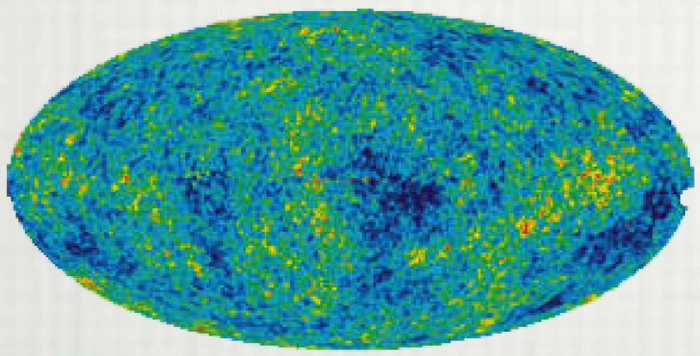
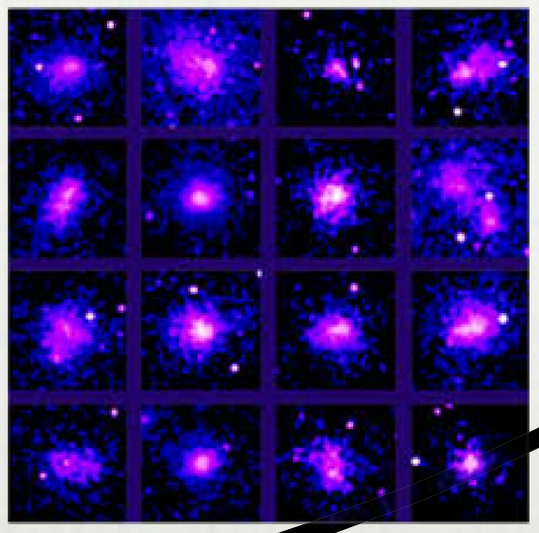
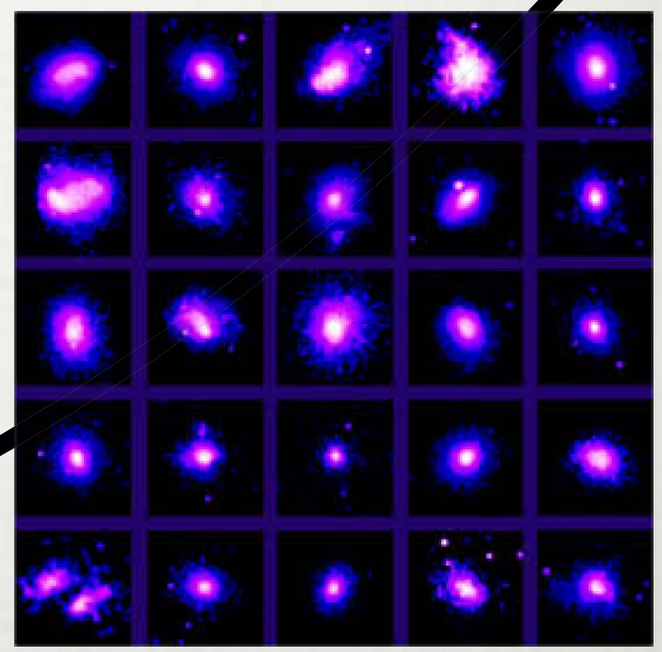
COSMOLOGY WITH GALAXY CLUSTERS

A.VIKHLININ







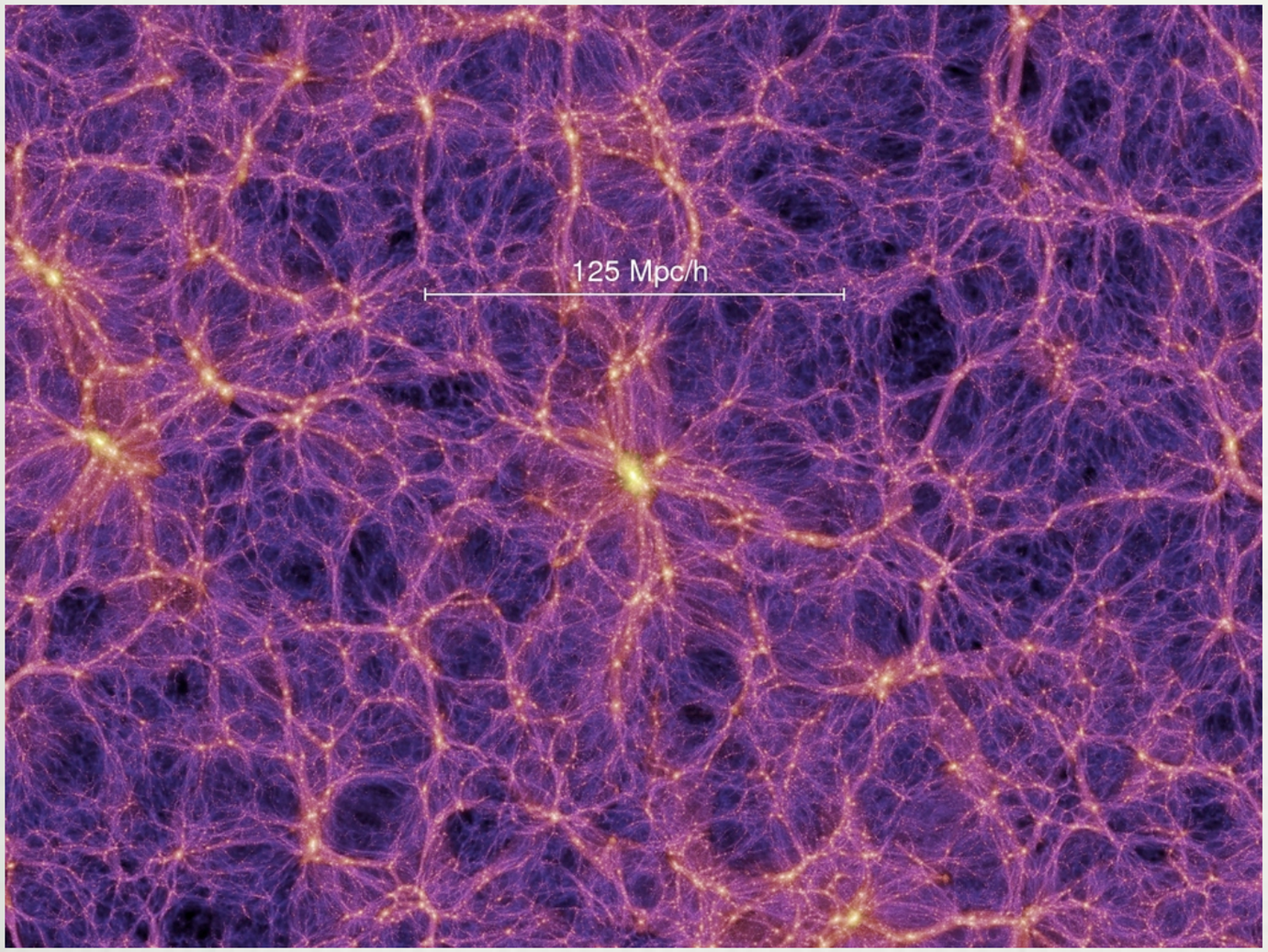
Dark Energy fraction

Time

$z = 1000$ $z = 0.5$ $z = 0$

Vasnetsov 1870. ***A warrior at the crossroads***

CLUSTERS & LSS & COSMOLOGICAL TESTS



$$f_x \sim n_e^2 d^{-2}$$

$$f_{SZ} \sim n_e T_e d^{-2}$$

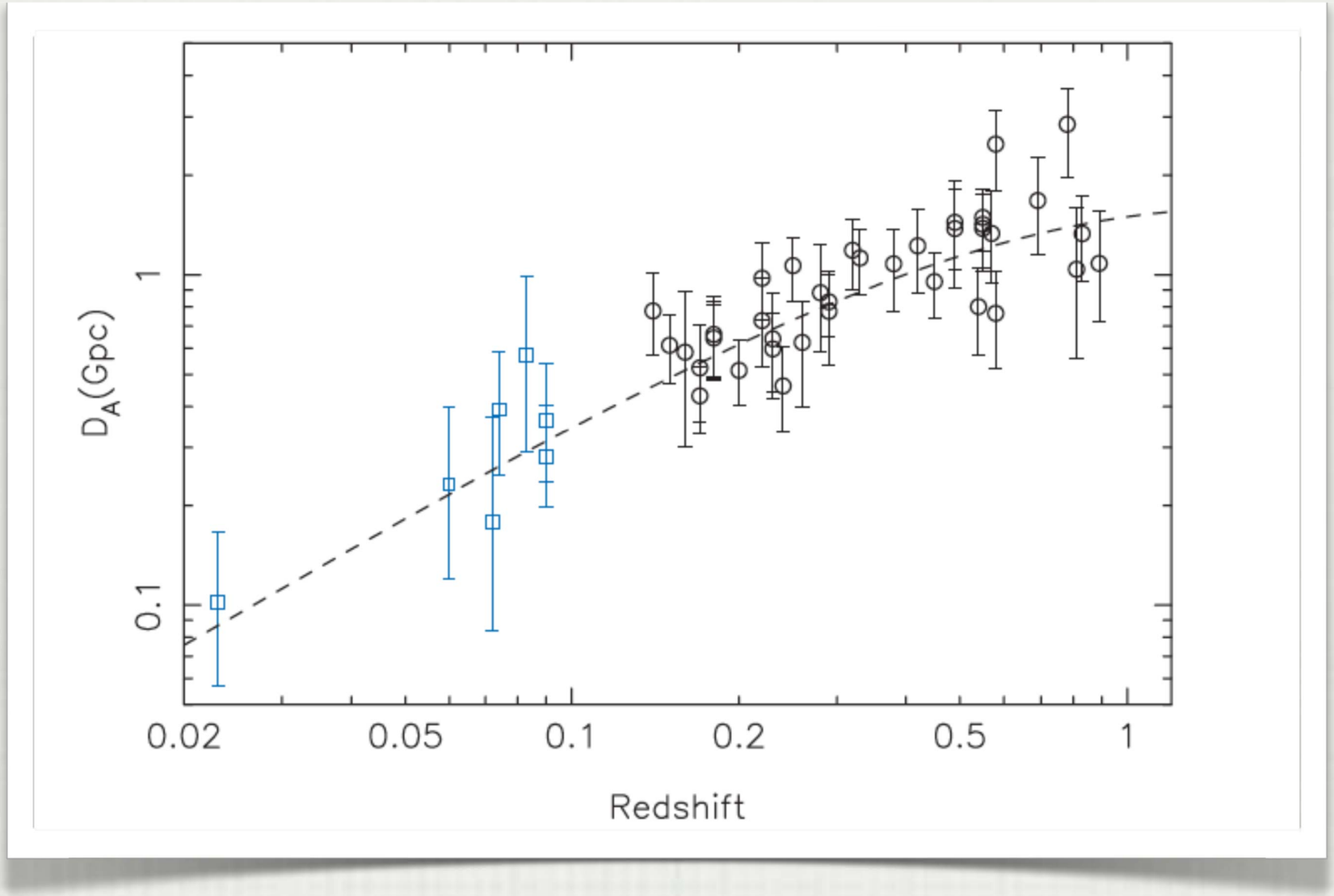
$$f_{opt} \sim N_{gal}$$

$$f_{lens} \sim M d^{-1}$$

Clusters located in high-amplitude peaks of the density field

- **high-bias tracers of large-scale structure**
- **number density exponentially sensitive to σ_8**

