Research Article

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K-band luminosity–density relation at fixed parameters or for different galaxy families

<https://doi.org/10.1515/phys-2020-0016>

received May 29, 2018; accepted February 14, 2020

Abstract: Using the apparent magnitude-limited Main galaxy sample of the Sloan Digital Sky Survey Data Release 10, we examine the K-band luminosity–density relation at fixed parameters or for different galaxy families. It is found that the limiting or fixing galaxy properties, such as galaxy morphology, stellar mass, and color, exert substantial influence on the environmental dependence of the K-band luminosity of galaxies, which suggests that the K-band luminosity–density relation is likely attributable to the relation between these galaxy properties and density.

Keywords: fundamental parameters of galaxies, statistic of galaxy, distance and redshifts

1 Introduction

In the past few decades, the environmental dependence of galaxy luminosity was investigated by many authors (e.g., [1–20]). Some studies demonstrated that the luminosity–density relation of galaxies likely follows different trends in different bands [18]. In this situation, one often wishes to examine the environmental dependence of different band luminosities and to understand the luminosity–density relation all round. The K band is a standard near-infrared photometric filter. Deng et al. [21] examined the environmental dependence of the K-band luminosity in different galaxy samples of Sloan Digital Sky Survey Data Release 10 (SDSS DR10) [22]. It was found that in the luminous volume-limited Main galaxy sample with the luminosity $-22.5 \leq M_r \leq -20.5$, the environmental dependence of the K-band luminosity still can be observed: luminous galaxies tend to reside in dense environments, whereas faint galaxies tend to reside in low-density regions, which is consistent with widely

accepted conclusion obtained in previous studies (e.g., [10,11,14,15,17]). But in the faint volume-limited Main galaxy sample with the luminosity $-20.5 \leq M_r \leq -18.5$, this dependence is very weak. Deng et al. [21] also applied the apparent magnitude-limited Main galaxy sample, divided the Main galaxy sample of the SDSS DR10 into subsamples with a redshift binning size of $\Delta z = 0.01$, investigated the environmental dependence of the K-band luminosity of subsamples in each redshift bin, and concluded that the K-band luminosity of Main galaxies shows substantial correlation with the local environment in many redshift bins.

Due to the close correlations among galaxy properties (e.g., [10,23–31]), it is difficult to study the environmental dependence of galaxy properties. The strong environmental dependence of a galaxy property is likely due to the environmental dependence of other galaxy properties and tight correlations between this galaxy property and other ones. Hence, following the discovery of strong correlations between certain properties of galaxies and environments, it is common to further examine the environmental dependence of these properties at fixed parameters or for different galaxy families (e.g., [11,16,27,32–38]). In this work, we also further examine the environmental dependence of the K-band luminosity at fixed parameters or for different galaxy families.

The outline of this article is as follows. Section 2 describes the data used. In Section 3, we discuss the environmental dependence of the K-band luminosity at fixed parameters or for different galaxy families. Our main results and conclusions are summarized in Section 4.

For calculating distances, we used a cosmological model with a matter density of $\Omega_0 = 0.3$, a cosmological constant of $\Omega_\Lambda = 0.7$, and a Hubble constant of $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

2 Data

The Main galaxy sample [39] of the SDSS includes galaxies brighter than $r_{\text{petro}} = 17.77$ (r -band apparent

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Figure 1: K-band luminosity distributions of early-type galaxies at both extremes of density in various redshift bins: the red solid lines represent the high-density samples, and the blue dashed lines represent the low-density samples. The error bars on the blue lines are 1σ Poisson errors. The error bars on the red lines are omitted for clarity.

Figure 2: Same as Figure 1, but for the K-band luminosity distributions of late-type galaxies at both extremes of density in various redshift bins.

Petrosian magnitude), in which most galaxies are located within the redshift range of $0.02 \leq z \leq 0.2$. Deng [40] downloaded the data of the Main galaxy sample from the

Catalog Archive Server of SDSS Data Release 10 [22] using the SDSS SQL Search (<http://www.sdss3.org/dr10/>), extracted 633172 Main galaxies with redshifts of $0.02 \leq z \leq 0.2$

(the Main galaxy sample corresponds to LEGACY_TARGET1 & (64|128|256) > 0), and constructed an apparent magnitude-limited Main galaxy sample. In this work, we also use this galaxy sample. The data set of the K-band luminosity measurements was downloaded from the StellarMass-StarformingPort table.

