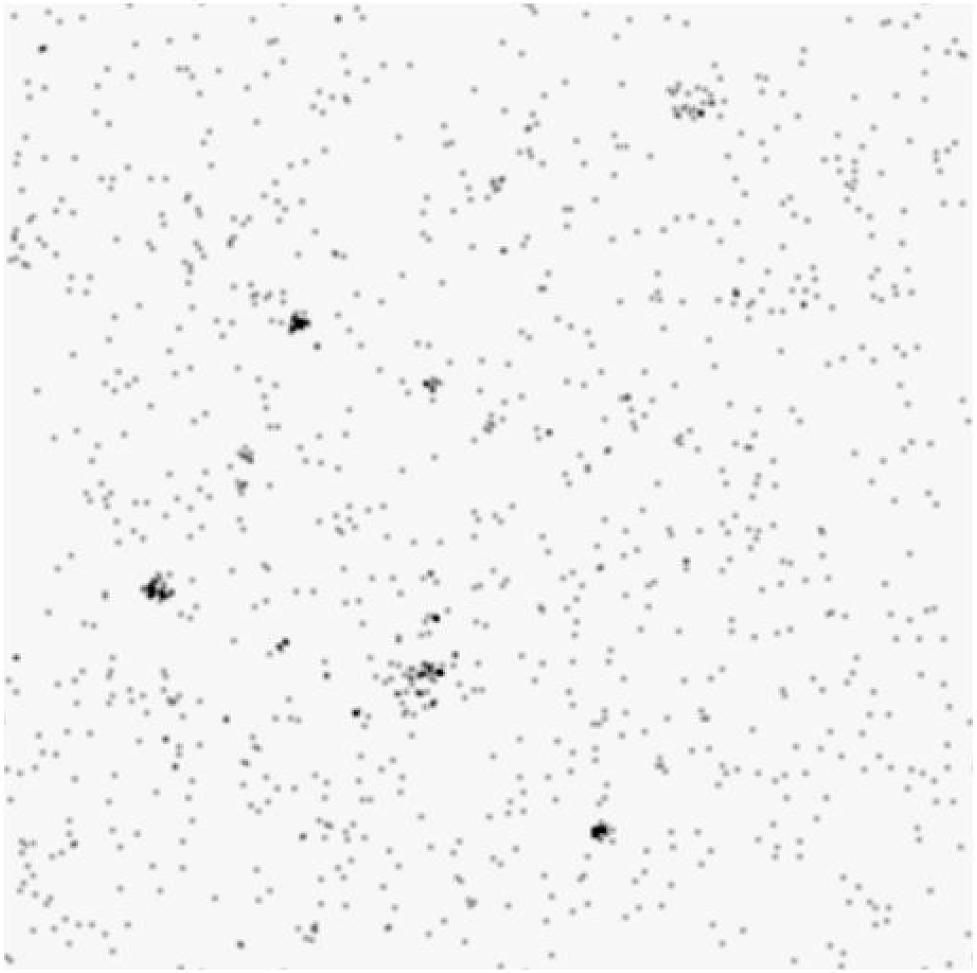
X-ray Cluster Evolution and Cosmology

A. Vikhlinin for the 160d survey team

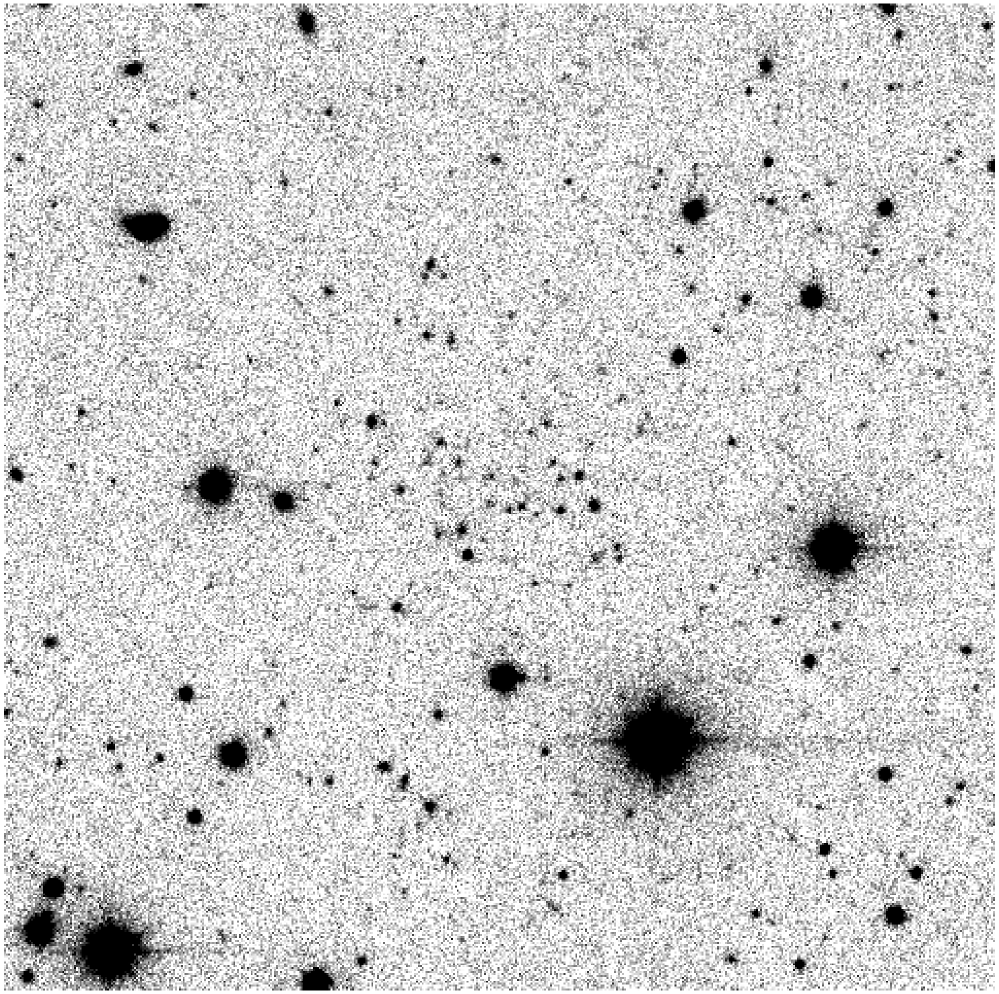
Data

- **Low z — *ROSAT* All Sky Survey:**
  - ➢ **BCS, REFLEX, NORAS, . . . — several hundreds of objects at all L_x**
  - ➢ ***ROSAT*, *ASCA*, *XMM*, *Chandra* followup for $\sim$ 50 brightest clusters HIFLUGCS by Reiprich & Böhringer**
- **High z**
  - ➢ ***Einstein* EMSS: many clusters at $z \sim 0.3$, a few at $z \gtrsim 0.5$.**
  - ➢ ***ROSAT* All-Sky survey NEP: 30 clusters at $z \sim 0.3$, 10 clusters at $z > 0.4$**
  - ➢ **Serendipitous surveys from *ROSAT* pointed observations (RDCS, WARPS, SHARC, 160 deg^2): $\sim$ 50 clusters at $z \sim 0.5$, a few at $z \sim 1$**
  - ➢ ***ROSAT* All-Sky Survey (MACS): many high-L_x clusters at $z \sim 0.3$, 10–20 at $z = 0.4 - 0.5$**

Cluster detection in the 160d survey: example



ROSAT, 2800 sec, 40 photons



FLWO 1.2m, 5min in R; $z = 0.70$

160 deg^2 survey

- **Large area** — 650 ROSAT PSPC pointings, 160 square degrees.
- **100% optically identified, spectroscopic z**
- **High quality:**

  Total sample . . . . 223 X-ray candidates, 201 real clusters

  $f_x > 1.4 \times 10^{-13}$ erg s^{-1} cm^{-2} . . . . 114 candidates, 111 real clusters
- **"Complete"** — survey area well-calibrated via Monte-Carlo simulations.
- **Large distant sample — 45 clusters at $z > 0.4$,**

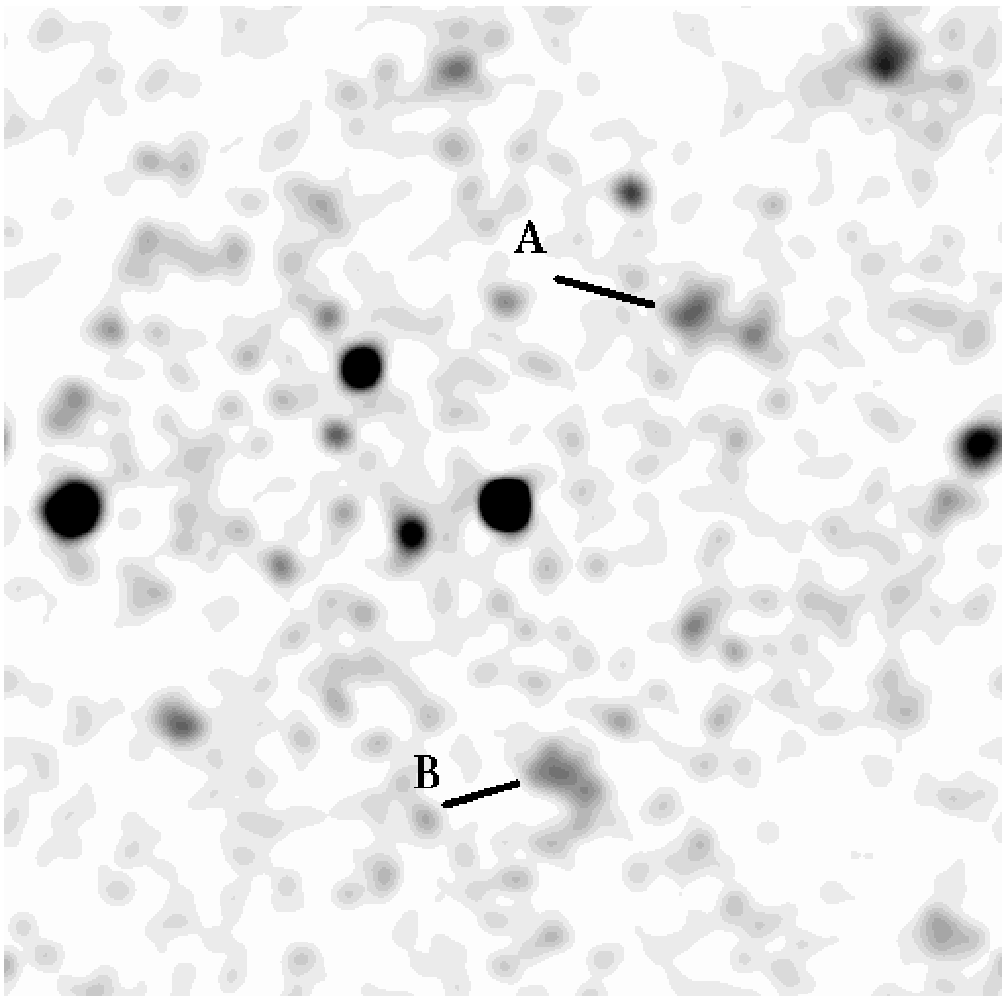
  V **similar to that within $z < 0.1$**
- ***Chandra*** **and** ***XMM*** **followup**

