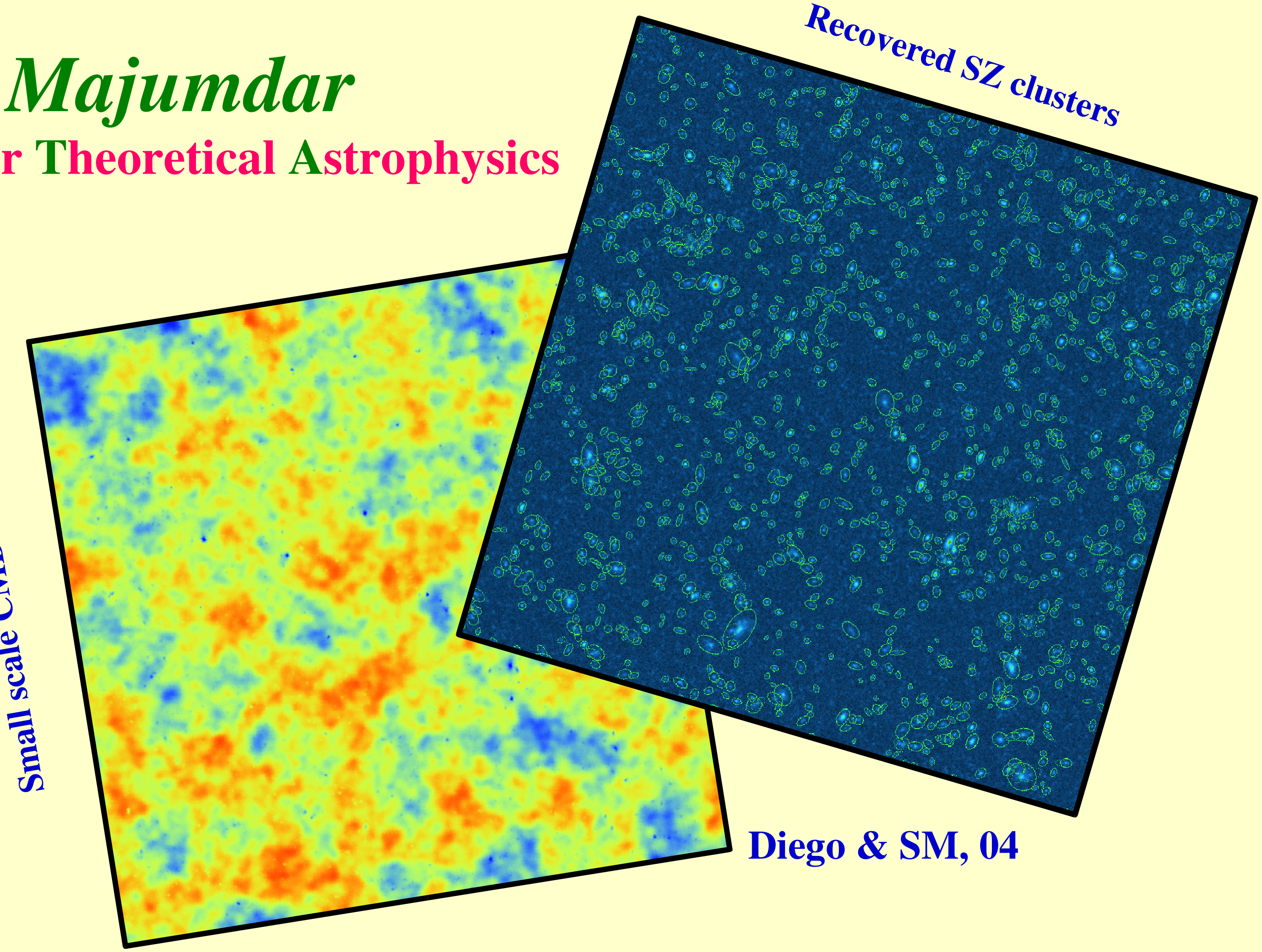
Self-Calibration in SZ Cluster Surveys

Subha Majumdar
Canadian Institute for Theoretical Astrophysics



Diego & SM, 04

With
Graham Cox
Joe Mohr
Martin White
Jose Diego

20th IAP Colloquium, 2004
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To begin…

There are quite a few planned/funded SZ surveys this decade
(SPT, APEX-SZ, ACT, AMI etc; Planck)
(Ruhl's; Kneissl's; Miller's talks)

High Angular resolution and high sensitivity surveys.
(Typically ~1' and rms ~ 10 μJy)

The idea is to measure the i) SZ angular power spectrum, C_l
ii) detect clusters thro their SZE, $N(S)$
If one can estimate the redshifts followups, then

$$N(S) + z\text{'s} = dN/dz$$

Cosmological potential of these surveys (SPT, Planck).
Complimentarity with other probes.
Designing cluster surveys.

cluster surveys: past & future…

Survey	Sensitivity	Area (deg^2)	No of clusters
Planck	>5μK ? (HFI)	All sky	7,000-30,000
SPT	~1μK (3 freq)	4000	>15,000-30,000
ACT	~1μK (3+ freq)	100	few 1000's
APEX-SZ	~1μK (3+ freq)	150-200	few 1000's
AMI	~10μK	100	~100 (detail)
SZA	<1μK (2 freq)	12	~ 100 (detail)