3 Environmental dependence of the K-band luminosity at fixed parameters or for different galaxy families

Following previous studies [18,38,40], we apply the projected local density $\Sigma_5 = N/\pi d_5^2$ (galaxies Mpc^{-2}), where d_5 is the distance to the fifth nearest neighbor within $\pm 1,000 \text{ km s}^{-1}$ in redshift (e.g., [27,41,42]), and divide the entire apparent magnitude-limited Main galaxy sample into subsamples with a redshift binning size of $\Delta z = 0.01$. As was done by Deng [18], in each subsample, we arrange galaxies in the density order from the smallest to largest and then select approximately 5% of the galaxies to construct each of two samples from both extremes of density. The low-density sample contains the first 5% of the galaxies in the density order, whereas the high-density sample consists of the final 5% of the galaxies in the density order.

3.1 Environmental dependence of the K-band luminosity at fixed morphology

Deng [38] studied the environmental dependence of U-band luminosity at fixed morphology and found that the abnormal environmental dependence of U-band luminosity for late-type galaxies is fairly strong in the redshift range of $0.03 \leq z \leq 0.09$, whereas this environmental dependence for early-type galaxies is very weak in nearly all redshift bins. Deng [40] also demonstrated that at a given galaxy morphology, the environmental dependence of the stellar velocity dispersion of the galaxies is substantially reduced, but can still be observed in several redshift bins for the late types. These results show that the limiting or fixing galaxy morphology exerts substantial influence on the environmental dependence of some galaxy properties, which suggests that much of some galaxy property–density relations is most likely attributable to the relation

between morphology and density. In this study, we examine the environmental dependence of the K-band luminosity for the early-type and late-type galaxies.

We use the early-type and late-type samples constructed by Deng [40]. As the concentration index is closely correlated with morphological type [43–47], it often served as a morphology-classification parameter [45–48]. Similar to Deng [38], Deng [40] applied the r -band concentration index $c_i = R_{90}/R_{50}$ to discriminate early-type ($c_i \geq 2.86$) galaxies from late-type ($c_i < 2.86$) galaxies [45,46]. R_{50} and R_{90} are the radii enclosing 50% and 90% of the Petrosian flux, respectively. From the apparent magnitude-limited Main galaxy sample of the SDSS DR10, Deng [40] constructed an early-type sample (containing 201630 galaxies) and a late-type sample (containing 431542 galaxies).

Figures 1 and 2 demonstrate the K-band luminosity distributions at both extremes of density in various redshift bins for the early-type and late-type samples. The Kolmogorov–Smirnov (KS) test demonstrates the degree of similarity or difference between two independent distributions in a figure, by calculating a probability value. It can serve as a quantitative comparison. The lower the probability value is, the less likely the two distributions are similar. Conversely, the higher the probability value is, the more similar the two

Table 1: KS test probabilities that the two independent distributions in each redshift bin of Figures 1 and 2 are drawn from the same parent distribution

Redshift bin	Early type		Late type	
	Galaxy number	P	Galaxy number	P
0.02–0.03	4571	0.23	19350	0.0013
0.03–0.04	6177	0.12	23517	0.00031
0.04–0.05	7075	0.49	25167	0.00040
0.05–0.06	8372	0.0028	28009	0.0017
0.06–0.07	11561	0.21	35390	0.21
0.07–0.08	15181	0.022	42233	2.42×10^{-6}
0.08–0.09	15263	0.094	39731	0.00082
0.09–0.10	13007	0.035	31309	0.0053
0.10–0.11	13668	0.049	30365	0.00022
0.11–0.12	15875	0.0010	31015	0.0010
0.12–0.13	14602	0.00066	26622	1.61×10^{-6}
0.13–0.14	15531	0.0019	25198	7.28×10^{-6}
0.14–0.15	13057	0.00051	19603	0.017
0.15–0.16	11872	0.039	16316	0.041
0.16–0.17	10857	0.054	13011	0.035
0.17–0.18	9486	0.014	10409	0.018
0.18–0.19	8412	0.78	8170	0.079
0.19–0.20	7063	0.49	6127	0.52

distributions are. When the probability value is 1, the two distributions are completely same. Table 1 lists the statistical results of the KS test. As indicated by Figures 1, 2 and Table 1, for the early-type and late-type samples, the environmental

Figure 3: Same as Figure 1, but for the K-band luminosity distributions of HSM galaxies at both extremes of density in various redshift bins.

