Using Planck Clusters
for
Cosmology and Calibration

Subha Majumdar

Tata Institute of Fundamental Research, Mumbai

Indo-UK Scientific Seminar:
Confronting particle-cosmology with Planck & LHC
IUCAA: 10-12 Aug, 2011

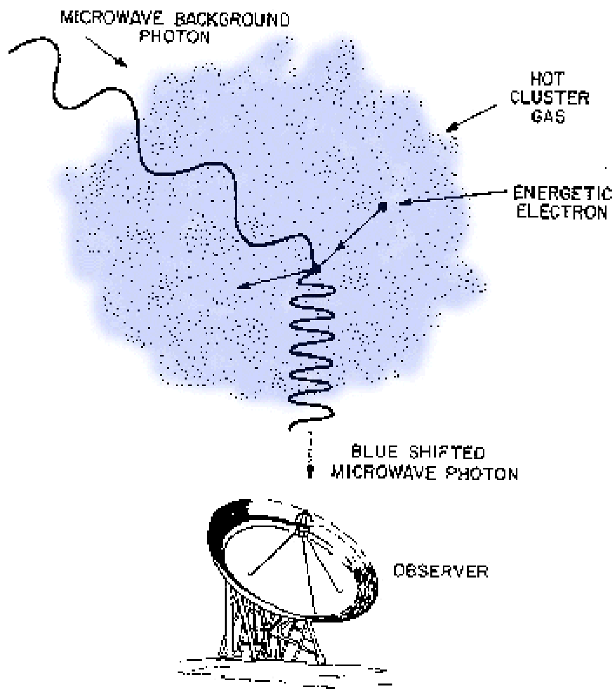
What can we do with Planck clusters ?

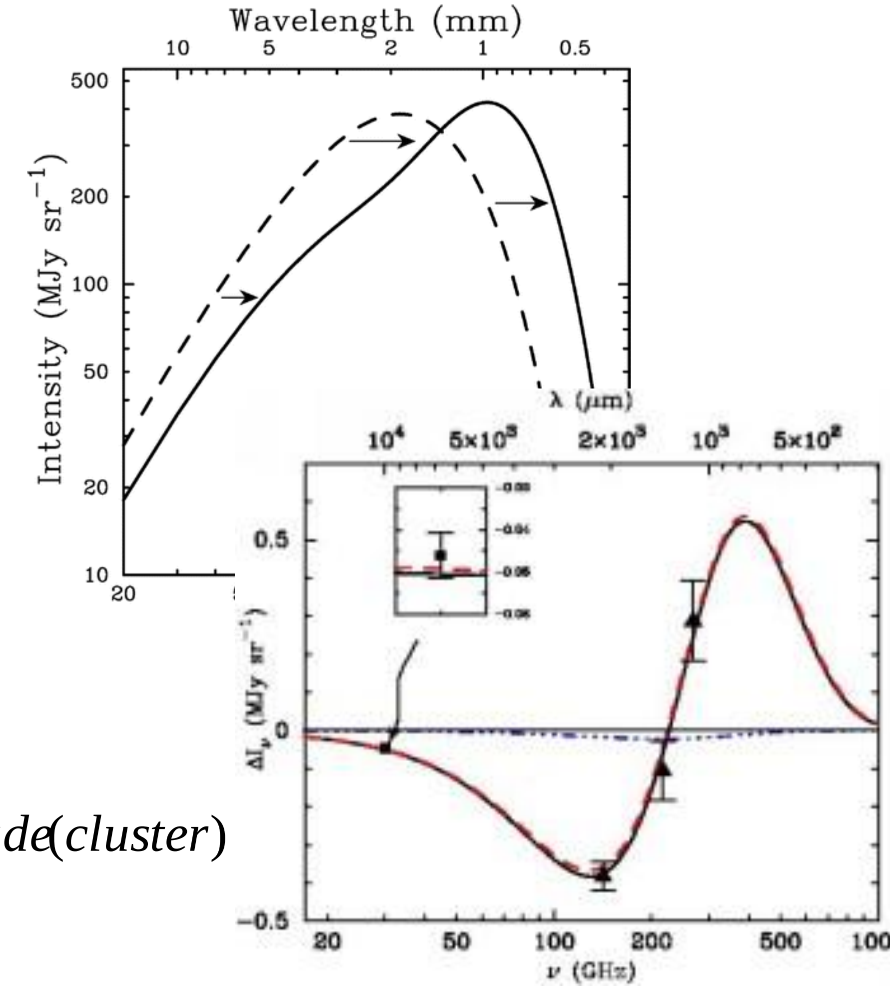
There are so many ways to do cosmology with clusters that we are spoilt with choice (*but unfortunately NOT with numbers in SZ*):

Cluster counts
SZ power spectrum
Use clusters as rulers
2D/3D P(k)
Cluster gas fraction
Mass/Luminosity function

Calibration sample within Planck or other cluster surveys

The basics of SZ Effect...

