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

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

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Background

(In which Joe speed reviews 3 older papers)

Context

- Clusters are big, biggest virialised things going
- We need to be able to find and characterise clusters
- This is an optical approach
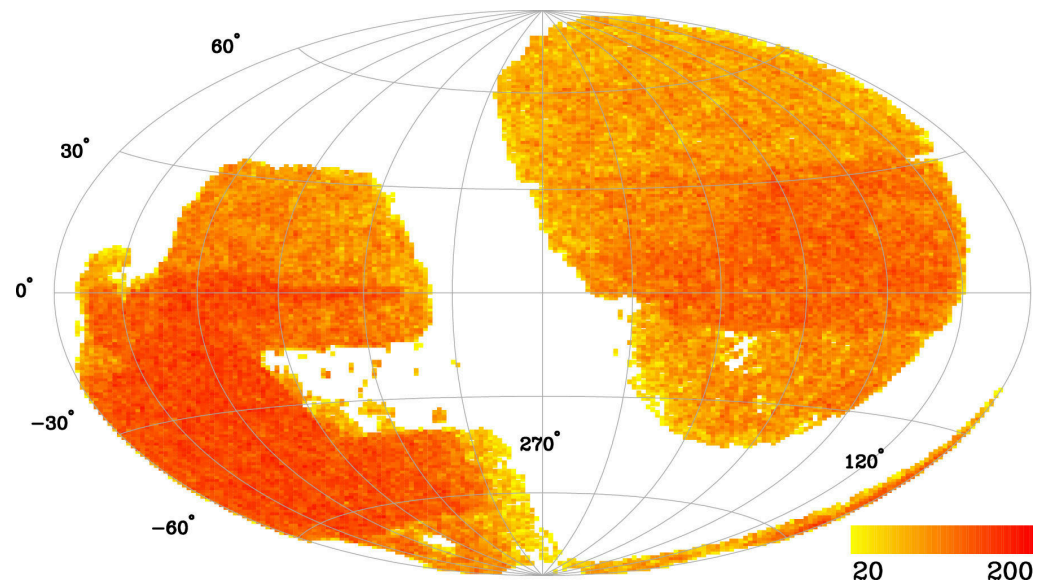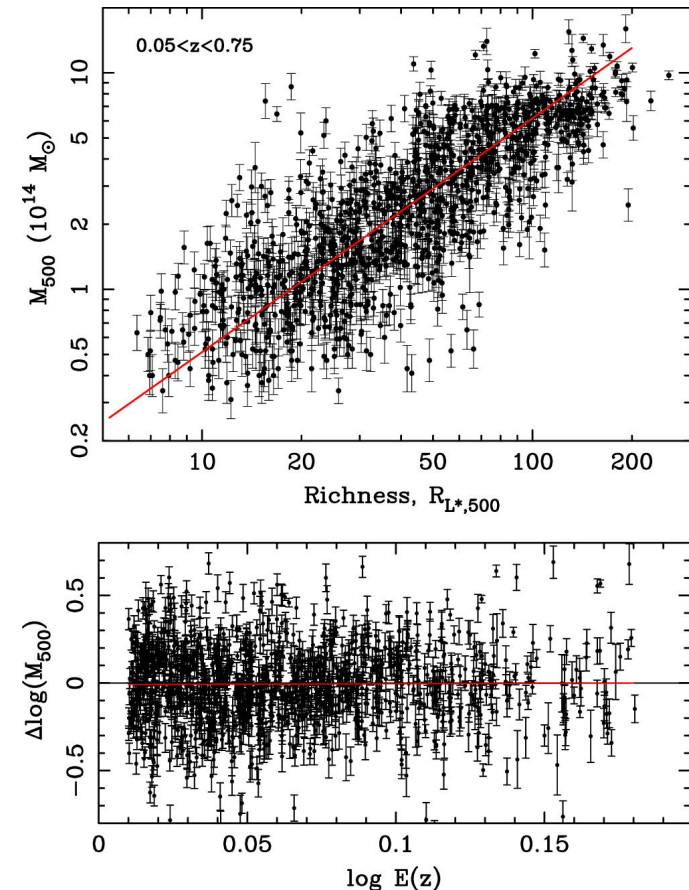- Culmination of over a decade of work

