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

Anja von der Linden

KIPAC / Stanford

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Motivation

- clusters of galaxies are excellent cosmological probes

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

- particularly sensitive to σ_8

- cluster count experiments require a mass-observable relation
  $\longrightarrow$ currently calibrated from hydrostatic mass estimates

- 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

$\Rightarrow$ **calibrate X-ray mass measurements (small scatter, possible bias)**
using weak lensing masses (large scatter, unbiased)

The Team

Optical:

Anja von der Linden (KIPAC)

Doug Applegate (KIPAC)

Pat Kelly (KIPAC)

Mark Allen (KIPAC)

Maruša Bradač (UC Davis)

X-rays:

Steve Allen (KIPAC)

Harald Ebeling (Hawaii)

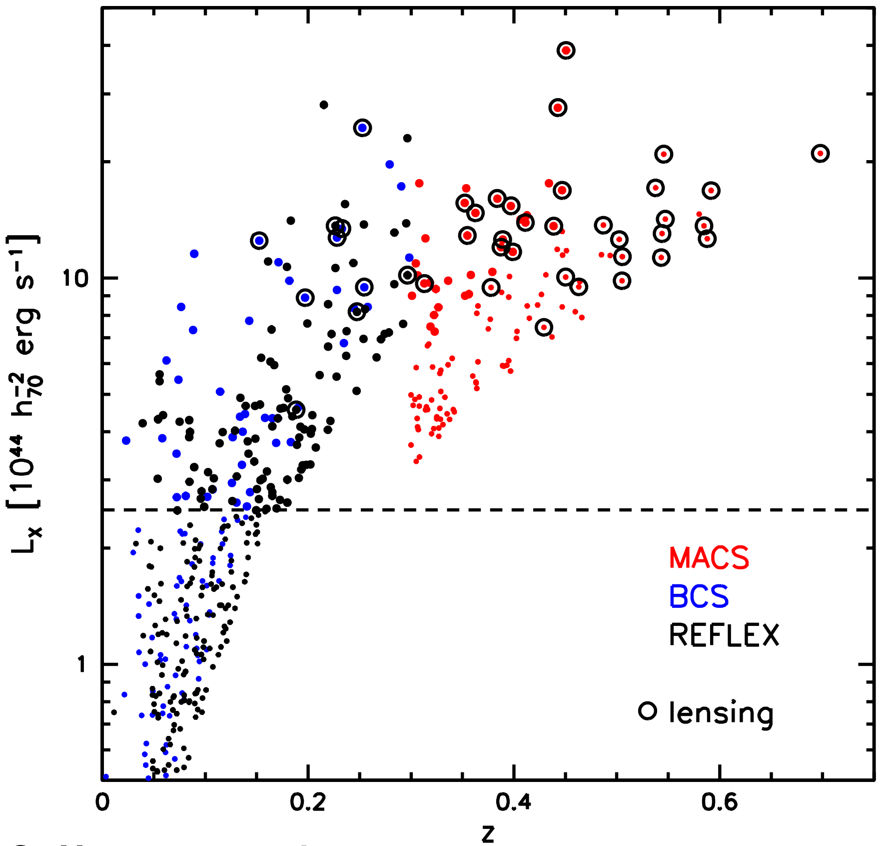
Glenn Morris (KIPAC)

Cosmology:

Adam Mantz (KIPAC; Goddard)

David Rapetti (KIPAC)

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:

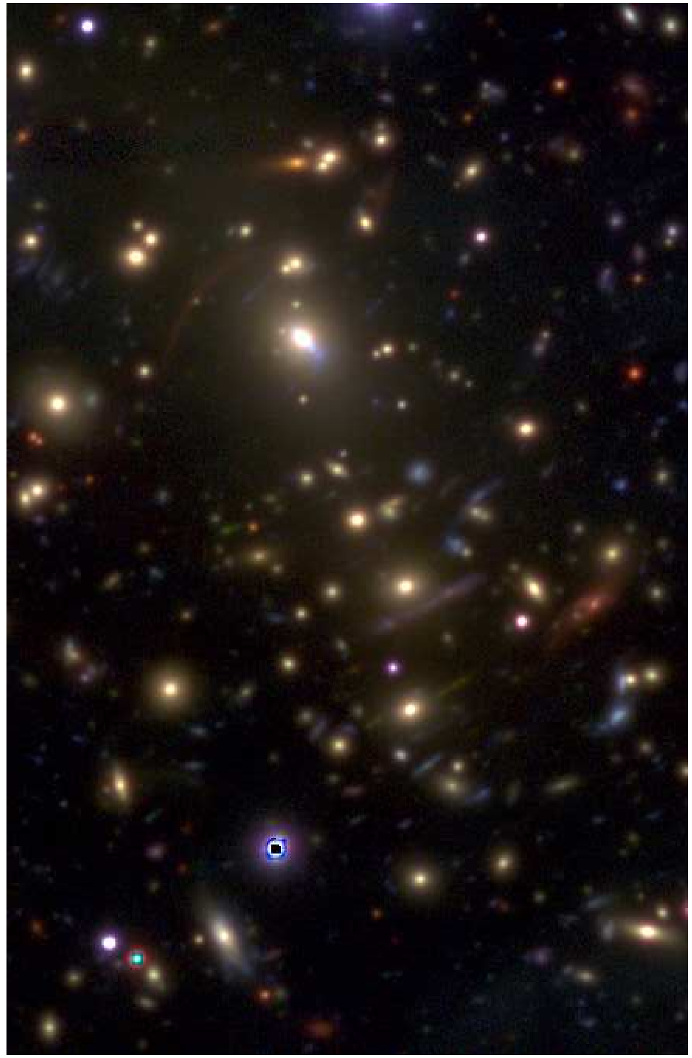
- optical multi-band imaging ($\sim$ 50 clusters)
  - SuprimeCam @ Subaru ($BVRIz$)
  - MegaPrime @ CFHT (u)
- Chandra X-ray imaging ($\sim$ 70 clusters)

Data challenges

- 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
- ...



X-ray masses: gas mass

for massive clusters ($kT_{2500} > 5$ keV):

- gas mass fraction ($f_{\rm gas}$) is constant with mass and redshift

  Allen et al. 2008

- $f_{\rm gas}$ has minimal scatter
  - ⋆ relaxed clusters:

    observationally: scatter undetected $< 5\%$

    Allen et al. 2008

    simulations: gas mass unbiased ($< 1\%$), scatter $\lesssim 3\%$

    Nagai et al. 2007

  - ⋆ in unrelaxed clusters:

    simulations: bias $\lesssim 6\%$, scatter $\lesssim 10\%$

    Nagai et al. 2007

- $M_{\rm gas}$ easier to measure than T, $Y_{\rm x} = M_{\rm gas} kT$

Weak lensing: biases / scatter

- substructure, triaxiality:
  $\longrightarrow$ cause scatter, but average mass unbiased $\surd$
  Clowe et al. 2004, Corless & King 2007
- associated structures (two-halo term):
  $\longrightarrow$ cause scatter, deviation from one-halo at $r \gtrsim 5$Mpc $\surd$
  Johnston et al. 2007
- 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 $p(z)$ leads to bias in mass
  $\longrightarrow$ not accounting for shape of $p(z)$ also leads to bias

Method take-away points

- X-ray mass measures:
  - + (some) have very small scatter
  - − may be biased at the $5-10\%$ level