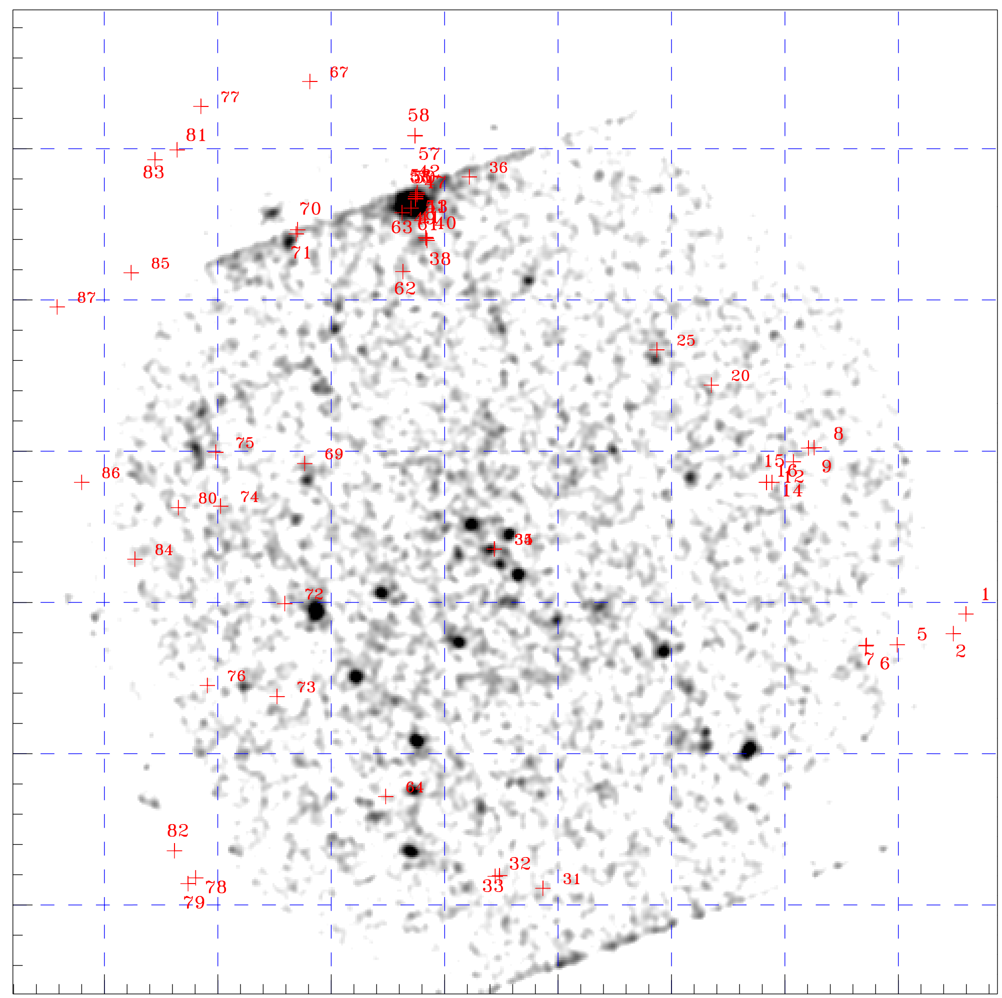
  7 brightest clusters at $z > 0.4$ in *Chandra* GTO program, 10 planned

  2 clusters observed by XMM, 2 more planned

False detections in 160d

- **Number of “false detections” agrees with expected from confusion of point sources (17–25 expected, 21 in the catalog)**
- **Some of the brightest false clusters observed by *XMM* and *Chandra*:**





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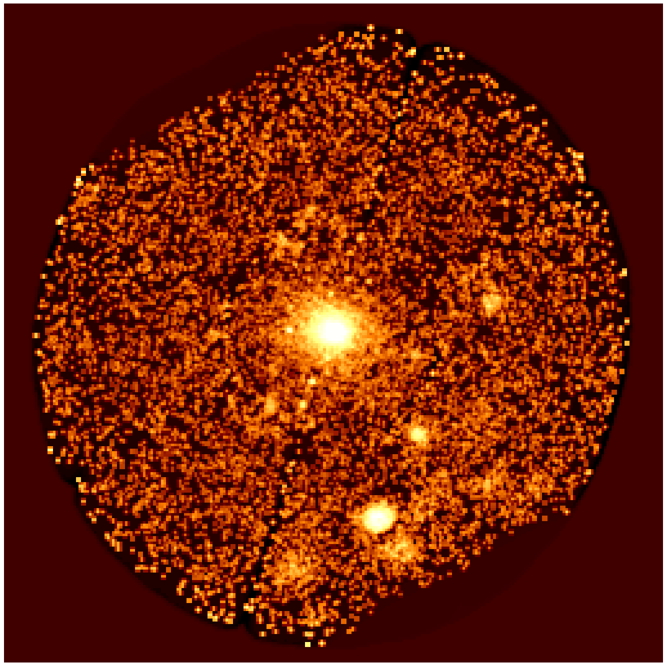
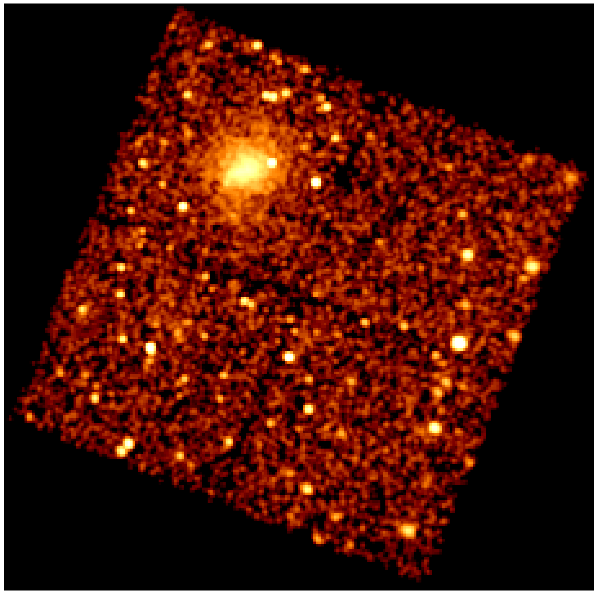
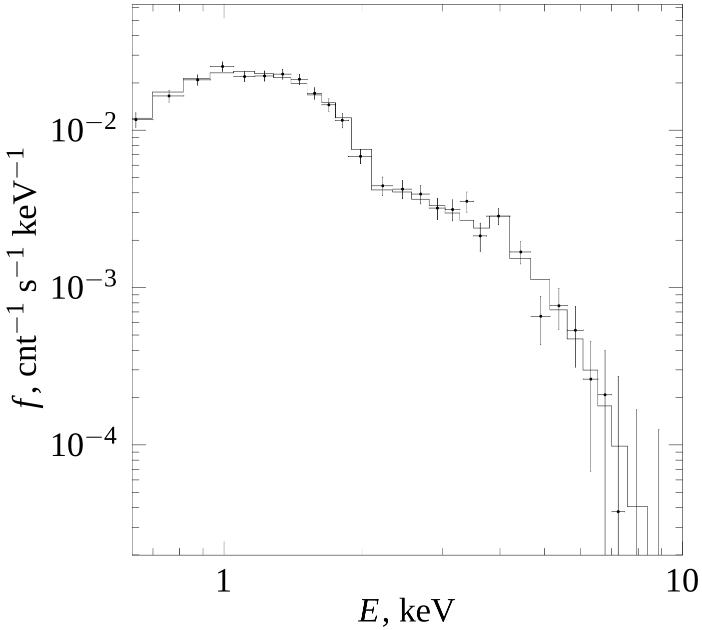
Chandra followup

A1651, $z = 0.085$, *ROSAT*



CL 1221+4918, $z = 0.70$, *Chandra*

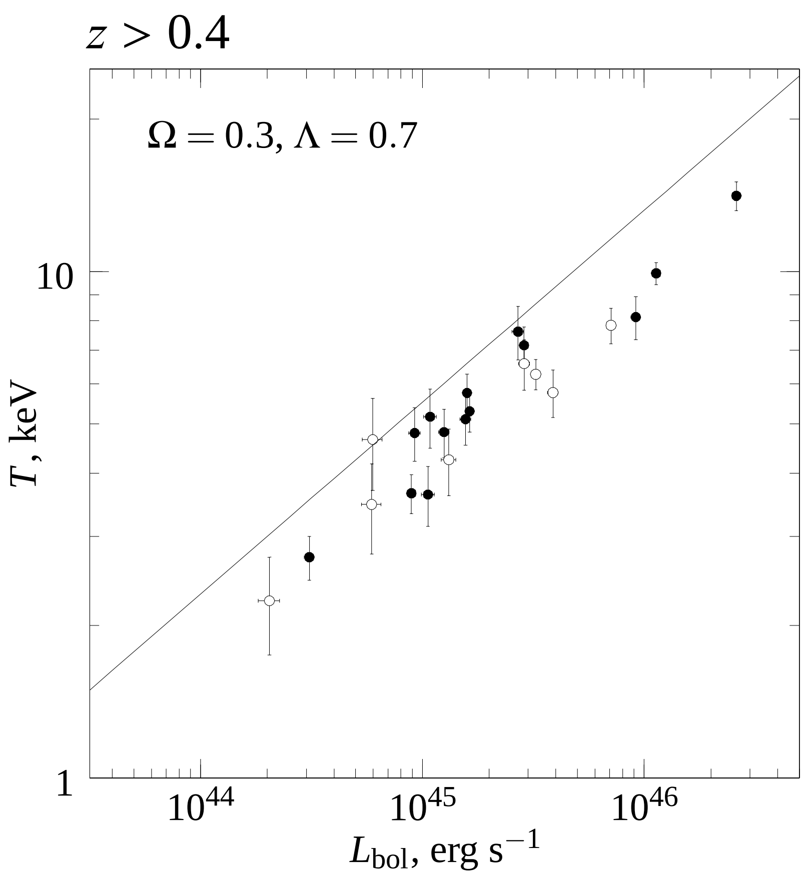




***Chandra* data provides $\Delta T/T \sim 10\%$, $\Delta M_g/M_g \sim 20\%$ for high-z clusters — comparable to *ROSAT* and *ASCA* uncertainties for low-z clusters**

