The estimation of the weak lensing cluster masses in DESC DC2 simulations

Constantin Payerne, Céline Combet, Calum Murray
Laboratoire de Physique Subatomique et Cosmologie, Grenoble, UGA

Cosmology with galaxy cluster abundance

Galaxy clusters:

- Are the largest gravitationally bound objects in the Universe
- M ~ 10^14 - 10^15 solar masses
- Richness : count of member galaxies within a cluster
- LSST will detect around 100 000 galaxy clusters

Cosmology with galaxy cluster abundance:

- The predicted cluster abundance is a useful probe for cosmology.

  In a redshift and richness bin

$$N = \Omega_s \int_{z_\alpha}^{z_\beta} dz \frac{d^2V(z)}{dz d\Omega} \int_{\lambda_{\alpha'}}^{\lambda_{\beta'}} d\ln\lambda \int_{M_{\min}}^{M_{\max}} dm \frac{dn(m,z)}{dm} P(\ln\lambda \mid m, z)$$

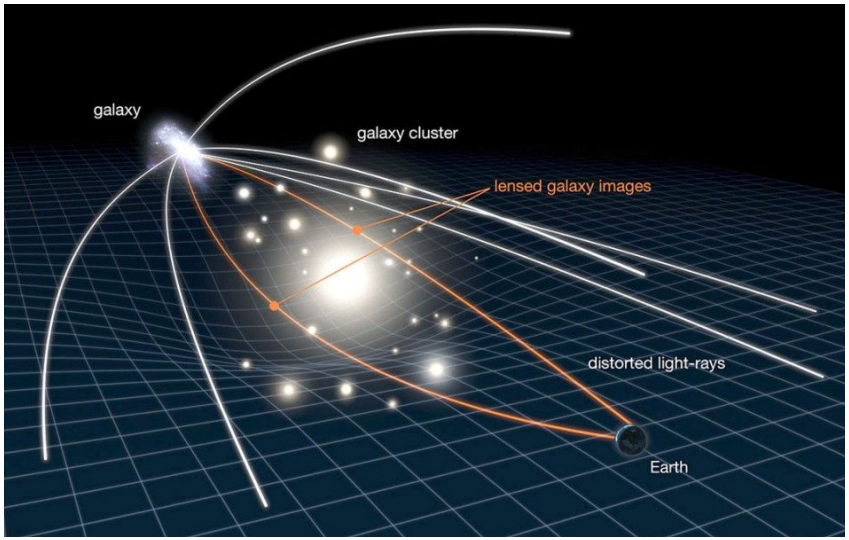
Partial comoving volume (cosmology)

Halo mass function (cosmology + large scale structure formation)

Mass-richness relation

- The mass-richness relation can be constrained using a subsample of galaxy cluster with estimated mass and richness.
- Weak lensing is a powerful tool to constrain galaxy cluster masses.

Weak gravitational lensing



- Gravitational lensing modifies the observed background galaxy shapes.
- Distortion is sensitive to the projected differential matter density around the cluster $\Delta\Sigma$.
- Taking the average observed ellipticities of galaxies at a distance R from the cluster center:

$$\widehat{\Delta\Sigma}(R) = \langle \Sigma_{\rm crit}(z_s, z_l)\, e_{+,s} \rangle\,|_R$$

Critical surface mass density

Tangential ellipticity

- The predicted shear signal is given by the sum of two contributions;

$$\Delta\Sigma_{\rm th}(R) = \Delta\Sigma_{\rm single}(R) + \Delta\Sigma_{\rm 2h}(R)$$

1h-term :Depends on the mass profile of the single cluster (< 4 Mpc)

2h-term: contribution from neighboring halos

Shear estimation in practice ->

Stacked shear estimation and mass reconstruction

- Stacked shear signal : measurement of the shear for an ensemble of cluster within a redshift and richness bin
  - High SNR, especially for low mass clusters

Single cluster

$$\widehat{\Delta\Sigma}(R) = \langle \Sigma_{\rm crit}(z_s, z_l)\ e_{+,s} \rangle |_R$$

stack

$$\longrightarrow \quad \widehat{\Delta\Sigma}(R) = \frac{1}{\sum_{l,s} w_{l,s}} \sum_{l,s} w_{l,s}\ \widehat{\Sigma_{\rm crit}}(z_s, z_l)\ e_{+,s} \Big|_R$$

$w_{l,s}$ = maximum SNR weights including effect of shape measurement and photometric redshifts of background galaxies

Mass reconstruction:

- 1h-term : NFW profile
- Covariance matrix are estimated via bootstrap resampling
- Fitting halo parameters by maximization of gaussian likelihood.

