Calibrating the masses of high-redshift clusters using HST weak lensing observations

Tim Schrabback (AIfA Bonn) with

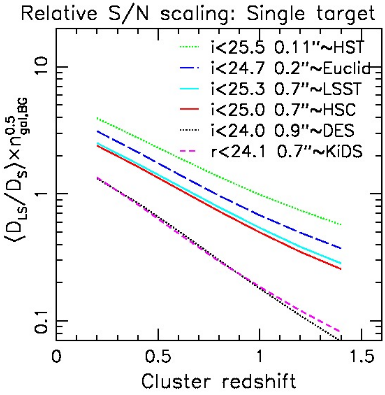
SPT HST-13 (arXiv:1611.03866): **D. Applegate**, **J. P. Dietrich** (⇒ Friday), **H. Hoekstra**, **S. Bocquet** (⇒ Thursday), A. H. Gonzalez, A. von der Linden, M. McDonald, C. B. Morrison, S. F. Raihan, S. W. Allen, M. Bayliss, B. A. Benson, L. E. Bleem, I. Chiu, S. Desai, R. J. Foley, T. de Haan, F. W. High, S. Hilbert, A. B. Mantz, R. Massey, J. Mohr, C. L. Reichardt, A. Saro, P. Simon, C. Stern, C. W. Stubbs, A. Zenteno

HAWK-I WL: M. Schirmer, **R. van der Burg**, **A. Buddendiek**, **H. Hoekstra**, M. Bradač, T. Eifler, T. Erben, B. Hernandez Martin, H. Hildebrandt, A. Muzzin, K. Sharon et al.

Galaxy Clusters 2017, Santander, July 03-07, 2017

Motivation: Extend mass calibration to higher z

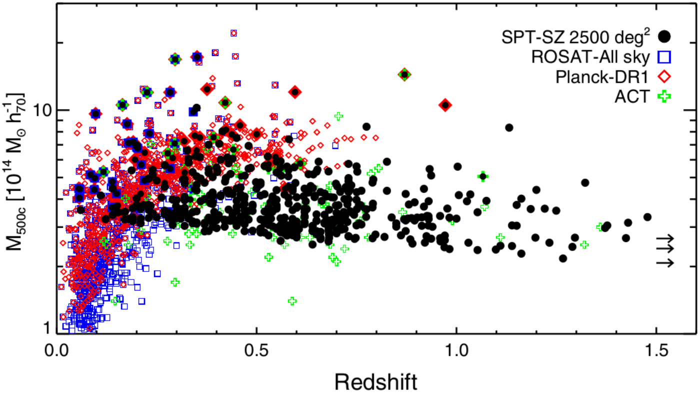
- A lot of the cosmological constraining power comes from the *growth* in the mass function.
- Needs accurate mass calibration *as function of redshift*.
- The lensing S/N drops quickly with redshift.
- Constraints for high-z, high-mass clusters currently most effectively obtained with deep pointed follow-up.
- Requires high resolution (e.g. HST) as most background sources ($z \sim 2$) are small.



Based on galaxy sizes from Schrabback+10 and photo-zs from Ilbert+09, assuming efficient background selection.

The South Pole Telescope SPT Cluster Survey

- SPT (Carlstrom+2011): 10m Millimeter survey telescope
- Detects clusters via the thermal Sunyaev-Zel'dovic (SZ) effect
- Selection well modelled, nearly redshift-independent mass threshold
- 2,500 deg^2 SPT-SZ survey: 387 clusters at $\xi > 5$ (Bleem+2015)



Bleem et al. 2015.

SPT weak lensing follow-up

- Low-z clusters from the ground ($z \lesssim 0.6$)
  - Magellan: High+2012, Chiu+2016, Dietrich+in prep. ⇒ **Jörg's talk on Friday** Applegate+in prep.
  - DES-SV: Stern+in prep.

