conference summary

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Mahalo!

Sponsors

fact/question responses:the tally…

72 total

- 69 anonymous
- 14 frivolous
- 1 sublime?
- 58 serious
  - 22 facts
  - 45 questions

some of the silly stuff

Did you know there are whales in front of the resort?

How can we learn to hula dance? How can we master fire dance?

Why are cluster astronomers so cool?

I want time to swim!!

When do clusters cease to exist?

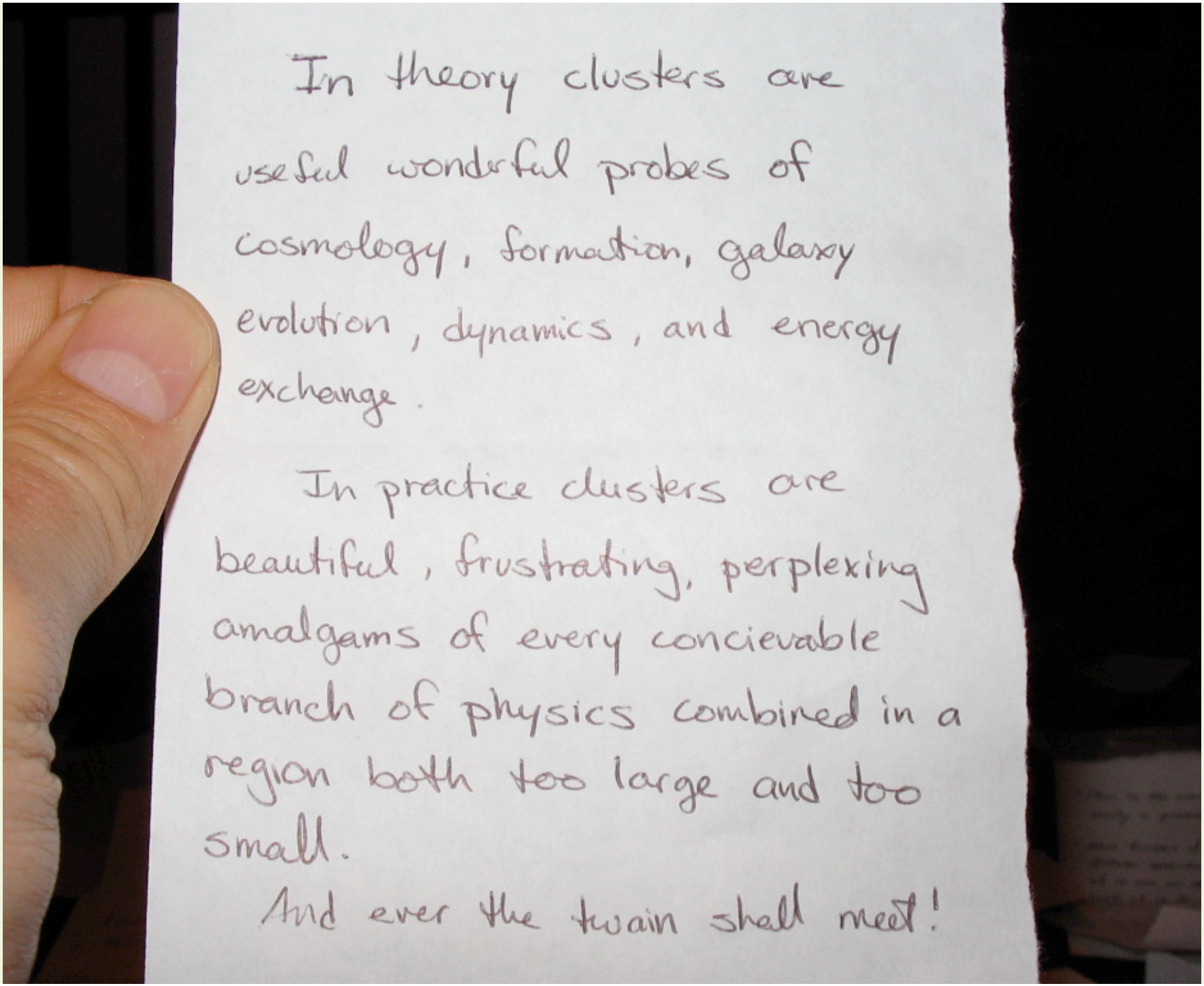
All possibilities are things.

Can we make something out of dark energy that is useful for everyday life?

What does President Bush know about cosmology? And why does he not know anything at all?

Who is the greatest organizer of conferences on galaxy clusters?

