АСТРОФИЗИКА

ТОМ 66 МАЙ, 2023 ВЫПУСК 2

DOI: 10.54503/0571-7132-2023.66.2-185

ENVIRONMENTAL DEPENDENCE OF DIFFERENT COLORS OF ACTIVE GALACTIC NUCLEUS (AGN) HOST GALAXIES

XIN-FA DENG, ZHI-YONG WU

Received 21 February 2023
Accepted 22 May 2023

Using the apparent-magnitude limited active galactic nucleus (AGN) host galaxy sample of the Sloan Digital Sky Survey Data Release 12 (SDSS DR12), we investigate the environmental dependence of the *u-r*, *u-g*, *g-r*, *r-i* and *i-z* colors of AGN host galaxies. We divide the whole apparent-magnitude limited AGN sample into many subsamples with a redshift binning size of $\Delta z = 0.01$, and analyze the environmental dependence of all five galaxy colors of subsamples in each redshift bin. It turns out that overall, all five galaxy colors of AGN host galaxies are weakly correlated with the local environment.

Keywords: *galaxies: fundamental parameters - galaxies: statistics*

1. *Introduction*. For a long time, there have been many studies that focus on the issue of the active galactic nuclei (AGNs) [1-9]. Carter et al. [1] showed that the AGN fraction is insensitive to the local environment. Kauffmann et al. [2] showed that galaxies in dense environments are less likely to host a powerful optical AGN ($L[OIII] > 10^7 L_{\otimes}$), but did not find the environmental dependence for the presence of weaker optical AGN. Using a large sample of local galaxies of the SDSS, Choi et al. [3] compared AGN host galaxies with non-AGN galaxies at matched luminosity, velocity dispersion, color, color gradient, or concentration index, to explore how AGN activity is related to galaxy properties. LaMassa et al. [4] studied a combined sample of 264 star-forming, 51 composite, and 73 active galaxies using optical spectra from the Sloan Digital Sky Survey (SDSS) and mid-infrared (mid-IR) spectra from the Spitzer Infrared Spectrograph. Manzer and De Robertis [5] explored possible environmental triggers of nuclear activity through a statistical analysis of a large sample of galaxy groups. Bufanda et al. [6] analyzed the fraction of galaxies in clusters hosting AGN as a function of redshift and cluster richness for X-ray-detected AGN associated with clusters of galaxies in Dark Energy Survey (DES) Science Verification data. By investigating 2727 galaxies observed by MaNGA, Wylezalek et al. [7] developed spatially resolved techniques for identifying signatures of AGNs. Comparat et al. [8] compiled an N-body simulation-based mock catalogue for X-ray-selected AGN samples. Liu et al. [9] presented a new,

complete sample of 14584 broad-line AGNs at $z < 0.35$.

As is well-known, galaxy colors strongly depend on the environment [10-16]. Brown et al. [10] and Zehavi et al. [11] demonstrated that clustering of galaxies strongly depends on color. Blanton et al. [13] observed that local density is a strong function of all colors. Blanton et al. [14] argued that galaxy color is the galaxy property most predictive of the local environment. Zehavi et al. [12] examined $g-r$ color dependence of the galaxy two-point correlation function, and claimed that redder galaxies exhibit a higher amplitude and steeper correlation function at all luminosity. Zhang & Deng [16] found that the redder galaxies preferentially inhabit the dense groups and clusters. Deng et al. [15] divided an apparent magnitude-limited Main galaxy sample [17] at redshift $0.02 \le z \le 0.2$ into subsamples with a redshift binning size of $\Delta z = 0.01$ and investigated the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors of the subsamples in each redshift bin. It was found that strong environmental dependence exists in the redshift region $0.02 \le z \le 0.15$.

The primary goal of this study is to compare the environmental dependence of colors of AGN host galaxies with the one of general galaxies. Considering the comparison with the result of Deng et al. [15] we attempt to explore the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors of AGN host galaxies. The outline of this paper is as follows. In Section 2, we describe the AGN host galaxy sample. The statistical method is described in Section 3. In Section 4, we present the environmental dependence of all five galaxy colors of AGN host galaxies. Our main results and conclusions are summarized in Section 5.

