Luminosity Functions of Galaxy Clusters in eROSITA Final Equatorial-Depth Survey

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Outline

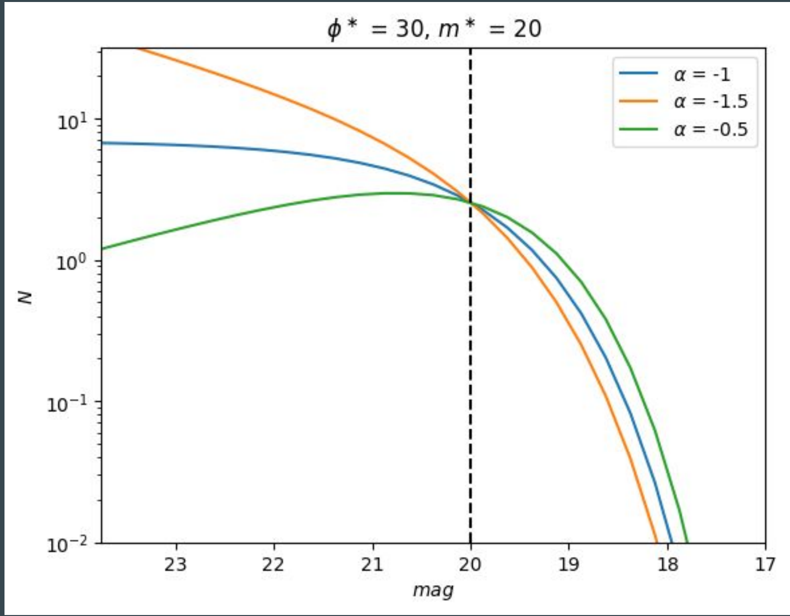
Introduction

Luminosity Function (LF)

- Number of galaxies v.s their luminosity (magnitude) in a cluster
- Depend on the environment and galaxy type
- Inform the galaxy formation and cosmic structure

The Schechter Function

Fig.6



- Fit the luminosity function
- The goal is to measure LF through it
- Three parameters: ϕ^*, α, L^* (or m^*):

  ϕ^*:

  Normalization (Galaxy abundance)

  α:

  Faint-end slope

  m^*:

  Characteristic magnitude

$$\frac{dN}{dm} = (0.4 \ln 10)\phi^* \left[10^{0.4(m^*-m)}\right]^{\alpha+1} \exp\left[-10^{0.4(m^*-m)}\right]$$

Remodel

- $m^* = m^*_{predict} + \Delta m$
- $\phi^* = \phi^*(M) = A(M / M_{piv})^B$, $M_{piv} = 10^{14}\, M_\odot$
- Expect $B \sim 1$, $\Delta m \sim 0$
- Four parameters in total: A, B, α, Δm

$$\frac{dN}{dm} = (0.4 \ln 10)\phi^* \left[10^{0.4(m^* - m)}\right]^{\alpha+1} \exp\left[-10^{0.4(m^* - m)}\right]$$

Data

The Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP)

- With camera Hyper Suprime-Cam (HSC) installed at the prime focus of the Subaru 8.2m telescope
- g/r/i/z/y bands with depth 26.5/26.5/26.2/25.2/24.2
- Three layers: 1. Wide
  2. Deep
  3. Ultradeep
- Cover ~ 1200 deg^2
- We used Wide, PDR3 as the galaxy data

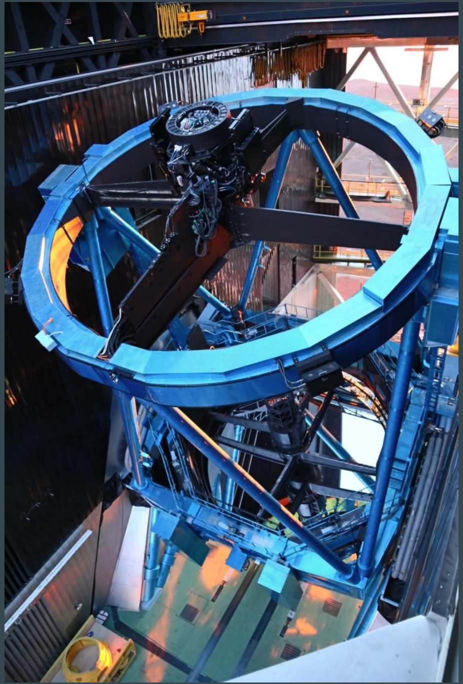


Fig.1

The eROSITA Final Equatorial-Depth Survey (eFEDS)

