Defining the Issues: Clusters

James G. Bartlett

APC - Université Paris Diderot
&
Jet Propulsion Laboratory, California Institute of Technology

First Paris-Berkeley Dark Energy Workshop 14-18 September, 2009

Clusters

- Clusters are one of the primary DETF dark energy probes
- Growth of structure
  - Dynamical test of dark energy
  - Tests gravity (e.g., γ_g)
- Volume element
  - Geometrical test of dark energy

Surveys: millimeter (SZ), Optical/IR, X-ray

Vantage Point

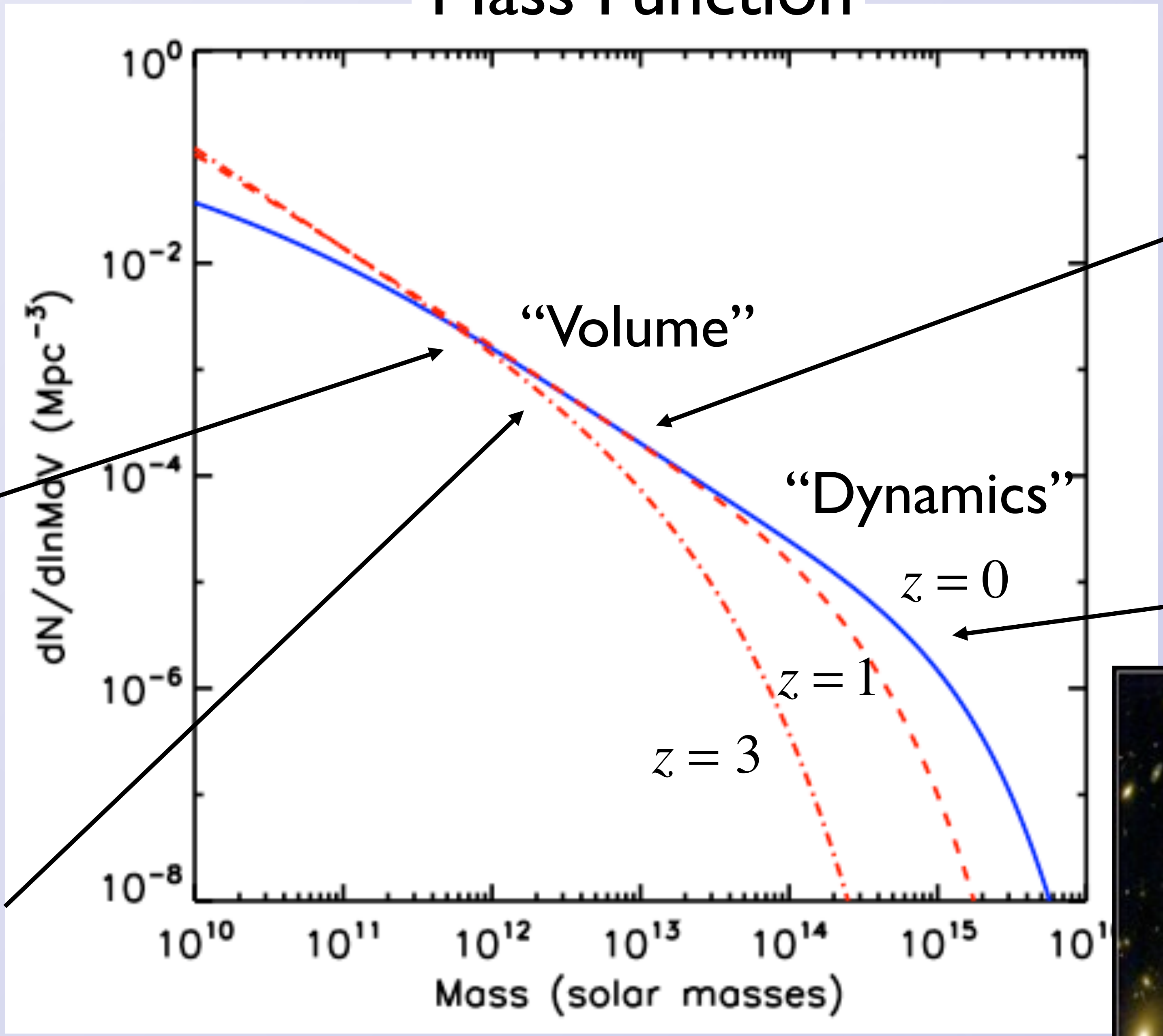
- Clusters are astrophysical objects (like others) whose ultimate quantitative utility depends on how many parameters are needed to standardize them for cosmological studies.
- This is the focal point from which emanate the many of the key issues that we will discuss.
- The ultimate answer is a point of fundamental research

The Method

Halo Mass Spectrum

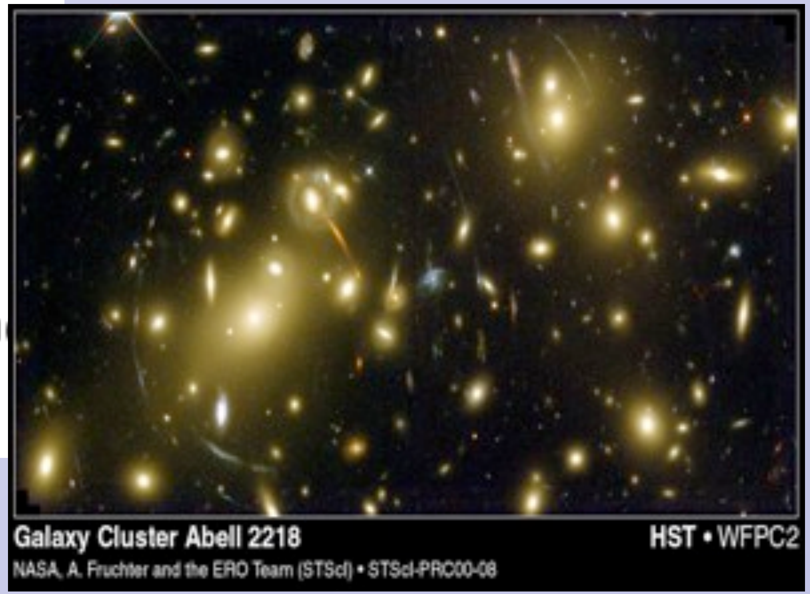
Galaxies
<~10^{12}

Mass Function



Groups ~ 10^{12}-10^{14}

Clusters >10^{14}



Clusters as a DE Probe

Abundance evolution ("the counts")

Catalog of detected clusters (dark matter halos) with $M > M_{det}$

ID	z	M
...	...	...
...	...	...

Geometry

$$\frac{dN}{dz\,d\ln M} = \frac{dV}{dz}\frac{dn}{d\ln M}(M,z)$$

Mass function: growth

➡Dark matter sector understood

➡Mass function well-modeled by N-body simulations (e.g., Jenkins et al. (2001) - Millennium Simulation)

Clusters as DE Probe

More generally, we observe a mass proxy M_o and must deal with:

Θ_C =Cosmological parameters

Θ_N =Cluster & other *nuisance* parameters

$$\frac{dN}{dz dM_o} = \Psi(M_o, z; \Theta_N) \frac{dV}{dz}(z; \Theta_C) \int d\ln M \, P(M_o | M, z; \Theta_N) \frac{dn}{d\ln M}(M, z; \Theta_C) + \left.\frac{dN}{dz dM_o}\right|_{contamination}$$

Selection function

- Completeness

➡Convolution with observable-mass relation

➡Distribution of what we observe in terms of mass (what we want!)

