Mass calibration of high-z* clusters

* 0.6<z<1.1

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High redshift = high sensitivity

The properties high-z clusters are very sensitive to the background cosmology. This was already clear at the end of the last century:

*A single “pink elephant” can rule out high $\Omega_m$ models.*
High redshift clusters are still relevant

The main open questions in cosmology now focus on the nature of dark energy. To constrain its equation-of-state or test “early DE” models we need to find and weigh high-z clusters!
z>1.4 is possible, but expensive...

Jee et al. (2017) studied a z=1.48 and z=1.75 cluster using data obtained as part of the HST “see change” program. Exposure times are ~15ks in F140W ➔ more than 200 sources/arcmin$^2$. 
There are enough clusters to study!

And this will improve further with SPT-3G, AdvACTpol eROSITA, etc.
High redshift = difficult

At $z \sim 1$ clusters are still being assembled, which complicates determining a robust selection function and weighing them using dynamical techniques $\Rightarrow$ we need lensing masses!
Need deep observations *and* high resolution

Wide area (shallow) lensing surveys can constrain the mass-observable scaling relations at low-z but they lack the depth/area to extend these to z~1.
**Challenges for high-z cluster studies**

Only source galaxies that are far behind the cluster contribute to the lensing signal.

- Lower number density
- Lensing efficiency low

The galaxies are small and faint

- Difficult to measure shapes
- Limited redshift information

These need targeted deep observations with high resolution

**Larger uncertainties**

**Larger biases**
HST observations of SPT clusters

- Schrabback et al. (2017) used a mosaic of HST observations to measure the masses of 13 SPT-SZ clusters with $0.6 < z < 1.1$.
- Analysis in progress: snapshot observations of 18 ($z_m \sim 0.9$) clusters
- Just observed: cycle 24 observations of 9 clusters ($z_m \sim 1.4$)
SPT J0615-5746 (z=0.972)
**Efficient selection of background sources**

Schrabback et al. (2017) used a novel/efficient approach to select a clean sample of background sources with minimal contamination by cluster members. This requires deep imaging in the red band.

\[ V-I \text{ vs redshift using CANDELS redshifts from 3D-HST.} \]

- Multiple independent pointings
- Depth matches our data
- Single colour cut can select a clean sample of sources!

Better determined than for \( z_{\text{clus}} \sim 0.3 \)!

These are at high-z!
Efficient selection of background sources

Schrabback et al. (2017): a simple colour cut can remove 98.5% of the cluster members, whilst preferentially selecting high-z sources.
Results for SPT-CL J2337-5942

Schrabback et al. (2017)
$M_{WL} - T_X$ relation at high-z

Schrabback et al. (2017)
Combined scaling relations

The ultimate aim is to combine results for larger high redshift samples with “standard” ground-based measurements for $z<0.6$ clusters.

Dietrich et al. (2017)
Schrabback et al. (2018): Good image quality (FWHM=0.35") VLT/HAWK-I Ks-band imaging combined with deep g+z images can compete with single orbit HST mosaics!
Precise weak lensing constraints from deep high-resolution $K_s$ images: VLT/HAWK-I analysis of the super-massive galaxy cluster RCS2 J232727.7−020437 at $z = 0.70^*$
VLT/HAWK-I is very promising!

Schrabback et al. (2018): we detect a very significant lensing signal for RCS2327-02. We plan a larger pilot of 16 clusters (40 hrs have already been allocated in P101).
Comparison with other measurements

\[ M_{500c}/(10^{15}M_\odot) = 1.50^{+0.19}_{-0.17}(\text{stat.}) \pm 0.09(\text{sys.}) \]
Conclusions

Determining weak lensing masses of high redshift clusters requires deep targeted observations.

Determining weak lensing masses of high redshift clusters will never be cheap but we have demonstrated that accurate masses can be determined rather efficiently with cleverly chosen colour cuts.

Deep high-resolution VLT/HAWK-I observations with deep g+z imaging can compete with single orbit HST mosaics!

Expect significant improvements in the next few years!