachentseva & Karachentsev 1983; Karachentsev 1990; Chernin & Mikkola 1991; Anosova et al. 1992; Zheng et al. 1993 and Aceves 2001). For the southern sky ($\delta < 3^\circ$), similar works have also been done on a sample of 76 isolated triplets, which are selected from the European Southern Observatory/Science and Engineering Research Council (ESO/SERC) and Palomar Observatory Sky Survey first release (POSS-I) (Karachentseva & Karachentsev 2000).

O'Mill et al. (2012) constructed a catalog of triplets with their primary galaxies ($Mr < -20.5$), hereafter called the O-sample, selected from a volume-limited sample in the Sloan Digital Sky Survey Data Release 7 (SDSS-DR7) (Abazajian et al. 2009). This catalog is comprised of 1092 triplets in a redshift range of $0.01 \leq z \leq 0.14$. However, due to the problem of fiber collision in SDSS (with a minimum separation of $55''$ between any two fibers), most of the companion galaxies in these systems were selected by only using their photometric redshifts ($z_{\rm phot}$). As a result of the relatively large uncertainty of $z_{\rm phot}$ (~ 0.0227), this catalog is inevitably contaminated by "projected triplets" and yet, in another respect, some of the real triplets could have been missed. In the O-sample, about one tenth of the triplets have spectroscopic redshifts for all their members. Duplancic et al. (2013, 2015) analyzed the configuration and dynamics of this sub-sample, and compared them with galaxy pairs and clusters. They found that the triplet galaxy members are more similar to the galaxies in compact groups and rich clusters than in galaxy pairs and concluded that the galaxy triplets may not be formed hierarchically. Very recently, Argudo-Fernández et al. (2015) published a sample of 315 isolated triplets in the local Universe ($z \leq 0.080$) using the spectroscopic redshifts ($z_{\rm spec}$) from SDSS DR 10 (hereafter the A-sample). In this sample, galaxies are considered to be physically bound to the primary galaxy at a projected separation up to $d \leq$450 kpc with a radial velocity difference of $\Delta v \leq 160\,{\rm km\,s^{-1}}$.

Given the limited data and studies summarized above, there are still not enough pieces to solve the puzzles of the formation and evolution scenario of the galaxy triplets. Any additional sample of physical triplets, especially compact cases, will be valuable for contributing to knowledge about this kind of system.

The galaxy system SDSS J084843.45+164417.3 (hereafter J0848+1644), which contains galaxies A, B and C (see Fig. 1 for details), is the spectroscopic triplet we report on and study in this paper. This triplet is not included in the A-sample because these three galaxies have very small angular distances and only galaxy B has a spectrum in SDSS, $z_{\rm spec} = 0.078829 \pm 0.000015$ (SpecObjID: 2565950139160094720) (Abazajian et al. 2009). Also, it is excluded from the O-sample since values for the $z_{\rm phot}$ of the other two galaxies ($z_{\rm phot} = (0.32, 0.08, 0.19)$ for galaxies A, B and C respectively) are all very different from $z_{\rm spec}$ of galaxy B. This galaxy triplet was reported as a galaxy pair in Shen et al. (2015), where they started a project that aims to compile the spectroscopic redshifts of all the main samples of galaxies ($r < 17.77$) that do not yet have redshifts measured in SDSS DR7 due to the problem of fiber collision. Their new redshift survey is being collected with the Guo Shou Jing Telescope (also known as the Large Sky Area Multi-Object Fiber Spectroscopic Telescope, hereafter LAMOST, Cui et al. 2012). Galaxy C is included in the complementary galaxy sample of the LAMOST spectral survey and its spectrum has been released in the LAMOST DR1 with $z_{\rm spec}$ = 0.07929 (Obsid: 78907168) (Luo et al. 2015)[1]. During the visual inspection of the galaxy pairs in Shen et al. (2015), we find that, including galaxy A, they very probably form a compact triplet system.

