International Journal of Astronomy and Astrophysics, 2018, 8, 258-266
http://www.scirp.org/journal/ijaa
ISSN Online: 2161-4725
ISSN Print: 2161-4717

The Great Wall of SDSS Galaxies

Lorenzo Zaninetti

Physics Department, Via P. Giuria 1, Turin, Italy
Email: zaninetti@ph.unito.it

How to cite this paper: Zaninetti, L. (2018) The Great Wall of SDSS Galaxies. *International Journal of Astronomy and Astrophysics*, **8**, 258-266.
https://doi.org/10.4236/ijaa.2018.83018

Received: July 16, 2018
Accepted: September 3, 2018
Published: September 6, 2018

Abstract

An enhancement in the number of galaxies as function of the redshift is visible on the SDSS Photometric Catalogue DR 12 at z = 0.383. This over-density of galaxies is named the Great Wall. This variable number of galaxies as a function of the redshift can be explained in the framework of the luminosity function for galaxies. The differential of the luminosity distance in respect to the redshift is evaluated in the framework of the LCDM cosmology.

Keywords

Galaxy Groups, Clusters, and Superclusters, Large Scale Structure of the Universe Cosmology

1. Introduction

We review some early works on the "CfA2 Great Wall", which is the name that was introduced by [1] to classify an enhancement in the number of galaxies as a function of the redshift that is visible in the Center for Astrophysics (CfA) redshift survey [2]. The evaluation of the two point correlation function was done by [3] on the three slices of the CfA redshift survey. A careful analysis was performed on Sloan Digital Sky Survey (SDSS) DR4 galaxies by [4]: The great wall was detected in the range $0.07 < z < 0.09$. The substructures, the morphology and the galaxy contents were analyzed by [5] [6] and the luminosities and masses of galaxies were discussed in the framework of SDSS-III's Baryon Oscillation Spectroscopic Survey (BOSS) [7]. The theoretical explanations for the Great Wall include an analysis of the peculiar velocities, see [8] [9], the nonlinear fields of the Zel'dovich approximation, see [10] [11] [12], and the cosmology of the Great Attractor, see [13]. The layout of the rest of this paper is as follows. In Section 2, we introduce the LCDM cosmology and the luminosity function for galaxies. In Section 3, we introduce the adopted catalog for galaxies and the theoretical basis of the maximum for galaxies as function of the redshift.

2. Preliminaries

This section introduces an approximate luminosity distance as a function of the redshift in LCDM and derives the connected differential. The Schechter luminosity function for galaxies is reviewed.

2.1. Adopted Cosmology

Some useful formulae in ΛCDM cosmology can be expressed in terms of a Padé approximant. The basic parameters are: the Hubble constant, H_0, expressed in km s^{-1}·Mpc^{-1}, the velocity of light, *c*, expressed in km·s^{-1}, and the three numbers Ω_{M}, Ω_K, and Ω_Λ, see [14] for more details. In the case of the Union 2.1 compilation, see [15], the parameters are $H_0 = 69.81\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}}$, $\Omega_{\mathrm{M}} = 0.239$ and $\Omega_\Lambda = 0.651$. To have the luminosity distance, $D_L\left(z; H_0, c, \Omega_{\mathrm{M}}, \Omega_\Lambda\right)$, as a function of the redshift only, we apply the minimax rational approximation, which is characterized by the two parameters *p* and *q*. We find a simplified expression for the luminosity distance, $D_{L,6,2}$, when $p = 6$ and $q = 2$

$$D_{L,6,2} = \frac{ND}{0.284483 + 0.153266z + 0.0681615z^2} \quad \text{for } 0.001 < z < 4, \tag{1}$$

where

$$\begin{aligned} ND = & -0.0017 + 1221.80z + 1592.35z^2 + 504.386z^3 \\ & + 85.8574z^4 + 0.41684z^5 + 0.186189z^6, \end{aligned} \tag{2}$$

The inverse of the above function, *i.e.* the redshift $z_{6,2}$ as function of the luminosity distance, is

$$\begin{aligned} z_{6,2} = & 3.3754 \times 10^{-5} D_L - 0.46438 + 2.1625 \times 10^{-14} \\ & \times \sqrt{2.4363 \times 10^{18} D_L^2 + 3.9538 \times 10^{23} D_L + 4.6114 \times 10^{26}}. \end{aligned} \tag{3}$$