A. C. Edge

Table 1.1. *ROSAT Survey Samples*

Survey	Identification Paper	Flux Limit (erg s^{-1}cm^{-2})	Area (□°)	Number Published?
XBACS	Abell clusters Ebeling et al. (1996)	5.0×10^{-12} (0.1–2.4 keV)	All-sky	276 Y
BCS	Abell, Zwicky, extended Ebeling et al. (1998)	4.5×10^{-12} (0.1–2.4 keV)	13,578	199 Y
RASS1BS	Abell, extended de Grandi et al. (1999)	$3\text{–}4\times10^{-12}$ (0.5–2.0 keV)	8,235	130 Y
Ledlow	Abell $z < 0.09$ Ledlow et al. (1999)	none	14,155	294 N
eBCS	Abell, Zwicky, extended Ebeling et al. (2000)	3.0×10^{-12} (0.1–2.4 keV)	13,578	29[illegible] Y
HIFLUGCS	All Reiprich & Böhringer (2002)	20×10^{-12} (0.1–2.4 keV)	27,156	63 Y
NORAS	extended Böhringer et al. (2000)	3.0×10^{-12} (0.1–2.4 keV)	13,578	378 Y
NEP	multiple Gioia et al. (2001)	0.03×10^{-12} (0.5–2.0 keV)	80.7	64 Y
CIZA	CCD imaging, $\|b\| < 20°$ Ebeling, Mullis, & Tully (2002)	5×10^{-12} (0.1–2.4 keV)	14,058	73 Y
SGP	optical plates scans Cruddace et al. (2002)	3.0×10^{-12} (0.1–2.4 keV)	3,322	112 Y
MACS	multiple, $z > 0.3$ Ebeling et al. (2001)	1.0×10^{-12} (0.1–2.4 keV)	22,735	120 N
REFLEX	multiple Böhringer et al. (2001)	3.0×10^{-12} (0.1–2.4 keV)	13,905	452 N

2460

the cluster redshift distribution - I…

$$\frac{dN(z)}{dz\,d\Omega} = \frac{dV}{dz\,d\Omega}\, n(z) = \frac{c}{H(z)} d_A^2 (1+z)^2 \int_{M_{\lim}}^{\infty} dM \; \frac{dn(M,z)}{dM}$$

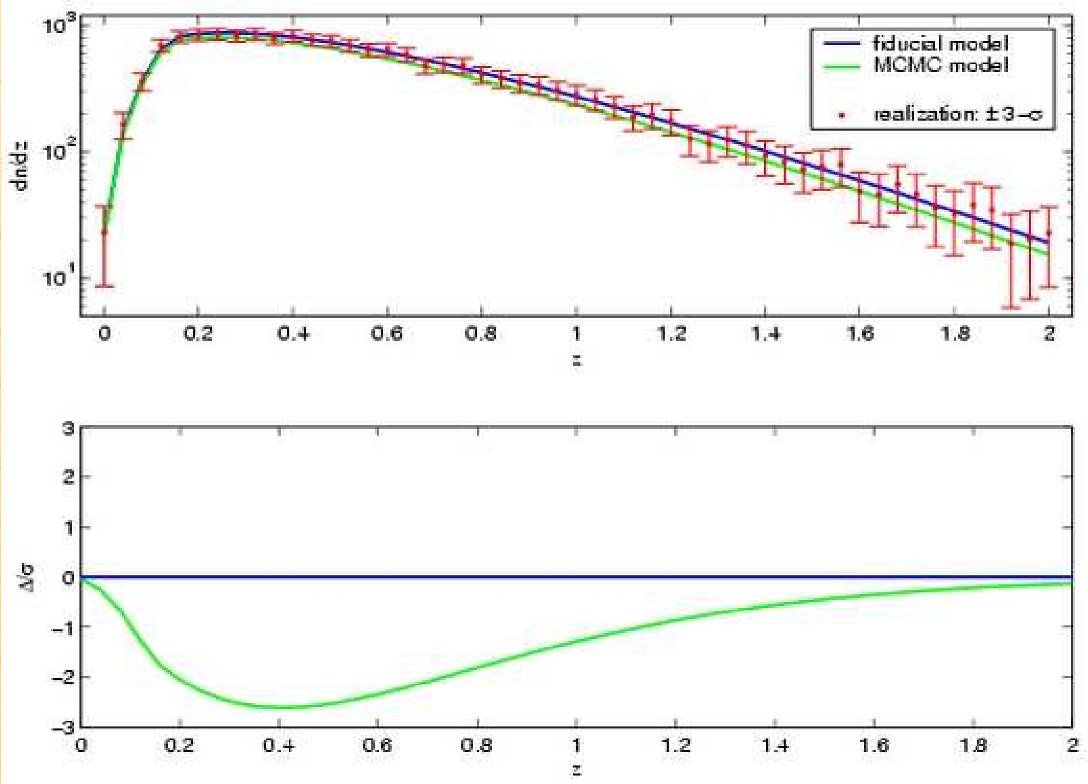
Volume Element — Abundance — Volume — Abundance

Cluster redshift distribution probes:

1) **volume-redshift relation**
2) **abundance evolution (growth factor)**

Typical limiting masses considered in the literature:
SPT ~ $2.5h^{-1}$ M_0 Planck ~ $8h^{-1}$ M_0

Estimating cosmological parameters a survey….



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the cluster redshift distribution - II...

$$\frac{dN(z)}{dz\,d\Omega} \propto \frac{dV}{dz\,d\Omega}\, n(z) \qquad = \frac{c}{H(z)}\, d_A^2 (1+z)^2 \int_{flux_{lim}}^{\infty} dM \frac{dn(M,z)}{dM}$$

Volume Element

Abundance

Volume

Abundance

Cluster redshift distribution probes:

1) volume-redshift relation

2) abundance evolution (growth factor)

3) Mass selection function (*some* flux-mass relation)