We have performed a follow-up spectroscopic confirmation of this triplet using the 2.16 meter optical telescope (hereafter 2.16 m) at Xinglong Station, administered by National Astronomical Observatories, Chinese Academy of Sciences (NAOC). In this paper, we first report the data from the spectroscopic observation on 2.16 m. After that, we combine all optical photometric and spectroscopic data and make a detailed study of this triplet. This paper is organized as follows. In Section 2, we describe the photometric and spectroscopic data of J0848+1644 and the measurements of the basic features of its members. In Section 3, we derive the global properties of this triplet, such as the compactness, configuration, environment, dynamical status, star formation rate (SFR), etc. Finally, we present discussions in Section 4 and list a summary in Section 5. Throughout this paper, we use cosmological parameters Ω_Λ = 0.7, Ω_M= 0.3 and $h = 0.7$.

[1] Based on SDSS DR7 photometry, galaxy C (r=17.06) belongs to the main galaxy sample whereas galaxy A (r=18.45) does not.

2 OBSERVATIONS AND DATA REDUCTION

In this section, we describe the observation of triplet J0848+1644 from the 2.16 m telescope and our new photometric data reduction that is applied to the SDSS images. All measurements of individual member galaxies are summarized in Table 1.

2.1 Spectroscopy

2.1.1 Observations

Our follow-up spectroscopic observation was taken by the BAO Faint Object Spectrograph and Camera (hereafter BFOSC), that is mounted on the 2.16 m optical telescope, on 2013 Dec. 31. The long slit of BFOSC is 1.8$''$ wide and covered all three galaxies simultaneously (as shown in Fig. 1). The spectral wavelength coverage is from 3870 to 6760 Å, and the resolution is $R \sim 700$ at 5000 Å.

The spectroscopic data were reduced following the standard procedures using the NOAO Image Reduction and Analysis Facility (IRAF, version 2.16) software package, including the bias and flat-field correction of the CCD and cosmic-ray removal. Wavelength calibration was performed by comparing with the ferrum/argon lamp spectra, which was exposed at both the beginning and end of that observation. Flux calibration of all spectra was performed using the additional observation of the standard star, Feige 34. The atmospheric extinction was corrected with the mean extinction coefficients for Xinglong Station.

The resultant 1D spectra have typical S/N $\sim$ 14. For galaxy B, we plot the spectrum of SDSS (see Fig. 2) for comparison. These two spectra match very well in their overlapping wavelength range, which also demonstrates the reasonability of our flux calibration of BFOSC.

2.1.2 Radial velocities and emission line strengths

To get the redshift measurements from the BFOSC spectra, we first measure the radial velocities of each individual emission or absorption line (z_l) by using the IRAF package `splot`. The redshift of each galaxy is then calculated by averaging the results of all its adopted spectral lines, $z = \langle z_{\rm l} \rangle$, and the error is estimated from their dispersion, $z_{\rm err} = \sigma_{z_{\rm l}}/\sqrt{N_{\rm l}}$. Some of the identified lines are not strong enough or are blended with sky lines, and therefore

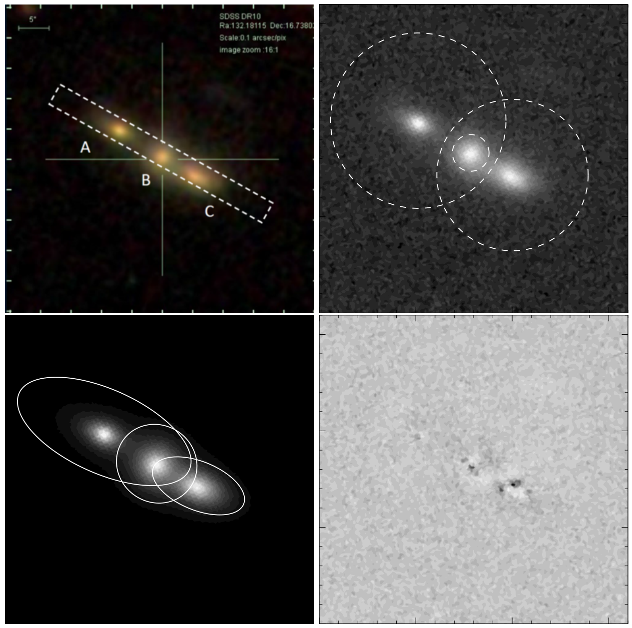

Fig. 1 Images of J0848+1644. *Top Left:* The optical image combined with SDSS g, r, i bands. The letters (A, B and C) labeled in the figure are used to denote the members of the triplet. The white dashed rectangle indicates the position of the long slit of the BFOSC that is mounted on the 2.16 m telescope. The $5''$ scale line at the top-left corner corresponds to 8.2 kpc at the redshift of this triplet. *Top Right:* The r-band SDSS frame image where the dashed circles indicate the Petrosian R_{90} from SDSS. *Bottom Left:* The best fitting model made by GALFIT where the solid lines indicate the isophotal ellipses enclosing 90% of the total model flux of individual galaxies. *Bottom Right:* Residual image of the best fitting; the grey scale from black to white indicates -5% to 8% of the maximum flux in the model image.