STATE OF THE ART FOR SZ+X-RAYS

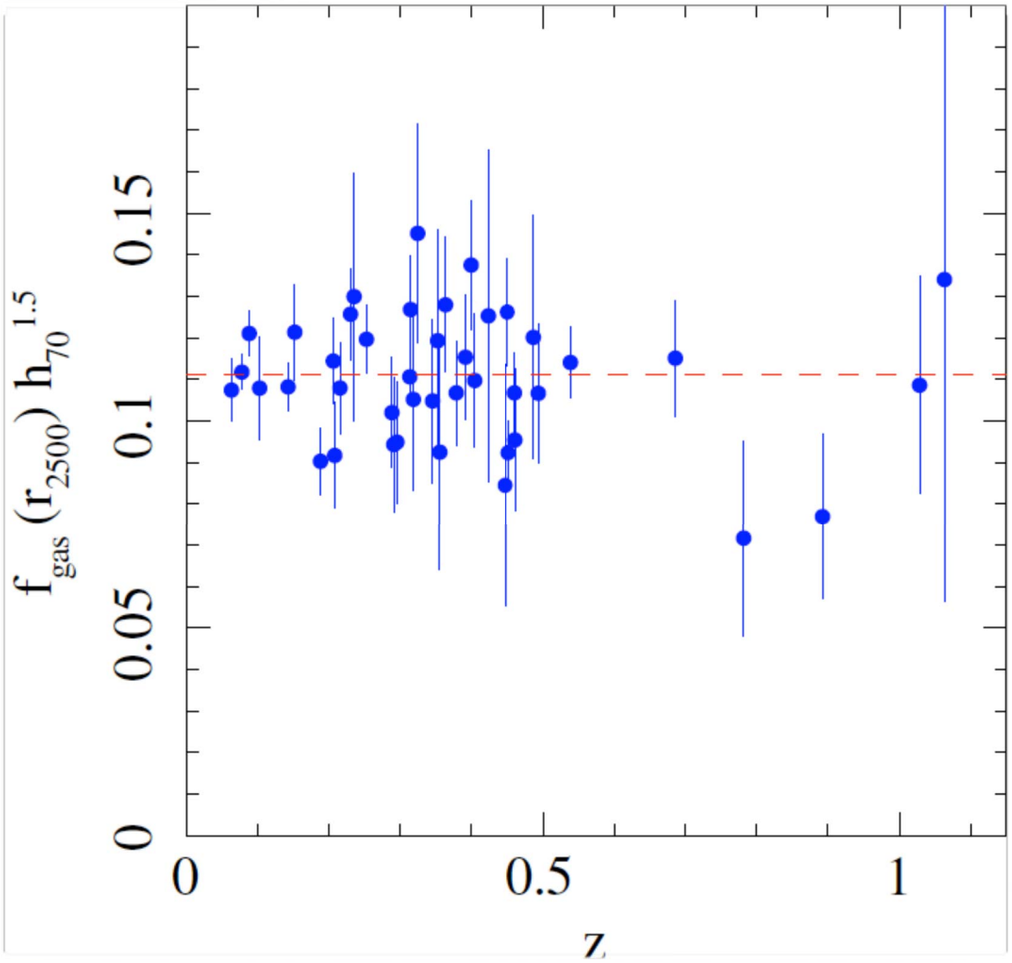


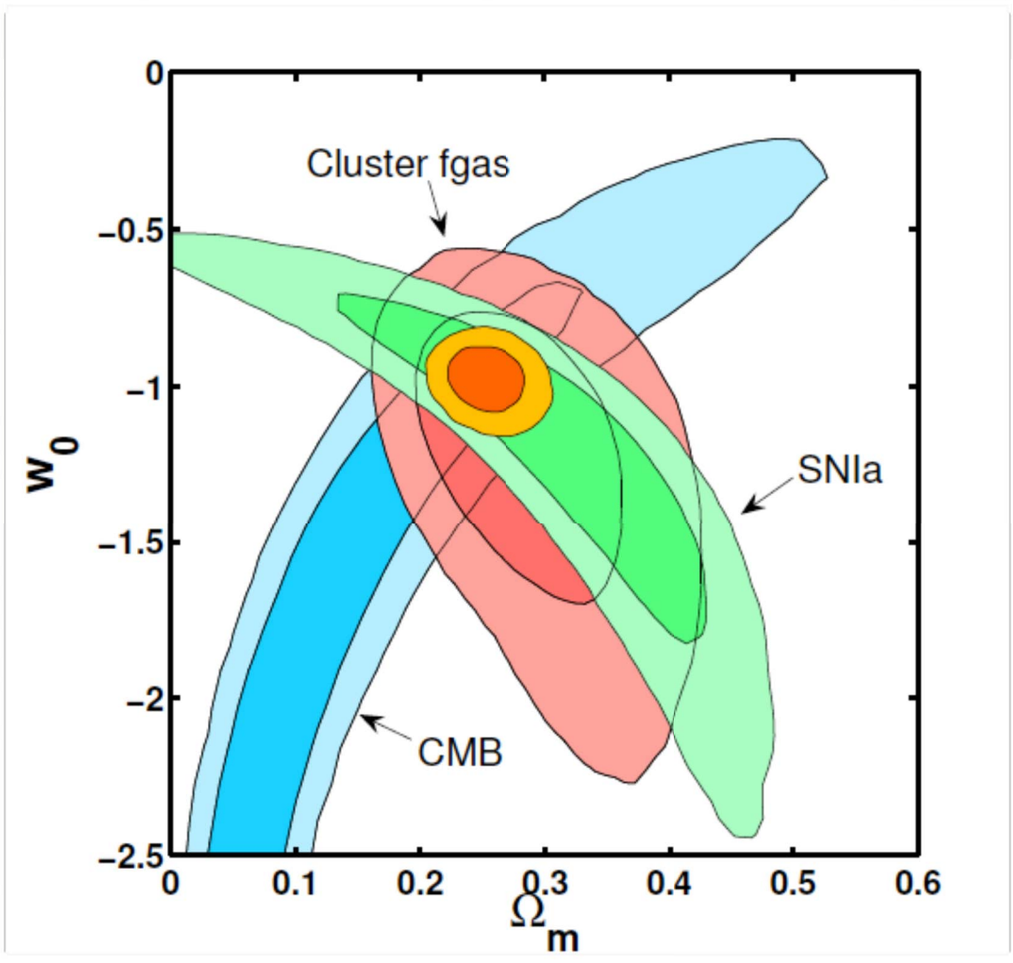
$H_0 = 77 \pm 3.5\ (\text{stat}) \pm 9\ (\text{sys})\ \ \text{km s}^{-1}\ \text{Mpc}^{-1}$

$f_x \sim n_e^2 d^{-2} \qquad f_{SZ} \sim n_e T_e d^{-2}$

Bonamente et al. '06

STATE OF THE ART WITH $f_{gas}(z)$



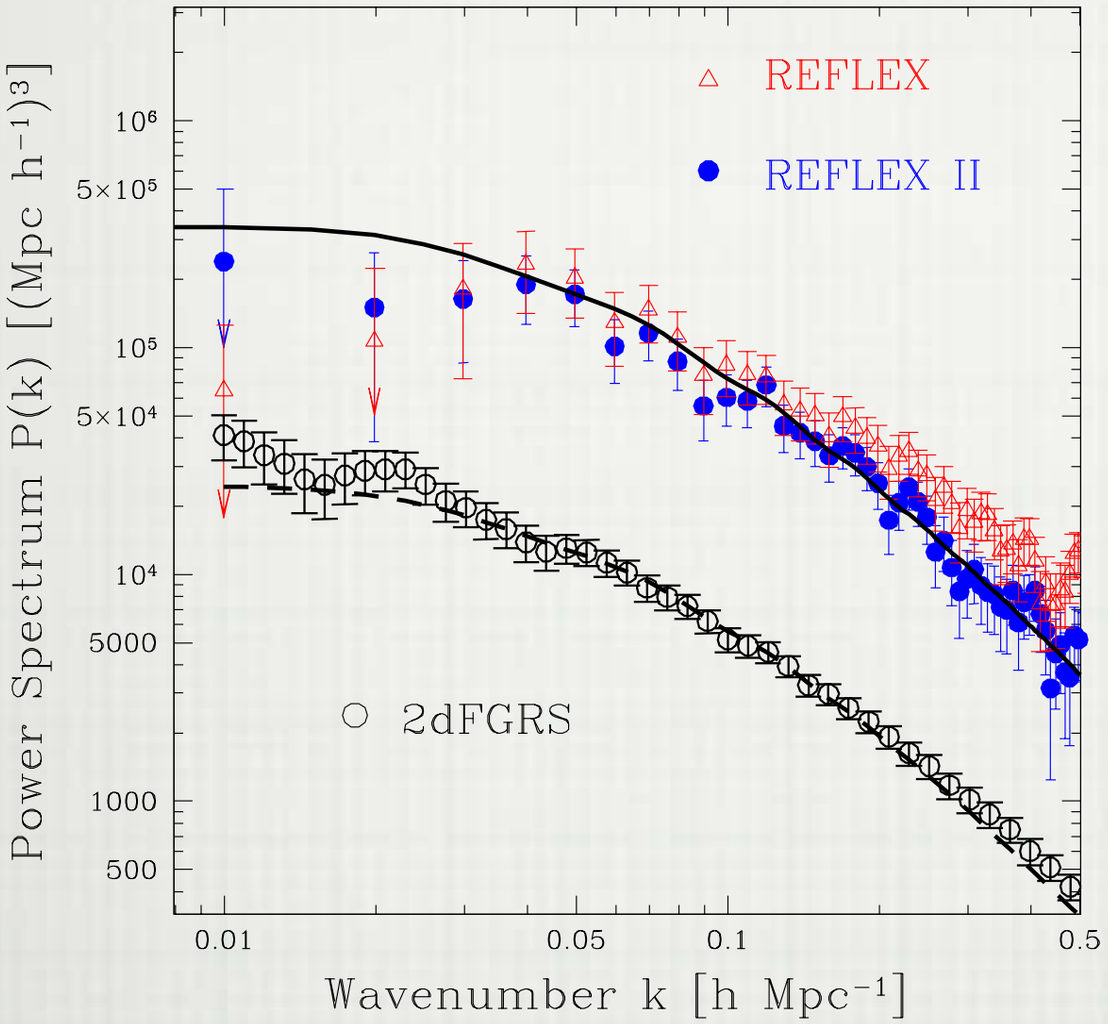


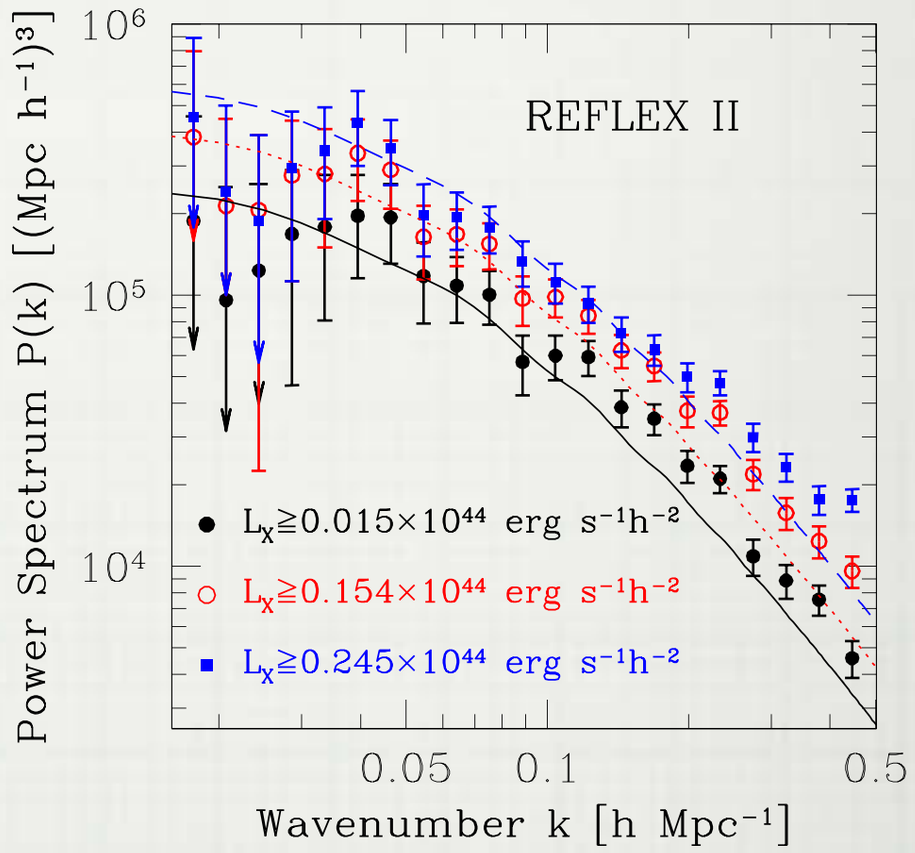
- **Independent geometric confirmation of accelerated expansion**
- **Constraints on equation of state, $w_0 = -1.14 \pm 0.31$**

