Weighing the Giants : Weak Lensing and X-ray Studies of the most Massive Clusters

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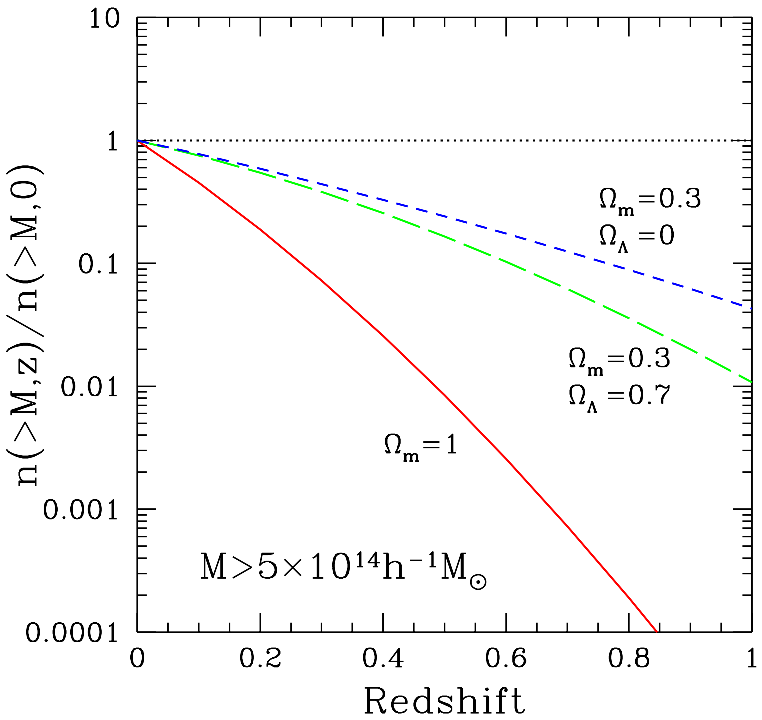
Cosmology with clusters



Rosati et al. 2002

- number of clusters $N(>M, z)$ sensitive to cosmology

$\longrightarrow$ cluster surveys promising cosmological probes

Mantz et al. 2008, 2010;
Vikhlinin et al. 2009; Rozo et al. 2010

- direct mass detection (weak lensing) too noisy
  (shear peak statistics?)
- cluster selection in X-rays, SZ, or optical more efficient, complete, pure

$\longrightarrow$ *but need to rely on mass proxies*

- mass proxies currently calibrated from hydrostatic mass estimates of relaxed clusters
- error budget (on σ_8) dominated by possible biases in hydrostatic masses
- need to reduce mass calibration uncertainty to $< 5\%$ for future cluster count experiments (e.g. eROSITA)
- currently: bias known to $\sim 10\%$ at $z \sim 0.25$

Mahdavi et al. 2007

- redshift evolution of bias?

