АСТРОФИЗИКА

ТОМ 58 МАЙ, 2015 ВЫПУСК 2

CORRELATION BETWEEN THE MORPHOLOGICAL TYPE AND DIFFERENT PHOTOMETRIC BAND CONCENTRATION INDEXES

XIN-FA DENG[1], GUISHENG YU[2]

Received 28 August 2014
Accepted 10 April 2015

In this work, we continue to examine whether the *u*-, *g*-, *i*- and *z*-band concentration indexes are a good morphological classification tool. Our statistical results demonstrate that comparing with *r*-band concentration index, *g*-band concentration index may be a better choice for using as a parameter in automated morphological classification schemes, while *u*-band concentration index should be the worst choice in five photometric band concentration indexes.

Key words: *galaxies: fundamental parameters: statistics*

1. *Introduction.* The morphological classification of galaxies is the key step of many works. In the past, one often classified galaxies according to Hubble's classification scheme [1]. However, this visual inspection procedure is highly labor intensive and was only applied in small galaxy samples. For great survey programs such as the SDSS and the two degree Field Galaxy Redshift Survey (2dFGRS, Colless et al. [2]), it is nearly impossible to classify galaxies into morphological classes through direct inspection of the galaxy images as previous studies. In this condition, one wished to find automated morphological classification schemes to classify large numbers of galaxies into early and late types. A popular method is to use some galaxy parameters that are closely correlated with morphological type for the morphological classification [3-12].

Many studies demonstrated that the concentration index has a strong correlation with the morphological type (Morgan [13]; Doi et al. [14]; Abraham et al. [15]; Shimasaku et al. [3]; Nakamura et al. [6]; Park & Choi [8]; Deng [16]). Shimasaku et al. [3] argued that the concentration index is perhaps the best parameter for the morphological classification. Shimasaku et al. [3] showed that when using such an index for the automated classification of early- and late-type galaxies, early-type and late-type galaxy samples have a completeness of $\approx$70%-90% and a contamination of $\approx$15%-20% from the opposite sample. Nakamura et al. [6] also separated galaxies into early and late types at a (inverse) concentration index of 0.35. The completeness and contamination of their early-type and late-type galaxy samples are 82% and 18%, respectively.

In the galaxy sample of the Sloan Digital Sky Survey Data Release 8 (SDSS DR8) (Aihara et al. [17]), Deng [16]) found that r-band concentration index $ci=2.85$ can be used to construct a reasonably pure late-type galaxy sample, but it is not an ideal selection for the construction of early-type sample. In this work, we attempt to further explore whether other band concentration indexes are a good morphological classification tool.

The outline of this paper is as follows. Section 2 describes the data used. In Section 3, we examine whether other band concentration indexes are a good morphological classification tool. Our main results and conclusions are summarized in Section 4.

2. *Data*. Galaxy Zoo is a web-based project (http://www.galaxyzoo.org) of the morphological classification of galaxies joined by hundreds of thousands of volunteers (Lintott et al. [18,19]). Such a data set has a remarkable degree of agreement (better than 90% in most cases) with those compiled by professional astronomers [18]. Each galaxy in this project is classified as belonging to one of six categories: Spiral (clockwise rotation), Spiral (anticlockwise rotation), Spiral (edge-on/rotation unclear), Elliptical, Merger, or Star/Don't Know. When performing studies that require only a simple split into elliptical and spiral samples, one often combined all three possible spiral classifications into a single classification. Table 2 of [19] contains visual morphological classifications of 667945 Main galaxies (Strauss et al. [20]) in the Sloan Digital Sky Survey Data Release 7 (SDSS DR7) (Abazajian et al. [21]). This table includes the raw votes, the weighted votes in elliptical (E) and combined spiral (CS = clockwise + anticlockwise + edge-on spiral) categories and flags indicating the inclusion of the galaxy in a clean, debiased catalog.