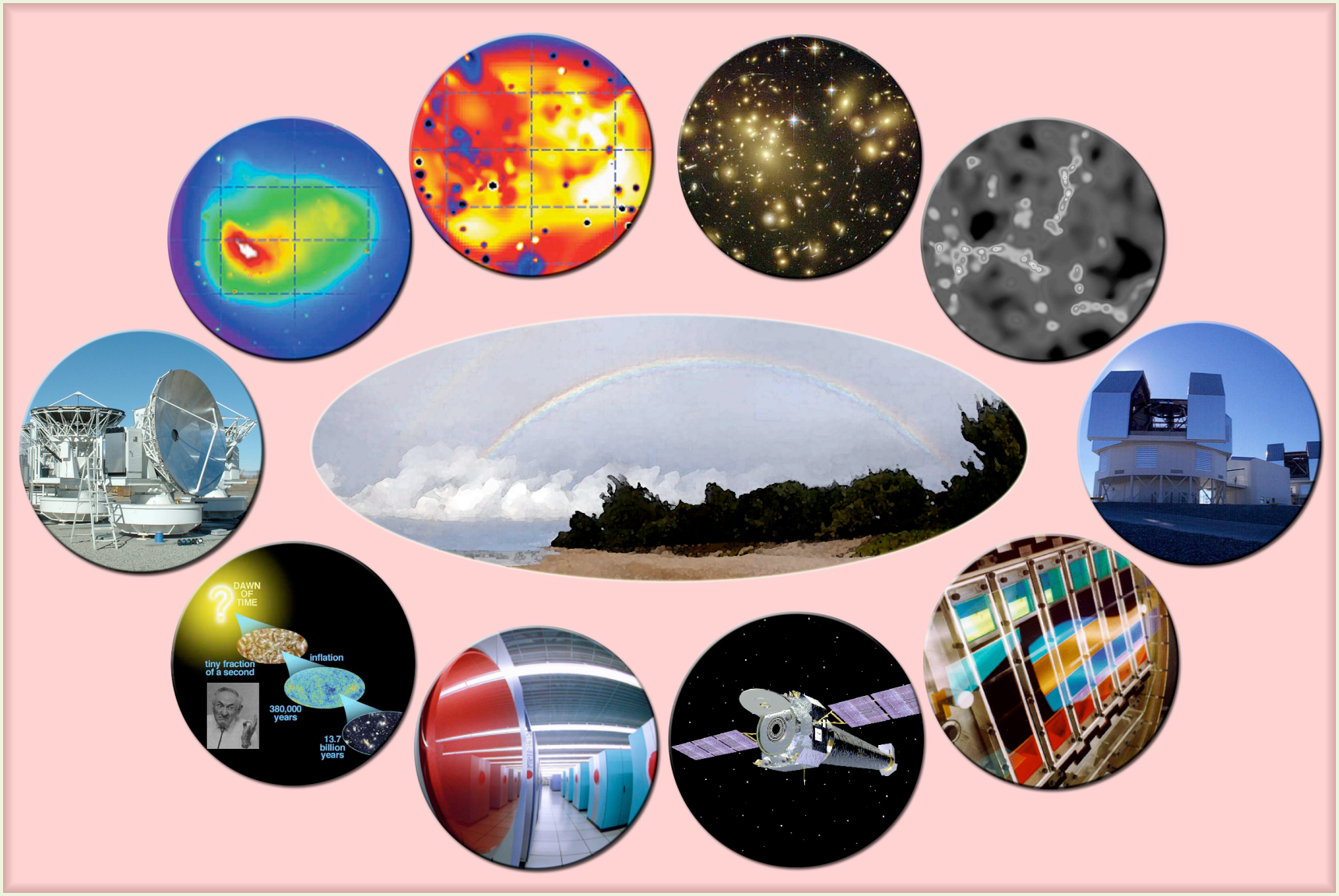
Clusters are the most massive collapsed objects in the uni.

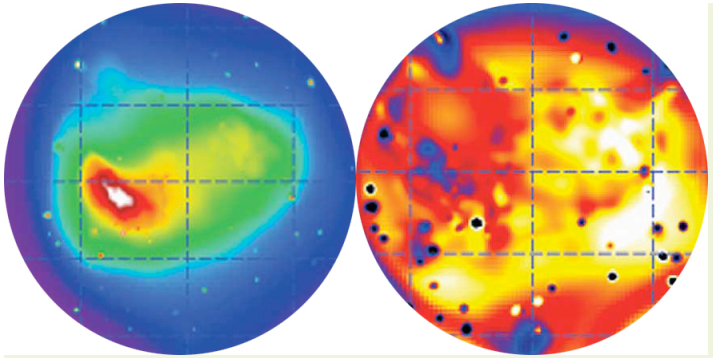

In theory clusters are useful wonderful probes of cosmology, formation, galaxy evolution, dynamics, and energy exchange.
In practice clusters are beautiful, frustrating, perplexing amalgams of every concievable branch of physics combined in a region both too large and too small.
And ever the twain shall meet!

The Future of Cosmology with Clusters of Galaxies

27 Feb - 2 Mar 2005

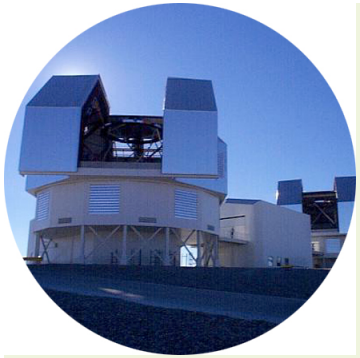
Waikoloa Beach Marriott Resort, Kona, HI

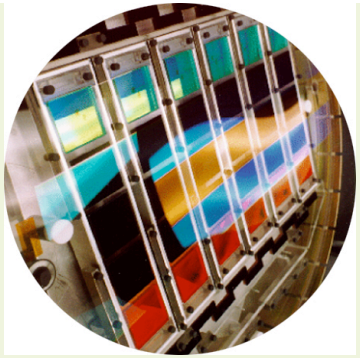




F. X-ray clusters are massive systems.
F. I am positive that clusters of galaxies evolve self-similarly.
F. I am sure that the baryon fraction inside the virial radius of clusters with mass > 1e15 Msun is at least 90% of the true universal value. (C. Frenk)
F. AGN's are the solution to the cooling flow problem.
F. AGN are the leper messiah of astrophysics.