Method

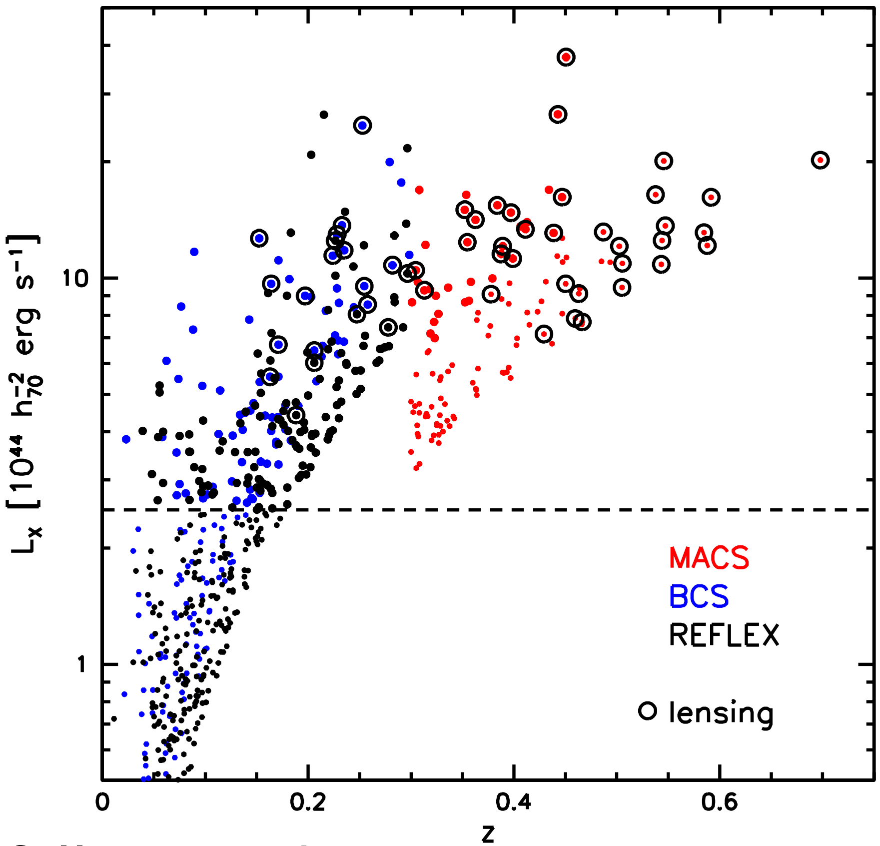
$\Rightarrow$ compare X-ray and weak lensing mass measurements of a large cluster sample

- X-ray mass measures:
  - $+$ some have very small scatter:
    gas mass, Y_X, core-excised luminosity / temperature
  - $-$ may be biased at the $5-10\%$ level

- weak lensing mass measures:
  - $+$ unbiased (if done right)
  - $-$ large scatter

CANNOT select on lensing properties

The Sample



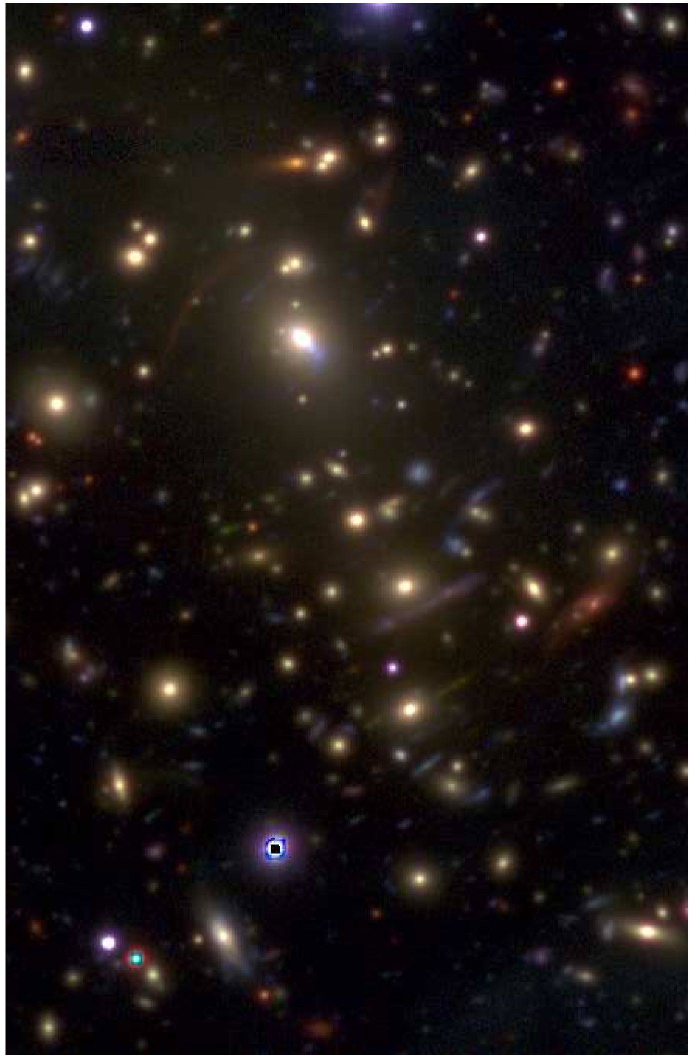
- massive, X-ray selected clusters used in cosmology analysis of
  Mantz et al. 2010abc, Rapetti et al. 2010
- MAssive Cluster Survey (MACS) at $z > 0.3$ (Ebeling et al. 2001,2007,2010)
- Bright Cluster Sample (BCS) at $z < 0.3$ (Ebeling et al. 1998)
- REFLEX at $z < 0.3$ (Böhringer et al. 2004)