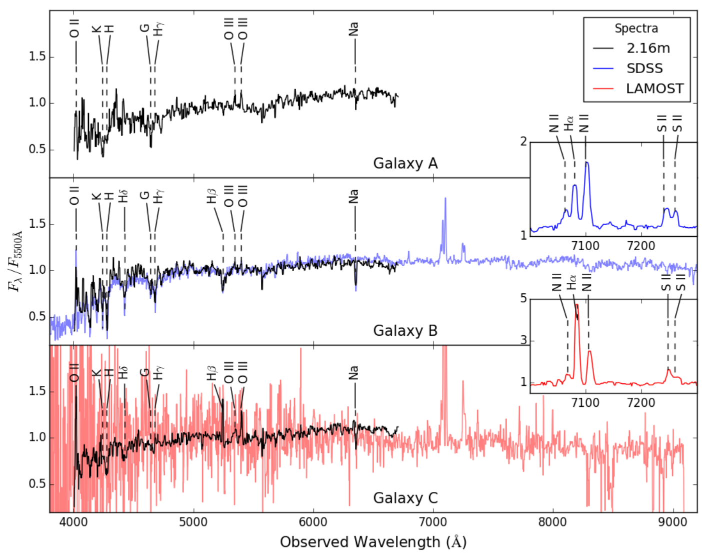

Fig. 2 The optical spectra of member galaxies of J0848+1644. The black lines are the spectra of the BFOSC that is mounted on the 2.16 m telescope. The blue and red lines are taken from SDSS for galaxy B and LAMOST for galaxy C respectively. All the spectra are normalized at 5500 Å and smoothed with a width of 11 Å. The redshifts of individual spectra are estimated by averaging the measurements of multiple spectral lines, whose species names are labeled with corresponding spectra in three main panels. Additionally, we show some spectral lines of SDSS and LAMOST spectra in small panels which are not covered by the 2.16 m telescope.

have not been used in the redshift calculation. The final adopted spectral lines for each spectrum are labeled in the main panels of Figure 2 and the redshift results are listed in Table 1. For galaxy B, the BOSFC redshift is in excellent agreement with the SDSS value ($z_{\rm SDSS} = 0.078829$). For galaxy C, the BOSFC redshift is also consistent with the LAMOST value ($z_{\rm LAMOST} = 0.0793$). Considering the internal consistency of the BOSFC spectra, we only take the BOSFC redshifts to study the kinematics and dynamics of J0848+1644 below.

Table 1 Observational and Derived Parameters of Individual Members of J0848+1644

Parameter	Unit	galaxy A	galaxy B	galaxy C
RA (J2000)	hh:mm:ss.ss	08:48:43.94	08:48:43.45	08:48:43.08
DEC (J2000)	dd:mm:ss.ss	+16:44:21.76	+16:44:17.36	+16:44:14.18
d_i [a]	kpc	13.97	–	10.44
$z_{\rm SDSS}$			0.078829±0.000015	
$z_{\rm LAMOST}$ [b]				0.07929
z		0.07852±0.00015	0.07848±0.00016	0.07883±0.00017
$v_{\rm r}$	km s^{-1}	23557±45	23544±48	23650±51
F(OII)	10^{-17} erg s^{-1} cm^{-2}	200.4	453.6	1396.1
$m_{\rm r}$ [c]		17.32	17.00	16.99
n_s [c]		6.0	2.1	1.6
$R_{\rm e}$ [c]	kpc	3.6	2.6	3.6
b/a [c]		0.45	0.94	0.50
θ [c]	degree	5.3	–5.2	7.6
$R_{a,90}$ [d]	kpc	21.0	9.0	11.0
$R_{c,90}$ [e]	kpc	14.9	8.9	8.3
$g-r$		0.75	0.77	0.78
log($M_*/M_\odot$) [f]		10.51	10.66	10.67
SFR [g]	$M_\odot\cdot$ yr^{-1}	0.38	0.86	2.64
log(SFR/M_*)		–10.9	–10.7	–10.3