4 Critical Issues

- 2 Surveying issues - depend on cluster detection technique

1. Selection function (sample completeness)
2. Contamination by false detections

- Mass measurement - depends on chosen mass proxy

3. M_o-*Mass* relation = probability distribution

- Redshifts

4. Follow-up (SZ, X-ray); photo-z errors (optical/IR)

Sources of Systematics

- Instrumental effects
  - e.g., foregrounds (SZ), PSF (X-ray), etc.
- Algorithms
  - e.g., detection methods: matched filters, wavelets, ...
- Astrophysics
  - e.g., observable-mass relation and its evolution

Quantified by nuisance parameters Θ_N

General Approach

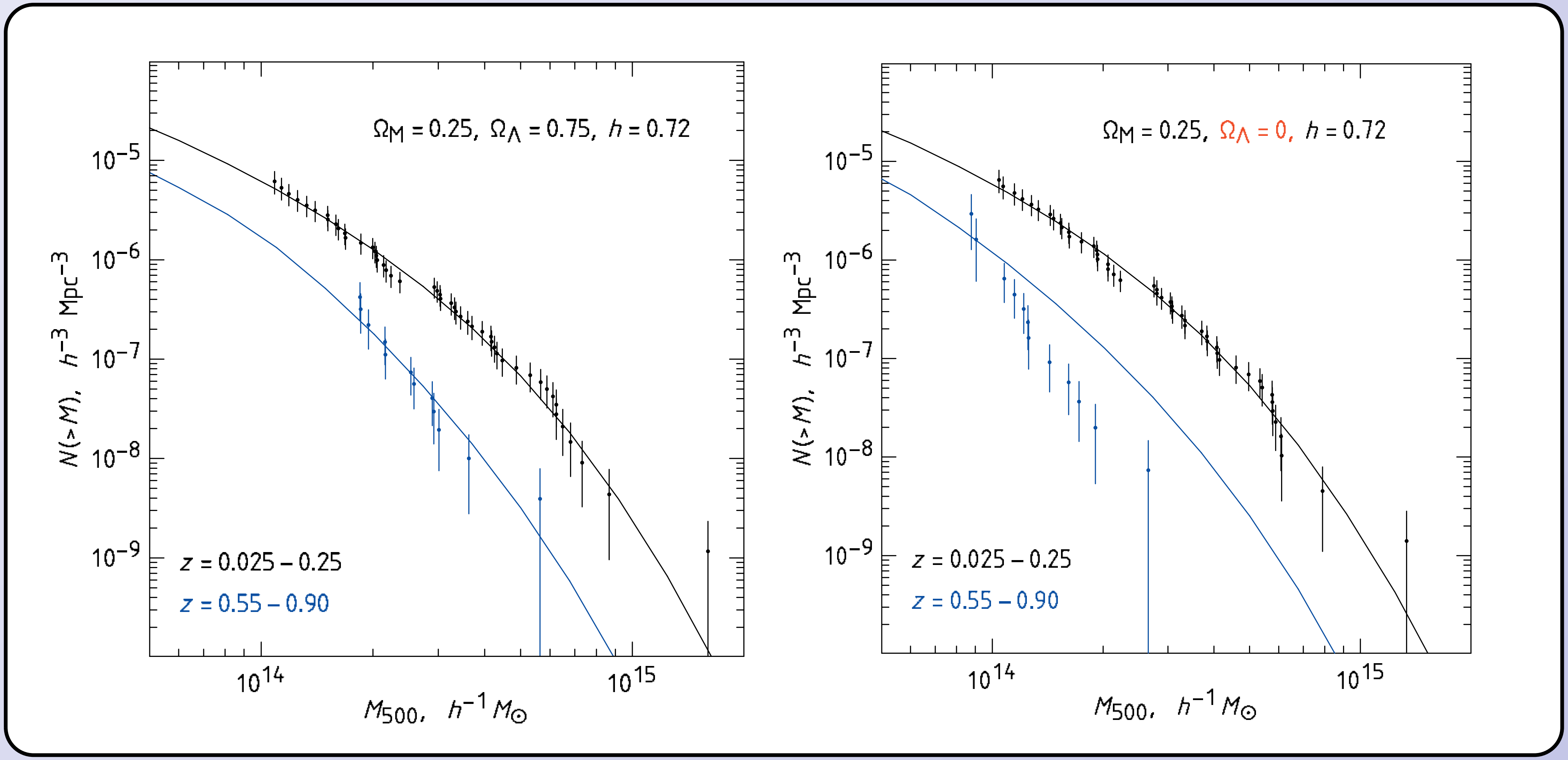
- Choose cluster catalog construction method
  - ➡ Identify nuisance parameters Θ_N, informed by theory & simulation: selection function, contamination, P
  - ➡ Use additional observations to put priors on nuisance parameters (e.g., shear mass measurements, galaxy clustering)
    - ➡ Calibration with external data sets
  - ➡ Fit observed cluster distribution and to estimate cosmological and nuisance parameters, Θ_N & Θ_C, simultaneously
    - ➡ Self-calibration (e.g., Lima & Hu 2004, 2005, Majumbdar & Mohr 2004)

State-of-the-Art: example

400 sq. deg. survey: Burenin et al. 2007, Vihklinin et al. 2009a,b

ROSAT clusters re-observed in detail with Chandra to get good mass proxy measurements. Two redshift bins:

- <z>=0.05, 49 clusters from RASS
- <z>=0.55, 37 clusters from PSPC pointings (400 sq deg).