Cluster evolution at $z \sim 0.5$

- **X-ray luminosity function — yes** (3 – 4σ significance)
- **X-ray scaling relations — yes** (using 20+ clusters at $z > 0.4$)



For fixed T, $L_x \propto (1 + z)^{1.5}$

Vikhlinin et al. ’02, Voevodkin et al. ’02, Markevitch ’98 + recent *XMM* results

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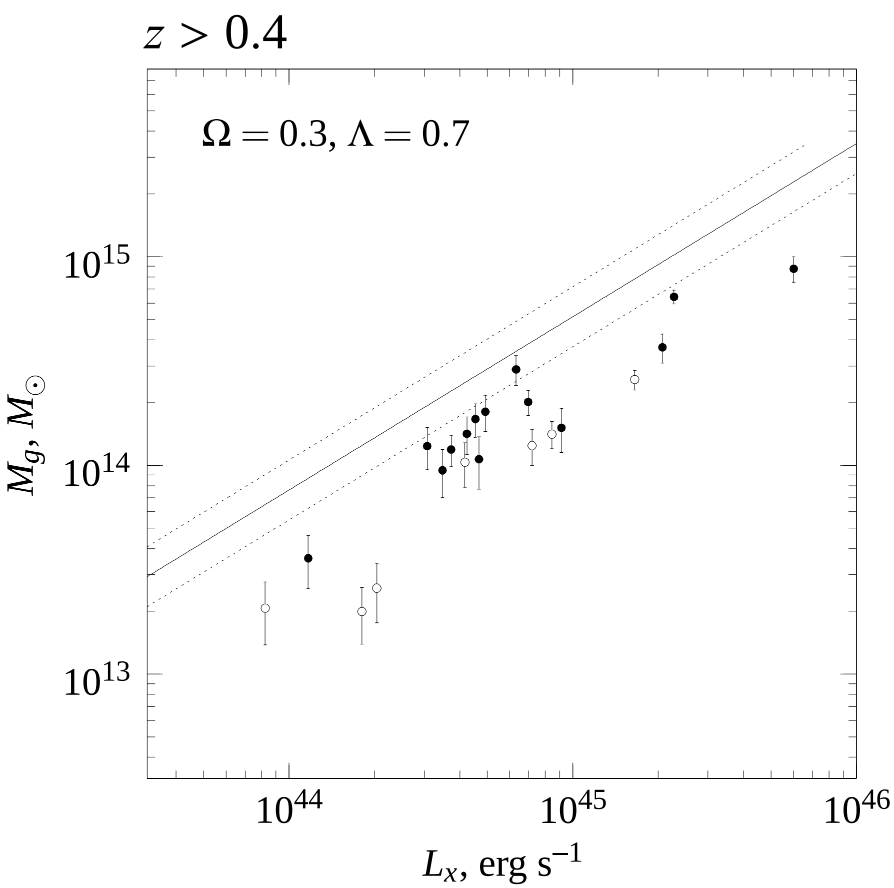

For fixed M_g, $L_x \propto (1 + z)^{2.4}$

Vikhlinin et al. ’02, Voevodkin et al. ’02, Markevitch ’98 + recent *XMM* results

Cluster evolution at $z \sim 0.5$

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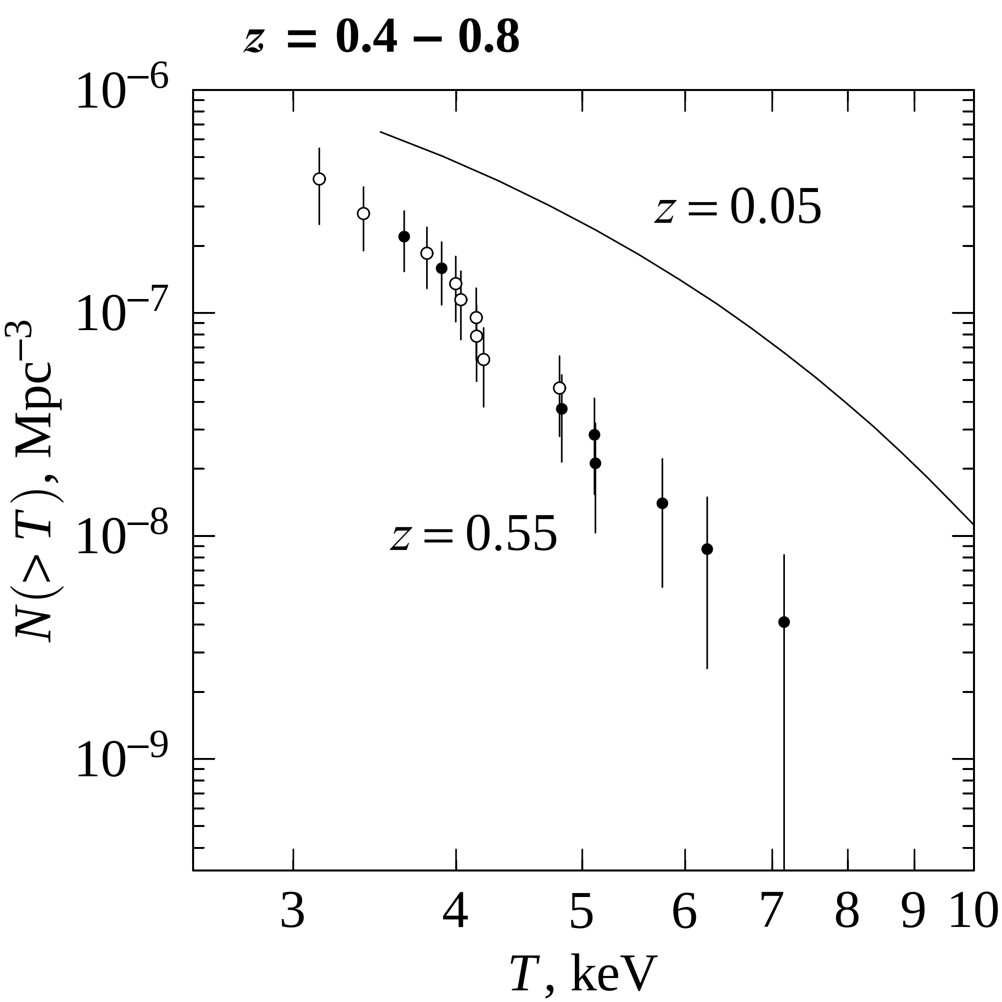
- **X-ray temperature function — yes** (see also Henry's talk)



local TF from Markevitch '98

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- **Cluster evolution constrains cosmological parameters**

Observations: **derive cluster mass function, $F(M)$, at different z**

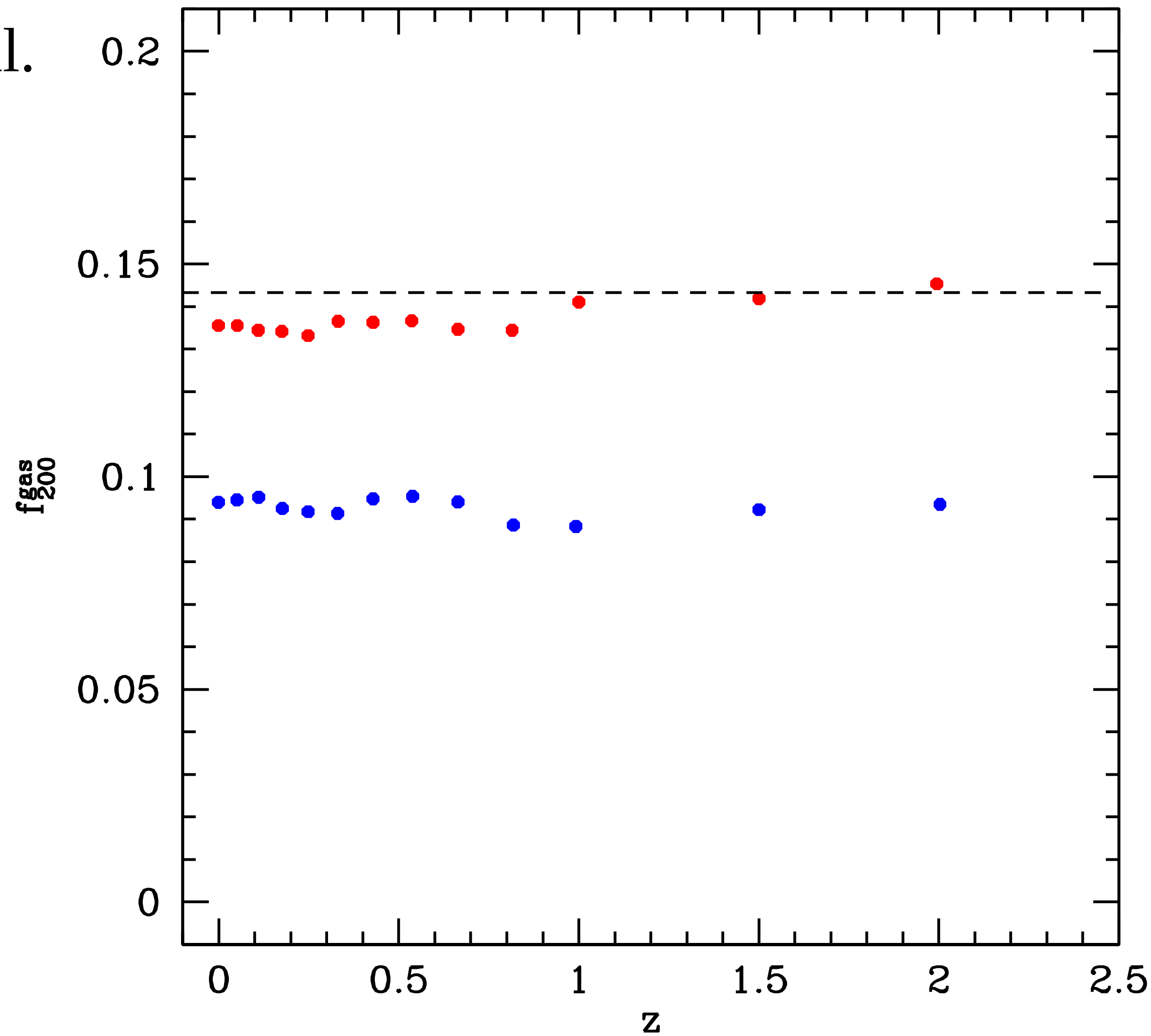
Theory: **predict $F(M, z)$ for different cosmological parameters:**

