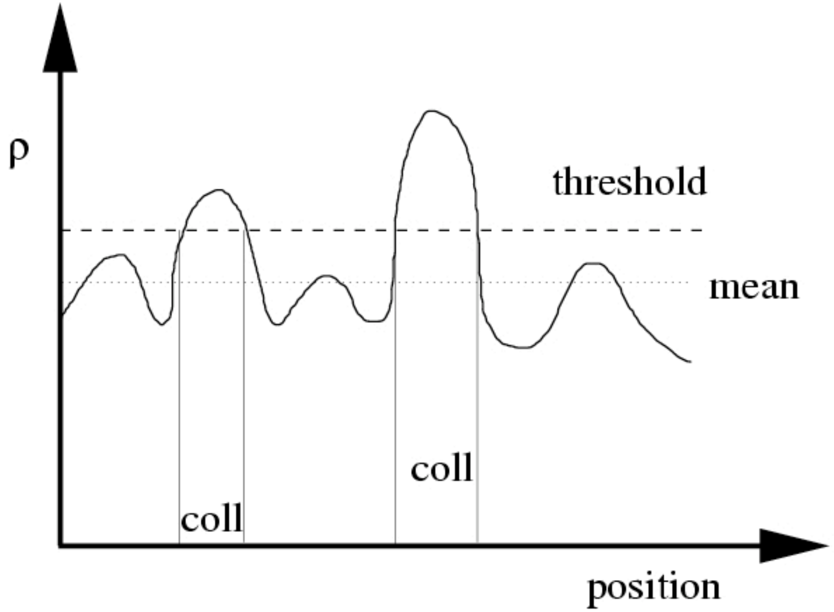
Cosmological Constraints with Galaxy Cluster Counts with the Euclid Imaging Survey

Jochen Weller (LMU,EXC, MPE)

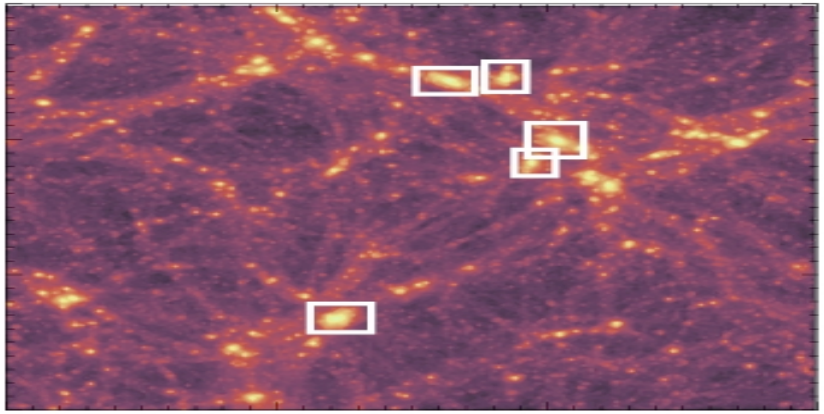
Filipe Abdalla (UCL), Nabila Aghanim (Orsay), Adam Amara (ETH), Joel Berge (JPL), Marian Douspis (Orsay), Tom Kitching (Edinburgh), Lauro Moscardini (Bologna), Alexandre Refregier (Saclay), Stella Seitz (LMU, MPE)

Galaxy Clusters as a Probe of Structure Formation in the Universe

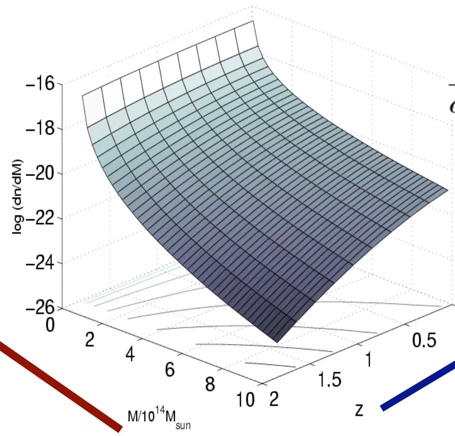


- If linear density perturbation exceeds threshold density the region will collapse and form a cluster
- Mass function sensitive to amplitude of perturbations (σ_8) and mass contents of the Universe (Ω_m); but also other cosmological parameters (w) !

Counting Dark Matter Halos



- Count halos in N-body simulations
- Measure "universal" mass function - density of cold dark matter halos of given mass



$$\frac{dn}{dM}(z, M) = -0.316 \frac{\rho_{m,0}}{M} \frac{d\sigma_M}{dM} \frac{1}{\sigma_M} \exp\left\{-\left|0.67 - \log[D(z)\sigma_M]\right|^{3.82}\right\}$$

Jenkins et al. 2001; also Sheth & Tormen 1999 for analytical function
Warren et al. 2004, Tinker et al. 2008

more low mass clusters

more low redshift clusters

Cosmology Dependence of the Mass Function

$$\frac{dn}{dM}(z,M) = -0.316\frac{\rho_{m,0}}{M}\frac{d\sigma_M}{dM}\frac{1}{\sigma_M}\exp\left\{-\left|0.67-\log[D(z)\sigma_M]\right|^{3.82}\right\}$$