- The eROSITA X-ray telescope on board the Spectrum-Roentgen-Gamma (SRG) observatory
- Collect X-rays in the 0.2-2keV energy band
- Identify 542 clusters with $0.1 < z < 1.3$
- Detecting regions overlaps with the HSC survey

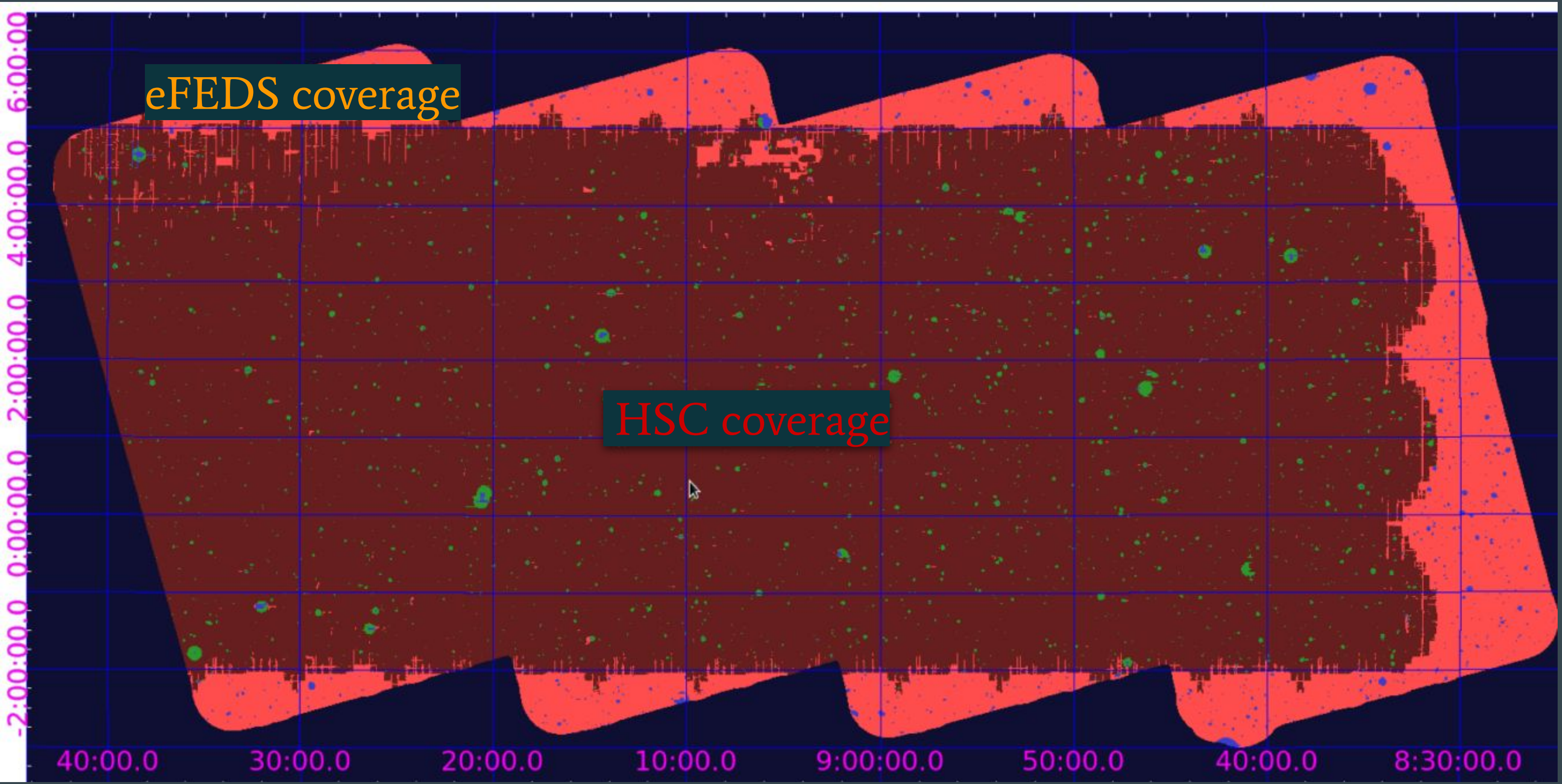


Fig.2:Klein et al. A&A, 661, A4 (2022)

The Cluster Mass & Radius & m* model

- Reason: We need the radii to identify the cluster regions, mass for the model, and $m^*_{prediction}$ for deciding the fitting magnitude range
- Halo masses (M_{500c}), Radii(r_{500c}):

  They are provided by Chiu, Klein, et al. (2023), through the empirical scaling relations between the cluster halo mass and the X-ray count rate, the optical richness, and the weak-lensing mass

  $m^*_{predict}$:

  The characteristic magnitude was predicted by fitting metallicity-luminosity relation to the red-sequence over density (Chiu in prep.), calibrated by a BC03 passively evolution model with exponentially decaying time scale tau = 0.4Gyr.