Figure 4: Same as Figure 1, but for the K-band luminosity distributions of LSM galaxies at both extremes of density in various redshift bins.

dependence of the K-band luminosity is fairly weak nearly in all redshift bins. We again note that the limiting or fixing galaxy morphology exerts substantial influence on the environmental dependence of the K-band luminosity of galaxies.

3.2 Environmental dependence of the K-band luminosity for high stellar mass (HSM) and low stellar mass (LSM) galaxies

From the apparent magnitude-limited Main galaxy sample of the SDSS DR10, Deng [40] constructed an HSM sample (containing 250653 galaxies) and an LSM sample (containing 382519 galaxies), above and below the threshold ($3 \times 10^{10} M_{\odot}$) developed by Kauffmann et al. [49]. In this work, we also use these two samples.

Previous studies demonstrated that the environmental dependence of galaxy properties at fixed stellar mass is somewhat complicated. Kauffmann et al. [32] and Bamford et al. [34] reported that at fixed stellar mass, some galaxy properties, such as color, star formation, and nuclear activity, still have a strong environmental dependence, whereas the morphology, size, and concentration weakly depend on the environment. Deng et al. [36] showed that for HSM and LSM galaxies, the color, morphology, and star-formation activity strongly depend on the environment, but the size has only a weak environmental dependence. When investigating such a subject, some works shed light on the apparent magnitude-limited Main galaxy sample. Deng [38] found that the abnormal environmental dependence of U-band luminosity for LSM galaxies is fairly strong in the redshift range of $0.03 \leq z \leq 0.09$, whereas this dependence for HSM galaxies is very weak in nearly all redshift bins. Deng [40] showed that the environmental dependence of the stellar velocity dispersion for HSM galaxies and LSM galaxies is much weaker than that for the entire apparent magnitude-limited Main galaxy sample, but can still be observed in certain redshift bins.

Figures 3 and 4 show the K-band luminosity distributions at both extremes of density in various redshift bins for the HSM and LSM samples. Table 2 also lists K-S probabilities. As shown by Figures 3 and 4 and Table 2, the environmental dependence of the K-band luminosity for HSM galaxies and LSM galaxies is very weak nearly in all redshift bins, which demonstrate that the limiting or fixing stellar mass exerts substantial

Table 2: KS test probabilities that the two independent distributions in each redshift bin of Figures 3 and 4 are drawn from the same parent distribution

Redshift bin	High mass		Low mass	
	Galaxy number	<i>P</i>	Galaxy number	<i>P</i>
0.02–0.03	2065	0.015	21856	4.50×10^{-8}
0.03–0.04	3196	0.20	26498	5.69×10^{-8}
0.04–0.05	4364	0.065	27878	8.02×10^{-6}
0.05–0.06	5747	0.0020	30634	0.0028
0.06–0.07	9231	0.0032	37720	0.26
0.07–0.08	13995	0.093	43419	0.025
0.08–0.09	16155	0.052	38839	0.18
0.09–0.10	15118	0.070	29198	0.050
0.10–0.11	17307	0.00012	26726	0.0010
0.11–0.12	21273	0.0011	25617	0.065
0.12–0.13	20473	0.00096	20751	0.042
0.13–0.14	22552	0.032	18177	0.021
0.14–0.15	19920	0.0057	12740	0.61
0.15–0.16	19144	0.092	9044	0.59
0.16–0.17	17834	0.034	6034	0.51
0.17–0.18	16069	0.00011	3826	0.95
0.18–0.19	14354	0.051	2228	0.62
0.19–0.20	11856	0.016	1334	0.94

influence on the environmental dependence of the K-band luminosity of galaxies.

3.3 Environmental dependence of the K-band luminosity for blue and red galaxies

We use the red and blue samples constructed by Deng [40]. According to the threshold (the observed $u-r$ color = 2.22) defined by Strateva et al. [24], Deng [40] classified galaxies in the apparent magnitude-limited main galaxy sample of the SDSS DR 10 as “red” and “blue”, respectively. The red sample contains 354337 galaxies. The blue sample includes 278835 galaxies. In this section, we examine the environmental dependence of the K-band luminosity of blue and red galaxies.

