A Catalogue of 1.58 Million Clusters of Galaxies from the DESI Legacy Survey

Z . L. Wen and J. L. Han (2024)

Joseph Hall

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Background

Context

- We need to be able to find and characterise clusters
- This is an optical approach
- Culmination of over a decade of work

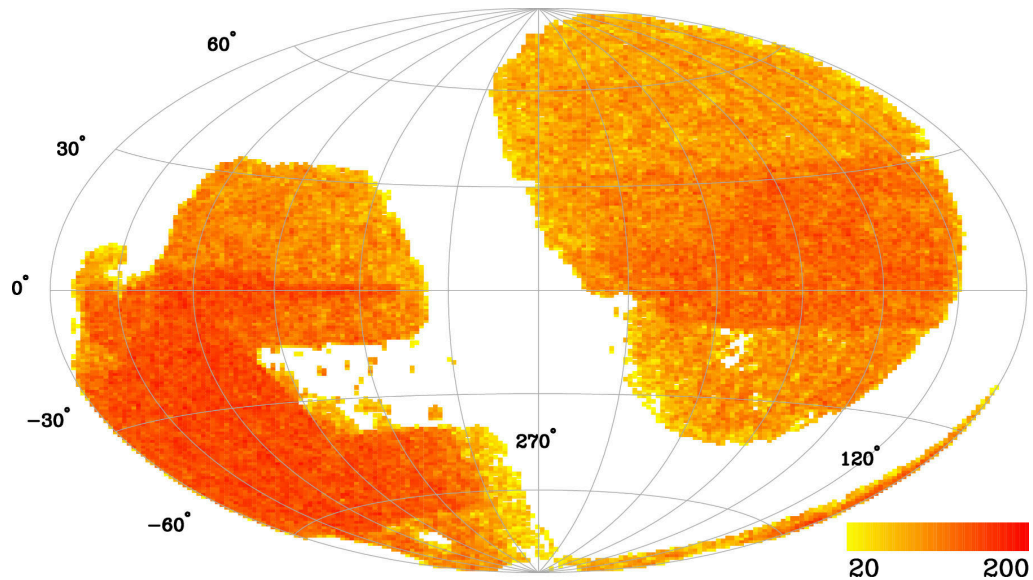

Figure 1: Density map of clusters from Wen and Han (2024, Fig. 6)

Wen and Han (2015) – Calibration

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CALIBRATION OF THE OPTICAL MASS PROXY FOR CLUSTERS OF GALAXIES AND AN UPDATE OF THE WHL12 CLUSTER CATALOG

Z. L. WEN, J. L. HAN
National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100012, China; zhonglue@nao.cas.cn.
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ABSTRACT

Accurately determining the mass of galaxy clusters is fundamental for many studies on cosmology and galaxy evolution. We collect and rescale the cluster masses of 1191 clusters of $0.05 < z < 0.75$ estimated by X-ray or Sunyaev–Zeldovich measurements and use them to calibrate the optical mass proxy. The total r-band luminosity (in units of L^*) of these clusters are obtained by using spectroscopic and photometric data of the Sloan Digital Sky Survey (SDSS). We find that the correlation between the cluster mass M_{500} and total r-band luminosity L_{500} significantly evolves with redshift. After correcting for the evolution, we define a new cluster richness $R_{L*,500} = L_{500}\,E(z)^{1.40}$ as the optical mass proxy. By using this newly defined richness and the recently released SDSS DR12 spectroscopic data, we update the WHL12 cluster catalog and identify 25,419 new rich clusters at high redshift. In the SDSS spectroscopic survey region, about 89% of galaxy clusters have spectroscopic redshifts. The mass can be estimated with a scatter of 0.17 dex for the clusters in the updated catalog.

Subject headings: galaxies: clusters: general — galaxies: distances and redshifts

1. INTRODUCTION

Clusters of galaxies are the most massive gravitationally bound systems in the universe. Statistics of cluster properties provides very powerful constraints on cosmology and galaxy evolution (see Allen et al. 2011; Wetzel et al. 2012). The cluster mass is a fundamental parameter for galaxy clusters and is related to observational features in the X-ray, optical, millimeter and radio bands (e.g., Voit 2005; Brunetti et al. 2009). Galaxies, intracluster hot gas and dark matter contribute about 5%, 15%, and 80% of the total cluster mass, respectively. Determining the cluster mass is the basis for many studies. For example, the mass function for a complete sample of galaxy clusters can be used to constrain cosmological parameters (e.g., Reiprich & Böhringer 2002; Vikhlinin et al. 2009b; Wen et al. 2010).