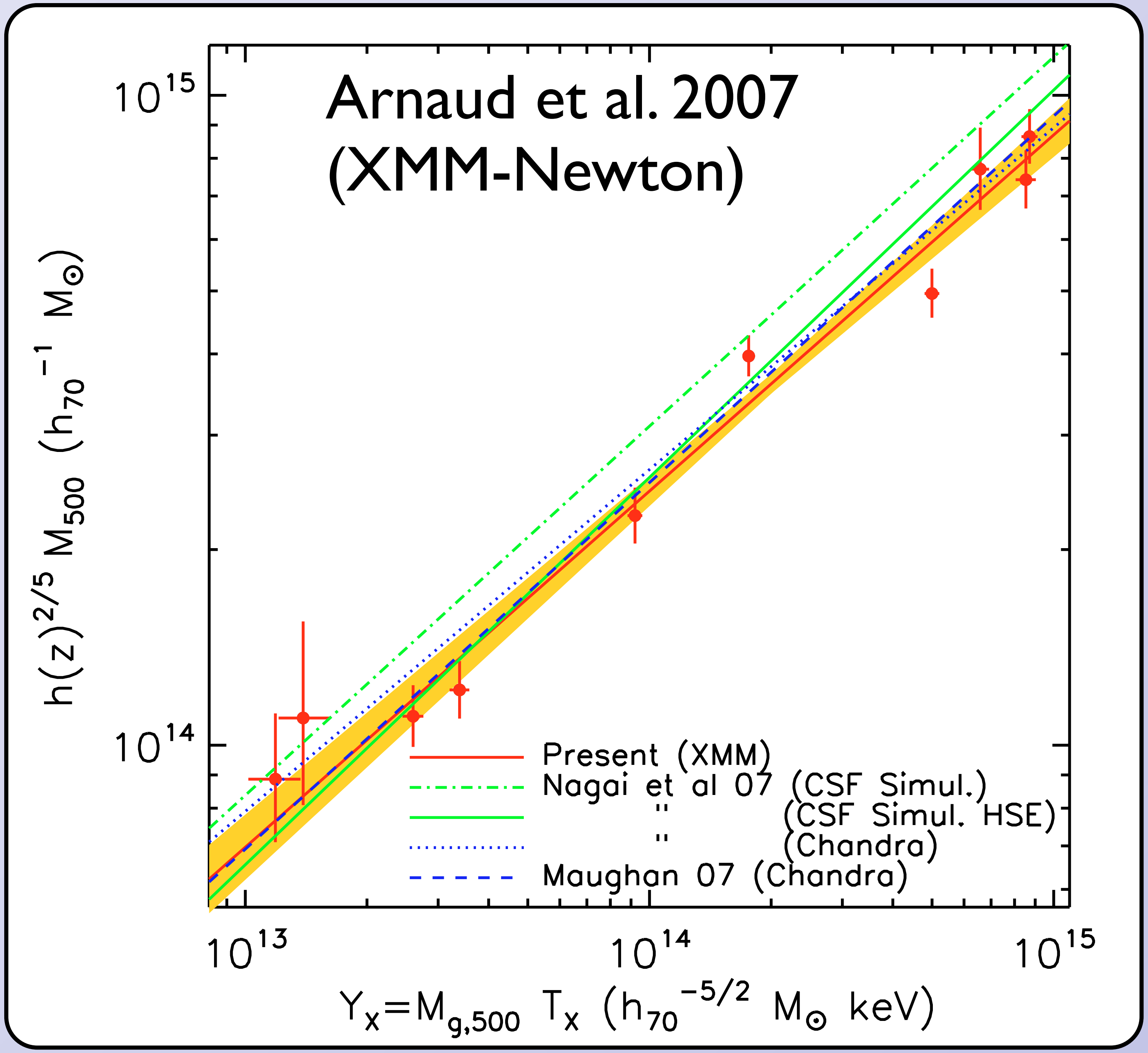


The Best We Have Now: Y_X-Mass

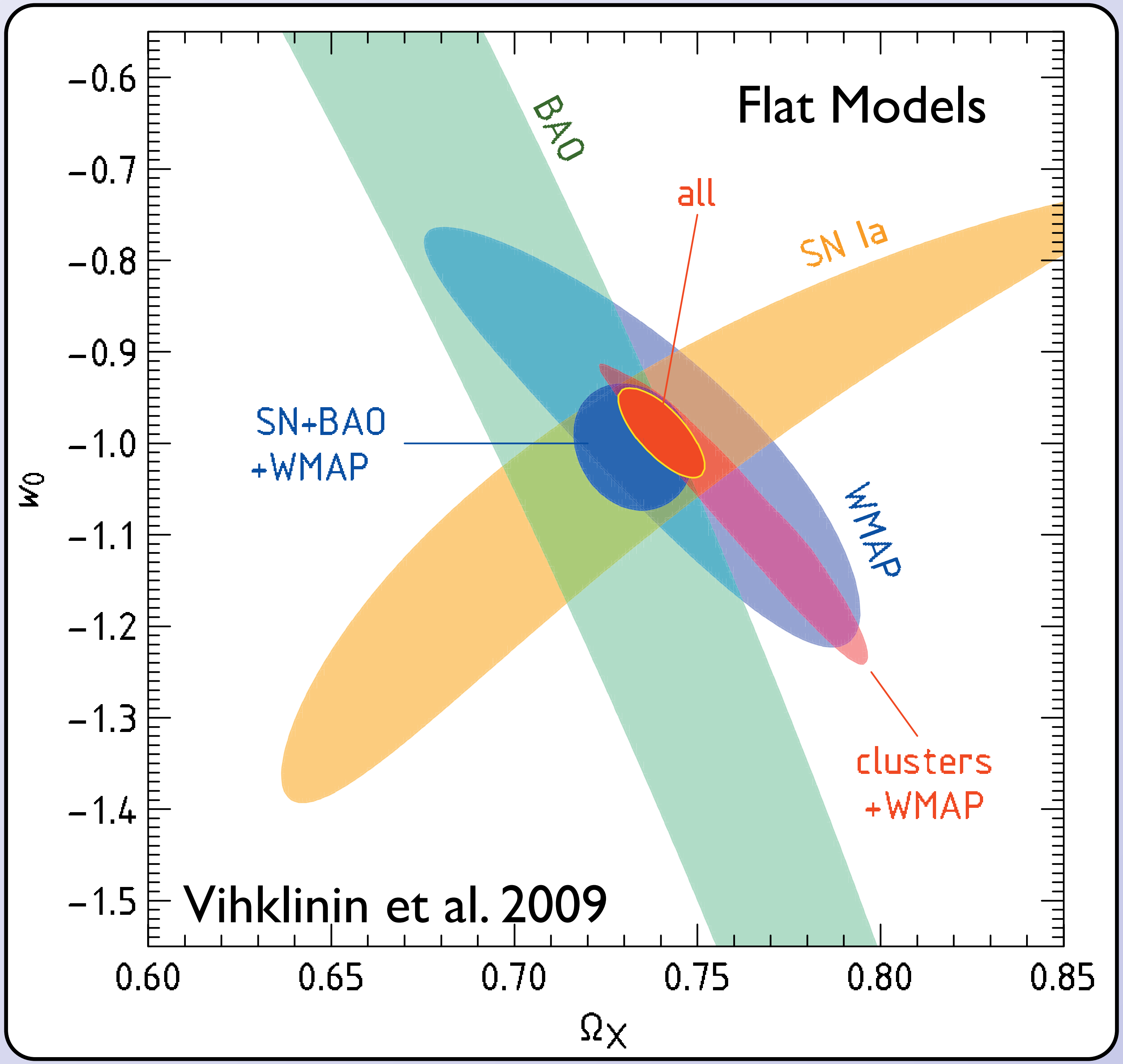
Kravstov et al. 2006, Nagai et al. 2007, Arnaud et al. 2007