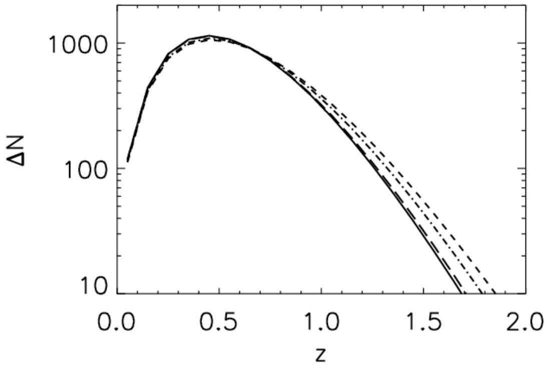
- mass density
- power law dependence on fluctuation amplitude
- power law dependence on growth factor

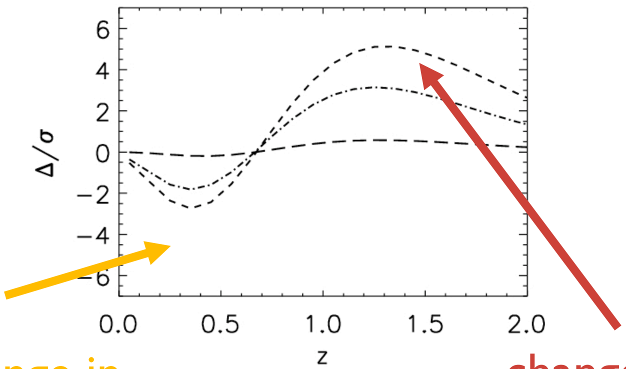
Predicting Cluster Number Counts

$$\Delta N(z) = \Delta\Omega \int_{z-\Delta z/2}^{z+\Delta z/2} dz \frac{d^2V}{d\Omega dz} \int_{M_{\rm lim}}^{\infty} \frac{dn}{dM}\, dM$$

- Survey sky coverage
- Redshift bins
- Volume element
- Limiting mass of survey (redshift dependent)
- Cosmology dependence driven by volume element and mass function

Cosmology Dependence of Number Counts

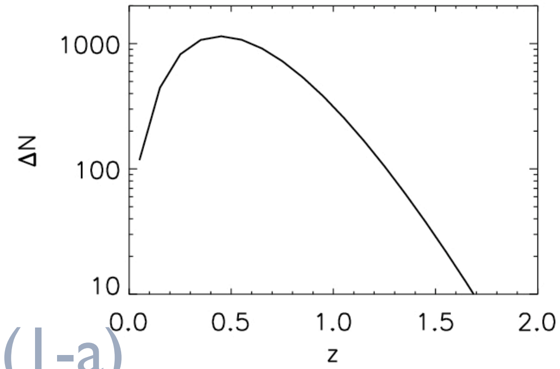




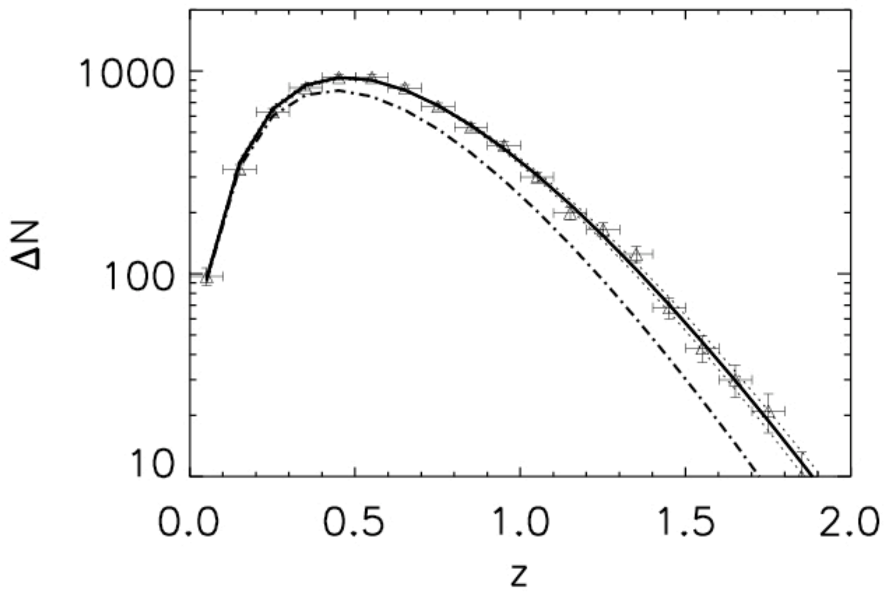
change in volume

change in growth factor

- concordance cosmology: $\Omega_m = 0.3$; $\sigma_8 = 0.78$; n=1, h=0.72; w=-1, $\Delta\Omega$ = 4.000 deg^2 $M_{lim} = 1.7\times10^{14} h^{-1} M_\odot$
- $\Omega_m = 0.4$
- $\sigma_8 = 0.85$
- w = - 0.8
- w = - 0.7
- w = -1+0.2(1-a)