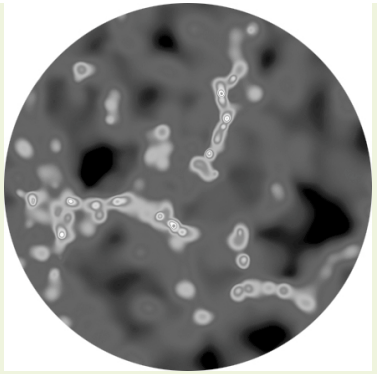
Q. Will we ever be able to tell that any cluster is in hydrostatic equilibrium?
Q. What is the highest redshift cluster that will be detected by XMM?
Q. Why does the [local] observed Lx-T relation of clusters not follow the self-similar prediction, even though the evolution with redshift does?
Q. Why is there still no next X-ray all-sky survey?
Q. Is the cooling flow problem really solved?





F. Optical surveys suck.
F. Galaxy cluster populations seem to be younger/bluer at both larger distances from the cores of clusters and at lower masses.
F. Rich clusters have more ellipticals than spirals.

Q. What fraction of baryons in clusters is in stars?
Q. What fraction of the stars are in the diffuse ICL? How much of it is detected today?
Q. I hope to know how well cluster galaxies trace the dark matter.
Q. Are there blue clusters (at $z<0.3$)?
Q. Does the poor X-ray appearance of RCS clusters indicate that multi-color optical selection @ high-z selects projected (aligned) supercluster filaments?
Q. What is the lack of low-z giant arc systems telling us?



F. Clusters exist at z>1.

F. Clusters are messy objects; clusters are the simplest astrophysical objects.

Q. What cluster-mass observable has been calibrated to an accuracy of 5%?

Q. Is the SZ flux going to be really as small-scatter a mass proxy as simulations suggest?

Q. Can scatter in the mass-observable relations be adequately handled by self-calibration, enabling a precision measurement of w?

Q. How do you (usefully!) define a virial radius observationally, and can we do it with current SZ instruments?

Q. How problematic are AGN's for SZ surveys!

Q. What is the best sample of clusters to use for cosmology?

Q. What is the epoch of cluster formation?

F. Clusters are remarkably regular, but not spherical, isothermal, self-similar or in [perfect] hydrostatic equilibrium.

F. “Virial mass” and “formation redshift” are not well defined terms.

Q. What is the thermal energy of a cluster of mass M?

Q. How well could I ever measure the mass of clusters on an object by object basis?

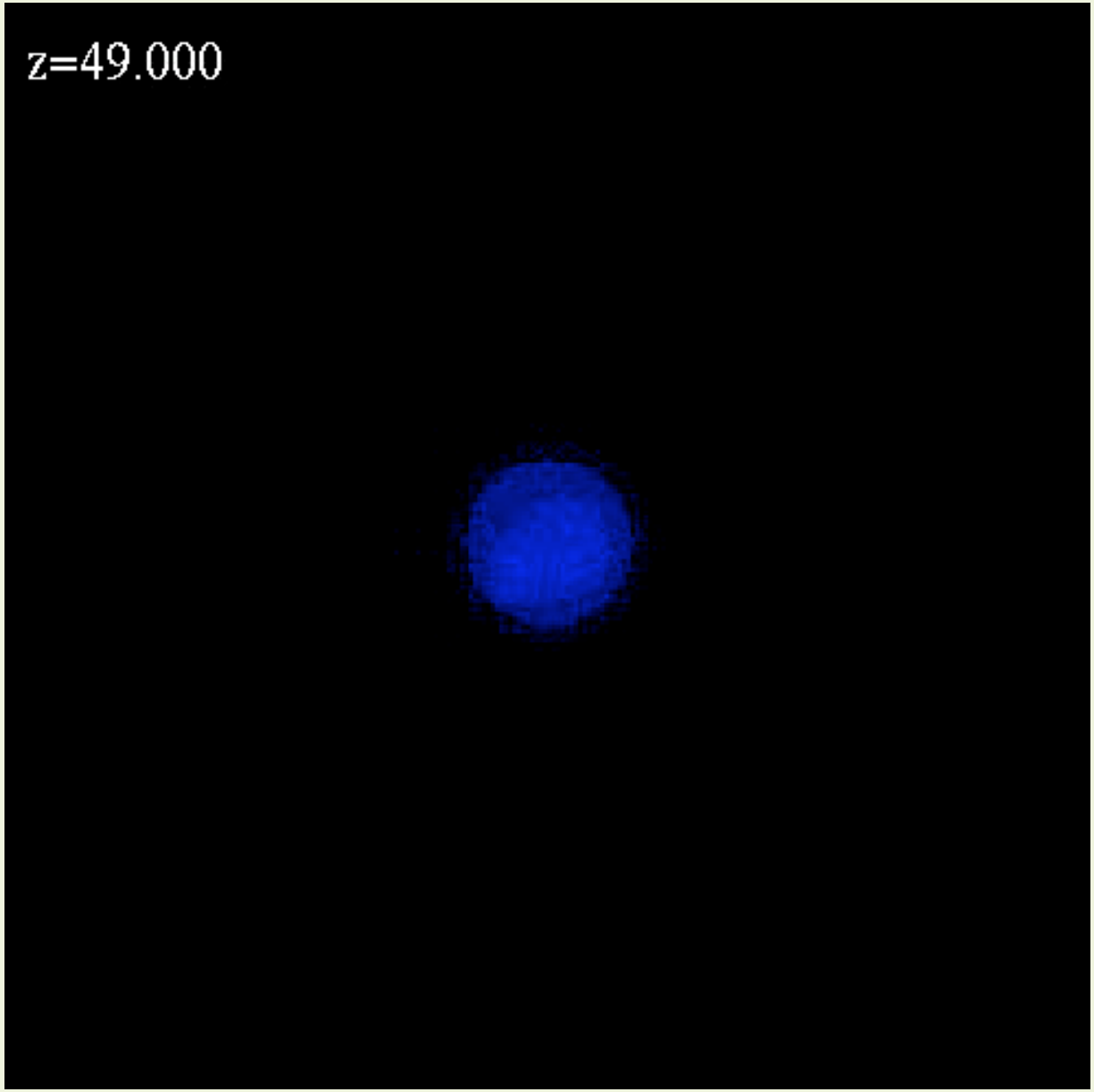
Q. As we use simulations more and more to test, calibrate and interpret surveys/observations, how do we