$$Y_X = M_{gas} T_X$$

$$\sigma_M \leq 10\%$$



Cosmological Constraints

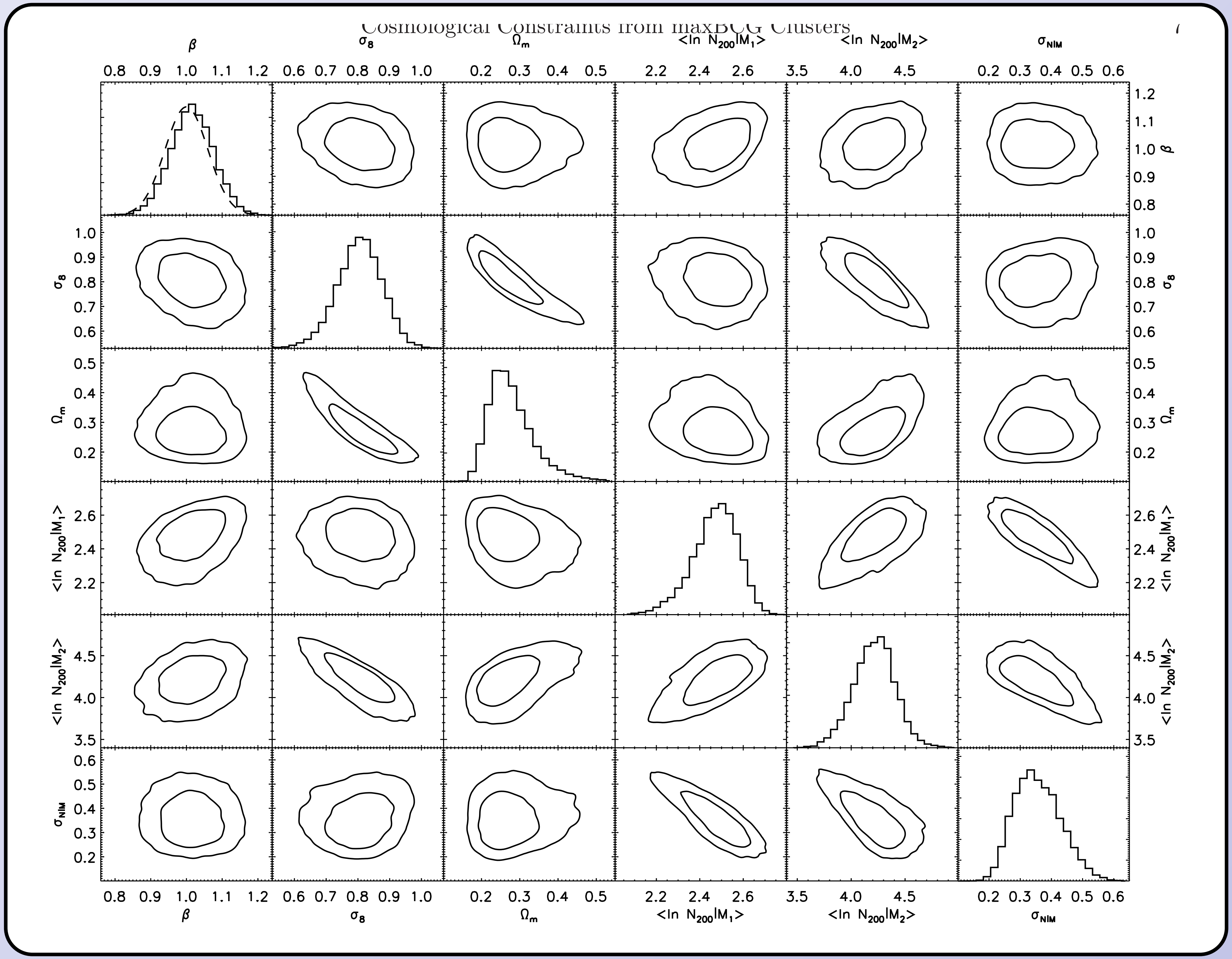


State-of-the-Art: example

MaxBCG: color-selected clusters in SDSS

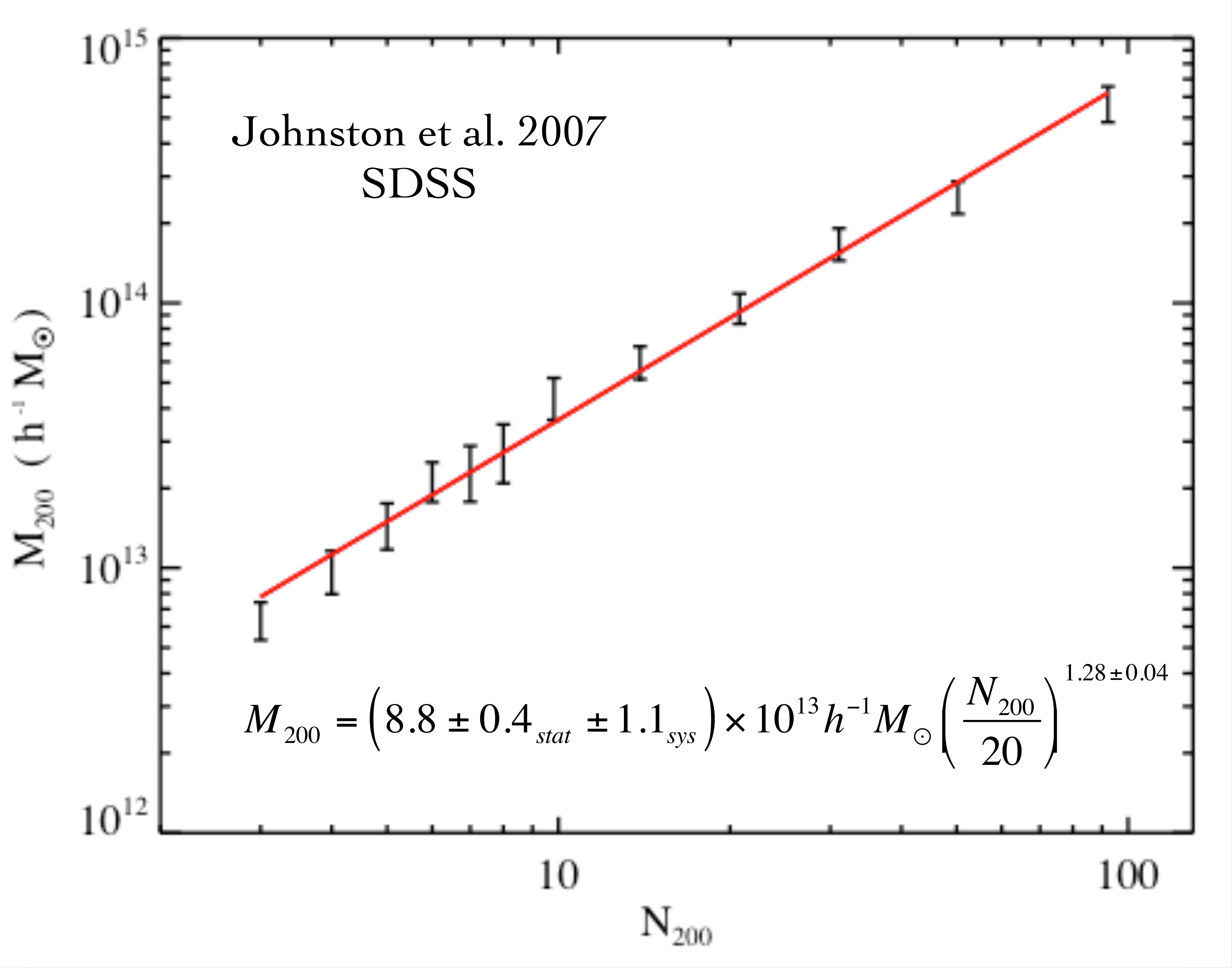
~14,000 clusters
0.1<z<0.3
6 parameters:
- 2 cosmo
- 4 cluster

Simultaneous fit to counts and lensing data (Johnston et al. 2007)