The SDSS DR8 of SDSS-III (Eisenstein et al. [22]) contains the data of the initial Galaxy Zoo classifications. From the Catalog Archive Server of SDSS Data Release 8 (Aihara et al. [17]), Deng [16] downloaded the initial Galaxy Zoo classifications and other parameters of the Main galaxy sample [20] using the SDSS SQL Search (with SDSS flag: best Primtarget&64>0) with a redshift range of $0.01<z<0.25$. In this catalog, those galaxies whose debiased votes give an unambiguous answer (>80%) of their morphology are explicitly labeled as elliptical or spiral, and all other galaxies are flagged as uncertain. In this work, we use the galaxy sample constructed by [16], which contains 617672 Main galaxies: 55112 elliptical, 178557 spiral and 384003 uncertain. Deng [16] found that in a redshift range of $z<0.15$, the de-biased type fractions are approximately flat (see Fig.1 of [16]), which shows that this redshift range is free from selection effects. Here, we limited the sampling to a redshift range of $z<0.15$, in which there are 31202 elliptical galaxies and 160577 spiral galaxies.

3. *Correlation of the u-, g-, i- and z- band concentration*

indexes with the Galaxy Zoo types. The concentration indexes are defined as $ci = R_{90}/R_{50}$. R_{50} and R_{90} are the radii enclosing 50% and 90% of the Petrosian flux in each band, respectively. We calculate the *u*-, *g*-, *i*- and *z*-band concentration indexes $ci = R_{90}/R_{50}$ and plot the *u*-, *g*-, *i*- and *z*-band concentration index distributions of elliptical and spiral galaxies. Deng [16] reported the bimodality of the r-band concentration index distribution: the majority of spiral galaxies correspond to low-concentration galaxies, while the majority of elliptical galaxies correspond to high-concentration galaxies. In Fig.1, we also observe the bimodality of the *u*-, *g*-, *i*- and *z*-band concentration index distribution.

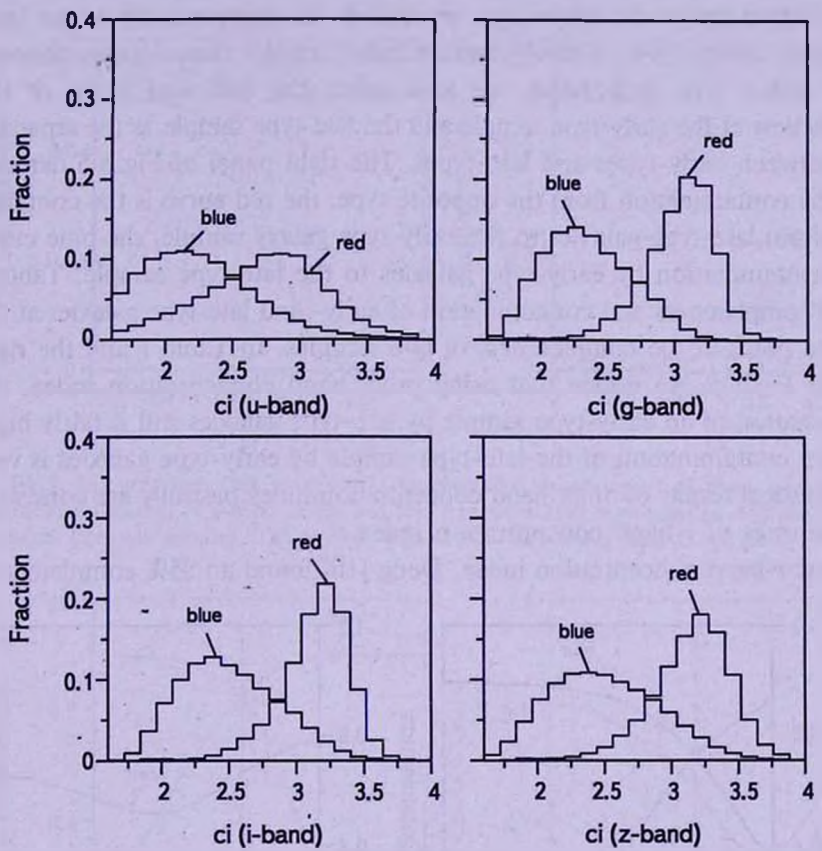

Fig.1. *u*-, *g*-, *i*- and *z*-band ci distributions of elliptical and spiral galaxies: the red line represents elliptical galaxies and the blue line represents spiral galaxies.