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

Wen and Han (2015) – Calibration

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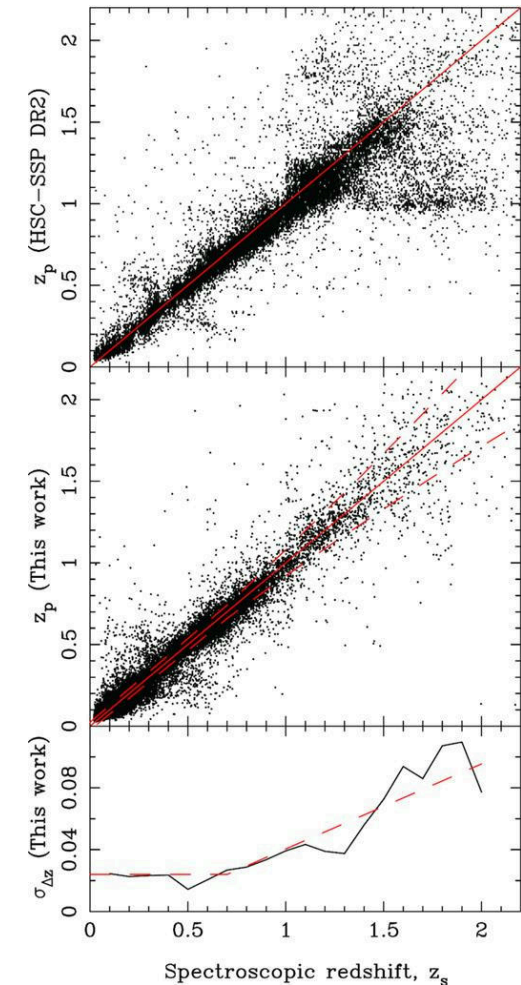- Established **richness** as an optical mass proxy:

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

- This is redshift independent & a good proxy

Wen and Han (2021) – Redshifts

- Combines spectroscopic and multi-band imaging surveys
- Places galaxies with spectro-z in colour space
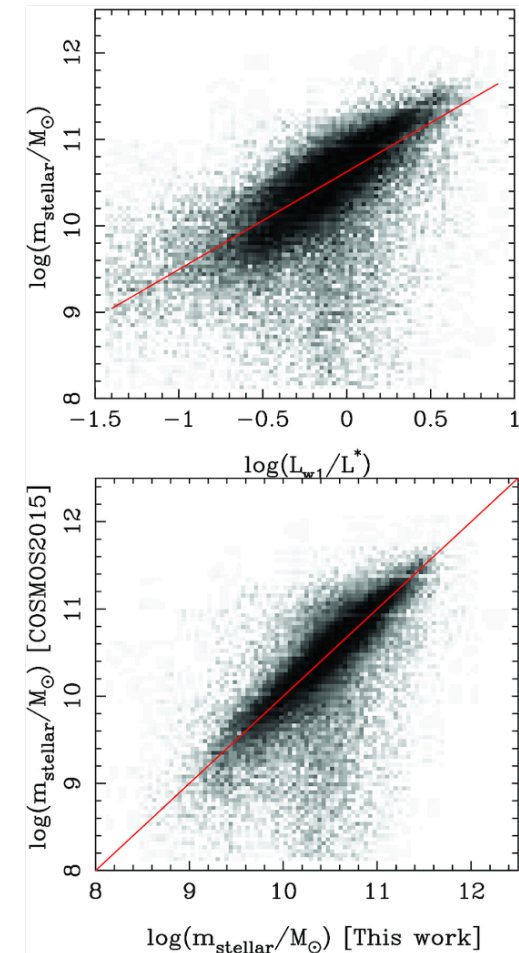- Uses a **nearest neighbour** algorithm to estimate the photo-z of galaxies only in imaging survey

Wen and Han (2021) – Masses

- Links stellar mass and luminosity:

$$\log\left(\frac{m_{\text{stellar}}}{M_\odot}\right) = \gamma \log\left(\frac{L_{\text{W1}}}{L_*}\right)$$

$$+ f(z, Z)$$

- Uses this to get a mass based **richness** similar to Wen and Han (2015):

$$\lambda_{500} = m_{500,\text{stellar}} \frac{(1+z)^{0.21}}{m_{*,\text{stellar}}}$$

Wen and Han (2022) – Extending Deeper

- Takes what they were doing before and uses **DES** to find clusters to $z = 1.5$