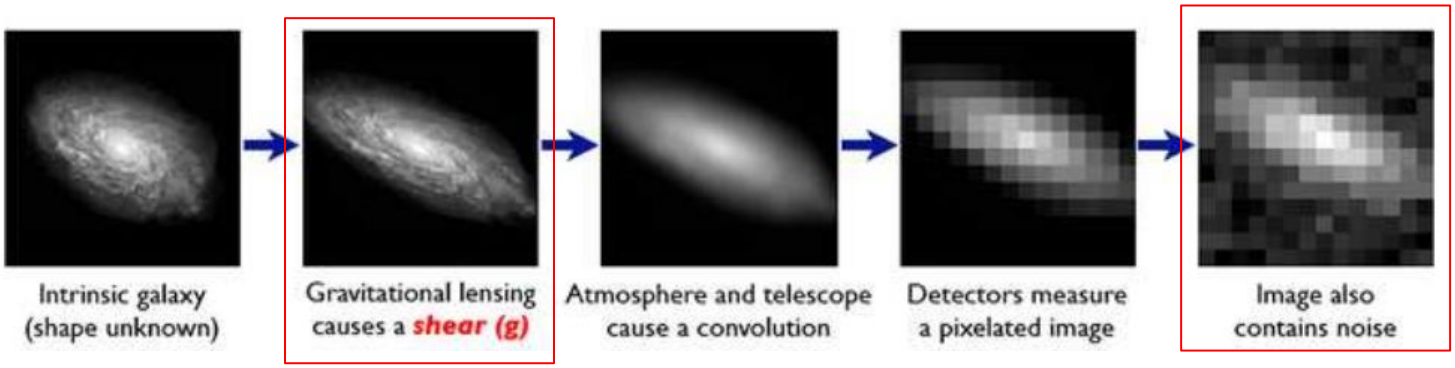
Application to the DESC DC2 catalogs ->

DESC Data Challenge 2 catalogs

- DC2 : Simulation of Large scale structure formation (440 deg^2, volume (4.2 Gpc)^3, z_max = 3)
- Here we study several catalogs:

  - cosmodc2 : input properties of galaxies.
    - known redshifts, ellipticities, magnitudes, etc..
    - Photozs: FlexZboost, BPZ (available as add-on catalogs of cosmoDC2)
      - BPZ : template based
      - FlexZboost : Machine Learning based
  - dc2_object : including observational systematics (atmosphere, detector)
    - Measured ellipticities (HSM, METACALIBRATION)
    - Photozs add-on : BPZ redshifts (available as add-on catalogs of dc2_object)

(Bridle et al. 2009)

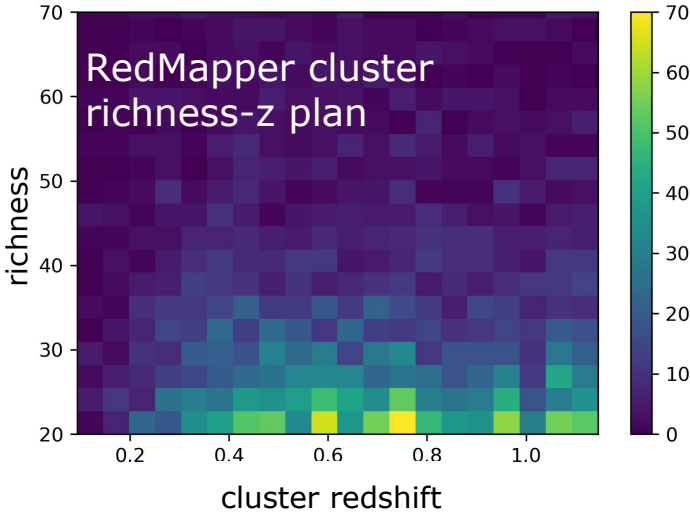


cosmodc2 dc2_object

Build the galaxy cluster catalog ->

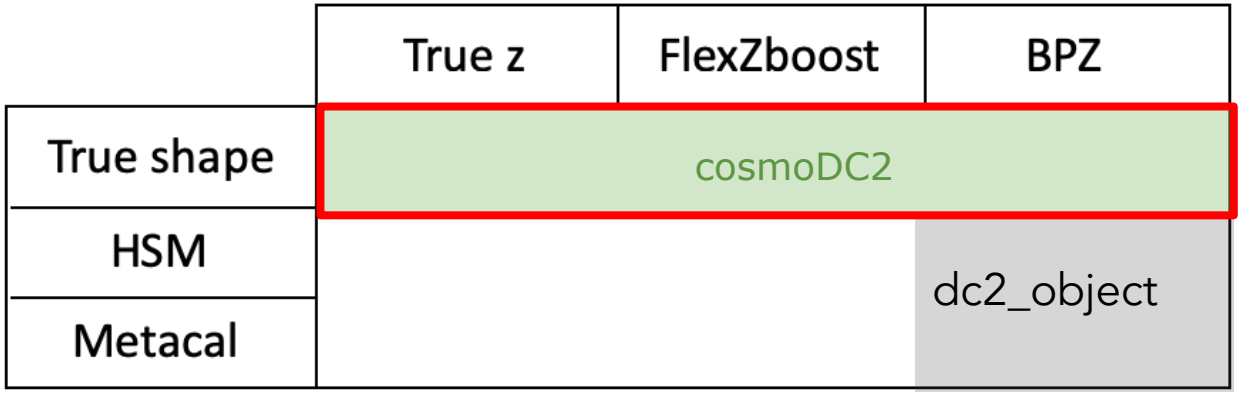
RedMapper galaxy cluster catalogs

- ~ 3500 RedMapper detected clusters (cosmoDC2_v1.1.4_redmapper_v0.5.7)
  - RedMapper : detection of overdensities of red sequence galaxies
  - Richness cut > 20
  - 0.2 < cluster z < 1.2