- validate simulations,
- ensure the work gets done,
- assign credit and resources,
- integrate the work into planning and data reduction?

evolution of dark matter - physical view

B. Moore, http://www.nbody.net

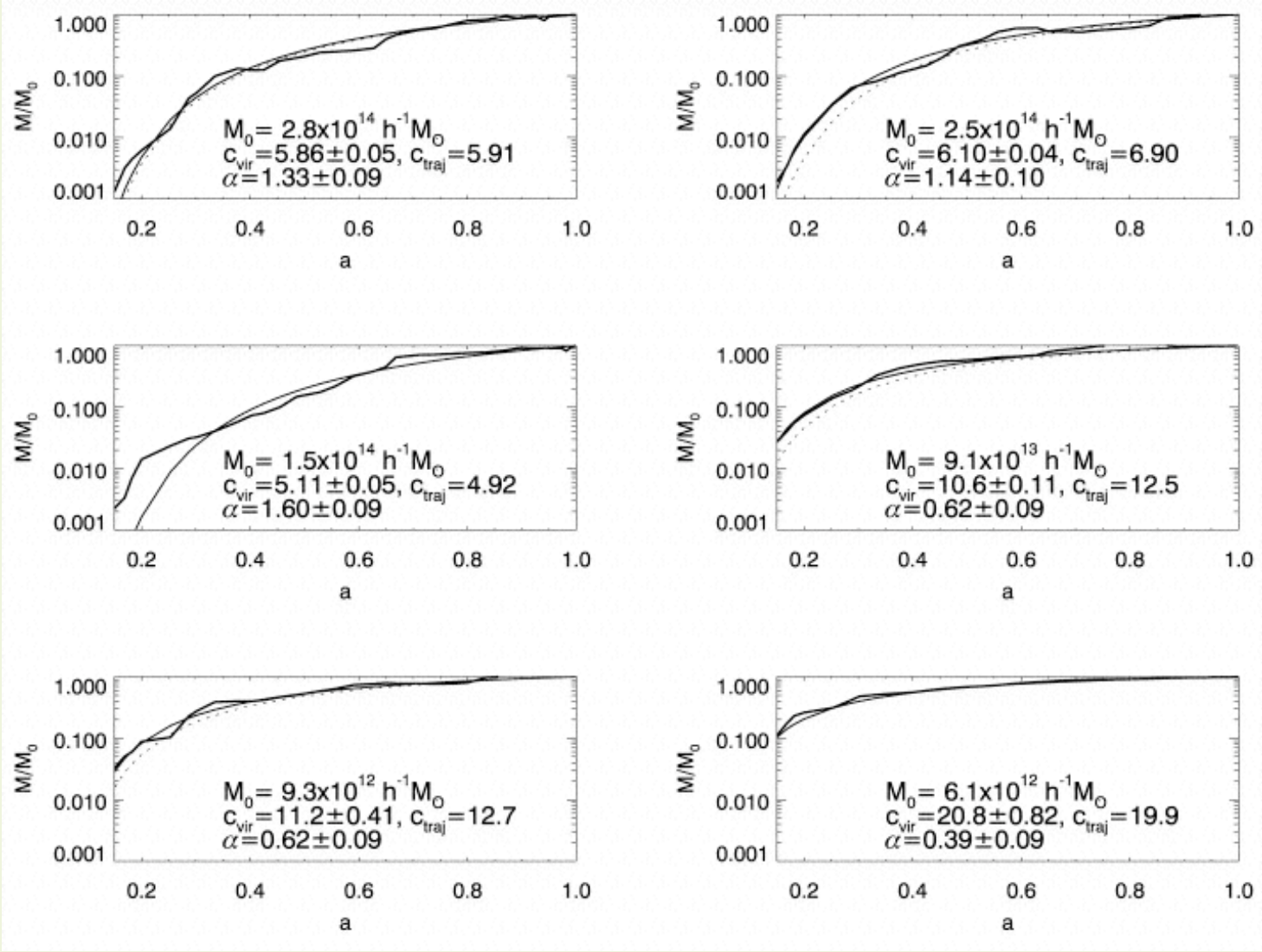
Galaxy Cluster =
“A large knot of quasi-equilibrium, self-gravitating matter components embedded within an evolving filamentary network (the `cosmic web’) of growing density perturbations.”



formation epoch from mass accretion history

Bullock et al 2001

Wechsler et al 2002



$$M_{\max}(a) = M_0 \exp[-a_c S(a_o/a - 1)] \;\; ; \;\; (S = 2)$$

clusters as spherical cows…

– an inner region of material in *hydrostatic and virial equilibrium*,

– outer region where matter is in *infalling and out of equilibrium*.

characteristic radius r_Δ & mass $M_\Delta \equiv M(<r_\Delta)$

$$\rho(< r_\Delta) \equiv 3M_\Delta / 4\pi r_\Delta^{\,3}$$

WARNING: multiple definitions in literature !