Cluster LF

Identify the LF observation

- We have the radii and the masses of the clutsters
- Observation is fitted by Model LF = Schechter + Background
- The galaxies enclosed by the circles are the member candidates

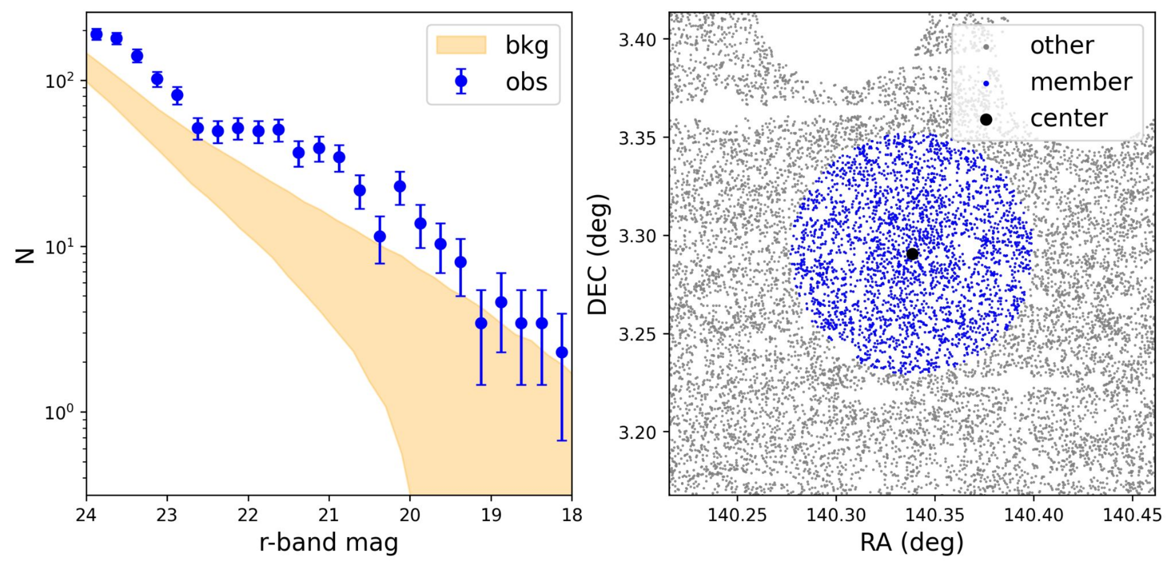


Fig.3

The Background LF

- Estimate the background by averaging the LF of random apertures
- r = median radius = 2.35′
- 3000 apertures
- Avoid clusters

