Cosmology with the Chandra cluster data

A. Kravtsov, D. Nagai

M. Markevitch, S. Murray, L. VanSpeybroeck, W. Forman, C. Jones, O. Kotov

R. Burenin, C. Mullis, B. McNamara, H. Quintana, A. Hornstrup, I. Gioia, P. Henry, H. Ebeling

The Goal: constrain dark energy

- **dark energy affects expansion of the Universe**

- **$H(z)$ can be "observed" through**
  - **distances: $D(z) \propto \int \frac{dz}{H(z)}$**
  - **growth of structure: $\ddot{\delta} + 2H\dot{\delta} - 4\pi G\rho_M\delta = 0$**

$$(\delta = \rho_M/\langle\rho_M\rangle - 1)$$

- **Given $\langle\delta^2(M)\rangle$, theory predicts $N_{\mathrm{clusters}}(M)$**

The Plan

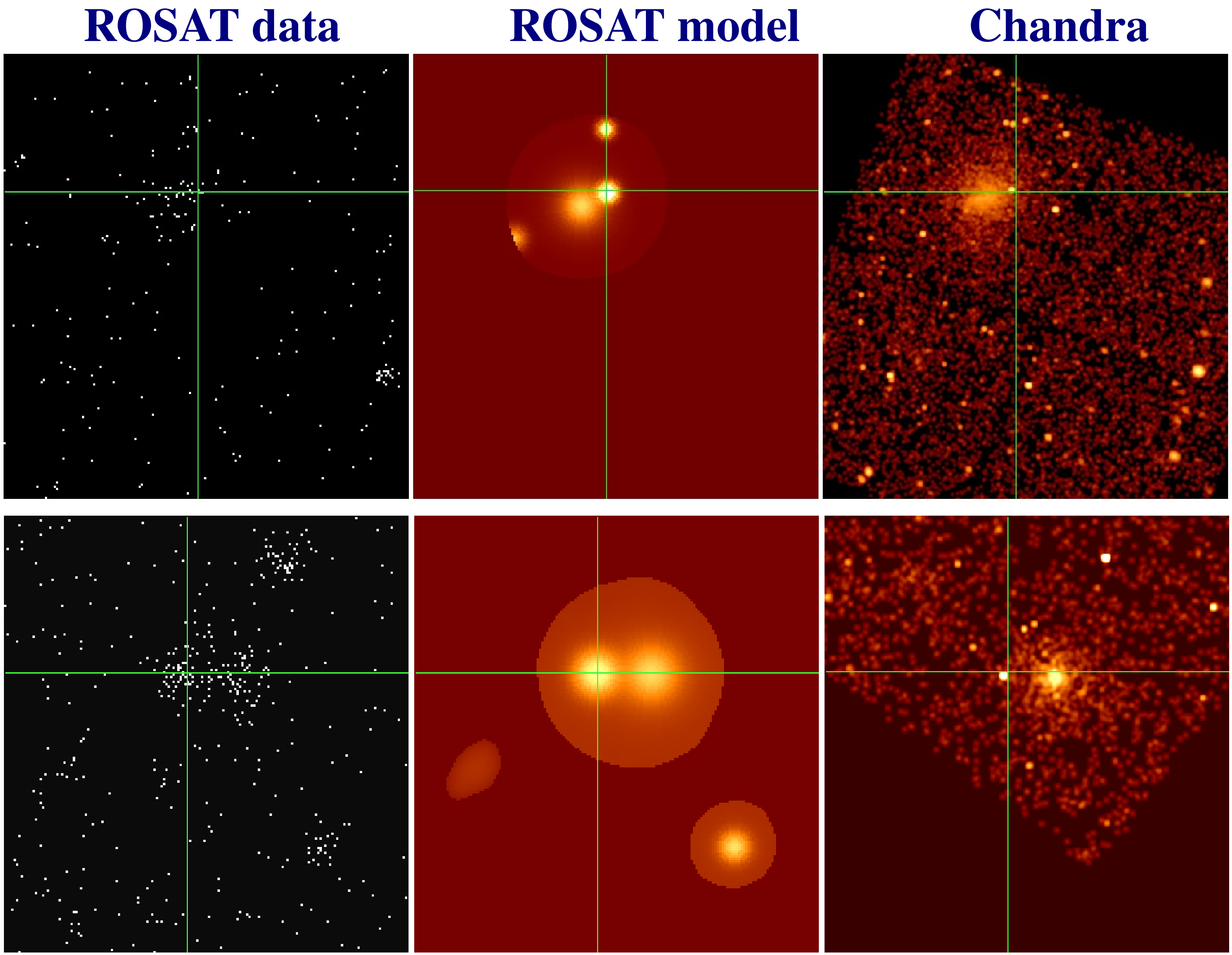
1. **Find many high-z clusters**

2. **Measure their M as accurately as possible**

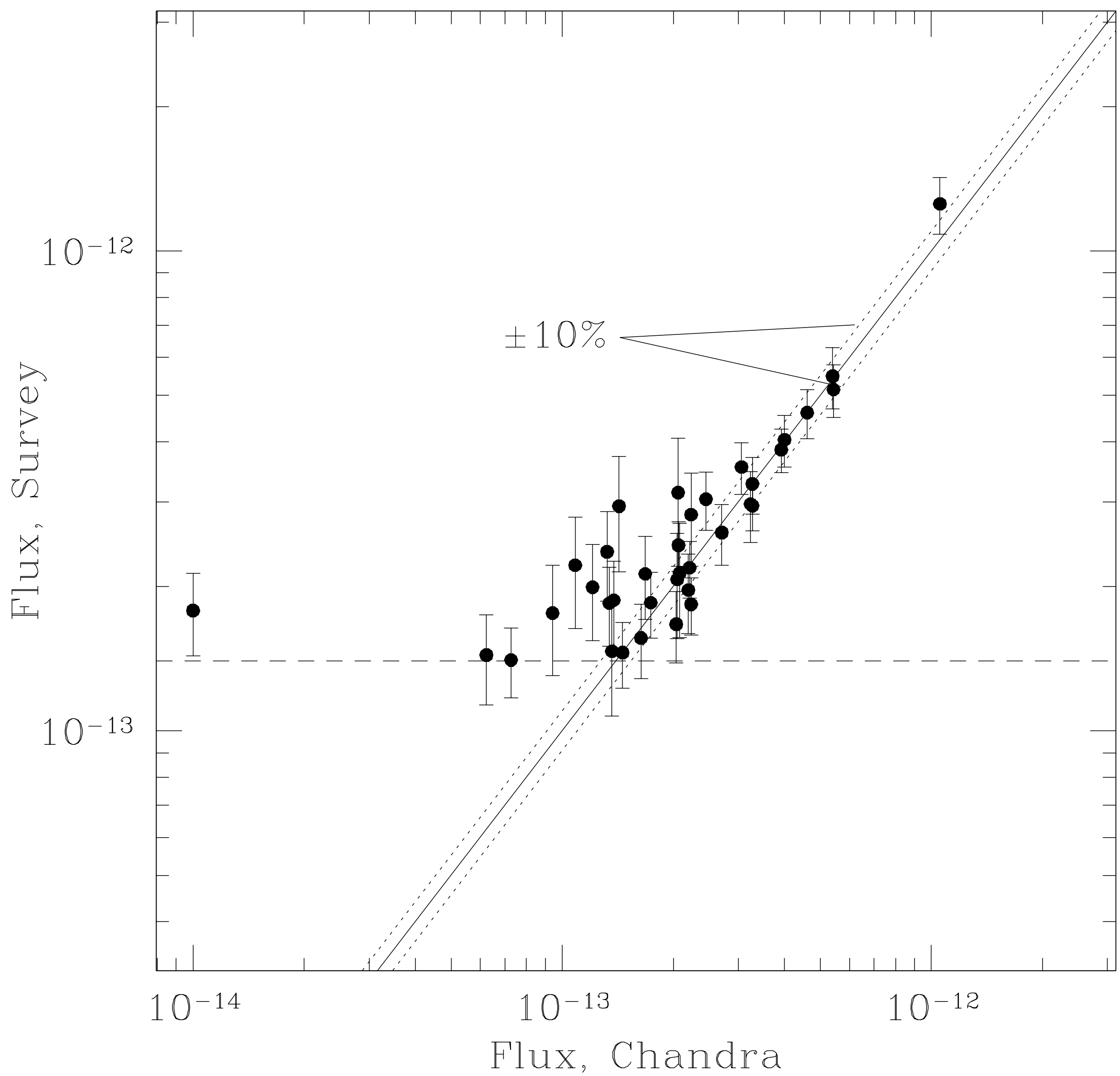
The Survey

- **Over 400 deg^2 of ROSAT pointed observations**
- **100% optically identified, 95% clean**
- **37 high-flux clusters at $z > 0.4$**
- **Volume $= 3 \times V(z < 0.1)$**
- **All distant clusters followed up with *Chandra* (nearly complete)**