1. critical contrast $\rho(< r_\Delta) \equiv \Delta \rho_c(z)$

$$\Delta = const \approx 10^2$$

2. variable "virial" contrast

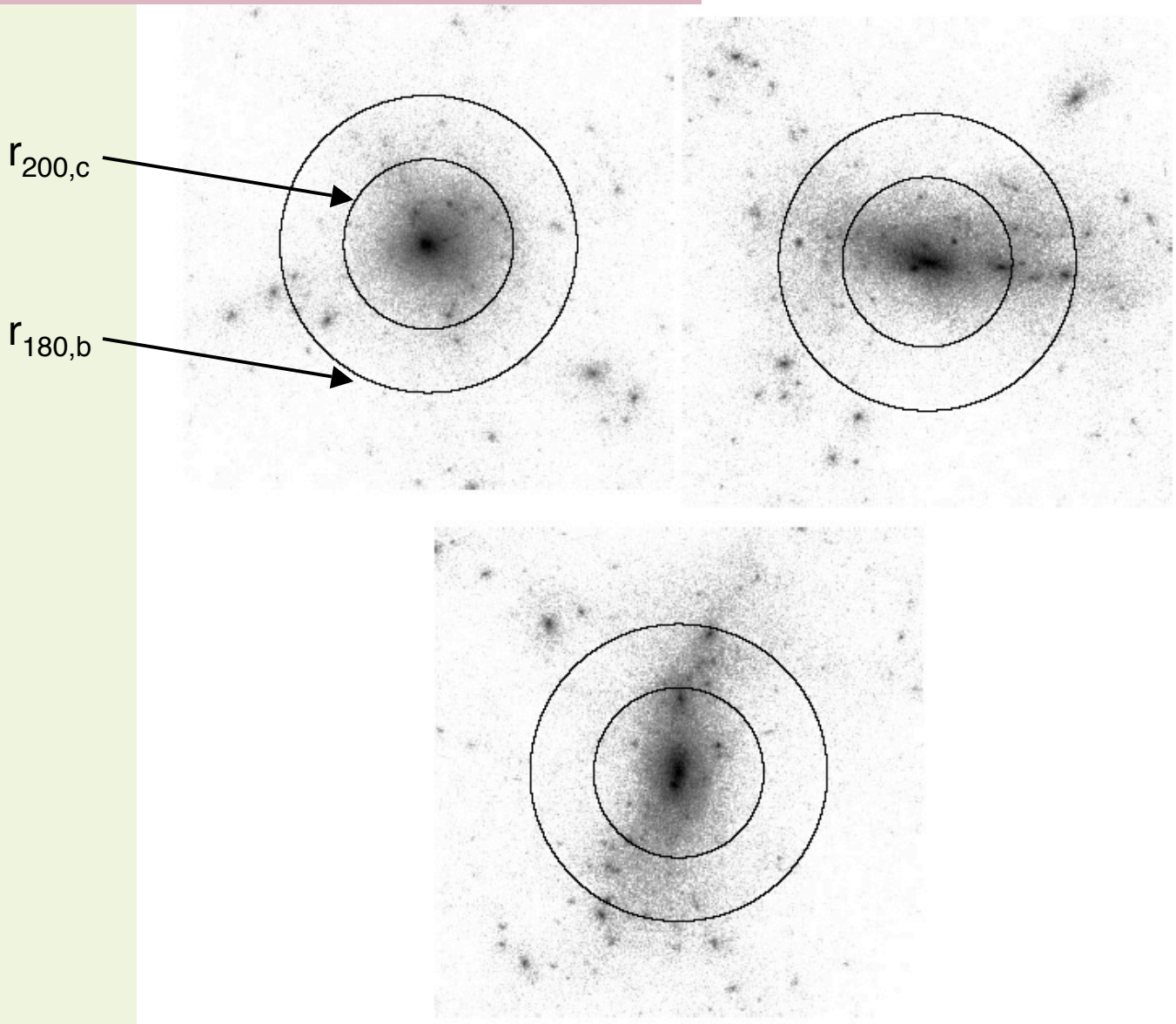
$$\Delta(\Omega_m) = 18\pi^2 + 82x - 39x^2 \;\; ; \;\; x \equiv \Omega_m(z) - 1$$

3. mean contrast $\rho(< r_\Delta) \equiv \Delta \overline{\rho}_m(z)$

$$\Delta = const \approx 10^2$$

spherical cows? where's the hide?