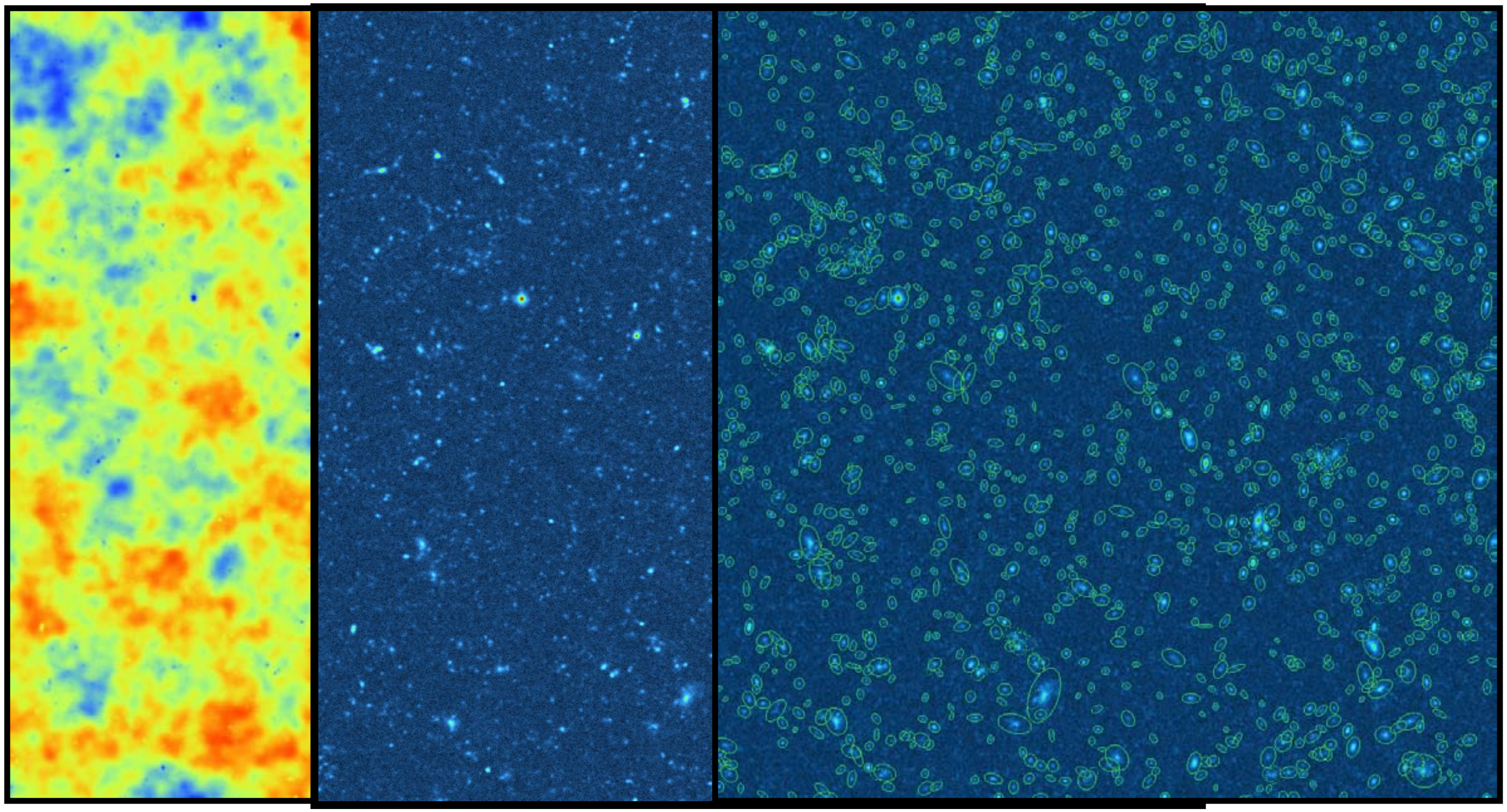




$$distortion = freq\_dependence \times amplitude(cluster)$$

$$amplitude \propto \int_{line-of-sight} gas\_pressure$$

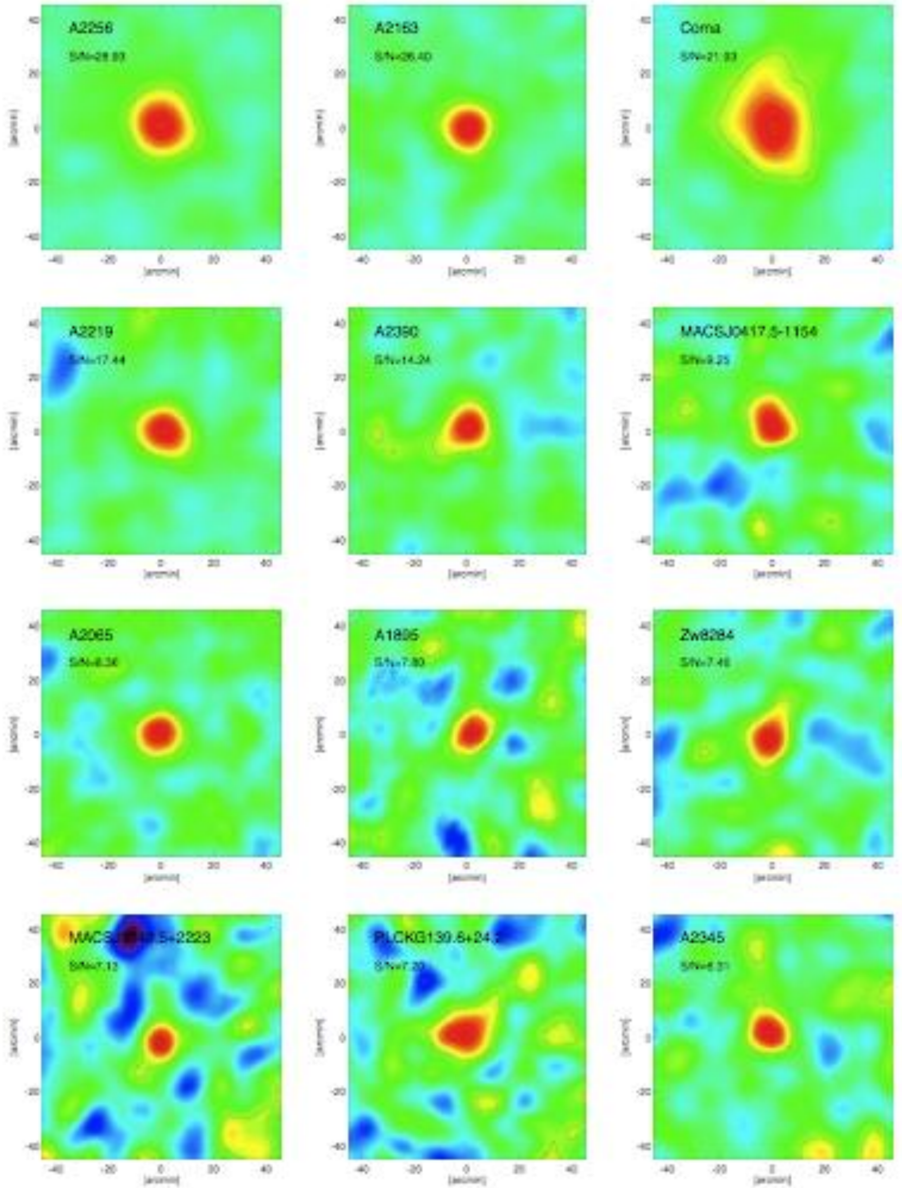
SZ clusters in Planck



10° x 10° map
145 GHz

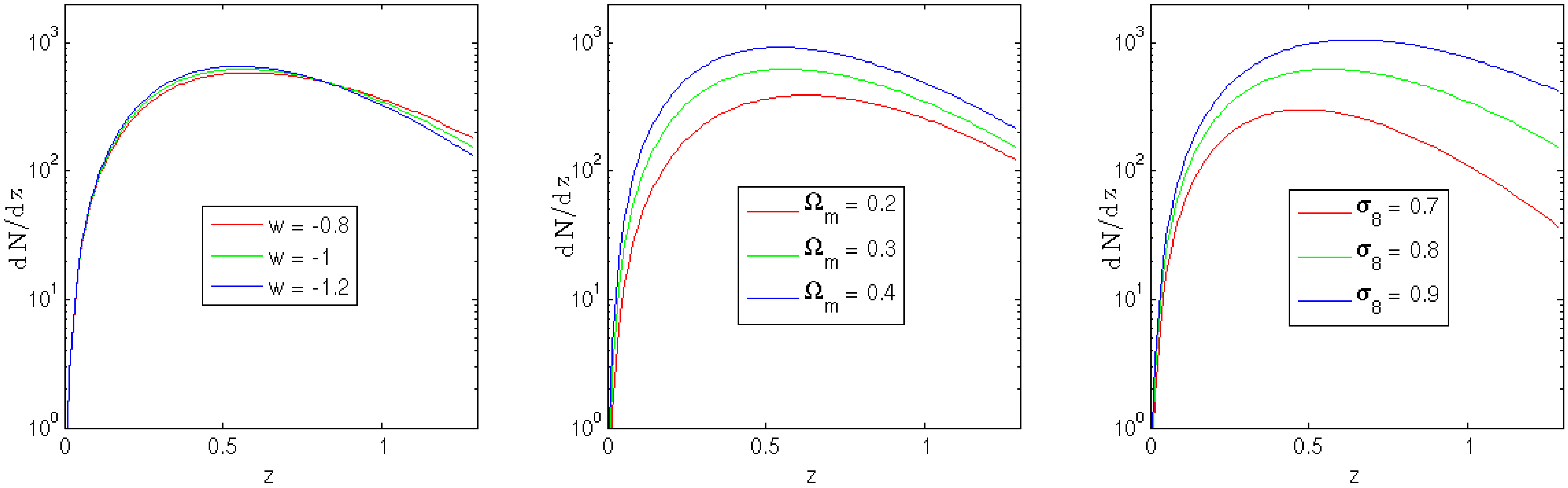
Diego & SM

Planck clusters *circa* Jan 2011



Confronting particle cosmology with Planck & LHC
IUCAA: 10-12 Aug, 2011

Cosmology with cluster numbers ?

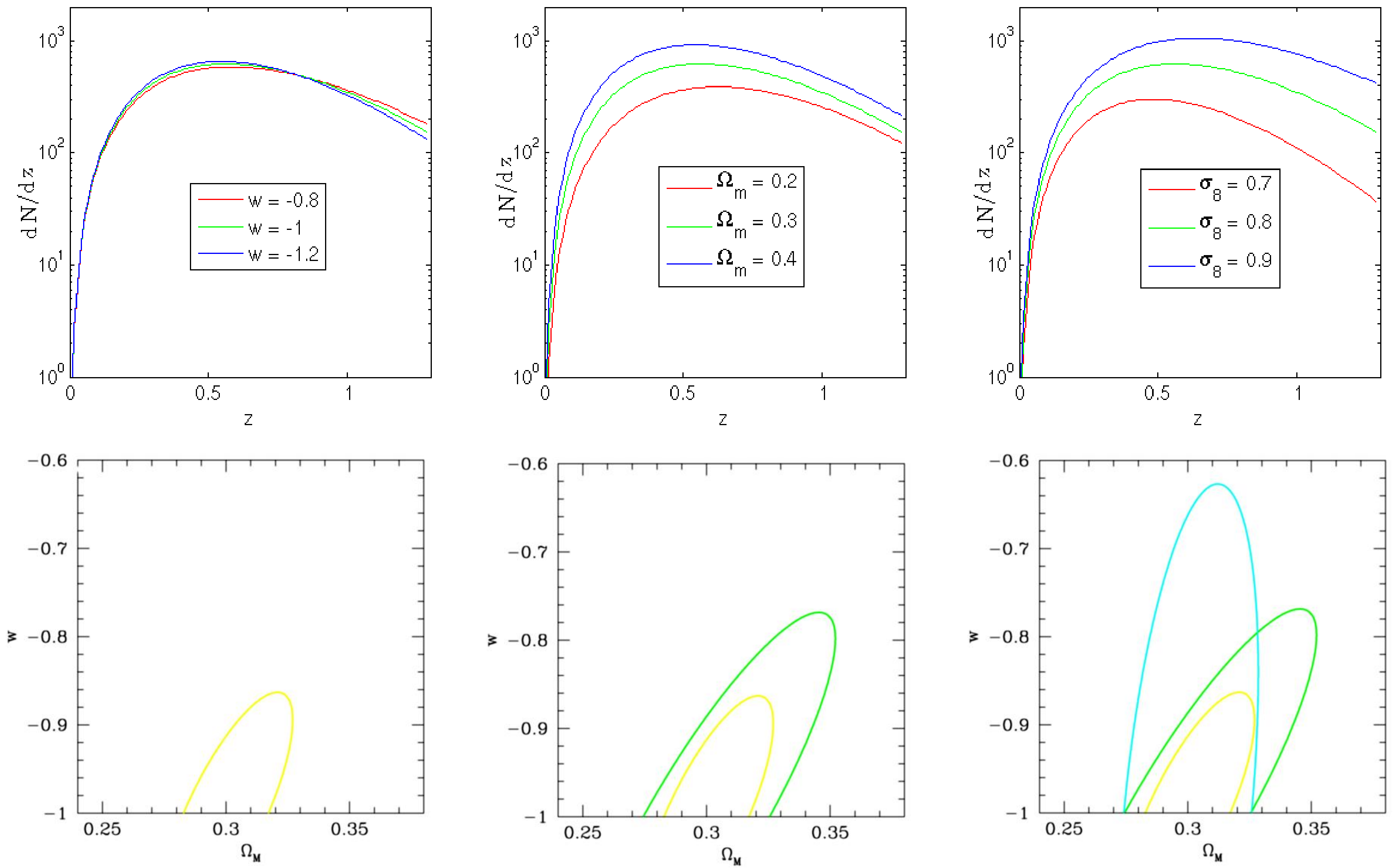


$$N(>z) = \int_{z_{\min}}^{z_{\max}} dz \frac{dV}{dz} \int_{M_{\min}}^{M_{\max}} dM \frac{dn(M,z)}{dM} F(M|z,O,sc,N,\ldots)$$

For the diffuse sky:

$$C_l = g_\nu^2 \int_{z_{\min}}^{z_{\max}} dz \frac{dV}{dz} \int_{M_{\min}}^{M_{\max}} dM \frac{dn(M,z)}{dM} \left|y_l(M,z)\right|^2$$

Cosmology with cluster numbers ?



Only cosmology
F(M|…) = 1

Uncertain F(M|O..) locally

Also need to know
z behaviour of F

The 'really' big question…
How many clusters will Planck find?

Good news: First set of Planck papers already has cluster catalog. Planck is indeed giving us an SZ selected all sky cluster catalog. Companion Planck papers have studied the cluster properties in details. Followup observations have also been done. Cross calibration with optical and Xrays done.

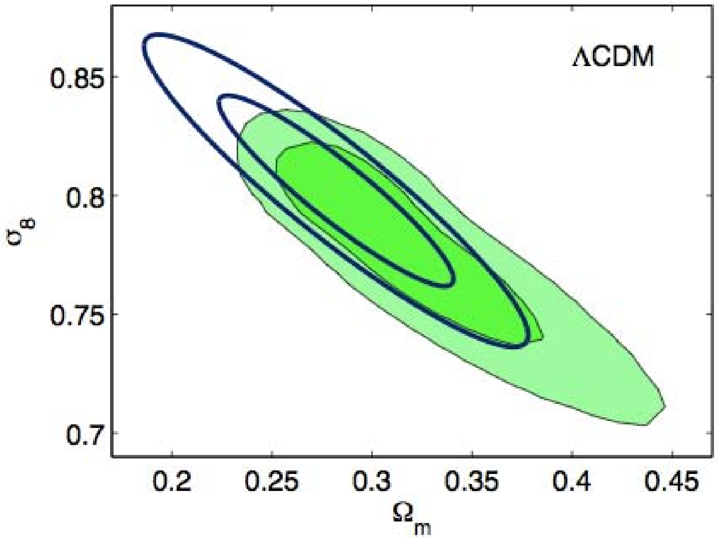
Bad News : We hoped for much larger sample!