Galaxy color is a parameter that is most predictive of the environments [11]. Some studies demonstrated that limiting the color exerts substantial influence on the environmental dependence of some galaxy properties [35,37,38,50,51]. In the apparent magnitude-limited Main galaxy sample, Deng [38] demonstrated that the abnormal environmental dependence of the U-band luminosity for blue and red galaxies is fairly weak in nearly all redshift bins. However, Deng [40] noted that

Figure 5: Same as Figure 1, but for the K-band luminosity distributions of red galaxies at both extremes of density in various redshift bins.

the environmental dependence of the stellar velocity dispersion for red galaxies is very strong in certain redshift bins, but that this dependence for blue galaxies

is fairly weak in all redshift bins. Deng et al. [37] also found that the environmental dependence of the star formation rate and specific star formation rate for blue

Figure 6: Same as Figure 1, but for the K-band luminosity distributions of blue galaxies at both extremes of density in various redshift bins.

galaxies is very weak, whereas that for red galaxies is fairly strong. In Figures 5 and 6, we plot the K-band luminosity distributions at both extremes of density in various redshift

bins for the red and blue samples. K-S probabilities are listed in Table 3. As shown by Figures 5, 6 and Table 3, the environmental dependence of the K-band luminosity for

Table 3: KS test probabilities that the two independent distributions in each redshift bin of Figures 5 and 6 are drawn from the same parent distribution

Redshift bin	Red		Blue	
	Galaxy number	<i>P</i>	Galaxy number	<i>P</i>
0.02–0.03	6310	0.011	17611	0.024
0.03–0.04	9376	2.63×10^{-5}	20318	0.0011
0.04–0.05	12076	0.14	20166	0.00023
0.05–0.06	14956	0.0078	21425	0.011
0.06–0.07	21635	0.0010	25316	0.023
0.07–0.08	29385	5.17×10^{-5}	28029	4.28×10^{-7}
0.08–0.09	30042	0.0087	24952	0.00032
0.09–0.10	24814	0.0064	19502	0.00093
0.10–0.11	26051	1.06×10^{-9}	17982	0.0010
0.11–0.12	29017	2.68×10^{-5}	17873	0.0029
0.12–0.13	26187	0.00089	15037	0.0047
0.13–0.14	27000	0.0047	13729	0.0018
0.14–0.15	22510	6.90×10^{-5}	10150	0.20
0.15–0.16	19824	0.0075	8364	0.12
0.16–0.17	17345	0.0066	6523	0.44
0.17–0.18	14792	0.00048	5103	0.24
0.18–0.19	12766	0.027	3816	0.67
0.19–0.20	10251	0.030	2939	0.69

blue and red galaxies is fairly weak in nearly all redshift bins, as well as the U-band luminosity.

4 Summary

Using the apparent magnitude-limited Main galaxy sample of SDSS Data Release 10 [22], we investigate the environmental dependence of the K-band luminosity at fixed parameters or for different galaxy families. Following Deng [18], we divide the entire apparent magnitude-limited Main galaxy sample into subsamples with a redshift binning size of $\Delta z = 0.01$ and perform statistical analyses in each redshift bin. Overall, our results demonstrate that the limiting or fixing galaxy properties, such as galaxy morphology, stellar mass, and color, exerts substantial influence on the environmental dependence of the K-band luminosity of galaxies, which suggests that the K-band luminosity–density relation is likely attributable to the relation between these galaxy properties and density.

Acknowledgments: The authors thank the anonymous referee for many useful comments and suggestions. This study was supported by the National Natural Science

Foundation of China (NSFC, Grant nos 11533004 and 11563005). Funding for SDSS-III has been provided by the Alfred P. Sloan Foundation, the Participating Institutions, the National Science Foundation, and the U.S. Department of Energy. The SDSS-III web site is <http://www.sdss3.org/>. SDSS-III is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS-III Collaboration including the University of Arizona, the Brazilian Participation Group, Brookhaven National Laboratory, University of Cambridge, University of Florida, the French Participation Group, the German Participation Group, the Instituto de Astrofísica de Canarias, the Michigan State/Notre Dame/JINA Participation Group, Johns Hopkins University, Lawrence Berkeley National Laboratory, Max Planck Institute for Astrophysics, New Mexico State University, New York University, Ohio State University, Pennsylvania State University, University of Portsmouth, Princeton University, the Spanish Participation Group, University of Tokyo, University of Utah, Vanderbilt University, University of Virginia, University of Washington, and Yale University.

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