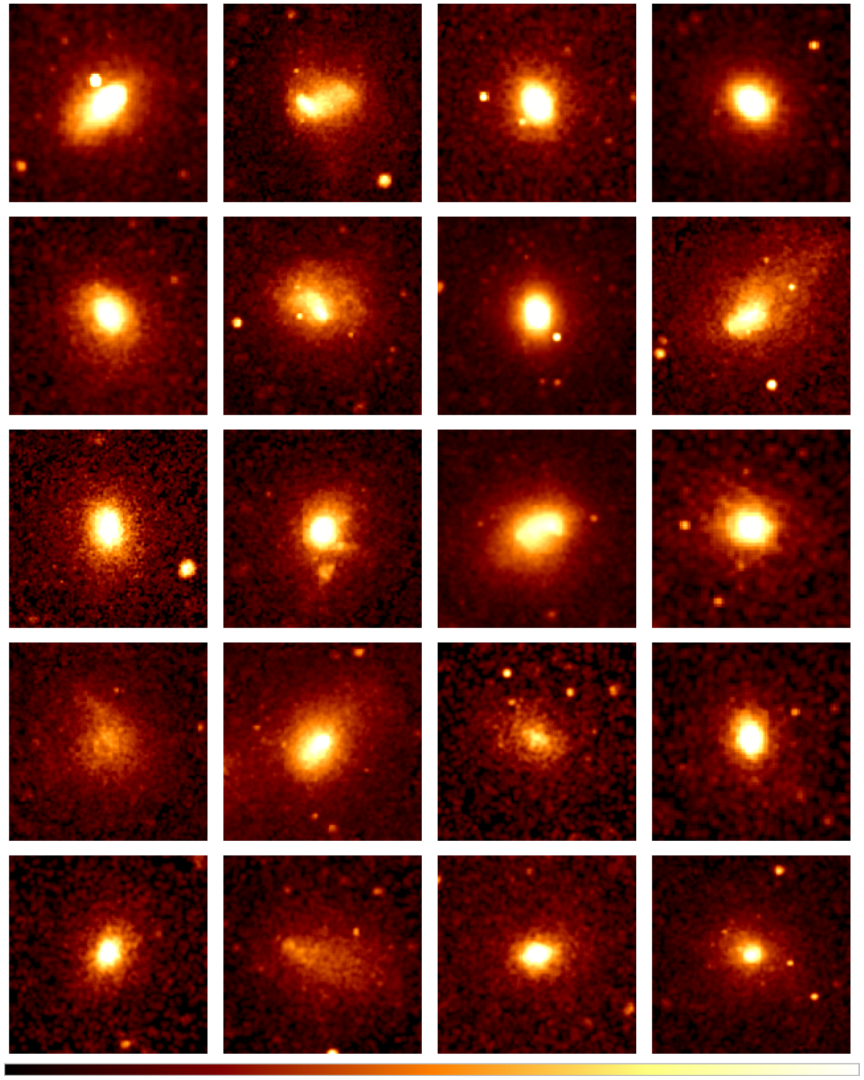
  $(\Delta T/T \simeq 10\% - 15\%)$


ROSAT data
ROSAT model
Chandra

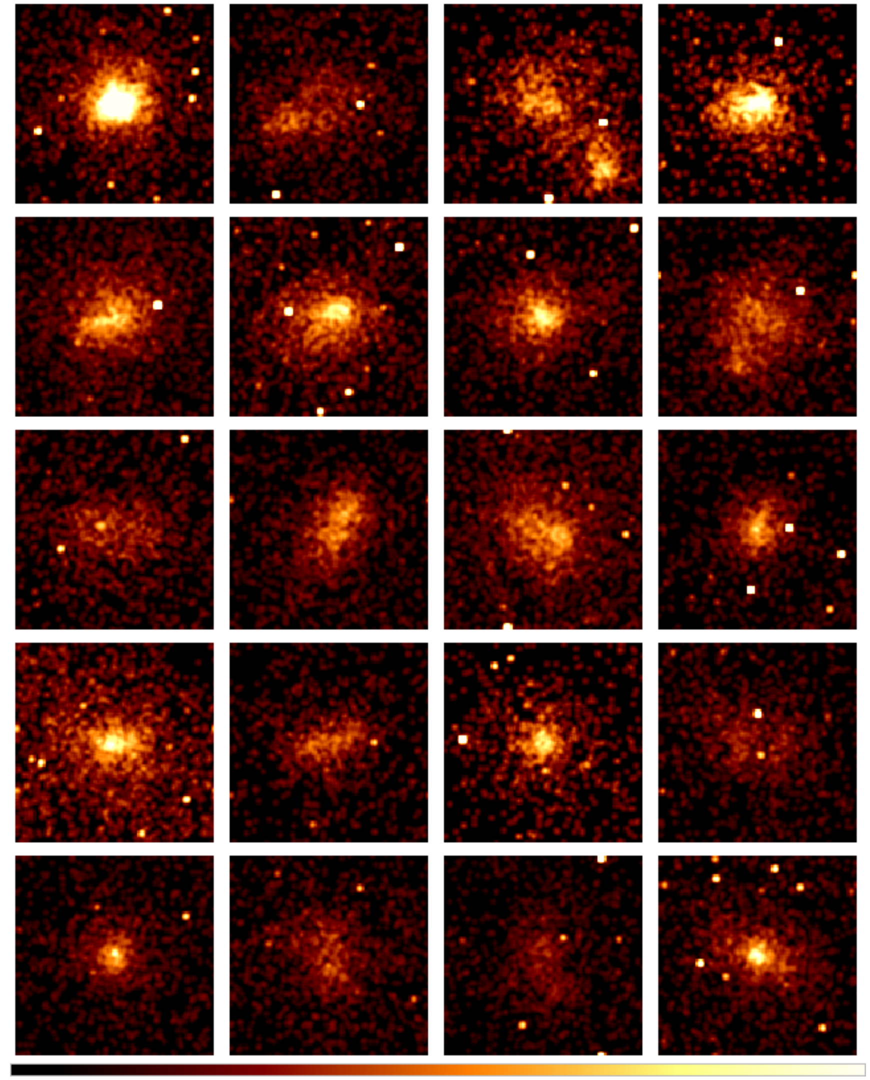
Comparison of ROSAT and Chandra fluxes