- …

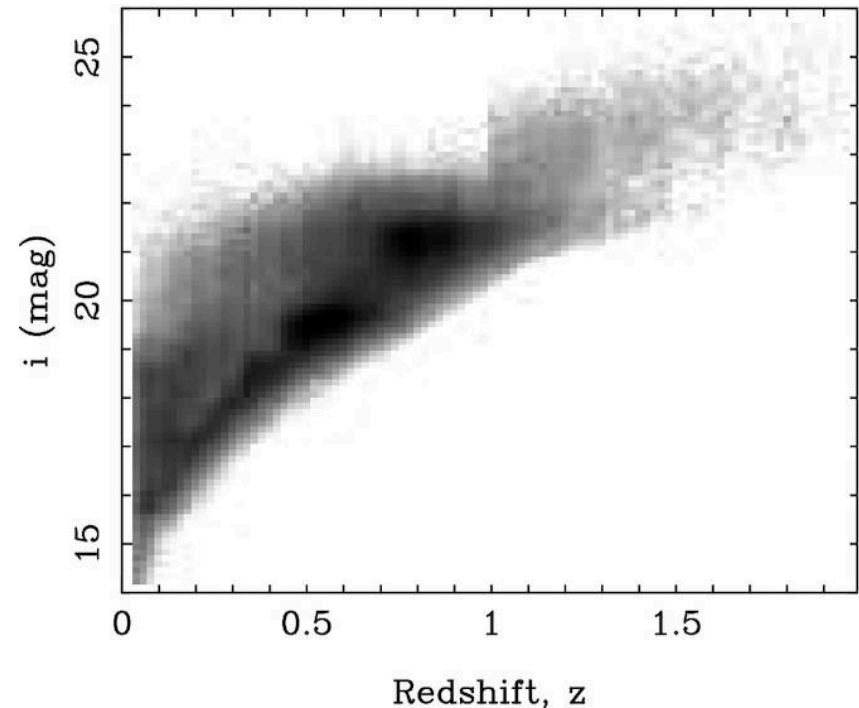- Not much else different but proves validity of methods to deeper data

Figure 5: i-band magnitudes of the training sample as a function of redshift. Taken from Wen and Han (2022, Fig. 1)

The Actual Paper

*(Trust me, it's **definitely** a pre-print)*

The Initial Data Processing

- Using **DESI** Legacy Imaging Surveys as the photometric base
- Same processes as before for finding redshifts, with spectro-z from past work
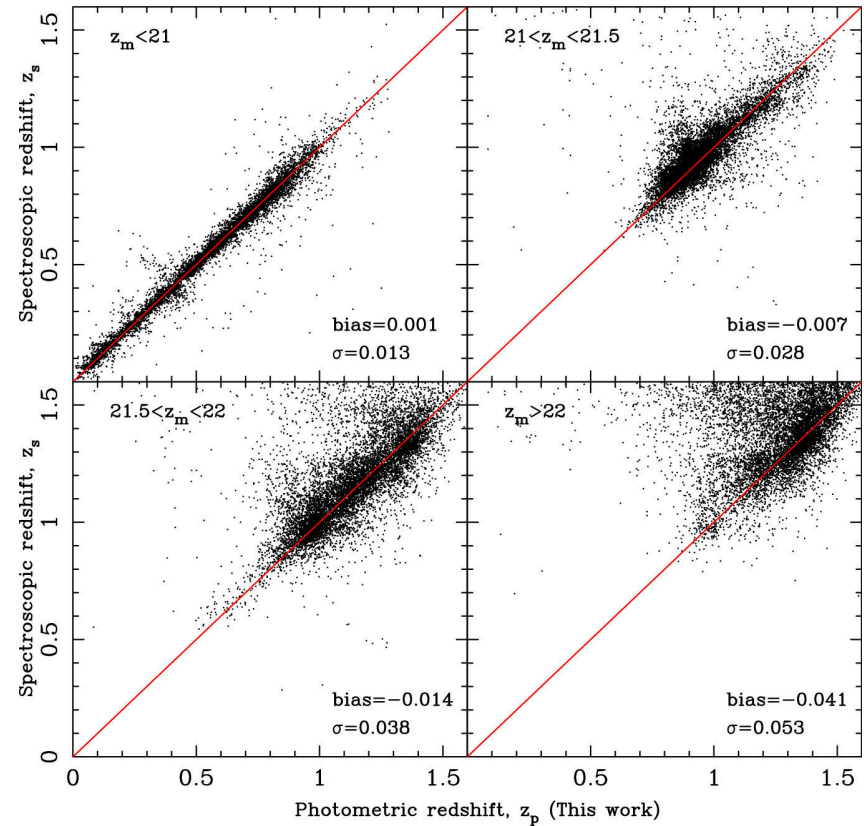- Slight tweak to finding m_{stellar}, using $r - z_m$ colour instead of $\mathrm{W}1$ luminosity