Magellan-Clay (Credit: D. Applegate)

- High-z clusters with HST
  - 13 clusters ($0.6 \lesssim z \lesssim 1.1$) incl. most massive (PIs: Stubbs, High) + VLT colors (PI: Mohr) ⇒ Schrabback+2016, **this talk**
  - 45 clusters ($z \gtrsim 0.7$) F606W Snapshots (PI: Schrabback) + Gemini i for colours (PI: Benson) for 18 ($z_{\rm m} = 0.9$)
  - Cycle 24: 9 cluster, $\xi > 6$, $z > 1.2$ F606W+F814W+F110W (PI: Schrabback) Deep *Chandra* (PI: McDonald)

Credit: NASA/ESA

HST-13 analysis: Team

Cluster Mass Calibration at High Redshift: HST Weak Lensing Analysis of 13 Distant Galaxy Clusters from the South Pole Telescope Sunyaev-Zel'dovich Survey

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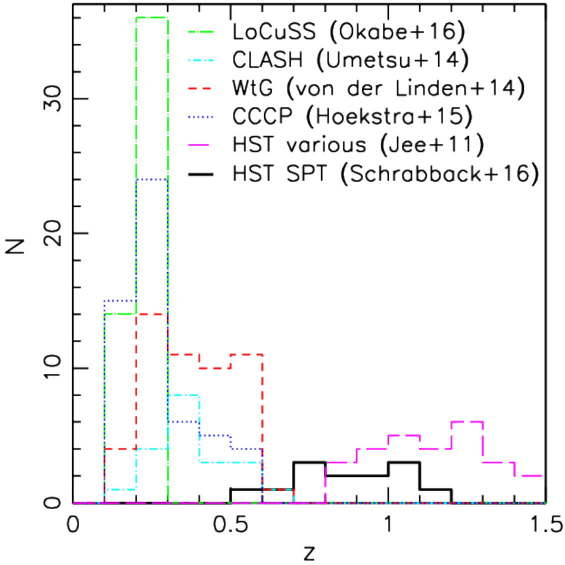
ABSTRACT

We present an HST/ACS weak gravitational lensing analysis of 13 massive high-redshift ($z_{\rm median} = 0.88$) galaxy clusters discovered in the South Pole Telescope (SPT) Sunyaev-Zel'dovich Survey. This study is part of a larger campaign that aims to robustly calibrate mass-observable scaling relations over a wide range in redshift to enable improved cosmological constraints from the SPT cluster sample. We introduce new strategies to ensure that systematics in the lensing analysis do not degrade constraints on cluster scaling relations significantly. First, we efficiently remove cluster members from the source sample by selecting very blue galaxies in $V-I$ colour. Our estimate of the source redshift distribution is based on CANDELS data, where we carefully mimic the source selection criteria of the cluster fields. We apply a statistical correction for systematic photometric redshift errors as derived from *Hubble* Ultra Deep Field data and verified through spatial cross-correlations. We account for the impact of lensing magnification on the source redshift distribution, finding that this is particularly relevant for shallower surveys. Finally, we account for biases in the mass modelling caused by miscentring and uncertainties in the mass–

HST-13 cluster sample



HST-13: Data

HST/ACS

All clusters:
F606W 2×2 mosaic $\Rightarrow$ shapes + central F814W tile $\Rightarrow$ colours

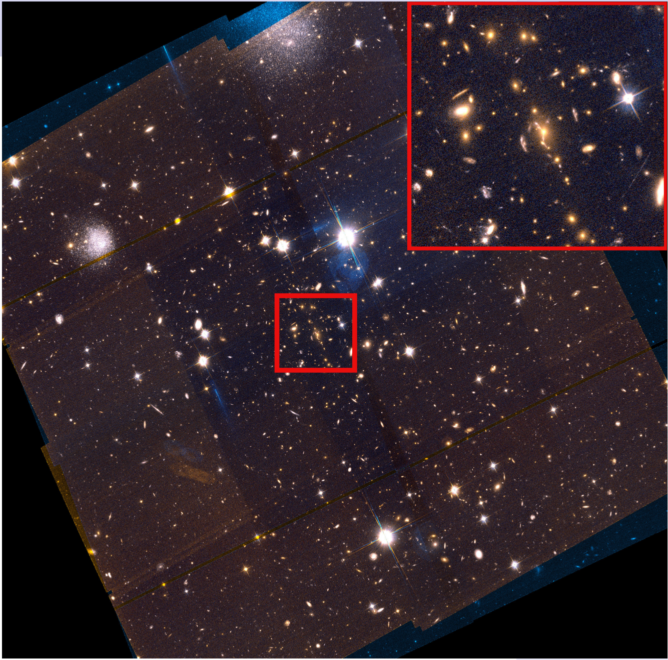
SPT-CL *J* 0615−5746:
Additional F814W 2×2 mosaic (PI: Mazzotta) $\Rightarrow$ colours

$n_{\mathrm{gal,bg}} = 16.8/\mathrm{arcmin}^2$

VLT/FORS2

I-band: typically 2.1ks, $\lesssim 0\farcs8$ seeing (PI: Mohr) $\Rightarrow$ colours

$n_{\mathrm{gal,bg}} = 5.2/\mathrm{arcmin}^2$



SPT-CL *J* 0615−5746 at $z = 0.972$.