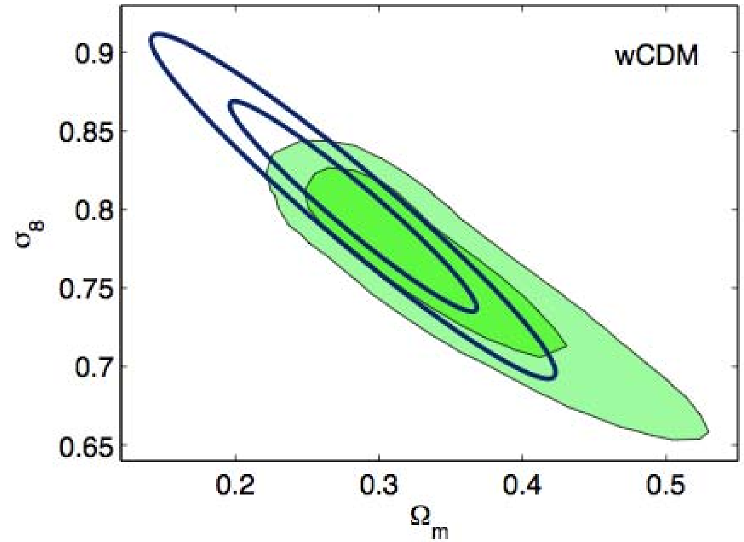
Bartelmann 2001 : N ~ few times 1e4
Moscardini etal 2002 : Mlim ~ 3.2/h e14 for z>0.2
Schaeffer & Bartelmann 2007: M>2.5/h e14 Msun between 0.2<z<0.8
SM & Mohr 2004 : N ~ 20000

Reality : N ~ 1000-2000, Mlim ~ 8e14/h Msun

Expectations (with external mass calibration) …

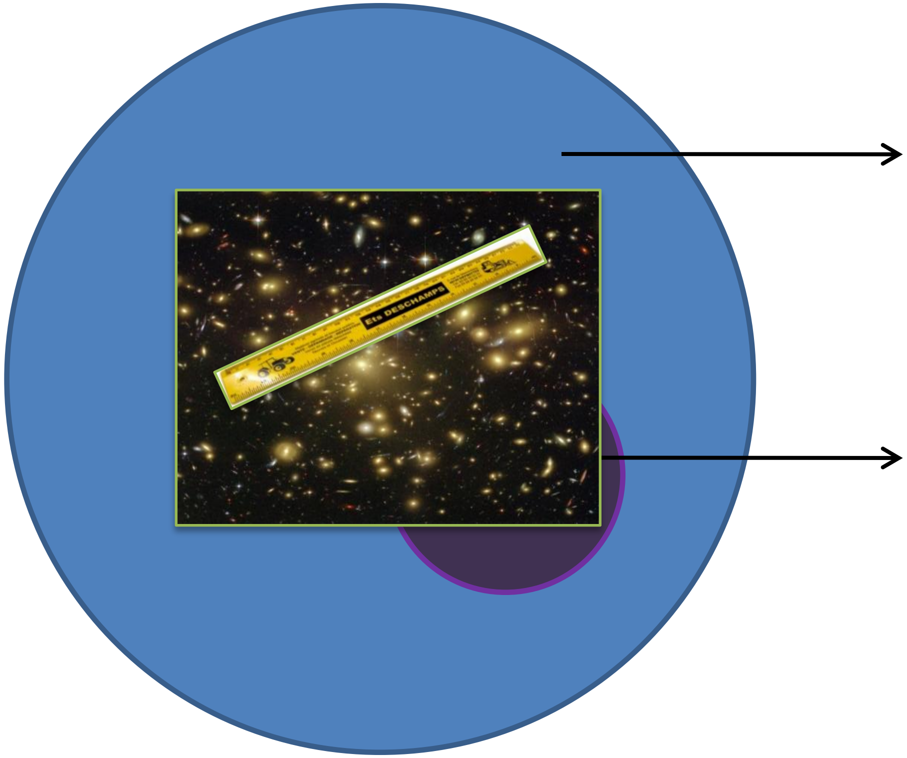
Khedekar & SM, 2011





	Planck				
model	ΛCDM		wCDM		
parameter	MCMC	Fisher	MCMC	Fisher	
Ω_m	0.044	0.039	0.064	0.057	0.01
w_0	—	—	0.199	0.189	0.175
σ_8	0.028	0.026	0.041	0.044	0.056
A	1.453	1.222	1.581	1.423	
α	0.098	0.082	0.107	0.096	
γ	0.136	0.146	0.184	0.181	

Once eROSITA is launched …



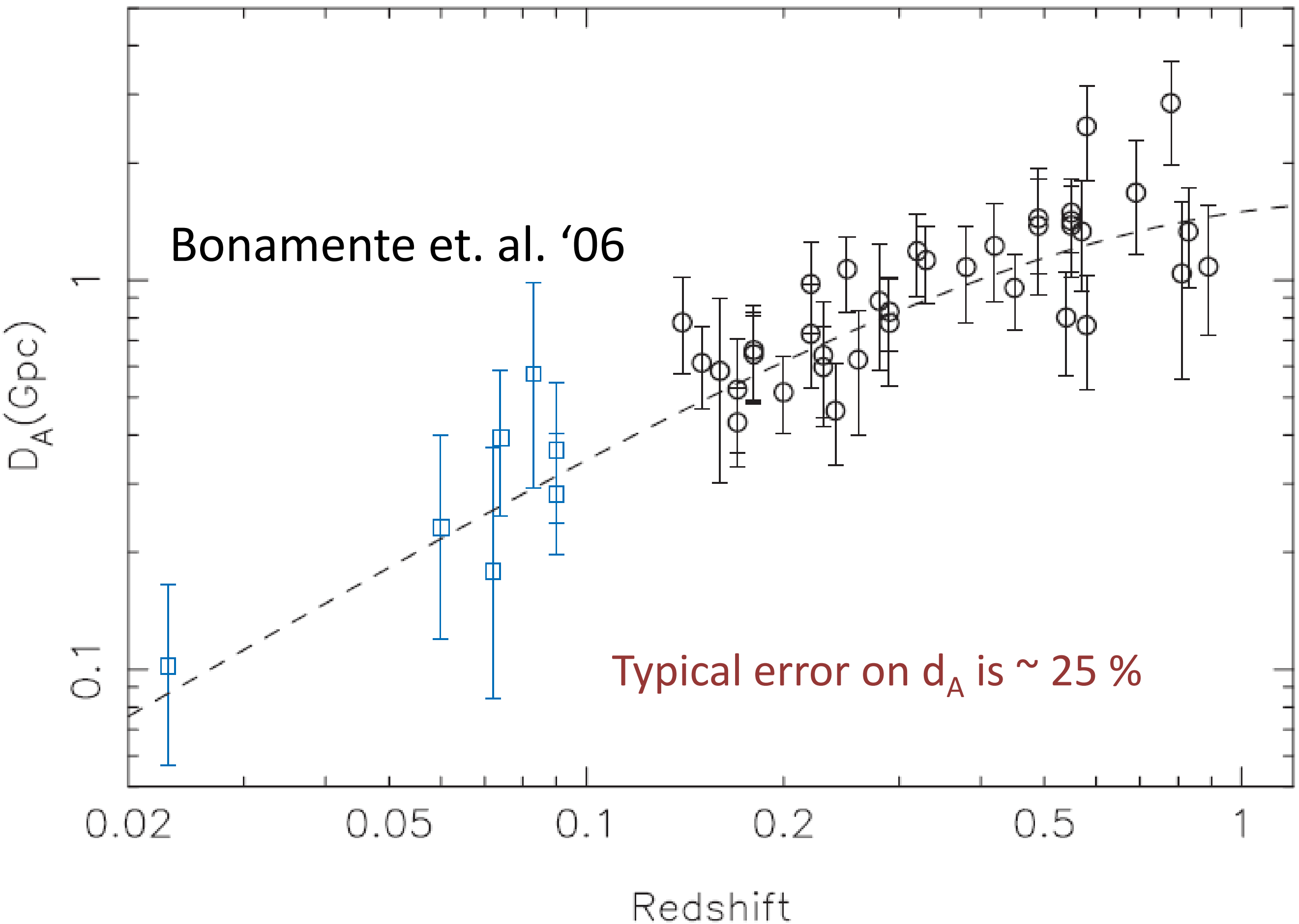
XRAY SURVEY
eROSITA ~ all sky.
(Maybe XMM at present)

SZ SURVEY
Planck ~ all sky
(also SPT/ACT ~ 2 k sq. deg.)

Find common clusters in the region of overlap between the 2 surveys.
Common clusters also ideal for Xray mass calibration (since Y-M can be compared)
--> so <T> should target these.
SZ clusters will have first go at the z's.

ESTIMATE $d_A(z)$ for each cluster.