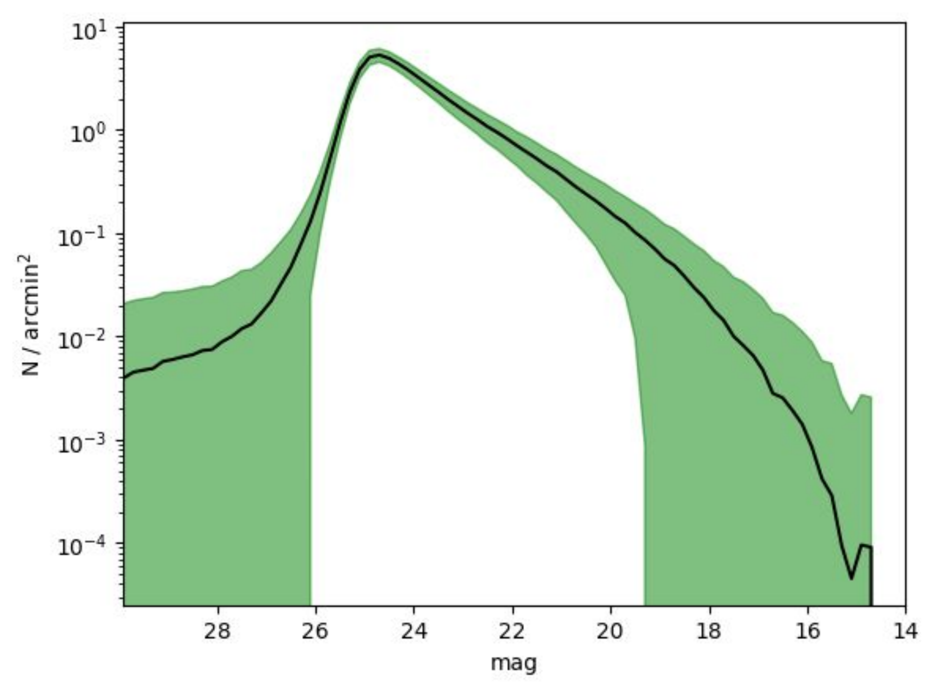


Fig.4

Defining Subsamples

Defining subsamples

- Clusters are grouped based on their redshift/masses
- 20 ~ 30 clusters for each group

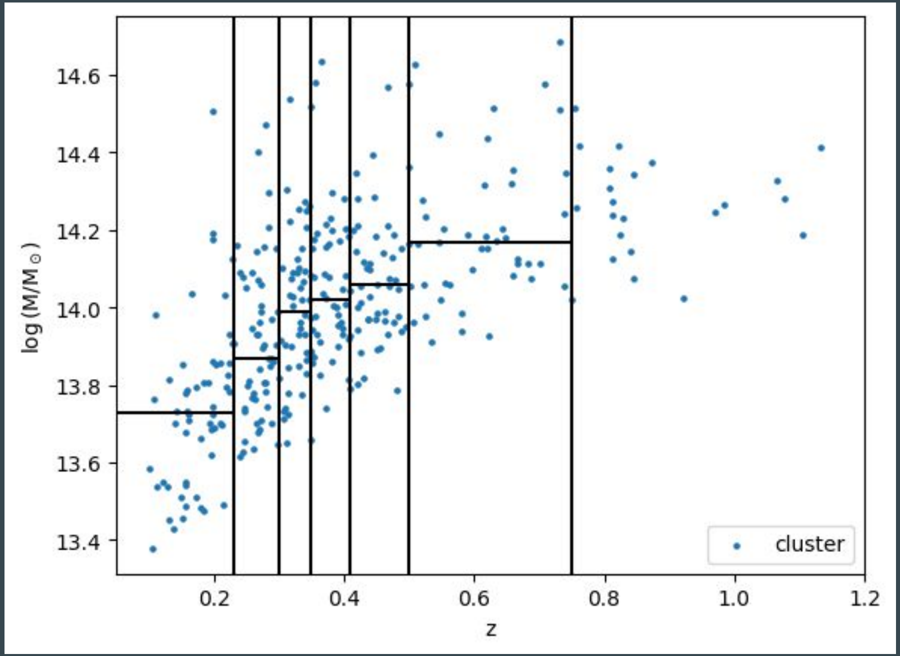


Fig.5

Fitting bands & magnitude range

- The bands which just redder than 4000Å break were used for each group
- Depend on the cluster redshift
- Only magnitude between $m^*_{prediction} \pm 2$ were used in the fitting