- **predict $F(M)$ given power spectrum**
  (Jenkins et al.)
- **predict $P(k)$ for different cosmological parameters**
  (Eisenstein & Hu, Hamilton, Linder & Jenkins)

M_b as a proxy for M_{tot}

- $f_b = \dfrac{M_b}{M_{tot}} = \dfrac{\Omega_b}{\Omega_M}$ — **(almost) independent of cluster M or z.**

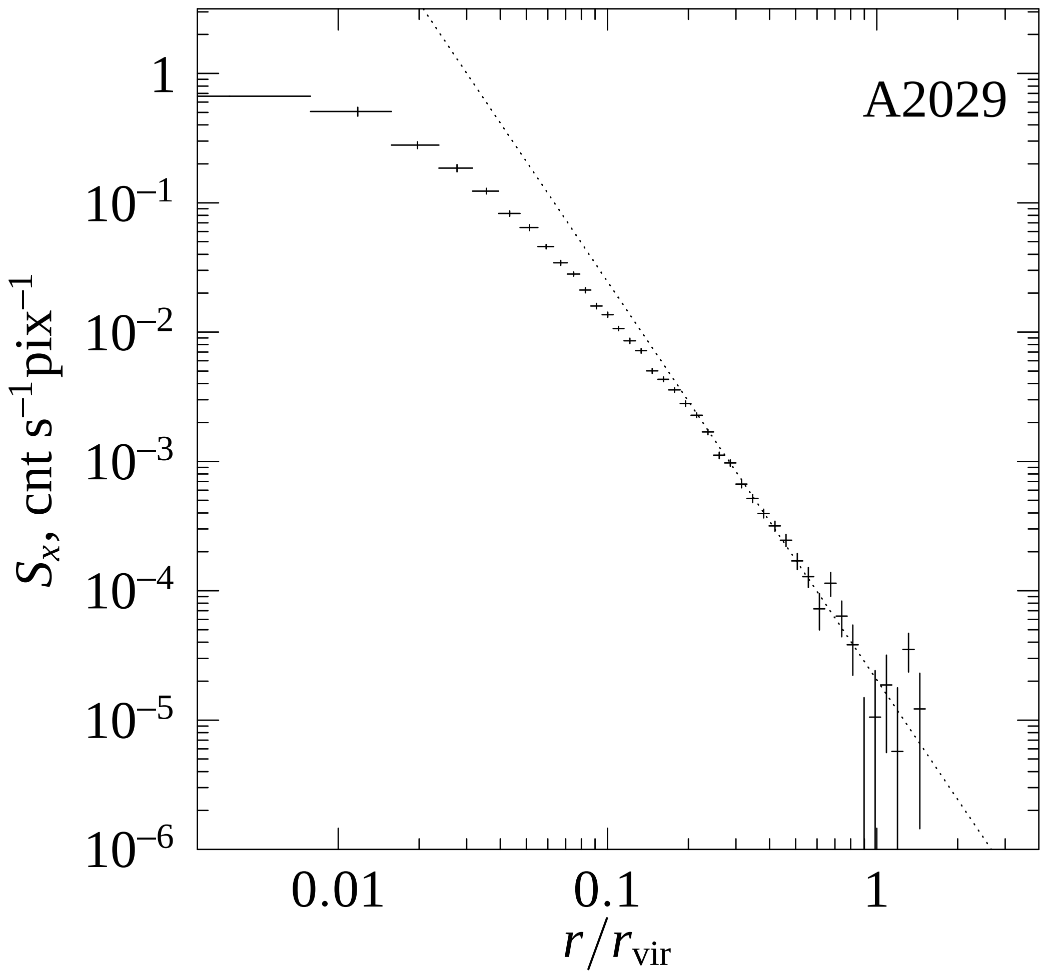
Simulations by Kravtsov et al.



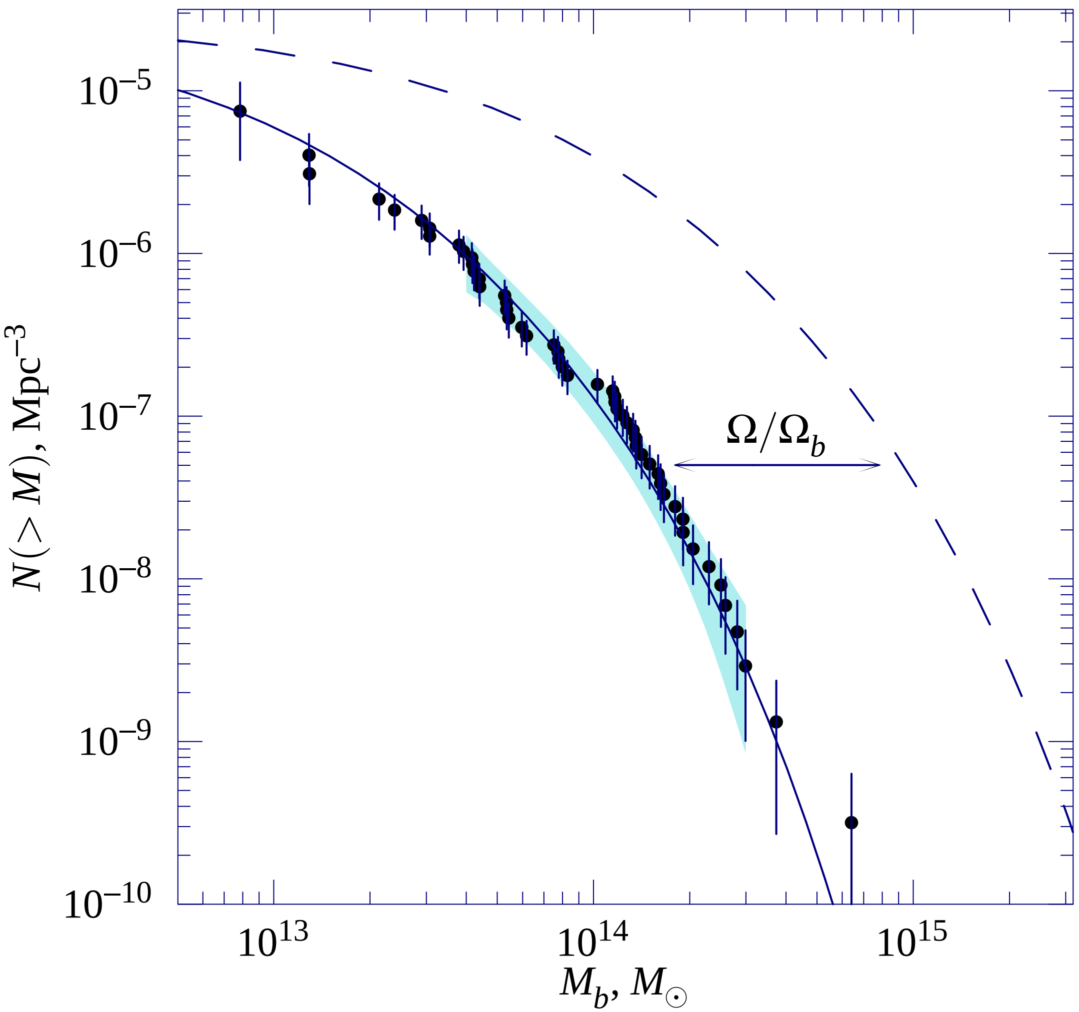
M_b as a proxy for M_{tot}

- $f_b = \dfrac{M_b}{M_{\text{tot}}} = \dfrac{\Omega_b}{\Omega_M}$ — (almost) independent of cluster M or z.