Goal :

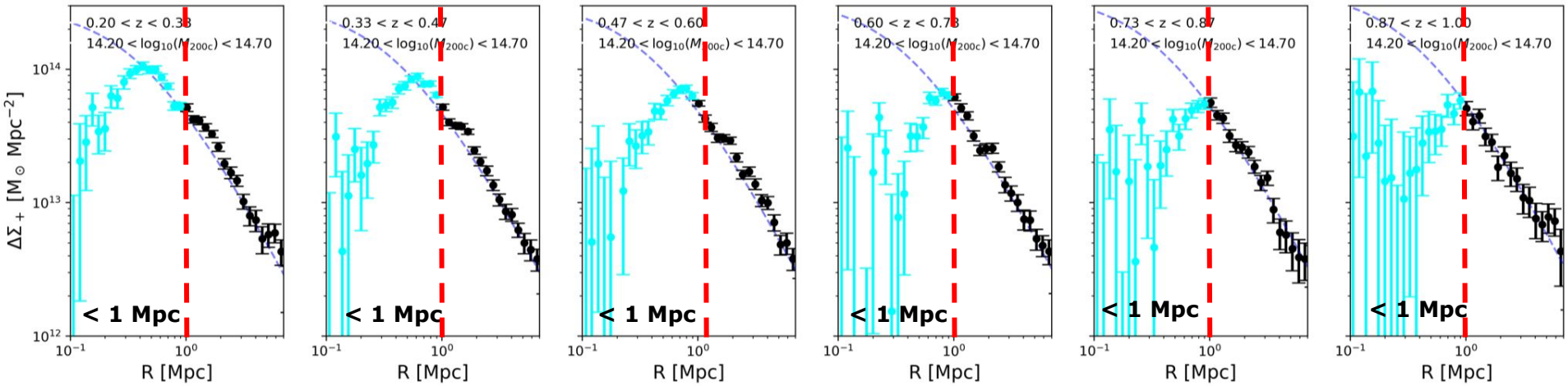
- study the effect of photometric redshifts of background galaxies
- and shape measurement on mass-richness relation



Stacked excess surface density in cosmoDC2

- True shapes from cosmodc2
  - True redshift
  - BPZ redshift (template based)
  - FlexZboost redshift (ML based)

- Validation test : Binning in the M200c-redshift plan of cosmoDC2 dark matter halos
- Limitations :
  - non-physical attenuation of the shear signal in the innermost region (ray-tracing resolution), increases with redshift

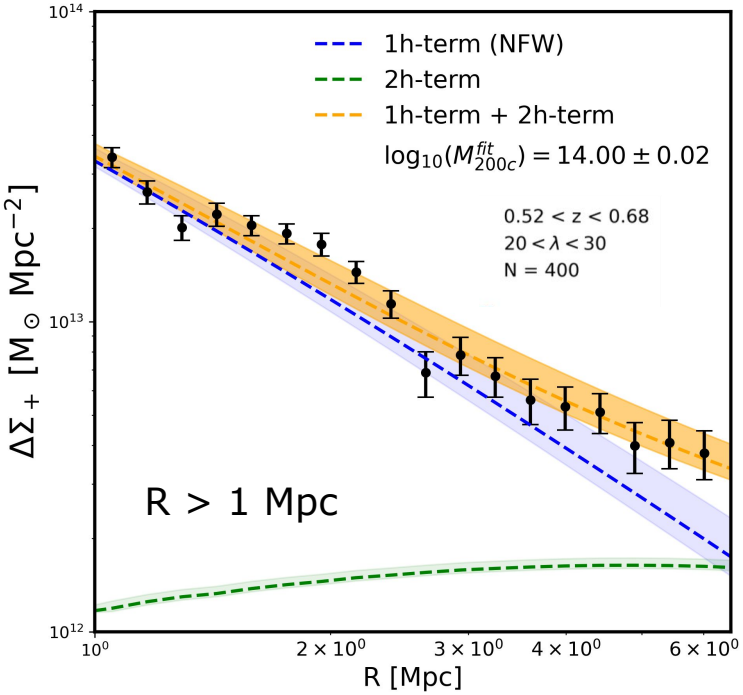


Stacked excess surface density in cosmoDC2; M200c - z binning
Data : cyan and black dots (error bars : from bootstrap covariance matrix)
Blue dashed line : 1h-term for mean mass and mean redshift within each bin