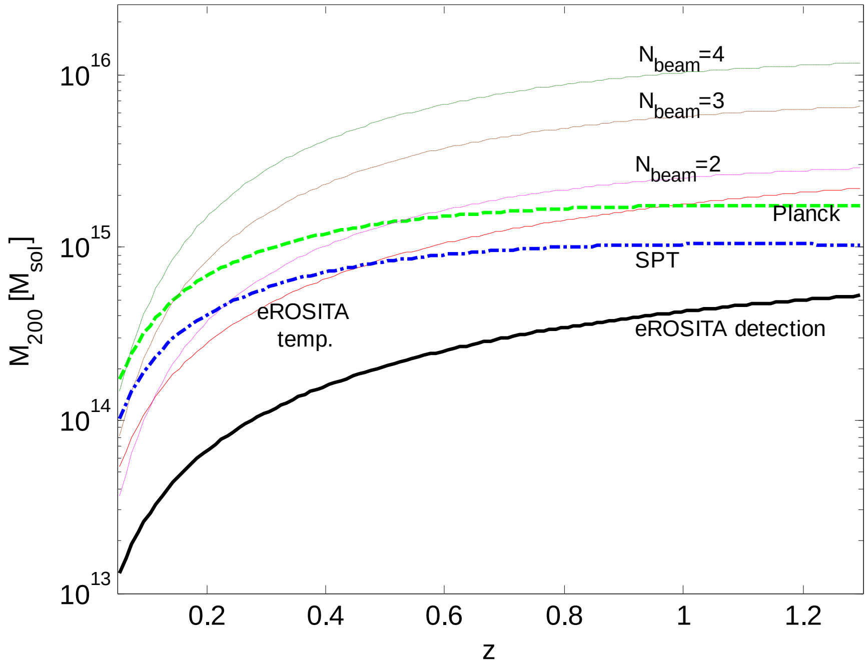
Current data on dA…

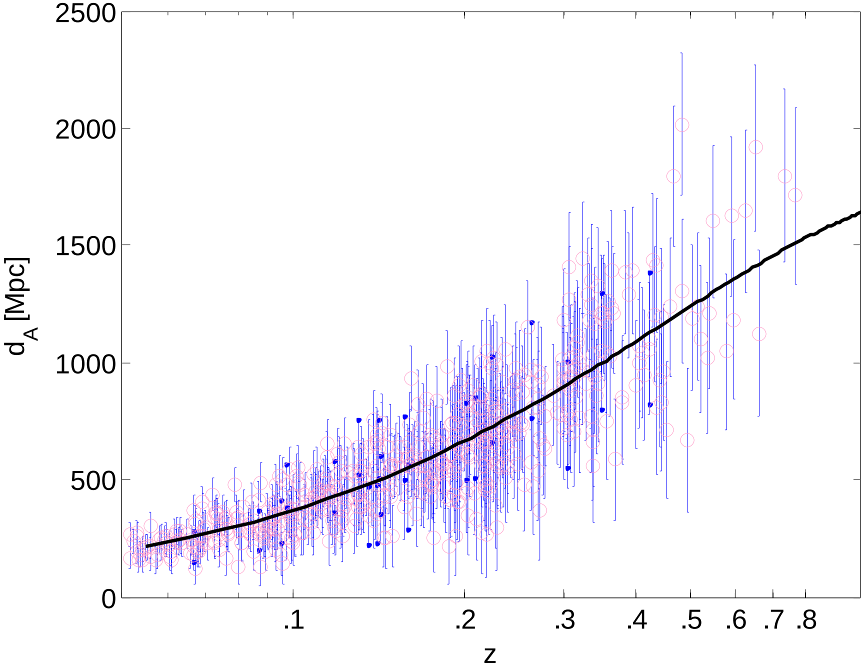


38 clusters
Chandra
+ OVRO
+ BIMA

Also Reese et. al. in '02

Xray+SZ survey synergy - making a mock $d_A(z)$ …





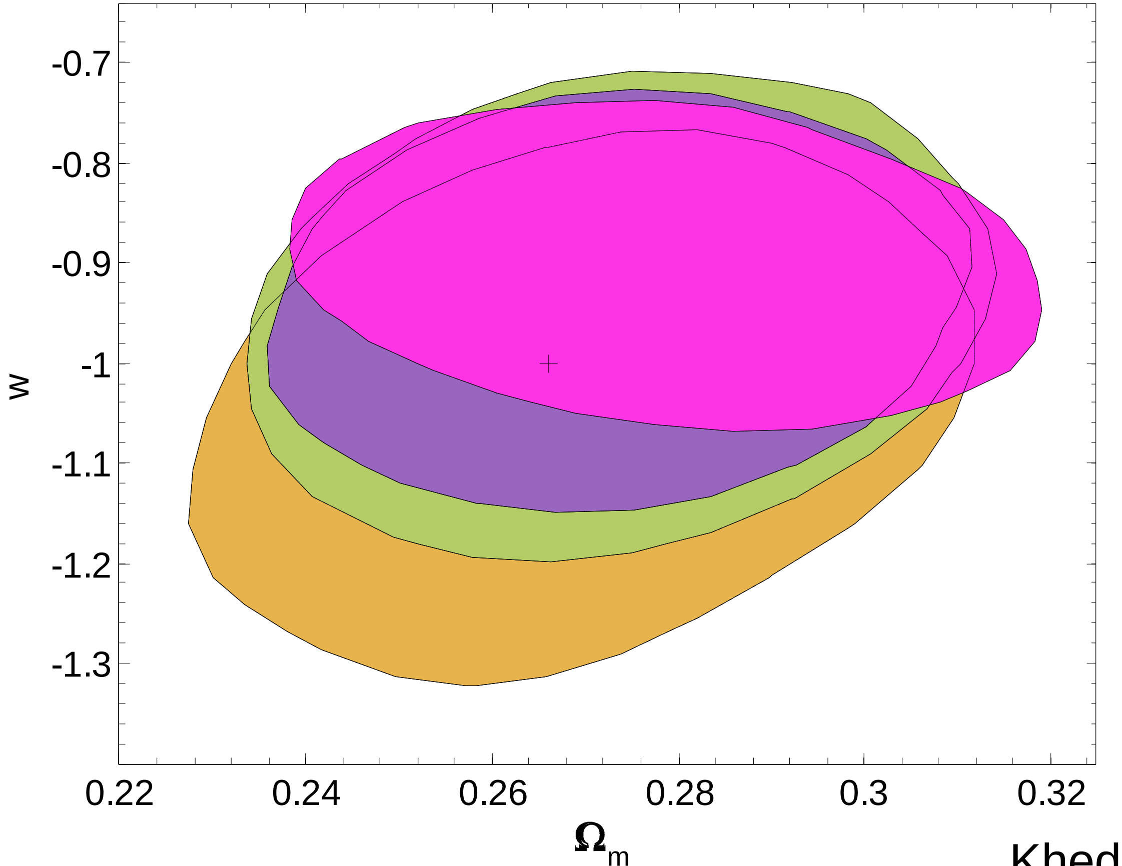
$$\theta_c \geq N_{\text{beam}} \theta_{\text{fwhm}};$$

$$\theta_{\text{fwhm}} = 16'' \text{ for eROSITA}$$

mock catalog of dA created from **SZ + eROSITA** for N_{beam}=2 with **25% errors (and scatter) in $d_A(z)$**.

Planck(dN/dz) + overlap with eROSITA

effect of various datasets… N_{beam}=2, 3, 4



Khedekar & SM 2010

Something different …

For the next few slides we'll leave Planck and go to Xray survey and use Planck cluster data as calibrator.

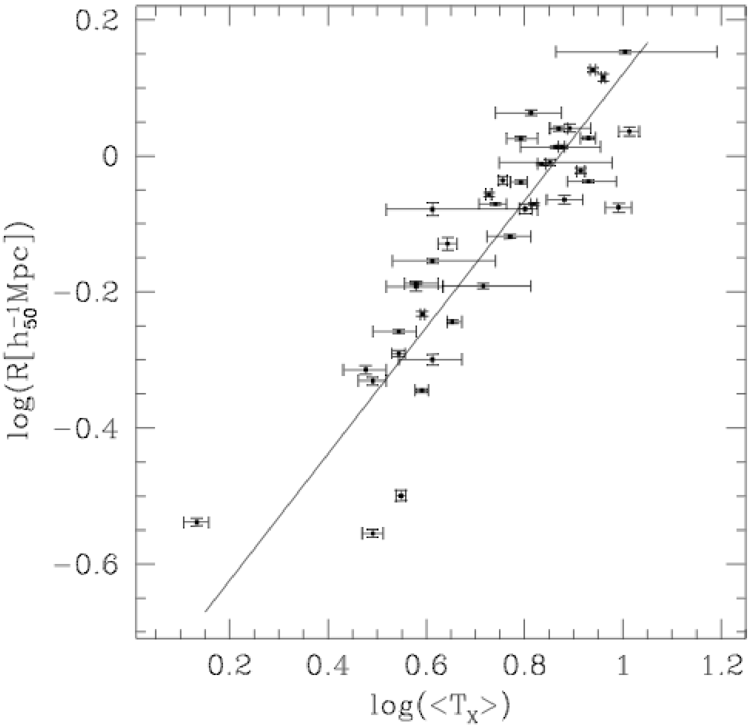
Something for the future: The Wide Field Xray Telescope
(PI - Riccardo Giacconni)

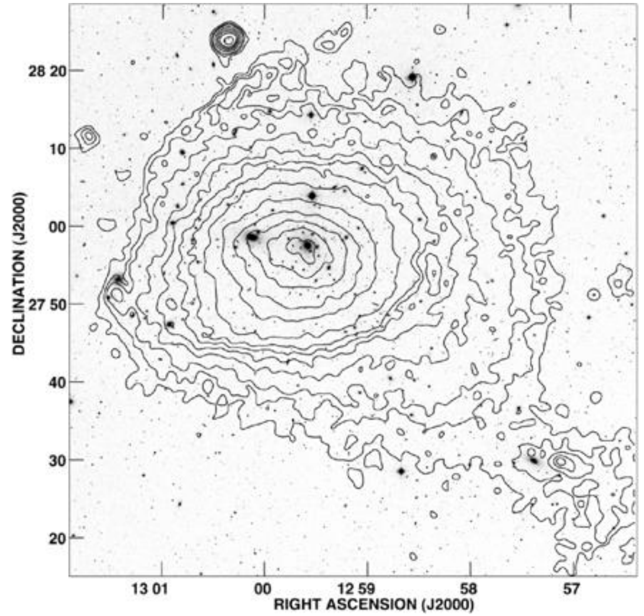
Xray Isophotes and scalings…

$$I(R) = A\Lambda\rho_0^2 R_c\left[1+(R/R_c)^2\right]^{-3\beta+1/2}$$

$$f_{ICM} = \frac{4\pi\rho_0 R_c^3\int_0^{R_{vir}/R_c} d\lambda\,\lambda^2(1+\lambda^2)^{-3\beta/2}}{M_{vir}}$$

$$I(R) = C\, f_{ICM}^2\, R^{-6\beta+1}$$





$$R_I = \sqrt{A_I/\pi}$$

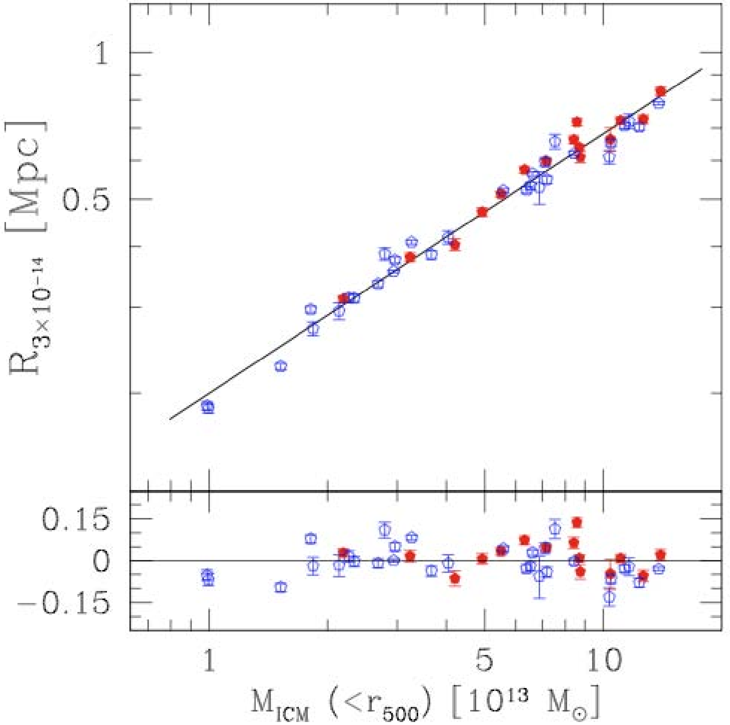
$$\log R_I = (0.93\pm0.11)\ \log\frac{\langle T_X\rangle}{6\ \mathrm{keV}} - (0.08\pm0.01)$$

AN X–RAY SIZE–TEMPERATURE RELATION FOR GALAXY CLUSTERS: OBSERVATION AND SIMULATION

Joseph J. Mohr[1,2] & August E. Evrard[1,3]

A very low scatter scaling …

Scaling Relation	Original Relations σ_{int}	Simulations[a] σ_{int}
$M_{ICM}(<r_{500})–T_X$	0.17	0.20
$M_{ICM}(<r_{2500})–T_X$	0.22	
$L_X(<r_{500})–T_X$	0.53	
$L_X(<r_{2500})–T_X$	0.67	
$L_{XCS}(<r_{500})–T_X$	0.28	0.27
$R_{3\times10^{-14}}–T_X$	0.14	0.10
$R_{1.5\times10^{-13}}–T_X$	0.17	
$L_{NIR}(<r_{500})–T_X$	0.19	
$R_{3\times10^{-14}}–M_{ICM}(<r_{500})$	0.06	
$R_{3\times10^{-14}}–L_{XCS}(<r_{500})$	0.05	
$R_{3\times10^{-14}}–L_{NIR}(<r_{500})$	0.16	