2.2. Luminosity Function for Galaxies

We used the Schechter function, see [16], as a luminosity function (LF) for galaxies

$$\Phi(L)\mathrm{d}L = \left(\frac{\Phi^*}{L^*}\right)\left(\frac{L}{L^*}\right)^\alpha \exp\left(-\frac{L}{L^*}\right)\mathrm{d}L, \tag{4}$$

here α sets the slope for low values of luminosity, L, L^* is the characteristic luminosity and Φ^* is the normalisation. The equivalent distribution in absolute magnitude is

$$\Phi(M)\mathrm{d}M = 0.921\Phi^* 10^{0.4(\alpha+1)(M^*-M)} \exp\left(-10^{0.4(M^*-M)}\right)\mathrm{d}M, \tag{5}$$

where M^* is the characteristic magnitude as derived from the data. The scaling with *h* is $M^* - 5\log_{10} h$ and $\Phi^* h^3 \left[\mathrm{Mpc}^{-3}\right]$.

3. The Photometric Maximum

This section models the Great Wall that is visible on the SDSS Photometric Catalogue DR 12. It also evaluates the theoretical number of galaxies as a function of the redshift.

3.1. The SDSS Data

We processed the SDSS Photometric Catalogue DR 12, see [17], which contains 10,450,256 galaxies (elliptical + spiral) with redshift. In the following we will use the generic term galaxies without distinction between the two types, elliptical and spiral. The number of galaxies for an area in redshift of 0.025×0.025 of the u-band is reported in **Figure 1** as a contour plot and in **Figure 2** as a cut along a line.

3.2. The Theory

The flux, *f*, is

$$f=\frac{L}{4\pi r^2}, \tag{6}$$

where r is the luminosity distance. The luminosity distance is

$$r=D_{L,6,2}, \tag{7}$$

and the relationship between $\mathrm{d}r$ and $\mathrm{d}z$ is

$$\mathrm{d}r=\frac{N}{D}\mathrm{d}z, \tag{8}$$

where

$$\begin{aligned}N={}&74813.67+10.9263z^7+49.05768z^6+2642.64259z^5+16024.51314z^4\\&+54307.16663z^3+127258.486z^2+195005.8564z,\end{aligned} \tag{9}$$

and

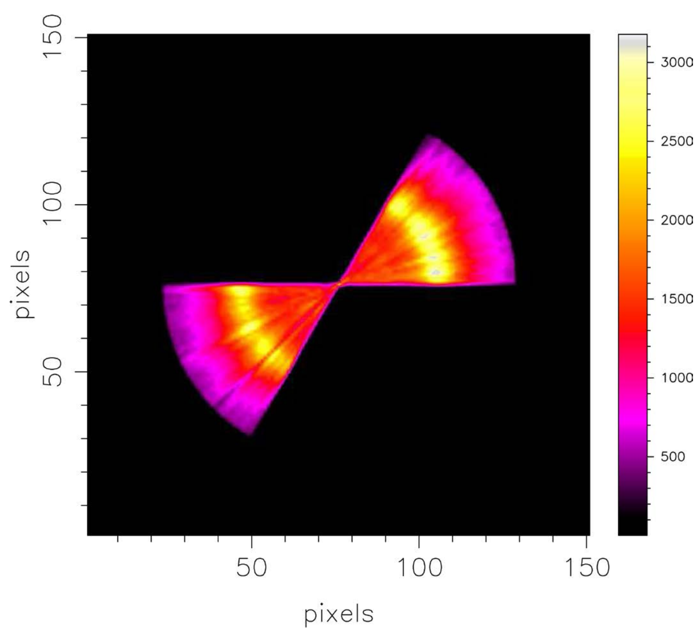

Figure 1. Contour for the number of galaxies (u-band) for areas of 0.025×0.025.