follow-up data:

- optical multi-band imaging ($\sim$ 50 clusters)
  - SuprimeCam @ Subaru ($BVRIz$)
  - MegaPrime @ CFHT (u)
- Chandra X-ray imaging ($\sim$ 70 clusters)

Data challenges

- need accurate shape measurements and accurate photometry
- 5 generations of SuprimeCam configurations
- some of the issues:

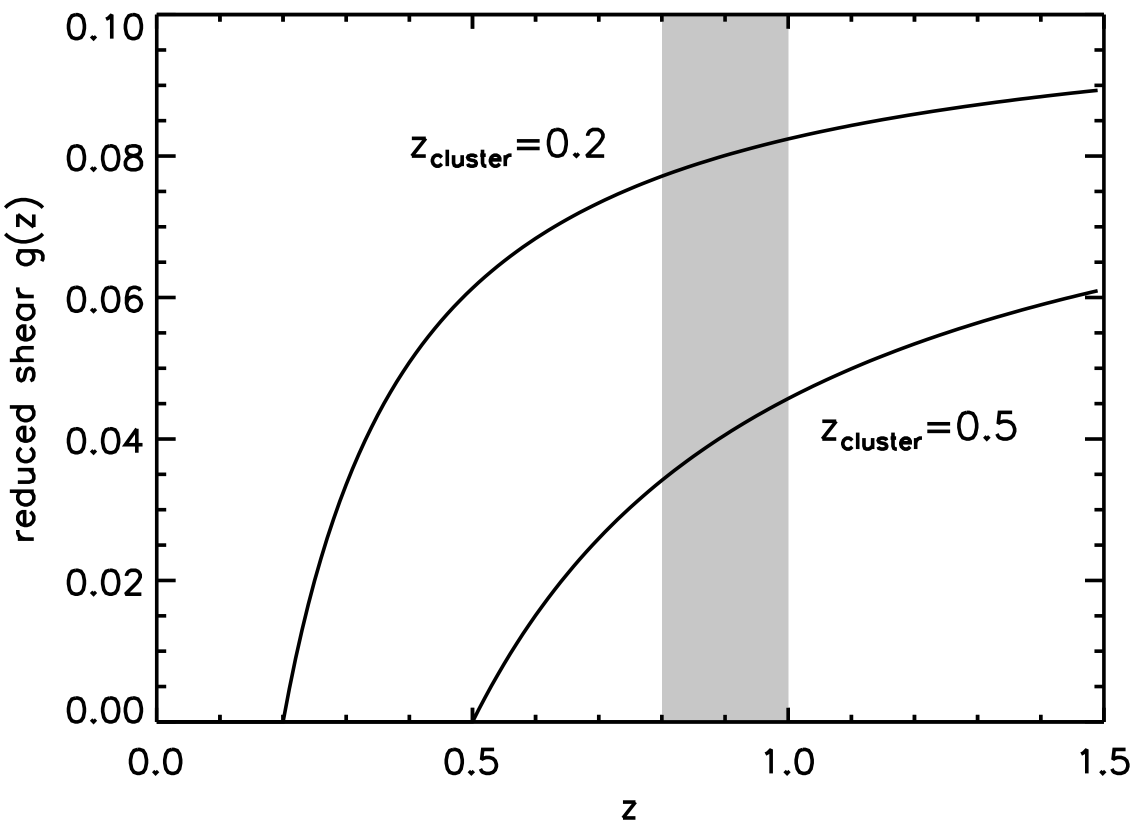


- scattered light correction
- non-linearity
- unstable flat-fields
- stellar halos/ghosts (and other artifacts)
- parts of a chip astrometrically offset (???)
- limited dynamic range
- non-square pixels
- ghosting
- CTE
- ...