$$S = f(\ )\, A_{SZ}\, M\ \ E(z)^{2/3} \qquad ; H(z) = H_0 E(z)$$

$$S = f(\ )\, A_{SZ}\, M\ \ E(z)^{2/3} (1+z)$$

Uncertainties/Incomplete understanding

Big Spoiler

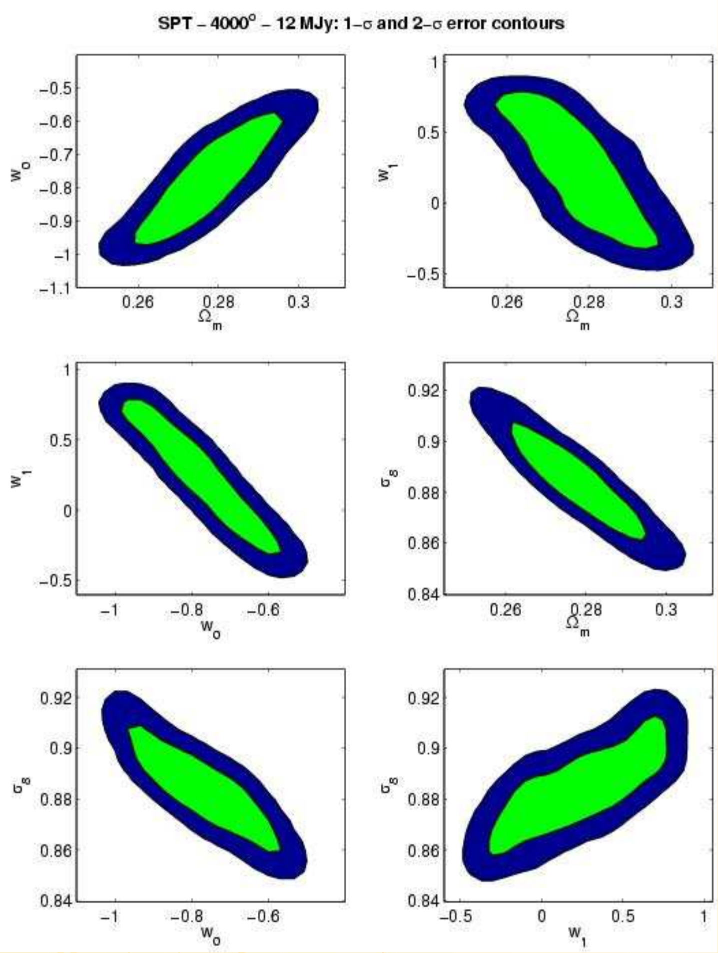
the cluster redshift distribution- III….

- Surveys are typically characterized by the *flux limits* (or how deep one can go) and the *area* coverage (width)

- The prevalent trend is to assume complete knowledge of cluster structure (and evolution). This is BIG assumption.
  Cosmological constraints/forecasts are `naive'.

- There exist `*till now*' irreconciable differences between observed and simulated mass-observable relations.

- Other than a form of scaling relation, we don't want to assume anything about the cluster structure or evolution, i.e we don't want to fix the scaling relation.



on cluster structure & evolution …

Tight scaling relations in cluster properties exist both in observations and in hydro simulations of structure (Evrard 99, Bryan & Norman 98, Mathiesen & Evrard 01)

These virial scaling relations appear to persist at intermediate redshift in observations (Mohr etal 99, 00; Sanderson etal 03, etc) and high redshifts (Ettori etal 04)

However, we know clusters are 'messy', with detailed substructures seen in Chandra observations. At high redshifts, they are young and have frequent mergers.
From simulations, mergers show departure from hydrostatic equilibrium (Ricker & Sarazin 02)

So, Is this the end of the story?

No, mergers are common but major mergers are rare (Lacey & Cole 94, Sheth & Tormen 99)
So, 'statistically' departure from equilibrium is in general 'small'

Dynamical relaxation occurs quickly . Example: 75 major mergers for 24 clusters, approx merger timescale 2.7 Gy, relaxation timescale 2.5 Gyr. Sample almost always at quasi-hydrostatic equlibrium (from Mathiesen & Evrard 01)

New: SZ M-T scaling reln agrees with XRay M-T reln ! (Kneissls' talk)

cluster surveys – self calibration …

Self Calibration: trying to determine the cluster mass-observable relation and its evolution from within the cluster survey itself.

Q1) Does this work?

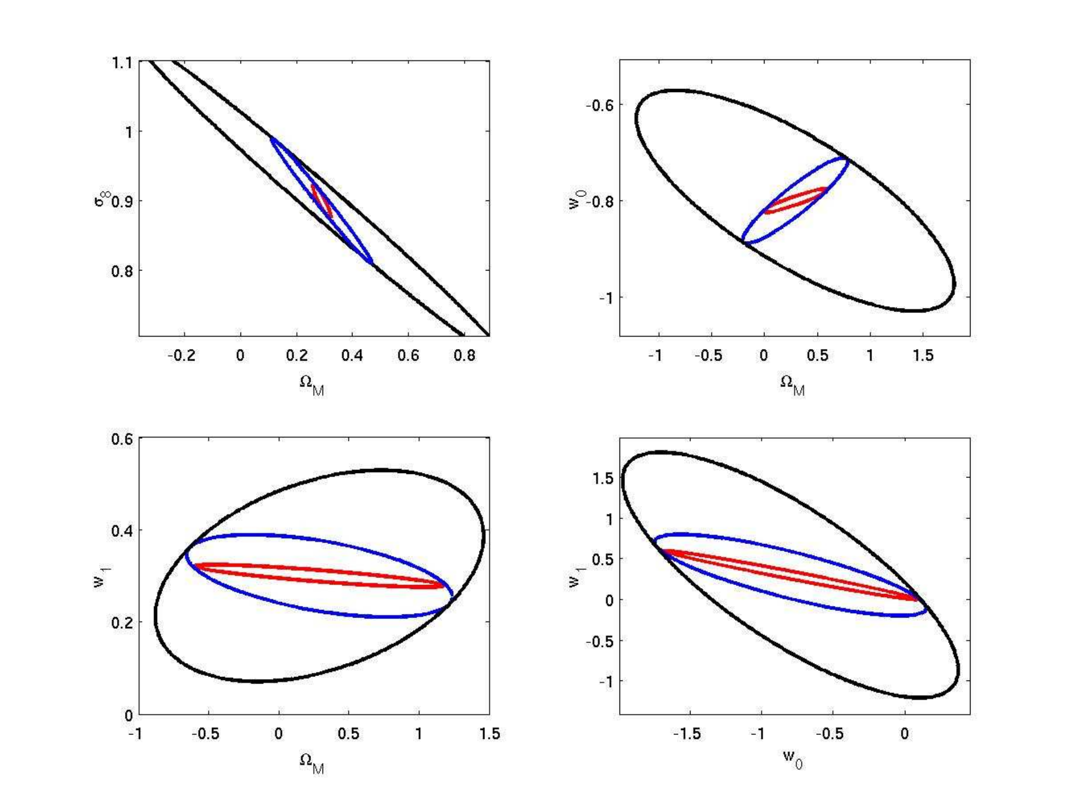
Q2) To what extent?