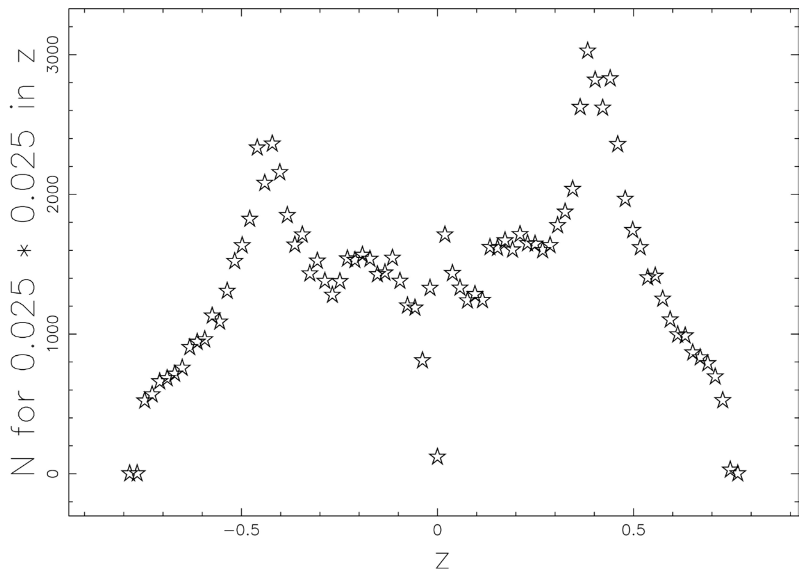

Figure 2. The number of galaxies (u-band) along a line for areas of 0.025×0.025.

$$D = \left(z^2 + 2.248575472z + 4.173664398\right)^2. \tag{10}$$

The joint distribution in z and f for the number of galaxies is

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega\mathrm{d}z\mathrm{d}f} = \frac{1}{4\pi}\int_0^\infty 4\pi r^2 \mathrm{d}r \Phi\left(L; L^*, \sigma\right)\delta\left(z - \left(z_{6,2}\right)\right)\delta\left(f - \frac{L}{4\pi r^2}\right), \tag{11}$$

where δ is the Dirac delta function, $\Phi\left(L; L^*, \sigma\right)$ has been defined in Equation (4) and $z_{6,2}$ has been defined in Equation (3). The explicit version is

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega\mathrm{d}z\mathrm{d}f} = \frac{NN}{DD}, \tag{12}$$

where

$$\begin{aligned} NN = {} & 644.3\left(z+1.058\right)^4\left(z-0.000001412\right)^4\left(z^2+4.889z+13.34\right)^4 \\ & \times\left(z^2-3.708z+464.6\right)^4 \mathrm{e}^{\frac{AA}{BB^2L^*}}\left(\frac{CC}{BB^2L^*}\right)^{\alpha}\Phi^*\left(z+0.5328\right) \\ & \times\left(z^2+5.047z+7.9141\right)\left(z^2+0.7z+7.011\right)\left(z^2-1.79z+231.58\right), \end{aligned} \tag{13}$$

$$\begin{aligned} CC = {} & f\left(z+1.058\right)^2\left(z-0.0000014124\right)^2\left(z^2+4.889z+13.343\right)^2 \\ & \times\left(z^2-3.708z+464.6\right)^2 \end{aligned} \tag{14}$$

$$DD = \left(z^2+2.248z+4.173\right)^6 L^* \tag{15}$$

$$\begin{aligned} AA = {} & -93.76 fz^{12} - 419.8 fz^{11} - 86945.4 fz^{10} - 701622.4 fz^9 \\ & - 22679411 fz^8 - 239083307 fz^7 - 1430432291 fz^6 \\ & - 4912205831 fz^5 + \left(4.540788\alpha L^* - 10191896880 f\right)z^4 \\ & + \left(20.4206\alpha L^* - 10524532830 f\right)z^3 + \left(60.862\alpha L^* - 4037704632 f\right)z^2 \\ & + \left(85.22\alpha L^* + 11406.2 f\right)z + 79.098\alpha L^* - 0.008055 f, \end{aligned} \tag{16}$$

$$BB = z^2 + 2.2485z + 4.173. \tag{17}$$

Figure 3 presents the number of galaxies that are observed in SDSS DR 12 as a function of the redshift for a given window in flux, in addition to the theoretical curve. The theoretical number of galaxies is reported in Figure 4 as a function of the flux and redshift, and is reported in Figure 5 as a function of α and redshift.