Weak lensing: biases / scatter

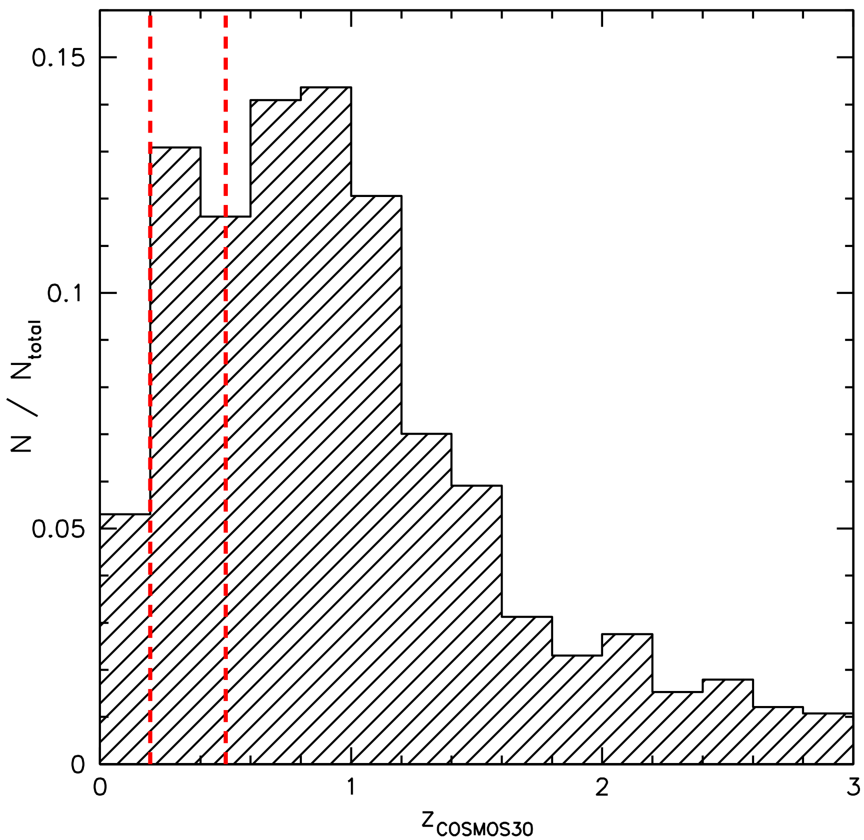
- substructure, triaxiality:
  $\longrightarrow$ cause scatter, but average mass unbiased $\surd$
  Clowe et al. 2004, Corless & King 2007, Meneghetti et al. 2010
- associated structures (two-halo term):
  $\longrightarrow$ cause scatter, deviation from one-halo at $r \gtrsim 5$Mpc $\surd$
  Johnston et al. 2007, Hilbert et al. 2009
- unassociated structures along line-of-sight:
  $\longrightarrow$ cause scatter, but average mass unbiased $\surd$
  Hoekstra 2003
- shear estimates:
  $\longrightarrow$ can be calibrated from Shear TEsting Program $\surd$
  Heymans et al. 2006, Massey et al. 2007
- redshifts of background sources:
  $\longrightarrow$ bias in z leads to bias in mass
  $\longrightarrow$ not accounting for shape of $p(z)$ can also lead to bias

Lensing by $z \sim 0.5$ clusters



- lensing signal small
- redshift errors $\rightarrow$ larger shear errors
- foreground contamination
- cluster area small $\rightarrow$ fewer background sources