- M_b is easily and directly measured at $r \sim r_{\text{vir}}$



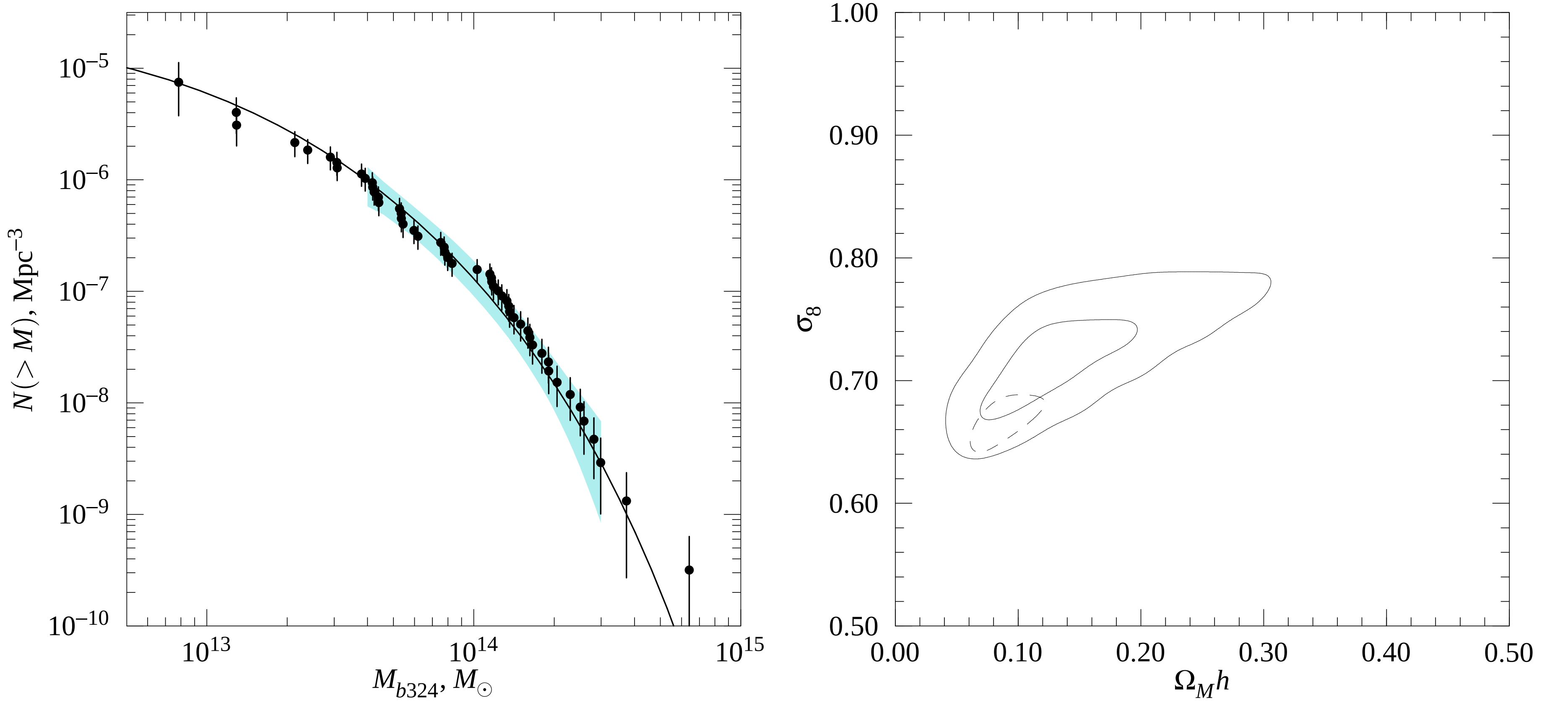
Cosmological fits with $F(M_b)$



- Ω_b from BBN: $\Omega_b h^2 = 0.020$ or WMAP $\Omega_b h^2 = 0.0224 \pm 0.001$.
- Models for $F(M_{tot})$ assume Ω_M, this fixes $M_{tot}/M_b = \Omega_M/\Omega_b$, $F_b(M_b) = F_{tot}(\Omega_M/\Omega_b M_b)$.
- *we do include* $f_b(M)$ *(from Bialek et al.)*

Results at z = 0

Voevodkin & Vikhlinin (astro-ph/0305549)



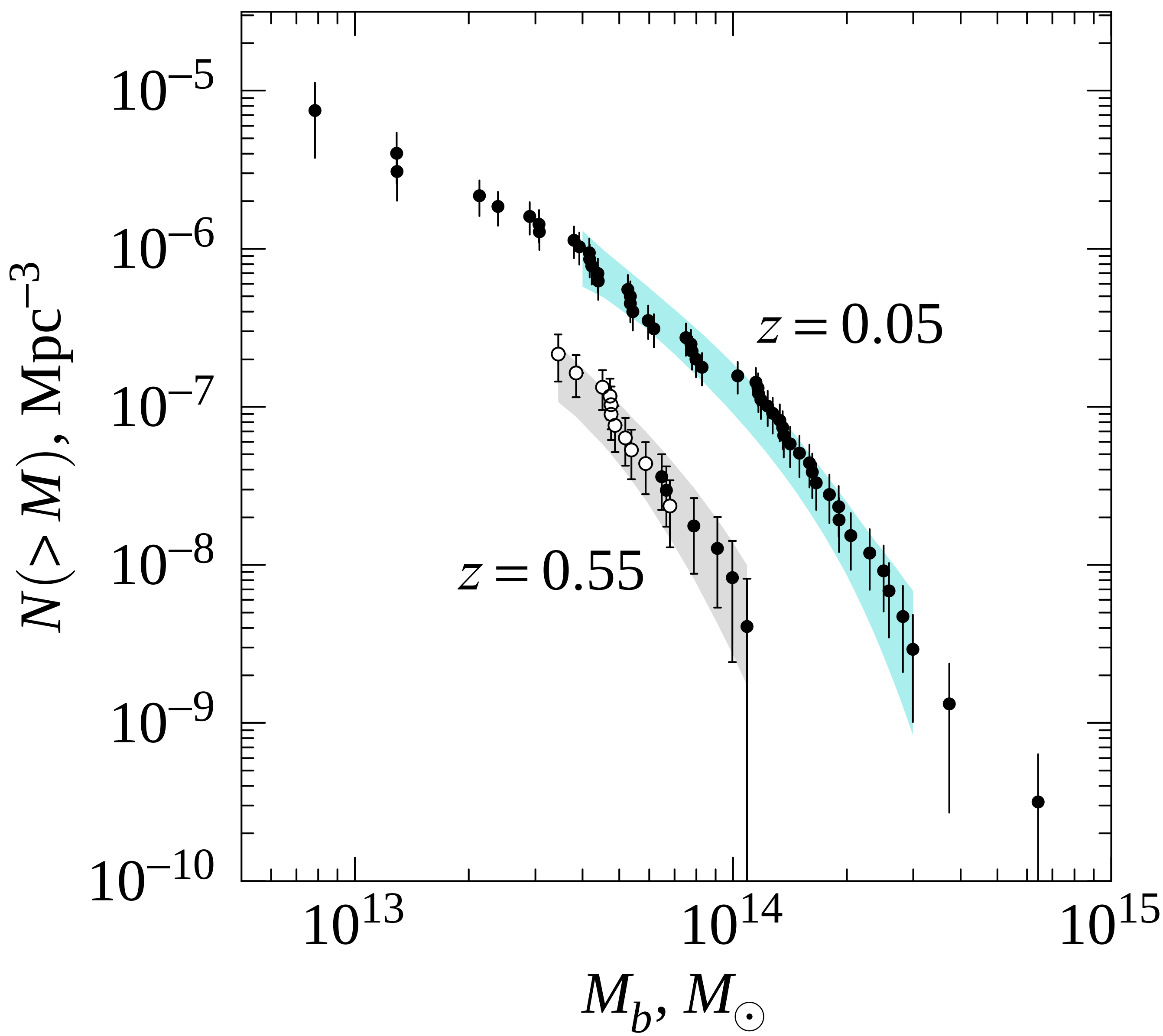
- $F(M)$ for $4 \times 10^{13} M_\odot < M_b < 4 \times 10^{14} M_\odot$ constraints σ_8 and slope of $P(k)$:

$\sigma_8 = 0.72 \pm 0.04$ $\quad\Omega_M h = 0.13 \pm 0.07$ $\quad(\Omega_M = 0.18 \pm 0.10$ for $h = 0.71)$

(assuming weak dependence of f_b on M from Bialek et al. consistent with observations)

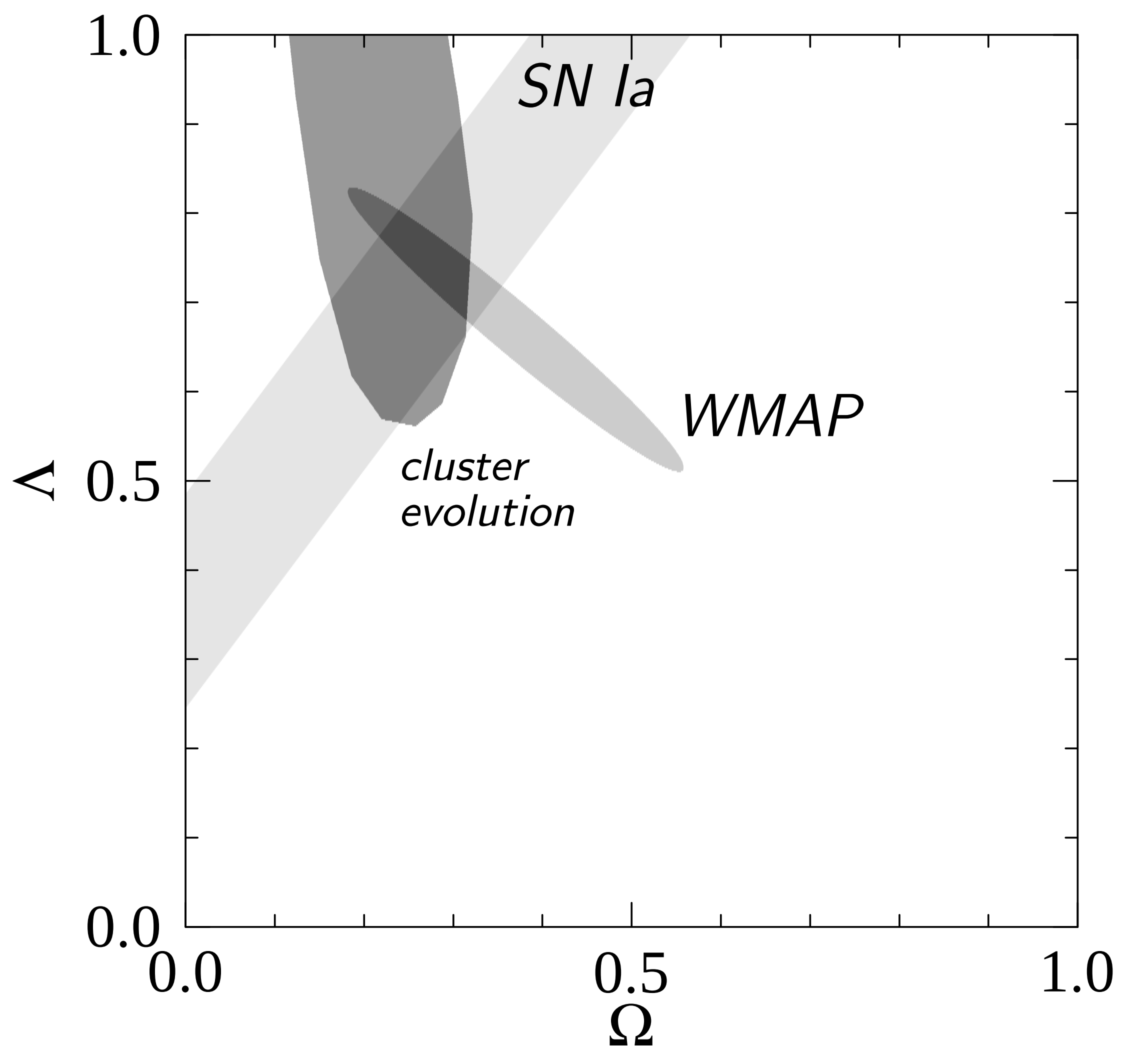
Evolution of $F(M_b)$

Baryon mass function at $0.4 < z < 0.8$ (17 brightest clusters from 160d)