[a] Projected distance from the central galaxy B.
[b] The redshift error of galaxy C is not provided in LAMOST DR1.
[c] Fitting parameters that were derived from GALFIT by modeling the r-band image with three Sersic profile components.
[d] Major axis of ellipse enclosing 90% of the model flux in the r-band.
[e] Radius of circle enclosing 90% of the model flux in the r-band.
[f] Stellar mass estimated according to Bell et al. (2003).
[g] Estimated from F (OII).

Besides the redshifts, the fluxes of OII emission lines of three BFOCS spectra have also been measured through a Gaussian fit and the correction of the long slit effect, which will be used as diagnostics of the current SFR of each galaxy.

2.2 Photometric measurements

The SDSS catalog has released a variety of photometric measurements for each galaxy, e.g. the Petrosian and model system (Stoughton et al. 2002; Abazajian et al. 2009). However, it is found that the SDSS photometric measurements have not been optimized for galaxies with close neighbors (Patton et al. 2011).

For J0848+1644, the galaxies A, B and C have sizes R_{90} (the circular aperture including 90% of the Petrosian flux) of 8.87, 1.84 and 7.65 arcsec respectively (the dashed circles in Fig. 3). The underestimation of the size of galaxy B is because the SDSS algorithm applies photometric measurements to each object after masking its neighbors. So, this small size further leads to an underestimation of the relevant Petrosian magnitude of galaxy B. To avoid such an over-subtraction, we reprocess the photometry of J0848+1644 using the frame image from the SDSS data archive. Rather than one by one, we analyze the photometry of their members simultaneously. We take the Sersic profile for each member galaxy and generate a combined fitting by using the 2D GALFIT routine (Peng et al. 2002).

The fitting results of the r-band image, including the total magnitude ($m_{\rm r}$), the Sérsic index ($n_{\rm s}$), the effective radius of the major axis ($R_{\rm e}$), the ellipticity (b/a) and the position angle of the major axis along the triplet alignment direction (θ), are listed in Table 1. The residual image of the model fitting is shown in the bottom right panel of Figure 1. For comparison, we plot the ellipse with $R_{a,90}$ that encloses 90% of the model flux with solid lines in the bottom left panel. It is clear that our fitting results do not suffer from the over-masking problem, so they should be more reliable for describing the photometric features of these member galaxies.

Similarly, we also fit the SDSS g-band image and further derive the $g-r$ color of each galaxy. The values listed in Table 1 are already corrected for Galactic extinction.

3 PHYSICAL PROPERTIES

In this section, we measure and discuss the global properties of J0848+1644 using the photometric and spectroscopic data described in the previous section, and summarize the results in Table 2.

3.1 Compactness and Configuration

The compactness of a galaxy triplet is defined as a measurement of the percentage of a system's total area that is filled by the light of member galaxies (Duplancic et al. 2013),

$$S = \frac{\sum_{i=1}^{3} R_{90}^2}{R_m^2}, \quad (1)$$

where R_{90} is the radius of a circle enclosing 90% of the model flux of a galaxy and R_m is the radius of the minimum enclosing circle that contains the geometric centers of all member galaxies in the triplet. The R_m of J0848+1644 is 12.2 kpc. Taking the R_{90} of galaxies in the $r-$band from our GALFIT fitting ($R_{c,90}$ in Table 1), the compactness is $S = 2.48$, which is far larger than those from the O-sample, whose median value is ~ 0.05.

It is worth mentioning that, for triplets, the apparent high compactness may be contaminated by the projection effect. Considering the projection, the apparent compactness actually represents its upper limit. At any rate, according to the S value, J0848+1644 has a very high probability of being a highly compact system.

Agekyan & Anosova (1968) suggested an elegant method (AA-map) to analyze the geometric configurations of triplet systems. They defined four types of configurations based on the shape of the triangle formed by their members.