In calculating the distance, 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 $H_0 = 70\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$.

2. *Data*. SDSS Data Release 12 (DR12) [18] is the final public release of spectroscopic data from the SDSS-III BOSS. In this work, the data of the Main galaxy sample [17] was downloaded from the Catalog Archive Server of SDSS Data Release 12 [18] by the SDSS SQL Search (with SDSS flag: LEGACY_TARGET1 & $(64|128|256) > 0$). We extract 631968 Main galaxies with the spectroscopic redshift $0.02 \le z \le 0.2$.

The *galSpecExtra* table contains estimated parameters for all galaxies in the MPA-JHU spectroscopic catalogue. BPT classification in this table is based on the methodology of Brinchmann et al. [19]:

All. The set of all galaxies in the sample regardless of the S/N of their emission lines.

SF. The star-forming galaxies. These are the galaxies with S/N > 3 in all four BPT lines that lie below lower line in Fig.1 of Brinchmann et al. [19]. This

lower line is taken from equation (1) of Kauffmann et al. [20].

C. The composite galaxies. They are the objects with S/N > 3 in all four BPT lines that are between the upper and lower lines in Fig.1 of Brinchmann et al. [19]. The upper line has been taken from equation (5) of Kewley et al. [21].

AGN. The AGN population consists of the galaxies above the upper line in Fig.1 of Brinchmann et al. [19]. This line corresponds to the theoretical upper limit for pure starburst models.

Low S/N AGNs. They have [NII] 6584/Hα > 0.6 (and S/N > 3 in both lines) [20], and still are classified as an AGN even if their [OIII]5007 and/or Hβ have too low S/N. Miller et al. [22] called such AGNs the "two-line AGNs".