M. White 2002



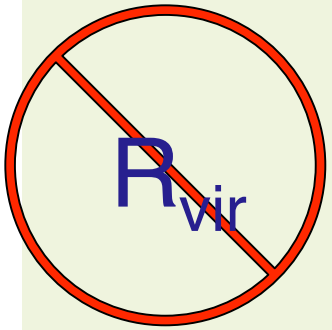
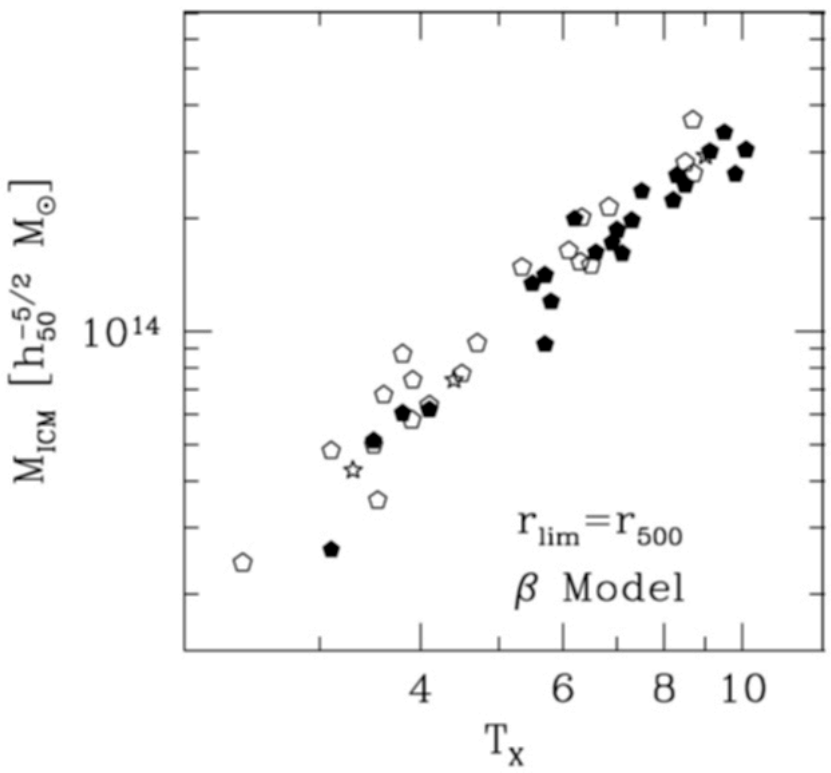


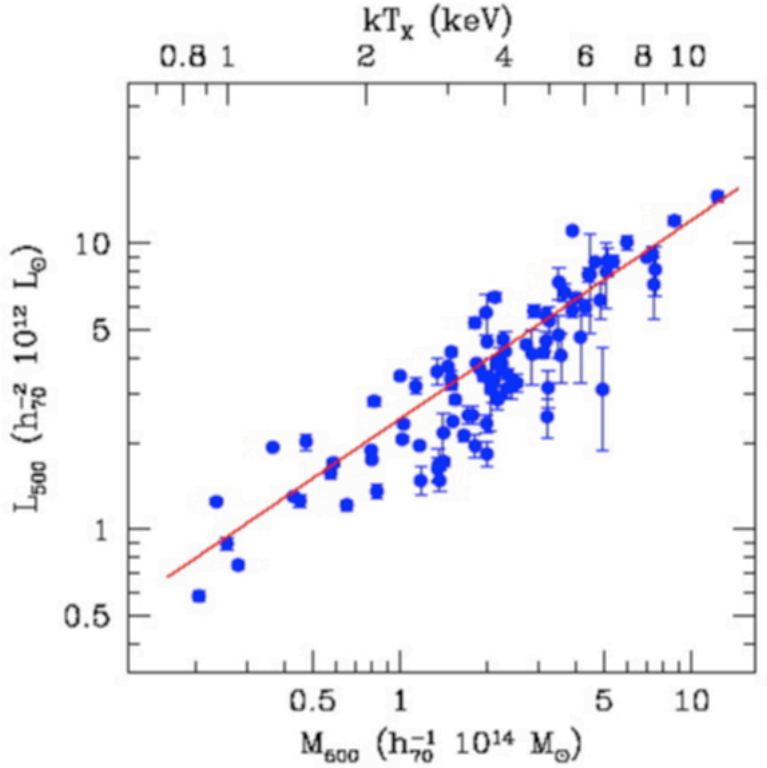
FIG. 2.—Projected density in a cube 10 h^{-1} Mpc on a side centered on the second most massive halo in the 512^3 particle simulation. The three panels are projections down the x-, y-, and z-axes of the box. The gray scale is logarithmic, running from 10^2 to 10^5 times the mean density. The solid circles show $r_{200c} \simeq 1.74\ h^{-1}$ Mpc (*inner*) and $r_{180b} = r_{54c} \simeq 3.04\ h^{-1}$ Mpc (*outer*). Within r_{180b} the material exhibits a wide range of density contrasts. Note that the halo is neither isolated nor spherical and has quite a bit of substructure.