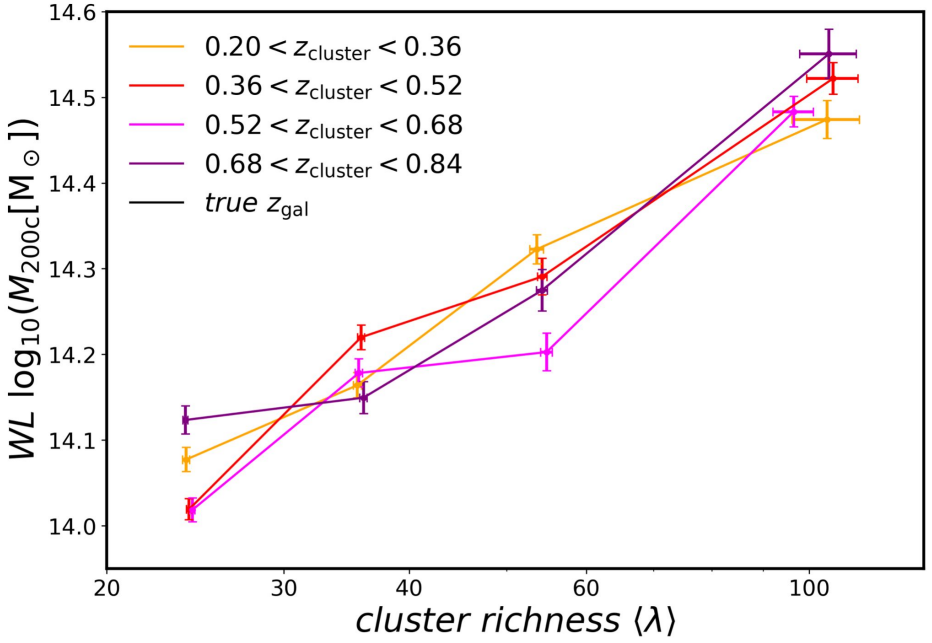
redshift

M200c-richness relation using WL masses

- True shapes from cosmodc2
  - True background galaxy redshift
  - BPZ galaxy redshift (template based)
  - FlexZboost galaxy redshift (ML based)
- for mass reconstruction, we use the foremost region > 1 Mpc (remove high SNR region for the mass reconstruction). (ex: DES Year 1 > 0.1 Mpc)



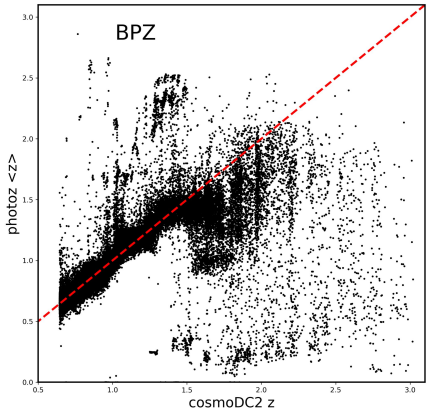
Results:

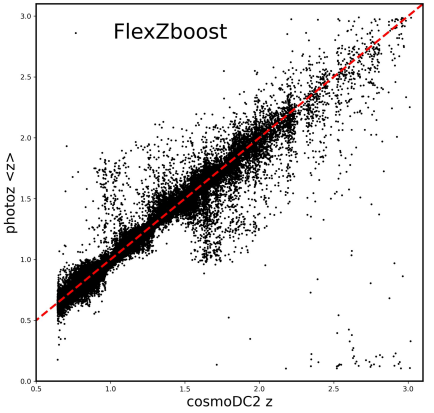


M200c weak lensing reconstruction as a function of mean richness in each bin

M200c-richness relation using WL masses

- True shapes from cosmodc2
  - True redshift
  - BPZ redshift (template based)
  - FlexZboost redshift (ML based)