Obviously, J0848+1644 has a chain-like (alignment) configuration (A-type) in the projected 2D AA-map. According to the simulation result of Duplancic et al. (2015), which counts the number of mock triplets in each area of the 3D and 2D AA-map, J0848+1644 has a 75% probability of having a real 3D alignment configuration and only a 5% probability of being located in the hierarchical region (H-type).

3.2 Environment

In environmental studies, a galaxy is typically defined as isolated if there is no neighboring galaxy with a difference in recessional velocity of $\Delta v \leq 500$ km s^{-1} at a particular projected distance, such as 1 Mpc. For J0848+1644, it is certainly an isolated galaxy system, since its nearest neighbor ($M_{\rm r} <$ –19.5) is 3.12 Mpc away.

To further quantify its isolation degree, following Argudo-Fernández et al. (2014), we also calculate another two parameters. One is the number density of neighboring galaxies $\eta_{k,\rm LSS}$, defined as follows

$$\eta_{k,\rm LSS} = \log\left(\frac{k-1}{V(r_k)}\right), \quad (2)$$

where $V(r_k) = \frac{4}{3}\pi r_k^3$ and r_k is the projected distance to the kth nearest neighbor of the large scale structure (LSS), with k equal to 5 or lower if there are not enough neighbors in the field. According to the data from SDSS, there are only four neighboring galaxies ($M_{\rm r} <$ –19.5) around with radial velocities $\Delta v \leq 500$ km s^{-1} in the volume of a 5 Mpc projected distance. For J0848+1644, the large scale number density of neighboring galaxies $\eta_{4,\rm LSS}$ is –2.10, which is much less than the median value of the A-sample ~ -1.4. This result even indicates that J0848+1644 is located in a lower density environment than other isolated triplets.

Another parameter is related to the tidal strength Q on the primary galaxy (here we use the central galaxy B instead) created by its neighbors i in the field

$$Q = \log\Big[\sum_i \frac{M_i}{M_P}\Big(\frac{D_P}{d_i}\Big)^3\Big], \quad (3)$$

where M_i is the stellar mass and d_i is the projected distance of the ith neighbor to the primary galaxy. $D_P = 2\alpha R_{90}$ is the diameter of the primary galaxy. It is scaled by a factor $\alpha = 1.43$ to recover D_{25} (Argudo-Fernández et al. 2014). Obviously, the larger the value of Q is, the less isolated the primary galaxy is.

For the triplet system, there are two measurements of the Q parameter. $Q_{\rm LSS}$ is generated by the neighbors of the triplet up to 5 Mpc, but excludes its own companion galaxies. This is an assessment of the isolation degree of the primary member galaxy in the LSS environment. On the other hand, $Q_{\rm Local}$ only considers two other members of the triplet (galaxies A and C for J0848+1644), which could represent the internal links within the system itself.

Stellar masses of galaxies are estimated by the relationship $\log_{10}(M/L_{\rm r}) = -0.306 + 1.097(g-r)$ from Bell et al. (2003). Thus, the Q parameters of J0848+1644 are $Q_{\rm LSS} = -5.70$ and $Q_{\rm Local} = 1.29$. It is worth mentioning that the $Q_{\rm triplet}$ may be overestimated because of the projection effect.

Compared with galaxy triplets in the A-sample as shown in Figure 3, $Q_{\rm LSS}$ (or $Q_{\rm Local}$) of J0848+1644 is much lower (or higher) than their median value of –5.0 (or –2.0). Additionally, the ratio of $Q_{\rm Local}/Q_{\rm total} = Q_{\rm Local}/(Q_{\rm LSS} + Q_{\rm Local}) \simeq 1.0$ shows uniform values. All these values clearly indicate that J0848+1644 is an extremely compact and isolated system.

3.3 Dynamics

To characterize the dynamics of J0848+1644, we calculate its projected harmonic radius $R_{\rm H}$, radial velocity dispersion $\sigma_{v_{\rm r}}$, dimensionless crossing time $H_0 t_c$ and virial mass $M_{\rm vir}$:

$$R_{\rm H} = \left(\frac{1}{N}\sum R_{ij}^{-1}\right)^{-1}, \quad (4)$$

$$\sigma_{v_{\rm r}}^2 = \frac{1}{N-1}\sum (v_{\rm r} - \langle v_{\rm r}\rangle)^2, \quad (5)$$

$$H_0 t_c = H_0 \pi R_{\rm H}/(\sqrt{3}\sigma_{v_{\rm r}}), \quad (6)$$

$$M_{\rm vir} = 3\pi N R_{\rm H} \sigma_{v_{\rm r}}^2/(N-1)G, \quad (7)$$

where values of R_{ij} are the projections of galaxy-galaxy separation and $N = 3$ for the triplet.