redshift	< 0.35	0.35 ~ 0.75	> 0.75
band	r	i	z

Result

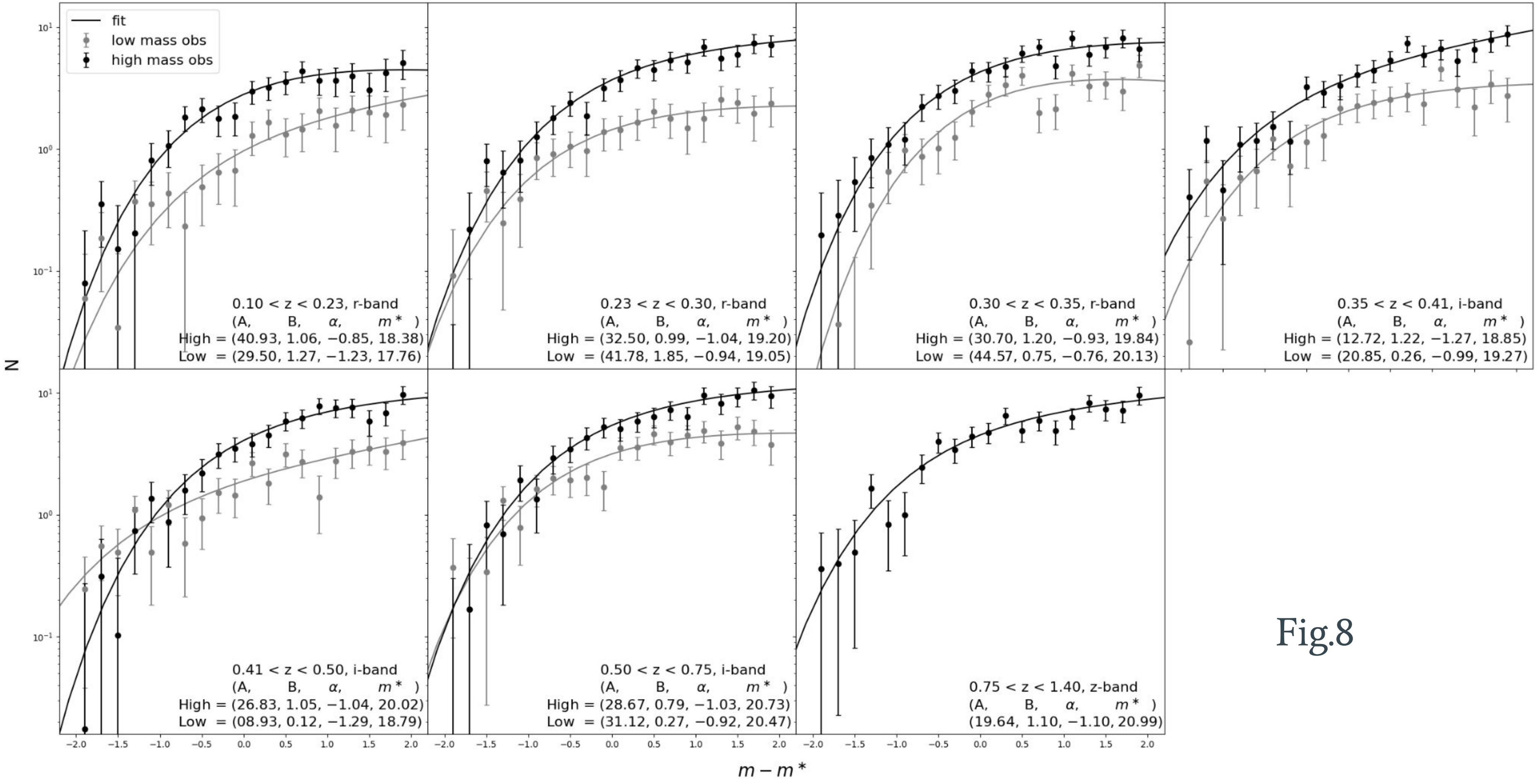

fit
low mass obs
high mass obs
N
0.10 < z < 0.23, r-band
(A, B, α, m*)
High = (40.93, 1.06, −0.85, 18.38)
Low = (29.50, 1.27, −1.23, 17.76)
0.23 < z < 0.30, r-band
(A, B, α, m*)
High = (32.50, 0.99, −1.04, 19.20)
Low = (41.78, 1.85, −0.94, 19.05)
0.30 < z < 0.35, r-band
(A, B, α, m*)
High = (30.70, 1.20, −0.93, 19.84)
Low = (44.57, 0.75, −0.76, 20.13)
0.35 < z < 0.41, i-band
(A, B, α, m*)
High = (12.72, 1.22, −1.27, 18.85)
Low = (20.85, 0.26, −0.99, 19.27)
0.41 < z < 0.50, i-band
(A, B, α, m*)
High = (26.83, 1.05, −1.04, 20.02)
Low = (08.93, 0.12, −1.29, 18.79)
0.50 < z < 0.75, i-band
(A, B, α, m*)
High = (28.67, 0.79, −1.03, 20.73)
Low = (31.12, 0.27, −0.92, 20.47)
0.75 < z < 1.40, z-band
(A, B, α, m*)
(19.64, 1.10, −1.10, 20.99)
m − m*

