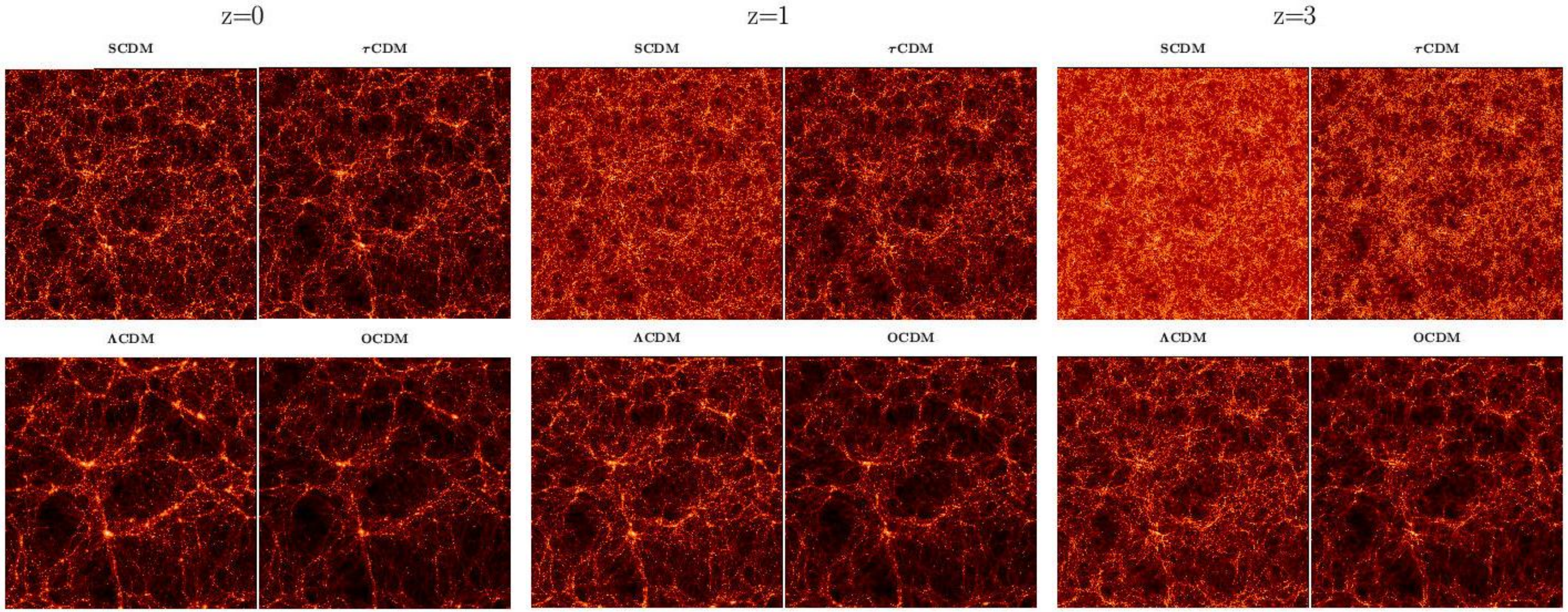
Cosmological Constraints from the Cluster Baryon Mass Function

A. Vikhlinin, A. Voevodkin, C. Mullis, L. VanSpeybroeck, B. R. McNamara, H. Quintana, A. Hornstrup, W. Forman, J. P. Henry, C. Jones, I. Gioia

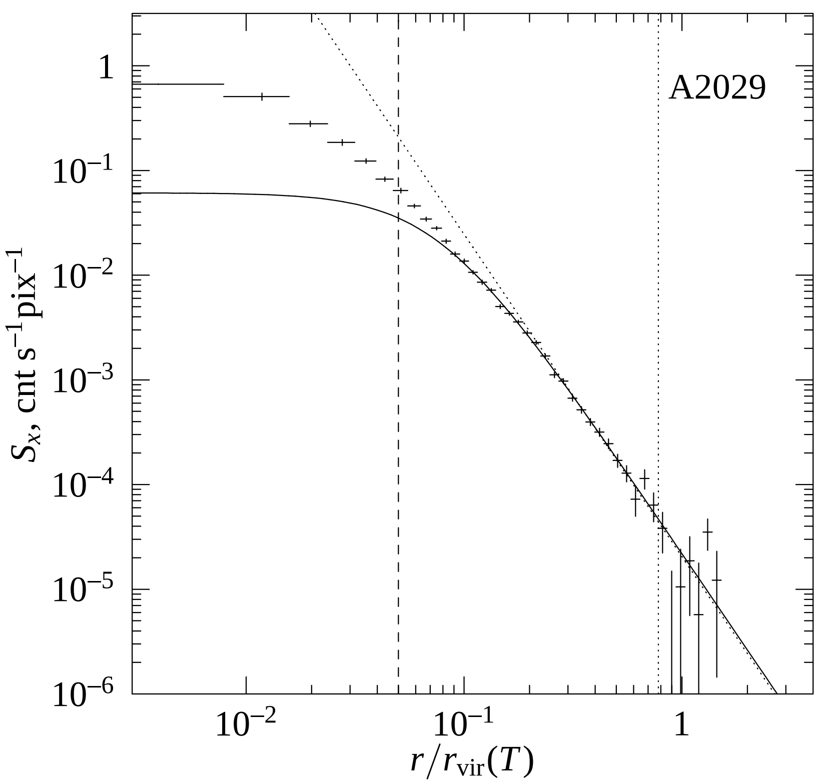
Clusters and cosmology

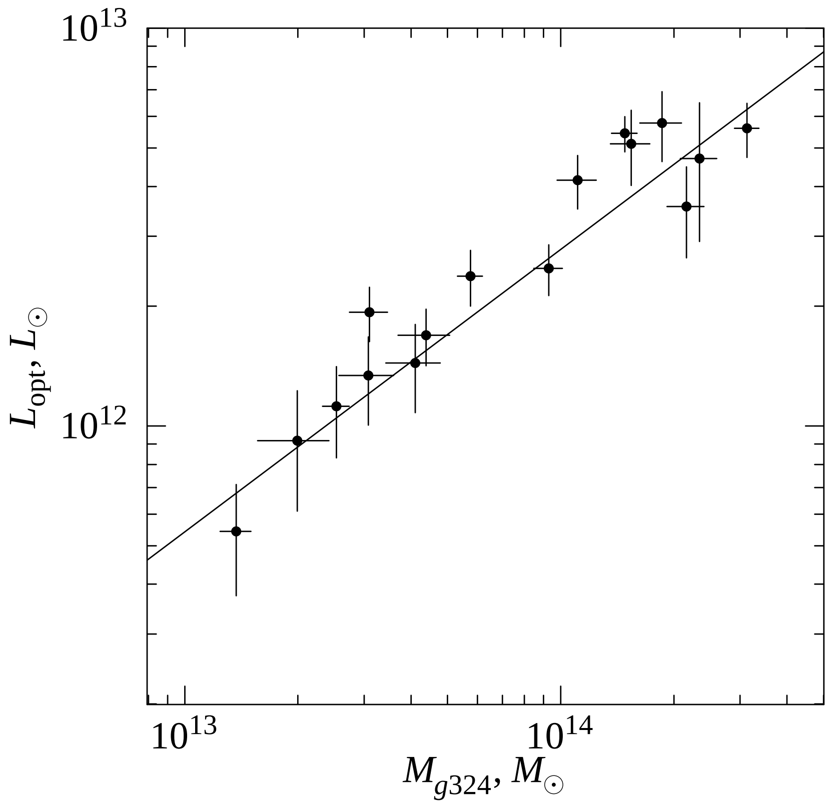
	Ω	Λ	h	σ_8
SCDM:	1	0	0.5	0.51
ΛCDM:	0.3	0.7	0.7	0.9
OCDM:	0.3	0	0.7	0.85
τCDM:	1	0	0.5	0.51



M_b as a proxy for $M_{\rm tot}$

- $f_b = \dfrac{M_b}{M_{\rm tot}} = \dfrac{\Omega_b}{\Omega}$ — **(almost) independent of cluster mass or redshift.** — *Steve Allen's talk*
- **M_b is easily and directly measured at $r \sim r_{\rm vir}$:**