Following Shimasaku et al. [3], Deng [16] calculated the completeness and contamination of the morphologically classified sample with the use of *r*-band concentration index. The completeness of the early-type sample and the late-type sample balances with a *r*-band concentration index $ci = 2.85$ at $\approx 85\%$. Deng [16] selected this balanced point (*r*-band concentration index $ci = 2.85$)

as the separator point between early-types and late-types, which is the same as that obtained by [6]. Deng [16] demonstrated that the contamination of an early-type sample by late-type galaxies is fairly high, while the contamination of the late-type sample by early-type galaxies is lower. This suggests that a reasonably pure late type galaxy sample can be constructed with the choice of r-band concentration index $ci=2.85$; however the opposite is not true due to the fairly high contamination of an early-type sample by late-type galaxies.

The left panel of Fig.2-5 shows the completeness as a function of other band concentration indexes: the red curve represents the completeness of the early-type galaxy sample with a concentration index larger than a given concentration index; the blue curve represents the completeness of the late-type galaxy sample with a concentration index smaller than a given concentration index. For each band, we also select the balanced point of the completeness of the early-type sample and the late-type sample as the separator point between early-types and late-types. The right panel of Fig.2-5 demonstrate the contamination from the opposite type: the red curve is the contamination from late-type galaxies to the early-type galaxy sample; the blue curve is the contamination by early-type galaxies to the late-type sample. Table 1 lists the completeness and contamination of early- and late-type galaxies at the balanced point of the completeness of two samples. In Table 1 and the right panel of Fig.2-5, we notice that using other band concentration index, the contamination of an early-type sample by late-type galaxies still is fairly high, while the contamination of the late-type sample by early-type galaxies is very low. Statistical results of other band concentration index basically are consistent with the ones of r-band concentration index.

Using r-band concentration index, Deng [16] found an 85% completeness,

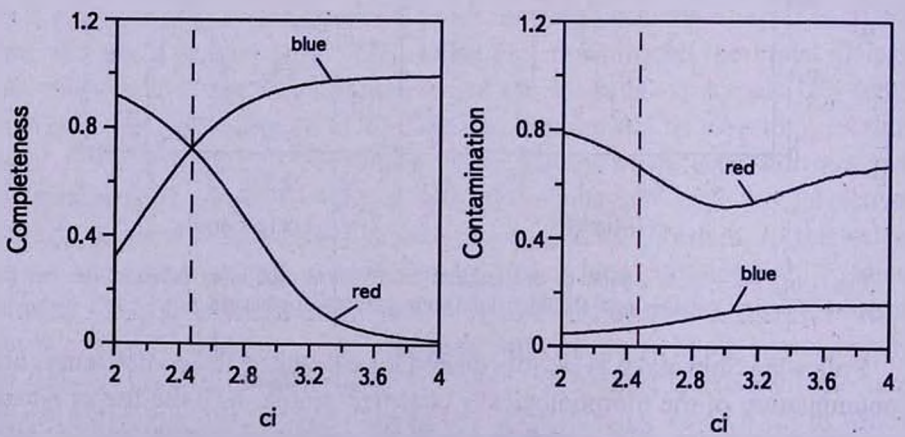

Fig.2. Completeness (left panel) and contamination (right panel) of early- and late-type galaxies as a function of u-band ci: the red line represents early-type galaxies, and the blue line represents late-type galaxies. The vertical dashed line indicates u-band $ci=2.47$.

an 47.43% contamination of the early-type sample by late-type galaxies and an 3.27% contamination of the late-type sample by early-type galaxies, in the same galaxy sample. In Table1, we note that the completeness of using *g*-band concentration index is slightly higher than the one of using *r*-band concentration index, while the contamination of using *g*-band concentration index is slight lower than the one of using *r*-band concentration index, which shows that *g*-band concentration index may be a better choice for using as a parameter in automated morphological classification schemes.