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

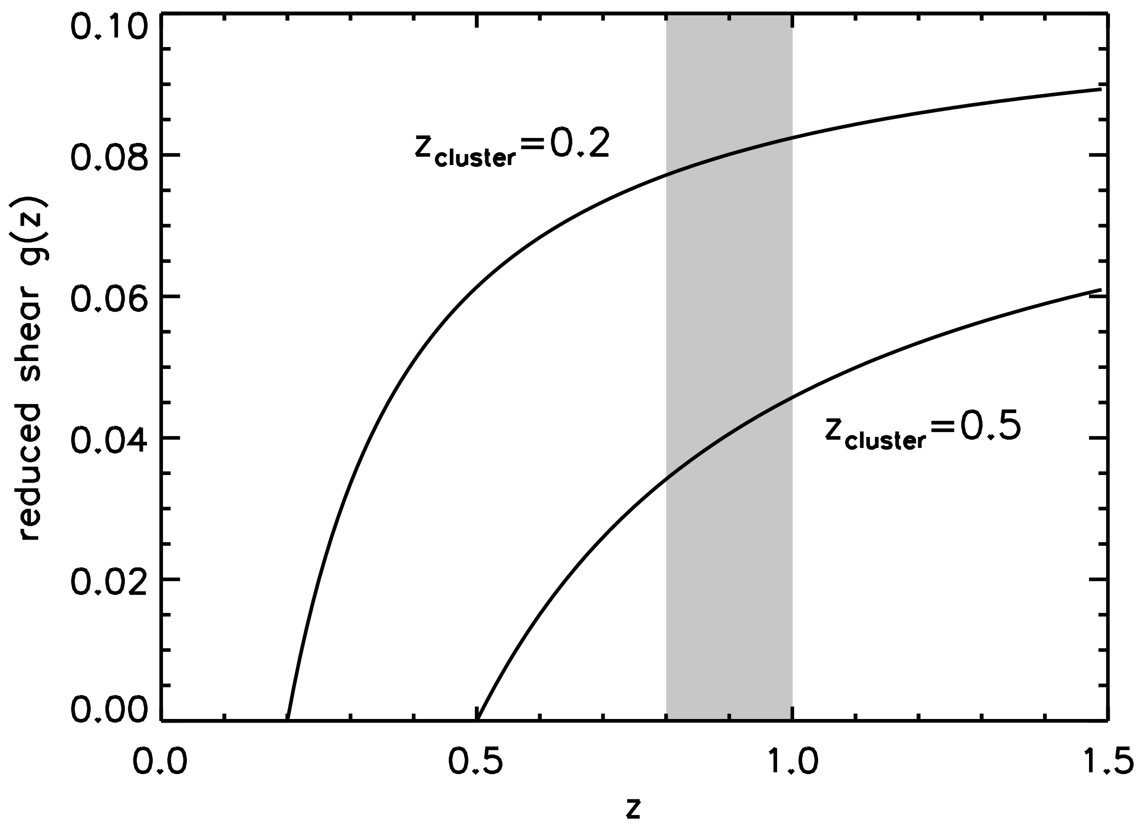
⇒ compare X-ray and weak lensing mass measurements of a large cluster sample

CANNOT select on lensing properties

- redshift (and mass) range of current and future cluster count experiments
- complementary to low-redshift studies (CCCP, LoCuSS)

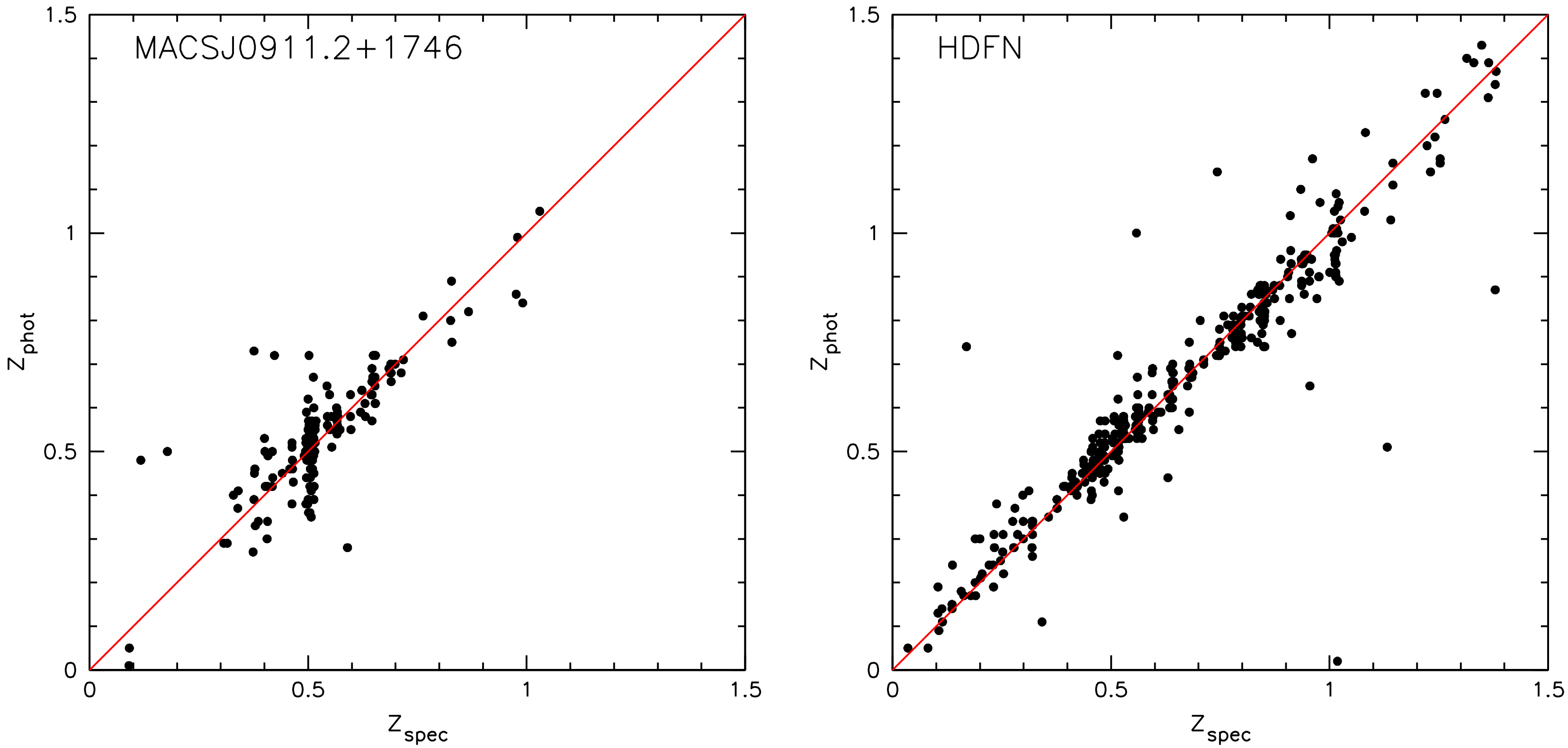
"Issues with cluster mass measurements"