The ansers are:

A1) YES ! (if there are enough clusters)

A2) As long as `evolution' is known (or separately constrained)

survey forcasts with self calibration …



Errors on parameters increase when cluster structure, especially evolution is solved simultaineously. This is, however, better, since it automatically takes into account cosmology-gas physics degeneracies.

restoring self-calibration with additional information ….

Different suggestions to restore self-calibration in presence of `evolution' exists in the literature

Options:

Limited mass follow-up

(SM & J Mohr 2003)

Followup-1: 100 clusters between $0.3<z<1.0$

Mass measurement uncertainty ~ 30-50%

(think of SZA or AMI/ XRay archives)

Using the cluster power spectrum in thick redshift bins

(SM & J Mohr 2004)

Adding information from counts-in-cell

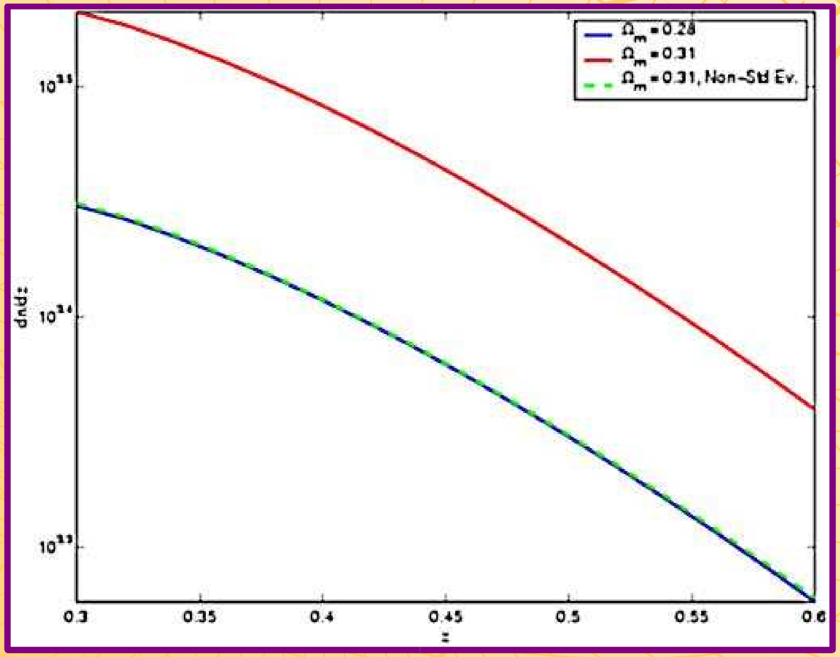
(M. Lima & W.Hu 2004)

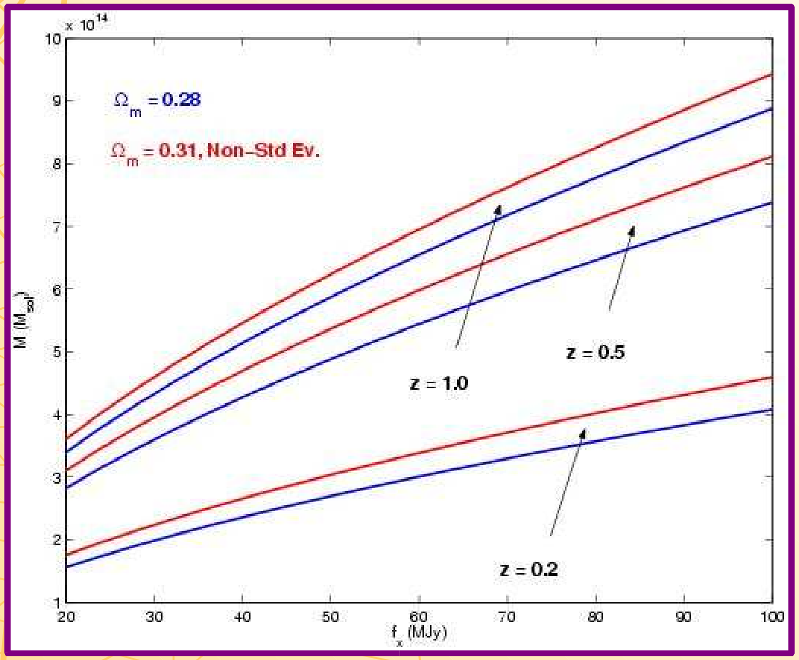
Using shape of SZ luminosity-function in a redshift slice

(W. Hu 2003)

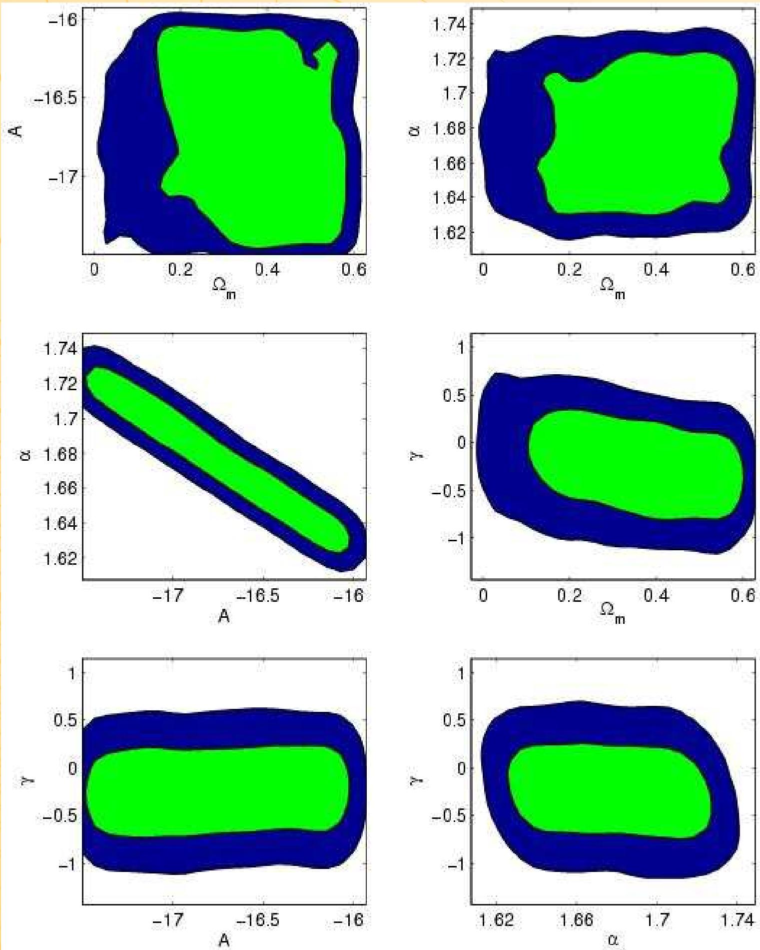
mass followup ….