Based on the $v_{\rm r}$ results from the BFOSC spectra (see Table 1 for details), we have $R_{\rm H} = 14.5$ kpc and $\sigma_{v_{\rm r}} = 58.1$ km s^{-1}. Then, we can derive another two parameters, $H_0 t_c = 0.032$ and $\log(M_{\rm vir}/M_\odot) = 11.2$.

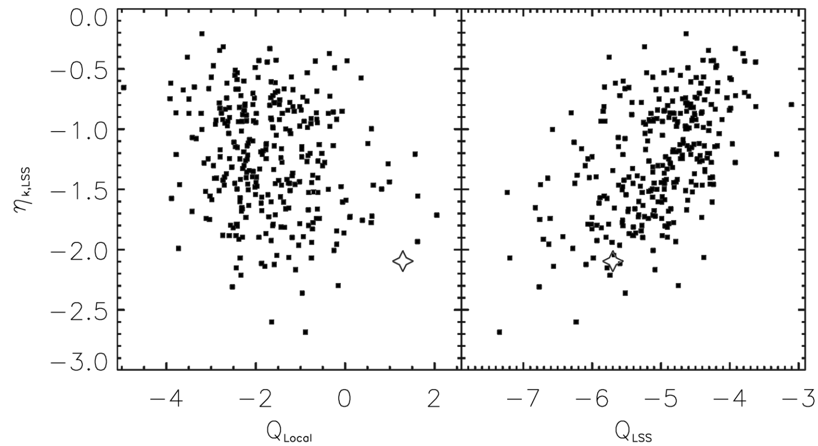

Fig. 3 The environment parameters of triplet J0848+1644 (*stars*) compared with other isolated triplets in the A-sample (*dots*).

It is very interesting that the $M_{\rm vir}$ of J0484+1644 is so small, even less than the total stellar mass of its member galaxies. We are not surprised by this result, because for a triplet system, the virial mass estimated by the radial velocity dispersion might be strongly related to the viewing angle. For example, if our line-of-sight happens to be perpendicular to the plane of three vectors representing the peculiar velocity of the triplet members, the $\sigma_{v_{\rm r}}$ could decrease to zero. So, this visual aspect reminds us that the $M_{\rm vir}$ estimation of a triplet system is only a combination of the velocity dispersion $\sigma_{v_{\rm r}}$ and scale length $R_{\rm H}$, which has the dimension of mass (Karachentseva & Karachentsev 2000). It cannot be considered as the true mass of individual triplets, but should be worthwhile in statistical analysis for a pretty large sample of triplets.

3.4 SFR

It is believed that galaxy interaction triggers star formation. The galaxies in compact groups are shown to have stronger star formation in comparison with those in fields (Gómez et al. 2003). For galaxy B or C of J0848+1644, we see a significant Hα emission line in their respective SDSS or LAMOST spectrum, which indicates their current star forming activities. Unfortunately, the LAMOST spectrum of galaxy C may be seriously affected by unreliable flux calibration and causes an unexpectedly stronger Hα emission which may lead to the wrong value of SFR.

Alternatively, we use the OII flux measured from the BFOSC spectra of all three galaxies to calibrate their SFR, following the relation of Kennicutt (1998),

$$\text{SFR}(M_\odot\ \text{yr}^{-1}) \sim 1.4 \times 10^{-41} L(\text{OII})(\text{erg s}^{-1}). \quad (8)$$

The SFR results, together with $\log(\text{SFR}/M_*)$, are calculated and listed in Table 1. For galaxy B, these two values are all consistent with those derived from the Hα flux. Then, we can sum up the SFR parameters for the whole triplet system and list them in Table 2.

From the result, galaxies A and B have lower SFRs than C, which cause OIII to be too weak, and even Hβ to be too weak to override stellar absorption (see Fig. 2) (Kennicutt 1992).