. . . for lensing by intermediate-redshift clusters



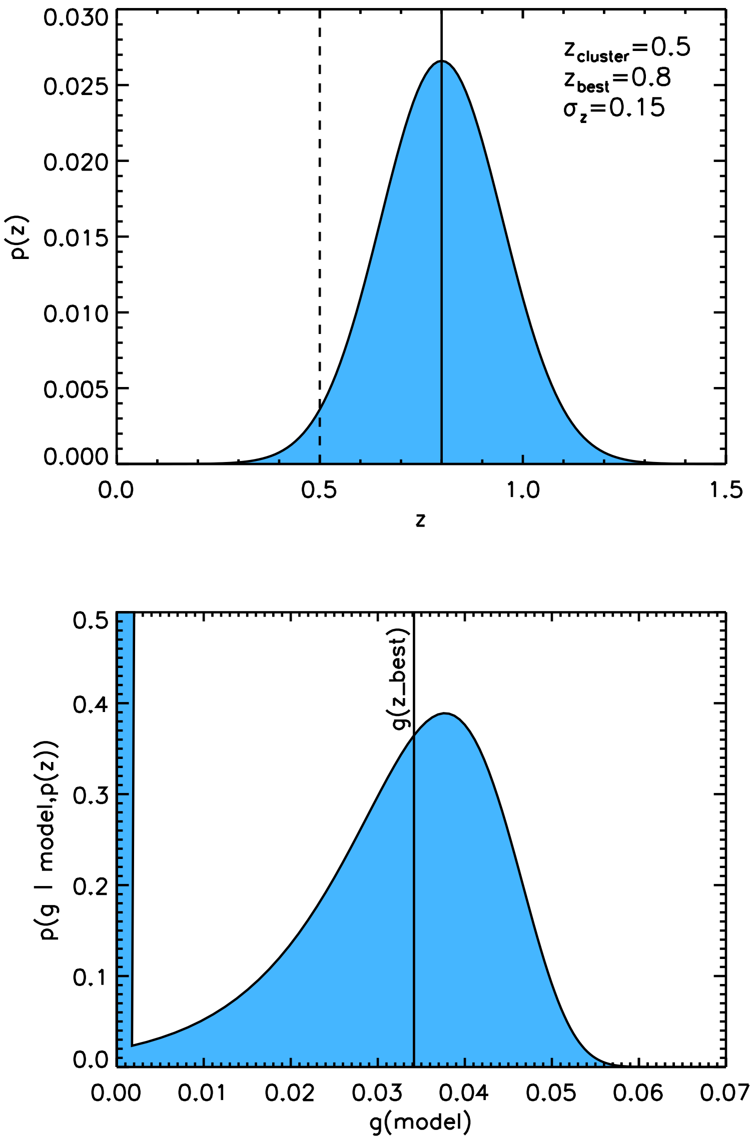
- lensing signal small
- redshift errors $\rightarrow$ larger shear errors
- foreground contamination
- cluster area small $\rightarrow$ fewer background sources