The total number of galaxies comprised between a minimum value of flux, $f_{\min}$, and a maximum value of flux $f_{\max}$, for the Schechter LF can be computed through the integral

$$\frac{\mathrm{d}N}{\mathrm{d}\Omega\mathrm{d}z} = \int_{f_{\min}}^{f_{\max}} \frac{NN}{DD}\mathrm{d}f. \tag{18}$$

This integral has a complicated analytical solution in terms of the Whittaker function $M_{\kappa,\mu}(z)$, see [18]. Figure 6 reports all of the galaxies of SDSS DR12 and also the theoretical curve.

A theoretical surface/contour of the Great Wall is displayed in Figure 7

4. Conclusions

1) ΛCDM cosmology

In this paper, we use the framework of ΛCDM cosmology with parameters $H_0 = 69.81\ \mathrm{km \cdot s^{-1} \cdot Mpc^{-1}}$, $\Omega_M = 0.239$ and $\Omega_\Lambda = 0.651$. A relationship for

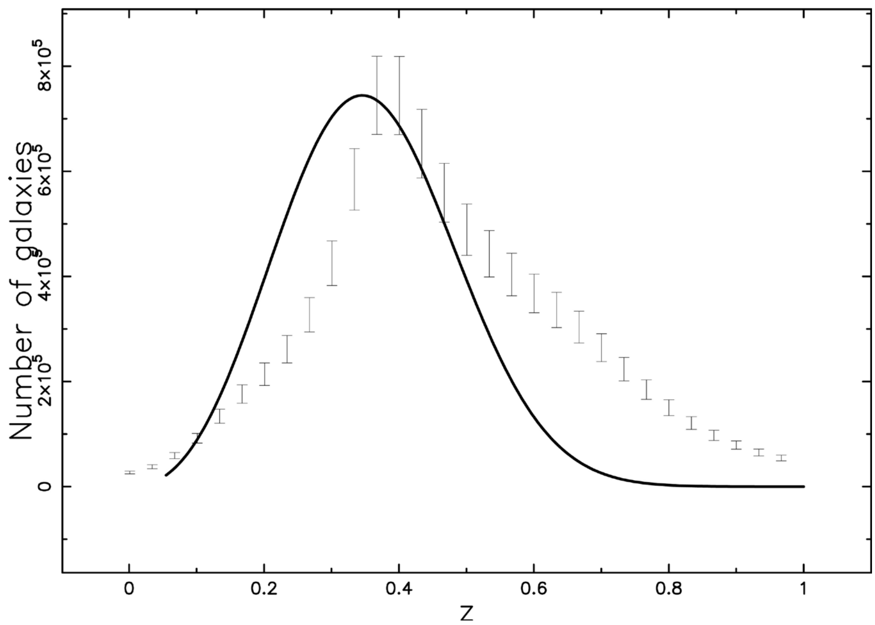

Figure 3. The galaxies of SDSS DR 12 (u-band) with $400L_\odot/\mathrm{Mpc}^2 \le f \le 5\times10^7 L_\odot/\mathrm{Mpc}^2$ are organized by frequency versus distance (empty circles) and the error bar is given by the square root of the frequency. The maximum frequency of the observed galaxies is at $z = 0.38$. The full line is the theoretical curve that is generated by $\frac{\mathrm{d}N}{\mathrm{d}\Omega\mathrm{d}r\mathrm{d}f}$ as given by the application of the Schechter LF, which is Equation (12), and the theoretical maximum is at $z = 0.382$. The parameters are $L^* = 2.038\times10^{10} L_\odot$ and $\alpha = -0.9$.