Background redshift distribution



COSMOS-30 photo-z's

Ilbert et al. 2009

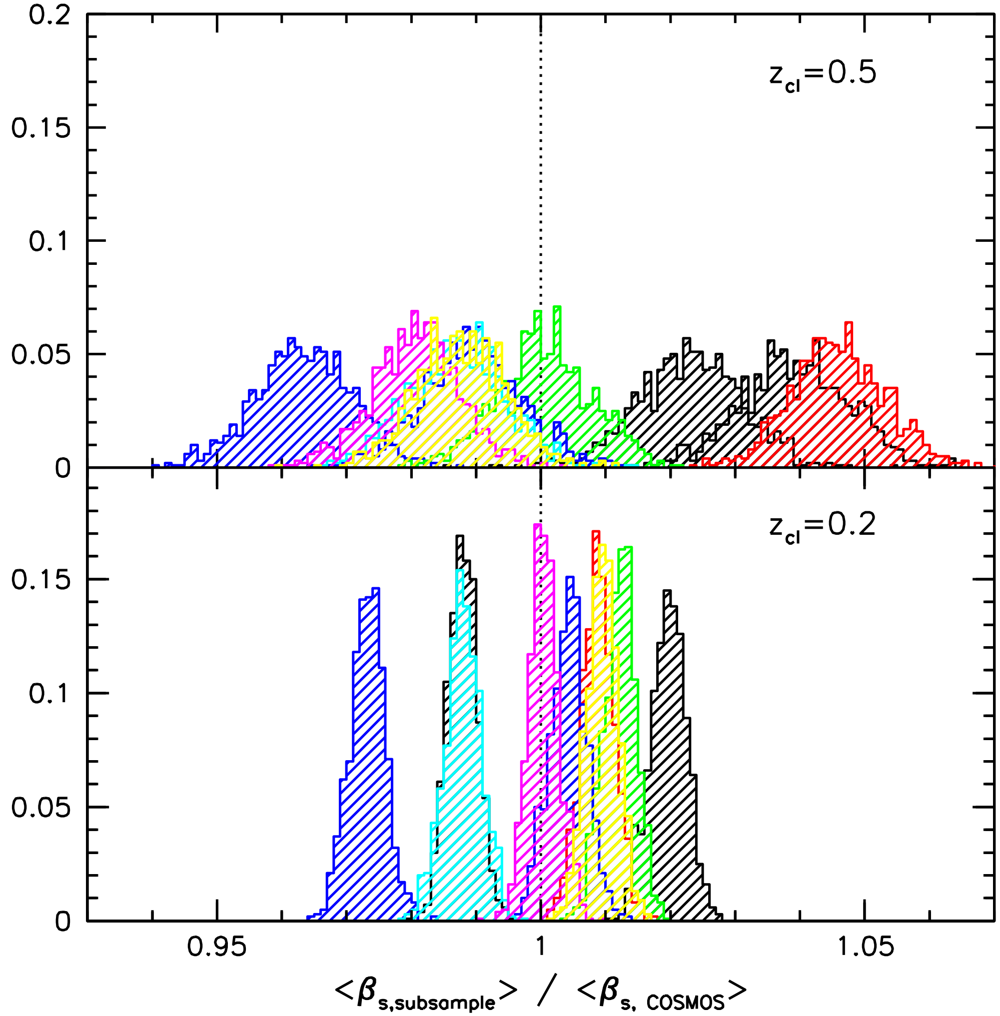
- to first order:

$$
\begin{aligned}
g(z) &\simeq \beta_s(z)\gamma_\infty \\
\beta_s(z) &= \beta(z)/\beta_\infty \\
\beta(z) &= \frac{D_{LS}}{D_S}
\end{aligned}
$$

- standard method: color cuts
- apply to cluster field and to standard deep field with good photo-z's
- assume $\langle\beta_s\rangle$ of standard field for cluster field

two effects:

- larger scatter in $\beta_{\mathrm{true}}/\beta_{\mathrm{assumed}}$ (think galaxy sample)
- cosmic variance: larger scatter in $\langle\beta_{\mathrm{true}}\rangle/\beta_{\mathrm{assumed}}$ (think cluster sample)