$$M_{gas} \sim d^{5/2} \quad M_{tot} \sim d \quad f_{gas} \sim d^{3/2}$$

Allen et al. '08

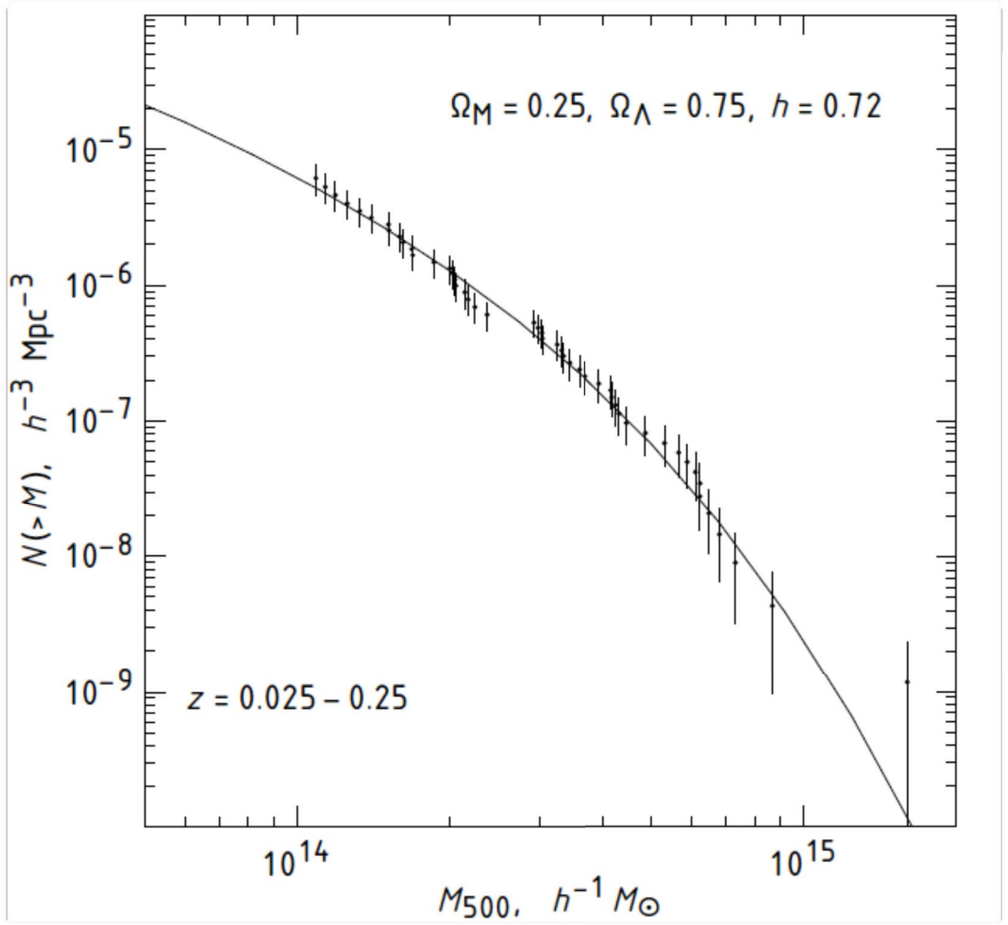
CLUSTER *P*(*k*) MEASUREMENTS

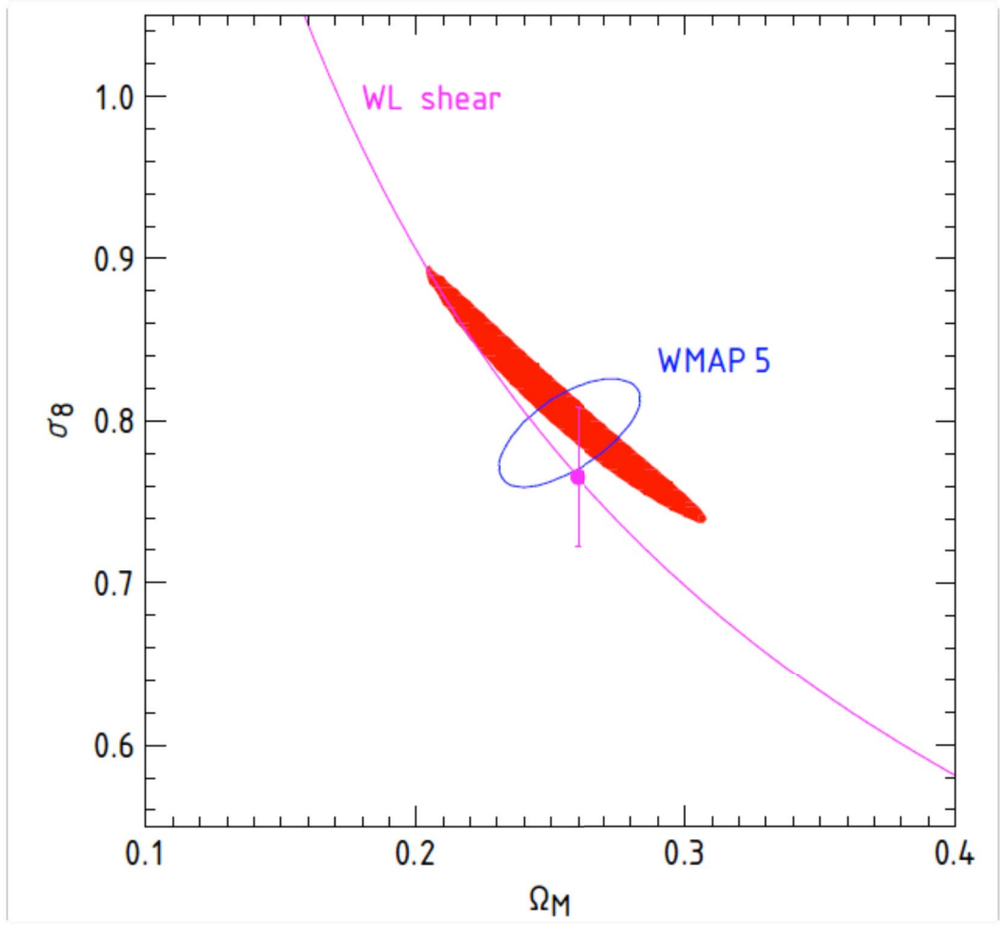




Balaguera-Antolínez et al. 2011

CLUSTER MASS FUNCTION TEST

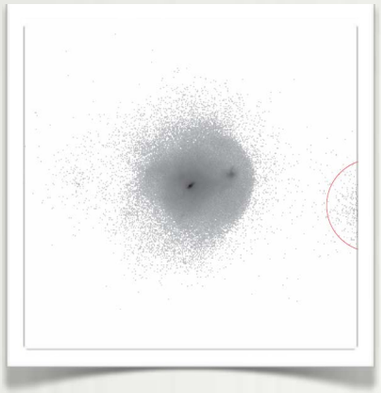


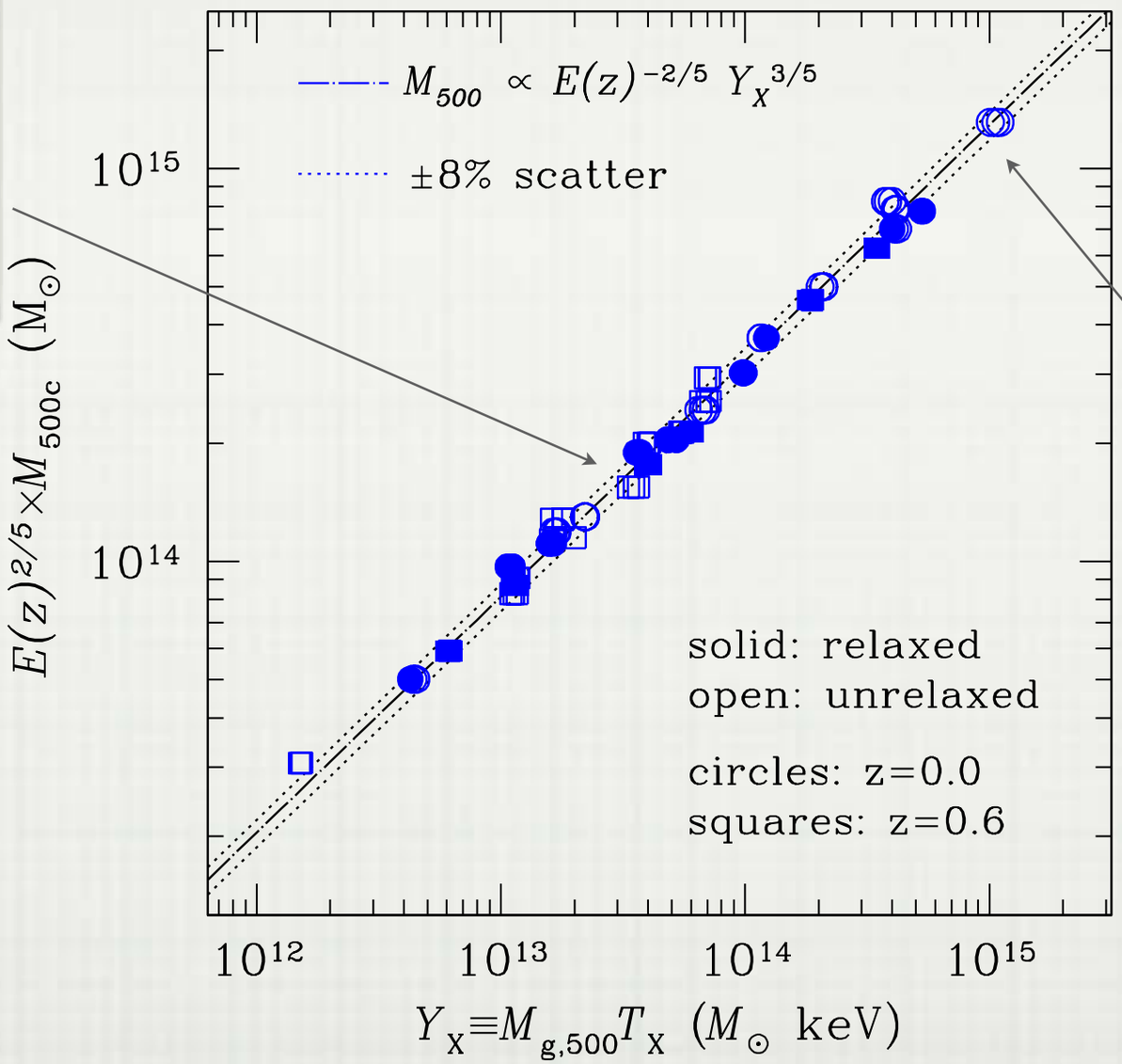


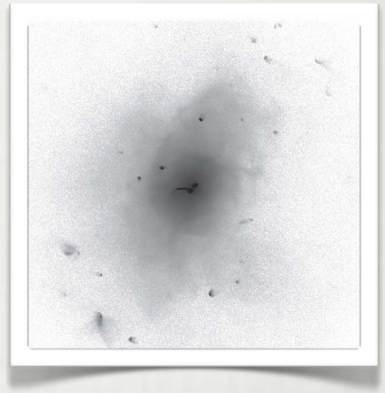
- **50 clusters $\Longrightarrow$ σ_8 to ±1.5% (±3% sys)**