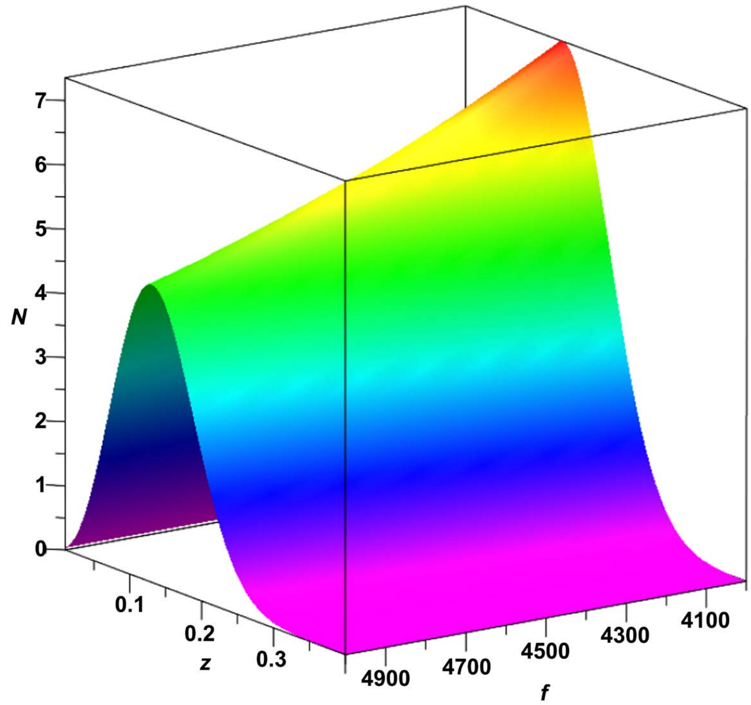

Figure 4. The theoretical number of galaxies divided by 1000 as a function of redshift and flux is expressed in $L_{\odot}/\text{Mpc}^2$. The parameters are $L^* = 2.038\times10^{10}L_{\odot}$, $\alpha = -0.9$ and $\frac{\Phi^*}{\text{Mpc}^{-3}} = 0.038$.

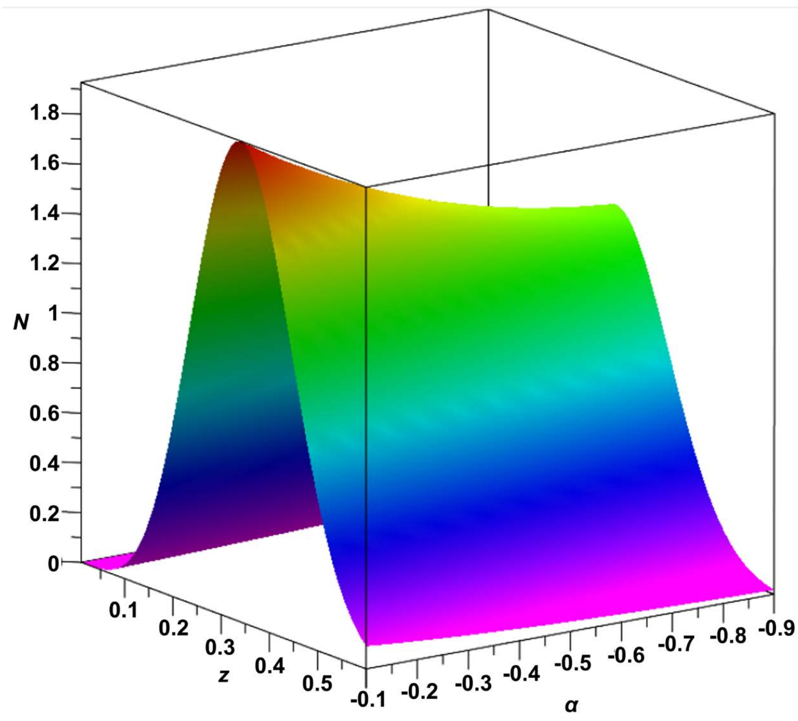

Figure 5. The theoretical number of galaxies divided by 100,000 as a function of α and redshift when $L^* = 2.038\times10^{10}L_{\odot}$, $f = 1000L_{\odot}/\text{Mpc}^2$, and $\frac{\Phi^*}{\text{Mpc}^{-3}} = 0.038$.