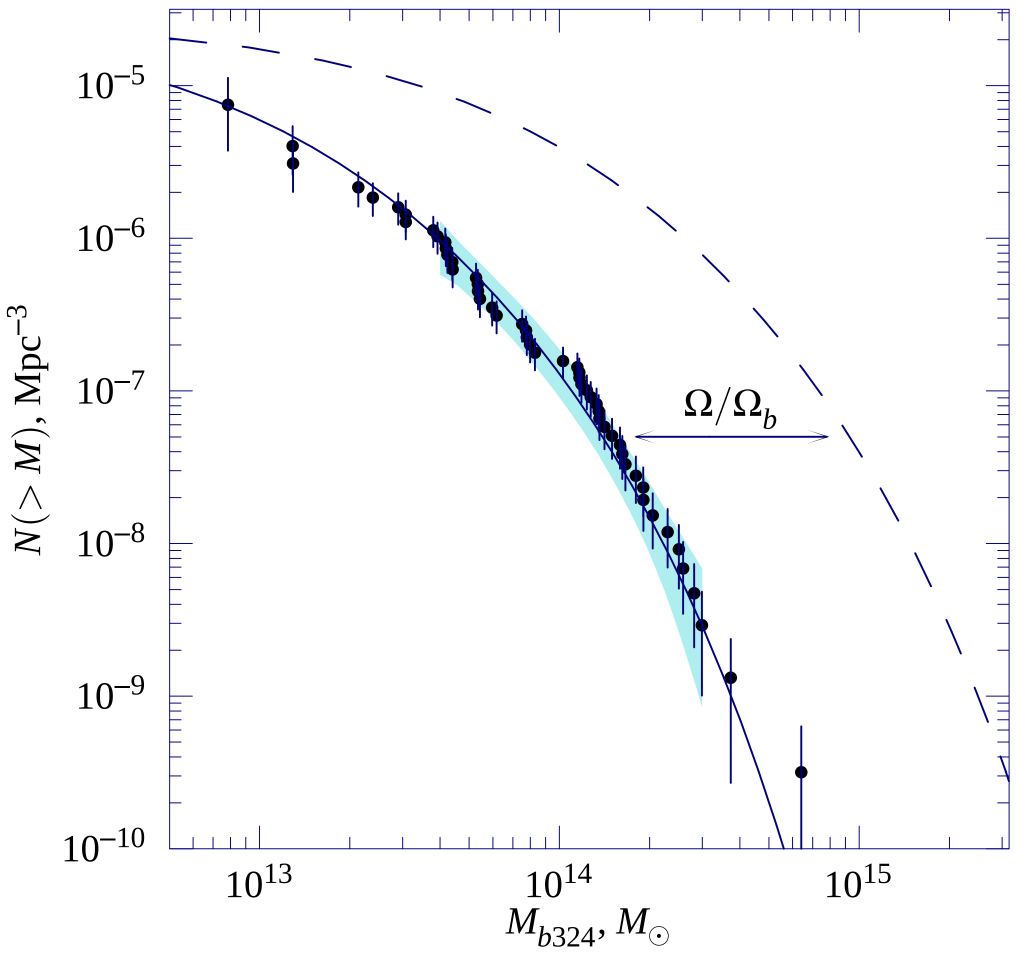
✓ X-ray imaging (*ROSAT*) provides surface brightness (gas mass profile) to $r \sim r_{\rm vir}$.

✓ $$\frac{M_b}{M_g} = 1.100 + 0.045\left(\frac{M_g}{10^{15}\,M_\odot}\right)^{-0.5}$$

✓ $\delta_b = \delta_M \quad \Longrightarrow \quad r_\delta$ can be estimated from the X-ray imaging alone

- **Cluster baryon mass functions are easily and directly measured.**

  @ $z = 0$ (HIFLUGCS sample): *Voevodkin & Vikhlinin astro-ph/0305549*



- **Absolute measurements of f_b not needed to fit cosmology:**
  - ✓ Ω_b known from BBN: $\Omega_b h^2 = 0.020$ (Burles et al.) or WMAP $\Omega_b h^2 = 0.0224 \pm 0.001$.
  - ✓ Models for the total mass function computed assuming an Ω_M, this fixes the scaling between a model for $F_{\rm tot}(M_{\rm tot})$ and measurements of $F_b(M_b)$: $F_b(M_b) = F_{\rm tot}(\Omega/\Omega_b M_b)$.
- **See Voevodkin & Vikhlinin astro-ph/0305549 for results on σ_8 and $\Omega_M\ h$.**

Cluster evolution: high-z sample

160 deg^2 survey

- Large area — 650 ROSAT PSPC pointings, 160 square degrees.
- 100% optically identified, fully published (Vikhlinin et al. 1998, Mullis et al. astro-ph/0305228)
- High quality:

  Total sample . . . . 223 X-ray candidates, 201 optically confirmed as clusters

  For $f_x > 1.4 \times 10^{-13}$ erg s^{-1} cm^{-2} . . . . 114 X-ray candidates, 111 confirmed as clusters
- X-ray fluxes are good: *Chandra* followup shows no bias within 5%.
- Survey area calibrated via extensive Monte-Carlo simulations.
- Large distant sample — 45 clusters at $z > 0.4$

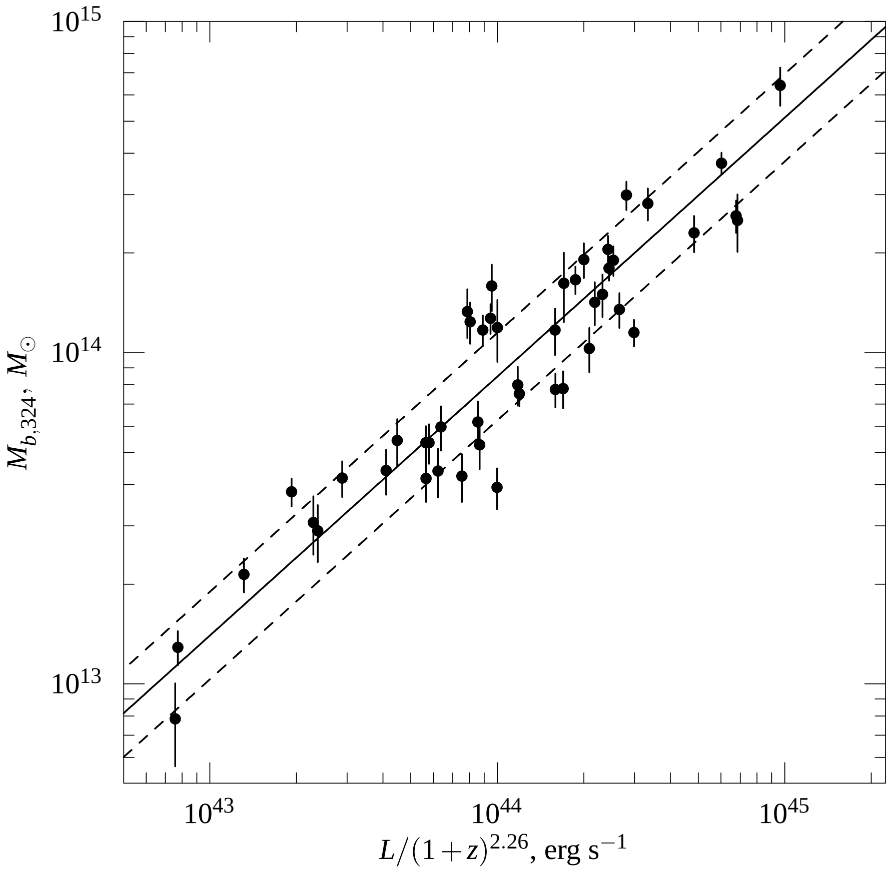
Chandra followup

7 brightest clusters at $z > 0.4$ observed with long exposures (PIs L. VanSpeybroeck, S. S. Murray).