2009 ApJ 692 1060

MASS PROXIES

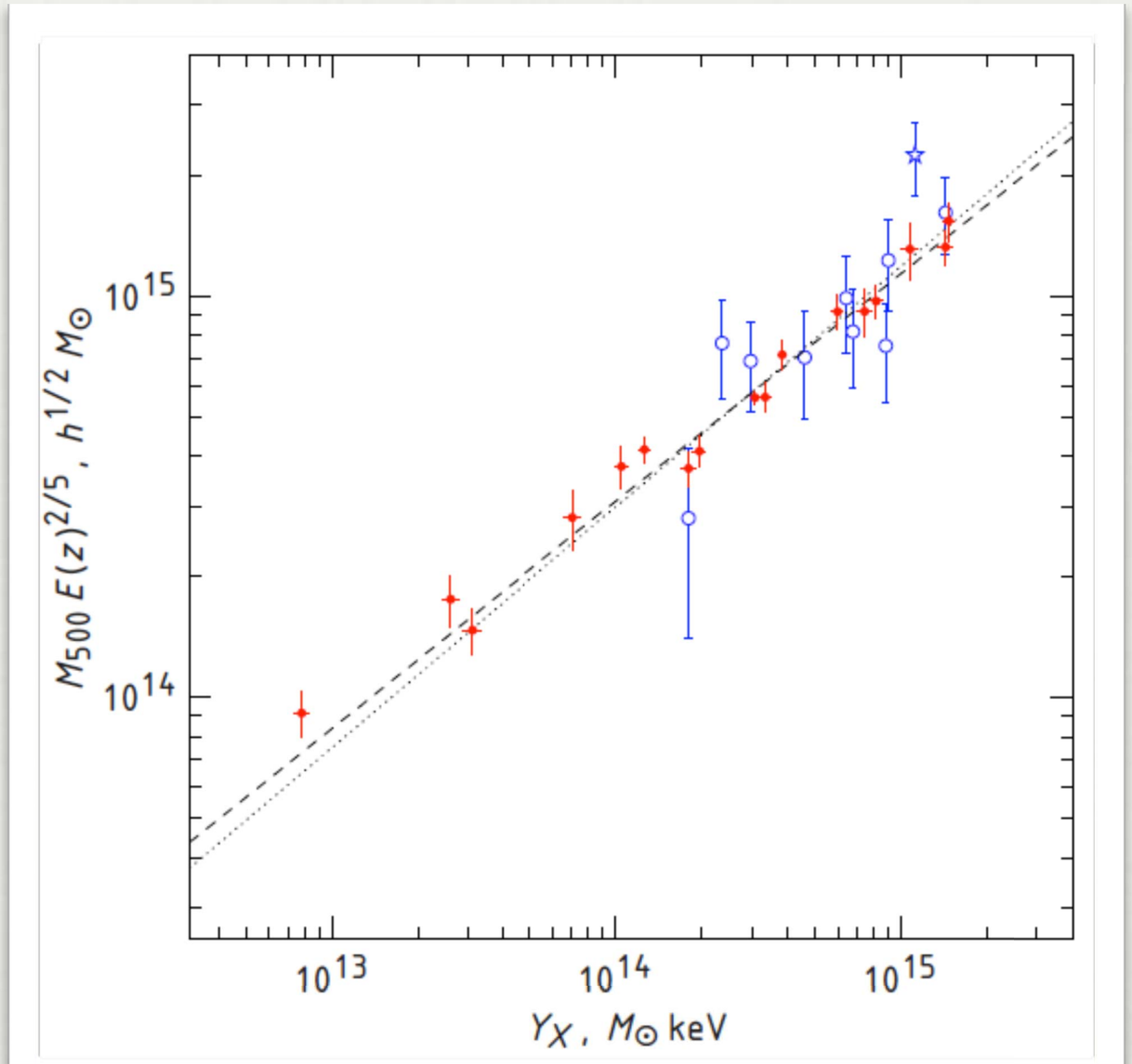






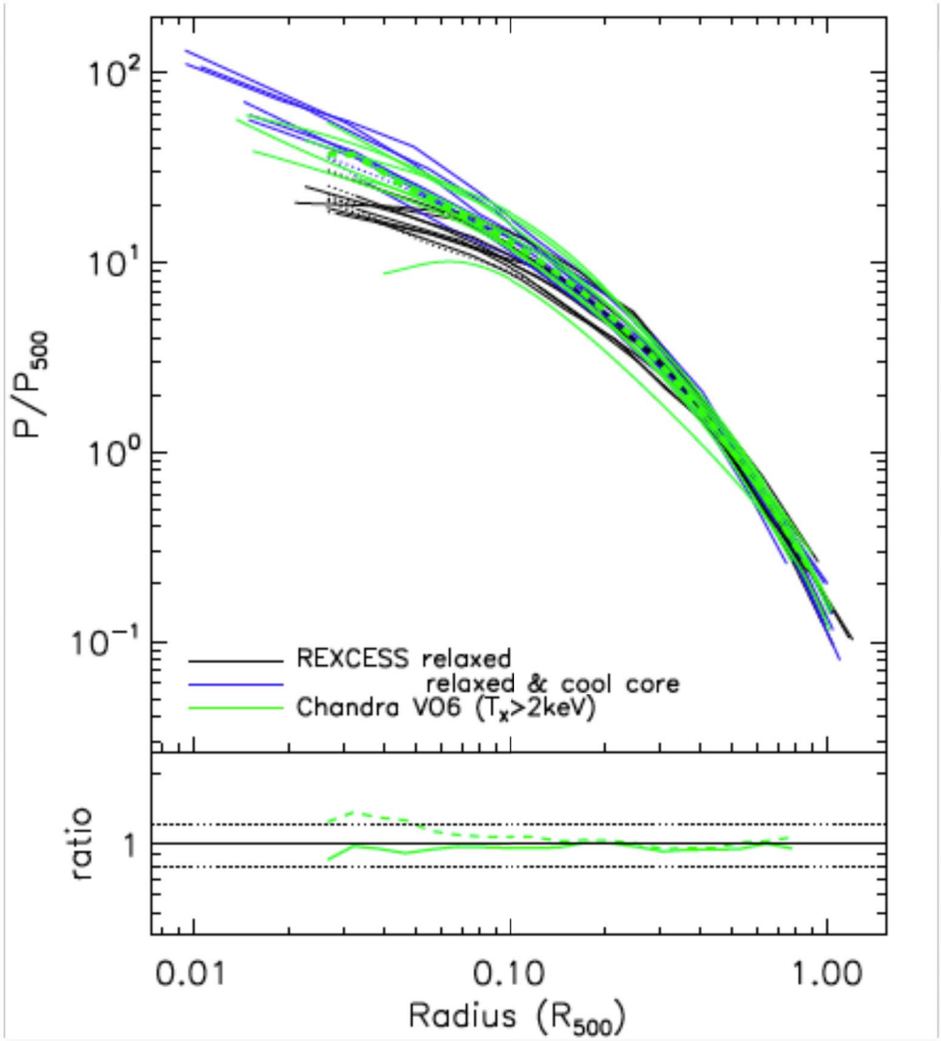
$M \propto Y_X^{3/5}\ E(z)^{-2/5}$ – self-similarity + virial theorem + "fair sample"

MASS PROXIES



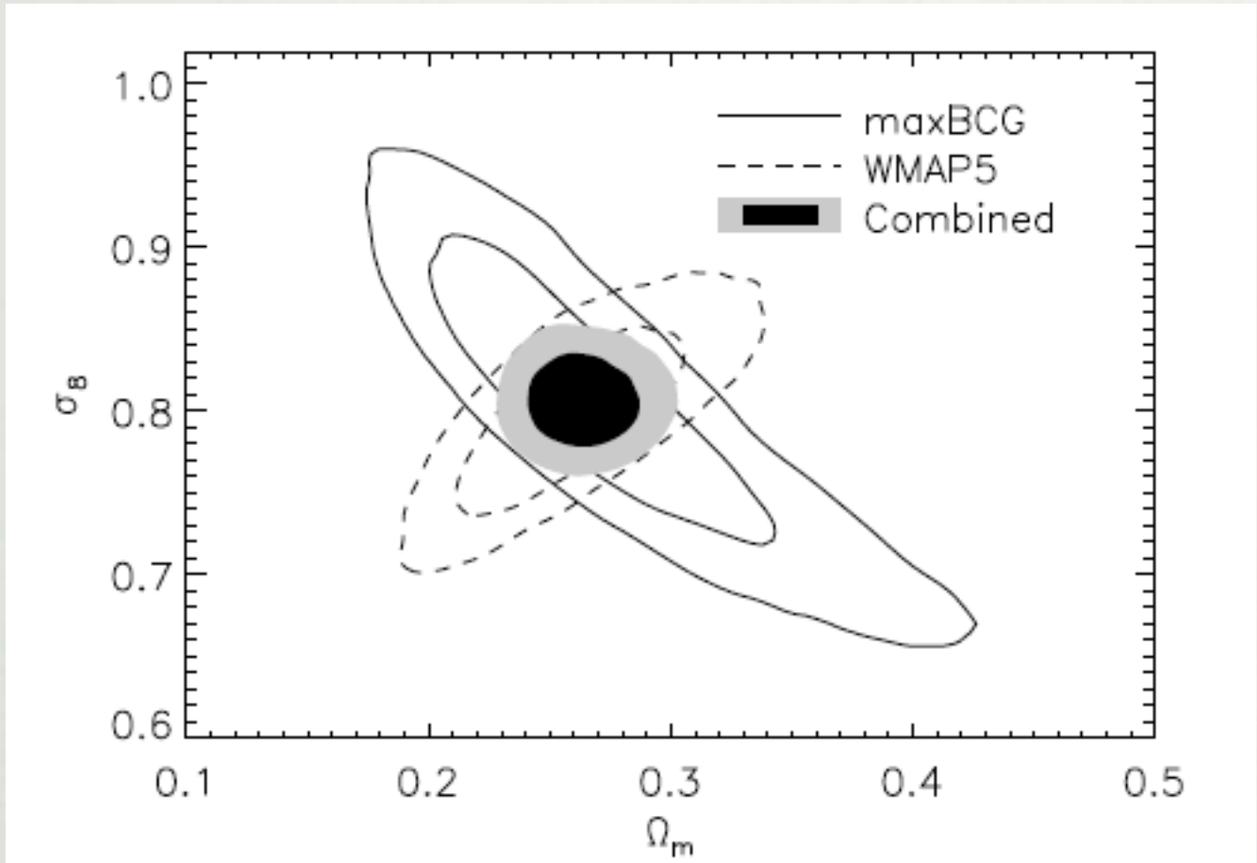
• – *Chandra*, hydrostatic ○ – Weak lensing, Hoekstra '07