Statistics for weak gravitational lensing features is the most direct method to determine the total cluster mass including contributions from member galaxies, hot intracluster gas and dark matter. However, this method requires high-quality image data and also redshift information for faint background galaxies and thus only a few massive clusters have their masses so determined (e.g., Dahle 2006; Bardeau et al. 2007; Okabe et al. 2010; von der Linden et al. 2014b). Based on the assumption that the hot intracluster gas is in hydrostatic equilibrium, the cluster mass can be estimated by using the X-ray surface brightness and temperature distributions (e.g., Finoguenov et al. 2001; Reiprich & Böhringer 2002; Kravtsov et al. 2006; Vikhlinin et al. 2006). A few thousands of galaxy clusters have their masses estimated from the X-ray observables (Vikhlinin et al. 2009a; Mantz et al. 2010; Piffaretti et al. 2011; Takey et al. 2013). In the millimeter band, the thermal Sunyaev–Zeldovich (SZ) effect provides robust mass estimates for more than one thousand massive clusters (Hasselfield et al. 2013; Reichardt et al. 2013; Planck Collaboration et al. 2014), which is independent of cluster dynamical state and redshift (Carlstrom et al. 2002).

The velocity dispersion of member galaxies is certainly a good measure of cluster mass (Girardi et al. 1998), which can be derived from optical spectroscopic data and have been obtained for a limited number of galaxy clusters. However, the spectroscopic observations are usually incomplete for cluster member galaxies, and cluster substructures often induce a bias on the estimated mass (Bird 1995; Sifón et al. 2013). On the other hand, photometric data can be used to identify galaxy clusters (e.g., Koester et al. 2007; Wen et al. 2009; Hao et al. 2010; Szabo et al. 2011; Wen et al. 2012; Oguri 2014; Rykoff et al. 2014). Cluster richness, defined as the total number of member galaxies or their total luminosity, can be used as an optical mass proxy (Popesso et al. 2005, 2007). The challenge is to accurately determine the membership of cluster galaxies by eliminating the contamination by field galaxies. Based on multicolor survey data, the member galaxies can be discriminated by using galaxy colors (e.g., Gladders & Yee 2000; Koester et al. 2007; Hao et al. 2010) or photometric redshifts (e.g., Wen et al. 2009; Szabo et al. 2011). The cluster richness derived from optical photometric data in general is poorly correlated with cluster mass. However, if the correlation is improved, the cluster richness can be used to estimate cluster mass for a very large sample of clusters even up to high redshifts.

The Sloan Digital Sky Survey (SDSS; York et al. 2000) offers an unprecedented photometric data in five broad bands (u, g, r, i, and z) covering 14,000 $\deg^2$ with the exceptional follow-up spectroscopic observations. The photometric data reach a limit of $r = 22.2$ (Stoughton et al. 2002), with the star–galaxy separation reliable to a limit of $r = 21.5$ (Lupton et al. 2001). The spectroscopic survey observes galaxies with a Petrosian magnitude of $r < 17.77$ for the main galaxy sample (Strauss et al. 2002) and a model magnitude $r < 19.9$ for the Luminous Red Galaxy sample (Eisenstein et al. 2001). These galaxies cover a footprint of 10,400 $\deg^2$ in the range of $-11^\circ \leq$ Decl. $\leq 69^\circ$. The latest Data Release 12 (DR12, Alam et al. 2015) includes the photometric data for about 200 million galaxies and the spectroscopic data for about 2.32 million galaxies.

The large samples of galaxy clusters or groups have been identified by using the SDSS spectroscopic data (e.g., Merchán & Zandivarez 2005; Berlind et al. 2006;

- Calibrated a relationship between r_{500} and $L_{1\ \mathrm{Mpc}}$
- Established **richness** as an optical mass proxy:

$$\lambda_{*,500} = \frac{L_{500}}{L_*} E(z)^{1.4}$$

- Find that this is redshift independent

Background

See Figure 3.

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Clusters of galaxies up to $z = 1.5$ identified from photometric data of the Dark Energy Survey and unWISE

Z. L. Wen[1,2★] and J. L. Han[1,2,3]

[1]*National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100012, China*
[2]*CAS Key Laboratory of FAST, NAOC, Chinese Academy of Sciences, Beijing 100101, China*
[3]*School of Astronomy, University of Chinese Academy of Sciences, Beijing 100049, China*

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ABSTRACT

Using photometric data from the Dark Energy Survey and the Wide-field Infrared Survey Explorer, we estimate photometric redshifts for 105 million galaxies using the nearest-neighbour algorithm. From such a large data base, 151 244 clusters of galaxies are identified in the redshift range of $0.1 < z \lesssim 1.5$ based on the overdensity of the total stellar mass of galaxies within a given photometric redshift slice, among which 76 826 clusters are newly identified and 30 477 clusters have a redshift $z > 1$. We cross-match these clusters with those in the catalogues identified from the X-ray surveys and the Sunyaev–Zel'dovich (SZ) effect by the *Planck*, South Pole Telescope and Atacama Cosmology Telescope surveys, and get the redshifts for 45 X-ray clusters and 56 SZ clusters. More than 95 per cent SZ clusters in the sky region have counterparts in our catalogue. We find multiple optical clusters in the line of sight towards about 15 per cent of SZ clusters.