Photometric redshifts



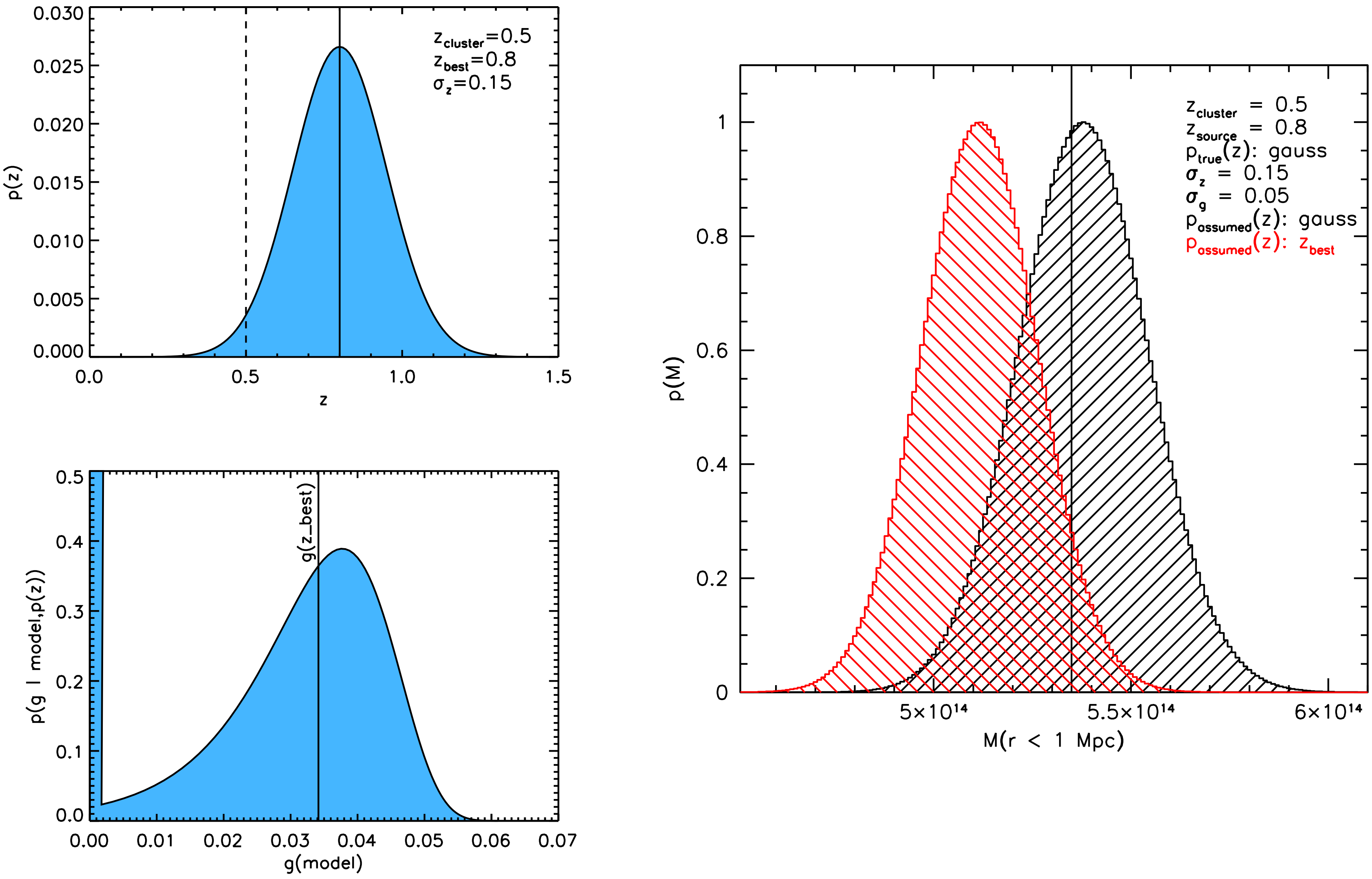
- $uBVRIz$ photometry; BPZ code (Benitez 2000)
- no training set (most clusters have little spectroscopic data)
- color calibration via stellar locus (High et al. 2009)

Photo-z probability distributions



- 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 biased mass
- need to account for full $p(z)$ distribution