MASS PROXIES

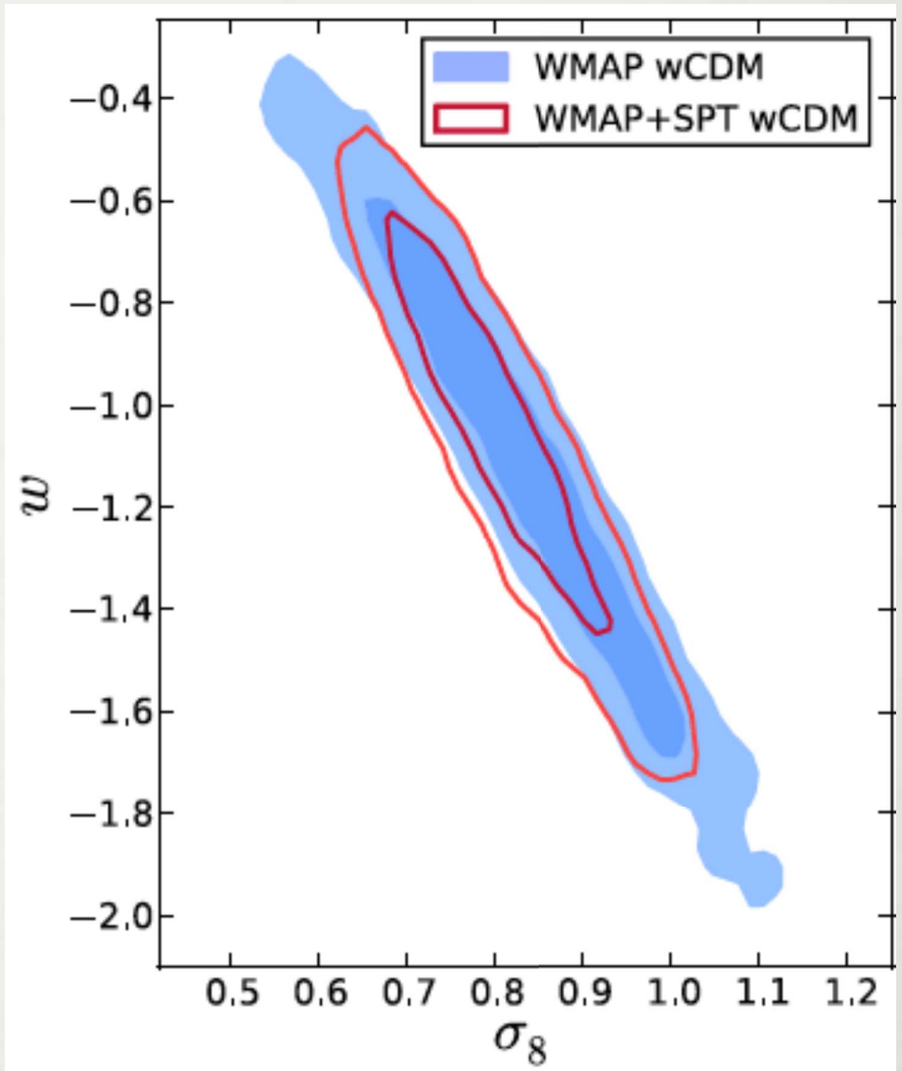


Arnaud et al. '09

ROLE OF GOOD MASS PROXIES



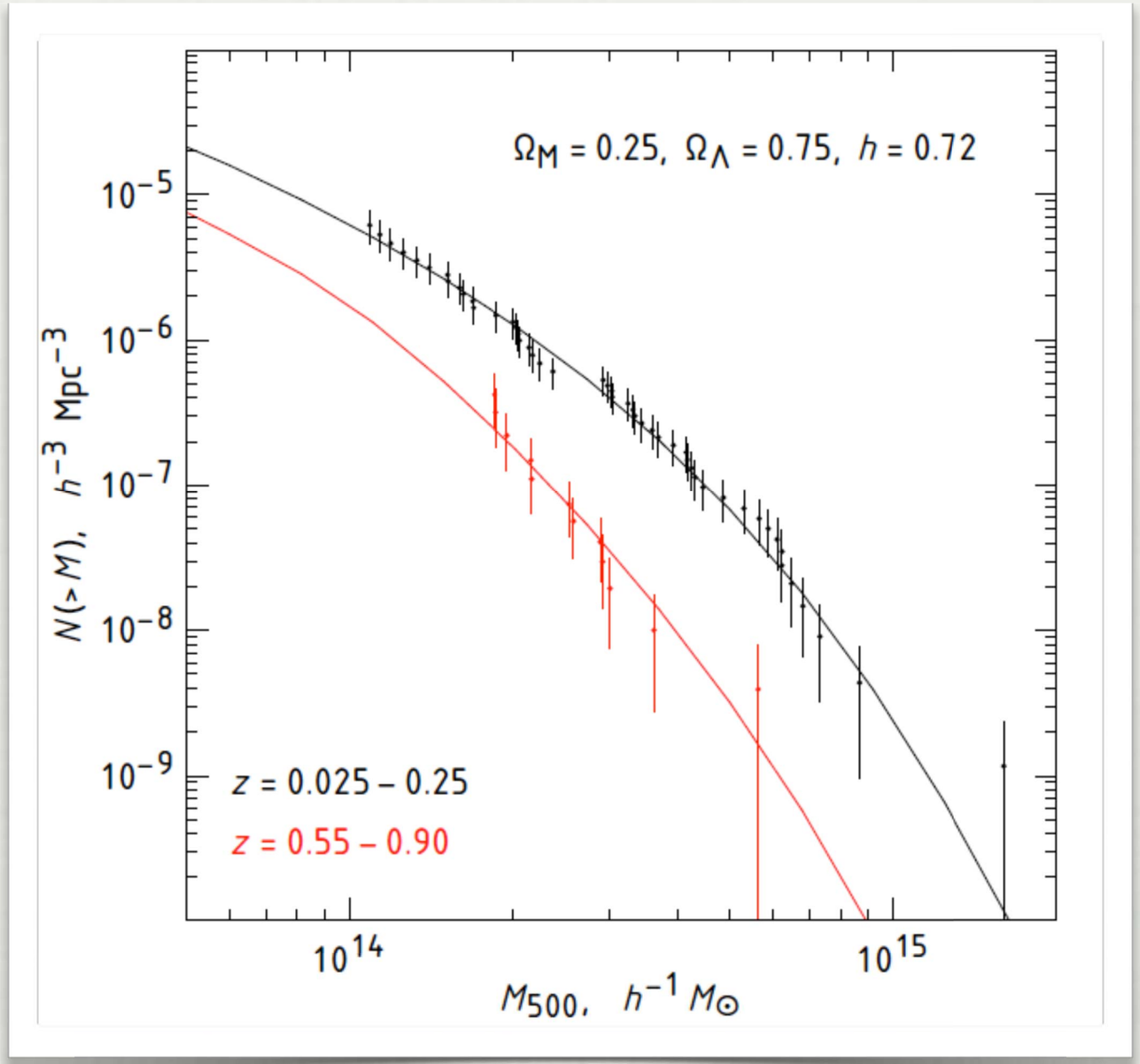
SDSS results, Rozo et al.



SPT, Vanderlinde et al.

- **X-rays: 50 clusters $\Longrightarrow$ σ_8 to ±1.5% (±3% sys)**
- **SDSS: 10,000+ clusters $\Longrightarrow$ σ_8 to ±3.3%**

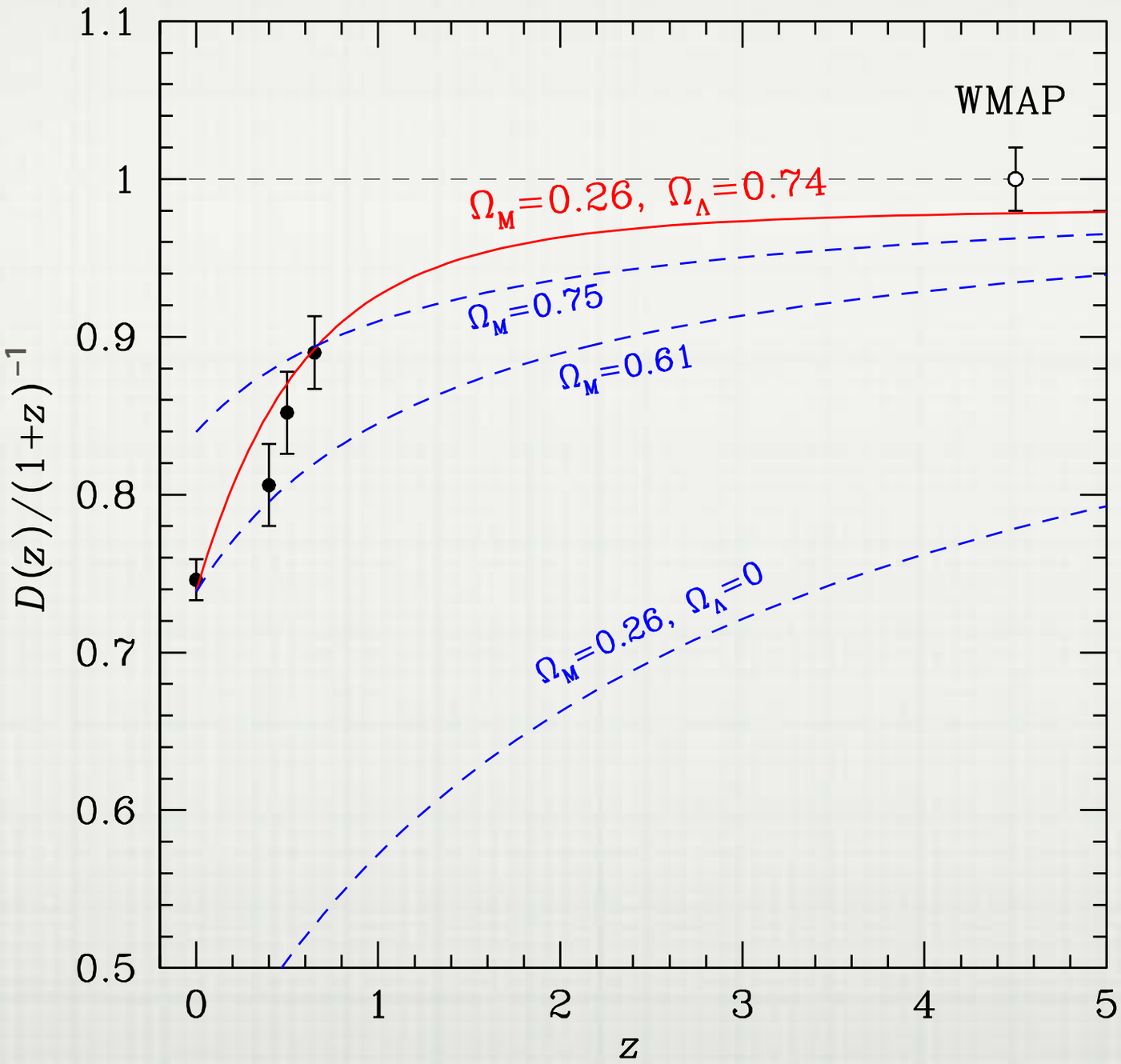
CLUSTER MASS FUNCTION TEST



Measure σ_8 at $z\approx0$ *and* z=0.35–0.45 *and* z=0.45–0.55 *and* z=0.55–0.9

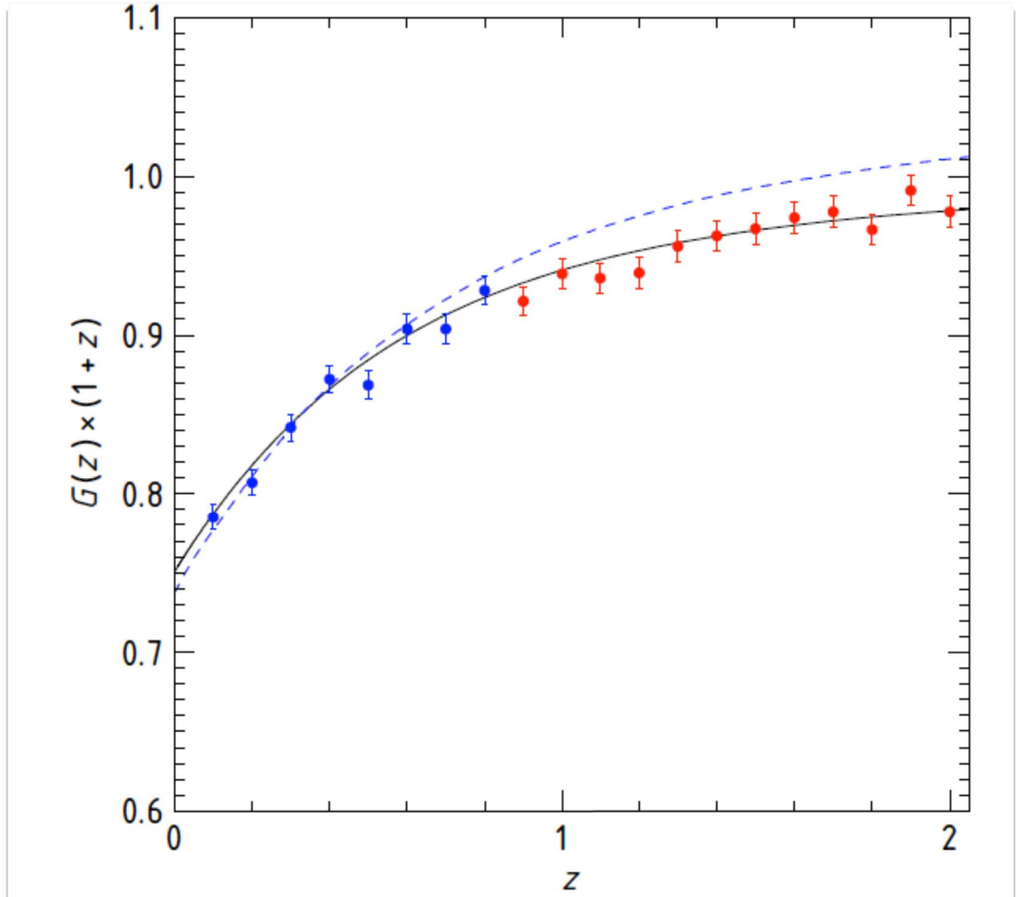
2009 ApJ 692 1060

CLUSTERS DETECT Λ & CONSTRAIN *w*



2009 ApJ 692 1060

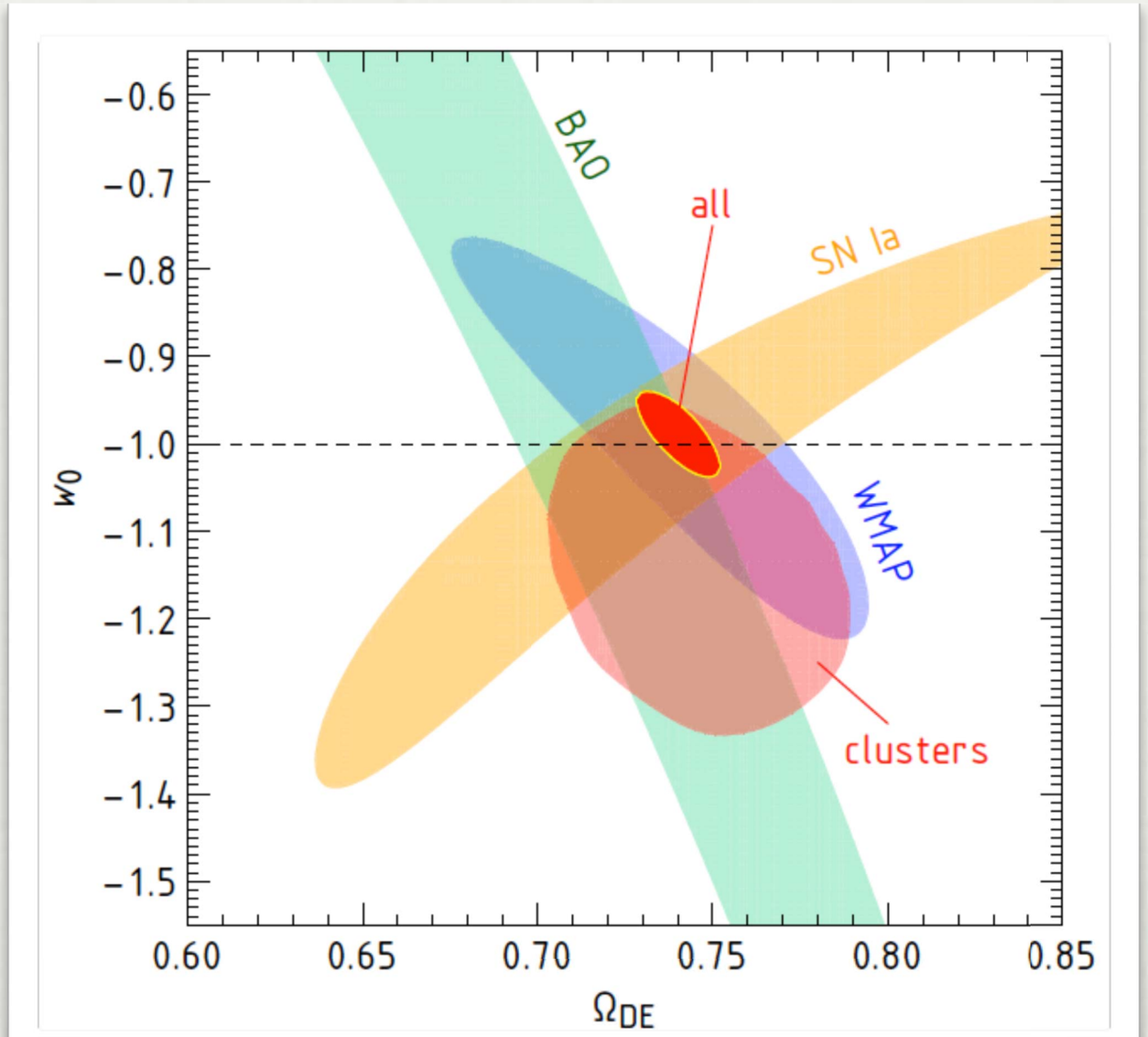
THE DREAM



- measure growth (z) to $z \approx 1.5–2$
- test non-GR theories (growth index, γ, to ± 0.02)
- $\times 2$ improvement in w in combination with distance (z)
- implementable with SXG/eRosita + IXO *or* Wide Field X-ray Telescope