Cluster Counts in DGP Model



- DGP number counts for $\sigma_8 = 0.75$, $n=1$, $M_{lim}=1.7\times10^{14}h^{-1}M_{\odot}$(from 'SPT')
- mock data assuming Poisson errors
- mimic DE model

significant difference between mimic DE and DGP: $>1\sigma$

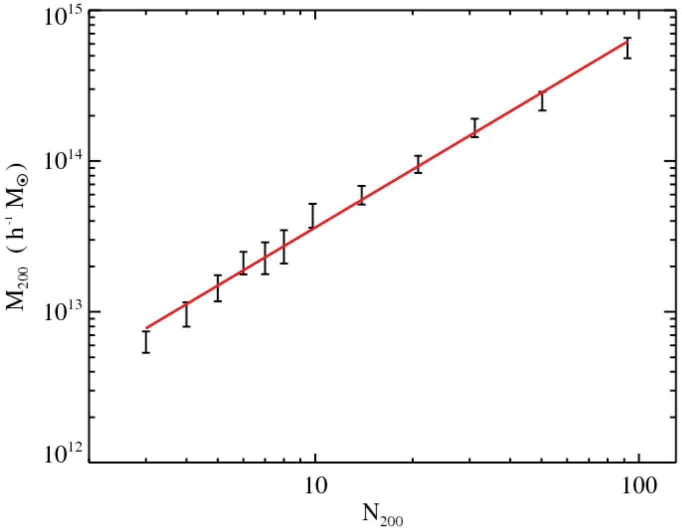
Selection Clusters with Euclid

- Weak lensing: e.g. peak statistics
- Galaxy overdensities
  - maxBCG
  - Voronoi Tesselation
  - Matched filters
  - Counts in Cells
  - Percolation Algorithms (FoF)
  - smoothing kernels
  - surface brightness enhancements
  - ...
- Strong Lensing

maxBCG as Baseline Method

- Brightest Cluster Galaxy (BCG) at centre of every cluster
- tight color-magnitude relation of BCG
  - used to (pre-) select
- Identifying ridgeline galaxies
  - use model for radial and color distribution
- maximize the two models as a function of redshift: estimate of redshift of cluster
- Iterative scheme: removal of most likely clusters and their satellites
- Apply probability chain, which has been calibrated with mock observations
- Successfully applied to SDSS sample (Rozo et al.)
- Biggest problem: Completeness and Purity of Sample
  - projection effects along line of sight; misestimate of cluster members

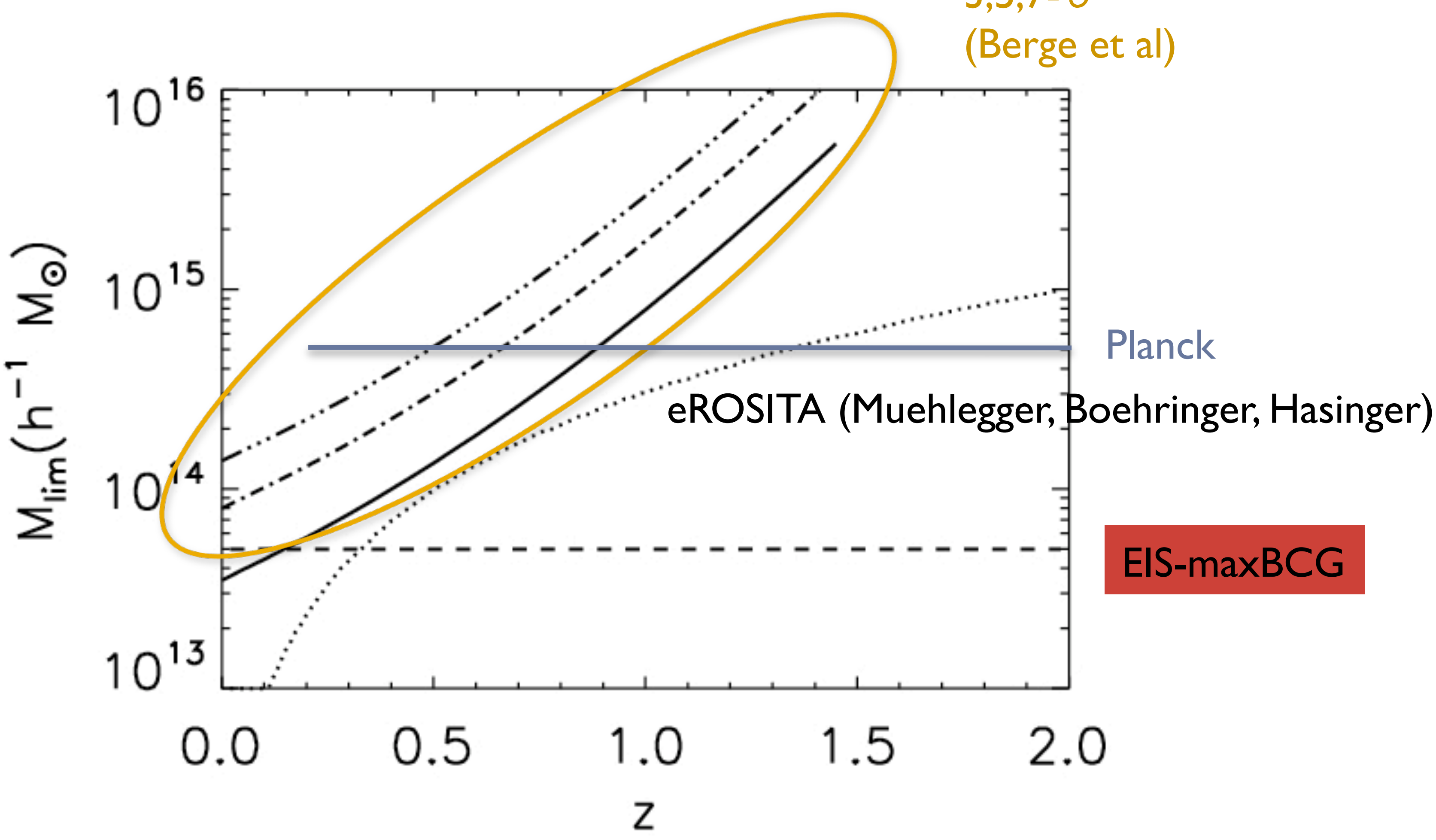
maxBCG Selection SDSS: A Lesson for Euclid ?