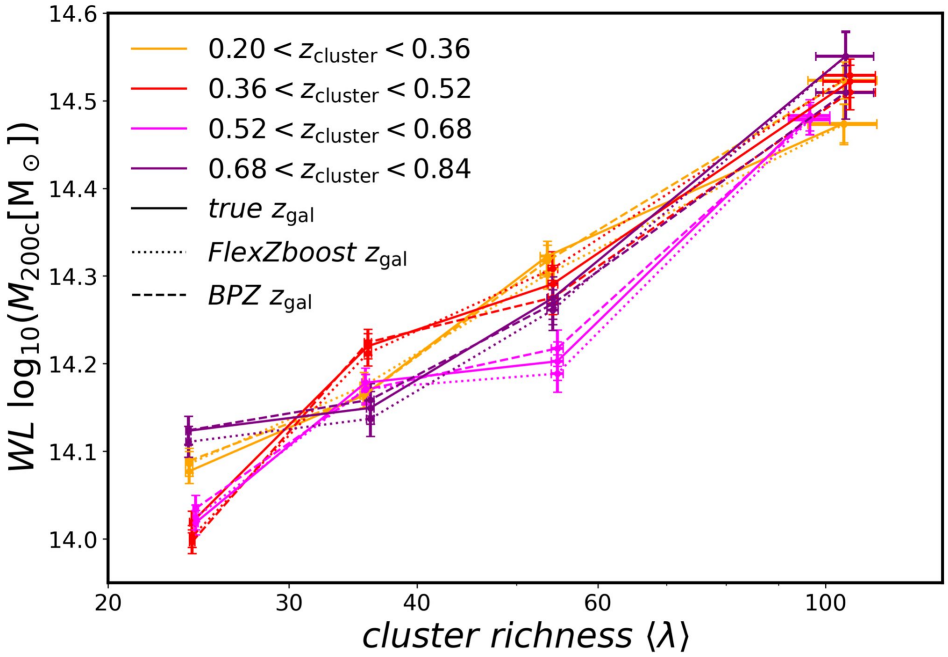




- The analysis takes account of the photoz PDF for each galaxy
- BPZ : “worst case” scenario including catastrophic photometric redshift

Results:

- FlexZBoost : good agreement the true redshift case
- BPZ: No strong effect of BPZ photometric redshift



M200c weak lensing reconstruction as a function of mean richness in each bin

M200c-richness relation in cosmoDC2

Mean Mass-richness relation (McClintock et al. 2019)

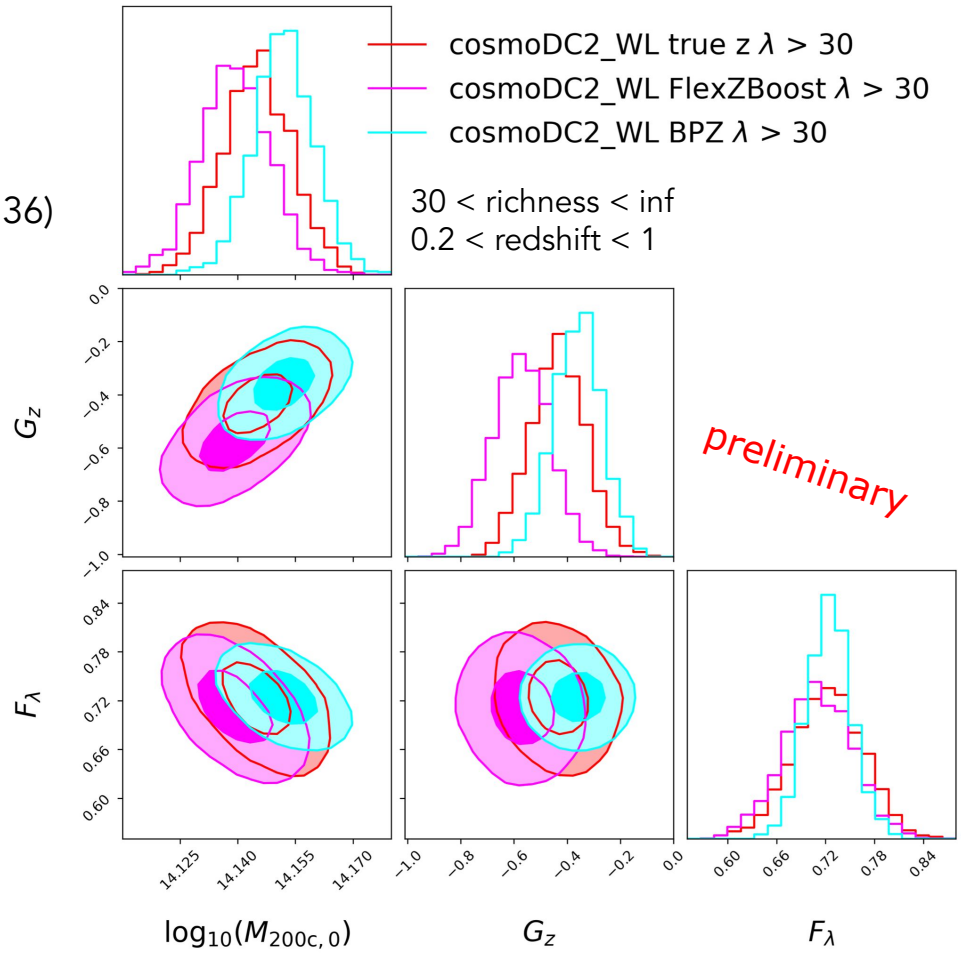
$$\langle M_{200c} \,|\, \lambda, z \rangle = M_{200c,0} \left(\frac{\lambda}{\lambda_0} \right)^{F_\lambda} \left(\frac{1+z}{1+z_0} \right)^{G_z}$$

- Mean value of the sample (z0 = 0.67, lambda0 = 36)
- Fit gaussian likelihood using MCMC
- We apply richness cut > 30 : low purity of RedMapper at richness < 30 in cosmoDC2 (cf. RedMapper validation work on cosmoDC2 M.Ricci)