In the past, the deviant behavior of the *u*-band statistical results was focused on [23-25]. For example, Deng & Zou [23] reported that the environmental

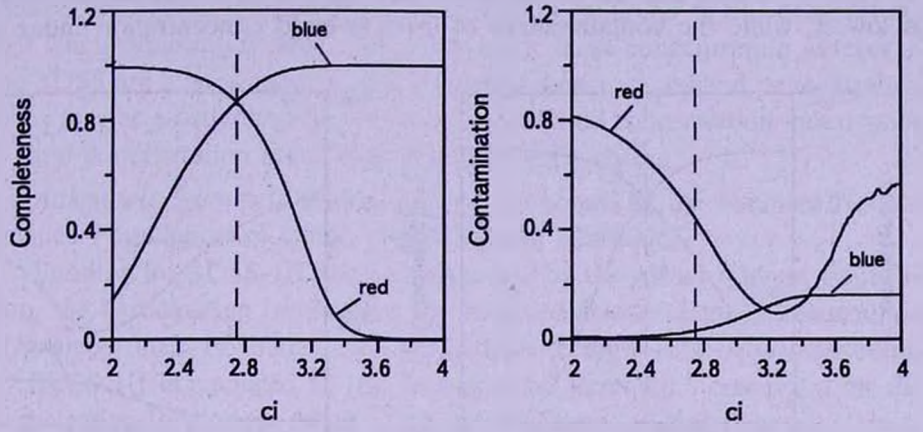

Fig.3. Completeness (left panel) and contamination (right panel) of early- and late-type galaxies as a function of *g*-band *ci*: the red line represents early-type galaxies, and the blue line represents late-type galaxies. The vertical dashed line indicates *g*-band $ci = 2.75$.

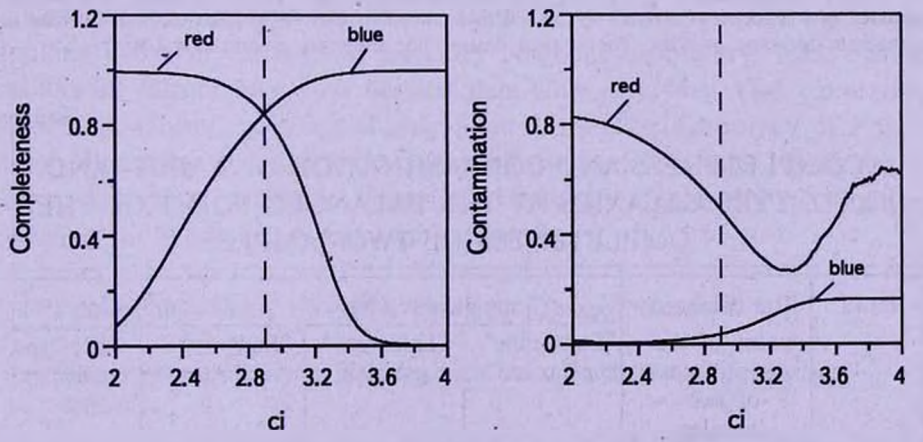

Fig.4. Completeness (left panel) and contamination (right panel) of early- and late-type galaxies as a function of *i*-band *ci*: the red line represents early-type galaxies, and the blue line represents late-type galaxies. The vertical dashed line indicates *i*-band $ci = 2.90$.

dependence of u-band concentration index is much stronger than the one of other band concentration indexes and claimed that the deviant behavior of the u-band concentration index may be due to measurement errors on low S/N (signal-to-noise ratio) data. Deng & Zou [24] and Deng [25] observed the abnormal environmental dependence of u-band luminosity: faint galaxies tend to reside in high density regions, while luminous galaxies tend to reside in low density regions. Deng [25] demonstrated that u- and z-band Petrosian flux errors are apparently larger than ones of g-, r- and i-bands, and have a strong environmental dependence. Larger u-band Petrosian flux errors likely is a factor which leads to the abnormal environmental dependence of u-band luminosity. In Table1, we note that the completeness of using u-band concentration index is lowest, while the contamination of using u-band concentration index is