tight local scaling relations = equivalent of SN Ia lightcurves

Mohr, Mathiesen & Evrard 99



Lin, Mohr & Stanford 2004

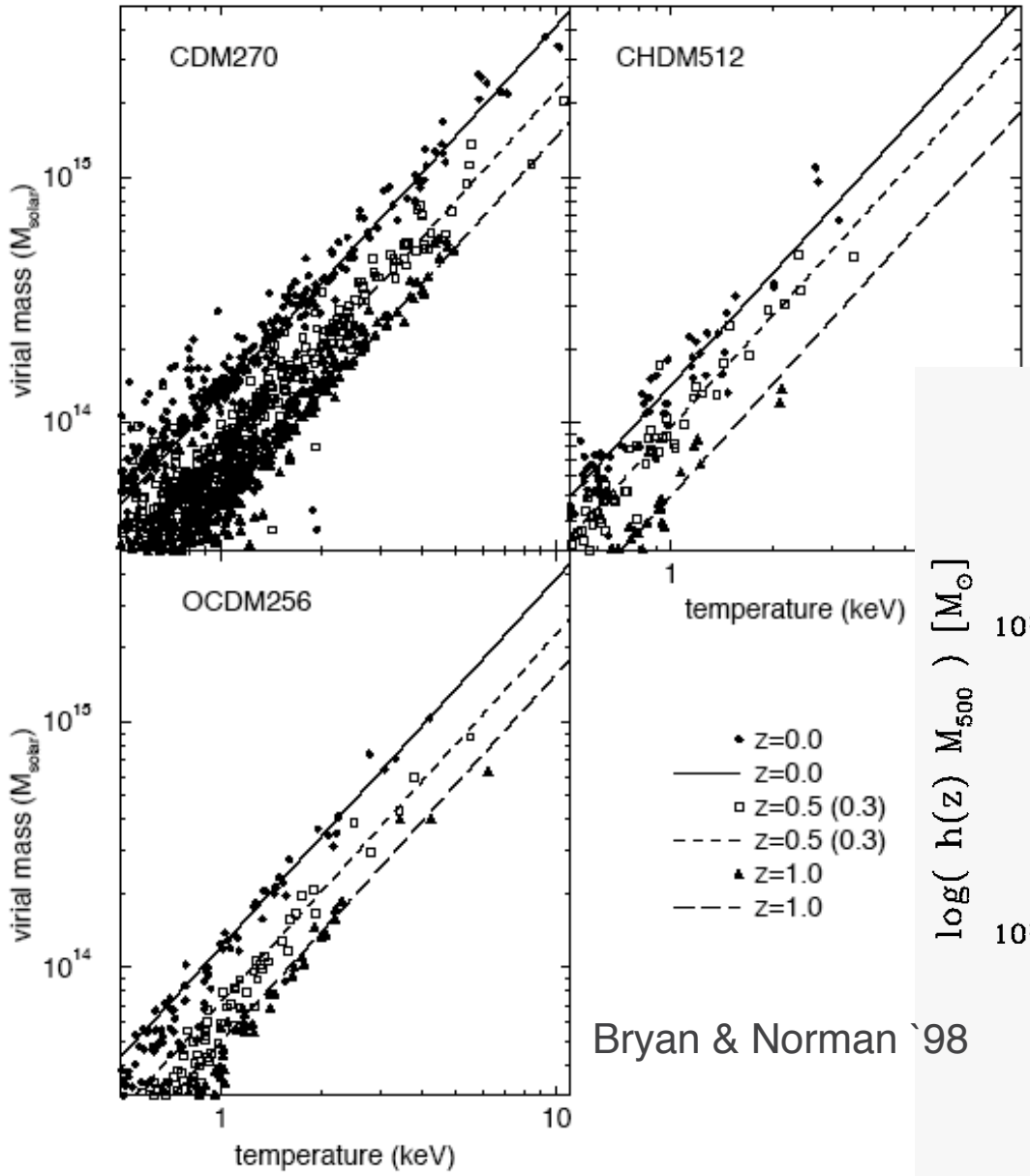


14 % scatter in M_{ICM} at fixed T_X

25 % scatter in L_K at fixed T_X

How do the slope/normalization/**scatter** depend on mass and redshift?

tight scaling relations expected from simulations

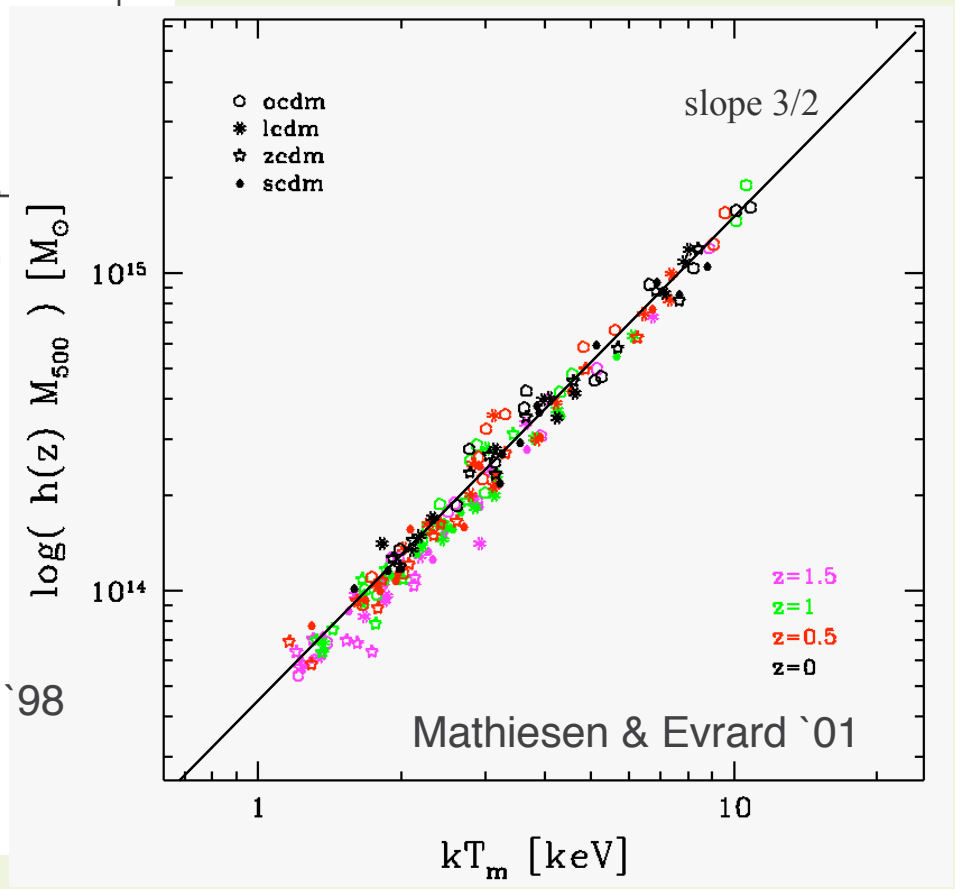


Bryan & Norman `98

"soft dynamics" allows respect for virial scaling

~11 % scatter in $h(z)M_{500}$ at fixed kT

n.b. merging is included !