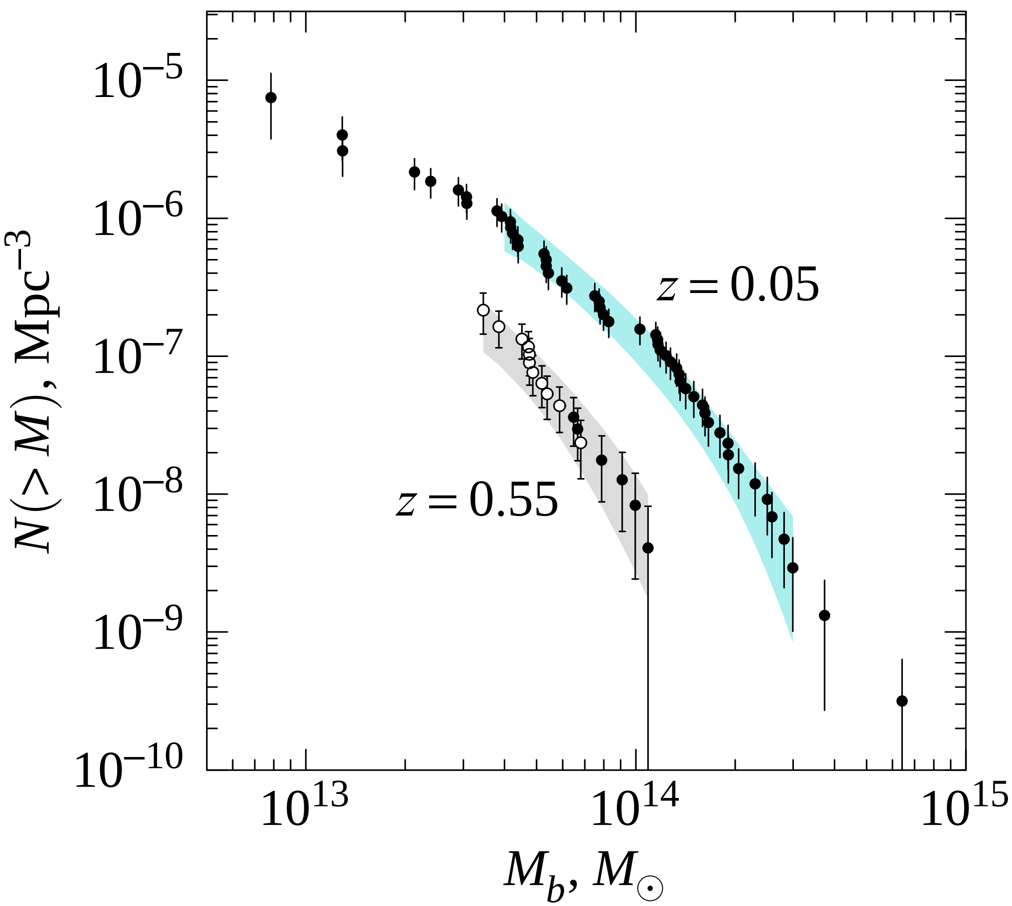
Cluster evolution constraints on Ω, Λ

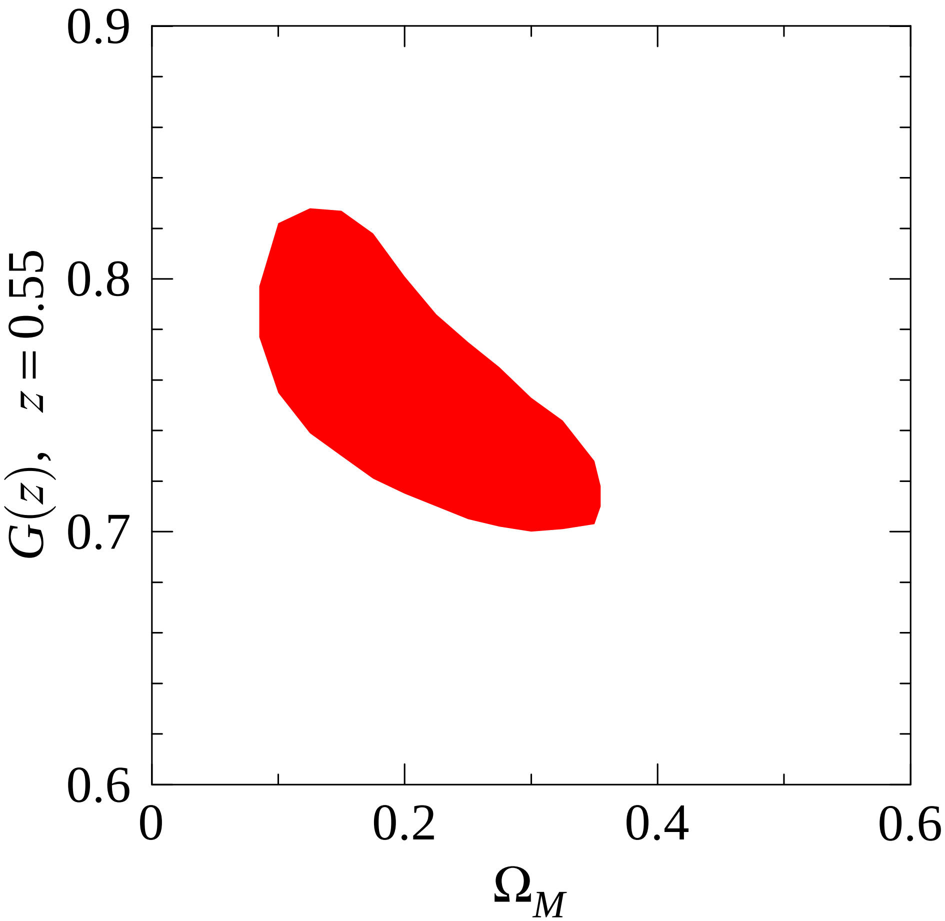
Evolution of $F(M_b)$ + Shape of the local mass function



Growth factor and equation of state

- **Perturbations growth factor *D*(*z*):**

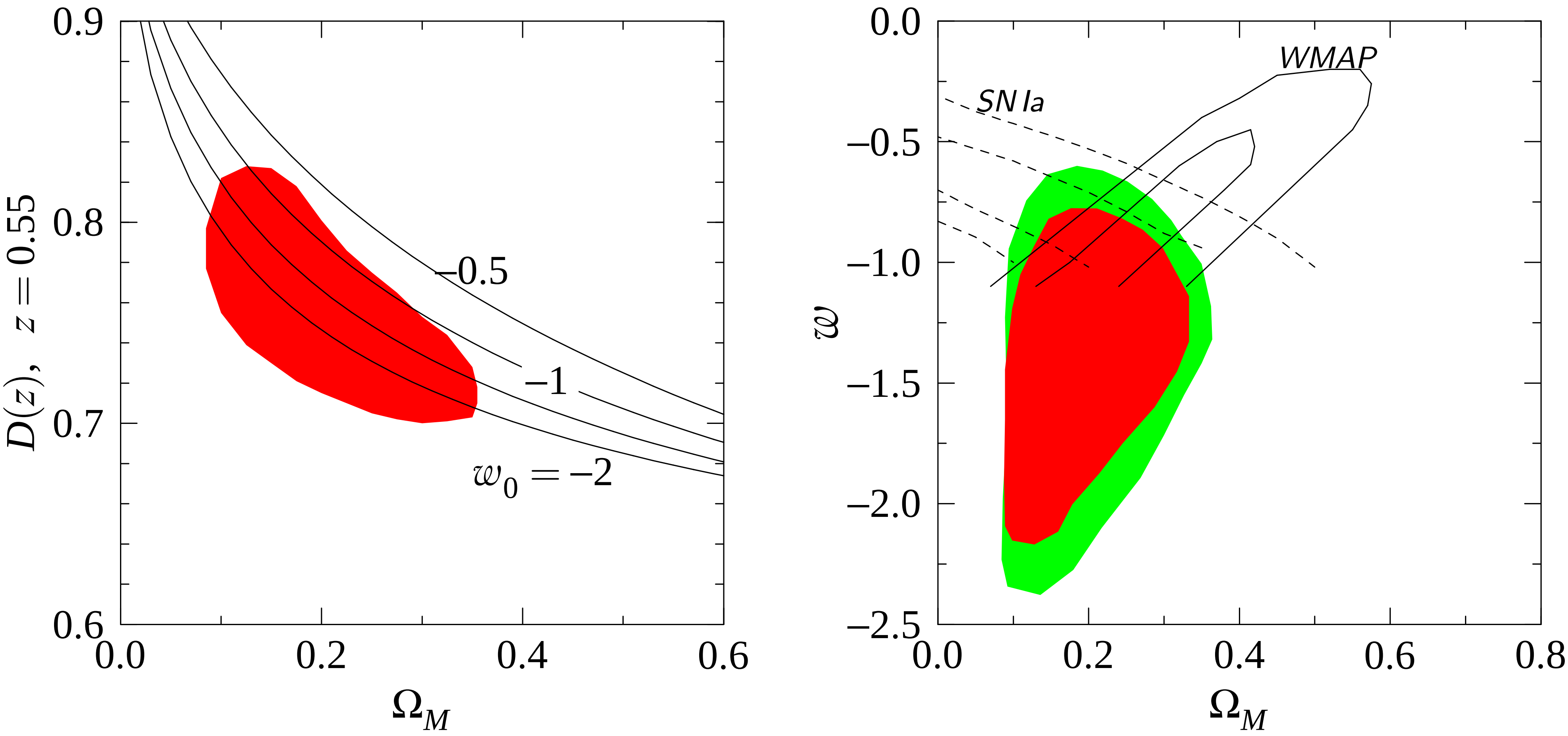




$$
\begin{aligned}
\boldsymbol{G(0.55)} &= \mathbf{0.726 \pm 0.027 \text{ for } \Omega = 0.3} \\
&= \mathbf{0.760 \pm 0.045 \text{ for } \Omega = 0.2}
\end{aligned}
$$