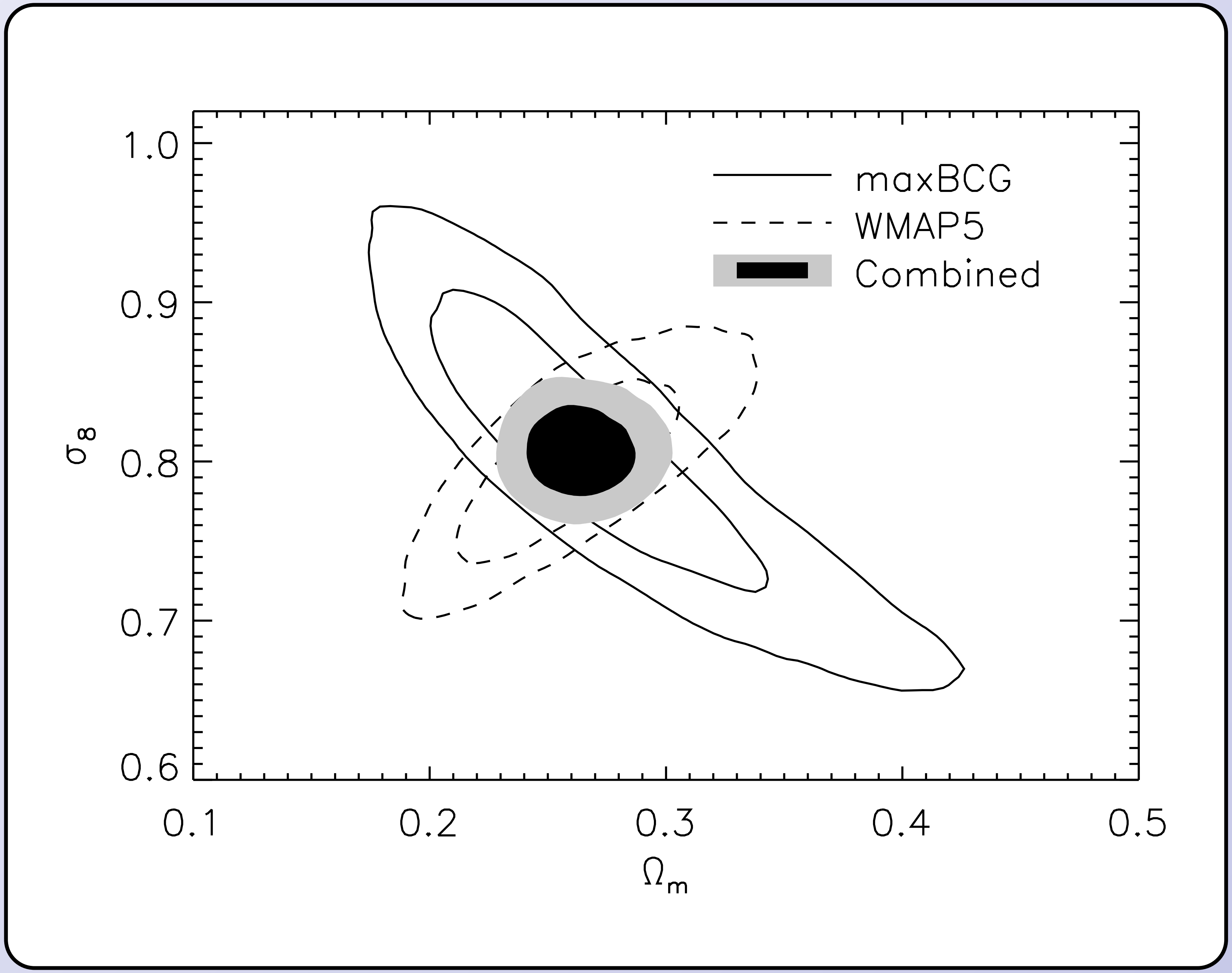
Rozo et al. 2009

Shear-Calibrated M_o-M



State-of-the-Art: example

Rozo et al. 2009



Illustrative Example

Obs-Mass distribution:

$$P = \frac{1}{\sqrt{2\pi}\sigma_{ln}} e^{-\frac{(\ln M_o - \ln \bar{M}_o)^2}{2\sigma_{ln}^2}}$$

$$\bar{M}_o = (M/M_*)^\alpha$$

$$M_* = \alpha = 1$$

$$\sigma_{ln} = 0.2$$

Varied parameters:

- Cosmology
  (Fid values from Dunkley et al.)
  $(\omega_M, \omega_Q, \omega_K, A_s, n_s, w_0, w_a, \gamma_g)$
- Cluster physics
  $(M_*, \alpha, \sigma_{ln})$

Figures of Merit:

$$FoM \equiv |F_{w_0,w_a}|^{1/2}$$ DETF

$$FoM_\gamma \equiv \frac{1}{\sqrt{C_{\gamma\gamma}}}$$ Growth rate

Cosmological Constraints

Example: low-mass cut-off to intermediate z

Gravity FoM values:

- No Obs-Mass priors

$$FoM_\gamma = 35$$

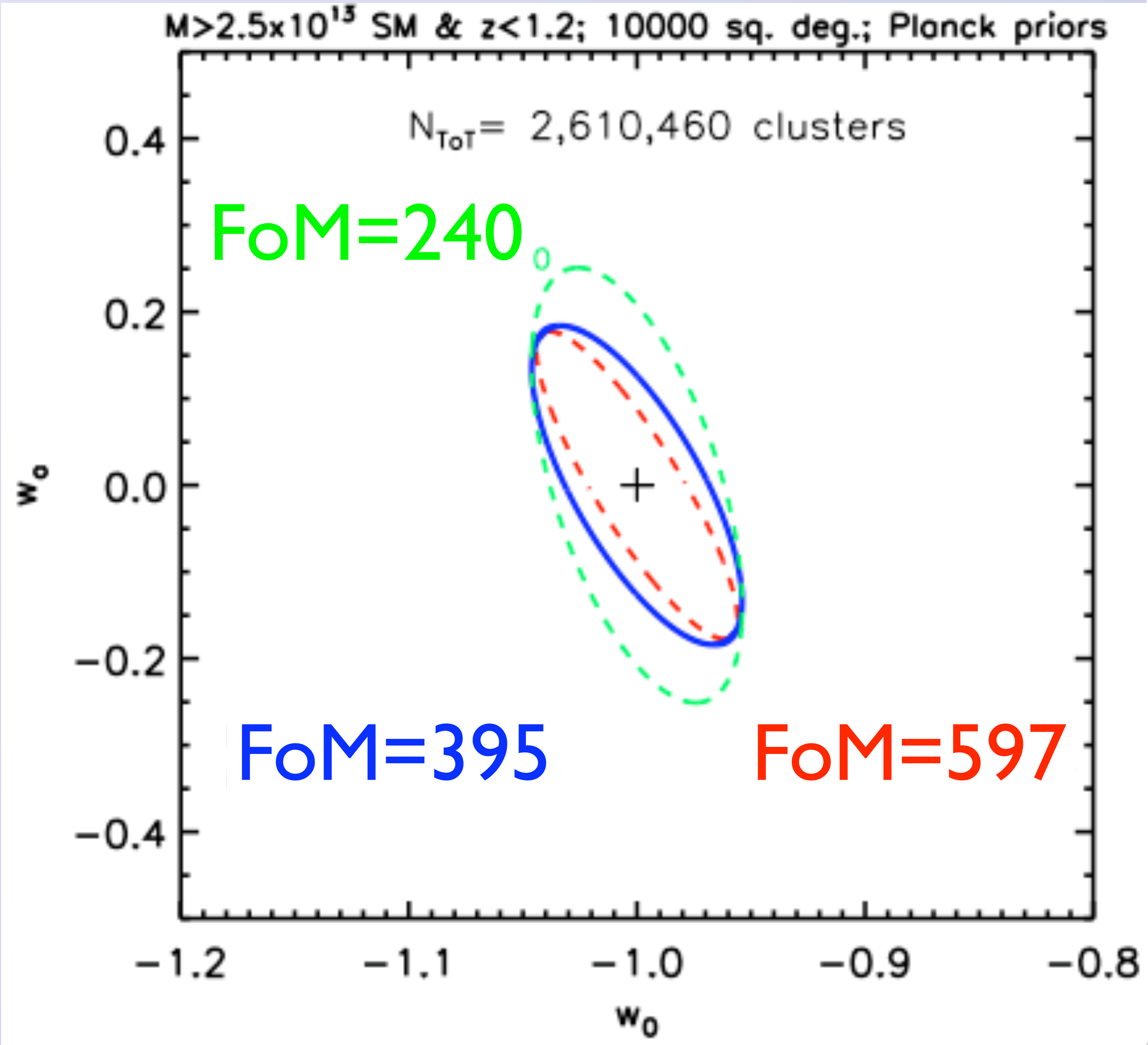
- Mean Obs-Mass fixed

$$FoM_\gamma = 72$$

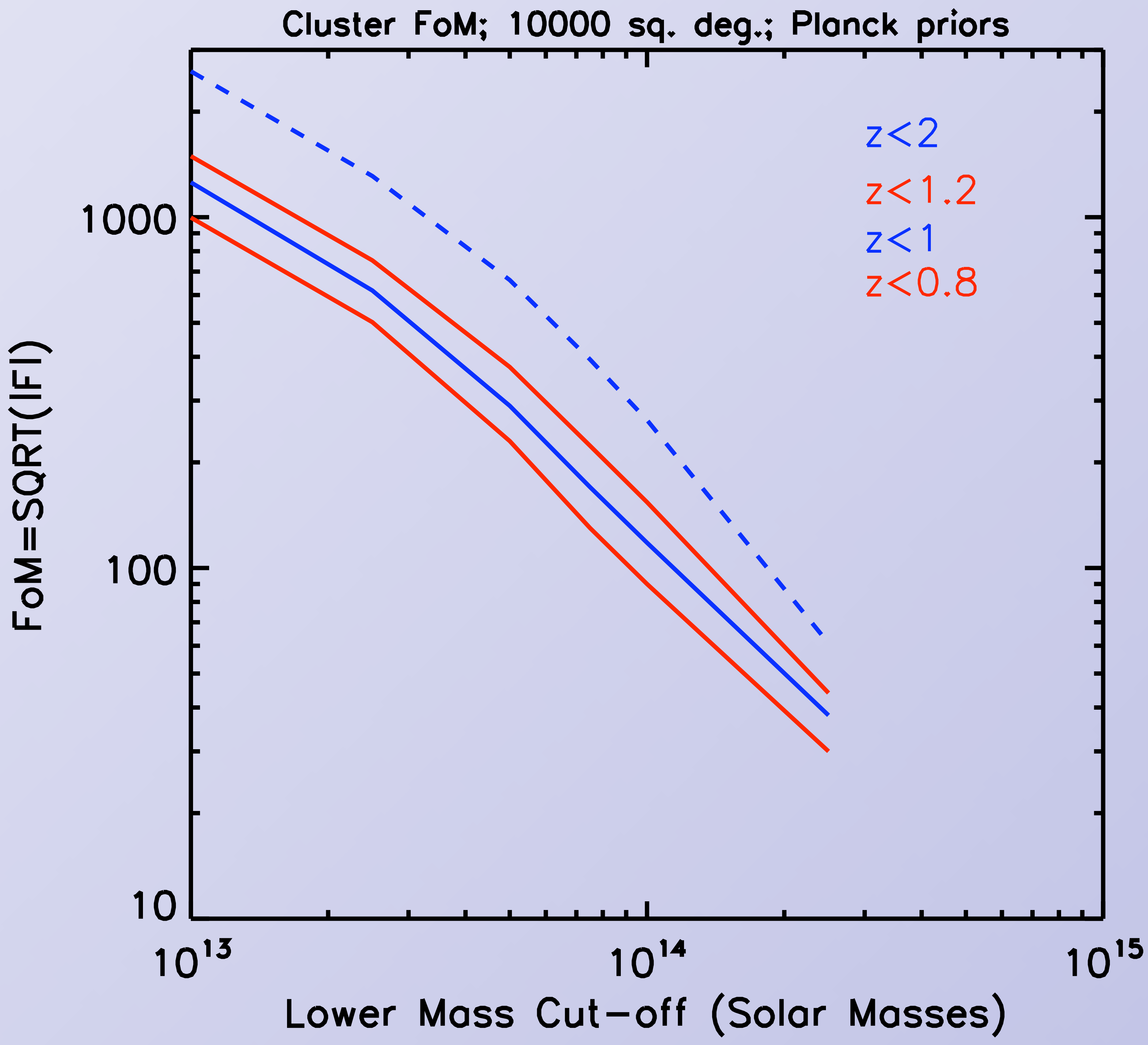
- Full Obs-Mass fixed

$$FoM_\gamma = 83$$

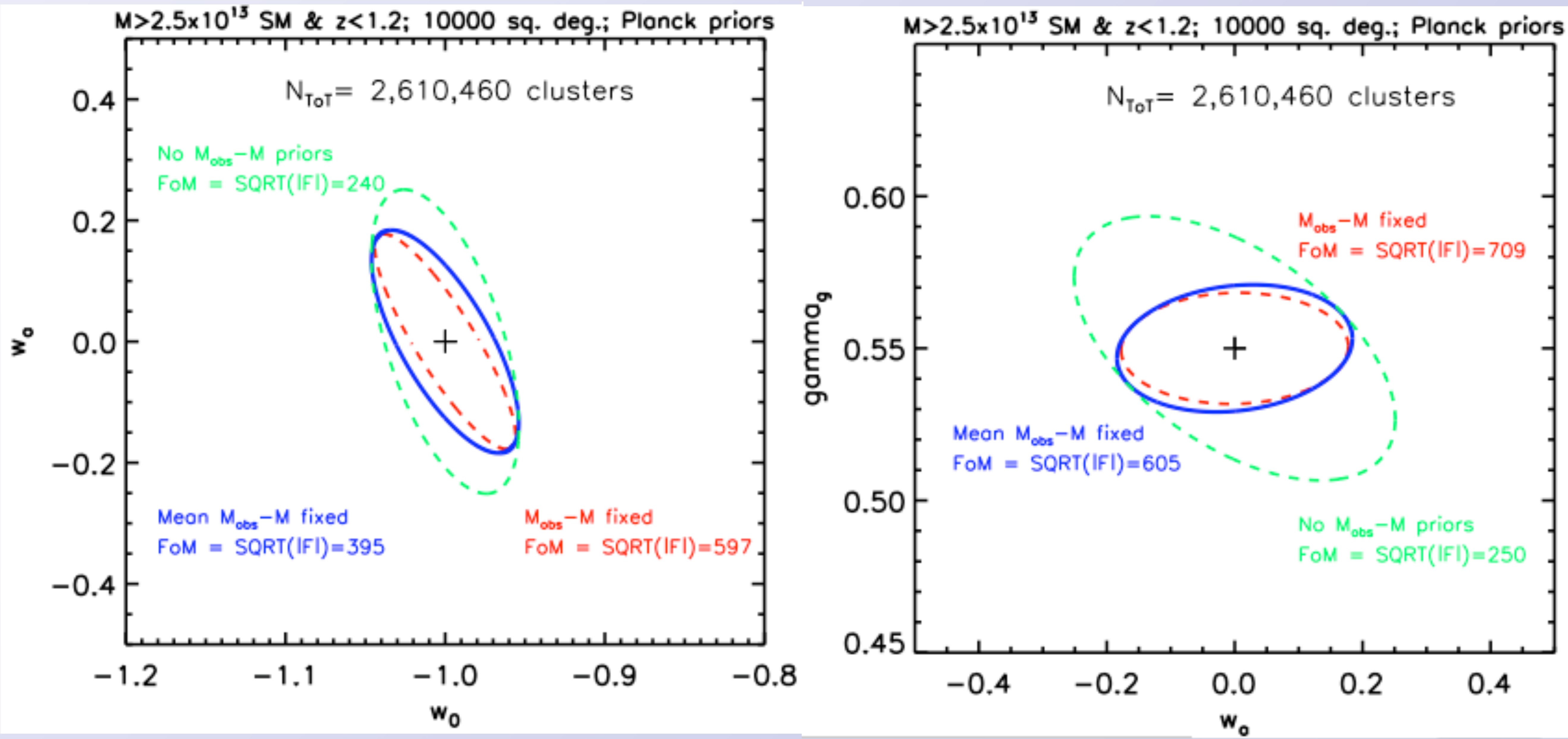
Bartlett et al. 2009



Dependence on Mass & z



Cosmological Constraints



Bartlett et al. 2009

Shear-Detected “Clusters”