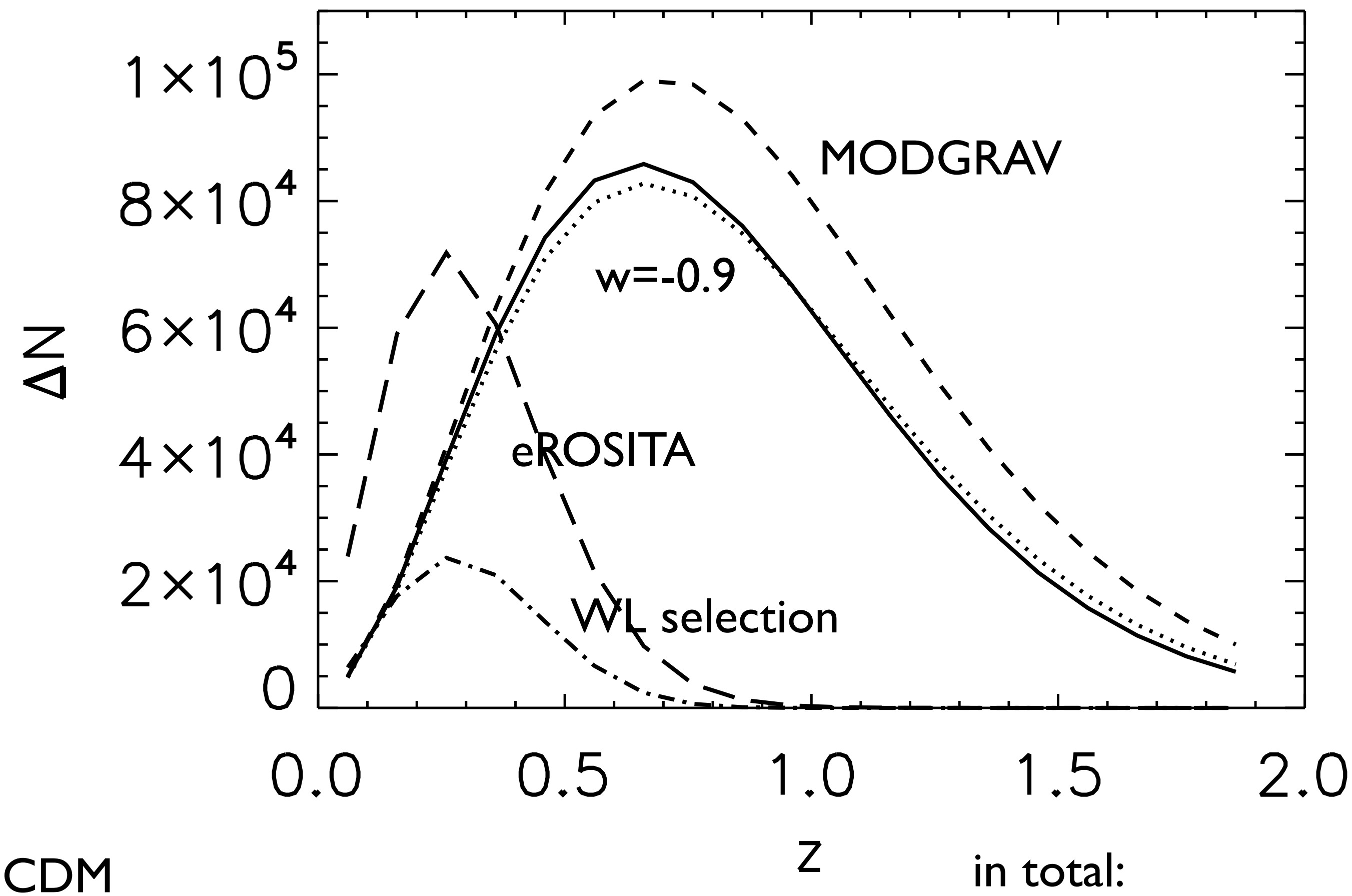
Johnston et al. 2007

- Mass – Richness relation
  - calibrated with statistical weak lensing measurements (for 130,000 groups)
  - Johnston et al. 2007
- Good purity and completeness to about: $M \sim 10^{13.5}\, h^{-1} M_\odot$
- however for SDSS only to: $z \sim 0.3$
- depth of Y, J and H filters
  - should be able to find ridgeline galaxies out to z=1.3-2.0
  - how far out do we find robust red sequence ?

Mass Limit for Euclid



Cluster Numbers for Euclid



solid: ΛCDM

in total:
well over 750,000#

Uncertainty in Mass Limit

- Mean mass observable relation
  - scaling laws dependent on method – not entirely determined: redshift and mass dependence
  - different methods can be used for cross calibration
- individual scatter in mass observable relation
  - how behave the tails
    - high redshift, low mass, high mass, etc.
  - degenerate with cosmology