Introducing a non-standard evolution model to offset a change of $\delta\Omega_m$=10% leads to offset in the SZ flux- temperature relationship for the clusters. One can add this extra information to break the cosmology-gas physics degeneracy!!





constraints from mass followup only …



MCMC runs :

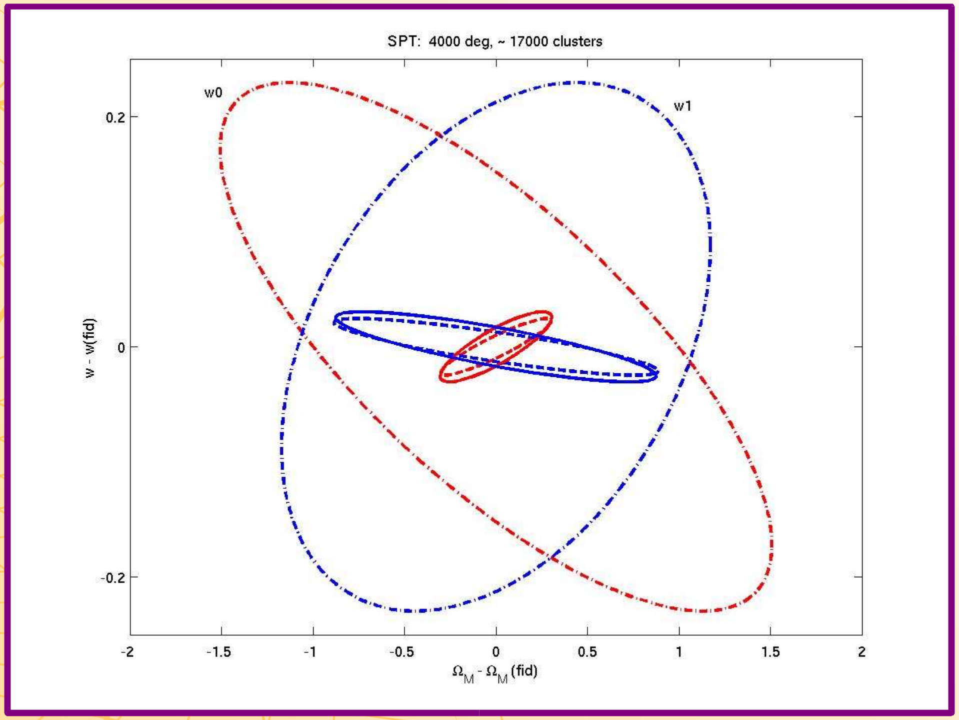
1. by themselves followup mass measurement give poor cosmological constraints.
2. however, one can have an estimate of gas-physics cosmology degeneracies

Adding followup to cluster redshift counts can great reduce errorbars

Note: Fisher errors are more underestimated when dealing with followup than dndz, compared to MCMC errors

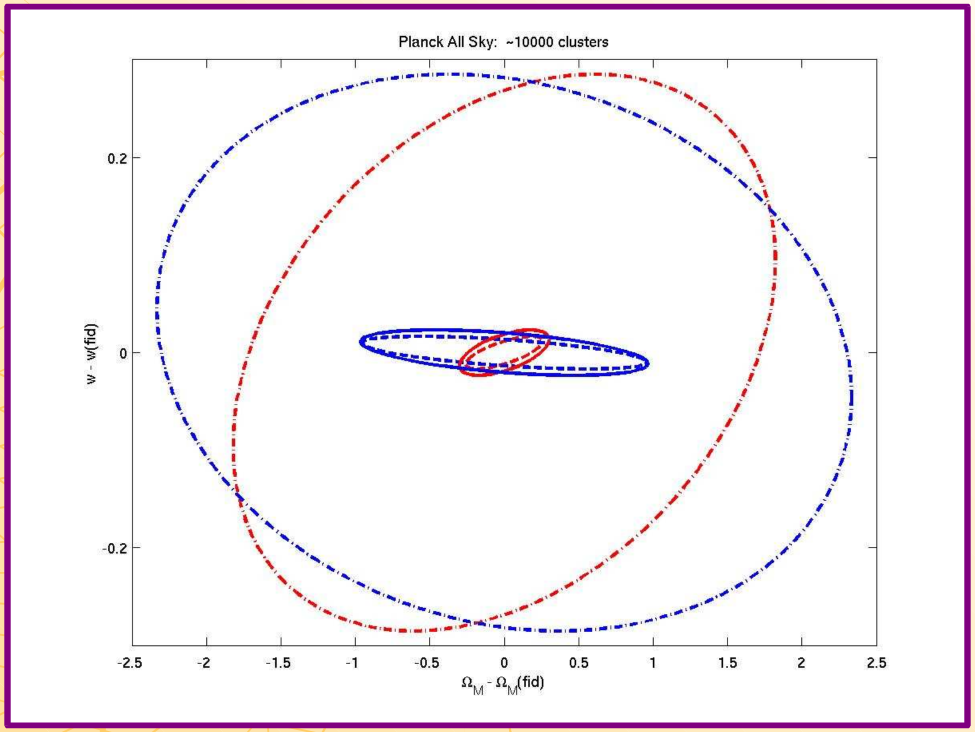
restoration of self-calibration : SPT (~17000 clusters) …