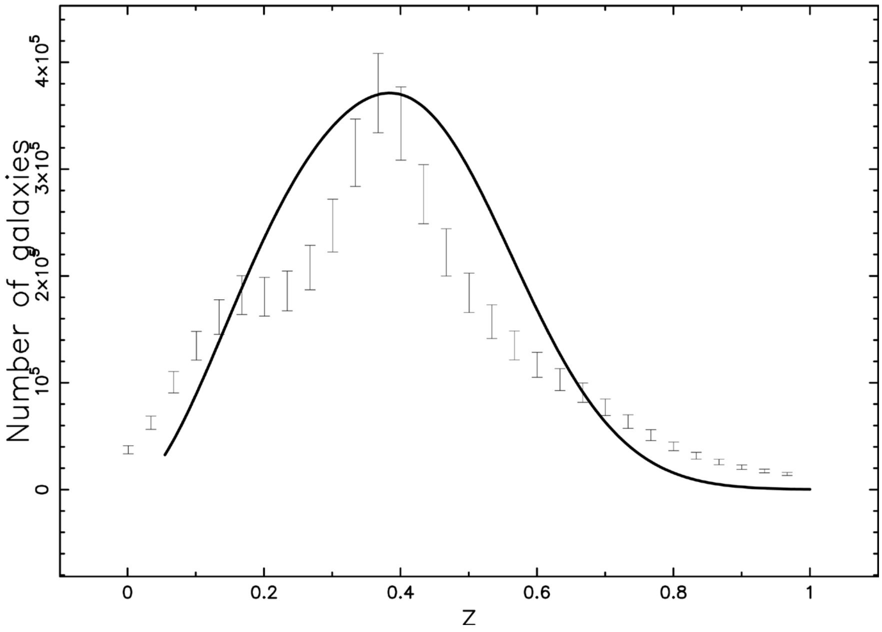

Figure 6. All of the galaxies of the SDSS DR12 catalog (u-band) are organized in frequencies versus spectroscopic redshift. The error bar is given by the square root of the frequency (Poisson distribution). The maximum frequency of all observed galaxies is at $z = 0.383$. The full line is the theoretical curve generated by $\frac{dN}{d\Omega dz}(z)$ as given by the numerical integration of Equation (18) with $L^* = 2.038 \times 10^{10} L_\odot$, $\alpha = -0.9$ and $\frac{\Phi^*}{\text{Mpc}^{-3}} = 0.038$.

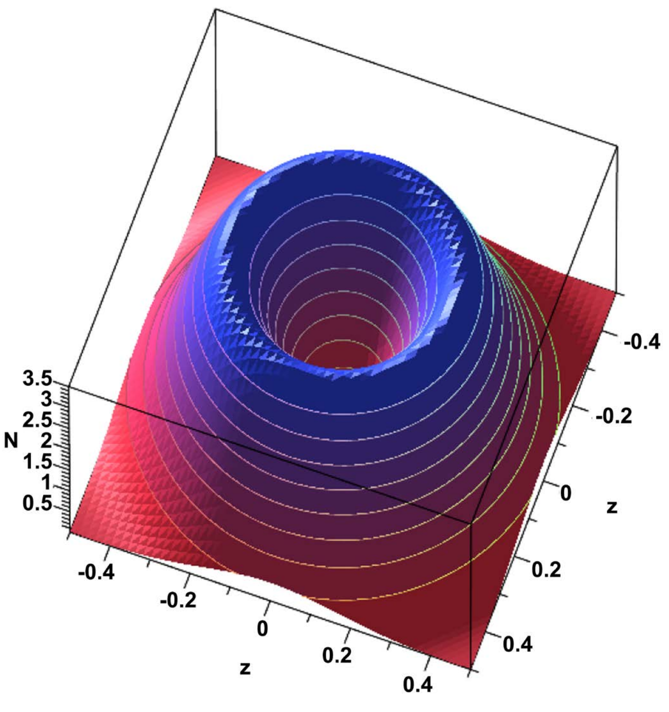

Figure 7. Theoretical surface/contour of the number of all the galaxies divided by 1,000,000 as a function of redshift. Parameters as in **Figure 6**.

the luminosity distance is derived using the method of the minimax approximation when $p=6$ and $q=2$, see Equation (2). The inverse relationship, the redshift as function of the luminosity function is derived in Equation (3).

2) The Great Wall

The enhancement in the number of galaxies as a function of the redshift for the SDSS Photometric Catalogue DR 12, which is at $z=0.383$, is here modeled by the theoretical Equation (12) that is derived in the framework of the Schechter LF for galaxies and the ΛCDM cosmology. **Figure 6** reports the observed maximum in the number of galaxies and also the theoretical curve. These results are in agreement with a catalog of photometric redshift of ≈3,000,000 SDSS DR8 galaxies made by [19]: their Figure 9 bottom reports that the count of elliptical galaxies has a peak at $z \approx 0.37$ when the spirals galaxies conversely peaks at $z \approx 0.08$.