COSMOS-30: $\sim 3 \times 3$ SuprimeCam pointings

applied color cuts for 0.2 and 0.5 cluster

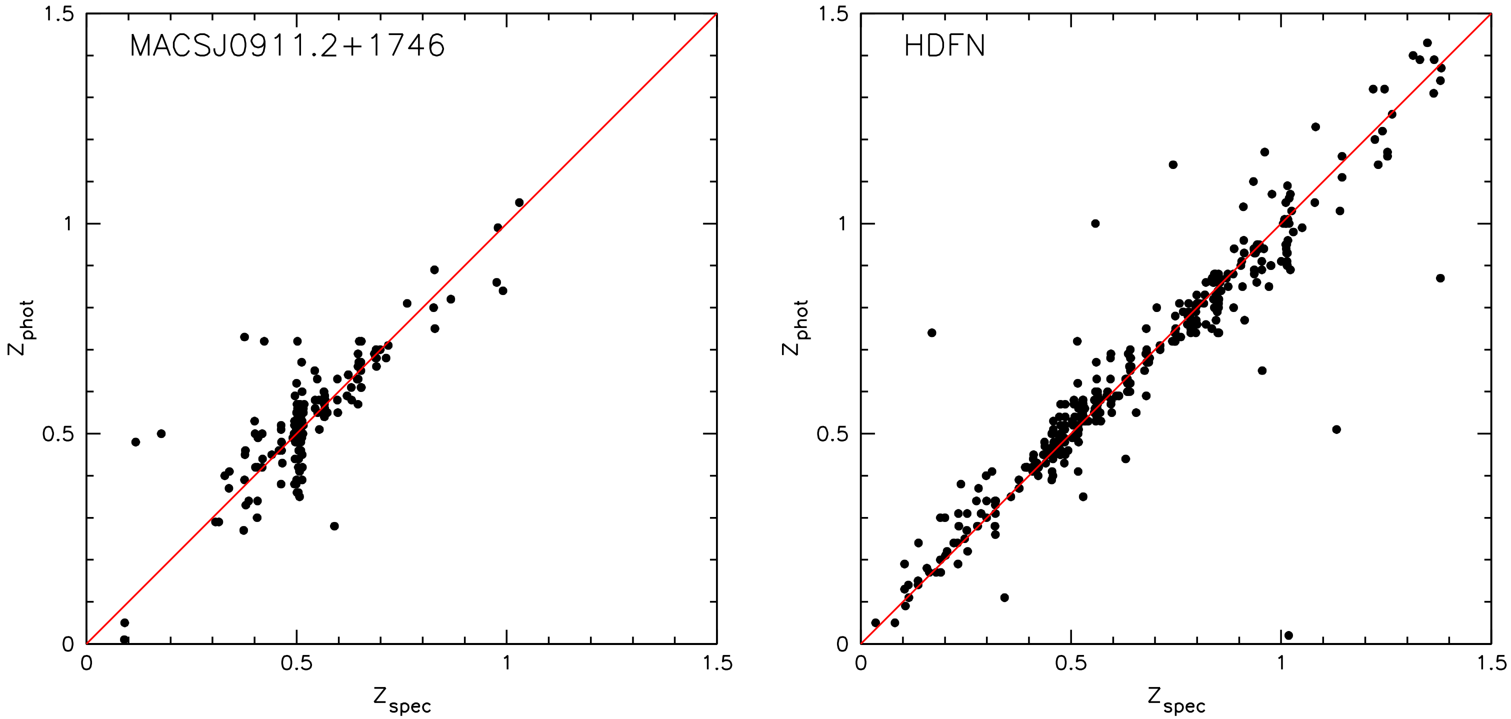
measure β_{assumed} on remaining 8 pointings

test variation of β_s in each pointing

(still too small to properly estimate cosmic variance)

Photometric redshifts

+ avoids scatter/bias from $\langle \beta_s \rangle$ assumption
+ evaluated per galaxy