Fig.8

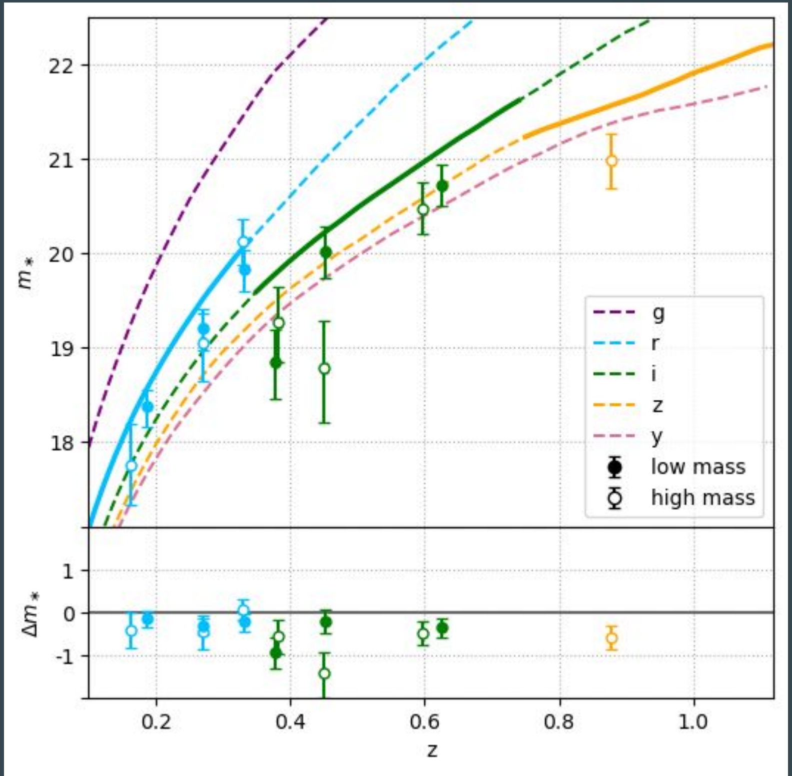
Conclusion

Conclusion

- $\alpha \approxeq -1$ for every group
- Δm tends to be negative

Possible reason:
The prediction didn't take the blue population into account
⇒ It's brighter in the fitting

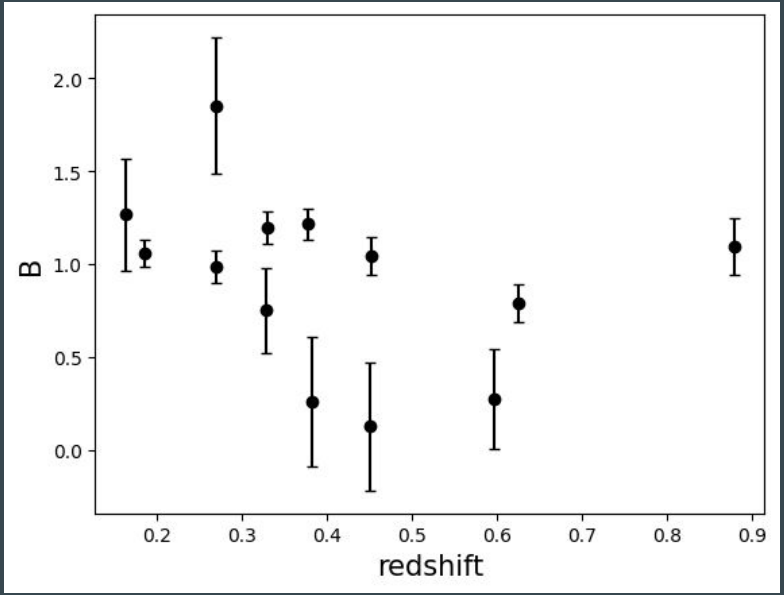
Fig.9



$\phi^* (M) = A(M / M_{piv})^B$

Conslusion

- Not all groups have B ≍ 1
- Heavier clusters have more stable B ≍ 1 and lower errors
- No redshift dependence