Results:

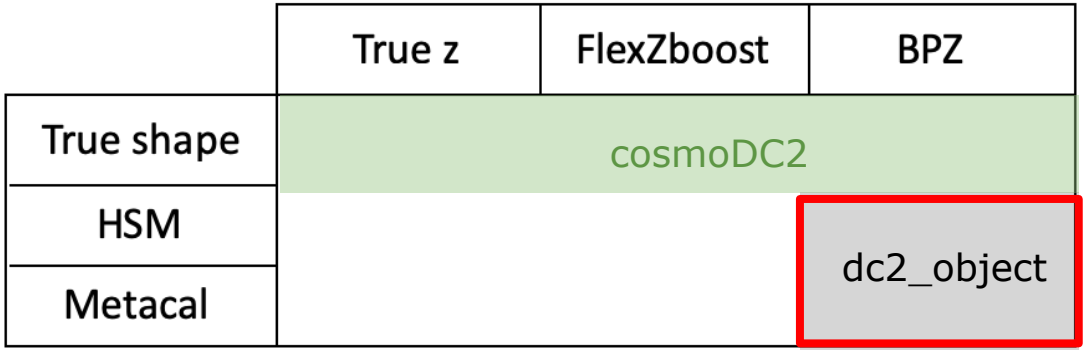
- The use of FlexZboost or BPZ photometric redshift give 1-sigma compatible results with the true redshift case

Here we used the true shapes from cosmoDC2



M200c-richness relation in DC2

Effect of shape measurement



M200c-richness relation in DC2

Effect of shape measurement

The shape catalogs in DC2:

HSM*

- Measurement of galaxy shapes with second moment of the surface brightness
- Needs external calibration from simulation

$$e_i^{\rm cal} = \frac{e_i^{\rm uncal} - c_i}{1 + m_i}$$

- Calibration coefficients not yet available
- Expected bias on the shear profile compared to ideal case

METACALIBRATION**

$$e \approx e\,|_{\gamma=0} + \left(\left. \frac{\partial e}{\partial \gamma} \right|_{\gamma=0} \right) \gamma = e\,|_{\gamma=0} + \mathrm{R}\ \gamma$$

True shear

- METACALIBRATION estimates the shear response R using artificially sheared version of the galaxy image

$$R_{\gamma,ij} = \frac{e_i^+ - e_i^-}{\Delta\gamma_j}$$

- The shear is given by $\langle \gamma \rangle = \langle R \rangle^{-1} \langle e \rangle$
-

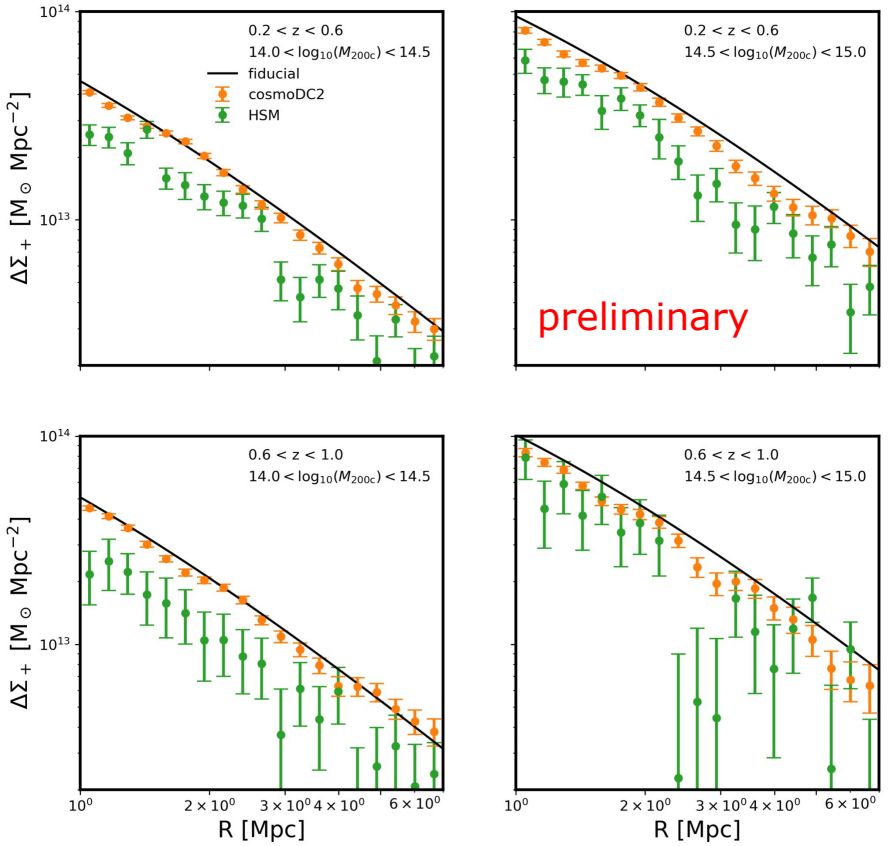
* Systematic errors in weak lensing: application to SDSS galaxy-galaxy weak lensing, R. Mandelbaum et al., 2005

** Practical weak lensing shear measurement with METACALIBRATIONE. Sheldon et al., 2017

M200c-richness relation in DC2

Effect of shape measurement - HSM

"Sanity check" on dc2_object catalog -> the shear profile using HSM uncalibrated shapes are biased relative to cosmoDC2 ideal case.