IXO White Paper

w_0 FROM COMBINATION OF METHODS

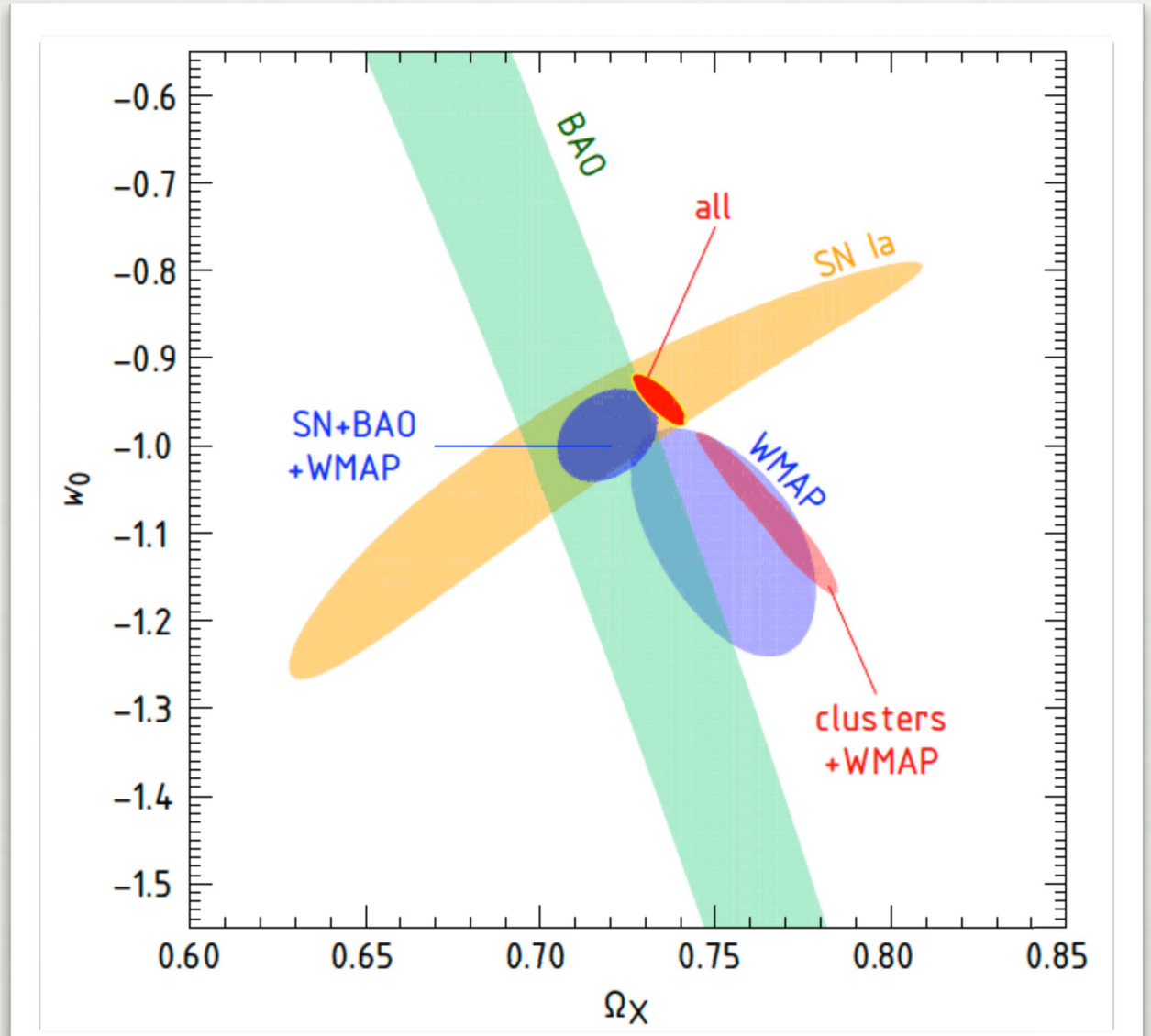


$w_0 = -0.99$ ± 0.045 (stat) (± 0.067 without clusters)

± 0.039 (sys) (± 0.076)

2009 ApJ 692 1060

w_0 FROM THE LATEST DATA

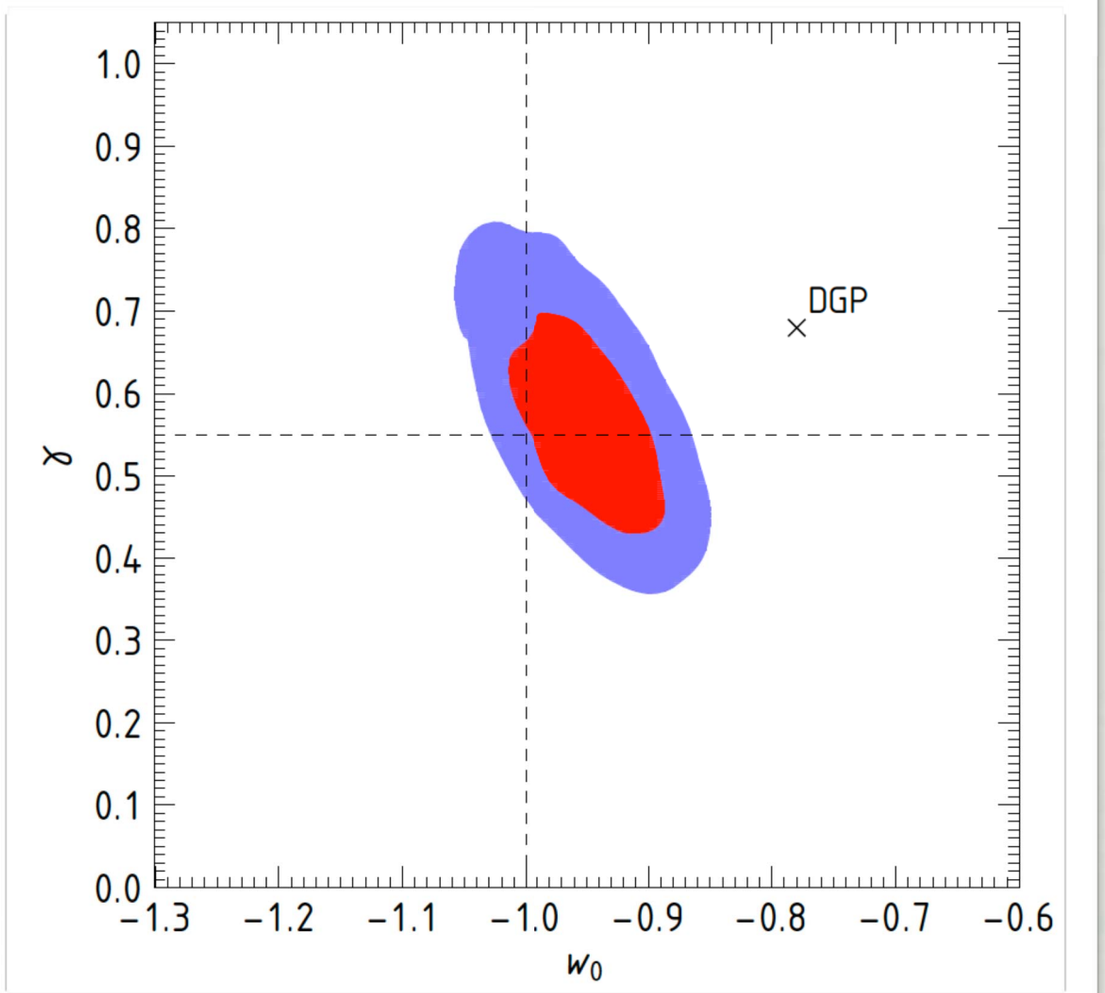


Same CCCP clusters +

- WMAP-7
- BAO from SDSS DR7 + 2dF
- H0 from Riess et al.
- SN Ia "Constitution" set

$w_0 = -0.951 \pm 0.029\ (\text{stat}) \pm 0.047\ (\text{sys})$

NULL TEST: GROWTH INDEX



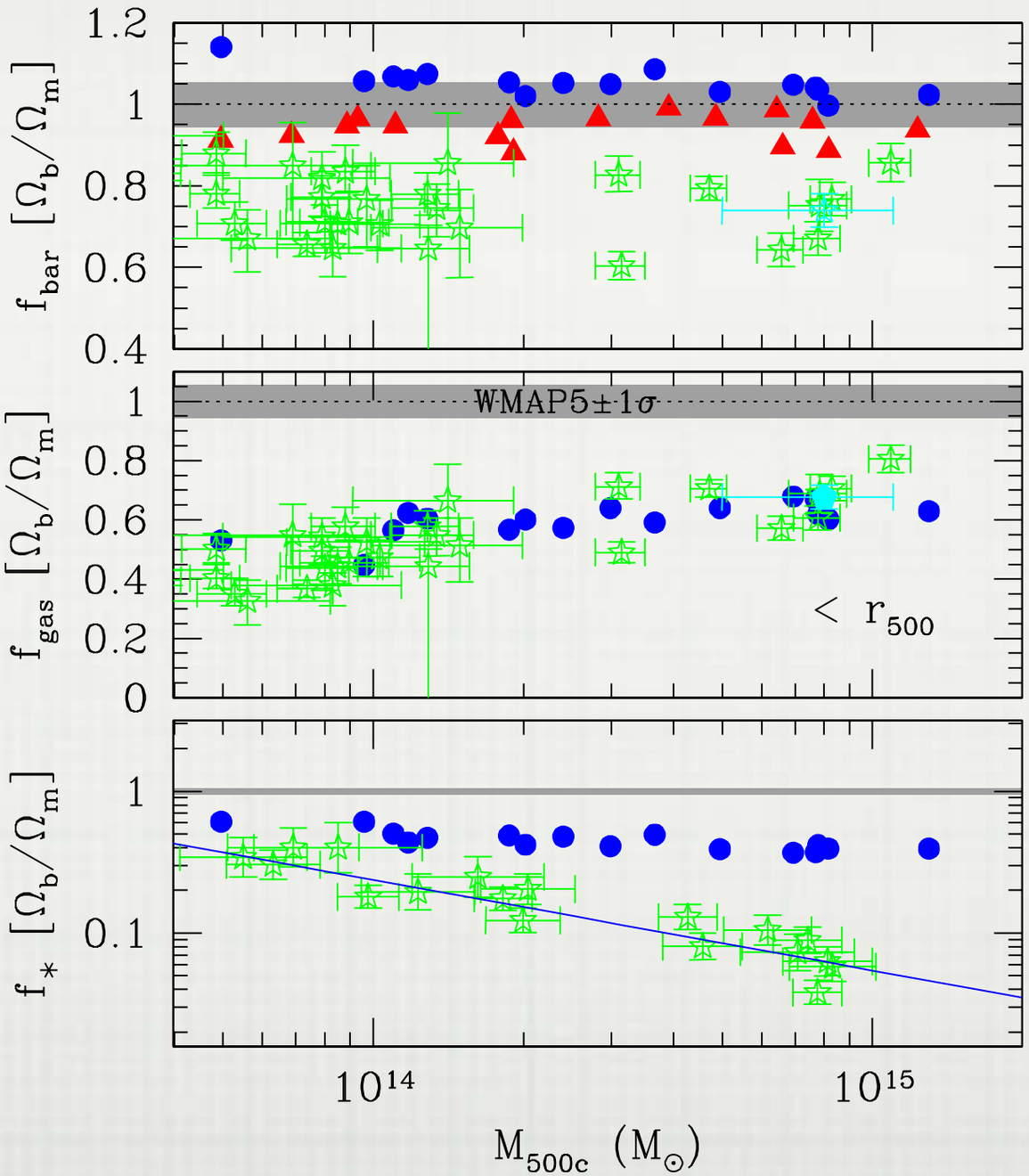
- **Growth index, γ:**

$$d\ln D/d\ln a = \Omega_M(a)^\gamma$$

- **$\gamma \approx 0.55$ for wCDM**
- **$\gamma = 0.55 \pm 0.08$ measured ± 0.10 without WMAP reference**