	dndz (Naive)	dndz (A,α)	dndz (A,α,γ)	+fup
$\Delta\Omega_m$	0.016	0.06	0.15	0.02
$\Delta\sigma_8$	0.022	0.12	0.43	0.035
Δw_0	0.18	0.33	0.99	0.22
Δw_1	0.57	0.62	0.77	0.60
Δw_{ef}				0.06



restoration of self-calibration : Planck (~10000 clusters) …

	dndz (Naive)	dndz (A,α)	dndz (A,α,γ)	+fup
$\Delta\Omega_m$	0.01	0.17	0.19	0.02
$\Delta\sigma_8$	0.015	0.46	0.51	0.03
Δw_0	0.17	0.77	1.2	0.22
Δw_1	0.63	0.93	1.54	0.68
Δw_{ef}				0.08



designing cluster surveys- I …

Deep or Wide ? Or Deep and Wide

Different surveys have different parameter degeneracies
Combining surveys can help breaking degeneracies.

Example 1: modified SPT

	SPT 50% deep (100deg)	+ 50% wide (2000 deg)	= Combined
$\Delta w_0 \sim$	0.56 ,	1.41	0.18
$\Delta w_1 \sim$	1.83 ,	1.10	0.55

Example 1: Planck + SPT

	Planck (24000 deg)	+ SPT (4000 deg)	= Combined
$\Delta w_0 \sim$	1.2 ,	0.99	0.14
$\Delta w_1 \sim$	1.54 ,	0.77	0.39

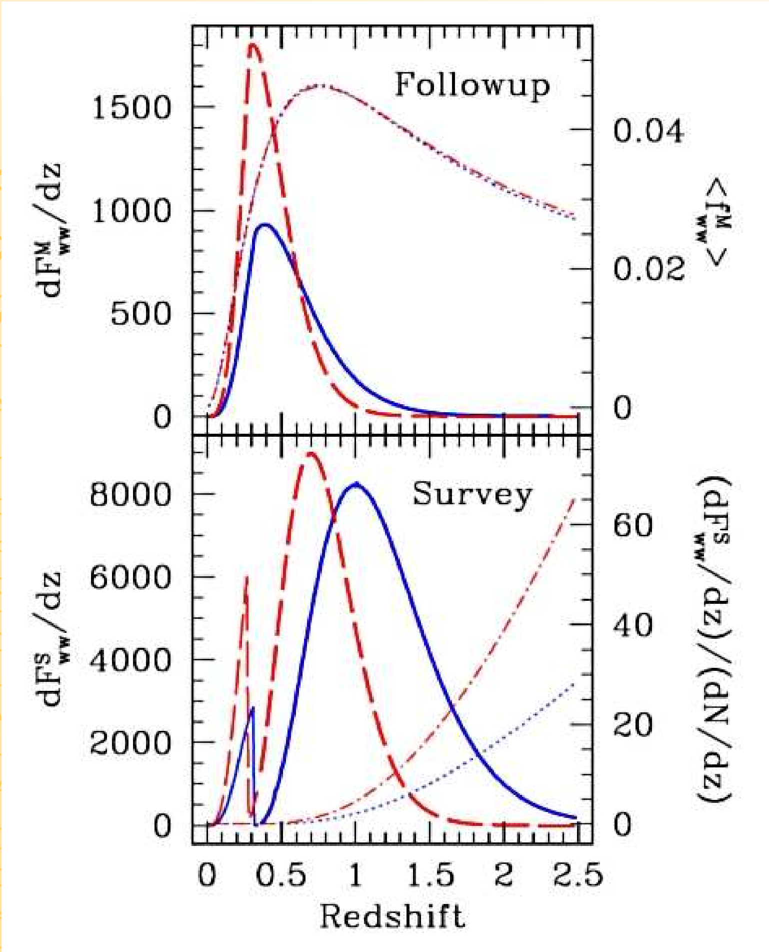
SM 2004

designing cluster surveys – II …

The important redshift range:
For the survey & per unit cluster detected)

•Need to get clusters above 0.5<z<1 .

•Need to follow-up high redshift cluster for a small followup.



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some real issues …

Observational:

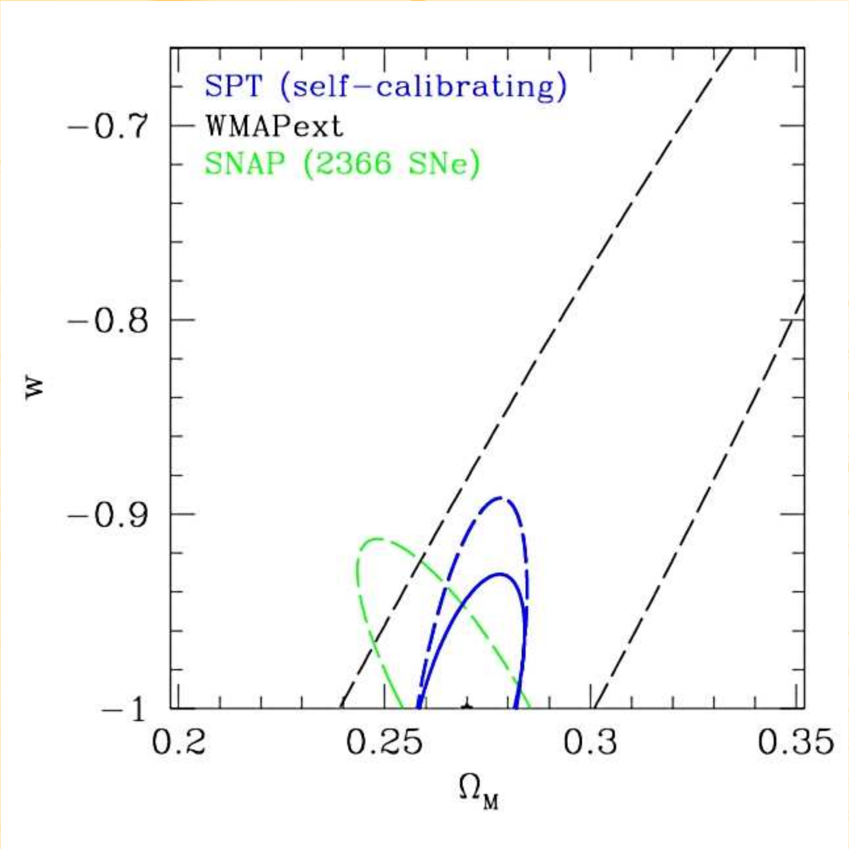
2. Can we detect all the clusters?
3. Can we get the redshifts?
4. How many clusters will get resolved/beam dilution?
5. Point sources at these low fluxe
5. Correlated contamination?
7. Scatter in mass-observable reln