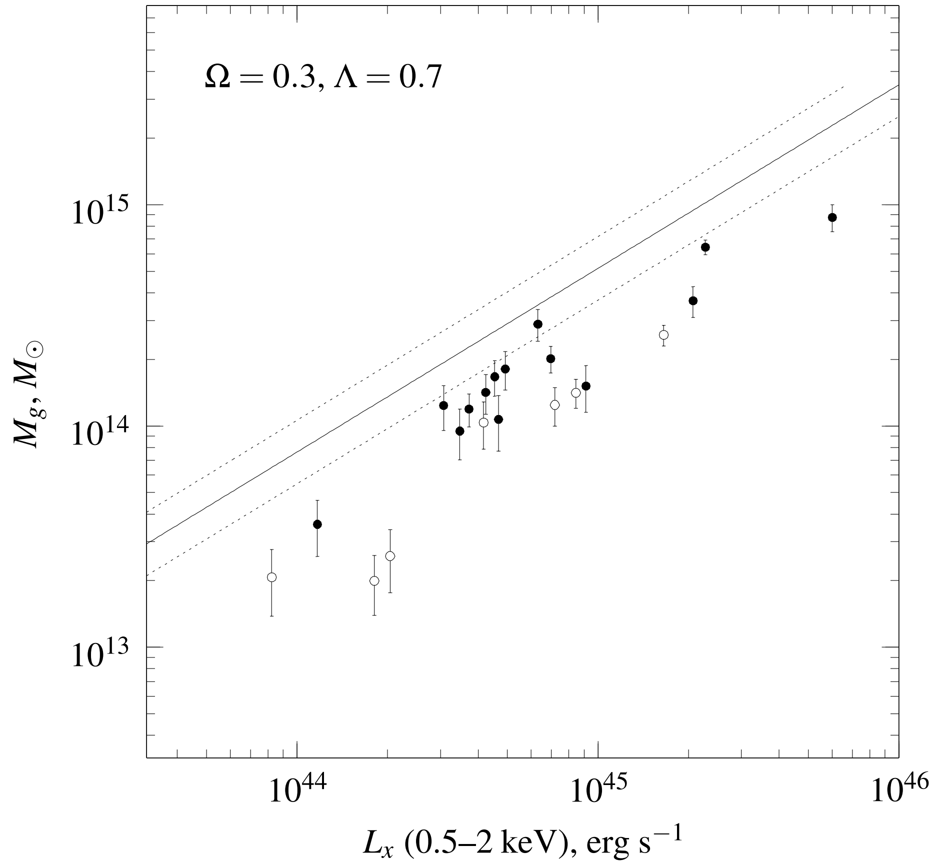
$\Delta T/T \sim 10\%$, $\Delta M_g/M_g \sim 20\%$

Cluster evolution: scaling relations at $z > 0.4$

$z = 0$



$z > 0.4$



$M_b \propto (1+z)^{-1.8\pm0.4}$ — mass at a fixed L_x decreases with z.

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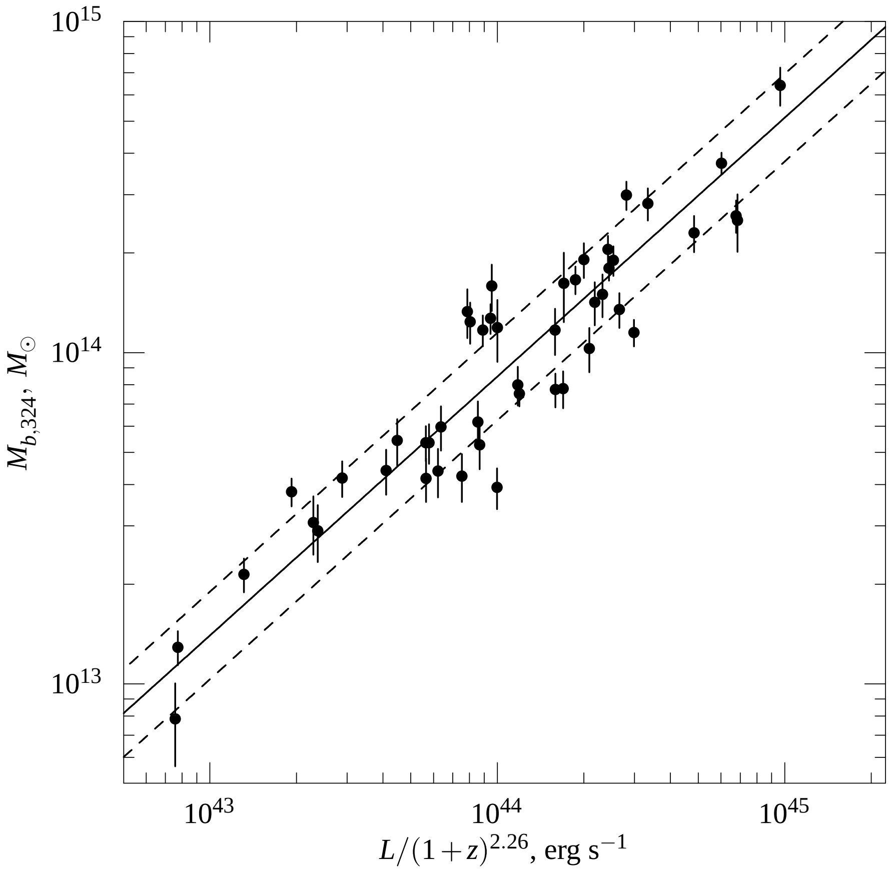

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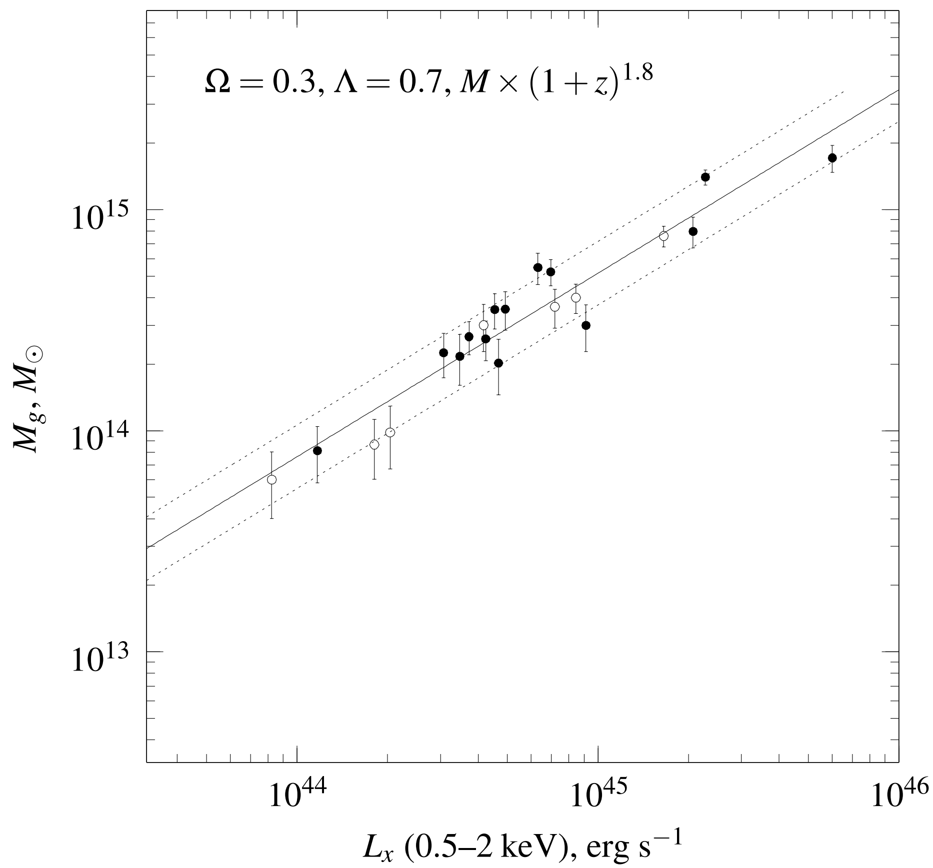