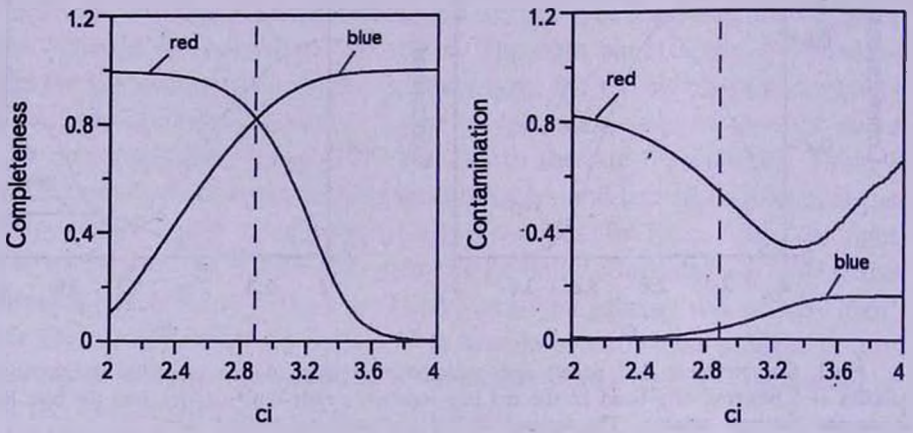

Fig.5. Completeness (left panel) and contamination (right panel) of early- and late-type galaxies as a function of z-band ci: the red line represents early-type galaxies, and the blue line represents late-type galaxies. The vertical dashed line indicates z-band $ci = 2.89$.

Table 1

COMPLETENESS AND CONTAMINATION OF EARLY- AND LATE-TYPE GALAXIES AT THE BALANCED POINT OF THE COMPLETENESS OF TWO SAMPLES

Band	The balanced point of the completeness of two samples	Completeness (%)		Contamination (%)	
		"Early-type" galaxies	"Late-type" galaxies	"Early-type" galaxies	"Late-type" galaxies
u-band	$ci=2.47$	72.17	72.40	66.31	6.95
g-band	$ci=2.75$	86.49	86.80	43.98	2.93
i-band	$ci=2.90$	83.81	84.35	49.00	3.60
z-band	$ci=2.89$	82.15	81.74	53.35	4.07

highest, which shows that in five photometric band concentration indexes, *u*-band concentration index should be the worst choice for using as a parameter in automated morphological classification schemes.

4. *Summary*. The study of Deng [16] demonstrated that using *r*-band concentration index $ci=2.85$, one can construct a reasonably pure late-type galaxy sample, but it is not an good selection for the construction of the early-type sample, which suggests that when classifying galaxies into morphological classes using the concentration index, one must treat statistical results of the early-type sample with caution. In this work, we attempt to use the same galaxy sample and further explore whether the *u*-, *g*-, *i*- and *z*-band concentration indexes are a good morphological classification tool. Our results demonstrate that when exploring whether five photometric band concentration indexes of the SDSS are a good morphological classification tool, *g*-band concentration index may be a better choice, compared with *r*-band concentration index, while *u*-band concentration index should be the worst choice.

Acknowledgements. This study was supported by the National Natural Science Foundation of China (NSFC, Grant 11263005).

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 Astrofisica 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.