Figure 6: z_m-band magnitude binned comparisons of spectro- and photo-zs. From Wen and Han (2024, Fig. 1)
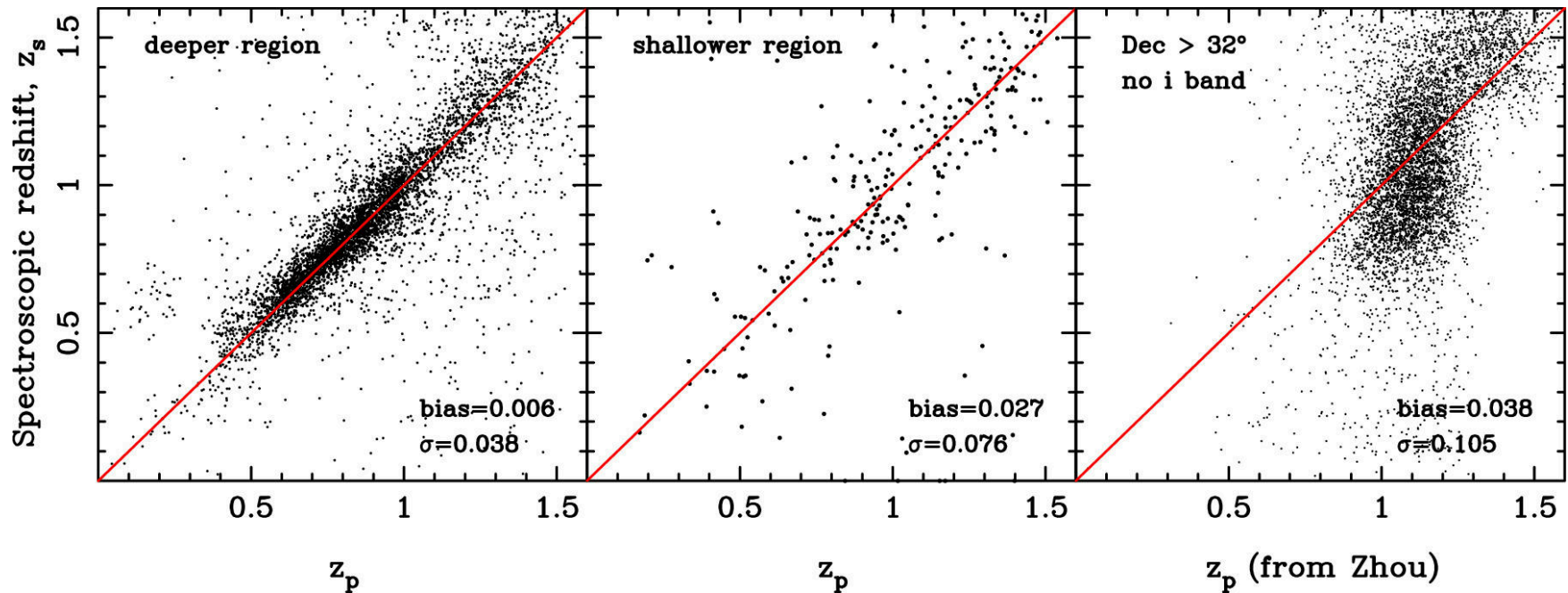
The Initial Data Processing

Figure 7: Comparisons of Wen and Han (2024) photo-z and those published by DESI in Zhou et al. (2021) without i-band mags

Finding Clusters

- Looking for overdensity in redshifts
- Take slices on **candidate "BCGs"** defined with half slice thickness:

$$\Delta z = \begin{cases} 0.04(1+z) \text{ for } z \leq 0.7 \\ 0.15z - 0.037 \text{ for } z > 0.7 \end{cases}$$