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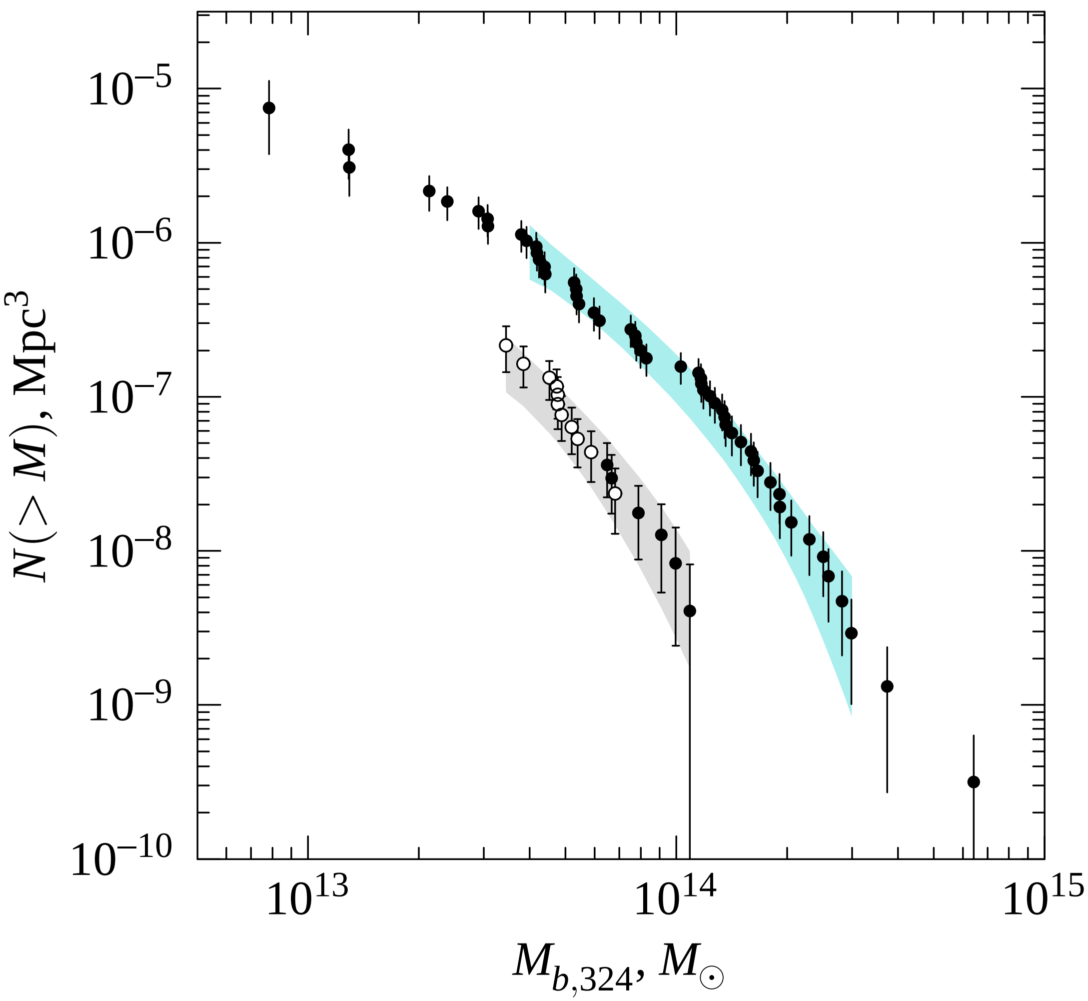
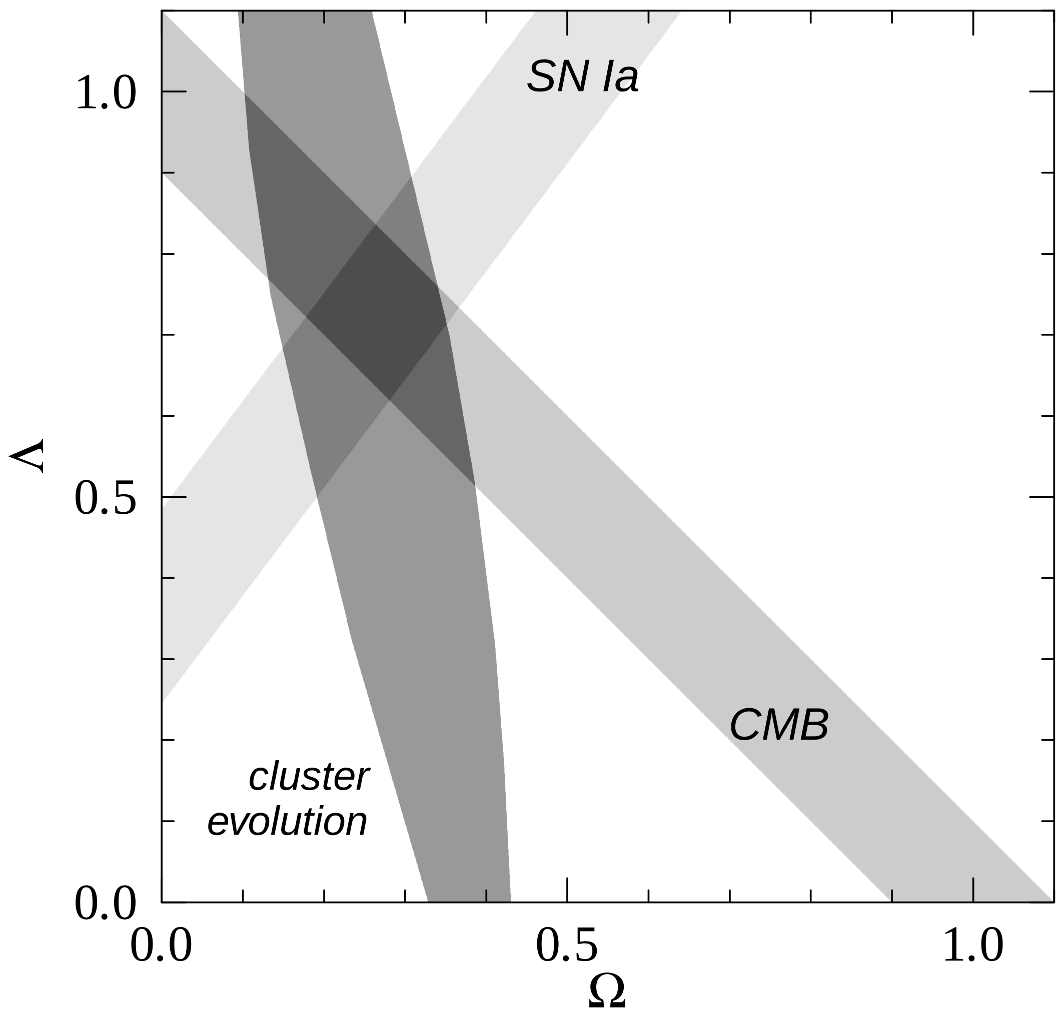
Evolution of the baryon mass function at $z > 0.4$