Fiducial : NFW profile with mean mass-redshift in each bin, mass-concentration Diemer & Krastov (2015)

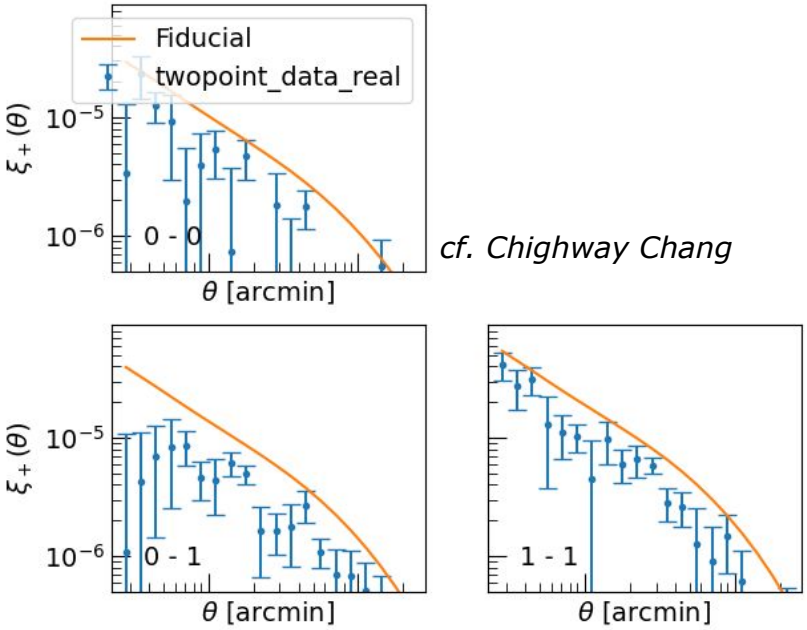
M200c-richness relation in DC2

Effect of shape measurement - METACALIBRATION

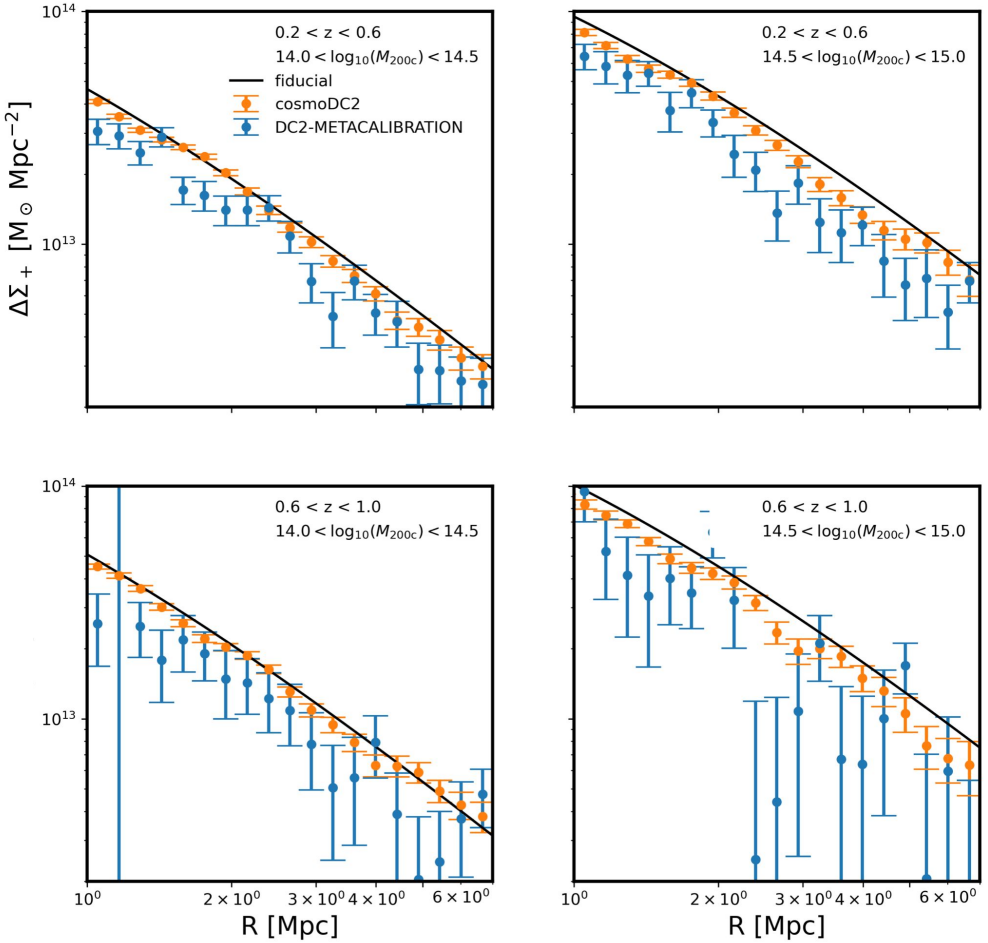
Results:

- Systematic negative bias is found comparing to cosmoDC2 shear profile

- This bias is consistent with other observables using METACALIBRATION shapes in DC2 (xi+: shear-shear correlation function) (ongoing progress on the question)



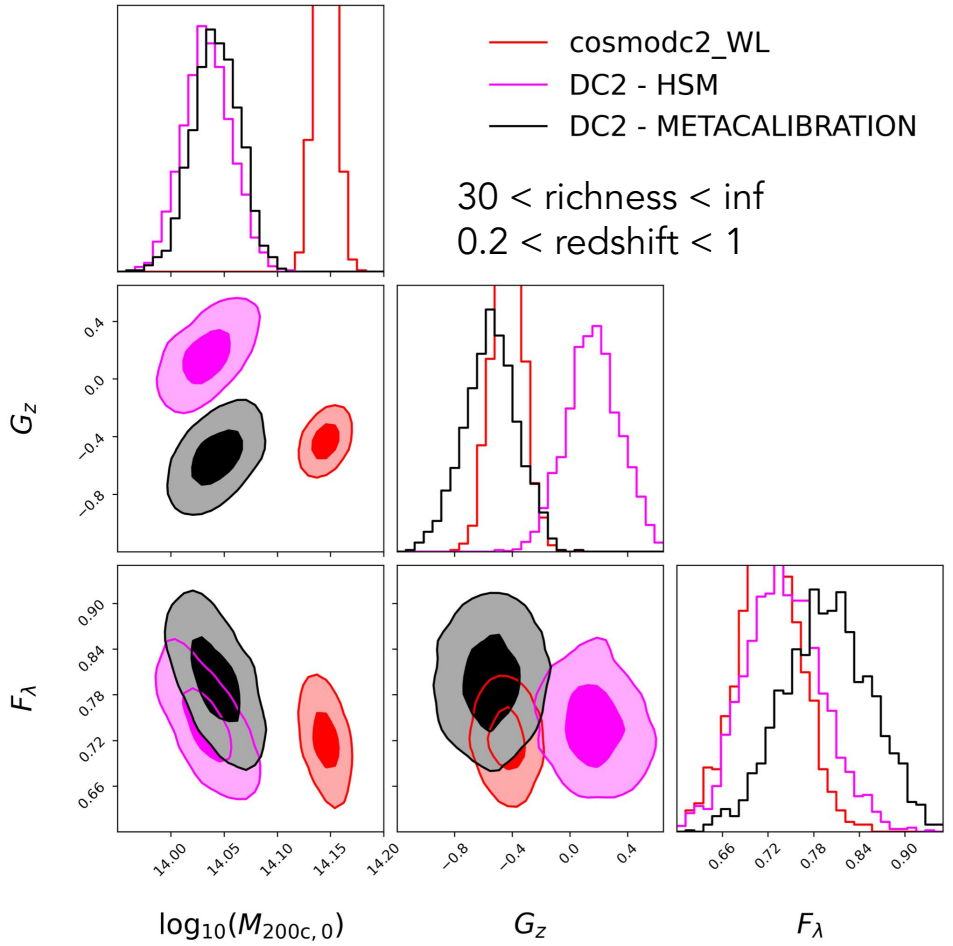
cf. Chighway Chang



M200c-richness relation in DC2_object

$$\langle M_{200c} \,|\, \lambda, z \rangle = M_{200c,0} \left(\frac{\lambda}{\lambda_0} \right)^{F_\lambda} \left(\frac{1+z}{1+z_0} \right)^{G_z}$$

- Expected bias on fitted parameters (HSM without calibration)
- METACALIBRATION issues appears in significant bias relative to ideal catalog.
- Large error bars compared to the ideal case due to shape measurement, more comparable to LSST-like survey (cosmoDC2 sky area)



- Conclusion:
  - mass -richness relaitons using photometric redshift are (1-sigma) compatible to the in the ideal case (preliminary)
  - Effect of shape measurement :
    - Expected bias with HSM
    - ongoing discussion on METACALIBRATION issues (cf. weak-lensing working group - DESC)

- Ongoing projects:
  - SkySim5000 catalog : Better ray-tracing resolution at small scales
    - Repeat the stacking analysis at small and large scales to increase precision on weak lensing masses
    - Testing fit of mass richness relation with other cluster finder (WaZP, M. Aguena)