The Challenge



$z < 0.1$



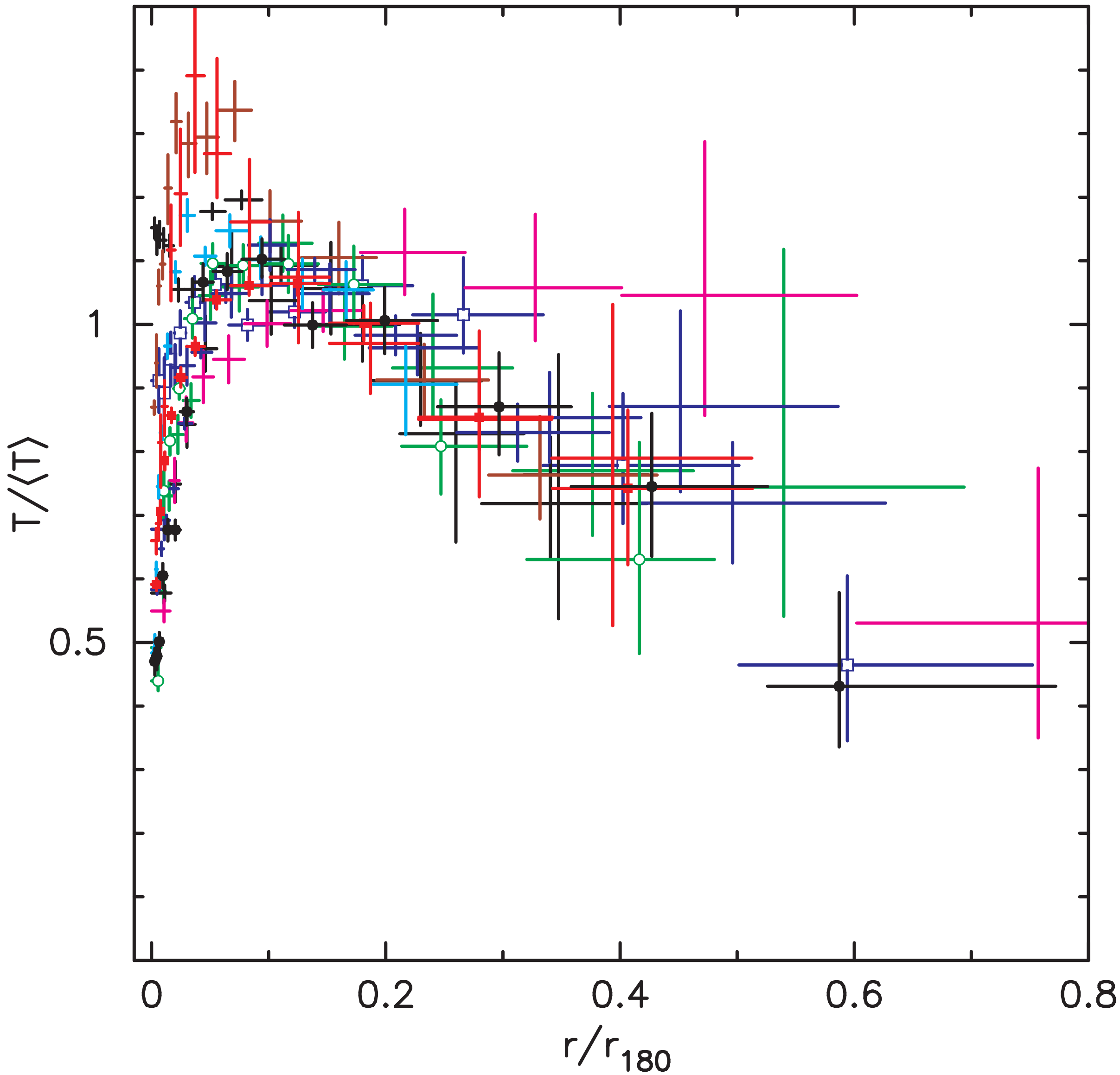
$z > 0.45$

For structure-cosmology connection, see Richstone, Loeb, Turner 1992; Jeltema et al. 2005