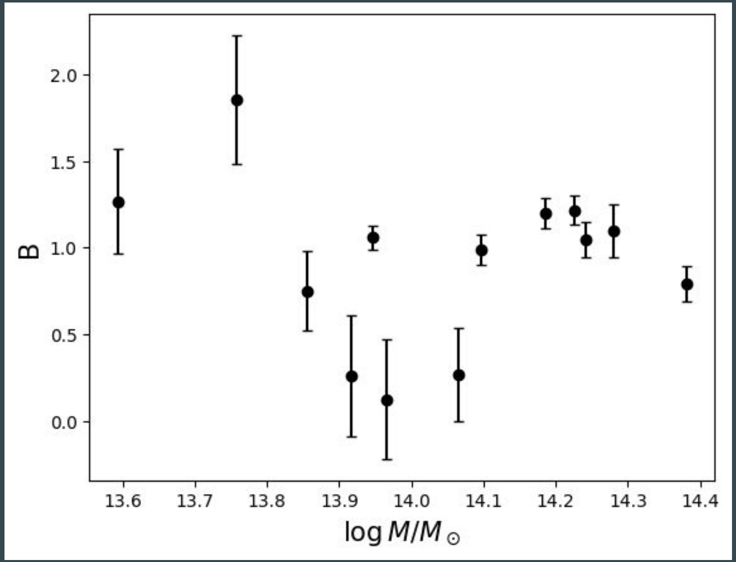


Fig.10

Reference

Fig.1: 開放博物館

Fig.2: Klein et al. A&A, 661, A4 (2022)

Reference

- Lan T.-W., Ménard B., Mo H., 2016, MNRAS, 459, 3998
- Klein et al. A&A, 661, A4 (2022)
- Aihara H., AlSayyad Y., Ando M., Armstrong R., Bosch J., Egami E., Furusawa H., et al., 2022, PASJ, 74, 247.
- Chiu, Klein, et al., Monthly Notices of the Royal Astronomical Society, Volume 522, Issue 2, June 2023, Pages 1601–1642,

Appendix

MCMC Fitting

Markov chain Monte Carlo Method (MCMC)

- Map a probability distribution by a random process
- Require a probability function ~ Prior × Likelihood to run

- Prior:
  $0 < \phi^* < 1000$, $15 < m^* < 25$, $-5 < \alpha < 5$
  background LF > 0. It follows $N(\mu_{bkg}, \sigma_{bkg}^2)$ ⟵ From 3000 random apertures

- Likelihood:
  It's Poisson(λ = model LF = Schechter + background) for the observational LF

Markov chain Monte Carlo Method (MCMC)

- The probability function of each group is the product of each cluster probability