4 DISCUSSION

4.1 Characteristics of J0848+1644

The most distinguished feature of J0848+1644 is its compactness. The parameter $S = 2.48$ is located in the most compact end for almost all current triplet samples. The lack of such compact triplets is partly because of the sampling bias of redshift sky surveys (see the next subsection for details), and the investigation of J0848+1644 provides a valuable example to reveal the nature of such a compact few body system. Combining with other properties, the apparent compactness seems to be real. All evidence points toward it coming from a sufficient dynamical evolution, while the interaction among member galaxies is still active.

From the projected 2D AA-map, J0848+1644 has a very high probability of having an aligned configuration rather than a hierarchical structure. It is believed that different configurations of the triplets may be reflecting different dynamical stages of the system. The A-type configuration therefore implies that it is a well formed system and its member galaxies may have co-evolved for a long time. Then, the diagnosis of isolation leads to more information about the relations between J0848+1644 and its environment. Generally speaking, the evolution of a galaxy may be affected by an external influence when the corresponding tidal force amounts to 1% of the internal binding force (Athanassoula 1984; Byrd & Howard 1992), which corresponds to a tidal strength of $Q = -2$. Obviously, J0848+1644 has $Q_{\rm LSS}$ (or $Q_{\rm Local}$) more than three orders of magnitude lower (or higher) than this level. That means this triplet has an extremely weak external influence from the LSS environment, but in contrast, has very strong internal connection among its members.

Additionally, the dimensionless crossing time $H_0 t_c$ is the ratio of the crossing time to the age of the Universe

Table 2 Global Physical Parameters of J0848+1644

Parameter	Unit	J0848+1644	Notes
S		2.48	Compactness parameter.
$\eta_{4,\mathrm{LSS}}$		–2.10	Projected number density.
Q_{LSS}		–5.70	Tidal force effect of LSS.
Q_{Local}		1.29	Tidal force effect in the triplet.
R_{H}	kpc	14.5	Projected harmonic radius.
$\sigma_{v_{\mathrm{r}}}$	km s^{-1}	58.1	Radial velocity dispersion.
$H_0 t_c$		0.032	Dimensionless crossing time.
$\log(M_{\mathrm{vir}}/M_{\odot})$		11.2	Virial mass. It may have a strong projection effect.
SFR	$M_{\odot}\cdot$ yr^{-1}	3.88	SFR
$\log(\mathrm{SFR}/M_{*})$		–10.51	sSFR

and is a convenient measurement of the dynamical stage of this system. For our triplet, $H_0 t_c = 0.035$ is similar to the median value of the O-sample (0.031) and not much longer than that of the K-sample (0.019). Obviously it is much less than 1, which indicates the sufficiency of dynamical evolution. The direct consequence of dynamical evolution is the member galaxies sinking into a deep gravitational well of the central region of the dark matter halo, which leads to a small velocity dispersion since it corresponds to a smaller amount of mass in the innermost part of the halo. The triplet J0848+1644 has a very small value of radial velocity dispersion. Although we have stated that it is probably due to the projection, it does not contradict the scenario of well evolution for this triplet.

The dynamical properties discussed above also reflect the physical features of three member galaxies. Overall, members of J0848+1644 are similar. They all have armless spherical shapes with similar luminosity and color. This similarity is regarded as more evidence of the long term co-evolution. All three members show significant but not strong activities indicative of current star formation, which means the interaction may continue to trigger star formation. It is worth mentioning that the colors and SFRs of these members are all near the boundary between two classifications of galaxies. They are a little bit bluer and a little bit more active than non-star-forming galaxies. We are not sure if this phenomenon is common for those very compact systems at their final stage, or it is just an individual case for J0848+1644. So, it is essential to find more examples of extremely compact triplets for future research.

4.2 Importance of Spectroscopic Redshifts

According to the spectroscopic observation taken with the BFOSC, which is mounted on the 2.16 m telescope, J0848+1644 is undoubtedly confirmed to be a bounded system, since the differences in z_{spec} of its members are much less than the typical radial velocity dispersions of triplet systems. The reasons why it was missed in previous samples, e.g. the O-sample and the A-sample that were all based on the SDSS, are the problem of fiber collision and the relatively large uncertainties in the z_{phot} measurements. These two factors are both related to the compactness of this triplet. Thus, there is a consequential question of whether these factors will seriously influence the study of few body systems.