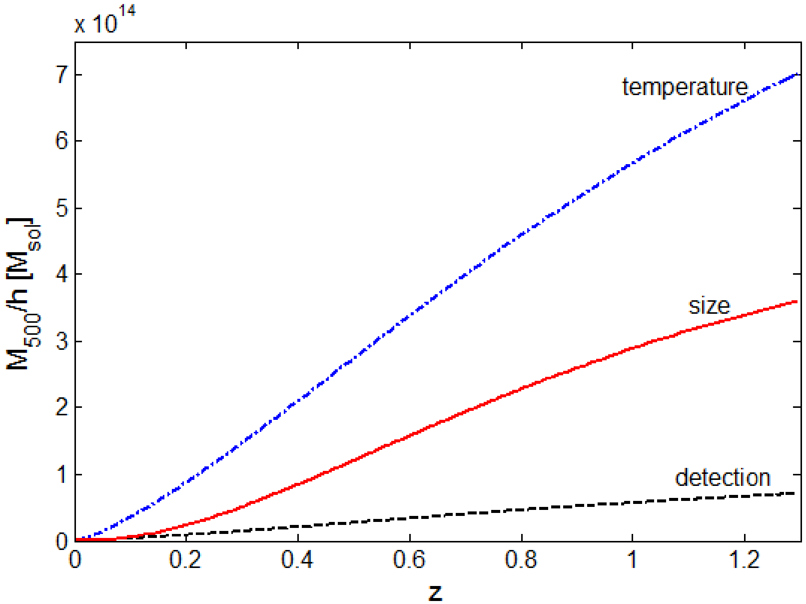
Compare this with ~10% scatter of Y_X-M reln (with central region excised)

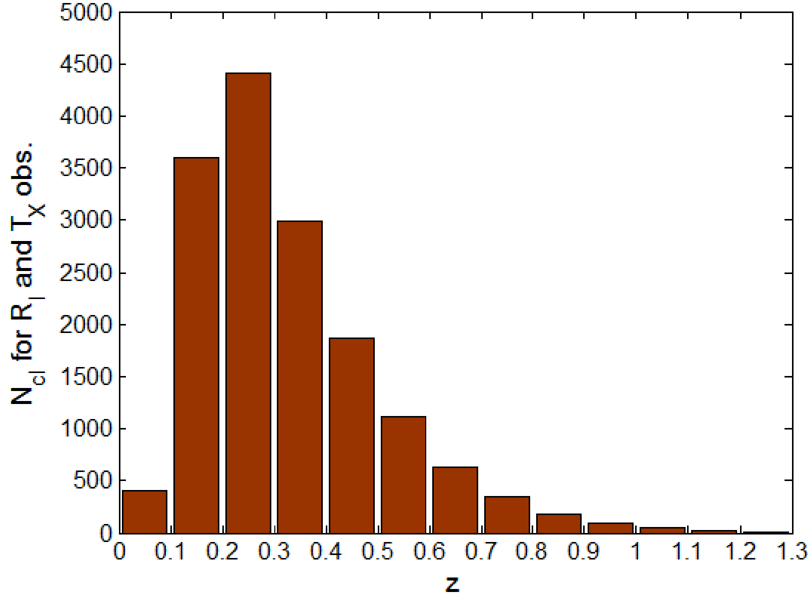
Given that M_{gas}-M_{tot} has very low scatter --> R_l-M_{tot} very low scatter.

(O'Hara etal 2006)

Constructing a mock catalog of WFXT isophotes .

Khedekar, SM & Mohr, 2011





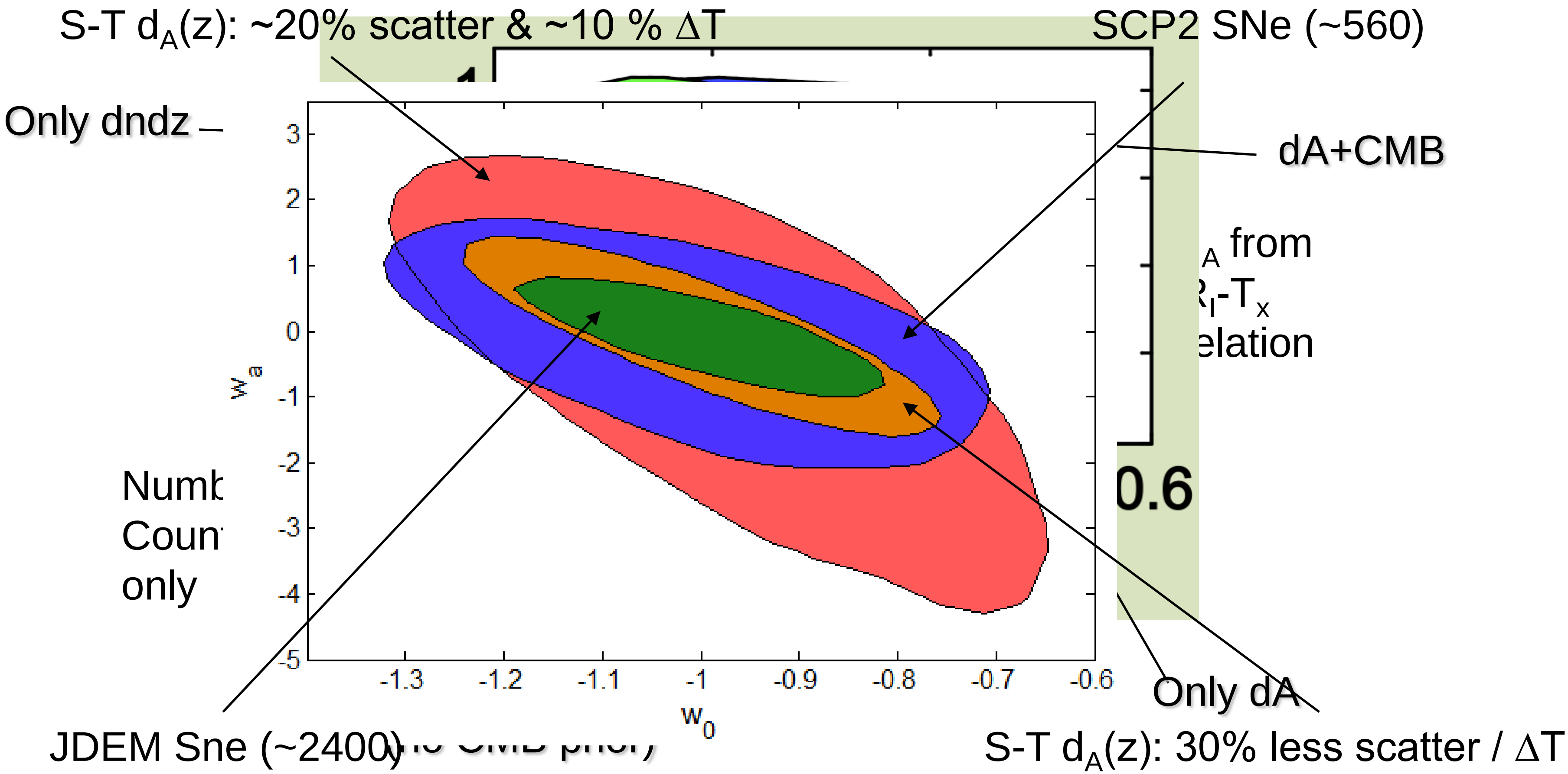
~15,000 clusters assuming a minimum of 2000 photon cts in [0.5-2.0 keV] band.

Isophotal sizes of all these clusters may be determined with a high precision ($\theta_I \geq 10\ \theta_{beam}$).

$$\frac{\Delta\theta_I}{\theta_I} = \frac{1}{2}\frac{\Delta A}{A} \simeq \frac{1}{\sqrt{2\pi}}\left(\frac{\theta_b}{\theta_I}\right)^{3/2}$$

~ 1% error

First attempt at cosmology with size – temp from Xrays : Use Planck clusters as calibrators



Very conservative estimate - Unknown evolution is the killer as its completely degenerate with w(a) when distance is measured.

More about internal calibration with Planck SZ cluster sample

And connected to it - the SZ power spectrum.

But first: lets talk Universal features in clusters.

Universal Profiles…

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

for isolated halos,
e. Based on GNFW
model (Nagai etal)

$$P_U \sim f(r_{500}, P_{500})$$

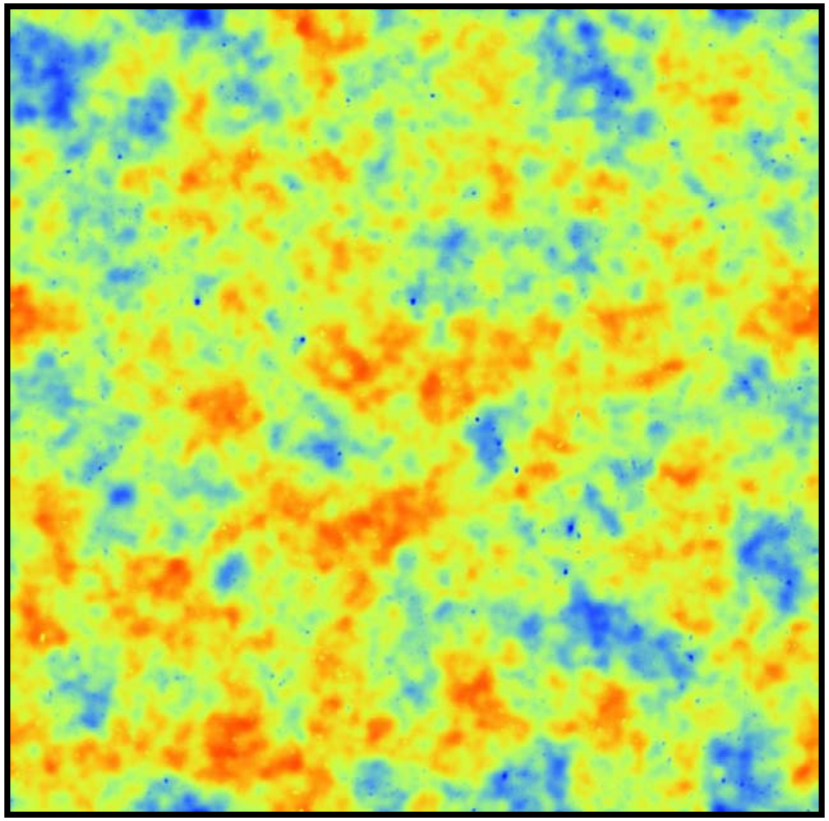
$$P_{500} \sim g(M_{500}, r_{500})$$

gas do no show universality.
ed it a year before) that

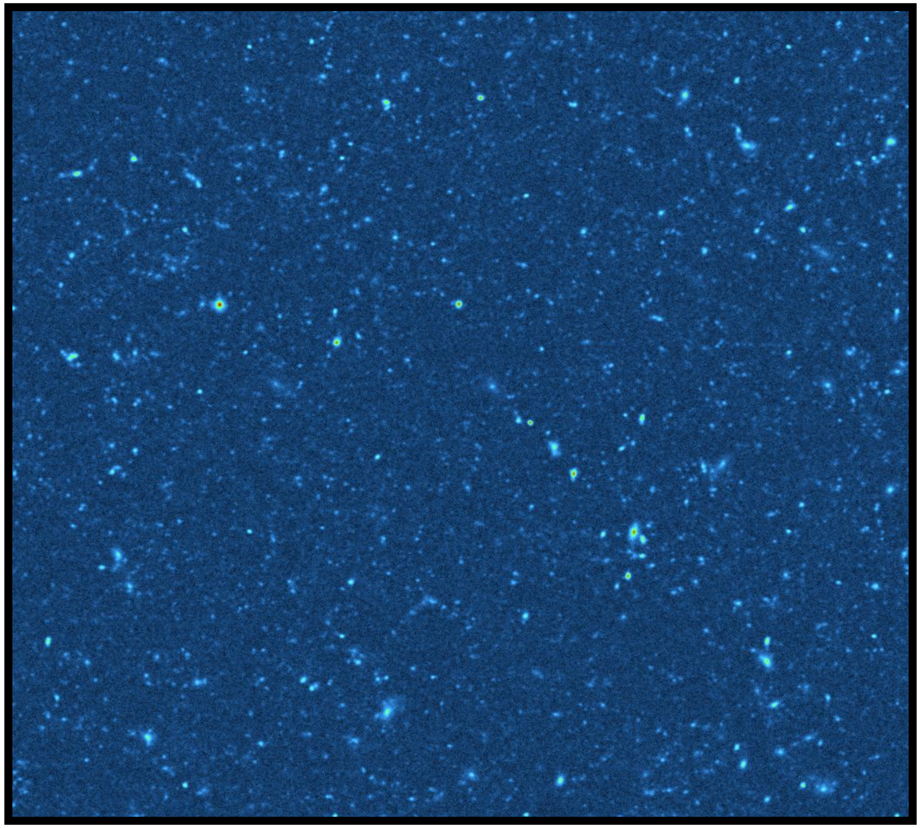
Arnaud etal 2010

All models now ‘must’ reproduce this universal profile in shape & amplitude for any given cluster mass.