The approach

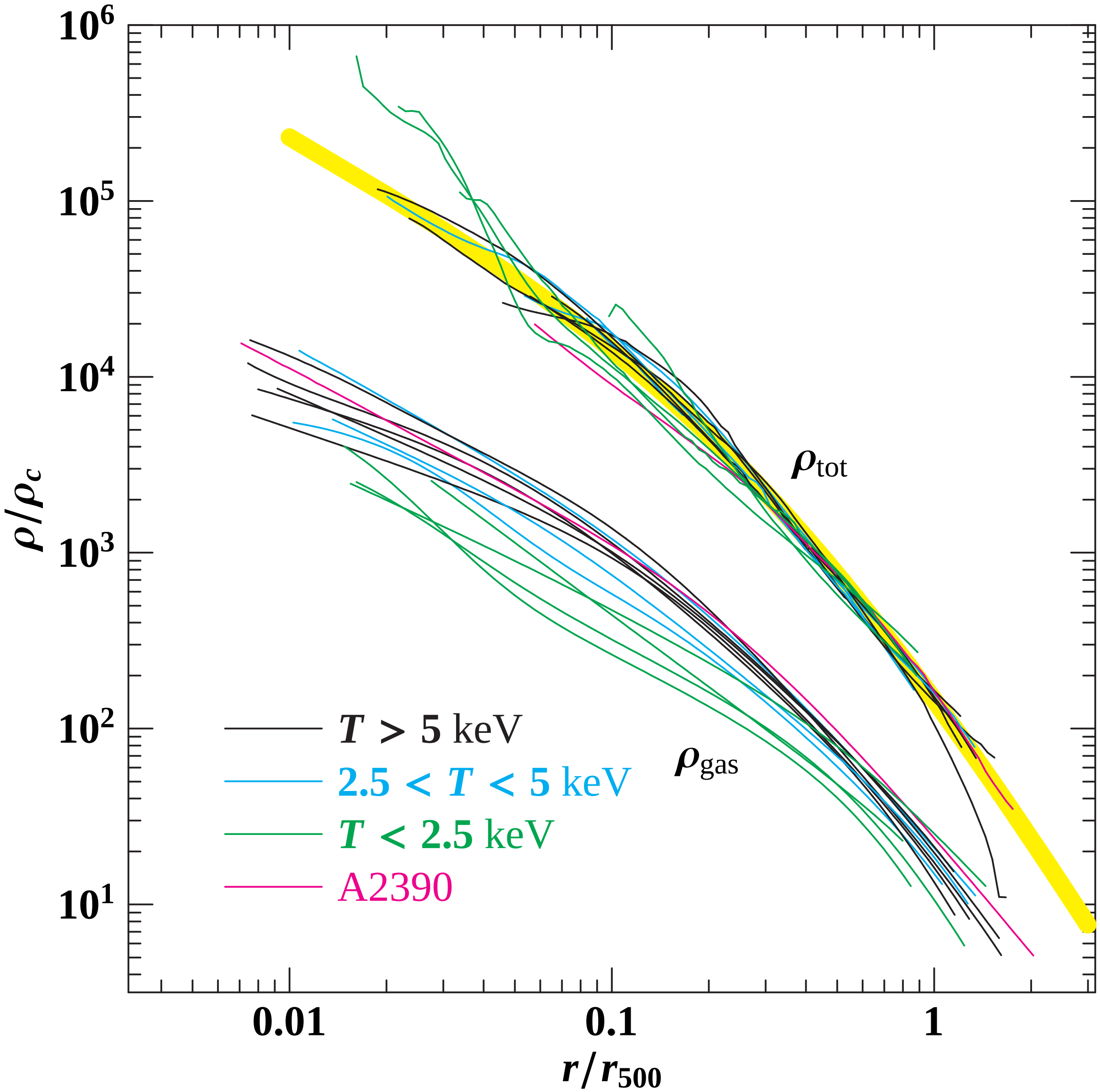
- **Develop structure-insensitive mass proxies**
- **Calibrate using realistic numerical simulations and *Chandra* observations of low-z clusters**
- **Use these proxies for high-z clusters**