  - can also be estimated by surveys
    - Rozo et al.: optical, x-ray and weak lensing find 0.45±0.20

General Form for Scaling and Scatter

- assign likelihood for observed mass for a true mass $p(M_{obs} \mid M)$ with a bias and a scatter included; allow to differ in redshift and mass bins

$$p(M_{obs}|M) = \frac{1}{\sqrt{2\pi\sigma^2_{\ln M}}} \exp\left[-x^2(M_{obs})\right]$$

$$x(M_{obs}) = \frac{\ln M_{obs} - \ln M - \ln M_{bias}}{\sigma_{\ln M}}$$

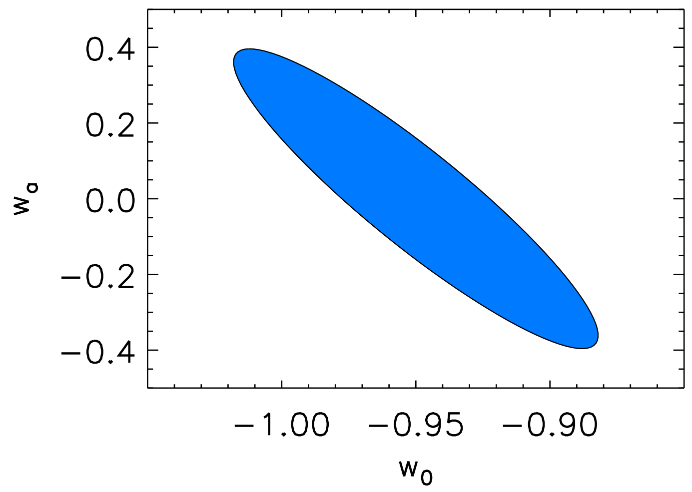
- completely free form does not allow cosmology fit (Lima & Hu)
- $\ln M_{bias} = A + n \ln(1+z)$
  - better form for particular selections possible
- $\sigma_{\ln M}^2 = A + Bz + Cz^2 + \ldots$
  - so far this is ad hoc

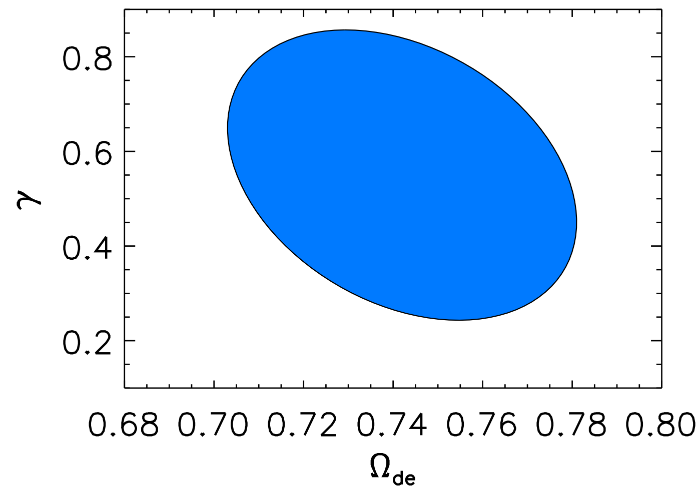
Self-Calibration

$$n_i = \int_{M_{obs}^i}^{M_{obs}^{i+1}} \frac{dM_{obs}}{M_{obs}} \int \frac{dM}{M} \frac{dn}{d\ln M} p(M_{obs}|M)$$