HST-13 analysis: Overview

Shape measurements

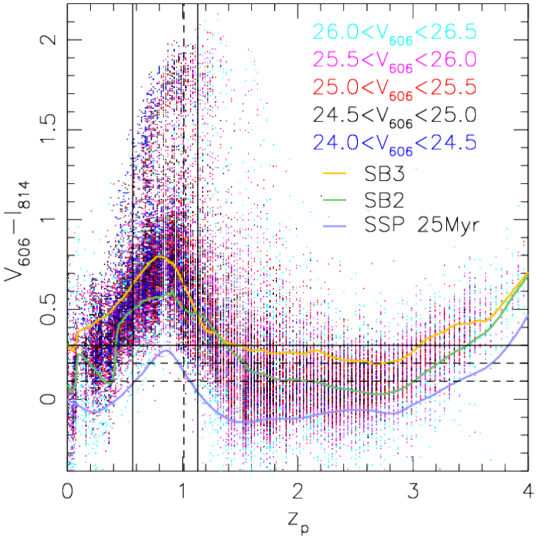
- PSF corrections: Noise bias-corrected KSB+ with PCA model for PSF variations (Schrabback+2010)
- Improved CTI correction (Massey+2014), find no indications for significant residuals

Estimating the redshift distribution

- Tie to CANDELS (Skelton+2014) ⇒ Match noise & cuts
- Requires accurate cluster member removal ⇒ Blue galaxies
- Account for systematic features of CANDELS photo-*z*s
- Account for impact of magnification on the redshift distribution

Calibrate mass modelling using simulations

Select blue galaxies in $V - I$

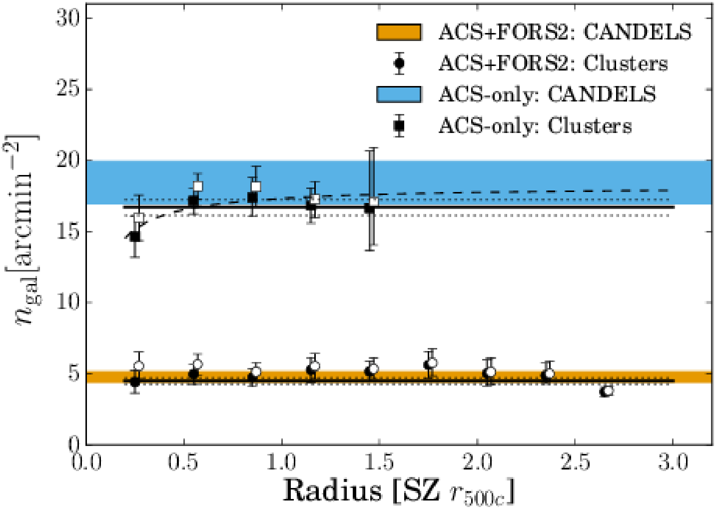


CANDELS photo-zs from 3D-HST (Skelton+2014)

Faint blue galaxies are great!

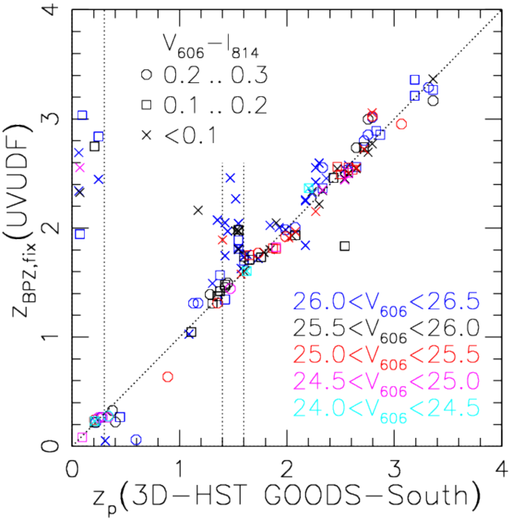
- Majority at high z
- Good removal of galaxies at the cluster redshift IF adequate filter pair & good S/N
- Interesting e.g. for Euclid+LSST

Efficiency of the Dutch approach



Consistent with no residual cluster member contamination.