[1] School of Science, Nanchang University, Jiangxi, China,
e-mail: xinfadeng@163.com

[2] Department of Natural Science, Nanchang Teachers College, Jiangxi, China

СВЯЗЬ МЕЖДУ МОРФОЛОГИЧЕСКИМ ТИПОМ И КОНЦЕНТРИЧЕСКИМИ ИНДЕКСАМИ РАЗЛИЧНЫХ ФОТОМЕТРИЧЕСКИХ ПОЛОС

ХИН-ФА ДЕНГ[1], ГИШЕНГ Ю[2]

В данной статье мы продолжаем исследовать - являются ли концентрические индексы в *u*-, *g*-, *i*- и z-полосах хорошими средствами морфологической классификации. Наши статистические результаты показали, что по сравнению с концентрическим индексом в *r*-полосе, концентрический индекс *g*-полосы может быть лучшим выбором для использования как параметра в автоматических морфологических классификационных схемах, тогда как морфологический индекс *u*-полосы должен быть худшим в пяти полосах концентрических индексов.

Ключевые слова: *галактики: основные параметры: статистика*

REFERENCES

1. *A.Sandage*, The Hubble Atlas of Galaxies (Washington: Carnegie Inst. Washington), 1961.
2. *M.Colless, G.Dalton, S.Maddox et al.*, Mon. Not. Roy. Astron. Soc., **328**, 1039, 2001.
3. *K.Shimasaku, M.Fukugita, M.Doi et al.*, Astron. J., **122**, 1238, 2001.
4. *I.Strateva, Z.Ivezic, G.R.Knapp et al.*, Astron. J., **122**, 1861, 2001.
5. *R.G.Abraham, S. van den Bergh, P.A.Nair*, Astrophys. J., **588**, 218, 2003.
6. *O.Nakamura, M.Fukugita, N.Yasuda et al.*, Astron. J., **125**, 1682, 2003.
7. *G.Kauffmann, S.D.M.White, T.M.Heckman et al.*, Mon. Not. Roy. Astron. Soc., **353**, 713, 2004.
8. *C.Park, Y.Y.Choi*, Astrophys. J., **635**, L29, 2005.
9. *C.Yamauchi, S.I.Ichikawa, M.Doi et al.*, Astron. J., **130**, 1545, 2005.
10. *C.J.Conselice*, Mon. Not. Roy. Astron. Soc., **373**, 1389, 2006.
11. *G.Sorrentino, V.Antonuccio-Delogu, A.Rifatto*, Astron. Astrophys., **460**, 673, 2006.
12. *C.Scarlata, C.M.Carollo, S.Lilly et al.*, Astrophys. J. Suppl. Ser., **172**, 406, 2007.
13. *W.W.Morgan*, Publ. Astron. Soc. Pacif., **70**, 364, 1958.
14. *M.Doi, M.Fukugita, S.Okamura*, Mon. Not. Roy. Astron. Soc., **264**, 832, 1993.
15. *R.G.Abraham, F.Valdes, H.K.C.Yee, S. van den Bergh*, Astrophys. J., **432**, 75, 1994.
16. *X.F.Deng*, RAA, **13**, 651, 2013.

17. *H.Aihara, C.A.Prieto, D.An et al.*, Astrophys. J. Suppl. Ser., **193**, 29, 2011.
18. *C.J.Lintott, K.Schawinski, A.Slosar et al.*, Mon. Not. Roy. Astron. Soc., **389**, 1179, 2008.
19. *C.J.Lintott, K.Schawinski, S.Bamford et al.*, Mon. Not. Roy. Astron. Soc., **410**, 166, 2011.
20. *M.A.Strauss, D.H.Weinberg, R.H.Lupton et al.*, Astron. J., **124**, 1810, 2002.
21. *K.N.Abazajian, J.K.Adelman-McCarthy, M.A.Agüeros et al.*, Astrophys. J. Suppl. Ser., **182**, 543, 2009.
22. *D.J.Eisenstein, D.H.Weinberg, E.Agol et al.*, Astron. J., **142**, 72, 2011.
23. *X.F.Deng, S.Y.Zou*, AN, **331**, 426, 2010.
24. *X.F.Deng, S.Y.Zou*, AN, **332**, 202, 2011.
25. *X.F.Deng*, Astron. J., **143**, 15, 2012.