- Only using massive clusters ($M_* \geq 10^{10} M_\odot$)
- Use the equations calibrated before to find cluster radii and richness
- Define a cluster when $\boldsymbol{\lambda_{500} \geq 10}$ **and** $\boldsymbol{N_{\mathrm{gal}} \geq 6}$
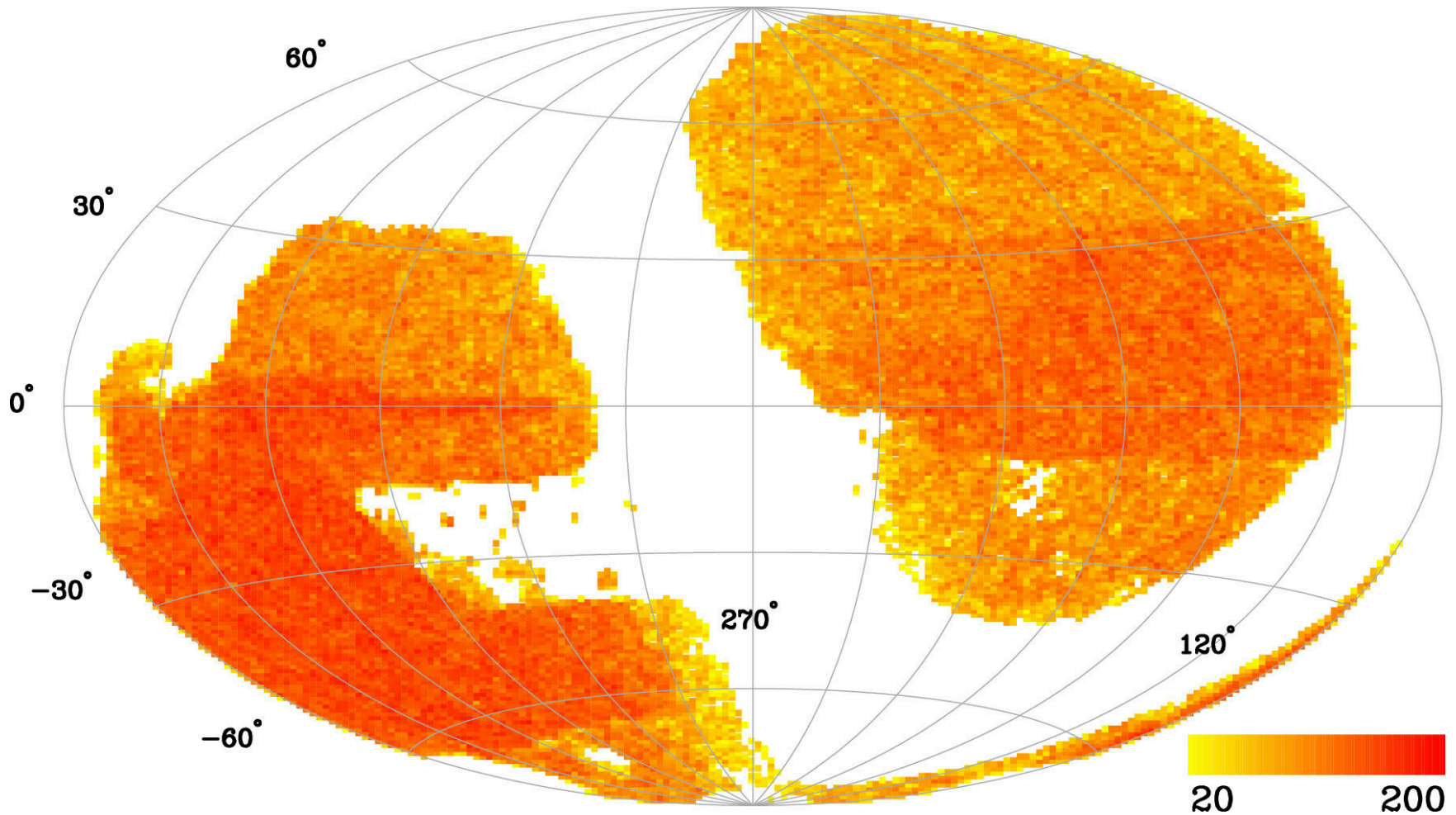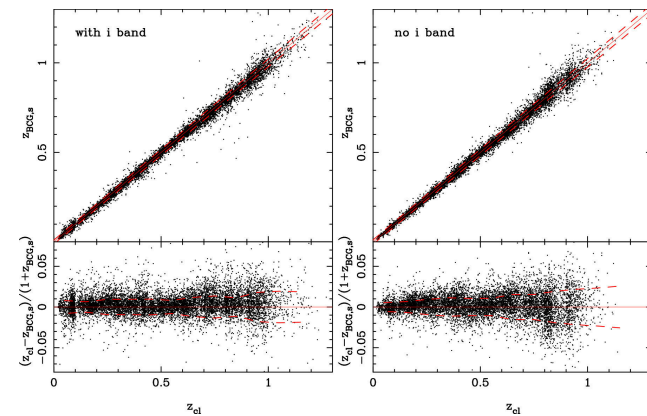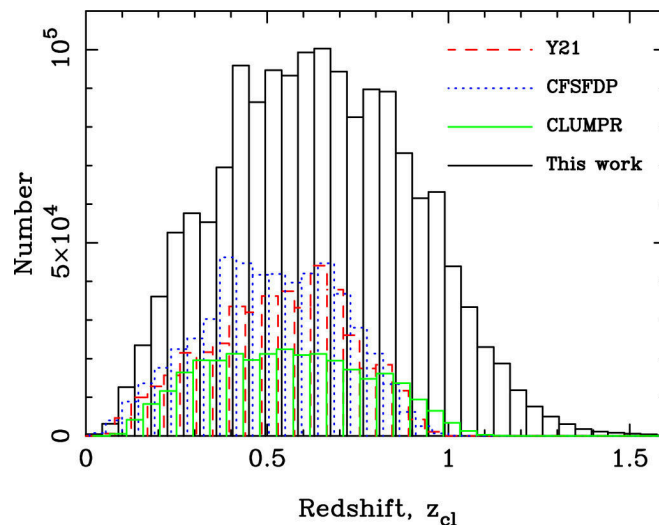
Found Clusters