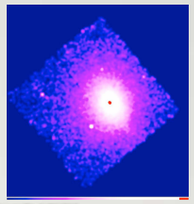
(For published results, see Rapetti et al '10)

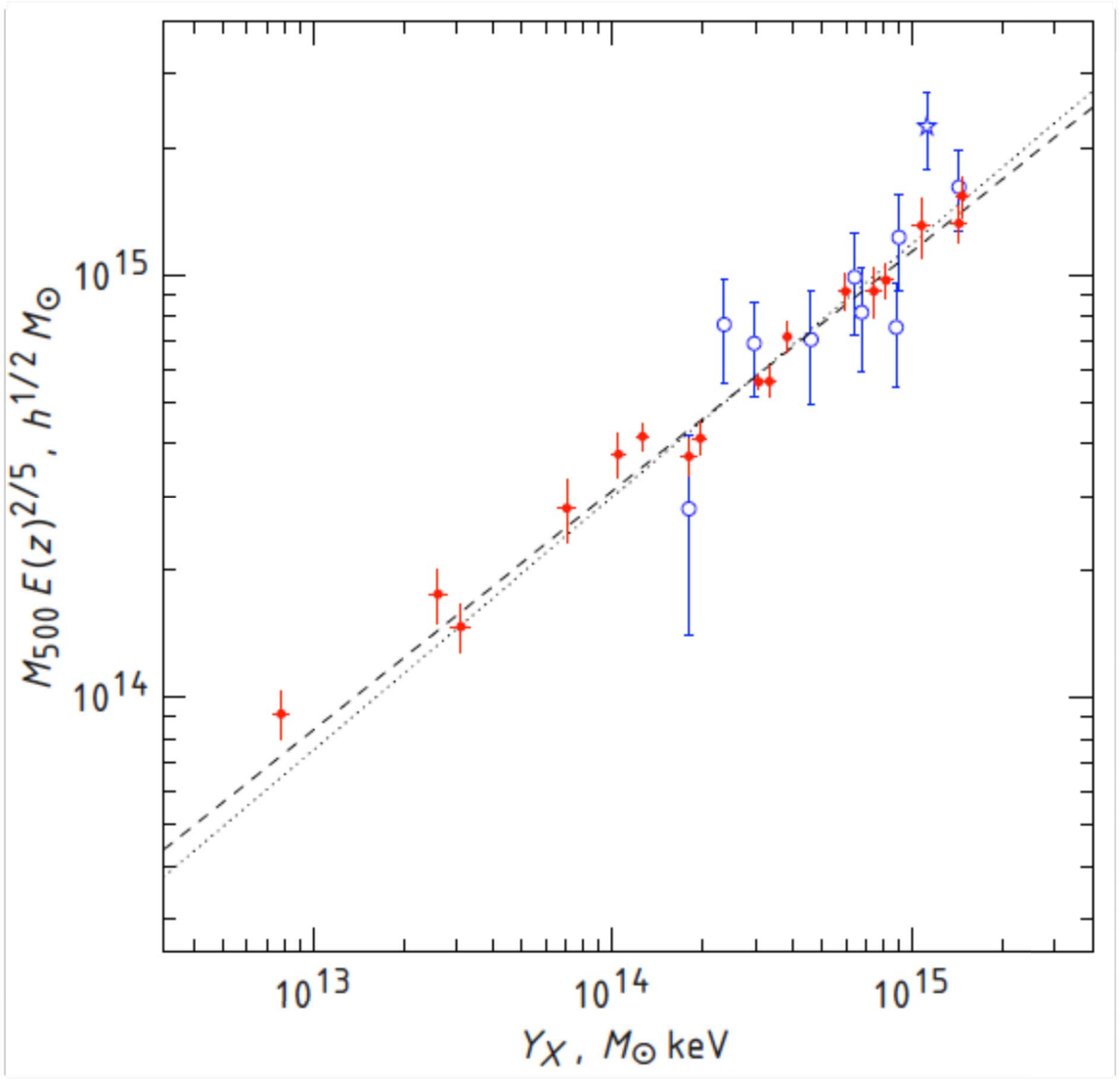
BARYON FRACTION PROBLEM



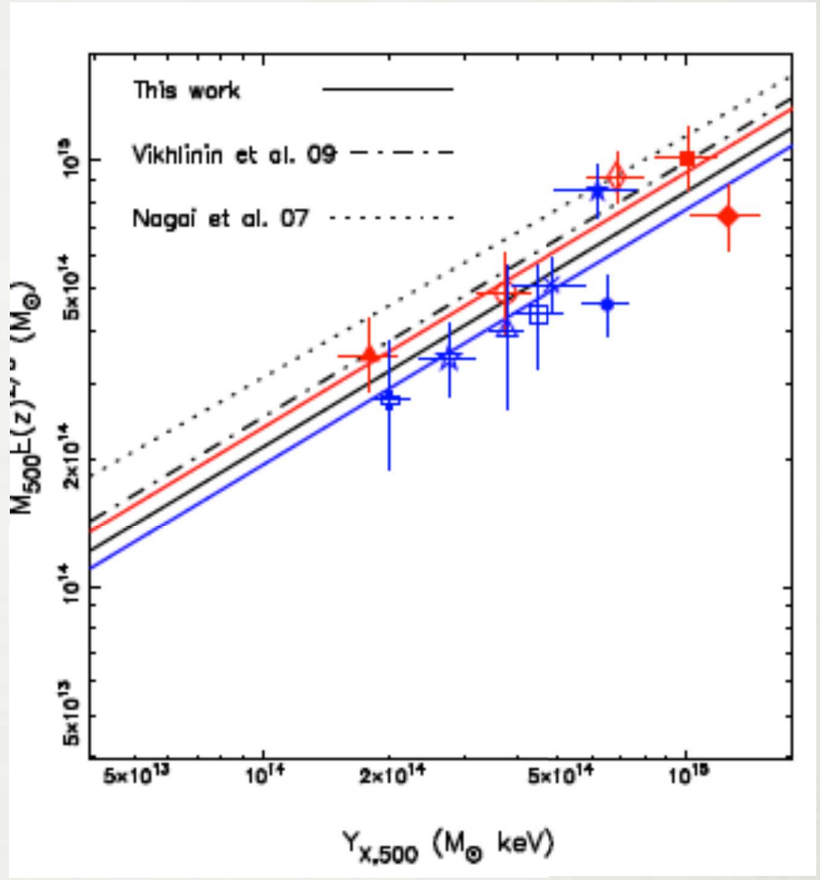
Compilation from Kravtsov et al. Astro10 White Paper

MASS CALIBRATION





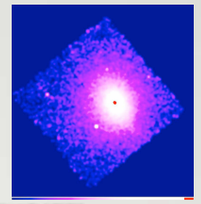
• – *Chandra*, hydrostatic ○ – Weak lensing, Hoekstra '07