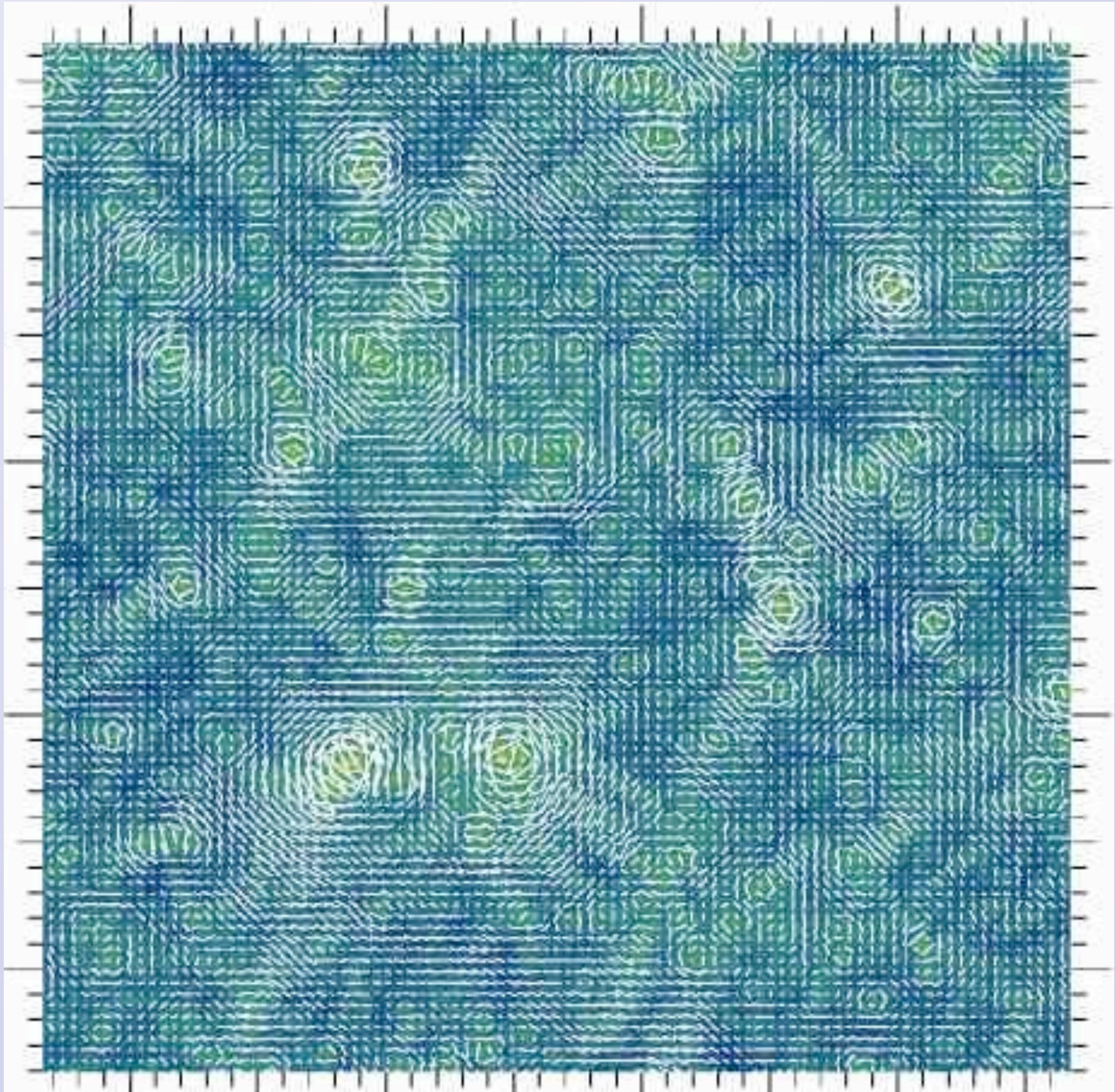
Shear-Selected Catalogs

- Detect shear "sources" in weak lensing map using, e.g., an optimal matched filter
  - Kaiser 1995, Schneider 1996, Kruse & Schneider 1999, Reblinski et al. 1999
- Identify clusters and measure (photo-)z's
- M_o-Mass (M_{shear}-Mass) relation involves just dark matter physics
  - And cosmological parameters => additional cosmological constraints