Planck SZ power spectrum ..



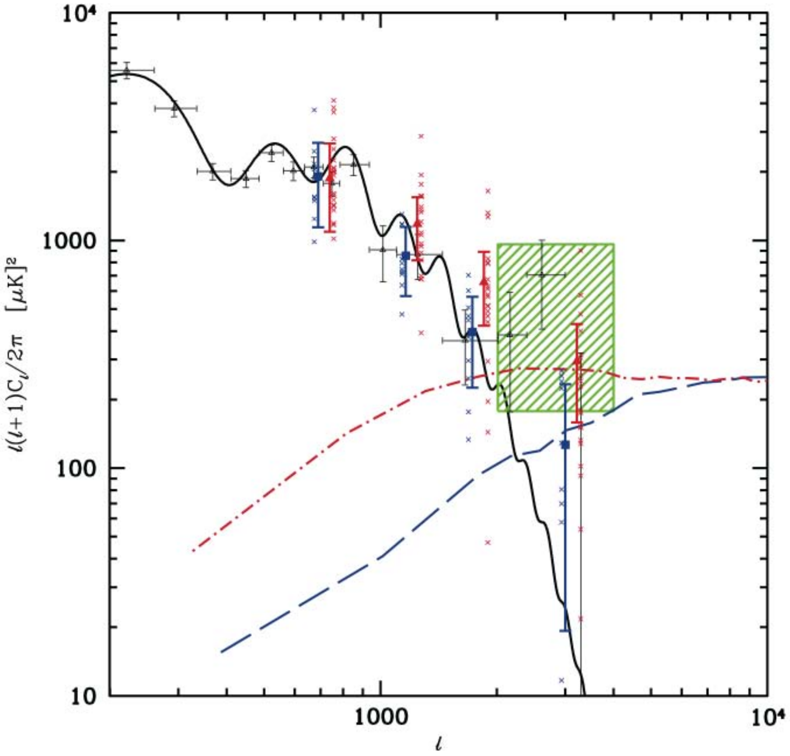
10^o x 10^o map
145 GHz



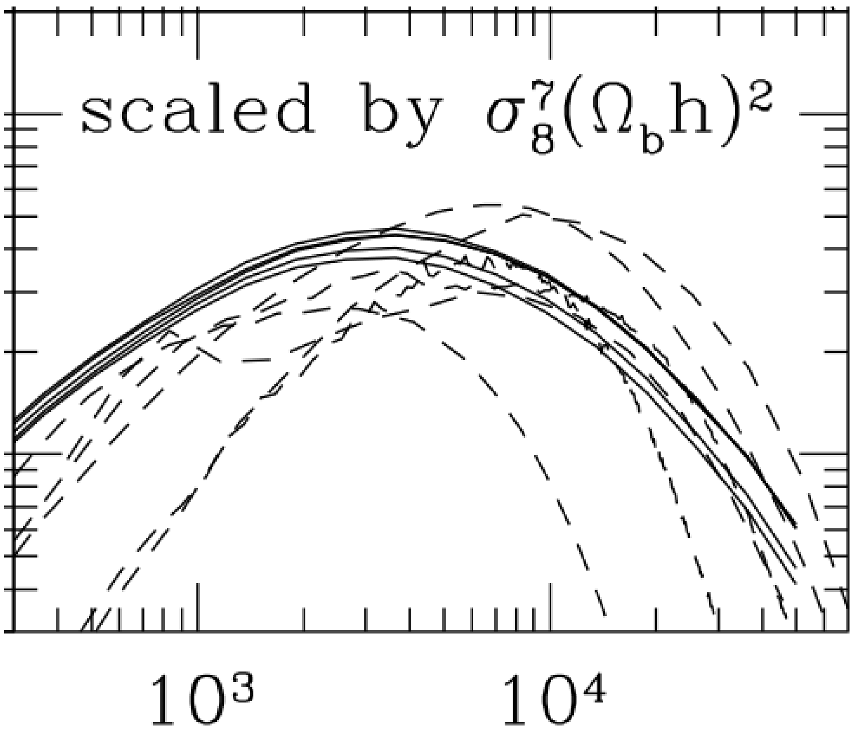
Diego & SM

$$C_l = g_\nu^2 \int_{z_{\min}}^{z_{\max}} dz \frac{dV}{dz} \int_{M_{\min}}^{M_{\max}} dM \frac{dn(M,z)}{dM} |y_l(M,z)|^2$$

More on SZ power spectrum - Importance of modelling



KS 2001



CBI observations
(ask Carlo)

Comparison of analytic and simulation models *till 2009*.

Factor of 2 offset in SZ power --> 0.1-0.15 offset in value of sigma8 !

Current (2011) agreement to SZ Cl's from different group ~ 20%.

To be competetive with Planck CMB constraint in sigma8 ($\sim\Delta\sigma_8 = 0.01$), we need to know SZ Cl to < 10% accuracy.
This is not easy to do in 'bottom up scenario'.

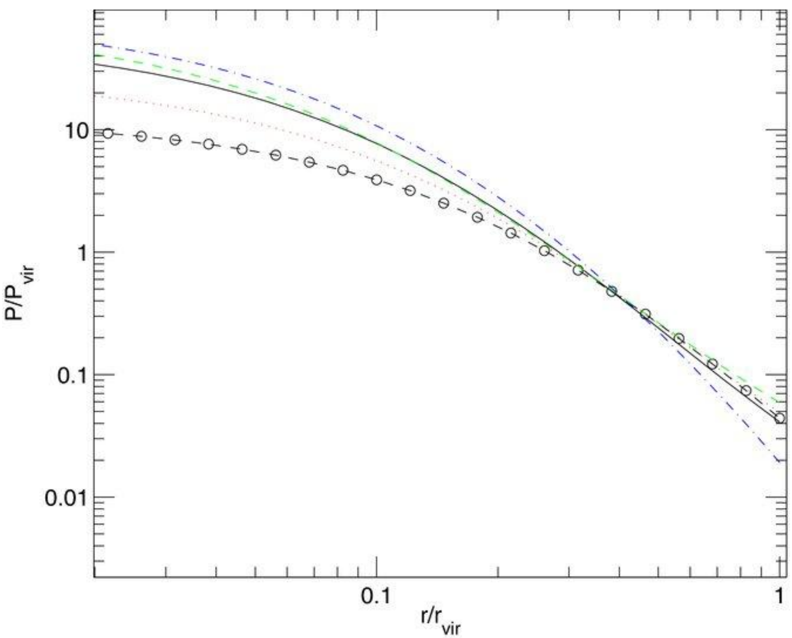
Ultimately, we want cluster 'pressure template' to be accurate to ~10-15%
We also need to know how this template evolves with redshift.

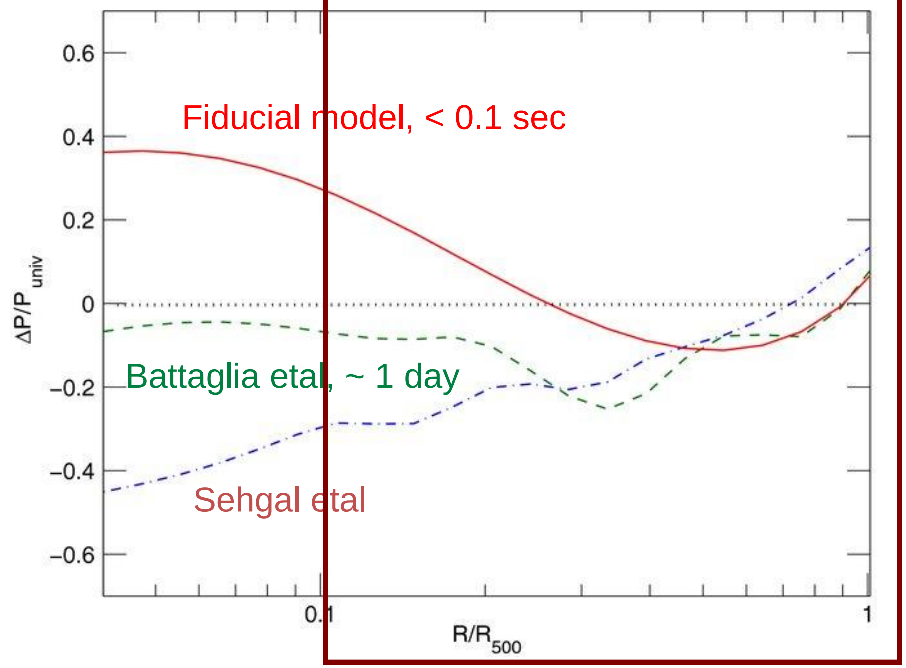
----> First step- build a simple 'phenomenological models' and calibrate it to SZ cluster observations (especially from within Planck).
The model also needs to be computationally fast.

Note: We use Planck Y-T reln for calibration.