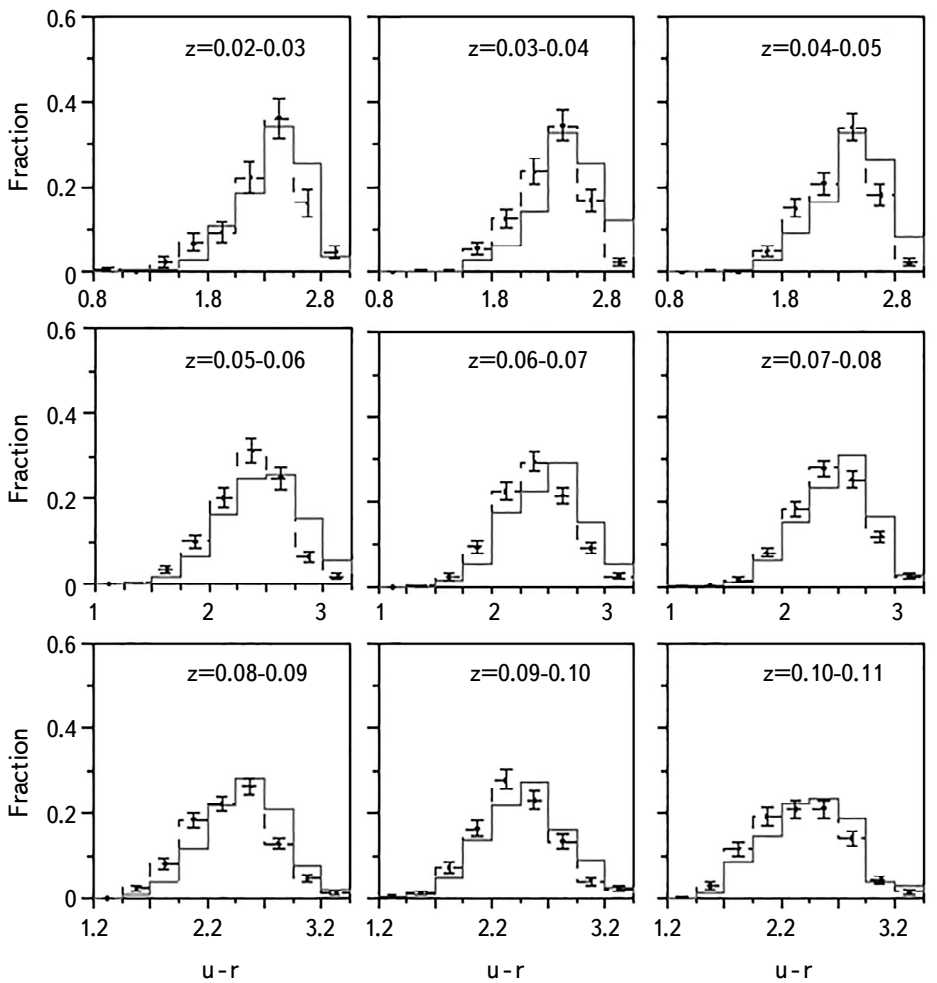

Fig.1. *u-r* color distribution at both extremes of density in different redshift bins: solid line for the sample at high density, dashed line for the sample at low density. The error bars of dashed lines are 1σ Poissonian errors. Error-bars of solid lines are omitted for clarity.

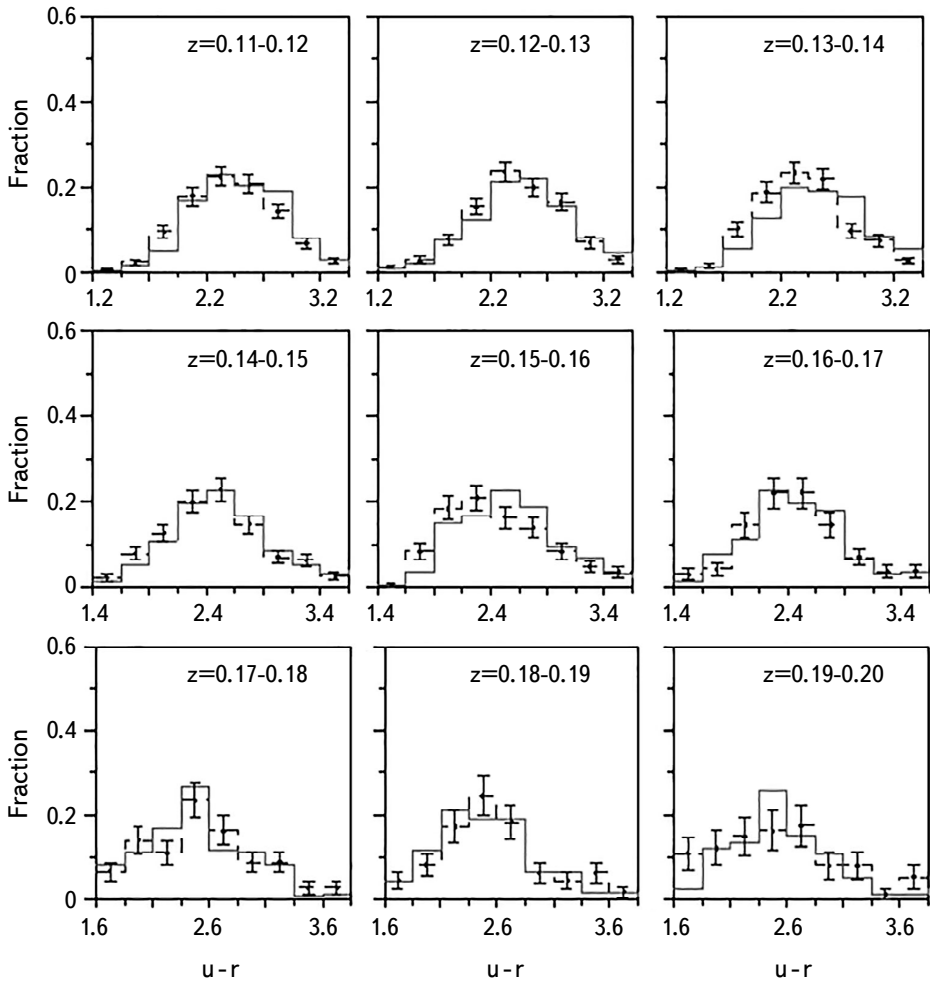

Fig.1. (The end).