Growth factor and equation of state

- **Perturbations growth factor $D(z)$ and w:**



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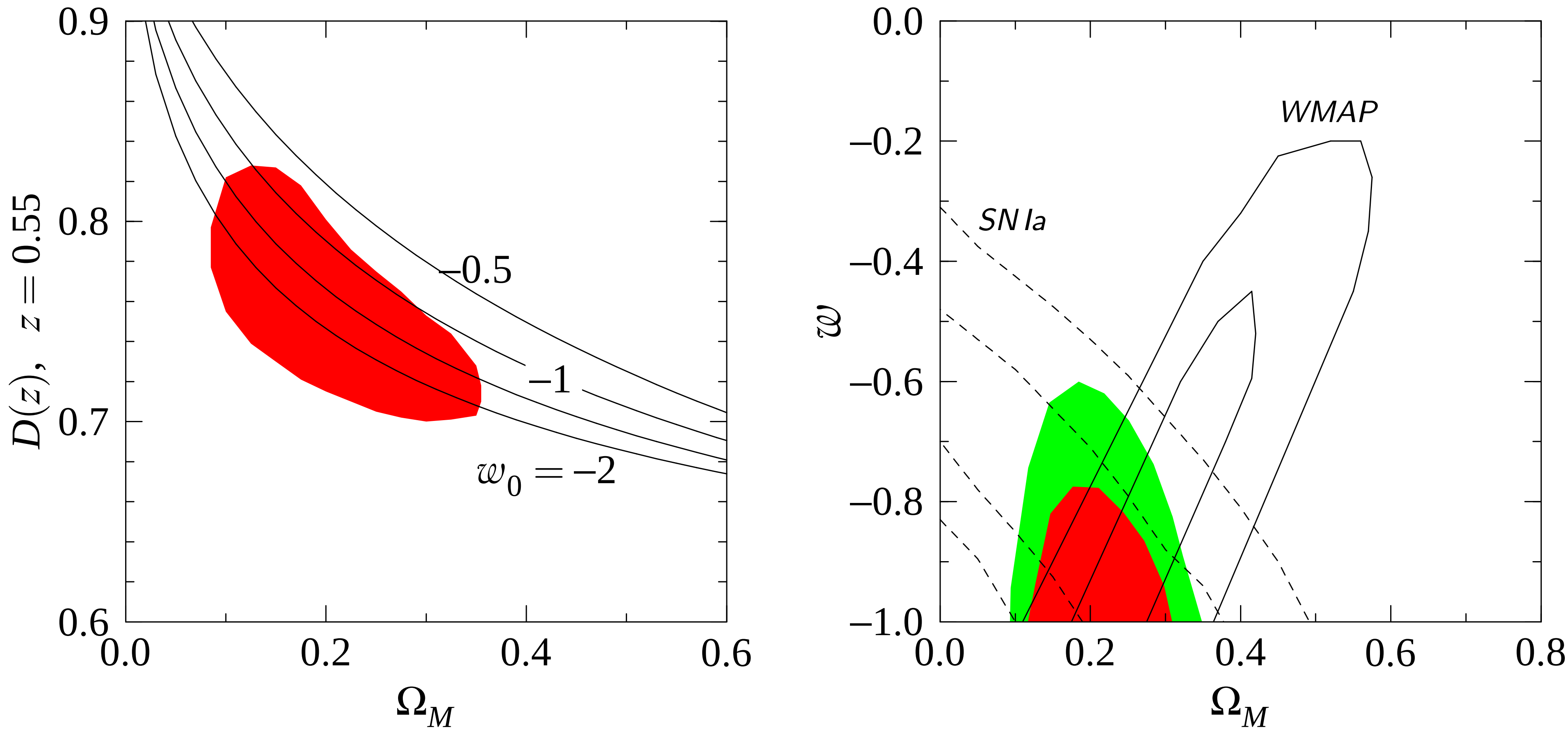


For $\Omega_M = 0.3$, $w < -0.9$ (68%),
< -0.7 (90%),
< -0.6 (95%)

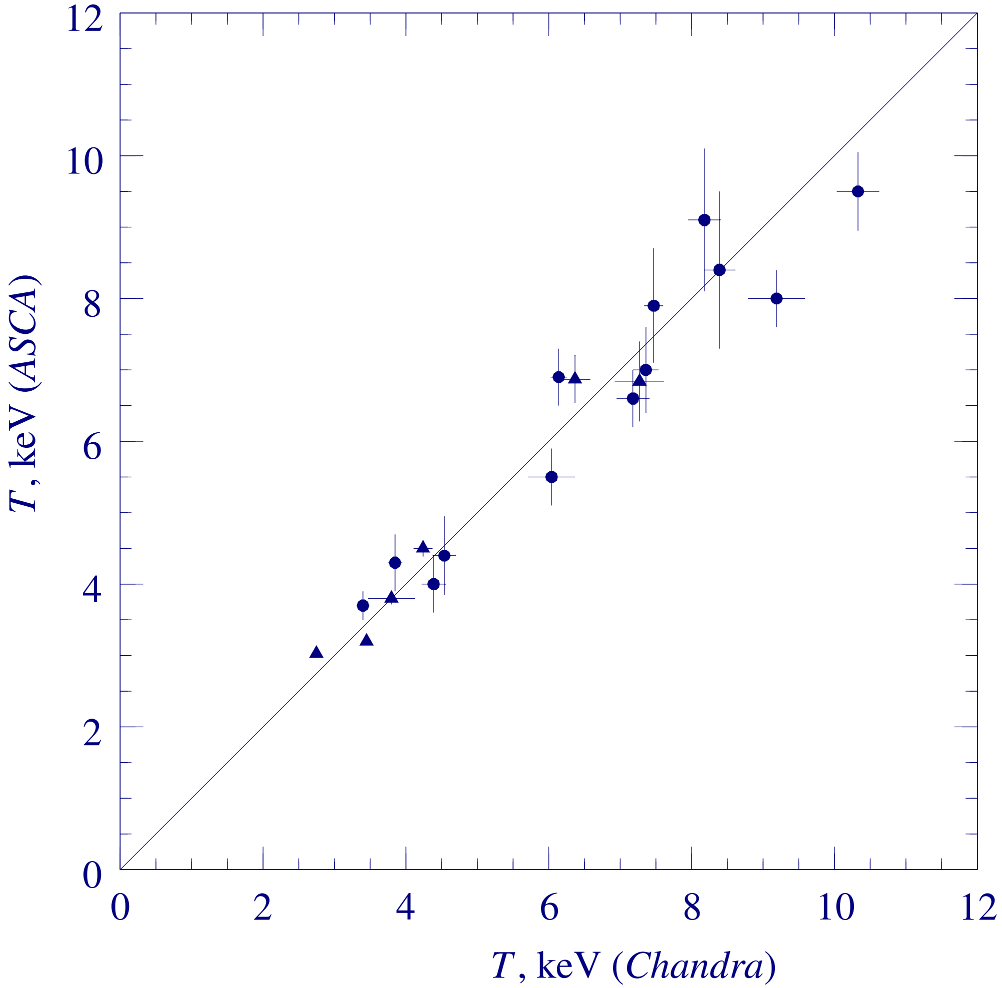
Future work

- **400d survey based on *ROSAT* archive:**
  - ➢ **same sensitivity as in 160d.**
  - ➢ **but a factor of 2.5 larger area**
  - ➢ **Status:**
    - **– X-ray data** ✔ **reduced**
    - **– Optical IDs** ✔ **finished**
    - **– Redshifts** ... **in progress (46 left)**

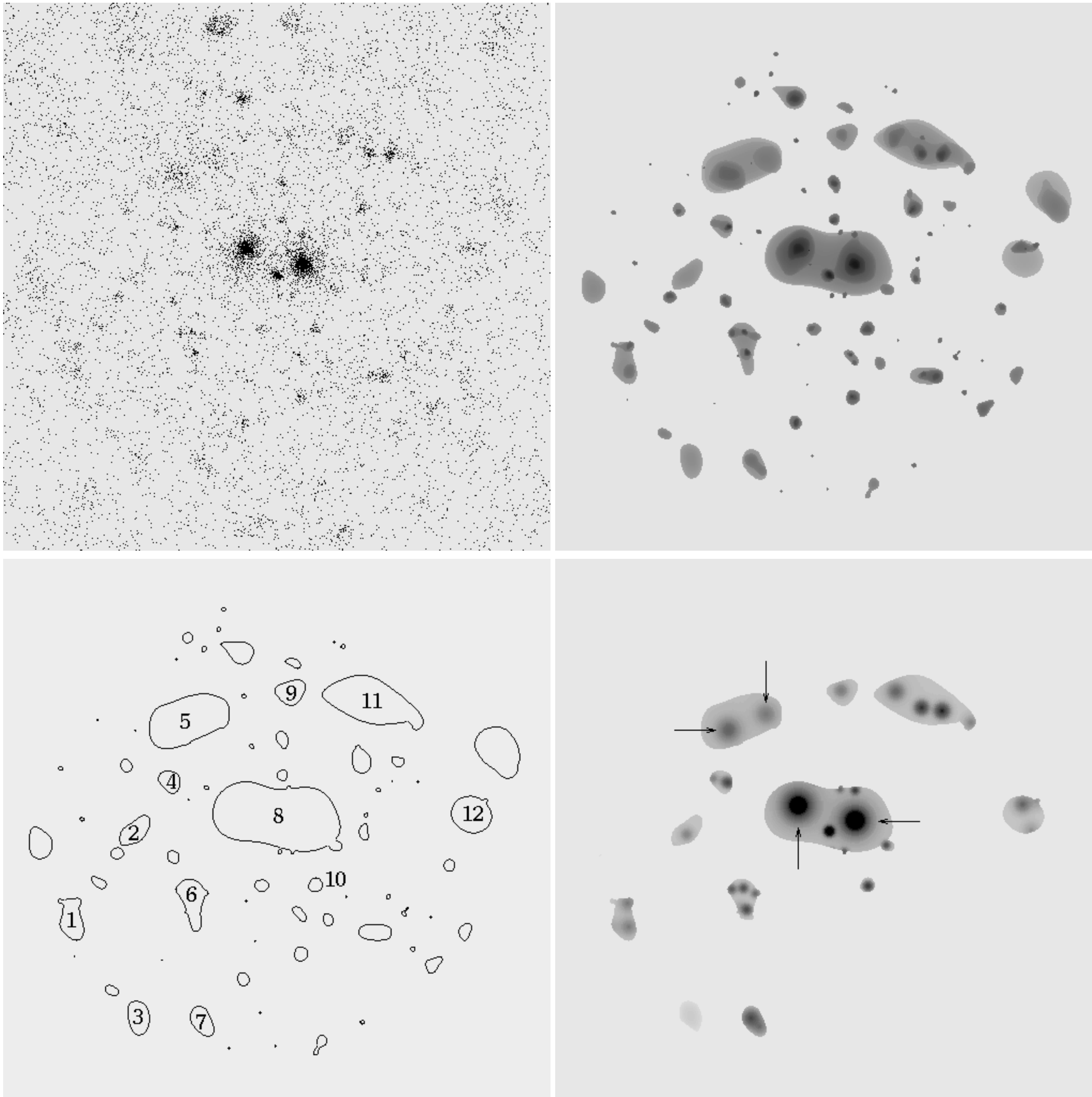
CONCLUSIONS

- **Good samples from ROSAT at $z = 0$ and $z = 0.4 - 0.7$ ($\sim$ 50 objects)**
- **Clusters evolve by $z \sim 0.5$ (XLF, XTF; scaling relations)**
- **Baryon mass function is a good proxy for the total mass function.**
  — Bypasses the need for total mass measurements
- **Cluster evolution constraints on (Ω, Λ) (from 17 $z > 0.4$ clusters in 160 deg^2) comparable in quality to SN Ia and pre-WMAP CMB results.**
- **Interesting constraints on w (favor cosmological constant, $w = -1$)**
  - ➢ higher accuracy achievable with *ROSAT*