- Exploit shape of mass function to calibrate for bias and scatter in constant mass bins
- Further use clustering of clusters (cross-correlated to other probes ? Not used here!)
- Result: scatter in mass-observable relation is not the problem: Increases number of clusters, hence better statistics
- Uncertainty in scatter is PROBLEM

Constraints from EIS Cluster Counts

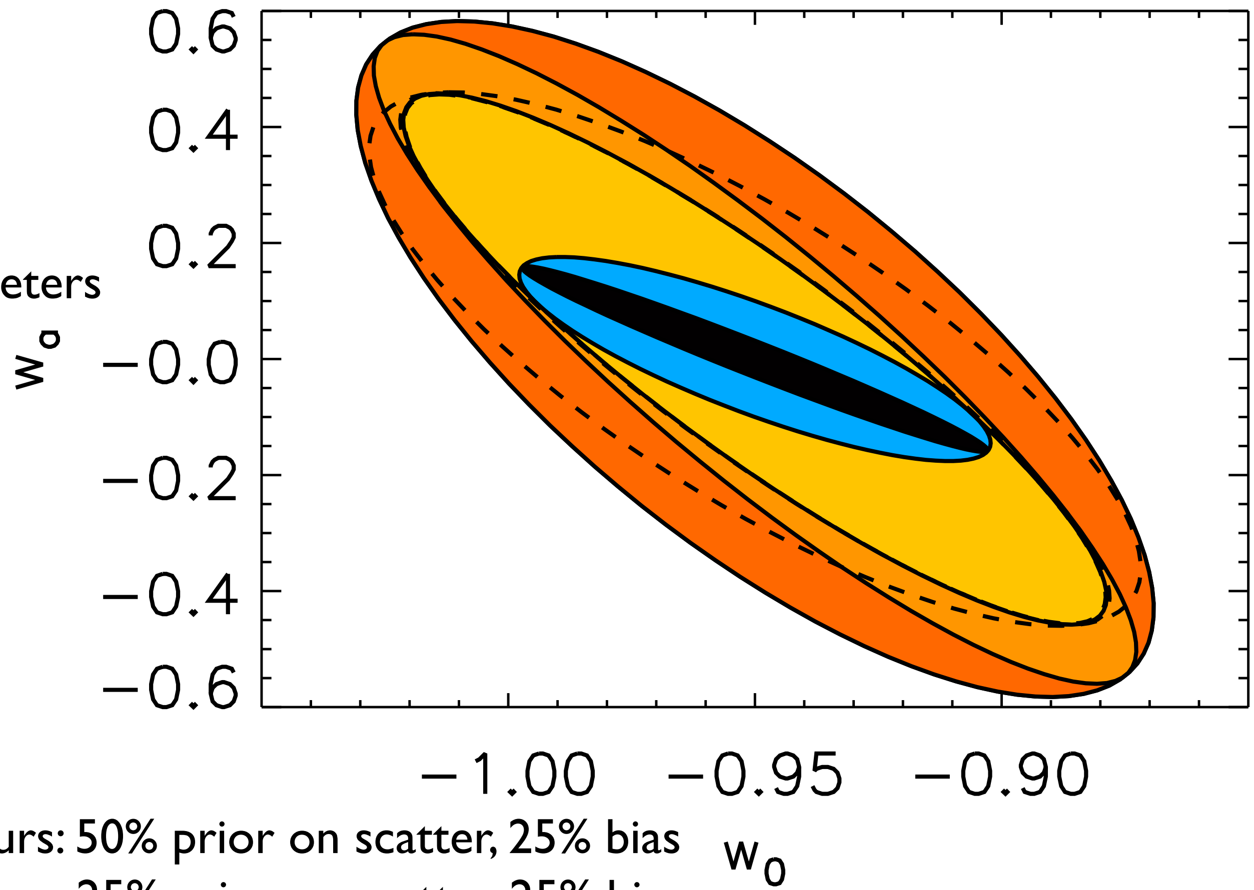




Including Planck priors and 5 cluster nuissance parameters; prior on scatter: 25%