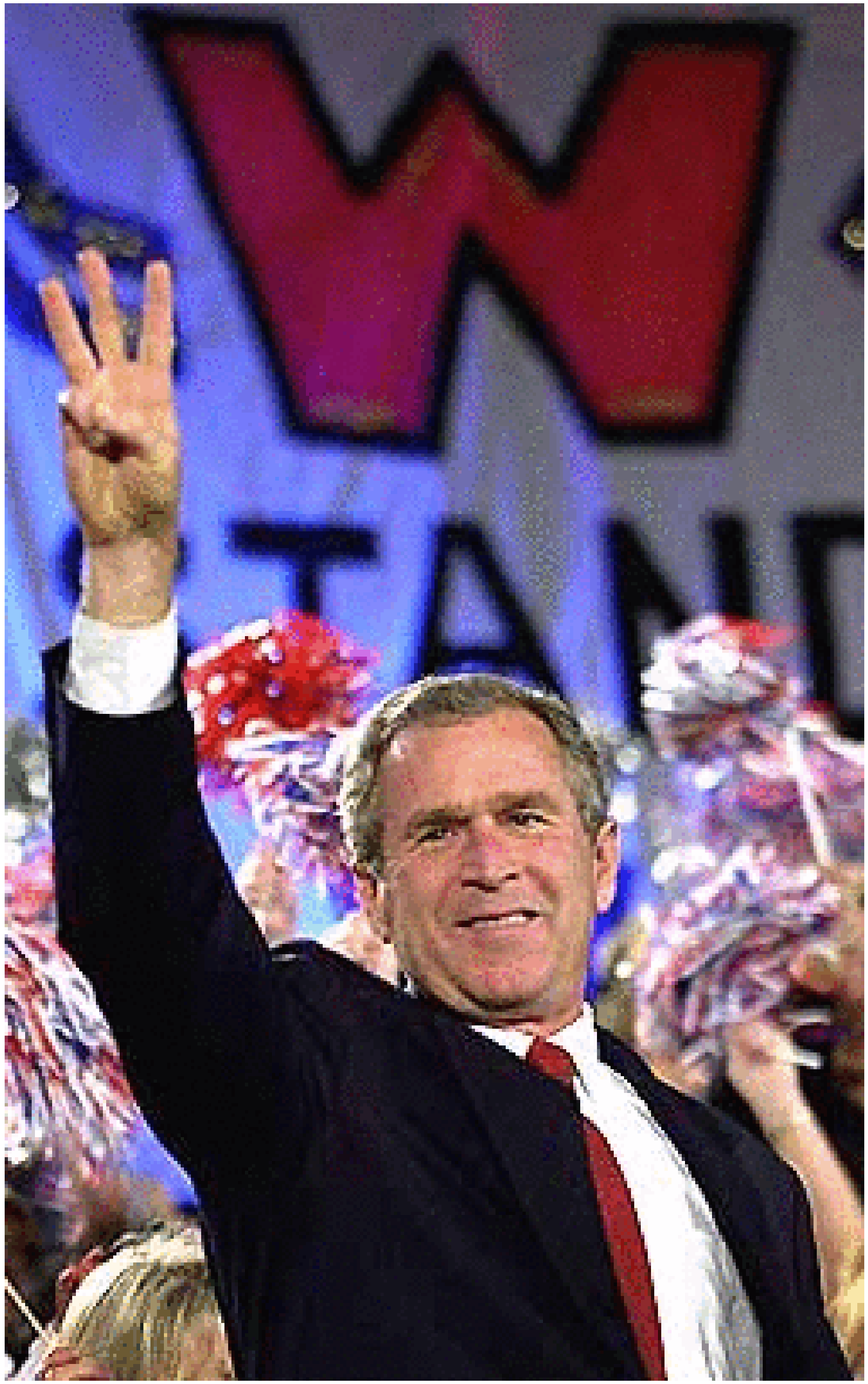


- Fix $\Omega_b h^2 = 0.0224$, $h = 0.71$, $n = 1$.
- Compute mass function models on a grid of Ω, Λ, and σ_8
- A pair of (Ω, Λ) is acceptable if model fits data at $z = 0$ and $z > 0.4$ for some σ_8.

Cluster evolution constraints on Ω, Λ

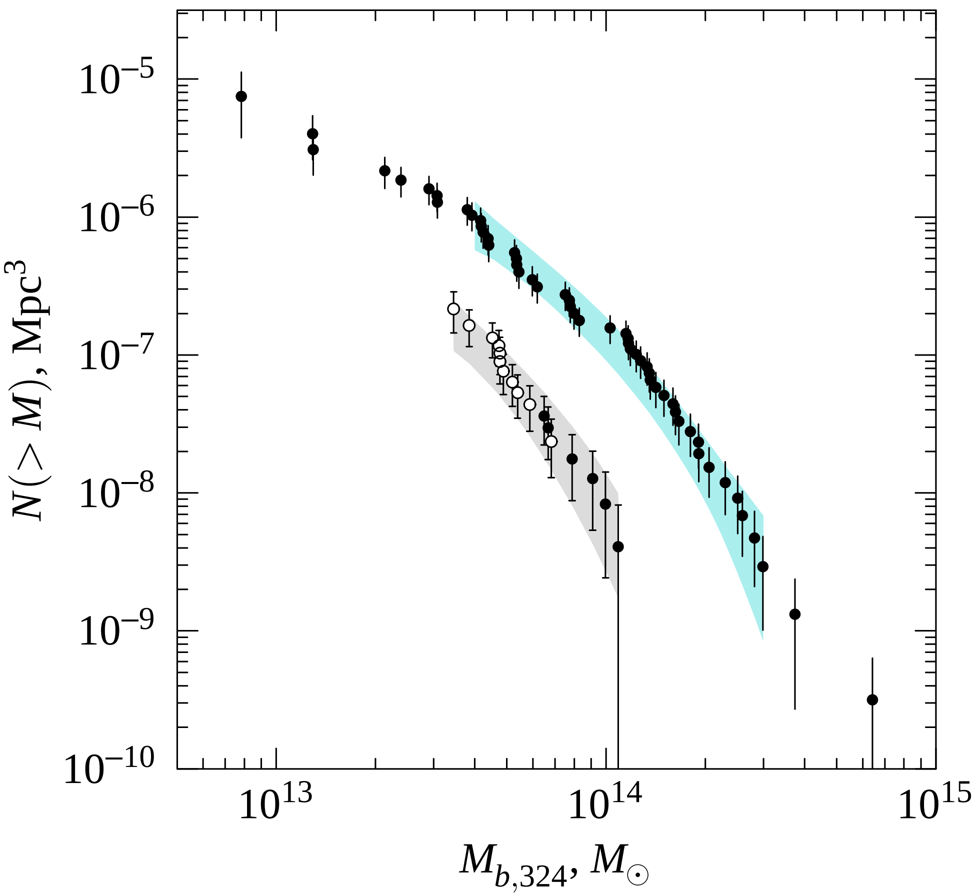
Vikhlinin et al. 2003 (astro-ph/0212075)




W

Growth factor and equation of state

Cluster evolution *really* constrains the growth factor for linear density perturbtions $D(z)$:



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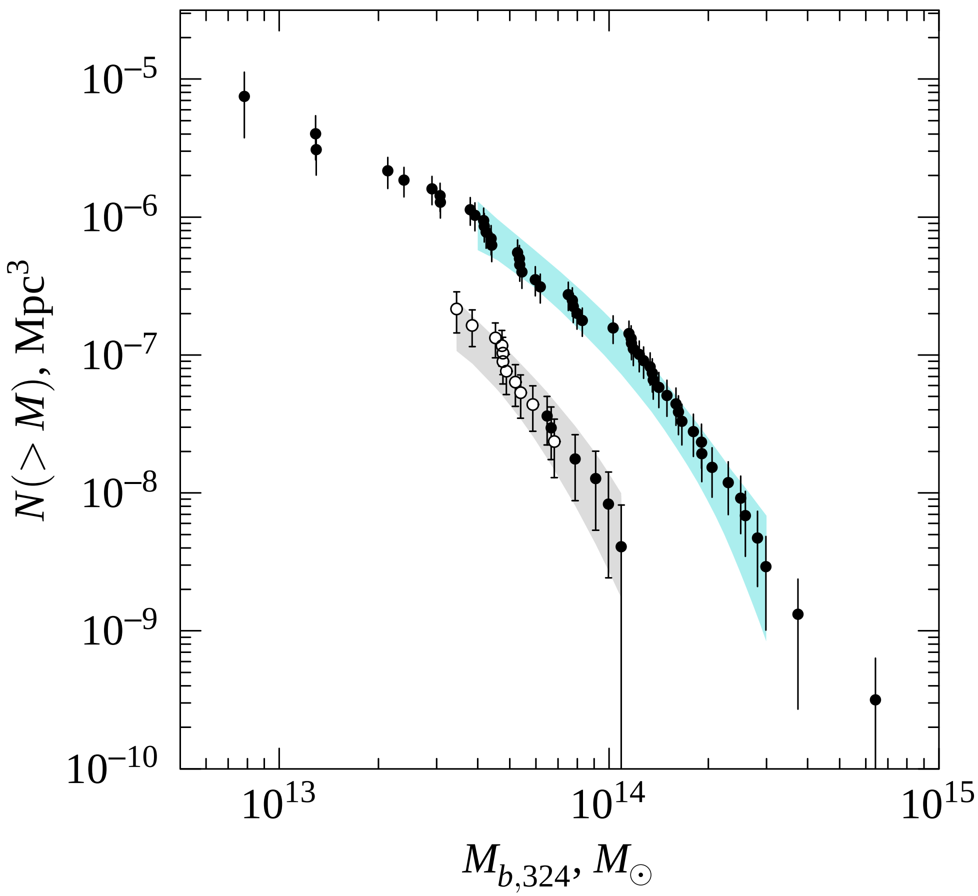
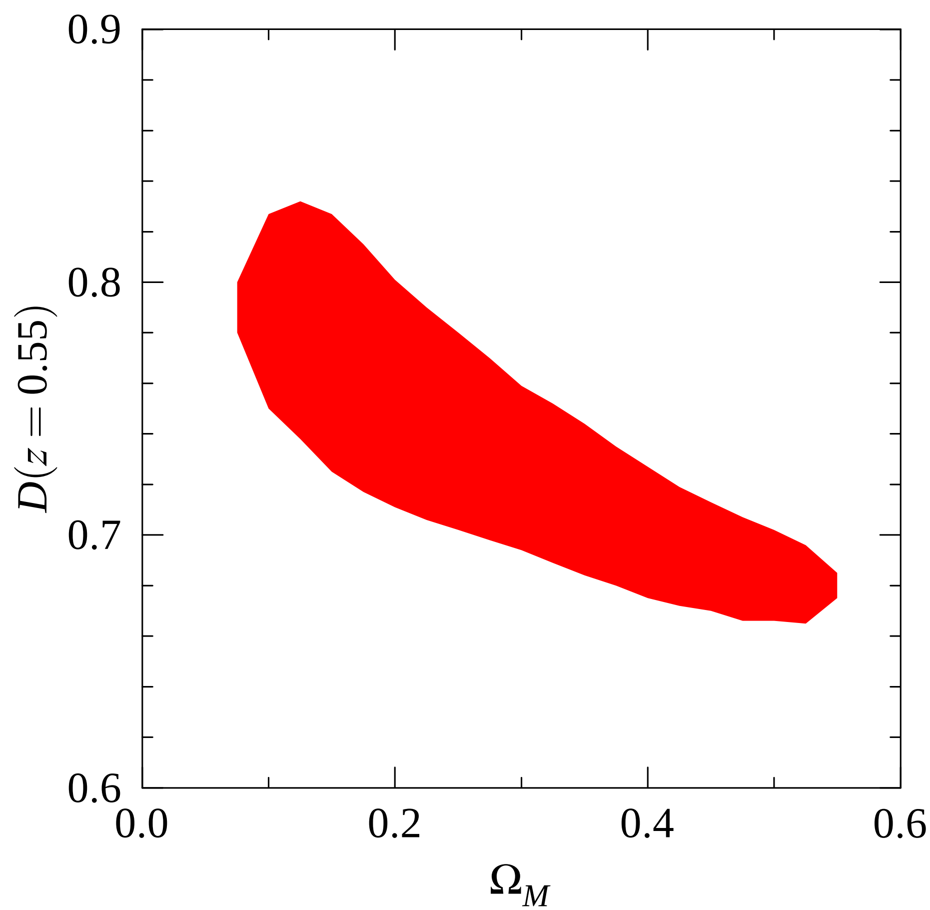
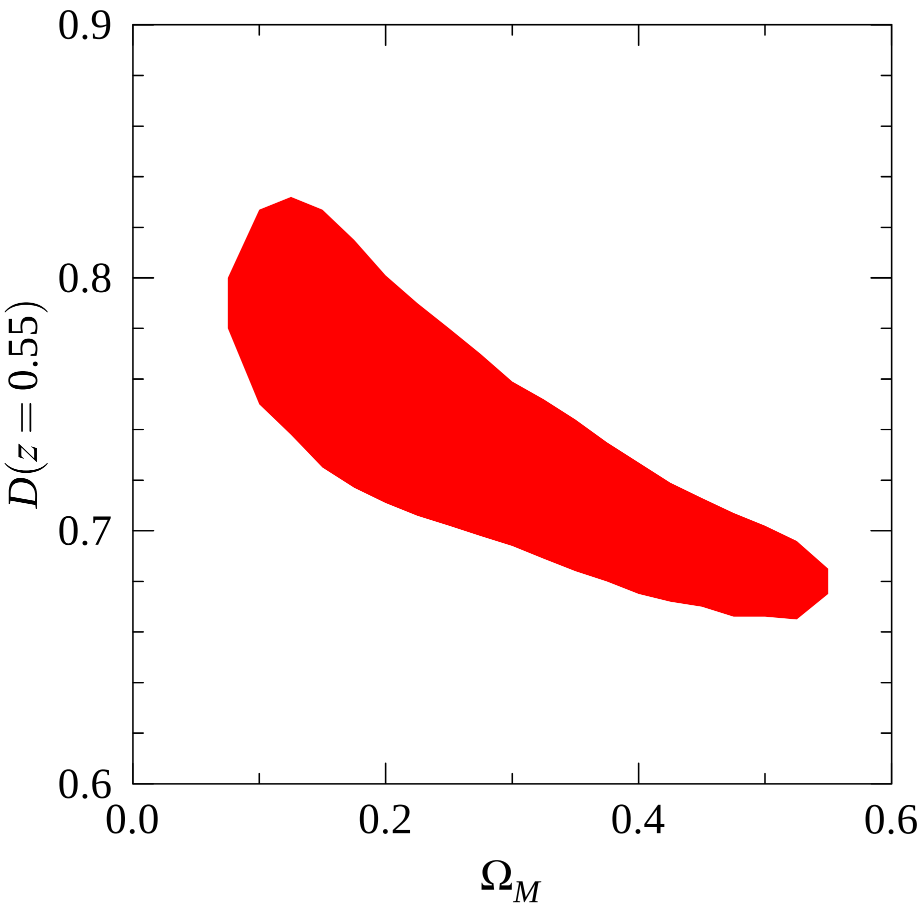


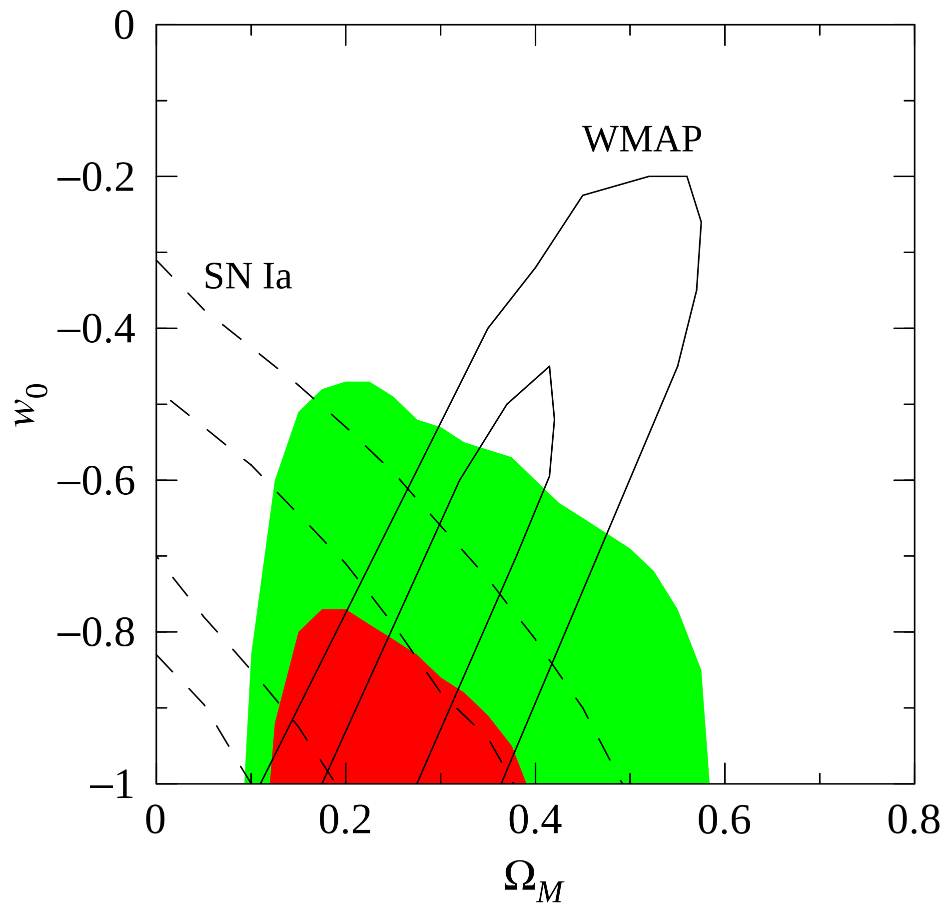


$D(0.55) = 0.727 \pm 0.033$ for $\Omega = 0.3$

Growth factor and equation of state

Assuming flat Universe, $D(z)$ converts to w:





For $\Omega_M = 0.3$, $w < -0.86$ (68%), < -0.67 (90%), < -0.5 (95%)