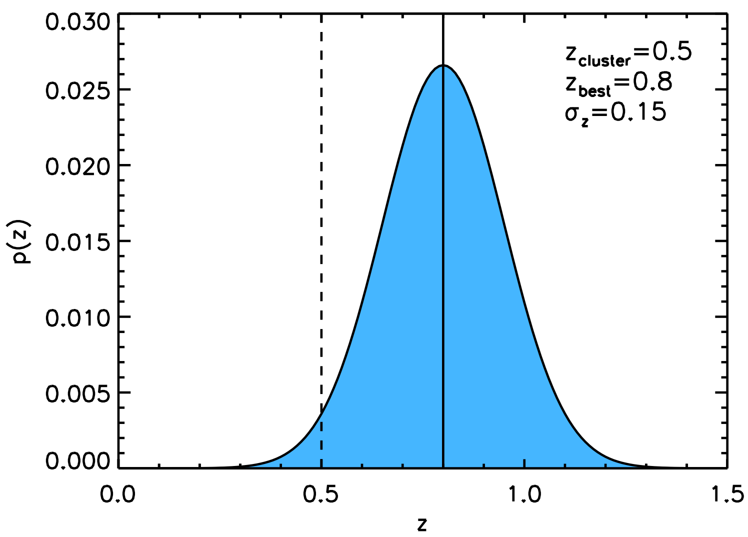


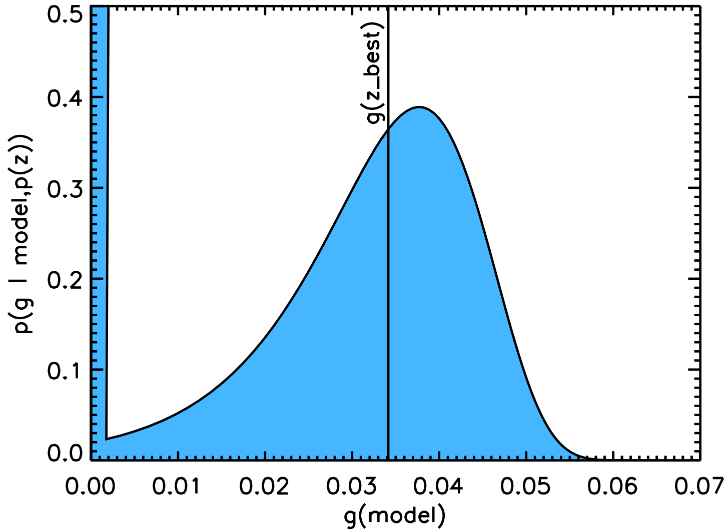
- $uBVRIz$ photometry; BPZ code (Benitez 2000)
- no training set (most clusters have little spectroscopic data)
- color calibration via stellar locus (High et al. 2009)
- one-point redshift estimate unbiased $\surd$

Photo-z errors

if we had $p(z)$ . . .

- $p(z)$ has finite width:
  - flux measurement errors
  - intrinsic width
  - template errors
  - prior
- even gaussian $p(z)$ are transformed to non-gaussian distributions of $g(z)$
- $p(z)$ generally not gaussian
- simple averaging or χ^2 minimization lead to bias
- need to account for full $p(z)$ distribution





Status of analysis

- goal: unbiased weak lensing masses of X-ray selected clusters
- as demonstrated: several small effects need to be taken into account
- "expected result" (consistency with previous, lower redshift samples)

$\longrightarrow$ "blind analysis", develop algorithms on mock clusters

- current question:
  - can we trust $p(z)$ returned by photo-z code?
  - if not, can we improve them empirically?

Summary

- future cluster count experiments require mass proxies calibrated to $< 5\%$ bias
- only observational method: weak lensing mass measurements (unbiased, large scatter) of large cluster samples (possibly biased masses, no scatter)
- this sample: redshift (and mass) range of current and future cluster count experiments
- complementary to low-redshift studies (CCCP, LoCuSS)

- with increasing cluster redshift:
  - source redshifts ever more important
  - color cuts very noisy
  - photo-z's promising way forward, but need to understand errors