Low S/N SF. The remaining galaxies with S/N > 2 in Hα are considered low S/N star formers.

Unclassifiable. Those remaining galaxies that are impossible to classify using the BPT diagram. This class is mostly made up of galaxies with no or very weak emission lines.

Deng & Wen [23] selected C, AGN and Low S/N AGN populations and constructed an apparent magnitude-limited AGN sample which contains 122923 AGN host galaxies. In this work, we use this AGN sample.

Deng et al. [15] argued that when all analyses are limited in the redshift bin $\Delta z = 0.01$. *K*-corrections are less important and can be ignored. Following Deng et al. [15], we use the observed color (not apply *K*-correction).

3. *Statistical method*. Following Deng [24], we measure the projected local density $\sum_5 = N/\pi d_5^2$ (Galaxies Mpc^{-2}), where d_5 is the distance to the 5th nearest neighbor within ± 1000 km/s in redshift [25-27] and divide this AGN sample into subsamples with a redshift binning size of $\Delta z = 0.01$. In each subsample, we arrange galaxies in a density order from smallest to largest, select approximately 5% of the galaxies, construct two samples at both extremes of density, and compare the distribution of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors of AGN host galaxies in the lowest density regime with those in the densest regime.

4. *The environmental dependence of all five galaxy colors of AGN host galaxies*. Fig.1 shows $u-r$ color distributions at both extremes of density in different redshift bins for the apparent magnitude-limited AGN sample. As seen form this figure, overall, $u-r$ color of AGN host galaxies is weakly correlated with the local environment. We also notice that other color indices demonstrate similar behavior.

The Kolmogorov-Smirnov (KS) test can show the degree of similarity or difference between two independent distributions in a figure by calculating a probability value. A large probability implies that it is very likely that the two distributions are derived from the same parent distribution. Conversely, a low probability implies that the two distributions are different. The probability of the two distributions coming from the same parent distribution is listed in Table 1, which is much larger than that obtained by Deng [24] (see Table 1 of [24]) and even is much larger than 0.05 (5%, is the standard in a statistical analysis). Such a result shows that two independent distributions in these two figures are very similar. This is in good agreement with the conclusion obtained by the histogram figures.

The redshift ranges of the AGN sample in this work is the same as one of the apparent-magnitude limited Main galaxy sample of the SDSS used by Deng et al. [15]. Using the same method, Deng et al. [15] investigated the environmental dependence of $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors in all redshift bins of the apparent-magnitude limited Main galaxy sample. It was found that overall, all the five colors strongly correlate with local environment: red galaxies tend to be located in dense regions, while blue galaxies tend to be located in low density regions. Deng et al. [15] also noted that with increasing redshift, the environmental dependence of galaxy colors becomes weak, especially in high redshift region $0.17 \le z \le 0.20$. Deng et al. [15] believed that this is likely due to these subsamples with high redshifts only containing luminous and red galaxies.

Deng [28] demonstrated that there still is a strong environmental dependence of galaxy age in faint volume-limited Main galaxy sample, but Deng & Wen [23]

reported that in the faint volume-limited AGN host galaxy sample, the environmental dependence of the age is fairly weak. Zheng et al. [29] presented the stellar age and metallicity distributions for 1105 galaxies on the SDSS-IV MaNGA (Mapping Nearby Galaxies at APO) [30] integral field spectra, and also found that the galaxy age depends on local density. Thus, Deng & Wen [23] believed that the environmental dependence of the age of AGN host galaxies is likely different from the one of general galaxies. Here, we again note that the environmental dependence of colors of AGN host galaxies is different from the one of general galaxies.