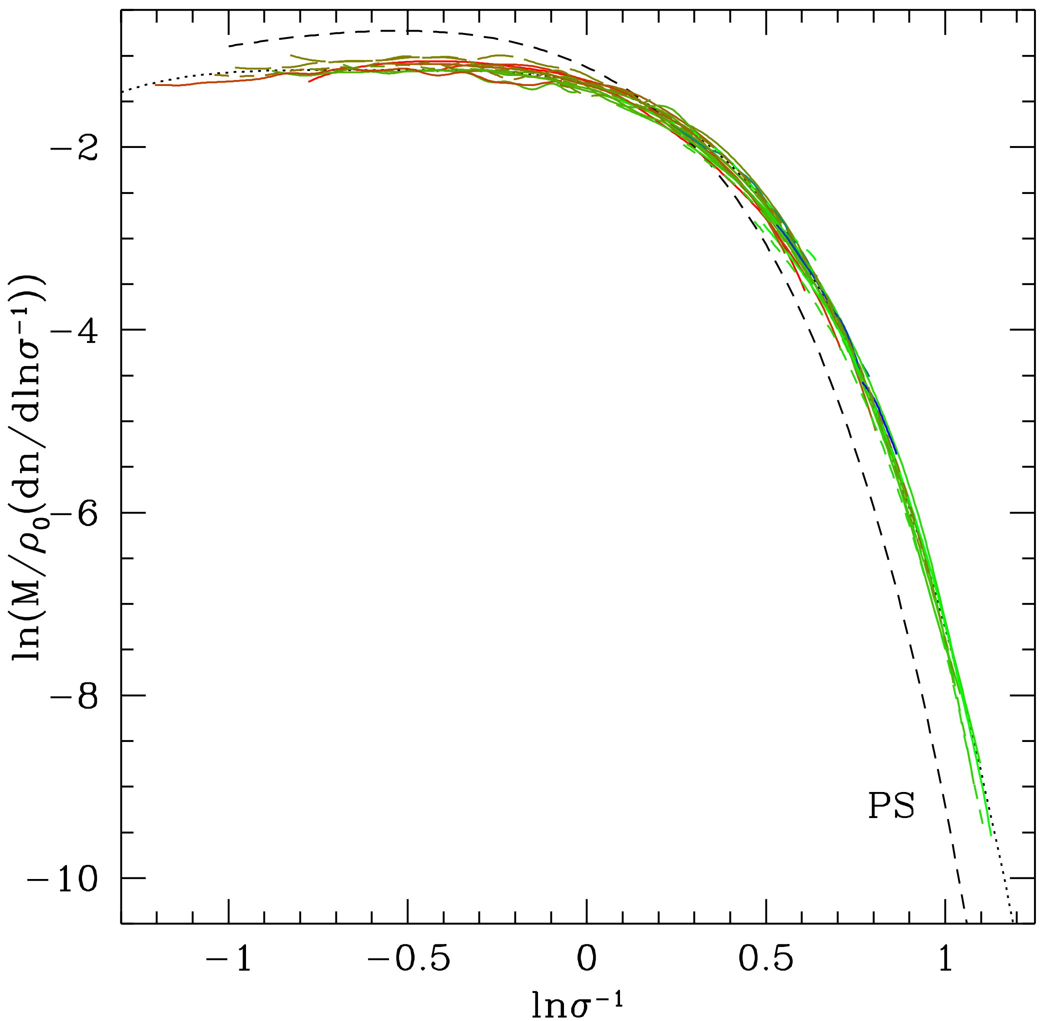
CONCLUSIONS

- Good samples from ROSAT to study local cluster population and evolution at $z = 0.4 - 0.7$ (~ 50 objects available).
- Evolution of scaling relations to $z \sim 0.5$ now directly observed by Chandra and XMM.
- Baryon mass function is a good proxy for the total mass function in clusters.
- Cluster evolution constraints on (Ω, Λ) (from 17 brightest $z > 0.4$ clusters in the 160 deg^2 survey) comparable in quality to SN Ia and pre-WMAP CMB results.
- Meaningful constraints on w (favor the cosmological constant, $w = -1$)

Theory for F(M)

- Jenkins et al., for $M_{\rm tot}$ at $\delta = 324$

$$\frac{M}{\langle\rho\rangle}\,\frac{d\,F(M)}{d\ln\sigma(M,z)^{-1}} = 0.316\,\exp\left(-\left|\,\ln\sigma(M,z)^{-1}+0.67\right|^{3.82}\right)$$



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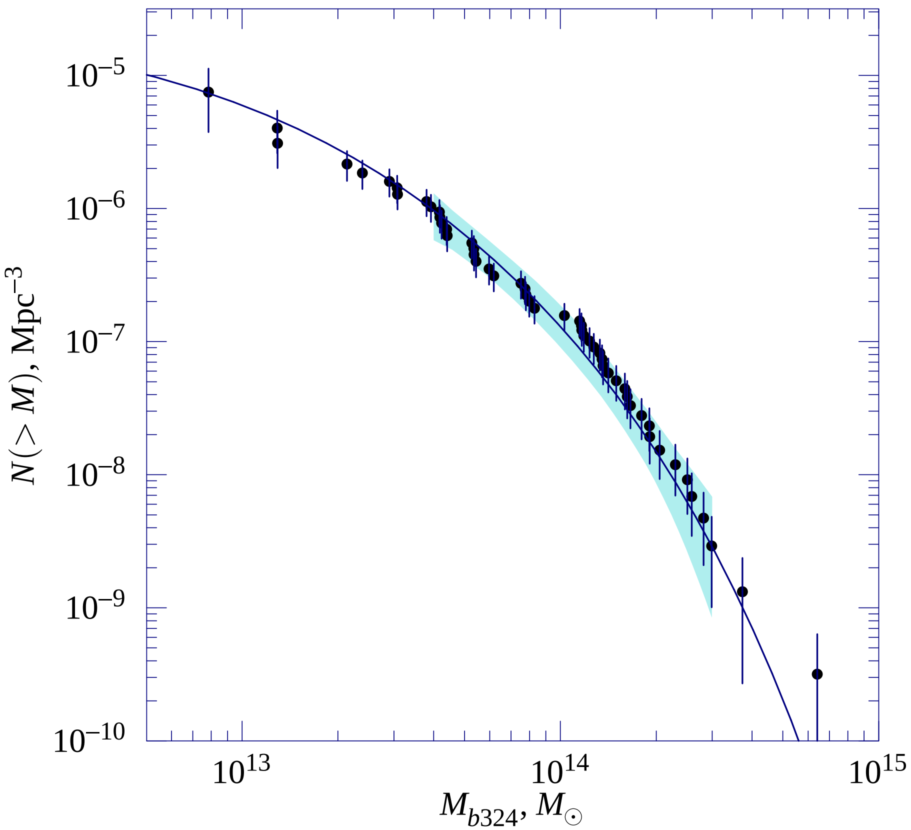
✓ $\sigma(M,z) = \sigma_0(M)\,D(z)$

✓ $\sigma_0(M) \Longleftrightarrow P(k) = k^n\,T^2(k)$, known for any n, Ω, h, Ω_b, σ_8 (analytical approximations for $T(k)$ in Eisenstein & Hu 1998)

✓ $D(z)$ known for any cosmology Ω, [Λ, [w . . .]].

Results at z=0

Voevodkin & Vikhlinin (astro-ph/0305549)



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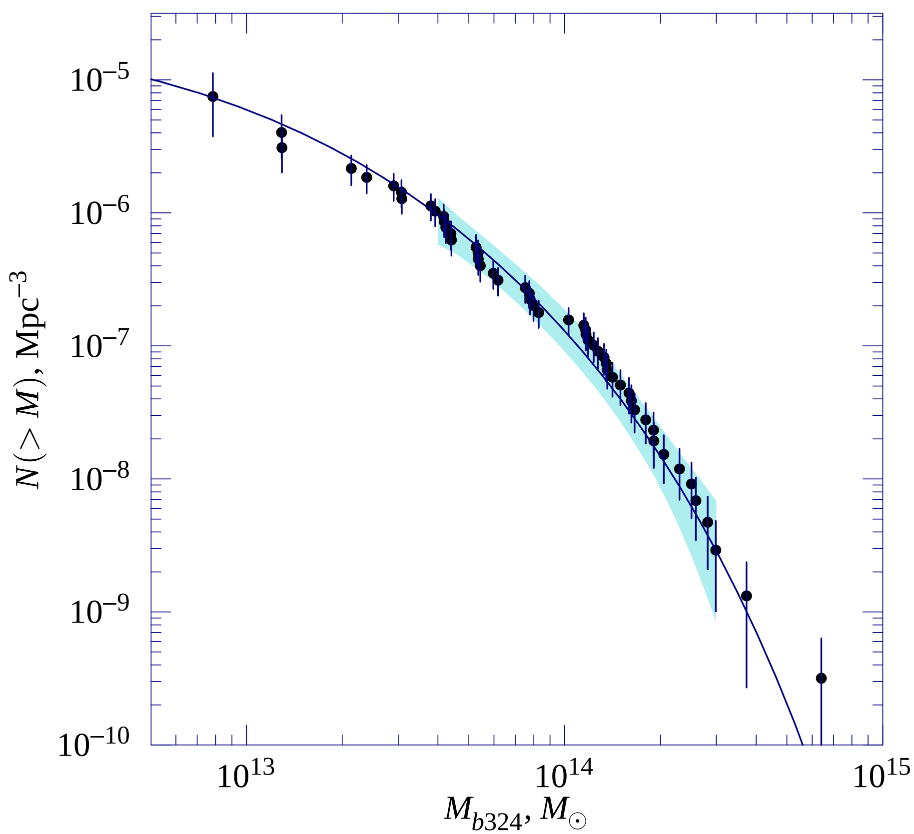