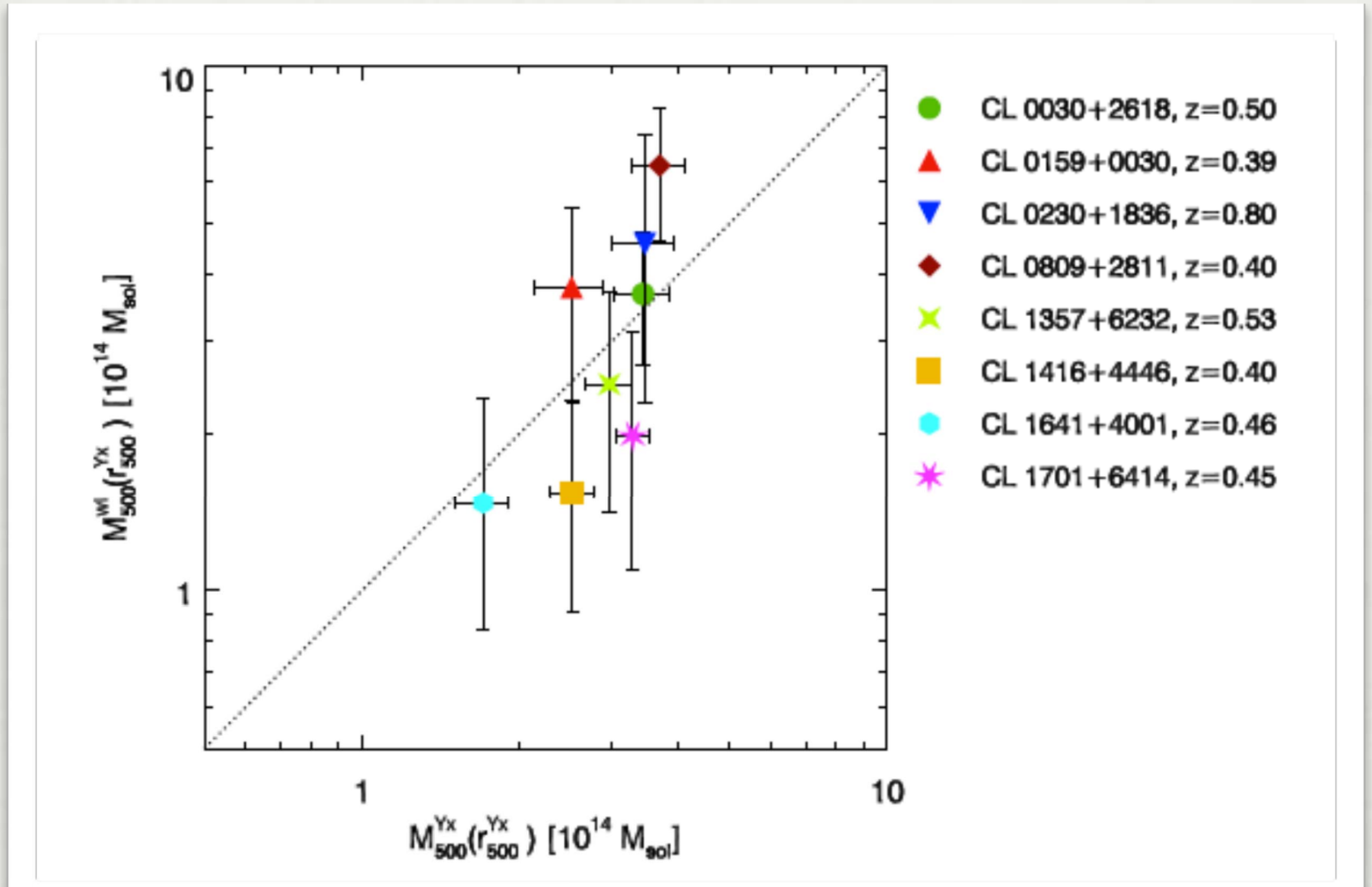


Okabe et al '10

Numerical work needed to eliminate %-level biases

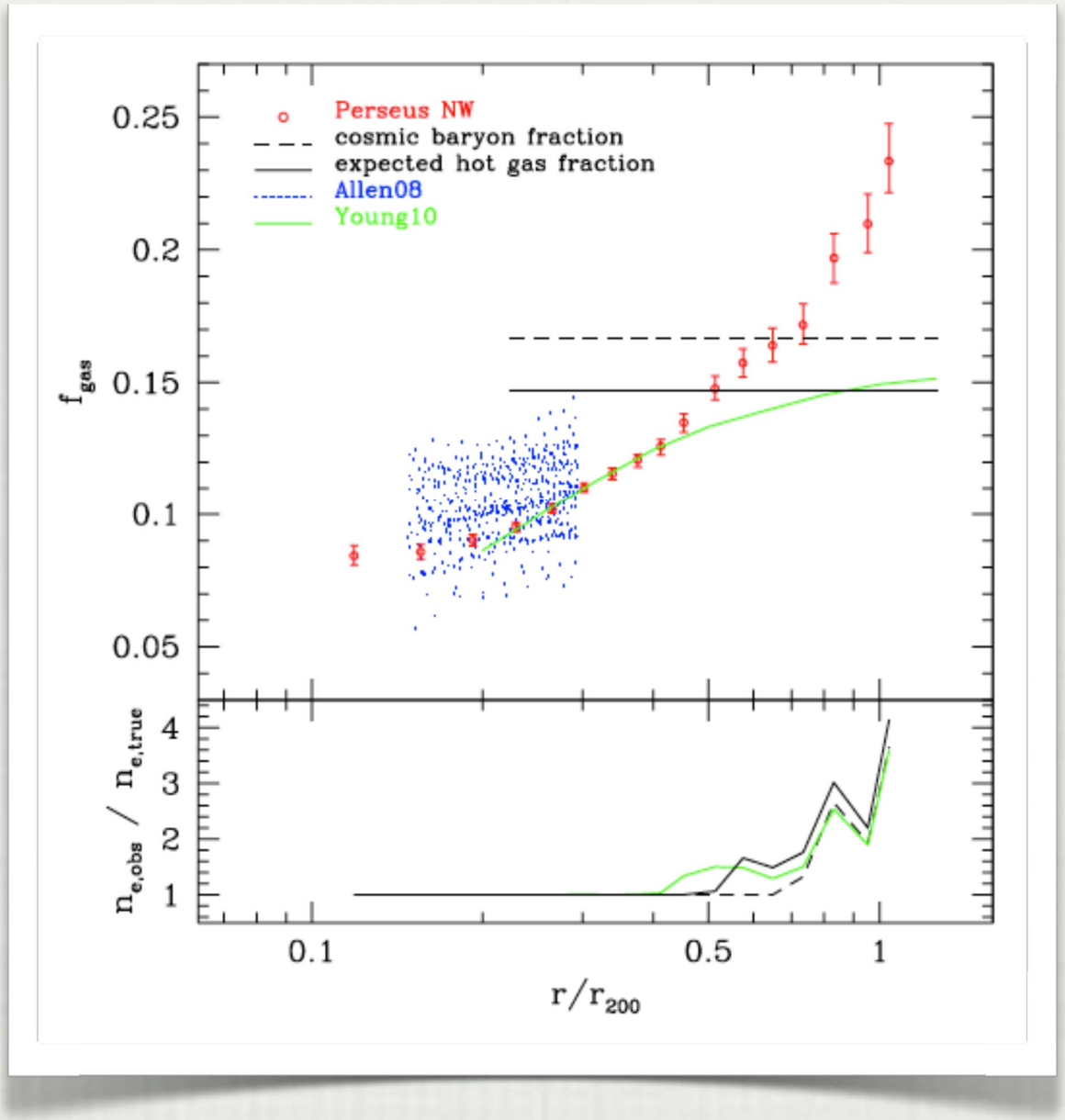
MASS CALIBRATION





Holger Israel's thesis — Yx vs. weak lensing masses at z=0.5

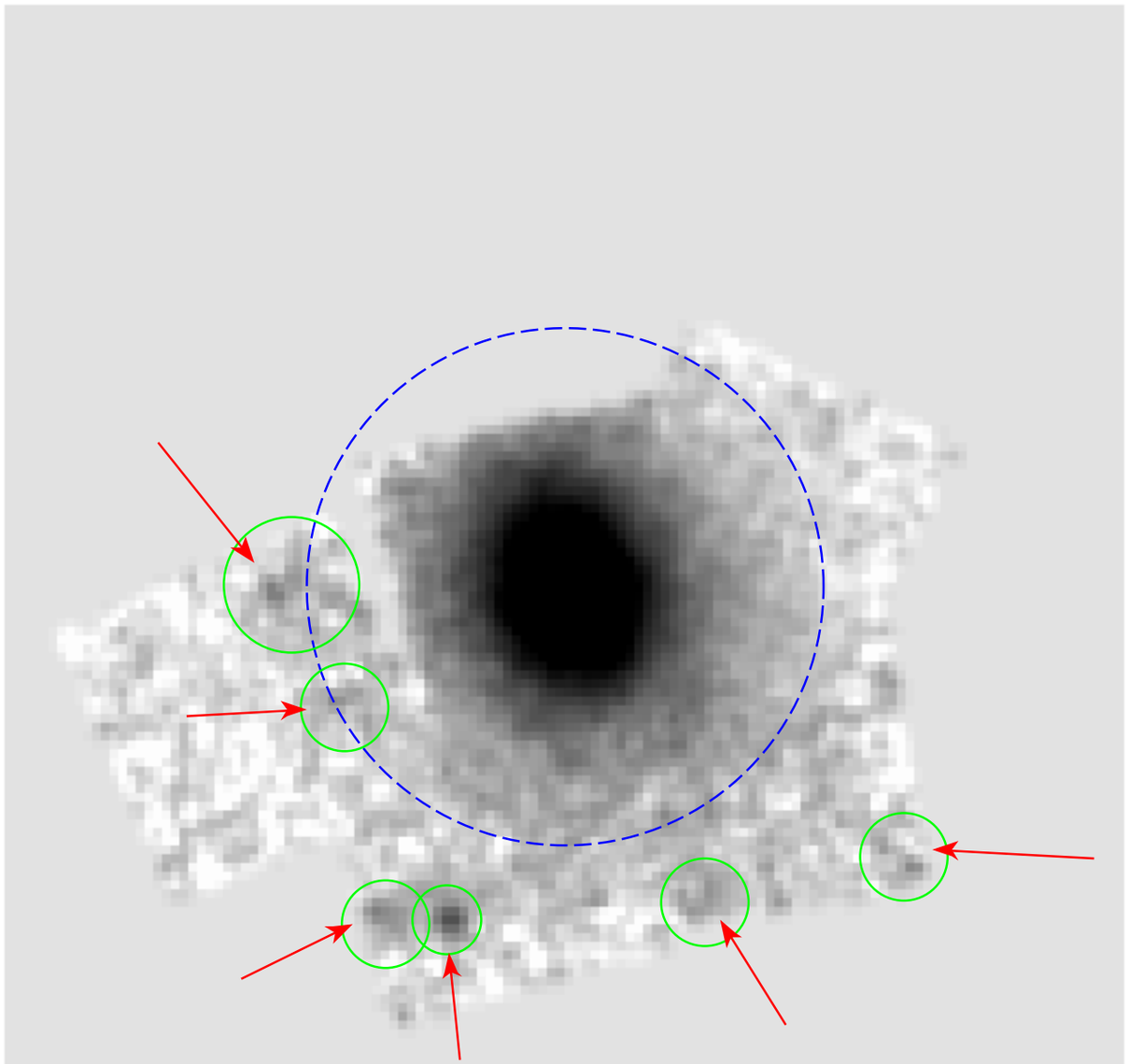
OUTSKIRTS



Huge effect beyond R_{500} ($\approx 0.6 R_{200}$)

Siminonescu et al. '11

OUTSKIRTS

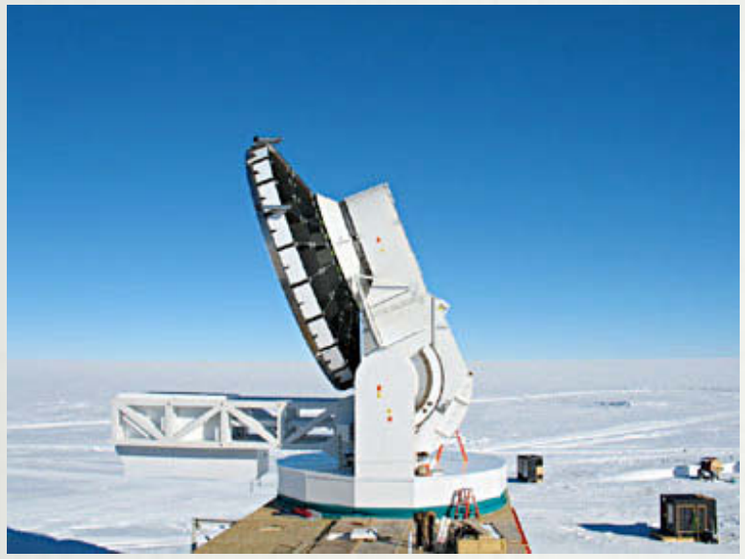


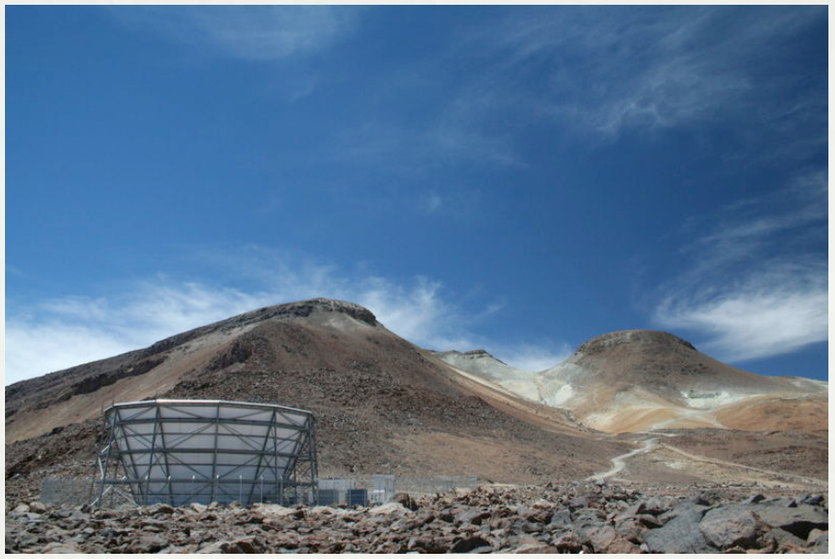
Chandra mosaic of A133

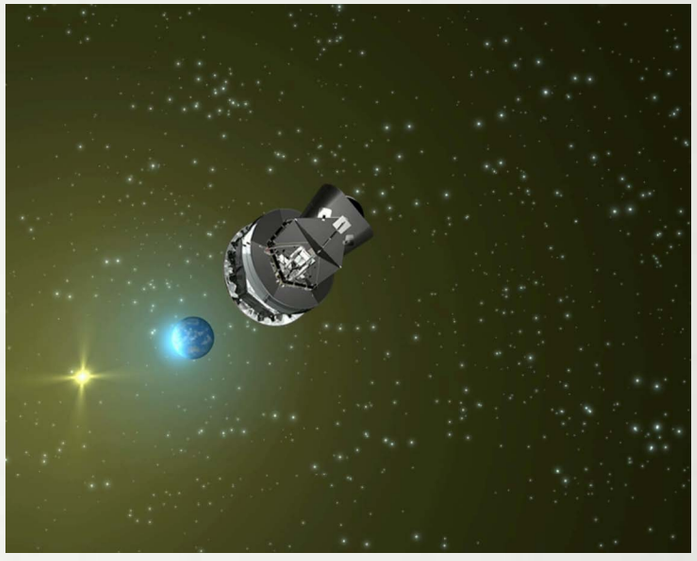
clumps have $T \approx 1.6$ keV and contribute >60% of flux at $r > R_{500}$

Where exactly is the sweet spot in *r* for cluster cosmology?

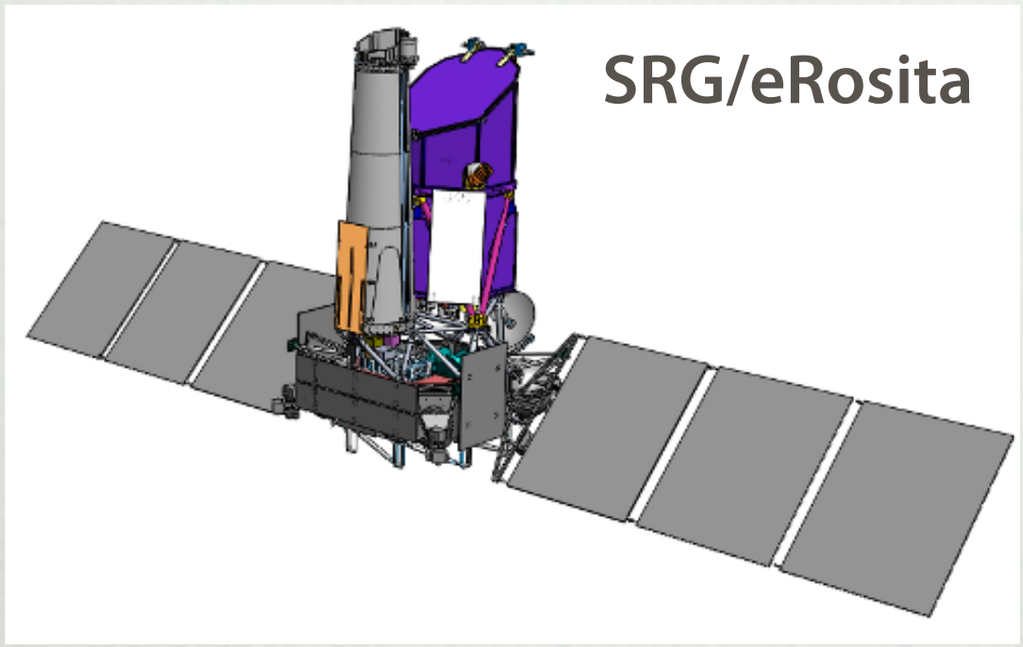
FUTURE







DES, XMM, ...



- $f_{min} \sim (2–4) \times 10^{-14}$ erg s^{-1} cm^{-2}
- 100,000 – 200,000 clusters, $z_{max} \approx 1.5$

Will clusters be *the* dark energy method of the 2010's?