$$Prob = \Pi_i \mathrm{Prior}(i) \times \mathrm{Likelihood}(i)$$

- The probability function is built $\Rightarrow$ We can run MCMC

Convergence

- Converge for every group

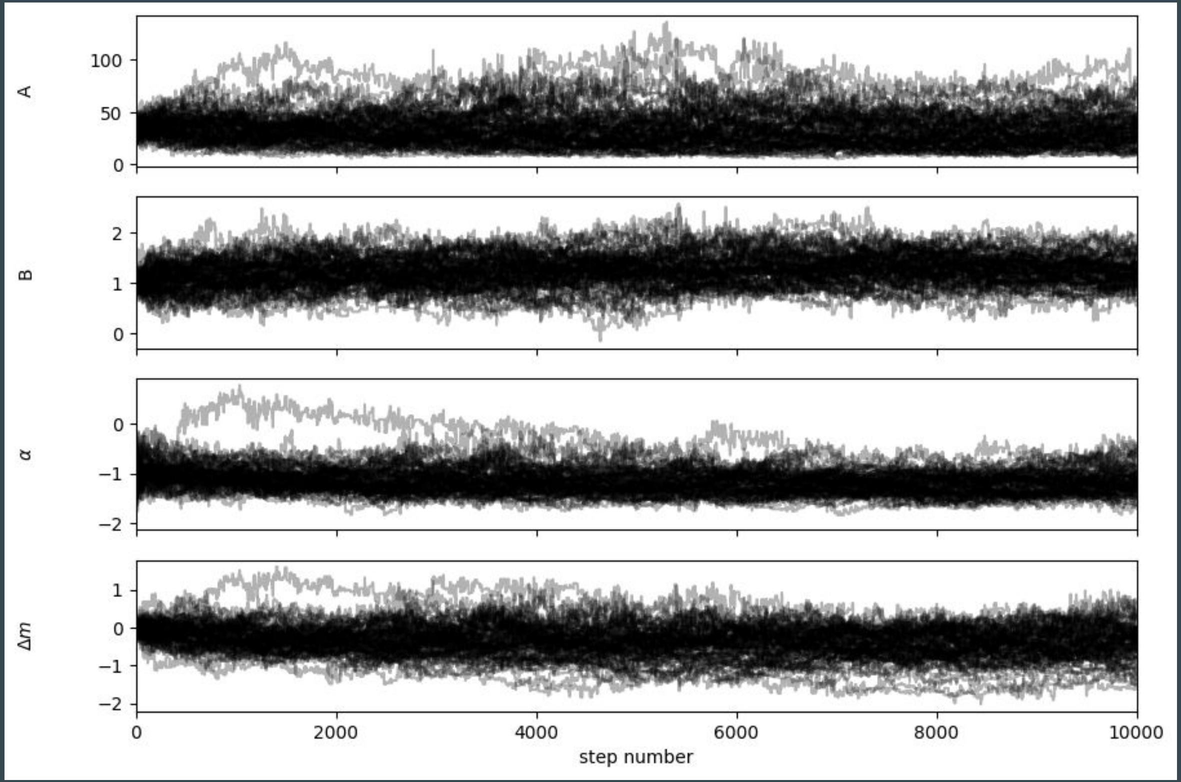
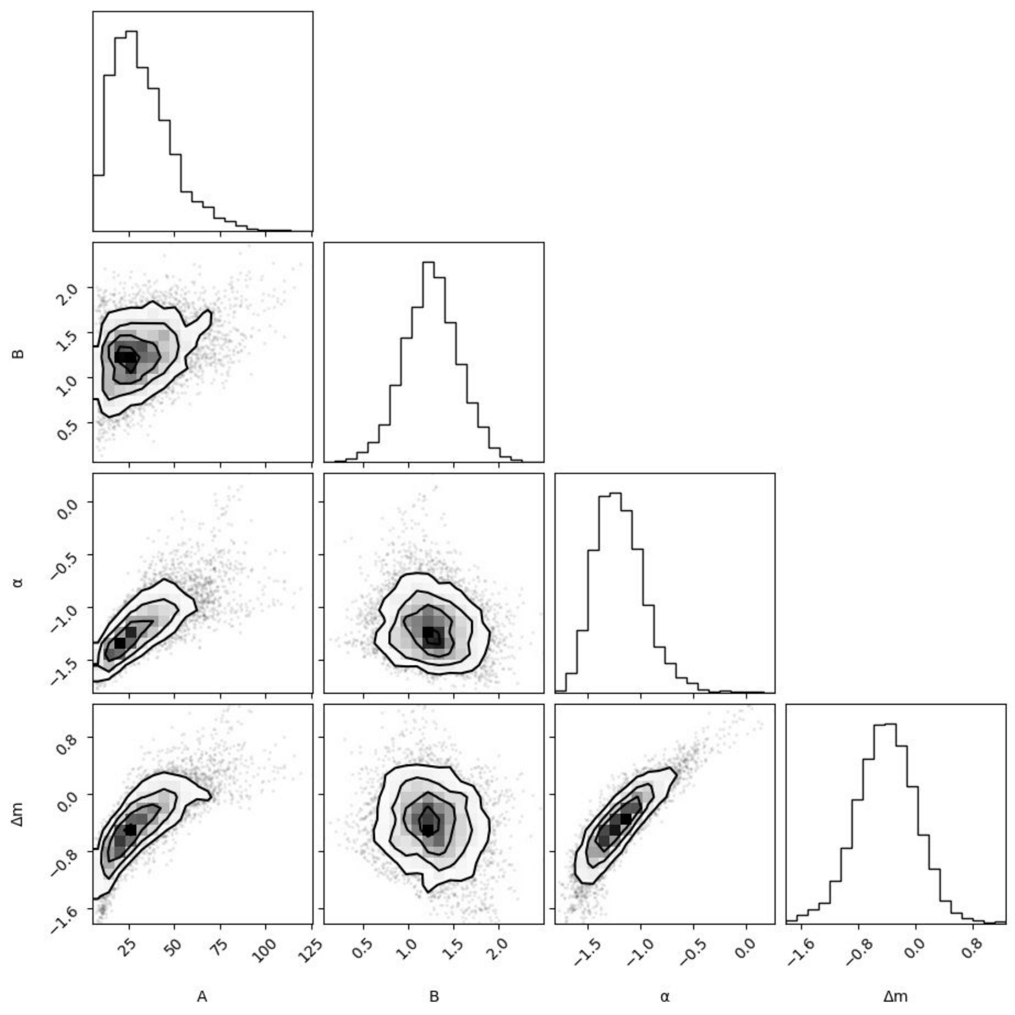


Fig.7



B
α
Δm
A
B
α
Δm
25 50 75 100 125
0.5 1.0 1.5 2.0
−1.5 −1.0 −0.5 0.0
−1.6 −0.8 0.0 0.8