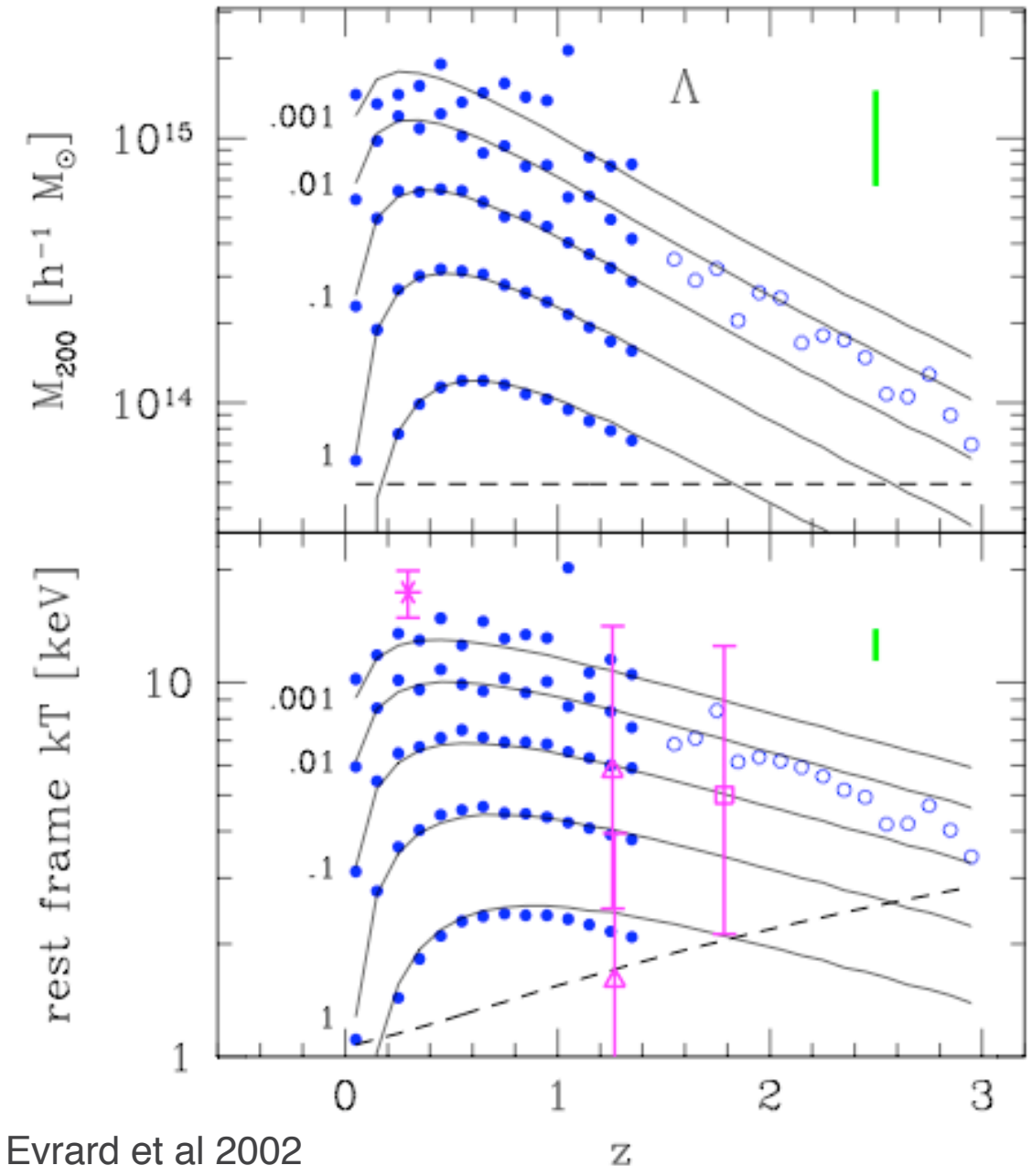


Mathiesen & Evrard `01

early emergence of hot groups/clusters in ΛCDM

expect ~50 per sq deg
kT>1 keV halos
@ z=2-3

M ~ few x10^{13} $h^{-1}M_{sun}$
R ~ 0.5 h^{-1} Mpc



Evrard et al 2002

a straw-person target

Near-term goal: 5% mass measurement of local ($z<0.3$) sample
=> 2% error on σ_8

How to achieve?

- X-ray hydrostatic estimates?
- virial galaxy estimates?
- weak lensing?
- ALL OF THE ABOVE!

Scatter in individual estimates typically few x10%
Don't know systematics to < 5%.

Need moderate/large (N>100) sample + smarter approaches to data analysis + honest estimates of systematics.

What is the future of Cosmology with Clusters of galaxies?