Shear Peak Catalogs

Ray tracing in
Millennium Simulation

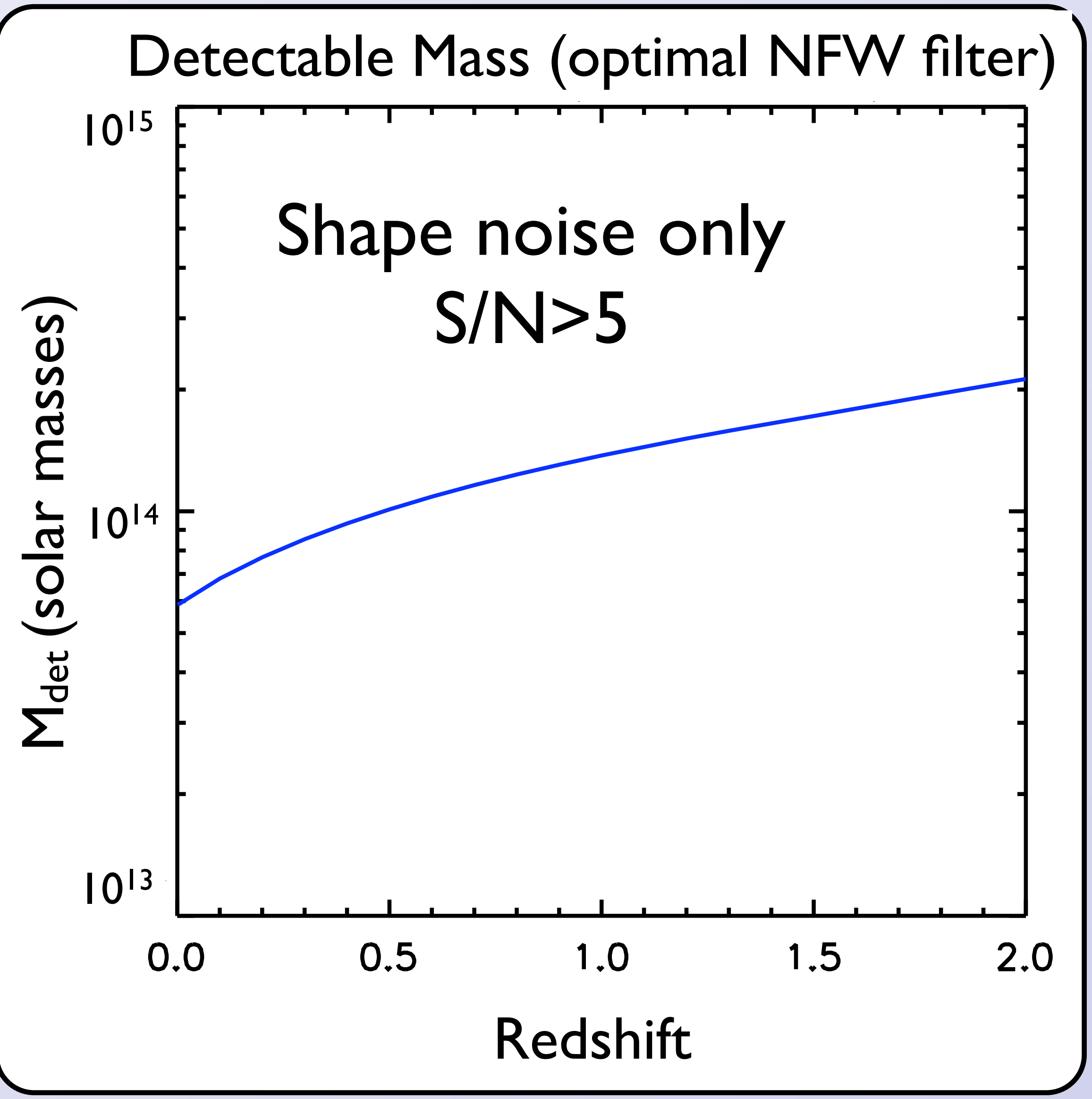
30’ shear field



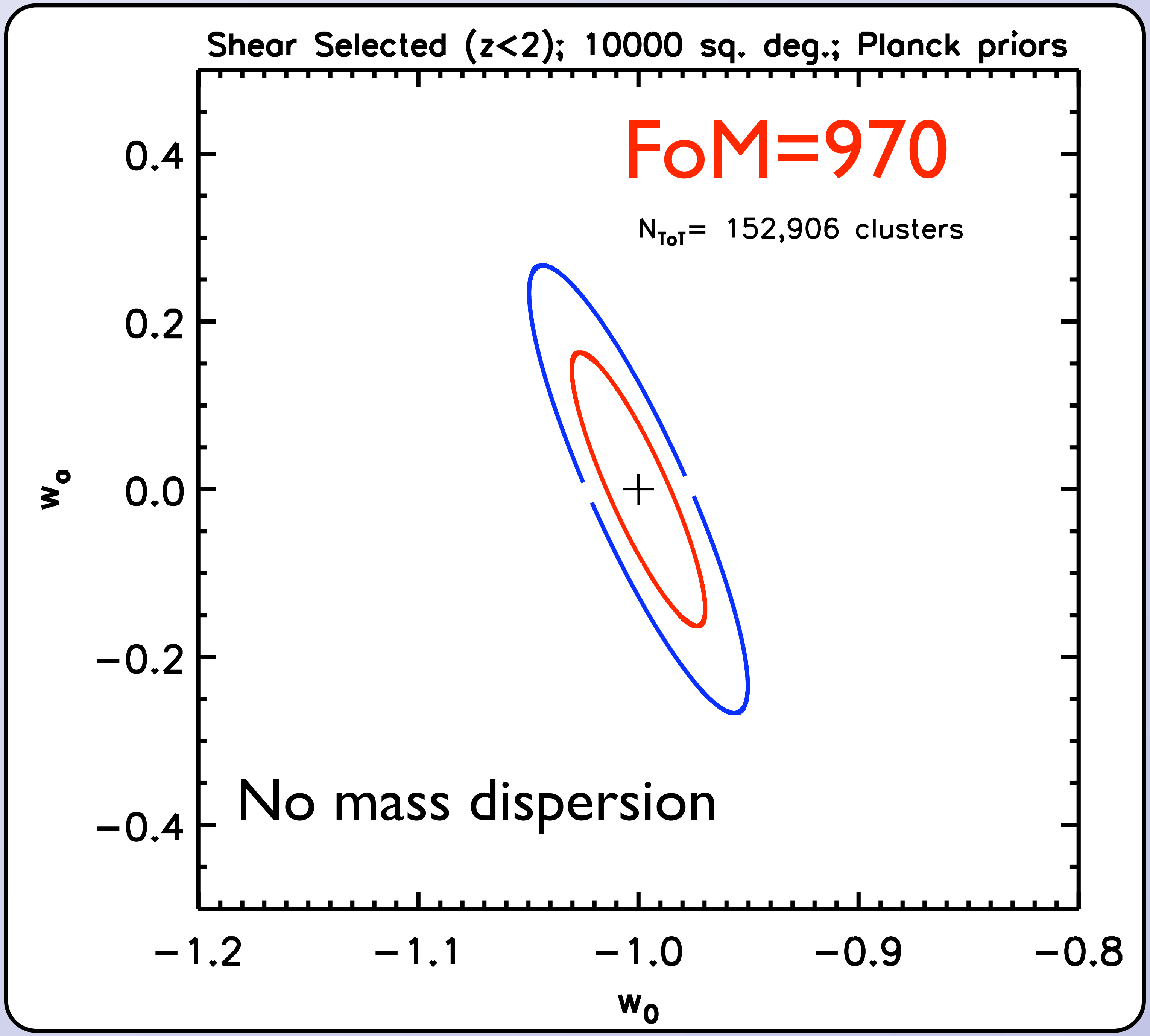
Hartlap et al.

Example: SNAP Study

dQ/dz from Marseille simulations
& with $\sigma_\gamma = 0.3$



WMAP-5 flat fiducial model



Bartlett et al. 2009

Shear-Peak Catalogs: Issues

- Problem: contamination by false peaks (projections)
  - Reblinsky & Bartelmann 1999, Metzler et al. 2001
- Individual mass measurements ~20% intrinsic scatter due to projection effects
  - Hoekstra 2001, 2004
- Can the contamination be controlled?

2D Shear Peak Statistics

- Ignore reality of detected peaks
- Directly use observed peaks as probe
  - Can be predicted from, e.g., N-body simulations
  - Analytical peak-abundance function? - Marian et al. 2008

- N-body: heavy calculation for each model
- 2D statistics less constraining than 3D

Closing Thoughts

- Clusters are astrophysical objects (like others) whose ultimate quantitative utility depends on how many parameters are needed to standardize them for cosmological studies.
    - Cluster surveys
    - Shear surveys (2D, 3D)
- Fundamental research - lots to do
- Multi-wavelength data will be very important
- Huge catalogs compared to today's - new frontier

List of Issues

- Clusters & shear peaks
  - Catalog completeness (selection function)
  - Catalog contamination
- Clusters
  - Proxy-Mass relation: full probability distribution
- Shear peaks
  - Comparison to theory
  - 2D versus 3D statistic

END