Key words: catalogues – galaxies: clusters: general – galaxies: distances and redshifts.

1 INTRODUCTION

As the largest virialized systems in the Universe, clusters of galaxies trace density peaks in the large-scale structure. Galaxy clusters have been identified from the survey data in optical, X-ray, and millimeter bands (e.g. Abell, Corwin & Olowin 1989; Piffaretti et al. 2011; Wen, Han & Liu 2012; Böhringer et al. 2013; Planck Collaboration XXVII 2016; Gonzalez et al. 2019; Hilton et al. 2021). Based on multiband optical photometric observations, clusters of galaxies can be found through the red sequence of galaxies (e.g. Oguri 2014; Rykoff et al. 2014) or photometric redshifts of galaxies (e.g. Wen et al. 2012; Yang et al. 2021; Zou et al. 2021). The X-ray observation data show the X-ray emission from hot intracluster medium. The Sunyaev–Zel'dovich (SZ) effect at the millimeter wavelengths has the advantage to detect massive clusters up to high redshifts (Carlstrom, Holder & Reese 2002).

The latest data sets observed for the southern Galactic cap provide an excellent opportunity to uncover clusters at high redshifts. The Dark Energy Survey (DES; Dark Energy Survey Collaboration 2016) released photometric data at five bands for a sky area of 5000 deg^2 region down to a limit of $i \sim 24$ magnitude, which is deep enough to detect clusters up to $z \sim 1.5$. A large number of clusters of galaxies have been identified from the DES data (Rykoff et al. 2016; Aguena et al. 2021; Yang et al. 2021; Zou et al. 2021), but mostly of $z < 1$. In the DES sky region, millimeter survey data have been obtained by the South Pole Telescope (SPT; Carlstrom et al. 2011) and the Atacama Cosmology Telescope (ACT; Swetz et al. 2011). About 850 and 1800 clusters have been already identified by using the SZ effect from the SPT and ACT survey data, respectively (Bleem et al. 2015, 2020; Huang et al. 2020; Hilton et al. 2021).

In this paper, we combine the DES optical data with the mid-infrared data from the Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) to identify clusters of galaxies. In Section 2, we cross-match the DES data with the WISE data for common galaxies, and estimate their photometric redshifts and stellar masses. In Section 3, we identify clusters of galaxies from the estimated photometric redshift data. In Section 4, we compare the identified clusters with those previously known in the sky region. A summary is presented in Section 5.

Throughout this paper, we assume a flat Lambda cold dark matter cosmology taking $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

2 PHOTOMETRIC REDSHIFTS AND STELLAR MASSES

Identification of galaxy clusters requires a large number of galaxies with known redshifts. The photometric redshifts can be used for the purpose, and can be estimated from photometric data (Wen & Han 2021). In addition, stellar masses of galaxies can be derived based on the mid-infrared luminosity of galaxies, which is useful to identify density peaks.

2.1 Photometric data of galaxies

The DES[1] made photometric observations at five broad optical bands (*grizy*), covering the southern Galactic cap of ~5000 deg^2 (Dark Energy Survey Collaboration 2016). The survey reaches a 10σ depth of $i \sim 24$ (AB magnitude) for point sources. The median full width at half-maximum of the point spread function is 0.88 arcsec in the i-band. From the latest public DES data release 2 (DR2; Abbott et al.

★ E-mail: zhonglue@nao.cas.cn

[1]https://www.darkenergysurvey.org/

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Why do we (I) care?

Bibliography

Wen, Z. L., Han, J. L., 2024. A Catalog of 1.58 Million Clusters of Galaxies Identified from the DESI Legacy Imaging Surveys. The Astrophysical Journal Supplement Series 272, 39.. https://doi.org/10.3847/1538-4365/ad409d

Wen, Z. L., Han, J. L., 2015. Calibration of the Optical Mass Proxy for Clusters of Galaxies and an Update of the WHL12 Cluster

Catalog. The Astrophysical Journal 807, 178..
https://doi.org/10.1088/0004-637X/807/2/178