Temperature profiles from *Chandra*



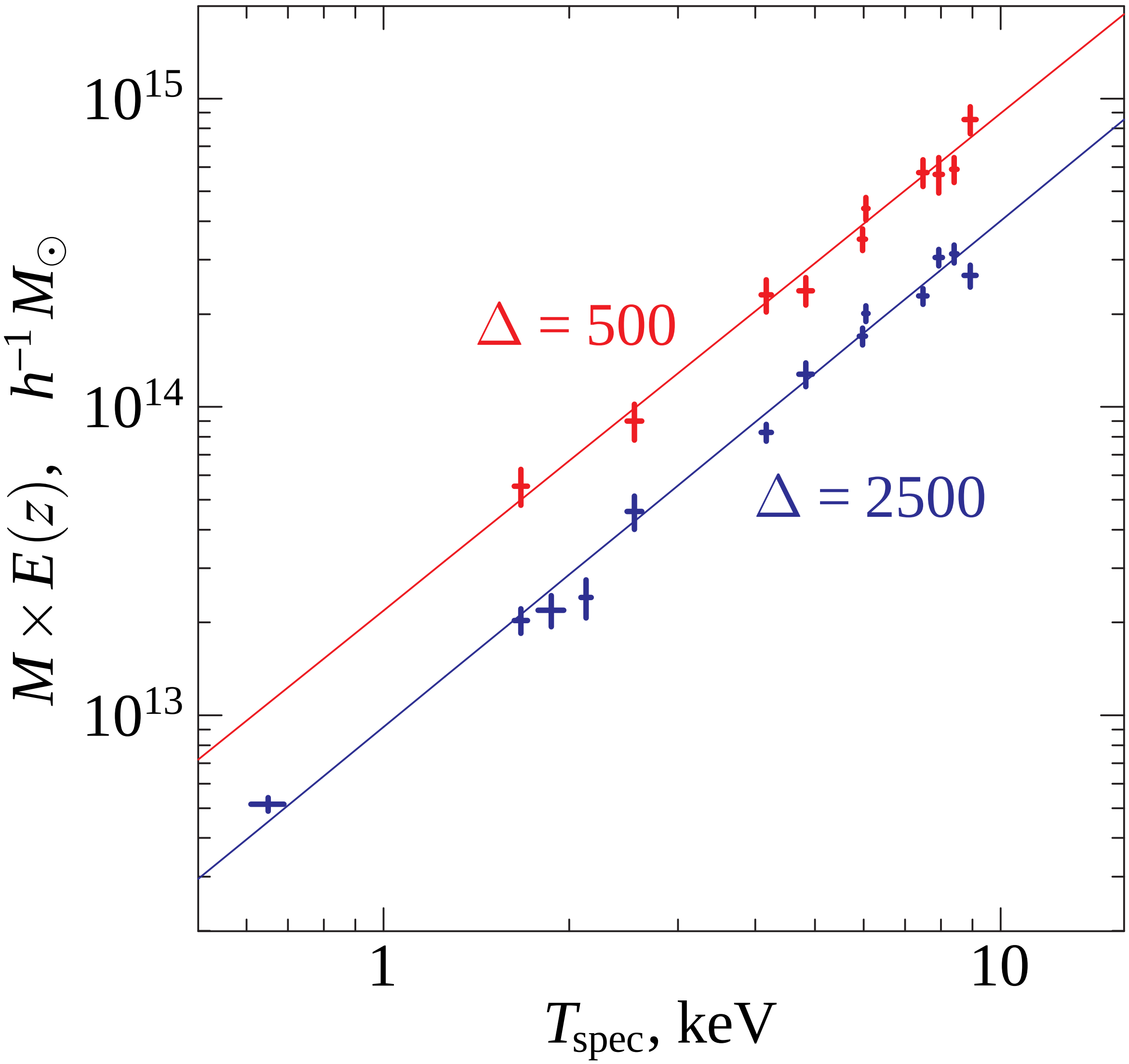
Vikhlinin etal astro-ph/0507092

Total and gas density profiles



Vikhlinin etal astro-ph/0507092

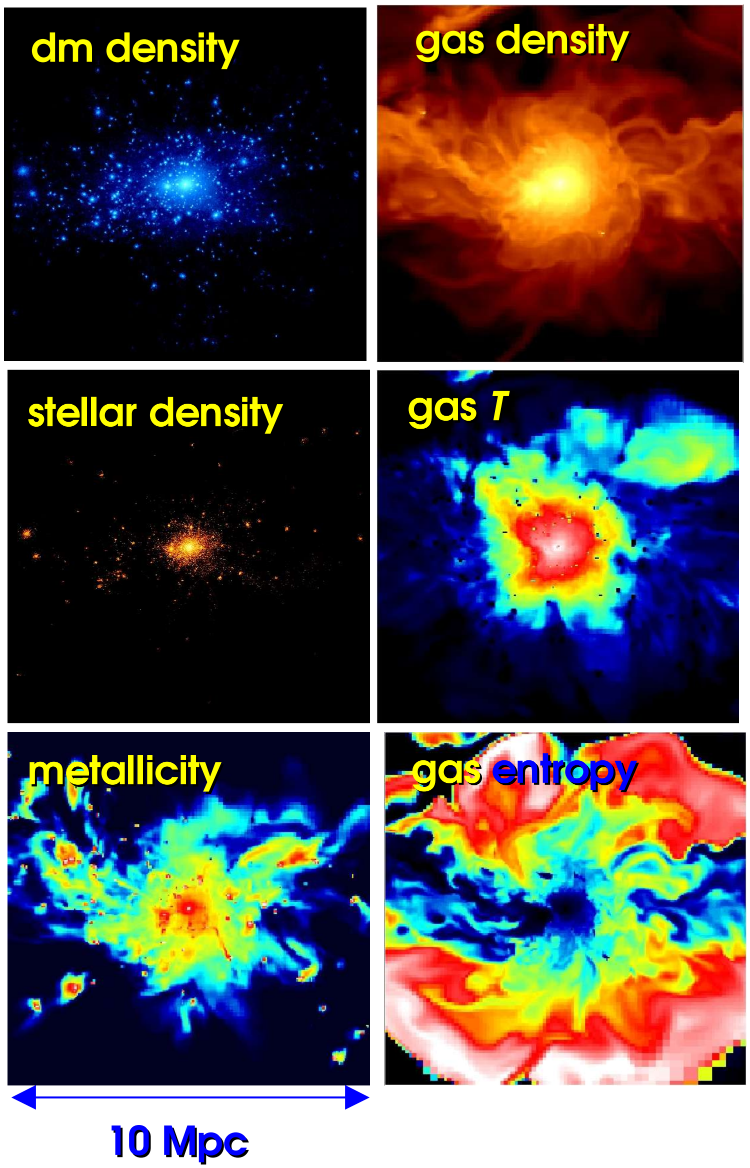
Observed M-T relation



- **Relations are nearly self-similar ($M \propto T^{\alpha}$, $\alpha = 1.6 \pm 0.1$)**
- **Evolution is also self-similar, $M/T^{3/2} \propto h^{-1}(z)$** **(Kotov & Vikhlinin '05)**

Simulated cluster sample

Kravtsov et al.