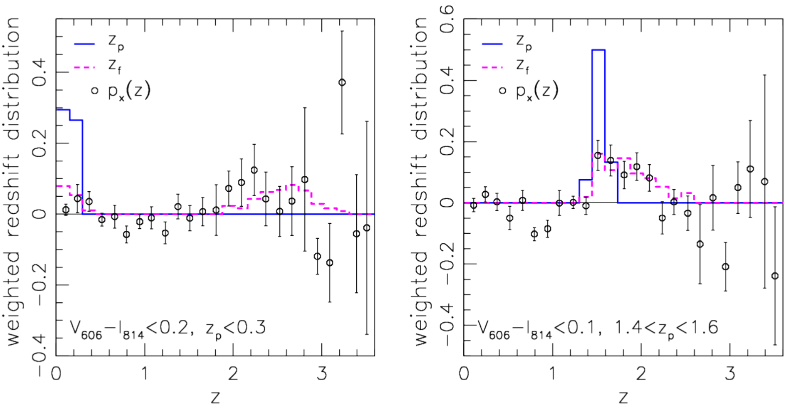
Catastrophic photo-*z* outliers



CANDELS 3D-HST photo-*z*s (Skelton+2014) vs. UVUDF photo-*z*s (Rafelski+2015).

- Revealed in comparison to HUDF photo-*z*s (Rafelski+ 2015) and grism/spec-*z*s (Brammer+ 2012, 2013)
- Statistical correction: Scatter CANDELS photo-*z* based on this comparison
- On average: 12% correction for cluster masses!
- Further investigated in Raihan+ in prep.

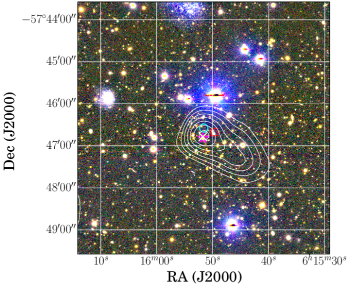
Cross-check using cross-correlations

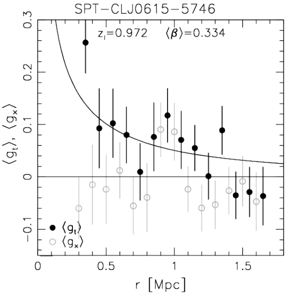


Spec-z/grism-z data for CANDELS from 3D-HST (Skelton+2014; Momcheva+2015).

Confirms the presence of the outliers and redshift focussing. Method: see Morrison+2016

SPT-CLJ0615-5746





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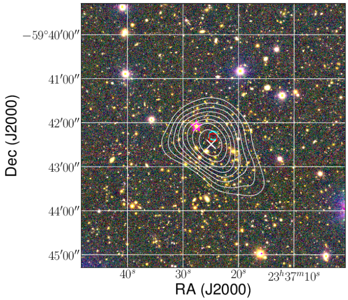
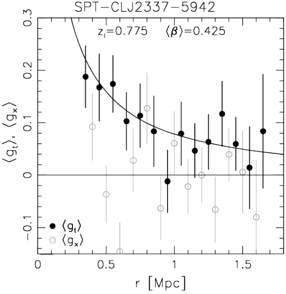
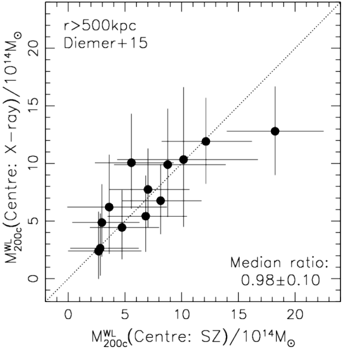




Calibrate the mass modelling on simulations

- Fit NFW profile with fixed *M*–*c* relation (Diemer+15) within $0.5\mathrm{Mpc} < r < 1.5\mathrm{Mpc}$
- Mimick analysis on simulated clusters from Millennium XXL + Becker & Kravtsov 2011 ⇒ Applegate+ in prep.