Figure 8: Density map of clusters from Wen and Han (2024, Fig. 6)

Cluster Redshifts

Defined in one of the following ways:

1. The **spectroscopic** redshift of the BCG, if available
2. Available spectroscopic redshifts of other galaxies, if within $0.025(1+z)$ of cluster photo-z
3. Unclear, but I think using the average photo-z of members as in Wen and Han (2022)

Verification

- Very important step when finding $> 800,000$ new clusters
- Compare results with clusters found and measured using X-ray and SZ observations
- Good completeness with X-ray – 82% of eRASS1 clusters detected in sample overlap
- 95% of SZ clusters overlap (in the ACT catalogue)
- No verification of cluster properties comparing with these measurements
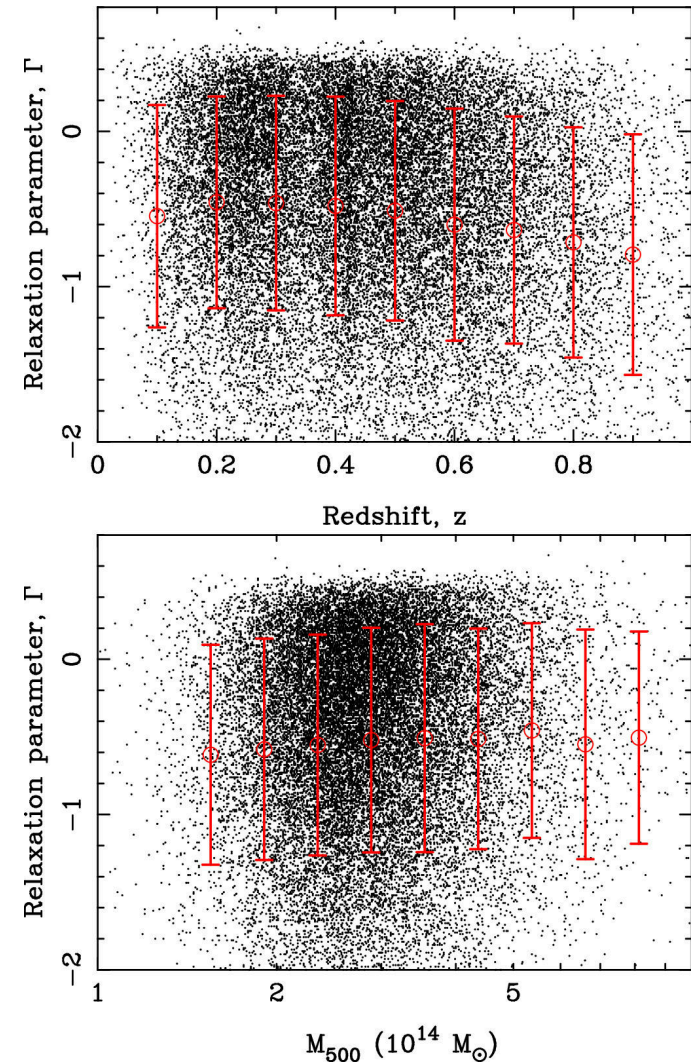
Verification

