Scaling relations from/for weak lensing

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Why am I interested in scaling relations?

For accurate cosmology we need to know/understand the effects of (g)astrophysics:

- Baryon physics determines the observable-mass relations for clusters
- Baryon physics affects the matter power spectrum and halo mass function

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Semboloni et al. (2011)

Planck collaboration, XXIV (2015)
How can we get a handle on the (g)astrophysics?
**Weak lensing measurements are useful**

Baryonic processes typically complicate the mass estimates inferred from dynamical techniques that require visible tracers.

Weak gravitational lensing provides a *direct* measurement of the ensemble average mass of a population of objects.

To be useful for scaling relations we do need to know

- the selection of the sample
- the underlying statistical distributions (e.g. intrinsic scatter)

*The measurements can help us to inform simulations and vice versa.*
Group signal as a function of luminosity

The combination of the GAMA redshift survey (large sample of galaxy groups) and KiDS weak lensing measurements have enabled a large number of unique studies (I hope you saw the poster by Andrej Dvornik)
A careful comparison to simulations

We observe the BAHAMAS simulations (McCarthy et al. 2016) the same way we observe/analyse the real Universe: same FoF algorithm, ray tracing (lensing), projected X-ray and tSZ maps ....

10.5 < log(M_{grp}) < 11.5
11.5 < log(M_{grp}) < 11.8
11.8 < log(M_{grp}) < 12.7

Jakobs et al. (in press): remarkable agreement between the data and BAHAMAS!
Comparison of the gas contents in groups

Jakobs et al. (in press): fair agreement between the data and BAHAMAS but the analysis revealed the difficulty in interpreting the data ➔ the group finding plays a key role and complicates simple comparisons.
Debackere et al. (in prep.): X-ray observations can help restrict the parameter space, but the next challenge is to understand the distribution of baryons in the outskirts of halos.
Cluster cosmology: lots of clusters to study!

And this will improve further with SPT-3G, AdvACTpol eROSITA, etc.
Cluster mass calibration

Without well-calibrated mass-observable relations these amazing cluster samples will not be useful for accurate cosmology.

Weak lensing has become the “weighing scale” of choice.

Canadian Cluster Comparison Project (0.2<z<0.55)  
*CCCP is good for the masses!*

Multi-Epoch Nearby Cluster Survey (0.05<z<0.15)

This work benefited tremendously from advances made for cosmic shear, and we can now reach accuracies of a few per cent; but constraints for individual clusters remain noisy (it will never be precise).
Comparison to dynamical estimates

Herbonnet et al. (in prep.)
To infer the underlying scaling relation we need to account for the sample selection, which itself depends on cosmology...

\[
\log_{10} M_{SZ} = a + b \log_{10} M_{WL}
\]

\[
M_{SZ} = (1 - b) M_{WL}
\]
Pushing to higher redshifts

Calibrated cluster scaling relations are now extended to higher redshifts thanks to HST and VLT follow-up studies.

Schrabback et al. (2017)

\[ E(z) \, M_{500c}^{\text{MW}} \quad \text{[}10^{15}\text{]} \]

\[ T_x \quad [\text{keV}] \]

\[ \langle g_i \rangle, \langle g_x \rangle \]

Schrabback et al. (2018)

RCS2 J232727.6–020437

\[ z_t = 0.6996 \quad \langle \beta \rangle = 0.481 \]

\[ \langle g_i \rangle \text{ (Sharon+15)} \]
Other scaling relations: subhalos

Sifon et al. (2018) studied the lensing signal around cluster members in the MENeaCS sample of clusters of galaxies.
Average mass of UDGs in clusters

The UDGs may be an extension of the overall satellite population, but the situation is currently rather unclear. HST lensing constraints are needed.
Pushing outwards

Contigiani et al. (in prep.): we can measure the splashback feature in clusters using weak gravitational lensing. With larger samples we can examine how it scales with cluster properties.

![Graph showing the relationship between lensing signal and radius (R_{com}) logged in [Mpc/h].]
This is only the beginning!

Amazing scaling relations using weak gravitational lensing:

- Smaller error bars
- Larger redshift range