Pressure profile for the clusters -

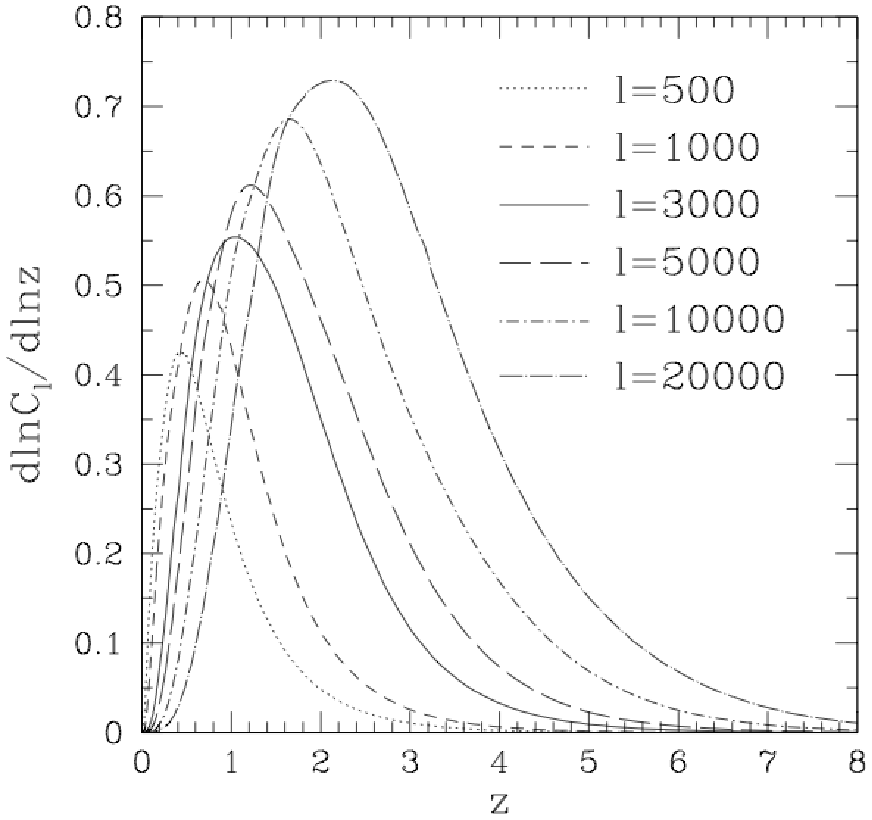
A simple, semi-analytic, phenomenological, iterative model which uses known (say Xray scaling relns) as inputs for normalization along with a non-thermal pressure component.



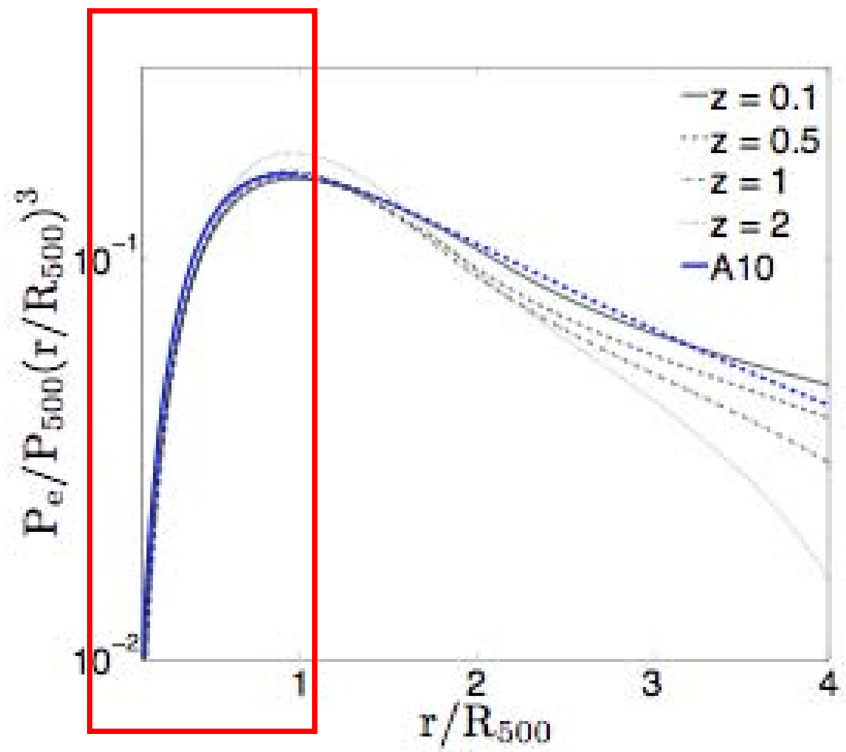


Compares well with Universal Pressure profile and the Y-M_{500} relns.
Very fast and so can be efficiently used in MCMC (just for SZ Cl or jointly with Xray scaling observations!) Chaudhuri & SM, 2010

SZ Cls - Importance of understanding evolution of pressure profile at high-z



Komatsu & Seljak2003



Shaw etal 2010

ICM Entropy …

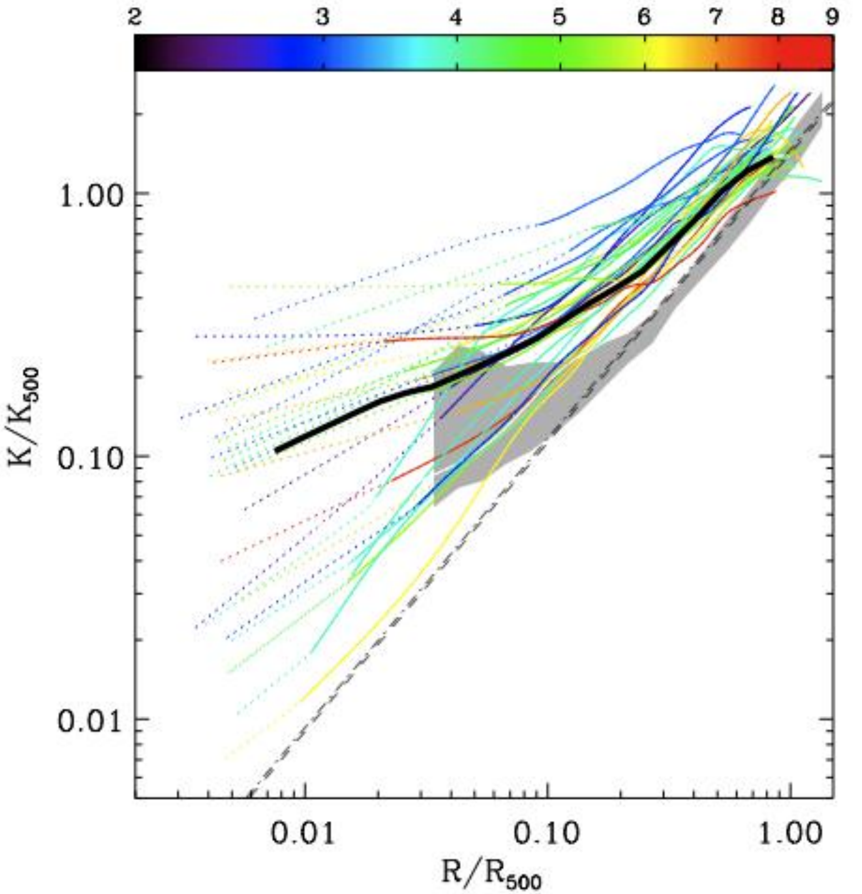
Entropy is fundamental because-
1) determines structure of the ICM
2) record the thermodynamic history of ICM.

Entropy distribution and DM potential completely determines the Xray properties of a relaxed cluster

The gas density and temperature profiles in this state of equilibrium are just

manifestations of its entropy distriution.

From Voit 2005

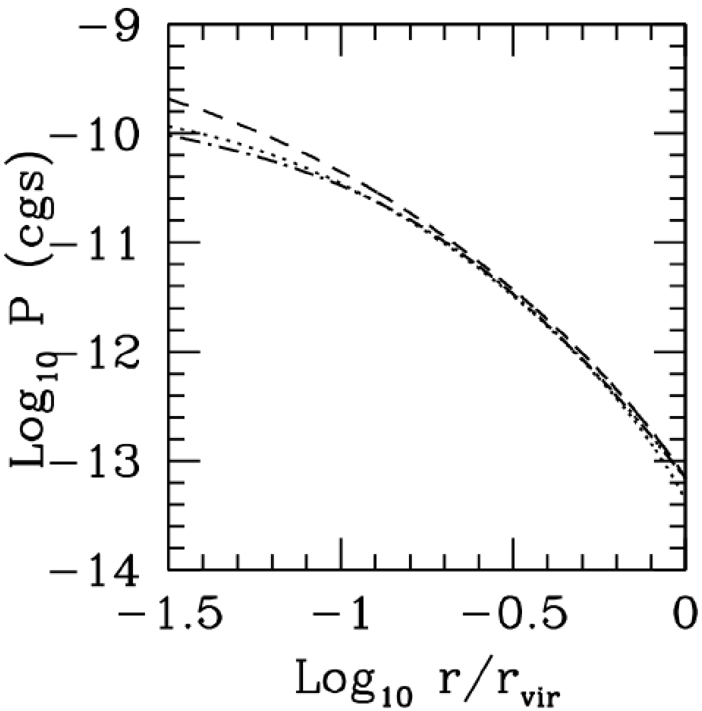


For clusters, Entropy: $S = k_B T n_e^{-2/3}$

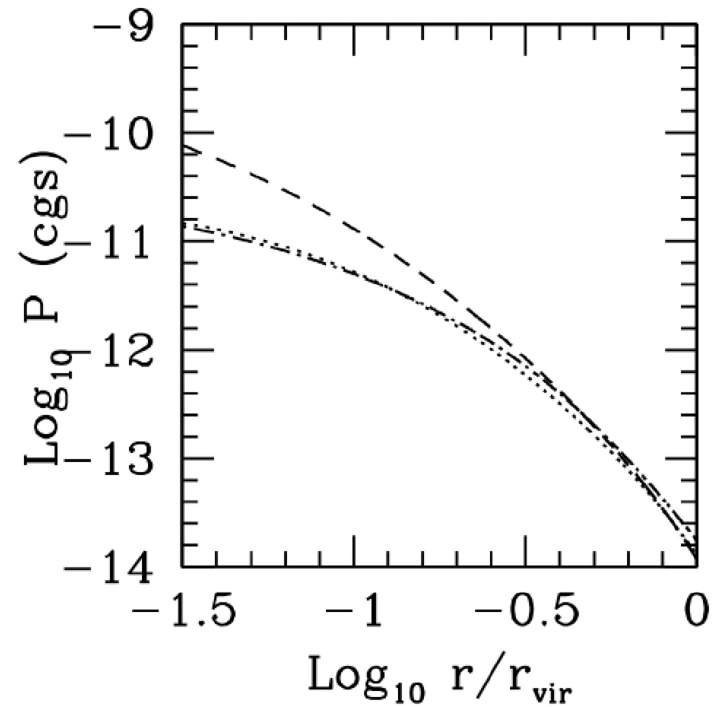
Entropy gives us an idea of the energy/particle in ICM

Pratt etal 2010

The prescription -



M = 10^{15}/h M_0



M = 10^{14}/h M_0

A "Universal" Entropy *Injection* Prescription

$$S_{inj}(F_g) = 200\,\mathrm{keV\,cm^{-2}} + 2\times\left(\frac{M_{vir}}{10^{14}\,h^{-1}\,M_\odot}\right)^{-0.2}\times S_i(F_g)$$