Acknowledgements

This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Geller, M.J. and Huchra, J.P. (1989) Mapping the Universe. *Science*, **246**, 897. https://doi.org/10.1126/science.246.4932.897

[2] de Lapparent, V., Geller, M.J. and Huchra, J.P. (1989) The Luminosity Function for the CfA Redshift Survey Slices. *Astrophysical Journal*, **343**, 1.

[3] Ramella, M., Geller, M.J. and Huchra, J.P. (1992) The Distribution of Galaxies within the "Great Wall". *Astrophysical Journal*, **384**, 396. https://doi.org/10.1086/170882

[4] Deng, X.F., He, J.Z., He, C.G., *et al.* (2007) The Sloan Great Wall from the SDSS Data Release 4. *Acta Physica Polonica B*, **38**, 219.

[5] Einasto, M., Tago, E., Saar, E., *et al.* (2010) The Sloan Great Wall. Rich Clusters. *Astronomy & Astrophysics*, **522**, A92.

[6] Einasto, M., Liivamägi, L.J., Tempel, E., *et al.* (2011) The Sloan Great Wall. Morphology and Galaxy Content. *Astrophysical Journal*, **736**, 51.

[7] Einasto, M., Lietzen, H., Gramann, M., *et al.* (2017) BOSS Great Wall: Morphology, Luminosity, and Mass. *Astronomy & Astrophysics*, **603**, A5

[8] dell'Antonio, I.P., Bothun, G.D. and Geller, M.J. (1996) Peculiar Velocities for Galaxies in the Great Wall. I. The Data. *The Astronomical Journal*, **112**, 1759.

[9] dell'Antonio, I.P., Geller, M.J. and Bothun, G.D. (1996) Peculiar Velocities for Galaxies in the Great Wall. II. Analysis. *The Astronomical Journal*, **112**, 1780.

[10] Zel'dovich, Y.B. (1970) Gravitational Instability: An Approximate Theory for Large Density Perturbations. *Astronomy & Astrophysics*, **5**, 84.

[11] Shandarin, S.F. (2009) The Origin of "Great Walls". *Journal of Cosmology and Astroparticle Physic*, **2**, 031.

[12] Shandarin, S.F. (2011) The Multi-Stream Flows and the Dynamics of the Cosmic Web. *Journal of Cosmology and Astroparticle Physic*, **5**, 015.

[13] Valkenburg, W. and Bjælde, O.E. (2012) Cosmology When Living near the Great Attractor. *Monthly Notices of the Royal Astronomical Society*, **424**, 495

[14] Zaninetti, L. (2016) Pade Approximant and Minimax Rational Approximation in Standard Cosmology. *Galaxies*, **4**, 4. http://www.mdpi.com/2075-4434/4/1/4

[15] Suzuki, N., Rubin, D., Lidman, C., Aldering, G., Amanullah, R., Barbary, K. and Barrientos, L.F. (2012) The Hubble Space Telescope Cluster Supernova Survey. V. Improving the Dark-Energy Constraints above z Greater than 1 and Building an Early-Type-Hosted Supernova Sample. *Astrophysical Journal*, **746**, 85.

[16] Schechter, P. (1976) An Analytic Expression for the Luminosity Function for Galaxies. *Astrophysical Journal*, **203**, 297. https://doi.org/10.1086/154079

[17] Alam, S., Albareti, F.D., Allende Prieto, C., *et al*. (2015) The Eleventh and Twelfth Data Releases of the Sloan Digital Sky Survey: Final Data from SDSS-III. *The Astrophysical Journal Supplement*, **219**, 12 (Preprint).

[18] Olver, F.W.J., Lozier, D.W., Boisvert, R.F. and Clark, C.W. (2010) NIST Handbook of Mathematical Functions. Cambridge University Press, Cambridge.

[19] Paul, N., Virag, N. and Shamir, L. (2018) A Catalog of Photometric Redshift and the Distribution of Broad Galaxy Morphologies. *Galaxies*, **6**.