11 individual galaxy clusters simulated with and without cooling
virial masses from 8×10^{13} to $10^{15} h^{-1}$ Msun

Cosmological N-body+gasdynamics ART code
(Kravtsov 1999, 2003; Kravtsov et al. 2002)
$m_{dm}=3 \times 10^{8} h^{-1}$ Msun, $m_{*} \sim 10^{6} h^{-1}$ Msun
peak resolution ~ $2 h^{-1}$ kpc
2-4 x 10^{7} mesh cells per cluster

Gasdynamics: Eulerian AMR (2nd order Godunov)
N-body dynamics of DM and stellar particles

Radiative cooling and heating of gas:
metallicity dependent taking into account
atomic and molecular processes

Star formation using the Kennicutt (1998) recipe

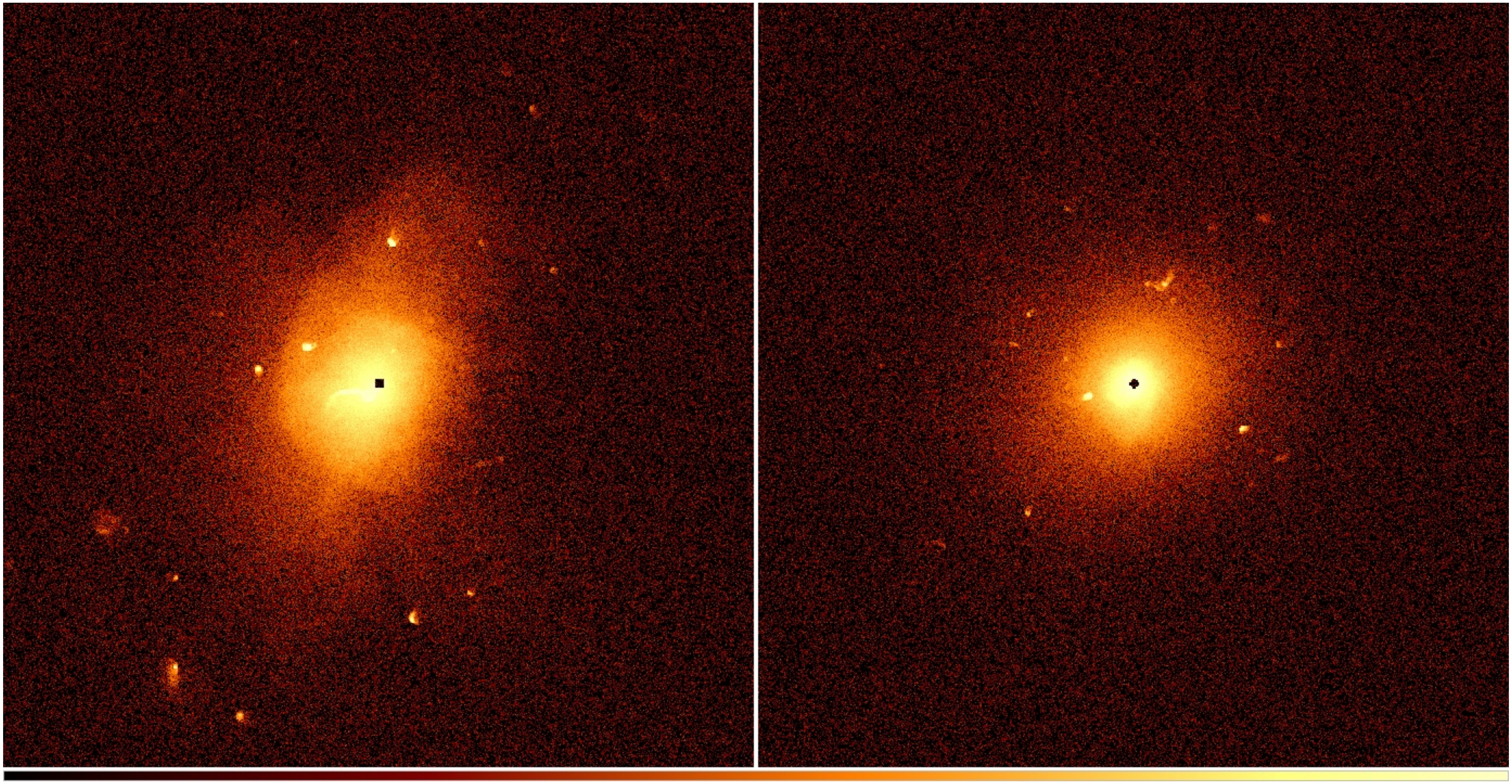
Thermal stellar feedback

Metal enrichment by SNII/Ia + **Advection of metals**

Testing Chandra measurement biases

work by D. Nagai, A. Kravtsov, A.V.

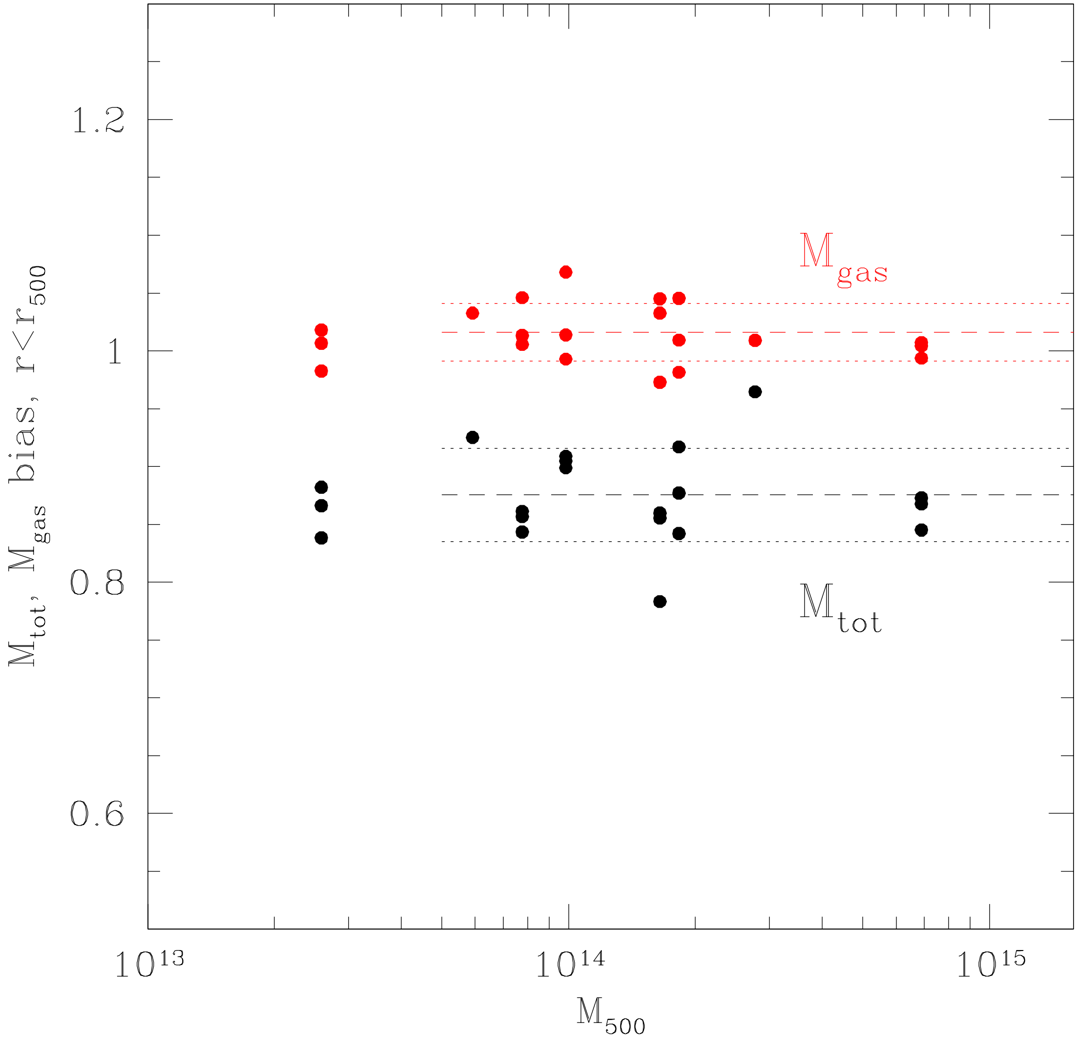
- generate "Chandra data" for clusters from cosmological simulations
- reduce with the real data analysis pipeline