The problem of fiber collision is common in many redshift surveys using fiber spectroscopy. Taking the minimum fiber separation of SDSS (55$''$) as a typical angular distance, even for low redshift galaxies ($z \sim 0.1$), the closet pairs of galaxies that can be observed in the same survey plate should have a distance larger than 100 kpc. So, usually we cannot find and identify a compact few body system by only using data from one scan of a fiber spectroscopic survey (see Shen et al. 2015). This is why O'Mill et al. (2012) use z_{phot} in their search for triplets. However, even taking the most accurate measurements of z_{phot} involves uncertainties of at least 5%, which lead to a difference of $1500\ \mathrm{km\ s^{-1}}$ in radial velocities at $z \sim 0.1$ and therefore is much larger than the typical velocity dispersion of poor galaxy groups. Furthermore, considering the neighboring effects in the photometric measurements (Section 2.2), like in J0848+1644, the uncertainties of radial velocity from z_{phot} are even larger.

For all of the above reasons, we believe that there is a significant fraction of compact triplets of galaxies that has not yet been identified in current samples. Such a compact system is still very rare, and we need to find more for further study.

The discovery and identification of the triplet J0848+1644 also demonstrates that it is really important to carry out a supplemental survey for current major galaxy redshift surveys, such as LAMOST, at least in the research field of compact few body systems (Shen et al. 2015). Fortunately, LAMOST has provided a good opportunity to undertake such a project. Although the LAMOST spectrum of galaxy C we used here is noisier than most (∼92%) DR1 spectra, it still provides some vital information for our work, especially the obvious Hα emission line which provides a reliable redshift rather than z_{phot}.

It is not easy to estimate how many compact triplet systems could be found before we have a complete z_{spec} sample. However, as a comparison, we only used z_{phot} to search for triplets in the A-sample though they all have z_{spec} measurements, and found that more than 60% of the real triplets will be missed. This result strongly implies that a considerable amount of compact triplets will be found after some effective supplemental surveys.

5 SUMMARY

We summarize the main results of this work as follows.

(1) The LAMOST spectral survey, which supplies new spectroscopic measurements to the main sample galaxies without redshifts in SDSS due to the fiber collision, found indications of a possible triplet, J0848+1644. It is further confirmed to be a real triplet by the follow-up spectroscopic observation of the BFOSC mounted on the 2.16 m telescope at Xinglong Station of NAOC.
(2) We surmised that J0848+1644 is an extremely compact isolated triplet, with an aligned configuration and very small radial velocity dispersion. The member galaxies of this triplet have similar properties in terms of their shapes, colors and SFRs. It gives an additional example of compact triplets, which are supposed to be a co-evolved system rather than a hierarchically forming structure.
(3) Compact systems like J0848+1644, e.g. close pairs or poor groups, are difficult to compile by a redshift survey based on fiber spectroscopy or using the current photometric redshift techniques. The serendipitous discovery of J0848+1644 shows the importance of future projects aiming at conducting major redshift sky surveys like the LAMOST complementary galaxy survey (Shen et al. 2015).

Acknowledgements We sincerely thank the anonymous referee whose suggestions greatly helped us improve this paper. We are also grateful to the kind staff at the Xinglong 2.16 m telescope for their support during the observations. This work is supported by the 973 Program (Grant No. 2014CB845705), "Strategic Priority Research Program The Emergence of Cosmological Structures" of the Chinese Academy of Sciences (Grant No. XDB09030200) and the National Natural Science Foundation of China (Nos. 11390373, 11573050 and 11433003). This work is also supported by the Science Foundation of Shanghai (No. 16ZR1442100). Funding for the creation and distribution of the SDSS archive has been provided by the Alfred P. Sloan Foundation, the participating institutions, NASA, the National Science Foundation, the US Department of Energy, the Japanese Monbukagakusho and the Max Plank Society. The SDSS website is *http://www.sdss.org*. SDSS is managed by the Astrophysical Research Consortium for the participating institutions. The Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST, now called the Guo Shou Jing Telescope) is a National Major Scientific Project built by the Chinese Academy of Sciences. Funding for the project has been provided by the National Development and Reform Commission. LAMOST is operated and managed by National Astronomical Observatories, Chinese Academy of Sciences.

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