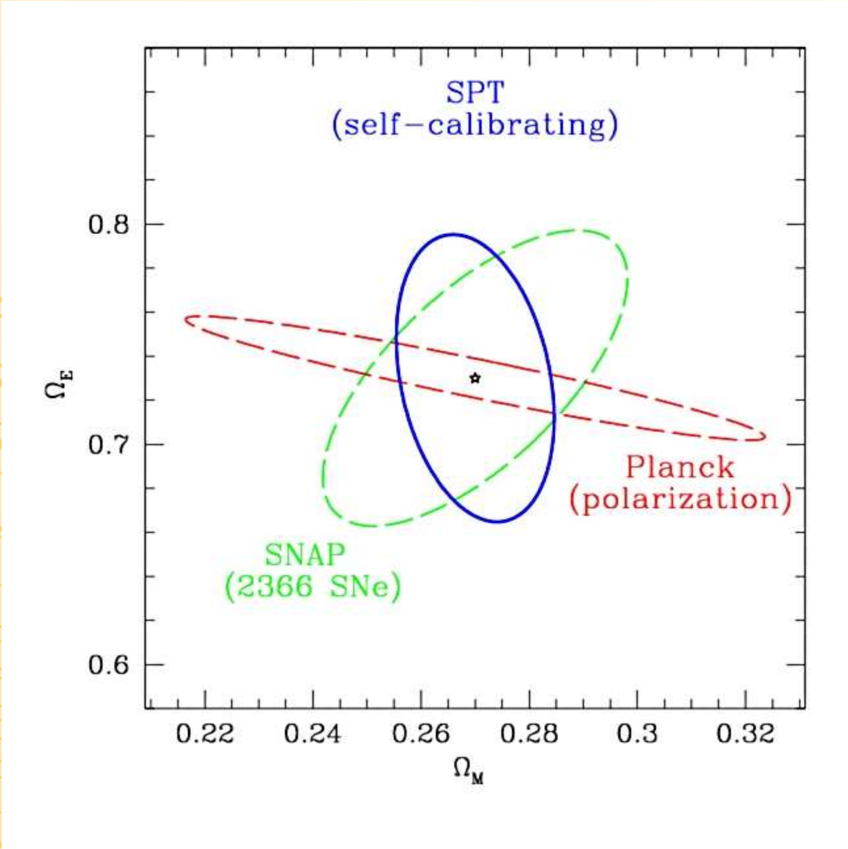
(White & SM 2004, Schulz & White 2003, Huterer etal 2004, Holder 2003, Levine etal 2002)

Theory:

- What w(z) should we take ?
- How well do we know the mass fn and bias from simulations?

how well did the surveys do ?





Competitive & Complimentary

Propaganda plot aimed at funding agencies!

So, to conclude …

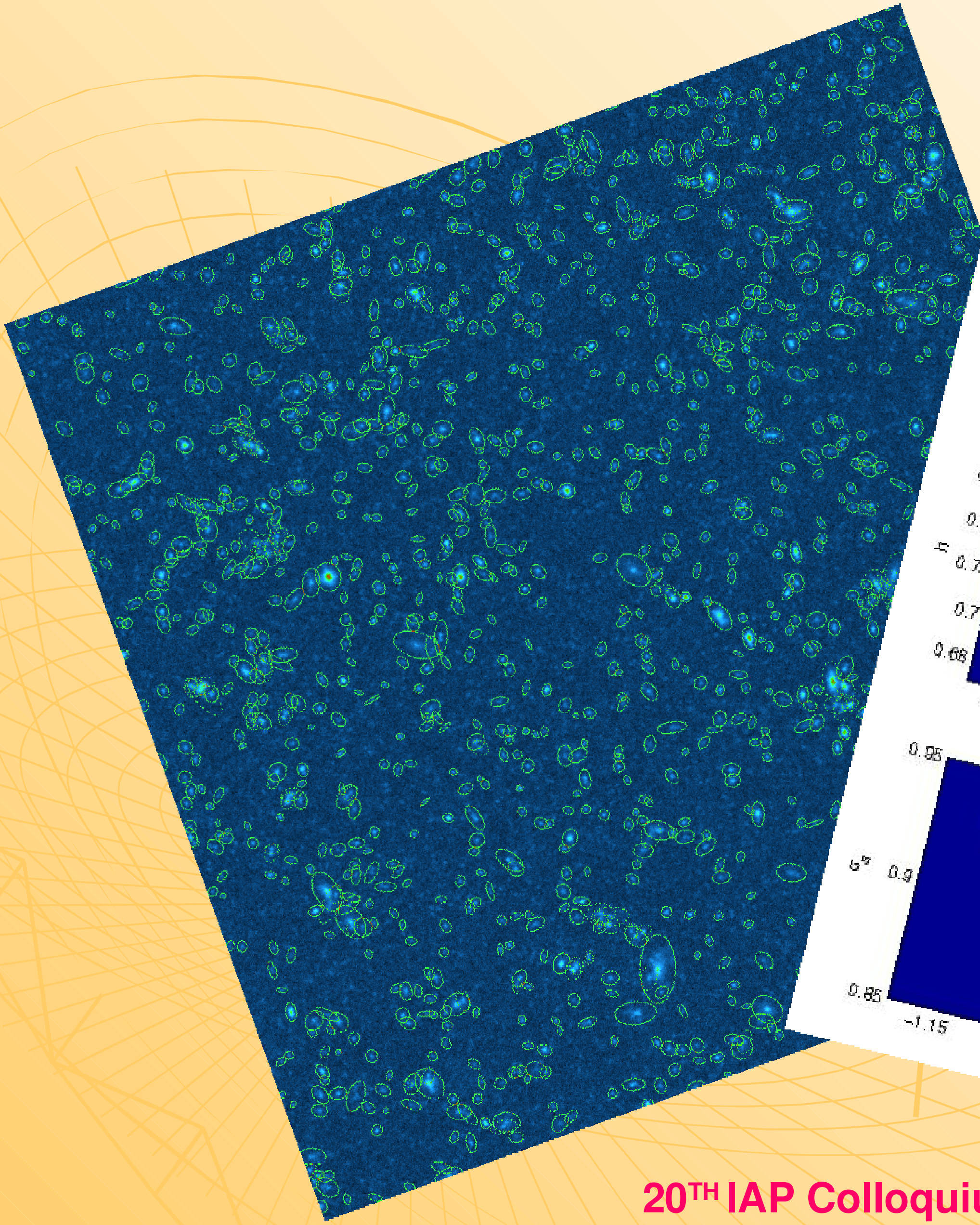
Cosmology and gas physics are intermingled in any study of cluster physics. We *cannot* ignore one when trying to get the other.