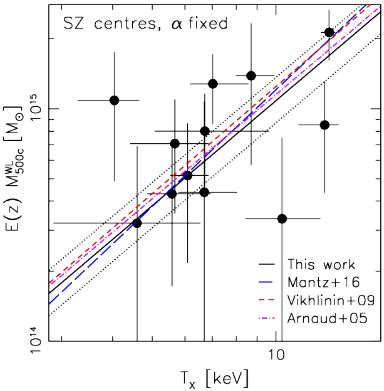


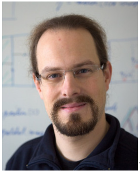
- Diemer+15 with no mis-centring: Mass bias −4%
- Add X-ray/SZ miscentring: Mass bias − = 9–15%
- Future: All observables from the same hydro-sims ⇒ Covariances. Lensing cross-checks on *c* & miscentring

M–T_{X} scaling relation

With a fixed slope $\alpha = 3/2$, the data are consistent with low-z calibrations and self-similar redshift evolution.

$$E(z) = \sqrt{\Omega_{\mathrm{m}}(1+z)^3 + \Omega_\Lambda}$$





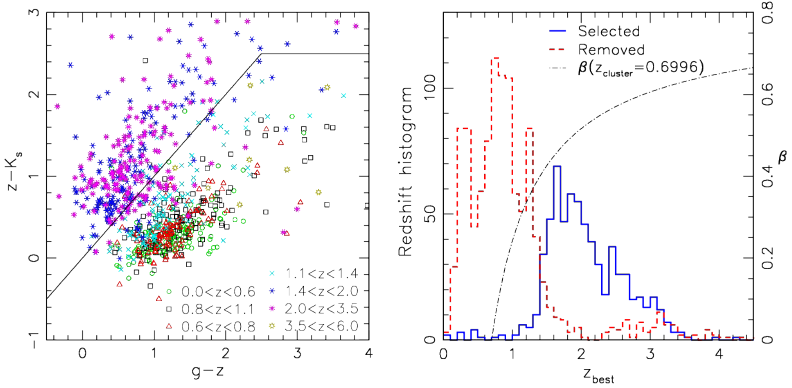
⇐ **Jörg's talk**: Further scaling relations (Dietrich+ in prep.)

Updated cosmological constraints: Bocquet+ in prep. ⇒ **Sebastian's talk** ⇒

Deep VLT/HAWK-I: An alternative to HST?

- Need excellent resolution & wide area (for massive clusters)
- HST expensive, especially mosaics
- Here: Analyse deep (6h) VLT/HAWK-I K_s images (PI: Schrabback) of RCS2 $J232727.7-020437$ ($z = 0.70$, Sharon+2015; Menanteau+2013)
- $\mathrm{FWHM} = 0''.35$ with $> 4\times$ the area of HST/ACS
- Also $g + z$ from LBT/LBC for colours (PI: Eifler)

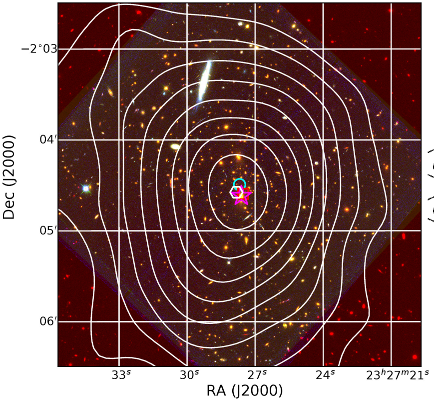
gzK_s colour selection

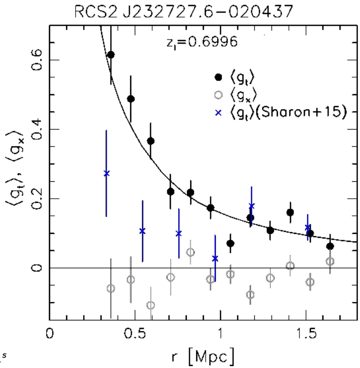


Colours from UltraVISTA-DR3 + Subaru (Muzzin+in prep.), redshifts from 3D-HST (Skelton+2014; Momcheva+2015).

- Very efficient background selection.
- Lower systematic uncertainty from z-distribution than for ACS analysis (NIR-selected, low low-z contamination).

RCS2 $J232727.7{-}020437$ results





- Peak significance in mass reconstruction: 9.4σ
- Shape noise mass error: 8%
- Weak lensing sensitivity of data similar to HST/ACS observations of single-orbit depth

Conclusions

- HST measurements of high-z clusters complement the weak lensing mass calibration from lower redshifts to constrain the evolution of scaling relations $\Rightarrow$ Growth
- Initial results in arXiv:1611.03866, more to come: SPT ACS SNAP program; Cycle 24 $z > 1.2$ program
- Deep good-seeing $K_{\rm s}$ imaging: Viable alternative to HST mosaics for massive clusters at $0.7 \lesssim z \lesssim 1.1$
- Interesting test case for future deep data, e.g. Euclid+LSST, WFIRST