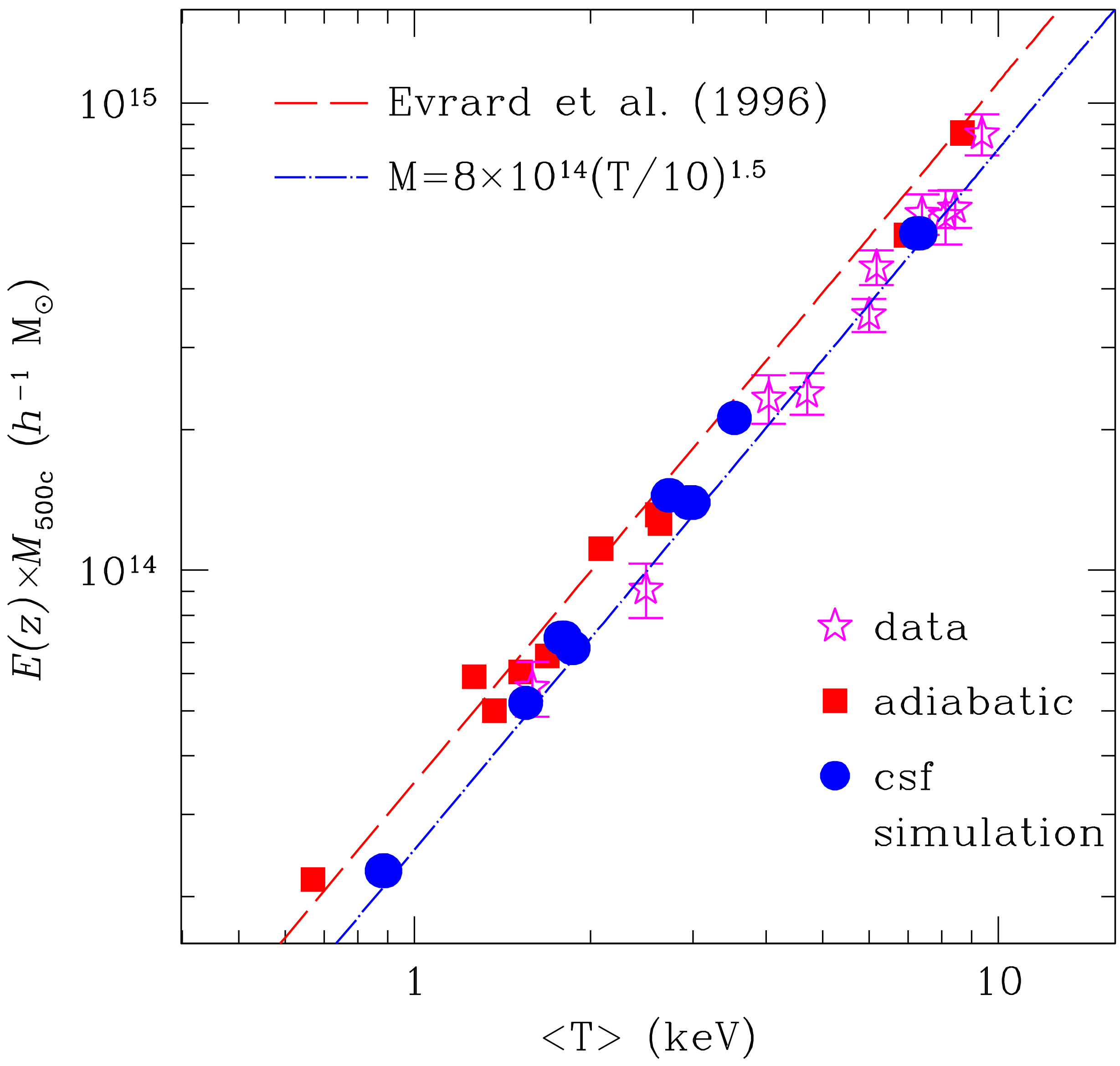
Testing Chandra measurement biases

work by D. Nagai, A. Kravtsov, A.V.