Cosmology and Priors on the Mass – Observable Relation

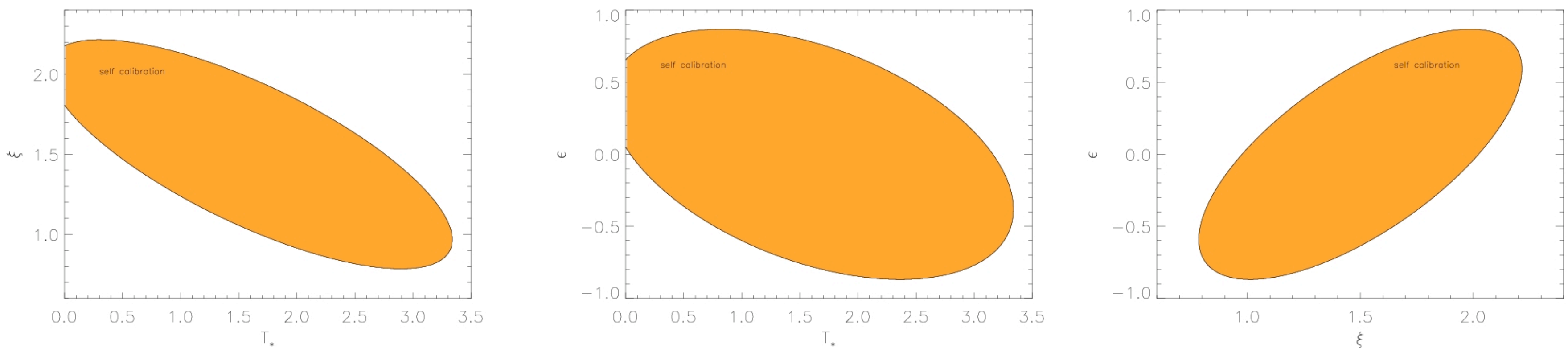
1,2 and 3
scatter parameters



orange contours: 50% prior on scatter, 25% bias
dashed contours: 25% prior on scatter, 25% bias
blue contour: fixed scatter
dark contour: fixed scatter and bias

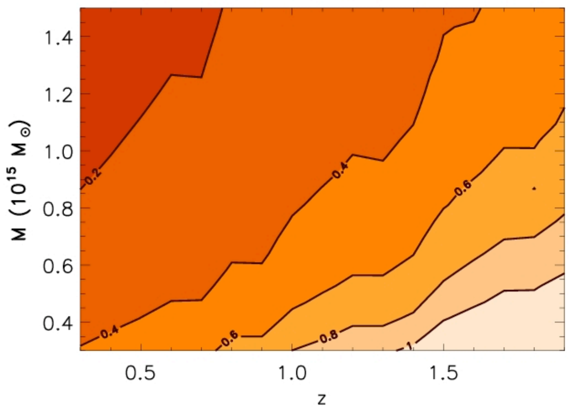
Self-Calibrate Uncertainty in Mass – Temperature Relation

- Relevant for SZ and x-ray surveys
- In addition to cosmological parameters fit for cluster parameters $T_* ; \xi ; \varepsilon$



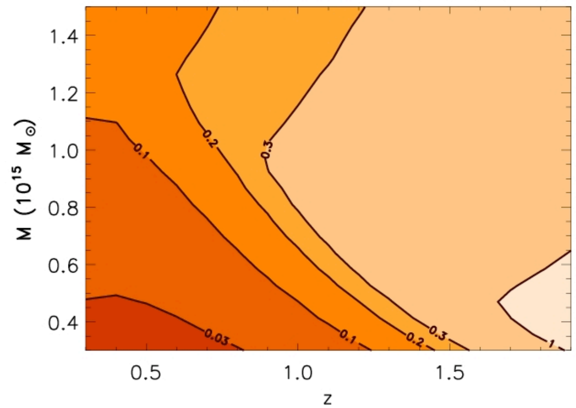
Weak Lensing Calibration of Mass - SZ Observable Relation

- Here simple estimate: 15 background (DES) galaxies/sq. arcmin
- Distribution: $dn/dz = \exp(-z/z_c)$; $z_c=0.5$