Table 1

K-S PROBABILITIES OF DIFFERENT COLORS THAT TWO SAMPLES AT BOTH EXTREMES OF DENSITY ARE DRAWN FROM THE SAME DISTRIBUTION

Redshift bins	Galaxy number	P (u-r)	P (u-g)	P (g-r)	P (r-i)	P (i-z)
0.02-0.03	3433	0.0845	0.353	0.0638	0.231	0.601
0.03-0.04	5105	1.854e-09	4.008e-07	1.036e-09	1.067e-06	0.000411
0.04-0.05	6281	0.000153	0.00206	5.935e-07	5.182e-05	0.000107
0.05-0.06	7757	6.633e-08	0.000115	6.239e-11	1.611e-12	0.000532
0.06-0.07	10503	1.081e-07	0.000116	1.545e-11	6.239e-13	3.256e-06
0.07-0.08	13062	0.000406	0.0108	5.291e-08	9.659e-05	0.0216
0.08-0.09	12860	7.808e-08	9.738e-07	7.808e-08	2.828e-07	0.0820
0.09-0.10	9824	4.376e-05	0.00918	2.531e-06	3.096e-09	0.00382
0.10-0.11	8186	0.00647	0.0550	0.000103	7.116e-06	0.000140
0.11-0.12	9109	0.110	0.151	0.0116	0.00934	0.00597
0.12-0.13	8136	0.0652	0.415	9.765e-05	3.324e-07	0.00299
0.13-0.14	7650	9.127e-06	0.000191	9.041e-09	1.246e-10	0.000477
0.14-0.15	6412	0.138	0.682	9.366e-05	6.631e-06	0.274
0.15-0.16	4787	0.00211	0.110	2.894e-05	8.245e-08	0.0326
0.16-0.17	3445	0.782	0.926	0.111	0.0256	0.601
0.17-0.18	2710	0.543	0.748	0.171	0.0174	0.0507
0.18-0.19	2190	0.506	0.0313	0.403	0.314	0.179
0.19-0.20	1473	0.879	0.961	0.961	0.616	0.879

5. *Summary*. In this study, we use the apparent-magnitude limited AGN sample of the SDSS DR12 [18] which contains 122923 AGN host galaxies and investigate the environmental dependence of the $u-r$, $u-g$, $g-r$, $r-i$ and $i-z$ colors of AGN host galaxies. Following Deng [24], we divide the whole apparent-magnitude limited AGN sample into many subsamples with a redshift binning size of $\Delta z = 0.01$, and analyze the environmental dependence of all five galaxy colors of subsamples in each redshift bin. The histogram figure and the (KS) test

show that overall, all five galaxy colors of AGN host galaxies are weakly correlated with the local environment.

Acknowledgements. This study was supported by the National Natural Science Foundation of China (NSFC, Grant 11533004, 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 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.

Jiangxi University of Software Professional Technology, Jiangxi, China, e-mail: xinfadeng@163.com

ЗАВИСИМОСТЬ РАЗЛИЧНЫХ ЦВЕТОВ РОДИТЕЛЬСКИХ ГАЛАКТИК АКТИВНЫХ ГАЛАКТИЧЕСКИХ ЯДЕР (АЯГ) ОТ ОКРУЖАЮЩЕЙ СРЕДЫ

КСИН-ФА ДЭНГ, ЧЖИ-ЮН ВУ

Используя ограниченную по видимой величине выборку родительских галактик активных галактических ядер (АЯГ) из Sloan Digital Sky Survey Data Release 12 (SDSS DR12), исследована зависимость цветов *u-r*, *u-g*, *g-r*, *r-i* и *i-z* родительских галактик АЯГ от окружающей среды. Вся выборка с ограниченной видимой величиной была разбита по красному смещению $\Delta z = 0.01$ на множество подвыборок и для каждой из них анализирована зависимость всех пяти цветов галактик (в каждом бине по красному смещению)

от окружающей среды. Оказалось, что в целом все цвета родительских галактик АЯГ слабо коррелируют с местным окружением.