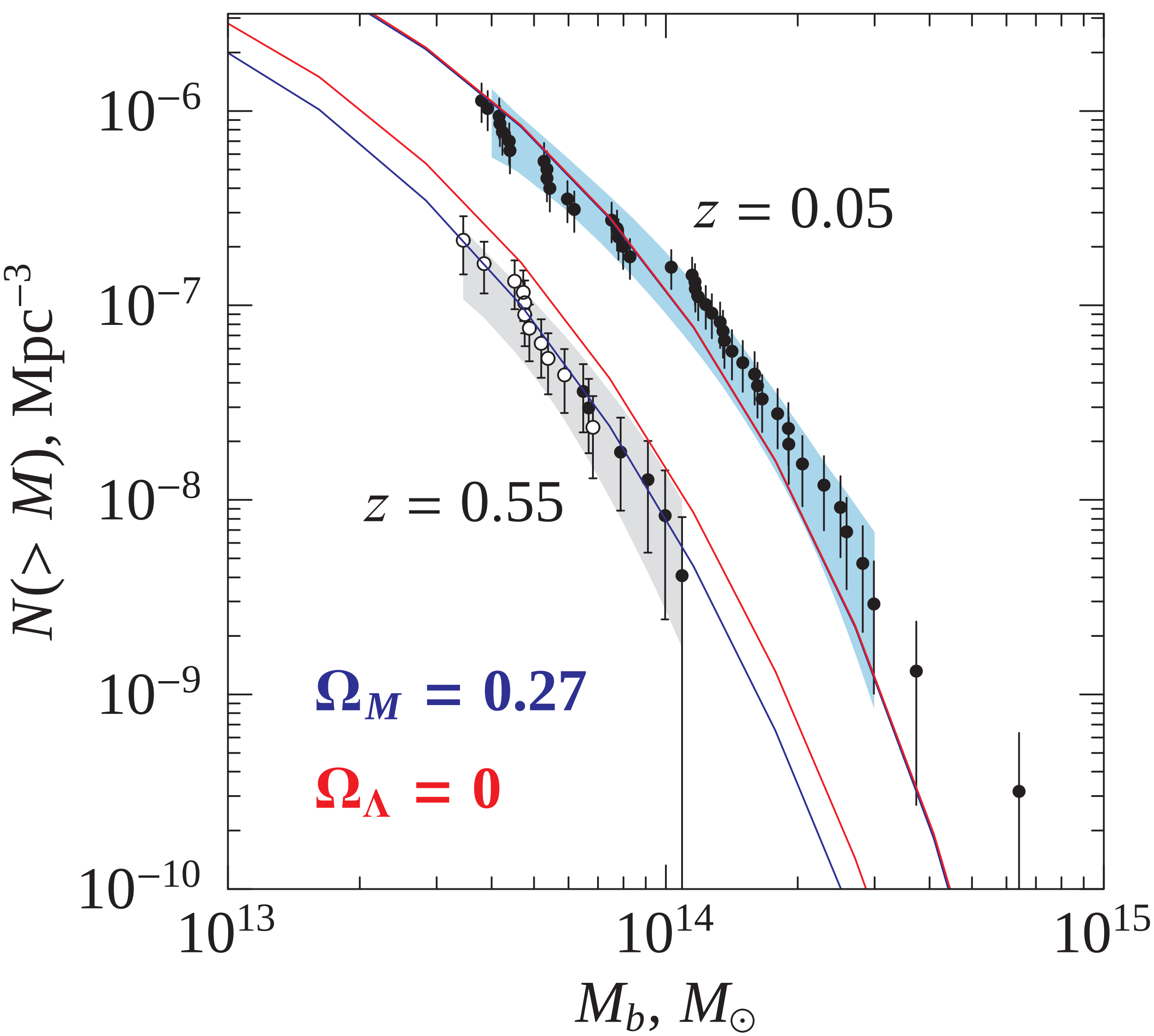
- **generate "Chandra data" for clusters from cosmological simulations**
- **reduce with the real data analysis pipeline**



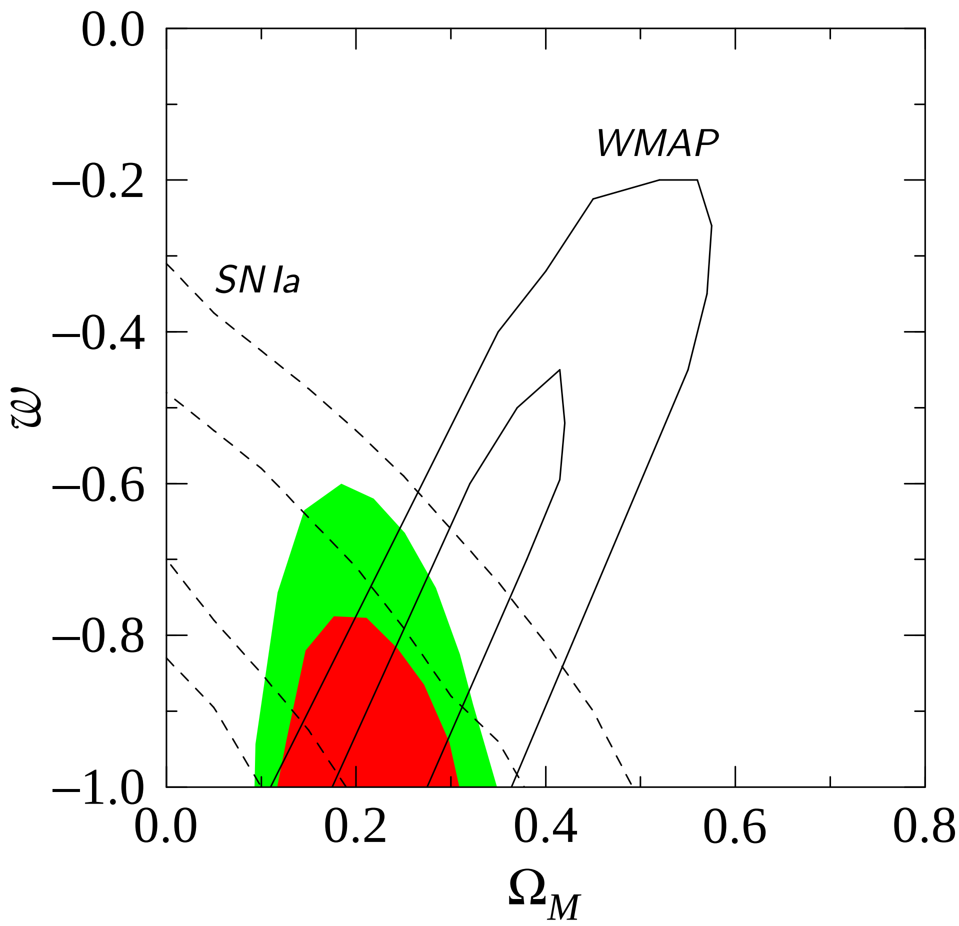
Are simulations realistic?



Current results: 160d



Current results: 160d: w



For $\Omega_M = 0.3$, $\quad$ $w < -0.9$ **(68%),**

< -0.7 **(90%),**

< -0.6 **(95%)**