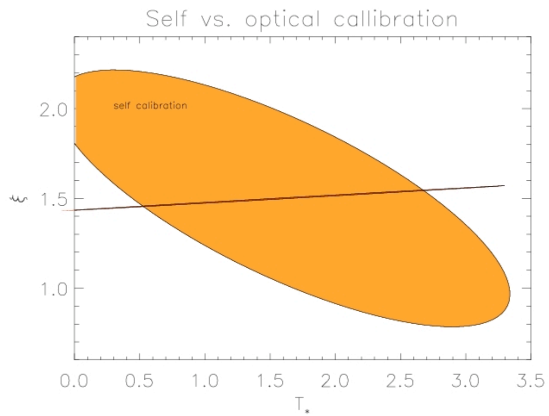
Projected errors on single cluster

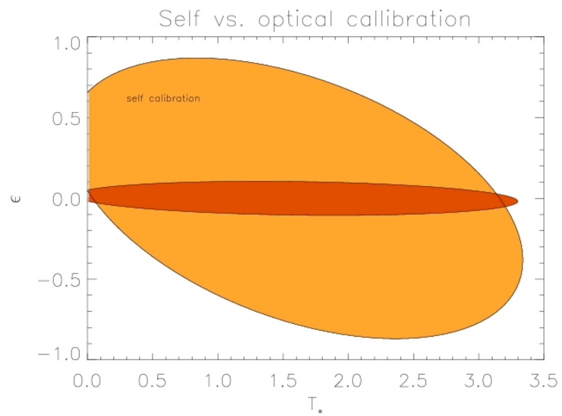
Dodelson & Weller: DES and SPT

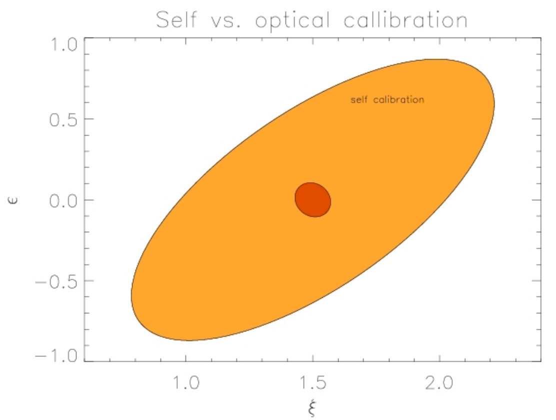


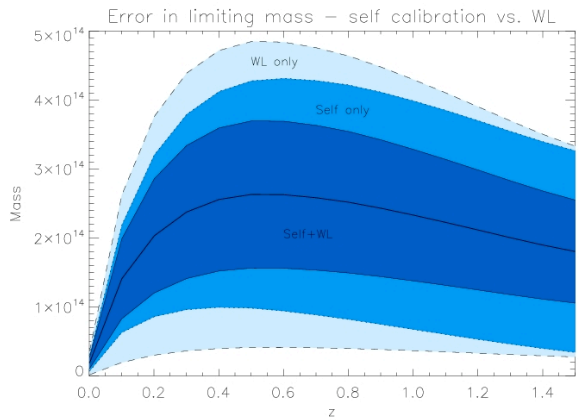
Fractional errors on cluster mass after stacking in redshift bins $\Delta z = 0.1$ and $\Delta M = 10^{14} M_\odot$

Weak Lensing Calibration

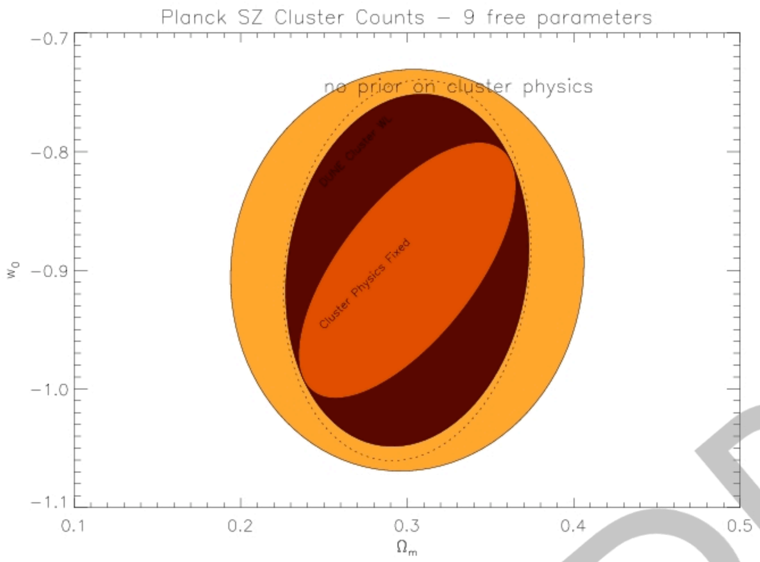


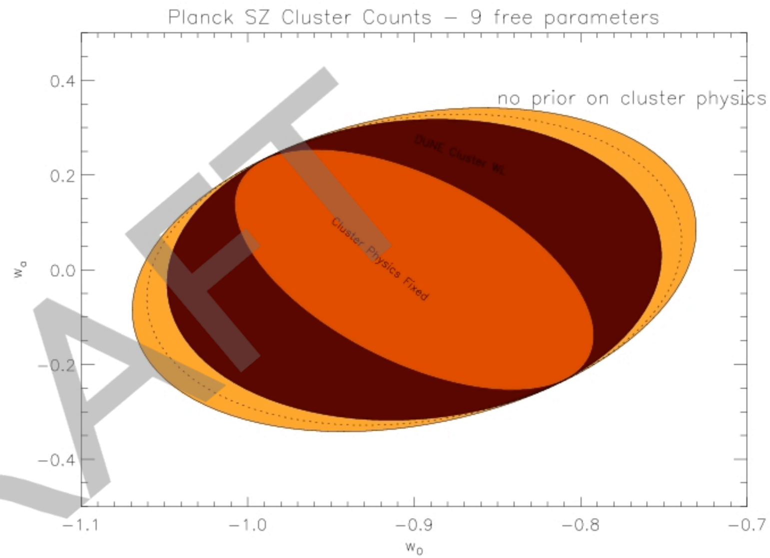






How can Euclid help Planck-SZ Clusters – *Very Preliminary !*





NO SCATTER; NO Planck Prior, see also Cunha et al., Wechsler et al.
But also vice versa: Improvement of FoM could be 50% from WL and x-ray

Conclusions

- EIS cluster counts complementary to primary science drivers
- sensitive in particular to modified gravity
- crucial to understand and control systematic, scatter and scaling
  - next step: simulations to understand selection and optimize method
  - lessons to be learned from surveys like DES
- in particular complementary to other full sky cluster probes
- ‘self-calibration together with Euclid Spectroscopic Survey !