Ключевые слова: *галактики: фундаментальные параметры - галактики: статистика*

REFERENCES

1. *B.J.Carter*, *D.G.Fabricant*, *M.J.Geller et al.*, Astrophys. J., **559**, 606, 2001.
2. *G.Kauffmann*, *S.D.M.White*, *T.M.Heckman et al.*, Mon. Not. Roy. Astron. Soc., **353**, 713, 2004.
3. *Y.Y.Choi*, *J.H.Woo*, *C.Park*, Astrophys. J., **699**, 1679, 2009.
4. *S.M.LaMassa*, *T.M.Heckman*, *A.Ptak et al.*, Astrophys. J., **758**, 1, 2012.
5. *L.H.Manzer*, *M.M. De Robertis*, Astrophys. J., **788**, 140, 2014.
6. *E.Bufanda*, *D.Hollowood*, *T.E.Jeltema et al.*, Mon. Not. Roy. Astron. Soc., **465**, 2531, 2017.
7. *D.Wylezalek*, *N.L.Zakamska*, *J.E.Greene et al.*, Mon. Not. Roy. Astron. Soc., **474**, 1499, 2018.
8. *J.Comparat*, *A.Merloni*, *M.Salvato et al.*, Mon. Not. Roy. Astron. Soc., **487**, 2005, 2019.
9. *H.Y.Liu*, *W.J.Liu*, *X.B.Dong et al.*, Astrophys. J. Suppl. Ser., **243**, 21, 2019.
10. *M.J.I.Brown*, *R.L.Webster*, *B.J.Boyle*, Mon. Not. Roy. Astron. Soc., **317**, 782, 2000.
11. *I.Zehavi*, *M.R.Blanton*, *J.A.Frieman et al.*, Astrophys. J., **571**, 172, 2002.
12. *I.Zehavi*, *Z.Zheng*, *D.H.Weinberg et al.*, Astrophys. J., **630**, 1, 2005.
13. *M.R.Blanton*, *D.W.Hogg*, *N.A.Bahcall et al.*, Astrophys. J., **594**, 186, 2003.
14. *M.R.Blanton*, *D.Eisenstein*, *D.W.Hogg et al.*, Astrophys. J., **629**, 143, 2005.
15. *X.F.Deng*, *C.H.Luo*, *Y.Xin et al.*, Baltic Astron., **22**, 133, 2013.
16. *F.Y.Zhang*, *X.F.Deng*, Astrophys. J., **58**, 21, 2015.
17. *M.A.Strauss*, *D.H.Weinberg*, *R.H.Lupton et al.*, Astron. J., **124**, 1810, 2002.
18. *S.Alam*, *F.D.Albareti*, *C.A.Prieto et al.*, Astrophys. J. Suppl. Ser., **219**, 12, 2015.
19. *J.Brinchmann*, *S.Charlot*, *S.D.M.White et al.*, Mon. Not. Roy. Astron. Soc., **351**, 1151, 2004.
20. *G.Kauffmann*, *T.M.Heckman*, *C.Tremonti et al.*, Mon. Not. Roy. Astron. Soc., **346**, 1055, 2003.
21. *L.J.Kewley*, *C.A.Heisler*, *M.A.Dopita et al.*, Astrophys. J. Suppl. Ser., **132**, 37, 2001.
22. *C.J.Miller*, *R.C.Nichol*, *P.L.Gómez et al.*, Astrophys. J., **597**, 142, 2003.
23. *X.F.Deng*, *X.Q.Wen*, RMxAA, **56**, 87, 2020.
24. *X.F.Deng*, Astron. J., **143**, 15, 2012.

25. *T.Goto*, *C.Yamauchi*, *Y.Fujita et al.*, Mon. Not. Roy. Astron. Soc., **346**, 601, 2003.
26. *M.Balogh*, *I.K.Baldry*, *R.Nichol et al.*, Astrophys. J., **615**, L101, 2004.
27. *M.Balogh*, *V.Eke*, *C.Miller et al.*, Mon. Not. Roy. Astron. Soc., **348**, 1355, 2004.
28. *X.F.Deng*, BASI, **42**, 59, 2014.
29. *Z.Zheng*, *H.Wang*, *J.Ge et al.*, Mon. Not. Roy. Astron. Soc., **465**, 4572, 2017.
30. *K.Bundy*, *M.A.Bershady*, *D.R.Law et al.*, Astrophys. J., 798, 7, 2015.