But do verify against other optical catalogues:
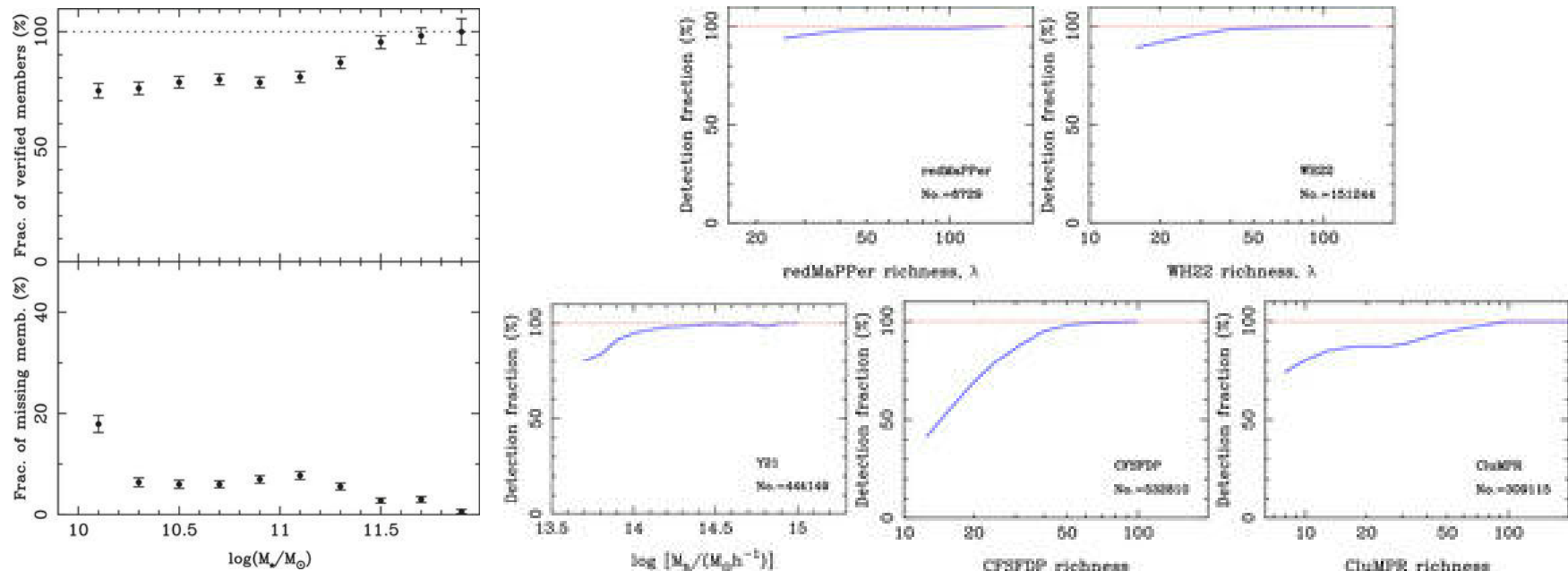
Evolution