Nath & SM 2011

$z = 0$, for $10^{14} \leqslant M_{vir}/M_\odot \leqslant 10^{15}$

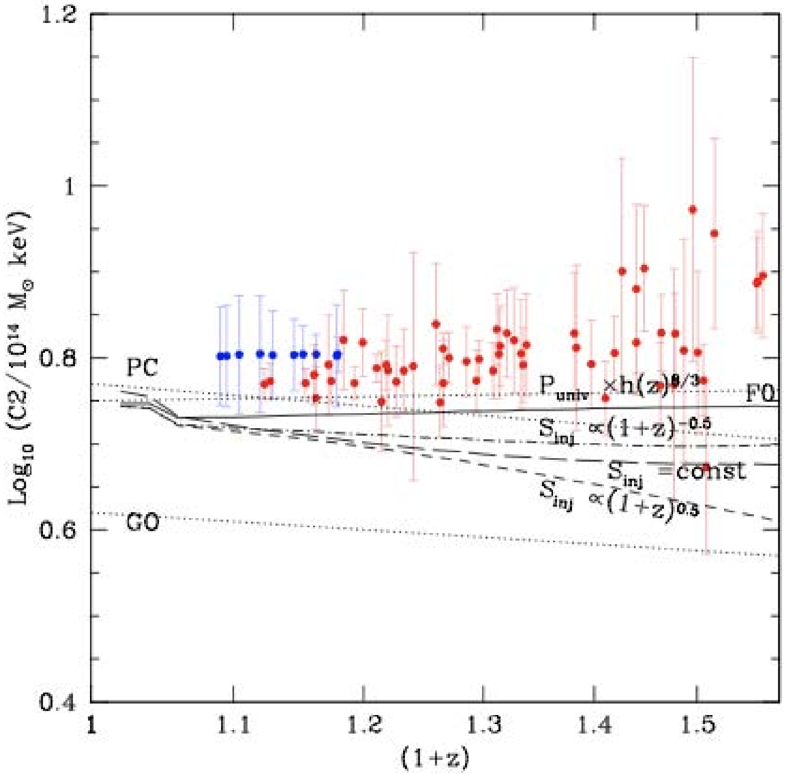
The Redshift Evolution of Entropy Injection

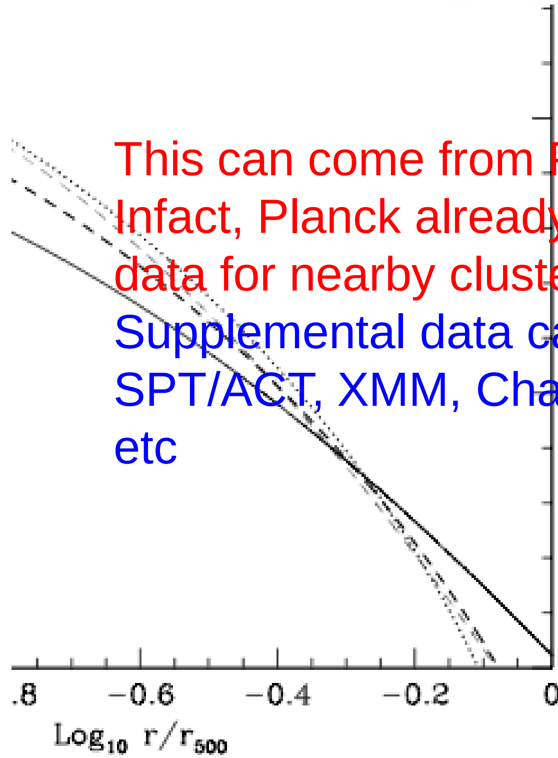
Prescription

$$S_{inj}(z) = (1+z)^{\alpha} S_{inj,z=0}$$

Look at this scaling:

$$Y_X E(z)^{-2/3} = C2\left(\frac{M_{500}}{5\times10^{14}\,h^{-1}\,M_\odot}\right)^{\alpha}$$





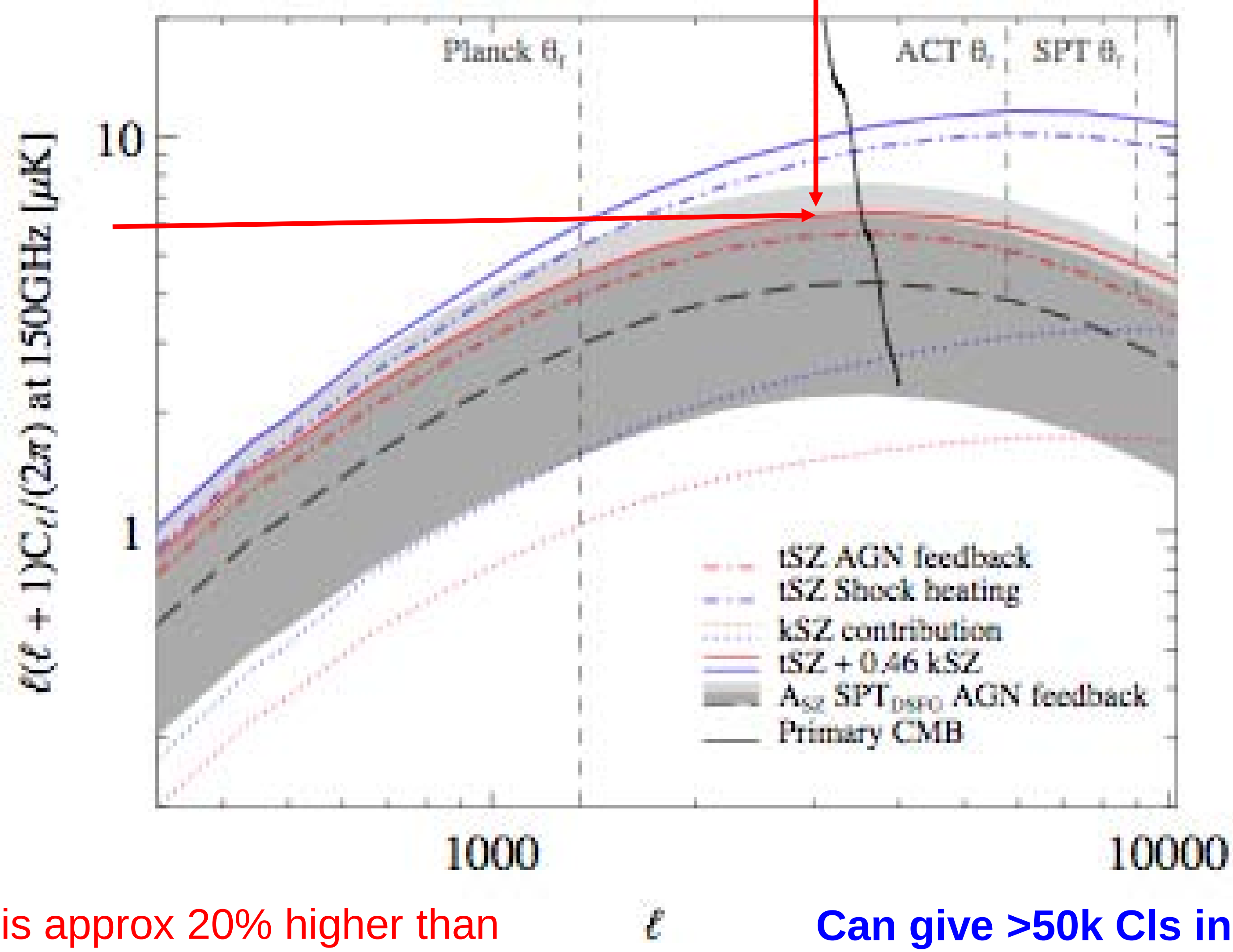
This can come from Planck data. Infact, Planck already has the first data for nearby clusters.

Supplemental data can come from SPT/ACT, XMM, Chandra, eROSITA etc

Atleast $S_{inj} \propto E(z)^{-2/3}(1+z)^{0.6}$

Needs more evolution than 'self-similar' scaling. At least $S_{inj} > (1+z)^{-1}$, i.e,

Finally, the SZ Cl…



SZ Cl is approx 20% higher than

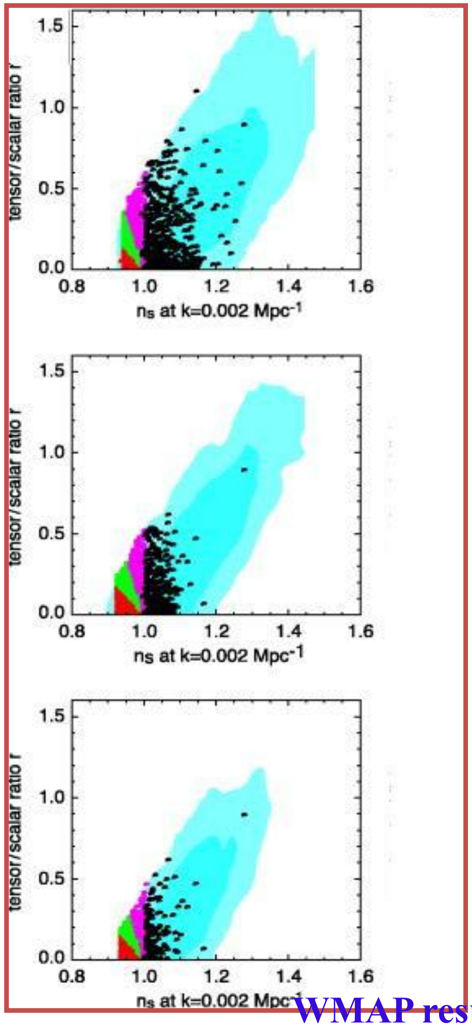
Battaglia etal.

Can give >50k Cls in the same time

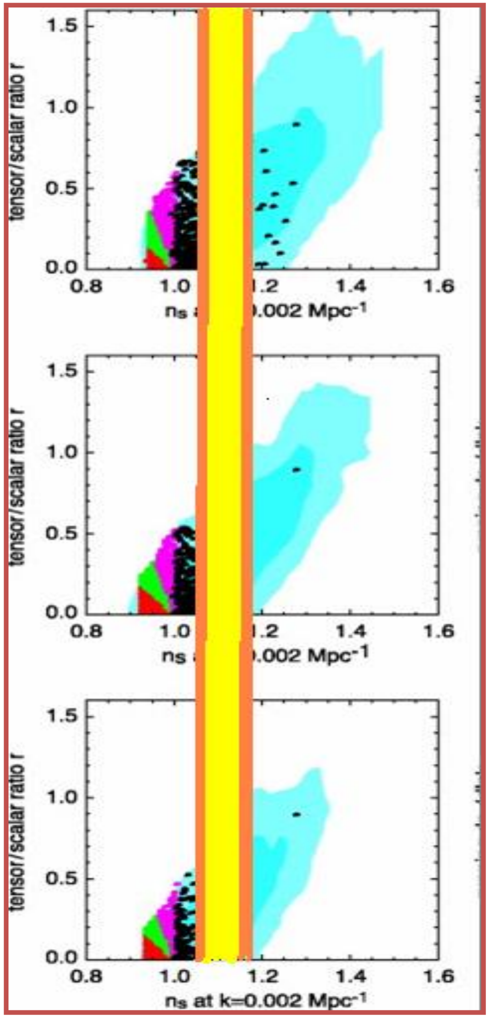
varying cosmo and gas physics.

Constraining inflationary models:

CMB



CMB
+
Clusters



WMAP results from Peiris etal 2004

Summary …

Planck is the first full sky SZ experiment. It will provide us with full sky SZ cluster catalogs and SZ diffuse maps for power spectrum.

The cluster numbers are small that past expectations (many reasons).
However,clusters alone can give competitive constraints on Ω_M and σ_8 compared to CMB anisotropies in Planck.
Needs extra info to give constraints on 'w'

Combined with Xray surveys, Planck clusters can trace out dA(z).

Planck clusters serve as very good calibration sample for -

1) Other dA(z) with clusters
2) Model calibrations for gas pressure profile and SZ Cl.

tifr

THANKS…