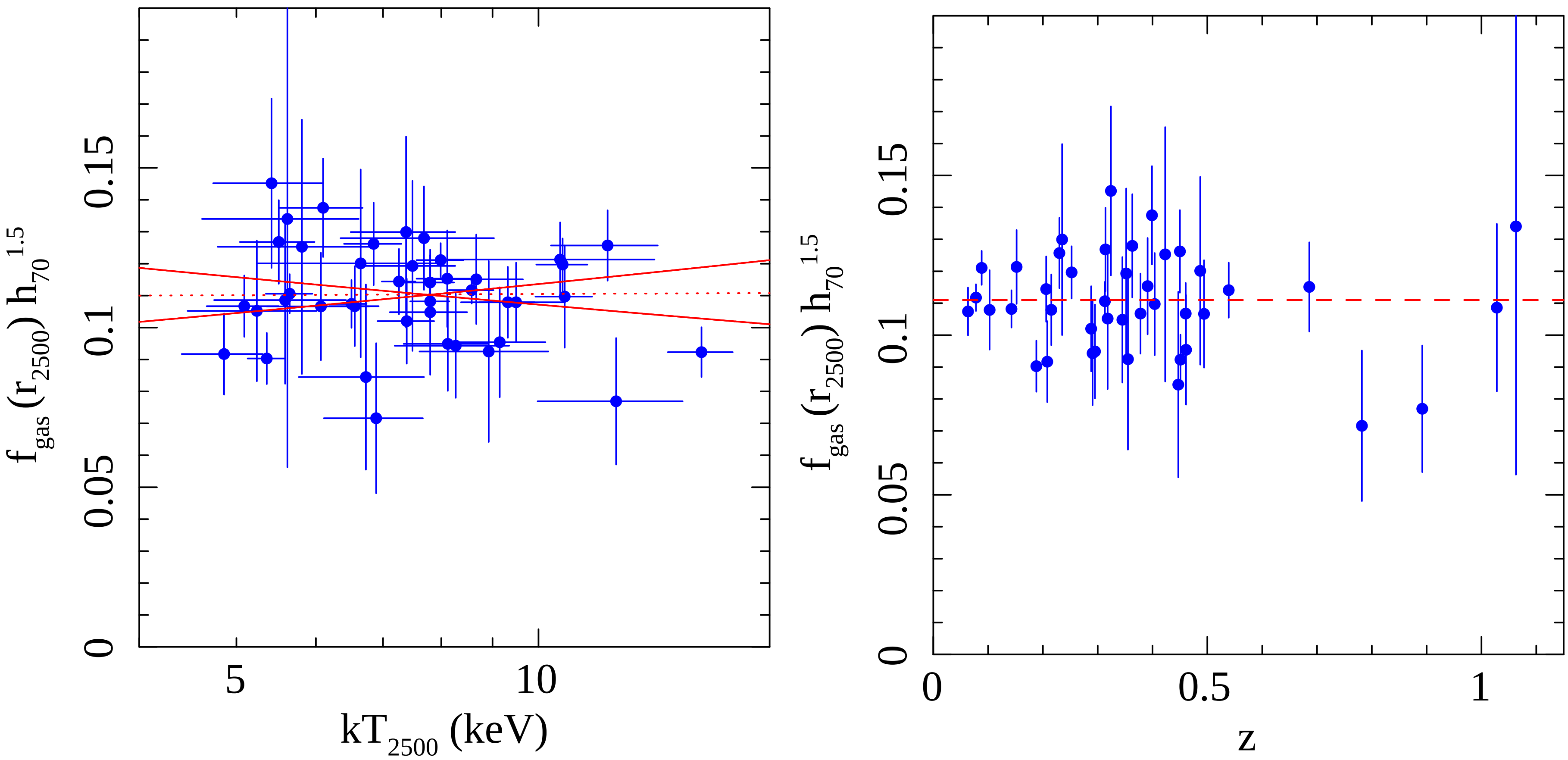
Photo-z probability distributions



So where's the plot?

- ($M_{\rm X}$ vs. $M_{\rm WL}$)
- "blind analysis":
  - several small effects (sources of bias) need to be included (e.g. error on $p(z)$)
  - develop mass estimation algorithm on mock clusters
  - not "de-blinded" yet

- stay tuned!


$f_{gas}(r_{2500})\,h_{70}^{1.5}$
0
0.05
0.1
0.15
5
10
kT_{2500} (keV)
$f_{gas}(r_{2500})\,h_{70}^{1.5}$
0
0.05
0.1
0.15
0
0.5
1
z