- Apparently, clusters evolve
- They look at two particular evolutions:
  ‣ Dynamical states
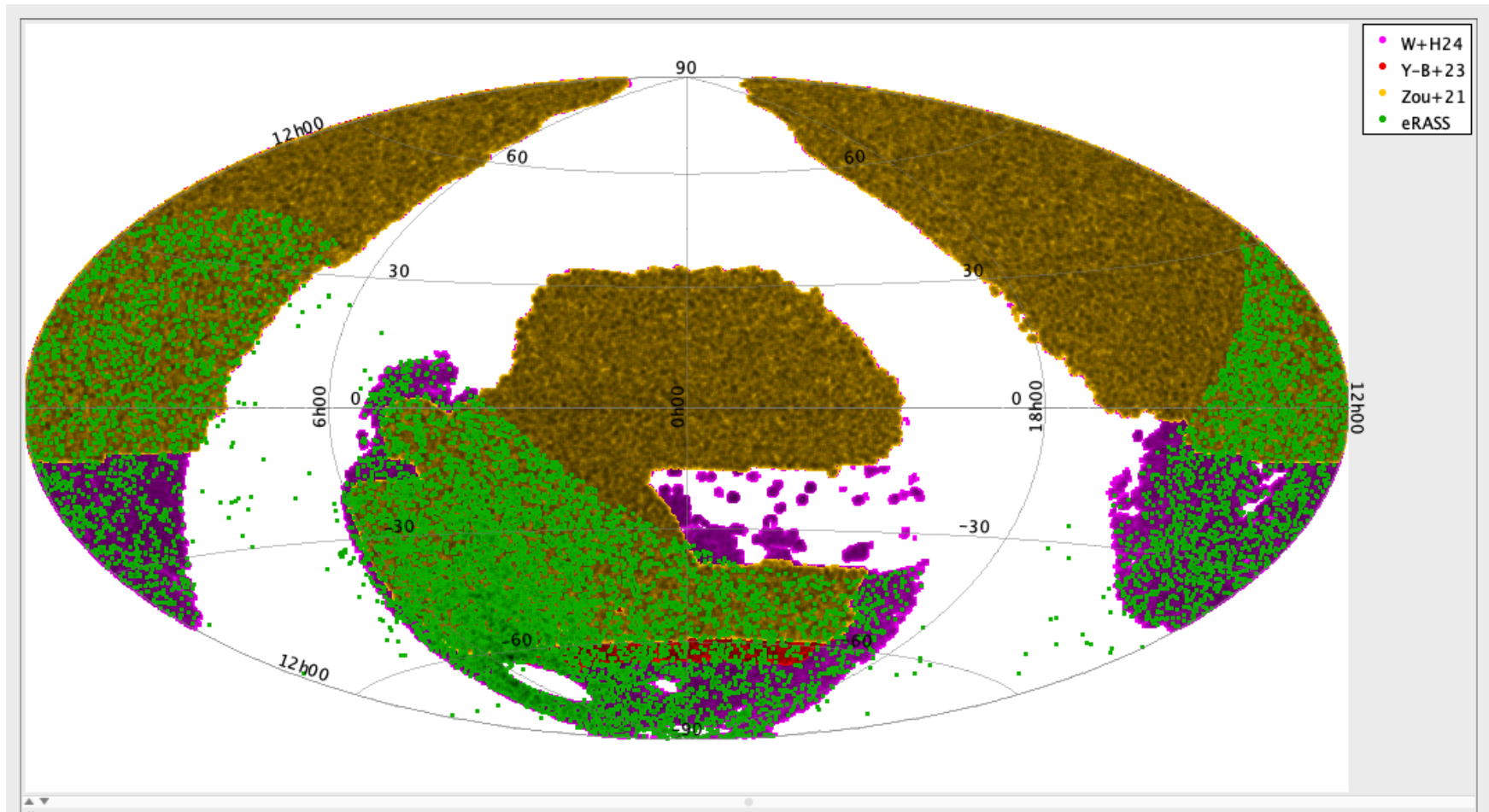 ‣ BCG growth

(I maybe didn't get round to reading this bit)

Why do *I* care?

(Yeah, why do you? Aren't you an X-ray astronomer?)

Why I care:

- My research looks at trying to understand differences in properties based on selection method
- I have an X-ray catalogue (eRASS)
- Need an optical and this one is:
  a. Really big
  b. Really well overlapped with eRASS

Why I care:

Summary

- This is a big catalogue (**1.58 Million!**) with reliable results
- Methods developed over a decade help to guarantee robustness of results
- Fantastic for work on cluster population studies
- Also does stuff with cluster evolution

Any Questions?

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., 2022. Clusters of galaxies up to z = 1.5 identified from photometric data of the Dark Energy Survey and unWISE. Monthly Notices of the Royal Astronomical Society 513, 3946–3959.. https://doi.org/10.1093/mnras/stac1149

Wen, Z. L., Han, J. L., 2021. Photometric redshifts for galaxies in the Subaru Hyper Suprime-Cam and unWISE and a catalogue of identified clusters of galaxies. Monthly Notices of the Royal Astronomical Society 500, 1003–1017.. https://doi.org/10.1093/mnras/staa3308

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

Zhou, R., Newman, J. A., Mao, Y.-Y., Meisner, A., Moustakas, J., Myers, A. D., Prakash, A., Zentner, A.

R., Brooks, D., Duan, Y., Landriau, M., Levi, M. E., Prada, F., Tarle, G., 2021. The clustering of DESI-like luminous red galaxies using photometric redshifts. \mnras 501, 3309–3331.. https://doi.org/10.1093/mnras/staa3764