Chandra calibration



160d survey detection algorith: example



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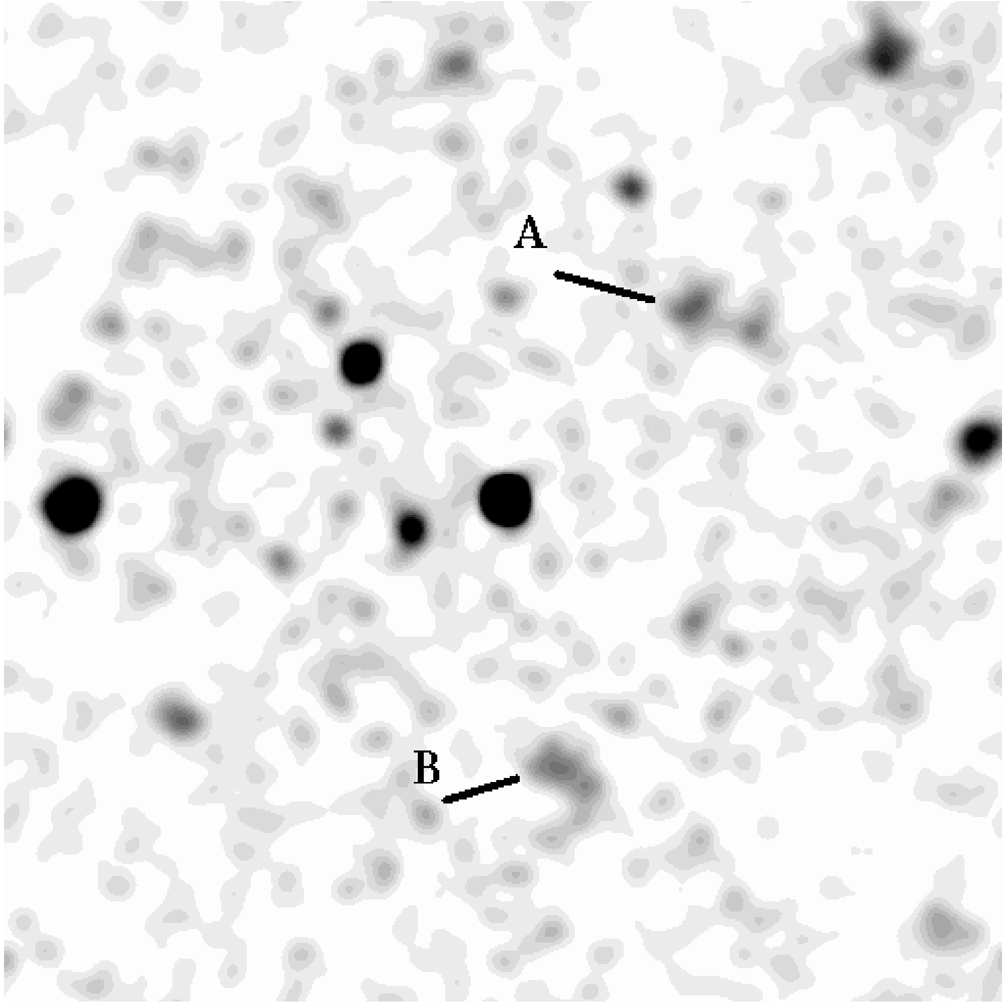
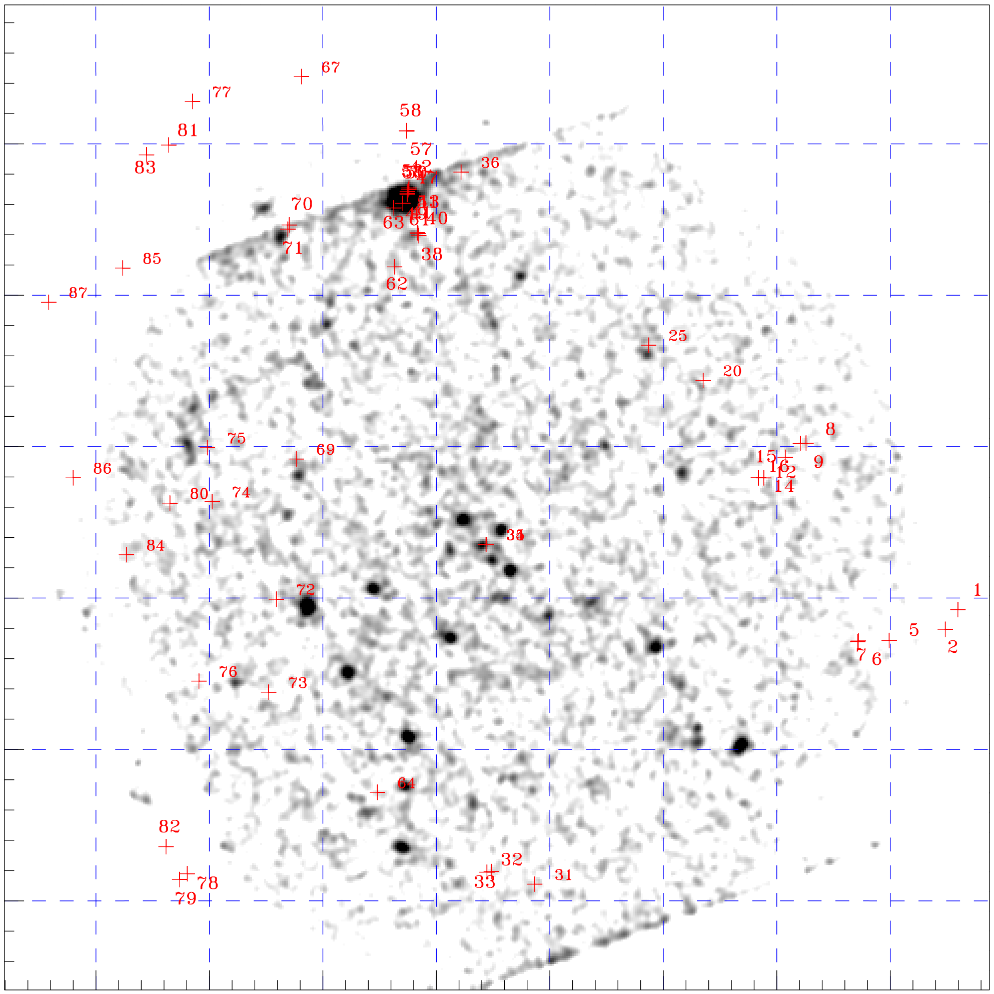


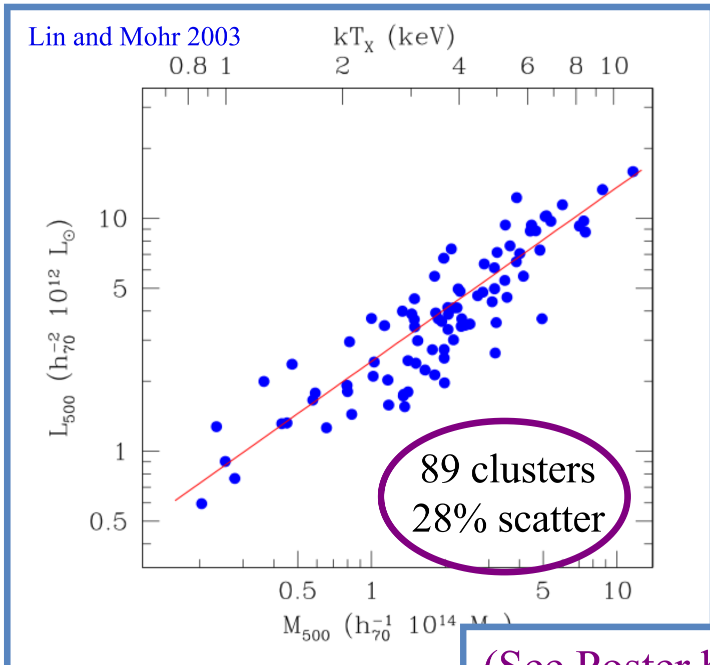


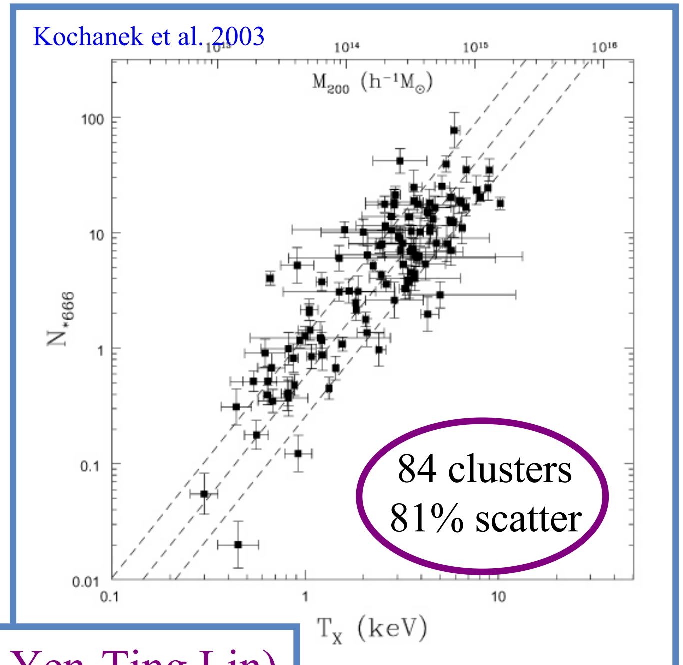
X-ray vs. optical

(From J. Mohr's talk:)

Why SZE or X-ray Surveys?

- The mass-observable relations in the optical are not as clean
  - » *On the left:* adopt X-ray emission peak as cluster center, choose cluster radius using the emission weighted mean X-ray temperature (calibrated by cluster studies with temperature profiles- Finoguenov, Reiprich & Boehringer)
  - » *On the right:* finding clusters and boot-strapping to the halo mass using only the K band galaxy data





(See Poster by Yen-Ting Lin)