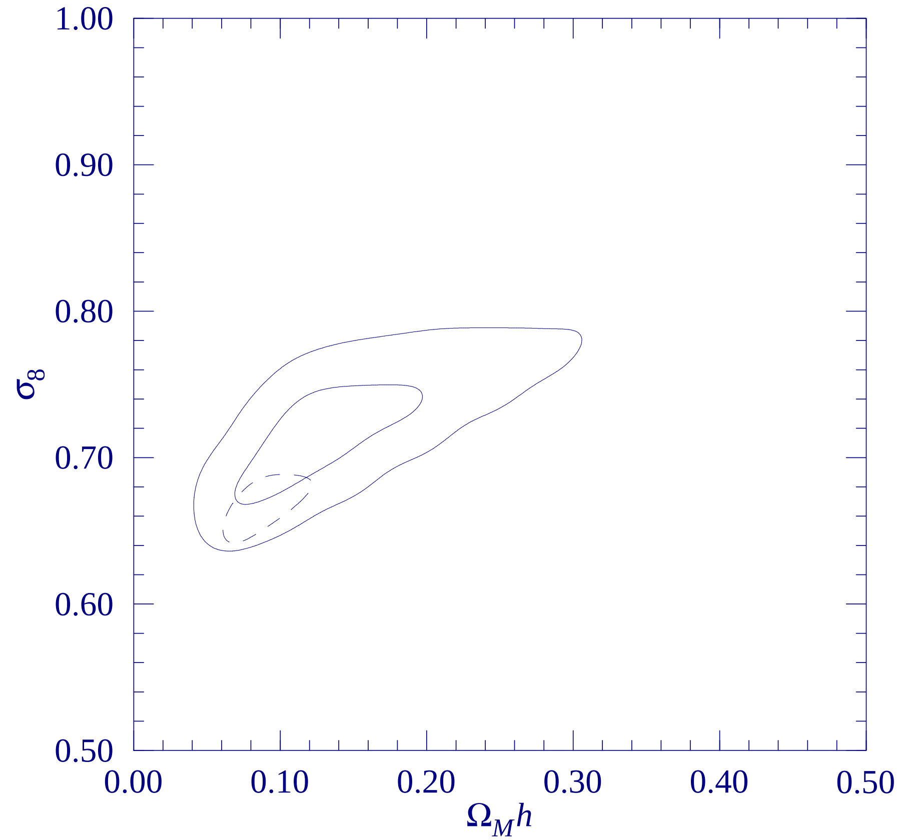

- $F(M)$ in a range of $4 \times 10^{13} M_\odot < M_b < 4 \times 10^{14} M_\odot$ constraints σ_8 and slope of $P(k)$:

$$\sigma_8 = 0.72 \pm 0.04 \qquad \Omega_M h = 0.13 \pm 0.07 \qquad (\Omega_M = 0.18 \pm 0.10 \text{ for } h = 0.71)$$

(we assume a weak dependence of f_b on mass from Bialek et al. consistent with observations)

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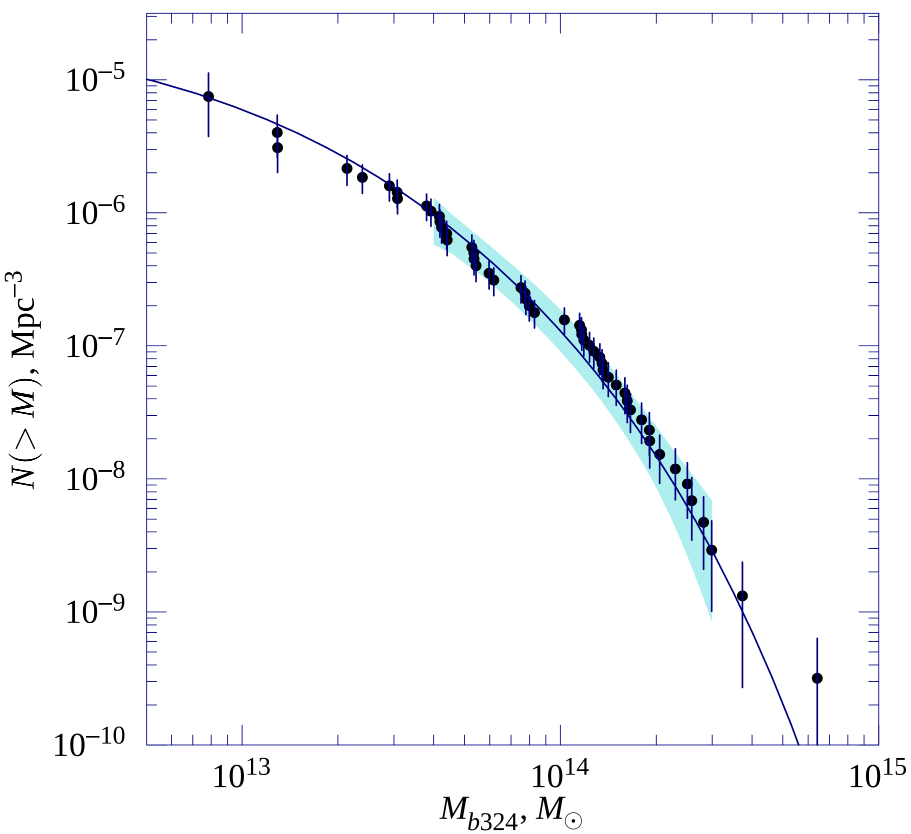

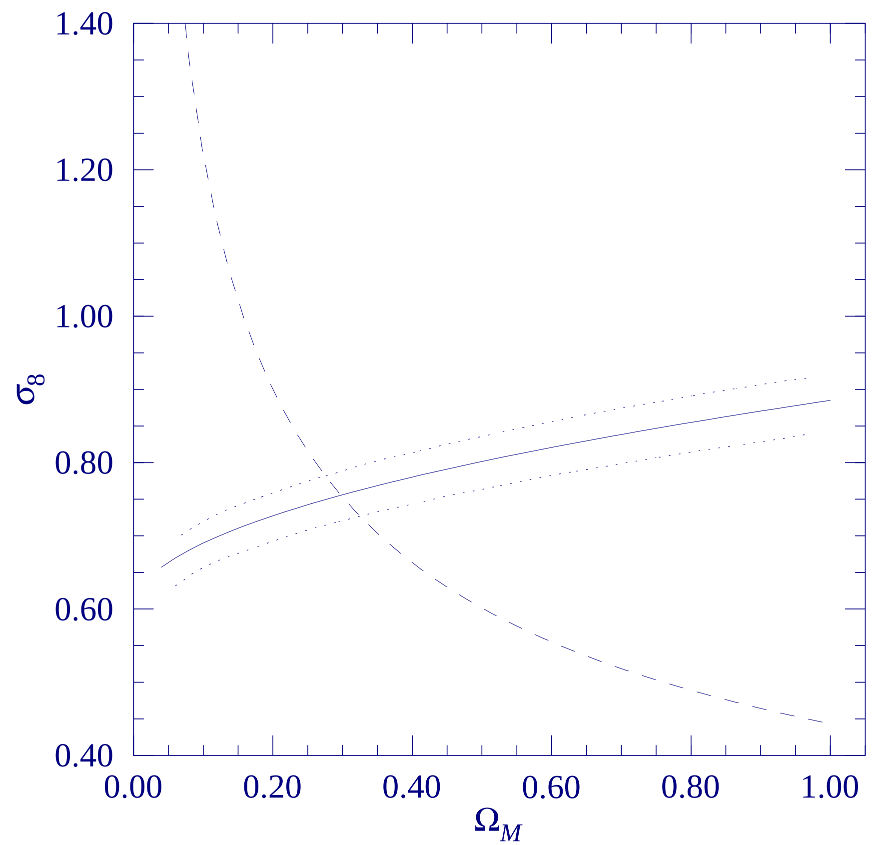

- Normalization of $F(M)$ at $M_b = 1.0 \times 10^{14} M_\odot$ constrains σ_8 as a function of Ω_M:

  $$\sigma_8 = 0.75 \pm 0.04 \text{ for } \Omega_M = 0.3$$