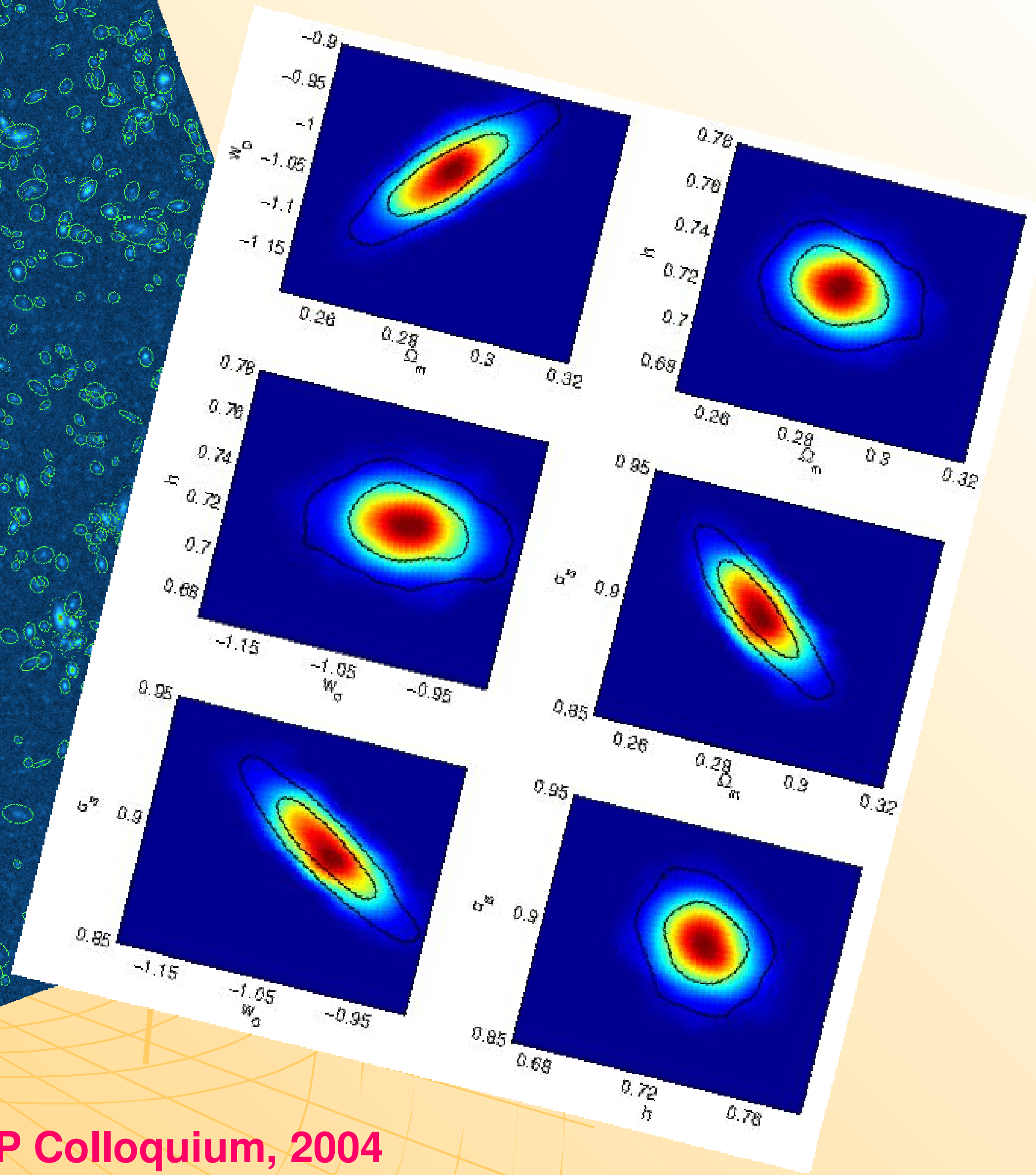
For large yield cluster surveys, '*Self-Calibration*' of cluster structure is possible within the surveys.

Even in presence of any unknown evolution, by using complimentary information from within the survey or follow-up, one can restore self-calibration

A self calibrating survey having both wide and a deep component does significantly better than either of them alone. Thus one should think of alocating a fraction time to each section. Similarly, combining different cluster survey sample will significantly strengthen constraints.

Ofcourse, adding CMB and SNE information helps. And cluster surveys will actually probe cluster physics extremely well.





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